IFAE

IFAE
Institut
de Física
d'Altes
Energies

Report
of Activities
2016

Barcelona Institute of Science and Technology
Institució CERCA Centres de Recerca de Catalunya
EXCELENCIA SEVERO OCHOA

IFAE

Institut de Física d'Altes Energies

Report of Activities **2016**

CONTENTS

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 2016, it operated under the auspices of the Department of Business and Knowledge (Departament d'Empresa i Coneixement), 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 UAB. In addition, since the creation of ICREA, several investigators from this prestigious research institution have joined IFAE. As of the end of 2016, this component of the Institute consists of seven ICREA research professors, with continuing tenure.

Personnel of the former 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 IFAE 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 three divisions, experimental, theoretical, and technical, as well as an administrative area. 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 and 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 program of UAB, in particular by teaching 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 Physics from a theoretical, experimental and technological point of view. The origins of the consortium lie in the Group 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 re-joined 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 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 80. 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 astronomy, 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 summarized in chapter 2.10 in this report.

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 three 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 led the PAU collaboration, comprised of several Spanish groups. The goal of this initiative remains 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

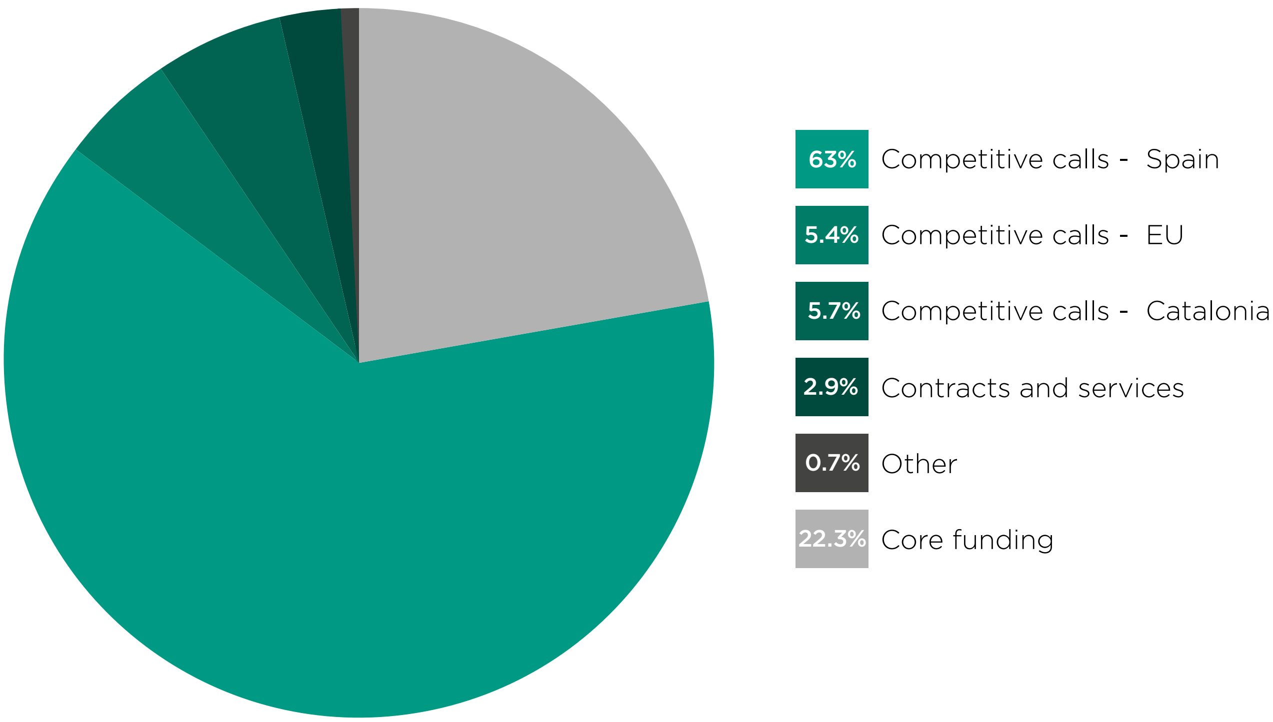
Since the past decade, the relationship between IFAE and the Generalitat of Catalonia is regulated under a Contract-Program, which codifies the support of the Institute from the Generalitat and the corresponding obligations of IFAE. Based on a strategic plan, the Contract-Program specifies the envisaged 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 has been extended one year at a time.

In 2012 IFAE was granted the Severo Ochoa award, 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 IFAE's 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. During 2016, its first full year of operation, the BIST has started preparing several joint initiatives, including a joint call for PhD grants; preparation of a BIST-wide MSc program in interdisciplinary research; joint application to two European Union COFUND actions; a program providing seed money for research projects carried out in at least two BIST institutes, etc.

1.3 FUNDING SOURCES IN 2016

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 2016 the ratio of competitive to core funding was about 3.5. It has been consistently above 3 throughout the history of IFAE. The total income in 2016 (including PIC) was 7.5 million euros.



$$\frac{\text{TOTAL COMPETITIVE \& CONTRACT FUNDING}}{\text{TOTAL CORE FUNDING}} = 3.5$$

1.4 IFAE GOVERNANCE IN 2016

GOVERNING BOARD

PRESIDENT

Jordi Baiget i Cantons
Minister for Business and Knowledge
Generalitat de Catalunya

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Generalitat de Catalunya

Pere Palacín i Farré
Director General for Energy, Mines and Industrial Safety,
Generalitat de Catalunya

Francisco Javier Lafuente i Sancho
Vice-Rector for Strategic Projects & Planning,
Universitat Autònoma de Barcelona

Caterina Biscari
Director,
ALBA Synchrotron

Antoni Méndez i Vilaseca
Dean of Sciences,
Universitat Autònoma de Barcelona

DIRECTOR

Ramon Miquel i Pascual
ICREA Research Professor,
IFAE

2. SCIENTIFIC **ACTIVITIES IN 2016**

OUTLINE

EXPERIMENTAL DIVISION

During 2016 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 2016, LHC continued its Run-2 operations at the highest ever center-of-mass energy of 13 TeV. This broader energy range, together with the excellent performances of accelerator and detector alike, has greatly increased the possibility of new discoveries. While the analysis of the 2016 data has not confirmed the hint of a possible new particle with a mass around 750 GeV reported in 2015, the record-breaking performance of the accelerator, providing 60% more collisions than anticipated in the year, has resulted in a vast increase in the available data for ATLAS analyses. The IFAE group has produced a number of high-profile results with the early Run-2 data, particularly in searches for monojets, for additional Higgs bosons, and for the associated production of Higgs bosons with top and anti-top quarks. Furthermore, two PhD theses were defended in the group, on searches for top quark decays to Higgs and for the supersymmetric partner of the top quark, respectively. PIC, as a Tier-1 LHC data-processing center, managed to cope admirably with the deluge of LHC data in 2016, keeping his world-leading reliability score. Furthermore, in 2016, the ATLAS Tier-2 analysis facility, also hosted at PIC, processed over 32 billion events and executed 1.4 million jobs.

2. The ATLAS upgrade, in preparation for a major renewal of the detector to take place by 2025. 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. In 2016, the group finished the production, installation and commissioning of the first arm of the ATLAS Forward Proton (AFP) detector, which continues the use of 3D pixel detectors and was successfully operated throughout the year. All this has provided the group with the track-record needed to play a leading role in the upgrade of the entire inner tracker of ATLAS, necessary for the LHC high-luminosity operations beyond 2025. In parallel, the group has continued its R&D into new promising technologies such as Low-Gain Avalanche Detectors (LGAD), with excellent timing capabilities, and monolithic HVCMOS pixel detectors, in view of their possible use in the ATLAS upgrade and other applications.

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

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 2016, T2K presented the first combined analysis with about ~50% neutrino and ~50% anti-neutrino data, which provided the first possible

hints of the existence of CP violation in the neutrino sector, a most fundamental result, if confirmed. The group at IFAE contributed to this effort leading the measurements in T2K's near detector necessary for the crucial normalization of the incoming muon-(anti)neutrino flux. In 2016, the group continued its involvement 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 are being tested.

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. Since its inception, IFAE has played a major role in the design, construction, operation and scientific exploitation of MAGIC. For instance, in 2016, IFAE scientists led six of the 15 papers published by MAGIC, including an accurate measurement of the extragalactic background light wavelength at around 1 μm and the first search for dark matter particles in cooperation with the Fermi-LAT satellite, covering the mass range from 10 GeV to 100 TeV. Furthermore, in 2016, the group has led several efforts aimed at expanding both the energy range and duty cycle of the MAGIC telescopes, including the design and installation of a new filter system that allows MAGIC to operate during full moon. During 2016, IFAE has continued to manage the MAGIC Tier-0 data center at PIC, as well as the common fund of the collaboration.

5. CTA, a worldwide collaboration that will build two multi-telescope observatories, in the Northern and Southern hemispheres, is now entering its construction 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 construction of the largest telescopes (LST) in CTA. During 2016, the final agreement was signed to site the CTA Northern observatory in the Canary island of La Palma, a major breakthrough in which IFAE played a crucial role. During 2016, IFAE coordinated the construction of the bogies of the first LST telescope, which will be installed in La Palma in late 2017. The integration of the camera of this first LST will take place in 2017 at IFAE, which is also 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. Other projects such as Euclid, DESI and LSST have followed.

6. The DES (Dark Energy Survey) collaboration at the Blanco telescope in Cerro Tololo (Chile) successfully completed in 2016 the third 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 and 2016, including the first results from the weak lensing technique. Five of the 35 papers published by DES in 2016 were (co-)led by IFAE scientists, including new results on gravitational lensing around foreground galaxies, on lensing around cosmological voids, and on the correlation between the temperature of the Cosmic Microwave Background radiation and the location of super-clusters of galaxies and super-voids in the sky. 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. A first GFA prototype was delivered to the Lawrence Berkeley National Lab in early August. After its integration into a prototype of the full focal plane of DESI, the GFA saw its first light in late August at the Mayall 4-m telescope in Arizona. Furthermore, in December 2016, IFAE joined the Large Synoptic Survey Telescope (LSST) project, which will be the leading imaging galaxy survey in the next decade, much like DES is in this decade. LSST will study the properties of the dark energy using an unprecedented sample of four billion galaxies.

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 then went through two short periods of scientific verification in November 2015 (almost useless due to terrible weather) and April 2016. The preliminary analysis of this data set indicates that the camera performs according to the specifications. In November 2016, the PAU Survey international collaboration started to use PAUCam to carry out a very precise photometric-redshift survey in order to help understand the properties of dark energy.

8. Euclid is a 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 galaxy 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 2016, the team at IFAE delivered to ESA the Structural and Thermal Model (STM) of the FWA as part of the STM for the whole Near-Infrared Spectrometer and Photometer (NISP), which successfully passed the Consolidation Design Review in July 2016. IFAE also delivered the necessary Ground Segment Equipment (GSE), a mounting tool, and is designing the additional GSE, a cryostat, needed for the additional tests that will take place in 2017.

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. First results are expected in 2017. 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. The second iteration, produced in 2016, was thoroughly tested and found to deliver the expected performance. In 2016, the group started a new RIS3CAT project to develop a 3D biopsy system in collaboration with several public and private partners (CNM-IMB, the Parc Taulí hospital, IDNEO Technologies SL, and VENTURA Medical Technologies). IFAE's main role is the development of a fully digital X-ray camera for the system.

10. Several other instrumentation projects produced exciting results in 2016. In particular, a novel light-detector system based on silicon photomultipliers coupled to wave-length shifters has been developed and is ready to be tested in real-life operation in MAGIC. Furthermore, in 2016 IFAE started a collaboration with a group at ICIQ to study the possible use of organic solar cells as photodetectors.

THE THEORY DIVISION

The activities of the Theory Division during 2016 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 2016 included: a new determination of the strong coupling constant using tau-lepton decays and including quark-hadron duality violations; the description of heavy-meson bound states and extraction of heavy quark masses (leading to a PhD thesis); leptonic and radiative decays of η and η' mesons; semi-leptonic and hadronic decays of B and B_s mesons; and the behavior of perturbation theory at high orders.

2. BEYOND THE STANDARD MODEL

In 2016 the BSM subgroup continued its search for theories that might supersede the Standard Model of particle physics and cure the theoretical and observational problems that afflict it. Some of the topics covered include: extending supersymmetry with custodial triplets (the subject of a 2016 PhD thesis); an attempt to explain the anomalies recently reported in several B-meson decays using warped extra dimensions; continuing studies concerning a possible composite structure of the Higgs boson and how to discern it at the LHC; and studies of the possible instability of the effective potential of the Standard Model at very high energy.

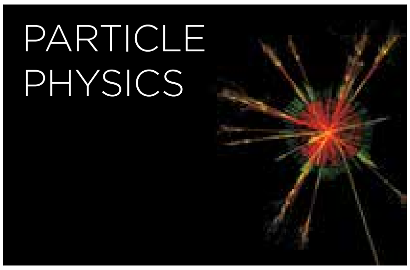
THE ACTIVITIES OF THE THEORY DIVISION FOCUS ON THREE LINES: STANDARD MODEL PHYSICS, BEYOND THE STANDARD MODEL AND ASTROPARTICLES & COSMOLOGY

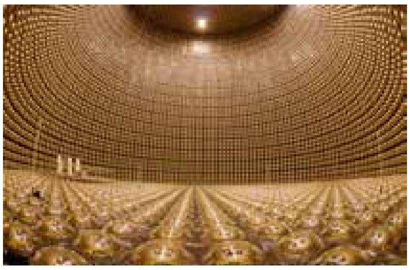
3. ASTROPARTICLES/COSMOLOGY

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 this group focused their work in 2016 include: the study of the consistency of scalar potentials from quantum de Sitter space, with possible implications in both the hierarchy and cosmological-constant problems; and the continuation of the very productive study of applications of the gauge/gravity duality to condensed matter problems (leading to a 2016 PhD thesis).

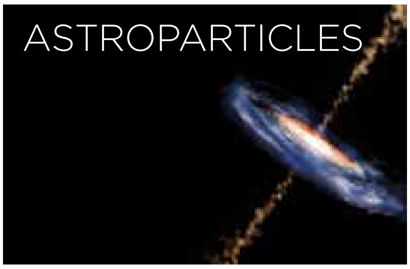
EXPERIMENTAL DIVISION

PARTICLE PHYSICS





ASTROPARTICLES

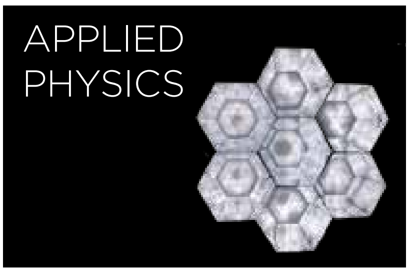
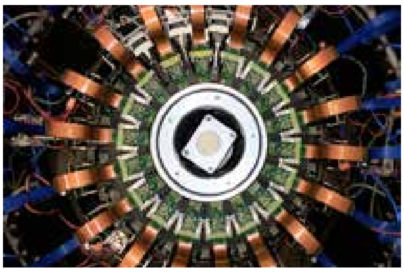


COSMOLOGY






APPLIED PHYSICS


2.1 ATLAS AT THE CERN LHC

AURELIO JUSTE

Since 1993, the IFAE group has made major contributions to the construction of the ATLAS detector, its trigger system, its physics reconstruction software, and preparatory physics studies. Over the last five years, with the arrival of the LHC Run 1 (2011-2012) and early Run 2 data (2015-2016), the IFAE group has carried out a strong physics program.

INTRODUCTION

During 2016 the LHC continued operating at a center-of-mass energy of 13 TeV. This was an exceptional year in terms of LHC performance. At the beginning of the year, the goal was to reach the machine's design instantaneous luminosity of $10^{34}\,cm^{-2}s^{-1}$, and by the end of the run the LHC was regularly operating at 30% above that. The initial target for integrated luminosity in 2016 was 25 fb^{-1}, while eventually 40 fb^{-1} were delivered to the ATLAS and CMS experiments.

THE IFAE GROUP HAS REMAINED STRONGLY INVOLVED IN BOTH DETECTOR OPERATIONS AND PHYSICS ANALYSES THROUGHOUT 2016

The IFAE group has remained strongly involved in both detector operations and physics analyses throughout the year. In particular, a large number of high-profile physics results were produced using early Run 2 data. The group has also maintained its visibility within the ATLAS Collaboration through a number of important management positions.
In the following sections, some details are given on the different activities of the group.

TILECAL OPERATIONS AND UPGRADE

In 2016, the IFAE group members contributed strongly to the Tile calorimeter (TileCal) operation, to the calorimeter calibration, and to the preparation of the detector upgrades for the high-luminosity LHC running (HL-LHC).

A IFAE PhD student, S. Fracchia, served as Tile Run Coordinator, a critical role rarely awarded to students. Other leading roles served by IFAE members in 2016, such as Beam Test Manager (I. Korolkov) and Calibration Coordinator (A. Cortés) also helped maintain IFAE's leading position within the ATLAS Calorimeter community.

IFAE's TileCal team (I. Korolkov, C. Fischer, M. Tripiana, L. Valéry, and J. Glatzer) continues its commitment to fully support the TileCal "Minimum Bias" data calibration system. The system is based on the components developed exclusively by IFAE and is used to monitor on a daily basis the stability of the TileCal response in time (see Fig. 1) and, together with other luminosity monitors of ATLAS, to measure the luminosity delivered to the ATLAS detector by the LHC. As the instantaneous luminosity delivered by the LHC increases, IFAE's supported monitoring becomes the main tool to correct for the several percent degradation of the TileCal optics (see Fig. 2) induced by the irradiation. The study of the TileCal irradiation using the Minimum Bias integrators was presented at the CALOR2016 conference.

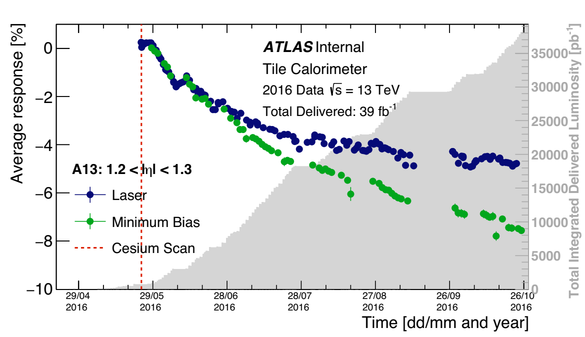


Fig. 1: Beam-induced drift of the gain of a given Tile readout channel measured by various calibration systems in 2016.

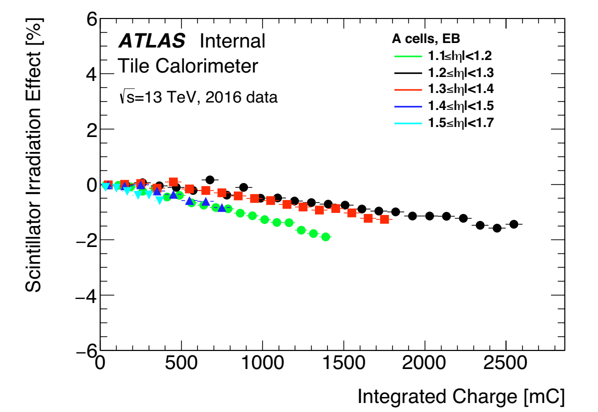


Fig. 2: The relative variation of the response measured by the integrator monitoring system, after subtraction of the photomultiplier drift, as a function of the integrated charge in the inner (A) layer of the Extended Barrel (EB) cells in 2016.

In 2016, the integrators-based luminosity monitor developed and maintained by the IFAE team has become one of the three most relevant tools to measure the luminosity in the ATLAS experiment, together with LUCID and TRACKS. In particular, this system and TRACKS were the only ATLAS luminosity monitors capable of transferring the luminosity calibration performed by LUCID during the so-called Van der Meer (VdM) scans to the nominal ATLAS conditions (in 2016). The difference of about 1.4% between the two methods (see Fig. 3) defines a fraction of the overall systematic uncertainty on the luminosity measurement in ATLAS.

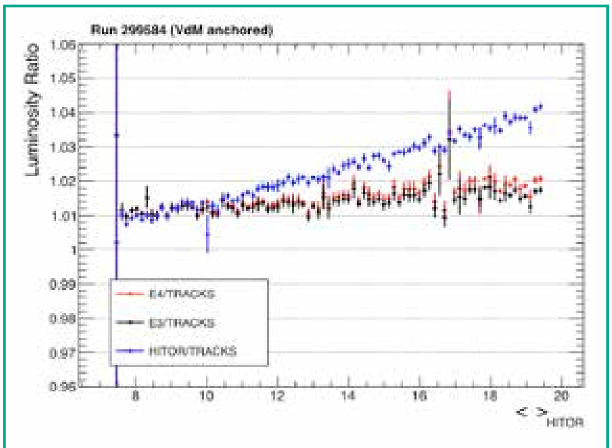


Fig. 3: Luminosity transfer from the VdM scan to the next ATLAS run if done by LUCID+TRACKS (in blue) and as it is done (2016) by Tile+TRACKS (in black and red).

Because of extremely well understood behavior of the integrator-based luminosity monitor in time, it also contributes to the overall ATLAS luminosity measurement in 2016, as shown in Fig. 4, where measurements of different ATLAS luminosity monitors are compared.

In 2016, the IFAE group contributed most strongly to the preparations for the upgrade towards the ever-increasing luminosity delivered by the LHC.

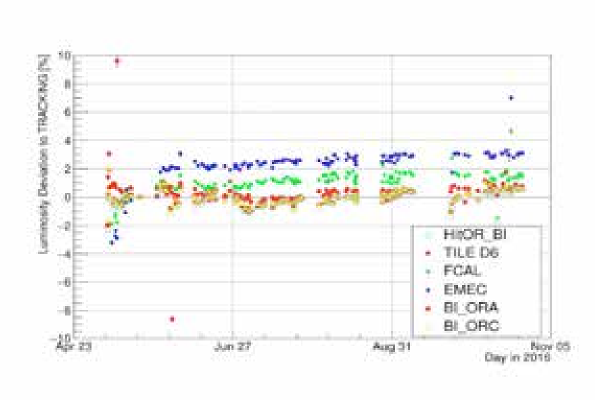


Fig. 4: Deviation of the luminosity measured by a given ATLAS subsystem from the luminosity measured by the tracker as a function of time in 2016.

The group's senior member, I. Korolkov, has coordinated the Beam Tests dedicated to the validation of the new TileCal readout electronics for the HL-LHC upgrade. During 2016, spare TileCal modules (see Fig. 5) were instrumented with prototype readout electronics and were exposed to different particle beams of muons, positrons and hadrons of different energies from the SPS. Beam instrumentation was installed to separate the different types of particles, to measure the beam position, and to trigger the data readout and synchronize it with the beam. The response of the new readout to a beam of positrons with energy of 100 GeV is shown in Fig. 6 as an example. Tests of more components with test beams will follow in 2017.

IFAE CONTRIBUTED TO THE TILECAL OPERATION AND CALIBRATION, AND TO THE UPGRADES OF THE DETECTOR FOR THE HIGH-LUMINOSITY LHC

Fig. 5: Picture of the TileCal test-beam modules and the mobile table in 2016.

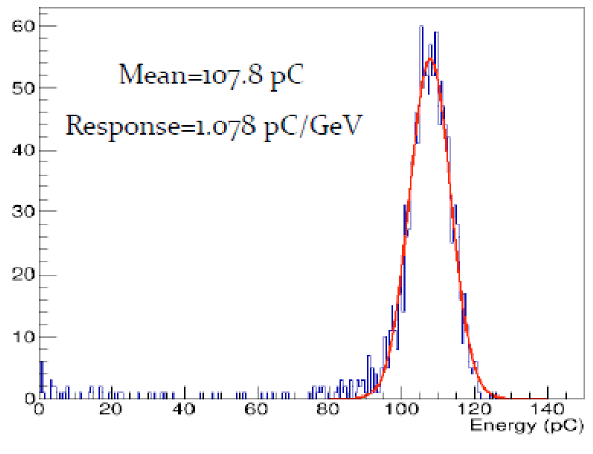


Fig. 6: Detector response to 100 GeV positrons in the 2016 test beam. The electronics readout used is one of the candidates for the HL-LHC upgrade.

TRIGGER OPERATIONS, PERFORMANCE AND UPGRADE

After having been heavily involved in the ATLAS High-Level Trigger (HLT) jet and tau signatures and in its infrastructure system during the Run 1 period, the IFAE group decided to be involved in a new Level-1 (L1) topological trigger processor (L1Topo) to be installed and used during Run 2. Work started during the Long Shutdown 1 where the IFAE group took the responsibility of writing the simulation of the topological trigger algorithms.

The L1Topo system is designed to perform real-time event selection based on event topological variables (e.g. invariant masses or angular differences) defined between trigger objects from the L1 muon and L1 calorimeter trigger systems. Its use allows maintaining a relatively high trigger efficiency for key physics processes involving W, Z and Higgs bosons, which would otherwise suffer from large inefficiency.

Postdoc D. Gerbaudo joined the group early in 2016 and developed validation tools that are used by the L1Topo commissioning group to validate all the L1 topological trigger algorithms included in the trigger menu. The IFAE group also worked on the emulation of various L1Topo algorithms: by using the L1 input objects from a selection of events, the topological selections were emulated and compared with the hardware decisions. Some differences were found and members of the IFAE team worked together with the L1Topo hardware experts to understand the reason and get a fix. In particular, the IFAE team worked on the validation of jet-related topological algorithms like HT (scalar sum of the transverse momenta of a selected sample of L1 trigger jets), DETA (difference in pseudorapidity between L1 jets) or MATCH (matching of small and large L1 jets) as well as the di-tau topological triggers. During 2016, I. Riu was the co-coordinator of the overall ATLAS L1Topo commissioning group. After proving a successful validation, some of the L1 topological triggers were enabled online to select events for physics analyses. Figure 7 shows the trigger efficiency turn-on curve for two HT triggers. Figure 8 shows the small fraction of events with different simulation and hardware decisions, probably due to a known not completely accurate simulation of the hardware. These figures were shown in several conferences, in particular by I. Riu at CHEP 2016 (http://chep2016.org) in San Francisco and published in proceedings (submitted to J. Phys. Conf. Ser. 2017).

The IFAE group continued to work within the ATLAS jet trigger group (in particular postdoc N. Anjos, until he left by middle 2016) on three critical components: pileup subtraction, jet calibration and jet cleaning. Pileup within a jet is estimated as the product of event energy density and jet area, and its subtraction from the jet was implemented in the trigger. A global jet energy calibration applying factors based on the jet energy deposits on different calorimeter layers was also implemented in the trigger. The jet trigger efficiency turn-on curve as well as the rejection of fake jets improved thanks to the implementation of these corrections.

IFAE also contributed to the trigger operations by providing support on the releases, jet trigger and validation group through various shift periods during the year. Furthermore, I. Riu was the co-editor of the publication describing the ATLAS trigger system in 2015, which was submitted to JHEP (arXiv:1611.09661).

The group organized in September 2016 at the Universitat Autònoma de Barcelona one of the yearly ATLAS TDAQ collaboration meetings with good assistance (around 100 people) and great success.

Finally, IFAE contributed to the TDAQ Phase 2 by studying the electron trigger acceptance and rejection after using the new supercells granularity of the calorimeters.

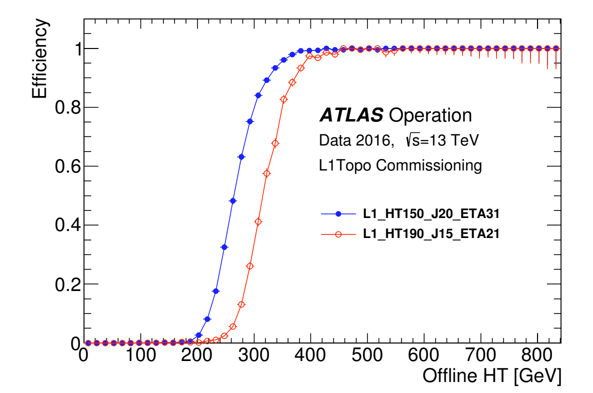


Fig. 7: Efficiency of two L1 topological HT triggers (HT>150 GeV and HT>190 GeV) with respect to the offline-reconstructed HT.

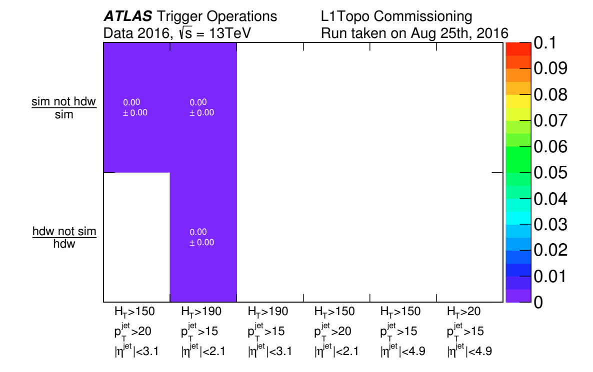


Fig. 8: Fraction of events showing differences between simulation and hardware decisions for several versions of the L1 topological HT trigger. Bins shown in white and blue mean that no events or less than 1% of events were found with differences respectively.

IFAE CARRIED OUT A STRONG PHYSICS PROGRAM, INCLUDING SEARCHES FOR SUPERSYMMETRY, DARK MATTER AND EXOTIC HEAVY QUARKS AS WELL AS HIGGS BOSON STUDIES

PHYSICS ANALYSES

The year 2106 was characterized by the prompt analysis of the data recorded by ATLAS at $\sqrt{s}$=13 TeV. IFAE continued to play a leading role in several physics research lines, including monojet searches (probing e.g. extra spatial dimensions and dark matter), searches for Supersymmetry (SUSY), searches for new phenomena in top-quark final states, as well as Higgs boson studies. A summary of the results obtained is provided below. Most of these analyses were released as preliminary results using an integrated luminosity of up to 14.8 fb^{-1}. Two PhD theses were completed in 2016.

SEARCHES FOR NEW PHENOMENA IN JET+X

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

In 2016, the IFAE team (A. Cortés, C. Fischer, M. Martínez, and R. Zaidan) brought to final publication the ATLAS searches for new phenomena in monojet final states, based on all the data collected by the experiment in 2015. Good agreement was observed between the data and the Standard Model (SM) predictions. The results were translated into significantly better exclusion limits, compared to those in Run 1, for searches for large extra spatial dimensions, the production of squarks in the framework of SUSY, and the search for dark matter (WIMP) production at the LHC. For the latter, simplified models for dark matter pair production with a heavy axial-vector mediator were considered (see Fig. 9), nicely showing the complementary between the LHC and direct detection experiments in searches for dark matter, and the unique sensitivity of the LHC experiments at low WIMP masses. M. Martínez acted as corresponding editor of the ATLAS paper published in Phys. Rev. D 94 (2016) 032005.

At the time of writing this report (early 2017) the team continues to play a central role on the monojet searches in Run 2 and M. Martínez is the corresponding editor of the second ATLAS Run 2 publication on the subject, based on about ten times more data. The results based on the whole 2016 data are being finalized and will be submitted for publication by Spring 2017. It will be part of the Ph.D. thesis of C. Fischer, to be defended in 2017.

SUPERSYMMETRY SEARCHES

One possible solution to the hierarchy problem is provided by weak-scale 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

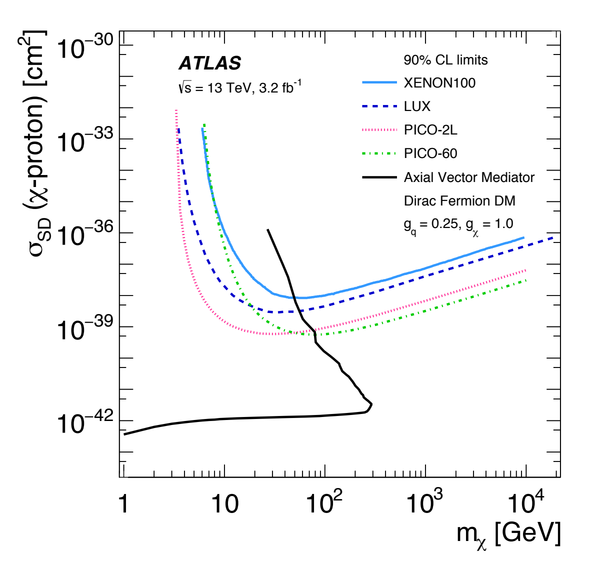


Fig. 9: Observed and expected 90% CL limit on the spin-dependent WIMP-proton scattering cross section as a function of the WIMP mass, in the context of a Z′-like simplified model with axial-vector couplings. The results from this analysis, excluding the region to the left of the contour, are compared with limits from the XENON100, LUX, and PICO direct-detection experiments. From Phys. Rev. D 94 (2016) 032005.

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 superpartners 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 (sbottom1 and stop1, respectively) 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.

SEARCHES FOR DIRECT SBOTTOM AND STOP PAIR PRODUCTION

In 2016, the IFAE team (A. Cortés, S. Fracchia, M. Martínez, A. Rodríguez, M. Tripiana and R. Zaidan) has continued to invest a significant effort in searches for 3rd-generation squarks in Run 2, for which the production cross sections increase by factors ~10-40 with respect to those in Run 1. In particular, M. Tripiana has played a central role as co-convener of the 3rd-generation ATLAS SUSY subgroup and later as convener of the SUSY background forum in ATLAS.

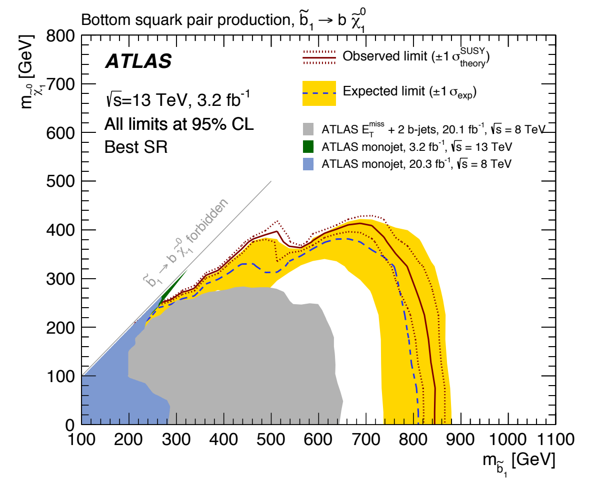


Fig. 10: Observed and expected exclusion limits at 95% CL, as well as ±1σ variation of the expected limit, in the sbottom-chi0 mass plane. The yellow band around the expected limit (dashed line) shows the impact of the experimental and SM background theoretical uncertainties. The dotted lines show the impact on the observed limit of the variation of the nominal signal cross-section by ±1σ of its theoretical uncertainties. The exclusion limits from the Run-1 ATLAS searches and from the 13 TeV monojet search are also superimposed. From Eur. Phys. J. C 76 (2016) 547.

The arrival of the Run 2 collisions in 2015 triggered a fast analysis of the data in the search for direct 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 already extended significantly previous exclusions from Run 1. In 2016, the team focused on bringing the results to final publication in Eur. Phys. J. C 76 (2016) 547. As shown in Fig. 10, sbottom masses up to 840 GeV are excluded for very light neutralinos. The results are complemented by the monojet results in very compressed scenarios characterized by a small mass difference between the sbottom and neutralino. Altogether, this constitutes the PhD Thesis of S. Fracchia, defended in December 2016.

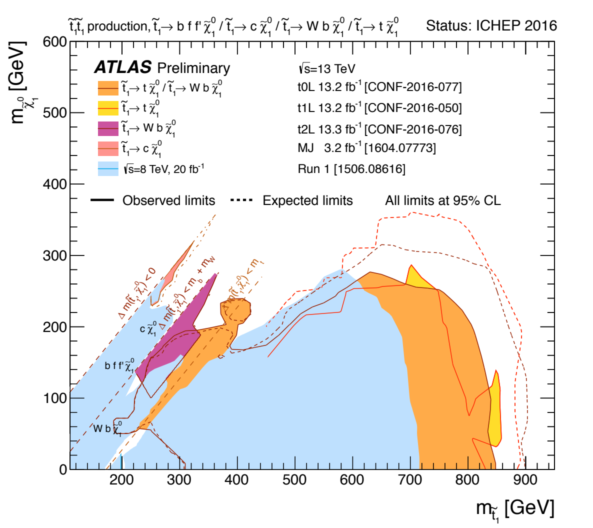


Fig. 11: Summary of the dedicated ATLAS searches for top squark (stop) pair production based on 13 fb-1 of pp collision data taken at √s=13 TeV. Exclusion limits at 95% CL are shown in the stop1-chi0 mass plane. The dashed and solid lines show the expected and observed limits, respectively, including all uncertainties except the theoretical signal cross section uncertainty (PDF and scale). Four decay modes are considered separately with 100% branching ratio: stop1→t+chi0 (where the stop1 is mostly right), stop1→W+b+chi0 (3-body decay for m(stop1)<m(top)+m(chi0)), stop1→c+chi0 and stop1→f+f′+b+chi0 (4-body decay). The latter two decay modes are superimposed. Note that these plots overlay contours belonging to different stop decay channels, different sparticle mass hierarchies, and simplified decay scenarios.

