LIST OF AVAILABLE PROJECTS FOR THE JAE Intro SOMdM 2019 at IFCA

The IFCA MdM Unit of Excellence is offering up to 5 fellowships 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 2019-2020 course. As part of the fellowship, 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 fellowships, please send an e-mail to mdmifca-info@ifca.unican.es indicating in the subject "JAE Intro SOMdM". For specific questions about the proposed projects, please e-mail the corresponding supervisor.

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Component separation in Cosmology

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.

Search for Dark Matter particles in the CMS detector at LHC

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

One of the big questions of new physics Beyond Standard Model (BSM) is the origin of Dark Matter (DM). Many cosmological evidences indicate its existence. Nevertheless, there has been no observation of DM at high-energy colliders neither at direct-detection (DD) experiments. The most compelling DM candidate is a weekly interacting massive particle (WIMP) that couples to SM particles. Such new particles, which could account for dark matter, appear in various theories BSM. In this scenario DM can be directly produced and studied at high-energy colliders. No trace of WIMP dark matter has been found so far.
The lack of BSM signals from the Run 1, and partially Run 2 of the LHC, just constrains the set of suitable BSM models, possibly reducing the appeal of some frameworks, which would now require a finer tuning of their parameters to remain viable. The search for BSM signals remains therefore a top priority for the LHC.
In this proposal, we seek to address whether we can identify particles as WIMP dark matter within the context of simplified models. In recent years, the dark matter

community has moved towards simplified models as a useful way to display the results from their searches for dark matter. The aim of a simplified model is to provide a bottom-up framework to characterize all of the relevant dynamical processes that occur in the production or scattering of dark matter with a small number of additional particles and parameters. We will continue working on the mono-Higgs channels, considering the final state with 2 leptons and missing transverse energy. We will consider also new pseudo-scalar mediator in 2HDM models. Pseudo-scalar mediators have the obvious advantage of avoiding constraints from DM direct detection experiments, so that the observed DM relic abundance can be reproduced in large regions of parameter space and LHC searches are particularly relevant to test these models. It is foreseen to yield stronger limits than mono-jet searches in large parts of the parameter space. It will be necessary to revise the analysis strategy, by increasing the signal efficiency and hence the sensitivity of the analysis. Current results are based on lepton triggers that require isolation cuts in the filter algorithms, and this kills most of our signal in the boosted regime. In order to recover signal events, we will define a new trigger selection, such the use of lepton triggers without isolation or MET triggers. A details study on this has to be done in each of the data taking periods.

Microwave Photonics Instrumentation Developments for the Study of CMB Polarization

Supervisors: Francisco J. Casas (casas@ifca.unican.es) and E. Martínez-González (martinez@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. In order to reach the instrumental sensitivity required for that, different detection technology can be used, depending on the frequency range. For frequencies higher than 50 GHz, bolometric technology, such as Transition Edge Sensors (TES) or Kinetic Inductance Detectors (KID) are the most suitable due to their sensitivity and capabilities of fabricating thousands of detectors in a common buffer. However, for frequencies lower than 50 GHz the use of other technologies, such us Microwave-Photonics receivers, results very promising due to their particular capabilities offered to correlate and detect hundreds of wide-band microwave signals.
The proposed project is oriented towards the study and characterization of several opto-electronic and photonic modules, which can be used to implement instrumentation to measure the polarization of the lowest frequency bands of the CMB, with the required sensitivity. Fibre and also Photonic Integrated technology will be considered for the implementation of reduced cost Microwave Photonics receivers.

Charge transport implementation for Silicon Detectors within the DAMIC (Dark Matter in CCDs) Experiment

Supervisors: Nuria Castelló (castello@ifca.unican.es) and Rocío Vilar (vilar@ifca.unican.es)

Who: We are looking for a highly motivated physicist with strong computational skills, in particular C++ and/or python.

Where: The Project will be on the subject of solid-state ionization detectors within the DAMIC experiment, and will take place in the Particle Physics and Instrumentation group of the Instituto de Física de Cantabria (IFCA, CSIC-UC) in Santander.
What: The goal of the project will be to implement the detailed charge transport for silicon detectors (in particular for CCD devices) into the DAMIC Geant4 simulations.
Background: Solid-state ionization detectors have been proposed for next-generation direct searches for dark matter. Thanks to their very low noise and the small band gap of the semiconductor target, these detectors are most sensitive to low-mass dark matter particles by their interactions with nuclei or electrons in the target. The interactions of dark matter particles in DAMIC produce ionization signals in the CCDs. Ionization charge produced basically at a point in the bulk silicon of the CCD and is drifted along the direction of the electric field. The holes (charge carries) are collected by the pixels. Because of thermal motion, the ionized chare diffuses transversely with respect to the electric field direction as it is drifted, with a spatial variance that is proportional to the carrier transit time. Therefore, a complete understanding and implementation of the charge transport is crucial to study the background in the bulk of the target (specially in the low energy regime) and mandatory for the success of low-mass dark matter searches.
The work itself: The project will consist of first familiarizing oneself with the charge transport mechanisms, study possible frameworks to obtain and characterize a full electrostatic simulations for the description of the electric field in silicon sensors (for instance the TCAD framework), and finally integrate the electric field within the full Geant4 DAMIC simulations.

