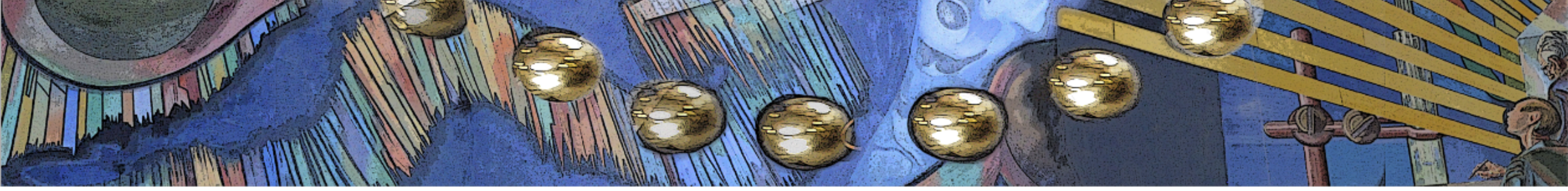

UiO **Department of Physics**
University of Oslo

Book of Abstracts

8th Workshop on Level Density and Gamma Strength, Oslo, 2022

	Monday	Tuesday	Wednesday	Thursday	Friday
	08:30 Registration and coffee	08:30 Coffee	08:30 Coffee	08:30 Coffee	08:30 Coffee
1st	Chair : Sunniva Siem	Chair : Magne Guttormsen	Chair :	Chair :	
	09:00 Welcome: Dean Kristensen	09:00 Kamila Sieja	09:00 Fabio Crespi	09:00 Dennis Mücher	Chair : Ann-Cecilie Larsen
	09:40 Peter von Neumann-Cosel	09:30 Sijing Chen	09:30 Pär-Anders Söderström	09:30 Atsushi Tamii	09:30 Kgashane Malatji
	10:10 Francesco Pogliano	10:00 Maria Markova	10:00 Jon Wilson	10:00 Artemis Spyrou	10:00 Stephane Hilaire
	10:40 Wouter Ryssens	10:30 Joa Ljungvall	10:30 Kevin C. W. Li	10:30 Coffee	10:30 Takaharu Otsuka
	11:00 Coffee	11:00 Coffee	11:00 Coffee	11:00 Darren Bleuel	11:00 Coffee
2nd	Chair :	Chair :	Chair :	11:30 Joey Gordon	Chair :
	11:30 Mathis Wiedeking	11:30 Andrew Voyles	11:30 Lee Bernstein		11:30 Sven Åberg
	12:00 Duy Duc Dao	12:00 Catherine Apgar	12:00 Dorthea Gjestvang		12:00 Jacob Bekker
	12:20 Steven Grimes	12:20 Rei Niina	12:20 Sophie Peru		12:20 Corentin Hiver
	12:40 Gustavo Nobre	12:40 Stanislav Valenta	12:40 Mejdi Mogannam		12:40 Ina Kullmann
	13:00 Lunch	13:00 Lunch	13:00 Lunch		13:00 Lunch
3rd	Chair :	Chair :	Chair :		Chair :
	14:30 Johann Isaak	14:30 Sifundo Binda	14:30 Adriana Sweet	14:00 Guided tour starts in the Norsk Folkemuseum at 14:00. You can enter earlier by saying that you are "with the University of Oslo" and they will give you a ticket.	14:30 Isabelle Brandherm
	14:50 Armand Bahini	14:50 Tamás Belgya	14:50 Felix Heim		14:50 Oliver Papst
	15:10 Eleanor Ronning	15:10 Erin Good	15:10 Austin Abbott		15:10 Refilwe Molaeng
	15:30 Jørgen Randrup	15:30 Richard Firestone	15:30 Ingrid Knapova		15:30 Andrea Richard
	16:00 Coffee	15:50 Coffee	15:50 Coffee		15:50 Closing Talk + Coffee
	17:00 Poster session: Physics Building, Origo	16:15 Discussion: level densities	16:15 Discussion: γ-ray strength functions	17:30 Workshop Dinner: Frognerseteren	

Dipole polarizability of ^{40,48}Ca and implications for the symmetry energy and the formation of neutron skins

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The dipole polarizability of nuclei carries information on the density dependence of the symmetry energy governing the properties of the Equation of State of neutron-rich matter relevant to neutron stars and core-collapse supernovae. In recent years, zero-degree polarized proton scattering has been developed at RCNP as an experimental tool to measure the dipole polarizability [1]. Such data also provide constraints on the neutron skin thickness of heavy nuclei [2]. A recent study of 40Ca together with results from a previous experiment on 48Ca [3] serve as a test of state-of-the-art ab initio [4,5] and energy densitiy functional [6] calculations. From the good agreement obtained for both methods one can set limits on the density dependence of the symmetry energy and the neutron skin thickness. These are clearly at variance with those derived [7] from the recently published result of the PREX-II experiment [8].

Supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 279384907 - SFB 1245.

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Indirect measurement of the $(n,\gamma)^{127}$Sb cross section from experimental level density and γ-strength function

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Nuclei in the ^{135}I region have been identified as a possible bottleneck for the i process. Nuclear properties such as the Maxwellian-averaged cross section are indispensable tools when trying to explain nucleosynthetic processes, but the instability of the region prevents us from carrying out direct measurements. In order to investigate it, we propose an indirect approach.

At the Oslo Cyclotron Laboratory we carried out the $^{124}\mathrm{Sn}(\alpha, p\gamma)^{127}\mathrm{Sb}$ reaction in order to extract the nuclear level density and the γ ray strength function of ^{127}Sb using the Oslo method, with the aim to calculate the Maxwellian-averaged cross section and the neutron-capture rate of the A-1 nucleus ^{126}Sb.

The level density in the low excitation-energy region agrees well with known discrete levels, and the higher excitation-energy region follows an exponential curve compatible with the constant temperature model. The strength function between $E_\gamma \approx 1.5$-8.0 MeV presents several features, such as an upbend and a possibly double-peaked pygmy-like structure. None of the theoretical models included in the nuclear reaction code TALYS seem to reproduce the experimental data.

The Maxwellian-averaged cross section for the $^{126}\mathrm{Sb}(n,\gamma)^{127}\mathrm{Sb}$ reaction has been experimentally constrained by using our level-density and strength-function data as input to TALYS. The results show good agreement with the JINA REACLIB, TENDL and BRUSLIB libraries, while the ENDF/B-VIII.0 library predicts a significantly larger cross section.

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Nuclear level densities from 3D Brussels Skyrme models

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The description of nuclear reactions, whether earth-based or in astrophysical scenarios, relies on the availability of nuclear data across entirety of the Segré chart. An overwhelming amount of this data concerns unstable and highly exotic nuclei that are out of experimental reach, especially in the context of nucleosynthesis and the description of the rapid neutron capture process.

Models based on nuclear energy density functionals (EDFs) are well suited to respond to this situation: they offer a microscopic description of nuclear structure, but their application to thousands of nuclei remains computationally tractable. The BSk-family have shown that EDF-based models of the Skyrme type can achieve a state-of-the-art global description of nuclear binding energies and charge radii through the inclusion of all nuclear masses in the fitting protocol (See Ref. [1] and references therein).

We have recently developed the first members of the BSk**G** family: Skyrme EDF-based models with parameters adjusted along the BSk protocol, but employing the MOCCa code [2]. This tool solves the self-consistent mean-field equations for Skyrme EDFs on a three-dimensional coordinate grid and allows us to include exotic nuclear configurations beyond the usual assumptions of axial symmetry and time-reversal invariance. The first entry in the series, BSkG1, included the possibility of triaxial deformation. The most recent entry, BSkG2, offers for the first time a complete description of odd-mass and odd-odd nuclei including all polarisation effects by so-called time-odd terms [3].

We are currently in the process of completing the data that the BSkG models can provide to applications, through systematic investigation of quantities of interest beyond masses and radii, such as fission barriers and level densities. We will discuss in this contribution our efforts towards the latter: we will present early results of systematic calculations of nuclear level densities with the BSkG2 model using the combinatorial approach of Ref. [4]. Particular attention will be paid to both our treatment and possible effects of exotic shape degrees of freedom.

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Photon Strength Function Studies: Progress and Outlook

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Significant progress has been made in the study of photon strength functions (PSF) over the last few years. The nature of the so-called low-energy enhancement of the PSF is being unravelled. In addition, PSF and nuclear level density (NLD) measurements have provided unprecedented constraints on nucleosynthesis processes through much improved neutron capture cross sections. The successful development of novel experimental and analytical techniques now allows for the investigations of previously inaccessible nuclei and improved reliability of results.

In this presentation, I will review recent experimental and analytical developments to study PSFs and NLDs at radioactive and stable ion beam facilities with a particular focus on the inverse-Oslo [1] and the Shape methods [2]. The latter determines the functional form of the PSF and the slope of the NLD, which can be obtained simultaneously, even in the absence of neutron resonance spacing data.

I will further discuss the current understanding of the underlying nuclear structure responsible for the low-energy enhancement and will demonstrate the power of PSF and NLD measurements to constrain nucleosynthesis processes and astrophysical environments for the production of ^{180}Ta [3] and ^{138}La [4] p-nuclei. In light of the many new and improved experimental facilities and capabilities now available across the world, I will conclude by exploring prospects for future PSF measurements.

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Discrete Non-Orthogonal Shell Model: recent developments

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The major challenge in the Shell Model framework is the diagonalization of the effective (generally two-body) Hamiltonian in the model space [1]. Indeed, this is a huge task for open shell nuclei as the model space dimension grows combinatorially with the number of particles. In this talk, I will present my recent work aiming to tackle this problem in a different way using a discrete non-orthogonal basis [2]. The formal justification of such basis has been pointed out a long time ago in the context of the generator coordinate method (GCM). Based on this, the resulting Discrete Non-Orthogonal Shell Model (DNO-SM) is the merging of two important techniques: the diagonalization method borrowed from the GCM theory and the minimization technique originally proposed by E. Caurier which provides a natural and efficient truncation scheme of the non-orthogonal many-body basis used in the diagonalization process. To illustrate the method, several examples from light, medium mass to superheavy nuclei will be presented. Future developments for studying level densities and γ–strength functions will be discussed.

