

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

NUC-RIA

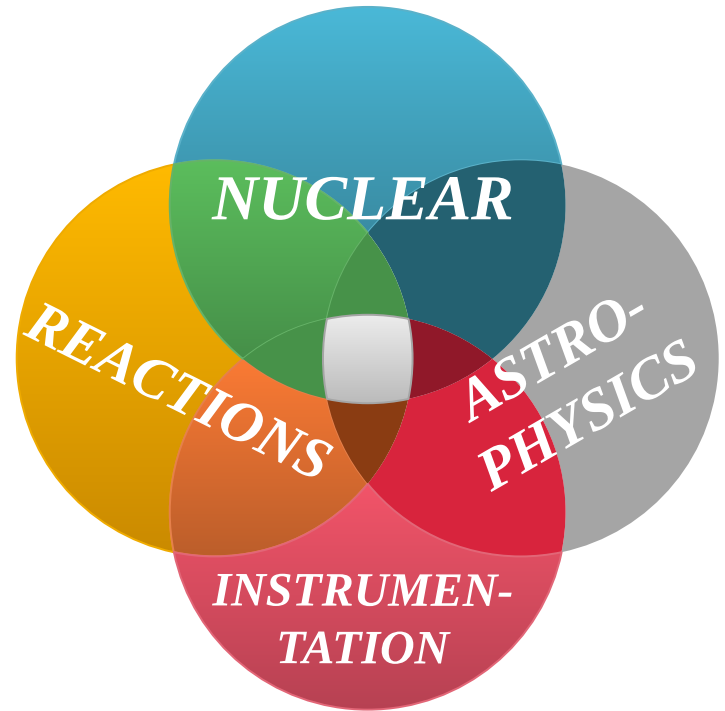
(a success story in Pandemic times)

D. Galaviz

Jornadas LIP

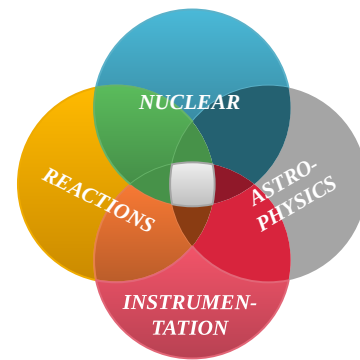
Coimbra, July 9th 2022

Outline



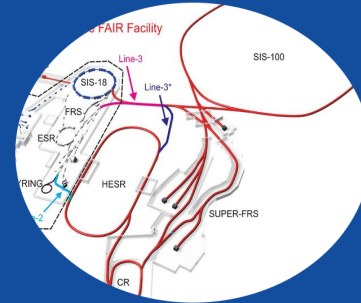
Outline

- Nuclear *Reactions* @ Relativistic Energies: R^3B
- Nuclear *Reactions* @ Low Energies:
 - *ISOLDE/CERN*
 - *CTN*
- Nuclear *Astrophysics*
- Nuclear *Instrumentation*: *Target Laboratory*
- *People & Synergies*



Nuclear Reactions

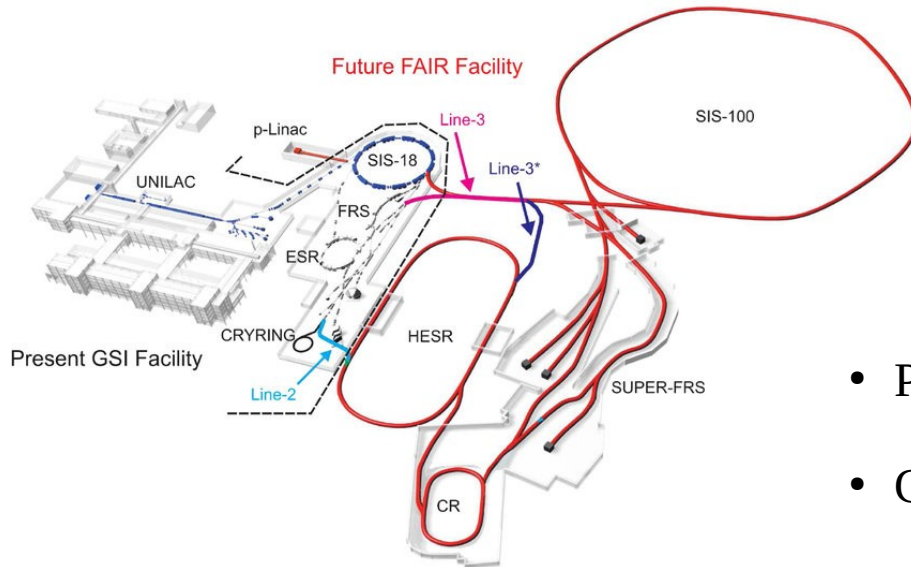
at Relativistic Energies



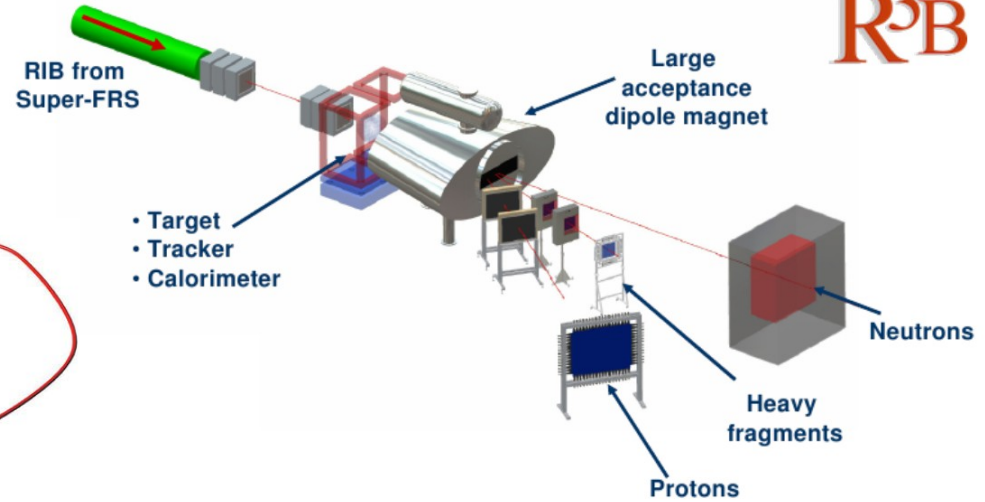
R³B



Facility for Antiprotons and Ion Research

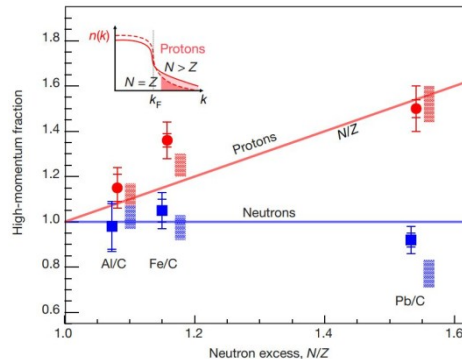
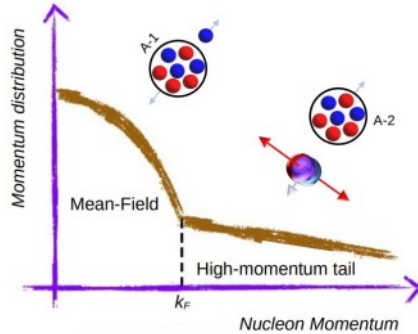


Reactions with Relativistic Radioactive Beams



- Participation since more than **10 years**
- Contributions to **CALIFA** and **NeuLAND**

