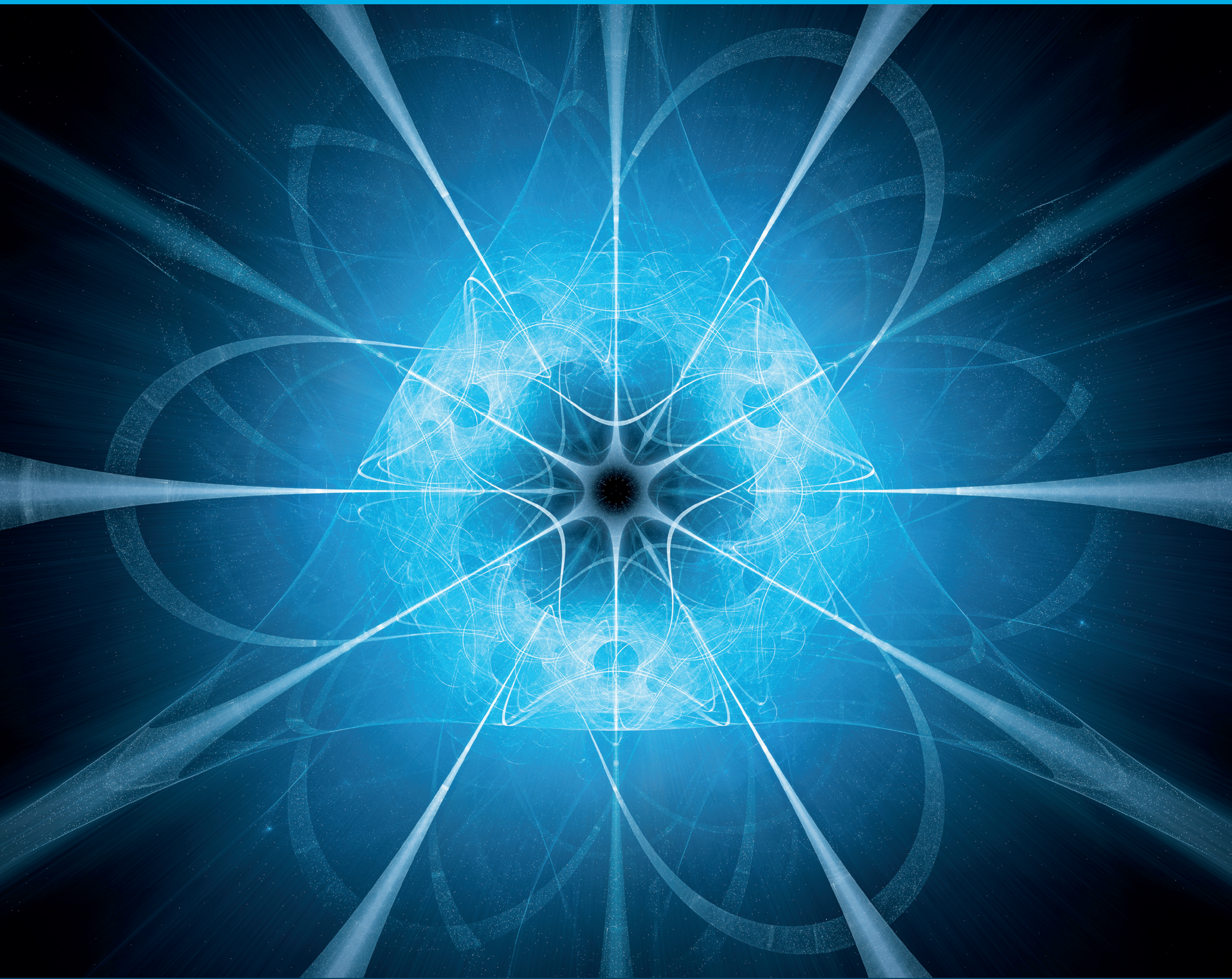
Abstract Book



IOP Annual Nuclear Physics Conference 2018

4–6 April 2018
University of the West of Scotland
Paisley, UK

Organised by the IOP Nuclear Physics Group

IOP Institute of Physics

Welcome

Welcome to the annual Institute of Physics Nuclear Physics conference for 2018. This year, the conference is being held in Paisley for the first time and is hosted by the University of the West of Scotland. Over the three-days of the conference, we will have about 15 plenary talks and almost 50 oral presentations in the parallel sessions, along with about 10 poster presentations. The conference is intended to be a showcase of nuclear-physics research in the UK so we have tried to represent all areas of UK nuclear-physics activity on the programme including nuclear structure, nuclear astrophysics, hadron physics, and applied nuclear physics. We also have a number of invited speakers from overseas, who will present an international perspective. The programme includes a public lecture by Professor Jim Al-Khalili on the first day, giving the general public an opportunity to engage with the conference. Social aspects of the conference are very important so that delegates can get to know each other in a more relaxed setting – on the first day we have a whisky tasking session alongside the poster session, and on the second day we have a conference dinner in the historic Paisley Abbey. We hope that you enjoy your visit to Paisley and that you find the conference rewarding and engaging.

John F. Smith

Conference chair

Programme

Wednesday 4 April

09:00	Registration and coffee
09:30	Welcome and Introduction

Plenary session 1

10:00	(invited) **Exploring beyond the proton drip line** Robert Page, University of Liverpool, UK
10:30	(invited) **Coulomb-excitation measurements as a probe of nuclear structure** Daniel Doherty, University of Surrey, UK
11:00	Coffee Break

Plenary session 2

11:30	**Isospin symmetry studies in the A=80 region** Ryan Llewellyn, University of York, UK *Summer school prize winner*
12:00	(invited) **Neutron reactions for astrophysics at n_TOF, CERN** Claudia Lederer-Woods, University of Edinburgh, United Kingdom
12:30	Lunch
13:30	**IOP Nuclear Physics Group annual general meeting**

	Parallel session 1	Parallel session 2
14:00	**Investigation of pygmy dipole resonance of ^{136}Xe** Pietro Spagnoletti, University of the West of Scotland, UK	**Shape coexistence and shape evolution of Bismuth isotopes in the neutron deficient lead region by in source laser spectroscopy** Christopher Raison, University of York, UK
14:15	**Multi-strange baryon production in p-Pb collisions at sqrt(s) = 8.16 TeV with ALICE at the LHC** Emily Willsher, University of Birmingham, UK	**Self-consistent collective path and two-body dissipation effect in nuclear fusion reactions** Kai Wen, University of Surrey, UK

14:30	**Study of the evolution of octupole collectivity in 218Ra** James Keatings, University of the West of Scotland, UK	**Investigation of excited states and octupole deformation in neutron-deficient ^{116}Ba** Nicola Kelly, University of the West of Scotland, UK
14:45	**Using a novel method to determine resonance strengths within ^{26m}Al(p,γ)^{27}Si using GRETINA and S800 Spectrometer** Samuel Hallam, University of Surrey, UK	**Exploring stellar helium burning with gamma-ray beams and active target detectors** Robin Smith, Sheffield Hallam University, UK
15:00	Coffee Break	
	Parallel session 3	Parallel session 4
15:30	**Gamma-ray spectroscopy of neutron deficient N ≈ 82 nuclei** Muhammad Majid Rauf Chishti, University of the West of Scotland, UK	**Proton imaging with silicon detectors** Marianna Chiesa, University of Birmingham, UK
15:45	**Observation of the $\Delta n = 0$ selection rule in the β decay of ^{207}Hg** Tom Berry, University of Surrey, UK	**Timing performance of the Birmingham lanthanum bromide array** Anthony Turner, University of Birmingham, UK
16:00	**3D printed patient-specific organ phantoms for SPECT quantification** Emlyn Price, University of Manchester, UK	**Calculations of infinite matter in a periodic box** Chris McIlroy, University of Surrey, UK
16:15	**Collinear resonance ionization spectroscopy for trace analysis** Sultan Alsufyani, University of Manchester, UK	**Polarimetry for linearly polarised photons using coherent pion production at MAMI** Abby Powell, University of Glasgow, UK

Plenary session 3

16:30 (invited) **On the road towards a nuclear clock: what do we know about the 229-Thorium isomer?**

Peter Thirolf, Ludwig-Maximilians-Universität München, Germany

Poster session

17:00 With exhibition and whisky tasting

Public Lecture

18:30 (invited) **Who split the atom?**

Jim Al-Khalili, University of Surrey, UK

19:30 Buffet dinner

IOP Annual Nuclear Physics Conference 2018

Thursday 5 April

08:30	Registration and coffee

Plenary session 4

09:00 (invited) **Transfer reactions for experiments: theory and its uncertainties**

Natasha Timofeyuk, University of Surrey, UK

09:30 (invited) **Hadron physics at Jefferson lab**

Bryan McKinnon, University of Glasgow, UK

10:00 (invited) **High-resolution laser spectroscopy experiments at the extremes of the nuclear chart**

Ronald F G Ruiz, University of Manchester, UK and European Organisation for Nuclear Research (CERN), Switzerland

IOP prize winner

10:30 (invited) **Nuclear structure physics at HIE-ISOLDE**

Liam Gaffney, European Organisation for Nuclear Research (CERN), Switzerland

11:00	Coffee Break

	Parallel session 5	Parallel session 6
11:30	**Decay of the 19- isomer in ^{156}Lu** Michael Lewis, University of Liverpool, UK	**Modelling (d,p) transfer reactions with non-local nucleon-target optical potentials** Michael Dinmore, University of Surrey, UK
11:45	**Development of 3D position sensitive scintillation detectors** Jamie Brown, University of York, UK	**Gamma emission from the ^{16}O* nuclei** Pedro Humberto Santa Rita Alcibia, University of Birmingham, UK
12:00	**Search for the decays of the 19^{-} multiparticle isomer in ^{160}Re** Andrew Briscoe, University of Liverpool, UK	**Towards a more precise measurement of the Q(2+) in 12C: testing state-of-the-art ab initio theories** Juan Saiz Lomas, University of York, UK
12:15	**Shape coexistence and decay spectroscopy in gold isotopes studied by in-source laser spectroscopy at RILIS-ISOLDE** Robert Harding, University of York, UK	**Study of the pygmy dipole resonance in 96Zr following the beta decay of 96Y** Konstantin Mashtakov, University of the West of Scotland, UK

12:30	Lunch

Plenary session 5

13:30 (invited) **The DEPICT Project - developing a gamma camera system for dosimetry of molecular radiotherapy**

Lucy McAreavey, University of Liverpool, UK

Summer school prize winner

14:00 (invited) **Characterising hot nuclear matter with ALICE**

Lee Barnby, University of Derby, UK

14:30 (invited) **Working at the limits - the three alpha break-up of the Hoyle state**

Tzany Kokalova-Wheldon, University of Birmingham, UK

15:00 (invited) **Coulomb excitation of superdeformed and non-axial structures in ^{42}Ca**

Kasia Hadynska Klek, University of Surrey, UK

15:30 Coffee Break

	Parallel session 7	Parallel session 8
16:00	**Decay spectroscopy of the proton-emitting isotopes ^{176,177}Tl** Muneerah Alaqeel, University of Liverpool, UK	**Modelling incomplete fusion of complex nuclei at Coulomb energies: superheavy element formation** Rafael Van den Bossche, University of Surrey, UK
16:15	**Upgrading the inner tracking system of ALICE** James Iddon, University of Liverpool	**Development of GRI+ as a radioactive waste characterisation system** Jaimie Platt, University of Liverpool, UK
16:30	**Λ(1520) beam asymmetry measurement at the GlueX experiment** Peter Pauli, University of Glasgow, UK	**Modelling superheavy element creation with dissipative quantum dynamics: Chebyshev propagator in a Fourier grid** Terence Vockerodt, University of Surrey, UK
16:45	**Fission measurements with STEFF at n_ToF, CERN** Nikolay Sosnin, University of Manchester, UK	**Study on the effect of background subtraction algorithm on jet shapes** Jakub Kvapil, University of Birmingham, UK
17:00	**Neutron-proton pairing correlations in a single-l shell model** Antonio Marquez Romero, university of York, UK	**Commissioning of TPEN: a triple-foil plunger for exotic nuclei (TPEN)** Michael Giles, University of Manchester, UK

18:00 Conference dinner

Paisley Abbey

Friday 6 April

09:00	Registration and coffee	
	Parallel session 9	Parallel session 10
09:30	**An Investigation into the structure of proposed cluster bands in ^{18}O** Stuart Pirrie, University of Birmingham, UK	**Λ_c baryon studies with ALICE at the LHC** Christopher Hills, University of Liverpool, UK
09:45	**Algorithm development for the non destructive assay of nuclear waste** Kevin Tree, University of Liverpool, UK	**Photoproduction of φ-mesons with linearly-polarized photons** Louise Clark, University of Glasgow, UK
10:00	**Studies of jet grooming and recursive splittings in pp and Pb-Pb collisions with ALICE** Harry Andrews, University of Birmingham, UK	**Polarisation observables at MAMI** Christopher Mullen, University of Glasgow, UK
10:15	**Collinear resonance ionisation spectroscopy (CRIS) studies of neutron-rich indium isotopes** Cory Binnersley, University of Manchester, UK	**A segmented inverted-coaxial germanium detector SIGMA** Fiona Pearce, University of Liverpool, UK
10:30	Coffee Break	

Plenary session 6

11:00	(invited) **Search for novel nuclear density functionals** Jacek Dobaczewski, University of York, United Kingdom
11:30	(invited) **Overview of current activities at the JYFL accelerator laboratory** Iain D Moore, University of Jyväskylä, Finland
12:00	(invited) **Laser-driven particle and radiation sources at SCAPA** Paul McKenna, University of Strathclyde, UK
12:30	Lunch
13:30	**STFC Town Meeting**
15:30	Coffee and departure

Poster Programme

P:1 **Inner tracker detector studies for a future electron-ion collider**
Håkan Wennlöf, University of Birmingham, UK

P:2 **Current research in PET scanners**
Rebeckah Trinder, University of Birmingham, UK

P:3 **Comparison of different neutron detectors and validation using MCNP simulations**
Sarah Kalantan, University of Liverpool, UK

P:4 **Imaging of prompt gamma emissions during proton cancer therapy for geometric and dosimetric verification**
Hamed Alshammari, University of Liverpool, UK

P:5 **Development of a multidimensional gamma-spectrometer in support of On-Site Inspection**
Jennifer Corkhill, University of Liverpool, UK

P:6 **Studying the use of Thallium Bromide as a radiation sensor**
Olivia Voyce, University of Liverpool, UK

P:7 **A compact linear Paul trap cooler buncher for CRIS**
Christopher Ricketts, University of Manchester, UK

P:8 **Nuclear data needs for accelerator based neutron sources**
Steven Lilley, STFC Rutherford Appleton Laboratory, UK

P:9 **Interrogation of active waste drum**
David Igwesi, University of Liverpool, UK

P:10 **Gamma-ray spectroscopy study of 31S and gateway reactions in nova explosions**
Adam Kennington, University of Surrey, UK

Wednesday 4 April

Plenary session 1

(Invited) **Exploring beyond the proton drip line**

R Page

University of Liverpool, UK

The observable boundaries of the nuclear landscape are inextricably linked to the limits of particle binding. For nuclei beyond the neutron drip line the boundary is expected to be rather abrupt, whereas the retarding effect of the Coulomb barrier means that nuclei beyond the proton drip line can have long enough half-lives to allow them to be separated and their decays studied. Combined with the fact that the proton drip line lies closer to the line of maximum beta stability than the neutron drip line, this means that proton-unbound nuclei have been easier to explore experimentally. This talk will review recent progress in the field and consider some perspectives for future studies.

