ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS

Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: **Alpha induced nuclear reactions of interest in fusion**

SUPERVISOR(S): Luis Mario Fraile (lmfraile@ucm.es)

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UNIVERSITY/RESEARCH CENTER: UNIVERSIDAD COMPLUTENSE DE MADRID, Grupo de Física Nuclear, EMFTEL department & IPARCOS,

ABSTRACT

Alpha particles are crucial in a magnetically confined fusion plasma as a heating source before escaping the plasma. The rate of alpha release from the plasma is therefore of importance and ITER is exploring methods to measure it, such as fast-ion loss detectors [1].

Other options such as activation foils have also been proposed [2] for reactions that occur at energies below 3.5 MeV and produce radionuclides with gamma detectable signals. Although the latter is challenging owing to the need to discriminate against gamma background arising from neutron activation, several candidate reactions have been put forward, such as $^{10}B(\alpha,n)$, $^{43}Ca(\alpha,p)$, $^{76}Ge(\alpha,n)$ among others [2]. Cross section data for key reactions is nevertheless scarce.

In this master thesis work we would like to measure the production yield of the α induced reactions in Ca isotopes in an energy range relevant for fusion environments. Measurements will take place at the newly commissioned (α,n) reaction beamline at the CMAM 5-MV tandetron [3] in Madrid. Yield and production cross sections [4] from the production threshold up to 3.5 MeV will be determined by using activation of a metallic calcium target and the offline measurement of the delayed emissions via gamma spectroscopy.

The results will be analysed in the framework alpha induced reactions in calcium for the deuterium-tritium cycle in Tokamaks, which have $^{43}Ca(\alpha,p)^{46}Sc$ and $^{44}Ca(\alpha,p)^{47}Sc$ as promising candidates.

[1] M. García-Muñoz et al., Rev. Sci. Instrum. 87 (2016) 11D829
[2] G. Bonheure et al., Fus. Eng. Des. **86** (2011) 1298
[3] Centro de Micronálisis de Materiales, https://www.cmam.uam.es/
[4] V.N. Levkovski (1991) Cross sections of medium mass nuclide activation (A=40-100) by medium energy protons and alpha-particles (E=10-50 MeV) / EXFOR.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: Energetic ion confinement in optimized stellarators

SUPERVISOR: José Luis Velasco

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UNIVERSITY/RESEARCH CENTER: Theory Group, Laboratorio Nacional de Fusión, CIEMAT

ABSTRACT

Very good confinement of fusion-generated alpha particles is a *sine qua non* for a fusion reactor. These very energetic ions are expected to contribute to heat the fusion reactants, which implies that their confinement time must be sufficiently longer than the time that it takes them to thermalize by giving their energy to the plasma. An even more restrictive criterion is set by the heat loads on the walls: alpha particles that are promptly lost, and that therefore retain most of their original energy, could damage the plasma-facing components of the reactor wall.

In magnetic fusion devices of the stellarator type, neoclassical processes are the main concern with respect to energetic ion confinement. Particles trapped in the magnetic field of axisymmetric tokamaks, while moving back and forth along the field lines, experience radial excursions that produce banana-shaped orbits, but, on average, no net radial displacement takes place in the absence of collisions. Things are different in a generic stellarator, where collisionless trapped orbits are not confined (this also applies to tokamaks in which axisymmetry is not perfect). For this reason, the magnetic configuration of a stellarator has to be carefully designed in order to minimize energetic ion losses.

The student will characterize the confinement of energetic ions in stellarators by numerically solving kinetic plasma equations. This will be done for a variety of optimized stellarator configurations, including Wendelstein 7-X (Greifswald, Germany) and the Large Helical Device (Toki, Japan). With his/her calculations, the student will be contributing to the participation of the Laboratorio Nacional de Fusión in the experimental campaigns of these two devices. Additionally, he/she will be taking part in a longer term project that has the goal of designing new optimized stellarator configurations that can be candidates for future fusion reactors.