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Level densities and spin cutoff parameters

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A recent paper pointed out that the standard Hauser-Feshbach (HF) formalism should be modified if the nuclei are deformed. A major part of the modification involves recognizing that the spin distribution of the level densities no longer follows the traditional Bethe formula. The magnitude of the changes in level densities derived from level counting for s-wave neutrons will be discussed. In addition, a summary of effects expected if a nucleus looses its deformation at high energy will be presented. Finally, the modification to HF formula also changes the magnitude of isomeric ratios. This can affect spin cutoff parameters derived from isomeric ratios.

Constraining level densities through machine learning applied to neutron resonances

G. P. A. Nobre[1], D. A. Brown[1], S. J. Hollick[2], S. Scoville[3], P. Rodríguez[4,5], M. Fucci[6], S. Ruiz[7], R. Crawford[8], A. Coles[1], M. Vorabbi[1], M. McLaurin[9], K. Mbacke[10]

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Nuclear level densities (NLD) and gamma strength functions (GSF) are important components in the modeling of the evolution and formation of the different elements and their relative abundance, as well as in the development in reaction nuclear data evaluations. One of the few experimental information used to constrain such nuclear properties relate to measurements of resonance states seen in compound nuclei formed by neutron-induced reactions. Therefore, a proper and reliable account of all resonances is crucial for the description of nuclear reactions.

The Atlas of Neutron Resonances [1] is the most comprehensive compilation of experimental and evaluated neutron resonances in the literature. It provides details on their individual properties and general behavior, such as average widths and spacings, which serve as an important constraint on NLDs and GSFs. However, thorough investigation [2] has shown that the Atlas may contain typos, spin misclassifications, missing resonances, affecting values and uncertainties of NLD constraints. Also, many values listed on the Atlas do not carry enough provenance information to allow them to be checked and updated in a reproducible manner.

To address this, we developed a systematic and reproducible method of extracting resonance average spacings and widths based on linear and non-linear fits of gamma widths and cumulative resonance distributions taking into account resonance energy uncertainties. This can impact reference constraints for NLD and GSF across the nuclide chart and can lead to future updated recommendations of average-spacing values. This work also made evident that many resonance sequences from the Atlas are contaminated by missing resonances and/or resonances with incorrect spin assignments. We therefore developed a Machine-Learning approach [3] to, using statistical properties of resonance parametrizations, make predictions relative to spin classifications.

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Isomer population control via direct irradiation of solid-density targets using a laser-plasma accelerator

Robert Jacob, Lee Bernstein, Josh Brown, Tobias Ostermayr, Dieter Schneider, Carl Schroeder, Jeroen van Tilborg, Eric Esarey, Cameron Geddes

A small component of spent nuclear fuel is both highly radioactive and long-enough lived to require costly long-term storage.

Efforts to reduce these lifetimes through excitation into the quasicontinuum via nuclear-plasma interactions are underway. We present our results on using a hundred terawatt laser-plasma accelerator to excite Bromine and Yttrium nuclei through pulsed ultra-fast (<10 fs) direct irradiation of solid-density active targets. These targets undergo nuclear-plasma interactions through the absorption and emission of real and virtual 5-30 MeV photons. The resulting population of excited states provides a sensitive probe of gamma strength and level densities in the nuclear quasicontinuum. Further probing of these nuclear-plasma interactions could have far-reaching impact, such as assisting in the development of clean energy sources and developing our understanding of heavy element formation in stellar interiors.

Recent developments in photonuclear reaction studies with quasi-monochromatic photon beams

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Photons provide a particular clean probe to study a variety of nuclear structure phenomena [1]. Their interaction with the atomic nucleus is described by the electromagnetic interaction, so that the nuclear response can be separated almost model independently from the details of the reaction mechanism.

One of the quantities being investigated in photonuclear reactions for decades is the photon strength function (PSF). The PSF characterizes the average probability for the emission and absorption of photons by atomic nuclei. Stellar reaction rate calculations needed for the modeling of the nucleosynthesis of most heavy elements are usually performed within the Hauser-Feshbach formalism [2] which, amongst others, relies on the input from PSFs. Therefore, the systematic study of PSFs across the nuclear chart are an important testing ground to benchmark microscopic and macroscopic models that allow for the extrapolation from mostly stable isotopes to experimentally unreachable exotic neutron-rich isotopes.

Many different experimental approaches are used to investigate PSFs either by the study of photoabsorption cross sections or by the observation of the γ decay behavior of excited nuclear states [3]. In several cases, the results from complementary methods show discrepancies, in particular when comparing data from real-photon scattering and particle-induced reactions [4, 5].

In this contribution, recent developments and new experimental results obtained from photonuclear reaction studies with quasi-monochromatic photon beams at the High Intensity γ-ray Source [6] are discussed in view of contradictory data sets, partly resolving existing discrepancies.

This work is supported by the State of Hesse under grant "Nuclear Photonics" within the LOEWE program and by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 279384907 - SFB 1245.

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Isoscalar giant monopole resonance in ^{24}Mg and ^{28}Si: Effect of coupling between the isoscalar monopole and quadrupole strength

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Background: In highly deformed nuclei, there is a noticeable coupling of the Isoscalar Giant Monopole Resonance (ISGMR) and the $K = 0$ component of the Isoscalar Giant Quadrupole Resonance (ISGQR), which results in a double peak structure of the isoscalar monopole (IS0) strength (a narrow low-energy deformation-induced peak and a main broad ISGMR part). The energy of the narrow low-lying IS0 peak is sensitive to both the incompressibility modulus K_∞ and the coupling between IS0 and isoscalar quadrupole (IS2) strength.

Objective: This study aims to investigate the two-peaked structure of the ISGMR in the prolate ^{24}Mg and oblate ^{28}Si nuclei and identify among a variety of energy density functionals based on Skyrme parameterisations the one which best describes the experimental data. This will allow for conclusions regarding the nuclear incompressibility.

Methods: The ISGMR was excited in ^{24}Mg and ^{28}Si using α-particle inelastic scattering measurements acquired with an $E_\alpha = 196$ MeV beam at scattering angles $\theta_{\text{Lab}} = 0^\circ$ and 4°. The K600 magnetic spectrometer at iThemba LABS was used to detect and momentum analyse the inelastically scattered α particles. An experimental energy resolution of ≈ 70 keV (FWHM) was attained, revealing fine structure in the excitation-energy region of the ISGMR. The IS0 strength distributions in the nuclei studied were obtained with the Difference-of-Spectrum (DoS) technique. The theoretical comparison is based on the quasiparticle random-phase approximation (QRPA) with a representative set of Skyrme forces.

Results: IS0 strength distributions for ^{24}Mg and ^{28}Si are extracted and compared to previously published results from experiments with a lower energy resolution. With some exceptions, a reasonable agreement is obtained. The IS0 strength is found to be separated into a narrow structure at about $13-14$ MeV in ^{24}Mg, $17-19$ MeV in ^{28}Si and a broad structure at $19-26$ MeV in both nuclei. The data are compared with QRPA results. The results of the calculated characteristics of IS0 states demonstrate the strong IS0/IS2 coupling in strongly prolate ^{24}Mg and oblate ^{28}Si. The narrow IS0 peaks are shown to arise due to the deformation-induced IS0/IS2 coupling and strong collective effects. The best description of the IS0 data is obtained using the Skyrme force SkP$^\delta$ with an associated low nuclear incompressibility $K_\infty = 202$ MeV allowing for both the energy of the peak and integral IS0 strength in ^{24}Mg and ^{28}Si to be reproduced.

Total Absorption Spectroscopy of Ground and Isomeric States in ^{70}Cu

E. Ronning[1,2], A. Richard[1,3], S. Liddick[1,2], A. Spryou[1], I. Yandow[1], R. Ringle[1], A. Chester[1], K. Childers[4], P. Deyoung[5], J. Owens-Fryar[1], A. Hamaker[1], C. Harris[1], R. Lewis[1], K. Lund[1], S. Lyons[6], A. Palmisano[7], D. Puentes[1], R. Sandler[8], C. Sumithrarachchi[1], M. Wiedeking[9,10], Y. Xiao[11]

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[3] Lawrence Livermore National Laboratory, Livermore, CA USA
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[5] Hope College, Holland, MI USA
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Theoretical models of the rapid nucleosynthesis process (r-process) require knowledge of astrophysical neutron-capture reaction rates. The Brink-Axel hypothesis, which is one of the underlying assumptions involved in calculations of astrophysical reaction rates, states that the γ-ray strength function (γSF) is independent of the initial excitation energy and spin of nuclear states in the compound nucleus [1]. Previous works by [2, 3] have studied the excitation energy independence of the Brink-Axel hypothesis, but thus far the spin-independence remains untested. In this work, we test the spin-independence by using ^{70}Cu, which has three β-decaying states (a spin-parity 6^- ground state, and two isomeric states with spin-parity 3^-, and 1^+) and offers an opportunity to study the γSF over different spin ranges at similar excitation energies in a daughter nucleus[4]. At the National Superconducting Cyclotron Laboratory ^{70}Cu was produced, isolated by the Low-Energy Beam and Ion Trap (LEBIT)[5], and then delivered to the Summing NaI (SuN) Total Absorption Spectrometer [6]. Preliminary results from total absorption spectroscopy following the β-decay of each of the three β-decaying states will be presented. The data will be used in future β-Oslo analysis to obtain γSF and nuclear level densities and test the spin-independence of the Brink-Axel hypothesis.

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Abstract by Jorgen Randrup (with Thomas Dossing and Ramona Vogt):

Probing fission fragment spins with gamma correlation measurements

The treatment of the gamma cascades in the fission code FREYA has been significantly refined: The E1 and E2 transitions now occur between discrete quantum states and the helicity-dependent angular distributions are simulated. An important improvement is the inclusion of the recoils which may change the direction of the fragment spin and lead to distinct angular correlations between sequentially emitted gammas. A novel approximate treatment makes it possible to simulate the quantal cascades fast and reliably. The new capabilities are described and illustrative applications are presented, particularly some showing how suitable correlation measurements may reveal the directions of and mutual correlations between the fission fragment spins.

Shell model investigations of photoabsorption and photoemission strength functions

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In this talk I will adress some of the recent shell-model calculations of dipole strength functions:
1. The magnetic dipole de-excitation strength functions will be discussed in sd-pf, pf and gds nuclei. The persistence of shell effects in the quasi-continuum of nuclear states will be adressed as well as possible links between the shape of such strength functions at low energy and the nuclear deformation [1, 2].
2. The electric dipole photoabsorption strength functions will be discussed along the Ne chain where the pygmy-dipole resonances were observed [3]. The validity of the Brink-Axel hypothesis in the PDR region will be verified based on these calculations [4].

