Abstract Book

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IOP Institute of Physics

(Invited) Light Hadron Physics – The Low Energy Frontier of the Standard Model

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) Theory and Phenomenology for Collider Physics

Jennifer Smillie

University of Edinburgh, UK

In recent years we have seen major advances in our calculational methods and tools within particle theory. These are critical to the interpretation and exploitation of experimental data. In particular, future runs of the Large Hadron Collider will demand increasing precision and increasingly sophisticated treatment of competing physical effects. We are also preparing for future colliders. In this talk, I will summarise some recent major developments in particle predictions and highlight key open questions and current steps towards the answers.

(Invited) Dark Matter Searches

Jim Dobson

University College London, UK

In this talk I will review the current status of experimental searches for Dark Matter. After a recap of the astrophysical and cosmological evidence for Dark Matter I will give an overview of the different experimental approaches to search for Dark Matter: indirect, collider and direct detection. I will then focus on the status of direct detection experiments and will present leading results from liquid noble, cryogenic and other searches. Finally I will consider the key drivers for the success of direct detection experiments and discuss future prospects for the next generation of experiments.

(Invited) The next decade in Particle physics

Jonathan Butterworth

University College London, UK

A vision for the next few years in particle physics, and the status of the European Strategy.

(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.

Further, 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.

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 [3] at TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) [4] located at the ISAC radioactive beam facility, Vancouver.

Titan is a multiple ion trap system capable of performing high-precision mass measurements and in-trap decay spectroscopy. In particular TITAN has specialized in fast Penning trap mass spectrometry of short-lived exotic nuclei. Although ISAC can deliver high yields for some of the most exotic species, many measurements suffer from a strong isobaric background distinct to the ISOL method of beam production. To overcome this limitation an isobar separator based on the Multiple-Reflection Time-Of-Flight Mass Spectrometry (MR-TOF-MS) [5] technique has been installed at TITAN, similar to other ion trap on-line facilities. The MR-TOF-MS enables mass measurements of very short-lived nuclides that are weakly produced from high isobaric background, however, at a reduced precision. Thus the new MR-TOF-MS allows for unique nuclear structure investigations far from stability [6].

Despite the success of the ISOL method, certain refractory elements are not efficiently released from the production target. 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 [7].

References:

[1] I. Bentley, et al., Phys. Rev. C 93, 044337 (2016)
[2] J. C. Hardy and I. S. Towner, Phys. Rev. C 91, 025501 (2015)
[3] M. P. Reiter et al., Phys. Rev. C 96, 052501(R) (2017)
[4] J. Dilling et al., NIM B 204, 2003, 492–496
[5] C. Jesch et al., Hyperfine Interact. 235 (1-3), 2015, 97–106
[6] E. Leistenschneider et al.: Phys. Rev. Lett. 120, 062503 (2018)
[7] W. R. Plass et al., NIM B 317 (2013) 457-462

(Invited) Ripples from the Dark Side of the Universe

Sir James Hough

University of Glasgow, UK

In this talk I will review progress in the field of gravitational wave detection where the laser interferometer detectors Advanced LIGO and Advanced Virgo have allowed gravitational waves to be detected and are opening up a new field of gravitational multi-messenger astrophysics with many new exciting results. A range of 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.

(Invited) Neutrino-Nucleus Interactions

Xianguo Lu

University of Oxford, UK

Understanding neutrino interactions in the GeV regime is essential for current and next generation accelerator-based neutrino programs. Recently, intensive experimental efforts have been made to study various nuclear effects in neutrino-nucleus interactions. MINERvA in the US and T2K in Japan are important experiments to study neutrino interactions, while for the future oscillation experiments DUNE and Hyper-K, suites of sophisticate near detectors are under design. The success of these efforts will enable the precision needed to explore physics beyond the Standard Model, such as the charge-parity violation in the lepton sector. In this talk, I will review recent progress in neutrino-nucleus interaction measurements and discuss potential future development.

(Invited) Cosmic Rays – Results relevant to Astrophysics and Particle Physics above 10^{18} eV

Alan Watson[1,2]

[1]University of Leeds, UK, [2] Emeritus Spokesperson, Argentina

Cosmic-ray studies were the bedrock of early explorations of what became particle physics through the discovery of the positron, the muon, the charged pions and several of the 'strange' particles. Since the early 1950s cosmic-ray work has focused largely on attempting to elucidate the origin of the highest-energy particles in Nature. In this talk I will focus on measurements made above 10^{18} eV using, primarily, the Pierre Auger Observatory, the largest cosmic-ray detector ever built. Results of relevance to astrophysics and particle physics will be described.

The energy spectrum has been measured with unprecedented precision using over 215k events with a new spectral feature identified above 10^{19} eV. Also, after decades of effort by many groups, convincing evidence of directional anisotropies has finally been obtained. Above 8×10^{18} eV, the Auger Collaboration has reported a dipole distribution of the particles, significant at over 6 σ, when the directions are examined in right ascension. The effect may be correlated with the positions of galaxies in the 2MRS (infra-red) survey. At higher energies, evidence for point sources is beginning to emerge. The closest radio galaxy, Centaurus A, and the nearby starburst galaxy, NGC 4945, are both possible sources of ultra-high energy cosmic-rays.

Data from the Auger Observatory on the atmospheric depth at which showers reach maximum (X_{max}) have been compared with predictions made using various models of hadronic interactions grounded in LHC information. Measurement based on 47,000 events, of which ~1000 have energies above 10^{19} eV, suggest that the manner of evolution of the depth of shower maximum and of $\sigma(X_{max})$ at the highest energies is consistent with a pure and heavy composition, while at lower energies the results are compatible with a lighter composition.

Implications of these results for our understanding of the origin of the highest-energy cosmic rays and for predictions of of the flux of high-energy astrophysical neutrinos, for which the Auger Observatory has been used to set the best limits above 10^{18} eV, will be described.

Data from the Observatory have also been used to study some features that relate to hadronic interactions at energies well-beyond those accessible at the LHC. It has been possible to make measurements of the proton-air cross-sections at a centre-of-mass energy of ~57 TeV and thus to infer the p-p cross-section.

Extrapolations of models of hadronic interactions have been compared with experimental data up to energies beyond 10^{19} eV. Several studies have led to strong evidence, over a wide range of energies, that the muon content observed in events of high energy is in excess of that predicted using current models of hadronic physics. The surfeit of muons may be related to the excess of high-multiplicity events observed in the ALICE detector [1]. The claim in [1] that these events can be understood in terms of the known mass composition at ~1 PeV in the context of a particular model (QGSJet04) of hadronic interactions is questionable: it will be shown that this model is inconsistent with data from the Pierre Auger Observatory and that the assumptions made about mass composition are over-simplified. Further studies of these high-multiplicity events are desirable as are LHC runs to study p-A and A-A collisions.

[1] The ALICE Collaboration JCAP **01**, 032 (2016) and arXiv 1507.07577

(Invited) Neutrino Oscillation Physics

<u>Alfons Weber</u>

University of Oxford, UK, UKRI/STF Rutherford Appleton Laboratory, UK

Neutrinos are always good for surprised. Over the last two decades it has been established that neutrino 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 shortbaseline accelerator-based oscillation experiments and give an overview where the field will go in the future.

(Invited) Ab Initio Computations of Nuclei and their Applications

<u>Carlo Barbieri</u>

University of Surrey, UK

Correlations—intended as multiple-nucleon mechanisms that cannot be modelled by a pure man-field potential—are the backbone of our deeper understanding of atomic nuclei. They are manifest in the fragmentation of the spectral strength which is encountered in one-nucleon addition and removal measurements.
In recent years, we have advanced high-performance computational many-body techniques, such as propagator theory, that can be used to compute the spectral function but that also allow meaningful predictions of radii and binding energies up to masses of A~130. 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. I will further discuss some cases in which the knowledge of the spectral function is important to predict, e.g., the interplay between structure and reactions and the response to neutrinos under the wide range of energies relevant to oscillation experiments.

(Invited) QGP physics with ALICE

<u>David Evans</u>

University of Birmingham, UK

Under extreme conditions of temperature and density, hadronic matter undergoes a phase transition in to a de-confined state of quarks and gluons known as a Quark-Gluon Plasma (QGP). Such a state of matter is thought to have existed up to ten microseconds after the Big Bang and could exist today in the core of neutron stars. Ultra-relativistic heavy-ion collisions provide the necessary conditions to create, study, and characterise this hot and dense QCD matter. The ALICE experiment at the CERN LHC is a general purpose heavy-ion detector designed to study the QGP in detail. ALICE also records data from proton-proton and proton-lead collisions in order to differentiate between QGP and normal hadronic phenomena. In this presentation, selected results from ALICE will be presented as discussed.

(Invited) Nuclear Structure and Decay Modes at the Proton Drip

David Joss

University of Liverpool, UK

Proton emission from nuclear ground states is expected to determine the limit of observable proton-rich nuclei for most elements. Considerable progress has been made in the study of proton-unbound nuclei since the advent of selective correlation techniques that have allowed particle and gamma-ray emissions to be studied. This paper reports recent experimental investigations into nuclear structure at large neutron deficiency and the search for new proton-emitting states from both nuclear ground-states and multiparticle isomers using electromagnetic recoil separators.

(Invited) Neutrino and Dark Matter Noble Gas Detector Technologies

Konstantinos Mavrokoridis

University of Liverpool, UK

Noble gas 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) or liquid xenon (i.e. LUX-ZEPLIN) 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.

(Invited) Translating Gamma-Ray Tracking Techniques to Medicine

Laura Harkness-Brennan, on behalf of the University of Liverpool nuclear instrumentation group and STFC Cancer Diagnosis Network+

University of Liverpool, UK

Gamma-ray tracking is a method used to locate the spatial origin of gamma-rays using arrays of large volume segmented germanium detectors, such as AGATA [1] and GRETINA [2]. Key to the success of gamma-ray tracking is the accurate measurement of energy and position for any interactions that the gamma-rays undergo within the detectors. Researchers at the University of Liverpool are developing novel methods to improve the measurement of energy and position of these interactions and the subsequent reconstruction of the gamma- ray path. These methods also can be used to improve the performance of gamma-ray imaging detectors for use outside nuclear structure physics, such as in medicine. In these applications, the patient is typically administered with a gamma-ray emitting radionuclide in order to study or treat disease within the body. Conventional medical gamma-ray imaging systems use a gamma camera that is composed of scintillation detectors coupled to a mechanical collimation device. The purpose of the collimator is to allow the distribution of the radiation to be inferred and is a necessary component in the current design. However, the collimator inherently results in an undesirable compromise between efficiency and image resolution. In contrast, systems that employ gamma-ray tracking techniques have excellent solid angle coverage, resulting in a vast increase in the fraction of radiation that is used to generate an image and their image resolution relies on accurate measurement of the gamma-ray interaction positions and energies within the detectors.

This presentation will showcase research and development being undertaken at the University of Liverpool to translate gamma-ray tracking techniques primarily developed for nuclear instrumentation used in nuclear structure physics experiments to secondary applications in healthcare. There will also be the opportunity to hear about how partnerships have been developed by the Liverpool team with the NHS and healthcare industry over the past 10 years to address specific clinical challenges and how to engage with a national research network addressing a range of challenges in cancer diagnosis.

[1] S Akkoyun et al Nuclear Instruments in Physics Research A 668: 26-58 (2012) [2] S Paschalis et al Nuclear Instruments in Physics Research A 709: 44-55 (2013)

The muon g-2 experiment at Fermilab

Rebecca Chislett

University College London, UK

The current world's best measurement of the muon magnetic anomaly made a Brookhaven nearly two decades ago lies about 3.5 sigma away from the theoretical prediction. The new g-2 experiment at Fermilab aims to investigate this discrepancy by measuring the value to 140ppb, a four fold improvement upon the current precision, in order to establish if this really is a sign of new physics. The experiment is currently in the third year of data taking with the analysis of the data well underway. I will discuss the principle of the measurement, the ongoing analysis and the current status and plans.

Results From A Search For New Physics In Final States With Large Jet Multiplicities and Missing Transverse Momentum Using $\sqrt{s}$ = 13TeV Proton-Proton Collisions Recorded by The ATLAS Experiment

Aaron O'Neill

The University of Oxford, UK

Results are presented from a search for new particles decaying via long cascades into final states containing 8 jets or more and a moderate amount of missing transverse momentum, Emiss. The entire 139f b−1 of LHC p-p collision data at a centre of mass energy of 13 TeV recorded by the ATLAS ex- periment is analysed. Events are selected according to their jet multiplicity and any events containing an isolated lepton in the final state are removed to reduce the contribution to Emiss from neutrinos. Further selection criteria in the number of b-jets and the event-level large-R jet mass are imposed to increase sensitivity to particular models of new physics. This latest search extends on a previous iter- ation that analysed a smaller set of collision data (36f b−1) and employs new experimental techniques including particle flow jets for better energy resolution and rejection of backgrounds not originating from the collision vertex of interest. A new definition for the reconstruction of Emiss and an improved significance allow sources of missing transverse momentum from real invisible particles rather than detector mismeasurement to be more easily identified.

QCD multi-jets from standard model processes constitute the main background and this is estimated using a novel data-driven technique known as the template method. The sub leading backgrounds from processes such as $t\bar{t}$ and the production of the intermediate vector boson W and hadronic jets (W + jets) are estimated using

Monte Carlo and corrected for mismodelling with control regions. No significant deviations from the standard model of particle physics are observed. The results were used to perform a mass exclusion and greatly improved limits on the excluded masses for the gluino, the supersymmetric partner of the gluon, for each of the simplified supersymmetry models considered.

In Search of Charged Lepton Flavor Violating Decay $\mu^+ \rightarrow e^+ e^+ e^-$ for the Mu3e Experiment and Development of MuPix-HV-MAPS Pixel Tracker in Liverpool Module

Afaf Wasili

The University of Liverpool, UK

The Mu3e experiment will search for the neutrinoless (lepton flavour violat- ing) 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^{-16} (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 inter- nal conversion, and combinatorial backgrounds.

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 work preparing for quality assurance measurements that will take place as part of the assembly work on the MuPix-HV-MAPS pixel tracker in Liverpool. 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 characterisation will be presented for MuPix8 Telescope as shown in Figure 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 2×1 cm2, see Figure 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.

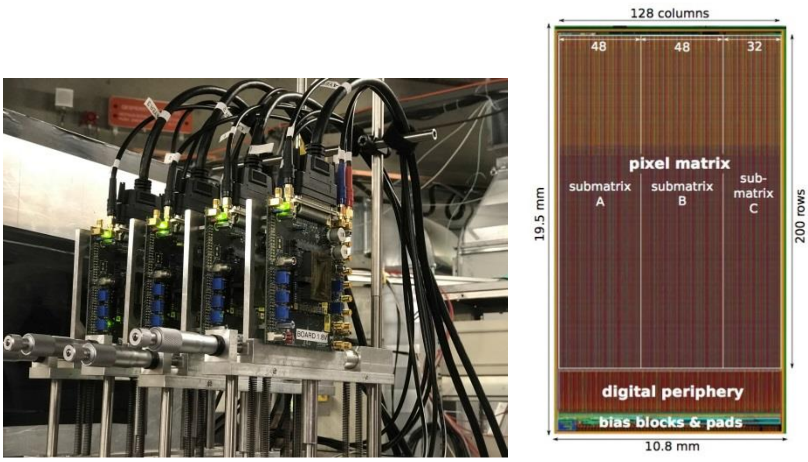


Figure 1: Left: Picture of the MuPix8 Telescope layout. Right: The MuPix8 chip

The Muon g-2 in 2020: the year of first results

Alex Keshavarzi[1], on behalf of the Muon g-2 Collaboration[2] & the Muon g-2 Theory Initiative

[1]The University of Manchester, U.K., [2]Fermi National Accelerator Laboratory, USA

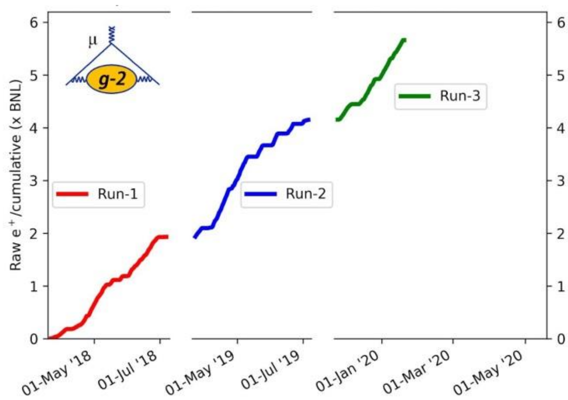
The study of the Muon g-2 stands as an enduring test of the Standard Model (SM), where the current 3.5σdiscrepancy between experiment and theory could be an indication of new physics beyond the SM.

Efforts to improve the measurement are currently underway at Fermilab (FNAL) with the aim to reduce the experimental uncertainty by a factor of four compared to the BNL measurements [1]. Concurrently, the precision of the SM prediction is also being improved to allow a better comparison between experiment and theory.

The Muon g-2 experiment at FNAL is nearly mid-way through its five year data-taking period, having already collected almost six-times as much data as the previous experiment at BNL (see Figure 1(a)). Ultimately, the experiment will accumulate a dataset over 20x that of the BNL experiment with systematic and statistical uncertainties of 100 ppb. The analysis of the first dataset is at an advanced stage and will achieve a statistical precision comparable with the BNL measurement. A publication is expected in 2020.

Members of The Muon g-2 Theory Initiative are working in tandem to improve the theory estimates and release a single community-approved value for the SM prediction. The uncertainty in this prediction is dominated by the hadronic contributions to g-2. Major improvements have been achieved in calculating both the hadronic vacuum polarisation and hadronic light-by-light contributions, where both can now be estimated via data-driven approaches and from lattice QCD (with the results from the lattice fast approaching a competitive precision). A white-paper detailing these calculations and including the community-approved SM estimate will be released before the first result from the FNAL experiment.

Should the final FNAL measurement have the same mean value as the BNL experiment and achieve its projected four-fold improvement in its uncertainty, the comparison between theory and experiment would yield a discrepancy of ~7σ[2] and herald the first indirect discovery of new physics beyond the SM (see Figure 1(b)). As Run Coordinator of the Muon g-2 experiment and a member of the Muon g-2 Theory Initiative, I will discuss the current status of the FNAL Muon g-2 experiment, the results of the analysis of the Run-1 dataset and the new calculations from the Theory Initiative.



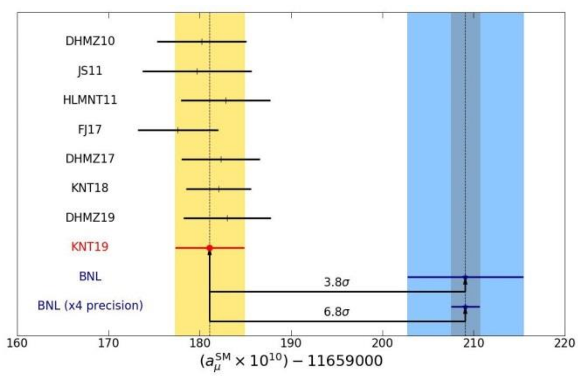


Fig. 1. (a) Accumulated raw statistics at FNAL. (b) Current comparison of experiment and theory [2].

[1] J. Grange *et al.* [Muon g-2 Collaboration], arxiv:1501.06858.

[2] A. Keshavarzi, D. Nomura and T. Teubner, Phys. Rev. D **97** 114025 (2018).

Fast simulation of muons produced at the SHiP experiment using Generative Adversarial Networks

Alex Marshall

University of Bristol, UK

This talk presents a fast approach to simulating muons produced in interactions of the SPS proton beams with the target of the SHiP experiment. The SHiP experiment will be able to search for new long-lived particles produced in a 400~GeV$/c$ SPS proton beam dump and which travel distances between fifty metres and tens of kilometers. The SHiP detector needs to operate under ultra-low background conditions and requires large simulated samples of muon induced background processes. Through the use of Generative Adversarial Networks[1] it is possible to emulate the simulation of the interaction of 400~GeV$/c$ proton beams with the SHiP target, an otherwise computationally intensive process. For the simulation requirements of the SHiP experiment, generative networks are capable of approximating the full simulation of the dense fixed target, offering a speed increase by a factor of $\mathcal{O}(10^6)$. To evaluate the performance of such an approach, comparisons of the distributions of reconstructed muon momenta in SHiP's spectrometer between samples using the full simulation and samples produced through generative models are presented. The methods discussed in this talk can be generalised and applied to modelling any non-discrete multi-dimensional distribution.

This work was recently published see [2]. Since this publication, a new architecture has been developed involving auxiliary tasks and multi-task learning. This new approach offers more stable training, faster converging and more accurate final results.

[1] Goodfellow, Ian, et al. "Generative adversarial nets." *Advances in neural information processing systems*. 2014.

[2] SHiP Collaboration, JINST 14 (2019) P11028.

Exclusive WW Production in Photon Scattering at the ATLAS Experiment

Alexandra Fell, Kristin Lohwasser, and Philip Sommer

University of Sheffield, UK

Exclusive WW production is a process predicted by the Standard Model and studied at the LHC using the ATLAS detector. The relativistic protons accelerated by the LHC collider can radiate off high energy photons. The high energy photons can interact to produce a W boson pair; either by the exchange of a W boson between the two incoming photons in the t- and u- channel or via a quartic coupling via the $\gamma\gamma$WW vertex. At high energies, the amplitudes for the t- and u- channels diverge due to the linear energy-dependence of the longitudinal polarization of the W boson. The amplitude of the quartic $\gamma\gamma$WW vertex cancels the tri-linear coupling amplitudes. Measuring the exclusive WW process can help gain further insight into the fundamental symmetry between tri-linear and quartic couplings which secures validity the Standard Model at high energies.

Even at lowest order only triple- and quartic coupling (TGC/QGC) vertices contribute to the exclusive WW process which makes this process sensitive to numerous BSM-models, but also causes its cross-section to be very small. Although, it is the fact that this process occurs at the lowest order that makes it sensitive to the anomalous triple- and quartic gauge couplings (aTGC/aQGC), which feature in numerous BSM-Lagrangians.

Exclusive WW production has been studied by the ATLAS collaboration using s=8TeV pp collision data during Run-1 [1] and by the CMS collaboration by combining their s=7TeV and s=8TeV pp datasets. In 2016, the CMS collaboration found a 3.6σ excess over the background-only hypothesis (2.4σ expected [2]). This talk will present work towards a measurement of the exclusive WW process using the Full Run-2 dataset of 139fb-1 collected with the ATLAS detector at s=13TeV.

[1] ATLAS Collaboration, *Measurement of exclusive $\gamma\gamma\rightarrow$ WW production and search for exclusive Higgs boson production in pp collisions at $\sqrt{s}$ = 8 TeV using the ATLAS detector*, Phys. Rev. D94 (2016) 0302011, arXiv:1607.03745v2 [hep-ex]

[2] CMS Collaboration, *Evidence for exclusive $\gamma\gamma\rightarrow$ WW production and constraints on anomalous quartic gauge couplings in pp collisions at $\sqrt{s}$ = 7 and 8 TeV*, JHEP 08 (2016) 119, arXiv:1604.04464v2 [hep-ex]

Construction of a novel HV-MAPS pixel tracker for use in the Mu3e experiment

Andrew Groves, Joost Voosebeld and Carlos Chavez Barajas

University of Liverpool, UK

The mu3e experiment is dedicated to the search for the decay $\mu^{"} \rightarrow e^{"} e^{\%} e^{"}$ with a sensitivity of $10^{\%()}$ using the world's most intense muon beam. This decay violates lepton flavor conservation and is strongly suppressed in the standard model, however there are many beyond models that do predict some level of flavor violations making this decay a great indicator for new physics.

There are many challenges to measuring this decay with this sensitivity, we need a detector with a large acceptance that is capable of recording up to $2 \times 10^{,}$ muon stops per second. We also need excellent momentum, space and time resolution to reduce background levels to below the $\sim 10^{(\cdot}$ level. Another challenge is that due to low momentum of the decay electrons the dominant source of the momentum uncertainty is multiply scattering. This thus requires a very strict material budget [1]. To be able to achieve this a long cylindrical pixel tracker design has been adopted using HV-MAPS sensors thinned to 50 $\mu m$for the pixel tracker. This not only provides the material budget needed but also allows for the granularity and rate capability needed.

Pixel sensors are then mounted on a high density interconnect (HDI) read out at either end.
This gives a total thickness in the active region for each pixel layer of 160 μmequivalent a radiation length of $X/X_4 = 1.16 \times 10^{\%8}$.
Liverpool is tasked with assembling the outer pixel tracker modules. These consists of 17 or 18 HV-MAPS chips mounted on an HDI and supported by 2 kapton v-folds glued to the bottom for structural support and providing a channel for the gaseous Helium cooling. The module design can be seen in fig. 1.

In the talk I will discuss the preparation in Liverpool for building these modules as well as the development of quality assurance tests once assembly begins. I will also discuss the cooling studies that have been done to allow us to operate up to 18 chips in the lab.

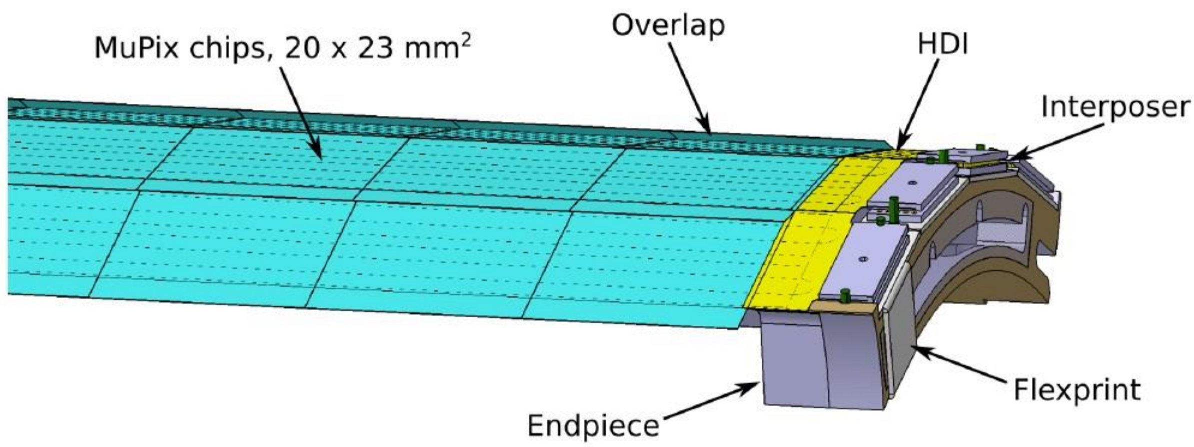


Fig. 1. CAD model of one of the outer pixel modules including one of the two plastic endpiece securing the 4 long ladders into place.

[1] A. Blondel et al. Research Proposal for an Experiment to Search for the Decay $\mu^{"} \rightarrow e^{"} e^{\%} e^{"}$ 2013

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.

Identifying α-cluster states in 1�Ousing the thick target inverse kinematics method

Angus Hollands[1], Tz. Kokalova[1], C. Wheldon[1], G. Rogachev[2], E. Koshchiy[2], J. Bishop[1],[2], S. Pirrie[1], T.S. Ahn[2], M. Barbui[2], D.H. Jayatissa[2], S. Upadhyayula[2], E. Aboud[2], and C. Hunt[2]

[1]The University of Birmingham, UK

[2]Department of Physics and Astronomy, 4242 TAMU, USA[2]

Since the origin of nuclear physics, cluster structures have been observed in the excited states of many light nuclei [1]. It is noted that αparticles are strong cluster candidates due to their significant binding energy and energy of their first excited states. Evidence for this clustering lies within the energy levels of the compound nucleus formed from resonance reactions, which correspond to resonances in the reaction cross section.

In a commissioning experiment in collaboration with Texas A&M University, the thick target inverse kinematics (TTIK) method has been used to perform continuous measurement of the elastic scattering excitation function of the 14O nucleus. Excited states above the αthreshol have been populated using the reaction 10C(4He, α)10C with a radioactive 10C beam. A

Micromegas parallel plate detector was used to facilitate high resolution track reconstruction, and silicon quadrant detector arrays employed to reconstruct the energies of the scattered light product.

