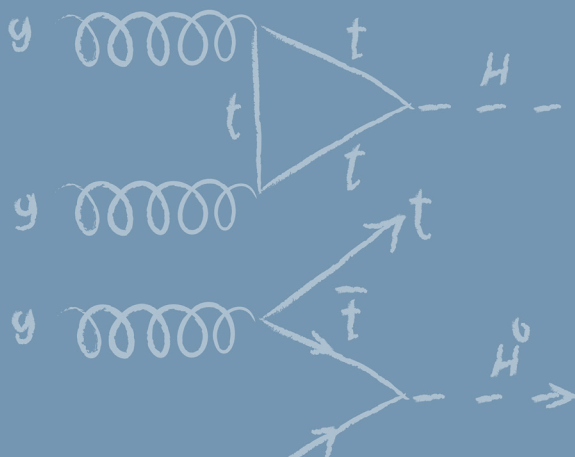
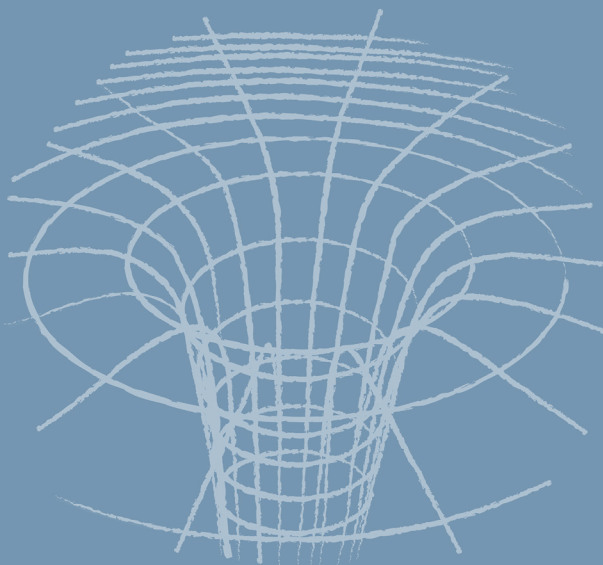
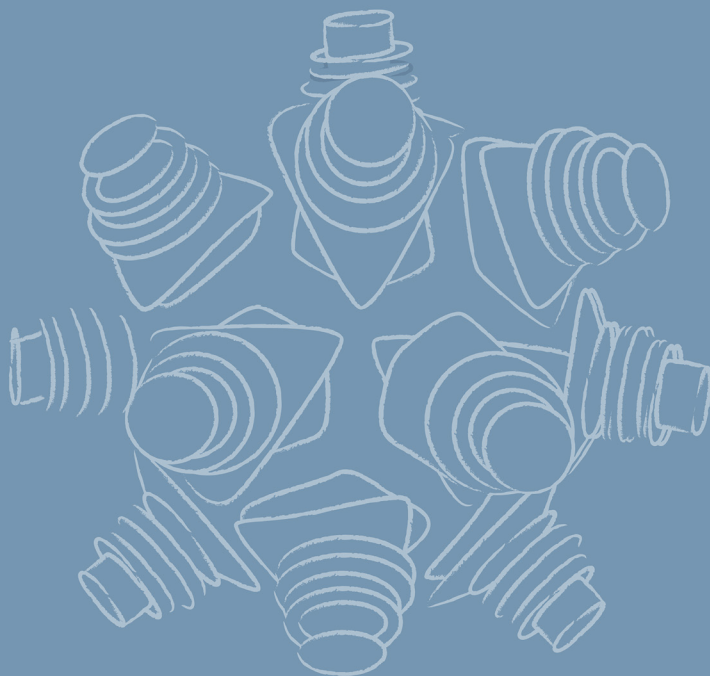
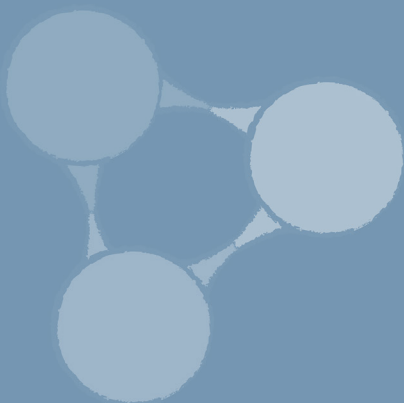
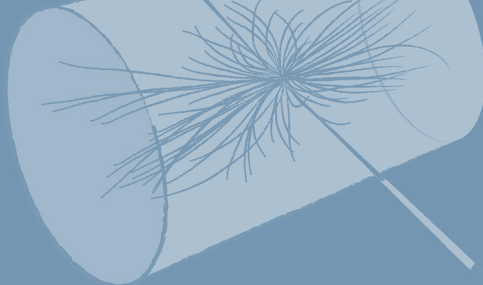