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Nuclear level densities and $\gamma-$ray strength functions of ^{120,124}Sn

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The concepts of the nuclear level density (NLD) and $\gamma-$ray strength function (GSF) are two essential tools in the statistical description of excited nuclei and their $\gamma-$decay, used not only in the basic nuclear physics research, but also in numerous large-scale astrophysical calculations of abundances of elements in the universe [1].

One of the widely used experimental techniques allowing simultaneous extraction of the NLD and GSF, the so-called Oslo method [2] was applied to the ^{120,124}Sn isotopes to extract these statistical quantities. The experimental GSFs were used to address the question on the validity of the generalised Brink-Axel hypothesis (gBA) [3, 4], used as a crucial assumption in the Oslo method and astrophysical calculations of neutron capture cross-sections based on the statistical model. In the most general form the hypothesis states an independence of the GSF of spins, parities and excitation energies of initial and final states and its dependence solely on the $\gamma-$ray energy. In order to asses the validity of the gBA hypothesis, the Oslo method GSFs were compared with the strengths extracted from the relativistic Coulomb excitation experiment [5], as well as the ground and the first excited state strengths obtained with the novel Shape method [6]. Additionally, the GSFs were studied as functions of initial and final excitation energies. The experimental NLDs of ^{120,124}Sn were used to estimate the values of the Porter-Thomas fluctuations [7] of these strengths, potentially hindering establishing of the validity of the gBA hypothesis. These fluctuations were also used to asses the applicability of the Shape method to the ^{120,124}Sn isotopes.

Comparison of the Oslo and Shape method GSFs with the Coulomb excitation data for both nuclei demonstrate a good agreement within the estimated error bars below the neutron separation energy. Moreover, the GSFs are shown to be on average independent of initial and final excitation energies. This suggests that the generalized BA hypothesis holds for the studied cases in this energy region, and experiments based on ground state photoabsorption provide the same information on GSFs as Oslo-type experiments. The estimated Porter-Thomas fluctuations support this conclusion and suggest a rather limited applicability range of the Shape method, providing reliable results for $\gamma-$ray energies above $\approx 5 - 5.5$ MeV for ^{120,124}Sn.

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A phase transition - or something else? A look at neutron deficient nuclei close to N=94

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Proton deficient nuclei around N=94 show the unusual feature of having a ratio B(E2;$4_1^+ \rightarrow 2_1^+$)/B(E2;$2_1^+ \rightarrow 0_1^+$)=$\mathrm{B}_{4/2}$ much smaller than one. This anomaly was first discovered in the neutron-deficient osmium isotopes [1] and later also found in tungsten [2, 3] and platinum istopes [4]. Such a behaviour is normally seen at closed shells where the seniority coupling scheme is valid. Therefore phase transition to a seniority like, i.e. where pairing dominating the dynamics of system, was proposed as an explanation to the phenomena by Cederwall et al. [4]. Another explanation is that γ-softness and triaxial shapes would at the origin of the anomaly [3].

Goasduff et al. [5] discuss the case of ^{170}Os showing the same low $B_{4/2}$ value as lighter osmium isotopes. The experiment was performed at the ALTO facility using the ORGAM HPGe detector array and the OUPS [6]. Although the setup had a very limited efficiency the lifetimes of the 2_1^+ and 4_1^+ were measured in gamma coincidences. The experimental results were compared to state of the art beyond-mean field calculations. Based on the Gogny D1S interaction it uses fully symmetry restored HFB states as a base for the generator coordinator method to calculate states of interest. Despite allowing triaxial states and including pairing in a self consistent way the calculations can not reproduce the small $B_{4/2}$ value suggesting that the proposed explanations [4, 3] are not the full story.

In an attempt to find clues to what is going we have proposed to redo the experiment, this time using the Nuball2 HPGe detector array, which will allow a large increase in the statistics. The Nuball2 array will consist of 24 HPHe Clover detectors and 15 coaxial HPGe detectors. We aim at measuring lifetimes higher up in the yrast band as well as in the negative parity band to probe higher order deformation. A pure spectroscopic study is also planned. The experiment will run end of March this year and I will present brand new results from this experiment.

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Investigating high-energy proton-induced reactions: Implications for level densities and the preequilibrium exciton model

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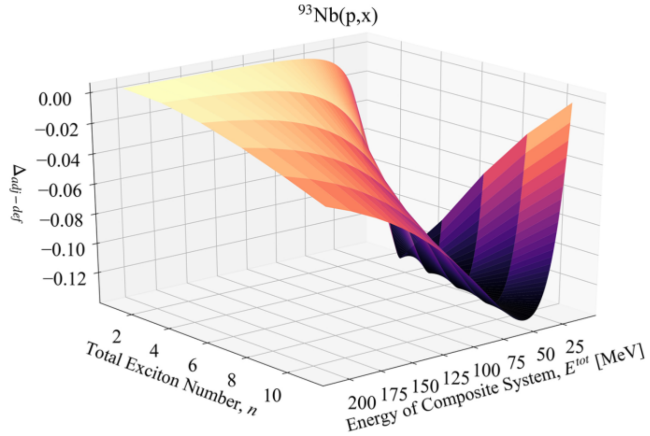
Multihundred MeV proton accelerators are promising sites for the large scale production of medical radionuclides due to the high production rates enabled by their high-intensity beam capabilities and the long range of high-energy protons. However, the ability to reliably conduct isotope production at these accelerators and model relevant (p,x) reactions in the 100–200 MeV range is hampered by a lack of measured data. The current suite of predictive reaction-modeling codes is only accurate to within approximately 20% for (p,x) and (n,x) reaction channels where a large body of experimental measurements currently exist. In cases where few data exist, these codes often exhibit discrepancies anywhere within a factor of 2–50. In order to address this deficiency, stacked-target irradiations were performed at LBNL, LANL, and BNL, measuring proton-induced reactions on niobium, arsenic, and lanthanum targets from threshold to 200 MeV.



^{93}Nb(p,x)

Figure 1: Visualization of impact from preequilibrium parameter adjustments across reaction phase space on the exciton model squared matrix element for the effective residual interaction. The color scale is a mapping of the z axis in each case.

Reaction modeling at these energies is typically unsatisfactory due to few prior published data and many interacting physics models. Therefore, a detailed assessment of the TALYS code was performed with simultaneous parameter adjustments applied according to a standardized procedure. Particular attention was paid to the formulation of the two-component exciton model in the transition between the compound and preequilibrium regions, with a linked investigation of level density models for nuclei off of stability and their impact on modeling predictive power. This assessment has revealed a systematic trend in how residual product excitation functions for high-energy proton-induced reactions on spherical nuclei are miscalculated in the current exciton model scheme. Additionally, adjustments made to the TALYS `ldmodel 4` (Goriely) and `ldmodel 6` (HFB+Gogny) level densities illustrate the reliance of reaction modeling upon well-characterized models of the nuclear level density at high excitation energy [1, 2].

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Improved measurements and reaction modeling for the production of ^{117m}Sn and ^{119m}Te via proton bombardment on natural antimony up to 200 MeV

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The Auger-emitting nuclides ^{117m}Sn and ^{119m}Sb (for which ^{119m}Te is a generator) are promising candidates for the treatment of small tumors and for use in radiosynoviorthesis, but there is little information available regarding their formation at the high energy proton facilities used for the large-scale isotope production. A more precise cross section measurement will inform a production pathway with high yield and minimal by-products. As part of the Tri-Lab Evaluated Nuclear Data Effort (TREND), cross sections for production of these isotopes have been measured up to 200 MeV.

Production cross sections were measured for protons up to 55 MeV at Lawrence Berkeley National Lab, up to 100 MeV at the Isotope Production Facility at Los Alamos National Lab, and up to 200 MeV at the Brookhaven Linac Isotope Producer at Brookhaven National Lab.

The results of cross section measurements, together with data from other measurements by the TREND collaboration on natural niobium, arsenic and thallium nuclides, will be compared to the predictions from charged particle reaction modeling codes, such as TALYS and EMPIRE, employing physically defensible level density and optical model adjustments as investigated in (Fox et al., 2021).

In addition to these results, future measurements of prompt gamma emissions from irradiations of thallium will provide yields for both very long-lived or stable isotopes and very short-lived isotopes, as well as detailed information regarding the population of residual nuclei as a function of angular momentum and parity. These additional reaction channels will provide insight into nuclear level density and particle transmission coefficients as a function of excitation energy and will help advise further parameter adjustments in nuclear reaction modeling.

Acknowledgments

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PANDORA project: photo-nuclear cross section measurements of light nuclei at RCNP

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Ultra-High-energy cosmic rays have been observed on Earth up to above 10^{20}eV. However, the locations where they are produced and the nuclides are unknown. We are trying to elucidate this from both theoretical and actual measurements. One of the key elements that is unknown in theory is the cross-section of the photonuclear reaction of nuclei. Experimental data other than neutron channels in photo-nuclear reactions are scarce. We are planning to conduct experiments to improve the accuracy of the cross-section.

For this purpose, we are planning to study the photoabsorption cross-sections and charged-particle decay branching rates of ^{10,11}B,^{12,13}C,^{27}Al,^{24,26} Mg nuclei from Coulomb excitations induced by inelastic scattering of protons in the forward angular direction using the Grand Raiden spectrometer [1] and Si detector array, SAKRA. Simultaneous measurement of γ rays will provide data on γ decay from excited states as well as γ decay of daughter nuclei after particle emission.

We investigated the stability of the gain and the gain found while preparing four of the eight LaBr3 detectors [2] that are planned to be used in the experiment. The energy resolution of each detector was then investigated. We are also currently designing a scattering chamber that can accommodate SAKRA for efficiently detecting backscattered charged particles and the LaBr3 detectors for γ-rays placed outside the SAKRA detectors. I will report on the plan of the measurement and status of the detector tests.

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Constraints on the dipole photon strength for the odd uranium isotopes

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The photon strength functions (PSFs) and nuclear level density (NLD) are key ingredients for calculation of the photon interaction with nuclei, in particular the reaction cross sections. These cross sections are important especially in nuclear astrophysics [1, 2], and in the development of advanced nuclear technologies [3].