Similarly, the IFAE team contributed significantly to searches for stop pair production in the fully-hadronic decay mode, with multiple jets and large missing transverse momentum (E_T^{miss}) in the final state. This analysis has demonstrated to have unique sensitivity in the scenario with a heavy stop decaying into a top quark and a neutralino. Preliminary results based on the full 2015 data at √s=13 TeV were finalized in time for the ICHEP2016 conference (ATLAS-CONF-2016-077). The good agreement observed between the data and the predictions for backgrounds are translated into new 95% CL limits on the stop and neutralino masses (see Fig. 11). The results exclude stop masses up to about 900 GeV for light neutralinos.

At the moment, the IFAE team is focused on the analysis of the full 2015+2016 dataset (~36 fb^{-1}) in terms of sbottom and stop pair production, with the aim of presenting results in time for the 2017 Spring conferences. This will constitute the main subject of the PhD thesis by A. Rodríguez, to be defended in 2018.

SEARCHES FOR GLUINO-MEDIATED STOP/SBOTTOM PRODUCTION

The search for gluino-mediated stop and sbottom production using early Run 2 data constitutes 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 E_T^{miss}, 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 $t\bar{t}$ production in association with jets, including heavy-flavor jets.

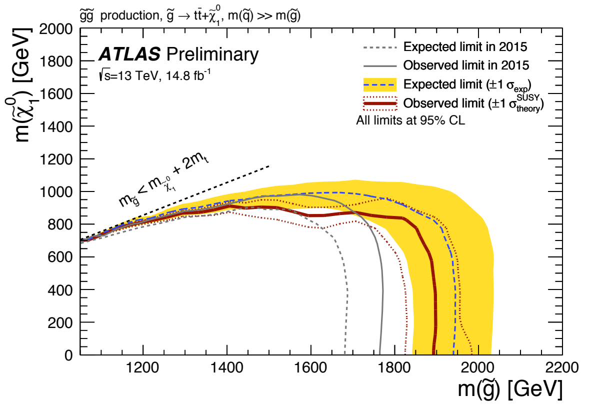


Fig. 12: 95% CL exclusion limits in the chi0 vs gluino mass plane for the Gtt model. The dashed and solid bold lines show the 95% CL expected and observed limits respectively. From ATLAS-CONF-2016-052.

These analysis efforts resulted in a first publication in Run 2 using 3.2 fb^{-1} of data collected in 2015 (Phys. Rev. D 94 (2016) 032003), which significantly extended the reach of Run-1 searches. This result was later superseded by a more sensitive search using up to 14.8 fb^{-1} of data (see Fig. 12), which was released as a preliminary result (ATLAS-CONF-2016-052) in time for the ICHEP2016 conference. Currently the analysis team is finalizing a publication result using the full 2015+2016 dataset (~36 fb^{-1}), to be submitted in time for the 2017 Winter conferences.

IFAE is playing a leading role in this search, with several members of the group actively involved (T. Farooque, A. Juste, C. Rizzi, and L. Valéry). Throughout the year both L. Valéry and T. Farooque acted as coordinators of the analysis team. T. Farooque acted as editor of the publication and the conference note, a role that now L. Valéry has taken for the upcoming publication using the full 2015+2016 dataset. This search will be part of C. Rizzi's PhD thesis, to be defended in 2018.

SEARCHES FOR NEW PHENOMENA IN TOP+X

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 (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.

During 2016 the IFAE team (M. Casolino, T. Farooque, D. Gerbaudo, A. Juste, and L. Valéry) continued to lead searches for pair-production of vector-like top quarks, with at least one of the T-quarks decaying into a top quark and a Higgs boson or a Z boson, leading to a busy environment with high jet and b-tagged jet multiplicities. These searches were also reinterpreted in the context of four-top-quark production, both within the SM and in several new physics scenarios, as well as in the context of heavy Higgs-boson production (both neutral and charged) in association with, and decaying into, third-generation quarks.

A first search for $T\bar{T}$→Ht+X and four-top-quark production in the lepton+jets (1-lepton) channel using 3.2 fb^{-1} of data at √s=13 TeV (ATLAS-CONF-2016-013) was presented at the Rencontres de Moriond Electroweak conference in March 2016. This search incorporated, for the first time, boosted object tagging, resulting in significant improvements in sensitivity. In a second iteration to this search, the IFAE team

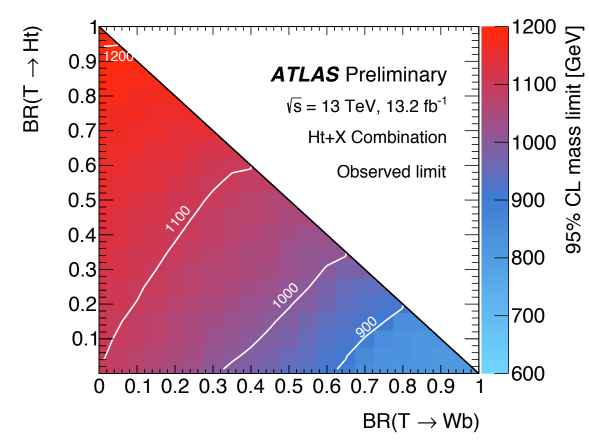


Fig. 13: Observed limit (95% CL) on the mass of the T quark in the plane of BR(T → Ht) versus BR(T → Wb) for the combination of the 1-lepton and 0-lepton TT→Ht+X searches. Contour lines are provided to guide the eye. From ATLAS-CONF-2016-104.

increased the analyzed integrated luminosity to 13.2 fb^{-1} and extended the scope of the search to include also a new and competitive analysis channel with multijets+E_T^{miss} (0-lepton). The corresponding result (see Fig. 13) is currently the single most-sensitive search for $T\bar{T}$ production at the LHC and was released in time for the TOP2016 workshop (ATLAS-CONF-2016-104). For both conference notes above, A. Juste acted as Corresponding Editor. These searches were coordinated by L. Valéry and are included in M. Casolino's PhD Thesis, to be defended in February 2017.

Currently the analysis team is focused on completing an improved search using the full 2015+2016 dataset (~36 fb^{-1}), to be published in time for the 2017 Summer conferences.

HIGGS BOSON PHYSICS

Following the discovery in 2012 by the ATLAS and CMS experiments of a SM-like Higgs boson with mass of 125 GeV, an ambitious program of studies of the Higgs sector was launched. This includes precision measurements of the properties of the SM-like Higgs boson, in particular its couplings to gauge bosons and fermions, as well as the search for additional Higgs bosons.

During Run 1 the IFAE team played a leading role in analyses probing the couplings of the Higgs boson to third-generation fermions: $VH(H\rightarrow b\bar{b})$ (V=W,Z) in the $b\bar{b}+E_T^{miss}$ channel, and $t\bar{t}H(H\rightarrow b\bar{b})$ in the lepton+jets channel. The corresponding publication results were used in the Run 1 ATLAS combination of Higgs-boson coupling constraints, published in Eur. Phys. J. C 76 (2016) 6, and the subsequent Run 1 ATLAS+CMS publication, JHEP 1608 (2016) 045. Members of the IFAE team had also contributed significantly to the first search for $t\bar{t}H(H\rightarrow b\bar{b})$ in the fully-hadronic final state using Run 1 data, which was published in JHEP 1605 (2016) 160. Another exciting topic the IFAE team was involved in is the search for flavor-violating Higgs interactions. In 2015 members of the team (S. Grinstein, A. Juste and S. Tsiskaridze) published a search for $t\rightarrow Hq(H\rightarrow b\bar{b})$ decays, which constituted the main subject of S. Tsiskaridze's PhD Thesis and whose defense took place in June 2016. On the other hand, postdoc D. Gerbaudo played a leading role in the search for $H\rightarrow e\tau/\mu\tau$ decays using Run 1 data. This result (arXiv:1604.07730 [hep-ex]) was recently accepted by Eur. Phys. J. C, with D. Gerbaudo acting as Corresponding Editor.
During Run 2 the IFAE team is strongly involved in the search for $t\bar{t}H(H\rightarrow b\bar{b})$, the search for $t\rightarrow Hq(H\rightarrow b\bar{b})$ decays, and searches for additional Higgs bosons, both charged and neutral.

SEARCH FOR $T\bar{T}H$ 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 SM particle most strongly coupled 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. 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 ($t\bar{t}H$). Searches are being performed in many final states, depending on the top-quark and Higgs-boson decay modes.

Since 2011 IFAE has lead searches for $t\bar{t}H$ production with $H\rightarrow b\bar{b}$, in the single-lepton channel. The final-state signature is characterized by one lepton and at least six jets, among which at least four jets are b-tagged. This analysis is very challenging due to the large background from $t\bar{t}$+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. Members of the IFAE team have made strong contributions towards addressing both challenges. In particular, PhD M. Casolino has played a leading role in the determination of corrections and systematic uncertainties for the dominant $t\bar{t}+\geq 1b$ background, which are of critical important for this analysis. To tackle the combinatorial background, M. Casolino and postdoc T. Farooque pioneered studies for $t\bar{t}H$ in the boosted regime, where the large transverse momentum of the Higgs boson allows reconstructing the two b-jets from its decay within a single large radius jet. T. Farooque continued to serve as coordinator of the boosted $t\bar{t}H$ analysis effort during part of 2016.

The first Run 2 analysis (ATLAS-CONF-2016-080) used 13.2 fb^{-1} of data at $\sqrt{s}$=13 TeV and constitutes one of the most sensitive searches for $t\bar{t}H$ to date (see Fig. 14). This search follows closely the strategy developed in Run 1, involving multiple analysis channels to constrain the effect of systematic un-

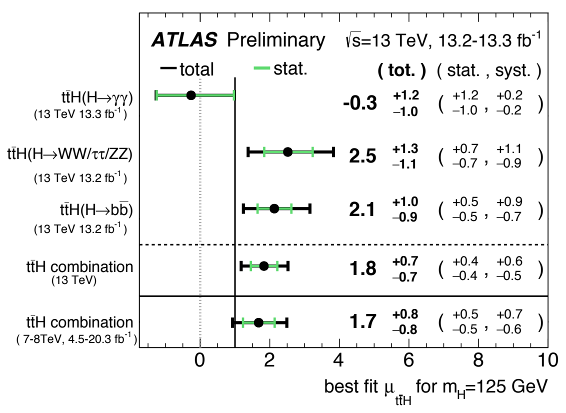


Fig. 14: Summary of the observed μttH signal strength measurements from the individual analyses and for their combination, assuming m_H=125 GeV. The total (tot.), statistical (stat.), and systematic (syst.) uncertainties on μ_{ttH} are shown. The SM μ_{ttH}=1 (0) expectation is shown as the black (grey) vertical line. The observed μ_{ttH} signal strength measurement obtained from the Run-1 combination is also shown for comparison (bottom). From ATLAS-CONF-2016-068.

certainties, as well as using multivariate techniques to discriminate signal from background. This result is also part of M. Casolino's PhD. Thesis.

Members of the IFAE team (A. Juste and Y. Rodina) continue its involvement in this search towards a publication using the full 2015+2016 dataset (~36 fb^{-1}) in time for the 2017 Summer conferences. In particular, Y. Rodina is developing a novel likelihood-based discriminating variable to separate signal from background, which will hopefully bring improvements in sensitivity. This result will be part of Y. Rodina's PhD thesis, expected by September 2017.

SEARCHES FOR ADDITIONAL HIGGS BOSONS

Many BSM scenarios incorporate an extended Higgs sector, typically with additional neutral Higgs bosons and at least a pair of charged scalar bosons. In the case of the charged Higgs bosons, their production and decay modes depend on the parameters of the model, and for heavy charged Higgs bosons ($m_{H+}>m_{top}$) the main production mode in most scenarios is in association with a top quark, with $H^+\rightarrow tb$ as the leading decay mode. The IFAE team (M. Bosman, M.P. Casado, J. Glatzer, Ll.-M. Mir, and I. Riu) is actively involved in this search. Its contributions in 2016 comprised the validation and production of the signal samples simulated with the MadGraph5_aMC@NLO generator. Such samples were used in the analysis presented at the ICHEP2016 conference (ATLAS-CONF-2016-089), which set limits to the production of charged Higgs bosons in the mass range 300 o 1000 GeV (see Fig. 15). In addition, the IFAE team is developing a discriminating variable based on kinematic information from the various resonances present in the decay and jet flavour identification, for optimal separation of signal and background. The idea is to include this variable in the discriminant BDT used in the analysis, to increase its separation power from the main background, $t\bar{t}$+≥1b production, which has the same final state as the signal. This separation is particularly difficult at low values of the charged Higgs mass (200-300 GeV).

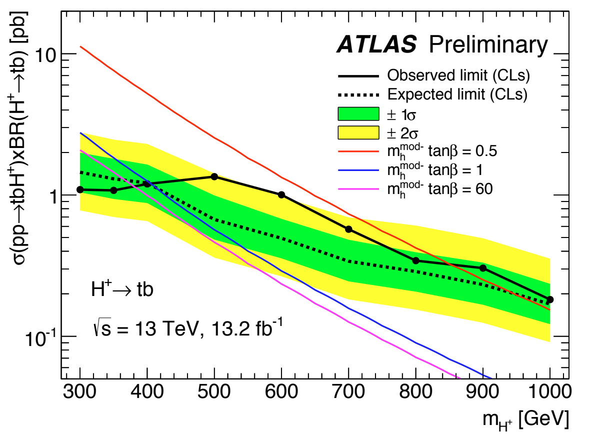


Fig. 15: Expected and observed limits for the production of $H^+\rightarrow tb$ in association with a top quark and a bottom quark. From ATLAS-CONF-2016-089.

Since March 2016 Ll.-M. Mir is coordinating this search within one of the ATLAS Higgs working groups, and acted as Corresponding Editor of the conference note presented at ICHEP2016.

In addition, the IFAE team (M. Casolino, T. Farooque, D. Gerbaudo, A. Juste, and L. Valéry) completed first searches for heavy neutral Higgs bosons (H, A) in $b\bar{b}H/A(H/A\rightarrow t\bar{t})$ and $t\bar{t}H/A(H/A\rightarrow t\bar{t})$ production in the single-lepton channel. These searches were obtained as a simple reinterpretation of the $T\bar{T}\rightarrow Ht+X$ search (ATLAS-CONF-2016-104), as mentioned previously. The analysis team is currently working towards a dedicated search for such signals using the full 2015+2016 dataset (~36 fb^{-1}). The same team also contributed to the first search for the Higgs boson produced in association with a W boson and decaying to four b-quarks via two spin-zero particles, which was published in Eur. Phys. J. C 76 (2016) 605.

DURING 2016, THE IFAE TIER-2 PROCESSED MORE THAN 32 BILLION EVENTS AND EXECUTED 1.4 MILLION OF JOBS WITH A DISK STORAGE OF 1.2 PETABYTE

COMPUTING INFRASTRUCTURE

The Tier-2 and Tier-3 LHC computing infrastructures of IFAE, under the supervision of A. Pacheco, provided efficient access to the analysis of the data recorded by the ATLAS detector in 2016, the second year of the LHC Run 2.

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

During 2016, the IFAE Tier-2 processed more than 32 billion events (see Fig. 16) and executed 1.4 million of jobs with a disk storage of 1.2 Petabyte. In order to address the local needs for the analysis of the Run-2 ATLAS data samples, the physicists of the ATLAS group at IFAE made also a very effective usage of the Interactive Analysis Facility (Tier-3) farm with additional resources.

Currently the Tier-3 farm counts with more than 675 TB of storage on disk, 100 TB of storage on tape and has completed more than 500.000 analysis

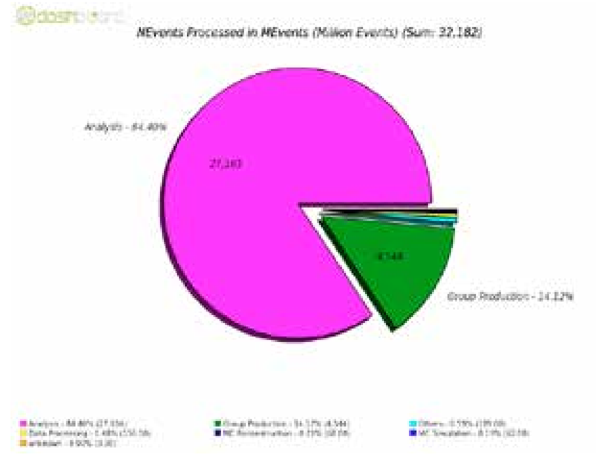


Fig. 16: Pie chart with the type of jobs processed in the IFAE Tier 2 during 2016. The Tier-2 facility processed 84% of events for user analysis, and 14% for group analysis.

jobs for the IFAE ATLAS group. 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 5528 processors and local access to the 10 Petabytes of ATLAS data stored on disk and tape at the same site. 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 2016, 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 2 monojet group; T. Farooque coordinated the boosted Higgs analysis efforts; S. Fracchia acted as TileCal Run Coordinator; A. Juste acted as convener of the Metadata subgroup of the ATLAS Data Preparation working group; I, Korolkov acted as Coordinator of Beam Test for Tile Calorimeter Upgrade; M. Martínez acted as member of the ATLAS Publication Committee and ATLAS Spokerpersons Sign-off delegate; Ll.-M. Mir, acted as member of the ATLAS Publication Committee; A. Pacheco acted as ATLAS Data Production and Analysis (DPA) Coordinator; C. Padilla is member of the ATLAS Speakers Committee; I. Riu acted as co-coordinator of the L1 Topological Trigger Commissioning group; M. Tripiana acted as Co-convener of the SUSY background forum in ATLAS; and L. Valéry continued as appointed co-contact person for the Run 2 VLQ Ht+X and SUSY multi-b analysis efforts.

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 the Standard Model of particle physics, ATLAS needs to identify and determine the path and origin 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, enabling the selection of interesting events through 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

The Pixel group at IFAE was formed in 2008 and has since taken a leading role in the ATLAS pixel upgrade program. In 2016 the main activities were divided in four fronts: the fabrication, commissioning and operation of the first arm of the ATLAS Forward Proton (AFP) detector tracker, the qualification of the 3D pixel technology for the ATLAS upgrade for the High-Luminosity LHC (HL-LHC) era, the investigation of the timing performance of Low Gain Avalanche Detectors (LGADs), and the design and testing of a monolithic pixel detector fabricated in the HV-CMOS technology. The activities were conducted in the framework of a Spanish (MINECO) project, led by IFAE, in collaboration with CNM (Centro Nacional de Microelectronica, Barcelona).

During 2016 the group finished the fabrication of the first arm of the AFP tracker, which has been successfully operated in several runs during the year. The module production for the second tracker arm was also recently completed. In the framework of the HL-LHC tracer upgrade, the group studied the performance of 3D sensors compatible with the ITk pixel geometries before and after irradiation, obtaining excellent results that are cementing the likeliness that this technology will be used in the innermost layer of the upgraded pixel detector. The first timing measurements of 50 μm thick LGAD samples before and after irradiation were also performed, yielding very interesting results that highlight the potential and possible limitations of this technology. Finally, the group has made the first measurement of a fully monolithic CMOS chip in the context of the ATLAS tracker upgrades with very encouraging results.

ATLAS FORWARD PROTON DETECTOR

The AFP detector extends the physics reach of ATLAS by enabling the identification of protons that emerge intact and at very low angles from the LHC proton-proton collisions. Such processes are usua-

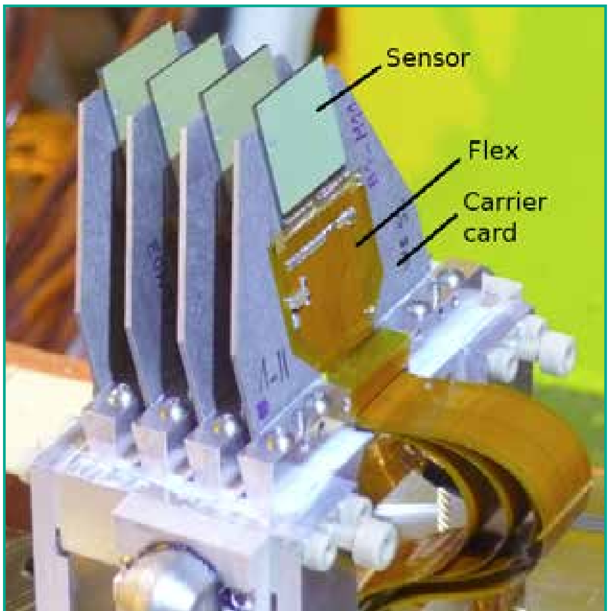


Fig. 1: Picture of one AFP tracker module.

DURING 2016 IFAE FINISHED THE FABRICATION OF THE FIRST ARM OF THE AFP TRACKER, WHICH HAS BEEN SUCCESSFULLY OPERATED IN SEVERAL RUNS DURING THE YEAR

lly associated with elastic and diffractive scattering. However, the AFP physics program ultimately aims to perform searches for new physics by exploring central exclusive production. The AFP detector will consist of high resolution pixel silicon tracker modules combined with a Time-of-Flight (ToF) system, placed in Roman Pots stations at about 210m from the ATLAS Interaction Point (IP) and at 2-3mm from the LHC beams.

The AFP detector is being installed in two stages. In the end-of-year 2015-2016 LHC shutdown, two tracker units have been placed in two stations at one side of the IP. After installation, the “one-arm” AFP detector has been operated during 2016. The full system with timing detectors, four tracker units and a total of four Roman Pot stations is planned to be completed during the extended end-of-year 2016-2017 shutdown.

With a very tight schedule, IFAE produced 17 silicon tracker 3D pixel modules during 2015-2016, and installed 7 of them in the first arm of AFP in February 2016. Figure 1 shows one AFP tracker station before installation. During the following months, the commissioning, integration and operation efforts were also led by IFAE (I. Lopez). Diffractive events were successfully collected during dedicated low luminosity runs in August and October 2016. Multiple high luminosity runs were also carried out through the year. Valuable experience in detector operation, performance and the interaction of AFP with other ATLAS sub-detector systems was obtained during these runs. IFAE is participating in the analysis of the first AFP data.

While the first arm of AFP was being commissioned, the second CNM 3D sensor production for the full (two-arm) AFP detector finished in March 2016 with 68 sensors of excellent quality. After the wafers were processed for bump-bonding, the modules were assembled in the second half of 2016. A total of 26 modules were bump-bonded, glued, wire-bonded and tested at IFAE. The yield of the sensor production was 85%, while the assembly yield was 96%. The tracker modules will be sent to CERN in February 2017, where F. Förster and J. Lange will conduct the quality assurance, installation, commissioning and integration of the selected modules, as was done for the first arm. Since the second sensor production has an electrical performance which is considerable better than the performance of the first production, the current plan is to replace the 7 modules of the first AFP arm. Hence, a total of 16 modules will be installed.

The group produced several publications regarding AFP during 2016, including an overview of the AFP project (S. Grinstein et al, NIM 273 (2016) 1180), results of the AFP tracker test-beams (J. Lange et al., JINST 11 (2016) P09005), and the description of the module fabrication process for the one-arm AFP detector (S. Grinstein et al. JINST 12 (2017) C01086).

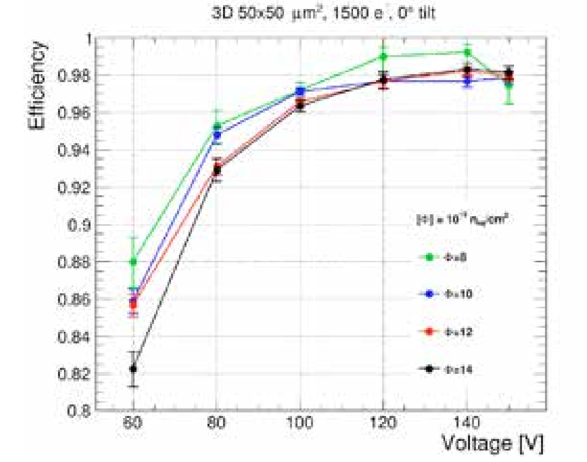


Fig. 2: Efficiency as a function of bias voltage for a 3D ITk-like sensor prototype with pixel pitch of 50×50 μm² at different fluencies.

3D PIXEL SENSORS FOR THE HL-LHC

The long-term aim of the IFAE Pixel group is to make a major contribution to the new ATLAS Inner Tracking detector (ITk) for the HL-LHC upgrade, which is currently foreseen for 2024. The group, in a coordinated project with CNM, is developing ultra-radiation-hard silicon pixel detectors, called 3D sensors, to cope with the unprecedented radiation doses that the innermost layers of the ATLAS pixel detector will face during the HL-LHC era.

The 3D technology is becoming the baseline for the innermost layer of the pixel detector thanks to the improved 3D sensor fabrication yield (see previous section) and the excellent results obtained by IFAE with the ITk-like 3D sensor productions from CNM during 2016. 3D device prototypes with sensor pixel sizes of 50×50 μm^2 and 25×100 μm^2 but compatible with the existing readout chip (FE-I4) were fully assembled at IFAE and irradiated to ITk fluencies (up to 1.4E16 1-MeV n_{eq}/cm^2) at different irradiation sites. The performance of these prototypes was studied in various test-beams during 2016 with excellent results: reconstruction efficiency >97% at normal track incidence with a very low power dissipation (J. Lange, 29th RD50 Workshop, CERN and D. Vazquez, 12th Trento Workshop, Trento 2017). Figure 2 shows the efficiency as a function of voltage for different fluences for a CNM 3D ITk prototype with pixel size of 50×50 µm2.

As a final step in the qualification effort, 3D sensor productions consistent with the fabrication process desired for ITk (single sided process, with 150 µm active thickness), are currently on-going at CNM and will be completed in 2017. It will be critical to evaluate the performance of these devices in terms of production yield, radiation hardness and power dissipation, in particular for sensors compatible with the ITk ASIC prototype (called RD53 chip), which will be available in the summer-fall of 2017.

The IFAE group is leading the 3D effort in ATLAS (S. Grinstein is part of the ITk Pixel TDR editor team, and co-leading the ITk Pixel Sensor group) and has presented results in several conferences during 2016 (J. Lange et al., JINST 11 (2016) C11024, and D. Vazquez et al., JINST 12 (2017) C01026).

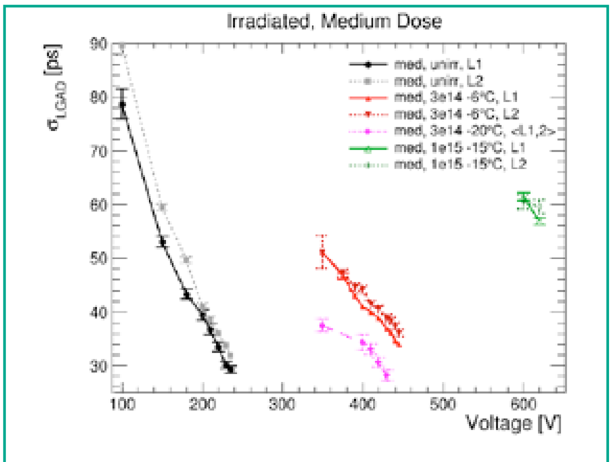


Fig. 3: Time resolution as a function of bias voltage for irradiated LGAD sensors. While an excellent timing resolution is obtained at 3E14 n_{eq}/cm^2 a significant degradation is observed at 1E15 n_{eq}/cm^2.

TIMING PERFORMANCE OF LOW GAIN AVALANCHE DETECTORS

Silicon detectors with moderate intrinsic charge multiplication (Low Gain Avalanche Detectors or LGAD, originally developed at CNM) are being investigated for timing applications, as the rapidly rising signal generated by these devices should provide improved time resolution. Possible use cases are the ATLAS High Granularity Timing Detector (HGTD) or a future upgrade of the AFP detector.

IFAE has been playing a leading role in the investigation of LGAD sensors. During 2016 J. Lange coordinated the characterization effort of devices from a recent CNM production on a 50 µm thin substrate, before and after neutron irradiation to 3E14 and 1E15 n_{eq}/cm^2 at Ljubljana. The gain was measured with Sr-90 beta particles, showing the expected gain degradation after irradiation, supposedly due

THE FIRST TIMING MEASUREMENTS OF 50 µM THICK LGAD SAMPLES YIELDED VERY INTERESTING RESULTS THAT HIGHLIGHT THE POTENTIAL OF THE TECHNOLOGY

to acceptor removal. The time resolution was studied at AFP test-beams in July and September at the CERN SPS complex. A time resolution of <30 ps was achieved before irradiation, as well as after a fluence of $3{\cdot}10^{14}$ n_{eq}/cm^2. At $1{\cdot}10^{15}$ n_{eq}/cm^2, a time resolution of 55 ps was measured at the maximum applied voltage of 620V. It was found that the time resolution before and after irradiation follow a similar behavior as a function of the gain achieved. These results were presented by IFAE recently at the 29th RD50 workshop at CERN and the 12th Trento meeting.

IFAE will continue to participate in the sensor R&D and module assembly efforts of the ATLAS HGTD project during the next year, with reinforced manpower and in close collaboration with CNM.

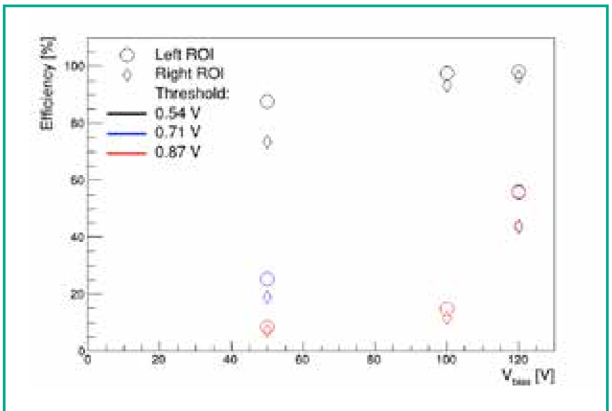


Fig. 4: Hit reconstruction efficiency of the monolithic H35demo device before irradiation for different threshold settings and two regions of interests (ROI).

MONOLITHIC PIXEL DETECTORS

Recently ATLAS started to investigate the use of depleted CMOS devices in the context of the tracker upgrade for the HL-LHC. In this standard process the electronics is placed inside deep n-wells while a depletion region is 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 (monolithic approach). IFAE’s focus is the development of monolithic depleted-CMOS detectors. In this context, R. Casanova designed the digital readout electronics of a full-size HV-CMOS device fabricated in the AMS 350 nm technology, called the H35 demonstrator (or H35demo) in collaboration with KIT and the University of Liverpool. The H35demo production was finalized at the end of 2015 and the devices were tested during 2016.

IFAE carried out the characterization program in two fronts: first understanding the charge collection properties with laser sources (transient current technique or TCT), and second evaluating its performance in test-beams. To this end E. Cavallaro coordinated a series of TCT measurements of samples of different resistivities irradiated to various doses, which ultimately showed the feasibility of using this technology at least up to fluences expected for the 5th pixel layer of ATLAS. The results were presented in the iWorid conference at Barcelona and TWEPP in Karlsruhe.

THE GROUP HAS MADE THE FIRST MEASUREMENT OF A FULLY MONOLITHIC CMOS CHIP IN THE CONTEXT OF THE ATLAS TRACKER UPGRADES WITH VERY ENCOURAGING RESULTS

In parallel, IFAE developed its own readout system for the H35demo chip, based on the Xilinx commercial Zync board (this system is also being used to develop a Medipix3-based camera in the context of a medical project). After a substantial effort led by S. Terzo an unirradiated H35demo sample was successfully tested with beam at CERN in November 2016 obtaining a preliminary hit reconstruction efficiency >98%. The results will be presented in the coming winter conferences.

New CMOS structures have been designed during 2016 by R. Casanova. Especially relevant for ATLAS is a monolithic detector with 50×50 μm^2 pixels that offers in-pixel discrimination and 8-bit time over-threshold information.

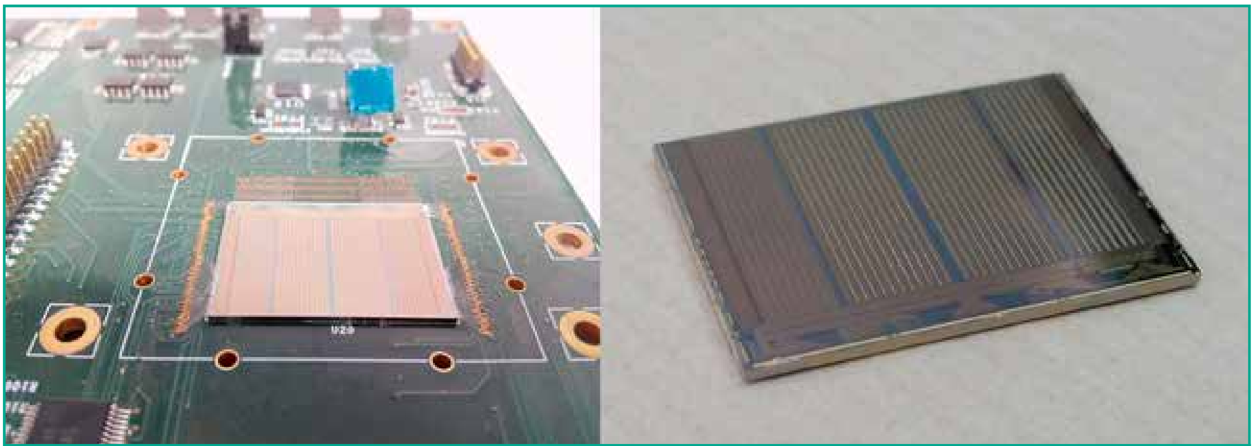


Fig. 5: The H35demo chip developed by IFAE.

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 a program in the search of evidence for Charge Parity violation in the lepton sector.

T2K

In T2K a high-intensity, 2.5º off-axis neutrino beam from the JPARC proton accelerator center in Tokai (Japan) is sent to the SuperKamiokande experiment in Kamioka, 295km away. The muon neutrino energy spectrum is optimized for searching the appearance of electron neutrinos. The beam is characterized at the near detector, 280m 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 θ_{13} by detecting the appearance of electron-type neutrinos. The muon neutrino beam also allows measuring the mixing matrix element θ_{23} 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 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 250kW in May 2013 with a total of $6.57 \cdot 10^{20}$ protons 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

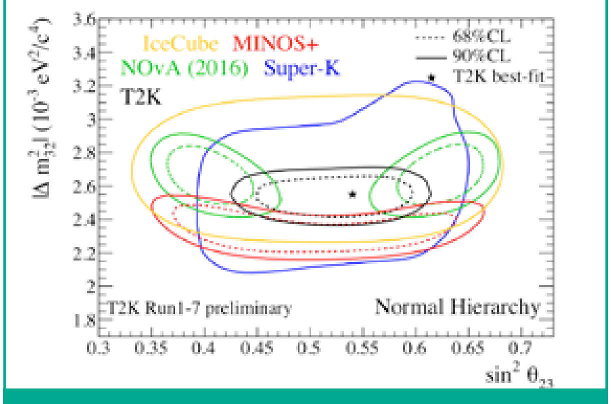


Fig. 1: T2K results on atmospheric mixing angle (θ_{23}) and mass difference (Δm^2_{23}). The plot includes the full neutrino and antineutrino runs until summer 2016.

electron anti-neutrino appearance. The anti-neutrino run continued until June 2016. The run started in fall 2016 was devoted to neutrino running. During this period the accelerator was performing beyond expectation, achieving a 450kW power record at the end of 2016.

The accumulated data until summer 2016 was acquired ~50% in neutrino and ~50% in antineutrino mode. The first combined analysis of neutrino and antineutrino data was performed using the whole available statistics. This provides the most precise measurements of θ_{23} mixing angle, see Figure 1, and the first marginal indication of CP violation in neutrinos, see Figure 2.

THE IFAE GROUP LED THE ANALYSIS OF THE INCLUSIVE CHARGED-CURRENT (CC) MUON AND ELECTRON NEUTRINO INTERACTIONS USED FOR NEUTRINO FLUX NORMALIZATION

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. IFAE has been always leading this analysis that is critical to constrain the neutrino flux using the near detector. During 2014 and 2015, IFAE developed a completely 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 2017 oscillation results and to be the main subject of A. García phD. This new phase space al-

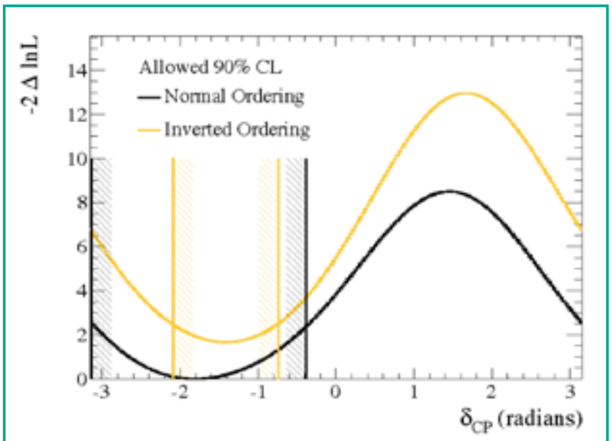


Fig. 2: T2K results on CP violation (δ_{CP}). The result excludes the no CP violation at the 90% CL. The plot includes the full neutrino and antineutrino runs until summer 2016.

