# IFAE

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## Institut de Física d'Altes Energies

## Report of Activities **2015**

BIST Barcelona Institute of Science and Technology

Institució CERCA Centres de Recerca de Catalunya

EXCELENCIA SEVERO OCHOA

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Institut
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d'Altes
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# 1. ABOUT **IFAE**

## 1.1 STRUCTURE

The Institut de Física d'Altes Energies (IFAE) is a consortium of the Generalitat de Catalunya and the Universitat Autònoma de Barcelona (UAB). It was formally created on July 16, 1991, by Act number 159/1991 of the Government of Catalonia (Generalitat de Catalunya). As a consortium, IFAE is an independent legal entity. In 2015, it operated under the auspices of the Department of Economy and Knowledge (Departament d'Economia i Coneixement, DECO), of the Generalitat.

The governing bodies of the Institute are the Governing Board (Consell de Govern) and the Director. The general lines of activity, the hiring of personnel, the annual budget and the creation and suppression of Divisions are among the responsibilities of the Governing Board, which also appoints the Director from a list of candidates nominated by the Rector of UAB. The Director is responsible for the execution of the decisions of the Governing Board. Additional management personnel, such as the directors of the several divisions, are nominated by the Director.

**THE INSTITUT DE FÍSICA D'ALTES ENERGIES (IFAE) IS A CONSORTIUM OF THE GENERALITAT DE CATALUNYA AND THE UNIVERSITAT AUTÒNOMA DE BARCELONA (UAB). IT WAS FORMALLY CREATED ON JULY 16, 1991**

IFAE enjoys a close collaboration with the Theoretical and Experimental High Energy Physics Groups of the Department of Physics of the UAB. In addition, since the creation of ICREA, several investigators from this prestigious research institution have joined IFAE. As of the end of 2015, this component of the Institute consists of seven ICREA research professors, with continuing tenure.

Personnel of the Departments of Structure and Fundamental Constituents of Matter and of Fundamental Physics of Universitat de Barcelona (UB) were also members of IFAE, under the terms of an agreement between the Institute and UB established in 1992. This agreement was modified in 2003. Under the new terms, the cooperation between IFAE and the UB is focused on specific goal-oriented projects.

IFAE is structured in two divisions, experimental and theoretical, as well as a technical division. The theory division faculty is composed of three ICREA research professors and an IFAE researcher. They share physical and human resources (postdocs and students) with the personnel from UAB. The personnel of the experimental division are mostly from IFAE itself, but it includes four research professors from ICREA. It collaborates with four UAB professors. The technical division includes a variable number of engineers and technicians.

IFAE also has the status of a "University Institute" attached to UAB. This formula allows the personnel of IFAE to participate in the educational programme of UAB, in particular by teaching Master courses in the Master in High Energy Physics, Astrophysics and Cosmology.

## 1.2 IFAE GOALS AND BRIEF HISTORY

As stated in the foundational Act 159/1991 of the Generalitat, the goal of IFAE is to carry out research and to contribute to the development of High Energy Physiscs from a theoretical, experimental and technological point of view. The origins of the consortium lie in the Department of Theoretical Physics and in the Laboratory for High Energy Physics (LFAE) of UAB. The theoretical group was established in 1971, soon after the university was founded. The Laboratory for High Energy Physics was created in 1984, in order to start research in experimental high-energy physics at UAB, particularly to effectively use the CERN laboratory, after Spain rejoined CERN in 1982. As mentioned in Act 159/1991, the existence of LFAE and of theoretical research groups in Catalonia, the desire to strengthen research in High Energy Physics, particularly in the experimental side, and the desire to collaborate in the Spanish Government's effort to develop this field, led the authorities of the Generalitat to create IFAE. In the following years the experimental division of IFAE grew from a staff of 10 to its present strength of about 70. The experimental program has expanded both in the number of projects and in their scope. In 1991 the division was involved in just one experiment in high-energy particle physics, ALEPH at LEP, while at present there are nine projects belonging to three main lines of fundamental research: particle physics at high energy accelerators, gamma-ray astrophysics, and observational cosmology. In addition, there is a small but very active line of applied physics, devoted to novel techniques in medical imaging.

The theory division also expanded its research program since IFAE was created. There are at present three main lines of research: Standard Model physics, Beyond the Standard Model, and Astroparticles/Cosmology.

An additional important development took place in 2003, driven by the strongly perceived need for remote handling of vast quantities of scientific data, not only for high-energy physics experiments but also for astrophysical facilities such as MAGIC. In 2003 three Spanish institutions, UAB, CIEMAT in Madrid and the Departament d'Universitats Recerca i Societat de la Informació (DURSI) of the Government of Catalonia, together with IFAE, jointly founded the Port of Scientific Information (PIC). This center is a focal point of the global computing grid for scientific projects requiring the processing of large amounts of data. PIC was chosen by the Spanish Ministry of Science and Education as a Tier-1 center for LHC computing. IFAE was charged by the other partner institutions with the administration of PIC. There is a very close collaboration with PIC on computational aspects of all IFAE experiments that are producing data or will do so in the near future. The scientific activities of PIC are described in its own reports.

It is worth emphasizing that, as an independent legal entity, IFAE can manage its own projects as well as certain external ones. These management activities have been a very visible contribution of IFAE to the development of Spanish scientific infrastructures, which might not have been possible otherwise. The most important among these activities are briefly recalled next.

From 1995 to 2001 the Synchrotron Light Laboratory of Barcelona (LLS) was administratively part of IFAE. The LLS was the organization that proposed and prepared the construction of ALBA, the Synchrotron Light Laboratory.

IFAE was responsible for the construction of the building that services the MAGIC telescopes at the Roque de los Muchachos site in the island of La Palma. IFAE also manages the maintenance and operation funds of the MAGIC collaboration.

From 1999 to 2004 IFAE managed the contract between CERN and a Spanish company for the construction of the vacuum vessels of the ATLAS Barrel Toroid. This very large project had a cost of about 3 million euro distributed over several years.

In 2007, the observational cosmology group of IFAE and others proposed the PAU (Physics of the Accelerating Universe) initiative, which was approved as a Consolider-Ingenio 2010 project. IFAE leads the PAU collaboration, comprised of several Spanish groups. The goal of this initiative is to survey a fraction of the Northern sky in order to measure parameters of cosmological interest by means of novel observational tools.

**IN 2012 IFAE WAS GRANTED THE SEVERO OCHOA PRIZE, A DISTINCTION GIVEN BY THE SPANISH STATE TO THE BEST RESEARCH INSTITUTES IN THE COUNTRY**

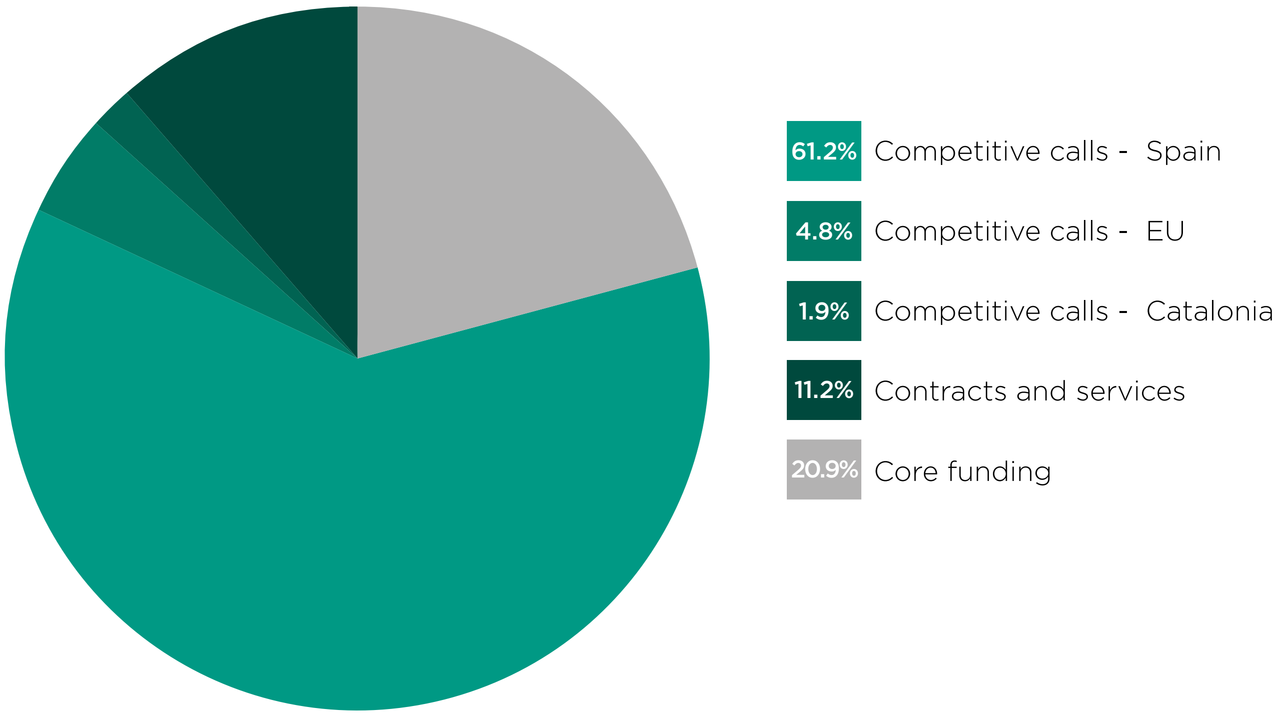
Since the past decade, the relationship between IFAE and the Generalitat of Catalonia is regulated under a Contract-Program, which codifies the support of the Institute from the Generalitat and the corresponding obligations of IFAE. Based on a strategic plan, the Contract-Program specifies the envisaged growth of the Institute's personnel and funding. The scientific and academic goals are specified in a set of numerical indicators, which are reported on a yearly basis. The past Contract-Program covered the period from 2007 to 2012 included. Since 2012, because of the current economic uncertainties, it is being extended one year at a time.

In 2012 IFAE was granted the Severo Ochoa prize, a distinction given by the Spanish ministry to the best research institutes in the country. The prize carries funding of 1 M€ a year for four years and is strengthening IFAE's activities and its capabilities to obtain additional funding. Manel Martínez is the scientific director of the Severo Ochoa award.

Finally, in 2015 IFAE joined five other top research centers in Catalonia (CRG, ICIQ, ICN2, ICFO and IRB, all Severo Ochoa prize winners), in areas ranging from nanotechnology and photonics to chemistry, genomics and biomedicine, to create The Barcelona Institute of Science and Technology (BIST), with the goals to cooperate in, among other areas, training and knowledge and technology transfer, to build critical mass for international visibility, and to encourage multidisciplinary research.

## 1.3 FUNDING SOURCES IN 2015

IFAE receives its core funding from Generalitat de Catalunya. Most of the overall funding, however, comes from competitive calls at the Catalan, Spanish and European levels. Additional funds are secured through contract research and services to third parties. As shown in the pie chart below, in 2015 the ratio of competitive to core funding was about 3.8. It has been consistently above 3 throughout the history of IFAE. The total income in 2015 was slightly under 6 million euros.




$$\frac{\text{TOTAL COMPETITIVE FUNDING}}{\text{TOTAL CORE FUNDING}} = 3.8$$

# 1.4 IFAE GOVERNANCE IN 2015

## GOVERNING BOARD

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# 2. SCIENTIFIC **ACTIVITIES IN 2015**

## OUTLINE

## EXPERIMENTAL DIVISION

During 2015 the Experimental Division's activities focused on 10 main projects, most of them long-term efforts. These projects span the fields of High Energy Physics, Astrophysics and Cosmology, and include the development of detectors for Medical Imaging applications as well as related instrumentation projects.

### HIGH ENERGY PHYSICS

High Energy Physics is represented by three major, long-term projects:

1. ATLAS, at the Large Hadron Collider (LHC) of CERN. In 2015, LHC started to operate at the highest ever center-of-mass energy of 13 TeV. This broader energy range opens the possibility of new discoveries. A tantalizing hint of a possible new particle with a mass around 750 GeV generated a lot of excitement within the community. However, more data, to be taken in the 2016 run, are necessary before any firm conclusions can be drawn. In the meantime, most analyses using the data acquired in the previous runs at 7 and 8 TeV were finalized in 2015, and three PhD theses were defended at IFAE, on topics ranging from studies of Higgs production and decay to searches for new physics in top-antitop final states.

2. The ATLAS upgrade, in preparation for a major renewal of the detector to take place at the end of this decade. Here the IFAE group focuses on pixelated semiconductor detectors for tracking in the central and very forward regions. The IFAE group made critical contributions to the ATLAS Insertable B-Layer (IBL), which included the first application of 3D pixels to a high-energy physics experiment. IBL was installed and commissioned in 2014, and successfully entered operation in 2015. Furthermore, the group started production of modules for the ATLAS Forward Physics (AFP) detector, which is being installed during the 2015/2016 shutdown. All this is providing the group with the know-how necessary to make a major contribution to the upgrade of the entire inner tracker of ATLAS, necessary for the LHC high-luminosity operations in the next decade.

3. T2K, a neutrino long base-line experiment in Japan. In 2012, after recovering from the devastating earthquake of 2011, T2K confirmed the earlier results on the oscillation of muon neutrinos into electron neutrinos. In addition, T2K published in 2013 the most precise measurements to-date of muon neutrino disappearance parameters. In May 2014, T2K started a new run with anti-neutrinos. First analyses, published in summer 2015, provided the most precise muon anti-neutrino disappearance result to-date. In 2015, the group also became involved in WA105, a large liquid-argon detector at CERN where the new detection techniques necessary for the future large DUNE long-baseline experiment in the US will be tested.

**THE ACTIVITIES OF THE EXPERIMENTAL DIVISION FOCUS ON TEN MAIN PROJECTS THAT SPAN THE FIELDS OF HIGH ENERGY PHYSICS, ASTROPHYSICS AND COSMOLOGY, AND INCLUDE THE DEVELOPMENT OF DETECTORS FOR MEDICAL IMAGING APPLICATIONS, AS WELL AS RELATED INSTRUMENTATION PROJECTS.**

### ASTROPHYSICS

IFAE's Astrophysics activities are centered on ground-based detection of very high-energy gamma rays from astrophysical and cosmological sources.

4. MAGIC, located on the Roque de los Muchachos on the Canary Island of La Palma, operates a recently upgraded stereoscopic system of two 17m diameter telescopes. Two MAGIC papers published in 2015 were led by IFAE scientists. Also, two PhD theses were published, one of which provided the first MAGIC measurement of the Extragalactic Background Light. Furthermore, IFAE led the efforts to validate a new topogical trigger to lower the energy threshold and to commission the new UV filters for moon observation and the measurement of the cosmic positron/electron ratio, a topic of great current interest. The first science measurements with the new filters will take place in 2016.

5. CTA, a worldwide collaboration that will build two multi-telescope observatories, in the Northern and Southern hemispheres, is now in an advanced design and prototyping phase. IFAE is involved in major aspects of this project, at the technical and the top management levels, and in particular in the design and prototyping for the largest telescopes (LST) in CTA. During 2015, the decision was taken to site the CTA Northern observatory in the Canary island of La Palma. Also, in October 2015, the groundbreaking ceremony for the first LST took place in La Palma. The integration of the camera of this first LST will take place at IFAE, which is taking care of the power system and developing the camera control system.

### OBSERVATIONAL COSMOLOGY

The Observational Cosmology program at IFAE began by joining an existing project, DES. In 2007 a new project, PAU, was launched.

6. The DES (Dark Energy Survey) collaboration at the Blanco telescope in Cerro Tololo (Chile) successfully completed in 2015 the second of its five seasons, which will lead to the measurement of position, redshift and shape for about 300 million galaxies in the Southern sky. A plethora of results from the Science Verification season in 2012/13 became available in 2015, including the first results from the weak lensing technique. Two of the papers were coled by IFAE scientists. In 2015, IFAE joined the Dark Energy Spectroscopic Instrument (DESI) collaboration, which will gather spectra for over 30 million galaxies and quasars, producing an unprecedented 3D map of the Universe. Together with its partners at ICE (IEEC-CSIC), CIEMAT and IFT/UAM, the IFAE group is responsible for the design and construction of the Guiding, Focusing and Alignment (GFA) cameras of the DESI instrument.

7. PAU (Physics of the Accelerating Universe) is an IFAE-led Spanish collaboration funded by a Consolider-Ingenio 2010 project. In June 2015, the PAU camera (PAUCam), built at IFAE, was installed and commissioned at the William Herschel Telescope (WHT) in La Palma, Canary Islands. The camera went through a short period of scientific verification in November 2015. Starting in 2016, the PAU Survey international collaboration will use PAUCam to carry out a very precise photometric-redshift survey in order to measure dark energy parameters.

8. Euclid is an European Space Agency (ESA) satellite mission within the Cosmic Vision program, which will be launched in 2020. Its main goal is to determine the properties of dark energy with unprecedented precision using both weak lensing and large-scale clustering probes. IFAE is responsible for the design and production of the Filter Wheel Assembly (FWA) of the infrared focal plane, which being a moving part in space, deserves extra care. In 2015, the team at IFAE produced the Structural and Thermal Model of the FWA, and successfully passed the Preliminary Design Review.

### APPLIED PHYSICS

The focus of the applied physics research at IFAE is to develop sensor technologies with applications in medical imaging, high-energy physics and other scientific or industrial fields.

9. The Medical Imaging group has developed a novel approach to Positron Emission Tomography, funded by an ERC Advanced Grant. The approach is based on a finely pixelized CdTe detector read out by a 100-channel ASIC designed at IFAE. 2015 saw the conclusion of the full production of the 180 VIP single-layer detectors and the box that holds them to form the PET detector. In 2014, the group started a new initiative (ERICA) in the field of X-ray line detection with quality control and security applications. During 2015, a first prototype of the ERICA ASIC was produced and then bumped-bonded to a CdTe pixel detector. Some of the activities of this group are carried out in collaboration with IFAE's spinoff company X-Ray Imatek. Several other instrumentation projects produced exciting results in 2015. In particular, a project that aims to develop a silicon-based Micro Pattern Gas Detector read-out by the MediPix chip and is carried out in collaboration with CNM, and another project is developing a novel light-detector system based on silicon photomultipliers coupled to wavelength shifters.

## THE THEORY DIVISION

The activities of the Theory Division during 2015 continued along three lines: Standard Model Physics, Beyond the Standard Model and Astroparticle Physics/Cosmology.

### 1. STANDARD MODEL PHYSICS

The main research themes pursued in the Standard Model (SM) group of the IFAE theory division during 2015 were leptonic and radiative decays of $\eta$ and $\eta'$ mesons; semi-leptonic decays of the B meson; hadronic decays of the tau lepton; the Lamb shift in muonic hydrogen and the proton radius; the behavior of perturbation theory at high orders; and the $\varepsilon'/\varepsilon$ parameter of direct CP violation in Kaon decays.

**THE ACTIVITIES OF THE THEORY DIVISION FOCUS ON THREE LINES: STANDARD MODEL PHYSICS, BEYOND THE STANDARD MODEL AND ASTROPARTICLES & COSMOLOGY**

## 2. BEYOND THE STANDARD MODEL

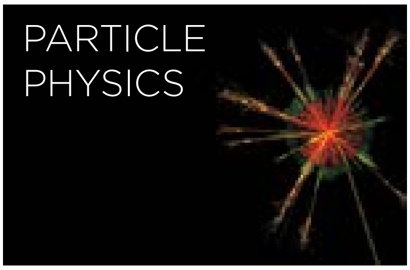
In 2015 the BSM subgroup followed two general lines of research, both related to the recent experimental results coming from the LHC. A first line consists on proposing theories that can accommodate all experimental results on the Higgs discovery as well as all bounds on new physics. In this directions a number of problems have been solved, in particular related to new solutions to the hierarchy problem, involving axion-like scalars. A second line consists on producing BSM theories that can explain the various excesses found in Runs 1 and 2 at the LHC, in particular, the apparent di-photon excess at 750 GeV observed by ATLAS and CMS in the LHC run at 13 TeV.

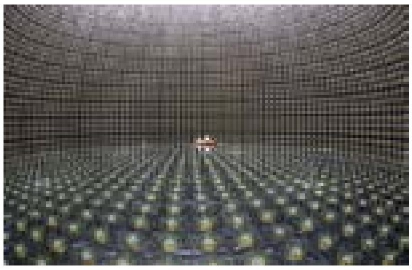
## 3. ASTROPARTICLES/COSMOLOGY

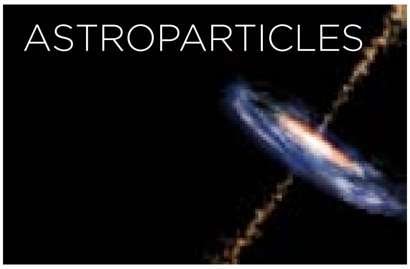
Astroparticle physics and particle cosmology are recent fields of research at the intersection between particle physics, astrophysics and cosmology. The goal is to exploit our knowledge of astrophysical and cosmological phenomena to answer fundamental physics questions, and vice-versa. The topics on which the members of the Theory Division from this research area focused their work in 2015 include: the vacuum instability problem; Higgs inflation; and applications of the gauge/gravity correspondence to condensed matter problems.

# I

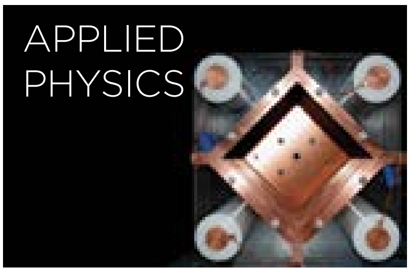
# **EXPERIMENTAL** DIVISION

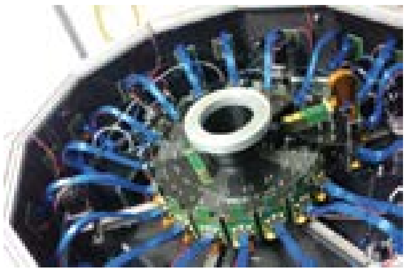








# 2.1 ATLAS AT THE CERN LHC

MARIO MARTÍNEZ

Since 1993, the IFAE group has given major contributions to the construction of the ATLAS apparatus, its trigger system, its physics reconstruction software and preparatory physics studies. During the last four years, with the arrival of the LHC Run I data, the IFAE group has carried out a strong physics program.

## INTRODUCTION

The LHC resumed operations in June 2015 with an increased center-of-mass energy of 13 TeV and delivered a total of 4 $fb^{-1}$. The IFAE group maintained a strong participation in both detector operations and physics analyses. In particular, in 2015 the remaining Run I analyses were brought to final publication and first results were presented for Run II, thanks to a prompt analysis of the incoming data. The group has been also very visible in important management positions.

In the following sections, some details are given on the different activities of the group.

## TILECAL OPERATIONS AND UPGRADE

In 2015, the IFAE group contributed most strongly to the Tile calorimeter operation, calibration and to the preparation to the detector upgrades.

IFAE postdoc, A. Cortés, served as Tile Run Coordinator, while IFAE student, S. Fracchia, served as Tile Deputy Run Coordinator, a critical role rarely awarded to students. Several other leading roles served by the IFAE members in 2015, such as Beam Test Coordinator, Calibration Coordinator and DQ Leader, resulted in IFAE leading position in the ATLAS Calorimeter community.

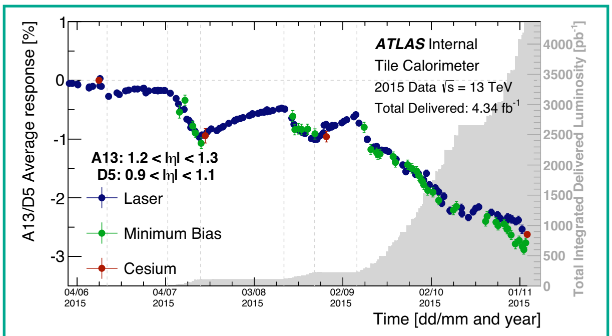



**Fig. 1: Beam induced drift of the gain of a given Tile RO channel measured by various calibration systems in 2015.**

**IN 2015, THE IFAE ATLAS GROUP MAINTAINED A STRONG PARTICIPATION IN BOTH DETECTOR OPERATIONS AND PHYSICS ANALYSES**

The IFAE group (A. Cortés, C. Fischer, M. Tripiana, S. Fracchia) maintains its commitment to fully support of the TileCal "Minimum Bias" data calibration system. The system is based on the components developed exclusively at IFAE and serves to monitor on the daily basis the stability of the Tile calorimeter response in time (as shown in Fig.1) and, together with other luminosity monitors of ATLAS, to measure the luminosity delivered to the ATLAS detector by the LHC. As the instant luminosity delivered by the LHC increases (see Fig. 2), the Tile based luminosity monitor becomes the major ATLAS tool to measure the luminosity. This is due to extremely well understood behavior of the calorimeter in the long term, compared to other luminosity monitors of the ATLAS experiment.

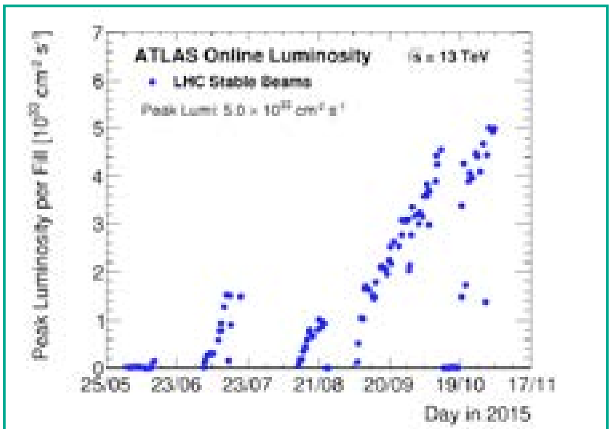



**Fig. 2: Online ATLAS Luminosity monitoring is also partially based on the system developed by the IFAE group**

In 2015, the IFAE group (I. Korolkov, M. Martínez, A. Rodríguez, M. Tripiana) made a significant contribution to the calorimeter performance studies by developing recovery algorithms for failures of high-energy measurements in Tile. Failures of the Tile modules affect jet measurement performance. The effects of two non-operational Tile modules (as it was in 2015) on the jet reconstruction performance was studied using simulated data. The recovery algorithm based on the expected jet hadronic shape was proposed. The algorithm was tuned for unbiased energy measurement on simulated di-jet data (as shown in Fig.3).

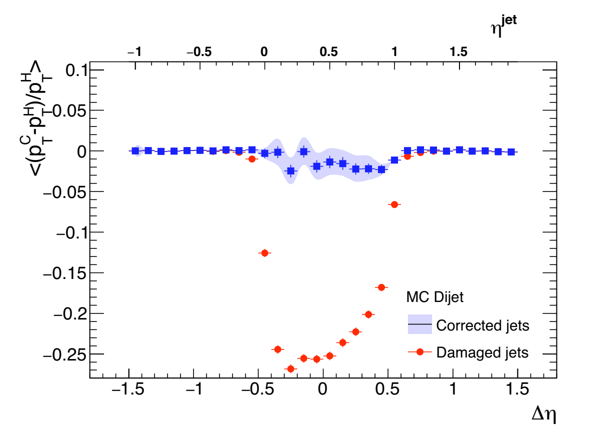



**Fig. 3: Impact of a Tile dead module on jet energy measurement before and after proposed correction.**

The corresponding degradation in the jet energy resolution was studied on di-jet and mono-jet samples. IFAE PhD student, A . Rodríguez, has obtained ATLAS authorship for developing the algorithm and implementing it as an optional tool for the Jet reconstruction in ATLAS.

In 2015, The IFAE group contributed most strongly to the preparations for the upgrade towards ever increasing luminosity delivered by the LHC. In addition to development of a new mechanical structure, known as "mini-drawers", the group senior, I. Korolkov, has coordinated the Beam Tests dedicated to validation of the new Tile RO electronics. All proposed electronics solutions have to pass such validation and the most performing options will be chosen for the ATLAS upgrade. One of three proposed front-end RO solutions was tested at the SPS beams already in 2015. The response of the new RO to the muons is shown in Fig.4 as an example. Tests of more components with the beams will follow in 2016.

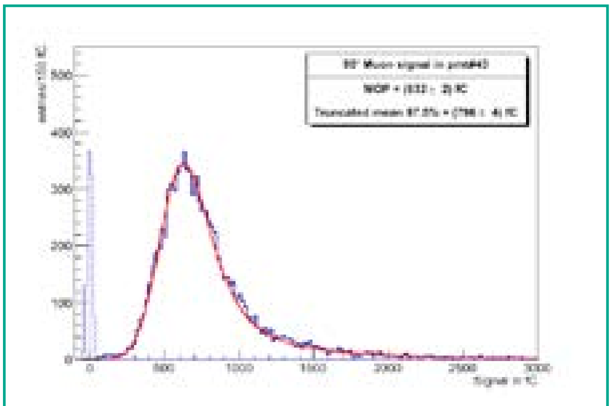


**Fig. 4: Tile response to muons read out by the electronics that is one of the candidates for the ATLAS upgrade.**

# TRIGGER OPERATIONS, PERFORMANCE AND UPGRADE

During the Run I period, the IFAE group held responsibilities in the ATLAS High Level Trigger (HLT) system, software-based 2nd (L2) and 3rd level triggers running in two large computer farms. IFAE played an important role in the tau and jet trigger signatures groups, in the overall coordination of trigger operations, in the coordination of the trigger menu and signatures group, in the commissioning of the infrastructure software, and in the integration of trigger algorithms, altogether helping to achieve excellent trigger efficiency.

In order to cope with the challenging LHC conditions expected for Run II and thus allow for keeping similar trigger object thresholds as in Run I, a new Level-1 (L1) topological processor (L1Topo) has been installed during LS1. It is designed to perform real-time event selection based on topological variables (e.g. invariant masses or angular differences) defined between trigger objects from the L1 muon and calorimeter trigger systems. Its use will allow to maintain relatively high trigger efficiency for key physics processes involving W, Z and Higgs bosons.

Since 2013, IFAE contributes in the L1Topo activity. Initially, IFAE contributed to physics studies that were published in the TDAQ Phase I TDR. Later, IFAE took the responsibility of simulating all the L1topo algorithms for Run II (V. Sorín) and participated in their validation (Ll. Mir, I. Riu). During 2015, IFAE continued working in the simulation of additional L1Topo selections and their validation, in particular of those involving jet trigger objects. IFAE also took the responsibility of the L1Topo algorithms commissioning.

The L1Topo commissioning with proton-proton and heavy ion collisions has started in 2015. Several L1Topo selections have been activated and the corresponding selected events saved in special files. IFAE has taken a leading role in the validation of the hardware trigger decisions. By using the L1 input objects from data, we emulated the selections based on the invariant mass between two leading jets, the scalar sum of jets pT or the minimum distance in phi between jets and missing transverse energy. Many differences were found and we worked with the L1Topo hardware experts to check if they could be explained by overflows at different steps of the chain. Commissioning and validation analysis will continue through 2016.

**IFAE TOOK THE RESPONSIBILITY OF SIMULATING ALL THE L1TOPO ALGORITHMS FOR RUN II AND PARTICIPATED IN THEIR VALIDATION**

After the Run I, the tau trigger activity focused on the measurement of the data-driven t +MET trigger efficiencies, result that was used in the search for charged Higgs bosons in the t+jets final state. Since the start of Run II, the work has concentrated on studying and implementing an online monitoring code for t-related L1Topo selections (M. Bosman, M.P. Casado).

With the work from N. Anjos, IFAE continues its contribution to the jet trigger algorithms software for Run II. IFAE is responsible of the development of the jet cleaning infrastructure code, necessary to control sudden increases of events rate due to noise in the calorimeters, as well as the jet calibration code, which closely follows what is done offline and improves the jet rejection. So far, triggers including jet cleaning are used in the di-jet mass resonance search analysis, currently under internal review.

In addition, IFAE also provided support to the jet trigger online and to the jet trigger users, and contributed in the preparatory work for 2016.

# PHYSICS ANALYSES

IFAE continued to play a leading role in several physics research lines including the study of the recently discovered Higgs boson (both ZH and ttH channels), the search for super-symmetry (SUSY), extra spatial dimensions, dark matter, and new phenomena in top-quark final states. The team focused on the completion of the Run I physics program, while playing already a leading role in the early Run II analyses. Altogether, this translated into three PhD theses completed in 2015. In the following, we present some results recently obtained.

## HIGGS BOSON PHYSICS

Since July 2012, when the discovery of a new boson was announced at the LHC, an extensive physics program was impelled to measure the properties of this new particle. In particular, IFAE is playing a leading role since 2012 in the analyses involving the decay of the Higgs boson in a pair of bottom quarks. The team has considered both the VH and the ttH production channels, in which the Higgs boson is either produced in association with a W/Z boson or is radiated out of a top-(anti)top pair in the final state. The focus has shifted towards measurements of its properties in order to determine whether it is indeed the SM Higgs boson, or whether it has a completely different (e.g. composite) nature.

### SEARCH FOR HIGGS IN THE VH (H → BB)

In 2015 the team (G. González, M. Martínez, V. Sorín) concluded the search for the Higgs boson in this channel, initiated in 2011. The final result includes a combination of cut-based and MVA techniques and all the data (7 + 8 TeV) collected to date. No signal of Higgs production was observed yet (with an expected sensitivity of about 2.6 sigmas) and the Higgs coupling to b-quarks is compatible with the SM expectations. This work led to a publication in JHEP 01(2015)069. This was the main topic of G. González PhD thesis defended in 2015.

### SEARCHES FOR TTH PRODUCTION

Of particular interest is the top-Higgs Yukawa coupling which, owing to the large top-quark mass, is close to unity, making the top quark the most strongly-coupled SM particle to the Higgs sector. Therefore, a measurement showing a significant deviation from the SM prediction may shed light on the underlying dynamics of electroweak symmetry breaking (EWSB).

The top-Higgs Yukawa coupling can be extracted by measuring the cross section for associated production of Higgs boson with a top-antitop quark pair (ttH). Searches are being performed in many final states, depending on the top-quark and Higgs-boson decay modes. Between September 2013 and March 2015 A. Juste coordinated these searches within one of the ATLAS Higgs working groups.

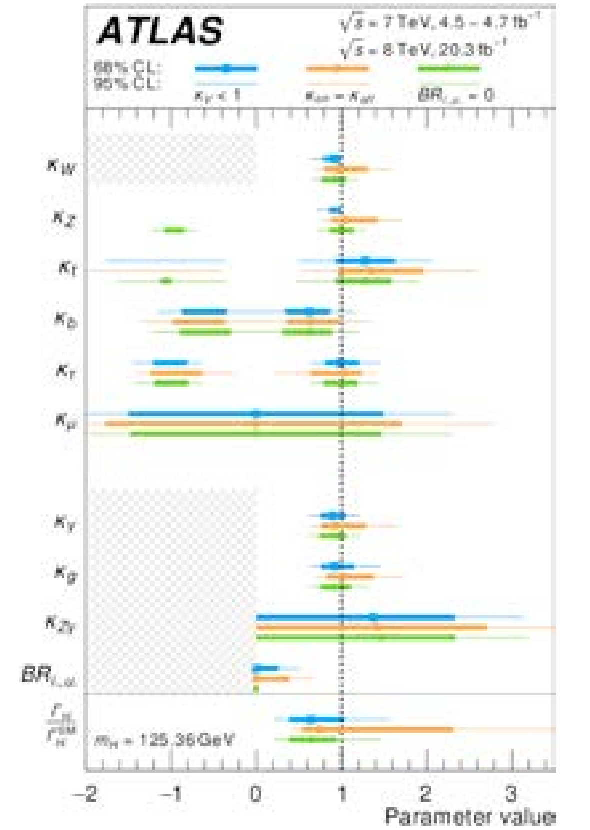



**Fig. 5: Best-fit Higgs coupling scale factors in the case of Generic Model 2. From Eur. Phys. J. C 76 (2016) 6.**

Since 2011 IFAE has led searches for ttH production with H→bb, in the single-lepton channel. The final-state state is characterized by one lepton and at least six jets, among which at least four are b-tagged. This analysis is very challenging due to the large background from tt+heavy-flavor jets production, affected by large uncertainties, as well as a large combinatorial background from the high-jet multiplicity, which makes very difficult the kinematic reconstruction of the final state. A very sophisticated search has been developed, considering multiple analysis channels to constrain the effect of systematic uncertainties, as well as using multivariate techniques to discriminate signal from background. The final Run 1 result using 20.3 $fb^{-1}$ of data at $\sqrt{s}$=8 TeV was published in Eur. Phys. J. C 75 (2015) 349. No significant excess of events above the background expectation was found and an observed (expected) 95% CL upper limit of 3.4 (2.2) times the SM cross section was obtained. This represents the single most-sensitive ttH search to date. The ratio of the measured signal yield to the SM expectation was found to be $\mu$=1.531.1. This result was included in J. Montejo's PhD thesis (June 2015) titled "Search for new physics in tt final states with additional heavy flavor jets", recipient of the 2015 ATLAS Thesis Award.

The VH and ttH results were also included in the ATLAS combination of Higgs couplings (published in Eur. Phys. J. C 76 (2016) 6), along with other ttH searches in diphoton and multilepton final states. The top-Higgs Yukawa coupling resulting from this combination is $\lambda_t$=1.28±0.34 (see Fig. 5).

Additional studies are underway on the application of large-radius jet reconstruction and jet substructure techniques to the subset of events where one of the top quarks and/or the Higgs boson have large boost, resulting in the collimation of its decay products. These techniques are expected to isolate kinematic regions with increased signal-to-background ratio and lead to better reconstruction of the Higgs boson mass with less combinatorial background. Several members of IFAE are actively involved in this search (M. Casolino, T. Farooque and A. Juste). In particular, T. Farooque is coordinating this analysis effort within the ATLAS Higgs group.

## SEARCH FOR A CHARGED HIGGS BOSON

No charged scalar bosons exist within the SM, but almost all BSM scenarios incorporate an extended Higgs sector with at least a pair of charged scalar bosons, H+ and H-. Charged Higgs bosons can be produced and decay in different ways depending on the choice of parameters of the model, in particular on the mass of the H+. For heavy H+(mH+>mtop), the main production mode for most scenarios is in association with a top quark, with H+→tb as prominent decay mode. IFAE (M. Bosman, M.P. Casado, Ll.-M. Mir, I. Riu) is heavily involved in this search in the final state where one of the top quarks decays leptonically. IFAE's contributions so far comprise the validation of the new signal Monte Carlo (MC) generator MadGraph5_aMC@NLO, used for the official ATLAS MC production at 13 TeV. This production has been used in the data/prediction comparisons with Run 2 data. In addition, IFAE is developing a discriminant variable based on kinematic information from the various resonances present in the decay, as well as jet flavour identification, for optimal reconstruction and separation of the signal and the dominant background from the production of top quarks with additional jets. Furthermore, the split of data in different categories according to the jet and b-jet multiplicities, and the use of different MC templates depending on parton flavour and jet reconstruction efficiency will help separating and constraining the background components.

## SEARCH FOR NEW PHENOMENA IN JET+X

The IFAE team continued to be a driving force in monojet analyses in ATLAS at $\sqrt{s}$= 8 TeV and 13 TeV, with postdoc A. Cortés being the contact person of the monojet analyses in the ATLAS SUSY/Exotics working groups.

The results on monojet events carried out within the ATLAS SUSY group and published in 2014 were reinterpreted in different SUSY scenarios leading to new results published in three separate ATLAS publications with the aim to provide a summary of Run I SUSY searches: Eur. Phys. J. C 75:51 (2015) (searches for third generation squarks); JHEP 10 054 (2015) (inclusive SUSY searches); and JHEP 10 134 (2015) (pMSSM searches).


**Fig. 6: Cover font page of EPJC showing the monojet results in EPJC 75 29 (2015). Observed and expected 95% CL limit on the fundamental Planck scale in 4+n dimensions, MD, as a function of the number of extra dimensions.**

In 2015, the team concluded the Run I Exotic search in this channel. This included exclusion limits on an invisibly decaying Higgs boson, models with large extra dimensions (LED), and effective models for dark matter (WIMPs) pair production. For the latter, a detailed study of the limited validity of the effective theory approach was carried out. This led to a separate publication in EPJC 75 29 (2015) for which M. Martínez acted as corresponding editor and became cover front page of the EPJC journal (see Fig. 6). Altogether this was included in R. Caminal PhD thesis defended in February 2015.

In addition, one of the PhD theses performed by the IFAE monojet team (V. Rossetti, 2013) received the Springer Verlag Prize for Outstanding PhD Research.