The role of the scissors mode in the $M1$ PSF of (well-deformed) actinides was investigated by several experimental techniques. They included mainly data from the Oslo technique [4, 5, 6] and neutron capture experiments [7, 8]. The significant differences were reported, especially on the strength of the mode. The shape of the low-energy tail of the giant electric dipole resonance is uncertain as well. In particular, some works proposed a presence of the $E1$ pygmy resonance just above 7 MeV. Because of these inconsistencies additional information on PSFs in this region is of great interest.

The γ-ray spectra from neutron-capture reactions on the ^{234}U, ^{236}U and ^{238}U nuclei have been measured with the total absorption calorimeter of the n_TOF facility [9, 10] at CERN. The background-corrected sum-energy and multi-step-cascade spectra were extracted for several isolated s-wave resonances up to about 140 eV.

The experimental spectra were compared to statistical model predictions coming from a large selection of models of photon strength functions and nuclear level density. No combination of PSF and NLD models from literature is able to globally describe our spectra. After extensive search we were able to find model combinations with modified generalized Lorentzian (MGLO) [11] $E1$ PSF, which match the experimental spectra as well as the total radiative widths. The constant temperature energy dependence is favored for a NLD. The tail of giant electric dipole resonance shows no hint of pygmy resonance. The $M1$ PSF must contain a very strong, relatively wide and likely double-resonance scissors mode. The mode is responsible for about a half of the total radiative width of neutron resonances and significantly affects the radiative cross section.

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Study of the ^{44}Ti$(\alpha, p)^{47}$V reaction rate using high precision ^{50}Cr$(p, t)^{48}$Cr measurements

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Formed in a region where most material is captured onto the compact object remaining at the end of the collapse, the observation of ^{44}Ti offers the best diagnostic tool for Core-Collapse Supernovae (CCSNe) [1]. The amount of ^{44}Ti produced in CCSNe has been shown to be strongly dependent on the ^{44}Ti$(\alpha, p)^{47}$V reaction, which controls the destruction of ^{44}Ti [2]. Direct measurements of the ^{44}Ti$(\alpha, p)^{47}$V reaction are challenging due to the low cross sections and radioactive ion beam intensities, so statistical models are used to predict reaction rates [3, 4]. Predictions for α-induced reactions on $N{=}Z$ nuclei might not be reliable due to the lower effective level density in the compound nucleus. High-resolution 0-degree ^{50}Cr$(p, t)^{48}$Cr measurements were performed using the K600 magnetic spectrometer at iThemba LABS to identify natural parity levels in ^{48}Cr. A number of levels in ^{48}Cr were observed for the first time. The number of levels observed was compared to level-density calculations, indicating a theoretical overestimation of the level density. The results of this measurement and theoretical calculations will be presented together with its implications for the ^{44}Ti$(\alpha, p)^{47}$V reaction rate.

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Abstract for Oslo workshop

Modelling gamma-ray spectra of radiative neutron capture and uncertainty calculations

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Reliable uncertainty estimation of both the unfolded experimental data and of the theoretical model is utmost to obtain adequate Chi-square estimation when fitting model parameters to the experimental gamma-ray spectra. To do that, preparation steps of experimental spectra had already been presented in Ref. [1] with complete uncertainty estimation. The obtained unfolded spectrum can then be directly compared to the model-provided spectrum, however, in the case of the extreme statistical model, such as BITS [2] lacked the missing uncertainty estimation, thus reliable Chi-square value.

In the talk, the complete uncertainty estimation will be presented on the example of several measured gamma spectra, including ones from radiative neutron capture. This achievement helps to decide which photon strength function parameter set is the best to describe the experimental spectrum. High-resolution comparison of experimental and model calculated spectra helps to develop decay-schemes [3] will be discussed too.

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Constraining the ^{75,76}Zn neutron capture reactions via the β-Oslo method

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Neutron-capture reactions far from stability are important to a number of astrophysical nucleosynthesis processes, such as the r- and i-processes. These processes are responsible for the creation of the majority of the neutron-rich heavy elements, but they are not yet fully understood. This is because of incomplete nuclear data in this region due to the difficulty in creating both neutron and exotic radioactive ion beams. The β-Oslo method uses β decay to populate highly excited nuclear states in the compound nucleus of interest and is used to extract the nuclear level densities (NLD) and γ-ray strength functions (γSF) from the decay of these states. These experimentally-determined properties reduce uncertainties in theoretical neutron-capture rates. I will specifically discuss the β decay of ^{76,77}Cu and the implementation of the β-Oslo method to reduce uncertainties in the current ^{75,76}Zn(n,γ)^{76,77}Zn reaction rates. These particular reactions are both in the mass region important for the weak r-process.

Deconstructing the Photon Strength

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A common misconception is that the photon strength, $f(E_\gamma)$, is a fundamental nuclear property. Photon strength is measured in photonuclear reactions and is the product of the average γ-ray transition strength, as defined by Weisskopf in Eq. 1, and the average level density, $\rho(E_x)$. Photon strength is defined in Eq. 2

$$\begin{aligned} B(EL)\downarrow &= \frac{\Gamma_\gamma(EL)\cdot L[(2L+1)!!]^2}{8\pi(L+1)e^2b^L}\left(\frac{\hbar c}{E_\gamma}\right)^{2L+1} \\ B(ML)\downarrow &= \frac{\Gamma_\gamma(ML)\cdot L[(2L+1)!!]^2}{8\pi(L+1)\mu_N^2b^L}\left(\frac{\hbar c}{E_\gamma}\right)^{2L+1} \end{aligned} \tag{1}$$

where σ_γ is the measured photoexcitation cross section populating levels at an excitation energy E_x. The

$$f(E_\gamma)=\frac{\sigma_\gamma(E_x)}{3\pi^2\hbar^2c^2E_\gamma}=\rho(E_x)B(E1)\uparrow= 9560\times\rho(E_x)\left[\frac{2J_f+1}{2J_i+1}\right]\frac{\Gamma_{E1}(E_\gamma)}{E_\gamma^3} \tag{2}$$

photonuclear reactions are dominated by E1 transitions as predicted by Eq. 1.

The level density is commonly calculated by Eq. 3, the Constant Temperature (CT) formula, where $N(E_x)$

$$\rho(E_x)=N(E_x)/T=N(E_0)e^{(E-E_0)/T} \tag{3}$$

is the level sequence number, T is the temperature, and E_0 is the back shift parameter. The CT formula is invalid because it attempts to model the total level density which is strongly spin dependent leading to nonphysical fitted values for E_0. In this talk I will present the CT-JPI model where the level density for each spin and parity is fit to a CT model with two parameters $E_0(J^\pi)$, a back shift energy for each J^π which is near its Yrast energy, and T, a constant temperature for all J^π. The CT-JPI parameters can be least-squares fit to the experimental J^π sequences and are constrained by the spin distribution function. The CT-JPI model is valid to well above the neutron separation energy and has been applied to nuclei with Z=7-92.

The photon strength in the Giant Dipole Resonance (GDR) region is described by a simple Laurentzian distribution as given by Eq. 4 where the summation accounts for the splitting of the GDR in deformed

$$f(E_\gamma)=\frac{1}{(3\pi\hbar c)^2}\sum_{i=1}^{i=2}\frac{\sigma_iE_\gamma\Gamma_i^2}{(E_\gamma^2-E_i^2)-E_\gamma^2\Gamma_i^2} \tag{4}$$

nuclei. There are three parameters for each GDR peak, energy E_i, width Γ_i, and cross section σ_i that are normally fit to experimental data. The GDR peak is often ascribed to "γ-rays exciting a motion in the nucleus in which the bulk of the protons move in one direction while the neutrons move in the opposite direction". This assumption is invalid. The GDR and all giant resonances are due to a sudden increase in level density at the harmonic oscillator shell gaps. The mean energy of the GDR, $\overline{E}$, has been fit to data for A=2-239 and is given by Eq. 5. It is slightly shifted from the well known $2\hbar\omega$ shell gap due to the E_γ^3 dipole

$$\overline{E}=2\hbar\omega=2(47.34\pm0.27)(A^{-1/3}-A^{-2/3}) \tag{5}$$

energy dependence. For spherical nuclei $\overline{E}=E_1$ and for deformed nuclei $\overline{E}=(\sigma_1E_1+\sigma_2E_2)/\sigma_1\sigma_2$. The splitting of the GDR in deformed nuclei is shown to be due to transitions from the GS to levels with oblate and prolate deformations, respectively, and is proportional to the β_2 deformation. A fit to experimental data gives $E_1=\overline{E}-(6.68\pm0.16)|\beta_2|$ and $E_2=\overline{E}+(4.45\pm0.11)|\beta_2|$. Similarly the GDR cross sections are fit to $\sigma_1=(0.193\pm0.010)A^{4/3}$ and $\sigma_2=(0.290\pm0.015)A^{4/3}$ and the widths to $\Gamma_1=(0.84\pm0.03)\overline{E}^{1/2}$ and $\Gamma_2=(1.26\pm0.04)\overline{E}^{1/2}$. Eq. 4 should be corrected for the contribution from the higher energy shell closures.

The level densities and E1 transition strengths are fundamental nuclear properties related by Eq. 2. For even-even nuclei photonuclear reactions populate $J^\pi=1^-$ levels so the reduced E1 transition strength is given by $B(E1)\uparrow=f(E_\gamma)/\rho(E_x,1^-)$ where $\rho(E_x,1^-)$ is calculated with the CT-JPI model. The $B(E1)\uparrow$ values are found to vary exponentially with energy. By extrapolating the $B(E1)\uparrow$ values to higher energy we can infer the level densities up to 30 MeV by $\rho(E_\gamma,1^-)=f(E_\gamma)/B(E1)\uparrow$. The calculated higher excitation energy level densities are comparable to values predicted by the Back-Shifted Fermi Gas Model (BSFG).

The Oslo data are not typically dominated by E1 transitions. The measured level densities represent an ensemble of levels populated by a given reaction. For these data the reduced γ-ray transition strengths can be determined from the ratio of the measured photon strengths to the measured level densities.

For more details see *Spin/Parity Dependent Level Density* (https://arxiv.org/pdf/2104.02693.pdf), *The Origin of the Giant Dipole Resonance* (https://arxiv.org/pdf/2009.03356.pdf), and *Level Densities from 0-30 MeV* (https://arxiv.org/pdf/2106.09088.pdf).

