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Dr S Nara Singh Bondili[1]

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In-beam gamma-ray spectroscopy with swift radioactive beams

K. Wimmer[1]

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The coexistence of single-particle and collective degrees of freedom in atomic nuclei gives rise to various exotic phenomena. In nuclei with very asymmetric proton-to-neutron ratios, the strong nuclear interaction drives shell evolution which alters the orbital spacing, and in some cases even the ordering present in stable nuclei. Such changes in the structure can have profound consequences for structure and dynamics of nuclei as well as the synthesis of elements in the universe.
In-beam gamma-ray spectroscopy is an excellent tool to study the structure of the most exotic nuclei in the laboratory.
In this talk, I will present the HiCARI project "High-resolution Cluster Array at RIBF". This hybrid array of segmented germanium detectors was constructed from contributions from around the world. The physics program includes a wide range of topics in nuclear structure addressing collective and single-particle structure of nuclei very far from stability.
In order to further enhance the sensitivity of the experimental method the use of active targets allows to determine reaction point and velocity. Such a new approach is the ERC project LISA "LIfetime measurements with Solid Active targets". Here, I will explain the basic principles and show the capabilities for future physics experiments at FAIR.

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Strangeness in Neutron Stars - Constraining the hyperon Nucleon Interaction

Nicholas Zachariou[1]
[1]*University Of York, , United Kingdom*

A comprehensive picture of the strong interaction can be obtained by extending our currently well understood nucleon-nucleon (NN) interaction to interactions involving strangeness degrees of freedom. The short lifetime of hyperons, however, prevents high-precision scattering experiments using typical procedures, and our efforts have been focused on complementary approaches utilising hypernuclear studies and final state interactions. The latter approach has only recently become feasible due to recent advancements in accelerator and detector technologies, which allow us to study exclusive reactions in hyperon photoproduction with high rates. Data collected using the CLAS detector housed in Hall-B of the Thomas Jefferson laboratory allow us to obtain a large set of observables, including cross section information [1] on the two-body (YN) and three-body (YNN) interaction and place stringent constraints on the underlying dynamics to address the “Hyperon Puzzle” [2]. In this talk I will provide an overview on the ongoing efforts currently underway that focus on extracting a large set of observables to constrain the interaction between hyperons and nucleons. Future prospects utilising the upcoming k-long facility will also be shown.

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Optimization of the relativistic energy density functionals with nuclear collective excitation properties and parity-violating electron scattering experiments

<u>Esra Yuksel[1]</u>
[1]*University of Surrey, Guildford, Surrey, GU2 7XH, United Kingdom*

The nuclear energy density functional (NEDF) theory represents a unified approach to study and understand the static and dynamic properties of atomic nuclei along the nuclide map and the equation of state of nuclear matter. Over the past decades, considerable progress has been made in constructing the NEDFs using the relativistic and non-relativistic frameworks. Until now, the NEDFs have mainly been parametrized using the experimental data on the ground-state properties (masses, charge radii, spin-orbit splitting, etc.) of nuclei, but these observables are inadequate to constrain the effective interaction completely, especially its isovector channel. The neutron skin thickness, isovector dipole excitations in nuclei, and neutron star mass and radii represent some observables that could probe the isovector channel of the EDFs; however, the experimental data on these observables had either been limited or had large uncertainties.
Recently, we have constrained new NEDFs based on the relativistic density-dependent point coupling model. In the optimization of these new functionals, we employ not only nuclear ground-state properties but also relevant properties of collective nuclear excitations to constrain the DD-PCX interaction [1] and experimental data of the weak-charge form factors from the PREX-II and CREX experiments to constrain the DDPC-PREX, DDPC-CREX, and DDPC-REX interactions [2]. By implementing the relevant experimental data in the optimization procedure, the isovector channels of the effective interaction have been uniquely constrained for each functional for the first time. In this talk, I will discuss the contradictory findings of these new functionals due to the differences between the experimental data and their impact on the calculations for nuclear properties.

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Nuclei with multiple shape coexistence

Paul Garrett
[1]*University of Guelph & KU Leaven*

It is now well understood that nuclei can posses shape coexistence, i.e., that states at low excitation energy in a nucleus that have different shapes. Over the past several decades, it has become apparent that this occurs in many regions throughout the nuclear chart, and indeed may be ubiquitous. Until very recently, there were only a few candidates suggested for nuclei possessing *multiple*, i.e., more than two, distinct shapes. Within the past several years, however, this has changed dramatically with detailed spectroscopy revealing structures not previously observed, and results interpreted with the aid of state-of-the-art shell model or beyond-mean-field calculations. Examples of these candidates, from the light-mass Mg-Si region to the Au-Pb region will be highlighted.

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Nuclear shape from combined laser and muonic x-ray spectroscopy of exotic isotopes
Thomas Cocolios

The nuclear shape - as measured from the changes in the mean square charge radii and the spectroscopic quadrupole moment - is a key ground-state property that allows to probe the collective behaviour of the nucleus. Laser spectroscopy has been prolific in the last few years in providing exciting experimental results against which to challenge state-of-the-art nuclear models [1-3]. Those are achieved thanks to continued technical developments that have systematically improved both resolution and sensitivity, towards exploring ever more exotic species [e.g. 4]. One such recent development is the Perpendicularly-Illuminated Laser Ion Source adn Trap at CERN ISOLDE, which has enabled the study of neutron-rich actinium and polonium isotopes in 2022 [5].
In spite of these exciting results, it remains that the extraction of the shape observables from the measured hyperfine structures and isotopes shifts requires benchmarking against other techniques, so that the atomic response to the nuclear perturbation may be properly calibrated. The best way to obtain charge radii across a long chain of isotopes is through the comparison with a triplet of absolute charge radii measured with a different technique, such as muonic x-ray spectroscopy or electron scattering. However, no odd-Z element nor any element beyond Pb (Z=82) possesses more than 2 stable isotopes, so that such measurements must be performed on radioactive nuclei.
At the Paul Scherrer Institute, the muX Collaboration has established a technique to efficiently study muonic x rays of samples as small as 5 ug of material [6]. Given the radioprotection constrains in an experimental hall, this corresponds to isotopes with half-lives as low as 20 years. The collaboration has already successfully studied stable Re isotopes [7] as a proof of principle, and achieved the first measurement for a radioactive isotope with Cm-248.
In this contribution, I will discuss the implications of those developments with a particular emphasis on actinides.

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[7] A. Antognini et al.; Measurment of the quadrupole moment of 185Re and 187Re from the hyperfine structure of muonic X rays; Physical Review C 101 (2020) 054313.

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Invited Speaker I: Constraining neutron capture rates relevant to r-process and i-process nucleosynthesis
Anne-Cecilie Larsen

April 4, 2023, 09:30 - 10:00

The element distribution we observe in the Universe, and in particular the diverse abundances of atomic nuclei, tells a fascinating story of nucleosynthesis events that have taken place throughout the 13.7-billion-year-long history starting with the Big Bang. Since the groundbreaking works of Burbidge, Burbidge, Fowler and Hoyle
and Cameron in 1957, it has been known that radiative neutron-capture reactions play a major role in synthesizing elements heavier than iron.
However, many questions remain when it comes to our understanding of neutron-capture processes in various stellar environments.
In particular, the intermediate and rapid neutron-capture processes are very challenging to describe, as they involve neutron-rich nuclei for which there exist little or no data on the much-needed neutron-capture rates.
In this talk, I will present possibilities to obtain experimental constraints of these rates, with the aim to improve our understanding of the r- and i-process nucleosynthesis.

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Invited Speaker II: High accuracy predictions of atomic and molecular properties in support of experiments Anastasia Borschevsky

Van Swinderen Institute for Particle Physics and Gravity (VSI), University of Groningen, Groningen

April 4, 2023, 10:00 - 10:30

Spectroscopic measurements on exotic, heavy, or unstable atoms or molecules containing such elements can yield information about the nuclear properties of these systems and be used for testing various nuclear theories. However, such experiments are extremely challenging due to the short lifetimes and the low quantities of these species. Specially developed experimental techniques are thus needed to carry out such studies, but no less important for their success is strong and reliable theoretical support. For example, predictions of the transition energies and other properties are necessary for planning the measurements and possible laser cooling or trapping schemes.

Furthermore, theoretical input is necessary for interpreting the results of these measurements and provides the link between the experimental spectroscopy and the nuclear physics. Knowledge of various atomic or molecular coupling factors is needed to extract the properties of interest, such as the various nuclear moments, from the measured energy shifts and splittings. In some cases, such as for the nuclear anapole moments, these coupling factors cannot be measured in principle. Other parameters, such as the hyperfine structure constants, are usually not available for exotic systems. Atomic and molecular electronic structure calculations are thus needed to provide these factors.

In order to be reliable and useful in experimental context, theoretical predictions should be based on high accuracy molecular structure calculations; furthermore, it is important that we are able to assign uncertainties on the predicted values. The relativistic coupled cluster (RCC) approach is considered to be most powerful and accurate method for treatment of heavy atoms and molecules. This approach has been recently extended to allow calculations of hyperfine structure parameters and nuclear anapole coupling constants, and shown to achieve very high accuracy (of single percent) for these properties [1-3]. Furthermore, we have recently proposed a scheme that allows us to use extensive computational investigations to set reliable uncertainties on the calculated parameters [4].

A brief introduction to the RCC method and the new development for estimation of uncertainties will be presented. The talk will focus on recent successful applications of the coupled cluster approach to atoms and molecules, in the context of nuclear physics [1-5].

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Nuclear anapole moment interaction in BaF from relativistic coupled-cluster theory
Phys. Rev. A **98**, 032510 (2018)

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Hyperfine structure constants on the relativistic coupled cluster level with associated uncertainties
J. Phys. Chem. A **124**, 3157 (2020)

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Nuclear spin-dependent parity-violating effects in light polyatomic molecules
Phys. Rev. A **102**, 052828 (2020)

[4] M. Denis, Y. Hao, E. Eliav, N. Hutzler, M. K. Nayak, R.G.E. Timmermans, and A. Borschevsky
Enhanced P,T-violating nuclear magnetic quadrupole moment effects in laser-coolable molecules
J. Chem. Phys **152**, 084303 (2020)

[5] A. Kanellakopoulos, X. F. Yang, M. L. Bissell, *et al.*
Nuclear moments of germanium isotopes near N = 40
Phys. Rev. C **102**, 054331 (2020)

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Invited Speaker III: The Electron-Ion Collider: a new frontier in the study of hadron structure

Daria Sokhan[1, 2]
[1]University of Glasgow, Glasgow, United Kingdom, [2]CEA, Paris-Saclay, , France

April 4, 2023, 11:00 - 11:30

The Electron-Ion Collider (EIC) [1,2], to be constructed at Brookhaven National Laboratory, USA, for start of operations in 2032, is expected to become the world's premier hadron physics facility. Colliding beams of polarised electrons with polarised protons and light ions, as well as unpolarised heavy nuclei all the way up to uranium, it will provide the widest range of nuclear species for studies of deep inelastic scattering and other related processes. Its variable range of centre-of-mass energies (20 - 140 GeV) will enable the study of nucleon structure from the valence quark region, where the constituent quarks of the Quark Model correspond to the observed parton distributions, to deep within the quark-gluon sea, where gluons vastly dominate over all quark flavours. The collider will also search for signals of gluon saturation, a hypothesised state of the nucleon which may contain a new form of matter: the Colour-Glass Condensate. Polarisation of both beams, a first for an electron-ion collider, gives a handle on spin-dependent distributions and is key to understanding the full composition of nucleon spin, especially the little-known contributions of gluons and of quark orbital angular momentum to it. The unprecedented luminosity of the EIC (1033-34 cm-2s-1, 100-1000 times more than the HERA collider) will make possible measurements of the rarest processes, amongst them those that enable 3D tomographic imaging of nucleon structure and its internal dynamics. Through them, the EIC will be able to address questions about the generation of nucleon mass from the bare mass of quarks and the distributions of pressure and shear forces inside the nucleon. The collider will likewise extend the study of the meson resonance spectrum and search for exotic states. We present details of the EIC, an overview of its physics programme and a review of its first detector, called ePIC, which is currently in the design phase.

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Invited Speaker IV: Exploring neutron-rich extremes of the nuclear landscape

Prof. Takashi Nakamura[1]
[1]Tokyo Institute of Technology, Meguro, Japan

April 4, 2023, 11:30 - 12:00

What are the characteristic features of nuclei with an extreme neutron-to-proton ratio? This talk is focused on the recent progress in experimental studies of neutron-rich nuclei near and beyond the neutron drip line using the large-acceptance multi-particle spectrometer SAMURAI (Superconducting Analyzer for MUrti-particles from RAdio Isotope Beams)[1,2,3] at RIBF, RIKEN. Such a wide-acceptance multi-purpose spectrometer has become essential in the new-generation RI beam facilities. After a brief description of the characteristic features of SAMURAI, this talk focuses on some experimental highlights of light neutron-dripline nuclei studied at SAMURAI [4]. The first highlight is the results of kinematically complete measurements of Coulomb and nuclear breakup of the one-neutron halo nucleus 31Ne. We discuss the results regarding the interplay between the shell, deformation, and halo properties. The exclusive Coulomb breakup result on the two-neutron halo nucleus 19B [5] and 22C is then discussed in terms of its few-body structure. The results on the observations of 27, 28O are then presented, where the latter is the candidate doubly-magic nucleus beyond the neutron drip line. I will discuss possible common features in the structures of the drip-line nuclei. Finally, I will provide some scopes of the spectroscopic studies along the neutron drip line in the near future using the large-acceptance multi-purpose spectrometer.

