Nuclear Physics in Astrophysics - X

Sunday, 4 September 2022 - Friday, 9 September 2022

CERN

Book of Abstracts

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Poster session / 2

Quantum vortex in neutron star's crust at finite temperatures

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Bardeen–Cooper–Schrieffer theory explains how the heat capacity of the superfluid vanishes when the temperature approaches zero. Various mechanisms may suppress the pairing gap in the superfluid, leading to an increased heat capacity. In turn, this may translate to changing the cooling rate and the thermal evolution of neutron stars. The presence of a vortex in a superfluid neutron matter will add extra degrees of freedom in which the energy is stored, hence contributing to the heat capacity.

From fully microscopic simulations, employing Superfluid Local Density Approximation (SLDA), it is possible to calculate the finite-temperature energy of the system. We use Brussels-Montreal type energy density functional, a very accurate nuclear functional designed to agree with existing astrophysical constraints. Using this state-of-the-art functional, we estimate the change in the heat capacity that results from the mere existence of a vortex in the system.

Field of work:

Tuesday - Session 1 / 4

The long-standing connection of BBN and Indirect measurements: the ^{3}He(n,p)^{3}H reaction at Big Bang energies

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Nuclear reactions play a key role in the framework of the Big Bang Nucleosynthesis. A network of 12 principal reactions has been identified as the main path which drives the elemental nucleosynthesis in the first twenty minutes of the history of the Universe. Among them an important role is played by neutron-induced reactions, which, from an experimental point of view, are usually a hard task to be measured directly. Nevertheless big efforts in the last decades have led to a better understanding of their role in the primordial nucleosynthesis network. In this work we apply the Trojan Horse Method to extract the cross section at astrophysical energies for the ^{3}He(n,p)^{3}H reaction after a detailed study of the ^{2}H(^{3}He,pt)H three–body process. The experiment was performed using the ^{3}He beam, delivered at a total kinetic energy of 9 MeV by the Tandem at the Physics and Astronomy Department of the University of Notre Dame. Data extracted from the present measurement are compared with other published sets available in literature. Astrophysical applications will also be discussed in details.

Field of work:

Poster session / 5

ANC experiments for nuclear astrophysics: the $^{26}\mathrm{Si}(p,\gamma)^{27}\mathrm{P}$ case

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The presence of ^{26}Al ($T_{1/2}$=1.04 Myr) in the interstellar medium has been strongly debated through the years: its 1.809 MeV γ-ray line has been appointed as a tracer of the recent nucleosynthesis in our galaxy, and its presence have been found spread along Galactic plane. Observations support the idea that this isotope can been formed through nucleosynthesis in massive stars and core-collapse Supernovae, but also Wolf-Rajet objects, AGB-stars, Novae and X-ray burst have been proposed as nucleosynthesis site. In all this sites, ^{26}Al can be produced via the $^{26}\mathrm{Mg}(p,\gamma)^{25}\mathrm{Al}(\beta^+)^{25}\mathrm{Mg}(p,\gamma)^{26}\mathrm{Al}^g$ reaction chain. A clear comprehension of the process is hampered by the presence of an isomeric state $^{26}\mathrm{Al}^m$($T_{1/2}$=6.34 sec), which can be directly fed by the $^{25}\mathrm{Al}(p,\gamma)^{26}\mathrm{Si}(\beta^+)^{26}\mathrm{Al}^m$ chain, reducing the quantity of $^{26}\mathrm{Al}^g$ produced in the process. The ^{26}Si produced in this way can also be depleted by the $^{26}\mathrm{Si}(p,\gamma)^{27}\mathrm{P}$ that will interfere with the creation of the isomeric state. This reaction can be therefore useful to understand the ratio between $^{26}\mathrm{Al}^g$ and $^{26}\mathrm{Al}^m$.
Experiments involving ^{26}Si are challenging due to its short half-life ($T_{1/2}$=2.24 sec), and for this reason an indirect measurement of the $^{26}\mathrm{Si}(p,\gamma)^{27}\mathrm{P}$ has been performed using the $^{26}\mathrm{Mg}(d,p)^{27}\mathrm{Mg}$ one, employing the so-called Asymptotic Normalization Coefficient (ANC) method in its extension for mirror nuclei. Using this method, it was possible to extract the contribution to the cross section of the direct capture in the ground state and the resonant one in the 1st excited state of ^{27}P. The reaction rate has been also evaluated, finding an enhancement with respect to the one already available in literature. In this contribution, after a brief overview about the ANC method and its extension for mirror nuclei, the experimental results regarding the $^{26}\mathrm{Si}(p,\gamma)^{27}\mathrm{P}$ will be presented.

Poster session / 6

Underground measurement at LUNA found no evidence for a low-energy resonance in the ^{6}Li(p, γ)^{7}Be reaction

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The ^{6}Li(p, γ)^{7}Be reaction is involved both in Big Bang Nucleosynthesis and ^{6}Li depletion in pre-main and in main sequence stars.
The ^{6}Li(p, γ)^{7}Be S-factor trend was poorly constrained at astrophysical energies because of conflicting experimental results reported in literature. A recent direct measurement, indeed, found a resonance-like structure at $E_{c.m.}$ = 195 keV, corresponding to an excited state at $E_x \sim$ 5800 keV in ^{7}Be which, however, has not been confirmed by either other direct measurements or theoretical calculations.

In order to clarify the existence of this resonance, a new experiment was performed at the Laboratory for Underground Nuclear Astrophysics (LUNA), located deep underground in Gran Sasso Laboratory. Thanks to the extremely low background environment, the ^{6}Li(p, γ)^{7}Be cross section was measured in the center-of-mass energy range E = 60-350 keV with unprecedented sensitivity. No evidence for the alleged resonance was found. LUNA results was confirmed by latest published indirect determination of ^{6}Li(p, γ)^{7}Be S-factor.

In the talk a detailed description of the experiment and of the final results will be provided.

Field of work:

Monday - Session 2 / 7

The TRISR Project – A Storage Ring for Neutron Captures on Radioactive Nuclei

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Heavy-ion storage rings connected to radioactive beam facilities offer a unique environment for nuclear physics experiments. However, so far they have been only coupled to in-flight fragmentation facilities, for example the ESR and the CRYRING at GSI Darmstadt/ Germany, the CSR at HIRF in Lanzhou/ China, and the Rare RI Ring at RIKEN Nishina Center in Japan.
Neutron capture reactions play a crucial role for the understanding of the synthesis of elements heavier than iron in stars and stellar explosions via the slow (s), intermediate (i), and rapid (r) neutron capture processes. Whereas most of the s-process neutron captures occur on stable or long-lived nuclei along the line of stability and have been experimentally constrained in the past decades, measuring directly the neutron capture cross sections of short-lived nuclides (T1/2 « 1 y) has been so far out of reach and lead to large deviations between various Hauser-Feshbach predictions for very neutron-rich nuclei.
Recently, a new method to couple a neutron-producing "facility" to a RIB storage ring was outlined [1]. The initial proposal involved a storage ring running through a high flux fission reactor to achieve high enough neutron densities. Later, a facility with a spallation neutron source was suggested [2], a proposal that is presently investigated at Los Alamos National Laboratory [3].
Our storage ring project at TRIUMF proposes to use instead a compact neutron generator coupled to a low-energy storage ring (E= 0.1-10 MeV/u) and the existing ISAC radioactive beam facility. The project is currently seeking funding in Canada for a feasibility study. The TRISR project is presented, and measurements are outlined that would become possible, especially with the availability of clean, intense radioisotope beams from the new ARIEL facility.
If this world-wide unique facility is funded and built, it could become a key player and lead within a decade of operation to a major reduction of uncertainties for neutron capture cross sections of radioactive nuclei.

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Tuesday - Session 2 / 8

Presolar Grain Isotopic Ratios as Constraints to Nuclear and Stellar Parameters of Asymptotic Giant Branch Star Nucleosynthesis

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Recent models for evolved low-mass stars (with M <=3 Mo), undergoing the asymptotic giant branch (AGB) phase assume that magnetic flux-tube buoyancy drives the formation of 13C reservoirs in He-rich layers. We illustrate their crucial properties, showing how the low abundance of 13C generated below the convective envelope hampers the formation of primary 14N and the ensuing synthesis of intermediate-mass nuclei, like 19F and 22Ne. In the mentioned models, their production is therefore of a purely secondary nature. Shortage of primary 22Ne has also important effects in reducing the neutron density. Another property concerns AGB winds, which are likely to preserve C-rich subcomponents, isolated by magnetic tension, even when the envelope composition is O-rich. Conditions for the formation of C-rich compounds are therefore found in stages earlier than previously envisaged. These issues, together with the uncertainties related to several nuclear physics quantities, are discussed in the light of the isotopic admixtures of s-process elements in presolar SiC grains of stellar origin, which provide important and precise constraints to the otherwise uncertain parameters. By comparing nucleosynthesis results with measured SiC data, it is argued that such a detailed series of constraints indicates the need for new measurements of weak-interaction rates in ionized plasmas, as well as of neutron-capture cross sections, especially near the N = 50 and N = 82 neutron magic numbers. Nonetheless, the peculiarity of our models allows us to achieve fits to the presolar grain data of a quality so far never obtained in previously published attempts.

Poster session / 9

Studies of low-energy K- - nucleus/nuclei interactions with light nuclei by AMADEUS

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The experimental investigation of the low-energy negatively charged kaons interaction with the nuclear matter is very important to understand the strength of the K-nuclei interaction and to provide essential input for understanding of the non-perturbative QCD in the strangeness sector. It has strong consequences in various sectors of physics, like nuclear and particle physics as well as astrophysics.

The AMADEUS collaboration aims to provide new experimental contraints to the K-–N strong interaction in the regime of non-perturbative QCD, exploiting low-energy –hadronic interactions with light nuclei (e.g. H,4He,9Be and 12C). The investigations are mainly focused on Λ(1405) properties studies and clarification of an existence of deeply bound kaonic states. The studies are performed with low-momentum kaons (~127 MeV/c) produced at the DAΦNE collider ideal to explore both

stopped and in-flight ⊠–nuclear captures. The KLOE detector is used as active target, allowing to achieve excellent acceptance and resolutions for the data.

In the talk the results obtained from the recent AMADEUS studies will be presented.

Field of work:

Thursday - Session 2 / 10

Measurement of the bound-state beta decay of Thallium-205 and its implications on the fate of Lead-205 in the early solar system

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Understanding the production and survival of $^{205}\mathrm{Pb}$ in stars is pivotal as $^{205}\mathrm{Pb}$ is the only short-lived radionuclide that is produced exclusively by the slow neutron capture process (*s*-process). The ratio of radioactive $^{205}\mathrm{Pb}$ to stable $^{204}\mathrm{Pb}$, when compared to the expected value from the continuous galactic nucleosynthesis, helps to constrain nucleosynthesis activity just prior to the Sun's birth. Concerns were raised on the validity of $^{205}\mathrm{Pb}$ as a cosmochronometer [1] as the $^{205}\mathrm{Pb}/^{204}\mathrm{Pb}$ ratio is strongly affected due to the existence of the 2.3 keV excited state in $^{205}\mathrm{Pb}$, from which the electron capture decay to $^{205}\mathrm{Tl}$ is expected to be significantly faster than from the ground state ($t_{1/2}$ = 17.3(7) Myr). However, it was pointed out [2] that the bound-state beta decay [3], an exotic decay mode in which an electron is directly created in one of the empty atomic orbitals instead of being emitted into the continuum, of $^{205}\mathrm{Tl}$ could counter-balance the reduction of $^{205}\mathrm{Pb}$.

In this talk, the authors report on the first direct measurement of the half-life of the bound-state beta decay of fully-stripped $^{205}\mathrm{Tl}^{81+}$ ions to the 2.3 keV excited state of $^{205}\mathrm{Pb}^{81+}$ ions [4], which was realized in the spring beamtime at the heavy-ion storage ring ESR at GSI, Darmstadt in 2020, wherein the entire accelerator chain was employed. $^{205}\mathrm{Tl}^{81+}$ ions (with no electron) were produced with the projectile fragmentation of $^{206}\mathrm{Pb}$ primary beam on $^{9}\mathrm{Be}$ target, separated in the fragment separator (FRS), accumulated, cooled, and stored for different storage times (up to 10 hours) in the experimental storage ring (ESR). The consequences of the measurement on the source of the live $^{205}\mathrm{Pb}$ in the early solar system will be stressed in the talk.

This research has been conducted in the framework of the SPARC, ILIMA, LOREX, NucAR collaborations, experiment E121 of FAIR Phase-0 supported by GSI. The authors received support from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (Grant Agreement No. 682841 "ASTRUm").

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Friday - Session 1 / 11

The importance of targetry in nuclear physics and astrophysics experiments

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This contribution highlights the importance of targetry in nuclear physics and astrophysics experiments. Three different stages are described: 1) production, purification and characterization of starting materials, with a concise description of the opportunity offered by PSI in this respect; 2) target manufacture, with emphasis on the last developments obtained at PSI; 3) characterization of final targets. The effects of each stage on the result of nuclear experiments, such as neutron cross sections measurements, is addressed.

Tuesday - Session 3 / 12

Astrophysical impact of new experimental data of nuclei around the 78Ni

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How elements are made in the Universe is an open long-standing question. Several processes are invoked to explain the observed elemental abundances in our Solar System [1] and in our galaxy [2].

Complex astrophysical simulations are used to study the origin of the heavy elements and quantify the contribution of the r-process to the observed elemental abundances (see e.g. [3]). The r-process proceeds through very neutron rich nuclei, most of them experimentally inaccessible so far and theoretical estimates make up for the lack of experimental data, introducing large uncertainties in the calculated abundances [4]. The main decay mode of such nuclei is beta-decay accompanied by the emission of one or more neutrons. Accurate experimental data of these nuclei, particularly their half-lives (T_{1/2}) and neutron emission probabilities (P_{xn}), will help to fine-tune theoretical models and thus contribute to a reduction the uncertainties for the calculated elemental abundances. This will allow a more meaningful comparison with the observed abundances and help to constrain the astrophysical conditions better, e.g. via reverse engineering methods [5].
The BRIKEN (Beta delayed neutron measurements at RIKEN) collaboration was launched in 2017 to provide precise new measurements of T_{1/2} and P_{xn} of very neutron rich nuclei which are important for the r-process nucleosynthesis [6]. We will report about the astrophysical impact of new experimental values for 38 nuclei between 75Co and 94Br, of which 12 P_{xn} and 7 T_{1/2} are measured for first time while improving the remaining.
Several explosive astrophysical scenarios were explored and we will present results for two, namely magneto-rotationally driven core-collapse supernova and disk ejecta in the aftermath of a neutron star merger. For these scenarios, sizable long range effects reaching lanthanides are observed.
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Field of work:

Poster session / 13

Binding energies, proton-neutron pairing and α-like quartetting for proton-rich nuclei close to N=Z line

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Binding energies, proton-neutron paring and α-like quartetting in proton-rich nuclei close to N=Z line

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The modelling of nucleosynthesis processes triggered by rapid proton capture requires accurate predictions for the binding energies of proton-rich nuclei far from stability. Such predictions are particularly difficult for nuclei close to the N = Z line, which are more bound than the neighboring nuclei. This extra binding, called Wigner energy, is not accounted for by the microscopic mass models [1]. Consequently, in these mass models the contribution of Wigner energy to the binding energy is added through a phenomenological term. For many years it was speculated that Wigner energy might be related to the proton-neutron (pn) pairing, but this fact was not proved by realistic mean-field calculations. Recent studies have shown that the pn pairing correlations can be accurately described not by Cooper pairs, as considered in the majority of mean-field calculations [2, 3], but by α-like quartets [4–12]. By employing a quartet formalism it was then demonstrated that the pn pairing can account for a large fraction of the Wigner energy [6, 10]. Very recently it was also shown [13] that self-consistent mean field calculations, with the pn pairing treated in terms of α-like quartets, provide reliable binding energies for nuclei with |N −Z|=0,2,4 and with the atomic masses up to A=100, where the rp-process starts to be inhibited by the α decay.

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Field of work:

Thursday - Session 3 / 14

Precision Measurement of the 12C(a,g) Reaction With Gamma Beams and a TPC Detector *

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The carbon/oxygen (C/O) ratio at the end of stellar helium burning is the single most important input to stellar evolution theory. However, it is not known with sufficient accuracy, due to large uncertainties in the cross section of the 12C(a,g)16O reaction. We present results based on a new method, which is significantly different from the experimental efforts of the past four decades [1]. With data measured inside one (TPC) detector with vanishingly small background, precise angular distributions of the 12C(a,g)16O reaction were obtained by measuring the inverse 16O(g,a)12C reaction with gamma-beams from the HIgS facility, and an optical readout Time Projection Chamber (O-TPC) detector.

We agree with current world data for the total reaction cross section and further evidence the strength of our method with angular distributions measured at Ecm = 2.0 - 2.6 MeV, where the interference angle of the ell = 1 and ell 2 partial waves (phi_12) varies rapidly. We measure, for the first time over this energy range (2.0 - 2.6 MeV), phi_12 values that agree with fundamental predictions based on the unitarity of the scattering matrix and reconcile these historical disagreement of data with Unitarity. We propose a "Unitarity-Test" of data to elucidate systematic error in measured angular distributions.

postscript note In a recent (April 11 - 15, 2022) measurement at the HIgS facility, our collaboration [2] measured data of the 16O(g,a) reaction using the same method of a TPC operating in gamma beams, but with an improved electronic readout TPC (eTPC) detector constructed at the University of Warsaw. First data measured at Eg > 11 MeV (Ecm > 3.8 MeV) are submitted to this NPA10 meeting [2].

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Thursday - Session 2 / 15

The study of the 20Ne(p,g)21Na reaction at LUNA

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The NeNa and MgAl cycles are relevant to the synthesis of Ne, Na, and Mg isotopes: a detailed knowledge of the involved nuclear processes is fundamental to determine the nucleosynthesis during various stages of stellar evolution, in particular in the Red Giant Branch (RGB) and Asymptotic Giant Branch (AGB) phases, as well as in Novae explosions. Key reactions of these cycles are also thought to be the main agents of the observed anti-correlations in O-Na and Al-Mg abundances exhibited by the stars of Galactic globular clusters.
The experimental activity at the LUNA-400 gas target line is presently focused on the study the ^{20}Ne(p,γ)^{21}Na reaction at proton energies below 400 keV. Having the slowest reaction rate, the ^{20}Ne(p,γ)^{21}Na reaction controls the speed at which the entire Ne-Na cycle proceeds: existing uncertainties on the cross section severely affect the estimated elements production in the whole NeNa cycle.
During 2021, the resonance at E_R = 366 keV in the ^{20}Ne(p,γ)^{21}Na reaction has been studied: a complete scan was made with the two HPGe detectors installed on the setup and the resonance strength and branching ratios for the γ-ray cascade measured in detail. The effect of the beam energy straggling was also measured in order to properly account for that in the analysis and to minimize the related uncertainty.
Moreover, the low background of the LUNA facility has already allowed to observed gamma transitions of the direct capture process down to proton energies of 260 keV. This is an important confirmation that the experimental setup is sensible to this component over a broad energy range.

In the talk the experimental setup will be described, and the results discussed.

Wednesday - Session 1 / 16

First measurement of a p-process reaction using a radioactive ion beam

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Approximately 30 stable nuclides on the neutron-deficient side of stability cannot be produced via the same neutron-capture driven mechanisms responsible for synthesizing all other elements heavier than iron. These "p-nuclei" are instead thought to originate from photodisintegration reactions on s- and r-process seed nuclei, which can occur in the extreme high-temperature environments of core-collapse supernovae. However, significant discrepancies exist, in some cases extending to orders of magnitude, between observed p-nuclei abundances, obtained via isotopic analysis of meteorite samples, and supernovae model predictions. Improvements on the available nuclear reaction data is an essential part of solving the puzzle of the p-nuclei, but experimental efforts in this regard must overcome significant technical challenges. This talk will describe the first ever measurement of a p-process reaction cross-section obtained with a radioactive ion beam. The 83Rb(p,γ)84Sr reaction was investigated at the TRIUMF-ISAC facility using a radioactive 83Rb beam impinged on CH2 foil targets. The recoiling reaction products were selected by m/q using the newly commissioned Electromagnetic Mass Analyser (EMMA), with γ-rays detected in-coincidence using the TIGRESS HPGe array. The selectivity of the EMMA-TIGRESS set-up allowed for detection of low-lying transitions in 84Sr populated by 83Rb(p,γ)84Sr. The measured partial cross-section was then combined with statistical model calculations to obtain a total reaction cross-section that is 4x smaller than predicted, in-turn affecting the abundance of the 84Sr p-nucleus predicted by massive-star models.

Poster session / 17

Turbulence and nuclear reactions in 3D hydrodynamics simulations of massive stars

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Our knowledge of massive star evolution and nucleosynthesis is limited by uncertainties related to multi-dimensional processes taking place in stellar interiors. Only recently, theoretical works are starting to improve 1D stellar evolution codes with the help of 3D hydrodynamics models, which are used to study multi-D processes on a short time range (minutes or hours) and improve 1D prescriptions.
In this talk, I will present results coming from a new set of high-resolution hydrodynamics simulations of the neon-burning shell in a massive star, employing the PROMPI code. I will focus in particular on the interplay between turbulence and nuclear reactions, discussing the impact that different boosting factors of the nuclear rates have on the results.

Tuesday - Session 2 / 18

The intermediate neutron capture process in AGB stars

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Despite considerable progresses over the past few decades, the origin of trans-iron elements is not yet fully understood. In addition to the slow (s) and rapid (r) neutron capture processes, an intermediate neutron capture process (i-process) is thought to exist at neutron densities intermediate between the s- and r-processes. The existence of this process is supported by the observation of metal-poor stars whose chemical compositions are intermediate between the s- and r-processes (the so called r/s-stars). The i-process is triggered when protons are mixed in a convective helium-burning zone (proton ingestion event or PIE). The astrophysical site(s) hosting PIEs and thus the i-process is (are) actively debated. Among the various possible sites, the early Asymptotic Giant Branch (AGB) phase of low-mass stars is a promising one. In this presentation, I will focus on the development of the i-process in state-of-the-art AGB stellar models of various masses and metallicities computed with the STAREVOL code. I will first show how the AGB evolution of models suffering a PIE can be dramatically altered. Then, I will discuss the i-process nucleosynthesis accompanying a PIE, identify key reaction rates, highlight the chemical fingerprint of these stars, present i-process yields as a function of mass and metallicity and eventually discuss the implication on galactic chemical evolution.

Wednesday - Session 2 / 19

New tool for sensitivity studies of r-process nucleosynthesis — a case study of the rare earth peak

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The rapid neutron capture process (r-process) is a complex nucleosynthesis mechanism for the creation of heavy nuclei, which occurs under extreme astrophysical conditions, such as binary neutron star mergers and core-collapse supernovae. Not only are the predictions of the r-process abundance pattern affected by such astrophysical conditions, the calculations also involve thousands of neutron-rich nuclides. While many of the neutron-rich nuclei may become experimentally accessible in the near future, it is important to accurately estimate the influence of each nuclear observable, such as masses, β-decay half lives, neutron capture cross sections, in order to guide the experimental efforts and effectively reduce the nuclear physics uncertainties in the r-process simulations.

In order to achieve such goals, a sensitivity analysis can be employed to assess the influence of the nuclear observables in the nuclear reaction network calculations. We introduce a novel technique called "variance-based sensitivity analysis" method, which not only can provide accurate estimates of interpretable sensitivity indices, but also allows us to gain insights into the dependences of the calculated abundances on the nuclear physics inputs through the inspection of Monte Carlo samples. In this presentation, we point out several limitations of the previously introduced sensitivity analysis methods, and discuss how our method can overcome them and extend the framework to correlated inputs/outputs. We demonstrate our method using experimental β-decay data from the BRIKEN campaign as well as several theoretical models, focusing on the rare-earth peak of the r-process abundance peak at $A \sim 165$. The rare-earth peak is postulated to form during the freeze-out of the r-process nucleosynthesis, when the neutrons in the environment are almost exhausted, and neutron captures and beta-decays operate on similar time scales while the material decays back to stability. Our new sensitivity analysis can be utilized to understand the competition of β-decays and neutron captures with respect to the formation of the rare-earth peak during the freeze-out, by analyzing the Monte Carlo samples generated for the sensitivity analysis.

