Master Thesis Topics – University of Catania – INFN-Ct – INFN-LNS

Academic year 2023-2024

EXPERIMENTAL/ACCELERATORS/PLASMAS

Title: Direct measurement of the $^{7}Li(p,\alpha)^{4}He$ reaction at astrophysical energies using ELISSA array

Abstract: The $^{7}Li(p,\alpha)^{4}He$ reaction is of significant astrophysical interest. It plays a prominent role during the Big-Bang as well as stellar nucleosynthesis. In the former case, it is intimately linked with the so-called "Cosmological Lithium Problem", because of the severe discrepancy between the observed ^{7}Li abundances from metal-poor halo stars and the predictions of standard Big-Bang Nucleosynthesis (SBBN) theory. The S(0) value from various direct and indirect measurements of reaction varies between 40 - 60 keV b (15-40 % uncertainty in the direct measurements), while the existing low energy angular distribution data are limited and cover a small angular range. Moreover, they suffer from large uncertainties due to normalization problems. Thus, a new direct measurement of the $^{7}Li(p, \alpha)^{4}He$ reactions was recently performed in an energy range from 75 keV to 1 MeV in the center-of-mass system, with a wide angular setup using the ELISSA silicon-strip detector array, required to reduce the uncertainty in the S(E) factor. The challenging data analysis requires to handle almost 100 channels and more than 10 detectors in order to obtain a new results that will improve the low energy angular distribution data of the $^{7}Li(p, \alpha)^{4}He$ reaction; reduce the uncertainty in the S(0) value and optimize and improve ELISSA detector configurations for future applications.

Supervisors: L. Lamia (UniCT), G.L. Guardo (INFN-LNS), D. Lattuada (UniKore), C. Matei (IFIN-HH, ELI-NP)

Title: In-plasma measurements of nuclear reactions of astrophysical interest.

Abstract: The study of nuclear reactions in the laboratory has always been hindered by the very low cross-sections values at energies of astrophysical interest (1-100 keV). This leads nuclear astrophysicists either to build huge and expensive underground laboratories where to perform long experiments with low and controlled background or to exploit indirect methods usually involving nuclear-structure models. Nevertheless, plasma in stellar objects is a very different state from the solid or gas targets commonly used in standard nuclear physics experiments involving conventional accelerators. A series of systematic studies of nuclear reaction rates of astrophysical interest occurring in a laboratory plasma with characteristics similar to the ones in astrophysical sites is being performed. The first measurement will be performed with a cryogenic target and a high-power laser in South Korea in December 2023 and the data analysis coming from different diagnostics involving charged particles, neutron and photon detectors will be analyzed with the goal to provide insights on the reaction rates of deuterium-deuterium fusion in the energy range 1-100 keV and to be part of a more extended study on the electron screening in plasma, involving other key processes for nuclear astrophysics such as the carbon burning, the oxygen burning, r-process and p-process. Also, an intense detector development activity with special focus on the laser-induced background will be carried on.

Supervisors: R.G.Pizzone (UniCT), D. Lattuada (UniKore), G.L. Guardo (INFN-LNS)

Title: Study of Reaction Mechanisms and isospin equilibration dynamics at Fermi energies

Abstract: The project aims at investigating topics related to reaction mechanisms, peculiar of heavy ion collisions at Fermi energies. The analysis of data collected in experiments performed with Chimera and Farcos multi-detectors, operating at Laboratori Nazionali del Sud, in Catania, will allow to study data analysis techniques employed in this energy domain. In particular, the influence of the isospin degree of freedom on reaction mechanisms will be investigated and variables useful to improve the knowledge of the behavior of nuclear matter will be analyzed. In particular, the competition between reaction mechanisms and the Intermediate Mass Fragment production phenomenon will be analyzed for the reactions produced accelerating ^{124}Sn, ^{124}Xe and ^{112}Sn beams at 20 AMeV on targets of ^{64}Ni, ^{64}Zn and ^{58}Ni. Comparisons of the experimental data with semiclassical transport models and/or molecular dynamics models will be encouraged.

Supervisors: E. Geraci (UniCT), P. Russotto (INFN-LNS), E. Pagano(INFN-LNS)

Title: Isospin dependence of Fragment Production in central collisions for 58,62Ni+40,48Ca systems at 35 AMeV

Abstract: The project aims at investigating the influence of the isospin degree of freedom on fragment production for sources formed in central collisions of 58,62Ni+40,48Ca systems at 35 AMeV. The experimental data, collected in an experiment performed with Chimera multi-detector at Laboratori Nazionali del Sud, in Catania, allow to investigate the multifragmentation process and to extract variables useful to study the decay path of sources of one hundred nucleons and excitation energies around 2-4 AMeV. The isotopic composition of fragments emitted in the two systems will allow to study and to explore the isospin dependence of the nuclear equation of state (EOS) of nuclear matter under laboratory-controlled conditions. In addition, information about the space–time evolution of the reaction zone could be obtained via fragment-fragment correlation functions. Comparisons of the experimental data with semiclassical transport models will allow to characterize the entering of the system in the spinodal region and to obtain valuable information on fragment formation at sub saturation densities.

Supervisors: E. Geraci (UniCT), E. De Filippo (INFN-sez Ct)

Title: Photonics crystals for ultracompact dielectric accelerators

Abtract: Laser acceleration of electrons with silicon dielectric structures was demonstrated in with accelerating gradients of more than 200 MeV/m. Many of the proposed configurations have an intrinsically limited interaction length, because they require a plane wave that impinges laterally throughout the whole structure's length. In order to have both high laser-induced accelerating gradients and adequate interaction length, this thesis work will focus on the EM design and beam dynamics study of hollow-core waveguides, based on photonic crystals, employed as accelerating structures (with possibly co-linear propagation of the accelerating electromagnetic field and the particle bunch to be accelerated).

UniCT Supervisor: David Mascali

Co-Tutors: Giuseppe Torrisi (INFN-LNS), Giorgio Mauro (INFN-LNS)

Title: Investigation of kinetic instabilities in laboratory plasmas emulating astrophysical emission of radio and X-ray bursts.