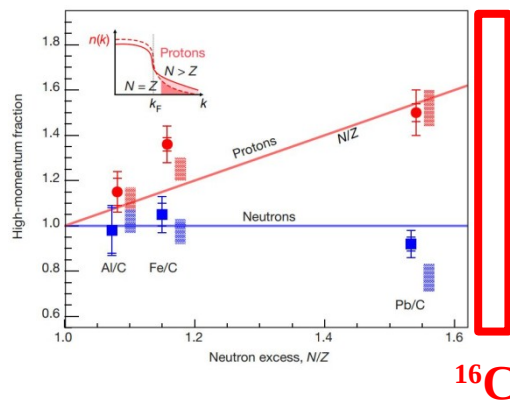
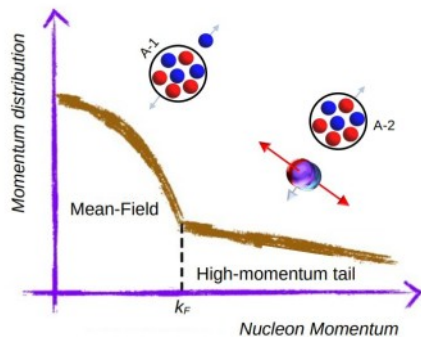
SRCs @ R^3B



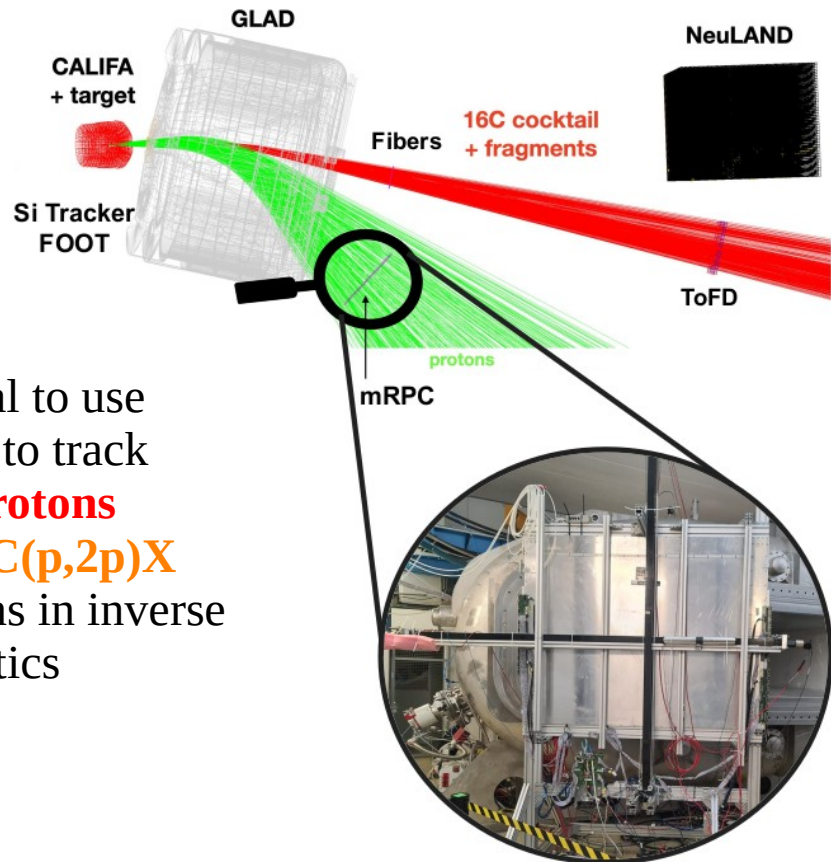
Nucleon-nucleon **Short Range Correlations**

- **High** relative **momentum**
- **Low center-of-mass** momentum
- Fraction of high momentum nucleons: **20%**
- Observed in **inelastic (e,e') scattering** (CLAS)
- Confirmed in **inverse kinematics (p,2p)**
- Experiments limited to **stable nuclei**

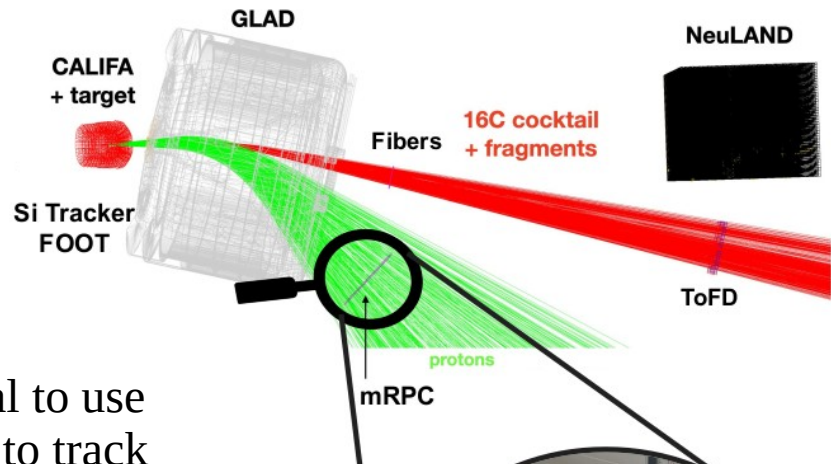
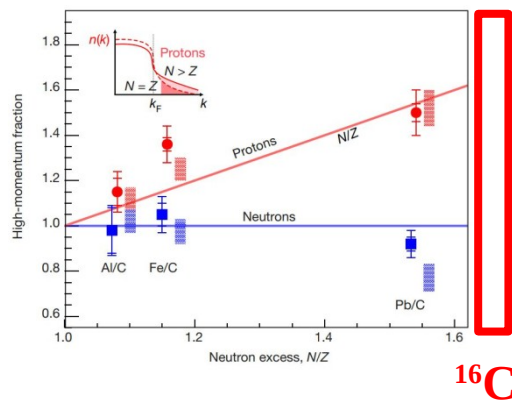
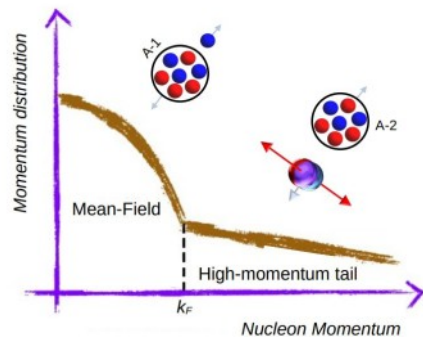
SRCs @ R³B



- Proposal to use **mRPC** to track **SRC protons** from $^{16}\text{C}(p,2p)X$ reactions in inverse kinematics

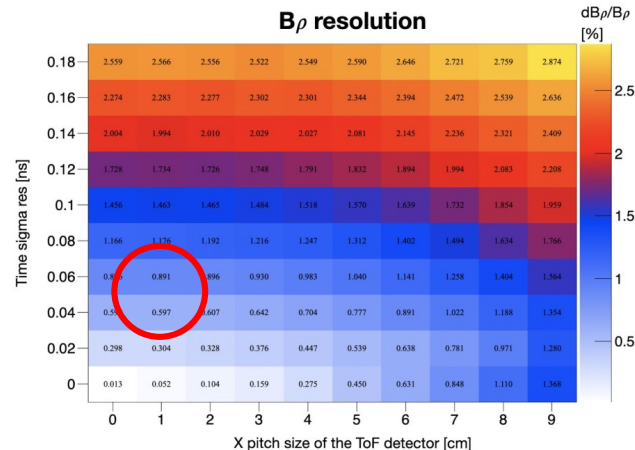


SRCs @ R³B



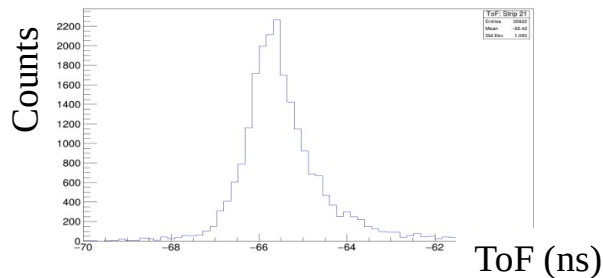
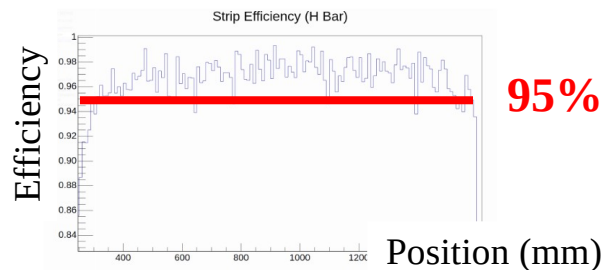
- Proposal to use **mRPC** to track **SRC protons** from $^{16}\text{C}(p,2p)X$ reactions in inverse kinematics

