ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

ITLE: Nuclear Matrix Elements for neutrinoless double beta decay

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

Xavier Roca Maza (Universitat de Barcelona)

SUPERVISOR(S) contact- email: colonna@lns.infn.it	Telephone: 0039 095 542668
email: gambacurta@lns.infn.it	Telephone: 0039 095 542648
email:xavier.roca.maza@fqa.ub.edu	Telephone: 00349340339399

UNIVERSITY/RESEARCH CENTER:
Laboratori Nazionali del Sud (INFN) – Catania (Italy)- Universitat de Barcelona)

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 and to compare these predictions with other state-of-the-art models.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

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

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

SUPERVISOR(S) contact- email: colonna@lns.infn.it Telephone: 0039 095 542668
email: burrello@lns.infn.it Telephone: 0039 3891772214
email: gambacurta@lns.infn.it Telephone: 0039 095 542648

UNIVERSITY/RESEARCH CENTER: Laboratori Nazionali del Sud (INFN) – Catania (Italy)

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 (changing their charge, but not their mass). These nuclear excitations present interesting connections with electroweak processes, such as (double) beta-decay and can be described employing modern nuclear structure models (such as QRPA and shell model). Comparing the calculated reaction cross section with experiments allows one to extract data-driven information on the Nuclear Matrix Elements characterizing these relevant nuclear excitations, establishing a link with beta decay processes and, in particular, with the search of neutrino-less double beta-decay.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

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

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

SUPERVISOR(S) contact- email: colonna@lns.infn.it Telephone: 0039 095 542668
email: burrello@lns.infn.it Telephone: 0039 3891772214

UNIVERSITY/RESEARCH CENTER: Laboratori Nazionali del Sud (INFN) – Catania (Italy)

ABSTRACT

Dissipative heavy ion collisions (HIC) allow to explore nuclear matter under extreme conditions of density, temperature and charge asymmetry. We propose to model HIC at intermediate energies with semi-classical transport theories employing refined nuclear effective interactions, which are linked to the features of the nuclear Equation of State (EoS). The latter is a very important object, which also plays a crucial role in the modeling of compact stars and the emission of gravitational waves. An interesting research path is represented by the implementation of emulators, based on Machine Learning techniques, of these transport models, aiming at a significant reduction in computational times. This would facilitate the direct comparison of the simulations with the data, to ultimately extract the desired information on the EoS.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Bayesian Inference of the Nuclear Matter Equation of State: Integrating Gravitational Wave Observations and Nuclear Physics

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

SUPERVISOR(S) contact- email: colonna@lns.infn.it Telephone: 0039 095 542668
email: burrello@lns.infn.it Telephone: 0039 3891772214
email: gambacurta@lns.infn.it Telephone: 0039 095 542648

UNIVERSITY/RESEARCH CENTER: Laboratori Nazionali del Sud (INFN) – Catania (Italy)

ABSTRACT

The study of dissipative heavy-ion collisions (HIC) at Fermi/intermediate energies offers a valuable approach to probe the nuclear matter Equation of State (EoS) in regions far from normal conditions, which is crucial for understanding compact stars. Recent astrophysical observations, such as gravitational waves from neutron star mergers detected by LIGO/VIRGO, along with precise neutron star mass and radius measurements, should be then combined with nuclear physics experiments to impose new constraints on the EoS. This thesis proposes to use a Bayesian inference framework that integrates nuclear structure data, HIC experiments, and gravitational wave observations to refine the EoS and provide deeper insights into the behavior of ultra-dense matter, accounting for uncertainties in both nuclear matter theory and observational data.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Development of a new **N**eutron detector **Ar**ray for **Co**rrelation and **S**pectroscopy (NArCoS)

SUPERVISORS:
Prof. Giuseppe Politi, Dr. Emanuele Vincenzo Pagano

SUPERVISORS contact- email: giuseppe.politi@ct.infn.it Telephone: 0953785398
email: epagano@lns.infn.it Telephone: 095542275

UNIVERSITY/RESEARCH CENTER:
Università degli Studi di Catania
INFN - Sezione di Catania
INFN - Laboratori Nazionali del Sud

ABSTRACT

Main aim of the work is to develop and build a novel detector array for, both, neutron and charged particle, to be used in heavy-ion nuclear reactions studies at Fermi (E/A ≈ 10-50 MeV/nucleon). The basic unit of the new detector is a cubic cell (3 cm side) of EJ276G scintillating material read out by SIPM matrices. This choice has shown very good neutron-gamma separation capabilities and time resolution. The student will take part in experimental tests, by using beams and radioactive sources, and simulation of detector response/performance, aiming to validate and drive the development of a 64 cells prototype.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Development of a new Radioactive Ion Beams (RIBs) tagging detector based on novel Sic technology

SUPERVISORS:
Prof. Elena Irene Geraci, Dr.ssa Nunzia Simona Martorana

SUPERVISORS contact - email: elena.geraci@ct.infn.it Telephone: 0953785359
email: nunzia.martorana@ct.infn.it Telephone:

UNIVERSITY/RESEARCH CENTER:
Università degli Studi di Catania
INFN - Sezione di Catania

ABSTRACT

Main aim of the work is to develop and build a novel detector for the tagging of Radioactive Ion Beams (RIBs), produced by means of the 'in-flight" technique. Intense RIBs will be available in the near future at the INFN-LNS laboratory, following the upgrade of the superconducting cyclotron and the building of a new fragment separator (FraISe). The new detector will be constituted by an array of several (≈ 120) Silicon Carbide independent pads, covering an active area of ≈ 6*3 cm^2, read out by newly developed fast integrated electronics. The use of this innovative material (SiC) will allow to obtain excellent detector performances in terms of sustainable rate and time resolution. The student will take part in experimental tests, by using beams and radioactive sources, and simulation of detector response/performance, aiming to validate and drive the development of the prototype.