Abstract: Several experiments demonstrated that plasma kinetic instabilities limit the flux of highly charged ions extracted from Electron Cyclotron Resonance Ion Sources (ECRIS]. Onset of the instability is typically characterized by fast RF and X-ray bursts and causes beam ripple and unstable ion source conditions. These instabilities are really relevant for astrophysical scenarios. Even if many studies have been carried out, the exact mechanism of turbulent regimes of plasmas is still under investigation. The thesis will be focused on the experimental setup that are able to reproduce and study these interesting phenomena of interest for astrophysics, such as the so-called Cyclotron Maser Instability, which is a typical kinetic turbulence occurring in astrophysical objects. The thesis activity will aim to investigate turbulent plasma regimes in Radio and X-ray domains in laboratory, performing space- and time-resolved spectroscopy simultaneously. The activities will be carried out at the INFN-LNS on the axis-symmetric Flexible Plasma Trap based on a Simple Mirror configuration. A multi-pins RF probe connected with a diode and an 80 Gs/s scope allows to obtain high-resolution time-resolved but fully integrated power emitted by the plasma to detect RF bursts (signature of the plasma instability regime), so this value will be used as trigger signal for an X-ray CCD camera to perform X-ray imaging and spectroscopy [1]

[1] E. Naselli et al., JINST, 17 C01009 (2022)

UniCT Supervisor: David Mascali ***Co-Tutors:*** Eugenia Naselli (INFN-LNS), Angelo Pidatella (INFN-LNS)

Title: Numerical and experimental study of the IRIS 3D metallic printed new resonant cavity for ion sources and magnetized plasmas

Abstract: This thesis is proposed to work on a prototype of the IRIS-shaped plasma chamber for advanced ion sources to be used in fundamental science, medicine and industry. Reshaping of plasma chamber and launching systems recalling fusion reactors (e.g., Stellarators), where vessels closely imitate the magnetic field structure, is here considered for maximizing the RF power absorption into the ECR (Electron Cyclotron Resonance) plasma core. The realization of the chamber will be done by Additive Manufacturing Technology. Numerical modelling and experimental characterizations are expected to be carried out.

UniCT Supervisor: David Mascali ***Co-Tutors:*** Giuseppe Torrisi (INFN-LNS), Giorgio Mauro (INFN-LNS)

Title: Studying spatial distribution of ion properties in ECR plasmas with self- consistent numerical codes for the PANDORA project

Abstract: Calculating the charge state distribution (CSD) and level population of ions as a function of their position in an ECR plasma is integral for understanding the nature of the extracted beam, as well as for estimating beta-decay rates of radioisotopes diffused into such systems [1,2]. To this effect, the thesis will be concerned with evaluating the 3D distribution of ion properties in ECR plasmas using self-consistent numerical codes connecting warm electron 3D space-resolved evolution in time with ion dynamics through collisional ionisation, charge exchange and particle transport models.

[1] D. Mascali et al., A novel approach to β-decay: PANDORA, a new experimental setup for the future in-plasma measurements, 2022 Universe 8, 80.

[2] K. Takahashi and K. Yokoi, Nuclear Β-Decays of Highly Ionised Heavy Atoms in Stellar Interiors, Nucl. Phys. A 404, 3 (1983)

UniCT Supervisor: David Mascali, **Co-Tutors:** A. Pidatella (INFN-LNS), B. Mishra (INFN-LNS)

Title: Microwave/mm-wave polarimetry for magneto-plasmas of ECR Ion Source

Abstract: Polarimetric setup - able to measure the magnetoplasma-induced Faraday rotation in a compact size plasma trap - has been proven to provide reliable measurement of the plasma line-integrated electron density [1]. This thesis work will develop an analysis method for polarimetric measurements on a mm-wave testbench [2] – based on the detection of Lissajous figure from a two channels scope (80 gigasample) in an x-y representation of a direct probing RF signals crossing the magnetoplasma. The system was on purpose designed and developed for the PANDORA chamber case study [3], which represents an "intermediate" case between the ultra-compact plasma ion sources and the large-size thermonuclear fusion devices.

[1] E. Naselli et al. (2018) JINST ***13*** *C12020.*

[2] G. Torrisi et al. (2022) Front. Astron. Space Sci. ***9*** *949920.*

[3] D. Mascali et al. (2022) Universe ***8****, 80.*

UniCT Supervisor: David Mascali ***Co-Tutors:*** Giuseppe Torrisi (INFN-LNS), Eugenia Naselli (INFN-LNS)

Title: Development of a movable Langmuir probe system for measuring local electron density and temperature in a magnetized plasma

Abstract: Langmuir probes are valuable diagnostics methods capable of measuring local plasma parameters such as electron density and temperature by reconstructing the current-potential (I-V) curve in both electrons and ions regions. Thermodynamical parameters are the reconstructed by appropriate models of electrostatic particle collection in the magnetized plasma. The thesis will consist in the theoretical investigation of an optimized tool to be used for the analysis of ECR plasmas, and then the realization of the probe to be tested in a real experimental setup.

UniCT Supervisor: David Mascali ***Co-Tutors:*** Angelo Pidatella (INFN-LNS)

Title: Development of an experimental setup and measurement of magneto-plasma opacity in laboratory

Abstract: Opacity is a key ingredient in many relevant astrophysical scenarios, which impact on the energy transport and spectroscopic observations is still debated. Electromagnetic transient signal emitted from neutron-star mergers (kilonova - KN) is of interest in the multi-messenger astronomy frame because of delivered information on the expelled plasma ejecta's composition (r-process nucleosynthesis), however its interpretation strongly depends on the system opacity, which is an almost unfolded observable. The activity

proposed in this thesis is in the context of experimental investigations of in-laboratory magneto-plasma opacities, for metallic species abundant in a specific time-stage of KN diffusion, at plasma electron density and temperatures resembling the ejecta plasma conditions [1, 2]. In this framework, the on-construction facility PANDORA, and the working Flexible Plasma Trap (FPT), both at the INFN – LNS (Catania, Italy) suite for the purpose. The thesis will concern the development of an experimental multi-diagnostic setup, based on optical spectroscopy and microwave interferometry, thus employing complementary techniques and methods, for studying opacity of gaseous plasmas magnetically confined in compact plasma traps. The setup assembling (design, calibration) and measurements will be carried out on the FPT, as ground experiments projected to be then extended in the PANDORA facility. The investigation will help in shedding light on atomic uncertainties on the KN problem, as well as to further extend knowledge on the stellar opacity problem for the Astrophysics and Nuclear Astrophysics interests.

[1] Pidatella, A., *et al.*, IL NUOVO CIMENTO 44 C (2021) 65.

[2] Pidatella, A., *et al.*, Frontiers in Astronomy and Space Sciences 9, 225 (2022).