Poster session / 20

Particle detectors for the observation of rare nuclear decay modes in storage rings

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Nuclear data such as masses, half-lives, reaction cross-sections and information on decay modes are vital in developing a deeper understanding of nucleosynthetic processes and the origin of the elements. However, these properties are not always constant, and can depend strongly on the atomic charge state experienced in different stellar environments. When nuclei exist as highly charged ions (HCI) for an extended period, they may exhibit changes in decay rates, as well as the availability of entirely new decay modes. This may have profound impact on nucleosynthesis pathways. Some examples of these effects include: the suppression of electron capture on fully ionised ⁷Be

extending its effective half-life in stellar cores and impacting energy generation [1]; the bound-state β-decay of HCIs, which may otherwise be stable at lower ionisation states, and its impact on the *s*-process pathway [2]; or the shift in decay rate of highly charged α-emitters, with potential consequences for *r*-process nucleosynthesis [3].

Storage rings offer one option to explore rare and exotic decay modes which occur only under extreme stellar conditions. As stored ions decay and their mass-to-charge ratio changes, their trajectory changes and may leave the acceptance of the storage ring. Strategically placed particle detectors, such as the prototype CsISiPHOS detector [4], can then observe the decay products and, along with in-ring detectors, conduct symbiotic measurements of several nuclear properties at once under conditions not easily attainable by other means.

As part of FAIR Phase-0, experiments conducted by the ILIMA collaboration at the Experimental Storage Ring (ESR) at GSI, Germany, aim to use novel detection techniques to study these exotic decay modes, as well as provide a new method by which to measure β-delayed neutron emission. A newly commissioned upgraded particle detector will significantly increase the efficiency of these measurements.

Presented here is a detailed look at these detectors, their design and results from a commissioning run in Spring 2022. We will demonstrate their use for unique measurements of changes in decay rates of highly charged ions and how their use in storage rings can complement and advance more traditional methods.

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Tuesday - Session 1 / 22

Measuring the 3He(α,γ)7Be and the 6Li(p,γ)7Be astrophysical factors down to zero energy using the ANC method

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Radiative-capture reactions leading to the formation of 7Be bear a particular interest in the field of nuclear astrophysics.
The most important ones are the 3He(α,γ)7Be and the 6Li(p,γ)7Be reactions.
The former is one of the primary sources of uncertainty in the prediction of the 7Be and 8B neutrino fluxes, being the first reaction of the 2nd and 3rd branch of the p−p chain. Despite its importance and the large number of experimental and theoretical works devoted to it, the knowledge of the reaction cross section at energies characterizing the core of the Sun (15 keV - 30 keV) is limited and further experimental efforts are needed to reach the desired (≈3%) accuracy.
The 6Li(p,γ)7Be reaction influences a variety of astrophysical scenarios, including big-bang and stellar nucleosynthesis, especially in relation to the primordial 7Li abundance problem. Since the production mechanism of 6Li and 7Li are completely different, the 6Li/7Li isotopic ratio can be used either to constrain the lithium production mechanisms and/or the galactic enrichment processes, e.g., the role played by spallation or by deep circulation in evolved stars. This, in turn, calls for an accurate determination of the 6Li(p,γ)7Be astrophysical S-factor. However, conflicting results of direct measurements have been published, reporting contradictory low-energy trends.
The precise knowledge on the external capture contribution to both reaction cross sections is crucial to assess the trend of the astrophysical factor at astrophysical energies. To this purpose, in this work we report on the indirect determination of the external capture contribution using the Asymptotic Normalization Coefficient (ANC) technique. The ANC is especially suited since the direct capture

cross section is proportional to the square of the ANC, so the ANC approach provides a direct link to the reaction rate and to astrophysical applications. To extract the ANCs for the 3He+α and 6Li+p channels, the angular distributions of deuterons emitted in the 6Li(3He,d)7Be α- and p-transfer reactions were measured with high precision at beam energies E3He= 3.0 MeV and E3He= 5.0 MeV for both the transfer to 7Be ground state and first excited state. The ANCs were then extracted from comparison of DWBA calculations to the measured data and the zero energy astrophysical S-factors were calculated using the modified two-body potential method. Particular care was adopted to size the model dependence of the results.
In the case of the 3He(α,γ)7Be reaction, the zero energy astrophysical was found to equal 0.534±0.025 [0.015; 0.019] keVb (in square parentheses, the first contribution is the experimental error dominated by the statistical uncertainty, while the second contribution is the systematic error due to the model dependence). The result agrees with the recommended value by Adelberger et al. (Solar Fusion II) [1], reducing the uncertainty from 7.1% to 4.6%. More details can be found in Ref.[2].
In the case of the 6Li(p,γ)7Be astrophysical factor, the present independent study supports the recent extrapolation of Piatti et al. [3], and thus disfavors the conclusions drawn by He et al. [4]. The calculated zero-energy astrophysical factor was found to equal 96.5±5.7 eVb, the error being mostly due to systematic uncertainties arising from the variation of the geometric parameters of the adopted Woods-Saxon potential. This value is in excellent agreement with the extrapolated S factor to zero energy [S(0) = 95 ± 9 eVb] of Piatti et al. [3], with an uncertainty 1.6 times lower. A more detailed discussion is given in Ref.[5].

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Tuesday - Session 4 / 23

Slow White Dwarf Mergers as a New Galactic Source of Trans-Iron Elements

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The astrophysical origins of the heaviest stable elements that we observe today in the Solar System are still not fully understood. While thermonuclear supernovae (SNe Ia) are known to have forged about two-thirds of the iron content in the Solar System, recent studies have demonstrated that H-accreting white dwarfs (WDs) in a binary system exploding as SNe Ia could be an efficient p-process source beyond iron. However, both observational evidences and stellar models calculating the progenitor phase indicate that less than 6% of these systems eventually explode as a SNe Ia.

In this work, we calculated the evolution and nucleosynthesis in slowly merging carbon-oxygen WDs using the stellar code MESA. As our models approach the Chandrasekhar mass during the merger phase, the dominant neutron source is the ^{22}Ne(α,n)^{25}Mg reaction. This is activated in the external layers of the primary WD, where the carbon-rich material accreted from the secondary WD is burned via the ^{12}C+^{12}C reaction, which provides the necessary α-particles via the ^{12}C(^{12}C,α)^{20}Ne channel. The resulting neutron capture abundance distribution closely resembles a weak s-process one and peaks at Zr, which is overproduced by a factor of 100 compared to solar. The mass of the most external layers enriched in first-peak s-process elements crucially depends on the ^{12}C+^{12}C reaction rate, being 0.06 Msun when our standard ^{12}C+^{12}C reaction rate is adopted, or even 0.1 $M_{\odot}$ when the ^{12}C+^{12}C reaction rate is increased by a factor of two. Finally, we discuss our first explosive nucleosynthesis models implementing this enriched trans-Fe abundance distribution as the initial composition. Our results indicate that slow white dwarf mergers can efficiently produce the lightest p-process isotopes (such as ^{74}Se, ^{78}Kr, ^{84}Sr, ^{92}Mo and ^{94}Mo) via photo-disintegration reactions if they explode via a delay detonation mechanism, or eject the unburned external layers highly enriched in first peak s-process elements in the case of a pure deflagration. In both cases, we propose for the first time that slow white dwarf mergers in binary systems may be a new relevant astrophysics source for elements heavier than iron.

Poster session / 24

Targeting the solar-abundance problem with a direct measurement of the ^{14}N(p,γ)^{15}O reaction using DRAGON

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As the slowest reaction in the carbon-nitrogen cycle of hydrogen burning, the ^{14}N(p,γ)^{15}O reaction modulates the rate of energy generation in stars in the cycle and thus determines the time spent on the main sequence. Astrophysical challenges, such as the age determination of globular clusters or the solar-abundance problem can be targeted by improving the precision on the low-energy S-factor that depends on the extrapolation over a wide energy range. This experiment aims to reduce the rate uncertainties by measuring the resonant and non-resonant cross sections within an energy range of $E_{c.m.} \sim 0.9$ MeV to ~ 1.7 MeV in the ^{14}N(p,γ)^{15}O reaction via direct, inverse kinematics measurement using the DRAGON recoil separator. Preliminary results from this measurement will be presented.

Field of work:

Poster session / 25

Sheding light on ^{17}O(n,α)^{14}C reaction at astrophysical energies with Trojan Horse Method and Asymptotic Normalization Coefficient

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The ^{17}O(n,α)^{14}C reaction is considered in astrophysical codes for its role in the astrophysically relevant "s(slow)-process" since it could act as a possible "neutron-poison" for the neutron induced nucleosynthesis thus influencing the final stellar abundances of some elements such as Fe, Ni or Sr. Thus, its reaction rate must be known in the energy region of interest for astrophysics, going from few keV's up to about 400 keV. At such energies, the intermediate ^{17}O+n$\rightarrow$^{18}O nucleus presents four excited levels (8038, 8125, 8213, and 8282 keV's) affecting the magnitude of the ^{17}O+n cross section at astrophysical energies because of the neutron emission threshold at 8044 keV for ^{18}O. Although the role of the two 8213 keV (J^π=2$^+$) and 8282 keV (J^π=3$^-$) was already investigated in the direct measurements, insufficient informations are up to now available about the 8125 keV (J^π=5$^-$) resonant level, thus requiring a detailed experiment.

Indirect methods have been largely proved in the past as a complementary way of accreting our knowledge about nuclear structure and low-energy cross section measurements. Among these, the neutron induced reaction cross section appear to be of particular interest since their role both for unstable and stable beams. In view of this, we report here the combined study of the ^{17}O(n,α)^{14}C accomplished by the Trojan Horse Method (THM) and the Asymptotic Normalization Coefficient (ANC) method. The low lying resonances 8038, 8125, 8213, and 8282 keV in ^{18}O are studied and Γ_n are derived. A comparison with recent data and recent THM experimental data is presented. The independent ANC investigation corroborate our previous THM results, confirms the consistence of the two indirect investigation and shows new frontiers also in view of neutron induced reactions with radioactive ion beams.

Friday - Session 1 / 26

Measurement of alpha-induced reaction cross sections for studying the weak r-process nucleosynthesis

Authors: Almudena Arcones[1]; György Gyürky[2]; Gábor Kiss[None]; Jacobi Maximilian[1]; Peter Mohr[2]; Tamás Szücs[2]; Thanassis Psaltis[1]; Tibor Szegedi[2]

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Neutron-rich isotopes between Sr and Ag are thought to be synthesized in the neutrino-driven ejecta of core-collapse supernova explosions via the weak r-process [1]. Recent nucleosynthesis simulations demonstrated that (α,xn) reactions play a crucial role in the formation of these isotopes [1-4]. The rates of the (α,n) reactions are provided by the Hauser-Feshbach model. The main uncertainty of the predictions comes from the α+nucleus optical potential [2-4]. Namely, there are several parameter sets and the differences between the calculated cross sections exceed even one order of magnitude at the relevant energy region.
To constrain the parameters of the α+nucleus optical potential, recently the cross sections of the 96Zr(α,n)99Mo and 100Mo(α,n)103Ru reactions were measured [5,6] and the study of the 86Kr(α,n)89Sr reaction is in progress. The high precision experimental data was analyzed in the statistical model and it was found that the calculations with the Atomki-V2 potential [7] provide the best reproduction of the experimental data. The strongly reduced reaction rate uncertainties led to very well-constrained nucleosynthesis yields. Details on the experimental approach, the theoretical analysis and the astrophysical impact of the measurements will be presented.

[1] A. Arcones and F. Montes, Astrophys. J. 731 5 (2011).
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Field of work:

Wednesday - Session 3 / 27

Experimental work at JRC Geel

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JRC Geel operates a neutron time-of-flight facility, based on an electron accelerator. At 11 flight paths experiments can be performed simultaneously, with available flight paths ranging from 5m to 400 m. Experimental setups to determine total and reaction cross sections (capture, elastic and inelastic shattering, fission and charged particle reactions) are available. Furthermore, during the last year a new beamline for experiments to determined gamma-ray induced reactions has been installed in the target hall.
While most of the experimental work is focussed on nuclear (energy) applications, regularly cross section also of interest for astrophysical problems are measured. This is mostly in collaboration with partners from the n_TOF collaboration.
Examples for such nuclei of common interest are transmission and capture experiments using isotopically enriched Zr and Gd samples. Besides capture and transmission experiments, special set-ups were installed by external users to study the 26Al(n,⊠) and 16O(n,⊠) reactions. These examples will be discussed in detail with a special emphasis on 16O(n,a) and the inverse 13C(a,n) reaction. A methodology for normalization of the cross section 16O(n,a) will be discussed. This approach should help to understand and resolve the discrepancies on the cross section normalization of approx. 20%, a discrepancy that has haunted both the reactor and the astrophysics community for well more than a decade.

Field of work:

Wednesday - Session 3 / 28

Direct measurement of the low energy resonances in 22Ne(α, γ)26Mg reaction

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The $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ is an important reaction in stellar helium burning environments as it competes directly with one of the main neutron source for the s-process $^{22}\mathrm{Ne}(\alpha,\mathrm{n})^{25}\mathrm{Mg}$ reaction. The reaction rate of the $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ reaction is dominated by low energy energy resonances at E_R^{lab} = 0.65, 0.83 MeV. The E_R^{lab} = 0.83 MeV resonance has been measured previously using both direct and indirect detection techniques, but there are large uncertainties in the previous measurements. We confirmed the measurement of the E_R^{lab} = 0.83 MeV resonance using solid implanted ^{22}Ne target and provide a resonance strength ($\omega\gamma$ = 35 $\pm$ 4 μeV) with smaller uncertainties. We also measured the E_R^{lab}= 851 keV resonance in $^{22}\mathrm{Ne}(\mathrm{p},\gamma)^{23}\mathrm{Na}$, and obtained a resonance strength ($\omega\gamma$ = 9.15 $\pm$ 0.7 eV), with significantly lower uncertainties compared to previous measurements. The other low energy resonance in $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ at
E_R^{lab} = 0.65 MeV, was measured directly for the first time and we provide an upper limit of $\omega\gamma< 0.028$ μeV for this resonance.

Field of work:

Tuesday - Session 4 / 29

The nucleosynthesis of magnetorotational supernovae in 3D

Author: Moritz Reichert[None]

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Magnetorotational supernovae (MR-SNe) are promising candidates for the enrichment of heavy elements in the early universe. We analyze the nucleosynthesis of four sophisticated 3D (Obergaulinger & Aloy 2021) and two long evolved 2D neutrino-magnetohyrodynamic models (Aloy & Obergaulinger 2021). We identified three main mechanisms to synthesize heavy elements. Namely, an early and prompt ejection of matter, a late change of the protoneutron star morphology, and high entropies in the center of strong jets produced by the magnetorotational supernovae. Additionally, we estimated masses of unstable isotopes such as ^{56}Ni. The obtained yields are in agreement with observed ^{56}Ni masses of the most energetic supernovae, so called hypernovae.

Poster session / 30

Dynamical Evolution of Globular Clusters with White Dwarfs, Neutron Stars and Black Holes using GPU Supercomputer

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We present some results from the DRAGON simulations, a set of four direct N-body simulations of globular clusters (GCs) with a million stars and five percent initial (primordial) binaries. These simulations were undertaken with the NBODY6++GPU code, which allowed us to follow dynamical and stellar evolution of individual stars and binaries, formation and evolution of white dwarfs, neutron stars, and black holes, and the effect of a galactic tidal field. The simulations are the largest existing models of a realistic globular cluster over its full lifetime of 12 billion years. In particular we will show here an investigation of the population of binaries including compact objects (such as white dwarfs - cataclysmic variables and merging black hole binaries in the model as counterparts of LIGO/Virgo sources); their distribution in the cluster and evolution with time.

Field of work:

Wednesday - Session 3 / 31

Towards a direct measurement of the $^{17}O(p,\gamma)^{18}F$ 65 keV resonance strength at LUNA

Authors: Denise Piatti[None]; Giovanni Francesco Ciani[1]

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The $^{17}O(p,\gamma)^{18}F$ reaction plays a crucial role in the hydrogen burning phases of different stellar scenarios. For example, at temperature of interest for AGB nucleosynthesis (20 MK< T < 80 MK) the main contribution to the astrophysical reaction rate come from the poorly constrained ER = 65 keV resonance. The strength of this resonance is presently determined only through indirect measurements, with a reported value of $\omega\gamma$= (1.6 ± 0.3) × 10^{-11} eV [1].
With typical experimental quantities for beam current, isotopic enrichment and detection efficiency, this strength yields an expected count rate of less than 1 γ-ray per Coulomb, making the direct measurement of this resonance extremely challenging.
A new high sensitivity setup has been installed at LUNA (Laboratory for Underground Nuclear Astrophysics) of Laboratori Nazionali del Gran Sasso [2]. The underground location of LUNA 400kV guarantees a reduction of cosmic ray background by several orders of magnitude and an intense proton beam with high energy resolution and time stability.
The residual background was further reduced by a devoted shielding of lead and borated polyethylene. On the other hand, the 4π BGO detector efficiency was optimized installing aluminum target chamber and holder. With more than 300 C accumulated on Ta_2O_5 targets, with nominal 17O enrichment of 90%, the LUNA collaboration has performed the first direct measurement of the 65 keV resonance strength [3].
In this talk, the setup used of the measurement and preliminary results of the challenging direct measurement performed at LUNA will be illustrated.

Field of work:

Poster session / 32

Neutron star crust microscopic simulations with realistic models

Author: David Barba González[1]

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We perform microscopic Molecular Dynamics simulations to study crystallization in the outer crust of Neutron Stars (NSs). We study the energetics and pressure in the electron screened nuclear system using a consistent nuclear population in the inner and outer crust under the approximation of one the component plasma (OCP) and multicomponent plasma (MCP) assuming some nuclear species contamination. We include Ewald summation techniques to allow a more efficient energy calculation. We go beyond previous point-like attemps by using a finite width gaussian ion charge distribution and finite temperature. We discuss how these results indicate that a less bound nuclear crust arises in this more realistic picture with respect to previous studies and how this may impact current and future prospects in gravitational wave sensitivity to NS observables.

Poster session / 33

Coulomb dissociation of ^{16}O into ^{4}He and ^{12}C

Authors: Lukas Bott[1]; Kathrin Göbel[2]; Michael Heil[3]; Rene Reifarth[1]

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Over the last decades huge efforts were made to determine the ^{12}C$(\alpha,\gamma)^{16}$O cross section, as it is key to understand the evolution of stars. Using direct methods with stable targets and a low-energy ion beam poses significant challenges to the experimental setup and data analysis. Center-of-mass energies down to 1 MeV were reached with sometimes large uncertainties of up to 100%.
Indirect methods propose to bridge the gap towards the stellar energy regime at a center-of-mass energy of 300 keV. Different indirect approaches have been developed posing the Coulomb dissociation as particularly promising.
Within the FAIR Phase-0 campaign at the GSI Helmholtzzentrum für Schwerionenforschung facility in Darmstadt, we performed the measurement of the Coulomb dissociation of ^{16}O into ^{12}C and ^{4}He with a beam energy of 500 MeV/nucleon. High beam intensities of 10^9 ^{16}O ions per second made radical changes of the setup at R^{3}B necessary to allow the passage of the unreacted ^{16}O ions, while ^{4}He and ^{12}C would hit the detectors' active areas.
We expect a significant reduction of uncertainties in the low-energy range by validation against data from previous measurements, especially for the $E2$ component and will extend the experimental data to lower energies than ever measured before.
An overview of the experimental method, status of analysis and preliminary results will be presented.

Poster session / 34

Stability analysis of population III supermassive stars: a new mass range for general relativistic supernovae.

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Observed supermassive black holes in the early universe have several proposed formation channels, in part because most of these channels are difficult to probe. One of the more promising channels, the directly collapse of a supermassive star, has several possible probes including the explosion of a helium supermassive star triggered by a general relativistic instability. We develop a straightforward method for evaluating the general relativistic radial instability without simplifying assumptions and apply it to population III supermassive stars taken from a post Newtonian stellar evolution code. This method finds that the instability occurs earlier in the evolutionary life of the star than according to previous methods. Using the stability analysis, we perform 1D general relativistic hydrodynamical simulations and find multiple general relativistic supernovae fueled by triple alpha and alpha capture reactions. The explosions, as well as several pulsations, occur in a lower and wider mass range (2.3e4-3.2e4 $M_{\odot}$) than had been suggested by previous works (5.5e4 $M_{\odot}$). We determine the explosion energy, velocity and ejecta composition, and compare the last of these to the abundances of observed metal poor stars. Because of the large explosion energy , these events should be visible to, among others, JWST.

Tuesday - Session 3 / 35

Constraining nucleosythesis in neutrino-driven winds using the impact of (α, xn) reaction rates

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Co-authors: Almudena Arcones [2]; Melina Avila [3]; Maximilian Jacobi [1]; Camilla Juul Hansen ; Zach Meisel [4]; Peter Mohr [5]; Fernando Montes [6]; Wei Jia Ong [7]; Hendrik Schatz [8]

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The lighter heavy elements of the first r-process peak, between strontium and silver, can be synthesized in the moderately neutron rich neutrino–driven ejecta of either core–collapse supernovae or neutron star mergers via the weak r–process [1]. This nucleosynthesis scenario exhibits uncertainties from the absence of experimental data from (α, xn) reactions on neutron–rich nuclei, which are currently based on statistical model estimates. We have performed a new impact study to identify the most important (α, xn) reactions that can affect the production of the lighter heavy elements under different astrophysical conditions, based on the work of Ref. [2] and using new, constrained (α, xn) reaction rates using the Atomki-V2 αOMP [3]. We have identified a list of relevant reactions that affect *elemental abundance ratios* that are observed in metal-poor stars [4]. Our results show how when reducing the nuclear physics uncertainties, we can use abundance ratios to constrain the astrophysical conditions/environment. This can be achieved in the near future, when the key (α, xn) reaction rates will be measured experimentally in radioactive beam facilities.

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Monday - Session 3 / 36

Stellar s-process neutron capture cross sections on ^{A}Se and ^{A}Ce

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Neutron-induced reactions remain at the forefront of experimental investigations for the understanding of stellar nucleosynthesis and chemical evolution of the Galaxy in the region of medium- and heavy-mass nuclides [1]. We report on measurements of the cross section of neutron capture reactions ^{74,80,82}Se(n,γ) and ^{138,140,142}Ce(n,γ) relevant, respectively, to the weak and main s-processes. The ^{A}Se data complement our recent study of the ^{69,71}Ga stellar (n,γ) reactions in the weak s-process regime [2]. The proton rich isotope ^{74}Se is a p nuclide, shielded from the s and r processes by stable nuclei in the region. The disentanglement of the different heavy-nuclide synthesis modes (s-, r- and p-processes) requires reliable and precise stellar neutron-capture cross sections. Such is the case also for the Ce isotopes [3]. In particular, ^{140}Ce is found to be one of the most important nuclides in the network of s-process reactions, affecting the abundances of a large number of isotopes [4]. The experiments were performed by the activation technique using a high-intensity (3-5$\times 10^{10}$ n/s) quasi-Maxwellian neutron beam that mimics conditions of stellar s-process nucleosynthesis. The neutron field was produced by a mA proton beam at E_p=1925 keV (beam power of 2–3 kW) as part of our experiment campaign at the Phase I of Soreq Applied Research Accelerator Facility (SARAF) [5], bombarding the Liquid-Lithium Target (LiLiT) [6,7]. The cross sections were measured by counting the resulted nuclei activities via γ spectrometry with a high-purity germanium detector.

This work was supported by the Pazy Foundation (Israel). M.P. acknowledges support by the European Union (ChETEC-INFRA, project no. 101008324).

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Poster session / **37**

Trojan Horse Method for n-induced reaction investigations at astrophysical energies: the 14N(n,p)14C cross section measurement

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Neutron-induced reactions play an important role in nuclear astrophysics in several scenario, such as Big Bang nucleosynthesis or heavy-element production via the s or r neutron capture processes [1]. To overcome some of the experimental difficulties typical of direct neutron cross section measurements, in the last years, the possibility of using the Trojan Horse Method (THM) to study neutron-induced reactions has been investigated and successfully applied [2-4].
In detail, the 14N(n,p)14C process is among the key reactions intervening in the s-process nucleosynthesis. Indeed, 14N is very abundant since it is a dominant product of the hydrogen-burning in the CNO cycle and, because of the relatively high cross section, can efficiently trigger the (n,p) reaction acting as a strong neutron poison in the reaction chain to heavier elements [1]. Moreover, 14N also impacts the 19F nucleosynthesis through the nuclear chain 14N(α,γ)18F(β+)18O(p,α)15N(α,γ)19F. Thus, the 14N(n,p)14C reaction plays a key role because of its double effect of removing neutrons and producing protons [1]. In addition, the protons can trigger the 18O(p,α)15N or the 13C(p,γ)14N reactions, being the last one in competition with the 13C(α,n)16O reaction [1,5].
Here, we report on the recent results of the indirect 14N(n,p)14C reaction cross section measurement by applying the THM to the quasi-free 2H(14N,p14C)p reaction. The 14N+2H experiment was performed at INFN-LNS by using a 50 MeV 14N beam provided by the TANDEM accelerator. The preliminary results show the population of several states of the intermediate 15N nucleus and, in particular, those at sub-threshold energies for the astrophysically relevant 14N(n,p)14C reaction. The details of the experiment and the corresponding THM data analysis will be discussed and compared with the direct data available in literature.