With the arrival of the Run II data in 2015, the IFAE team focused on the fast analysis of the data and the production of early results. At the moment of writing this report (early 2016) the team continues to play a central role on the monojet searches in Run II. A. Cortés is still acting as convener of ATLAS monojet group and M. Martínez is the corresponding editor of the first ATLAS Run II publication on the subject. First results based on the whole 2015 data are being submitted for publication on Phys. Rev. D. It will be part of the Ph.D. thesis of C. Fischer, to be defended in 2017.

## TOP QUARK PHYSICS & EXOTIC SEARCHES

### MEASUREMENT OF THE TT CHARGE ASYMMETRY

The observation of an unexpectedly large forward-backward (FB) asymmetry in tt production by the CDF and D0 experiments, ~2 sigma above the SM predictions, has constituted for some time one of the most tantalizing hints of New Physics (NP) in the top quark sector. The large top quark samples collected by the ATLAS experiment offer the exciting possibility of precise measurements that could shed light on the Tevatron anomaly. At the LHC, despite the charge-symmetric initial state, it is possible to define a charge asymmetry (AC) sensitive to the same underlying dynamics as the FB asymmetry at the Tevatron. However, this is a quite challenging measurement since at the LHC the expected asymmetry from NP would be quite small (~5-10%), which requires to develop strategies to enhance it, as well as keeping systematic uncertainties below 1%.

Since 2012 the IFAE group has been leading the measurement of the tt charge asymmetry in the semileptonic decay channel, performing inclusive measurements as well as differential measurements as a function of three relevant kinematic variables of the tt system (mass, transverse momentum and rapidity). The most recent measurements used the full dataset collected by ATLAS at √s=8 TeV, corresponding to an integrated luminosity of 20.3 $fb^{-1}$ (see Fig. 7). These results were published in Eur. Phys. J. C 76 (2016) 87 and represent some the most precise LHC measurements to date. F. Rubbo was the main analyzer and corresponding editor for the publication. This measurement was included in F. Rubbo's PhD thesis (November 2015) titled "Measurements of the charge asymmetry in top quark pair production at the LHC with the ATLAS detector".

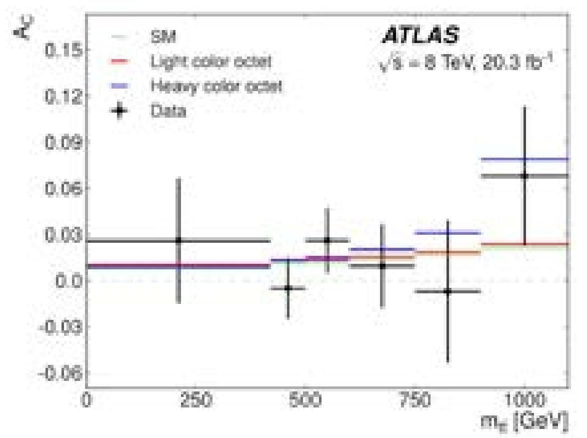



**Fig. 7: Measured Ac as a function of mtt. The Ac values after the unfolding (points) are compared with the SM predictions (green lines) and the predictions for a colour-octet axigluon with a mass of 300 GeV (red lines) and 7000 GeV (blue lines) respectively. Taken from Eur. Phys. J. C 76 (2016) 87.**

### SEARCH FOR FCNC T→HQ DECAYS

An exciting possibility is the presence of flavor-changing neutral current (FCNC) interactions between the Higgs boson, the top quark, and an u- or c-quark. Since the Higgs boson is lighter than the top quark, these interactions would manifest themselves as FCNC top quark decays, t→Hq (q=u,c). In the SM, such decays are extremely suppressed, with branching ratios below 10-15. On the other hand, enhancements of many orders of magnitude are possible in some NP scenarios, such as in two-Higgs doublet models.

Searches for t→Hq decays have been performed at the LHC exploiting the large samples of tt events collected during Run 1. In these searches, one of the top quarks is required to decay into Wb while the other quark decays in Hq, yielding tt→WbHq. Previous searches were focused on the H→gg and H→WW decay modes. IFAE pioneered a search that exploits the highest branching ratio Higgs boson decay mode, H→bb, resulting in a lepton-plus-jet final state. To separate the signal from the background, the search exploits the high multiplicity of b-jets characteristic of signal events, and employs a novel likelihood discriminant developed at IFAE that combines information from invariant mass distributions and the flavor of the jets.

This search used the full dataset collected by ATLAS at √s=8 TeV, corresponding to an integrated luminosity of 20.3 $fb^{-1}$. No significant excess of events above the background expectation was found, and observed (expected) 95% CL upper limits of 0.56% (0.42%) and 0.61% (0.64%) were derived for the t→Hc and t→Hu branching ratios, respectively, making this the most sensitive single search to date. This result, along with the combination with other ATLAS searches in the diphoton and multilepton final states (see Fig. 8), was published in JHEP 12 (2105) 061. This result will be included in S. Tsiskaridze's PhD thesis (June 2016). A. Juste acted as coordinator for this analysis and corresponding editor for this publication.

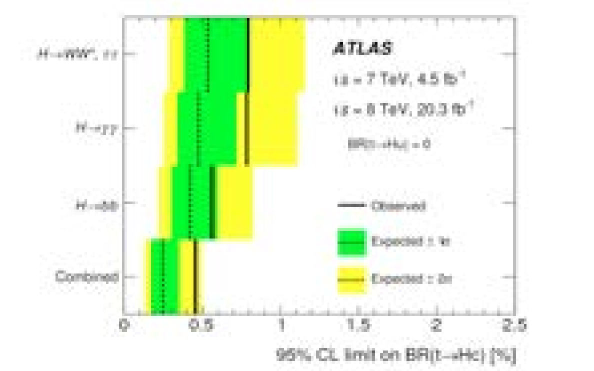



**Fig. 8: 95% CL upper limits on BR(t→Hc) for the individual ATLAS searches as well as their combination, assuming BR(t→Hu)=0. Taken from JHEP 12 (2015) 061.**

## SEARCHES FOR VECTOR-LIKE QUARKS / FOUR-TOPS

Many new physics models aimed at addressing some of the limitations of the SM involve the presence of exotic quarks, heavier than the top quark. A prominent example is weak-isospin singlets or doublets of vector-like quarks (VLQ), which appear in many extensions of the SM such as Little Higgs or extra-dimensional models. In these models a top-partner quark, for simplicity here referred to as T, often plays a key role in canceling the quadratic divergences in the Higgs boson mass induced by radiative corrections involving the top quark. At the LHC, these new heavy quarks would be predominantly produced in pairs via the strong interaction for masses below ~1 TeV. In the case of VLQs, several decay modes are possible, T→Wb, Zt and Ht, all with sizable branching ratios, resulting in a rich spectrum of possible final state signatures.

Since 2011, IFAE is playing a leading role in the program of heavy-quark searches in the single-lepton final state in ATLAS. The group has developed two complementary searches for vector-like quarks able to probe large portions of the branching ratio plane BR(T→Ht) vs BR(T→Wb) as a function of heavy quark mass (mT). This allows searching for these particles in a quasi-model-independent way, a strategy that was pioneered by the group.

One search, referred to as TT→Wb+X, is designed to probe the region of high BR(T→Wb) and was optimized at higher mT by exploiting the characteristic topology of boosted W bosons in the decay of heavy quarks. The other search, referred to as TT→Ht+X (with H→bb), is designed to probe scenarios with high BR(T→Ht), resulting in spectacular signatures with high jet and b-jet multiplicities. Both searches were carried out using 20.3 $fb^{-1}$ of data at √s=8 TeV and combined. No significant excess of events above the SM expectation is observed. The 95% CL observed lower limits on the T quark mass range between 715 GeV and 950 GeV for all possible values of the branching ratios into the three decay modes (see Fig. 9).

In addition, the TT→Ht+X analysis is used to search for 4-top production, both within the SM and in several BSM scenarios (contact interaction within an Effective Field Theory, scalar gluon pair production, universal extra-dimensions compactified in the real projective plane), resulting in some of the most restrictive bounds on this process to date: e.g. scalar gluons decaying dominantly to tt and with mass below 1.1 TeV are excluded at 95% CL.

These results were published in JHEP 08 (2015) 105 and were included in J. Montejo's PhD thesis. A. Juste acted as coordinator for these analyses and corresponding editor for this publication.

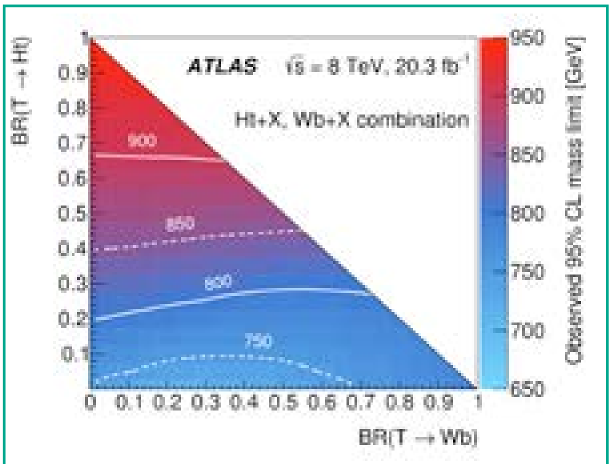



**Fig. 9: Observed limit (95% CL) on the mass of the T quark from the the combination of the TT→Wb+X and TT→Ht+X searches, and presented in the plane of BR(T→Ht) versus BR(T→Wb). From JHEP 08 (2015) 105.**

## SUPERSYMMETRY SEARCHES

One possible solution to the hierarchy problem is provided by weak-scale Supersymmetry (SUSY), which extends the SM by introducing supersymmetric partners for all SM particles. In the framework of the R-parity conserving minimal supersymmetric extension of the SM (MSSM), SUSY particles are produced in pairs and the lightest supersymmetric particle (LSP) is stable. In a large variety of models, the LSP is the lightest neutralino, which is weakly interacting, thus providing a possible candidate for dark matter. The colored superpartners of quarks and gluons, the squarks and gluinos, if not too heavy, would be produced in strong interaction processes at the LHC. SUSY can naturally solve the hierarchy problem, by preventing “unnatural” fine-tuning in the Higgs sector, provided that the super-partners of the top quark (stop) have masses not too far above the weak scale and typically below 1 TeV. This condition requires also that the gluino is not too heavy due to its contribution to the radiative corrections to the stop masses. The constraint on the stop masses also implies that the left-handed sbottom is expected to be relatively light because of the SM weak isospin symmetry. As a consequence, the lightest sbottom and stop could be produced with relatively large cross sections at the LHC, either directly in pairs or through gluino pair production followed by decays into a top and stop, or bottom and sbottom.

IFAE plays leading role in the early Run II SUSY searches, as demonstrated by the fact that M. Tripiana (postdoc of IFAE) has acted as co-convener of the SUSY 3rd-generation (stop/sbottom) SUSY working group in ATLAS.

## SEARCH FOR DIRECT SBOTTOM PAIR PRODUCTION AT 13 TEV

In 2014-2015, the IFAE team invested a significant effort in the preparation of the early Run II analyses, with emphasis on those searches for new phenomena that would immediately benefit from the increased centre-of-mass energy at the LHC Run II. This includes the search for 3rd –generation squarks in SUSY for which the production cross sections increase by factors 10 to 40 with respect to those in Run I. The IFAE team (A. Cortés, S. Fracchia, M. Martínez, M. Tripiana) played a leading role in such studies, presented in Moriond 2015 conference (ATLAS-PHYS-PUB-2015-005).

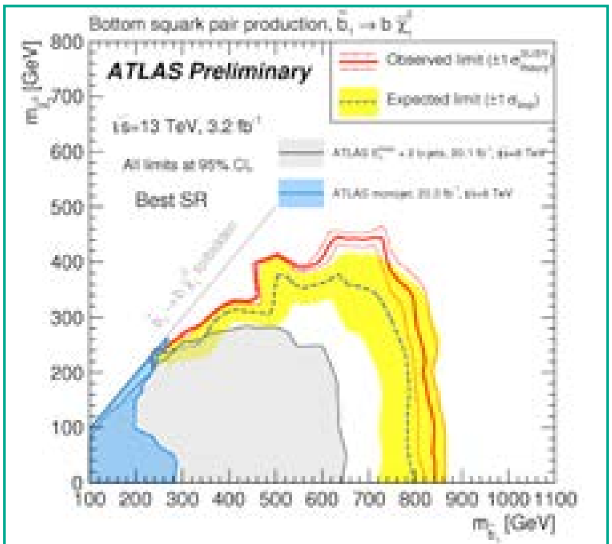



Fig. 10: 95%CL exclusion region in the sbottom-neutralino mass plane. The dashed and solid bold lines show the 95% CL expected and observed limits respectively. The figure includes both the results from the direct sbottom pair production and the re-interpretation of Run I monojet results in a SUSY compressed scenario. Taken from ATLAS-CONF-2015-066.

The arrival of the Run 2 collisions in 2015 triggered a fast analysis of the data in the search for SUSY sbottom pair production, in the channel in which the sbottom decays into a bottom quark and a neutralino (chi0) (ATLAS-CONF-2015-066). The results extend significantly previous exclusions from Run I (see Fig. 10). Sbottom masses up to 840 GeV are excluded for very light neutralinos. Similar studies are being carried out for direct stop pair production in the full hadronic decay. Altogether, this constitutes the Ph.D. thesis of S. Fracchia to be defended in 2016, and it will have its continuation with the full Run 2 statistics in A. Rodriguez’s Ph.D. thesis to be defended in 2018.

## SEARCHES FOR DIRECT PAIR PRODUCTION OF THE HEAVIER STOP QUARK

The scenario where the lightest stop quark (stop1) is very light, with a mass comparable to the top quark, is very challenging for most direct searches for stop pair production in ATLAS. An alternative is searching for pair production of the heavier stop quark (stop2), which would typically have decay modes into the lightest stop quark and either a Z boson, a Higgs boson or a neutralino (chi0). Whenever at least one Higgs boson is present among the decay products, its dominant decay into bb would give again a signature with high jet and b-tag multiplicities. IFAE performed such search for the first time in ATLAS, setting quasi-model independent limits in the two-dimensional plane of branching ratios for the heavy stop quark, as a function of its mass. This result reached sensitivity complementary to that obtained by a similar search involving instead a leptonically-decaying Z boson, or a top quark and a neutralino, which probe different regions of the branching ratio plane (see Fig. 11). This search achieved significantly better sensitivity than that obtained by the corresponding CMS search, and was included in the ATLAS summary paper of searches for third generation squarks (Eur. Phys. J. C 75 (2015) 510). These results were included in J. Montejo’s PhD thesis.

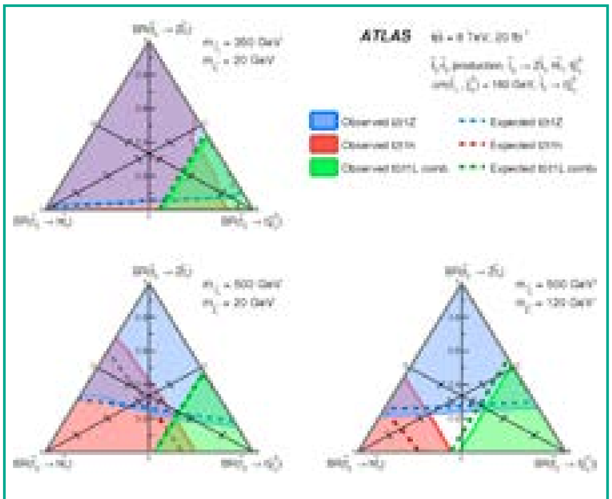



Fig. 11: 95% CL exclusion limits as a function of the stop2 branching ratio for stop2→stop1+h, stop2→stop1+Z, and stop2→t+chi0. From Eur. Phys. J. C 75 (2015) 510.

### SEARCHES FOR GLUINO-MEDIATED STOP/ SBOTTOM PRODUCTION AT 13 TEV

The search for gluino-mediated stop and sbottom production using early Run 2 data zconstitutes one of the highest-profile SUSY searches underway. The stop and sbottom quarks would decay via cascades including multiple top and b quarks and ending with the LSP. The undetected LSP results in high missing transverse energy, while the rest of the SM particles yield final states with multiple jets, b-jets, and possibly leptons. Several event selections were optimized to probe different gluino decay modes as a function of the gluino and LSP masses. The main background in this search is tt production in association with jets, including heavy-flavor jets.

Using 3.3 $fb^{-1}$ of data collected in 2015 at $\sqrt{s}$=13 TeV, this search did not find any significant excess above the SM prediction, and could exclude gluino masses up to about 1.8 TeV, significantly extending the reach of Run 1 searches (see Fig. 12). This preliminary result (ATLAS-CONF-2015-067) was among the few ATLAS results presented at a special seminar at CERN on December 15, 2015, and will be submitted to publication soon.

IFAE is playing a leading role in this search, with several members of the group actively involved (T. Farooque, A. Juste, Ch. Rizzi, and L. Valéry). L. Valéry is coordinating the analysis team, while T. Farooque is acting as editor of the conference note and the publication. This search will be part of Ch. Rizzi's PhD thesis.

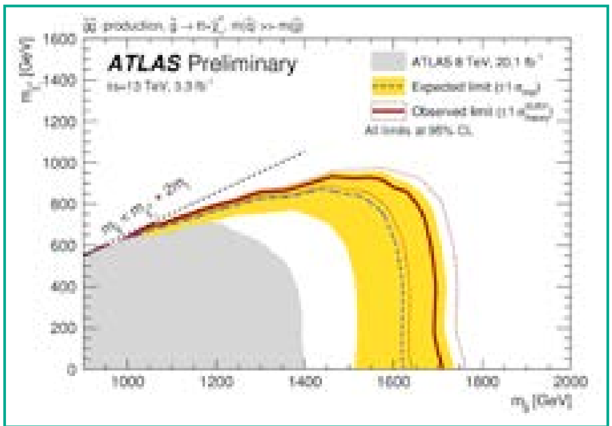



Fig. 12: 95% CL exclusion limits in the chi0 vs gluino mass plane for the Gtt model. The dashed and solid bold lines show the 95% CL expected and observed limits respectively. From ATLAS-CONF-2015-067.

# COMPUTING INFRASTRUCTURE

The Tier-2 and Tier-3 LHC computing infrastructure of IFAE, under the supervision of A. Pacheco, provided efficient access to the analysis of the data recorded by the ATLAS detector in the first year of the LHC Run2 in 2015.

All the infrastructure of the ATLAS Tier-2 and Tier-3 farms were hosted at Port d'Informació Científica (PIC) together with the Spanish ATLAS Tier-1, and fully integrated within its production services (like automatic cluster management, monitoring, etc.), providing a robust and stable environment that maximizes the availability of the facilities.

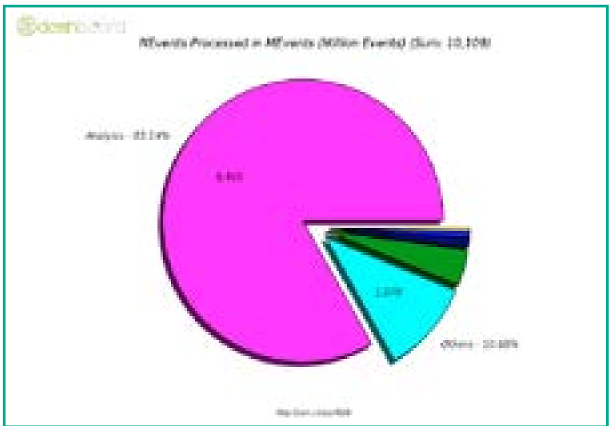


Fig. 13: Pie chart with the type of jobs processed in the IFAE Tier2 during year 2015. The Tier2 facility processed 83% of events for user analysis, 4% for group analysis.

During 2015, the IFAE Tier-2 processed more than 10 billion events (see Fig. 13) and executed 2 million of jobs with a storage of the order of 1 Petabyte. In order to address the local needs for the analysis of the full Run1 ATLAS data samples the group progressively upgraded the Tier-3 farm with additional resources.

Currently the Tier-3 farm counts on more than 4000 HepSpecs of CPU power and 320 TB of disk, some of these resources are available in form of a proof parallel event-processing farm for the latest stages of analysis. As the farm is integrated with the ATLAS Tier-1 and Tier-2 facilities at PIC, it has local access to the whole farm of 5164 processors and local access to the 3 petabytes of ATLAS data stored. Before the key physics conferences the computing power and disk available for analysis is increased automatically thanks to the dynamic resource allocation of PIC.

# MANAGEMENT POSITIONS

During 2015, the group maintained the visibility in management and physics coordination positions in ATLAS: M. Bosman acted as Spanish National Contact Physicist in ATLAS; A. Cortés continued as appointed Co-contact person for the Run II monojet group and acted as Run Coordinator and Calibration Coordinator of the Tile Calorimeter in the ATLAS experiment; S. Fracchia acted as Deputy TileCal Run Coordinator; A. Juste acted as co-cordinator of the Higgs WG8 in ATLAS and convener of the Metadata subgroup of the ATLAS Data Preparation working group; I, Korolkov acted as Coordinator of Beam Test for Tile Calorimeter Upgrade; T. Farooque coordinated the boosted Higgs analysis efforts; A. Pacheco acted as ATLAS Grid Production (GDP) Coordinator; M. Martinez acted as member of the ATLAS Publication Committee; C. Padilla is member of the ATLAS Speakers Committee; M. Tripiana acted as Co-convener of the SUSY stop/sbottom subgroup; and I. Riu is L1 Topological trigger commissioning co-coordinator.

# 2.2 PIXELS FOR ATLAS UPGRADES

SEBASTIÁN GRINSTEIN

As the LHC accelerator is improved to further probe the energy frontier, the pixel sensors and the associated front-end electronics have to be upgraded to maintain their performance. The Pixel group at IFAE was formed in 2008 and has since taken a leading role in the ATLAS pixel upgrade program. The Pixel group is investigating and developing new technologies for the high-luminosity LHC era.

## INTRODUCTION

In order to test the predictions of different theories of particle physics, ATLAS needs to identify and determine the path of the particles that are produced in the LHC proton-proton collisions. Silicon pixel detectors are especially important for the precise determination of tracks and vertices, allowing the particle momentum determination and the identification of b-jets (b-tagging). As the LHC accelerator is improved to further probe the energy frontier, pixel sensors and the associated front-end electronics have to be upgraded to maintain their performance.

The Pixel group at IFAE was formed in 2008 and has since taken a leading role in the ATLAS pixel upgrade program. In 2015 the main activities were related to the evaluation of the ATLAS forward physics detector (AFP) performance in beams tests, the production of the AFP pixel modules at the IFAE clean rooms, and the first step of the qualification program for the 3D pixel technology for the ATLAS high-luminosity LHC (HL-LHC) upgrade. In parallel other technologies are being evaluated: silicon devices with intrinsic charge multiplication and HVCMOS devices. The activities are conducted in the framework of a Spanish (MINECO) project, led by IFAE, in collaboration with CNM (Centro Nacional de Microelectronica, Barcelona).

The group has made a critical contribution to the IBL detector, which is now taking data in the core of the ATLAS detector. Following this effort, the 3D sensors were qualified for the AFP experiment early in 2015. The fabrication of the tracker modules, which is carried out completely at IFAE, is underway, with seven modules already delivered to CERN and installed in the LHC tunnel. The R&D program to develop 3D sensors for the HL-LHC has also been started. As a first step, the limits of the existing generation of 3D sensors (IBL, AFP) were studied. The excellent results obtained in terms of radiation hardness and power dissipation make this technology very attractive for the innermost layer of the ITk detector. Furthermore, a dedicated HL-LHC generation of 3D detectors is being developed. In parallel, the pixel group is investigating and developing new sensor technologies (like LGAD and HVCMOS).

**THE PIXEL GROUP WAS FORMED IN 2008. TODAY 3D DEVICES PRODUCED IN BARCELONA ARE INSTALLED IN THE IBL AND AFP DETECTORS**

## THE IBL DETECTOR

In May 2015 the first collisions were recorded with the new pixel layer, called IBL, fully operational. IFAE played a special role in the IBL construction, as more than 50% of the installed 3D sensors of the detector were produced in Barcelona. During 2015 some operational problems were encountered. The initial high current of some of the 3D modules was

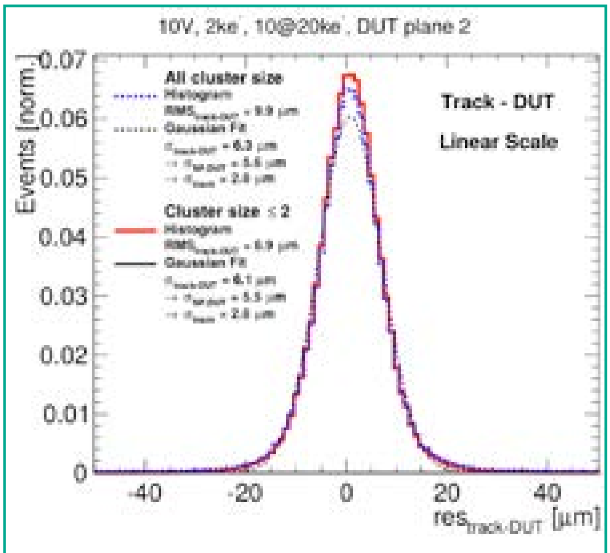



**Fig. 1: The residual distribution showing the spatial resolution of a single AFP tracker plane. The distributions for all cluster sizes and for cluster sizes smaller than three are shown. In both cases the single-plane resolution is better than 6 Qm, giving a full-tracker resolution of about 3 Qm.**

understood as surface effects and in fact are not longer a concern, since the currents were found to improve with further dose. Currently there are two issues that are being monitored in the IBL: a distortion caused by a difference in the coefficients of thermal expansion of the IBL stave components, and the increase of the front-end electronics current consumption. The IFAE group is closely following IBL operations.

## THE ATLAS FORWARD DETECTOR INTEGRATION

ATLAS plans to install a Forward Physics detector (AFP) during the current 2016 LHC shutdown, in order to identify diffraction-scattered protons at ~210m from the interaction point. To this end, the AFP detector will include a high-resolution pixelated silicon tracking system combined with a timing detector for the removal of pile-up protons. In its first phase in 2016, the AFP tracker unit will consist of a total of eight pixel layers located in two Roman Pot stations 2-3 mm from the LHC proton beam in one side of the ATLAS experiment (one arm detector). The outer station will also contain time of flight detectors. Based on the successful production of CNM 3D sensors for the IBL, and after the qualification work carried out by IFAE, the Barcelona sensors were selected for the AFP tracker. The current AFP scenario foresees low-luminosity operation during short dedicated LHC runs, whereas the system can be upgraded (second arm installation) at a later stage and take data at higher luminosities as part of the regular LHC runs.

**IFAE DEVELOPED AN INTENSIVE PROGRAM TO INTEGRATE THE AFP DETECTOR AND EVALUATE IF THE PERFORMANCE REQUIREMENTS WERE SATISFIED**

During 2014 and 2015, an intensive program to integrate the AFP detector and evaluate if the performance requirements were satisfied was carried out by IFAE. In September 2015 J. Lange coordinated a beam test at the CERN-SPS 120 GeV pion line that included prototypes of the tracker, timing, trigger and DAQ systems. The results showed that the timing requirements were met (full system resolution of 35 ps was achieved), while the tracker performance largely outperformed the requirements, since a single plane position resolution below 6 Qm was found (a factor of 2 better than the 10 μm AFP requirement). The results of the sensor qualification are presented in JINST 10 C03031 (2015), while a more detailed publication focusing on the integration is in preparation. Furthermore, most of the key results included in the AFP Technical Design Report, CERN-LHCC-2015-009, were produced by the IFAE group. This effort concluded with the approval of AFP by the LHC Experiments Committee (LHCC) and ATLAS Collaboration Board during 2015.

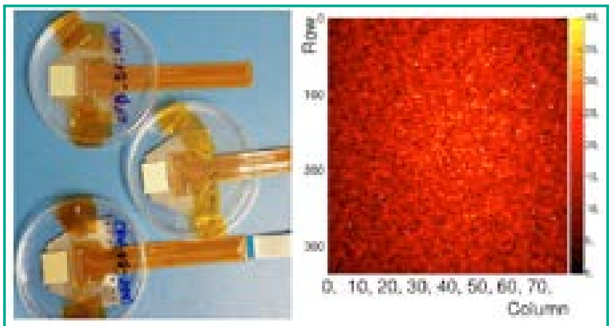



**Fig. 2: AFP tracker modules produced at IFAE. The plot in the right shows the radiation source test indication that all pixels are working correctly.**

## THE AFP TRACKER PRODUCTION

After the approval of the AFP detector by ATLAS and the LHCC, IFAE started the production of the tracking modules. The assembly line was already in place and had been exercised during the fabrication of the AFP module prototypes in 2014 and 2015. However, for the final production procedures were implemented to ensure the correct documentation of all the steps during module assembly and testing. The manpower of the group was also increased to ensure that the tight delivery schedule was met. The assembly and quality control procedures rely heavily on the infrastructure of IFAE: the FC-150 flip-chipping machine, the AVT reflow oven, the Delvotec wire-bonding machine, the DAGE bond-tester, the Finetech pick-and-place machine and the X-ray inspection machine are all used during the tracker module assembly process.

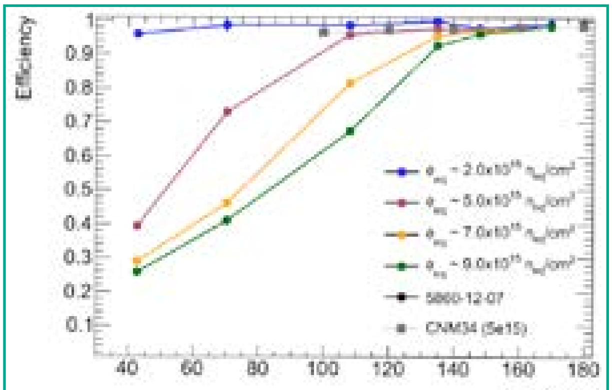



**Fig. 3: Hit reconstruction efficiency of IBL 3D sensors after irradiation to HL-LHC fluencies as a function of the bias voltage. At the highest fluence, the non-optimized geometry of the IBL devices are able to obtained an efficiency of 98%.**

The production started in November 2015. The complex bump-bonding and reflow and inspection process is carried out by senior personnel, while a dedicated engineer supervises the assembly process. Students perform the testing and qualification of modules at IFAE. The selected devices are shipped to CERN where I. Lopez (who is at an extended stay in Geneva as part of his Ph.D.) performs the integration of the modules and verification with the final DAQ system. Eleven modules have been produced this far, and seven have been delivered to CERN for early installation (February 2016). A total of about twenty modules will be produced and the best ones selected for installation. Since access to the AFP tracker in the LHC tunnel is possible during long beam stops, new modules can be inserted in a later stage.

## 3D PIXEL SENSORS FOR THE HL-LHC

The long-term aim of the IFAE Pixel group is to make a major contribution to the ATLAS phase-2 upgrade of the tracking detector, called ITk. To this end, the group is researching and developing new pixel technologies that can cope with the unprecedented radiation doses that the inner layers of the ATLAS pixel detector will face during the HL-LHC era.

The 3D technology has proven to be, to this date, the most radiation hard, but it is more expensive than the standard planar approach. However, for the innermost layer of the phase-2 detector, performance is expected to be the critical factor, making 3D detectors a viable candidate. The IFAE group is leading the 3D effort in ATLAS and has developed a three level strategy. As a first step, the limit of the existing technology has been explored. 3D sensors of the IBL and AFP generation were irradiated to HL-LHC fluencies and their performance evaluated in laboratory and several beam tests carried out at DESY (Hamburg) and CERN (Geneva) in March, July and September 2015. Excellent reconstruction efficiency and power dissipation results were obtained from these studies (J. Lange and I. Lopez, 27th RD50 Workshop, CERN).

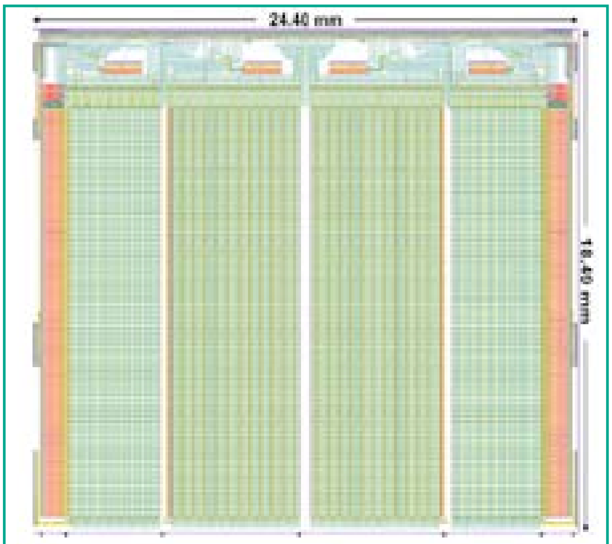



**Fig. 4: The layout of the H35 demonstrator, fabricated in AMS 350 nm technology. The read out cell as well as other digital blocks have been designed by IFAE.**

**THE IFAE PIXEL GROUP IS INVESTIGATING AND DEVELOPING NEW SENSOR TECHNOLOGIES (LIKE LGAD AND HVCMOS)**

As a second step, 3D devices with small pixels but compatible with the existing electronics (by reducing the active area of the sensor) were recently produced at CNM in collaboration with RD50 (CERN). The group is currently studying these devices, but the initial results are very encouraging. As a final step, a 3D production with devices compatible with the newly developed ITk chip will be designed and fabricated during 2016.

## OTHER PIXEL TECHNOLOGIES

Detectors with intrinsic charge multiplication (Low Gain Avalanche Detectors or LGAD) could allow the fabrication of more radiation hard devices, if part of the charge amplification is retained after irradiation. Furthermore, the charge multiplication mechanism also enables the use of these devices for timing studies, as the fast signal should provide improved time resolution. Simple diode-like structures that exhibit charge multiplication up to moderate irradiation doses have been already successfully produced at CNM. Initial tests of pixelated devices showed no charge multiplication. However the production process has been recently optimized and new LGAD productions will be tested in 2016. A new transient-current-technique (TCT) setup has been commissioned at IFAE by undergraduate students under the supervision of J. Lange and E. Cavallaro. TCT allows insight into signal formation in semiconductor devices, and, in particular, the study of charge multiplication effects.

Recently, ATLAS started to investigate the use of silicon devices produced in high-voltage CMOS technology (HVCMOS). In this standard industrial process the electronics is placed inside deep n-wells while a depletion region can be grown on the same substrate to collect the charge generated by the incoming radiation. These “active” sensors can then be combined with more complex electronics (via DC or AC coupling) or be operated on their own (i.e. monolithic approach). IFAE is participating in the ATLAS HVCMOS effort together with other institutions (Karlsruhe, Liverpool and University of Geneva) to create a demonstrator during 2015. R. Casanova designed the digital readout electronics for a matrix of 60x50 pixels. The H35 demonstrator production was finalized during later 2015 and the devices will be tested during 2016. IFAE will also develop techniques to assemble HVCMOS devices in the framework of a Horizon-2020 project (AIDA-2020).

# 2.3 NEUTRINO EXPERIMENTS

FEDERICO SÁNCHEZ

For more than a decade IFAE has been contributing to several key experiments in this field, such as K2K, which obtained the first measurement of neutrino oscillations with a neutrino beam from an accelerator, and T2K, that presented in 2011 the first indication of the transformation of muon neutrinos into electron neutrinos, thereby demonstrating a non-zero value for the third mixing angle.

## INTRODUCTION

The phenomenon of neutrino oscillations is solidly proved by many results obtained over the past two decades. For more than a decade IFAE has been contributing to several key experiments in this field, such as K2K, which obtained the first measurement of neutrino oscillations with a neutrino beam from an accelerator, and T2K, that presented in 2011 the first indication of the transformation of muon neutrinos into electron neutrinos, thereby demonstrating a non-zero value for the third mixing angle. In 2013 the T2K collaboration produced solid evidence of the transition of muon neutrinos to electron neutrinos, improved the measurement of the muon disappearance parameters and provided the first indication of charge parity (CP) violation in the lepton sector. T2K is concentrating on the anti-neutrino data taking in the search of evidence for Charge Parity violation in the lepton sector.

The research carried out by the IFAE neutrino group at the K2K and T2K collaborations has been recognized by the "Breakthrough Prize on Fundamental Physics 2015" together with another six experiments that firmly established the neutrino oscillation phenomena. The awarded present and past IFAE members are: Ester Aliu, Sofia Andringa, Stefania Bordoni, Javier Caravaca, Raquel Castillo, Xavier Espinal, Enrique Fernández, Michela Ieva, Gabriel Jover, Thorsten Lux, Federico Nova, Ana Yaiza Rodriguez and Federico Sánchez.

## THE T2K COLLABORATION

In T2K a high-intensity, 2.5° off-axis neutrino beam from the JPARC proton accelerator center in Tokai (Japan) is sent to the SuperKamiokande experiment in Kamioka, 295 km away. The muon neutrino energy spectrum is optimized for searching the appearance of electron neutrinos. The beam is characterized at the near detector, 280 m after production (ND280). Neutrinos of the electron type (but not of the tau type) are detected in Super-Kamiokande. T2K has a rich neutrino physics program. At the moment it is the only experiment that measured the mixing parameter θ13 by detecting the appea-

THE RESEARCH CARRIED OUT BY THE IFAE NEUTRINO GROUP AT THE K2K AND T2K COLLABORATIONS HAS BEEN RECOGNIZED BY THE "BREAKTHROUGH PRIZE ON FUNDAMENTAL PHYSICS 2015"

rance of electron-type neutrinos. The muon neutrino beam also allows measuring the mixing matrix element θ23 and the neutrino mass difference via muon neutrino disappearance. The experiment also contributes to the search for sterile neutrinos.

These measurements require a precise understanding of the neutrino flux and the cross sections of neutrinos with nuclei at energies around 1 GeV. The near detector complex was designed with these requirements in mind. It is a magnetic detector, consisting

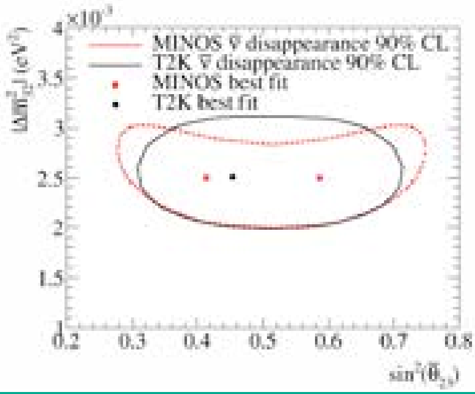



**Fig. 1: Muon anti-neutrino disappearance results from T2K (in back) compared to the results from previous experiment MINOS (red).**

**CONTRIBUTIONS OF THE IFAE GROUP TO THE T2K EXPERIMENT FOCUSED ON THE NEAR DETECTOR, SPECIFICALLY IN THE CONSTRUCTION OF THE TRACKER'S TIME PROJECTION CHAMBER (TPC) AND IN THE PREPARATION OF THE MAGNET.**

of two sections: the P0D that detects neutral pions and the charged particle tracker (FGD and TPC). The detector is surrounded by an electromagnetic calorimeter, ECAL, to measure photons and a muon catcher (SMRD) to identify muons. The contributions of the IFAE group to the T2K experiment focused on the near detector, specifically in the construction of the tracker's Time Projection Chamber (TPC) and in the preparation of the magnet. After the installation and successful operation of the apparatus during 2010, the IFAE focused its efforts on the maintenance of the sub-detectors and on data analysis.

The JPARC accelerator provided the first neutrino beam in April 2009, and the near detector saw the first interactions in November 2009. The physics run began in February 2010 and continued until March 2011, stopped by the severe earthquake that shook the northeast coast of Japan. After recovery from earthquake damage the beam intensity increased significantly reaching steady operation around 250 kW in May 2013 with a total of 6.57x1020 protons

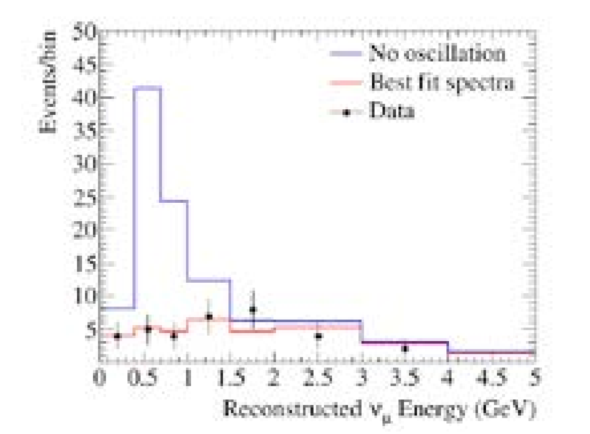



Fig. 2: Energy reconstructed spectrum of the muon anti-neutrinos detected in SuperKamiokande. In blue, the expected spectrum in absence of oscillations and in red the spectrum computed with the best fit oscillation parameters.

