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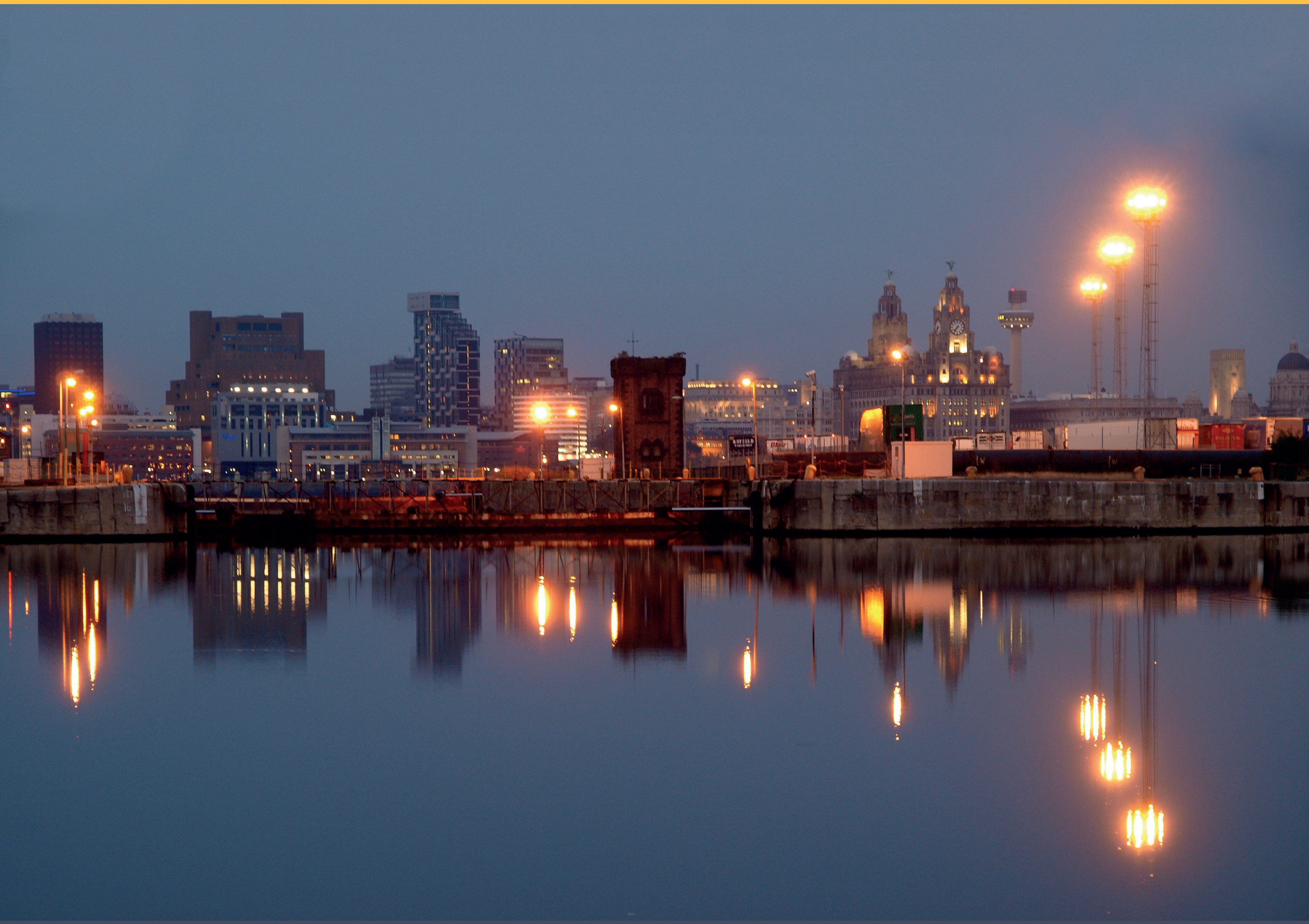

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(invited) **Superheavy element research at GSI**

C Düellmann

Johannes Gutenberg University Mainz, Germany

Current superheavy element research activities at GSI and in Mainz encompass a variety of aspects of these special elements; most pronouncedly their synthesis and decay properties, nuclear structure, atomic mass, and their chemical properties. I will give an overview of the status of the field and the rich program centered at Mainz and Darmstadt and then focus i) on the search for new elements with Z>118 and ii) detail some of our recent atom-at-a-time chemical experiments focusing on flerovium (Fl, element 114), the heaviest element whose chemical properties were studied to date.

(invited) **Illuminating strongly interacting matter**

D Watts

University of Edinburgh, UK

The talk will present some recent highlights from our research exploiting the intense electromagnetic beams provided by the Thomas Jefferson national laboratory (JLAB) [1] in the USA and the MAMI microtron [2] in Germany. The research aims to deepen our understanding of the structure of the nucleus and strongly interacting matter.

The talk will include the latest results from our programme to measure neutron skins using coherent π^0 meson photoproduction. Such measurements are not only of interest to the nuclear community but also help to constrain the properties of the equation of state for neutron rich matter, impacting our understanding of neutron stars. The size of the neutron skin in a heavy nucleus constrains the structure, mass-radii relationship, cooling mechanisms and gravitational wave emission from neutron stars [4,5]. The first measurement in the programme gave a leading determination of the size and shape of the neutron distribution in ^{208}Pb [3]. Preliminary analysis of new experimental data will be presented - including studies of the neutron skin for a range of tin and calcium isotopes. The latter is an important next step to provide data at the bridge between ab-initio nuclear calculations and nuclear density functional theories [6].

Recently a new narrow resonant structure has been observed for the np system. The state has peculiar properties, a mass of 2.38 GeV and an unusually narrow width of 70 MeV. The quantum numbers of the state are compatible with $I(J^P) = 0(3^+)$. The structure is supported by a wealth of recent NN scattering measurements, including inelastic two-pion production channels and elastic NN scattering [7]. The plans to improve our understanding of the nature of this resonance by establishing its photocoupling using the Edinburgh nucleon polarimeter [8] at MAMI will be outlined.

The JLAB facility is currently restarting operations after an upgrade in beam energy from 6 to 12 GeV. The UK is contributing to the construction of the Forward Tagger (FT) apparatus, which will enable a new programme of photoproduction measurements. The programme includes searches for hybrid mesons, particles predicted by the basic theory of the strong interaction (QCD) [9], yet never observed. Their observation would provide one of the cleanest experimental signatures to test our understanding of the nature of quark confinement. The status of the FT detector will be presented along with future plans.

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Studying exotic nuclear shapes and shape evolution using low-energy Coulomb excitation

D Doherty

University of York, UK

With recent advances in the production and delivery of radioactive beams, Coulomb excitation at safe energies has become a powerful tool in nuclear-structure studies. In particular, the measurement of transition probabilities and spectroscopic quadrupole moments allows for definitive conclusions about a number of intriguing phenomena to be made; in particular the existence of exotic shapes and shape coexistence.

Neutron-rich nuclei around A~100 have been investigated extensively in recent years, both via theoretical and experimental approaches. Such studies are motivated by the observation of a particularly sudden increase in deformation when moving from N=58 to N=60 in the Zr and Sr isotopes as well as the possible existence of low-lying, non-axial shapes in the neutron-rich Ru and Mo isotopes. However, Coulomb excitation studies of these neutron-rich, refractory isotopes have only recently become feasible thanks to CARIBU facility at Argonne National Laboratory.

The neutron-deficient A~70 region is another active area for the study of nuclear shape phenomena with several experiments already planned for the recently upgraded HIE-ISOLDE facility at CERN. In this talk plans for these upcoming experiments will be discussed.

(invited) The role of nuclear data in the nuclear industry and nuclear medicine

S Judge[1,2] and P Regan[1,2]

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

'Nuclear data' is the multi-disciplinary science of mapping the nuclear properties of matter – quantifying how ionising radiation interacts with matter and how radioactive materials decay. It is the science that enables nuclear engineers to deal with legacy nuclear wastes safely, to assess reactor safety and to design new reactors; it is also the science that underpins nuclear medicine, ensuring that radiopharmaceuticals can be used safely and effectively for diagnostic scans and cancer therapy.

There are four stages in this mapping process: first, the parameters of a particular reaction or radionuclide are measured; second, these data are evaluated to determine the best available value; third, the values are processed for recording in a database; finally, the database is used for reactor modelling codes, patient dosimetry calculations etc. The process is cyclic, as the final stage identifies missing or inadequate data that are needed. The process involves many organisations – universities, national laboratories, international organisations (such as CERN & the IAEA) and commercial organisations.

National measurement laboratories (NMIs), such as the UK's National Physical Laboratory, have an important role to play in this field. NMIs can act as the interface between nuclear physics studies for nuclear structure research and astrophysics, and the applications of such work in the nuclear industry and nuclear medicine.

This presentation will cover nuclear data R&D at NMIs – the new specialist instruments that are being developed, the work that is in progress to improve the accuracy of measurements and to encourage best practice in measurement through, for example, the Decay Data Evaluation Project. The contribution that nuclear physics is making to the developing of new radiopharmaceuticals for cancer therapy (such as ^{223}Ra) will be highlighted.

Parallel session 1

Recoil polarimetry 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 and target polarisations are well established. However, recoil nucleon polarisation requires a secondary scattering interaction making it significantly more challenging, particularly for measurements with neutrons. A large acceptance recoil polarimeter has been developed for use in photoproduction reactions with the crystal ball detector at MAMI to attempt to remedy this situation. It plans to use a novel polarimetry technique to gain significant new data with both recoiling neutrons and protons in order to constrain the excitation spectrum of the nucleon. A brief summary of work to date, including previous results using this technique, will be presented along with a description of future work.

Partial wave decomposition of finite-range effective interactions

A Pastore

University of York, UK

We discuss some infinite matter properties of two finite-range interactions widely used for nuclear structure calculations, namely Gogny and M3Y interactions [1-2]. We show that some useful information can be deduced for the central, tensor and spin-orbit terms from the partial wave decomposition of the symmetric nuclear matter equation of state. We show in particular that the central part of the Gogny interaction should benefit from the introduction of a third gaussian and the tensor parameters of both interactions can be deduced from special combinations of partial waves. We also discuss the fact that the spin-orbit of the M3Y interaction is not compatible with gauge invariance. Finally, we show that the zero-range limit of both interactions coincides with a particular form of the N3LO SkyrmeÕs interaction [3] and we emphasize from this analogy the benefits of N3LO [4].

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Measurement of the ^{23}Na(α,p)^{26}Mg reaction and its astrophysical reaction rate

N Hubbard[1,2], A Howard[2], M Munch[2], H Fynbo[2], O Kirsebom[2], K Laursen[2], C Diget[1], S Fox[1], A Laird[1], J Tomlinson[1] and M Pignatari[3]

[1]University of York, UK, [2]Aarhus University, Denmark, [3]University of Hull, UK

Within the C/Ne convective shell of a massive star the ^{23}Na(α,p)^{26}Mg reaction is an important source of protons for ^{26}Al production [1]. This shell is also the main source of Na ejected by core-collapse supernovae. A new experimentally determined reaction rate has been calculated across the relevant temperature range based on 3 new cross-section measurements [2-4] and angular distributions measured at the Aarhus University 5 MV Van de Graaff.

A recent measurement by Almaraz-Calderon *et al.* [2] found cross-sections 40 times greater than statistical-model cross-sections. Two additional experiments were performed by Howard *et al* [3]. and Tomlinson *et al.* [4], who both found results more consistent with statistical cross-sections. A follow up study by Almaraz-Calderon *et al.* identified a scaling problem in their original data, and after correcting this [5], it is more consistent with the others.