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Invited Speaker V: Stellar nucleosynthesis in core-collapse supernovae and x-ray burst environments

<u>Heshani Jayatissa</u>

April 4, 2023, 12:00 - 12:30

Stellar nucleosynthesis in core-collapse supernovae and x-ray burst environments Understanding the nucleosynthesis processes in various astrophysical scenarios such as x-ray bursts and supernovae involve the study of numerous capture re actions. A Type-I x-ray burst (XRB) is an explosion in a binary system of an accreting neutron star and a companion star. The dominant (p, γ) nucleosynthe sis flow in XRBs is halted at several waiting point nuclei such as 22Mg, 24−26Si, 28−30S and 34Ar due to (p, γ)-(γ, p) equilibrium. It has been suggested that the flow can be bypassed by alpha-capture reactions on these waiting point nuclei (αp-process). However, the present uncertainties in the relevant alpha-capture reaction rates at these waiting points hinder the ability to accurately predict the light curve and ash composition of XRBs. Core-collapse supernovae (CCSNe) occur when massive stars exhaust their core fuel, resulting in the gravitational collapse of the iron core leading to an outward shock wave that results in one of the strongest explosions in the universe, ejecting a variety of chemical elements into the interstellar medium. Properties of CCSNe can be obtained by studying the signatures from prominent remnants such as 44Ti and 56Ni, of which the observed abundances are affected by proton, alpha and neutron captures. A large number of nuclear reactions affect the nucleosynthesis in these two environments, and precise knowledge of these nuclear reaction rates are needed to constrain astrophysical models to better understand the underlying explosion mechanisms. Constraining many of these reaction rates using direct techniques is experimentally difficult due to low reaction cross sections and the need for sufficiently intense radioactive beams. Sensitivity studies that have been per formed for these two astrophysical scenarios, as well as several experimental techniques currently utilized to constrain a few of these reaction rates affecting the nucleosynthesis in XRB and CCSNe environments will be presented

Characterizing GAGG Crystals for In Beam Gamma-Ray Spectroscopy at the RIBF

William Marshall[1], Ryo Taniuchi[1], Stefanos Paschalis[1], Martha Liliana Cortes[2], Pieter Doornenbal[2], Pankaj Joshi[1], Marina Petri[1]
[1]University of York, York, United Kingdom, [2]RIKEN, , Japan

Det/med, April 4, 2023, 13:30 - 15:00

GAGG(Ce) is a novel scintillator that shows promise as a future material for gamma spectrometers. It has several benefits over traditional materials such as NaI(Tl) including its superior resolution (4.0±0.3%, Intrinsic FWHM at 662 keV), fast timing (O(100 ps)), higher density, and it being non-hygroscopic [1][2]. A new scintillator-based array is planned to be deployed at the RIBF (Radioactive Isotope Beam Factory, Japan) for in beam gamma-ray spectroscopy. In this facility, the gamma-rays are emitted by fast-moving projectiles and are Lorentz-boosted up to energies of around 10 MeV necessitating large crystals for full gamma-ray absorption. At the same time, the effect of Doppler broadening in the reconstructed gamma-ray spectrum is driven by the size of the crystal and a high granularity of the array is required to correct for the angular dependence in the Doppler correction. Alternatively, superior Doppler correction can be achieved with position sensitive scintillators. Large, long, cuboidal shapes are being considered currently. It is therefore necessary to test and confirm that these larger crystals sizes maintain the material's desirable properties such as light-yield uniformity, and resolutions.

In this study, we present the characterisation results of a 1”x1” cylindrical GAGG crystal and a 1”x3” cylindrical HR-GAGG crystal (Figure 1) using various radioactive sources and a slit-collimator system. This has been done with different light collection methods, mainly using SiPMs (Silicon Photomultipliers) placed at different faces of the crystal. Additionally, the performance of the crystal has been tested using different wrapping materials, namely PTFE tape and ESR foil.

In particular, I plan to discuss the dependence of the signal on the gamma-ray interaction position within the volume of the crystal. This includes the observed variation in the mean gamma-ray energy, the energy resolution, and the pulse shape of the signal at different positions of the collimator. This dependence may be due to uneven doping concentration, if this could be controlled consistently by the manufacturer this could be exploited for position reconstruction.

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Isomeric and Beta Decays in Os-202 and Ir-203

<u>Gee Bartram[1]</u>, Professor Zsolt Podolyák[1]
[1]University Of Surrey, Guildford, United Kingdom

Nuclear structure, April 4, 2023, 13:30 - 15:00

As part of the May 2022 campaign at GSI Darmstadt, Germany, a high-intensity, 208Pb primary beam of 1 GeV/u was fired at a 9Be target to populate neutron-rich fragmentation products at N≈ 126. The study of such nuclei forms an important part of our understanding of nuclear structure and the testing of nuclear shell model predictions. Fragmentation products from GSI's fragment separator were implanted in AIDA active silicon stoppers, surrounded by eight newly developed DEGAS high-purity Ge detectors as well as two EUROBALL germanium detectors. The main aim of this experiment was to study the structure of N=126 nuclei, through the observation of isomeric and beta decays. In 202Os, isomers are predicted with Iπ=10+, 7− and 5−, while in 203Ir a long-lived 11/2− state is expected. Furthermore, the beta-decay half-lives of several nuclei in this region will be obtained, in addition to information on excited states in their daughter nuclei. GSI's fragment separator was centered on 203Ir and 202Os for one day and three days, respectively. The knowledge gained from this experiment is valuable for understanding potential shell evolution at N=126, and also to contribute to the theoretical predictions of r-process path properties in this region.
Preliminary analysis has identified all previously observed isomeric states in 203Pt, 204Pt, and 203Ir [1]. In addition, known gamma lines following the beta decays of Pt and Hg isotopes were observed [2]. The collected statistics on neutron-rich nuclei such as 203Ir are much higher than in previous experiments. Furthermore, potential new gamma transitions have been observed both through internal decays and beta decays. The obtained experimental results in combination with shell-model predictions will be presented.

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A virtual reality platform for intervention planning in radiation environments

Martin R. Jaekel[1], Kristin Lohwasser[2], **Luis Rene Montana Gonzalez[2]**, Kirsty Lynn Veale[1]
[1]CERN, , Switzerland, [2]University of Sheffield, , United Kingdom

Det/med, April 4, 2023, 13:30 - 15:00

The European Organization for Nuclear Research, CERN, is planning to upgrade to the High Luminosity LHC (HL-LHC) [1] to increase the amount of data that can be taken at its associated experiments. During the Long Shutdown 3 (LS3, 2026), several detectors and components of the experiments need to be refurbished to take full advantage of the increased collision rate. As these detectors have been exposed to intense high-energy beams for several years, they constitute a challenging radiation environment for the personal designated to work on the installation of the new detector parts. Careful estimation and optimisation of the individual and collective dose for the personnel involved is therefore an essential part of these works.
We have developed a novel dose estimation system for radiation intervention planning. The prototype combines the existing CAD drawings of the detectors with improved radiation simulations (FLUKA), creating a 3D virtual environment which monitors the instantaneous dose rate with respect to position within the environment.
As first use case, we applied this concept to the removal of the ATLAS Inner Detector (ID), which will be replaced by the ATLAS Inner TracKer (ITk) during LS3. Using a commercially available motion tracking system, we were able to capture the real-time movements of a person while training the ID removal on a full-size mock-up. Working with realistic positions inside the radiation field of about 10 µSv/h allowed us to predict the collective dose of the intervention with a much improved accuracy compared to spreadsheet-based prior attempts [2]. After the prototype stage, the virtual reality radiation dose estimation system has now been re-implemented using the game engine Unity to be compatible with other CERN-based activities (e.g. the robotics framework used for some tasks in the LHC accelerator tunnel).
We are currently in the process of extending the ways to record, analyse and display positioning data, opening new fields of possible applications. For example, a real time display of corresponding radiation values can be used to optimise procedures during the training of personnel on the mock-ups. Importantly, stored positional data of each person during the decommissioning training can be used to directly test the potential efficiency of various shielding concepts before production, by applying a corresponding, modified radiation dose map to the existing virtual model and recalculating the received radiation dose.
We will show the strengths and weaknesses of the system and discuss its usability and how the system can be applied for various other radiation critical interventions, where detailed CAD drawings and dose maps are readily available. In particular, for the HL-LHC, radiation levels will sharply increase with luminosity (LS4 and beyond), the radiation protection aspects during interventions will become significantly more challenging. Hence a future use case would be the exchange of the ITk Inner System in LS4 or LS5 where radiation fields of 50 µSv/h could be the norm. Additionally, the use of the system for applications inside the LHC tunnel would be interesting where the ambient radiation environment is already now of the order of tens of mSv/h and will increase by a factor of 5-10 until 2040.

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Photonuclear Integral Cross Sections in Zinc

Mamad Eslami[1], David Jenkins[1], Mikhail Bashkanov[1]
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Det/med, April 4, 2023, 13:30 - 15:00

The use of unstable nuclei is an emerging modality in medicine for both therapeutic and diagnostic purposes. Unfortunately, production of radioisotopes is a costly and cumbersome task, which limits the spread of these modern techniques to very few locations. Majority of isotopes are produced with extremely expensive cyclotrons utilising various proton-induced reactions. Recent progress in laser-induced photon beams has changed direction of research to exploring possibilities of producing medical radioisotopes with rather clean and extremely intense photon beams. In this work we have investigated the feasibility of photoproton production of 67Cu, an emerging theranostic counterpart, using the alternative reaction 68Zn(γ,p)67Cu, estimating the specific activity and production yield after a week-long irradiation. In this regard, the photonuclear integral cross sections in zinc isotopes are investigated, irradiating high purity natural Zn targets by bremsstrahlung photons. The cross section and yield per equivalent quanta of the residual nuclei such as 67Cu, 64Cu, 61Cu, 62Zn and 63Zn are measured. The experiment is carried out utilising the bremsstrahlung photons produced by the electron beam from Mainzer Mikrotron (MAMI) [1] hitting a radiator in the A2 hall. The photon flux versus energy is measured by the Glasgow photon tagging spectrometer [2], normalised against the tagging efficiency. The maximum energy of photons is 855 MeV, with average current of 9 nA. Residual nuclei are identified by their half-lives and the characteristic gamma lines with a high purity germanium (HPGe) detector. The efficiency of the detector is measured using a standard mixed gamma source. A Monte Carlo simulated photon flux as a function of energy is convoluted with theoretical reaction cross sections to benchmark with the obtained experimental data.

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Study of the effect of cannulation on blood flow during extracorporeal membrane oxygenation using positron emission particle tracking

Kiran Nutter[1,2], Tzany Kokalova Wheldon[1,2], Sern Lim[3], Zhong-Nan Wang[4], Christopher Windows-Yule[1,5], Tony Price[2]
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Det/med, April 4, 2023, 13:30 - 15:00

Extracorporeal membrane oxygenation (ECMO) is a life-saving technique that can provide support for patients with both cardiac and respiratory dysfunction. Different variations of ECMO are used depending on the needs of the patient, but these all rely on the cannulation of particular blood vessels. Although ECMO has been successfully used as a form of life support for over 30 years, there are complications that can arise during treatment, which increase the mortality rate significantly [1]. For many of these complications, there is a limited understanding of the causes, making it challenging to propose and find solutions. When patients are treated using ECMO, the angle of insertion of the cannula will vary on a case-by-case basis. This will impact the flow from, and around, the cannula, and thus finding an optimal angle could minimise the turbulence in the flow, and therefore reduce the occurrence of complications, such as blood clots. Additionally, the datasheets for the cannulae used in clinical settings only provide measurements of water flow through the cannula, in coarse units of L/min.

The aim of this study is to investigate the blood flow in such a system with higher precision, and in turn, provide insight on potential causes of some of the common complications. To do this, experimental flow measurements through a cannula and model vascular system were acquired using positron emission particle tracking (PEPT), a technique pioneered at the University of Birmingham. PEPT experiments were carried out while systematically varying both the angle of insertion of the cannula and the fluid used in the model system.

In parallel to the experimental work, we’ve been developing a computer simulation of the system using computational fluid dynamics (CFD). These simulations will be compared to the experimental results, and subsequently used to test more complex systems. The results from the first run of experiments, and the related CFD simulations will be presented.

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Search for the missing proton emitter 125Pm

<u>Daniel Doherty</u>[1]
[1]*University of Surrey, Guildford, United Kingdom*

Nuclear structure, April 4, 2023, 13:30 - 15:00

The phenomenon of proton radioactivity, where the atomic nucleus is energetically unstable to the spontaneous emission of a proton is a crucial source of nuclear structure and mass-landscape information at, and beyond, the proton drip line. In addition, in contrast to alpha decay where the formation of an alpha particle close to the nuclear surface must be considered, the pre-existence of protons within the nucleus allows for a cleaner theoretical treatment. This phenomenon has been observed in the most neutron-deficient isotopes of all odd-Z nuclides with atomic numbers between 53 and 83, with promethium (Z=61) being the only exception.
Previous searches for proton emission from 125Pm have been unsuccessful likely due to either a smaller than expected cross section or a short half-life for decay. However, recent theoretical calculations of proton emission, utilizing a non-adiabatic quasiparticle model, have indicated that observing the decay of 125Pm should be within the limits of state-of-the-art experimental setups utilizing digital electronics that allow for the analysis of pile-up waveforms with sophisticated analysis techniques. The observation of proton emission from 125Pm will be an important benchmark for both theories of proton decay, given the large, predicted deformation and the important role of the Coriolis interaction, and of mass models.
Here, we report on a recent experimental search using the Fragment Mass Analyzer (FMA) at Argonne National Laboratory's ATLAS facility. Evidence for proton emission from 125Pm will be presented and the important role of fine structure in the decay discussed. In addition, perspectives will be presented for future observation of even more exotic nuclear decays.

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Investigation of bound and unbound states in 20C

Liam Atkins[1], Dr Marina Petri[1], Dr Stefanos Paschalis[1], Dr Ryo Taniuchi[1], Dr Sidong Chen[1], Dr Julien Gibelin[2], Dr Miguel Marques[2], Dr Nigel Orr[2]
[1]University Of York, York, United Kingdom, [2]LPC Caen, Normandie Université, Caen, France

Nuclear structure, April 4, 2023, 13:30 - 15:00

The experimental investigation of the carbon isotopic chain is a unique case to test nuclear theories. The proton shell gap at Z=6 is established due to the spin-orbit splitting but it is not clear whether it survives towards the neutron drip line. The carbon isotopic chain is accessible experimentally up to the neutron drip line and several theoretical approaches are established in this region including ab initio approaches based on effective nucleon-nucleon forces. In order to shed light on the evolution of the Z=6 shell gap, we study the structure of 20C.