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Field of work:

Poster session / 38

Experimental study of alpha-induced nuclear reactions on Tellurium isotopes for the astrophysical gamma-process

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Heavier p isotopes are believed to be produced through the γ-process. The path of γ-process can be modelled with network calculations. These calculations include about 20000 reactions on more than 2000, mostly unstable nuclei. Theoretical cross section of reactions involving alpha-particles are found to be very sensitive to the alpha-nucleus optical potential, which is not known well enough at low, astrophysical energies. This potential can be studied experimentally by measuring the cross section of (α,n) reactions close above the reaction threshold. The aim of the present work is thus to measure the cross section of the ^{122}Te(α,n)^{125}Xe, ^{124}Te(α,n)^{127}Xe and ^{130}Te(α,n)^{133}Xe reactions for which no data exist in literature.
The half-life of the produced Xe isotopes allows us to use the activation technique. Tellurium targets with natural isotopic composition will be used in order to measure the three reactions in parallel. The experiments are in progress using the cyclotron accelerator of ATOMKI. In this poster details of the experimental technique and the preliminary results of the first test measurements will be presented.

Thursday - Session 1 / 39

Deuterium burning measurement at LUNA and its astrophysical and nuclear implications

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Light elements were produced in the first few minutes of the Universe through a sequence of nuclear reactions known as Big Bang Nucleosynthesis (BBN). Among the light elements produced during BBN, deuterium is an excellent indicator of cosmological parameters because its abundance is highly sensitive to the primordial baryon density. Although astronomical observations of primordial deuterium abundance have reached percent accuracy, theoretical predictions based on BBN were hampered by large uncertainties on the cross-section of the deuterium burning D(p,γ)^{3}He reaction, before the LUNA measurement. We will report the recent LUNA results on the D(p,γ)^{3}He reaction recently published in Nature (Nature 587 (2020) 210-213). In addition, new results on the measurement of the angular distribution with an innovative technique will also be shown. To further improve the theoretical predictions on the primordial deuterium abundance, it is now important to perform a new and precise measurement of the D(d,n)3He and D(d,p)3H reactions. Future prospects to solve this issue will also be presented.

Tuesday - Session 1 / 40

Indirect measurements of neutron-induced reaction cross-sections at storage rings*

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Obtaining reliable cross sections for neutron-induced reactions on unstable nuclei nuclei is crucial to our understanding of the stellar nucleosynthesis of heavy elements. However, the measurement of these cross sections is very complicated as both projectile and target are radioactive. The NECTAR (NuclEar reaCTions At storage Rings) project aims to circumvent these problems by using the surrogate-reaction method in inverse kinematics. A heavy, radioactive nucleus in the beam is to interact with a light, stable nucleus in the target to produce the compound nucleus formed in the neutron-induced reaction of interest via an alternative or surrogate reaction such as transfer or inelastic scattering. This compound nucleus may decay by fission, neutron or gamma-ray emission, and the probabilities for these modes of decay are to be measured as a function of the excitation energy of the compound nucleus. This information is used to constrain model parameters and to inform much more accurate predictions of neutron-induced reaction cross sections [1].
Yet, the full development of the surrogate method is hampered by the numerous long-standing target issues. The objective of the NECTAR project is to solve these issues by combining surrogate reactions with the unique and largely unexplored possibilities at heavy-ion storage rings. In a storage ring, heavy radioactive ions revolve at high frequency passing repeatedly through an electron cooler,

which will greatly improve the beam quality and restore it after each passage of the beam through the internal gas-jet serving as ultra-thin, windowless target. This way, excitation energy and decay probabilities can be measured with unrivaled accuracy.

In this contribution, we will present the conceptual idea of the setup, which is being developed within NECTAR to measure for the first time simultaneously the fission, neutron and gamma-ray emission probabilities at the storage rings of the GSI/FAIR facility. We will also discuss the technical developments that are being carried out towards these measurements, in particular we will present the first results of the proof of principle experiment, which will be conducted in June 2022 at the ESR storage ring of GSI/FAIR.

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Tuesday - Session 3 / 41

First measurement of the 86Kr(α,n)89Sr reaction cross section using inverse kinematics at relevant energies for the weak r-process

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The r-process has been shown to be robust in reproducing the abundance distributions of heavy elements seen in ultra-metal poor stars. In contrast, observations of elements in the range $36 \leq Z \leq 47$ display overabundances relative to r-process model predictions [1]. A proposed solution to this discrepancy is an additional source of early nucleosynthesis that preferentially produces the lighter heavy elements; one candidate is the weak r-process in the neutrino driven winds of core collapse supernovae. Which reactions are most important to the weak r-process in moving matter to higher

Z number depends on the conditions found in the winds however, models suggest that in the case of slightly neutron rich neutrino driven winds (α,n) reactions are crucial. Models of nucleosynthesis here must depend on Hauser-Feshbach theory for (α,n) cross sections as few have been measured at astrophysically relevant energies (corresponding to temperatures of 2 ≤ T(GK) ≤ 5). Unfortunately, cross section predictions at these energies and within this mass range can vary by up to two orders of magnitude depending on the alpha optical potential used in the calculations [3]. In order to constrain the final abundance predictions of nucleosynthesis in the weak r-process, these reactions' cross sections must be measured [2].

An ongoing experiment at TRIUMF has already used the EMMA recoil separator and the TIGRESS gamma-ray spectrometer to measure the cross section of the reaction 86Kr(α,n)89Sr and plans to measure 94Sr(α,n)97Zr over the summer. Both these reactions are identified as "affecting many elemental abundances under many astrophysical conditions" in the weak r-process and therefore are priorities to study [4]. Both measurements utilise a novel type of Helium containing target [5] and this experiment represents their first use in a cross section measurement. Analysis of the data from the first experiment will be presented.

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Monday - Session 3 / 42

Direct measurement of $^{13}C(\alpha,n)^{16}O$ reaction towards its s-process Gamow peak

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The $^{13}C(\alpha,n)^{16}O$ reaction is the prevalent neutron source for the main s-process, taking place in thermally pulsing low mass AGB stars. The direct measurement of this reaction at stellar temperature (~ 90 MK), corresponding to a Gamow window between 140 - 230 keV, has so far not been possible due to the very low cross section at these energies.
The LUNA collaboration performed the measurement of the $^{13}C(\alpha,n)^{16}O$ cross section in the low-background environment of the Laboratori Nazionali del Gran Sasso (LNGS), where the natural neutron background is reduced by over three orders of magnitude compared to the surface laboratories. The deep underground location, combined with a high-efficiency low intrinsic background detector based on ^{3}He counters, a highly stable intense alpha beam with 200 µA and a pulse shape discrimination technique for the rejection of the intrinsic detector background, for the first time allowed to reach the high-energy edge of the s-process Gamow window with direct measurement. The new data in the $E_{c.m}$=230-300 keV range with drastically reduced uncertainties compared to previous measurements contribute to the better understanding of the dynamics of mixing episodes in AGB stars.
In this talk the experimental techniques and the final results of the LUNA experiment will be presented, together with the astrophysical impact of our revised reaction rate.

Field of work:

Wednesday - Session 2 / 43

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

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The concepts of the nuclear level density (NLD) and $\gamma-$ray strength function (GSF) are two essential tools for the statistical description of excited nuclei and their $\gamma-$decay, used in numerous large-scale astrophysical calculations of abundances of elements in the universe. In this work, one of the widely used experimental techniques, the Oslo method was applied to the ^{120,124}Sn isotopes to extract these statistical quantities for astrophysical purposes.

Firstly, the experimental GSFs were used to address the question on the validity of the generalised Brink-Axel hypothesis (gBA), adopted as a crucial assumption in astrophysical calculations of neutron capture cross-sections within the statistical model. In its most general form, the hypothesis states that the GSF can be treated as a function of γ energy only. In order to test this and ensure the reliability of the slopes and absolute values of the extracted strengths, the Oslo method results were cross-checked with the strengths obtained with the novel Shape method and in the relativistic Coulomb excitation experiment. Comparison of all strengths for both nuclei demonstrates a good agreement within the estimated error bars below the neutron separation energy. This agreement suggests that the gBA hypothesis can be considered valid for any astrophysical calculations for the studied cases in this energy region.

Secondly, the experimental GSFs and NLDs of ^{120,124}Sn were further used as an input to the nuclear reaction code TALYS to calculate the Maxwellian-averaged cross section for the ^{119}Sn(n, γ)^{120}Sn and ^{123}Sn(n, γ)^{124}Sn reactions. These results will be presented for the first time; they are expected to provide better constrains of the neutron capture cross-sections for these nuclei than the theoretical GSF and NLD models included in the TALYS code. As both nuclei demonstrate quite significant resonance features below the neutron separation energy, such as the pygmy dipole resonance, this study also addresses the particular importance of this nuclear feature for rates of the astrophysical s and r processes in the vicinity of Sn isotopes in the nuclear chart.

Thursday - Session 3 / 44

A new 12C+12C reaction rates: Impact on stellar evolution

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Among the reactions driving stellar evolution, ^{12}C + ^{12}C fusion gives the key ingredients during carbon burning. This system reveals many resonances [1], but also regions with suppressed fusion cross-sections [2,3]. The reaction was recently measured by the STELLA collaboration utilizing the gamma-particle coincidence technique for precise cross-section measurements reaching down to the Gamow window of massive stars. From the experimental data, reaction rates were determined by approximating a hindrance trend and by adding on top a resonance at the lowest measured energy. The impact of these reaction rates on the evolution of massive stars was explored with models of 12 and 25$M_\odot$ using the stellar evolution code GENEC [4], and a detailed study of the resulting nucleosynthesis with a 1454 elements network [5] was performed. The sensitivity of the STELLA experimental cross-sections on the temperature range for C-burning for the stellar models studied will be presented. The final abundances and their impacts on stellar evolution will be discussed in detail in this contribution [6].

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Poster session / 45

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

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Recent measurement of coherent π0 photoproduction on Pb lead to a most accurate determination of the neutron skin, constraining nuclear matter Equation of State (EoS) at around ρ~1ρ0. A natural next step is elucidating the nuclear EoS at higher densities to tune our understanding of the most violent process in the Universe - neutron stars mergers. It was demonstrated that at densities above ~3ρ0 dibaryonic degrees of freedom come into play [1]. The work presented in this talk is aiming to improve our knowledge of dibaryon behaviour in dense nuclear matter by measuring coherent π0π0 photoproduction off Ca-40/48 nuclei. The experiment was performed at the A2@MAMI facility in Mainz (Germany). The goal of the analysis is to identify the first genuine hexaquark, the d*(2380), photoproduction on nuclei. We are expecting to determine the medium modifications of the d*(2380) in nuclear matter and constrain its couplings [2]. These new results will further improve our understanding of the neutron stars equation of state and allow precise determination of the maximum neutron star mass as well as provide key ingredients for calculation of the neutron stars merger dynamics. Also, an interplay between the hexaquark, quark-gluon and hyperon degrees of freedom in the EoS of a dense nuclear matter will be discussed. The effective coupling constants obtained in this experiment can further constrain the possibility of hexaquark condensate dark matter [3].
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Monday - Session 4 / 46

Galactic Chemical Evolution with radioactive isotopes

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In addition to the insights gained by studying the galactic evolution of chemical elements, short lived radioisotopes contain additional information on astrophysical nucleosynthesis sites.
Meteorites can carry information about the nucleosynthetic conditions in the early Solar System using short lived radioisotopes [1][2], while detections of live isotopes of cosmic origin in the deep sea crust help us understand recent nucleosynthetic processes in the Solar neighborhood [3]. We use a three dimensional, high resolution chemical evolution code to model the conditions at the time of the formation of the Solar System, as well as to explain why different classes of radioisotopes should often arrive conjointly on Earth, even if they were produced in different sites. Further, we included radioisotope production into a cosmological zoom-in chemodynamical simulation of a Milky Way-type galaxy, which provides a map of gamma-rays from the decay of radioactive Al-26 consistent with the observations by the INTEGRAL instrument [4].

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Thursday - Session 1 / **47**

Beta-decay spectroscopy of neutron-deficient nuclei

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Beta decay has a direct access to the absolute values of the Fermi and Gamow-Teller transition strengths. The comparison with complementary charge exchange reactions, such as the (^{3}He,t) reaction performed on the mirror stable targets at RCNP Osaka, allows us the investigation of fundamental questions related to the role of the isospin in atomic nuclei. A systematic study of neutron-deficient nuclei has been carried out by decay spectroscopy experiments with implanted radioactive ion beams (RIBs) at GANIL and RIKEN. We have obtained remarkable results [1-4], among which the discovery of the exotic β-delayed γ-proton decay in ^{56}Zn [1] and the first observation of the 2^{+} isomer in ^{52}Co [3]. These studies were extended to higher masses and more extreme nuclear conditions at RIKEN thanks to the high-intensity RIBs available. An overview of the most important results will be presented, together with the new results on ^{60}Ge and ^{62}Ge [4] obtained from the RIKEN experiment.
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Thursday - Session 1 / **48**

Understanding 22Na cosmic abundance

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Simulations of explosive nucleosynthesis in novae predict the production of the radioisotope ^{22}Na. Its half-life of 2.6 yr makes it a very interesting astronomical observable by allowing space and time correlations with the astrophysical object. This radioisotope should bring constraints on nova models. It may also help to explain abnormal ^{22}Ne abundance observed in presolar grains and in cosmic rays. Its gamma-ray line at 1.275 MeV has not been observed yet by the gamma-ray space observatories. Accurate yields of ^{22}Na are required. At peak nova temperatures, the main destruction reaction ^{22}Na(p, γ)^{23}Mg has been found dominated by a resonance at ER=0.204 MeV corresponding to the Ex=7.785 MeV excited state in ^{23}Mg. However, the measured strengths of this resonance disagree by more than a factor 3, see Ref. [1, 2].
An experiment was performed at GANIL facility to measure both the lifetime and the proton branching ratio of the key state at Ex=7.785 MeV. The principle of the experiment is based on the one used in [3]. With a beam energy of 4.6 MeV/u, the reaction ^{3}He(^{24}Mg, α)^{23}Mg* populated the state of interest. This reaction was measured with particle detectors (spectrometer VAMOS++, silicon detector SPIDER) and gamma tracking spectrometer AGATA. The expected time resolution with AGATA high space and energy resolutions is 1 fs. Several Doppler based methods were used to analyse the lineshape of γ-ray peaks.
Our new results will be presented. Doppler shifted γ-ray spectra from ^{23}Mg states were improved by imposing coincidences with the excitation energies reconstructed with VAMOS. This ensured to suppress the feeding from higher states. Lifetimes in ^{23}Mg were measured with a new approach. Proton emitted from unbound states in ^{23}Mg were also identified. With an higher precision on the measured lifetime and proton branching ratio of the key state, a new value of the resonance strength ωγ was obtained, it is below the sensitivity limit of the direct measurement experiments. The ^{22}Na(p, γ)^{23}Mg thermonuclear rate has been so reevaluated with the statistical Monte Carlo approach. The amount of ^{22}Na ejected during novae will be discussed as a tool for better understanding the underlying novae properties. The detectability limit of ^{22}Na from novae and the observation frequency of such events will also be discussed with respect to the next generation of gamma-ray space telescopes.

References

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Wednesday - Session 2 / 49

A novel method for constraining experimental neutron capture rates in unstable nuclei

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Experimental neutron capture rates of short-lived neutron-rich nuclei are of pivotal importance for our understanding of explosive nucleosynthesis. In this contribution we present an improved method for constraining neutron capture rates in exotic nuclei experimentally with beam intensities down to a few pps using the β-Oslo method.

While a powerful technique to access the most exotic nuclei in radioactive ion beam experiments, the traditional β-Oslo method requires input of the absolute nuclear level density around the neutron separation energy, an unknown quantity in unstable nuclei. In this work, we show that combining the recently introduced Shape method with the β-Oslo technique allows for the extraction of the nuclear level density without the need for theoretical input. 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 and determine the absolute partial level density for the short-lived ^{88}Kr nucleus, provided by CARIBU at Argonne National Laboratory. 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.

Wednesday - Session 3 / 51

(α, n) reactions as a neutron source and neutrino background

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(α, n) reactions provide a source for neutrons in many stellar environments, fueling the production of the heavy elements. The key (α, n) reactions for the s-process are thought to be ^{13}C and ^{22}Ne, but reactions on other nuclei, including ^{17,18}O and ^{24,25}Mg may also play important roles. In addition, (α, n) reactions are sources of background for neutrino and dark matter detection in ton scale systems, produced from the high energy α decays of trace actinides in support structures and the detection volumes. Recent new experimental studies have put the spotlight on the $^{13}\mathrm{C}(\alpha, n)^{16}$O reaction, both through the measurement of new very low energy cross sections at underground facilities and by new types of measurements at higher energies, both of which resolve inconsistencies in past measurements. In this talk, I will review these latest measurements, discuss how they contribute to the overall evaluation over a wide energy range, and use a BRICK MCMC R-matrix analysis to estimate the effect of these new data on the extrapolation of the low energy S-factor to stellar energies. In particular, new measurements at the University of Notre Dame, 20 point angular distributions covering a center-of-mass range from 0.6 to 6.5~MeV using ODeSA, will be presented.

Poster session / 52

Discrete Relativity : a Prediction in Nuclear Physics

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Null four-vectors of General Relativity (GR), suggest mathematical developments. Two of them are presented. It is reminded that in GR a privileged frame exists, which is the frame in whch time elapses the most. It is showned that a particle generates locally a space-time deformation, which transforms this privileged frame according to the boost associated with its velocity in this frame. From this remark in physics and those mathematical developments, the motivation as well as the first developments of a new and discrete relativity appears naturally. It uses a four-momentum instead of the stress-energy tensor for calculation of space-time structure. It is showned that the surrounding effect prevailing in [1] appears also as the inner part of such a model. Under an unifying assumption, this surrounding effect appears in particle physics as well and suggests a scheme for a possible solution of the Yang-Mills Millennium problem.
[1] F. Lassiaille, EPJ Web of Conf 182 03006 (2018).

Poster session / 53

Surrounding: latest developments

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The latest developments in Surrounding Matter Theory [1] are presented. They include the fitting to Tully-Fisher law, without regression on the previous model's predictions. A following and ambitious search for of a new type of calculation of General Relativity space-time structure is presented. Some possible insight into Nuclear Physics are mentionned.
[1] F. Lassiaille, EPJ Web of Conf 182 03006 (2018).

Monday - Session 3 / 54

Indirect study of 17O(a,n)20Ne and 17O(a,g)21Ne reactions via 17O(7Li,t)21Ne alpha-transfer reaction and its impact on the s-process in rotating poor-metal massive stars

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Recent models of low metallicity rotating massive stars show the possibility of a large production of *s*-elements between strontium and barium. The efficiency of the *s*-process in these stars depends strongly on the ratio of the reaction rates of the two competing ^{17}O(α,n)^{20}Ne and ^{17}O(α,γ)^{21}Ne reactions [1]. This ratio determines the influence of the poisoning effect of ^{16}O which consumes the neutrons released by the ^{22}Ne(α,n)^{25}Mg reaction, the main neutron source for the weak component of the s-process in massive stars. Indeed, the neutrons consumed by ^{16}O(n,γ)^{17}O may either be released by ^{17}O(α,n)^{20}Ne or lost for good via ^{17}O(α,γ)^{21}Ne. However, the reaction rates of these two competing reactions are poorly known because of the lack of spectroscopic information (Γ_α, J$^\pi$, Γ_n, Γ_γ,...) of the astrophysical relevant states in the compound nucleus ^{21}Ne. To have a better determination of ^{17}O(α,n)^{20}Ne and ^{17}O(α,γ)^{21}Ne reaction rates, the α-widths of the states of interest were determined experimentaly for the first time through the measurement of their α-spectroscopic factors. The latter were determined from the α-transfer reaction ^{17}O(^{7}Li,t)^{21}Ne measurement [2] performed at MLL-Munich, using the high-energy resolution magnetic spectrometer Q3D. The measured and calculated DWBA differential cross sections of the different populated states will be presented as well as the obtained α-spectroscopic factors and the α-widths of the relevant states in ^{21}Ne. Finally, the ^{17}O(α,n)^{20}Ne and ^{17}O(α,γ)^{21}Ne reactions rates calculations and their corresponding uncertainties using our obtained α-widths and the most recent measured neutron widths [3] will be presented. Our rates favour the neutron recycling via ^{17}O(α,n)^{20}Ne reaction instead of losing them via ^{17}O(α,γ)^{21}Ne reaction and suggest an enhancement by a very large factor of the *s*-elements between Ba and Sr.

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Poster session / 55

Activations for lower s-process temperatures

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Heavy elements beyond iron are mainly synthesizing neutron capture reactions. The slow neutron capture process (s-process) is responsible for 50\,\% of the heavy elemental abundances. The corresponding neutron energies in the different astrophysical sites range from a few keV to about hundred keV. By using the activation technique, neutron capture reactions have been studied over the last decades at $k_\mathrm{B}T = 25$\,keV. The neutrons were produced by protons impinging on a lithium target via the reaction ^{7}Li(p,n)^{7}Be. Neutrons are emitted within a 120 degree cone. With a modified approach, we measured neutron capture cross sections for lower s-process temperatures. With ring-shaped samples, a specific range of neutron emission angles is covered such that the neutron energy distribution corresponds to a Maxwell-Boltzmann distribution of $k_\mathrm{B}T$ =7.75\,keV. The new technique and first results will be presented.

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Statistical Hauser-Feshbach Model Description of (n, α) Reaction Cross Sections for the Weak s-Process

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One of the main goals of modern nuclear physics and astrophysics is to determine the neutron induced reaction cross sections in stars and various astrophysical events such as supernova explosions and neutron star mergers. Modeling the cross sections is essential, since in many cases astrophysically important reactions involve nuclei that are beyond the reach of the most advanced experimental facilities. In this study, (n, α) reaction cross sections are studied for as set o nuclei relevant in modeling weak s-process, in comparison to other neutron-induced reactions with various channels [1]. Model calculations are based on comprehensive nuclear reaction research framework that combines statistical Hauser-Feshbach theory with nuclear properties from advanced theoretical models [3] to calculate the (n, α) and other neutron induced reaction cross sections. Statistical model calculations were made with the TALYS nuclear reaction program [3], with consistent description of nuclear masses and level densities based on Skyrme energy density functional. The Maxwellian averaged cross sections have been calculated and analyzed for the range of temperatures in stellar environment for nuclei contributing in the weak s-process [1]. Model calculations determined astrophysically relevant energy windows in which (n, α) reactions occur in stars and in this way provide a guidance for the priority energy ranges to be measured in the future experimental studies [1]. In order to assess the evolution of (n, α) reactions across the nuclide map, the isotopic dependence of the respective cross sections has been investigated and discussed in several isotope chains [2].

Field of work:

Poster session / 57

Precision Deuterium in Big Bang Nucleosynthesis: the Critical Role of Nuclear Reactions

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Big Bang Nucleosynthesis (BBN) accounts for the cosmic origin of the lightest elements, and deuterium (D/H) plays a key role in probing the physics of the early universe. The simplicity of BBN theory allows for few-percent-level precision of D/H prediction, which is not normally possible in nuclear astrophysics. Under such precision, the comparison between predicted and observed primordial D/H not only provides a crucial test of the standard cosmology but also hints at new physics. The push to further improve this precision brings its own challenges and rewards: sharpening the power of BBN constraints on new physics.

The nuclear uncertainties of deuterium destruction reactions now block our way to a better D/H prediction. The reactions $d(p,\gamma)^3$He, $d(d,n)^3$He, and $d(d,p)t$ are known to dominate the D/H theory error budget. Recent cross section measurements from LUNA significantly reduced the uncertainty of $d(p,\gamma)^3$He, and the state-of-the-art D/H theory error is $\sim 3\%$. However, this excellent theory uncertainty still falls behind the observed counterpart; precision measurements of the primordial D/H from high redshift quasar absorption systems in the past several years have contributed to an impressive $\sim 1\%$ error. The future improvement of D/H prediction relies on new precision measurements of $d(d,n)^3$He and $d(d,p)t$ at BBN energies. Moreover, *ab initio* theory cross section for $d(p,\gamma)^3$He mismatches the precise LUNA data while agreeing with other datasets outside the BBN range. Additional theory study for $d(p,\gamma)^3$He cross section is also needed to understand such a puzzling discrepancy.

