Abstract Book

ONLINE EVENT

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IOP Institute of Physics

(Invited) Future Directions in Particle physics

Jonathan Butterworth

University College London, UK

I will discuss the implications of the recently updated European Strategy for Particle Physics, and progress since its publication. I will also give some personal views on the future.

(Invited) Hadron Physics

David Ireland

University of Glasgow, UK

Hadrons represent the manifestation of the strong nuclear interaction in the real world, so they must be a key part of understanding why the world is the way it is. This talk will look at a few key aspects of hadron physics that are being addressed by current experimental programmes, including the light baryon spectrum, exotic mesons, nucleon and meson structure and the robustness of old measurements.

(Invited) Quark Flavour Physics

Evelina Gersabeck

The University of Manchester, UK

The Standard Model of the elementary particles has proven to be very successful and robust. Yet, we know it is incomplete and there are tensions between experimental measurements and theoretical expectations. One of the ways to probe the physics beyond the Standard Model is to look for discrepancies in Standard Model processes through high precision measurements. This indirect method is sensitive to the highest energy scales. I will present the most recent quark flavour physics results from experiments including LHCb, BESIII, BelleII and NA62. I will also discuss the physics potential of future upgrades.

(Invited) The g-2 experiment at Fermilab

Rebecca Chislett

University College London, UK

(Invited) LHC Upgrades

Steve McMahon

Rutherford Appleton Laboratory, UK

(Invited) High-Precision Mass Measurements for Nuclear Structure Investigations and Standard Model Tests

Moritz Pascal Reiter[1], for the TITAN[2] and FRS Ion Catcher[3] collaboration

[1]University of Edinburgh, UK, [2]TRIUMF, Canada, [3]GSI Helmholtzzentrum für Schwerionenforschung, Germany

The internal structure of the nucleus, a finite quantum system of protons and neutrons, manifests itself in the occurrence of nuclear shells at the well-known magic numbers. Here, due to large energy gaps in the single-

particle orbitals, unique pattern in the otherwise smooth nuclear observables appear [1]. High-precision mass measurements of single isotopes allow a determination of the binding energy, reflecting the sum of all interactions within the nucleus, and calculation of the nucleon-separation energies. Many nuclear properties, in particular particle-emission probabilities and half-lives, depend on the available energy and phase-space of the decay. They are, therefore, affected by sudden changes in the total binding energy caused by changes in the underlying nuclear structure.

High-precision Q-value measurements via mass spectrometry of superallowed $0^+ \rightarrow 0^+$ beta decays allow for a precise determination of vector coupling strength in the weak interaction [2]. These tests are possible in this unique electroweak decay mode, since the transition operator that connects the initial and final 0^+ states is independent of any axial-vector contribution to the weak interaction.

TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) [3,4] is a multiple ion trap system capable of performing high-precision mass measurements and has specialized on mass spectrometry of particular short-lived exotic nuclei. Despite the success, certain refractory elements are not efficiently released from the production target at TRIUMF. Those elements can be accessed via the In-Flight production scheme e.g. at the FRagment Separator (FRS) at GSI, Germany, and measured by an MR-TOF-MS part of the FRS Ion Catcher experiment [5].

In this contribution we will discuss recent results of high-precision mass measurements for nuclear structure investigations and applications to Standard Model test based on superallowed beta decays at TITAN and the FRS Ion Catcher.

References:

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[3] J. Dilling et al., NIM B 204, 2003, 492–496
[4] C. Jesch et al., Hyperfine Interact. 235 (1-3), 2015, 97–106
[5] W. R. Plass et al., NIM B 317 (2013) 457-462

(Invited) Searches for BSM physics at the LHC

Yanyan Gao

University of Edinburgh, UK

With the successful completion of two multi-year operations, Run-1 and Run-2, at the end of 2018, the Large Hadron Collider has collected an unprecedented data for proton-proton collisions at the highest collision energies ever achieved. Discovering new physics beyond the Standard Model (BSM) is one of the most important goals of the LHC experiments. This talk reviews the current status of searches for BSM physics by the ATLAS, CMS, and LHCb experiments, covering many different experimental final states. Results from these searches probe a considerable fraction of the parameter space for a wide variety of new physics scenarios, ranging from well-motivated models such as supersymmetry and extra dimensions to phenomenological driven simplified models.

(Invited) Precision spectroscopy of exotic nuclei using AGATA

Michael Bentley

University of York, UK

High-resolution gamma-ray spectroscopy has been the cornerstone of nuclear structure physics for many decades, and large arrays of hyper-pure germanium detectors have become established at the leading nuclear physics facilities worldwide. These arrays have traditionally been able to distinguish between photoelectric (= good) events and Compton-scattered (= bad) events, through use of active shielding techniques ("Compton-suppression"), improving the peak-tobackground ratio. However, to maximise both efficiency and spectral quality, the aim must be to build the "ideal" gamma-ray spectrometer - a high-solid-angle device constructed solely from Ge crystal with the ability track (position and energy) gamma rays as they scatter through Ge volume, allowing full energy and spatial reconstruction of many gamma rays simultaneously. This gamma-ray tracking technique has been developed over the last 20 years and has come to fruition in two major projects - AGATA (Advanced Gamma-ray Tracking Array) in Europe and GRETA, the parallel project in the USA. The use of radioactive-beam facilities provides a special set of challenges (e.g. low beam intensity or high beam velocity) that make the use of a gamma-ray tracking arrays highly desirable (and in some cases essential), and they are already having a major scientific impact. In this presentation, the AGATA device and the underpinning tracking methodology will be presented, along with latest results from AGATA from two of the leading facilities in Europe - GANIL (France) and GSI (Germany). Some highlights of how the UK is leading developments in the gamma-ray tracking technique will be presented.

(Invited) The Dark Sector at the LHC

Philip Ilten

University of Cincinnati, USA

The dark sector is a hypothetical sector of hidden particles that are weakly connected to the standard model and, if found, could provide possible candidates for dark matter as well explain outstanding experimental anomolies. This talk will explore state-of-the-art searches for hidden sectors from the LHC experiments ATLAS, CMS, and LHCb.

(Invited) Current Status and Challenges for Ab Initio Nuclear Theory

Carlo Barbieri

University of Surrey, United Kingdom, UK

In recent years, we have advanced high-performance computational many-body techniques, such as self-consistent Green's function theory [1], that can be used to compute the spectral function (and correlations effects) of atomic nuclei but that also allow meaningful predictions of radii and binding energies up to masses of A~140 [2,3]. This talk will review such progress and aim at giving a broader perspective of ab initio theory, in which large scale computations are not only used to benchmark the theories of nuclear forces but they can also help to constrain our insight about nuclear phenomena [4,5]. In particular, I will aim at covering some recent applications, including: the charge distribution of Sn and Xe isotopes which will become accessible to through electron scattering in radioactive ion traps, the ab initio formulation of the optical potential as a path to learn the interplay between structure and reactions [6], the performance of Lattice-QCD interaction in describing hyper nuclei, and opportunities for precise investigation of neutrino interactions with nuclei.

[1] V. Somà, Frontiers in Physics 8, 340 (2020).
[2] P. Arthuis, CB, M. vorabbi. P. Finelli, Phys. Rev. Lett. 125, 182501 (2020).

[3] V. Somà, P. Navrátil, CB, et al., Phys. Rev. Lett. 101, 014318 (2020); arXiv:2009.01829.
[4] L. Coraggio, S. Pastore, CB, Frontiers in Physics 8, 626976 (2021), doi: 10.3389/fphy.2020.626976
[5] H. Hergert, Frontiers in Physics 8, 379 (2020).
[6] A. Idini, CB, and P. Navrátil, Phys. Rev. Lett. 123, 092501 (2019).

(Invited) Ripples from the Dark Side of the Universe

Sir James Hough

University of Glasgow, UK

The existence of Gravitational Waves – the gravitational analogy of radio waves – was one of the most controversial predictions of Einstein's General Theory of Relativity. In this talk I will review progress in the field of gravitational wave detection from the first days of the aluminium bar detectors to the present time where the laser interferometer detectors Advanced LIGO and Advanced Virgo have allowed gravitational waves from coalescing black holes to be detected and are opening up a new field of gravitational multi-messenger astrophysics. Many experimental challenges had to be overcome and new challenges are presenting themselves as we look to further enhance the performance of ground based detectors and look to lower frequencies with the space based detector LISA. Further the most recent discoveries by the collaboration will be discussed.

(Invited) FAIR, the Universe in the Lab

Paulo Giubellio

FAIR, the Universe in the Lab Paolo Giubellino FAIR Facility for Antiproton and Ion Research in Europe, Germany;
GSI Helmholtzzentrum für Schwerionenforschung, Germany

The construction of FAIR is proceeding rapidly. The tunnel for the SIS 100 accelerator is almost complete, and the realization of the experimental halls advances. The components of the accelerators of the future facility are in production and are arriving progressively on the campus of the GSI Helmholtzzentrum for Heavy-Ion Research in Darmstadt, Germany. While the full science potential of FAIR can only be harvested once the new suite of accelerators and storage rings is completed and operational, some of the experimental detectors and instrumentation are already available and are used for a precursor science program called FAIR Phase-0, exploiting also the significantly upgraded GSI accelerator chain. The program has started in the summer of 2018 and continues with a few months of beam time per year. The progress of the FAIR realization and the status as well as prospects of science at FAIR will be presented.

(Invited) News from the Standard Model -- SM and Higgs Physics at the LHC

Kristin Lohwasser

University of Sheffield, UK

The status quo of particle physics is: a light Higgs particle has been discovered that is perfectly compatible with the electroweak Standard Model (SM). The Standard Model is thus one of the most successful theories up-to-date. While this is undoubtedly a historic step in particle physics, it is not entirely satisfactory, as in its current state the SM leaves many questions unanswered.

The LHC Run-2 with its large dataset of L=150 fb-1 has allowed for a broad range of measurements to further test the Standard Model, including properties of the Higgs boson and its interactions. In this talk, the most exciting results of the past two years will be presented , including precision measurements of the strong and electroweak forces and properties of the tHiggs boson.

(Invited) Applying Heavy-Ion Storage Rings for Precision Experiments at the Intersection of Atomic and Nuclear Physics

Yuri A. Litvinov

GSI Helmholtzzentrum für Schwerionenforschung, Germany

The storage of freshly produced radioactive particles in a storage ring is a straightforward way to achieve the most efficient use of such rare species as it allows for using the same rare ion multiple times. Employing storage rings for precision physics experiments with highly-charged ions (HCI) at the intersection of atomic, nuclear, plasma and astrophysics is a rapidly developing field of research. Until very recently, there were only two accelerator laboratories, GSI Helmholtz Center in Darmstadt, Germany (GSI) and Institute of Modern Physics in Lanzhou, China (IMP), operating heavy-ion storage rings coupled to radioactive-ion production facilities. The experimental storage ring ESR at GSI and the experimental cooler-storage ring CSRe at IMP offer beams at energies of several hundred A MeV. The ESR is capable to slow down ion beams to as low as 4 A MeV (b=0.1). Beam manipulations like deceleration, bunching, accumulation, and especially the efficient beam cooling as well as the sophisticated experimental equipment make rings versatile instruments [1]. The number of physics cases is enormous. The focus here will be on the most recent highlight results achieved within FAIR-Phase 0 research program at the ESR. First, the measurement of the bound-state beta decay of fully-ionized 205Tl was proposed about 35 years ago [2] and was finally accomplished in 2020. Here, the ESR is presently the only instrument enabling precision studies of decays of HCIs. Such decays reflect atomnucleus interactions and are relevant for atomic physics and nuclear structure as well as for nucleosynthesis in stellar objects. Second, the efficient deceleration of beams to low energies enabled studies of protoninduced reactions in the vicinity of the Gamow window of the p-process nucleosynthesis [3]. Proton capture reaction on short-lived 118Te was attempted in 2020 in the ESR. Here, the well-known atomic charge exchange cross-sections are used to constrain poorly known nuclear reaction rates. The performed experiments will be put in the context of the present research programs at GSI/FAIR and in a broader, worldwide context, where, thanks to fascinating results obtained at the presently operating storage rings, a number of new exciting projects is planned. Experimental opportunities are being now dramatically enhanced through construction of dedicated low-energy storage rings, which enable stored and cooled secondary HCIs in previously inaccessible low-energy range. The first such facility, CRYRING, has just been constructed at GSI to receive decelerated beams of HCIs from ESR [4]. Thanks to the fascinating results obtained at ESR and CSRe as well as to versatile experimental opportunities, there is now an increased attention to the research with ionstorage rings worldwide. An isochronous storage ring for mass measurements, R3, has just been commissioned at RIKEN. Dedicated ring facilities are proposed for ISOLDE at CERN, TRIUMF, LANL, and JINR. [1] M. Steck and Y. Litvinov, Prog. Part. Nucl. Phys. 115, 103811 (2020) [2] F. Bosch, et al., Prog. Part. Nucl. Phys. 73, 8 (2013) [3] J. Glorius, et al., Phys. Rev. Lett. 122, 092701 (2019) [4] M. Lestinsky, et al., Eur. Phys. J. Special Topics 225, 797 (2016)

(Invited) Quantum Entanglement in PET Imaging

R Newton[1], D P Watts[1], J Bordes[1], J R Brown[1], A Cherlin[2], J Allison[3],[4], M Bashkanov[1], N Efthimiou[5] and N A Zachariou[1]

[1]University of York, UK, [2]Kromek Group plc, UK, [3]Geant4 Associates International Ltd, UK, [4]University of Manchester, UK, [5]University of Hull, UK

Our understanding and measurement of photon quantum entanglement at the MeV scale is currently poor compared to the optical regime. However, advances in detector technologies and simulation methods mean that the detailed study of entanglement at higher energies is becoming realisable for the first time. This opens up a wealth of new opportunities for fundamental tests and applications. In this talk, we demonstrate the potential benefits to Positron Emission Tomography (PET) by exploiting the previously neglected entanglement between annihilation photons [1]. To do this, a new entangled GEANT4 simulation was developed, and the predictions verified against experimental data from a cadmium zinc telluride PET demonstrator [2]. We present a simple method to quantify and remove in-patient scatter and random backgrounds using only the entanglement information in the PET events, corrections which normally require a full simulation of the patient using information from a prior CT scan [3]. As part of the project we also obtained a first experimental measurement of entanglement loss at the MeV scale. Other near term plans for the project will be discussed, including the path to a first measurement of the fundamental cross sections for reactions of entangled photon pairs.

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[2] Watts, D. P. et al., Photon quantum entanglement in the MeV regime and its application in PET imaging. Nature Communications (forthcoming) arXiv:2012.04939.
[3] Cook, G. J., Wegner, E. A. & Fogelman, I. Pitfalls and artifacts in 18FDG PET and PET/CT oncologic imaging. Semin. Nucl. Med.34, 122–133 (2004).

(Invited) Making the calculation of nuclear matrix elements easier

Antonio Marquez Romero

University of North Carolina, USA

By means of energy and orthogonality considerations we optimize the computation nuclear matrix elements (NME) of neutrinoless double-β (0νββ), calculated using the generator-coordinate method (GCM) with symmetry-restored constrained mean-field states. A selection mechanism is proposed to choose the most relevant mean-field states, giving the major contributions to the NME. We calculate the NME of the 76Ge→76Se transition using the quadrupole deformations and the isoscalar pairing coordinate as relevant constrained degrees of freedom. Our results show that not all states are necessary to be included in the GCM calculation, reducing the computational cost of solving the Hill-Wheeler-Griffin equation.

(Invited) Status of the LZ Experiment

Theresa Fruth

University College London, UK

LUX-ZEPLIN (LZ) is a dark matter direct detection experiment currently being commissioned at the Sanford Underground Research Facility in Lead, South Dakota. At the heart of the detector is a dual-phase time projection chamber containing 7 tonnes of active liquid xenon. During its 1000-day science run, LZ aims to achieve unprecedented sensitivity to Weakly Interacting Massive Particles (WIMPs) down to a WIMP-nucleon spin-independent cross section of about 1.4 x 10-48 cm2 for a 40 GeV/c2 mass WIMP. In this talk I will present an overview of the LZ detector and the current status of the experiment which is on track to start data taking later this year.

(Invited) Theory and LHC Phenomenology

Jennifer Smillie

University of Edinburgh, UK

The Large Hadron Collider (LHC) has been an incredibly successful experiment so far, delivering large quantities of rich data to be analysed. It is a challenge to the theoretical community to match the precision of this data in theoretical predictions. Already, in some important cases, the error on the experimental predictions is dominated by uncertainty on theoretical input. In this talk, as we are preparing for the start of LHC Run 3, I will discuss specific topics where there has been great progress in recent years and areas where important work is ongoing. I will choose examples across Standard Model predictions and the efforts to disentangle signs of new physics, and will also try to cover a balance of improvements to tried-and-tested methods and entirely new approaches. I therefore hope to give an accessible overview of current exciting developments in theory and LHC phenomenology.

(Invited) The year that was Covid

Mark Thompson

STFC, UK

(Invited) Very High Energy Gamma-ray Astronomy with the Cherenkov Telescope Array

Jon Lapington

University of Leicester, UK

The Cherenkov Telescope Array (CTA) is the next generation ground-based very high energy gammaray astronomy observatory, comprising more than 100 telescopes located at sites in the northern and southern hemispheres. With 10 times higher sensitivity that current gamma-ray telescope arrays, CTA will transform our understanding of the high-energy universe and explore questions in physics of fundamental importance. It will also be the first ground-based gamma-ray observatory open to the worldwide astronomical and particle physics communities as a resource for data from unique, high-energy astronomical observations.

Three telescope configurations are required to cover the full CTA energy range (20 GeV to 300 TeV): 23 m diameter Large-Sized Telescopes, (LST), 12 m diameter Medium-Sized Telescopes (MST), and 4 m diameter Small-Sized Telescopes (SST). The first LST prototype is now being commissioned at the CTA-North site in La Palma, and a European Research Infrastructure Consortium (ERIC) agreement for construction and operation of the observatory is being finalized with construction expected to begin soon.

The CTA Small-Sized Telescope (SST) array, to be sited at CTA-South, will comprise up to 70 telescopes spread over several square kilometres and provide sensitivity at the highest energies, from a few TeV to 300 TeV. The UK-CTA collaboration has played a leading role in the development of the Compact High Energy Camera (CHEC), which has now been selected as the baseline camera design for the SST array. First light for CHEC was achieved in combination with the Italian ASTRI-Horn telescope structure in April 2019 at the Serra La Nave Observatory on Mount Etna in Sicily, and design finalization of the SST for the production phase is now underway.

(Invited) Neutrino Oscillation Physics

Alfons Weber

University of Oxford, UK, Rutherford Appleton Laboratory, UK RI/STFC, UK

Neutrinos are always good for a surprise. Over the last two decades it has been established that neutrinos have mass and that the mass and weak-interaction eigenstates are not the same, leading to the effect of neutrino oscillations. The phenomenology has been studied using natural and man-made neutrino sources and we now have a good understanding of the parameters governing this process. There are even some first hints for CP-violation in the neutrino sector. But not all results are consistent and future and current experiments are important to really understand the neutrino. This presentation will report on the status of the long- and short-baseline accelerator-based oscillation experiments and give an overview where the field will go in the future.

(Invited) Direct reactions probed in inverse kinematics with the ISOLDE Solenoidal Spectrometer - recent highlights and future developments.

David Sharp

University of Manchester, UK

The first physics experiments using the ISOLDE Solenoidal Spectrometer (ISS) have both been a success. This talk will present the results from the two measurements made before CERN's Long Shutdown 2 (LS2). The ^{28}Mg(*d,p*)^{29}Mg reaction probed single-particle structure near the island of inversion and towards the neutron drip line. In particular, this measurement focused on identifying the negative-parity intruder states and investigating how they evolve in this region of the nuclear chart. These data are compared to shell-model calculations using new effective interactions that aim at better describing cross-shell interactions. At the other end of the nuclear chart, the second measurement with ISS of the ^{206}Hg(*d,p*)^{207}Hg reaction identified excited states in a *terra incognita* region of the nuclear chart. This first spectroscopy of ^{207}Hg is the first step in extending our knowledge of nuclear structure towards r-process nuclei in this region of the nuclear chart. These data provide constraints on calculations predicting the limit of finite binding in N=127 nuclei.

These results cover two very different regions of the nuclear chart and so highlight the operation of ISS in different mass regimes and the considerations needed in the differing set ups.

(Invited) Progress with the Segmented Inverted Coaxial Germanium Detector, SIGMA

L Harkness-Brennan[1], F Pearce[1], A Alharbi[1], A Boston[1], O Griffiths[1], F Holloway[1], D Judson[1], R Page[1] and P Nolan[1], E Rintoul[1], M Labiche[2], J Simpson[2] and C Unsworth[2]

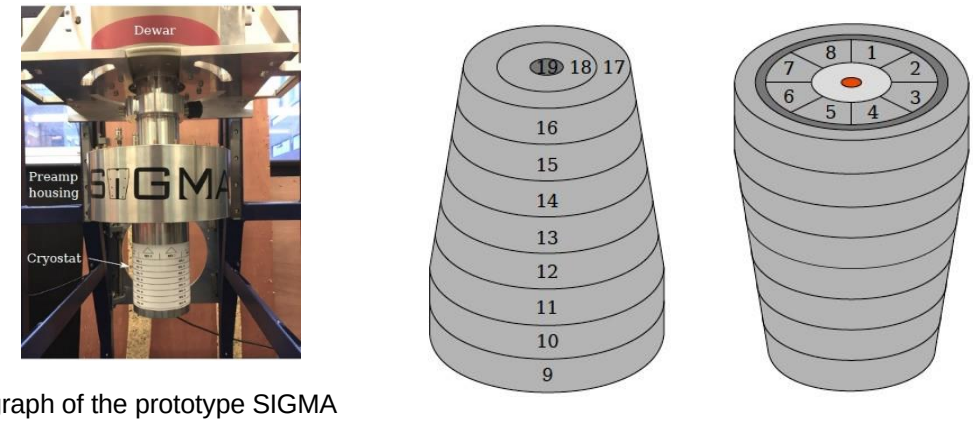
[1]University of Liverpool, UK, [2]STFC Daresbury Laboratory, UK

The Segmented Inverted-coaxial GerMAnium (SIGMA) detector has been designed to offer enhanced performance for gamma-ray spectroscopy, tracking and imaging. Achieving these aims relies on using SIGMA to measure the energies and positions of gamma-ray interactions with a precision that is unrivalled by other germanium detectors.

SIGMA is revolutionary due to a unique electrode configuration and crystal shape, which significantly alters the characteristic signal response of a conventional coaxial detector. The position resolution performance will be made possible through the increased charge collection times that have a complex dependence on gamma-ray interaction position [1]. The segmentation scheme produces 19 signals from 8 longitudinal rings, 1 concentric segment on the front face, 8 sectors, 1 core segment and a point-like

contact on the rear face, as illustrated in Fig 1. The signal from the point-like contact has low-noise properties due to its low capacitance and therefore provides energy resolution superior to current state-of-the-art germanium detectors, such as those used in the Advanced Gamma Tracking Array (AGATA). The signals readout from the rings and sectors are digitized and processed using pulse shape analysis algorithms to provide longitudinal and azimuthal gamma-ray interaction position. The prototype SIGMA detector is the first p-type sensor of its kind to be manufactured and is shown in Figure 1.

Fig. 1.



Photograph of the prototype SIGMA detector (left) and illustration of the segmentation scheme, with the point contact shown in red (right).

The prototype SIGMA detector has been undergoing experimental evaluation at the University of Liverpool to characterise energy resolution, efficiency, active volume of each segment and its position dependent signal response. This information is all key to determine which methods are most appropriate for Pulse Shape Analysis (PSA) and tracking. This talk will report on the experimental progress to date and outline the next steps needed to demonstrate the full capabilities of the detector for gamma-ray tracking and imaging

[1] J. Wright, L.J. Harkness-Brennan et al, NIM A. **892**, 84-92 (2018).

(Invited) Laboratory-based neutrino mass measurements and new results from KATRIN

Susanne Mertens

TU Munich, Germany

With a mass at least six orders of magnitudes smaller than the mass of an electron – but non¬zero – neutrinos are a clear misfit in the Standard Model of Particle Physics. On the one hand, its tiny mass makes the neutrino one of the most interesting particles, one that might hold the key to physics beyond the Standard Model. On the other hand this minute mass leads to great challenges in its experimental determination. In this talk, an overview laboratory-based approaches to determine the neutrino mass will be given. These entail the search for neutrino less double beta decay and a direct determination via the kinematics of a single beta decay. Besides a general overview, the talk will focus on new results of the KATRIN experiment. With its second data release, KATRIN reaches for the first time in the history of direct neutrino mass experiments a sub-eV sensitivity to the neutrino mass.

(Invited) Direct Dark Matter Searches

Jim Dobson

University College London, UK

In this talk I will review the current status of Dark Matter direct detection experiments. After a recap of the astrophysical and cosmological evidence for Dark Matter I will focus on the status of direct detection experiments covering leading results from liquid noble, cryogenic and other searches. I will then consider the key drivers for the success of direct detection experiments and discuss future prospects for the next generation of experiments.

(Invited) Indirect methods to constrain Nuclear Astrophysics

Aurora Tumino

Università degli Studi di Enna "Kore", Italy and INFN-Laboratori Nazionali del Sud, Italy

Nuclear reactions sustain burning stars for millions to billions of years and are responsible for the element nucleosynthesis inside them. Over the past forty years nuclear physicists have been trying to measure the rates of the most relevant reactions, but there is still considerable uncertainty about their values. Although the stellar temperatures are high, on the order of hundred million degrees, they correspond to sub-Coulomb energies. As a consequence, the Coulomb barrier causes a strong suppression of the cross-section, which drops exponentially with decreasing energy. Thus, the corresponding reaction rates are extremely small, making it difficult for them to be measured directly in the laboratory. In addition, the electron screening effect due to the electrons surrounding the interacting ions prevents one to measure the bare nucleus cross-section. Typically, the standard way to determine the bare nucleus cross-section at the relevant energies consists in a simple extrapolation of available higher energy data. This is done by means of the definition of the astrophysical S(E) factor, which essentially represents the cross-section free of Coulomb suppression. However, the extrapolation may introduce additional uncertainties due for instance to the presence of unexpected resonances or to high energy tails of sub-threshold resonances.

A valid alternative approach is represented by indirect methods developed to overcome some of the limits of measuring at astrophysical energies. A common feature shared by indirect methods is to replace the relevant two-body reaction at low energies by a high- energy reaction usually with a three-body final state. In particular, the Trojan Horse Method (THM) is applied to charged particle reactions either resonant or non-resonant and allows to extract the energy-dependence of their S(E) factors. I will recall the basic ideas of a sample of indirect methods. Then, I will focus on the THM and show some recent results.

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[4] A. Tumino et al., Nature 57 (2018) 687

(Invited) Neutrino-Nucleus Interactions

Xianguo Lu

University of Oxford, UK

One of the most surprising properties of neutrinos is that they have mass and oscillate among flavors during propagation. Measuring neutrino and antineutrino oscillations is a crucial step to answer existential questions like why the universe is dominated by matter over antimatter. In the current (future) long-baseline experiments NOvA and T2K (DUNE and Hyper-Kamiokande), neutrinos and antineutrinos of few-GeV energies are produced and their oscillations are compared. GeV-neutrinos can also come from cosmic rays interacting with the Earth's atmosphere. They can help determine the neutrino mass ordering but they are also an important background of the searches for rare events like the proton decay. In this talk, I will discuss the

science case of neutrino-nucleus interactions in the GeV regime and provide an overview of recent measurements from accelerator-based experiments. In particular, I will demonstrate how new analysis techniques like transverse kinematic imbalance [1,2]—an analogue of the missing energy [3] technique used in collider experiments—can provide in-depth understanding of GeV-neutrino interactions.

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(Invited) Cosmic Rays above 1018 eV: Results of relevance to Astrophysics and Particle Physics

Alan Watson

University of Leeds, UK

Cosmic-ray explorations were the bedrock of what became particle physics yielding the discovery of the positron, the muon, the charged pions and several of the 'strange particles'. Since the early 1950s cosmic-ray studies have focused largely on attempting to elucidate the origin of the highest-energy particles in Nature. In this talk I will describe measurements above 1018 eV made, primarily, at the Pierre Auger Observatory in Argentina, the largest cosmic ray detector ever built. Results of relevance to astrophysics and particle physics will be discussed.

The energy spectrum of cosmic rays has been measured with unprecedented precision using over 215k events with a new spectral feature identified above 1019 eV. Additionally, the Auger Collaboration has reported a dipole distribution for the arrival directions of particles with energies above 8 x 1018 eV at a significance of over 6 σ. The effect may be correlated with the positions of galaxies in the 2MRS (infra-red) survey, demonstrating for the first time that such particles originate outside of our galaxy. At higher energies evidence for point sources, such as Centaurus A, is emerging.

Some interpretations of the data will be discussed but insights are hampered by lack of knowledge of the primary mass which come from limited information about the hadronic physics at energies beyond the LHC. Consistent features about the variation of the mass with energy are emerging – although dramatic changes in hadronic interactions at extreme energies, such as a huge rise the p-air cross-section, cannot be excluded. To help clarify the situation, a measurement of the p-air cross-section at a centre-of-mass energy of 57 TeV has been made which is found to agree well with extrapolations from machine energies. However discrepancies are found between what is predicted and what is observed in the muon content of showers. Similar anomalies may have been seen in the multi-muon observations at the LEP experiments and in ALICE. These results call for further refinement of the extrapolations from LHC energies and may therefore lead to new insights about hadronic interactions at the highest energies.

(Invited) Reconstruction machine learning

Emmanuel Olaiya

Rutherford Appleton Laboratory, UK

Machine learning is the science of enabling machines to learn algorithms which are not explicitly programmed. The science behind machine learning has been around for decades, however it is only in the

last decade that we have seen the rapid growth of machine learning applications. This is because machine learning required two significant inputs; the data to learn from and the hardware to drive the learning. Both the quantities of data and the performance of hardware required have only recently become readily available. Consequently, machine learning is rapidly being applied and developed in many fields, particularly the world of high energy physics. In my talk I will introduce basic neural networks such as deep neural networks, and then present examples of how machine learning is being used for event reconstruction in particle physics.

(Invited) Q The ALICE Experiment at the CERN LHCGP physics with ALICE

David Evans

University of Birmingham, UK

ALICE is one of the four main experiments at the CERN LHC and is a general purpose heavy-ion detector. The primary goal of ALICE is to study Quantum ChromoDynamics (QCD) at the highest energy densities reached in the laboratory by utilising high-energy heavy-ion collisions at the LHC. In particular, ALICE aims to characterise the hot and dense QCD matter composed of de-confined quarks and gluons - called a Quark-Gluon Plasma (QGP). Full characterization of the quark-gluon plasma and phase transition between hadronic matter to the quark-gluon plasma is extremely important for the understanding of the non-perturbative aspects of the QCD such as colour confinement and chiral symmetry restoration/breaking and the evolution of the very early Universe.

The ALICE detector is designed and optimized for the heavy-ion collisions at the LHC energies. Since 2010, ALICE inspected ~150 μb-1 Pb-Pb collisions at √s NN = 2.76 TeV in Run1 (2009-2013) and ~1.3 nb-1 Pb-Pb collisions at √s NN = 5.02 TeV in Run2 (2015-2018). Proton-proton and proton-lead data have also been recorded. The ALICE detector is currently undergoing a major upgrade for Runs 3 and 4, which will enable it to record lead-lead collisions at fifty times the rate as in Run 2.

In this presentation, a selection of results, with a UK focus, will be presented together with the status of the ALICE upgrade.

(Invited) Neutrino and Dark Matter Liquid Argon Detector Technologies

Konstantinos Mavrokoridis

University of Liverpool, UK

Liquid argon detectors are instrumental for neutrino physics and direct dark matter detection. Within the DUNE program four liquid argon (LAr) modules on the 10-kton scale are planned and prototypes up to 300 tons (protoDUNEs) have already been successfully operated. As such huge efforts towards the realization of these colossal detectors have gained momentum, optimized and novel proposals have emerged such as the fast optical imaging employed and demonstrated with the ARIADNE dual phase LAr detector or pixelated charge readout in single phase detectors, like ArgonCube. On the direct dark matter detection front, dual phase LAr (i.e. DarkSide-20k) are pioneering these detectors especially in the regime of low energy thresholds and low background that is required. The future direct dark matter detectors are growing in size and some of the technologies or challenges can find an overlap which can benefit both fields. An overview of all the major technologies will be given.

(Invited) Short-baseline neutrino oscillations

Roxanne Guenette

Harvard University, USA

While the 3-neutrino paradigm have been strongly established, many anomalies observed in short-baseline experiments along the past decades have raised the possibility of new physics. After briefly reviewing the status of the different experimental results, I will present the current and next generation of short-baseline experiments. I will also discuss the wide-rage of new physics searches happening or proposed at those experiments.

(Invited) Coulomb excitation and deformation in the FRIB era

Jack Henderson

University of Surrey, UK

The emergent phenomenon of deformation in atomic nuclei provides a sensitive diagnostic for underlying microscopic behaviours. For example, the breaking down of traditional magic numbers comes hand-in-hand with an enhancement of deformation. With the coming online of the next generation of nuclear physics facilities, experimental studies of deformation will probe new regions of the nuclear landscape with unprecedented precision. Sub-barrier Coulomb excitation provides the most straightforward method to establish and quantify deformation in unstable nuclei, especially with regards to the nature of quadrupole deformation. I will briefly introduce the experimental technique and limitations, present recent experimental results, and discuss potential avenues of investigation at FRIB and other next-generation facilities.

Results from the Search for Supersymmetry in Final States Containing Multiple b-jets with 139^{fb-1} with the ATLAS Detector

Jack Hall

The University of Sheffield, UK

The blinded results from the search for the pair-production of gluinos decaying to sbottom and stop at the LHC is reported. It utilises a proton-proton dataset of $\sqrt{s}$=13 TeV with an integrated luminosity of 139ifb collected with the ATLAS detector. The signal is searched for in events containing several energetic jets, of which at least three must be *b*-tagged, large missing transverse energy and either zero or at least one charged lepton.

Prompt gamma-ray measurements with nanoparticles for in vivo range verification and dose enhancement in protontherapy

Sonia Escribano-Rodriguez[1], Stefanos Paschalis[1], Mei Xiao[1], Sebastian Heil[1], Ina Syndikus[1] and D. Watts[1]

[1]University of York, UK

Proton therapy is an emerging modality for cancer treatment. It produces a better dose conformation, reducing the damage to structures and tissues nearby [1]. However, in vivo range verification is desirable to understand the range uncertainties, minimizing beam delivery errors during the treatment. The most promising range verification technique is the prompt gamma imaging (PGI) [2]. In addition, the use of radiomarkers enhances the dose received by the tumor. High atomic number particles amplify radiation-induced biological damage [3].

The aim of this project is the combination of both techniques in order to prove that it is possible to enhance in the dose, while verifying the range of protons with the detection of the prompt gamma rays emitted by the radiomarkers used. To answer this question, we conducted two in-beam measurements using a proton beam. The first experiment was developed in Birmingham University, with a beam energy of 38 MeV. The proton beam hit a radiomarker target, and after the irradiation the gamma rays emitted were measured with two detection systems simultaneously. Two different scintillators were used: a CLLB detector of 2 inches and an array of 128 LFS crystals coupled to silicon photomultiplier (SiPM) arrays. The second experiment took place at the KVI-CART facility, with an energy of 66.5 MeV. In this case the radiomarker target was placed inside a water phantom, to mimic the tissue composition. After the irradiation with the proton beam the gamma rays emitted were measured with the same detection systems.

Preliminary results will be presented and compared to a Monte Carlo (MC) simulation model that was developed in Geant4 within the project.

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Measurement of the Electron-Neutrino Charged-Current Inclusive Cross-Section on Argon in MicroBooNE

Krishan Mistry

The University of Manchester, UK

Electron-neutrino appearance is a crucial channel for searches of sterile neutrinos in short-baseline experiments and measurements of Charge-Parity (CP) violation in long-baseline oscillation experiments. The precise knowledge of the electron neutrino cross section will, therefore, play a key role in reducing the uncertainties of these future experiments. There are only a handful of electron neutrino cross section measurements in the hundred MeV to GeV range and only one on argon. Therefore, there is a need for new, high statistics measurements of this quantity. MicroBooNE is a Liquid Argon Time Projection Chamber (LArTPC) located at Fermilab which simultaneously receives a flux of neutrinos from the on-axis Booster Neutrino Beam (BNB) beam and off-axis Neutrinos at the Main Injector (NuMI) beam. While MicroBooNE uses BNB data for short baseline sterile oscillation searches, data from the NuMI beam provide an excellent opportunity to simultaneously measure the electron-neutrino cross section, thanks to its higher electron-neutrino flux component. This talk will cover the current status of inclusive charged-current electron neutrino cross-section measurement on argon in MicroBooNE using the NuMI beam.

Search for the $K^+ \longrightarrow \pi^+\nu\nu$ decay at the NA62 Experiment at CERN

Joel Swallow

University of Birmingham, UK

The ultra-rare $K^+ \longrightarrow \pi^+\nu\nu$ decay has a branching ratio of $(8.4\pm1.0)\times10^{-11}$ in the Standard Model. However, this branching ratio is sensitive to potential beyond the standard model scenarios, meaning its measurement could reveal indirect effects of new physics. The NA62 experiment at the CERN SPS, designed to measure the branching ratio of $K^+ \longrightarrow \pi^+\nu\nu$ with a decay-in-flight technique, collected a data set in 2016-18.

Results from the analysis of this data set will be presented, including first evidence for the $K^+ \longrightarrow \pi^+ \nu\nu$ decay at 3.5σ significance and the strongest limits to date on $K^+ \longrightarrow \pi^+$+invisible searches.

Measuring the CP structure of the Yukawa coupling between the Higgs boson and leptons

Mohammad Hassan Hassanshahi on behalf of the CMS collaboration

Imperial College London, UK

The Standard Model of particle physics predicts that the Higgs boson is even under charge-parity (CP) inversion. Therefore, any deviation from a pure CP-even scenario indicates a clear sign of new physics. In this study, we perform the first direct measurement of the CP structure of the Yukawa coupling between the Higgs boson and leptons in the $H \rightarrow \tau^+\tau^-$ decay channel.

The analysis is based on the data from proton-proton collision recorded by the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) during 2016 to 2018. The data set corresponds to a total of 137 fb^{-1} integrated luminosity and includes a combined analysis of the $\tau_h\tau_h$ and $\mu\tau_h$ final states, in which τ_h represents the hadronic decays of lepton. The CP of the coupling was measured using the angular correlation between the decay planes of the leptons, with a method originally proposed in [1]. Dedicated techniques were deployed to reconstruct the decay planes and machine learning methods were used to distinguish between the signal (Higgs) and background as well as to differentiate between different decay modes.

The measured value for the mixing angle between a pure CP-even and CP-odd scenario was found to be $4^\circ \pm 17^\circ$. This result is compatible with the Standard Model predictions within uncertainties and excludes a pure CP-odd scenario at 3.2 confidence level. [2]

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[2] CMS Collaboration, "*Analysis of the CP structure of the Yukawa coupling between the Higgsboson and leptons in proton-proton collisions at* Summary CMS-PAS-HIG-20-006*,* 2020

Measurement of differential cross-sections of top-quark pair production in association with additional jets in highly boosted events

Jonathan Jamieson[1], Mark Owen[1], Federica Fabbri[1], Kevin Sedlaczek[2], Johannes Erdmann[2] and Kevin A. Kroeninger[2]

[1]University of Glasgow, UK, [2]Technische Universität Dortmund, Germany

Top anti-top ($t\bar{t}$) pair production at the Large Hadron Collider (LHC) is often observed in the presence of additional high energy radiation. Similarly boosted $t\bar{t}$ events, where one top-quark recoils receiving a high transverse momentum (p_T) "boost", are common. Comparing the latest data measurements with different QCD theory models at the intersection of these two regions helps test how suited current theories are to estimating complex, multi-scale, and above leading order $t\bar{t}$ processes. This talk presents such measurements, showing single and double-differential $t\bar{t}$ cross-section measurements as functions of kinematic properties of additional QCD radiation. Results are derived from proton-proton collisions, at a centre of mass energy of $\sqrt{s} =$ 13TeV, using events with a high p_T, large-radius, re-clustered jet, one muon or electron and at least two b-tagged jets in the final-state, using data recorded by the ATLAS detector from 2015 -- 2018. Unfolded results

are shown in a fiducial phase space for a subset of 1D and 2D variables related to properties of additional-jets and the $t\bar{t}$ system.

Time-dependent CP-violation at LHCb with $B \to D_{CP}\, \pi\pi$ decays

A. G. Morris

University of Warwick, Coventry, UK

Time-dependent Dalitz plot analysis of $B \to D_{CP}\, \pi\pi$ using LHCb Run 1 and Run 2 data allows us to probe the CKM angle β without suffering from the penguin-pollution which exists in the 'golden mode's mediated by $b \to c\bar{c}s$ decays. Since both modes are fairly precise, any differences found in the measurements of sin(2β) will necessarily indicate the presence of new physics, likely to be contained within the penguins of the golden modes. Furthermore, this decay gives sensitivity to cos(2β) and is expected to be world-leading in the precision of that measurement.

Developing an Active-Target detector for studying nuclear reactions of astrophysical significance

Soham Chakraborty[1], Alison Laird[1], Warren Lynch[1], Lars Martin[2]

[1]University of York, UK, [2]TRIUMF, Canada

Active-Target technology enables a gas target also to act as the detection gas, eliminating the physical barrier between the target and the detection volumes. Detectors using this technology play a significant role in low energy nuclear physics. The ability to use radioactive beams and a flexible choice of target gas, enable these detectors to efficiently study various nuclear reactions with astrophysical importance.

The prototype Active-Target detector is being jointly developed by University of York, UK and TRIUMF, Canada. We will use helium as the detector gas to study alpha induced reactions at low centre of mass energies. In order to detect events with low energy deposition, a GEM (Gas Electron Multiplier) structure was previously used inside the detector, which provides electron multiplication inside the detector volume. This amplification stage enables the detection of events over a larger dynamic range. Currently we are modifying the existing prototype at University of York by using state of the art μ-RWELL GEM configuration. The new setup will provide a higher gas gain and better immunity from discharges in the detector at higher operating voltages, compared to the previously used GEM configuration. Moreover, the detector traps the ionization electrons generated by the unreacted beam inside the central cathode cage by virtue of the cylindrical geometry and two concentric cathodes at different potentials. In comparison to other Active-Target detectors, this structure enables it to accommodate high beam intensities without pile-up. One of the benefits of the setup is, it allows detection of nuclear reactions taking place at different centre of mass energies at different positions along the beam-line inside the central cathode cage. The detector can efficiently measure the energy loss of reactions products and reconstruct their tracks inside the detection volume to give a precise location of the reaction vertex. This enables the measurement of excitation function using a single incident beam energy.

We will present the underlying physics, detailed mechanism and the astrophysical motivation behind the development of the detector.

The first angular analysis of the $B^+ \to \pi^+\mu^+\mu^-$ decay using Run I and Run II data at the LHCb experiment

Maria Flavia Cicala
University of Warwick, United Kingdom

Rare semi-leptonic $b \to s l^+ l^-$ and $b \to d l^+ l^-$ decays can be probed with the large LHC data set. These decays are rare in the Standard Model (SM) because they are loop-suppressed, making them especially sensitive probes for New Physics effects. Measurements of branching fraction and angular distribution can be performed to test hypotheses regarding potential extensions to the SM that consider alternative flavour structures. The data collected during Run I of the LHC allowed measurements of $b \to s$ transitions to be made. These measurements present some tension with SM predictions. Until recently, there was not a large enough data set to study $b \to d$ processes in detail due to the additional CKM suppression of these decays. The large number of b hadrons produced in LHC collisions during Run I and II of the LHC has enabled the study of semi-leptonic $b \to d l^+ l^-$ decays for the first time.

This presentation focusses on the decay $B^+ \to \pi^+ \mu^+ \mu^-$, which was first observed by LHCb in the Run I data set. The combined Run I and Run II dataset enables an angular analysis to be performed for the first time. The angular distribution of this decay provides sensitivity to effects beyond the SM through observables that can be accurately compared to SM predictions. The decay can be described by a single angle, defined by the angle between the positively charged lepton direction and the pion direction in the dilepton rest-frame. The angular distribution depends on two parameters, a constant term, F_H, and a forward-backward asymmetry, A_{FB}. Both F_H and A_{FB} are predicted to be close to zero in the SM for muons and electrons but can be significantly enhanced in extensions of the SM. Progress towards a measurement of F_H and A_{FB} using the full Run I and II data set will be presented.

Alternative Design for Large Scale Liquid Scintillator Detectors: Stratified LIquid Plane Scintillator (SLIPS)

Iwan Morton-Blake

University of Oxford, UK

The construction of large-scale liquid scintillator detectors is complicated by the need to separate the scintillation region from photomultiplier tubes (PMTs) due to their intrinsic radioactivity. This is generally done using acrylic/nylon barriers, whose own activity can also lead to substantial cuts to the fiducial detection volume for a number of low energy (~MeV) studies. Such barrier constructions become increasingly difficult and expensive for larger detector volumes, with JUNO already pushing the boundaries of what might be achievable.