UniCT Supervisor: D. Mascali (UniCT-DFA, INFN-LNS), **Co-Tutors:** A. Pidatella (INFN-LNS)

Title: Space-resolved X-ray spectroscopy and imaging of ECR plasmas using quasi-optical methods

Soft X-ray spectroscopy is a powerful passive diagnostic technique to characterize warm electrons in ECR plasmas whose properties govern the sequential ionisation processes. Using special optical setups like pinholes coupled with CCD cameras, the technique can be extended to investigate spatial structure of the plasma and confinement dynamics, performing X-ray imaging and space-resolved spectroscopy. The thesis will be focused on performing a new set of measurements to characterize magnetoplasmas confined in the Flexible Plasma Trap, the compact trap installed at INFN-LNS specifically designed as test bench of PANDORA [1]. The work will involve sequential application of a set of algorithms developed indigenously at INFN-LNS, and in collaboration with the ATOMKI laboratories (Debrecen, Hungary) to generate 2D space-resolved maps of X-ray fluorescence, followed by interpretation of the results [2]. The diagnostic system will be also upgraded by installing a new mechanical X-ray shutter able to suppress the CCD camera readout effects and to allow acquisition at low exposure times as never done before (∼ ms), in order to perform simultaneous time and space-resolved investigations of the X-ray fluxes emitted by the plasmas.

*[1] D. Mascali et al. (2022) Universe **8**, 80.*

*[2] E. Naselli et al. (2022) Condens. Matter **7**, 5.*

UniCT Supervisor: David Mascali (INFN-LNS and UNICT-DFA), **Co-Tutors:** E. Naselli (INFN-LNS), G. Finocchiaro (INFN-LNS e UniCT)

Title: Improving gamma detection by isolating signal from background - a machine learning approach

Abstract: In-plasma measurement of beta-decay rate is based on tagging the secondary gamma released by the excited daughter nucleus. The gamma photon emitted from radioisotopes considered lies in the keV range which overlaps with high energy bremsstrahlung from the plasma. In order to separate the gamma peak from the self-emission background with n-sigma level certainty, the plasma needs to be kept stable for days or weeks [1, 2]. This thesis will be a feasibility study to assess whether the measurement time can be reduced by using machine learning and deep neural networks as peak finding algorithms [3].

[1] D. Mascali et al, The PANDORA project: an experimental setup for measuring in-plasma beta-decays of astrophysical interest, EPJ Web of Conferences 227, 01013 (2020).

[2] E. Naselli et al., Design study of a HPGe detector array for β-decay investigation in laboratory ECR plasmas, Front. Phys. 10, 935728 (2022).

[3] S. Wu et al, Peak-searching method for low-count rate gamma spectrum under short-time measurement based on a generative adversarial network, Nuclear Inst. And Methods in Physics Research A 1002, 165252 (2021).

UniCT Supervisor: David Mascali (INFN-LNS and UNICT-DFA), **Co-Tutors:** E. Naselli (INFN-LNS), A. Pidatella (INFN-LNS), D. Santonocito (INFN-LNS), B Mishra (INFN-LNS and UniCT)

Title: Transport solutions for the INFN-LNS laser-driven acceleration facility

Supervisor: GA Pablo Cirrone (INFN-LNS, UNICT), pablo.cirrone@lns.infn.it

** This is a thesis work envisaging experimental measurements campaigns at International laboratories

ABSTRACT: Plasma-based accelerators use the strong electromagnetic fields that can be supported by plasmas to accelerate charged particles to high energies. Accelerating field structures in plasma can be generated by powerful laser pulses or charged particle beams. At INFN-LNS a new high-power short-pulse laser system will be installed in the next years. It will be part of a new facility (I-LUCE: INFN Laser induced particle acceleration) where the laser will be dedicated to particles (electrons and ions) acceleration. Accelerated particle must be then transported in vacuum and air up to the irradiation point where irradiations will be performed. The work here proposed is related to the study and implementation of new transport solutions of laser accelerated particles. The developed solutions will be then implemented in the new facility that is in construction at INFN-LNS.

Title: INVESTIGATION OF THE ANEUTRONIC PROTON-BORON FUSION REACTION IN PLASMA FOR ENERGETIC STUDIES

Supervisors: G.A.P Cirrone (Unict, LNS-INFN) pablo.cirrone@unict.it**;** G. Milluzzo (LNS-INFN) gmilluzzo@lns.infn.it**;** G. Petringa (LNS-INFN) petringa@lns.infn.it

Abstract: The interaction of protons with 11B atoms triggers the following aneutronic fusion reaction:

$$11B + p \rightarrow 3\alpha + 8.7 \text{ MeV}$$

In such reaction, the final product is the generation of three energetic α-particles having a large energy spectrum strongly peaked around 4 MeV. In particular, a main resonance occurs at 675 keV proton energy in the lab frame, with a maximum cross section of 1.2 barn [1]. The absence of produced neutrons makes the pB fusion reaction particularly appealing involving the possibility to build an ultraclean nuclear-fusion reactor where no activation of the material and no radioactive wastes are expected [2]. Recently, the pB fusion reaction has become an interesting topic also for applications in the space domain as well as for the medical physics with the possibility to use the alpha particles generated by the reaction to improve the biological efficiency of protontherapy [3]. In this context, a huge effort of the researchers has been addressed on the possibility to induce the pB fusion reaction in plasma using the high power-laser matter interaction. The extremely high flux (up to 1012 p/s) typical of laser-accelerated proton beams [4], is indeed a great advantage allowing to enhance the reaction rate and the alpha particle production yield, which might be interesting also for the applications previously mentioned. Moreover, the theoretical as well as the experimental investigation of the energy and angular distribution of the reaction products, i.e. alpha particles, are particularly interesting for the study of the fusion reaction in plasma induced by high power lasers. Many experiments have been carried out so far demonstrating the increase of the alpha particle production (up to1011) in the laser-induced pB reaction in comparison with the classical scheme [5,6]. The activity here proposed, regards the experimental study of the pB fusion reaction in plasma and of the alpha particles yield, angular and energy spectrum using innovative detectors through the systematic variation of the following fundamental parameters: laser energy and pulse duration, contrast, target thickness, target material and structure. A particular effort will be addressed to develop new solutions for the on-line and simultaneous diagnostics of protons and alpha particles. A part of the experimental as well as theoretical (through Monte Carlo simulations) activity could also be dedicated to the study the possible modification on the stopping power values of protons and ions when traversing extremely high-density and hot plasma.

References

[1] S. Stave et al., Phys. Lett. B 696, 26 (2011).

[2] H. Hora et al., Energy Environ. Sci. 3, 479 (2010).
[3] G. A. P. Cirrone, et al., Sci. Rep. 8, 1141 (2018).

[4] A. Macchi, M. Borghesi, M. Passoni, Rev. Mod. Phys. 85, 751 (2013)

[5] A. Picciotto et al., Phys. Rev. X 4, 031030 (2014).

[6] L. Giuffrida al., Phys. Rev. E 101, 013204 (2020).