Poster session / 58

The γ-process nucleosynthesis in core-collapse supernovae

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The nucleosynthesis of elements heavier than iron in stars is one of the most relevant topics in nuclear astrophysics. The neutron-capture processes made most of the abundances of heavy elements in the solar system, but they are not able to make a number of rare proton-rich stable isotopes (p-nuclei) lying on the left side of the stability valley. The γ-process, i.e. a chain of photodisintegrations on heavy nuclei, is the most established process for the synthesis of p-nuclei in core-collapse supernovae. In this talk, I will present the main features of the γ-process nucleosynthesis in massive stars, considering a range of different progenitor stars and supernova explosions. I will discuss present uncertainties affecting the γ-process, and the discrepancies between theory and observations affecting the production of the stable p-nuclei and of the radioactive isotopes ^{92}Nb and ^{146}Sm, which signature has been measured in Early Solar System material.

Poster session / 59

Barium stars as tracers of s-process nucleosynthesis in AGB stars

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The Barium (Ba) star phenomenon is unmissable from the study and understanding of nucleosynthetic processes occuring in asymptotic giant branch (AGB) stars. Ba stars belong to binary systems, where the former AGB polluted the companion, a less evolved star, which became enriched with material produced through the slow neutron capture process (s process). While the AGB has evolved to a white dwarf, the currently observed Ba star preserves the abundance pattern of the AGB, allowing us to test the imprints of the s process. Comparing different AGB nucleosynthetic models and Ba star abundances, we are able to constrain the effect of the initial rotation velocity or the neutron source in the interior of the AGB star. Additionally to the large, homogeneous observational sample of Ba stars of de Castro et al. (2016) an extended list of heavy element abundances was published by Roriz et al. (2021a,b), including Sr, Mo, Ru and re-determined La values. Here I will present the results for individual Ba stars using a simplified method of normalising the models to the determined [Ce/Fe] abundances and calculating dilution factors for each star and model. The results of the comparison of models with initial AGB masses from an independent source and the analysis of 28 Ba giant star abundances confirm that the polluting AGBs are of low mass (< 4 MSun). There is a good agreement between the models and the abundance pattern for most of the stars, with some peculiarities at the first s-process peak. Nb, Mo and Ru values higher than the model predictions indicate the operation of a different nucleosynthesis path, which needs further investigation.

Field of work:

Poster session / 60

Evaluation of the 35K(p,γ) 36Ca reaction rate using the 37Ca(p,d)36Ca transfer reaction

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A recent sensitivity study has shown that the 35K(p,γ)36Ca reaction is one of the ten (p,γ) reaction rates that could significantly impact the shape of the calculated X-ray burst light curve [1]. Its reaction rate used up to now in type I X-ray burst calculations was estimated using an old measurement for the mass of 36Ca and theoretical predictions for the partial decay widths of the first 2+ resonance with arbitrary uncertainties [2]. In this work, we propose to reinvestigate the 35K(p, γ)36Ca reaction rate, as well as related uncertainties, by determining the energies and decay branching ratios of 36Ca levels, within the Gamow window of X-ray burst, in the 0.5 to 2 GK temperature range.

These properties were studied by means of the one neutron pick-up transfer reaction 37Ca(p,d)36Ca in inverse kinematics using a radioactive beam of 37Ca at 48 MeV/nucleon. The experiment was performed at the GANIL facility using the liquid Hydrogen target CRYPTA, the MUST2 charged particle detector array for the detection of the light charged particles and a zero degree detection system for the outgoing heavy recoil nuclei.

The atomic mass of 36Ca is confirmed and new resonances have been proposed together with their proton decay branching ratios. This spectroscopic information, used in combination with very recent theoretical predictions for the γ-decay width, were used to calculate the 35K(p,γ)36Ca reaction rate. The recommended rate of the present work was obtain within a uncertainty factor of 2 at 1 sigma. This is consistent, with the previous estimate in the X-ray burst temperature range. A large increase of the reaction rate was found at higher temperatures due to two newly discovered resonances. The 35K(p, γ) 36Ca thermonuclear reaction rate is now well constrained by the present work in a broad range of temperatures covering those relevant to type I X-ray bursts [3]. In this oral presentation, these results will be presented as well as the experimental method.

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[2] C. Iliadis *et al.*, Nuclear Physics A 841, 31 (2010)
[3] L. Lalanne *et al.*, Phys. Rev. C 103, 055809 (2021)

Poster session / 61

X17 search project with the EAR2 neutron beam

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Two significant anomalies have been recently observed in the emission of electron-positron pairs in the 7Li(p,e− e+)8Be and 3H(p,e− e+)4He reactions [1, 2]. These anomalies have been interpreted as the signature of the existence of a boson (hereafter referred to as X17) of mass M_X17 = 16.8 MeV that could be a mediator of a fifth force, characterised by a strong coupling suppression of protons compared to neutrons (protophobic force). Beyond the importance of such a discovery - if confirmed -, this scenario could explain, at least partially, the long-standing (recent) anomaly on the muon (electron) magnetic moment. More in general, the possible existence of a new particle is of paramount importance in particle physics and in cosmology (dark matter). Therefore, the ATOMKY claim [1, 2],

clearly calls for new experimental studies.
We are carrying on an experiment at n_TOF, where the excited levels of 4He, 8Be can be populated via the conjugated 3He(n,e− e+)4He and 7Be(n,e− e+)8Be reactions. This approach has two relevant advantages: (i) for the first time X17 existence is investigated through neutron induced reactions; and (ii) the experimental setup is completely different with respect to the one used by the ATOMKY group. More in detail, the ATOMKI experimental setup used for the 3H(p,e− e+)4He reaction (a very similar one was used for the other reaction) consists of a tritium target adsorbed on Ti layer, bombarded with a 900 keV proton beam with a current of about 1 μA.
The main limitations of ATOMKI measurement are: (i) a monochromatic beam of 900 keV, i.e. no information about the X17 production at different energies is available; (ii) no tracking and vertex recognition, (iii) only particles produced orthogonally to the beam line are detected; (iv) no charge and particle identification, i.e. the ejectiles are only deduced to be e− e+ pairs.
Our approach aims to realise a suited detection setup for the determination of particle kinematics and able to discriminate particles, i.e. the reaction ejectiles (assumed to be e− e+ pairs) in a wide energy range. If the existence of X17 is confirmed, with the here-proposed experimental setup it will be possible to establish quantum numbers and mass of the X17 boson, and to shed light on the so-called protophobic nature of a fifth force. In fact, state-of-the-art "ab-initio" calculations are in good agreement with present literature data (in particular for the "few body" 4He nucleus) and would provide quantitative predictions to establish the X17 nature, e.g. if it is a scalar, pseudoscalar, vector or axial boson and to get information on the interaction of the X17 boson with quarks and gluons.
The study of the 3He(n,e− e+)4He and 7Be(n,e− e+)8Be reaction can be performed at the EAR2 station of the n_TOF facility at CERN. In fact, the facility provides a pulsed neutron beam in a wide energy range, which broadly covers the region of interest for this experiment, i.e. 10^3 < E_n(eV) <10^7 . In addition, count-rate estimations have demonstrated that the neutron intensity at EAR2 is high enough to carry on a conclusive experiment within about 1 month of measurement. We present and discussthe project of this measure at EAR2: the detection setup and the final goals in order to say a definitive word about X17 puzzle.

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Field of work:

Poster session / 62

A new Multi-Channel and Monte Carlo R-Matrix analysis for the estimate of ^{17}O destruction rate in stars

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When stars approach the red giant branch, a deep convective envelope develops and the products of the CNO cycle appear at the stellar surface. In particular, the ^{17}O is enhanced in RGB and AGB stars. Then, spectroscopic analyses of O isotopic ratios of these stars provide a powerful tool to investigate the efficiency of deep mixing processes, such as those powered by convective overshoot, rotation, thermohaline instability, gravity wave and magnetic field. However, this method requires a precise knowledge of the reaction rates that determine the ^{17}O abundance in a H-burning shell,

among which the $^{17}O(p,\gamma)^{18}F$ and the $^{17}O(p,\alpha)^{14}N$ reactions are the more relevant. Since the last release of rates compilations (see the JINA reaclib database, https://reaclib.jinaweb.org/) a number of experiments have updated the reaction rates, incorporating new low-energy cross section measurements. In order to provide up-to-date input to the astrophysics community we performed simultaneous multi-channel and Monte Carlo R-Matrix analyses of the two reactions including all newly available data, resulting in realistic uncertainty ranges for the rates. In this talk we give an overview of the input data, the methodology, present the updated reaction rates and give an outlook on planned evaluations of other CNO-cycle reactions using the same approach.

Wednesday - Session 3 / 63

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.

Field of work:

Friday - Session 2 / 64

Potential experimental evidence of an Efimov state in 12C and its influence on astrophysical carbon creation

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Recently we measured the gamma decay probability of 12C levels over the threshold for particle decay as the Hoyle and the 9.64 MeV levels [1] measuring for the first time the two gamma decay of such last level. We observe in our data a large gamma decay width, 3 times larger than the already larger than systematic result of Kibedi et al [2]. Investigating also on the 3-alpha decay channel of the state [3] we have noted that our data are compatible with the population and direct decay of an Efimov state at 7.458 MeV recently proposed [4]. Moreover, our data exclude the sequential decay of such state. The population of an Efimov state with 0.3% population probability with respect to the one of the Hoyle state could explain the large measured gamma decay probability observed in our data. However, astrophysical consequences of the presence of the Efimov state could be dramatic as recently outlined by Bishop et al [5], with the violation of the Suda limit [6] for the formation of red giant stars. We will show that the exclusion of the sequential decay mode of the Efimov state strongly reduces the astrophysical impact of such a state on the creation of 12C at stellar temperature in the range from 10^7 to 10^8 K.

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Poster session / 65

Populating α-unbound states in 16O via 19F(p,α)16O

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Several reactions of light nuclei require a better understanding in Nuclear Astrophysics. The most relevant one is 12C(α,γ)16O. The reason for this is both, the unmitigated importance of the reaction,

and the complexity of its cross section at the relevant energies of static helium burning (300 keV) which uncertainty is still undesirably large. As there is no state of natural parity to serve as a resonance for radiative capture in the energy region of interest, the total cross section originates from a sum of resonance tails and direct captures, both, to the ground and excited states of 16O. Among the resonance tails contributing are two bound subthreshold states, i.e., the 1- state at -45 keV and the 2+ state at -200 keV below the α+12C threshold [1]. One of the methods to estimate these contributions consists in determining all the important reduced α-widths of the subthreshold states by indirect measurements, that are more sensitive to the α-width than the direct radiative capture measurement.

With this aim, a study of the 19F(p,α)16O reaction is being performed at CMAM facility (Madrid, Spain), using a proton beam with energies between 1.3 and 2.9 MeV to populate α-unbound states in 16O [2]. The experimental setup consists in 14 pixelated silicon detectors forming a quarter sphere configuration that cover forward angles from 27° to 87° [3] with an angular resolution of 9°. In the backward direction, three multi-segmented silicon detectors that cover from 82° to 171° backwards with an angular resolution of 3°, and an array of four scintillator units of 4 cm LaBr3(Ce) coupled with 6 cm LaCl3(Ce).

In this work we will present branching ratios to the population of the different 16O levels at different energies, measured, for the first time, through the study of the ⊠-particles and γ-rays emitted in the reaction simultaneously in this energy range. We will conclude discussing the relative cross section obtained for those subthreshold levels that were highly populated at these energies.

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Poster session / 66

Tension between implications from PREX-2 data and gravitational tidal response on dense matter equation of state

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The isospin dependent nuclear saturation property has a salient role to play in understanding the matter behaviour at high density regimes. Very recently an improved value of neutron skin thickness of ^{208}Pb was reported in Lead Radius EXperiment-II (PREX-2) to be $R_{\text{skin}} = R_n - R_p = (0.283 \pm 0.071)$ fm which corresponds to high estimations of nuclear symmetry energy (E_{sym}) and its slope (L_{sym}). The updated values of E_{sym} and L_{sym} commensurating to the neutron star observable estimations exterior to the astrophysical observed range. Gravitational waves detected from binary compact star merger events and subsequent estimations of tidal deformabilities ($\tilde{\Lambda}$) also play a vital role in constraining dense matter nature. The higher values of L_{sym} at n_0 deduced from recent PREX-II data correlates to matter being easily deformable (yielding higher radius values) around intermediate matter densities leading to higher values of $\tilde{\Lambda}$.

The coupling restrictions for hyperonic sector are extracted from Λ and Ξ hypernuclei experiments and those in Δ-resonances from scattering off nuclei and heavy ion collision data. In this work, we find that the appearance of heavier non-strange baryons at lower density regimes leads to easing off this tension by exploring the meson-Δ baryon coupling parameter space.

Tuesday - Session 3 / 67

r-Process Radioisotopes from Near-Earth Supernovae and Kilonovae

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The astrophysical sites where ⊠-process elements are synthesized remain mysterious: it is clear that neutron-star-mergers (kilonovae, KNe) contribute, and some classes of core-collapse supernovae (SNe) are also possible sources of at least the lighter ⊠-process species. The discovery of 60Fe on the Earth and Moon implies that one or more astrophysical explosions have occurred near the Earth within the last few Million years (Myr), probably SNe. Intriguingly, 244Pu has now been detected, mostly overlapping with 60Fe pulses. However, the 244Pu flux may extend to before 12Myr ago, pointing to a different origin. Motivated by these observations and difficulties for ⊠-process nucleosynthesis in SN models, we propose that ejecta from a KN enriched the giant molecular cloud that gave rise to the Local Bubble where the Sun resides. Accelerator Mass Spectrometry (AMS) measurements of 244Pu and searches for other live isotopes could probe the origins of the ⊠-process and the history of the solar neighborhood, including triggers for mass extinctions, e.g., at the end of the Devonian epoch, motivating the calculations of the abundances of live ⊠-process radioisotopes produced in SNe and KNe that we present here. Given the presence of 244Pu, other ⊠-process species such as 93Zr, 107Pd, 129I, 135Cs, 182Hf, 236U, 237Np and 247Cm should be present. Their abundances and well-resolved time histories could distinguish between SN and KN scenarios, and we discuss prospects for their detection in deep-ocean deposits and lunar regolith. We show that AMS 129I measurements in Fe-Mn crusts already constrain a possible nearby KN scenario. Thus, we urge searches for ⊠-process radioisotopes in deep-ocean Fe-Mn crusts, and in the lunar regolith samples brought to Earth recently by the Chang'e-5 lunar mission and upcoming missions including Artemis.

Poster session / 68

Special Muons

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Muon are the subatomic particles. with very high speed(2.9*10^8).with this speed it can travel a distance of 456meters.But the muon formed in the atmosphere travel the distance of 15 km whish is shown by research.
This phenomenon is called muon paradox if we can differentiate between these special muon (of muon paradox which undergoes in time dilation and length contraction) and normal muon which can be obtained from beam of particles moving in high speed.

These results can help us understand quantum physics and nuclear reactions in a new way and can give us clues of existence of new unknown subatomic particles. Which can change our way of understanding today's present universe.

Field of work:

Monday - Session 4 / 69

Experimental Study of the 30Si(p,γ)31P for understanding elemental anomalies in Globular Clusters

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Globular clusters are key grounds for models of stellar evolution and early stages of the formation of galaxies. Abundance anomalies observed in the globular cluster NGC 2419, such as the enhancement of potassium and depletion of magnesium [1] can be explained in terms of an earlier generation of stars polluting the presently observed stars [2]. However, the nature and the properties of the polluting sites are still debated. The range of temperatures and densities of the polluting sites depends on the strength of a number of critical thermonuclear reaction rates. The ^{30}Si(p,γ)^{31}P reaction is one of the few reactions that have been identified to have an influence for elucidating the nature of polluting sites in NGC 2419 [3]. The uncertainty on the ^{30}Si(p,γ)^{31}P reaction rate has a strong impact on the range of possible temperatures and densities of the polluter sites.

Hence, we investigated the ^{30}Si(p,γ)^{31}P reaction with the aim to reduce the uncertainties associated to its reaction rates by determining the strength of resonances of astrophysical interest. In this talk, I will present the study of the reaction ^{30}Si(p,γ)^{31}P that we performed via the one-proton ^{30}Si(^{3}He,d)^{31}P transfer reaction at the Maier-Leinbnitz-Laboratorium Tandem. Direct measurements, performed using the DRAGON recoil spectrometer at TRIUMF, will be presented as well.
The high resolution Q3D magnetic spectrograph was used to measure the angular distributions of the light reaction products. These angular distributions are interpreted in the DWBA (Distorted Wave Born Approximation) framework to determine the proton spectroscopic factor needed to deduce the proton partial width of the states of interest. For the direct measurements, the \ph recoils are detected in coincidence with the γ-rays emitted during the proton capture, which allows a direct estimation of the strength of higher energy resonances.
This information was used to calculate the ^{30}Si(p,γ)^{31}P reaction rate. The uncertainties on the reaction rate have been significantly reduced, and key remaining uncertainties have been identified [4].

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Poster session / 70

Investigation of the γ-ray angular distribution of the 3He(α,γ)7Be reaction at the Felsenkeller shallow-underground laboratory

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The 3He(α,γ)7Be reaction plays a role in two distinct astrophysical scenarios, solar fusion processes as well as the Big Bang nucleosynthesis. The astrophysical S-factor of this reaction has been studied several times for energies above 0.3MeV and once for energies between 0.1MeV and 0.2MeV, but never directly for energies below 0.1MeV. The energies in between and below the measured range are relevant for solar fusion, but rely on extrapolation of the existing data. A recent theory work by Zhang et al. suggests a connection between the angular distribution of the emitted γ-rays from the 3He(α,γ)7Be reaction and the value of S(0), the S-factor at E=0.
At the 5 MV Felsenkeller underground accelerator implanted 3He targets and a setup of 21 HPGe detectors are used to study the angular distribution of this reaction, resulting in an improvement of the extrapolation to lower energies to have better predictions on the Big Bang 7Li nucleosynthesis and the solar 7Be and 8B neutrino fluxes. First results of the ongoing campaign will be outlined.

Poster session / 72

Results of total and partial cross-section measurements of the ^{87}Rb$(p,\gamma)^{88}$Sr reaction

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The existence of most of the stable very neutron deficient nuclei - the p nuclei - cannot be explained via neutron-capture reactions. Therefore, at least one other process has to exist in order to describe their origin, the γ process. Since most photodisintegration reactions involved in the process are not directly accessible, reliable statistical model calculations are needed to predict cross sections and reaction rates. To improve the calculations the nuclear input parameters need to be constrained and a large experimental database is needed. Via comparison of experimental data to theoretical predictions different models can be excluded or constrained.
In order to study the ^{87}Rb$(p,\gamma)^{88}$Sr reaction, for the first time an in-beam experiment at the high-efficiency HPGe γ-ray spectrometer HORUS at the University of Cologne was performed. Proton beams with energies between $E_p = 2.0 - 5.0$ MeV inside the Gamow window were provided by the 10 MV FN Tandem accelerator.

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Poster session / 73

12C+12C reactions for Nuclear Astrophysics

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^{12}C fusion reactions are among the most important in stellar evolution since they determine the destiny of massive stars. Over the past fifty years, massive efforts have been done to measure these reactions at low energies. However, existing data present several discrepancies between sets and large uncertainties specially at the lowest energies. Factors such as beam/environmental backgrounds, extremely low cross sections and insufficient knowledge of the reaction mechanism contribute to these problems.
Recently, the ERNA collaboration measured the ^{12}C+^{12}C reactions at $E_{c.m}$ = 2.51 - 4.36 MeV with energy steps between 10 and 25 keV in the centre of mass. Representing the smallest energy steps to date.
In these measurements, beam induced background was minimised and S-factors for the proton and alpha channels were calculated. Results indicate that a possible explanation for the discrepancies between data sets is the wrongly assumed constant branching ratios and isotropical angular distributions.
Given the excellent performance of the detectors for low energy measurements, a collaboration with the LUNA group (LNGS) has started. Background measurements underground are being performed and results indicate it could be possible to measure the ^{12}C+^{12}C reactions directly into the Gamow Window.

Field of work:

Poster session / 74

Background gamma measurement for low energy astrophysical reaction at FRENA

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Facility for Research in Experimental Nuclear Astrophysics (FRENA), an upcoming tandem accelerator facility at Saha Institute of Nuclear Physics, Kolkata, India. This is a low energy (0.2-3 MV) high current facility primarily designed for nuclear astrophysical studies. Most of the astrophysical reactions have very low cross-sections with large error bars[1]. So the background studies in this region is very crucial for accurate measurements. The wall thickness of FRENA is ~1.2m thick in order to reduce the cosmic background but those walls become a source for gamma background from natural isotopes like ^{238}U, ^{40} K and, ^{232}Th [2]. In this work, a detailed background measurement is performed during beam on and off conditions. Different scintillator detectors (NaI & $LaCl_2$) are used to measure gammas at different positions of the accelerator building. With and without reduced background by Lead brick array (Pb, Z=82) and detail CPS calculation is done to understand the counts coming from a particular element. The machine parts themselves are made up of SS-304 (mainly consisting of Chromium, Nickel, and Carbon), Tantalum and copper. During beam on condition, neutrons are generated in beam dump and these neutrons interact with different isotopes present vicinity, gives gamma photon as background. Some of them have long half-life too[3]. Caen digitizer (DT5730) was used as data acquisition system. The same will be used in the future for the FRENA experiments. An experiment is planned to study the formation of ^{106,108}Cd at FRENA.

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Field of work:

Poster session / 75

New experimental study of the ^{3}He(α,γ)^{7}Be reaction around ^{7}Be known levels

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The ^{3}He(α,γ)^{7}Be nuclear reaction has been investigated in several times before [1]. The importance of this reaction is manifested in two astrophysical scenarios. It plays a role in the nucleosynthesis of the Big Bang (BBN) through the production of lithium and is also a branching reaction in the solar p-p chain. The astrophysically relevant energy range of this reaction in the two scenarios is $E_{c.m.} = 160 - 380$ keV and $E_{c.m.} = 15 - 30$ keV.

The energy range investigated in previous studies covers mostly $E_{c.m.} = 300 - 3100$ keV. In addition, part of the BBN energy range $E_{c.m.} = 93 - 170$ keV has been studied [2]. Experimental investigation at such low energies is very difficult, thus low energy extrapolation inevitable to predict the reaction rate at solar energies. Recently the reaction cross section has been measured around the ^{7}Be proton separation threshold at $E_{c.m.} = 4000 - 4400$ keV [3]. At higher energies known energy levels of ^{7}Be exist. No α-capture cross section data are available around these energy levels, which would constrain the level parameters, thus the extrapolations toward low energies. With this motivation, the $E_{c.m.} = 4300 - 8300$ keV energy range was investigated using the α beam from the ATOMKI MGC-20 cyclotron.

For the cross-section determination, the activation technique was used. The experiments were performed using a thin-windowed gas cell confining high purity ^{3}He gas. During the irradiation, α particles bombarded the ^{3}He nuclei and the resulting ^{7}Be nuclei were implanted into a cather foil. The half-life of the ^{7}Be reaction product is 53.22 days and the relative decay probability to the first excited state in ^{7}Li is 10.44 %. The yield of the γ rays deexciting this E= 477.6 keV level was measured using high-purity germanium (HPGe) detectors.

The characteristics and technical details of the measurement are presented in detail along with the preliminary results.

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Poster session / 76

MULTINUCLEON-TRANSFER REACTIONS AT THE IGISOL FACILITY: INSTRUMENTATION AND PROSPECTS FOR R-PROCESS EXPERIMENTS

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Multinucleon-transfer (MNT) reactions have gained a lot of attention in the last decade following the theoretical prediction of larger than expected production cross sections for heavy neutron-rich nuclei [1] playing a key role in the astrophysical rapid neutron capture process (r process) [2]. At the Ion Guide Isotope Separator On-Line (IGISOL) facility [3] in the JYFL Accelerator Laboratory, either proton- or deuteron–induced fission on uranium or thorium targets has been traditionally used to produce neutron-rich nuclei of interest, however, the measurements have been limited to the fission fragments (A~70-170). MNT reactions are a promising method to produce a broad range of neutron-rich nuclei and in particular for the third r-process peak region close to N=126.