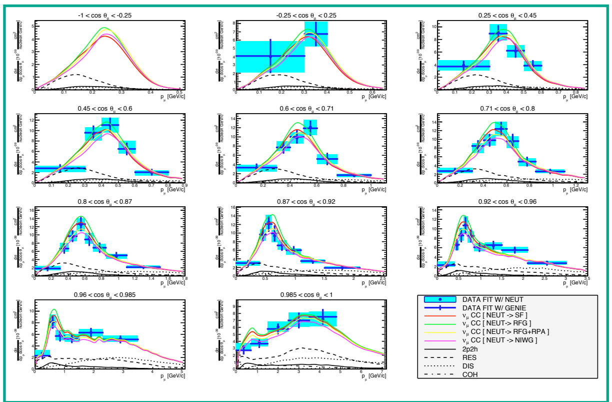


Fig. 3: Double differential neutrino-Carbon Charged Current single pion production cross-section. Red line shows the prediction of the Neut cross-section model.

most matches the one of the far detector and it will allow to reducing the uncertainties in the cross-section modeling. This event selection was the base of the first measurement of CC inclusive interactions in Carbon with full detector acceptance, see Figure 3, that was done at IFAE.

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 4. The main contribution to the analysis is the development of a neutrino cross-section model that does not rely on previous experiments that might be biased by the presence of sterile neutrino oscillations.

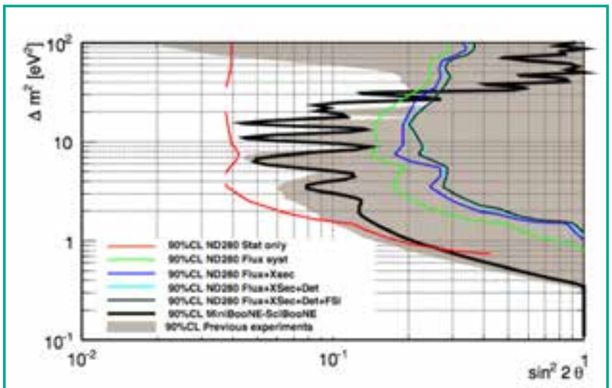


Fig. 4: Exclusion plot of sterile neutrino oscillation parameters from the T2K near detector muon neutrino disappearance analysis compared to previous results.

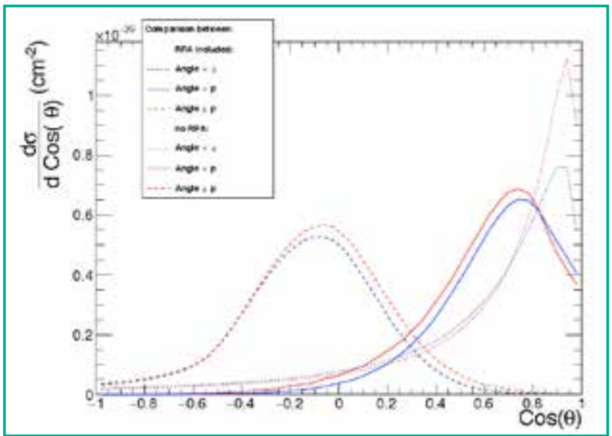


Fig. 5: CCQE differential cross-section as function of the muon angle as predicted by the new model implemented by the neutrino group.

IFAE has been also involved in the development of a new event generator to simulate (anti) neutrino nucleus two body current charged current quasi-elastic cross-sections based on the Nieves et al. model [Phys.Rev.D88, 113007(2013)]. 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. IFAE also developed the monte carlo for the charged current quasi-elastic based on the model from Nieves et al. [Phys.Rev. C70 (2004) 055503]. Figure 5 shows the relative effect of the long-range correlations as function of the radial position and the transferred momentum of the interaction. These two implementations represent the first coherent description for the charged current interactions with most of the recent model developments. The monte carlo will make these developments available to experiments. This will be the phd topic of B. Bourguille. The neutrino group developed new observables, see Figure 6, to measure experimentally the ratio of resonant to non-resonant contributions to the pion production in neutrino interactions [Phys. Rev. D93, 9 (2016), 093015]. These observables have been used already by the T2K collaboration analysis and it is expect to help improving pion production theoretical models.

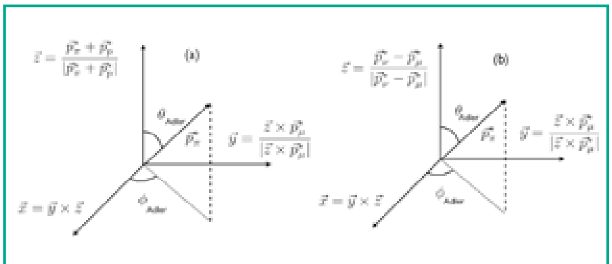


Fig. 6: Definition of Adler angles for interactions with nucleons (left) and for nucleus (right).

In 2016, T2K presented a proposal to run the experiment for a total of 20·10^{21} protons on target [arXiv:1609.04111]. This extension of the run will allow the experiment to reach 3.5 sigma significance for maximal CP violation in neutrinos. Together with the increased integrated neutrino flux, a program to upgrade the near detector has been submitted to T2K and to CERN [CERN-SPSC-2017-002]. The upgrade, which will have an IFAE contribution, consists on the replacement of the scintillator tracker targets and the addition of 4 TPC's to improve the angular acceptance of the experiment.

In 2016, IFAE assumed the responsibility of the maintenance of the ND280 magnet to be added to support activities to TPC maintenance tasks. The main activity devoted to magnet coordination has been the definition of a maintenance plan to be able to operate the magnet until 2025.

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 cam-

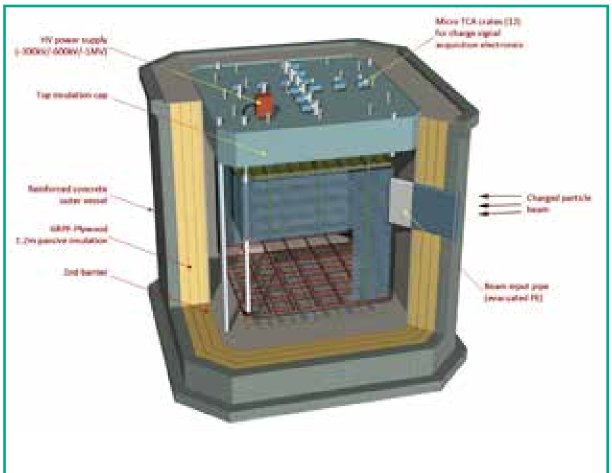


Fig. 7: Schematic representation of the TPC inside the cryostat. The inner detector has dimensions of 6x6x6m^3.

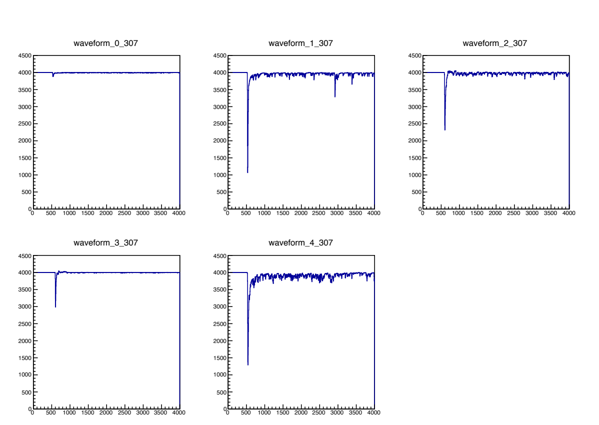


Fig. 8: Waveform, ADC value vs time, obtained with the 5 3x1x1 PMT's from a cosmic trigger in gaseous Argon.

paign 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 7, is a 6x6x6m^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 is involved on the first tests with small 3x1x1m^3 prototype at CERN to take place in 2016. IFAE developed the data acquisition system to read the photomultipliers, first results already show light emitted by cosmic rays in gas argon during the commissioning of the 3x1x1 prototype, see Figure 8. IFAE purchased already 20 (out of 40) of the Hamamatsu R5912/02 8" photomultipliers, see Figure 9, and it is developing the laser calibration system in coordination with CIEMAT and the coating for the light wavelength shifting with 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

IFAE is one of the leading institutes of the MAGIC Collaboration. It is its second group by size and one of the most active ones. We have high-level roles in the management of the Collaboration, notably O. Blanch as its Deputy Spokesperson since 2014. We are responsible for the maintenance of our contributed hardware, like the so-called receiver boards and the DAQ cooling system, and we built and operate the MAGIC Data Center. In addition, we are active in R&D for future instrumentation in Gamma-ray Astronomy, including a new concept for photo-detectors, a new low-energy trigger system, and UV filters for the MAGIC cameras (that are now used during regular observations under strong Moon illumination). After the last major hardware upgrade, completed in 2012, the main focus of MAGIC is the scientific exploitation of the instrument. IFAE has led 6 of the 15 MAGIC papers published during 2016, including an accurate measurement of the extragalactic background light at around 1μm and the first MAGIC/Fermi-LAT combined search for dark matter particles in the mass range between 10 GeV and 100 TeV.

Fig. 1. The MAGIC telescopes at the Observatorio del Roque de los Muchachos in La Palma. 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.

THE MAGIC TELESCOPES

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 ~50GeV and ~50TeV.

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 production 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 2016 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, 5 post-docs and 6 PhD students. The dedication of most of the group members is shared to some extent between MAGIC and CTA. One of the PhD students (M. Çolak) and one post-doctoral fellow (K. Noda) have joined our group during 2016.

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.

MAGIC IS CURRENTLY IN A PERIOD OF STEADY ASTRONOMICAL OBSERVATIONS AND INTENSE SCIENTIFIC EXPLOITATION

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, O. Blanch has been the Deputy Spokesperson of the Collaboration. In addition, several members of the group have served in several committees, such as the Time Allocation Committee, the Technical and Software Boards, as conveners of several Physics working groups and as Common Fund Manager. During 2016, five IFAE group members have travelled to La Palma for participating in 1-month observational shifts with the MAGIC telescopes. Among them, A. Fernández, J. E. Ward and D. Guberman were acting as shift leaders (the highest authority during MAGIC operations).

R&D FOR GAMMA-RAY ASTRONOMY

After the last major hardware upgrade in 2011-2012, MAGIC 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 2016, which are summarized in the following paragraphs.

• 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. At IFAE, we constructed a prototype of a new concept for a non-expensive, wide active surface, SiPM-based detector, and evaluated its performance. During 2016, in collaboration with the Max Planck Institute for Physics in Münich, we have designed and begun construction of several of these devices (called "Light-Trap" pixels), and have also started the process of integrating them into a 7-pixel cluster that is compatible with the MAGIC cameras, where they will be tested in the near future. For more details, see Section "Applied Physics".

• Topo-trigger: 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 2016 we have published a technical paper with the characterization of this novel trigger system.

WE HAVE BEEN INVOLVED IN SEVERAL HARDWARE DEVELOPMENTS, AIMED AT EXPANDING FURTHER THE ENERGY RANGE AND DUTY CYCLE OF CHERENKOV TELESCOPES

• 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. We recently built at IFAE UV-pass filters for both MAGIC telescopes, which are easy to mount on and dismount from the cameras, and we tested them in the telescopes. During 2016, we have extensively used the filters during regular MAGIC observations under strong Moon illumination, in particular with about 50 hours of observations of the supernova remnant Cassiopeia A, which have resulted in important new scientific measurements (publication pending). In addition, we have written a technical paper about the performance of MAGIC observations with filters, now in the latest stages before publication.

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 2). 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.

During 2016, the amount of raw data stored in the permanent storage of the MAGIC Data Center reached 1 million files, which represents 1.3 PB of data. The user's activities generated more than 200 support requests. One of the main challenges of the year was the massive reprocessing of around 50TB of data, which represented the most massive data reprocessing ever done in MAGIC. This activity also

Fig. 2. The MAGIC Data Center is a centerpiece for the efficient MAGIC data analysis and its outstanding scientific record. It processes and stores 200-300 TByte of data per year, and provides the MAGIC collaboration with official analysis and data products, and other data/software related services.

triggered new implementations in the ToMaRe (Tool for Massive Reprocessing) tool developed in 2015. Additionally, two major implementations related to the Data Center web services were performed during 2016. The first one was the migration of the daily transfers software to the FTS 3.5.8 version. This introduced important changes in the API used to manage the transfers through FTS that were adapted to the middleware used to manage and monitor the transferences.

DURING 2016, THE AMOUNT OF RAW DATA STORED IN THE PERMANENT STORAGE OF THE MAGIC DATA CENTER REACHED 1 MILLION FILES, WHICH REPRESENTS 1.3PB OF DATA

The second implementation represents a new service provided to the whole MAGIC Collaboration, designed to collect the information associated to the detection of gamma-ray flaring events. This information is useful because these events are quite important from a scientific point of view (and not so common), in particular, e.g. in research about the quantum nature of space-time.

SCIENCE WITH MAGIC

During 2016 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.

One of the group theses defended in 2015 (Very-high-energy gamma-ray observations of pulsar wind nebulae and cataclysmic variable stars with MAGIC and development of trigger systems for IACTs, by R. López-Coto) has been selected during 2016 for publication in the Springer Theses series, in recognition for its “scientific excellence and impact on research”.

During 2016 the MAGIC Collaboration has produced 15 scientific papers, out of which IFAE members have led (corresponding authorship) 6 of them, which are briefly summarized in the following paragraphs:

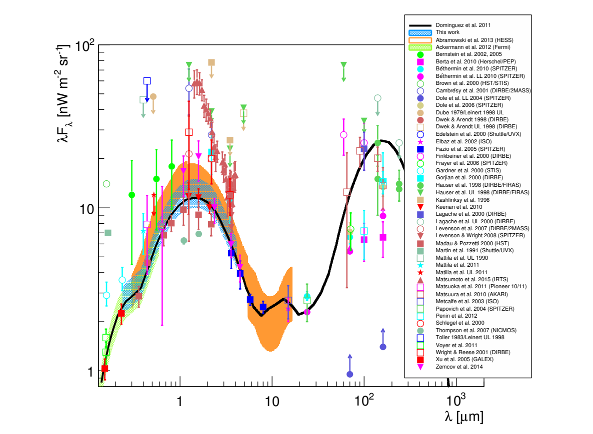


Fig. 3. Extragalactic background light intensity versus wavelength at z=0 model and measurements. The azure shaded area shows the constraints obtained by MAGIC from observations of the blazar 1ES 1011+496 as part of one of the KOP projects led by IFAE.

• The major upgrade of the MAGIC telescopes, Part II: A performance study using observations of the Crab Nebula (corresponding author: J. Sitarek, while being an IFAE post-doctoral fellow). We present the full characterization of the performance of the MAGIC stereoscopic system after the 2011-2012 major upgrade, using observations of the Crab Nebula. This paper is the base for assessing MAGIC capabilities for the different scientific questions that are yearly proposed for the consideration of the MAGIC Time Allocation Committee.

• Detection of very-high-energy gamma-ray emission from the gravitationally-lensed blazar QSO B0218+357 with the MAGIC telescopes (corresponding author: J. Sitarek, who started this work while being at IFAE as a post-doctoral fellow). QSO B0218+357 is a gravitationally lensed blazar located at a redshift z=0.944. The gravitational lensing splits the emitted radiation into two components, spatially indistinguishable by gamma-ray instruments, but separated by a 10-12 day delay. In July 2014, QSO B0218+357 experienced a violent flare observed by the Fermi-LAT and followed by the MAGIC telescopes, which, for the first time in the VHE band, detected the deflected signal at the expected time delay. QSO B0218+357 is the farthest VHE source detected to date.

• Super-orbital variability of LS I +61º303 at TeV energies (corresponding author: A. López Oramas, while being at IFAE as a PhD student). The gamma-ray binary LS I +61º303 was established as a VHE source by MAGIC, and we also detected a periodicity of the gamma-ray emission coincident with the orbital period of the system. In this work, based on a four-year observational campaign with MAGIC plus archival and published data from MAGIC and VERITAS we detected, for the first time, a 4.5 year modulation of the intensity of the orbital VHE outbursts.

USING MAGIC AND FERMI-LAT OBSERVATIONS ON DWARF SATELLITE GALAXIES, WE HAVE OBTAINED LIMITS TO THE ANNIHILATION CROSS-SECTION OF WIMPS OF MASS BETWEEN 10 GEV AND 100 TEV

• Search for VHE gamma-ray emission from Geminga pulsar and nebula with the MAGIC telescopes (corresponding author: R. López-Coto). The Geminga pulsar, one of the brightest gamma-ray sources, is a promising candidate for emission of very-high-energy (VHE > 100 GeV) pulsed gamma rays. Also, detection of a large nebula has been claimed by water Cherenkov instruments. We performed deep observations of Geminga with the MAGIC telescopes, yielding 63 hours of good-quality data, and searched for emission from the pulsar and pulsar wind nebula. We did not find any significant detection, and derived upper limits to its VHE emission.

• MAGIC observations of the February 2014 flare of 1ES 1011+496 and ensuing constraint of the EBL density (corresponding authors: A. González, while being at IFAE as a PhD student, and A. Moralejo). This is the first paper produced as part of one of the mentioned KOP projects led by IFAE. Using data from MAGIC observations of an extraordinary flare of this blazar, we were able to obtain one of the strongest constraints to the density of Extragalactic Background Level in the wavelength range around 1.4μm (see Figure 3).

• Limits to dark matter annihilation cross-section from a combined analysis of MAGIC and Fermi-LAT observations of dwarf satellite galaxies (corresponding authors: J. Aleksić, former IFAE PhD student, and J. Rico). In this paper we present the first joint analysis of gamma-ray data from the MAGIC Cherenkov telescopes and the Fermi Large Area Telescope (LAT) to search for gamma-ray signals from dark matter annihilation in dwarf satellite galaxies. We combine 158 hours of Segue 1 observations by MAGIC with 6-year observations of 15 dwarf satellite galaxies by the Fermi-LAT. We obtain limits on the annihilation cross-section for dark matter particle masses between 10 GeV and 100 TeV - the widest mass range ever explored by a single gamma-ray analysis (see Figure 4). These limits improve on previously published Fermi-LAT and MAGIC results by up to a factor of two at certain masses. Our new inclusive analysis approach is completely generic and can be used to perform a global, sensitivity-optimized dark matter search by combining data from present and future gamma-ray and neutrino detectors.

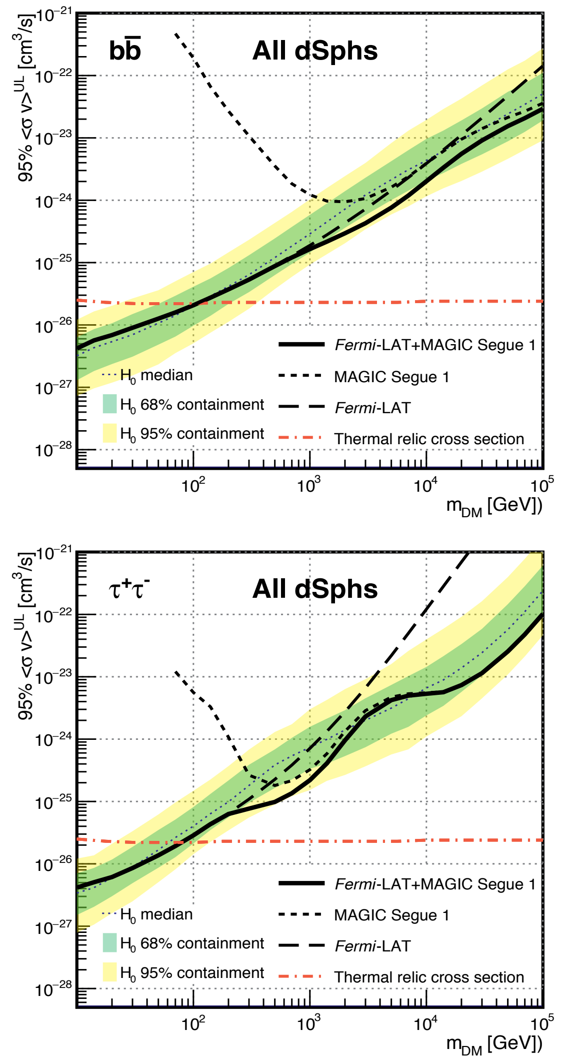


Figure 4. Limits to the thermally-averaged cross section for dark matter particles annihilating into different Standard Model particle pairs. Thick solid lines show the limits obtained by combining 6 years of Fermi-LAT observations of 15 dwarf satellite galaxies with 158 hours of MAGIC observations of Segue 1. Dashed lines show the observed individual MAGIC and Fermi-LAT limits. The bands are the 68% and 95% containment regions, respectively, expected for the no dark matter signal case.

2.5 CTA: CHERENKOV TELESCOPE ARRAY

MANEL MARTÍNEZ

The Cherenkov Telescope Array (CTA) is 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, postdocs and PhD students and shares its time between the CTA project and the MAGIC Telescopes. In addition about 10 engineers and technicians (software, mechanics and electronics) expend a good fraction of their time for the CTA project at IFAE.

INTRODUCTION: PROGRESS OF THE CTA PROJECT IN 2016

During 2016 the CTA project has reached key milestones such as the signature of the agreement for the CTA-North site at the Roque de los Muchachos Observatory ORM, a big scientific success for Spain for which IFAE has been instrumental, and the agreement with ESO for the construction of CTA-South in Chile and its later approval by the ESO Council.

Additional key decision taken in 2016 are installing the definitive CTA Project Office in Bologna, and setting up the SDMC (Science Data Management Center) in Berlin-Zeuthen.

Fig. 1: The IAC Director, prof. R. Rebolo and the CTAO Director, prof. U. Straumann signing the agreement for the construction of CTA North at the Roque de los Muchachos Observatory ORM in November 2016.

Furthermore, the CTA Council approved in 2016 the CTAO Business Plan, which lays down the foundations for the starting of the CTA construction phase. Prototypes of all CTA telescope types are already in testing phase around the globe. The exception is the prototype of the Large Size Telescope LST1 that has started in 2016 its construction at ORM (http://webcam.lst1.iac.es/stream1view.htm) and is scheduled for inauguration on November 15th, 2017. Due to its high cost and complexity, LST1 will serve already also as a

DURING 2016 THE CTA PROJECT HAS REACHED KEY MILESTONES SUCH AS THE SIGNATURE OF THE AGREEMENT FOR THE CTA-NORTH SITE AT THE ROQUE DE LOS MUCHACHOS OBSERVATORY ORM

preproduction telescope and should be at the same time the first LST in CTA North starting, de-facto, the CTA construction phase.

In 2016 IFAE has continued participating with high impact and visibly in CTA, keeping important responsibilities also at the management level. IFAE has two representatives at the highest management level of the LST Collaboration: J. Cortina is the Co-PI of the project and M. Martinez serves as the Chair of its Steering Committee. Additionally O. Ballester is the LST Systems Engineer, O. Blanch is the Camera Coordinator, A. Moralejo the Software Coordinator and J. Cortina the Infrastructure Coordinator. All them are members of the Executive Board of the LST project. In addition, J. Rico continued serving the whole CTA Consortium as the Chair of its Speaker's and Publication Office (SAPO) and M. Martinez continued as the leader of the 11 Spanish groups that presently constitute the CTA-Spain consortium.

MECHANICS AND INFRASTRUCTURE

During the last years we have designed the foundations of LST1 and its camera access tower with the aid of an external architecture company. The foundations are expected to sustain a peak wind speed of 200km/h blowing perpendicular to the 400m^2 telescope mirror. The telescope foundation is a wheel-shaped 600m^3 concrete slab weighing 1500 tones. It was finished in 2016 (see picture). The area around the telescope has been properly conditioned for the telescope installation during 2017.

IFAE coordinates all infrastructure deployment at the ORM. Work is ongoing to design the power and computing infrastructure, which should be deployed in 2017 and 2018. We have also produced a preliminary design for the foundations of the next three LSTs at ORM, with an eye especially to their location at the observatory.

IFAE is responsible of designing and building the undercarriage of the LST. The undercarriage allows the telescope to rotate in azimuth. It consists of a circular rail and six wheel bogies running on top of it. Similar to the foundation, the undercarriage is also designed to tolerate strong vertical forces both in the downward and upward directions. The design finished in 2015 and was partly validated using a test setup at IFAE in 2016.

IFAE IS RESPONSIBLE OF DESIGNING AND BUILDING THE UNDERCARRIAGE OF THE LST

Fig. 2: The foundation of the LST1. Javier Herrera, deputy coordinator of LST infrastructure, stands in front of the 24m diameter concrete slab, which goes 1 to 2m deep underground and is designed to sustain the wind forces exerted on the large telescope mirror.

The rail has been finally produced at a German company, whereas the construction of the different mechanical parts for the six bogies has taken place at different institutes belonging to the LST sub-consortium (IFAE, CIEMAT, INFN Padova, MPI Munich and University of Hamburg) under IFAE's supervision. The parts were later transported to IFAE, where they were assembled at the mechanical workshop. The bogies have been tested and are ready for delivery to ORM in Spring 2017.

Fig. 3: Two of the 6 bogies for LST1 designed and assembled at IFAE and ready for shipment to ORM.

CAMERA ELECTRONICS AND INTEGRATION

IFAE is responsible for the coordination, integration and commissioning of the camera for the LSTs. During 2016, partial integration has started in several of the institutes where the camera elements are being produced. The final integration of the camera will happen at IFAE in 2017 for which 265 readout modules with 7 PMTs each will be installed inside the camera structure that measures 3x3 meters. In 2016 the first step of the integration tests was a 19 modules mini-camera setup at ICRR, Tokyo. It was followed by the integration of 35 modules in the final camera mechanics at CIEMAT, Madrid (see Figure 4). IFAE actively participated in both of them not only as responsible of the camera integration but also because of the elements for the camera being done at IFAE: power system, cabling, camera trigger and camera control (CaCo).

The power system for the LST cameras includes the Power Distribution Box (PDB), the power supplies (PS) and the power distribution system based on bus bars. On the one hand, the full concept of the PDB and PS had already been finalized from the electric point of view. During 2016, their mechanical interfaces to be installed inside the camera were crosschecked and verified. The PDB was also compared to the plan developed by the CTA project office defining how the electronic elements in CTA should be protected. It was shown to be fulfilling the requirements. The used PS are switching power supplies and they could induce noise in the camera electronics. Low levels of induced and radiated noise were two of the criteria to select the used PS. Still, the different integration setups as well as specific setups done at

IFAE have been used to show that the additional noise due to the use of switching supplies is negligible for the operation. Finally, the power distribution system was very depending on the exact mechanics in the rear part of the camera. Although the use of bus bars was decided long time ago to minimize the cabling inside the camera, it has not been until 2016 that the dimension and location of them have been decided. At IFAE we have also developed an intelligent switch that allows powering the camera section by section. This was needed due to a huge inrush current of the camera electronics and it makes maintenance much easier.

Fig. 4: 35 modules that include the camera trigger decision installed on the final mechanics for the first LST camera.

The camera will be controlled remotely through CaCo, which needs to communicate both to the different subsystems and to the telescope control. In 2016, the communication with all hardware in the camera was developed as well as several algorithms to calibrate them. The integration setups were used to check both the communication and the calibration algorithms. For hardware that was not available in those setups, the communication was checked remotely. First tests for the communication with the telescope control were also done. All together led to a first version of CaCo that can control all subsystems in the camera and can make the link with the central control.

One of the key elements in Cherenkov telescopes is the trigger decision system, which selects when the light reaching the camera is worth being recorded. The trigger decision systems look for an excess of signal localized in a relative small region of the camera within a time window of a few nanoseconds.

IFAE IS RESPONSIBLE FOR THE COORDINATION, INTEGRATION AND COMMISSIONING OF THE CAMERA FOR THE LSTs

This approach allows reducing the trigger rate due to Night Sky Background accidentals, whereas the trigger efficiency for gamma-like events remains high due to the compactness of their associated camera image. IFAE is the responsible institution for the hardware where the trigger decision is taken. During 2016, all the boards needed for the trigger decision of the first LST camera were built, and they were intensively used in the integration setups, not only to test the trigger decision but also the trigger distribution and data taken. On view of what will be needed for the next telescopes, a quality control that could be outsourced was developed for the boards were the trigger system is implemented.

MONTE CARLO STUDIES

During the last few years, IFAE has played an important role in the CTA Monte Carlo working group, with the development of an independent analysis chain within the framework of the MAGIC reconstruction software (MARS). During 2016, the main activities of IFAE were centred on the analysis of the third official large-scale CTA MC production (Prod-3) with the main goal of optimizing the telescope layouts of the two observatories. This new production was launched after the final selection of the CTA sites, and hence made use of more realistic telescope positions (e.g. avoiding particularly steep areas at the ORM site in La Palma, as well as conflicts with existing buildings). It also incorporated up-to-date telescope specifications, following the development of the various telescope elements in the past years.

This new round of simulations aims at defining not just the final layouts of the two observatories (so-called "baseline arrays") but also the optimal staging scenarios, to maximize the scientific output during the deployment of the arrays. These partial CTA implementations are also dubbed "threshold arrays" since they are considered the minimal configurations for which funding should be secured before the telescope production starts.

The performance of a large number of possible telescope layouts was analyzed, with IFAE's analysis being one of the two (the other being from DESY-Zeuthen), which were used in the process of assessing the various performance parameters (mainly flux sensitivity, angular resolution and spectral resolution). The CTA MC group then issued a recommendation on the baseline arrays for the North and the South hemispheres, and presented it to the CTA project committee (in the internal document OBS-SCI/160420), and later to

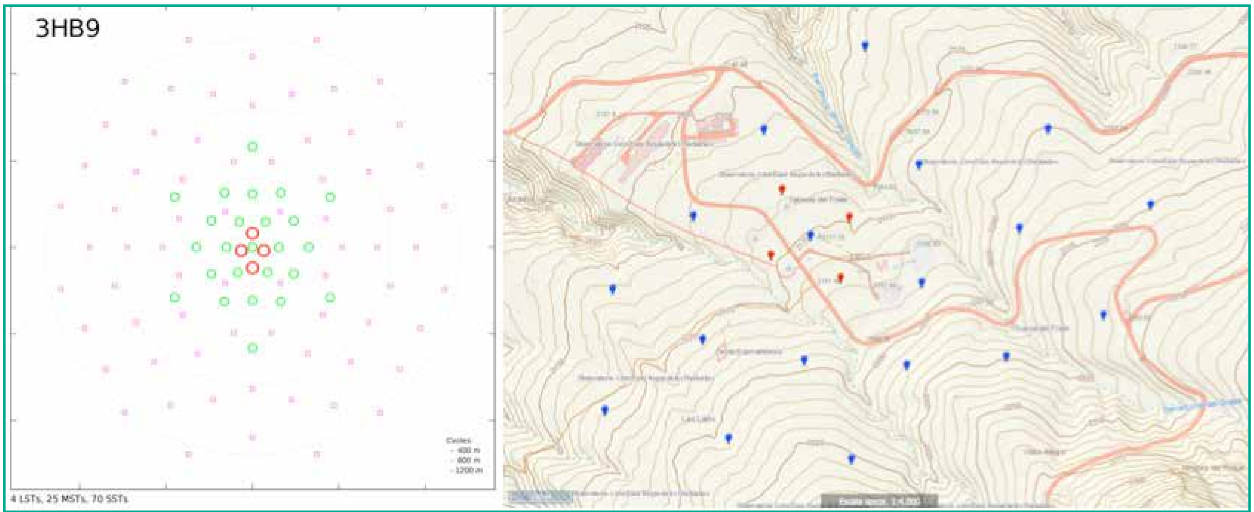


Fig. 5: Left: CTA baseline array layout for the South observatory in Paranal (Chile), with 4 LSTs, 25 MSTs and 70 SSTs. Right: layout for the North observatory at the ORM in La Palma, with 4 LSTs and 15 MSTs (yet to be selected from the 18 positions displayed).

the consortium board, which approved it on May 20th 2016. The South array will have 4 LSTs, 25 MSTs and 70 SSTs, whereas the North will have 4 LSTs and 15 MSTs. In the case of the North observatory, however, the recommendation on the telescope arrangement is currently being revised because of partial overlap of one of the LSTs with an existing road (which was earlier considered expendable), and because of a request from the MST team to enlarge the size of the free area around each telescope.

DATA MANAGEMENT ACTIVITIES

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. In the last years IFAE has participated in the activities related to Data Model, particularly focused on the format of high-level data (DL3), the scientific products that will be provided to the guest observer.

Within the CTA Data Model working group, IFAE has been deeply involved in 2016 in the development of the Instrument Response Functions (IRFs) data format, and prototyped the first FITS IRF generator software: flexIRF. In addition, benefiting from the participation in the European project ASTERICS, IFAE was part in the creation, associated discussion and development of the first open high-level data format for Atmospheric Cherenkov telescopes data, allowing for the first time joint analysis between different IACT experiments. IFAE has also been responsible of the subgroup in charge of the development of the required tools for exporting MAGIC data into the CTA-compliant open DL3 format, in order to test and validate those formats, together with the associated analysis tools.

IFAE WAS PART IN THE CREATION OF THE FIRST OPEN HIGH-LEVEL DATA FORMAT FOR ATMOSPHERIC CHERENKOV TELESCOPES, ALLOWING FOR THE FIRST TIME JOINT ANALYSIS BETWEEN DIFFERENT IACT EXPERIMENTS

RAMAN LIDAR

For the IFAE/UAB Raman LIDAR project, during the year 2016 there has been significant progress in a key part of the LIDAR, namely the polychromator, designed by the project itself and constructed and assembled during the first half of 2016. During the second half of 2016, the polychromator was characterized with respect to its capability to separate the different wavelengths (355nm, 387nm, 532nm, 607nm). It was found to operate according to specifications, particularly light leakage from the elastic channels (532nm and 355nm) into the much dimmer Raman channels (387nm and 607nm) could be excluded to at least less than one per mile.

In parallel, the photomultiplier tubes used for the light detection at the exit of the polychromator have been characterized with respect to their relative acceptance (including QE, CE and gain). A set of neutral-density filters has been purchased for that aim.

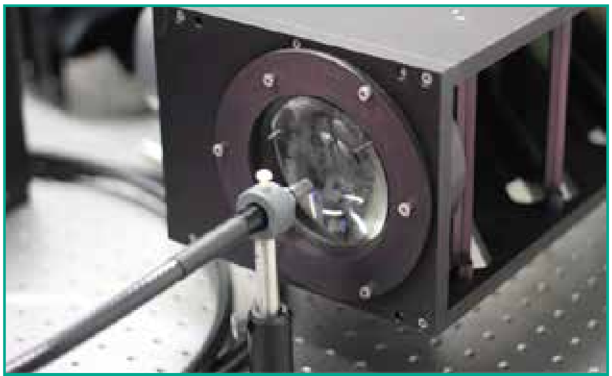


Fig. 6: The Raman LIDAR polychromator while being commissioned in our optics lab.

The laser, a key part of the system, broke for unknown reasons during 2016 and was repaired by the local company "Protonlaser". That company also re-aligned the internal mirrors and slightly improved its beam-opening angle. A lead panel has been purchased for easy characterization of the laser beam, which was carried out in the end of 2016 and revealed stable performance within specifications again. Two members of the group followed a laser-safety course before starting to operate the laser for these tests.

Towards the end of 2016, the internal communication has started to be re-programmed according to the CTA software standards (in Java). An internal business logic model has been established for that case. It contains a mock LIDAR data and hardware generator for tests.

In November 2016, a meeting was arranged with the representatives of the IEEC to evaluate whether their software for surveillance and control of systems and state machines (so-called "OpenRocs") was suitable for the Raman LIDAR. After some discussion this option was discarded, at least until the full internal business logic has been established.

A lengthy discussion about where to perform long-term tests of the Raman LIDAR (options were the Observatory of the Montsec, a place in the French Pyrenees, the EARLINET station in L'Aquila and La Palma) lead to the conclusion that La Palma was the best suited site for this task, due to the already frequent, easy cheap access of members of IFAE/UAB to that place, and the availability of all kind of services potentially required.

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), 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 DESI (Dark Energy Spectroscopic Instrument), led by LBNL (USA). In 2016 the group has joined the Large Survey Synoptic Telescope (LSST), led by SLAC (USA).

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 electronics.

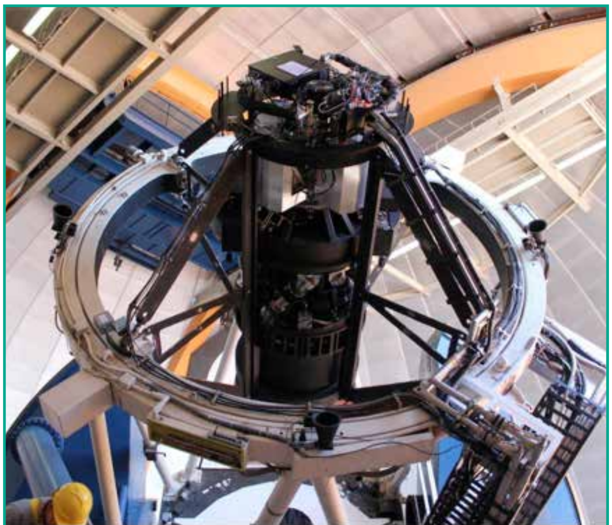


Fig. 1: The DES camera, DECam, installed at the prime focus of the Víctor M. Blanco 4-meter telescope at the Cerro Tololo Inter-American Observatory (CTIO) in the Chilean Andes.

IN 2016, THE GROUP AT IFAE (CO-)LED 5 OF THE 33 PAPERS PUBLISHED BY THE DES COLLABORATION, WHILE COMPRISING ONLY ABOUT 3% OF ITS SCIENTISTS

In the course of a five-year period that started in August 2013, DES will map an entire octant (5000 sq. deg.) of the 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. Seasons 2 and 3 followed, with season 4 currently underway and scheduled to finish in February 2017. Since 2014, DES has published over 80 papers, almost 50 of which with analyses using the science-quality SV data set. More than 10 papers have been published using the year 1 (Y1) data, which covers over 1800 sq. deg., although at a reduced depth compared with that of SV. Most of the cosmological analyses including Y1 data are still on going, with the relevant papers scheduled to be published in spring 2017.