The structure of low-lying 1^- states in ^{90,94}Zr from (α,$\alpha'\gamma$) and (p,$p'\gamma$) reactions

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The low-lying dipole strength in the ^{90,94}Zr nuclei was investigated via (p,$p'\gamma$) resction at 80 MeV and via (α,$\alpha'\gamma$) reaction at 130 MeV [1]. These experiments, performed at the Research Center for Nuclear Physics (RCNP, Osaka University), made use of the high-resolution magnetic spectrometer Grand Raiden (for the detection of inelastically scattered particles) and the array CAGRA (HPGe clovers), for the detection of γ-rays. These are the first data of this kind available for the ^{94}Zr nucleus, while for the case of ^{90}Zr previous (α,$\alpha'\gamma$) data already existed [2], but in that case low resolution γ-ray detectors were used. The comparison of the present results with existing (γ,γ') data shows that the used hadronic probes produce a different excitation pattern. In these experimental conditions, in fact, both α and p are exciting the investigated 1^- states mainly trough the nuclear force.

DWBA calculations were made using form factors deduced from specific transition densities, characterized by a strong neutron component at the nuclear surface and based on RPA. A combined analysis of the two reactions was performed, for the first time, to investigate the isoscalar character of the 1^- states in ^{90,94}Zr. The (p,$p'\gamma$) cross section was calculated using values of the isoscalar electric dipole energy-weighted sum rule (E1 ISEWSR) obtained from the (α,$\alpha'\gamma$) data. The isoscalar strength for ^{90}Zr was found to exhaust 20 ± 2.5% of the EWSR in the energy range up to 12 MeV. In case of ^{94}Zr, a strength of 9 ± 1.1% of the EWSR was found in the range up to 8.5 MeV.

Although an overall general description was obtained in the studied energy intervals, not all (p,$p'\gamma$) cross sections were well reproduced using the isoscalar strength from (α,$\alpha'\gamma$). This might suggest mixing of isoscalar and isovector components and that this mixing and the degree of collectivity are not the same for all the 1^- states below the particle binding energy.

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Recent measurements with the ELIGANT-GN γ-ray and neutron detection systems

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The ELIGANT-GN setup has been installed and commissioned with sources at the ELI-NP facilities [1, 2]. This setup comprises a large set of detectors: 36 EJ-301 liquid scintillator detectors and 25 GS20 ^{6}Li glass detectors fast and slow neutrons, respectively, and a mixed array of CeBr$_3$ scintillators and LaBr$_3$:Ce scintillators for high-energy γ rays. The intended use of this detector setup is with the high-brilliance ELI-NP γ-ray beam that is currently under construction. While the γ-ray beam is under construction, the ELIGANT-GN instrumentation is used for experiments either without beam, by performing measurements of neutron- and γ-ray correlations from the spontaneous fission of ^{252}Cf, or with the beam from the 9MV Tandem facility at IFIN-HH. For the latter purpose, the large-volume LaBr$_3$:Ce detectors have been installed in the anti-Compton shields of ROSPHERE [3], creating a unique setup for very clean γ-ray spectroscopy of Giant Dipole Resonances, Pygmy Dipole Resonances, and electromagnetic properties of weak transitions in light nuclei.

In this contribution, we will present the detailed performance of the ELIGANT-GN setup from simulations and as commissioned with radioactive sources and discuss the pre-γ-beam physics program that is ongoing. In particular, the current status of detailed fission measurements of ^{252}Cf both with ELIGANT-GN as a stand-alone system and together with the ELI-THGEM device for fission fragments will be presented. We will also show some preliminary characterisation and preliminary results from the currently ongoing physics campaign at the 9MV Tandem facility.

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Fission studies with the nu-Ball spectrometer

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Gamma-ray spectroscopy is a versatile tool which can be used to study the decay of the excited fragments produced in the complex process of nuclear fission. Gamma ray coincidence and relative time information can give important information on both the nuclear structure of exotic neutron-rich nuclei and the fission process itself. Major results on fission spectroscopy from the first nu-Ball experimental campaign will be reviewed and their importance for both fundamental and applied nuclear physics will be discussed. Currently the nu-Ball2 campaign at the ALTO facility of IJC Lab has just began. The prospects for new and innovative measurements using gamma spectroscopy of fission will be presented.

Breath of the Hoyle('s) ghost

K.C.W. Li, Abstract for the Oslo Workshop 2022

Knowledge of the low-lying monopole strength in ^{12}C—the enigmatic Hoyle state in particular—is crucial for our understanding of both the astrophysically important triple-α reaction and of α-particle clustering in general. Multiple theoretical models have predicted a breathing mode of the Hoyle State at $E_x \approx 9$ MeV, corresponding to a radial in-phase oscillation of the underlying α clusters. The $^{12}\mathrm{C}(\alpha,\alpha')^{12}\mathrm{C}$ and $^{14}\mathrm{C}(p,t)^{12}\mathrm{C}$ reactions were employed to populate states in ^{12}C in order to search for this predicted breathing mode. A self-consistent, simultaneous analysis of the inclusive spectra, together with angular distributions of charged-particle decay, yielded clear evidence for excess monopole strength at $E_x \approx 9$ MeV which is highly collective. Reproduction of the experimentally observed inclusive yields using a fit, with consistent population ratios for the various broad states, required an additional source of monopole strength. The interpretation of this additional monopole resonance as the breathing-mode excitation of the Hoyle state would provide evidence supporting a $\mathcal{D}_{3h}$ symmetry for the Hoyle state itself. However, some recent calculations also support different interpretations for both the Hoyle state and the additional monopole strength. Independent of the detailed structure, this excess monopole strength may complicate the analysis of the properties of the Hoyle state, modifying the temperature dependence of the 3α rate at $T_9 \approx 2$ and ultimately, the predicted nucleosynthesis in explosive stars.

The Bay Area Nuclear Data Group

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The Purpose of the Bay Area Nuclear Data (BAND) Group is to address the nuclear data needs of the applied and basic nuclear science and engineering community while training the next generation of scientists and engineers in the process. Over the past two years the BAND group has published more than 3 dozen peer-reviewed papers and 5 Ph.D. dissertations on nuclear data needs on the properties of neutron-rich nuclei, the production of medical isotope, nonproliferation, detector design, fission product yields and machine-learning augmented nuclear data evaluation. A central theme of much of this work is the importance of statistical nuclear properties (e.g., nuclear level densities and photon strength functions) that forms the underpinning of this workshop series. In this talk I will review of some of the highlights from the BAND research program and discuss plans to launch a new effort to address nuclear data needs to design shielding and to protect astronauts and the spacecraft they rely on in order to enable space exploration.

A new technique for extracting isomeric yield ratios of fission fragments

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P. Davies,[18] C. Delafosse,[2] M. Fallot,[19] B. Fornal,[15] L. Fraile,[12] A. Gottardo,[20] V. Guadilla,[19] G. Häfner,[2,7] K. Hauschild,[2]
M. Heine,[16] C. Henrich,[5] I. Homm,[5] F. Ibrahim,[2] Ł. W. Iskra,[13,15] P. Ivanov,[4] S. Jazrawi,[3,4] A. Korgul,[9] P. Koseoglou,[5,21]
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Ever since discovering that the nuclear fission fragments emerge with about $6-9$ units of angular momentum [1], scientists have been investigating how this angular momentum is generated and what mechanism that underlies it. An observable that is strongly coupled to a fragment's angular momentum is its isomeric yield ratio (IYR), defined by the amount of fragment decays that passes though a metastable state. Isomeric yield ratios have therefore been measured over the last four decades, where various techniques allow the IYR extraction of isomers with different half-lives, see eg. Refs. [2], [3], [4].

A new technique for extracting IYRs of fission fragments is under development. With this technique, isomers with half-lives on the order of 10^{-7} seconds become accessible. We show preliminary values for the IYRs of ^{134}Te produced in the ^{238}U(n,f) and ^{232}Th(n,f) reactions. Furthermore, this technique allows for the control of the number of neutrons emitted from the system as well as the minimum spin of the partner fragment, which adds new information to our understanding of angular momentum generation in nuclear fission.

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Recent advances within the QRPA framework to improve gamma strength function prediction

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The Gogny-based QRPA approach based developed in CEA, DAM, DIF [1] can be applied to spherical as well as to axially deformed nuclei, from light (i.e. oxygen) to superheavy elements [2]. For electric and magnetic dipole modes, intensive computational efforts have been made to produce a large scale data set of gamma strength functions with as little as possible phenomenological ingredients. The resulting photon strength functions have been shown to reproduce the bulk of experimental data with a high level of accuracy [3]. The most recent calculations also include the transition probabilities for the decay of the QRPA excited states down towards the ground state, regardless of the electromagnetic multipolarity.

In In this talk, I will also present some successes obtained by the QRPA approach in the reproduction of additional experimental data. More particularly, the method has been applied to the N=100 isotones in order to describe their 4- isomeric states. Since the calculated half-lives of pure K=4 states are too large by several orders of magnitude, the Coriolis coupling between QRPA states has been introduced to reproduce and interpret the variation of the lifetime along the N=100 isotonic chain [4]. Such a coupling requires the calculation of transition probabilities between QRPA excited states that can also be used to describe microscopically and consistently the low-energy de-excitation photon strength function, known as the upbend, observed in Oslo data and of particular relevance for reaction and astrophysical studies.

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β-decay Strength Distribution of ^{73}Co From Total Absorption Spectroscopy

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Measured β-decay rates, β-decay branching ratios, and β-delayed neutron emission probabilities along with detailed level schemes of neutron-rich isotopes are critical for informing r-process simulations as well as nuclear structure models. Far from stability, where β-decay Q-values tend to be large, daughter nuclei can be populated in regions with high level densities and at high excitation energies. This can lead to a fragmented decay scheme with many weak β-decay branches and multiple γ-decay pathways to the ground state. The β-feeding to each level in the daughter nucleus can be reconstructed by measuring β particles and γ-rays in coincidence and summing individual γ-ray energies. In this work, the β decay of ^{73}Co was studied at the National Superconducting Cyclotron Laboratory (NSCL) using the Summing NaI(Tl) (SuN) Total Absorption Spectrometer [1]. Studies of the β-decay properties of neighboring isotopes along the Z=28 shell closure have been previously done [2-3]. The Gamow-Teller strength distribution (B(GT)) for the β decay of ^{73}Co as well as constraints on the β-delayed neutron emission probability of ^{73}Co will be presented. This work is complementary to previous work involving the extraction of Nuclear Level Density and γ-ray Strength Function parameters from ^{71,72,73}Ni in order to constrain neutron capture cross sections of ^{70,71,72}Ni [4].