A dedicated gas cell and target platform have been designed for MNT reactions at the IGISOL facility using numerical calculations in CFD Module of COMSOL Multiphysics. MNT products from the 136Xe+209Bi or 136Xe+198Pt reactions enter into a gas cell through a thin entrance window of the gas cell, after which they are stopped, thermalized and transported by helium gas flow towards the sextupole ion guide (SPIG) and extraction chamber [4]. The new MNT gas cell has been characterized offline with a 223Ra alpha-recoil source to define lower limits for the production rates and lifetimes of nuclei that are accessible. The first online tests with the new gas cell were successfully performed with the 136Xe+209Bi reaction, and showed an increase of the measured count rates compared to our earlier results performed with another gas cell [5]. Results of the aforementioned tests and prospects for studies using the 136Xe+198Pt reaction will be reported in this contribution.

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Poster session / 77

Study of 19F(p,α) Reaction in Nuclear Astrophysics

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^{19}F (p,α) reaction is one of the crucial reactions in the CNO Cycle. It has the utmost importance in the astrophysical region particularly below the Coulomb barrier [1]. In an astrophysical scenario, the importance astrophysical S-factor is crucial for the understanding of discrepancies in fluorine nucleosynthesis [2-4] and the contribution of direct or resonance at such low energies [5-9]. The THM measurements predicted the presence of 113 KeV resonance contribution to the S-factor [4] . The low energy S-factor also have significant contribution from non-resonant part. Our recent calculation shows an appreciable non-resonant contribution to S-factor in low energy region [9]. The S(0) from the DWBA calculation is found to be 20.357 MeV-b with 40 % uncertainty. The calculation is comparable to NACRE non-resonant value [10]. So, the measurement of ^{19}F (p,α) to get sufficient data points at low energy region is necessary. For that purpose, good quality of target is one of the key factors for this reaction. LiF targets are deposited on self-supporting Ag backing using vacuum

evaporation. The thickness of deposited Lithium fluoride is measured by three line alpha sources (^{239}Pu, ^{241}Am, and, ^{244}Cm). The thickness of deposited LiF targets is ~224 μg/cm^2 . The XPS confirms the presence of Li and F on surface of targets. An experiment is planned at FRENA facility, Kolkata to measure astrophysical S-factor in low energy regions.

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Field of work:

Wednesday - Session 1 / 78

Felsenkeller shallow-underground 5 MV accelerator

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For low-background cross-section measurements, it is beneficial to host an ion accelerator in an underground setting, shielded from cosmic rays. The Felsenkeller 5 MV underground ion accelerator in Dresden, Germany, is the second such facility in Europe and has recently become accessible using EU-supported transnational access. The contribution will review recent progress at Felsenkeller: The three main ion beam species (H-1 and He-4 from the internal and C-12 from the external ion source) have now all been developed successfully. The first experiment by external users has been completed. An HPGe-detector based offline gamma-counting setup with muon veto has been commissioned and tested.

Field of work:

Poster session / 79

Development of a jet gas target system for the Felsenkeller underground accelerator

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For direct cross section measurements in nuclear astrophysics, in addition to suitable ion beams and detectors, also highly pure and stable targets are needed. Here, using a gas jet as a target offer an attractive approach that combines high stability even under significant beam load with excellent purity. Such a target is currently under construction at the Felsenkeller underground ion accelerator lab for nuclear astrophysics in Dresden, Germany. The target thickness will be measured by optical interferometry, allowing an in situ determination including also beam-induced effects. The contribution will report on the status of this new system and outline possible applications in nuclear astrophysics.

Poster session / 80

Investigation of ^{170,172}Yb(α, n)^{173,175}Hf cross sections in a stacked target experiment

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In spite of decades of research, many observed nuclear abundances remain that can not be reproduced by p-process nucleosynthesis calculations [1].
This is mainly due to the lack of constraints for the involved nuclear physics models.
Previous studies have shown that key reactions affecting the abundance of the p-nucleus ^{168}Yb are the ^{164,166}Yb(α, γ) reactions and that these are mostly sensitive to the α-optical-model-potential (α-OMP) [2,3].
To study the α-OMP in the Yb chain and its dependence on the proton-to-neutron ratio, a stacked target activation experiment was performed at the University of Cologne's *Cologne Clover Counting* setup investigating the ^{170,172}Yb(α, n)^{173,175}Hf reaction cross sections.
The results were validated by simultaneous measurements of the well established ^{55}Mn($\alpha, (2)n$)^{57,58}Co and ^{54}Fe(α, n)^{57}Ni reaction cross sections.
All measurements were compared to Hauser-Feshbach statistical model calculations [4].

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Monday - Session 2 / 81

^{40}Ar proposed as probe of neutron-induced reactions in a high-density stellar-like plasma at the National Ignition Facility

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The plasma density, temperature and pressure in laser-induced deuterium-tritium (DT) inertial fusion implosions at the National Ignition Facility (NIF) are comparable to those in the center of stars. Neutrons are produced within a radius of ≈50 μm and a time of ≈100 ps, representing a uniquely high neutron density approaching 10^{22} cm^{-3}, close to that of the astrophysical r process, and fluxes of 10^{31} cm^{-2}s^{-1} [1]. Recent experiments at NIF first passed the burning-plasma threshold [2,3], where self-heating exceeded the external heating applied to the fuel and produced record fusion yields of ≈1 MJ . In a dedicated NIF high-power laser shot, we plan to investigate neutron-induced reactions on ^{40}Ar incorporated in the capsule gas. The choice of Ar as probe of such reactions is motivated by the chemical inertness of noble gas Ar allowing for reliable collection of Ar isotopic reaction products and by the existence of three convenient neighboring isotopes ^{39}Ar ($t_{1/2} = 268$ y), ^{41}Ar (110 min) and ^{42}Ar (33 y). The ^{40}Ar$(n, 2n)^{39}$Ar reaction is a direct monitor of the fast-neutron flux; the ^{40}Ar$(n, \gamma)^{41}$Ar and a potential ^{40}Ar$(2n, \gamma)^{42}$Ar capture reactions are sensitive to energy downgraded neutrons. A search for ^{42}Ar may provide an indication of the feasibility to study the important astrophysical ^{58}Fe$(2n, \gamma)^{60}$Fe reaction [4] in the laboratory. The long-lived ^{39}Ar and ^{42}Ar nuclides are detected and counted by Noble-Gas Accelerator Mass Spectrometry (NOGAMS) at Argonne National Laboratory. We report here on a separate first measurement of the total yield of the ^{40}Ar$(n, 2n)^{39}$Ar reaction in a 14 MeV neutron activation. The neutron activation was performed with the DT neutron generator of Technical University Dresden located at Helmholtz-Zentrum Dresden-Rossendorf. First direct ultra-sensitive detection of the ^{42}Ar nuclide by NOGAMS in a ^{40}Ar sample activated by the slow double-neutron capture reaction ^{40}Ar$(n, \gamma)^{41}$Ar$(n, \gamma)^{42}$Ar is demonstrated. The latter activation (8 days) was performed at the high-flux nuclear reactor of Institut Laue-Langevin (Grenoble, France). Preliminary results of these experiments, which will help calibrate the ^{40}Ar activation at NIF, are presented.

Support from the Pazy Foundation (Israel) and USA-Israel Binational Science Foundation is gratefully acknowledged. This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357. This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility.

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Thursday - Session 2 / **82**

Measurement of the 140Ce(n,γ) cross section at n_TOF and astrophysical implications

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Among the nucleosynthesis mechanism involving the heavy nuclei, the so-called slow (s-)process is one of the better known. Being responsible of about half of the element heavier than iron, many models were built in order to describe the process and the final element abundances.
The s-process take place in the inner layers of AGB stars, where the heavy elements are produced during interpulses periods (when the $^{13}C(\alpha,n)^{16}O$ generates the neutrons necessary for the process) as well as during thermal pulses (when the $^{22}Ne(\alpha,n)^{25}Mg$ is activated) through a succession of neutron captures and beta decays. The accurate knowledge of the neutron capture cross sections for all the elements involved in the process plays a key role, and in particular those with a neutron magic number. Therefore in last decades great efforts have been undertaken in order to improve the accuracy of these data.

At the n_TOF facility at CERN a recent experiment to measure the ^{140}Ce neutron capture cross section has been performed, motivated by a large discrepancy between the models predictions and the astronomical observation for the cerium abundance[1]. This measurement was characterized by an unprecedented combination of the high energy resolution of the n_TOF neutron beam and a highly enriched ^{140}Ce sample. The experimental apparatus was based on four gamma detectors based on C_6D_6 liquid scintillators, which are characterized by a very low neutron sensitivity.

In total, 81 resonances were measured and fitted. For each, the capture and neutron widths were determined, highlighting the large discrepancies respect to the major nuclear libraries. These new data allowed to calculate the $^{140}Ce(n,\gamma)$ MACS with an uncertainty lower than 5%, significantly improving the experimental data available for the libraries update. The measurement results and their implications on the Ce abundances predicted by the stellar models will be presented.

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Field of work:

Poster session / 83

Comprehensive study of silicon photomultiplier based readout of the large plasticscintillator based neutron detector NeuLAND

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The NeuLAND (New Large-Area Neutron Detector) plastic scintillator based time of flight detector for 0.2-1.6 GeV neutrons is currently under construction at the Facility for Antiproton and Ion Research (FAIR), Darmstadt, Germany. In its final configuration, NeuLAND will consist of 3,000 2.7 m long plastic scintillator bars that are read out on each end by fast timing photomultipliers. Here, data from a comprehensive study of an alternative light readout scheme using silicon photomultipliers (SiPM) are reported. For this purpose, a typical NeuLAND bar was instrumented on each end with a prototype of the same geometry as a 1" photomultiplier tube, including four 6×6mm^2 SiPMs, amplifiers, high voltage supply, and micro-controller. Tests were carried out using the 35 MeV electron beam from the ELBE superconducting linac with its ps-level time jitter in two different modes of operation, namely parasitic mode with one electron per bunch and single-user mode with 1-60 electrons per bunch, using Acqiris fast digitizers. In addition, offline tests using cosmic rays and theNeuLAND data acquisition scheme were carried out. Typical time resolutions of $\sigma \leq 100$ ps were found for ≥99% efficiency, improving on previous work at ELBE and exceeding the NeuLAND timing goal of $\sigma < 150$ ps. Over a range of 10-300 MeV deposited energy in the NeuLAND bar, the gain was found to deviate by ≤10% (≤20%) from linearity for 35μm (50μm) SiPM pitch, respectively, satisfactory for calorimetric use of the full NeuLAND detector. The dark rate of the prototype studied

was found to be 70-200 s^−1, sufficiently low so as not to overload the data acquisition system if the standard trigger condition is applied.

Poster session / 84

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}Sn$(\alpha, p\gamma)^{127}$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 of calculating 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 well the experimental data.

The Maxwellian-averaged cross section for the ^{126}Sb$(n,\gamma)^{127}$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.

Field of work:

Wednesday - Session 2 / 85

A global comparison of experimental and theoretical (p,γ)-reaction data relevant for the p process

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While most of the heavy elements in our universe are produced via neutron-capture processes, the nucleosynthesis of the neutron-deficient p nuclei is still an open question in nuclear astrophysics. The p nuclei are most likely produced in explosive stellar scenarios by the astrophysical γ process, which is a complex network of thousands of nuclear - mostly photodisintegration - reactions on stable and unstable nuclei. Many of the involved reactions include exotic or unstable nuclei and hence, cannot be accessed in the laboratory. Therefore, theoretical predictions obtained within the framework of the Hauser-Feshbach model are required. Enlarging the available experimental database of measured reactions at astrophysically relevant energies as well as systematic studies of the underlying nuclear physics properties that govern the output of the Hauser-Feshbach calculations is therefore of utmost importance. In this contribution, the systematic campaign of measuring several (p,γ) reactions at the University of Cologne in the last years and the experimental results will be presented. A global overview of the total available database of (p,γ)-reaction data and a systematic comparison to Hauser-Feshbach calculations using state-of-the art nuclear models reveals that excellent agreement can be achieved over the whole nuclear chart and (p,γ)-reaction rate data can be provided with high precision.

Field of work:

Poster session / 86

Thermonuclear electron-capture supernovae – New production sites completing the solar inventory of isotopes?

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It has long been postulated that the onset of electron captures in degenerate high-density ONe cores of super-AGB stars would trigger a supernova, resulting in a collapse into a neutron star (NS). New models of these so-called electron capture supernovae (ECSNe) suggest that while the full collapse to a NS is still a possibility, the energy release by the electron-capture reactions can also trigger a thermonuclear runaway initiating explosive thermonuclear burning and leaving behind a bound ONeFe remnant in a "thermonuclear ECSN" (tECSN). So far, however, tECSNe remain purely in the realm of theory. No optical observables have been predicted form simulations that could be used for a direct comparison with astronomical observations of such transients, thus confirming or denying their existence.
Initial studies suggest that tECSNe could reproduce the solar abundances of important and so far problematic isotopes such as ^{48}Ca, ^{50}Ti, ^{54}Cr, together with ^{58}Fe, ^{64}Ni, ^{82}Se, and ^{86}Kr as well as several Zn-Zr isotopes, without introducing new tensions with the solar abundance distribution. If tECSNe proved to exist in nature, even at a low occurrence rate, they would provide an elegant way to cover these remaining blemishes on the charts of astrophysical element production.
The tECSN scenario could not only establish a new production sites for thus far problematic isotopes in the solar inventory, it could also have implications on NS formation rates or provide an additional way of probing nuclear reaction rates. To this end, we plan complement our three-dimensional hydrodynamic explosion simulations with detailed radiative transfer calculations to reliably predict observables from such events. This will eventually form the basis for building evidence for or against the existence of tECSNe, either by comparison with literature data or data from dedicated transient surveys.

Poster session / 87

The impact of n_TOF data on s-process nucleosynthesis

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We show the impact on AGB stellar nucleosynthesis of the maxwellian averaged capture cross sections determined at n_TOF over the past 20 years. We developed an automated procedure to derive MACSs from evaluated data libraries, which are subsequently used as input to stellar models computed by means of the FUNS code.
In this contribution, we present a number of s-process abundances obtained using different data libraries as input to stellar models, with a focus on the role of n_TOF data.

Field of work:

Poster session / 88

Maxwell–Boltzmann-like neutron spectrum production at kT=28 keV for Maxwellian averaged cross section measurement.

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To calculate the reaction rate in the neutron capture processes it is common to work with the Maxwellian Average Cross Section (MACS), defined as the reaction rate scaled by the most probable neutron velocity of the Maxwell-Boltzmann distribution. For the s-process mainly, the MACS directly describes the reaction rate inside the stars, for a given temperature and neutron density. Hence, the importance of determining the MACS with the least possible uncertainty. Before any MACS measurement, a characterized neutron beam with a spectrum as similar as possible to the stellar spectrum is mandatory, and this is the main purpose of this work. The experiment was performed at the CN Van der Graaff accelerator at the LNL-INFN, in Italy. In the experimental measurement, the ^{7}Li(p,n)^{7}Be nuclear reaction was employed as neutron source. A method based on the idea of shaping the proton beam energy to shape the neutron beam spectrum was used to produce a Maxwell-Boltzmann neutron spectrum. To obtain a Maxwell-Boltzmann neutron spectrum with 28 keV of thermal temperature, an initial proton energy of 3170 keV and a 51 μm thickness aluminum (Al) foil, as proton energy shaper, were employed. Using a 600 kHz proton pulsed beam at the Van de Graaff accelerator, the neutron time of flight spectrometry (TOF) was implemented to determine the neutron spectrum over a flight path of 50 cm. Differential angular neutron energy distributions from 0 to 90 degrees in steps of 10° were measured to obtain the 0°-90° integrated neutron spectra. The results of the experimental measurement will be reported in the talk.

Friday - Session 1 / 89

Surrogate Reactions for Nuclear Astrophysics

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Neutron-induced reactions on unstable nuclei play an important in nuclear astrophysics and for applications of nuclear technology. However, due to the radioactive nature of the nuclei involved, these reactions are extremely difficult or impossible to directly measure. The importance of these reactions has motivated the development of several indirect methods for constraining their properties, one of which is the Surrogate Reactions Method (SRM). In the SRM, a different reaction, which forms the "same" compound nucleus as the (intractable) desired reaction, is measured. Observations of the decay of the compound are then used to constrain calculations of the desired reaction.

I will describe this approach, show results from benchmarking measurements, discuss other applications, and share possible future applications relevant to nuclear astrophysics.

Poster session / 90

Nuclear reaction measurements using CARME at CRYRING FAIR

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The CRYRING Array for Reaction Measurements (CARME) has been mounted at CRYRING FAIR and offers a novel methodology for nuclear reaction measurements utilising storage rings. CARME can be used to study direct nuclear reactions of astrophysical interest in addition indirect studies of key nuclear properties and atomic physics experiments. The CARME system has recently been fully installed and has completed its commissioning beamtime run. I will present the CARME system and its technical capabilities.

Poster session / 92

Commissioning of the SECAR recoil separator

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Stellar explosions such as novae, supernovae, and X-ray bursts involve thermonuclear reactions on rare isotopes. Interpretation of observations such as the light curves from X-ray bursts, elemental abundances, or γ-rays from nuclear decay as well as predictions of nucleosynthesis are notably impacted by large uncertainties in the nuclear reaction rates. Many of these reactions either have no experimental data available or have only been constrained indirectly.
The SECAR (SEparator for CApture Reactions) recoil separator, recently commissioned at the Facility for Rare Isotope Beams (FRIB), enables direct measurements of the relevant proton- and alpha-capture reaction rates on proton-rich nuclei. SECAR takes advantage of radioactive beams produced by FRIB via projectile fragmentation, which are then stopped, and reaccelerated to low astrophysical energies at the ReA3 facility. Reactions are studied in inverse kinematics by impinging the beam on a hydrogen or helium target in gaseous or solid form. The reaction recoils are counted at SECAR, where a sequence of magnets and velocity filters separate them from the unreacted beam.

I will present the astrophysical motivation for SECAR's development and the results from measurements that have been performed with SECAR during commissioning in 2021.

Poster session / 94

Direct measurement of the 19F(p,α)16O reaction

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The ^{19}F(p,α)^{16}O reaction is important for understanding the fluorine abundance in the outer layers of asymptotic giant branch (AGB) stars and it might also play a role in hydrogen-deficient post-AGB star nucleosynthesis. Up to now, theoretical models overproduce F abundances in AGB stars with respect to the observed values, thus calling for further investigation of the reactions involving fluorine. Indeed, in the last years, new direct and indirect measurements improved significantly the knowledge of the ^{19}F(p,α)^{16}O cross section at deeply sub-Coulomb energies (below 0.8 MeV). Nevertheless, those data are larger by a factor of about 1.4 with respect to the previous data reported in the NACRE compilation in the energy region 0.6-0.8 MeV. In order to solve these discrepancies we present here a direct experiment performed at INFN-LNS using a silicon strip detector array (LHASA - Large High-resolution Array of Silicon for Astrophysics). Our results clearly confirm the trend of the latest experimental data in the energy region of interest. ^{19}F(p,α)^{16}O reaction rate is the sum over the (p,α_0), (p,α_π) and (p,α_γ) channels. While the (p,α_0) rate is well constrained by the present existing data, down to the lowest energies, almost nothing is known from experiments on the (p,α_π) and (p,α_γ) rates. Despite its importance, the S-factors and the branching ratio between the α_0, α_π and α_γ outgoing channels in the ^{19}F(p,α)^{16}O reaction are still largely uncertain at astrophysical energies, emphasizing the need for better measurements. Thus, a direct measurement using the new detector, ELISSA (Extreme Light Infrastructure – Silicon Strip Array), coupled with LHASA will be performed in September 2022 at IFIN-HH. This setup is allowing us to discriminate the (p,α_π) and (p,α_γ) reaction rates at very low energies.

Poster session / 95

GEANT4 simulations for a design study of a HPGe detectors array for in-plasma β-decays investigation of nuclear astrophysical interest

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In the frame of the PANDORA (Plasmas for Astrophysics Nuclear Decays Observation and Radiation for Archaeometry) project [1], a new experimental approach aims at measuring, for the first time, in-plasma β-decays lifetimes as a function of thermodynamical conditions of a plasma-environment able to mimic some stellar-like conditions. Theoretical predictions [2] and former experiments on fully stripped ions [3] have shown that the ionization state can dramatically modify β-isotopes lifetimes (e.g., by bound state β-decay). The experimental approach consists in a direct correlation of nuclear activity and plasma environment, and this can be done by simultaneously identifying and discriminating - through an innovative multi-diagnostic system which will work synergically with a γ-rays detection system - the photons emitted by the plasma (from microwaves to hard X-ray domains) and γ-rays emitted after the isotope β-decay [4, 1]. In this work the numerical simulations

performed in GEANT4 focused on the design of the array of γ-ray detectors and investigating the total efficiency in terms of detectors type and of their optimal displacement around the trap (including collimation systems and shielding) are presented. The best compromise, due to technical constraints, is to use an array of 14 HPGe detectors (70% of relative efficiency with a total photopeak efficiency of $\sim$ 0.1 - 0.2%) and about 16 non-invasive diagnostic tools surrounding the high-performance totally superconducting plasma trap. The feasibility of the PANDORA experiment was specifically checked by "virtual experiment runs", by exploring the feasibility of measuring the decay rates in terms of 3σ-confidence-level of several nuclei involved in s-processing nucleosynthesis (i.e., ^{134}Cs, ^{94}Nb, ^{176}Lu) of nuclear astrophysical strong interest. The experimental run duration needed to get enough statistical significance should take several days to 3 months, depending on the isotope under investigation, thus shading new light on the role of weak interaction on the stellar nucleosynthesis. The specific sensitivity for discriminating among the set of theoretical predictions [5] was investigated as well as eventually fit the nucleosynthesis data [6] which disagree from the current decay rate predictions [2].

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Poster session / 96

The ASTRAL database for neutron-capture nucleosynthesis studies

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Present nuclear reaction network computations for astrophysical simulations involve many different types of rates, including neutron-capture reactions of interest for the modeling of heavy-element nucleosynthesis. While for many of them we still have to rely on theoretical calculations, an increasing number of experimentally-determined cross sections have now become available. In this contribution, we present the "ASTrophysical Rate and rAw data Library" (ASTRAL), a new online database for neutron-capture cross sections based on experimental results, mainly obtained through activation and time-of-flight measurements. For the evaluation process, cross sections were re-calculated starting from raw data and by considering recent changes in physical properties of the involved isotopes (e.g., half-life and γ-ray intensities). We show the current status of the database, the techniques adopted to derive the recommended maxwellian-averaged cross sections, and future developments.

Wednesday - Session 1 / 97

57Zn β-delayed proton emission to constrain 56Ni rp-process waiting point

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Type-I X-rays bursts are thermonuclear flashes ignited on the surface of a neutron star which is accreting hydrogen and helium-rich material from its companion star. With an hours-long stellar half-life and a low proton capture Q value (~690 keV), doubly magic 56Ni has long been defined as one of the waiting points in the rapid proton capture (rp) process that powers the type-I X-ray bursts. However, a strong bypass circumventing 56Ni and diverting the rp-process flow through the path 55Ni(p,γ)56Cu(p, γ)57Zn(β+)57Cu(p,γ) 58Zn has been proposed [1]. The astrophysical 55Ni(p,γ) and 56Cu(p, γ) forward and reverse reaction rates calculated with the recently measured mass of 56Cu [2] show that the rp-process flow redirects around the 56Ni waiting point through the 55Ni(p,γ) route. The dominant source of uncertainty regarding the strength of this bypass is the β delayed proton emission decay branch of 57Zn, having a present estimate of 78±17% [3]. We measured the β-delayed proton (βp) and γ emission at the National Superconducting Cyclotron Laboratory. We substantially improved the precision for the beta-delayed proton emission branching ratio for 57Zn, definitively determining that there is a 56Ni bypass, with 14-17% of the rp-process flow taking this route. We also identified four new γ-ray transitions forming the exotic β-γ-p decay branch.

References:
1. W.-J.Ong et. al, Phy. Rev C 95 055806 (2017).
2. A.A. Valverde et. al, Phy. Rev. Lett. 120, 032701 (2018)
3. B. Blank et. al, Eur. Phys J. A, 31 (3) 267-272 (2007

Field of work:

Tuesday - Session 4 / 98

Heavy Element Nucleosynthesis from the Birth of Black Holes

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The astrophysical origin of the rapid neutron capture (r-process) remains an outstanding mystery in nuclear astrophysics. I will review our evolving understanding of potential r-process sites, particularly those associated with the merger of binary neutron stars and the core collapse of massive rotating stars. I will describe how these diverse channels are directly probed by the thermal kilonova or r-process-enriched supernova emission which follows these events, highlighting also the connection with the gravitational wave emission detected by LIGO/Virgo. Time permitting, I will describe a new type of stellar explosion - a "super-kilonova" - produced by the birth of the most massive spinning black holes, which may be discovered following gamma-ray bursts or by future infrared observations with the Roman Space Telescope.