Webpages:
http://fusionsites.ciemat.es/jlvelasco/
http://fusionsites.ciemat.es/multitranstell/

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: Global gyrokinetic simulations in stellarators

SUPERVISOR(S): Edilberto Sánchez González

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UNIVERSITY/RESEARCH CENTER: Theory Group, Laboratorio Nacional de Fusión, CIEMAT

ABSTRACT

Turbulence is considered one of the key issues limiting energy and particle confinement in present magnetic confinement fusion devices. Nowadays, the study of turbulence in magnetized plasmas largely relies on gyrokinetic theory [1]. This formalism, based on first principles, makes plasma turbulence more tractable and permits the development of simulation codes. Nevertheless, the numerical simulation of plasma instabilities and the turbulence they produce using gyrokinetic codes requires huge computational resources and is only possible using large supercomputers.

This master's thesis proposal deals with the numerical simulation of plasma instabilities and turbulence in stellarator devices employing the global gyrokinetic code EUTERPE [2], which allows the simulation of the full radial domain. It continues previous work carried out at the Laboratorio Nacional de Fusión, CIEMAT [3]. The project will include simulations in the Mare Nostrum [4] and Marconi [5] supercomputers. The outcome of numerical simulations will eventually be compared with experimental measurements from the stellarators TJ-II [6], operated at the Laboratorio Nacional de Fusión, in Madrid, and W7-X [7], the most advanced stellarator in the world, in operation at the Max Planck Institute für Plasmaphysik, in Greifswald, Germany.

[1] P. Catto. Plasma Phys. 20 719-722 (1978).
[2] G. Jost, et al. Physics of Plasmas, 8(7) 3321 (2001).
[3] http://fusionsites.ciemat.es/picgklnf/
[4] https://www.bsc.es/es/marenostrum/marenostrum
[5] https://www.hpc.cineca.it/hardware/marconi
[6] http://www.fusion.ciemat.es/tj-ii-2/
[7] https://www.youtube.com/watch?v=u-fbBRAxJNk

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 2023/2024

MASTER THESIS PROPOSAL

TITLE: Theory and simulation of stellarator plasma turbulence

SUPERVISOR: José Manuel García Regaña, Iván Calvo

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UNIVERSITY/RESEARCH CENTER: Theory Group, Laboratorio Nacional de Fusión, CIEMAT

ABSTRACT

Thermonuclear fusion and its success as a future energy source rely on achieving tolerable levels of heat losses out of the confined plasma. In present day experiments, these losses are attributed, to a large extent, to the turbulent processes associated with fluctuations of the plasma electromagnetic fields with characteristic spatial scale of the order of the Larmor radius of the plasma species. The theoretical framework for the study of these fluctuations is gyrokinetic theory [1]. The quantitative evaluation of the transport driven by gyrokinetic turbulence is in most situations carried out by numerical simulations performed in massive parallel computing platforms. For tokamaks, gyrokinetic codes are mature and have been extensively validated against experiments. Whereas tokamaks are axisymmetric (which reduces the dimensionality of the equations to be simulated), stellarators are intrinsically three-dimensional, and this has led to specific difficulties and, until recently, a comparatively slower progress of the field (see e.g. [2]). The aim of the present master's thesis project is to investigate turbulence in stellarator plasmas by means of the modern, advanced gyrokinetic code `stella` [3]. The project includes applications to present-day stellarators such as W7-X (Greifswald, Germany) [4], LHD (Toki, Japan) [5] and TJ-II (Madrid, Spain) [6]. Interest of the candidate on theory and numerical simulations is highly recommended.