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ANNUAL REPORT

2019



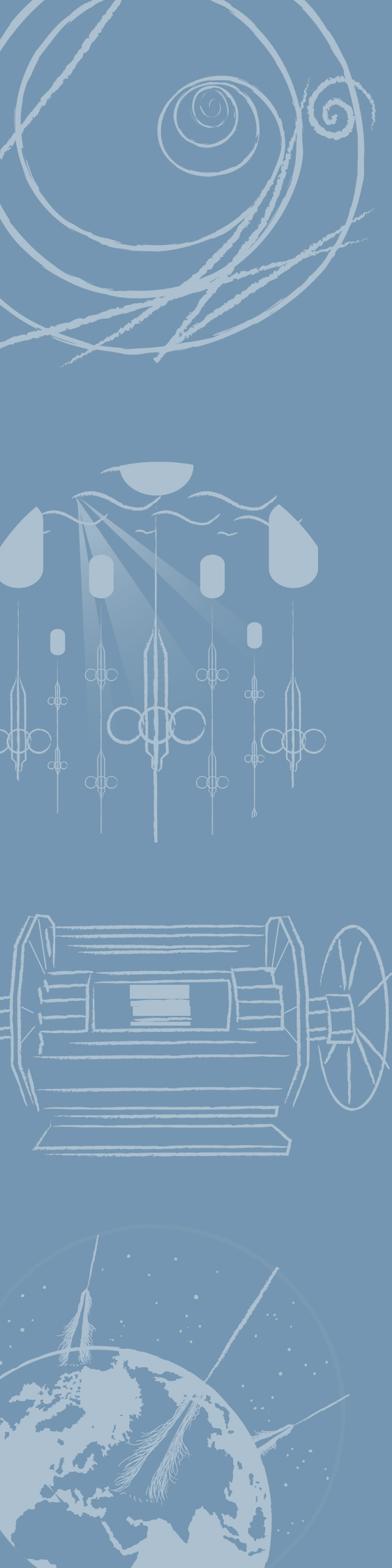


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WELCOME

Nuria Rius Dionis, Director of IFIC



At the end of 2019, and with the aim of developing a new proposal to qualify for the Severo Ochoa Center of Excellence distinction and to enhance synergies between IFIC's theoretical and experimental departments, the research lines were reorganized into three large groups. The groups better reflect the questions about Nature that we want to answer, as well as the advanced technology developed at IFIC to do so. These groups are:

- 1. Origin of mass: understanding the fundamental laws of physics.**
- 2. Origin of matter: understanding the Universe.**
- 3. Advanced instrumentation and computing: from fundamental physics to society.**

Each one contains several sub-lines, both experimental and theoretical, and in particular the last one wants to highlight the strong effort recently made by IFIC to transfer the knowledge and technology developed in our institute to society, while remaining leaders in the basic research in particle, astroparticle and nuclear physics, which is our main mission. The most outstanding scientific results of the year 2019, together with the relevant publications, can be found in the Research Activities section. Here I would like to position IFIC's theoretical and experimental research groups within the above-mentioned three themes.

1. Origin of mass: understanding the fundamental laws of physics. Research on this topic can be grouped into three general lines:

L1. The Higgs Force. The Accelerator-Based High Energy Physics group is involved in the ATLAS experiment at the LHC, where the properties of the Higgs boson, discovered in 2012, are studied, among other things. On the other hand, to be able to correctly interpret the experimental results, in particular from a hadronic collider such as the LHC, a precise theoretical calculation of the corrections due to the strong interaction (QCD) is necessary. In the IFIC High Energy Physics Phenomenology group there are experts in this type of perturbative calculations, which curiously can also be applied to the study of the gravitational interaction, as well as an intense activity proposing and analyzing new physics models that can be tested at the LHC.

L2. Neutrinos and lepton flavour. This line includes two experimental groups and two theoretical groups: The IFIC's Neutrino Physics group is leading the NEXT experiment, whose objective is to measure a rare process that has not been observed to date: neutrinoless double beta decay. If observed, this process would imply that the neutrino is its own antiparticle. It also participates in the T2K and DUNE experiments, which are devoted to measuring neutrino oscillations. The experimental Nuclear Physics group also plays an important role in neutrino physics. In particular in 2019 they have applied a new technique to the study of the so-called beta decays, which has a great impact on the prediction of the antineutrino spectrum in reactors; a crucial piece of information to correctly interpret the neutrino oscillation data produced in nuclear power plants. Complementarily, in the IFIC theoretical physics department, this line brings together researchers from the area of high energy physics phenomenology, experts in neutrinos and lepton flavor physics, as well as from the group of effective field theories in hadron and nuclear physics, who lead the calculations related to interactions of neutrinos with nuclei, the basis for the detection of elusive neutrinos in oscillation experiments.

L3. Flavour and quark matter. In the experimental part, the Accelerator-Based High Energy Physics group also participates in the LHCb experiment at CERN, and in the Belle II experiment in Japan, both of them devoted to the study of the bottom quark. Furthermore, the IFIC-ATLAS group is involved in the analysis of precision measurements of the top quark properties. In the theoretical department, this line includes researchers from the area of High Energy Physics Phenomenology, leaders in flavour physics, as well as researchers from effective field theories in hadron and nuclear physics and from QCD and strong interactions, experts in exotic hadrons (such as the so-called pentaquarks) and in lattice QCD calculations.