(Invited) **Coulomb-excitation measurements as a probe of nuclear structure**

D Doherty

University of Surrey, UK

This talk will address nuclear structure studies in several critical regions of the nuclear chart; the neutron-deficient selenium isotopes around mass A~70 and the mass A~100 region in the vicinity of the neutron number N~60. Both regions display sudden evolution of nuclear shapes, shape coexistence phenomena and, furthermore, state-of-the-art theoretical calculations suggest that possible non-axially deformed (or triaxial) nuclear shapes may be present in these mass regions. Coulomb excitation is an ideal experimental probe of such phenomena owing to the well-understood interaction between collision partners and the relatively large reaction cross sections.

Beams of the radioactive isotope ^{72}Se were delivered by new the HIE-ISOLDE facility, CERN where the newly increased beam energy means that it is now possible to probe states further from the nuclear ground state. However, many of the most interesting nuclei in the neutron-rich A~100 region are examples of so-called 'refractory' elements which cannot be extracted from traditional ISOL targets. Instead, therefore, these studies take place primarily at ANL's CARIBU (CAlifornium Rare Isotope Breeder Upgrade) facility where beams of refractory isotopes can be produced from thermalized fission fragments. The recent results on ^{110}Ru represent the very first successful post-acceleration of a beam of an unstable refractory isotope.

Finally, our new Coulomb-excitation programme at LNL, Italy will be discussed. In the first instance we aimed to study type-II shell evolution in ^{94}Zr. Here, the initial results will be presented as well as perspectives for further studies with stable beams at LNL and radioactive beams at the future SPES facility.

Plenary session 2

Isospin symmetry studies in the A=80 region

R Llewellyn[1], M Bentley[1], B Wadsworth[1], H Iwasaki[2], D Weisshaar[2] and P Bender[2]

[1]University of York, UK, [2]NSCL, Michigan State University, USA

Mirror energy differences (MED) in nuclei have been found to be underestimated by ~7%, with isospin non-conserving (INC) terms being the main factor in this discrepancy between shell model calculations and experimental data. An experiment was carried out at NSCL, MSU in April 2017 involving N=Z nuclei in the A=80 region to examine these isospin effects in this previously unexplored area. It is in these N=Z nuclei that the interaction between neutrons and protons is at its highest. Determining values such as MED and lifetimes of states in these nuclei will help create a clearer picture of the level of neutron/proton collectivity in N=Z nuclei and the spin and orbital dependence of the INC interaction.

The work presented includes some preliminary analysis in this mass region which will eventually lead to lineshape simulations of the $2^+ \rightarrow 0^+$ and $4^+ \rightarrow 2^+$ transitions of the N=Z nuclei 80Zr and 78Y. These simulations will be used to deduce the lifetimes of these states and subsequently calculate the B(E2)s and determine the level of np collectivity, a method that has succesfully been used with 76Sr [1].

[1] A. Lemasson et al., Phys. Rev. C. 85:041303 (2012)

(Invited) Neutron Reactions for astrophysics at n_TOF, CERN

C Lederer-Woods

School of Physics and Astronomy, University of Edinburgh, UK

All chemical elements from Carbon onwards are produced in stars. The abundance pattern of these elements in our solar system, distant stars, and meteorites, provides us with clues about how the elements came to be produced in a variety of astrophysical environments. To understand the processes and astrophysical sites producing the elements, the understanding of the reactions and properties of key nuclei responsible for element formation is indispensable.

An important outstanding question relates to the origin of the elements heavier than iron. It is known that these are mainly produced by neutron capture reactions in two distinct processes, the slow neutron capture process (s-process), and the rapid neutron capture process (r-process). The s-process takes place during helium burning stages of stars, where neutron captures and subsequent beta decays build up elements between Fe and Bi, and the reaction paths follows the valley of stability. The r-process takes place in stellar explosion at high temperatures and neutron densities, thus reactions involve exotic, short lived nuclei. The astrophysical sites of the r-process are still unknown but neutron star mergers are emerging as prime candidates.

Neutron induced reaction measurements are of key importance to study neutron capture nucleosynthesis. I will talk about recent neutron reaction measurements of relevance for heavy element and explosive nucleosynthesis at the neutron time-of-flight facility n_TOF at CERN. n_TOF provides a highly intense neutron flux with energies ranging from thermal (25 meV) to several GeV.

An experimental area at a distance of about 200 m from the spallation target allows cross section measurements with high resolution and precision. The recent installation of a second, high intensity beam line at a flight path of about 20 m allows reaction studies of small cross sections, and measurements on radioactive samples, which are typically only available in small quantities.

I will talk about stellar nucleosynthesis, recent nuclear reaction studies, and their relevance to our understanding of the origin of the elements.

Parallel session 1

Investigation of pygmy dipole resonance of ^{136}Xe

P Spagnoletti

University of the West of Scotland, UK

For a number of neutron-rich nuclei an additional accumulation of E1 strength is observed as a resonance-like structure situated upon the low-energy tail of the Isovector Giant Dipole Resonance (IVGDR). The IVGDR is observed across the nuclear chart and is understood to be an out of phase oscillation between separate proton and neutron bodies. The IVGDR exhausts approximately 100% of the Thomas-Reiche-Klein (TRK) sum rule. The additional E1 strength on the IVGDR's tail has been denoted as the Pygmy Dipole Resonance (PDR). The PDR has been described as an out of phase oscillation of the excess neutrons against an isospin saturated (N≈Z) core. However this picture remains uncertain and other mechanisms have been proposed.

A vast number of PDR experiments have been performed using (γ, γ') Nuclear Resonance Fluorescence (NRF). Given the spin-selective nature of the reaction, the excitation of J=1 states is dominant. There are, however, drawbacks to NRF experiments. Scattering of the atomic electrons dominates over nuclear scattering leading to significant background contamination in the recorded spectra. Consequently decays to lower-lying levels are often unobserved, which results in an under-determination of the E1 strength.

We investigate whether gamma-ray spectroscopy following beta decay is a suitable probe for PDR studies. We present results from an experiment performed at the Lohengrin instrument at the Institut Laue Langevin (ILL). Exploiting the high Q value (7 MeV) of the decay and the low ground-state spin of the parent nucleus (^{136}I) to populate 1^- levels in the energy region of the PDR. The level population is compared to ^{136}Xe (γ, γ') data. We aim to observe decays of these 1- states to lower-lying levels that go unobserved in NRF studies, as well as other 1- states with more complex configurations that are too weakly excited with NRF to be observed.

Multi-strange baryon production in p-Pb collisions at $\sqrt{s}$ = 8.16 TeV with ALICE at the LHC

E Willsher, D Evans, R Lietava

University of Birmingham, UK

The ALICE experiment at the LHC is used to study particle production in high-energy pp, p-Pb and Pb-Pb collisions. Strange particle production is of particular interest as it provides information about the system produced in these collisions. In particular, the enhancement of strangeness production is a signal for the production of a Quark-Gluon Plasma (QGP) in heavy-ion collisions [1]. Such an enhancement of strangeness production has indeed been reported by ALICE in Pb- Pb collisions at $\sqrt{s}$ = 2.76 TeV compared to pp collisions, [2]. However, a key result from this first data taking period, before 2013, was an enhanced production of strange particles in very high charged particle multiplicity pp and p-Pb collisions at 7 and 5.02 TeV respectively [3,4], where QGP formation is not expected. This talk will present new results from p-Pb data at 8.16 TeV collected in 2016, allowing the energy dependence of this phenomenon to be studied. The strangeness enhancement is investigated by measuring the yields of multi-strange hadrons (Ξ^-, Ξ^+, Ω^-, Ω^+) as a function of transverse momentum and charged particle multiplicity. The results at new energies will be compared to the lower energy results, as well as the different collision systems.

[1] J. Rafelski and B. Müller, Phys. Rev. Lett. 48 (1982) 1066
[2] ALICE Collaboration, Phys. Lett. B728 (2014) 216-227
[3] ALICE Collaboration, Nature Physics 13 (2017) 535-539
[4] ALICE Collaboration, Phys. Lett. B758 (2016) 389-401

Study of the evolution of octupole collectivity in ^{218}Ra

J Keatings

University of the West of Scotland, UK

The reflection asymmetric deformation of nuclei is a well observed phenomenon in nuclear physics [1]. This octupole deformation causes nuclei to take on a ‘pear-like’ shape, and is strongest in the region just beyond the N = 126 and Z = 82 closed shells [2]. The nucleus ^{218}Ra is on the limits of this strongly octupole-correlated region of the nuclear chart. Previous studies [3,4] have shown that it features an interleaving positive and negative parity band, a clear spectroscopic signature of octupole deformation. A discontinuity in the yrast band at approximately 20ħ has also been observed, and is believed to be caused by a rapid change in the quadrupole deformation. An experiment has been performed at the INFN Legnaro National Laboratory to study unobserved excited states, and measure the B(E1)/B(E2) ratios to measure this change of deformation. The nuclei of interest were produced using a ^{208}Pb(16O, α2n) reaction, and products were studied using the Galileo, Euclides, and Neutron Wall setup. In this talk the current status of the analysis will be presented and discussed.

[1] P. A. Butler and W. Nazarewicz, Rev. Mod. Phys 68, 349 (1996)
[2] W. Nazarewicz *et al.*, Nucl. Phys. A429, 269 (1984)
[3] J. Fernández-Niello *et al.*, Nucl. Phys. A391, 221 (1982)
[4] N. Schulz *et al.*, Phys. Rev. Lett. 63, 2645 (1989)

Using a novel method to determine resonance strengths within ^{26m}Al(p,γ)^{27}Si using GRETINA and S800 Spectrometer

S Hallam[1], G Lotay[1], W N Catford[1], D Doherty[1], M Moukaddam[1], D Weisshaar[2], P Bender[2], R Zegers[2], A Gade[2], J Pereira[2], D Rhodes[2], F Montes[2], B Longfellow[2], A Estrade[3], D Seweryniak[4], S Jin[2], J Browne[2], K Schmidt[2] and O Wei-Jia[2]

[1]University of Surrey, United Kingdom, [2]National Superconducting Laboratory, USA, [3]University of Central Michigan, USA, [4]Argonne National Laboratory, USA

The first direct piece of evidence for ongoing nucleosynthesis was the subsequent 1.809 MeV γ-ray decay from $_{26}$Al within the interstellar medium. Since this original discovery, the COMPTEL and INTEGRAL satellite missions have measured the distribution of this γ-ray throughout the galactic plane, with the identification of Core-Collapse Supernovae and highly evolved Wolf-Rayet stars as the likely astrophysical sources. It is thought that (p,γ) reactions will dominate the destruction of ^{26}Al within these environments, but of special interest, is that within CCSN the ground state ($J^{\pi} = 5^+$, $t^{\beta}_{1/2} = 7.2 \times 10^5$ yr), and an isomeric state ($E_x = 228.3$ keV, $J^{\pi} = 0^+$, $t^{\gamma}_{1/2} = 6.3$ s) can communicate through thermal excitations involving higher levels. This isomeric state exhibits a superallowed β+-decay directly to the ^{26}Mg ground state, without the 1.809 MeV γ-ray decay. Therefore within this environment the creation/destruction rate of the isomeric state may have significant impact on the overall cosmic γ-ray emission. Using a novel method to exclusively populate low-spin excited states of critical importance within ^{27}Si for the ^{26m}Al(p,γ)^{27}Si reaction. A recent ^{26}Si(d,p)^{27}Si experiment has been performed at the NSCL, using GRETINA and the S800 spectrometer. Measuring the neutron partial widths of this analogue reaction can be used to determine the proton partial widths of the astrophysical reaction, via isospin symmetry, allowing resonance strengths to be extracted. The use of the 0^+ isobaric triplet ^{26}Si-^{26m}Al-^{26}Mg should remove the background related to ^{26}Al ground state, a typical contaminant in attempts to measure this reaction directly. The preliminary results from this study will be presented.

Parallel session 2

Shape coexistence and shape evolution of Bismuth isotopes in the neutron deficient lead region by in source laser spectroscopy

C Raison[1], A Andreyev[1], J Cubiss[1] and A Barzakh[2]

[1]University of York, UK, [2]ISOLDE, CERN, Switzerland

The Bismuth isotope chain in the Z=82 region is thought to be a key chain in the neutron deficient lead region for the study of shape evolution and shape coexistence. Over the past several years, multiple successful laser and nuclear spectroscopic studies have been carried out in the lead region using in-source laser spectroscopy with RILIS at ISOLDE . The results have shown many examples of shape staggering and shape coexistence. The Bismuth isotopes are believed to be an important part of the lead region as they lie between the spherical lead isotopes and the strongly deformed polonium isotopes[1]. An experiment was carried out in July 2016 to determine the shape evolution of these Bismuth isotopes using the Windmill setup at the ISOLDE facility. This was done using lasers to resonantly excite the isotopes and isomers under investigation and then using the Alpha decays from these states to produce HFS spectra. Analysis is currently underway in order to produce the charge radii for this chain.