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Statistical properties of neutron-rich strontium isotopes

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Understanding of neutron-induced reactions on nuclei far from stability has far-reaching implications for cosmogenic nucleosynthesis and fundamental nuclear physics. Direct measurement of the radiative-capture cross section is experimentally inaccessible for these short-lived nuclei; however, indirect methods such as the β-Oslo Method enable the experimental constraint of key nuclear properties that are inputs for reaction-theory calculations.

An experiment to determine the γ-ray strength (γSF) and nuclear level density (NLD) for ^{93,94,95}Sr isotopes using high-intensity and purity Californium Rare Isotope Breeder Upgrade (CARIBU) beams of Rb was performed at Argonne National Laboratory (ANL). The γSF and NLD, properties extracted from the measured γ-ray spectra using the β-Oslo Method, contribute the greatest uncertainty in Hauser-Feshbach calculations of neutron-capture reaction rates for short-lived neutron-rich nuclei. Additionally, this work on very-neutron-rich nuclei, which have low neutron separation energies and high β-delayed neutron branches, examines a smaller region of statistical decays than previous applications of the β-Oslo Method. The experimental techniques and preliminary results of this work will be presented. Furthermore, the results of this work will shed light on nuclear structure properties for Sr isotopes, leading to significantly improved predictive reaction modeling.

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Extracting Photon Strength Function of ^{58}Fe from ^{57}Fe(d,pγ)^{58}Fe reaction using DAPPER

Austin Abbott

March 14, 2022

Photon strength functions (PSFs) are a necessary input for neutron-capture cross-section calculations and are important for astrophysical models seeking to illustrate stellar life cycles and the production of elements heavier than iron. DAPPER (the Detector Array for Photons, Protons, and Exotic Residues) has been constructed at the Texas A&M University Cyclotron Institute for the purpose of measuring PSFs via (d,pγ) reactions in inverse kinematics. The array consists of 128 BaF$_2$ scintillators to measure γ-rays emitted from the excited residual nucleus and an S3 silicon detector to detect protons, giving a measurement of the excited states initially populated in the reaction. The commissioning run for the array was performed in August of 2021 at the end of the Momentum Achromat Recoil Spectrometer (MARS) line at TAMU using a beam of 7.5 MeV/u ^{57}Fe and various CD$_2$ targets in order to measure the PSF for ^{58}Fe populated in the ^{57}Fe(d,pγ)^{58}Fe reaction. Interest in this isotope stems from previous work done on other iron isotopes and elements in this mass region where the PSFs exhibited an enhancement in the low γ-ray energy region, coined the “upbend”. This feature has been modeled and could have a potentially large impact on neutron-capture reaction rates of rare neutron-rich isotopes produced in r-process nucleosynthesis. The Oslo Method will be used to extract the PSF from this experiment and will be compared to results obtained from the Forward analysis method and to data taken from an experiment populating the nucleus via the direct neutron capture reaction at Los Alamos National Laboratory. Current work consists of calibrations of the silicon and BaF$_2$ detectors in the array and corrections for degradation of targets and changing beamspot positions, which will be discussed alongside the future plans for the analysis.

Nuclear level densities and γ-ray strength functions from radiative proton capture reactions

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The nucleosynthesis of heavy nuclei is affected by the reaction rates of radiative capture reactions. Many of the astrophysical relevant rates cannot be obtained from experiments but are obtained from theoretical models [1, 2]. The γ-decay widths that are derived from radiative strength functions as well as the density of nuclear states belong to the key nuclear physics input parameters in those calculations. Among the numerous methods that have been established in the last decades, radiative proton capture reactions are a well-suited tool to obtain insights into these two nuclear properties [3]. From the intensity of prompt γ-ray transitions information about the dipole strength function can be extracted. This can be done either via detecting the prompt γ rays directly or by detecting $\gamma\gamma$ concidences and applying the ratio method [4, 5]. The latter allows to increase the number of transitions used for the γ-ray strength function studies. Total reaction cross sections complement the yield of experimental observables and are valuable to test various level density and γ-ray strength function models. In the last years, several proton-induced experiments have been conducted at the University of Cologne and proved this method to deliver reliable results for those two properties. In this contribution, the underlying reaction mechanism of radiative capture reactions will be presented as well as a detailed description of how they can be used to study statistical nuclear properties. Experimental results for the γ-ray strength function of ^{64,66}Zn as well as ^{94}Mo are discussed and compared to data obtained from other methods as well as from recent theoretical descriptions.

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Results from the resonance neutron capture on ^{167}Er measured with DANCE

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The γ rays following radiative neutron capture on ^{167}Er sample were measured with the γ-ray calorimeter Detector for Advanced Neutron Capture Experiments (DANCE) [1, 2] at the Los Alamos Neutron Science Center. DANCE is well-suited for precise coincident detection of complete γ cascades thanks to its high segmentation, efficiency, and solid angle coverage.

We were able to gather the so-called multistep cascade (MSC) spectra for 12 and 15 well-isolated s-wave neutron resonances with $J^\pi = 3^+$ and $J^\pi = 4^+$, respectively. The nuclear level density and the photon strength functions were determined by comparing these spectra with their counterparts simulated using DICEBOX code [3]. The photon strength functions were found to be similar to those reproducing such spectra in other well-deformed rare-earth nuclei [4, 5, 6].

Furthermore, the timing precision of DANCE enabled us to gather data related to the isomeric state at excitation energy 1094 keV, with a lifetime of $\approx$ 100 ns [7]. The measured population of the isomeric state appears to be significantly higher than the population simulated within the statistical model using nuclear level density and photon strength functions models describing the γ cascades to the ground state.

The measured multiplicity distribution (as a function of neutron energy) was processed using the Optimized γ-multiplicity-based spin assignment method [8]. We confirm a majority of the spin assignments up to $\approx$ 285 eV as found in Mughabghab's atlas [9]. For three resonances with the previously unknown or uncertain spin, we assign one and we changed the assignment for four resonances. More importantly, our analysis revealed at least three close, previously unobserved doublets of complementary spins. Such doublets are extremely hard to detect by other experimental techniques and pose a challenge when determining completeness of a resonance sequence and hence average resonance spacing D_0 in odd-A samples.

Traditionally, the completeness of resonance sequences is determined by comparing them to Random Matrix Theory predictions using Gaussian Orthogonal Ensemble. Our tests using the Δ_3 statistic suggests that we miss at least two resonances. This conclusion is supported by simulations of artificial resonance sequences of which only a few percent have no resonances below the experimental $g\Gamma_n$ threshold, most probably four resonances are missed. The same tests suggest that the resonance sequences from Mughabghab's atlas [9] are not complete with three or more resonances missed. Our resulting spacing $D_0 = 3.86(12)$ eV is consistent with values from literature. On the other hand, the partial spacings $D_0^+ = 6.70(25)$ eV and $D_0^- = 9.03(48)$ eV are in sharp disagreement with $D_0^+ = 10.8(14)$ eV; $D_0^- = 6.8(12)$ eV from Mughabghab's atlas [9]. The ratio of these spacings is slightly higher than provided by conventionally used LD models.

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Extracting model-independent nuclear level densities away from stability

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In this contribution we present the first model-independent measurement of the absolute partial nuclear level density (NLD) for a short-lived nucleus. For this purpose we adapt the recently introduced "Shape method" [1] for β-decay experiments for the first time, providing the shape of the γ-ray strength function for exotic nuclei. In this work, we show that combining the Shape method with the β-Oslo technique [2] allows for the extraction of the nuclear level density without the need for theoretical input [3]. This development opens the way for the extraction of experimental NLDs far from stability with major implications in astrophysical and other applications. We benchmark our approach using data for the stable ^{76}Ge nucleus, finding excellent agreement with previous experimental results. In addition, we present new experimental data from an experiment using CARIBU [4] at Argonne National Laboratory and determine the absolute partial level density for the short-lived ^{88}Kr nucleus. Our results suggest a five-fold increase in the level density and neutron-capture reaction rate for the case of ^{88}Kr, compared to the recommended values from microscopic Hartree-Fock Bogoliubov calculations in the RIPL3 nuclear data library. However, they are in good agreement with other semi-microscopic level density models.

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Experimental Study at RCNP for the PANDORA Project

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Photo-nuclear reactions in the mass region below $A \sim 56$ are planned to be systematically investigated, both experimentally and theoretically, to study nuclear structure, astro-particle physics, and applications in the project PANDORA (Photo-Absorption of Nuclei and Decay Observation for Reactions in Astrophysics). Virtual-photon exchange by proton scattering and high-intensity real-photon beam by laser Compton scattering will be used to study each decay channel's photo-absorption cross-sections and branching ratio. Several nuclear models, such as anti-symmetrized molecular dynamics, mean-field type models, large-scale shell model, and ab. initio models, will be employed to predict the photo-nuclear reactions and their systematic behavior.

Ultra-high-energy cosmic rays (UHECRs) are observed on earth up to above 10^{20} eV by large cosmic-ray air-shower observatories such as Pierre Auger [1] and Telescope Array[2]. The origin and the acceleration mechanism of the UHECRs remain a mystery. Their composition is also unknown. However, a recent analysis of the air-shower depth distribution showed a trend to be heavier in the mass composition at the highest energy between the proton and the iron mass. UHECR nuclei are predicted to lose their energy primarily by emitting particles after photo-nuclear excitation by absorbing a cosmic microwave background (CMB) photon. Thus photo-nuclear reaction cross-sections and decay branching ratios are the key ingredients to understanding the energy and mass evolution of UHECRs during extragalactic propagation.

I will introduce the plan of experimental studies at the Research Center for Nuclear Physics, Osaka University, for the PANDORA project employing the virtual-photon excitation induced by proton scattering.

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Constraining the ^{139}Ba(n,γ)^{140}Ba reaction rate for the astrophysical i process

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In recent years the plethora of new astronomical observations has shown that the synthesis of heavy elements cannot be explained just by the three traditional processes (s, r, and p). For this reason, new processes have been proposed that are able to explain these new observations. The "intermediate" or i process is one such process and corresponds to neutron densities and time scales intermediate between the slow (s) and the rapid (r) neutron-capture processes. It involves nuclei that are roughly 5 neutrons away from the last stable isotope and as such the majority of their nuclear properties are experimentally known. The only missing piece of information from the nuclear physics side is the neutron-capture reaction rates. In a collaboration between Michigan State University (MSU), the University of Guelph, the University of Oslo, iThemba LABS and Lawrence Livermore National Lab we have an established experimental program that aims at constraining important neutron-capture reactions for the astrophysical i process. In this talk I will present the overall i-process program of the collaboration and focus on one particular reaction, the ^{139}Ba(n,γ)^{140}Ba reaction using the β-Oslo method. This reaction was identified by our collaborators at the University of Victoria as one of the most important reactions that impacts the production of lanthanum and cerium. The measurement of the relevant reaction took place at the CARIBU facility at Argonne National Lab. A ^{140}Cs beam was isolated and delivered to the center of the SuN detector onto the SuNTAN tape transport system. The β-Oslo method was used to extract the nuclear level density and the γ ray strength function which were used to constrain the neutron capture reaction rate on ^{139}Ba.

