

## S23 Nuclear Physics

### Física Nuclear (GEFN)

11/07 Monday afternoon, Aula 1.15

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- 15:30-16:00 Guillermo Megías (USevilla)  
*The relevance of Nuclear Physics in neutrino oscillations*
- 16:00-16:30 Yassid Ayyad (USC)  
*The relevance of Nuclear Physics in neutrino oscillations*
- 16:30-16:45 Antía Graña González (USC)  
*Quasi-free (p,2p) reactions in inverse kinematics for studying the fission yield dependence on temperature and its implication in the stellar nucleosynthesis r-process*
- 16:45-17:00 Gabriel García Jiménez (USC) and the R3B Collaboration  
*Study of (p,2p) events at the CALIFA calorimeter in knockout induced fission of  $^{238}\text{U}$*
- 17:00-17:30 **Coffee Break**
- 17:30-17:45 A. Martín Sánchez (UNEX)  
*Recisión de datos nucleares de  $^{212}\text{Po}$*
- 17:45-18:00 F. Barranco Blázquez (CSIC-I3M)  
*Correlation between optical density and particle density in passive PADC (CR-39) detectors for high fluences*
- 18:00-18:15 M. C. Jiménez-Ramos (USevilla/CNA)  
*Angular measurements on LGADs to study plasma effects using a Nuclear Microprobe*
- 18:15-18:30 M. Pallàs (UPC)  
*Study of decay properties for La to Nd nuclei (A 160) relevant for the formation of the r-process rare-earth peak*
- 18:30-18:45 Gustavo Alcalá (CSIC-IFIC)  
*Beta Decay Spectra Measurement for the Study of the Reactor Antineutrino Anomaly*
- 18:45-19:00 M. A. Millán Callado (USevilla/CNA)  
*Behaviour of particle detectors in a laser-driven neutron source*
- 19:00-19:15 A. Perez de la Rada (CIEMAT)  
*?-delayed neutron spectroscopy of  $^{85}\text{As}$  with MONSTER*
- 19:15-19:30 J. R Murias (UCM)  
*Investigation of  $^{130}\text{Sn}$  populated in the  $\beta$  decay of isomerically-purified  $^{130}\text{In}$  isomers*

## S23 Nuclear Physics

### Física Nuclear (GEFN)

12/07 Tuesday afternoon, Aula 1.15

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- 15:30-16:00 M. C. Jimenez Ramos (Usevilla/CNA)  
*Medical Applications with Ion Beams at Centro Nacional de Aceleradores*
- 16:00-16:15 Consuelo Guardiola (IMB-CNM-CSIC)  
*Experimental microdosimetry maps in proton therapy*
- 16:15-16:30 Isabel Abril Sánchez(UA)  
*Interaction of swift-ions and secondary electrons in liquid water: Bragg peaks and radial deposited dose*
- 16:30-16:45 Michael Seimetz (i3M-CSIC-UPV)  
*Scintillating fibre proton beam monitor for biomedical applications*
- 16:45-17:00 Nerea Encina Baranda (UCM)  
*Prompt-Gamma Correction in  $^{124}\text{I}$  PET Imaging*
- 17:00-17:30 **Coffee Break**
- 17:30-17:45 Juan Peñas (USC)  
*A laser-driven proton source for medical radioisotope production*
- 17:45-18:00 Gabriela Llosá Llácer (IFIC, CSIC-U. Valencia)  
*MACACO Compton camera for medical applications*
- 18:00-18:15 Teresa Rodríguez (USevilla/CNA)  
*Experimental study of proton-induced cross sections of  $\beta^+$  isotopes for PET range verification in particle therapy*
- 18:15-18:30 D. Godos-Valencia (UNAM-UHU)  
 *$^{46}\text{Mn}$  beta-decay experimental studies and its connection with CCSN*
- 18:30-18:45 J. García-Marcos (UCM)  
*Quasielastic neutrino-nucleus scattering within realistic nuclear model and Monte Carlo event generator*
- 18:45-19:00 V. Lérida Toro (CNA)  
*Unified radiochemical method to determine  $^{129}\text{I}$  by AMS in different matrix analysed in oceanographic studies*
- 19:00-19:15 A. Tarifeño (UPC)  
*Neutron spectrometry with HENSA: from underground physics to space weather applications*
- 19:15-19:30 Martina Feijoo Fontán (USC) and R3B collaboration  
*Study of multi-nucleon knockout reactions of exotic nuclei in the region of Sn*

# **Quasi-free (p,2p) reactions in inverse kinematics for studying the fission yield dependence on temperature and its implication in the stellar nucleosynthesis r-process.**

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Although the importance of the fission fragment treatment in stellar nucleosynthesis r-process calculations is well established, an aspect of the phenomenological descriptions of fission that has so far remained relatively unexplored in the r-process is the dependence of the fission yields on the excitation energy or temperature of the compound nuclei [1]. Moreover, the fission yields and fission barrier heights of nuclei far from the stability line are also crucial to correctly describe the r-process cycle as well as the transitions from symmetric to asymmetric fission [2]. To determine all these observables, we have carried out at the GSI facility a new experiment in inverse kinematics and using quasi-free (p,2p) reactions as a novel technique to induce the fission process [3]. These new measurements have been performed with state-of-the-art detectors especially designed to measure the fission products with high detection efficiency and acceptance, which were developed by the R3B collaboration [4]. The analysis of this new data will give us for the first time access to the excitation energy of the fissioning system by using the missing mass method and thus it will allow us to investigate the evolution of fission yields with the temperature.