[1] AN Andreyev et al. 2000 Nature 405 430

Self-consistent collective path and two-body dissipation effect in nuclear fusion reactions

K Wen[1], T Nakatsukasa[2], M Barton[1], A Rios Huguet[1] and P Stevenson[1]

[1]University of Surrey, UK, [2]University of Tsukuba, Japan

I will present results of numerical simulations of nuclear fusion at low energies. Our studies are from theoretical perspective and based on two different methodologies.

First, I will talk about an adiabatic method to study large amplitude collective motion, this method provides the collective reaction path for the fusion process at sub-barrier energies [1, 2]. We focus on the reactions of N = Z stable nuclei, $\alpha + \alpha$, $\alpha + {}^{16}O$ and ${}^{16}O + {}^{16}O$. The reaction paths turn out to deviate from those obtained with standard mean-field calculations with constraints on quadrupole and octupole moments.

Then, I will discuss time-dependent simulation based on the time-dependent density matrix (TDDM) model [3], which goes beyond the standard mean-field approximation and takes into account the effect of two-body correlations, this study aims at providing a more realistic description for the dissipation process in nuclear fusion/fission reactions.

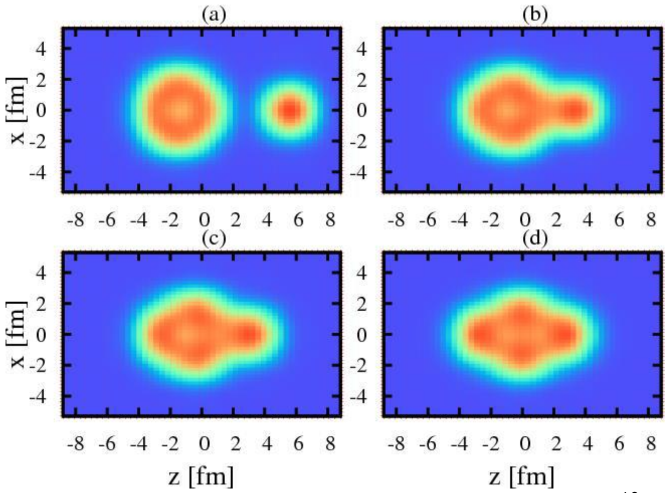


Fig1: Density profiles on the adiabatic fusion path α + ^{16}O

[1] K. Wen, T. Nakatsukasa, Phys. Rev. C 94, 054618 (2016)

[2] K. Wen, T. Nakatsukasa, Phys. Rev. C 96, 014610 (2017)

[3] M. Tohyama, A. S. Umar, Phys. Rev. C 65, 037601 (2002)

Investigation of excited states and octupole deformation in neutron-deficient ^{116}Ba

N Kelly[1], J F Smith[1]

[1]University of the West of Scotland, United Kingdom

Octupole deformation is predicted to occur in the neutron-deficient barium (Z=56) isotopes [1, 2]. This deformation is a result of the interactions between orbitals near the Fermi level whose angular momenta differ by ΔI=Δj=3. In the neutron-deficient region, the proton Fermi level lies in the low h11/2 orbital while the neutron Fermi level lies in the mid to high $h_{11/2}$ orbital. The octupole correlations occur due to the interactions of the orbitals from the $h_{11/2}$ and $d_{5/2}$ subshells and are expected to increase as N approaches Z. Some tentative evidence of octupole correlations has been observed in the neutron-deficient 118,122-125Ba isotopes [3, 4, 5, 6]. An experiment using the reaction ^{64}Zn(^{58}Ni,α$2n$)^{116}Ba was carried out at Legnaro National Laboratory using the Galileo gamma-ray spectrometer along with the Euclides charged-particle detector array and the Neutron Wall. In-beam gamma-ray spectroscopy techniques will be used to identify excited states and investigate octupole deformation in ^{116}Ba. The data analysis is in progress, and some preliminary results from the data will be presented.

[1] W. Nazarewics *et al.*, Nucl. Phys A 429, 269 (1984)

[2] J. Skalski, Phys. Lett. B 238, 6 (1990)

[3] J. F. Smith *et al.*, Phys. Rev. C 57, R1037 (1997)

[4] Zhu Sheng-Jiang *et al.*, Chin. Phys. Lett. 18, 1027 (2001)

[5] X. C. Chen *et al.*, Phys. Rev. C 94, 021301(R) (2016)

[6] P. Mason *et al.*, Phys. Rev. C 72, 064315 (2005)

Exploring stellar helium burning with gamma-ray beams and active target detectors

R Smith[1], M Gai[2], M W Ahmed[3,4], M Freer[5], I Gheorge[6], C R Howell[3], and S R Stern[2]

[1]Sheffield Hallam University, UK, [2]University of Connecticut, USA, [3]TUNL, Duke University, USA, [4]North Carolina Central University, USA, [5]University of Birmingham, UK, [6]IFIN-HH/ELI-NP, Romania

Stellar helium burning results in the formation of carbon and oxygen [1]. However, the carbon-to-oxygen ratio at the end of helium burning is not well known, despite its importance in stellar evolution theory. The gamma-ray beam facility at HIgS (Duke University, USA) coupled with active target detectors, present an ideal opportunity for solving this problem, by allowing precise measurements of the cross sections for the 12C(a,g) reaction by measuring the reverse 16O(g,a) reaction.

This talk will discuss the Optical Readout Time Projection Chamber (O-TPC) at HIgS [2] and the experiment that was performed to measure the photo-disassociation of 16O. The experimental analysis so far will be discussed with a focus on the unique opportunity that this detector provides to precisely measure detailed angular distributions.

[1] W. A. Fowler, Rev. Mod. Phys. 56, (1984)
[2] M. Gai, et al., JINST 5 (2010)

Parallel session 3

Gamma-ray spectroscopy of neutron deficient N ≈ 82 nuclei

M M R Chishti and David O' Donnell

University of the West of Scotland, UK

Gamma-ray spectroscopy of three neutron deficient N ≈ 82 nuclei is performed for gamma rays generated as a result of fusion evaporation reactions by using recoil isomer tagging technique at K130 Cyclotron laboratory, University of Jyväskylä. High spin states have been identified above seniority isomers in N=83 isotones, $\frac{153}{70}$, $\frac{152}{69}Tm$ and N=82 nucleus $\frac{152}{70}Yb$. Level schemes above the previously known isomers [1,2,3] have been constructed by gamma-gamma coincidence analysis for prompt & delayed gamma transitions. Spin and parities are assigned in case of $\frac{153}{70}Yb$ and $\frac{153}{69}Tm$ by measuring angular correlations between gamma transitions.

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Observation of the $\Delta n = 0$ selection rule in the $\boldsymbol{\beta}$ decay of ^{207}Hg

T A Berry[1], Z Podolyák[1], R J Carroll[1], R Lica[2,3], C Sotty[3], H Grawe[4] and ISOLDE Decay Station collaboration *et al.*

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For the β decay of the ^{207}Hg ground state ($\nu 1g_{9/2}$) into ^{207}Tl, only one daughter state meeting the standard criteria for allowed decay ($\Delta l = 0,\pm1$ and $\Delta\pi$ = no) is known to lie below the Q_β-value: the $\pi 0g_{7/2}$ proton hole state at 3.474(6) MeV [1]. However, from an experiment which took place at the ISOLDE Decay Station in 2014, we report the non-observation of transitions de-populating this state, leading to a limit log*ft*>8.53(7). This is far higher than is generally the case for allowed Gamow-Teller transitions, and similarly high results have been recorded for only a handful of nuclei across the chart with little discussion.

The phenomenon is attributed primarily to the $\Delta n = 0$ selection rule in Gamow-Teller decay; n being the number of nodes in the radial wavefunction, here equal to 1 for the initial and 0 for the final state. Secondarily, the destructive interference of 3p-2h contributions [2] is thought to explain the absence of any population arising from Coulomb effects. The result allows us to place limits on the overlap integrals and hence the relative proton and neutron radius parameters of the two orbitals involved.

One other non-observation of this type was made for the decay of ^{209}Tl into ^{209}Pb and was discussed in detail [3,4]. The proximity of the two decays in the chart suggests that the region south-east of ^{208}Pb could be one in which this $\Delta n = 0$ rule is more prominent, due to interactions between the Z=82-126 and N=82-126 orbital wavefunctions.

We predict in particular that β decay of ^{207}Au might exhibit the same behaviour. Any influence on β-decay half-lives in this region would be of importance to r-process pathways.

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[2] J.-I. Fujita and K. Ikeda, Nuclear Physics 67, 145 (1965)
[3] R. D. Lawson, *Nuclear gamma and beta decay*, Technical report, 1974
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3D printed patient-specific organ phantoms for SPECT quantification

E J E Price[1,2], A P Robinson[3], J Tipping[2], N Calvert[2], D M Cullen[1], D Hamilton[2], C Oldfield[1,2], E Page[2], S Pells[1] and B Pietras[1]

[1]University of Manchester, UK, [2]Christie Medical Physics and Engineering, Christie NHS Foundation Trust, UK, [3]National Physical Laboratory, UK

Treatments in Molecular Radiotherapy often involve the administration of a standard activity of a radioisotope. To optimise the treatment for a given patient the distribution of the radionuclide must be quantified. This quantification is done using a SPECT (Single Photon Emission Computed Tomography) camera for photon-emitting isotopes. The reconstruction of images from these scanners involves corrections for multiple image-degrading effects.

These scanners must be calibrated to relate the detected count rate in a region to the activity in that region. Usually a spherical object containing a known activity is used to calculate a calibration factor. It has been demonstrated that such a distribution is not suitable for all patient activity distributions [1, 2]. The unsuitability is particularly relevant for small objects of a similar size to the scanner resolution due to partial volume effects.

3D printed models of a selection of organs of interest were produced. These were based on a CT scan taken as part of a clinical therapy sequence of a patient. These models, and others based on the Cristy and Eckermann phantom series [1], were scanned on a clinical SPECT scanner. Calibration factors were calculated for each of these inserts. The patient specific inserts were then assembled in the correct anatomical configuration to provide a known patient-representative activity distribution. The impact of organ- and patient-specific calibration factors on activity recovery was assessed.

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Collinear resonance ionization spectroscopy for trace analysis

S J Alsufyani

University of Manchester, UK

Due to large isobaric contamination, experimental techniques such as mass spectrometry and laser spectroscopy are often prevented from detecting rare isotopes with natural abundances of below 1 ppt. Progress has been made recently to measure these difficult cases using the technique of collinear resonance ionization spectroscopy (CRIS). This methodology has been developed at CERN [1] and consists of two techniques, the first is collinear laser spectroscopy (CLS) and the second technique is resonance ionization spectroscopy (RIS). CRIS uses a high resolution pulsed lasers to excite and ionize an atomic beam for measurements of the hyperfine structure of rare isotopes [2]. The lasers are overlapped collinearly with bunched ions or atoms or fast atoms (neutralized in charge exchange cell). The CRIS technique is an ideal technique because it provides high resolution and therefore high selectivity, high detection efficiency and ultra—low background [1],[3]. This presentation will present the technique and demonstrate its application for the detection of ^{14}C and ^{41}Ca.

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[3] de Groote, R.P., et al., *Use of a Continuous Wave Laser and Pockels Cell for Sensitive High-Resolution Collinear Resonance Ionization Spectroscopy.* Physical Review Letters, 2015. 115(13): p. 132501

Parallel session 4

Proton imaging with silicon detectors

M Chiesa

University of Birmingham, UK

With the increasing development of proton therapy for cancer treatment, new techniques to create images of the patient and the tumor are needed, especially to reduce the uncertanties derived from the conversion from Hounsfield Units (used in conventional Computed Tomography performed with photons) to proton stopping power. Having a system which uses protons to provide images and information about the tissues for treatment planning in proton therapy would solve these problems.

PRaVDA (Proton Radiotherapy Verification and Dosimetry Application) consortium has developed a new instrumentation based on silicon detectors to track the protons and to measure their residual energy, to create a proton CT. In its complete configuration the device is composed of four silicon strip detectors for proton tracking (two of them placed before the patient and two after) and a range telescope consisting of 21 silicon strip sensors, to measure the range of the outgoing protons.

I will present a brief overview of the PRaVDA project but the main focus will be on results achieved during my studentship thus far: in particular, my work is concentrated on testing the performance of the tracking detectors and building a new tracker to be used to check the characteristics of the proton beam at the University of Birmingham MC40 Cyclotron.

Timing performance of the Birmingham lanthanum bromide array

A Turner, C Wheldon, P S Rita, T Kokalova

University of Birmingham, UK

The timing characteristics of $LaBr_3$(Ce) detectors were investigated. This was carried out in preparation of an array for in-beam experiments at the Birmingham MC40 cyclotron. During the initial project in which these detectors were constructed, the use of Timing Filter Amplifiers in series with Timing Single Channel Analysers resulted in an underwhelming 1.76(4) ns resolution. In continuing this characterisation, sub-nanosecond (<300 ps) resolution has since been demonstrated after optimisations in the electronics and methodology. This was tested in a multi-channel time spectroscopy circuit utilising two $LaBr_3$(Ce) detectors. Constant fraction discriminators were chosen for time pick-o_, which was taken directly after the anode without a pre-amplifier or any additional shaping. Practical application of the timing system was demonstrated through measurement of the $5/2^-$ excited state of Bi-207 at

569.7 keV. A half-life of 127(2) ps was determined experimentally, and is consistent with the 130.5(8) ps published value.

Calculations of infinite matter in a periodic box

C McIlroy, C Barbieri

University of Surrey, UK

The aim of this project is to use many-body techniques to study large systems, with a particular interest in simulating the conditions found at the core of dense celestial bodies such as neutron stars. To do this we perform Green's function calculations of infinite matter using periodic boundary conditions (PBC), based on a two-nucleon potential derived from Chiral Effective Field Theory (χEFT) [1]. The self-energy is computed using the third-order algebraic diagrammatic construction [ADC(3)] approximation, which is a fully non-perturbative approach, as required for the problem. When analysing calculations of the Hartree-Fock (HF) energies, the results show that the implementation of the two-nucleon interaction is behaving well when benchmarked against other approaches [2]. A study implementing the full ADC(3) will be provided, with an emphasis on convergence properties and observing the expected finite size effects. Finally, a discussion in to the initial attempts to incorporate the N2LO three-nucleon interaction matrix elements in to the calculations will be presented.