ERASMUS MUNDUS JOINT MASTER DEGREE IN NUCLEAR PHYSICS

UNIVERSIDAD DE SEVILLA

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

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS

Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Investigation of universal behaviors in Heavy Quark Dynamics in Ultra-Relativistic Heavy-Ion Collisions

SUPERVISOR(S): Prof. S. Plumari (University of Catania, INFN-LNS), Prof. V. Greco (University of Catania, INFN-LNS)

SUPERVISOR(S) contact-email: salvatore.plumari@dfa.unict.it Telephone: 0039 3925543554
vincenzo.greco@dfa.unict.it Telephone: 0039 095 542276

University of Catania, Department of Physics and Astronomy "E. Majorana"

ABSTRACT

Ultra-Relativistic Heavy-Ion Collisions (uRHICs) provide a valuable framework for investigating the Quark-Gluon Plasma (QGP), a deconfined state of matter where quarks and gluons interact strongly. Recent experimental observations have shown collective effects even in smaller collision systems, such as proton-nucleus and proton-proton collisions in high-multiplicity events. These findings challenge the conventional view that QGP formation is exclusive to large systems like nucleus-nucleus collisions. Theoretical studies have shown a universal behavior emerging from the scaling properties of relativistic hydrodynamic and microscopic transport models. This scaling behavior could explain why different collision systems, despite differing initial conditions and system sizes, exhibit similar macroscopic properties. In this thesis, we will employ a 3+1D transport approach to explore the potential existence of a universal behavior in the dynamical evolution of heavy quarks undergoing a Brownian motion as well as the existence of dynamical attractors in their dynamics. This study aims to provide deeper insights into the dynamics of heavy quarks in high-energy collisions, furthering our understanding of QGP evolution across different system sizes.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: **Study of Quarkonium Suppression in Strongly Interacting Matter through an Open Quantum Systems Approach**

SUPERVISOR(S): Prof. Gabriele Coci (University of Catania, INFN-LNS), Prof. Salvatore Plumari (University of Catania, INFN-LNS)

SUPERVISOR(S) contact- email: gabriele.coci@dfa.unict.it Telephone:
email: salvatore.plumari@dfa.unict.it Telephone: 0039 3925543554

UNIVERSITY/RESEARCH CENTER:
University of Catania, Department of Physics and Astronomy "E. Majorana"

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

This work proposes the development of a theoretical model based on the open quantum systems approach to describe the suppression of heavy quarkonia (charmonia and bottomonia), which serves as a key probe for studying the properties of strongly interacting matter created in heavy-ion collisions. The quantum master equation in the Born-Markov regime will be derived from a microscopic model, where the interaction between quarkonia and the surrounding quark-gluon plasma (QGP) environment is encoded in spectral functions and heavy-quark transport coefficients, obtained from perturbative QCD or effective field theory models available in the literature. A numerical framework will be developed to study quarkonium suppression in a one-dimensional static thermal bath at temperatures relevant to the QGP phase transition. Finally, the quantum evolution of the quarkonium density matrix will be coupled to a realistic three-dimensional description of QGP expansion from hydrodynamics or transport models, allowing quantitative comparison with other theoretical approaches and available experimental observables.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Conceptual design and performance study of an innovative non-invasive beam diagnostic system

SUPERVISOR(S): Prof. Agatino Musumarra
Dr. Grazia D'Agostino

SUPERVISOR(S) contact- email: agatino.musumarra@unict.it Telephone: +39 095 3785307
email: grazia.dagostino@lns.infn.it Telephone: +39 095 542550

UNIVERSITY/RESEARCH CENTER: University of Catania, INFN-LNS (National Institute for Nuclear Physics – South National Laboratory)

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

Have you ever wondered how a scientific idea turns into a real experimental instrument?
This Master's thesis offers the opportunity to take part in the early stages of that process — from concept to design. A research project has been funded by INFN to develop a novel experimental device aimed at performing innovative non-invasive beam diagnostics for applied and fundamental physics. The thesis work will combine theoretical analysis, numerical modeling, and simulation to explore how such a system could operate and what performance it could achieve. It will be carried out within a collaboration between University of Catania and INFN. The thesis provides an excellent opportunity for motivated students to translate physics concepts into real-world technology, contributing to an innovative device while developing a strong foundation for future careers in research or industry.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Hydrodynamic behavior of over-occupied gluon systems in high-energy nuclear collisions

SUPERVISOR(S): Marco Ruggieri, Vincenzo Greco

SUPERVISOR(S) contact- email: marco.ruggieri@dfa.unict.it Telephone: 3668148420
email: greco@lns.infn.it Telephone:

UNIVERSITY/RESEARCH CENTER: Physics and Astronomy Department, Catania University

ABSTRACT

The pre-equilibrium stage of high-energy proton-nucleus (pA) and nucleus-nucleus (AA) collisions at the Large Hadron Collider, is commonly described by an over-occupied gluon system evolving as a classical field via the Yang-Mills equations. The behavior of such system has recently been compared to that of a viscous fluid that evolves according to viscous relativistic hydrodynamics. However, recent studies have been limited to the use of small evolution time expansions, as well as to AA collisions. We aim at performing a complete study based on the numerical solution of the Yang-Mills equations for pA and AA collisions, to quantitatively investigate the hydrodynamics behavior in the early stage, computing the evolution of the stress tensor components, as well as the momentum and the transverse plane anisotropies. We also aim at studying, quantitatively and qualitatively, the difference of the hydrodynamic behavior of the over-occupied gluon system between pA and AA collisions.
The work will be developed at the Physics and Astronomy Department of Catania University.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Radioprotection Measurements and Studies for an electron FLASH accelerator for preclinical studies

SUPERVISOR(S): Giorgio Russo

SUPERVISOR(S) contact- email: giorgio-russo@cnr.it Telephone: +393473010337 (only WhatsApp)

email: Telephone:

UNIVERSITY/RESEARCH CENTER:
Institute of Bioimaging & Complex Biological Systems (IBSBC) - National Research Council (CNR)
University of Catania

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

At the CAPIR preclinical center of the University of Catania, an electron accelerator is currently being installed for radiotherapeutic treatment of small animals using the FLASH regime, which involves a high dose rate (Gy/s). This innovative radiotherapy technique has attracted significant interest from the scientific community, as the use of high dose rates allows for a reduction in side effects on healthy tissue while maintaining the therapeutic effect on tumor tissue.