The current status of the analysis will be presented, starting from track identification via an iterative implementation of the Hough Transformation [2]. Discussion of the analysis will be presented in the context of the 14C mirror nucleus, and the role of the excitation function in identifying clustering behaviour.

[1] A. Di Pietro et al., Journal of Physics: Conference Series 366, 12013 (2012).

[2] C. Dalitz, T. Schramke and M. Jeltsch, Image Processing On Line 7, 184-196 (2017).

Neural networks for challenges in radio-isotope identification

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Accurate automated characterisation of radioactive material is crucial for applications in decommissioning and security. While detection hardware rarely changes outside of bespoke solutions, improvements in Radio-Isotope~IDentification (RIID) algorithms have become a significant research focus. A generalised gamma simulator has been built using the Geant4 toolkit to provide a rapid development environment.

The core challenge facing algorithms is the explicit handling of transient effects that alter the profile of a spectrum. Machine learning approaches have the advantage of operating based on generalised rules learned from experience, where the spectrum is taken as a whole. In this work, Convolutional Neural Networks (CNN) were used to classify multi-isotope sources from their gamma spectra. The results presented demonstrate the use of CNNs in the RIID problem space, accommodating challenging scenarios such as significant shielding, large gain shifts, and poor statistics.

Search for the Decay of the Higgs Boson to Charm Quarks with the ATLAS Experiment

António J. Costa, Paul Thompson, Andrew Chisholm, Tom Neep, and Konstantinos Nikolopoulos
University of Birmingham, UK

A direct search for the Standard Model Higgs boson decaying to a pair of charm quarks is presented, 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 H → cc¯ decay, while reducing contamination from H → b¯b decays. This search is expected to improve the limit on the H → cc¯ cross-section previously presented by ATLAS, using an integrated luminosity of 36 fb−1 of proton-proton collisions at the same centre-of-mass energy.

First Observation of $\boldsymbol{B^0_{(s)} \to \overline{D}^*(2007)^0 K^\pm \pi^\mp}$ decays using fully reconstructed $\boldsymbol{\overline{D}^*(2007)^0}$ mesons at LHCb

Arnau Brossa Gonzalo

University of Warwick, UK

We report on a study of $B^0_{(s)} \to \overline{D}^*(2007)^0 K^\pm \pi^\mp$ decays using 5.9 fb^{-1} of *pp* data recorded at LHCb during the Run 2 of data taking. The reconstructed $\overline{D}^*(2007)^0$ decays used in this analysis have been reconstructed from both of their possible decay channels: $\overline{D}^*(2007)^0 \to \overline{D}^0 \gamma$ and $\overline{D}^*(2007)^0 \to \overline{D}^0 \pi^0$

Hidden Photons and Axion Like Particles in the LUX-ZEPLIN (LZ) experiment

Athoy Nilima

University of Edinburgh, UK

Motivated by possible theoretical extensions to the standard model, hidden photons (HPs) are a candidate for the cold dark matter. Their possible masses cover a broad range, from 10^{-12} to 10^{6} eV/c^2 [1]. The multi-ton scale, low threshold LUX-ZEPLIN (LZ) experiment, built primarily to detect WIMPs, is also sensitive to HP dark matter via the so-called hidden photoelectric effect. This work presents the projected LZ sensitivity for hidden photon search in the 2-70 keV/c^2 mass range.

Reference :
[1] P.Arias, et al., JCAP06(2012)013, “WISPy cold dark matter”

Locating the gamma-ray emission in Flat Spectrum Radio Quasars

Atreya Acharyya, Paula Chadwick, Anthony Brown

Durham University, UK

We present a study of the gamma-ray emission from the nine brightest flat spectrum radio quasars (FSRQs) detected with the *Fermi* Large Area Telescope (LAT) during its first eight years of operation, with the aim of constraining the location of the gamma-ray emission from these objects.

Using the brightest flares, we find the shortest variability timescales for our sources, which we then use to constrain the size and location of the emission region assuming a simple one zone emission model. The emission was found to be predominantly from inner regions of the broad line region (BLR). The flares were also studied in more detail to look for for evidence of spectral cut-offs as well as searching for energy dependence of cooling timescales. We found evidence of gamma-ray absorption which further supports the argument for BLR emission, although the study of energy dependent cooling is limited by the large uncertainties in both the fluxes and decay timescales for these objects.

Finally, we use simulations to compare the expected onset of the intrinsic cutoff in our sample due to Lyman alpha absorption with the highest energy photons observed from these bright FSRQs. For most objects, the results are compatible with a BLR origin for the gamma- ray emission, with the exception of CTA 102 and PKS 0454+234, suggesting that at least in these objects a more sophisticated emission model is required.

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

Barney Philippou, D. Hollywood, K. Majumdar, K. Mavrokoridis, K. J. McCormick, S. Powell, A. Roberts, N. A. Smith, G. Stavrakis, C. Touramanis[1], J. Vann

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]. 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, off 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 is ideal for colossal two-phase LAr neutrino detectors, allowing for ultra-fast, calorimetric, mm spatial resolution from an externally mounted, single optical device. EMCCD results from the beam-test and the TimePix3 cameras will be presented detailing the many benefits and capabilities of these optical technologies.

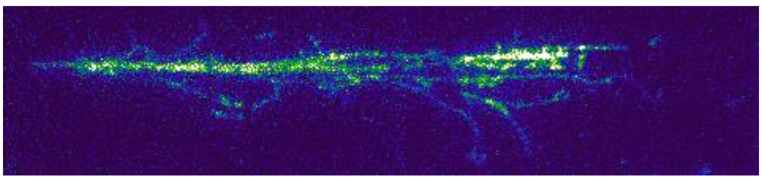
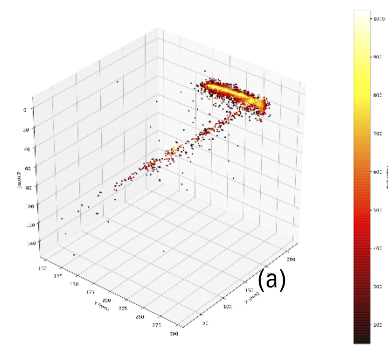


Fig. 1. (a) A 5.0GeV electro-magnetic shower captured with EMCCDs;



(b) A cosmic muon captured with a TimePix3 camera.

[1] D. Hollywood et al., ARIADNE -- A Novel Optical LArTPC: Technical Design Report and Initial Characterisation using the CERN T9 Testbeam and Cosmic Muons. arXiv:1910.03406.

[2] A. Roberts et al., First demonstration of 3D optical readout of a TPC using a single photo sensitive Timepix3 based camera. arXiv:1810.09955.

Changes in Neutron Occupancy in the A = 116 Neutrinoless Double-Beta Decay Candidate System

Benjamin Cropper[1], David Sharp[1], Sean Freeman[1], Paul Davies[1], Ralf Hertenberger[2,3], Thomas Faestermann[2,4], Patrick MacGregor[1], and Hans-Friedrich Wirth[2,3]

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Neutrinoless double-beta (0ν2β) decay is a yet unobserved process, but it is the subject of many current experimental searches. An observation would be extremely exciting, because it would prove that the neutrino is a Majorana particle - its own antiparticle. An observation of the decay, and thus a deduction of the decay rate, also provides access to the absolute mass scale of the neutrino. However, any accurate determination of the neutrino mass is dependent on the nuclear matrix element (NME). This can only be determined through calculation, as no other process samples the same NME. Current calculations using different theoretical frameworks differ by factors of 2-3 for any given candidate system[1].

In this work, we deduce the change in single-particle occupancies in the 0ν2β candidate system ^{116}Cd→^{116}Sn, which is a candidate for the CUPID experiment[2]. As the decay involves the change of two neutrons into protons,the change of the ground-state occupancies must be important. Any model used to calculate the NME should therefore be able to reproduce this change. As such the data can be used to benchmark the calculations. This has been done successfully for the ^{76}Ge→^{76}Se system, where the disagreement between different frameworks has been reduced by 40-70% [3][4].

The (d,p), (p,d), and (3He,α) reactions were measured on the parent nucleus ^{116}Cd, the daughter ^{116}Sn, and ^{114}Cd as a consistency check. This was done at the Q3D spectrometer at the Maier-Leibnitz Laboratorium (MLL) in Munich. Preliminary values for the obtained changes in occupancy will be presented and compared to calculations using the same frameworks to deduce the NME.

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[3] B. P. Kay et al. Phys. Rev. C **79,** 021301 (2009).

[4] J Menéndez et al. J. Phys: Conf, **312(7),** 072005 (2011).

Estimating the fake lepton background in the ttH(bb) dilepton channel using data from the ATLAS detector

Callum Booth, Dave Thomas, Pedro Teixeira-Dias

Royal Holloway, University of London, UK

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 channel that will be focussed on in this talk will be when both tops decay leptonically, the so-called dilepton ttH(bb) channel.

A small contribution to the overall background in the ttH(bb) dilepton channel is from events that contain fake or non-prompt leptons. Fake leptons are particles that register as leptons (e/μ) in the detector but have a non-leptonic origin whereas non-prompt leptons are real leptons but do not originate at the hard scatter. From previous studies, it is expected that the contribution of fake leptons to the overall background is small.

Fake lepton enriched samples are used where the lepton charge requirement is inverted so that the two selected leptons have the same electrical charge. The simulated events are split up into fake (those events that have at least one fake/non-prompt lepton) and prompt using truth information from the MC. Data-driven correction factors are then derived to correct the fakes in the MC to the observed level of fakes in the data. In this talk we will present the method and its results, and will include a comparison with previous results, as well as a study of the impact of this background on the fit used to extract the Higgs signal strength.

Performance of a novel MultiMesh-ThGEM detector and micromegas in low pressure negative ion gas.

Callum Eldridge

University of Sheffield, UK

Negative ion gases such as SF_6 provide a way to reduce the diffusion of charge in a detector's drift volume, this frequently comes at the cost of reduced gas gain and pushes amplification devices to the limits of their performance. Development of stable, large area amplification devices which can operate in negative ion gases will be useful for future large volume gas TPC's for applications such as dark matter searches and neutron monitoring.

Thick Gaseous Electron Multipliers (ThGEMs) are relatively cheap, self-supporting amplification devices for gas based detectors. The MultiMesh-ThGEM (MMThGEM) is an iteration on the successful ThGEM which adds several planes of mesh in the holes of the device to allow for fine control of the amplification and collection fields and to escape the sparking and dependence on dielectric charge up which are features of the normal ThGEM.

In this talk results from the operation of a unique MMThGEM prototype in low pressure SF_6, CF_4 and CF_4:SF_6 mixtures are presented. Gain and energy resolution measurements are presented along with a discussion of the collection efficiency and some of the unexpected effects encountered in the operation of the device. Additionally, results from coupling the MMThGEM to a resistive strip micromegas for x-y sensitivity and tracking will be presented.

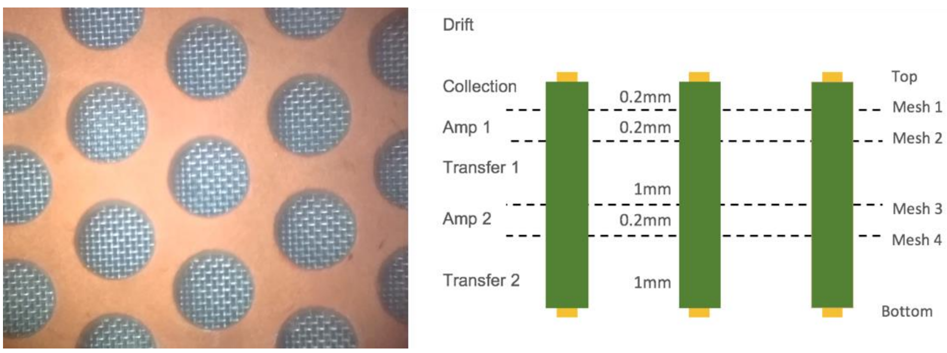

Fig 1. (a) MMThGEM top view (b) MMThGEM cross-section diagram with field (left) & mesh (right) labels

Designing a control region for a search in large eTmiss + bb final states

Candice Basson

University of Manchester, UK

The Standard Model (SM) of particle physics is one of the most precise, well measured theories of the sub-atomic world but is not able to explain everything that has been experimentally observed. Two such examples are astrophysical observations of evidence of the existence of Dark Matter (DM) and the observed Higgs mass of 125 GeV requiring unnatural fine-tuning, leading to the 'hierarchy problem'. Supersymmetry (SUSY) is a potential beyond the Standard Model (BSM) theory that could provide a solution to these gaps in the SM. In a minimal SUSY R- parity conserving model a new particle known as the lightest supersymmetric particle (LSP) is predicted that shares properties with the theorised weakly interacting massive particle (WIMP) and is therefore a viable candidate for DM.

This talk presents 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 Ö13 TeV. This 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.
Results pertaining to the design and optimisation of the Z control region as well as fitting the sbottom signal region are shown. Potential biases that can result from the choice (or lack of) methodology for the correction of SM predictions in the search region are also discussed.

New opportunities for nuclear astrophysics with the CARME chamber at the CRYRING storage ring in GSI FAIR Laboratory

Carlo Bruno, for the CARME/CRYRING collaborations

The University of Edinburgh, UK

Nuclear astrophysics is an interdisciplinary field at the border between nuclear physics and astrophysics. It aims at answering fundamental questions such as how and where are elements synthesised, how is energy generated in stars and how stars evolve and eventually die. Nuclear astrophysics experiments use Earth-bound facilities to investigate nuclear reactions and nuclear properties of interest in stellar scenarios.

I will focus in particular on nuclear reactions occurring in explosive scenarios, such as novae. In these stellar sites, burning reactions on radioactive nuclei play a major role in the synthesis of elements and isotopes, as directly observed in e.g. novae ejecta and isotopic abundances in meteorites. A number of key nuclear reaction rates are still largely unconstrained due to difficulties in producing beams of specific radioactive isotopes with sufficient intensity using extant facilities and methods (e.g. ISOL). A novel approach [1,2] of using heavy ion beams decelerated and cooled in-flight in storage rings, pioneered at GSI Laboratory (Germany), offers a potential solution to this problem. The advantage of the in-flight beam production technique is the possibility of producing any isotope without chemical constraints. However the beam purity is generally poor, resulting in backgrounds from contaminants. This drawback can be solved by circulating the beam through a storage ring (acting as a series of analysing magnets) leaving only the isotope of interest behind. This opens up the possibility to use high quality beams of previously inaccessible isotopes/elements to bombard pure, in-ring targets. After each target interaction the unreacted beam is re-circulated in the ring significantly improving (a factor $\sim 10^5$) the luminosity.

GSI is in the process of commissioning a new storage ring, CRYRING [2] (part of FAIR Phase 0), allowing circulation of low-energy beams (100 keV/A<E<10 MeV/A) ideally suited for studies of nuclear reactions directly at energies of astrophysical interest (the Gamow peak). To exploit this unique opportunity, a reaction chamber called CARME (CRYRING Array for Reaction Measurement) is being constructed and commissioned by the University of Edinburgh and STFC UK. I will present CARME, and focus on the scientific opportunities that will be opened up at GSI Laboratory in the near future. Using beams recirculating in a storage ring, CARME will allow us to perform direct and indirect nuclear physics measurements to improve our understanding of key observables in novae and supernovae, as well as allowing us to probe early universe cosmology.

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[2] J. Glorius et al., Phys. Rev. Lett. 122 092701 (2019)
[3] M. Lestinsky et al., EPJ Special Topics 225 797-882 (2016)

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

Charlie Devlin[1] , Bradley Cheal[1] , Paul Campbell[2], Tommi Eronen[3], Sarina Geldhof[3], Ruben de Groote[3] , Ágota Koszorús[1,4], Mustapha Laatiaoui[5], Ross Mathieson[1] , Iain Moore[3], Mikael Reponen[3], and Sami Rinta-Antila[3]

[1]University of Liverpool, UK, [2]University of Manchester, UK, [3]University of Jyväskylä, Finland, [4]KU Leuven, Belgium, [5]Helmholtz-Institut Mains, Germany

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 theorists today. One such example of this is the shape coexistence present in ^{98}Y between its ground and first isomeric state. This was 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 depends 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 in to 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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Measurement of ΛC baryon production in pp and p-Pb collisions with ALICE at the LHC

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Heavy-flavour quarks (charm and beauty) are effective probes of the strongly-interacting medium, known as the Quark-Gluon Plasma (QGP), created in ultra-relativistic heavy-ion collisions. They are produced in the early stages of the collision, in hard scattering processes, and interact with the QGP throughout its entire evolution. Measurements of the ΛC baryon and charmed mesons production cross-sections allow the baryon-to-meson ratio ($\Lambda C/D^0$) to be evaluated, probing hadronisation and thermalisation mechanisms of charm quarks in the medium. Measurements in pp collisions, besides constituting a natural reference for larger collision systems, allows for testing of the expected universality of charm fragmentation at the TeV energy scale. The measurement in p-Pb collisions can help separate the hot and cold nuclear matter effects seen in Pb-Pb collisions.

The ALICE detector, with its excellent vertex reconstruction and hadron identification capabilities, allows for first measurements of Λ_C production. In this contribution the p_T -differential cross section of the Λ_C baryon through the $\Lambda_C \rightarrow pK\pi$ decay channel measured in pp and p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, along with the baryon-to-meson ratios, will be presented and discussed. Combined results from both the $pK\pi$ and pK^0 decay channels will also be shown as well as a comparison to previous results in pp and p-Pb collisions. In addition, the experimental results will be compared with current theoretical models.

Fundamental properties of nuclear ground and isomeric states in neutron-deficient indium from laser spectroscopy

Christopher Ricketts[1], Jon Billowes[1], Cory Binnersley[1], Mark Bissell[1], Thomas Cocolios[2], Gregory Farooq-Smith[2], Kieran Flanagan[1], Serge Franchoo[4], Ronald Garcia Ruiz[5], Wouter Gins[2], Ruben de Groote[6], Fredrik Gustafsson[2], Anastasios Kanellakopoulos[2], Ágota Koszorús[2], Gerda Neyens[2,5], Henry Stroke[7], Adam Vernon[1], Klaus Wendt[8], Shane Wilkins[5], and Xiaofei Yang[10]

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Hyperfine structure measurements of the neutron-deficient indium (Z = 49) isotopes, approaching the heaviest self-conjugate doubly-magic nucleus ^{100}Sn, have been performed using collinear resonance ionization spectroscopy [1]. This study provides nuclear model independent measurements of nuclear electric quadrupole and magnetic dipole moments, as well as changes in mean-square nuclear charge radii, which can be used to benchmark the development of nuclear many-body methods, which are now able to predict properties around the Z=N=50 shell closure [2,3].

States in previously measured odd-even indium isotopes have shown a remarkably simple single- particle behaviour, whether this trend in the electromagnetic moments continues will give insight into the strength of the shell closure. This first experimental determination of ground-state electromagnetic moments and changes in mean-square charge radii of neutron-deficient $^{101\text{-}103}$In isotopes will shed light on the evolution of nuclear structure around ^{100}Sn.

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[2] T.D. Morris et al., Phys. Rev. Lett. **120**, 152503 (2018).

[3] T. Togashi et al., Phys. Rev. Lett. **121**, 062501 (2018).

Measurement of inclusive Z γ production at 13 TeV with the ATLAS detector

Daniel Lewis

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The inclusive production cross-section of a leptonically-decaying Z boson in association with an isolated photon is measured to a precision of 3% using 139 fb-1 of LHC proton-proton collision data. The cross-section is also measured differentially in variables which are particularly sensitive to higher-order corrections and are compared to state-of-the-art NNLO perturbative QCD calculations. A previously unconsidered source of background is described, arising from the high number of interactions in each LHC bunch crossing. Prospects for expanding the analysis of this process, for example with the addition of third EWK boson (VZy, V=Z, W, γ), are also presented.

Quantum-entangled PET Imaging

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

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Positron Emission Tomography is a technique widely used for medical research and clinical diagnosis. It utilises the back-to-back emission of annihilation photons to image metabolic processes inside of the body. The method is hindered by in patient scattering and random backgrounds, which reduce image resolution and contrast [1,2]. We demonstrate, for the first time, the benefits of exploiting the previously ignored quantum entanglement between the two annihilation photons [3].

To do this a new quantum entangled GEANT4 simulation was developed and the results verified against experimental data from a cadmium zinc telluride PET demonstrator.

As an indication of the potential benefits we present a simple method to quantify and remove in patient scatter and random backgrounds using only the entanglement information in the PET events. We also show preliminary results of entanglement measurement in a mini-PET setup mimicking the full body EXPLORER system [4], to test the feasibility of this method in preexisting clinical setups. It is shown how this technique can open up new possibilities to further our understanding of entanglement breaking on the MeV scale.

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Unfolded four-lepton invariant mass measurement with the ATLAS Detector

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. 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. Key changes to the analysis with respect to the previous round are motivated by improving inclusivity and acceptance across the invariant mass range, and maximizing future re-interprebility.

The Electron-Ion Collider: a window into the quark-gluon sea

Daria Sokhan

University of Glasgow, UK

The Electron-Ion Collider, to be built at Brookhaven National Lab in the coming decade and designed entirely with hadron physics in mind, will be the main next-generation facility to study structure of hadrons and nuclei at high precision, from just below the valence quark region to deep into the quark-gluon sea [1]. It will be the world's first polarised electron and polarised proton / light-ion collider and will also collide electrons with unpolarised species of heavier ions up to uranium. Its centre-of-mass energies will range from 20 to 100 GeV (upgradable to 140 GeV) and its design luminosity is 10^{34} $cm^{-2}s^{-1}$. This will enable it to address questions such as the composition of nucleon spin and the contribution of glue to it, the role of gluons in the origin of nuclear mass, how colour charge propagates through nuclear matter and hadronises, where the regime of gluon saturation sets in and what the properties of this new phase of matter are. We present an overview of this new international project, the current design of the accelerator and detectors and the main physics topics it will address.

[1] A. Accardi *et al.* Eur. Phys. J. **A** 52:268 (2016).

Search for a Top Quark Pair Produced In Association with a Higgs Boson Decaying to a Bottom Quark Pair (ttH(bb)) in the Dilepton Channel with the ATLAS Detector

Dave Thomas, Callum Booth, Pedro Teixeira-Dias

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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 ttH comprises only ~1% of the total Higgs production cross- section. In spite of this, 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 LHC, thereby presenting a gateway to 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) from a top quark are the most sensitive when measuring ttH(bb) production, as they do not suffer from the fundamental difficulty of the all-hadronic channel 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. Within the scope of this talk, studies presented will concern the dilepton channel specifically. 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.

An overview of various validation checks for the ttH(bb) dilepton analysis will be presented. The primary study discussed will pertain to the use of data-driven methods to estimate 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.

MODEL-INDEPENDENT METHOD FOR MEASURING THE ANGULAR COEFFICIENTS OF B0 -> D* TAU NU DECAYS

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Reconstruction of the $B0 \to D*^{-}\tau^{+}\nu\tau$ angular distribution is complicated by the strongly biasing effect of losing the neutrino information from both the B and τ decays. In this presentation, a novel method for making unbiased mea- surements of the angular coefficients while preserving the model independence of the angular technique is demonstrated. The twelve angular functions that describe the signal decay, in addition to background terms, are modelled in a multidimensional fit, using template probability density functions that encapsu- late all resolution and acceptance effects. Sensitivities at the LHCb and Belle II experiments are

estimated, and sources of systematic uncertainty are discussed, notably in the extrapolation to a measurement of the branching fraction ratio $R(D*) = B(B0 \to D*-\tau+\nu\tau)/B(B0 \to D*-\mu+\nu\mu)$.
Abstract based on work published in 10.1007/JHEP11(2019)133

A Terabit Readout System for the LHCb Upgrade Vertex Locator

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LHCb is in the process of installing a major upgrade in the LHC long shutdown in 2019-2020, with 90% of all detector channels, and 100% of all readout electronics being replaced. As part of this upgrade the LHCb Vertex Locator (VELO), a silicon microstrip detector, will be replaced with a new pixel detector in the LHCb upgrade. The LHCb upgrade will run without a hardware trigger, and as such the readout system is designed to operate at full rate readout at 30 MHz.

The aim of this talk is to present the architecture of the readout chain with emphasis on the challenges of the high speed data transmission and processing.

Three main stages of the readout can be distinguished: the front-end module comprising the VeloPix ASICs and the control and timing ASIC (GBTx) with the closest VeloPix ASIC 5.1 mm from the beam; the optical conversion and power distribution board placed outside the vacuum tank ~1 m away from the beam; and the back-end FPGA boards (PCIe40s) ~300 m away at the surface.

The detector readout chain starts with a new radiation hard, high speed ASIC (VeloPix) based on the Timepix family. The highest occupancy ASICs will produce data rates above 900 Mhit/s giving a total bandwidth of ~4 Tb/s for the whole detector. The VeloPix is placed in a retractable system inside a vacuum in an extremely high radiation environment. One of the challenges of the system is the transmission of data at 5.13 Gb/s out of the detector acceptance with low mass and flexible links. Due to the importance of these links, a long campaign of simulation and testing has been carried out in the last five years. The main task of the back-end board is to synchronously collect and process data from an entire front-ends and send them to the high level trigger at 100 Gb/s.

Observation of Higgs boson decays to bottom quarks and VH production at the ATLAS Experiment

Dwayne Spiteri

University of Glasgow, UK, The ATLAS Collaboration, CERN

As the newest elementary particle to be discovered, the Higgs boson and its couplings are of great interest to theorists and experimentalists alike. The most likely decay of the Higgs boson is to b-quarks (H->bb); however, observing this decay mode at the LHC is extremely challenging owing to the large backgrounds of jets that occur in proton collisions. These can be greatly suppressed by requiring additional objects in co-incidence; in this case, selecting events with either missing transverse energy, or leptons coming from the decay of a weak vector boson produced alongside the Higgs boson (VHbb). The resulting measurements allow the Yukawa coupling of the Higgs boson to bottom-type quarks to be probed.

In this talk, the latest results from the search for H->bb decays associated with a W or Z boson with the ATLAS detector will be presented with some emphasis on the new analysis techniques that are new since the published observation [1]. Furthermore, updated VHbb differential cross section measurements in bins of the transverse momentum of the vector bosons will be discussed. It is through these measurements that Beyond Standard Model Physics can be probed using an Effective Field Theory framework.

[1] Physics Letters B Volume 786, 10 November 2018, Pages 59-86

Increasing the Sensitivity of the T2K Oscillation Analysis

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The T2K experiment is a long-baseline neutrino experiment in Japan that measures neutrino oscillations to world-leading precision. The Japan Proton Accelerator Research Complex (J- PARC) facility provides a muon (anti-)neutrino beam which is aimed towards the far detector, Super-Kamiokande, giving a baseline of 295km. The near detectors INGRID and ND280 are used to constrain the unoscillated neutrino flux uncertainties and neutrino interaction model. Data collected at Super-Kamiokande are used to search for muon (anti-)neutrino disappearance and electron (anti-)neutrino appearance which give constraints on the PMNS matrix parameters. A Markov Chain Monte-Carlo is used to sample the likelihood of the T2K event prediction model to these data collected at Super-Kamiokande. Prior constraints on the expected, unoscillated event rate and its uncertainty are provided by the near detectors and external data. The treatment of systematic uncertainties in this analysis is crucial and T2K's upcoming analysis will feature significant improvements to the neutrino interaction and flux models. In addition to improved treatment of systematic uncertainties, additional data samples at Super-Kamiokande will be included in future analyses. An additional sample of events originating from charged-current interactions resulting in a muon and a charged pion in the final state will be described in this talk. Of particular importance for using this sample is the implementation of new systematic uncertainties relating to neutrino-induced charged pion production; the first steps towards these new systematic uncertainties is underway.

Adversarial Neural Networks for ttH()

Emily Petrova Takeva, Dr. Liza Mijović, Prof. Philip Clark

The University of Edinburgh, UK

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(H->ɣɣ) 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. To date, the adversarial neural networks have been used on Monte Carlo simulated data and ttɣɣ(dominant in real data) background and have proven to minimise the sculpting as shown on Fig. 1, while keeping the efficiency of background rejection and the performance of the networks at a high level (Fig 2.). Future work includes optimisation of the method and application to the data taken by ATLAS.