The SLIPS concept is to do away with such physical barriers entirely by instead mounting PMTs on the bottom of a wide cavity and covering them with a distillable, lipophobic liquid, above which a less dense scintillator is layered (e.g. various ethylene glycols*).*

Thin and highly reflective (>90%) surfaces near the top and side areas of the detector provide a buffer region against radioactivity from the walls and to reflect scintillation light back to the bottom PMT array. Initial simulation studies indicate that using a similar fiducial volume to JUNO, a similar energy resolution can be achieved with half the number of PMTs using this approach.

This design may allow for a much more simple and economical construction of large-scale scintillation detectors, which could have impact in a number of areas; 0νββ and solar, supernova and geoneutrinos along with long baseline monitoring of reactors, which require scintillator masses of the order of ~50kT.

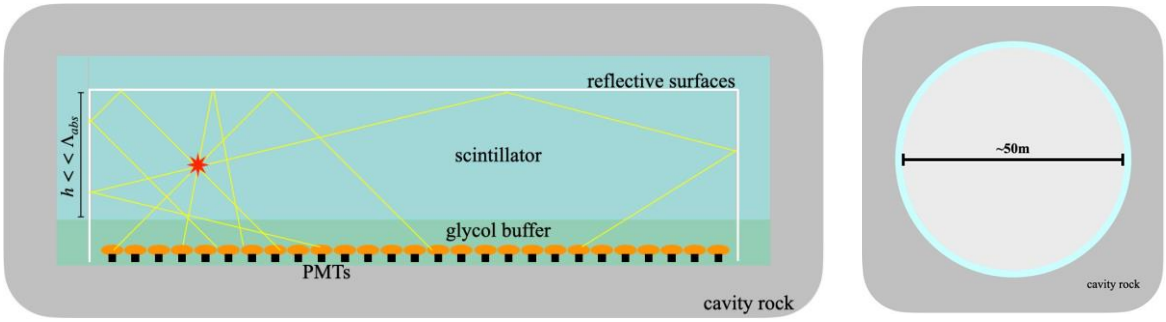

Fig. 1. SLIPS design. Left - cross-sectional side view; right - top view.

The MARA Low-Energy Branch: The first tests and next steps

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[1]STFC Daresbury Laboratory, UK, [2]University of Jyväskylä, Finland, [3]University of Liverpool, UK

The MARA low-energy branch (MARA-LEB) [1,2] is a novel facility currently under development at the University of Jyväskylä. The primary aim of MARA-LEB will be to study ground and isomeric-state properties of exotic proton-rich nuclei employing in-gas-cell and in-gas-jet resonance ionisation spectroscopy and mass measurements. Initially these studies will focus on nuclei close to the *N*=*Z* line and in the region of ^{100}Sn which are of particular interest to the astrophysical *rp* process [3] and the study of the proton-neutron interaction [4], before expanding to other regions of the nuclear chart.

For the study of exotic nuclei, special experimental conditions are required to isolate the ions of interest from the overwhelming amount of unwanted nuclei produced during nuclear reactions. In MARA-LEB these conditions will be achieved by combining the MARA vacuum-mode mass separator [5,6] with a buffer gas cell, an ion guide system [7] and a dipole mass separator for stopping, thermalising and transporting reaction products to the experimental stations.

Resonance laser ionisation spectroscopy will be possible either in a separate region inside the gas cell or inside a hypersonic gas jet at the exit of the cell, which will allo for more accurate measurements [8]. A dedicated state-of-the-art Ti:Sapphire laser system will be used to provide reliable experimental data on the ground and isomeric-state properties of exotic isotopes.

Mass measurements will be achieved using a radiofrequency quadrupole cooler and buncher coupled to a multi-reflection time-of-flight mass spectrometer [9]. These devices will allow for fast and accurate mass measurements of several isotopes with high impact on the *rp* process or isotopes which can be used as test grounds for state-of-the-art nuclear models.

In this presentation we will give an update on the current state of the MARA-LEB facility and the outcome of preliminary tests.

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Selecting charged current ν_μ interactions with final state γs in the T2K near detector

T. A. Doyle[1], M. Lawe[1], and H. M. O'Keeffe[1] (on behalf of the T2K collaboration)

[1]Lancaster University, UK

The Tokai to Kamioka (T2K) experiment [1] is a long-baseline neutrino oscillation experiment based in Japan. Charged current (CC) neutrino interactions are of particular importance to the oscillation analysis of the experiment. The CC interactions at the near detector can be used to reduce the systematic uncertainties in the prediction of the number of oscillated events at the far detector. CC samples from the off-axis near detector ND280 are split into three categories based on the number of charged pions in the final state: events with no charged pions in the final state (CC0π), events with one charged pion in the final state (CC1$\pi^{\pm}$), and events with any other number of mesons in the final state (CCOther). The CCOther sample contains all CC events with a final-state π^0, almost 99% of which decay to two photons. This work aims to develop a selection to divide the CCOther sample into two samples, based on the presence or absence of photons in the final state. The resulting CCPhoton sample is a higher purity multiple pion selection at the near detector than the traditional CCOther, giving a better understanding of the underlying physics and a more robust analysis. With extrapolation to the far detector, Super-Kamiokande, the CCPhoton sample helps constrain background in the one ring electron-like sample, and signal in the multi-ring sample. In turn, this can help to constrain overall event rates and neutrino energies at the far detector.

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Adversarial Neural Networks for ttH(γγ)

Emily Petrova Takeva, Philip Clark and Liza Mijović

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The ATLAS and CMS experiments at CERN have recently reported first observation of the top quark Yukawa coupling. This work uses innovative machine learning technique, adversarial neural networks, to improve the sensitivity of the ATLAS measurement.

The ttH(γγ) channel is crucial for the precise measurement of the top Yukawa coupling. The narrow distribution of the di-photon invariant mass (M!!) enables efficient separation

between the ttH signal and the backgrounds. The photon kinematic variables can be used to

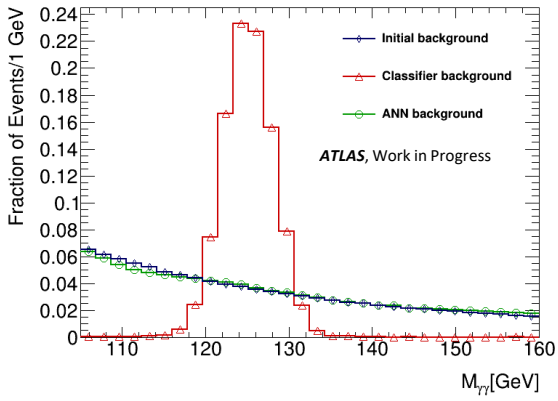
increase the background rejection; however, they introduce a problem. Rejecting events using the photon kinematics sculpts the background if the variables used are correlated with

the M!!. The goal of this work is to use photon kinematics to separate the signal ttH from the

main backgrounds with negligible background sculpting and optimal sensitivity.

The adversarial neural networks (ANNs) have been trained to separate the simulated ttH signal from either of the simulated ttyy background, or the background data events. ANNs have proven to minimise the sculpting significantly (Fig. 1), while keeping the efficiency of background rejection and the performance of the networks at an excellent level (Fig 2.). The talk will discuss the performance and challenges of using the ANNs in H->yy analysis.

Finalising the work includes a clear proof of a better ANN performance compared to the currently used classification method.



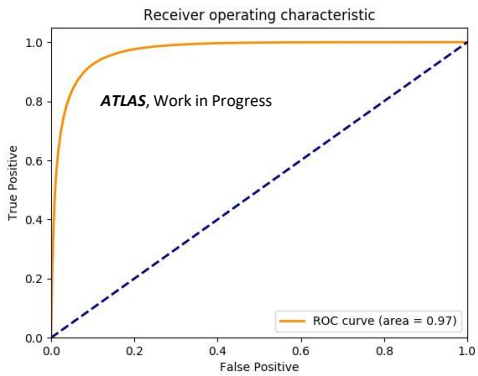


Fig.1 Current result for the M!! distribution. Fig 2. Current performance of the ANNs Background initial distribution is in blue, after classifier training in red and after ANN training in green.

Collectivity beyond ^{78}Ni: Lifetime measurements of low-lying states in neutron-rich ^{82}Zn

Z Chen[1], Zs Podolyák[1], F Flavigny[2], M Górska[3], and the RIBF196 collaboration

[1]University of Surrey, UK, [2]LPC Caen, France, [3]GSI Darmstadt, Germany

Magicity and shape coexistence around doubly magic ^{78}Ni has attracted much attention in recent years[1-3]. Observation of low-energy core-excited states in this region[2,3] indicates the onset of deformation which could be attributed to the intruder configurations originating from multiparticle-multihole excitations above the major shell gap. Observables such as lifetimes of excited states could provide crucial information on the properties of collective structures.

In a recent gamma spectroscopy study of ^{82,84}Zn[4], the magicity was confined to N = 50 in ^{80}Zn only while an onset of deformation for low-lying states was identified with the help of

$E(2_1^+)$ and $E(4_1^+)/E(2_1^+)$ ratios towards heavier Zn isotopes. However, the lifetimes of these states are still unknown. Therefore, we performed a new experiment to measure the lifetimes of low-lying states in ^{82}Zn to further investigate the development of collectivity beyond N = 50.

In this talk, I will briefly introduce our new experiment performed at the RIKEN Nishina Center. ^{82}Zn was populated mainly in ^{83}Ga(p,2p)^{82}Zn reaction. The consequent gamma rays were detected by the high-revolution HiCARI germanium array so that the lifetimes of low- lying states could be determined by line shape analysis. I will present some preliminary gamma spectra, first lifetime measurements, and comparisons with shell model calculation.

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Measurement of charm mixing and strong-phase parameters using multi-body decays at LHCb

Kamil Fischer

University of Oxford, UK

The study of fundamental particles is critical to searches for new physics phenomena beyond the Standard Model. Dedicated experiments allow for precise measurements of charge-parity violating observables in decays of *b* and *c*-hadrons. Improving the precision of such studies is crucial in the search for deviations from Standard Model predictions. These measurements can be performed by considering the decay-time and phase-space distributions of multi-body decays of neutral mesons.

The first single-experiment observation of D^0- $\overline{D}^0$ oscillations has only been performed in the last decade, whilst only recently direct CP-violation in *D*-meson decays has been observed by the LHCb collaboration for the first time. Such an effect has not yet been seen in mixing related phenomena (indirect CP-violation). Additionally, the mass difference between neutral meson interaction eigenstates has not been shown to conclusively differ from zero. As such, the charm sector is an ideal probe of the SM since contributions from massive particles participating in long-range scattering could potentially enhance the transition rates between neutral mesons and the corresponding anti-mesons. Furthermore, the strong-phase information that can be obtained from mixing-studies in multi-body *D*-meson decays is vital input for measurements of the CKM angle γ in *B*-meson decays, which in turn can be used to test the consistency of the SM.

A measurement of charm mixing and CP-violating parameters is presented using the $D^0 \rightarrow K_S^0 K^+ K^-$ decay mode, which adopts a model-independent approach known as the `bin-flip' method. The approach is applied to this decay mode for the first time, having already been successfully used for the $D^0 \rightarrow K_S^0 \pi^+ \pi^-$ mode. The status of the measurement is described, and the implications for our knowledge of charm mixing and CP violation, and the measurement of γ is discussed.

An improved muon neutrino charged-current single positive pion cross section on water using michel electron reconstruction in the T2K near detector

Sam Jenkins

University of Sheffield, UK

The T2K (Tokai to Kamioka) experiment is a long baseline accelerator neutrino experiment, situated in Japan, whose primary goal is to measure neutrino oscillation parameters. T2K is composed of two detector sites; the near detector complex is located next to the neutrino beamline at the Japan Proton Accelerator Research Complex (J-PARC), Tokai, where multiple particle detectors are used to monitor the unoscillated beam. 295 km downstream from the neutrino production point, the Super-Kamiokande detector is used as the far detector for T2K, to observe interactions from the neutrino beam after having undergone oscillation.

To measure oscillation parameters, a good understanding of neutrino interaction cross sections is required, in order to minimise systematic errors in the measurements. The near detector site includes a magnetised tracking detector, ND280, which sits 280 m downstream of the beam production point at the same off-axis angle as Super-K. Along with monitoring the beam composition, ND280 is designed to measure different neutrino interaction rates, to give a better understanding of the individual cross sections.

I will present the status of an updated measurement of the muon neutrino charged current cross section with one positively charged pion in the final state ($\nu_\mu CC1\pi^+$) in ND280. The updated measurement will include greater statistics and, in particular, access to new regions of phase space, with the inclusion of kinematic reconstruction of the charged pion from its subsequent decay chain to Michel electrons, the first time this technique will have been used.

New or updated neutrino cross section measurements will be used to compare to our current interaction models, in order to reduce model-related systematics, which will be particularly important for next generation oscillation experiments.

Exploring Neutron stars EoS with coherent π^0 π^0 photoproduction at A2@MAMI

Mihai Mocanu

University of York, UK

Recent measurement of coherent π^0 photoproduction on Pb lead to a most accurate determination of the neutron skin, constraining nuclear matter Equation of State (EoS) at around $\rho \sim 1\rho_0$. A natural next step is elucidating nuclear EoS at higher densities to tune our understanding of the most violent process in the Universe - neutron stars mergers. It was demonstrated that at densities above $\sim 3\rho_0$ dibaryonic degrees of freedom come into play. The work presented in this talk is aiming to improve our knowledge of dibaryon behavior in dense nuclear matter by measuring coherent $\pi^0\pi^0$ photoproduction off Ca-40/48 nuclei. The experiment was performed at the A2@MAMI facility in Mainz (Germany). The goal of the analysis is to identify the first genuine hexaquark, the *d*(2380)*, photoproduction on nuclei. We are expecting to determine the medium modifications of the *d*(2380)* in nuclear matter and constrain its couplings. These new results will further improve our understanding of the neutron stars equation of state and allow precise determination of the maximum neutron star mass as well as provide key ingredients for calculation of the neutron stars merger dynamics. Also, an interplay between the hexaquark, quark-gluon and hyperon degrees of freedom in the EoS of a dense nuclear matter will be discussed.

New Physics Searches with Low Energy Electron Recoils in the LUX ZEPLIN Experiment

Elizabeth Leason

University of Edinburgh, UK

Dark matter makes up 85% of the matter content of the universe, but its nature remains a mystery. A range of experiments have now ruled out much of the allowed parameter space for conventional dark matter

models, such as weakly interacting massive particles (WIMPs). Alongside the traditional nuclear recoil WIMP search, direct detection experiments can carry out complementary electron recoil searches, using interactions of electrons with low mass fermions or bosons to probe a range of dark matter and new physics models.

The LUX-ZEPLIN (LZ) experiment is a next generation time projection chamber under construction at SURF, which aims to achieve world leading WIMP sensitivity with a combination of high exposure (5.6 tonne fiducial mass, 1000 live days) and low background rates. Here the projected sensitivity of the LZ experiment to a range of different low energy electron recoil signals is presented. These include nonstandard neutrino interactions, solar axions, axionlike particles, hidden photons, mirror dark matter and leptophilic dark matter. World leading sensitivity is expected in each case. The dependence of the sensitivity on the level of electron recoil background is also examined.

Measurement of the Charge Asymmetry in Beauty Dijet Production at the LHCb Experiment

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We present work towards a new measurement of the charge asymmetry in beauty dijet production at the LHCb detector. We calculate the asymmetry in several bins of the invariant mass of the dijet system. The angular distribution of beauty dijet production is predicted to have a small asymmetry in the Standard Model (SM), with the leading order source of this coming from production via the Z boson. A previous measurement at the LHCb experiment showed agreement with the SM but the new analysis uses a dataset which is ten times larger. A similar measurement was also made at the LEP experiments, and showed a 2.8σ tension with the SM, and is one of the long standing tensions with the SM in the Electroweak sector. The new LHCb measurement will add further information on this existing tension. In the longer term, if combined with a similar measurement of charm dijet production LHCb can probe the Zbb and Zcc couplings at a sensitivity comparable to the current world's best.

Using inclusive electron scattering data to improve the uncertainty on the nucleon removal energy systematic at T2K

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The T2K experiment is a long-baseline neutrino experiment based in Japan, with the primary focus on the measurement of neutrino oscillation parameters. In order to make these measurements, particularly of the mass difference Δm^2, it is vital to have a correct modelling of the reconstructed neutrino energy. The total systematic error on these calculations has a variety of contributions. However, it is widely reported the dominant systematic is the nucleon removal energy: the energy required to remove one nucleon from the nucleus.

In T2K's current neutrino-nucleus interaction model, the nuclear model and kinematic factors are separated. Using inclusive electron scattering data, we can move beyond this approximation and reduce the systematic on the removal energy, whilst also removing a portion of the associated bias.

I will present the status of the ongoing work to break the factorisation of the nuclear model and the kinematic factor. It will focus on the development of a 'pseudo-electron' model in the NEUT generator, along with comparisons to inclusive electron data in order to produce a physically driven correction. The effect of

this correction on existing CC0π measurements is also discussed, to observe the sensitivity of cross-section experiments to this alteration.

Instrumentation of the Darkside-20K Outer Detector

Samuel Hill

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The DarkSide-20K dark matter direct detection experiment has set a target of achieving a background rate of <0.1 events in an exposure of 200 tonne-years. Neutrons are a key contribution, due to their ability to imitate dark matter signals, therefore the outer detector surrounding the TPC is designed to identify and veto neutrons with high efficiency. The outer detector consists of two liquid argon buffers separated by gadolinium-loaded acrylic. Neutrons capture in the acrylic creating a 9MeV gamma shower. The veto detector will be instrumented with approximately 3000 photo-detector modules (PDMs) made of tiled silicon photomultipliers (SiPMs). This talk will discuss the simulation of the outer detector, with focus on the simulation of the PDMs, review the expected backgrounds resulting from the veto and photosensors themselves, and describe the neutron tagging algorithm performance.

In Search of Charged Lepton Flavor Violating Decay $\mu^+ \rightarrow e^+e^+e^-$ for the Mu3e Experiment and Test-Beam Data Acquisition System for Characterization of High Voltage Monolithic Active Pixel

Afaf Wasili

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The Mu3e experiment will search for the neutrinoless (lepton flavour violating) decay of an anti-muon to two positrons and an electron $\mu^+ \rightarrow e^+e^+e^-$, with a sensitivity to a branching ratio smaller than 10^{-15} (phase I) and 10^{-15} (phase II). To achieve the proposed sensitivity, the Mu3e experiment requires excellent vertex resolution, accurate timing, and momentum measurements. These are needed to reduce the main background processes: Michel decays with an internal conversion and combinatorial background.

The proposed talk will present an overview of the Mu3e experiment. A study of the projected sensitivity of the experiment is presented as well as tracking performance studies on realistic detector conditions. The novel MuPix HV-MAPS chip developed for the Mu3e pixel tracker has been tested in the laboratory and at test beams at PSI and DESY. The latest results from laboratory and test beam characterization will present for MuPix8 Telescope as shown in Fig 1 (left). The MuPix8 is the first large-scale prototype in the MuPix group proving the scalability of the HV-MAPS technology with a total active area of 2×1 cm^2, see Fig 1 (right). It was shown to have a very good detection efficiency of above 99%, a signal to noise ratio of better than 20, good spatial and time resolution for single-pixel hits.

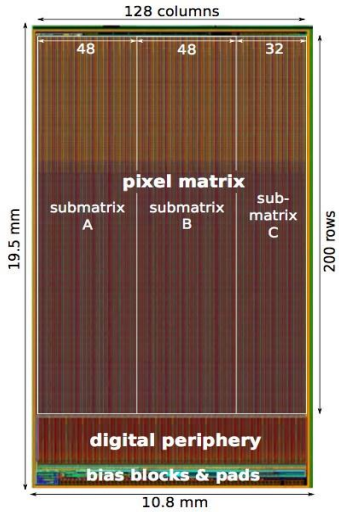

Fig 1: Left: Picture of the MuPix8 Telescope layout. Right: The MuPix8 chip.

Towards the Discovery of First Strange Hexaquark with CLAS12

G. Clash

University of York, UK, for the CLAS Collaboration

Quantum Chromo Dynamics (QCD) is our current best description of interactions between quarks and gluons and it not only predicts the existence of the well understood meson (two-quark) and baryon (three-quark) states it also predicts exotic Tetra-, Penta- and Hexaquarks.

Experiments taking place at Thomas Jefferson Lab in Virginia, USA using the upgraded CLAS12 detector system allows a detailed investigation of exotic hadron systems. In our experiment electrons accelerated to an energy of 10.6GeV, scatter off either a liquid hydrogen or deuterium target. Various interesting effects can be explored in these reactions, including production of exotic hadrons, such as hybrids, pentaquarks or hexaquarks the latter being the subject of my research.

In my talk I will present the analysis of data recently collected at CLAS12, which provides the first search for a d_s hexaquark, a particle with quark content uuudds or uuddds an quantum numbers J^p=3^+. Preliminary results on most promising decay channels, e.g. $ed \rightarrow e'K^+d_s \rightarrow e'K^+\Lambda n$ and $ed \rightarrow e'K^+d_s \rightarrow e'K^+dK^-$ will be shown. To enhance analysis sensitivity to these rare channels an improved PID (Particle Identification) method was developed. All experimental methods were verified utilizing more conventional reactions with similar final states, in particular $ep \rightarrow e'K^+\Lambda$, $ep \rightarrow e'\rho^0 p$ and $ep \rightarrow e'\omega p$. These reactions on proton target were used as benchmarks to tune analysis techniques applied for the experiment's with deuterons. First results on a d_s searches will be confronted with analysis of empirical and simulated data of the most prominent background channels.

A profound theoretical study utilizing Monte Carlo calculations to simulate different decay branches acquiring the branching ratios and partial decay widths was also carried out to clarify the reaction dynamics for the d_s hexaquark. The results of these calculations will be discussed as well.

Optimizing the search for pair production of Higgs bosons in the $b\bar{b}b\bar{b}$ final state using data collected from proton-proton collisions in the ATLAS detector

Lucas Santiago Borgna

University College London, UK

The Standard Model predicts the pair-production of Higgs Bosons with well-defined couplings. The measurement of these processes enables us to examine the shape of the Higgs potential by constraining the Higgs trilinear coupling and potentially probe into new physics. The Standard Model predicts pair-production cross sections of 2 orders of magnitude less than the single Higgs production. The $b\bar{b}b\bar{b}$ final state has the highest branching fraction of 0.34 and is used to examine the pair production process [1]. The main challenge behind this final state is the large multi-jet background, which cannot be reliably reproduced by Monte Carlo generators. Run 2 has concluded and we are now able to leverage a total integrated luminosity of 126.7 fb^{-1}, which is over 3.5 times more than the previous search [2].

The pair production searches are split into two streams, resonant and non-resonant. The resonant search uses either a spin-2 Graviton or a scalar resonance to produce the Higgs pairs as a benchmark signal. The non-resonant search uses a Standard Model Higgs for pair production. The event reconstruction of the resonant search is split into two regimes, resolved and boosted, in order to optimize how jets are reconstructed across the entire mass spectrum. To increase the signal acceptance across the full kinematic phase space a combination of multi-b-jet triggers are used. This is an unconventional approach as it does not support the standard calibration factors derived by ATLAS. Instead, the triggers are orthogonalized into different trigger categories such that some events are discarded.

The background estimate is obtained through a data-driven approach by utilizing a control region with little signal contamination. The data is used to train a neural network in order to perform density ratio estimation. This reweighting mechanism can then be extrapolated into the signal region to yield the nominal background estimate. An alternative model is derived in the validation region and these two models are used to provide an uncertainty to the background estimate. The background model and the assigned systematic uncertainty were validated in an orthogonal control sample. This control sample showed that the background model provides suitable coverage of mismodelling from extrapolating towards the signal region.

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Cross-section measurements for the production of theragnostic terbium isotopes at the Birmingham cyclotron facility

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Theragnostics is the combination of both sides of Nuclear Medicine; therapy and diagnostic imaging. Initially two different elements were used for a theragnostic style of cancer treatment; ^{177}Lu as a β-therapy isotope and ^{68}Ga for PET (positron emission tomography) imaging. However, in the last 9 years there has been an interest in using the same element but different isotopes. Terbium has been of great interest due to four of its isotopes being ideal for medical use, as demonstrated by C. Müller et al. [1,2,3,4].

Currently MEDICIS at CERN are the main producers of these isotopes, using a mass spectrometer to separate the desired terbium isotopes from a target. However, these isotopes are time sensitive and for terbium to be a viable hospital treatment a local and cheaper method of production is required.

At the University of Birmingham, investigations into terbium isotope production using stationary targets at the MC40 cyclotron have been performed. Following our preliminary studies irradiating both gadolinium and europium targets presented at the 2019 INPC [5], our latest work to improve cross-section measurements at the MC40 cyclotron will be presented along with cross- section measurements of an alpha beam on a europium target.

Nine natural europium foils were used to measure alpha-europium cross-sections for theragnostic ^{152}Tb and ^{155}Tb production. The nine cross-section measurements covered an alpha energy range of 23 – 39 MeV. The production and cross-section of other terbium isotopes were also measured and the importance of these contaminants will be discussed. In addition, experimentally measured cross-sections will be compared against theoretically predicted values calculated by TALYS [6].

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Search for tZq production in association with a Z boson in the dilepton final state

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First observed by the CDF [1] and D0 [2] collaborations at Fermilab in 1995, the top quark is the heaviest of the known elementary particles and has a mass of around 172.6 GeV [3]. Its heavy mass leads to it having a short lifetime of 10^{-24} s [3], which is less than the time scale required for hadronization. Therefore, unlike other quarks, the top quark can pass on spin information to its decay particles. Its mass also enables it to be the only quark heavy enough to decay into a W boson and bjet. These are some of the reasons that motivate the study of top quark production. In the LHC, the dominant production mode is top-antitop pair production, but the top quark can also be produced singly, in association with a heavy vector boson. An example of this is tZq production, which has been observed by CMS in the t-channel in the trilepton final state [4]. The tZq production mechanisms are predicted by the Standard Model (SM) and are sensitive to both the tZ and WWZ couplings. They therefore can be used to probe electroweak interactions that involve a top quark. Additionally, tZq production forms an irreducible background to rare SM processes, such as tH production and to Beyond the Standard Model processes, such as flavour changing neutral current production (tZq-FCNC). This talk will discuss the current search for tZq production in the t-channel in the dilepton final state. For the search, a shape-based analysis is conducted of data recorded by the CMS detector in 2016, 2017 and 2018, and of simulation samples.

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A search for unvirialized axions in ADMX

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The axion was initially hypothesized to explain the invariance of strong interactions under the transformations *P* and *CP.* If axion exists and has a small mass, it could make up the majority of the dark matter in the Milky Way halo. The Axion Dark Matter eXperiment (ADMX) searches for axions using a high-Q microwave cavity inside the bore of an 8-T solenoid magnet. A recent run of the ADMX covered a frequency range of 680 MHz – 800 MHz, corresponding to axions with 2.81 – 3.3 μeV masses. The high-resolution channel in ADMX looks for unvirialized axions; these may be due to late in-fall into the halo from intergalactic space. Unvirialized axions may have a velocity dispersion of $v/c = O(10^{-6})$. Due to the motions of Earth in the galaxy relative to the axion flow, the signal undergoes a diurnal and annual modulation. The frequency modulation is around 10 mHz per 100 second scan at a cavity frequency of 1 GHz. The high-resolution data have a frequency resolution sensitive to such modulations. In this talk, I will present the results of this analysis for the ADMX Run 1B.

Towards a Gas Filtration Setup for Ultra-Sensitive SF6 Gas Based Rare-Event Physics Experiments

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The gas SF_6 has become of interest as a negative ion drift gas for use in directional dark matter searches [1]. However, as for other gas targets in such searches, it is important that contamination can be removed as problems with signal detection can arise. Radon gas contamination can decay and produce unwanted background events, able to mimic genuine signals [2]. Outgassing and leaking introduce contaminants such as water, oxygen and nitrogen, which can capture interaction-produced electrons, thus suppressing signals [3]. Many gas rare- event physics experiments manage contamination with continuous flow and disposal of the target gas. However, SF_6 is the most potent greenhouse, making this method problematic. Therefore, an alternative method must be implemented for future SF_6 based experiments, where the gas is reused and recycled.

The demonstration of radon removal from SF_6 gas with molecular sieves (MS) was a significant advance towards an SF_6 filtration system [4]. It was also found that other MS types were able to capture water, oxygen and nitrogen from SF_6. This makes it possible to remove both radon and air contaminants by using an MS filter mixture. Unfortunately, since commercial MS are primarily used in the petroleum industry, where having low radioactive content is not essential, commercial MS intrinsically emanate radon at levels unsuitable for ultra-sensitive rare-event physics experiments.

A method to produce low radioactive MS has been developed in Nihon University (NU) [5]. A comparison with a commercially available Sigma-Aldrich MS was made by calculating a parameter indicating the amount of radon intrinsically emanated by the MS per unit radon captured from SF_6. It was found that the NU developed MS emanated radon 61±9% less per radon captured [6], making it a better candidate for use in an SF_6 filtration system. An MS SF_6 filtration setup has been designed and is under construction. The gas system utilises a Vacuum Swing Adsorption (VSA) technique [7], making on-site regeneration of the MS possible. The regeneration functionality enables the MS filter to be reused, allowing continuous long-term operation of the filtration setup. The gas system's capabilities are planned to be tested with a small-scale low-pressure SF_6 TPC detector. A long-term comparison of the detector's performance with and without

the gas system operating can provide a demonstration of significantly reducing the total amount of gas required for ultra-sensitive SF_6 gas rare-event physics experiments.

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Rare Measurements and Forbidden and Exotic Searches at NA62

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The NA62 experiment at CERN collected data between 2016 and 2018 with the main goal being to measure $K^+ \to \pi^+ \nu \bar{\nu}$, a decay with branching ratio $\sim 10^{-10}$. Besides this, NA62 has a wide-ranging physics programme. Recently published measurements of rare processes (such as $K^+ \to \pi^+ \mu^+ \mu^-$) and searches for forbidden decays and exotic particles (such as $K^+ \to \pi^\pm \mu^\mp e^+$, $K^+ \to \pi^- l^+ l^+$ and heavy neutral leptons in $K^+ \to l^+ N$) will be presented.

New Algorithms for Reconstructing Event Pairs in Gd-H_2O for Reactor Anti-neutrino Detection

Liz Kneale

University of Sheffield & AWE, UK

Inverse beta decay (IBD) interactions of anti-neutrinos in Gadolinium-doped water (Gd-H_2O) give a correlated positron-neutron signal. We have developed a combined position reconstruction which uses information from both interactions to give a common IBD vertex. We are also investigating using machine learning to improve vertex reconstruction.

Gd-H_2O for anti-neutrino detection is an emerging technology, which has been adopted by experiments including Super-K Gd and ANNIE. The WATCHMAN collaboration has proposed a Gd-H_2O detector to demonstrate a scalable application for remote reactor monitoring at large distances. This is unique to WATCHMAN as a primary goal.

The gadolinium brings advanced neutron detection capabilities which boost sensitivity to low-energy reactor anti-neutrinos. The correlation of the positron and neutron pair also enables the suppression of backgrounds which would otherwise overwhelm the signal.

The combined reconstruction improves vertex resolution. This is expected to facilitate a lower threshold energy for detection compared to a single-event reconstruction. Reconstructing pairs helps reject random coincidences of uncorrelated radioactive background events and methods are being developed to discriminate optimally between the signal and background for more powerful background reduction.

This talk presents the current status of the new reconstruction algorithms and plans for further development.

Probing the internal structure of the neutron: Hard Exclusive π0-Production off neutrons using a deuteron target at CLAS12

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Generalised Parton Distributions (GPDs) encode a wealth of information about the internal structure of nucleons. This includes the ability to create a 3D tomographic image of the nucleon, as GPDs relate the longitudinal momentum fraction of quarks with their transverse position. As such, they have been a compelling and active area of research in Hadron physics for the last couple of decades. GPDs are accessed via measurements of hard-exclusive processes such as Deeply-Virtual Compton Scattering (DVCS) and Hard Exclusive Meson Production (HEMP). In these reactions, a leptonic probe is scattered off a target nucleon with sufficiently high four-momentum transfer (Q2) such that the scattering takes place off individual quarks inside the nucleon. In the case of DVCS this produces a high-energy photon, and in HEMP it produces a meson.

The need for exclusive reconstruction of the final state, where the scattered lepton, recoiling nucleon and produced photon or meson are all detected, has meant that the vast majority of research to date has been performed on proton target experiments. However, for a fuller understanding of the nature of nucleons, and to perform flavour separation of GPDs for the up and down quarks, measurements on neutron targets are also required.

Jefferson Laboratory (JLab) is host to the Continuous Electron-Beam Acceleration Facility (CEBAF) which was recently upgraded to provide an electron beam at energies up to 12 GeV to fixed targets in four experimental halls. Hall B houses the recently completed CLAS12 detector suite. This includes the Central Neutron Detector (CND) which was included in CLAS12 to enable exclusive reconstruction of neutron recoil channels.

In this talk we present a preliminary extraction of the Beam-Spin Asymmetry of Hard Exclusive π0-Production off neutrons using a deuterium target with CLAS12 - a first-time measurement and exciting step forward in the study of nucleon structure.

New advancements in the shape coexistence and the onset of deformation at ^{98}Y

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The nature of the transition between contrasting shapes of nuclei at competing energy levels remains one of the biggest puzzles still to be solved by nuclear structure physicists today. One such example of this is the

shape coexistence present in ^{98}Y between its ground state and low-lying isomer. This coexistence discovered in 2007 [1] by extraction of the mean-square charge radius and electric quadrupole moments of these states by means of laser spectroscopy. Whilst the existence of this shape change was established beyond doubt, the results of this work depend on the knowledge of the spin of this isomeric state (presumed at the time to be either 4 or 5). However, recent studies from GAMMASPHERE suggest a possible spin of as high as 7 [2] which means that the nature of this transition may not yet be fully understood.

To further this investigation, laser spectroscopy has again been used at the IGISOL lab of the JYFL Facility, University of Jyväskylä to study these nuclear states, this time with a different atomic transition: 4d5s $^3D_2$ -> 4d4p $^3P_1$, as developed in [3]. The new transition allows for the study of many more hyperfine components and therefore an unambiguous measurement of the nuclear spin; in turn, this allows for a reliable extraction of the nuclear parameters and an insight into the nature of this shape transition.

This contribution will present new values for the magnetic dipole and electric quadrupole moments and the nuclear charge radius of ^{98m}Y. These complementary measurements of deformation, alongside its confirmed nuclear spin value, now give us a new insight into the nuclear rigidity.

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An Electron Neutrino Selection in the Short Baseline Near Detector (SBND)

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The Short Baseline Neutrino (SBN) program aims to address the long standing tension surrounding the LSND and MiniBooNE anomalies hinting at the existence of a fourth, sterile neutrino[1][2]. As the detector closest to the Booster Neutrino Beam (BNB) target, SBND plays a vital role in constraining the uncertainties for MicroBooNE and ICARUS, the intermediate and far detectors. All three detectors are Liquid Argon Time Projection Chambers (LAr TPCs) affording excellent spatial and calorimetric resolution, alongside the reduction in systematic uncertainty obtained by using common detector technology. Due to the proximity to the beam target, SBND has an extremely high neutrino flux which enables the possibility of making world leading neutrino-nucleus interaction measurements and dark matter searches[3].

Despite recent measurements, large uncertainties remain around the modeling of neutrino-nucleus interactions; this is especially true for Argon which is both more complex and less well understood than water and hydrocarbon targets previously used in neutrino experiments[4][5]. The uncertainties are particularly large for electron neutrinos as these typically make up only a small fraction of neutrino beam, thus there are fewer measurements available which are often statistically limited. SBND expects over 5 million ν_μ CC interactions and 40,000 ν_e CC interactions over 3 years of running, an increase of several orders of magnitude over existing cross section measurements on Argon[6][7][8]. The increased statistics also allows SBND to probe many exclusive interaction channels, an ability which is enhanced by the exceptional resolution available with a LAr TPC.

This talk will outline a procedure for selecting these ν_e CC interactions in SBND, in turn allowing for precise physics measurements to be made. This begins with combining the TPC, Cosmic Ray Tagger (CRT) and Photon Detection System (PDS) to remove cosmic ray background associated with a surface level detector. Furthermore, utilizing the powerful ability of LAr TPCs to perform particle identification on tracks and showers allows for distinguishing the ν_e CC interactions in a beam that is dominated by ν_μ. Track identification allows for excellent discrimination between muons,

protons and pions to be made and shower identification for powerful separation between electrons and photons. Combining these elements yields a selection which rejects the vast majority of backgrounds whilst maintaining a reasonable efficiency for ne CC interactions.

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Advances towards the measurement of γ-transitions from clustered states in $^{16}O^*$

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University of Birmingham, UK

A study of the $^{12}C(\alpha,\gamma)^{16}O^*$ reaction is presented in this work. The experimen- tal data analysed in this work were recorded in 2019 at the University of Birming- ham's MC40 Cyclotron using the **B**irmingham **A**rray for **L**igh**t** nuclei **I**nvestigation (**BALTI**) which is a combination of a target surrounded by a compact charged- particle detector array and LaBr3 gamma detectors.

A comparison between simulations and experimental data has been performed to understand gamma transitions between clustered states in rotational bands in $^{16}O^*$. This comparison is important to prepare the next iteration of the experiment which is planned to be performed in 2021.

The motivation for this work is to measure or put constraints on the B(E2) values in the ^{16}O nucleus. Such observations enable the unambiguous assignment of rotational levels built on cluster configurations.

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Identification of sub-μs isomeric states in the odd-odd nucleus 178Au.

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The neutron-deficient gold (Z = 79) isotopes in the vicinity of the neutron mid-shell N = 104 provide prolific examples of shape coexistence and isomerism at low excitation energy. Recently, an extended ISOLDE (CERN) campaign measuring the ground state charge radii of such nuclei established a

shape transition, from almost spherical to deformed. In alpha- decay studies of ^{178}Au, two long-lived alpha decaying states were determined, a low spin ground state (^{178}Au^{g}) and a high spin isomer (^{178}Au^{m}) [1]. Identification of these states show that ^{178}Au is key to understanding the spherical to deformed transition in gold nuclei.

To complement this investigation excited states above the alpha-decaying states were studied in an experiment at the RITU gas-filled separator at JYFL Jyväskylä by applying recoil-decay tagging techniques [2]. Two new isomeric states with half lives of 294(7) ns and 373(9) ns were observed with use of a segmented planar germanium detector at the focal plane, with a high efficiency at low energies. These isomers were observed to decay to the two long-lived alpha-decaying states, ^{178}Au^{g,m} discovered in the ISOLDE campaign.

With knowledge of these sub-μs isomers, isomer-decay tagging has been used to reveal rotational bands in ^{178}Au. Further knowledge of the level scheme of ^{178}Au is key to understanding the shape transition seen in the gold nuclei

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Near detector constraint on beam and interaction model parameters in the T2K long-baseline neutrino oscillation analysis

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T2K is a long-baseline neutrino oscillation experiment [1] which aims to measure and place limits on the mixing angles, the CP-violating phase [2], and the mass-squared differences of the neutrino mass states in the PMNS parameterisation of neutrino mixing. A beam of muon (anti)neutrinos travels 295 km from the J-PARC accelerator facility in Tokai on the east coast of Japan to the Super-Kamiokande detector in the Kamioka mountains on the west coast. Super-Kamiokande is a 50,000-tonne water-Cherenkov detector which sits off-axis to the neutrino beam to increase the flux of neutrinos with the desired energy. Measuring the relative numbers of muon-type and electron-type neutrinos through their charged-current interactions allows us to measure the probability of oscillation from muon (anti)neutrinos to electron (anti)neutrinos.

A suite of near detectors 280 m downstream of the neutrino production target characterises the beam's intensity, direction and composition prior to oscillation. Fitting beam flux and neutrino interaction models to the data from these detectors allows the 14% overall systematic uncertainty on the event rates at the far detector that can be achieved through fitting to external data such as NA61/SHINE [3] to be further reduced to 4%. There are two cross-validated fits to the off-axis near detector ND280. A frequentist gradient descent method finds the best-fit values of the parameters as well as their covariances which are passed on to the oscillation analysis fitters. A Bayesian Markov Chain Monte Carlo method produces posterior probability density functions for comparison with the frequentist fit and can perform a joint fit with the far detector to estimate the oscillation parameters directly.

Extensive updates to the neutrino interaction model have been made since the 2019 result [2] further improving T2K's world leading precision oscillation parameter measurements. Collection of new data has allowed for the implementation of new selections of the ND280 data which are more similar to those used at the far detector. External data from the NA61 experiment using a replica of T2K's neutrino production target

as opposed to thin-target data has reduced the pre-fit unoscillated right-sign neutrino flux uncertainty from external data from order of 10% to 5% in the peak of the T2K flux. This presentation will discuss the techniques and updates described above.

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How good a poison is ^{16}O?

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The nucleus ^{16}O is a neutron poison for the s-process in massive stars. Neutrons produced from the $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ neutron source are absorbed on the abundant ^{16}O in the star. These neutrons may be recycled through the $^{17}\mathrm{O}(\alpha,n)$ reaction which competes with the $^{17}\mathrm{O}(\alpha,\gamma)$ reaction. The efficacy of the s-process strongly depends on the ratio of the $^{17}\mathrm{O}(\alpha,n)$ and $^{17}\mathrm{O}(\alpha,\gamma)$ reactions.
The $^{17}\mathrm{O}(\alpha,n)$ and $^{17}\mathrm{O}(\alpha,\gamma)$ reactions proceed through states in the compound nucleus, ^{21}Ne. Considerable experiment effort has been expended on measuring these two reactions, using direct measurements and indirect probes. Significant uncertainties remain in the reaction rates at the relevant astrophysical temperatures. In this contribution, we report an experimental study of the ^{20}Ne(*d,p*)^{21}Ne reaction using a neon-implanted carbon target and an Enge magnetic spectrograph. From the differential cross section of the ^{20}Ne(*d,p*)^{21}Ne reaction, the neutron widths are determined and used to constrain the spin and parity, and the relative $\mathrm{neutron}/\gamma$ branching of excited ^{21}Ne states. Based on these results, we provide updated reaction rates for the $^{17}\mathrm{O}(\alpha,n)$ and $^{17}\mathrm{O}(\alpha,\gamma)$ reactions and report on the astrophysical impact of these new rates on the efficacy of the s-process.

The Potential for Supernova Model Discrimination with NEO

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Supernovae are the most luminous antineutrino sources known, producing high-flux bursts of antineutrinos. These supernova antineutrino bursts not only provide an early warning for optical observations, but they also carry information from within the supernova progenitor star potentially providing valuable physics data.

Neutrino Experiment One (NEO) is a proposed kiloton-scale water Cherenkov detector in the north east of England at the existing STFC Boulby Underground Laboratory facility. This planned detector will use a gadolinium-doped water volume surrounded by photomultiplier tubes to observe antineutrinos by detecting coincident positrons and neutrons from inverse beta decay (IBD). The detector's main goal is to demonstrate the technology's capability for non-proliferation applications but this tuning for IBD events will also allow it to observe antineutrino bursts from supernovae within our galaxy, providing spectral information.

Since supernova models are currently constrained by the measurement of a single supernova, SN1987a, new data provided by the observation of a supernova antineutrino burst with an energy and time spectrum would deliver new information to improve our understanding of the processes driving supernovae. A detector's capability to distinguish between existing models acts as a useful benchmark to determine the detector's ability to provide information that can improve the current understanding of

supernova physics.
This study explores the model discrimination capabilities of NEO for a baseline design as well as design variations. The impact of detector design choices such as detection volume and photo coverage are shown using a selection of supernova models as well as different supernova progenitors. Detector simulations of the different supernova burst spectra are used to determine identification and misidentification rates and determine supernova distance predictions from each input model, showing the effective range of NEO as a supernova observatory.

Systematic Uncertainties in the NOvA ν_μ Disapearance Analysis

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NOvA is a long-baseline accelerator neutrino oscillation experiment using the NuMI neutrino beam at Fermilab. Its physics goals are probing the neutrino mass hierarchy, CP-violating phase δ_{CP} and octant of ϑ_{23} mixing angle by observing the ν_e appearance and ν_μ disappearance signals. Two functionally identical detectors are placed off-axis from the centre of the NuMI beam. The near detector at Fermilab is 100 m underground, blocking a great number of cosmic rays, and the far detector located at Ash River, 810 km away from the beam source. Systematic uncertainties originating from beam flux, cross section, detector response, calibration, and other sources play a significant role in the NOvA analysis. This talk will present techniques used to deal with systematic uncertainties and their effects on NOvA's latest precision measurements in the ν_μ disappearance oscillation channel.