From a radiation protection point of view, the installation of the machine requires verification of all safety systems and mapping of the ambient equivalent dose in the surrounding areas, to be compared with those obtained through FLUKA Monte Carlo simulations. The student will be involved in conducting experimental radiation protection measurements, analysing data for comparison with Monte Carlo simulations, and assessing the dose received by both the population and workers.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Montecarlo studies, using FLUKA toolkit, for a low energy proton beam for nuclear physics and heritage applications

SUPERVISOR(S): Giorgio Russo

SUPERVISOR(S) contact- email: giorgio-russo@cnr.it Telephone: +393473010337 (only WhatsApp)
email: Telephone:

UNIVERSITY/RESEARCH CENTER:
Institute of Bioimaging & Complex Biological Systems (IBSBC) - National Research Council (CNR)
University of Catania

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

At the University of Catania, Department of Physics and Astronomy, there is a proton accelerator capable of reaching energies up to 1.5 MeV, currently used for materials science studies. The aim of the thesis work is to set up a Monte Carlo simulation using the FLUKA toolkit to study the dose distribution—both gamma and neutron—for a generic nuclear physics experiment and the cultural heritage applications.
The nuclear physics activity involves interactions with targets under vacuum conditions. The cultural heritage application consists of irradiating samples, mainly ceramics, in air. In this case, the material radioactivation during a typical experiment has to be assessed using Monte Carlo FLUKA simulations.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Structure of 12C in a Three-Body Model and Its Impact on the Triple-Alpha Process

SUPERVISOR(S): Manuela Rodríguez Gallardo and Stefano Burrello

SUPERVISOR(S) contact- email: mrodri@us.es Telephone: +34.954559510
email:burrello@lns.infn.it Telephone: +39.3891772214

UNIVERSITY/RESEARCH CENTER: Universidad de Sevilla and INFN-Laboratori Nazionali del Sud

ABSTRACT
The triple-alpha process, which produces the 12C nucleus, plays a crucial role in stellar evolution. In order to study this reaction, it is essential to understand in detail the structure of 12C within a three-body $\alpha+\alpha+\alpha$ model. To this end, we will employ the pseudo-state method to describe the states of 12C, with particular emphasis on resonant states such as the Hoyle resonance.
We will test different basis sets in order to identify the most suitable set for accurately reproducing the relevant observables. Finally, we will attempt to estimate the radiative capture reaction rate of the triple-alpha process by first calculating the electromagnetic transition reduced probabilities from the ground state to the excited states.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Stopping Power in nanosecond laser-produced plasma

SUPERVISOR(S): Salvatore Tudisco

SUPERVISOR(S) contact- email: tudisco@lns.infn.it Telephone: 347 3506618

UNIVERSITY/RESEARCH CENTER: Università degli Studi di Catania, Dipartimento di Fisica e Astronomica/Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud (INFN-LNS)

ABSTRACT

Laser-produced plasma (LPP) is a quasi-neutral state of matter generated by high-power laser ablation. The National Institute of Nuclear Physics (INFN), at Laboratori Nazionali del Sud (LNS), is carrying out studies on Stopping Power (SP) of light ions moving through LPPs. SP is the rate at which a charged particle loses energy as it moves through a medium; however, it strongly depends on the potential acting on the particles while they are moving through the target, bringing to very different results between energy loss in ordinary or ionized matter. The study of SP in plasma has then an impact on both nuclear and astrophysical contexts and new outcomes are expected in the near future.
The candidate is thus asked to produce developments on the dynamical evolution of ns-LPP and on the analysis of SP in transient plasmas, choosing between one or more of the following options at his discretion:
1. development of techniques of measurement of SP in ns-LPP;
2. evolution of Monte Carlo (MC) or differential algorithms of numerical simulation;
3. production of new models of SP with many-body theory-based or diagrammatic approaches.
The results will have to be benchmarked with the experiments or the literature.
The workplace will be the section of LNS of INFN in Catania, which is in contact with other national or international research centers for the study of SP in ns-LPP.

Keywords:
Stopping Power (SP), nanosecond laser-produced plasma (ns-LPP), transient plasma, high-power laser, SP measurements, SP models, numerical simulations

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Study of non-equilibrium plasmas in nuclear fusion and Big-Bang nucleosynthesis environments

SUPERVISOR(S): Salvatore Tudisco

SUPERVISOR(S) contact- email: tudisco@lns.infn.it Telephone: 347 3506618

UNIVERSITY/RESEARCH CENTER: Università degli Studi di Catania, Dipartimento di Fisica e Astronomica/Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud (INFN-LNS)

ABSTRACT

The characterization of plasmas in far-from-equilibrium conditions in terms of dynamics and particle concentrations is crucial both in the study of fundamental physics and in various technical applications. These plasmas can be produced by high-power lasers interacting with target materials. The INFN, LNS section in Catania, has conducted plasma-material interaction experiments, and the new I-LUCE equipment will be available soon.
This thesis proposal concerns plasma evolution in two fields of application for non-equilibrium plasmas: nuclear fusion and Big-Bang Nucleosynthesis (BBN). While nuclear fusion will be the principal energy supply of the near future, Big-Bang Nucleosynthesis is the process of formation of the light elements of the periodic table in the early Universe and offers a way to probe the first minutes of our Universe.
Nuclear fusion can be analyzed in both inertial confinement (ICF) and magnetic confinement (MCF); while the study of BBN cannot ignore the relativistic approach. The concentration ratios of fusion products in plasma can be determined using systems of differential equations, which allow the plasma to be characterized in terms of temperature and electron density. The thesis work will be conducted at the LNS section of the INFN in Catania and the Department of Physics and Astronomy of the University of Catania, with remote working opportunities to be agreed upon.

