LIST OF AVAILABLE PROJECTS FOR THE JAE Intro SOMdM and JAE Intro ICU 2020 at 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 the Cosmos of the Universidad Internacional Menéndez Pelayo (UIMP) and Universidad de Cantabria (UC) in the 2020-2021 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 (a description of each of the projects is given after the table). 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.

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Searching for Primordial Gravitational Waves

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 was 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, what give 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.
During the last two decades, the advance in the knowledge of our Universe has been very large, partially due to the available high-quality CMB data, mainly in intensity. At present, there is a large effort dedicated to the search of the B-mode of polarization with experiments already working (such as QUIJOTE in Tenerife, where we participate) or planned. However, CMB data contain not only this radiation but also a number of 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. Moreover, these astrophysical emissions are of interest by themselves, and provide also additional valuable information. Therefore, a key point to analyze the CMB data is to develop specific methodology that allows one to separate and reconstruct all these different components. There already exist a number of techniques to carry out this problem, but they have been mainly tested on intensity data, and it is necessary to adapt them to the problem of polarization.
The student will learn about the CMB field, and would develop a component separation method that will be tested with simulations and with real CMB data.

Study of the properties of the Higgs boson in the LHC CMS experiment

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

The main purpose of the project is the participation in the scientific exploitation of the LHC collider data taken with the CMS detector during the Run2. The objective of the present work is the measurement of the production cross section of a Higgs boson in the decay channel to two W bosons at a center of mass energy of 13 TeV in proton-proton collisions. The final di-lepton channel will be used for this, in which each of the two W bosons decays leptonically. The differential cross section may also be measured as a function of different kinematic variables associated with the final leptons.

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

Supervisor: María Teresa Ceballos (ceballos@ifca.unican.es) and Diego Tuccillo (tuccillo@ifca.unican.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.

Particle detection with 3D pixels in the CMS experiment

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

The new 3D pixel detection technology is being tested and intensively characterized 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 on this field to take advantage of the knowledge and expertise of the group and the supervisor. The student will familiarize 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 emulating the pass of particles through the detector with lasers, and studying the detector response in the same working conditions than 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 analyze real data taken from test beams with the help of the supervisor. This part of the work will allow the student to be exposed into a very important aspect in any Particle Physics research work or project: the development and use of highly specialized software.

Searching obscured AGNs with J-PAS

Supervisor: Ignacio González Serrano (gserrano@ifca.unican.es)

We propose to develop a method to search for reddened QSOS in large-area extragalactic surveys. In particular, this method would be applied to the survey J-PAS. This method will be based on machine-learning techniques starting from existing data in radio, infrared, optical and UV ranges, more specifically on surveys FIRST, SDSS, DES, Galex, WISE, and UKIDSS amongst others.

We will apply methods based on unsupervised clustering (manifold learning and gaussian mixture models) as exploratory data analysis (EDA) and, later, we will apply neural networks for source classification. First stage will be a characterization of known obscured AGNs. At a second stage, this will be applied to the survey J-PAS.

Main goal is to obtain a candidate catalogue including an estimation of the redshift.

Plan:
(1) Recopilation of known obscured AGNs in the aforementioned surveys
(2) Adaptation of our own methods to improve efficiency and completeness of classification.
(3) Aplication to J-PAS data

Studying the capabilities of future CMB experiments to detect the primordial gravitational wave background

Supervisor: Enrique Martínez González (martinez@ifca.unican.es)