Combining these data, a full reaction rate study incorporating newly measured angular distributions has been performed. Experimental data is particularly important for this reaction, as the statistical models are not expected to have good predictive power because of the low density of states [1]. The data from [3] include measured angular distributions which have been extended and are used to reduce the systematic uncertainties in [4] and [5]. A combined reaction rate is calculated to a low uncertainty, improving the reliability of theoretical predictions of ^{23}Na and ^{26}Al in massive stars.

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[3] A. M. Howard *et al.*, Phys. Rev. Lett. 115, 052701 (2015)
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Activity quantification of caesium-137 point sources using the ProSPECTus Compton camera

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University of Liverpool, UK

Compton-geometry gamma cameras [1] offer a promising tool for a range of applications in nuclear medicine, industry and security. However, efficiency is dependent on source position within a Compton camera's field-of-view (FoV), causing difficulty in deducing activity from the measured imaging event rate. Work to characterise the spatially-dependent response of the ProSPECTus system [2] and hence enable accurate estimation of point source activities is presented.

The spatial dependence of the ProSPECTus device response was investigated by simulating 1000 ^{137}Cs point sources evenly distributed within a 90 × 90 × 90 mm phase space using GAMOS [3], yielding a spatially-dependent correction function *f(x,y,z)*. To validate it experimentally, a ^{137}Cs point source was placed at 5 locations spanning the simulated FoV and the event rate measured.

The validated function was then used to estimate source activity at a further 15 positions within the phase space (Table 1). The accuracy shows a clear deterioration above a source-detector separation of z = 100 mm. This is suspected to be due to failure of *f(x,y,z)* to characterise the spatial dependence of the response in this region; work to investigate this is ongoing. Furthermore, activity estimates based on source positions as determined by ProSPECTus will be calculated.

Source position x (mm)	Source position y (mm)	Source position z (mm)	Estimated activity (MBq)	Ratio of estimated to known activity
-45	-45	40	0.189±0.010	1.057
-35	-35	50	0.187±0.010	1.044
25	-25	60	0.199±0.010	1.111
15	-15	70	0.194±0.009	1.083
5	-5	80	0.191±0.008	1.069
-5	5	90	0.178±0.007	0.994
-15	15	100	0.169±0.005	0.942
-25	25	110	0.143±0.004	0.801
35	35	120	0.143±0.004	0.798
45	45	130	0.125±0.003	0.696

Table 1: A selection of activity estimations for a ^{137}Cs point source at various positions in the field of view of the ProSPECTus system (one for each z-value). The origin of the coordinate system is the centre of the scatterer front face.

The successful reconstruction of point source activity at known locations across a limited phase space represents a solid foundation from which to progress to extended sources across larger phase spaces at unknown positions. The calibration obtained is specific to gamma ray energy, phase space geometry and detector assembly, but the

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[2] L. Harkness, et al., 'Development of the ProSPECTus semiconductor Compton camera for medical imaging,' Nuclear Science Symposium Conference Record, IEEE (2009) 2452

[3] http://fismed.ciemat.es/GAMOS/method is generally applicable.

Λ_c baryon studies with ALICE at the LHC

J Norman

University of Liverpool, UK

Heavy quarks (charm and beauty), produced in ultra-relativistic heavy-ion collisions, are formed in hard partonic scattering processes in the early stage of the collision, and therefore offer a unique opportunity to probe the properties of the strongly-interacting medium created. For example, the baryon to meson ratio Λ_c/D can probe thermalisation and hadronisation mechanisms in the medium. In addition, the measurement of the Λ_c in pp collisions can test perturbative QCD calculations, as well as provide a baseline for Pb-Pb collisions, and the corresponding measurement in p-Pb collisions can help to separate hot and cold nuclear matter effects present in Pb-Pb collisions.

The ALICE detector, designed and optimised for the study of heavy-ion collisions but also capable of studying pp and p-Pb collisions, through its excellent vertex resolution and hadron identification, allows for the study of Λ_c production. This talk will focus on the measurement of $\Lambda_c \rightarrow pK\pi$ decay channel in p-Pb collisions at $\sqrt{sNN}$ = 5.02 TeV, with special focus on the multivariate methods used to improve the signal extraction. Future prospects of the Λ_c measurement in Pb-Pb collisions, after the upgrade of the Inner Tracking System to be installed during the LHC Long Shutdown 2 in 2019-20 will also be reported.

Parallel session 2

Strange particle production measurements in ultra-relativistic proton-proton, proton-lead and lead-lead collisions using the ALICE detector

L Barnby

University of Birmingham, UK

Collisions of nuclei, such as lead-lead (Pb-Pb), at ultra-relativistic centre-of-mass energies of several GeV per nucleon and above, form a short-lived de-confined medium of quarks and gluons: the quark-gluon plasma (QGP). The subsequent hadronisation of the QGP populates the hadron spectrum, apparently according to statistical laws, and in the process many strange and multi-strange hadrons are produced. The production of these hadrons is much greater than if the reactions proceeded via multi-step hadronic channels, an observation that was used as early evidence for the formation of the QGP.

The question of whether a QGP may form in smaller collision systems, such as proton-proton (pp) and proton-lead (p-Pb) collisions, can be addressed by the ALICE experiment at the Large Hadron Collider. At LHC energies these collisions may produce tens or even hundreds of charged particles. We have measured the production of strange particles as a function of the charged particle multiplicity in pp, p-Pb and Pb-Pb collisions and determined that the ratio of various strange baryons to pions is a smooth function of the multiplicity, regardless of the colliding system. The ratio measurements are compared to statistical models which go beyond the grand canonical approach, in which the system volume cancels out, with the temperature being the effective parameter. These extended models also consider the effect of the volume of the system in the ratio calculation. Perspectives for improving these measurements with LHC Run 2 data, with the aim of discriminating among different explanations, will also be discussed.

Using collinear laser spectroscopy to determine the nuclear spin and moments of odd-A isotopes of Zn (Z=30)

C Wraith

University of Liverpool, UK

A laser spectroscopy experiment was performed on Zn (Z=30) isotopes at ISOLDE-CERN. Using the high-resolution collinear laser spectroscopy setup (COLLAPS) we have produced hyperfine spectra for the ground and isomeric states of $^{62\text{-}80}$Zn. For an efficient spectroscopic technique, the metastable 4s4p$^3P_2$ atomic state was populated using sodium vapour for the charge exchange process. This facilitated the 481.1873 nm spin sensitive transition via laser excitation to the 4s5s$^3S_1$ state.

Investigations of isotopes around the Z=28 regions allow us to investigate level migrations and shell structure over the N=40 and N=50 shell closure. Our results will provide clarification of the tentative spin assignments of neutron rich odd-A Zn isotopes and isomers. The subsequent nuclear moments are a sensitive probe of the nuclear wave function, which are essential in testing shell model calculations.

In this contribution, the experimental set-up and laser spectroscopy techniques will be discussed, along with some of the results in relation to nuclear moments and spin of the odd-A isotopes and their isomers. The resulting moments are compared to shell model calculations in the f_5pg_9 model space, and a novel interaction is used to predict the magnetic dipole moment of the newly confirmed isomeric state in ^{79}Zn.

Microscopic calculations of nucleon resonances' widths in light nuclei

N Timofeyuk

University of Surrey, UK

Traditionally, widths of nucleon resonances are very often calculated as products of single-particle widths, calculated in standard potential models, and spectroscopic factors obtained in phenomenological shell model. The problem with such an approach is that the geometry of the potential used to generate the single-particle scattering wave functions is not related to the shell model, which does not have any radial wave functions at all and relies on the NN matrix elements treated as fitting parameters. The shell model can, however, be used directly to predict the nucleon width through calculations of the source term. In this talk I present results of the source term approach (STA) calculations for widths of some 0p-shell nuclei. I show that, similar to the case of bound nucleon states, where experiment shows reduction of spectroscopic strength, the STA widths are often smaller than those obtained in the standard approach. The STA also does better on average when compared to experimental data.

Photoproduction of φ - 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. In particular, photoproduction of the φ-meson, considered to be a pure s s state, can be used to investigate violation of the OZI rule, and the strangeness content of the proton. Initial analysis of data collected with the CLAS detector and the Hall B tagged-photon beam at the Thomas Jefferson National Accelerator Facility are presented. The reaction $\gamma p \rightarrow \varphi\, p$ with $\varphi \rightarrow K^+K^-$ is studied and planned steps to extract polarization observables are described.

Investigation of low-lying collective excitations in Mo-96

E T Gregor

University of the West of Scotland, UK

Information about proton-neutron interaction can be obtained from nuclear states particularly sensitive to the proton-neutron degree of freedom, of which low-lying isovector states are representatives. Our goal is to test the existence of a low-lying isovector octupole excitation in near-spherical nuclei, for which recently candidates were proposed. This assignment is based on strong M1-transitions to the first excited 3- state and enhanced cross sections in (p,p') and (e,e') experiments. The approaches are twofold: Exploiting existing data and theory the necessary condition for the formation of an isovector state, the situation of proton as well as neutron 1p1h states between the isoscalar and isovector state are explored. The theoretical calculations are conducted using a self-consistent mean-field approach with particle-vibration coupling corrections. Furthermore, at ILL Grenoble 95Mo(n,gamma gamma) and 143Nd(n, gamma gamma) experiments were performed to verify the experimental data the assignment is based upon.

Parallel session 3

Search for an Isospin I=3 dibaryon and status of d*(2380)

M Bashkanov and D Watts

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The recent strong indications for a resonance in the 6-quark system offer exciting possibilities to obtain a deeper understanding of QCD and bound quark systems beyond the usual 3q and q-qbar systems. The 6q or "Dibaryon" spectroscopy is a rapidly developing endeavor at modern nuclear physics facilities, complementing the recent developments in 4q (tetraquark) and 5q (pentaquark) studies.

For the recently established dibaryon resonance d^*(2380) with $I(J^P) = 0(3^+)$ all decay branching's into NN and $NN\pi\pi$ channels have been determined. The extracted branching ratios agree with a subthreshold $\Delta\Delta$ configuration. However, the width of the d^*(2380) is narrower than expected for $\Delta\Delta$ molecule. Future d^*(2380) photoproduction experiments at MAMI will provide important information about the internal structure of the d* (2380) dibaryon (hexaquark vs molecule).

Many theoretical studies predict also another, truly exotic state with mirrored quantum numbers $I(J^P) = 3(0^+)$, i.e. decoupled from the NN system and consisting of just six up-quarks in its $I_z = +3$ state. Such a state may be searched for in four-pion production. The status of this search by use of WASA data on the $pp \rightarrow pp\pi^+\pi^+\pi^-\pi^-$ reaction will be reported.

Nonlocal interactions in (d,p) reactions: Deuteron d-state effects

G Bailey, J Tostevin and N Timofeyuk

University of Surrey, UK

Models of the direct (d,p) reaction are key to spectroscopic studies in nuclear physics. Usually these models use local optical model potentials to represent the deuteron-target interaction. Within this framework the deuteron d-state is normally associated with spin observables and polarisation effects. However recent work [1], that includes the inherent nonlocality of the nucleon-target optical model potentials in adiabatic (d,p) reaction theory (which accounts for deuteron break up), shows that deuteron potentials are influenced by large n-p relative momenta in the deuteron. We believe this points to the potential for d-state effects to be significant in calculations of cross sections and deduced spectroscopic factors. The present work incorporates the d-state into the Johnson-Tandy model [2] of (d,p) reactions in the presence of nonlocal nucleon-target interactions.