[1] N. Vassh et al., J. Phys. G: Nucl. Part. Phys. 46, 065202 (2019)

[2] T. Kajino et al., Prog. Part. Nucl. Phys. 107, 109 (2019)

[3] J. Benlliure and J.L Rodríguez-Sánchez, Eur. Phys. J. Plus 132, 120 (2017)

[4] <https://www.r3b-nustar.de/>

# Study of $(p,2p)$ events at the CALIFA calorimeter in knockout induced fission of $^{238}\text{U}$

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Nuclear fission has been used as a tool for the study of nuclear properties since its discovery in 1939. A new approach was performed in the context of the R3B collaboration, at the FAIR facility, in which knockout reactions were used to induce fission in  $^{238}\text{U}$ , which will allow to characterise the excitation energy of the process. The CALIFA calorimeter, a key part of the set-up, will be used to reconstruct the momentum of the two protons coming out the  $(p,2pf)$  reaction. Preliminary results show that kinematic variables are well reconstructed and in good agreement with theory.

## Revisión de datos nucleares de $^{212}\text{Po}$

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Rutherford and Woods [1] ya observaron en 1916 que unas pocas partículas alfa tenían un rango de unos 11,6 cm en aire, que era considerablemente mayor que el rango (8,6 cm) alcanzado por las bien conocidas partículas de 8,78437 MeV [2] emitidas por  $^{212}\text{Po}$ , alcanzando el nivel fundamental de  $^{208}\text{Pb}$ . Hoy en día es perfectamente conocido que estas partículas de largo alcance son emitidas desde los estados excitados de  $^{212}\text{Po}$ . En este núcleo, la vida media parcial para desintegración alfa es comparable con su homónima para desintegración gamma, de tal manera que una pequeña fracción de los núcleos excitados de  $^{212}\text{Po}$  decaerán directamente desde esos niveles excitados al nivel fundamental del  $^{208}\text{Pb}$ . Las energías e intensidades de estos grupos de partículas de largo alcance (“long-range alpha-particles”) fueron recopiladas por Rytz [3]. Se han realizado muy pocas revisiones de estos resultados [4], y los valores iniciales son prácticamente los que siguen vigentes desde entonces, incluso en las compilaciones de datos revisados más recientemente [5].

En nuestro laboratorio se han llevado a cabo nuevas medidas, chequeando los valores de las energías y las intensidades. Estas mediciones se realizaron con espectrometría de partículas alfa de baja resolución en cámara de vacío. La fuente usada ha sido un disco colimado de  $^{232}\text{U}$  (en equilibrio con sus hijos) con un área activa de 20 mm<sup>2</sup>, fabricada por electrodeposición en el CIEMAT. Se utilizó un detector de silicio, tipo PIPS, marca Canberra, con 50 mm<sup>2</sup> de área activa. La distancia fuente-detector fue de 65 mm. Se tomaron cerca de 90 espectros con objeto de realizar un análisis estadístico adecuado de los resultados obtenidos.

El hecho de que haya pocos resultados experimentales del efecto estudiado puede deberse a las dificultades que se presentan en la medida de estas partículas. En primer lugar, aparece su escasez, ya que su número es al menos cuatro órdenes de magnitud más bajo respecto a las consideradas emisiones más “normales”. Por otro lado, debido a la corta vida media del  $^{212}\text{Po}$ , se producen sumas en coincidencia entre las emisiones alfa procedentes del estado fundamental, y las partículas beta procedentes de las emisiones de  $^{212}\text{Bi}$ , haciendo muy difícil el estudio de la región del espectro por encima de la línea de 8,78437 MeV, lugar esperado de aparición de las partículas alfa de largo alcance [6]. Para tratar de evitar estas interferencias, se incluyó un potente imán entre la fuente y el detector. Los resultados experimentales alcanzados permiten chequear los valores existentes en las tablas de datos nucleares, junto con sus incertidumbres, estimadas éstas, por primera vez, únicamente de manera experimental. Esto es importante, porque en la actualidad, las incertidumbres mostradas en las tablas de datos nucleares son solamente las medias no ponderadas de ciertos valores existentes con anterioridad [7], pero nunca han sido estimadas de un modo directo, como se ha realizado ahora en nuestro laboratorio.

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[2] E. Browne, R. B. Firestone, *Table of radioactive isotopes*, New York (1986).

[3] A. Rytz, *J. Recherches Centre Natl.* **25**, 254 (1953).

[4] G. T. Emery, W. R. Kane, *Phys. Rev.* **118**, 755 (1960).

[5] M. J. Martin, *Nucl. Data Sheets* **108**, 1583 (2007).

[6] A. Martín Sánchez, F. Vera Tomé, C. J. Bland, *Nucl. Instrum. Methods Phys. A* **295**, 273 (1990)

[7] A. L. Nichols, *Table de radionucleides*, LNE-LNHB/CEA (2011).

**Agradecimientos:** Trabajo parcialmente financiado por la Junta de Extremadura y el Fondo Europeo de Desarrollo Regional a través de la Ayuda GR21002.

# Correlation between optical density and particle density in passive PADC (CR-39) detectors for high fluences

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Preclinical research is witnessing the growing importance of determining as precisely as possible the radiation dose deposited by ultra-intense ion bunches. In view of this growth, the use of passive detectors with a wide dynamic range is gaining in value, as they are less prone to saturation effects, making them attractive for cross-calibration of real-time devices and radiation dose monitoring.

For this calibration, two types of passive detectors have been irradiated with proton pulses with a width of 100  $\mu$ s and energy 0.8 MeV. These detectors are the transparent polymer polyallyl-diglycol-carbonate (PADC) (CR-39) and radiochromic films of EBT3-U material. As a higher sensitivity has been observed in PADC, it is the most suitable material for measuring individual particles with the microscope [1,2]. However, counting traces becomes quite difficult for densities higher than  $10^7$  p/cm<sup>2</sup> due to the overlap between the tracks left by protons passing through the material. For higher fluences than this, the optical density of the material ( $OD_{net}$ ), measured from images taken with a flatbed optical scanner and the software *imageJ*, shows a correlation with the density of particles passing through the 1 cm<sup>2</sup> chips of the material.