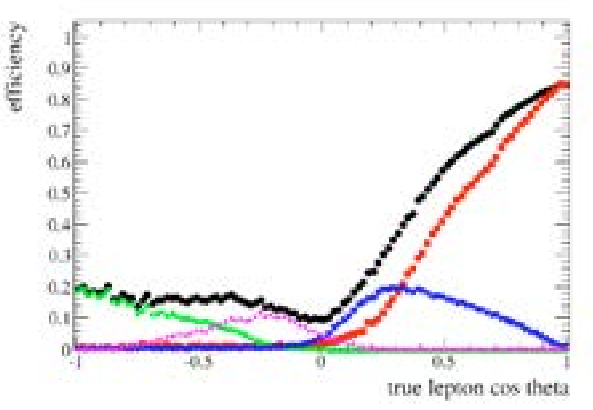



Fig. 3: Muon detection efficiency is shown as function of the angle between the muon and the neutrino. Results until 2015 included only the red curve, the new analysis from IFAE in black recovers events in the backward direction.

on target. This accumulated flux represents only 10% of the total expected by T2K. Since May 2014, T2K has changed the polarity of the focusing magnetic horns to produce predominantly anti-neutrinos. Since then, T2K has been running in this mode accumulating antineutrinos to measure both the muon anti-neutrino disappearance and the electron anti-neutrino appearance. The anti-neutrino run continued until June 2015 and the first results were presented shortly after. This data provides the most precise muon anti-neutrino disappearance result at to date, see Figure 1 and 2. The same data is analyzed to search for the transition from muon anti-neutrino to electron anti-neutrino. T2K has observed 3 electron neutrinos, which is not sufficient to claim the evidence of the process. More compelling results are expected from 2016 data.

For this analysis, the muon neutrino selection at the near detector developed at IFAE in 2014 will still be used. The IFAE group led the analysis of the inclusive Charged-current (CC) muon and electron neutrino interactions used for neutrino flux normalization.

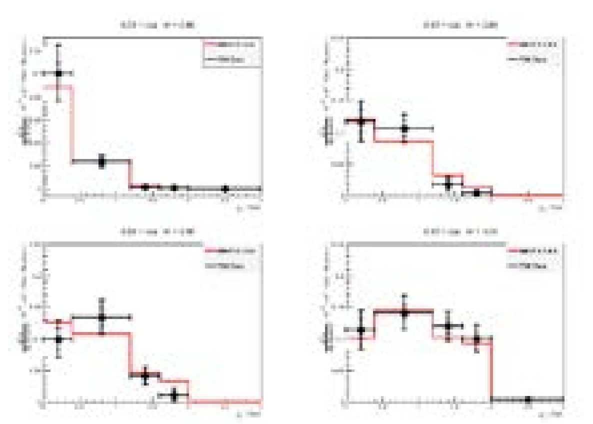


Fig. 4: Double differential neutrino-Carbon Charged Current single pion production cross-section. Red line shows the prediction of the Neut cross-section model.

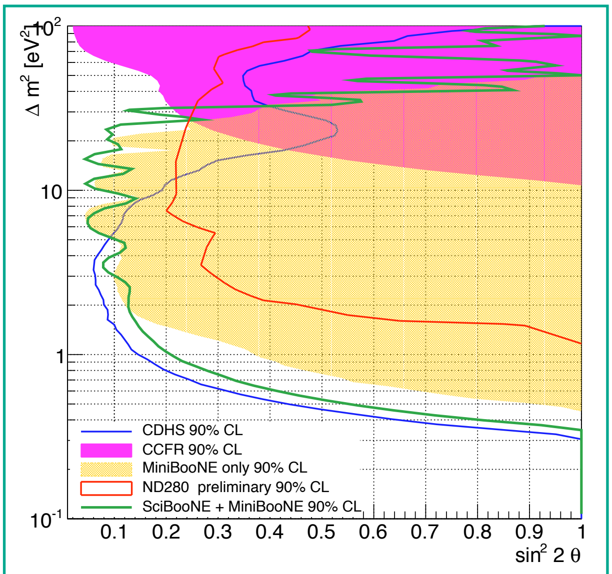



**Fig. 5: Exclusion plot of sterile neutrino oscillation parameters from the T2K near detector muon neutrino disappearance analysis compared to previous results.**

IFAE has been always leading this analysis that is critical to constrain the neutrino flux using the near detector. During 2014 and 2015, IFAE has started to work on a new analysis to improve the CC results by integrating high angle tracks and reducing the background coming from the pion-muon confusion in the detector. The new analysis is expected to be ready for 2016 oscillation results and to be the main subject of A. García phD. The new analysis expands the detection phase-space, see Figure 3, adding the negative muon angles. This new phase space almost matches the one of the far detector and it will allow to reducing the uncertainties in the cross-section modeling.

The analysis of the charged current interaction with the production of one pion in the final state was finalized during 2015 and presented by R. Castillo for her phD. The cross-section results shown in Figure 4 are the first exhaustive measurement of several experimental observables that should help to develop and check some of the existing pion production models.

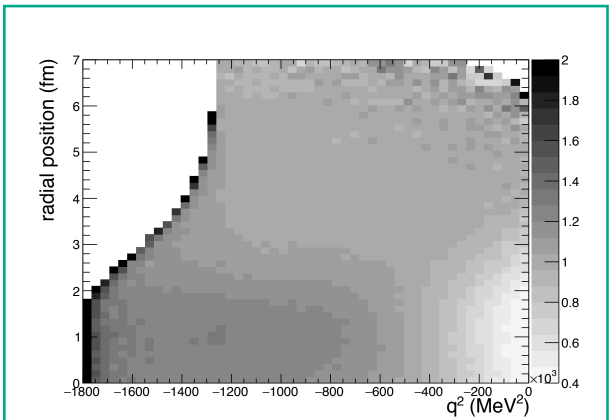



**Fig. 6: Relative correction from the long range correlation on the total muon neutrino charged current quasielastic with nucleus as function of the transferred momentum and radial position of the interaction.**

The search for neutrino oscillations on a very short baseline using the T2K near detector is another IFAE contribution. The transformation of muon neutrinos into electron neutrinos or the disappearance of the muon neutrinos at very short distances will provide indications on the existence of sterile neutrinos. After the completion of the electron neutrino disappearance in 2014, IFAE started the analysis of muon neutrino disappearance at the near detector. This is a method to search for sterile neutrinos in short base line oscillations as shown in Figure 5. The analysis will be extended in the future to consider at the same time muon neutrino disappearance, electron neutrino appearance and disappearance in a single analysis.

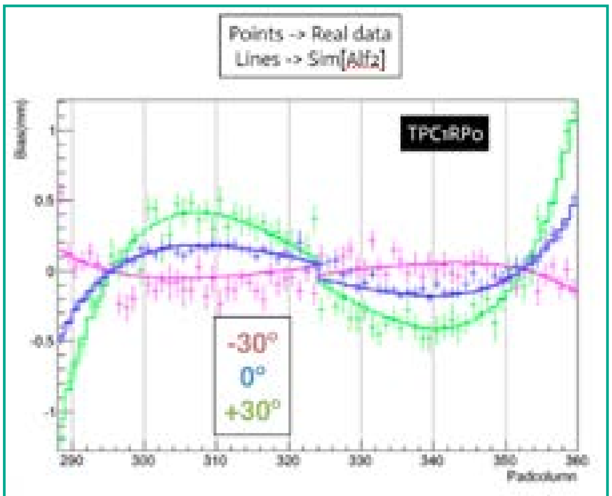



**Fig. 7: Difference between the fitted particle trajectory and the TPC reconstructed electron cluster (Bias) as function of the detector location. The colors represent different track angles and the solid line the predicted distortion obtained from the electric field modeling.**

IFAE has been also involved in the development of a new event generator to simulate (anti) neutrino nucleus charged current quasi-elastic cross-sections based on the Nieves et al. model [Phys.Rev.D88, 113007(2013)]. The new event generator includes the main contributions of this model (local Fermi gas, long range correlations, lepton coulomb corrections) and it is able to predict the kinematics of the lepton and hadron final states. The model also predicts the radial position of the interaction inside the nucleus affecting the trajectory of the emitted particles in their way out of the nuclear media. This model will be published along 2016 and it is expected to form part of the official T2K event generators in the near future. Figure 6 shows the relative effect of the long-range correlations as function of the radial position and the transferred momentum of the interaction.

Additional activities at IFAE include the particle identification in the TPC that was revisited between years 2013 and 2014 to improve on the performance for high angle tracks in the TPC. IFAE also started in 2014 to develop a technique to identify electric field distortions in the TPC. The distortion of the electric field drifting electrons in the TPC is an important source of uncertainties in the particle charge and momentum determination but also on the track momentum scale. This development allowed providing a model of distorted electric field that agrees accurately with experimental data as shown in Figure 7. IFAE also contributes to magnet and TPC maintenance tasks.

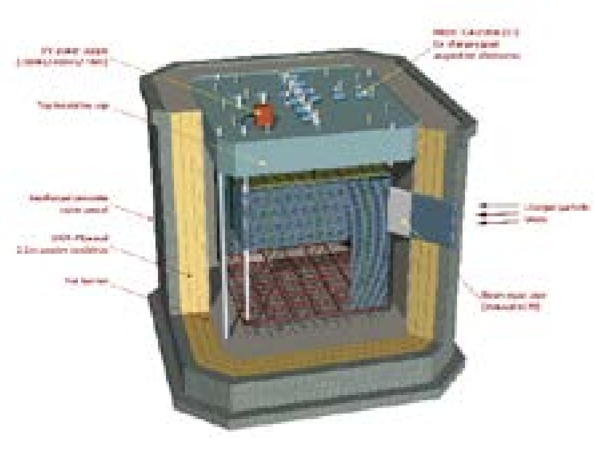


**Fig. 8: Schematic representation of the TPC inside the cryostat. The inner detector has dimensions of 6x6x6m$^3$.**

## WA105

After the last years developments, the field of oscillation physics is taking momenta towards the next goals: neutrino mass ordering and CP violation. Both goals are at reach at running experiments but will need a new generation of medium (300km) long base (>1000km) line experiments to cover the majority of the parameter phase space.

IFAE joined in 2014, together with CIEMAT, the R&D towards this new generation of experiments. Among all possible projects, a large liquid argon tank at CERN (WA105) looks the most promising because it joins european groups around a CERN base project and it is a technology with large potential inside and outside particle physics. Both IFAE and CIEMAT has previous experience in the field enlarging the potential impact of their contribution. The largest liquid argon tracking calorimeter ever built is the 600-ton ICARUS detector and a 40-kton Dune (previously LBNF project at Fermilab) detector represent a substantial scale-up in detector size. A mandatory milestone in view of future long-baseline experiments is a concrete prototyping effort towards the envisioned large-scale detectors, and an accompanying campaign of beam measurements aimed at assessing the performance and the systematic errors that will be affecting the long-baseline physics program. In this respect, there is already and approved 5 year plan at CERN, the "so-called" CERN Neutrino Platform (CENF), to develop the technology for future long base line neutrino oscillation experiments. WA105, see Figure 8, is a 6x6x6 m$^3$ liquid argon detector being build at CERN for testing technological solutions. WA105 will make use of available particle accelerators at CERN to characterize the response of the detector to several particles. The exposure at different particles is unique feature of the WA105 and an important added value that will help reducing uncertainties in future neutrino oscillation experiments. IFAE will be involved on the first tests with small 3x1x1 m$^3$ prototype at CERN to take place in 2016. IFAE is developing the data acquisition system to read the photomultipliers. IFAE is developing a methodology to deposit a thin layer of Tetra Phenyl Butadiene (TPB) in front of the photomultiplier to convert the 128nm light from argon scintillation to a wavelength that can be detected by the light sensor, see Figure 9. IFAE is collaborating with the group "Capes Fines i Enginyeria de Superficies (CFES)" at the Universitat de Barcelona. This will allow IFAE to import and control the technology for future applications instead of using the facilities at CERN.

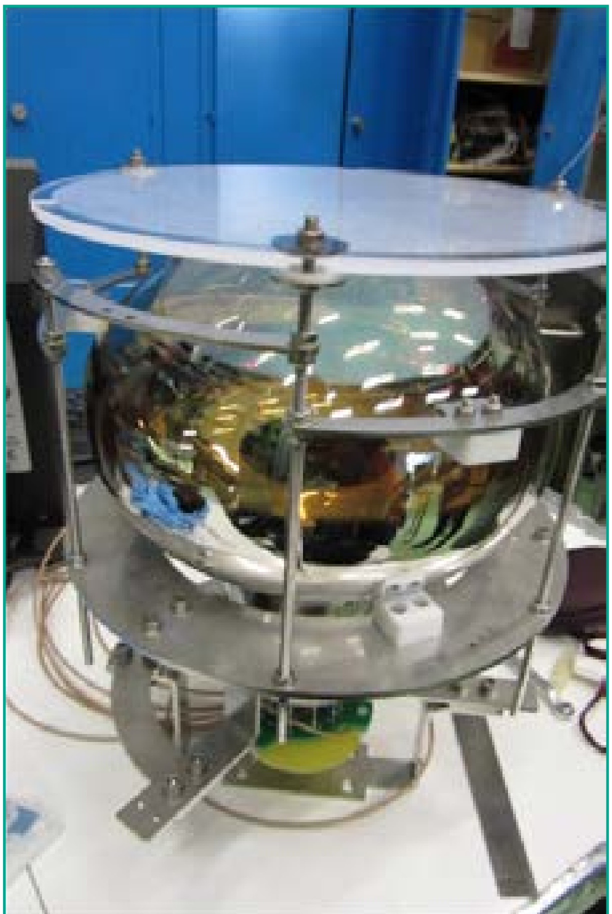


**Fig. 9: PMT support structure housing a photomultiplier designed and constructed in CIEMAT. IFAE is in charge of the photon conversion coating of the upper disk.**

# 2.4 THE MAGIC TELESCOPES

JAVIER RICO

The MAGIC telescopes explore the most violent phenomena of the Universe and search for dark matter through the detection of gamma rays in the 50 GeV – 50 TeV range with high spectral and spatial resolutions. MAGIC is currently in a period of steady astronomical observations and intense scientific exploitation.

## INTRODUCTION

MAGIC ("Major Atmospheric Gamma Imaging Cherenkov", see Figure 1) is a system of two gamma-ray telescopes located at the Observatorio del Roque de los Muchachos, at the Canary Island of La Palma. MAGIC detects the Cherenkov light produced by the particle showers initiated by cosmic and gamma rays entering the Earth atmosphere. Cherenkov images of the showers are used to reconstruct the calorimetric and spatial properties, as well as the nature of the primary particle. Thanks to its large reflectors (17 meter diameter), plus high-quantum-efficiency and low noise photomultiplier tubes (PMTs), MAGIC achieves a high sensitivity to Cherenkov light and a low energy threshold. The MAGIC telescopes are able to detect cosmic gamma rays in the very-high-energy (VHE) domain, i.e. in the range between ~50 GeV and ~50 TeV.

**MAGIC ACHIEVES A HIGH SENSITIVITY TO CHERENKOV LIGHT AND A LOW ENERGY THRESHOLD THANKS TO ITS LARGE REFLECTORS AND HIGH-QUANTUM-EFFICIENCY, LOW-NOISE PMTS**

VHE Astronomy is one of the fundamental pillars of Astroparticle Physics. It is an essential tool to study fundamental phenomena in Astrophysics, Cosmology and High Energy Physics. VHE gamma rays are the most energetic known form of electromagnetic radiation. They are produced in the most violent, non-thermal cosmic environments. Their main pro-

Fig. 1. The MAGIC telescopes at the Observatorio del Roque de los Muchachos in La Palma. From left to right: MAGIC-I, control house and MAGIC-II. Thanks to their large mirrors, the MAGIC telescopes working in stereoscopic mode are able to detect gamma rays of energies between ~50 GeV and ~50 TeV. They are powerful eyes to observe the most violent phenomena: the non-thermal Universe. Credit: MAGIC Collaboration.

duction mechanisms are radiation and interaction of accelerated charged particles, either electrons or protons. Thus, by the detection of gamma rays we can learn about cosmic particle accelerators. Furthermore, VHE Gamma-ray Astronomy addresses fundamental questions such as the nature of dark matter, the intensity and evolution of the extragalactic background light, the quantum nature of Gravity or the origin of Galactic cosmic rays.

MAGIC is currently in a period of steady astronomical observations and intense scientific exploitation of the acquired data. The activities of the IFAE MAGIC group during 2015 have been focused on: telescopes operation; maintenance of our hardware contributions to the telescopes; R&D for new instrumentation for Gamma-ray Astronomy (including non-disruptive tests during MAGIC observations); operations of the MAGIC Data Center and all its services; keeping the leading role of the group in analysis software development and scientific interpretation of MAGIC data.

## THE MAGIC GROUP AT IFAE

The MAGIC group at IFAE is composed of 5 staff scientists, 1 computer engineer, 1 electronic engineer, 4 post-docs and 5 PhD students (one more PhD student will join in the near future). The dedication of most of the group members is shared to some extent between MAGIC and CTA. During 2015, two members of the group (O. Blanch and J. Rico) were tenured. One of the PhD students (D. Ninci) and three post-doctoral fellows (P. Cumani, T. Hassan, and S. Griffiths) have joined our group during 2015.

**DURING 2015, DR. OSCAR BLANCH HAS CONTINUED BEING THE DEPUTY SPOKESPERSON OF THE COLLABORATION (SINCE 2014), AND HIS MANDATE HAS BEEN EXTENDED FOR THE PERIOD 2016-2017**

The IFAE group joined the R&D effort towards the design and construction of the first MAGIC telescope in 1996, and built its PMT camera, which was operated until 2012. For the second telescope, IFAE contributed the production of key elements of the readout and data acquisition systems, like the receiver boards and the signal digitizers. IFAE also led a major hardware upgrade during 2011-2012, where all the electronics and the camera of the first telescope were replaced. In addition, since the beginning of the project, IFAE has full responsibility of the development, deployment and maintenance of the Central Control system. IFAE has also designed and operates the MAGIC Data Center, which processes and serves ~200-300 TB/year of raw data and analysis products to the entire MAGIC Collaboration, and has pioneered the use of Grid technology in Gamma-ray Astronomy.

Since the beginning of the MAGIC project, IFAE has been deeply involved in the management of MAGIC (for instance, M. Martínez and J. Cortina served in the past as Spokesperson of the Collaboration). Since 2014, Dr. Oscar Blanch has been the Deputy Spokesperson of the Collaboration, and his mandate has been recently extended for the period 2016-2017. In addition, several members of the group have served in several committees, such as the Time Allocation Committee, the Technical and Software Boards, or as the Convener of the Fundamental Physics Working Group and the Common Fund Manager. During 2015, five IFAE group members have traveled to La Palma for participating in 1-month observational shifts with the MAGIC telescopes. Among them, R. López and J. Palacio were acting as shift leaders (the highest authority during MAGIC operations), and A. Fernández as deputy shift leader.

## TECHNICAL DEVELOPMENTS

After the last major hardware upgrade in 2011-2012, MAGIC has entered a phase of steady astronomical observations and physics exploitation of the telescopes, which lasts until today. At MAGIC-IFAE we have been, in addition, involved in several hardware developments, aimed at expanding further the energy range and duty cycle of Cherenkov telescopes, which we have developed and/or tested in MAGIC (in a way that does not interfere with regular observations) during 2015, which are summarized in the following paragraphs.

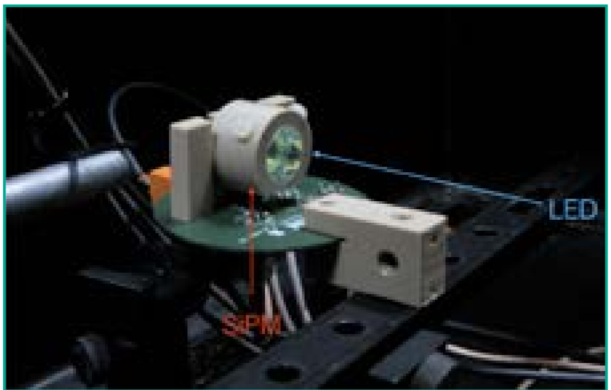



**Fig. 2. Light-Trap: A disk of PMMA doped with wavelength-shifter is used to make a pixel with an increased effective area relative to a single SiPM, that is also sensitive to UV light from Cherenkov radiation. This pixel utilizes a commercially available blue/green-sensitive SiPM. In the image, the SiPM is facing upwards into the disk, while a UV led flashes the pixel.**

### SILICON PHOTO-MULTIPLIERS

Silicon photo-multipliers (SiPMs) are considered one of the most promising technologies to replace the current PMTs in the cameras of Cherenkov telescopes like MAGIC. During 2015 we have constructed a prototype of a new concept for a non-expensive, wide active surface, SiPM-based detector, and we have started evaluating its performance (see Figure 2). In collaboration with the Max Planck Institute for Physics in Münich, we have paved the way for the construction of a SiPM 7-pixel module, to be tested in real observational conditions in the MAGIC camera during 2016.

### TOPO-TRIGGER

The Topo-trigger is a new concept of trigger for lowering the energy threshold of MAGIC. It combines the information of the spatial distribution of the triggering images in both MAGIC cameras to distinguish shower images from accidental triggers caused by the light of the night sky, hence rejecting the latter. We have carried out an activity together with the Max-Planck Institute in Munich and the INFN-Pisa MAGIC groups to develop this new concept. The technique has been demonstrated to work using Monte Carlo simulations, and confirmed with observations using the MAGIC telescopes. Thanks to the Topo-trigger we are able to reject 85% of the accidental triggers while keeping 99% of the gamma-ray events. Thanks to this, the energy threshold is reduced by 8%. At IFAE, we have led the Monte Carlo simulations and we have also participated in the hardware installation in La Palma and tests. During 2015 we have finished these studies and written a technical paper with the characterization of this novel trigger system, now on the refereeing process.

### UV FILTERS FOR OBSERVATIONS UNDER MOONLIGHT

MAGIC was designed to observe under moderate Moon illumination conditions. Thanks to its low-gain PMTs, MAGIC performs observations under moonlight for 300-400 hours per year, about 25-30% of the total available observation time. This feature is unique to MAGIC among Cherenkov telescopes. During the last few years, we have built at IFAE UV-pass filters for both MAGIC telescopes, which are easy to mount on and dismount from the cameras. During 2015, we have concentrated on the commissioning and performance assessment of the telescopes with the filters. We have confirmed our expectations based on laboratory measurements and simulations, i.e. a moonlight transmission of about 20% and a Cherenkov light transmission of about 45%. This allows the observation of sources down to an angular distance of 5 degrees to the Moon, even during Full Moon. We have established the observation procedure with filters, and measured the energy threshold and flux sensitivity as a function of the camera illumination. The Collaboration has approved 10 hours during the current observation cycle for observing the deficit of cosmic electrons caused by the presence of the Moon, as well as 100 hours of observations of the supernova remnant Cassiopeia A. Based on the results, we will establish a general strategy for the use of UV filters with MAGIC and other Cherenkov observatories. Results of this activity were presented in the 2015 summer conferences.

## THE MAGIC DATA CENTER

In 2006, the IFAE MAGIC group, in collaboration with Port d'Informació Cientifica (PIC), joined to set up the MAGIC Data Center (see Figure 3). The Data Center started to operate with a limited performance in 2006 and ever since stored and served the data of the first telescope. In 2009 (when the second telescope started operating) it became the official MAGIC Data Center under full responsibility of IFAE and the coordination of J. Rico. The Data Center is a fundamental element in the scientific exploitation of MAGIC, and one of the major current IFAE contributions to the project. The services provided by the Data Center include: automatic, Grid-integrated transfer of all MAGIC data via network (~200-300 TB/year); official and automatic data processing (including intensive data re-processing when improvements are made or bugs are fixed in the official analysis tools); storage, preservation and access to data at all levels, as well as computing resources (CPU+disk) for all MAGIC collaborators; user support; repositories for collective programming (cvs, bug-tracker, wiki, etc); documentation; and access to the MAGIC public data (including the interface to the Virtual Observatory). In the MAGIC Data Center we have pioneered the use of the Grid technologies in Astroparticle Physics research, an approach now followed by other projects like CTA. Today, the Data Center has a very high level of reliability, and has become a centerpiece for the efficient MAGIC data analysis and its outstanding scientific record.

**Fig. 3. The MAGIC Data Center at Port d'Informació Científica processes and stores about 200 TByte of data per year, and provides the MAGIC collaboration with official analysis and data products, and other data/software related services.**

During 2015, the total volume of data processed stored at the Data Center has reached 1100 TByte on magnetic tapes (an increase of 200 TByte with respect to the previous year) plus 145 TByte on disk. This data volume has been completely transferred from La Palma to PIC through Internet, thanks to the Grid data transfer system (FTS v3) that we have installed between the MAGIC site and the Data Center. In addition, we have developed and tested a new tool for the massive data processing and analysis. This tool is used for the official data processing pipeline, particularly in the first stages of data analysis, and we are working on its expansion so that it can also take care of subsequent analysis steps.

**THE MAGIC DATA CENTER HAS REACHED 1100 TBYTE OF DATA PROCESSED AND STORED IN MAGNETIC TAPES (AN INCREASE OF 200 TBYTE WITH RESPECT TO THE PREVIOUS YEAR)**

## SCIENCE WITH MAGIC

During 2015 IFAE has continued being one of the leading institutes in the physics exploitation of the MAGIC data. In 2013 the MAGIC Collaboration approved its Key Observation Program (KOP), composed of six different projects defining the main MAGIC scientific objectives until the end of its lifetime, expected in about 4 years from now. The KOP projects are given maximum priority in terms of observation time and resources. A Principal Investigator (PI) proposes and leads each of the projects, and IFAE members are PIs for two of them.

Also during 2015, two PhD students and three master students have defended their theses based on MAGIC data:

A. González (PhD, now post-doc at the Universidad Nacional Autónoma de México) presented the first measurement of the Extragalactic Background Light with the MAGIC telescopes in a thesis entitled “Measurement of the gamma-ray opacity of the Universe with the MAGIC telescopes” defended in April 2015, and supervised by Dr. A. Moralejo.

R. López Coto (PhD, now at the Max-Planck Institute for Nuclear Physics in Heidelberg, Germany) presented a thesis entitled “Very-high-energy gamma-ray observations of pulsar wind nebulae and cataclysmic variable stars with MAGIC and development of trigger systems for IACTs”, defended in July 2015 and supervised by Dr. O. Blanch and Dr. J. Cortina. Among other results, this work describes the discovery and characterization of the high-energy emission of the least luminous known pulsar wind nebula, 3c58. This result motivated the revision of the existing models for this kind of systems.

C. Sans Ponseti, presented a master thesis entitled “Effects of the Image Cleaning on Monte Carlo simulations of Moonlight observations with the MAGIC telescopes” in July 2015, supervised by Dr. O. Blanch.

M. Cassanyes presented a master thesis entitled “MAGIC sensitivity to Primordial Black Hole bursts and modelization of BH chromospheres and gamma-ray emission spectra”, defended in September 2015 and supervised by Dr. J. Rico and Dr. O. Pujolàs (from the IFAE theory division).

E. Font presented a master thesis entitled “Stand alone performance of the first Large Size Telescope for the Cherenkov Telescope Array”, defended in September 2015 and supervised by Dr. O. Blanch.

One of the group theses defended in 2013 (Optimized dark matter searches in deep observations of Segue 1 with MAGIC, by J. Aleksić) has been published during 2015 in the Springer Theses series, in recognition for its “scientific excellence and impact on research”. In addition, the main result of this thesis has been included in the 2015 update of the Particle Data Review [K. A. Olive et al. (Particle Data Group), Chin. Phys. C38 (2015 update) 090001], becoming the first ever MAGIC result to be included in this review.

During 2015 the MAGIC Collaboration has produced ten scientific papers, out of which IFAE members have led two (corresponding authorship), which we summarized briefly:

The first observations at the TeV band of the system MWC 656 (corresponding author A. López). MWC 656 is a high-mass X-ray binary (HMXB) system, consisting of a black hole orbiting around a massive (M>10 solar masses) Be star, the only known system with such a composition. The search for TeV emission in HMXBs has been the aim of extensive studies during the past few decades, with only a handful of those systems confirmed as gamma-ray emitters. In July 2012, the AGILE gamma-ray satellite observed a

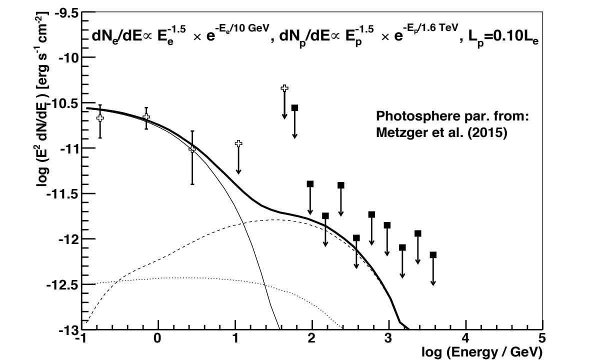



**Figure 4. Upper limit to the flux from V339 Del as measured by MAGIC (filled squres) and the flux measured by Fermi-LAT (empty crosses). The lines show the contributions of gamma-rays from leptonic (dotted) and hadronic (dashed) origin, assuming a luminosity ratio Lp/Le=0.15**

transient gamma-ray signal that has been associated to MWC 656. In May-June 2012 and June 2013, MAGIC performed observations of this object, with a total observation time of 21 hours. No significant gamma ray flux was detected in the MAGIC energy range, and we could set constraining limits to the VHE gamma-ray flux at the level of 2.4% of the Crab Nebula flux, above 300 GeV, which has helped understand the particle acceleration mechanism at work in the system.

## OBSERVATIONS OF NOVAE WITH THE MAGIC TELESCOPES HAVE CONSTRAINED THE RATIO OF LUMINOSITIES BY ACCELERATED PROTONS AND ELECTRONS IN THE SYSTEM V339 DEL

Observations of novae and dwarf novae with the MAGIC telescopes (corresponding author R. López). In the last five years the Fermi Large Area Telescope instrument has detected GeV gamma-ray emission from five novae. This emission can be interpreted in terms of an inverse Compton process of electrons accelerated in a shock. In this case it is expected that protons in the same conditions can be accelerated up to much higher energies. Consequently they may produce a second component in the $\gamma$-ray spectrum at TeV energies. With MAGIC we searched for electromagnetic emission above 50 GeV in order to better understand the acceleration processes of leptons and protons in nova explosions. In particular, we observed the classical nova V339 Del shortly after the 2013 outburst (see Figure 4), triggered by optical and subsequent GeV detections. We also performed observations of the symbiotic nova YY Her and the dwarf nova ASASSN-13ax. No significant TeV emission was found from any of the studied sources. We consequently computed upper limits to the steady and night-by-night fluxes from these sources. In particular, the combined GeV and TeV observations of V339 Del limit the ratio of proton to electron luminosities to $L_p/L_e<0.15$.

# 2.5 CTA: CHERENKOV TELESCOPE ARRAY

OSCAR BLANCH

The Cherenkov Telescope Array (CTA) project is a worldwide initiative to build the next generation ground-based very-high-energy gamma-ray observatory. The gamma-ray group at IFAE is formed by about 15 physicists with similar proportion of senior scientists, post-docs and PhD students. Most of the members of the group share the majority of their time in the CTA project and the MAGIC telescopes.

## INTRODUCTION

The CTA observatory will serve a wide astrophysics community and will provide in-depth insight into the non-thermal high-energy universe. The improvement in sensitivity respect to the present generation of imaging atmospheric Cherenkov telescopes (H.E.S.S., MAGIC, and VERITAS) is expected to match the development achieved by X-ray and low-energy (20 MeV-50 GeV) gamma-ray space-borne telescopes in recent decades.

**IN 2015, THE “OBSERVATORIO DEL ROQUE DE LOS MUCHACHOS” WAS SELECTED TO START FINAL NEGOTIATIONS TO INSTALL THE NORTHERN OBSERVATORY**

The design foresees a factor 5 to 10 better sensitivity in the current very high energy gamma-ray domain, from about 100 GeV to some 10 TeV, and an extension of the accessible energy range from few tens of GeV to above 100 TeV. To achieve that goal the CTA observatory will have one observatory in each hemisphere with telescopes of three different sizes being the Large-Sized Telescopes (LSTs) instrumental for studies related to fundamental physics. The LSTs are the telescopes on which the gamma-ray group at IFAE devotes most of the effort. In 2015, the “Observatorio del Roque de Los Muchachos” (ORM) was selected to start final negotiations to install the northern observatory.

The gamma-ray group has been deeply involved all over the year on the effort to finally get the northern observatory to La Palma. In parallel, the group has kept its presence at the highest management level inside the LST project. Being IFAE one of the main partners in the LST project, the group has important commitments for the construction of the first LST. In this sense prototypes and first series of the hardware for which IFAE is responsible have been produced.

The group has also been carrying on activities that are needed to efficiently exploit the telescopes once they are built: software control, analysis software, Monte Carlo simulations and data management. Additionally, the group has kept developing a LIDAR in collaboration with the “Radiation Group” of the Universitat Autònoma de Barcelona to monitor the atmosphere above the CTA observatory.

## CTA-NORTH SITE: THE ORM IN LA PALMA

The full CTA-Spain Consortium had proposed the Canary islands as a site for the Northern CTA Observatory since the very beginning. For many years, huge efforts were done to collect all possible objective information to show that the proposed sites in the canary islands were good locations for gamma-ray astronomy. All hours devoted to evaluate and promote the Canarian sites finally paid off in 2015. The “Observatorio del Roque de los Muchachos” (ORM, La Palma) was chosen as the site for the northern site of the CTA Observatory.

The LST project inside CTA went one step further and it has already been decided with the agreement of the full CTA Consortium to use the ORM as the site for the first LST. The telescope is both a proto-

Fig. 1: First Stone Ceremony for the LST at the “Observatorio El Roque de Los Muchachos”, La Palma.

**IFAE LED THE DECISION OF THE LOCATION OF THE FIRST LARGE SIZE TELESCOPE**

type and one of the 8 LSTs expected to be deployed in the CTA observatories. IFAE led the decision of the exact position where the first LST will be built and took care of requesting all needed permissions to the relevant administrations to built the telescope during 2016. Officially, the construction of the first LST started on October 9th 2015 with the first stone ceremony (Figure 1).

## MANAGEMENT AT NATIONAL AND INTERNATIONAL LEVEL

During 2015 the LST project has become a real international collaboration with a Memorandum of Understanding signed by all parties involved. IFAE has two representatives at the highest management level of the LST collaboration. J. Cortina is the Co-Principal Investigator and M. Martínez is the chair of the Steering Committee. These roles imply to be involved on both technical and political decisions that were very frequent and critical since the moment to start the construction of the first telescope was approaching. Additionally, A. Moralejo has become the software coordinator and O. Blanch keeps coordinating the effort to build the cameras for the LSTs.

In parallel, IFAE members kept their representation in the management of the full CTA consortium through M. Martínez who substituted O. Blanch as the IFAE representative in the Consortium Board and through J. Rico who is acting as the chair of the Speaker's and Publication Office of CTA.

Additionally, M. Martinez also continued as the leader of the 9 Spanish groups that presently constitute the CTA-Spain Consortium. He has been representing the CTA-Spain Consortium in multi-party discussions and decisions mainly related to the choice of the northern site and its funding. It is fair to say that the CTA-IFAE group acted globally as the backbone of the CTA-Spain consortium.

## CAMERA ELECTRONICS AND INTEGRATION

IFAE is not only doing the coordination to build the camera of the LSTs but it is also actively participating in its construction. In particular, the final integration of the full camera will happen at IFAE. Linked to the coordination and integration responsibilities, IFAE is also taking care of the power system and cabling inside the camera, as well as the development of the Camera Control (CaCo) software.

The power supplies to be used had already been chosen to fulfill the requirements coming from the full CTA as well as to cope with the specific ones from the LST. During 2015, the full concept of the power distribution inside the camera was finalized. This includes the design of a power distribution box, which is equipped with surge and over-voltage protections devices to avoid damaging the electronics inside the camera, as well as the identification of which elements need to be in power line backed by an UPS. Additionally, we had to check if the power supplies are able to provide enough power after a late specification change. The electronics in the camera needs about 50% more power when switching on than expected. Fortunately, this is only for a short period of time and the power supplies that had been chosen showed to be able to provide such additional power for short time intervals.

CaCo will be physically outside the camera but it will be in charge to control the subsystems inside the camera. In particular the elements in the camera are subdivided in 4 subsystems plus two related subsystems also controlled by CaCo but not in the camera: the data acquisition system sitting in a central computing building and the calibration box placed in the center of the telescope dish. The communication with all subsystems is done through the industrial M2M communication protocol OPC-UA, which has been defined as the standard inside CTA. During the first half of 2015, the state machine for the full camera was defined and implemented using simulation modules for the subsystems. In the second half, we started to test the communications with the actual subsystems and to develop the calibration algorithms. Most of the efforts were dedicated to the most complex subsystem that includes the photosensors as well as the readout and the trigger electronics. The control of this subsystem is done through a library called ClusCo for which the link to the OPC-UA protocol has also been developed at IFAE.

One of the key elements in Cherenkov telescopes is the trigger decision system, that selects when the light reaching the camera is worth being recorded. The trigger decision systems looks for an excess of signal localized in a relative small region of the camera within a time window of a few nanoseconds. This approach allows reducing the trigger rate due

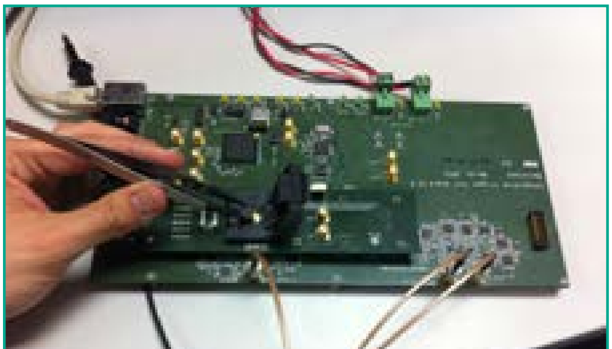


**Fig. 2: Quality Control of the L0 ASICs that will be installed in the first LST.**

to Night Sky Background accidentals, whereas the trigger efficiency for gamma-like events remains high due to the compactness of their associated camera image. Although the conceptual design of the trigger systems for the LST was developed at IFAE,

**Fig. 3: Pre-production series of boards with the camera trigger functionality.**

the final implementation based on several ASICs has been a joint effort from the CTA-Spain Consortium. The trigger decision system is divided in two levels: the L0 based on individual photosensors and the L1 using also the neighbor photosensors. IFAE is the responsible of testing the ASICs where the L0 trigger level is implemented as well as designing the board where the ASICs are used, which include the control logic and analogical adjustable delay li-

**THE FINAL INTEGRATION OF THE LSTs CAMERAS WILL HAPPEN AT IFAE**

nes. In 2015, the L0 ASICs needed for the first LST passed the quality control at IFAE (Figure 2) using the software and procedure that we had developed. While testing the ASICs the reliability and speed of the quality control was optimized reaching a level acceptable even for productions of several thousand ASICs. We also validated the final version of the board that includes the ASICs with the trigger functionalities, including a pre-production series (Figure 3) to evaluate the reliability of the process and involved companies for the massive production. This pre-production is already being used for the final validation of other elements of the camera electronics produced elsewhere. Additionally, IFAE also developed an ASIC that complements the trigger decision system by participating in the trigger distribution. The developed ASIC replicates the output signal from the L0 trigger ASIC and distribute it to the neighboring groups of 7 photosensors (Figure 4). Its functionalities and performance were validated during 2015.

## THE BOGIE AND FOUNDATION

The structure of the Large Size Telescope will move in its azimuth axis on an "undercarriage". The undercarriage consists of wheels (assembled into six "bogies"), a set of motors, a ground support for the wheels and a concrete foundation. IFAE is in charge for the undercarriage of the LST structure as well as for the foundations of the telescope. Both have been already designed. Very relevant for the design of the undercarriage is the fact that the telescope is so light that strong winds are expected to lift it up.

During 2015, the paper work and the final drawings to build the foundation at the ORM were completed. This include a detailed study of possible positions to install not only the first LST but all telescopes that will eventually be part of the northern site. The opening of the bidding for its construction was the point of no return to start building the first LST. In parallel a full bogie was built and assembled at the mechanical workshop of IFAE (Figure 4), which is used to validate the design before going to the production of the full systems for the first LST. The construction will be shared among several workshops belonging to the LST Consortium and coordinated by IFAE. All in all, the road was cleared in 2015 to produce the bogies for the first LST during the first half of 2016.