We will present the first results of this approach. We calculate nonlocal deuteron-target potentials in the adiabatic model of deuteron stripping using nonlocal nucleon-target optical model potentials with a Perey-Buck energy independent nonlocality [3] and realistic (AV18 [4]) deuteron wavefunctions. This is used to calculate deuteron channel wavefunctions. We show that the d-state affects the central part of the potentials and significantly increases the calculated differential cross sections, when compared to nonlocal pure s-state calculations. This will correspond to changes in deduced spectroscopic factors. We will show results for various incident energies, targets and states in the final nucleus. The d-state also produces a tensor component of the deuteron-target potential, but this has negligible effects on cross section calculations.

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The nuclear shape and structure of the ground and isomeric states in ^{102}Y

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Studies focusing on the A~100 region have revealed that neutron-rich nuclei exhibit a rapid change from spherical to deformed nuclear shapes at N=59 [1]. The sudden onset of this shape change has made this region a source of intrigue. ^{102}Y beta decays into ^{102}Zr and two separate experiments have suggested a possible beta-decaying isomeric state in ^{102}Y. An experiment at the TRISTAN facility at Brookhaven National Laboratory studied ^{102}Y produced from the β-decay of ^{102}Sr, which populates the low-spin states in ^{102}Zr [2]. However, at the JOSEF recoil separator at the Research Centre Julich ^{102}Y produced in the direct fission of ^{235}U, which primarily populates the high-spin states in ^{102}Zr [3] were studied. The different decay patterns indicate the existence of two states, but it was not possible to identify which is the ground and which the isomeric state. In order to provide identification of the two states in ^{102}Y an experiment was recently conducted at IGISOL. The double Penning trap system, JYFLTRAP [4], utilised the Ramsey cleaning technique [5] to separate ions in the ground state from ions in the isomeric state. The aim was to measure the subsequent gamma decay independently for the two states, and to make a comparison with the feeding patterns already obtained [2,3]. This comparison would make it possible to establish which state in ^{102}Y is the high-spin state and which is the low-spin state. This presentation will focus on the results obtained and provide more detail about this new technique and future work.

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Characterisation of a CZT detector for dosimetry in molecular radiotherapy

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Molecular radiotherapy (MRT) involves the internal administration of radiopharmaceuticals to deliver high radiation doses to targeted tissue with minimal damage to surrounding healthy tissue. Current MRT treatment plans are undesirably generic as the administered activity is fixed for a procedure or scaled according to patient weight. The uptake and retention of the MRT therapeutic agents however, and hence the radiation dose, can vary by up to two orders of magnitude in different patients due to the wide range of biokinetics. Information of the dose would ideally be calculated through accurate real-time quantitative imaging of the radiation distribution in the patient. At present the patient is often treated first, and dosimetry worked out later.

Single Photon Emission Computed Tomography (SPECT) can be used to image the radiopharmaceutical distribution, if gamma rays are emitted. However, the quantitative dosimetric information is lost due to dead time because diagnostic SPECT systems are not optimised for high activity measurements. In this project, a custom-designed

SPECT system is being developed to facilitate quantitative dosimetry for MRT, based on a collimated pixelated CZT detector. The system will give an assessment of the radiation dose delivered to the patient tailored specifically for MRT of the thyroid with ^{131}I.

The current focus has been on the characterisation of the CZT detector. Important performance parameters such as dead time, energy resolution, uniformity and optimum operating conditions have been investigated and will be presented in this talk, alongside preliminary gamma-ray images.

Studying Nuclear PDFs using J/Psi Production in Pb-Pb Interactions at the LHC

K Graham

University of Birmingham, UK

Ultra-peripheral collisions (UPC) of lead ions, in which the two nuclei pass close to each other but at an impact parameter larger than the sum of their radii, can be used to study the momentum distributions of partons inside nuclei. The ALICE Collaboration has published results based on the production via parton-parton scattering of J/psi mesons in such reactions. Recently more data have become available from the LHC Run 2 in 2015. In this talk, the status of J/psi production via UPC will be reviewed.

Parallel session 4

Break-up modes of the ^{12}C Hoyle state and astrophysical implications

R Smith, Tz Kokalova, C Wheldon, M Freer, N Curtis, J Bishop and D J Parker

University of Birmingham, UK

Current calculations of the triple-alpha reaction rate in red giant stars assume that the production of ^{12}C through the famous 7.65 MeV 0^+ Hoyle state proceeds sequentially via the ground state of ^{8}Be. The reaction rate depends on the Hoyle state resonance properties such that

$$R = T^{-3/2}\frac{\Gamma_{\alpha 0}\Gamma_{\gamma}}{\Gamma} e\left(-\frac{\mathrm{E}}{\kappa T}\right),$$

where T is the temperature, k is Boltzmann's constant and $\Gamma_{\alpha 0}$, Γ_{γ} and Γ are the α + ^{8}Be, radiative, and total widths of the Hoyle state respectively [1]. Typically, it is assumed that the total α decay width is approximately equal to the sequential decay width Γ_{α} = $\Gamma_{\alpha 0}$. However, a recent experimental study suggested that the Hoyle state has an appreciable width for direct 3-body break-up such that (Γ_{α} - $\Gamma_{\alpha 0}$)/ Γ_{α} = 0.17(5) [2]. If this were true it would lead to a reduction in the reaction rate. More recent studies have placed the direct branching-ratio limit at < 0.005 [3].

Here we present the preliminary analysis of an experimental study, performed at the Birmingham MC40 cyclotron, where the break-up branching ratios of the Hoyle state were measured. The Hoyle state was populated through the inelastic scattering channel ^{12}C(^{4}He,^{4}He')3α and the decay products were measured using a double-sided silicon strip detector telescope along with resistive charge division strip detectors, which offer unrivaled position resolution. A novel timing approach was used to improve the signal-to noise ratio of the resistive strip detectors.

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[3] O.S. Kirsebom *et al.*, Phys. Rev. Lett. 108, 20 (2012)

Improvement of the performance of broad energy germanium detectors using pulse shape analysis for environmental applications

N Ali

University of Liverpool

The optimisation of High Purity Germanium (HPGe) detector performance for different gamma-ray interactions is an active area of research in the field of nuclear physics. This goal requires a theoretical study of the detector response from the simulation point of view and experimental sets of measurements for validation. Consequently, simulations were used to model the response of a broad energy germanium (BEGe) detector, produced by Canberra, using unique pieces of software, MCNP4C, GAMOS and MATLAB for analyzing simulation outputs.

In routine sample counting, for instance, the gamma-ray energies are required to be exactly determined so the radionuclides within samples can be identified and quantified. The drawback of germanium detectors is their poor peak to Compton response that can make achieving this objective difficult. Therefore, this work aims to increase the peak-to-Compton (P/C) ratios while maintaining both the excellent energy resolution and the detector efficiency. This will result in an improvement in the detector sensitivity. To achieve this, Digital Pulse Processing (DPP) techniques were applied to gamma spectroscopy measurements which focus on measuring and counting samples. DPP allowed pulse-shaping parameters to be optimised and pulse shapes to be recorded for off-line analysis.

Data from a digital acquisition (DAQ) system has been analysed by sets of sort codes to produce spectra after the application of energy and rise time gates. Several Figures of Merit (FOM) were then constructed each considering a specific class of events which is described as Compton escaped events, in an attempt to expand the proportion of the full energy events in the processed spectra. One of the figures was focusing on the forward scattering events, provided a remarkable improvement in the P/C values compared to those for the original (or ungated) spectrum of all recorded events.

Valence neutron properties of ^{136}Ba - nuclear structure relevant to neutrinoless double beta decay

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Neutrinoless double beta decay is an exciting prospect in physics. A direct observation would confirm that the neutrino is its own antiparticle as well as yielding information on the absolute mass scale of the neutrino. A major obstacle in extracting information about the neutrino mass scale lies in the uncertainty in the nuclear matrix element, which to date, can vary by a factor of 2-4 depending on the calculation method. Single-nucleon transfer reactions can be used to probe the occupancy and vacancy of valence nucleon orbitals, and by comparing the relative change between the parent and daughter, constraints can be applied on matrix element.

Neutron-addition [(α,^{3}He) & (d,p)] and removal [(^{3}He,α) & (p,d)] reactions were performed on ^{136}Ba, the daughter of ^{136}Xe. Additional measurements were made on ^{134}Ba as a consistency check. The relevant neutron orbitals between N = 50 and N = 82 are $g_{7/2}$, $d_{5/2}$, $d_{3/2}$, $s_{1/2}$, and $h_{11/2}$. In order to reliably extract information, it is important consider angular-momentum matching conditions. High Q-value reactions are better matched for extracting occupancies of the high l states, the $g_{7/2}$ and $h_{11/2}$ states, and low Q-value reactions are better suited for the $s_{1/2}$ and d states. The change in neutron occupancy between ^{136}Xe and ^{136}Ba can then be used to constrain the relevant nuclear matrix elements.

This work is supported by the UK Science and Technology Facilities Council; the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract Number DE-AC02-06CH11357.

Design of a quantitative imaging system for molecular radiotherapy

S Colosimo[1], H.C Boston[1], P Cole[1], L Harkness-Brennan[1], D.S Judson[1], L McAreavey[1], P.J Nolan[1], G Fluxx[2], M Carroll[3] and I Radley[4]

[1]University of Liverpool, UK, [2] Royal Marsden Hospital, UK, [3] The Royal Liverpool and Broadgreen University Hospitals, UK, [4] Kromek, UK

Molecular Radiotherapy (MRT) using ^{131}I is a well-established tool in the treatment of thyroid conditions and cancers. In order to determine the absorbed dose and therefore efficacy of treatment, real-time dosimetry would ideally be performed. Within nuclear medicine, the use of diagnostic gamma cameras is common for most imaging studies. However, limitations in capabilities of standard systems, dead time arising from high count rates (3-10GBq initial dose) and limited energy resolution have meant that accurately determining the quantity and distribution of the Radioisotopes in MRT treatments is not possible. Utilising commercially available Cadmium Zinc Telluride (CZT) detectors as well as custom designed collimators, we aim to create an imaging system capable of dosimetry for MRT measurements.

The CZT detector, manufactured by KROMEK, has been commissioned and shows a resolution of 3% at 356keV as well as count rate capabilities up to 40kcps. A simulation of the system has been written using GAMOS [1], a GEANT4 framework, and has been experimentally validated. Two collimator types are currently being investigated, one parallel hole and one pinhole. In order to optimise the design of the parallel hole collimator, a study of transmission has been performed. Results of the collimator simulation optimisation will be presented.

[1] P. Arce, et al., GAMOS: a GEANT4-based easy and flexible framework for nuclear medicine applications, in: IEEE NSS/MIC Conference Proceedings, 2008.

Giant magnetic dipole resonances in ^{52}Cr using time dependent Hartree-Fock

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Giant dipole resonances have been extensively investigated both experimentally [1–4] and theoretically [5]. Time Dependent Hartree-Fock (TDHF) has been shown to be an effective method in predicting the energy at which these transitions occur for electric dipole transitions. This work investigated the use of TDHF with a full Skyrme force to see the effect the tensor force has on the predictions of M1 transitions. By investigating these dipole modes, it was found that the method was useful for finding the range of energies likely to induce a magnetic dipole transition. Fine detail in the strength functions could not be resolved due to an instability in the spin-orbit force [6]. ^{52}Cr was chosen to allow easy comparison with the experimental data [1–3]. ^{52}Cr was also chosen as it has been studied recently for low-lying giant dipole resonances which this work also predicts [2,3].

