Master thesis proposals in Padova and LNL for A.A. 2023-24

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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.

Supervisor: Andrea Rossi
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Co-Supervisor: Himanshu Sharma, INFN
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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.

Supervisor: Andrea Dainese
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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.

3) Title: Study of the evolution of the spin-orbit splitting at N=19 via direct transfer reactions @ GANIL

Contacts: Franco Galtarossa (franco.galtarossa@pd.infn.it) and Daniele Mengoni (daniele.mengoni@unipd.it)
Place: Università degli Studi di Padova and INFN LNL

Abstract:
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.

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

Contacts: Daniele Mengoni (daniele.mengoni@unipd.it) and Giacomo de Angelis (giacomo.deangelis@lnl.infn.it)
Place: JYFL (Finland), Università degli Studi di Padova and, INFN-LNL.

Abstract: 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 preparation and tailoring of the setup, experimental run and data analysis. The experiment is expected for next spring at Jyvaskyla Laboratory in Finland and the rich International environment of the collaboration will represent a strong growing opportunity for the student.

5) Title: Study of the 23Na(p,alpha)20Ne reaction 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 isotope. This is very interesting 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.

6) Title: Study of the 14N(p,gamma)15O reaction at LUNA

Thesis type: Experimental, Branch: Nuclear Physics, Astrophysics

Supervisor: Antonio Caciolli

Physics and Astronomy Department Padova University

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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. Another setup to investigate the branching ratios at extremely low energies will be also used at the LUNA400 accelerator. The candidate will participate at the design and setup construction and at its characterization. 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.

7) Title: Study of the 12C+12C reaction at astrophysical energies under the Gran Sasso Laboratory

Thesis type: Experimental, Branch: Nuclear Physics, Astrophysics

Supervisor: Antonio Caciolli

Physics and Astronomy Department Padova University

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Abstract:

12C+12C process is the trigger of Carbon burning, therefore it is strictly connected with the Mup parameter which determines the mass required to a star to undergo trough explosive scenarios. This challenging reaction will be studied at the new MV accelerator installed at the Laboratory of Gran Sasso. The setup will be installed in 2024. The student will participate at all phases of the work and to the characterization of the setup. 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.

8) Title: Innovative batteries for Space, Medicine And RemoTe sensing applications Thesis type: Experimental, Branch: Applied Nuclear Physics. ***Supervisor***: 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.

9) Title: Synthesis and characterization with nuclear techniques of high purity solid targets for nuclear astrophysics experiments

Thesis type: Experimental, Branch: Nuclear Physics, Astrophysics

Supervisor: Valentino Rigato, Antonio Caciolli

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Abstract:

The activity will be carried out mainly at the Materials for Nuclear Physics laboratory and the AN2000 and CN accelerators of the INFN Legnaro National Laboratories (LNL). Test measurements at the Gran Sasso National Laboratories (LNGS) with the LUNA 400 accelerator and, in the future, LUNA MV, can be programmed. The activity involves the synthesis in the form of thin films (10nm-10μm) with modern pulsed sputtering techniques in reactive plasma on different nitride and metal substrates with high purity, high resistance to radiation and low interferential gamma background induced by energy protons from 0.05 to 1.5 MeV. The materials will be characterized at LNL with Ion Beam Analysis techniques such as Elastic Back-Scattering of α particles and protons, PIXE and PIGE with regards to composition and thickness and by electron microscopy (SEM) and atomic force microscopy (AFM) with regards to the properties superficial (roughness). The selected student will take part in the experimental activity of synthesis and characterization of materials in all main phases.

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

Thesis type: Experimental, Branch: Nuclear Physics

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

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Abstract:

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.

11) *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 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 $^{13}C+^{24}Mg$, 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.

12) *Title:* The fusion dynamics far below the barrier for $^{12}C+^{16}O$ by gamma-particle coincidences with AGATA + Silicon detectors

Thesis type: Experimental, Branch: Nuclear Physics, Astrophysics

Supervisors: 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 $^{12}C + ^{16}O$ was possibly observed in recent experiments where, however, the large uncertainties prevent clear-cut conclusions. The work of this thesis will be focused on a further experiment on $^{12}C + ^{16}O$ aiming at the precise measurement of fusion cross sections down to about 10 nb with the combined set-up of AGATA and a dedicated 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.

13) *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.

14) *Title:* Feasibility study of the competitive double-gamma decay measurement

Thesis type: Experimental, Branch: Nuclear Physics

Supervisor: Jose Javier Valiente Dobon/Rosa Perez
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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.

15) Title: Lifetimes measurement in the 48Ca region

Thesis type: Experimental, Branch: Nuclear Physics

Supervisor: A. Gottardo, J.J. Valiente-Dobon, D. Mengoni, D. Brugnara
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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 4pi gamma-ray tracking spectrometer. It provides cutting-edge performances in terms of efficiency and resolution, making it possible to measure the lifetime of otherwise unreachable nuclear states. The region around 48Ca has longly been the object of many studies on the N=28 shell closure and the neutron-rich nuclei beyond it. The recent discovery of large charge and matter radii in neutron-rich calcium isotopes, as well as of the charge density bubble in 46Ar, demands further investigation into the nuclear structure in this region. In this regard, lifetimes of nuclear states decaying by gamma-ray emission provide a unique probe of the nuclear wave function predicted by theoretical models. The student will participare in the measurement with the AGATA-PRISMA setup at LNL, also in the preparation of the targets and reaction chamber, and in the analysis of the collected data, learning and applying various techniques to measure lifetimes in the order of 0.1-10 ps.

16) Title: Study of compact high intensity linear accelerators.

Thesis type: Experimental, Branch: Applied Nuclear Physics

Supervisor: Andrea Pisent
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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.