ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: Lifetime measurements around ^{48}Ca

SUPERVISOR(S): Dr. Andrea Gottardo
Dr. José Javier Valiente Dobón
Giuseppe Andreetta, PhD student

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UNIVERSITY/RESEARCH CENTER: UNIPD (Padova, Italy) / INFN-LNL (Legnaro, PD, Italy)

ABSTRACT
(just few lines 5-10 explaining briefly the idea of the proposed work and the place where it will be developed).

The region around ^{48}Ca is characterized by puzzling phenomena despite being close to a double shell closure. In order to investigate how the shell structure evolves going towards the neutron-rich isotopes, an experiment was performed in April 2024 at LNL with the AGATA tracking array coupled to the large acceptance magnetic spectrometer PRISMA. The isotopes of interest were populated via multi-nucleon transfer reaction ^{48}Ca + ^{238}U: the reaction products and the gamma rays coming from their de-excitation were detected by PRISMA and AGATA respectively.
In particular, the aim of the experiment was to identify several excited states in Ca isotopes and measure their lifetimes using the Recoil Distance Doppler-Shift (RDDS) technique and the DopplerShift Attenuation Method (DSAM). From the lifetimes, it will be possible to access and investigate the wave function of the excited states.
The candidate will take part to the analysis of the data, performing the particle identification with PRISMA and combining this information with the AGATA array to get the gamma-ray spectra and, ultimately, the lifetime of several excited states of interest.

ERASMUS MUNDUS JOINT MASTER DEGREE IN NUCLEAR PHYSICS

Co-funded by the Erasmus+ Programme of the European Union

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS

Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: Refinement of nuclear models and experimental tools for a reduction of neutrino interaction cross sections at the GeV scale

SUPERVISOR(S): Guillermo D. Megias (University of Seville), Stephen Dolan (CERN), Andrea Longhin (Physics and Astronomy Department, Padova University)

UNIVERSITY/RESEARCH CENTER: University of Padova

ABSTRACT

(just few lines 5-10 explaining briefly the idea of the proposed work and the place where it will be developed).

Future long baseline neutrino experiments (Hyper-Kamiokande, DUNE) require an improved understanding of GeV-scale neutrino interaction models and cross sections. The proposed activity includes a phenomenological work on nuclear models to improve the description of final states at the T2K neutrino energies of about 600 MeV. This part will be based on University of Seville and the CERN group. The second part of the thesis (Padova) will be mostly focused on experimental aspects: 1) first analysis and commissioning of the newly installed High-Angle Time Projection Chambers at the T2K near detector or 2) the analysis of data collected with the ENUBET demonstrator in the context of producing high precision neutrino beams for the next generation experiments.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: ***Innovative batteries for Space, Medicine And Remote sensing applications***

SUPERVISOR(S): Daniele Mengoni

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UNIVERSITY/RESEARCH CENTER: University of Padova, INFN Sezione di Padova and INFN Laboratori Nazionali di Legnaro

ABSTRACT
(just few lines 5-10 explaining briefly the idea of the proposed work and the place where it will be developed).

The conventional electrochemical batteries have limited longevity and a strong tendency to degrade under extreme environmental conditions. Hence, the need to develop nuclear betavoltaic devices, which are reliable, long-lived, high energy-density power sources for operating electrical systems in hostile and inaccessible environments. For situations where battery replacement is inconvenient or impossible, such as in remote sensing, space or medical applications and where low-power generation can be utilized, betavoltaic batteries are safe, clean and suitable alternative to electrochemical battery technologies. Other possible applications of betavoltaic batteries include implanted medical devices whose long lifespan of more than 30-40 years can improve life quality of patients due to reducing healthcare costs and eliminating periodical invasive surgeries for maintenance. In current state, the simulated maximum efficiency for the Si-based beta cells is 13.7% whereas in real devices it is mostly below 1%. In order to understand how to enhance the efficiency of such devices, the candidate will be engaged in the simulation using Montecarlo code to explore suitable beta emitters and the interaction of beta rays with materials, by determining the energy deposition and penetration depth. Moreover, the candidate will be finding the best geometrical configuration for the battery, using the complementary COMSOL suite, able to model the key components of the semiconductor device and its power yield by using finite element numerical calculations. Finally, the student will be measuring experimental values of power to compare with the simulated values.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: ***Study of the evolution of the spin-orbit splitting at N=19 via direct transfer reactions @ GANIL***