Update on the Observation of Nuclear-Plasma Interactions at the National Ignition Facility

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At the sixth Oslo Workshop, we presented "intriguing," though not definitive, evidence for a plasma-environment influence on nuclear reactions observed at the National Ignition Facility (NIF). The signature of this effect is the decreased population of a high-spin isomer, relative to the ground state, following ^{134}Xe(n,2n)^{133}Xe reactions in a high energy density plasma [1]. A follow-up experiment was planned to reduce uncertainties through increased reaction and detection statistics. Although that data was complicated by environmental fission fragments in the NIF chamber produced in previous uranium-hohlraum shots, weighted averaging of multiple control shots allowed a re-examination of the initial results leading to more definitive evidence of nuclear-plasma interactions.

Furthermore, an inverse-kinematics Oslo-method experiment has since produced strength function and level density measurements for ^{133}Xe [2], allowing a more robust interpretation of observed plasma-induced effects. The change in isomer population from a quasi-continuum cascade following (n,2n) reactions is a competition between gamma-ray decay and electron-mediated nuclear-plasma interactions such as Nuclear Excitation by Electron Capture (NEEC) or Transition (NEET). These are influenced respectively by the gamma strength of ^{133}Xe at high energy (∼1-5 MeV) vs. very low (∼5 keV) energy. Such low-energy measurements are not currently possible but the lowest-energy measurements to date in this and similar-mass nuclei have suggested a dipole enhancement which has been supported by M1 shell model calculations.

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γ-ray strength functions of heavy nuclei in the framework of the configuration-interaction shell model

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A low-energy enhancement (LEE) has been observed in the γ-ray strength function (γSF) of mid-mass nuclei, and configuration-interaction (CI) shell model calculations suggest that this enhancement occurs in the magnetic dipole ($M1$) γSF [1]. However, conventional CI shell model calculations are intractable in heavy nuclei, and the existence of a LEE in heavy nuclei has been an open problem.

The shell model Monte Carlo (SMMC) method [2] is a powerful method to calculate thermal observables in model spaces that are many orders of magnitude larger than those that can be addressed in conventional methods, but it cannot be used to calculate directly γSFs. In SMMC, it is only possible to calculate the imaginary-time response function, whose inverse Laplace transform is the γSF. However, this transform is numerically ill-defined. The standard method to carry out numerically the analytic continuation is the maximum-entropy method whose success depends crucially on a good choice of a prior strength function.

The static path plus random-phase approximation (SPA+RPA) reproduces well SMMC state densities [3]. We implemented an extension of the SPA+RPA [4] to calculate γSFs in the framework of the CI shell model for a pairing plus quadrupole Hamiltonian [5]. We then use the SPA+RPA γSF as a prior in a maximum-entropy method that reproduces the SMMC imaginary-time response function [5].

The SPA+RPA becomes computationally expensive for the interactions used in SMMC, and instead we use as prior strength the SPA γSF [6].

We applied these methods in chains of samarium [5] and neodymium [6] isotopes and identified a LEE in their $M1$ γSF. We also observed a scissors mode and a spin-flip mode that are built on top of excited states. We discuss how these modes change in the crossover from spherical to deformed heavy nuclei.

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Measurements of the ^{56}Fe(n,n'γ) reaction at GENESIS

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Improved inelastic neutron scattering and neutron-induced gamma-ray production data are needed for the next generation of nuclear technologies, from advanced reactors to space exploration, shielding applications, and detection platforms based on prompt neutron interrogation analysis. The Gamma Energy Neutron Energy Spectrometer for Inelastic Scattering (GENESIS), located at the 88-Inch Cyclotron at Lawrence Berkeley National Lab, is the first-ever array of neutron detectors coupled to high-purity germanium detectors designed to address these nuclear data needs. In addition to single particle measurement of quantities like double-differential gamma-ray production, GENESIS can more accurately measure secondary neutron energy-angle distributions by tagging on coincident, characteristic gamma-rays. Experiments with a 99.98%-enriched ^{56}Fe target were performed at GENESIS. These experiments used a broad-energy collimated, time-resolved incident neutron spectrum from 14 MeV Thick-Target Deutron Breakup (TTDB), measured *in situ* with a newly developed, kinematic-based neutron spectrometer. Some experimental challenges arising due to the time structure of the neutron beam motivated the development of a forward modeling approach for analysis and interpretation of GENESIS data. This presentation will describe the design of the forward model and preliminary results from the

^{56}Fe experiments, including double-differential gamma ray production cross sections, and gamma-ray tagged scattered neutron angular distributions.

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Investigating the M1 scissors resonance in well deformed Samarium isotopes

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The rare-earth isotopic chain of Samarium provides an excellent opportunity to systematically investigate the evolution of nuclear structure effects from the near-spherical (β_2=0.00) ^{144}Sm isotope to the well-deformed system (β_2=0.27) ^{154}Sm. As the nuclear shape changes, statistical properties such as the nuclear level density (NLD) and γ-strength function (γSF) are expected to be affected. In particular resonance modes, such as the Pygmy Dipole (PDR), Scissors Resonances (SR), and the recently discovered Low-Energy Enhancement (LEE) in the rare-earth region may reveal interesting features when their evolution is investigated across several nuclei in an isotopic chain. An experiment was performed at Oslo Cyclotron Laboratory (OCL) where the NaI(Tl) γ-ray array and silicon particle telescopes were utilized to measure particle-γ coincidence events from which the NLDs and γSFs have been extracted below the neutron threshold, using the Oslo Method [1]. The deuteron beam was used to populate excited states in ^{153,155}Sm through transfer reaction (d,pγ). Based on the results from these measurements, the extracted NLDs and γSFs have been used to investigate the evolution of nuclear structure effects, in particular the SR, in ^{153,155}Sm. Furthermore, the results are compared to the microscopic NLD calculations as well as the γSF QRPA calculations based on the D1M Gogny interaction.

In this talk, I will discuss the results of statistical properties of ^{153,155}Sm and put them in perspective of results on other neighboring isotopes extracted from the Oslo Method and the nuclear resonance fluorescence measurements.

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Coupling the HFB plus combinatorial approach for nuclear level densities with D1M+QRPA predictions

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The combinatorial approach for nuclear level densities (NLDs) based on the Gogny D1M effective nucleon-nucleon interaction has shown its ability to provide relevant results [1]. However, it still contains a significant part of phenomenogical inputs. In particular, for low excitation energies, the quality of our results partly stems from the use of vibrational levels whose nature cannot be described within the independent particle picture on which relies the combinatorial approach. An alternative to this problem is offered by the QRPA approach [2] which enables to treat within the same framework both incoherent and coherent excitations as long as they can be described as single quasiparticles. It is therefore natural to combine these two approaches to improve the description of NLDs at low energies of particular relevance to the calculation of radiative neutron capture cross section. We will discuss the strategy behind this project and show the first results we have obtained within this context, including with some comparison with experimental NLD extracted from the Oslo method.

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Non-equilibrium level densities

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Level densities measured e.g., by the Oslo method relate to excited states build on the nuclear ground-state. Level densities built on non-equilibrium shapes may play an important role in nuclear dynamics e.g., in fission. However, such level densities are not possible to directly measure but must be theoretically described. In our approach the level density is calculated by considering all nuclear single-particle states at a given deformation, and combinatorically build up states with given values of excitation energy, angular momentum and parity. The single-particle states are obtained in the well tested FRLDM microscopic-macroscopic model. Out-of-equilibrium shapes often correspond to an unfavored shell structure (positive shell-correction energy), and consequently with large pairing gaps, see Fig.1. In addition, the calculations describe changes of shell structure and pairing with increasing excitation energy.

In this talk I shall describe the role of non-equilibrium level densities in some examples from fission dynamics. In particular, I will discuss the three physical situations:

a) The observed transition from asymmetric to symmetric fission fragment mass distributions as the excitation energy is increased e.g. in the ^{235}U(n, f) reaction. It turns out to be crucial to properly describe the level density of shapes corresponding to the ridge separating symmetric and asymmetric shapes. Pairing properties at such exotic shapes may be important.

b) At scission the excitation energy of the fissioning nucleus is statistically partitioned between the two protofragments determined by their level densities. Since the shapes of the protofragments are different from the corresponding ground-state shapes, non-equilibrium level densities must be calculated. The obtained excitation energy, together with the distortion energy from the transition to ground-state shapes, then determines the neutron multiplicity of each fission fragment and can be compared to data.

c) In the fission of nuclei around ^{258}Fm clustering plays an important role in determining the fission fragments (close to double-magic ^{132}Sn). This clustering effect disappears with increasing excitation energy. This is due to transitions in the fission dynamics from the symmetric super-short fission path to an asymmetric elongated path (that is, not because the shell structure is diminished with excitation energy). The transition involves level densities at the ridge separating the two fission paths.

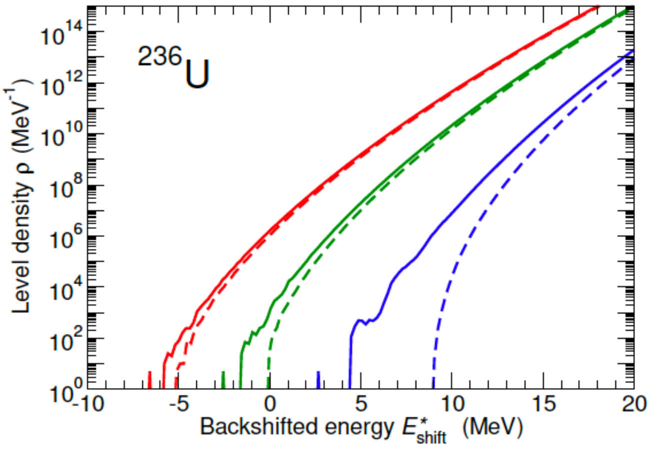

Fig. 1 Calculated level densities in ^{236}U at three different deformations: second minimum (red; equilibrium), outer symmetric fission barrier (blue; non-equilibrium), a shape in between (green; non-equilibrium). The dashed lines show results without pairing. For the plotted backshifted energy, $E^*_{shift} = E^* + E_{pc} + E_{sh}$, the pairing correction and shell correction energies are added to the excitation energy E^*. For the second minimum $E_{pc} = -1.5$ MeV and $E_{sh} = -5.4$ MeV, while for the outer barrier $E_{pc} = -6.1$ MeV and $E_{sh} = +8.7$ MeV.