Field of work:

Tuesday - Session 4 / 100

Nucleosynthesis in the ejecta of neutron star mergers and the role of nuclear masses.

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Binary neutron star mergers have been expected to synthesize r-process elements and emit radiation powered by the radioactive decay of the freshly produced isotopes, called kilonovae. Although the observation of the kilonova was the first direct evidence of the operation of the r-process nucleosynthesis at the GW170817/AT2017gfo event, no trace of individual elements has been identified except for strontium. The blue and red components of AT2017gfo have been interpreted as the signatures of multi-component ejecta in the merger dynamics. However, the exact properties of the ejecta remain largely unconstrained. These recent observations can be used as a probe for the astrophysical conditions of neutron star merger ejecta.

Nuclear physics quantities play a crucial role in the r-process modeling. Several key parameters such as nuclear masses, β-decay half-lives, β-delayed neutron emission, fission yields, and neutron-capture rates are needed to model the r-process. While these quantities are experimentally known in the proximity of the stability line, as we move away toward the neutron drip line experimental information becomes sparse. The unavailability of experimental nuclear data dictates the use of theoretical models, which can largely differ in their predictions of nuclear properties. Sensitivity studies can provide a comprehensive framework to identify the most crucial nuclear quantities needed for the r-process.

The kilonova lightcurve and the solar r-process abundance pattern remain the only available datasets to evaluate nucleosynthesis studies and the impact of new experimental data. We performed nucleosynthesis calculations for a wide range of electron fractions, entropy, and expansion time scale conditions as well as for different nuclear physics inputs. We will present our findings concerning the sensitivity of final r-process abundances on nuclear masses. We will stress the importance of high precision mass measurements and highlight the impact of recent mass measurements from the IGISOL group.

Poster session / 101

Measuring $^{12}C(\alpha,\gamma)^{16} with ERNA: improvements and perspectives

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$^{12}C(\alpha,\gamma)^{16}O$ has been, and still is, one of the central topic in nuclear astrophysics.\\
Reason for this is that stellar models are very sensitive to the ratio $^{12}C/^{16}O$ produced by the helium buring stage. Knowing the value of the $^{12}C(\alpha,\gamma)^{16}O$ S-factor at the energy of astrophysical interest ($E_0 \sim$ 300 keV) to a precision better than 10\% would constrain our prediction on the isotopic aboundances and the fate of a star at the end of its evolution.\\
The expected cross section at E_0 ($\sim 10^{-17}$ b) makes the direct measurement unfeasible and the complex ^{16}O energy levels structure require high precision measurement at higher energies to improve extrapolations of the S-factor.\\
Recent developments have improved the ERNA separator installed at the Tandem laboratory of the

University of Campania, Caserta that is now capable of measuring the $^{12}C(\alpha,\gamma)^{16}O$ cross section and its gamma emission angular distribution down to 1.0 MeV. \\
In this contribution the commissioning of ERNA for the $^{12}C(\alpha,\gamma)^{16}O$ and perspective on the measurement campaign will be shown.

Poster session / 102

Fission fragment distributions of neutron-rich nuclei based on Langevin calculations in the r-process region

Author: Itoshi Nishimura[1]

Co-authors: Nobuya Nishimura [2]; Shoya Tanaka ; Shinya Takagi [1]; Wataru Miyasakai ; Masahisa Ohta ; Yoshihiro Aritomo

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The nuclear fission of very neuron-rich nuclei is essential for the termination of the r-process flow on the nuclear chart and the determination of the final abundances. Nevertheless, most of the available fission data for neutron-rich nuclei are based on theory predictions mostly by phenomenological treatments. In this study, we calculated a series of nuclear fission distribution for neutron-rich nuclei away from the stability line. We are based on theoretical calculations based on the dynamical fission model with the Langevin method. We compared the obtained mass and charge distributions with experimental data and the results of the GEF code. We also show the results of the systematic behaviour of mass distribution for neutron-rich U and Fm isotopes: the asymmetric feature of fission changes symmetric as isotopes become neutron rich.

Field of work:

Poster session / 103

Core collapse supernova explosions driven by the QCD phase transition

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The subject of massive star explosions driven by a first-order hadron-quark matter phase transition has gained increasing attention in the community, e.g., providing a novel path to the existence of massive pulsars of 2 solar masses at birth [1] and the creation of ejected r-process material in these explosive events [2]. However, no final conclusions can yet be drawn from these results about the very existence of such supernova explosions. It would require a more detailed analysis of the role of both, the stellar progenitors and the QCD equation of state. These are the subjects of active research in the field. In my presentation, I am going to focus on these aspects and discuss the recent findings with regard to the supernova explodibility as well as connections to observational aspects. The latter refers to a nonstandard, non-monotonous neutrino emission, associated with the presence of a QCD phase transition, which yields the launch of a millisecond neutrino burst that is observable for the present generation of neutrino detectors for a galactic event.

[1] Fischer et al., Nature Astronomy, Vol.2, p. 980 (2018)
[2] Fischer et al., The Astrophysical Journal, Vol.894, 9 (2020)

Field of work:

Poster session / 104

The evaluation of fission mode and fragment yields of neutron-rich nuclei evaluated by the dynamical model

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Nucleosynthesis by the rapid neutron-capture process (r-process) produces elements heavier than iron via neutron-rich nuclides, observed in the solar system and stars with various metallicities. In the r-process, fission plays a fundamental role by recycling the matter during neutron irradiation and by shaping the final r-abundance distribution. Nevertheless, most of the fission data available for r-process calculations are based on theoretical predictions with phenomenological models treatments due to the difficulty of experimental approaches. In this study, we focused on the transition of fission mode from asymmetric to symmetric in neutron-rich isotopes, which has been suggested in recent experiments for fermium isotopes. We investigated the fission of neutron-rich nuclei by a theoretical calculation based on the dynamical model and employed Langevin equations to calculate the evolution of nuclear shape with time. In this model, fission modes can be discussed based on the time evolution of the nuclear shape on the potential energy surface.

Friday - Session 2 / 105

Proton capture on stored radioactive ions

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By combining two unique facilities at GSI (Helmholtz Centre for Heavy Ion Research), the fragment separator (FRS) and the experimental storage ring (ESR), the first direct measurement of a proton capture reaction of a stored radioactive isotope has been accomplished. The combination of sharp ion energy, ultra-thin internal gas target, and the ability to adjust energy of the beam in the ring enables precise, energy-differentiated measurements of the (p,γ)-cross-sections. Our new results provide a sensitive method for measuring (p,γ) and (p,n) reactions relevant for nucleosynthesis processes in supernovae, which are among the most violent explosions in the universe and are not yet well understood.

The cross section of the ^{118}Te(p,γ) reaction was measured at energies of astrophysical interest. The heavy ions were stored with energies of 6 MeV/nucleon and 7 MeV/nucleon and interacted with a hydrogen jet target. The produced ^{119}I ions were detected with double-sided silicon strip detectors. The radiative recombination process of the fully stripped ^{118}Te ions and electrons from the hydrogen target was used as a luminosity monitor.

These measurements follow a proof-of-principle experiment which was performed in 2016 to validate the method on the stable isotope ^{124}Xe [1].
An overview of the experimental method and preliminary results from the ongoing analysis will be presented.

[1] J. Glorius et al., Phys. Rev. Lett. 122, 092701 (2019)

Poster session / 106

Neutron-induced charged particle reaction studies in nuclear astrophysics with a Micromegas based gaseous detector

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Neutron-induced charged particle reactions (n, p) and (n, α), especially on unstable proton-rich isotopes, play an important role in understanding explosive astrophysical scenarios and interpreting their remnants. In a recent publication [1], a novel approach is described to study experimental cross-sections of (n, p) and (n, α) reactions at explosive stellar temperatures for various nuclei for which experimental data is poor or even non-existent. Currently, we are pursuing the first phase of

the project as described in [1, 2], where a Micromegas based gaseous detector for the detection of charged particles for our neutron-induced charged particle reaction studies is being developed. The simulation study of the experimental set-up and testing of the detector and its performance will be discussed in detail, and the astrophysics implications of various reactions being considered for our detailed investigation will be discussed.

References:
[1] M. Friedman; Eur. Phys. J. A 56 (5) (2020)1-7.
[2] C. Yadav, M. Friedman; EPJ Web Conf., 260 (2022) 11048.

Field of work:

Monday - Session 4 / 107

Gamma-ray lessons about galactic diffuse radioactivities

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Diffuse gamma-ray emission from the decay of radioactive 26Al and 60Fe is a messenger about the nucleosynthesis activity in our current-day galaxy. Because this material is attributed to ejections from massive stars and their supernovae, we can learn from the gamma-ray signal about massive stars and their feedback into surrounding interstellar medium. Our method of population synthesis of massive-star groups has been refined as a diagnostic tool for this purpose. It allows to build a bottom-up prediction of the diffuse gamma-ray sky when known massive star group distributions and theoretical models of stellar evolution and core-collapse supernova explosions are employed. We find general consistency of an origin in such massive-star groups, in particular we also find support for the clumpy distribution of such source regions across the Galaxy, and characteristics of large cavities around these. A discrepancy in the integrated 26Al gamma-ray flux is interpreted as an indication for excess 26Al decay in nearby regions. The 60Fe gamma-ray signal is much weaker (<40%) than the 26Al signal, and plausibly consistent with our bottom-up modeling, within uncertainties. Comparisons to hydrodynamical simulations of radioactivity ejections from such massive-star groups have proven useful to help understand how massive-star feedback shapes surrounding medium and distributes ejecta.

Field of work:

Thursday - Session 3 / 109

The K600 magnetic spectrometer and the CAKE silicon detector array: measurements relevant to type-I X-ray bursts and classical novae

Authors: Johann Wiggert Brummer[1]; Phil Adsley[2]; Thomas Rauscher[3]

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The K600 magnetic spectrometer and the CAKE silicon detector array form a powerful tool for coincidence measurements in many nuclear physics measurements including nuclear astrophysics. These instruments have been used, among others, in studies measuring proton decays from α-unbound states in ^{22}Mg through the ^{24}Mg(p,t)^{22}Mg reaction to study the ^{18}Ne(α,p)^{21}Na cross section relevant in type-I X-ray bursts (XRBs). The thermonuclear reaction rate of ^{18}Ne(α,p)^{21}Na is one of the important rates that affect the behaviour of the XRB lightcurve [1]. This talk will examine the ^{24}Mg(p,t)^{22}Mg experiment that was performed at iThemba LABS, Cape Town and discuss future experiments with the ^{28}Si(p,t)^{26}Si reaction to study proton decays from α-unbound states in ^{26}Si to study the cross section and thermonuclear reaction rate of ^{22}Mg(α,p)^{25}Al and its influence on type-I XRBs [2-4]. The coincidence measurements that can be performed using the K600 and the CAKE also include reactions relevant to classical novae such as ^{21}Na(p,γ)^{22}Mg and ^{30}P(p,γ)^{31}S. These experiments will also be discussed in this talk.

Poster session / 110

The $^{12}C+^{16}O$ fusion reaction in carbon burning: study at energies of astrophysical interest using the Trojan Horse Method

Author: Alessandro Alberto Oliva[1]

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Carbon burning is a fundamental process for the advanced stages of a massive star ($M > 8M_\odot$) evolution. It mainly occurs through the $^{12}C +^{12} C$ fusion, however at temperatures higher than $10^9 K$ the $^{12}C +^{16} O$ fusion can become prevalent due to the increased abundance of ^{16}O in the ashes of the helium burning. The $^{12}C +^{16} O$ reaction also plays a role both in the explosive carbon burning and in the oxygen burning. Thus, the astrophysical energy region of interest ranges from 3 to 7.2 MeV in the center-of-mass frame.

In the literature there are various measurements of the cross section between 4 and 7.2 MeV in the center-of-mass, however, none of them goes below 4 MeV, making extrapolation necessary. Recently the reactions $^{16}O(^{12}C, \alpha)^{24}Mg$ and $^{16}O(^{12}C, p)^{27}Al$ have been studied in the entire energy region of astrophysical interest by applying the Trojan Horse Method to three-body processes $^{16}O(^{14}N, \alpha^{24}Mg)^2H$ and $^{16}O(^{14}N, p^{27}Al)^2H$. In this talk, after a brief description of the method, the experimental setup as well as the preliminary phases of the data analysis will be presented and discussed.

Thursday - Session 3 / 111

A technique for studying (n,p) reactions of astrophysical interest using radioactive beams with SECAR.

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Neutron-induced reactions are essential to the nucleosynthesis of the elements heavier than iron. Recent studies show that key (n,p) reactions, such as the ^{56}Ni(n,p)^{56}Co and ^{64}Ge(n,p)^{64}Ga, accelerate the so-called neutrino-p process (νp-process), enabling the process to create heavy elements between nickel (Ni) and tin (Sn) in type II Supernovae. The νp-process occurs in slightly proton-rich regions in the neutrino driven wind of core-collapse supernovae, via a sequence of proton-capture reactions and (n,p) reactions. The small abundance of neutrons that drives the (n,p) reactions originates from anti-neutrino captures on free protons.

The study of such (n,p) reactions is achievable via the measurement of the reverse (p,n) reactions. While such proton-induced reaction measurements are particularly challenging, as the recoils and the unreacted projectiles have nearly identical masses, an appropriate separation level can still be achieved by SECAR, the SEparator for CApture Reactions at FRIB. In a recent experiment, the first direct measurement of the p(^{58}Fe,n)^{58}Co reaction was possible by the in-coincidence detection of the recoil ^{58}Co at the end of SECAR and the emitted neutrons near the SECAR target/entrance. As the ^{58}Fe(p,n)^{58}Co reaction has been measured in the past only via the activation method, this direct measurement is expected to improve the cross-section data available, especially for energies close to the Coulomb barrier, and to pave the path for many other (p,n) reaction measurements of great astrophysical interest with low abundance isotope - as is the case for the ^{58}Fe, or radioactive beams. In this talk, some preliminary results of the aforementioned experiment, along with the experimental details for the (p,n) reaction study with SECAR, will be discussed.

Friday - Session 2 / 112

Measurement of the 7Be(p,γ)8B reaction cross section at astrophysical energies with the recoil mass separator ERNA

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The $^7\mathrm{Be}(\mathrm{p},\gamma)^8\mathrm{B}$ represents one of the more important reaction for the prediction of high energy component of solar neutrino spectrum. The importance of this reaction triggered an intense experimental work over the last decades, where discrepancies were observed between the results of different measurements.
The origin of this discrepancy limit the overall precision and accuracy of the estimate of the astrophysical rate of $^7\mathrm{Be}(\mathrm{p},\gamma)^8\mathrm{B}$ reaction. In addition, there is a question about possible common systematic effects, considering that all measurements performed so far share the same experimental approach, i.e. an intense proton beam impinging on a $^7\mathrm{Be}$ radioactive target. A direct measurement using a radioactive $^7\mathrm{Be}$ ion beam on a pure hydrogen gas target by means of the detection of the $^8\mathrm{B}$ recoils, can shed light on such systematic effects. Efforts attempted so far were limited by the low $^7\mathrm{Be}$ beam intensity.
Here we present the results obtained using the intense $^7\mathrm{Be}$ beam in combination with a windowless gas target available at the Tandem Accelerator Laboratory at CIRCE (Center for Isotopic Research on Cultural and Environmental heritage), University of Campania, Italy coupled to the recoil mass separator ERNA (European Recoil mass separator for Nuclear Astrophysics) in the energy range $E_{cm} = 367$ to 812 keV 1.

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Tuesday - Session 4 / 113

Evolution of accreting neutron star common envelopes and their nucleosynthesis

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In massive-star binary systems, upon reaching later stages of stellar evolution one star can expand as a giant and envelope its companion. The enveloped companion, here a neutron star, can begin to accrete matter. The angular momentum of the accreting material will result in the formation of an accretion disk. Accretion onto common-envelope-phase neutron stars can result in material ejected from the accretion disk having undergone burning near the neutron star's surface 1. Much about the nucleosynthesis that occurs in this system is not known, nor do we know what impact it has on galactic chemical evolution (GCE). In particular exploration of p-nuclides, an underproduced set of proton rich isotopes, is of interest. As such, further exploration of this system is required.
The equations which govern the accretion disk which forms in this scenario are not well constrained. The trajectories used in Keegans et al. (2019) are modelled from Popham et al. (1999) and are adapted from equations describing the interaction of a black hole with a helium core 1,[3]. Shakura and Sunyaev's alpha disk solutions [4] are widely used to describe accretion disks, however they apply for an accretion disk dominated by gas pressure. At the small radii of accretion disks in this scenario, radiation pressure is thought to dominate and as such different equations must be employed [5]. The presented study builds on work by Keegans et al. (2019) 1. We have taken Popham's [3] equations and worked to solve them for the conditions of an accreting neutron star common envelope, with the aim of more accurately modelling this radiation dominated system. Details of the model will be presented, and their implications will be discussed with emphasis on nucleosynthetic impact of this system.

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Field of work:

Poster session / 116

Investigation of the ^{7}Li(p,n)^{7}Be neutron fields at high energies

Authors: Benjamin Brueckner[1]; Cem Deniz Kurtulgil[2]; Christoph Langer[3]; Kafa Al-Khasawneh[1]; Kathrin Goebel[4]; Mario Weigand[1]; Markus Reich[1]; Meiko Volknandt[1]; Michael Wiescher[5]; Philipp Erbacher[1]; Ralf Heinrich Nolte[6]; Rene Reifarth[2]; Tanja Heftrich[7]

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The neutron activation method is well-suited to investigate neutron-capture cross sections relevant for the main s-process component. Neutrons can be produced via the ^{7}Li(p,n) reaction with proton energies of 1912 keV at e.g. Van de Graaf accelerators, which results in a Maxwellian spectrum of neutrons corresponding to a temperature of $k_B T$ = 25 keV. This mimicks the s-process scenario in low-mass asymptotic giant branch (AGB) stars. However, the weak s-process takes place in massive stars at temperatures between 25 and 90 keV. Neutron spectra corresponding to a Maxwell-Boltzmann distribution with $k_B T$ > 25 keV cannot be produced by the ^{7}Li(p,n) reaction. Simulations using the PINO 1 code suggest that a Maxwellian spectrum for higher energies can be produced by a linear combination of different neutron spectra. The resulting spectrum averaged cross sections can be combined to e.g. $k_B T$ = 90 keV Maxwellian Averaged Cross Section (MACS). To validate the PINO code at proton energies $E_p \neq$ 1912 keV, measurements were carried out at the PTB Ion Accelerator Facility (PIAF) at the Physikalisch-Technische Bundesanstalt in Braunschweig, Germany. The neutron fields were measured using a pulsed proton beam and three 6Li-glass scintillation detectors mounted at different angles. The neutron energy was determined by time-of-flight (TOF).

1 R. Reifarth et. al., Nuclear Instruments and Methods in Physics Research A 608, 139 (2009)

Wednesday - Session 3 / 118

MACS measurements for nuclear astrophysics at n_TOF/NEAR: Feasibility study and first results

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Half the atomic nuclei heavier than iron are created through the s-process, i.e. a series of neutron captures and subsequent beta decays. Accordingly, the accuracy of neutron capture rates is of significant importance for these astrophysical calculations and for our understanding of the observed isotopic abundances 1. In particular, fundamental input can be provided through the determination of Maxwellian Averaged Cross-Sections (MACS) of neutron capture reactions for temperatures matching stellar environments[2].
During CERN's Long Shutdown 2 (2019-2021), a new experimental area was constructed at the n_TOF facility. This new experimental area, NEAR, is a high-flux irradiation station only 3m away from the facility's spallation target, suitable for the study of radiation effects on materials and electronics, as well as for measuring neutron-induced reaction cross-sections through the activation technique[3].
The energies of the neutrons reaching the irradiation station cover a wide energy range, from thermal up to the GeV region. With the use of proper materials as filters and moderators and with a careful choice of their dimensions, the neutron beam of NEAR can be shaped into Maxwell-Boltzmann distributions corresponding to different stellar temperatures. In this way, the MACS of various isotopes can be directly measured by means of the activation technique[4].
In this work, the feasibility study of MACS measurements at NEAR/n_TOF will be presented, along with the first results coming from the experimental validation of the filtering method to be used for the shaping of the neutron beam.

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Monday - Session 3 / 119

Trap System for Measuring Neutron Capture Cross Section of Short-lived Isotopes

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One of the current limitations of predicting the nuclear astrophysics r-process abundance is the lack of experimental data on neutron-capture cross-sections of radioactive neutron-rich isotopes. These cross-sections are also invaluable for nuclear reactions and nuclear structure in general. Their measurement is currently considered impossible due to the instability of the targets and projectile. We propose a method to overcome this limitation. We plan to select and store fission fragments in a RF system (coined "NG-Trap" 1), which will form a trapped 'cloud target' that will consequently be irradiated by an intense neutron beam. The reacted ions will be mass-selected, identified and counted using a multiple-reflection time-of-flight mass-spectrometer (MR-TOF-MS), thus extracting (n,γ) cross-sections.

This talk will mainly focus on the NG-Trap system that will be developed for the Soreq Applied Research Accelerator Facility (SARAF) [2], currently under construction in Yavne, Israel. We will further present an existing triple-RFQ system [3], which is presently being set up at Tel-Aviv University for research and development of the cloud target concept, and preliminary estimations of event rates for numerous radioactive target isotopes.

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Poster session / 120

Study of decay properties for La to Nd nuclei (A~160) relevant for the formation of the r-process rare-earth peak

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Around half of the elemental abundances heavier than iron are created via the rapid neutron capture process (r-process). For nuclear masses $A > 100$, there are two main peaks in the r-process abundances, located at $A \sim 130$ and $A \sim 195$. These peaks are associated with neutron shell closures. In contrast, the rare-earth peak (REP) is a small - but clear - peak around mass $A = 160$, appearing in late phases of the freeze-out after neutron exhaustion. The formation of the REP offers a unique probe for the study of the late-time conditions on the r-process site. According to theoretical models and sensitivity studies, half-lives $(T_{1/2})$ and beta-delayed neutron emission probabilities (P_n) of very neutron-rich nuclei for $55 \leq Z \leq 64$ are the most influential ones on the formation of the REP [1,2]. The BRIKEN project [3,4] has been in operation from 2016 up to 2021 at the Radioactive Isotope Beam Factory (RIBF) in the RIKEN Nishina Center, Japan. BRIKEN has performed an ambitious measurement program of beta-decay properties of nuclei on the path of the r-process. The overall expected outcome of the BRIKEN project is to report for the first time about 120 half-lives and 300 measurements of single and multiple beta-delayed neutron emitters. Moreover, the BRIKEN-REP experiment has recently measured $T_{1/2}$ and P_n-values of nuclei from Ba to Eu (A $\sim$ 160), belonging to the region which is the most influential to the REP formation [5,6]. In this contribution, we will discuss the status of the BRIKEN-REP experiment. The first experimental results of new P_{1n}-values and $T_{1/2}$ for nuclei in the neutron-rich region from La to Nd will be presented.

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Poster session / 121

Observational and Astrophysical study of Black Holes

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Black holes have ignited thought-provoking ideas for decades because of their peculiar origin of existence and very nature. Once only thought to be merely a mathematical curiosity, black holes have now become an integral part of Astrophysics and Astronomy that devour copious amounts of matter. Given the advancement from the first speculation to the latest research, an up-to-date review report is required to sum up the development and achievements made in the field. We have designed this study to give an introductory overview of black holes and super massive black holes that will help to understand the common trait running between nuclear physics and astrophysics. In this review, we discuss the different flavours of black holes ranging from 10^{-8} kg to 6.6×10^{10} $M_\odot$ ($M_\odot$ = 1.9891×10^{30} kg), keeping super massive black holes as our main focus. We present a simplified method for comprehending active galaxies and categorising them based on radio-loud and radio-quiet active galactic nuclei. We also provide our readers with a mathematical approach to the physical and spin properties of black holes and, hence, a collection of the properties of 70 well-known super massive black holes and 101 active galactic nuclei respectively that will help us to understand the physics on which nuclear physics can be modelled.