SUPERVISOR(S):Franco Galtarossa (franco.galtarossa@pd.infn.it) and Daniele Mengoni (daniele.mengoni@unipd.it)

UNIVERSITY/RESEARCH CENTER: University of Padova, INFN Sezione di Padova and INFN Laboratori Nazionali di Legnaro

ABSTRACT
(just few lines 5-10 explaining briefly the idea of the proposed work and the place where it will be developed).

The monopole part of the nucleon-nucleon interaction, composed of a central, a spin-orbit and a tensor component, is the driving force of the so-called shell evolution, related to the appearance and disappearance of magic numbers and local shell closures along isotopic and isotonic chains in the nuclear chart.
The region around the doubly-magic ^{34}Si nucleus offers a unique possibility to test the density and proton-to-neutron (isospin) dependence of the nuclear spin–orbit potential, which is yet poorly constrained.
We plan to run an experiment at the GANIL laboratory to determine the evolution of the 2*d* spin-orbit splitting descending along the N=19 isotonic chain, in particular in ^{33}Si, by measuring the distribution of the $2d_{3/2}$ and $2d_{5/2}$ single-particle strength. We will employ the ^{34}Si(*p*,*d*)^{33}Si neutron pick-up reaction at 50 AMeV, with a radioactive ion beam of ^{34}Si impinging on a CH_2 target, and we will detect the light recoils in coincidence with the γ rays emitted by the heavy ejectiles.

The thesis work will mainly focus on the Zero-Degree Detection (ZDD) system used to detect the beamlike particles. The student is expected to perform simulations with the LISE++ software and take part in the measurement at GANIL. He/She will analyse the data from the ZDD to determine resolutions, efficiencies and quality of the particle identification. If time allows, the student will also look into the γ-particle spectra to identify the states populated in the reaction and the main γ-ray transitions observed.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: Pushing the limit of detection of the PRISMA magnetic spectrometer: identification of nuclei with A~200

SUPERVISOR(S): Franco Galtarossa and Alain Goasduff

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UNIVERSITY/RESEARCH CENTER: INFN Sezione di Padova and INFN Laboratori Nazionali di Legnaro

ABSTRACT
(just few lines 5-10 explaining briefly the idea of the proposed work and the place where it will be developed).

Multi-nucleon transfer (MNT) reactions are nuclear reactions between heavy ions that allow to produce exotic nuclei through the exchange of many neutrons and protons between the two reactants. The use of these reactions has been suggested as a promising way to produce neutron-rich nuclei close to the N=126 shell closure, important for studies related to nuclear structure and astrophysics, or to populate nuclei in the actinide and trans-actinide regions, where experimental information is particularly scarce. Normally, due to experimental constraints, the study of MNT reactions is performed detecting the light reaction partner in a magnetic spectrometer and deducing the corresponding physical quantities for the heavy reaction partner from momentum conservation. A real breakthrough in this field would be represented by the direct identification of the heavy nuclei directly in the magnetic spectrometer.
At INFN LNL we performed two experiments using the $^{208}Pb+^{130}Te$ and $^{129}Xe+^{232}Th$ MNT reactions, detecting the Pb-like and Th-like ions directly in the magnetic spectrometer PRISMA. The student will take care of the analysis of a selected subset of data from these experiments with the aim of demonstrating for the first time the possibility to employ PRISMA for the direct detection of nuclei with mass A~200. He/She will also have the opportunity to cross-check the obtained identification performing gamma-ray spectroscopy of the detected nuclei thanks to the coincidence between PRISMA and the gamma-ray tracking array AGATA. In the same period the student will be also involved in the ongoing experimental campaign with AGATA.
The work will be performed at the INFN Laboratori Nazionali di Legnaro (LNL).