2. Origin of matter: understanding the Universe. This group, oriented more towards cosmology and cosmic messengers, contains three research lines:

L4. Baryons, dark matter and cosmic messengers. The IFIC Astroparticle Physics group participates in the ANTARES and KM3NeT experiments, neutrino telescopes located in the Mediterranean Sea. The first has been collecting data for over a decade, and the second, which is an evolution of ANTARES, is currently being built. The IFIC group participates in multi-messenger searches, trying to correlate the detection of neutrinos with that, for example, of very high energy gamma rays, or with gravitational waves. This group has also led the combination of data from ANTARES and IceCube (another neutrino telescope located at the South Pole), to search for dark matter at the galactic center, as well as the analysis of non-standard neutrino interactions. In addition, the Accelerator-Based High Energy Physics group participates in dark matter searches at the LHC, and plays an important role within the MoEDAL experiment, in close collaboration with researchers from the theoretical department. MoEDAL looks for magnetic monopoles and can detect massive, highly ionizing, metastable particles. Finally, researchers in the area of Theoretical Astroparticle Physics and Cosmology study cosmic rays, neutrinos of astrophysical or cosmological origin, and dark matter.

L5. Gravity and the dark Universe: gravitational waves and black holes. The L5 line is essentially theoretical, including researchers from Theoretical Astroparticle Physics and Cosmology, and from High Energy Theoretical Physics: Quantum Black Holes, Supergravity and Cosmology. It is noteworthy that, in 2019, the IFIC participated in the organization of the international conference GR22- Amaldi13, the most prestigious and representative worldwide in the area of Relativity, Gravitation and Gravitational Waves.

L6. The synthesis of nuclei. This line is purely experimental. It comprises researchers from the Gamma and Neutron Spectroscopy group and from the AGATA group. The objectives include understanding the structure of nuclei, and also how elements were formed and evolved in the Universe, through nuclear reactions in stars. IFIC is heavily involved in CERN's n_TOF experiment, in particular in the development of the new i-TED photon detection system, capable of measuring both the energy and the trajectory of gamma rays (HYMNS ERC Consolidator Grant project).

3. Advanced instrumentation and computing: from fundamental physics to society. This line is cross-disciplinary, and involves all experimental groups in which cutting-edge technology is developed for the most advanced detectors worldwide in particle, astroparticle and nuclear physics. It also includes various developments in computing, mainly related to the treatment of Big Data and to the Machine Learning techniques used by both theoretical and experimental researchers. Concerning the technology for fundamental physics, the Accelerator-Based High Energy Physics group is involved both in the construction of the necessary detector components for the future phases of the LHC (Run3 and High Luminosity, HL-LHC) and of the Belle II experiment, as well as in the design of the next-generation linear collider experiments, ILC in Japan and CLIC, led by CERN. The GRID and e-science group at IFIC develops algorithms for the management and analysis of the vast amount of LHC data, including Artificial Intelligence techniques. The Neutrino Physics group is actively working on the future DUNE oscillation experiment, based on the liquid argon "Time Projection Chamber" (TPC) technology. The Nuclear Physics group is involved in the design of the future AGATA detector, which will be the most accurate photon detector for nuclear structure studies.

The most immediate applications of the advanced technology of particle, astroparticle and nuclear physics are in the field of Medical Physics, a line of research that is rapidly growing at IFIC. These applications include the development of a Compton telescope for the monitoring of hadron therapy (MACACO), two prototypes for proton therapy (an online neutron dosimeter and a computed tomography scanner based on silicon detectors), Artificial Intelligence applications for a precise, personalized and predictive medicine, the innovative design of a PET using liquid xenon (PETALO ERC Starting Grant project) and various projects in the field of brachytherapy, radiation protection, dosimetry, etc.

It is worth mentioning that in 2019 the IFIC high-gradient radio-frequency laboratory was inaugurated, developed in collaboration with CERN. This laboratory is used to test radio-frequency cavities, one of the basic elements of particle accelerators, both those used to study the matter of the Universe (such as the LHC) and those used to treat cancer. Another application of the technology developed at IFIC is the use of a detector similar to i-TED (called GUALI) to improve the management of radioactive waste in the dismantling of nuclear power plants.

In 2019, two new committees were created to organize the institute's activities in cross-cutting areas that we consider very important. On the one hand, the dissemination committee coordinates the numerous outreach activities carried out by IFIC members: visits and talks in secondary schools and high schools, several international Masterclasses to introduce particle physics to high school students, actions to promote the presence of women in physics, etc. On the other hand, the artificial intelligence committee (AI @ IFIC) seeks to promote and improve the use of Machine Learning techniques in different groups, through training courses, the creation of discussion forums that allow an optimal use of the IFIC platform for artificial intelligence (ARTEMISA), and by fostering multidisciplinary collaborations.