During the DayOne campaign at RIKEN, a 21N beam was impinged on a carbon target inducing proton removal reactions to form 20C. Inclusive and exclusive cross sections are extracted with the SAMURAI setup, a multi-particle reconstruction system with a large acceptance dipole magnet. These cross sections can infer the proton amplitude of the 2+ bound and unbound states, yielding information on the Z=6 magic number at the dripline [1, 2, 3]. In this talk I will discuss the experiment, calibrations and final results of this investigation.

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Low Power, Compact, Dual Mode Detectors for Nuclear Security Applications

David Bennett[1]
[1]*University of Glasgow, Glasgow, United Kingdom*

Det/med, April 4, 2023, 13:30 - 15:00

Detection of nuclear materials remains a matter of utmost importance due to potential security issues. Current detection techniques for neutrons and gammas involve using a combination of a 3He proportional counter, which allows for detection of thermal neutrons, along with a plastic scintillator, which allows for detection of gammas. This in itself creates issues as 3He is a rare and expensive material, with dwindling global supply, and as such a detector which does not rely on 3He is favourable.

Not only should a new detector meet these requirements, but it should also be low power, robust, and relatively small, which would allow the detector to be deployed in many field settings, allowing for wide and varied use that would be necessary to evaluate any potential nuclear material.

This is possible using dual mode detectors, a material that would allow for both neutrons and gammas to be detected. To accomplish this, pulse shape discrimination (PSD) algorithms would be used to analyse recorded data and determine whether a neutron or gamma was detected.

The scintillator materials selected for investigation were, CLLBC, an inorganic scintillator made of Cerium, Lanthanum, Lithium and BromoChloride. As well as EJ-276, an organic plastic scintillator. These materials will be paired with Silicon Photomultipliers (SiPM's), which were chosen to meet the requirements of being robust and having a low operating voltage, along with single photon sensitivity.

Initial tests have taken place with these materials and photomultiplier tubes (PMT's), which were chosen to begin with due to their greater stability when compared to SiPM's. Results taken using CLLBC have demonstrated a 5% energy resolution at 662KeV.

Once this preliminary stage has been completed, an SiPM will replace the PMT. Firstly, a GEANT4 simulation will be developed to yield idealised results, then PSD algorithms will be developed to effectively separate neutron and gamma spectra, with final testing then taking place to ascertain whether an analog or digital form will be best to meet the initial low power criteria.

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Lifetime measurements of excited states in 169,171,173Os

<u>WEI ZHANG</u>[1]
[1]*University Of York, , United Kingdom*

Nuclear structure, April 4, 2023, 13:30 - 15:00

In this presentation we report the results of our recent lifetime measurements in the low-lying excited states [1] in the vi13/2+ bands of the neutron-deficient osmium isotopes 169,171,173Os. Using the recoil distance Doppler shift and recoil-isomer tagging techniques, lifetimes of low-lying excited states were measured by coupling the Jurogam germanium detector array with the ancillary device DPUNS (differential plunger for unbound nuclear states), the gas-filled recoil separator RITU, and GREAT the decay spectrometer situated at the RITU focal plane. An unusually low value is observed for the ratio B(E2; 21/2+ → 17/2+)/B(E2; 17/2+ → 13/2
+) in 169Os, similarly to the "anomalously" low
values of the ratio B(E2; 4+1 → 2+1)/B(E2; 2+
1 → 0+gs) previously observed in several transitional rareearth nuclides with even numbers of neutrons and protons, including the neighboring 168,170Os as
well as the 166W and 172Pt [2–5]. The evolution of B(E2; 21/2+ → 17/2+)/B(E2; 17/2+ → 13/2+) with increasing neutron number in the odd-mass isotopic chain 169,171,173Os is observed to follow the same trend as observed previously in the even-even Os isotopes. These findings indicate that the possible quantum phase transition from a seniority conserving structure to a collective regime as a function of neutron number suggested for the even-even systems is maintained in these odd-mass osmium nuclei, with the odd valence neutron merely acting as a "spectator". As for the even-even nuclei, the phenomenon is highly unexpected for nuclei that are not situated near closed shells

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Quantum Entanglement of Annihilation Gamma: Recent progress

<u>Dawid Grabowski[1]</u>, Daniel Watts, Mikhail Bashkanov, Jamie Brown, Peter Caradonna, Ruth Newton, Nick Zachariou, Julien Bordes

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Det/med, April 4, 2023, 13:30 - 15:00

The York group has led recent developments in the experimental measurement and simulation of quantum entanglement between the two photons produced in electron positron annihilation [1]. Polarisation determination of the two photons using Compton scattering in segmented calorimeter systems (CZT and LYSO based) enables a clear and essentially noise free witness of entanglement. The ongoing programme will explore further applications in medical imaging as well as using the clear entanglement witness for fundamental tests.

Previous data employed a 22Na positron source (annihilating in plastic) as the photon source. In this talk recent results measuring the entanglement witness using actual PET imaging radioisotopes (18F) with annihilation in tissue media will be presented. The data were obtained at the Hull PET research centre where a variety of medically appropriate sources were produced and utilised in the measurements.

The ongoing programme of measurements at York for medical imaging and fundamental tests of entanglement at the MeV scale will also be outlined. The latter include distance tests, centrifuge measurements and a first measurement of the cross section for the double Compton scattering of entangled photon quanta.

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Nuclear structure of exotic nuclei in the 132Sn region

<u>Tom Parry</u>[1], Professor Zsolt Podolyàk[1]
[1]*Univeristy Of Surrey, , United Kingdom*

Nuclear structure, April 4, 2023, 13:30 - 15:00

The r-process produces roughly half of all nuclei heavier than iron, thus understanding the mechanism in which these nuclei are produced is an important topic of research. Properties of nuclei with magic numbers of neutrons are key to understanding the r-process. N=82 nuclei below 132Sn are connected to the mass abundance peak at A~130. In addition, studies of nuclei in this difficult to reach region provide information on nucleon-nucleon interactions and possible shell evolution.
Here we present experimental results obtained during the RIBF-189 experiment at RIKEN utilising the HiCARI high resolution germanium array. Particle identification was achieved on an event-by-event basis by the BigRIPS and Zero Degree spectrometers. New gamma-ray transitions have been observed for a large number of nuclei. Transitions from previously unseen configurations of 130Cd πg9/2 p1/2 to the known yrast 4+ state πg29/2 have been observed. This allows for the investigation of the proton-proton interaction below Z=50. Transitions observed in 132In and 130In provide information about the proton-neutron interaction above and below N=82 respectively. The obtained level schemes are supported by modern shell model and particle removal reaction calculations. Experimental details and physics results on these extremely neutron-rich nuclei will be presented.

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Single-particle state evolution along the N=127 isotone chain using the d(212Rn, p)213Rn reaction

Daniel Clarke[1]
[1]*The University of Manchester, Manchester, United Kingdom*

Nuclear structure, April 4, 2023, 13:30 - 15:00

The study of single-particle states can provide insight into properties of nuclear structure. In light neutron-rich systems, features of single-particle states along isotonic chains have highlighted changes in shell closures, such as the weakening of N = 20 and formation of N = 16 [1, 2]. In heavier closed-shell stable nuclei, trends have been seen in the behaviour of high-j states from the filling of other high-j orbitals, the effects of which have been attributed to the tensor interaction [3]. From the availability of radioactive beams at ISOLDE, these studies can be extended in the region around N = 126. Currently, states up to Z = 84 are known with spectroscopic factors and assignments [4, 5]. Above this, there is very little information on the single-particle properties of nuclei. Only the energies of states are available with tentatively assigned orbital configurations and no spectroscopic information. In order to probe single-particle nature beyond this, the reaction d(212Rn, p)213Rn has been performed at the ISOLDE Solenoidal Spectrometer (ISS) with a 7.63 MeV/u radioactive beam at an intensity of ~106 pps. States have been identified up to ~4 MeV and single-particle centroids have been extracted for the neutron outside of N = 126, providing information on the magnitude of monopole shifts caused by the interaction between the neutron and protons filling the π0h_(9/2) orbital. These data will also be used to inform modern shell-model calculations in this region of the nuclear chart. Preliminary data from measurements will be presented.

3

Cross-shell interactions at the N=28 shell closure via 47K(d,p) and 47K(d,t) with MUGAST+AGATA+VAMOS

Mr Charlie James Paxman[1], A. Matta[2], W. N. Catford[1], M. Assié[3], E. Clément[4], A. Lemasson[4], D. Ramos[4], F. Galtarossa[3], L. Achouri[2], D. Ackermann[4], D. Beaumel[3], L. Canete[1], P. Delahaye[4], J. Dudouet[5], B. Fernández-Domínguez[6], D. Fernández-Fernández[6], F. Flavigny[2], C. Fougères[4], G. de France[4], S. Franchoo[3], J. Gibelin[2], N. Goyal[4], F. Hammache[3], D. S. Harrouz[3], B. Jacquot[4], L. Lalanne[3], C. Lenain[2], J. Lois-Fuentes[6], T. Lokotko[2], F. M. Marqués[2], I. Martel[7], N. A. Orr[2], L. Plagnol[2], D. Regueira-Castro[6], N. de Séréville[3], J.-C. Thomas[4], A. Utepov[4]
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Nuclear structure II, April 4, 2023, 15:30 - 17:00

hell evolution in the region around the magic numbers N = 28 and Z = 20 is of great interest in nuclear structure physics. Moving away from the doubly-magic isotope 48Ca, in the neutron-rich direction there is evidence of an emergent shell gap at N = 34 [1], and in the proton-deficient direction, the onset of shape deformation suggests a weakening of the N = 28 magic number [2]. The 47K(d,p)48K reaction is uniquely suited to investigating this region, as the ground state configuration of 47K has an exotic proton structure, with an odd proton in the π(1s1/2
) orbital, below a fully occupied π(0d3/2
) orbital [3]. As
such, the selective neutron transfer reaction (d,p) will preferentially populate states in 48K arising from
π(1s1/2
) ⊗ ν(f p) cross-shell interactions. The implications of this extend both down the proton-deficient N = 28 isotonic chain, where these interactions are expected to dominate the structure of the exotic, short-lived 44P nucleus [4], and across the neutron-rich region, where the relative energies of the ν(f p) orbitals is the driving force behind shell evolution.
The first experimental study of states arising from the interaction between π(1s1/2
) and the orbitals
ν(1p3/2
), ν(1p1/2
) and ν(0f5/2
) has been conducted, by way of the 47K(d,p) reaction in inverse kinematics.
A beam of radioactive 47K ions was delivered by the GANIL-SPIRAL1+ facility, with a beam energy of 7.7 MeV/nucleon. This beam was estimated to be > 99.99% pure, with a typical intensity of 5 × 105 pps, and was impinged upon a 0.3 mg/cm2 CD2 target. The MUGAST+AGATA+VAMOS detection setup [5] allowed for triple coincidence gating, providing a great amount of selectivity. An analysis based both on excitation and gamma-ray energy measurements has revealed a number of previously unobserved states in 48K, and preliminary differential cross sections for the most strongly populated of these states will be presented. Spectroscopic factors for these states will be discussed in the context of shell model calculations, with regard to the N=28, 32 and 34 shell gaps. Additionally, results for positive and negative parity states in 46K, measured simultaneously via the 47K(d,t) reaction, will also be presented.

7

The first nuclear reaction measurements on the CRYRING storage ring using the CARME array

Mr Jordan Marsh[1]
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Nuclear structure II, April 4, 2023, 15:30 - 17:00

Storage rings provide a new and unique opportunity to resolve long standing problems in astrophysics by performing nuclear reactions using stored heavy ion beams on an ultra-thin internal gas-jet target. The CRYRING storage ring, part of FAIR phase-0, is unique worldwide by allowing ion beams to be decelerated, cooled and circulated at energies of astrophysical interest. The CRYRING Array for Reaction MEasurements (CARME) array utilises this novel methodology and will be used to study direct nuclear reactions at energies of astrophysical interest in addition to indirect studies of key nuclear properties with consequences for quiescent and explosive astrophysical environments. CARME utilises high resolution (30 keV FWHM), highly segmented (128x128 strip) Double-Sided Silicon Strip Detectors (DSSSD) installed directly under vacuum with no pockets or windows. The detectors are capable of movement which is required to avoid the un-cooled beam when it is first injected into the storage ring. CARME was installed in September 2021 and demonstrated that XHV pressures (~10-12 mbar), required for circulation of beam around the ring, could be achieved with detectors and the accompanying electrical cabling installed under vacuum. CARME was successfully commissioned in February 2022. I will present the technical capabilities of the CARME array and results of the first commissioning run. This was the first use of the internal gas target, the first beam on target and the first observation of nuclear reactions at the CRYRING and acts as a launch pad for the exciting physics programme ahead

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Two-centre self-consistent approach to fission with arbitrary distance, deformations and orientations of fragments

Dr Adrian Sanchez Fernandez[1]
[1]*University Of York, York, United Kingdom*

Theory, April 4, 2023, 15:30 - 17:00

Fission is one of the most challenging processes to describe in nuclear physics. Contrary to most of the nuclear properties, which can be explained in terms of a smaller set of valence nucleons out of an inert core, in fission all the particles are involved. Because of this, many-body approximations and theoretical assumptions that simplify the problem are mandatory when trying to describe mathematically the whole process. For connecting the properties of the nascent fragments to the structure of the initial compound nucleus, it seems adequate to consider a two-centre basis to build the single particle states of the nuclear wave functions [1-3]. Even though there are some existing results computed with that approach, in all of them axial symmetry was preserved [4], which appears as a limitation for describing more complex phenomena. In the present work, for the first time, symmetry-unrestricted two-centre harmonic oscillator states are used within the density functional solver HFODD [5] to solve the Hartree-Fock-Bogoliubov equations.
The effects of the separation and orientations between centres are analysed in super-deformed states (as doorway states to scission configurations) and the results are compared to the usual one-centre calculations as a benchmark.
This novel work opens the door to developing more sophisticated theoretical technologies in the near future. Timedependent methods will allow computing properties relevant to both spontaneous and neutron-induced fission (collective inertia, mass distributions or angular momenta of the fragments) without the classical assumptions about adiabaticity or thermalisation[2].