## THE LIDAR

A LIDAR (LIght Detection And Ranging) is an optical remote-sensing technology that can measure the distance to a target and more of its properties by illuminating the target with pulses from a laser. Although it has also been used for other applications, the first LIDAR systems were used for studies of atmospheric composition, structure, clouds, and aerosols. This is still one of its most common applications. The LIDARs installed in the CTA observatory will be used to monitor and characterize the atmosphere. This should allow to reduce the systematic uncertainties affecting the imaging air Cherenkov technique and to increase the duty cycle of observations by correcting for the atmosphe-

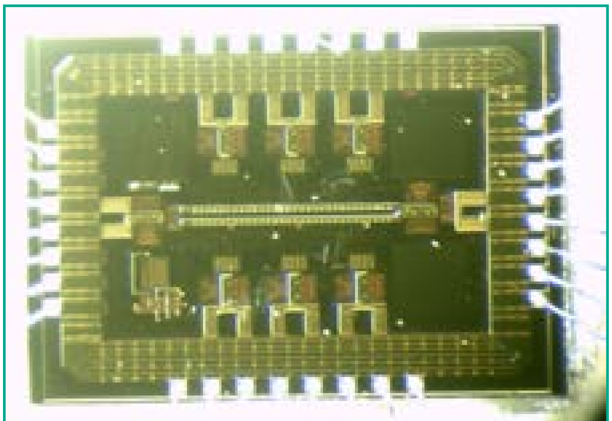


**Fig. 4: Die micrograph for the L0 fanout ASIC.**

ric conditions. Although LIDARs are commercially available, they do not meet the requirements set by CTA. To reduce the systematic uncertainties at the desired level, the atmospheric absorption should be known with a precision of about 5%. This entails the need to also use Raman lines, which have much less intensity. Furthermore, one needs to characterize the atmosphere up to the altitude where the Cherenkov photons are produced, which is about 10 km above ground.

IFAE had acquired two old telescopes with a 1.8 m diameter already installed in a standard ship container. They were part of the former CLUE experiment. One of them is installed on the campus of the Universitat Autònoma de Barcelona (UAB) and it has been used to develop a Raman LIDAR that fulfills the needs of the CTA observatory in collaboration with the UAB. In addition to the telescope, one needs the following elements to transform it into a LIDAR: a Laser, an alignment system to have the laser beam parallel to the telescopes axis, a light guide to transmit the light collected by the mirror from the focal to the optical detector, and the optical detector itself. To be Raman, the optical detector needs to look not only to the wavelengths emitted by the laser but also to wavelength produced through inelastic scattering on different molecules, which is orders of magnitude less intense than the elastic scattering. In 2015, the LIDAR was commissioned with an optical detector only sensible to the elastic scattering. In parallel the optical detector able to look at the Raman line was built and will be commissioned in 2016.

## DATA MANAGEMENT AND MONTE CARLO

VHE gamma-ray astronomy is evolving with CTA away from the old model of collaboration-led experiments towards that of a public observatory, where guest observers will submit observation proposals and have access to the corresponding data, software for scientific analysis and support services. The CTA Data Management project is in charge of developing the services and infrastructures needed to handle the large amount of data generated by the CTA observatory, and must fulfill the requirements of a public observatory.

Fig. 5: Bogie for the LST built and assembled at IFAE.

In the last years IFAE has participated in the activities related to Data Model. IFAE has been responsible of the subgroup devoted to the model for the Instrument Response Functions (IRF), with strong links with other parts of the CTA project, such as Monte Carlo or the Science Gateway. Based on the work that led to define the high- and middle-level requirements as well as the specifications that will define the CTA Data Model, we had produce the first version of a framework that described the IRF. During 2016 and benefiting from the participation into the European project ASTERICS, we produced IRFs using the defined framework. This activity will be instrumental for the analysis of CTA data and developing this activity will help IFAE to have a leading role in physics exploitation of CTA.

**THE CONSTRUCTION OF THE FIRST LST STARTED ON OCTOBER 9TH 2015 WITH A CEREMONY ATTENDED BY THE PHYSICS NOBEL PRIZE TAKAAKI KAJITA**

As already mentioned the IRF has strong links with the Monte Carlo work package. In 2015 the third official large-scale CTA MC production (Prod-3) was launched, with the main goal of optimizing the detailed layout of the two CTA observatories. IFAE was involved on the detailed definition of the parameters to be used in the simulation that better describe the current design of the hardware, in particular for the Large Size Telescopes. The input parameters used for this production were much closer to what is expected from the real hardware than in previous Monte Carlo productions. The analysis of the production 3 is in progress, and will be finalized in 2016, with IFAE contributing one of the three analyses from which the final CTA configuration will be determined.

# 2.6 THE DES AND DESI PROJECTS

RAMON MIQUEL

Since 2005, a group at IFAE, together with a group at ICE (Institut de Ciències de l'Espai), located also in the Bellaterra campus, and another at CIEMAT (Centro de Investigaciones Energéticas, Medio Ambientales y Tecnológicas) and Universidad Autónoma de Madrid (UAM), collaborates in the DES (Dark Energy Survey) international project, led by Fermilab (USA) and, since 2015, in the development of the DESI (Dark Energy Spectroscopic Instrument) international project.

## DES

During the fall of 2012, the Dark Energy Survey (DES) collaboration installed and commissioned DECam, a 570 mega-pixel (74 CCDs) optical and near-infrared camera with a large 3 sq. deg. field of view, set at the prime focus of the 4-meter Víctor M. Blanco telescope in the Cerro Tololo Inter-American Observatory (CTIO) in the Chilean Andes. The completed DECam can be seen in Fig. 1, after being installed at the Blanco. In return for providing the camera, DES is granted 525 nights, 30% of all the observation time for five seasons. DES is an international consortium led by Fermilab (USA) and including universities and research laboratories from USA, Spain, UK, Brazil, Germany, Switzerland, and Australia. The IFAE group, together with a group at CIEMAT (Madrid), was responsible for the design of three quarters of the read-out electronics of DECam, and for the production and test of the whole system.

**Fig. 1: The complete DES camera, DECam, installed at the prime focus of the Víctor M. Blanco 4-meter telescope at the Cerro Tololo Inter-American Observatory (CTIO) in the Chilean Andes.**

**USING THE WEAK-LENSING TECHNIQUE, DES PUBLISHED IN 2015 THE LARGEST CONTIGUOUS DARK-MATTER MAP PRODUCED TO DATE, WHICH HOWEVER ONLY COVERS ABOUT 3% OF THE AREA THAT DES WILL EVENTUALLY SURVEY**

In the course of a five-year period that started in August 2013, DES will map an entire octant (5000 sq. deg.) of the Southern sky in five bands (grizY) to unprecedented depth ($i_{AB}$ ~ 24), measuring the position on the sky, distance and shape of almost 300 million galaxies, together with over 10,000 galaxy clusters, up to a redshift z ~ 1.4. Furthermore, another ~30 sq. deg. of the sky are repeatedly monitored with the goal of measuring magnitudes and colors of over 3000 distant type-Ia supernovae. With this data set, DES will study the properties of the mysterious dark energy that powers the current accelerated expansion of the Universe using four main probes: galaxy clustering on large scales, weak gravitational lensing, galaxy-cluster abundance, and supernova distances. The four probes are complementary both in their dependence on the properties of dark energy and on their sensitivity to different systematic effects, which will therefore be kept under tight control.

A "Science Verification" (SV) period of observations, lasting from November 2012 until late February 2013, followed the DECam commissioning phase, and provided science-quality images for over 150 sq. deg. at the nominal depth of the survey. The first DES complete season started in late

August 2013 and went on until mid February 2014. This resulted in the imaging of about 1800 sq. deg. to about half the nominal depth of the survey. The data was reduced and made available in late 2014. The observations of the second season took place between August 2014 and February 2015, and the data taken are still being reduced at the time of this writing. The third season started in mid-August 2015 and will go on until February 2016. Currently, DES, and the IFAE group, are finalizing the analysis of the first DES science-quality data set, obtained during the SV period.

**IFAE IS CONCENTRATING ITS ANALYSIS WORK ON PROBING DARK ENERGY THROUGH ITS INFLUENCE ON THE LARGE-SCALE STRUCTURE OF THE MATTER DISTRIBUTION IN THE UNIVERSE**

The techniques DES uses to measure the properties of dark energy have the distance to the observed galaxies as a necessary ingredient. The distance determination is carried out from the redshift (z) of the galaxies, which in turn is obtained by photometric techniques using the flux in the five DES filters, resulting in the so-called photometric redshift, or photo-z. For photo-z's to be useful for cosmological studies, they need to be calibrated, understanding in detail the statistical properties of the distribution of the differences between true redshifts and photo-z's: its mean value (bias), width (resolution), and tails (outlier fraction). For this calibration process, one needs to have a large set of galaxies with spectroscopic redshift measurements, ideally with a galaxy population reproducing that in the photometric survey.

Part of the area observed during the SV season overlaps with existing spectroscopic surveys with a depth comparable to that of DES. The galaxy redshifts from those spectroscopic surveys have been, therefore, extremely useful in order to understand the performance of the photo-z algorithms in real DES data. The IFAE group led this very important photo-z calibration effort, leveraging the expertise built during the design phase of the PAU Survey (see chapter 2.7), and a member of the group (Carles Sánchez, a PhD student) was the lead author in the resulting paper (C. Sánchez et al. 2014, *Photometric redshift analysis in the Dark Energy Survey Science Verification data*, MNRAS 445, 1482), which became the very first published DES science paper.

A MSc student, Isaac Tutusaus, worked in 2015 in a complementary technique for photo-z calibration that uses the angular cross-correlation between a sample of galaxies whose redshift one wants to calibrate and a reference sample with known redshifts (for instance, a spectroscopic sample). The two samples will only show a significant cross-correlation if they overlap in 3D, which helps pinpoint the unknown redshift distribution. Figure 2 shows the result of a first attempt to use this technique on simulated data. Two graduate students at IFAE, Pauline Vielzeuf and Marco Gatti, have recently taken up this work, and belong to a DES-wide task force to develop and test the best algorithms. One of the advantages of this technique is that, unlike in the standard technique in Sánchez et al. 2014, here the reference sample does not need to be representative of the unknown sample in terms of magnitude and color distributions. The two samples only have to overlap in angular and redshift spaces.

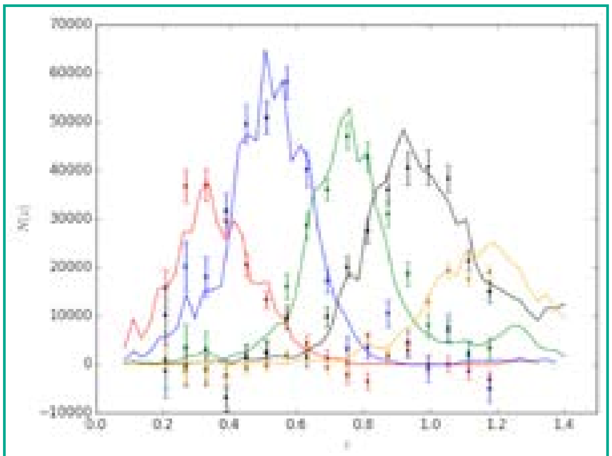



**Fig. 2: True distributions (solid lines) and distributions recovered using the cross-correlation technique described in the text (points with error bars) of simulated galaxies as a function of redshift for a patch of 50 sq. deg. with ~3 million unknown objects and ~20000 reference objects with $i_{AB} < 24$. The 5 tomographic bins represented span the photo-z ranges 0.2-0.4, 0.4-0.6, 0.6-0.8, 0.8-1.0 and 1.0-1.2, respectively. Note that the reference sample only covers the redshift range $0.2 < z < 1.2$. Taken from I. Tutusaus's MSc thesis.**

Beyond photo-z calibration, IFAE is concentrating its analysis work on probing dark energy through its influence on the large-scale structure of the matter distribution in the Universe. In particular, the IFAE group is deeply involved in the weak-lensing working group. Weak lensing holds the potential to be the most powerful probe of dark energy. In 2015, DES published the first batch of papers highlighting the quality of its weak-lensing data. Particularly impactful was a set of two papers (Chang et al. 2015, *Wide-Field Lensing Mass Maps from Dark Energy Survey Science Verification Data*, PRL 115, 051301; Vikram et al. 2015, *Wide-field lensing mass maps from Dark Energy Survey science verification data: Methodology and detailed analysis*, PRD 92, 022006) that use weak-lensing measurements to provide the largest contiguous mass map to date. Figure 3 contains this (mostly dark) matter map together with a map of visible galaxy clusters, showing the tight correlation between their positions. IFAE researchers Chris Bonnett, András Kovács (both post-doctoral researchers), and Carles Sánchez contributed to several aspects of this analysis.

Several other DES weak-lensing papers were published in summer 2015. Chris Bonnet was the first author of the DES paper that studied the photometric redshift distribution of the galaxies used in the first-round of DES weak-lensing papers (Bonnett et al. 2015, *Redshift Distributions of Galaxies in the DES Science Verification Shear Catalogue and Implications for Weak Lensing*, arXiv:1507.05909 [astro-ph.CO]). In Figure 4 we can see the effect of the uncertainties on the photo-z calibration on the most sensitive weak-lensing observable: the main component of the two-point shear-shear correlation function, $\xi^+$. For the SV data set, these systematic uncertainties are still significantly smaller than the statistical errors (mostly shape noise and sample variance), but for larger data sets this may become a limiting systematic error. During this period, Chris Bonnett was the convener of the "Photometric Red-

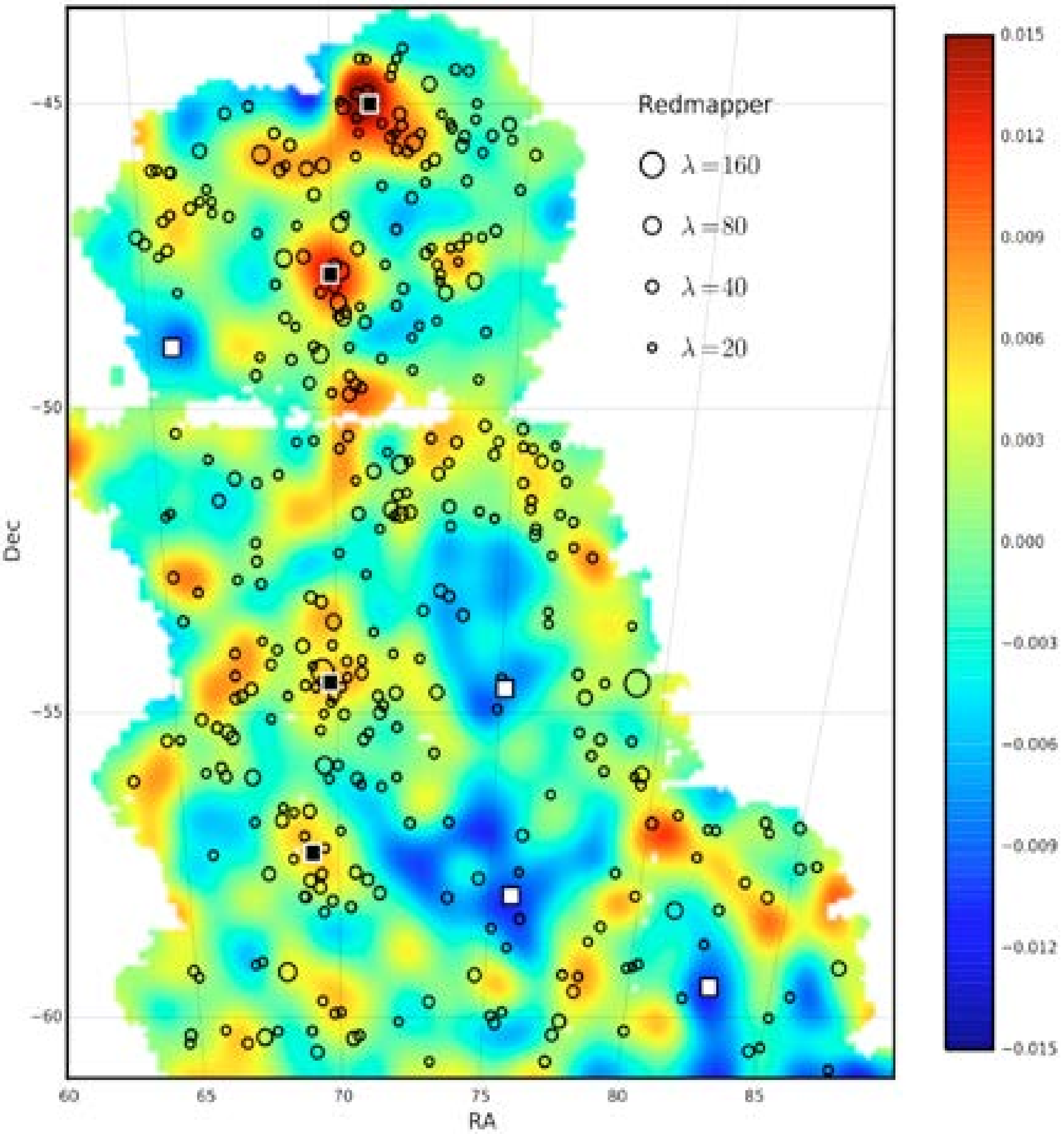



**Fig. 3: First mass map from DES, corresponding to approximately 140 sq. deg. in the sky. Redder areas contain more (mostly dark) matter, while bluer areas contain less. The gray dots correspond to visible foreground galaxy clusters, also observed by DES. Larger dots correspond to clusters with more galaxies. One can clearly see a tight correlation between the mass map and the distribution of galaxy clusters. Several super-clusters (black squares) and voids (white squares) can be identified in the joint map. This is the largest contiguous mass map produced to date, and it covers less than 3% of the area that DES will eventually survey. Taken from V. Vikram et al. 2015, *Wide-field lensing mass maps from Dark Energy Survey science verification data: Methodology and detailed analysis*, PRD 92, 022006.**

shifts for Weak Lensing" sub-working group, which combines the two research topics highlighted above. Since September 2015, he is the convener of the whole DES "Photometric Redshift" working group, and, as such, he is a member of the DES Science Committee.

In 2015, within the weak-lensing group, IFAE has been particularly active in the measurement of galaxy-galaxy lensing (tangential shear of background galaxies around foreground galaxies) in the SV data set, a powerful probe of the (mostly dark) matter distribution in and around galaxies. Three DES papers on this topic (co-)led by IFAE scientists are in preparation and will be published in the next few months. One, led by Judit Prat (a graduate student), presents the measurements of galaxy bias (the relationship between the spatial galaxy distribution and the underlying dark matter distribution) using galaxy-galaxy lensing around a magnitude-limited foreground galaxy sample; another, co-led by Carles Sánchez measures galaxy-galaxy lensing around luminous red galaxies (LRGs), while a third, co-led also by Carles Sánchez, combines the results from the previous paper with measurements of the angular clustering of LRGs to extract cosmological information.

Another post-doctoral researcher, Jelena Aleksić, was a lead author in another DES paper in 2015 (Suchyta et al. 2015, *No galaxy left behind: accurate measurements with the faintest objects in the Dark Energy Survey*, arXiv:1507.08336 [astro-ph.GA]). This paper introduces Balrog, a novel simulation technique embedding fake objects in real images, that provides a robust determination of the completeness and purity of any algorithm that attempts to select galaxies in the DES images, and hence allows the efficient use of DES data up to the magnitude limit of the survey. Figure 5 shows an example of an analysis that uses this technique to perform accurate measurements with galaxies as faint as the magnitude limit of DES.

The IFAE group is also involved in cosmological void

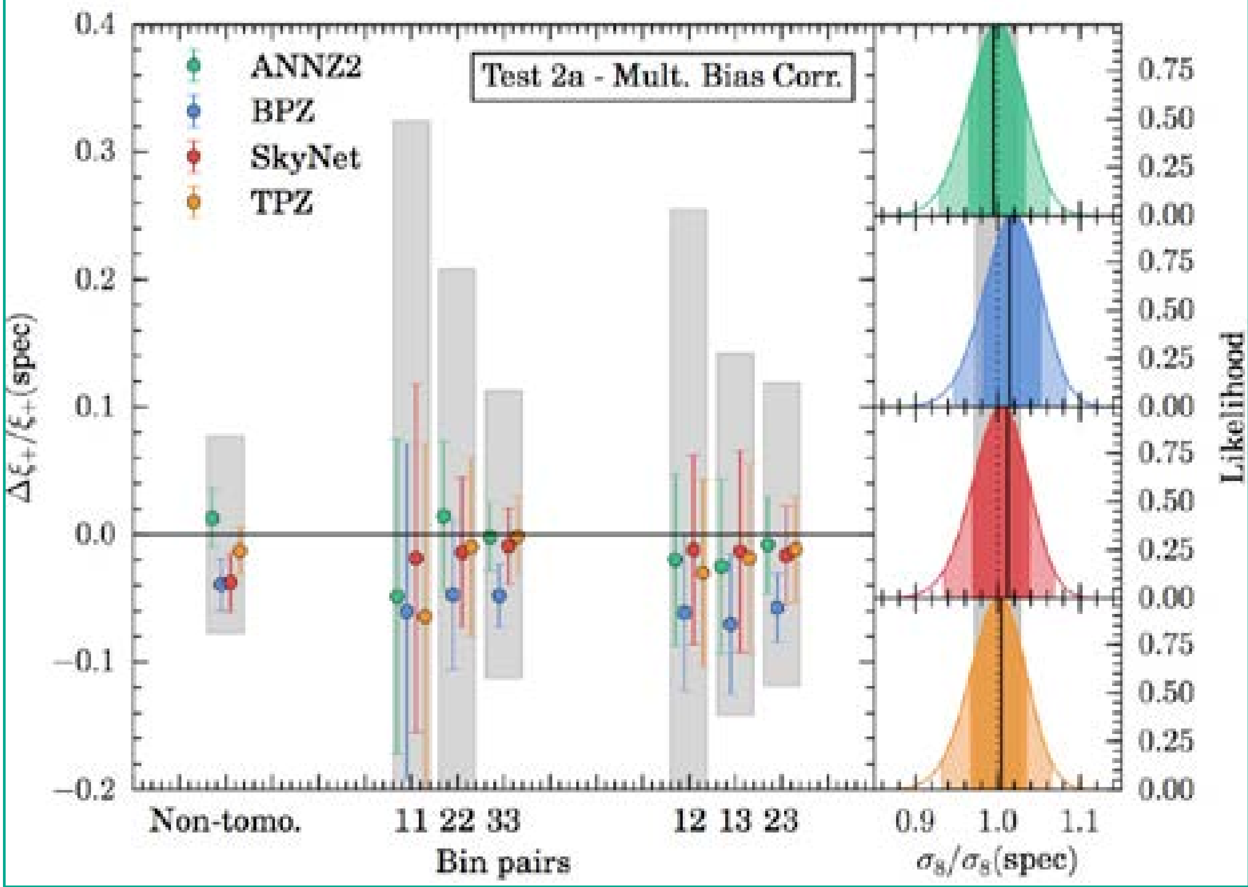



**Fig. 4: A comparison of the relative agreement of the redshift distribution estimates from four photo-z codes and an independent spectroscopic galaxy sample. Left panel: The change in the magnitude of the correlation function with respect to the spectroscopic prediction is shown for the overall $\xi^+$, the auto-correlations in 3 redshift bins (11, 12, 33), and three cross-correlations (12, 13, 23 bin pairs). The gray band is the actual uncertainty in the magnitude of $\xi^+$ measured from DES SV data. Error bars on the points correspond to the 1-$\sigma$ error on the difference of $\xi^+$ obtained by bootstrapping the distribution of the spectroscopic sample. Right panels: The corresponding constraints on the amplitude of the power spectrum of matter density fluctuations at a scale of 8 Mpc/h, $\sigma_8$, normalized to one (vertical dotted black line). The likelihood histograms, color-coded to match the $\xi^+$ points on the left, are shown for each photo-z code. The vertical gray band is the corresponding 1-$\sigma$ bootstrap error in $\sigma$. In all cases, a bias correction was applied to the mean of each photo-z bin. Taken from Bonnett et al. 2015, *Redshift Distributions of Galaxies in the DES Science Verification Shear Catalogue and Implications for Weak Lensing*, arXiv:1507.05909 [astro-ph.CO].**

science. Two DES papers are in preparation: one on lensing around voids, co-lead by Carles Sánchez and András Kovács, and another on the Integrated Sachs-Wolfe effect (CMB photons changing wavelength when crossing large over- or under-dense regions) across large voids and superclusters, led by András Kovács.

In 2015 our institutional involvement in the governance of DES has been kept at a high level, with a member of the IFAE group being a member of the DES management committee, the publication board, and the DES builders' committee, which grants paper authorship rights to the DES participants who have made substantial contributions to its infrastructure.

**DESI IS A SPECTROSCOPIC GALAXY AND QUASAR SURVEY THAT WILL PRODUCE MEASUREMENTS OF THE PROPERTIES OF THE DARK ENERGY ONE ORDER OF MAGNITUDE MORE PRECISE THAN THOSE PRODUCED BY THE SURVEYS CURRENTLY ONGOING**

## DESI

The Dark Energy Spectroscopic Instrument (DESI; http://desi.lbl.gov) is a Stage IV ground-based dark-energy experiment that will study Baryon Acoustic Oscillations and the growth of structure through redshift-space distortions with a wide-area galaxy and quasar spectroscopic survey. DESI is led by Lawrence Berkeley National Lab (LBNL) and funded mostly by the USA Department of Energy (DOE). Starting in 2019, DESI will cover 14000 sq. deg. of the celestial sphere in five years, obtaining more than 30 million galaxy and quasar redshifts, reaching at least an order of magnitude improvement over the measurements of dark energy in current (Stage III) projects and providing unprecedented measurements of the expansion rate of the Universe. In addition, DESI will measure the sum of neutrino masses with an uncertainty of ~17 meV, enough to guarantee a first direct detection of the sum at more than $3\sigma$ significance, and rule out the inverted mass hierarchy at 99% C.L. if the hierarchy is normal, even if the masses are minimal. DESI will also place significant constraints on theories of modified gravity and of inflation by measuring the spectral index of the matter power spectrum and its running with spatial scale. DESI is expected to provide the definitive measurement of the BAO scale, since it will be able to determine it with extreme precision in a huge range of redshifts, from z~0 to z~3.5. The determination at low redshift is done using different types pf galaxies, while from z~2 to z~3.5 the Lyman-alpha forest in quasar spectra is used.

The DESI focal plane includes a set of 10 cameras to guide and focus the instrument as it points to the sky. These are the only imaging systems in DESI, crucial to the operation of the spectrograph, and they perform these two fundamental tasks while

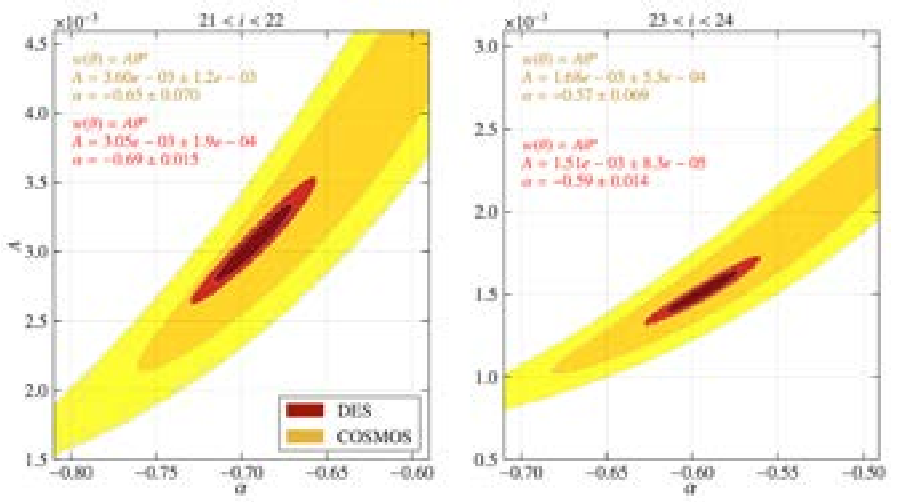



**Fig. 5: Power-law fits to the angular galaxy correlation function measured in DES (red) and in a matched sample of galaxies from the deeper (but much smaller) COSMOS survey (yellow). Contours correspond to 68% and 95% confidence intervals. On the left plot, only relatively bright galaxies, with 21 < $i_{AB}$ < 22, are used. At these magnitudes, DES is essentially complete, and the efficiency corrections are minimal. On the right plot, only the faintest galaxies, with 23 < $i_{AB}$ < 24, are used. At these magnitudes, DES is highly incomplete and the efficiency corrections are large. The use of the Balrog simulation tool allows a robust computation of these corrections, so that the results of the fit agree with those from the COSMOS sample. Taken from Suchyta et al. 2016, *No galaxy left behind: accurate measurements with the faintest objects in the Dark Energy Survey*, MNRAS 457, 786.**

also being part of the precision alignment system. IFAE, together with the groups at ICE (CSIC-IEEC), CIEMAT and UAM/IFT, is responsible for the design, construction and commissioning of the whole GFA system: 10 (+ 2 spares) cameras complete with mechanical enclosures, filters, CCDs, readout electronics, thermal control, etc.

The DESI focal plane assembly is made of 10 petals , each with 500 fiber positioner robots, one GFA unit, and 7-10 illuminated fiducials. The GFA cameras will use stars to provide the guide signal and to measure focus and alignment of the DESI instrument. Six of the GFA units are for guiding, while four are for focus / alignment, via wavefront measurements. The sensors can also measure the tip/tilt of the focal surface.

Each of the 10 nearly identical GFA cameras contains a single CCD sensor, mounted and operated as a standalone instrument. The cameras operate at ambient temperature, without a shutter, in frame transfer mode, and are sealed with a broad range (red) optical filter mounted atop the CCD. Each camera contains all CCD readout electronics and all controls, and requires only DC power and a Gigabit Ethernet connection. The two types of GFA package, guiding and focusing, are different only in the filter installed atop the sensor. The guide configuration has a filter of uniform thickness, while the focus configuration has a stepped filter, such that half of the image is ahead of focus and half of the image is behind. Each GFA has illuminated fiducials attached rigidly to the same frame that mounts the sensor. The e2v CCD230-42 detector has been selected for the GFA cameras, due to its relatively low dark-current signal at room temperature.

The main challenges in the design of the read-out electronics are the small space available (see Fig. 6) and the tight constraints on power dissipation. The readout of the CCD will be fully digital. The output signal from each CCD amplifier will be digitized

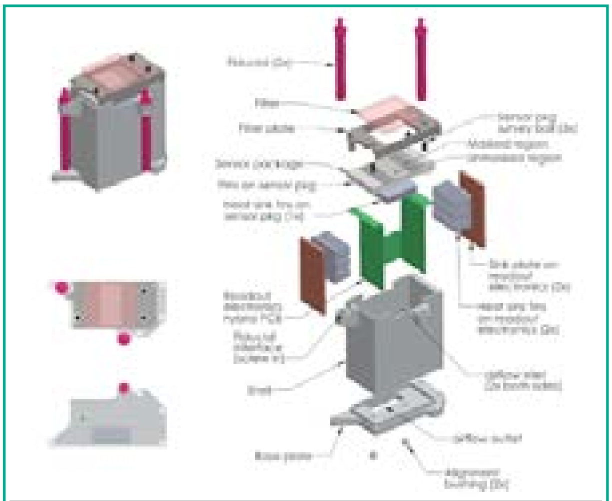


**Fig. 6: Detailed concept design for a GFA camera.**

**THE DESI FOCAL PLANE INCLUDES A SET OF 10 CAMERAS TO GUIDE AND FOCUS THE INSTRUMENT AS IT POINTS TO THE SKY**

at a high rate (100 Msps), and then a digital correlated double sampling will be applied. The system will also include electronics for bias and clock generation needed to operate the CCD. The design is based on a Xilinx FPGA that includes a System On Chip (SOC) ARM Linux system that will implement the control. The control system will be split between a server and a client. The server will reside in the embedded Linux system, which will receive commands and will send raw data (either telemetry or CCD raw data) to a client. Data transmission to the server will be performed using an Ethernet connection.

Based on the experience with the characterization of the PAUCam detectors and the peculiar operational conditions of the GFA devices, we will have to characterize the behavior of each CCD, including spares, at the working conditions. As the CCDs will operate at ambient temperature, the characterization setup consists on an enclosure with controlled and monitored temperature filled with nitrogen, and with a window to illuminate the CCD. The characterization suite is composed by six measurements: read-out noise; dark current at several temperatures up to 25 C; Photon Transfer Curve (PTC); response to X-rays ($^{55}Fe$); quantum efficiency; and cosmetic defects.

The mechanical design for the enclosure involves the gluing of a filter on top of the CCD, and then the gluing of this assembly to the camera proper, creating an air-tight enclosure that will be filled with nitrogen to avoid moisture on the sensor. Careful alignment and metrology from the active area of the sensor to the fiducials mounted on the camera are necessary to implement this design. A schema of the mechanics of a GFA camera can be seen in Fig. 6. A full prototype of a GFA camera has to be ready in the second quarter of 2016.

# 2.7 THE PAU PROJECT

ENRIQUE FERNÁNDEZ

The goal of the PAU (Physics of the Accelerating Universe) project is to prepare an internationally competitive experiment on the study of the accelerated expansion of the Universe led by Spanish groups. Scientifically that entails two main tasks: to build an appropriate instrument for that purpose (a large field of view camera, the main deliverable of the project) and to prepare, scientifically, technically and organizationally, to carry out a large galaxy redshift survey.

## INTRODUCTION

After many years of preparation, namely since 2008, the PAU Camera saw the first light at the William Herschel Telescope in La Palma on June 3 of 2015. This event marks the end of the PAU (Physics of the Accelerating Universe) project, which had as main goal the delivery of that instrument.

The PAU project was funded by the Consolider Ingenio 2010 Program of the Spanish Ministry of Research and Innovation. The goal of the Consolider Program was to strategically fund scientifically competitive projects proposed by Spanish research groups, with the potential to advance in specific areas of science.

In 1997 the cosmology group at the IFAE teamed with groups of other six Spanish Institutions, at CIEMAT (Madrid), IAA (CSIC, Granada), IEEC (Barcelona), IFIC (Valencia), IFT (Madrid) and PIC (Barcelona), to submit a project to the Consolider Program. The five-year project was approved in the summer of 2007, effectively started in early 2008 and was extended until the end of 2014, when it finished from the administrative point of view.

The PAU project consisted on a series of activities focused on a main strategic goal: the preparation of an internationally competitive experiment on the study of the accelerated expansion of the Universe (hence the acronym PAU), led by Spanish groups. Scientifically that entailed two main tasks: to build an appropriate instrument for that purpose (a large field of view camera, the main deliverable of the project) and to prepare, scientifically, technically and organizationally, to carry out a large galaxy redshift survey. The two tasks are clearly not independent, as the instrument design is conditioned by the scientific goals and vice-versa.

Here we describe the two main tasks of the PAU project: the construction and installation of the PAU camera at the William Herschel Telescope in the Canary island of La Palma and the preparation of the PAU Survey. These two tasks have been carried out in close collaboration with the IEEC and PIC groups, also located at the campus of Universitat Autònoma de Barcelona, and the CIEMAT and IFT/UAM groups in Madrid. These groups also collaborate closely on the DES project, described elsewhere in this report.

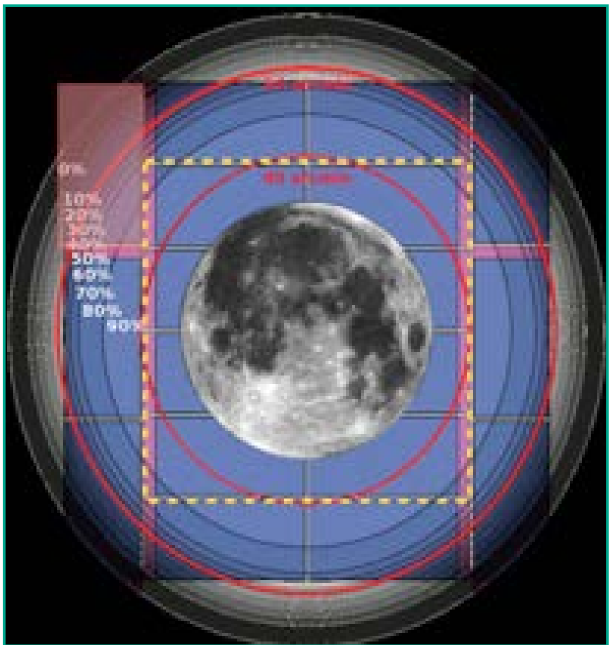



**Fig. 1: Scheme of the position and coverage of PAUCam's CCDs. The Moon was put in the center of the image, to give an idea of its size.**

## THE PAU CAMERA (PAUCAM) AND THE PAU SURVEY (PAUS)

Early in the project we decided to carry out a photometric (as opposed to spectroscopic) survey, with images taken with a large number of filters as to obtain what we could call a pseudo spectrum, or low-resolution spectrum. The goal was to obtain a resolution in redshift z better than 0.0035(1+z), which, based on simulations, would require about 40 filters.

After considering several options for a telescope it became clear, at the end of 2009, that there was the possibility of installing an imaging instrument at the prime focus of the William Herschel Telescope (WHT) in La Palma. This is a 4m-diameter telescope (part of the Isaac Newton Group) formerly belonging to the UK and now run by a Consortium of the Netherlands, Spain and the UK.

In April 2010 a formal proposal was sent to the board of the ING in order to install the PAU Camera (PAUCam) at the WHT as a visiting instrument, with the provision that it could also be used by interested members of the WHT community of users, when not dedicated to the PAU survey. At their meeting on May 26th 2010, the ING board approved the status of visitor instrument for PAUCam and the Memorandum of Understanding was finally signed in early 2012.

**PAUCAM IS A UNIQUE INSTRUMENT BECAUSE IT IS ABLE TO PROVIDE LARGE QUANTITIES OF PRECISE REDSHIFTS FOR ALL OBJECTS IN THE FIELD OF VIEW**

The final design of PAUCam was done to meet the specifications of the WHT. WHT has a field of view (FoV) of 1º in diameter with 85% light collection efficiency (of which 40' have 100% efficiency, see Fig. 1). PAUCam covers the entire FoV of the telescope with 18, 2k x 4k fully-depleted red-sensitive Hamamatsu CCDs with 15 μm pixels, giving a 0.26"/pixel plate scale. The camera is equipped with 40 narrow-band filters and six standard ugrizY wide-band filters (see below), taking advantage of the excellent sensitivity of the Hamamatsu CCDs across the entire wavelength range from 300 to 1000 nanometers.

Fig. 1 is a scheme of how the Moon can be imaged in the PAUCam focal plane. The CCDs are the blue rectangles in the background. The central part of the focal plane (the 8 CCDs marked by the yellow dashed rectangle), are almost entirely within the 40 arcmin fully illuminated field of view. Only the images from these CCDs will be used for science. The rest of the CCDs, which are vignetted, will be used for guiding and pointing, as well as for the extra photons, when possible.

As a survey camera, PAUCam can cover ~2 deg2 per night in all filters, delivering low-resolution (R~50) spectra for ~30000 galaxies, ~5000 stars, ~1000 quasars, ~10 clusters per night. The resolution in redshift z depends on the exact number, width and location of the narrow filters.

**Fig. 2: The telescope simulator, with PAUCam mounted on it. The camera is open, and most of the elements are not installed inside.**

A filter optimization study was carried out, converging in a solution with 40 narrow band filters (~ 10nm wide in wave length) covering the range between ~470 and ~830 nm. With this configuration PAUCam will be able to deliver very precise redshifts ($\sigma_z$~0.0035x(1+z)) for all galaxies with magnitude iAB below 22.7, at the same time providing typical photometric redshift precision ($\sigma_z$~0.035x(1+z)) for galaxies with iAB between 22.7 and 24.

What makes PAUCam a unique instrument is to be able to provide large quantities of precise redshifts for all objects in the field of view. A survey performed with PAUCam can therefore combine a large galaxy density (larger than typical spectroscopic surveys such as BOSS) with a high redshift accuracy (higher than typical broadband photometric surveys such as DES) to provide a highly competitive determination of the dark energy parameters.

Our studies have centered in two dark-energy related observables: redshift-space distortions and weak-lensing magnification, for which PAU is uniquely suited.