In conclusion, I would like to thank all IFIC members for their work and dedication, both the teaching and research staff as well as the technical, administrative and communication staff. They have made possible all the activities described in this report. I also acknowledge the management and effort of the previous IFIC directorate, who was in charge until July 2019, as well as their availability ever since.



Nuria Rius Dionis

BIENVENIDA

Nuria Rius Dionis, Directora del IFIC

A finales de 2019, y con el objetivo de elaborar una nueva propuesta para optar al distintivo de Centro de Excelencia Severo Ochoa y de potenciar las sinergias entre los departamentos teórico y experimental del IFIC, se reorganizaron las líneas de investigación en tres grandes grupos, que reflejan mejor las preguntas sobre la Naturaleza que queremos responder, así como la avanzada tecnología desarrollada en el IFIC para poder hacerlo. Dichos grupos son:

- 1. Origen de la masa: entender las leyes fundamentales de la Física.**
- 2. Origen de la materia: entender el Universo.**
- 3. Instrumentación avanzada y computación: de la Física fundamental a la sociedad.**

Cada uno contiene varias sublíneas, tanto experimentales como teóricas, y en particular el último quiere poner de manifiesto el decidido esfuerzo realizado por el IFIC recientemente para transferir el conocimiento y la tecnología desarrollada en nuestro instituto a la sociedad, sin dejar de ser líderes en la investigación básica en física de partículas, astropartículas y nuclear, que es nuestra misión principal. Los resultados científicos más destacados del año 2019, junto con las publicaciones relevantes, se pueden encontrar en la sección Research Activities; aquí me gustaría encuadrar los grupos de investigación teóricos y experimentales del IFIC dentro de las tres temáticas mencionadas.

1. Origen de la masa: entender las leyes fundamentales de la Física. La investigación en este tema puede agruparse en tres líneas generales:

L1. La Fuerza de Higgs: El grupo de Física experimental de altas energías en aceleradores está involucrado en el experimento ATLAS del LHC, donde se estudian entre otras cosas las propiedades del bosón de Higgs, descubierto en 2012. Por otro lado, para poder interpretar correctamente los resultados experimentales, en particular de un colisionador hadrónico como el LHC, es necesario un cálculo teórico preciso de las correcciones debidas a la interacción fuerte (QCD). En el grupo de Fenomenología de altas energías del IFIC hay expertos en este tipo de cálculos perturbativos, que curiosamente también se pueden aplicar al estudio de la interacción gravitatoria, así como una intensa actividad proponiendo y analizando modelos de nueva física que puedan testarse en el LHC.

L2. Neutrinos y sabor leptónico: Esta línea incluye dos grupos experimentales y dos teóricos: El grupo de Física de Neutrinos del IFIC lidera el experimento NEXT, cuyo objetivo es medir un raro proceso, que hasta ahora no se ha observado: la desintegración doble beta sin neutrinos, que de producirse implicaría que el neutrino es su propia antipartícula. Asimismo, participa en los experimentos T2K y DUNE, que están dedicados a medir las oscilaciones de neutrinos. El grupo de Física Nuclear experimental también juega un papel importante en la física de neutrinos, en particular en 2019 han aplicado una nueva técnica al estudio de las llamadas desintegraciones beta, que tiene un gran impacto en la predicción del espectro de antineutrinos en reactores; un dato crucial para interpretar correctamente los datos de oscilaciones de neutrinos producidos en las centrales nucleares. Complementariamente, en el departamento teórico del IFIC esta línea agrupa tanto investigadores del área de Fenomenología de altas energías, expertos en neutrinos y física de sabor leptónico, como del grupo de Teorías efectivas en física hadrónica y nuclear, que lideran los cálculos relativos a las interacciones de los neutrinos con núcleos, base de la detección de los elusivos neutrinos en los experimentos de oscilaciones.

L3. Sabor y materia hadrónica: En la parte experimental, el grupo de Física de altas energías en aceleradores también participa en los experimentos LHCb del CERN, y en Belle II en Japón, dedicados al estudio del quark bottom. Además, el grupo IFIC-ATLAS está involucrado en el análisis de medidas de precisión de las propiedades del quark top. En el departamento teórico, trabajan en esta línea investigadores del área de Fenomenología de altas energías, líderes en la física del sabor, de Teorías efectivas en física hadrónica y nuclear y de QCD e interacciones fuertes, expertos en hadrones exóticos (como los llamados pentaquarks) y en cálculos de QCD en el retículo.