[1] R. Machleidt, "The high-precision, charge-dependent Bonn nucleon-nucleon potential", *Physical Review C*, vol. 63, 024001, 2001, 10.1103/PhysRevC.63.024001

[2] A. Carbone, A. Polls, A. Rios, "Symmetric nuclear matter with chiral three-nucleon forces in the self-consistent Green's functions approach", *Physical Review C*, vol. 88, 044302, 2013, 10.1103/PhysRevC.88.044302

Polarimetry for Linearly Polarised Photons using Coherent Pion Production at MAMI

A Powell, K Livingston and D Ireland

University of Glasgow, UK

Background: The degree of linear polarisation in real photon experiments has direct impact on measurements of polarisation observables. Measurement of the linear polarisation is often the biggest source of systematic error in these experiments. Purpose: To determine whether it is possible to make an improved measurement of the degree of linear polarisation using a polarimeter based on a 12C target. Methods: Coherent π_0 meson production from a spin-zero nucleus has a photon asymmetry of 1 and hence provides a direct method of measuring the beam polarisation. Results: Current methods of measurement are being employed as a comparison. Simulated statistics of π0 mesons produced off the polarimeter suggest the measurement is viable. Early results from production data support this. Conclusions: A spin-zero nucleus such as carbon will be developed as a polarimeter for measuring the degree of linear polarisation in hadron physics experiments with tagged photons of up to 1557 MeV.

Plenary session 3

(Invited) On the road towards a nuclear clock: what do we know about the 229-Thorium isomer?

P G Thirolf

Ludwig-Maximilians-Universität München, Germany

Today's most precise time and frequency measurements are performed with optical atomic clocks. However, it has been proposed that they could potentially be outperformed by a nuclear clock, which employs a nuclear transition instead of an atomic shell transition. There is only one known nuclear state that could serve as a nuclear clock using currently available technology, namely, the isomeric first excited state of ^{229}Th. Since 40 years nuclear physicists have targeted the identification and characterization of the elusive isomeric ground state transition of ^{229m}Th. Evidence for its existence until recently could only be inferred from indirect measurements, suggesting an excitation energy of 7.8(5) eV. Thus the first excited state in ^{229}Th represents the lowest nuclear excitation so far reported in the whole landscape of known isotopes. Recently, the first direct detection of this nuclear state could be realized via its internal conversion decay branch, which confirms the isomer's existence and lays the foundation for precise studies of its decay parameters, in particular its half-life and excitation energy. Subsequently, a measurement of the halflife of the neutral isomer was achieved, confirming the expected reduction of 9 orders of magnitude compared to the one of charged ^{229m}Th. Most recently, collinear laser spectroscopy was applied to resolve the hyperfine structure of the thorium isomer, providing information on nuclear moments and the charge radius. Thus a considerable increase of insight into the properties of this elusive nuclear state could be achieved in the last two years, paving the way towards an all-optical control and thus the development of an ultra-precise nuclear frequency standard. Moreover, such a nuclear clock promises intriguing applications in applied as well as fundamental physics, ranging from geodesy and seismology to the investigation of possible time variations of fundamental constants.

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[2] B. Seiferle, L. v.d. Wense, P.G. Thirolf, Phys. Rev. Lett. 118, 042501 (2017)
[3] B. Seiferle, L. v.d. Wense, P.G. Thirolf, Eur. Phys.. Jour. A 53, 108, (2017)
[4] L. v.d. Wense et al., Phys. Rev. Lett. 119, 132503 (2017)
[5] J. Thielking et al., Nature, in press; arXiv: 1709.05325 (2017)

Public lecture

(Invited) Who split the atom?

J Al-Khalili

University of Surrey, United Kingdom

Apart from the confusion about what this popular phrase means – it is of course the nucleus that is being split, not the entire atom – there is also debate about when it was achieved and who should take the credit. One thing that is not in doubt is that Ernest Rutherford will have been involved in some way. So, what was the father of nuclear physics working on exactly one hundred years ago, in 1918, just before the end of the Great War and just before he moved down from Manchester to the Cavendish? Digging into the history, we see that he was in fact busy... 'splitting the atom'. This talk will look back at some of the key moments in nuclear physics in the first decades of the 20th century.

Thursday 5 April

Plenary session 4

(Invited) **Transfer reactions for experiments: theory and its uncertainties**

N Timofeyuk

University of Surrey, UK

Experiments with exotic radioactive beams often use reactions in which one nucleon is transferred between target and projectile as a tool to study spectroscopic strength of nuclear states. The information obtained, such as spectroscopic factors and asymptotic normalization coefficients, can be used, for example, to predict rates of nuclear reactions in various stellar environments. This information is obtained through comparison of the experimental cross sections with theoretical predictions. It is therefore important to have adequate theoretical models that take the most important physics of these reactions into account.

In this talk I will present the latest theoretical developments for a particular class of transfer reactions, deuteron stripping reactions (d,p)- one of the most popular tools for structure studies - and discuss their uncertainties. The cross sections of these reactions are strongly affected by the deuteron breakup and its understanding is very important. Recently, it has been found that theory that includes breakup gives different predictions when neutron-target and proton-target optical potentials are nonlocal. In this case, new types of uncertainties are found. I will describe these uncertainties as well as ongoing theoretical work to remove them.

(Invited) **Hadron physics at Jefferson lab**

B McKinnon

University of Glasgow, UK

The Thomas Jefferson National Accelerator Facility (Jefferson Lab) is a U.S. Department of Energy Office of Science national laboratory. Located in Newport News, Virginia, the primary research programme exploits the Continuous Electron Beam Accelerator Facility (CEBAF) and four complementary experimental Halls, to probe the quark and gluon structure of hadrons and nuclei through the processes of Quantum Chromodynamics. Having completed an energy upgrade from 6 to 12 GeV and with the recent beginning of full operations, JLab and its almost 1600 international researchers will explore the organisation of subatomic matter and emergent phenomena, study quark-gluon dynamics via the hadron excitation spectra and searches for exotic/hybrid mesons, and determine the mechanisms responsible for the generation of hadronic mass and spin. Major highlights from the 6 GeV era will be presented along with an overview of the 12 GeV physics programme, with emphasis on U.K. contributions.

(Invited) **High-resolution laser spectroscopy experiments at the extremes of the nuclear chart**

R F G Ruiz

University of Manchester, UK and European Organisation for Nuclear Research, Switzerland

Laser-spectroscopy techniques provide a powerful tool to perform highly-efficient and precise measurements of the electromagnetic properties of exotic nuclei. Such experiments allow access to observables that are key for our understanding of the nuclear many-body problem: nuclear ground-state spins, electromagnetic moments, and changes in the root-mean-square charge radii [1,2]. Moreover, a precise knowledge of the interaction between the atomic nucleus and the surrounding electrons offers complementary information for the development of atomic many-body methods [3].

This contribution will present the recent results from collinear laser spectroscopy experiments at ISOLDE-CERN [4-6]. The developments that have allowed the extension of high-precision laser-spectroscopy studies in extreme regions of the nuclear chart, where exotic isotopes are produced at rates of only a few ions/s, will be presented [7,8]. The relevance of these results in connection with the recent advances in nuclear, atomic and quantum-chemistry theory will be discussed.

[1] Garcia Ruiz et al. Nature Physics 12, 594 (2016)
[2] Garcia Ruiz et al. Phys. Rev. C 91, 041304(R) (2015)
[3] Garcia Ruiz, Vernon, Binnersley et al. Submitted (2018)
[4] Flanagan et al., Phys. Rev. Lett. 111, 212501 (2013)
[5] De Groote et al., Phys. Rev. Lett. 115, 132501 (2015)
[6] Yang et al., Phys. Rev. Lett. 116, 182502 (2016)
[7] Garcia Ruiz, Gorges et al., J. Phys. G 44 044003 (2017)
[8] De Groote et al. Phys. Rev. C 96, 041302(R) (2017)

(Invited) **Nuclear structure physics at HIE-ISOLDE**

L Gaffney

European Organisation for Nuclear Research (CERN), Switzerland

HIE-ISOLDE [1] at CERN will this year begins its third year of full operation and will run with four cryomodules for the first time, reaching the original design energy of 10 MeV/u for radioactive ion beams. Experiments have been focused on two experimental setups so far, with the Miniball HPGe array [2] taking most of the beam time. The ISOLDE Solenoidal Spectrometer (ISS) [3] is currently being commissioned on the second beam line with the aim of performing few-nucleon transfer reactions in the magnetic field of a former MRI magnet. At Miniball, a total of five experiments were performed in 2016, four of them being Coulomb-excitation experiments. As HIE-ISOLDE operation becomes routine, the number of experiments also increases and in 2017 there were 12 experiments in a campaign running from July until December. In addition to Coulomb excitation, last year also saw multi-nucleon transfer reactions and g-factor measurements. In this talk I will present the HIE-ISOLDE project and the show preliminary status of experiments from two years of operation. Some of the selected physics cases will be, amongst others, Coulomb-excitation at both ends of the Sn isotopic chain, 110Sn and 132Sn, studying octupole collectivity around 144Ba, and pushing south-east of 208Pb in multi-nucleon transfer reactions. Additionally, I will show plans for 2018 when a full complement of experimental setups are expected to get beam time, including ISS.

Figure 1: Current layout of HIE-ISOLDE and its experimental setups

[1] M. Lindroos, P. Butler, M. Huyse, and K. Riisager, Nucl. Instrum. Meth. B 266, 4687 (2008)
[2] N. Warr et al., Eur. Phys. J. A 49, 40 (2013)
[3] S. J. Freeman et al., CERN-INTC 031, 099 (2010)

Parallel session 5

Decay of the 19^- isomer in ^{156}Lu

M C Lewis

University of Liverpool, UK

A multiparticle spin-trap isomer has been observed in the proton-rich nucleus ^{156}Lu. The properties of the isomer and its decay have been measured using the GREAT spectrometer located at the University of Jyväskylä. The 19^- isomer is interpreted as $\pi h_{11/2}^{-3} \otimes \nu f_{7/2}\, h_{9/2} i_{13/2}$ configuration, analogous to isomers observed in other N=85 isotones, such as the odd-Z neighbour ^{158}Ta.

Coincidence analysis has revealed parallel decay paths depopulating the 19^- isomer, which has allowed the relative ordering of the $[\pi h_{11/2}^{-1} \otimes \nu f_{7/2}]9^+$ and $[\pi h_{11/2}^{-1} \otimes \nu f_{9/2}]10^+$ states at the bottom of these cascades to be determined for the first time, revealing an inversion in the systematics of the N=85 isotones.

Development of 3D position sensitive scintillation detectors

J R Brown, S. Paschalis, F. Alsomali, P. Joshi, D. Jenkins

University of York, UK

Position sensitive gamma-ray scintillation detectors are of interest for a variety of applications such as nuclear security and safety, medical imaging, as well as for fundamental physics experiments. This is often achieved using segmented scintillator crystals coupled to an array of photosensors. The position resolution of such systems is typically limited by the granularity of the scintillator elements. An alternative approach uses monolithic scintillators and measures the light distribution from a scintillation event allowing the reconstruction of the interaction position. Some success has been reported using this technique but is typically limited to thin scintillators and/or 2D position reconstruction.

We report on the development of a 3D position sensitive scintillator detector. Position sensitivity will be achieved through measuring the light distribution on one or more faces of the scintillator, using arrays of silicon photomultipliers (SiPMs) coupled directly to monolithic scintillator crystals. A number of scintillator materials are considered, including CsI:Tl and $CeBr_3$.

A high precision, x-y scanning station has been designed and built to allow characterization of the response of different scintillator/SiPM configurations. Characterization results will be presented, along with Geant4 simulations of optical photon transportation used to investigate the optimum scintillator/SiPM configuration for this technique.

Search for the decays of the 19- multiparticle isomer in 160Re

A Briscoe

University Of Liverpool, UK

It is now recognised that high-spin multiparticle isomers could blur the boundaries of the nuclear landscape by providing the last observable nuclear states beyond the proton drip line. Examples of recent studies include the 19^- isomers of the N=85 isotones ^{156}Lu [1] and ^{158}Ta [2]. These isomers were found to have fragmented gamma-decay paths and in the case of 158Ta, a weak competing alpha-decay branch was also identified. Despite being unbound to proton emission by more than 3 MeV, no proton decays were identified from the ^{158}Ta isomer.

These investigations have prompted a search for the corresponding isomer in the protonemitting isotone ^{160}Re. Latest results from the search for gamma-ray and charged-particle emission from this isomer will be presented.

[1] M.Lewis et al. - this conference
[2] R.J Carrol et al. - Physical Review Letters 112 (2014) 092501

Shape coexistence and decay spectroscopy in gold isotopes studied by in-source laser spectroscopy at RILIS-ISOLDE

R D Harding*

University of York, UK and EP Department, CERN

*On behalf of the York-KU Leuven-Gatchina-Mainz-Manchester-Bratislava-UWS-RILIS-WindMill-ISOLTRAP-ISOLDE collaboration

The neutron-deficient nuclei surrounding the Z = 82 shell closure are laden with competing spherical, prolate and oblate configurations. As such, they have proven a fertile ground for the study of shape coexistence [1]. The first observations of a sudden change in charge radii of the Au (Z = 79) isotopes were made almost 30 years ago [2]. A sudden increase in charge radius was observed, with ground states being weakly deformed down to mass A = 187 then becoming well deformed from mass A = 186 down to the neutron midshell at N = 104, A = 183.

This talk presents data from the IS534 experiment at ISOLDE, that took place in May, 2015. By combining the high sensitivity of the in-source laser spectroscopy technique, ISOLDE mass separation with either the Windmill decay station [3], or the Multi-Reflection Time-of-Flight (MR-ToF-MS) mass separation technique [4], it was possible to measure the isotope shifts of ground and Isomeric $^{176\text{-}198}$Au, from which mean-squared charge radii were extracted. Along with these measurements, dedicated decay spectroscopy studies of ^{176}Au - ^{180}Au were made using the Windmill decay station.