Keywords:
Non-equilibrium plasma, Nuclear fusion, Big-Bang nucleosynthesis (BBN), numerical simulations, differential equations

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Characterization activities of sensor prototypes for the ITS3 upgrade

SUPERVISOR(S): Paola La Rocca (UniCT & INFN CT), Antonio Trifirò (UniME & INFN CT)

SUPERVISOR(S) contact- email: paola.larocca@ct.infn.it Telephone: +39-095-3785214
email: antonio.trifiro@unime.it Telephone: +39-090-6765027

UNIVERSITY/RESEARCH CENTER: Department of Physics and Astronomy, University of Catania

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

The activity will take place in the context of the ITS (Inner Tracking System) detector of the ALICE experiment at CERN and its ITS3 upgrade, namely the replacement of the three innermost ITS layers with three layers of large-area monolithic pixel sensors in 65 nm CMOS technology, thinned to about 50 µm, supported in a cylindrical geometry by minimal carbon-foam structures and air cooled — an innovative solution to reduce the material budget.
The student will take part in the characterization of new prototypes of the final sensor, full-scale and fully functional, through laboratory measurements and particle beam tests. The acquired skills will also be applicable in the broader context of sensor development for the future ALICE 3 detector.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Microdosimetric studies for Linear Energy Transfer and Biological damage prediction with clinical ion beams

SUPERVISOR: Dr Giada Petringa Dr GAP Cirrone

SUPERVISOR contact- email: giada.petringa@lns.infn.it

RESEARCH CENTER: Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud

ABSTRACT

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

ABSTRACT

Accurate prediction of radiation-induced biological effects with ions hinges on how energy is stochastically deposited at micrometric scales. This thesis will investigate the relationship between Linear Energy Transfer (LET), microdosimetric spectra, and Relative Biological Effectiveness (RBE) for clinical beams of protons, helium, carbon, and oxygen. The approach combines detailed Monte Carlo (Geant4) transport to map dose- and track-averaged LET with targeted measurements using two complementary solid-state detectors: the silicon-on-insulator Bridge Microdosimeter (CMRP, University of Wollongong) and a custom Silicon Carbide (SiC) microdosimeter developed at LNS-INFN. Experimental campaigns will be carried out at CNAO (Pavia, IT) and HIT (Heidelberg, DE), sampling pristine and modulated beams at multiple depths across the Bragg peak to capture the evolution of microdosimetric quantities (e.g., lineal energy distributions, yF and yD).

Key objectives are: (i) to establish robust detector response functions and calibration procedures in mixed radiation fields for the two technologies; (ii) to quantify links between measured microdosimetric metrics and LET distributions from simulations; and (iii) to propagate these metrics into established RBE frameworks to generate biologically weighted dose maps. The expected outcomes include validated microdosimetric datasets for p/He/C/O beams at CNAO and HIT, improved LET-RBE correlations with quantified uncertainties, and practical guidelines for integrating microdosimetry into treatment-planning verification and Quality Assurance. Ultimately, the work aims to provide clinically relevant evidence on how microdosimetry can refine biological dose prediction beyond LET alone, supporting safer and more effective ion-beam therapy.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Characterization of a new Silicon Carbide dosimeter for conventional and FLASH beam dosimetry

SUPERVISOR: Dr Giada Petringa Dr C Guarrera, Dr GAP Cirrone

SUPERVISOR contact- email: giada.petringa@lns.infn.it

RESEARCH CENTER: Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud

ABSTRACT

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

ABSTRACT

This thesis proposes a full experimental characterization of a newly developed Silicon Carbide (SiC) dosimeter engineered for reliable use in both conventional dose-rate and ultra-high dose-rate (FLASH) conditions. The device is encapsulated and water-proof, allowing direct deployment in water phantoms and reference geometries with minimal perturbation and straightforward clinical handling. SiC is an attractive sensing medium thanks to its fast charge collection, low dark current, and pronounced radiation hardness, which together promise stable response under high cumulative doses and very intense instantaneous dose rates.

The experimental program will be conducted at CNAO (Pavia) for clinical proton, helium and carbon beams operated at conventional dose rates, and in Turin for electron FLASH beams. At CNAO, measurements will span pristine Bragg peaks and SOBPs, sampling multiple depths to probe energy dependence and high-gradient regions. At Turin, FLASH campaigns will systematically vary dose-per-pulse and instantaneous dose-rate to stress the detector’s dynamic behavior and to identify any saturation or recombination effects.

The characterization will quantify: (i) dose linearity across a clinically relevant range; (ii) short- and long-term stability and reproducibility; (iii) energy and particle-type dependence (p/He/C, depth in water); (iv) dose-rate and dose-per-pulse dependence up to UHDR; (v) temporal response (rise/collection time) and signal-to-noise; (vi) polarity, angular, and temperature dependence; and (vii) water calibration and uncertainty estimates suitable for clinical QA reporting. Cross-validation will be performed against reference ionization chambers in conventional conditions and against suitable UHDR dosimeters in FLASH, with additional spot checks using radiochromic films.

By delivering robust evidence on performance across particles, energies, and dose-rate extremes, the work aims to enable dependable, high-throughput dosimetry in today’s ion therapy and tomorrow’s FLASH applications.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Transport and innovative diagnostic solutions for I-LUCE: the INFN-LNS laser-driven proton/ion acceleration facility

SUPERVISOR: Dr G A Pablo Cirrone, J Suares-Vargas

SUPERVISOR contact- email: pablo.cirrone@lns.infn.it

RESEARCH CENTER: Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud

ABSTRACT

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

ABSTRACT

Plasma-based accelerators exploit the ultra-strong electromagnetic fields sustained in a plasma to boost charged particles to high energies over millimetre–centimetre scales—orders of magnitude shorter than conventional RF machines. These accelerating structures can be driven either by intense, ultrashort laser pulses or by high-current particle beams, producing electron and ion bunches with exceptional peak currents and ultrashort durations. However, the very properties that make laser-plasma sources so compelling—large initial divergence, broad energy spread, source jitter, and high instantaneous charge—also make beam capture, transport, and delivery uniquely challenging.

At INFN-LNS, a new high-power, short-pulse laser will anchor the I-LUCE (INFN Laser-Induced Radiation/Particle Acceleration) facility, dedicated to the generation of laser-driven electron and ion beams. To translate source performance into usable irradiation capabilities, the accelerated particles must be efficiently collected in vacuum, conditioned, energy-selected, and transported up to the irradiation point, with a controlled transition to air when required by experimental end-stations.

This thesis focuses on the design, optimization, and experimental validation of novel transport solutions tailored to laser-accelerated beams at I-LUCE. The work will cover one or more than one of these aspects:

- Define optics for beam capture and matching (e.g., high-gradient solenoids and/or compact quadrupol) that accommodate large emittance and initial divergence.
- Implement energy selection and spectral shaping using dipole spectrometers and adjustable apertures to achieve target bandwidths (e.g., $\Delta E/E \leq 5$–10% where needed).
- Stabilize beam pointing and spot size at the irradiation plane via achromatic optics and feedback from online diagnostics.
- Integrate diagnostics and dosimetry (ICTs, TOF detectors, scintillator screens, spectrometers, Faraday cups) to quantify transmission, shot-to-

shot stability, temporal structure, and delivered fluence.