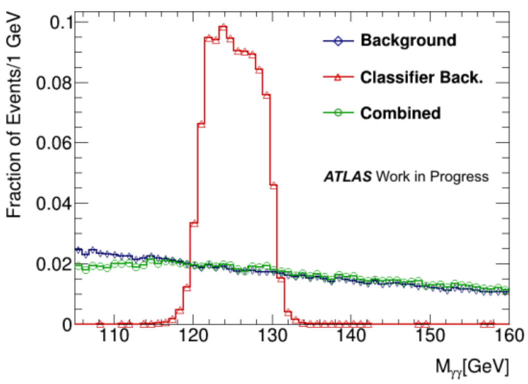
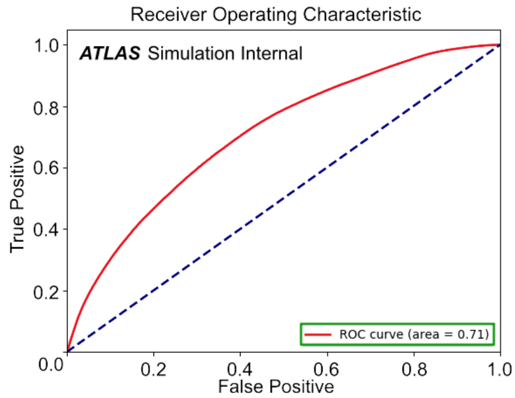


Fig 1. Current result for the M$$ distribution. Initial background distribution is shown in blue, after classifier training (background rejection) in red and final after adversarial training in green.

Fig 2. Current performance of the adversarial neural networks. Receiver operating characteristic curve is calculated to have an area of 0.71.



Deep Science at Boulby Underground Laboratory: Subterranean studies at the UK's deep underground science facility

Emma Meehan

Science and Technology Facilities Council, UK

For more than three decades UK astrophysicists have been operating experiments to search for Dark Matter 1100m below ground in a purpose-built 'low-background' facility at Boulby mine in the North East of England. This facility - the Boulby Underground Laboratory - is one of just a few places in the world suited to hosting these and other science projects requiring a 'quiet environment', free of interference from natural background radiation. The race to find Dark Matter continues and Boulby currently supports the DRIFT/CYGNUS directional dark matter detector programme and operates a growing suite of high sensitivity Germanium detectors for material screening for future Dark Matter detectors (inc. LZ) and other rare-event studies. In the meantime, the range of science projects looking for the special properties of deep underground facilities is growing and new projects operating at Boulby range from astro & particle physics to studies of geology/geophysics, climate, the environment, life extreme environments on Earth and beyond. This talk will give an overview of the Boulby Underground Laboratory, the science currently supported and plans for science at Boulby in the future.

Identification of the 3 − state in 220 Th

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There has been substantial experimental and theoretical progress in the investigation of reflection- asymmetric nuclear shapes through the study of the octupole degree of freedom [1]. Octupole deforma- tion is linked to the close proximity of shell model orbits with $\Delta l = \Delta j = 3$ [2]. This leads to the pre- diction of strong correlations near closed shells in the neutron-rich lanthanides and light actinides. The nucleus ^{220}Th lies at the lower boundary of the octupole region of the actinides. A strong dependence on the octupole degree of freedom can be inferred from the presence of band structure with interleaving positive- and negative-parity sequences. This characteristic structure has previously been identified in the yrast band of ^{220}Th [3]. The identification of low-lying negative-parity states is crucial for determin- ing if octupole excitations are predominantly rotational or vibrational in nature. An experiment was performed at the INFN LNL in which the ^{208}Pb(^{16}O,4n) reaction was used to produce ^{220}Th. Prompt γ-ray emissions were detected using the Galileo spectrometer, the evaporated particles were detected using the Euclides Si detector array, and the Neutron Wall array of liquid scintillators [4][5][6]. Analysis of triple γ-ray coincidence events in the data has led to the identification of the first 3^- state in ^{220}Th at an energy of 727.2(2) keV and a measured $B(E1)/B(E2)$ ratio of 1.5(2) $\times 10^6$fm^2 for the transitions from the first 5^- state. These results fit very well with predictions made by recent dinuclear model calculations, undermining a vibrational interpretation of the octupole degree of freedom [7].

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Measurement of the CKM angle gamma with B → DKpipi decays at the LHCb Experiment

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Measurements of CP-violation with B- and D-mesons are central to the physics programme at the LHCb experiment, particularly measurements related to the unitarity triangle that constrains CP-violation in the quark sector. Among the angles of the unitarity triangle, gamma is unique in that it can be measured at tree level and therefore has a negligible theoretical uncertainty, but due to experimental challenges in its determination it remains one of the least well constrained Standard Model parameters. Sensitivity to gamma is usually achieved through interference between B-meson decays via a D0 or a D0-bar to a common final state.

The decay mode B → DKpipi, D → Kspipi (D is a neutral D-meson) is an ideal complement to the standard decay mode for these measurements (B → DK), due to its high branching fraction, and the 3 body D-decay allows the use of the powerful GGSZ method [1] for extraction of CP-parameters. In this method, the full resonance structure across the D-decay phase space is considered in order to enhance the sensitivity. This analysis is a measurement of gamma using the full LHCb Run 1 and 2 dataset, and progress towards a full measurement using both model dependent and independent methods will be presented.

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Study of high-spin states in ^{219}Ra

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Theoretical and experimental studies of octupole deformation in specific regions of the nuclear chart have provided evidence that nuclei can exhibit pear shapes [1]. In this regard, nuclei with proton and neutron numbers close to Z~88 and N~134 have become of tremendous importance; they lie in the region where the most favourable evidence of reflection asymmetry is observed [2, 3]. Previous spectroscopic studies of 219Ra were able to establish the presence of an interleaving opposite-parity band in this nucleus [4, 5]. For the present study, an experiment was performed at the Argonne National Laboratory, using the Gammasphere gamma-ray spectrometer [6] together with the HERCULES evaporation-residue detector [7]. The nucleus of interest was produced through the 208Pb(18O,α3n) fusion-evaporation reaction. Using timing information and pulse-height analysis the large background of gamma rays produced following prompt fission of the 226Th compound nucleus was removed. Using high-fold gamma-ray coincidence analysis we have been able to tentatively identify new excited states in the alternating-parity band. The current status of the analysis will be presented and discussed. Data such as parity splitting and rotational-frequency ratios will be presented and for odd-A radon (Z=86), radium (Z=88), and thorium (Z=90) nuclei in the light-actinide region. These data will be discussed in the context of a study of the evolution of octupole correlations as a function of neutron number in these isotopic chains.

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Investigating the influence of magnetic field on the sensitivity to double beta decay for SuperNEMO

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Neutrinoless double beta decay (0vbb) is a beyond standard model interaction which if observed will help clarify many ongoing questions we have regarding the nature of neutrinos and neutrino mass.

The NEMO-3 experiment probed 0vbb using various different two-neutrino double beta (2vbb) decaying isotopes including ^{82}Se and ^{100}Mo. There was no evidence of a 0vbb signal for any of the seven 2vbb decaying isotopes explored by the NEMO-3 experiment. ^{82}Se was the isotope of choice for the next generation detector and successor to NEMO-3, SuperNEMO. NEMO-3 measured the half-life of 2vbb decaying ^{82}Se as 9.39×10^{19} yr using a 0.932 kg sample measured for a total of 5.25 years[1].

Initially three different magnetic fields were investigated: a 25 Gauss field (uniform); 0 Gauss field (no field) and a mathematically computed representation of what we expect the field to look like in reality (realistic field). The different magnetic fields vary the means by which we can determine whether events are classified as double beta decay events or as background so directly influences our sensitivity to 0/2vbb.

Simulations were generated for ^{82}Se (two-neutrino and neutrinoless) as well as the major ^{82}Se backgrounds, ^{208}Tl & ^{214}Bi. Decays from the single β^- decaying backgrounds ^{208}Tl & ^{214}Bi can result in signal like events (0/2vbb) due to various quantum mechanical processes including Møller and Compton scattering.

Backgrounds were simulated throughout the detector as well as external to the detector to determine their influence on our sensitivity to 0/2vbb decays. Maximising our signal to background ratio ($s/\sqrt{b}$) will make us more sensitive to a potential 0vbb event whilst allowing us to set improved limits on the unobserved 0vbb half-life and upper mass limit for an effective Majorana mass.

Alongside the magnetic field studies, there are ongoing investigations into the nature of the double beta decay intermediate state. There are two dominant hypotheses for the intermediate state of double beta decay, higher state dominance (HSD), where various higher energy states mediate the interaction and single state dominance (SSD), where a single intermediate state mediates the decay. There are only subtle observable differences between the two states, the most significant of which is the electron energy of the daughter electrons. Our objective is to determine how we can fit these decay modes (HSD and SSD) to real data to determine which decay mode is favoured.

[1] R. Arnold et al.: Final results on 82Se double beta decay to the ground state of 82Kr from the NEMO-3 experiment (2018)

Micro-eV scale dark matter searches in the UK

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[1]Lancaster University, UK, [2]Cockcroft Institute of Accelerator Science and Technology, UK [3]Sheffield University, UK

The identification of the dark matter that dominates the mass distribution of galaxies and plays a key role in our understanding of cosmology is a central unsolved mystery of modern physics. Attention over the past 20 years has focused on weakly interacting dark matter (WIMPs); however, a smaller but active community has been searching instead for light hidden-sector particles, including the axion and axion-like particles, using some of the most sensitive electronics in the world.
In the micro-eV mass range of most interest to light dark matter searches, axions would emit extremely-weak electromagnetic signals, about a millionth of an attowatt, into terrestrial detectors in the presence of a strong magnetic field.
A group of UK researchers is involved in existing and proposed experimental direct searches for light hidden sector dark matter. Here we describe ongoing and planned research, conducted in collaboration with the ADMX experiment in the US.

Simple Charge and Flash Matching to better constrain cosmic background in SBND

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The Short-Baseline Near Detector (SBND) will be a 112 ton liquid argon time projection chamber devoted to researching neutrino oscillations. Located 110 m downstream from the Fermilab Booster Neutrino Beam (BNB) target, SBND is the near detector of the three-detector Short Baseline Neutrino (SBN) program at Fermilab. The SBN program will probe neutrino oscillations at the ~ 1 eV^2 scale, addressing tensions pointing to the possible existence of sterile neutrinos. Being at the surface means that one of the main background sources are cosmic rays. This talk presents a straightforward method to match the reconstructed charge with light read-out information in order to decrease the cosmogenic background and to better identify neutrino induced interactions in the SBND detector, which may also be applied to the SBN far detector.

Measurement of the fast neutron background energy spectrum in Boulby with a nitrogen-based spherical proportional counter

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Experiments for rare events searches such as dark matter, neutrinoless double beta decay and neutrino coherent scattering, are reaching a level of sensitivity that requires careful strategies to mitigate any possible background. Going deeper underground, for additional shielding from cosmic radiation is the first step but is not adequate. Modern experiments rely on careful material handling to limit activation, for example, underground storage and construction. That is why a detailed understanding of the neutron spectra in-situ is required to estimate neutron-induced backgrounds not only during operation but also during construction and material storage. Neutron energy spectra can also be used to benchmark Monte Carlo simulations that experiments heavily rely on to estimate their sensitivity and background. The University of Birmingham in collaboration with Boulby underground laboratory has installed a nitrogen-based Spherical Proportional Counter underground aiming to provide spectral information about the flux of fast neutrons in the facility. The method is based on the $^{14}N(n, \alpha)B^{11}$ and $^{14}N(n, p)C^{14}$ reactions for the detection of fast neutrons. This safe, inexpensive, and reliable way to measure neutron energy can pose as an alternative to ^3He based detectors. This method could be used at other underground and surface laboratories providing a service to the rare event searches community.

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

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The Recoil Decay Doppler Shift (RDDS) method for measuring nuclear lifetimes 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 gamma emission 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].

The charge plunger technique uses a movable foil (plunger), placed between the target and the separator. A nuclear transition which proceeds through internal conversion creates a vacancy in the inner atomic shell and the ensuing Auger cascade results in a large increase in the charge state of the ion. If the internal conversion happens before the plunger the charge state of the ion will be reset to a lower value after passing through the foil. If the internal conversion happens after the plunger the charge is not reset. A low [high] charge component will appear in the charge state distribution (CSD) due to decays before [after] the foil. Using several target-plunger distances and comparing the ratio of these two components in the CSD a decay curve can be obtained (see figure 1), similar to those observed using the RDDS method. From this decay curve, the lifetime of the state can be found.

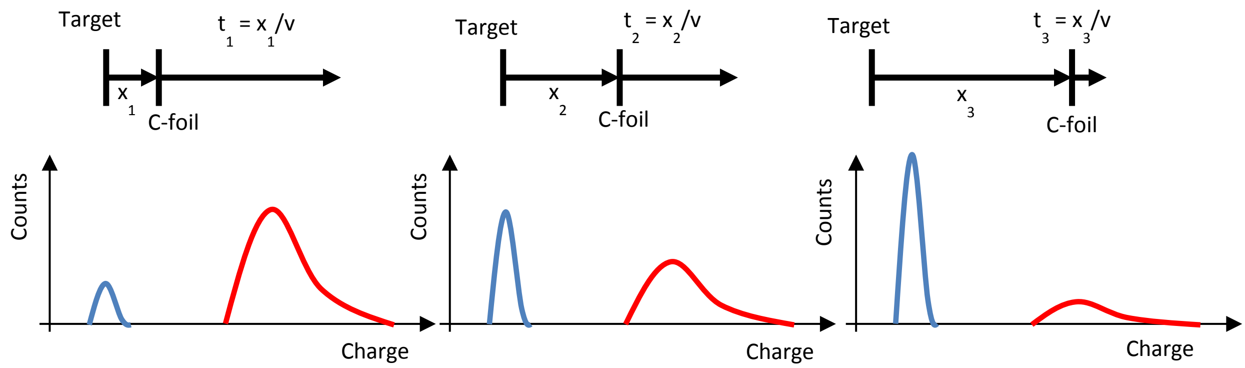

Figure 1: At different plunger distances the ratio between different components in the CSD will change. By comparing how this ratio changes at different distances we can measure the lifetime of the decaying nuclear state.

The results from a recent experiment performed at the accelerator laboratory in Jyväskylä are presented here. The reaction $^{152}Sm(^{32}S,6n)^{178}Pt$ ran at a beam energy of 192 MeV. The Differential Plunger for Unbound Nuclear States (DPUNS) was used to employ the plunger method and the vacuum separator MARA was used to observe the intensities of different charge states. The germanium array Jurogam3 was used to identify recoiling ^{178}Pt

nuclei. The lifetime of the yrast 2^+ state in this nucleus has been measured in previous experiments to be 412(30) ps [2].

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Measurement of the Associated Production of a Z boson and bottom or charm quarks with the ATLAS experiment

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The first steps in obtaining unfolded cross sections of the Z→(μμ)+b and Z→(μμ)+bb channels in addition to measurements of kinematic variables will be presented. The analysis builds on the work of previous analyses at lower energies to enhance the measurement of unfolded cross sections further than ever before.

Material presented will clearly explain the motivations and value of the analysis, and demonstrate the value of standard ATLAS analysis techniques in analyses where precision is of the utmost importance. The analysis uses data collected by the ATLAS experiment at the LHC during Run-II of p-p collisions corresponding to $139fb^{-1}$ at a center of mass energy of $\sqrt{s}$ = 13 TeV.

Investigation of the Dipole Response of ^{58}Ni and ^{60}Ni

Jacqueline Sinclair

University of the West of Scotland, UK

Investigations of the Pygmy Dipole Resonance (PDR) has gained much interest over the past few years due to its implications in the field of astrophysics. These resonances only contribute 1-5% of the total electric dipole (E1) strength in nuclei, hence the name “Pygmy”. However, due to its energy, the implications of the PDR are significant. The PDR typically occurs in the energy region near the particle thresholds and is visualised as a “skin” of excess neutrons forming around an isospin-saturated core and oscillating against this N≈Z core [1]. This phenomenon generates much interest because the formation of the neutron skin around the nucleus is an example of pure neutron matter, which is typically only observed elsewhere in neutron stars. Therefore, investigating this characteristic of neutron-rich nuclei could help understand the behaviour of neutron star matter. Furthermore, the dependency of the E1 strength as a function of the ratio between the number of protons and neutrons in the nucleus also provides insight into the symmetry parameter of the nuclear equation of state (EOS). Studying the neutron skin which is related to the properties of these pygmy resonances may allow for constraints to be added to the symmetry term of the EOS [2], thus allowing a better understanding of exotic stellar environments such as those of neutron stars and binary mergers. It is important to study the E1 response in N≈Z nuclei, such as 58- and 60-nickel, as these nuclei will provide a better understanding to which extent this phenomenon occurs even without the formation of a neutron skin. Moreover, comparing these resonances in 58Ni and 60Ni to those observed in more neutron-rich nuclei would also give an insight into the contribution that the neutron skin has on the E1 strength. The nickel isotopes are also interesting to investigate as they are some of the first nuclei to be produced in the r-process, thus giving insight into the role the PDR plays in the formation of almost half of the isotopes in the universe heavier than iron. To study the dipole response of stable nuclei, the most common technique that is used is nuclear resonance fluorescence (NRF) [3] using bremsstrahlung at facilities such as the ELBE facility [4] at the Helmholtz-Zentrum Dresden-Rossendorf and quasi-monochromatic fully-polarised photons at HIGS [5] at TUNL. Nuclear excited states which have spin J=1 are excited due to the incident photons carrying an intrinsic angular momentum of 1ħ. This makes NRF a powerful technique for studying the characteristic J p=1--PDR states and Jp=1+ levels which form Gamow-Teller resonances. Gamow-Teller resonances are also predicted to have an influence on r-process nucleosyntheses. They provide information about the neutrino-nucleus interactions which act as the heating mechanism driving type-II supernova explosions [6]. The contribution that the study of these J=1 levels have in the field of astrophysics is considerable. Using NRF, which selectively populates these states, physicists can further understand the cosmic events that are responsible for creating many of the heavy elements in the universe.

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Probing jet quenching effects through hadron+jet measurements with ALICE at the LHC

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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, a medium known as the Quark Gluon Plasma (QGP). The semi-inclusive measurement of jets recoiling from a trigger hadron 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 also 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 jet quenching effects in pp collisions, where to date no significant jet quenching has been observed. This talk will summarise the most recent hadron+jet measurements from the ALICE experiment at the LHC.

Commissioning of the New ALICE Inner Tracking System

James Iddon

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The upgrade of the Inner Tracking System (ITS) of the ALICE detector will extend measurements of heavy-flavour hadrons and low-mass dileptons to a lower pT and increase the read-out capabilities to incorporate the full interaction. Furthermore, the tracking efficiency will be improved at low pT. Some of the new measurements of heavy-flavour probes possible after the ITS upgrade and with an integrated luminosity of $10nb^{-1}$ include the nuclear modification factor and anisotropic flow down to pT of 2 GeV/c and 3 GeV/c respectively for the Λcbaryon[1].c baryon [1].

To achieve this, the new ITS is comprised of 7 layers of a custom monolithic active pixel sensor design known as ALPIDE. The use of the ALPIDE-based detector design will reduce the material budget to 0.35% X0 per layer for the inner most three layers, and to 1.0% X0 per layer for the outer most four layers, compared to 1.14% X0 per layer in the previous ITS. The readout rate will be improved to 100kHz for Pb-Pb interactions, which is the double of the upgrade requirement. In addition, the radius of the first layer of the ITS will be reduced from 39mm to 23mm and the pixel size reduced to O(30μm) x O(30μm).m) x O(30μm) x O(30μm).m).

The effort in over 10 construction sites, including the Liverpool Semiconductor Detector Centre and Daresbury Laboratory, has resulted in a fully assembled and connected detector, which is currently under going on surface commissioning before it will be installed in the ALICE cavern in July 2020. This contribution will discuss the current status of the commissioning of the new ITS, including the methods used to characterise the detector and the results obtained so far.

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Solving the deuteron few-body problem with neural networks

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The application of Artificial Neural Networks (ANNs) have had broad success in recent years towards solving numerous quantum many-body problems in a variety of different scenarios [1-3]. ANNs can efficiently encapsulate the information of many-body wavefunctions, and can be used to variationally solve for the ground-state of a given Hamiltonian.

In our work we use a simple one-layer neural network to represent the nuclear wavefunction of the deuteron. We use the Entem-Machleidt N3LO interaction [4], and find that a neural network with just 6 hidden nodes can reproduce the ground-state energy to within 5 KeV of an exact benchmark [5].

I will describe the ANN architecture, training, and energy minimisation algorithm used to solve this first application to theoretical nuclear physics. I will then consider the extension to higher mass numbers, and identify key challenges in the use of neural networks to nuclear theory applications.

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[3] - Pfau, David, et al. "Ab-Initio Solution of the Many-Electron Schrödinger Equation with Deep Neural Networks." *arXiv preprint arXiv:1909.02487* (2019).
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First alpha transfer measurement of ^{15}O alpha capture for neutron stars in binary systems

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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 has been performed, populating the relevant states at temperatures up to 1GK. In this, we take advantage of the ^{15}O Radioactive Ion Beam provided at GANIL and the state-of-the art detection system VAMOS + AGATA + MUGAST 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 $^{15}O(\alpha,\gamma)^{19}Ne$ reaction.

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Search for the K+® p+nn decay at the NA62 Experiment at CERN

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The ultra-rare K^+® p^+nn decay has a precisely predicted branching ratio of $(8.4\pm1.0)\times10^{-11}$ in the Standard Model. However, this is very sensitive to potential beyond the standard model scenarios, making it one of the best candidates to reveal indirect effects of new physics. The NA62 experiment at the CERN SPS, designed to measure the branching ratio of K^+® p^+nn with a decay-in-flight technique, collected a data set in 2016-18. Results from the analysis of the 2017 data is presented, representing an improvement in sensitivity by a factor of 10 over the previous result based on the 2016 data set.

Tests of Lepton Universality Using B+→K*+ll and B0→Ksll Decays at LHCb

Harry Cliff, Valerie Gibson, and <u>John Smeaton</u>

University of Cambridge, UK

This presentation details an upcoming test of lepton-universality in B0→Ksll and B+→K*+ll decays, performed using data collected by the LHCb detector during run-1 and run-2 of the LHC. These decays are examples of b→sll flavour-changing neutral current processes, of which numerous recent analyses have found tensions with Standard Model (SM) predictions. Global fits of effective field theory parameters hint at a coherent pattern to these tensions, possibly arising from the contributions of beyond-SM particles, such as Z' bosons or leptoquarks [1].

Ratios of branching fractions for muon-mode and electron-mode b→sll processes can be predicted to O(1%) precision under the SM, and can provide stringent experimental tests of beyond-SM models which violate lepton-universality [2]. Previous LHCb measurements of these ratios for B+→K+ll and B0→K*0ll decays (the isospin partners of B0→Ksll and B+→K*+ll) found significant tensions with SM expectations [3,4]. Measurements of lepton-universality ratios for B0→Ksll and B+→K*+ll will provide additional, complementary information on the structure of b→sll processes.

The LHCb detector's sophisticated tracking and particle-identification systems are used to sort these decays from physical and detector-induced backgrounds. A mix of simulation-based and data-driven techniques are used to study the detector performance, with particular attention paid to differences in the reconstruction of muons and electrons.

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[3] R. Aaij, et al. (LHCb Collaboration), Phys. Rev. Lett. **122**, 191801 (2019).

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APEX: A' EXperiment. A search for Dark Matter at Jefferson Lab

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The A' EXperiment (APEX) at JeffersonLab is a search for a new vector gauge boson, A', within the mass range of 65 MeV< $m_{A'}$ < 550 MeV, and with a coupling to electrons of $\alpha'/\alpha = 6 \times 10^{-8}$. Such a Boson could serve as an explanation of several dark matter related phenomena, via its interactions with both SM (Standard Model) and dark matter. A successful test run in 2010, searching in the mass range of 175 MeV < $m_{A'}$ < 250 MeV showed the absence of the A' boson in this region [1]. This generated wide interest and proved the viability of the experiment.

A production run took place in 2019 using a similar set-up to the test run, the two High Resolution Spectrometers (HRSs) of Hall A were used to detect the e^- and e^+ particles produced from the electron beam of Jefferson Lab colliding with a fixed tungsten foil target. Produced through a process analogous to Bremsstrahlung in EM interactions, A' bosons could potentially be observed as small peaks in the e^+e^- invariant mass spectrum. The HRSs will provide an invariant-mass resolution of $\delta m/m = 0.5\%$ [2], allowing great sensitivity to the mass and coupling of a potential A' boson. This talk will present the latest updates in the analysis of the 2019 run.

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

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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-R 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 the properties of additional-jets.

Measurement of the Drell-Yan production cross-section at LHCb

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This poster presents an outline of the ongoing measurement of the Drell-Yan cross-section through the dimuon channel at LHCb. The measurement will be made using the data collected from 2016-18 by LHCb at $\sqrt{s}$ = 13 TeV, complementing the previous measurement using 37 fb^{-1} 2010 data at $\sqrt{s}$ = 7 TeV [1]. The cross-section will be measured differentially in bins of dimuon mass and rapidty, as well as dimuon mass and transverse momentum. Yields are obtained via fits of the χ^2_{IP} variable, based on the method used in the Search for Dark Photons at LHCb, using templates for a prompt signal with displaced and misidentification backgrounds [2].

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Effective field theory interpretation of Higgs boson measurements at CMS

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Since the discover of the Higgs Boson in 2012, both the CMS and ATLAS experiments have shifted focus towards precision measurements of Higgs boson couplings. Such measurements provide a unique tool for probing the electroweak symmetry breaking sector of the Standard Model, effectively opening up a new window in the search for beyond-the- Standard Model physics. This has led to the advancement of techniques in both the experimental and theoretical particle physics communities, in order to better characterise the Higgs Boson.

Simplified template cross sections (STXS) provide a framework for the progression of Higgs boson coupling measurements with increasing statistics. The inclusive Higgs boson phase space is split into orthogonal regions firstly by production mode and subsequently by the kinematics of the event constituents. A measurement of the cross section in each of these phase space regions allows a more granular picture of the Higgs boson to be developed. Such measurements are being performed by the both the CMS and ATLAS experiments in all of the dominant Higgs boson decay channels.

One of the advantages of the STXS framework is that it provides a platform for the subsequent re-interpretation of results. In this talk, I will discuss an an effective field theory interpretation of STXS measurements at CMS. The Higgs effective Lagrangian is used to parametrise our lack of knowledge of the electroweak symmetry breaking sector by extending the Standard Model Lagrangian to higher orders in momentum expansion.

Initially, the status of STXS measurements at CMS are summarised. Following this, I will describe the derivation of scaling functions which model the dependence of a given region of the STXS framework on effective field theory parameters. The equations are then used to extract constraints on such parameters, by fitting STXS measurements from a combination of Higgs boson decay channels.

Analysing anode-piercing cosmic muons in ProtoDUNE-SP

Joshua Thompson

The University of Sheffield, UK

ProtoDUNE-SP is a large scale prototype of the first module of the planned Deep Underground Neutrino Experiment (DUNE) far detector which utilises liquid argon TPC (LArTPC) technology, using full size prototype DUNE components located at the CERN neutrino platform. Charged particles interacting within liquid argon generate both ionisation electrons and scintillation light; in a LArTPC the electrons are drifted to a series of wire planes which record their position and times of arrival, while light is collected by a photon detection system. Due to the surface location of ProtoDUNE-SP, a high cosmic ray flux and relatively long electron drift time restricts the ability to absolutely locate particle tracks in the drift direction. A method of matching scintillation light to reconstructed tracks allows a highly pure sample of cosmic muons which enter the detector through the anode planes to be identified. I will present a summary of this method and an analysis of anode-piercing muons tagged in this manner, which can be used to calibrate the detector response.