[1] D. I. Sober *et al*, Physical Review C, Volume 31, Number 6, 1985 Magnetic Dipole Excitations in the N=28 isotones ^{50}Ti, ^{52}Cr and ^{54}Fe
[2] Krishichayan and Bhike *et al*, Physical Review C, 91, 044328 (2015) Polarized photon scattering off ^{52}Cr: Determining the parity of J = 1 states
[3] Pai, H. *et al*, Physical Review C, 88, 054316 (2013) Low-lying dipole strength in the N = 28 shell-closure nucleus ^{52}Cr
[4] P. M. Goddard *et al*, Physical Review C, 88, 064308 (2013) Dipole response of ^{76}Se above 4 MeV
[5] V O Nesterenko, *et al*, Journal of Physics G: Nuclear and Particle Physics Volume 37 Number 6 064034 (2010) Spin-flip M1 giant resonance as a challenge for Skyrme forces
[6] A. Pastore *et al*, Physica Scripta T154 (2013) 014014 Fitting Skyrme functionals using linear response theory

Thursday 31 March 2016

(invited) **Recent results from the ALICE experiment at the LHC**

M Floris

CERN, Switzerland

Recent results from the ALICE experiment at the LHC. The ultimate goal of heavy-ion collisions is the study of the properties of the deconfined and chirally restored state of matter known as the Quark-Gluon Plasma. Collisions of lead ions have been studied at the Large Hadron Collider (LHC) at a center of mass energy per nucleon sqrt(s_NN) = 2.76 TeV (run I), and, more recently, at sqrt(s_NN) = 5.02 TeV (run II). ALICE is the LHC experiment dedicated to the study of heavy ion collisions. In this talk, the main highlights from run I and early results from run II will be presented. Special emphasis will be given to measurements of collective effects, strangeness, open and hidden heavy flavours.

(invited) **Novel energy density functionals for low-energy nuclear phenomena**

J Dobaczewski

University of York, UK

Density functional theory (DFT) is a very popular method of modeling atomic, molecular, and condensed-matter systems. It is based on using the density distribution of electrons as a basic degree of freedom, whereupon the total energy of the system becomes a function of a function, that is, a functional of the density. Since early seventies of the last century, an entirely analogous method has been used in nuclear physics under the name of Hartre-Fock or Hartree-Fock-Bogoliubov theory with effective interactions. In nuclei, the basic degrees of freedom to model low-energy phenomena are the neutron and proton densities along with their derivatives.

On the one hand, numerous applications of nuclear DFT have shown a tremendous success of the approach, which allows for a correct description of a multitude of nuclear phenomena. On the other hand, 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 the central issue of the present-day investigations in this domain of nuclear-structure physics.

In this talk, I will present the status of theoretical developments aiming to improve present-day nuclear EDF approaches. The main lines of current attempts are in the expansions based on higher-order derivative corrections and/or including three- or four-body terms. Novel EDFs are based on zero-range or finite-range pseudopotentials and may have local, quasilocal, or nonlocal character. Some of the new developments have already lead to implementations in numerical codes and preliminary applications to finite nuclei are gradually becoming available.

(invited) **The structure of nuclei involved in neutrinoless double beta decay**

B Kay

Argonne National Laboratory, USA

An observation of neutrinoless double beta decay is one of the most exciting prospects in contemporary physics. It follows that calculations of the nuclear matrix elements for this process are of high priority. The change in the wave functions between the initial and final states of the neutrinoless-double-beta-decay candidates ^{76}Ge, ^{82}Se, ^{100}Mo, ^{130}Te, and ^{136}Xe have been studied with transfer reactions, using a variety of different experimental techniques. The resulting data allow for a description of the change in the occupancies of the valence orbitals in the ground states as two neutrons decay into two protons. The results set a strict constraint on any theoretical calculations describing this rearrangement, which currently vary by factors of 2-3 in terms of the nuclear matrix element and by as much as an order of magnitude in half-life. I review the program of transfer reaction measurements, making detailed comparisons between the latest theoretical calculations and the experimental data.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract Number DE-AC02- 06CH11357.

(invited) **Nuclear photonics - opportunities for photonuclear reactions at the ELI-NP facility**

A Zilges

University of Cologne, Germany

The response of an atomic nucleus exposed to an electromagnetic field is multifaceted and can give insight into many aspects of nuclear structure and nuclear astrophysics. The Extreme Light Infrastructure - Nuclear Physics (ELI-NP) is a 300 M€ investment European research facility presently being built near Bucharest, Romania. Its gamma beam system (GBS) will provide a tunable, completely polarized very intense photon beam in the energy range 0.2-19.5 MeV. Due to its narrow bandwidth in the sub percent range, manipulation of single nuclear excitations will become feasible. Full operation of the facility is scheduled to start in 2018.

The talk will give an overview about research opportunities using the gamma beams system at ELI-NP [1], the planned day-one experiments and the present status of the experimental setups.

This work is partly supported by the BMBF (05P2015) and by ELI-NP Phase I.

[1] D. Filipescu et al. EPJA 51 (2015) 185

Parallel session 5

Using jets to study the quark-gluon-plasma with the ALICE experiment

N Zardoshti

University of Birmingham, UK

Relativistic heavy ion collisions at the ALICE experiment are the culmination of efforts to create and study a de-confined medium of quarks and gluons known as a Quark-Gluon-Plasma (QGP). Clusters of particles resulting from the fragmentation of partons scattered through high momentum transfers in the initial stages of the collisions, known as jets, provide an excellent probe to study the properties of the QGP. Major advancements in this field, such as new classes of jet finding algorithms and sophisticated methods to subtract background, particularly in PbPb collisions, have brought jets to the forefront of experimental and theoretical interest. Key results from the ALICE experiment, using jets, will be presented with particular emphasis on the exploration of the modification of jets in the medium. A new set of observables, known as jet shapes, will also be introduced and their physics potential discussed.

Digital data acquisition and the timing response of the NAtional Nuclear Array, NANA

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The lifetime of isomeric states is one of the best observables to use as a probe to understand the underlying structure of atomic nuclei. The NAtional Nuclear Array (NANA) is a 12 module $LaBr_3$(Ce) scintillation detector coincident gamma-ray spectrometer array which can be used to measure the lifetimes of excited nuclear states of the order of 10 ns down to tens of picoseconds. In recent years significant progress has been made in the analogue implementation of the centroid shift method for timing measurements [1], specifically for γ-γ energy-time coincidence measurements using two or more $LaBr_3$ detectors. Using a similar analysis procedure to these analogue measurements, a full characterisation of the digital timing profile for the CAEN digitizer (V1751C, 1 GHz sampling frequency) and NANA has been conducted, using the reference source ^{152}Eu to provide near prompt and delayed γ-ray coincident cascades. This includes the implementation of pulse shape analysis algorithms for more precise timing responses. The different discrete energy gamma-ray emissions has allowed for the formation of a prompt response function and prompt response differences of the system over a considerable range of primary gating energies and energy pairs. The presentation will show the results of this detailed characterisation together with example lifetime measurements of excited states from radioactive sources in the sub-100 ps regime which showcase the power of the digital system.

[1] J. Régis *et al.*, Nuclear Instrumentation and Methods, A684 36 (2012)

Change in proton occupancies in the $0\nu2\beta$ candidates ^{130}Te and ^{136}Xe

J P Entwisle[1], B P Kay[2], S J Freeman[1], S Adachi[3], N Aoi[3], J A Clark[2], H Fujita[3], Y Fujita[3], T Furuno[4], T Hashimoto[5], C R Hoffman[2], O H Jin[3], E Ideguchi[3], T Ito[3], C Iwamoto[3], T Kawabata[4], B Liu[3], M Miura[3], J P Schiffer[2], D K Sharp[1], G Süsoy[6], T Suzuki[3], S Szwec[1], M Takaki[7], A Tamii[3], M Tsumura[4] and T Yamamoto[3]

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Neutrinoless double beta decay (0ν2β) is a potential rare decay that is the subject of significant experimental and theoretical interest. If observed it will reveal that the neutrino has a Majorana nature, that it is its own antiparticle. Further, a measurement of the 0ν2β half-life will provide access to the neutrino mass scale. However, extracting the effective neutrino mass depends on calculation of the nuclear matrix element. Current calculations of the nuclear matrix element vary by factors of 2-3. Measurements of relevant nuclear structure properties can help to test the validity of the calculations.

The proton occupancies for the $g_{7/2}$, $d_{3/2,5/2}$, $s_{1/2}$ and $h_{11/2}$ orbitals have been extracted by measuring (d,^{3}He) reactions on ^{130}Te and ^{136}Xe and their daughter nuclei ^{130}Xe and ^{136}Ba. Additional measurements were made on ^{128}Te, ^{132}Xe, ^{134}Xe and ^{138}Ba as a consistency check. For the xenon isotopes, a gas target was used. The experimental data are compared with recent theoretical calculations of the change in proton occupancies between the parent and daughter. This work was carried out at the Research Center for Nuclear Physics (RCNP), Osaka University, Japan.

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Carbon-12 production in stellar evolution

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^{12}C is produced in massive stars via the triple-α process. The precise evaluation of the rate of this reaction is required to be able to understand the subsequent stages of stellar nucleosynthesis and the elemental abundances in the universe. The triple-α process primarily proceeds through a resonance in the ^{12}C nucleus, famously known as the Hoyle state. The cluster nature of this state allows the formation of a rotational band built upon it. The first member of the band is thought to be in the 9-11 MeV region, with $J\pi$=2+ [1-4], with the most recent data indicating an energy of 10.03 MeV [5]. Further knowledge of this state would help not only to understand the debated structure of the ^{12}C nucleus in the Hoyle state, but also to determine the reaction rate of the triple-α process more precisely. Due to the significance of the resonance, a reconciliation of the data from different available probes is highly desirable.

The experiment was performed at the IGISOL facility at JYFL, Jyväskylä, Finland. The states of interest were populated by the β-decay of ^{12}N to ^{12}C which subsequently breaks into three α-particles. The coincident detection of the β-particle with the α-particles from the following breakup is to be used to determine the angular correlation between β-decay and the breakup. This can be used to establish the spin-parity of the state to gain selectivity against 0^{+} strength in the region.

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Spectroscopy of Au-179

F Wearing

University of Liverpool, UK

The phenomenon of shape coexistence in exotic nuclei is a topic of considerable interest in nuclear physics. An accelerated (5pnA) beam of Kr-82 bombarding a Ru-100 target was used to study nuclei in the vicinity of the Z=82 shell gap and the proton drip line. Gamma ray and conversion electron coincidences were measured using the SAGE spectrometer in conjunction with the RITU separator and the GREAT tagging spectrometer at the University of Jyvaskyla. The analysis of the p2n channel probing the structure of coexisting states in the neutron-deficient nuclide Au-179 is reported.

Studies of the ground and isomeric state in ^{178}Au at ISOLDE

J Cubiss on behalf of the Windmill – RILIS – MR-ToF MS collaboration

University of York, UK

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. In recent years an extended campaign has been made at the ISOLDE facility by the Windmill - RILIS - MR-ToF MS collaboration to investigate the mean-square charge radii and decay properties of the Tl, At, Au and Hg isotopes. The measurements rely on the high sensitivity provided by combing the in-source laser spectroscopy from the Resonance Ionization Laser Ion Source (RILIS), mass separation by ISOLDE and the Windmill spectroscopy setup. The talk will present the results from the 2015, IS534-IV experiment on a chain of Au isotopes ranging from ^{176}Au to ^{198}Au (Z=79, N=97-119). Particular focus will be given to the measurements made on two isomers in ^{178}Au. With the use of RILIS, isomerically pure beams were achieved, which made it possible to perform independent spectroscopic studies by the Windmill and mass measurements by MR-ToF MS.