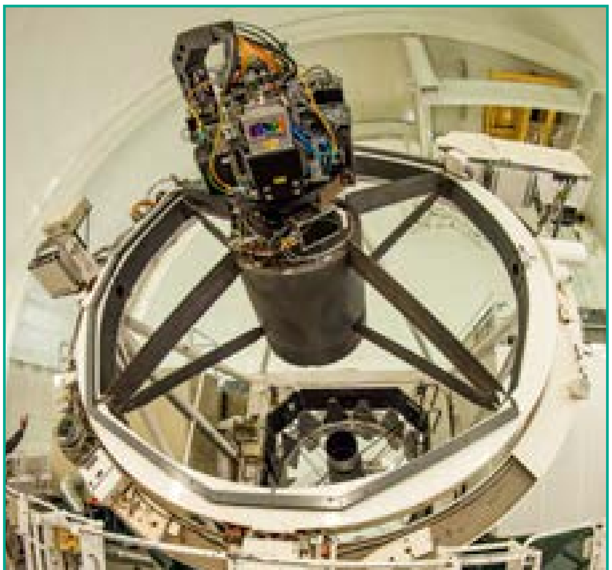


**Fig. 3: Photograph of PAUCam mounted at the prime focus of the William Herschel Telescope.**

Redshift-space distortions originate in the peculiar velocities of galaxies, which trace the surrounding matter density fields. By measuring anisotropies in the galaxy 2-point correlation function, it is possible to determine the growth of structure at any given redshift, a most sensitive probe of dark energy. The relevant scales (~10 Mpc/h) are well matched to the redshift precision that PAUCam can deliver.

Weak-lensing magnification affects the measured galaxy number density. In this case, the main observable is the cross-correlation between galaxies in different redshift bins as a function of angular separation. This is sensitive to dark energy through both the growth of structure in the universe and its geometry.

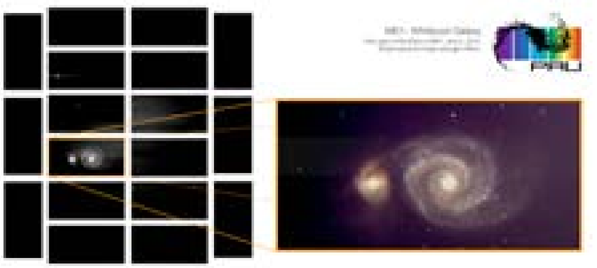


**Fig. 4: Galaxy M51, known as the Whirlpool galaxy, situated at about 23 million light years from Earth. (Image acquired June 6th, 2015).**

For the details of the reach of these observables and of the possible combination of measurements of the same area, combining photometric and "low resolution spectroscopic" (such as PAU), we refer to E. Gaztañaga et al., MNRAS, 422(2012) 2904. The combination of a deep photometric survey with a more shallow spectroscopic or PAU-like photometric survey of the same area, can give very competitive results, even with a relatively small (200 deg2) surveyed area.

# PAUCAM DESIGN AND CONSTRUCTION

Here we briefly explain the main design characteristics of PAUCam as well as its construction at the IFAE Mechanical Workshop.

Most of the details of installing PAUCam at the WHT, both technically and administratively, were planned during 2011. One of the main issues is the camera weight limitation of 235 Kg, which resulted in a design in which the camera enclosure is made in carbon fiber as opposed to aluminum, which is the usual material in this type of instruments. Additionally, the walls of the camera are curved in order to minimize the wall thickness while still maintaining the needed strength. The mechanical design was finalized in 2011.

PAUCam construction started in 2012 after successful design and prototyping. At the end of 2012 most of the major components were in hand and construction was well underway. The Carbon fiber body was built by injecting the material into a mold designed and fabricated in-house at the IFAE. The injection of the Carbon fiber into the mold took place at the enterprise Magma-Composites, located in Alcañiz, Teruel, during 2012. Once the camera body was back at the IFAE, all the tests done with the full-size Alluminum prototype were repeated. It was found out that some of the joints were not completely vacuum tight. After careful debugging and interaction with the construction company, this problem was solved.

The construction continued during 2013 as planned. Two major issues were the cooling and the vacuum systems needed for operation. The vacuum during operations maintained with a getter pump (a Saes Getter GP500 model). The level obtained in the lab with the actual camera body and this pump was $10^{-7}$ ppm and this has been reproduced at the telescope.

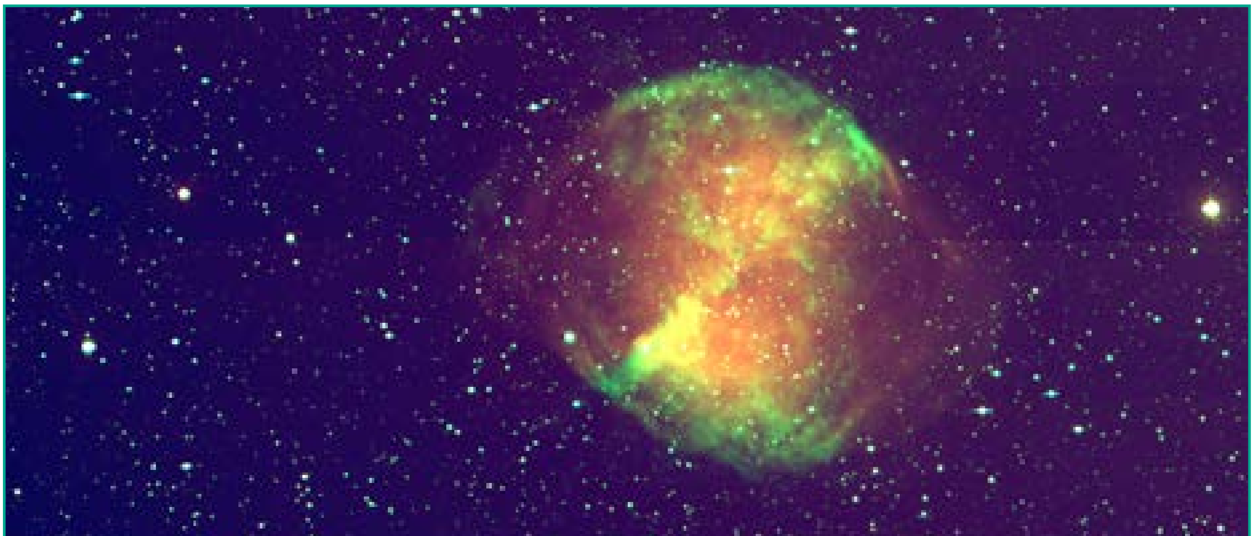


**Fig. 5: Planetary nebula M27, known as the Dumbbell Nebula, situated in our own galaxy, the Milky Way, at a distance of about 1000 light years from Earth. (Image acquired June 3rd, 2015).**

The PAUCam operating temperature is about -100ºC. This is achieved with a set of two Polycold (Cryotiger) PCC PT30. Nitrogen cooling is also be possible when the camera is not in use and out of the WHT prime focus.

One of the key elements of the PAU camera is the positioning of the filter trays inside the camera enclosure to place them as close as possible to the CCD's, therefore maximizing the FoV coverage. In order to accomplish this, a system of two tray lifts, each of them with seven trays, is installed. One lift carries the filters needed for the PAU survey. The other carries a set of standard broadband filters (the u g r i z Y set) that can be used by other astronomers. Additionally, a system to install a filter outside the camera enclosure is foreseen.

Many studies of the materials, the cooling, the vacuum and the system to move the trays were done with a test setup made in aluminum, with a size similar to that of the actual camera. Also tested with this setup were many aspects of the control system, which involves a large amount of software. All these tests took place during 2011 and 2012, before the arrival of the final camera body. Many more tests have been done with the actual body of the camera during 2013. At every instance the control software, which is a major item of the project, was used to do these tests.

At the end of 2013 all major systems of the camera were finalized and the assembly was started. The focal plane mechanics, the cooling, the vacuum system, the filter-tray assembly and many other mechanical systems of the camera were tested in the lab. On the other hand the acquisition of the narrow band filters took longer than anticipated and this was the main reason for asking for an extension of the project.

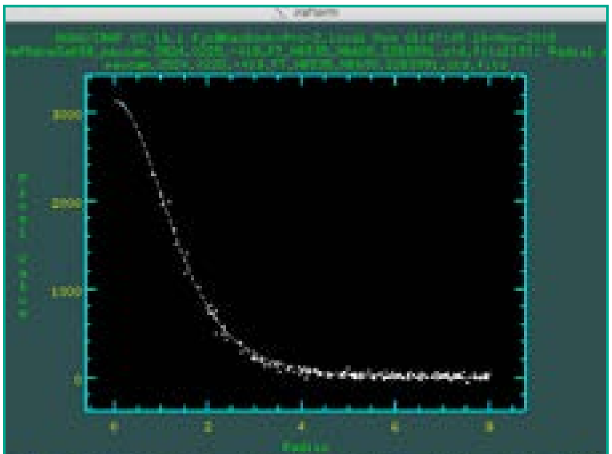


**Fig. 6: A start profile as seen by PAUCam.**

Another important tool for the construction and testing of PAUCam was the so-called "Telescope Simulator". The simulator was a device that interfaced the telescope and camera as in the actual WHT telescope. The device had two rotation axes and could bring the camera to virtually every position to be used in the actual survey. The simulator was also very useful to study the routes for cables from the camera to the outside. Figure 2 is an actual photograph of the device with the camera, at some stage of construction, was mounted on it.

The original plan was to install the camera during 2014, but in July of 2014 we had an unexpected problem reading the CCDs, which effectively caused another half-year delay in the installation at the telescope. The problem appeared when making tests of the complete system: the images had dark spots. A visual inspection of the CCDs showed that they also had spots which looked very much like ice droplets.

In order to understand the problem the camera was again opened. Many test were done, with the conclusion that, most likely, the camera had a very small vacuum leak or some water inside. After reassembly the problem never happened again, after operating the camera for months, at the lab and at the telescope.

PAUCam was shipped to La Palma in May of 2015, by truck, from the IFAE workshop to the Port of Barcelona, by boat from Barcelona to Santa Cruz de La Palma and again by truck to the William Herschel Telescope at the Roque de Los Muchachos. The installation of the camera at the WHT went very smoothly. Figure 3 is a photograph showing the camera in position at the WHT.

PAUCam started operations on June 3. The alignment of the camera with the telescope axis was essentially correct, no change in the mounting of the camera had to be made. The focusing took only a few hours and already during the first night the camera was producing images. The Data Acquisition System and the Control Software, although not complete, were sufficient to operate the camera and record the data. The data were in fact transmitted to the remote storage at the PIC, in Barcelona, also the first night.

Figures 4 and 5 show images of two well-known objects as observed by PAUCam. The images already make use of several filters and involve some preliminary calibrations.

The five days run of PAUCam was indeed very successful. We had a long list of checks to be made and all were done. During the last night some actual data was taken, with wide-band and narrow-band filters. This data has been invaluable to check more carefully the quality of the images and to calibrate the instrument, a work that is now in progress.

After the first light in June, the PAUS survey has properly started. We have established contacts with other European groups that were interested in the science to be explored with PAUCam and they have since joined the collaboration. These are groups from the Linden Observatory in the Netherlands, from Durham University and University College of London University, in the UK, and from ETH-Zurich, in Switzerland.

# 2.8 THE EUCLID PROJECT

CRISTÓBAL PADILLA

Euclid is a mission for the European Space Agency (ESA) Cosmic Vision (CV) 2015-25 programme to explore how the Universe evolved over the past 10 billion years to address questions related to fundamental physics and cosmology on the nature and properties of dark energy, dark matter and gravity, as well as on the physics of the early universe and the initial conditions which seed the formation of cosmic structure.

## INTRODUCTION

The satellite is expected to be launched in the first quarter of 2020 by a Soyuz ST-2.1B rocket and then travel to the L2 Sun-Earth Lagrangian point for a six years mission. To accomplish its goals, Euclid will carry out a wide survey of 15,000 deg$^2$ of the sky free of contamination by light from the Milky Way and the Solar System and a 40 deg$^2$ deep survey to measure the high-redshift universe. The complete survey represents hundreds of thousands of images and several tens of Petabytes of data. Euclid will observe about 10 billion sources out of which more than one billion will be used for weak lensing. Several tens of million galaxy redshifts will be also measured and used for galaxy clustering. With these images Euclid will probe the expansion history of the Universe and the evolution of cosmic structures by measuring the modification of shapes of galaxies induced by gravitational lensing effects of dark matter and the 3-dimension distribution of structures from spectroscopic redshifts of galaxies and clusters of galaxies. Euclid data will provide improvement factors of ~30 in the measurement of the neutrino mass and up to ~400 in the uncertainty of the parameters of the cosmology state equation and will leave legacy catalogs in many areas of galaxy science with exquisite imaging quality and superb Near Infrared Spectroscopy.

**EUCLID WILL PROBE THE EXPANSION HISTORY OF THE UNIVERSE BY CARRYING OUT A WIDE SURVEY OF GALAXIES IN 15,000 DEG$^2$ OF THE SKY**

Fig. 1: The Filter Wheel Assembly (FWA) of the NISP Instrument. One can see the three filtres, the open and closed position and the Cryomechanism installed in the center of the wheel.

**Fig. 2: The STM wheel in the IFAE Clean room after assembly**

## THE EUCLID INSTRUMENTS

Euclid will be equipped with a 1.2 m diameter Silicon Carbide (SIC) mirror telescope made by Airbus Defense and Space feeding 2 instruments, VIS and NISP, built by the Euclid Consortium. These instruments are a high quality panoramic visible imager (VIS), a near infrared 3-filter photometer (NISP-P) and a slitless spectrograph (NISP-S).

The IFAE has team up with the ICE (Institut de Ciències de l'Espai) and the PIC (Port d'Informació Científica) to participate in the simulation, in the science performance studies, the Spanish Science Data Center and the NISP Filter Wheel Assembly (FWA). During these years, the IFAE has concentrated efforts on the FWA development of the NISP.

The Near Infrared Spectrometer and Photometer (NISP) instrument aims at providing near infrared (between 1000 and 2300 nm) photometry of all galaxies observed by VIS and near infrared low resolution spectra and redshifts of them. The near infrared photometry will be combined with VIS data to derive redshifts and rough estimates of distances of galaxies seen by VIS. The near infrared spectra will be used to derive accurate redshifts and distances of galaxies and how they changed over the last 10 billion years.

Euclid data will have to be complemented with ground-based observations to reach the photo-z required precision. Notably, the data taken with DES and with PAU will serve as calibration for the photo-z resolution of the galaxies and the studies of intrinsic alignment which is one of the main systematic errors in the weak lensing measurements.

**EUCLID WILL BE LAUNCHED IN THE FIRST QUARTER OF 2020 AND THE MISSION WILL LAST SIX YEARS**

The NISP focal plane is composed of a matrix of 4x4 2000x2000 teledyne TIS H2RG detectors covering a field of view of 0.53 deg$^2$. The spectroscopic channel will be equipped with 4 different low resolution near infrared grism. The photometric channel will be equipped with 3 broad band filters (Y, J and H). The NISP-FWA, that is responsibility of the IFAE, is the system that contains and selects the filter to be used for the image to be taken by Euclid.

The FWA is composed of the Filter Wheel (FW) the Filter Mounts where the 3 filters are glued and the Cryomechanism (CM), which is responsible to move the wheel into the selected position. The FWA should also have, in addition to the 3 filters, an open position and a shutter (closed) position.

**Fig. 3: The Filter Wheel Assembly (FWA) of the NISP Instrument. One can see the three filtres, the open and closed position and the Cryomechanism installed in the center of the wheel.**

## IFAE IS RESPONSIBLE FOR THE FILTER WHEEL ASSEMBLY OF THE SPECTROMETER AND PHOTOMETER INSTRUMENT OF EUCLID

The developments implies thorough engineering studies in order to ensure the FWA will withstand the vibrations that will suffer during launching and the thermal conditions in the open space. Thorough testing on the gluing and assembly procedure are needed to ensure the thermal stresses are correctly taken into account and the optical quality of the filters are maintained during the whole life of the Euclid mission. The manufacturing and assembly procedures need to be controlled to ensure they are reproducible. In order to accomplish all these, several models of the FWA will be constructed and tested.

Fig. 4: The STM being tested in Applus

The IFAE has already produced a Bread Board model (BBM) that has been successfully tested, has made a lot of essays of the gluing procedure and constructed the Structural and Thermal Model (STM) which has to be delivered to ESA as part of the NISP-STM. The project has already successfully accomplished the Preliminary Design Review (PDR) and the team is focused on the detailed studies for the Consolidation Design Review (CDR). During the next years, the assembly and manufacturing procedures will be fully qualified and additional models, approaching to the Flight Model, will be built.

# 2.9 APPLIED PHYSICS

MOKHTAR CHMEISSANI & THORSTEN LUX

The focus of the applied physics research at IFAE is to develop sensor technologies with applications in medical imaging, high-energy physics and other scientific or industrial fields by exploting the valuable knowledge available at IFAE and fostering collaborations with other research centres in Catalonia like the Centro Nacional de Microelectronica (CNM) or the Institut de Ciències Fotòniques (ICFO) , medical centers like Hospital Parc Tauli, or companies like XRI and Multiscan Technologies.

## INTRODUCTION

IFAE's medical imaging group is focused mainly on the development of new generation of Positron-Emission-Tomography (PET) Scanner that will resolve many intrinsic limitations that are embedded in the current PET devices. The group has experience in semiconductor pixel detectors technology and its use in digital medical imaging. Semiconductor pixel detectors are used in many detectors in the field of High Energy Physics and the aim of our research line is to mold this existing technology into a useful form to serve the interest of the public.
In this section we also summarize new instrumentation projects which arose from other IFAE projects and exploit synergies between different IFAE groups and with other research institutes in Catalonia and have the potential to develop into larger projects with time.

**Fig 1: The VIP PET box which will host 18 VIP module. The box is connected to cooling network to keep the detector at controlled temperature between 5 and 20 degrees Celsius in N2 atmosphere to avoid any humidity which affect the operation of the pixel CdTe sensor.**

## VOXEL IMAGING PET (VIP)

The full production of 180 VIP single layers was concluded in 2015. Every 10 single layers will be stacked above each other, to form single VIP module, which will be mounted inside the VIP PET Box. The PET box, seen in fig.1, was completed in 2015 and it is ready to host VIP PET ring.

**THE FULL PRODUCTION OF 180 VIP SINGLE LAYERS WAS CONCLUDED IN 2015**

Analysis of data samples collected from VIP pixel CdTe sensor using $Co_{57}$ and $Na_{22}$ at room temperature and at a bias of 500V/mm shows excellent results. An energy resolution (FWHM) = 2.27% at 511keV was measured. It is larger than 1.57%, what we have measured earlier using coplanar detector. Nonetheless the two measurements are still compatible within the systematic errors. However one should point out that there is a possibility of loss in the collected charge on single pixel due to the charge sharing among adjacent pixels and this could deteriorate the energy resolution.

Charge sharing between pixels is a process that happens in pixel detectors and its rate increases as the pixel size decreases or for the same size pixel, the energy of the X-ray photon increases. The charge of one X-ray photon shared among many pixels, could be the result of energy deposition at the edge of the pixel, or due to the Compton scattering inside the pixel. Figure 3 shows the scatter plot of the energy of one pixel versus the energy measured in adjacent pixel. One can see clearly the correlated events at 511keV, and 1275keV. Because of good energy resolution, one can recover such events and improve the overall detection efficiency for 511keV photons.


**Fig 2: The average energy resolution (FWHM) of VIP CdTe pixel sensor is (2.27+/-0.31)% @511keV and (3.23+/-0.14)% @122keV.**

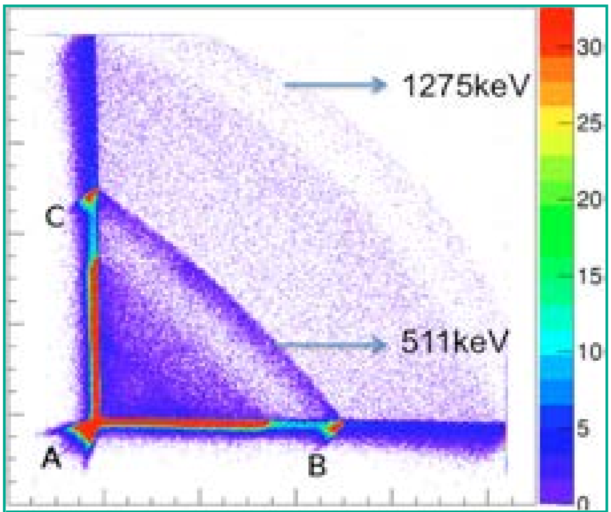



**Fig 4: Shows the scatter plot of energy deposited in one pixel versus the adjacent one. It is those events that sum 511keV and 1275keV from $Na_{22}$**

# THE ERICA PROJECT

ERICA (Resolving Inline Camera) is a project funded by RETOS to develop a photon counting X-ray line camera for scan machine for use in the field of quality control (non destructive) and airport security scanner. A prototype scanner is under development with a line camera of 200mm x 2.66mm (600 x 8 pixel matrix array). The ERICA ASIC is set, by design, to pipe out the acquired data at a rate of 1kHz, as the object passes over the sensor so that one can compile a clear image via the technique known as Time Delay Integration (TDI). The line camera uses pixellated CdTe detector, 1mm thick, to achieve high detection efficiency for X-ray photons in the range from 20keV to 130keV.

**ERICA IS A PROJECT TO DEVELOP A PHOTON COUNTING X-RAY LINE CAMERA TO USE IN QUALITY CONTROL AND AIRPORT SECURITY**

ERICA single pixel covers an area of 330um x 330um and it has a preamplifier with a dynamic range to the equivalent of 200keV X-ray photons, a range of energy that covers almost all the applications in the field of non-destructive quality control and security. The pixel has 8 thresholds and 8 counters, each is 8 bits long. In addition, it has a logic to minimize to sum the charge shared among adjacent pixels in order to preserve the spectroscopic capability of the sensor in order to allocate each photon, according to its energy, in the corresponding energy bin, or better in one of the eight counters. The schematic layout of the ERICA pixel can be seen in figure 4a.

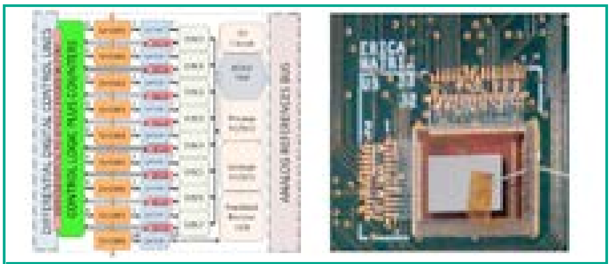


**Fig 4: 4a Shows the schematic layout of single pixel of ERICA ASIC. In 4b it shows the prototype RUN1 with the pixel CdTe bonded to the ASIC. The dimension of the sensor is 4.2mm x 3.2mm**

A first prototype of the ERICA ASIC was produced with TSMC 0.25um. 80um BiSn solder balls were deposited on the ASIC prototype and then a pixel CdTe was bonded to the ASIC, shown in figure 4b. The pixel CdTe sensor was fully packaged in IFAE clean room, which is dedicated for pixel detectors. The test bench results indicate that most of the components are operational as expected. However, the noise is higher than expected due to the coupling of the output signal with an internal clock as one can see in figure 5. A new prototype RUN-II submission is in progress to correct the design problems appeared in RUN-1. It is planned to submit it in the first quarter of 2016.

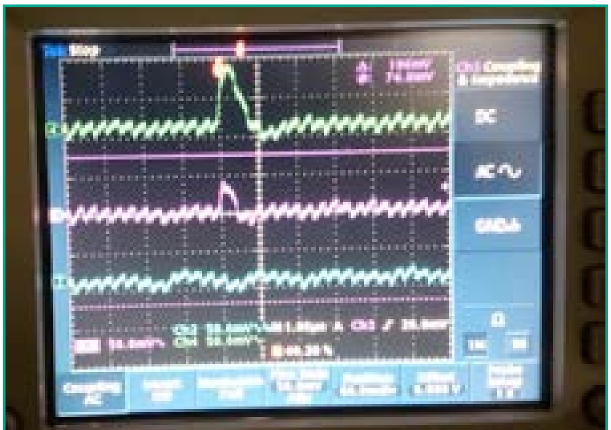


**Fig 5: Shows the analog output of 3 adjacent channels. One can see the coupling of 3.3Mhz clock and two of channels have signals at the same time indicating that the charge of an X-ray photon is spread over the two pixels. The pixel CdTe detector has ohmic contacts, 1mm thick, with pixel size 290um x 290um, and it is biased at -100V.**

# NEW INSTRUMENTATION PROJECTS

In this section we summarize instrumentation projects which arose from other IFAE projects and/or exploit synergy effects between different IFAE groups and/or with other research institutes in Catalonia and have the potential to develop to larger projects with time. One project aims on the development of a Si-MPGD and is carried out in collaboration with the institute "Centro Nacional de Microelectronica" (CNM) and the other is related to the development of a light detection system based on wavelength shifter and SiPMs. Latter is considered to have potential for the camera of a Cherenkov telescope or within a gas detector to detect primary and secondary scintillation light.

## DEVELOPMENT OF SI-MICRO-PATTERN GAS DETECTORS COUPLED TO A MEDIPIX ASIC

The Goal of this project is to develop a sensor using the MediPix chip to read out an integrated silicon Micro Pattern Gas Detector (MPGD). With funding from the Plan Nacional it is planned to upgrade of existing MPGD prototypes in order to obtain higher spark resistivity and allow operation at cryogenic temperatures. In parallel, various applications are being explored, such as like in tissue-equivalent-proportional-counters (TEPC) used to study the interaction between radiation and human tissue and applications for beam monitoring in proton beam therapy centers.

The project profits from knowledge available at the IFAE and the neighboring research center CNM. Over the last few years the IFAE neutrino group at IFAE accumulated valuable knowledge on the operation of gas detectors including those with MPGD readout. On the other hand, the medical imaging group has expertise in the operation of the MediPix chip and the group from CNM completes the team with its experience in processing silicon.

In 2015 project at IFAE we performed the testing and characterization of the sensors provided by CNM. Fig. 1 shows the principle structure of the Si-MPGD. 2 Versions of the final design were produced: one with an aluminum layer (in light gray) only on top of the device and one with an additional medal layer on the bottom side as indicated in Fig. 1.

**THESE PROJECTS EXPLOIT THE TECHNOLOGIES DEVELOPED AT IFAE OVER THE LAST FEW YEARS. THE NEUTRINO GROUP HAS ACCUMULATED VALUABLE KNOWLEDGE ON THE OPERATION OF GAS DETECTORS AND THE MEDICAL IMAGING GROUP HAS EXPERTISE IN THE OPERATION OF THE MEDIPIX CHIP**

The samples were characterized using a Fe55 source. One of the spectra obtained is shown in Figure 2. In this spectrum one also can see one of the problems of this first version of the Si-MPGD. In the spectrum the 5.9 keV peak is clearly visible. High gains of several $10^5$ could be achieved and the gain follows the expected exponential behaviour.

The complexity of the production process lead to delays in the project, so that it was not possible to integrate the Si-MPGD within the project, which ended 12/2015, to a Medipix chip. However, based on the knowledge gained during this project, we are continuing to establish the production of MPGDs in Spain and a group from the University of Zaragoza is joining these efforts.

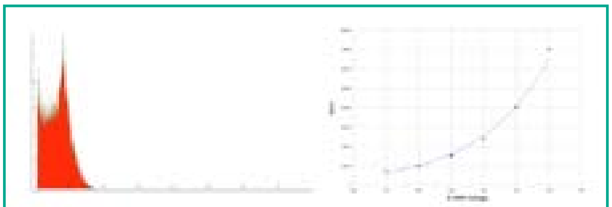


**Fig 2: (Left) Fe-55 spectrum obtained. (Right) Calibrated gain curve in function of the applied MPGD bias voltage.**

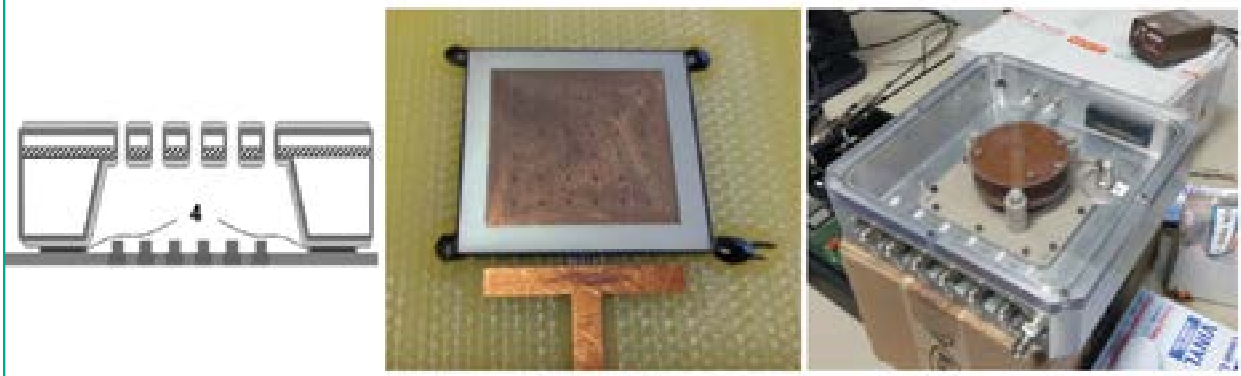



**Fig 1: (Left) Si-MPGD structure using a BESOI wafer. #4 indicates the electrical connection between the bottom metal and the detection PCB. (Middle) Photo of one of the samples. (Right) The test chamber.**

## DEVELOPMENT OF A LIGHT DETECTION SYSTEM BASED ON WAVELENGTH SHIFTER AND SIPMS

This project profits from synergy effects from the collaboration of two IFAE research group, the CTA/Magic and the Neutrino groups. Both groups require the detection of light over large area.
The common idea which both groups developed independently was to use for this purpose SiPMs coupled to wavelength shifter. While the choice of the wavelength shifter depends strongly on the particular application, many experimental problems are common to both groups.

Ground-based gamma-ray astronomy in the Very High Energy (VHE, E>100 GeV) regime has fast become one of the most interesting and productive sub-fields of astrophysics today. Utilizing the Imaging Atmospheric Cherenkov Technique (IACT) to reconstruct the energy and direction of incoming gamma-ray photons from the universe, several source-classes have been uncovered by previous and current generations of IACT telescopes (e.g. Whipple, MAGIC, HESS, VERITAS).
For future IACT experiments as CTA the possibility is considered to replace PMTs with SiPMs. However SiPMs are not yet mature enough to replace PMTs for several reasons: sensitivity to unwanted longer wavelengths while lacking sensitivity at short wavelengths, small physical area, high cost and electronic noise. John E. Ward from the IFAE CTA/Magic group proposes a novel method to build relatively low-cost SiPM-based pixels utilizing wavelength-shifting material which overcome some of these drawbacks by collecting light over a larger area than standard SiPMs, and improving sensitivity to shorter wavelengths while reducing background. The aim is to optimize the design of such pixels (called a "Light-Trap" pixel), integrating them in an actual 7-pixel cluster which will be inserted into a MAGIC camera and tested during real observations in summer 2016.

The Neutrino group on the other hand is interested in this kind of light detection system for liquid argon (LAr) detectors for future neutrino oscillation experiments. In these detectors light of 128 nm has to be detected over an area of a few thousand square meters. The aim of the group is to develop a first prototype which could be installed in the WA105 detector, a 6x6x6 m3 large LAr prototype to be constructed at CERN until 2017.

Both groups developed a common Geant4 simulation framework and perform laboratory measurements to prove the viability of such devices. The device currently being tested utilizes a commercially available blue/green-sensitive SiPM, along with a custom-doped scintillating PMMA disk purchased from industry in the case of CTA/Magic and a PMMA mask coated at the Universidad Autonoma de Barcelona with Tetraphenyl butadiene (TPB).

The setup of the tests carried by the CTA/Magic group is shown in Fig. 3 (left). The Neutrino group uses for the tests an electroluminescence (EL) detector; results from this kind of detectors were presented in previous years. A new EL detector was constructed during 2015, Fig. 3 (right), and will be used for testing the devices at 128 nm exploiting that EL light from pure Ar is emitted with the same wavelength.

However, sensors directly sensitive to this kind of light and with fine pixels could be an improvement to current systems. The chamber will be used also for tests with sensors based on graphene and organic solar cells provided by other BIST institutes.

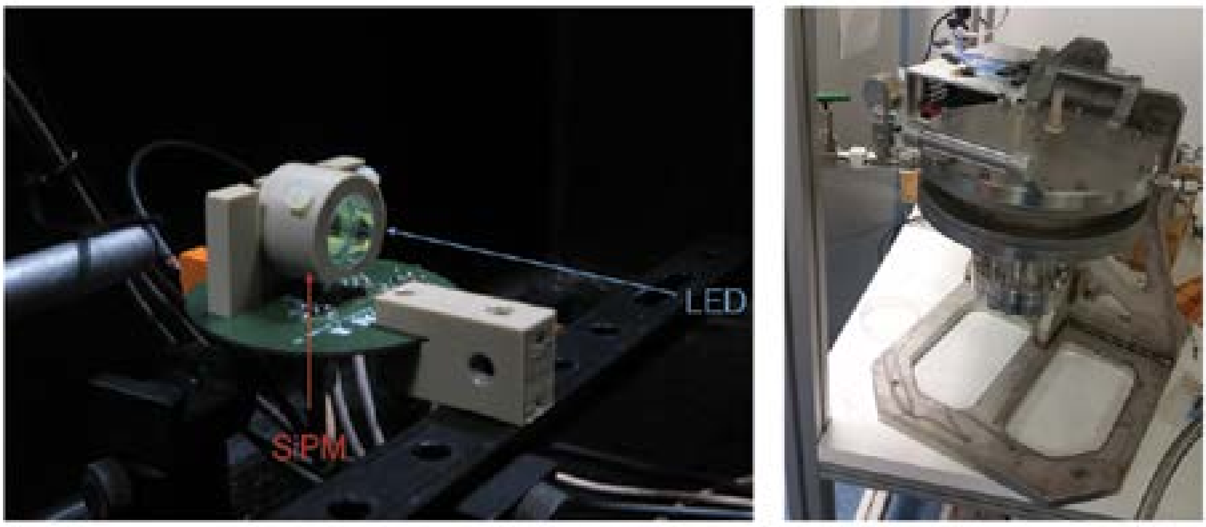



**Fig 2: Figure 2: (Left) Setup of the CTA/Magic group (Right) EL detector which will be used for the tests of the Neutrino group.**

# 2.10 X-RAY IMATEK

## ALBERT SANCHO, CEO

X-Ray Imatek goes its way to become a company of reference in the X-ray detectors market. The company is always presented as a spin-off from IFAE, and is always doing efforts to strengthen the relations with the institute by supporting different projects as well as exploring new ways of collaboration together with the Technology Transfer department.

## INTRODUCTION

In this report we offer a brief overview of the most important milestones achieved or started during year 2015.

## NEWS & MILESTONES

### MEDIPIX 3RX VENDOR

The market of the Hybrid Pixel Detectors is growing as the new versions of the Medipix ASIC are released. The Medipix 3RX is the latest commercial version of the famous chip and it's including amazing capabilities for X-ray imaging purposes, like an spectroscopic mode of operation for colour imaging and an innovative charge-sharing compensation system. X-Ray Imatek has become a Medipix3 vendor by acquiring a commercial license from CERN in July, 2015.

### ISO 9001:2016

During year 2015, X-Ray Imatek has started the process to be certified with the quality standard ISO 9001:2016. The process is being monitored by the Cambra de Comerç de Sabadell and implies the standardization of the processes, tracking of incidences and monitor of different markers with the aim of leading the company to a high quality standard. Is expected that X-Ray Imatek will be certified by the ISO 9001:2016 by mid-2016.

### NEW STAFF

In December 2015, the staff of Imatek has grown thanks to the incorporation of Federico Rubio. He will be in charge of laboratory tasks and also will manage the full supply chain of the detectors produced by company.

**X-RAY IMATEK IS BECOMING A COMPANY OF REFERENCE IN THE X-RAY DETECTORS MARKET**

### NEW OFFICE AND WEBSITE

Since the Imatek family is growing, we have moved from our small office in the ground floor of the Eureka building to a 70m2 space in the first floor. The new premises are big enough to hold up to 8 people, and provides the convenient resources that the company deserves in this new stage.
This new wave of changes has been completed with the release of a new website, an improved card of presentation which is aimed to be the main showroom of the company worldwide.

## MARKETING ABROAD

As every year, X-Ray Imatek has attended to two of the most important events for HPDs, the iWoRiD and the IEEE.

The iWoRiD was held by DESY in Hamburg this year. It was a very interesting apparel to show our newest developments like the eX detector family and we also announced the acquisition of the new Medipix 3 license.

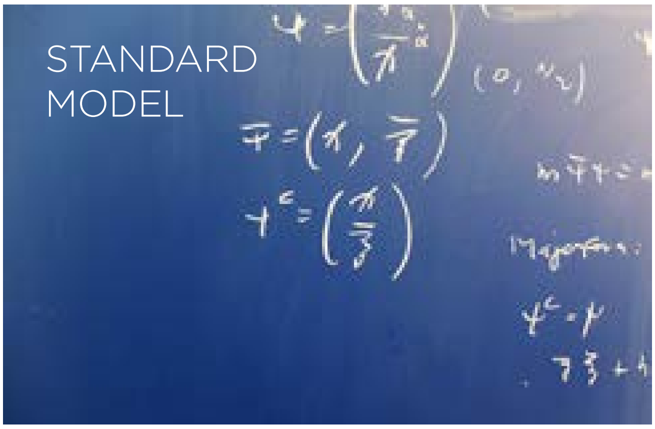
The IEEE NSS/MIC 2015 was held in San Diego and had more than 2000 attendees, with a special dedication in the field of medical imaging.

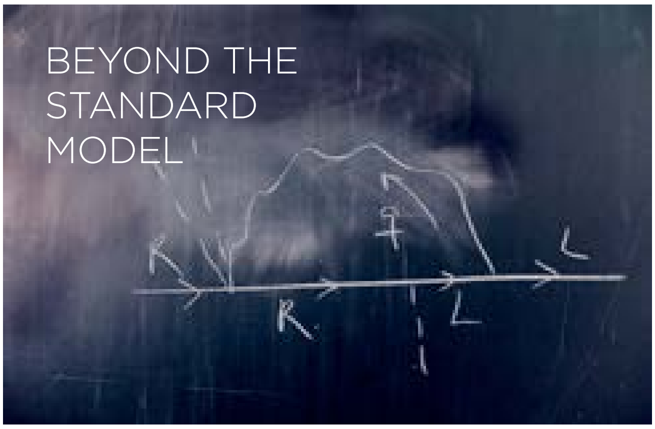
# FORECAST 2016

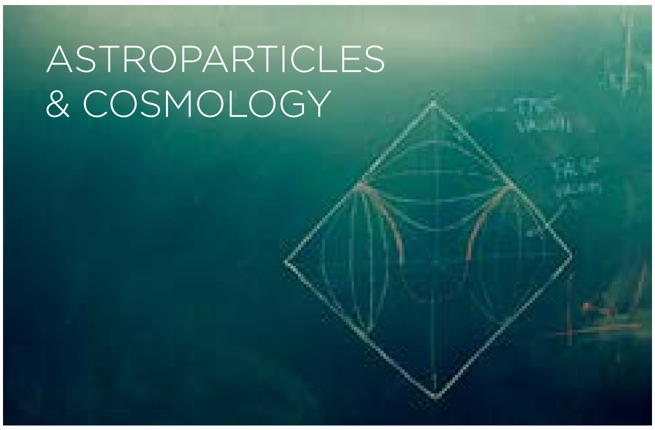
In year 2016 the iWoRiD conference will be held in Barcelona organised by IFAE, CNM and X-Ray Imatek, also with the collaboration of the ALBA Synchrotron. The event will be celebrated in July in the AXA Auditorium of Barcelona.

For this special occasion the company will participate as an exhibitor, sponsor and will prepare an special showroom.

# THEORY DIVISION



# 2.11 STANDARD MODEL

MATTHIAS JAMIN

The Standard Model of particle interactions is one of the major achievements of fundamental science. Within this framework a wide range of phenomena can be described to an impressive degree of accuracy. As a matter of fact, few are the branches of Physics where the predictive power of a theory has been tested to such a level of precision.

## INTRODUCTION

The Standard Model (SM) subgroup of the IFAE theory division investigates the phenomenology of particle physics within the realms of the Standard Model. Even if physics going beyond the SM is expected, suggested for example by the presence of dark matter or neutrino masses, precise values of the fundamental SM parameters like couplings and masses are essential inputs for predictions within the SM, and beyond-SM physics should show up as clashes between those predictions and the experimental measurements. During 2015, the central research fields in our group were leptonic and radiative decays of $\eta$ and $\eta'$ mesons, semi-leptonic decays of the B meson, hadronic decays of the tau lepton, the Lamb shift in muonic hydrogen and the proton radius, the behaviour of perturbation theory at high orders and renormalons, as well as the parameter of direct CP violation in Kaon decays $\varepsilon'/\varepsilon$.