2. Origen de la materia: entender el Universo. Este grupo, orientado más hacia la cosmología y los mensajeros cósmicos, contiene tres líneas de investigación:

L4. Bariones, materia oscura y mensajeros cósmicos: El grupo de Física de Astropartículas del IFIC participa en los experimentos ANTARES y KM3NeT, telescopios de neutrinos situados en el mar Mediterráneo. El primero lleva tomando datos más de una década, y el segundo, que es una extensión de ANTARES, se está construyendo actualmente. El grupo del IFIC participa en búsquedas multi-mensajero, tratando de correlacionar la detección de neutrinos por ejemplo con la de rayos gamma de muy alta energía, o con las ondas gravitacionales. También ha liderado la combinación de datos de Antares y IceCube (otro telescopio de neutrinos situado en el polo Sur), para buscar materia oscura en el centro galáctico, así como el análisis de las interacciones no estándar de los neutrinos. Además, el grupo Física de altas energías en aceleradores participa en la búsqueda de la materia oscura en el LHC, y juega un importante papel dentro del experimento MoEDAL, en cercana colaboración con investigadores del departamento teórico. Este experimento busca monopolos magnéticos y puede detectar partículas masivas metaestables, altamente ionizantes. Finalmente, investigadores del área de Física teórica de astropartículas y cosmología estudian rayos

cósmicos, neutrinos de origen astrofísico o cosmológico, y materia oscura.

L5. Gravedad y el Universo oscuro: ondas gravitacionales y agujeros negros. La línea L5 es fundamentalmente teórica, incluyendo investigadores de la Física teórica de astropartículas y cosmología, y de Física teórica de altas energías: agujeros negros cuánticos, supergravedad y cosmología. Es de destacar que, en 2019, el IFIC participó en la organización de la conferencia internacional GR22- Amaldi13, la más prestigiosa y representativa a nivel mundial en el área de Relatividad, Gravitación y Ondas Gravitatorias.

L6. Materia nuclear y síntesis de los elementos. Está línea es puramente experimental. Participan el grupo de Espectroscopía Gamma y de Neutrones, y el grupo AGATA. Los objetivos incluyen entender la estructura de los núcleos, y también cómo se formaron y evolucionan los elementos en el Universo, a través de las reacciones nucleares en las estrellas. El IFIC está muy involucrado en el experimento n_TOF del CERN, destacando el desarrollo del nuevo sistema de detección de fotones i-TED, capaz de medir tanto la energía como la trayectoria de los rayos gamma (proyecto ERC Consolidator Grant HYMNS).

3. Instrumentación avanzada y computación: de la Física fundamental a la sociedad. Esta línea es transversal, e involucra a todos los grupos experimentales, en los que se desarrolla tecnología puntera para los detectores más avanzados del mundo en física de partículas, astropartículas y nuclear. También incluye los diferentes desarrollos en computación, relacionados sobre todo con el tratamiento de Big Data, y las técnicas de Machine Learning empleadas tanto por los investigadores teóricos como los experimentales. Dentro de la tecnología para física fundamental, el grupo de Física de altas energías en aceleradores está implicado tanto en la fabricación de los componentes necesarios para las futuras fases del LHC (Run3 y High Luminosity, HL-LHC) y del experimento Belle II, como en el diseño de la próxima generación de aceleradores lineales, ILC en Japón y CLIC, liderado por el CERN. El grupo de GRID y e-ciencia del IFIC desarrolla algoritmos para la gestión y análisis de la ingente cantidad de datos del LHC, incluyendo técnicas de Inteligencia Artificial. El grupo de Física de neutrinos trabaja activamente en el futuro experimento de oscilaciones DUNE, basado en la tecnología de "Time Projection Chambers" (TPCs) de argón líquido. El grupo de Física nuclear está involucrado en el diseño del futuro detector AGATA, que será el más preciso detector de fotones para estudios de la estructura nuclear.

Las aplicaciones más inmediatas de la avanzada tecnología de física de partículas, astropartículas y nuclear son en el campo de la Física Médica, una línea de investigación del IFIC que está en pleno crecimiento, incluyendo el desarrollo de un telescopio Compton para la monitorización de la terapia hadrónica (MACACO), dos prototipos para terapia con protones (un dosímetro de neutrones para usar online y un escáner para hacer tomografía basado en detectores de silicio), aplicaciones de Inteligencia artificial para una medicina precisa, personalizada y predictiva, el diseño innovador de un PET utilizando xenón líquido (proyecto ERC Starting Grant PETALO) y diversos proyectos en el campo de la braquiterapia, protección radiológica, dosimetría, etc.

Es de destacar que en 2019 se inauguró el laboratorio de radiofrecuencia de alto gradiente del IFIC, desarrollado en colaboración con el CERN. En este laboratorio se testean cavidades de radiofrecuencia, uno de los elementos básicos de aceleradores de partículas, tanto los que se usan para estudiar la materia del Universo (el LHC) como los que sirven para tratar el cáncer. Otra aplicación de la tecnología desarrollada en el IFIC es la utilización de un detector similar al i-TED (GUALI) para mejorar la gestión de residuos radioactivos en el desmantelamiento de centrales nucleares.

En 2019 se crearon dos nuevas comisiones para organizar las actividades del instituto en sendas áreas transversales que consideramos muy importantes. La comisión de divulgación coordina las numerosas actividades divulgativas llevadas a cabo por miembros del IFIC: visitas y charlas en colegios e institutos, varias Masterclasses internacionales para acercar la física de partículas a los estudiantes de enseñanza secundaria, acciones para fomentar la presencia de las mujeres en la física, etc. La comisión de inteligencia artificial (AI@IFIC) busca potenciar y mejorar el uso de técnicas de Machine Learning en los distintos grupos, por medio de cursos formativos, creando foros de discusión que permitan optimizar el uso de la plataforma del IFIC para inteligencia artificial (ARTEMISA), y propiciando colaboraciones multidisciplinares.