PADC chips of type RS39 (Radosys) were irradiated to a maximum fluence of about  $10^{11}$  p/cm<sup>2</sup>, and the results show a correlation with the optical density of the material up to  $10^{10}$  p/cm<sup>2</sup> approximately, after the realisation of different etching processes. These results were compared with the results obtained for the radiochromic films (EBT3-U) which were irradiated with 0.8 MeV protons. For these, it was also observed that the grey values of the uniformly irradiated areas showed correlation with the fluence up to  $10^{11}$  p/cm<sup>2</sup>. However, PADC shows a wider dynamic range for particle density.

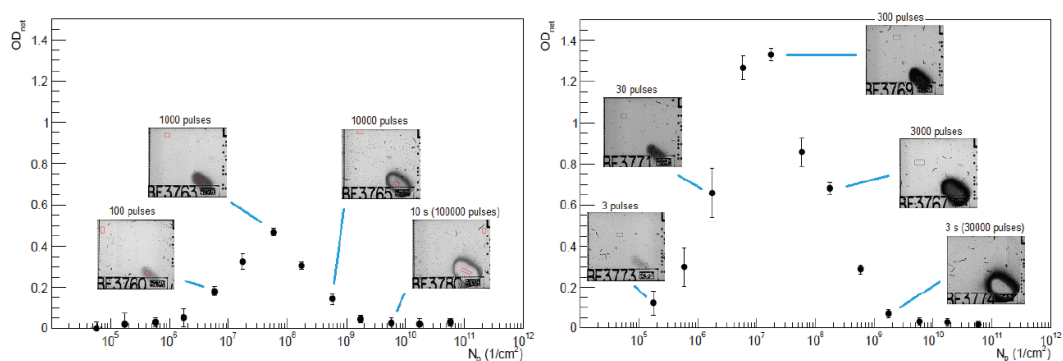


Figure 1. Results obtained after 1 hour (left) and 2 hours of etching (right), respectively, with the images obtained from the scanning of the chips.

[1] M. Seimetz, et al. *Phys. Med.* **76**, 72-76 (2020).

[2] M. Seimetz, et al. *Rev. Sci. Instrum.*, **89**, 023302 (2018).

**Acknowledgements:** Funded by Government of Spain, RTI2018-101578-B-C22, and by Generalitat Valenciana, AICO/2020/207. Co-financed by FEDER, IDIFEDER/2021/004, and Generalitat Valenciana, action EDGJID/2021/204.

## Angular measurements on LGADs to study plasma effects using a Nuclear Microprobe

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The study of a Low Gain Avalanche Detector (LGAD) has been carried out by Ion Beam Induced Charge (IBIC) and Time Resolved Ion Beam Induced Charge (TRIBIC) using the nuclear microbeam line of the Centro Nacional de Aceleradores (CNA). For that purpose, a 3 MeV H ion beam was employed, and the results were compared to that obtained by the Transition Current Technique (TCT) using an infrared laser at the SSD laboratory at CERN and at the Clean Room of the Physics Institute of Cantabria (IFCA). Although the charge collection time is the same for both techniques, near the onset voltage the shape of the induced current pulses is significantly different. Moreover, the values of the absolute gain curve are considerably higher when measured by TCT. This gain suppression is related to the shielding effects of the electric field in the multiplication layer, which depend on the generated carrier density. Therefore, in order to study how the plasma effects change with the generated carrier density, experiments have been carried out by varying the proton incidence angle from 0° to 85°.

In this talk, the gain curves for all angles will be shown. The results indicate that when mean ionization density projected on the multiplication layer is minimum (50°) the measured gain is maximum. Also, at very large angles (> 70°) the electron path in the multiplication layer is the dominant factor for the gain suppression. TRIBIC results will also be shown, from which some conclusions can be drawn about the decrease in the hole gain and plasma effects outside the multiplication layer when the Bragg peak falls inside the detector.

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

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Around half of the nuclei 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 elemental solar system abundances, located at  $A \sim 130$  and  $A \sim 195$ , which are associated with the neutron shell closure during the  $(n, \gamma) \leftrightarrow (\gamma, n)$  equilibrium. In contrast, the rare-earth peak (REP) is a small - but clear - peak around mass  $A = 160$ , which originates from the freeze-out during the late phases 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. 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 about 120 new half-lives and 300 new 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 work, we discuss the status of the BRIKEN-REP experiment and present the first experimental results of new  $P_n$ -values and  $T_{1/2}$  for nuclei in the region from La to Nd.

[1] M. R. Mumpower et al, *Phys. Rev. C* **85**, 045801 (2012).

[2] A. Arcones and G. Martinez Pinedo, *Phys. Rev. C* **83**, 045809 (2011).

[3] J.L. Tain et. al, *Acta physica polonica B* **49(03)**, 417 – 428 (2018).

[4] A. Tolosa-Delgado et. al, *NIM A* **925**, 133 – 147 (2019).

[5] G. Kiss et al, *RIKEN Accel. Prog. Rep.* **53**, 33. (2020).

[6] A. Tarifeño-Saldivia et al, *RIKEN Accel. Prog. Rep.* **54**, 27. (2021).

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# $\beta$ Decay Spectra Measurement for the Study of the Reactor Antineutrino Anomaly.

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The Reactor Antineutrino Anomaly (RAA) has been a topic of great interest for the physics community in recent years [1]. The generally accepted Huber-Muller conversion model [2,3] to calculate the reactor's  $\bar{\nu}$  spectrum has raised several questions about the experimental results and the different approximations used. In view of this, improved measurements of nuclear data of relevant isotopes plus the use of the Summation Calculation method [4] for the determination of the  $\bar{\nu}$  spectrum brings a plausible alternative way of calculation. Critical calculations of this spectrum using standard databases'  $\beta$  feedings can suffer from the Pandemonium Effect problem, which can be solved by applying the Total Absorption Gamma Spectroscopy (TAGS) method [5].