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 the 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 a large set of galaxies with spectroscopic redshift measurements, ideally with a galaxy population reproducing that in the photometric survey. During the analysis of the SV data set, 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), with two members of the group (Carles Sánchez, a PhD student, and Chris Bonnett, a post-doc) becoming lead authors of the two resulting papers: Sánchez et al. (DES Collaboration) 2014, MNRAS 445, 1482, which became the very first published DES science paper, and Bonnett et al. (DES Collaboration) 2016, PRD 94, 042005.

Starting in 2015, several IFAE MSc and PhD students have worked on 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 galaxy sample). The two samples will only show a significant cross-correlation if they overlap in 3D, which helps pinpoint the unknown redshift distribution. 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. Currently, two graduate students at IFAE, Marco Gatti and Pauline Vielzeuf, play a leading role in the DES-wide task force that is producing photo-z estimates for the Y1 data sample based on this technique. A paper presenting the techniques and results is currently in preparation.

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, using the SV data set, DES published the first batch of papers highlighting the quality of the DES weak-lensing data, focusing on mass mapping and shear-shear correlations. IFAE researchers Chris Bonnett, András Kovács (both post-doctoral researchers), and Carles Sánchez contributed to several aspects of these analyses. In 2016, the attention turned to the measurement

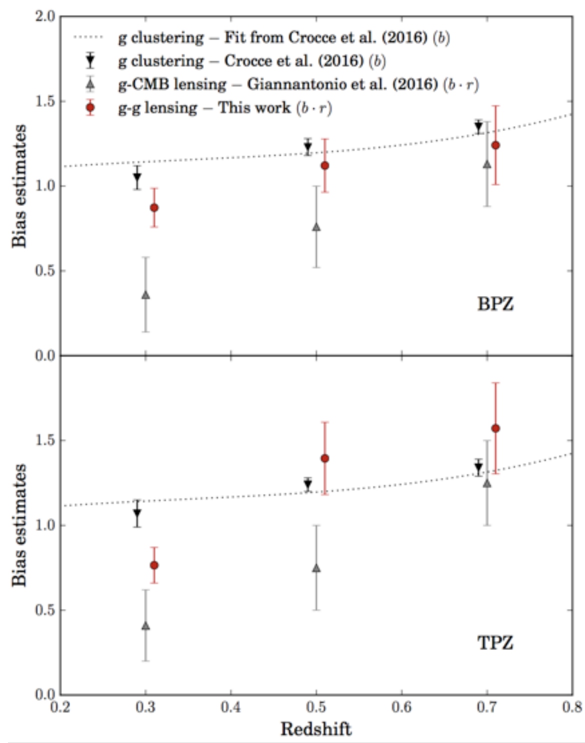


Fig. 2: Measurements of galaxy bias using galaxy-galaxy lensing (g-g lensing, red points) as a function of redshift, compared with previous measurements over the same magnitude-limited sample of galaxies from the DES Science Verification (DES-SV) data set obtained using galaxy clustering (g clustering, black down triangles) and CMB lensing (g-CMB lensing, gray upper triangles). Top panel: Lens redshift bins are defined with the BPZ photo-z code and the lens redshift distribution N(z) is estimated using BPZ as well. Bottom panel: Lens redshift bins are defined with the TPZ photo-z code and the lens N(z) is estimated using TPZ as well. The points have been offset horizontally for clarity purposes. Taken from Prat, Sánchez, Miquel et al. (DES Collaboration) 2016, "Galaxy bias from galaxy-galaxy lensing in the DES Science Verification Data", arXiv:1609.08167.

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 were published, all of them led or co-led by IFAE scientists. 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 (Prat, Sánchez, Miquel et al. (DES Collaboration) 2016, "Galaxy bias from galaxy-galaxy lensing in the DES Science Verification Data", arXiv:1609.08167). The bias measurements are shown in Fig. 2 and compared to other results obtained in DES over the same sample of foreground galaxies using other techniques, such as galaxy clustering, mass and galaxy maps, and CMB lensing around DES galaxies. The figure shows an intriguing discrepancy between some of the measurements at low redshift, perhaps indicating a previously unforeseen stochasticity between the galaxy and matter distributions. Another, co-led by Carles Sánchez (Clampitt, Sánchez et al. (DES Collaboration) 2016, "Galaxy–galaxy lensing in the Dark Energy Survey Science Verification data", arXiv:1603.05790, MNRAS 465 (2017) 4204) measured galaxy-galaxy lensing around a sample of luminous red galaxies (LRGs), whose redshift can be more reliably estimated with photometric techniques. Finally, the third, co-led also by Carles Sánchez (Kwan, Sánchez et al. (DES Collaboration) 2016, "Cosmology from large scale galaxy clustering and galaxy-galaxy lensing with Dark Energy Survey Science Verification data", arXiv:1604.07871, MNRAS 464 (2017) 4045), combined the results from the previous paper with measurements of the angular clustering of LRGs to extract cosmological information. Figure 3 shows the constraints obtained in the Ω_m-σ_8 plane, where Ω_m is the total matter density now in units of the critical density and σ_8 is the amplitude of the power spectrum of matter density fluctuations at 8 Mpc/h scales, a standard benchmark of the inhomogeneity of the matter distribution. The constraints are in agreement with the 2015 DES results from cosmic shear, while, as most weak-lensing results, they seem to point towards a lower value for σ_8 than that reported by the Planck mission.

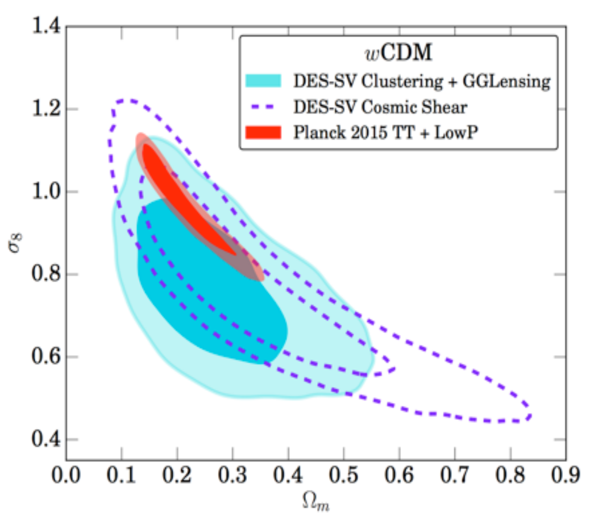


Fig. 3: Constraints (68% and 95%) on the cosmological parameters Ω_m (the total matter density now in units of the critical density) and σ_8 (the amplitude of the power spectrum of matter density fluctuations in 8 Mpc/h scales) obtained from a combination of galaxy clustering and galaxy-galaxy lensing measurements in the DES Science Verification (DES-SV) data set. The constraints assume a CDM universe with the w parameter left free, and are compared to the DES-SV results obtained from cosmic shear measurements and with the latest results from the CMB obtained by the Planck satellite. Taken from Kwan, Sánchez et al. (DES Collaboration) 2016, "Cosmology from large scale galaxy clustering and galaxy-galaxy lensing with Dark Energy Survey Science Verification data", arXiv:1604.07871, MNRAS 464 (2017) 4045.

During 2016, the IFAE group has also been vigorously involved in cosmological void science. Two DES papers were published: one on lensing around voids, led by Carles Sánchez (Sánchez, Clampitt, Kovács et al. (DES Collaboration) 2016, "Cosmic voids and void lensing in the Dark Energy Survey Science Verification data", arXiv:1605.03982, MNRAS 465 (2017) 746) and another on the Integrated Sachs-Wolfe effect (CMB photons changing wavelength when crossing large over- or under-dense regions) across large voids and super-clusters, this one led by András Kovács (Kovács, Sánchez et al. (DES Collaboration) 2016, "Imprint of DES super-structures on the Cosmic Microwave Background", arXiv:1610.00637, MNRAS 465 (2017) 4166). Figure 4 shows the main result of this second paper: when crossing large under-densities detected by DES, the CMB photons seem to lose more energy than expected in the standard ΛCDM cosmology, while they seem to gain as much energy as expected when crossing large over-dense regions. This result confirms previous findings with other galaxy samples and has received significant attention.

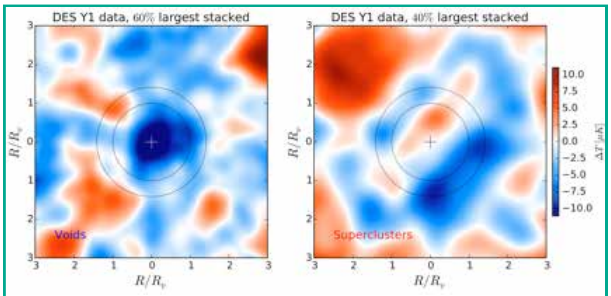


Fig. 4: CMB temperature fluctuations (color scale) stacked over regions in the DES Year 1 catalog with prominent voids (left panel) and super-clusters (right panel). The distances in both axes are scaled to each void or supercluster radius. The standard ΛCDM cosmological model predicts that the temperature should be 1-2 μK lower (higher) than average for CMB photons traversing voids (superclusters), in agreement with the observations for superclusters, but in some tension with the findings for voids. Taken from Kovács, Sánchez et al. (DES Collaboration) 2016, "Imprint of DES super-structures on the Cosmic Microwave Background", arXiv:1610.00637, MNRAS 465 (2017) 4166.

Our institutional involvement in the governance of DES was kept at a high level during 2016, with a member of the IFAE group being a member of the DES management committee, the publication board, the DES builders' committee, which grants paper authorship rights to the DES participants who have made substantial contributions to its infrastructure, and the newly formed DES advisory board, in charge of advising the DES director in all matters related to the collaboration.

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 direct detection of the sum at more than 3σ 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 of 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, and they perform these two fundamental tasks while 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. This is the only imaging instrument in DESI, and crucial to the operation of the spectrograph.

The DESI focal plane assembly is made up 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.

IN AUGUST 2016, IFAE DELIVERED THE FIRST PROTOTYPE OF THE GUIDING, FOCUSING AND ALIGNMENT (GFA) CAMERAS FOR THE DESI PROJECT. THE PROTOTYPE WAS SUCCESSFULLY TESTED AND COMMISSIONED IN AUGUST 2016 AT THE MAYALL TELESCOPE IN THE KITT PEAK OBSERVATORY IN ARIZONA (USA)

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.

Fig. 5: A picture of the first prototype of the GFA cameras for the DESI project. The yellow cap protects the CCD under it. The read-out electronics is fully contained in the black enclosure. The prototype was delivered to Lawrence Berkeley National Lab in early August 2016.

Fig. 6: : First raw on-sky image, depicting the M2 globular cluster, obtained with the first prototype of the GFA cameras installed at the 4-meter Mayall telescope in the Kitt Peak Observatory in Arizona (USA) on August 26, 2016.

In early August 2016, IFAE delivered the first GFA camera prototype (Fig. 5) to Lawrence Berkeley National Lab, where it was further characterized before being mounted onto the protoDESI prototype of the DESI focal plane and shipped to the Kitt Peak Observatory in Arizona. The design and integration of both the electronics and the mechanics were performed fully by IFAE engineers and technicians.

The main challenges in the design of the read-out electronics were the small space available (see Fig. 5) and the tight constraints on power dissipation. The readout of the CCD is fully digital. The output signal from each CCD amplifier is digitized at a high rate (100 Msps), and then a digital correlated double sampling is applied. The system includes 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 implements the control. The control system is split between a server and a client. The server resides in the embedded Linux system, which receives commands and sends raw data (either telemetry or CCD raw data) to a client. Data transmission to the server is performed using an ethernet connection.

The mechanical design for the enclosure involved 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 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 were necessary to implement this design.

The GFA prototype saw its first light on August 26, 2016 (Fig. 6), after which the commissioning phase continued throughout September 2016, including its integration with the guiding software. In mid-September 2016, the main goal of the protoDESI project was achieved, as light from three guiding stars was simultaneously measured down the three fibers available, using the GFA images in the process of moving the robotically-controlled fibers to their proper positions in the focal plane.

After an extensive review in the fall of 2016, several useful modifications and improvements to the GFA camera were identified. The next prototype is due in 2017, with the production finishing by Q2 2018.

A member of the IFAE group has been recently appointed to the DESI Speakers Board, in charge of allocating speakers to DESI talks in conferences and workshops.

IFAE HAS JOINED THE LSST PROJECT, THE PRE-EMINENT IMAGING SURVEY IN THE NEXT DECADE, WHICH WILL PROVIDE COSMOLOGICAL MEASUREMENTS WITH AN UNPRECEDENTED SAMPLE OF 4 BILLION GALAXIES

LSST

In December 2016, IFAE (together with ICE (CSIC-IEEC), CIEMAT and IFT/UAM) joined the Large Survey Synoptic Telescope (LSST) project. LSST will be the pre-eminent imaging survey in the next decade, being three times faster, four times wider and 3 mags deeper than DES. The 3.2 gigapixel LSST camera will be installed in a new 8.4-meter telescope in Cerro Pachón (Chile), near the DES site. The camera has an enormous 9.6 sq. deg. field of view, resulting in an unprecedented etendue. The 10-year survey will visit each point in its 20,000 sq. deg. footprint 825 times, generating about 10 million alerts per night. At the end of the survey, the 500 PB of images will contain over 40 billion astronomical objects. From this huge data set, cosmological measurements will be performed using a sample of 4 billion galaxies, over 13 times the DES sample. The commissioning of LSST is scheduled to start in 2021, with the survey proper expected to get underway in 2023.

2.7 THE PAU SURVEY

ENRIQUE FERNÁNDEZ

Physics of the Accelerating Universe Survey (PAUS) is an ongoing extragalactic survey carried out with the William Herschel Telescope in La Palma, Canary Islands, equipped with the PAUCam Camera. PAUS originated in the context of the PAU Project funded by the Consolider Ingenio 2010 Program of the Spanish Ministry of Research and Innovation. The PAU project was approved in 2007 and ended in 2014. The main deliverable of the project was the PAUCam camera, briefly described below.

INTRODUCTION

At present PAUCam is a Visitor's Instrument at the William Herschel Telescope. The instrument is operated by the PAUCam collaboration, formed by 5 of the 7 groups originally in the Consolider Project, namely CIEMAT and IFT (in Madrid), and IEEC, PIC and IFAE (in Barcelona). These are the groups that also built the PAU Camera and its software and also collaborate closely in other projects such as DES and DESI, described elsewhere in this report.
A Memorandum of Understanding between the ING Group of Telescopes and the PAUCam Collaboration, signed in 2012, regulates the operation of PAUCam at the WHT. PAUCam is a Visitor Instrument but it is also offered for public use by interested members of the WHT community of users, when not dedicated to the PAUS survey. At present external groups are assisted by the PAUCam collaboration in the operation of PAUCam.

PAUCam had first light on the night of June 3, 2015, and took data during the 4 following nights. The data was invaluable for various calibrations and for checking the Data Acquisition System and the Control Software existing at the time. All the data were transmitted to the remote storage at the PIC, in Barcelona. The operation of the camera was very successful and the last night was actually spent taking science-ready data. Since then, we had observation nights in 2015B (Nov 10-18), 2016A (Mar 30 – April 11) and 2016B (Nov 17 – Dec -11). Before this last period the camera was opened (in the clean room of the GranTecan) to correct two problems that had already been noticed during the initial observation period in 2015.

One problem had to do with the motion of the trays holding the filters, namely that some of the trays were blocked from moving into position (with the nominal force foreseen for that motion). Since the trays are inside the vacuum of the camera and since the reason for the blocking was not known we decided not to exercise more force than the nominal to bring them into place. It was found that moving the telescope-camera to the zenith position and then back again to the desired position, effectively unblocked the motion of the trays. This operation then became the procedure to follow in the few cases in which we actually had the problem (a picture of the trays can be seen in Fig. 1).

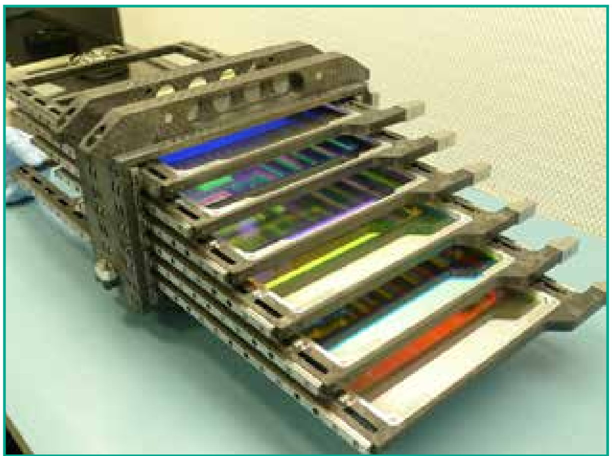


Fig. 1: A photograph of the filter tray system, in this case filled with the large-size wide-band filters (one per tray). When inside the camera the trays can be moved in and out, and up and down, to be placed in front of the focal plane of PAUCam.

The second problem had to do with the frame around the CCDs, used to hold them in place in the trays (see Fig. 2). As it was originally installed, the frame let some scattered light to reach the CCDs. The problem affected a few rows and column of pixels near the edges of the CCDs, which were subsequently masked for the analysis. This problem was corrected during the intervention but the problem with the motion of the trays re-appeared again in the fall of 2016 period. We suspect that some of the "rails" to put the trays in position may be slightly loose. For the moment we will operate the camera as explained, although we may need to open it again in the future.

Another development during 2016 was that four European formally joined the PAUS collaboration: the Linden Observatory in the Netherlands, Durham University and University College of London, in the UK, and ETH-Zurich, in Switzerland, bringing to 9 the groups now in PAUS.

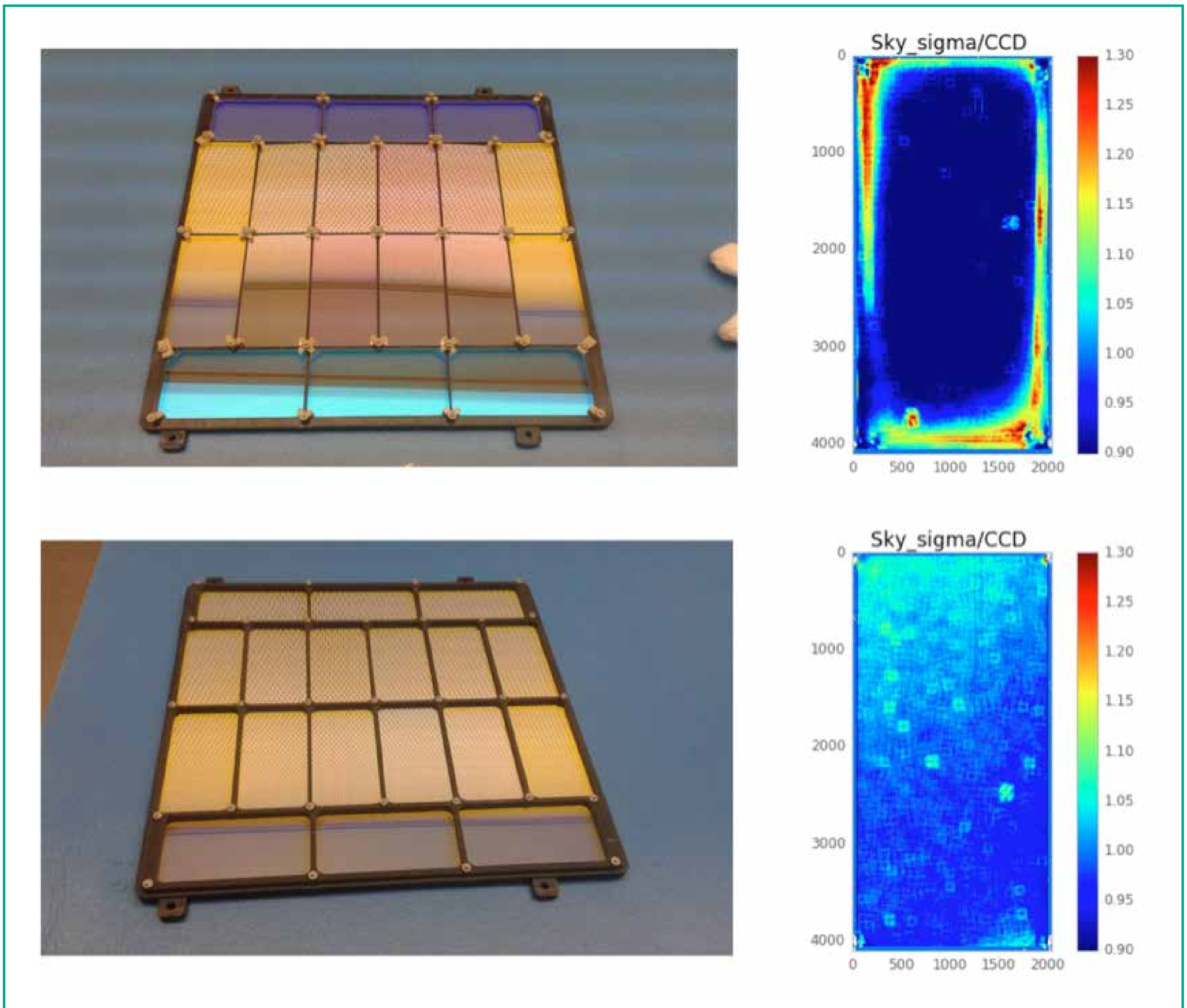


Fig. 2: Photograph of a filter tray before and after the intervention in the fall of 2016. One can see that the scatter light around the periphery of the filters has been greatly reduced.

THE PAU CAMERA (PAUCAM)

PAUS is 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.

The final design of PAUCam was done to reach the above goal and to meet the specifications of the WHT. WHT has a field of view (FoV) of 1^{o} in diameter with 85% light collection efficiency (of which 40' have 100% efficiency). 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.

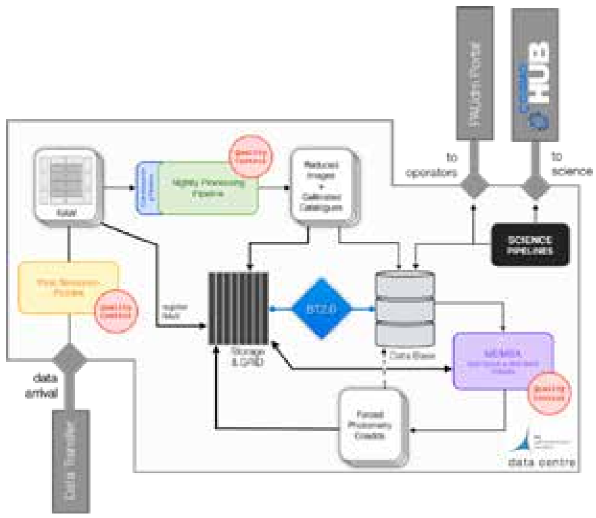


Fig. 3: The PAUS Data Management System. All the components are in hand, with some of them are still being improved. As of February 2017 there have been 26 nightly productions, 75 MEMBA productions, 1.5 million registered images and 5.5 million coadd sources.

Fig. 4: Detail of the image captured by one PAUCam CCD. Stars and galaxies, at many depths, are clearly visible.

The construction of PAUCam has been described in detail in the 2015 IFAE Report of Activities. The central 8 CCDs 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, in an optimal night, PAUCam can cover ~2 deg^2 per night in all filters, delivering low-resolution (R~50) spectra for ~30000 galaxies, ~5000 stars, ~1000 quasars, ~10 clusters. The resolution in redshift z depends on the exact number, width and location of the narrow filters.

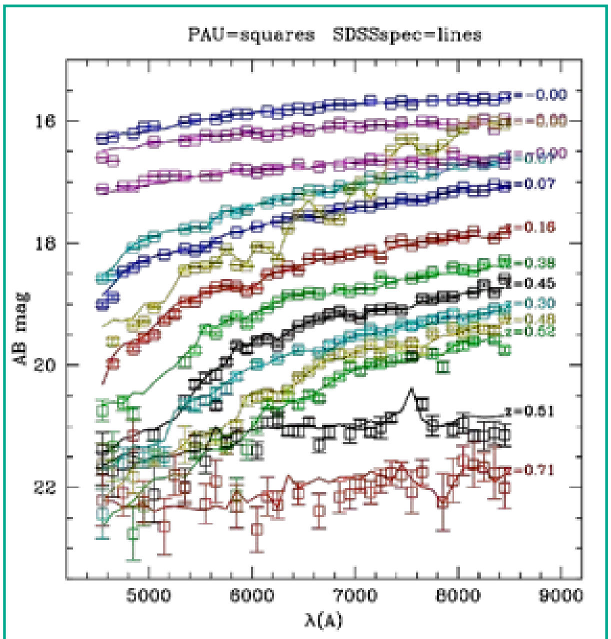


Fig. 5: Magnitudes of objects in the PAUCam filter system (squares). These objects were also measured by SDSS and the solid lines are the SDSS prediction for the magnitudes in the PAUS filters.

During the design a filter optimization study was carried out, converging in a solution with 40 narrow band filters (~10nm wide in wavelength) covering the range between ~470 and ~830nm. With this configuration PAUCam will be able to deliver very precise redshifts (σ_z~0.0035x(1+z)) for all galaxies with magnitude i_{AB} below 22.7, at the same time providing typical photometric redshift precision (σ_z~0.035x(1+z)) for galaxies with i_{AB} 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.

* 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.

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 PAUS), we refer to E. Gaztañaga et al., MNRAS, 422(2012) 2904. The combination of a deep photometric survey with a more shallow spectroscopic or PAUS-like photometric survey of the same area, can give very competitive results, even with a relatively small (200 deg^2) surveyed area.

Other topics of interest are being explored. For example PAUCam could be used to measure intrinsic alignment, which at present is one of the limitations in weak lensing surveys. It can also provide targets for future deep surveys now being planned.

PRELIMINARY RESULTS

The operation of the camera, including the control software and its interface with the WHT system, is now well established. The data are taken at the WHT and after some local processing are sent to the PIC almost immediately. Once at PIC the main task is to reduce the data, in particular to go through the MEMBA (Multi Epoch and Multi-Band Analysis) pipeline. It is inside MEMBA where the data are corrected and calibrated and where the objects are found. MEMBA has all the elements needed to deliver science-ready data for further analysis, although many of its components are changing as we add more and more refinements to the treatment of the data. Fig. 3 shows the overall PAU Data Management System.

PAU STUDIES ARE CENTERED IN TWO DARK-ENERGY RELATED OBSERVABLES, FOR WHICH PAUCAM IS UNIQUELY SUITED

Here we show only a few plots that illustrate where we are with the data analysis. Fig. 4 shows an image in one CCD, enlarged to increase the details. The quality of the image is quite good and one can see stars and galaxies of various magnitudes, Fig. 5 is a plot of light curves (in magnitudes) of several objects found in PAU that are also in the SDSS catalogue. The squares are the magnitudes in the PAU filters (not all of them have been exposed yet) while the curves are from SDSS. The agreement is quite good for objects at a wide interval of red-shifts, from z=0 to z=0.71.

Shown in Fig. 6 are the PAUS-spectra of two quasars at z = 6.08 and z = 3.108 as determined by SDSS. The former shows the typical Lyman Alpha Forest absorption lines that fall inside the wavelength reach of PAUS. The latter shows emission lines from the Lyman-Alpha to the C-III.

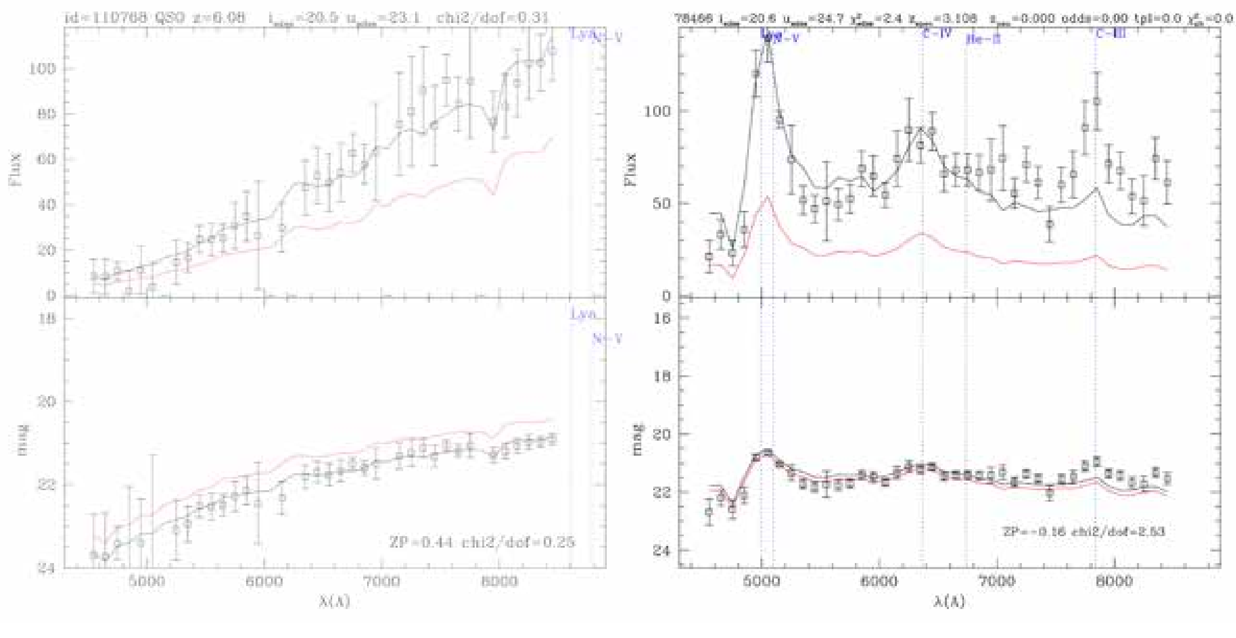


Fig. 6: The squares and bars in the two figures are the fluxes and errors of two quasars as measured in the 40 narrow band filters of PAUCam. The red lines show the fluxes of the same objects measured by SDSS in the PAU bands and the black lines are the same SDSS fluxes adjusted to the PAU aperture. As it can be seen the agreement between PAU and SDSS is very good. The figure on the left is a quasar at z=6.08 and what one sees are the Lyman-Alpha forest absorption lines. The Hydrogen Lyman emission line falls just outside the range of the wavelengths observed by PAU (vertical blue line). The figure on the right is from another quasar, at z=3.108. In this case one sees the region of the Lyman Alpha and N-V emission lines, where there is an obvious excess of flux as expected. One can also see enhancements in the flux at the C-IV and C-III emission lines.

2.8 THE EUCLID PROJECT

CRISTÓBAL PADILLA

Euclid is a mission for the European Space Agency (ESA) Cosmic Vision (CV) 2015-25 program 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

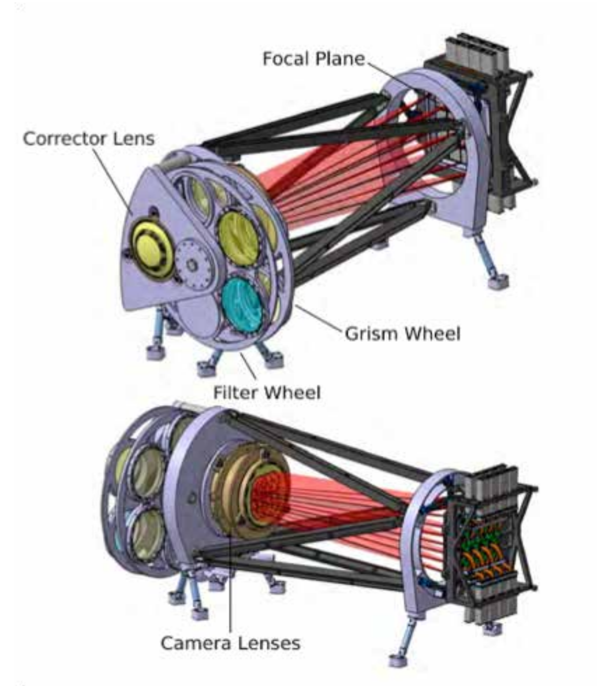


Fig. 1: Artistic view of the NISP Instrument. The FWA is mounted in front and select the filter that it is positioned in the light path coming from the mirror before being detected in the Focal Plane.

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 (Portal d'Informació de Catalunya) 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, 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 2300nm) photometry of all ga-

Fig. 2: Artist View of the Euclid satellite (Copyright ESA).

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 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

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

laxies 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.

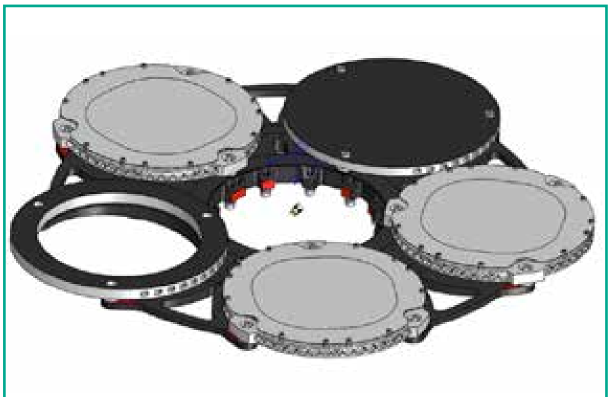


Fig. 4: The STM being tested in Applus.

Fig. 3: The STM wheel in the IFAE clean room after assembly.

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.

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. 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 Mo-

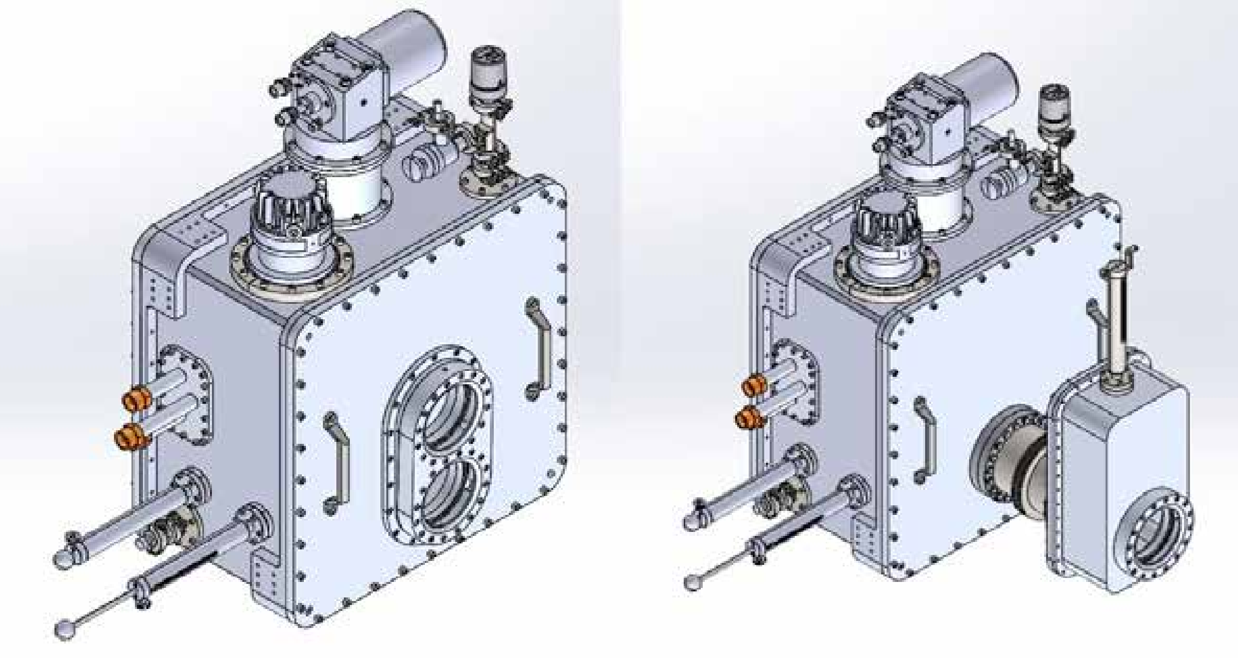


Fig. 5: Left: Drawing of the GSE to be used for the requirement verification at operational temperature. Right: The GSE configured for the interferometric measurements at operational temperature.

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

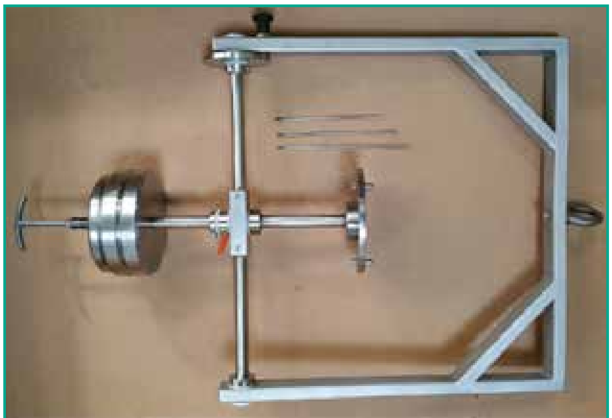


Fig. 6: The Mounting GSE delivered to LAM.

del (STM) which has been successfully delivered to ESA as part of the NISP-STM, together with the GSE mounting tool. During 2016, the project has reached the level of Consolidation Design Review (CDR), which is the step required to continue with the construction of the Engineering Qualification Model (EQM). Additional optical requirements at the NISP level have resulted in the introduction of baffles to collimate the light in the filters. That has resulted in a small redesign of the FWA to accommodate the filter mount baffles while maintaining the stringer requirements on total weight and Center of Gravity. The new design and the simulation studies have been finished. During 2016 there has been a lot of effort in defining the procedures to test the requirements of the FWA in operational conditions. To achieve this, a GSE (cryostat) has been fully designed at IFAE. This cryostat is under construction and will be used to thoroughly test the FWA models to be built during 2017: FWA-BBM (a non-deliverable model to perform internal tests), the EQM (Engineering Qualifying Model), the FM (Flight Model) and the FS (Flight Spares).