Field of work:

Friday - Session 1 / 122

Fusion of 12C + 24Mg at extreme sub-barrier energies

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The study of heavy-ion fusion reactions of light systems is essential for the understanding of the astrophysical reaction networks responsible for the energy production and elemental synthesis in stellar environments. At far sub-barrier energies, fusion is influenced by the hindrance phenomenon 1. Fusion of light heavy-ions is characterised by a positive Q-value and establishing the presence of hindrance in such systems requires challenging measurements. In the two relevant cases 12C+12C and 16O+16O the available data give indication of the existence of hindrance, but the situation is far

from being well established, especially for 12C+12C fusion where the several resonances observed 1, make very controversial any conclusion. The study of slightly heavier systems is then appealing, because their low-energy fusion trend may provide a reliable guidance for the extrapolation to the lighter cases of astrophysical interest.
We have measured [2] the fusion excitation function (and consequently the S-factor) for the system 12C+24Mg, using the magnesium beam from the XTU Tandem accelerator of INFN-LNL and 50 micro-g/cm2 12C targets enriched to 99.9% in mass 12, down to around sigma_fus=4.7 micro-b. Fusion hindrance shows up because the S-factor displays a well-defined maximum vs energy below the barrier around sigma_fus=1 mb. It is remarkable that the lowest cross sections are consistent with a simple one-dimensional barrier penetration calculation. The S-factor trend is well reproduced using an empirical formula in the spirit of the adiabatic model [3], as well as using the phenomenological hindrance model [4].
Measurements at energies slightly below the present ones are in schedule and will allow a deeper insight into the fusion dynamics far below the barrier. Far-reaching consequences may be envisaged for the lighter systems relevant for astrophysics.

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[4] C.L. Jiang et al., Phys. Rev. C75, 015803 (2007)

Wednesday - Session 1 / 124

Beta decay in Neutron Star Crusts

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Low Mass X-ray Binaries that transiently accrete matter onto their neutron stars are excellent laboratories for studying dense matter physics. These systems go in and out of the quiescence phase over observational timescales of decades. Monitoring the surface temperatures of neutron stars in this phase reveals a great deal of information about their structure and composition. However, to infer these properties, it is necessary to have a complete understanding of different nuclear reactions that heat or cool the crust. Urca cooling is one such source of neutrino cooling in the crust that strongly depends on the ground-state to ground-state β-decay transition strengths. $A = 33$ mass chain, and specifically the ^{33}Mg - ^{33}Al transition is the strongest Urca cooling agent for crusts composed of X-ray burst ashes. This relies partly on the strong ground state branch measured in high resolution β-delayed γ-spectroscopy of ^{33}Mg. However, recent measurements of a negative parity ground state in ^{33}Mg makes this a first forbidden decay and the strong transition strength is questioned in the literature, citing Pandemonium effect as a possible reason. We try to resolve this anomaly using Total Absorption Spectroscopy that is mostly free of this Pandemonium effect. I will present the β-decay of ^{33}Mg experiment performed at the National Superconducting Cyclotron Laboratory (NSCL) with NERO/BCS/SuN detector system and discuss results from ongoing analysis. This measurement will also provide more information about the nuclear structure effects near the $N = 20$ island of inversion and how they manifest in astrophysical systems.

Monday - Session 4 / 125

Big-Bang Nucleosynthesis Reloaded: Beyond the Lithium Problem?

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We will summarize the status of big-bang nucleosynthesis (BBN), which describes the production of the lightest nuclides during the first three minutes of cosmic time. We will emphasize the transformational influence of cosmic microwave background (CMB) experiments culminating today with Planck, which pin down the cosmic baryon density to exquisite precision. Standard BBN combines this with the Standard Model of particle physics, and with nuclear cross section measurements–notably recent precision measurements of d(p,g)3He by the LUNA collaboration. These allow BBN to make tight predictions for the primordial light element abundances, with the result that deuterium observations agree spectacularly with these predictions, and helium observations are in good agreement. This CMB/BBN concordance marks a great success of the hot big bang, and BBN and the CMB together now sharply probe cosmology, neutrino physics, and dark matter physics at times around 1 second. But this success is tempered by lithium observations (in metal-poor halo stars) that are significantly discrepant with BBN+CMB predictions. We will summarize possible resolutions to this "lithium problem," highlighting recent work that strengthens the case for a a solution involving stellar astrophysics, while solutions involving new physics are becoming ever more constrained. We conclude with an outlook for how future CMB, astronomical, and laboratory measurements can better probe new physics, and shed light on the solution to the lithium problem.

Field of work:

Tuesday - Session 2 / 126

Origin of Short-lived Radio nuclides in the Early Solar System

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The short-lived radionuclides (SLRs) have a half-life ≤ 100 Myr. The excess abundance of their daughter nuclides in various meteoritic phases confirms the existence of SLRs in the early solar system (ESS). In this work, we have developed Galactic chemical evolution (GCE) models to understand the stellar sources of SLRs, ^{26}Al, ^{36}Cl, ^{41}Ca, ^{53}Mn, and ^{60}Fe in the ESS. In these models, the solar neighborhood (8-10 kpc from the galactic center) is divided into spatial grids of area, 0.1-1 kpc^2. Each grid area evolves over the galactic timescale distinctly in terms of nucleosynthetic contributions of various generations of stars.

In our simulations, the solar system forms inside a stellar cluster and has canonical values of ^{60}Fe/^{56}Fe and ^{53}Mn/^{55}Mn in the ESS. We have also proposed a possible scenario to explain the observed abundance of ^{26}Al/^{27}Al and ^{41}Ca/^{40}Ca in the ESS. In addition, the results of the temporal and spatial evolution of abundance trends of SLRs in the galaxy from 2-18 kpc will be presented.

Poster session / 127

Direct reactions for nuclear astrophysics

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The neutron activation technique is a well established method to measure neutron capture cross sections relevant for the s-process.The ^{7}Li(p,n) reaction at $E_p = 1912\,\text{keV}$ is often used as a neutron source since the energy distribution of the emitted neutrons closely resembles a Maxwell-Boltzmann spectrum of $k_BT = 25\,\text{keV}$ mimicking the ^{22}Ne(α,n) phase in TP-AGB stars. The weak s-process, which takes place in massive stars, can reach energies up to $k_BT = 90\,\text{keV}$. Neutron spectra corresponding to a Maxwell-Boltzmann distribution with $k_BT > 25\,\text{keV}$ cannot be produced by the ^{7}Li(p,n) reaction directly.
We developed a method to obtain quasi-Maxwellian neutron capture cross sections over a wide energy range by combining a set of spectrum average cross sections measured at six different proton energies and distances between the lithium target and the sample. The measured spectrum averaged cross section can be used to calculate the Maxwellian averaged cross-section from $k_BT = 25\,\text{keV}$ to $k_BT = 90\,\text{keV}$. Over the last two years neutron capture cross sections on over 20 isotopes were measured at Goethe University Frankfurt using this method.
An overview of the current experimental method, challenges during data analysis and the first results are presented.

Poster session / 128

The impacts of dynamical nuclear fission for neutron-rich actinoids on r-process nucleosynthesis

Authors: Nobuya Nishimura[1]; Shoya Tanaka[2]; Itoshi Nishimura[3]; Wataru Miyasakai[None]; Shinya Takagi[3]; Yoshihiro Aritomo[None]; Masahisa Ohta[None]

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The nuclear fission of very neuron-rich nuclei is essential in the r-process for the termination of nucleosynthesis flows and the final abundances. Nevertheless, most of the available fission data for the r-process simulations are based on phenomenological calculations. In the present study, we investigate the theoretical uncertainty of nuclear fission related to the r-process. Focusing on the dynamical process in fission, we focus on the impacts of fission-fragment distribution on the r-process. We calculate a series of nuclear fission distribution for the neutron-rich isotopes of U to Fe away from the β-stability line with a dynamical fission model with the Langevin method. As the isotope becomes more neutron-rich, the asymmetric feature in fission distribution changes to the symmetric, which is significantly different from the results of the phenomenological model. We find the difference in fission yields show the impacts on the r-process final abundances around the second peak.

Poster session / 129

Onset of pressure gradient on collective flow through balance and transition geometry

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The impression of mean field and spectator matter has been studied through the collision geometry dependence of reduced flow and elliptical flow in heavy-ion collisions (HICs) at intermediate energies using Isospin-dependent Quantum Molecular Dynamics (IQMD) model for the reaction of $^{50}_{20}$Ca+$^{50}_{20}$Ca and $^{197}_{79}$Au+$^{197}_{79}$Au at incident energy between 50 MeV/nucleon and 450 MeV/nucleon. We observe that at particular incident energy, the magnitude of both types of flow changes its sign from positives to negative (or vice-versa) as the collision geometry increases. The impact parameter at which the reduced flow and elliptical flow changes its sign is termed as balance geometry ($\hat{b}_{bal}$) and transition geometry ($\hat{b}_{trans}$) of flow, respectively. Our study reveals that ($\hat{b}_{bal}$) and ($\hat{b}_{trans}$) increases with increase in incident energy. In addition to this, the effect of nuclear charge radius has also been studied by using the isospin-independent as well independent nuclear charge radii parameterizations.

Field of work:

Thursday - Session 3 / 131

Studies of photonuclear reactions at astrophysical energies with an active-target TPC

Authors: Mikolaj Cwiok[1]; Wojciech Dominik[1]; Aleksandra Fijalkowska[2]; Mateusz Fila[1]; Zenon Janas[1]; Artur Kalinowski[2]; Magdalena Kuich[2]; Chiara Mazzocchi[2]; Marcin Zaremba[1]; Moshe Gai[3]; Deran Kurt Schweitzer[3]; Sarah Stern[4]; Udo Friman-Gayer[5]; Dimiter Balabanski[6]; Kris Haverson[7]; Mark Griffiths[8]; Stuart Pirrie[8]; Pedro Santa Rita Alcibia[9]

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Thermonuclear reactions that power the stars take place at different energies according to their respective stellar environments. Such energies are well below the Coulomb barrier and the respective cross-sections are incredibly small, often below experimental reach. Modelling energy production in stars requires experimental data on cross-sections for low energies; these data are sparse. As a consequence extrapolations are made, with a large degree of unavoidable uncertainty. Of special interest are (p,γ) and (α,γ) reactions, in particular those that regulate the ratio of C and O and those that burn ^{18}O and, therefore, regulate the ratio between ^{16}O and ^{18}O in the Universe. One of the benchmark reactions to be investigated in this work is the ^{12}C(α,γ)^{16}O at energies down to 1 MeV in the centre-of-mass reference frame.

A new active target detector (time-projection chamber - TPC) optimised for experiments with high-intensity γ-ray beams was developed and built at the University of Warsaw 1. It is characterised by the fact that it uses a 3-coordinate planar electronic readout acting as virtual pixels, read-out by GET electronics with negligible dead-time for the reaction rates (incl. background) expected for the reactions of interest with the available high-intensity γ beams. Moreover, it can work with pure CO_2 gas at pressures as low as 80 mbar.
The detector was employed in April 2022 in a measurement at the High Intensity Gamma-Ray Source (HIγS) facility at the Triangle Universities Nuclear Laboratory (TUNL), Durham, NC, USA. In this pilot experiment, the time-inverse photo-disintegration processes induced by high energy photons were studied, using a monochromatic γ-ray beam at energies ranging from 11.1 to 13.9~MeV (centre-of-mass energies 3.9−6.7~MeV), which interacted with the CO_2 gas in the chamber. The charged reaction products, namely ^{12}C and α particles, were detected, and their momenta reconstructed in 3D. The principles of the experiment will be illustrated, together with preliminary results. An outlook on future plans to go beyond the presently established lower limits [2] will be given.

1 M. Cwiok et al., Acta Phys. Pol. 49 (2018) 509.

[2] R. Smith et al., Nature Comm. 12, 5920 (2021) and M. Gai, NPA10 contribution.

Thursday - Session 1 / 132

Mass measurement in the N=40 region with JYFLTRAP

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We report on a precise mass measurement of 69Co and 70Co performed at the IGISOL facility 1.
The nuclear structure above the N=40 subshell closure remained for long unclear due to lack of information on neutron-rich nuclei in this region. This region is known for shape coexistence and intruder states have been observed in neutron-rich cobalt isotopes toward N=40 [2]. The two-neutron separation energies and the empirical two-neutron shell-gap determined from the mass value give important insight on the evolution of the subshell closure. In nuclear astrophysics, the 68Co(n,γ)69Co reaction have been highlighted in sensitivities studies to strongly influence the abundance pattern for the weak r process, which produces the lightest r-process elements [3]. The ratio of the photo-disintegration to the neutron-capture rate depends exponentially on the reaction Q-value, stressing the need of precise mass value.
The double Penning trap JYFLTRAP [4] at the University of Jyväskylä has been successfully used to measure the masses of 12 nuclides in the N=40 region. Among these, the masses of 69Com and 70Co were determined for the first time 1. The isotopes of interest were produced via proton-induced fission at the IGISOL facility [5] during one week of experiment. The time-of-flight ion cyclotron resonance (TOF-ICR) technique [6] was used for the mass measurements. The ½- isomer in 69Co has been determined via ion beam manipulation technique, taking advantage of the difference of half-lives between the ground and the isomeric state in 69Co. In addition, the phase-imaging ion cyclotron resonance technique (PI-ICR) [7] was used for the first time online to determine the composition of the 70Co beam and the long living state of 70Co was precisely determined. Our experimental data were compared to large-scale shell model calculations and confirm the weakening of the N=40

subshell closure below nickel. We also considerably reduced the mass-related uncertainty in the photodisintegration rate 69Co(γ,n)68Co and in the ratio of the photodisintegration to the neutron-capture rate.
In this talk, the experimental method and the impact of our results on astrophysics and nuclear structure in the N=40 region will be discussed.

1 L. Canete et al., Phys. Rev. C 101, 041304 (R) (2020).
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[3] R. Surman et al., AIP Advances 4,041008 (2014).
[4] T. Eronen et al., Eur. Phys. J. A 48, 46 (2012).
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[6] M. König et al., Int. J. Mass Spectrom. Ion Process. 142, 95 (1995).
[7] S. Eliseev et al., Phys. Rev. Let. 110, 082501 (2013).

Poster session / 133

New results on the level structure of ^{26}Si and consequences for the ^{25}Al(p,γ)^{26}Si reaction in Classical Novae environments

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The ^{25}Al(p,γ)^{26}Si reaction is of tremendous interest in nuclear astrophysics. The production of the γ-ray emitter ^{26}Al ground state can be bypassed in classical novae via the production of ^{26}Si which decays to an isomeric state of ^{26}Al. In order to more precisely estimate the amount of ^{26}Al that is of classical novae origin, it's crucial to determine the rate of the ^{25}Al(p,γ)^{26}Si reaction at nova-burning temperatures. The production of ^{26}Si is dominated by resonant captures to several excited states above the proton threshold in ^{26}Si. There has been considerable experimental effort in recent years to observe and identify theses states 1, but the properties of the key resonances in ^{26}Si remain unsettled.
The combination of GRETINA [2] coupled with the Fragment Mass Analyzer (FMA) [3] at Argonne National Laboratory (ANL), provided a powerful opportunity to identify transitions in ^{26}Si, owing to the large acceptance of the separator and the Doppler-reconstruction capabilities and high-energy efficiency of the GRETINA array. The experiment, presented here, follows an earlier γ-ray spectroscopy study of the ^{26}Si mirror nucleus, ^{26}Mg, performed with Gammasphere at ANL where a l=1 resonance was identified for the first time (fig.1) [4]. In the same study, the lifetime of the 3+, 6125-keV state in ^{26}Mg was measured via the Doppler shift attenuation method. The 3+, 414-keV resonance in ^{26}Si dominates the ^{25}Al(p,γ) reaction over most of the novae peak temperature range, while the introduction of the new 1- state increases the reaction rate by ~25% at the highest novae temperatures.
In this talk, new results on ^{26}Si from the GRETINA+FMA study will be presented along with further information gained on the A=26 system. Information on both the level structure of ^{26}Si and the impact on the astrophysical ^{25}Al(p,γ)^{26}Si reaction will be discussed.

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[2] D. Weisshaar et al, Nucl. Instrum. Methods Phys. Res. A 847, 187 (2017).
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[4] L. Canete et al, Phys. Rev. C 104, L022802 (2021).

Field of work:

Poster session / 134

Low-energy Cross Section Measurments of $^{12}\mathrm{C}(\mathrm{p},\gamma)$ and $^{13}\mathrm{C}(\mathrm{p},\gamma)$ Deep Underground at LUNA

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Cross section measurements of $^{12,13}\mathrm{C}(\mathrm{p},\gamma)^{13,14}\mathrm{N}$ have been performed at the Laboratory for Underground Nuclear Astrophysics (LUNA), where the low-background environment and high beam currents of the 400 kV accelerator allowed to obtain cross section data for these reactions at lower energies and with smaller statistical uncertainties than previously available towards astrophysical energies. Considering possible systematic uncertainties, the two reactions were studied using different solid targets and complementary detection setups. We will present the experimental campaigns and their results.

135

Sn p-nuclei and nuclear reaction mechanisms: contributions to cosmological production

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An analysis of the co-occurrence of several nuclear mechanisms responsible for generating Sn p-nuclei for photon and proton energies up to 25 MeV was conducted. The astrophysical temperature during nucleosynthesis lies in the region of 0.01<T9<10 (that nearly corresponds to incident particle energies < 1 MeV). There is one p-nucleus among those considered, 112Sn, that is bypassed by a low energy p-process, 113Sn(p,2n)112Sn. Other Sn isotopes are mainly produced via s-processes. The p, r, and rp processes can occur in hot astrophysical plasmas at higher incident energies.
Taking into account all reaction types, contributions of different nuclear reaction mechanisms into cross-sections values and Sn p-nuclei yields for each process are theoretically evaluated. On the basis of work done, the evaluation of different processes contribution (compound nucleus, direct capture etc.) on proton radiation capture rates are theoretically described applying statistical model Hauser – Feshbach.
For each reaction type, an analysis is performed to estimate the weight assigned to different nuclear reaction mechanisms to cross-section values and p-nuclei yields. Using a statistical model Hauser-Feshbach, this research will explore how different nuclear reaction mechanisms (compound nucleus, direct capture, etc.) impact proton radiation capture rates. Protons with energies less than a few MeV mainly undergo compound processes, whereas at higher energies direct processes and pre-equilibrium mechanisms cannot be ignored.
The theoretical calculations were assessed by comparing the results with experimental data, such as global predictions by Thielemann and Brussels groups.

Field of work:

Tuesday - Session 2 / 136

Sensitivity of X-ray burst models to nuclear reaction rates for a range of low-mass X-ray binaries

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Accreting neutron stars offer unique opportunities to study the properties of matter in extreme density environments and nuclear processes involving very unstable isotopes. X-ray burst are one of the rich observables that can be used to test models of accreting neutron stars. The burst are driven by thermonuclear reactions near the surface of the neutron star that proceed through (a,p) and (p,g) reactions and drive the reaction flow towards the proton dripline, involving nuclei with poorly constrained nuclear reaction rates. Sensitivity studies to evaluate the impact of these reactions in the results of X-ray burst are an effective method to guide efforts to measure and constrain the rates experimentally 1. We present results of a single-zone sensitivity study that extend previous work of Cyburt et al to a range of different low-mass X-ray binary systems. Our study accounts for the variability in the accretion rate and composition of the accreted material observed in these systems [2]. We discuss how the impact of different reaction rates depends on these parameters.

1 R. Cyburt et al, ApJ 830, 55 (2016)
[2] D. K. Galloway, A. J. Goodwin, L. Keek, PASA 34, e019 (2017)

Thursday - Session 2 / 137

A new approach to β-decays studies impacting nuclear physics and astrophysics: the PANDORA setup

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Theory [1,2] predicts that lifetimes of beta-radionuclides can change dramatically as a function of their ionization state. Fully stripped ions in storage rings [3] have proven to change their lifetimes by several orders of magnitudes. The PANDORA (Plasmas for Astrophysics, Nuclear Decay Observation and Radiation for Archaeometry) [4,5] experiment is conceived to measure, for the first time, nuclear β-decay rates in stellar-like conditions as a function of temperature (i.e. using magnetized laboratory plasmas). These measurements will be extremely relevant for those radionuclides involved in nuclear-astrophysics processes (BBN, s-processing, CosmoChronometers, Early Solar System formation). PANDORA is based on a compact B-minimum magnetic trap (with Bmax = 3.0 T), where plasmas are heated by microwaves via Electron Cyclotron Resonance at 18-21 GHz up to densities $n_e \sim 10^{11} \div 10^{13} cm^{-3}$, and temperatures T_e~0.1-30 keV. The decay rates can be measured as a function of the density and temperature, whose combination determines the charge state distribution of the in-plasma ions. This contribution will describe the overall setup including a 14 HpGe detectors array for deducing the decay rates and a plasma multi-diagnostics system (RF interferopolarimeters, optical and X-ray spectroscopy and imaging) for the simultaneous measurement of plasma density and temperature. The setup will also allow to measure plasma optical opacities

that are relevant for the kilonovae scenarios. Tens of physics cases of potential interest have been singled out, with a shortlist of priorities including ^{94}Nb ($t_{1/2}$ $2x10^4y$), ^{134}Cs ($t_{1/2}$ $\sim$ $2,05y$) [6], ^{176}Lu ($t_{1/2}$ $\sim$ $3.76x10^{10}s$). In particular, it is still debated if 176Lu is a cosmo-thermometer or a cosmo-chronometer; ^{134}Cs investigation is relevant for the production of the s-only isotopes ^{134}Ba and ^{136}Ba; and ^{94}Nb is relevant for determining the abundance of ^{94}Mo in single or binary systems of stars. The TDR of the project was released in 2021. Discovery potentialities will be presented in this paper, as well as the further implementation of advanced diagnostics and the theoretical analysis of the expected decay rates, which is now carried out as a "virtual experiment" including predictions of the β-decays due to the change of the atomic structure (ionisation and excited states) in a self-consistently simulated plasma scenario reproducing laboratory features, with the aim to characterize the overall experimental sensitivity of the setup.

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[2] K. Takahashi and K. Yokoi, Beta-decay rates of highly ionized heavy atoms in stellar interiors, Atomic Data and Nuclear Data Tables. Volume 36, Issue 3, May 1987, Pages 375-409 DOI: https://doi.org/10.1016/0092-640X(87)90010-6
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[4] D. Mascali et al., European Physical Journal A 03/2017; 53(7)., DOI:10.1140/epja/i2017-12335-1
[5] D. Mascali, et al. Universe 2022, 8, 80. https://doi.org/10.3390/universe8020080
[6] Palmerini S. et al., Presolar Grain Isotopic Ratios as Constraints to Nuclear and Stellar Parameters of Asymptotic Giant Branch Star Nucleosynthesis, The Astrophysical Journal 2021, 921 (1), 7

Field of work:

Tuesday - Session 1 / 138

FIRST MEASUREMENT OF THE 94NB NEUTRON CAPTURE CROSS-SECTION AT THE CERN N_TOF FACILITY

Authors: Adria Casanovas Hoste[1]; Cesar Domingo Pardo[2]; Javier Balibrea Correa[2]; n_TOF Collaboration[3]; Ariel Esteban Tarifeno Saldivia[2]; Carlos Guerrero Sanchez[4]; Emilio Andrea Maugeri[5]; I Mönch[6]; Ion Ladarescu Palivan[2]; Jorge Lerendegui Marco[2]; Köster U.[6]; Luis Caballero Ontanaya[2]; Maria Dorothea Schumann[7]; Paco Calvino Tavares[1]; Rugard Dressler[5]; Stephan Heinitz[7]; Victor Babiano Suarez[2]

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One of the crucial ingredients for the improvement of stellar models in the framework of nucleosynthesis studies is the accurate knowledge of neutron capture cross-sections for the different isotopes involved. This type of measurements can shed light on the discrepancies between observed and predicted isotopic abundances by the stellar models and thus help to constrain the stellar media conditions where these reactions take place.
In the particular case of the radioactive ^{94}Nb, the 94Nb(n,γ) cross-section could play a role in the determination of the s-process production of ^{94}Mo in AGB stars, which presently cannot be reproduced by state-of-the-art stellar models1. As today, there exists no previous ^{94}Nb(n,γ) experimental data for the resolved and unresolved resonance regions mainly due to the difficulties in producing high-quality samples and also to limitations in conventional detection systems commonly used in time-of-flight experiments.
Motivated by this situation, an experiment to measure ^{94}Nb(n,γ) has been carried out at CERN n_TOF [2] including new detection systems and a high quality sample based on hyper-pure 93Nb material

activated at the high- flux reactor of ILL-Grenoble. The experiment profited from the high-flux beam-line of n_TOF EAR2 [3] and an array of small Total-Energy Detectors in an innovative ring-configuration around the capture sample, which allowed us to significantly enhance the signal-to-background ratio during the experiment. In addition, two conventional C6D6 detectors and a high-resolution LaCl3(Ce) were employed for addressing reliably systematic effects and uncertainties. At the time of the conference preliminary results on the ^{94}Nb(n,γ) cross-section will be presented together with a discussion on possible implications of this cross-section measurement for the s-process in the region of the Mo isotopes.