The decay of only a relatively small number of neutron rich fission products contribute the most to the reactor  $\bar{\nu}$  spectrum in the energy region where the anomaly is stronger [6]. Therefore, with the objective to directly determine the shapes of these  $\beta$  decay spectra, experimental campaigns have been carried out in the IGISOL facility at Jyväskylä with newly developed telescope detectors. Several  $\beta$  decay spectra of utmost relevance for the study of the RAA were measured, and more measurements are being planned.

This presentation is aimed to introduce the problem of the RAA and how the determination of the  $\bar{\nu}$  spectrum is improved with the use of the Summation method with TAGS  $\beta$  feedings. Developed computational tools required for this study will be presented. Some preliminary results of the analysis of the data will be shown as well.

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[2] P. Huber, *Physical Review C* **84**, 24617 (2011); *Physical Review C* **85**, 029901 (2012).

[3] T. A. Muller et al., *Physical Review C - Nuclear Physics* **83**, 054615 (2011).

[4] M. Estienne et al., *Physical Review Letters* **123**, 022502 (2019).

[5] A. Algora et al., *European Physical Journal A* **57**, 85 (2021).

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## Behaviour of particle detectors in a laser-driven neutron source

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High power (~PW) ultrashort pulse (~fs) lasers are emerging as a promising alternative to conventional accelerators as compact sources of secondary radiation, including the production of neutron beams. These neutron beams, suitable for time-of-flight (TOF) experiments, can be characterized by time resolution, intensity per pulse, and frequency or repetition rate. In this context, short-pulse and high instantaneous flux laser-driven neutron sources (LDNS) are particularly attractive for nuclear physics applications based on the TOF technique.

Neutrons produced using this alternative method could reach higher instantaneous neutron fluxes than conventional neutron sources. However, it is necessary to characterize the experimental conditions associated with this type of sources, since the potential applications of these laser-driven neutrons rely on the performance of nuclear physics detectors in the environment produced by the laser-plasma interaction, which affects the response of the detectors commonly used in this type of measurements.

This work reports the preliminary results of an experimental campaign carried out in autumn 2021 at the DRACO laser facility (PW) of the Helmholtz Center Dresden Rossendorf (HZDR) in Dresden, Germany, with the objective of studying the feasibility of carrying out TOF nuclear reaction measurements in the harsh environment of a LDNS. The experiment consisted of characterizing and optimizing the response of different neutron detectors to these conditions under different ion acceleration and neutron production configurations.

While previous work has been performed either with high repetition rate but low power, or with high power (PW) but low repetition (single-shot mode); in DRACO we have succeeded in producing high-repetition neutron beams (~200 shots per day) in a high-power system. The production of a high-frequency beam has allowed us to use a low-efficiency detector, i.e: a diamond detector, to measure individual signals produced by fast neutron interactions, which is the first step towards neutron-induced reaction experiments in an LDNS.

## $\beta$ -delayed neutron spectroscopy of $^{85}\text{As}$ with MONSTER

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A better quantitative understanding of  $\beta$ -delayed neutron emission rates and spectra is relevant for nuclear structure, astrophysics, and reactor applications:  $\beta$ -delayed neutrons provide valuable information on the  $\beta$ -decay process, are needed in network calculations for understanding the stellar nucleosynthesis process, and can improve the understanding of the kinematics and safety of new reactor concepts loaded with new types of fuels. The field has experienced an increased activity during the last decades [1] thanks to the advances in nuclear experimental techniques and the radioactive ion beam facilities. More accurate measurements of  $\beta$ -delayed neutron emission properties like the emission probability,  $\beta$ -feeding, and energy spectrum from individual precursors are being made with advanced neutron detectors [2, 3, 4], digital data acquisition systems [5], and high intensity ion beams [6, 7, 8, 9].

The  $\beta$ -delayed neutron emission in the  $^{85}\text{As}$  decay has been measured at the Ion Guide Isotope Separator On-Line (IGISOL) facility [9] of the JYFL Accelerator Laboratory of the University of Jyv skyl . The  $^{85}\text{As}$  isotopes were produced by proton-induced fission reactions in  $^{238}\text{U}$ , separated from the rest of the fission fragments with IGISOL, and implanted onto a tape. The complete decay has been studied with the help of a complex setup which consists of a plastic scintillator detector for the emitted  $\beta$ -particles, a HPGe Clover and four LaBr<sub>3</sub> detectors for the emitted  $\gamma$ -rays, and the **MODular Neutron SpectromETER** (MONSTER) [4, 10] for the detection of the emitted neutrons. MONSTER consists of an array of 48 cylindrical cells of 200 mm diameter and 50 mm height, filled with BC501A or EJ301 scintillating liquid. Each cell is coupled through a light guide of 31 mm thickness to a R4144 or R11833 PMT. The neutron energy is determined by the time-of-flight technique, using the signals from the plastic detector and MONSTER as the start and stop signals, respectively.

In this conference, we report the results obtained from the measurement at JYFL. The  $\beta$ -delayed neutron energy distribution of the  $^{85}\text{As}$   $\beta$ -decay has been determined by unfolding the time-of-flight spectrum with the iterative Bayesian unfolding method [11], and their partial branching ratios to the excited states in the final nucleus by applying  $\beta$ -n- $\gamma$  coincidences. We also compare the results of this work to existing data [12, 13].

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## Investigation of $^{130}\text{Sn}$ populated in the $\beta$ decay of isomerically-purified $^{130}\text{In}$ isomers

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The understanding of the evolution of shell structure far from the  $\beta$ -stability line is one of the major challenges in nuclear structure. Neutron-rich nuclei with a number of protons and neutrons close to magic numbers are an ideal testing ground for shell model calculations. The structure of the even-even

## Proton-induced cross sections of $\beta^+$ isotopes of interest in PET range verification

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In PET-based beam range verification for particle therapy, new measurements and evaluations of the reaction cross-sections producing  $\beta^+$  emitters are required in order to compare the measured and simulated activity distribution in the patient.