[1] P. Catto, Plasma Phys. 20, 719 (1978)
[2] P. Helander et al., Plasma Phys. Control. Fusion 54, 124009 (2012)
[3] M. Barnes et al., J. Comput. Phys. 391, 365 (2019)
[4] https://www.youtube.com/watch?v=u-fbBRAxJNk
[5] http://www.lhd.nifs.ac.jp/en/home/lhd.html
[6] http://fusionsites.ciemat.es/tj-ii

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: Study of exotic nuclei with GRIFFIN

SUPERVISOR(S): Bruno Olaizola Mampaso

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UNIVERSITY/RESEARCH CENTER: IEM-CSIC, Madrid, Spain

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

The GRIFFIN array at TRIUMF, Canada, is currently the state-of-the-art spectrometer, with one of the highest gamma-ray efficiencies and a suit of ancillary detector that allows for in-depth decay experiments. It is routinely used to study the structure of some of the most exotic isotopes with extreme neutron-to-proton ratios.

What are you going to do? The master research project will consist of the data analysis of recent GRIFFIN experiments. You will analyze the beta decay of exotic nuclei and build their level schemes, making use of different nuclear physics techniques, such as angular correlations, conversion electron spectroscopy or ultra-fast timing.

What are you going to learn? During this work, you will familiarize yourself with GRIFFIN and TRIUMF, a world-leading laboratory. You will also learn to use powerful analysis tools like ROOT, the most commonly used software in the nuclear and particle physics field. Finally, you will gain in-depth knowledge about nuclear structure far from stability and a wide range of nuclear physics detectors, able to detect gamma rays or charged particles.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: In-beam spectroscopy and lifetime measurements in the north-east region of ^{80}Zr

SUPERVISOR(S): Andres Illana

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UNIVERSITY/RESEARCH CENTER:
Universidad Complutense de Madrid / Grupo de Física Nuclear

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

The mass region above ^{80}Zr (Z = N = 40) has gained much attention during the last two decades due to the recent theoretical and experimental works published. Nuclei in this region can exhibit a transition from collective behaviour to spherical configuration. The latest results show a clear competition of the shape coexistence with triaxiality for nuclei above ^{80}Zr. However, there is a deficit of experimental information in this region. Hence, the aim of this master thesis is to study the transition probabilities of the low-lying bands in Mo and Zr nuclei. The nuclei of interest be populated via the ^{24}Mg(^{64}Zn,2n) fusion-evaporation reaction at JYFL. The results will be discussed and combated to different theoretical calculations.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: Modeling of post-irradiation radiochemistry in high-rate radiotherapy (FLASH).

SUPERVISOR(S): Daniel Sánchez Parcerisa

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UNIVERSITY/RESEARCH CENTER: UCM, Faculty of Physics

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

High-rate radiotherapy or FLASH has been a revolution in radiotherapy, as it has been shown that it could allow a significant decrease in the side effects of radiation, while maintaining its tumor control capacity. The radiobiological mechanisms underlying the FLASH effect are still unknown. The work proposes to use Monte Carlo modeling tools such as TOPAS-nBIO and others developed internally within the Nuclear Physics Group to study the chemical kinetics of free radicals created in water radiolysis, which are determinants in the biological effects of radiation. With these data we intend to make experimentally testable predictions (such as the concentration of molecular oxygen or post-irradiation hydrogen peroxide) to design future experiments by controlling the irradiation conditions.

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 2023/2024

MASTER THESIS PROPOSAL

TITLE: Gamma fast-timing spectroscopy of neutron-rich nuclei in the vicinity of ^{132}Sn

SUPERVISOR(S): Luis Mario Fraile & Andrés Illana Sisón

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UNIVERSITY/RESEARCH CENTER:
Universidad Complutense de Madrid / Grupo de Física Nuclear

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

The region of exotic nuclei around ^{132}Sn is of particular interest for nuclear structure studies due to its proximity to the magic numbers both for protons and neutrons, and also because of the potential impact of nuclear properties on the astrophysically-relevant r-process path. The master thesis work will be devoted to data-analysis of relevant nuclei in the region populated in β decay and fission at large-scale facilities, such ISOLDE/CERN and Institut Laue-Langevin. Gamma spectroscopy with high-resolution HPGe detectors will be used to construct the level scheme and the Advanced Time-Delayed $\beta\gamma\gamma$(t) method will be employed for the measurement of excited level lifetimes, in order to derive transition probabilities. The results will be discussed in the wider context of nuclei in the region and compared to theoretical calculations. The analysis work will be developed in the Faculty of Physics at Universidad Complutense de Madrid.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: Proton range verification in protontherapy using prompt gamma detection