Quarkonia production in jets at LHCb

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Measurements of J/Ψ meson production in jets have been performed at a centre of mass energy of 13 TeV and a pseudorapidity range of $2.5 < \eta(\text{jet}) < 4.0$ at LHCb. The prevailing picture of J/Ψ meson production in parton-parton scattering predicts a large degree of transverse polarisation, whereas minimal polarisation is observed in data. Alternatively, quarkonium production in parton showers can explain the lack of observed polarization. This theory also predicts that J/Ψ mesons are rarely produced in isolation. Measurements of the J/Ψ isolation in data, given by $z(J/\Psi) \equiv pT(J/\Psi)/pT(\text{jet})$, have been found not to agree with the current prompt production model. This measurement is repeated for various quarkonia states. Investigations into the polarisation of the J/Ψ versus z(J/Ψ) are also underway.

Supernova Pointing with Multi-Detector Neutrino Light Curve Matching

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Neutrino signals from galactic core-collapse supernova sources are expected to arrive Earth hours prior to the emitted electromagnetic waves. This early signal is already used by the global SNEWS neutrino detector network to provide an alert to the astronomical observer community [1]. Time differences between the neutrino detectors can also be used to reconstruct the supernova direction. In the past, this method was limited by the low event yield of existing detectors [2]. The next generation of kilotonne detectors, however, when linked by an upgraded SNEWS network [3], will be able to provide a rapid estimate of

the direction which can guide subsequent observers [4-6]. Moreover, the neutrino signal conveys information from the deep core of the supernova and may influence follow-up observation strategy. In our studies, we have investigated methods to characterize and compare the neutrino light curves measured by different experiments using a range of supernova models spanning different progenitor masses, whether they form a black hole, and other possible phenomena.

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Electrons for Neutrinos at Jefferson Lab

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Current and future neutrino facilities, including MicroBooNE, MINERvA, DUNE and T2K, rely on reconstructing the incident neutrino beam properties (energy and flux) from the measurement of reaction products from neutrino-nucleus interactions in their detectors. The extraction of physics quantities from these experiments, such as neutrino oscillation parameters, depends on good neutrino energy reconstruction which is highly sensitive to nuclear physics which is currently poorly constrained.

The Electrons for Neutrinos project (e4nu) at the Thomas Jefferson National Accelerator Facility (JLab) uses wide phase space exclusive electron scattering data from past and future experiments on nuclear targets with the CLAS and CLAS12 detector systems to obtain a comprehensive understanding of the interaction of leptons with matter. Data from JLab provides us with the tools needed to constrain the available theoretical tools that are crucial in modelling the neutrino-nucleus interaction, and thus play a key role in the precise determination of the physics observables from neutrino-nucleus interactions measured at neutrino experimental facilities.

We will discuss prospects for future e4nu experiments as part of the CLAS12 experimental program, using CLAS data and event generator descriptions of the A(e,e'p pi) reaction on various nuclear targets as a benchmark for the development of analysis tools that will allow all relevant CLAS and CLAS12 datasets to be analysed in a common framework.

Towards a test of the Standard Model's lepton flavour universality with the ratio of branching fractions $\boldsymbol{B(W \to \tau\nu) / B(W \to \mu\nu)}$ at LHCb

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Precision tests of Standard Model (SM) predictions are powerful way-finders in the hunt for new physics. Measuring the ratio of branching fractions $R_{!"} = B(W \to \tau\nu) / B(W \to \mu\nu)$ is particularly interesting, as

it probes the key SM property of *lepton flavour universality* (LFU): that the nuclear weak force treats all 3 generations (or *flavours*) of leptons equally. Up to small, well- understood corrections due to the differing masses of the τ and μ, $R_{!"}$ = 1 in the SM. A measurement of this parameter that disagrees is therefore clear evidence for new physics.

This measurement also takes place in a fascinating context. At the Large Hadron Collider, the LHCb experiment continues to discover persistent hints of LFU violations in semi-leptonic B decays, in measurements such as $R_{\#}$ and $R_{\#*}$. Furthermore, the previous LEP combination of $R_{!"}$ exhibited an intriguing 2.8σ deviation from the SM. Although a recent ATLAS result in $t\bar{t}$ decays has found no such deviation, a competitive second measurement at the LHC - in a complementary channel - would shed more light on the anomalies in this sector.

LHCb is well-designed to make such a measurement. In both of our channels of interest, the final state is high-transverse-momentum muons, which are either promptly produced ($W \rightarrow \mu\nu$) or displaced from the primary interaction ($W \rightarrow (\tau \rightarrow \mu\nu\nu)\nu$). LHCb's high-precision tracking system, in particular the fine-grained Vertex Locator (VELO), allows us to distinguish prompt and displaced muons by their differing impact parameter and transverse momentum. Combinatorial QCD backgrounds or muons from the in-flight decays of hadrons can be suppressed by picking out those muon tracks that are isolated – something that can be well understood with LHCb.

In this talk I will go into further detail on the motivations for making this measurement, before talking through the strategy, challenges and current status of the analysis, as well as prospects for its completion.

Search for charged lepton flavour violation in top quark decays

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Charged lepton flavour violation (cLFV) is predicted by many beyond the Standard Model theories of particle physics. A search for cLFV in top quark decays is presented, using proton-proton collision data collected by the ATLAS detector in Run 2 of CERN's Large Hadron Collider. We explore the possibility of a top quark decaying to an opposite-sign different-flavour lepton pair with an additional (up or charm) jet. The cLFV decay is treated model-independently, using an Effective Field Theory (EFT) interpretation. Details of the cLFV signature, the multi-variate technique for discriminating between signal and background and the maximum-likelihood fit to extract the signal strength will be presented.

Structure of neutron rich nuclei in the ^{132}Sn region

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The r-process contributes to approximately half of all nuclei produced that are heavier than iron. Magic number nuclei produce abundance peaks due to reduced neutron capture probabilities. The N=82 nuclei below the doubly magic ^{132}Sn are connected to the r-process an abundance peak at around A=130. A key question in modern nuclear physics is how the shell structure evolves across the N=82 closed shell. Currently theoretical calculations have to be relied upon which can prove problematic for regions far from stability.

One such N=82 r-process path nucleus is ^{129}Ag which has 3 proton holes below ^{132}Sn. The aim of this work was to obtain experimental data on the single particle structure of ^{129}Ag which can be applied to achieve a

better understanding of the abundance peak produced via the N=82 r-process mechanism. The single particle states can be populated via a proton knockout reaction of ^{130}Cd. As these nuclei are far from stability a radioactive beam facility which has the ability to produce high energy beams with high intensity is required. The RIBF at RIKEN was chosen as it fits the above criteria. The experiment to study ^{129}Ag was carried out in November 2020 at the RIBF using a 345 MeV/nucleon primary beam of ^{238}U impinging on a 4 mm ^{9}Be initial target with a beam intensity of approximately 60 pnA. Fission fragments were then separated and identified by the BigRIPS fragment separator using a $B\rho - \Delta E - B\rho$ method on a particle by particle basis. BigRIPS was tuned to center on ^{130}Cd and this secondary beam was impinged onto a secondary 6mm ^{9}Be target. After which the new high resolution HPGe HiCARI array was located. Further particle identification was carried out using the ZeroDegree spectrometer to center on ^{129}Ag by using the same method applied in BigRIPS.

The experiment was able to successfully observe gamma spectra for a wide variety of nuclei in the ^{132}Sn region including tentative ones in ^{129}Ag. High statistic gamma spectra of other neighboring nuclei have been produced in which new gamma-ray transitions have been observed. Examples of which are the single proton and single neutron hole isotope ^{130}In and the single proton hole and single neutron isotope ^{132}In. These are of importance as they can provide information on the proton-neutron interaction both south-west and south-east of ^{132}Sn. Furthermore, the well-known 2+ and 4+ states in ^{128}Cd [1] have been observed. Based on their Doppler shifts the half-life of these states, and consequently reduced transitions strengths can be determined. This will shine a light on how collectivity arises as we move away from ^{132}Sn.

In the talk I will report on the most important isotopes and relevant transitions found so far.

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Identifying α -cluster states in ^{14}O using the TexAT TPC.

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Nuclear clustering, the observation of nuclei-like substructures within the nucleus, is a long- studied artifact of the strong interaction. Light nuclei have been useful systems for studying this phenomenon, with the highly deformed $\alpha-\alpha$ configuration presenting a striking candidate for the ^{8}Be ground state. Their relatively few degrees of freedom can prove tractable for certain computational models, which may permit the theory describing the forces that give rise to nuclear structure to be tested and further developed.

Beyond N=Z systems, it is theorised that the presence of additional "valence" nucleons serves to stabilise unbound nuclei, giving rise to nuclear molecules such as ^{9}Be. Anti- symmetrised molecular dynamics (AMD) modeling of ^{14}C and its lesser studied mirror ^{14}O, the subject of this talk, suggests the existence of states with molecular-like structures. Greater experimental measurement of the structure of these nuclei is needed[1] in order to identify whether these predicted states exist, and to determine their corresponding properties.

In collaboration with Texas A&M University, excited states above the α threshold in ^{14}O have been populated using a ^{4}He(^{10}C,α)^{10}C elastic scattering reaction with inverse kinematics. The Texas Active Target (TexAT) [2] time projection chamber (TPC) at the Cyclotron Institute, Texas A&M University, was used in conjunction with a Micromegas (MICRO-MEsh GASeous) detector to determine (charged) particle trajectories within the active volume, and an array of segmented silicon detectors to record the energy of particles leaving the gas. Information from these detectors was acquired using the General Electronics for TPCs (GET) system [3].

In this talk, I will discuss an approach to reconstruct the event-by-event kinematics in order to build an

excitation function, starting with the signal waveforms recorded by the GET electronics. The current state of the analysis will be presented.

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Decay spectroscopy of nuclei near doubly magic ^{100}Sn with the Advanced Implantation Detector Array (AIDA) at RIKEN.

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The proton-rich region of the nuclear chart surrounding the doubly magic nucleus ^{100}Sn (N = Z = 50) is of great interest in nuclear structure studies. Measurement of the properties of nuclei in this region serves as a direct test of the nuclear shell model.
The Advanced Implantation Detector Array (AIDA) is a state-of-the-art silicon detector array which is used to measure the decay properties of exotic, short-lived unstable nuclei. AIDA was used in conjunction with the Decay Total Absorption γ-ray Spectrometer (DTAS), a NaI crystal array γ detection system, during an experimental campaign at the Radioactive Ion Beam Factory (RIBF), RIKEN in Japan, the primary aim of which was to measure the properties of proton-rich nuclei in the ^{100}Sn region. This presentation provides an overview of early analysis of data collected with AIDA from the experiment.

A Silicon Pixel system for monitoring Primary and Secondary Radiation during Hadron Therapy

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There has been a rapid worldwide increase in the number of hadron therapy centres over the last 20 years which include Proton and Carbon beam usage as a radiation treatment beam rather than conventional X-Ray radiotherapy. This increase is driven by hadron therapy's advantageous dose distribution when compared to treatment with photons. While the prescribed dose is delivered to the tumour with minimal entrance and low exit dose to the surrounding healthy structures, one of the concerns particular to hadron therapy is the secondary radiation that is created during treatment. This radiation is created as a result of proton/carbon interactions with human tissue will increase the probability of secondary cancers developing in surrounding tissues. The quantity of the radiation created depends on tissue type, beam energy, and delivery technique.

In this project we are using Geant4 to simulate the hadron beam and its interactions with a silicon pixelated detector that is fully submerged in the water phantom and located in the main path of the beam. The designed system involves two silicon sensors separated by a thermal neutron converter layer to make the detector sensitive to detecting thermal neutrons by capturing them and measuring the resulting fission products produced (alpha at 2.05 MeV and triton at 2.73 MeV) will be emitted in opposite directions from the converter material.

A full simulation study which will provide a better understanding of the hadron therapy behaviour within a water phantom via monitoring and tracking the beam distribution of the primary hadrons and investigating the associated secondary radiation will be presented.

Measurement of Λ_c^+ production in pp, p-Pb, and Pb-Pb collisions with the ALICE experiment at the LHC

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In heavy ion collisions, a deconfined state of matter, called the quark-gluon plasma (QGP), can be created. Heavy quarks are created at the beginning of the collision and interact with the QGP during all stages of the system evolution, and can act as a useful probe of energy loss and hadronisation mechanisms. In particular, the charmed baryon-to-meson ratio Λ_c^+/D^0 is sensitive to hadronisation mechanisms and the role of fragmentation vs coalescence (or recombination) in the hadronisation of charm quarks. Theoretical models of hadronisation, taking into account different mechanisms and effects, can be compared to experimental results.

The ALICE detector is built specifically for the high multiplicity environment of heavy ion collisions, and has a very high vertex reconstruction and particle identification capability. Recently, measurements of the Λ_c^+/D^0ratio in pp and p-Pb collisions have been published by ALICE [1],[2]. The Λ_c^+ candidates were reconstructed using both the $\Lambda_c^+ \to pK^-\pi^+$ and $\Lambda_c^+ \to pK_s^0$ decay channels. They show an increased Λ_c^+/D^0 ratio compared to e^+e^- and ep collisions, which challenges the usual assumption of collision-system independent fragmentation. Currently an analysis is ongoing to measure the Λ_c^+ production in Pb-Pb collisions using the $\Lambda_c^+ \to pK^-\pi^+$decay channel, in addition to a previous measurement using $\Lambda_c^+ \to pK_s^0$ decay channel [3]. In this contribution these recent measurements of Λ_c^+ in ALICE will be presented.

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β-delayed neutron emission from r-process nuclei along the N=82 shell closure

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The rapid-neutron capture process (*r*-process) is thought to be responsible for the production of half of the elements heavier than iron. Despite being first proposed over 60 years ago [1], the astrophysical conditions under which the process takes place are still a matter of debate [2]. The recent observation of the

gravitational wave event GW170817 [3] and its accompanying electromagnetic counterpart [4] point to binary neutron-start mergers as a significant source of *r*-process material in the galaxy. However, it is not yet known whether these events are only partially or entirely able to reproduce the *r*-process abundance pattern observed throughout the galaxy. Determining the robustness of the *r*-process occurring in these environments involves the accurate modeling of the nucleosynthesis taking place under these explosive conditions requiring precise nuclear input data, including nuclear masses, beta-decay half-lives, and beta-delayed neutron emission probabilities [5]. For the exotic neutron-rich nuclei that are of importance to the r-process, relatively few of these values are known experimentally. There is, therefore, high demand for experimental measurements along the r-process path which can be used as direct inputs in *r*-process calculations and as reference points for the development of theoretical models in regions far from stability.

Beta-delayed neutron measurements were performed in the region near the doubly magic isotope ^{132}Sn at the Radioactive Isotope Beam Factory (RIBF) at RIKEN, Japan. Exotic neutron-rich nuclei were produced via the in-flight fission of ^{238}U and implanted in the active stopper AIDA the Advanced Implantation Detector Array [6]. Here beta-decays were measured in coincidence with neutrons that were detected using the BRIKEN neutron counter array [7]. This talk will present the analysis methods used to obtain the beta-delayed neutron emission probabilities of nuclei along the *N*=82 shell closure.

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A Simulation Framework for Spherical Proportional Counters

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The spherical proportional counter [1] is a gaseous detector currently applied to a wide range of fields, including direct dark matter searches [2], neutrino-less double beta decay searches [3] and fast neutron spectroscopy [4]. A dedicated simulation framework [5] is presented that combines the strengths of the Geant4 and Garfield++ toolkits. The framework allows the detector's properties to be studied in detail, providing insights for detector R&D, experiment design optimisation, and data analysis and interpretation. Example applications of this simulation framework to different experimental contexts will be presented. Validation of the simulation is ongoing with data collected with spherical proportional counters across the world.

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Unbound states in ^{16,18,20}C with the R^{3}B/LAND setup: the search for the mixed- symmetry 2^+state

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The evolution of the traditional nuclear magic numbers away from the valley of stability is an active field of research. Experimental efforts focus on providing key spectroscopic information that will shed light into the structure of exotic nuclei and understanding the driving mechanism behind the shell evolution. Recently, ^{A}N(p,2p)$^{A-1}$C quasi-free scattering reactions were employed at the R^{3}B/LAND setup at GSI to measure the proton component of the 2^+ state of ^{16,18,20}C in order to investigate the Z = 6 spin-orbit shell gap towards the neutron dripline. The experimental findings support the notion of a moderate reduction of the proton $1_{p1/2}-1_{p3/2}$ spin-orbit splitting towards the neutron dripline [1, 2].We work upon the model of a two-state mixing of pure proton and pureneutron excitations to describe excited 2^+ states in neutron-rich carbon isotopes[3, 4]. The coupling of the unperturbed proton and neutron 2^+ states should give rise to a second 2^+ state of mixed symmetry character expected to be strongly populated in these (p,2p) reactions. This mixed-symmetry 2^+ state should lie at an excitation energy of about 7 MeV, above the neutron separation energy,and thus, decay by neutron emission. The goal of this work is to identify this mixed-symmetry 2^+ state. Its observation will add weight to our simple pictureof describing the neutron-rich C isotopic chain, giving us great insight into the shell evolution towards the neutron dripline at Z=6. In this contribution, I will present the current status of the experimental investigation of the structure of unbound states of ^{16}C,^{18}C and ^{20}C induced via quasi-free scattering (p,2p) reactions from ^{17}N,^{19}N, and ^{21}N, respectively.

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Structure of ^{23}F following a one-neutron removal reaction

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The neutron-rich light isotopes have attracted a lot of experimental and theoretical interest in recent years and constitute a fertile testing ground for theoretical models ranging from mean- field shell model to couple-cluster techniques. When approaching the neutron dripline, the inclusion of three-nucleon forces in the calculations is of paramount importance; this has been demonstrated, for example, in reproducing the abrupt termination of bound oxygen isotopes at ^{24}O [1].

Although the neutron drip line (and even beyond that) has been reached experimentally for the light nuclei, fundamental spectroscopic information is still missing in the bound neutron- rich isotopes. Odd fluorine

neutron rich isotopes with just one proton outside the Z=8 close shell and an even number of neutrons can provide important shell structure information since an interpretation of single-particle degrees of freedom on top of a closed-shell core can be assumed and tested.

The ^{23}F isotope (N=14) in particular can be viewed as a ^{22}O core with a single valence proton. In this work we studied the bound excited states of ^{23}F via a one-neutron removal reaction using the high-resolution gamma-ray spectrometer array, GRETINA, coupled to the S800 spectrometer at the NSCL. Several new transitions have been observed in the gamma- ray spectrum and by performing gamma-gamma coincidence analysis, an extended level scheme has been built for ^{23}F. Our findings will be compared to phenomenological shell model and ab initio calculations using interactions derived from chiral Effective Field Theory.

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Development of a Z+jets dedicated treatment within the scope of the search for the decay of the Higgs Boson to charm quarks with the ATLAS experiment

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A direct search for the Standard Model Higgs boson decaying to a pair of charm quarks is currently underway in ATLAS, probing the Higgs Yukawa couplings to the second generation of fermions. This analysis makes use of the full LHC ATLAS Run 2 dataset, corresponding to an integrated luminosity of 139 fb^{-1} of proton-proton collisions at a centre-of-mass energy of 13 TeV.

Higgs boson production in association with a W or Z boson is targeted, where only leptonic W/Z boson decays are considered. The analysis is then divided in three channels according to the reconstructed lepton multiplicity. Both charm and bottom jet tagging algorithms are used to identify the signature of the $\mathrm{H} \rightarrow \mathrm{c}\bar{\mathrm{c}}$ decay, while reducing contamination from $\mathrm{H} \rightarrow \mathrm{b}\bar{\mathrm{b}}$ decays.

The $Z(\rightarrow \mathrm{l}\bar{\mathrm{l}})\mathrm{H}(\rightarrow \mathrm{c}\bar{\mathrm{c}})$ channel benefits particularly from the additional statistics, allowing for improvements with respect to the previous ATLAS search built around this channel, that used an integrated luminosity of 36.1 fb^{-1} of proton-proton collisions at the same centre-of-mass energy [1].

This channel exhibits the simplest background composition in terms of parton level processes, being heavily dominated by Z+jets production. However, owing to the performance of the flavour tagging algorithms used, the background composition in terms of jet flavour (i.e. b, c and light flavour jets) is diverse and often not described by MC event generators to the precision required. I will outline a strategy, based on the definition of several signal and control regions dependant on the multiplicity of c-tagged jets, which can accurately determine the flavour composition of Z+jets from the data itself. This event categorisation approach, combined with a carefully designed statistical analysis procedure, leads to improvements in both the robustness and expected sensitivity of the analysis.

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New dark matter searches with missing energy and b-quark final states at ATLAS

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This talk presents latest results in the search for new physics in final states with b-tagged jets and large

missing transverse energy using the data recorded by the ATLAS detector from 2015-2018 from proton-proton collisions at a centre-of-mass energy of 13 TeV. The data analysis is interpreted in two scenarios: the minimal SUSY R-parity conserving model where the sbottom is assumed to decay into a b-quark and LSP, and a simplified DM model where a spin-0 mediator s- channel decays into WIMPs produced in association with b-quarks. Particular focus is given to the strategies and limitations of ensuring that Standard Model processes that can fake a dark matter signal are well-modelled and constrained from data such that discoveries are not missed nor are erroneous signals claimed.

ARIADNE – A Liquid Argon Time Projection Chamber (LArTPC) featuring an ultra-fast optical readout

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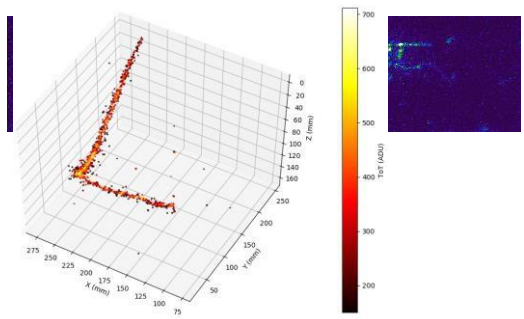
The University of Liverpool, UK

ARIADNE [1] is a state-of-the-art, 1-ton, two-phase, Liquid Argon Time Projection Chamber (LArTPC), featuring an innovative optical readout, to image the secondary scintillation light produced in THick Gaseous Electron Multiplier (THGEM) holes. Initially, ARIADNE utilised single photon sensitive, Electron-Multiplying (EM)CCD cameras. More recently, ARIADNE has successfully undergone further enhancement through integration of an ultra-fast, data driven, imaging system, based on the well- established TimePix3 sensor [2] [3]. With this technology, a dream TPC has been achieved in which calorimetry + 3D positioning 'videos' of particle interactions are produced, from above threshold pixels only, with ns time resolution and mm spatial resolution, acquired through a single optical device.

ARIADNE underwent testing at the T9 beam line, CERN East Area, in Spring 2018, where it became the first two-phase LArTPC with photographic capabilities to be positioned in a charged particle beamline. In doing so ARIADNE successfully imaged beautiful particle-LAr interactions with 1 mm track resolution at momenta between 0.5GeV to 8GeV. ARIADNE readout technology is ideal for colossal two-phase LAr neutrino detectors, such as the proposed kton scale DUNE modules. With attributes allowing for ultra-fast, data driven readout, with calorimetry and mm spatial resolution from an externally mounted, single optical device. EMCCD results from the beam-test and results from TimePix3 cameras will be presented detailing the many benefits and capabilities of these optical technologies.

(a)



(b)

Fig.1. (a) A 5.0GeV beamline electro-magnetic shower, captured with EMCCDs

(b) A cosmic muon to Michel electron decay, captured with a TimePix3 camera.

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Searches for Rare and Forbidden Exclusive Decays of the Higgs and Z Bosons to a Meson and a Photon with the ATLAS Experiment

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The Higgs boson continues to provide an exciting window to potential new physics, following its discovery in 2012. To-date, direct evidence exists only for the third-generation quark Yukawa couplings, and inclusive searches for Higgs boson decays to the lighter generations are made challenging by large QCD backgrounds. Exclusive decays of the Higgs boson to a meson and a photon offer an alternative probe to these couplings, made possible by their distinct experimental signatures: during Run-2 of the LHC, the ATLAS experiment employed triggers dedicated to their detection. Several such investigations have already been published using 36 fb^{-1} of $\sqrt{s} = 13$ TeV proton-proton collisions collected at the LHC and include the analogous Z boson decay channels.

A new set of ATLAS exclusive-decay searches is underway, using the full 139 fb^{-1} of Run-2 data, and includes the first explorations of several channels forbidden at tree-level in the Standard Model: observation of the decays
$H \to D^*\gamma, Z \to D^0\gamma$ and $Z \to K_s\gamma$ would imply the existence of flavour-violating couplings of the Higgs and Z bosons. These searches are characterised by the displaced vertices of the D^0 and the K_s. Both D^* decay modes are captured, to $D^0\pi^0$ and $D^0\gamma$, and the decays $D^0 \to K^-\pi^+$ and $K_s \to \pi^+\pi^-$ are targeted using techniques from previous searches. These analyses are presented as well as the updated search for $H(Z) \to J/\psi\gamma, \psi(2S)\gamma$ and $\Upsilon(nS, n = 1,2,3)\gamma$, which aims to set world-leading limits; this search probes the b- and c-quark Yukawa couplings and focuses on the decay of the quarkonium states to a pair of oppositely charged muons, giving $\mu^+\mu^-\gamma$ final states.

A Search with the ATLAS Detector for the Standard Model Higgs Boson Produced In Association with a Top Quark Pair and Decaying to a Bottom Quark Pair (ttH(bb))

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Higgs boson production in association with a pair of top quarks, ttH, is the most favourable Higgs production mode with respect to attaining a direct measurement of the top-Higgs Yukawa coupling. Although it comprises only ~1% of the total Higgs production cross-section, the ttH production mode remains accessible due to the large quantity of p-p collision data (139 fb^{-1}) collected at the ATLAS detector over the course of Run 2 of the Large Hadron Collider. It is therefore possible to study ttH in the context of many different Higgs decay modes, the decay to two bottom quarks (H→bb) occurring the most frequently. H→bb permits the reconstruction of the kinematics of the Higgs boson, and by extension, offers additional knowledge on the nature of the top-Higgs interaction.

Final states including at least one lepton (electron or muon) originating from a top quark are the most sensitive when measuring ttH(bb) production, as they do not suffer from the fundamental difficulty the all-hadronic channel possesses surrounding the discernment of ttH signal from underlying QCD processes. Consequently, the Run 2 ttH(bb) analysis includes only leptonic final states, that is to say the semileptonic

and dileptonic channels. While the dilepton channel has a comparatively low branching fraction of approximately 5%, it has the benefit of being only negligibly sensitive to the aforementioned QCD background processes. Within the scope of this talk, studies presented will concern the dilepton channel specifically.
An overview of various validation checks for the ttH(bb) dilepton analysis will be presented. The primary study discussed will pertain to the implementation of data-driven methods in estimating corrections to the modelling of the Z+jets process, which contributes ~3% to the overall background and is known to have a degree of cross-section mismodelling, particularly in the case that the associated jets are heavy flavour (i.e. c- or b-jets). In order to verify and correct if necessary the normalisation of the simulated sample, scale factors have been derived by selecting events from a Z+jets-enriched region of phase space, where the dilepton invariant mass is required to be within 8 GeV of the Z mass; this is orthogonal to the selection applied for the nominal analysis fit to data. Checks for consistency with the factors obtained during the previous ttH(bb) analysis, which used 36.1 fb^{-1} of data, have also been made.

Cosmic ray Tomography of the Wylfa Reactor Site Using VIDARR

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The VIDARR detector was deployed at the Wylfa reactor site from July 2014 to February 2016. The detector is designed to measure anti-neutrinos emitted from a nuclear reactor for monitoring purposes. During the deployment at Wylfa cosmic muons were taken alongside these anti-neutrinos.

This data has been examined using a custom cosmic-ray track reconstruction. By observing the attenuation of cosmic rays the reconstructed theta and phi distributions can be used to approximate the width and height of the buildings at Wylfa. These approximated building heights are then compared against a GEANT4 simulation of the buildings improving the reconstruction. Background data taken at the University Liverpool between 2016 and 2018 is used to further improve the reconstruction of the Wylfa site building shadows.

The VIDARR detector can resolve surrounding buildings of appropriate densities. With all uncertainties quantified, the measured and simulated building positions from Wylfa converge on the site buildings occupying the azimuthal being between 10 to 170 degrees , while the height of the site buildings extends from 0 to 60 degrees in the zenith.

The ttH(bb) leptonic analysis at ATLAS

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The magnitude of the coupling of the Higgs boson to fermions is expected to be proportional to the fermion's mass. With the top quark being the heaviest particle in the standard model, its Yukawa coupling to the Higgs is therefore expected to be the largest. This coupling can be measured directly when the Higgs is produced in association with a top/anti-top quark pair, or ttH. The Higgs decays most often to a bottom/anti-bottom quark pair and each top quark can decay either hadronically or leptonically. The specific channels that will be focussed on in this talk will be when one or both tops decay leptonically.
The analysis will be outlined and a number of studies that were completed for this analysis will be presented in this talk, including the migration of events across bins of Higgs p_T and de-correlating the tt+≥1b systematic uncertainty into the three sub-components that it comprises of. These studies make up part of a larger effort that is currently on-going to publish a full run-2 leptonic ttH(bb) result.

Investigation of Isospin Symmetry Violation via One- and Two- Nucleon Knockout Reactions in $T_z = \pm 3/2$ nuclei

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The phenomenon of isospin symmetry in nuclear physics arises due to the exchange symmetry between protons and neutrons. Although the symmetry is not perfect in reality, isospin symmetry aids us to understand the structure of nuclei on either side of the N=Z line and creates a pathway to extrapolate the behaviour of nuclei close to the proton-drip line. The interactions that could cause the breaking of isospin symmetry can be studied through the comparison of isobaric analogue states[1]. To develop our understanding of isospin breaking effects, an in-beam gamma-ray spectroscopic study of the exotic proton-rich ^{47}Mn was performed via a one-neutron knockout reaction from a radioactive ^{48}Mn beam produced by the National Superconducting Cyclotron Laboratory (NSCL). Simultaneously, the exotic proton-rich ^{45}Cr, produced via a two-neutron knockout reaction from ^{47}Cr, was studied. Subsequently, the analogue one-proton knockout reaction of ^{48}V to ^{47}Ti and the analogue two-proton knockout reaction of ^{47}V to ^{45}Sc was also conducted respectively. A novel technique- i.e `mirrored' knockout reactions, provides comprehensive comparison of both of the analogue reaction process (i.e. -1n, -2n and -1p and -2p knockout from a pair of mirror nuclei respectively) and the resulting level schemes of the mirror pair via mirror symmetry arguments. By exploiting the direct nature of the knockout process, assignment of the unknown states in the proton-rich system can be achieved with confidence- i.e ^{47}Mn and ^{45}Cr in this case. This approach allows for the measurement of mirror energy differences (MED) which provide a stringent test of the state-of-the-art microscopic nuclear models. The measurements from such analogue reactions also have the potential to inform discussion about the suppression of spectroscopic strength in knockout reactions-see reference [2].

This work is influenced by the research from S. A. Milne who performed mirrored knockout reactions to analogue states in the A=53 mirror nuclei[3]. The experiment was performed at the NSCL facility using radioactive beams selected by the A1900 fragment separator. The beams were impinged into a ^{9}Be target to produce the pair of mirror nuclei of interest, ^{47}Mn/^{47}Ti and ^{45}Cr/^{45}Sc. Prompt gamma-rays were detected using the state-of-the-art tracking array, GRETINA. The latest results from the analysis of ^{47}Mn and ^{45}Cr will be presented, including a preliminary level scheme, a mirror-energy difference analysis and the latest theoretical predictions.

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The ^{22}Ne(α,n)^{25}Mg reaction rate and its key role in low metallicity AGB stellar nucleosynthesis

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The slow neutron-capture process (*s*-process) is one of the two main processes forming elements heavier than iron in stars. Its efficiency critically depends on key (α,n) reactions, which represent the

main sources of neutrons to trigger the neutron-capture chain, producing all elements up to bismuth [1]. In this work, we compute the evolution and *s*-process nucleosynthesis of low-mass AGB stars at low metallicities using the MESA stellar evolution code [2]. The combined data set includes models with initial masses M_{ini} /M_{sun} = 2 and 3 for initial metallicities around one tenth that of the Sun. The nucleosynthesis was calculated for all relevant isotopes by post-processing with the NuGrid mppnp code [3]. We compared our theoretical predictions with observed surface abundances on low-metallicity stars, finding that the ^{22}Ne(α,n)^{25}Mg reaction rate plays a critical role in the *s*-process at low metallicities. Additionally, our results indicate that recent re-evaluation incorporating indirect measurements [4,5] of the ^{22}Ne(α,n)^{25}Mg reaction rate strongly impact our stellar nucleosynthesis calculations, bringing them into much better agreement with observations. We finally discuss which resonances need future complimentary studies and the impact of current rate uncertainties on the *s*-process.

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Developing a charge plunger method for lifetime measurements in the heavy elements

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The Recoil Distance Doppler-Shift (RDDS) method for measuring the lifetime of excited nuclear states relies on the detection of gamma rays. In cases where the internal conversion coefficient (ICC) becomes large, e.g. for low energy transitions in heavy nuclei, the intensity of γ-ray emissions may be small and the RDDS method becomes impractical. To overcome this difficulty, a charge plunger technique has been previously employed by G. Ulfert et al. [1].

This technique relies on two effects that change the charge state of an ion. Firstly, the large increase of an ionic charge state due to a cascade of Auger electrons that follow the internal conversion of a transition depopulating an excited nuclear state [2]. Secondly, when an ion passes through a thin foil it will pick up electrons causing the charge state to reset to a lower value [3]. In a plunger setting this results in high and low charge components in the ionic charge state distribution (CSD) with intensities that depend on the flight time of the ions between the target and charge reset foil, the ICC of the transition and the lifetime of the excited state. Therefore, an analysis of high and low charge components can be used for lifetime measurements.

The charge plunger method has recently been used at the accelerator laboratory in Jyväskylä, Finland, to perform a lifetime measurement on the yrast 2^+ state in ^{180}Pt [4]. Lifetime measurements of yrast states in ^{178}Pt, taken during the same experimental run, are presented here. The reaction ^{152}Sm(^{32}S,6n)^{178}Pt at a beam

energy of 192 MeV was used to populate excited states in ^{178}Pt. The Differential Plunger for Unbound Nuclear States (DPUNS) was employed together with the vacuum separator MARA to observe the intensities of different charge states. The Jurogam3 array was used to detect prompt γ-ray emission and identify ^{178}Pt nuclei. From a differential decay curve method (DDCM) [5] analysis of high and low charge components in coincidence with an appropriate γ ray detected in Jurogam3, the lifetime of the 2_1^+ state was measured to be 430(20) ps. In an alternative analysis, ^{178}Pt recoils were identified instead by their alpha decay in a double-sided silicon strip detector (DSSD) at the focal plane of MARA. A Bateman fit was performed on the intensities of the high and low charge components, modelling the ground-state band as a rigid-rotor nucleus, and obtained lifetime for the 2_1^+ state of 430(50) ps.

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New measurement of oxygen-15 alpha capture for neutron stars in binary systems through radioactive ion beam alpha transfer

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We present a study of the astrophysical ^{15}O alpha capture reaction [1]. This is a key breakout route from the Hot CNO cycle leading to explosive nucleosynthesis via the rp-process on the surface of neutron stars in binary systems. Determining an accurate cross section for the relevant states is critical for a better understanding of the X-ray burst energy production and light-curves [2], as well as other novel binary stellar systems involving neutron stars and their potential impact on nucleosynthesis [3].

An indirect ^{7}Li(^{15}O,t)^{19}Ne alpha transfer reaction in inverse kinematics is presented. In this reaction we populate the relevant states for temperatures up to 1GK. We take advantage of the post-accelerated ^{15}O Radioactive Ion Beam provided at GANIL and the state-of-the art detection system VAMOS[4] + AGATA [5]+ MUGAST [6] coupled together for the first time, allowing us an unrivalled selectivity for detecting triple

coincidences in this reaction. We will present the experimental set-up and analysis, as well as preliminary results for the strongest populated resonances in ^{19}Ne. We will finally relate this to the higher temperature scenarios for the astrophysical ^{15}O(α,γ))^{19}Ne reaction.

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Improving CP violation sensitivity with improved electron neutrino cross-section measurements at Hyper-Kamiokande

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The high precision era of long baseline neutrino oscillation experiments will require corresponding improvements in the modelling of neutrino-nucleus interactions. These are challenging to calculate due to the low energy of the neutrino probe and the nucleon-nucleon interactions within the nucleus, and so there are large theoretical uncertainties in the neutrino cross-section. In particular, the ratio of the electron neutrino to anti-electron neutrino cross-section has a significant effect on CP violation sensitivity and has not previously been precisely measured experimentally.

Direct measurements of this cross-section ratio at the GeV scale have been hampered by the low electron neutrino component available in these traditional beams, necessitating a large detector with excellent background separation. An approach utilising such a proposed near detector for Hyper-K; the IWCD is shown and the impact of this measurement on the discovery potential for CP violation is discussed.

Contrast to Noise Ratio Method: Quantitative Assessment of Image Reconstruction Algorithms for Muon Scattering Tomography Technique

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Monitoring nuclear waste packages is an important requirement in safeguarding, to control and keep the packages and their contents safe. Hence, it is important to develop a technique that offers a non-destructive mode to investigate the radioactive waste inside well-shielded casks. Avoiding the cost of opening the packages and the hazard of being exposed to a high-dose radiation are possible since the waste packages are investigated non-invasively. Several non-destructive techniques, including Muon Scattering Tomography (MST) are now being investigated by the CHANCE project [1] to characterise radioactive waste materials in conditioned nuclear waste drums.

MST has been shown as a valuable method, especially for investigating well-shielded objects. The efficacy of using MST to investigate such well-shielded materials is ascribed to the fact that muons are highly penetrating particles. The fundamental principle of MST is based on the nature of the object being traversed by muons, for

instance the density and the atomic number (Z) of the object being investigated. Muons undergo Multiple Coulomb Scattering (MCS) as they travel through a material and hence muons experience deflections. In theory, the deflection angle will be larger when muons encounter high-Z material such as Uranium. Two identical muon tracking detectors are typically placed above and below the volume of interest to register the muon hits within the investigated area. This information is used to calculate the scattering angles of muons by reconstructing the trajectories of muon that pass through the volume of interest.

Investigating The Astrophysical s-Process with DRAGON: Direct Measurement of the $^{22}Ne(\alpha,\gamma)^{26}Mg$ Reaction

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Nearly half of all the elements in our Galaxy heavier than iron were formed by the astrophysical s-process. This process involves a series of neutron captures on nuclei lying at or near stability and, as such, represents one of the most experimentally well-studied astrophysical processes to date [1]. However, significant difficulties remain in successfully modelling the astrophysical s-process, due to large uncertainties in the nuclear reactions responsible for the production of neutrons in stellar environments.

In this regard, the $^{22}Ne(\alpha,n)^{25}Mg$ reaction has been identified as the primary source of neutrons for the weak s-process neutrons in AGB stars at temperatures of 0.2 - 0.35 GK, which is responsible for the production of elements in the mass range, A ~ 60 – 90 [2].

Unfortunately, the production of neutrons, in these scenarios, is strongly influenced by the competing $^{22}Ne(\alpha,\gamma)^{26}Mg$ reaction, which gains prominence at lower temperatures, due to its positive Q value. Moreover, the $^{22}Ne(\alpha,\gamma)^{26}Mg$ reaction, itself, carries significant uncertainties, due to the unknown properties of key resonances, which makes it extremely difficult to accurately model s-process nucleosynthesis in AGB stars.

Recently, a first direct measurement of the $^{22}Ne(\alpha,\gamma)^{26}Mg$ reaction in the Gamow energy window of helium burning in AGB stars was performed using the DRAGON recoil separator at TRIUMF National Laboratory, Canada. In this talk the methodology used for this study will be discussed and preliminary results will be presented.

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A search for invisibly decaying Higgs Bosons in the fully hadronic final state, targeting the ttH and VH production modes

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The invisible decay of the Higgs boson provides a window into the study of dark matter. This analysis derives an upper limit on the Higgs-to-invisible branching ratio in the ttH and VH production mode, including final states with boosted hadronic top and W decays. The boosted ttH topology Is categorised by multiplicity of boosted Ws and boosted tops, whilst the resolved ttH topology captures final states with a a high multiplicity

of jets and one or more b-tagged jets. The VH search focuses on a resolved dijet topology with dijet mass compatible with that of a W or Z boson.

A Review of Machine Learning for Quantum Many-Body Systems

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The emergence of Machine Learning techniques within the physical sciences has grown substantially within recent years and has lead to the creation of state-of-the-art new ansätze for a multitude of different physical systems [1,2]. Machine Learning techniques have the ability to encapsulate the information of many-body wavefunctions in a compressed manner and to high-degree of accuracy.

I will present a brief overview of the success of Machine Learning techniques towards quantum many-body systems, and will present 2 practical examples. The first being the use of a simple one-layer neural network applied to the deuteron with an Entem-Machleidt N3LO potential [3] which can accurately model the deuteron to within 5 KeV [4]. Secondly, I will present a more broader neural network approach for trapped fermions.

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Measurement of the mass of the Higgs boson decaying to a pair of Z bosons in the four lepton channel using proton-proton collision data collected by the ATLAS detector at CERN

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Since the discovery of the Higgs boson in 2012, the aim is to measure its properties with higher precision. During this talk, the Higgs boson mass measurement analysis is discussed for a Higgs boson decaying to a pair of Z bosons in the four charged lepton channel. The analysis is performed using the latest data of proton-proton collision events collected by the ATLAS detector [1], corresponding to an integrated luminosity of 139 fb^{-1}, and a centre-of- mass energy of 13 TeV. Although the analysis is still ongoing, preliminary results are presented. The value of the Higgs boson mass is measured to be 124.92 0.21 GeV, where the measurement is statistically dominated.

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Benchmarking New Hardware and Software For Machine Learning In Particle Physics

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Over the last ten years, the popularity of Machine Learning (ML) has grown exponentially in all scientific fields, included particle physics. The amount of data and its complexity has grown as well, and the computing power required to perform inference can nowadays hardly be managed by the existing technology. Central Processing Units (CPUs) are generally affordable and ready to use but their ability to run Artificial Intelligence (AI) is very limited. In recent years, Graphics Processing Units (GPUs) have started to be used with very good results but they expensive, require a lot of power, and they are difficult to program since they were not invented for this task. Recently, Google has produced a brand new Edge Tensor Processing Unit (TPU) made explicitly to perform inference. It is cheap, it consumes less power than a GPU, and it comes with the portable size of a USB-key. A generic Liquid Argon Time-Projection Chamber (LArTPC) has been simulated and images produced by fictitious neutrino interactions have been used to benchmark the Edge TPU. The performance of the Edge TPU running different popular Deep Learning (DL) algorithms has been tested and compared with CPUs and GPUs, as well as the performance of different TensorFlow (TF) Lite optimisations.

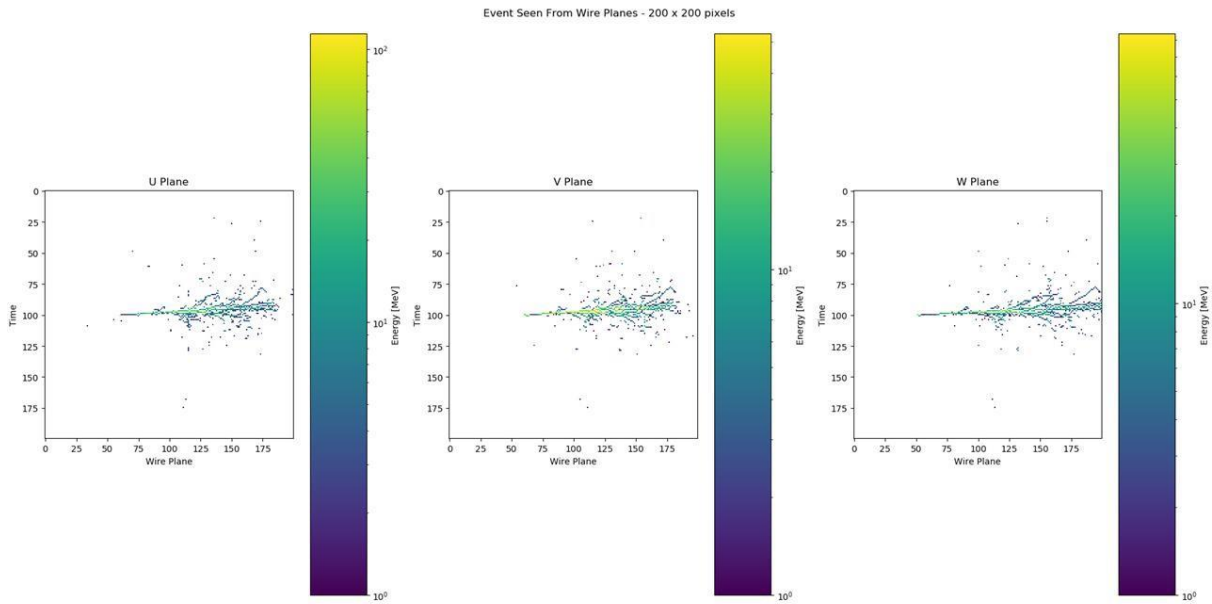

Fig. 1. Simulated neutrino interactions inside the generic LArTPC.