We have conducted a comprehensive measurement campaign at several irradiation facilities using different ion types in the therapeutic energy regime and different PET imaging technologies to detect short-lived (online PET monitoring) and long-lived (offline PET monitoring) radionuclides. The following experimental data will be presented:

a) The proton-induced production of the long-lived  $^{11}\text{C}$  ( $t_{1/2}=20$  min),  $^{13}\text{N}$  ( $t_{1/2}=9.9$  min) and  $^{15}\text{O}$  ( $t_{1/2}=2$  min) isotopes produced in the main elements of the human body (C, N and O) were measured at the Centro Nacional de Aceleradores (CNA) up to 20 MeV, and at the West German Proton Therapy Center (WPE) from 30 up to 200 MeV. The employed method combines the activation of an array of thin foils with the induced activity measurement using a clinical PET scanner. The carbon-induced production of  $^{11}\text{C}$  was obtained at Heidelberg Ion Therapy Center (HIT) up to 400 MeV/u measuring the activation in graphite foils with NaI scintillation detectors.

b) The proton-induced cross-sections of the short-lived  $^{12}\text{N}$  ( $t_{1/2}=11$  ms) in C,  $^{38\text{m}}\text{K}$  ( $t_{1/2}=0.92$  s) in Ca and  $^{29}\text{P}$  ( $t_{1/2}=4$  s) in P up to 200 MeV and the carbon-induced cross-sections of  $^{12}\text{N}$  and  $^{10}\text{C}$  ( $t_{1/2}=19$  s) in C up to 400 MeV/u were measured at HIT. The experiments consist in the activation of pure targets and “online” acquisition with LaBr<sub>3</sub> scintillation detectors operating in coincidence.

The results from these experimental campaigns will be presented and the relevance of the new data for PET range verification will be discussed.

# $^{46}\text{Mn}$ beta-decay experimental studies and its connection with CCSN

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Stars with initial mass greater than  $8 M_{\odot}$  end their lives through a Core Collapse Supernova (CCSN) explosion. Besides,  $^{44}\text{Ti}$  nucleosynthesis takes place in CCSN; making this nucleus a good gamma astronomy tracer for Super Nova (SN) events due to the characteristic gamma rays emitted on its decay chain. Furthermore, the comparison between observations and models of the synthesized  $^{44}\text{Ti}$  in CCSN gives important constraints to the models. In the later, reaction networks are used for modelling nucleosynthesis occurring in the last stages of those stars with thermonuclear reaction rates as its inputs [1,2,3].

Unfortunately, a direct measurement of the cross section for a given thermonuclear reaction is extremely difficult in the current laboratories worldwide. Therefore, indirect methods can be used for this purpose, especially when the reaction rate is dominated by a narrow isolated resonance. In this context, beta-delayed proton emission is very useful with  $(p,\gamma)$  reactions involving low and medium mass proton-rich radioactive nuclei. That is a consequence of the fact that in those reactions narrow isolated resonances are likely to occur [1,4].

In this work we present the preliminary results of analysing the  $^{46}\text{Mn}$  decay channel as a way to study the  $^{45}\text{V}(p,\gamma)^{46}\text{Cr}$  reaction. This is due to the thought that nucleosynthesis of  $^{44}\text{Ti}$  in CCSN explosions is quite sensitive to that reaction [5]. The  $^{46}\text{Mn}$  was selected among other species in the cocktail beam delivered by LISE fragment separator at GANIL (Caen, France) in order to study its beta decay and the excited states of his daughter nucleus  $^{46}\text{Cr}$ . We present the proton and gamma emission peaks related to the  $^{46}\text{Mn}$  decay and compare them with the work from references [6,7].

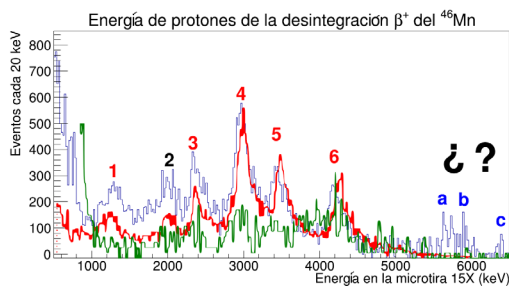


Figure 1.  $^{46}\text{Mn}$  decay proton energies spectra comparison. The curves in: green shows [7] results multiplied by 20; red shows [6] results multiplied by 2; and blue shows our results. Some interesting structures can be seen only in our work.

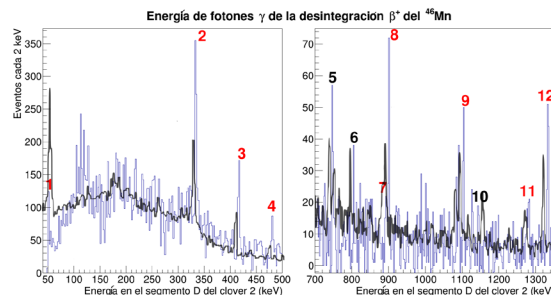


Figure 2.  $^{46}\text{Mn}$  decay gamma energies spectra comparison. The curves in: black shows [6] results divided by a factor of 4 (left) and 2 (right); blue shows our results. More structures can be seen in our work.

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# Quasielastic neutrino-nucleus scattering within realistic nuclear model and Monte Carlo event generator

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Neutrino oscillation experiments are essential to reach key goals in neutrino physics such as measuring  $CP$ -symmetry violation phase, neutrino mixing angles, and determining neutrino mass ordering, as well as searching physics beyond the Standard Model. These objectives require severe accuracy when evaluating the neutrino oscillation probability, which depends, among other parameters, on the neutrino energy. In current and future generation of oscillation experiments (T2K, DUNE, NOvA...) the neutrino beams used are not monoenergetic. Thus, in order to reduce systematic errors, the focus is on the interaction between neutrinos and targets, which are made of complex nuclei such as  $^{12}\text{C}$ ,  $^{16}\text{O}$  or  $^{40}\text{Ar}$ . These are the reasons why a deep study of neutrino-nucleus scattering is needed [1].

