List of available projects for the JAE Intro ICU 2022 at the Unidad de Excelencia María de Maeztu IFCA

The IFCA MdM Unit of Excellence is offering several scholarships for introduction to research and to follow the Master's Degree in Particle Physics and Physics of the Cosmos of the Universidad de Cantabria (UC) and the Universidad Internacional Menéndez Pelayo (UIMP) in the 2022-2023 course. As part of the scholarship, the student will join one of the international research groups at IFCA carrying out a research project in a topic to be chosen from the list below. The student can choose up to three different projects in order of priority. For general enquiries about the scholarships, please send an e-mail to mdmifca-info@ifca.unican.es indicating in the subject "JAE Intro". For specific questions about the proposed projects, please e-mail the corresponding supervisor.

Microwave Instrumentation Calibration for the Study of CMB Polarization

Supervisor: Francisco Javier Casas (casas@ifca.unican.es)

The measurement of the Cosmic Microwave Background (CMB) polarization is considered a unique tool to study the inflationary process of the universe, in particular by means of the B-mode polarization characterization. To take advantage of the instrumental sensitivity offered by present and future detection technology, specific calibration methods are required.
Ground-based observations result nowadays strongly affected by systematic errors. To mitigate their effect, it is required the implementation of calibration systems allowing to correct the systematic errors to a level enough to exploit the potential sensitivity provided by hundreds or even thousands of detectors, that have already reached the quantum limit in terms of added noise.
The proposed project is oriented towards the study of a calibration system that will be onboard a satellite orbiting the earth. This satellite will be oriented to the characterization of the instrumental systematic errors, both in intensity and polarization, of ground based cmb polarization experiments like BICEP (Background Imaging of Cosmic Extragalactic Polarization), ACT (Atacama Cosmology Telescope) or SPT (South Pole Telescope) between others. The calibration cases will be studied, the characteristics and operation of the calibration system will be described and, if possible, laboratory characterization measurements will be performed.

Search for Dark Matter with CCDs

Supervisor: Nuria Castelló (castello@ifca.unican.es), Rocío Vilar (vilar@ifca.unican.es)
The search for Dark matter is one of the hot topics in modern physics. The CCDs are unique devices to search for sub/GeV DM candidates due to exquisite position resolution, and energy and a readout noise below the single electron. This allows a very low threshold that will have an unprecedented sensitivity to search in the e-scattering and electron absorption modes. The prototype of the DAMIC-M experiment, 2 skippers CCDs located in the Subterrain Laboratory of Modane, is taken data now and also the preparation for the installation of the DAMIC-M in the same place will start during next year. In this project, we propose to participate in the understanding of the data taken from the prototype and in the study of the backgrounds for the DAMIC-M experiment.

Calibration requirements of the LiteBIRD instruments

Supervisor: Patricio Vielva (vielva@ifca.unican.es)

One of the limiting factors of future CMB polarization experiments, such as JAXA's LiteBIRD mission, comes from the systematic effects that could eventually be above the instrumental sensitivity. This project aims to define what are the requirements that some systematic effects must satisfy to meet the scientific objectives. Special attention will be paid to the polarization angle.

Cosmology with SKAO

Supervisor: Patricio Vielva (vielva@ifca.unican.es)

The Square Kilometre Array Observatory (SKAO) is an outstanding radio telescope that will operate at the end of the 2020s. Among other fields, it will be particularly relevant for cosmology. This project pretends to forecast some of these capabilities. Special attention will be paid to the component separation of the intensity mapping images.

Search for new physics signals with 2 leptons and missing energy using data from the CMS detector of the LHC collider

Supervisor: Alicia Calderon (calderon@ifca.unican.es)

In this proposal, we seek to address whether we can search for new physics studying different signals with 2 leptons and missing energy in the final state, using data from the CMS detector of the LHC experiment. Among the different signals we will search for a dark matter particle, using as interpretation different simplified models associated with a dark higgs or a SM higgs.
We will make a special effort on understanding the composition of the sample and the sensitivity to new signal processes. It is required to have python and C++ knowledge.

Screening of astronomical X-ray images by means of Deep Learning techniques

Supervisors: M. Teresa Ceballos (ceballos@ifca.unican.es), Diego Tucillo (tucillo@ifca.unica.es)

The XMM-Newton space observatory of the European Space Agency regularly observes the sky. The images produced are used to produce catalogs of X-ray astronomical sources.
However, some of the images show regions that are not appropriate for source detection and should be marked and excluded. Until now, this task has been carried out manually by experts who examine the images one by one, selecting the defective areas and creating exclusion regions around them.
Recently, deep learning-based approaches have introduced cutting-edge performance in image classification problems, due to their self-learning ability to extract image features and their ability to quickly handle large amounts of data. However, the object detection task exceeds the image classification task in terms of complexity. This technique, known as segmentation, consists of creating bounding boxes around the objects contained in an image and classifying each of its pixels. Challenges arise when the context of the entire image has to be taken into account, objects can have very different shapes, and insufficient high-resolution data is lacking.
The purpose of this work is to use Deep Learning techniques to fully automate the selection of the defective areas of the images produced by the XMM-Newton telescope (with a future focus on the Athena mission). From the point of view of data science, these images present many challenges that transform this work into something of special interest, from the perspective of both astronomy and data science.