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), medical centers like Hospital Parc Taulí, or companies like Multiscan Technologies.

INTRODUCTION

IFAE's medical imaging 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 th group's research line is to mold this existing technology into a useful form to serve the interest of the public.

The group is developing a new generation of Positron-Emission-Tomography (PET) Scanner called VIP (Voxel Imaging PET) that will resolve many intrinsic limitations that are embedded in the current PET devices. In 2015 the full production of 180 VIP single layers was concluded and in 2016 the development continued while the group focused in other projects such as ERICA and a 3D-Breast Biopsy System. The VIP project is expected to presents its results in 2017.

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.

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

THE ERICA PROJECT

The ERICA (Energy Resolving Inline CAmera) project is funded by RETOS to develop a photon counting X-ray line camera for future scanner machine mainly in the field of quality control (non destructive) and airport security. To improve the imaging quality and in particular to detect relative minute difference in the material, the design of the ERICA chip includes an scheme to reduce the impact of the pixel charge sharing and hence regaining the spectroscopy feature in photon counting while maintaining small size pixel electrode. This resulted in patent application.

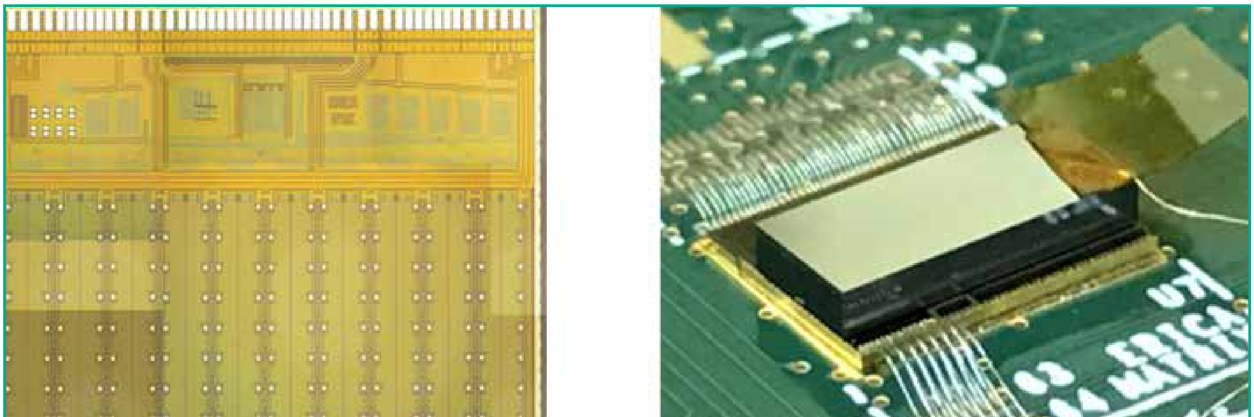


Fig. 1: Left: microphotography of ERICA-RUN2 ASIC. The top part of the ASIC is the backend where the DACs, and the backend control of the chip is. In bottom part of the ASIC one can see an array of 20 x 8 small circles indicating the input pad for each pixel. Right: image of ERICA-RUN2 chip bonded to pixel CdTe detector and wire bonded on a dedicated chip carrier. The packaging of the CdTe detector to the ERICA ASIC was done at IFAE.

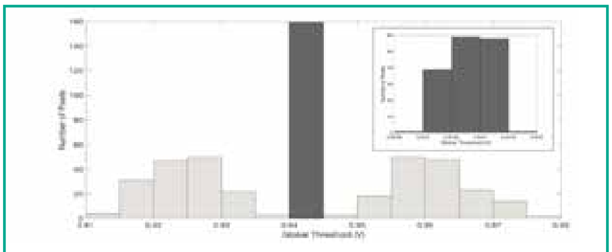


Fig. 2: shows the spread of the channels base line, which is around 35mV p-p, and after having the channels equalized the spread is around 1.5mV p-p.

A first prototype of the ERICA ASIC (RUN1) was produced in 2015. The prototype was extensively checked and few bugs were found. As a result of this, ERICA-RUN2 was submitted and produced in 2016 with the proper size, 6.8mm x 4.9mm, which represent an array of 20x8 pixels each 330μm x 330μm. 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 6 thresholds and 6 counters, each is 8 bits long. In Figure 1 one can see the image of the naked chip. The tests results showed good behavior and the chip is fully operation. The equalization of the base line for 160 channels can be seen in Figure 2 before and after equalization.

Each pixel has a 4-bits DAC for gain adjustment. This is an important feature needed when a photon counting pixel ASIC has more than one discriminator/counter in order to make sure that each counter has seen the photons of the energies between thresholdN and thresholdN+1. As shown in Figure 3, the gain equalizations of 160 channels has a spread from 400mV (6σ) before equalization and drops to to 20mV≈ 6keV (6σ) after equalization.

In order to allow the pixel handle high flux of rate without suffering pileup, the each pixel can be set to enable an automatic reset circuit based on constant current discharge that is enabled by the trigger of the pixel after a programmable delay as one can see in Figure 4. The characteristics of the ERICA ASICs are summarized in Table 1.

Table I. Main specifications of ERICA ASIC.

Pixel matrix dimensions	**8 x 20 pixels**
Pixel size	**330 μm x 330 μm**
Max count rate with charge summation	**1 Mcps/pixel**
Max frame rate @ 40 MHz clock	**3300 frame/s**
Charge sharing sum algorithm	**Digital**
# Energy bins	**6**
Technology	**TSMC 250 nm CMOS**
ASIC power consumption	**150 mW @ 40 MHz**
Voltage supply	**+2.5 V**
Average pixel front-end ENC	**90 e- RMS**
Gain dispersion after equalization	**220 e- RMS**
Offset dispersion after equalization	**33 e- RMS**
Dynamic range	**200 keV**
Preamplifier gain	**3.5 mV/keV**
Detector's leakage compensation	**Up to 5 nA/pixel**

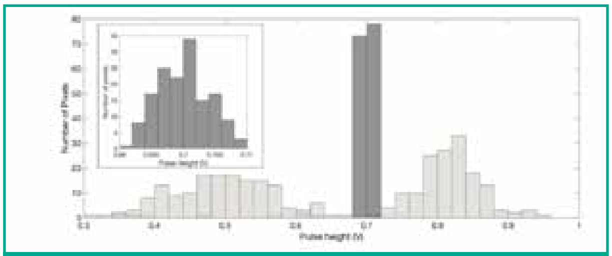


Fig. 3: shows gain spread of the 160 channels 400mV (6σ) before and 20mV(6σ) after gain equalization.

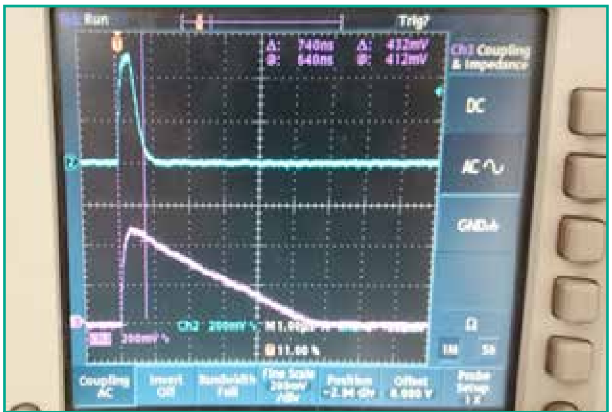


Fig. 4: shows the analog output of two pixels. The top pulse is from a pixel with automatic reset implemented and this forces the amplifier go back to the base line after 1μsec, while the bottom analog output is with the normal settings.

3D-BREAST BIOPSY SYSTEM

In the 2nd half of 2016 IFAE, Centro Nacional de Microelectronica (CNM-IMB), Hospital Parc Tauli, IDNEO Technologies S.L., and VENTURA Medical Technologies, were awarded a RIS3CAT grant to develop state of the art prone table 3D breast biopsy system, which is based, in part on a concept that has been invented by researchers from IFAE, CNM-IMB, and Hospital Parc Tauli.

This new system should make it easier for the medical doctor to perform the biopsy with more certainty and less trauma for the patient. The IFAE role is to develop a full X-ray camera, 5.4cm x 5.4cm. This include the design of the PCB holder of the pixel sensors, the production of the sensor assemblies with the flip-chip technique bonding the pixel CdTe to the pixel ASIC, wire bonding the sensor assembly on the Camera PCB, providing the read-write hardware-software drivers for the camera, cooling system to maintain the sensors at a controlled temperature, and as well the protection box with thin carbon fiber window in order not to attenuate the X-ray flux. The camera will be able to provide 10 frames/second. The project duration is 3 years.

"3D biopsy in tomosynthesis", RIS3CAT (reference COMRDI15-1-0022, Generalitat de Catalunya and FEDER)

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 focuses on investigating possible uses of HVCMOS tracking devices for near infrared detection, imaging, and soft X-ray detection. The other project profits from synergy effects from the collaboration of two IFAE research groups, 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.

HVCMOS DEVICES BEYOND HEP

The ATLAS pixel group is investigating the use of HVCMOS tracking devices for applications beyond HEP. This technology may overcome the limitations of current solutions on the market for near infrared detection, imaging, and soft X-ray detection. Furthermore, monolithic devices fabricated with standard CMOS technologies are potentially more cost effective. However, a lot of R&D is still required before having devices able to compete with existent products on the market. With this aim, the pixel group is working on the development of a detector based on HVCMOS for soft X-ray detection. A pixel matrix of 26 rows and 52 columns with a pixel size of 75 x 75 μm^2 was submitted for fabrication on November of 2016. The chip was designed with a 150nm HVCMOS process from LFoundry. The samples will be fabricated in two different substrate resistivities, 500 Ω·cm and 1900 Ω·cm, they are expected to be delivered in March 2017. The design effort was led by Raimon Casanova in collaboration with the University of Liverpool. The production cost was shared between IFAE, the University of Geneva and the University of Liverpool.

This is a first prototype and its main purpose is to demonstrate that it is possible to integrate the electronics for performing photon counting and the photodiode in the same pixel. Figure 5 (left) shows a cross section of the pixel with a block diagram of the main electronics elements. The sensing diode is the p-n junction between the DNWELL and the p-substrate. The junction is reverse biased from the top to a negative HV using a p-well (PW) ring that surrounds the DNWELL. A buried deep p-well (called PSUB in this technology) isolates the n-well (NW) from the DNWELL and allows the integration of digital CMOS electronics in the pixel. The collecting node is AC coupled to a charge sensitive amplifier. The rest of the electronics are a discriminator with a 4-bits DAC to fine tune the threshold voltage, and a 16 bits binary counter. The counter of a pixel can be enabled/disabled and readout independently from the other pixels.

Figure 5 (right) shows the layout of the chip. The total chip size is of 5mm x 2.5mm. The pixel matrix occupies the large part of the chip, 3900μm x 1950μm, and is surrounded by several guard rings. There are several test structures at the top of the pixel matrix, to perform TCT measurements.

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

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

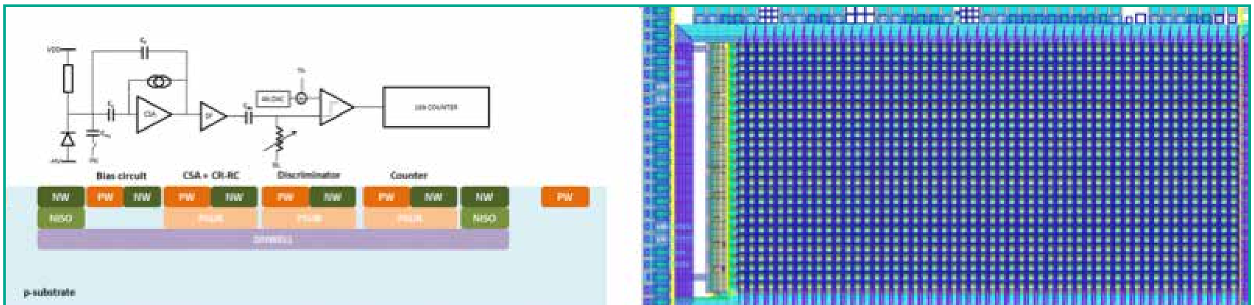


Fig. 5: Left: Cross section of the pixel. Right: layout of the photon counting chip.

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 construction of several of these pixels (called a "Light-Trap" pixel) has begun, with aims to integrate a 7-pixel cluster into a MAGIC camera in Spring, 2017.

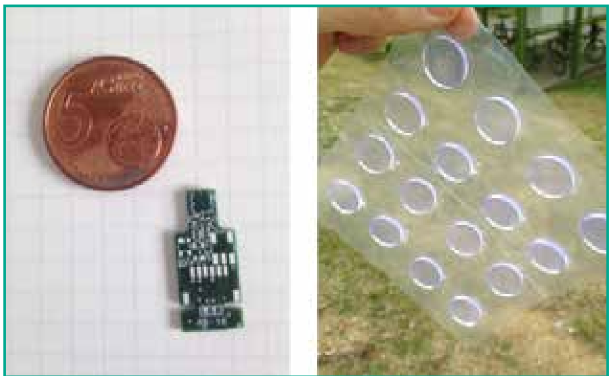


Fig. 6: Left: Newly developed IFAE SiPM read-out board . Right: 20mm Light-Trap disks to be used for Light-Trap prototype cluster.

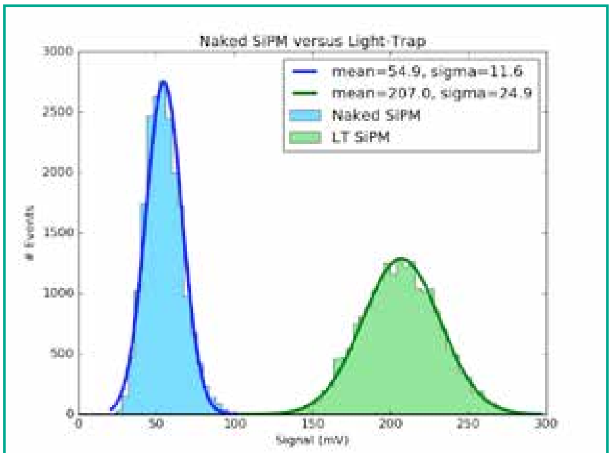


Fig. 7: SiPM (Blue) and Light-Trap (Green) signal amplitude distributions for UV light illumination.

CHARACTERIZATION OF ORGANIC SOLAR CELLS AS PHOTODETECTORS

In 2016, we initiated an interdisciplinary research project with the group of Emilio Palomares at the chemistry research institute ICIQ in Tarragona. The group is especialized in the development of organic solar cells for energy production. We obtained few samples from ICIQ and with the help of several undergraduates students we studied the response of the sensors to low intensity and fast pulsed light. The sensors were characterized as current sources. The layout of the ICIQ cell is shown in Figure 8.

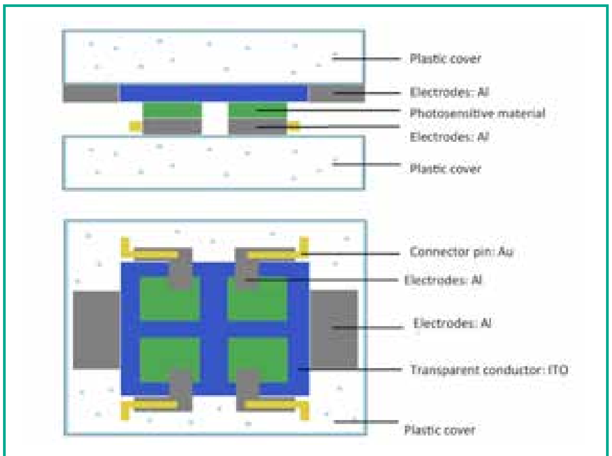


Fig. 8: Vertical and Horizontal projection of the cell components. The green squares represent the photoactive material. ITO is necessary to allow light transmition and to conduct electrons extracted from the material.

Measurements were performed with a load resistor that transformed the current into voltage that was read out by an ADC NI USB-6281 with an intrinsic noise of 6μV. The sensor was also polarised to evaluate the performance at different bias voltages. Finally, the system was illuminated with a pulsed LED and a 405nm laser. Typical pulses are shown in Figure 9. Results show a fast response followed by a pronounced reduction of the output current. This reduction in the response increases with the ilumination and reduces for inverted polarization as shown in Figure 9. The measurements show also different recombination times and a pronounced current inversion at the end of the ilumination. Preliminary results indicates that the sensor internal charge dynamics can be studied with this technique to optimize the sensors both for solar cell and for photodetection.

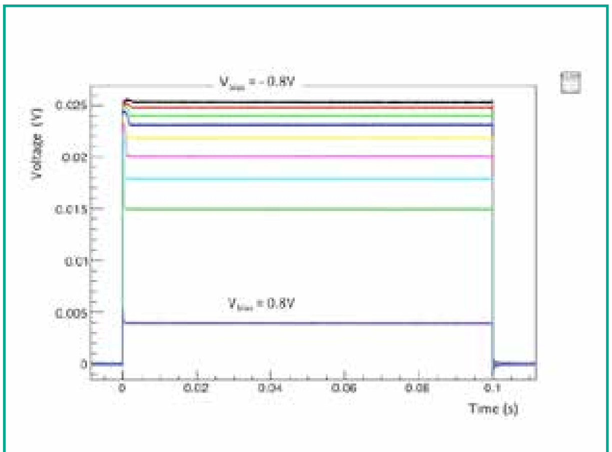


Fig. 9: Sensor response for constant led illumination with a pulse of 100 ms and different bias voltages. The most positive and negative biases are indicated. The other lines are taken in steps of 0.2 V.

2.10 PORT D'INFORMACIÓ CIENTÍFICA (PIC)

MANUEL DELFINO

The Port d'Informació Científica (PIC) is an innovative research support center, maintained under a collaboration agreement between IFAE and CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas). Using distributed computing technologies that include clusters, Grid, Cloud and Big Data, it offers services to manage large amounts of data to scientific collaborations whose researchers are spread all over the world.

DATA CENTER INFRASTRUCTURE

PIC's data center is located in UAB's Building D, which also contains UAB's University Computer Center and a point of presence of the Catalan Academic Network (Anella Científica).

PIC has two different vaults in the same building with different characteristics and energy efficiency profiles:

• A $150m^2$ air-cooled room which hosts the storage and computing IT equipment.
• A $25m^2$ liquid-cooled room which hosts only computing resources.

Fig. 1: PIC's liquid-cooled room with the CarnotJet System.

PIC HAS THE ONLY LIQUID IMMERSION DATA CENTER IN SPAIN, OPERATING SINCE EARLY 2016

PIC's air-cooled room, renewed in 2013-2015, has a raised-floor with 34 racks and 1400 rack units for IT equipment and a StorageTek SL8500 tape library (6600 slots, 56PB maximum capacity using T10KD cartridges). Complete hot-air containment increases cooling efficiency while ensuring optimal temperature conditions for the IT equipment according to the recommendations from organizations like the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE).

PIC's liquid-cooled room is in a fireproof enclosure in the basement of building D. Four Green Revolution Cooling oil immersion tanks (CarnotJet System) with specially designed oil to water heat exchangers are installed in the enclosure. This is the only liquid immersion data center in Spain and has been running in PIC since early 2016.

During 2016 we have been offering computing services deployed in this new IT facility. No incidents have occurred and the service has been available for scientific users with more than 97% availability.

To ensure service continuity from an electrical point of view, PIC has a modular 550KVA UPS. UAB provides three 500kVA motor generators to provide backup power for the whole building, which has a power feed of 2MVA.

SERVICE CATALOGUE

PIC supports a variety of scientific projects deploying computing and storage resources for intensive processing and analysis of huge amounts of data.

PIC's Data Center has a computing cluster with 6000 cores running on Linux servers and a hierarchical mass storage service currently holding about 7 PetaBytes on disk and 18 PetaBytes on magnetic tape. The main services we offer to the projects are listed below:

• Data handling and storage: About 25 PB of data are handled with two open source applications: dCache for disk storage and Enstore for tape. This capacity is expected to double by 2019.

• Data Processing. The computing batch system is based on PBS and HTCondor. This allows us to integrate computing resources from the WLCG (WorldWide LHC Computing Grid) and also local users. More than 16 million jobs have been executed during 2016, with an average computing power of 72 kHS06.

• Data Transfer, data access and network. External connectivity is based on a 20 Gbps link which implement a layer 2 private network (LHCOPN) between PIC, CERN and the other WLCG Tier-1s. We are also connected to the LHCONE network to connect to WLCG Tier-2s, as well as general-purpose NREN connectivity. The external network is deployed by collaboration between the Catalan NREN (CSUC, Anella Científica), the Spanish NREN (RedIRIS) and the Géant pan-European network. PIC is also well connected with La Palma, one of the Canary Islands where the Roque de los Muchachos observatory is located. The data recorded by the MAGIC and PAU telescopes in La Palma are transferred to PIC where they are quickly analysed just a few hours later in order to adjust the calibration parameters for the next observation period.

• Front-End services and user support: PIC offers to end users different options to access and analyse their scientific data. Depending on the project needs we deploy customized front-ends in order to optimize the delivery of users' scientific results.

The PIC data center and the Service Catalogue are manage and operated by the Infrastructure and Services group (V. Acin, E. Accion, C. Acosta, J. Casals, M. Caubet, R. Cruz, F. Lopez, E. Planas, B. Rodriguez).

	Active Files	Used Capacity (GB)
CTA	23.868	2.399
EUCLID	3.786	5.952
PAU	515.193	54.382
MICE	739.171	380.800
LHCb	382.266	983.293
MAGIC	1.382.016	1.564.984
ATLAS	4.257.862	4.035.969
CMS	1.615.201	4.444.029
TOTAL	8.919.363	11.471.808

Table 1: Tape capacity for each project supported by PIC.

	AssignedCapacity (GB)
VIP	9.771
Cosmohub	10.000
Mice	13.595
CTA	27.101
T2K	39.084
EUCLID	39.687
PAU	117.374
ATLAS-Tier3	276.067
MAGIC	382.139
LHCb	943.660
ATLAS-Tier2	1.156.790
CMS	1.690.700
ATLAS	2.366.947
Total	7.072.915

Table 2: Disk capacity for each project supported by PIC.

PIC is involved in the EU HNSciCloud Pre-Commercial Procurement project lead by CERN in order to deploy hybrid cloud prototypes oriented to science needs.

THE SPANISH WLCG TIER-1 DATA CENTER

The Worldwide LHC Computing Grid (WLCG) is a grid-based distributed computing infrastructure comprising resources from more than 170 centres in 34 countries. The WLCG is used to analyse the unprecedented rate of hundreds of Petabytes (PB) of data generated each year by the LHC. In WLCG, the computing centres are functionally classified in Tiers. Eleven of these centres (Tier-1s) receive a fraction of the raw data in real time from the Tier-0 at CERN. They are in charge of massive data processing, storage and distribution. The Spanish Tier-1 centre, located at PIC, provides services to three of the LHC experiments, accounting for 5.1% of the total Tier-1 capacity for ATLAS and CMS, and 6.5% for LHCb. The Tier-1 project at PIC was led during 2016 by Manuel Delfino (IFAE PI) and Josep Flix (CIEMAT PI).

At the end of 2016, the resources deployed by PIC for the Tier-1 were about 60 kHS06 (which correspond to about 4600 cores), around 5PB for disk storage space, and about 14PB for tape storage space. The resources deployed for the Tier-1 are typically ~80% of the total resources deployed at PIC.

The ATLAS, CMS and LHCb experiments consumed in 2016 about 26.8 kHS06, 18.8 kHS06, and 10.3 kHS06, respectively, of computing power (daily average) at PIC, about 78% of the total capacity.

The Tier-1 processed 43% of all the WLCG jobs executed in Spain (50% including the PIC ATLAS Tier-2 contribution, see below). At the end of 2016, disk usage for ATLAS, CMS and LHCb was 2.4PB, 1.7PB, and 0.9PB and tape usage was 4.0PB, 4.4PB, and 1.0PB, respectively.

One of the main characteristics of Tier-1 centres, beyond a very large storage and computing capacity, is being able to provide these resources through services that need to be extremely reliable. Being closely connected to the detectors' data acquisition, a maximum time for unintended interruption of the services in a Tier-1 is set to 4 hours, and a maximum degradation of Tier-0 to Tier-1 data acceptance of 6 hours. Critical services in a Tier-1 operate in 24x7 mode.

Service quality and stability are amongst the cornerstones of the project, therefore they are closely tracked by monitoring two metrics: site availability and reliability. These are built from dozens of sensors, for each of the experiments, which hourly probe the entire site Grid services, ensuring peer pressure and guaranteeing that the reliability of WLCG services keeps improving.

Figure 2 shows the site reliability ranking results of the Tier-1s in 2016. PIC Tier-1 is at the top of these rankings (99.7% ATLAS, 99.5% CMS, 99.8% LHCb), and well above the WLCG target, which is set to 97%, according to the MoU. The project has an expert contact person per experiment on site (Aresh Vedaee, Antonio Pérez-Calero, and Jordi Casals), communicating and coordinating experiment's priorities and resolving operational problems. These liaisons work in an integrated fashion with the Infrastructure and Services group to deploy and operate the challenging services needed, typically placing PIC at top reliability and stability levels.

2016 has been a year with many R&D activities at the PIC Tier-1: enabling IPv6 addresses for some of the services (after more than 3.5 years of extensive services tests), the increase of the PIC WAN connectivity to 20 Gbps (LHC transferred from/to PIC around 30PB of data during 2016), thorough testing and deployment of HTcondor as a replacement of the current batch system (Torque/MAUI), and tests and validation of the new OS (CentOS 7).

The next phase funding proposal to the Spanish National Research Plan for WLCG participation was submitted during 2016, and the corresponding coordinated project between IFAE and CIEMAT started 30th December 2016. The project is led by Josep Flix as project coordinator (CIEMAT PI) and Andreu Pacheco Pages (IFAE PI), with José Hernández and Carles Acosta as CIEMAT and IFAE co-PIs. This new project aims to federate the Tier-1 and the ATLAS and CMS Tier-2 resources from both institutions, aligning with the WLCG strategies towards HL-LHC. This multi-site federation of high performance data services presents many R&D challenges to face in the next three years.

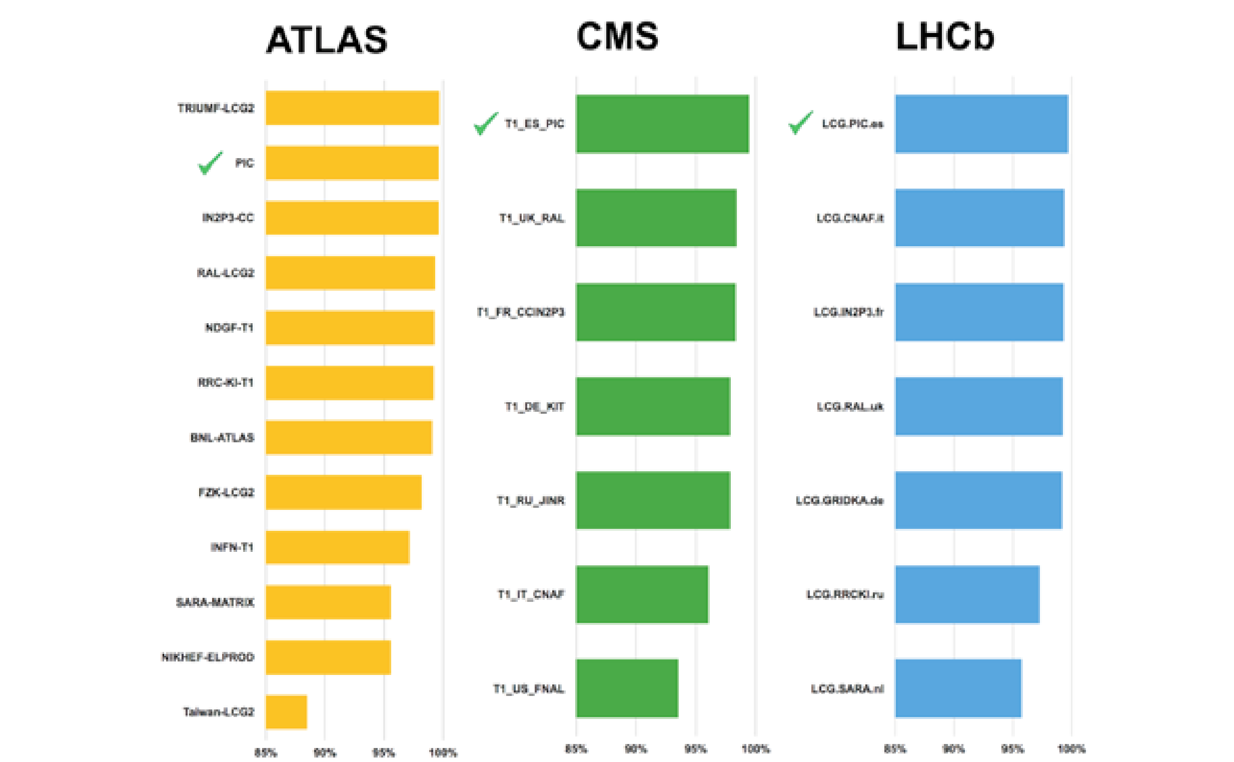


Fig. 2: ATLAS, CMS and LHCb Tier-1 reliability rankings 2016. Target 97%, according to MoU.

THE ATLAS TIER-2 INFRASTRUCTURE AND THE TIER-3 INTERACTIVE ANALYSIS FACILITY

Complementing the Spanish Tier-1 facility for the LHC projects, there are two other facilities related to ATLAS located at PIC: the IFAE Tier-2 and the IFAE Tier-3 Interactive Analysis Facility. PIC is the largest center in Spain providing computing resources to the LHC experiments and the only one covering all the workflows from raw data reprocessing to end-user analysis.

The ATLAS Tier-2 infrastructure at PIC is part of a federated service provided by a coordinated project between the Institut de Fisica Corpuscular (IFIC-CSIC) in Valencia, the Departamento de Física Teórica of the Universidad Autónoma de Madrid (UAM) and IFAE, funded by the Ministerio de Economía, Industria y Competitividad in Spain. Andreu Pacheco (IFAE PI) leads the project with the support of Aresh Vedaee and Alex Guinó.

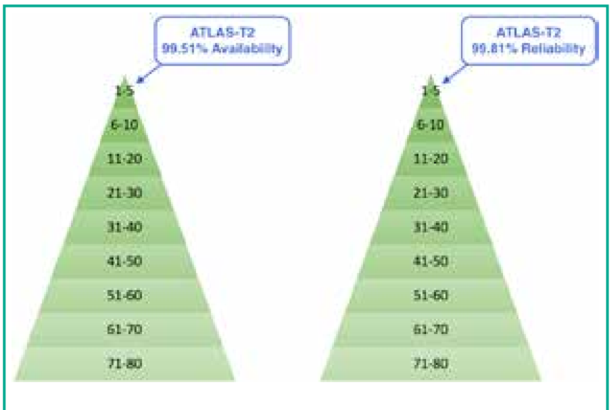


Fig. 3: These pyramidal figures show the ranking in reliability and availability between the ATLAS Tier-2 instance at PIC and the rest of the 78 LCG Tier-2 sites. The ATLAS-Tier2 at PIC also ranks at the top among all Tier2 Sites also with respect to the job CPU efficiency.

In terms of used resources, the ATLAS Tier-2 at PIC consumed in 2016 a daily average of 9.6 kHS06 (about 13% of the total PIC capacity), and 1.2 petabytes of disk storage at the end of the year. A total of 3.4 million jobs were submitted to the Tier-2 in 2016.

The Interactive Analysis Facility (Tier-3) facility at PIC is oriented to provide to ATLAS physicists at IFAE the efficient platform for the analysis of their data. The Tier-3 farm provides over 300 TB of group storage on disk, 100TB of storage on tape and has completed more than 500.000 analysis jobs for the IFAE ATLAS group.

As the farm is integrated with the ATLAS Tier-1 and Tier-2 at PIC, it has local access to the whole ATLAS data sample (4PB on disk and 4PB on tape). Computing power and disk available for analysis are increased automatically when needed, especially prior to key physics conferences, thanks to the dynamic resource allocation of PIC.

ASTROPHYSICS AND COSMOLOGY DATA PROCESSING

Services offered include support the Major Atmospheric Gamma Imaging Cherenkov Telescopes (MAGIC) Data Center, the development of simulations for the Euclid space mission, the integral treatment of data from the Physics of the Accelerating Universe (PAU), data quality analysis of the Dark Energy Survey (DES) project and support for the exploitation and distribution of the simulations of the Marenostrum Institut de Ciències de l'Espai (MICE) project.

The Astrophysics and Cosmology support group (C. Neissner , N. Tonello, J. Carretero, P. Tallada, J. Delgado, F. Torradeflot) develops innovative solutions to the data processing challenges in this area, deploying and operating services in collaboration with the Infrastructure and Services group.

MAGIC

PIC provides the reference Data Center for MAGIC, providing essential services of data transfer from the La Palma observatory, massive permanent storage of the data, real-time analysis, massive reanalysis and data distribution to the collaboration.

The amount of RAW data stored in the permanent storage of PIC, reached 1M files in 2016, which represents 1.3PB of data. User activities generated more than 200 support requests in the usage of the Data Center facilities. One of the main challenges of the year was the massive reprocessing of around 50TB of data, the largest reprocessing ever done by MAGIC. This massive reprocessing used new implementations of the ToMaRe (Tool for Massive Reprocessing) tool developed in 2015.

A major change in 2016 was the migration of the daily transfers software to FTS 3.5.8 version (provided by CERN, FTS is the tool used for LHC data transfers). This introduced important changes in the API that is used to manage transfers through FTS.

A new service provided to the whole MAGIC collaboration was designed and implemented according to requirements transmitted by the MAGIC group at IFAE. It is based on a database to collect the information associated to the detection of Flare events. This information is useful because these events are quite important and not so common in the observations, and also are associated to a specific analysis and publication. Thanks to this service, each user can query and quickly collect parameters related to Flare events.

EUCLID

During 2016 an advanced version of the Science Ground Segment infrastructure was implemented at the SDC-ES (the Spanish Euclid Data Center provided by PIC). This included new versions of the Infrastructure Abstraction Layer, the Distributed Storage System and the local part of the Euclid Archive System. The pipeline execution environment was also improved. In order to take the maximum advantage of PICs generic computing farm, we opted for the use of a semi-virtualized infrastructure where the pipelines run on containers based on Docker images.

The infrastructure has been tested in several data challenges focussing on functionality and/or performance. In addition, it is already used to produce simulated data for OU-SIM (the Simulation Organizational Unit) on a large scale.

In 2016 we produced simulations for the different Euclid channels: 2.1TB for VIS, 360GB for NIP and 270GB of images for NIS. The overall data challenges proved the interoperability of the different SDCs and the orchestration of data management and data processing.

Future work includes the development, testing and operation of updated versions of the SGS components. Further components will be developed as the project evolves.

While in 2014 and 2015 first prototypes and advancements of the simulation pipelines were tested, in 2016 more mature and complex simulators were implemented. That means that the actual simulators satisfy a broader spectrum of the requirements provided by the different OUs. First data sets have been produced and delivered to the OUs, where the data quality is evaluated.

During the development phase there is a very close working relationship with OU-SIM. Software development tasks are shared between SDC-ES and the different OU-SIM working groups. In our actual resource situation, this is the only way to keep the simulation schedule provided by OU-SIM on the basis of the OU requirements.

For the production of simulated images for the different Euclid channels, input from the Cosmological Science Working Groups is needed. We use the output of cosmological simulations provided by MICE and, more recently, from the Zürich group to provide input to the True Universe model used in OU-SIM. The simulation data are stored and later exploited at PIC. Using data processing pipelines developed at PIC we generate galaxy thumbnails (10s of TB) and catalogues (760GB) from dark matter distribution derived from N-particle simulations.

PAU

PAU had two observation periods in 2016, one in June and the other one in November. In total the camera produced 6.5TB of raw images, which were transferred through the network and stored at PIC. The data reduction of the raw data is executed automatically on arrival and produced a total of 9.3TB of data. The reduction pipelines are developed at PIC in collaboration with ICE.

COSMOHUB: A TRANSVERSAL SUPPORT PROJECT FOR EUCLID, PAU, DES AND MICE

2016 saw an immense increase in the number of users and provided object catalogues distributed through CosmoHUB. Of particular interest is the distribution of DES catalogues based on data of the first year of observation. Since the amount of distributed data has grown exponentially, the previous SQL based infrastructure has been replaced by a scalable Big Data solution. Work started in 2015 and a year later a new, scalable and more complex version of CosmoHUB was made public. The service includes for the first time real-time analysis and visualization of cosmological data. CosmoHUB was presented in several meetings and conferences, and became a premium product for the cosmology community.

The development of the platform at PIC has been carried out by J. Carretero, P. Tallada, J. Casals, M. Caubet, C. Neissner, N. Tonello, J. Delgado, F. Torradeflot and M. Delfino, in collaboration with S. Serrano and P. Fosalba from Institut d'Estudis Espacials de Catalunya (ICE-IEEC) .

