1. ***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 Legnaro National Laboratories, allows for 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 $^{12}C+^{26}Mg$, 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 take part in the setup preparation, data taking and data analysis.

2. ***Title:*** The fusion dynamics far below the barrier for $^{12}C+^{24}Mg$ by gamma-particle coincidences with AGATA + Silicon detectors

Thesis type: Experimental, Branch: Nuclear Physics, Astrophysics

Supervisor: Giovanna Montagnoli
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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 $^{12}C + ^{24}Mg$ was observed in a recent experiment where the excitation function was measured down to 4 μb. The work of this thesis will be focused on a further experiment on $^{12}C + ^{24}Mg$ aiming at the measurement of fusion cross sections below the μb range with the combined set-up of AGATA and an array of silicon detectors. The fusion events will be identified by coincidences between the prompt gamma-rays and the light-charged particles (p, α) evaporated from the compound nucleus. The student will participate in the preparation of the experiment to be performed at Legnaro, in the data taking, and will take care of the first phase of the data analysis.

3. ***Title***: In-beam commissioning of the AGATA Tracking array with ancillary instrumentation.

Thesis type: Experimental, Branch: Nuclear Physics

Supervisor: Contacts: Franco Galtarossa (franco.galtarossa@lnl.infn.it), Daniele Mengoni (daniele.mengoni@unipd.it)
INFN-LNL and University of Padova.

Abstract:
The ^{46}Ar isotope, located between the doubly-magic ^{48}Ca and the collective ^{44}S nucleus, has challenged the existing shell-model description of nuclei in this region. While some observables related to the neutron contribution are well described by the theory, others, where the role of protons is relevant, are not. Two different measurement of the B(E2; $2^+ \rightarrow 0^+$), one performed via direct lifetime measurement, the other via intermediate Coulomb excitation, give conflicting results.
We plan to re-measure the lifetime of the first excited 2^+ state in ^{46}Ar by means of the Recoil Distance Doppler Shift method, employing the magnetic spectrometer PRISMA in coincidence with AGATA, at LNL. The thesis work will focus on the participation in the experimental shifts and the analysis of part of the experimental data, in order to extract the lifetime of the level of interest and compare with state-of-the-art shell model calculations.

4. ***Title***: Study of the 23Na(p,alpha) and 27Al(p,alpha) reactions at astrophysical energies Thesis type: Experimental, Branch: Nuclear Physics, Astrophysics

Supervisor: Antonio Caciolli
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Abstract:
The LUNA experiment is going to start an interesting experimental campaign on (p,alpha) reactions on 23Na and 27Al isotopes. Those are very interesting candidates to understand better the hydrogen burning in advanced stellar phases. In particular, the destruction

mechanisms of 23Na is very important to understand better the O-Na anticorrelation which is still a puzzle in globular clusters. The reaction study will be performed at the LUNA400 accelerator and it is the object of a recently founded ERC starting grant.
The candidate will work on the design of the setups and in the following data taking. Then will perform the analysis of the data acquired with both setups in order to obtain the cross section. The experiment will be performed at LUNA, placed at the Gran Sasso National Laboratory of INFN (the biggest underground laboratory worldwide). Therefore the candidate will do shifts in this research centres in order to work on the setup.

5. ***Title:*** Study of the 14N(p,gamma)15O reaction at the LUNA-MV machine at astrophysical energies
   Thesis type: Experimental, Branch: Nuclear Physics, Astrophysics

Supervisor: Antonio Caciolli
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Abstract:
The proton capture on 14N is the slowest reaction of the CNO cycle and therefore it controls the entire cycle. This reaction has been studied at very low energies by the LUNA collaboration but with the new MV machine installed in the Gran Sasso Laboratory of INFN it will be possible to explore a wide energy range also at higher energies I order to better constraint the extrapolation at the energy of the Sun. As a matter of fact, solar energies cannot be reached by experimental data. This measurements is crucial in order to introduce the cross section on solar models and to derive the internal metallicity of the Sun combining the nuclear inputs with the CNO neutrino detection recently done by the BOREX collaboration. A setup, characterised by three HPGe detectors, will be installed on the LUNA-MV accelerator at the beginning of 2023 to measure the cross section up to 1.5 MeV. The candidate will participate at the design and setup construction and at its characterisation. The LUNA experiment is placed at the Gran Sasso National Laboratory of INFN (the biggest underground laboratory worldwide), therefore the candidate will do shifts there in order to work on the setup.

6. ***Title:*** Performance figures of AGATA at high gamma-ray energies Thesis type: Experimental, Branch: Nuclear Physics

Supervisor: Jose Javier Valiente Dobon/Rosa Perez
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Abstract:
The Advanced GAmma Tracking Array (AGATA), recently installed at the National Laboratories of Legnaro (LNL), is a collaborative European project to construct and operate a 4π gamma-ray tracking spectrometer. This spectrometer is the next generation of gamma-ray spectroscopy instruments and involves achieving the goal of a 4π Ge ball through the technique of gamma-ray energy tracking in

electrically segmented Ge detectors. AGATA is allowing the pursuit of a very rich science program using both radioactive and stable ion beams. In order to check the feasibility of future experiments with AGATA at LNL, the full characterization of the AGATA spectrometer is required, and especially at high energies where this information is not reachable with radioactive sources. In 2023 we expect to perform and in-beam measurement to populate high gamma ray energies to evaluate the performance figures of AGATA beyond 2 MeV. The student will contribute to preparation and analysis of the sorting stages of AGATA for the in-beam experiment. In the local level processing, that handles the crystals separately for the PSA task, the energy and time calibrations together with the important corrections for an improved energy and position resolutions (such as cross-talk corrections and neutron-damage corrections) will be carried out. In the global level processing, where the tracking is performed, the relevant parameters for the best performance will be optimized. Lastly, the student will perform GEANT4 simulations in order to validate the AGATA simulation codes and tools.