Towards a more precise measurement of the Q(2+) in C12: testing state-of-the-art *ab initio* theories

Juan Saiz[1], Marina Petri[1], and the J22 experiment collaboration[1,2,3,4]

[1]University of York, UK, [2]Lawrence Berkeley National Laboratory, USA, [3]University of Jyväskylä, Finland, [4]Technische Universität Darmstadt, Germany

Electromagnetic diagonal matrix elements are sensitive to the details of the nuclear inter- action and can constrain NN+3N Hamiltonians derived from chiral Effective Field Theories (EFT) used in *ab initio* calculations [1-3]. Large-scale No Core Shell Model calculations for the quadrupole moment of the 2^+ state of ^{12}C [4] show a significantly smaller uncertainty when compared to the currently adopted experimental value [5,6]. Thus, a more precise measurement of the $Q(2^+)$ provides an excellent opportunity to test, benchmark and refine these state-of-the-art *ab initio* theories.

A Coulomb excitation experiment was performed at the JYFL in Jyväskylä using a ^{12}C ion beam and a ^{208}Pb target. The aim of the experiment was to extract the quadrupole moment of the 2^+ state of ^{12}C. The Jurogam II array was used to measure the 2^+ state de-exciting γ-rays in coincidence with backward-scattered ^{12}C ions, measured with a CD Si detector. The uncertainty in the measured $Q(2^+)$ is considerably improved and will provide unparalleled testing ground for modern *ab initio* calculations. The results of the analysis will be presented as well as their impact on *ab initio* calculations using state-of-the-art interactions derived from chiral EFT.

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Search for Light Dark Matter with NEWS-G

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University of Birmingham, UK

The NEWS-G experiment is searching for light dark matter candidates using a spherical proportional counter. Light gases, such as H, He and Ne are used as targets, providing access in the mass range from 0.1 to 10 GeV. Detector operation under the required experimental conditions is demanding in terms of gas gain, intensity of the volume electric field and stability of operation, combined with a demand for low radioactivity. NEWS-G produced first results with a detector installed at LSM (France), excluding cross-sections above $4.4 \bullet 10^{37}$ cm^2 for 0.5 GeV WIMP using Ne gas. NEWS-G has constructed a full scale detector, 130 cm in diameter, made of ultra- radiopure copper, equipped with compact shielding. The commissioning at LSM and on-going installation in SNOLab (Canada) will be discussed, along with the plans for up-coming data-taking.

Measurement of the charged-current electron-neutrino inclusive cross-section on argon in MicroBooNE using the NuMI beam

Krishan Mistry

The University of Manchester, UK

MicroBooNE is a Liquid Argon Time Projection Chamber (LArTPC) located on the Booster Neutrino Beam (BNB) at Fermilab, Chicago. One of the primary goals of MicroBooNE is to measure neutrino argon cross-sections. Traditional neutrino experiments commonly use light targets such as water or carbon as the basis of their detector.

Studying the electron-neutrino cross-section on argon can help us probe the complicated nuclear effects within the nucleus which are not well understood. This will provide key information to measurements of CP- violation and searches for the sterile neutrino performed by experiments such as DUNE and SBN, respectively. MicroBooNE also receives a highly off-axis neutrino flux from the NuMI beam. This flux has an order of magnitude higher electron neutrino component (~5%) compared to the BNB and has a broad span of energy. This makes it an ideal source to study a large statistics electron neutrino on argon cross-section at MicroBooNE. This talk will cover the current status of an inclusive charged-current electron neutrino cross-section measurement on argon performed using data from the NuMI beam.

Coupling Halo EFT structure to transfer, breakup and radiative-capture reaction models: a test-case study on ^{15}C

Laura Moschini[1], Jiecheng Yang[2,3], and Pierre Capel[4,2]

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Aside from being a one-neutron halo nucleus, ^{15}C is an interesting nuclear system because it is involved in reactions of relevance for several astrophysical scenario such as inhomogeneous Big Bang models, neutron induced CNO cycles, and neutrino driven wind models for the r-process. The aim of this work is to provide good predictions for various reactions involving this nucleus, using only one structure model based on halo effective field theory (Halo EFT) [1], as it has been done for ^{11}Be [2,3,4]. First we adjust the Halo EFT potential to reproduce the one-neutron binding energy of ^{15}C ground state and its asymptotic normalization coefficient (ANC), fixed through the analysis of the $^{14}C(d,p)^{15}C$ transfer reaction at 17.06 MeV [5]. Using this description of ^{15}C, we study the breakup at intermediate (68AMeV) [6] and high energies (605AMeV) [7] using an eikonal model with a consistent treatment of nuclear and Coulomb interactions at all orders, which takes into account proper relativistic corrections [4]. Finally, we study the $^{14}C(n,\gamma)^{15}C$ radiative capture [8]. Our theoretical predictions are in good agreement with all experimental data, thus assessing the robustness of the structure model provided as well as the importance of the inclusion of relativistic corrections [9].

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Investigations of the bound and unbound states in ^{20}C

Liam Atkins[1], Stefanos Paschalis[1], Marina Petri[1], Julien Gibelin[2], Miguel Marques[2], Nigel Orr[2] For the SAMURAI DayOne collaboration

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The carbon isotopic chain is accessible experimentally up to the neutron drip line and provides a unique opportunity to study the evolution of shell structure with isospin asymmetry. Of particular interest is the proton component of the 2^+ state along the C isotopes, which can shed light to the evolution of the Z=6 spin-orbit shell gap [1,2,3,4]. We study bound and unbound states of ^{20}C following a proton knockout reaction from a ^{21}N beam, where information on the proton component of the 2^+ state in ^{20}C can be extracted. The experiment was performed at RIKEN during the DayOne campaign and the SAMURAI setup is used to investigate the structure of ^{20}C.

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Commissioning a new charge plunger device to measure the lifetimes of excited nuclear states with high internal conversion

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The charge plunger is a device that can be used to measure the lifetimes of excited nuclear states using transitions that have high rates of internal conversion. The technique [1] is a development of the standard plunger lifetime analysis technique, however, the charge state of the recoiling ions is measured rather than the Doppler shift of de-exciting recoils. A commissioning experiment has been performed in which the DPUNS plunger [2] has been adapted to function as a charge plunger.

The device consists of a target foil and a charge-reset foil. Nuclei of interest are produced through a reaction at the target in an excited state, with some velocity v. The highly converted transition of interest can occur before or after passing through a charge reset foil. After an internal conversion event, the nuclei will emit Auger electrons and be in a high charge state. If an internal conversion event occurs before the nuclei of interest passes a charge reset foil, the nuclei will gain electrons from the foil and return to a lower charge state. If, however, an internal conversion event occurs after the charge reset foil, the nuclei will remain in a highly charged state. The charge state of the nuclei must then be measured downstream of the plunger device. Measurement of the charge state distribution as a function of distance between the plunger foils can be used to determine the nuclear lifetime.

Here we present the results of the commissioning experiment for the DPUNS charge plunger device performed at the Accelerator Laboratory at the University of Jyväskylä. The charge state was deduced using the mass separator MARA [3]. The $^{32}S(^{152}Sm, 4n)^{180}Pt$ reaction was used to produce ^{180}Pt nuclei in an excited state and the lifetime of the 2^+ state was measured. This has a known lifetime and depopulates through a highly converted transition, so was a good candidate to test the charge plunger technique. The dependence of the internal conversion coefficient and fluorescence yields on the DDCM lifetime analysis approach is presented. Additionally, some potential future applications of this device will be outlined.

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Measurement of the Muon Anti-Neutrino Charged-Current Single π^- Production Cross Section on Water with the T2K Near Detector

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T2K (Tokai to Kamioka) is a long baseline neutrino oscillation experiment [1] based in Japan. The experiment consists of a neutrino beamline at the Japan Proton Accelerator Research Complex (J-PARC) and two detector complexes. The near detector complex consists of various particle detectors at multiple off-axis angles with respect to the beam. The far detector – Super-Kamiokande – is located in a mine 295km from the beamline in Gifu prefecture.

In order to better constrain the unoscillated neutrino beam, a magnetized tracking detector – the ND280 – measures the beam composition and various interaction rates at a distance of 280m from the beam target at the same off-axis angle as Super-Kamiokande.

We present the ongoing work to produce a measurement of the muon anti-neutrino cross section with a single, negatively charged pion in the final state ($\nu_\mu CC1\pi^-$) in the ND280. This will be the first measurement of this channel by T2K, and will benefit from new analysis techniques which will reduce the effects of the input model and other systematic uncertainties on the final result.

Measurements such as this will provide constraints on neutrino interaction models, as well as the associated nuclear models used for particle propagation inside the nucleus. These constraints are vital for future experiments – such as Hyper-Kamiokande [2] and DUNE [3] – to reduce model-related systematic uncertainties, and attain their sensitivity goals.

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Combined Reconstruction of Event Pairs in Gd-H_2O for Reactor Anti-neutrinos

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Inverse beta decay (IBD) interactions of anti-neutrinos in gadiated water give a correlated positron-neutron signal. We are developing a combined position reconstruction which uses information from both events to give a common IBD interaction vertex.

Gadolinium-doped water for anti-neutrino detection is an emerging technology and the WATCHMAN collaboration has proposed a Gd-H_2O detector to demonstrate a scalable application for remote reactor monitoring.

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 fit improves position resolution. This is expected to lower the threshold energy for detection compared to a single-event fit. Reconstructing pairs helps reject random coincidences of uncorrelated radioactive background events and a method of pair selection is being developed to discriminate optimally between the signal and background for more powerful background reduction.

This talk presents the current status of the IBD pair reconstruction and plans for further development.

Electromagnetic Transition Rates in ^{22}O

Luke Tetley and Marina Petri for the ANL #1732 collaboration

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The lifetime of the first 2+ state of the neutron-rich ^{22}O isotope will be directly measured for the first time at Argonne National Laboratory (ANL). Using the state-of-the-art tracking gamma-ray detector GRETINA coupled to the Fragment Mass Analyser (FMA), the lifetime will be measured by the Doppler Shift Attenuation Method (DSAM). The ^{22}O will be produced via the two proton exit channel of the fusion evaporation reaction of a radioactive ^{14}C beam on a ^{10}Be target attached to a carbon backing. The electromagnetic transition strengths extracted from this lifetime measurement will be useful in refining the chiral interactions used in various many-body methods. In this contribution, I will describe the development and characterisation of the radioactive ^{10}Be target, as well as presenting the expected sensitivity of the lifetime measurements, as studied via simulations.

Derivation of the Tau Fake Factors using the Universal Fake Factor method and development of the Tau Fake Factor Tool at the ATLAS experiment

Mario Grandi

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Hadronically decaying tau leptons (referred as t_{Had}) are important final-state components in both Standard Model and Beyond Standard Model processes being studied at the ATLAS experiment, but are unique with respect to the other charged leptons in their hadronic decay modes [1-2]. Hadronically decaying tau leptons are normally indicated as τ_{Had}. Understanding how well tau-leptons are identified in data and Monte Carlo simulations, and more importantly, how many hadronic jets 'fake' the tau-identification, is crucial in any final state event with taus, because it can have a large impact on the difference between the number of expected and observed τ_{Had} in an event. When reconstructing the final-state event objects at the ATLAS detector, a large number of jets are misidentified as τ_{Had} [3]. In this talk, I will discuss one of the methods studied by the ATLAS experiment to estimate the jets faking tau leptons called 'fake factor (FF) method'. The FF is a data-driven correction factor applied to data in order to estimate the jet-originating fake-τ background in a particular region enriched in well reconstructed tau events (the 'Signal Region (SR)'). In principle, this correction factor depends on whether the jet-faking tau is originating from a quark or gluon jet and it's also dependent on the considered SR. It is possible to show that the dependence of quark and gluon-initiated jet composition in an arbitrary region may be derived from the fake factor of a pure quark and pure gluon sample. The tool being developed by a dedicated task-force within the ATLAS experiment, of which I am one of the main analyzers, derives the quark fraction using a template fit for a given region that is orthogonal in the level of tau-identification to the SR of interest and interpolate between quark and gluon abundant regions to derive the fake factor. The quark and gluon fractions are found both in data and in simulations, using Z+jets and multi-jet regions respectively, to provide two working methods for the tool to derive the fake factors. The current status of the development and functionality of the method and tools as well as results will be discussed.

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[3] ATLAS Collaboration, Eur. Phys. J. C **76**, 295 (2016)

Impact of $low p_T$ b-tagging techniques in the search for new physics in final states with high E_T^{miss} and b-hadrons.

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Compressed supersymmetric scenarios, where the mass difference between the scalar top/bottom $(\tilde{t}/\tilde{b})$ and the lightest supersymmetric particle $\tilde{\chi}_1^0$ is $\Delta m\left(\tilde{t}/\tilde{b}, \tilde{\chi}_1^0\right) \leq 20GeV$, are favoured by, e.g., models of electroweak baryogenesis. Scalar top and bottom may be pair produced at the LHC, and then decay through $\tilde{t}/\tilde{b} \rightarrow t/b\tilde{\chi}_1^0$. These scenarios are not easy to be investigated because the p_T of the b-hadrons is too low to be identified by the standard b-tagging: searches for the exclusive decay $\tilde{b} \rightarrow b\tilde{\chi}_1^0$ with the ATLAS detector have been so far very sensitive for large $\Delta m\left(\tilde{b}, \tilde{\chi}_1^0\right)$, but less so to compressed models. To investigate these topologies, we developed a dedicated technique to identify low p_T b-hadrons generated in the compressed regime. We will present an overview of the algorithm definition and performance, together with its impact on the $\tilde{b} \rightarrow b\tilde{\chi}_1^0$ searches with $139fb^{-1}$ with the ATLAS detector.

Mixing and CP violation in D0->KSpipi at the LHCb detector

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[1]University of Manchester, UK

A presentation is made of the measurement of the mixing parameters of the D0 meson using D0->KSpipi decays at the LHCb detector.

Mixing is the time-dependent phenomenon of a neutral meson changing into its antiparticle and vice versa. This occurs because the mass eigenstates are linear combinations of the flavour eigenstates. In the Standard Model, mixing occurs via the exchange of W bosons and heavy quarks. However, new virtual particles may contribute to the amplitude, changing the oscillation rate. Therefore any deviation from Standard Model predictions may be a hint of new physics. These time-dependent oscillations are governed by the mixing parameters *x* and *y, analogous to the mass and decay width differences in the corresponding B sector.*

The self-conjugate decay D0->Kspipi is considered the 'Golden Mode' as it offers access to both the Cabibbo favoured and doubly-Cabibbo suppressed decays in the same mode. Therefore the flavor-oscillated decays can be separated due to the rich resonant structure of the Dalitz plane of this channel. The decay time and phase-space of the D0->KSpipi decay is influenced by meson-antimeson oscillations and differences between matter and antimatter. These are characterised by the parameters *x*, *y*, *q/p* and *phi*. The D0->KSpipi decay offers direct access to these parameters by a time and phase-space dependent amplitude fit.

The signal model consists of resonant and non-resonant components and a background model is derived from a data-driven approach. To perform this fit we also need a detailed understanding of how the detector and selection requirements influence the decay-time and phase-space leading to non-uniform efficiencies and a finite decay-time resolution. These inputs are derived from simulation.

The fit model is built using GooFit, a fitting framework for time-dependent amplitude fitting which can be run efficiently on GPUs.

I will present the data selection, the inputs derived from simulation and some initial toy studies and fit validation using GooFit.

Towards a measurement of the W boson mass with the LHCb experiment

Martina Pili

University of Oxford, UK

Global fits to precision electroweak observables are a powerful probe of physics beyond the Standard Model. The W boson mass (mW) is particularly interesting because its indirect determination from global electroweak fits is more precise than its direct measurement. The Large Hadron Collider, in particular, is a challenging environment in which measure mW. LHCb is a single-arm spectrometer with full charged particle tracking and identification capabilities in a phase space region complementary to ATLAS and CMS. It has been previously suggested that a measurement of mW with the LHCb experiment would have a significant impact in an LHC combination. We will present the current status of the W mass measurement with LHCb, with an overview of the preliminary work that has been done and current and future challenges towards the completion of the measurement.

ANNIE: The Accelerator Neutrino-Nucleus Interaction Experiment

Matthew Malek

The University of Sheffield, UK

The Accelerator Neutrino-Nucleus Interaction Experiment (ANNIE) will measure cross- sections and neutron yield for muon neutrino interactions on water, whilst also serving as an R&D testbed for advanced detection technologies.

The experiment consists of three detectors; in sequence along the beam axis, these are:

- an upstream array of scintillator paddles that will act as an active veto for entering events,
- a 26 tonne gadolinium-loaded water Cherenkov detector. The water volume serves as the neutrino target, with gadolinium loaded in a 0.2% $Gd_2(SO4)_3$ solution that enhances neutron capture, and
- a downstream iron + scintillator muon range detector (MRD) used to identify low-Q^2 forward-going events and reconstruct their energy.

This suite of detectors is located along the axis of the Booster Neutrino Beam (BNB) at the Fermi National Accelerator Laboratory in the United States. The experimental hall is 100 metres downstream from the BNB target.

ANNIE began taking neutrino data in early 2020, with first physics results expected by the end of the year.

In addition to its core physics measurements, ANNIE will be used to evaluate new detector technologies. These include the first use of the micro-channel plate based imaging photosensors known as ‘Large-Area Picosecond Photo-Detectors’ (LAPPDs), and the first measurements of a Gd-loaded water Cherenkov detector in a neutrino beam. Future plans include deployment of a 500 litre volume of water-based liquid scintillator within the detector. These technology demonstrations will be of use to next-generation neutrino experiments, such as Hyper-Kamiokande, Theia, and WATCHMAN.

Iterative gaussian process emulation for learning energy surfaces for the inner crusts of neutron stars

Matthew Shelley and Alessandro Pastore

University of York, UK

The neutron star equation of state (EoS) plays a crucial role in determining the properties of a neutron star, both static and dynamics. The latter has recently received significant attention due to the “multi-messenger” detection of a neutron star merger [1].

An important component of the EoS is its low-density part, which represents the crust region. In this, we expect finite nuclei, embedded in an electron gas (the outer crust), or in electron and neutron gases (the inner crust). Determining the proton numbers (Z) of these nuclei at a given density in the inner crust is typically done by performing an energy minimization at beta equilibrium for different values of Z. This has been a longstanding problem in nuclear physics [2], partly because of the computational burden of the calculations. This energy minimization must be performed across the density range of the inner crust, thereby creating a two-dimensional energy surface. The determination of this surface requires significant computational time.

Gaussian Process Emulation (GPE) is a regression method from machine learning, with a wide range of applications in nuclear physics, and in many other scientific domains. Its main purpose is to emulate the output of a complex, time-consuming computer program, providing both a good approximation of the output, and associated uncertainties.

We have already successfully applied GPE to the emulation of the inner crust energy surface [3,4], made with nuclear energy density functional calculations. Here I will show an iterative version of GPE for learning the energy surface, building on previous work [3,4,5]. We use here semi-classical calculations with the Thomas-Fermi approximation, including corrections for shell and pairing effects. With iterative GPE, we can dramatically reduce the number of calculations needed to determine the composition of the inner crust. This will enable us to expand our investigations into the structure, by including temperature effects and by using fully microscopic calculations.

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First Experimental Campaign of the EMMA Recoil Mass Spectrometer

Matthew Williams (On behalf of the EMMA & TIGRESS Collaboration)

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The electromagnetic mass analyser (EMMA), located at the TRIUMF-ISAC facility [1], is a new recoil mass spectrometer designed to separate the products of nuclear reactions from the unreacted beam, and disperse them according to their mass/charge ratio onto detectors at the focal plane [2]. Utilizing EMMA allows for beam rejection at zero degrees and the ability to select weak reaction channels in the presence of high background. Last year, EMMA was successfully integrated with the TIGRESS γ-ray spectrometer [3], following a significant upgrade of the TIGRESS data-acquisition system to a free running trigger-less system first developed for the GRIFFIN spectrometer [4]. After concluding initial testing of the combined set-up over summer 2019, the first EMMA experiments were conducted in September and December 2019. The first of these experiments, ^{83}Rb(p,γ)^{84}Sr, was the first time that a supernovae reaction has been performed directly with a radioactive ion beam. The background suppression provided by EMMA was critical in discerning γ-rays emitted from the decaying ^{84}Sr produced in the reaction. The second experiment, an alpha transfer study on ^{17}O, was the first time utilizing charged-particle, γ-rays and heavy-ion triple coincidences at EMMA. Here we used the ^{17}O(^{7}Li,t)^{21}Ne reaction to study states in ^{21}Ne that contribute to the ^{17}O(α,γ)^{21}Ne reaction. The competition between the aforementioned reaction and $^{17}O(\alpha,n)^{20}Ne$ is important for determining the role of ^{16}O as a light element neutron poison for the weak s-process [5]. Preliminary results from these first experiments will be presented alongside an overview of the facility and future planned experiments.

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Search for long-lived slepton production in events with displaced leptons in √s=13 TeV *pp* collisions with the ATLAS detector

Melissa Yexley

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This talk will focus on a search for the production of long-lived sleptons using events containing two displaced, opposite sign muons with no requirement that the leptons originate from the same vertex. The analysis makes use of data collected by the ATLAS Experiment in 2015-2018, corresponding to a total integrated luminosity of √s = 139 fb −1. The results of the analysis will be interpreted in the context of SUSY-inspired simplified models with direct slepton (£˜) production, with direct decays to lepton (£) + gravitino (G˜).

Three-Nucleon Force Contribution to Deuteron-Target Potential in (d,p) Transfer Reactions

Michael Dinmore, Natasha Timofeyuk, and Jim Al-Khalili

University of Surrey, UK

Deuteron breakup is known to be important for (d,p) reactions. We point out, for the first time, that a new term arises in the effective deuteron-target potential from the three-nucleon (3N) interaction between the neutron and proton in the deuteron and one of the target nucleons.
We estimate the importance of this term within Watanabe and ADWA models using a hypercentral 3N force with a strength fixed by chiral effective field theory at next-to- next-to-leading order [1], varying the range of this interaction.
We present the astrophysically important 26Al(d,p)27Al reaction as an example. In our calculations we used a N2LO model deuteron wavefunction and different target density profiles for several parameterisations of nonlocal nucleon-target optical potentials. Our results are strongly dependent on 3N interaction range, and, given the importance of regularisation to 3N potentials, they show that (d,p) reactions can be a useful tool in tuning models of the 3N force.

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Looking for Boosted Higgs decaying to two b-quarks in events with an associated jet at ATLAS

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The most common decay of the Higgs is to two b-quarks, making it an invaluable tool to gain further insight into the properties of the Higgs boson and probe for any shortcomings of the Standard Model.

The high transverse momentum requirements of ATLAS jet triggers constrain the selection of the b- quark jet decays of the Higgs.

In this topology, the boost gives the Higgs decay products enough energy to pass the triggers, and makes them collimate into a single large-radius jet with a distinct two-pronged structure, which combined with b-tagging techniques, can be used to reduce the QCD backgrounds significantly.

This signature is also sensitive to BSM physics. At high transverse momentum, the Higgs boson production cross-section through gluon-gluon fusion is sensitive to the presence of BSM couplings, and this final state can be used to perform a search for dark matter mediator particles decaying to a pair of b-quarks.

The first ATLAS results of this search have been published [1].

[1] *Search for boosted resonances decaying to two b-quarks and produced in association with a jet at √s = 13 TeV with the ATLAS detector*, Tech. Report ATLAS-CONF-2018-052, CERN, Nov 2018, url: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2018-052/

$\boldsymbol{d}^*(\mathbf{2380})$ 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.

Spectroscopic factors from Source Term calculations with effective 3N interactions

Natalia Timofeyuk

University of Surrey, UK

The Source Term Approach (STA) makes it possible to restore overlap functions for one-nucleon removal reactions using the simplest nuclear many-body models while at the same time accounting for nucleon-nucleon correlations via effective interactions of the removed nucleon with the rest. In particular, the STA can explain the reduction of spectroscopic factors (SFs) while using the same shell model that overestimates the experimental removal cross sections [1]. Thus, the STA explains the SF reduction in double-closed-shell nuclei in a universal way, from 4He to 208Pb, while assuming the simplest possible shell-model structure of these nuclei [2]. The STA also provides reasonable agreement between theoretical and experimental asymptotic normalization coefficients (ANCs) for 0p-shell nuclei [3]. However, it is well-known that using minimal model spaces in many-body calculations necessarily leads to the appearance of induced effective three-nucleon (3N) forces. In this talk I will discuss effects due to including the 3N force on spectroscopic factors for double-closed shell nuclei and its influence on the asymmetry in the SF reduction.

[1] N.K. Timofeyuk, Phys. Rev. Lett. 103, 242501 (2009)

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Spin Correlations in top quark pairs

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According to the Standard Model of particle physics the top quark is one of the fundamental building blocks of matter in our universe. Discovered in 1995 by the DØ and CDF experiments in the USA [1,2] the top quark is the most massive elementary particle and as such provides an important and unique window into possible new physics. Often produced in pairs consisting of one quark and one antiquark, top quarks decay in about 10^{-24} seconds after their production. To study the behavior of such short-lived particles one must investigate their decay products, the statistical properties of which are precisely predicted by the Standard Model.

The top quark is a spin ½ "fermion" and the spin directions of pair produced top quarks are correlated according to the Standard Model. Any discrepancy from these predictions could point to new physical processes taking place in their production or decay. The so-called spin 'correlations' and 'polarizations' are however non-trivial to measure. The reason being that a direct measurement of a top quark's spin direction is impossible with the modern detectors at particle colliders like the Large Hadron Collider where top quark pairs are produced in abundance. Instead one must analyse the statistical distributions of the top quark's flight direction and combine the information with the flight direction of the top quark's decay products. The determination of the top quark flight direction requires the reconstruction of the top quark from the particles into which it decays, this is made problematic by the undetectable nature of some of the decay particles.

The decay of top quarks into leptons describes a very 'clean' environment but the associated production of two undetectable neutrinos means that putting the decay products back together to reconstruct the 'parent' top quark requires a degree of guess work. The guessing involved in essence determines the accuracy of the measurement. This talk and/or poster will present the methods used to reconstruct the top quarks in the face of vital missing information; the theoretical combination of observables needed to produce the spin correlation and polarization measurements; and the results of on going efforts to side step the top quark reconstruction all together using machine learning and access the spin correlations and polarization directly from the high-level information available from observing proton-proton collisions at 13 TeV with the ATLAS detector at CERN.

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Searches for heavy neutral lepton production and lepton number violation in kaon decays at the NA62 experiment

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Searches for heavy neutral lepton production in K+ --> e+N and K+ --> mu+N decays using the data set collected by the NA62 experiment at CERN in 2016-18 are presented. Upper limits on the elements of the extended neutrino mixing matrix $|U_{e4}|^2$ and $|U_{\mu4}|^2$ are established at the levels of 10^{-9} and 10^{-8}, respectively, improving on the earlier searches for heavy neutral lepton production and decays in the kinematically accessible mass range. Improved upper limits on the lepton number violating decays of the charged kaon obtained using the NA62 data are also presented.

Investigating strange particle production at √s_NN = 8.16 TeV with ALICE at the LHC

Oliver Jevons

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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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Thallium Bromide as a Room Temperature Gamma-ray Detector

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[1]University of Liverpool, UK, [2]CapeSym, USA

Gamma ray spectroscopy is a common assay method used in the identification and characterisation of radioactive samples at nuclear sites as it can be used to extensively survey, identify and assess the magnitude of waste in contaminated areas of such facilities. Thallium Bromide (TlBr) is a wide band gap semiconductor with excellent physical properties for gamma ray detection. These include large bulk resistivity (1010-1011Ωcm), composition from and high atomic number elements (ZTl=81, ZBr=35) and a large density of 7.56 g/cm3, which leads to high gamma ray stopping power. In addition, the ease of growing TlBr from melt ensures that it is a cost effective competitor to existing materials such as CZT.

Having said this, the long-term performance of these sensors is inhibited by the degradation of the device through ionic polarization of the crystal and subsequent reaction of bromine with the electrode materials. At room temperature, this degradation ultimately leads to device failure which is typically mitigated by either cooling the detectors or periodically reversing the bias. However, neither of these techniques extend the lifetime of the devices indefinitely and require extra electronics as well as downtime in which the detector cannot be used. Previous studies by CapeSym [1] demonstrate that by using metal oxide contacts rather than the typical Noble metals results in low noise, stable and long-term functionality under unidirectional bias. To this end, X-ray photoelectron spectroscopy (XPS) studies in addition to radiometric evaluation of the detectors are currently underway to assess and quantify the role of metal oxide contacts in extending the performance and life of TlBr detectors.