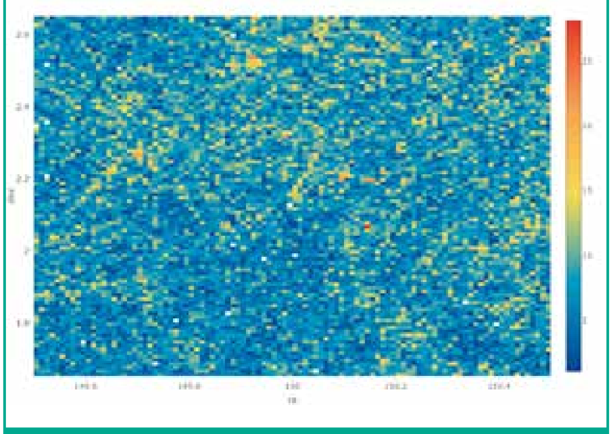
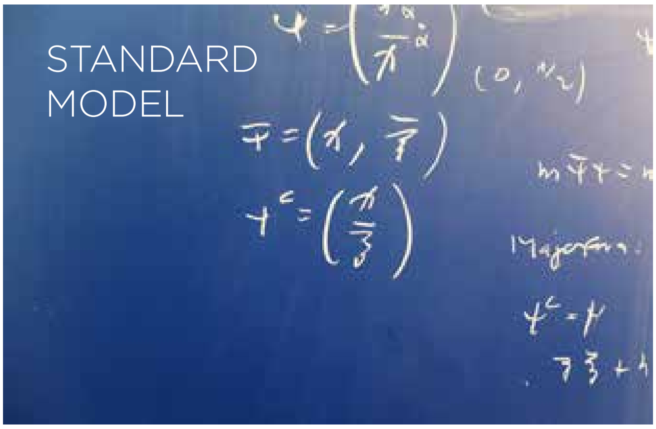
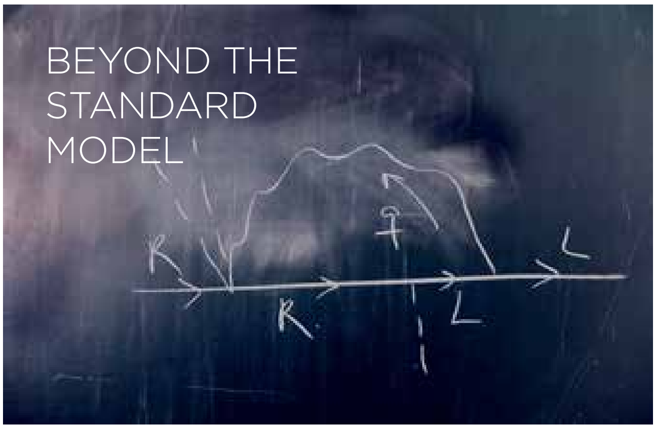
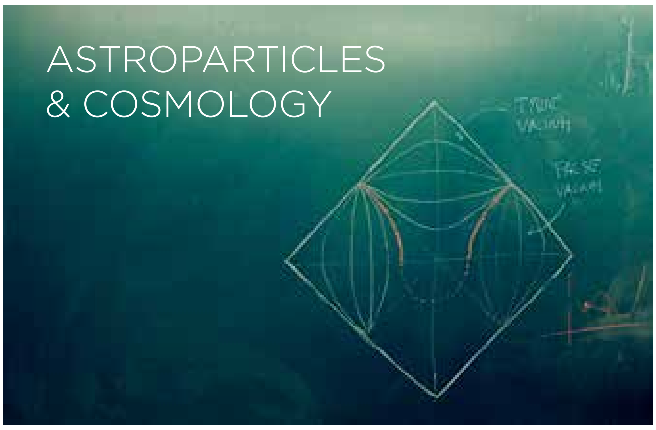


Fig. 4: Galaxy count for 1 square degree of the COSMOS region derived from first PAU survey data. The plot was generated using the CosmoHUB service.

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 2016, the central research fields in our group were studies of QCD at low energies, in particular a determination of the strong coupling from τ decays including duality violations, the description of heavy meson bound states and extraction of heavy quark masses, leptonic and radiative decays of η and η' mesons, semileptonic and hadronic decays of B and Bs mesons, as well as the behaviour of perturbation theory at high orders, its renormalisation scheme dependence, and renormalons.

THE GROUP INVESTIGATES THE PHENOMENOLOGY OF PARTICLE PHYSICS WITHIN THE REALMS OF THE STANDARD MODEL

Several different analysis methods have been developed to determine the strong coupling via finite-energy sum-rule analyses of hadronic τ decay data. While most methods agree on the existence of the well-known ambiguity in the choice of a resummation scheme due to the slow convergence of QCD perturbation theory at the τ mass, there is an ongoing controversy over how to deal properly with non-perturbative effects. These are small, but not negligible, and include quark-hadron "duality violations" (i.e. resonance effects), which are not described by the operator product expansion (OPE). In one approach, an attempt is made to suppress duality violations enough that they might become negligible. The number of OPE parameters to be fit, however, then exceeds the number of available sum rules, necessitating an uncontrolled OPE truncation, in which a number of higher-dimension OPE contributions in general present in QCD are set to zero by hand. In the second approach, truncation of the OPE is avoided by construction, and duality violations are taken into account explicitly, using a physically motivated model. In the work by S. Peris and collaborators, they provide a critical appraisal of a recent analysis employing the first approach and demonstrate that it fails to properly account for non-perturbative effects, making the resulting determination of the strong coupling unreliable. The second approach, in contrast, passes all self-consistency tests, and provides a competitive determination of the strong coupling from τ decays.

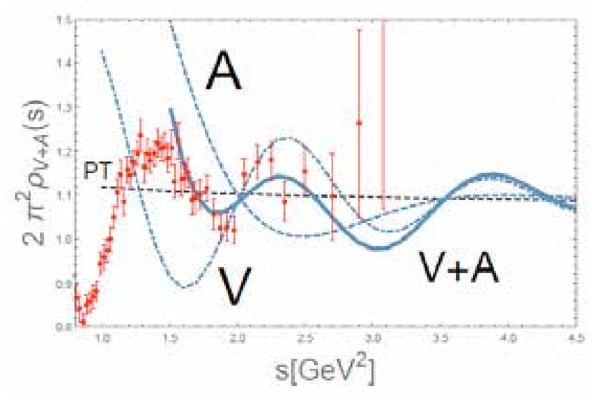


Fig 1: Blow-up of the large-s region of the V+A non-strange spectral function. Black dashed line: the perturbative (CIPT) representation of the model. Blue curve: full model representation, including DVs. Blue dot-dashed curves: separate V and A parts of the model spectral function. The blue curve shows maximal duality violations in V+A above 1.5 GeV^2 precisely at the τ mass scale.

S. Peris et al. furthermore investigated finite-volume effects in the hadronic vacuum polarization, with an eye toward the corresponding systematic error in the muon anomalous magnetic moment. Both recent lattice data as well as lowest-order, finite-volume chiral perturbation theory are considered, in order to get a quantitative understanding. Even though leading-order chiral perturbation theory does not provide a good description of the hadronic vacuum polarization, it turns out that it gives a good representation of finite-volume effects. They find that finite-volume effects cannot be ignored when the aim is a few percent level accuracy for the leading-order hadronic contribution to the muon anomalous magnetic moment.

Clara Peset, Antonio Pineda and Maximilian Stahlhofen have computed the spectrum of the B_c meson with next-to-next-to-next-to-leading order accuracy for the ground state and the excitations. The phenomenological analysis of this result may lead to competitive determinations of the bottom and charm masses from these systems They have also computed the effective theory (in particular the potentials) in the non-equal mass case with analogous accuracy. This result can be applied to different observables of the B_c system, as well as to future comparisons with lattice simulations.

Cesar Ayala, Gorazd Cvetic and Antonio Pineda have produced an updated value of the bottom quark mass from the NNNLO expression of the Upsilon(1S) mass, which is quite competitive if compared with other analyses.

The group of J. Matias and collaborators have been exploring in this period from a theoretical point of view, using QCD factorisation (QCDF) but also flavour symmetries, the problem associated to the very low experimental value of the longitudinal polarisation fraction of the non-leptonic $B0_s$->K*0 anti-K*0 decay. Recently in collaboration with LHCb experimentalists we have been analysing any possible source that could be responsible for this suppressed value. Our focus was on the strong tension between the branching ratio $B0_s$->K*0 anti-K*0 and the result found by other experiments concerning the U-spin related process Bd->K*0 anti-K*0 that turns out to be in good agreement with the QCDF prediction. We were using our experience in analysing different sources of uncertainties (S-wave or power corrections) for b to s transitions to understand this non-perturbative problem.

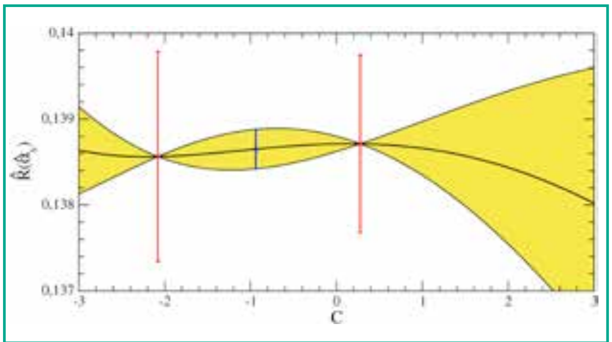


Fig 3: Prediction of the perturbative series for the Higgs decay rate into quark-antiquark pair. The yellow band indicates the higher-order uncertainty. Our best prediction corresponds to the blue dot and bar for values of C around -1.

The η' transition form factor was reanalysed by the goup of R. Escribano in view of the recent first BESIII observation of the radiative Dalitz decay $\eta' \to e^+e^-\gamma$ in both space- and time-like regions at low and intermediate energies using the Padé approximants method. The present analysis provides a suitable parameterisation for reproducing the measured form factor in the whole energy region and allows to extract the corresponding low-energy parameters together with a prediction of its values at the origin, related to $\Gamma_{(\eta' \to \gamma\gamma)}$, and the asymptotic limit. The η-η' mixing is reassessed within a mixing scheme compatible with the large-Nc chiral perturbation theory at next-to-leading order, with particular attention to the OZI-rule—violating parameters. The J/Ψ, $Z \to \eta^{(\prime)}\gamma$ decays are also considered and predictions reported.

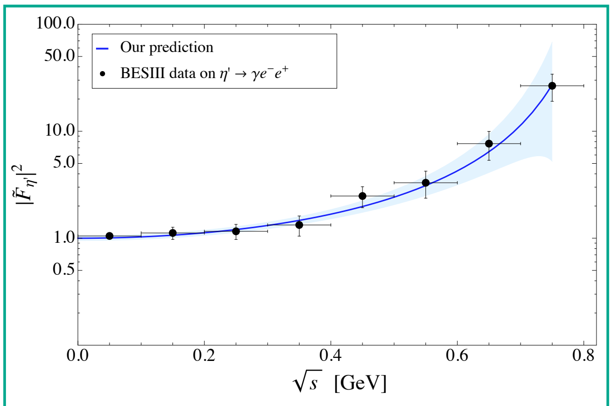


Fig 2: The prediction for the η' transition form factor in the time-like region obtained from our fit to space-like data as a function of the invariant mass. Experimental data points are from the BESIII measurement.

We analyse the second-class current decays $\tau^- \to \pi^- \eta^{(\prime)} \nu_\tau$ in the framework of Chiral Perturbation Theory with resonances. Taking into account π^0-η-η' mixing, the $\pi^- \eta^{(\prime)}$ vector form factor was extracted, in a model-independent way, using existing data on the $\pi^- \pi^0$ one. For the participant scalar form factor, we have considered different parameterisations ordered according to their increasing fulfilment of analyticity and unitarity constraints. We start with a Breit-Wigner parameterisation dominated by the $a_0(980)$ scalar resonance and after we included its excited state, the $a_0(1450)$. Furthermore, we provided an elastic dispersion relation representation through the Omnès integral. Then, we illustrated a method to derive a closed-form expression for the $\pi^- \eta$, $\pi^- \eta'$ (and $K^- K^0$) scalar form factors in a coupled-channels treatment. Finally, predictions for the branching ratios and spectra were discussed emphasising the error analysis. An interesting result of this study is that both $\tau^- \to \pi^- \eta^{(\prime)} \nu_\tau$ decay channels are promising for the soon discovery of second-class currents at Belle-II. We also predict the relevant observables for the partner $\eta_{l3}^{(\prime)}$ decays, which are extremely suppressed in the Standard Model.

M. Jamin and collaborators investigated the renormalisation scheme dependence of physical two-point correlation functions like the Adler function or the purely perturbative correction to the hadronic τ decay rate. Since the QCD coupling is not a physical observable but depends on scale and scheme choices, this also influences the higher-order behaviour of the respective perturbative series. These studies lead to a novel definition of the QCD coupling whose scale runing is explicitely scheme invariant. The scheme dependence of this new coupling can then be parametrised by a single parameter C. Hence, we call the new coupling the C-scheme coupling even though we are actually considering a whole class of schemes. It can then be demonstrated that appropriate choices of C can lead to substantial improvements in the perturbative prediction of physical observables.

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 is of great interest 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-β_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 has been performed. Furthermore, especially in the case of the scalar correlation function the introduction of the C-scheme coupling lead to substantial improvements in the perturbative prediction e.g. of the Higgs decay rate into a quark-antiquark pair.

2.12 BEYOND STANDARD MODEL

JOSÉ RAMÓN ESPINOSA

There are a number of reasons, both theoretical (hierarchy problem, strong CP problem, flavor problem, the origin of matter-antimatter asymmetry,...) and experimental (Dark Matter...) 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

The Standard Model (SM) stands as an impressive achievement but leaves open too many questions to be considered the ultimate fundamental theory, and we have strong reasons to expect physics beyond this SM (BSM). The IFAE BSM group explores what theories might supersede the SM and what experimental implications they would have, mostly at the Large Hadron Collider now in operation at CERN.

IFAE BSM GROUP EXPLORES WHAT THEORIES MIGHT SUPERSEDE THE SM AND WHAT EXPERIMENTAL IMPLICATIONS THEY WOULD HAVE

During 2016, the main research carried by the BSM group at IFAE has dealt with the following topics:

SUPERSYMMETRY

Mariano Quirós and Mateo García-Pepin, have collaborated with A. Delgado (U. of Notre Dame, USA), G. Nardini (U. of Bern, Switzerland), J. Santiago, R. Vega-Morales (U. of Granada), I. Antoniadis and K. Benakli (U. de Paris VI, Paris, France) studying supersymmetry breaking from five-dimensional theories using the Scherk-Schwarz mechanism, to obtain natural supersymmetry, and extending the MSSM by custodial triplets. The phenomenology and cosmological capabilities of the latter models have been analyzed in detail.

STRONG DYNAMICS/ COMPOSITE HIGGS MODELS

Giuliano Panico, collaborating with O. Matsedonskyi (DESY, Germany) and A. Wulzer (CERN, Switzerland), derived implications of the 8 TeV LHC data for the status of composite Higgs models. In particular they used the experimental data for the searches of new vector-like quarks to derive constraints on top partners both within an effective field theory approach and in more explicit models.

Alex Pomarol and Giuliano Panico proposed a new framework for realizing the flavor structure of composite Higgs models. The new scenario is built upon the assumption that the fermion Yukawa couplings for the different generations are generated at different dynamical scales. This framework proves very efficient in reducing the tension with the flavor

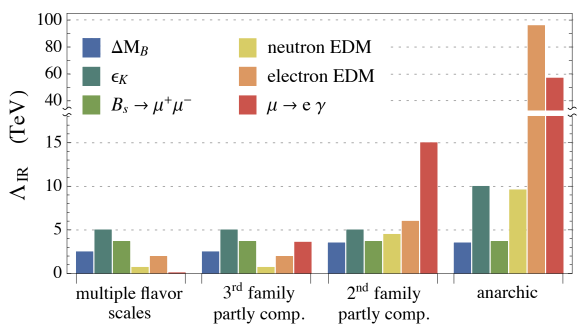


Fig. 1: Typical lower bounds on the new-physics scale Λ_{IR} coming from different flavor observables. The first set of bounds corresponds to the new scenario with different scales associated to each fermion generation. The second and third set of bounds correspond to scenarios in which the third and second generations follow the partial compositeness framework and are composite at the Λ_{IR} scale. Finally the fourth set of bounds corresponds to the anarchic flavor scenario.

constraints, especially in CP-violating observables, see Figure 1. Surprisingly, these scenarios are able to pass all flavor and CP-violating constraints.

Alex Pomarol, collaborating with D. Liu, R. Rattazzi (EPFL, Switzerland) and Francesco Riva (CERN), presented an exhaustive classification of patterns of strong dynamics that manifest exclusively through higher-derivative interactions, and explained how the LHC could access them. This allows to provide better strategies for the LHC in, for example, dibosons searches.

DIPHOTON CHANNEL

Some work motivated by the ATLAS diphoton excess (unfortunately gone in more recent experimental data) continued during 2016. Giuliano Panico, collaborating with A. Wulzer (CERN), proposed a general characterization of the resonant diphoton production channel. The framework can be used to obtain a comprehensive model-independent interpretation of the experimental data.

BSM EXPLANATION FOR THE B ANOMALIES

Mariano Quirós, Giuliano Panico and Oriol Pujolàs, in a collaboration with Eugenio Megías (MPI Munich, Germany) have searched for BSM explanations of the LHCb anomaly in B-meson decays. They found that this anomaly can be naturally explained in the context of BSM theories built on a warped extra dimension. The flavor anomalies can be easily reproduced by assuming that the bottom and muon fields have a sizable degree of compositeness. This degree of compositeness, quantified by the localizing coefficients c_{bL} and $c_{\mu L}$, is shown in Figure 2 which summarizes this work.

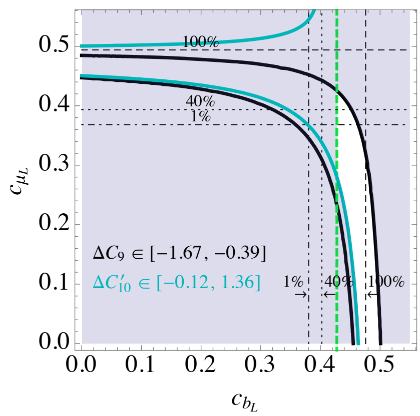


Fig. 2: Region that accommodates the Wilson coefficients C_9 (inside black lines) and C_{10} (inside green lines). Points to the left of the vertical dashed green lines are excluded by the flavor bounds.

EFFECTIVE POTENTIAL STABILITY

José Ramón Espinosa, in collaboration with M. Garny (CERN), T. Konstandin (DESY) and A. Riotto (U. Geneva), studied how to give a gauge-independent characterization of several physical scales associated with the possible existence of an instability of the SM effective potential extrapolated to the ultraviolet. This determination can be relevant for the BSM scale of physics that cures the instability, for the size of the tunneling critical bubbles, or the fate of the electroweak vacuum during inflation, see Figure 3 for an example.

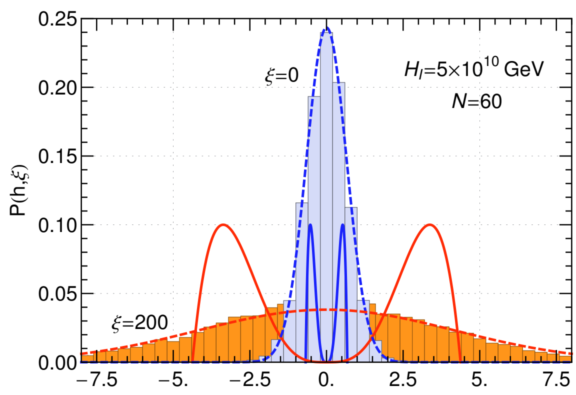


Fig. 3: Distribution of the Higgs field after 60 e-folds of inflation and SM effective potential, for two different values of the gauge-fixing parameter ξ. In spite of the apparent gauge-dependence it is possible to give a gauge-invariant definition of the probability to find the Higgs field inside the stable region of the potential.

José Ramón Espinosa, in collaboration with M. Garny (CERN) and T. Konstandin (DESY) also studied the connection between a solution of the infrared problem that afflicts the effective potential and its gauge dependence. They showed that the same resummation of the Goldstone propagator that cures the IR divergence problem also fixes the residual gauge dependence of radiatively generated minima.

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, key questions addressed also include: the nature of dark energy and dark matter as well as the development of modified gravity models. Last but not least, we also list here the application of new methods originating from modified gravity models and the gauge/gravity correspondence that can be useful for other areas like condensed matter physics. During 2016, the work done by the members of the Theory Division in this research area includes the following topics:

CONSISTENCY OF SCALAR POTENTIALS FROM QUANTUM DE SITTER SPACE

In collaboration with J.-F. Fortin and M. Trépanier (U de Laval, Quebec), J.R. Espinosa studied several aspects that emerge from the Standard Model scalar potential. Consistency of the interpretation of de Sitter space as a quantum theory of gravity with a finite number of degrees of freedom requires that Coleman-De Luccia tunneling rates to vacua with negative cosmological constant should be interpreted as recurrences to low-entropy states. This demand translates into two constraints, or consistency conditions, on the scalar potential which are generically: 1) 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 2) 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. These consistency conditions shed a different light on both outstanding hierarchy problems of the Standard Model of particle physics: the scale of electroweak symmetry breaking and the scale of the cosmological constant. Specifically, in this interpretation of quantum gravity the consistency with the scalar potential imples: i) a lower bound on the Higgs mass around 129 GeV. This grants that within this version of QG, new physics must appear below Planck scale; ii) An upper bound on the present vacuum vacuum energy, that could shed light on the Cosmological Constant problem.

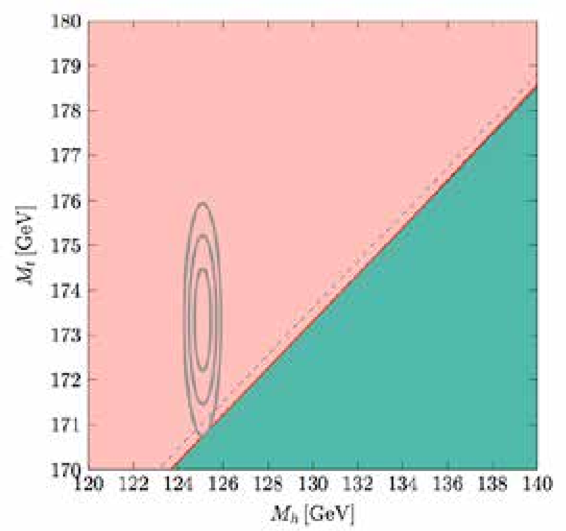


Fig. 1: Stability of the SM vacuum with the assumption that quantum de Sitter space is a quantum theory of gravity with a finite number of degrees of freedom. The 1σ (68% C.L.) to 3σ (98% C.L.) ellipses correspond to the measured values of the top (Mt = 173.3430.76GeV) and Higgs (Mh = 125.0930.24GeV).

APPLICATIONS OF THE GAUGE/GRAVITY CORRESPONDENCE TO CONDENSED MATTER PROBLEMS

The holographic (or gauge/gravity) duality has become 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 2016, O. Pujolàs and PhD student M. Baggioli have studied the application of Massive Gravity theories to model the response of strongly correlated materials – materials where interactions/correlations play a significant role. Examples of these materials include basically all known high-temperature superconductors and most strange metals. It is widely accepted that one can distinguish 3 different mechanisms responsible for the nontrivial (electrical) transport: electron-phonon (e-ph), electron-disorder (e-dis), and electron-electron (e-e) interactions. Remarkably, the gauge/gravity methods can clearly match these 3 mechanisms. The holographic models include 2 dynamical sectors (or operators): the charge current operator (encoding the mobile charges) and the translation-breaking operator that encodes both the phonons and the disorder, and which at the same time is reponsible for momentum non-conservation. With these ingredients, one can model and study materials where, e.g., a drop in the conductivity is due to a large interaction between the charges and phonons (e-ph), between the charge and disorder (e-dis) or even amongst the charges themselves (e-e) interactions. Mott insulators refer to the latter type, where charge-carrier self-interactions are dominant. The heuristic picture that summarizes the Mott behaviour is that of an electronic traffic jam: strong enough e-e interactions should, of course, prevent the available mobile charge carriers to efficiently transport charge.

O. PUJOLAS AND M. BAGGIOLI HAVE STUDIED THE APPLICATION OF MASSIVE GRAVITY THEORIES TO MODEL THE RESPONSE OF STRONGLY CORRELATED MATERIALS

In 2015, O. Pujolas and student M. Baggioli studied the models displaying electron-phonon interactions. In 2016, they constructed models for the electron-disorder and electron-electron interactions. Specifically, in JHEP 1612 (2016) 107, they constructed simple models of a metal-insulator transition that is driven by the electron-phonon interactions. These models "predict" a clear correlation between the presence of a drop in the conductivity due to these interactions and strong effects in the nonlinear electric response that can be seen in the current-voltage diagrams (Fig. 2). In JHEP 1701 (2017) 040, they constructed simple electron disorder models where a drop in the DC conductivity is generated only in presence of the coupling between the charge and the translation-breaking sector (Fig. 3).

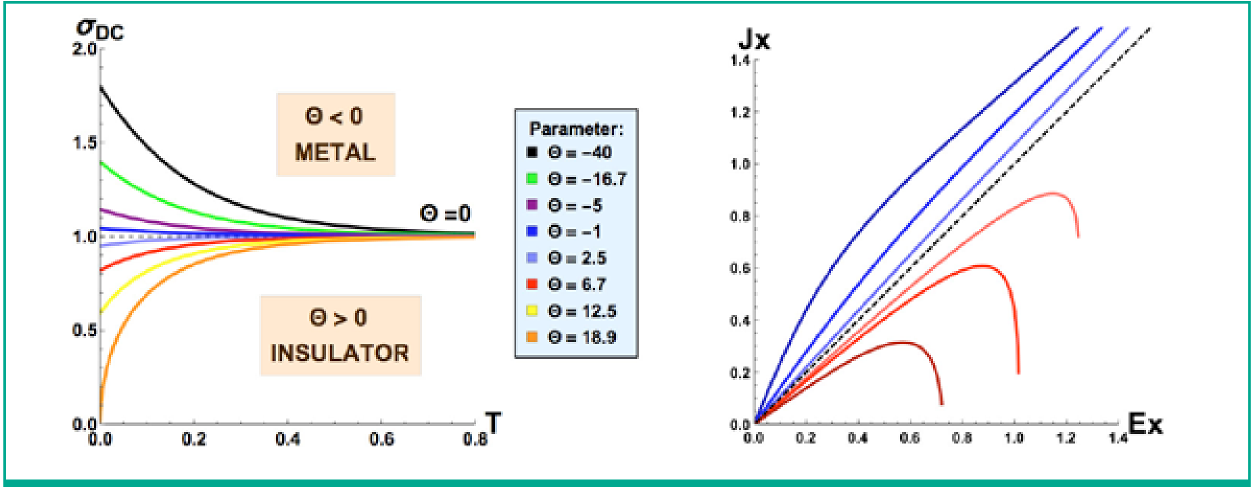


Fig. 2: Left: DC conductivity for the holographic models that include charge self-interactions, parametererized by the coupling Θ. For Θ>0 the interaction is repulsive and leads to insulator-like behaviour, whereas for Θ>0 it leads to metal-like behaviour.
Right: Current-Voltage diagram for the same non-linear models. The dashed line is Θ=0, (darker) red colour is for (more) positive Θ and blue for negative. This implies that a stronger metal-insulator transition is accompanied by stronger nonlinear effects in the nonlinear response.

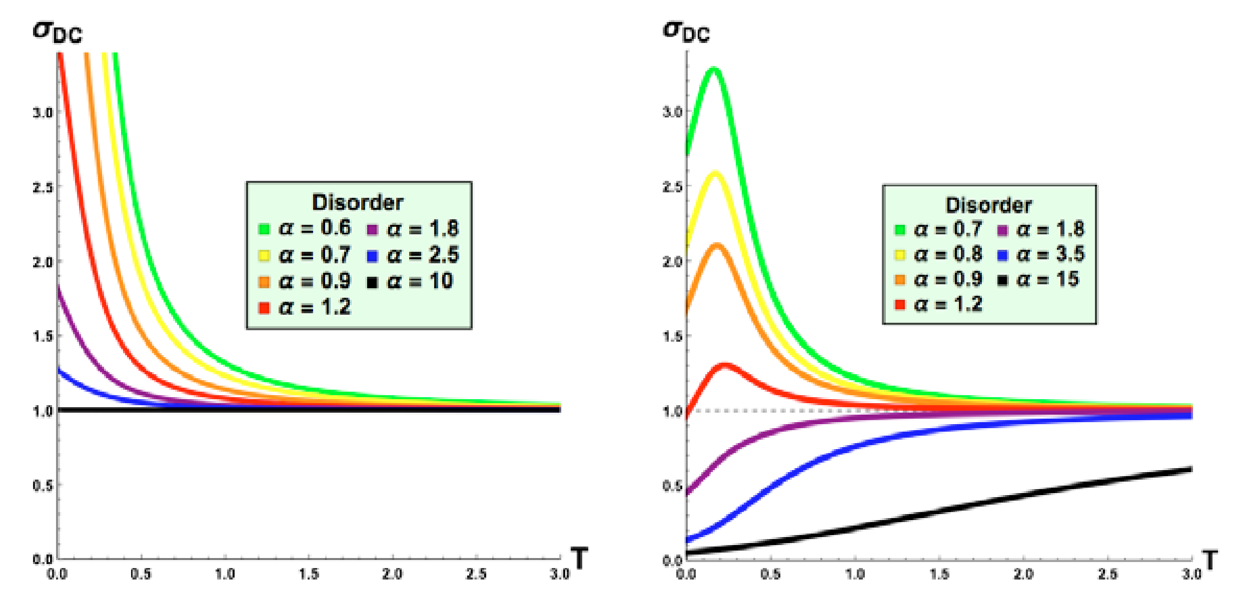


Fig. 3: Temperature-dependence of the DC conductivity at different disorder strengths, α, (i.e. graviton mass) for a model considered with fixed density of charge carriers, $\rho = 1$;
Left: In the models with no coupling between charge sector and disorder ($\kappa = 0$), one sees a metal-incoherent metal transition.
Right: Allowing the electron-disorder coupling $\kappa = 0.5$ (in the safe region of parameter space), metal-insulator transition is generated.

UNIVERSALITY OF THE VISCOSITY-TO-ENTROPY BOUND

Using AdS/CFT methods Kovtun Son and Starinets (KSS) found in 2004 a 'universal' bound on the viscosity to entropy density ratio. The "KSS" bound has been seen to hold in fluids and it is only close to be saturated in the quark-gluon plasma produced at heavy ion colliders, and a few other examples.

In collaboration with L. Alberte (ICTP Trieste), O. Pujolàs and PhD student M. Baggioli found (JHEP 1607 (2016) 074) that the KSS bound does not hold in a large class of certain black hole solutions of massive gravity models (similar to those used for the condensed matter applications). They found that these black holes exhibit both elasticity and visco-elasticity, that is, they behave like viscoelastic materials. In the constructed examples, both the shear elastic modulus, G, and the shear viscosity, η, can be easily computed and are both nonzero. They also proposed that viscoelastic materials may obey a generalized bound that combines the viscosity-to-entropy ratio and the shear elastic-to-pressure ratio, so that the two cannot be simultaneously arbitrarily small – see Fig. 4.

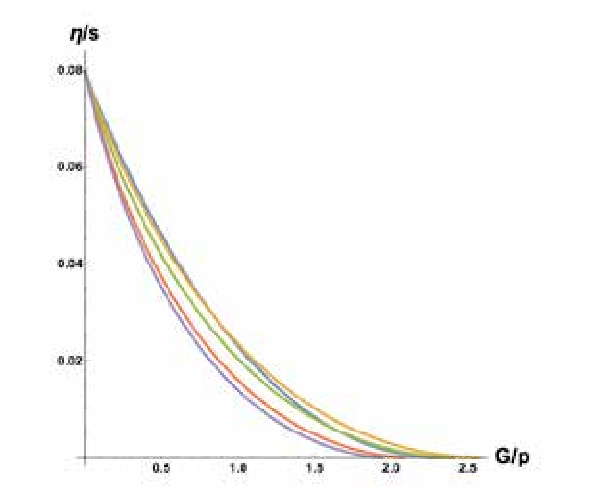


Fig. 4: Relation between the shear-viscosity and the shear-elasticity for the black holes in the simplest models, including the gravitational backreaction and a chemical potential $\mu = 1$ at different values of the black hole horizon location. The value of the graviton mass, m, and the temperature are changing along the solid lines, with m = 0 at the point where $\eta/s = 1/4\pi \approx 0.08$. Similar plots are obtained by keeping m constant and varying the temperature only.

3. PROJECTS **IN 2016**

ACTIVE PROJECTS

EUROPEAN COMMISSION

1. 653477
   Astronomy ESFRI and Research Infrastructure Cluster
   Javier Rico
2. 644294
   Japan and Europe Network for Neutrino and Intensity Frontier Experimental Research
   Federico Sánchez
3. 654168
   Advanced European Infrastructures for Detectors at Accelerators
   Sebastián Grinstein
4. 687614
   Helix Nebula – The Science Cloud (HNSciCloud)
   Manuel Delfino
5. 660138
   A SiPM upgrade for VHE Astronomy and beyond
   Juan Cortina

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

1. FPA2014-59855-P
   Física de neutrinos en T2K y I+D para futuros experimentos
   Federico Sánchez, Thorsten Lux
2. FPA2015-69260-C3-1-R
   Participación en el experimento ATLAS en el LHC: física, operación y actualización del detector
   Martine Bosman, Aurelio Juste
3. FPA2015-69818-P
   Operación y explotación científica de los telescopios MAGIC
   Javier Rico
4. FPA2013-48308-C2-1-P
   Detectores de pixels actuales y futuros para el experimento ATLAS
   Sebastián Grinstein
5. FPA2015-69260-C3-2-R
   Participación de IFAE en el experimento ATLAS en el LHC: actualización del detector
   Sebastián Grinstein
6. FPA2015-68048-C3-1-P
   Física fundamental y Cosmología con cartografiados extragalácticos
   Ramon Miquel, Enrique Fernández
7. FPA2013-47986-C3-1-P
   Cosmología y física fundamental con cartografiados extragalácticos
   Ramon Miquel
8. ESP2015-66861-C3-3-R
   Cartografiados cosmológicos para estudio de la Energía Oscura, preparación para Euclid
   Cristobal Padilla
9. ESP2014-58384-C3-2-P
   Cartografiados cosmológicos de Energía Oscura, preparando Euclid
   Cristobal Padilla
10. ESP2015-66861-C3-2-R
    Centro de Datos para Cartografiados Cosmológicos de Energía Oscura - 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. ESP2014-58384-C3-2-P
    Cartografiados Cosmológicos de Energía Oscura - preparando Euclid
    Christian Neissner
13. FPA2015-69210-C6-1-R
    Integración y puesta en funcionamiento del primer "Large Size Telescope" y otros elementos clave del proyecto ESFRI CTA
    Manel Martínez, Abelardo Moralejo
14. SEV-2012-0234
    IFAE
    Manel Martínez
15. 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
16. FPA2014-55613-P
    Física de las Interacciones Fundamentales
    Matthias Jamin
17. FIS2015-63313-CIN
    18th International Workshop on Radiation Imaging Detectors
    Thorsten Lux

IFAE | REPORT OF ACTIVITIES 2016 | **PROJECTS** 83

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

ACC10 (FEDER)

1. COMRDI15-1-0022
   3D biopsy in tomosynthesis, RIS3CAT
   Mokhtar Chmeissani

FECYT

1. FCT-15-9957
   Cazadores de Rayos Gamma
   Òscar Blanch

4. KNOWLEDGE & TECHNOLOGY **TRANSFER IN 2016**

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.

2016 TECH. TRANSFER OUTPUT AT IFAE

0.7M€

COMPETITIVE FUNDS FROM COLLABORATIVE RESEARCH AND INNOVATION ACTIONS WITH PRIVATE SECTOR

54k€

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

2

PCT APPLICATION FILED

1

EUROPEAN PATENT APPLICATION FILED

COLLABORATIVE RESEARCH

- Catalan R&D 3D Biopsy system project funded within the "RIS3CAT TEC-HEALTH Community" (ACCiÓ, Generalitat de Catalunya) with the participation of 2 companies, 1 research center and 1 hospital (Spain).

CONTRACT RESEARCH & SERVICES

- 6 Technical Services executed (mechanical engineering, microelectronics, computing)
- 2 R&D Agreements signed with companies (electronics engineering, computing)
- 8 Customers (2 new)
- 1 Pre-accreditation granted for supplying IFAE technology to CERN via public tenders.

PROTECTION, VALORIZATION & LICENSING

- 8 Disclosure of Inventions evaluated (weather & environment, synchrotron beams, communications, computing, quality control imaging, subsoil imaging, medical imaging x2) including patent & product search, market research, exploitation and protection strategy analysis.
- 2 PCT applications filed (energy resolving line scan camera, PSK demodulator for IoT devices)
- 1 European patent application filed: Innovative PET system and method for advanced medical imaging.
- 2 Patents in force in 9 international patent extensions (medical physics and communications).
- 1 Open source license for a data management software (CTA project).
- 1 Course of intangible assets valuation co-organized and hosted at IFAE (Herrero & Asociados - BIST).