In the field of meson interactions, the transition form factor of the eta meson was analysed by Rafel Escribano and Sergi Gonzàlez-Solís, for the first time and simultaneously in the space- and time-like regions at low and intermediate energies through the use of a model-independent approach based on rational approximants, so-called Padé approximants.

The recent experimental data in the very-low energy region of the di-electron invariant mass distribution of the $\eta \to e^+e^-$ radiative decay provided by the A2 Collaboration at MAMI allowed us to extract the most precise up-to-date values for the slope and curvature parameters of this form factor. The impact of these new results on the $\eta$-$\eta'$ mixing parameters and on the determination of the VP$\gamma$ couplings (V=$\rho$, $\omega$, $\Phi$; P=$\eta$, $\eta'$) was also discussed.

The same type of analysis has been performed also for the $\eta'$ transition form factor. In this case, it has been the very recent first observation of the $\eta' \to e^+e^-\gamma$ radiative decay by the BESIII Collaboration that allowed to further constrain the low-energy parameters of the corresponding form factor.

## PRECISE VALUES OF STANDARD MODEL PARAMETERS ARE ESSENTIAL INPUTS FOR PREDICTIONS

The precision achieved with this new type of analysis has permitted to study the OZI-rule violating parameters associated to the $\eta$-$\eta'$ mixing scheme and the J/$\Psi \to \eta(\eta')\gamma$ decays. At the same time, and profiting from the analysis of $\eta$ and $\eta'$ transition form factors solely in the space-like region, the di-lepton invariant mass spectra and branching ratios of the single ($P \to l^+l^-\gamma$) and double ($P \to l^+l^-l^+l^-$) Dalitz decays with P=$\pi_0$, $\eta$, $\eta'$ and l=e, $\mu$ have been then predicted in a model-independent manner.

The agreement between these predictions and the in some cases existing experimental measurements is quite remarkable, thus giving support to the method of analysing data at low and intermediate energies by means of rational approximants. Our results have been presented at the 10th International Workshop on $e^+e^-$ collisions from $\Phi$ to $\Psi$ (PhiPsi15) in Hefei (China). During 2015, a work performed in 2014 on a combined analysis of the decays $\tau^- \to K_S \pi^- \nu_\tau$ and $\tau^- \to K^- \eta \nu_\tau$ was presented at the 8th International Workshop on Chiral Dynamics (CD15) in Pisa (Italy).

The semi-leptonic decay $B \to K^* (\to K\pi)\, \mu^+ \mu^-$ constitutes one of the most exciting channels in the search for physics beyond the SM since the data released in 2013 by the LHCb collaboration has indicated significant deviations from SM expectations. In 2015, Joaquim Matias has completed the theoretical analysis of the 3 $fb^{-1}$ data set from LHCb for a set of semi-leptonic B decays. In particular we observed that the anomaly detected in the 1 $fb^{-1}$ dataset on the observable $P_5'$ is confirmed by the 3 $fb^{-1}$ data set. The global analysis of all measurements points to significances in the range between 4 to 5 sigma depending on the selected Wilson coefficients that are switched on.

The solution that we proposed in 2013 to solve the $B\rightarrow K^* \mu^+ \mu^-$ anomaly with a contribution $C_9^{NP}$= -1 is confirmed and reinforced. We have included in our theoretical predictions various corrections including power corrections and charm-loop effects and we have deconstructed wrong arguments in the literature by Jäger et al. and Silvestrini et al. about large power correction or out of control charm-loop effects. We have furthermore discussed in detail the symmetries of the S-wave contribution to this mode and possible impact of violation of lepton flavour universality.

Regarding the field of hadronic decays of the tau lepton, in 2015 Santiago Peris has applied an analysis method previously developed for the extraction of the strong coupling from the OPAL data to the recently revised ALEPH data for non-strange hadronic tau decay modes. Our analysis yields the values $\alpha_s(M_\tau^2)=0.296\pm0.010$ employing fixed-order perturbation theory (FOPT), and $\alpha_s(M_\tau^2)=0.310\pm0.014$ using contour-improved perturbation theory (CIPT). Averaging these results with our previously obtained values from the OPAL spectral functions, we find $\alpha_s(M_\tau^2)=0.303\pm0.009$ and $\alpha_s(M_\tau^2)=0.319\pm0.012$, respectively. In Figure 1, we display a comparison of the ALEPH spectra for V+A, integrated up to an energy $s_0$, $R_{V+A}(s_0)$, with the theoretical descriptions in the FOPT and CIPT resummation schemes.

We also presented a critique of the analysis method employed previously, for example in analyses by the ALEPH and OPAL collaborations, and compare it with our own approach. Our conclusion is that non-perturbative effects limit the accuracy with which the strong coupling, an inherently perturbative quantity, can be extracted at energies as low as the tau mass. Our results further indicate that systematic errors on the determination of the strong coupling from analyses of hadronic tau-decay data have been underestimated in much of the existing literature.

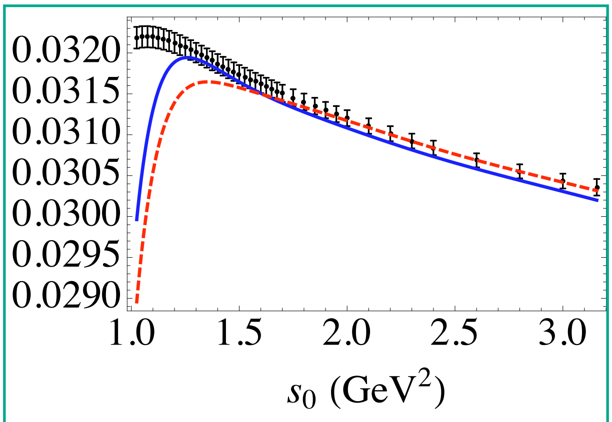



**Fig 1: A comparison of the ALEPH spectra for V+A, integrated up to an energy $s_0$, $R_{V+A}(s_0)$, with the theoretical descriptions in the FOPT and CIPT resummation schemes is displayed. The result for this curve at the kinematical endpoint $s_0=M_\tau^2$ corresponds to the total tau hadronic branching fraction $R\tau$.**

## THE SEMI-LEPTONIC DECAY OF THE B BOSON IS AN EXCITING LINE OF RESEARCH FOR PHYSICS BEYOND THE STANDARD MODEL

Furthermore, we also determined the NLO chiral low-energy constant $L_{10}^r$ and combinations $C_{12}^r\pm C_{61}^r+C_{80}^r$, $C_{13}^r-C_{62}^r+C_{81}^r$, $C_{61}^r$ and $C_{87}^r$, of the NNLO chiral low-energy constants incorporating recently revised ALEPH results for the non-strange vector (V) and axial-vector (A) hadronic tau decay distributions and recently updated RBC/UKQCD lattice data for the non-strange V-A two-point function. We found $L_{10}^r$= -0.00350(17), $C_{12}^r+C_{61}^r+C_{80}^r$= 0.00237(16) GeV$^{-2}$, $C_{12}^r-C_{61}^r+C_{80}^r$= -0.00056(15) GeV$^{-2}$, $C_{13}^r-C_{62}^r+C_{81}^r$= 0.00046(9) GeV$^{-2}$, $C_{61}^r$=0.00146(15) GeV$^{-2}$, and $C_{87}^r$= 0.00510(22) GeV$^{-2}$. These constants are part of the Chiral Lagrangian describing QCD at low energies and are, therefore, an important ingredient for describing the corresponding physics. Finally, we also considered the dimension-six and dimension-eight coefficients in the operator product expansion of the V-A current correlator.

The measurement of the Lamb shift in muonic hydrogen and the associated determination of the root mean square electric radius of the proton: $r_p$ = 0.84087(39) fm has led to a lot of controversy. The reason is that this number is 7.1$\sigma$ away from the CODATA value, $r_p$ = 0.8775(51) fm. This last number is an average of determinations coming from hydrogen spectroscopy and electron-proton scattering. In order to assess the significance of the discrepancy, it is of fundamental importance to perform the computation of the Lamb shift in muonic hydrogen (in particular of the errors) in a model independent way.

Clara Peset and Antonio Pineda have performed such an analysis in the framework of effective field theories, which allowed to assess the importance of the different contributions through power-counting rules. Even more importantly, these power-counting rules permit to parametrically control the size of the uncalculated terms and, thus, give an educated estimate of the uncertainty. One important result was that the two-photon-exchange contribution, which gives the bulk of the theoretical error, is chirally dominated. It could, and was computed by us, yielding a pure prediction with no free parameter. Our final result was $r_p$ = 0.8413(15) fm, giving further significance to the proton radius puzzle.

The operator product expansion (OPE) is a fundamental tool for theoretical analyses in quantum field theories. Its validity is only proven rigorously within perturbation theory but not beyond. It can hardly be overemphasised that (except for direct predictions of non-perturbative lattice simulations, e.g.,

**THE STANDARD MODEL GROUP AT IFAE IS WORKING ON MONTE-CARLO GENERATORS FOR HIGH-ORDER PERTURBATION THEORY**

on light hadron masses) all QCD predictions are based on factorisations that are generalizations of the above generic OPE.

Gunnar Bali and Antonio Pineda have recently summarised their work on checking and testing general ideas about renormalons and the non-perturbative OPE in the context of lattice simulations: for the first time ever, perturbative expansions at orders where the asymptotic regime is reached have been obtained for the static-light meson mass and the plaquette validating general expectations from renormalon analysis. After subtracting them from non-perturbative Monte Carlo data of the static-light meson mass and of the plaquette, the differences scale according with expectation from the non-perturbative formulation of the OPE, thereby validating the OPE for these cases beyond perturbation theory. The scaling of the difference for the case of the plaquette with the lattice spacing confirms the dimension d = 4. Therefore, it was possible to obtain a model independent number for the gluon condensate.

Another work in this direction was the investigation of the renormalon structure of vector and axialvector two-point correlation functions by Dirk Hornung and Matthias Jamin. The large-order behaviour of QCD correlation functions is related to the singular structure of its Borel transform, and singularities on the positive real axis are connected to higher-dimensional operator contributions in the OPE. In our work we investigated in detail the singular structure related to the complete set of dimension-6 four-quark operators that arise in the OPE for V and A correlators. This allowed in particular to determine the strength of the corresponding renormalon poles and in the future might permit to improve models for the perturbative series based on the known renormalon-pole structure.

Another important two-point correlation function is the scalar correlator which for example plays an important role in the Higgs decay into quarks, or the extraction of quark masses from QCD sum rules. Therefore, it would be very interesting to also have available estimates of the large order behaviour of this correlation function. A complication compared to the vector correlator is the fact that in contrast to the vector current which is a renormalisation group invariant object, the renormalisation group properties of the scalar current are linked to the quark mass. As a consequence, already the large-$\beta_0$ approximation for the scalar correlation function is considerably more complicated. Still, work on a model for the all-order perturbative behaviour of the scalar correlator is in progress and should be available in the near future.

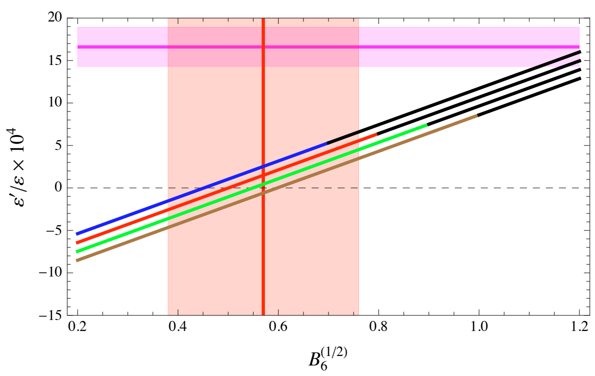



**Fig 2: Our theoretical expectation for ε'/ε is displayed as a function of the hadronic parameter $B_6^{(1/2)}$ and for different values of the hadronic parameter $B_8^{(3/2)}$ from 0.7 (blue) to 1.0 (brown). The vertical pink band represents the lattice-QCD determination of $B_6^{(1/2)}$ and the horizontal band corresponds to the experimental average. The disparity between both results is clearly observed.**

A last work that should be mentioned concerned an update in the theoretical expectation for the parameter of direct CP violation ε'/ε by Matthias Jamin and collaborators. Recent determinations of the required hadronic matrix elements from lattice QCD, together with the use of relations between those operator matrix elements developed earlier by our group, enabled a refined theoretical prediction for ε'/ε. This theoretical prediction is summarised in Figure 2. With the improved precision, it turned out that ε'/ε is found roughly 3 sigma below the experimental measurement. Possible sources for this discrepancy, in and beyond the SM, have also been discussed in our work.

# 2.12 BEYOND STANDARD MODEL

MARIANO QUIRÓS

There are a number of theoretical (hierarchy problem, strong CP problem, flavor problem, the origin of matter-antimatter asymmetry, …) and experimental (Dark Matter, …) reasons why we believe that the Standard Model of strong and electroweak interactions cannot be the ultimate theory of particle interactions. This has motivated the development of theories beyond the Standard Model (BSM), which is the main task of the BSM subgroup of the IFAE Theory Group, and the experimental search of BSM physics, which in particular is being undertaken at the LHC.

## INTRODUCTION

In 2015 the BSM subgroup has followed two general lines of research, all of them related to the recent experimental results released by the ATLAS and CMS Collaborations at the LHC. A first line consists in selecting and proposing theories which could accommodate all experimental results on the Higgs discovery as well as all bounds on new physics. In this directions a number of problems have been solved, in particular related to the features of effective field theories (EFT), as the Standard Model including the Higgs field, supersymmetric theories encompassing the experimental value of the Higgs mass, the problem of quadratic divergences in the Standard Model, and new solutions to the hierarchy problem. A second line followed by the BSM subgroup is producing BSM theories which could explain the various excesses found in Runs 1 and 2 at the LHC. In particular, they have first considered the excess found by ATLAS and CMS in Run 1 in diboson resonances producing fat jets, and consistent with a 2 TeV resonance. Second they have considered theories which could explain the diphoton excess at 750 GeV found by ATLAS and CMS in Run 2 at 13 TeV.

## NON-ABELIAN LANDAU-YANG THEOREM

J.R. Espinosa, in collaboration with M. Cacciari, L. del Debbio, A. Polosa and M. Testa, studied whether the Landau-Yang (LY) theorem (which forbids the decay of a massive vector particle into two on-shell photons) holds in non-Abelian theories (that is, for the decay of a massive color-octet vector state into a pair of on-shell massless gluons). Using elementary considerations of Lorentz invariance, Bose symmetry and BRST invariance, they showed how such decay becomes possible in a non-Abelian SU(N) Yang-Mills theory, thereby invalidating the LY theorem in such theories. They constrained the form of the amplitude of such decay process and offered a simple understanding of these results in terms of effective-action operators.

**IN 2015, THE GROUP HAS FOLLOWED TWO GENERAL LINES OF RESEARCH RELATED TO THE RECENT EXPERIMENTAL RESULTS RELEASED BY THE ATLAS AND CMS COLLABORATIONS**

## CONSISTENCY OF POTENTIALS FROM QUANTUM DE SITTER SPACE

In collaboration with J.F. Fortin and M. Trepanier (U. Laval, Canada), J.R. Espinosa derived constraints on the scalar potential of a quantum field theory in de Sitter space. The constraints should be understood as consistency conditions for quantum field theories in de Sitter (dS) space, and originate from a consistent interpretation of quantum dS space through its Coleman-De Luccia tunneling rate. Indeed, consistency of de Sitter space as a quantum theory of gravity with a finite number of degrees of freedom suggests the tunneling rates to vacua with negative cosmological constants be interpreted as low-entropy state recurrences. Demanding the tunneling rate to be such recurrence imposes two constraints, or consistency conditions, on the scalar potential. Generically: the distance in field space between the de Sitter vacuum and any other vacuum with negative cosmological constant must be of the order of the reduced Planck mass or larger; and the fourth root of the vacuum energy density of the de Sitter vacuum must be smaller than the fourth root of the typical scale of the scalar potential. They then applied these consistency conditions to the case of the Standard Model of particle physics finding that, for the SM to be dS consistent, the experimental values of the Higgs and top masses must be extremely close to the stability line. As this seems to be disfavored at present, one can argue that new physics must appear below the Planck scale in order to make the model consistent. This results from the first dS consistency condition, which in terms of the Higgs mass, is approximatively equivalent to the condition of stability of the SM effective potential. The second dS consistency condition on the cosmological constant leads to a very weak constraint.

## SUPERSYMMETRIC CUSTODIAL TRIPLETS

Higgs triplet models are known to have difficulties obtaining agreement with electroweak precision data and in particular constraints on the rho-parameter. Either a global SU(2)LxSU(2)R symmetry has to be

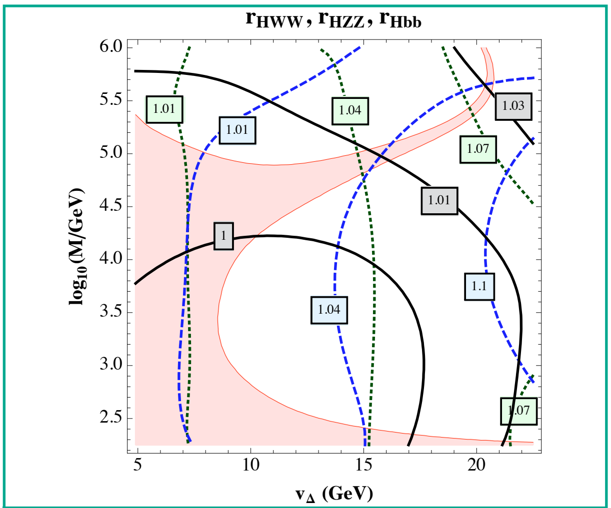



**Fig. 1: Contours of rHWW (dark green dotted), rHZZ (blue dashed) and rHbb (black solid) for typical values of the supersymmetric parameters and gaugino mass 1.2 TeV. The shadowed region is where the rho parameter agrees with experimental data.**

imposed on the scalar potential at the electroweak scale, as done in the well-known Georgi-Machacek (GM) model, or the triplet vacuum expectation values must be very small. M. Quirós and M. García-Pepin in collaboration with S. Gori(Perimeter Institute), R. Vega-Morales (Orsay), R. Vega (Southern Methodist University, Dallas) and T.T. Yu (Stoney Brook University) constructed a supersymmetric model that can satisfy constraints on the rho-parameter, even if these two conditions are not fulfilled. They supersymmetrize the GM model by imposing the SU(2) LxSU(2)R symmetry at a scale M, which they argue should be at or above the messenger scale, where supersymmetry breaking is transmitted to the observable sector. They show that scales M well above 100 TeV and sizable contributions from the triplets to electroweak symmetry breaking can be comfortably accommodated. They discuss the main phenomenological properties of the model and demonstrate that the departure from custodial symmetry at the electroweak scale, due to radiative breaking, can show up at the LHC as a deviation in the 'universal' relation for the Higgs couplings to WW and ZZ. This fact is exhibited in Fig. 1

## ELECTROWEAK VACUUM STABILITY AND QUADRATIC RADIATIVE CORRECTIONS

If the Standard Model (SM) is an effective theory, as currently believed, it is valid up to some energy scale to which the Higgs vacuum expectation value is sensitive throughout radiative quadratic terms. The latter ones destabilize the electroweak vacuum and generate the SM hierarchy problem. For a given perturbative Ultraviolet (UV) completion, the SM cutoff can be computed in terms of fundamental parameters. If the UV mass spectrum involves several scales the cutoff is not unique and each SM sector has its own UV cutoff. M. Quirós, in collaboration with I. Masina (University of Ferrara) and G. Nardini (Desy Laboratory), has performed this calculation assuming the Minimal Supersymmetric Standard Model (MSSM) is the SM UV completion. As a result, from the SM point of view, the quadratic corrections to the Higgs mass are equivalent to finite threshold contributions. For the measured values of the top quark and Higgs masses, and depending on the values of the different cutoffs, these contributions can cancel even at renormalization scales as low as multi-TeV, unlike the case of a single cutoff where the cancellation only occurs at Planckian energies, a result originally obtained by Veltman. From the MSSM point of view, the requirement of stability of the electroweak minimum under radiative corrections is incorporated into the matching conditions and provides an extra constraint on the Focus Point solution to the little hierarchy problem

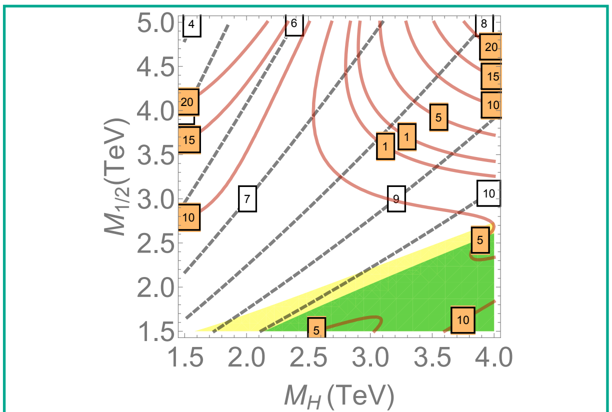



**Fig. 2: Contour lines of log (M/GeV) (white labels) and stability (fine-tuning) parameters (orange labels) for light Higgsinos. The (yellow) external shadowed region corresponds to right-handed stop masses < 750 GeV, and the (green) internal shadowed region to tachyonic right-handed stop masses.**

in the MSSM. Then even for relatively heavy spectra they can identify the region of the parameter space where the fine-tuning is small. This is shown in Fig. 2 for some values of supersymmetric parameters.

## THE DIBOSON EXCESS AT RUN 1

The ATLAS collaboration reported an intriguing excess found at Run 1 in hadronically decaying diboson (WW=WZ=ZZ) resonant production peaked around 2 TeV. The observed excess corresponded to significances of 3.4, 2.6 and 2.9 standard deviations for the WZ, WW and ZZ channels respectively. Hadronically decaying Z and W are not easy to distinguish so the three channels are not exclusive. This excess is illustrated in Fig. 3.

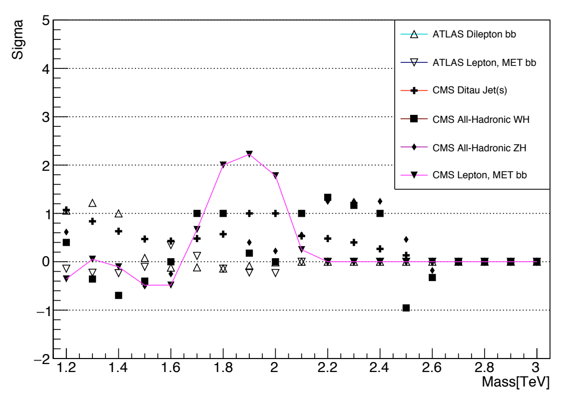



**Fig. 3: Comparison of the excess magnitudes in high mass resonance searches in units of standard deviations for decays including a Higgs boson.**

M. Quirós, in collaboration with A. Carmona (ETH, Zurich), A. Delgado (University of Notre Dame, Indiana) and J. Santiago (Universidad de Granada), has shown that the recent M=2 TeV diboson excess found in ATLAS can be explained in the context of the non-custodial composite Higgs models proposed some years ago to accomodate Kaluza Klein modes with electroweak observables. The model has 5 relevant parameters: the mixing between the composite vectors and the SM gauge bosons (gV) and the couplings of the composite vectors to leptons (gl), light quarks (gq), left-handed top and bottom quarks (gq3) and to right-handed top quark (gtR). The allowed parameter space is shown in Fig. 4 in the space (gq,gl) where they have fixed M=1.9 TeV, gV=0.75, gtR=0.3, gq3=0.3. The white region passes all electroweak tests and direct and indirect LHC bounds and it is able to accomodate the ATLAS diboson excess.

## THE DIPHOTON EXCESS AT RUN 2

The ATLAS and CMS collaborations have recently presented the first data obtained at the LHC Run 2 with pp collisions at energy 13 TeV. The ATLAS collaboration has 3.2/fb of data and claims an excess in the distribution of events containing two photons, at the diphoton invariant mass of 750 GeV with 3.9 standard deviation of local statistical significance (2.3 standard deviations of global statistical significance). The ATLAS excess consists of about 14 events which suggests a best-fit width of 45 GeV. The result is partially corroborated by the CMS collaboration with integrated luminosity of 2.6/fb.

A. Pomarol, in collaboration with R. Franceschini, G. Giudice, J. Kamenik, M. McCullough (CERN), R. Rattazzi (EPFL), M. Redi (Firanze), F. Riva, A. Strumia (CERN) and R. Torre (EPFL), have analyzed the data in terms of a new boson, extracting information on its properties and exploring theoretical interpretations. Scenarios covered include a narrow resonance and, as preliminary indications suggest, a wider resonance. They conclude that if the width indications persist, the new particle is likely to belong to a strongly-interacting sector. They also show how compatibility between Run 1 and Run 2 data is improved by postulating the existence of an additional heavy particle, whose decays are possibly related to dark matter.

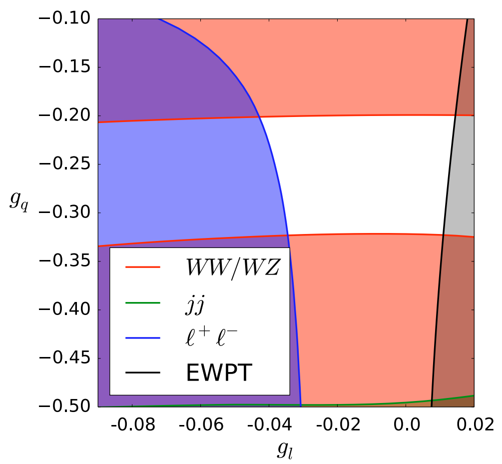



**Fig. 4: Constraints on the model from the diboson signal, tt, jj, ll and EWPT. The colored areas correspond to the region excluded by the different bounds.**

M. Quirós and O. Pujolas, in collaboration with E. Megias (Max-Planck Institute, Munich) have studied one of the natural candidates to strongly couple to photons and gluons and thus a natural candidate to explain the diphoton excess: the dilaton in conformal theories or equivalently the radion in extra-dimensional theories. They study soft wall models, parametrized by two real parameters (a,c), that can embed the Standard Model and a naturally light dilaton. Exploiting the full capabilities of these models they identify the parameter space that allows to pass Electroweak Precision Tests with a moderate Kaluza-Klein scale, around $2$ TeV. An example of the values of the KK mass and the dilaton mass is shown in Fig. 5.

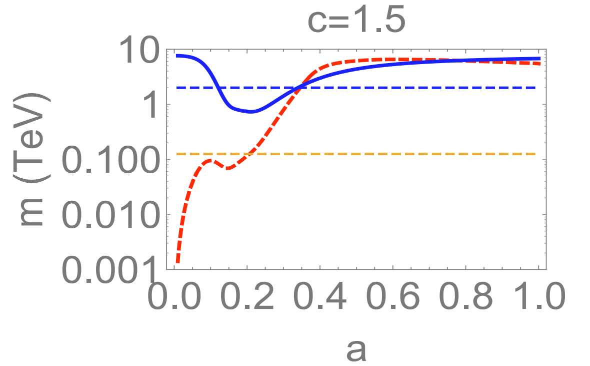



**Fig. 5: Bounds on KK masses (blue solid lines) as functions of a for c=1.5 from electroweak observables. The corresponding dilaton masses are in dashed (red) lines. To guide the eye we have drawn horizontal dashed lines corresponding to 125 GeV (lower dashed) and 2 TeV (upper dashed).**

They analyze the coupling of the dilaton with Standard Model (SM) fields in the bulk, and discuss two applications: i) Models with a light dilaton as the first particle beyond the SM pass quite easily all observational tests even with a dilaton lighter than the Higgs. However, the possibility of a 125 GeV dilaton as a Higgs impostor is essentially disfavored; ii) They show how to extend the soft wall models to realize a 750 GeV dilaton that could explain the recently reported diphoton excess at the LHC. One conclusion is that if the radion has to describe the diphoton excess the model has to be modified in some way. They introduce the simplest higher dimensional operator that do not affect the background and can have an impact on the coupling of the radion to photons and gluons. This operator is parametrized by a real parameter d in terms of which the excess can be fitted. A plot of the parameter d as a function of a for c=1.5 (as in the Fig. 5 plot) is shown in Fig. 6.

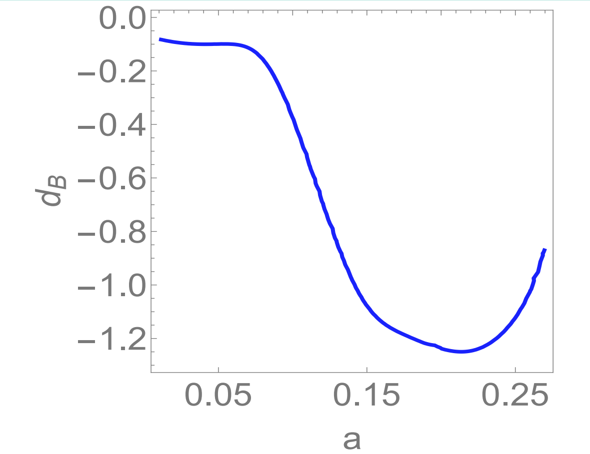



**Fig. 6: Contour plot fitting the diphoton excess in the plane (a,d) for c=1.5.**

Another appealing possibility to explain the diphoton excess is provided in supersymmetric theories by the sgoldstino: a signal of low-energy supersymmetry-breaking scenarios. The sgoldstino, a scalar, couples directly to gluons and photons, with strength related to gaugino masses, that can be of the right magnitude to explain the excess. However, fitting the suggested resonance width ~ 45 GeV, is not so easy. J.R. Espinosa, in collaboration with J.A. Casas and J.M. Moreno (IFT-UAM/CSIC, Madrid), explored several possibilities to enhance the sgoldstino width, via the decay into two Higgses, two Higgsinos and through mixing between the sgoldstino and the Higgs boson. They also studied an alternative and more efficient mechanism to generate a mass splitting between the scalar and pseudoscalar components of the sgoldstino, which has been suggested as an interesting alternative explanation to the apparent width of the resonance. It is tantalizing that this (hint of a) signal could correspond to an sgoldstino, a particle that lies at the very heart of supersymmetry breaking, similar in a sense to the central role of the Higgs for electroweak symmetry breaking. If nature is kind to us, this could represent a huge step forward in our understanding of the origin of electroweak symmetry breaking and the role that supersymmetry presumably plays in it.

# 2.13 ASTROPARTICLES & COSMOLOGY

ORIOL PUJOLÀS

The Astroparticles and Cosmology group studies the properties of elementary particles and their interactions in astrophysical and cosmological settings. Many things can be learned about particle physics in these settings because they allow to access processes that are very difficult to reproduce in the laboratory. We are interested in: axion physics, neutrinos (atmospherical and solar), phase transitions in the early universe, dark matter and, of course, dark energy.

## INTRODUCTION

Astroparticle physics and particle cosmology are recent fields of research at the intersection between particle physics, astrophysics and cosmology. The main goal is to exploit our knowledge of astrophysical and cosmological phenomena to answer fundamental physics questions. Aside from using cosmology and astrophysics as a probe of high-energy physics such as for the electroweak scale, key questions addressed include: the origin and nature of dark energy, dark matter, the strong CP problem or the matter-antimatter asymmetry of the universe. Last but not least, we also include here the development and application of new methods originating from modified gravity models and the gauge/gravity correspondence that can be useful for other areas such as modeling of strongly correlated materials. During 2015, the work done by the members of the Theory Division in this research area can be divided in the following topics.

## THE COSMOLOGICAL HIGGSTORY OF THE VACUUM INSTABILITY

The potential of the Standard Model Higgs field becomes unstable at large field values, due to radiative corrections from the heavy top quark. In collaboration with Gian F. Giudice (CERN), Enrico Morgante, Antonio Riotto (Geneva U.), Leonardo Senatore (Stanford U. & SLAC), Alessandro Strumia (INFN, Pisa) and Nikolaos Tetradis (Athens U.), J.R. Espinosa further studied several aspects of this instability. First, they clarified the issue of gauge dependence of the effective potential and then studied the cosmological evolution of the Higgs field in presence of this instability throughout inflation, reheating and the present epoch. The conclusion of this thorough analysis was that anti-de Sitter patches in which the Higgs field might end up during such cosmological epochs are lethal for our universe. From this result, they derived upper bounds on the Hubble constant during inflation, which depend on the reheating temperature and on the Higgs coupling to the scalar curvature or to the inflaton. Finally they

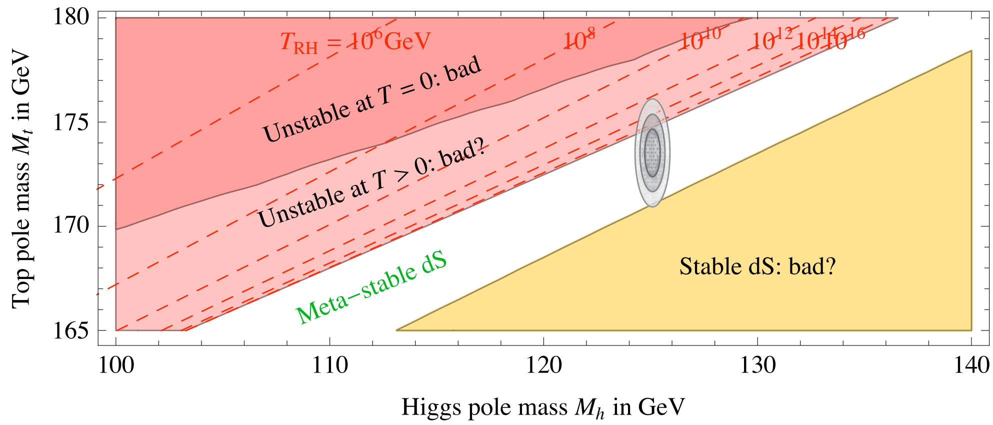



**Fig. 1: The allowed meta-stability window of the Higgs mass. The ellipse indicates the measured values of Mh and Mt. The orange region is excluded by assuming that "stable dS" is unacceptable. The red region is excluded by vacuum decay at zero temperature. The pale-red region is excluded by the requirement that the universe must have been hot in the past (the dashed red curves show boundaries for different values of the reheating temperature).**

studied how a speculative link between Higgs metastability and consistence of quantum gravity leads to a sharp prediction for the Higgs and top masses, which is consistent with measured values.

**THE PROBLEM OF REALIZING A NATURALLY LIGHT DILATON CAN GIVE VERY VALUABLE INSIGHTS TOWARDS THE RESOLUTION OF THE TRUE COSMOLOGICAL CONSTANT PROBLEM.**

## HIGGS INFLATION AS A MIRAGE

The possibility of using the Standard Model Higgs field to provide cosmological inflation is a very attractive possibility that has received much attention in recent years. However, the simplest realization of this idea faces a unitarity problem, associated with the fact that the cutoff of the effective theory describing the mechanism is lower than the scale associated with the inflationary behaviour of the potential. José R. Espinosa and Joan Elias-Miro, in collaboration with J.L.F. Barbon and J.A. Casas (IFT-UAM/CSIC, Madrid) revisited this problem and discussed a simple unitarization of Higgs inflation that is genuinely weakly coupled up to Planckian energies. A large non-minimal coupling between the Higgs and the Ricci curvature is induced dynamically at intermediate energies, as a simple ratio of mass scales, therefore providing a simple mechanism to generate a large value for such coupling. Despite not being dominated by the Higgs field, inflationary dynamics simulates the `Higgs inflation' one would get by blind extrapolation of the low-energy effective Lagrangian, at least qualitatively. Hence, Higgs inflation arises as an approximate `mirage' picture of the true dynamics. They further speculated on the generality of this phenomenon and showed that, if Higgs-inflation arises as an effective description, the details of the UV completion are necessary to extract robust quantitative predictions. Moreover, solving the unitarity problem of the original formulation of Higgs inflation generically requires the introduction of a new scalar field that takes over the role of inflating, thereby removing the most atractive feature of the original proposal.

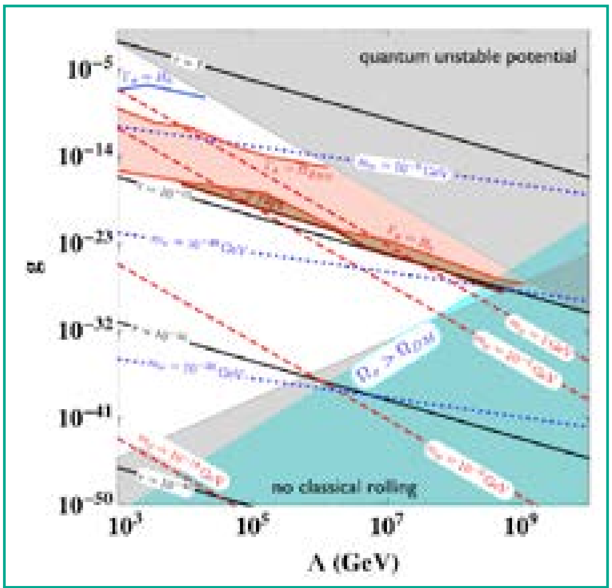



Fig. 3: Parameter space for a successful solution of the hierarchy problem ensured by the cosmological evolution of the fields $\phi$ and $\sigma$, for $\Lambda$= f and $g\sigma/g$ = 0.1. In the grey shaded areas the relaxation mechanism does not work naturally. In the pink and brown shaded areas the impact of the heavier singlet $\phi$ on Big Bang Nucleosynthesis and in present cosmology can be unviably large. In the cyan area the $\sigma$ scalar provides a viable Dark Matter candidate.

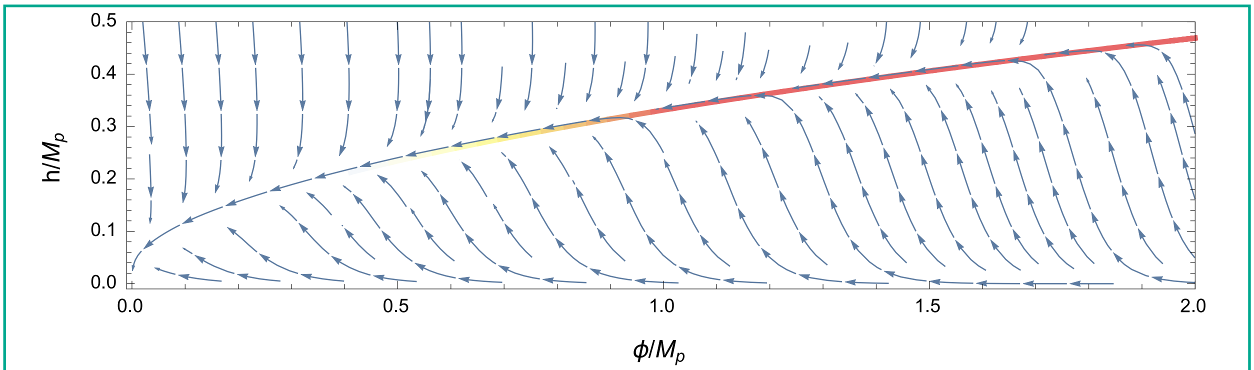



Fig. 2: Illustration of the lines of flow of a slow-rolling field in the potential V ( h,$\phi$), where h is the Higgs scalar and $\phi$ the new field introduced to solve the unitarity problem of the original Higgs inflation proposal. The red line shows the inflationary trajectory along the potential valley (with the transition to yellow indicating that slow-roll no longer holds). Notice how the inflationary valley is aligned with $\phi$, which plays the role of inflaton.

# COSMOLOGICAL RELAXATION MECHANISMS FOR THE ELECTROWEAK SCALE

In 2015 an IFAE collaboration composed of JR. Espinosa, C. Grojean, G. Panico, A. Pomarol, O. Pujolas and G. Servant contributed to the Cosmological Relaxation mechanisms for the Higgs mass whereby the dynamics during inflation of axion-like scalars play a key role in rendering the Higgs mass at present much smaller than high-energy 'new physics' scale. Our collaboration contributed with a model with enhanced capabilities because it does not require additional sources that break the electroweak symmetry. The resulting Cosmological Higgs-Axion Interplay (CHAIN) model augments the Standard Model by only two axion-like scalars up to rather high energies – up to 109 GeV – without interfering with naturalness or phenomenological viability.

# APPLICATIONS OF THE GAUGE/GRAVITY CORRESPONDENCE

The holographic (or gauge/gravity) duality has become nowadays a powerful tool to study strongly coupled systems and has found numerous applications, ranging from modeling QCD and heavy ion collisions to quantum liquids and high-temperature superconductivity. During 2015, O. Pujolas in collaboration with PhD student M. Baggioli have studied the application of Massive Gravity theories to model realistic strongly coupled materials with momentum disipation. Specifically, they constructed simple models of a metal-insulator transition that are driven by the electron-phonon interactions. In these models, the metal-insulator transition is accompanied by the formation of polaron resonances in the AC electrical conductitvity.