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Nuclear collective inertia in the adiabatic time-dependent Hartree-Fock-Bogoliubov method

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Theory, April 4, 2023, 15:30 - 17:00

A novel method to solve equations of the adiabatic time-dependent Hartree-Fock-Bogoliubov (ATDHFB) method is developed and applied to study nuclear collectivity. Collective motion, in which many nucleons act coherently, is of fundamental importance in nuclear physics and attracts both experimental and theoretical attention. Although the collective motion can be described by the phenomenological liquid drop model or Bohr Hamiltonian [1, 2], the physical determination of the inertia against this motion needs knowledge about nuclear microscopic dynamics. In the Hartree-Fock-Bogoliubov theory, each nucleon moves independently in a field created by all the others. Once excited, the nucleus evolves with time along a collective path in the multidimensional energy surface. The ATDHFB method assumes the velocity of the collective motion is much smaller than that of single-particle motion. It allows for a microscopic evaluation of the inertia for surface vibrations, rotations and fission. As such, the ATDHFB method is a bridge between the microscopic many-body theory and phenomenological models based on collective variables.
To study full vibration-rotation collective motion in the adiabatic limit without constraints, we implement the ATDHFB method for the Skyrme density functional solver HFODD [3]. The nuclear Hartree-Fock-Bogoliubov problem is solved on a 3D Cartesian deformed harmonicoscillator basis to deal with arbitrary shapes and angular rotational frequencies. The ATDHFB equation is solved iteratively which avoids the explicit calculations of the stability matrix [4]. Since the collective motion is not time-reversal invariant, the proper treatment of the time-odd mean fields is essential. Neglecting the time-odd term would lead to incorrect collective inertias [5, 6]. In this work, the dynamical effects of the time-odd mean fields are highlighted by comparing the ATDHFB results with those obtained in the cranking approximation.
The ATDHFB method implemented in this work gives universal and reliable estimations of collective inertia for both even and odd heavy nuclei, which will be helpful to determine the collective path for spontaneous fission. In the future, we will study the influence that non-axial deformation and the pairing interaction have on the nuclear collective inertias, as well as investigate the possible impacts of the isospin-breaking terms and finite-range higher-order regularized terms in the density functional. By performing extensive calculations across the Segre chart, the information on collective nuclear observables will be included in building novel nuclear density functionals

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Precision laser spectroscopy of exotic nuclei using in-flight ion traps

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Nuclear structure II, April 4, 2023, 15:30 - 17:00

High-resolution laser spectroscopy has developed to be a powerful tool to investigate nuclear structure. At the IGISOL-4 facility, the collinear laser spectroscopy programme has recently, and successfully, focused on nuclear phenomena observed in the refractory elements between Ca (Z=20) and Ni (Z=28), focusing near the N = Z systems. Results from the spectroscopy contribute to our understanding of the evolution of the nuclear structure by providing model-independent measures of the nuclear mean-square charge radii, spins and electromagnetic moments of ground state or long-lived nuclear states in exotic nuclei [1]. Through the development of new, high transparency, electrostatic ion traps ("ConeTraps") we aim to achieve environments for optical pumping that are free from the macro-motion and buffer gas perturbations that limit spectroscopy in our existing Paul traps. The performance of our new traps, measured at a bespoke testbed in Manchester, will be reported and the prospects for new spectroscopy discussed. The final, now optimized, design sees a trap entirely constructed from metallic mesh that will newly facilitate nuclear decay spectroscopy as well as providing complete optical access to the trapped exotic ensembles.

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Achievements and future perspectives in microscopic optical potentials

Matteo Vorabbi[1], Dr Paolo Finelli[2], Prof Petr Navrátil[3], Michael Gennari[3,4]
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Theory, April 4, 2023, 15:30 - 17:00

The optical potential is a well-known and successful framework to describe nucleon-nucleus scattering processes. Within this approach it is possible to compute the scattering observables for elastic processes across wide regions of the nuclear landscape and extend its usage to inelastic processes and other types of reactions such as nucleon transfer, knockout, capture or breakup. A phenomenological approach is usually preferred to achieve a good description of the data; however, it lacks predictive power due to the presence of free parameters contained in the model that need to be fixed. With the upcoming facilities for exotic nuclei, such as FRIB, we strongly believe that a microscopic approach, completely free from phenomenology, will be the preferred tool to make reliable predictions, assess the unavoidable approximations, and provide a clear physical interpretation of the process under consideration. Few years ago, we started a project devoted to developing a microscopic optical potential using two- and three-nucleon interactions as the only input. Within the framework of the Watson multiple scattering theory, the optical potential is obtained as the folding integral of the nucleon-nucleon scattering matrix and the nuclear density, that represent the two fundamental ingredients of the model. After two decades of advances in theoretical nuclear physics, it is now possible to calculate these two quantities using the same inter-nucleon interaction that is the only input of our calculations. Despite the good results obtained so far [1,2,3], there are still several extensions of the model currently under development, such as the inclusion of medium effects for low-energy calculations, the extension to heavier systems, the inclusion of double scattering effects, and the extension to inelastic scattering. The last one is particularly important for an entire class of experiments that usually need the subtraction of inelastic contributions to perform a correct data analysis. A summary of the past achievements along with a detailed explanation of the new challenges will be presented

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Development of self-calibration techniques for γ-ray energy-tracking arrays

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Nuclear structure II, April 4, 2023, 15:30 - 17:00

The development of γ-ray energy-tracking arrays using highly segmented High Purity Germanium (HPGe) detectors is currently the technological frontier of high-resolution gamma-ray spectroscopy for modern nuclear physics investigations[1]. The tracking capability of such arrays strongly depends on the performance of the Pulse Shape Analysis (PSA), which uses the position-dependent response of the detector signals to determine the γ-ray interaction positions within the detector volume. The PSA algorithm is performed by comparing the measured signal pulse shape to expected pulse shapes associated with different interaction positions from the signal basis. Therefore, producing a reliable signal basis is one of the key points for PSA.

A novel method to generate a reliable signal basis in a notably simple experimental way was proposed in reference[2]. In this method, a γ-ray source illuminates the full array and the Compton scattering data is obtained. Starting with the assumption of a segment-sized position resolution for every interaction point and using an iterative minimization procedure based on the tracking of Compton scattering events, it is possible to converge to the real positions after several iterations, which is so-called self-calibration. The self-calibration method was demonstrated in reference[2] with the simulation of a simplified geometry for the array and without considering electronic pulses.

This report presents the development of the self-calibration technique with a realistic geometry for the AGATA array with pulse shape signals. To demonstrate the performance of this technique, it is first applied to a simulation data obtained using the interaction points produced by the AGATA Geant4 simulation package combined with a pulse shape signal basis generated by the AGATA Detector Library (ADL)[3]. The signal basis produced by self-calibration method is compared with the initial ADL basis to show the validity of the method. This method is then applied to signals from a real gamma source calibration data to generate an experimental signal basis. The experimental signal basis is compared with the currently used ADL basis. PSA with both signal bases are attempted and observe reasonable results. Further development of the self-calibration technique is discussed. A more reliable experimental basis generated by the self-calibration technique is foreseen in the near future.

New Experimental Prospects for the MARA-LEB Facility

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Nuclear structure II, April 4, 2023, 15:30 - 17:00

The Low-Energy Branch (LEB) [1] for the MARA separator [2] is a facility under construction at the Accelerator Laboratory of the University of Jyväskylä. The facility will be used to study the ground-state properties and decay modes of exotic nuclei far from stability combining multiple techniques to investigate nuclear properties of isotopes far from stability.
MARA-LEB will stop and neutralise reaction products selected by the MARA separator in a small-volume buffer gas cell. A state-of-the-art Titanium:Sapphire laser system allows for reionsiation of selected species and for laser spectroscopic analysis. Re-ionised atoms can be extracted and accelerated by the ion transport system [3] and further mass- and velocityselected before being directed either into specialised detector stations, for decay spectroscopy, or a dedicated cooler-buncher and Multi-Reflection Time-of-Flight Mass Spectrometer, for high-precision mass measurements.
In a recent experiment at MARA, where the dynamics of non-fusion reaction channels was studied by the GSI-JYFL collaboration various heavy nuclei in the $84 \leq Z \leq 92$ region, which includes some light actinides, were produced. Data analysis from this experiment is still under way [4]. Nevertheless, preliminary experimental yields show that laser spectroscopy of these heavy nuclei may be feasible in the MARA-LEB facility.
This is a promising prospect given the recent increased interest in the study of exotic species in this region via the use of laser spectroscopical techniques [5]. There is limited information on the actinides due to low production cross-sections combined with the lack of stable isotopes for many of the elements in this group. The use of non-fusion reactions such as Multi-Nucleon Transfer (MNT) has been proposed as a way to enhance access to this region of the nuclear chart and thus improve the prospects for laser ionisation of these elements.
MARA-LEB will combine the required mass resolution and laser spectroscopic capabilities to carry out studies in with these new experimental conditions.
An update on the current status of MARA-LEB will be presented, alongside a discussion of the feasibility of laser spectroscopy experiments in the new facility given the cross-sections extracted from these recent MARA experiments.

Benchmark of proton detection using CALIFA at R3B

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Nuclear structure II, April 4, 2023, 15:30 - 17:00

Quasi-free scattering (p,2p) experiment of the Calcium isotopic chain 38−50Ca at 450 MeV/u were performed by the R3B collaboration as part of FAIR phase 0. We perform a systematic study on the dependency of the quenching of spectroscopic factors to the isospin asymmetry by employing quasi-free scattering reactions in inverse kinematics, extending our previous investigation [Atar et al.] towards this medium mass region. CALIFA has been used to measure the momentum of both the recoil and the knocked-out proton. In this contribution, we will discuss the simulations that were performed to study (p,2p) reactions using the CALIFA detector to quantify the detector efficiency for protons; this is a critical step in extracting the measured cross sections for the quasi-free scattering (p,2p) process. We will also show the comparison between results from simulation and experimental data.

4

Alpha-Clustering from a Skyrmion Perspective

__**Prof Nicholas Manton[1]**__
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Theory, April 4, 2023, 15:30 - 17:00

Skyrmions are the topological solitons of an EFT of pions, where the conserved topological charge is interpreted as baryon (nucleon) number B. Like other EFTs, the dynamics is that of a nonlinear sigma model. A basic Skyrmion's ground state has spin and isospin one-half, and represents a nucleon. Skyrmions of higher B are configurations of partially-merged basic Skyrmions. The B=4 solution is particularly stable, and its spin-0 ground state represents an alpha-particle. These Skyrmion alpha-particles form clusters in various ways. Solutions for B=8, 12 and 16 have been studied in detail. Their quantized dynamics, including rotational and vibrational motion, and also tunnelling between different cluster shapes, gives a rich spectrum of excited states that matches experimental spectra of Be-8, C-12 and O-16 quite well. Predictions are made for the spin/parity of some of the experimentally uncertain states above 12 MeV in O-16.
A current challenge is to understand the rotational bands in Ne-20. Some of these arise from a vibrational excitation of a bipyramidal five-alpha-particle cluster. The dynamics of this vibrational mode extended to large amplitude mimics the dynamics of a Newton cradle, physically interpreted as alpha-O-16 dynamics. When this mode is coupled to rotations, the kinetic energy defines a spatial wormhole geometry.
These results have been obtained with collaborators including P.H.C. Lau, C. Halcrow, C. King and J. Rawlinson, and are summarised in NSM's recent book [1]

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Invited IX: Heavy-mass frontier of nuclear ab initio calculations

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April 5, 2023, 11:30 - 12:00

The applicability of nuclear ab initio calculation is expanding, and the systematic calculations can be performed up to mass number A~100, for example, using the valence-space in-medium similarity renormalization group (IMSRG) approach [1], one of the ab initio calculation methods. However, the applications for heavier systems are limited primarily due to the memory-expensive three-nucleon (3N) interaction matrix elements. Modern nuclear ab initio calculations begin with the nucleon-nucleon (NN) and 3N interactions, benefitting from the order-by-order expansion in chiral effective field theory. For medium- and heavy-mass nuclei, one can apply basis expansion methods such as the coupled-cluster method, self-consistent Green's function method, many-body perturbation theory, and IMSRG, starting from the NN and 3N matrix elements expressed with the spherical harmonic-oscillator (HO) basis set, where a typical calculation is performed within 13 or 15 major-shell space. The memory requirement of the 3N matrix elements in such space will exceed 10 TB, and one needs another truncation for 3N matrix elements, known as E3max defined by the sum of 3N HO quanta. It turns out that the current E3max limit does not allow us to obtain converged results for nuclei heavier than A~100. To overcome the limitation, we propose a new storage scheme for the 3N matrix elements [2], where we exploit the feature of the normal-ordered two-body approximation widely used in the basis expansion methods. This new scheme enables us to compute the known heaviest doubly magic nucleus 208Pb [3].
In this presentation, I will briefly explain the new 3N storage scheme and show some ab initio results for the heavy-mass nuclei, including a prediction for the neutron-skin thickness of 208Pb.

P.2

A microscopic study of 12C+12C fusion interactions

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Lunch/Poster session, April 5, 2023, 12:30 - 14:00

The study of 12C+12C fusion interactions was performed using time-dependent Hartree-Fock (TDHF) approximation [1]. The cross section reaction has been computed with SKI3 and SVbas Skyrme forces at different orientations. The Sky3D TDHF code has been used to calculate static properties, and fusion reaction of the 12C+12C system [2]. Our findings produced reasonable resonances at each center of mass energy. The structures of the resonances appear explicitly in the fusion cross section for 12C+12C, due to overcoming angular momentum fusion barriers [3]. Our results are compared to those obtained experimentally via several techniques [4, 5, 6]. It is observed that, at low energy, our data is in a good agreement with the experimental data.The disagreement becomes visible with increasing incident energy, where the TDHF approximation begins to break down.