SUPERVISOR(S): Luis Mario Fraile & José Manuel Udías

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UNIVERSITY/RESEARCH CENTER:
Universidad Complutense de Madrid / Grupo de Física Nuclear

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

Protontherapy is a radiotherapy technique that profits from proton beams to treat tumours with high precision. One of the key challenges in protontherapy is to ensure that the range of the protons is adequate so that they deposit the dose at the tumour and avoid unnecessary damage to surrounding healthy tissues. This is why real-time proton range verification is essential. In this context, the detection of prompt gamma radiation generated during the interaction of protons either with tissues or with contrasts introduced ad hoc has become a promising technique. The aim of this master's thesis is the optimization of a proton range monitoring system in proton therapy based on prompt gamma detection with fast scintillators, by means of Monte Carlo simulations, laboratory measurements. The work will be developed at Universidad Complutense de Madrid. Tests will be performed with low-energy beams at the CMAM accelerator in Madrid, and under realistic conditions in one of the proton therapy centers currently in operation in Spain.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: Evaluation of new scintillator materials for gamma ray and charged particle detection

SUPERVISOR(S): José Manuel Udías & Luis Mario Fraile

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UNIVERSITY/RESEARCH CENTER:
Universidad Complutense de Madrid / Grupo de Física Nuclear

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

Experimental work for characterization and fine tuning of state-of-the-art instrumentation. The objective is to perform measurements of the energy and time response of different types of scintillators (inorganic, plastics, scintillating fibers) for their application to the detection of gamma radiation and charged particles, with applications in spectroscopy experiments, low energy nuclear reactions, excited state time measurements, range monitoring in proton therapy and others. The work will be developed at the nuclear physics group research and instrumentation laboratory, in the premises of the Faculty of Physics at Universidad Complutense de Madrid.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: New particle identification algorithm in the HypHI Phase 0 and WASA-FRS experiments

SUPERVISOR(S): Christophe Rappold, Samuel Escrig López

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UNIVERSITY/RESEARCH CENTER: Instituto de estructura de la materia, CSIC.

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

In the experiments of the HypHI collaboration, the phase 0 experiment and the WASA-FRS experiment, light hadron were measured. A new particle identification algorithm is in development based on statistical method. Efficiency study must be carry out and the experimental yield ratio of identified hadron will be estimated. The research work will consist of studying the efficiency of the particle identification algorithm on the GEANT4 simulations of the Phase 0 and of the WASA-FRS experiments. Once the differential efficiency of algorithm as function of the physical observable is defined, the yield ratio of the different identified hadron in the minimum bias dataset of the Phase 0 experiment will be estimated. Further improvement by designing a machine learning classifier will then investigated with the use of automated machine learning (autoML) framework.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: Development of a machine learning discriminator for improving the hypernuclear signal in HypHI Phase 0 experiment

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UNIVERSITY/RESEARCH CENTER: Instituto de estructura de la materia, CSIC.

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

In the previous experiment of the HypHI collaboration, the Phase 0 experiment, the light hypernuclei $^{3}_{\Lambda}H$ and $^{4}_{\Lambda}H$ were observed in the collision of $^{6}Li+^{12}C$ at 2 GeV/u. The goal of the proposed Master thesis is to use of machine learning techniques for improving the signal-to-background ratio of $^{3}_{\Lambda}H$ and $^{4}_{\Lambda}H$ experimental signal. The work during the Master thesis will consist to use the different machine learning framework for tabular dataset to improve the analysis of the experimental data of the HypHI Phase 0 experiment. The experimental data and Monte-Carlo simulations will be used for creating, teaching and evaluating the different ML algorithms. More advance on usage of automated machine learning (AutoML) will be also investigated to evaluate the obtained efficiencies and possible improvements on ML architectures, pipelines and other optimization for the hypernuclear discriminator.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: Beam dynamics study on linear accelerator for hadrontherapy