- Proton momentum resolution **below 1%**



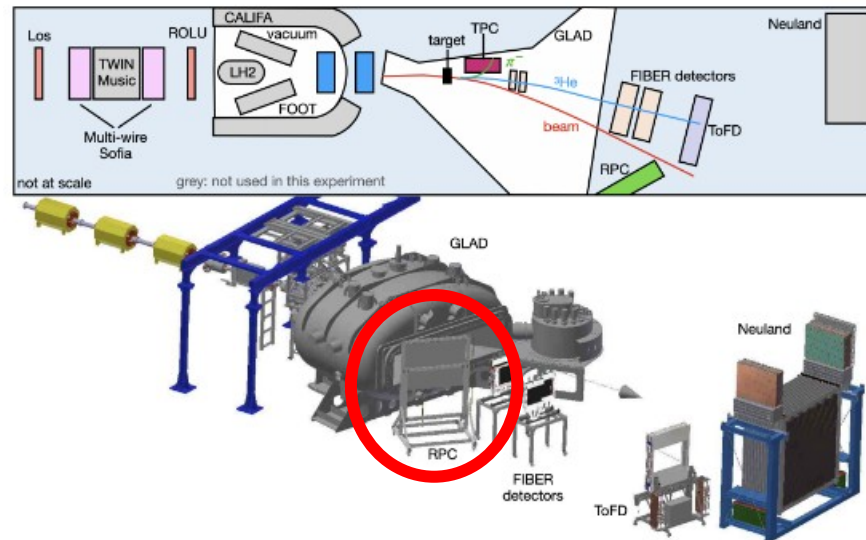
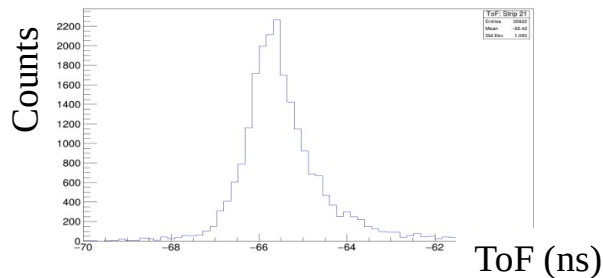
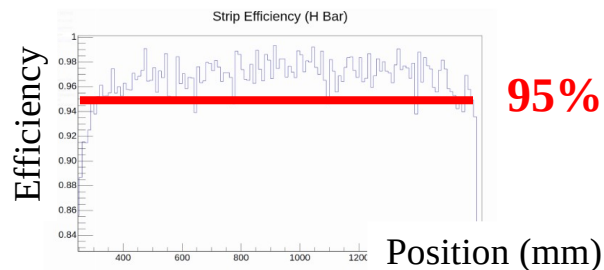
R³B (future)

- **Excellent performance** in two experiments of the **FAIR-Phase0**



R³B (future)

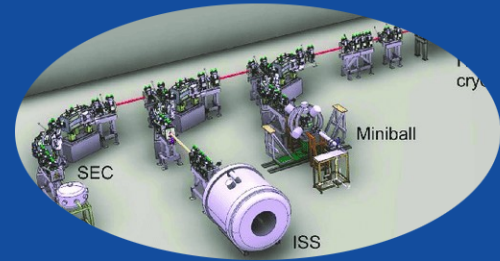
- **Excellent performance** in two experiments of the **FAIR-Phase0**



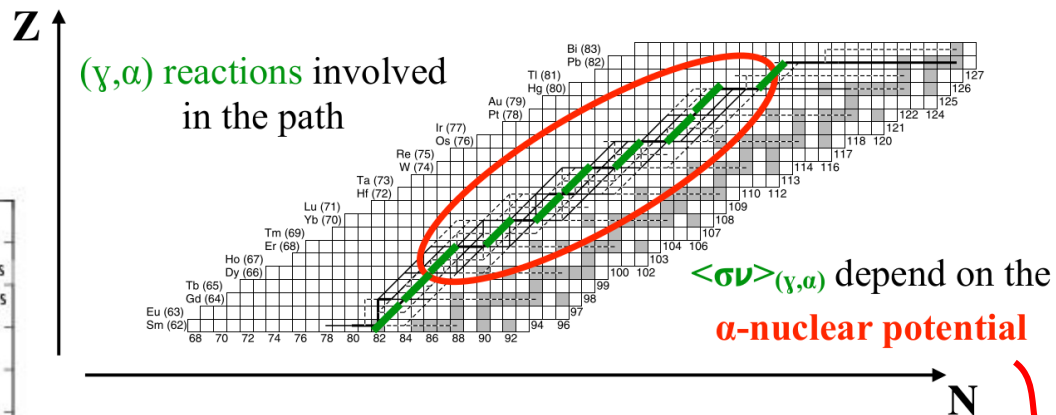
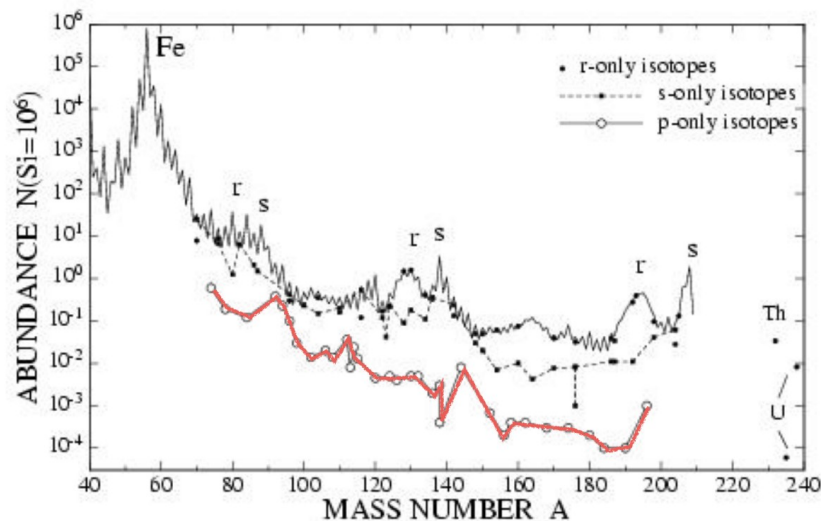
- mRPC considered as part of the **standard R³B** setup for upcoming **2023-2024 campaigns**
- Considering creation of **PAS-ToF Working Group** for **future** detector

Nuclear Reactions

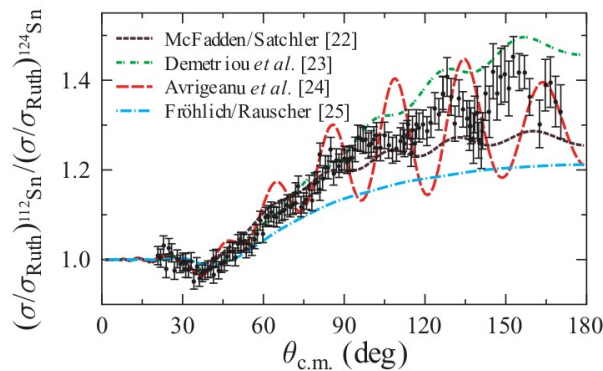
for Nuclear Astrophysics



Astrophysical p -process



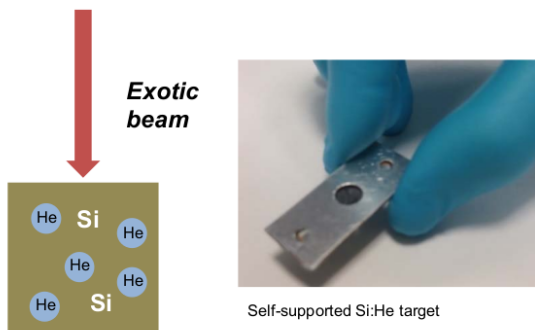
W. J. Rapp *et al.*, *Astrophys. J.* 653, 474 (2006)