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[6] J. Patterson, H. Winkler, and C. Zaidins, “Experimental investigation of the stellar nuclear reaction 12c+12c at low energies,” The Astrophysical Journal, vol. 157, p. 367, 1969

P.6

Identifying particle reaction channels using CALIFA's QPID

Matthew Whitehead

Lunch/Poster session, April 5, 2023, 12:30 - 14:00

The R3B setup at GSI employs many different detectors to study nuclear reactions. The CALorimeter for In Flight detection of gamma rays and high energy charged pArticles (CALIFA) is a highly segmented scintillation detector surrounding the target. It is formed from CsI(Tl) crystals, with a scintillation process formed from a fast and slow component with decay times of 700ns and 3.34s respectively. The generated pulse from an incident particle is analysed by recording the charge function in a first short and then delayed large window following the trigger signal [1]. Each component is dominant in the corresponding window and the contribution of light emitted is dependent on the type of particle incident, thus analysis of this feature allows for quick particle identification (QPID).

Analysis of a recent quasi-free scattering experiment will provide insight in CALIFA's capabilities to distinguish different particle reaction channels and will help facilitate the employment of CALIFA in the future. Future experiments at R3B include measurements of p,pd QFS reaction cross sections for neutron rich carbon isotopes which will rely on CALIFA to correctly identify deuterons produced.

[1] Anna-Lena Hartig, "Evolution of CALIFA: From single detector modules to benchmark reactions", 2021

P.5

A Study Into A=78 Sr, Rb, And Kr Nuclei Using GRETINA + FMA

Reuben Russell[1], Jack Henderson[1], Jacob Heery[1], Daniel Doherty[1], Charlie Paxman[1], Ben Reed[1], Letitia Canete[1], Patrick Regan[1], Wilton Catford[1], Gavin Lotay[1], Adam Kennington[1], Claus Muller-Gatermann[2], Gemma Wilson[2], Walter Reviol[2], Daniel Santiago-Gonzalez[2], Mike Carpenter[2], P Copp[2], Torben Lauritsen[2], Marco Siciliano[2], Robert Wadsworth[3], Marina Petri[3], L Tetley[3], R Taniuchi[3]
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Lunch/Poster session, April 5, 2023, 12:30 - 14:00

The structure of deformed nuclei is known to greatly differ from that which is predicted by an independent particle model. 78Sr lies in the region of Z=N=40, which is a region displaying strong quadrupole deformation, with experimental data for 78Sr matching closely to that expected for a strongly-deformed nucleus. However, the existence of low-lying 02 + and 22 + states in other nuclei in this region hint a high potential for coexisting or triaxial shapes respectively. An experiment was performed at Argonne National Laboratory to populate low-lying levels in 78Sr via fusion-evaporation. A 56Fe beam was impinged onto a 24Mg target at an energy of 150 MeV/nucleon. 78Sr was produced via the 2-neutron channel. Strong contaminants include 77Kr, 77Rb, 78Kr and 78Rb which make up the vast majority of the total cross section. The GRETINA+FMA setup was used to perform gamma-recoil coincidence analysis of the data. Findings from this experiment will be presented, including transitions in 78Sr, 78Kr and 78Rb.

P.8

A Large Area Optical Sensor for Water Cherenkov Detectors Detecting Anti-Neutrinos

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Lunch/Poster session, April 5, 2023, 12:30 - 14:00

The discovery of Cherenkov radiation prompted the invention of a new class of high-energy particle physics detectors which use photomultiplier tubes (PMTs) to measure the light emitted from charged particles travelling faster than the speed of light in water. These detectors have exceptionally high speed of response arising from the directional nature of the radiation, and they can be used to detect, count, and identify the particle in question. There has been growing interest in the application of these detectors for the purposes of surveillance and non-proliferation, as they can be used to trace electron anti-neutrinos from the beta decay of fission products in a nuclear reactor.

A novel photodetector (FRANCIS) has been developed for use in Water Cherenkov Detectors which uses a wavelength shifting plate and silicon photomultipliers (SiPMs) as a detection system. FRANCIS is lower cost than the PMTs that are currently in use, operates at a lower voltage and carries no implosion risk. It offers a range of other benefits, including insensitivity to magnetic fields and a flatter profile, which allows for a great fiducial volume.

A FRANCIS prototype was constructed and compared to a Hamamatsu R14374 PMT by undergoing scans with a 404 nm picosecond pulse laser. These scans have revealed that FRANCIS has a uniform photon detection efficiency (PDE) across the entire detection surface, with small areas of lower PDE between the angular range of 0-12° arising from the SiPM angular acceptance. The PMT showed relatively uniform PDE across its entire surface, with a drop off towards the edges. The time offset between the laser trigger and peak pulse was shorter for FRANCIS than for the PMT, with values ranging between 296-308 ns and 325-360 ns respectively.

A GEANT4 simulation was also developed to explore and optimise the design of the FRANCIS detector. It returned a greater range of angles the SiPM would not accept, at 0-35°, but otherwise had good agreement with the experimental findings. This simulation can therefore be used with some modifications to obtain vital information about the geometry and SiPM placement required to optimise the performance of FRANCIS for future prototypes.

P.4

Underground Measurements of the 16O(p,γ)17F Reaction at LUNA

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Lunch/Poster session, April 5, 2023, 12:30 - 14:00

The 16O(p,γ)17F reaction is the slowest proton-induced reaction in the CNO cycle [1]. This is due to the fact that at energies of astrophysical interest it has no resonances, making it an example of a pure direct capture reaction [2]. The ratio of 16O/17O depends strongly on the rate of this reaction. This ratio is an important probe of nucleosynthesis and mixing processes in the interior of stars, as it can be measured directly [3]. At astrophysical energies, i.e. centre of mass energies below around 500 keV, there is little experimental data for this reaction, and what data there is tends to have relatively large uncertainties [4]. In addition, Bayesian estimations of the reaction s-factors carried out by Iliadis et al. in [4] do not closely match the low energy experimental data, particularly for direct capture to the ground state.

An experimental campaign is in progress at the LUNA underground accelerator at Gran Sasso National Laboratory in Italy, aiming to measure the reaction rate for 16O(p, γ)17F. The very low background in the underground laboratory combined with lead shielding allows for direct measurements of this weak reaction to be carried out. Protons are accelerated onto a tantalum oxide target, and the resulting prompt gamma rays are detected using two cerium bromide scintillators and a high-purity germanium detector.

I will report on the characterisation of the setup and the data that has been taken.

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P.7

The UK-XFEL Facility Conceptual Design - Opportunities for Nuclear Physics & Applications

Dr Peter Williams[1], Dr Joe Crone[1]
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Lunch/Poster session, April 5, 2023, 12:30 - 14:00

Following on from the 2020 Science Case, STFC has initiated a 3-year Conceptual Design Phase for a UK X-Ray Free Electron Laser facility, funded by the UKRI Infrastructure fund. X-ray FELs can provide coherent, tune-able photons from EUV to hard X-ray wavelengths for use over a wide range of scientific disciplines – including Nuclear Physics. The UK-XFEL project also includes an opportunity to augment the FEL output with high flux, mono-energetic gammas from 100’s keV to 100 MeV via inverse Compton scattering of the primary electron beam. In this presentation we outline the project and facility concept, and discuss opportunities for Nuclear Physics from this potential new UK capability.

P.1

A Quantum Algorithm for the Linear Response of Nuclei

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Lunch/Poster session, April 5, 2023, 12:30 - 14:00

The response of a quantum many-body system to an external perturbation has been at the forefront of nuclear structure theory. Recent advancements in the simulation of such many-body systems using quantum algorithms provide a unique opportunity to probe the nuclear structure using quantum computers. We present a quantum algorithm to obtain the response of the atomic nucleus to a small external electromagnetic perturbation [1]. We use mean-field approximation to simulate the underlying single-particle nuclear structure where the Hamiltonian of the system is presented by a harmonic oscillator. The linear combination of unitaries (LCU) based method is utilized to simulate the Hamiltonian on the quantum computer to calculate the energy spectra with corresponding many-body wavevectors. The output of the Hamiltonian simulation is utilized in calculating the dipole response with the SWAP test algorithm. The results of the response function computed using the quantum algorithm are compared with the experimental data and provide a good agreement. We show the results for 120Sn and 208Pb to corroborate with the experimental data in Sn and Pb regions and also compare the results with those obtained using the conventional linear response theory.

[1] Abhishek, et al., ArXiv. https://doi.org/10.48550/arXiv.2210.08757 (2022)

P.3

Next Generation Muon Imaging

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Lunch/Poster session, April 5, 2023, 12:30 - 14:00

Muon tomography is a non-destructive, passive imaging technique that has seen successful use in imaging of both large-scale, massive volumes and medium-scale, heavily shielded volumes. There exist two methods of obtaining images using muons, either by measuring scattering in the imaging volume or by measuring change in muon flux due to massive objects, these are known as Muon Scattering Tomography (MST) and Muon Absorption Radiography (MAR) respectively. While both have been employed successfully as imaging techniques there remain many challenges to be overcome with the aim of further improving imaging time, image quality and noise reduction.

The cause of these issues lies in the nature of the cosmic ray muons used as probing particles. The muon flux at sea level is fixed by factor outside of human control, such as solar weather and cloud coverage. Furthermore, the angular distribution of incident muons is centered around zenith, meaning that image accuracy in the vertical dimension is limited by the smearing introduced from the lack of projection angles.

To overcome these challenges and improve muon imaging we suggest the development of machine learning algorithms. Machine learning comes in many forms and ranges in complexity from simple optimization algorithms to complex neural networks, meaning it is well suited to be employed to solve a wide range of problems. It can be used to denoise images using convolutional neural networks (CNNs), while simpler optimization algorithms can be used to distinguish between muons and secondary particles, reducing the number of non-muon events being used in calculations and it can be employed to more accurately reconstruct the path of a muon within the imaging volume.

Despite the opportunities represented by machine learning it comes with limitations of its own. CNNs can distort the underlying data, resulting in inaccurate analysis of the imaging volumes contents. In addition, they suffer from poor edge preservation, meaning the sharpness of the resulting image can be affected. The optimization algorithms also struggle with a disposition to falling into local minima, rather than the global minimum if the problem is not well defined.

Keeping this in mind initial results show that machine learning will be able to improve muon imaging, in particular regarding reducing the number of non-muon events counted. The main challenge is to ensure the problems to which we apply machine learning are well defined and well understood to ensure the accuracy and efficacy of the results produced by machine learning.

2

AMBER: a new QCD facility at the CERN SPS M2 beam line

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Hadron, April 5, 2023, 14:00 - 15:00

AMBER (NA66) is a newly proposed fixed-target experiment at the M2 beam line of the SPS, devoted to various fundamental QCD measurements, with a proposal recently approved by the CERN Research Board for a Phase-1 program and a Letter of Intent made public for a longer term programme.
Such an unrivalled installation would make the experimental hall EHN2 the site for a great variety of measurements to address fundamental issues of strong interactions in the medium and long-term future.
The elastic muon-proton scattering process, using high-energy muons, is proposed as a novel approach to the long standing puzzle of the proton charge radius. Such a measurement constitutes a highly-welcomed complementary approach in this area of world-wide activity.
Operating with protons, the antiproton production cross section, which is currently known with poor precision, can be measured, which constitutes important input for the upcoming activities in searches for Dark Matter.
Especially the world-unique SPS M2 beam line, when operated with high-energy pions, can be used to shed light on the emergence of hadron masses and to address the question of how we can explain the emergence of the proton mass and the nearly masslessness of the pion. The origin of hadron masses is deeply connected to the parton dynamics and their differences between baryons and mesons.
For a longer-term programme an upgrade of the M2 beam line with radio-frequency separation technique will provide kaon and antiproton beams of high purity. This will allow to perform precise spectroscopy studies and open new unique opportunities to shed new light on the light meson structure and properties..

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Overview and Preliminary Results of GEN-II Experiment

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Hadron, April 5, 2023, 14:00 - 15:00

Electromagnetic form factors, which are available via elastic scattering, encapsulate information on the charge and current structure inside the nucleons. The novel Super Bigbite Spectrometer (SBS) experimental setup in Jefferson Lab Hall A seeks to extend measurements of the nucleon form factors to unprecedented high values of the four momentum transfer squared Q2
. Jefferson Lab's 12 GeV era
make this possible. The electric form factor (GE
n
) of the neutron is the least well understood of the four
Sachs form factors, due to its small magnitude and the experimental complexity required in accessing it. The ongoing GEN-II experiment, which uses novel techniques to utilise a polarised helium-3 target, will provide results for GE
n at three kinematic points 2.9 GeV2
, 5.52 and 9.92
. I provide an overview of the
experimental technique and present preliminary results from the completed kinematic points.

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Insight to the Explosion Mechanism of Core Collapse Supernovae Through γ-ray Spectroscopy of 46Cr

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Astro, April 5, 2023, 14:00 - 15:00

Currently, the explanation behind the explosion mechanism of core collapse supernovae is yet to be fully understood. New insight to this phenomena may come through observations of 44Ti cosmic γ rays; this technique compares the observed flux of cosmic 44Ti γ rays to that predicted by state-of-the-art models of supernova explosions. In doing so, the mass cut point of the star can be found, a key hydrodynamic property
of supernova that provides an understanding of the material that is either ejected from the explosion or bound to the residual neutron star or black hole. However, a road block in this procedure comes from a lack of precision in the nuclear reactions that destroy 44Ti in supernovae, most notably the reactions 44Ti(α, p)
47V and 45V(p, γ)
46Cr [1]. Therefore, this study aims to better understand the 45V(p, γ)
46Cr
reaction by performing γ-ray spectroscopy of 46Cr with the aim of identifying proton-unbound resonant states.
The experiment was conducted at the ATLAS facility at Argonne National Laboratory, using the GRETINA+FMA setup. A beam of 120-MeV 36Ar ions are impinged onto a 200 μg·cm−2
thick 12C target,
producing 46Cr via the fusion-evaporation reaction 12C(36Ar,2n). The cross section for producing 46Cr, in this reaction, is estimated to be in the μb range. Nevertheless, with the power of the GRETINA+FMA setup, we show that it is possible to cleanly identify γ rays in 46Cr. These include decays from previously unidentified states above the proton-emission threshold, corresponding to resonances in the 45V + p system.
This represents the state-of-the-art for in-beam γ ray studies for full spectroscopy up to the excitation energy
region relevant for astrophysical burning.

