ERASMUS MUNDUS MASTER IN NUCLEAR PHYSICS
Academic Year 2022/2023

MASTER THESIS PROPOSALS BARCELONA

BCN-01
Title: Weak decay of doubly-strange hypernuclei
Tutors: Assumpta Parreño & Laura Tolos   assum@fqa.ub.edu , tolos@ice.csic.es

Abstract: Hypernuclei are bound systems of nucleons and strange baryons (hyperons), which are unstable against the weak interaction, decaying through processes that do not conserve parity, isospin, or flavor. The study of these systems extends our knowledge of the strong and weak interactions from the flavor sector SU(2) to SU(3). Being L hypernuclei the lightest strange nuclei that can be produced in experiments, the study of their structure and disintegration have focused most of the experimental and theoretical efforts for more than 60 years. Recently, attention has shifted to doubly strange nuclei, with experimental programs dedicated to the production of LL and X hypernuclei, including laboratories in Europe, the United States, and Japan. The Barcelona group has extensive experience in computations involving strong and weak interactions using both phenomenological models and effective theories. In this work we intend to extend the existing theoretical work for the disintegration of strangeness -2 systems, including a complete description of the effects of the strong interaction in this process.

BCN-02
Title: Femtoscopy measurements at the LHC for the determination of the D-meson interaction
Tutors: Juan Torres-Rincon y Àngels Ramos   torres@fqa.ub.edu , ramos@fqa.ub.edu

Abstract: Experimental measurements of hadron correlations in particle accelerators can help to discern the details of the interaction among particles. The ALICE collaboration at the LHC has recently presented preliminary results of such measurements for D-meson and light meson pairs, which help to understand their interactions at low energies. This project will consist of the study of the experimental correlation measurements as function of the scattering amplitudes obtained from an effective field theory. The analysis will pay special attention to those channels whose interaction, according to the current theoretical models, seem to be incompatible with the experimental results of the ALICE collaboration.

BCN-03
Title: Causal transport coefficients of heavy particles
Tutors: Juan Torres-Rincon (Barcelona University), Lucia Oliva (Catania University)
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Abstract: The dynamics of heavy-flavor particles can be described via the Langevin equation. Transport coefficients, obtained from fundamental interactions, are necessary inputs to solve this equation. To be respectful with the special relativity principles, a recent study has considered a causal version of the Langevin equation which requires an additional coefficient, the memory time. In this project, the nature of the memory time will be studied from the microscopic interactions of heavy-flavor particles. By applying the theory of hydrodynamic fluctuations, this memory time will be extracted for real systems like D mesons or charm quarks, by performing numerical simulations.

BCN-04
Title: Determination of the exotic meson properties from implemantation of dispersion relation in data analysis
Tutors: Vincent Mathieu vmathieu@ub.edu

Abstract: The COMPASS collaboration (CERN) has reported the observation of a exotic meson in the eta-pi and eta'-pi finals states [1]. The presence of the same exotic meson in both final states has been confirmed by a data analysis in the mass region below 2 GeV [2]. Theoretical developments indicate that this particle would be a quark anti-quark pair in which the gluon field is in an excited state. The data above 2 GeV can actually provide information about the nature of this new resonance and possibly confirm this interpretation [3]. These regions are connected by dispersion relations. This project proposes to derive the dispersion relations for the COMPASS reactions pi- p --> eta(') pi- p and implement them in a data analysis.

[1] https://inspirehep.net/literature/1311486
[2] https://inspirehep.net/literature/1697661
[3] https://inspirehep.net/literature/1859521

BCN-05
Title: Thermal index of neutron stars
Tutors: Arnau Rios arnau.rios@icc.ub.edu

Abstract: The temperature dependence of the neutron-star equation of sate is an essential ingredient for neutron-star merger simulations. In this project, you will use state-of-the-art many-body simulations and nuclear interactions derived from effective field theory to predict the temperature and density dependence of this quantity. To accelerate the numerical simulations, you will also implement a machine learning pipeline that will allow for reliable simulations and consistent error estimations.

BCN-06
Title: Quantum computing the shell model
Tutors: Antonio Márquez Romero, Javier Menéndez, Arnau Rios a.marquez.romero@fqa.ub.edu ; menendez@fqa.ub.edu ; arnau.rios@icc.ub.edu ;

Abstract: The second quantum revolution is making quantum computers a reality at tremendous speed. Among other relevant results, quantum computers can be used to simulate quantum many-body systems without requiring an exponentially large amount of resources. In this project, you will implement a variational eigensolver and apply it to solve a nuclear shell model Hamiltonian [1,2]. Your work will optimise the architecture of quantum computers to perform nuclear theory simulations; will quantify the quantum resources that are required to solve nuclear systems; and will estimate the robustness of quantum computer simulations to noise.

[1] A. Marquez Romero et al, Phys. Rev. C 105, 064317 (2022), arxiv: 2203.01619

[2] O. Kiss et al, Phys. Rev. C 106, 034325 (2022), arxiv:2205.00864

BCN-07

Title: Shape coexistence along the N=Z line
Tutors: Antonio Márquez Romero, Javier Menéndez, Arnau Rios
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Abstract: Atomic nuclei are unique systems which can exhibit coexistence of different shapes at low energies: spherical, lentil-shaped, melon-shape, pear-shape... While these effects are more common in heavy nuclei, light N=Z nuclei such as oxygen-16 also show this property. In this work you will study shape coexistence in light nuclei both from an analytical (based on SU(3) symmetry) and a numerical approach making use of the nuclear shell model and the generator coordinate method. The ultimate goal will be to predict deformation band in some nuclei which could be explored experimentally.

BCN-08

Title: Nuclear theory for searches of physics beyond the Standard Model
Tutors: Javier Menéndez menendez@fqa.ub.edu

Abstract: Several kind of experiments use atomic nuclei to search for physics beyond the standard model (BSM) of particle physics. Since they use nuclei, their interpretation relies on some nuclear theory input which encodes the information of the structure of the nucleus. In this TFM you will calculate nuclear matrix elements for some of these processes. For instance, precision measurements of the beta decay of some nuclei (eg Cs and Ne) are currently testing BSM physics, but to do so they need precision matrix elements to compare with the standard model prediction. You will calculate this beta-decay matrix elements for the first time, as they are currently unknown for Cs and Ne [1]. Another TFM project would involve modelling the interaction of dark matter particles with nuclei. While this has been done in particular cases, high-quality nuclear calculations for several dark matter models are still lacking. You will obtain the nuclear matrix elements corresponding to this dark matter-nucleus interactions, based on previous similar works[2].

References:
[1] https://arxiv.org/abs/2107.14355
[2] https://arxiv.org/abs/1412.6091