SUPERVISOR(S):
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UNIVERSITY/RESEARCH CENTER: Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT)

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

Study on beam dynamics for a linear accelerator designed specifically for hadrotherapy applications. Hadrotherapy is an emerging cancer treatment modality that utilizes charged hadron beams to deliver highly targeted radiation therapy to cancerous tissues while minimizing damage to surrounding healthy tissue.
The primary objective of this study is to optimize and fine-tune the beam dynamics within the accelerator to ensure precise control and delivery of the hadron beams. The research will involve detailed simulations employing optimization algorithms and machine learning to characterize the field maps and the beam properties, including energy, intensity, and beam size, at various stages of the linac. We will also investigate methods to improve beam stability and minimize beam loss during transport, a critical factor in ensuring the effectiveness and safety of hadrotherapy.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: Beta decay experiments at ISOLDE, CERN

SUPERVISOR(S): Bruno Olaizola Mampaso
Andres Illana Sison

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UNIVERSITY/RESEARCH CENTER: IEM-CSIC, Madrid, Spain

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

The ISOLDE laboratory pioneered the development of radioactive beams, and it is still considered a world-class laboratory in nuclear physics. One of its experimental lines is the ISOLDE Decay Station (IDS), which is the permanent setup to conduct decay experiments of exotic nuclei, with a special focus on beta decay. The CSIC and UCM groups routinely use IDS to unravel the nuclear structure of isotopes far from the Valley of Stability.

What are you going to do? The master research project will consist of the data analysis of recent IDS experiments. You will analyze the beta decay of exotic nuclei, building their level schemes and measuring the lifetime of excited state in the picoseconds (10^{-12} s) range.

What are you going to learn? During this work, you will familiarize yourself with the fundamental aspects of decays experiments at IDS, and with the ISOLDE facility at CERN. You will also learn how to use powerful analysis tools like ROOT, the most popular software in the nuclear and particle physics field. Finally, you will gain in-depth knowledge about nuclear structure far from stability and a wide range of nuclear experimental techniques.

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: Full wave simulations of ECRH beam broadening induced by turbulence

SUPERVISOR(S): José Martínez Fernández
Álvaro Cappa Ascasíbar

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UNIVERSITY/RESEARCH CENTER: CIEMAT

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

Electron Cyclotron Resonant Heating (ECRH) is a widely used technique for plasma heating in magnetic confinement devices. The work proposed will be focused on the computation, by means of full wave simulations, of the broadening of an ECRH beam when facing plasma turbulence. Experimental data from the TJ-II stellarator and its ECRH system will be used to build the microwave beam and to create the simulated plasma. Due to the full wave simulations being resource intensive, only 2-D simulations are foreseen. They will be performed using HPC computing resources available at CIEMAT. The work will be developed mainly at CIEMAT with some possibility of remote working.

English Versions

1- **Machine-learning applied to search for heavy neutral leptons with the SBND neutrino experiment at Fermilab**

The neutrino mass represents the strongest hint of the existence of physics beyond the Standard Model. New particles known as heavy neutral leptons proposed in extensions of the Standard Model offer a mechanism to realize the neutrino masses. The SBND experiment, a liquid argon time projection chamber located just 110 m downstream from the origin of the Booster Neutrino Beam (BNB) at Fermilab (Illinois, USA) will search for them. In this Master Thesis machine-learning techniques will be explored to boost the sensitivity of SBND to heavy neutral leptons.