Uncertainties in extrapolation

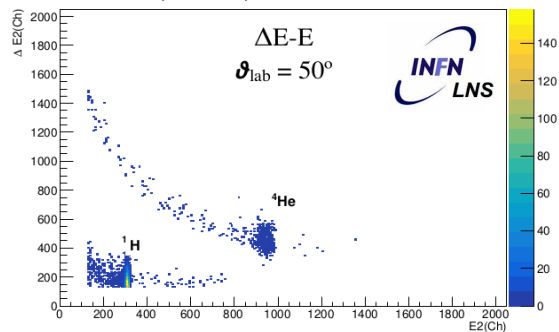
ISOLDE

Target developments in Seville



Allowed experiment in **inverse kinematics**

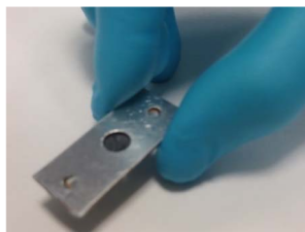
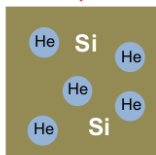
${}^4\text{He}({}^{58}\text{Ni}, \alpha){}^{58}\text{Ni}$ @ 150 MeV



ISOLDE

Target developments in Seville

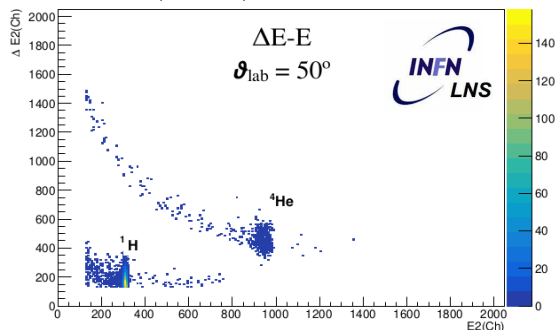
Exotic beam



Self-supported Si:He target

Allowed experiment in **inverse kinematics**

$^4\text{He}(^{58}\text{Ni}, \alpha)^{58}\text{Ni}$ @ 150 MeV



Proposal of **experiment**,
led by LIP team, of
experiment on **exotic Sn**
isotopes at **HIE-
ISOLDE**

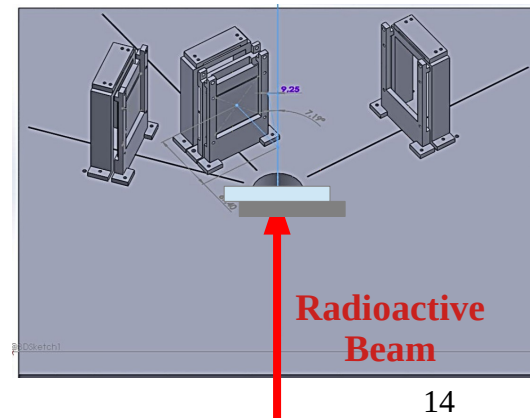
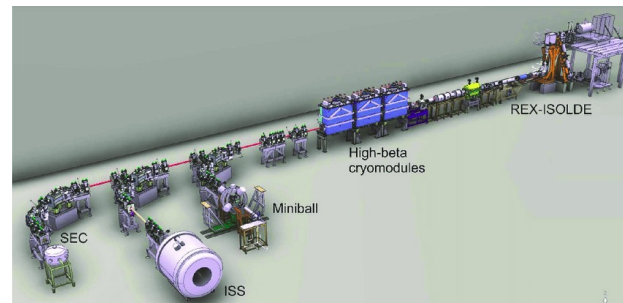