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Identifying the Origin of Presolar Grains: Gamma-Spectroscopy of 35Ar

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Astro, April 5, 2023, 14:00 - 15:00

Classical novae are the second most common explosive stellar phenomena in the Universe [1] and, as such, play an important role in the enrichment of the interstellar medium and chemical abundances we observe in the galaxy. One observable, which is key to understanding the processes that drive classical novae, is presolar grains. It is, therefore, important that we are able to characterise the origin of presolar grains based on their isotopic ratios. One issue that still remains is being able to distinguish between grains of nova and supernova origin.
It has been suggested that the 34S/32S isotopic ratio could be used, in conjunction with the well-known 32S/33S ratio [2], in order to distinguish between solar and novae presolar grains [3,4]. The abundance of 34S is dependent on the 34g,mCl(p,γ)35Ar rp-process reaction rate. In order to determine this reaction rate, one has to know the energy, spin and parity of the contributing resonances in 35Ar. The energies of all states above the proton threshold have been measured [3], however almost all of the spins and parities remain unknown.
Here, we report a gamma-spectroscopy measurement of 35Ar with the aim of observing gamma decay from states above the proton-emission threshold. This experiment was conducted at Argonne National Laboratory's ATLAS facility. States in 35Ar were populated via the 9Be(28Si,2n)35Ar fusion-evaporation reaction. The excited states decay via the emission of gamma rays, which are detected using Gammasphere, in coincidence with the recoils at the focal plane of the Fragment Mass Analyzer (FMA).
This measurement represents the first observation of gamma-decays from states above the proton threshold in 35Ar and led to more precise measurements of the resonance energies of the key states. The gamma-decay branches enable restrictions to be placed on the spin-parity quantum numbers. Further refinements to the spin-parity assignments can be made using mirror symmetry arguments and the measured angular distributions of gamma-rays from the mirror nuclei, 35Cl. This represents an important step to determining the 34g,mCl(p,γ)35Ar reaction rate and the 34S/32S isotopic ratio in novae.

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The APEX Experiment; a dark matter search at Jefferson Lab Hall A
Oliver Jevons

Hadron, April 5, 2023, 14:00 - 15:00

The A Prime (A’) Experiment was a search performed at Hall A of the Thomas Jefferson National Accelerator Facility (Jefferson Lab, or JLab), looking for evidence of a dark vector gauge boson (also called a ‘dark photon’). The dark photon of interest, denoted as A’, is theorised to interact with the Standard Model through kinematic mixing, which is characterised by a strength parameter, ε. In February 2019, JLab’s Hall A was host to the APEX experiment, which recorded e+e- production from a 2.138 GeV electron beam incident on a tungsten target. A blinded peak search was performed on 10% of the data, which did not find any evidence of the A’ within the mass range 130 − 220 MeV, and established the strongest limits on A’ production within this range. A final peak search on the full APEX data set is currently underway, and final results are expected in the near future.

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Lifetime measurements of exotic nuclei with the nu-ball2 spectrometer

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Astro, April 5, 2023, 14:00 - 15:00

The nuclear chart comprises approximately 3000 nuclei, summarizing the limits of experimentally known nuclei. For many of them, especially those located close to the drip lines, detailed spectroscopic information is missing, most of the time only the energies of the lowlying states are known. Lifetimes, known to be some of the most sensitive observables, are usually unavailable due to the low production yields of such exotic isotopes, resulting in lowstatistics spectra. In order to extend the experimental information and constrain the available theoretical models, a better knowledge of these properties is needed, especially on the neutron-rich side.

To address this issue, a dedicated fission experiment has been performed, having the advantage of populating some nuclei with exotic combinations of protons and neutrons with high yields. Preliminary results of the n-ball2 N-SI-120 238U fast-neutron-induced fission experiment will be presented. The neutron beam was produced by the LICORNE source [1] in an inverse kinematics reaction with a pulsed 7
Li beam delivered by the ALTO Tandem
accelerator, incident on an H2 gas cell. The resulting neutron beam with an average energy of about 2 MeV induced fissions on the 238U secondary target. The emitted g rays were detected by the hybrid high-efficiency n-ball2 array comprising 24 clover detectors and 20 UK FATIMA LaBr3(Ce) scintillators.

The combination of such detectors is well suited for lifetime measurements using the fasttiming technique [2,3]. This method uses the fast response of the LaBr3(Ce) detectors to measure time differences between gamma rays populating and depopulating the level of interest. This way, lifetimes as short as several tens of picoseconds [4] can be measured for the excited states of these exotic nuclei. An overview of the experiment will be reported

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Exploring Neutron stars EoS with coherent π0 π0 photoproduction at A2@MAMI

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Hadron, April 5, 2023, 14:00 - 15:00

Recent measurement of coherent π0 photoproduction on Pb lead to one of the most accurate determinations of the neutron skin [1], constraining nuclear matter Equation of State (EoS) at around ρ~1ρ0. A natural next step is elucidating the nuclear EoS at higher densities to tune our understanding of the most violent process in the Universe - neutron stars mergers. It was demonstrated that at densities above ~3ρ0 dibaryonic degrees of freedom come into play [2]. The work presented in this talk is aiming to improve our knowledge of dibaryon behavior in dense nuclear matter by measuring coherent π0π0 photoproduction off Ca-40/48 nuclei. The experiment was performed at the A2@MAMI facility in Mainz (Germany). The goal of the analysis is to identify the first genuine hexaquark, the d*(2380), photoproduction on nuclei. We are expecting to determine the medium modifications of the d*(2380) in nuclear matter and constrain its couplings [3]. These new results will further improve our understanding of the neutron stars equation of state and allow precise determination of the maximum neutron star mass as well as provide key ingredients for calculation of the neutron stars merger dynamics. Also, an interplay between the hexaquark, quark-gluon and hyperon degrees of freedom in the EoS of a dense nuclear matter will be discussed. The effective coupling constants obtained in this experiment can further constrain the possibility of hexaquark condensate dark matter [4].

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Kink in Mean-square Charge Radii of Tl Isotopes Studied by In-source Laser Spectroscopy

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Nuclear structure III, April 5, 2023, 15:30 - 17:00

It is well-known that there is a kink in nuclear charge radii when the neutron number crosses a magic number[1]. This phenomenon has been observed in the Pb (Z=82) [2], Bi (Z=83) [3], and very recently, Hg (Z=80) [4] isotopes when crossing N=126 along their isotopic chain. However, the charge radii of Tl (Z=81) isotopes are only known up to 208Tl (N=127). In order to determine whether such a kink is present in the Tl isotopic chain, at least one more isotope needs to be measured to differentiate it from usual odd-even staggering in charge radii, where an odd-N isotope has a smaller charge radius than the average of its two even-N neighbours. In this contribution, I will present the results from a laser spectroscopy study of 205-209Tl (N=124-128) isotopes. Laser spectroscopy is a powerful tool for measuring electromagnetic moments and change in charge radii of exotic nuclides. During the April 2022 experiment at ISOLDE, a combination of Resonance Ionization Laser Ion Source (RILIS) and ISOLDE Decay Station was used to measure the isotope shift and hyperfine structure of neutron-rich Tl isotopes, the study of which is usually hampered by strong, isobaric Fr contaminants. The RILIS in Laser Ion Source Trap (LIST) mode was applied to suppress such contaminations. The results establish a kink in the charge radii of Tl isotopes when crossing N=126, as well as providing the first measurements of the magnetic moments and charge radii of the 11/2- isomeric state of 207Tl and the 1/2+ ground state of 209Tl

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Coulomb Excitation in 96Mo

Reuben Russell[1], Jack Henderson[1], Jacob Heery[1], Calem Hoffman[2], Tobias Beck[3], Peter Farris[3], Alexandra Gade[3], Stephen Gillespie[3], Ava Hill[3], Stanimir Kisyov[4], Anthony Kuchera[5], Claus Muller-Gatermann[2], Elizabeth Rubino[3], Roy Salinas[3], Andrew Sanchez[3], Ching-Yen Wu[4], Jin Wu[3]
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Nuclear structure III, April 5, 2023, 15:30 - 17:00

Nuclear shape change is a feature of nuclei in the region of N=60. The shape change has been observed to be abrupt for Zr and Sr isotopes, but for Molybdenum nuclei it has been found to be more gradual. Contributing to the steady evolution is the role of shape mixing between the nominally spherical and deformed configurations. Therefore, to be able to explore this effect in Mo, the ground state shape of the nucleus before state mixing becomes a major contributing factor must be ascertained for use as a baseline. Molybdenum-96 is the last member of the isotropic chain for which shape mixing is unlikely to contribute to the ground state deformation. For this reason, it is well placed to act as the baseline to study the shape change at N=60 for Mo. Coulomb excitation was carried out on 96Mo using a 196Pt target in the Janus setup at NSCL. From the data obtained in the experiment, information such as the electric quadrupole moment of the first 2+ state can be extracted. The first results from this experiment will be presented in this work.

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Coulomb excitation of 166Er and 150Nd: Results from the recent CHICO2 campaign at Argonne National Laboratory

Dr Jacob Heery[1], Dr Jack Henderson[1], Dr Stanimir Kisyov[2], Dr Ching-Yen Wu[2], Professor Akaa Daniel Ayangeakaa[7], Dr Laetitia Canete[1], Dr Scott Carmichael[3], Dr Mike Carpenter[3], Professor Wilton Catford[1], Dr Patrick Copp[3], Chris Cousins[1], Dr Matt Devlin[6], Dr Daniel Doherty[1], Dr Liam Gaffney[10], Professor Paul Garret[8], Dr Kasia Hadyńska-Klęk[9], Dr Heshani Jayatissa[3], Dr Filip Kondev[3], Professor Daniel Lascar[5], Dr Torben Lauritsen[3], Professor Gavin Lotay[1], Dr Claus Müller-Gatermann[3], Dr Soumen Nandi[3], Connor O'Shea[1], Dr Sorin Pascu[1], Charlie Paxman[1], Ben Reed[1], Professor Patrick Regan[1], Dr Walter Reviol[3], Dr Elizabeth Rubino[4], Reuben Russell[1], Dr Darek Seweryniak[3], Dr Marco Siciliano[3], Dr Gemma Wilson[3], Dr Kasia Wrzosek-Lipska[9]
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Neodymium-150 and Erbium-166, lie in a region of the nuclear landscape in which dramatic changes are known to take place. Of interest is the quantification of the evolution of both quadrupole and octupole degrees of freedom around Z = 60, N = 90 in 150Nd, and a comparison to state-of-the-art Monte-Carlo shell-model calculations of the (assumed) strongly axially deformed 166Er [1, 2].

This presentation reports on recent Coulomb-excitation measurements performed at Argonne National Laboratory on 150Nd, 166Er. The experiments utilised the coupled CHICO2 and GRETINA arrays to observe γ rays emitted in coincidence with scattered projectile-target events. Beams of 58Ni and 92Mo were impinged onto a 166Er target. Beams of 150Nd and 166Er were impinged onto a 208Pb target. GOSIA calculations were used to obtain yields for γ rays emitted in the de-excitation of nuclear states populated through Coulomb excitation. A χ
2
minimisation was performed to obtain reduced transition probabilities (B(E2) and B(E3)) and spectroscopic quadrupole moments (Qs) for each beam-target combination.

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Polarisation Observables from Strangeness Photoproduction on a Polarised Target at Jefferson Lab

Dr Stuart Fegan
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Hadron II, April 5, 2023, 15:30 - 17:00

The FROST experiment at Jefferson Lab used the CLAS detector in Hall B with the intention of performing a complete and over-determined measurement of the polarisation observables associated with strangeness photoproduction, as part of a program of similar experiments at JLab. This was achieved by utilising the FROST polarised target in conjunction with polarised photon beams, allowing direct measurement of beam-target observables.

Although sufficient observables have now been measured to enable the associated reaction amplitudes to be determined, facilitating a near model-independent partial wave analysis, global data in strangeness channels is a couple of orders of magnitude smaller than pion photoproduction, so some ambiguities remain. These can be resolved by measuring observables spanning combinations of beam, target and recoil polarisation. Furthermore, the recent revision to the value of the weak decay parameter makes a wider range of observable measurements even more desirable as a cross-check of interpretations of previous data. Studies on strangeness photoproduction reactions may provide evidence of previously undetermined resonances, due to the different coupling strengths of these states to other reaction channels.

The G polarisation observable is one of the beam-target double polarisation observables, associated with a longitudinally polarised target and a linearly polarised photon beam, and its measurement for the strangeness reaction γp → K+Λ is the focus of the work presented. Prospects for measuring target-recoil observables on this data and extending the analysis to incorporate the similar γp → K+Σ0 reaction will also be discussed.