The main interaction mechanism in the neutrino-nucleus scattering when the energy of the neutrinos is up to 1 GeV is the so-called quasielastic (QE) scattering, where an incoming neutrino scatters off a bounded nucleon. This region is the core of neutrino energy distribution for several neutrino oscillation experiments such as T2K [1,2]. The way nuclei are described via different nuclear models is the main challenge we face when trying to extract information from these sorts of processes.

In this study, we consider the state-of-the-art spectral function, the so-called Rome spectral function (RSF) as our nuclear model [3]. The RSF provides a realistic description of the initial states of the nucleons inside the nucleus and gives us the probability of finding a nucleon with certain energy and momentum. Since the phase space of this process is vast, Monte Carlo (MC) generator is chosen so as to have a more efficient way of calculating our results. MC code generates randomly millions of possible kinematics belonging to phase space. Then, via acceptance-rejection method, the phase space is filled with all allowed kinematic configurations. The main advantage of this method is that only one run of the code is enough. At that point, results can be acquired just performing the corresponding computations.

This work is meant to be the benchmark for highly-developed analysis, using more sophisticated nuclear models such as the so-called relativistic mean field (RMF) model [4]. In such manner, we compare our results, either for inclusive and semi-inclusive differential cross sections, with recent data from the T2K ( $\nu_\mu$  on  $^{12}\text{C}$ ) [2]. We also compare our results with the up-to-date predictions obtained in Ref. [5], where three different nuclear models are used (see Fig. 1). Discrepancies between models and data come from other interaction mechanisms (mainly final state interactions and 2p2h) and Pauli blocking effects [6] that are not being taken into account in this work and contribute to experimental data.

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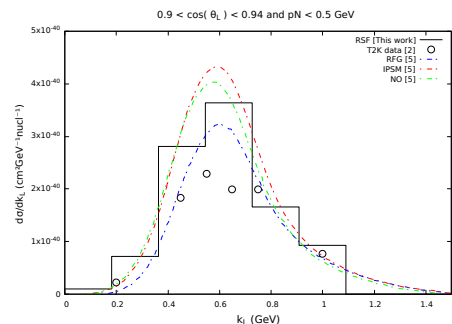


Figure 1. The T2K CC0 $\pi$  inclusive  $\nu_\mu$ - $^{12}\text{C}$  cross section for RSF model, compared with experimental data [4], and other models [5].

# Unified radiochemical method to determine $^{129}\text{I}$ by AMS in different matrix analysed in oceanographic studies

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$^{129}\text{I}$  is a long-lived radioisotope ( $t_{1/2}=15,7\cdot 10^6$  years) whose origin is mainly anthropogenic. Its main sources are i) fallout from nuclear test carried out in 1945-1980, ii) nuclear accidents and iii) discharges from Nuclear Fuel Reprocessing Plants (NFRPs) [1]. Iodine is present in all environmental compartments and is conservative in water. This facts, together its long half-life and its continuous release in documented amount from NFRPs, make this radionuclide an excellent ocean tracer [2].

In oceanographic studies some samples of different matrix are analysed apart from seawater. For example, algae and mussel are frequently used as bioindicators. The impact of the radioactive contamination in aquatic systems is often recorded in sediments. These, depending on their biogeochemical behaviour, can give detailed information on the history of the discharges from the sources and the environmental processes related to the transportation of the radionuclides to the sediment.

For some long-lived radioisotopes as  $^{129}\text{I}$ , only high sensitivity techniques as Accelerator Mass Spectrometry (AMS) (Figure 1) can measure its concentration at environmental levels [3]. To determine  $^{129}\text{I}$  in environmental samples, application of a specific radiochemical methods to extract iodine different species from the matrix is needed. The isolation of the problem isotope is necessary in order to obtain the isotope in the appropriate form (silver iodide, AgI) for the measurement and reduce interferences as much as possible.

The proposed radiochemical method consists of: a) pre-treatment depending on the sample matrix (filtering for seawater and microwave digestion for solid samples), b) redox process to decompose organic matter and adjust all iodine species oxidation status, c) iodine purification by a double extraction (first in an organic solvent and then in a reducing solution), d) silver iodide precipitation and e) cathode preparation for AMS measurement. Microwave digestion is a fast method to prepare solid samples and reduce cross contamination to a minimum.

In this work, a unified radiochemical method to determine  $^{129}\text{I}$  by AMS in solid and liquid environmental samples has been applied in seawater from Namibian coast and core sediments of different texture from Celtic Sea.  $^{129}\text{I}$  concentration measurement values range between  $(0.19-7.16)\cdot 10^{12}$  at./kg for sediment cores and between  $(0.75-1.45)\cdot 10^7$  at./kg for seawater. These results have made it possible to evaluate the sources of  $^{129}\text{I}$  in the sampled areas. We found that the greatest influence in the Celtic Sea is the Sellafield NFRP and the main source of  $^{129}\text{I}$  in the North of Benguela ecosystem is global fallout. As a conclusion, it can be noted that proposed radiochemical method is effective for the preparation of environmental samples of different matrices and with significantly variable  $^{129}\text{I}$  concentrations.

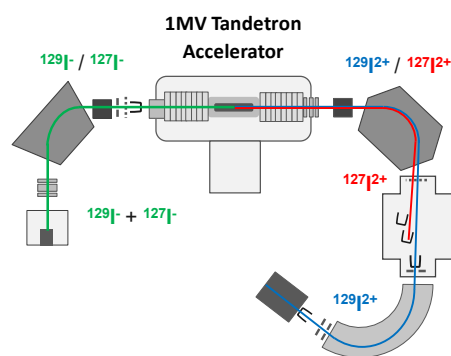


Figure 1. Spanish Accelerator for Radionuclide Analysis (SARA), the CNA AMS system.