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: ***Quantal Rotation and proton-neutron interaction: lifetime measurements in the N=Z=31 62Ga @ JYFL (Finland)***

SUPERVISOR(S): Daniele Mengoni (daniele.mengoni@unipd.it) and Giacomo de Angelis (giacomo.deangelis@lnl.infn.it)

UNIVERSITY/RESEARCH CENTER: University of Padova, INFN Sezione di Padova and INFN Laboratori Nazionali di Legnaro

ABSTRACT

(just few lines 5-10 explaining briefly the idea of the proposed work and the place where it will be developed).

Odd-odd nuclei with equal numbers of protons and neutrons are particularly interesting due to the competition between isoscalar (T=0) and isovector (T=1) states arising from neutron-neutron (nn) or proton-proton (pp) (T=1) and neutron-proton (np) (T=1 and T=0) correlations. Since in N=Z nuclei protons and neutrons occupy the same orbitals the overlap of wave functions is maximal which may lead to enhanced pn pairing correlations in the isoscalar T=0 channel. Shell effects from protons and neutrons are here in phase magnifying the impact of pn pairs on the collective behavior and in particular on the quantal rotation of triaxial systems that can be explored by lifetime measurements.

The candidate will work in the analysis of data collected during the experiment last January, extracting lifetime and comparing with theoretical predictions.
The activity will be held in the rich International environment of the collaboration which represents a strong growing opportunity for the student.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: ***Exploring the limit of nuclear stability: the structure of 56Ni and 60Zn***

SUPERVISOR(S): Matus Balogh (INFN-LNL), Franco Galtarossa (INFN-PD)

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UNIVERSITY/RESEARCH CENTER: INFN Sezione di Padova and INFN Laboratori Nazionali di Legnaro

ABSTRACT
(just few lines 5-10 explaining briefly the idea of the proposed work and the place where it will be developed).

Two recent experiments performed at LNL focused on the investigation of the N=Z region through the study of ^{56}Ni and ^{60}Zn isotopes. These experiments aim to measure nuclear lifetimes using the Doppler Shift Attenuation Method (DSAM) for measuring lifetime as short as femtosecond, employing a 16O beam at 80 MeV and an advanced detection system comprising AGATA and the OSCAR dE-E telescope. The experimental setup and data collection were performed in back-to-back experiments with identical configurations. The current phase of analysis is focused on optimizing the energy calibration of the telescopes to improve excitation energy resolution. Accurate identification of the populated excited states is essential for refining the DSAM analysis, which will contribute to a deeper understanding of nuclear structure in the N=Z region.

As part of this research, the student will either contribute to the data analysis or participate in the ongoing scientific campaign, both of which offer excellent opportunities for growth within a familiar yet international environment.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: Neutrino physics from gamma spectroscopy

SUPERVISOR(S): José Javier Valiente Dobón, Damiano Stramaccioni

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UNIVERSITY/RESEARCH CENTER: Laboratori Nazionali di Legnaro (I.N.F.N.)

ABSTRACT
(just few lines 5-10 explaining briefly the idea of the proposed work and the place where it will be developed).

Experimental studies of nuclear matrix elements (NMEs) related to neutrinoless double-β decays (DBDs) and astroneutrino (ν) inverse β decays (IBDs) are essential for advancing our understanding of neutrino physics beyond the Standard Model, as well as for astro-neutrino research. Accurate theoretical calculations of NMEs are challenging due to their strong sensitivity to the nuclear models and parameters used.