Lifetime measurements of the non-yrast structure in ^{102}Mo

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A study of the low-lying non-yrast structure in the even-even nucleus ^{102}Mo has been undertaken using the ^{100}Mo(^{18}O,^{16}O)^{102}Mo transfer reaction, with a 50 MeV beam of ^{18}O delivered by the tandem accelerator at

the Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH) in Bucharest, Romania. The aim of this work was to measure lifetimes for the most strongly populated excited states in ^{102}Mo. Lifetimes of the levels of interest are in the picosecond range, and as such a plunger was used to perform a Recoil Distance Doppler Shift (RDDS) measurement. Gamma rays emitted in the decay of the ^{102}Mo nuclei were detected by the ROSPHERE array [1], in a configuration consisting of 25 HPGe detectors. In conjunction with this setup a particle-detection array SORCERER [2] was mounted inside the target chamber, used to gate on recoiling nuclei and produce cleaner spectra for analysis. Statistics were sufficient to measure 22 gamma rays originating from 14 excited states, and measurements for the lifetimes of 11 excited states were obtained, including each state in the two-phonon and three-phonon vibrational structures. Results are interpreted and discussed in the framework of the U(5) and X(5) symmetries [3] of the Interacting Boson Model (IBM-1).

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Dark Noise Emission and Correlated Cross-Talk in Silicon Photomultipliers

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This talk presents a characterization of the light emission from dark noise in Silicon Photomultipliers (SiPMs), as well as correlated cross-talk resulting from photon emission. SiPMs are the light detection devices of choice for next generation experiments in astroparticle physics including the DarkSide-20k search for dark matter, the nEXO search for neutrinoless double beta decay, and precision neutrino oscillation measurements in DUNE. SiPMs are made of arrays of $\sim 10^4$ single photon avalanche diodes (SPADs) which are known to emit photons during the charge avalanche process. The spectral shape and emission rates of these photons are crucial data for understanding correlated cross-talk in these devices. This talk will present measurements of the dark noise emission spectra of the Fondazione Bruno Kessler (FBK) VUV- HD3 SiPM and the Hamamatsu Photonics K.K. (HPK) VUV4 SiPM, using a custom Light Emission and Injection Microscopy apparatus, for photon wavelengths between 400–1050 nm and as a function of over-voltage. We measured and studied correlated cross-talk in these devices using the same apparatus in a modified configuration such that charge avalanches are stimulated by a laser instead of dark noise.

Neutral current quasielastic neutron tagging analysis with Super- Kamiokande-Gd

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When searching for supernova relic neutrinos (SRN), the candidate neutrino event can be detected through an inverse beta decay (IBD) reaction in a water Cherenkov detector, such as the Super-Kamiokande experiment. The signal from this reaction consists of a prompt signal and the delayed signal: the prompt signal being the Cherenkov light produced by the positron from the IBD reaction and the delayed signal being Cherenkov light from the capture of the neutron from this reaction after hundreds of microseconds.

A firm background in the SRN search is the prompt and delayed signal of the NCQE interactions of atmospheric neutrinos which closely mimics the IBD signal. In NCQE interactions the prompt signal is yielded by the emitted gamma ray, while the delayed capture is the same as in IBD.

Previous NCQE neutron tagging analyses have looked at neutron capture on hydrogen. The recent addition of gadolinium sulphate octahydrate to the Super-Kamiokande detector allows for better detection of SRN

neutrinos and their background due to the higher energy gamma cascade signal of neutron capture on gadolinium of 8 MeV [1,2], compared with the 2.2 MeV for neutron capture on hydrogen, shown in Fig 1.

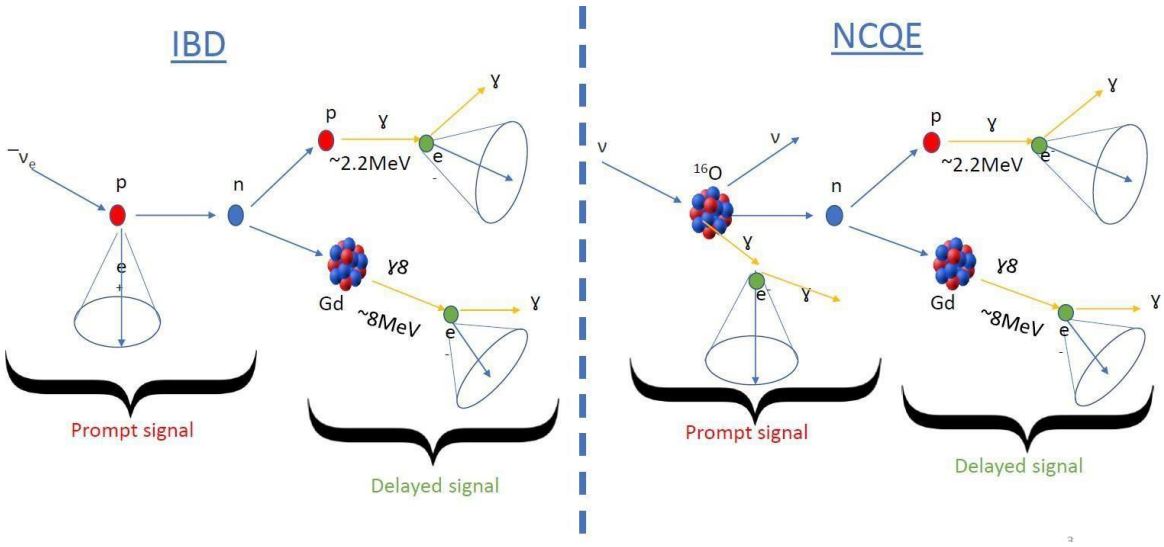

Fig. 1. Schematics of the IBD and NCQE interactions, showing neutron capture on H and Gd

I will present the status of my analysis which involves a neutron tagging algorithm specifically written for neutron capture on both ^{155}Gd and ^{157}Gd which is applied to MC samples. Neutron capture on gadolinium is simulated with the correct gamma cascade and energy spectra. Valid neutron candidates for tagging are selected using a primary selection based on hit and timing criteria, and a secondary selection which uses a neural network to decide whether the neutron candidate is signal or background.

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AN ELECTROSTATIC ION TRAP FOR LASER SPECTROSCOPY OF EXOTIC TECHNETIUM ISOTOPES

D. J. Pitman-Weymouth[1], Z. Shen[1], P. Campbell[1] and the laser-IGISOL Tc collaboration[2,3,4].

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Theoretical and experimental explorations of the onset of nuclear collectivity in the N=43 isotones [1] have resulted in a proposal to make complementary measurements in the Z=43 (technetium) isotopes at the IGISOL-4 facility, JYFL. In particular, it is proposed that the mean-square charge radii and nuclear moments of $^{90\text{-}113}$Tc (crossing the well-known N=60 shape change) are measured using laser spectroscopy. To optically study technetium, however, there are a number of experimental challenges that must be overcome.

The element technetium has no stable isotopes (prohibiting a conventional off-line optimization of the spectroscopy) and the species of interest have both high atomic and nuclear spins (resulting in dispersed and multi-component hyperfine structures). Successfully observing and identifying resonance structures is prohibitively (beam) time-consuming to attempt using standard high- resolution collinear spectroscopy.

The Tc study has been selected, as the demonstration case, for the development and commissioning of a new and highly efficient, incremental spectroscopic technique, in which an initial low-resolution, high-efficiency spectroscopy is first performed (enabling resonance location), followed by a targeted high-resolution study within the same apparatus.
The method relies on an ultra-high efficiency optical pumping technique and a bespoke on-line electrostatic ion trap, in which to optimally perform the optical pumping. The latter is under development at the University of Manchester.

The new spectroscopy, ion trap and test rig will be reviewed in the presentation. Upon successful on-line demonstration, the technique and ion trap will be applicable to a range of elements which lack stable isotopes, pertinently, for our collaboration, the heaviest elements and those with poorly known atomic structure.

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^{21}Ne and the Lighter Heavy Elements

P. Adsley[3], C. Angus[1,6], M. Avila[2], S. Chakraborty[1], J. Frost-Schenk[1], C. Hoffman[2], H. Jayatiss[2], B. Kay[2], A. Laird[1], R. Longland[4], C. Muller-Gatermann[2], J. Rojo[1], I. Tolstukhin[2], T. L. Tang[2] & G. Wilson[2,5]

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Observations of Ultra Metal Poor stars such as HD 221170 [1] show that the abundances of elements heavier than silver can be reliably predicted by models of nucleosynthesis. However, elements between iron and silver have much higher observed abundances than predicted by models which only consider the 'normal' r- and s- processes. A potential solution for these underestimates is an extension of the s-process to rapidly rotating metal poor stars. Whether or not these stars contribute significantly to the abundances of the lighter heavy elements depends on several nuclear reactions; of specific interest is the ratio of ^{17}O(α,n)^{20}Ne to ^{17}O(α,γ)^{21}Ne [2]. This ratio is important as it determines the efficiency of the s-process in these stars. However, the cross section is too low to measure directly which means we must calculate the rate based on the relevant states.

When modelling these reactions, the spin-parities of nuclear energy levels are important as rates of reaction depend upon them. Several states within the Gamow window in neon-21 have unknown spin-parities and this is a significant source of uncertainty in the model predictions [3]. In order to address this, an experiment has been conducted using the HELIOS spectrometer at Argonne National Laboratory to determine the unknown spin-parities as well as measure the neutron widths of the relevant states, via a study of the 21Ne(d,p) reaction. The angular distribution for each state was determined and compared with Distorted-Wave Born Approximation predictions. The astrophysical motivation behind the experiment and details of the ongoing analysis will be presented.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract Number DE-AC02-06CH11357. This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility.

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Axion searches in rare Higgs decays at ATLAS

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A search for pseudo-scalar low mass particles, *a*, in Higgs decays at the ATLAS detector. Axions and axion-like-particles (ALPs) are theoretical particles resulting from the Peccei- Quinn mechanism that describes a possible solution to the CP problem by introducing a dynamic field to explain the CP-violating terms. Theoretical studies by Bauer et al (2017) suggest that there are possible parameter regions were axion particles in the mass range 0.1-10 GeV could be probed in the decay channel h→Za [1].

Using LHC Run-2 data collected by the ATLAS detector, we aim to search for h→Za decays with the Z boson decaying into a pair of lepton and axion decaying into a pair of photons. The axions low mass means that it is possible the two photons are sometimes collimated and therefore reconstructed together. This poses a real challenge for this search and as such we are required to examine different selection categories and techniques based on whether or not the photons are merged together.

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High-mass Drell-Yan measurements at the ATLAS experiment and their phenomenological interpretation

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After finding no evidence yet of the existence of new heavy gauge bosons in the dilepton and lepton and missing energy decay channels in proton-proton collisions at $\sqrt{s}$=13 TeV [1-3], the ATLAS experiment pursues precision measurements of the production cross sections of both processes. These provide a crucial benchmark to test our knowledge of Standard Model, being well-known processes for which highly accurate theoretical predictions (NNLO QCD+NLO EW) are available.

Expanding previous ATLAS analysis at lower energies [4], we aim to study the single- ($d\sigma/dm_{ll}$) and double-differential ($d\sigma/dm_{ll}d|y_{ll}|$) cross section for the Drell-Yan production of dileptons in the range $116<m_{ll}<5000$ GeV, exploring a phase space crucial to set constraints on the parton distribution functions (PDFs), covering a wide range of the proton's momentum fraction (explored Bjorken-*X* ranges from 10^{-3} to ~0.7).

The Run 2 ATLAS dataset, consisting of an integrated luminosity of 139 fb^{-1} of proton-proton collisions taken at a center of mass energy of 13 TeV, offers wealth of data to explore regions of the kinematic space that had never been measured before with percent-level precision to test the available theoretical predictions. In addition, these results are used to test more subtle SM deviations such as encoded in Effective Field Theory (EFT) interpretations, motivated by the observed indications that new physics' deviations from Standard Model occur at an energy scale beyond the TeV frontier. The large dilepton invariant mass range that this analysis covers allows us to search for shape deviations introduced by high-dimensional operators, whose effects are suppressed by powers of the new physics energy scale (Λ)[5].) [5]. Sensitivity to high-dimensional operators is studied with respect to different kinematic variables, to be contrasted with the on-going precision Drell-Yan measurements, as well as hinting at relevant distributions

future analyses may focus on. The impact of the input parameter scheme choice, as well as higher order corrections, on the SMEFT predictions will be discussed, following the latest developments in EFT studies in the LHC community.

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Analysis of $\gamma p \rightarrow \pi^+\pi^- p$ at GlueX

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University of Glasgow, UK

GlueX is a photoproduction experiment based at the Thomas Jefferson National Accelerator Facility (JLab) in Newport News, Virginia. A 12 GeV electron beam originating from the CEBAF accelerator is converted into a linearly polarised photon beam by coherent bremsstrahlung on a thin diamond radiator. This beam is directed towards a liquid hydrogen target, positioned at the centre of a hermitic detector configuration with excellent tracking and calorimeter performance. GlueX is expected to provide new insights into the bound quark regime of QCD through the photoproduction and measurement of gluonic excitations of mesons. Excitations with quantum numbers forbidden by the conventional q-qbar meson model are predicted by QCD. These so-called 'exotic hybrids' have not yet been observed, and are of particular interest to GlueX. This talk will provide an overview of the GlueX experiment. Progress made on ρ(770) spin density matrix element measurements will also be summarised.

J/ψ near threshold photoproduction at CLAS12

Richard Tyson

University of Glasgow, UK

J/ψ near threshold photoproduction plays a key role in the physics program at the Thomas Jefferson National Accelerator Facility (JLab) 12 GeV upgrade due to the wealth of information it has to offer. J/psi photoproduction proceeds through the exchange of gluons in the t-channel and is expected to provide unique insight about the nucleon gluonic form factor. The 2015 and later 2019 announcements by the LHCb collaboration of the discovery of potential pentaquark states with hidden charm also require verification from independent experimental data.

The JLab based CLAS Collaboration, which uses the CEBAF Large Acceptance Spectrometer (CLAS12), aims to measure the J/ψ near threshold photoproduction cross section using both a proton and a deuteron target. The latter further offers the possibility of searching for isospin partners to the LHCb pentaquarks. Several analysis procedures, such as event selection and machine learning based particle identification techniques, have already been designed and tested on CLAS12 data taken towards these measurements.

This talk will describe the aims and experimental design for the measurement of J/ψ near threshold photoproduction on proton and deuteron targets with the CLAS12 detector along with the current stage of the data analysis.

J/Psi photoproduction in Pb-Pb UPC: from $x \sim 10^{-2}$ to 10^{-5}

Simone Ragoni, on behalf of the ALICE Collaboration

University of Birmingham, UK

Ultra-peripheral collisions (UPC) offer a unique opportunity to access the nuclear gluon PDFs, thus providing useful insights into the phenomenon of *nuclear shadowing* i.e. the J/Psi photoproduction cross section on a nucleus being smaller than would be expected if the nucleus were considered as an incoherent sum of nucleons.

The Pb-Pb dataset collected with the ALICE detector provides a useful tool to understand nuclear shadowing. It is possible to extract the degree of nuclear shadowing involved in the interaction at a specific Bjorken-*x*, as dictated by the analysed vector meson and the energy of the collision.

The results currently available can probe $x \sim 10^{-2}$ at forward rapidity and $x \sim 10^{-3}$ at mid-rapidity. A new technique, based on the tagging of the neutrons due to additional photon interactions, would allow for the extraction of a low $x \sim 10^{-5}$ contribution in nuclei, thus providing a new constraint to models.

The photon being exchanged in a UPC collision has a low virtuality, often described as *quasi-real*. In a separate study, the polarisation of the J/Psi is being investigated, which could confirm the applicability of *s-channel helicity conservation* (SCHC) in such reactions.

Calculated octupole spectra near Pb-208 with a time-dependent method

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The nature of octupole deformation in nuclei is a continuing topic of interest [1]. Strong octupole collectivity shows itself in a few regions of the nuclear chart, including around the doubly-magic ^{208}Pb nucleus, in which the first excited state is a $J^{\pi}=3^{-}$ octupole level.

From a single-particle shell model point of view, the octupole states are due to $\Delta\ell=\Delta j=3$ interactions (e.g. the $f_{7/2}$ and $i_{13/2}$ levels above the 82 particle shell closure), and it is the availability of such orbitals that allows particular regions of the nuclear chart to show octupole effects.

We present calculations using Skyrme-type effective interactions and the time-dependent response to an octupole excitation, allowing coupling to all other energetically-available multipole deformations, to explore the energy levels excited by octupole excitation in the vicinity of ^{208}Pb. In particular, we find the low-lying (663 keV) state in ^{210}Hg [2] is reproduced with interactions which have a suitable effective mass and correspondingly good set of single-particle levels.

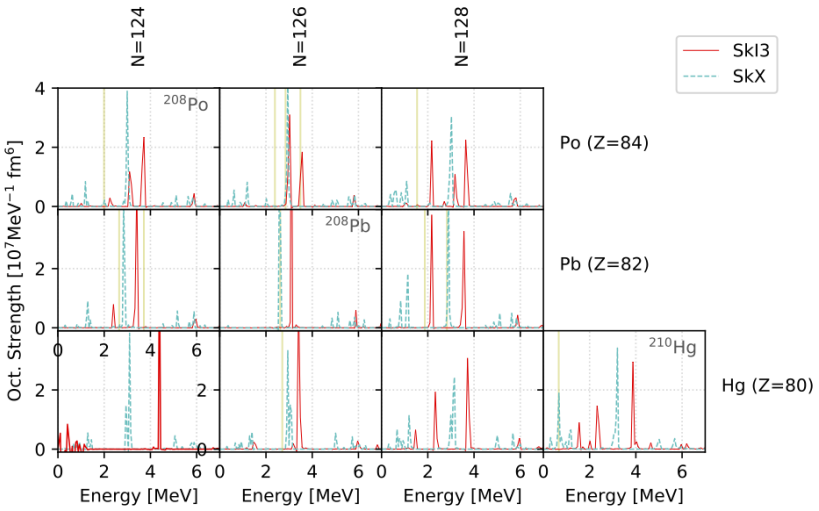

Fig. 1. Octupole (E3) strength for low-lying states in nuclei near ^{208}Pb calculated with two different Skyrme effective interactions, labelled SkI3 and SkX. Experimental lines, where known, are vertical gold-coloured lines.

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[2] A. Gottardo, *et al.*, Phys. Lett. B **725**, 292 (2013).

Cosmogenic muon induced background tagging in the SNO+ scintillator phase

Lorna Nolan

Queen Mary University of London, UK

The SNO+ detector is a multipurpose neutrino detector based at SNOLAB, Canada[1]. The detector has recently been filled with liquid scintillator, replacing the water from the first phase of the experiment. This talk will provide a brief overview and analysis from data collected during the filling process. The scintillator phase allows for studies of solar neutrinos, predictions of the signal and background of which can be seen in Figure

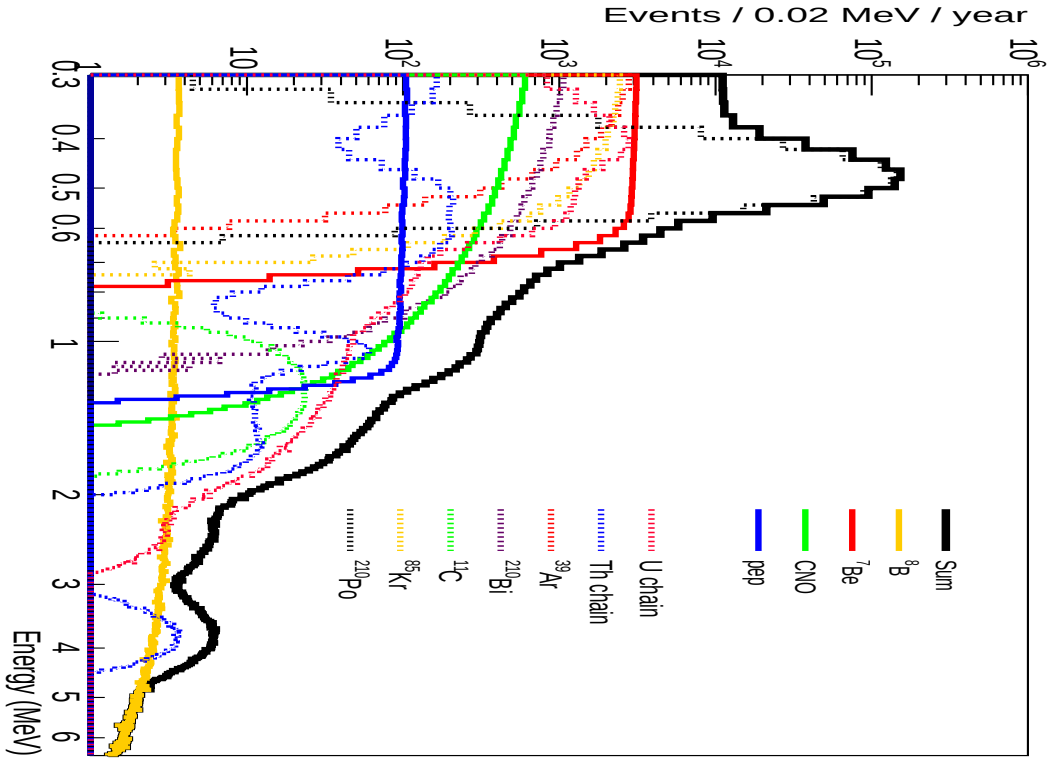

Figure 1: simulated events per 0.02 MeV for one year of pure scintillator data taking in the SNO+ detector. The dotted green line shows the Carbon-11 contribution.

1. This talk will focus on background reduction for these studies by identifying cosmogenic muon induced backgrounds, particularly Carbon-11, and the plans to reject these from data as well as measuring their production rate.

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Improving Gamma-Ray Position Resolution in Pixelated CZT Detectors for use in Molecular Breast Imaging Applications

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Breast cancer is the UK's most common form of cancer. Currently used x-ray mammography and ultrasound screening methods have reduced diagnostic performance for patients with mammographically dense breasts [1]. An alternative screening method that overcomes this is Molecular Breast Imaging (MBI), which uses the radioactive tracer ^{99m}Tc in conjunction with a gamma-camera to image malignant breast tissue.

The image quality of such a device is paramount and requires the accurate measurement of the position and energy of gamma-interactions within the imaging device. This information can be achieved with room-temperature pixelated CZT semiconductor detectors which, when combined with a collimator, form a gamma-camera. Position resolution within the detector can be improved through finer pixelization, which has drawbacks in increased channel number and complexity, or through the application of Pulse Shape Analysis (PSA) techniques [2].

At the University of Liverpool an experimental read-out system, Figure 1, has been designed and constructed that enables the digitisation and analysis of signals from 3 x 3 pixel clusters. This has been used to analyse the signal read out of a 22 x 22 x 5 mm CZT detector with 2 mm pixel pitch taken from a Kromek D-Matrix gamma-ray imager [3], which is typically ASIC-coupled.

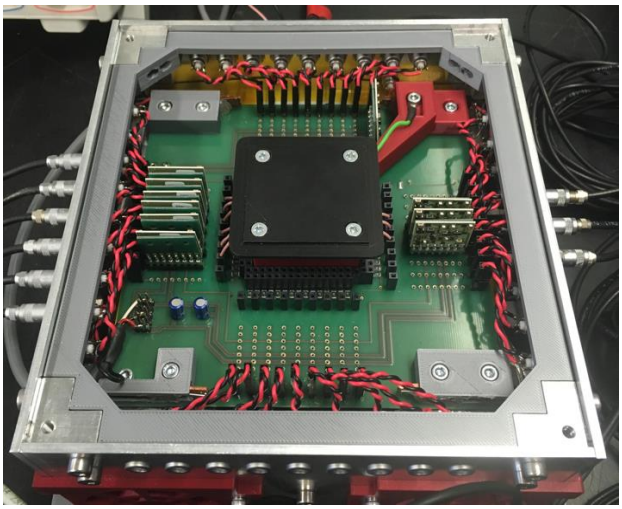

Fig. 1. Pixel-cluster read-out system. Preamplifier cards, situated around the covered crystal, output to a digital acquisition system (not pictured) for analysis.

The detector has been characterised using a high-precision collimated scanning system. The detector surface response has been investigated with low-energy 59.5 keV gamma rays, while higher energy 122.1 keV gamma rays have been used to map the response through the depth of the detector. A database of signals, constrained in interaction location, has thus been formed. Parameterisation of the charge collection times as a function of depth, and of the transient image charges induced in neighbouring pixels as a function of lateral position, has enabled the development of PSA methods. These parameterisation-based methods aim to achieve sub mm^3 position resolution while remaining computationally light weight such that they may be implemented within typical detector subsystem firmware.

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[2] Vetter, K., et al. "Three-dimensional position sensitivity in two-dimensionally segmented HP-Ge detectors." Nucl. Instrum. Methods Phys. Res 452.1-2 (2000): 223-238

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Understanding the interplay of different reaction channels in nuclear direct reactions with weakly-bound nuclei

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Direct reactions of weakly-bound nuclei involve the interplay of different channels: elastic and inelastic scattering, transfer, and breakup. An effective theoretical description of such processes has to take into account the continuum [1]. Time-dependent approaches are often used to disentangle the reaction mechanism [2-3], so in Ref. [4] a simple model, that assumes semiclassical relative motion and neglects angular coordinates, was used to understand how the continuum impacts on direct reactions with one-neutron halo nuclei. In particular, a coupled-channels solution involving different continuum configurations was compared to the numerical solution of the time dependent Schrödinger equation (TDSE). The use of sets of continuum states which are sensible to the phase shift induced by only one nucleus was found not to be very accurate in the case of dominant breakup channel. Our purpose is to extend this simple time-dependent framework to include a two center "molecular" description of the continuum [5-7]. This consists of a set of dicretized states that reflect the phase shift induced by both nuclei involved in the process and vary with the internuclear distance. This constitutes an improvement respect to the previous technique, not only for the good agreement with the TDSE, but also because we are able to follow the interplay of the reaction channels at each moment, thanks to the unitarity of the time- evolution operator throughout the entire process. We will report on the good outcomes of our calculations which push our investigation towards the refinement of the molecular continuum basis: its inclusion in the two-center model is in fact a novel feature respect to the state of the art.

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Investigation of 3N forces from atomic mass data

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The quest to understand properties of nuclear systems in terms of forces acting between the nucleons is a long-standing goal of nuclear science. While effective two-nucleon (NN) shell model interactions successfully explain many aspects of nuclear structure, recent studies are pointing to the important role of

three-body (3N) forces in the predictions of neutron-rich nuclei and in the evolution of shell structure [1], in particular from an ab-initio point of view.

Nuclear masses and binding energies provide basic data to map the structural evolution across the nuclear landscape. At the same time, an accurate knowledge of nuclear masses is required to understand fundamental processes in nuclear astrophysics.

The aim of this work is to investigate whether we can describe atomic masses using valence- shell corrections that include both NN and 3N forces in the mass-formulae. We will present preliminary results obtained by performing local and global fits of the liquid drop model plus the additional NN and 3N terms to the latest experimental mass compilation AME2016 [2,3].

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[3] Meng Wang et al., Chinese Phys. C 41 030003 (2017)

Investigating strange particle production at $\sqrt{s_{NN}}$ = 8.16 TeV with ALICE at the LHC

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The ALICE detector uses ultra-relativistic lead-lead collisions in order to investigate the state of matter known as the Quark-Gluon Plasma (QGP). As the QGP has a lifetime of roughly 10 fm/c [1] (of the order of 10^{-23} s), it cannot be observed directly; instead, a series of signatures and observables are used to infer the presence of a QGP within a given heavy ion collision, and subsequently measure its properties. One such signature is the enhanced production of strange quarks relative to the lighter flavours of quark.

In addition to the lead-lead collisions which ALICE uses to generate this QGP state, proton-proton and proton-lead collisions are also studied. These lighter collision systems are used primarily as references, in order that the QGP effects can be extracted from the results of heavy ion collisions. However, recent results have shown that strangeness enhancement exists not only in lead-lead collisions, but also high-multiplicity proton-proton and proton-lead collisions [2].

This talk will present recent results regarding the production of singly strange hadrons in high multiplicity proton-lead collisions at a centre-of-mass-energy-per-nucleon of 8.16 TeV; roughly twice the centre-of-mass energy of previous studies. The talk shall make particular emphasis on the differential production of these hadrons as a function of final state multiplicity, and how these yields compare to those of charged pions.

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The Development of Novel Pulse Shape Analysis Algorithms for the Advanced Gamma Tracking Array(AGATA)

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Index Terms— Signal Processing, Gamma Tracking, Pulse Shape Analysis, Machine Learning, Topological Data Analysis

I. INTRODUCTION

Standing at the forefront of Gamma-Ray Spectroscopy, the **A**dvanced **GA**mma **T**racking **A**rray (AGATA) provides insight into a wide variety of Nuclear Physics, by employing Gamma-Ray Tracking (GRT) AGATA is able to provide significant improvements to efficiency, doppler correction and position resolution.

As all tracked photons occur solely within the germanium volume without the need of additional ancillaries a critical component of GRT the field of Pulse Shape Analysis (PSA) is required. PSA uses characteristics of the measured signals from the segmented electrodes of each crystal to directly infer the positions of the gamma-ray interactions.

II. DEVELOPMENT OF NEW PSA TECHNIQUES

Several methods were developed over the course of this project as possible PSA methods for AGATA, the use of Convolutional Neural Networks for regression was investigated and appears to offer a viable solution on simulated data. Advancements in GPU hardware allowed for a model to be produced that executes at 3kHz with a reasonable prediction accuracy.

Utilising Topological Data Analysis the use of graph accelerated k-Nearest Neighbour algorithms for Fold-1 interaction prediction combined with Manifold-Learning assisted dimensionality reduction has allowed for a significant improvement in processing rate with little loss to prediction accuracy. In particular the algorithms, FAISS, HNSWLIB, MKS and Nanoflann were profiled on various embedded representations.
To allow for higher fold solutions an event pair selection algorithm based off recursive Voronoi cell interpolation culling was developed and generalised to work on standard M-Tree structures. This approach allows for event pairs and their relative mixing fractions to be precomputed and applied to a hyper-efficient hierarchical structure. The resulting structure provides a robust, dynamic and efficient approach to High-Fold PSA that traditionally requires significant computation.

III. EXPERIMENTAL CHARACTERISATION

In order to profile the performance of these algorithms a set of constrained experimental data was collected at Liverpool. Utilising 1GBq ^{137}Cs and ^{241}Am sources on a high-precision 2-axis linear stage, 90 Compton scatters of the 662keV gamma-ray were gated using the combination of physical ring collimators placed between the crystal and the surrounding 40 BGO ancillaries and by gating on the fold, energy depositions in the A005 bulk and BGOs (374keV & 288keV respectively).
In total around 20,000,000 pulses were recorded, over 1500 (x,y,z) positions were deemed usable for experimental validation alongside around 20,000 (x,y) single-scan positions.

The Commissioning of the SuperNEMO Demonstrator Module Calorimeter and an investigation into the effects of Helium Poisoning of PhotoMultiplier Tubes

William Quinn

University College Lodnon, UK

The SuperNEMO experiment is designed to search for the thus far elusive neutrinoless double-beta decay phenomenon. If detected, it would provide strong evidence to support the neutrino being Majorana in nature. The SuperNEMO Demonstrator Module is currently being commissioned at LSM, France, as a proof-of-concept design for the larger, modular detectors using its tracker-calorimeter design. The Demonstrator is comprised of a source foil containing the double-beta decaying isotope Se-82, sandwiched between a helium rich wire tracker and a segmented scintillator-PMT calorimeter. SuperNEMO is unique in the field as it is able to reconstruct full event topologies.

I present my work on the commissioning of the demonstrator module calorimeter. Specifically, I will show my use of a matched-filtering technique on PMT waveforms in an attempt to improve the time and energy resolution of the calorimeter, and to use pulse shapes to identify potential PMT defects. I also present my study into the effects of helium exposure on PMT performance, which can degrade by helium induced after-pulsing. I will explain the hypothesis that the rate of after-pulses can be used as a direct measure of the concentration of helium within the PMT vacuum. This can be used as a monitor of the ageing of the SuperNEMO PMTs, which are at risk of helium contamination from the adjacent tracker.

Developing a distributed water Cherenkov detector array

Simeon Bash and Jennifer Thomas

University College London, UK

The CHIPS (Cherenkov detector In mine PiTS) experiment was a prototype neutrino detector with the goal of reducing the cost and complexity of building large scale water Cherenkov detectors in neutrino beams. The CHIPS collaboration has extended this to the broader concept of distributed photomultiplier tube (PMT) deployment. An obvious use case for this is sampling high energy cosmic ray showers: where a large detector array is needed across a wide area. The distributed design of the electronics and high coverage of water Cherenkov designs is an obvious use case.

The CHIPS collaboration has developed a new innovative electronics system for control, readout and data acquisition of photomultiplier tubes (PMT) utilising modern smartphone era components and off the shelf hardware called the microdaq. The "microdaq" provides a flexible platform for PMT deployment and can be used to power, trigger, record and return data from each PMT individually. The microdaqs are attached to a wider network of hardware that provides data, timing and power links and allows PMTs to act independently and autonomously. Each PMT is fully autonomous and PMTs can be deployed in small distributed groups that act as part of a wider network independently regardless of their proximity and do not require a physical connection. In this talk I will talk about the development and features of this system and the plans for deployment under London. For example, in London Underground tube stations.

Reducing sensitivity to systematic uncertainties of the deep neural networks employed in the NOvA experiment

K. Mulder

University College London, UK

In the NOvA experiment, with its pixelated detectors, measured events can be recorded in an image format. This allows for the usage of powerful image identification techniques such as convolutional neural networks (CNN's) for the purposes of event classification.

The training data for these networks mostly consists of simulated Monte Carlo data, which closely but not perfectly matches the measured detector data. This leads to the possibility of different performance of the networks on the real data. The differences in the data are thoroughly investigated and quantified in the form of systematic uncertainties.

Here we will firstly utilize the systematic uncertainties to evaluate network performance before deployment. Then we will show that including different systematic domains during training can boost both performance and confidence in the networks predictions. Finally we leverage advances in domain adaption to reduce the effects of systematic uncertainties in the network training itself.

Improved reconstruction of charged pions and other particles in the NOvA near detector

Cathal Sweeney

University College London, UK

Neutrino-nucleus interactions are a large source of systematic uncertainty in current neutrino oscillation measurements. It is therefore important to measure cross sections for exclusive and semi-inclusive channels, including those containing charged pions. In this talk I will present work aimed at improving reconstruction of particles in the NOvA near detector, with an emphasis on charged pions.

The NOvA near detector is a liquid-scintillator-based tracking calorimeter located 1 Km from the target of the NuMI beam at Fermilab, used both for oscillation measurements as well as cross section measurements. The aim of the work outlined in this talk is to improve pion identification and energy resolution, leading to more robust measurements of cross sections for channels containing charged pions in the final state.

SNO+, Supernova neutrinos and Supernova Burst Trigger

Michal Rigan

University of Sussex, UK

SNO+ is a general-purpose neutrino experiment located in Sudbury, Ontario, Canada. It is an upgrade of SNO experiment that was awarded the Nobel Prize in 2015 for "the discovery of neutrino oscillations, which shows that neutrinos have mass" [1]. The main physics goal of the experiment is to observe the neutrinoless double beta decay ($0\nu\beta\beta$) however the detector is also sensitive to nucleon decay, solar neutrinos, reactor neutrinos and geoneutrinos. SNO+ is currently finishing filling the detector with liquid scintillator, transitioning from water phase to pure scintillator phase. The talk will focus on SNO+ experiment with emphasis on the supernova sensitivity, detection channels and the new supernova burst trigger.

Additionally, SNO+ could observe supernovae neutrinos if a supernova occurs. They are extremely rare, with the rate of Core collapse supernovae (CC) in the Milky way estimated to be approximately 3 per century, the last observed CC supernova being the SN1987a [2]. During a supernova, almost all of the immense available energy is lost to neutrinos making them unprecedented fountains of high energy neutrinos of all flavours. As such they are effectively gates into rare physics and they can help us understand several compelling phenomena such as neutrino mass hierarchy, sterile neutrinos or even black hole formation.

There are three interaction channels for supernova neutrinos in liquid scintillator. These are Inverse beta decay (IBD), neutrino-proton scattering and interactions with ^{12}C nuclei. However, neutrino-electron scattering in water is also present in SNO+ and can be used for pointing. The calculated energies of these interactions are presented in Fig.1a. Regarding backgrounds, these are negligible above 1MeV and the IBD channel is essentially background free as a result of neutron tagging. The advantage of liquid scintillator medium is good energy resolution and low thresholds. Being underground also results in low rate of cosmogenics. The main drawback is the small volume. Nonetheless, major feature of SNO+ is the sensitivity to all neutrino flavours.

In order to promptly detect and analyze the supernova burst signal (O(10s)) a specific burst trigger was developed. The main goal is to monitor for bursts and alarm if significant signal is observed with minimal latency. Burst trigger's design, functionality and sensitivity are the focus of the talk. The trigger's efficiency as a function of the supernova distance is exhibited in Fig.1b.

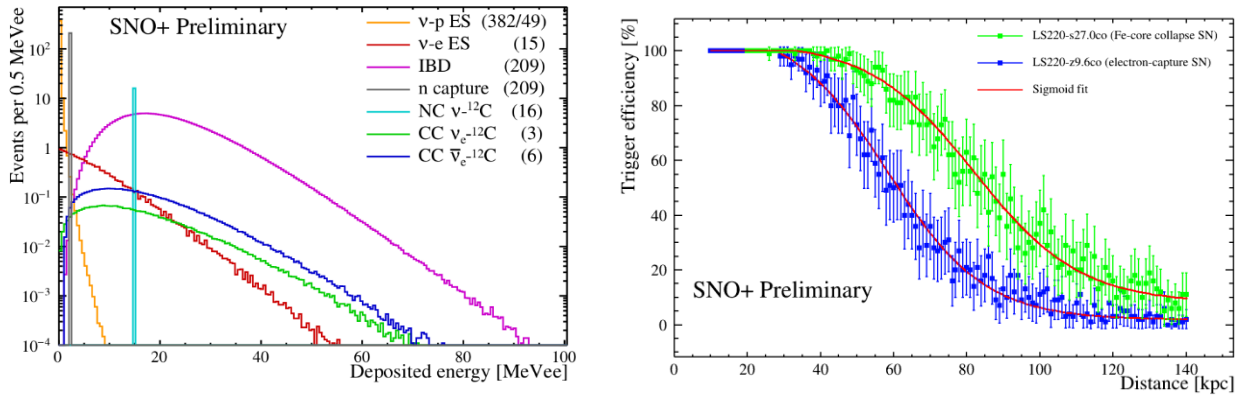

Fig. 1. (a) Supernova deposited energy spectrum and event rate; (b) Supernova burst trigger efficiency by supernova distance.

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Nucleosynthesis inside common envelope accretion

Alexander Hall-Smith

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When a star reaches the end of the core hydrogen burning stage it can undergo expansion and proceed to burn Helium in the core. This expansion can happen in binary systems that contain a main sequence star and a neutron star, the expansion can then go on to engulf the neutron star and form a common envelope. Inside this common envelope nucleosynthesis can occur inside the accretion disk orbiting around the neutron star. This may involve rp-process like nucleosynthesis, equivalent to the rp-process that occurs inside x-ray bursts. However, this material may be mixed into the envelope and later ejected into the interstellar medium, unlike with an X-ray burst where the remains of the previous burst stay on the surface of the neutron star. This scenario was studied using the NuGrid post-processing code. This presentation will cover the results of the sensitivity studies that were conducted inside NuGrid to identify which reactions are the most influential, these are reactions that produce proton rich isotopes and are known rp-process reactions. This talk will also discuss the results of different input trajectories and the impact of angular momentum on nucleosynthesis.

Search for Heavy Neutral Leptons using the ArgoNeuT detector at Fermilab

Patrick Green

The University of Manchester, UK

ArgoNeuT was a 0.24 ton Liquid Argon Time Projection Chamber (LArTPC) detector at Fermilab running from 2009 to 2010. It was located along the NuMI neutrino beam and collected six months of data in the anti-neutrino beam mode. ArgoNeuT has performed several first neutrino cross-section measurements on argon, however its dataset can also be used to probe physics beyond the Standard Model. One such model is heavy neutral leptons (HNL) that couple to the standard model via mixing with tau neutrinos. These would be produced by the NuMI beam via decays of D-mesons into secondary taus, which then decay into HNLs. The HNLs then travel along the NuMI beamline and can decay into an active neutrino and a muon and anti-muon pair either within ArgoNeuT or in the cavern upstream of the detector. This talk presents the results of the search for such HNLs with ArgoNeuT and the limits that can be applied to the HNL mass and mixing angles.

Event reconstruction in ALICE's run 3 continuous readout environment

Aimeric Landou

University of Derby, UK

After the long shutdown 2 of the LHC, the ALICE detector will see an increase in luminosity that will increase the average interaction rate inside the central barrel by two orders of magnitude, up to a Pb-Pb collision rate of 50kHz. To fully take advantage of the increased statistics in the measurement of probes with very low signal-to-background ratio, the detectors of ALICE are being upgraded and the reconstruction framework updated. The data will be read out continuously, without trigger, and processed online to compress it to a manageable size so that it can be stored.

One challenge introduced by the continuous readout is the ambiguity in the attribution of a track in the Time Projection Chamber (TPC), the primary tracking detector in ALICE, to the collision point. The data will be separated into 20ms timeframes gathering about a thousand collisions. For the TPC, an average of 5 events can overlap in one drift time window.

Fortunately, the Inner Tracking System (ITS) time resolution is small enough to significantly ease the attribution of tracks spanning across both the TPC and the ITS to the collision point they originate from. However, the reconstruction of decayed daughter tracks remains challenging as the decay vertices cannot be pinpointed by as many tracks as primary ones, which originate from the collision: there are typically only 2 or 3 daughters per decay.

This talk will give a brief description of the detector upgrade, present the reconstruction challenges that arise from it and reconstruction strategies being built to answer them, then give a quick overview of the current performance in strangeness tracking.

Search for invisible particles in association with jets using the ATLAS detector

Aidan Kelly[1], Emily Nurse[1], Christian Gütschow[1], Jon Butterworth[1], Yoran Yeh[1], Louie Corpe[2], Matous Vozak[3], Andy Pilkington[3], Stephen Menary[3], Darren Price[3], Monica Dunford[4], Pavel Starovoitov[4], Sebastian Weber[4], Martin Klassen[4], Martin Habedank[5]

[1]University College London, UK, [2]CERN, Switzerland, [3]University of Manchester, UK, [4]Heidelberg University, Germany, [5]DESY Zeuthen, Germany

As part of the ongoing effort to test the Standard Model (SM) with high precision and search for evidence of Dark Matter production at the LHC, we look at events with large missing transverse momentum in association with jets using proton-proton collisions recorded by the ATLAS detector. The dominant SM process

contributing to this signature are the Z boson decaying to two neutrinos and also the leptonic decay of the W boson where the charged lepton is outside detector acceptance.

These processes are very similar to the leptonic decays of the Z and W boson and can be exploited using dedicated one and two lepton control regions to constrain our theoretical and experimental systematic uncertainties.

We measure the differential cross section as a function of the missing transverse momentum and some other jet variables for three different phase spaces which are sensitive to various Dark Matter production mechanisms. The data is corrected for detector effects by unfolding, which makes it easy for theorists to compare to different New Physics (NP) models without the need for detector simulation.

In this presentation, we show our limit setting results for different Dark Matter models and the methodology behind it.

ADNIF@Bham – an Accelerator-Driven Neutron Irradiation Facility

C. Wheldon, M. Freer and B. Phoenix

University of Birmingham, UK

The status and capabilities of the high-flux accelerator-driven neutron irradiation facility will be presented (see figure below). The facility is under construction and on track to be commissioned in early 2022. Using >30 mA protons to induce the ^{7}Li(p,n)^{7}Be reaction will provide >10^{12} neutrons/cm^{2}/s, which, when coupled to a selection of end stations, will enable a broad spectrum of activities. These will be primarily materials focused and fission and fusion data related, but also include high-power target research, medical physics and radio-biology, nuclear metrology and nuclear physics. The facility will be particularly well suited to studies of the astrophysical slow-neutron caption process due to the similar neutron-energy spectrum just above the lithium neutron production threshold.