Parallel session 6

The R3B silicon tracker: detector production

M Borri, L Lazarus, R Lemmon and J Thornhill

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Detectors for the R3B silicon tracker are under production at the Liverpool Semiconductor Detector Centre. This contribution will outline the recent progress made in such activity. It will describe the physics goal of the R3B experiment, the detector technology in use and the workflow for the detector production.

R3B (Reaction studies with Relativistic Radioactive Beams) is a fixed-target experiment. It will be installed at the end of this decade at FAIR (Facility for Antiproton and Ion Research) in Germany. The R3B experiment has been designed to perform kinematically complete measurements of reactions with high-energy radioactive beams. Its high efficiency, acceptance, and resolution will enable to study exotic nuclei far off stability with unprecedented precision.

The silicon tracker detector is surrounding the target volume of the experiment. It detects light charged particles (like protons) from the target region. It provides precise tracking and vertexing, as well as energy and multiplicity measurements.

The detectors populating the tracker are made of double-sided micro-strip silicon sensors which are wire bonded to a custom made ASIC (Application Specific Integrated Circuit). There are 30 detectors making the tracker. They are spread over three layers: one inner layer with 6 detectors; and 2 identical outer layers with 12 detectors each. The tracker has a total sensitive area of $\sim$5600 cm^2. A total of 912 ASICs will be required to read out the 116,736 strips of the 30 detectors.

Direct measurement of the $^{19}Ne(p,\gamma)^{20}Na$ reaction using DRAGON

R S Wilkinson[1], G Lotay[1,2], C Ruiz[3], G Christian[4], C Akers[5], W N Catford[1], A A Chen[6], D S Connolly[3], B Davids[3], D A Hutcheon[3], D Jedrejcic[7], A M Laird[5], A Lennarz[3], E McNeice[3], J Riley[5] and M Williams[3,5]

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Determining the rates of proton radiative capture reactions in explosive stellar environments is of critical importance for our understanding of the chemical evolution of the MilkyWay. Of particular significance is the rate of the $^{19}Ne(p,\gamma)^{20}Na$ reaction. This reaction is expected to strongly influence the final ejected abundance of ^{19}F in oxygen-neon (ONe) novae [1], as well as providing a key step in the breakout sequence from the hot-CNO cycles into the rp process in astrophysical X-ray bursts [2]. In such stellar environments, the $^{19}Ne(p,\gamma)^{20}Na$ reaction is thought to be dominated by a single, narrow resonance, 457 keV above the proton emission threshold in ^{20}Na [3]. The exact nature of this resonance has been a matter of significant scientific debate over the past 3 decades and as such, has resulted in large uncertainties in the $^{19}Ne(p,)^{20}Na$ reaction rate. In order for us to fully understand the latest observational data obtained on ONe novae and X-rays bursts by modern telescopes, it is essential that these reaction rate uncertainties are reduced. The $^{19}Ne(p,\gamma)^{20}Na$ reaction has been recently studied at TRIUMF National Laboratory, Canada, using the DRAGON recoil separator. Preliminary results of the strength of the 457 keV resonance from this study will be presented, and its implications for nucleosynthesis in explosive stellar environments will be discussed.

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[2] R. K. Wallace and S. E. Woosley, Astrophysical Journal Suppl. Ser, 45, 389 (1981)
[3] J. P. Wallace, P. J. Woods, G. Lotay et al, Physics Letters B 712, 59 (2012)

Measurment of prompt fission γ rays from ^{235}U using STEFF at n_TOF, CERN

J A Ryan[1], T Wright[1], J Billowes[1], A G Smith[1] and S G Warren[1] and the n_TOF Collaboration[2]

[1]University of Manchester, UK, [2]European Organisation for Nuclear Research (CERN), Switzerland

The Nuclear Energy Agency (NEA) High Priority Request List [1] is a compilation of nuclear data improvement requests deemed most important to the nuclear energy community, designed to help guide nuclear data research. Present on this list is a request for more accurate knowledge of the energy spectrum and multiplicity of prompt γ -rays produced during 235 U fission, due to the heating effects these γ -rays have on reactors [2]. Previous works have studied this phenomenon and these nuclear data are being improved, however the majority of this work has been performed using ther- mal neutrons to induce fission, while the submitted request has expressed an interest in improving the quality of data in neutron energies across the whole energy spectrum. Previous work also ex- hibits discrepancies up to approximately 15%, whereas the target uncertainty for this measurement is 7.5%; demonstrating the need for a more accurate measurement.

In response to this, the 'SpecTrometer for Exotic Fission Fragments' (STEFF), a detector designed at the University of Manchester, has performed experiments at the neutron Time-Of-Flight (n_TOF) facility at CERN. This facility uses a beam of 20 GeV/c protons impinging upon a lead spallation target to produce a white spectrum of neutrons, with energies ranging from thermal to above 1 GeV. The neutrons are emitted almost isotropically from the target and the facility has two beamlines leading to experimental halls: one is horizontal and approximately 185 m in length (n_TOF EAR1), the other is vertical and approximately 20 m (n_TOF EAR2). STEFF was situated in EAR2 containing a thin (100 μg cm^{-2}) sample of ^{235}U. Using a system of gas ion chambers and fast timing multi-channel plates, in conjunction with an array of NaI γ -ray scintillators of approximately 7.6% total efficiency, STEFF can measure very accurately the fission fragments and γ -rays released in (n,f) reactions. Using a time-of-flight technique to determine neutron energies, measurements of the prompt γ -rays have been recorded from thermal energies up into the keV energy region. The preliminary results from this experimental work will be presented.

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Shining a light on odd-even staggering in the charge radii of Hg isotopes

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Neutron-deficient mercury isotopes are one of the prime examples of shape coexistence any- where in the nuclear chart [1]. Wide-ranging and complementary experimental and theoretical approaches have been used to investigate their structure over the last few years [2]. Most strik- ing, however, is the well-known odd-even staggering behaviour of their mean-square charge radii about the mid-shell, observed as early as the 1970's [3], as shown in Figure 1.

Since then, charge radii measurements have only been extended down to 181Hg [4], leaving the open question “where does the staggering end?”.

This talk will show results from a recent experiment performed using the Resonant Ionisation Laser Ion Source (RILIS) at ISOLDE, CERN, that directly and unambiguously answer this question through measurements of isotope shifts down to ^{177}Hg. A new ion-source combination, coupled to a molten-lead target allowed this advance in spectroscopic sensitivity by removing contaminant species. This in turn facilitated our studies of the neutron-rich isotopes ^{207,208}Hg.

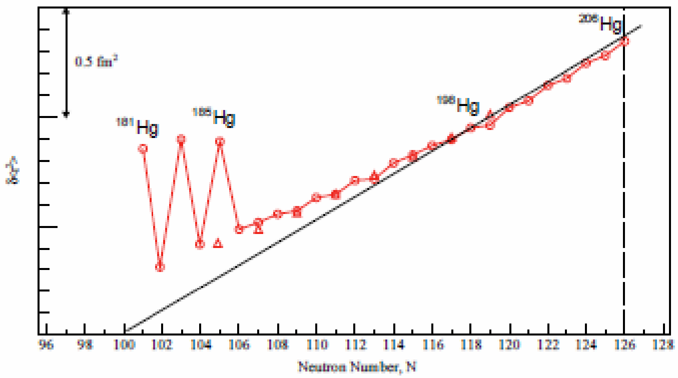

Figure 1: Relative changes in mean-square charge radii for the Hg isotopic chain known before the present experiment. The solid line shows the liquid-drop prediction, normalised to 198 Hg. Ground states are represented by circles and isomeric states by triangles. Data taken from Ref. [4].

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Modelling charge collection in Broad Energy Germanium detectors for industrial applications

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

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Broad Energy Germanium (bege) 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 of interest are obscured by the presence of other higher activity radionuclides. A key example is when the low energy gamma rays from ^{241}Am are concealed in the spectrum by the Compton scattered gamma rays from ^{137}Cs.

In this project, algorithms will be developed to distinguish low energy gamma rays that are absorbed near the outer surface of the bege, from Compton scattering events that are as a result of higher energy gamma rays interacting in the bulk of the detector. The digital Compton suppression algorithm will significantly reduce counting times with improved isotope identification in the presence of large backgrounds, without the requirement for Compton suppression shielding.

The technique exploits the knowledge of position dependent charge collection times in bege detectors. Simulations using the Agata Detector Library1 (adl) have been made to model the charge collection times of the detector. The modelled data has been used within MatLab to calculate risetimes corresponding to (x,y,z) gamma ray interaction positions. In this talk, the project aims and modelling work will be described. Presented results will include risetime maps of the bege, in both the XY and XZ planes. Additionally, the radial dependence has been investigated.

[1] B. Bruyneel and B. Birkenbach, AGATA Detector simulation Library (ADL) v3, http://www.ikp.uni-koeln.de/research/agata

Study of isomer decays in the N=Z nucleus ^{96}Cd populated via fragmentation

P J Davies[1], R Wadsworth[1], A Blahzev[2] and P Boutachkov[3] on behalf of the RIKEN RIBF83 collaboration

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This presentation will discuss new results obtained from an experiment designed to investigate the decay properties of isomeric states in N = Z nuclei residing below 100Sn. Specifically, new decay properties of the known 16^+ spin-gap isomer in ^{96}Cd [1] will be presented, along with data which provides evidence for the isomeric gamma decaying states in the same nucleus. The experiment was performed at the Radioactive Isotope Beam Factory (RIBF) at RIKEN as part of the first EURICA campaign. The nuclei of interest, including ^{98}In, ^{94}Ag, were produced by the fragmentation of a 345 MeV/nucleon ^{124}Xe primary beam colliding with a 9Be target and the isotopes of interest were identified using the BigRIPS spectrometer.

The first evidence for β-delayed proton decay from the 16^+ isomer in 96Cd will be presented. The beta delayed proton branching ratio has been measured, along with upper and lower limits for the B(GT) strength of the decay from the 16^+ isomer to the 15^+ isomer in ^{96}Ag and decays to the predicted 'resonance-like' states, respectively. The experimental β-delayed proton observations reveal some discrepancies with large scale shell-model calculations [1] for +Ag using the *sdg* model space, which necessitates further theoretical investigation. Evidence for new gamma decaying isomer data in ^{96}Cd will be presented and the results compared with large scale shell model calculations.

[1] B. S. Nara Singh, et al. Phys. Rev. Lett, 107, 172502 (2011)

Friday 1 April 2016

(invited) **Nuclear physics in the stars – the new challenge from astrophysics**

A Laird

University of York, UK

Recent satellite missions are producing a wealth of new astronomical data. ESA's Gaia satellite will determine stellar properties, including elemental composition, for a billion stars in our Galaxy. The NuSTAR satellite has already observed supernova remnants in high precision. These data will provide unprecedented information on the origin and evolution of the stars and galaxies. Similarly, the capability of now modelling stars in 3D has delivered new insights into the complex processes within stars, and their impact on stellar evolution and nucleosynthesis, which were previously unconsidered in 1D and 2D models. These advances in observations and modelling are driving the need for improved nuclear physics input to allow the impact on our understanding of the Milky Way, the origins of the Solar System and galactic chemical evolution to be fully realised. This talk will outline the developments in required nuclear physics data and report on recent experimental measurements.

(invited) **Neutron-rich nuclei beyond N=126**

Z Podolyak

University of Surrey, UK

The understanding of how shell structure arises and develops is a major goal in contemporary nuclear physics. To this end, it is of particular importance to measure the properties of nuclei in the vicinity of closed shells.

To date, our knowledge of the properties of heavy neutron-rich nuclei at or near the $N = 126$ shell is very limited. In the case of nuclei with $Z < 82$ and $N > 126$, excited states were previously reported only in ^{208}Tl [1] and ^{209}Tl [2,3]. Recently several experiments were performed, with the nuclei of interests being populated in relativistic-energy fragmentation. Gamma-ray spectroscopy following internal decays provided information on the yrast structure of ^{208}Hg [4], ^{209}Tl [4] and ^{210}Hg [5].