Para terminar, quiero reconocer el trabajo y dedicación de todos los miembros del IFIC, tanto el personal docente e investigador como el personal técnico, de administración y comunicación, que han hecho posibles las numerosas actividades descritas en esta memoria. Y también agradezco la gestión y el esfuerzo del anterior equipo directivo, que estuvo al frente hasta julio de 2019, y su disponibilidad desde entonces.



Nuria Rius Dionis

BENVINGUDA

Nuria Rius Dionis, Directora del IFIC

A la fi de 2019, i amb l'objectiu d'elaborar una nova proposta per a optar al distintiu de Centre d'Excel·lència Severo Ochoa i de potenciar les sinergies entre els departaments teòric i experimental de l'IFIC, es van reorganitzar les línies d'investigació en tres grans grups, que reflecteixen millor les preguntes sobre la Naturalesa que volem respondre, així com l'avançada tecnologia desenvolupada en l'IFIC per a poder fer-ho. Aquests grups són:

- 1. Origen de la massa: entendre les lleis fonamentals de la Física.**
- 2. Origen de la matèria: entendre l'Univers.**
- 3. Instrumentació avançada i computació: de la Física fonamental a la societat.**

Cadascun conté diverses sublínies, tant experimentals com teòriques, i en particular l'últim vol posar de manifest el decidit esforç realitzat per l'IFIC recentment per a transferir el coneixement i la tecnologia desenvolupada en el nostre institut a la societat, sense deixar de ser líders en la investigació bàsica en física de partícules, astropartícules i nuclear, que és la nostra missió principal. Els resultats científics més destacats de l'any 2019, juntament amb les publicacions rellevants, es poden trobar en la secció «Research Activities»; ací m'agradaria enquadrar els grups d'investigació teòrics i experimentals de l'IFIC dins de les tres temàtiques esmentades.

1. Origen de la massa: entendre les lleis fonamentals de la Física. La investigació en aquest tema pot agrupar-se en tres línies generals:

L1. La Força de Higgs: El grup de Física experimental d'altres energies en acceleradors està involucrat en l'experiment ATLAS del LHC, on s'estudien entre altres coses les propietats del bosó de Higgs, descobert en 2012. D'altra banda, per a poder interpretar correctament els resultats experimentals, en particular d'un col·lisionador hadrònic com el LHC, és necessari un càlcul teòric precís de les correccions causades per la interacció forta (QCD). En el grup de Fenomenologia d'altres energies de l'IFIC hi ha experts en aquesta mena de càlculs perturbatius, que curiosament també es poden aplicar a l'estudi de la interacció gravitatòria, així com una intensa activitat proposant i analitzant models de nova física que puguin comprovar-se en el LHC.

L2. Neutrins i sabor leptònic: Aquesta línia inclou dos grups experimentals i dos teòrics: El grup de Física de neutrins de l'IFIC lidera l'experiment NEXT, l'objectiu del qual és mesurar un estrany procés, que fins ara no s'ha observat: la desintegració doble beta sense neutrins, que de produir-se implicaria que el neutrí és la seua pròpia antipartícula. Així mateix, participa en els experiments T2K i DUNE, que estan dedicats a mesurar les oscil·lacions de neutrins. El grup de Física nuclear experimental també juga un paper important en la física de neutrins, en particular en 2019 s'ha aplicat una nova tècnica a l'estudi de les anomenades desintegracions beta, que té un gran impacte en la predicció de l'espectre d'antineutrins en reactors; una dada crucial per a interpretar correctament els resultats d'oscil·lacions de neutrins produïts en les centrals nuclears. Complementàriament, en el departament teòric de l'IFIC aquesta línia agrupa tant investigadors de l'àrea de Fenomenologia d'altres energies, experts en neutrins i física de sabor leptònic, com del grup de Teories efectives en física hadrònica i nuclear, que lideren els càlculs relatius a les interaccions dels neutrins amb nuclis, base de la detecció dels elusius neutrins en els experiments d'oscil·lacions.

L3. Sabor i matèria hadrònica: En la part experimental, el grup de Física d'altres energies en acceleradors també participa en els experiments LHCb del CERN, i en Belle II al Japó, dedicats a l'estudi del quark bottom. A més, el grup IFIC-ATLAS està involucrat en l'anàlisi de mesures de precisió de les propietats del quark top. En el departament teòric, treballen en aquesta línia investigadors de l'àrea de Fenomenologia d'altres energies, líders en la física del sabor, de Teories efectives en física hadrònica i nuclear i de QCD i interaccions fortes, experts en hadrons exòtics (com els anomenats pentaquarks) i en càlculs de QCD en el reticle.