[1] K. Heyde and J. Wood, Rev. Mod. Physics 83, 1467 (2011)

[2] K. Wallmeroth et al., Phys. Rev. Lett. 58, 1516 (1987)
[3] A. N. Andreyev et al., Phys. Rev. Lett. 105, 252502 (2010)
[4] R. N. Wolf et al., Nucl. Instr. and Meth. A 686, 82-90 (2012)

Parallel session 6

Modelling (d,p) transfer reactions with non-local nucleon-target optical potentials

M J Dinmore, N K Timofeyuk, and J S Al-Khalili

University of Surrey, UK

We compare the impact of using different non-local energy-dependent nucleon-target potentials and using different models of the deuteron wavefunction to generate deuteron-target distorted waves and differential cross sections at a beam energy of 6 MeV/u for ^{40}Ca(d, p)^{41}Ca and the astrophysically relevant ^{26}Al(d, p)^{27}Al transfer reaction. Deuteron-target potentials are calculated within an extension of the adiabatic distorted wave approximation [1,2] and generated using nucleon-target potentials from both a global optical model [3] and a modern non-local dispersive optical model [4]. These calculations are repeated using different deuteron wavefunctions, with the choice of wavefunction found to have a large impact on (d,p) differential cross sections.

[1] N. K. Timofeyuk, R. C. Johnson, Phys. Rev. C 87, 064610. (2013)
[2] R. C. Johnson, N. K. Timofeyuk, Phys. Rev. C 89, 024605 (2014)
[3] M. M. Giannini, G. Ricco, A. Zucchiatti, Annals of Physics 124, 208-246 (1976)
[4] M. H. Mahzoon, *et al,* Phys. Rev. Lett. 112, 162503 (2014)

Gamma emission from the ^{16}O* nuclei

P Santa Rita Alcibia, T Kokalova, C Wheldon, J Bishop, N Curtis, M Freer, R Smith, A Turner, D J Parker, J Walshe

University of Birmingham

An overview of the ^{12}C(α,γ)^{16}O*experiment at the University of Birmingham's MC40 cyclotron is presented in this work. The experimental set-up was a combination of the existing charged particle expertise and capability of the group and the ability to measure the emitted gamma rays using our new $LaBr_3$ detector array. The motivation for this is to measure or put constraints on the B(E2)s for the ^{16}O nucleus. Such observations aid the assignment of rotational levels built on cluster configurations. This work is part of my PhD research and will lay the foundation of my future research.

Towards a more precise measurement of the Q(2+) in 12C: testing state-of-the-art ab initio theories

J Saiz Lomaz[1], M Petri[1], H Badram[2], T Calverley[2], D Cox[2], U Forsberg[2], S Fox[1], T Grahn[2], P Greenlees[2], S Heil[3], J Hilton[2], M Jenkinson[1], R Julin[2], S Juutinen[2], J Konki[2], I Y Lee[4], M Leino[2], M Mathy[3], J Ojala[2], J Pakarinen[2], P Papadakis[2], J Partanen[2], P Rahkila[2], P Ruotsalainen[2], M Sandzelius[2], J Saren[2], C Scholey[2], S Stolze[2], I Syndikus[3], J Uusitalo[2] and R Wadsworth[1]

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

Electromagnetic diagonal matrix elements are sensitive to the details of the nuclear interaction and can constrain NN+3N Hamiltonians derived from chiral Effective Field Theories used in ab initio calculations. Theoretical large-scale No Core Shell Model calculations for the quadrupole moment of the 2+ state of 12C show a significantly smaller uncertainty when compared to the currently adopted experimental value. 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 “safe” Coulomb excitation experiment was performed at the JYFL in Jyväskylä using a 12C ion beam and a 208 Pb target. The aim of the experiment is to extract the quadrupole moment of the 2+ state of 12C. The Jurogam II array was used to measure the 2+ state de-exciting γ-rays in coincidence with backward-scattered 12C ions, measured with a CD Si detector. The uncertainty in the measured Q(2+) is expected to be a factor of three smaller than the currently adopted value, providing unparalleled testing ground for modern ab initio approaches. The status of the analysis will be presented.

Study of the pygmy dipole resonance in ^{96}Zr following the beta decay of ^{96}Y

K. Mashtakov

University of the West of Scotland, UK

The pygmy dipole resonance (PDR) is a nuclear phenomenon which is associated with the movement of a *neutron skin* of a nucleus against a mixed proton-neutron core [1, 2]. The nature of the PDR is of particular interest due to its importance in many areas of nuclear and astrophysics [3].

Current experimental techniques used to study this phenomenon produce not consistent results [1]. This is mostly due to the unknown branching behaviour of the $J\pi = 1^-$ levels which form the PDR. We use beta decay in order to populate these levels and study the PDR of ^{96}Zr. The main reason this particular nucleus was selected is that in the beta decay of its mother nucleus (^{96}Y) the states with energies almost up to the Qβ value (7.1 MeV) are populated. This alternative approach is not affected by the branching issue and the obtained results will not only provide us with improved spectroscopic information of the PDR but will also clarify the origin of the reactor antineutrino anomaly, which has effects on nuclear reactor safety.

The thermal-neutron-induced fission of ^{235}U at the ILL high-flux reactor was used in order to produce ^{96}Y nuclei which undergo beta decay to produce ^{96}Zr. Large volume high-purity germanium and silicon β-particle detectors were employed to obtain γ-γ and β-γ coincidence measurements. Gamma-ray spectra were then recorded and are being analysed to identify branching transitions to lower-lying excited states.

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[2] N. Paar et al., Rep. Prog. Phys. 70, 691 (2007)
[3] J. Beller et al., *Constraint on 0νββ matrix elements from a novel decay channel of the scissors mode: the case of 154Gd.* . Phys Rev Lett. 2013 Oct 25;111(17):172501

Plenary session 5

The DEPICT Project - Developing a gamma camera system for dosimetry of molecular radiotherapy

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Molecular radiotherapy (MRT) is a cancer treatment that involves the internal administration of radiopharmaceuticals to deliver a high radiation dose to targeted tumour tissue, whilst minimising the damage to surrounding healthy tissue. Current MRT treatment plans are undesirably generic as the administered activity is fixed for a certain procedure or scaled according to patient weight. However, it has been found that for the same initial administered activity, the uptake and retention of the MRT therapeutic agents, and hence the radiation dose, can vary by up to two orders of magnitude in different patients due to the wide range of biokinetics [1,2]. The absorbed radiation dose in the tissue of interest would ideally be calculated through accurate real-time quantitative imaging of the radiation distribution in the patient.

Single Photon Emission Computed Tomography (SPECT) can be used to image the radiation distribution, if gamma rays are emitted. In current SPECT systems however, quantitative activity information is lost due to dead time because diagnostic SPECT systems are not optimised for high-activity therapeutic measurements. The aim of the Dosimetry Imaging with CZT (DEPICT) project is to develop a custom-designed SPECT system to facilitate quantitative imaging, based on a collimated, pixelated CZT detector and a high-energy parallel hole collimator. The system will give an assessment of the radiation dose delivered to the patient, tailored specifically for MRT of the thyroid with radioiodine (^{131}I).

The CZT detector has been characterised and optimised for ^{131}I MRT [3] and gamma-ray images of a thyroid phantom have been acquired with a custom-designed high-energy parallel hole collimator and high-activity ^{131}I. Preliminary 3D reconstruction data of calibration vials has been acquired to assess the feasibility of obtaining accurate quantitative information with the DEPICT system.

[1] G. D. Flux *et al.*, A dose-effect correlation for radioiodine ablation in differentiated thyroid cancer. European Journal of Nuclear Medicine and Molecular Imaging (2010)

[2] G. Sgouros *et al.*, Patient-Specific Dosimetry for ^{131}I Thyroid Cancer Therapy Using ^{124}I PET and 3-Dimentional-Internal Dosimetry (3D-ID) Software. Journal of Nuclear Medicine (2004)

[3] L. McAreavey *et al.,* Characterisation of a CZT detector for dosimetry of molecular radiotherapy, Journal of Instrumentation 12 (2017)

(Invited) **Characterising hot nuclear matter with ALICE**

L Barnby

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In high-energy collisions of nuclei a deconfined state of matter is formed. This was initially conceived as a weakly coupled quark-gluon plasma. However, measurements from Brookhaven's Relativistic Heavy-Ion Collider experiments and later from those at the Large Hadron Collider (LHC) supported the idea that the deconfined state acts like a 'perfect fluid'. The energies densities created in the collision and temperatures which reach several 10^{12} K, are thought to correspond to the conditions prevalent a few microseconds after the Big Bang.

A Large Ion Collider Experiment (ALICE) at the LHC is designed to study Pb-Pb collisions with centre-of-mass energies of several TeV per nucleon which produce many thousands of charged particles. In this challenging experimental environment, the multiple detector systems track and identify the species of these hadrons as well as inferring the presence of weakly decaying particles containing strange or charm quarks. By measuring the abundances, momentum distributions and correlations among these particles, ALICE aims to investigate the nature of the deconfined matter.

Recent results from LHC Run 2 will be presented, including some from the short Xe-Xe data-taking in October 2017. These will help to understand the initial state of the nuclei at the partonic level which is an important ingredient in extracting the properties of the hot, dense system. Further results from Run 1 on the production of rare probes such as hadrons containing the heavy charm quark as well as light nuclei and anti-nuclei which appear in the final state hadron spectra will also be included.

The future plans for ALICE in Run 3, after the upcoming two-year shutdown, will be briefly described. ALICE will run with improved precision tracking and increase the data-taking rate by more than one order of magnitude, with attendant challenges in triggering, data processing and analysis.

Working at the limits - the three alpha break-up of the Hoyle state

T Kokalova-Wheldon

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This talk will report recent experimental results placing a new limit on the direct, 3alpha decay of the carbon-12 Hoyle state - the key gateway state to the production of heavier elements.

Lying just above the 3alpha threshold, this state has been investigated in an experiment at the Birmingham MC40 cyclotron facility, pushing conventional particle spectroscopy techniques to the limits, in order to shed light on its underlying structure.

(Invited) Coulomb excitation of superdeformed and non-axial structures in ^{42}Ca

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Superdeformed bands have been in focus of experimental nuclear physics studies for past decades. They have been reported in several regions of the nuclear chart and since then they also have become a new challenge for the nuclear structure theory. Recently, this phenomenon has also been discovered in the A~40 mass region. Unlike in the heavier nuclei, in calcium region the strongly deformed bands are linked to the normal deformed bands with the discreet gamma transitions, suggesting a possible mixing between these structures. Up to now the SD structures have been observed mainly in light-particle scattering and fusion-evaporation reactions, and the known B(E2) values were extracted from the lifetime measurements. However, recently also the Coulomb excitation technique has been hired to populate the SD structures in atomic nuclei.

A dedicated Coulomb excitation experiment aiming to investigate the properties of the superdeformed structure in ^{42}Ca was performed at INFN Laboratori Nazionali di Legnaro in Italy [1,2]. Gamma rays from the Coulomb excited ^{42}Ca beam on ^{208}Pb and ^{197}Au targets were measured by the AGATA HPGe spectrometer in coincidence with back-scattered projectile nuclei detected in the MCP detectors array.

The level of acquired statistics was sufficient to extract a rich set of reduced matrix elements allowing to precisely describe the electromagnetic properties of low-lying yrast and non-yrast states in ^{42}Ca. The quadrupole deformation parameters of the ground state and the side bands in ^{42}Ca were determined from the measured matrix elements. The recently published results, indicating that two structures differing in overall deformation coexist in ^{42}Ca, were compared to state-of-the-art large-scale Shell Model and Beyond Mean Field calculations. In addition, the triaxiality parameter measured for the excited 0^+ state provides the first experimental evidence for non-axial character of SD bands in the A~40 mass region.

In this talk I will present the benefits and the challenges of applying the Coulomb excitation method to study highly-deformed structures in atomic nuclei.

[1] K. Hadyńska-Klęk et al., Phys. Rev. Lett. 117, 062501 (2016)
[2] K. Hadyńska-Klęk et al., Phys. Rev. C97, 024326 (2018)

Parallel session 7

Decay spectroscopy of the proton-Emitting Isotopes ^{176,177}Tl

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Measurements of proton-decay properties provide an important source of spectroscopic information at the limits of known nuclei. The decay energies can be compared with proton separation energies predicted by mass models and in some cases atomic masses can be determined by linking decay chains to known masses, allowing direct comparisons with models to be made. The orbitals from which the protons are emitted can also be deduced from comparing partial proton-decay half-lives with predictions of theoretical models using the measured proton energies. Spherical proton emitters are important for testing models of proton emission and the most nearly spherical cases are expected to be the Ta nuclei closest to N = 82 and the proton-emitting isotopes ^{176,177}Tl that lie just 1 proton below Z = 82 shell closure and are the focus of this study.

The ^{176,177}Tl nuclei were produced in fusion-evaporation reactions induced by beam of ^{78}Kr ions bombarding a ^{102}Pd target using two bombarding energies of 397MeV and 376MeV. The fusion products were separated in-flight using the evacuated mass recoil separator MARA and implanted into a double-sided silicon strip detector. Both ground and isomeric states of the proton emitter ^{177}Tl were identified. The alpha-particle emission from the isomeric state of this isotope and the following alpha decay of ^{173}Au were observed. Correlated charged-particle decays showed some events which can be assigned to proton emission from the ground state of ^{176}Tl followed by decay of the alpha emitter ^{175}Hg. Identification of the nuclei was based on position, time and energy correlations between the implants and subsequent decays and the resulted values consistent with the previous studies. In addition, the possibility of the alpha decay of this isotope was searched for.

Upgrading the inner tracking system of ALICE

J P Iddon

University of Liverpool, UK

The ALICE collaboration at CERN is constructing a major upgrade of its detector for installation during LHC Long Shutdown 2 (2019-2020), motivated by the full exploitation of the scientific potential of the LHC for fundamental studies of QCD, with the main emphasis on heavy-ion collisions. It will enable the exploration of new phenomena in QCD and a detailed and quantitative characterisation of the high density, high temperature phase of strongly interacting matter; where above a critical energy density of 0.7 GeV/fm^3, the measured degrees of freedom strongly suggest it is composed of partons rather than nucleons The main physics topics to be addressed require the measurement of heavy-flavour hadrons, quarkonia, and low mass dileptons at low transverse momenta. These measurements in Pb-Pb collisions are characterised by a very small signal-to-background ratio, which require high statistics data samples of well measured and often complicated events and their topological features. The latter require a significant improvement of the track reconstruction efficiency and spatial precision.