The basic ingredients of shell model calculations are the single particle energies and two-body matrix elements. In the case of calculations performed for Z<=82 and N>=126 nuclei, the single particle energies are taken from the known experimental spectra of ^{207}Tl and ^{209}Pb. The one proton hole, one neutron particle nucleus ^{208}Tl should provide the two-body matrix elements, therefore it is a key nucleus.

In 2014 an experiment to study ^{208}Tl was performed at CERN-ISOLDE. ^{208}Hg was populated by a 1.4 GeV proton beam impinging on a molten lead target. The structure of ^{208}Tl was studied via the beta decay of ^{208}Hg. The level scheme of ^{208}Tl was obtained [6] and compared with shell-model calculations. ^{208}Hg can beta decay via first-forbidden transitions to negative parity states and/or allowed transitions to very low wave-function components (requiring mixing with states above the Q_beta value) of positive parity states. Therefore ^{208}Hg provide a unique test of the competition between first-forbidden and allowed transitions.

The talk will focus on recent experimental results on heavy neutron-rich nuclei and their interpretation in the framework of the shell-model. The role of first-forbidden beta-decay transitions on the understanding of how heavy nuclei are produced in the rapid neutron capture process [7] will be also discussed.

[1] M. J. Martin, Nucl. Data Sheets 108, 1583 (2007)
[2] C. Ellegaard, P. D. Barnes, and E. R. Flynn, Nucl. Phys. A259, 435 (1976)
[3] M. J. Martin, Nucl. Data Sheets 63, 723 (1991)
[4] N. Al-Dahan et al., Phys. Rev. C 85, 034301 (2012)

[5] A. Gottardo et al., Phys. Lett. B725, 292 (2013)
[6] R. Carroll et al, to be published
[7] N. Nishimura et al., to be published

(invited) **Recent result from the CRIS experiment**

K Flanagan

University of Manchester, UK

Due to low production yields and frequently the presence of high isobaric contamination, our knowledge of exotic nuclei is often limited to just a few nuclear observables such as the half-life, mass and few low lying excited states. In order to provide a more complete description of the nucleus it is essential that additional observables are measured. High resolution laser spectroscopy measures electric and magnet moments, changes in charge radius and the spin of the nucleus. Furthermore these are determined without introducing any assumptions associated with a particular nuclear model. While many sub-Doppler techniques have been developed in the last 40 years, they are typically not universally applicable or are limited to cases with yields greater than 1000 atoms/second. The Collinear Resonance Ionization Spectroscopy (CRIS) experiment at ISOLDE, achieves both high resolution (linewidth of less than 50 MHz) and high sensitivity (yields below 100 atoms second) by resonantly ionizing a bunched atom beam in a region of ultra high vacuum. The experiment has the capability to deliver a pure beam of isomers to a decay spectroscopy station allowing overlapping hyperfine structure components to be separated.

This talk will report on the recent laser spectroscopy results and laser assisted nuclear decay spectroscopy.

Parallel session 7

Optimisation of liquid scintillator arrays in active fast neutron assay of uranium oxides for use in safeguards applications

H Parker and M J Joyce

Lancaster University, UK

Nuclear safeguards plays a significant role in the nuclear industry ensuring that accurate accounts of Special Nuclear Material (SNM) are maintained and helping to minimise the risk of proliferation. A significant proportion of non-destructive methods for uranium are based on stimulated fission in ^{235}U(n, xn)FF reactions using ^{3}He in proportion counters. Helium-3 benefits from being relatively immune to γ-rays and environmentally stable. However, it is necessary to thermalise fission neutrons prior to detection in ^{3}He and in so doing, the potential fast timing finesse associated with fast neutrons is degraded. Organic liquid scintillators are of interest for detecting mixed fields of radiation in NDT applications because thermalisation is not required. Liquid scintillators can be utilised in various scenarios due to their modular design which when choosing to assay SNM leaves the inherent risk of inefficient geometries being chosen. In this work an investigation into efficiencies of arrangements of detectors has been carried out for active fast-neutron assay of small quantities (< 400 g) of low-enriched uranium oxide materials. The investigation includes geometries of up to 32 detectors including arrays that are currently utilised in industry; the latter providing a good benchmark. The investigations were carried out in MCNP-5 and include the use of an americium-lithium neutron source as the interrogator and varying masses and enrichments of uranium oxide compounds. The research concludes with a ranking of each geometry simulated. Effects of scattering have been explored briefly along with the physical shape that the uranium oxide is presented in with further work into the effects of these parameters in prospect.

Evolving collective structure in neutron deficient tungsten isotopes ^{161}W and ^{162}W

E Higgins

University of Liverpool, UK

The onset of collective behaviour outside of closed shells is of great interest in Nuclear Physics. This work probes the development of collective motion in the tungsten isotopes above N=82. Excited states in ^{161}W and ^{162}W were investigated using the γ–ray spectrometer Jurogam. The level schemes established here show a marked difference between N = 87 ^{161}W and N = 88 ^{162}W.

These results are discussed in the context of aligned angular momentum as a function of rotational frequency and the systematics of neighbouring tungsten isotopes.

Development of a novel radio-frequency cooler buncher for accepting radioactive recoils based on an ion funnel

C Binnersley on behalf of the CRIS Collaboration

University of Manchester, UK

We are investigating options for a new radio-frequency cooler buncher design at the collinear resonance ionisation spectroscopy (CRIS) experiment at ISOLDE, CERN. The two primary options being examined are a reverse-extracted Radio Frequency Quadrupole (RFQ) and a novel design based on a RF ion funnel. The latter design is currently being developed using SIMION 8.1 simulations and will be tested using radioactive sources in a set up known as ACBARR

– A Cooler Buncher for Accepting Radioactive Recoils. Initial simulations indicate it could be simpler and more compact cooler buncher option for low-energy ion beam experiments.

Study of isospin symmetry in the mass 70 analog triplet: Spectroscopy of ^{70}Kr

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It is well known that an isospin non-conserving component of the nuclear interaction is required to account for the difference between shell model calculations and experimental data for the triplet energy difference (TED) values of T=1 isobaric analog states in the lower fp shell region [1]. A key question is whether such a component is also required in other regions of the nuclear chart, such as the fpg shell. The mass 70 region at the proton-drip line is also of interest to due to it being a region of strong shape mixing and coexistence [2]. Furthermore, the mass 70 T=1 analog triplet across the N=Z line is of interest due to the unusual behaviour of the Coulomb energy difference (CED) for ^{70}Br/^{70}Se compared to other N=Z, N=Z-2 pairs in this and other mass regions [3]. In the present work two candidate transitions in ^{70}Kr have been identified using the recoil beta tagging technique, the UoYTube and the ^{40}Ca(^{32}S,2n) fusion evaporation reaction. These have been assigned to the decay of the 2^+ and 4^+ states, thus enabling an analysis of the TED values for the analog states. The results will be compared with shell model calculations and other TED results in the region.

[1] M.A. Bentley, S.M. Lenzi, Prog. Part. Nucl. Phys. 59, 497 (2007)
[2] A. Petrovici, Phys. Rev. C, 91, 014302 (2015)
[3] B.S. Nara Singh *et al.,* Phys. Rev. C 75, 061301 (2007)

Structure of neutron-rich Sb nuclei near ^{132}Sn studied through gamma-ray spectroscopy

J M Keatings

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Newly observed excited states have been identified in various Sb isotopes through the β and β-n decay of ^{136,137,138}Sn using the RIBF facility at the RIKEN Nishina Centre. A 345-MeV/u ^{238}U beam was used to produce Sn isotopes, which were identified on an ion-by-ion basis in the BigRIPS and ZeroDegree spectrometer [1]. Prompt γ rays were observed in EURICA [2], an 84 HPGe crystal array, following the detection of β particles in WAS3ABi [3], an 8 layered DSSSD. The currently known excited structure for ^{136}Sb through isomer decay [4, 5] has been extended, and the first excited states in 137,138 Sb have been observed.

[1] T. Kubo, Nucl. Instrum. Methods Phys. Res. B 204, 97 (2003)
[2] P.-A. Soderstrom, Nucl. Instr. and Meth. B 317, 649 (2013)
[3] S. Nishimura, RIKEN Accel. Prog. Rep. 46 (2013)
[4] G. S. Simpson, Phys. Rev. C 76 (2007)
[5] R. Lozeva, Phys. Rev. C 92 (2015)

High-K isomer band in ^{174}Re using the CAESAR array

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High-K isomers in the well deformed A = 170 - 190 region of the nuclear chart are not uncommon, yet their properties remain difficult to predict. Small changes in features such as transition energy may have large effects on the half-life of a state [1]. The study of isomers towards the edge of this region may provide information crucial for understanding important features responsible for determining the properties of isomers across the nuclear landscape. To this end, finding and measuring the properties of new isomers is vital.

A possible candidate for a new isomer is ^{174}Re. Previous studies of this nucleus reveal several bands [2] but it is not known how all of the observed structures link to each other. A possible explanation is that one of these structures feeds a high-K isomer, likely a four-quasiparticle state, whose lifetime obscures its connection with the rest of the decay scheme.

The search for this state was performed at a recent experiment at Australian National University (ANU). Nuclei of interest were produced using the fusion-evaporation reaction ^{160} Dy(19 F, 5n)^{174}Re, in which a pulsed ^{19} F beam was delivered from the ^{14}UD Pelletron to a ^{160}Dy target located at the focus of the CAESAR array. During this experiment, the CAESAR array was comprised of nine Compton-suppressed HPGe detectors and two unsuppressed Low-Energy Photon Spectrometer (LEPS) detectors. All of the CAESAR detectors were accompanied by TDCs that accept signals from a corresponding detector and the beam pulse. Consequently, it is possible to investigate γ-ray transitions based on their temporal proximity to the initial reaction, which is ideal for searching for isomers in the $\sim$100 ns region.

This presentation will detail the observation of a new isomeric state in ^{174}Re and the multi-quasiparticle band built upon it. Measurements of the half-life will be accompanied by *gK* values for the new isomer band and the structures assigned to these states will be discussed.

[1] P. M. Walker and G. D. Dracoulis, Hyp. Int. 125 (2001) 83
[2] S. Guo *et al.* Phys. Rev. C 86 (2012) 014323

Parallel session 8

Study of beta-decaying mid-shell nuclei

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The region Z=50-82, N=82-126 is useful for studying collective effects in heavy nuclei. The nucleus of dysprosium-170 possesses 66 protons and 104 neutrons, placing it halfway between the doubly-magic ^{132}Sn and ^{208}Pb. ^{170}Dy is the heaviest 'perfectly mid-shell' species we can create, and so by studying this region experimentally we aim to learn much about collective behaviour.

An experiment at the RIKEN facility in 2014 used fission of a 345 MeV/u 238U beam to produce nuclei in the mid-shell region. With BigRIPS and the ZeroDegree spectrometer [1], fission products of interest were separated and identified before passing through a plastic scintillator trigger and impacting upon silicon strip detectors (DSSDs) in the centre of a EURICA/fast-timing array [2,3]. This arrangement is capable of relating detected gamma photons to an incident nucleus and any beta decay it undergoes, recording energy, position and timing information for each particle.