2. Origen de la matèria: entendre l'Univers. Aquest grup, orientat més cap a la cosmologia i els missatgers còsmics, conté tres línies d'investigació:

L4. Barions, matèria fosca i missatgers còsmics: El grup de Física d'astropartícules de l'IFIC participa en els experiments ANTARES i KM3NeT, telescopis de neutrins situats en la mar Mediterrània. El primer porta prenent dades més d'una dècada, i el segon, que és una extensió d'ANTARES, s'està construint actualment. El grup de l'IFIC participa en cerques multi-missatger, tractant de correlacionar la detecció de neutrins, per exemple, amb la de raigs gamma de molt alta energia, o amb les ones gravitacionals. També ha liderat la combinació de dades d'ANTARES i IceCube (un altre telescopi de neutrins situat en el pol Sud), per a buscar matèria fosca en el centre galàctic, així com l'anàlisi de les interaccions no estàndard dels neutrins. A més, el grup Física d'altres energies en acceleradors participa en la cerca de la matèria fosca en el LHC, i juga un important paper dins de l'experiment MoEDAL, en estreta col·laboració amb investigadors del departament teòric. Aquest experiment busca monopols magnètics i pot detectar partícules massives metaestables, altament ionitzants. Finalment, investigadors de l'àrea de Física teòrica

d'astropartícules i cosmologia estudien raigs còsmics, neutrins d'origen astrofísic o cosmològic, i matèria fosca.

L5. Gravat i l'Univers fosc: ones gravitacionals i forats negres. La línia L5 és fonamentalment teòrica, incloent investigadors dels grups de Física teòrica d'astropartícules i cosmologia, Física teòrica d'altres energies i de forats negres quàntics, supergravetat i cosmologia. És de destacar que, en 2019, l'IFIC va participar en l'organització de la conferència internacional GR22- Amaldi13, la més prestigiosa i representativa a nivell mundial en l'àrea de Relativitat, Gravitació i Ones Gravitatòries.

L6. Matèria nuclear i síntesi dels elements. Aquesta línia és purament experimental. Participen el grup d'Espectroscòpia gamma i de neutrons, i el grup AGATA. Els objectius inclouen entendre l'estructura dels nuclis, i també com es van formar i evolucionen els elements en l'Univers, a través de les reaccions nuclears en les estrelles. L'IFIC està molt involucrat en l'experiment n_TOF del CERN, destacant el desenvolupament del nou sistema de detecció de fotons i-TED, capaç de mesurar tant l'energia com la trajectòria dels raigs gamma (projecte ERC Consolidator Grant HYMNS).

3. Instrumentació avançada i computació: de la Física fonamental a la societat. Aquesta línia és transversal, i involucra a tots els grups experimentals, en els quals es desenvolupa tecnologia capdavantera per als detectors més avançats del món en física de partícules, astropartícules i nuclear. També inclou els diferents desenvolupaments en computació, relacionats sobretot amb el tractament de Big Data, i les tècniques de Machine Learning emprades tant pels investigadors teòrics com els experimentals. Dins de la tecnologia per a física fonamental, el grup de Física d'altres energies en acceleradors està implicat tant en la fabricació dels components necessaris per a les futures fases del LHC (Run3 i High Luminosity, HL-LHC) i de l'experiment Belle II, com en el disseny de la pròxima generació d'acceleradors lineals, ILC al Japó i CLIC, liderat pel CERN. El grup de GRID i e-ciència de l'IFIC desenvolupa algorismes per a la gestió i anàlisi de la ingent quantitat de dades del LHC, incloent tècniques d'intel·ligència artificial. El grup de Física de neutrins treballa activament en el futur experiment d'oscil·lacions DUNE, basat en la tecnologia de "Time Projection Chambers" (TPCs) d'argó líquid. El grup de Física nuclear està involucrat en el disseny del futur detector AGATA, que serà el més precís detector de fotons per a estudis de l'estructura nuclear.

Les aplicacions més immediates de l'avançada tecnologia de física de partícules, astropartícules i nuclear són en el camp de la Física Mèdica, una línia d'investigació de l'IFIC que està en ple creixement, incloent el desenvolupament d'un telescopi Compton per al monitoratge de la teràpia hadrònica (MACACO), dos prototips per a teràpia amb protons (un dosímetre de neutrons per a usar online i un escàner per a fer tomografia basat en detectors de silici), aplicacions d'intel·ligència artificial per a una medicina precisa, personalitzada i predictiva, el disseny innovador d'un PET utilitzant xenó líquid (projecte ERC Starting Grant PETALO) i diversos projectes en el camp de la braquiteràpia, protecció radiològica, dosimetria, etc.

És de destacar que en 2019 es va inaugurar el laboratori de radiofreqüència d'alt gradient de l'IFIC, desenvolupat en col·laboració amb el CERN. En aquest laboratori es comproven cavitats de radiofreqüència, un dels elements bàsics d'acceleradors de partícules, tant els que s'usen per a estudiar la matèria de l'Univers (el LHC) com els que serveixen per a tractar el càncer. Una altra aplicació de la tecnologia desenvolupada en l'IFIC és la utilització d'un detector similar a l'i-TED (GUALI) per a millorar la gestió de residus radioactius en el desmantellament de centrals nuclears.