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# Neutron spectrometry with HENSA: from underground physics to space weather applications

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In underground facilities neutrons are produced from nuclear reactions induced by the intrinsic radioactivity of the materials in the rock and cavity walls. These radiogenic neutrons constitute a background which is a limiting factor for low counting rate experiments in astrophysics, dark matter and neutrino searches. Therefore, a proper characterization of the spectral distribution of radiogenic neutrons is required in order to properly assess or mitigate the neutron background component affecting experiments in underground facilities. On the other hand, neutrons are continuously produced as a secondary radiation from cosmic-ray interactions in the upper atmosphere of our planet. This component is the main contribution to the ambient neutron background observed at ground level or high altitudes. The measurement of cosmic-ray neutrons is connected with different fields such as environmental radioactivity, single event upsets (SEUs) in microelectronics, the physics of cosmic-rays and space weather.

In this contribution the High Efficiency Neutron Spectrometry Array (HENSA) will be presented. HENSA is a state-of-the-art detection system for neutron background spectrometry in low radioactivity facilities, such as underground laboratories, and for the measurement of secondary neutrons produced by cosmic-rays. The HENSA spectrometer has a spectral sensitivity 5-15 times larger than conventional spectrometers in a wide neutron energy range spanning from thermal up to GeV's. For cosmic-ray neutrons, HENSA provides near real-time measurements of the neutron spectrum on a time scale of tens of minutes up to few hours, thus enabling possible applications in space weather as a neutron monitor with spectral sensitivity. Since 2019 HENSA is being used for a long-term characterization of the neutron background at the Canfranc Underground Laboratory (LSC), which includes continuous measurements in hall A and hall B. Moreover, in 2020 HENSA has been used to map the cosmic-ray neutron background along the spanish territory during quiet solar conditions at the beginning of the solar cycle #25. Currently, a new version of HENSA, called HENSA++, is being developed at IFIC for space weather applications. The status of the HENSA project ([www.hensaproject.org](http://www.hensaproject.org)) and future perspectives will be discussed in this talk.

# Study of multi-nucleon knockout reactions of exotic nuclei in the region of Sn

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The experimental data collected during the S515 experiment performed by R3B collaboration at GSI/FAIR represent a great opportunity to obtain nucleon knockout cross sections of exotic nuclei around  $^{132}\text{Sn}$ . These cross sections can be used to extract information about short-range correlations (SRCs), which emerge from pairs of nucleons having large relative momentum compared to their centre-of-mass momentum [1]. Recently, several works based on inclusive measurements [2,3] have shown that these SRCs could reduce the single nucleon knockout cross sections by around 50%, depending on the neutron excess ( $N/Z$ ) of the initial projectile. The S515 data could help us to go further in this investigation because we could correlate the knockout cross sections of one and two nucleons with the number of protons and neutrons detected by CALIFA and NeuLAND and perform complete kinematical studies to separate between SRC events and others involving evaporation of particles. At the moment, the identification of the fragments between FRS and Cave C is done for the  $^{124}\text{Sn}$  settings ( $^{136}\text{Xe}$  fragmentation), as well as charge calibrations for the LOS and R3B-MUSIC detectors and energy calibration for CALIFA crystals. Thus, the resulting yields for different incoming energies and targets can be compared.

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## Measurement of $^{27}\text{Al}(\alpha,n)^{30}\text{P}$ thick target neutron yields at CMAM using the miniBELEN-10A neutron counter

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Neutron production through  $\alpha$ -induced nuclear reactions is relevant in several fields. Specifically,  $(\alpha,n)$  reactions are interesting in nuclear astrophysics as a source of neutrons for the slow neutron capture nucleosynthesis (the s-process) [1] and in the  $\alpha$ -particles capture process (the  $\alpha$ -process) [2, 3]. Other fields of interest include the neutron-induced background in underground laboratories [4] and in nuclear facilities such as nuclear reactors and particle accelerators [5]. Currently, evaluated data is only available for a limited number of isotopes and the databases present large discrepancies in some cases of interest.

The Measurement of Alpha Neutron Yields and spectra (MANY) collaboration is a coordinated effort by several Spanish research groups with the aim to carry out measurements of  $(\alpha,xn)$  reactions yields, cross-sections and neutron spectra. The project relies on the exploitation of the existing infrastructure in Spain, in particular, the  $\alpha$ -beams produced by the accelerators at CMAM [6] and CNA [7], and the use of neutron detection systems such as miniBELEN [8], a  $4\pi$  counter with a nearly flat response up to 10 MeV based on the use of  $^3\text{He}$  thermal neutrons counters and a high-density polyethylene moderator, and MONSTER [9,10], a time-of-flight spectrometer based on the use of BC501/EJ301 liquid scintillation modules. Both systems are complemented by  $\gamma$ -spectroscopy measurements using an array of fast  $\text{LaBr}_3(\text{Ce})$  scintillation detectors of the FATIMA type [11] with angular resolution capabilities. All instruments are coupled to high performance digital electronics.

In this work we report the results of the measurement of thick target total neutron yields and cross-sections from the  $^{27}\text{Al}(\alpha,n)^{30}\text{P}$  reaction using miniBELEN. This measurement has been part of the commissioning of miniBELEN and the  $45^\circ$  beam-line at CMAM for the MANY program in  $(\alpha,n)$  reactions.