Supervisors: Dr. José I. Crespo-Anadón (CIEMAT) (jcrespo@ciemat.es), Dr. Inés Gil-Botella (CIEMAT) (ines.gil@ciemat.es)

2- **LiquidO: A Novel Neutrino Technology**

The unknowns in neutrino physics demand huge detectors (>kton), with high energy resolution and accurate particle identification. A simple and not costly detector fulfilling these requirements would be a game-changer in neutrino physics. LiquidO is an R+D project for the development of a new neutrino detection technology which uses opaque liquid scintillator. This new technology represents a breakthrough with respect to the traditional neutrino detection with liquid scintillator, essential for future neutrino physics experiments. The tasks proposed in this End-of-Master project cover the development of simulations and the data analysis of several prototypes testing the performance of this new technology. LiquidO is an international collaboration that includes research institutes and universities from France, Italy and Japan.

Supervisor: Dr. Carmen Palomares Espiga (CIEMAT) (mc.palomares@ciemat.es)

3- **Measurement of the photon detection efficiency of the photosensors of the Deep Underground Neutrino Experiment (DUNE)**

The DUNE neutrino experiment aims to measure neutrino oscillations with precision, detect astrophysical neutrinos from a supernova or solar neutrinos, and perform physics searches beyond the Standard Model. To this end, a powerful neutrino beam is being built together with a near detector at Fermilab (USA) and a 67 kton liquid argon far detector at the SURF underground laboratory (USA). The CIEMAT neutrino group participates in the design and characterization of the scintillation light detection system of this detector, which consists of light-collecting modules called X-ARAPUCAs. From the functional point of view, these modules are light traps that capture 127-nm photons, shift them into longer wavelength photons and transport them through light guides to silicon photosensors, where they are detected and converted into an electrical signal.

The objective of this work is to measure the light detection efficiency of X-ARAPUCAs in CIEMAT laboratories. This measurement is crucial to optimize the design of the photodetectors and to compare the experimental data taken with ProtoDUNE at CERN with Monte Carlo simulations which is critical to achieve the physics goals of DUNE.

Supervisor: Dr. Clara Cuesta Soria (CIEMAT) (Clara.Cuesta@ciemat.es)

4- **Study of the coupling between the Higgs boson and the tau lepton for future e+e- colliders**

The only established and measured coupling of the recently discovered Higgs boson to leptons, is the Higgs to tau (H-τ) coupling. This coupling will be measured more precisely at the LHC Run3, and in its high-luminosity version, HL-LHC. However, it will be in a future electron-positron collider, at the TeV collision energies, when this coupling will be determined at a much higher resolution, enabling searches for deviations relative to Standard Model predictions. This TFM will focus in developping analysis based on simulated data from future e+e- colliders still in a conceptual and development phase.

Supervisor: Dr. María Cepeda Hermida (CIEMAT) (mariacepeda@cern.ch)

5- **A study of the Higgs boson coupling structure in the VH(WW) leptonic channel at the CMS experiment.**

A momentous breakthrough in particle physics emerged in 2012 when the CERN LHC's ATLAS and CMS experiments discovered the Standard Model (SM) Higgs boson. This pivotal particle has undergone analysis across various final states, including the Higgs to WW fully leptonic decay. The Higgs boson's production at the LHC hinges on key processes: gluon fusion (ggH), vector boson fusion (VBF), and associated production with a electroweak vector boson (VH, encompassing ZH or WH). By leveraging the kinematics of the Higgs boson decay and associated particles, we can probe the Higgs coupling structure and search for new physics beyond the Standard Model (BSM). Research underscores the heightened sensitivity of the VBF and VH production channels to BSM coupling effects. Nevertheless, the VH leptonic channel—where associated Z/W particles decay leptonically—awaits exploration in a HWW coupling analysis. Our proposal advocates a simulation-based study of Higgs boson couplings within the VH leptonic channel at the CMS experiment. This endeavor entails devising event selection criteria and designing optimal observables to study the Higgs boson couplings within this channel.

Supervisor: Dr. Dermot Moran (CIEMAT) (Dermot.Moran@ciemat.es)

6- **Search for new Long-Lived particles at CMS experiment in LHC, using pp data collisions at a centre-of-mass energy of 13.6 TeV**

There are significant regions in the parameter space of Beyond the Standard Model (BSM) physics that contain long-lived particles (LLPs) which, despite their appeal in addressing fundamental questions of particle physics, have not yet been experimentally explored.