However, key NMEs associated with electromagnetic transition operators in both DBD and IBD processes—such as effective weak couplings—can be experimentally determined by measuring the corresponding electromagnetic (gamma) transitions from the isobaric analog states (IASs) of the relevant nuclei. To address this, the GAMMA group at the I.N.F.N. Laboratori Nazionali di Legnaro (Italy) has launched an innovative experimental campaign aimed at exploring the interface between gamma spectroscopy and neutrino physics.

The student is invited to join this cutting-edge project and focus on two main activities, which can be tailored according to their interest and background:

- Developing GEANT4 simulations to estimate the sensitivity of the detection setup for future experiments.
- Analyzing data collected from the first experiment of the campaign, which focused on studying the rare gamma decay of the Double Isobaric Analogue state in 48Ti.

ERASMUS MUNDUS JOINT MASTER DEGREE IN NUCLEAR PHYSICS

Co-funded by the Erasmus+ Programme of the European Union

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: Investigating the structure of nuclei in the vicinity of the N=126 region by employing the reversed plunger configuration

SUPERVISOR(S): Jose Javier Valiente Dobon
Daniele Brugnara
Julgen Pellumaj

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UNIVERSITY/RESEARCH CENTER: Laboratori Nazionali di Legnaro, INFN-LNL

ABSTRACT

The so-called 'reversed plunger' is a new technique used for the first time in Laboratori Nazionali di Legnaro to measure lifetimes of nuclear-excited states, in the order of picoseconds, of neutron-rich nuclei in the vicinity of N=126 where shape transitions from prolate to oblate are predicted to occur.
The experiment was performed in 2023 employing the PRISMA magnetic spectrometer for the identification of the reaction products and the Advanced Gamma-Ray Tracking Array (AGATA) for measuring gamma rays. The plunger device was placed in the geometrical center of the reaction chamber in the reversed configuration.

The student will analyze one of the reaction channels:
- Identify the reaction products in mass, atomic number, and velocity using the data from the PRISMA magnetic spectrometer.
- Optimize the performance of the AGATA array (calibration, time alignment, neutron damage correction, tracking optimization, etc).
- Obtain the level scheme of the nucleus of interest and extract lifetimes using the standard analysis technique of plunger data sets and by employing Geant4 simulations.

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1) Title: Study of the hadronization process in hadronic collisions via the reconstruction of charm-baryon decays with machine-learning techniques with the ALICE experiment.

Thesis type: Experimental, Branch: Nuclear Physics.

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Abstract

The formation of hadrons in a system composed of quarks is a fundamental process in nature that can be studied at particle colliders. The ALICE experiment is currently conducting extensive research into the hadronization process in proton-proton and Pb-Pb collisions at the CERN Large Hadron Collider. In particular, important constraints to theoretical models can be set by measuring the production of charm baryons. This is a challenging task because it requires the reconstruction of the decay of these rare particles and the identification of signal candidates in a huge combinatorial background. The student will learn how to use machine-learning classification algorithms for signal-background discrimination, exploiting at best the vertexing and particle-identification information provided by the ALICE silicon-pixel, time-projection chamber, and time-of-flight detectors. She/he will perform an invariant-mass analysis using standard fitting techniques to estimate the signal yield. Though applied to a specific physics case, the data-analysis procedures, the vertexing and particle-identification techniques that the student will learn are of general use in nuclear and high-energy particle physics.

2) Title: Study of the performance and optimization of the design of the future ALICE 3 detector at the LHC.

Thesis type: Experimental, Branch: Nuclear Physics.

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Abstract

The ALICE Collaboration has proposed to build a completely new experimental apparatus, called ALICE 3, to study heavy-ion collisions at the LHC with unprecedented performance in the 2030s. Particles trajectories and momenta will be reconstructed in a large tracking detector with a diameter of 1.6 m and a length of 8 m. This detector will be completely instrumented with silicon pixel sensors with space point resolution of 2-3 microns for the innermost layers and 10 microns for the outer layers. The momentum measurement will be enabled by a superconducting solenoid magnet with a field strength of 1-2 Tesla.