The ALICE upgrade strategy is based on the LHC plans to increase progressively, after Long Shutdown 2, the luminosity of Pb beams eventually reaching an interaction rate of about 50kHz, i.e. instantaneous luminosities of $L=6\times10^{27}cm^{-2}s^{-1}$. The ALICE detector will be significantly upgraded by replacing the current ITS layers with 7 layers (3 inner layers, 2 middle layers and 2 outer layers) of Monolithic Active Pixel Sensors (MAPS). MAPS are Complementary Metal Oxide Semiconductor (CMOS) pixel sensors where the amplification, read out circuitry and sensor are all integrated onto one chip. A key feature of the MAPS design ALICE will use, ALPIDE, is a deep p-well shielding an n-well, meaning PMOS and NMOS transistors can be incorporated into the chip to form an in-pixel discriminator, amplifier, signal shaper and multiple event buffers.

In total, 24120 ALPIDE chips will need to be incorporated into Hybrid Integrated Circuits (HICs) at various sites. The Liverpool Semiconductor Detector Centre (LSDC) at the University of Liverpool is producing 1/5 of outer layer HICs; whilst Universite de Strasbourg (France); INFN Bari (Italy); Central China Normal University (China); and Pusan National University (South Korea) are taking care of the rest. The HICs are mounted to 192 staves in total, which take care of spacial structure, cooling and signal propagation. Approximately one third of outer layer staves are being constructed locally at STFC Daresbury Laboratory, whilst the rest are being constructed at NIKEF (Netherlands); LBNL (USA); INFN Torino (Italy) and INFN Frascati (Italy).

Following this construction phase staves will be assembled into the full ITS system on ground level at LHC point 2, followed by an extensive campaign to commission, calibrate and take reference data for the ITS with cosmic rays, first on ground level and eventually in the ALICE cavern before commissioning the new detector with beams in 2021. This contribution will outline the scope of the project and recent progress made in its construction, highlighting the detector technology and the work undertaken in the UK institutes.

Λ(1520) beam asymmetry measurement at the GlueX experiment

P Pauli (for the GlueX Collaboration)

University of Glasgow, Scotland

The GlueX experiment is the flagship experiment of the 12 GeV upgrade of the CEBAF accelerator at Thomas Jefferson National Accelerator Facility (JLab) in Newport News, VA, USA. It is a ~4pi detector with excellent calorimetry and tracking capabilities. A linearly polarised photon beam is produced from 12 GeV electrons in coherent bremsstrahlung on a thin diamond radiator and incident on a LH2 target. This setup makes GlueX an excellent facility to study excited hyperons, like the Λ (1520), in photoproduction. These measurements are an important first step to achieving GlueX's main goal, the measurement of gluonic excitations of mesons. To achieve that it is important to have a good understanding of photoproduction mechanisms in different reaction channels. Beam asymmetry measurements can help to provide valuable information for the necessary partial wave analyses. The talk will give an introduction to the GlueX experiment and will show first preliminary results of the photoproduction of strange baryons at high photon energies.

Fission measurements with STEFF at n_ToF, CERN

N Sosnin

University of Manchester, UK

The discovery of nuclear fission by Otto Hahn and Friedrich Strassman is approaching its 80th anniversary, however many aspects of the complex process of fission remain poorly understood. The angular momentum modes of the fissioning systems are one such aspect. SpecTrometer for Exotic Fission Fragments (STEFF) was built at the University of Manchester in order to measure gamma emission correlated to fission fragments. These measurements will provide insight into the fission angular momenta modes as well as address the NEA High Priority Request for measurements of gamma rays in fission needed for Generation IV reactor modeling. Data analysis of such measurements of ^{235}U neutron-induced fission products at the Neutron Time-of-Flight Facility at CERN is ongoing.

[1]Neutron-proton pairing correlations in a single l-shell model

A Marquez Romero, J Dobaczewski and A Pastore

University of York, UK

The long standing problem of neutron-proton pairing correlations is revisited by employing the Hartree-Fock-Bogoliubov formalism with neutron-proton mixing in both the particle-hole and particle-particle channels. We compare numerical calculations performed within this method with an exact pairing model based on the SO(8) algebra. The neutron-proton mixing is included in our calculations by performing rotations in the isospin space using the isocranking technique.

Parallel session 8

Modelling incomplete fusion of complex nuclei at Coulomb energies: superheavy element formation

R Van den Bossche

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Superheavy elements (SHE) have an atomic number Z > 104, and their existence was predicted almost 50 years ago due to quantum shell effects that influence their stability and decay [1]. SHE production is very challenging (due to very small cross sections in the range of a few picobarns or less), with complete fusion of heavy ions being one of the most successful ways of producing SHEs. The complete fusion mechanism produces neutron-deficient SHEs, making investigation into new methods of production crucial for further progress in SHE research.

The aim of the project is to investigate the incomplete fusion of neutron-rich projectiles with heavy stable targets, following the multi-fragmentation of a projectile at Coulomb energies. This mechanism has not been thoroughly explored yet, and could prove to be an effective way of producing neutron-rich SHE isotopes with low excitation energies [2].

To this aim, a semi-classical dynamical model is being developed by combining a classical trajectory model with stochastic breakup, as implemented in the PLATYPUS code [3], with a dynamical fragmentation theory [4] treatment of two-body clusterisation and decay of a projectile. A finite-difference method solution to the time-independent Schrödinger equation in the charge asymmetry coordinate is being explored by way of diagonalising a tridiagonal matrix with periodic boundary conditions.

Ultimately, this new model will be tested against existing experimental data [2] and used to make predictions for producing new SHE isotopes in future experiments planned at the Joint Institute for Nuclear Research in Dubna, Russia, and elsewhere [5].

[1] S. Hofmann at al., Eur. Phys. J. A 52 (2016) 180

[2] C. Borcea et al., Nucl. Phys. A 415 (1984) 169, and references therein

[3] A. Diaz-Torres, J. Phys. G 37 (2010) 075109; Computer Physics Communication 182 (2011) 1100

[4] S.N. Kuklin at al., Eur. Phys. J. A 48 (2012) 112
[5] C. Borcea et al., "Superheavy Elements: A New Paradigm", Proc. Int. Symp. on Exotic Nuclei (EXON-2016), http://www.worldscientific.com/doi/abs/10.1142/9789813226548_0021

Development of GRI+ as a Radioactive waste characterisation system

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The UK Government's long-term strategy for managing higher-activity waste is through disposal via a Geological Disposal Facility which is to be run by Radioactive Waste Management Limited. Current characterisation of waste is poor as it assumes a homogenous mixture and does not account for variations such as the presence of distributed sources and different materials. Also, along with chemical degradation of the waste bins, the current composition of the waste is largely unknown due to the decay of radioisotopes leading to various amounts of daughter nuclides.

Research is taking place to look at non-destructive analysis techniques in order to help improve on waste characterisation. Developments in gamma-ray imaging include advancements in Compton Camera systems. By using multiple position and energy sensitive detectors, the initial path of a gamma ray can be reconstructed using Compton kinematics.

The GRI+ Compton Camera at the University of Liverpool is a three-tier semiconductor detector system which is being developed to improve upon initial characterisation techniques to classify radioactive waste. Events interacting in a 2-tiered detector system, including a Canberra Si(Li) strip planar scatter detector of volume 3500 mm^2 and a Canberra HPGe strip planar detector of active volume 60x60x20mm, were compared against a 3-tiered system which also included a coaxial HPGe.

The purpose of the work outlined in this presentation was focusing on the ability to measure sources through attenuating material and the effects the attenuation has on correctly identifying different isotopes, the quality of the spectra, peak-to-total ratios and the image resolution. The experimental method investigated the degradation in performance due to a relatively dense attenuating material, and how it affected the quality of the reconstructed images; a problem which will be faced in nuclear decommissioning. Varying thicknesses of copper were placed in between the detector and two point sources of Cobalt- 60 and Caesium-137 relatively close to the scatter detector face. The data were analysed using MTSORT and a filtered back projection analytical image reconstruction code, to see how attenuation through the copper affected both the spectra and the images. The final results showed that different isotopes were still easily identified spectroscopically with maximum thickness of attenuating material, however reconstructed images showed that the ability to distinguish between two different isotopes is only possible through energy gating.

Modelling superheavy element creation with dissipative quantum dynamics: Chebyshev propagator in a Fourier grid

T Vockerodt

University of Surrey, UK

Superheavy elements (SHE) have an atomic number $Z > 104$, and their existence was predicted almost 50 years ago due to quantum shell effects that influence their stability and decay [1]. SHE production is very challenging (due to very small cross sections in the range of a few picobarns or less), with complete fusion of heavy ions being one of the most successful ways of producing SHEs.

The complete fusion mechanism of complex nuclei is poorly understood. Currently, most existing models for low-energy reaction dynamics of complex nuclei do not address the dissipative quantum dynamics in the pre equilibrium phase of these collisions, which occurs in a timescale of zeptoseconds ($t \approx 10^{-21}$s). In this work, we aim to investigate the dissipative pre-equilibrium quantum dynamics of the fusion and quasi-fission of heavy dinuclear systems leading to the formation of superheavy nuclei, and calculate the associated cross sections. This will be very useful for understanding the complete fusion mechanism as well as for interpreting and planning new experiments in this field.

As a starter project, we model the dynamics of an unperturbed 1-D wave- packet approaching a Gaussian potential, in a Fourier grid. We develop a quantum propagator in FORTRAN using Chebyshev polynomials [2], due to its convergent properties. Throughout the propagation, the wave-function normalisation is conserved close to unity, with an error on the order of 10^{-14}, indicating the good quality of the implemented propagator. After a long time propagation with the wave-packet energy equal to the barrier height, we observe a transmission coefficient close to 50%, as expected. An energy-projection method is also being implemented to calculate energy-resolved transmission and reflection coefficients [2].

Future work includes introducing new collective coordinates to the wave- function, as well as dissipation in the propagator.

[1] S. Hoffman et al. European Physical Journal A, vol. 52, p. 180, 2016
[2] M. Boselli and A. Diaz-Torres Physical Review C, vol. 92, p. 044610, 2015

Study on the effect of background subtraction algorithm on jet shapes

J Kvapil, P Jones, H Andrews

University of Birmingham, UK

A hot and dense medium of de-confined quarks and gluons (Quark Gluon Plasma) is created in Pb-Pb collisions at Large Hadron Collider in CERN. Jets, which are collimated cones of hadrons created during hadronization of energetic partons, can be used to study the properties of this newly created matter. This medium induces an energy loss of highly-energetic partons traversing through it, modifying jet properties, also known as jet shapes, such as momentum dispersion p_T^D, first radial moment g, jet mass m_{jet}, 1- and 2-subjetiness T1,2, jet splitting function z_g and groomed radius $\Delta\mathcal{R}$. Heavy-ion collision jets measured by ALICE experiment are reconstructed in a presence of a large uncorrelated background. In this talk we will present effect of background subtraction method on these shapes.

Commissioning of TPEN: a triple-foil plunger for exotic nuclei (TPEN)

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A new Triple-foil Plunger for Exotic Nuclei (TPEN) has been commissioned at the University of Jyväskylä using the inverse reaction ^{24}Mg(^{136}Xe, 4n)^{156}Dy. In contrast to a standard plunger device, TPEN has one target-foil and two degrader-foils. The additional degrader foil decreases the beam time required for lifetime measurements compared to the standard two foil plunger, extending lifetime measurements to more exotic nuclei with lower production cross sections. The additional foil allows for a direct measurement of the 'differential' of the decay curve. The well-known $4^+ \rightarrow 2^+$ lifetime in ^{156}Dy was measured to validate this analysis technique and confirm the reduction in beam time requirements. Additionally the third foil can be used measure two very different lifetimes simultaneously, for example in this commissioning experiment the 9.04(15) ps $6^+ \rightarrow 4^+$ and the 45.6(5) ps $4^+ \rightarrow 2^+$ lifetimes were measured simultaneously.

IOP Annual Nuclear Physics Conference 2018

Friday 6 April

Parallel session 9

An investigation into the structure of proposed cluster bands in $^{18}O^*$

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A series of proposed bands in ^{18}O with potential nuclear molecule structures, such as $^{14}C \otimes \alpha$ or $^{12}C \otimes 2n \otimes \alpha$, are being investigated.

This follows the work of W. von Oertzen et. al done previously at the Maier-Leibnitz Laboratory [1]. Measurements to determine the absolute α-particle decay widths of high-energy excited states in $^{18}O^*$ have been performed, also at the Maier-Leibnitz Laboratory, looking for evidence of these structures. These measurements were performed through the use of the Munich Q3D spectrometer in coincidence with an array of double-sided silicon strip detectors to determine both the position and energy of fragment particles to enable high-resolution reconstruction. This talk will outline the current state of the analysis.

[1] Molecular and cluster structures in 18O - W. von Oertzen et al. Eur. Phys. J. A 43, 1733 (2010)

Algorithm development for the non destructive assay of nuclear waste

K Tree[1], L Harkness-Brennan[1], H Boston[1], A Boston[1], C Unsworth[1], D Judson[1], P Nolan[1], B Ripper[2], G Bolton[3], A Adekola[4], J Colaresi[4], J Cocks[4], W Mueller[4] and M Sarsfield[5]

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Broad Energy Germanium detectors are routinely used for gamma ray spectroscopic analysis of nuclear waste streams to ascertain the type and relative activity of radionuclides. Challenges arise when low activity radionuclides which are of interest are obscured by the presence of higher activity radionuclides. A key example is when Compton scattered gamma rays from ^{137}Cs conceal the presence of low energy gamma rays from ^{241}Am in the γ-ray spectrum. The Compton scattering events manifest in a continuum within the spectrum, elevating noise. Current methods to overcome this problem involve mechanical Compton suppression systems such as those that use a central broad energy germanium detector surrounded by a guard ring of additional detectors.

In this talk, the development of an algorithm to perform digital Compton suppression (DCS), together with its benefits in γ-ray spectroscopy will be discussed. The development of the algorithm has been achieved by distinguishing low energy γ-rays that are absorbed near the outer surface of the germanium detector, from Compton scattering events that are as a result of higher energy -rays interacting throughout the bulk of the detector. The technique exploits the knowledge of how the detector signal varies as a function of γ-ray interaction position, characterised by position-dependent charge collection times. The DCS algorithm significantly reduces counting times with improved low energy isotope identification when in the presence of large backgrounds, without the requirement for Compton suppression shielding. It also allows for a “one detector” system to be utilised.

Presented results will include the dependence of charge collection times on both radius and depth (z) within a Broad Energy Germanium detector. Additionally, the results of the application of the DCS algorithm to data that has been acquired using a variety of point sources at Central Labs, National Nuclear Laboratory will be presented. The results show that the DCS algorithm is successful and has enabled an improvement of 30% in the Minimum Detectable Activity of the detector. This reduction will enable waste producers to re-characterise some of their low level waste as very low level waste. Very low level waste can be diverted to licensed land fill sites rather than being sent to the low level waste repository.