SPIN-OFF CREATION

- 1 Entrepreneurship course for Post-Doc researchers co-organized, “From Science to Business” (ESADE - BIST).

5. PERSONNEL **IN 2016**

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.
In 2016 IFAE received the 'HR Excellence in research' award for the Human Resources Strategy and the Action Plan 2016-2019 submitted to Euraxess. In this framework, IFAE developed a protocol for dealing with, preventing and eradicating workplace harassment.

EXPERIMENTAL DIVISION
FACULTY

Blanch, Òscar	Research Associate Professor, GAMMA-RAY, IFAE
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
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
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
Riu, Imma	Research Associate Professor, ATLAS, IFAE
Sánchez, Federico	Research Associate Professor, NEUTRINOS, IFAE

SCIENTIFIC POST-DOCS

Aleksić, Jelena	COSMOLOGY
Bonnet, Christopher	COSMOLOGY (until May 2016)
Bordoni, Stefania	NEUTRINOS (until Mar 2016)
Cortés, Arely	ATLAS, Juan de la Cierva Fellow (until Mar 2016)
Cumani, Paolo	GAMMA-RAY
Farooque, Trisha	ATLAS, (until September 2016)

Glatzer, Julian	ATLAS, P-SPHERE Fellow (since Jul 2016)
Gerbaudo, Davide	ATLAS, Juan de la Cierva Fellow (since Jan 2016)
Gonçalvez dos Anjos, Nuno	ATLAS, Beatriu de Pinos Fellow (until May 2016)
Griffiths, Scott	GAMMA-RAY
Hassan, Tarek	GAMMA-RAY
Herrera, Javier	GAMMA-RAY
Kolstein, Machiel	VIP
Kovács, András	COSMOLOGY, Juan de la Cierva
Lange, Joern	ATLAS-Pixel, Juan de la Cierva Fellow
Leyton, Michael	NEUTRINOS, SPHERE Fellow (since Jul 2016)
Noda, Koji	GAMMA-RAY, SPHERE Fellow (since Dec 2016)
Terzo, Stefano	ATLAS Pixels, (since Apr 2016)
Tripiana, Martín	ATLAS
Valery, Loïc	ATLAS
Ward, John E.	GAMMA-RAY, Marie Curie Individual Fellowship
Will, Martin	GAMMA-RAY
Zaidan, Remi	ATLAS (since Sep 2016)

DOCTORAL STUDENTS

Bourguille, Bruno	NEUTRINOS, PhD Fellowship SO-LA CAIXA
Casolino, Mirko	ATLAS, FI AGAUR
Cavallaro, Emanuele	ATLAS-Pixels, PhD Fellowship SO-LA CAIXA
Çolak, Merve	GAMMA-RAY, PhD Fellowship SO-LA CAIXA (since May 2016)
Fernández, Alba	GAMMA-RAY, PhD Fellowship FPI-MINECO
Fischer, Cora	ATLAS, PhD Fellowship FPI-MINECO
Foerster, Fabian	ATLAS-Pixels, PhD Fellowship SO-MINECO
Fracchia, Silvia	ATLAS (until Nov 2016)
García, Alfonso	NEUTRINOS, PhD Fellowship FPI-MINECO
Gatti, Marco	COSMOLOGY, PhD Fellowship SO-LA CAIXA
Guberman, Daniel	GAMMA-RAY, PhD Fellowship SO-MINECO
López, Iván	ATLAS-Pixels, PhD Fellowship SO-MINECO
Manna, María	ATLAS-Pixels, (since May 2016)
Nogués, Leyre	GAMMA-RAY, PhD Fellowship SO-MINECO
Ninci, Daniele	GAMMA-RAY, PhD Fellowship SO-LA CAIXA
Palacio, Joaquim	GAMMA-RAY, PhD Fellowship SO-MINECO
Prat, Judit	COSMOLOGY, PhD Fellowship SO-MINECO
Rizzi, Chiara	ATLAS, PhD Fellowship SO-LA CAIXA
Rodríguez, Andrea	ATLAS, PhD Fellowship SO-MINECO
Sánchez, Carles	COSMOLOGY, PhD Fellowship SO-MINECO
Tsiskaridze, Shota	ATLAS-Pixels, FI AGAUR (until Jun 2016)
Van Daalen, Tal	ATLAS, PhD Fellowship SO-LA CAIXA (since Oct 2016)
Vázquez, David	ATLAS-Pixels, PhD Fellowship FPI-MINECO
Vielzeuf, Pauline	COSMOLOGY, PhD Fellowship SO-La Caixa

THEORY DIVISION
FACULTY

Escribano, Rafel	Associate Professor, UAB
Espinosa, José Ramón	Research Professor, ICREA
Jamin, Matthias	Research Professor, ICREA
Massó, Eduard	Professor, UAB
Mathias, Joaquim	Associate Professor, UAB
Méndez, Antonio	Professor, UAB
Pascual, Ramon	Professor Emeritus, UAB
Peris, Santi	Associate Professor, UAB
Pineda, Antonio	Associate Professor, UAB
Pomarol, Àlex	Professor, UAB
Pujolàs, Oriol	Research Associate Professor, IFAE
Quirós, Mariano	Research Professor, ICREA

SCIENTIFIC POST-DOCS

Anzai, Chihaya	IFAE (since Oct 2016)
Franceschini, Roberto	IFAE (Oct 2016 until Dec 2016)
Lorente, Òscar	UAB
Masjuan, Pere	Visitor Professor, UAB (since Sep 2016)
Panico, Giuliano	IFAE, SO Fellowship (since Oct 2016)

DOCTORAL STUDENTS

Baggioli, Matteo	PIF Fellowship UAB (until Sept 2016)
Cáncer, Víctor	PhD Fellowship SO-La Caixa (since Sep 2016)
Capdevilla, Bernat	PhD Fellowship SO-MINECO
García, Mateo	PIF Fellowship UAB
González, Sergi	PhD Fellowship FPI-MINECO (until Nov 2016)
Hornung, Dirk	PIF Fellowship UAB
Lobregat, Xavier	PhD Fellowship SO-La Caixa (since Jan 2016)
Miravitllas, Ramon	PhD Fellowship FPI-MINECO
Montull, Marc	Teaching Assistant (until Nov 2016)
Moreno, Daniel	PhD Fellowship SO-MINECO
Peset, Clara	Predoctoral Student (until Sep 2016)
Petrossian, Rudin	PhD Fellowship BIST (since Oct 2016)
Riembau, Marc	PhD Fellowship SO-LA CAIXA
Salas, Lindber	PhD Fellowship SO-MINECO
Vantalon, Thibaud	PhD Fellowship SO-MINECO
Yang, Ke	Chinese Scholarship Council (until Mar 2016)

TECHNICAL SERVICES
ENGINEERING STAFF

Abril, Óscar	Electronics Engineer (until Mar 2016)
Ballester, Otger	Software Engineer
Boix, Joan	Electronics Engineer
Cardiel, Laia	Electronics Engineer
Casanova, Raimon	Electronics Engineer
Gálvez, José Antonio	Mechanical Engineer
García, Rafael	Mechanical Engineer (until Oct 2016)
García, Jorge	Electronics Engineer
Illa, José Mª.	Electronics Engineer
Jiménez, Jorge	Electronics Engineer
Lamensans, Mikel	Mechanical Engineer (until Dec 2016)
Llorente, Paloma	Electronics Engineer (until Jan 2016)
Macías, José Gabriel	Microelectronics Designer
Martínez, Óscar	Electronics Engineer
Mundet, Julià	Mechanical Engineer
Pío, Cristóbal	Software Engineer
Prats, Xavier	Electronics Engineer
Puigdengoles, Carles	Electronics Engineer

COMPUTER SCIENTISTS

Campos, Marc	Computer Scientist
Guinó, Alex	Computer Scientist
Martínez, Ivette	Computer Technician (since Jan 2016)
Pacheco, Andreu	Senior Applied Physicist (Computing), IFAE

TECHNICIANS

Arteche, Carlos	Mechanical Technician (until Apr 2016)
Benedico, David	Mechanical Technician
Colombo, Eduardo	MAGIC Support Technician
Delgado, Noel	Mechanical Technician (since Jun 2016)
González, Álex	Electronics Technician
Gaweda, Javier	Mechanical Technician
Peregrina, Eric	Electronics Technician
Quispe, Armando	Electronics Technician (since May 2016)
Román, David	Software Technician (since May 2016)
Sánchez, David	Support Technician (since Jun 2016)
Vera, Janick	Mechanical Designer (since Feb 2016)

PORT D'INFORMACIÓ CIENTÍFICA

Accion, Esther	Engineer, Infrastructure & Services, IFAE
Acin, Vanessa	Engineer, Infrastructure & Services, IFAE
Acosta, Carles	Researcher, Infrastructure & Services, IFAE
Carretero, Jorge	Researcher, Astrophysics & Cosmology, IFAE
Casals, Jordi	Engineer, Infrastructure & Services, CIEMAT
Caubet Serrabou, Marc	Engineer, Infrastructure & Services, CIEMAT
Cruz, Ricard	Technician, Infrastructure & Services, IFAE
Delfino, Manuel	Professor, PIC, UAB
Delgado, Jordi	Researcher, Astrophysics & Cosmology, IFAE
Flix, Jose	Researcher, LHC Computing, CIEMAT
Lopez, Fernando	Engineer, Infrastructure & Services, CIEMAT
Neissner, Christian	Researcher, Astrophysics & Cosmology, IFAE
Perez-Calero, Antonio	Researcher, LHC Computing, CIEMAT
Planas, Elena	Engineer, Infrastructure & Services, IFAE
Porto, Mari Carmen	Project Manager, CIEMAT
Rodriguez, Bruno	Engineer, Infrastructure & Services, IFAE
Tallada, Pau	Engineer, Astrophysics & Cosmology, CIEMAT
Tonello, Nadia	Researcher, Astrophysics & Cosmology, IFAE
Torradeflot, Francesc	Engineer, Astrophysics & Cosmology, IFAE (since Sep 2016)
Trilla-Kessler, Ada	Secretary, IFAE (until Oct 2016)
Vedaee, Aresh	Researcher, LHC Computing, IFAE

RESEARCH SUPPORT
TECHNOLOGY TRANSFER

Esparbé, Isaac	Head of KTT Department
De la Rosa, Gloria	KTT Officer

COMMUNICATION AND PUBLIC OUTREACH OFFICE

Grinschpun, Sebastián	Communication & Public Outreach Manager
Labián, Alícia	Communication & Public Outreach Officer

RESEARCH PROJECTS OFFICE

Balza, Marta	Research Project Manager

ADMINISTRATION

Bosch, Joaquim	General Manager
Cárdenas, Cristina	Secretary, UAB
El Kouraichi, Ijlal	Administrative Assistant
Gaya, Josep	Senior Administrator, UAB
Jiménez, Elisabet	Administrative Assistant
Gómez, Marta	Administrative Assistant
Strauch, Sara	Administrative Assistant

6. INSTITUTIONAL **ACTIVITIES IN 2016**

In this section we list the institutional activities undertaken by IFAE in 2016. 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.

2016 SCIENTIFIC OUTPUT AT IFAE

239

NUMBER OF INDEXED JOURNAL ARTICLES

94.1%

% ARTICLES IN FIRST QUARTILE JOURNALS

4.9

AVERAGE JOURNAL IMPACT FACTOR (IF)

TOP 5 JOURNALS (BY IF) WHERE IFAE PUBLISHED IN 2016	NUMBER OF ARTICLES
Phys. Rev. Lett. (IF 7.3)	9
J. High Energy Phys. (IF 5.2)	45
Astrophys. J. (IF 5.9)	14
JCAP (IF 5.6)	1
Astron. Astrophys. (IF 5.2)	10

TOP 5 JOURNALS WHERE IFAE PUBLISHED MOST FREQUENTLY	
Phys. Rev. D (IF 4.5)	46
J. High Energy Phys. (IF 6.1)	45
Eur. Phys. J. (IF 4.9)	42
Phys. Lett. B (IF 4.8)	30
Mon. Not. Roy. Astron. Soc. (IF 4.9)	20

DOCTORAL THESES: **8**

NUMBER OF PRESENTATIONS AT INTERNATIONAL CONFERENCES: **120**

6.1 MASTER & DOCTORAL THESES IN 2016

MASTER & DIPLOMA

Laura Cabanyol
Improvement of the first images taken by the PAUCam camera.
February 2016, Advisor: Enrique Fernández

M. Granado
Characterization of 3D Strip Silicon Detectors with the Transient Current Technique
September 2016, Advisors: Stefano Terzo and Sebastián Grinstein

Lluís Simon
TCT Measurements on 3D Small Pitch Strip Detectors
September 2016, Advisors: Joern Lange and Sebastián Grinstein

Alejandro Bellotti
Discriminant studies for H^+->tb in the one-lepton-channel
July 2016, Advisor: LL.-M. Mir

Héctor Salvador
Search for production of vector-like top quark pairs in the lepton-plus-jets-plus-E_T^{miss} final state in simulated pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector at the LHC
September 2016, Advisor: A. Juste

Ángel Joaniquet Tukiainen
A comparison of Transposition Relations in non-linear non-holonomic mechanics
September 2016, Advisor: R. Escribano

Mateo Garcia-Pepin
Supersymmetry with custodial triplets
June 2016, Thesis Advisor: Mariano Quirós

Sergi Gonzàlez-Solís
Phenomenological applications of eta and eta' mesons
July 2016, Thesis Advisor: R. Escribano

Matteo Baggioli
Solid applications of Holographic Massive Gravity
September 2016, Thesis Advisor: O. Pujolàs.

Marc Montull
Higgs Phenomenology and the Hamiltonian Truncation Method
November 2016, Thesis Advisor: Alex Pomarol and Francesco Riva

Silvia Fracchia
Search for third generation squarks in all-hadronic final states at the LHC with the ATLAS detector
December 2016, Thesis Advisor*: M. Martínez Pérez*

DOCTORAL THESES

Clara Peset
Effective field theories for heavy quarkonia and hydrogen-like bound states
April 2016, Thesis Advisor: A. Pineda

Sonia Fernández
A novel Depleted Monolithic Active Pixel Sensor for future High Energy Physics Detectors
May 2016, Advisor: Cristobal Padilla

Shota Tsiskaridze
Search for flavor-changing neutral current top quark decays t->Hq, with H->bb, in pp collisions at $\sqrt{s}$=8 TeV with the ATLAS detector
June 2016, Thesis Advisor: A. Juste

6.2 IFAE PUBLICATIONS IN 2016

EXPERIMENTAL DIVISION

PUBLICATIONS BY THE ATLAS GROUP

1. G. Aad et al., ATLAS Collaboration, *Measurement of the tt production cross-section using eμ events with b-tagged jets in pp collisions at √s=7 and 8 TeV with the ATLAS detector,* Eur. Phys. J. C74 (2014) 3109, [Addendum: Eur. Phys. J.C76 (2016) 642].

2. G. Aad et al., ATLAS Collaboration, *Search for massive supersymmetric particles decaying to many jets using the ATLAS detector in pp collisions at √s=8 TeV,* Phys. Rev. D91 (2015) 112016, [Erratum: Phys. Rev. D93 (2016) 039901].

3. 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, [Erratum: Eur. Phys. J. C76 (2016) 152].

4. G. Aad et al., ATLAS Collaboration, *Centrality, rapidity and transverse momentum dependence of isolated prompt photon production in lead-lead collisions at* $\sqrt{s_{NN}}$*=2.76 TeV measured with the ATLAS detector,* Phys. Rev. C93 (2016) 034914.

5. G. Aad et al., ATLAS Collaboration, *ATLAS Run 1 searches for direct pair production of third-generation squarks at the Large Hadron Collider,* Eur. Phys. J. C75 (2015) 510, [Erratum: Eur. Phys. J. C76 (2016) 153].

6. G. Aad et al., ATLAS Collaboration, *Measurements of the Higgs boson production and decay rates and coupling strengths using pp collision data at √s=7 and 8 TeV in the ATLAS experiment,* Eur. Phys. J. C76 (2016) 6.

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IFAE role: S. Griffiths corresponding author

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IFAE role: J. Sitarek corresponding author

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IFAE role: A. López-Oramas corresponding author

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IFAE role: R. López-Coto corresponding author

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IFAE role: A. González & A. Moralejo corresponding authors

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6.3 TALKS & POSTERS BY IFAE MEMBERS IN 2016

ATLAS GROUP

MARTINE BOSMAN

- "Recent ATLAS results", PLANCK 2016, Valencia, Spain, May 2016

MIRKO CASOLINO

- "Results from ttH/VH Searches with the ATLAS Detector", International Conference on Discovery Physics at the LHC, Kruger Gate, South Africa, December 2016

DAVIDE GERBAUDO

- "H->μ/e+tau, Z->e/μ+tau, high mass LFV Z'", ATLAS Beyond the Standard Model Higgs and Exotics Joint Workshop, Grenoble, France, April 2016
- "Triggering on multijets at the LHC", Higgs Tasting Workshop 2016, Benasque, Spain, May 2016.
- "L1Topo trigger validation", ATLAS Trigger and Data Acquisition week, Barcelona, Spain, September 2016
- "Search for non-standard and rare decays of the Higgs boson with the ATLAS detector", International Conference on High Energy Physics (ICHEP 2016), Chicago, USA, August 2016

TRISHA FAROOQUE

- "SUSY searches - squark and gluino production (RPC and RPV)", ATLAS Week, New York, USA, July 2016
- "Massive vector-like quarks using boosted particle reconstructions", BOOST2016, Zurich, Switzerland, August 2016

CORA FISCHER

- "Study of TileCal Scintillators Irradiation using the Minimum Bias Integrators", CALOR 2016, Daegu, Republic of Korea, May 2016
- "Search for new phenomena in monojet plus missing transverse momentum final states in pp collisions at 13 TeV using the ATLAS detector", DM@LHC Workshop 2016, Amsterdam, The Netherlands, April 2016

SILVIA FRACCHIA

- "Search for direct stop and sbottom pair production with the ATLAS detector", SUSY 2016, Melbourne, Australia, July 2016
- POSTER: "Search for bottom squarks in ffls=13 TeV pp collisions with the ATLAS detector", LHCC Meeting, CERN, Geneva, Switzerland, March 2016

AURELIO JUSTE

- "Searches for Top and Higgs Compositeness 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, China, January 2016
- "Searches for New Phenomena at the LHC", XLIV International Meeting on Fundamental Physics, Instituto de Física Teórica (IFT), Universidad Autónoma de Madrid, Madrid, Spain, April 2016.
- "Status and Prospects of Direct Searches for Top and Higgs Compositeness at the LHC", 3rd NPKI Workshop at Seoul: "The lessons from the first results of Run 2 at the LHC, New Physics Korea Institute, Korea University, Seoul, Republic of Korea, June 2016
- "Status Model Higgs Boson Studies at the LHC", PASCOS 2016: 22nd International Symposium on Particles, Strings and Cosmology, XIIth Rencontres du Vietnam, ICISE, Quy Nhon, Vietnam, July 2016
- "Searches for ttH at the LHC", Higgs Days at Santander 2016 Workshop, Instituto de Física de Cantabria, Santander, Spain, September 2016

MARIO MARTÍNEZ

- "Status of the Spanish Program for Particle Physics and Accelerators", XLIV International Meeting on Fundamental Physics, Instituto de Física Teórica (IFT), Universidad Autónoma de Madrid, Madrid, Spain, April 2016

LLUÏSA M. MIR

- "H+ searches in ATLAS (II): $H^{+}\rightarrow tb$", CHARGED 2016, Uppsala, Sweden, October 2016

IMMA RIU

- "The ATLAS Level-1 Topological Trigger Performance in Run 2", CHEP 2016, San Francisco, USA, October 2016
- "Top and Standard Model Results of ATLAS and CMS in Run 2", CPAN Days, Universidad de Zaragoza, Zaragoza, Spain, November 2016

LOIC VALERY

- "Overview of SUSY searches at the LHC", Théory LHC France Workshop, Orsay, France, November 2016
- "Searches for new phenomena in ttbar+heavy-flavor final states at ATLAS", CPAN Days, Universidad de Zaragoza, Zaragoza, Spain, November 2016

PIXELS GROUP

RAIMON CASANOVA

- "A Verilog-A Model of a Charge Sensitive Amplifier for a HV-CMOS Pixel Sensor", SMACD 2016, Lisbon, Portugal, 27-30 June 2016
- "A Fully Monolithic HV-CMOS Pixel Detector with a Time-to-Digital Converter for Nanosecond Time Measurements", Topical Workshop on Electronics for Particle Physics (TWEPP 2016) Karlsruhe, Germany 25-30 September 2016

EMANUELE CAVALLARO

- "First measured results on the H35Demo chips for application in ATLAS tracker upgrade", IWORID 2016, Barcelona 3-7 July
- "Edge TCT study on irradiated AMS H35 CMOS devices for the ATLAS ITk", Topical Workshop on Electronics for Particle Physics (TWEPP 2016) Karlsruhe, Germany 25-30 September 2016
- "Edge TCT study on irradiated AMS H35 CMOS devices for the ATLAS ITk", 2nd TCT Workshop, Ljbubljana, Slovenia,17-18 October 2016

FABIAN FOSTER

- "Beam test of 3D pixel detectors up to fluences of 9e15 neq/cm2", 4th Beam Telescopes and Test Beams Workshop 2016, LAL Orsay, France 3-5 Feb 2016

SEBASTIÁN GRINSTEIN

- "3D Sensores for the HL-LHC", 11th Trento Meeting on Advanced Silicon Radiation Detectors, LPNHE, Paris 22-24 Feb 2016
- "Experience with the AFP 3D Silicon Pixel Tracker", 8th International Workshop on Semiconductor Pixel Detectors for Particles and Imaging (PIXEL 2016) Sestri-Levante, Italy 5-9 September 2016
- "Spanish activities in the ATLAS upgrade", VIII CPAN DAYS Zaragoza 28-30 November 2016

JOERN LANGE

- Beam tests of the ATLAS Forward Proton (AFP) Detector", 4th Beam Telescopes and Test Beams Workshop 2016, LAL Orsay, France 3-5 Feb 2016
- "AFP Beam Tests – Integration and Tracker", LHC Working Group on Forward Physics and Diffraction, CERN, Geneva 15-16 March 2016
- "HVCMOS Activities at IFAE", AIDA 2020 First Annual Meeting, Hamburg, Germany 13-17 June 2016
- "3D Sensors for the HL-LHC", 8th International Workshop on Semiconductor Pixel Detectors for Particles and Imaging (PIXEL 2016) Sestri-Levante, Italy 5-9 September 2016

IVÁN LOPEZ

- "AFP tracker production and testing", LHC Working Group on Forward Physics and Diffraction, CERN, Geneva 15-16 March 2016
- "AFP Silicon tracker", 3rd Elba Workshop on Forward Physics @ LHC Energy Elba, Italy 30 May - 1 June 2016
- "Installation and Commissioning of the ATLAS Forward Proton (AFP) detector", ICHEP 2016, Chicago, USA 3-10 August 2016

L. SIMON

- "TCT Measurements on 3D Small Pitch Sensors", 2nd TCT Workshop Ljbubljana, Slovenia 17-18 October 2016

DAVID VÁZQUEZ

- "IFAE Track reconstruction with EUTelescope", 4th Beam Telescopes and Test Beams Workshop 2016 LAL Orsay, France 3-5 Feb 2016
- "3D sensors for HL-LHC", IWORID 2016, Barcelona, 3-7 July

NEUTRINO GROUP

BRUNO BOURGUILLE

- Poster at the Taller de Altas Energias 2016 (TAE) Benasque (Huesca), 4-17 Sept

MICHAEL LEYTON

- "Neutrino geoscience and reactor monitoring with direction-sensitive detectors" at Applied Antineutrino Physics, Liverpool, United Kingdom, 1-2 Dec

FEDERICO SÁNCHEZ

- "CERN neutrino platform" 29th November 2016 VIII CPAN days Zaragoza (Spain)
- "Tensors in 2p2h Nieves Model" 22-28th April 2016 Saclay(France)
- "MC and experiments" 22-28th April 2016 Saclay(France)
- "Physics prospects for neutrino-nucleus cross-section" 24th November 2016, 100th Plenary ECFA meeting CERN (Switzerland)
- "Precision oscillation neutrino experiments, nuclear physics and the need for near detectors" 14th December 2016, Univ. Geneva (Switzerland)
- "Neutrino Oscillatons: state of the subject" , 14th June 2016 GSI Darmstadt (Germany)
- "IFAE" talk at the CERCA annual meeting. 8th June 2016 (CCCB) Barcelona

GAMMA-RAY GROUP

ÒSCAR BLANCH

- "Recent highlights of the MAGIC telescopes". 6th International Symposium on High-Energy Gamma-Ray Astronomy, Heidelberg (Germany) July 11-15, 2016

JUAN CORTINA

- "VHE Gamma-ray sources in view of the Cherenkov Telescope Array". Frontier Research in Astrophysics – II, Mondello (Palermo), Italy, May 23-28 2016

- "Overview and Status of the Cherenkov Telescope Array", IEEE Nuclear Science Symposium 2016, Strasbourg, France. Oct 29th-Nov 5th, 2016

ALBA FERNÁNDEZ-BARRAL

- "VHE gamma-ray observations of binary systems with the MAGIC telescopes". TeV Particle Astrophysics conference 2016, CERN, Geneva (Switzerland), Sept 12-16, 2016
- POSTER: "Detection of gamma rays of likely jet origin in Cygnus X-1", TeV Particle Astrophysics conference 2016, CERN, Geneva (Switzerland), Sept 12-16, 2016
- POSTER: A. Fernández-Barral "VHE gamma-ray observations of the Type Ia Supernova SN 2014J with the MAGIC telescopes", 6th International Symposium on High-Energy Gamma-Ray Astronomy, Heidelberg (Germany) July 11-15, 2016

DANIEL GUBERMAN

- POSTER: "MAGIC under strong moonlight: an instrument to measure the shadowing of cosmic ray electrons/positrons by the Moon?". 20th International School of Cosmic Ray Astrophysics "Maurice M. Saphiro", Erice (Italy). August 2016

MANEL MARTÍNEZ

- "CTA" Meeting of the Sociedad Española de Astrofísica (SEA), Bilbao (Spain), July 2016
- "Astroparticles: the cosmic high energy frontier. Extreme Universe, extreme detectors", Taller de Altas Energías (TAE) Benasque (Spain) 2016

ABELARDO MORALEJO

- "Measuring the Extragalactic Background Light with gamma-ray telescopes" . Talk at the Dipartimento di Fisica, Padova University, 30-06-2016

JOAQUIM PALACIO

- "Exploring the physics frontier with the MAGIC Telescopes: Indirect dark matter searches". Identification of Dark Matter, Sheffield (UK), July 18-22, 2016

JAVIER RICO

- "Review of Fundamental Physics results with the MAGIC telescopes". 6th International Symposium on High-Energy Gamma-Ray Astronomy, Heidelberg (Germany) July 11-15, 2016
- "Gamma-rays/CTA". XLIV International Meeting on Fundamental Physics, Madrid (Spain) April 4-7, 2016
- "The Cherenkov Telescope Array and its Core Science Program". IV Fundamental Cosmology Meeting, Barcelona (Spain) June 15-17 2016
- "Global Dark Matter limits from a combined analysis of MAGIC and Fermi-LAT data". "LIV F2F Meeting", Institució CERCA, Barcelona (Spain) Nov 7-9, 2016

J. E. WARD

- "Light-Trap: A SiPM Upgrade for VHE Astronomy and Beyond". 18th International Workshop on Radiation Imaging Detectors, Barcelona (Spain) July 3-7, 2016
- "Light-Trap Cluster: Design Proposal". Light-Trap Cluster meeting, MPI, Munich (Germany) October 27, 2016
- "Towards an Open High-Level Data Format for Gamma-Ray Astronomy". LIV F2F meeting, Institució CERCA, Barcelona (Spain) Nov 7-9, 2016

COSMOLOGY GROUP

JELENA ALEKSIĆ

- "Digging Deeper in Imaging Surveys", Statistical Challenges in 21st Century Cosmology, Chania (Greece), May 2016

ANDRÁS KOVÁCS

- "Imprint of DES super-structures in the Cosmic Microwave Background", poster at Meeting on Fundamental Cosmology, ICCUB Barcelona (Spain), June 2016
- "Cosmic troublemakers: the Cold Spot, the Eridanus Supervoid, and the Great Walls", poster at Statistical Challenges in 21st Century Cosmology, Chania (Greece), May 2016
- "Dark Energy illuminated by cosmic voids in the DES footprint", poster at Statistical Challenges in 21st Century Cosmology, Chania (Greece), May 2016
- "Cold imprint of supervoids in the Cosmic Microwave Background", IberiCOS meeting, Porto (Portugal), March 2016
- "Cosmic voids in the Dark Energy Survey", cosmology seminar at Sussex University (UK), January 2016
- "Probing the ISW imprint of photo-z voids with SDSS, Pan-STARRS1, and DES", theoretical cosmology seminar talk at the Institute of Cosmology and Gravitation, Portsmouth (UK), January 2016
- "The Integrated Sachs-Wolfe imprint of voids: implications to the CMB Cold Spot anomaly", cosmology seminar at University College London (UK), January 2016

RAMON MIQUEL

- "Large Scale Structure Surveys: Results from DES", 28th Rencontres de Blois: Particle Physics and Cosmology, Blois (France), June 2016
- "Dark Energy: Galaxy Surveys", APPEC Town Hall Meeting, Paris (France), April 2016

CARLES SÁNCHEZ

- "Early Weak Lensing results from the Dark Energy Survey", COSMO16, University of Michigan, Ann Arbos (USA) August 2016

- “Galaxy clustering and weak gravitational lensing in the Dark Energy Survey Science Verification data”, Department of Astronomy and Cerro Calán Observatory, Universidad de Chile, Santiago (Chile), January 2016
- “Galaxy clustering and weak gravitational lensing in the Dark Energy Survey Science Verification data”, European Southern Observatory (ESO), Santiago (Chile), January 2016

MARCO GATTI AND PAULINE VIELZEUF

- "Clustering-based redshift estimation for photometric surveys: application to DES", ICTP school, Trieste (Italy), June 2016

VIP GROUP

MOKHTAR CHMEISSANI

- "Circuit Design to reduce the impact of Charge sharing in pixel semiconductor detector", CMOS Emerging Technology Research Conference. May May 25 – 27, 2016, Montreal, Canada

GROUP POSTERS

- "Simulation of Positron Emission Mammography Imaging with Pixelated CdTe", Presented in IWDM 2016 – 13th International Workshop on Breast Imaging, June 19 - 22, 2016, Malmö Live, Malmö, Sweden
- "Using Compton Scattering for Random Coincidence Rejection", 18th International Workshop on Radiation Imaging Detectors (IWORID2016), July 3 -7, 2016, Barcelona, Spain
- "ERICA: an energy resolving photon counting readout ASIC for X-ray in-line cameras", 18th International Workshop on Radiation Imaging Detectors (IWORID2016), July 3 -7, 2016, Barcelona, Spain
- "Simple Algorithm to Sum Charge Sharing in Photon Counting Pixel Semiconductor Detector", 18th International Workshop on Radiation Imaging Detectors (IWORID2016), July 3 -7, 2016, Barcelona, Spain

THEORY DIVISION

JOSÉ RAMÓN ESPINOSA

- "Cosmological Implications of Higgs Near-Criticality" Helsinki Higgs Forum", Dec. 14 - 16, 2016, Helsinki (Finland)
- "Higgs Inflation as a Mirage" Bethe Forum 'Beyond the standard Higgs-system', Nov. 28 - Dec. 2, 2016, BCTP Bonn (Germany)
- "Higgs Inflation as a Mirage", Theoretical Cosmology Meetings, Nov. 4, 2016, Utrecht (The Netherlands)
- "Cosmological relaxation of the electroweak scale" ElectroWeak Interactions and Unified Theories, 51st Rencontres de Moriond, March 12-19, 2016, La Thuile (Italy)

GIULIANO PANICO

- "Theory Introduction to HH production", plenary talk given at the 'HH at HL-LHC' meeting, CERN, 10 May 2016
- "Double Higgs production at the LHC and Beyond", plenary talk given at the 'Higgs Hunting 2016' workshop, 31 August - 2 September 2016, LPNHE, Paris, France
- Series of three lectures on the topic "Composite Higgs" given at the '6th NExT PhD Workshop: The Quest for New Physics in the LHC Run II ERA', 20-23 June 2016, University of Sussex, UK.
- Lectures on the topic "Introduction to composite Higgs models" given at DESY Hamburg in the SFB Lectures series, 1, 8, 15 July 2016

ALEX POMAROL

- ”Higgs couplings from the perspective of BSM physics” Zurich Phenomenology Workshop (ZPW 2016), Zurich (Switzerland)
- ”Theory Summary” 51st Rencontres de Moriond: Electroweak Interactions and Unified Theories, La Thuile (Italy)
- ”First Impressions at 13 TeV” 11th Franco-Italian Meeting on B Physics, Paris (France)
- ”New dynamics in the EW sector” 2016 Phenomenology Symposium, Pittsburg (USA)
- ”Theory overview of new phenomena” Fourth Annual Large Hadron Collider Physics Conference (LHCP2016), Lund (Sweden)
- ”Flavor without symmetries” A First Glance Beyond the Energy Frontier, ICTP, Trieste (Italy)
- ”BSM Theory Overview” The 12th Central European Seminar on Particle Physics and Quantum Field Theory, Vienna (Austria)
- ”Physics Beyond the Standard Model” (4 lectures), TAE School, Benasque (Spain)

MARIANO QUIRÓS

- “Natural Supersymmetry from Extra Dimensions,” Plenary talk at "Planck 2016: from the Planck scale to the electroweak scale", Valencia, Spain, 23-27 May 2016
- “Supersymmetry/Theory,” Plenary talk at "XLIV International Meeting on Fundamental Physics", IFT/UAM-CSIC, Madrid, 4-8 April 2016

PIC

JOSÉ FLIX

- "Consolidating WLCG topology and configuration in the Computing Resource Information Catalogue", International conference on Computing in High Energy and Nuclear Physics, CHEP 2016, San Francisco, USA, 10-14 Oct. 2016
- "Evaluation of lightweight site setups within WLCG infrastructure", International conference on Computing in High Energy and Nuclear Physics, CHEP 2016, San Francisco, USA, 10-14 Oct. 2016

- "Investigating options for future Nordic Tier-1 operations", GDB at CERN, 14 September 2016
- "IPv6 at PIC Tier-1", Pre-GDB, IPv6 Workshop at CERN, 7 June 2016
- "HTCondor deployment at PIC", HTCondor Workshop, Barcelona, Spain, 29 Feb. - 03 Mar. 2016
- "Comparison of accounting and pledges for Tier1 sites", WLCG Management Board at CERN, 16 Feb. 2016

ANTONIO PÉREZ-CALERO

- "CMS Connect", International conference on Computing in High Energy and Nuclear Physics, CHEP 2016, San Francisco, USA, 10-14 Oct. 2016
- "CMS readiness for multi-core workload scheduling", International conference on Computing in High Energy and Nuclear Physics, CHEP 2016, San Francisco, USA, 10-14 Oct. 2016
- "Connecting restricted, high-availability, or low-latency resources to a seamless Global Pool for CMS", International conference on Computing in High Energy and Nuclear Physics, CHEP 2016, San Francisco, USA, 10-14 Oct. 2016
- "Effective HTCondor-based monitoring system for CMS", International conference on Computing in High Energy and Nuclear Physics, CHEP 2016, San Francisco, USA, 10-14 Oct. 2016
- "Stability and scalability of the CMS Global Pool: Pushing HTCondor and glideinWMS to new limits", International conference on Computing in High Energy and Nuclear Physics, CHEP 2016, San Francisco, USA, 10-14 Oct. 2016
- Exploiting multicore compute resources in the CMS experiment, 17th International workshop on Advanced Computing and Analysis Techniques in physics research, ACAT2016, Valparaíso, Chile, 18-22 January 2016

JORGE CARRETERO

- "A web portal to analyze and distribute cosmology data" Jornadas Técnicas de RedIRIS 2016 (XXVII edición), Valencia, Spain, 18 Nov. 2016

MARC CAUBET

- "PIC SRM deployment for a multi-VO based dCache storage " dCache Workshop, Barcelona, Spain, 11-12 Apr 2016

VANESSA ACÍN

- "CPD del Port d'Informació Científica (PIC) con tecnología de inmersión líquida", TECNIRIS-53, 29 Nov 2016

6.4 PROCEEDINGS & BOOKS BY IFAE MEMBERS IN 2016

THEORY DIVISON

1. R. Escribano
eta transition form factor: A combined analysis of space- and time-like experimental data through rational approximants,
J. Univ. Sci. Tech. China 46 (2016) 462.

2. R. Escribano
A data-driven approach to eta and eta' Dalitz decays,
EPJ Web Conf. 130 (2016) 04001.

3. R. Escribano
tau -> K_S pi^- nu_tau and tau -> K^- eta nu_tau decays: a combined analysis,
PoS CD 15 (2016) 047.

4. B. Capdevila, S. Descotes-Genon, L. Hofer, J. Matias and J. Virto
BSM fits for b -> s l^+ l^- decays,
PoS BEAUTY 2016 (2016) 044.