Methodologically, the project will combine start-to-end simulations (from realistic source distributions to the irradiation point) with iterative hardware tests on the developing I-LUCE beamlines.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS

Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Electron acceleration by high power laser for FLASH and VHEE radiotherapy applications

SUPERVISOR: Dr G A Pablo Cirrone, Dr S Arjmand

SUPERVISOR contact- email: pablo.cirrone@lns.infn.it

UNIVERSITY/RESEARCH CENTER: Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud

ABSTRACT

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

ABSTRACT

This thesis aims to enable electron FLASH (ultra-high dose-rate) studies at the new I-LUCE facility (INFN-LNS) by developing two core elements of the experimental chain: (i) a robust, tunable laser-plasma target for high-charge, quasi-monoenergetic electron production, and (ii) a diagnostics suite capable of fully qualifying the beam for preclinical irradiation.

On the target side, the work will design, commission, and compare gas-based injectors—single/nozzle gas-jets and discharge-capillary waveguides—optimized for laser wakefield acceleration. The study will map operational windows in plasma density, interaction length, and injection schemes (self-injection vs controlled) to maximize charge-per-pulse while controlling divergence and energy spread. Supporting subsystems (gas delivery, fast valves, discharge timing, focal-spot quality/contrast) will be engineered to ensure repeatability and thermal stability at the intended repetition rate. A key performance goal is to sustain electron bunches that, after transport to the irradiation plane, deliver dose-per-pulse and instantaneous dose rate compatible with the FLASH regime.

The diagnostics program will implement absolute and time-resolved measurements along the beamline: integrated current transformers and Faraday cups for charge; a magnetic spectrometer with scintillator/camera readout for spectrum and energy spread; scintillating screens/OTR for profile, divergence, and pointing; fast photonics triggers for shot-to-shot synchronization; and downstream UHDR dosimetry cross-checks (radiochromic films and UHDR-capable references) to verify dose delivery at the sample position.

Expected outcomes include: (1) a validated, operation-ready electron target for I-LUCE with documented stability and tuning procedures; (2) a calibrated, traceable diagnostics toolkit covering all beam-critical parameters (charge, spectrum, emittance proxy, pointing, pulse-to-pulse stability); and (3) demonstration of irradiation conditions—dose-per-pulse and dose-rate—consistent with FLASH preclinical studies. Collectively, the results will transition I-

LUCE from electron generation to electron beams qualified for FLASH applications.

ERASMUS MUNDUS JOINT MASTER DEGREE IN NUCLEAR PHYSICS

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

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS

Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Investigation of the aneutronic proton-boron fusion reaction in plasma for energetic studies

SUPERVISOR: Dr G A Pablo Cirrone
SUPERVISOR contact- email: pablo.cirrone@lns.infn.it
UNIVERSITY/RESEARCH CENTER: Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud

ABSTRACT

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

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

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

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ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Optimisation and diagnostic of laser-plasma accelerated particles

SUPERVISOR: J Suarez, A Sciuto, GAP Cirrone

SUPERVISOR contact- email: pablo.cirrone@lns.infn.it

UNIVERSITY/RESEARCH CENTER: Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud

ABSTRACT

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

ABSTRACT

This thesis has a concrete, two-part goal at I-LUCE (INFN-LNS):
(1) design and validate the laser transport from compressor to target so that the pulse reaches focus with the required spatio-temporal quality;
(2) define and benchmark the diagnostics needed to measure both the laser at target and the plasma/beam it generates.
Practically, you will

- (i) model the vacuum beamline with wave-optics propagation and ray tracing (relay imaging with OAPs, apertures, adaptive optics) to set alignment tolerances on wavefront error, temporal contrast, pointing jitter, pulse-front tilt, and B-integral;
- (ii) (specify and simulate the laser diagnostics stack—wavefront sensor, near/far-field cameras, spectral-phase retrieval (FROG/SPIDER), third-order cross-correlator for contrast, fast energy and pointing monitors, and in-situ focus metrology—producing calibration procedures and uncertainty budgets;
- (iii) (iii) design the plasma/beam diagnostics informed by PIC outputs: shadowgraphy/interferometry (density maps), optional Thomson scattering/pump-probe (wake structure and injection timing), and downstream electron/ion monitors (LANEX/OTR screens for profile/divergence, magnetic spectrometers for energy spread, ICT/Faraday cup for charge, Thomson parabola for ions);
- (iv) (iv) run sensitivity analyses to quantify how realistic imperfections (wavefront residuals, contrast pre-pulses, target density ramps, pointing drifts, window scattering) degrade beam quality, and translate the results into alignment checklists, QA tests, interlock thresholds, and acceptance criteria for commissioning.

The deliverables are a validated optical transport design, a calibrated diagnostics suite with traceable error bars, and ready-to-use operating envelopes (what is in-spec vs out-of-spec) that become day-one commissioning recipes—shortening the path from first light to stable, reproducible electron/ion production.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Towards the I-LUCE facility: cutting-edge PIC simulation of Laser-Plasma Interactions for protons and electron production

SUPERVISOR: Dr G A Pablo Cirrone, Dr A Sciuto, Dr S Arjmand

SUPERVISOR contact- email: pablo.cirrone@lns.infn.it

UNIVERSITY/RESEARCH CENTER: Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud

ABSTRACT

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

ABSTRACT

At the core of I-LUCE (INFN Laser indUCEd Radiation Facility) is a high-power, short-pulse laser delivering up to ~350 TW peak power in sub-23 fs pulses, with ~7 J at 1 Hz. This operating window accesses extreme light-matter regimes ($a_0 \gg 1$) enabling robust electron injection and wake excitation at plasma densities ~10^{18}–10^{19} cm^{-3} and, with suitable targets, laser-driven ion acceleration. To de-risk commissioning and shorten the path from first light to usable beams, we propose a comprehensive simulation program that couples Particle-In-Cell (PIC) modeling for both laser-wakefield electrons and target-normal-sheath/radiation-pressure proton sources with start-to-end transport and dosimetric predictions tailored to I-LUCE's hardware.