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Towards the Discovery of First Strange Hexaquark with CLAS12

Mr Geraint Clash[1], Dr Mikhail Bashkanov[1]
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Hadron II, April 5, 2023, 15:30 - 17:00

Quantum Chromo Dynamics (QCD) is our current best description of interactions between quarks and gluons. It not only predicts the existence of the well understood mesons (two-quark) and baryons (three-quark) it also predicts exotic Tetra, Penta and Hexaquark states.
Experiments taking place at Thomas Jefferson Lab in Virginia, USA using the upgraded CLAS12 detector system allows a detailed investigation of exotic hadron states. In our experiment electrons accelerated to an energy of 10.6 GeV scatter off either a liquid hydrogen or liquid deuterium target. Various interesting effects can be explored in these reactions, including production of exotic hadrons, such as hybrids, pentaquarks or hexaquarks, the latter being the subject of this research.
This talk will present the analysis of data recently collected at CLAS12, which provides the first search for the ds hexaquark, a particle with quark content uuudds or uuddds with the most promising decay channel is expected to be ed→e’K+ds→ e’K+"Λ" n. The results of the analysis were benchmarked utilizing more conventional reactions. First results on a ds search will be presented, through the lens of polarization of the Lambda. From theory and the analogous d* → pn reaction, we know that a peak in polarization should be seen at the mass of the ds. The polarization measurement will be benchmarked with independent measurements of the "ep→" "e" ^"'" "K" ^"+" "Λ" reaction.
Our experimental studies will be confronted with state-of-the-art theoretical calculations on ds branching ratios and partial widths. It will be demonstrated that the expected ds width is well within measuring capabilities of the CLAS12 setup, regardless of the nature of the ds dibaryon (hexaquark or molecular). It will be shown that precise knowledge of the ds mass and width constrains its internal structure.

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Isomeric structures in 250Fm

Mr Jamie Chadderton[1], Daniel Cox[1], Philippos Papadakis[2], Rolf-Dietmar Herzberg[1], Tom Calverley[1], Paul Greenlees[2], Dieter Ackerman[3], M. Airiau[4], Kalle Auranen[2], Hussam Badran[1], R. Brislet[4], Peter Butler[1], A. Drouart[4], Toumas Grahn[2], Karl Hauschild[5], Andrej Herzan[2], F.P. Hessberger[3], Ulrika Jakobsson[2], Daniel Judson[1], Rauno Julin[2], S. Juutinen[2], Matti Leino[2], Araceli Lopez-Martens[5], Joonas Konki[2], Andrew Mistry[1], G. O'Neill[1], Janne Pakarinen[2], Eddie Parr[1], Jani Partanen[2], P. Peura[2], Panu Rahkila[2], Panu Ruotsalainen[2], Mikael Sandzelius[2], Jan Saren[2], Catherine Scholey[2], L. Sinclair[6], Juha Sorri[2], Sanna Stolze[2], B. Sulignano[4], Christophe Theisen[4], Juha Uusitalo[2], Martin Venhart[7], Andrew Ward[1]

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Nuclear structure III, April 5, 2023, 15:30 - 17:00

In 2016, the S20 experiment was performed at the University of Jyväskylä, utilising the established JUROGAM and RITU [1] setup in conjunction with the SAGE electron spectrometer [2], to produce the isotope 250Fm in the 204HgS(48Ca, 2n)250Fm fusion-evaporation reaction with a beam energy of 209 MeV. 250Fm has been previously studied at Jyväskylä [3,4] and has been observed to exhibit a rotational structure based on the isomeric state Kπ=8- with a half-life of 1.92(5) µs. Another isomer, with a half-life of 8(2) µs, has been suggested [5], however its configuration remains undetermined. The primary objective of this experiment was to further study the rotational structure of the Kπ=8- isomer first identified by Ghiosoro et al [6], and to unambiguously assign its configuration by implementing the recoil-electron tagging capability of SAGE, through the measurement of highly converted, low energy M1 transitions. Secondly, the goal was to determine the configuration of the suggested short-lived isomer, and study the states that feed into it. Analysis of the short-lived isomer is expected to provide greater understanding of two-quasiparticle excitations in heavy elements and the regional systematics of these excitations. This information can be used to determine various collective properties of the nucleus, such as the moment of inertia and quadrupole moment, and evaluate the validity of theoretical models, providing a greater understanding of the properties of heavy elements leading to the island of stability [7]. Work on the S20 dataset has recently commenced and is ongoing, experimental methods and the status of the analysis will be presented.

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Kinematic Fitting of Deep Inelastic Scattering measurements with ePIC at the Electron Ion Collider

Stephen Maple[1], Professor Paul Newman[1]
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Hadron II, April 5, 2023, 15:30 - 17:00

Deep Inelastic Scattering (DIS) measurements can be used to obtain many underlying physics quantities. The inclusive physics program at the future Electron Ion Collider (EIC) [1] will use such measurements to obtain proton, neutron, and nuclear Parton Distribution Functions (PDFs). A precise reconstruction of the kinematic variables x, y, Q2
is essential for
these physics goals.
Conventional reconstruction methods usually rely on two of the four measured quantities (energy and angle of the scattered electron and hadronic final state) with the resolution of these methods depending on the kinematic regime under study, detector performance, and initial-state photon radiation. A kinematic fit using all measured quantities can fully exploit the available information to obtain a best estimate of the kinematic variables, as well as the energy of any initial state radiation.
For the presented work, a technique applying a Bayesian method with suitable priors has been applied to fully simulated inclusive neutral current EIC data in the context of the planned ePIC detector. The performance of the kinematic fitting method is compared with conventional methods. The impact of the precise kinematic reconstruction on the physics output of the experiment is explored.
Measured quantities from ePIC can be obtained from either the tracking detector, calorimeters, or a combination of both. The quality of reconstruction using both conventional reconstruction methods and the kinematic fit depend on the absolute performance of these detectors, accuracy of particle identification, and the combination of detector information. Dedicated R&D to further optimise ePIC's detector subsystems, as well as the development of electron finding and particle flow algorithms present opportunities improve and assess the impact of ePIC within the inclusive physics program.

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Measuring neutron polarisation in pn production using CLAS

William Booth[1], Dr Nicholas Zachariou[1], Prof Daniel Watts[1], Dr Mikhail Bashkanov[1]
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Hadron II, April 5, 2023, 15:30 - 17:00

The existence of hexaquark states has far-reaching consequences, such as our understanding of quark structure, and the mechanisms involved inside neutron stars[1]. Predicted in 1964[2], and recently discovered, the simplest non-trivial hexaquark, is the d*(2380), an “excited deuteron” state. The deuteron, comprised of a proton and neutron, can be excited to this state during deuteron photo-disintigration reactions with high photon energies (Eγ ~500-600 MeV). Several other bound/quasibound N-N* dibaryonic states can also be studied in this reaction. Unfortunately, the world dataset of deuteron photo-disintegration has significant gaps in terms of photon energy and angular coverage, particularly in measurements of polarisation observables. To address this problem, we have utilised experimental data from the CEBAF large acceptance spectrometer (CLAS) in a unique way.
CLAS was a many-component detector housed in Hall B of Jefferson Lab, a world leading international facility. One such component, the start counter, consisting of a set of thin plastic scintillators surrounding the beamline, was used to determine the start time of an event originating in the target via photo-induced reactions. A novel approach that exploits the start counter as a nucleon polarimeter is implemented by this project. We will show analysis that has led to measurements of neutron induced polarisation by circularly polarised photons in deuteron photodisintegration for beam energies of 0.6 to 2.2 GeV, making use of CLAS’s wide angular range, covering N-N* reaction dynamics in second and third resonance regions, and providing exciting new insights into hexaquark studies.

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Probing the strange meson spectrum via the analysis of photoproduction reaction $\gamma p \longrightarrow K^+K^-\gamma \gamma p$ at the GlueX experiment

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Hadron II, April 5, 2023, 15:30 - 17:00

The GlueX experiment at Jefferson Lab studies the hadron spectrum via photoproduction off an LH2 target. One of the experiment's primary goals is to study hybrid meson candidates -- mesons that could possess an additional gluonic degree of freedom. This talk gives an update on the analysis for the reaction channel γp → K+K-γγp, looking in particular at the excited ϕ meson state ϕ(1850) and the hybrid meson candidate Y(2175) in the strange region of the meson spectrum.

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Combined γ-ray and conversion electron spectroscopy of 186Pb employing the SAGE spectrometer

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Nuclear structure III, April 5, 2023, 15:30 - 17:00

Shape coexistence is a phenomenon in which the same nuclei can possess different macroscopic shapes. A unique triplet of 0+ states has been observed in the α-decay study for 186Pb [1]. These 0+ states are associated with spherical, prolate and oblate shapes. The in-beam γ-ray spectroscopy experiments have shown collective bands built upon these 0+ deformed states [2; 3]. However, E0 transitions cannot be detected in γ-ray spectroscopy which proceeds primarily through internal conversion. These transitions are typically present in nuclei featuring shape coexistence.
Simultaneous conversion electron and γ-ray studies for 186Pb have been conducted exploiting the SAGE spectrometer [4] and the recoil-decay tagging technique, employing a 106Pd(83Kr,3n)186Pb fusion-evaporation reaction. The experiment was performed at the Accelerator Laboratory of the University of Jyväskylä.
Direct feeding of the first excited 0+ state was observed in this experiment. This observed feeding allowed us to reassign the shapes of the excited 0+ states in the 186Pb. Also, the 0+->0+ transitions from the excited 0+ states to the ground state, the E0 transitions of the 2+->2+ and the 4+->4+ interband transitions were observed. The E0 interband transitions showed a rather weak mixing between deformed structures. These results have been published in Communication Physics [5].

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Elucidating Exotics with Strangeness scaling behaviour
<u>Matthew Nicol</u>

Hadron II, April 5, 2023, 15:30 - 17:00

The vast quantity and variety of information that can be extracted from scaling behaviours has always attracted physicists. The internal structure of baryons and mesons was one of the first things explored by scaling behaviours. Studies have been performed to investigate the scaling behaviour of strange production off protons and deuterons in order to try and tackle new exotic states. Strangeness was first observed in the 40s, yet over half a century later, there is still much left to understand and discover. For example, every N* state should have a corresponding Δ, Λ, Ω, two Σ and Ξ states. However, as of 2020, there are 21 N*, 12Δ (9 missing), 9Σ (33 missing), 14Λ (7 missing), 6Ξ (36 missing), and 2Ω (19 missing) states with three- or four-star significance in the particle data group. As strange particles have a fairly narrow width and large abundance one can investigate molecular and multiquark states in detail, making hyperon physics an ideal ground to search for exotics. The majority of conventional strangeness production reactions, like in-flight kaon production, have very similar dynamics on protons and neutrons, however, some exotic strange processes are expected to be proto- or neutro-phobic leading to peculiar scaling behaviour.

This talk will present the world's first scaling behaviour measurements for the single-, double-, and triple-strange systems for both single baryon and di-baryonic objects. A novel technique was developed aimed at identifying possible energy regimes where strange exotic production is enhanced. The data used for this study was produced using a high intensity 12 GeV electron beam and hydrogen/deuterium targets with hermetic CLAS12 detector at Jefferson Laboratory. As we go down in strangeness, a large suppression in the production cross section is observed, in agreement with theoretical predictions. Initial constraints have been placed on possible exotics in the di-baryonic systems. First results for the meson-baryon exotic studies look very encouraging.

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Laser assisted decay spectroscopy of 178Au at the ISOLDE Decay Station, CERN

Christopher Page[1]

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Nuclear structure III, April 5, 2023, 15:30 - 17:00

In the region around the Z=82 shell closure and the N = 104 midshell, competition between spherical and deformed configurations leads to the phenomenon of shape coexistence [1]. Previous work (e.g. [2]) has sought to understand the properties of isotopes of platinum (Z=78) and gold (Z=79) to establish the extent to which such competition dictates their structures. A recent in-source laser-spectroscopy study [3] has shown that 178Au has two well-deformed states – a low-spin ground state and a high-spin isomeric state.
In August 2021, a decay spectroscopy experiment was performed [4] at the ISOLDE Decay Station (IDS) with isomerically pure beams of 178Au provided by RILIS. The isomerically selective separation and high beam intensities available at ISOLDE, combined with the detection efficiency of IDS have allowed many new states to be identified within the α decay daughter of 178Au, 174Ir, and the β+/EC daughter of 178Au, 178Pt.
In this contribution, I will summarise the experimental techniques used to collect these data and present the preliminary decay schemes of the two states of 178Au. An update on the status of an extensive upgrade to IDS that is currently underway will also be given. This upgrade will increase the number of HPGe clover detectors at IDS from 6 to 15, paving the way for more detailed spectroscopic studies by increasing detection efficiency and allowing for angular correlation measurements. The upgrade also includes improved fast timing, neutron time of flight and conversion electron detection as well as the addition of a second decay chamber for the study of daughter nuclei.

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Keynote I: Long-range imaging of alpha emitters

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April 6, 2023, 09:00 - 09:15

Alpha particles are harmful to humans. If ingested, inhaled or injected into the body, they can cause cell damage and even cancer. Alpha particles can only travel a few centimeters in air, and thus they are hard to detect. Current detection methods are labour and time consuming due to the close proximity required to detect alpha particles. Personnel are therefore put at risk of contamination and dose uptake.
Alpha particles can ionize surrounding molecules and generate low energy secondary electrons when they travel though air. Those electrons can excite surrounding air molecules (mainly nitrogen) to a higher energy stage. When those molecules de-excite, they will emit photons. This phenomenon is called Alpha Radio-luminescence (RL). These photons can be used to determine the position of the alpha emitters at long distance.
A High-sensitive CCD camera combined with UV fused silica lenses and filters was used to detect the photons from alpha RL. Our result showed the ability to detect a 29kBq Am-241 alpha source (from a smoke detector pellet) at meters in minutes in dark environment.

With careful selection of filters, it is also possible to image alpha emitters under artificial ambient light conditions. The main emission of alpha RL is 337 nm. We used a combination of 337 nm band-pass filters and demonstrated the ability to detect a 3 MBq alpha source at 5 meters under room light.
The next challenge is detecting alpha emitters under sunlight. The sunlight intensity in 300nm-400nm is much higher than the signal from alpha RL. Therefore, it is impossible to image alpha RL directly under sunlight without filters. Sunlight below 280 nm is absorbed by the atmosphere providing a spectral window for outdoor alpha detection, this region is also called solar-blind region. However, high blocking rate solar-blind filters is hard to find. We are going to update our detection system with suitable cameras and filters to image alpha RL under sunlight. We are also designing new lens systems which would improve the detection efficiency by tens of times.
Finally, we are going to develop a prototype with detector, portal power supply and minicomputer. The system will be light-weighted and easy to deploy. It will have great application prospects in areas like nuclear forensics and decommissioning.