The student will learn the analytical relations between the tracking detector parameters and performance for track reconstruction. They will then adapt and use a fast simulation software based on ROOT to study the dependence of the performance on the detector configuration (number and position of layers) and the pixel sensor specifications (size of pixels, amount of material for the active and inactive structures). These studies will be carried for different particles species (electrons, pions, kaons, protons). The student will acquire knowledge about the main physics effects involved in charged particle tracking and will have the opportunity to contribute to the optimization of the design of a future collider experiment.

Master thesis proposals on Heavy Ion Fusion in Padova and LNL for A.Y. 2024-25

Title: Low-energy heavy-ion fusion measurements with the PISOLO setup using coincidences between evaporation residues and light-charged particles

Thesis type: Experimental, Branch: Nuclear Physics, Astrophysics

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Abstract

In the field of nuclear physics, measurements of fusion cross sections far below the barrier are of deep interest to understand fusion dynamics and the structure of interacting nuclei. When medium-mass and light systems are considered, the interest goes beyond nuclear physics, and the astrophysical implications of the process come into play. The PISOLO electrostatic deflector, installed at LNL, allows for the measurement of cross sections down to 0.5-1 μb through the detection of fusion-evaporation residues (ER). The sensitivity of the setup will be increased by detecting the light-charged particles evaporated by the compound nucleus in coincidence with ER. The coincidence will allow suppression of the background of beam-like particles not rejected by the electrostatic deflector. The experiment will be performed at the XTU Tandem accelerator and will concern the system $^{16}O+^{48}Ca$, to extend the fusion excitation function below the 1 μb level. Light particles will be detected by dedicated Silicon detectors installed around the target. The higher sensitivity will allow us to reach unexplored energy regions and give decisive information on the low-energy trend of the fusion cross-section below the hindrance threshold.

The student will participate in the setup preparation, data taking and data analysis.

Title: Data analysis of the sub-barrier fusion experiment for $^{12}C+^{16}O$ performed by gamma-particle coincidences with AGATA + Silicon detectors

Thesis type: Experimental, Branch: Nuclear Physics, Astrophysics

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Abstract

Heavy-ion fusion reactions are essential to investigate the fundamental problem of quantum tunnelling of many-body systems in the presence of intrinsic degrees of freedom, and the fusion of light systems is very important from the astrophysical point of view. At far sub-barrier energies the fusion dynamics is complicated by the hindrance phenomenon. Fusion hindrance in the system ^{12}C + ^{16}O was possibly observed in recent experiments where, however, the large uncertainties prevent clear-cut conclusions.
The work of this thesis will focus on the analysis of a further experiment on ^{12}C + ^{16}O, recently performed with the combined setup of AGATA and a dedicated array of silicon detectors. The fusion events have been identified by coincidences between the prompt gamma-rays and the light-charged particles (p, α) evaporated from the compound nucleus. The student will take care of the first phase of the data analysis.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: Study of the proton induced reactions on 19F at LUNA

SUPERVISOR(S):
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UNIVERSITY/RESEARCH CENTER: DFA of UNIPD

ABSTRACT
(just few lines 5-10 explaining briefly the idea of the proposed work and the place where it will be developed).

The rates of 19F(p,g)20Ne and 19F(p,a)16O reactions control the oxygen-fluorine section of the CNO cycle, with their ratio defining the probability of breaking out of the CNO cycle and starting a nucleosynthesis chain towards Ne and the heavier elements, instead of closing the cycle back to 16O. The break-out via the (p,g) channel is crucial to understand the abundances measured in old, very metal-poor stars that formed in the early Universe. Those reactions will be studied at LUNA with a solid target setup and an high efficiency BGO detector. The targets will be produced at the Legnaro laboratories and characterised at LUNA in the gran sasso lab. The students will carry on the data taking and analysis to obtain the final cross section to be compared with the recent results obtained in literature.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: Impact of novel gauge bosons on stellar cooling

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UNIVERSITY/RESEARCH CENTER: Università di Padova

ABSTRACT
(just few lines 5-10 explaining briefly the idea of the proposed work and the place where it will be developed).