APPLIED/MEDICAL

Title: Multi-technique characterization of polychrome surfaces located within historical-artistic sites selected for the SAMOTHRACE Ecosystem project

Abstract: The project aims at investigating, through the employment of a combined approach involving spectrophotometric, multispectral imaging and Raman techniques, polychrome surfaces present within three different sites selected in the framework of the "*SiciliAn MicronanOTecH Research And Innovation CEnter – SAMOTHRACE*" innovation Ecosystem. In particular, a first phase will be devoted to the realization of a model based on the quantitative cross-analysis of the integrated data obtained by emulating realistic scenarios in the laboratory, with the aim to identify potential *smart markers* for knowledge and diagnostics. The constructed model will be then tested in-situ for the comprehensive characterization of polychrome surfaces located within both museal and excavation environments, *i.e. The Norman Castle of Aci Castello*, *Ursino Castle Civic Museum* and the *Agrigento archaeological open-air site*: *Area Pubblica*, with the aim to validate the model and establish a reliable and efficient methodology for pigment identification. It is worth of note that the obtained results will be crucial not only for the development of novel integrated diagnostic systems and procedures, based on micro- and nano-technology, capable to provide answers to open questions related to the execution technique and provenance of the investigated artworks, but also would allow the definition of proper methodological choices in the view of optimized restoration and conservation strategies to be applied.

Supervisors: Anna M. Gueli (UniCT), Giuseppe Paladini (UniCT)

Title: Improvement of historical building dating by TL/OSL dating techniques. The case study of the "Terme della Rotonda" (Catania, Italy).

Abstract: Within the framework of the PNRR project "*Sicilian MicronanoTech Research And Innovation Center - SAMOTHRACE*", a research activity involves the archaeological site "Terme della Rotonda" in Catania. The primary aim of this research is to explore the complex construction and historical phases of the structure.
The site incorporates a range of construction periods spanning from the 1st century BC to the medieval era. A distinctive aspect is the site's use as thermal baths during the Arab occupation, which led to the classification of distinct areas as "hot" and "cold". The thesis project aims to improve dating methodologies based on thermally and optically stimulated luminescence (TL/OSL) applied to bricks and mortar samples after collection and measurements in site. The aim is to determine the different construction phases of various areas and acquire information regarding the ultimate timeframe during which the "hot" areas were employed as thermal baths. To achieve these goals, the project involves the characterization of luminescent signals of dosimetric interest emitted by crystalline phases extracted from mortars and bricks; studying the effects on the loss of luminescent signals due to optical and/or thermal bleaching; studying combined kinetic TL/OSL models; optimizing the procedures for measuring the sample's internal radioactivity through integral alpha counting measurements.

Supervisors: Anna M. Gueli (UniCT)

Title: PET Radiomics Studies

Abstract: Positron Emission Tomography (PET) imaging is increasingly utilized for treatment evaluation purpose in oncological patients. Radiomic analysis of uptake distribution inside the tumor in PET images may be helpful for a more personalized patient care of cancer. Nevertheless, many technical and clinical challenges still need to be addressed in radiomic studies.

The extracted radiomic features are grouped into first-order, second-order, and higher-order features. First-order features derive from the histogram of PET voxel intensities. Second-order textural features provide information about the regional spatial arrangement of the voxels such as their homogeneity, and contrast simulating the human perception of tumors in PET images. Higher-order features provide information on local collinear voxels with the same grey level. A total of 106 imaging features can be calculated for each tumor, considering additional 49 standardized uptake value (SUV) statistic indices.

The aim of this thesis is to analyze radiomic features using Artificial Intelligence (AI) methods, like Machine Learning and Deep Learning, to improve treatment response prediction and prognostication, and potentially allowing personalization of cancer treatment.

The IBFM-CNR has massive experience in the development of quantification tool in Nuclear Medicine environment. The group exhibits a long-standing collaboration with the LNS-INFN, Cannizzaro Hospital in Catania and Fondazione G. Giglio in Cefalù (PA). The student will take care of the analysis of PET images in order to extract new functional parameters both in oncological patient and pre-clinical PET studies. The obtained results will be relevant from the point of view of the demands of everyday clinical activity in order to support healthcare operators in cancer treatment decision making. Possibility of joint project with other clinical PET institutes.

Supervisors: G.Russo (IBFM-CNR), A.Stefano (IBFM-CNR)

Title: Gamma-Ray Spectrometry Measurements & Analysis for contamination detection in PET radiotracer production labelled with ^{11}C

Abstract: Carbon-11 is generally produced with a cyclotron by proton bombardment of nitrogen gas according to the 14N(p,α)11C nuclear reaction. It subsequently undergoes radiochemical processing to synthesize some drugs. However, numerous by-products may be formed as a result of interaction between the proton beam and the target assembly, potentially affecting radionuclidic purity and necessitating appropriate waste management protocols.

The goal of this thesis was to detect and quantify impurities generated during routine drugs labelled with ^{11}C production at Cannizzaro Hospital in Catania, Italy, using high-resolution gamma-ray spectrometry. An 18 MeV proton beam was used to irradiate nitrogen gas housed in a niobium target chamber with a Havar entrance window. Reaction vials, tubes, and cartridges used during synthesis will be analysed.

Specific activities (Bq/kg) will have to be reported for the impurities detected.

Supervisors: G.Russo (IBFM-CNR), G.Rapisarda (UNICT)

Title: Dosimetric approaches and detector developments for "Flash radiotherapy"

Supervisors: GA Pablo Cirrone (INFN-LNS, UNICT), pablo.cirrone@lns.infn.it
Giada Petringa (INFN-LNS), giada.petringa@lns.infn.it

** This is a thesis work envisaging experimental measurements campaigns at International laboratories

ABSTRACT: In the last decades, ion acceleration from laser-plasma interaction has become a popular topic for multidisciplinary applications and opened new scenarios in the protontherapy framework, representing a possible future alternative to classic acceleration schema. The high-intensity dose rate regime that can be obtained with this approach is also strongly attracting the radiation oncologist community thanks to the evident reduction of the normal tissue complication probability, this new radiotherapy technique was called “flash radiotherapy”. One of the many challenges to bring laser acceleration to a clinical setting consists in the development techniques and technologies that allow for accurate dosimetry of a short and intense ion bunch length.
In comparison with conventional accelerators, dosimetry of laser-accelerated beams is an ambitious task. Conventional accelerators typically operate at quasi-continuous milliampere currents rather than proton bunches with a temporal structure of the order of nanoseconds. Several international collaborations and experiments have been launched in the last years aiming at exploring the feasibility of using laser-driven sources for potential medical applications. A collaboration between the LNS-INFN, ELI-Beamlines (Czech Republic) and Queen’s University (Ireland) was recently established to develop and investigate new devices for diagnostic and dosimetric purposes for laser-driven ion beams.