For electrons (LWFA), PIC runs resolve relativistic dynamics, nonlinear plasma response, ionization-induced injection, and self-consistent field evolution using high-order solvers and (where beneficial) adaptive meshing to span sub-micron to millimetre scales. We map actionable design spaces linking focal quality/contrast, spot size, and pulse-front tilt to captured charge, energy spread, divergence, and pointing stability, and quantify tolerances on gas-jet and discharge-capillary density profiles (ramps, lengths, peak density). Synthetic diagnostics—virtual magnetic spectrometers, scintillating-screen/OTR imaging, spectral/angle distributions, phase-space trackers, and time-resolved field probes—yield observables directly comparable to commissioning data, enabling rapid model-to-measurement validation and feedback.

For protons/ions, we extend PIC to ultrathin solid targets (single- and multi-layer foils) to capture sheath formation and radiation-pressure dynamics (TNSA/RPA/BOA-like regimes), explicitly tracking the build-up of accelerating fields, contaminant-layer effects, and the resulting ion phase-space (energy, divergence, emittance proxy, shot-to-shot stability). The PIC-derived source is then injected into a start-to-end transport chain—solenoids/quadrupole triplets for capture, dipole energy selection with adjustable slits, and vacuum-to-air interface modeling—to predict transmission, bandwidth (ΔE/E), spot size at the

irradiation plane, and deliverable dose-per-pulse. A lightweight Monte Carlo transport/dosimetry stage converts the transported phase-space into depth-dose and lateral profiles in water/PMMA, accounts for scattering in windows/air, and estimates secondary radiation for shielding and interlock thresholds. Proton synthetic diagnostics (virtual Thomson parabola, TOF detectors, MCP/CR-39 surrogates) provide a like-for-like comparison with the I-LUCE beamline instrumentation planned for commissioning.

The outcome is a set of optimized target/laser settings, capture-and-transport tolerances, and start-up recipes that translate simulation insight into day-one guidelines. In sum, this dual-track (electron + proton) PIC-driven program delivers a practical blueprint for I-LUCE—bridging design and experiment, accelerating commissioning, and laying the groundwork for stable, repeatable electron and proton beams for downstream applications in dosimetry, detector testing, and FLASH-relevant irradiation studies at INFN-LNS.

ERASMUS MUNDUS JOINT MASTER DEGREE IN NUCLEAR PHYSICS

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

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Building a FLASH Platform: End-to-End Commissioning and Dosimetry of the SIT Sordina Electron Accelerator at the University of Catania

SUPERVISORs: R. Catalano

SUPERVISOR contact- email: catalano@lns.infn.it

RESEARCH CENTER: Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud

ABSTRACT

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

ABSTRACT

This thesis will carry out the end-to-end commissioning and dosimetric characterization of a dedicated electron FLASH accelerator realized at CAPIR of the University of Catania and modelled on the ElectronFlash platform from SIT Sordina that is in operation in Pisa, and used internationally as a reference for UHDR research. The commissioning program will verify machine safety and functionality, establish energy settings and reference geometry with PMMA cylindrical applicators, and qualify beam delivery across the clinically relevant operating envelope. Dosimetry will be performed in air and water to determine absolute output (dose per pulse and average/instantaneous dose rate), depth-dose curves (PDD), lateral profiles, field uniformity, and penumbra for the available field sizes and nominal energies of 7 and 9 MeV, consistent with ElectronFlash specifications reported for the CPFR facility in Pisa. Where appropriate, the Pisa experience will be used to benchmark procedures and performance figures, e.g., dose-per-pulse from ~0.03 up to ≥1–10 Gy depending on configuration, instantaneous dose rates reaching the 10^3–10^4 Gy/s range, and operation with applicators that set field size and Normal Treatment Distance, while recognizing site-specific differences in bunker layout, beamline metrology, and QA workflows. The detector suite will combine UHDR-capable sensors and transfer standards (radiochromic films for 2D mapping, plastic-scintillator or diamond/SiC systems for online monitoring, and charge diagnostics such as ICT/Faraday cup) to address saturation, recombination, and readout linearity at ultra-high currents; measurement uncertainty will be evaluated with attention to pulse structure, repetition rate, SSD, scattering through air/windows, and detector dose-rate dependence. Deliverables include: acceptance and reference data packages; calibrated beam models and operating curves (output vs. PRF/SSD/applicator); reproducibility and stability metrics (shot-to-shot and thermal drift); and a validated protocol to demonstrate FLASH conditions (≥ 40 Gy/s) at the irradiation plane with traceable uncertainties suitable for preclinical studies.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Modelling DNA damage with Geant4-DNA Monte Carlo simulations and comparison with radiobiological data.

SUPERVISOR(S): : Dr Serena Fattori, Dr. G A Pablo Cirrone

SUPERVISOR(S) contact- email: serena.fattori@lns.infn.it Telephone:
email: pablo.Cirrone@lns.infn.it Telephone:

UNIVERSITY/RESEARCH CENTER: Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud

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

Studies of DNA damage are essential to understand the biological effectiveness of radiotherapy and to guide the development of more efficient treatment strategies. The Monte Carlo (MC) method represents a powerful tool for estimating radiation-induced DNA damage, accounting for both direct effects, arising from physical interactions with the biological medium, and indirect effects, resulting from chemical reactions that generate free radicals subsequently attacking biomolecules.
However, the accuracy and reliability of MC results depend critically on the interaction cross sections, transport algorithms, and simulation parameters employed. Within this context, the objective of the project is to perform a series of MC simulations reproducing DNA damage under different experimental conditions, by varying the cell type and/or the radiation modality. The simulations will be carried out using the Geant4-DNA toolkit, and the results will be benchmarked against experimental data to assess model performance and improve predictive capability.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Monte Carlo Investigation of Water Radiolysis under FLASH Irradiation Conditions with Geant4-DNA.