The expected outcome of this work is the development of a novel portable gamma ray sensor with significantly reduced counting times and improved isotope identification compared to existing technologies. In this presentation, the fabrication methodology and first experimental studies of TlBr detectors will be reported on. This will be discussed in the context of manufacturing TlBr for in-situ detection of gamma rays.

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Search for Heavy Neutral Leptons in the MicroBooNE LArTPC

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Heavy Neutral Leptons (HNLs) offer an extension of the Standard Model which provides an explanation for the origin of the small neutrino masses. HNLs with masses up to 493 MeV can be produced from meson decays in the high-intensity Booster Neutrino Beam, via mixing with the active neutrino flavours. These particles would then travel to the MicroBooNE detector where some fraction would decay in-flight to detectable Standard Model particles. This talk presents the first search for these particles in a liquid argon time projection chamber (LArTPC). A number of methods are used to distinguish the HNL decays from the neutrino and cosmic ray background including utilising the time of flight of the massive HNL with respect to the active neutrinos. As the first search of its kind in a LArTPC this work pioneers techniques applicable for large scale searches in both the upcoming full Fermilab Short Baseline Neutrino program and the future DUNE near detector.

MALTA: A Radiation Hard Depleted Monolithic Active Pixel Sensor for Particle Physics Applications

Patrick Freeman

CERN, Switzerland

MALTA is a depleted monolithic active pixel sensor in TowerJazz 180nm CMOS technology designed with a to meet the radiation specifications (1e15 neq/cm2) of the outer pixel layers in the proposed ATLAS Inner Tracker. The pixel has a small capacitance collection electrode (~3 fF), low noise (20 e), fast signal response (25 ns), and the chip has an asynchronous readout architecture for high data rates. We present preliminary test beam and laboratory results with devices produced on 300 um thick high-resistivity Czochralski silicon and irradiated up to 2e15 neq/cm2. These devices feature the n- gap and extra-deep p-well substrate modifications previously studied in the miniMALTA prototype.

The 28Mg(d,p) measurement at the ISOLDE Solenoidal Spectrometer

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Singe-particle structure has been observed to evolve away from stability. The ordering and separation between levels varies to the extent that the established magic numbers change. For example, in the neutron-rich region where Z=8–20, the N=20 shell closure weakens, with a new closure emerging at N=16 in 24O [1]. Low-lying negative-parity intruder states are symptomatic of this region. In order to understand the evolution of these shell closures, and provide robust data for the development of shell-model interactions, it is crucial to measure the single-particle properties of nuclei in this region. Historically, shell-model calculations have struggled to describe these states, due to a lack of data on properties of these states, and in particular the negative-parity states.

Single-particle transfer reactions are an ideal probe of the single-particle properties of nuclei. Away from stability, it is necessary to perform them in inverse kinematics using radioactive ion beams. Here we present a measurement of the 28Mg(d,p)29Mg reaction, probing the single-particle properties one neutron outside N=16, in 29Mg. Cross sections, excitation energies, and angular momenta for the observed nuclear states were extracted, and spectroscopic factors were deduced. These data can then be used to test new shell-model interactions developed to better describe this region of the nuclear chart [2,3].

This marks one of the first experiments using the new ISOLDE Solenoidal Spectrometer, a helical-orbital spectrometer based on HELIOS at Argonne National Laboratory [4]. Solenoidal spectrometers such as these are well-suited for studying transfer reactions in inverse kinematics, because they are able to remove unwanted kinematic effects that limit the resolving power of tradional fixed-angle spectrometers [5].

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Studying neutron structure via pi0 meson production in electron scattering off the deuteron at Jefferson Lab

Paul Naidoo and Daria Sokhan for the CLAS12 collaboration

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General Parton Distributions (GPDs) describe spatial and momentum distributions of partons inside hadrons. They relate the longitudinal momentum fraction of quarks and gluons to their transverse position, offering a way of imaging nucleons through 3D tomography. Additionally, GPDs encode information on the composition of nucleon spin and mechanical properties of the nucleon such as pressure and shear forces [1]. They can be accessed experimentally in processes such as Deeply Virtual Compton Scattering (DVCS) and Deeply Virtual Meson Production (DVMP), where a high energy electron scatters from a quark inside a nucleon and a high energy photon or meson is produced as a result [2,3].
Up until recently, analyses of DVCS and DVMP have been primarily carried out with proton-target experiments due to the relative simplicity of an H_2 target and the need for an exclusive reconstruction of the final state. As such, data on the neutron is sparse. Not only are measurements on the proton and neutron complementary, but they are necessary to facilitate access to the full set of GPDs and to enable their flavour separation [2].
Jefferson Lab has recently completed its upgrade, now delivering electron beams up to 11 GeV to fixed target experiments in halls A, B and C. Hall B houses the new, large-acceptance CLAS12 detector array optimised for measurements of DVCS and DVMP in the newly accessible kinematic regime. To enable exclusive reconstruction of DVCS and neutral-meson DVMP from a neutron target, a dedicated detector for recoiling neutrons -- the Central Neutron Detector (CND) -- was integrated into CLAS12. We present a preliminary look at the analysis of pi0-DVMP off a neutron with data from the first CLAS12 deuteron-target experiment.

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The role of the nuclear surface energy in collisions and resonances

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A recent set of effective interactions of the Skyrme type has been developed [1] in which the value of the surface energy is systematically varied in the fitting process.

The surface energy is one of the coefficients of the most basic form of the Bethe–Weizsäcker semi-empirical mass formula, and as such its value is a basic characteristic of nuclear matter.

By systematically using the set of interactions in which the surface energy is varied in calculations, one can study the effect that the surface energy has on different observables. In the original paper by Jodon [1], large effects were seen in e.g. the large deformations associated with the fission landscape.

Here, we use these forces in time-dependent calculations to understand the effect of the surface energy on dynamics, in nuclear fusion reactions to see the effects on the Coulomb barrier [1] and cross sections, and in giant resonances to see the effect that surface energy has on modes in which surface vibrations may be expected. The underlying effect of the interactions on the ground state structure is also discussed.

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Studying Long-Lived Particles with the proposed CODEX-b detector

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To date after many rigorous tests of the Standard Model (SM) no definitive example of physics Beyond the Standard Model (BSM) has been found, so signature-based searches should be considered. One set of these type of BSM models which are currently difficult to detect at the Large Hadron Collider (LHC) is long-lived particles (LLPs). LLPs have a large possible range of lifetimes or masses that are not covered by current experiments.

The COmpact Detector for EXotics at LHC-b (CODEX-b) has been proposed to be installed in the DELPHI/UXA cavern near to LHC-b to aid the search for LLPs. It is predicted to provide good coverage for a variety of models including Axion-like particles, Heavy neutral leptons, and an Abelian Hidden Sector. The current timeline would be to install a demonstrator unit (CODEX-β) during Run 3 and install the full detector in two stages: before and after Run 4 [1].

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Advances towards the measurement of gamma transitions from cluster states in light nuclei

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Alpha clustering in light nuclei has been thoroughly studied by looking at the emission of charged particles. In this work we study this phenomenon by searching for gamma transitions between clustered states, which can provide information on the collectivity in order to assign states to rotational bands.

Above the alpha-emission threshold, the gamma-to-alpha branching ratio is especially low in light nuclei as particle decay dominates. To be able to measure gamma transitions therefore requires a high precision measurement using alpha-gamma correlations.

We present data from the 12C(alpha,alpha)12C* reaction. We investigate alpha-gamma coincidences from the decay chain by using the experimental set-up BALTI (Birmingham Array LaBr3 Timing) at the Birmingham MC40 cyclotron facility, which combines a series of scintillators along with a DSSD (Double-sided Silicon Strip Detector) array.

An overview of the MARA Low-Energy Branch

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The MARA low-energy branch (MARA-LEB) [1,2] is a novel facility currently under development at the University of Jyväskylä. Its main focus will be the study of ground-state properties of exotic proton-rich nuclei employing in-gas-cell and in-gas-jet resonance ionisation spectroscopy and mass measurements of nuclei close to the $N=Z$ line and of particular interest to the astrophysical rp process [3].

MARA-LEB will combine the MARA vacuum-mode mass separator [4] with a gas cell, an ion guide system and a dipole mass separator for stopping, thermalising and transporting reaction products to the experimental stations. The gas cell has been designed and built based on a concept developed at KU Leuven [5].

Following extraction from the cell the ions will be transferred by radiofrequency ion guides and accelerated towards a magnetic dipole for further mass separation before transportation to the experimental setups [6]. Laser ionisation will be possible either in the gas cell or in the gas jet using a dedicated Ti:Sapphire laser system and will provide reliable experimental data on the ground-state properties of exotic isotopes close to the $N=Z$ line.

Mass measurements will be achieved through a dedicated radiofrequency quadrupole cooler and buncher and a multiple-reflection time-of-flight mass spectrometer [7] which will be developed for the facility. These devices will allow for mass measurements of several isotopes with high impact on the rp process and which could be used as test grounds for state-of-the-art nuclear models.

In this presentation we will discuss the scientific capabilities of the MARA-LEB facility and give an update on its current status.

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Self-Consistent Green's Functions computation on radius and charge distribution up to A=140

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The last few decades in nuclear structure theory have seen a rapid expansion of ab initio theories, aiming at describing the properties of nuclei starting from the inter-nucleonic interaction. Limited for a long time to very light nuclei, they are now able to access nuclei with up to A ~ 100 particles. Such an expansion relied both on the tremendous growth of computing power and novel formal developments, with methods scaling polynomially with the number of particles.

Ab initio methods are nonetheless now confronted with new limitations in terms of mass range, stemming both from storage and computing needs growing with the size of the studied nucleus, as well as deficiencies of the used nuclear interactions, some of which struggle at reproducing nuclear properties from the calcium isotopic chain onwards. Recently, new interactions have been proposed that aims at addressing such shortcomings.

Here we present the first ab initio calculations for open-shell nuclei past the tin isotopic line, focusing on Xe isotopes as well as doubly-magic Sn isotopes, using the NNLOsat interaction and the self-consistent Green's function method. We reproduce experimental charge radii and predict its value for 100Sn. We additionally reproduce the experimental cross-section obtained at SCRIT for 132Xe. This paves the way for studies of radii and density distributions at the limits of the present ab initio mass domain.

Measurement of RK with the full LHCb dataset

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Recent measurements of b-hadron decays involving leptons are in tension with the Standard Model (SM). Each of these so-called B 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
$R_K = B(B^\pm \to K^\pm \mu^+ \mu^-)/B(B^\pm \to K^\pm e^+ e^-)$. Its sensitivity to lepton flavour universality leads to a very precise theoretical prediction. The world-leading experimental result from LHCb [1] is 2.5 standard deviations away from its SM prediction, however twice as much data is available at the moment. An update of this measurement is underway, and will enhance the experimental sensitivity by an estimated factor of 40%, thus improving our understanding of the B anomalies. This talk will cover the status of the update, with emphasis on techniques to overcome various challenges faced by measurements such as R_K at LHCb.

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Theragnostics - The Production of Terbium at the University of Birmingham

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B. Russell[2], B. Webster[2], P. Regan[2,3], D. Cullen[4], S. Pells[4], A. Robinson[2], S. Pirrie[1], P. Santa Rita[1] A. Turner[1]

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Theragnostics (or theranostics) is the combination of both sides of Nuclear Medicine; therapy and diagnostic imaging. Initially two different elements were used for a theragnositc style of cancer treatment; ^{177}Lu as a β-therapy isotope and ^{68}Ga for PET (positron emission tomography) imaging. However, in the last 8 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 proven by C. Müller et al. [1,2,3,4].

Currently MEDICIS, 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 last year at the INPC, 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.

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Investigation of Isospin Symmetry Breaking in the f7/2 Region, via One-nucleon Knockout Reactions to 48Fe and 48Ti

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Isospin symmetry is related to the charge symmetry and charge independence of strong interactions of the same isospin T. In the absence of isospin breaking interactions, one would expect 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 ɣ- rays spectroscopy experiment has been performed to identify new excited states in the exotic proton-rich nucleus A = 48(TZ = -2) 48Fe and its mirror nucleus (TZ = +2) 48Ti in the f7/2 shell, produced via one-nucleon knockout reactions using A1900 fragment separator, and Gamma-Ray Energy Tracking In-Beam Nuclear Array (GRETINA) with the S800 spectrometer at the National Superconducting Cyclotron Facility (NSCL). This work is based on the mirror symmetry study of one- nucleon knockout reactions to the A = 53 (TZ = 3/2) mirror nuclei by S. A. Milne et al. [4]. The aim is to investigate Isospin symmetry through the examination of analogue spectroscopic factors in mirrored knockout reactions in a weakly bound system. In this work, a preliminary excitation energy spectra of 48Fe by comparison to its mirror nuclei 48Ti will be presented.

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Development of a computational tool to automate the running of Talys and EMPIRE nuclear reaction codes for rapid comparison in isotope production

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Nuclear reaction codes such as Talys and EMPIRE are used extensively to simulate nuclear reactions within nuclear physics, outputting cross-sections, a valuable metric used to determine production yields. These codes have become a staple in optimising reactions within the isotope production community, for both medical and industrial applications. These data allow the optimum energy and irradiation time to be determined - maximising the yield of the desired product, while minimising the production of by-products.

This work aims to greatly reduce the time required to run simulations and compare reactions through automation. A computational package has been developed, written in python to interface with these nuclear reaction codes, running and comparing any number of required reactions. Taking just a short string of the reaction, eg: 'natMo-a', and an energy range,
eg: ' 0-40'(MeV). The code will automatically write an input file, run the code and extract the data into a convenient .csv format.

The cross-sections against energy, yield against irradiation time and activity following a given period of radiative cooling are given for each reaction. These may be conveniently overlaid and compared either using an inbuilt plotting tool or numerically.

The project is now in its final stages, with future work focusing on reparameterising of the model. Reaction parameters, such as level densities, may be iterates over a range of values.
Work will also focus on the automation of fitting the reaction models to experimental cross-section and yield data. For a given set of experimental data points, the code would
reparamaterise the model, minimising the function of the simulated data to the experimental. The optimum parameters may then be extracted in a .csv format.

Testing lepton flavour universality in semileptonic B-decays to a dibaryonic final-state at LHCb

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A number of anomalous results in semileptonic B decays have recently generated a considerable amount of interest. The measurements of the so-called R(D) and R(D*) observables at both the LHCb experiment and at the b-factories BaBar and Belle hint at a violation of lepton flavour universality. These observables are a ratio of branching fractions between decay modes with a different flavour of leptons. This work presents the status of an analogous measurement of the ratio of muon and tau branching fractions in the decay ppℓνℓ, R(pp), which will serve as a probe of the flavour structure of any new physics.

Measurement of the Muon Neutrino Charged-Current Single Positive Pion Cross Section on Water with the T2K Near Detector

Sam Jenkins

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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 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 can 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.

Addressing Domain Adaptation Issues When Using Convolutional Recurrent Neural Networks as an Event Classifier for VERITAS and the Cherenkov Telescope Array

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Recent simulation results have shown Convolutional Recurrent Neural Networks (CRNNs) to be a very promising method of event classification for arrays of Imaging Atmospheric Cherenkov Telescopes such as H.E.S.S. [1]. Development of such new techniques is important for the analysis of future Cherenkov Telescope Array (CTA) data [2]. However, it is clear that differences between simulations and observations can confuse the classifier when testing. We explore these issues with the current VERITAS array, and describe how we used both a novel simulation approach and a Bayesian Hyperparameter Optimization deep learning technique to obtain the first significant detection of the Crab Nebula using a CRNN classifier.

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Monte Carlo simulation of a multilayered Compton camera for prompt gamma imaging for range verification in proton therapy

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The Gamma Ray Imager (GRI+) developed at the University of Liverpool is investigated for its suitability for range verification of Proton Therapy (PT). The verification is done by imaging the prompt gamma emissions (PG) during treatment; which provides an online method for proton range verification[1]. The PG emitted following inelastic scattering of the proton off target nuclei are in the high energy region ranging from 2 to 10 MeV. GRI+ consists of three layers of semiconductor detectors employing Compton kinematics for the detection of high energy gamma rays. The simulation will be tested against measurements at Clatterbridge Cancer Centre (CCC), where 60 MeV proton beam is used for treatment of eye cancer, and is aimed to be applicable at higher proton beam energies.[2]

This abstract is for an oral presentation at the Nuclear Physics Conference, discussing the work done towards the development of a Monte Carlo simulation application for the GRI+. This simulation study will aim to evaluate the performance of the system in a clinical setup at CCC.

Previous investigations of the system's imaging efficiency and imaging resolution of a point source of 1836 keV energy were presented at the IEEE 2019 conference [3]. The imaging efficiency was estimated to be $9*10^{-5}$ for a 1836 keV gamma ray from a point source Y^{88} placed at 10 cm. The simulation was validated against experimental measurement in the laboratory. Preliminary results will be presented.

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Search for Contact Interactions using 139 fb^{-1} of pp collision data collected at $\sqrt{s}$=13 TeV with the ATLAS detector

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A search for new physics with non-resonant signals in dielectron and dimuon final states in proton-proton collisions at the Large Hadron Collider (LHC) in the mass range above ∼2 TeV is presented. The data, corresponding to an integrated luminosity of 139 fb^{-1}, were recorded by the ATLAS experiment at a centre-of-mass energy of $\sqrt{s}$=13 TeV during Run 2 of the LHC. The physics benchmark model is a two-quark and two-lepton contact-interaction, which would enhance the dilepton event rate at the TeV mass scale. To model the contribution from background processes a functional form is fitted to the dilepton invariant-mass spectra in data. This is done in a low-mass control region, while the function is extrapolated to several high-mass signal regions where an enhancement of signal events is expected above the background processes. The multi-jet and W+jets processes in the dielectron channel are estimated from the data using the Poisson likelihood implementation of a technique known as the 'Matrix Method'. A limit on the number of events in the signal regions is provided along with signal efficiencies for several different contact-interaction models. In addition, upper limits are also placed on the signal rates (cross-section times branching ratio) in the signal regions.

Beam flux measurements in the T10 test beam area at CERN for a High Pressure Time Projection Chamber beam test

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A High Pressure Time Projection Chamber (HPTPC) is under consideration as a component of several future long baseline neutrino experiments [1]. This technology is favoured due to the low energy threshold required for charged particles to produce a track (< 10 MeV of kinetic energy for a proton in Argon at 10 bar [2]). This low particle energy threshold and low density compared to liquid argon allows accurate identification of final state particles in neutrino interactions which is an essential factor in reducing systematic uncertainties for future long baseline neutrino oscillation experiments.

A prototype HPTPC has been constructed at Royal Holloway, University of London. In August & September 2018 a beam test was conducted with this HPTPC in the T10 beamline at CERN with the aim of making measurements of the proton-argon cross section at proton kinetic energies of < 50 MeV. In order to decrease the incident proton kinetic energy and change the p/π/μ flux of the beam, a series of acrylic blocks were placed in the beam path and the HPTPC was placed at an off-axis position.

To make accurate measurements of the proton-argon cross section, it is essential to measure the flux and composition of the off-axis beam. To this end, two time of flight systems were operated in an off-axis position in the beamline. These made measurements of the off-axis beam upstream and downstream of the HPTPC. Measurements made with these time of flight systems are presented, including the beam composition and energy as a function of off-axis position. The off-axis technique allowed the reduction of proton kinetic energy to the desired range as well changing the composition of the beam as a function of the off-axis angle.

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Differentiable local surrogate models for SHiP experiment design optimisation

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The optimisation of complex stochastic processes is a significant challenge in High Energy Physics (HEP), since modern physics' simulators are extremely sophisticated and costly to run. We propose a novel method for gradient-based optimization of black-box simulators using differentiable local surrogate models. We demonstrate that these local surrogates can be used to approximate the gradient of the simulator, and thus enable gradient-based optimization of simulator parameters. In cases where the dependence of the simulator on the parameter space is constrained to a low dimensional submanifold, we observe that our method attains minima faster than all baseline methods, including Bayesian optimization [1], numerical optimization, and REINFORCE driven approaches[2]. We further apply the developed algorithm for the optimisation of the muon shield of the SHiP experiment and show that we are able to find a new configuration of the magnetic shield.

More specifically, we aim to solve the following minimization problem argminψ E (R(y)) , p(y|x, ψ) where y represents the distribution of muon hits in the detector, x represents kinematic variables of the muon flux, such a position and momenta, and ψ is the parameters of the magnet. Risk function R is defined in the way to minimise the flux of the muons through the detector and is the one be minimised. Below, we present the dynamic of the risk function as a function of optimisation iteration in Fig.1. We also show how a set of magnet parameters evolves during the optimisation in Fig.1. In Fig.2 we present the comparison in the hits distribution of the newly obtained optima versus the previous one, found by Bayesian optimisation. The animation of the optimisation can be found in [3].

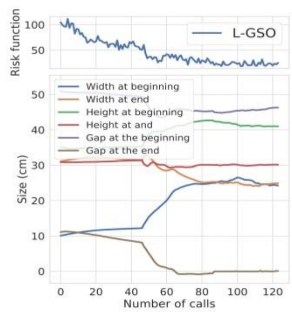

Figure 1.(Top) Risk function value during optimization.(Bottom) $\bpsi$ Subsample of six parameters values during optimization.

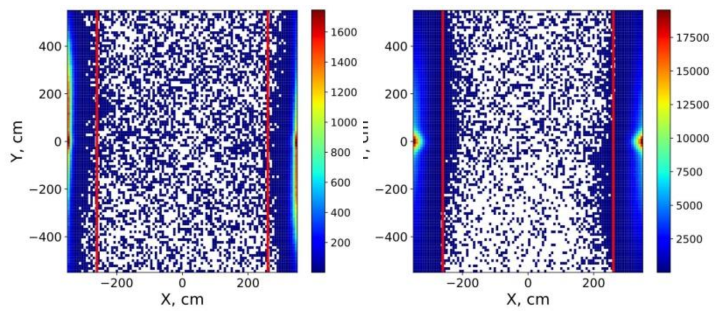

Figure 2.Histogram of the muons hits distribution in the detector (depicted as red contour) obtained by Bayesian optimisation (Left) and by our algorithm (Right). Color represents number of the hits in a bin.

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Categorisation studies in the Higgs to two photons decay at the CMS experiment

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This talk presents studies for tagging the vector boson fusion and vector boson associated production modes of the Higgs boson, using the Higgs to two photons decay in data taken with the CMS experiment. Boosted decision tree discriminators, trained on Monte Carlo simulation samples, are used to distinguish between signal and background processes. A data-driven method is presented and serves to estimate the backgrounds in cases where the simulation samples are statistically limited. The diagnostic decision-making capabilities of the trained discriminators are evaluated through receiver operating characteristic curves and categories are defined by optimising thresholds on the discriminator output scores. Results on Higgs boson production rates, obtained from applying the classifiers to vector boson fusion categorisation in the new analysis framework, based on simplified template cross sections, will be presented.

Unbound states in $^{16,18,20}C$: the search for the mixed-symmetry 2^+ state

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We 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. The experiment was carried out at the R^3B-LAND setup at GSI-FAIR during the S393 campaign.

We work upon the model of a two-state mixing of pure proton and pure neutron excitations to describe excited 2^+ states in neutron-rich carbon isotopes [1][2]. The first 2^+ state of ^{16}C has been measured [1] to be dominated by neutron excitations and recently confirmed in a study that has determined the proton amplitude of the first 2^+ state for ^{16}C, ^{18}C and ^{20}C [3]. We want to identify the mixed-symmetry 2^+ state, which is above the neutron separation energy and therefore unbound. Its observation will add weight to our simple picture of describing the neutron-rich C isotopic chain, giving us great insights into the shell evolution towards the neutron dripline at Z=6.

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A jet finding algorithm for the CMS Phase-2 trigger upgrade

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The High-Luminosity LHC [1] will open an unprecedented window on the weak-scale nature of the universe, providing high-precision measurements of the standard model as well as searches for new physics beyond the standard model. Such precision measurements and searches require information-rich datasets with a statistical power that matches the high-luminosity provided by the Phase-2 upgrade of the LHC. Efficiently collecting those datasets will be a challenging task, given the harsh environment of 200 proton-proton interactions per LHC bunch crossing. For this purpose, CMS is designing an efficient data-processing hardware trigger (Level-1) that will include tracking information and high-granularity calorimeter information [2]. The current conceptual system design is expected to take full advantage of advances in FPGA and link technologies over the coming years, providing a high-performance, low-latency computing platform for large throughput and sophisticated data correlation across diverse sources. The envisaged L1 system will closely replicate the full offline object reconstruction, to perform more sophisticated and optimized selection of the data. A dedicated Correlator Trigger will be used as central processor to compute high-level trigger objects and correlation among objects. A Time-Multiplexed approach is considered to provide enough latency for the implementation of sophisticated algorithms such as particle flow reconstruction. An algorithm able to find hadronic jets from particle flow inputs has been developed. Jets are found by building a histogram of the inputs and considering the total energy in a fixed area around local maxima. This trigger algorithm has been implemented using High-Level Synthesis, a tool that enables users to write FPGA firmware in high-level languages, demonstrated on hardware, and validated against software emulation. Its expected physics performance has been studied using Monte Carlo samples with hıgh pile-up, simulating the harsh conditions of the HL-LHC. The algorithm performance is comparable to Anti-KT with a radius of 0.4, i.e. the main jet reconstruction algorithm used by CMS for offline analyses, run on the same inputs. The jet algorithm presented in this talk has been adopted as the flagship particle flow jet algorithm for the CMS Phase-2 trigger menu studies enabling CMS detector to maintain the same jet trigger thresholds at HL-LHC as in Phase-1.

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Investigation of Isospin Symmetry Violation via One- Nucleon Knockout Reactions

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The study of nuclei near the N=Z line region on the nuclear chart provides a pathway to investigate proton rich systems in proximity of the proton – drip line, where isospin symmetry plays a significant role. Isospin symmetry occurs due to the exchange symmetry between protons and neutrons that occurs through an almost identical nuclear force between the two types of nucleon.Isospin symmetry allows the isobaric analogue states to be compared to understand the factors that could cause isospin symmetry violation[1,2]. Lastly, the exploration of proton – rich nuclei towards the limit of nuclear binding could provide essential understanding about the nucleosynthesis of elements in astrophysical sites in long term study.

A novel technique has been used at the National Superconducting Cyclotron Facility (NSCL), using `mirrored' knockout reactions – i.e one-neutron and one-proton knockouts from a mirror pair of beams (^{48}M�/^{48}V respectively) to make a pair of mirror nuclei (^{47}M�/^{47}T�respectively) that have a higher negative isospin, T. The primary aim of this experiment was to measure analogue spectroscopic factors to investigate the underlying causes of the isospin symmetry violation. Neutrons and protons were knocked out from the �$_{7/2}$shell by using secondary beams of ^{49}F�, ^{48}M�, ^{47}C�and $^{46}V$from the A1900 fragment separator alongside the secondary beams of their corresponding mirror nuclei. This work is influenced by the research from S. A. Milne[3] who performed knockout reactions of analog states in the A=53 mirror nuclei. The aims, experimental methodology, preliminary analysis and results on new data of 47M�will be presented in this talk.

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

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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 in-beam measurements using a proton beam at KVI-CART facility, with an energy of 66.5 MeV, hitting a radiomarkers target placed in water, to simulate the human internal environment. After the irradiation with the proton beam the gamma rays emitted were measured with two detection systems simultaneously. Two different scintillators are used: a CLLB detector of 2 inches and an array of LFS crystals coupled to silicon photomultiplier (SiPM) arrays.

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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Establishing quantitative SPECT of novel theranostic terbium

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Four radioisotopes of terbium have been identified as candidates for therapy and diagnostic imaging in nuclear medicine: Tb-161 emits beta and Auger electrons suitable for therapy; Tb- 155 emits gamma-rays suited to Single-Photon Emission Computed Tomography (SPECT); Tb-152 emits positrons of a suitable energy for Positron Emission Tomography (PET); and Tb-149 emits alpha particles appropriate for therapy. As isotopes of the same element, their identical chemical properties mean they can be attached to the same pharmaceutical and will be processed identically in the body. For this reason, they form a *theranostic set* and can provide integrated therapy and diagnostic imaging [1].