7. ***Title:*** Feasibility study of the competitive double-gamma decay measurement Thesis type: Experimental, Branch: Nuclear Physics ------→ ***ALREADY ASSIGNED TO DAMIANO***

Supervisor: Jose Javier Valiente Dobon/Matus Balogh
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Abstract:
The double-gamma decay is process in which two photons are emitted simultaneously as a result of a direct decay of an excited nuclear state to another. This second-order process occurs also when emission of single gamma is possible but with extremely low branching ratio, which is predicted to be at least 5 orders of magnitude lower. The energy difference between the initial and final state is distributed continuously between the two prompt gamma rays. These properties present an enormous experimental challenge, due to the low counting rates of such process and due to the processes, that mimics it, such as Compton scattering. In order to examine feasibility of the double-gamma decay measurement, comprehensive simulations are being carried out to study the experimental limitations with the goal to propose a sensitive detection setup, that will be capable of measuring this exotic process. The student will contribute to the development of the GEANT4 simulations and will analyze the data with a goal to estimate the sensitivity of the detection setup to the double-gamma decay regarding experimental configurations, decay rates, transitional energies and multipolarities.

8. ***Title:*** Study of compact high intensity linear accelerators.
   Thesis type: Experimental, Branch: Applied Nuclear Physics
   Supervisor: Andrea Pisent
   INFN Laboratori Nazionali di Legnaro Viale Università 2 I 35020 Legnaro (Padova) ***mail*** andrea.pisent@lnl.infn.it
   Abstract:
   In recent years there have been important developments in the low energy components of linear accelerators, for applications such as materials testing for fusion (IFMIF), transmutation of radioactive waste (TRASCO, MYRRHA), materials testing with neutron probes (spallation sources), fundamental nuclear physics (radioactive beam production), medical applications (therapy, BNCT, or radioisotope production). The development of ion sources, RFQ and DTL are the key elements to obtain high intensity beams. The purpose of this study will be the use of the results achieved and the components developed for new compact high-performance accelerators.

9. ***Title****:* Innovative batteries for Space, Medicine And RemoTe sensing applications Thesis type: Experimental, Branch: Applied Nuclear Physics. ***Supervisor****:* Carmen Altana (carmen.altana@pd.infn.it) and Daniele Mengoni (daniele.mengoni@unipd.it)
   Università degli Studi di Padova and INFN LNL
   Abstract:
   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 battery and its power yield.

10. ***Title****:* beta-delayed gamma-ray spectroscopy of 101Cd.
    Thesis type: Analysis, Branch: Nuclear Physics

Contacts: Gungxin Zhang (guangxin.zhang@pd.infn.it), Daniele Mengoni (daniele.mengoni@unipd.it)
University of Padova, INFN-Padova and INFN-LNL.
Abstract:

^{101}In is produced via in-flight fission of ^{124}Xe beam on Be target, and indented by FRS spectrometer in GSI. The structure of ^{101}Cd can be studied by collecting the gamma rays which are in coincidence with the beta rays emitted from ^{101}In after being stopped by AIDA (double-side silicon-strip detector). By using $LaBr_3$ and beta-plastic scintillators for the detection of gamma-rays and beta-rays, respectively, the lifetimes of the excited states which are larger than few hundreds ps in ^{101}Cd can be measured by the beta-gamma or gamma-gamma time difference method.

11. ***Title***: In-beam gamma-ray spectroscopy of ^{43}Sc with the JUROGAM3 spectrometer and MARA separator

Thesis type: Experimental, Branch: Nuclear Physics

Supervisor: Kseniia Rezynkina (kseniia.rezynkina@pd.infn.it), Francesco Recchia(francesco.recchia@unipd.it)
University of Padova, INFN-Padova and INFN-LNL.

Abstract:
The thesis work consists in the analysis of the experimental data, in order to extend the level scheme of ^{43}Sc to higher excitation energies and higher spin states. The excited states in ^{43}Sc are populated in a fusion-evaporation reaction, with the ^{33}S beam impinging on a ^{12}C target. The experiment was performed in JYFL laboratory in Jyvaskyla, Finland. ^{43}Sc is selected by the separator MARA, with the prompt gamma-rays detected with the JUROGAM3 array of high-purity germanium detectors.
The student will learn to treat the experimental data using recoil-decay correlations, and will extract the gamma-ray yields de-exciting the high-lying states in ^{43}Sc, constructing the level scheme based on the gamma-gamma coincidences in JUROGAM3. The data will be interpreted in frame of the Shell Model calculations, considering cross-shell particle-hole excitations from the *sd* shell.