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Keynote II: Quasi-free scattering reactions along the calcium isotopic chain

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April 6, 2023, 09:15 - 09:30

Several properties of atomic nuclei are known to be sensitive to the neutron-to-proton (isospin) asymmetry. In particular, the evolution of the single-particle strength as a function of isospin has been the subject of experimental and theoretical debate.
Quasi-free scattering reaction is an established method to probe the structure of atomic nuclei. This reaction in inverse kinematics using radioactive-ion beams at relativistic energies has been successfully employed as an effective tool to study very exotic nuclei with high luminosity. Recent studies [1, 2] reported on the evolution of the proton single-particle strength as a function of isospin asymmetry using (p,2p) quasi-free scattering reactions along the Oxygen isotopic chain and found a weak or no dependence. This result is at variance with nucleonremoval reactions [3] where they report a single-particle strength that is strongly correlated with isospin. The reduction of the single-particle strength has been attributed to nucleonnucleon correlations and a recent phenomenological study [4] has quantified the long and short-range part of these correlations and their dependency with isospin.
To shed light on this puzzle, we performed a systematic study of (p,2p) and (p,pn) cross sections along the calcium isotopic chain (from 39
Ca to 50
Ca) at 500 MeV/nucleon. The
experiment was performed with the large acceptance spectrometer GLAD with the R3B setup at GSI-FAIR. The results of the analysis and comparison to the theoretical calculations will be discussed in this contribution.

Keynote III: A first look at the extraction of a Time-Like Compton Scattering signal from recent data-taking with the CLAS12 detector at Jefferson Lab

Kayleigh Gates[1], Dr Daria Sokhan[1,2], Dr Rachel Montgomery[1], The CLAS Collaboration
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April 6, 2023, 09:30 - 09:45

Time-Like Compton Scattering (TCS) is a hard, exclusive scattering process, wherein a real photon scatters from a nucleon, producing a virtual photon, which decays to a lepton pair in the final state. Studies of TCS observables are used to broaden our understanding of Generalised Parton Distributions (GPDs) which can offer insights into the internal structure of the nucleon.

The photo-production of a highly virtual photon is dominated by the Bethe Heitler (BH) process, which has the same final state as TCS, but where the final state photon is emitted from the incoming or scattered lepton and therefore does not probe nucleon structure in the GPD formalism. BH interferes with the TCS signal at the amplitude level, thus the crosssection measured has contributions from pure TCS, pure BH and their interference. In order to distinguish the processes and access GPD observables, polarisation asymmetries can be extracted, which enhance the contribution of the interference term.

To this end, data has, and is still currently being taken with the CLAS12 detector at Jefferson Laboratory, with a range of polarization configurations, which can allow access to different TCS observables. I will be presenting a first look at extracting a TCS signal with this data.

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Keynote IV: Structure of A=22 analogue states revealed through mirrored-transfer

Jack Henderson[1], Philip Adsley[2], Jacob Heery[1], Greg Hackman[3], Barry Davids[3], Reuben Russell[1]
[1]*University of Surrey, , United Kingdom,* [2]*Texas A&M University, , United States of America,* [3]*TRIUMF, , Canada*

April 6, 2023, 09:45 - 10:00

The isospin formalism describes protons and neutrons as two projections of the nucleon and provides a powerful tool for identifying and classifying states in the vicinity of the line of N = Z. Under the assumption that isospin is a good quantum number, a number of relations arise to describe isobaric analogue states their properties. This provides access wealth of information, from tests of the isospin-symmetry conserving nature of the nuclear interaction, to applications in nuclear astrophysics. In truth, however, this assumption is known to be false, broken by the Coulomb interaction and components of the nucleon-nucleon interaction.
Here, we employ mirrored transfer reactions using beams of radioactive 21Na and stable 21Ne delivered by the ISAC-II facility at TRIUMF. These are used to populate isobaric analogue states in 22Na and 22Ne, respectively, through (d,p). Making use of proton-γ coincidences, we are able to selectively probe the single-particle nature of individual states, and probe their isospin purity. I will present initial findings, focusing on the role of isospin mixing in 2+ states through single-particle transfer, as well as future directions involving (d,n) data taken simultaneously to the (d,p).

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Keynote V: The Search for Proton Emitting Isotopes near the N=82 Shell Closure

Mr Adam McCarter[1], David Joss[1], Robert Page[1], Juha Uusitalo[2], Andy Briscoe[2], Muneerah Al'Aqeel[4], Betool Alayed[1], Kalle Auranen[2], Hamid Ayatollahzadeh[3], George Beeton[3], Monika Birova[8], Ville Bogdanoff[2], James Cubiss[6], James Deary[3], Tuomas Grahn[2], Paul Greenlees[2], Andres Illana Sison[2], Henna Joukainen[2], Rauno Julin[2], Henri Jutila[2], James Keatings[3], Marc Labiche[7], Matti Leino[2], Jussi Louko[2], Minna Luoma[2], Shiyamjith Nathaniel[1], David O'Donnell[3], Joonas Ojala[2], Christopher Page[6], Janne Pakarinen[2], Philippos Papadakis[7], Adrian Montes Plaza[1,2], Panu Rahkila[2], Emmanuel Rey-herme[5], Jorge Romero[1,2], Panu Ruotsalainen[2], Jan Sarén[2], John Smith[3], Conor Sullivan[1], Holly Tann[1,2], Alvaro Tolosa Delgado[2], Eetu Uusikylä[2], Martin Venhart[8], Lorna Waring[1], George Zimba[2]
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April 6, 2023, 10:00 - 10:15

Proton radioactivity provides a unique probe of nuclear structure far from stability, and for odd-Z elements it is expected to be the decay mode that determines the limit of observability for these neutron deficient nuclei. Establishing these limits of observability and identifying the nuclear structure at these limits is a long-standing challenge in nuclear physics. The nuclei in the region of the nuclear chart bounded by the N=82 and Z=82 shell closures are ideal candidates for this study since their proximity to the shell closures and the presence of a few valence neutrons in high-j orbitals creates many multiparticle spin-trap isomers [1,2].
Research is ongoing to search for more isotopes and isomers in this region of the nuclear chart using the Mass Analysing Recoil Apparatus (MARA) mass separator [3] at the University of Jyväskylä in Finland. In this work the nuclei studied were produced by fusionevaporation reactions between a 58Ni beam and either a 102Pd or a 106Cd target. The products were then mass separated and implanted into a double-sided silicon strip detector (DSSD) surrounded by an array of germanium detectors, where their alpha, proton and gamma decays could be observed.

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Keynote VI: Onset of deformation in the neutron-rich krypton isotopes with the ISOLDE Solenoidal Spectrometer

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April 6, 2023, 10:45 - 11:00

In the A = 100 region, the dramatic shape change observed for Zr [1-3] and Sr [4-7] (Z = 40 and 38, respectively) is not present in Kr (Z = 36) isotopes [8-10]. The 2+1 energies and the B(E2; 2+1 → 0+1) values vary smoothly across the Kr isotopes but Sr and Zr isotopes display a large jump at N = 60, indicating a significant increase in the ground state deformation of these isotopes. The νg7/2 orbital is filled in the ground states of krypton isotopes around N = 59 and is thought to lower the energy of the πg9/2 orbital and help to drive deformation in this region.
Previous studies in this region have shown a smooth onset of deformation in Kr isotopes at N = 60 [9,10], and evidence of a new oblate structure coexisting with the prolate ground state [11]. Accurately predicting ground-state spins and parities of odd-mass isotopes in this region is challenging due to the large valence space, and lack of ESPE data and accurate shell-model interactions. The single-particle energy differences and spectroscopic factors extracted from neutron adding reactions will provide a more complete experimental picture of the underlying single-particle configurations, which will allow for comparison to modern shell-model calculations [12] that try to describe the onset of deformation around A = 100.
The evolution of neutron single-particle properties and their role in the onset of deformation towards N = 60 in the neutron-rich Kr isotopes has been studied via the one-neutron transfer reactions 92,94Kr(d,p). These were performed in inverse kinematics at an energy of 7.5 MeV/u using the ISOLDE Solenoidal Spectrometer at ISOLDE, CERN. The main goals are to determine the energy difference between the 2νs1/2 and 0νg7/2 orbitals below N = 60 using the 92,94Kr(d,p) reactions to identify the likely Δl = 4 transfer to the 7/2+ state. Preliminary results obtained in the October 2022 experiment will be presented.

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Keynote VII: Mapping Neutrino-Nuclei Interactions Using Electrons

Rhidian Williams[1]

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April 6, 2023, 11:00 - 11:15

Next generation neutrino facilities, such as DUNE, rely on precise modelling of neutrino induced hadron knockout processes from nuclei in the detector medium (e.g. Argon) to determine the initial (untagged) neutrino beam energy and determine the neutrino flux. However, uncertainty in the modelling of these nuclear interactions is currently the largest systematic uncertainty in extracting the key physics, including the neutrino oscillation parameters.

Within the e4nu collaboration at the Thomas Jefferson National Laboratory (JLab) we address this by studying the same knockout reactions exploited at neutrino facilities, but using incident electron beams of precisely determined energy (Up to 12 GeV). A range of hadron knockout reactions from light to heavy nuclear targets are determined with nearly complete acceptance by the CLAS12 spectrometer. This expansive data set will be used to benchmark nuclear calculations (GiBUU and GENIE) in the poorly constrained kinematic regime of DUNE and will directly affect the achievable accuracy for the key physics outputs of DUNE. Our current results, the first from e4nu at CLAS12, will be presented and implications for neutrino facilities discussed.

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Keynote VII: Systematic nuclear-DFT calculations of electromagnetic moments of proton 7/2+ and neutron 11/2- quasiparticle configurations in heavy deformed open-shell odd nuclei with 50 <= Z <= 64

Dr. Herlik Wibowo[1], Dr. David Muir[1], Dr. Adrián Sánchez-Fernández[1], Dr. Xuwei Sun[1], Prof. Jacek Dobaczewski[1,2]
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April 6, 2023, 11:15 - 11:30

The study of nuclear electromagnetic moments can provide detailed information on nuclear structure [1]. While the quadrupole moments serve as an excellent tool to probe nuclear deformation and collective behavior, the magnetic moments are significantly affected by the single-particle orbits of unpaired nucleons. The shell model [2] has been successfully applied to describe the experimental electromagnetic moments, albeit with the necessity to introduce the g-factors and effective charges in the dipole and quadrupole operators, respectively.
In our recent work [3,4], systematic calculations of the electric quadrupole and magnetic dipole moments were performed using the nuclear-density-functional-theory (nuclear-DFT).
The spectroscopic moments of angular-momentum-projected (AMP) wave functions were determined and compared with the available experimental data. It was shown that a good agreement with data can be achieved without the use of effective g-factors and charges. In the present contribution we consider triaxial deformations. As the triaxial deformations strongly modify the single-particle orbits, it is instructive to investigate its effects on nuclear magnetic moments. The nuclear magnetic dipole properties of ground and γ-vibrational bands in Dy and Er isotopic chains have been studied using the triaxial projected shell model [5]. The study has found that the g-factor ratio of the 2
+ state in ground bands to that of γ-bands varies as a
function of triaxiality. This result motivates us to investigate the effects of triaxial deformations on the properties of nuclear magnetic moments both for even-even and odd nuclei. Specifically, we perform systematic calculations of magnetic dipole and electric quadrupole moments for paired nuclear states associated with the proton (neutron) quasiparticles blocked in the 7/2
+ (11/2−) configurations of deformed open-shell odd nuclei shown in Fig. 1. The self-consistent shape and spin core polarizations are established in the self-consistent calculations based on the spherical and time-reversal symmetry breaking. Calculations are performed using code HFODD. To consider the triaxiality, we first perform the potential energy surface (PES) calculations (0 ≤ γ ≤ 180) in the gamma-unstable region around 126Ba nucleus. For the obtained triaxial shapes, we then determine the spectroscopic moments of the AMP wave functions.

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Plenary: Charge plunger technique for 222Th with multiple levels exhibiting internal conversion

Dr S Nara Singh Bondili[1]

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April 6, 2023, 15:30 - 16:00

Lifetime measurements in nuclei provide valuable information on transition strengths that can be used to deduce the magnitude of nuclear deformation. Investigations of nuclear shapes, particularly in heavy nuclei where not only quadrupole but also higher-order deformations play a significant role, can be used to improve our understanding of the strong nuclear interaction. Most of the techniques employed to measure lifetimes are based on the detection of γ rays. However, these methods are not suitable for some nuclei, especially those in the heavy-mass region on account of the conversion decays of excited states that compete with γ-ray emission. Therefore, as yet, there is quite limited information on the measurements of lifetimes in heavy nuclei. In these cases, the charge plunger technique (CPT) based on the detection of atoms in high charge states, following conversion decays of excited states in nuclei, is more appropriate. This method was successfully used nearly 40 years ago [1, 2]. Recently, using the MARA setup, the CPT was employed to measure the lifetimes of the 2+ states in 178,180Pt nuclei [3, 4]. The first excited state in 178,180Pt has a considerable conversion coefficient (α), while all the other excited states have insignificant internal conversion probabilities. The analysis technique was established, and the results for lifetimes are found to be consistent with the literature values and constitute an improvement in the precision in comparison to the previously reported values. Some of the most interesting physics cases in heavy nuclei are 223Th [5] and 254No [6], wherein several excited states decay primarily through internal conversion. To establish the feasibility of the CPT for these cases, and to determine from the experiment the magnitude of octupole deformation in the thorium region, an exploratory measurement has been performed for 222Th, wherein the low-lying states have significantly converted decays. In the case of 222Th, lifetimes for the 2+ and 4+ states are known [7], and it is expected that this measurement will help validate the CPT for heavy nuclei with multiple levels exhibiting internal conversion, in addition to providing insight on the magnitude of quadrupole and octupole deformations in 222Th. Preliminary results from this experiment will be presented at the conference.