Title: ELIMED project
First dosimetric and radiobiological measured with laser-accelerated ion beams at ELI-beamlines (Prague, CZ)

Supervisors: GA Pablo Cirrone (INFN-LNS, UNICT), pablo.cirrone@unict.it
Giacomo Cuttone, INFN-LNS, UNICT), cuttone@lns.infn.it
Giada Petringa (INFN-LNS), giada.petringa@lns.infn.it

ABSTRACT: INFN-LNS realized the first Users'-open beamline (called ELIMED) completely dedicated to the transport of proton/ion beams generated in the laser-matter interaction. The ELIMED beamline is now installed at the ELI-Beamlines facility (Prague, CZ) and first experiments with this new accelerated beams will start within the end of 2019. INFN-LNS also developed and realized the dosimetric system of the beamline and will be responsible for the first cell irradiations that will be carried out within 2020. The thesis work will be focused on the characterization of the developed dosimetric devices (ionization chambers, Faraday cup, Gafchromic films, ...) and on the preparation of the first experimental runs at the ELI-Beamline facility.
Travels to ELI-Beamlines will be expected.

Title: Modelling parameters of interest in radiobiology (LET, RBE) using a Monte Carlo approach at both macro and micro-dosimetric scale.

Supervisors: GA Pablo Cirrone (INFN-LNS, UNICT), pablo.cirrone@unict.it
Serena Fattori (INFN-LNS), serena.fattori@lns.infn.it

ABSTRACT: A reliable prediction of the spatial Linear Energy Transfer (LET) distribution in biological tissue is a crucial point for the estimation of the radiobiological parameters on which are based the current treatment planning. Nowadays, the accuracy and approach for the LET calculation can significantly affect the reliability of the calculated Relative Biological Effectiveness (RBE).

Monte Carlo (MC) technique is considered the most accurate method to account for complex radiation transport effects and energy losses in a medium. However, as a computation method, the accuracy and precision of the MC calculation result strongly depend on the physics interaction cross sections applied as well as the simulation algorithms used and the transport parameters are chosen. In this framework, the goal of the project consists of the development, study and validation of a completely new open-source tool based on Geant4 code for the calculation of the LET-track, LET-dose and RBE distributions of therapeutic proton and ion beam completely independent of transport parameters.

Title: Investigation of new irradiation and imaging approaches to enhance the radiobiological effectiveness of proton beams using nuclear reactions. Experimental and simulation activities

Supervisors:
Giacomo Cuttone (INFN-LNS), cuttone@lns.infn.it
GA Pablo Cirrone (INFN-LNS), pablo.cirrone@unict.it

ABSTRACT: A charged particle inverted dose-depth profile represents the physical pillar of protontherapy. Reduced integral dose to healthy tissues entails lessened risk of adverse effects. On the other hand, there is no obvious radiobiological advantage in the use of protons since their LET in the clinical energy range (a few keV/micron) is too low to achieve a cell-killing effect significantly greater than in conventional radiotherapy. Thus, enhancing proton RBE is desirable. To this end, the INFN-funded NEPTUNE (Nuclear process-driven Enhancement of Proton Therapy UNravEled) project will exploit the possibility to use the p + 11B → 3α reaction to generate high-LET alpha particles with a clinical proton beam. The p-11B reaction will be studied in all their relevant aspects: from modeling (using analytical and Monte Carlo approaches) to microdosimetry and radiobiology.

Title: Detectors development for 2D dosimetry of conventional and laser-accelerated ion beams

Supervisors: GA Pablo Cirrone (INFN-LNS, UNICT), pablo.cirrone@unict.it
R Catalano (INFN-LNS), catalano@lns.infn.it

ABSTRACT: Hadrontherapy currently represents the most advanced form of external radiation modality in tumor treatments, thanks to the increased selectivity of charged particles in terms of dose released and biological effectiveness compared to photons. It makes use of high energetic proton/ion beams accelerated by cyclotrons or synchrotrons, while, in the last years, many efforts have been addressed to validate the clinical feasibility of laser-driven beams.

We propose the development of a device for 2D relative dosimetry of both conventional and laser-accelerated ion beams based on innovative optical and geometrical solutions. The system will allow the on-lime determination of all clinical-relevant beam quality parameters and will be characterized by extremely high efficiency and spatial resolution. The validation of the system will be carried out with both conventional

and laser-accelerated proton beams at the TIFPA-INFN (Trento, Italy) and ELIMED (Prague, Czech Republic) beamlines, through an inter-comparison with other routinely-used devices for QA tests.

Title: New transport solution for eye-protontherapy beamlines

Supervisors:
GA Pablo Cirrone (INFN-LNS, UNICT), pablo.cirrone@unict.it
Giacomo Cuttone (INFN-LNS, UNICT) cuttone@lns.infn.it
Giuliana Milluzzo (INFN-LNS), gmilluzzo@lns.infn.it

ABSTRACT: Nowadays, the use of particle beams in clinical radiotherapy is applied in an increasing number of particle therapy centers worldwide [1]. In particular, hadrontherapy, based on the use of protons and ions for cancer treatment, shows many physical and biological advantages with respect to the conventional radiotherapy with X- and gamma rays, such as the higher ballistic precision in the radiation release which allows maximizing the damage to the cancer volume while sparing the surrounding healthy tissues [2]. Recently, a collaboration between the INFN-LNS and the BEST Cyclotron company has been established for the development and the commercialization of a new protontherapy beamline for the eye treatment with the 70 MeV protons accelerated from a BEST Cyclotron. The beamline component will be designed by the LNS-INFN also providing a complete Monte Carlo Geant4 simulation of the beam transport. The Monte Carlo simulation will serve to choose the beam line element characteristics in terms of material, thickness and shape in order to respect the clinical tolerances of the beam parameters for protontherapy. New solutions are currently under investigation for making the beamline as compact and automatic as possible as for instance for what concern the modulation and the degradation section of the beam line. Moreover, in order to open to the possibility to use the beam line with high-dose rate proton beams (>40 Gy/s in the so-called flash regime [3]) the implementation of an innovative ionization monitor chamber for the relative dosimetry along the beam line which would allow correcting for the ion recombination effect due to the high-dose rate, is currently under discussion.

References

[1] J.S. Loeffler , M. Durante, Nature Rev. Clinical Oncology, 10, 411 (2013)

[2] Particle Therapy Co-Operative Group (PTCOG), http://www.ptcog.ch/index.php/ptcog-patient-statistics

[3] Vozenin M-C, Hendry JH, Limoli CL. Biological Benefits of Ultra-high Dose Rate FLASH Radiotherapy: Sleeping Beauty Awoken. Clin. Oncol. (Royal Coll. Radiol. (Great Britain)) 2019;31:407–415. doi: 10.1016/j.clon.2019.04.001.