Proposal **approved** by
INTC

IS698 experiment
currently **under
preparation**



Francisco
Barba



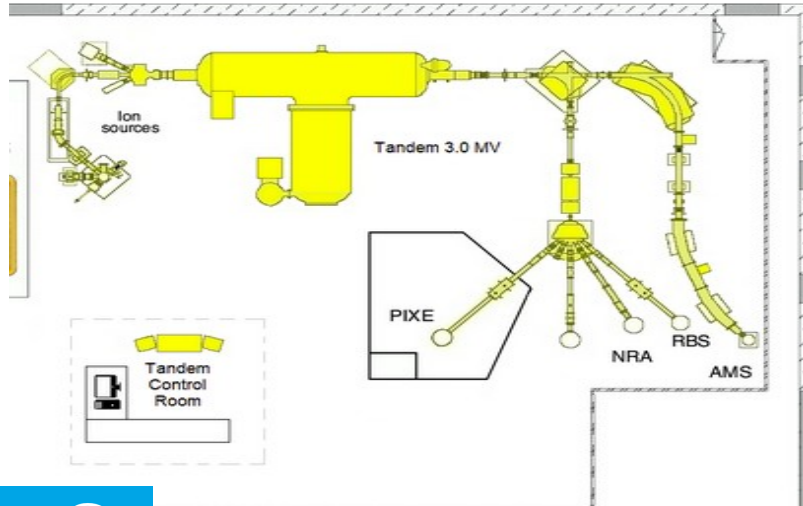
CTN

Low energy beams

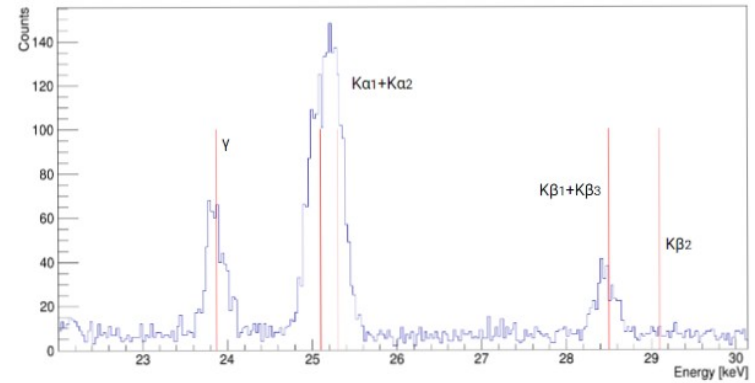


Ideal for **Nuclear Astrophysics**

First (p, γ)
cross section measurement
using **X-rays**



$^{nat}\text{Sn}(p,\gamma)\text{Sb}$



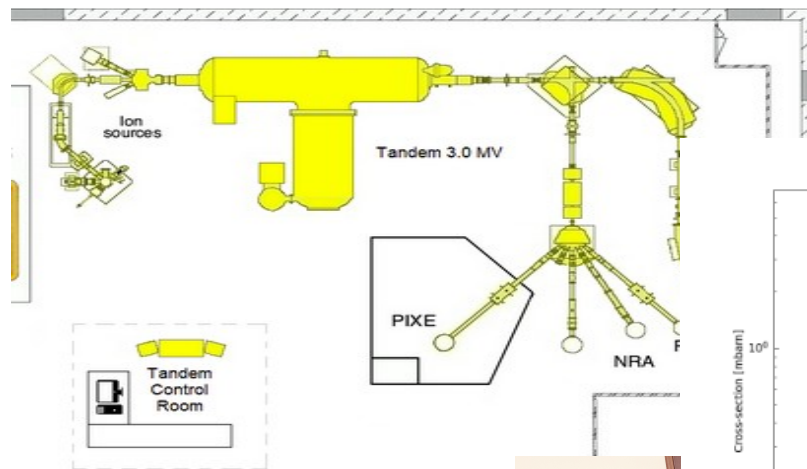
CTN

Low energy beams



Ideal for **Nuclear Astrophysics**

First (p, γ)
cross section measurement
using **X-rays**



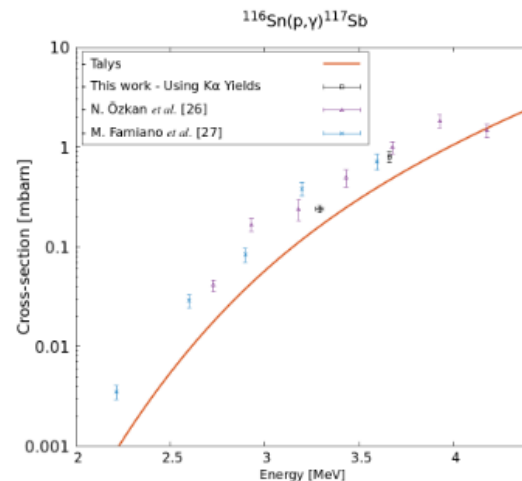
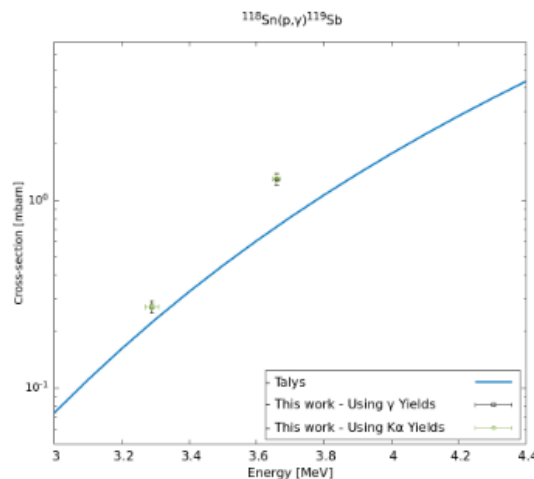
Manuel
Xarepe



Ricardo
Pires



Margarida
Paulino



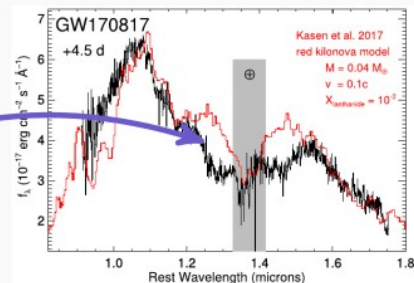
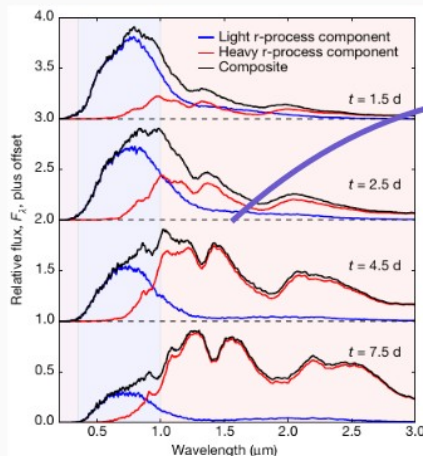
Local **training** prior to participation at **larger scale** facilities

Modelling

for Nuclear Astrophysics



Kilonova



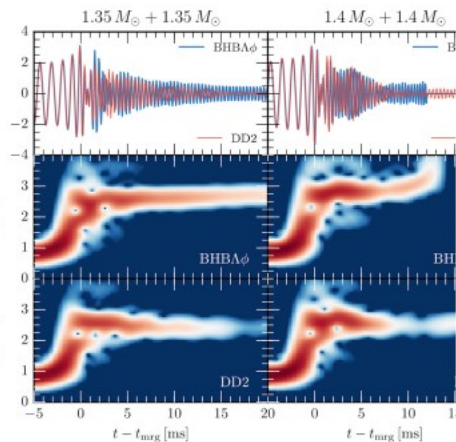
Heavy r-process models (lanthanides) close to match observations

$$\mathcal{L} \approx 5 \times 10^{40} \text{ erg s}^{-1} \times \left(\frac{M}{0.01 M_\odot} \right)^{1-\frac{\alpha}{2}} \left(\frac{v_{ej}}{0.1c} \right)^{\frac{\alpha}{2}} \left(\frac{\kappa}{1 \text{ cm}^2 \text{ g}^{-1}} \right)^{-\frac{\alpha}{2}}$$

- Old simulations using Fe-like ions
 \Rightarrow need of complete set of atomic data for heavy r-process ions
- What about actinides?

Left plot: Kasen et al. *Nature* (2017)

Right plot: R. Chornock et al. *ApJL* (2017)