Here a wide analysis of beta-decaying states in the Z = 61-68, A = 159-176 region is performed, leading to a number of new spin-parity identifications for the parent nuclei. For example, by comparing the intensities of the gamma peaks in 166Gd observed following time-correlated ion- and β-detections, we suggest a previously unidentified ground-state spin-parity J^{π} = 5^{+} for the ^{166}Eu parent. This conclusion is supported by performing Bardeen-Cooper-Schrieffer (BCS) calculations [4], with a suggested configuration of $\nu\frac{5}{2}[512]\pi\frac{5}{2}$ [532]. The presentation will focus on this analysis carried out for a range of nuclei, and the interpretation of the results.

[1] T. Kubo et al., Prog. Theor. Exp. Phys. 2012, 03C003 (2012)
[2] P.-A. Soderstrom et al., Nucl. Instr. Meth. Phys. Res. B 317, 649 (2013)
[3] P.-A. Soderstrom et al., JPS Conf. Proc. 1, 013046 (2014)
[4] K. Jain et al., Nucl. Phys. A 591, 61 (1995)

Lifetime measurements of short lived nuclear states in ^{138}Gd using an array of LaBr3 detectors and corrections for a distributed source (DSSD)

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Looking toward the testing and implementation of $LaBr_3$ detectors for use in the FATIMA Fast TIMing Array, a test experiment was commissioned and carried out to measure the lifetime of a known nuclear state. ^{138}Gd was chosen as it has a known lifetime within a range good for testing the LaBr3 detectors using the Mirror Symmetric Centroid Shift method.

Analysis of data acquired at the University of Jyväskylä using an array of 8 $LaBr_3$ detectors at the GREAT focal plane. By measuring coincident decays in the DSSD, fast timing measurements were made of sub-isomer states. The method of time correction for the DSSD not being a point source is shown.

A demonstration of the viability of this set up is provided with a lifetime measurement of the ^{138}Gd ground state band 2^+ excited state of half-life of 185 +/- 11 ps. This result is compared to previously measured results to show the consistency of this approach. While the result is unlikely to change much, it is still not (yet) a final value.

Investigating proton-neutron pairing correlations in ^{42g,42m}Sc via collinear laser spectroscopy

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University of Liverpool, UK

Odd-odd self-conjugate ($N=Z$) nuclei provide an ideal testbed for studies of proton-neutron pairing. If one assumes the nucleon-nucleon interaction to be charge independent, then a proton-neutron system should be considered a nucleon-nucleon pair same as a proton-proton or neutron-neutron pair. Using this rather intuitive picture aids investigation of the odd-even staggering (OES) across an isotope chain, where the charge radii of odd-N isotopes are, generally speaking at least, smaller than the average of their even-N neighbours – a phenomenon poorly understood from a quantitative perspective. It can be inferred from this that nuclear states with $I=0$ should have greater charge radii than states with $I>0$, due to either the restricted number of states an $I>0$ proton-neutron pair can mix with or the presence of Pauli blocking due to an unpaired proton or neutron.

Collinear laser spectroscopy [1] has been performed on the odd-odd self-conjugate nucleus ^{42}Sc – an $N=Z$ neighbour of doubly-magic ^{40}Ca – and the change in charge radius between the 0+ ground state and 7+ isomer found via a direct measurement of the ^{42g,42m}Sc isomer shift. This yielded the result of a smaller charge radius for the isomer – in agreement with the qualitative prediction offered by the proton-neutron pairing picture. This follows the results of a recent study looking at proton-neutron pairing in ^{38g,38m}K – the other $N=Z$ neighbour of ^{40}Ca [2].

[1] P. Campbell, I. D. Moore, M. R. Pearson *Prog. Part. Nucl. Phys* vol. 86, pp. 127-180, 2016
[2] M. L. Bissell *et al. Phys. Rev. Lett.* vol. 113, 052502, 2014

Characterization of neutral trapped antihydrogen in the ALPHA experiment

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The Antihydrogen Laser Physics Apparatus (ALPHA) experiment at CERN is designed to carry out detailed studies of the properties of neutral antihydrogen atoms. A comparison of the properties of hydrogen and antihydrogen allows a sensitive probe of fundamental symmetries in Nature. Recent achievements have paved the way for precision measurements. Experiments are performed through the adaption of well documented methods in atomic physics to the challenging environment of neutral antimatter handling.

ALPHA has recently reached several important milestones en route to precision measurements. These include trapping of cold antihydrogens, long confinement, and the first spectroscopic measurement. Methods to study gravitational effects have been demonstrated and the charge neutrality of trapped antihydrogen has also been tested to high precision.

A unique Silicon Vertex Detector (SVD) surrounding the neutral atom trap is used for the identification of antihydrogen annihilation. The SVD provides diagnostics of the antiproton plasma time evolution and, most importantly, individual antihydrogen annihilation event vertex locations. Characteristics of the SVD and analytical methods applied to the data produced by the SVD, in different experimental setups, will be presented. In addition, an overview of the ALPHA physics goals and current progress will be reviewed.

Lifetime measurements of excited states in ^{99}Zr from EXILL-FATIMA

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The neutron rich Zirconium isotopes with N=58-60 are an interesting case in nuclear physics as they undergo a rapid change of shape in their ground state. This can be observed from the large reduction of the first 2^+ energy from 1223 keV of ^{98}Zr, which has a spherical ground state shape, to 212 keV in ^{100}Zr, which has a prolate deformed ground state and shape coexistence has been reported for both nuclei.

For the case of ^{98}Zr a deformed 0+ level at 1436 keV and for ^{100}Zr and an excited 0^+ level a 331 keV. These excited 0^+ states have different mean square charge radii from their respective ground states but also mixing of these excited states with the ground states. Consequently ^{99}Zr, which contains spherical low-lying states as well as rotational bands with differing deformations is ideal for studying why the change of shape occurs so rapidly within this region.

The excited states were populated using neutron induced fission of ^{235}U while the lifetimes were measured using an array of 16 $LaBr_3$ detectors used for their excellent timing resolution which surrounded the target and an array of EXOGAM clovers was used with their superior energy resolution to select the isotope of interest. The EXILL-FATIMA campaign allowed the determination of five previously unknown lifetimes of ^{99}Zr.

The quadrupole moment of ^{203}Fr

S Wilkins

University of Manchester, UK

Collinear Resonance Ionization Spectroscopy (CRIS) exploits the high resolution attained through performing laser spectroscopy on an accelerated radioactive beam in the collinear geometry. By utilising resonance ionization spectroscopy as its method of measurement, CRIS is able to improve upon the sensitivity offered by traditional collinear laser spectroscopy. This allows the measurement of ground state properties in exotic nuclei to be performed further from stability than previously possible.

The investigation into the evolution of deformation of francium isotopes below the N = 126 shell closure has been extended, complimenting findings from previous experimental campaigns. This talk will present the first measurement of the quadrupole moment of ^{203}Fr as well as new measurements of ^{207}Fr. The implications of these results to our understanding of the region will be discussed.

Parallel session 9

Extracting the spectral signature of alpha clustering in medium mass nuclei

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[1]University of Birmingham, UK, [2]Institut Ruder Bŏskovíc, Croatia, [3]Niğde University, Turkey, [4]Laboratoire de Physique Corpusculaire de Caen, France, [5]'Horia Hulubei' National Institute of Physics and Nuclear Engineering (IFIN-HH), Romania, [6]Universidade de Santiago de Compostela, Spain, [7]Grand Accélérateur National d'Ions Lourds, France

Both experimental and theoretical investigations have shown the important role played by α-clustering in the description of the structure of many light nuclei[1]. However, extending these investigations to heavier systems has, for a variety of reasons, proved challenging. One such challenge is that often experimental spectra appear far more complex in heavier systems, due to a significantly increased level density. These more complex spectra are then far more difficult to analyse rigorously using traditional techniques, dramatically slowing the analysis of experimental data.

A novel technique has been developed [2], which efficiently identifies a signature of α-clustering in regions of high level density by exploiting the fragmentation of α-clustered states using the Continuous Wavelet Transform. This technique is found to be extremely powerful when applied to resonant scattering measurements made using the Thick Target Inverse Kinematics technique [3]. This presentation will describe this new technique, as well as its application to the investigation of α-clustering in ^{44,48,52}Ti, using measurements of the ^{4}He(^{40,44,48}Ca,α) resonant scattering reactions.

[1] W. von Oertzen, M. Freer, and Y. Kanada-En'yo, Physics Reports 432, 43 (2006).
[2] S. Bailey, Tz. Kokalova, M. Freer et al, Submitted to Phys. Rev. Lett. (2015).
[3] K. P. Artemov et al, Sov. J. Nucl. Phys. 52, 408 (1990).

Structure of Zn isotopes beyond *N*=50

C Shand[1], Z Podolyák[1], M Górska[2], P Doornenbal[3], A Obertelli[4], K Sieja[5] and the SEASTAR Collaboration

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Shell evolution and the role of collectivity is an intriguing area of investigation, particularly for nuclei beyond major shell closures. For instance, nuclei beyond ^{78}Ni (Z = 28, N = 50), the most neutron-rich doubly-magic nucleus, are predicted to exhibit a faster onset of collectivity in comparison to nuclei below N = 50 [1,2].

The SEASTAR (Shell Evolution and Search for Two-plus energies At the RIBF) project aims to measure first excited states for neutron-rich nuclei below Z = 40. The first two campaigns of the SEASTAR project were conducted at the RIBF, RIKEN, Japan in 2014 and 2015. Fragmentation beams were produced by impinging a ^{238}U primary beam of 345 MeV/u onto a Be target. The BigRIPS spectrometer was used to identify and select the secondary beams impinged on MINOS [3], the liquid hydrogen target system. In-beam gamma-ray spectroscopy of the reaction products was performed using DALI2 [4], an array of 186 NaI detectors. The ZeroDegree spectrometer was used to identify the reaction products, for reaction channel selection.

^{81,82,84}Zn were produced primarily by (p, 2p) proton knockout reactions during the two SEASTAR campaigns. A new low-lying excited state in ^{81}Zn was observed in the first campaign, providing new information of single-particle states beyond the doubly-magic ^{78}Ni shell. Measurements of 2^{+} energies in ^{82,84}Zn were made in the second campaign; extending the systematics in the Zn chain from N = 50 up to N = 54. Results of these measurements and comparisons to state-of-the-art shell model calculations will be presented.

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Fine structure in the alpha decay of ^{222}Th and implications for octupole collectivity in ^{218}Ra

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An investigation of the α-decay fine structure of ^{222}Th using $\alpha\gamma$ coincidences will be presented. The hindrance factors to the J^{π}= 1^{-} and 3^{-} states in ^{218}Ra show a reversal in the trend of decreasing values with decreasing neutron number. This is possible evidence for a boundary to the region of ground-state octupole deformation in the light actinides. The J^{π}= 1^{-} state in ^{218}Ra has been identified for the first time, the position of which suggests that the low-energy negative-parity states in this nucleus are due to an octupole-vibrational mechanism, as opposed to α clustering or rotations of a reflection-asymmetric octupole-deformed shape. These results are used to speculate on the development of octupole collectivity in the light actinides.

In-beam spectroscopy of high-K states in No-254

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The deformed region around ^{254}No is one of the most important areas of the nuclear chart for the study of K-isomers. The observation and structural assignment of these isomers provides information on the location of the Nilsson states involved, including some of those bending down from either side of the next spherical shell gap, the 'island of stability'. This can give useful experimental constraints on models predicting the location of this island [1].

Previous work has identified two K-isomers in ^{254}No, with half-lives of 263 ms and 183 μs respectively. The longer-lived isomer is thought to be a two quasi-particle state but its underlying single-particle structure is still not clear and different decay paths from the shorter-lived isomer have also been proposed [2,3].

Results will be presented from a recoil-isomer tagging experiment using the SAGE combined γ-ray and conversion electron spectrometer [4] at the University of Jyväskylä Accelerator Laboratory (JYFL) to identify prompt radiation from states above the slow isomer.