Automated spectral characterisation of highly obscured active galaxies

Supervisor: Amalia Corral (corral@ifca.unican.es)

Active Galactic Nuclei (AGN) are the brightest persistent sources in the Universe. The origin of this emission is accretion of matter onto supermassive black holes at the core of their host galaxies. In most cases, most of this emission is absorbed by the large amount of material that surrounds the black hole, we call these sources obscured AGN. They are a key ingredient in the models for formation and evolution of galaxies. X-rays, thanks to their high penetrating power, are the most efficient method to detect and characterise these sources. After the launch of Athena (the new great X-ray observatory of the European Space Agency) it is expected that thousands of these sources will be detected routinely in its sky surveys.
Determining the distance (redshift) for these sources is fundamental, but requires optical and/or infrared spectroscopy. This is not feasible for large samples of AGN, due to the need for extensive observational campaigns in ground-based 8-m class telescopes.
We propose to develop an automated method to estimate distances to these AGN based only on X-ray spectroscopy. This method takes advantage of two great advantages of observing obscured AGN in X-rays:
1) Observations based in photon counting (the method of work in X-rays) provide spectral information without additional observations
2) One of the most common spectral characteristics of obscured AGN is the presence of an intense lie at energies between 6.4 and 6.9 keV (FeK alpha) due to Fe fluorescence, which is relatively easy to detect and characterise using automated methods

This method will be applied to large existent AGN samples, obtained from large surveys with XMM-Newton and Chandra. The method will be optimised using simulations for future missions, such as eROSITA and, mostly, Athena.

Using Gravitational Waves to constrain Dark Matter

Supervisor: José M. Diego Rodríguez (jdiego@ifca.unican.es)

Thanks to the LIGO and Virgo detectors, Gravitational Waves (GWs) have recently become a new probe of astrophysical phenomena. One of the puzzles emerging from recent results on GWs is the relatively high abundance of black holes with masses around 30 solar masses. One possible explanation for such high abundance is that some (or all) of these black holes are Primordial Black Holes (PBHs). PBHs can be produced during the first instants of the universe and they could account for a fraction of the mysterious Dark Matter (DM). Recent results show that GWs are sensitive to the structure of DM on very small scales, for instance PBHs. This project will explore this new area through the use of numerical simulations that simulate the effect of compact dark matter on GWs. The project is expected to produce novel results relative to the abundance of this candidate for dark matter and offer a possible interpretation to the results obtained by LIGO/Virgo.

Study of the capability 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.

Properties of the material responsible for the obscuration of the giant black holes

Supervisor: Silvia Mateos (mateos@ifca.unican.es)

Giant black holes, with masses of millions to thousand millions the mass of our Sun (SMBH, SuperMassive Black holes), reside in the centres of the most massive galaxies. Active galaxies (AGN, Active Galactic Nuclei) are those that host SMBH in an active phase of growth, i.e., increasing their mass through accretion of material from the galaxy.

Most of the accretion phenomenon throughout the history of the Universe occurs in a phase in which AGN are extremely luminous, but they are obscured by huge quantities of gas and dust, which make their detection very difficult. The identification of this important phase in the growth of SMBH remains a major challenge in modern Cosmology.

In order to be able to determine how many AGN we are missing, it is necessary to understand the properties of the material responsible for the absorption of the emission from the nuclear region of AGN (quantity of gas and dust, localisation, geometry) and its dependence on the properties of the accretion onto SMBH (luminosity, accretion rate...). This is the main goal of this project.

A sample of about 100 luminous AGN selected in the mid infrared will be used to quantify the covering factor of the material that obscured the AGN. The spectral energy distributions of the objects will be built and fit with different AGN and galaxy models to isolate the emission from the absorbing material. The analysis of this emission with models already available in the literature and tools developed by our group will allow the determination of the covering factor of the material for each AGN. The results will be analysed to investigate which parameters of the accretion phenomenon have a direct influence on the structure of the obscuring material.