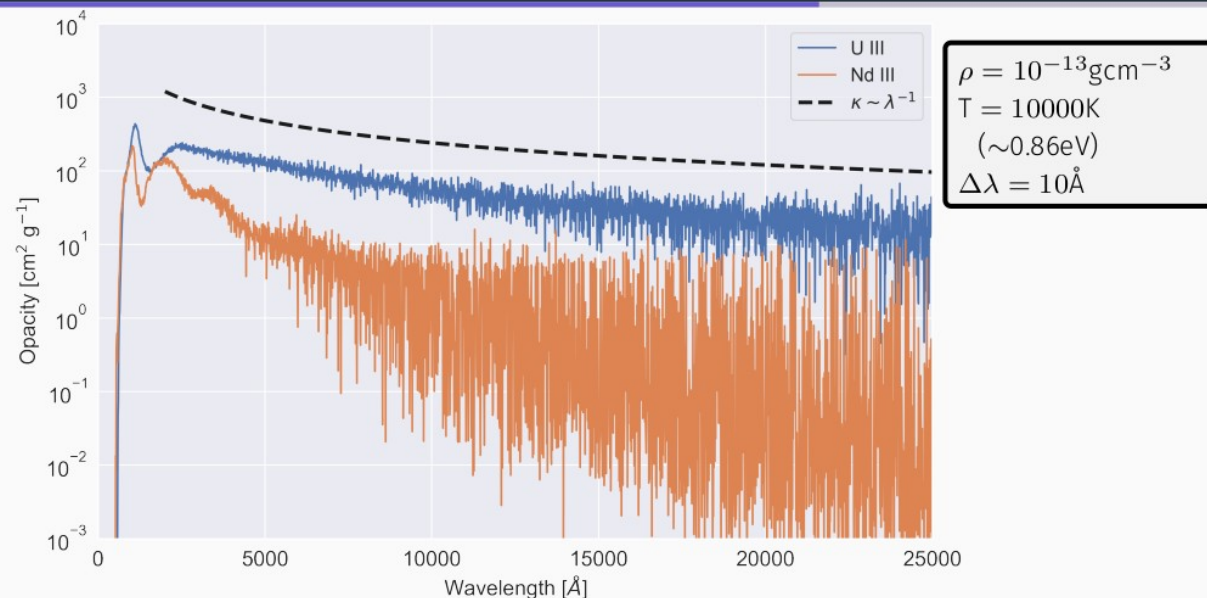


Kilonova



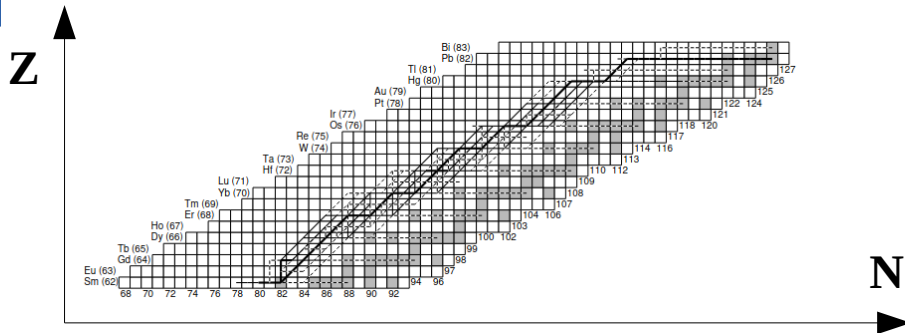
Ricardo
F. Silva

Opacities U III VS Nd III

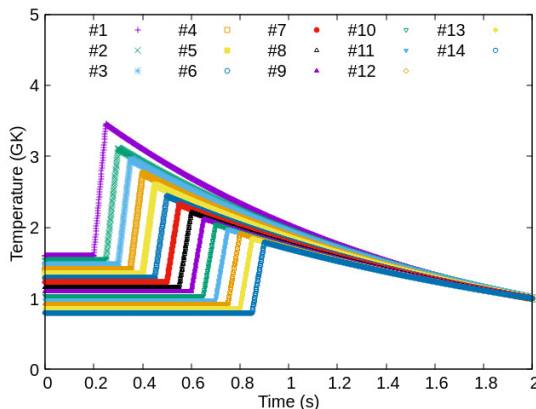


- Higher density of low lying levels \Rightarrow higher opacity (in LTE)
- Actinide opacities may have a non-negligible impact in kilonovae lightcurves

p-process



W. Rapp, *et al.* *Astroph. J.* 653, 474 (2006)



João Afonso Jantarada

Understanding the origin of the elements using nuclear reactions



M. Xerepe, F. Barba, A. Jantarada, R. Pires, D. Galaviz,

for the NUC-RIA group at LIP



SN-1987A



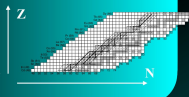
Heavy Element Nucleosynthesis

Nuclei are the DNA of the cosmos [1]. The understanding of the most basic characteristics that govern the strong, weak and electromagnetic interactions at the nuclear scale is of crucial importance to explain how our universe was formed and how it is evolving, how stars are born and die, and ultimately, how life came to exist.

Beyond the iron natural abundance peak, heavier elements are produced predominantly via neutron capture reactions in the framework of the r-process [2] and the s-process [3].

However, about 35 proton-rich naturally occurring isotopes between Sr and Hg cannot be produced by neutron capture processes. These isotopes are commonly referred to as p-nuclei, with the letter p corresponding to their lower neutron-to-proton ratio (N/Z), relative to other stable isotopes of the same element. The origin of this particular group of nuclei, which is the rarest among the stable species, has been a long-standing puzzle in nuclear astrophysics.

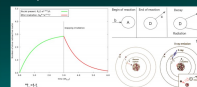
The considered explosive scenario [4,5] for their production are thus extremely sensitive to the stellar conditions (temperature, density, particle flux, $n\sigma v$), and to the nuclear physics inputs (interaction potentials, resonances, cross sections).



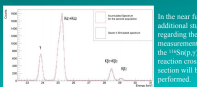
How do we study the production of heavy nuclei @ LIP/Ciências?

Proton Activation Experiments

It is generally accepted that the more abundant α and τ nuclei serve as seeds for the p-process through a network of (p, γ) and (p, n) reactions. In the effort to constrain the model parameters, cross-section measurements of radiative proton-capture reactions can have a crucial contribution towards understanding the p-process, improving predictions for currently unmeasured reactions. The proton activation experiments are one of the latest state of NUC-RIA. Below the main characteristics of the activation technique are shown.



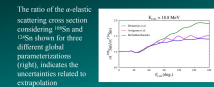
Work has already been done on measuring the cross-section of the $^{198}\text{Au}(p, \gamma)^{199}\text{Au}$ reaction at the CERN-ISOLDE laboratory in Lausanne, Portugal. The spectrum of the emitted X-ray during the decay phase is shown in the figure below.



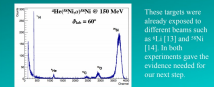
In the near future, additional studies regarding the measurement of the $^{198}\text{Au}(p, \gamma)^{199}\text{Au}$ reaction cross-section will be performed.

Elastic α -scattering with radioactive beams

Uncertainties in the knowledge of the α -nuclear potential in the heavy region of the nucleon chart constitute the main source of uncertainty in the production of the heavy nuclei p-nuclei [7,8]. Despite the various experimental efforts done over the past decades, studies on the α -nuclear potential have always been limited to stable isotopes [9,10,11]. Network calculations had to rely on the extrapolation of the theoretical models towards unstable nuclei [4,8].



Recent advances in the production of targets through magnetron sputtering allowed to produce a self-supporting film of Se containing quantities of ^{76}Se in the order of 10^4 atoms/cm 2 [12], bringing the possibility of making α -elastic scattering studies in inverse kinematics.



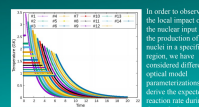
These targets were already exposed to different beams such as ^{16}O [13] and ^{18}O [14]. In both experiments, the evidence needed for our next step.

Recently, an experiment to measure the scattering of ^{76}Se on ^{198}Au in the making use of the new target was approved at ISOLDE-CERN, performing the first measurement of these reactions and of the nuclear potential in radioactive nuclei involved in the p-process.

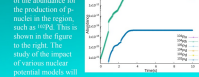
Reaction Network Calculations

The impact of the nuclear input on the production of heavy p-nuclei is usually investigated by performing calculations of nuclear reaction networks under stellar conditions, similar to those found in explosive nucleosynthesis.

Within our group, we are currently implementing the conditions found at the SeO layers of a Type II Supernova, as these present the correct conditions to synthesize significant quantities of p-nuclei. The figure shows the typical 14. In the figure, the conditions considered in these figures of the SNa explosion [15], representing temperature variation in the simulated zones.



Using the NUC-RIA Tools Framework [16], we are able to study the evolution of the abundance for the production of p-nuclei in the region, such as ^{76}Se . This is shown in the figure.



In the figure, the study of the impact of the nuclear input on the production of heavy p-nuclei is usually investigated by performing calculations of nuclear reaction networks under stellar conditions, similar to those found in explosive nucleosynthesis.

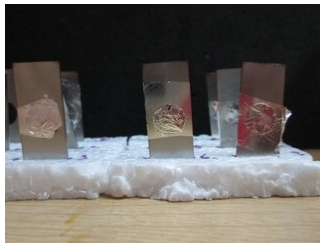
References:

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- [15] NUC-RIA Tools, <https://nucler-ria.net/nucler-tools/home/Home/>

Instrumentation

for Nuclear Reaction Experiments





Possibilities for **thin coating** production



Pamela
Teubig



Synergies



Dosimetry



Introduction

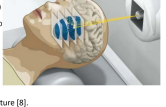
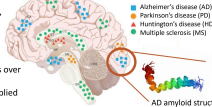
Degenerative cognitive diseases are characterized by the presence of toxic protein structures known as amyloids [1,2].

Most common degenerative cognitive diseases and their position in the brain [3].

Proton radiotherapy (PT) for the destruction of amyloid structures [4].

Low-dose radiotherapy, with photons, has shown positive results on Alzheimer's disease (AD) or Parkinson's disease (PD) [5,6].

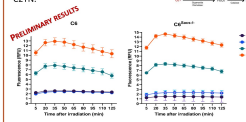
Proton therapy has several advantages over conventional radiotherapy: Reduced integral dose, and already clinically applied to noncancerous brain tumours [7].



Multidisciplinary Approach: Biochemistry and Nuclear Physics join forces

Study the radiation effects on the brain using established cell lines

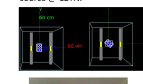
Reactive oxygen species (ROS) indicate the healthiness of the cells [9]. Protocols have been optimized to study the brain tissue cell – irradiation system using ^{60}Co gamma-ray source @ CTN.



Simulation



Simulation of the experimental setup with TOPAS [11], regarding the irradiations performed with ^{60}Co gamma source @ CTN.