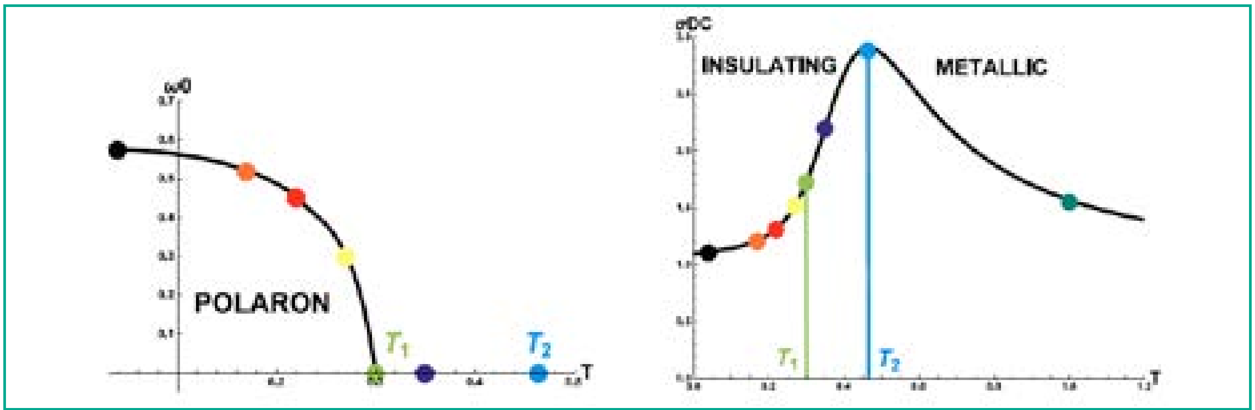



**Fig. 4: Right: DC electrical conductivity for a representative holographic massive gravity model with metric potential V(X)=X+X5 where X is the Stueckelberg fields kinetic term. The model exhibits a crossover with metal/insulator behaviour at high/low temperatures. The transition is accompanied by the formation of a 'polaron' – an electron-phonon bound state resonance with finite energy-gap w0. Left: The temperature dependence of the polaron mass $\omega_0$ in function of temperature shows a clear correlation between polaron formation and the metal-insulator transition.**

# 3. PROJECTS **IN 2015**

## ACTIVE PROJECTS

### EUROPEAN COMMISSION

1. 250207
Voxel Imaging PET Pathfinder
Mokthar Chemeissani
2. 653477
Astronomy ESFRI and Research Infrastructure Cluster
Javier Rico
3. 631962
Higgs precision era at the LHC
Christophe Grojean
4. 644294
Japan and Europe Network for Neutrino and Intensity Frontier Experimental Research
Federico Sánchez
5. 654168
Advanced European Infrastructures for Detectors at Accelerators
Sebastián Grinstein
6. 665919
P-SPHERE
Ramon Miquel
7. 660138
A SiPM upgrade for VHE Astronomy and beyond
John E. Ward

### MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

1. AIC-A-2011-0660
Participación Española en la Fase Preparatoria del Cherenkov Telescope Array (CTA)
Manel Martínez
2. FPA2011-29823-C02-02
Participación en el experimento T2K
Federico Sánchez
3. FPA2012-38713
Fisica en colisiones protón protón en el LHC usando el detector ATLAS
Mario Martínez Pérez
4. FPA2012-39502
Explotación del upgrade de MAGIC
Javier Rico
5. TEC2012-39150-C02-02
Detección de nanomoleculas mediante el uso de sensores gaseosos microestructurados
Mokthar Chemeissani
6. FPA2011-25948
Física de las Interacciones Fundamentales
Mariano Quirós
7. FPA2013-48308-C2-1-P
Detectores de pixels actuales y futuros para el experimento ATLAS
Sebastián Grinstein
8. FPA2013-47986-C3-1-P
Cosmología y física fundamental con cartografiados extragalácticos
Ramon Miquel
9. ESP2013-48274-C3-3-P
Cartografiados cosmológicos para estudio de la Energía Oscura, preparación para Euclid
Cristobal Padilla
10. ESP2013-48274-C3-2-P
Centro de Datos para Cartografiados Cosmológicos de Energía Oscura - preparando Euclid
Christian Neissner
11. FPA2013-48082-C2-1-R
Implantación del Sistema de Computación Tier1 Español para el Large Hadron Collider Fase IV
Manuel Delfino
12. FPA2014-59855-P
Física de neutrinos en T2K y I+D para futuros experimentos
Federico Sánchez
13. ESP2014-58384-C3-2-P
Cartografiados Cosmológicos de Energía Oscura - preparando Euclid
Cristobal Padilla
14. FPA2014-55819-C4-1-P
Participación española en el diseño y prototipado del Cherenkov Telescope Array: contribución de IFAE/UAB
Abelardo Moralejo
15. SEV-2012-0234
IFAE
Manel Martínez
16. FPA2013-47424-C3-3-R
Tier-2 Distribuido Español para el experimento Atlas (LHC) Fase 3 y su papel en la gestión y procesamiento de grandes cantidades de datos
Andreu Pacheco

17. FPA2014-55613-P
Física de las Interacciones Fundamentales
Matthias Jamin

18. FIS2015-63313-CIN
18th International Workshop on Radiation Imaging Detectors
Thorsten Lux
Agència de Gestió d'Ajuts Universitaris i de Recerca

## AGÈNCIA DE GESTIÓ D'AJUTS UNIVERSITARIS I DE RECERCA

1. 2014 SGR 696
Grups de recerca consolidats: IFAE ATLAS
Aurelio Juste

2. 2014 SGR 1308
IFAE-Astropartícules
Oscar Blanch

3. 2014 SGR 1177
Particle Detectors and Instrumentation group at IFAE
Sebastián Grinstein

# 4. KNOWLEDGE & TECHNOLOGY **TRANSFER IN 2015**

IFAE performs frontier research in particle physics, astrophysics, and cosmology, fields of knowledge requiring advanced engineering, electronics and software technologies not existing in the market. IFAE research & engineering teams develop their own technology, transferring it to industry by means of joint ventures, partnerships, R&D agreements, technical services based on singular scientific infrastructures, training sessions, consultancy, licensing and spin-off creation.

## 2015 TECH. TRANSFER OUTPUT AT IFAE

**400k€**

COMPETITIVE FUNDS FOR COLLABORATIVE RESEARCH ACTIONS WITH PRIVATE SECTOR

**125k€**

NON COMPETITIVE FUNDS COMING FROM INDUSTRIAL AGREEMENTS AND SERVICES OFFERED TO EXTERNAL ENTITIES

**1**

PCT APPLICATION IN RADIATION DETECTION

**1**

EUROPEAN PATENT APPLICATION FILED IN MEDICAL IMAGING

### COLLABORATIVE RESEARCH

- 1 European Post-Doc research project financed. (H2020 - MSCA-CO-FUND grant) with the collaboration of 5 companies
- 2 European Research & Industry projects submitted (H2020 - RIS3CAT Health) both including public health entities
- 1 Consultancy on business models for CERN valorised technologies in the framework of an European Research Network project (Talent project - MSCA - ITN)
- 7 Cooperation Research and Development Agreements negotiated (ASTERICS, DESI, AIDA, JENNIFER, DESY, HELIX NEBULA and P-SPHERE projects)

## CONTRACT RESEARCH & SERVICES

- 5 Industrial Agreements negotiated and signed (mechanical engineering, medical physics, electronics engineering and big data)
- 6 Technical Services budgeted and executed (mechanical engineering, computing, microelectronics assembly)
- 7 Confidential Disclosure Agreements arranged and signed (automotive, chemical and bio sectors)
- 6 Customers (3 new)

## PROTECTION, VALORIZATION & LICENSING

- 2 Disclosure of Inventions evaluated (communications, astronomy) and complemented with patent search, market survey and exploitation strategy analysis
- 1 Proof of Principle Proposal assessed and submitted (AGAUR - Llavor grant)
- 1 state-of-the art and market research study developed on photon sensitive devices for medical industry for Health Industry granted with a Business course sponsored by CRG
- 1 PCT application (photon counting method) and corresponding market volume and market share analysis performed
- 1 European patent application filed (device for detecting highly energetic photons) as a result of a market survey study
- 2 Patents in force - 9 international patent extensions (medical physics)

## SPIN-OFF GROWTH

- 1 Investment search cooperation agreement arranged (Casa Cresques-BIST)
- 1 Collaborative research project submitted to AGAUR (microelectronics for graphene sensors)
- 1 "Acción de dinamización de la comunicación de resultados científico-técnicos o de la innovación en congresos internacionales de alto nivel 2015 granted" (MINECO - CNM, CSIC, IFAE) performing a market survey for the sponsorship of IWORID'16 international workshop

# 5. PERSONNEL **IN 2015**

IFAE complements its own staff (hired directly by the Institute) with personnel of ICREA and collaborates with personnel from the UAB as shown in the following list.

## EXPERIMENTAL DIVISION
## FACULTY

| | |
|---|---|
| **Blanch, Oscar** | Research Associate Professor, GAMMA-RAY, IFAE (since Jul) |
| **Bosman, Martine** | Research Professor, ATLAS, IFAE |
| **Casado, Mª. Pilar** | Associate Professor, ATLAS, UAB |
| **Cavalli-Sforza, Matteo** | Research Professor, ATLAS/NEUTRINOS IFAE |
| **Chmeissani, Mokhtar** | Research Professor, APPLIED PHYSICS, IFAE |
| **Cortina, Juan** | Research Associate Professor, GAMMA-RAY, IFAE |
| **Crespo, José Mª.** | Professor, UAB |
| **Delfino, Manuel** | Professor, PIC, UAB |
| **Fernández, Enrique** | Professor, COSMOLOGY, UAB |
| **Grinstein, Sebastián** | Research Professor, ATLAS Pixels, ICREA |
| **Juste, Aurelio** | Research Professor, ATLAS, ICREA |
| **Korolkov, Ilya** | Research Associate Professor, ATLAS, IFAE |
| **Lux, Thorsten** | Research Associate Professor, APPLIED PHYSICS, IFAE (since Jul) |
| **Martínez, Manel** | Research Professor, GAMMA-RAY, IFAE |
| **Martínez, Mario** | Research Professor, ATLAS, ICREA |
| **Miquel, Ramon** | Research Professor, COSMOLOGY, ICREA |
| **Mir, Lluïsa Mª.** | Research Associate Professor, ATLAS, IFAE |
| **Moralejo, Abelardo** | Research Associate Professor, GAMMA-RAY, IFAE |
| **Padilla, Cristóbal** | Research Associate Professor, COSMOLOGY, IFAE |
| **Rico, Javier** | Research Associate Professor, GAMMA-RAY, IFAE (since Jul) |
| **Riu, Imma** | Research Associate Professor, ATLAS, IFAE |
| **Sánchez, Federico** | Research Associate Professor, NEUTRINO, IFAE |
| **Sorin, Verónica** | Researcher, Ramon y Cajal, ATLAS, IFAE (until Sep) |

## SCIENTIFIC POST-DOCS

| | |
|---|---|
| **Aleksić, Jelena** | COSMOLOGY, UAB |
| **Bonnet, Christopher** | COSMOLOGY |
| **Bordoni, Stefania** | NEUTRINOS |
| **Cortés, Arely** | ATLAS, Juan de la Cierva Fellowship |
| **Cumani, Paolo** | GAMMA-RAY (since May ) |
| **De Lorenzo, Gianluca** | VIP (until May) |
| **Farooque, Trisha** | ATLAS |
| **Gonçalvez dos Anjos, Nuno** | ATLAS, Beatriu de Pinos Postdoctoral Fellowship |

| | |
|---|---|
| **Griffiths, Scott** | GAMMA-RAY (since Oct) |
| **Hassan, Tarek** | GAMMA-RAY (since Jul) |
| **Herrera, Javier** | GAMMA-RAY |
| **Kolstein, Machiel** | VIP |
| **Kovács, András** | COSMOLOGY |
| **Lange, Joern** | ATLAS-Pixel, Juan de la Cierva Fellowship |
| **Le Menedeu, Eve** | ATLAS (until Jan) |
| **Tripiana, Martin** | ATLAS |
| **Valery, Loic** | ATLAS |
| **Ward, John** | GAMMA-RAY, Marie Curie Individual Fellowship |
| **Will, Martin** | GAMMA-RAY |

## DOCTORAL STUDENTS

| | |
|---|---|
| **Ariño, Gerard** | VIP (until Apr) |
| **Bourguille, Bruno** | NEUTRINOS, PhD Fellowship Severo Ochoa-MINECO |
| **Casolino, Mirko** | ATLAS, FI AGAUR |
| **Castillo, Raquel** | NEUTRINOS (until Apr) |
| **Cavallaro, Emanuele** | ATLAS-Pixel, PhD Fellowship Severo Ochoa-MINECO |
| **Fernández, Alba** | GAMMA-RAY, PhD Fellowship FPI -MINECO |
| **Fischer, Cora** | ATLAS, PhD Fellowship FPI -MINECO |
| **Foerster, Fabian** | ATLAS-Pixel, PhD Fellowship SO MINECO (since Nov) |
| **Fracchia, Silvia** | ATLAS |
| **García, Alfonso** | NEUTRINOS, PhD Fellowship FPI -MINECO |
| **Gatti, Marco** | COSMOLOGY, PhD Fellowship SO LA CAIXA (since Oct) |
| **González, Adiv** | GAMMA-RAY, PhD Fell. Multi-Dark Consolider (until Mar) |
| **Guberman, Daniel** | GAMMA-RAY, PhD Fellowship Severo Ochoa-MINECO |
| **López Coto, Ruben** | GAMMA-RAY, PhD Fellowship FPI -MINECO (until Sep) |
| **López Paz, Ivan** | ATLAS-Pixel, PhD Fellowship Severo Ochoa-MINECO |
| **Nogués, Leyre** | GAMMA-RAY, PhD Fellowship Severo Ochoa-MINECO |
| **Ninci, Daniele** | GAMMA-RAY, PhD Fellowship SO LA CAIXA (since Oct) |
| **Palacio, Joaquim** | GAMMA-RAY, PhD Fellowship Severo Ochoa-MINECO |
| **Prat, Judit** | COSMOLOGY, PhD Fellowship Severo Ochoa-MINECO |
| **Prats, Xavier** | VIP-ERICA (since Apr) |
| **Rizzi, Chiara** | ATLAS , PhD Fellowship Severo Ochoa- LA CAIXA |
| **Rodríguez Pérez, Andrea** | ATLAS, PhD Fellowship Severo Ochoa-MINECO |
| **Sánchez Alonso, Carles** | COSMOLOGY, PhD Fellowship Severo Ochoa- MINECO |
| **Tsiskaridze, Shota** | ATLAS-Pixel, FI AGAUR |
| **Tutusaus, Isaac** | COSMOLOGY (MSc student ) (until Sep) |
| **Vázquez, David** | ATLAS-Pixel, PhD Fellowship FPI-MINECO |
| **Vielzeuf, Pauline** | COSMOLOGY, PhD Fellowship Severo Ochoa-La Caixa |
| **Viruez, Raul** | NEUTRINOS (until Mar) |
| **Vo, Jonathan** | NEUTRINOS, PhD Fellowship SO-MINECO (until Jul) |

# THEORY DIVISION
## FACULTY

| | |
|---|---|
| **Escribano, Rafel** | Research Associate Professor, UAB |
| **Espinosa, José Ramón** | Research Professor, ICREA |
| **Grojean, Christophe** | Research Professor, ICREA (until Jul) |
| **Jamin, Matthias** | Research Professor, ICREA |
| **Massó, Eduard** | Research Professor, UAB |
| **Matias, Joaquim** | Research Associate Professor, UAB |
| **Méndez, Antonio** | Research Professor, UAB |
| **Pascual, Ramon** | Professor Emeritus, UAB |
| **Peris, Santi** | Research Associate Professor, UAB |
| **Pineda, Antonio** | Research Associate Professor, UAB |
| **Pomarol, Àlex** | Research Professor, UAB |
| **Pujolàs, Oriol** | Research Associate Professor, IFAE (since Oct) |
| **Quirós, Mariano** | Research Professor, ICREA |
| **Servant, Géraldine** | Research Professor, ICREA (until Jul) |

## SCIENTIFIC POST-DOCS

| | |
|---|---|
| **Hofer, Lars** | Post doc IFAE (until Sep) |
| **Llorente, Oscar** | Post doc Institut de Ciències de l'Espai UAB |
| **Chihaya, Anzai** | Post doc UAB (since Oct) |
| **Panico, Giuliano** | Post doc |

## DOCTORAL STUDENTS

| | |
|---|---|
| **Baggioli, Matteo** | PIF Fellowship UAB |
| **Capdevilla, Bernat** | PhD Fellowship Severo Ochoa- MINECO (since nov) |
| **Elias, Joan** | PhD Fellowship FPU -MECD (until Dec) |
| **García Pepin, Mateo** | PIF Fellowship UAB |
| **González, Sergi** | PhD Fellowship FPI -MINECO |
| **Hornung, Dirk** | PIF Fellowship UAB |
| **Miravitllas, Ramon** | PhD Fellowship FPI -MINECO (since nov) |
| **Peset, Clara** | Predoctoral Student |
| **Riembau, Marc** | PhD Fellowship Severo Ochoa- LA CAIXA |
| **Salas, Lindber** | PhD Fellowship Severo Ochoa- MINECO (since Jul ) |
| **Vantalon, Thibaud** | PhD Fellowship Severo Ochoa- MINECO |
| **Yang, Ke** | Chinese Scholarship Council |

# TECHNICAL SERVICES
## ENGINEERING STAFF

| | |
|---|---|
| **Abril, Oscar** | Electronics Engineer |
| **Ballester, Otger** | Software Engineer |
| **Boix, Joan** | Electronics Engineer |
| **Cardiel Sas, Laia** | Electronics Engineer |
| **Casanova, Raimon** | Electronics Engineer |
| **Gálvez, Jose Antonio** | Mechanical Engineer (since Jun) |
| **García Gil, Rafael** | Mechanical Engineer |
| **García Rodríguez, Jorge** | Electronics Engineer |
| **Grañena, Ferran** | Mechanical Engineer (until Feb) |
| **Illa, José Mª.** | Electronics Engineer |
| **Jiménez Rojas, Jorge** | Electronics Engineer (since Jul) |
| **Lamensans, Mikel** | Mechanical Engineer |
| **Llorente, Paloma** | Mechanical Engineer |
| **Macias, José Gabriel** | Microelectronics Designer |
| **Martínez, Oscar** | Electronics Engineer |
| **Pio, Cristóbal** | Software Engineer |
| **Puigdengoles, Carles** | Electronic Engineer |

## COMPUTER SCIENTISTS

| | |
|---|---|
| **Campos, Marc** | Computer Scientist |
| **Guinó Feijoo, Àlex** | Computer Scientist |
| **Pacheco Pages, Andreu** | Senior Applied Physicist (Computing) |

## TECHNICIANS

| | |
|---|---|
| **Arteche, Carlos** | Mechanical Technician |
| **Benedico, David** | Mechanical Technician |
| **Colombo, Eduardo** | MAGIC Support Astronomer |
| **Gaweda, Javier** | Mechanical Technician |
| **González, Alex** | Electronic Technician |
| **Peregrina, Eric** | Electronic Technician (since Dec) |

# RESEARCH SUPPORT
## TECHNOLOGY TRANSFER

| | |
|---|---|
| **Esparbé, Isaac** | Technology Transfer Manager |
| **De la Rosa, Gloria** | Technology Transfer Assistant (since Nov) |

## COMMUNICATION AND PUBLIC OUTREACH OFFICE

| | |
|---|---|
| **Grinschpun, Sebastián** | Comm. & Public Outreach Manager (since Apr) |
| **Labián, Alícia** | Comm. & Public Outreach (since Nov) |

## RESEARCH PROJECTS OFFICE

| | |
|---|---|
| **Balza, Marta** | Research Project Manager |

## ADMINISTRATION

| | |
|---|---|
| **Bosch, Joaquim** | General Manager (since Sep) |
| **Cárdenas, Cristina** | Secretary, UAB |
| **El Kouraichi, Ijlal** | Administrative Assistant (since Dec) |
| **Gaya, Josep** | Senior Administrator, UAB |
| **Jiménez, Elizabeth** | Administrative Assistant |
| **Gómez, Marta** | Administrative Assistant |
| **Strauch, Sara** | Administrative Assistant |

# 6. INSTITUTIONAL **ACTIVITIES IN 2015**

In this section we list the institutional activities undertaken by IFAE in 2015. This includes the scientific output produced at IFAE such as scientific publications, conference proceedings, doctoral theses and talks in international conferences as well as other activities such as outreach activities and seminars and colloquia organized at IFAE.

## 2015 SCIENTIFIC OUTPUT AT IFAE

| 181 | 89.5% | 5.2 |
|---|---|---|
| NUMBER OF INDEXED JOURNAL ARTICLES | % ARTICLES IN FIRST QUARTILE JOURNALS | AVERAGE JOURNAL IMPACT FACTOR (IF) |

| TOP 5 JOURNALS (BY IF) WHERE IFAE PUBLISHED IN 2015 | NUMBER OF ARTICLES |
|---|---|
| Rev. Mod. Phys. (IF 29.6) | 1 |
| Phys. Rev. Lett. (IF 7.5) | 16 |
| Phys. Lett. B (IF 6.1) | 14 |
| J. High Energy Phys. (IF 6.1) | 38 |
| Astrophys. J. (IF 5.9) | 5 |

| TOP 5 JOURNALS WHERE IFAE PUBLISHED MORE FREQUENTLY | |
|---|---|
| J. High Energy Phys. (IF 6.1) | 38 |
| Phys. Rev. D (IF 4.6) | 35 |
| Eur. Phys. J. (IF 5.0) | 26 |
| Phys. Rev. Lett. (IF 7.5) | 16 |
| Mon. Not. Roy. Astron. Soc. (IF 5.1) | 16 |

DOCTORAL THESES: 10

NUMBER OF PRESENTATIONS AT INTERNATIONAL CONFERENCES: 151

# 6.1 MASTER & DOCTORAL THESES IN 2015

## MASTER & DIPLOMA

**Cristina Sans Ponseti**
*Effects of the Image Cleaning on Monte Carlo simulations of Moonlight observations with the MAGIC telescopes.*
July 2015, Advisor: O. Blanch

**Miquel Cassanyes**
*MAGIC sensitivity to Primordial Black Hole bursts and modelization of BH chromospheres and gamma-ray emission spectra.*
September 2015, Advisors: J. Rico and O. Pujolàs

**Eudald Font**
*Stand alone performance of the first Large Size Telescope for the Cherenkov Telescope Array.*
September 2015, Advisor: O. Blanch

**Judit Prat**
*Galaxy bias from galaxy-galaxy lensing measurements in the DES Science Verification data set,*
July 2015, Advisor: R. Miquel.

**Isaac Tutusaus**
*Clustering-based redshift estimation*
September 2015, Advisor: R. Miquel.

**Jordi París López**
*SU(3)-symmetric sum rules for B->PP decays*
July 2015, Advisor: R. Escribano.

**Dirk Hornung**
*1-Loop Anomalous Dimensions of 4-Quark Operators*
September 2015, Advisor: M. Jamin

**Ramon Miravitllas Mas**
*Singularity Analysis, an application to heavy quark vacuum polarization functions*
July 2015, Advisor: S. Peris

## DOCTORAL THESES

### EXPERIMENTAL

**Roger Caminal**
*Search for new phenomena in jets plus missing transverse energy final states at the LHC.*
February 23th 2015,
Thesis advisor: Mario Martinez

**Garoé González**
*Search for the SM Higgs boson in the (W/Z)H channel with H->bb using the ATLAS detector at the LHC.*
Februrary 20th 2015
Thesis advisor: Mario Martinez

**Adiv González Muñoz**
*Measurement of the gamma-ray opacity of the Universe with the MAGIC telescopes.*
April 24th 2015
Thesis advisor: A. Moralejo

**Gerard Ariño**
*Characterization of a CdTe Detector Module for Nuclear Medicine Application.*
April 27th 2015
Thesis advisor: M. Chmeissani

**Javier Montejo**
*Search for new physics in ttbar final states with additional*
*heavy-flavor jets with the ATLAS detector.*
June 11 2015
Thesis advisor: A. Juste

**Ruben López-Coto**
*Very-high-energy gamma-ray observations of pulsar wind nebulae and cataclysmic variable stars with MAGIC and development of trigger systems for IACTs.* July 2nd 2015
Thesis advisor: O. Blanch and J. Cortina

**Raquel Castillo**
*Muon neutrino interactions and muon neutrino single charged current single pion production cross section on CH in the T2K near detector.*
July 27th 2015
Thesis advisor: F. Sánchez

**Dunia Bachour**
*Estimation of Direct Normal Irradiance Using Ground Solar Station, Satellite Data and Lidar. Application to Qatar Solar Resource Assessment*
July 6th 2015.
Thesis advisor: M. Chmeissani

### THEORY

**Joan Elias Miró**
*Theoretical Implications of the Higgs Discovery.*
October 2nd 2015
Thesis advisor: J.R. Espinosa

# 6.2 IFAE PUBLICATIONS IN 2015

## EXPERIMENTAL DIVISION

### PUBLICATIONS BY THE ATLAS GROUP

1. G. Aad et al., ATLAS Collaboration
*Search for a Charged Higgs Boson Produced in the Vector-boson Fusion Mode with Decay $H^{\pm}\to W^{\pm}Z$ using pp Collisions at $\sqrt{s}$=8 TeV with the ATLAS Experiment*
Phys. Rev. Lett. 114, 231801 (2015)

2. G. Aad et al., ATLAS Collaboration
*Measurement of three-jet production cross-sections in pp collisions at 7 TeV centre-of-mass energy using the ATLAS detector*
Eur. Phys. J. C (2015) 75

3. G. Aad et al., ATLAS Collaboration
*Measurement of colour flow with the jet pull angle in $t\bar{t}$ events using the ATLAS detector at $\sqrt{s}$=8 TeV*
Physics Letters B (2015) 475-493

4. G. Aad et al., ATLAS Collaboration
*Search for low-scale gravity signatures in multi-jet final states with the ATLAS detector at $\sqrt{s}$=8 TeV*
JHEP 07 (2015) 032

5. G. Aad et al., ATLAS Collaboration
*Centrality and rapidity dependence of inclusive jet production in sqrt(s_NN) = 5.02 TeV proton-lead collisions with the ATLAS detector*
Phys. Lett. B 748 (2015) 392-413

6. G. Aad et al., ATLAS Collaboration
*Determination of the top-quark pole mass using tt+1-jet events collected with the ATLAS experiment in 7 TeV pp collisions*
JHEP 10 (2015) 121

7. G. Aad et al., ATLAS Collaboration
*Search for invisible decays of the Higgs boson produced in association with a hadronically decaying vector boson in pp collisions at ffls=8 TeV with the ATLAS detector*
Eur. Phys. J. C (2015) 75:337

8. G. Aad et al., ATLAS Collaboration
*Search for squarks and gluinos in events with isolated leptons, jets and missing transverse momentum at $\sqrt{s}$=8 TeV with the ATLAS detector*
JHEP 04 (2015) 116

9. G. Aad et al., ATLAS Collaboration
*Constraints on new phenomena via Higgs boson couplings and invisible decays with the ATLAS detector*
JHEP 11 (2015) 206

10. G. Aad et al., ATLAS Collaboration
*Search for a CP-odd Higgs boson decaying to Zh in pp collisions at $\sqrt{s}$=8 TeV with the ATLAS detector*
Physics Letters B 744 (2015) 163-183

11. Aad G et al., ATLAS Collaboration 2015
*Search for the $b\bar{b}$ decay of the Standard Model Higgs boson in associated (W/Z)H production with the ATLAS detector*
JHEP 01 (2015) 069

12. G. Aad et al., ATLAS Collaboration 2015
*Search for $H\to\gamma\gamma$ produced in association with top quarks and constraints on the Yukawa coupling between the top quark and the Higgs boson using data taken at 7 TeV and 8 TeV with the ATLAS detector*
Physics Letters B 740 (2015) 222-242, B740 222.

13. G. Aad et al., ATLAS Collaboration
*A search for $t\bar{t}$ resonances using lepton-plus-jets events in proton--proton collisions at $\sqrt{s}$=8 TeV with the ATLAS detector*
JHEP 08 (2015) 148

14. G. Aad et al., ATLAS Collaboration
*Search for supersymmetry in events containing a same-flavour opposite-sign dilepton pair, jets, and large missing transverse momentum in $\sqrt{s}$=8 TeV pp collisions with the ATLAS detector*
Eur. Phys. J. C75 (2015) 318

15. G. Aad et al., ATLAS Collaboration
*Search for invisible particles produced in association with single-top-quarks in proton-proton collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector*
Eur. Phys. J. C (2015) 75:79

16. G. Aad et al., ATLAS Collaboration
*Search for type-III Seesaw heavy leptons in pp collisions at $\sqrt{s}$=8 TeV with the ATLAS Detector* ,
Phys. Rev. D 92, 032001 (2015)

17. G. Aad et al., ATLAS Collaboration
*Measurement of the top quark mass in the $t\bar{t}\rightarrow$lepton+jets and $t\bar{t}\rightarrow$dilepton channels using $\sqrt{s}$=7 TeV ATLAS data*
Eur. Phys. J. C (2015) 75:330

18. G. Aad et al., ATLAS Collaboration
*Searches for heavy long-lived charged particles with the ATLAS detector in proton-proton collisions at sqrt(s) = 8 TeV*
JHEP 01 (2015) 068

19. G. Aad et al, ATLAS Collaboration
*Study of (W/Z)H production and Higgs boson couplings using $H\rightarrow WW^*$ decays with the ATLAS detector*
JHEP 08 (2015) 137

20. G. Aad et al., ATLAS Collaboration
*Search for long-lived, weakly interacting particles that decay to displaced hadronic jets in proton-proton collisions at $\sqrt{s}$=8 TeV with the ATLAS detector*
Phys. Rev. D 92, 012010 (2015)

21. G. Aad et al., ATLAS Collaboration
*Search for charged Higgs bosons decaying via $H^\pm \rightarrow \tau^\pm$ nu in fully hadronic final states using pp collision data at $\sqrt{s}$ = 8 TeV with the ATLAS detector*
JHEP 03 (2015) 088

22. G. Aad et al., ATLAS Collaboration
*Z boson production in p+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV measured with the ATLAS detector*
Phys. Rev. C 92, 044915 (2015)

23. G. Aad et al., ATLAS Collaboration
*Measurements of the Total and Differential Higgs Boson Production Cross Sections Combining the $H\rightarrow\gamma\gamma$ and $H\rightarrow ZZ^*\rightarrow 4l$ Decay Channels at $\sqrt{s}$=8 TeV with the ATLAS Detector*
Phys. Rev. Lett. 115 (2015) 091801

24. G. Aad et al., ATLAS Collaboration
*Search for direct production of charginos and neutralinos decaying via the 125 GeV Higgs boson in $\sqrt{s}$=8 TeV pp collisions with the ATLAS detector*
Eur. Phys. J. C (2015) 75:208

25. G. Aad et al., ATLAS Collaboration
*Measurement of the $t\bar{t}W$ and $t\bar{t}Z$ production cross sections in pp collisions at $\sqrt{s}$=8 TeV with the ATLAS detector*
JHEP 11 (2015) 172

26. G. Aad et al., ATLAS Collaboration
*A search for high-mass resonances decaying to $\tau^+\tau^-$ in pp collisions at $\sqrt{s}$=8 TeV with the ATLAS detector*
JHEP 07 (2015) 157

27. G. Aad et al., ATLAS Collaboration
*Search for s-channel single top-quark production in proton-proton collisions at $\sqrt{s}$=8 TeV with the ATLAS detector*
Phys.Lett. B740 (2015) 118

28. G. Aad et al., ATLAS Collaboration
*Search for Higgs boson pair production in the $b\bar{b}b\bar{b}$ final state from pp collisions at $\sqrt{s}$=8 TeV with the ATLAS detector*
Eur. Phys. J. C (2015) 75:412

29. G. Aad et al., ATLAS Collaboration
*Search for a Heavy Neutral Particle Decaying to $e\mu$, $e\tau$, or $\mu\tau$ in pp Collisions at $\sqrt{s}$=8 TeV with the ATLAS Detector*
Phys. Rev. Lett. 115, 031801 (2015)

30. G. Aad et al., ATLAS Collaboration
*Search for new phenomena in events with a photon and missing transverse momentum in pp collisions at $\sqrt{s}$=8 TeV with the ATLAS detector,*
Phys. Rev. D 91, 012008 (2015)

31. G. Aad et al., ATLAS Collaboration
*Study of the spin and parity of the Higgs boson in diboson decays with the ATLAS detector*
Eur. Phys. J. C75 (2015) 476

32. G. Aad et al., ATLAS Collaboration
*Search for a new resonance decaying to a W or Z boson and a Higgs boson in the $ll/l\nu/\nu\nu+b\bar{b}$ final states with the ATLAS Detector*
Eur. Phys. J. C (2015) 75: 263

33. G. Aad et al., ATLAS Collaboration
*Observation and measurement of Higgs boson decays to WW* with the ATLAS detector*
Phys. Rev. D 92, 012006 (2015)

34. G. Aad et al., ATLAS Collaboration
*Run 1 searches for direct pair production of third-generation squarks at the Large Hadron Collider*
Eur. Phys. J. C75, 10 (2015), 510.

35. G. Aad et al., ATLAS Collaboration
*Measurement of charged-particle spectra in Pb+Pb collisions at $\sqrt{sNN}$=2.76 TeV with the ATLAS detector at the LHC*
JHEP 09 (2015) 050

36. G. Aad et al., ATLAS Collaboration
*Search for Higgs and Z Boson Decays to $J/\psi$ gamma and $\Upsilon(nS)$ gamma with the ATLAS Detector*
Phys. Rev. Lett. 114 (2015) 121801

37. G. Aad et al., ATLAS Collaboration
*Search for lepton-flavour-violating $H\rightarrow\mu\tau$ decays of the Higgs boson with the ATLAS detector*
JHEP 11 (2015) 211

38. G. Aad et al., ATLAS Collaboration
*Search for new phenomena in final states with an energetic jet and large missing transverse momentum in pp collisions at √s=8 TeV with the ATLAS detector*
European Physical Journal C, 75:299.

39. G. Aad et al., ATLAS Collaboration
*Summary of the ATLAS experiment's sensitivity to supersymmetry after LHC Run 1 - interpreted in the phenomenological MSSM*
JHEP 10 (2015), 134

40. G. Aad et al., ATLAS Collaboration
*Search for production of vector-like quark pairs and of four top quarks in the lepton-plus-jets final state in pp collisions at √s=8 TeV with the ATLAS detector*
JHEP 08 (2015) 105

41. G. Aad et al., ATLAS Collaboration
*Evidence of Wγγ production in pp collisions at √s=8 TeV and limits on anomalous quartic gauge couplings with the ATLAS detector*
Phys. Rev. Lett. 115, 031802 (2015)

42. G. Aad et al., ATLAS Collaboration
*Search for the Xb and other hidden-beauty states in the π+π−Υπ+π−Υ(1S) channel at ATLAS*
Phys. Lett. B740 (2015), 199–217.

43. G. Aad et al., ATLAS Collaboration
*Search for heavy lepton resonances decaying to a Z boson and a lepton in pp collisions at √s=8 TeV with the ATLAS detector*
JHEP 09 (2015) 108

44. G. Aad et al., ATLAS Collaboration
*Search for production of WW/WZ resonances decaying to a lepton, neutrino and jets in pp collisions at √s = 8 TeV with the ATLAS detector*
Eur. Phys. J. C (2015) 75:209

45. G. Aad et al., ATLAS Collaboration
*Search for new phenomena in events with three or more charged leptons in pppp collisions at √s= 8 TeV with the ATLAS detector*
JHEP 08 (2015) 138

46. G. Aad et al., ATLAS Collaboration
*Search for heavy Majorana neutrinos with the ATLAS detector in pp collisions at √s=8 TeV*
JHEP 07 (2015) 162

47. G. Aad et al., ATLAS Collaboration
*Measurement of the correlation between flow harmonics of different order in lead-lead collisions at √sNN=2.76 TeV with the ATLAS detector*
Phys. Rev. C 92, 034903 (2015)

48. G. Aad et al., ATLAS Collaboration
*Observation and measurements of the production of prompt and non-prompt J/ψ mesons in association with a Z boson in proton-proton collisions at ffls = 8 TeV with the ATLAS detector*
Eur. Phys. J. C75 (2015) 229

49. G. Aad et al., ATLAS Collaboration
*Search for photonic signatures of gauge-mediated supersymmetry in 8 TeV pp collisions with the ATLAS detector*
Phys. Rev. D 92 (2015) 072001

50. G. Aad et al., ATLAS Collaboration
*Search for massive, long-lived particles using multitrack displaced vertices or displaced lepton pairs in pp collisions at √s = 8 TeV with the ATLAS detector*
Phys. Rev. D 92, 072004 (2015)

51. G. Aad et al., ATLAS Collaboration
*Evidence for the Higgs-boson Yukawa coupling to tau leptons with the ATLAS detector*
JHEP 04 (2015) 117

52. G. Aad et al., ATLAS Collaboration
*Searches for Higgs boson pair production in the hh→bbττ, γγWW∗, γγbb, bbbb channels with the ATLAS detector*
Phys. Rev. D 92, 092004 (2015)

53. G. Aad et al., ATLAS Collaboration
*Differential top--antitop cross-section measurements as a function of observables constructed from final-state particles using pp collisions at √s=7 TeV in the ATLAS detector*
JHEP 06 (2015) 100

54. G. Aad et al., ATLAS Collaboration
*Measurements of the WW production cross sections in association with jets with the ATLAS detector*
Eur. Phys. J. C (2015) 75:82

55. G. Aad et al., ATLAS Collaboration
*Measurement of differential J/ψ production cross-sections and forward-backward ratio in p+Pb collisions with the ATLAS detector*
Phys. Rev. C 92, 034904 (2015)

56. G. Aad et al., ATLAS Collaboration
*Measurement of the forward-backward asymmetry of electron and muon pair-production in pp collisions at √s = 7 TeV with the ATLAS detector ,*
JHEP 09 (2015) 049

57. G. Aad et al., ATLAS Collaboration
*Measurement of the inclusive jet cross-section in proton--proton collisions at √s=7 TeV using 4.5 $fb^{-1}$ of data with the ATLAS detector*
JHEP 02 (2015) 153

58. G. Aad et al., ATLAS Collaboration
*Search for metastable heavy charged particles with large ionisation energy loss in pp collisions at sqrt(s) = 8 TeV using the ATLAS experiment*
Eur. Phys. J. C (2015) 75:407

59. G. Aad et al., ATLAS and CMS Collaborations
*Combined Measurement of the Higgs Boson Mass in pp Collisions at $\sqrt{s}$ = 7 and 8 TeV with the ATLAS and CMS Experiments*
Phys. Rev. Lett. 114, 191803 (2015)

60. G. Aad et al., ATLAS Collaboration
*Measurement of the transverse polarization of $\Lambda$ and anti-$\Lambda$ hyperons produced in proton-proton collisions at $\sqrt{s}$=7 TeV using the ATLAS detector*
Phys. Rev. D. 91, 032004 (2015)

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# 6.3 TALKS BY IFAE MEMBERS IN 2015

## ATLAS GROUP

### PILAR CASADO

- Status and prospects for BSM ((N)MSSM) Higgs searches at the LHC (ATLAS). Linear Collider Workshop 2015 (LCWS15), Vancouver, Canada. November, 2015

### ARELY CORTÉS

- SUSY Third Generation Squarks Searches. IAS Program on the Future of High Energy Physics, Institute for Advanced Study, The Hong Kong University of Science and Technology. Hong Kong SAR, China. January, 2015
- Tile Calorimeter operations and performance. ATLAS Week, CERN, Switzerland. June, 2015

### ILYA KOROLKOV

- Upgrade of the ATLAS Calorimeters for Higher LHC Luminosities. EPS conference, Vienna, Austria. July, 2015

### AURELIO JUSTE

- Status and Prospects for Top Quark Measurements, The vacuum of the Universe: from cosmology to particle physics. Institute of Cosmos Sciences (ICCUB), Barcelona, Spain. October 21-23, 2015
- Direct Probes of Top and Higgs Compositeness at the LHC, Gearing up for LHC13. The Galileo Galilei Institute for Theoretical Physics, Florence, Italy. October 13-16, 2015
- Probing Flavor-Violating Top-Higgs Interactions. ATLAS HTop Workshop, CERN, Geneva, Switzerland. September 28-29, 2015
- Genoa Workshop: Metadata Summary. ATLAS Software and Computing Workshop, CERN, Geneva, Switzerland. September 21-25, 2015
- Searches for tt-H at the LHC. Higgs Days at Santander 2015 Workshop, Instituto de Física de Cantabria, Santander, Spain. September 14-18, 2015
- Top-Higgs Couplings Measurements at the LHC and Beyond. IAS Program on "The Future of High Energy Physics", Hong Kong University of Science and Technology, Jockey Club Institute of Advanced Study, Hong Kong. Jan 19-22, 2015

### MARIO MARTÍNEZ

- Review of Searches for New Physics in ATLAS, GGI, Florence, Italy. October, 2015
- Notes on FCC (Future Circular Colliders) Meeting, IFAE and ALBA Seminars, Bellaterra, Spain. April, 2015
- Higgs Physics, Hasco School, Goettingen University, Germany. July, 2015
- The Role of the National Institutes at the LHC, UIMP (Menedez Pelayo), Santander, Spain. July, 2015
- Beyond Standard Model Searches in ATLAS, Corfu Summer School, Corfu, Greece. September, 2015

### IMMA RIU

- ATLAS Physics Objects: Status and Performance at 13 TeV. Top Workshop 2015, Ischia, Italy. September 14, 2015
- L1Topo algorithms commissioning status. TDAQ Week, Edinburgh, UK. November 30, 2015
- L1Topo menu proposal for 2016. ATLAS menu workshop for 2016, CERN, Switzerland. December 9, 2015

### MARTIN TRIPIANA

- Searches for 3rd generation SUSY partners in ATLAS and CMS. European Physical Society Conference on High Energy Physics (EPS-HEP), Vienna. July, 2015

### LOIC VALERY

- Searches for new phenomena with heavy quarks and multileptons at the LHC. Rencontres de Blois, France. May, 2015

## PIXELS GROUP

### RAIMON CASANOVA

- "Digital readout electronics for the H35 demonstrator", ATLAS HV-MAPS Workshop Heidelberg, Germany 6/8/2015.