SUPERVISOR(S): : Dr Serena Fattori, Dr. G A Pablo Cirrone

SUPERVISOR(S) contact- email: serena.fattori@lns.infn.it Telephone:
email: pablo.Cirrone@lns.infn.it Telephone:

UNIVERSITY/RESEARCH CENTER: Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud

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

The recent advent of FLASH radiotherapy -ultra-high dose rate irradiation capable of delivering therapeutic doses within milliseconds— has demonstrated in precliical studies a remarkable capacity to spare normal tissues while maintaining tumor control, a phenomenon known as the FLASH effect. Despite its promising clinical potential, the underlying radiochemical and biological mechanisms leading to this differential response remain unexplained.
This thesis aims to explore the physicochemical basis of the FLASH effect through Geant4-DNA Monte Carlo simulations of water radiolysis, focusing on the early stages of radiation chemistry. Simulations will model pulse-structured irradiations to analyze how dose rate, pulse duration, and oxygen conditions affect the yields and recombination of radiolytic species. The goal is to optimize radiation chemistry modeling under ultra-high dose-rate conditions and provide new insights into radical kinetics potentially responsible for the FLASH effect. The outcomes will contribute to improving the predictive capability of Monte Carlo tools for future FLASH radiotherapy optimization.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Effects of cross section uncertainties in the interaction rate through the Earth

SUPERVISOR(S): S.Cherubini-Silvio.cherubini@unict.it-

SUPERVISOR(S) C. Distefano-distefano_c@lns.infn.it

UNIVERSITY/RESEARCH CENTER:
DFA University of Catania and INFN-LNS The master Thesis is focused

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

The Goal of Master Thesis is the challenging study of the systematics in the cross section calculation of the neutrino transmission through the earth. Moreover in the framework of the Master thesis the general studies of ARCA neutrino telescope systematics will be carried out.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: **Design and Performance Characterization of the DRICH (dual-radiator Ring Imaging Cherenkov) detector for Particle Identification at Electron Ion Collider (EIC)**

SUPERVISOR(S): Tuvè Cristina Natalina

SUPERVISOR(S) contact- email: Cristina.tuve@ct.infn.it Telephone: 0953785437

UNIVERSITY/RESEARCH CENTER: Catania, CERN, BNL

ABSTRACT

The Electron-Ion Collider (EIC) project at Brookhaven National Laboratory (BNL), led by the U.S. Department of Energy (DoE), has initiated extensive R&D programs aimed at selecting and developing suitable detector technologies.

In July 2022, a new experimental collaboration, ePIC, was established to carry out the EIC physics program.

The Catania group is actively involved in the design, construction, and testing of a dual-radiator Ring Imaging Cherenkov (dRICH) detector. The forward RICH (dRICH) at the ePIC experiment is designed to provide hadron particle identification over a wide momentum range (from 3 GeV/c up to 60 GeV/c) by employing a dual-radiator configuration (gas and aerogel) together with focusing mirrors optimized for acceptance.

The INFN is expected to play a leading role in the design, construction, and commissioning of this detector. Particular attention is being given to the replacement of fluorocarbon gases, which have a high global warming potential (GWP), with pressurized argon as an environmentally friendly alternative.

Further R&D activities focus on the aerogel radiator, a critical component given the current unavailability of the main producer that supplied aerogel for the CLAS12 RICH, previously based in Russia. A dRICH prototype was constructed in Italy, and beam tests were conducted at CERN using beams from the PS and SPS accelerators. Additional beam tests were scheduled throughout 2026 to continue performance evaluation and optimization.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: **Deep Inelastic Scattering at the Electron-Ion Collider (EIC) at Brookhaven National Laboratory (BNL)**

SUPERVISOR(S): Tuvè Cristina Natalina

SUPERVISOR(S) contact- email: Cristina.tuve@ct.infn.it Telephone: 0953785437

UNIVERSITY/RESEARCH CENTER: Catania, BNL

ABSTRACT

Deep Inelastic Scattering (DIS) experiments have long served as a natural link between high-energy physics and nuclear physics. This connection arises both from their scientific objectives—probing the internal structure of the nucleon and exploring how Quantum Chromodynamics (QCD) shapes the properties of nuclear matter—and from the shared expertise and technologies within the involved research communities.

The Electron-Ion Collider (EIC) will continue this tradition. As the most powerful facility dedicated to the study of QCD in the coming decade, the EIC will combine high luminosity, a versatile center-of-mass energy range, a broad selection of ion beams, and the capability to use polarized beams. These unique features will allow for precision measurements aimed at advancing our understanding of the strong force and the fundamental structure of matter.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Indirect measurement of the cross section of the thermonuclear reaction $^{11}C(\alpha,p)^{14}N$ in the context of supernova nucleosynthesis.

SUPERVISOR(S): Prof.ssa SERGI MARIA LETIZIA, Prof. LAMIA LIVIO

SUPERVISOR(S) contact- email: marialetizia.sergi@dfa.unict.it Telephone: +39095542385
email: livio.lamia@dfa.unict.it Telephone: +39095542547

UNIVERSITY/RESEARCH CENTER: Department of Physics and Astronomy "E. Majorana"- University of Catania

ABSTRACT

Neutrino-induced nucleosynthesis in supernovae contributes to the production of several nuclides, including ^{7}Li, ^{11}B, ^{19}F, ^{92}Nb, ^{98}Tc, ^{138}La, and ^{180}Ta. Recently, the impact of nucleosynthesis involving nuclei in the A=11 mass region has been extensively studied, with particular reference to the role of the $^{11}C(\alpha,p)^{14}N$ nuclear reaction, for which currently no experimental data are available in the 0.25-1 MeV energy range of astrophysical interest.
The student is required to work on the data analysis of the measurement already carried out for the reaction $^{11}C(\alpha,p)^{14}N$ by applying the principle of detailed balance to the $^{14}N(p,\alpha)^{11}C$ cross section obtained through the already assessed indirect Trojan Horse Method (THM). In particular, he/she will have to deal with the calibration in angle and energy of the detectors, the selection of the reaction channel and the quasi-free mechanism and the study of the resonances present in the region of astrophysical interest due to excited states of ^{15}O in the energy range below 4 MeV.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: **Data analysis of the photodisintegration of ^{112}Sn in the astrophysical p-process**

SUPERVISOR(S): Prof. Livio Lamia
Prof. Dario Lattuada

SUPERVISOR(S) contact- email: llamia@lns.infn.it Telephone:
email: lattuadad@lns.infn.it Telephone:

UNIVERSITY/RESEARCH CENTER: University of Catania, Physics and Astronomy Department
Laboratori Nazionali del Sud - INFN