Measurement of the photoabsorption cross section of ^{24}Mg.

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Abstract. Accurate nuclear data is a key factor in determining the suitability and reliability of many theoretical nuclear models and large scale calculations. This is especially true for cases where the systematic calculations are challenging such as light and deformed nuclei. One of current drives in nuclear astrophysics is the attenuation of ultra high energy cosmic rays by electromagnetic interaction with the cosmic microwave background. This study investigates the total photoabsorption cross section via excitation of the giant dipole resonance of ^{24}Mg, one of the keystone nuclei in these propagation simulations. The giant dipole resonance was probed using 200 MeV protons via the virtual photon production method. This was done at the iThemba labs facility using the Separated Sector Cyclotron and the K600 Spectrometer in the zero degree configuration mode. The high resolution focal plane detection suite combined with the Eikonal model for virtual photon production proved to be an effective combination for extracting the electromagnetic response of light nuclei as is shown in the 24Mg case. The obtained photoabsorption spectrum is presented alongside the total photoabsorption cross section obtained from real gamma measurements.

Studying the gamma decay of fission shape isomers with Nu-Ball2

C. Hiver, J.N. Wilson, M. Lebois

Since the first observation of fission isomers in the early 1960's, more than 30 fission shape isomers have been discovered in the actinide region, from ^{235}U to ^{245}Bk. These long-lived states have a super deformed prolate shape – they can visually be described as rugby balls. They are Class II states, meaning they are trapped in the hollow of the double humped fission barrier. These meta-stable states mostly decay by fission, but for the lightest actinides they can also decay to the first well emitting a high energy gamma ray. Experimental information on states in the second minimum is extremely sparse and is currently limited to just 3 isotopes, namely ^{240f}Pu, ^{236f}U and ^{238f}U.

A great unknown about fission isomers remains the gamma back decay to the first well. For lighter nuclei, the outer fission barrier is higher than the inner barrier, which makes them much more likely to decay back to the first well. The emitted gamma-rays' energy is of the order of the excitation energy of the isomers, about 2 MeV. Gamma rays are much harder to detect efficiently than fission fragments. The only known nuclei for which some gamma-back decay data exists are Uranium isotopes ^{236f}U and ^{238f}U, and with only one unambiguous result provided by experiments performed with Darmstadt 4π Crystal-Ball[2].

In this context we perform high precision spectroscopy of ^{236f}U using the Nu-Ball 2 spectrometer. It is a hybrid spectrometer gamma array, composed of 24 HPGe clovers and 46 Paris phoswitches, covering almost 90% of solid angle with a high energy detection efficiency. The reaction proposed for the experiment is ^{235}U(d,p)^{236f}U – the similar to the Darmstadt experiments. To select events likely to be fission isomers, we will measure the "missing energy", which is defined as the difference of the "input" energy – beam energy and reaction's Q value – and the prompt released energy – the outgoing proton's energy and the prompt gamma ray's energy sum. If the missing energy matches the delayed gamma energy, then the origin is most likely population of the isomer.

Spectroscopy of these gamma-back rays will allow precise determination of the parameters of fission barriers, which play an important role in the theory of fission. A better description of fission will also lead to improved simulations for energy applications which are particularly needed for the next generation of advanced nuclear reactors.

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The r-process sensitivity to variations in the nuclear input

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Many advances have been made in the recent years to explain the origin of the heaviest elements in the Universe, however, many challenges remain from both the astrophysics as well as nuclear-physics points of view. The abundance distribution of about 50% of the elements heavier than iron up to uranium can be explained by the rapid neutron-capture process or r-process, which require nuclear information for an extensive amount of experimentally unknown neutron-rich nuclei.

In this work we have based our r-process nuclear network calculations on state-of the art astrophysical hydrodynamical calculations of NS+NS mergers which include both the early phase, the so-called dynamical ejecta, and the material ejected from the BH-torus which may form after the merger.

By coherently varying the nuclear input to our r-process calculations, we have studied their impact on the final abundance distribution. These include the nuclear masses, the radiative neutron capture rates (including direct capture), beta-decay rates and different properties of fission. A particular emphasis will be made on the impact of varying the nuclear level density and gamma-strength function. In addition, we have investigated the sensitivity to the heating rate produced by the freshly synthesized r-process elements, which impact the kilonova light curve.

Electric and magnetic dipole response in ^{58}Ni from high-resolution inelastic proton, electron and photon scattering

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Inelastic proton scattering at very forward angles is an excellent tool for studying the dipole response in nuclei [1]. Reactions with intermediate proton energies of a few hundred MeV and scattering angles at extreme forward angles are particularly suited to investigate the electric dipole response over a wide excitation energy range. This enables the extraction of photoabsorption cross sections as well as the electric dipole polarizability. The later is correlated to the neutron-skin thickness and the symmetry parameter in the equation of state [2, 3]. Furthermore the isovector spin-flip M1 resonance can be probed due to the strong spin-isospin dependent part of the effective proton-neutron interaction at small momentum transfer.

An inelastic proton scattering experiment with a 295 MeV proton beam on a ^{58}Ni target was performed at the Research Center for Nuclear Physics in Osaka. Scattering angles from 0.4° to 5.15° were measured, covering an excitation energy range from 5 MeV to 25 MeV. A high energy resolution of $\approx$ 20 keV FWHM could be achieved due to dispersion matching. Electric and magnetic dipole contributions to the cross section were obtained by performing a multipole decomposition analysis based on DWBA calculations. Furthermore a peak-by-peak analysis was performed for well-resolved transitions up to 13 MeV.

A detailed comparison of the present experiment to measurements using electromagnetic probes such as photons [4, 5] and electrons [6] was performed. This allows the magnetic dipole strength to be decomposed into spin and orbital contributions and the isospin structure to be studied. Moreover it reveals an unusual nature of some low-energy electric dipole transitions pointing towards a toroidal nature[7].

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γ-decay of the Pygmy Dipole Resonance of ^{150}Nd

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The isovector giant dipole resonance dominates the E1 photon strength function of atomic nuclei. Axial nuclear deformation results in the K-splitting of this resonance into two parts, corresponding to oscillations along and perpendicular to the nucleus' symmetry axis. A similar sensitivity is expected for the Pygmy Dipole Resonance [1], a low-lying enhancement of E1 strength observed for heavy nuclei that is often attributed to a semi-collective oscillation of a neutron skin.

In this work, the dipole response of the deformed ($\beta_2 = 0.285$) ^{150}Nd was studied in nuclear resonance fluorescence experiments. These were performed at the Darmstadt High Intensity Photon Setup (DHIPS) [2] at the S-DALINAC with continuous bremsstrahlung beams and with quasi-monochromatic linearly polarized photon beams at the High Intensity γ-ray Source (HIγS) at the γ^3 setup [3]. The low energy of the 2_1^+ state of heavy deformed nuclei makes photonuclear experiments challenging. For the first time for such a nucleus, a new high-resolution operating mode of HIγS made it possible to separate the decay of excited strength to the 0_1^+ state from the decay to the 2_1^+ state at $E(2_1^+) = 130.21\,\mathrm{keV}$ without resolving individual transitions for excitation energies of 3 MeV to 7 MeV. The resulting average decay branches and partial photoabsorption cross sections are presented and discussed.

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Development of (p,p$'\gamma$) detection capabilities at iThemba LABS through the study of low-lying $E1$ strength in ^{58}Ni

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This study aims to test and develop the (p,p$'\gamma$) detection capabilities of the K600 magnetic spectrometer coupled to the Ball of Germanium and Lanthanum bromide detectors (BaGeL) at zero degrees at iThemba LABS. This is done through an investigation into the low-lying dipole strength of ^{58}Ni with a proton beam of $E_\mathrm{p} =$ 80 MeV. The use of proton inelastic scattering at forward angles favours the electric dipole excitation and thus gives access to the full strength of the $E1$ resonance. Detecting these protons in coincidence with the subsequent γ decay improves the selectivity to low spin transfer, allows for the separation of nearby excitations and the assignment of multipolarities. Moreover, the high energy-resolution γ detectors used in decay studies allow for an improvement of the standard energy resolutions obtainable with magnetic spectrometers. Results from both (p,p') and (p,p'γ) for the low-lying states of ^{58}Ni will be compared to elucidate the advantages of coincidence measurements at iThemba LABS. Important decay paths as well as transition levels will be presented.

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Impact of the experimentally constrained ^{102,103}Mo(n,γ) reaction rates on the Mo, Ru and Rh abundances predicted for the *i*-process

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Heavy element nucleosynthesis is a longstanding question in Nuclear Astrophysics. Recent observations of carbon-enhanced metal poor stars (CEMP) show that observed abundance patterns cannot be reproduced by the traditional neutron-capture processes (s and r), and indicate that an additional process known as the intermediate neutron-capture process (i-process) is needed to describe observed abundances [1]. Occurring at intermediate neutron densities, the majority of nuclear physics properties (mass, half-life, etc.) are well constrained, however the neutron-capture cross sections and reaction rates remain largely unmeasured. Using the β-Oslo method [2], an indirect technique in which the nuclear level density (NLD) and γ-strength function (γSF) are extracted following the β-decay of a neutron-rich parent, the neutron-capture cross section can be experimentally determined. In this work, ^{103,104}Mo were studied at the National Superconducting Cyclotron Laboratory via the β-decay of ^{103,104}Nb and detected using the Summing NaI (SuN) total absorption spectrometer [3]. Results on the NLD, γSF, neutron-capture cross sections, and reaction rates of ^{102}Mo(n,γ)^{103}Mo and ^{103}Mo(n,γ)^{104}Mo using the β-Oslo method will be presented. These new rates were used in Nucleosynthesis Grid (NuGrid) extended network calculations to determine their impact on Mo, Ru, and Rh abundances predicted in the i-process; results from this study will also be discussed.

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