Looking at the large-scale anomalies of the CMB in polarization

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

Thanks to the cosmic microwave background (CMB) we have established the most accurate picture on the origin, content and evolution of the Universe. In particular, it has offered several evidences on the role played by the inflationary mechanism on defining its global properties. Together with this successful definition of the standard cosmological model, the WMAP and Planck data have provided evidences of the so-called CMB large-scale anomalies: some hints of statistical deviation of the isotropy and Gaussianity of the temperature fluctuations, which are fundamental properties predicted by the simplest inflationary models. The information provided by the CMB temperature has reached already the maximum of its sensitivity (limited by the cosmic variance) and, therefore, other observables should be explored. Among them, the polarization of the CMB is one of the most important ones. This work aims to explore what future missions, like LiteBIRD, could provide us in relation to some of the CMB anomalies.

Radiation tolerance assessment of Low Gain Avalanche Detectors (LGAD) for the timing detectors of the HL-LHC

Supervisor: Iván Vila Álvarez (ivan.vila@csic.es)

For the high-luminosity LHC upgrade (HL-LHC), the ATLAS and CMS experiments are planning to include dedicated detector systems to measure the arrival time of Minimum Ionising Particles (MIPs) to disentangle the signal proton-proton scattering from the huge underlying background due to other multiple proton-proton hard scatterings. Such systems should provide a timing resolution of 30 ps per MIP. State-of-the-art timing technologies integrating Silicon photo-multipliers and plastic scintillators do not tolerate the hadron fluences expected at the end-cap detector regions (up to $3\times10^{15} n_{eq}/cm^2$). To cope with these requirements, a Silicon sensor with integrated signal amplification, the Low Gain Avalanche Detector (LGAD) is the baseline sensing technology of the end-cap timing detector systems at HL-LHC. A comprehensive radiation tolerance study of LGAD pad-like sensors manufactured at IMB-CNM and irradiated at CERN's PS-IRRAD proton facility up to a fluence of $3\times10^{15} n_{eq}/cm^2$ will be carry out in this project. Two different active thicknesses will be studied: 35 μm and 50 μm.

Searching for Dark Matter with the DAMIC experiment

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

The nature of dark matter (DM) is today one of the most important and central mysteries of physics. One of the strategies used to explore dark matter is direct detection, where it is conjectured that the DM particle collides with ordinary matter, with an atom or detector core. DAMIC is a direct material search experiment. It uses dark technology that uses silicon technology as detection technique, in order to have the highest detection sensitivity in the area of very low mass. The experiment is based on the use of CCDs modified and optimized for this type of interactions. The successful use of this new technology in the Dark matter search has been achieved with a prototype of small volume located in the laboratory SNOLAB, lab. underground in Sudbury, Ontario Canada. This prototype, 7 CCDs with a total mass of 40gr, will be updated to reach a total mass of 1kg composed of 50 CCDs improved (DAMIC-M).
In this type of experiment, controlling the backgrounds is essential to be able to detect, if this is the case, the movement of the nucleus as a result of the elastic collision of the DM particle with the silicon crystal lattice. This background studies will be the topic of research for the student. In particular, initiate the student in the DAMIC-M project, working on specific and critical aspects such as the radiopurity studies of the materials that will be used in the construction of the detector, essential for unraveling a possible detection of dark matter. Part of the radiopurity measurements of materials (such as electronics, protective materials, cables, etc.) are going to be made in the Canfranc Underground Laboratory (LSC).
Specifically, the student would have work on the optimization of the simulation of the particles emitted by the source and collected by the radiopurity detector, with the GEANT4 program, to get better efficiency and therefore more precise measurements. Also another important part that would help with the simulations, is analyze the

measures of radiopurity of the samples that have been taken at Canfranc to get the rate of this impurities.
One of the novelties of this project is that we include the use of National laboratory specially designed to search for dark matter and searches related to neutrinos. The laboratory is a Spanish infrastructure that has a radiopurity facility to perform very low level measurements with 7 high Germanium detectors purity, HpGe, which can detect activities less than 1 mBq/kg (~10-12 g/g). We would participate in the measurements and preparation of the samples of DAMIC-M, in addition to the Monte Carlo simulation and analysis of data in the LSC itself. During this work we are supported by the technical staff of LSC and we have the support of the management for the use of the Laboratory in what we need. But the most important thing about this Project and that will occupy most of the student, will be participation in work new and important to help future measurements of radiopurity made in Canfranc which consists of the MonteCarlo code optimization for germanium detectors and calculation of efficiencies when calibrated detectors with sources from IAEA (International Atomic Energy Agency).