Stars can be used as laboratories of fundamental physics. The emission of feebly interacting particles, that can be produced in stellar cores and leave without further interactions, results in an energy-loss channel. White dwarfs represent the final state of stars with small initial masses. As they have no nuclear energy sources, their evolution is determined by cooling processes, dominated in the hottest phase by neutrino emission through plasmon decay. Novel gauge bosons beyond the Standard Model (SM) of particle physics, motivated e.g. by the measurement of the muon anomalous magnetic dipole moment, can couple to neutrinos and accelerate the cooling of white dwarfs. The final goal is the obtain state-of-the art constraints from white dwarf cooling on new interactions. The student will conduct the research at the Department of Physics and Astronomy of the University of Padova, and learn about particle physics of and beyond the SM, the cooling of degenerate stars, and the observational consequences of the existence of new particles.

ERASMUS MUNDUS JOINT MASTER DEGREE IN NUCLEAR PHYSICS

UNIVERSIDAD DE SEVILLA

Co-funded by the Erasmus+ Programme of the European Union

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2024/2025

MASTER THESIS PROPOSAL

TITLE: Exploitation of artificial neural networks for particle identification with silicon detectors in nuclear physics

SUPERVISOR(S): Daniele Brugnara
Daniele Mengoni

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UNIVERSITY/RESEARCH CENTER: Laboratori Nazionali di Legnaro, INFN-LNL

ABSTRACT

The identification of light charged particles emitted from a nuclear reaction is a crucial aspect for most experiments in nuclear physics. In the case of silicon detectors, the identification is usually performed with several techniques such as correlating the maximum current (the derivative of the collected charge) with the total energy.
We propose to study the performance of artificial neural networks for the discrimination of different charged particles in silicon detectors. The student will have access to several datasets and a preliminary version of the code. The student will be able to evaluate the outcomes of different approaches such as:

- Supervised learning: feeding the network the charge signal for a classification problem where labels are assigned with the alternative method of correlating partial and total energy deposition in the layers of silicon
- Unsupervised learning: exploiting the autoencoder topology to extract features from the charge signal that could lead to the separation of different particles. This approach can be particularly useful for detectors that do not measure the partial deposited energy.

TITLE: The Tracking System of the RIB Facility EXOTIC

SUPERVISOR(S): Prof. M. Mazzocco, Dr. S. Pigliapoco

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UNIVERSITY/RESEARCH CENTER: DFA - UniPD

ABSTRACT

The facility EXOTIC [1] has been operational at INFN-LNL for the production of Radioactive Ion Beams (RIBs) since 2003. RIBs are produced in inverse kinematics by means of heavy-ion beams delivered by the LNL tandem accelerator impinging on gas targets and separated through a proper combination of eight ion-optical elements (six magnetic quadrupoles, a dipole magnet and a velocity filter). Being the product of a nuclear reaction, RIBs are characterized by large emittance (the product of the beam-size and transversal momentum). The use of a high-efficiency event-by-event tracking system to reconstruct the trajectory and the target position hit by the secondary beam particles could help to improve the angular resolution of the experiments. For this purpose, we have recently developed two large-area x-y position sensitive MicroChannelPlate (MCP) detectors to be installed upstream the secondary target.

The candidate will work at the characterization of the detectors, at the development of the tracking algorithm and will participate to the final in-beam commissioning foreseen in Autumn 2024. The installation of the MCPs constitutes a stepping-stone for the recommissioning of the facility in view of the upcoming campaign of experiments with the EXOTIC RIBs and the gamma-ray spectrometer AGATA [2].

[1] V.Z. Maidikov et al., Nucl. Phys. A 746, 389c (2004).
[2] J.J. Valiente-Dobón et al. Nucl. Inst. and Meth. A 1049, 168040 (2023)