Simulation of the ROS production inside a cell, due to the interaction with ionizing radiation, using TOPAS-nBio [11].

Outlook

Comparison of different modalities: Preparation for exploratory experiments using a clinical LINAC at CHULN (Hospital Santa Maria) are under way.

Planning the experiments at the CMAM (Madrid, Spain) proton beam facility during fall period.



This line of research looks at proton therapy as something more than a means to eliminate cancer. We focus on using it as an alternative treatment strategy for neurodegenerative diseases, for which no cure to-date exist. More information can be found at [12].

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1. J. Perle, J. Shin, J. Schumann, B. Faddgeon, and H. Paganetti. Topas: An innovative proton monte carlo platform for research and clinical applications. Medical Physics, 39:6818–6837, 10 2012. ISSN 00942455. doi: 10.1118/1.4758060.
2. J. Perle, J. Shin, J. Schumann, B. Faddgeon, and H. Paganetti. Topas: An innovative proton monte carlo platform for research and clinical applications. Medical Physics, 39:6818–6837, 10 2012. ISSN 00942455. doi: 10.1118/1.4758060.
3. J. Perle, J. Shin, J. Schumann, B. Faddgeon, and H. Paganetti. Topas: An innovative proton monte carlo platform for research and clinical applications. Medical Physics, 39:6818–6837, 10 2012. ISSN 00942455. doi: 10.1118/1.4758060.
4. J. Perle, J. Shin, J. Schumann, B. Faddgeon, and H. Paganetti. Topas: An innovative proton monte carlo platform for research and clinical applications. Medical Physics, 39:6818–6837, 10 2012. ISSN 00942455. doi: 10.1118/1.4758060.
5. J. Perle, J. Shin, J. Schumann, B. Faddgeon, and H. Paganetti. Topas: An innovative proton monte carlo platform for research and clinical applications. Medical Physics, 39:6818–6837, 10 2012. ISSN 00942455. doi: 10.1118/1.4758060.
6. J. Perle, J. Shin, J. Schumann, B. Faddgeon, and H. Paganetti. Topas: An innovative proton monte carlo platform for research and clinical applications. Medical Physics, 39:6818–6837, 10 2012. ISSN 00942455. doi: 10.1118/1.4758060.
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Acknowledgments

Authors thank the following people for their contribution to this work: J. Perle, J. Shin, J. Schumann, B. Faddgeon, and H. Paganetti. This work was supported by the European Union Horizon 2020 research and innovation programme under the Marie Skłodé Curie grant agreement No 101019719.



Lia Pereira



Rita Pestana



Development of a standard methodology for online dose calculation in air

Motivation

At the Centre for Micro Analysis of Materials, CMAM, in Madrid, there is an ion accelerator with a terminal voltage of 5 MV. An external beamline is used for irradiations with 10 MeV protons and the current is only measured using Faraday cups that stop the beam.



This project aims to develop a methodology to measure the beam intensity in air without compromising the irradiation. This is important for experiments related to nuclear physics and radiobiology, for instance.

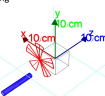
Specifications

- A metallic piece
- High generation of secondary electrons
- Low activation of the piece
- High conductance of the charge
- Electrons $\propto I_{\text{protons}}$
- Do not affect the irradiation



Simulations

- Using TOPAS¹
- Included the end of the beamline, a water cube on the position of the sample and an aluminium disk with blades rotating



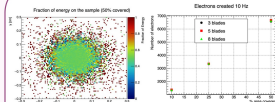
- Analysed the irradiation pattern on the water
- Measured the electrons created in the metal
- Parameters changed in the simulations:
 - Number of blades (3, 5 and 8)
 - Area covered by the blades (10%, 25% and 50%)
 - Frequency of rotation (1 Hz, 10 Hz, 20 Hz and 30 Hz)

Rita Pestana¹, Silvia Viñals², Daniel Galaviz²

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2- Centre for Micro Analysis of Materials (CMAM)

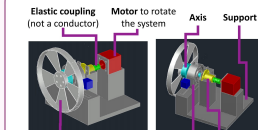
Simulations



- The device does not affect the irradiation pattern
- Number of protons lost \propto Area covered by the blades
- Number of electrons \propto Area covered by the blades

Design

- Using AutoCAD



- Disk with 5 blades covering 50% of the area
- Bearing (not a conductor)
- Slip ring to collect the charge from the rotating disk (sensitive to pA currents)

Future work

- Production of the device
- Tests
- Calibration
- Test the device at other facilities

References

- 1 - J. Perle, J. Shin, J. Schumann, B. Faddgeon, and H. Paganetti. Topas: An innovative proton monte carlo platform for research and clinical applications. Medical Physics, 39:6818–6837, 10 2012. ISSN 00942455. doi: 10.1118/1.4758060.



Carina Coelho



RPC



Manuel
Xarepe

Jornadas LIP | July 2022

Integration of a mRPC for Precise Measurement of High-Momentum Protons in SRC

Manuel Xarepe^{1,2}, for the R³B Collaboration

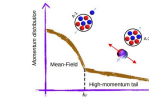
1 - LIP - Laboratory of Instrumentation and Experimental Particle Physics

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Supported by Portuguese FCT, Project Refs: 2021/05736-BD and EXPL/FIS-NUC/0364/2021



Brief Introduction



Short Range Correlations:

- Brief fluctuations of nucleon pairs, characterized by:
 - High relative momentum*
 - Low center-of-mass momentum
- SRC pair can be pp, pn and nn, where the pn are dominant
- Fraction of high momentum nucleon in nuclei is about 20%
*in reference to Fermi Momentum (k_F)

How do we measure them?

- High energy probes:
 - Inelastic electron scattering
 - Quasi Free Scattering (QFS) in Inverse Kinematics

What has been done?

- Mainly electron scattering [1]
 - The number of on pairs increases with neutron excess

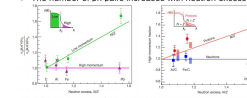


Fig 1: Relative abundances of high- and low-initial-momentum neutrons and protons (Left). Relative high-momentum fractions for neutrons and protons (Right). [1]

QFS 12C(p,2p)X in Inverse Kinematics [2]

- First measurement of SRC in Inverse Kinematics

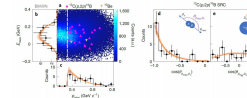


Fig 2: Selection of SRC breakup events and angular correlations [2]

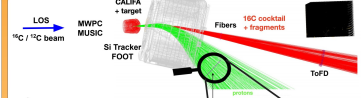
Next Step?

- QFS in Inverse Kinematics using exotic beams

References

- [1] The GLAS Collaboration. "Theming high-momentum protons and neutrons in neutron-rich nuclei." *Nature* 560, 617–621 (2018).
- [2] Patykus, M., et al. "Unperturbed inverse kinematics nucleon knockout measurements with a carbon beam." *Nature Physics* 17, 6 (2021): 693–699.
- [3] Bianco, A., et al. "The SHIP timing detector based on mRPC." *Journal of Instrumentation* 15, 10 (2020): C10107.

R³B Setup



R³B experiment

- High Energy branch of the NUSTAR pillar of FAIR
- Reactions with Relativistic Radioactive Beams performed in Inverse Kinematics
- Setup allows for a complete characterization of the kinematics

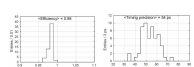
SRC at R³B

- ¹²C and ¹³C beams at 1.25 GeV/u
- First measurement with complete kinematics of A(p,2p)A-2 reaction
- Momentum of the forward emitted proton measured using mRPC detector

multigap Resistive Plate Chamber (mRPC) Detector

mRPC Properties:

- Gaseous detector
- Active area of 1.5x1.2 m² ≈ 1.8 m²
- Good time precision σ_t = 50 ps [3]
- Good efficiency > 98 %



Measurement of High-Momentum Protons in SRC at R³B using mRPC

Due to the excellent timing properties of this detector, it was proposed to measure the momentum of forward emitted protons using the time of flight method (ToF), with a resolution of around 1 %.