Studies of jet grooming and recursive splittings in pp and Pb-Pb collisions with ALICE

H Andrews (on behalf of the ALICE Collaboration)

University of Birmingham, UK

Hard splittings in the evolution of a jet may be modified by the presence of a dense strongly interacting medium. Grooming procedures can be used to isolate such hard components of a jet and allows one to focus on the two subjets resulting from a suficiently hard partonic splitting. The modification of these splittings in medium could highlight the role of jet induced medium response as well as potential single hard scatterings (higher-twist) and multiple soft medium induced radiation (BDMPS). Measurements of the symmetry parameter (z_g) and angular separation of such subjets as measured in pp and Pb-Pb collisions at $\sqrt{s}$ = 7 TeV and $\sqrt{sNN}$= 2.76 TeV respectively using the ALICE detector at the CERN LHC are reported. Results are compared to predictions using Monte Carlo generators. The use of recursive splittings and their mappings to identify interesting regions of phase space will also be discussed with comparisons made between Monte Carlo generators and data in pp and Pb-Pb collisions.

Collinear Resonance Ionisation Spectroscopy (CRIS) studies of neutron-rich indium isotopes

C Binnersley

University of Manchester, UK

With a proton hole in the Z = 50 shell closure, the indium isotopic chain (Z = 49) provides a compelling environment to explore the evolution of nuclear-structure properties in the vicinity of the doubly-magic isotopes ^{100}Sn (Z, N = 55) and ^{132}Sn (N = 82). This contribution will focus on recent measurements of neutron-rich indium isotopes, $^{113\text{-}131}$In, at the Collinear Resonance Ionisation Spectroscopy (CRIS) experiment at CERN. The CRIS technique combines the high resolution attained using collinear laser spectroscopy with the sensitivity provided by resonance ionisation spectroscopy. From the measured hyperfine spectra, the spins, electromagnetic moments, and changes in root-mean-squared charge radii of several ground and isomeric states have been determined for the first time, extending our experimental knowledge up to N = 82.

The recently installed ablation ion-source at the CRIS experiment has enabled rigorous assessment of ionisation schemes used during radioactive beam experiments. Development of this ion-source and results from two stable beam indium experiments will also be discussed.

Parallel session 10

Λ_c baryon studies with ALICE at the LHC

C Hills

University of Liverpool, UK

Heavy flavour quarks (charm and beauty) offer a unique opportunity to study 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, allowing the heavy quarks to interact with the QGP throughout its entire evolution. The measurement of the Λ_c baryon and of the charmed mesons allows the baryon-to-meson ratio to be evaluated, probing hadronisation and thermalisation mechanisms in the medium. This measurement, made in p-Pb collisions, will also help to separate the hot and cold nuclear matter effects seen in Pb-Pb collisions.

The ALICE detector, with its excellent vertex reconstruction and hadron identification, allows for the study of Λ_c production. The measurement of the p_T–differential cross section of the Λ_c baryon through the $\Lambda_c \rightarrow pK\pi$ decay channel in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV will be presented.

Photoproduction of Ø-mesons with linearly-polarized photons

L Clark

University of Glasgow, UK

Analysis of observables from vector meson photoproduction by linearly-polarized photons is a useful tool for investigating hadronic processes. These observables are combinations of helicity amplitudes parametrized by spin density matrix elements. In particular, photoproduction of the Ø-meson, considered to be a pure $s\bar{s}$ state, can be used to investigate production mechanisms, violation of the OZI rule, and the strangeness content of the proton. The data were collected with the CLAS detector and the Hall B tagged-photon beam at the Thomas Jefferson National Accelerator Facility. Analysis of the decay angular distributions from the reaction γp → Ø p with Ø → K+K- is presented along with preliminary extraction of 9 spin density matrix elements.

Polarisation observables at MAMI

C Mullen

University of Glasgow, UK

The composite nature of the nucleon as a strongly interacting system of valence quarks, gluons and sea quarks implies a multitude of excited states exist. To infer the existence and properties of these states a range of meson photoproduction experiments can be performed with measurements of the beam, target proton and recoil proton spin polarisations. In addition it is necessary to measure reactions with different isospin components, for example by using both a proton and neutron target, to extract the isospin quantum numbers of the states. Techniques for measuring beam polarisation observables are well established. However, measurements of observables using these techniques are lacking, particularly for neutron channels. An experiment was undertaken in August 2016 at the A2 experiment in Mainz to gain significant new data with both protons and neutrons in order to constrain the excitation spectrum of the nucleon. A brief summary of the results to date will be presented.

A segmented inverted-coaxial germanium detector SIGMA

F Pearce[1], A J Boston[1], L J Harkness-Brennan[1], D S Judson[1], M Labiche[2], P J Nolan[1], R D Page[1], D C Radford[3], J Simpson[2], C Unsworth[1], J P Wright[1]
[1]University of Liverpool, UK, [2]STFC, Daresbury Laboratory, UK, [3]Physics Division, Oak Ridge National Laboratory, USA

SIGMA is a novel gamma ray tracking detector utilising point contact technology to potentially deliver exceptional energy and position resolution, superior to current large volume germanium detectors. The small size of the point-like contact offers reduced capacitance resulting in low series noise and precision energy resolution. Unique electrode configuration gives a significantly different charge collection profile from standard coaxial detectors, with long drift times related to interaction position. Using pulse shape analysis techniques, it has been predicted that a position resolution superior to current state of the art large volume detectors, such as AGATA, could be achieved. A Geant4 model of the SIGMA detector has been developed, which has allowed for an investigation into the efficiencies that could be achieved when using an array of SIGMA detectors. The model will also be used to produce Monte-Carlo data to study gamma-ray tracking performance. An update on the progress of the SIGMA project will be given.

Plenary session 6

(Invited) **Search for novel nuclear density functionals**

J Dobaczewski

University of York, United Kingdom

Numerous applications of nuclear DFT have shown a tremendous success of the approach, which by using a dozen-odd coupling constants allows for correct description of a multitude of nuclear phenomena. However, recent analyses indicate that the currently used models have probably reached their limits of precision and extrapolability. The question of whether these can be systematically improved appears to be one of the central issues of the present-day investigations in nuclear-structure theory. In this talk, I will present status of theoretical developments that aim to build novel nonlocal energy density functionals (EDFs).

In particular, we recently proposed [1] to use two-body regularized finite-range pseudopotential to generate nuclear EDFs in both particle-hole and particle-particle channels, which makes them suitable for beyond-mean-field calculations. We derived a sequence of pseudopotentials regularized up to next-to-leading order (NLO) and next-to-next-to-leading order (N2LO), which fairly well describe infinite-nuclear-matter properties and finite open-shell paired and/or deformed nuclei. Solutions of the corresponding self-consistent equations were implemented in spherical, axial, and triaxial symmetries, codes FINRES4 [2], HFBTEMP [3], and HFODD [4], respectively.

In Ref. [5] we showed results of the Hartree-Fock-Bogolyubov calculations performed using these two parametrizations. Recently, we focus on developing novel functionals in the particle-hole channel and on extending the formalism to non-local functional generators. In the talk, I will present the current status of these developments.

[1] K. Bennaceur, A Idini, J Dobaczewski, P Dobaczewski, M Kortelainen, and F Raimondi, J. Phys. G: Nucl. Part. Phys. 44 (2017) 045106
[2] K. Bennaceur et al., to be submitted to Comp. Phys. Comm
[3] M. Kortelainen et al., to be submitted to Comp. Phys. Comm
[4] J. Dobaczewski et al., to be submitted to Comp. Phys. Comm

[5] K. Bennaceur, J. Dobaczewski, and Y. Gao, Proc. of the 6th International Conference on "Fission and Properties of Neutron-Rich Nuclei" (World Scientific, Singapore, 2018), p. 27, arXiv:1701.08062

(Invited) **Overview of current activities at the JYFL Accelerator Laboratory**

I D Moore

University of Jyväskylä, Finland

The JYFL Accelerator Laboratory (JYFL-ACCLAB) is one of the leading stable beam facilities in Europe, conducting world class research on basic natural phenomena [1]. Presently the laboratory hosts four accelerators with a variety of ion sources and innovative instrumentation for fundamental research, ion-beam based materials physics and applications. The current main research equipment includes the fast and universal on-line isotope separator IGISOL producing low-energy radioactive ion beams (RIBs) which are coupled to ion/atom traps and laser systems, two recoil separators (gas-filled, RITU, and vacuum mode, MARA) with novel multi-detector systems for low cross-section in-beam and stopped-beam spectroscopy experiments, infrastructure for a variety of ion beam analysis methods and a RADiation Effects Facility, RADEF.

The IGISOL facility hosts one of the leading groups in high-precision mass measurements of exotic nuclei with over 330 atomic masses measured for nuclear structure and astrophysics, as well as for fundamental interactions. Recent developments in ion manipulation have provided isotopically and isomerically purified beams for decay studies and applications. Collinear laser spectroscopy and novel variants is performed to study both macroscopic and microscopic nuclear structure, with new efforts focused on the actinide elements as well as developments towards the first spectroscopy of fast atomic beams.

The nuclear spectroscopy team, with state-of-the-art detector systems coupled to recoil separators, have produced a wealth of in-beam and decay studies, probing structures and phenomena in proton drip-line nuclei and superheavy elements produced via heavy-ion fusion-evaporation reactions. With the successful commissioning of the MARA recoil separator, a new campaign of studies of proton dripline nuclei has begun, while the preparations to house the JUROGAM3 array of germanium detectors which will be available for physics at both MARA and RITU is being finalized.

In this presentation I will present an overview of the current status of the facility and will explore a number of exiting new projects. At IGISOL we are extending our activities towards cold atom physics in collaboration with UCL, with laser cooling and trapping techniques aimed at realizing the first Bose-Einstein Condensate (BEC) of radioactive isomers. Most recently, a new French-led project has received funding which aims to search for physics beyond the Standard Model via precision nuclear beta decay. For the first time, the two main research groups, IGISOL and nuclear spectroscopy, are combining expertise and efforts to realize a novel low-energy beam facility at MARA (MARA-LEB). This facility will provide unique access to ground-state nuclear structure properties of nuclei along or close to the $N=Z$ line, and is complementary to future large scale facilities including S3, SPIRAL2. Along the way I will highlight the important collaboration the facility maintains with our UK collaborators as we look forward to an exciting future.

[1] A. Jokinen, Nuclear Physics News 24, 10 (2014)

(Invited) **Laser-driven particle and radiation sources at SCAPA**

P McKenna

University of Strathclyde, UK

High power laser-driven particle and radiation sources are an enabling technology due to the unique properties of the radiation pulses produced and the compact nature of the laser driver. They are opening up the exploration of new approaches to radiation biology (e.g. ultrahigh dose irradiation) and to medical imaging (e.g. high resolution 3D tomography of bone structure). Multiple types of radiation beams (electrons, positrons, ions, X-rays and neutrons) can all be produced using the same laser driver and synchronised to ultrashort timescales. This can potentially open up new avenues of investigation in nuclear physics, in addition to driving nuclear reactions and the production of radioisotopes. In this talk I will present progress in the development of the Scottish Centre for the Applications of Plasma-based Accelerators (SCAPA), which is collaborative venture between the University of Strathclyde, the Scottish Universities Physics Alliance (SUPA) and external partners, focusing on the science and exploitation of laser-driven radiation sources. I will also discuss how research performed at SCAPA complements planned research at the international Extreme Light Infrastructure (ELI) Nuclear Physics facility under construction near Bucharest.

Poster session

Inner tracker detector studies for a future electron-ion collider

H Wennlöf, L Gonella, P G Jones, P R Newman and P P Allport

University of Birmingham, UK

There are plans for building an electron-ion collider (EIC) in the United States in order to study the internal physics of nucleons. In our research group, we look specifically at potential inner tracking detectors for such a collider. For an inner tracker at an electron-ion collider it is important to have very high spatial resolution, low material budget, and low power consumption. We currently look at depleted silicon monolithic active pixel sensors (DMAPS), investigating performance of different technologies and pixel layouts. Depletion enables charge collection by drift, which leads to a smaller charge cloud, making smaller pixel pitches viable and thus increasing spatial resolution.

Primarily we look at a test vehicle prototype chip from TowerJazz, comparing the performance of two manufacturing processes; one with partial depletion (the ALPIDE sensor for the ALICE ITS upgrade), and one made with a new process aiming for full depletion. Each chip contains several pixel matrices of different configurations, and comparative measurements have been made for pixel sizes of 20x20 μm^2, 28x28 μm^2, and 50x50 μm^2. The poster will give an overview of the different processes, and results of the comparative measurements so far.

Current research in PET scanners

R R Trinder, T Kokalova, D J Parker

University of Birmingham, UK

This poster will discuss how the emission of positrons can be used to image structures and functions of an object. The detector setup of common PET (positron emission tomography) scanners and basic image theory used to reconstruct the data collected will also be presented.

PET has many applications, an important example of which is in cancer research. New cancer therapies are being investigated such as the use of different radioactive isotopes of the same element to simultaneously perform the imaging and treatment of cancer cells. Different positron emitting isotopes effect PET image quality. By collaborating with NPL, myself and my colleges at the University of Birmingham aim to produce new isotopes and test their possibility and practicality for PET imaging and radiotherapy.

Currently my work is focused on collaborating with NPL to investigate copper and cobalt isotopes. Initial investigations will use phantom “mice” made from polymers containing ^{63}Cu or ^{59}Co. The poster will explain how we plan to activate the phantoms to ^{64}Cu and ^{60}Co (positron emitters) for the purpose of performing PET images.

Comparison of different neutron detectors and validation using MCNP simulations

S Kalantan[1,2] and A Boston[1]

[1]University of Liverpool, UK and [2]King Abdulaziz University, Saudi Arabia

A good understanding of the performance of a detector system is essential for the deployment of systems in experiments and industrially relevant environments. For this, Monte Carlo modelling of the detection system plays a vital role in interpreting the experimental results. Validation of the simulation with experimental measurements gives confidence in the scenarios used to compare the performance of different neutron detectors.
This abstract will report on the comparison between the detection performance of three common thermal neutron detectors. A He^3 proportional counter; a BF^3 proportional counter; and a ^{6}LiI(Eu) scintillation detector. Experimental measurements and Monte Carlo simulations have been performed. Using the code MCNP, a detailed insight into the performance of these detector systems was delivered.