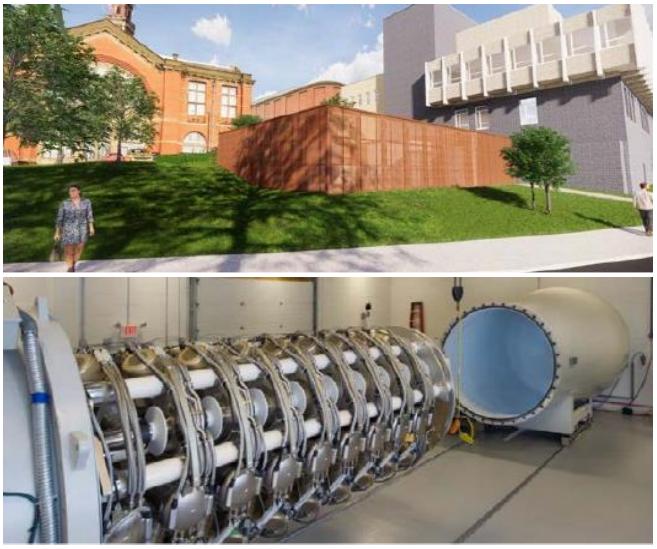

Fig. 1. Clockwise from bottom-left: the Neutron Therapeutics proton accelerator at the heart of ADNIF; an impression of the new bunker that will house the accelerator; construction of the bunker, mid Feb. 2021;

From measurement to reinterpretation: ATLAS four-lepton invariant mass spectrum and a study of vector-like quarks

Danping Joanna Huang

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The measurement of the four-lepton invariant mass spectrum is presented with the ATLAS detector, at an integrated luminosity of 140 fb-1 and a centre of mass energy of 13 TeV [1]. This measurement is designed with re-interprebility in mind, by maximizing inclusivity and acceptance across the invariant mass range. The differential and double differential cross- sections are measurement for events containing two same-flavour, opposite-sign, lepton pairs. These are corrected for detector effects and unfolded to the particle level. The four- lepton invariant mass spectrum contains a wide variety of physics processes, with regions dominated by single Z, Higgs, and on-shell ZZ production, and is sensitive to possible BSM contributions. All unfolded data and uncertainties are made available on HEPData, and the analysis workflow is preserved in Rivet. These steps allow the data to be reinterpreted by experimentalists and theorists alike, in various BSM studies not directly targeted by LHC searches. A recent study of the sensitivity of LHC measurements to vector-like quarks is presented [2], where the ability of existing measurements to exclude new regions of VLQ parameter space is demonstrated.

[1] ATLAS Collaboration, *Measurements of differential cross-sections in four-lepton events in 13 TeV proton-proton collisions with the ATLAS detector.* ATLAS-CONF-2020-042, URL: https://inspirehep.net/literature/1811753

[2] A. Buckley, J. M. Butterworth, L. Corpe, D. Huang and P. Sun, *New sensitivity of current LHC measurements to vector-like quarks*, SciPost Phys. 9(5), 069 (2020), doi:10.21468/SciPostPhys.9.5.069, 2006.07172.

Dark photon searches using plasma wakefield acceleration

Hartin, A. Scaachi, and M. Wing[1]

University College London, UK

Ongoing advances in the field of plasma wakefield acceleration motivate further study into the applications of high energy electron beams. One such application involves the firing of these electrons at a fixed target in search of dark photons, a potential mediator particle that arises from many hidden sector models. Standard model particles generally deposit all of their energy within the target, therefore the detection of such particles after the target suggests that a dark photon propagated through the target before decaying back into standard model particles. This experimental concept has been demonstrated using single electron beams, however debate centers on whether the bunched electron beam structure produced by plasma wakefield accelerators can provide any significant benefit over single electrons. Compared to currently planned single electron beam experiments, a dark photon search using plasma wakefield acceleration can be expected to provide a factor of 10^4 more electrons on target, resulting in a much larger probability to produce dark photons. However, this bunched electron beam structure introduces many challenges as the signal criteria must be identified over the background arising from an entire electron bunch as opposed to just a single electron, this necessitates changes to the experimental design which in turn reduces the sensitivity to dark photon signals. Simulations were used to optimise the experimental configuration such that the sensitivity to dark photons is maximised while maintaining a tolerable background level, allowing for the discovery potential of a dark photon search using an early stage plasma wakefield accelerator to be assessed in comparison to currently planned experiments with similar project schedules.

Search for Supersymmetry in final states with tau leptons at the ATLAS experiment

Daniela Koeck

University of Sussex, UK

Supersymmetry (SUSY) is a proposed extension to the Standard Model of particle physics that can explain

many of its shortcomings, such as the so far elusive Dark Matter. In models with R parity conservation, the lightest supersymmetric particle is the neutralino, and this can be an excellent Dark Matter candidate. SUSY models with light sleptons (scalar leptons) are particularly interesting at the current LHC energies.

In this talk I will discuss my leading contributions to the search for chargino and neutralino pairs at the ATLAS detector, where the two SUSY particles decay (via production of staus) to at least two hadronically decaying taus with the same electric charge. Using LHC proton-proton collision data collected by the ATLAS detector at 13 TeV centre-of- mass energy between 2015-2018, this analysis is extending significantly previous results already published [1], based only on final states with two opposite-sign tau leptons.

[1] The ATLAS Collaboration, Eur. Phys. J. C (2018) 78:154.

Semileptonic Vector Boson Scattering at the ATLAS detector

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The amplitude of the vector boson scattering process diverges towards high energies. In the Standard Model of particle physics this divergence is exactly canceled by interference of processes involving Higgs boson exchange. Divergences from this delicate cancellation may point towards a window to physics beyond the Standard Model.

Experimentally events involving vector boson scattering are characterized by the presence of a highly boosted dijet system in opposite hemispheres of the detector together with the decay products of two gauge bosons.

Studies towards a search for electroweak diboson (WW/WZ/ZZ) production in association with a high-mass dijet system using the full Run-2 ATLAS data set are presented. A decay mode in which one boson decays leptonically while the other boson decays hadronically is studied. The measurements are sensitive to the vector boson scattering production mechanism providing a fundamental test of the gauge structure of the Standard Model. The analysis uses proton-proton collisions collected at a center of mass energy of $\sqrt{s} = 13$ TeV with an integrated luminosity of $139\ \mathrm{fb}^{-1}$. An interpretation with respect to anomalous quartic gauge couplings within the framework of an effective field theory approach is performed.

Design of an imaging collimator for application in low dose Molecular Breast Imaging

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Breast cancer is the most common form of the disease in the UK, directly affecting 1 in 8 women. Approximately half of women of screening age have mammographically dense breasts, which limits the diagnostic abilities of the screening methods that are currently available, resulting in late or misdiagnosis. [1] These limitations can be overcome using the functional imaging technique Molecular Breast Imaging (MBI). MBI uses the radioisotope Technetium-99m to identify lesions within the breast. Cadmium Zinc Telluride (CZT) is a desirable detector material for use in MBI primarily due to its good position resolution. This property makes the detector highly sensitive to 141 keV gamma rays and therefore allows for an isotope of lower activity to be administered to patients, without compromising the image quality.

One of the primary aims of MBI is to optimise a detector system that minimises the dose delivered to the patient. The system consists of both a CZT detector and an imaging collimator, whose properties both contribute to the overall system performance. The collimator is required in order to reconstruct the path of the

detected gamma-rays. It is desired that the collimator is optimised such that it complements the sub mm^3 resolution achieved (through PSA) within the CZT. The desired imaging properties of good position resolution and high sensitivity are conflicting requirements in terms of collimator design and hence the collimator must be designed such that this trade-off is surmounted. [2]
A Geant4 simulation has been developed in order to model the response of CZT to 141 keV gamma-rays. Various collimator designs have been modelled in Geant4 in order to compare the imaging properties of potential collimator designs, including a multi-lofthole collimator. The collimator parameters have been optimised in attempt to meet the design requirements and maximise the attainable position resolution of the imaging collimator and, in turn, the MBI system.

[1] Hendrick RE. "*Radiation doses and cancer risks from breast imaging studies",* Radiology. (2010): 257:246-253

[2] Gunter D. "*Gamma camera collimator characteristics and design*", Nuclear Medicine, vol 1, p 107-126.

Subterranean Science and Ultra-Low Background Studies at Boulby Underground Laboratory

E. Banks, P. Scovell[1], S. Paling et al.

Boulby Underground Laboratory, STFC, UK

Boulby Underground Laboratory is the UK's deep underground science facility located 1.1km below ground in Boulby mine; a working potash, polyhalite, and salt mine in the North East of England. Boulby is a special place for science, enabling a wide range of studies requiring access to the geologically interesting and ultra-low background deep underground environment. A quiet place in the universe, the low radiation environment allows for unique experiments which require minimal background to operate.

Most famously, this includes the search for the elusive dark matter particles, in the form of WIMPs. Over the decades of its operation, Boulby laboratory has hosted several generations of dark matter detectors, including novel technologies and limit-setting experiments. The science programme is now much wider, including geology studies, radiocarbon dating, renewable energy storage, nuclear security, life in extreme environments, and astrobiology studies.

The astrobiology studies also involve a yearly event called MINAR, where institutions from around the world, including NASA and the ESA descend to Boulby to test techniques and technologies for future space exploration missions. This includes testing of rovers and experiments to search for signs of life.

In this talk Ed Banks (a science technician at Boulby) will give an overview of the facility and the experiments being conducted there, as well as providing a virtual tour.

Probing jet quenching in heavy-ion collisions through hadron+jet measurements with the ALICE experiment

Jaime Norman

University of Liverpool, UK

The quenching (energy loss) of jets in heavy-ion collisions is one of the clearest signatures of the formation of a deconfined state of quarks and gluons, known as the Quark-Gluon Plasma (QGP). The semi-inclusive measurement of jets recoiling from a high-p_T hadron (hadron+jet) in heavy ion collisions uniquely enables the exploration of medium-induced modification of jet production and acoplanarity over a wide phase

space, including the low jet pT region for large jet resolution parameter *R*. This technique crucially provides a precise data-driven subtraction of the large uncorrelated background contaminating the measurement. In addition, this measurement also provides a precise way to search for quenching effects in pp and p-Pb collisions, where to date no significant jet quenching has been observed.

This talk will give an overview of hadron+jet measurements from the ALICE experiment at the LHC. Special focus will be given to the recent measurement of the first fully-corrected hadron+jet azimuthal correlation ( ) distribution in Pb-Pb collisions at a centre-of-mass energy per nucleon-nucleon collision of s_{NN} = 5.02 TeV.

Excited Sates in the Rare-Earth Nucleus 129Pr

Lorna Waring[1], David Joss[1], Robert Page[1], Juha Uusitalo[2], Holly Tann[1], Conor Sullivan[1], Andrew Briscoe[2]

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Neutron-deficient rare-earth nuclei in the mass region 130 ≤ A ≤ 140 are predicted to be among the most deformed nuclei in their ground states. To achieve a complete understanding of these rare-earth nuclei at and beyond the proton drip line, it is necessary to acquire information relating to their decay properties and the structure of excited states. The data analysed during this study were obtained from an experiment conducted at the University of Jyväskylä with JUROGAM3 and MARA. This was the first experiment in a planned future programme using a range of tagging techniques with MARA to establish the excited states of proton-unbound nuclei in this mass region. The primary aim of the experiment was to investigate excited states in the proton emitter 131Eu. However, several other nuclei including 129Pr were also observed, enabling the identification of rotational band structures. In this region of highly deformed nuclei numerous band structures are observed. Many of these are 'floating' bands, in that the transitions connecting these isomeric band heads with the low-lying states are not always known. Here the latest results investigating the correlations between band heads and the relative ordering of states for the nucleus 129Pr will be presented.

Mass measurements of the low-lying states of ^{102}Y

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[1]University of Brighton, UK. [2]University of Surrey, UK. [3]University of Jyväskylä, Finland

Previous studies have suggested that ^{102}Y has two beta decaying states, a ground state and an isomeric state with half-lives of 300(10) ms [1] and 360(40) ms [2]. However, the energy separation between these two states is only known to have an upper limit of 100 keV [3]. Therefore the high resolution Phase Imaging – Ion cyclotron Resonance (PI-ICR) method [4] has been employed using the JYFLTRAP Penning trap at the IGISOL facility at the University of Jyväskylä, Finland to measure the energy separation of the two states. The ^{102}Y states were produced via nuclear fission using a 30 MeV proton beam and ^{238}U target.

The data collected does not show a clear resolution of two states, but at long accumulation times a bimodal distribution was observed. Due to these long accumulation times, the distribution obtained could have been due to ^{102}Y ion collisions with the Helium gas present in JYFLTRAP or the decay of the ^{102}Y ions, both of which would result in a distorted image on the detector.

Therefore, additional measurements were taken in the same manner as the ^{102}Y measurement for single state nuclei in the A=100 region, namely ^{99}Sr, ^{99}Y and ^{102}Zr to establish systematics as a function of both half-life and mass number when utilising long accumulation times. These results can then be compared to the ^{102}Y measurement to ascertain whether or not two states are present and provide a limit for their energy separation. The ongoing analysis of this data will be presented and discussed in this presentation.

[1] J. C. Hill et al, Phys. Rev. C, **43**, 2591 (1991).

[2] K. Shizuma et al, Phys. Rev. C, **27**, 2869 (1983).

[3] C. R. Nobs, PhD thesis, University of Brighton, (2017).

[4] S. Eliseev et al, Applied Physics B: Lasers and Optics, **114**, 396 (2013).

Boulby Underground Laboratory - Delivering outreach during the pandemic

Emma Meehan

STFC, UK

This past year has been a challenge for all kinds of work including public engagement and outreach. Due to the unique situation of STFC's Boulby Underground Laboratory, our already established remote outreach delivery has been expanded and utilised with great effect during this pandemic. This talk will give a brief overview of outreach in general at Boulby, and some of the events undertaken in this last challenging year

Searching for Light Dark Matter with NEWS-G

Tom Neep

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The NEWS-G collaboration, consisting of 10 institutes in 5 countries, is searching for light dark matter using spherical proportional counters. Light and hydrogen-rich gases, such as CH4 and Ne, are used as targets, allowing dark matter masses in the range 100 MeV to 10 GeV to be probed. The collaboration has previously searched for dark matter using the SEDINE detector at LSM, setting competitive limits on dark matter candidates with masses of ~1GeV.

A new 140 cm diameter detector, SNOGLOBE, was constructed and operated at LSM, before being moved to SNOLAB where it will start to take data later this year. The new detector includes a multi-anode readout, which allows for high gain operation, high electric fields inside the detector volume, and coarse directionality; and has been electroplated with ultra-radiopure copper, to reduce background contamination. These developments, the current status of the SNOGLOBE detector, and the future plans for the collaboration, will be presented.

The Impact of Nuclear Physics Uncertainties on Nucleosynthesis in the First Stars

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[1]University of Edinburgh, UK, [2]University of Victoria, Canada

The first stars formed when the Universe was about 100 million years old. They play a fundamental role in explaining the origin of the chemical elements we observe today, providing a link between the present day and the primordial composition of the early Universe. There are no confirmed observations of the earliest stars to date; however, their nucleosynthetic fingerprints may be present in their direct descendants' stellar composition, providing hints about the properties and nucleosynthesis processes in the precursor stars.

In this work, we aim to explain the elemental abundance pattern observed in old carbon enhanced metal-poor (CEMP) stars with a form of light element neutron capture nucleosynthesis, which likely occurred in the interiors of the first stars. We estimate uncertainties in the elemental abundances produced in our models by using a Monte Carlo approach, where neutron capture reaction rates are varied according to their experimental or theoretical uncertainties. For our Monte Carlo studies, we use the PPN post process nucleosynthesis code developed by the NuGrid[1] collaboration, modified to model the high neutron density environment suggested by stellar models. While experimental neutron capture rate uncertainties were adopted from literature, uncertainties of theoretical neutron capture rates were estimated by calculating neutron capture cross-sections with the code TALYS[2], using different input models for gamma-ray strength functions and Level density.

We present a comparison between observations and this model, analysing where we can replicate observations. Additionally, we highlight key nuclear reaction rates whose uncertainties have the largest impact on results, which may help identify priority candidates for future experimental measurements.

[1] https://nugrid.github.io/

[2] https://tendl.web.psi.ch/tendl_2019/talys.html

Search for electroweak production of charginos and neutralinos in final states with two and three leptons and missing transverse momentum with the ATLAS experiment

Marco Aparo

University of Sussex, UK

Supersymmetry, or SUSY, is a viable extension to the Standard Model, and resolves important limitations of the latter, such as those arising from the hierarchy problem [1]. It introduces new particle states which may be produced at the ATLAS experiment taking data at a cenrtre of mass energy of 13 TeV at the Large Hadron Collider (LHC).

Due to existing constraints on the value of the masses of strongly coupled SUSY particles, the electroweak production of weakly interacting sparticles may become the key mechanism to search for beyond-the-Standard-Model physics at the LHC [2].

SUSY searches for direct electroweak production of charginos and neutralinos are possible in many channels, among which, those resulting in final states with two light leptons – electrons or muons – of the same electric charge or three light leptons and missing transverse momentum. An overview on two SUSY searches, based on the data collected by the ATLAS experiment, on each of these two channels is presented. Results are interpreted is the context of R-parity-conserving simplified models in which charginos and neutralinos undergo decays via the intermediate production of W and Z bosons or W and Higgs (h) bosons, as shown by the diagrams in Fig 1.

Newly-released ATLAS results on the three-lepton final state using the full Run 2 data sample [3] significantly extend previous constraints on relevant sparticle masses, compared to those obtained with early Run 2 data [4,5]. Results in the same-sign model via Wh are currently available with early Run 2 (36.1 fb^{-1}) data [5].

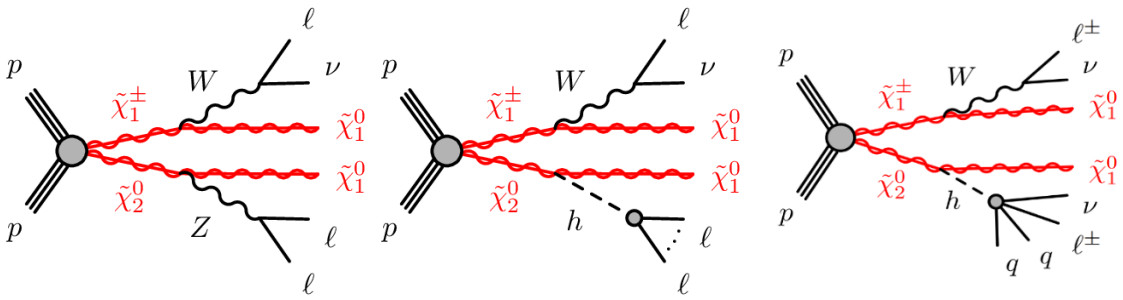

Fig. 1. Chargino-neutralino production models: (a) via W and Z bosons in three leptons (left); (b) via W and Higgs bosons in three leptons (middle); (c) via W and Higgs bosons in two leptons of the same charge (right).

[1] S. P. Martin, Adv. Ser. Direct. High Energy Phys.18,1(1998)

[2] https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections

[3] The ATLAS Collaboration, ATLAS-CONF-2020-015.

[4] The ATLAS Collaboration, Eur. Phys. J. C 78 (2018) 995.

[5] The ATLAS Collaboration, PhysRevD.100.012006.

Measuring the electric dipole moment of the muon at the Fermilab Muon $g-2$ experiment

Sam Grant

University College London, UK

The new $g-2$ experiment at Fermilab aims to improve on the current limit on the magnitude of the electric dipole moment (EDM) of the muon [1], by two orders of magnitude. The significance of this measurement is that a non-zero EDM would constitute the first evidence of CP violation in the lepton sector, which could account for the matter-antimatter asymmetry of the universe. In addition, since the Standard Model predicts a muon EDM of less than $\sim 10^{-27}\ \mathrm{e}\cdot\mathrm{cm}$, far beyond what current experiments are capable of measuring, any observation of an EDM at Fermilab would provide clear evidence of new physics [2].

In this presentation, the EDM analysis strategy at $g-2$ will be reviewed. Analysis efforts using simulated data will be presented, as well as a dedicated <1 ppm measurement of the radial magnetic field: a dominant source of systematic uncertainty for the EDM analysis.

[1] E821 Collaboration, G. W. Bennett, et al., Phys. Rev. D **80**, 052008 (2009)

[2] R. Chislett, EPJ Web of Conferences **118**, 01005 (2016).

Alpha – Neutron Background Characterisation Within the SNO+ Detector

Matthew A Cox

University of Liverpool, UK, Laboratory of Instrumentation and Experimental Particles Physics (LIP), Portugal

SNO+ is a multiphase neutrino detector situated 2km underground in Sudbury, Canada. The detector's main physical goal is the detection of the radioactive process known as neutrinoless double beta decay. Other physics goals include: the constraint of invisible nucleon decay

lifetimes; measurement of low energy solar neutrinos, and the measurement of geo and reactor antineutrinos.

The SNO+ detector is currently in a transitional phase between using ultrapure water and LAB liquid scintillator as its active medium. Analysis of data from the partially filled detector provides initial information on various background levels within the detector which will form the basis for background characterisation for future phases of the detector's lifetime.

Antineutrinos are detected in the liquid scintillator medium through Inverse Beta Decays (IBD) displayed in Fig. 1. (a), p + $\bar{\nu}$ -> e^+ + n. A major background for the reactor and geo-antineutrinos is the (α,n) reactions on nuclides of the scintillator (particularly ^{13}C). These reactions mimic the characteristic prompt-delay IBD signal via 3 distinct prompt channels, as displayed in Fig. 1. (b).

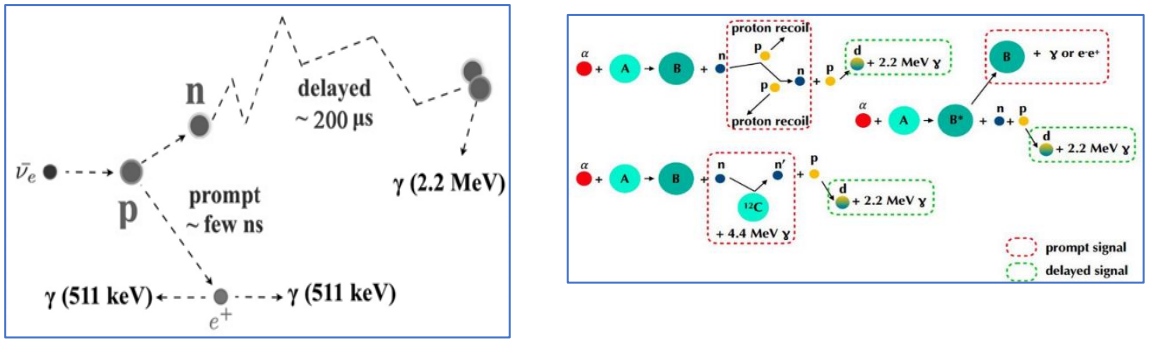

Fig. 1. (a) IBD process of antineutrino; (b) The 3 distinct (α,n) reactions present within the SNO+ detector.

Radon daughters are the main source of (α,n) reactions, with the most prominent contribution from the ^{210}Po isotope. Alpha sources can be introduced into the detector in 3 ways: during LAB filling (as there is a small residual level of alpha particles inherent in the scintillator); through the ingress of Rn gas from the headspace above the detector (caused by small leaks in seals or the introduction of instrumentation into the detector etc.); or via daughter atoms leaching from the Acrylic Vessel {AV} (which contains the detector's active medium). Leaching occurs as Rn daughters (such as ^{210}Pb) were embedded in the AV's surface throughout the detector's lifetime. The ingress of Rn is minimised by a cover- gas system and constant background monitoring, whereas the inherent and leaching alpha contributions must be calculated to fully constrain the (α,n) background.

This talk will discuss the analysis used to tag and characterise this background during the partially filled (water-scintillator) detector phase, and outline plans to mitigate the impact of (α,n) events in antineutrino measurements for the full liquid scintillator detector.

[1] L. Teng, et al., Chinese Phys. C **41** 066201 (2017)

[2] V. Lozza, (α,n) Yield in Low Background Experiments Conference, SNO+ talk (2019)

Supernova Model Discrimination with Hyper-Kamiokande

Jost Migenda for the Hyper-Kamiokande Collaboration

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Core-collapse supernovae are among the most magnificent events in the observable universe. They produce many of the chemical elements necessary for life to exist and their remnants -- neutron stars and black holes -- are interesting astrophysical objects in their own right. However, despite millennia of observations and

almost a century of astrophysical study, the explosion mechanism of core-collapse supernovae is not yet well understood. Hyper-Kamiokande is a next-generation neutrino detector that will be able to observe the neutrino flux from the next galactic core-collapse supernova in unprecedented detail. We focus on the first 500 ms of the neutrino burst, corresponding to the accretion phase, and use a newly-developed, high-precision supernova event generator to simulate Hyper-Kamiokande's response to five different supernova models. We show that Hyper-Kamiokande will be able to distinguish between these models with high accuracy for a supernova at a distance of up to 100 kpc. Once the next galactic supernova happens, this ability will be a powerful tool for guiding simulations towards a precise reproduction of the explosion mechanism observed in nature.

MAGIS-100: A Matter-wave Atomic Gradiometer with Sensitivities to Dark Matter

Sam Hindley on behalf of the MAGIS-100 Collaboration

University of Liverpool, UK

MAGIS-100 is a next-generation atom interferometer under construction at Fermilab that aims to explore fundamental physics over a 100-metre baseline, using the latest atomic clock technologies [1]. The experiment will search for ultra-light dark matter [2] and new forces, while also providing an opportunity to test quantum mechanics at new length scales. The 100-metre baseline will also serve as a technology pathfinder to future gravitational wave detectors in a previously unexplored frequency band.
The collaboration will extend the work done with state-of-the-art atom interferometers [3] by applying the same techniques to a pair of 50-metre interferometers, connected across a vertical baseline of 100 metres. Each interferometer utilizes strontium atoms in superposition and allows them to fall freely under gravity. The difference in output between the two interfermoeters can be interpreted as a measure of either dark matter or new physics, providing backgrounds are fully accounted for. Operating two interferometers in this vertical configuration on a shared laser baseline enables the removal of common-mode background noise.
The 100-metre experiment will be a step towards the future construction of a 1 km detector, which will be sensitive to gravitational waves in the frequency range 0.1 Hz - 10 Hz, in between the projected ranges of the Advanced LIGO and proposed LISA experiments.

[1] J. Coleman, ICHEP Proceedings, arXiv:1812.00482v1 (2018). [2] A. Arvanitaki, *et al.*, Phys. Rev. D. **97**, 075020 (2016).

[3] J. Rudolph, *et al.*, Phys. Rev. Lett. **124**, 083604 (2020).

The $^{12}C+^{12}C$ fusion cross-section at sub-coulomb barrier energies

Jose Gustavo Vega Romero[1], David Jenkins[1], Luke Morris[1], Sandrine Courtin[2], Marcel Heine[2], Mohamad Moukaddam[2], and the STELLA collaboration

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Measuring the fusion cross-sections of production reactions that form chemical elements is at the centre of interest regarding some astrophysical scenarios. The processes of nucleosynthesis give birth to heavier elements and, in the carbon scenario, can develop into supernovae type Ia explosions or superbursts from accreting neutron stars. In particular, given the significance of carbon to life in general, the reaction $^{12}C+^{12}C$ is vitally important to understand and has therefore long been studied. However, previous theoretical and experimental efforts show considerable discrepancies as the energy approaches that of the Coulomb barrier, resulting in differing values obtained for the astrophysical S-factor [1,2].

Particularly at low energies, these discrepancies lead to vastly differing hypotheses to describe this phenomenon.

In this work, we present the approach taken to obtain the value of the fusion cross- section using STELLA (STELar LAboratory) at IPN, Orsay in France, where charged particles and gammas from the fusion products of the reactions were detected [3]. The main difference between previous efforts and this work is that coincidences between charged particles and gammas were obtained.

We discuss the current state of this analysis and place it in the context of previous studies.

[1] E. F. Aguilera, *et al.*, Phys. Rev. C **73**, 064601 (2006)

[2] C. L. Jiang, *et al.*, Phys. Rev. Lett. **89**, 052701 (2002)

[3] M. Heine *et al.*, Nucl. Inst. Methods A **903**, 1–7 (2018)

Development of an upgraded National Nuclear Array (NaNA) at the National Physical Laboratory

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[1]National Physical Laboratory, UK, [2]University of Surrey, Guildford, UK

In 2015, the National Physical Laboratory commissioned their first fast-timing coincidence array comprising twelve 2" x 1.5" $LaBr_3$(Ce) scintillation crystal detectors [1-3]. Since then NPL have investigated its capability for nuclear decay data studies and the primary activity standardization of radionuclides [4]. Since, NPL has become more focused on providing precise nuclear decay data for novel radionuclides being investigated for diagnostic and therapeutic applications in nuclear medicine. These radionuclides typically have low-energy gamma rays, and the need for higher resolution and reduced interference from inherent radiation background has become apparent. Preliminary work towards the creation of a hybrid gamma-ray coincidence array, the upgraded National Nuclear Array (NaNA) at the National Physical Laboratory is presented. This array consists of 20 1" x 1.5" $CeBr_3$ scintillation detectors and, initially, three electro-cooled HPGe spectrometers; two 20% relative efficiency n-type HPGe spectrometers and one low-energy photon HPGe spectrometer. The addition of the semiconductor devices can allow for increased spectroscopic resolution, and coupled to the fast-timing scintillator detectors allows for high precision studies of many decay parameters of nuclides, including but not limited to; level scheme construction, lifetimes of excited states in the ps/ns regime, gamma emission probabilities, and even absolute standardizations of coincident gamma ray emitting nuclides. CADs of the array are presented as well as nptool [5] GEANT4-based simulations of the expected response of the device. Case studies of potential areas benefitting from the upgraded capabilities of the array are presented, with reference to the medically relevant ^{155}Tb and ^{227}Th, and the current limitations of the literature decay data of these nuclides.

[1] P.H. Regan *et al.*, J. Phys: Conf Series **620**, 012005 (2015)

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[3] R. Shearman *et al.*, Radiat. Phys. Chem. **140**, 475-479 pp (2017)

[4] S.M. Collins *et al.*, Appl. Radiat. Isot. **134**, 290-296 pp (2018).

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Probing the fragmentation and hadronisation processes of charm quarks using ALICE experiment at LHC

jakub Kvapil

University of Birmingham, UK

Charm quarks are mostly produced in hard partonic scattering processes in the early stages of a collision. Because of their large mass, the production cross-section can be calculated using perturbative quantum chromodynamics down to zero transverse momentum. Therefore, they can be used to probe charm-quark hadronization by measuring the relative abundance of various particle species to test different hadronization models. Moreover, the measurement of charm mesons and baryons is also a fundamental reference for heavy-ion collisions, where hadronization via coalescence can be studied.
Measurements of heavy-flavour tagged jets bring more relevant information of the initial parton kinematics than inclusive hadron measurements. They can provide information on the fragmentation process, which plays important role in understanding the heavy-quark energy loss in the hot dense medium created during ion collisions, in particular on how the radiated energy is dissipated in the medium. This talk focuses on the latest results of charm-tagged jets and open charm production with the ALICE detector at the LHC with a focus on measurements closely related to fragmentation and hadronization processes.

LUX-ZEPLIN optical photon simulations using GPUs

Sam Eriksen

University of Bristol, UK

The LUX-ZEPLIN experiment aims to directly detect dark matter - nucleon interactions, using 7t of liquid xenon (LXe) as active material. The core of the detector consists of a dual-phase LXe time projection chamber. WIMP-like neutron backgrounds are vetoed through interactions in an outer detector, filled with Gadolinium-doped liquid scintillator. Light signals resulting from interactions inside the detector volume are recorded with photo multiplier tubes. Once operational, the observed signals will be compared to the simulated detector response. The most computationally intense part of this is photon propagation, accounting for in excess of 96% of CPU time.
The work presented here explores the possibility of both speed and accuracy improvements to simulations by using graphics processing units for optical photon propagation.

Measurement of the interference between short- and long- distance contribution in B^+ to $K^+\mu^+\mu^-$ decays

Lakshan Ram Madhan Mohan for the LHCb Collaboration

University of Bristol, UK

Multiple b to sll transition measurements show anomalies which potentially indicate lepton flavour universality (LFU) violation in vector dilepton couplings. Precision measurements are needed to understand these anomalies and probe for new physics (NP). The observation of LFUV would be a clear sign of NP. However, in order to precisely determine the couplings involved, intermediate hadronic resonances which contribute to the final state of these transitions needs to be well understood. The work presented in this poster studies the interference of these non-local and long-distance contribution with the short-distance contribution in the decay B^+ to $K^+\mu^+\mu^-$ to precisely probe the vector dilepton couplings. For this, proton-proton collision data collected at LHCb from run1 and run2 is used. This analysis will set stringent constraints on the vector dilepton couplings potentially highlighting NP effects.

Augmenting background hit datasets in COMET with Generative Adversarial Networks

Matthias Dubouchet

Imperial College London, UK

The Coherent Muon-to-Electron Transition (COMET) experiment is a high-intensity physics experiment, currently under construction at J-PARC in Japan, which aims to measure the rate of neutrino-less muon-to-electron conversion, a process which is theoretically highly suppressed in the Standard Model of Particle Physics.

In COMET Phase-I, a Cylindrical Drift Chamber (CDC) will be used to reconstruct charged-particle tracks and identify signal candidates. The characteristics of signal and background events can be estimated via Monte Carlo (MC) simulations, however the high intensity of the experiment restricts the speed of a procedural simulation and thus the size of our background dataset in the detector. In order to produce samples more efficiently, we propose a Generative Adversarial Network (GAN) model for hits in the CDC. By training on simulation data, we expect the generator to produce faithful hit samples orders of magnitude faster than the MC method.

This talk will outline how the GAN model was designed to address the specific requirements of the CDC hit dataset. Our results will be shown and the generated samples compared to the training data.

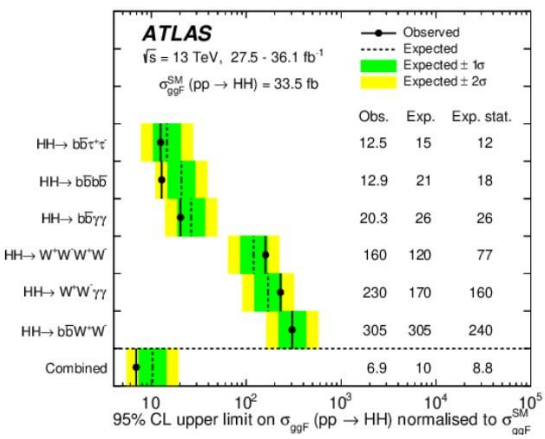
Combining di-Higgs decay channels to measure a combined limit on the di-Higgs cross section with the ATLAS detector

Natasha Hehir on behalf of the ATLAS HH combination team

Queen Mary University of London, UK

This talk will present the ongoing combination of searches for Higgs boson pair production using the ATLAS full Run-2 dataset of 139ifb. The combination is performed for the non- resonant channels, i.e. the Standard Model case, and also in the resonant mass searches where a resonant mass decays into two Higgs boson in order to explore any potential beyond the Standard Model physics.

Since the discovery of the Higgs boson in 2012 at the Large Hadron Collider, many measurements of the Higgs boson have been undertaken. The discovery of the Higgs boson was an experimental confirmation of the Brout-Englert-Higgs mechanism of electroweak symmetry breaking. This mechanism predicted the existence of the Higgs boson and that the scalar particle is able to self-couple. Therefore, measuring the di-Higgs production and Higgs boson self-coupling is an important validation of the Brout-Englert-Higgs mechanism. As such, any deviation from the Standard Model prediction would be an indication of new physics. This motivates many searches in different di-Higgs decay channels to set limits on the HH cross-section and by performing a combination of these channels we are able to improve the limits set on the HH production cross-section further.



The first HH combination used a subset of the Run-2 data of 36ifb and was able to set combined observed (expected) limit at 95% confidence level on the non-resonant Higgs boson pair production cross-section at 6.9 (10) times the predicted Standard Model cross- section as shown in Fig 1. [1]

Fig. 1. (a) Upper limits at 95% CL on the cross-section of the ggF SM HH production normalised to its SM expectation from the bbττ, bbbb, bbγγ, WWWW, WWγγ and bbWW searches, and their statistical combination.[2]

Now performing the combination with the full Run-2 dataset and with the inclusion of the improvements

made in the individual channels, we expect to see a considerable amount of improvement and place further constraint on the HH cross-section.

[1] F. Englert and R. Brout, Broken Symmetry and the Mass of Gauge Vector Mesons, Phys. Rev. Lett. 13 321 (1964)
[2] The ATLAS Collaboration, Combination of searches for Higgs boson pairs in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector, Phys. Rev. Lett. 800, 135103 (2020).

Treatment of the $^{13}C(\ ,n)^{16}O$ background in the SNO+ antineutrino analyses

Charlie Mills

University of Sussex, UK

SNO+ is a multipurpose liquid scintillator neutrino detector located in Sudbury, Canada. While the main physics goal of the experiment is the search for neutrinoless double beta decay, SNO+ is sensitive to a large program of neutrino physics including the detection of reactor antineutrinos and geoneutrinos [1]. Reactor antineutrinos are detected via inverse beta decay (IBD), leading to a distinct coincidence signal in the detector consisting of a prompt positron-electron annihilation event and a delayed neutron capture event.

The main background in the SNO+ reactor antineutrino analyses is the $^{13}C(\ ,n)^{16}O$ interaction which mimics the IBD coincidence signal. I will present a technique to distinguish between prompt (,n) events and prompt IBD events. Preliminary results using this technique show that the (,n) background in the low energy (< 3 MeV) prompt event region can be reduced by a factor of 2.

[1] S. Andringa, *et al.*, Advances in High Energy Physics **vol. 2016**, 6194250 (2016).

Search for the Higgs boson decaying to two electrons using the full Run 2 data set collected by the CMS detector at the LHC

J. Davies, J. Langford, E. Scott, N. Wardle

Imperial College London, UK

We present a search for the Higgs boson decaying to two electrons using the full Run 2 data set collected by the CMS detector at the LHC. The data set corresponds to 137 fb^{-1} of proton-proton collisions at a centre-of-mass energy of 13 TeV, collected between 2016 and 2018. An upper limit is set on the branching fraction for the Higgs boson decay to two electrons.

The search is particularly challenging, given the extremely small branching fraction pre- dicted by the Standard Model ($\sim 5 \times 10^{-9}$). Although the process is extremely rare, the increased size of the available data set offers additional statistical power in comparison to the best existing result from the CMS experiment. To enhance the sensitivity further, we use multiple modern machine learning techniques, including a long short-term memory deep neural network. We therefore expect to set the most sensitive limit on the Higgs boson decay to two electrons from the CMS Collaboration to date. With this new result, a direct constraint can be placed on the Higgs boson's Yukawa coupling to the electron, for which no other direct measurement exists

Track Finding in the CMS Level 1 Trigger for HL-LHC: Challenges, Design and Implementation

David Monk

Imperial College London, UK

The Compact Muon Solenoid (CMS) physics program for the upcoming High Luminosity LHC (HL- LHC) will require the Level-1 (L1) custom hardware trigger to maintain sufficiently low thresholds to select processes at the electroweak scale. With an expected 200 pileup interactions, the inclusion of tracking information at L1 will be critical to achieve this. A silicon-based track trigger at the scale of the CMS will be unprecedented; it will provide a novel handle, which in addition to preserving trigger rates could enable entirely new physics studies.

At Level-1, high data throughput and a decision window of 12.5 μs present the primary challenges in reconstructing tracks. The CMS Outer Tracker for HL-LHC will use modules with pairs of sensor layers to read out hits only compatible with charged particles above 2-3 GeV. These hits are combined into tracks within the L1 track finding system, built on Xilinx Virtex® UltraScale+™ FPGA technology.

The track finding pipeline will consist of two distinct stages, physically separated in hardware. The Data, Trigger and Control (DTC) card serves as the interface between the on-detector electronics and the remaining processing hardware located within the counting room. It will receive, format and route trigger data, but must also control the behaviour of the detector modules. The Track Finding (TF) card will then take the trigger data and reconstruct tracks to be used in the L1 trigger. All communication between the hardware described will be performed over high-speed optical links, operating at up to 25 Gbs^{-1}.

This presentation will introduce the CMS L1 track finding system: the algorithm and its estimated performance, hardware prototypes, demonstrators and infrastructure software.

Searching for long-lived heavy neutral leptons in hadronic decays with the CMS detector using a novel deep neural network-based displaced jet tagger

Julia-Suzana Dancu on behalf of the CMS Collaboration

Imperial College London, UK

Due to the robust theoretical motivation of heavy neutral leptons (HNLs) and their potential importance in explaining various observed Beyond Standard Model (BSM) phenomena, the search for HNLs is at the forefront of the physics programme of many experiments in the high energy physics community in recent years. Prompt HNL searches are typically governed by multi-GeV HNLs decaying close to their production vertex, below typical detector resolution. Long-lived HNLs, however, have lower masses, hence longer lifetimes. They travel significant distances in the detector before decaying; therefore, their decay vertex is separable from their production vertex. Since HNLs are sterile, they do not leave tracks or energy deposits in the detector system. Consequently, HNL signals can only be identified through their displaced decay products following topologies predicted by theory.

A novel approach in searching for hadronically decaying long-lived HNLs in Run-2 CMS data is presented in this analysis. A gradient-boosted decision tree classifier algorithm is employed to separate heavy neutrino signal from background events in data. The event classifier is used as a complementary tool to a novel deep neural network-based displaced jet tagger algorithm recently developed by the CMS collaboration to search for signs of BSM physics [1]. The tagger is expanded to accommodate cases where a displaced lepton is present (clustered) inside a displaced jet, which allows to tag the HNL decay products with high efficiency. Preliminary results show promising signs of gain in HNL detection sensitivity.

[1] CMS Collaboration, “A deep neural network to search for new long-lived particles decaying to jets”,

Sci. Technol. **1** (2020) 035012, doi:10.1088/2632-2153/ab9023, arXiv:1912.12238.

Measurement of R_K with the full LHCb dataset

R.D. Moise[1], D. Lancierini[3], K. Petridis[2], M. McCann[1], M. Patel[1], N. Serra[3], P. Owen[3], P. Álvarez Cartelle[4], S. Maddrell-Mander[2]

[1]Imperial College London, UK, [2]University of Bristol, UK, [3]University of Zürich, Switzerland, [4]University of Cambridge, UK

Recent measurements of *b*-hadron decays involving leptons are in tension with the Standard Model (SM). Each of these so-called flavour anomalies diverge by up to 3 standard deviations from their SM predictions. There are various new physics scenarios (e.g. leptoquarks) which can explain the anomalies in a coherent fashion.
Although some tensions could be due to theory uncertainties, certain observables are immune to such ambiguities. One of these observables is the branching fraction ratio $R_K = \mathrm{BR}(B^\pm \to K^\pm \mu^+ \mu^-)/\mathrm{BR}(B^\pm \to K^\pm e^+ e^-)$. Its sensitivity to lepton flavour universality leads to a very precise theoretical prediction. This talk will cover the currently most precise measurement of R_K, based on the proton-proton collision data collected by the LHCb experiment thus far.

Searching for Heavy Neutrinos in the ATLAS playground

Neofytos Themistokleous

The University of Edinburgh, UK

Searching for right-handed W bosons and right-handed neutrinos in a two lepton plus two jet final state (Keung-Senjanović process) at $\sqrt{s}$=13 TeV with the ATLAS experiment. These particles are introduced as part of the Left-Right Symmetric Models and the See-saw Mechanisms, which attempt to restore parity to the Standard Model and explain the small masses of the known neutrinos.

Measurement of $\Delta \Gamma_s$ using the B_s decays to the final states $J/\psi \eta^{\prime}$ and $J/\psi f_0$

S. Petrucci

University of Edinburgh, UK

The main aim of the Large Hadron Collider beauty (LHCb)[1] experiment at the Large Hadron Collider (LHC) is to study CP violation and rare decays of beauty and charm hadrons. Measurement of B_s^0 mixing parameters τ_L, τ_H and ϕ_s provides a precise test of the Standard Model (SM). New physics in the B_s^0 mixing can give additional phase changing ϕ_s from the SM predictions. Information about ϕ_s can be extracted combining the lifetime measurements for the CP-even and CP-odd states. The work presented is focused on measuring $\Delta \Gamma_s$ from the ratio between the CP odd and even eigenstates $B_s \rightarrow J/\psi f_0$ and $B_s \rightarrow J/\psi \eta^{\prime}$. This is the first time the lifetime has in the $B_s \rightarrow J/\psi \eta^{\prime}$ decay channel has been studied experimentally. Due to the higher yields, the $\eta^{\prime}$ is selected from the $\left(\rho^0 \rightarrow \pi^+ \pi^- \right)$ γ sub-decay. τ_H is measured from the $B_s \rightarrow J/\psi \left(f_0 \rightarrow \pi^+ \pi^- \right)$ channel. This channel was chosen due the similarity between its final state and the $\eta^{\prime}$ one: they both have four charged tracks (two muons and two charged pions). Using similar final states helps to cancel the time acceptance effects introduced by the detector once performing the ratio of the two

modes. The analysis uses the full data set recorded by the LHCb experiment during run 1 and run 2 $\left(8.7 fb^{-1} \right)$

[1] Alves, A. A., et al. “The LHCb Detector at the LHC.” JINST 3, LHCb-DP-728 2008-001. CERN-LHCb-DP-2008-001: (2008) S08,005.