Title: Dose spatial fractionation through minibeam radiotherapy

Abstract: The minibeam Radiotherapy (MBRT) is a irradiation modality approach based on the spatial fractionation of the dose. In particular, it makes use of sub-millimetric parallel beams (0.5-1 mm) spaced in 1-3 mm and has recently gained renovated interest thanks to the observed reduced toxicity in the healthy tissues while maintaining or enhancing the tumoral control in in-vivo and in vitro experiments [1]. In this contest, the "MIni beam RadiOtherapy (MIRO)" INFN project recently financed by the CSN5 (INFN National Committee for interdisciplinary and technological research) and led by the INFN Catania and Pisa divisions will systematically study the quantitative dependencies of the minibeam effect on the beam parameters, by controlling the various spatial parameters of both electron and proton minibeams through dedicated in vitro and in vivo radiobiological experiments. In particular, the thesis work will focus on the dosimetric characterization of the different minibeam geometrical configurations, with electron and proton mini beams exploring the possibility of developing new high spatial resolution (<100 um) dosimeters for the dose distribution measurements. Monte Carlo (Geant4) simulations will be also developed to design the final collimators for the production of electron and proton minibeams. The student will have the opportunity to learn both experimental and simulation methods and to work in an international environment thanks to the collaboration with several Research Institutes in Europe.

[1] Prezado Y et al. (2018) Proton minibeam radiation therapy widens the therapeutic index for high-grade gliomas. Scientific Reports 8, 16479.

Supervisors: L. Lanzanò (UNICT), F. Romano (INFN – Sez CT), G. Milluzzo (INFN – Sez CT)

Title: Development of a Silicon Carbide array detector for transversal dose profile measurement in FLASH radiotherapy

Abstract: A big effort is recently put on developing new technologies for accurate dosimetry and real-time monitoring of ultra-high dose rate (UHDR) beams, to facilitate the clinical transition of FLASH radiotherapy [1]. In particular, Silicon Carbide detectors (SiC) detectors recently emerged as a promising dosimetric approach for such applications, as recently demonstrated thanks to a collaboration between the INFN Catania Division and the ST-Lab start-up company in Catania [2]. In the perspective of the clinical translation of this novel irradiation modality, a more complex geometrical configuration with high spatial resolution consisting of an array of multiple SiC detectors is currently under development. The aim of this innovative design is to perform the measurement of the transversal dose profiles in the FLASH regime in a single-shot measurement, addressing the challenges related to the high dose rates and radiation protection. The work will be performed at the INFN Catania Division within the framework of the DREAM (Silicon carbide array DetectoR for dose profilE meAsureMents at FLASH regimes) INFN Research for Innovation (R4I) project, recently financed by the INFN CNTT (National Committee for the Technological Transfer) and led by INFN Catania Division. The student will be involved in the design of the system, through Monte Carlo simulations, and experimental characterization of the new protype at facilities where UHDR electron and proton beams are produced. The student will have the opportunity to learn both experimental and simulation methods and to work in an international environment thanks to the collaboration with several Research Institutes in Europe.

[1] F. Romano et al., Med Phys, vol. 49, no. 7, pp. 4912–4932, Jul. 2022,
[2] F. Romano, G. Milluzzo *et al.*, *Applied Sciences*, vol. 13, no. 5, p. 2986, Feb. 2023

Supervisors: L. Lanzanò (UNICT), F. Romano (INFN – Sez CT) G Milluzzo (INFN – Sez CT)

Title: Microdosimetry for clinical hadron beams

Abstract: Microdosimetry is the only experimental method to assess the biological effectiveness of different type radiations and aims at establishing measurable characteristics of the particle track structure at the micro-meter scale that can be translated into radiation quality factors. Several technologies, namely mini-Tissue Equivalent Proportional Chambers, silicon and diamond detectors, can now offer methods for microdosimetric characterization of clinically relevant beams. The thesis will focus on the optimization and the experimental characterization of novel Silicon Carbide microdosimeters, developed by the ST-Lab start-up company in Catania and characterized by the INFN Catania Division. A cross-comparison with different microdosimeters will be also carried out through dedicated experimental campaigns with proton and ion beams in national and international laboratories. Monte Carlo Geant4 simulation code will be also used for a detailed study of the radiation´s spatial pattern of energy deposition for the simulation of the detectors. The student will have the opportunity to learn both experimental and simulation methods and to work in an international environment thanks to the collaboration with several Research Institutes in Europe.

Supervisors: L. Lanzanò (UNICT), F. Romano (INFN – Sez CT)

Title: Reference dosimetry with Ultra High Dose Rate beams for FLASH Radiotherapy

Abstract: Preclinical studies have shown that the use of ultra-high dose rate (UHDR) beams may substantially improve normal tissue sparing (so-called FLASH effect) while maintaining high tumour control probability (TCP) compared to conventional dose-rate radiotherapy. The clinical transition of FLASH radiotherapy which is characterized by average dose rates of dozens/hundreds of Gy/s instead of only a few Gy/min of conventional radiotherapy, certainly requires the establishment of new protocols and guidelines for the absolute and reference dosimetry [1,2]. The activity proposed will explore the possibility to develop new detectors for the reference dosimetry in FLASH radiotherapy with particular focus on the use of a novel small portable graphite calorimeter as secondary standard for reference dosimetry in FLASH radiotherapy, which have recently gained interest thanks to the demonstrated suitability and advantages with UHDR beams [3]. A prototype was realized at the metrology institute in the UK, the National Physical Laboratory (NPL) and will be characterized in the framework of the INFN project "FLASH Radiotherapy with hIgh Dose-rate particle beAms" (FRIDA) at the INFN Catania Division. Experimental campaigns with conventional as well as UHDR electron and proton beams will be carried out at different facilities aiming at establishing the performances of the dosimeter. The student will be also involved in the modelling of the calorimeter through Monte Carlo simulations, in close collaboration with the NPL researchers. The student will have the opportunity to learn both experimental and simulation methods and to work in an international environment thanks to the collaboration with several Research Institutes in Europe.

[1] F. Romano et al., Med Phys, vol. 49, no. 7, pp. 4912–4932, Jul. 2022
[2] A. Subiel and F. Romano, *Br J Radiol*, 2023, doi: 10.1259/bjr.20220560.
[3] G. A. Bass, D. R. Shipley, S. F. Flynn, and R. A. S. Thomas, *British Journal of Radiology*, vol. 96, no. 1141, 2023

Supervisors: L. Lanzanò (UNICT), F. Romano (INFN-CT), G Milluzzo (INFN-CT).