5. Descotes-Genon, L. Hofer, J. Matias and J. Virto
QCD uncertainties in the prediction of B -> K^* mu^+ mu^- observables,
Nucl. Part. Phys. Proc. 273-275 (2016) 1442, arXiv:1411.0922 [hep-ph].

6. D. Boito, M. Golterman, K. Maltman and S. Peris
alpha_s analyses from hadronic tau decays with OPAL and ALEPH data,
Mod. Phys. Lett. A 31 (2016) 1630024, arXiv:1606.08899 [hep-ph].

7. S. Peris, D. Boito, M. Golterman and K. Maltman
The case for duality violations in the analysis of hadronic tau decays,
Mod. Phys. Lett. A 31 (2016) 1630031, arXiv:1606.08898 [hep-ph].

8. C. Aubin, T. Blum, P. Chau, M. Golterman, S. Peris and C. Tu
Finite-volume effects in the hadronic vacuum polarization,
PoS LATTICE 2015 (2016) 112, arXiv:1510.05319 [hep-lat].

9. D. Boito, A. Francis, M. Golterman, R. Hudspith, R. Lewis, K. Maltman and S. Peris
Low-energy constants from ALEPH hadronic tau decay data,
PoS CD 15 (2016) 049, arXiv:1509.08125 [hep-ph].

10. M. Golterman, K. Maltman and S. Peris
A hybrid strategy for the lattice evaluation of the leading order hadronic contribution to (g – 2)_mu,
Nucl. Part. Phys. Proc. 273-275 (2016) 1650, arXiv:1410.8405 [hep-lat].

11. C. Ayala, G. Cvetic and A. Pineda
Mass of the bottom quark from Upsilon(1S) at NNNLO: an update,
J. Phys. Conf. Ser. 762 (2016) 012063, arXiv:1606.01741 [hep-ph].

12. G.S. Bali and A. Pineda
Phenomenology of renormalons and the OPE from lattice regularization: the gluon condensate and the heavy quark pole mass,
AIP Conf. Proc. 1701 (2016) 030010, arXiv:1502.00086 [hep-ph].

13. G. Brooijmans et al.
Les Houches 2015: Physics at TeV colliders - new physics working group report
arXiv:1605.02684 [hep-ph].

14. G. Panico
Prospects for double Higgs production
Frascati Phys. Ser. 61 (2016) 102

15. A. Pomarol
Future Directions Beyond the Standard Theory
Adv. Ser. Direct. High Energy Phys. 26 (2016) 455.

16. E. Megias, O. Pujolas and M. Quiros
On light dilaton extensions of the Standard Model
EPJ Web Conf. 126 (2016) 05010 [arXiv:1512.06702 [hep-ph]].

17. G. Panico and A. Wulzer
Monograph: The Composite Nambu-Goldstone Higgs
Lect. Notes Phys. 913 (2016) pp. 1-316 [arXiv:1506.01961 [hep-ph]].

EXPERIMENTAL DIVISION

18. T. Maciaszek et. al.
Euclid near infrarred spectrophotomer instrument concept and first test reslts at the end of phase C
SPIE, Vol 9904, id. 99040T (2016)

19. M. Kolstein and M. Chmeissani
Simulation of Positron Emission Mammography Imaging with Pixelated CdTe
Proceedings "Breast Imaging: 13th International Workshop, IWDM 2016" Malmö, Sweden, June 19-22, 2016. 122-129 Springer International Publishing

20. S. Grinstein for the AFP Collaboration,
The ATLAS Forward Proton Detector (AFP)
Nuclear and Particle Physics Proceedings 273–275 (2016) 1180–1184

21. J. Lange, M. Carulla Areste, E. Cavallaro, F. Förster, S. Grinstein, I. López Paz, M. Manna, G. Pellegrini, D. Quirion, S. Terzo, D. Vázquez Furelos,
3D silicon pixel detectors for the High-Luminosity LHC
JINST 11 (2016) C11024

22. J.E. Ward, J. Cortina and D. Guberman
Light-Trap: A SiPM Upgrade for VHE Astronomy and Beyond.
Journal of Instrumentation, Volume 11 (2016)

23. P. Casado
Status and prospects for BSM ((N)MSSM) HIggs searches at the LHC
SLAC-econf-C151102.1, arXiv:1602.08970 [hep-ex]. Talk presented at the International Workshop on Future Linear Colliders (LCWS15), Whistler, Canada, 2-6 November 2015

24. C. Fischer
Study of TileCal Scintillators Irradiation using the Minimum Bias Integrators
J. Phys. Conf. Ser. Talk presented at the 17th International Conference on Calorimetry in Particle Physics (CALOR 2016), Daegu (Republic of Korea), 15-20 May 2016

25. D. Gerbaudo
Search for non-standard and rare decays of the Higgs boson with the ATLAS detector
PoS (ICHEP2016) 413. Talk presented at the 30th International Conference on High Energy Physics (ICHEP 2016), Chicago (USA), 3-10 August 2016

26. A. Pacheco
How to keep the Grid full and working with ATLAS production and physics jobs
J. Phys. Conf. Ser. 2017. Talk presented at the 22nd International Conference on Computing in High Energy and Nuclear Physics (CHEP 2016), San Francisco (USA), 14-16 October 2016

27. I. Riu
The ATLAS Level-1 Topological trigger performance in Run 2
J. Phys. Conf. Ser. 2017. Talk presented at the 22nd International Conference on Computing in High Energy and Nuclear Physics (CHEP 2016), San Francisco (USA), 14-16 Oct 2016

28. J. Montejo
Search for New Physics in $t\bar{t}$ Final States with Additional Heavy-Flavor Jets with the ATLAS Detector
Doctoral Thesis. Published by Springer.

29. R. 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
Doctoral Thesis. Published by Springer.

PIC

30. J E Ramírez, A Pérez-Calero Yzquierdo, J M Hernández
Exploiting multicore compute resources in the CMS experiment
J. Phys. Conf. Ser. 762 (2016) 012018

6.5 IFAE IN THE MEDIA IN 2016

1. January 8th 2016, Ahora
Ver la oscuridad

2. April 1th 2016, La Vanguardia
El CERN busca la partícula que revolucionará la física

3. November 12th 2016, Ara
Tu pots ser un caçador de raigs gamma

4. November 23rd 2016, Catalunya Radio
Un web per fomentar les vocacions científiques

5. Desember 13th 2016, El Temps
Els investigadors de l'Univers

6. May 2016, Investigación y Ciencia
La Red de Telescopios Cherenkov

7. May 2016, Investigación y Ciencia
Reconstruir la historia del universo

8. August 27th 2016, Ara
Ulls de gegant per detectar rajos gamma

9. August 20th 2016, La Vanguardia
Interview to Gary Bernstein

10. January 31st 2016, La Vanguardia
Interview to Mario Martínez

11. February 22nd 2016, UAB Divulga
Els Bojos per la Física ja tenen el seu programa

12. April 16th 2016, TV3
La UAB és una de les universitats que més estalvia en energia

13. April 21st 2016, La Vanguardia
HAWC, el detector benjamín de las altas energías del universo

14. April-June 2016, DatacenterDynamics
Cover: PIC's cooling system with oils

15. June 28th 2016, La Vanguardia
Andreu Mas-Colell, nuevo presidente del Barcelona Institute of Science and Technology

16. August 12th 2016, Nature News
Morphing neutrinos provide clue to antimatter mystery

17. July 8th 2016, CERN Courier
Japan eyes up its future

18. July 2016, Materia (El País)
Un Universo Gravitacional

19. February 2016, Gencat
El Govern aprova la concessió de la Medalla i de la Placa Narcís Monturiol a 16 personalitats i 3 institucions

20. March 29th 2016, NHK Japanese TV
Cosmic front

21. December 2016, Estratos
Observar rayos gamma para saber cómo funciona el universo

6.6 PARTICIPATION IN EXTERNAL COMMITTEES IN 2016

VANESSA ACÍN

- Member, Technical Committee for the EU HNSci-Cloud Pre-Commercial Procurement project

ÒSCAR BLANCH

- Member, Common Service Committee of "Observatorio El Roque de los Muchachos"
- Deputy Spokesman, MAGIC Collaboration
- Member, MAGIC Executive Board
- Member, MAGIC Technical Board
- Member, MAGIC Collaboration Board
- Member, MAGIC Time Allocation Committee
- Convener, LST-CAM working group in CTA
- Member, LST Executive Board

CHRISTOPHE BONNETT

- Convener, Photometric Redshift science working group in DES

MARTINE BOSMAN

- IFAE Representative, ATLAS Collaboration Board
- Spanish National Contact Physicist, ATLAS
- Member, CERN Associates and Fellows Selection Committee
- Member, Comisión de Infraestructuras de Física de Partículas y Aceleradores (CIFPA), MINECO, Spain
- Member, Equal Opportunities committee of European Physical Society
- Member, Comissió d'Igualtat d'Oportunitats i Gestió de la Diversitat (CERCA)
- Member, Expert Panel of FWO (Flanders Research Foundation - Belgium)
- Member, International Evaluation Committee of INFN (Italy)

JUAN CORTINA

- Member, MAGIC Technical Board
- Member, MAGIC Time Allocation Committee
- Co-Principal Investigator, CTA Large Scale Telescopes (LST)
- Member, CTA LST Executive Board

MANUEL DELFINO

- Chair, Collaboration Board of the EU HNSciCloud Pre-Commercial Procurement project
- Member, Cherenkov Telescope Arrary (CTA) Collaboration Board
- Member, IceCube Scientific Computing Advisory Panel
- Member, Worldwide LHC Computing Grid Overview Board
- Member, CERN LHC Computing Resources Scrutiny Group
- Member, EU-T0 Executive Board
- Member, PAU Survey Management Committee

JORDI DELGADO MENGUAL

- Member, MAGIC Software Board

JOSE FLIX MOLINA

- Member, Worldwide LHC Computing Grid Collaboration Board
- Member, Worldwide LHC Computing Grid Overview Board
- Member, Worldwide LHC Computing Grid Management Board
- Convener, Worldwide LHC Computing Grid Operations Coordination team
- Member, CMS Computing Resource Board
- Convener, CMS Computing Resource Management Office
- Member, CMS Computing Management Board
- Scientific and technical advisor, Nordic e-Infrastructure Collaboration (NeIC)

SEBASTIAN GRINSTEIN

- Convener, ATLAS ITk Pixel Sensor working group
- Member, ITk Pixel coordination team
- Member, ATLAS Forward Detectors Institutional Board
- Member, ATLAS Pixel Institute Board
- Institute Leader, RD50 (Radiation hard semiconductor devices for very high luminosity colliders – CERN) Collaboration Board
- IFAE representative , AIDA-2020 Governing Board

ENRIQUE FERNÁNDEZ

- Member, Scientific Advisory Board of the Institute of Physics of the University of Freiburg, Germany.

TAREK HASSAN

- Convener, MAGIC DL3 working group

AURELIO JUSTE

- Member, Scientific Committee of the OCEVU (Origins, Constituents, and Evolution of the Universe) LabEx, France (since October 2012).
- Member, Editorial Board of the journal Advances in High Energy Physics.
- Convener, Metadata subgroup of the ATLAS Data Preparation working group

ILYA KOROLKOV

- Member, Tile Calorimeter Collaboration Institution Board.
- Member, Tile Calorimeter Management Board.
- Member, ATLAS Calorimeter Upgrade Review Committee

JOERN LANGE

- Deputy Institute Representative, RD50 (Radiation hard semiconductor devices for very high luminosity colliders - CERN) Collaboration Board

FERNANDO LÓPEZ

- Member, WLCG Network Throughput Working Group

MANEL MARTÍNEZ

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

MARIO MARTÍNEZ

- IFAE Representative, ATLAS Collaboration Board
- Member, ATLAS Publication Committee at CERN
- Manager, Programa Nacional de Física de Partículas, Spain
- Scientific Delegate for Spain , CERN's Council
- Member, ATLAS Spokerperson's article approval delegation

RAMON MIQUEL

- Member, Scientific Advisory Committee of the Astroparticle Physics European Consortium (APPEC)
- Member, DES Management Committee
- Member, DES Builders Committee
- Member, DES Publication Board
- Member, DES Advisory Board
- Member, DESI Speakers Board
- Member, PAU Survey Management Committee
- Member, EU-T0 Collaboration Board

LLUÏSA M. MIR

- Member, ATLAS Publication Committee
- Convener, Charged Higgs-Higgs beyond the Standard Model subgroup, ATLAS
- Convener, ttHbb-HTop subgroup, ATLAS

ABELARDO MORALEJO

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

CHRISTIAN NEISSNER

- Lead, Euclid Spanish Science Data Center (SDC-ES)
- Lead, Euclid PAQA

KOJI NODA

- Deputy convener, LST optics working group in CTA
- Deputy convener, ACTL-LST IF working group (telescope control software) in CTA
- Member, LST Executive Board

ANDRÉS PACHECO PAGES

- Member, ATLAS Distributed Computing Coordination Group
- Coordinator, ATLAS Data Production and Analysis (DPA)

CRISTOBAL PADILLA

- Member, ATLAS Speakers Committee
- Project Manager, Euclid Near Infrared Spectrometer and Photometer (NISP) - Filter Wheel Assembly (FWA)
- Instrument Scientist, PAU

ANTONIO PÉREZ-CALERO YZQUIERDO

- Convener, CMS Computing Submission Infrastructure
- Member, CMS Computing Management Board

ANTONIO PINEDA

- Member, Juan de la Cierva commitee.

MARI CARMEN PORTO FERNÁNDEZ

- Member, Collaboration Board of the EU HNSciCloud Pre-Commercial Procurement project

JAVIER RICO

- IFAE Representative, MAGIC Collaboration Board
- Coordinator, MAGIC Data Center
- Manager, MAGIC Common Fund
- Convener, MAGIC Astroparticles & Fundamental Physics Working group
- Chair, CTA's Speakers And Publications Office (SAPO)

IMMA RIU

- Member, ECFA HL-LHC Trigger, Online and Offline Computing preparatory group
- Member, ATLAS Collaboration Board Chair Advisory Board

CARLES SÁNCHEZ

- Convener, DES galaxy-galaxy lensing working group

FEDERICO SÁNCHEZ

- Member, T2K Executive Committee
- Member, T2K Institutional Board
- Member, WA105 Institutional Board
- Member, NusTec Executive Committee

NADIA TONELLO

- Group Coordinator, Euclid SIM Validation

JOHN E WARD

- Member, CTA's Speakers And Publications Office (SAPO)

6.7 CONFERENCES, WORKSHOPS & MEETINGS ORGANIZATION

EXPERIMENTAL DIVISION

MARTINE BOSMAN

- Co-organizer of the Standard Model session of the research program "Experimental Challenges for the LHC Run II" at the Kavli Institute for Theoretical Physics, University of California, Santa Barbara, USA, March 28-June 3, 2016

JUAN CORTINA

- Chair of the Scientific Organizing Committee of the Symposium "High and Very-High Energy Gamma-ray Astronomy: status and future" of the European Week of Astronomy and Space Science (EWASS), Athens (Greece) July 4-8 2016

MOKHTAR CHMEISSANI

- Local Organizing Committee for the 18th International Workshop On Radiation Imaging Detectors (IWoRiD), 3-7th of July 2016, Barcelona

SEBASTIAN GRINSTEIN

- Organizer, ATLAS ITk Pixel Sensor meeting, 18-20 July 2016, Barcelona

JOSEP FLIX

- Member of the organizing committee of the 1st WLCG Collaboration Workshop 2016 (1-3 Feb. 2016, LIP, Lisbon, Portugal)
- Member of the organizing committee of the 2nd WLCG Collaboration Workshop 2016 (8-9 Oct. 2016, San Francisco, USA),
- Local organizer of the Workshop for HTCondor and ARC-CE users (29 Feb. - 4 Mar. 2016, ALBA Synchrotron Lab, Cerdanyola del Vallès, Spain - 70 participants), co-organized by PIC and ALBA.

AURELIO JUSTE

- Chair of the workshop "Higgs Tasting Workshop 2016: Higgs and Flavor in the LHC Era", Centro de Ciencias de Benasque Pedro Pascual, Benasque, May 15-21, 2016

JOERN LANGE

- Organizer, ATLAS ITk Pixel Sensor meeting, 18-20 July 2016, Barcelona

THORSTEN LUX

- Local Organizing Committee for the 18th International Workshop On Radiation Imaging Detectors (IWoRiD), 3-7th of July 2016, Barcelona

MANEL MARTÍNEZ

- Organising Committee for the "LIV F2F Meeting", Institució CERCA, Barcelona (Spain) Nov 7-9, 2016

MARIO MARTÍNEZ

- Member of the International Advisory Committee (LHCP 2016 Conference), Lund, Sweden, June 2016

ABELARDO MORALEJO

- Chair of the Scientific Organizing Committee of the Symposium "High and Very-High Energy Gamma-ray Astronomy: status and future" of the European Week of Astronomy and Space Science (EWASS), Athens (Greece) July 4-8 2016

LEYRE NOGUÉS

- Organising Committee for the "LIV F2F Meeting", Institució CERCA, Barcelona (Spain) Nov 7-9, 2016

JAVIER RICO

- Chair of the Scientific Organizing Committee of the Symposium "High and Very-High Energy Gamma-ray Astronomy: status and future" of the European Week of Astronomy and Space Science (EWASS), Athens (Greece) July 4-8 2016

IMMA RIU

- Chair of ATLAS TDAQ Week, Barcelona, Spain, September 2016

JOHN E WARD

- Member of the Organising Committee for the "1st BIST PostDoc Day", Recinte Modernista de Sant Pau, Barcelona (Spain), November 23 2016.
- Organising Committee for the "LIV F2F Meeting", Institució CERCA, Barcelona (Spain) Nov 7-9, 2016

THEORY DIVISION

ORIOL PUJOLÀS

- BIST Workshop on Holography and Entanglement, ICFO + IFAE, 10-11 Oct 2016
- CERN Institute "Emergent properties of space-time" from 20 June 2016 to 1 July 2016, CERN

6.4 OUTREACH ACTIVITIES IN 2016

OUTREACH & EDUCATION ACTIVITIES

BOJOS PER LA FÍSICA

One-year educational program targeted for high-school students. 150 students applied.

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

http://bojosperlafisica.ifae.es/

- **Aurelio Juste & Mirko Casolino**: La física de partícules al detector ATLAS de l'LHC - February 2016
- **Jelena Aleksić, Carles Sánchez & Judit Prat**: Cosmologia Observacional - March 2016
- **Òscar Blanch, Abelardo Moralejo, Joaquim Palacio, Daniel Guberman, John E. Ward, Paolo Cumani**: Astrofísica amb dades dels telescopis MAGIC de la Palma - April 2016
- **Federico Sánchez, Thorsten Lux, Michael Leyton**: Tecnologies de detecció de partícules - September 2016

CAZADORES DE RAYOS GAMMA

Web Application for High Energy Astrophysics outreach targeted for high-school students. 400 registered online users at the end of 2016.

Activity Funded by FECYT.

http://www.cazadoresderayosgamma.com/

- **Òscar Blanch, Sebastián Grinschpun, Alícia Labián**

PHYSICS MASTERCLASSES

All-day educational activity promoted by CERN and the IPPOG. 50 students participated in 2016.

- **Martine Bosman**: CERN international MasterClasses (tutor) - February 2016.

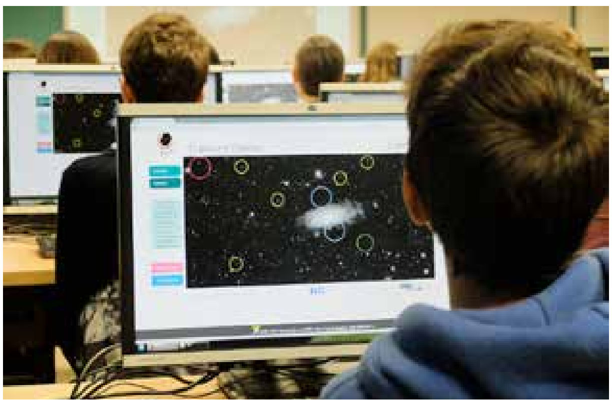
SUMMER FELLOWSHIPS AT IFAE

Educational activity for undegraduate students that offer a 1-month stay at IFAE in July. 50 applications in 2016.

Activity funded by the Severo Ochoa program.

http://summerfellowships.ifae.es/

- **András Kovács**: 'Cosmology: Redshift and weak lensing analysis', supervisor of IFAE summer student Bernat Molero, July 2016
- **Oriol Pujolàs:** 'Simulations in Classical Yang-Mills theory', Àlex Molas and Joan Solà, July 2016



- **Federico Sánchez**: 'New light sensors based on graphene and organic solar cells' Maria Miró and Albert Albesa, July 2016
- **John E. Ward:** 'Silicon PMs and Light-Traps for Cherenkov telescopes', Clara Fernández, July 2016
- **Manel Martínez**: 'High time resolution astronomy with the MAGIC Telescopes', supervisor of IFAE summer student Bruno Giménez, July 2016
- **Sebastián Grinstein:** 'Characterization of Pixel Detectors', Adrián Suñer, July 2016

HIGH-SCHOOL STUDENTS AT IFAE

More than 10 high-school students have had their first experience in research at IFAE in 2016 through different programs, namely Joves i Ciència, Premis Extraordinaris de Batxillerat and Treballs de Recerca.

- **Judit Prat:**
  - TdR: “The dark universe” by Laia Gamero and Duna Tejón (INS Gorgs), 2016
- **András Kovács:**
  - TdR: “The changing properties of galaxies” by Queralt Portell (INS Manuel Carrasco i Formiguera), 2016
- **Martine Bosman**
  - TdR: 'Recerca en acció: descobrint la física de partícules amb l'LHC' by Andrea Pérez, 2016
  - TdR: ,'La física de partícules amb l'LHC' Carla y Silvia Van den Bogaart Marzola, 2016
- **Mario Martínez**
  - Joves i Ciència: 'Cerca de matèria fosca a l'LHC', Pau Autrand, July 2016
- **Joaquim Palacio, Daniel Guberman**
  - Joves i Ciència: 'Astrofísica amb dades del telescopi MAGIC de La Palma', Heimdall Amerigo, July 2016
  - Premi Extraordinari Batxillerat: Diego Artacho, 2016
- **Emanuelle Cavallaro, Iván López**
  - Joves i Ciència: ' Detecció de radiació amb dispositius semiconductors', Adrià Lleal, July 2016
  - Premi Extraordinari Batxillerat: Ramón García, 2016
- **Michael Leyton, Thorsten Lux, Federico Sánchez**
  - Joves i Ciència: Anastasia Sokolenko
  - Premi Extraordinari Batxillerat: Pau Matarrodona, 2016

ESCOLAB

PIC is very active in the ESCOLAB program since 2011, an initiative that offers outreach activities for high-schools in the Barcelona area. Josep Flix coordinates the visit program, with the participation of Antonio Pérez-Calero, Jorge Carretero, and Nadia Tonello. Around 350 have visited PIC in 2016.

TREBALLS DE FINAL DE GRAU

IFAE researchers tutorize projects developed by undergraduate students in their last year of their degree.

- **Imma Riu**
  - "ATLAS trigger performance study for the upgrade of the LHC" by Roman Moreno. UAB, September 2016
  - "Commissioning of the ATLAS Level-1 Topological Trigger in Run 2" by Marc Seuba. UAB, September 2016
- **Lluïsa M. Mir**
  - "Search for a charged Higgs boson at the LHC with the ATLAS detector'" by Joel Pérez. UAB, September 2016
- **Martine Bosman**
  - "Improving the sensitivity of the search for a hypothetical electrically charged Higgs boson with the ATLAS experiment at the Large Hadron Collider'" by Rafael Ruz. UAB, September 2016
- **Oriol Pujolàs**
  - "Axionic Oscillons" by exchange (Erasmus) undergraduate student Manuel Kreutle, September 2016
  - "Non-linear scalar gravitation" by Àlex Molas, June 2016

TALKS BY IFAE RESEARCHERS

IFAE researchers have given more than 35 outreach talks in 2016 in the context of different outreach programs, namely CPAN en los institutos, the Science at School Day, the Science Week, and science fairs like Ciència entre Tots and Festa de la Ciència.

- **Òscar Blanch**
  - "L'Univers", at Escola Virolai for school students. Barcelona, 7 March 2016
  - "L'Univers", at Institut Doctor Puigvert for high-school students. Barcelona, 13 and 14 Octubre 2016
- **Martine Bosman**
  - Master Class, introductory lecture, "La física de partículas y como estudiarlas experimentalmente", February 15, 2016
- **Pilar Casado**
  - "Nanociència i Nanotecnologia", Ajuntament de Sabadell, Sabadell, February 16, 2016
  - "El bosó de Higgs i la frontera de la física". CPAN en el instituto. Participating high schools: INS Manuel Carrasco Formiguera, Barcelona, Spain, April 2016; Institut Secretari Coloma, Barcelona, Spain, November 2016; IES Gerbert d'Aurillac, Sant Fruitòs, Spain, December 2016
  - "Nanociència i Nanotecnologia", Jornades de Portes Obertes de la UAB, January 31-February 2, 2016
- **M. Cavalli-Sforza**,
  - "La Física de les Partícules: una perspectiva experimental". HEP course to work with high-school teachers new ways of introducing HEP research in the classroom, IFAE, Bellaterra, Spain, April 12-14, 2016
- **Juan Cortina**
  - "Cómo ser un científico", talk for ESO students at "Ángel de la Guarda" school in Alicante, 2016
- **Manuel Delfino**
  - Talk at "La computación del CERN al servicio de la ciencia y su impacto en la sociedad", May 12, 2016
- **Alba Fernández**
  - "Astrofísica de muy altas energías a través de los telescopios MAGIC", talk at the High School Francisco Aguiar in Betanzos (A Coruña), December 16, 2016
- **Enrique Fernández**
  - 'El Lado Oscuro del Universo', XXIX edición de La Semana Negra de Gijón, Gijón (Spain), July 2016
  - 'De las Ondas Gravitatorias a la Expansión del Universo', I Semana de la Ciencia, Oviedo (Spain), March 2016.
- **Tarek Hassan**
  - "Astronomia de molt altes energies: Dels telescopis Magic al projecte CTA (Cherenkov Telescope Array)", talk at the ASTER Agrupació Astronómica de Barcelona, July 7, 2016
- **Aurelio Juste**
  - "La Cara Oscura del Universo", Biblioteca Central de Terrassa, Terrassa, Spain, November 18, 2016
  - "El Bosón de Higgs y la Frontera de la Física", 1a Semana de la Ciencia Valle de Benasque, Benasque, Spain, November 19, 2016
  - "El universo cuántico a tu alcance", Bojos per la Física, IFAE, Bellaterra, Spain, February 6, 2016
  - "El Bosón de Higgs y la Frontera de la Física", Dia de la Ciència a les Escoles, Teatre Municipal Aqua, Montcada i Reixac. Spain, November 16, 2016
  - "El Bosón de Higgs y la Frontera de la Física". CPAN en el instituto. Participating high schools: IES Vidreres, Vidreres, February 12, 2016; IES Ribera del Sió, Agramunt, Spain, April 1, 2016; IES Mare de Deu de la Candelera, L'Ametlla de Mar, Spain, April 29, 2016
  - "El Bosón de Higgs y la Frontera de la Física", Escola Cultura Pràctica, Terrassa, Spain, February 1, 2016; IES Jaume Mimó, Cerdanyola, Spain, February 3, 2016; IES Egara, Terrassa, Spain, May 2, 2016
  - "La Cara Oscura del Universo", IES Arnau Cadell, Sant Cugat del Vallès, Spain, November 14, 2016; IES Pere Calders, Cerdanyola, Spain, November 17, 2016

- "Explorando la Terascala", HEP course to work with high-school teachers new ways of introducing HEP research in the classroom, IFAE, Bellaterra, Spain, April 12-14, 2016
- "El Bosón de Higgs y la Frontera de la Física", FUB+GRAN, Universitat de Manresa, Manresa, Spain, November 2, 2016

• **Thorsten Lux, Federico Sanchez**
- Science Exibition "Ciencia entre tots", 13th April 2016, Girona (Spain)

• **Manel Martínez**
- "El Universo Extremo de los Telescopios Cherenkov". Ciudad de las Artes y las Ciencias, Valencia, 4 de Mayo del 2016
- "La ventana a la luz más energética del Universo". CaixaForum de Zaragoza, 10 de Mayo del 2016
- "L'altra cara de l'univers". Sopar amb les Estrelles a l'Observatori Fabra, Barcelona, 1 de Septiembre del 2016

• **Mario Martínez**
- Spain@LHC, BBVA Foundation "Ciclo de Conferencias 2016", Madrid, Spain, November 2016

• **Ramon Miquel**
- "Observant l'univers invisible", talk at Institut Vil.la Romana high school, La Garriga (Spain), November 2016.

• **LluÏsa-Maria Mir**
- "El bosó de Higgs i la frontera de la física". CPAN en el instituto. Participating high schools: IES Castell del Quer, Prat de Lluçanès, Spain, March 2016; IES Gerbert d'Aurillac, Sant Fruitòs, Spain, December 2016

• **Abelardo Moralejo**
- "Astronomía gamma de muy alta energía: MAGIC y CTA", talk at the Agrupación astronómica de Sabadell, February 3, 2016

• **Leyre Nogués**
- "¿Viaja realmente la luz a la velocidad de la luz?", talk at Festa de la Ciència, 19th June 2016, in the Parc de la Ciutadella, Barcelona

• **Antonio Pérez-Calero**
- "La investigación en el CERN i el LHC: Del Big Bang al bosón de Higgs y más allá mediante el Big Data", Institut Arquitecte Manuel Raspall de Cardedeu, November 16, 2016
- "Charlas CPAN IES 2016-2017 en Barcelona: El bosón de Higss y la frontera de la física". Instituto INS El Foix, Sta. Margarida i els Monjos, November 23, 2016

• **Oriol Pujolàs**
- Summer Outreach course on "Cosmology" at the "Juliols de la UB", 8/7/2016 Universitat de Barcelona
- Public talk "Energia Fosca" 25/5/2016, Agrupacio Astronomica de Sabadell

• **Imma Riu**
- "La recerca i el descobriment del Boso de Higgs". CPAN en el instituto. Participating high schools: IES El Escorial, Vic, Spain, April 29, 2016; IES Begues, Begues, May 20, 2016

• **Federico Sánchez**
- Science Exibition "Ciencia entre tots", 13th April 2016, Girona (Spain)
- ¨Neutrinos: las particulas invisibles" February 2016. UAB (Spain)
- Introduction to Neutrino Physics", 14th June 2016 GSI Darmstadt (Germany)

• **András Kovács**
- "Modern astronomy and cosmology", talk at Jurisich Miklos Gimnazium high school, Budapest (Hungary), March 2016.
- "How to be a scientist?", talk at primary school Pankasz, Kisrakos, Viszak Altalanos Iskolaja (Hungary), March 2016

• **Carles Sánchez**
- "Cosmology with the Dark Energy Survey", Lecture on Cosmology at Barcelona International Youth Science Challenge (BIYSC), St. Benet (Spain), July 2016.
- "Cosmologia amb el Dark Energy Survey", Cosmology seminar at the Astronomical Association of Sant Cugat-Valldoreix, St. Cugat (Spain), May 2016

6.7 IFAE COLLOQUIA & SEMINARS IN 2016

IFAE COLLOQUIA

1. "Eureka" - Technology transfer at Nikhef
   January 11 2016
   Niels van Bakel (Nikhef, Amsterdam)

2. The cosmic high-energy frontier: A look to the next decade
   January 12 2016
   Christian Spiering (DESY-Zeuthen)

3. What Does the Eye Tell the Brain? A Journey from High Energy Physics to Neural Systems
   July 8 2016
   Alan Litke (University of California Santa Cruz & CERN)

4. Looking beyond the energy frontier with precision flavour physics at LHCb
   October 14 2016
   Jonas Rademacker (Bristol U)

IFAE SEMINARS

1. The Sun as laboratory for particle physics
   February 5 2016
   Núria Vinyoles (IEEC ICE, Barcelona)

2. The DarkSide Program for Direct Dark Matter Searches at LNGS
   February 15 2016
   Cristian Galbiati (Princeton University, USA)

3. e-ASTROGAM, a wide-field observatory for the MeV / sub-GeV energy band
   February 18 2016
   Margarita Hernanz ICE (CSIC-IEEC)

4. A study of the gamma-ray Galactic center excess with the Fermi LAT Pass 8 data and limits on dark matter annihilation
   February 26 2016
   Dmitry Malyshev (University of Erlangen-Nuremberg)

5. Probing Gravitational Waves from First-Order Phase Transitions at eLISA
   February 29 2016
   Germano Nardini (Institute for Theoretical Physics, University of Bern)

6. Disambiguating the Cosmological Dark Sector
   March 18 2016
   Iggy Sawicki (Geneva U)

7. Some new ideas on dark matter decay
   April 8 2016
   Òscar Catà (LMU Universitaat Munich)

8. Electronvolt sterile neutrinos: a critical appraisal
   April 29 2016
   Pedro A. N. Machado (IFT Madrid)

9. Low-energy effective action for pions and a dilatonic meson
   June 10 2016
   Maarten Golterman (San Francisco State University)

10. Managing astrophysical uncertainties in direct dark matter detection
    June 21 2016
    Francesc Ferrer (Washington U, St. Louis)

11. Can cosmological magnetic fields explain the Baryon Asymmetry of the Universe?
    July 8 2016
    Kohei Kamada (Arizona State University)

12. Adler, Bell and Jackiw in a Metal
    September 30 2016
    Karl Landsteiner (IFT Madrid)

13. Minimally extended SILH
    October 7 2016
    Oleksii Matsedonskyi (DESY Hamburg)

14. Precision and New Physics After LHC run2
    October 21 2016
    Roberto Franceschini (IFAE)

15. Relaxing the Cosmological Constant: a Proof of Concept
    October 28 2016
    Lasma Alberte (SISSA, Trieste)

16. Remedios - What are we searching for in SM precision tests?
    November 7 2016
    Francesco Riva (CERN)

17. Non-perturbative analysis of the spectrum of meson resonances in an ultraviolet-complete composite-Higgs model
    November 11 2016
    Michele Frigerio (Montpelier U)

18. TSPT: a new method for large scale structure in the mildly non-linear regime
November 17 2016
Diego Blas (CERN)

19. Black hole paradoxes, old and new
November 24 2016
Jose Barbón (IFT Madrid)

20. Solid-state imaging detectors for low-energy particle physics
November 28 2016
Alvaro E Chavarria (Kavli Institute for Cosmological Physics University of Chicago)

21. Large scale separation and resonances within LHC range from a prototype model for new physics
December 16 2016
Oliver Witzel (Edinburgh U)

22. Adler function and Bjorken sum rule: generalizations of the Crewther relation in SU(Nc), the β-expansion of PT series, conformal symmetry limit and the way from PMC to the special extension of BLM approach
December 20 2016
Andrei Kataev (Institute for Nuclear Research of the Russian Academy of Science Moscow, Russia)

PIZZA SEMINARS

1. What are Renormalons
20-Jan-2016
Matthias Jamin

2. Triggering AGN activity in galaxies: galaxy interactions vs. disk instabilities
10-Feb-16
Marco Gatti

3. Human Resources Strategy for IFAE Researchers, 2016 - 2019
27-Feb-16
Joaquim Bosch

4. Phenomenological applications of rational approximants
02-Mar-16
Sergi Gonzalez-Solís

5. Status of CTA and latest news from the CTA Management
9-Mar-16
Rene Ong

6. What is the technology transfer? How can it help to my research?
16-Mar-16
Isaac Esparbé

7. The LST Camera
6-Apr-16
Scott Griffiths

8. IFAE Retreat Review
13-Apr-16
Ramon Miquel

9. The IFAE Technical Division
20-Apr-16
Laia Cardiel

10. Prospects For WIMP Dark Matter Detection in Liquid Argon TPCs
4-May-16
Matteo Cavalli-Sforza

11. The MAGIC Sum-Trigger-II
11-May-16
Jezabel R. García

12. The CTA LST bogies
25-May-16
Julià Mundet

13. Prospects for finding Planet 9 in DES data
1-Jun-16
Andras Kovács

14. New inputs for T2K oscillation measurements
8-Jun-16
Alfonso García

15. Dark Matter Perseus
29-Jun-16
Joaquim Palacio

16. About the radius of (heavy) quarkonium and its radiative transitions
13-Jul-16
Antonio Pineda

17. New neutrino CP violation results
20-Jul-16
Federico Sánchez

18. AFP, a newly installed LHC Detector made in Barcelona
27-Jul-16
Iván López Paz

19. Searches for New Physics in ATLAS
14-Sep-16
Loic Valery

20. Physics in Biology
21-Sep-16
Antonella Sucurro

21. IFAE Communications: new outreach project
28-Set-16
Sebastián Grinschpun

22. Ultrasound for probing the underground
19-Oct-16
Matteo Cavalli-Sforza

23. A (very) brief description of Flavour anomalies in b->sll: where we are and what's next?
26-Oct-16
Joaquim Matías

24. T2K phase II proposal
2-Nov-16
Federico Sánchez

25. Galaxy bias from weak gravitational lensing in DES
09-Nov-16
Judit Prat

26. A novel QCD coupling
23-Nov-16
Matthias Jamin

27. Development of a CCD Readout for DESI
30-Nov-16
Otger Ballester

28. IceCube: catching cosmic neutrinos at the South Pole
21-Dec-16
Gonzalo Merino

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