One of the most important challenges in cosmology is the detection of primordial gravitational waves that originated from quantum fluctuations during the inflationary phase of the universe. The best way to detect them is indirectly, through the genuine imprint left in the polarization of the Cosmic Microwave Background. Many experiments are currently being designed that attempt to measure this footprint, both from the ground and from artificial satellites. They have very different configurations and strategies that result in very different characteristics in terms of instrumental sensitivity, angular resolution, frequency and sky coverage, and systematic effects. While the instrumental sensitivity, resolution and coverage of the sky directly affect the accuracy of the measurement of the amplitude of the gravitational waves, the frequency coverage and the control of the systematic effects of the instrument are relevant to separate the cosmological signal from the other astrophysical signals and to limit the degradation and bias in the measurement, respectively.
The work to be carried out will consist in a comparative analysis of the different experimental configurations and strategies proposed for the measurement of the amplitude of the primordial gravitational waves. The most important characteristics of each experiment will be taken into account, and its impact on the error bar and on the expected bias of the measurement of the amplitude of the primitive gravitational waves will be quantified. Based on these results, it will be discussed which is the ideal configuration, as well as the configurations that represent a greater complementarity when measuring the parameter r.

Use of generative adversarial neural networks to improve the simulation of quark-antiquark top pair events

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

This project aims at exploring the usage of generative adversarial neural networks (GANN) to produce realistic simulations of quark-antiquark top pair events at the LHC accelerator. The focus of the analysis will be put on the distribution of the MT2 variable. This variable is widely used in searches for the supersymmetric partner of the top quark (stop), because it presents a sharp edge for standard model quark-antiquark top events, while it is unbounded for stops. The GANN will be trained using real data collected by the CMS experiment, targeting to improve the simulation provided by the MADGRAPH generator and the GEANT4 program. It is important to remark that most of the complexity of the searches involving top quarks in the final state, is related to the correction and assignment of the systematic uncertainties to the simulated MT2 distribution. This proposal, directly addresses this problem by trying to produce more realistic simulations using automatic learning from data. The project will require to use standard tools in the market such as Tensorflow and Keras. The results will be presented in the Third-Generation Searches groups of CMS of which I was coordinator in the past. The algorithms will be executed in the computing cluster of the High Energy Physics group at the Institute of Physics of Cantabria.

The cosmic microwave background polarization as a new window to look at the large-scale anomalies.

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

The cosmic microwave background (CMB) is, probably, the most precise observable that is currently helping us to build up the standard cosmological model. Thanks to it, we know that the observable universe is about 13700 million years old, that has an almost flat spatial geometry, that its dynamic and evolution are given, at the actual time, by 5% of baryonic matter, 27% of a cold and dark form of matter, and 68% of dark energy, actually responsible of the current accelerated expansion of the universe. In addition, the CMB has being corroborating many of the predictions made by the cosmic inflation mechanism, which is the framework to explain the cosmological properties of the universe, as well as the origin of the large-scale structure. This success, grounded on observations from the NASA WMAP satellite and, moreover, from the ESA Planck mission, was accompanied by the so-called large-scale anomalies: indications that, contrary to what is predicted by the simplest inflationary models, the universe shows some statistical deviations related to the isotropy and the Gaussianity, two of the fundamental hypotheses derived form such models. It is not possible to go further into the characterization and a possible explanation for these anomalies by studying the intensity fluctuations of the CMB, and additional information is needed from the polarization anisotropies. This research project aims, on one side, to derive predictions of possible CMB polarization observations related to the large-scale anomalies for future space-borne missions and, on the other side, to study the capability to obtain new maps for the CMB fluctuations that include the correlations between the intensity and polarization fluctuations.

GEANT4 simulations for the DAMIC-M experiment

Supervisor: Rocío Vilar (vilar@ifca.unican.es)

This research project is based on a new initiative to search for Dark Matter (DM) through Direct Search at underground Laboratories, called DAMIC-M (DArk Matter In CCDs at Modane). DAMIC-M is a next generation experiment that will be located at the Laboratoire Souterrain de Modane (LSM), Modane (France). This experiment uses as detection technique scientific CCDs with the new skipper readout that get single electron resolution with the idea to increase the sensitivity to very light DM particles. The design of DAMIC-M will have unprecedented sensitivity to sub-GeV dark sector DM particle. The study of the different backgrounds is an essential part to get the goal, in this project we propose to do GEANT4 simulations of the different materials and the DAMIC-M detector to determine the amount of background expected and help to the final design of the detector.