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# Realistic treatment of nuclear structure in the neutrino-nucleus interaction

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An unprecedented activity has been unleashed in recent years to determine neutrino properties and their interactions. It has been firmly established that neutrinos oscillate and hence are massive particles. Some of the oscillation parameters, such as the neutrino mixing angles, have been measured with some precision, but other properties remain to be determined, such as their masses or the phase that quantifies the possible charge-parity violation. These are some of the goals of the new generation of accelerator-based neutrino oscillation experiments NOvA, DUNE and HyperKamiokande, with which neutrino physics enters a new 'Precision Era' [1].

The fact that all neutrino oscillation experiments use complex nuclei as target material in the detectors, for example mineral oils, water or liquid argon, complicates the analysis of the results since nuclear effects must be considered. In the energy region covered by the neutrino oscillation experiments, the neutrino-nucleus scattering cross section is not very precisely known, so that it is currently one of the largest contributions to the error [2]. This is what makes the study of neutrino-nucleus interactions a hot topic and brings theoretical nuclear physics to the stage.

Among all the reaction mechanisms that take place in neutrino experiments, we focus on the quasielastic channel (QE), where the scattering off a bound nucleon which is knocked out from the nucleus occurs. This process is studied within a realistic nuclear framework, using a state of the art relativistic mean-field based model for the description of the nuclear dynamics and final state interactions within a quantum mechanical framework (see [3] and references there in). Residual interactions between the bound nucleons through pion exchange are also included. We extend the usual treatment of QE scattering, based on a one-body current operator, by incorporating a two-body meson-exchange current (MEC) one. In this work, MEC include the dominant Delta-resonance mechanism (excitation of the  $\Delta(1232)$  resonance and its subsequent decay into  $N\pi$ ) and the background contributions deduced from the chiral perturbation theory Lagrangian of the pion-nucleon system [4].

The connection of electron scattering experiments with neutrino scattering allows to scrutiny the available theoretical models by a first comparison to electron scattering data. Then, in our work [5], we compare our calculation of the electromagnetic responses of the  $^{12}\text{C}$  nucleus with the available experimental data. We find that the effect of the two-body currents is only significant in the transverse channel, where the response is increased up to a 34%, leading to an improved description of the data compared to the one-body case (Fig. 1). The key contribution of this work is the incorporation of the two-body meson exchange current contribution.

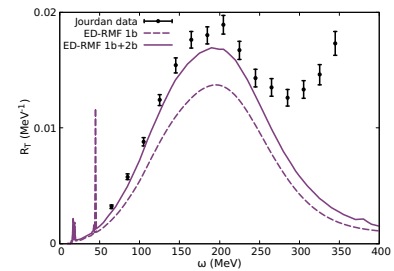


Figure 1.  $^{12}\text{C}$  electromagnetic transverse response using the ED-RMF model to describe the final nucleon. The transferred momentum  $q$  is 570 MeV/ $c$ .

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# Quantum simulation and machine learned analysis of an extended Agassi model

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## Summary

In this work, we study an extended Agassi model, which describes a many-body system in Nuclear Physics. It is a two-level system that includes a combination of long range monopole-monopole and short range pairing interactions. It presents a very rich quantum phase diagram that gives rise to several quantum phase transitions (QPTs) of different character, making it of great interest in the field of QPTs. We present the aforementioned model, propose an experimental setup for its quantum simulation and analyze its QPTs using machine learning tools.

## The model

The Agassi model [1] is a two-level system consisting of  $N$  interacting fermions, with each of the levels having a  $\Omega$  degeneracy. The labeling for the single particle states are  $\sigma = 1$  for the upper level and  $\sigma = -1$  for the lower one. In this work an extended Agassi model is considered, introduced in [2], which includes a more general pairing interaction. Its Hamiltonian is written as

$$H = \varepsilon J^0 - g \sum_{\sigma, \sigma' = -1, 1} A_{\sigma}^{\dagger} A_{\sigma'} - \frac{V}{2} \left[ (J^+)^2 + (J^-)^2 \right] - 2h A_0^{\dagger} A_0. \quad (1)$$

With three parameters  $g$ ,  $V$  and  $h$  that specify the quantum phase of the system. For its quantum simulation, we apply a Jordan-Wigner mapping that maps the Hamiltonian into spinless fermion operators. This leaves the Hamiltonian as a sum of Kronecker products of Pauli matrices, which can be simulated through single qubit gates and so-called Mølmer-Sørensen quantum gates.

## Quantum Phase Transition analysis

We study, for a system of size  $N=8$ , a correlation function between sites  $i, j$ , which is expressed as:  $C(i, j)_{\alpha, \beta} = \langle \sigma_i^{\alpha} \otimes \sigma_j^{\beta} \rangle - \langle \sigma_i^{\alpha} \rangle \langle \sigma_j^{\beta} \rangle$ , where  $\alpha, \beta = x, y$  or  $z$  and  $\sigma$  represents the corresponding Pauli matrix. In previous works it was shown that the time dynamics of these correlation functions, evolving from a generic initial state, hold information about the quantum phase of the system [3]. Furthermore, for a digital experimental simulation of the model, where the time evolution is not exact and instead follows Trotterized dynamics, this information is conserved (and even enhanced), even for a small amount of Trotter steps.

To extract the quantum phase of the system, a convolutional neural network (CNN) was trained with classically computed data of the exactly solvable Agassi model and then used to predict another set of computed data. The results are showed in Fig. (1), both using the exact evolution and the Trotter expansion. This CNN accurately predicted the quantum phase of the system in 98.69% (categorical accuracy) of the test cases for the exact evolution. Using the Trotterized evolution with only 6 Trotter steps, the CNN was capable of obtaining a categorical accuracy of 99.21% [4].

Another benefit of the CNN is that it can predict the values of the parameters  $g$ ,  $V$  and  $h$ , renamed as  $V = \frac{\varepsilon \chi}{3}$ ,  $g = \frac{\varepsilon \Sigma}{3}$ ,  $h = \frac{\varepsilon \Lambda}{3}$  for convenience. Fig. (2) shows the predicted values of  $\Sigma$  for the same