The focus of this Master's Thesis will be on the study of these regions of phase space in various BSM models, where previous searches for LLPs had limited discovery potential. Different types of LLP signals will be studied, and new analysis strategies will be examined for detecting these particles in proton-proton collision data from Run 3 of the LHC, which is being collected with the CMS detector at a center-of-mass energy of 13.6 TeV.

Supervisors: Dr. Alberto Escalante del Valle (CIEMAT) (a.escalante.del.valle@cern.ch), Dr. Begoña de la Cruz Martínez (CIEMAT) (begona.delacruz@ciemat.es)

7- **Study of Transverse Energy-Energy Correlations in models with new fermions beyond the Standard Model.**

The ATLAS Collaboration has recently published a measurement of Transverse Energy-Energy Correlations in events with high-pT jets. These measurements have been compared to theoretical predictions to third perturbative order (NNLO) in QCD, allowing for the most precise determination of the strong coupling constant beyond the TeV scale to date. Given the high experimental precision of these measurements, these data are ideal to study the reinterpretations of the theory in new scenarios with strongly coupled fermions, by means of the variations of the Renormalization Group Equation induced by such fermions.
In this work, such scenatios will be studied using approximate predictions at NNLO, which will be compared to the recent ATLAS measurements with the goal of setting new lower limits on the masses of new fermions at the 95% confidence level.

Supervisors: Dr. Javier Llorente Merino (CIEMAT) (javier.Llorentemerino@ciemat.es), Dr. Isabel Josa Mutuberría (CIEMAT) (isabel.josa@ciemat.es)

8- **Gravitational waves studies with data from the Virgo experiment**

The CIEMAT Gravitational Waves group participates in the data analysis of the Virgo experiment. We are especially interested in fundamental physics studies, like dark energy, dark matter and the estimation of cosmological parameters. In this TFM, the student will contribute to relevant analyses like the study of compact binary mergers (CBC), stochastic background, or Supernovae explosion detection. We envisage introducing Machine Learning and Deep Learning techniques for these studies, focusing on Explainable Artificial Intelligence (XAI). XAI will be carried on to generate robust and unbiased classifiers and predictors, that allow identifying the most relevant variables for the predictions.

Supervisors: Dr. Pablo Garcia Abia (CIEMAT) (pablo.garcia@ciemat.es), Dr. Carlos Delgado Méndez (CIEMAT) (carlos.delgado@ciemat.es), Miguel Cárdenas Montes (CIEMAT) (Miguel.Cardenas@ciemat.es)

9- **Search for Dark Photons from the Sun with Spaceborne Experiments**

Dark matter constituents may only interact with the Standard Model through the kinetic mixing of the so-called *dark photons*, i.e. the gauge bosons of a broken U(1) symmetry, with Standard Model photons. Within this scenario, dark photons are copiously produced in the annihilation of gravitationally captured dark matter in the Sun. These dark photons leave the Sun and decay into pairs of charged SM particles that can be detected by spaceborne cosmic ray detectors. The discovery potential of current experiments (AMS-02, DAMPE, CALET) and future instruments (HERD, ALADInO, AMS-100) will be investigated.

Supervisor: Dr. Miguel Angel Velasco Frutos (CIEMAT) (MiguelAngel.Velasco@ciemat.es)

10- **Gamma Ray Transients and Multi-messenger Physics with Spaceborne Experiments**

Continuous monitoring of the high energy gamma ray sky is a powerful tool to identify transient events associated to the most energetic phenomena in the cosmos. As an example of this multi-messenger approach, the detection of the high-energy afterglow of the short gamma ray bursts associated to the electromagnetic counterpart of gravitational wave (GW) events may provide key information about the nature and location of the GW progenitor. The potential of future large field-of-view cosmic ray experiments (HERD, AMS-100) to detect transient gamma ray signals will be investigated.