THEORETICAL

Title: Axions in dense quark matter

Abstract: The project aims at investigating topics related to the properties of the axion in an environment made of dense quark matter. The axion is a hypothetical particle predicted in Quantum Chromodynamics, namely the theory of strong interactions. It was introduced as a part of a mechanism that aims at explaining the strong CP problem, that is the lack of the explicit breaking of the CP symmetry; it might have played a role in the early universe, and might still play a role in the cooling of neutron stars mergers as well as young neutron stars. We will investigate the interaction of the QCD axion with dense quark matter, as the one that could be found in the core of compact stellar objects. Potential applications of the projects involve the capture of axions in the core of the compact stellar objects (neutron stars), the formation of axion walls in the core of neutron stars, the cooling of the neutron stars mergers, and the enhancement of the axion self-coupling near the critical endpoint of the QCD phase diagram.

Supervisors: M. Ruggieri (UniCT and INFN-Sezione Catania), V. Greco (UNiCT and INFN-LNS)

Title: Glasma in high energy proton-proton collisions and its impact on charmed baryon to meson ratio

Abstract: The project aims at investigating the impact of the Glasma on the final state observables in high energy proton-proton collisions. These are collisions currently run at the Large Hadron Collider at the upper energy of 14 TeV. Consequently, many particles are produced after the collision, and one can adopt a classical description, namely the Glasma, to model the very early stage of the system which eventually turns into droplets of hot plasma of quarks and gluons. We aim at studying the whole evolution of the system, from its very early stage up to the final one in which hadrons are formed, and compute hadronic observables, in particular the ratio of charmed baryon to meson number.

Supervisors: M. Ruggieri (UniCT and INFN-Sezione Catania), V. Greco (UNiCT and INFN-LNS)

Title: Systematic comparison of the Glasma and the Lund model in high energy proton-proton, proton-nucleus and nucleus-nucleus collisions

Abstract: The project aims at investigating the similarities, and highlight the differences, between the Glasma model and the Lund model for the very early stage of high energy nuclear collisions at the energies of the Large Hadron Collider. In the Glasma model, one has colored strings containing both color-electric and color-magnetic fields, connecting the two colliding objects and that evolve as classical fields; eventually they would dilute and liberate gluons. On the other hand, in the Lund model there are purely color-electric strings that decay into quark-antiquark pairs. We will perform a systematic study of the two models, implementing the initialization and the evolution of the Glasma strings and of the Lund strings, aiming at finding observables differences among the two, as well as the qualitative and the quantitative similarities.

Supervisors: M. Ruggieri (UniCT and INFN-Sezione Catania), V. Greco (UNiCT and INFN-LNS)

Title: Splitting of dipole strength for the Pygmy Dipole Resonances in presence of nuclear Deformation

Abstract: Nuclei far from the stability line have shown interesting and out of ordinary features that were not even envisaged in stable nuclei. In particular, the presence of neutron excess is responsible of the growth of a small bump in the low energy part of the dipole strength distribution. This peak, far enough in energy from the position of the Giant Dipole Resonance (GDR), has become known as the Pygmy Dipole Resonance (PDR) and it has been extensively studied both theoretically and experimentally. Recent interest has been raised on the effect of deformation on the dipole strength distribution in the low-energy region for neutron-rich nuclei. Such effect is well known for the standard GDR, where due to the coupling of dipole and quadrupole degrees of freedom, the total strength is split into two or three bumps in the case of axial or triaxial deformations. In the hydrodynamical model these different states correspond to oscillations along the different principal axis of the system. If the same mechanism is valid also for the nuclei with neutron excess, then we should observe a splitting also for the PDR bump.

Supervisors: A. Rapisarda (UniCT), J.A. Lay (Universidad de Sevilla)

Title: Machine learning to investigate the astrophysical S-factor

Abstract: We will employ a feed-forward artificial neural network to determine the astrophysical S-factor extrapolation to low energies for reactions of astrophysical interest such as the very important reaction 14N(p,gamma)15O which being the slowest one of the CNO cycle plays a crucial role for the energy production of the more massive main sequence stars and the detailed understanding of the neutrino spectrum from the sun.

Supervisors: S. Romano (UniCT), I. Vidaña (INFN-CT)

Title: Nuclear Matrix Elements for neutrinoless double beta decay

Abstract: The experimental observations of neutrino's oscillations indicate that they have non- zero mass but do not provide any information on the absolute scale of their masses. The neutrinoless double beta decay, if observed, would shed light on many fundamental aspects such as: the absolute neutrino mass scale; whether the neutrino is a Dirac or a Majorana particle; the type of neutrino mass ordering (normal or inverted). The neutrinoless double beta decay rate can be factorized in terms of a phase-space factor, the Nuclear Matrix Element (NME) containing the nuclear structure information and a term depending on the combination of the neutrino's masses, the mixing coefficients and the Majorana phases. A reliable extraction of the neutrino masses is possible only if the NMEs are known with sufficient precision. One of the most employed and promising approaches for the evaluation of NMEs is the Skyrme-Quasiparticle Random Phase Approximation (QRPA). The goal of this thesis is to employ and extend a Skyrme-QRPA code for the calculations of the NMEs. Moreover, the role of the proton-neutron pairing and deformation on the NMEs will be studied.

Supervisors: D.Gambacurta (INFN-LNS), M. Colonna (INFN-LNS and UniCT)

Title: Modeling of charge-exchange nuclear reactions and study of the analogies with electroweak (beta and double beta decay) processes

Abstract: Heavy ion reactions at low energies are modeled with quantum scattering theory. We propose to investigate reaction mechanisms of current experimental interest, inducing charge-exchange excitations in nuclei. These nuclear excitations present interesting connections with electroweak processes, such as (double) beta-decay. Comparing the calculated reaction cross section with experimental data allows one to extract data-driven information on the Nuclear Matrix Elements characterizing beta decay processes.

Supervisors: M.Colonna (INFN-LNS and UniCT), S.Burrello (INFN-LNS), D.Gambacurta (INFN-LNS)

Title: Theoretical description of dissipative Heavy Ion Collisions and impact on the nuclear Equation of State

Abstract: Heavy ion reactions at intermediate energies are modeled with semi-classical transport theories employing nuclear effective interactions. These dissipative collisions allow to explore nuclear matter under several conditions of density, temperature and charge asymmetry. Hence, from the comparison of the simulations with data, one can extract information on the nuclear Equation of State, which has a crucial role in the modeling of compact stars and gravitational wave emission.