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[2] J. Balibrea et al: CERN-INTC-2020-062
[3] C. Weiss et al., NIM-A 799, 90-98 (2015)

Field of work:

Wednesday - Session 3 / 139

Nuclear astrophysics at storage rings

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Storage rings offer a unique approach to measure nuclear reactions using stored radioisotope beams impinging on ultra-pure internal targets. This approach has been pioneered at the ESR storage ring in GSI Laboratory (Germany).

The newly commissioned CRYRING, part of FAIR Phase-0, opens up new and ground-breaking possibilities for nuclear astrophysics at storage rings. CRYRING is the first and the only ring in the world where radioisotopes can be stored at the energies of interest for most astrophysical scenarios (<10 MeV/A).

In order to exploit this opportunity, the new CRYRING Array for Reaction MEasurement (CARME), designed specifically to detect charged-particle reactions at CRYRING, was commissioned with stored beam in 2022. CARME science programme will now be supported by an ERC Starting Grant, ELDAR.

I will introduce the topic of nuclear reaction measurement at storage rings, and describe specifically the novel scientific opportunities opened up by CARME in a wide range of stellar sites.

Field of work:

Thursday - Session 1 / 140

Exotic nuclei: Toward the dripline

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About half of the elements heavier than iron that exists in nature are believed to be synthesized by astrophysical rapid neutron capture process (r-process), a sequence of neutron captures and β decays in extreme neutron-rich stellar environments. The astronomical site and the mechanism of

the r-process are not yet fully understood. Reliable nuclear data inputs such as nuclear masses, β-decay half-lives, β-delayed neutron-emission probabilities of very neutron-rich nuclei are required to connect the elemental distribution with the astrophysical conditions[2].
Various experiments have been performed for harvesting the nuclear properties toward the neutron dripline at the Radioactive Isotope Beam Facility (RIBF). In this talk, the highlights of recent experiments will be presented together with the perspective of future experimental programs[3].

1 E.M Burbidge, G.R. Burbidge, W.A. Fowler, and F. Holye, Rev. Mod. Phys. 29, 547 (1957).
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[3] S. Nishimura, Prog. Theo. Exp. Phys. 2012, 03C006 (2012).

Field of work:

Friday - Session 1 / 141

The slow neutron capture process in AGB stars

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Asymptotic giant branch (AGB) stars are responsible for the production of the main component, i.e. nuclei from Sr to Pb, of the solar s-process distribution. Despite tremendous advances in the theoretical modeling of these objects over the last few decades, many uncertainties remain. An example is represented by the still-unknown mechanism leading to the ^{13}C neutron source. The nucleosynthetic signature of AGB stars can be observed in a variety of different stellar sources, from spectroscopic observations of intrinsic and extrinsic stars to the heavy-element isotopic compositions of presolar grains found in meteorites. In this view, the wealth of available observational data allows putting constraints on the processes occurring in AGB interiors and the nuclear physics data relevant for the s-process nucleosynthesis. In this contribution, I will present recent results from new AGB models including the effects of mixing triggered by magnetic fields, and show comparisons of the related s-process nucleosynthesis with available observations.

Field of work:

Monday - Session 1 / 142

Neutron induced cross section measurements

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In this presentation, I shall give an overview of neutron-induced cross section measurements at n_TOF, both past and present. A selection of the principal characteristics of the time-of-flight facility n_TOF at CERN is given together with several examples of measurements of interest to Nuclear Astrophysics.

Finally, I will present some ideas of possible future experiments, including the ones that could become feasible thanks to the availability of NEAR, a new irradiation station available at n_TOF. The possibility to produce sample material at the present or upgraded ISOLDE facility and then irradiated at the NEAR station will represent therefore a great opportunity for synergy between these two CERN facilities.

Field of work:

Monday - Session 1 / 143

Nuclear physics in the N~126 region relevant to the r process

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Half of the nuclei heavier than iron were synthetized in the r process. The r-process yield peak at A~195 is linked to the N=126 closed neutron shell. In contrast to lighter mass regions, the r-process waiting point nuclei at N=126 still cannot be studied experimentally, and the yield calculations rely entirely on theoretical nuclear physics properties.
The most neutron rich N=126 nuclei for which basic observables such as the ground-state lifetime and mass were determined are 204Pt (Z=78) and 206Hg (Z=80), respectively. Therefore information on features which determine these values, single-particle energies and nucleon-nucleon interactions are crucial in order to increase the predictive power of nuclear theories. Nuclear structure information, like excited state energies, gamma-ray transition energies and transition strength are known "down" to 203Ir (Z=77).
In the case of the beta decay of N~126 nuclei there is a strong competition between allowed and first-forbidden transitions. First-forbidden (FF) transitions can be dominant, with profound implications on their half-lives and therefore on the r-process 1. And FF transitions are notoriously difficult to calculate. The beta decay of 208Hg into 208Tl was studied at ISOLDE Decay Station at CERN. Three negative parity excited states in 208Tl were populated directly in beta decay. In contrast none of the positive parity states were populated. This latter can be understood by considering the properties of the single proton and neutrons involved [2]. Similarly to 208Hg, 207Hg also decays predominantly via first-forbidden decays [3]. In addition, the validity of the less known Δn=0 selection rule in Gamow-Teller beta decay was investigated [4]. This selection rule has little importance for nuclei close to stability, but is essential for the Z<82, N>126 r-process waiting point nuclei, lengthening their lifetimes. Furthermore, accelerated radioactive beams at HIE-ISOLDE allowed for the first exploration of proton states beyond the N=126 closed shell [5], and the measurement of the transition strength B(E2; 2+->0+) transition strength in 206Hg [6].
In conclusion, the status of nuclear physics knowledge in the N~126 region relevant to the r-process will be presented. Future opportunities will be also discussed.
1 N. Nishimura, Zs. Podolyák, D.-L. Fang, T. Suzuki, Phys. Lett. B 756, 273 (2016).
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[3] T.A. Berry et al., Phys. Rev. C. 101, 054311 (2020).
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[6] L. Morrison et al., to be published.

Field of work:

Tuesday - Session 3 / 144

Mass measurements and studies for the r process at IGISOL

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The Ion Guide Isotope Separator On-Line (IGISOL) facility 1 in the JYFL Accelerator Laboratory at the University of Jyväskylä offers plenty of opportunities for r-process studies. At IGISOL, neutron-rich nuclei relevant for the r process have been typically produced using proton-induced fission on natural uranium target. Recently, multinucleon-transfer (MNT) reactions to produce neutron-rich nuclei beyond the fission fragment region have been investigated at IGISOL [2]. A new ion

guide gas cell and target platform have been designed and commissioned. The goal is to broaden the range of nuclei that can be studied at IGISOL via decay spectroscopy or high-precision mass measurements, which utilise the JYFLTRAP Penning trap [3] or the new Multi-Reflection Time-of-Flight mass spectrometer.

We have recently measured masses of dozens of neutron-rich nuclei with the JYFLTRAP Double Penning-trap mass spectrometer. With the Phase-Imaging Ion-Cyclotron Resonance (PI-ICR) technique at IGISOL [4,5], we have resolved the ground and isomeric states in several neutron-rich nuclei for the first time and improved the accuracy of the ground-state masses. In this contribution, I will give an overview on recent activities related to the r process at IGISOL, with a focus on high-precision mass measurements of fission fragments and prospects for the MNT reactions at IGISOL.

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[4] D.A Nesterenko et al., Eur. Phys. J. A 54 (2018) 154.
[5] D.A Nesterenko et al., Eur. Phys. J. A 57 (2021) 302.

Field of work:

Friday - Session 2 / 145

Radioactive Nuclei from Recent Near-Earth Supernovae as Telltale Signatures for our Solar System History

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Within our solar neighbourhood (150-500 light years) tens of star explosions, i.e., supernovae, occurred within the last ~10 Myr. Their expanding shock fronts swept across our Solar System leaving traces of newly formed nucleosynthesis products on Earth, particularly long-lived radioactive nuclei such as ^{60}Fe ($t_{1/2}$=2.6 Myr). I will present an overview on (1) accelerator mass spectrometry (AMS) measurements of radioactive nuclei in deep-ocean deposits revealing our Earth's exposure to nearby supernovae in the past and (2) theoretical methods to constrain the timing and locations of these past supernovae and their impact on our solar neighbourhood.

Field of work:

Thursday - Session 3 / 146

Relic and nascent neutrinos

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As standalone detections or in the context of multi-messengers signals, neutrinos offer opportunities to understand our Universe in unprecedented ways. Their weakly interacting nature provides information about the interior of cooling neutron stars, their mergers, and black hole accretion disks. Interpreting neutrino observations from compact objects relies on models of neutrino emission and their interaction with highly dense stellar matter. In this talk, I shall outline the insights posed by the possible detection of neutrinos from collapsars, neutron-star mergers and accretion disks.

Field of work:

Tuesday - Session 1 / 148

Recent results from LUNA

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The cross sections of nuclear reactions relevant for astrophysics are crucial ingredients to understand the energy generation inside stars and the synthesis of the elements. In stars, nuclear reactions take place at energies well below the Coulomb barrier. As a result, their cross sections are often too small to be measured in laboratories on the Earth's surface, where the signal would be overwhelmed by the cosmic-ray induced background.

An effective way to suppress the cosmic-ray induced background is to perform experiments in underground laboratories. LUNA (Laboratory for Underground Nuclear Astrophysics), located at Gran Sasso National Laboratories (Italy), has paved the way for underground nuclear astrophysics.

Over the years, the LUNA collaboration has studied many crucial reactions involved in stellar evolution and Big Bang Nucleosynthesis. The presentation will provide an update on the latest results and future perspectives of the LUNA experiment.

Field of work:

Nuclear structure and reactions: experiments and theory

Monday - Session 3 / 149

Neutron-induced cross section measurements using the Liquid Lithium Target at SARAF

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Neutron-induced reactions play an important role in several stellar nucleosynthesis scenarios. Experimental determination of their rates are limited by the available neutron flux at the relevant energies, sample size, especially in the case of unstable isotopes, and detection. The Soreq Applied Research Accelerator Facility (SARAF) enabled enhanced opportunities for such measurements by providing a mA proton beam at energies of up to 5 MeV via the $^{7}\text{Li}(p,n)$ reaction. At a proton energy of $E_p = 1.912$ MeV the resulting neutron spectrum resembles that of a Maxwellian flux at $kT \approx 30$ keV, with a neutron flux on the order of 10^{10} n/s/cm^2 on the sample.
The Liquid Lithium Target (LiLiT) was built to serve as a lithium-based neutron-production target at SARAF, designed to deal with the ≈ 8 kW SARAF beam and, over the last decade, allowed the measurements of many (n,γ) Maxwellian-Averaged Cross-Sections (MACS) of interest to the s-process.

We will summarize the past activity at LiLiT, and discuss future opportunities and challenges for other ideas that are being explored. Specifically, we are developing a method for measurements of (n,p), (n,α) and (n,f) MACS values at the temperature range of $1.5-3.5$ GK, which are relevant for explosive stellar scenarios. Examples for interesting cases are the ^{26}Al, ^{44}Ti and ^{56}Ni (n,p) cross sections. A prompt detection of the outgoing charged-particles imposes a substantial challenge due to the huge γ and neutron radiation. Several detection solutions are currently considered and will be presented.

Field of work:

Thursday - Session 2 / 150

New detection systems for an enhanced sensitivity in key stellar (n,γ) measurements

Author: Jorge Lerendegui Marco[1]

Co-authors: Cesar Domingo Pardo [1]; Ion Ladarescu Palivan [1]; Javier Balibrea Correa [1]; Victor Babiano Suarez [1]

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Neutron capture cross-section measurements are fundamental in the study of astrophysical phenomena, such as the slow neutron capture (s-) process of nucleosynthesis operating in red-giant and massive stars. One of the best suited methods to measure neutron capture (n,γ) cross sections over the full stellar range of interest is the time-of-flight (TOF) technique.

TOF neutron capture measurements on key s-process branching isotopes are very challenging due to the limited mass (~mg) available and the high experimental background arising from the sample activity and the dominant neutron scattering cross section. As a consequence of these challenges, only five out of the 21 key s-process isotopes (^{63}Ni, ^{151}Sm, ^{171}Tm, ^{147}Pm y ^{204}Tl) have been measured by means of the time-of-flight technique to date. Overcoming the current experimental limitations requires the combination of facilities with high instantaneous flux, such as n_TOF, with detection systems with an enhanced detection sensitivity and high counting rate capabilities.

This contribution will review some of the latest developments in detection systems for (n,γ) measurements at n_TOF. The focus will be set on i-TED, an innovative detection system which exploits the Compton imaging technique to reduce the dominant neutron scattering background. The discussion will be illustrated with preliminary results of the first measurement of the s-process branching-point reaction ^{79}Se(n,γ).

Field of work:

Monday - Session 2 / 151

Nuclear Astrophysics and GSI/FAIR: Present and Future

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The GSI/FAIR facility close to Darmstadt, Germany offers a large suite of experimental possibilities with radioactive ions. Stable ions between hydrogen and uranium can currently be accelerated with the synchrotron SIS-18. Fragmentation on combination with a powerful fragment separator (FRS) enable the experiments with a wide range of radioactive isotopes. Single pass can be used to investigate rather short-lived at higher energies. Ring experiments allow high precision experiments on longer-lived isotopes at lower and higher energies. Currently ongoing upgrades will increase the rate of radioactive ions by up to 4 orders of magnitude, which opens a new era of research with radioactive ions.
I will review a few of the recent experiments with astrophysical motivation and provide some ideas about possible future capabilities.

Field of work:

Wednesday - Session 1 / 152

Beta-decay along the N=Z line and its relevance in rp-process and X-Ray bursts

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Nucleosynthesis in Type I X-ray bursts (XRB) proceeds eventually through the rp-process near the proton drip-line. Several N=Z nuclei act as waiting points in the reaction network chain. Astrophysical calculations of XRB light curves depend upon the theoretical modelling of the beta decays of interest, with the N=Z and their second-neighbours N=Z+2 being key nuclei in this context.

Several such theoretical calculations have shown that, in the high-density and high-temperature scenario of the XRB, continuum electron capture and decay rates from excited states play an important role, in particular for nuclear species at and around the waiting-point nuclei.

In this contribution I will present the experimental results of different campaigns carried out at ISOLDE (CERN) to measure properly the B(GT) distributions in the decay of several N=Z & N=Z+2 of particular relevance in rp-process calculations. These results provide benchmarks for testing and constraining models under terrestrial conditions that can be used later for predictions in stellar environments.

Field of work:

Poster session / 153

Neutron capture cross-sections of ^{53}Mn

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Short-lived radionuclides, i.e. radioactive isotopes with half-lives of less than 100 Ma, were present as primordial isotopes in the proto-solar cloud and during the formation of our solar system. The origin of specific short-lived radionuclides is still a matter of dispute. Because of their comparatively short half-lives, these isotopes are no longer present in cosmic samples today, but are evident as enrichments of their decay products, e.g., in meteorite samples.
An notable case is ^{53}Mn, which is likely one of the most abundant short-lived radioisotopes. In fact, the majority of ^{53}Cr, the second most abundant stable chromium isotope, originates from the decay of ^{53}Mn. S. Sahijpal modeled the general galactic chemical evolution of the local cluster of stars surrounding our solar system over galactic timescales 1. ^{53}Mn can be efficiently produced in supernova explosions and ejected into the interstellar medium to reach our solar system. Analysis of manganese crust samples from the deep sea shows layers with elevated 53Mn abundance, indicating sedimentation after supernova explosions [2]. Furthermore, analysis of about 500 kg snow sample from Antarctica has shown that ^{53}Mn is still now continuously deposited on Earth [3].

In contrast to other short-lived isotopes, ^{53}Mn can also originate from spallogenic reactions with already condensed material. The estimate of this production route and its relationship to the amount produced in supernovae events has not yet been conclusively understood. Secondary particle reactions are one of the essential components in this debate. However, the dominant nuclear reactions in this scenario are proton- and neutron-induced reactions on iron. In such an environment, one must also consider the subsequent reactions of ^{53}Mn. In any case, the synthesized ^{53}Mn must pass through regions of high neutron density and is therefore subject to further nuclear reactions that will modify the overall ^{53}Mn content. One of the possible reaction causing such an effect is neutron capture.
Due to the rarity of ^{53}Mn on Earth - it occurs in usable quantities only in meteorites - the measurement of nuclear properties is challenging. Consequently, only the thermal neutron capture cross section has been determined so far with samples containing about 10^{13} atoms of 53Mn. Through the ERAWAST (Exotic Radionuclides from Accelerator Waste for Science and Technology) initiative, a supply of about 10^{19} atoms of ^{53}Mn was obtained from proton-activated materials at PSI. Some of these were used to produce samples for measuring neutron capture cross sections of ^{53}Mn at different neutron facilities. Thus neutron capture cross sections were measured in a wide range of neutron energies, from very cold neutrons to stellar neutrons, using different neutron facilities [4].

Acknowledgment:
We would like to thank T. Jenke, St. Roccia and U. Köster at the Institut Laue-Langevin (France) for the support conducting experiments at the very cold neutron beam line PF2; N. Kneip, D. Studer, T. Kieck, and K. Wendt of the Johannes Gutenberg-Universität Mainz (Germany) for preparing samples using the RISIKO off-line laser mass separation facility for the experiments at the PF2 beam line; L. Viererbl ,M. Vinš, H. Assmann-Vratislavská of the Research Centre Řež (Czech Republic) for conduction the thermal and epithermal neutron activations at the research reactor LRV-15; O. Aviv, A. Barak, Y. Buzaglo, H. Dafna, B. Kaizer, D. Kijel, A. Kreisel, M. Tessler, L. Weissman, Z. Yungrais of the Soreq National Research Center (Israel) for providing the proton beam at the LiLiT Neutron Source at SARAF and support and participating in the experiment at stellar neutron energy; M. Paul and E. Peretz of Racah Institute of Physics at the Hebrew University Jerusalem (Israel) for participating and co-analysing the experiment at stellar neutron energy; as well as the following colleagues of the Paul Scherrer Institut: M. Ayranov and T. Wieseler for elaborating the chemical extraction methods and performing the purification to create the stock of ^{53}Mn; P. Sprung for determining the total ^{53}Mn quantities of the used samples via ICP-MS measurements and A. Kaestner for support to perform experiments at the cold neutron beam line ICON at the neutron source SINQ at PSI.
1 S. Sahijpal, J. Astrophys. Astron. 35 (2014) 121
[2] G.Korschinek, et al.: Phys. Rev. Lett.125 (2020) 031101
[3] D. Koll, et al.: Phys. Rev. Lett. 123 (2019) 072701
[4] J. Ulrich, PhD thesis 2020, High precision nuclear data of ^{53}Mn for astrophysics and geosciences, University of Berne, Switzerland

Field of work:

Friday - Session 2 / 154

Latest half-life measurements of Sm-146, Gd-148, and Dy-154 at Paul Scherrer Institute

Authors: Nadine Mariel Chiera[None]; Rugard Dressler[None]; Peter Sprung[1]; Zeynep Talip[None]; Dorothea Schumann[None]

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Precise nuclear data is extremely important for several scientific applications, ranging from the calculation of reaction rates for the description of galactic events, to the evaluation of the toxicity of nuclear waste. As it was recently shown, the re-evaluated half-life data of a considerable number of radionuclides (e.g., Fe-60 1, Se-79 [2, 3], and Sm-146 [4]) was in substantial disagreement with previous values. In particular, the shorter measured half-life for 146Sm entails a higher abundance of this radionuclide in the early Solar System, and thus, planetary events dated with the Sm-146/Nd-142 chronometer converge now to a shorter time span than previously estimated. This value is still awaiting for confirmation. At present, there is no agreement on which half-life value for Sm-146 has to be adopted for derivations and calculations using the Sm-146/Nd-142 radiometric pair. Similarly to the Sm-146 case, the currently available half-life data of other radio-lanthanides Gd-148 and Dy-154, important for the evaluation of p-process reactions, are inconsistent or affected by uncertainties even up to 50% [5, 6].

In the framework of the "ERAWAST - Exotic Radionuclides from Accelerator Waste for Science and Technology" [7] initiative, we obtained exotic Sm-146, Gd-148, and Dy-154 from the reprocessing of radioactive materials already available at the Paul Scherrer Institute site. The development of a state-of-the art radiochemical separation allowed us to attain extremely pure fractions of the mentioned elements, in sufficient amounts for half-life measurements. The latter proceeded by applying the "direct" method, which consists on the determination of the number of atoms of interest, combined with the measurement of their activity.

Here, preliminary results on the measured half-lives of Sm-146, Gd-148, and Dy-154 with unprecedented low uncertainties, will be presented.

Acknowledgement
This project is funded by the Swiss National Science Foundation (SNF grant no 200021-159738).

1 Rugel G., et al. 2009. Physical review letters, 103, p. 072502. [2] Jörg G., et al. 2010. Applied Radiation and Isotopes, 68, pp. 2339-2351. [3] Bienvenu P., et al. 2007. Applied Radiation and Isotopes, 65, pp. 355-364. [4] Kinoshita N., et al. 2012. Science, 335, pp. 1614-1617. [5] Nica N., et al. 2014. Nuclear Data Sheets, 117, pp. 1-229. [6] Reich C. W. 2009. Nuclear Data Sheets, 110, pp. 2257-2532. [7] Schumann D., et al. 2007. Journal of Physics G: Nuclear and Particle Physics, 35, p. 014046.

Field of work:

Tuesday - Session 2 / 156

Explosive nucleosynthesis of massive stars

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Field of work:

Friday - Session 2 / 158

Closing

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Field of work:

Opening / 159

Welcome to CERN

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Field of work:

Opening / 160

Introduction & Welcome to NPA-X

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Monday - Session 1 / 162

Relating lab-based and space-based science at CERN

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From n_TOF and ISOLDE up to the LHC experiments, a remarkable common denominator of all CERN physics programmes is their interplay with central questions in astrophysics and cosmology. This edition of NPA-X will highlight novel opportunities in precision nucleosynthesis, neutron star physics, cosmic ray physics and chemical stellar evolution that arise from combining the latest observations of astrophysical sources and messengers with lab-based precision measurements at n_TOF, ISOLDE and other nuclear physics laboratories. My opening talk will complement this focus of your conference with a broader overview of the cross-talk between space-based and lab-based science enabled at CERN.

Field of work:

Wednesday - Session 2 / 163

Kilonova: A signature of r-process nucleosynthesis

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A kilonova is an electromagnetic transient powered by the radioactive decay of nuclei freshly synthesized by the rapid neutron capture process (r-process). Its observation following the gravitational wave event GW170817 provided the first evidence that the r-process operates in neutron star mergers. Kilonova observations provide unique opportunities to learn about the in-situ operation of the r-process, the distribution of elements produced in individual events, and the dynamics of the event. Addressing these important questions requires to improve our understanding of two fundamental ingredients of kilonova modelling. The first is related to radioactive energy input that depends on the exact distribution of nuclei produced. The talk will discuss the important role of beta-decays and fission and their possible fingerprints in kilonova light curves. The second is related to the photon opacity of the material as it determines the spectral evolution of the emission. The opacity is determined by bound-bound atomic transitions and dominated by the contribution of Lanthanides and Actinides. First kilonova models based on a complete set of atomic opacities will be presented and the main spectral features discussed.

Field of work:

Excursion + banquet dinner / 164

Excursion/banquet dinner on the Lac Leman

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VEVEY
Belle Epoque - Diesel-electric paddle boat

Freshly renovated! The first paddle boat with diesel-electric propulsion was fully and superbly renovated in 2013. Just as its twin ITALIE, it offers all year round, therefore even in winter, Belle Epoque cruises on Lake Geneva. These two boats are CGN's only pair of identical Belle Epoque boats to survive after the demolition of the GENERAL DUFOUR built in 1905 (twin of the MONTREUX) and the VALAIS built in 1913 (twin of the SAVOIE). It is equipped with the most modern technology in a hull more than a hundred years old, and has an extremely attractive, bright first-class lounge with chestnut marquetry enhanced with chiseled bronze trimmings. On the upper deck, the former "smoking room", separated from the rest of the deck by the smoke stack, was rebuilt to its original state.

Field of work:

Closing / 166

Closing & Au revoir

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