Accurate patient dosimetry is required to determine the doses received by malignant cells and healthy tissue after a therapy. Dosimetry relies on relating imaging measurements to a distribution of activity in the patient's body, so quantitative imaging is essential. This means that radioactivity standards, accurate nuclear data measurements, and image-correction protocols are vital for any isotopes used for nuclear medicine imaging. This work reports on establishing these criteria to permit the first quantitative imaging of Tb-155 and Tb-161.

Samples of Tb-161 were produced by irradiation of enriched Gd-160 at the high-flux nuclear reactor at Institut-Laue-Langevin, followed by radiochemical separation at Paul Scherrer Institute. Tb-155 was produced and collected at CERN-ISOLDE and CERN-MEDICIS. Primary radioactivity standards and nuclear data measurements were performed at the National Physical Laboratory, providing the foundation for quantitative imaging. SPECT phantom studies of both isotopes were conducted at the National Physical Laboratory and at the Christie NHS Foundation Trust. Monte Carlo simulations of each SPECT scanner used in this study have been developed and validated to optimise imaging protocols and corrections, providing a basis for clinical quantitative SPECT with these isotopes.

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Benchmarking New Hardware 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. Images with different sizes have also been tested to investigate the performance as a function of the size of the images.

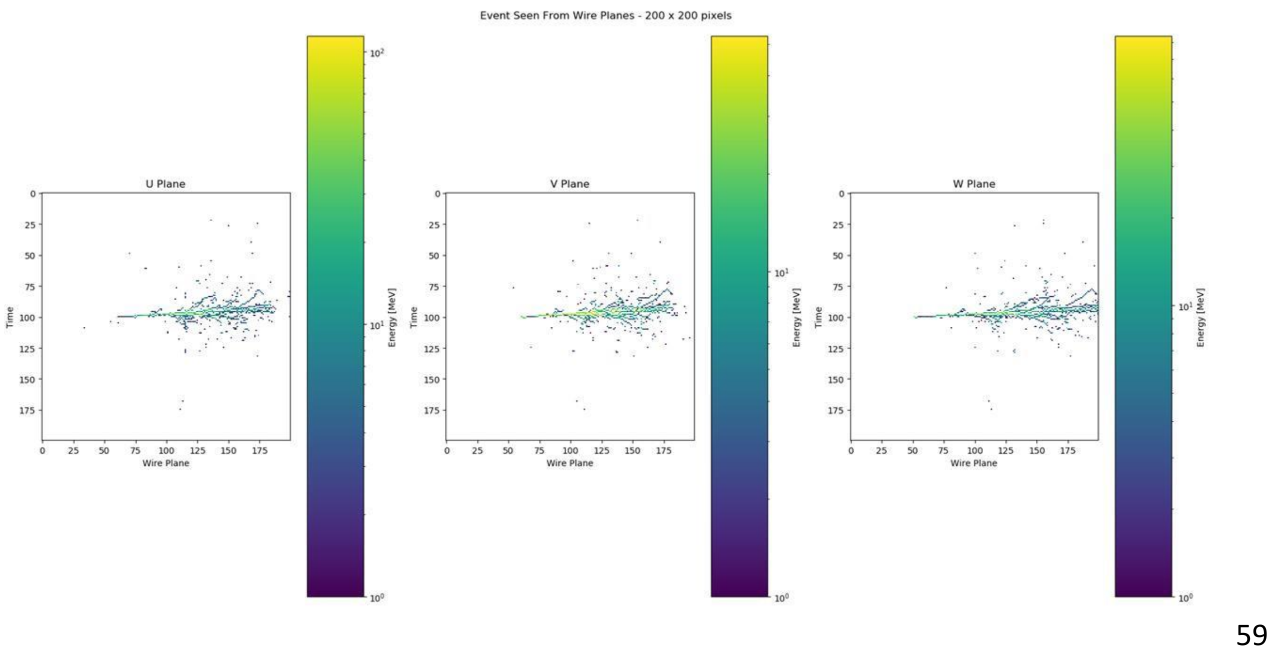

Fig. 1. Simulated neutrino interactions inside the generic LArTPC.

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 present work comparing CLAS data with event generator descriptions of the A(e,e'p pi) and A(e,e'p) $1p0pi$ reactions on He, C and Fe targets at 1, 2, and 4 GeV; two of several final states that are analysed to tune nuclear physics modeling in neutrino-nucleus event generation.

Assessing the validity of proposed cluster bands in ^{18}O through absolute branching ratio measurements

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The study of the nuclear force is fundamental to our understanding of the universe, providing information on both everyday objects as well as the astrophysical formation of matter. In nuclear physics, the largely successful nuclear shell model has been able to accurately predict the properties of many nuclei and their interactions. However, there are certain nuclear configurations that are not predicted by the shell model, such as the collective motion displayed by α-clustered nuclei, that can elucidate aspects of the nature of the nuclear force, as well as present a good test for nuclear models.

An experiment was performed at the Maier-Leibnitz Laboratory (MLL) in Munich by von Oertzen *et al.* [1], in which 30 new states in ^{18}O were measured. With both these and previously determined states, rotational fitting was performed to tentatively assign rotational bands comprised of proposed α-cluster structures, $^{12}C \otimes 2n \otimes \alpha$ (nuclear molecule) and $^{14}C \otimes \alpha$ (core+α).

In order to determine the validity of these rotational bands, an experiment was performed at MLL by the current authors using the Q3D magnetic spectrograph in conjunction with the Birmingham DSSD array to determine the absolute branching ratios of states from 7.0 MeV to 16.0 MeV in ^{18}O. This information, along with measured widths, enables a comparison of the partial α-decay widths to the Wigner limit on a state-by-state basis. Thus, the tendency towards α-clustering of each state can be quantified, and hence the existence of the proposed rotational bands assessed. The final results and conclusions of the analysis will be presented.

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A simulation framework for spherical proportional counters

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The spherical proportional counter (SPC) is a novel gaseous detector [1], with many applications, including low-mass dark matter searches and neutron spectroscopy [2]. A framework to simulate SPCs has been developed, which combines the strengths of the Geant4 and Garfield++ toolkits. The framework allows the properties of SPCs to be studied in detail, providing insights for detector R&D, experiment design optimisation, and data analysis and interpretation. The details of the framework will be presented, along with its performance in terms of computing resources. Representative physics results will be shown, demonstrating the predictive power of such simulations. The validation of the simulation using data collected at the University of Birmingham and at the Boulby Underground Laboratory will be discussed.

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Stellar Modelling for Nuclear Astrophysics: AGB stars and the importance of neutron-capture reactions

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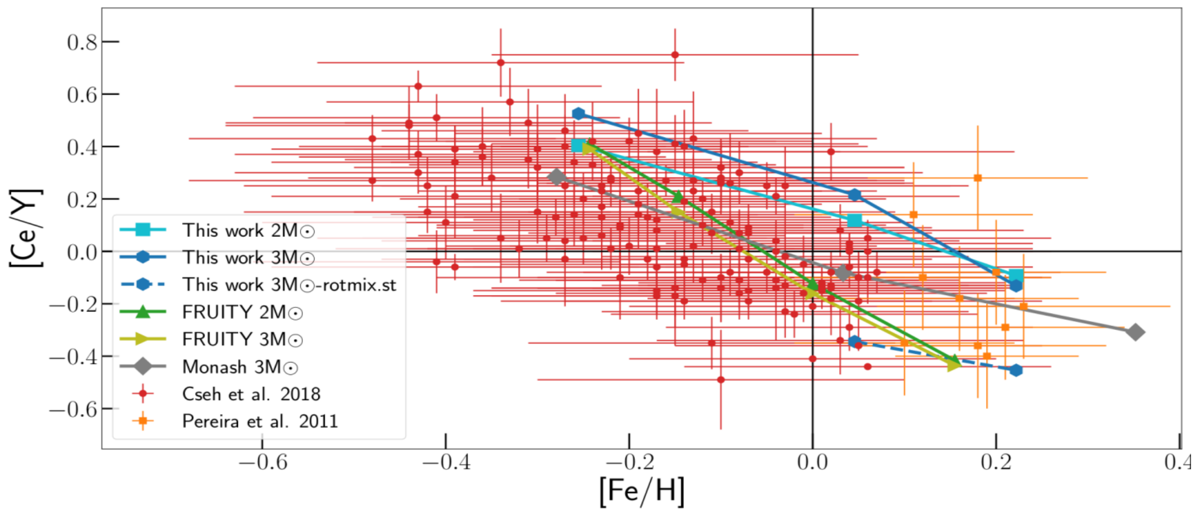
The production of the elements heavier than iron that we observe today in the Solar System is mostly the result of the combined contribution of the *rapid* neutron-capture process (the *r* process) and *slow* neutron-capture process (the *s* process). In the case of the *r*-process, the n-densities are high ($N_n > 10^{20}$ cm^{-3}), and the timescale of successive n-capture reactions on heavy isotopes is faster than the beta-decay timescale, while the *s*-process is characterized by lower neutron densities ($N_n < 10^{10}$ cm^{-3}) [1]. Low-mass asymptotic giant branch (AGB) ($1.5 < M/M_{sun} < 3$) and massive ($M > 10M_{sun}$) stars have been identified as the main site of the s-process. In this work we consider the evolution and nucleosynthesis of low-mass AGB stars.



We provide a new set of low-mass AGB models with initial masses M/M_{sun}= 2,3 and near-solar initial composition, including an improved model of mixing processes at convective boundaries in stellar interiors. The convective-boundary-mixing model leads to the formation of an amount of ^{13}C, the main neutron source in AGB star interiors, three times larger compared to the one obtained in the previous set of models. Nucleosynthesis predictions are compared to other stellar datasets available in the literature and to a wide range of observations, including carbon-stars, barium stars, post-AGB stars, and pre-solar grains, showing a globally close agreement (see Fig. 1). Using these results, we identify the nuclear reaction-rates which provide the dominant contribution to the production uncertainties, highlighting which of those are realistic candidates for future experimental measurements.

Fig. 1. Comparison of observed surface abundances of Ce, Y, Fe and H on barium-stars to our theoretical results We also include results from the FRUITY [2] and Monash [3] database models as a comparison.

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Evaluation of nuclear reaction cross sections via proton induced reactions on ^{72}Ge and ^{76}Se for the production of ^{72}As:a potential entrant for theranostic pairs

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Theranostic applications of radiopharmaceuticals have revolutionized present era specially, dealing with cancer diseases. Increase in the uses of radionuclides in nuclear medicine has resulted in the demands of optimized new radionuclides to be produced focussing on the economy, simplicity and maximum yield. Two radionuclides of arsenic offer a well agreed theranostic systems namely 77As and 72As. Some arsenic radionuclides have wide range of positron-emission, half-lives ranging from an hour to weeks and have potential to be used for nuclear medicine. Present work will elucidate all over the production of 72As on Germanium (Ge) and Selenium (Se). The experimental results obtained by several nuclear reactions were compared with the results of nuclear model calculations using the codes ALICE-IPPE, EMPIRE 3.2 and TALYS 1.9. The thick target yields (TTY) of 72As were calculated from the recommended excitation functions. Analysis of radio-impurities was also discussed. A comparison of the various radio-impurities showed that to produce 72As, 72Ge(p, n)72As, 73Ge(p,2n)72As, 74Ge(p,3n)72As and 76Se(p, x)72As reactions in different energy ranges. We have identified the nuclear process which gives high yield with minimum impurities to make it as a potential candidate for theranostic applications and in particular in Positron Emission Tomography (PET).

Key words: Nuclear reaction cross section, 72As, Theranostic, PET

A look at the initial results of the beam tests of a novel scintillator detector design for the T2K experiment

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The development of next-generation experiments such as Hyper-Kamiokande [1] and DUNE [2] herald a new era of long baseline neutrino experiments. With current generation experiments we have seen glimpses of possible Charge-Parity (CP) violation in neutrino oscillations. These new experiments will be able to collect the required statistics with reduced systematic uncertainties to measure the quantifying variable of CP violation to five sigma, settling the question of neutrino oscillation CP violation once and for all and giving insight into the matter-antimatter asymmetry of our universe.

In order to reduce systematic uncertainties relative to current-generation experiments, new detector designs are required. One possible design is the Super Fine-Grained Detector (SFGD), which uses cubes of plastic scintillator threaded with optical fibres along three orthogonal planes to track charged particles from their interaction vertex with almost 4π coverage [3]. This design will allow improved reconstruction of neutrino energies in neutrino interactions with the scintillator, compared to previous fine-grained detector designs as used in the Tokai-to-Kamioka (T2K) long baseline experiment [4].

The SFGD design has been proposed for the upgrade of T2K's near detector, ND280. There is also a possibility of including a detector with a similar design – the Three Dimension Scintillator Tracker (3DST) - in the DUNE experiment.

The installation of the ND280 upgrade will start in 2021, and there have been two beam tests of a SFGD prototype to prepare for the upgrade. In July-August 2018, there was a beam test at CERN using a charged particle beam, mainly comprised of protons. In December 2019, a beam test was performed at the Los Alamos National Laboratory (LANL) using a neutron beam. Detecting neutrons - or rather, the charged particles resulting from neutrons interacting with the detector - is an important requirement of the SFGD design as anti-neutrino interactions typically result in neutron production.

This talk will cover the two beam tests of the SFGD prototype and the ensuing analysis. The advantages and design challenges of the SFGD will be discussed, with an in-depth view of the impact of the SFGD detector on future T2K results.

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Investigation of the low-lying structure of ^{17}C via the (d,p) reaction

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It has been demonstrated that traditional magic numbers evolve when nuclei far from stability are explored. In particular, recent experiments have provided evidence to support the existence of shell closures at N=14, 16 in neutron-rich oxygen isotopes and the vanishing of the N=20 [1-3]. This has been understood as an effect of the monopole part of the nucleon-nucleon interaction [4,5]. However, the extent to which these gaps at N=14, 16 persist in neutron-rich carbon isotopes is unclear. In an effort to answer this question we have probed the low-lying level structure of ^{17}C using the (d,p) transfer reaction in inverse kinematics to locate the neutron single-particle orbitals involved in the formation of these new shell gaps.

Excitation energies and spectroscopic factors were deduced for the ground state ($3/2^+$) and the first ($1/2^+$) and second ($5/2^+$) excited states. A large spectroscopic strength was observed for the $1/2^+$ and $5/2^+$ states, while a very small spectroscopic factor was deduced for the ground state, in good agreement with shell model calculations, and the size of the N=14 was estimated. In addition, the possible halo configuration of the state $1/2^+$ will be discussed.

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Posters

A feasibility study of using muon tomography for imaging a large volume V/52 CASTOR drum

Ahmad Alrheli[1], Daniel Kikola[2], Anna Kopp[3], Mohammed Mhaidra[2], John Stowell[1], Lee Thompson[1], Holger Tietze-Jaensch[4], Elie Valcke[5], Jaap Velthuis[3] and Michael Weekes[1]

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In nuclear waste management level, the characterisation of radioactive waste before disposal leads to safe monitoring and controlled storage inside special casks. However, cases such as conditioned waste are more complex due to that fact that they come from different sources and possess a complex radiological spectrum. Imaging the conditioned nuclear waste ideally requires non-invasive methods to identify the materials which create this complex spectrum. Studying such well-shielded objects needs a method that can penetrate through the cask shielding material which is enough to stop X-ray and γ-ray. Muon tomography (MT) is a non- destructive technique that exploits cosmic muons imaging to produce a three dimensional image of structures using information that is extracted from Multi Columb Scattering (MCS) of the muons that passed through the probe volume. The muons' scattering angles are larger in materials with a High-Z number than those with medium and Low Z materials, hence the contents of the investigated object can, in principle, be classified according to their atomic number.

This study is a part of the EU H2020-funded CHANCE project that aims to investigate the interior of nuclear waste drums by several methods including the MT technique [1]. In partnership with University of Bristol and Warsaw University of Technology, the University of Sheffield is developing a MT system to investigate conditioned nuclear waste drums. A new detector system has been built to discriminate the contents of the drums by reconstructing the muon trajectory as it enters and leaves the drum of interest. In this poster we will report on an investigation into the feasibility of using MT to image large drums by simulating a large CASTOR drum, type V/52, filled with fuel assemblies containing mainly Uranium pellets. For Validation purposes, the V/52 CASTOR was simulated by using Geant4 exactly the same one that designed by Gesellschaft für Nuklear-Service (GNS) for storing and transporting fuel assemblies from boiling water reactors (BWRs) [2]. Two reconstruction algorithms are used in this study which are based on the same principle, Point of Closest Approach (PoCA) [3], and Binned Clustering algorithm [4]. Two identical true muon detectors with dimensions of 2 m $\times$ 2 m are placed horizontally above and below the cask. The simulated true muon detectors are modelled assuming perfect efficiency and perfect spatial resolutions. The results of the reconstructed images will be presented.

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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

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As one of the three liquid-argon 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 is a Liquid Argon Time Projection Chamber (LArTPC) neutrino experiment. 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 effects of identifying the ionisation electrons caused by the particles can be studied using Monte Carlo simulations, so a noise model is required to provide realistic Monte Carlo 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.

Recording stages of the ATLAS ID Decommissioning using Motion Capture

Alice Cryer

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During the next Long Shutdown, the current ATLAS inner detector (ID) will be removed and the new inner tracker (ITk) will be installed. Due to potential risk of excessive radiation dose, human intervention to decommission the inner detector must be carefully planned. A Virtual Reality intervention planning and evaluation platform was developed to assess the radiation exposure risk for human interventions and train for the decommissioning process [1].

The addition of motion capture was motivated by the main drawback to VR-based training and simulation platforms, where work carried out in VR has no effort, skewing the dose estimate as tasks are easier and faster to accomplish. The motion capture records the technician's movements while performing decommissioning tasks in real-time on a mockup of the ATLAS ID, meaning that the location and timing in completing the tasks is accurate.

The presentation will present the intervention planning platform and the motion capture setup for recording, and post-processing of the data, including does estimation results.

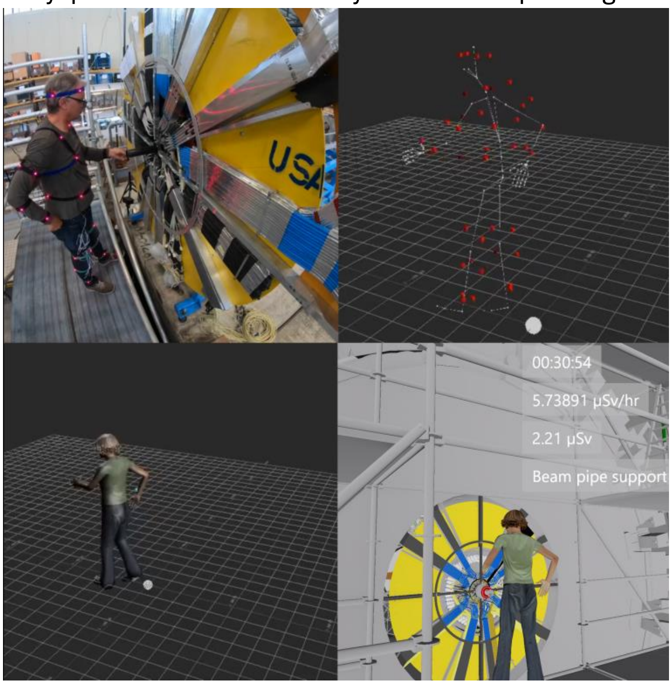

Fig 1 Top left: Technician performing decommissioning step with LEDs for Motion Capture; Top right: the MoCap data with Skeleton; Bottom left: The MoCap data in MotionBuilder; Bottom right: The MoCap data in the Intervention Planning Platform

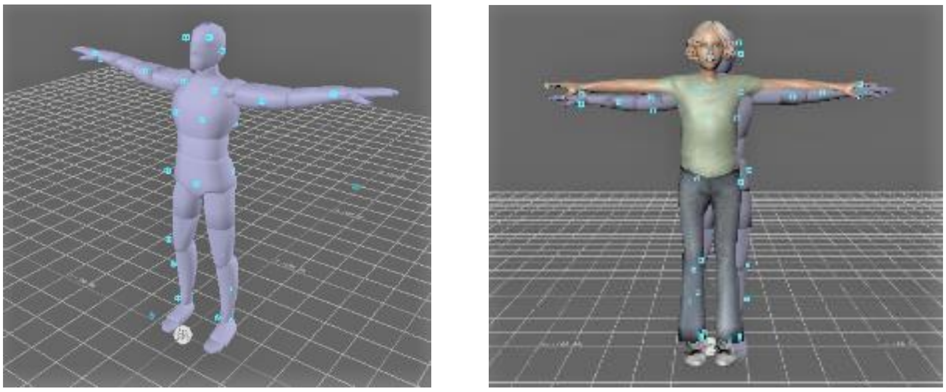

Fig. 2. (a) The ``actor" is aligned with the motion capture points in MotionBuilder;
(b) The ``character skin" is added to the actor in MotionBuilder

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Application of Graph Neural Networks to the LHCb Calorimetry for Particle Identification

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[1]Université Paris-Saclay, France, [2]University of Cambridge, UK

The main purpose of the calorimeter detector subsystem is to measure the energy and position of showers produced by incident particles interacting with the detector material [1]. The typical calorimetric detector geometry is driven by constraints resulting from the need to perform clustering of the showers, energy and direction regression and track classification. Such demands result in a sequence of detector modules with varying pixel granularity matching the variable hit density across the calorimeter surface [2]. Recently, there has been a significant amount of research investigating the applications of convolutional neural networks (CNN) to the raw image from calorimetric readouts [4]. The hybrid granularity of the electromagnetic and hadronic calorimeter modules at the LHCb detector [1,3], however, breaks the translational symmetry assumed by convolutional neural networks. In addition to the variation in pixel size, the sparsity of calorimetric data and the overlap of the detector components demand the investigation of deep learning techniques capable of extracting features from non-euclidean, irregular data. Within the domain of geometric deep learning, graph neural networks (GNN) have emerged as a technology capable of addressing such demands and learning the detector geometry without any preprocessing of the training data[5]. An investigation of the application of GNNs to the LHCb calorimetry is detailed in this study. With minimal preprocessing of two-dimensional images produced by the electromagnetic and hadronic calorimeters, a classification of the shower deposits is performed to produce a per-candidate energy reconstruction along with an estimate of its associated resolution. The GNN model developed in this study is finally benchmarked against convolutional neural networks inspired by the state-of-the-art image recognition architectures.

[1] R. Dzhelyadin, "The LHCb calorimeter detectors," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 581, no. 1–2. pp. 384–388, 2007 [Online]. Available: http://dx.doi.org/10.1016/j.nima.2007.08.010

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[3] A. A. Alves, L. M. Andrade, F. Barbosa-Ademarlaudo, I. Bediaga, and G. Cernicchiaro, "The LHCb Detector at the LHC," JINST, vol. 3, no. LHCb-DP-2008–001. CERN-LHCb-DP-2008–001, p. S08005, 2008.

[4] Carminati, F., Khattak, G., Pierini, M., Vallecor-safa, S. and Farbin, A., "Calorimetry with deep learning: particle classification, energy regression, and simulation for high-energy physics," NIPS 2017, 2017 [Online].

Available: https://dl4physicalsciences.github.io/files/nips_dlps_2017_15.pdf
[5] Qasim, S. R., Kieseler, J., Iiyama, Y., & Pierini, M., “Learning representations of irregular particle-detector geometry with distance-weighted graph networks,” arXiv:1902.07987 [physics.data-an], 21-Feb-2019 [Online]. Available: https://arxiv.org/abs/1902.07987

First cross-section measurement of the $^{94}Sr(\alpha,n)^{97}Zr$ reaction at relevant energies for the weak r-process

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

Observations of Ultra Metal Poor stars such as HD 221170 [1] show that while the abundances of elements heavier that Silver are in good agreement with models, elements between Iron and Silver have much higher abundances than models of nucleosynthesis which only consider the 'normal' r- and s- processes predict. A potential source of these over-abundances is the weak rprocess which takes place in the neutrino-driven winds of a core-collapse supernova. This process has been shown to be very sensitive to (a,n) reaction rates [2] however, to date no measurements of (a,n) reactions on unstable nuclei at the relevant energies have been made. This project aims to study $^{94}Sr(a,n)^{97}Zr$; a reaction which has been shown to have a significant impact on the final abundances of elements in the ranges of 37 < Z < 42 and 44 < Z < 47 [3]. The experiment is planned for TRIUMF using EMMA – the Electromagnetic Mass Analyser. The radioactive ^{94}Sr beam will impinge on a novel type of Helium target. This target is a solid film of silicon with ^{4}He contained inside pores. The ^{4}He density of this target is 5×10^{18} atoms/cm^2 [4] which is comparable to the gas target chambers currently used but has the benefits of a solid foil. A comparison of Hauser-Feshbach models for the cross-section will be presented along with the proposed set up for the experiment.

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[2] J. Bliss, *et al.*, J. Phys. G: Nucl. Part. Phys. 44, 054003 (2017).
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[4] V. Godinho, *et al.*, ACS Omega 1, 1229-1238 (2016).

Surface and Bulk Alpha Measurements at Boulby Underground Laboratory

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[1]Boulby Underground Laboratory, UK [2]University of Edinburgh, UK

Boulby Underground Laboratory, a facility situated 1.1km under the north east coast, houses an array of high purity germanium detectors for low background gamma spectroscopy. The primary role of BUGS (Boulby Underground Germanium Suite) is to conduct and, latterly, refine material screening for dark matter searches, amongst other rare event physics studies.

As the dark matter community approaches third generation dark matter detector scales, the focus of reducing backgrounds turns from identifying intrinsic material radioactivity to that of surface cleanliness, owing to the vast exposed regions of detector vessels to detecting media.

For this reason, as a complementary addition to the suite, Boulby lab introduced an XIA UltraLo-1800 alpha counter for radon surface deposition studies. Since its instalment in late 2017, the counter has been operational, taking both background and sample data, the highlights of which are presented alongside other relevant factors.

Movement towards quick assessment and comparison of TALYS and EMPIRE simulated nuclear reaction cross-sections with existing and acquired experimental data

David Hampel, Tzany Kokalova Wheldon, Carl Wheldon, Ross Allen

University of Birmingham, UK

In recent years, the use of nuclear reaction codes, such as EMPIRE and TALYS, used to predict reaction cross-sections have become a point of interest to the radioactive isotope/tracer production industry. Whether the calculations are used to predict optimal target irradiation energy range where experimental data do not exit or double check newly acquired cross-section data, the codes offer a base against which new experimental data can be acquired.

The current focus of this work is to produce a code which can be used to quickly and easily process any amount of cross-section data produced by TALYS and EMPIRE nuclear reaction codes. In a few keyboard presses, these data can be exported into current and human friendly formats, plotted and compared against one another, and even plotted and compared against available experimental and evaluated databases.

One of the features of the code is the automated creation of input files as well as their automatic execution. Using this method, a reaction can be run a multitude of times with varying input parameters based on user selected ranges in order to test the sensitivity of the calculated cross-sections.

Future improvements to the code include modules for target yield calculations, reaction cross-section calculations for targets of different compositions based on simulated data, and the possibility to determine sets of optimised parameters by trying to minimise the difference between the simulated cross-sections and experimental data, where available. A module for calculation of stopping power or importing stopping power data from external tools is also envisaged.

A High Pressure gas TPC for future long-baseline neutrino experiments

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Imperial College London, UK

Future long-baseline neutrino experiments, such as Hyper-Kamiokande (Hyper-K) and the Deep Underground Neutrino Experiment (DUNE), will have sensitivity to measure Charge- Parity (CP) violation in the neutrino sector to 5 sigma. To reach this level of precision, systematic uncertainties have to be reduced significantly from their current level, typically from 5–10% to 1–2%. In particular, understanding neutrino-nucleus interaction cross sections is key to reducing these systematic errors.

A High Pressure gas Time Projection Chamber (HPgTPC) is a key component of the DUNE near detector reference design [1], because it will allow DUNE to reach this level of uncertainty on neutrino-nucleus cross-sections. An HPgTPC has a low momentum threshold, making it ideal for reconstructing low momentum particles exiting the nucleus.