A good agreement between the simulation and the experiment was achieved. The intrinsic efficiency of the small ^{6}LiI(Eu) scintillator was found to be comparable to that of the much larger proportional counters. The limiting factors influencing the performance of all the detector systems will be discussed.

Imaging of prompt gamma emissions during proton cancer therapy for geometric and dosimetric verification

H Alshammari[1], 3, L Harkness-Brennan[1], A Boston[1], A Caffrey[1], B L Crom[2], C Unsworth[1], D Judson[1] and E Rintoul[1]

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

Protons are used in radiation therapy of cancerous tissue as they have the potential benefit of sparing dose to healthy tissue, due to manipulation of the positioning of the Bragg Peak as a function of depth in the body[1]. However, there is a need for a more precise method for range verification and the monitoring of dose delivery in real-time[2]. The University of Liverpool have developed the prompt-gamma imaging (PGI+) system, to measure the prompt gamma rays emitted and therefore the dose distribution of the proton beam during proton therapy. The PGI+

system is composed of a triple-layer semiconductor Compton camera (two position-sensitive scatter detectors and an absorber detector). The prompt gamma rays can deposit their energy across the detector system in a large variety of sequences. The system's performance has so far been investigated using the simplest event sequence, which is a single interaction event in each detector. In this case, a spatial image resolution of around 5 mm was determined. However, for high photon energies, such as those observed in proton therapy, multiple interaction events are probable. In this study, the effective use of multiple interaction events will be discussed. The poster will also outline plans for an experiment to be conducted at the Clatterbridge Cancer Centre, UK, as part of the next phase of the project.

Development of a multidimensional gamma-spectrometer in support of On-Site Inspection

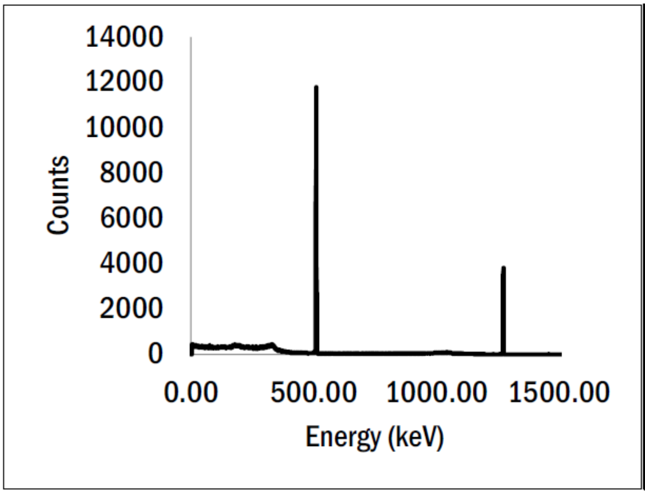
J Corkhill[1], A J Boston[1], A V Davies[2], D T Joss[1]

[1]University of Liverpool, UK, [2]AWE, UK

The aim of this research project is to characterise a dual detector coincidence system, consisting of two detectors. The motivation for building and characterising this detector system is so that it can be used to perform nuclear forensics. The system will aim to identify which radioactive sources are being measured, where they have come from and who has been involved in their production [1] [2]. This system has several advantages including:

a) A reduction in the background radiation of up to a factor of 200
b) The ability to accurately select the cascading radionuclides of interest
c) The ability to log all the detector events by the signal processor. This opens up new possibilities for data analysis and interpretation.

The system was characterised in terms of the energy and timing performance. Typical values were of the order of 1-3 keV for the energy resolution and 10 ns for the timing resolution [3] [4].



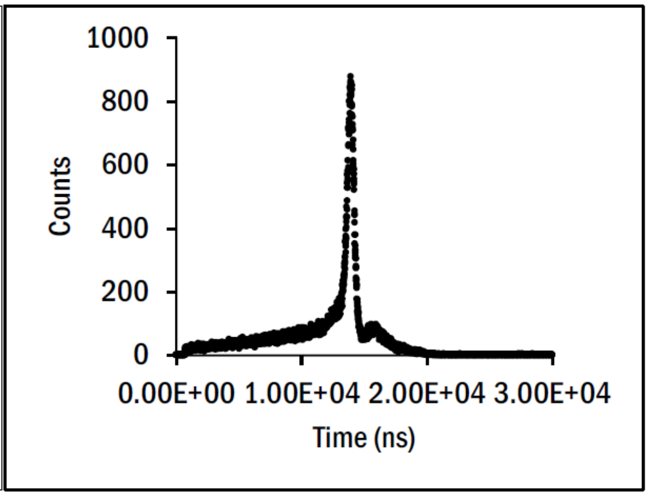


Figure 1 (Left): An energy spectrum for 22Na, as measured by the BEGe 2825 detector, using digital processing. The FWHM of the 511.00 keV peak is 0.95 keV and for the 1274.53 keV peak, the FWHM is 1.28 keV [3] [4]. Figure 2 (Right): An ungated TAC spectrum using a 22Na source, using the ORTEC GEM – 15180 – P detector [5].

[1] The Atomic Weapons Establishment, "Nuclear data and modelling for monitoring compliance with the Comprehensive Test Ban Treaty," The Atomic Weapons Establishment, 2016
[2] The University of Liverpool, "Development of a multidimensional gamma-spectrometer in support of On-Site Inspection," The University of Liverpool, Liverpool, 2015
[3] J. L. Corkhill, "First-Year Report," The University of Liverpool, Liverpool, 2017
[4] http://nucleardata.nuclear.lu.se, "http://nucleardata.nuclear.lu.se/," 27 December 2017. [Online] Available: http://nucleardata.nuclear.lu.se/toi/nuclide.asp?iZA=110022. [Accessed 27 December 2017]

[5] ORTEC®, "https://www.ortec-online.com," 31 May 2017. [Online]. Available https://www.orteconline.com/-/media/ametekortec/brochures/gem.pdf. [Accessed 31 May 2017]

Studying the use of thallium bromide as a radiation sensor

O Voyce, T Veal, L Harkness-Brennan, P Nolan, D Judson and L Jones

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Research is being undertaken at the University of Liverpool into the development of thallium bromide (TlBr) as a radiation sensor for deployment in the nuclear industry. This compound is expected to excel as a room temperature semiconductor detector owing to its wide band gap energy (2.68eV), low intrinsic carrier concentration and high detection efficiency. It has a large bulk resistivity of the order 10^{10} - 10^{11} Ω which reduces the dark current and electronic noise and its composition from high atomic number elements (Z_{Tl} = 81, Z_{Br} = 35) combined with large density of 7.5g/cm^3 allows for very thin crystals to be fabricated. The long term performance of TlBr devices however, is inhibited by the degradation of the device through ionic polarization of the crystal. It is thought that ions migrate through the bulk via the mechanism of vacancy hopping which is facilitated by the presence of defects at the surface. To this end, preliminary research is being conducted into the influence of various chemical treatments in the conditions of the TlBr surface. Composition analysis and band structure information will be obtained through x-ray photoelectron spectroscopy and the surface stoichiometry will be analysed through atomic force microscopy. It is expected that the concentration of surface defects will be reduced with chemical treatment which will therefore improve device performance and longevity.

These initial results will be used to understand the contribution to performance in gamma-ray spectrometry.

A compact linear Paul trap cooler buncher for CRIS

C Ricketts

University of Manchester, UK

Collinear resonance ionisation spectroscopy (CRIS) combines ionisation spectroscopy with a collinear geometry to provide Doppler-free measurements of atomic hyperfine structure, used to determine changes in root mean square charge radii, nuclear ground state spins and nuclear ground state electromagnetic moments. In the technique, an atomic beam is collinearly overlapped with multiple laser fields to resonantly excite then ionise the atoms of interest for deflection and detection.

As the high-power pulsed-lasers required are only available with relatively low repetition rates (<200 Hz), the ion beam must arrive in bunches to avoid duty-cycle losses. This requirement for a bunched beam necessitates the use of an ion trap. The CRIS experiment at ISOLDE, CERN currently makes use of the shared linear Paul trap, ISCOOL. Installing a cooler buncher after the independent ion source at CRIS would allow for continual optimisation of the beam transport and quality. This would reduce the setup times needed before time-pressured experimental runs studying radioactive isotopes and would simplify rapid switching to a stable reference isotope.

This poster presents the work completed towards a compact linear Paul trap cooler buncher for CRIS measurements with the Artemis project at The University of Manchester. The project also acts as an initial prototype for a future ion trap at CRIS, ISOLDE. The design incorporates many 3D printed and PCB based DC optics and mounting pieces, greatly increasing the speed of manufacture. Initial vacuum tests have demonstrated the vacuum compatibility of these plastics, reaching pressures of 6 x 10^{-7} mbar.

Nuclear data needs for accelerator based neutron sources

S Lilley[1] and M Fleming[2]

[1]ISIS, STFC, Rutherford Appleton Laboratory, UK and [2]UK Atomic Energy Authority, Culham Science Centre, UK

Accelerator based neutron sources can be divided into two categories; spallation sources using high energy (>500 MeV) proton beams onto high Z targets such as Tungsten or Mercury and so called compact neutron sources using low energy beams (< 100MeV) onto a low Z material. In either case, the resulting neutrons must be moderated from their MeV emission energies down to sub-eV energies in order to be used for neutron scattering experiments. Radiation transport and isotope inventory simulations are utilised to optimise spallation facilities and plan for operational scenarios. These codes require validated nuclear data to provide the underlying nuclear reaction physics.

The main nuclear data issue for both compact neutron sources and spallation sources is a lack of experimental data to validate the cross sections, yields or physics models used across the full range of particle and energies encountered in the system. The majority of data in the international EXFOR database [1] is from experiments with incident energies below 20MeV and the majority of nuclear data libraries (such as ENDF/B-VIII.0 or JEFF-3.3) exclusively contain data below 20 MeV.

Proton and neutron transmutation in the high mass targets of spallation sources produce a large range of residual radioactive products. Recent work on proton residuals has resulted in the HEIR library [2], employing the most recent intra-nuclear cascade and de-excitation models, to provide data to enable FISPACT-II to perform inventory calculations with incident particles up to 1 GeV. This library includes over 2000 target isotopes, most with more than 1000 products. The available experimental data cover less than 1% of these reaction channels, presenting a challenge from a validation perspective. There is a general need for high quality experimental data for proton reactions, notably on tungsten and tantalum, including the 181Ta(p, Xn) yields, total gas production, and residual isotope cross sections for total decay heat at short times scales.

Compact neutron sources typically use low energy proton beams between 10 – 100 MeV on low mass materials such as beryllium. These sit at the low energy end of physics models used for spallation, but above many of the nuclear data libraries. Hence there is a need for high quality nuclear data in order to validate the transition from models to data libraries. In particular, the Be9(p,n)B9 has no experimental data in EXFOR above 10 MeV, while the available data is not in agreement with the evaluated nuclear data libraries.

Many existing neutron sources use cold moderators such as liquid hydrogen, but there are many other materials which could be considered. However, the lack of thermal scattering data for some materials presents a challenge for the design of systems with novel moderator materials. In order to calculate the scattering kernel parameters, experimental data on neutron transmission as a function of energy and density of states is required. Recent work at ISIS using TOSCA and VESUVIO instruments has successfully measured both the transmission and density of states at high resolution.

[1] EXFOR: Experimental Nuclear Reaction Data. URL: www-nds.iaea.org/exfor/

[2] M. Fleming, J. Eastwood, T. Stainer, J-C. David and D. Mancusi. HEIR: a High-Energy Intra-Nuclear Cascade Liège-based Residual Nuclear Data Library for Simulation with FISPACT-II, in preparation. URL: http://fispact.ukaea.uk/

Interrogation of active waste drum

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The demand for efficient technique for complex and heterogeneous radioactive waste characterisation is increasingly high. Segmented gamma scanning being the most widely used technique for non-destructive assay in radioactive waste drum characterisation relies on the assumption that radionuclides activity distribution and waste matrix are homogeneous in each segment of the waste system [1]. However, the radioactive distribution and matrix composition for radioactive waste system are usually non-homogeneous and can introduce great uncertainties in measurements which evidently are not always corrected for using most standard measurements like segmented gamma scanner [2]. The new technique; tomographic gamma scanning is employed in this work to acquire 3-dimensional transmission and emission tomographic measurement of radioactive waste drum. It scans waste drum in three degrees of freedom. MCNP simulation of a point transmission source modelled with germanium detector and standard radioactive waste drum of different matrices composition was performed to determine the attenuation of gamma rays by the matrices. The MCNP results will be validated through laboratory measurements.

[1] Venkataraman, R., Villani, M., Croft, Stephen., McClay, P., McElroy, R., Kane, S., Mueller, W., and Estep, R. 2007. An integrated tomographic gamma scanning system for non-destructive assay of radioactive waste. Nucl. Instr. Meth. Phys. Res. A 579, 375 – 379

[2] Thanh, T. T., Trang, H. T., Chuong, H. D., Nguyen, V. H., Tran, L. B., Tam, H. D., and Tao, C. V. 2016. A prototype of radioactive waste drum monitor by non-destructive assays using gamma spectrometry. Appl. Radiat. Isot. 109. 544 – 546.

Gamma-ray spectroscopy study of 31S and gateway reactions in nova explosions

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The 30P(p,gamma)31S reaction is expected to act as the bottleneck for the production of heavy elements in oxygen-neon (ONe) nova explosions. Its rate, therefore, critically influences abundances of elements observed in ONe nova ejecta as well as 30Si/28Si isotopic abundance ratios observed in presolar grains found in primitive meteorites.

At present, a direct measurement of the 30P(p,gamma)31S reaction, at the temperatures relevant to nova explosions, is not possible owing to the difficulty in producing beams of radioactive 30P. As such, various indirect methods have been employed in order to determine the properties of key resonant states in 31S that govern the reaction rate. These include a number of gamma-ray spectroscopy studies with large arrays of HPGe detectors. Here, we report on initial results of a further gamma-ray spectroscopy study of 31S with the addition of recoil selection using ANL's Fragment Mass Analyser (FMA) to search for hitherto unobserved gamma-ray transitions direct to the ground state and to the first 5/2+ level. The results of this study will help to rectify discrepancies that exist between the gamma-ray studies and those from transfer and charge-exchange reactions.

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