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

The nucleosynthesis of the so-called p-nuclei is one of the most puzzling problems yet to be solved. In order to explain the abundances of these proton-rich nuclei (with mass A between 74 and 196) that cannot be synthesized by neutron-capture processes (s- or r-process), a third mechanism called p-process has been introduced. This mechanism, which is supposed to take place in explosive scenarios, involves s-nuclei as seeds and a succession of (γ,n), (γ,p), (γ,α) reactions and their inverse processes happening at high temperatures ($T > 10^9$K) and short time scales. Among the others, the crucial (γ,α) photodisintegration cross section of ^{112}Sn is still not directly measured.
Thus, an experiment was performed at the High Intensity Gamma-Ray Source (HIgS, Duke University) with a collimated photon flux with energies from 11 MeV to 20 MeV using the SIDAR array. The research activity aims to analyze the experimental data (in ROOT format) starting from the calibration of the detectors involved and performing devoted simulation using GEANT4 in order to cross check the results.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: The in-plasma measurement of the deuterium-deuterium fusion reaction at astrophysical energies

SUPERVISOR(S): Prof. Livio Lamia
Prof. Dario Lattuada

SUPERVISOR(S) contact- email: llamia@lns.infn.it Telephone:
email: lattuadad@lns.infn.it Telephone:

UNIVERSITY/RESEARCH CENTER: University of Catania, Physics and Astronomy Department
Laboratori Nazionali del Sud - INFN

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

Studying nuclear reactions at astrophysical energies (1–100 keV) is challenging due to their extremely low cross sections, requiring either costly underground laboratories (e.g., LUNA, JUNA) or indirect methods like the Trojan Horse Method (THM) and Asymptotic Normalization Coefficient (ANC). However, traditional experiments using solid or gas targets differ significantly from the plasma conditions in stellar environments, where effects such as electron screening play a crucial role.
A new setup - featuring a cryogenically cooled supersonic nozzle and neutron/charged-particle detectors - will enable systematic studies of laser-induced deuterium fusion, laying the groundwork for future investigations of heavier-nuclei fusion (e.g., ^{12}C) and plasma screening effects.
A devoted experiment was carried out at the GIST laser facility applying the Coulomb Explosion Mechanism to the deuterium-deuterium fusion at astrophysical energy range. The research activity aims to analyze the experimental data (in ROOT format) starting from the calibration of the detectors involved and performing devoted simulation using GEANT4 in order to cross check the results.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: p-11B fusion reaction cross section measured with ELISSA

SUPERVISOR(S): Prof. Livio Lamia
Dr. Giovanni Luca Guardo

SUPERVISOR(S) contact- email: llamia@lns.infn.it Telephone:
email: guardo@lns.inf.it Telephone:

UNIVERSITY/RESEARCH CENTER: University of Catania, Physics and Astronomy Department
Laboratori Nazionali del Sud - INFN

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

Light elements in astrophysics represent one of the most interesting and intriguing topic. Their importance is indeed related to different scenario affecting the nucleosynthesis in the Cosmos, ranging from primordial nucleosynthesis to the stellar one. With respect to this last aspect, the trio of light elements lithium, beryllium and boron (LiBeB) is used for understanding stellar mixing phenomena acting inside stellar interiors. Besides the role in nuclear astrophysics, the 11B(p,α)αα reaction has gained prominence primarily due to its relevance in nuclear fusion reactor development, where it seems highly appealing to researchers, because of the lack of neutrons in the reactions products. For such a reason, devoted cross section measurements have been performed during these years. In order to complement the already available information and to measure angular distribution at energy range where no or discordant measurements exist, we performed a devoted 11B(p,α)8Be experiment in collaboration with IFIN-HH/ELI-NP (Romania) by using the 3MV accelerator. The detection setup used was ELISSA, a freshly and highly efficienty silicon detection setup particularly useful for low-energies cross section measurements. The research activity aims to analyze the experimental data (in ROOT format) starting from the calibration of the detectors involved and performing devoted simulation using GEANT4 in order to cross check the results. The student will work in strict connection with researcher by University of Catania and INFN, in a fruitful and highly motivated environment.

JOINT EUROPEAN MASTER IN NUCLEAR PHYSICS
Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: Machine learning-based extrapolation of the astrophysical S-factor in nuclear astrophysics

SUPERVISOR(S): Jorge Segovia, Isaac Vidaña and Edoardo G. Lanza

SUPERVISOR(S) contact - email: jsegovia@upo.es Telephone: +34 635187048
email: isaac.vidana@ct.infn.it Telephone:
email: lanza@ct.infn.it Telephone:

UNIVERSITY/RESEARCH CENTER:

Universidad Pablo de Olavide, de Sevilla, INFN di Catania, and Università di Catania

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

The astrophysical S-factor is a crucial quantity in nuclear astrophysics, representing a reparameterization of the nuclear reaction cross-section that removes the dominant Coulomb barrier effects. It plays a central role in calculating reaction rates in nucleosynthesis processes, including those occurring in stellar interiors, supernovae, and during the Big Bang. Accurate knowledge of the S-factor is essential for modeling the production of chemical elements and predicting neutrino fluxes from stars.

Despite its importance, the S-factor is challenging to determine theoretically and experimentally. At the low energies relevant for astrophysical environments (often in the keV range), direct measurement of reaction cross-sections becomes infeasible due to the exponential suppression by the Coulomb barrier. Theoretical models often involve large uncertainties, especially for complex or weak interactions. As a result, experimental data are typically obtained at higher energies and then extrapolated down to astrophysical energies—a process highly sensitive to the chosen fitting method and underlying physical assumptions.

This project aims to explore the application of machine learning (ML) techniques to improve the extrapolation of the S-factor from experimental data. ML models—such as Gaussian processes, neural networks, or physics-informed regression—will be trained on existing high-energy cross-section data and constrained by known physical laws (e.g., threshold behavior, resonance structures). The objective is to develop a ML-based framework that provides robust uncertainty quantification and enhances predictive power at low energies.

The project will involve:

- Gathering and preprocessing experimental cross-section and S-factor data for selected

reactions (e.g, p+p, $^{3}He+^{3}He$, $^{12}C+a$).

- Implementing and comparing ML models for function extrapolation.
- Incorporating physical constraints into the models.
- Evaluating the extrapolated S-factors against theoretical predictions and low-energy benchmarks.

The outcome is expected to contribute both to the methodological field of scientific ML and to nuclear astrophysics by offering improved tools for reaction rate modeling under stellar conditions.