Supervisors: M.Colonna (INFN-LNS and UniCT), S.Burrello (INFN-LNS)

Title: Constraint Molecular Dynamics and Equilibration Phenomena

Abstract: Nuclear Iso-vectorial forces determining the not-well known EOS for asymmetric matter lead in finite systems the "so called" Isospin equilibration phenomena. The project aims at investigating this equilibration process and the connection with the excitation and decay of the pre-equilibrium Dipolar ɣ-ray emission as a precursor messenger of the process.
The goal is to get information on the Iso-Vectorial forces at density far from the saturation one.
Calculations obtained with the recently improved Costraint Molecular Dynamics Model [Papa M, Phys. Rev. C 87 014001, M.Papa et al PRC 91 041601] will be performed for systems 48Ca+27Al and/or Ni+Ca isotopes at 20-40 AMeV. The study will be focused on reaction mechanisms mainly produced in central/semi-central collisions. For such systems some experimental data were collected with Chimera apparatus at Laboratori Nazionali del Sud, in Catania.
Therefore, comparisons of the calculations with experimental data could be performed.
The thesis project could thus include:
-calculation with the model of the dipolar signal from the charge and mass distribution of the produced clusters for different reaction mechanisms.
-calculation of the same quantity microscopically in the overlap region.
-calculation of the pre-equilibrium ɣ-ray yield
-improvement of the clusterization stage.

Supervisors: E. Geraci (UniCT), M. Papa (INFN-sez Ct)

HIGH ENERGY

Titolo: **Radiation tolerance tests for SiPM candidates as sensors for a dRICH detector at EIC**

Abstract: The Electron Ion Collider **(EIC)** project at Brookhaven National Laboratories (BNL) by the US Department of Energy (DoE) has triggered intense R&D programs, towards the choice of detectors. A new experimental Collaboration is born **(ePIC)** on July 2022. The experimental activity in which the Catania group is involved is to build and to test an dRICH (dual-radiator Ring Imaging Cherenkov) detector. The forward RICH (dRICH) at ePIC experiment is expected to cover the intermediate and high momenta hadron particle identification exploiting a dual radiators (gas and aerogel) design and with mirrors providing focusing off acceptance. The photosensors currently considered as baseline option are Silicon PhotoMultipliers (SiPM). INFN is currently leading a structured R&D program, supported also by DoE, to investigate the radiation effects on these devices, while maintaining the possibility to act as single photon detectors. The radiation environment will be moderately hostile, with a radiation load that should reach at maximum a fluence of 1011 1-MeV neq cm−2. An irradiation campaign on SiPM has been carried out at the TIFPA (Trento Institute for Fundamental Physics and Applications) and at the Laboratorio Nazionale di Legnaro (LNL) and others will take place in the coming months.

Supervisors: Prof. Cristina Natalina Tuvè (Università di Catania)

Titolo: **Study the forward dRICH (dual-radiator Ring Imaging Cherenkov) detector at Electron Ion Collider (EIC) for particle identification**

Abstract: The Electron Ion Collider **(EIC)** project at Brookhaven National Laboratories (BNL) by the US Department of Energy (DoE) has triggered intense R&D programs, towards the choice of detectors. A new experimental Collaboration is born **(ePIC)** on July 2022. The experimental activity in which the Catania group is involved is to build and to test an dRICH (dual-radiator Ring Imaging Cherenkov) detector. The forward RICH (dRICH) at ePIC experiment is expected to cover the intermediate and high momenta (from 3 GeV/c up to 60 GeV/c) hadron particle identification exploiting a dual radiators (gas and aerogel) design and with mirrors providing focusing off acceptance. The INFN is expected to have a major role in designing, constructing and commissioning such detector. The possibility to replace a fluorocarbon gas with high GPW with pressurized Argon is actively pursued. R&D activity is also carried out about the aerogel, a very sensitive topic nowadays given the main producer for the CLAS12 RICH aerogel was based in Russia and it is no longer available. A dRICH detector prototype was built in Italy and tests beam were made at CERN in 2021,2022 and 2023 with beams from the accelerators PS and SPS. Other test beams will be scheduled during 2024

Supervisors:
Prof. Cristina Natalina Tuvè (Università di Catania)

Titolo: **Physics at The Electron Ion Collider (EIC)**

Abstract: The Electron Ion Collider (EIC) project at Brookhaven National Laboratories by the US Department of Energy has triggered intense simulation on Physics topics. The Electron Ion Collider facility will allow the study of collisions between electrons and ions ranging from proton to Uranium, with 70% polarized beams for electrons and light ions (proton, 3He, 3H, 7Li), at variable center-of-mass energy between 20 and 140 GeV and a foreseen peak luminosity of 1034 cm−2 s−1. Given its unique features, the EIC is expected to play a major role in investigating important aspects of the structure of nucleons and nuclei, such as the origin of nucleon mass and spin, and our understanding of how nuclear forces and binding emerge from QCD, the theory of strong interactions.

Supervisors: Prof. Cristina Natalina Tuvè (Università di Catania)

Titolo: **Heavy flavor production and hadronization at Electron Ion Collider (EIC) project at Brookhaven National Laboratories (BNL**)

Abstract: The Electron Ion Collider (EIC) project at BNL by the US Department of Energy will be a machine that will unlock the secrets of the strongest force in Nature. The largest center-of mass energy and luminosity will allow the study of heavy flavor production and hadronization to a level that was not accessible to experiments like ZEUS, H1 and HERMES. The breaking of universality of fragmentation fractions of heavy flavors in different collision systems (observed by ALICE at the LHC), and the many exotic hadrons observed by LHCb can be studied at the EIC in a much different and cleaner environment, with large statistics.

Supervisors: Prof. Cristina Natalina Tuvè (Università di Catania)

Titolo: **Deep Inelastic Scattering at Electron Ion Collider (EIC) project at Brookhaven National Laboratories (BNL**)

Abstract: Deep Inelastic Scattering experiments have been always a natural bridge between high energy and nuclear physics. This is true in terms of the physics reach (investigating the inner structure of the nucleon and how QCD determines the properties of nuclear matter) and with respect to the involved communities and technologies. The EIC will not be an exception. As the most powerful machine studying QCD in the next decade (in terms of luminosity, versatility of center-of-mass energy range and of ion beams, use of polarized beams

Supervisors: Prof. Cristina Natalina Tuvè (Università di Catania)

Titolo: **Artificial Intelligence (AI) at Electron Ion Collider (EIC) project at Brookhaven National Laboratories (BNL, USA)**

Abstract: The ePIC EIC detector can be one of the first large-scale detectors to be designed with the assistance of Artificial Intelligence. Specifically, given the very large throughput expected from the dRICH (dual-radiator Ring Imaging Cherenkov), the EIC groups will investigate AI algorithms to compress and reduce data during the online processing. Generally speaking, the expertise that it will be gained in this area during the upcoming years of the EIC design and construction could be applied to other projects and other research fields (medicine) so well also in applications in the society of the future.

Supervisors: Prof. Cristina Natalina Tuvè (Università di Catania)