An HPgTPC prototype has been built and commissioned at Royal Holloway, University of London. The prototype underwent a beam test at the CERN East Area T10 beamline from August to September 2018 with the goals being to test the technology as well as to measure low-momentum proton-scattering in gaseous argon.
Analysis of the beam test data will be presented.

[1] J. Martin-Albo, "A pressurized argon gas TPC as DUNE near detector," Journal of Physics: Conference Series, vol. 888, p. 012154, Sep 2017

New L1 seeds for HLT jet triggers in ATLAS Run 3

Elena Villhauer

University of Edinburgh, UK, CERN, Switzerland

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 LAr supercell and the 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 are much finer resolution in eta-phi than Run 2 L1 jets, and have more calibration options available. The incorporation of 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. Studying the performance of Run 2 L1 jets allows for the determination of areas of improvement for Run 3 L1 jet triggers. Presented are trigger efficiencies for Run 2 L1 jets for various years, as well as trigger efficiencies for Run 3 L1 jets. Calibrations are derived for Run 3 jFEX jet triggers. The resulting L1 jet triggers that should seed each HLT chain are determined.

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

Fraser Holloway

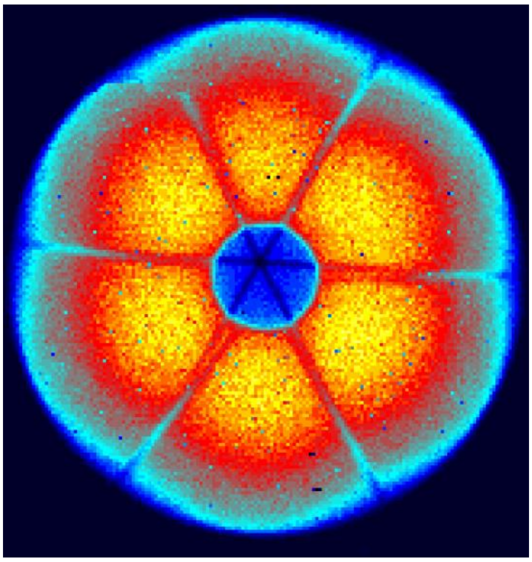
The University of Liverpool, UK

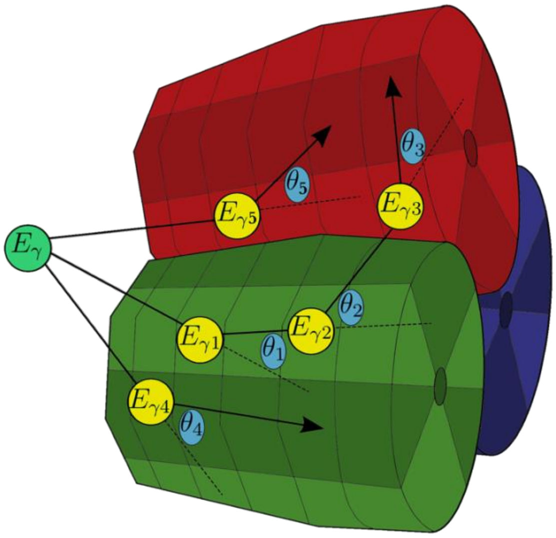
In the field of Gamma-Ray Spectroscopy the development of Gamma-Ray Tracking in large scale arrays is critical in pushing the boundaries of our understanding of Nuclear Physics. The significant positional resolution required for this technique to work demands the most advanced crystals, electronics and data processing techniques ever created in this field. Pulse Shape Analysis (PSA) is necessary for detector arrays like AGATA to determine position information with reasonable accuracy however current techniques are not sufficient to keep up with the large influx of data produced by these arrays.

The purpose of this project is to develop novel techniques to improve the accuracy and processing rate of PSA with the ultimate goal to produce techniques that can be used for future generations of gamma-ray tracking arrays. The use of Topological Data Analysis (TDA) to form and search hyperdimensional data structures and the use of Convolutional Disentangled Variational Autoencoders alongside other advanced Machine Learning techniques for Feature Extraction, Tagging, Compression & Rejection are explored.

Due to the complex nature of pulse generation in HPGe crystals all interactions in AGATA are stored in a simulated basis set. Therefore, this project also entails improving the simulation of interactions inside large volume HPGe arrays and the induced effects present in their acquisition electronics in an attempt to improve their consistency with observed values. The development of dynamically generated adaptive basis sets is explored to improve algorithm performance at segmentation boundaries and areas of high sensitivity.

In order to validate the simulation work in this project and evaluate the performance of each novel PSA algorithm developed this project has also required significant work in the sub-millimetre experimental characterisation of the AGATA A005 crystal using Liverpool’s BGO coincidence scanning apparatus utilising collimated ^{137}Cs and ^{241}Am sources.





Steps Towards the Search for a Hexaquark with CLAS12

Geriant Clash

University of York, UK, for the CLAS Collaboration

Experiments taking place at Thomas Jefferson Lab in Virginia, USA using the upgraded CLAS12 detector system allows a detailed investigation of exotic hadron states. In our experiment electrons accelerated to an energy of 10.6MeV, 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.
Here I will present the analysis of data from one of the experiments recently conducted at CLAS12, which provides the first search for a d_s hexaquark, a particle with quark content uuudds, predicted to decay most preferably to the Δ^{++}(uuu)and $\sum^{*-}$(dds) baryons. An improved PID (Particle Identification) method was developed and tested during these studies. The results of analysis were verified on several, more conventional reactions with similar final state, in particular e'p→$K^0\sum^+$ and e'p→ρ^0p. These reactions were used as benchmarks to tune analysis techniques applied for the experiment's with deuteron target. First results on a d_s search will be presented, together with analysis of empirical and simulated data of the most prominent background channels.

Tune-able, high-flux, monoenergetic, 1-40 MeV gamma source driven by energy recovery linac for nuclear physics, decommissioning, security and medical isotopes

Peter Williams[1], Gusavo Perez-Segurana[2], Ian Bailey[1], Joe Crone[2], Hywel Owen[3] and Bruno Muratori[1]

[1]STFC, UK, [2]Lancaster University, UK, [3]University of Manchester, UK

We describe a new proposed facility, Daresbury Industrial Accelerator for Nuclear Applications (DIANA). This will be a ~1 GeV, ~100 mA, multi-pass, superconducting energy recovery electron linac driving three user facilities. Firstly, a high average power EUV-FEL for semiconductor chip lithography industry research; secondly, a high-flux, narrowband 1-40 MeV inverse Compton scattering gamma source for nuclear physics, nuclear decommissioning, security and medical isotope research; and thirdly an internal target experimental station for precision electroweak measurements and dark matter searches. Additionally, DIANA will serve as technology testbed for the future proposed large-scale academic facilities UK-XFEL and CERN LHeC / FCC.
In this presentation, we describe the properties of the DIANA gamma source and its potential, concentrating on societal applications.
The high spectral flux at 1-5 MeV is expected to enable development of verification techniques for non-proliferation security, such as active SNM and contraband detection, through nuclear resonance

fluorescence (NRF) computed tomography and non-destructive assay of components through the whole nuclear fuel cycle, for example spent fuels and unknown legacy wastes.
Combining NRF with irradiation at higher photon energy (5 – 40 MeV) and narrower bandwidth (< 0.1 %) is expected to enable development of techniques to identify specific isotopes, and possibly selectively transmute at industrially relevant quantities. This will be used to investigate waste management techniques via induced photofission of actinides and long-lived fission products, without the need for expensive chemical partition of wastes. This may also make the production of novel medical radio-isotopes economically viable.
In an academic context, discrete photonuclear transitions will be able to be resolved, aided by the pencil-like and optionally polarized nature of the source. The polarization of both laser and electrons would enable the production of gammas with orbital angular momentum (OAM) gammas with implications for measurements relevant to stellar dynamics. In the context of particle physics the gamma source would enable unprecedented measurements of Delbrück scattering (QED vacuum) and light-by-light scattering.

Silicon vertex tracker studies for the electron-ion collider

Håkan Wennlöf, L. Gonella, P.G. Jones, P.R. Newman, P. Ilten, P.P. Allport

University of Birmingham, UK

The electron-ion collider (EIC) [1] is the next frontier of nuclear physics, and has recently been approved by the US Department of Energy for construction at Brookhaven National Laboratory [2]. The EIC will perform studies of nuclear and nucleon structure with unprecedented accuracy over a wide range of energies.
At the University of Birmingham, work on the EIC research and development is focused on the silicon vertex tracker, which is the detector closest to the interaction point. Simulations are carried out in an effort to determine the performance of different silicon vertex tracker layouts, and tests are made on individual sensors to find the optimal technology to use, utilising the Birmingham Instrumentation Laboratory for Particle physics and Applications (BILPA).
Depleted monolithic active pixel sensors (DMAPS) are the primary path of investigation. The performance of different settings and pixel sizes and layouts are investigated, primarily using prototype test chips from TowerJazz. The goal is to use the information gathered from experiments on the test chips to develop a new sensor for the EIC, with improved spatial and temporal resolution compared to current state-of-the-art silicon vertex tracker detectors.
The presentation will give an overview of the EIC and the work carried out at the University of Birmingham relating to the EIC R&D, presenting results and conclusions so far as well as current simulation work and future prospects in silicon sensor development.

[1] A. Accardi, J. Albacete, M. Anselmino, et al. *Electron Ion Collider: The Next QCD Frontier-Understanding the glue that binds us all.* arXiv preprint arXiv:1212.1701, 2012.

[2] Department of Energy. *U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility.*

Detecting prompt gamma emission during proton therapy: the effects of detector angle from the proton beam

Hamed Alshammari[1, 3], Laura Harkness-Brennan[1], Andrew Boston[1], Adam Caffrey[1], Benjamin Le Crom[2], Daniel Judson[1], and Ellis Rintoul[1]

[1]University of Liverpool, UK, [2]The University of Edinburgh, UK, [3]Imam Abdulrahman bin Faisal University, Saudi Arabia

Proton beam radiotherapy is used in certain types of cancer treatment to precisely target a tumour, whilst offering sparing of healthy tissue in comparison to X-ray radiotherapy. Recent studies have shown a strong correlation between the prompt gamma rays (PG) emitted from patients during irradiation and the dose distribution from the proton beam. [1]. The University of Liverpool is therefore developing a system to image the emission location of prompt gamma rays, to verify the dose distribution. The purpose of the work to be presented in this talk is to characterise how PG detection changes as a function of angle from the proton beam to find out the best position for the prompt-gamma imaging (GRI+) system. This experiment was conducted at the Clatterbridge Cancer Centre with a 60 MeV passive scattering proton beam, using the HPGe detector for PG detection and a 3He detector for the neutron background. Both detectors were placed at different angles, at forward angles from the beam axis (8, 33, 71, 73, 86, and 90) (fig. 1). Then, the gamma spectrum was analysed by gf3 Radware gamma spectroscopy software. The main focus was on the characteristic 6.13 MeV PG emission from ^{16}O and the 4.4 MeV PG emission from ^{12}C emitted during proton irradiation. The results show that the feasibility of PG emission from ^{16}O and ^{12}C was at 71 degrees from the beam axis, and the lowest neutron count per second (cps) was at 33 degrees from the beam axis. Use of a shield was investigated and showed that the use of a paraffin wax shield reduces the neutron cps by 13%. More investigation is needed to find out the most suitable position for a GRI+ system for the feasibility of PG emission with the lowest neutron background.

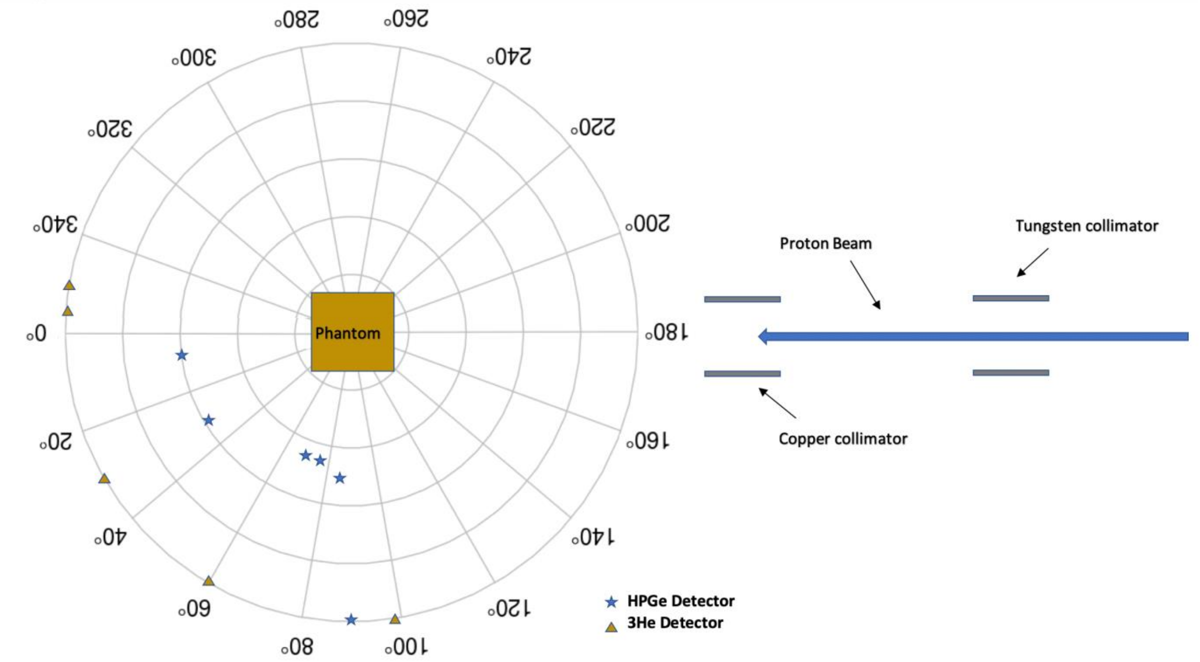


Fig. 1. An illustration diagram of the experiment setup

[1] C.-H. Min, C. H. Kim, M.-Y. Youn, and J.-W. Kim, "Prompt gamma measurements for locating the dose falloff region in the proton therapy," *Appl. Phys. Lett.*, vol. 89, no. 18, p. 183517, Oct. 2006.

Quantification of charge sharing effects in a pixelated CZT detector for application in Low Dose Molecular Breast Imaging

Hannah Brown[1], L. Harkness-Brennan[1], E. J. Rintoul[1], D. Judson[1], A. J. Boston[1] and I. Radley[2]

[1]University of Liverpool, UK, [2]Kromek Group plc, Sedgefield, UK

Molecular Breast Imaging (MBI) is a diagnostic technique which 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. The DMatrix Nuclear Imager is a pixelated CZT detector which has been developed by Kromek for applications including Medical Imaging. The detector has previously been characterized at the University of Liverpool for high activity application in Molecular Therapy. [1] We propose the development of the system to be tailored towards low activity application in MBI. The optimisation of the system for this function faces contrasting challenges compared to previous work due to the clinical desire to minimise the dose delivered to the patient. In order to obtain a high-quality image with limited statistics, good position resolution is required to ensure the best use of the data. One of the primary challenges in maximising the attainable position resolution of the system involves accounting for multiple pixel events. At gamma energies of 141 keV, multiple pixel events can occur as a result of both charge and radiation transport effects. True multiple pixel interactions occur due to scattering of gamma-rays, finite electron range and gamma interactions occurring close to the electrodes within the crystal. Differentiating between these phenomena allows us to both quantify and account for charge sharing. The isotope ^{99m}Tc possesses the ideal properties for its use in MBI, however its short half-life makes it less desirable for experimental use in prototype development. Henceforth, its charge sharing properties were compared to Cobalt-57 (with a comparable gamma energy 122 keV).

A Geant4 simulation has been developed to model Kromek's DMatrix system and to explore its response to irradiation of 141 keV and 122 keV gamma rays. [2] Understanding the interaction profile of 141 keV gammas has allowed us to begin to quantify charge sharing effects in CZT. It was found that the interaction properties of 122 keV gammas characteristic of ^{57}Co are comparable to 141 keV gammas characteristic of ^{99m}Tc, hence validating the use of this isotope within the MBI charge sharing study.

Experimental data of a ^{99m}Tc source have been acquired with the DMatrix and analysed accordingly to quantify how many pixels produce a charge signal above the noise levels. The experimental and simulated results differ for events in which more than one pixel produces a signal. Since multiple pixel events can only arise due to Compton scattering (which is modelled in Geant4) or Charge sharing (which are not modelled in Geant4), it is hypothesised that the discrepancy between experimental and simulated event fold is indicative of the charge sharing contribution. The ultimate aim of the project is to develop and optimise a system which possesses the desirable properties for clinical application in MBI. The quantification of charge sharing is a vital first step to improve and implement charge sharing correction techniques and hence maximise the performance of our system.

L. Mcareavey, L. Harkness-Brennan, S. Colosimo, D. Judson, A. Boston, H. Boston, P. Nolan, G. Flux, A. Denis-Bacelar, B. Harris, I. Radley, and M. Carroll, "Characterisation of a czt detector for dosimetry of molecular radiotherapy," *Journal of Instrumentation,* vol. 12, pp. P03 001–P03 001, 03 2017.

Kromek, "Dmatrix gamma-ray imager," May 2019. [Online]. Available: https://www.kromek.com/product/dmatrix-czt-based-gamma-ray-imager/

ATLAS e/gamma Trigger Algorithms at the High-Luminosity LHC

Harry Cooke

University of Birmingham, UK

Results are presented with potential improvements to ATLAS's electron and photon triggers at the initial hardware trigger level, enabling good performance at the anticipated high pileup conditions of High-Luminosity LHC. The study focuses on the new Global Trigger proposed for the Phase II upgrade, and the enhanced resolving power that comes with its access to the full granularity calorimeter data. Rates and efficiencies from Global are compared to those from the earlier Run-3 system.

Development of a photoionization mass spectrometer for measurement of atmospheric 85Kr

Holly Perrett, Kieran Flanagan, Giles Edwards, Ben Cooper, Christopher Ricketts

The University of Manchester, UK

85Kr is a volatile radioactive fission product that is released into the atmosphere during civil nuclear operations and plutonium breeding, making it a useful isotope for monitoring reprocessing activities and detecting unreported Pu production. Additionally, 85Kr measurement can be a useful tool for leak detection in the assessment of nuclear waste. A photoionisation mass spectrometer is being developed for rapid measurement of atmospheric 85Kr, reducing associated costs and improving on the sensitivity of existing radiometric techniques for trace isotope detection.

The proposed device makes use of an electron cyclotron resonance (ECR) ion source for the production of positive ions from atmospheric samples, resonant ionization for selecting 85Kr from interference mass species and an EPT Magnetof for detection. A pre-existing ECR ion source will be optimized for the production of Kr+ ions. Using this ion source, it is possible to continuously sample the atmosphere at a rate of 1 cc / min, detecting changes in the concentration of atmospheric 85Kr over 10 minute intervals.

The design utilizes the technique of collinear resonance ionization spectroscopy (CRIS) [1] developed at the ISOLDE facility in CERN for the study of short-lived nuclei. In this implementation of the technique, the ion beam will be mass separated and trapped in a compact gas-filled linear Paul trap (currently under construction and simulation). The ion bunch will be neutralised by passing it through an alkali metal vapour. The resulting atoms can then be resonantly excited into Rydberg states with an infrared laser, from which they can be field ionized and detected. Work at CERN has demonstrated that the CRIS technique is capable of reaching sensitivities of below 1 part in 1016, representing an enhancement factor of over 100 when compared with ICP-MS. By changing the frequency of the resonant lasers used other isotopes can be selected for measurement, making the CRIS spectrometer a versatile tool for environmental monitoring.

[1] T.E Cocolios, H.H.A Suradim et al, Nucl Instrum Meth B. 317, pp 565-569 (2013).

Using Model-Assisted Generative Adversarial Networks to Produce a Fast Simulation of the LHCb Particle Identification Response

Saúl Alonso-Monsalve[1], Christopher R. Jones[2], Leigh H. Whitehead[2] and Ifan Williams[2]

[1]CERN, Switzerland, [2]University of Cambridge, UK

Particle identification (PID) is a fundamental requirement of any high energy physics (HEP) experiment. The PID system of the LHCb detector makes use of information from several subdetectors: these include two Ring Imaging Cherenkov Detectors (RICH), a calorimetry system and five muon stations [1]. Efficient particle identification is provided over a wide range of different particle momenta. The system is key for distinguishing particles that have similar properties, such as different charged leptons and hadrons or neutral particles such as photons and neutral mesons. PID is also essential to differentiating processes that have a similar decay structure. Simulation of the subdetectors devoted to particle identification is non-trivial. Correctly computing the detector response requires accurate modelling of parameters such as the particle kinematics, the detector occupancy and the experimental conditions associated with the detector. Due to these complexities, this stage of the full LHCb simulation is by far the most time-consuming stage of the overall simulation runtime [2]. The number of particle decays and the complexity of these decays is set to increase as the scope of the experiment is expanded in the future [3]. This means that the time taken to simulate the PID response using the full LHCb simulation will also be increased substantially. This project, as part of a collaboration with CERN openlab, aims to address these issues by investigating a method to produce an accurate, fast-simulation of the LHCb RICH PID response, based on the use of Model-Assisted Generative Adversarial Networks (MAGAN) [4]. A MAGAN is trained to produce a simulated particle identification response indistinguishable from simulated data, given the same set of input conditions, and in a significantly shorter timescale than running the full simulation. Typically, a conventional GAN can only produce an output based on the particular experimental conditions of the data that were used to train the model.

In this model, the variables most affected by a change in data- taking conditions are made explicit as input parameters, so that the model can be made to be self-adjusting to different data-taking conditions. The performance of the final model developed in this study is benchmarked against the full LHCb simulation, in terms of accuracy, runtime and overall reliability.

[1] A. A. Alves, L. M. Andrade, F. Barbosa-Ademarlaudo, I. Bediaga, and G. Cernicchiaro, “The LHCb Detector at the LHC,” JINST, vol. 3, no. LHCb-DP-2008–001. CERN-LHCb-DP- 2008–001, p. S08005, 2008 [Online]. Available: https://cds.cern.ch/record/1129809?ln=en

[2] A.Dotti et al., “Geant4 Computing Performance Benchmarking and Monitoring,” J.Phys. Conf. Ser., vol. 664, no. 6, p. 062021, Dec. 2015 [Online]. Available: https://cds.cern.ch/record/2134601

[3] LHCb Collaboration, “LHCb PID Upgrade Technical Design Report,” CERN-LHCC-2013-022. LHCB-TDR-014, Nov. 2013 [Online]. Available: https://cds.cern.ch/record/1624074

[4] S. Alonso-Monsalve and L. H. Whitehead, “Image-based model parameter optimisation using Model-Assisted Generative Adversarial Networks,” arXiv, 2018 [Online]. Available: http://arxiv.org/abs/1812.00879 (Accepted for publication in IEEE Trans. Neural Netw. Learn. Syst)

Search for the decay of the di-Higgs to four b-quarks in the Vector Boson Fusion production channel at the Large Hadron Collider (LHC) with the ATLAS detector

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The di-Higgs to four b-quarks search performed with the ATLAS detector via the Vector Boson Fusion (VBF) production mode is outlined and discussed. Measuring the decay of the di- Higgs allows a unique insight into the trilinear Higgs self-coupling, a Standard Model parameter that governs the shape of the Higgs potential and has yet to be measured. The Higgs coupling strength is dependent on particle mass and so the decay to a pair of b-quarks is the dominant decay channel, offering the chance to determine highly competitive limits on the trilinear Higgs self- coupling. The VBF channel significantly contributes to the overall signal and to any limit set on the coupling. Additionally, the VBF channel has a particular sensitivity to C2V, the coupling of two Higgs bosons to two vector bosons, especially if influenced by Beyond the Standard Model (BSM) physics. Building on the work of ATLAS's most precise limit on this value so far, this analysis has the potential to produce a leading limit on this parameter.

Studying jet charge with ALICE at the LHC

Jonathan Colburn, Peter Jones, David Evans

University of Birmingham, UK, ALICE Collaboration, Switzerland

Hadronic jets are observed in high-energy nuclear collisions. They result from quarks or gluons that are scattered across large angles in the initial collision. Jets can be used as a probe for the deconfined state of matter created from these collisions, a quark gluon plasma (QGP). Quark-gluon plasma 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 the QGP, 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 [1] is used to distinguish between jets originating from quarks or gluons. This is important as quark and gluons interact differently with the QGP. Experimentally, reconstructing the jets in the high multiplicity environment which results from a heavy-ion collision is challenging. The background from the collision must be subtracted to study a jet's substructure. Feasibility has been established through a study that reconstructs jets charge for simulated jets from the Pythia event generator. A randomly generated background was added to these jets to simulate the background environment from Pb-Pb collisions. This poster will assess the possibility of measuring jet charge in pp, p-Pb and Pb-Pb events from LHC run 2 data.

[1] Field, R.D. and Feynman, R.P., 1978. A parametrization of the properties of quark jets. *Nuclear Physics B*, *136*(1), pp.1-76.

Measurement of the Drell-Yan production cross-section at LHCb

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[1]CERN , Switzerland [2]University of Liverpool, UK [3]University of Birmingham, UK [4] Universitaet Zuerich, Switzerland

This poster presents an outline of the ongoing measurement of the Drell-Yan cross-section through the dimuon channel at LHCb. The measurement will be made using the data collected from 2016-18 by LHCb at $\sqrt{s}$ = 13 TeV, complementing the previous measurement using 37 fb^{-1} 2010 data at $\sqrt{s}$ = 7 TeV [1]. The cross-section will be measured differentially in bins of dimuon mass and rapidty, as well as dimuon mass and transverse momentum. Yields are obtained via fits of the χ^2_{IP} variable, based on the method used in the Search for Dark Photons at LHCb, using templates for a prompt signal with displaced and misidentification backgrounds [2].

[1] LHCb Collaboration, LHCb-CONF-2012-013

[2] LHCb Collaboration, Phys. Rev. Lett. 120 (2018) 061801

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

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Measuring the fusion cross-sections of the production reaction that form the chemical elements is at the centre of interest regarding some astrophysical scenarios. In particular, and given the significance that carbon has to do with life in general, the reaction $^{12}C+^{12}C$ is important to understand the further processes of nucleosynthesis that give birth to heavier elements which takes place in supernovae type Ia or in superbursts from accreting neutron stars. Therefore, this reaction has been studied since long time ago, however they show considerable discrepancies as the energy approaches the energy of the Coulomb barrier, resulting in obtaining different values of the astrophysical S-factor [1,2]. The particular behaviour it, at low energies, lead to different hypothesis to explain its behaviour in the nuclear structure regime.

In this work, it will be shown the approach it was 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 the previous efforts of measuring this reaction and this present work is that coincidences between charged particles and gammas were obtained.

Data analysis is currently ongoing nonetheless some plots are shown.

[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)

Measurement of conversion coefficients using a charge plunger and the MARA mass separator

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Keatings[1], M. Leino[5], M. Luoma[5], D. O'Donnell[1], J. Ojala[5], J. Pakarinen[5], P. Rahkila[5], P. Ruotsalanen[5], M. Sandzelus[5], J. Sarén[5], J. Sinclair[1], J.F. Smith[1], J. Sorri[6], H. Tann[5], J. Uusitalo[5], G. Zimba[5]

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The charge plunger technique is based on the internal conversion process that dominates over the gamma decay of the excited states, particularly in heavy nuclei. When nuclei decay through conversion process, atoms typically obtain high charge states. In a plunger setup with one target foil (where excited states in nuclei of interest are produced) and a reset foil (that resets ionic charge state), charge state distribution (CSD) of ions at the exit of the reset foil can be measured using a mass separator. The measured CSD can be used to extract lifetimes of the excited states in nuclei without directly observing nuclear transitions [1]. However, a good knowledge of the internal conversion coefficients, α, for the excited states is required to extract lifetimes from CSD. The importance of experimentally obtaining this coefficient lies in the fact that for each CSD, contributions come both from electron and gamma-ray emission. Specifically, lower charge values in CSD have contributions both from the gamma-ray emissions before and after the reset foil. To estimate these contributions and to extract lifetimes of excited states in nuclei reliably, the conversion coefficients for excited states are required.