### EMANUELE CAVALLARO

- "Status of 3D silicon pixel detectors for the ATLAS Forward Physics experiment (AFP)", 10th "Trento" Workshop on Advanced Silicon Radiation Detectors Trento, Italy 17-19 February 2015.

### JOERN LANGE

- "Recent Progress on 3D Silicon Detectors", 24th International Workshop on Vertex Detectors Santa Fe, USA 1-5 June 2015.

- "Recent progress on 3D pixel detectors ", 26th RD50Workshop Santander, Spain 22-24 June 2015
- "Radiation hardness of 3D pixel detectors up to 2e16 neq/cm2", 27th RD50 Workshop, CERN, Geneva, 2-4 Dec 2015.

### IVÁN LOPEZ

- "Characterization of silicon for the ATLAS Forward Physics experiment", Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2015 Lisbon, Portugal 20-24 April 2015.
- "Recent testbeam results of 50 Qm pitch 3D sensors at high incidence angle for HL-LHC", 26th RD50 Workshop, Santander, Spain 22-24 June 2015.
- I. Lopez, "Beam test of 3D pixel detectors up to fluences of 9e15 neq/cm2", 27th RD50 Workshop, CERN, Geneva , 2-4 Dec 2015.

## NEUTRINO GROUP

### STEFANIA BORDONI

- Poster: Searches for Short-Baseline neutrino oscillations with the T2K off-axis near detector. XVI Workshop on Neutrino Telescopes, Venice, IT, March 2015. Best poster award.
- Neutrino oscillation measurements with T2K. July 2015 , LNGS, L'Aquila, (Italy)
- Recent results of the T2K experiment. May 2015. Università di Bologna (Italy).

### FEDERICO SÁNCHEZ

- NuPhys 2015 (London) December 2015. Neutrino cross-section: Experiments (invited)
- International XLIII Meeting on Fundamental Physics. (Benasque) "Long Base Line Experiments ", February 2015 (invited)
- T2K: present results and challenges, 22nd December 2015, RWTH (Aachen) Germany.

### THORSTEN LUX

- LBNO-DEMO (WA105): a large demonstrator of the Liquid Argon double phase TPC, RD51 Meeting, October 2015, Trieste (Italy).

## GAMMA-RAY GROUP

### ÒSCAR BLANCH

- MAGIC gamma-ray binaries. Variable Galactic Gamma-ray Sources III, Heidelberg, Germany. May 4th, 2015
- MAGIC: Present and Future. RIA/MAGIC-CTA Meeting, MINECO, Madrid, Spain. April 21st, 2015
- Technical capabilities at IFAE. GAMMA-400 Workshop, Barcelona, Spain. June 30th, 2015
- Camera slow control: LST-CAM. Second camera Workshop, CTA, Bellaterra, Spain. October 30th, 2015
- Recent highlights of the MAGIC telescopes. 28th Texas Symposium, Geneve, Switzerland. December 16th, 2015

### JUAN CORTINA

- MACHETE: A transit Imaging Atmospheric Cherenkov Telescope to survey half of the VHE gamma ray sky. International Cosmic Ray Conference, The Hague, The Netherlands. August 3rd, 2015
- MACHETE: A transit Imaging Atmospheric Cherenkov Telescope to survey half of the VHE gamma ray sky. The future of Research on Cosmic Gamma Rays, La Palma, Spain, August 26-29, 2015
- CTA: the next generation VHE gamma ray observatory. IVICFA's Fridays, Valencia, Spain, October 2nd, 2015

### PAOLO CUMANI

- Simulation Studies of GAMMA-400. GAMMA-400 Workshop, Barcelona, Spain. June 30th, 2015
- A Scientific Simulator for GAMMA-400. GAMMA-400 Workshop, Barcelona, Spain. June 30th, 2015

### ALBA FERNÁNDEZ-BARRAL

- VHE gamma-ray observations of transient and variable stellar objects with the MAGIC telescopes. International Cosmic Ray Conference, The Hague, The Netherlands. August 1st, 2015

### DANIEL GUBERMAN

- Status on the Moon Shadow project. MultiDark Consolider Workshop, Salamanca, Spain. April, 2015

### RUBÉN LÓPEZ-COTO

- Glimpse to the present and future of TeV gamma-ray astronomy: Discovery of the pulsar wind nebula 3C 58 and MACHETE, a new IACT to survey half of the gamma-ray sky. Weekly seminars at UCLA, Los Angeles, USA. April 2015
- Glimpse to the present and future of TeV gamma-ray astronomy: Discovery of the pulsar wind nebula 3C 58 and MACHETE, a new IACT to survey half of the gamma-ray sky. Weekly seminars at MPIK, Heidelberg, Germany. June 2nd, 2015
- Discovery of TeV gamma-ray emission from the pulsar wind nebula 3C58 by MAGIC. International Cosmic Ray Conference, The Hague, The Netherlands. July 30th, 2015
- MACHETE: A transit Imaging Atmospheric Cherenkov Telescope to survey half of the Very High Energy gamma-ray sky. International Astronomical Union, Honolulu, USA. August 5th, 2015

### ABELARDO MORALEJO

- MAGIC observations of the February 2014 flare of 1ES 1011+496 applied to the measurement of the extragalactic background light. TeV Particle Astrophysics 2015, Kashiwa, Japan. October, 2015

### JOAQUIM PALACIO

- Constraining the Dark Matter decay lifetime with very deep observations of the Perseus cluster with the MAGIC telescopes. International Cosmic Ray Conference, The Hague, The Netherlands. August 1st, 2015

### JAVIER RICO

- Data Center: MAGIC & CTA. RIA/MAGIC-CTA Meeting, MINECO, Madrid, Spain. April 21st, 2015
- Global Dark Matter limits from a combined analysis of MAGIC and Fermi-LAT data, European Physics Society Conference on High Energy Physics (EPS-HEP) 2015, Vienna, Austria. July 23rd, 2015

### J. E. WARD

- Light-Trap: A SiPM Upgrade for VHE Astronomy and Beyond. Invited Physics Seminar, Washington University in St. Louis, USA. November, 2015

## COSMOLOGY GROUP

### JELENA ALEKSIĆ

- Dark Energy Survey: Status and First Results. European Physical Society Conference on High Energy Physics (EPS-HEP) 2015, Vienna (Austria), July 2015

### CHRISTOPHE BONNETT

- Photo-z for Weak Lensing in DES-SV. Theoretical and Observational Progress on Large-scale Structure of the Universe, Garching (Germany), July 2015

### ANDRÁS KOVÁCS

- Detection of a Supervoid Aligned with the Cold Spot of the Cosmic Microwave Background WISE at 5: Legacy and Prospects, Pasadena (USA), February 2015
- Cold imprint of supervoids in the Cosmic Microwave Background reconsidered with Planck and BOSS DR10. European Week of Astronomy and Space Science (EWASS), Tenerife (Spain), June 2015
- Cold imprint of supervoids in the Cosmic Microwave Background reconsidered with Planck and BOSS DR10. Theoretical and Observational Progress on Large-scale Structure of the Universe, Garching (Germany), July 2015
- Cold imprint of supervoids in SDSS, Pan-STARRS1, and DES. Cosmo Seminar, Helsinki Institute of Physics, Helsinki (Finland), September 2015

### RAMON MIQUEL

- Dark Energy: Galaxy Surveys. Fourth Meeting of the Astroparticle Physics European Consortium (APPEC) Science Advisory Group. Rome (Italy), May 2015.

### CARLES SÁNCHEZ

- Combining galaxy-galaxy clustering and galaxy-galaxy-lensing in DES-S. DES Combined Probes Workshop, University of Pennsylvania (USA), March 2015
- Cosmic Voids in DES-SV. Astronomy Seminar, University of Pennsylvania (USA), June 2015

## VIP GROUP

### MOKHTAR CHMEISSANI

- VIP Voxel Imaging PET. Symposium on "Advanced Seminconductor Detector for Medical Applications" University of Munich, Munich, Germany, 13-Feb-2015
- 3D Semiconductor Sensor For Position Emission Tomography. CMOS Emerging Technology Research Conference. May 20-22, 2015, Vancouver Canada.
- Novel Sensor Design for Future Nuclear Medicine Scanner Based on Pixel CdTe Detector. Texas A&M Qatar Campus, Doha, Qatar. 3rd of December, 2015
- PET Scanner based on pixel CdTe detector for future Nuclear Medicine. Masdar, Abu Dhabi, UAE. 9th of December 2015

## THEORY DIVISION

### JOAQUIM MATIAS

- "$B \to K^{(*)}\mu^+\mu^-$: SM versus New Physics", ZPW2015. The flavour of new physics. Zurich University, 7-9, Switzerland. January 2015.
- "Theory interpretation of $B \to K^*(\to K\pi)\mu\mu$", 50th Rencontres de Moriond ElectroWeak, 14-21 March 2015.
- "Exploring New Physics in radiative B-decays and a bit more", 2nd radiative decays @LHCb Workshop, Barcelona, 4-6 May 2015.
- "Symmetries in P and S wave for $B \to K^*\mu^+\mu^-$, LHCb Workshop New Physics in radiative B-decays, Edimburgh, May 2015.
- "The path towards New Physics using B->K*(->Kpi)mumu", The Standard Model and Beyond in the LHC Era, Albufeira, Portugal, October 2015.
- Hadronic Uncertainties of B->K*(->Kpi)mumu", LHCb Workshop, CERN, November 2015.
- "Global analysis of b->sll anomalies", LIO Conference on Flavour, Composite Models and dark Model, Lion, November 2015.

### JOSÉ RAMÓN ESPINOSA

- "Higgs Effective Field Theory", Summer School and Workshop on the Standard Model and Beyond, Corfu 2015, Sep. 1-11, 2015, Corfu (Greece).
- "Cosmological Higgs-Axion Interplay for a Naturally Small Electroweak Scale", Particle Physics at the Dawn of the LHC 13, Oct.19-Dec.19, 2015, ICTP-SAIFR, Sao Paulo (Brazil).
- "Metastability of the EW Vacuum and Implications", The Vacuum of the Universe: from cosmology to particle physics, Oct. 21-23, 2015, Inst. of Cosmos Sciences, Barcelona (Spain).
- "Implications of Mt (and Mh) for vacuum stabi-

lity", 8th International Workshop on Top Quark Physics, TOP2015, Sep. 14-18, 2015, Ischia (Italy).

### EDUARD MASSÓ

- "Higgs Effective Lagrangians", Invited seminar Invited Seminar in Workshop "Trends in Theoretical Physics and Cosmology. Festschrift for Prof. E. Elizalde celebrating his 65th Birthday", ICE, UAB, March, 8, 2015
- "Higgs boson, BSM interpretations", Invited seminar 27th Rencontre de Blois -Particle Physics and Cosmology-Blois (France) Date, 2015
- "Higgs effective Lagrangians and physics beyond the Standard Model" Invited seminar 17th Lomonosov Conference on Elementary Particle Physics, Moscow (Russia), August 2015
- "Electroweak Physics before and after the Higgs", Invited seminar Trobades IFIC, IFIC Valencia Date November 2015

### SANTI PERIS

- "The muon g-2: A theoretical challenge", invited talk given at the "Bay Area Theoretical Physics Seminar" series (BATPS), February 2015, San Francisco, USA.

### ALEX POMAROL

- "The Physics of the LHC-Run2", XLIII International Meeting on Fundamental Physics, Centro de Ciencias de Benasque (Spain)
- "Perspectives in EWSB and Higgs physics", Workshop on Weak Interactions and Neutrinos (WIN2015), Heidelberg (Germany),
- "Cosmological Higgs-Axion Interplay for a Naturally Small Electroweak Scale", Anticipating discoveries: LHC14 and beyond, MIAPP, Munich (Germany)
- "Dynamical relaxation to critical points: A new approach to the hierarchy problem", Physics on the Riviera 2015: an isthmus between high energy and condensed matter theoretical physics, Sestri Levante (Italy)
- "Searching for New Paradigms After the Higgs", Brookhaven Forum 2015: Great Expectations, a New Chapter, Brookhaven National Laboratory (USA),
- "Quantum structure of indirect BSM effects", Gearing up for LHC13, Galileo Galilei Institute, Florence (Italy)
- "On the quantum structure of indirect BSM effects", Scalars 2015, Warsaw (Poland)

### ORIOL PUJOLÀS

- Status of Non-Relativistic Quantum Gravity 1st Erlangen Workshop on Cosmology and Quantum Gravity Erlangen (Germany) 9-13 Feb 2015
- Solid Applications of Massive Gravity New Directions in Theoretical Cosmology (Scuola Normale Superiore) Pisa, Italy 24-26 June 2015

### MARIANO QUIRÓS

- "GMSB with light stops", Planck 2015: from the Planck scale to the electroweak scale, University of Ioannina, Greece, May 25, 2015
- "The SM in warped space", Beyond the Standard Model of Particle Physics and Cosmology, University of Ioannina, Ioannina, Greece, May 24, 2015
- "Baryogenesis and CP-violation", 3rd Warsaw Spring Workshop, University of Warsaw, Warsaw, Poland, April 13-14 2015
- "SUSY Custodial Higgs Triplets", Standard Model and Beyond - Unscaling SUSY, University of Athens, January the 9th 2015.

### ANTONIO PINEDA

- Renormalons in heavy quark physics and lattice: the pole mass and the gluon condensate (Invited Talk) eNLarge Horizons Madrid,España,2015
- Renormalons in heavy quark physics and lattice: the pole mass and the gluon condensate (Invited Talk), High-precision QCD at low energy, Benasque, España, 2015
- Renormalons in heavy quark physics and lattice: the pole mass and the gluon condensate (Invited Talk)International Workshop on Particle Physics and Cosmology, Sendai, Japón, 2015
- Precision calculations with nonrelativistic EFTs: proton radius from muonic hydrogen (Invited Talk), Intersections of BSM Phenomenology and QCD for New Physics Searches, INT,USA,2015
- Heavy Quarkonium magnetic dipole transitions in pNRQCD, (Invited Talk), 3rd Belle II Theory Interface Platform (B2TiP) Workshop, KEK, Japón, 2015
- Heavy Quarkonium magnetic dipole transitions in pNRQCD (Invited Talk), ICCUB Christmas Meeting, Barcelona, España, 2015

### RAFEL ESCRIBANO

- "Combined analysis of the decays $\tau\to K_S\pi\nu_\tau$ and $\tau\to K\eta\nu_\tau$". , CD2015: 8th International Workshop on Chiral Dynamics, June 30, 2015, Polo Fibonacci (Pisa, Italy)
- "Combined analysis of the decays $\tau\to K_S\pi\nu_\tau$ and $\tau\to K\eta\nu_\tau$". PHIPSI2015: 10th International Workshop on e+e- collisions from Phi to Psi 2015, September 24, 2015, USTC (Hefei, China)
- "The eta transition form factor from space- and time-like experimental data", PHIPSI2015: 10th International Workshop on e+e- collisions from Phi to Psi 2015, September 24, 2015, USTC (Hefei, China)
- "Combined analysis of the decays $\tau\to K_S\pi\nu_\tau$ and $\tau\to K\eta\nu_\tau$". Institute of Cosmos Sciences (ICCUB), University of Barcelona, April 16, 2015, Barcelona (Spain).

### MATTHIAS JAMIN

- "QCD studies in tau decays", QCD 15: 18th High-Energy Physics International Conference on Quantum Chromodynamics, Monpellier, France, 1.7.2015.

# 6.4 OUTREACH ACTIVITIES IN 2015

## OUTREACH ACTIVITIES ORGANIZED BY IFAE

### LA CARA FOSCA DE L'UNIVERS

Cicle de Conferències: La Cara Fosca de l'Univers, un 95% per descobrir, November 2015.

Talks by Gary Bernstein, Michelangelo Mangano, Daniel Eisenstein and Gianfranco Bertone.

Activity organized in collaboration with Fundació Obra Social "La Caixa"

http://universfosc.ifae.es/

### BOJOS PER LA FÍSICA

One-year educational program targeted for high-school students.

Activity Coordinated in collaboration with ICN2 and Funded by Fundació Catalunya-La Pedrera.

http://bojosperlafisica.ifae.es/

## EDUCATION ACTIVITIES

### TREBALLS DE FINAL DE GRAU

- **Oriol Pujolàs**
  - * "Forats de Cuc Lorentzians" by Andreu Llabrés i Brustenga. Joint TFG UAB Physics and Mathematics. Co-supervisors: Marcel Nicolau & Oriol Pujolàs. July 2015
- **Sebastián Grinstein & Joern Lange**
  - * "Charge Collection Studies of 3D Pixel Detectors'" by Alejandro Belloti Arnau. UAB. July 2015
  - * "Commissioning of a TCT Setup" by Lluis Simon Argemi. UAB. July 2015

### UNDERGRADUATE SUMMER FELLOWSHIPS

- **Federico Sánchez**: Supervision of two summer students on the topic "Graphene electronic noise characerization", July 2015.
- **Oriol Pujolàs**: Supervision of four summer students on the topic "Simulations in Classical Yang-Mills theory", July 2015.


### JOVES I CIÈNCIA

- **Jelena Aleksić**: Supervision of 1 highschool student on the topic "Cosmology", July 2015.
- **Andras Kovacs**: Supervision of 1 highschool student on the topic "Super-Voids", July 2015.
- **Joaquim Palacio & Daniel Guberman**: Supervision of 1 highschool student on the topic "Astroparticles", July 2015.

### TREBALLS DE RECERCA

- **Federico Sánchez**:
  - * "Neutrins: Fermions Majorana o Dirac" by David Puertollano Martín (INS Rovira-Fons Santa Perpètua de Mogoda (Barcelona) ).
  - * "Neutrins i Violació de CP " by Joel Trinidad Martín (INS Rovira-Forns Santa Perpètua de Mogoda (Barcelona) ).
  - * "Radiació Cherenkov: de la teoría a la construcció d'un detector " by Roger Silvestre i Anglada (Collegi La Salle Manlleu (Barcelona) ).

- **Sebastián Grinstein:**
  * 3 Treballs de recerca supervised
- **Joaquim Palacio & Daniel Guberman:**
  * "Detecció d'una font emisora de Raigs Gamma: Nebulosa de Cranc " by Roger Serrat (INS F. X. Lluch i Rafecas) ).

### INTERNATIONAL PHYSICS MASTERCLASSES

- **Mirko Casolino**: CERN international MasterClasses (tutor) -- March 2015.
- **Loic Valery**: CERN international MasterClasses (tutor) -- March 2015.
- **Trisha Farooque**: CERN international MasterClasses (tutor) -- March 2015.

## TALKS BY IFAE RESEARCHERS

### OSCAR BLANCH

- Talk: La història de l'Univers, at Escola Virolai for school students. Barcelona, 10 March 2015.
- Talk: La història de l'Univers, at IE Francesc Cambó for school students. Verges, 26 March 2015.
- Talk: L'Univers, at Institut Doctor Puigvert for high-school students. Barcelona, 14 and 16 Octubre 2015.
- Talk: L'Univers, at Escola Sant Julià for school students. Arboç, 26 November 2015.

### CHRISTOPHER BONNETT

- Applying Machine Learning to the photometric redshift problem in Cosmology. Machine Learning Meetup, Barcelona (Spain), January 2015.

### MARTINE BOSMAN

- La búsqueda del Bosón de Higgs y la Frontera de la Física, Talk at IES Guillem de Bergeda, Berga 23 April 2015

### PILAR CASADO

- "Nanociència i Nanotecnologia", Jornades de Portes Obertes de la UAB, 3 i 4 de Febrer, 2015, a 200 estudiants.
- "Nanociència i Nanotecnologia", Ajuntament de Sabadell , 26 de Febrer, 2015, a 20 estudiants.
- Participació Saló de l'Ensenyament 2015, 18 (matí) i 21 (tarda) de març.

### MATTEO CAVALLI-SFORZA

- Els grans problemes de la Física de Partícules. Associació Astronómica Sant Cugat i Valldoreix 12th February 2015
- Einstein i la llum. Associació Astronómica Sant Cugat i Valldoreix 14th March 2015

### RAFEL ESCRIBANO

- "L'ALBA i l'LHC, dues eines útils per a la ciència i la tecnologia", Setmana de la Ciència 2015, 18 de novembre de 2015, Institut Pere Calders (Cerdanyola)

### TRISHA FAROOQUE

- "Introduction to Particle Physics and CERN" - Lecture for UAB undergraduate visit to CERN (November 2015)

### ENRIQUE FERNÁNDEZ

- Fotografiando el Universo Oscuro (la expansión cósmica)Conference organized by the Ateneo de Villaviciosa, Villaviciosa (Spain), August 2015.
- Los neutrinos y sus enigmas. Encuentros sobre fronteras de la Ciencia, Universidad de Valladolid (Spain), December 2015.
- El Universo invisible: Materia y Energía Oscuras. Conference organized by Asociación de Antiguos Alumnos y Amigos del Real Instituto de Jovellanos de Gijón, Gijón (Spain), December 2015.

### SEBASTIÁN GRINSTEIN

- "Los experimentos de la Física de Partículas", Teatro La Amsitad, Mollerussa (18/11/2015), 20a Semana de la Ciencia.

### AURELIO JUSTE

- "El Boson de Higgs y la Frontera de la Fisica"
  * IES Federica Montseny, Badia del Valles, Spain, November 18, 2015. Outreach talk within the program "La Setmana de la Ciencia".
  * IES Arnau Cadell, Sant Cugat del Vallees, Spain, November 20, 2015.
  * Biblioteca Central de Terrassa, Terrassa, Spain, November 19, 2015.
  * IES Pere Calders, Cerdanyola, Spain, November 16, 2015.
  * IES Investigador Blanxart, Terrassa, Spain, January 15, 2015.

### RUBÉN LÓPEZ-COTO

- El bosón de Higgs y los límites de la física, Institut Narcís Xifra, Girona, March 2015.

### THORSTEN LUX, FEDERICO SANCHEZ

- "Ciencia entre tots", 25th April 2015, Girona (Spain)

### MARIO MARTÍNEZ

- HIGGS PHYSICS, HASCO SCHOOL, Goettingen University, July 2015
- The Role of the National Institutes at the LHC, UIMP (Menedez Pelayo)- Santander, July 2015
- Beyond Standard Model Searches in ATLAS, Corfu Summer School, Corfu, September 2015
- ICREA Colloquium, Results from the LHC Run II, ICREA, Barcelona, Nov 2015

### EDUARD MASSÓ

- Conference “Moments estelars de l’univers”, Aula Gent Gran de Castellar del Vallès, (Barcelona), 10 February 2015

### RAMON MIQUEL

- Interview within the TV program “Lab24” (TVE) (December 8, 2015).

### LLUÏSA-MARIA MIR

- IFAE's coordinator of the talks "El CPAN en el instituto". Throughout the year.
- Talk "El bosó de Higgs i la frontera de la física" for High School students at Institut Montserrat, BCN (april) and La Salle Reus (december)

### JOAQUIM PALACIO

- Cerca de matèria fosca amb telescopis Cherenkov, Institut Antoni de Martí i Franquès, Tarragona 20 November 2015, Spain.

### ORIOL PUJOLÀS

- Public conference: Einstein, 100 anys gravitant 24/03/15,  AASCV Sant Cugat del Valles
- Public conference: La gravetat einsteiniana, cent anys després. 08/04/15, AAS Sabadell

### IMMA RIU

- "El Boso de Higgs i la frontera de la fisica", Institut Ferran Tallada, Barcelona, 22 April 2015
- "La recerca i el descobriment del Boso de Higgs", 2 June 2015, Museu de Sant Cugat, AASCV

### FEDERICO SÁNCHEZ

- Los neutrinos: las partículas camaleónicas. 5th December 2015, Institut d’Estudis Catalans (Barcelona).

# 6.5 IFAE IN THE MEDIA IN 2015

1. April 12th 2015, El País
*España y México compiten por el mayor cazador de rayos gamma*

2. April 14th 2015, La Vanguardia
*Publican mayor mapa de materia oscura de Universo con participación española*

3. April 16th 2015, La Vanguardia
*Una colisión de cuatro galaxias deja entrever la materia oscura del Universo*

4. May 7th 2015, SINC
La UE impulsa la astronomía europea con 15 millones de euros

5. May 27th 2015, SINC
*Un experimento con antineutrinos en Japón registra cómo desaparecen*

6. May 28th 2015, Recercat
*El mapa més gran de matèria fosca*

7. June 1st 2015, El Periódico
*Una gran burbuja en el cielo*

8. June 3rd 2015, RAC 1
Interview Mario Martinez on LHC Run2

9. June 4th 2015, La Vanguardia
*El LHC vuelve a explorar los límites de la física*

10. June 7th 2015, ARA
*Què hi ha després del bosó de Higgs?*

11. June 9th 2015, El Mundo
*En busca de la energía oscura*

12. June 9th 2015, Investigación y Ciencia
*Primera luz de la cámara PAUCam en el telescopio William Herschel de La Palma*

13. June 12th 2015, El Pais
*Una cámara española para sacar a la luz la energía oscura del universo*

14. July 16th 2015, El País
*España albergará el mayor telescopio de rayos gamma del mundo*

15. July 17th 2015, El Mundo
*España albergará el mayor telescopio de rayos gamma del mundo*

16. July 17th 2015, Periódico
*La Palma albergará el mayor telescopio mundial de rayos gamma*

17. July 20th 2015, Periódico
*Más allá del pentaquark*

18. November 11th, ARA
*LISA Pathfinder: a la recerca de les ones gravitacionals*

19. December 8th 2015, La2 RTVE
*TV Program Lab24*

20. December 13th, ARA
*Un grup de físics catalans, premiats per contribuir a la física de neutrins*


EN BUSCA DE LA ENERGÍA OSCURA

# 6.6 PARTICIPATION IN EXTERNAL COMMITTEES IN 2015

## EXPERIMENTAL DIVISION

### ÒSCAR BLANCH

- Member of the Common Service Committee of "Observatorio El Roque de los Muchachos"
- Deputy Spokesman of MAGIC Collaboration.
- Member of the MAGIC Executive Board
- Member of the MAGIC Technical Board
- Member of the MAGIC Collaboration Board
- Convener of LST-CAM working group in CTA
- Member of the LST Executive Board
- Representative of IFAE in Consortium Board of CTA collaboration

### CHRISTOPHE BONNETT

- Convener of the Photometric Redshift science working group in DES

### MARTINE BOSMAN

- Spanish National Contact Physicist (since 1 July 2015)
- Comisión de Infraestructuras de Física de Partículas y Aceleradores (CIFPA)
- Equal Opportunity Committee of the European Physical Society
- Comissió d'Igualtat d'Oportunitats i Gestió de la Diversitat (CERCA)
- ECFA Committee, member of plenary ECFA (until October 2015)
- Fonds Wetenschappelijk Onderzook van Vlanderen (Belgium), FWO-Expert Panel
- CERN Associates and Fellows Committee, CERN
- Research Opportunities in High Energy Physics Panel, DOE, Washington
- International Advisory Committee: EPSHEP2015 European Physical Society Conference on High Energy Physics / Austria

### MATTEO CAVALLI-SFORZA

- International Committee for evaluation of candidates for promotion at IFAE, July 2015
- Internationals Advisory Committee to Manager of Spanish National Program for Particle Physics and Astrophysics, November-December 2015.

### JUAN CORTINA

- Member of the MAGIC Technical Board.
- Member of the MAGIC Time Allocation Committee.
- Member of CTA LST Executive Board
- Co-PI of the CTA LST project

### SEBASTIAN GRINSTEIN

- Convener of the 3D Pixel ITk ATLAS group
- Member of the AFP Management Board
- Member of the ATLAS Pixel Institute Board
- RD50 Institute Leader (Radiation hard semiconductor devices for very high luminosity colliders – CERN)
- AIDA-2020 Governing Board representative for IFAE

### ENRIQUE FERNÁNDEZ

- Member of International Doctorate Network in Particle Physics, Astrophysics and Cosmology-Program. Advisory Committee, (IDPASC-PAC).
- Member of Scientific Advisory Board of the Institute of Physics of the University of Freiburg, Germany.

### AURELIO JUSTE

- Member of the Editorial Board of the journal Advances in High Energy Physics.
- Member of the Scientific Committee of the OCEVU LabEx (France).
- Referee for the Spanish National Evaluation and Foresight Agency (ANEP).
- Co-convener of the "Metadata" session at the Database and Metadata Technical Interchange Meeting, Genoa University, Genoa, Italy, September 7-9, 2015.

### ILYA KOROLKOV

- Coordinator, Beam Test for Tile Calorimeter Upgrade

### JOERN LANGE

- Member of AFP Management Board as AFP testbeam coordinator
- 3D ITk pixel testbeam contact
- RD50 deputy institute representative (Radiation hard semiconductor devices for very high luminosity colliders - CERN)

### RUBEN LÓPEZ-COTO

- Member of the MAGIC software board

### MANEL MARTÍNEZ

- Chair of the CTA LST Steering Committee.
- Member of MAGIC Time Allocation Committee (TAC)
- Spanish Delegate in APIF (Astroparticle Physics International Forum) of OECD.
- Member of the Scientific Advisory Board of the Helmholtz alliance for Astroparticle Physics (HAP)
- Member of the Commitee for Infrastructures of the FPA National Program (CIFPA).
- Member of the committee for CTA of the Research Infrastructures for Astronomy committee (RIA)

### MARIO MARTINEZ

- IFAE Representative at ATLAS Collaboration Board
- Member of ATLAS Publication Committee at CERN
- Member of International Advisory Committee (LHCP 2014/2015/2016 Conference)
- Referee for the Spanish National Evaluation and Foresight Agency (ANEP).
- Manager of the Spanish HEP Program (since July 2015)
- Scientific Delegate for Spain in CERN's Council (since July 2015).
- Referee of APS Physical Review

### RAMON MIQUEL

- Member of the Scientific Advisory Committee of the Astroparticle Physics European Consortium (APPEC)
- Member of the DES Management Committee
- Member of the DES Publication Board
- Member of the DES Builders' Committee
- Member of the PAU Executive Board
- External rapporteur to the scientific council of the Institut National de Physique Nucléaire et Physique des Particules (IN2P3), France

### ABELARDO MORALEJO

- Member of the MAGIC Speakers' bureau
- Member of the MAGIC software board
- Analysis software convener of the LST project
- Member of the LST Executive Board

### ANDRES PACHECO PAGES

- Member of the ATLAS Distributed Computing Coordination Committee
- Deputy member of the ATLAS International Computing Board
- Representative of IFAE in the RedIRIS Academic Network
- Acting as Referee for ANEP Spanish Agency

### CRISTOBAL PADILLA

- Member of the ECFA Detector Pannel Committee.

### JAVIER RICO

- Representative of IFAE at MAGIC Collaboration Board
- Coordinator of MAGIC Data Center
- Manager of MAGIC Common Fund
- Convener of the MAGIC Astroparticles & Fundamental Physics Working group
- Chair of CTA's Speakers And Publications Office (SAPO)
- IFAE representative at the ASTERICS (H2020) General Assembly

### IMMA RIU

- ATLAS L1 Topological trigger commissioning co-coordinator
- Member of the "ECFA HL-LHC Trigger, Online and Offline Computing" preparatory group

### FEDERICO SÁNCHEZ

- Member of the T2K Executive Committee.
- Member of the T2K Institutional Board.
- Member of the WA105 Institutional Board.
- Member of the CPAN Executive Committee.
- Member of the NusTec Executive Committee.
- Member of the Scientific Program Committee of Nuint 2015, 16th-21st November 2015, Osaka (Japan).

## THEORY DIVISION

### JOSÉ RAMÓN ESPINOSA

- Concours de recrutement de Professeur des Universites, Univ. Pierre et Marie Curie. PR-29 0262 (4313) 2015.

### ANTONIO PINEDA

- Juan de la Cierva commitee.

# 6.7 IFAE COLLOQUIA & SEMINARS IN 2015

## IFAE COLLOQUIA

1. Cien años de gravedad / One hundred years of nigritude
   February 2 2015
   Roberto Emparan (U Barcelona & ICREA)

2. One, No One and One Hundred Thousand or Indirect Dark Matter detection as a guide to the path Beyond the Standard Model
   March 9 2015
   Pasquale Serpico (Annecy, LAPTH)

3. 50 years of Bell inequalities
   April 20 2015
   Albert Bramon (UAB Emeritus Professor)

4. Dark Matter direct detection
   May 4 2015
   David G Cerdeño (IPPP Durham U)

5. The Synchrotron Alba
   September 28 2015
   Caterina Biscari (ALBA Synchrotron Light Source)

6. Big Data for Biosciences
   November 9 2015
   Roderic Guigó (Centre de Regualció Genòmica, Barcelona)

7. Simulating the proton
   November 27 2015
   Gunnar Bali (Regensburg U)

8. Search for Dark Matter with liquid argon
   December 11 2015
   Aldo Ianni (Research Division, INFN Gran Sasso Laboratory)

9. Axion Landscape
   December 21 2015
   Georg Raffelt (Max Planck Institut, Munich)

## IFAE SEMINARS

1. Dark Nuclear Physics
   January 9 2015
   Matthew Mccullough (CERN)

2. Physical parameters of the electroweak crossover
   January 23 2015
   Michela D'Onofrio (Helsinski U)

3. Phenomenological approaches of inflation and their equivalence
   January 30 2015
   Lotfi Boubekeur (Valencia U & IFIC)

4. Signals of natural SUSY
   February 13 2015
   Antonio Delgado (Notre Damme U)

5. Heavy quark masses from QCD sum rules
   February 20 2015
   Pere Masjuan (Mainz U)

6. Three tales for three scalars
   February 27 2015
   Giovanni Villadoro (ICTP Trieste)

7. Hamiltonian Truncation methods: solving strongly-coupled QFTs numerically
   March 6 2015
   Lorenzo Vitale (EPFL Lausanne)

8. Gauge-Higgs unification after the discovery of the Higgs particle
   March 13 2015
   Chong-Sa Lim (Tokyo Woman's Christian Univ.)

9. Recent progress in massless and massive event shapes
   March 19 2015
   Vicent Mateu (Vienna U)

10. Top mass from the bottom (at NLO)
    March 20 2015
    Roberto Franceschini (CERN)

11. Single top + Higgs: quantum interference and the sign of y_t
    April 9 2015
    Andrea Giammanco (CERN)

12. Study of the Higgs properties at a muon collider
    May 8 2015
    Mario Greco (INFN and Univ. Roma 3)

13. Accidental matter at the LHC
    April 28 2015
    Luca Di Luzio (U Genova)

14. Mining the Golden Channel: Searching for New Physics in Higgs decays to four leptons
    May 15 2015
    Roberto Vega-Morales (LPT-Orsay, Paris)

15. Solar constraints for particle physics
May 22 2015
Aldo Serenelli (IEEC UAB)

16. Thermo-electric transport properties in holography with momentum dissipation
June 4 2015
Nicodemo Magnoli (Genova U)

17. Aspects of string phenomenology in particle physics and cosmology
June 5 2015
Ignatios Antoniadis (Ecole Polytechnique, Paris)

18. A Cosmological Solution to the Electroweak Hierarchy Problem
June 12 2015
David E Kaplan (Johns Hopkins University, Baltimore, USA)

19. Ultra-light dark matter and pulsar timing observations
June 18 2015
Andrei Khmelnitsky (Ben Gurion U of Negev)

20. Searching for dark mediators
June 19 2015
Felix Kalhofer (DESY Hamburg)

21. Higgs and QCD axion implications for baryogenesis
June 29 2015
Géraldine Servant (IFAE)

22. Dark matter halos as particle colliders
June 30 2015
Sean Tulin (York University)

23. Topological insulators from theory to experiments and viceversa
July 10 2015
Alessandro Braggio (Genova U)

24. A goldstino at the end of the cascade
September 22 2015
Daniele Musso (ICTP Trieste)

25. Geometrical destabilization of heavy scalar fields during inflation
October 9 2015
Sébastien Renaux-Petel (IAP Paris

26. Discovery through precision: perturbative QCD at the dawn of Run II
October 30 2015
Juan Rojo (Oxford University)

27. Probing dark matter above TeV and below meV
December 4 2015
Giovanni Grilli di Cortona (SISSA Trieste)

28. CP asymmetry in heavy Majorana neutrino decays at finite temperature
December 15 2015
Simone Biondini (TUM Munich)

# PIZZA SEMINARS

1. Multi-APD Xe Electroluminescence TPC
14-Jan-15
Alfonso Garcia

2. Much Ado About Nothing: Cosmic Voids
21-Jan-15
András Kovács

3. Advances with THGEM detectors
28-Jan-15
Shikma Bressler

4. Effective QFT
04-Feb-15
Eduard Masso

5. Supersymmetry and Higgs
11-Feb-15
Mateo García Pepin

6. The ATLAS Jet Trigger for Run 2
18-Feb-15
Nuno Anjos

7. New discoveries in first-year Dark Energy Survey data
11-Mar-15
Jelena Aleksić

8. ttH (H->bb) with ATLAS
18-Mar-15
Javier Montejo

9. Tau + MET trigger efficiencies in Run 1 at LHC
25-Mar-15
Pilar Casado

10. Future Circular Collider (FCC)
08-Apr-15
Mario Martinez

11. Overview of the Cherenkov Telescope Array MC analysis
15-Apr-15
Tarek Hassan

12. Neutrino cross sections
22-Apr-15
Federico Sanchez

13. Using UV-pass filters for bright Moon observations with MAGIC
29-Apr-15
Daniel Guberman

14. 3D Pixel Detectors for AFP
06-May-15
Ivan Lopez

15. WA105
13-May-15
Thosten Lux

16. GAMMA-400
20-May-15
John E Ward

17. Gauge theories, Higgs boson and Finance
27-May-15
Christophe Grojean

18. Weak Lensing with DES
16-Sep-15
Ramon Miquel

19. Graphene
23-Sep-15
Neutrino students

20. A GAMMA-400 Overview: Geometry, Performance & Simulation Studies
30-Sep-15
Paolo Cumani

21. Characterisation of Silicon Detectors
07-Oct-15
pixels students

22. Digging Deeper (and More Greedily) in Imaging Surveys
14-Oct-15
Eric Suchyta

23. Overview of the 100xCIENCIA forum
21-Oct-15
Sebastian Grinschpun

24. Towards a global dark matter search
28-Oct-15
Javier Rico

25. Recent T2K antineutrino results.
04-Nov-15
Federico Sanchez

26. OSETI: a second (intelligent) life for MAGIC ?
11-Nov-15
Manel Martinez

27. Soliton colliders: results and cosmological implications
18-Nov-2015
Jan Olle

28. HV-MAPS for the Mu3e Experiment
25-Nov-15
Fabian Foerster

29. Microquasars: the Big Challenge for the Very High Energy Astronomy
02-Dec-15
Alba Fernandez

30. A complete pheno-toolchain
09-Dec-15
Kilian Nickel

31. Future experiments with muon beams
16-Dec-15
Matteo Cavalli-Sforza

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d'Altes Energies

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