4D vertex reconstruction in the CMS detector

Supervisor: Pablo Martínez Ruiz del Árbol (parbol@ifca.unican.es)

The HL-LHC will impose very harsh conditions on the CMS detector. In particular the number of spurious collisions is expected to be in the range 140-200, adding complexity to the reconstruction process. The Mips Timing Detector (MTD) is a new sub-detector that will be installed in CMS in order to measure the time of passing of charged particles. This information will allow us to add a new dimension to the vertexing problem: the time. This work aims at using the current Deterministic Annealing algorithm to find the vertices and extend it to improve the reconstruction. Additionally new algorithms based on Machine Learning will be explored for this task.

Particle detection with 3D pixels in the CMS experiment

Supervisor: Jordi Duarte-Campderros (duarte@ifca.unican.es)

The new 3D pixel detection technology is being tested and intensively characterised in order to be used in the innermost layers of Phase-2 Tracker system of CMS detector placed at CERN. The IFCA group, and in particular, the supervisor of this work, are an important part of this effort in the CMS collaboration. The formation and research plan for this work is lying in this field to take advantage of the knowledge and expertise of the group and the supervisor. The student will familiarise him/herself with the 3D pixel technology combining both bibliography study and observational experiments of these

devices in the lab, using the usual characterization techniques. The supervisor will introduce those techniques: TCT (Transient Current Technique) to study the detector response by emulating the pass of particles through the detector with lasers, and studying the detector response in the same working conditions as in the real experiment (test beam data taking). Both tools have been proven to be very useful from an educational point of view, giving to the student the insights to understand the mechanisms of the semiconductor detectors from the real research work perspective.

The student will learn the basics of those techniques, will perform TCT measurements in the lab, and will analyse real data taken from test beams with the help of the supervisor. This part of the work will allow the student to be exposed to a very important aspect in any Particle Physics research work or project: the development and use of highly specialised software.

Simulating the disruption of Dark Matter miniclusters

Supervisor: Bradley J Kavanagh (kavanagh@ifca.unican.es)

The axion is a light, scalar particle which is a well-motivated candidate for the Dark Matter in our Universe. Depending on their exact properties, axions may form relatively dense, gravitationally bound structures in the early Universe, known as "miniclusters". These miniclusters may be observable in microlensing surveys, or through the conversion of the axion inside them into radio photons, in the presence of strong magnetic fields. However, encounters with stars may disrupt miniclusters, spoiling our chances of detecting them.

In this project, we will study how axion miniclusters behave when perturbed by stars and how their properties are changed through these interactions. To do this, we will use and adapt existing codes to simulate the dynamics of miniclusters when the wave-like nature of the axion becomes important. With these results, we will explore the implications for the survival of axion miniclusters and for their possible observational signatures.

Top quark properties with the CMS detector at the LHC

Supervisor: Javier Brochero (brochero@ifca.unican.es)

The Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) has a robust program in top quark physics. The LHC, considered a top quark factory, makes possible many precise measurements of the top quark properties. In this Master Thesis (TFM), we aim to perform a measurement of the top quark pair production cross section in association with additional jets and bosons (W, Z and H). We will focus our attention on those tt events containing leptons and jets in the final state due to their relevance in the recent observation of the ttH process and the searches of new physics. We will use the latest ML developments in jet identification and event categorization.

Characterization of Galactic foregrounds in CMB observations

Supervisor: R. Belén Barreiro (barreiro@ifca.unican.es)

The Cosmic Microwave Background (CMB) is a very weak radiation that reaches us from all the directions of the sky. It originated shortly after the Big Bang and constitutes the oldest radiation that we can observe in the Universe. It shows tiny differences in temperature from one point to another of the sky, giving us very valuable information about the early universe and how it evolved. CMB radiation is also polarized. In particular, if we were able to detect the so-called B-mode of polarization, this would imply the existence of a Primordial Background of Gravitational Waves, as predicted in inflation. This would constitute a very solid proof of this theory as well as a major discovery in Physics.

However, CMB observations also contain a number of contaminant astrophysical signals and instrumental noise, that are mixed with the signal of interest and that must be separated from the CMB before deriving any meaningful cosmological conclusion. Therefore, a key point to analyse CMB data is to develop specific methodology that allows one to separate and/or characterise the contaminants coming from our Galaxy, in particular the synchrotron and thermal dust emissions.

The student will learn about the CMB field, and would apply advanced statistical tools in order to study these emissions. The performance of these techniques will be tested with simulations and/or real CMB data.