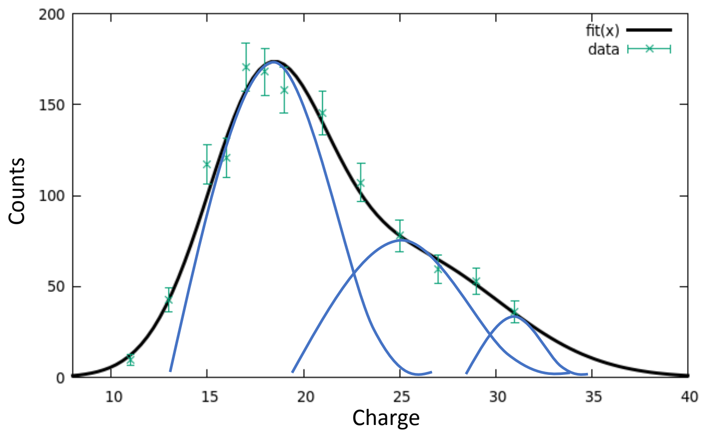

Figure 4: At small plunger distances the recoil always decays after the foil. From the ratio between CSD one can measure *α*.

A test experiment for the charge plunger technique was performed at the accelerator laboratory in Jyväskylä with the MARA setup [2]. Figure shows a charge state distribution measured in this experiment for the decay of the excited states in ^{178}Pt when target and reset foils are very close and almost touching. During the workshop, results on conversion coefficients, α, for excited states in ^{178}Pt nuclei obtained from such CSD will be presented. The influence on the result for lifetime will be discussed.

[1] G. Ulfert *et al.*, Nucl. Instr. Meth. In Phys. Res. A **148**, 369 (1978).
[2] B.S. Nara Singh, (M16) Proof of principle test of lifetime measurements using charge plunger at MARA, July 2019.

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

Lakshan Ram for the LHCb Collaboration

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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+ μ+ μ- 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.

Online Event Classification for trigger using Sparse Convolutional Neural Networks at DUNE

Lewis Lappin, on behalf of the DUNE Collaboration

University of Edinburgh, UK

The Deep Underground Neutrino Experiment (DUNE) is an experiment for long-baseline neutrino oscillation studies, neutrino astrophysics and nucleon decay searches. The far detector will be composed of a series of liquid Argon time projection chambers (LArTPC) which will produce image like data of particle tracks travelling through the detector. One of the main scientific goals of DUNE is to observe a supernova event, which is expected over the course of the experiments lifetime [1]. Such an observation would provide huge insights into the mechanics of these astrophysical events. Although DUNE is able to trigger on beam line neutrino bursts, due to the unpredictable nature of supernovae, a robust online triggering mechanism is required in order to capture one of these events. The image like nature of the data produced from DUNE makes it an ideal target for deep learning approaches, which is long established. The effectiveness of two approaches, Convolutional Neural Networks and Sparse Convolutional Networks will be used for classifying supernova neutrinos from backgrounds enabling a High Level Trigger decision to stream the SNB data to the dedicated DAQ buffer. Convolutional Neural Networks (CNN) have great effectiveness in image like data with spatial correlations, however traditionally this data is information dense, unlike the data produced by DUNE, making training and evaluation more computationally intense. Sparse CNNs take advantage of this and thus reduce the computational requirements, making them more suitable for online evaluation of large data sets [2].

[1] DUNE Collaboration, The DUNE Far Detector Interim Design Report, Volume 3: Dual-Phase Module, arXiv:1807.10340 [physics.ins-det] (2018)

[2] B. Graham, Spatially-sparse convolutional neural networks, arXiv:1409.6070 [cs.CV] (2014)

Combined Reconstruction of Event Pairs in Gd-H2O for Reactor Anti-neutrinos

Liz Kneale

University of Sheffield & AWE, UK

Inverse beta decay (IBD) interactions of anti-neutrinos in gadiated water give a correlated positron-neutron signal. We are developing a combined position reconstruction which uses information from both events to give a common IBD interaction vertex.
Gadolinium-doped water for anti-neutrino detection is an emerging technology and the WATCHMAN collaboration has proposed a Gd-H2O detector to demonstrate a scalable application for remote reactor monitoring.
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 fit improves position resolution. This is expected to lower the threshold energy for detection compared to a single-event fit. Reconstructing pairs helps reject random coincidences of uncorrelated

radioactive background events and a method of pair selection is being developed to discriminate optimally between the signal and background for more powerful background reduction.
This talk presents the current status of the IBD pair reconstruction and plans for further development.

Graph neural network for event reconstruction in DUNE

Marin Mlinarevic, on behalf of DUNE collaboration

University of Edinburgh, UK

The Deep Underground Neutrino Experiment (DUNE) is due to start taking neutrino beam data in 2026. It will use a 40kt fiducial mass far detector and the most intense neutrino beam. It will use a near detector at Fermilab and a far detector 1300 km away at the Sanford Underground Research Facility (SURF), allowing it to perform long-baseline neutrino oscillation studies. The far detector will consist of four 10-kt fiducial mass liquid argon time projection chambers and will also be used for nucleon decay searches and neutrino astrophysics. A number of approaches are being explored for reconstructing events from the hits produced in the detector. The goal is an efficient implementation that will be used as a trigger for data reduction within the DAQ. This poster presents the use of graph neural networks for pattern recognition.

Mass measurement and energy level analysis of 190-Re using the Q3D magnetic spectrograph

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Studies into the properties of nuclear isotopes are important as accurate experimental measurements can be compared to known theories and help elucidate any issues or shortcomings. In some cases, further practical uses for isotopes may be found subsequent to the study of their properties, such as isotopes which are used in medical applications, either for treatment or imaging.

The Q3D magnetic spectrograph at the Maier-Leibnitz Laboratory (MLL) in Munich [1] was used to produce the isotopes 190-Re and 192-Ir by bombarding targets of 192-Os and 194-Pt, respectively, with an 18 MeV deuteron beam. The desired isotopes were produced alongside α-particles in the 192-Os(d,α)190-Re and 194-Pt(d,α)192-Ir reactions. The spectrograph was then used to measure the energy of the α-particles in order to reconstruct the excited states in both Re-190 and Ir-192. Gating on energy and energy-loss in various stages of the focal plane detector was used to identify the α-particles.
States in 190-Re and 192-Ir were fitted with Gaussian functions in order to assign centroid values to the peaks. An energy calibration was produced by comparing peaks in the well known 192-Ir spectrum to known energy levels [2]. This calibration was used to obtain the difference in Q-values for the reactions 192-Os(d,α)190-Re and 194-Pt(d,α)192-Ir. As the values for the masses of 194-Pt, 192-Os and 192-Ir are well known, this difference enabled measurement of the atomic mass of 190-Re to a higher precision than previously published.

[1] C.A. Wiedner et al. Performance of a QDDD spectrograph. *Nucl. Instrum. Methods*, 105:205-210, 1972.
[2] Coral M. Baglin, Nucl. Data Sheets 113, 1871 (2012).

Quality Assurance measurements on quartz windows for the Ring Imaging Cherenkov detector (RICH1) of the LHCb Upgrade

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University of Oxford, UK

The LHCb experiment has two RICH detectors which provide pion/kaon particle identification in a momentum range between 2-100 GeV/c. The Cherenkov light produced in RICH1 (upstream) is focused onto the lower and upper photodetector planes by spherical and planar mirrors. The photodetector planes are separated from a volume of C4F10 Cherenkov radiator gas by two transparent planes of quartz, called "windows". As part of the upcoming upgrade of the LHCb detector, new quartz windows have been commissioned. Excellent transmission performances are required to maintain high detection standards. For quality assurance purposes, transmission measurements on small manufacturing samples have been performed at the CERN Optics facility. We will present the method used to perform the measurements and the results.

Upgrade of the ALICE Inner Tracking System in LS3 Based on Ultra-thin, Wafer-scale Bent Monolithic Active Pixel Sensors

Matthew Buckland

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. In order to achieve this, ultra- thin (20-40 μm), wafer scale (300 mm) Monolithic Active Pixel Sensors 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 allowing an unprecedented low material budget of below 0.05% X0 per layer and a distance of 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. This contribution aims to give a summary of the physics motivations and details about the detector and R&D plans.

Search for dibaryon with CLAS12 collaboration

Matthew Nicol

University of York, UK

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.

Investigation of coherent $\pi^0\pi^0$ photoproduction at A2@MAMI and its connection to the mass of the neutron stars

Mihai Mocanu

University of York, UK

Quantum chromodynamics does not forbid particles that result from higher numbers of quarks. Previous experiments have shown that higher quark configurations (four, five, six) are possible. The work presented is looking at the coherent production of $\pi^0\pi^0$ from the photoexcitation of a Ca-40/48 targets using a 1.5GeV Bremsstrahlung photon beam at the A2@MAMI experiment in Mainz (Germany). The experiment is looking for the production of the best known candidate for the hexaquark, the d*(2380). The d*(2380) hexaquark is an exotic particle formed of six quarks (uuuddd), whose nuclear interactions are currently unclear. This analysis is used to investigate the d*(2380) production inside nuclear medium, the interaction strength between hexaquarks and the coupling constants to σ and ω mesons associated with such interactions. The implications of the d*(2380) in-medium properties to the equation of state of the neutron star will be discussed. Astrophysical consequences of hexaquark matter formation on the maximum allowed mass of the neutron star as well as on gravitational wave observations of the neutron stars mergers will be outlined.

ATLAS ITk Strip Detector Module Production for the High-Luminosity LHC

Mitchell Norfolk and Trevor Vickey

The University of Sheffield, UK

Preparation is underway for an upgrade of the ATLAS experiment inner tracking detector for High Luminosity LHC (HL-LHC) operation. The HL-LHC hopes to achieve an ultimate instantaneous luminosity of 7.5×10^{34} $cm^{-2}s^{-1}$, corresponding to 200 inelastic proton-proton collisions per beam crossing (pile-up) [1]. To compliment this, ATLAS is aiming to take 3000 fb^{-1} worth of data over a 10 year period. In order to meet this enormous challenge, production of components for an all silicon Inner Tracker (ITk) will commence shortly. The inner detector will be composed of a pixel detector surrounded by a strip detector. The ITk strip detector will consist of 4 central barrel layers and 6 end-cap disks each containing modules for the detection of charged particles [1]. This work shows the assembly of the prototype ITk strip barrel modules, many institutions will be required to assemble these modules and log metrology, electrical performance and other properties to the Inner Tracker Production Database (ITkPD) currently under development.

[1] ATLAS Collaboration, Technical Design Report for the ATLAS Inner Tracker Strip Detector, CERN-LHCC-2017-005

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

Mohammad E. Alsulimane[1 2], Jon Taylor[1], Carlos Barajas[1], Gianluigi Casse[1], Alan Taylor[1], A. Omar[3], Sergey Burdin[1]

[1]University of Liverpool, UK, [2]King Abdulaziz University, Saudi Arabia, [3]Military Technical College, Egypt

There has been a rapid worldwide increase in the number of proton therapy PT centres over the last 20 years. This increase is driven by proton therapy's advantageous dose distribution when compared to treatment with photons. While the prescribed dose is delivered to the tumour with minimal exit dose to the healthy structures beyond, one of the concerns particular to PT is the secondary radiation that is created during treatment. Neutrons created as a result of proton interactions with human tissue will increase the probability of secondary cancers developing in surrounding tissues. The quantity of neutrons created depends on tissue type, beam energy, and delivery technique. Therefore, the aim of this research is to investigate, monitor and track the dose distribution of protons and associated neutrons, when delivering the prescribed dose to the targeted cells.

In this project we are using Geant4 to simulate the pencil proton beam and its interactions with a water phantom and sandwich detector which involves two silicon pixel sensors separated with 6LiF film/6Li foil as a thermal neutron converter layer to increase the thermal neutron capture probability in order to measure the thermal neutrons generated in the water volume of the phantom. The sandwich detector is fully submerged in the water phantom and located in the main path of the proton beam in order to track the primary proton particles, measure the Bragg peak by means of the particle energy loss in the sensors and monitor the thermal neutron productions.

Feasibility study for the implementation of flavour-k_T jet algorithm

Naomi Cooke[1], Philip Ilten[1], and Rhorry Gauld[2]

[1]University of Birmingham, UK, [2]Nikhef, The Netherlands

Massless NNLO calculations of heavy flavour production require the use of the flavour-k_T algorithm in jet clustering. However, in flavour-k_T, the combined flavour of the partons in each jet must be known. Two avenues of implementation will be investigated. Firstly, to test the implementation of the flavour-k_T algorithm at the experimental level. Secondly, through an unfolding procedure to map flavour-k_T to anti-k_T [1].

[1] - A. Banfi et al. "Infrared safe definition of jet flavor". In: *Eur. Phys. J.* C47 (2006), p. 113-124.

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

Oscar Hall on behalf of the BRIKEN collaboration

University of Edinburgh, UK

The rapid-neutron capture process (r-process) is thought to be responsible for the production of around half the elements heavier than iron. Despite first being proposed almost six decades ago, the astrophysical site of the r-process remains an open question. The multi-messenger observation of gravitational waves originating from a binary neutron star merger (GW170817) and its electromagnetic counterpart provided evidence indicating that a possible r- process had occurred, providing a possible answer to this question. The accurate modelling of the nucleosynthesis processes taking place in such mergers requires precise nuclear input data, including nuclear masses, beta-decay half-lives, and beta-delayed neutron emission probabilities. 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 $^{132}_{82}\mathrm{Sn}$ 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. Here beta-decays were measured in coincidence with neutrons that were detected using the BRIKEN neutron counter array. This poster will present the analysis methods used to obtain the beta-delayed neutron emission probabilities of nuclei along the N=82 shell closure.

Will Sk-Gd discover supernova relic neutrinos?

Owen Stone

University of Sheffield, UK

It has long been known that when high-mass stars 'die' they explode as a core-collapse supernova. These climactic events produce immense amounts of energy (~1053 ergs) primarily in the form of neutrinos. 24 neutrinos from SN1987A in the Large Magellanic Cloud were observed in 1987, sparking long-lasting interest and kick-starting multi-messenger astronomy. Unfortunately, there have been no similar supernovae since, which has driven the community to search for supernova neutrinos in a different form. Assuming neutrinos are absolutely stable, the neutrinos from every core-collapse supernova throughout all of history should exist as a diffuse background in the Universe. These are termed supernova relic neutrinos (SRN). Super-Kamiokande (SK) is a water Cherenkov detector that has been used to search for SRN. The dominant process by which SRN are observed in SK is inverse beta decay (a positron and coincident neutron). To date, no signal has been conclusively detected owing to significant backgrounds, primarily Michel electrons from sub-Cherenkov muons created by low-energy atmospheric muon neutrinos interacting in the detector. Observing the neutron in SK would suppress many of these background events, but is challenging because of the low neutron capture cross-section in water. SK is soon to be upgraded by doping the water with gadolinium (Gd) to increase the efficiency of neutron tagging. Efficient detection of the neutrons allows exploitation of the delayed coincidence to discriminate the SRN signal from the background. Here I will discuss the prospects of SK-Gd regarding the detection of SRN.

Muon Ionization Cooling Demonstration by Normalised Transverse Emittance Reduction in MICE

Paul Bogdan Jurj

Imperial College London, UK

Low emittance muon beams are central to the development of facilities such as a Neutrino Factory or a Muon Collider. The international Muon Ionization Cooling Experiment (MICE) was designed to demonstrate and study the cooling of muon beams. Several million individual muon tracks have been recorded passing through a liquid hydrogen or lithium hydride absorber. A beam sampling routine was implemented to account for imperfections in the beam optics and optimise the cooling performance. Measurements of the change in normalised transverse emittance are presented and the characteristics of the cooling effect are discussed.

A time-dependent Hartree-Fock study of triple-alpha dynamics

Paul Stevenson

University of Surrey, UK

Time-dependent Hartree-Fock calculations have been performed for fusion reactions of ^{4}He + ^{4}He -> $^{8}Be^*$, followed by ^{4}He + $^{8}Be^*$. Depending on the orientation of the initial state, a linear chain vibrational state or a triangular vibration is found in ^{12}C, with transitions between these states observed. The vibrations of the linear chain state and the triangular state occur at ~9 and ~4 MeV respectively.

[1] Paul D. Stevenson and Jamie L. Willerton, *accepted for proceedings of EFB24 conference, to be published in SciPost Phys. Proc.* (1909.01924)

Far-field nuclear reactor monitoring with antineutrinos

Robert Foster

University of Sheffield, UK

Nuclear reactors produce immense numbers of antineutrinos (~10^{20} GWth^{-1} s^{-1}) during the fission process. The antineutrino emission cannot be shielded and therefore interest has been shown in using antineutrino detection as a tool for monitoring nuclear reactors to ensure that they are used only for

peaceful purposes. Near-field (< 100 m) reactor monitoring using antineutrinos has been successfully demonstrated but far-field monitoring has yet to be achieved.
The WATCHMAN collaboration has proposed a 6 kt gadolinium-doped water Cherenkov antineutrino detector which will be situated at Boulby Underground Laboratory in North Yorkshire. From this location it will attempt to remotely monitor the Hartlepool nuclear reactor complex, some 26 km away. Antineutrinos will be detected through the inverse beta decay process ($\bar{\nu}_e + p \rightarrow e^+ + n$), which produces a positron and neutron that are observable in the detector. The positron emits Cherenkov light and the neutron captures on gadolinium, which de-excites in a photon cascade. These two coincident signals form an unambiguous antineutrino signature.
This poster will provide an overview of the current status of the detector design and ongoing work including the prototyping of a nitrogen-16 calibration method and sensitivity studies with water-based liquid scintillator, a novel detection medium that could be used in the initial or future phases of the detector.

Dark matter detection and background studies with the COSINE-100 NaI detecto

Robert Neal

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COSINE-100 is a dark matter detection experiment based at the Yangyang underground laboratory in South Korea that uses NaI(Tl) crystals to search for an annual modulation signal generated from the changing flux over the year of WIMPs through the Earth, generated by Earth’s motion around the Sun. The same target material and signal measured by the DAMA experiments which is the only dark matter detection experiment to achieve a positive (although contested) dark matter signal.

Since the COSINE-100 experiment uses the same target material as DAMA it can provide a model-independent test of the DAMA result. Unlike DAMA, COSINE-100 utilises active shielding including 2000 L of Linear Alkyl-Benzene liquid scintillator (LS) which allows for more detailed understanding of backgrounds and a more complete understanding of signal and background events in NaI experiments.

This poster will describe the COSINE-100 detector in more detail, in particular the long-term stability and annual modulation behavior of backgrounds in the LS, as well as recent results placing constraints on the DAMA signal [1,2].

[1] G. Adhikari et al. (COSINE-100 Collaboration), *Nature* 564, 83 (2018).

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

Measuring the Reconstruction Efficiency of the ATLAS Inner Detector for Close-by Tracks

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Boosted objects in hadronic final states are sensitive probes to potential new physics. In such cases, jet substructure studies are crucial to unveil the underlying physics. However, the separation between charged particles in these jets are of the order of the granularity of the ATLAS inner detector, hindering their reconstruction. To optimise the performance of the inner detector, a dedicated optimisation for dense environments was performed and was implemented in ATLAS for LHC Run 2. In this work, a data-driven measurement of the inner detector reconstruction efficiency for close-by tracks is presented, using the tag-and-probe method on boosted $J/\psi \rightarrow \mu\mu$ decays. To achieve the required boost, the high pT component of the J/ψ production is used. In this region of the phase space it is a challenge to model the background and signal with simulation. To overcome this a resampling technique is implemented.

Systematic measurements of proton decay-energies

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Proton emission is an important spectroscopic tool used in exploring the structure of nuclei beyond the proton drip line. The extreme sensitivity of proton-decay half-lives to the energy of the emitted protons allows the orbitals from which the protons are emitted to be identified, while systematics of reduced proton-decay widths provide a crucial test of theoretical model calculations. However, it has become apparent that the non-linear energy response of silicon detectors needs to be considered properly to obtain reliable measurements of the proton energies and size of the effects could have a significant systematic impact on previous results. To investigate the scale of these effects and their consequences, an experiment was conducted at the University of Jyväskylä using beams of ^{58}Ni and ^{78}Kr ions to bombard ^{92}Mo, ^{96}Ru, ^{102}Pd and ^{106}Cd targets to populate and study ~20 known proton-emitting states. The latest results from the data analysis will be presented.

[1] Page R.D. et al. 1996 Physical Review C **53** 660

[2] Lennard W.N. et al. 1990 Nuclear Instruments and Methods in Physics Research B **45** 281

[3] Hofmann S. 1989 Particle Emission from Nuclei, vol. 2, CRC Press

Electronics developed for the CHIPS neutrino detector

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The CHIPS (CHerenkov detectors In mine PitS) experiment is prototype neutrino detector in the path of the NuMI beam with the goal of building large water Cherenkov detectors in a flexible yet cheap way. The CHIPS collaboration has developed a new innovative electronics system for photomultiplier tubes (PMTs) for readout and control utilizing modern smartphone era components and off the shelf hardware. The "microdaq" provides a flexible platform for PMT deployment and can be used to power, trigger, record and return data. It is reprogrammable so can be used for pre-processing detector data. The CHIPS detector utilizes planes of PMTs, each detector plane has a central control board which communicates with microdaqs and receives data, which is designed around a BeagleBone single board Linux computer so each detector plane is capable of independent operation and acts like a full computer system. CHIPS uses the White Rabbit timing system to provide nanosecond precision timing signals to the microdaqs so each PMT hit has full timing precision [1]. Due to the flexibility of the microdaq software and the fact that each plane is a computer, work is continuing to utilizing the hardware to its full potential and potentially expanding the hardware for further use. The CHIPS detector was deployed in Autumn 2019 with 6 planes using the new electronics.

[1] White Rabbit. https://www.ohwr.org/projects/white-rabbit.

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

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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. Furthermore, the future goals and development prospects in light of the unique opportunities it can provide in the field of low energy nuclear physics.

A Novel Hit-Based Method to Distinguish Tracks and Showers in ProtoDUNE Single Phase

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Pandora [1,2] is a pattern recognition software used in liquid argon time projection chamber (LArTPC) experiments such as MicroBooNE, DUNE, SBND, ICARUS, and ProtoDUNE Single Phase (SP). The output of a LArTPC can be considered a high-resolution 2D image and energy depositions, called hits, from particles in a LArTPC create complicated topologies that are broadly classified into tracks and showers. The event reconstruction is particularly challenging when there are multiple overlapping particles and in order to fully harness the imaging capabilities of those experiments, Pandora needs to separate them. A hit-based approach to this problem is presented, which analyses small regions around each hit in data events from ProtoDUNE-SP and from those regions it calculates local variables that are used subsequently in a machine learning approach. After this stage, it is given to each hit a probability to belong to a track or shower-like particle. Results will show the performance of separation between tracks and showers.

[1] Eur. Phys. J. C (2018) 78: 82.

[2] Eur. Phys. J. C (2015) 75: 439.

Underground Measurement of ^{6}Li(p,α)^{3}He and ^{6}Li(p,γ)^{7}Be at LUNA

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Big Bang Nucleosynthesis (BBN) theory coupled with Cosmic Microwave Background measurements provides accurate abundance predictions for cosmological light element abundances [1], which are then compared to measurements from stellar environments. ^{6,7}Li isotopic abundances are determined from spectral analysis of radiation emitted from the outer atmospheres of low mass pre-main sequence (PMS)

stars. Currently the measured abundance of ^{6}Li is 5000 times higher than predicted. Two proton-induced destructive reactions of ^{6}Li: ^{6}Li(p,α)^{3}He and ^{6}Li(p,γ)^{7}Be, have an impact on the predicted ^{6}Li abundances. The ^{6}Li(p,γ)^{7}Be reaction was previously measured down to low centre-of-mass energies (E_{cm} < 300 keV) whereby a drop in the reaction S-factor is reported [2]. This drop was attributed to a resonance at E_{cm} = 195 keV, Γ_p = 50 keV, which has not been confirmed by previous direct measurements nor by theoretical predictions.
To investigate this reaction mechanism further, both reactions were studied at astrophysically relevant energies during an experimental campaign at the Laboratory for Underground Nuclear Astrophysics (LUNA), using the LUNA-400kV accelerator located under the Gran Sasso mountain in Italy. Thanks to its underground location, LUNA benefits from additional cosmic-ray suppression, resulting in a millionfold natural background reduction compared to surface laboratories [3]. As a result, measurements can be carried out at lower energies, i.e. those of direct astrophysical interest. The experimental set-up and the current status of the data analysis will be shown.

[1] R. H. Cyburt et al, Rev. Mod. Phys. 88, 015004 (2016).
[2] J. He et al. Phys. Lett. B. 725, 287-291 (2013).
[3] A. Caciolli et al, EPJ A. 39, 179 – 186 (2009).

Mass-decorrelated jet substructure classification of hadronically decaying vector bosons

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Substructure variables are useful in the classification of large-radius jets encompassing highly boosted and consequently collimated decay products. Estimators from multivariate classifiers utilising such variables exhibit generally non-linear correlations to the reconstructed jet-mass. In an analysis, the application of such estimators may lead to unwanted sculpting of the jet-mass distribution of the background biasing it towards the shape of the signal. Several methods (adversarial neural networks, distance correlation penalty, genetic training) are presented of how to optimise a classifier with respect to the opposing objectives of classification power and mass-decorrelation. They are applied and compared in the case of a tagger for hadronically decaying vector bosons.

Selecting charged current ν_μ interactions that result in γs in the T2K near detector

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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 expected number of CC interactions at the far detector in the case of no oscillation can be predicted using information from the near detectors. CC samples at 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 more than one charged pion or 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. In addition to π^0 decays, there are also non-negligible decay modes of etas, kaons and lambdas that lead to photon production. 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 established CC0π and CC1$\pi^\pm$ samples have some small contamination from CCOther events. This work has shown promise for providing a method to remove these events from the samples. Results from the selection will be implemented into the T2K oscillation analysis framework and thus used to improve the systematic uncertainty associated with these photon-producing events. In turn, this can help to constrain event rates and neutrino energies at the far detector Super-Kamiokande.

[1] T2K Collaboration. The T2K Experiment. Nucl. Instr. Meth. Phys. Res. A, 659(1), 2011

Improving global fits of neutrino oscillation data using the GAMBIT framework

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Neutrino oscillations are an important area of physics to study as they are a clear deviation from the standard model. There are many experiments studying neutrino oscillations, including long and short baseline accelerator and reactor experiments; and atmospheric and solar neutrino experiments. These experiments all produce their own constraints on the oscillation parameter space. Combining the results would increase the constraints even further, but this is no easy task considering the myriad of different analysis techniques used to reach the results of each experiment. This can be simplified by reducing the experimental results to likelihood values, which can be easily combined to produce a joint result. Global fits like this have been done in the past - most notably by nuFit [1] - however, these fits are often performed by physicists outside of the experimental collaborations that collect the neutrino oscillation data, hence they do not have access to certain information and data that could help improve the accuracy of the fit. This poster presents details of the global fitting tool, GAMBIT, and plans on how to implement an improved global fit of three neutrino oscillation data within its framework using knowledge from the T2K collaboration.

[1] I. Esteban, *et al.,* J. High Energ. Phys. 2019 106 (2019).

DUNE FD calibration using cosmic- ray muons

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The Deep Underground Neutrino Experiment (DUNE) is an international project for neutrino physics and astrophysics and a search for rare events predicted by theories beyond the standard model. The excellent imaging, tracking and particle identification of Liquid Argon Time Projection Chamber (LArTPC) technology utilised in the Far Detector (FD) allow the experiment to achieve high sensitivity to various high-energy phenomena. Detector calibration is essential to exploit the DUNE FD LArTPC technology fully and to understand detector response. Cosmic-ray muons can be used for various calibrations approaches. Using the MUon Simulation Underground (MUSUN) particle generator tool, cosmic muons have been simulated and analysed within the LAr software framework LArSoft. This poster presents a characterisation of cosmic muon events in the DUNE FD, focusing on energy and angular distributions of the muons, and determination of rates of different classes of muon events: stopping muons, muons crossing anode/cathode planes, etc. An initial study of the measurement of drifting electron lifetime is also presented.

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