Assembling the LZ Detector

Angelides Nicolas

University College London, UK

At the forefront of the search for dark matter, the LUX-ZEPLIN (LZ) direct detection experiment holds discovery potential as it is anticipated to survey unexplored regions of candidate model parameter space. At the centre of the LZ detector is a large liquid xenon Time Projection Chamber (TPC), a well-established technology for the direct detection of WIMP dark matter for masses greater than a few GeV/c^2. The TPC was fully assembled on the surface of the Sanford Underground Research Facility, in Lead, South Dakota, before being transported to the Davis Campus on the 4850’ underground level, where it is hosted. This talk will feature key steps in assembly, leading to the delivery of the world’s most sensitive dark matter detector

Enhancing physics reach with improved triggers in Run 3

Elena Villhauer

University of Edinburgh, UK

Enhancing physics reach with improved triggers in Run 3 The Run 2 ATLAS trigger system is comprised of two levels: a hardware level (L1) and a software higher level trigger (HLT). Between late 2018 and early 2021, the ATLAS trigger system is undergoing upgrades. Two major sets of upgrades to the ATLAS level 1 trigger system will be the increase in read-out granularity in the LAr detectors ("supercells") and the addition of new Feature EXtractors (FEXs): Jet FEX (jFEX), global FEX (gFEX), and electromagnetic FEX (eFEX). The jFEX identifies jets and calculates missing transverse momentum and other energy sums. The gFEX identifies large radius jets. The new Run 3 L1 jets will make use of the improved resolution and the added algorithm flexibility provided by these upgrades. The incorporation of the jFEX and gFEX in Run 3 will cause L1 jet triggers to change significantly. To maintain the efficiency of the HLT and L1 jet chains and to maximize use of L1 rate, it is crucial that the performance of Run 3 L1 jet triggers is optimized. Jet triggers for low-threshold multijet triggers and for trigger-level analyses will benefit from polished Run 3 L1 jets. Presented here is a calibration for jFEX jets and its importance for Run 3 searches.

Investigation of Isospin Symmetry Breaking Through Mirrored One-Nucleon Knockout Reactions to the T_z=±2 A=48 Mirror Nuclei

Rehab Yajzey[1,9 *], M. A. Bentley[1], S. Uthayakumaar[1], X. Pereira-Lopez[1], P. J. Davies[1], T.Haylett[1], L. Morris[1], B. Wadsworth[1], E. C. Simpson[2], D. Bazin[3], J. A. Belarge[3], P. C. Bender[3], B. A. Elman[3], A. Gade[3,4], H. Iwasaki[3,4], N. Kobayashi[3], B. R. Longfellow[3], E. M. Lunderberg[3], D. Weisshaar[3], F. Recchia[5,6], J. A. Tostevin[3,7], S. M. Lenzi[5,6], D. R. Napoli[8], D. Kahl[9] and S. J. Lonsdale[9]

[1]University of York, UK, [2]Australian National University, Australia, [3]National Superconducting Cyclotron Laboratory,Michigan State University, USA, [4]Michigan State University, USA, [5]INFN Sezione di Padova, Italy, [6]Dipartimento di Fisica e Astronomia, Università degli Studi di Padova, Italy, [7]University of Surrey, UK, [8]INFN, Laboratori Nazionali di Legnaro, Italy, [9]University of Edinburgh, UK, [9]Jazan University, Saudi Arabia

The nuclear force can be assumed to be both charge symmetric and charge independent of the same isospin *T*, which therefore gives rise to the concept of isospin symmetry. Based on this assumption, one would expect, in the absence of isospin breaking interactions, the analogue states in nuclei of the same mass number to be degenerate [1,2]. However, the differences in excitation energy spectra in mirror nuclei will break the degeneracy due to Coulomb interactions and charge dependence of the nucleon interaction. Therefore, differences in excitation energies between Isobaric Analogue States (IASs) can be interpreted to Isospin Non-Conserving (INC) interactions, causing isospin symmetry violation [3].

An in-beam γ rays spectroscopy experiment has been performed at the National Superconducting Cyclotron Facility (NSCL) to identify new excited states in the exotic proton-rich nucleus A = 48 (T_Z = -2) ^{48}Fe and its mirror nucleus (T_Z = +2) ^{48}Ti in the $f_{7/2}$ shell, produced via mirrored one-nucleon knockout reactions. The radioactive beams were identified on an event-by-event basis by their time-of-flight (ToF) using the A1900 fragment separator. Gamma rays of nuclei of interest were detected using Gamma-Ray Energy Tracking In-Beam Nuclear Array (GRETINA) with the S800 spectrometer.

The aim is to investigate Isospin symmetry by examining analogue spectroscopic factors in mirrored knockout reactions in a weakly bound system [4]. This work is based on the mirror symmetry study of one-nucleon knockout reactions to the A = 53 (T_Z = ±3/2) mirror nuclei by S. A. Milne et al. [5]. Mirror energy differences (MED) of the ^{48}Fe / ^{48}Ti mirror pair will also be investigated to further past MED analysis in the f*p*-shell. A pronounced cross-section asymmetry was observed for the mirror nuclei since the analysis shows that the inclusive cross-section of the proton-rich nucleus ^{48}Fe is about ~ 9 times smaller than that of the more stable mirror ^{48}Ti. This large asymmetry of the reaction cross-sections may arise from the asymmetry in binding energies. The experimental and predicted exclusive cross-section calculations for the knockout process performed to interpret the population of individual states in ^{48}Fe will be presented.

[1] M. Bentley and S. Lenzi, Prog. Part. Nucl. Physics.vol. 59, no. 2, pp. 497–561, (2007)
[2] D. Warner et al., Nature Phys, vol. 2, no. 5, p. 311, (2006)
[3] M. Bentley et al., Phys. Rev. C, vol. 92, no. 2, p. 024310, (2015) [4] J. A. Tostevin and A. Gade, Physical Review C, 90 (2014)
[5] S. A. Milne et al., Phys. Rev. C, 93, 024318, (2016)

Observation of excited Ω_c^0 baryons in exclusive Ω_b^- decays

Sara Mitchell[1], Misha Mikhasenko[2], Franz Muheim[1], Marco Pappagallo[3]

[1]The University of Edinburgh, UK, [2]CERN, UK [3]University and INFN of Bari, Italy

This talk will present the first observation of the $\Omega_b^- \to \Xi_c^+ K^- \pi^-$ decay using proton proton collision data at centre-of-mass energies of 7, 8 and 13 TeV collected by the LHCb experiment, corresponding to an integrated luminosity of 9 fb^{-1}. A branching ratio is measured relative to the $\Omega_b^- \to \Omega_c^0 \pi^-$ decay mode and a precise measurement of the Ω_b^- mass is obtained. Four excited Ω_c^0 baryons are observed in the $\Xi_c^+ K^-$ mass projection of the $\Omega_b^- \to \Xi_c^+ K^- \pi^-$ decays. Their relative productions, masses and natural widths are measured and a test of spin hypothesis is performed to probe their spin-parity quantum numbers.

Constraining the Higgs-top Yukawa Coupling with the ATLAS Experiment at the LHC

Thomas Carter

The University of Edinburgh, UK

The Higgs-top quark Yukawa interaction was discovered through an observation of *ttH* production by the ATLAS and CMS experiments at the LHC in 2018. This interaction describes how the Higgs boson couples with the top quark in the Standard Model (SM). Since observation, research is now focused on measuring the strength of the Higgs-top Yukawa interaction (Y_t).

Limits are set on the strength of the Higgs-top Yukawa coupling compared to the Standard Model prediction, $\kappa_t = Y_t^{obs} / Y_t^{SM}$. The latest limits, from the combination of Higgs boson final state analyses, are not able to exclude negative values of κ_t [1]. However, now with the full set of *Run 2* data at a luminosity of 139 fb^{-1}, we are able to design analyses that are sensitive to the rare single-top Higgs (*tH*) process Fig. 1.a. The *tH* process is extremely sensitive to the sign of κ_t, and so provides an excellent opportunity to constrain the Higgs-top Yukawa coupling strength.

Our work aims to take full advantage of this new sensitivity to *tH* in the $H \rightarrow \gamma\gamma$ channel, to constrain the allowed values of κ_t. We employ novel multivariate analysis techniques to maximise our analysis sensitivity to the sign of κ_t within the *tH* process. Using our technique, we expect to be able to exclude negative values of κ_t at > 95% CL (Fig. 1.b). Any significant deviation in our measured strength of the Higgs-top Yukawa interaction from the SM prediction would be an indication of exciting new physics.

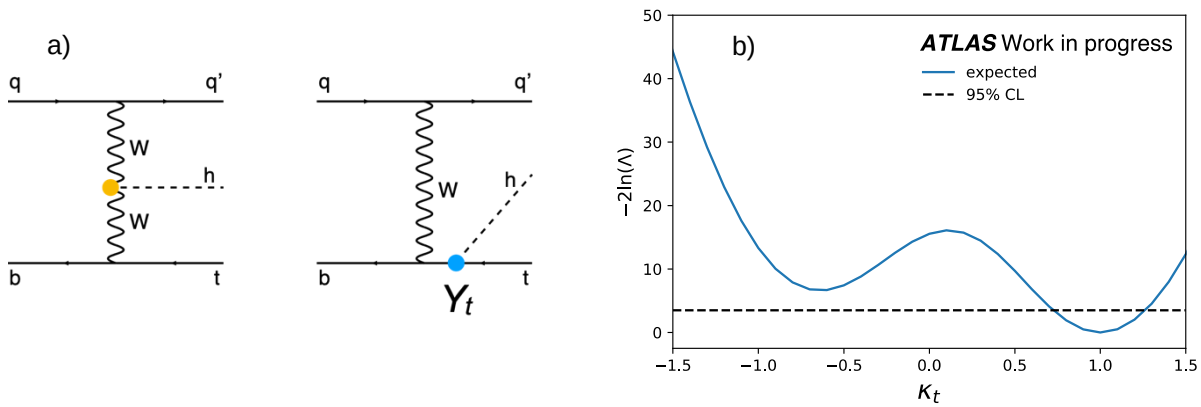


Fig. 1. a) t-channel leading order Feynman diagrams of the *tH* process. Interference effects between these two possible diagrams makes the *tH* process extremely sensitive to the sign of κ_t. b) Expected constraining power in κ_t with our multivariate analysis models applied.

[1] ATLAS Collaboration, Phys. Rev. D 101, 012002 (2020)

Posters

Topic: High Energy Particle Physics

Lowering the energy threshold of the COSINE-100 experiment to 0.5 keV for increased sensitivity dark matter searches

Robert. J. Neal

University of Sheffield, UK and Institute for Basic Science, South Korea

COSINE-100 is a dark matter search experiment located at the Yangyang underground laboratory in South Korea that uses NaI(Tl) crystals to detect an annual modulation signal generated from the changing velocities of the dark matter particles over the year through the Earth, generated by Earth's motion around the Sun. The same target material and signal used by the DAMA experiments which is the only experiment claiming an observation of dark matter signals through the annual modulation.

Results from 1.7 years of data taking have already been published [1], but further increases in exposure and sensitivity are required for a conclusive test of the DAMA result. As such, a calibration run using a 22Na source has been carried out to allow for the energy threshold to be reduced to 0.5 keV. A good quality scintillation sample is provided to remove electronic noise events caused by photomultipliers via multi-variable machine learning training [2].

This poster will describe the COSINE-100 detector as well as the efforts to achieve the low energy threshold using the 22Na calibration data, and the forecast effects on the COSINE-100 dark matter search.

[1] G. Adhikari et al. (COSINE-100 Collaboration), *Physical Review Letters* 123.3 (2019)

[2] G. Adhikari et al. (COSINE-100 Collaboration), *arXiv preprint (2020) arXiv:2005.13784*

Tracking and vertexing at ATLAS

Helen Maguire

University of Sheffield, UK

The ATLAS detector in the large hadron collider (LHC) at CERN studies particles and forces created in high energy proton-proton (pp) collisions by analysing the tracks left by the final state particles in the detector. The tracks are reconstructed via the trajectories produced from each event. These tracks emanate from the site of the collision, known as the interaction vertex. At each bunch crossing, multiple individual pp collisions will occur. One of these may be a high-energy collision and of interest for further study – the hard-scatter (HS), the rest are lower energy events and are known as pile-up. The pile-up events can cause contamination of the data and prevent accurate resolution of the HS vertex. This issue will become more substantial as the LHC moves to Run 3 and the high-luminosity phase, as pile-up density will increase (current pileup ~ 30 to 60 per crossing, with a prediction of 200 per crossing in the HL-LHC). The existing tracking software requires improvement to improve the ability to distinguish between HS and pile-up tracks and to correctly assign them to suitable vertices.

The poster will explain tracking and vertexing in the ATLAS detector and the problems due to pile-up. There will be a short explanation of the proposal to improve the vertex reconstruction for Run 3 to mitigate the

effects of increased pile-up. Some preliminary results will be presented possibly including plots showing how merged vertices differ from matched ones.

A novel DAQ platform for big detector arrays in particle physics experiments

Yuri Venturini[1], Andrea Abba[2], Paola Garosi[1], Carlo Tintori[1], Massimo Venaruzzo[1]

[1]CAEN SpA, Italy, [2]Nuclear Instruments Srls, Italy

Modern particle physics experiments usually rely on very big experimental setup where it is possible to find a wide variety of detectors: silicon microstrip trackers, plastic scintillator calorimeters, LAr cryostats readout by a Time Projection Chamber, spectrometers composed of several drift tubes and resistive plate chambers. Moreover, other large and medium scale setups for the search of neutrinos and astroparticles use thousands of scintillation detectors read out by photomultipliers or SiPMs.

ATLAS, CMS, LHCb, Super (and the future Hyper) Kamiokande, WATCHMAN, SBND, DUNE, are just some examples of completed or on-going particle physics experiments, where a big amount of readout channels is involved. Nowadays, waveform digitizers and/or ASIC-based front-end cards are well-established readout electronics to build a scalable and reliable system hosting up to thousands of channels.

Since several years, CAEN brings its experience into the particle physics community to provide the most advanced solutions matching the requirements of such demanding experiments; Double-Chooze, ICARUS and Xenon are some examples of this successful collaboration that looks also to other physics field in which big, distrusted or highly segmented detectors are involved.

The FERS-5200 is the new CAEN Front-End Readout System, answering the challenging requirement to provide flexibility and cost-effectiveness in the readout of huge detector arrays [1]. FERS-5200 is a distributed and easy-deployable platform integrating the whole readout chain of the experiment, from detector front-end to DAQ. It is based on compact ASIC-based front-end cards integrating A/D conversion and data processing, which can be ideally spread over a large detector volume without drawbacks on the readout performance. Synchronization, event building and DAQ is managed by a single Concentrator board, capable of sustaining thousands of readout channels . Using the appropriate Front-End, the solution perfectly fits a wide range of detectors such as SiPMs, multianode PMTs, GEMs, Silicon Strip detectors, Wire Chambers, Gas Tubes, etc , thus matching the requirements of different applications.

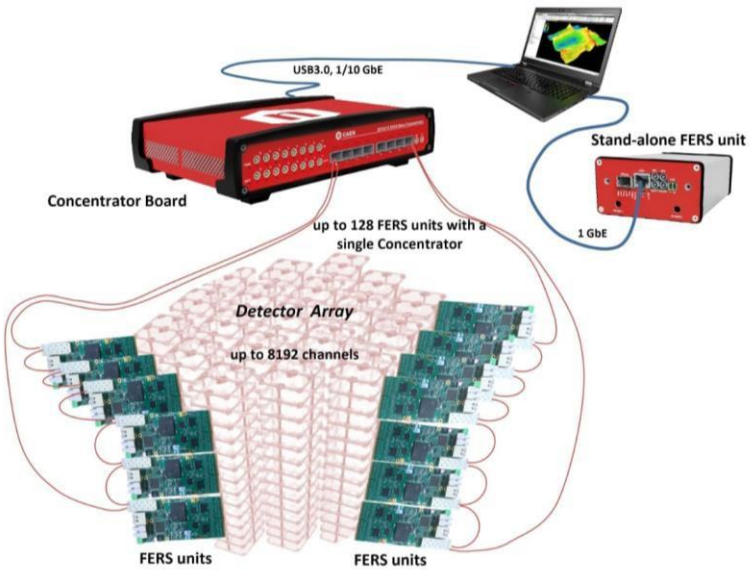


Fig. 1: (a) CAEN FERS-5200

[1] M.Venaruzzo, A.Abba, C. Tintori, Y.Venturini, IEEE Real Time Proceedings 2020.

Time-dependent CP-violation at LHCb with $B \to D_{CP}\, \pi\pi$ decays

A. G. Morris

University of Warwick, UK

Time-dependent Dalitz plot analysis of $B \to D_{CP}\, \pi\pi$ using LHCb Run 1 and Run 2 data allows us to probe the CKM angle β without suffering from the penguin-pollution which exists in the 'golden mode's mediated by $b \to c\bar{c}s$ decays. Since both modes are fairly precise, any differences found in the measurements of sin(2β) will necessarily indicate the presence of new physics, likely to be contained within the penguins of the golden modes. Furthermore, this decay gives sensitivity to cos(2β) and is expected to be world-leading in the precision of that measurement.

Screening for Radioimpurities in $Gd_2(SO_4)_3{\cdot}8H_2O$ for Super Kamiokande

Matthew Thiesse

University of Sheffield, UK

The goal of the next phase of the Super Kamiokande water Cherenkov neutrino experiment in Japan, "SK-Gd", is to dissolve $Gd_2(SO_4)_3{\cdot}8H_2O$ to a concentration of 0.2% w/w into the fiducial volume of the detector. Gadolinium has a higher neutron capture cross section than hydrogen or oxygen, which will allow SK-Gd to more readily detect neutrinos from supernovae and allow neutrino/antineutrino discrimination. Radioimpurities present in the raw Gd source material will raise the background event rate of the detector and, if the level of activity is above a certain threshold, could negatively affect low-energy physics sensitivities. Samples taken from 13 half-ton batches of $Gd_2(SO_4)_3{\cdot}8H_2O$ were screened for their natural radioimpurity concentration on ultra-low background (ULB) high purity germanium (HPGe) gamma spectrometers at STFC's Boulby Underground Laboratory. This talk will summarise the screening effort for these samples at Boulby, including the method of spectra analysis and results.

Electron lifetime measurement in SBND using crossing cosmic muon tracks

Vu Chi Lan Nguyen

University of Sheffield, UK

The Short Baseline Near Detector (SBND) is a Liquid Argon Time Projection Chamber (LArTPC) to be part of the Short Baseline Neutrino (SBN) program at Fermilab. The SBN program aims to search for sterile neutrinos and make precise cross section measurements at the Booster Neutrino Beam (BNB). The detection principle of LArTPC is based on a charged particle ionizing argon atoms, which produces ionisation electrons drifting under an applied electric field to be detected by a series of wire planes. Electronegative impurities present in liquid argon determines electron attenuation and hence, it is essential for purity monitoring and calorimetry reconstruction that electron lifetime is accurately measured. This study aims to develop a method to measure drift electron lifetime using cosmic-ray muons that cross both anode and cathode planes and apply the correction for calorimetry measurements.

New technologies and stretch goals for a kiloton scale neutrino detector

Stephen Wilson (for the WATCHMAN Scientific Collaboration)

University of Sheffield, UK

The WATCHMAN Scientific Collaboration aims to demonstrate the feasibility of using antineutrinos for non-proliferation, via remote reactor monitoring. This is planned to be accomplished via Neutrino Experiment One (NEO), a 6 kilotonne water Cherenkov detector situated at STFC's Boulby Underground Laboratory in North Yorkshire, 26 km from the EDF Hartlepool dual-core nuclear reactor complex.

Alongside the non-proliferation goals, the WATCHMAN collaboration aims to demonstrate innovative new detector technologies as part of the Advanced Instrumentation Testbed (AIT) facility. These technologies may include gadolinium doping, water-based liquid scintillators (WbLS), and new photo-sensing technology such as large area picosecond photo-detectors (LAPPDs).

These technologies could open the door to fundamental science possibilities. For example, the use of WbLS allows a low energy threshold and improved energy resolution, which enables new goals such as the measurement of neutrinos from the Carbon-Nitrogen-Oxygen (CNO) cycle in the Sun, neutrino oscillation measurements, and reactor ranging. This poster provides an overview of the proposed design of NEO as well as the energy reconstruction employed in a WbLS loaded detector, and its sensitivity to CNO solar neutrinos.

Searching for beyond the standard model physics using Tau Leptons

Mitch Norfolk and Trevor Vickey

University of Sheffield

A search for heavy neutral Beyond the Standard Model (BSM) particles decaying into the t+ t- final state is performed using the LHC Run 2 dataset, corresponding to an integrated luminosity of 139 fb-1 of pp collisions at $\sqrt{s}$ = 13 TeV [1]. The results are interpreted in the context of the Minimal Supersymmetric Standard Model (MSSM) which among other things, predicts heavy neutral Higgs bosons belonging to an extended Higgs sector. Heavy Z' bosons predicted by models such as the Sequential Standard Model (SSM) and the decay of third generation leptoquarks (LQs) are considered as additional signal interpretations. The data collected are in good agreement with the background prediction. Limits are set on MSSM benchmark scenarios, and these can be used to extract likely values for the free parameters associated with the theory, allowing phenomenologies to be further constrained. Model- independent limits based on these results are also shown.

[1] ATLAS Collaboration, Phys.Rev.Lett. 125, 051801 (2020).

Development of a Cherenkov Diffraction Radiation-based Beam Position Monitor for operation at the AWAKE experiment at CERN

Collette Pakuza[1], Philip Burrows[1], Michal Krupa[2], Thibaut Lefevre[2], Stefano Mazzoni[2], Eugenio Senes[2], Manfred Wendt[2]

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The Advanced Wakefield Experiment (AWAKE) at CERN [1] uses a 400 GeV, high intensity proton bunch to drive large amplitude wakefields in a laser-ionized rubidium plasma cell. These high-gradient wakefields are used to accelerate an electron witness bunch to high energies within a short distance provided that the injected electron bunch is at the correct temporal location and spatial trajectory. Therefore, a simultaneous

position measurement of the two beam bunches near the plasma cell is key for achieving an efficient acceleration.

Since the electron bunch is travelling in close proximity to the more intense proton bunch, the signal of a conventional electromagnetic beam position monitor (BPM pickup) is dominated by the proton bunch. However, the length of the proton and electron bunches are very different which allows a frequency discrimination to measure the low intensity electron bunch position by cutting off the majority of the proton signal spectrum, providing the electron BPM measurement is performed at a high detection frequency in the order of tens of GHz. To overcome the limits of conventional BPMs operating at these high frequencies, a new generation of BPMs based on Cherenkov Diffraction Radiation (ChDR) is under development. These devices promise to measure the electron beam position in the presence of an intense proton bunch. This contribution presents the study of a ChDR BPM prototype, starting from a basic concept with analytical estimations to a variety of numerical studies performed with CST Studio to optimize the design. The design of a prototype for in-air beam tests is also described.

[1] Aldi, E. et al., "Acceleration of electrons in the plasma wakefield of a proton bunch", Nature, 561, 363-368 (2018).

Calibration of the Super-Kamiokande Outer-Detector System

Joanna Gao[1], Teppei Kator[1], Shunichi Mine[2], Baran Bodur[3], Thomas Wester[4], and Linyan Wan[4]

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The Super-Kamiokande (Super-K) detector is a water Cherenkov neutrino detector with the shape of a cylinder 39m in diameter and 42m in height. The water tank is optically divided into two parts, the inner- (ID) and the outer-detector (OD) regions. The ID is the main volume, designated for neutrino detections, while the OD is mainly used as a veto for backgrounds such as atmospheric muons. The OD region is covered with white tyvek sheet to improve reflection, and it was constructed with 1885 8-inch photomultiplier tubes (PMTs) equipped with 50cm square wavelength-shifting plates. This poster presents the calibration effort and recent study of OD events using Super-K simulation and cosmic-ray data.

Electron identification at the ATLAS detector

Joshua Puddefoot

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The ATLAS detector detects and measures particles produced from high energy proton- proton collisions at the Large Hadron Collider (LHC). Efficient reconstruction and identification of electrons is essential to the precise study of electroweak processes at high energy colliders. Electron identification both offline and in the trigger is being optimized in preparation for an expected doubling of luminosity for LHC Run-3. The current likelihood- based approach to electron identification is summarized. Probability density functions of observables with significant discriminating power between prompt electrons and background will be presented.

Group energy with no fixed dimensions

Narayan Prasad Agarwal[1] and Krishna Kumar Choudhury[2]

[1]Indian Science News Association, India, [2]University of Calcutta, India

A Particle Is a Collapsed Wave Function. It also means we are also made of collapsed waves. But it also true that particles or group of particles absorb or reflect energy causing waves. According to quantum field theory, particles are excitations of quantum fields that fill all of space. Particles are "representations" of "symmetry groups. Particles are at a very minimum described by irreducible representations of the Poincaré group. Quarks, the elementary constituents of atomic nuclei, exist in a probabilistic combination of three possible states. Quarks live in group of three. Why particles and others remain in groups? Is strong force kept them binding or something else? The best answer is its enjoyment/charge of group energy etc that keeps all universal groups (particles & bodies etc) binding. Quarks to proton, electrons, neutrons etc to elements to all bodies are bounded by group energy. Neither time nor any other dimension remains fixed for groups. Water hydrogen bonding (groups) of particles is best examples of all biological lives Particles have three properties. One is energy. Deep down, energy is simply the property that stays the changing when the object shifts in time. Momentum is the property that stays changing as the object moves through space.Key property is "spin." All matter particles, meanwhile, have two spin degrees of freedom. The spin of a single electron could ultimately allow futuristic quantum computers. Mind spinning behavior is also caused by spin of particles.

Elementary particles don't just have the minimum set of labels needed to navigate space-time; they have extra, somewhat superfluous labels as well. They can carry different amounts of electric charge. Particles have many layers. Particles may be vibrating strings. Multiple strings cannot say that there are multiple universes of our present scale or any other scale as proposed by Stephen Hawking.

A particle is a deformation of qubit ocean. Space & time could be quantum error code. Holographic space-time has always particles' states distinguishing quantum systems. Particles are what we measure at detectors. Quasi particles & ions flows lead many biological & physical events. In groups Particles can be atoms, molecules or ions. Atoms are single neutral particles. Molecules are neutral particles made of two or more atoms bonded together. An ion is a positively or negatively charged particle. Calcium, sodium, potassium ions & all other ion channels carry vital biological functions with respective signaling. Universe is filled with group energy. Too much stress, pressure, energy etc causes groups to break but also result in new groups of particles & bodies.

Reference – quantum magazine.

MaCh3 oscillation analysis at T2K

Henry Israel

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The T2K experiment is a long baseline neutrino oscillation experiment located in Japan, its latest release has provided the most accurate measurement of δ_{CP}, significantly this strongly suggests CP-violation within the neutrino sector. To perform oscillation analysis 3 methods are used, this poster will focus on the MaCh3 analysis group. MaCh3 uses Markov Chain Monte Carlo to perform a Bayesian analysis of the T2K dataset. This poster will discuss the MCMC technique as well as its advantages in analysing high dimensional data sets.

Development of Mixed Field Neutron and Gamma Detectors for the Oil and Gas Well Logging Industry

James Greer

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The Oil and Gas industry relies on precision data for the evaluation of geological formations to make high value economic decisions. Many of the favoured techniques involve the use of high activity neutron sources downhole to probe the formation, most commonly AmBe chemical sources. The presence of Americium-241 in highly dispersible oxide powders has over recent years ignited fears over their use in Radioactive Dispersal Devices (RDDs) [1]. In addition to fears over RDDs, well operators must also handle these high activity sources when mounting sources onto the logging tool. In addition, sources have in the past been lost downhole, leading to costly environmental monitoring efforts prompting further pressure to adopt safer techniques for the industry [2]. As a result, the application of electrical D-D and D-T generators to well-logging is desirable. This is contingent upon whether they can provide accurate log data in sufficient measurement times and maintain similarity to historical data based upon AmBe sources [2]. Potential solutions to this problem include the moderation of the 14 MeV neutron spectrum from D-T sources, to replicate emitted energies from conventional AmBe sources. Attempts in the past, such as those performed in [1] using depleted uranium sleeves, showed little success in replicating an AmBe source spectrum. In this work, FLUKA simulations are performed using a variety of materials and geometries to investigate the feasibility of D-T spectrum manipulation. In addition to the moderation of D-T neutrons, it is also considered that machine learning techniques may be applicable to neutron porosity log data obtained using D-T or D-D neutrons, such as those used in [3]. Consideration will also be given to types of detector available for well logging. Plastic scintillators will be investigated to observe temperature degradation of their material properties and scintillation performance, with a view to investigate the feasibility of applying plastics to downhole devices. The hostile borehole environment requires careful consideration of operational temperature for detector volumes and associated instrumentation, with tools requiring stable operation in the range of 75-175ºC [4]. Therefore, stable performance over this temperature range would be a positive for the development of low-cost well-logging detectors.

[1] Frankle, C. M., & Dale, G. E. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 723 (2013).

[2] J. Griffin, T. Moran and L. Bond, Radiation Source Replacement Workshop, US Dep. of Energy, Pacific Northwest National Laboratory, (2010).

[3] Zhang D., Chen Y., & Meng J., Petroleum Exploration and Development, 45(4) (2018)

[4] A. Nikitin and S. Bliven, *IEEE Nuclear Science Symposium & Medical Imaging Conference,* Knoxville, TN, pp. 1214-1219 (2010)

Neutrino induced Σ0 Production at MicroBooNE

Niam Patel for the MicroBooNE Collaboration

Lancaster University, UK

MicroBooNE is a single-phase Liquid Argon Time Projection Chamber (LArTPC) massing 85 active tons operated at Fermi National Accelerator Laboratory. One of the primary physics programs is to determine the nature of the low energy excess observed by the MiniBooNE experiment and the study of neutrino-argon scattering [1]. One of the interesting interactions that will be measured in MicroBooNE is a charged current scattering with hyperons in the final state. Hyperons were a focus of study several decades ago; however, there is little experimental data on direct hyperon production. Further study of hyperons with current technology can provide simulation advancements via enabling more accurate constraints on hyperon interaction models [2].

The Neutrinos at the Main Injector (NuMI) beam provides an off-axis neutrino beam available for MicroBooNE in neutrino and antineutrino modes, with a mean muon antineutrino energy of approximately 1.6 GeV at the detector. The high muon antineutrino flux offers the opportunity to measure larger numbers of hyperon events than in past experiments for low energy beams. Approximately 30 Σ0 direct production

events are expected to occur within the Run 1 NuMI data within the active volume. However, detection efficiency for this study is still to be ascertained.

Σ0 CC quasi-elastic events result in a 3 tracks (muon, proton and charged pion) and 1 shower (photon) signature with a specific topology due to a Λ0 hyperon's production, which subsequently decays. The high resolution of the LArTPC allows detection of the Λ0 decay gap between the photon-muon and proton-pion vertices. The liquid argon medium allows for good separation between photons and electrons, aiding in reducing the backgrounds.

Despite these advantages, several issues are still impinging upon the detection of Σ0 hyperons that will be discussed and quantified. This includes differences in kinematics between directly produced Σ0 and Λ0 hyperons; the separation or removal of miscategorized showers and tracks and the current state of preselection for Σ0 events.

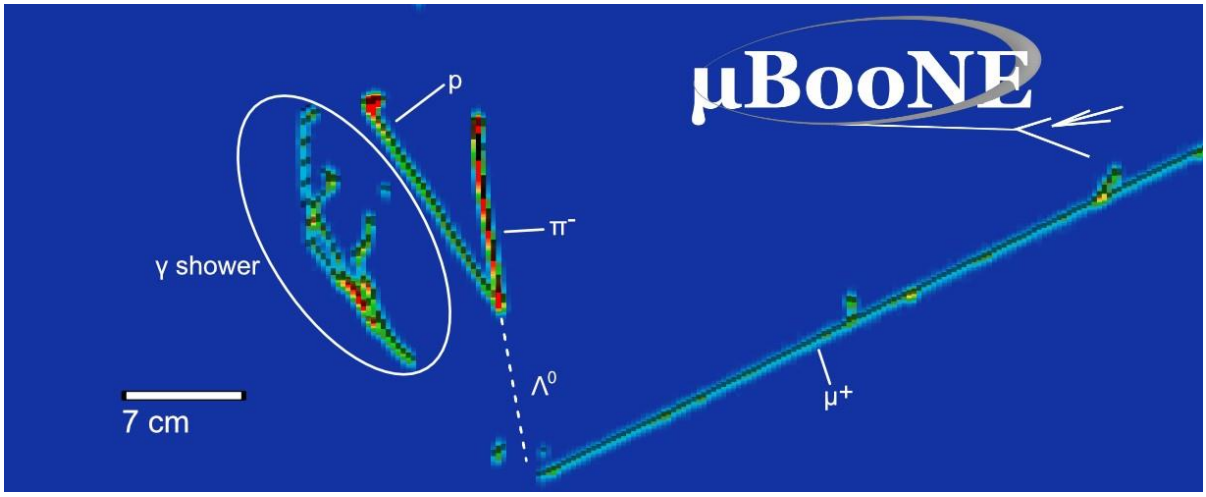

Fig. 1: A labelled Simulated Σ0 Interaction in the MicroBooNE Detector.

[1] MicroBooNE Collaboration. Design and Construction of the MicroBooNE Detector. J Inst. 12 P02017 (2017).

[2] Thorpe C, Nowak J, *et al.* Second Class Currents, Axial Mass and Nuclear Effects in HyperonProduction. arXiv:201012361 [hep-ph]. (2020).

Adding the 4pi sample into T2K ND280 near detector fit

Yongheng Xu on behalf of the T2K collaboration

Lancaster University, UK

The Tokai-to-Kamiokande (T2K) is a Japan-based long-baseline neutrino-oscillation experiment. The near detector, ND280, is used to characterize the neutrino beam and measure interaction cross- sections. Results from ND280 are used to reduce systematic uncertainties in the prediction on the number of oscillated events at the far detector, Super-Kamiokande. We model the neutrino flux and cross-sections, first constraining them using experiments prior to ND280, then fitting to the data collected at ND280 to further constrain the model parameters and thereby significantly reduce the systematic uncertainties. This poster will focus on the ND280 fitting framework. In Super-Kamiokande, muons from neutrino interactions may be produced in any direction. However, the current samples used in the ND280 fit only includes final-state muons that go forward. In this work we aim to enlarge the angular acceptance of the charged-current selection to a full 4pi solid angle acceptance. This is made possible by using the time-of-flight information between the tracker detectors and the electromagnetic calorimeter to correctly identify the direction of the muon tracks. Including the 4pi

sample in the ND280 fit will help to better compare ND280 data to Super-Kamiokande data and reduce further the systematic uncertainties on the neutrino oscillation parameters.

A study analyses the impacts of identifying ionisation deposition in the SBND detector for two main noise simulations: a white noise model and a data-driven noise model

Ala Zglam

University of Sheffield, UK

As one of the three Liquid Argon Time Projection Chamber (LArTPC) neutrino detectors sitting in the Booster Neutrino Beam (BNB), the Short-Baseline Near Detector (SBND) is currently being built at Fermilab as part of the Short Baseline Neutrino Program. The SBND detector, with an active mass of 112 tons, is being conducted in a new building 110 meters from the neutrino source. The detection principle of LArTPC is where charged particles crossing the detector ionise the liquid argon, and the ionisation electrons drift by an applied electric field. The output signals of the ionisation electrons caused by the particles can be studied using Monte Carlo (MC) simulations. Because the output signals will usually be accompanied by background noise, a noise model is required for realistic MC simulations. This study analyses the impacts of identifying ionisation deposition in the SBND detector for two main noise simulations: a white noise model and a data-driven noise model developed by MicroBooNE, one of the SBN program detectors.

Optical calibration design for the Hyper-Kamiokande Outer Detector

Celeste Pidcott

University of Sheffield, UK

Hyper-Kamiokande will be a next generation water Cherenkov detector, an order of magnitude larger than Super-Kamiokande. It will serve as the far detector for long baseline neutrino beams produced at J-PARC. It will also be used to study proton decay, atmospheric neutrinos, and neutrinos from astronomical sources, with far greater precision than its predecessor.

The detector will consist of both inner (ID) and outer (OD) detectors filled with ultrapure water. The ID will be instrumented with 20” photomultiplier tubes (PMTs) facing inwards to detect Cherenkov light produced in neutrino interactions and potential nucleon decays. In the OD 3” PMTs with wavelength shifting plates will be deployed on the OD inner wall facing outwards. This has the primary purpose of vetoing background events originating outside of the detector, as well as determining whether or not events occurring in the ID are fully contained.

An optical calibration system has been designed for the Hyper-Kamiokande ID, incorporating collimated and diffuse beams of light to measure both PMT response and the optical properties of the water. A similar system is intended for use in the OD, with similar goals. Light is delivered by optical fibres from the LED pulser sources to the diffusers and collimators which are distributed throughout the OD. In the OD it is important to measure the PMT response at single photoelectron level, the gain of the PMTs, and system saturated at high light levels. Diffusers are used for this purpose to ensuring wide illumination from each optical source. A specific challenge of this design arises due to the geometry of the OD and sensor support structures within it, necessitating many light injection points to illuminate the PMTs. It is important to allow sufficient redundancy should any sources become non-functional, while also minimising the final number of injection points to mitigate costs as this system is optimised.

An additional goal of the OD optical calibration system will be to measure the water properties in the OD, something not previously achieved in a water Cherenkov detector. Studies performed in simulation have

demonstrated that by using intense beams of collimated light directed parallel to the faces of the PMTs (across the diameter of the endcaps and the height of the barrel), we are able to detect changes in the water properties from changes to the distribution of charge collected by the PMTs and thus measure these properties in the OD for the first time.

This talk will present the current status of the Hyper-Kamiokande OD calibration system, its optimisation and analysis plans.

Calibration of the Hyper-Kamiokande inner detector

Pablo Fernandez

University of Liverpool, UK

aHyper-Kamiokande (HK) is the project for the next-generation large-scale water-Cherenkov detector and approved in Japan. Its physics program addresses some of the most challenging questions in fundamental physics like the precise measurement of the neutrino oscillation parameters (solar, atmospheric, accelerator), the investigation of astrophysical neutrino sources (supernovae, SRN) and the search for proton decay.

The default detector design consists of a tank containing 258 kton of ultra-pure water and with 187 kton fiducial volume for the physics analyses. Like Super-Kamiokande, it will be optically divided into outer (OD) and inner (ID) detectors, and instrumented with ~20k 50-cm PMTs facing inwards. Given the required precision of the measurements to achieve the physics program, it is crucial to understand and monitor the status and performance of the detector. This task largely relies on the calibration of the inner detector.

In this talk, an overview of the HyperK ID calibration techniques will be presented, and special emphasis will be dedicated to the light injection systems developed in the UK.

This system is currently under R&D and consists of a modular system with multiple laser heads independently operated and coupled to a single fibre, from which the multiplexing is done via optical switches. The injected short (<1 ns) pulses of light will be then split into a collimator and a diffuser, this shaping enables the sensitivty to the different optical properties of the water (symmetric and asymmetric scattering, absorption, transparency), and the monitoring in response of the PMTs as function of angle. The details on the design and the impact on the calibration of HK will be discussed.

Fast neutron spectroscopy: The nitrogen-filled Spherical Proportional counter

Giomataris I.[2], Green S.[1], Katsioulas I.[1], Knights P.[1,2], Manthos I.[1], Matthews J.[1], Neep T.[1], Nikolopoulos K.[1], Papaevangelou T.[2], Phoenix B.[1], Sanders J.[1], R. Ward[1]

[1]University of Birmingham, UK, [2]Universite Paris-Saclay, France

A dedicated, precise, and in-situ measurement of the neutron flux in underground laboratories is of paramount importance for many direct dark matter search experiments, as neutron induced background can mimic the standard dark matter signal.

For that purpose, two Spherical Proportional Counters (SPC) are installed and operated at the University of Birmingham and the Boulby underground laboratory, aiming to provide detailed measurements of the fast neutron spectrum. This is achieved with nitrogen-based gas mixtures, to exploit the $^{14}N(n, \alpha)B^{11}$ and $^{14}N(n, p)C^{14}$ reactions for the detection of fast and thermal neutrons, respectively. This method is a safe, inexpensive, effective, and reliable alternative to ^{3}He based detectors, and its proof of concept has been previously demonstrated [1]. Recent advancements in SPC instrumentation, in particular the multi-anode, resistive sensor [2] improve the field homogeneity in the volume of the detector, provide

efficient charge collection with high gain and allow increased target masses. Using these developments, measurements at atmospheric and higher pressure with fast and thermal neutrons from an Am-Be source have been conducted and will be presented.

[1] E. Bougamont *et al.*, Nucl. Instrum. Meth. A 847, 10-14, (2017)

[2] I. Giomataris et al., JINST 15 P11023, (2020)

Calibration of DUNE FD using cosmic-ray muons

Praveen Kumar (on behalf of the DUNE collaboration)

University of Sheffield, UK

The Deep Underground Neutrino Experiment (DUNE) is an international project for neutrino oscillation studies, neutrino astrophysics, and beyond the Standard Model searches, such as dark matter, neutron-antineutron oscillation and nucleon decay searches. These benefit highly from the large target mass and excellent imaging, tracking, and particle identification capabilities of Liquid Argon Time Projection Chambers (LArTPCs). Detector calibration is essential in order to make precise physics measurements, such as the amount of CP violation in the lepton sector, which require accurately reconstructed particle energy. Cosmic muons are a freely available natural source and can be used for calibrating various detector parameters. This poster presents characterisation of muon events simulated in Geant4 within Liquid Argon Software (LArSoft) and using the Muon Simulation Underground (MUSUN) generator in the DUNE Far Detector (FD), focusing on energy and angular distributions of muons, and on the rates of different classes of the muon events. Finally, the analysis of the invariant mass from $\pi^0 \rightarrow 2\gamma$ events produced by cosmic muons is presented together with the measurements of drifting electron lifetime. Both are important calibrations which address the measurement of absolute and relative energy loss in the DUNE FD volume.

Feature Recognition in Water Cherenkov Detectors

Daniel Martin

Imperial College London, UK

Super-Kamiokande is a Gadolinium-doped water Cherenkov detector that measures neutrino fluxes from natural sources as well as acting as the far detector for the T2K experiment. Uncertainty in Photmultiplier tube (PMT) positions due to their buoyancy can affect event reconstruction and therefore analysis measurements. Photogrammetry techniques could provide a digital reconstructing of the inner detector to estimate any shift in the tank geometry and reduce the uncertainty in PMT positions. Machine learning can be used to identify and label the 11,000 PMTs in Super-K. This poster presents algorithms that can identify and label each PMT so that they can be tracked between images in order to improve the performance of the photogrammetry reconstruction.

Long-range discovery of a nuclear reactor with a kilotonne-scale water-based antineutrino detector

Rob Foster, for the WATCHMAN collaboration

University of Sheffield, UK

Antineutrino detectors make use of the inverse beta decay process to detect the copious antineutrino emission from nuclear reactors. Since the highly penetrating antineutrino signature is inextricably linked to the presence of fissioning material, antineutrino detection is of interest as a possible complement to or extension of existing nuclear reactor safeguarding techniques. The WATCHMAN collaboration aims to demonstrate

remote far-field detection and monitoring of nuclear reactors. To fulfill this goal, a kilotonne-scale water-based antineutrino detector, Neutrino Experiment One (NEO), is planned to be deployed at Boulby Underground Laboratory as the first installation at the Advanced Instrumentation Testbed (AIT). AIT is a purpose-built facility to be constructed as an extension to Boulby Underground Laboratory, in order to house NEO and potential follow-on experiments. The principal physics goal is to measure the inverse beta decay interactions from Hartlepool nuclear power station from a distance of 26 km. The final design of the detector is in development but right cylinders with equal diameter and height, ranging from 14 m to 20 m, and photocathode coverages of 10% to 40% are under consideration. The detector will contain either gadolinium-doped water or water-based liquid scintillator (WbLS), a novel detection medium that aims to combine the advantages of water and liquid scintillator. Each design is being evaluated for its ability to achieve a number of collaboration goals, both nonproliferation and science-based, of which the demonstration of detection of Hartlepool is the priority.

A secondary nonproliferation goal is the discovery of reactors at even greater distances. A study was conducted into the sensitivity of the Gd-H2O, WbLS, and Gd-WbLS-loaded detector candidates to discovery of Heysham nuclear power station, a 4 core reactor complex located 148 km from Boulby. A customised Monte Carlo package was used to simulate signal and background events in the detector and subsequent analysis determined the significance of the Heysham signal over background in 365 days of observation time.

This poster will discuss WbLS as a new detection medium, discuss the potential benefits and complications that it presents for far-field reactor discovery, detail the WATCHMAN simulations framework and present results of the sensitivity to discovery of the Heysham complex for various detector designs.

Search for exclusive hadronic W boson decays with the ATLAS experiment

J. Silva and K. Nikolopoulos

University of Birmingham, UK

Since its discovery in 1983, the W boson has been studied extensively, primarily through its leptonic and inclusive hadronic decay modes. However, its exclusive hadronic decays are yet to be observed. These would offer novel precision studies of QCD factorisation [1]. With Standard Model branching fractions ranging from $O(10^{-8})$ to $O(10^{-12})$, and a high QCD background, the search for these decays has proven to be an experimental challenge. Given the large datasets collected, the LHC is the ideal laboratory to pursue the study of these challenging decays.