Brief history of "mRPC" time at R³B:

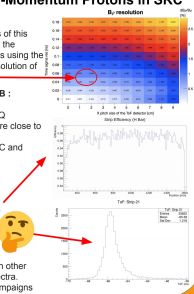
- Arrival at GSI in November 2021
- Integrated into R³B Cave and DAQ
- Online and offline analysis software close to fully developed
- Electronic resolution between RPC and Start detector around 35 ps

Participated in two FAIR Phase-0 experiments, S522 and S509:

- Excellent performance with:
 - Very high detection efficiency
 - Good ToF resolution

Immediate Future steps:

- Finish the mRPC calibration
- Analyse the data in correlation with other detectors to clean up the ToF Spectra.
- Prepare the detector for future campaigns

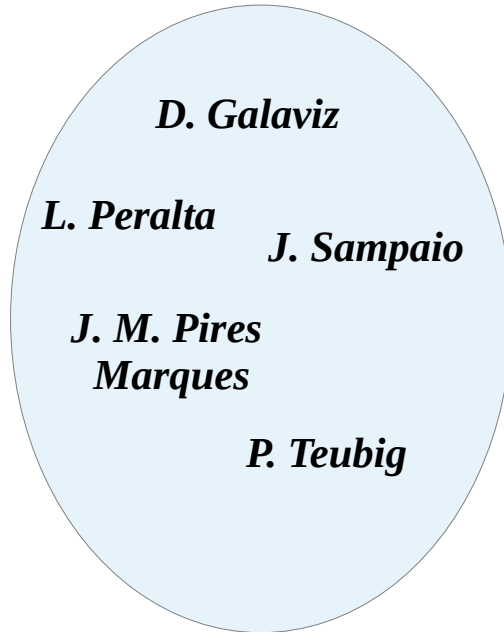


People

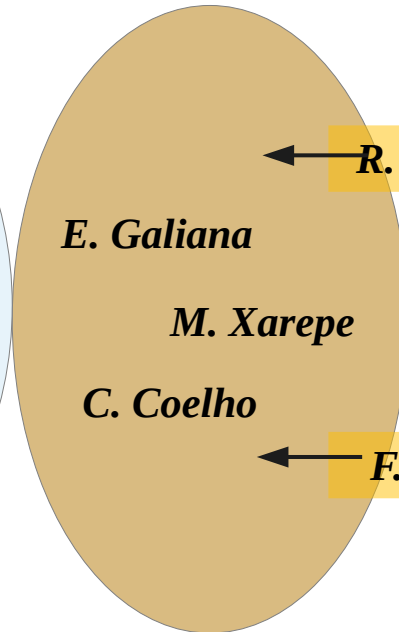


People

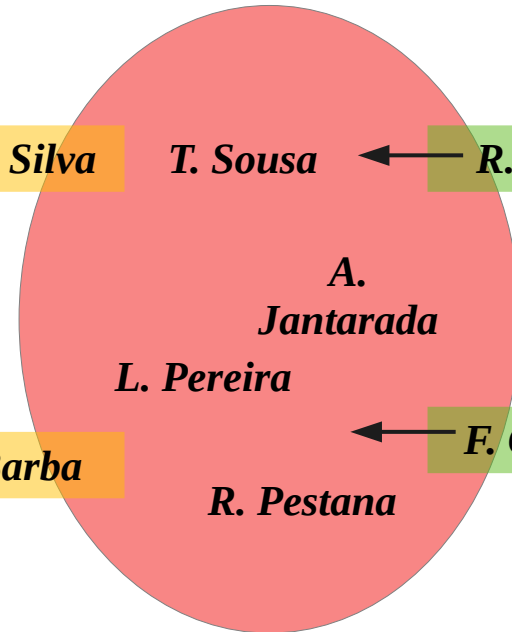
Senior



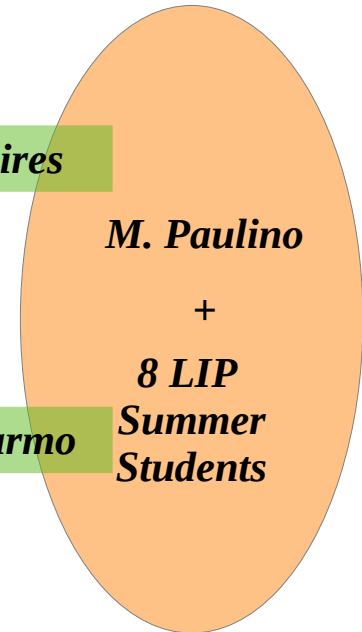
Ph.D.



M.Sc.



B.Sc.



← *R. F. Silva*

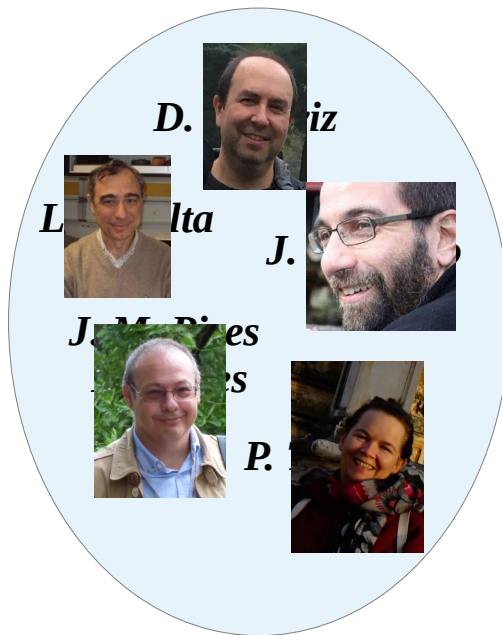
← *R. Pires*

← *F. Barba*

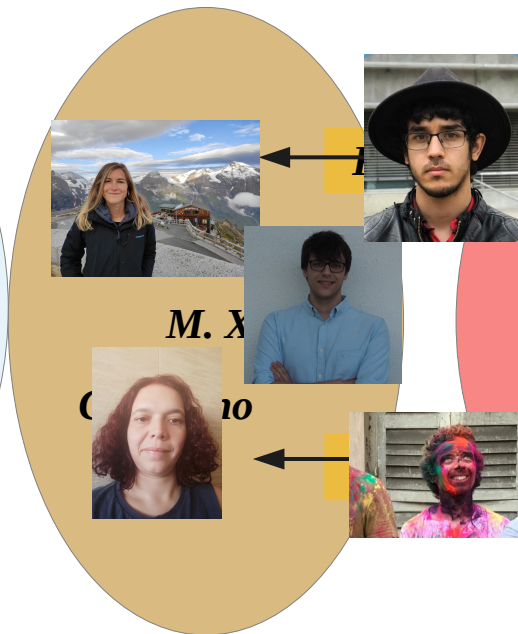
← *F. Carmo*

People

Senior



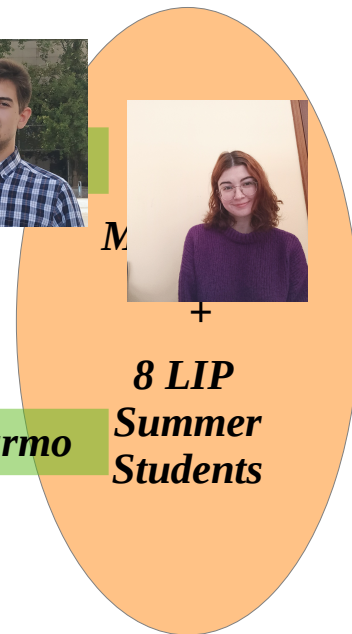
Ph.D.



M.Sc.



B.Sc.



Thanks!



Any questions?
You can contact us nucria@lip.pt