Supervisor: Dr. Jorge Casaus Armentano (CIEMAT) (Jorge.Casaus@ciemat.es)

11- **Analysis of the data of the DEAP-3600 Dark Matter Direct Detection Experiment**

The nature of dark matter is one of the still open questions in modern physics with great potential for the discovery of new physics. One of the explanations that best fits the experimental observations involves the existence in the Universe of massive and weakly interacting particles called WIMPs, which would be relics from the Big Bang.

There are various experimental projects for the direct detection of dark matter, aiming to capture the scarce signals arising from WIMP interactions. These experiments are conducted in underground laboratories because the cosmic radiation flux on the surface is too intense and produces a background that masks any potential signal. The CIEMAT-DM group is involved in acquiring and analyzing data from the DEAP-3600 experiment, which is operational at SNOLAB in Canada. The purpose of this Master's thesis is to contribute to the analysis of the data collected by this detector, by developing advanced algorithms for background event rejection to optimize the experiment's sensitivity in detecting WIMP signals.

Supervisor: Dr. Roberto Santorelli (CIEMAT) (Roberto.Santorelli@ciemat.es)

12- **Characterization and Data Analysis of the DArT Detector for Dark Matter Search**

The direct detection of dark matter requires the construction of more sensitive detectors and smarter solutions to the challenges that arise in this field. The international DArT/ArDM experiment, currently under construction in the underground laboratory of Canfranc, aims to search for radiopure argon. This material, being the only target capable of ensuring the search for WIMPs in conditions of complete absence of radiogenic background, plays a crucial role in the next generation of direct dark matter search experiments. The CIEMAT-DM group leads this experiment and is responsible for both the construction of the detector and the analysis of the data obtained in an initial test configuration.

The objectives of this Master's thesis can be tailored to the student's interests, offering the opportunity to gain experience in various aspects of physics experiments. This includes the development of advanced algorithms for data analysis, the performance of Monte Carlo simulations necessary to estimate the contribution of background processes in the experiment, as well as aspects related to hardware and the design/construction of a particle detector.

Supervisor: Dr. Luciano Romero Barajas (CIEMAT) (luciano.romero@ciemat.es)

13- **Study, Construction, and Development of a Two-Phase Detector for Direct Dark Matter Detection**

Many experiments are dedicated to the search for the scarce signals resulting from possible WIMP interactions, so far without success. To overcome the current limits in this field, a new generation of massive detectors unaffected by background is required. The most advanced detector for direct dark matter detection with argon is DarkSide-20k, whose construction has commenced at the Gran Sasso Underground Laboratory in Italy. This experiment will offer unprecedented sensitivity to potential WIMP signals.

In DarkSide-20k, it is essential to distinguish the rare WIMP interaction signals from processes generated by standard model particles. This goal requires a deep understanding of the intrinsic detector background, which can be produced, for example, by natural radioactivity. The objectives of the Master's thesis can be tailored to the student's interests, whether focusing on the analysis of detector's material radiopurity, or carrying out the Monte Carlo simulations needed to estimate the contribution of these interactions to the experiment's background. The proposed tasks entail rigorous learning in particle physics, nuclear physics, and detection techniques, providing excellent preparation for pursuing a Ph.D. in the field of particle physics or astrophysics.

Supervisor: Dr. Vicente Pesudo Fortes (CIEMAT) (Vicente.Pesudo@ciemat.es)

ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2023/2024

MASTER THESIS PROPOSAL

TITLE: Image reconstruction of proton Computed-Tomography (pCT) images

SUPERVISOR(S): José Antonio Briz, Joaquín López Herráiz y José Manuel Udías

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

Proton Computed Tomography is a medical imaging technique currently in research and development phase to be used as main imaging technique for proton therapy treatment plans. In this Master thesis, advanced image reconstruction algorithms will be developed and tested for his potential use in proton therapy treatment plans. Standard algorithms used in PET and X-ray CT reconstruction will be tested before being adapted for the peculiarities of the interactions of protons with matter.