The searches for $W\pm \rightarrow \pi \pm\gamma$, $W\pm \rightarrow K \pm\gamma$ and $W\pm \rightarrow \rho \pm\gamma$ at the LHC, with the ATLAS detector are presented. The data analysed corresponds to 139 fb-1 of proton-proton collisions at $\sqrt{s}$ = 13 TeV. The most stringent upper limit of $\mathcal{B}(W\pm \rightarrow \pi \pm\gamma) < 7 \times 10{-}6$ has been set by CDF [2], while this is the first direct search for the $W\pm \rightarrow K \pm\gamma$ and $W\pm \rightarrow \rho \pm\gamma$ decays.

[1] Grossman, Y. et al., *Exclusive Radiative Decays of W and Z Bosons in QCD Factorization*, JHEP 04 (2015) 101.

[2] T. Aaltonen et al., Search for the Rare Radiative Decay: $W \rightarrow$ ⬚γ in pp Collisions at $\sqrt{s}$ = 1.96 TeV, Phys. Rev. D 85 (2012) 032001.

Data-driven measurement of track reconstruction efficiency in dense environments with the ATLAS detector

Júlia Silva and Kostas Nikolopoulos

University of Birmingham, UK

Many new physics searches and Standard Model measurements at the LHC are performed in dense environments. Events with dense environments, like the cores of highly energetic jets, are characterised by

a higher charged particle density, which may lead to reduced track reconstruction efficiency. A fully data-driven method has been developed to determine the extent of these losses [1]. The method relies on the modelling of the distribution of energy depositions by one or multiple charged particles in the ATLAS inner detector. The fraction of tracks that were not reconstructed can be determined by the number of times a single reconstructed track is associated to a cluster with energy deposition compatible with multiple charged particles.

Latest developments in the modelling of the distribution of energy depositions versus the charged particle multiplicity will be presented. These are then used to measure the track reconstruction efficiency inside jets with transverse momenta between 200 and 1800 GeV, using proton-proton collision data at $\sqrt{s}$ = 13 TeV.

[1] Aaboud, M., Aad, G., Abbott, B. et al. *Performance of the ATLAS track reconstruction algorithms in dense environments in LHC Run 2*. Eur. Phys. J. C 77, 673 (2017).

Improvements in near detector fitting techniques for the proposed new Hyper-Kamiokande near detector, IWCD

Charlie Naseby

Imperial College London, UK

As Hyper-Kamiokande operation approaches, iterative improvements in analysis techniques will be necessary to make use of the high statistics datasets made available. One analysis area of importance to CP sensitivity is the measurement of the ratio of the electron neutrino to anti-electron neutrino cross-section which has not previously been well constrained experimentally. Direct measurements of this cross-section ratio at the GeV scale have been hampered by the low electron neutrino component available in these traditional beams, necessitating a large detector with excellent background separation. An analysis approach utilising such a proposed near detector for Hyper-K; the IWCD is shown. In addition, the impact of improvements to the analysis technique; additional detector systematic uncertainties, the inclusion of antineutrino mode data, and different cross-section parameterisations are shown.

The Pandora multi-algorithm approach to pattern recognition for the DUNE far detector

Ryan Cross

Lancaster University, UK

The Deep Underground Neutrino Experiment [1] (DUNE) is a next-generation experiment that will perform precise measurements of neutrino physics and astrophysics using multi-kiloton liquid argon time projection chambers (LArTPCs). DUNE will require advanced reconstruction algorithms to fully exploit its fine-grain LArTPC images. The Pandora multi-algorithm toolkit [2] is a state-of-the-art approach to pattern recognition, already in use in a range of experiments across particle physics. Here, we present the Pandora reconstruction for the single-phase DUNE far detector; a LArTPC whose instrumented anode consists of three non-parallel planes of wires. In the multi-algorithm approach, the complex neutrino event topologies are gradually pieced together through a chain of focused algorithms, each addressing a small piece of the pattern recognition until the complete event is reconstructed. This enables targeted improvements to increase performance in required areas, improving the final physics results.

[1] DUNE Collaboration, arXiv:2002.03005

[2] R. Acciarri, *et al.*, Eur. Phys. J C78 no. 1 (2018) 82

Measurements of the Higgs boson inclusive, differential and production cross sections in the 4l decay channel at $\sqrt{s}$ = 13 TeV with the ATLAS detector

Panagiotis Bellos

University of Birmingham, UK

Higgs boson properties are studied in the four-lepton decay channel $H \rightarrow ZZ^* \rightarrow 4l$ ($l = e, \mu$). Differential fiducial cross sections are measured for a variety of observables which are sensitive to the Higgs boson production and decay properties. Cross-sections times branching ratio are measured for the main Higgs boson production modes in several exclusive phase-space regions. The measurements are interpreted in terms of coupling modifiers. All measurements are in agreement with the Standard Model (SM) predictions and they are used to constrain Beyond SM effects. The results are based on proton-proton collision data produced at the Large Hadron Collider at a centre-of-mass energy of 13 TeV and recorded by the ATLAS detector from 2015 to 2018, equivalent to an integrated luminosity of 139 fb^{-1}.

Search for the exclusive decays of the Higgs boson to a Z boson and a light resonance with the ATLAS Experiment

Mihaela Marinescu and Kostas Nikolopoulos

University of Birmingham, UK

Decays of the Higgs boson to light resonances are predicted by many extensions of the Standard Model. Considering the small natural decay width of the Higgs boson, even small contributions from such decays can result in substantial branching fractions. At the same time, although the couplings between the Higgs boson and third generation charged fermions have been observed, couplings to first and second generation fermions are yet to be confirmed experimentally. Exclusive Higgs boson decays involving mesons, can provide improved access to these couplings through distinct experimental signatures.

In this analysis, we search for the decay of the Higgs boson to a Z boson and a hadronically decaying light resonance, in the two-lepton plus two-tracks exclusive final state, targeting masses of the light resonance below 1.5 GeV. ATLAS has recently published limits on the Higgs boson production cross section times branching fraction to a Z boson and a hadronically decaying light resonance, where the hadronic decay of the light resonance was reconstructed inclusively [1]. The exclusive final state has the advantage of improved background rejection and resolution, to suppress the dominant Z+jets background. The search is interpreted both in terms of a BSM search, $h \rightarrow Za$, and as a search for the Standard Model processes $h \rightarrow Z\rho$ and $Z\varphi$.

[1] G. Aad et al. (ATLAS Collaboration), *Search for Higgs Boson Decays into a Z Boson and a Light Hadronically Decaying Resonance Using 13 TeV pp Collision Data from the ATLAS Detector*, Phys. Rev. Lett. 125 (2020) 221802.

The ATLAS Electron trigger performance in Run 2 and its correction in simulation

Daniela Koeck

University of Sussex, UK

The High Level Trigger system in ATLAS is crucial to reduce the collected proton-proton collision data and select events of interest for data analysis. Among many signatures, electrons are crucial in many different physics analyses, so understanding the performance of electron triggers in data as well as Monte Carlo simulation is important both for Standard Model measurements and BSM searches.

In this poster, I will highlight my leading contributions to the performance studies of electron triggers during the Run 2 proton-proton collisions at the LHC (2015-18). I will also discuss how trigger correction factors for Monte Carlo simulation are obtained, in order to mirror the trigger performances in data. These studies have been published in the first ATLAS paper on Electron and Photon triggers in Run 2 [1].

[1] The ATLAS Collaboration, Eur. Phys. J. C **80** (2020) 47.

The CERN Water Cherenkov Test Experiment (WCTE) and R&D of Future Water Cherenkov Technologies

Lauren Anthony

Imperial College London, UK

The Water Cherenkov Test Experiment (WCTE) is a small-scale water Cherenkov detector which will be constructed in 2022 and placed in the T9 beam area in CERN. The WCTE will be a test bed for future water Cherenkov technologies, including performance testing of new multi-PMT (mPMT) modules, testing of automated calibration source deployment systems (CDS), and the added opportunity to collect data of Cherenkov ring shapes and pion/hadron scattering on water. The CDS and a laser ball calibration source are currently being designed and built at Imperial College London. The CDS is comprised of a guide tube and sweeping rail, which will be permanently deployed in the detector. The design is such that interchangeable calibration sources, including the laser ball, can be moved along the rail in the horizontal direction and deployed at various depth positions, giving the freedom to change the calibration source position remotely. The CDS has also been incorporated into the Water Cherenkov Simulation (WCSim) software package in order to assess the impact that the system has on event reconstruction.

The large water Cherenkov experiment, Hyper-Kamiokande, will welcome the addition of an Intermediate Water Cherenkov Detector (IWCD), which is on the same scale order as WCTE. The IWCD will be located underground in Tokai, Japan, approximately 1km away from the J-PARC accelerator facility. It will be able to move in the vertical plane of a newly excavated shaft with the intention to measure the neutrino energy as a function of on/off-axis beam position. The measurements from which will be fed into the oscillation analyses as a method of reducing uncertainties in the analysis. Many of the same technologies that will be deployed at WCTE will be used at IWCD, including the mPMT modules and a larger, scaled version of the CDS. WCTE will therefore provide an invaluable insight into the physics capability of IWCD, alongside a full-scale test bed of newly developed bespoke hardware.

Precision measurements of photosensor components for the Hyper-Kamiokande Outer Detector

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[1]Oxford University, UK, [2]Rutherford Appleton Laboratory, UK

Hyper-Kamiokande (HK) is a next generation water Cherenkov detector that will be instrumented with high-sensitivity Photo-Multiplier Tubes (PMTs) to enable measurements of neutrino interactions with exceptional statistical precision [1]. The detector's capability to discriminate candidate neutrino interactions from cosmic muon spallation and atmospheric neutrino backgrounds, which dominate in low energy searches between 6 - 18 MeV, is dependent upon constructing an effective Outer Detector (OD) [2]. The baseline design, similar to Super-Kamiokande, proposes deploying around 13 thousand 3-inch hemispherical PMTs each coupled to an acrylic wavelength shifting (WLS) square plate around the bulb of the PMT [1]. Carrying out optical measurements of these components will be beneficial for increasing the relative light yield of the photosensor in order to optimise the performance of the OD photosensor configuration.

We have constructed a test facility to conduct precision measurements of these different components such as the properties of the WLS plate and the effect that the optical interface has on the light collection efficiency of the photosensor. This talk will cover the experimental progress including characterization of the setup and the performance of PMT and WLS plates in the test facility in comparison to detailed simulation studies in GEANT4.

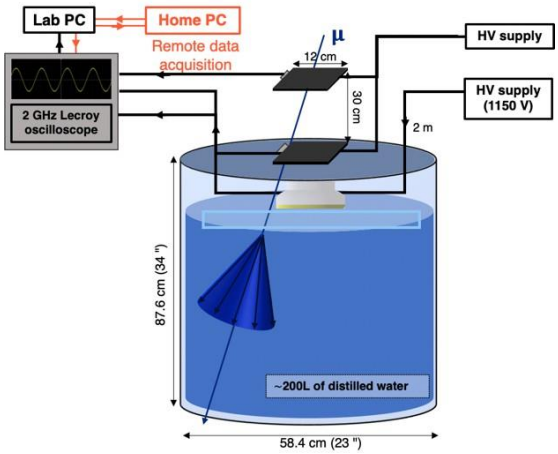

Fig. 1. Schematic diagram of the experimental setup.

[1] Hyper-Kamiokande Collaboration, arXiv e- prints, page arXiv:1805.04163, 2018.

[2] S. W. Li and J. F. Beacom. Phys. Rev. D, 91(10):105005, 2015.

The detection system of the MAGIS-100 atom interferometry experiment

Leonie Hawkins, on behalf of the MAGIS collaboration

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MAGIS-100 is a 100 m scale quantum sensor to be built at Fermilab. It will be the world's largest atom interferometry experiment and will be used to search for physics beyond the standard model.

An atom interferometer uses the superposition of atomic states to search for the effects of external forces on the phases of atoms, specifically those caused by new physics such as ultralight dark matter and gravitational waves [1,2]. MAGIS-100 will be composed of multiple atom interferometers spaced across a single baseline to measure a differential phase shift, allowing many of the limiting systematics to drop out.

The data taking process for the experiment involves fluorescing the atomic cloud with a detection laser pulse and capturing images of the cloud with high resolution cameras. The phase is determined by measuring the ratio of atomic states. Phase-shear imaging [3] will be used to allow single-shot imaging. This involves retro-reflecting the final laser pulse of the interferometer sequence to imprint interference fringes across the cloud, allowing single-shot measurements of the phase to be read out.

To determine the operating parameters of the detection system, simulation work models the wavefunction that describes the cloud at the output of the interferometer and includes multiple systematics to reproduce the

phase-shear readout. Systematics include the camera parameters (pixel dimensions, noise, etc.), diffusion of the cloud, large momentum transfer, contrast loss and smearing caused by the optics.

References:

[1] A. Arvanitaki et al. *Search for light scalar dark matter with atomic gravitational wave detectors*. Physical Review D (2018).

[2] P. W. Graham, J. M. Hogan, M. A. Kasevich, S. Rajendran & R. W. Romani. *Mid-band gravitational wave detection with precision atomic sensors* (2017).

[3] A. Sugarbaker, S. M. Dickerson, J. M. Hogan, D. M. S. Johnson & M. A. Kasevich. *Enhanced atom interferometer readout through the application of phase shear.* Physical Review Letters (2013).

Designing a discriminant for electron and photon triggers for the high-luminosity upgrade of the ATLAS detector at the LHC

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The High-Luminosity Large Hadron Collider (HL-LHC) upgrade plans to greatly increase the data-taking potential of the collider, allowing experiments such as ATLAS to take data at 7 times the rate of the original LHC design [1]. This increased rate is achieved by colliding 200 protons simultaneously at each bunch crossing, resulting in enhanced pileup in the detector.

This pileup puts an increased strain on the trigger, whose job is to select events which contain signs of interesting physics. To handle this strain, a comprehensive upgrade is planned for the trigger [1]. The work presented here represents a part of this upgrade – focusing on hardware-level fast triggers to select electrons and photons. The performance is studied for an algorithm which would be implemented in the Global Event Processor (GEP). This algorithm, E_{ratio}, takes advantage of the ultra-fine granularity of the strip layer in the electromagnetic calorimeter. This will be the first time any element of the trigger has access to such high-granularity calorimeter information, due to recent advances in technology.

This talk shows that the E_{ratio} algorithm has significant potential to improve the background rejection of the trigger. Parameters of the algorithm are tuned to try to create an optimal discriminant, maximising the background rejection whilst keeping the signal efficiency as high as possible.

[1] The ATLAS Collaboration, "Technical Design Report for the Phase-II Upgrade of the ATLAS TDAQ System.", https://cds.cern.ch/record/2285584 (2017)

Searching for long-lived heavy neutral leptons in hadronic decays with the CMS detector using a novel deep neural network-based displaced jet tagger

Julia-Suzana Dancu on behalf of the CMS Collaboration

Imperial College London, UK

Due to the robust theoretical motivation of heavy neutral leptons (HNLs) and their potential importance in explaining various observed Beyond Standard Model (BSM) phenomena, the search for HNLs is at the forefront of the physics programme of many experiments in the high energy physics community in recent

years. Prompt HNL searches are typically governed by multi-GeV HNLs decaying close to their production vertex, below typical detector resolution. Long-lived HNLs, however, have lower masses, hence longer lifetimes. They travel significant distances in the detector before decaying; therefore, their decay vertex is separable from their production vertex. Since HNLs are sterile, they do not leave tracks or energy deposits in the detector system. Consequently, HNL signals can only be identified through their displaced decay products following topologies predicted by theory.

A novel approach in searching for hadronically decaying long-lived HNLs in Run-2 CMS data is presented in this analysis. A gradient-boosted decision tree classifier algorithm is employed to separate heavy neutrino signal from background events in data. The event classifier is used as a complementary tool to a novel deep neural network-based displaced jet tagger algorithm recently developed by the CMS collaboration to search for signs of BSM physics [1]. The tagger is expanded to accommodate cases where a displaced lepton is present (clustered) inside a displaced jet, which allows to tag the HNL decay products with high efficiency. Preliminary results show promising signs of gain in HNL detection sensitivity.

[1] CMS Collaboration, "A deep neural network to search for new long-lived particles decaying to jets", *Sci. Technol.* **1** (2020) 035012, doi:10.1088/2632-2153/ab9023, arXiv:1912.12238.

Topic: Nuclear Physics

Search for dibaryon with CLAS12 collaboration

Matthew Nicol

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CLAS12 has been performing experiments at Thomas Jefferson National Laboratory (JLab) in which electrons of energy 10.5 GeV are impingand on liquid hydrogen or deuterium targets. One of the key programmes of these experiments is the search for exotic particles, like hybrids, tetraquarks, pentaquarks and hexaquarks. CLAS12@JLab has a unique possibility to study hexaquarks, including the recently discovered d*(2380).

Hexaquarks could have a great impact on our understanding of strong interactions, especially many body effects within Quantum Chromo Dynamics (QCD), but also our models of neutron stars. This work is searching for a candidate for a very strange hexaquark (d_sss) (with strangeness of -3), very negative (electric charge of -2) and with highest possible spin, J=3. If found the d_sss hexaquark could potentially have implications on "strange stars". The first steps of this analysis will be presented together with the studies of various conventional background channels, such as N* resonances with lager decay branches to states with strangeness and evidence of excited Λ*s states.

$\mathbf{d}^*(\mathbf{2380})$ hexaquark: from Photoproduction to Neutron Stars

Mikhail Bashkanov

University of York, UK

A resonance like structure mass $M = 2.38\,GeV$, width $\Gamma = 70\,MeV$ and $I(J^P) = 0(3^+)$ has been consistently observed in a wealth of reaction channels, supporting the existence of a resonant hexaquark state - the $d^*(2380)$. It was recently indicated that this new particle may set a limit on achievable neutron star masses, play a key role in the dynamics of neutron star merger events (including resultant gravitational wave emission) and has the potential to contribute to dark matter problem.

The talk will present the first results on d* photoproduction, obtained with the Crystal Ball at MAMI with linearly and circularly polarised photon beams. The new analysis indicated that the $d^*(2380)$ is likely to be excited predominantly through an *M3* transition rather than an *E2* transition, which is consistent with its proposed compact nature and constrain the $d^*(2380)$ shape. A first measurement of the spin polarisation of the recoiling neutron in deuterium photodisintegration, utilising a new large acceptance polarimeter will be reported. A very high neutron polarization observed in this experiment at $d^*(2380)$ energy range, can be associated with production of the $d^*(2380)$ hexaquark. The $d^*(2380)$ is likely be the first genuine hexaquark. Further possible astrophysical implications will also be outlined.

Plombox - development of a low-cost CMOS device for environmental monitoring

A. Aguilar-Arevalo[4], E. Alba Posse[1], M. Alvarez[1], H. Arnaldi[2], H. Asorey[2,7], X. Bertou[2], A. Colque[1],

A. Deisting[6], A. Dias[6], J.C. D'Olivo[4], F. Favela-Pérez[4], Y. Gándola[1], E. A. Garcés[4], J. Gasulla[1],

M. Gómez Berisso[2], A. González Muñoz[4], J. O. Guerra-Pulido[4], S. Gutierrez[2], S. Jois[6], J. Lipovetzky[2],

J. Lovera[2], M.B. Lovino[2], D.J. Marín-Lámbarri[4], L. Marpegan[2], D. Martín[1], M. Martinez Montero[4], S. Mejía Muñoz[1], J. Monroe[6], A. Nadra[1], S. Paling[2], R. Pregliasco[2], G. Rumi[2], A. Rossen[3], J. Santos[1], P. R. Scovell[5], M. Tallis[2], A. Teijeiro[1], M. Triana[1], E. Vázquez-Jáuregui[4]

[1]University of Buenos Aires, Argentina, [27]CNEA-CONICET National University of Cuyo, Argentina, [3]National Water Institute, Argentina, [4]National Autonomous University of Mexico, Mexico, [5]Boulby Underground Laboratory, UK, [6]Royal Holloway University of London, UK, [7]CNEA-CONICET National University of San Matin, Argentina

This presentation will look at the use of a novel CMOS device employing lead-sensing bacteria to assay lead in drinking water. In low- and middle-income countries access to accredited laboratories is limited and possibly expensive. The objective of the PlomBox project is to develop a low-cost sensor (~50€) which can expedite access to on-demand assay methods and thus help mitigate lead intake through contaminated drinking water. The PlomBox technology follows three development paths: a) Certain bacteria have the capacity to fluoresce when in the presence of lead. This project used a genetically modified strain of Escherichia coli which is sensitive to lead concentrations up to 10 ppb. Its response to the presence of lead, which occurs via color changes and light emissions, will be reported on. b) The bacteria response was imaged using a microprocessor module (ESP32) with a camera module. This constitutes the optical metrology component of the Plombox. c) The communication between the user and the Plombox is achieved through a Bluetooth connection via the PlomApp, a mobile phone application that works as the slow control for the Plombox's Data Acquisition (DAQ) system. All acquired data was sent from the PlomApp to a central database where analysis methods provide a result of the lead concentration in a sample of water. We will report on the instrumentation challenges of developing the electronics for the PlomBox and on the first prototype built in Dec. 2020. Its performance will be presented such as the accuracy of the lead measurement.

Time-like Compton Scattering at the Electron-Ion Collider

Kayleigh Gates[1], Daria Sokhan[1], and Pawel Sznajder[2]

[1]The University of Glasgow, UK, [2]National Centre for Nuclear Research (NCBJ), Warsaw

The Electron Ion Collider (EIC) was approved in December 2019 to be built on the Brookhaven National Laboratory site which presently houses the Relativistic Heavy Ion Collider (RHIC). The EIC is projected to

achieve a collision luminosity up to 10^{34} cm^{-2} s^{-1}, center of mass energies between 20-100 GeV and a wide coverage in phase space, making it ideal for probing nucleon structure from the valence quark region to the quark-gluon sea.

Time-like Compton Scattering (TCS) is a hard-exclusive process, often referred to as the inverse process to Deeply Virtual Compton Scattering (DVCS), wherein an electron or photon scatters from a nucleon, producing either a real or virtual photon in the final state, in DVCS and TCS respectively. The final state photon decays into a lepton pair. Both TCS and DVCS give access to Generalized Parton Distributions (GPDs), the parameterizations of the 'soft' part of nucleon structure, which can be interpreted as relating the transverse positions of quarks to their longitudinal momentum. Studies of both processes allow investigations into the universality of GPDs.

A deeper understanding of three-dimensional nucleon structure through the mapping of GPDs is one of the key goals of the EIC. In this talk we present a simulation study of the TCS process and the feasibility of its measurement at the EIC, based on the current detector design.

Measurement of particle and fluid mechanics with positron emitting tracers

T. W. Leadbeater, A. Buffler, K. Cole, M. R. van Heerden, N. Hyslop, A Camroodien

University of Cape Town, Rondebosch, South Africa

Short lived positron emitting species are used as tracer particles placed inside physical and engineering devices. The pairs of photons produced by positron annihilation are detected in coincidence by large arrays of high speed position sensitive detectors. The coincidence response is used to determine the near-instantaneous position of the tracer, and hence to infer the resulting bulk dynamics occurring inside the device. This technique, known as Positron Emission Particle Tracking (PEPT), was developed at the University of Birmingham in the early 1990s, and has been utilised at the University of Cape Town in a dedicated PEPT laboratory since 2009 [1].

At the largest multidisciplinary national research facility in South Africa, the iThemba Laboratory for Accelerator Based Sciences (iThemba LABS), PEPT is used by the University of Cape Town group to study dynamic physical processes and multiphase flow phenomena [2]. Such studies are of interest to industry, particularly in the South African context of mining and minerals processing. Further applications have been recently expanded to address global challenge topics including investigation of problems in water scarce environments, reducing industrial waste, and towards sustainable economies through improved process efficiency and informing design led approaches to industrial systems.

The applications of PEPT, and alternative complimentary measurement techniques, have enabled the development of flow metrology systems applicable to real world problems. Recent research produced by the PEPT Cape Town laboratory will be discussed, including aspects of our four key themes: instrumentation & detector development, radioisotope tracer techniques (physical and chemical), data acquisition & processing, and the applications of such measurements.

[1] Leadbeater, Parker, Gargiuli,. Particuology 10, 146 (2012).
[2] Buffler, Cole, Leadbeater, van Heerden, Int. Journal of Modern Physics: Conference Series 48, 1860113. (2018).

A portable neutron spectrometer: first measurements and applications

Tanya Hutton[1], Erin Jarvie[1] and Andy Buffler[1]

[1]University of Cape Town, South Africa

A compact neutron detector has been developed for use in mixed radiation fields, with a focus on measuring neutron energies between 1 - 100 MeV. Building upon previous work [1,2], the detector consists of a 6 x 6 x 50 mm^3 EJ-276 plastic scintillator coupled to a SensL Type-C silicon photomultiplier with digital data acquisition. The new detector was characterised relative to a reference EJ-301 organic liquid scintillator in terms of the quality of the pulse shape discrimination, efficiency and energy resolution. Measurements were made at the n-lab [3], University of Cape Town, using a range of gamma ray sources, an AmBe radioisotopic source and a D-T sealed tube neutron generator. Neutron and gamma ray energy spectra for each detector were unfolded from the measured light output spectra using GRAVEL and MAXED [4]. A detector of this type has many applications within nuclear and non-nuclear fields, and in this instance the design was tailored towards the measurement of secondary neutrons produced in the atmosphere at aviation altitudes during solar radiation storms [5]. The application to other neutron fields with energies up to 100 MeV are discussed.

[1] A. Buffler, *et al.*, Int. Jour. Mod. Phys. 44, 1660228 (2016).

[2] A. Comrie, *et al.*, Nucl. Instr. Meth. A, 772, 43–49 (2015).

[3] T. Hutton, A. Buffler, SAIP2017, 324–330 (2017).

[4] M. Reginatto, *et al.*, Nucl. Instr. Meth. A, 476, 242-246 (2002).

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Simulated response for the DESPEC gamma array at FAIR-0

M.M.R Chishti[1], R. Shearman[2], S. Jazrawi[1,2], P.H. Regan[1,2], Z. Podolyak[1], A.Goasduff[6], G.X. Zhang[7], A. Banerjee[3], G. Benzoni[8], A. Sharma[3,9], A.K. Mistry[3,5], A.Yaneva[3], H.M.Albers[3], N.Hubbard[3], M. Gorska[3], M. Polettini[4], M. Rudigier[3,5], for the DESPEC collaboration

[1]University of Surrey, UK, [2]National Physical Laboratory, UK, [3]FAIR/GSI Facility, Germany, [4]University of Milan, Italy, [5]TU Darmstadt, Germany, [6]INFN, National Laboratories of Legnaro, Italy, [7]University of Padua, Italy, [8]INFN, Section of Milan, Italy, [9]Indian Institute of Technology Ropar, India

Monte-Carlo simulations for the DESPEC (DEcay SPECtroscopy) setup at the FAIR-0 facility at Darmstadt, Germany are presented using the Geant4-based NPTool [1] framework to evaluate the gamma-ray response functions for cascades depopulating isomeric decays in ^{94,96}Pd. The experimental set-up which was simulated consisted of a hybrid γ-ray array with 6 High Purity Germanium HPGe GALILEO triple Cluster GTC detectors [2], and 36 $LaBr_3$(Ce) detectors from the FATIMA array [3]. The ions of interest were implanted into a stopper detector consisting of three double sided silicon strip detectors and two plastic detectors. The simulations are aimed at maximizing the functionality of the gamma-ray array by comparing the Full Energy Peak Efficiencies (FEP) with the first experimental data from the DESPEC experimental campaign at GSI, performed in February 2020 (Expt. S480). The nuclei of interest with microsecond meta-stable isomeric states and discrete gamma-rays in ^{94,96}Pd [4] were populated by using the projectile fragmentation reaction using a ^{124}Xe beam impinging upon a ^{9}Be target. The simulated results are discussed in detail and compared with the data in first phase of the DESPEC experiment at GSI.

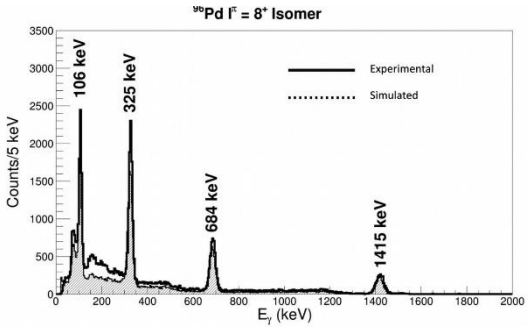

Figure 1: Simulated and experimental responses for the $T_{1/2}$ = 2.2(1) s, I =8^+ isomeric decay in ^{96}Pd [4] from the S480 experiment at FAIR-0

[1] A. Matta, et al., J. Phys. G: Nucl. Part. Phys. 43, 045113 (2016).
[2] E. Farnea et al. Nucl. Instruments Methods Phys. Res. Sect. A621, 331–343 (2010).
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[4] T.S. Brock et al., Phys. Rev. C82, 061301(R) (2010)

Investigating the Strangeness of Neutron Stars

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Understanding the nature of the nuclear force in terms of the fundamental degrees of freedom of the theory of strong interaction, Quantum Chromodynamics (QCD), is one of the primary goals of modern nuclear physics. While the nucleon-nucleon (NN) interaction has been studied for decades and is relatively well understood, very little is known regarding the interaction between other members of the octet and namely the hyperons (Y). To obtain a comprehensive understanding of the strong interaction, dynamics involving strange baryons must be studied. A detailed study of the YN interaction will shed light on the role hyperon might play in Neutron stars and address the Hyperon Puzzle.

In this talk I will describe our current work on investigating the interaction between the Sigma- hyperon and protons utilising final state interaction in exclusive hyperon photoproduction reactions. I will present preliminary analysis done using the E06- 103 experiment performed with the CLAS detector in Hall B at Jefferson Lab. The large kinematic coverage of the CLAS combined with the exceptionally high quality of the experimental data allows to identify and select final-state interaction events in the reaction $\gamma d \rightarrow K^+\Sigma^-(p)$ and to establish their kinematical dependencies.

Undergraduate experiments with ^{44}Ti and half-life measurement of the ^{44}Sc second excited state

S. Pirrie, G. Tungate, Tz. Kokalova, C. Wheldon, K. Nikolopoulos, P. Santa Rita and A. Turner

University of Birmingham, UK

The ^{44}Ti source is an especially useful source for demonstrating practical nuclear physics measurement techniques. Both the decay sequence and its corresponding daughter nuclei, ^{44}Sc and ^{44}Ca, enable a range of experimental measurements. In particular, five experiments using this source will be discussed which illustrate several nuclear physics topics and experimental techniques, such as coincidence and lifetime measurements. This source also has a long half-life of 59.1 years, making it appropriate and accessible as a source for undergraduate and postgraduate teaching labs. Production methods for this source [1] are also discussed.

One of these investigations, in which the half-life of the second excited (0^-) state in ^{44}Sc is determined, is discussed in more detail. A new value for this half-life has been measured using typical teaching laboratory equipment, with extra care taken to reduce background due to high rate effects. The methodology and results are discussed in this presentation.

[1] S. Pirrie, G. Tungate, Tz. Kokalova, C. Wheldon et al., Eur. J. Phys. **42** 015805 (2020).

Validating heterogeneity-based radiomics metrics in PET using noise-equivalent count rate, Monte Carlo simulation & 3D-printed patient-specific tumour phantoms

George Needham[1,2], Peter Julyan[2], David Cullen[1], Jill Tipping[2], David Hamilton[2], Sophia Pells[1,2], Alex Fish[1,2], Emma Page[2], Jose Anton-Rodriguez[2]

[1]University of Manchester, UK, [2]The Christie NHS Foundation Trust, UK

Radiomics is an emerging field in quantitative positron emission tomography (PET) whereby large amounts of data are extracted from medical images, with the aim of machine-aided diagnosis and treatment monitoring. Harmonization and standardization of data collection and image reconstruction both between individual scans and across centers have prompted questions over the reliability and reproducibility of radiomics metrics. The noise equivalent count rate (NECR) approximates collected PET data once scattered and random coincidence noise has been removed [1]. It is hypothesized in this work that by comparing curves of NECR against activity in the field of view (FOV) and heterogeneity metrics against FOV activity, the reproducibility of these metrics can be quantified.

The NECR-activity curves are collected from a 12-hour acquisition of a phantom filled with fluorine-18. These curves should demonstrate a peak at a geometry- and scanner-dependent activity value, beyond which random coincidence noise swamps the scanner timing circuitry and true coincidences are not reliably measured. Seen in Fig 1, images reconstructed from this data are observed to exhibit noise statistics with a nadir concurrent with this peak. Assessing the relative change in amplitude, and the nadir relative to the NECR-activity peak, of the heterogeneity-activity curves measures the susceptibility of that metric to data noise.

By carrying out these studies on phantoms of different geometries, these metrics can then be assessed for shape-dependent changes in these characteristic noise curves. Following a thorough validation process, it is expected that a patient-specific Monte Carlo simulation could be used to provide appropriate uncertainties on any radiomics metrics extracted from a PET scan, providing potential security for their usage in the clinical setting.

The presentation details work currently underway on this experiment, with data acquisitions, adhering to new COVID-19 protocols, going ahead at the time of writing. Further details include how the GATE simulation toolkit for Geant4 [2] is being used to perform Monte Carlo simulations of this experiment for a cylindrical phantom, a NEMA Image Quality phantom and additional non-standard geometries. These ascertain to lung, colorectal and oesophageal tumours which have been extracted from existing patient data, that are being 3D-printed at on-site facilities.

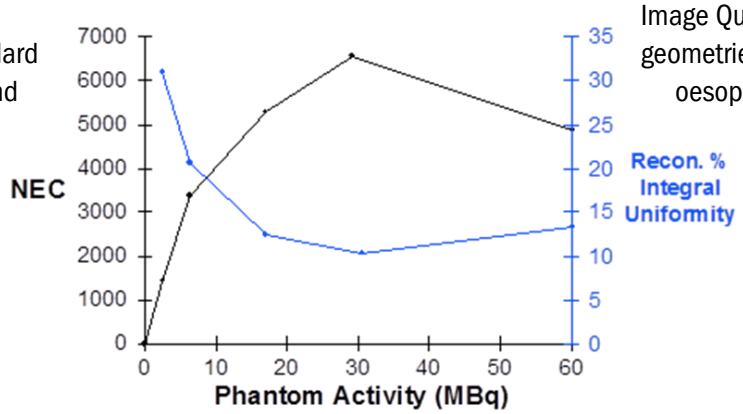

Fig. 1: Noise equivalent counts and percentage integral uniformity against activity for a particular cylinder. Figure provided by P.Julyan et al., The Christie NHS Foundation Trust.

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[2] S. Jan, G. Santin, D. Strul et al., Phys Med Biol, 49(19):4543-4561 (2004)

Measurement of the spectrum-averaged cross section of ^{117}Sn(n,n')^{117m}Sn using a ^{252}Cf source at the National Physical Laboratory

Michael Bunce, Matthew Birch, Graeme Taylor and Neil Roberts

National Physical Laboratory, UK

Four natural tin foils (radius 0.75 cm, 0.1 cm thickness) were irradiated in the National Physical Laboratory's low scatter facility using a ^{252}Cf spontaneous fission source. The fluence rate was approximately 42,000 cm^{-2}.s^{-1} and the foils were irradiated for 18 days. The delayed gamma emission from the 1st isomer in ^{117}Sn was measured using a NaI scintillator detector for a period of 43 days (^{117m}Sn $t_{1/2}$~14 d). Radiation transport calculations were performed using the codes GEANT4 and MCNP6 to determine detector-efficiency geometry corrections to convert measured point source calibration data to the extended geometry of the activated foil. Time-binned peak areas were measured, and the cross section was determined using an extrapolated fit to the data and by calculating the saturated activity. The measured cross sections are compared to literature by folding evaluated cross sections with the ISO 8529 and ENDF/BVII.1 spectra for ^{252}Cf. Good agreement between published data and the measured cross section is achieved. Further work will involve several monoenergetic and ^{252}Cf irradiations to confirm the results.

Measuring neutron polarization using the CLAS detector at Jefferson Lab

William Booth

University of York, UK

Jefferson Lab, Virginia, USA, is a world leading international facility in nuclear and particle physics. JLab houses a superconducting RF particle accelerator known as CEBAF (Continuous Electron Beam Accelerator Facility) and had an almost hermetic detector known as CLAS (CEBAF large acceptance spectrometer). CLAS was composed of many detection systems, including the start counter, which is a set of scintillators used to determine the time at when an event originated within the target in photo induced reactions. Presented in this poster are studies in which we investigate the utilization of the start counter as a neutron polarimeter. This study will pave the way for further analyses where polarization determinations can provide an insight to underlying physics, allowing us to shed light in hexaquark states.

Collinear laser spectroscopy of chromium isotopes

R. Mathieson[1], A. Koszorus[1], P. Campbell[2], B. Cheal[1], R. P. de Groote[3], C.S. Devlin[1], I.D. Moore[3],

D. Pitman-Weymouth[2], and the IGISOL group.

[1]University of Liverpool, UK, [2]University of Manchester, UK, [3]University of Jyväskylä, Finland

Laser spectroscopy allows us to probe nuclear properties such as: the magnetic dipole moment, the electric quadrupole moment, the mean-square-charge-radius and the spin of a nucleus. One particular region of interest in the chart of radionuclides is between the two magic proton numbers Z=20 and Z=28. Measurements of charge radii in this region are scarce, with many elements only having had the charge radii of their stable isotopes determined: Cr is one example. It is only the Ca isotope chain for which charge radii measurements are available across both neutron shell closures; interestingly the charge radii of both the N=20 and N=28 isotopes of Ca are the same, despite the 40% additional nucleons forming the later. The charge radii of Ca isotopes also form a parabola with significant odd-even staggering between the two magic numbers, this OES phenomena is also present in lighter Z isotopes, for example Ti (Z=22), but to a lesser extent.

The aim of this study, which will take place at the IGISOL facility at the University of Jyväskylä, is to determine the charge radii of $^{47\text{-}55}$Cr in order to add to the scarce amount of data in this region. Measurements of the neutron rich ^{55}Cr would add to our understanding of the evolution of charge radii beyond the N=28 closure, whereas measurements of the neutron deficient Cr isotopes will allow us to compare the odd-even staggering to that observed in Ti and Ca; it may be the case that with a proton number situated in the middle of the two shell closures that trends in charge radii are more strongly dominated by a relative increase in nuclear deformation. Spectroscopic measurements of ^{47}Cr and ^{55}Cr should also allow for the determination of their nuclear moments for the very first time.

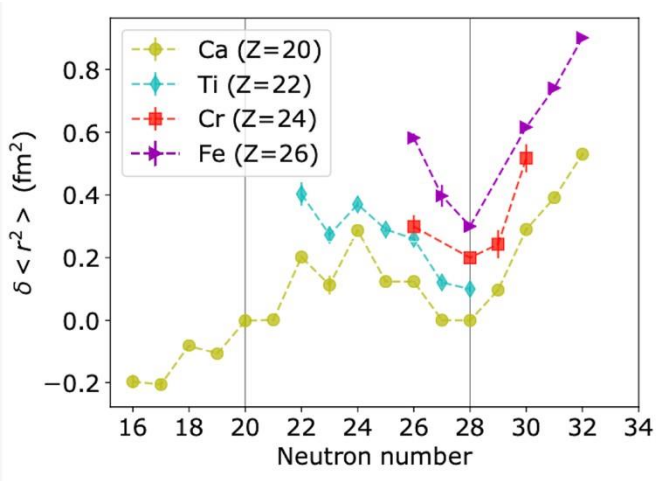

Fig. 1: Changes of mean square charge radii relative to the N=28 isotope across various isotope chains in the calcium region. An arbitrary offset has been applied to the absolute values for additional clarity.

Study of Nuclear reactions at astrophysically relevant energies using the CRYRING Array for Reaction Measurements (CARME)

Jordan Marsh

University of Edinburgh, UK

Key uncertainties remain for several thermonuclear reactions which significantly influence astrophysical processes; such as in Novae, Supernovae and the Big Bang. The CRYRING Array for Reaction MEasurements (CARME), offers a new method to constrain such uncertainties with excellent angular and centre of mass energy resolution. The novel

possibility to store radioactive and stable beams inside storage rings, in particular at the CRYRING, directly at energies of astrophysical interest will allow us to take a step forward in these scenarios. In my talk, I will mention the first scientific objectives for this new device, the d(p, γ)3He, 44Ti(α, p)47V and 30P(d, p)31P reactions.

Yrast state lifetime measurements in ^{94,96}Pd using the DESPEC@GSI experimental setup

S. Jazrawi[1,2], M.M.R. Chishti[1], P.H. Regan[1,2], R. Shearman[2], A. Yaneva[3,4], A. Banerjee[3], T. Arici[3], N. Hubbard[3,5], A.K. Mistry[3,5], H.M. Albers[3], M. Rudigier[5], M. Polettini[6,7], B. Das[8], Zs. Podolyák[1], M. Górska[3], J. Gerl[3], B. Cederwall[8], J. Jolie[4], G. Benzoni[7], O. Hall[9], T. Davinson[9] and the DESPEC collaboration

[1]University of Surrey, UK, [2]National Physical Laboratory, UK, [3]GSI Helmholtz Centre for Heavy Ion Research, Germany, [4]University of Cologne, Germany, [5]Technical University of Darmstadt, Germany, [6]University of Milan, Italy, [7]INFN Milano, Italy, [8]KTH Royal Institute of Technology, Sweden, [9]University of Edinburgh, UK

The first G-PAC approved experiment of the DESPEC@GSI setup (S480) was conducted in March 2020 with the goal of measuring B(E2) values for transitions between the yrast states of ^{94}Pd and ^{96}Pd through the direct measurement of isomer delayed gamma-ray cascades. ^{94}Pd and ^{96}Pd possess long lived isomeric states with $I^{\pi}=14^{+}$ [1] and 8^{+} [2] respectively. In the experiment, a ^{124}Xe primary beam of energy 850 MeV per nucleon impinged on a 4 gcm^{-3} thick ^{9}Be production target, with the fragments of interest transmitted into the focal plane by the GSI FRagment Separator (FRS). Discrete energy transitions identified event-by-event were measured using a hybrid HPGe-$LaBr_3$ gamma-ray spectroscopic array which enabled high-resolution and fast-timing measurements to be made. The DESPEC setup enables one to view coincidence events as a result of the time-stitching event building process which is implemented into the pre-sorted data. Off-line gates were applied on multiple particle detection systems in coincidence, allowing for a high degree of channel selection and associated low background gamma-ray spectra as seen in figure 1 which shows a spectrum from the FATIMA $LaBr_3$ array [3] gated on ^{96}Pd ions identified by various DESPEC detectors. The time difference between successive gamma rays in individual nuclear cascades allows time differences to be measured using the $LaBr_3$ detectors in this set-up, and a specific focus was placed on the determination of inter-band transitions following the isomeric decays in ^{94}Pd and ^{96}Pd. Mach et al. have reported such lifetimes in ^{96}Pd and these data were used as an internal calibration and verification for the methodology incorporated for lifetimes in the ns regime. Using this methodology, lifetimes of excited states populated in the gamma-ray cascade following the isomeric decay of ^{94}Pd were established for the first time in the current work. The experimental set-up was also validated by measurements of isomeric ratios for ^{94,96}Pd which were found to be in line and consistent with previous studies following the relativistic projectile fragmentation of a ^{124}Xe beam [4]. The current state of the analysis of these data will be presented, in particular with regards to the determination of B(E2) values in the T_z=+1 nucleus ^{94}Pd.

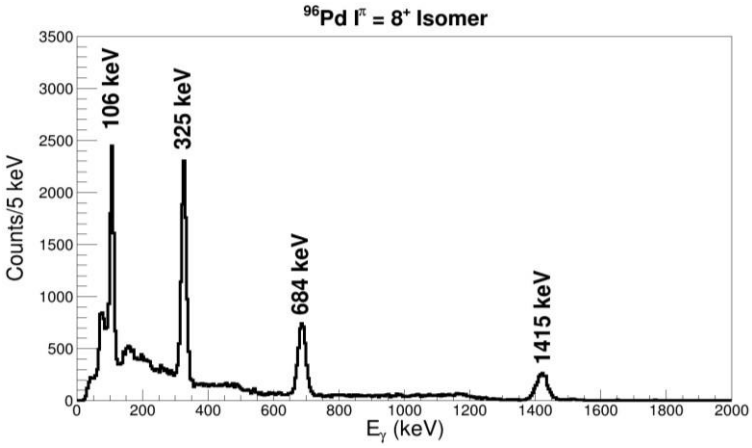

Fig. 1: The isomer delayed gamma-ray spectrum observed below the $I^{\pi}=8^{+}$ state in ^{96}Pd using the FATIMA LaBr3 array 40ns to 400ns after the prompt implantation in AIDA, gated on particle detectors in the DESPEC setup.

[1] M. Górska *et al.*, Z. Phys. A. **353**, 233 (1995). [2] D. Alber *et al.*, Z. Phys. A. **322**, (1989).