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Parallel session 10

Review and indirect measurement of ^{19}Ne states relevant to novae explosions

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^{18}F is an unstable nucleus produced via the HCNO cycle during thermonuclear runaway in novae. Decaying via positron emission, its 110 minute half-life makes it one of the strongest observable sources of gamma rays during the first few hours of the explosion. Observations of this radiation would provide a direct test for current hydrodynamic models, however the distance at which this emission can be feasibly detected is dependent on the amount of ^{18}F produced.

Abundance estimates are therefore critical and whilst production rates of the isotope are well known, its destruction via proton capture through unbound states in ^{19}Ne requires further constraint. Despite previous experimental effort, predictions of ^{18}F production still vary by a factor of two [1,2]. The subject of this work has been to reevaluate ^{19}Ne state contributions to this uncertainty using an R-matrix analysis and to address these by performing an indirect experiment examining properties of the states of interest.

The region close to the proton threshold was studied closely using the charge exchange reaction ^{19}F(^{3}He,t) ^{19}Ne at IPN, Orsay. A Splitpole spectrometer analysed the momentum of the tritons in coincidence with the ^{19}Ne decay products. Tagging on the tritons, a highly segmented Si array provided branching ratios and spin assignments for the states of interest. The results of this experiment and their impact on the reaction rate will be presented along with the implications for future studies of ^{19}Ne.

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Study of isomerism around Z=82 by mass measurements of the 13/2^{+} states in the neutron-deficient nuclides ^{195,197}Po

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We present measurements investigating the isomerism between low and high-spin states in the neutron-deficient isotopes ^{195}Po and ^{197}Po. These isotopes were produced at the on-line isotope mass separator ISOLDE at CERN and delivered to the ISOLTRAP experiment[1] where mass measurements and α-decay-spectroscopy were carried out. The decay-spectroscopy studies were performed with the assistance of ISOLTRAP's multi-reflection time-of-flight mass spectrometer (MRTOF MS) [2], which delivered an isobarically pure beam to an α−decay station. The resonant ionization laser ion source (RILIS) of ISOLDE was used to selectively enhance either the isomer or the ground state [3] of the investigated isotopes. The mass values of $^{(195,197)m,g}$Po were measured with high-precision Penning-trap mass spectrometry using the TOF-ICR technique [4], from which we determined the state ordering and the excitation energy of the $13/2^+$ state in ^{195,197}Po for the first time, completing the knowledge of the energy systematics in the region. Additionally, the masses of isomeric states of lead, radon, and radium isotopes in this region were obtained from links along α-decay chains. The evolution of the nuclear structure in the neutron-deficient lead region and in particular the competition between the neutron i13/2 and p3/2 orbitals will be discussed.

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[4] M. König et al., Int. J. Mass Spectrom. 142, 95 (1995)

Searching for alpha-gas states in silicon-28 with CHIMERA and FARCOS

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The observation of a potential transition of nuclear matter from a fermionic liquid to a bosonic gas has been an experimental challenge since the work of Ikeda [1] in 1968. Clustering in N-alpha nuclei has not been conclusively observed in systems heavier than ^{12}C (N=3) [2]. The excitation energy associated with the increasingly heavy alpha-conjugate systems makes experimental observation of these states difficult.

An experiment was performed at INFN-LNS utilising the LNS Superconducting Cyclotron and the CHIMERA [3] and FARCOS [4] detector systems to investigate N-alpha structure states in ^{28}Si in the ^{12}C(^{16}O,^{8}Be+^{8}Be+^{8}Be)α, ^{12}C(^{16}O, ^{12}C(0_2^+)+^{8}Be)^{8}Be and ^{12}C(^{16}O,^{12}C(0_2^+)+^{12}C(0_2+)α channels. The measurement of an N-alpha state in ^{28}Si requires the detection of 7 alpha-particles creating experimental difficulties. The combination of the CHIMERA and FARCOS detector systems makes the set-up well suited to such measurements having near-4π solid-angle coverage, excellent particle identification, pulse-shape analysis and time-of-flight information. This talk will discuss the current state of the experimental analysis and the CHIMERA+FARCOS set-up for studying light nuclei.

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Search for the alpha decay of ^{160}Os

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A search has been performed for the α decay of ^{160}Os. The experiment, in which a beam of ^{58}Ni ions was incident on a ^{106}Cd target at an average intensity of 6.8 pnA, was performed at the University of Jyväskylä Accelerator Laboratory. The nuclei of interest were separated using the RITU gas filled separator and studied using the GREAT spectrometer. ^{160}Os is expected to be the lightest α-decaying osmium isotope and might be expected to have an 8^+ isomer based on the systematics of the N=84 isotones. The results of this analysis will be presented and discussed.

Poster programme

A new charge-exchange cell for the CRIS beamline at ISOLDE

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A poster briefly describing the CRIS (Collinear Resonance Ionization Spectroscopy) experiment at ISOLDE, the role of the charge-exchange cell (CEC) in this experiment, and the results of simulations of potential designs for a new charge-exchange cell, presently under construction, which will help solve present reliability and beam-tuning issues. A method for calculating charge exchange cross-sections is also mentioned with accompanying results.

Fast-timing measurements using $LaBr_3$:Ce detectors coupled with GAMMASPHERE

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A fast-timing experiment was performed at the Argonne National Laboratory between December 2015 and January 2016, with the purpose of understanding the structural evolution of nuclei in the mass A≈110 and A≈150 regions. The nuclei of interest were populated in the spontaneous fission of ^{252}Cf and the maxima of the fragment mass distribution lie approximately in the centre of the regions of interest. The aim of the experiment was to measure the lifetimes of the lowest lying states of nuclei belonging to these deformed regions.

The ^{252}Cf source was placed at the focus of one hemisphere of the GAMMASPHERE array (51 HPGe) which was coupled with a fast timing array, comprising 25 $LaBr_3$:Ce scintillator detectors. Each sub-array covered $\approx 2\pi$ of the solid angle. $LaBr_3$:Ce scintillator detectors have been extensively used in the past to perform fast-timing measurements thanks to their capability to access the sub-nanosecond timing regime. This property combined with the high energy resolution of HPGe detectors conferred to this combined array the right features to perform fast-timing measurements. This was the first time that the GAMMASPHERE array was successfully coupled with an array comprising such a large number of $LaBr_3$:Ce detectors. Details of the entire setup and the logic behind the acquisition system will be presented focusing on the signal processing and the coincidence mechanism. The latter is of prime importance since the two acquisition systems were kept separate. Some preliminary results will be shown in order to prove the effectiveness of this arrangement.

Work at ANL is funded by the US Department of Energy, Office of Science, Office of Nuclear Physics, under Contract Number DE-AC02-06CH11357. This research used resources of Argonne National Laboratory's ATLAS facility, which is a DOE Office of Science User Facility.

Using jets to study the quark-gluon plasma in ultra-relativistic heavy ion collisions at ALICE

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The principal aim of the ALICE experiment is to explore the properties of the quark-gluon plasma (QGP) by studying ultra-relativistic heavy-ion collisions at the Large Hadron Collider. The QGP is a deconfined phase of quarks and gluons formed in the early stages of these collisions, which subsequently cools until hadronisation occurs, whereupon quarks and gluons become bound again in hadrons.

In any two-body scattering process, the hardness of the collision is characterised by the transferred four-momentum. Hard scattering involves a large four-momentum transfer where the scattered partons recoil at large angles transverse to the beam direction. These fast moving partons fragment to form collimated jets of hadrons that experiments are designed to detect. In heavy-ion collisions, jets have been shown to be highly suppressed giving experimental access to the properties of the QPG medium. It is hoped that more differential studies of the structure of jets will give further insights into the mechanism of energy loss and the interplay between radiative and collisional effects in the plasma.

Studies of jets from RUN1 at the Large Hadron Collider by the ALICE experiment have begun to investigate a variety of shape variables that characterise the momentum distributions of hadrons within a jet. This poster will explore some of the experimental challenges of reconstructing jets in the high multiplicity environment of ultra-relativistic heavy-ion collisions at the LHC and discuss some of the shape variables that may shed light on the mechanisms responsible for the strong quenching of jets that has already been observed.

Development of a gamma-imaging technique pairing a Compton camera and FARO Lidar system for 3D source visualisation

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Gamma-ray spectroscopy techniques are widely used in the characterisation of nuclear waste. Visualisation of a gamma-ray source in 3D would enhance nuclear decontamination efforts by further pinpointing the position of radioactive substance on an object or surface.

Compton cameras determine the position of a gamma-ray source through electronic collimation, which requires kinematic reconstruction of the gamma-ray interactions. Multiple imaging methods have been envisaged which return the coordinates of the source in 3D space as a maxima of Compton overlaps. From this, and the manipulation of the source's coordinate system, it is possible to couple the information gained from a Compton camera with the mapping capabilities of a Lidar system.

Algorithms have been developed that fuse the radiometric imaging data generated through the University of Liverpool Compton image reconstruction software and data produced from a FARO Lidar system. The system has been tested with a series of sources differing in both energy and activity. The effects upon the determined position and size of the source to that of the actual situation was investigated.

The poster will outline the Compton imaging and data fusion principles, the test methodology used and the results from the investigation.

LEGO nuclear chart - Inspiring future physicists

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It can be hard to grasp nuclear physics. However, through workshops for schools and teachers we give the participating students a hands-on experience in actually building a nuclear chart. The present project is focused on developing the LEGO Chart of Nuclides as a practical educational tool, trialing the implementation for three different focus groups, demonstrating its effectiveness, and developing a legacy of impact for the participating schools. The LEGO chart will be built during schools workshops for up to 100 participating students (or teachers). During the workshop, the participants will engage with active researchers, typically PhD students, across a wide range of research areas, as well as with undergraduate physics students. During the construction of the nuclear chart, the researchers and ambassadors have time to share their passion for physics with the participating students, as well as talking about specific research.

The project is funded by an *STFC Public Engagement Small Award*, complemented by an External Engagement Award, funded by the University of York. The workshop has so far been implemented at seven different events, including two public events and incorporating four different schools.

Improvement of the performance of broad energy germanium detectors using pulse shape analysis for environmental applications

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The optimisation of High Purity Germanium (HPGe) detector performance for different gamma-ray interactions is an active area of research in the field of nuclear physics. This goal requires a theoretical study of the detector response from the simulation point of view and experimental sets of measurements for validation. Consequently, simulations were used to model the response of a broad energy germanium (BEGe) detector, produced by Canberra, using unique pieces of software, MCNP4C, GAMOS and MATLAB for analyzing simulation outputs.

In routine sample counting, for instance, the gamma-ray energies are required to be exactly determined so the radionuclides within samples can be identified and quantified. The drawback of germanium detectors is their poor peak to Compton response that can make achieving this objective difficult. Therefore, this work aims to increase the peak-to-Compton (P/C) ratios while maintaining both the excellent energy resolution and the detector efficiency. This will result in an improvement in the detector sensitivity. To achieve this, Digital Pulse Processing (DPP) techniques were applied to gamma spectroscopy measurements which focus on measuring and counting samples. DPP allowed pulse-shaping parameters to be optimised and pulse shapes to be recorded for off-line analysis.

Data from a digital acquisition (DAQ) system has been analysed by sets of sort codes to produce spectra after the application of energy and rise time gates. Several Figures of Merit (FOM) were then constructed each considering a specific class of events which is described as Compton escaped events, in an attempt to expand the proportion of the full energy events in the processed spectra. One of the figures was focusing on the forward scattering events, provided a remarkable improvement in the P/C values compared to those for the original (or ungated) spectrum of all recorded events.

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