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The search for exotic mesons in the three pion reaction channel with CLAS12

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The constituent quark model describes mesons as a quark-antiquark pair. However, QCD which describes the strong force governing the interaction, does not forbid the existence of states outside this simple picture – so called exotic states. A goal of hadron spectroscopy is to investigate whether such exotic states exist, and by doing so, achieve a greater understanding of QCD. One particular configuration of an exotic state is a so-called hybrid which contains a constituent gluon alongside the quark-antiquark. The photoproduction of a three pion final state from a proton target may be used to search for hybrid states as the final state angular distributions can contain contributions only possible for intermediate hybrids states with quantum numbers not possible from a quark-antiquark pair alone. Previous results on this final state have been published on experimental data acquired at CLAS and COMPASS, the latter of which is showing strong evidence for the hybrid state.

Data was taken using the upgraded CEBAF Large Acceptance Spectrometer (CLAS12) at the Thomas Jefferson National Accelerator Facility (Jefferson Lab). This talk will discuss the aims and experimental procedures of analysing the data with the aim of isolating the three pion final state.

Ion trapping developments at Edinburgh University, towards precise mass measurements of light exotic nuclei at TITAN

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[1]University of Edinburgh, UK, [2]TRIUMF, Canada, [3]University of Victoria, Canada, [4]University of British Columbia, Canada

High-precision mass measurements are essential for understanding the structure of exotic nuclei. These measurements also serve as excellent tests of ab-initio nuclear models and provide key inputs for calculations in nuclear astrophysics.

The TITAN (TRIUMF's Ion Trap for Atomic and Nuclear science) collaboration [1] at TRIUMF has specialised in the measurement of short-lived nuclei using a Penning trap and a recently installed multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS) [2].

However, many light exotic nuclei are currently inaccessible at TITAN. Among these are several nuclei which would provide important insight concerning the island of inversion and the evolution and quenching of shell closures. Of particular interest is the halo nucleus 14Be. The halo nuclei 11Li, 6He, and 8Be have all been measured at TITAN using the Penning trap [3], but a precise measurement of 14Be remains elusive due to its

exceptionally low half-life and production rate. A first direct measurement of its mass would be an unprecedented test of current nuclear models.

The MR-TOF-MS excels at measuring scarcely produced nuclei with very low half-lives, and as such it increases TITAN's reach to include more exotic nuclei. This has allowed many new measurements, a recent example being the precision measurement of neutron-rich Scandium near the N=32 and N=34 shell closures [4]. But to leverage this strength towards the study of light nuclei, a high frequency driver must be developed for the radio-frequency quadrupole (RFQ) system.

A high frequency sine-wave driver has already been set up, but it has been shown to not be ideally suitable for the above-mentioned nuclei of interest. As such, work is currently taking place at Edinburgh to develop a new square-wave driver.

This contribution will report on these ongoing developments in ion trapping at the University of Edinburgh, that will ultimately enable precise mass measurements of several light nuclei including 14Be, 19C, and 17Ne.

[1] J. Dilling *et al.,* International Journal of Mass Spectrometry 251, 198 (2006)

[2] C. Jesch *et al.*, Hyperfine Interact 235, 97 (2015)

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Many Proton Knock-Out From Nuclear Targets Using Real Photon Beams

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University of York, UK

The main goal for modern nuclear physics is to build a fundamental understanding of the nuclear structure and dynamics from fundamental principles of the strong nuclear force (QCD). A plethora of experimental data exist on light and heavier nuclei utilizing experiments at Thomas Jefferson laboratory (JLAB) and the CEBAF Large Acceptance Spectrometer that can be used to study nuclear reactions in great detail. In this poster we will present our work in which we utilize a real photon beam to studying many proton knock-out reactions. Our preliminary results are compared with predictions from theoretical models and specifically from Giessen Boltzmann-Uehling-Uhlenbeck project (GiBUU), to obtain a better understanding of the underlying dynamics in such many-body systems.

Measurement of fission product gases using a high-resolution beta-gamma coincidence detection system

M. A. Goodwin[1,2], S. J. Bell[3], R. Britton[4], A. V. Davies[1], M. Abilama[3], S. M. Collins[2,3], R. Shearman[3], P. H. Regan[2,3]

[1]AWE Aldermaston, UK, [2]University of Surrey, UK, [3]NPL, UK, [4]CTBTO, Austria

Gaseous fission products have been produced via neutron irradiation of a highly-enriched uranium (HEU) target and extracted using a custom gas processing system for measurement on a prototype high-resolution beta-gamma coincidence detection system. The gas was extracted in two phases in order to measure the prompt and delayed fission products using high-resolution germanium (HPGe) and silicon detectors. We present an overview of the system used to produce gaseous fission products, and the results of the advanced coincidence spectrometry techniques used to identify and quantify the radionuclides present (see [1]).

This work demonstrates the capability to produce gaseous radionuclides for quality-assurance, testing and calibration of detectors in Radionuclide Laboratories supporting the Comprehensive Nuclear-Test-Ban Treaty (CTBT) as well as for the calibration of equipment used for criticality monitoring.

Electron and photon spectra are presented, and the signatures of key radionuclides of interest to nuclear explosion monitoring, such as Xe-133, Xe-135 and Xe-133m are identified. The high-resolution beta-gamma coincidence spectrometry demonstrates the greatest available electron and photon energy resolution, in order to discriminate interfering emissions from one another, improving detection sensitivity in higher-activity measurements.

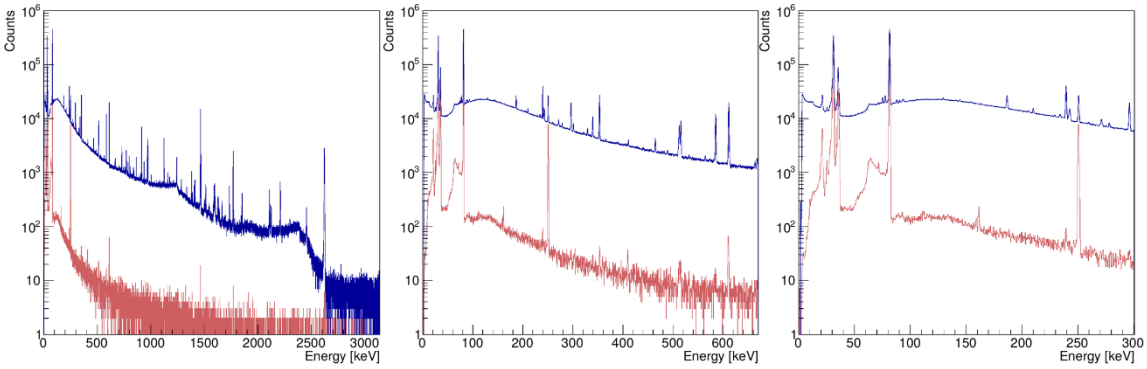

Fig. 1: High-resolution gamma-ray spectra from the measurement of extracted fission-product gases from a HEU target, irradiated at NPL. Blue: gamma-singles spectra, red: beta-gated gamma spectra. Left to right zooms the energy axis to the 0-300 keV region. The X-rays of Xe & Cs, Xe-133 gamma ray at 81 keV and Xe-135 gamma-ray at 250 keV are all clearly visible in the beta-gated spectra.

[1] M. A. Goodwin, R. Britton, A. V. Davies. S. J. Bell, S. M. Collins, P. H. Regan, Nuclear Inst. and Methods in Physics Research, A **978** 164452 (2020)

The Multi-Grid detector: results obtained at the V20 beamline at HZB

A. Backis et. al.

University of Glasgow, UK and European Spallation Source ERIC, Sweden

The European Spallation Source (ESS), a next generation neutron scattering facility, is currently under construction in Lund, Sweden [1]. To cope with the expected high flux at the facility, as well as the current unreliable supply of helium-3 [2], new detector technologies are being explored. One of these detectors is the boron-10 based Multi-Grid detector [3]. This is a large area cold to epithermal neutron detector, invented at the Institut Laue–Langevin (ILL), and jointly developed with ESS thereafter. The detector is intended for time-of-flight neutron spectroscopy, and is currently in development for the upcoming CSPEC [4] and T-REX [5] instruments at ESS. To detect neutrons, the Multi-Grid detector uses a stack of $^{10}B_4C$-coated aluminum substrates placed within a multi-wire proportional counter (MWPC). Incident neutrons hit the coated substrates perpendicularly, and can then be absorbed at discrete distances corresponding to the location of the layers. If a neutron is absorbed, one of the conversion products is ejected into the gas volume, and the neutron event is inferred from the released charge in the MWPC. The purpose of this work was to characterize two small prototypes of the Multi-Grid detector, which differed in design parameters, while comparing them to a typical helium-3 tube. Specifically, the magnitude of internal neutron scattering was investigated. Data were taken during a series of measurements at the Helmholtz Zentrum Berlin (HZB), on the ESS test beamline V20, where the detectors were tested in a direct beam. Using a Fermi-chopper, the 70 ms wide source pulse was cut into a series of ~10 μs short pulses before reaching the detectors a few centimeters down-stream. From the data, the magnitude of internal scattering in the two prototypes of the Multi-Grid detector could be compared and studied in detail. This is important

information which will be used when considering the design choice for the final detector.

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[5] T-REX https://europeanspallationsource.se/instruments/t-rex

Future Upgrade of the ALICE Inner Tracking System Based on Ultra-thin, Wafer-scale Bent Monolithic Active Pixel Sensors

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University of Liverpool, UK

While the second generation of the ALICE Inner Tracking System (ITS) is currently being installed and commissioned for Run 3, R&D is under way to replace the innermost tracking layers during LS3 with a fully cylindrical, bent silicon tracker. To achieve this, ultra-thin (20-40 μm), wafer scale (300 mm) Monolithic Active Pixel Sensors in 65 nm technology will be used. At this thickness, the silicon becomes flexible and can be bent into truly cylindrical half-barrels. Additionally, the sensor design also means that no supporting material for the powering, cooling and data transmission will be necessary in the active area. This allows an unprecedented low material budget of below 0.05% X_0 per layer and 18 mm from the interaction point for the first layer. The new detector will also have improved tracking efficiency and an intrinsic spatial resolution of 2 μm in both the z- and rφ-directions. This enhancement, along with the reduced material budget, will allow for a significant improvement in some of ALICE's main physics goals: the measurement of low-momentum charm and beauty and low-mass dielectrons in heavy-ion collisions. Due to the similarities of the proposed sensor to the designs and goals of other projects, the R&D is collaborative with groups from the EIC and CERN EP contributing to the work.

This contribution aims to give a summary of the physics motivations, review the detector concept, and give details about the R&D status and plans. The first results from tests with bent sensors will also be presented.

Generation and Validation of a Theoretical Signal Database for the Segmented Inverted-coaxial Germanium (SIGMA) Detector

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[1]University of Liverpool, UK, [2]Qassim University, KSA, [3]Oak Ridge National Laboratory, USA

The prototype SIGMA detector is the first p-type segmented inverted-coaxial germanium detector to be manufactured for γ-ray tracking and imaging purposes [1,2]. The γ-ray tracking and imaging capability of SIGMA requires a high precision of measuring the interaction positions of γ-ray radiation with the detector which is strongly dependent upon the achieved position resolution. The γ-ray interaction position is determined by extracting the charge pulses from both a small p-type point contact on the rare face of the detector and the outer n-type electrode which is electrically segmented into 18 segments. In order to determine the position resolution of SIGMA, pulse shape analysis (PSA) methods using chi-squared minimisation technique will be applied which require a signal database of all possible positions of γ-ray interactions with the detector volume. For this reason, the detector response has been simulated using Agata Detector Library (ADL) [3] to generate

theoretical pulse shapes for the SIGMA detector. The simulated signals were validated against their equivalent experimental signals at known positions in order to build such signal database which is currently being developed.

[1] Jonathan P Wright, LJ Harkness-Brennan, AJ Boston, DS Judson, M Labiche, PJ Nolan, RD Page, F Pearce, David C Radford, J Simpson, et al. Position resolution simulations for the inverted-coaxial germanium detector, sigma. Nu- clear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 892:84–92, 2018.

[2] Jonathan Wright. Sigmaupdate. https://indico.in2p3.fr/event/16944/contributions/60400/attachments/47897/60341/AGATA GRETINA Meeting Jonathan Wright.pdf, 2018.

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Measurement of the B(E2; $4^+ \rightarrow 2^+$)/ B(E2; $2^+ \rightarrow 0^+$) ratio in ^{164}W

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Recent lifetime measurements revealed that the $B(E2)_{4+/2+}$ ratio is far less than unity in several nuclei in the mass region $160 \leq A \leq 170$ namely ^{166}W [1], ^{168}Os [2], ^{170}Os [3], and ^{172}Pt [4]. From a theoretical point of view, the origin and the underlying structure of this anomalous behavior remains unexplained. On the other hand, a quantum phase transition from seniority-conserving structure to a collective regime as a function of neutron number around $N \approx 90$ - 94 has been proposed for these nuclei from phenomenological point of view [4]. In the present work, we aimed to extend our investigation of the anomalous B(E2; $4^+ \rightarrow 2^+$)/ B(E2; $2^+ \rightarrow 0^+$) ratio phenomenon this mass region in order to provide more data for the future theoretical calculations. We chose ^{164}W as a good candidate to investigate because, it has a pivotal position with N = 90 to test the hypothesis of a quantum phase transition as the mechanism for the $B(E2)_{4+/2+}$ anomaly. We used the DPUNS [5] plunger device in conjunction with the RITU gas-filled separator [6] and the JUROGAM II and GREAT [7] spectrometers for the measurement of mean lifetimes of excited states in ^{164}W. The fusion evaporation reaction ^{106}Cd(^{60}Ni,2p2n)^{164}W* at a beam energy of 270 MeV provided an initial recoil velocity v/c of 3.3%. The analysis of the data revealed that ^{164}W has a similar $B(E2)_{4+/2+}$=0.56(13) < 1 anomaly as in the ^{166}W, ^{168}Os, ^{170}Os, and ^{172}Pt nuclei. Experimental B(E2) values have been compared to the state-of-the-art beyond-mean-field calculations. However, the theoretical predictions disagree with experimental findings. In the present work, details of the experimental procedure and analysis steps will be explained and the results for the lifetime measurements of first excited 2^+ and 4^+ states will be presented.

This work has been supported by the UK Science and Technology Facilities Council under grants ST/P004598/1, ST/L005670/1 and ST/L005794/1; the Scientific and Technological Research Council of Turkey (TUBITAK Project No: 117F508); the EU HORIZON2020 programme “Infrastructures”, project number: 654002 (ENSAR2) and by the Academy of Finland under the Finnish Centre of Excellence Programme (Nuclear and Accelerator Based Physics Pro-gramme at JYFL). The UK/France (STFC/IN2P3) Loan Pool and

GAMMAPOOL network are acknowledged for the HPGe escape-suppressed detectors of the JUROGAM II array.

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Quark Jet Enhancement with jet charge in pp and Pb-Pb with ALICE

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Hadronic jets are observed in high-energy nuclear collisions. They result from quarks or gluons that are scattered in the initial collision. Jets can be used as a probe for the state of matter created from these collisions. Quark-gluon plasma (QGP) is found to suppress jets in high-energy heavy-ion collisions. This is due to energy loss from collisions and radiation while travelling through the quark-gluon plasma. By studying the suppression of jets by this plasma, theoretical models can be developed to determine the properties of high-temperature QCD matter.

Jet shapes are observable parameters which characterise the structural properties of jets. In this study, the transverse momentum-weighted jet electric charge , jetcharge, is used to distinguish between jets originating from quarks or gluons. Building up distributions of jet charge from multiple jets allows the average characteristics of these jets to be studied.

Predictions from perturbative QCD calculations suggest an enhancement in the fraction of quark generated jets in Pb-Pb compared to pp. This is due to gluons suffering a larger energy loss than quarks when traversing the QGP [1]. Hence, by examining jet charge distributions, generated using PYTHIA 8, and by comparison to real data, the relative fraction of quark and gluon jets can be determined. In this study, data at $S_{NN} = \sqrt{5.02}$ GeV from the ALICE experiment is examined and compared to PYTHIA 8 predictions to investigate the relative fraction of gluon and quark jets in pp and PbPb collisions.

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Imaging ability of the Compton camera imaging system (GRI+) for thyroid phantom filled with ^{99m}Tc

Hamed Alshammari[1,3], Laura Harkness-Brennan[1], Andrew Boston[1], Adam Caffrey[1], Emily Fittock[2], Daniel Judson[1], and Ellis Rintoul[1]

[1]University of Liverpool, UK, [2]Norfolk and Norwich University Hospitals NHS Foundation Trust, UK, [3]Imam Abdulrahman bin Faisal University, Saudi Arabia

Nuclear medicine imaging utilises the gamma-ray emitted from radiotracers to investigate physiological bodily functions. The distribution of radiotracer material in the body is commonly imaged using a single-photon emission computed tomography (SPECT) system [1]. However, SPECT systems display inherent limitations with respect to image spatial resolution and sensitivity because a SPECT system consists of a scintillation detection system equipped with a mechanical collimator. The University of Liverpool has developed a Compton camera imaging system (GRI+) consisting of two position-sensitive semiconductor detectors and one coaxial

detector, and this imaging system is electronically collimated (Fig. 1). The GRI+ system achieved an angular resolution of 8.5° for a point-like ^{137}Cs source (662 keV) [2]. The current study investigated the imaging ability of the GRI+ system in medical applications by imaging a thyroid phantom, which was designed to mimic the real anatomical geometry of the human thyroid and which was filled with ^{99m}Tc solution (141.5 keV) (Fig. 2). The phantom was imaged from different angular projections, and Compton images were reconstructed using analytical and iterative image reconstruction codes. Based on the preliminary images of the thyroid phantom, the GRI+ system successfully visualised and distinguished the two thyroid lobes using one angle projection (Fig. 3). Further analyses are warranted to determine whether Compton imaging is a promising modality for future nuclear medicine applications and whether it will significantly reduce the radiation dose delivered to patients.

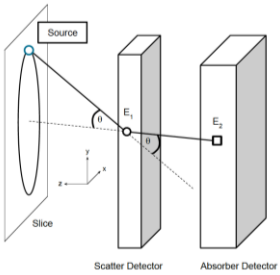

Fig.1 schematic diagram of a two-layer

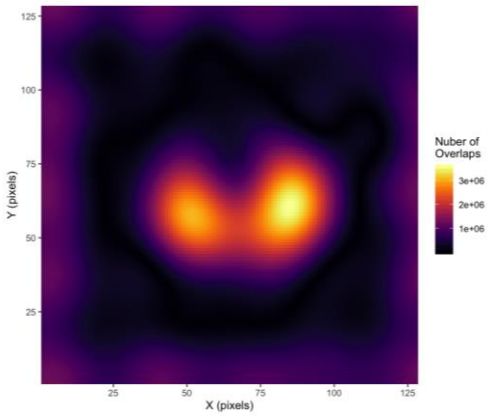

Fig.3 Imaging slice of thyroid phantom analytical reconstruction code use High pass filter

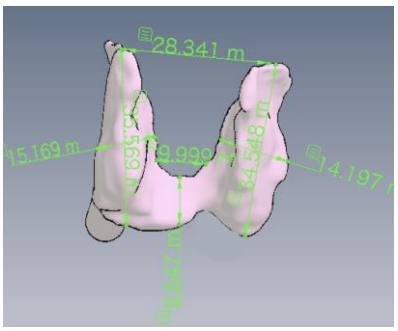

Fig.2 Thyroid lobs inside the phantom

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WallPEPT: Particle tracking in tall industrial machinery

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Positron emission particle tracking (PEPT) is a developing technique used for three- dimensional tracking of radioactively labelled particles in a variety of fluidised media. This technique is able to track particles

through thick, metal-walled industrial machines and in opaque materials where common visual particle tracking techniques fail to perform. Recent developments in the field had shown PEPT systems being able to track multiple particles with high spatial and temporal resolutions.[1] Being built using detectors from retired positron emission tomography (PET) scanners, PEPT systems can take many forms and sizes to suit individual experiment's geometrical requirements. WallPEPT is a series of metal racks containing modules from a Siemens ECAT 951 PET scanner that were designed to fit over an existing Philips/ADAC Forte gamma camera at the University of Birmingham Positron Imaging Centre. Being split into two halves, the system can be easily manoeuvred around and positioned to match the head spacing of the ADAC Forte. Both the ADAC Forte and the Siemens ECAT 951 systems had been previously converted for PEPT data acquisition needs but alone lack the necessary field-of-view to encompass heavy industrial machinery. When running, both systems acquire their own datasets which are later combined into a single dataset with a much greater combined field- of-view of the system and the particle being observed.
The current focus of this work is to fully assemble and test the system. System calibration and data synchronization methods are also currently being developed to easily and quickly process the two datasets together. The system is planned to be used in a variety of experiments: from analysis of particle mixing in recycling machines to two-phase flow experiments. The basic PEPT principles, PET/PEPT system configuration, and data acquisition and processing will be discussed.

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Commissioning of the Upgraded ALICE Inner Tracking System for LHC Run 3

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Major upgrades of the ALICE experiment are underway and will be completed during the LHC Long Shutdown 2 to enhance the physics capacities of ALICE for LHC Run 3 and Run 4. One key part of this upgrade is the new Inner Tracking System, a CMOS monolithic active pixel sensor based pixel detector. The upgraded Inner Tracking System consists of three innermost layers (50 μm thick sensors) and four outermost layers (100 μm thick sensors) covering 10 m^2 and containing 12.5 billion pixels with a pixel pitch of 27 μm x 29 μm. The smaller pixel size, the thinner sensor in combination with a lightweight support structure and the increased number of layers of the upgraded detector compared with the former inner tracker, as well as a smaller radius and thinner wall beam pipe configuration, will result in a significant improvement of impact parameter resolution and tracking efficiency.

The assembly of the full detector and the commissioning in the laboratory were completed in 2019 and 2020 respectively. The detector is currently being moved and installed in the ALICE experiment, and a few months of on-site commissioning will follow. In this talk, an overview of the concept and the assembly of this upgrade as well as the detector commissioning status and plans will be presented.

A novel detector system for high-energy, ultra-intense gamma beams from laser-plasma accelerators

James R Brown, Nicholas Zachariou and Luke Morris

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Recent advances in laser technology have lead to a revolution in compact electron accelerators. These are able to produce ultra-intense, nearly mono-energetic electron beams up to 2 GeV, and have the

potential to approach 10 GeV [1]. These electron beams can be readily converted to gamma beams, with potential applications in radiotherapy (FLASH-RT [2]), medical imaging, homeland security, and material science. However, at present there are no existing technologies able to characterise the gamma beams from sources such as these. Energies can reach 150 MeV and instantaneous rates as high as 10^8 photons (plus other particles) in a femtosecond pulse will overwhelm any conventional gamma detector. Furthermore, electronics are susceptible to damage from the intense electromagnetic and particle flux.

Here we report on the design, construction, and initial testing of a prototype detector system able to characterise gamma beams from high-energy, ultra-intense gamma sources. The system employs a novel detection mechanism, utilizing a hydrogen-containing target material placed in the gamma beam for the photoproduction of pions. These will be detected in a stack of plastic scintillators placed at backward angles, allowing the gamma energy to be reconstructed from the implantation depth and angle. Although the intense pulse of radiation will swamp the initial energy deposit generated by the pions, the subsequent delayed weak decay can be detected in a relatively background-free environment. Furthermore, by using optical fibres for the collection of scintillation light, the light detection (SiPMs) and readout electronics can be located some distance from the gamma source and shielded from the intense radiation.

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Towards a Timepix3 photon pair polarimeter

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In recent years, determining the degree of photon linear polarization at hadron physics experiments has become the dominating source of systematic uncertainty in physics results. A new detector, aimed at reducing this uncertainty, is under development which will perform a direct measurement of polarization by exploiting the inherent analysing power of photon-pair conversion.

A detector prototype using Timepix3 chips has been built alongside a Geant4 simulation. In 2019 a series of tests were carried out in the A2 Hall at the MAMI facility, in Mainz, where the polarimeter was synchronized with the tagged photon spectrometer. In parallel, development of a new Timepix3 readout system is ongoing by the Nuclear Physics Detector group in Daresbury. The new system is expected to facilitate integration of data from Timepix3 chips into large experiment data acquisition systems.

Early results are presented along with discussion of the challenges encountered with the detector setup and data analysis. Finally, an overview of the promising future of the project and the next stages of development will be put forth.

First particle tracks with the Outer Barrel of the new ALICE Inner Tracking System

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The upgraded Inner Tracking System (ITS) of ALICE consists of 7 concentric layers of a custom monolithic active pixel sensor design known as ALPIDE [1]. The ALPIDE-based detector design reduces the material budget to 0.35% X_0 per layer for the innermost three layers (Inner Barrel), and to 1.0% X_0 per layer for the outermost four layers (Outer Barrel), compared to 1.14% X_0 per layer in the previous ITS. The readout rate has been improved to 100kHz for Pb-Pb interactions, the radius of the first layer of the ITS reduced from 39mm to 23mm and the pixel pitch reduced to O(30μm) x O(30μm). These changes will improve the impact parameter resolution and tracking efficiency of heavy-flavour hadrons and dileptons at low transverse momenta; launching ALICE into the precision era of hot QCD physics.

The Outer Barrel was constructed at 10 sites around the world before being fully assembled into the intended barrel geometry and integrated into the readout electronics at CERN by the end of 2019. In the first half of 2020, the Outer Barrel underwent a series of verification tests to explore the performance of the finalised system. In the latter half of 2020, roughly 7 million cosmic muons events were measured by the Outer Barrel to further characterise the detector performance and provide a data set to be used for spatial alignment.

This contribution will include a summary of the verification procedure, as well as a discussion of the details of the cosmic muon collection campaign and subsequent results, including a first measurement of the detector efficiency.

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Studying possible rp-process nucleosynthesis in common envelope neutron star binary systems

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In massive-star binary systems, upon reaching later stages of stellar evolution one star can expand as a giant and envelop its companion. If the star enveloped is a neutron star, then mass will rapidly accrete onto the neutron star. Accretion onto common-envelope-phase neutron stars can result in ejected matter that has undergone burning near the neutron star's surface [1]. This process may be similar to that which occurs within an X-ray burst and is thought - like X-ray bursts - to be a site of the rp-process which produces proton rich elements. Due to the environment, the proton rich material produced may be ejected into the envelope of the companion star. When the companion undergoes its supernova phase this proton rich material can feed the ISM and therefore contribute to galactic chemical evolution. These common envelope systems are not well understood and as such are an active site of investigation - a notable potential common envelope scenario is described in Arcavi, I., Howell, D., Kasen, D. *et al.* [2].

We study the nucleosynthesis yields of this ejected matter using PRISM (Portable Routines for Integrated nucleoSynthesis Modeling) - a program built for time-dependent composition tracking of nucleosynthesis in an astrophysical environment. Building on the work of Keegans et. al (2019), collaborators have developed and assessed the impact of more realistic accretion trajectories by adding considerations for angular momentum in the accreted matter, an essential component for the formation of an accretion disk around the neutron star. We particularly present the preliminary results of a comparison of the relative nucleosynthetic abundances and mass fractions resulting from the trajectories presented by Keegans et

al. in comparison with the updated trajectories.

Our end goal is to identify key nuclear reactions in the common-envelope rp-process scenario for future experimental work. We will present the altered input trajectories, as well as preliminary results.

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Evidence for the decay of a microsecond seniority isomer in ^{155}Hf

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An experiment has been performed at Jyväskylä to search for an isomeric state in the even-odd neutron-deficient nuclide ^{155}Hf. The proton-rich N=82 and 83 isotones below Z=73 have been investigated by McNeill et al., who identified seniority isomers with half-lives in the microsecond range and compared their measured properties with shell-model calculations [1]. However, they reported no evidence for such an isomer in ^{155}Hf, even though one might be expected from the systematics.

The nuclei of interest were produced by 2p3n evaporation channel in reaction induced by 293 MeV beam of ^{58}Ni ions bombarding a 1000 μg/cm^2 thick ^{102}Pd fixed target irradiated for 22 hours. The fusion-evaporation reaction products were separated in flight using Mass Analysing Recoil Apparatus (MARA) and implanted into the DSSD at its focal plane, which was surrounded by Clover Ge detectors to measure delayed gamma rays. One challenge to be overcome when searching for gamma-ray emissions from an isomeric state in ^{155}Hf is that the beta decays of its ground state, which is the only known level in this nuclide, do not provide a selective tag [2]. In this analysis the alpha decays of its daughter, ^{155}Lu, have been used instead, with additional selection provided by the JYUTube detector placed around the target to measure evaporated charged particles. The latest results from the analysis of these data will be presented.

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In-beam spectroscopy of ^{94}Ag

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The concept of isospin has been introduced to account for the apparent charge independence of the nucleon-nucleon interaction. However, if the nuclear force were the same for protons and neutrons properties such as masses and excitation energies would depend only on the mass number A. Recent studies have shown that the Coulomb force cannot account for all deviations, suggesting that other isospin-symmetry- breaking components must be present. N~Z systems present the perfect testing ground to probe isospin symmetry phenomena [1-3]. In particular, pairing correlations have a significant influence in the description of the nuclear structure of N=Z nuclei, where protons and neutrons are arranged occupying the same orbits, allowing T=0 np pairing in addition to the normal T=1. It was recently suggested that spin-aligned T=0 np pairs dominate the wavefunction of the y-rast sequence in ^{92}Pd [4]. Subsequent theoretical studies were devoted to probe the contribution of np pairs in other N=Z A>90 nuclei [5-6], suggesting the potential for a similar pairing scheme in these nuclei. In an effort to answer this question, a recoil beta tagging experiment for the identification of the T=0 and T=1 states in odd-odd N=Z ^{94}Ag using the ^{40}Ca(^{58}Ni,p3n)^{94}Ag reaction was conducted using MARA recoil separator and JUROGAM3 array at the Accelerator Laboratory of the University of Jyväskylä.

The detailed goals of the experiment, the setup, tentatively identified transitions, experimental CED and nuclear shell model predictions will be shown in this presentation. A preliminary interpretation of the experimental results will also be discussed.

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Spectroscopic Quadrupole Moments of ^{107}Ag Using Coulomb-Excitation with Miniball

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The Miniball spectrometer [1] at the ISOLDE facility in CERN was used to perform a Coulomb-excitation experiment between ^{22}Ne and ^{107}Ag. From this, the spectroscopic quadrupole moment, Q_s, of excited states in ^{107}Ag can be determined, serving as a test of the particle-vibrator coupling description in nuclei below Z=50 [2]. The results can also be compared to more sophisticated effective field theory calculations of vibrational nuclei [3], which predict significant negative values for Q_s in ^{107}Ag.

A stable beam of ^{22}Ne at a beam energy of 4.00 MeV/u was scattered off of a ^{107}Ag foil target. The scattered particles and their corresponding γ rays emitted during the Coulomb-excitation process were detected in coincidence. Both the beam and target scattered particles were detected using the double-sided silicon strip "CD" detector to provide position resolution and consequently, the angular distribution of particle-γ coincidences have been determined.

A total of 7 states have been populated and the differential Coulomb-excitation cross sections have been constructed for the lowest lying $3/2^-$ and $5/2^-$ states. The data can be compared to calculations using the least-squares fit code, GOSIA [4], in order to extract $Q_s(3/2^-)$ and $Q_s(5/2^-)$ in ^{107}Ag for the first time.

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Topic: Astroparticle Physics

Development of micromegas charge readout technology for use in a low pressure time p rojection chamber for dark matter detection

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Low pressure negative ion TPCs can be used for identifying the direction of nuclear recoil tracks induced by WIMP dark matter. Previous work has demonstrated the successful implementation of a Micromegas charge readout device in combination with a MM-ThGEM to achieve a sufficient gain. In its current state, the Micromegas has 16 fully instrumented channels. This poster lays out a plan to instrument at least a further 16 channels to improve track reconstruction capabilities. A review of Machine Learning in the field of dark matter detection was conducted and it was found that track reconstruction could benefit from these types of algorithms but there has been little work in this area. A description of a Machine Learning algorithm that could be suitable for this purpose is proposed.

Lighting a path out of gravitational darkness – space-time revisited

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A path to a gravitational theory that reproduces the predictions of General Relativity but removes the need for ad hoc hypotheses such as dark matter and dark energy exists. The necessary first step is to show that a linked and malleable space and time that are altered by relative motion can be replaced by a real

background that affects the properties of moving objects.

Lorentz discovered a transformation which related the time and distance intervals of charged particles moving at high-speed relative to a stationary aether. It had a contraction of distance and a dilation of time which was consistent with the null result of the Michelson-Morley experiments. Einstein's derivation of the Lorentz transformation in his 1905 paper [1] was taken as strong evidence for the correctness of Special Relativity and its two postulates. The first, the principle of relativity, was based on physical laws appearing to be independent of motion at constant speed. The second was that the speed of light was independent of the speed of the emitting body. The latter was subtly altered to the claim that the apparent or measured speed of light was the same for all observers. This is seen in the standard derivation [2] which claims that the propagation speed of light is the same with respect to stationary and moving coordinate frames. This amounts to the claim the radiation of the same photons is seen as spherical by both stationary and moving observers. However, this is not true unless the arrival time of reflected signals is adjusted for movement of the observer during signal transmission. The coordinate transformation achieves this only if both distance and time intervals are contracted. This is opposite to the contraction of distance being matched by the expansion of time proposed by Lorentz. It arose because Minkowski and Einstein both interpreted time as the sum of time intervals so that shorter time intervals meant less time elapsed. This contradicts the understanding that fewer events occur in the frame with larger intervals between the ticks of its clock.

Einstein noted that an absolute significance could not be given to simultaneity of separated events in a stationary frame, if assessed by an observer in a moving frame, due to the finite travel time of light. He therefore imagined an experiment in which the timing of events in a moving and stationary frame were always referred back to an array of synchronous clocks in the stationary frame. However, this method essentially examines reflected signals and cannot yield information about the rate of the clock in the moving frame because its time is not examined.

It can be shown that the observed transformation can apply to either the apparent distance and time of events in a moving frame if the underlying clock-rate is unchanged, or to the actual (instantaneous) distance when there is a real slowing of the moving clock. The concept of a malleable space and time dependent on relative motion therefore applies to apparent effects. It can be replaced by a space that is not distorted by motion provided movement at high-speed relative to our approximately stationary position in respect to the background of massive objects (the "fixed stars") introduces a slowing of time for massive clocks.

Time dilation occurs for massive objects moving relative to the free-fall, approximately stationary, background. Unconnected, relatively stationary, objects maintain a fixed separation unless acted on by a force (distances only appear contracted). The Lorentz transformation still holds so the revised interpretation is consistent with experimental results. The speed of massless light is dependent only on the magnitude of the background and independent of the movement of massive objects. There is no requirement that this speed be constant in all frames because Special Relativity only applies within an inertial frame, i.e. one in which the background from massive objects is constant. The idea that time and space are malleable and linked into a space- time is based on interpreting apparent effects as real.

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Searching for continuous and long-duration gravitational waves with ground-based interferometry

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Advanced LIGO detected the first gravitational waves from the merger of two black holes on 14 September

2015 [1]. The discovery is one of humanity's greatest scientific achievements. To date, over 50 gravitational wave events and candidate events [2] have been detected. These have all been compact binary inspiral gravitational waves.

Fig 1: Aerial photographs of the LIGO Hanford (left) and Livingston (right) observatories (courtesy of the LIGO Scientific Collaboration).

Spinning neutron stars, asymmetric with respect to their rotation axis, are thought to be a source of potentially observable continuous gravitational wave signals, which have not yet been directly detected [3]. Imperfections in the star's spherical shape or bumps on its surface generate gravitational waves as it rotates. The signals are quasi-monochromatic with a very slow intrinsic evolution of frequency and amplitude. In essence, the search for such signals comprises applying a fast Fourier transform to the strain data and searching for peaks in the power spectrum.

Searches for continuous gravitational waves employ matched filtering in which the data are correlated with templates that model the signal's amplitude and phase evolution with time; a detection statistic is used to maximise the signal-to-noise ratio [4]. A coherent search, where a fast Fourier transform of the data is performed for each independent point, has a parameter space volume proportional to T^6(T is the observation time) so a semi-coherent search method of summing strain powers from many smaller time intervals, discarding those that do not meet the detection statistic, may be adopted to reduce computational cost [5].

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Silicon Photomultipliers in the DarkSide-20k experiment

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Dark Matter Direct Detection experiments operating at cryogenic temperatures commonly use Photomultiplier Tubes, but the DarkSide-20k experiment will replace these detectors with Silicon Photomultipliers (SiPMs). The many benefits of using SiPMs include a high photon detection efficiency, improved radio-purity, and a low dark count rate at LAr temperature. The challenge for the DarkSide collaboration was to develop this technology to instrument 20 m^2 in the DS20k detector. This talk will discuss the characterisation of the DS20k SiPMs and present noise measurements at LAr temperature.

Exploring the sensitivity of dark matter direct detection experiments to non-standard interactions

Ellen Sandford

University of Manchester, UK

Liquid noble direct dark matter detection experiments aim to detect galactic dark matter scattering off nuclei in highly sensitive detectors on Earth. No conclusive signal for dark matter has yet been observed, and so it is crucial that current and future experiments broaden search strategies to include non-standard dark matter models in order to maximise discovery potential. This presentation reports new constraints on a class of isospin-violating dark matter models from existing Xenon and Argon target data and presents sensitivity projections for Xe/Ar experiments running in the coming decade that highlight the complementarity of these searches. Furthermore, we quantify how the low mass sensitivity and reach of existing experimental data can be dramatically enhanced through exploitation of the Migdal effect. We present new constraints from existing data and future projections for a range of possible dark matter interactions.

Analysis of Neutron Activation Background in the LUX-ZEPLIN Experiment

Tom Rushton on behalf of the LUX-ZEPLIN Collaboration

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Weakly Interacting Massive Particles (WIMPs) are a well-supported candidate particle for dark matter. The LUX-ZEPLIN (LZ) experiment is a dual-phase liquid-gas xenon time projection chamber (TPC) which seeks to discover these particles or to set limits on WIMP- nucleon cross sections down to 1.4 ×10−48 cm2 at a WIMP mass of 40 GeV/c2 with a 90% confidence level. To have the necessary sensitivity to detect the very rare interactions between the WIMPs and the xenon nuclei, the LZ detector needs to be almost completely free from background. The focus of this study is the background from scheduled neutron calibrations, which will produce radioactive isotopes such as 127Xe, 129mXe and 131mXe through neutron activation of the xenon. The detector's response to these background sources have been simulated and the results analysed so their effect on the detector can be accounted for in subsequent analysis.

Refined ultra-light dark matter searches with compact atom interferometers

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Atom interferometry is a powerful experimental technique that could be employed to detect the oscillation of atomic transition energies induced by ultra-light scalar dark matter (ULDM). Previous studies only considered the sensitivity to ULDM of long-baseline atom gradiometers, where atom interferometers are located at the ends of the baseline. In this work, we generalize the time-dependent signal induced by a linearly-coupled scalar ULDM candidate for all vertical atom gradiometers. Using this result, we refine the

sensitivity estimates for AION10 and discuss optimal experimental parameters that enhance the sensitivity to ULDM.

Sensitivities of Atomic and Molecular Targets to Sub-GeV Dark Matter

Louis Hamaide and Christopher McCabe

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Despite decades of searching, signals from dark (DM) scattering with experiments on Earth remain elusive. Over the past 5 years, the strategy of searching for signals induced when DM scatters with a bound-state electron in an atom or molecule has emerged as a promising way to probe DM with a mass between the MeV and GeV scales. Motivated by the NEWS-G [1] series of direct detection experiments, which can operate with different mixtures of atomic and molecular species, we present the results of ionisation form factor calculations for helium, neon and xenon atoms, and methane and iso-butane molecules. With these results, we present estimates of the DM sensitivity in the MeV to GeV mass range of the proposed DarkSphere detector, the largest detector under design by NEWS-G and which could be hosted at the Boulby Underground Laboratory.

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Cosmic inflation and the cosmological constant

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This paper attempts to discuss the cause of the accelerated expansion i.e., the non-zero energy density of the vacuum also called the Cosmological Constant or Dark Energy. The shortcoming of the standard Big Bang Model is summarised together with their resolution by Inflationary Cosmology. In this paper, the New Inflation Model leading to a special case of Inflation Model is examined and how the Inflaton (inflation field) can be regarded as an Oscillating Field which can lead to the formation of matter particles.

Keywords: Big Bang, Cosmological Constant, Inflation, Scalar Field

Pulsars and interstellar medium

Vedant Subash

Indian Institute of Technology Roorkee, India

This article attempts to summarize how the pulse dispersion transpires when the different frequencies of the pulse travel at different speeds because of free electrons. The deviations in Time of Arrival (TOA) of pulses due to Pulse Dispersion are calculated and taken into account in calculating Pulsar Timing which is crucial in measuring the dynamics of pulsars and studying the medium between Earth and the Pulsar.

Keywords: Pulsars, Interstellar medium, Time of Arrival, Pulse Dispersion

The origin of photons in early universe

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Studying the origin of photons in the early universe can help us to unravel the fine structure of the universe and in understanding its behavior. There are countable processes through which light; more precisely photons can be produced. In the early universe, the only path to produce photons was through matter and antimatter. The annihilation of matter and antimatter and the generation of photons is discussed. We re-analyze the cosmic microwave background (CMB) and extrapolate the baryon densities and photon densities. The CMB photons and the curve fits are reviewed. We also discuss the literature with respect to the photon epoch after the big bang. The study suggests that the primordial light is produced by the annihilation of matter-antimatter in the early universe.

Recent advancements on the spherical proportional counter instrumentation for NEWS-G

Ioannis Katsioulas

University of Birmingham, UK

NEWS-G (New Experiments With Spheres-Gas) is an innovative experiment aiming to shine a light on the dark matter conundrum with a novel gaseous detector, the spherical proportional counter. It uses light gases, such as hydrogen, helium, and neon, as targets, to expand dark matter searches to the 0.05 - 10 GeV/c^2 mass region. NEWS-G produced its first results with a detector -60 cm in diameter- installed at LSM (France), excluding cross-sections above 4.4 ▪ 10^{37} cm^2 for 0.5 GeV/c^2 WIMP using neon gas. Currently, a larger detector -140 cm in diameter- is being installed at SNOLAB (Canada) and the commissioning is expected to commence in March 2021, before operation later this year. In this talk, I present developments incorporated in this new detector: a) sensor technologies using resistive materials and multi-anode read-out that allow high gain - high-pressure operation, b) gas purification 210 techniques to remove contaminants (H_2O, O_2) and radon impurities, c) reduction of Pb induced background through copper electroforming methods, d) utilisation of UV-lasers for detector calibration, detector response monitoring and estimation of gas-related fundamental properties, e) field correction electrodes to achieve a homogenous response from the whole detector volume. This next experimental phase of NEWS-G will allow searches for low mass dark matter with unprecedented sensitivity.

Template for preparation of abstracts to be submitted to the Joint APP, HEPP and NP Conference

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King's College London, UK

(in association with work with the MIGDAL Collaboration (PI Pawel Majewski, RAL)

The MIGDAL Collaboration [1] has been formed to measure the elusive 'Migdal effect', an atomic physics effect that leads to the emission of a bound-state electron from atomic systems when the atomic nucleus is suddenly perturbed. This effect has been shown to extend the sensitivity of dark matter direct experiments to lighter mass dark matter candidates [2]. The effect has already been exploited by xenon-based and germanium-based dark matter detectors. However, the effect has yet to be measured experimentally. This is why the MIGDAL Collaboration was formed: to measure the effect in the lab for the first-time using DT and DD neutron sources at RAL. In this talk, I will present the atomic-physics theory underlying the Migdal effect and present estimates for the number of events that can be observed at the experimental set-up at RAL [3].

[1] https://migdal.pp.rl.ac.uk

[2] Dolan, Kahlhoefer, McCabe, PRL, doi: 10.1103/PhysRevLett.121.101801

[3] McCabe et al, in preparation

Calibrating IceCube track reconstructions by using DM-Ice coincidence events

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IceCube is a neutrino observatory situated within the South Pole ice cap, dedicated to detecting astrophysical and atmospheric high energy neutrinos by measurement of Cherenkov light. DMIce-17 comprises of two 8.5kg NaI(Tl) scintillator crystals located beneath the IceCube array. We demonstrate that it is possible to distinguish muons detected in DMIce-17 from background, and then use this to determine the coincidence rate between high energy tracks measured in IceCube and said muons for data covering 2012-2020. Finally, we discuss how this may be used to improve the track reconstruction of IceCube.

Boulby Underground Screening (BUGS) Facility

Paul Scovell

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The Boulby Underground Screening (BUGS) facility is the UKs only deep underground radio-assay facility specialising in the measurement of materials for low background particle physics experiments. The facility has been through several phases of evolution, most recently expanding from solely hosting low background high purity germanium detectors to being able to provide a wider array of radio-assay based material characterisation techniques. In addition to this expansion, the sensitivity of the germanium detectors in the BUGS facility have been substantially improved.

This talk will discuss recent improvements in the backgrounds of our high purity germanium detectors, the ongoing expansion of the facility and our plans for the future to realise our eventual aim of moving the facility towards being regarded as one of the world leading centres of excellence for the development of material cleanliness techniques for future low-background applications (both in fundamental particle physics and beyond).

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