En 2019 es van crear dues noves comissions per a organitzar les activitats de l'institut en sengles àrees transversals que considerem molt importants. La comissió de divulgació coordina les nombroses activitats divulgatives dutes a terme per membres de l'IFIC: visites i xerrades en col·legis i instituts, diverses Masterclasses internacionals per acostar la física de partícules als estudiants d'ensenyament secundari, accions per a fomentar la presència de les dones en la física, etc. La comissió d'intel·ligència artificial (AI@IFIC) busca potenciar i millorar l'ús de tècniques de Machine Learning en els diferents grups, per mitjà de cursos formatius, creant fòrums de discussió que permeten optimitzar l'ús de la plataforma de l'IFIC per a intel·ligència artificial (ARTEMISA), i propiciant col·laboracions multidisciplinàries.

Per a acabar, vull reconèixer el treball i dedicació de tots els membres de l'IFIC, tant el personal docent i investigador com el personal tècnic, d'administració i comunicació, que han fet possibles les nombroses activitats descrites en aquesta memòria. I també agraiïc la gestió i l'esforç de l'anterior equip directiu, que va estar a càrrec fins a juliol de 2019, i la seua disponibilitat fins ara.



Nuria Rius Dionis

STRUCTURE AND ORGANIZATION

ABOUT IFIC

The **Institute for Corpuscular Physics** (Institut de Física Corpuscular, IFIC) of Valencia is a joint research institute belonging to two institutions: the Spanish National Research Council (Consejo Superior de Investigaciones Científicas, CSIC) and the University of Valencia (Universitat de València – Estudi General, UVEG). The synergies between the two institutions make IFIC a reference centre, both in terms of personnel and infrastructures.

IFIC's origins date back to 1950, when Prof Joaquín Catalá formed a group in Valencia to study atomic nuclei and elementary particles using the nuclear emulsion technique, a research activity not previously developed in Spain. Hence, IFIC is one of the oldest Spanish institutes in Experimental Physics and the first studying particle and nuclear physics.

The mission of IFIC covers a wide range of subjects. In a broad sense, we study the fundamental interactions (gravitational, electroweak and strong) and the building blocks of matter, considering both the theoretical and experimental aspects. Our aim is to understand the nature of these interactions and their phenomenological consequences in the laboratories, to predict the behaviour in future experiments and, as a final goal, to search for a unified theory of all of them. In parallel, we wish to know which physical processes occur in the Universe, and how it has evolved from its initial conditions.

It is our aim to keep our level as an international reference centre in Particle, Astroparticle and Nuclear Physics both in the theory and experimental domains. Although IFIC is clearly oriented towards basic research, we are also committed to work on applications that may derive from our activities on fundamental physics, such as advanced instrumentation, distributed computing, medical physics and artificial intelligence (machine learning) techniques. In addition, we want to maintain and improve IFIC's training capabilities at the PhD and postdoctoral level. Last but not least, we plan to strengthen our connection with society through our outreach activities.

IFIC is structured in two scientific divisions: experimental and theoretical physics. Both divisions present an excellent research record and impact at the international level. The balance between these two divisions, a situation that is not very common in Spain, is one of the main strengths of IFIC and the close collaboration among their members is extremely fruitful. In addition, the support and managing services provide the adequate administrative and technical help for our research.

IFIC is a joint research institute belonging two institutions: the Spanish National Research Council (CSIC) and the University of Valencia. Our aim is to keep our level as an international reference in Particle, Astroparticle and Nuclear Physics, both in the theory and experimental domains.

A bit of history

In the autumn of 1950 Prof Joaquín Catalá formed a group at Valencia to study atomic nuclei and elementary particles using the nuclear emulsion technique¹, after working with Prof Cecil F. Powell at Bristol. This technique had been successfully employed to detect particles in cosmic rays and fixed target experiments leading to the discovery of the pion in 1947 by Powell, who was awarded the Nobel Prize in Physics in 1950.



Prof Catalá's group first operated as a local division of the Instituto de Óptica Daza de Valdés belonging to CSIC and specialized in photo-nuclear studies. The group's research program is considered the birth of institutional research in experimental nuclear and particle physics in Spain.

One of Catalá's students, Fernando Senent, who became later professor and director of IFIC, was the author in 1954 of the first Spanish thesis in experimental particle and nuclear physics, whose title was: *Distribuciones angulares de los protones producidos en el bombardeo del carbono 12 por deuterones*. Another of his students, Eugenio Villar, obtained his PhD in 1957 and was later the person leading the particle physics group in Santander, now known as Instituto de Física de Cantabria (IFCA).

It was at the beginning of 1960 when the Institute got its present name, Instituto de Física Corpuscular (IFIC). During many years, the Institute shared the building, offices and facilities with the department of Atomic, Molecular and Nuclear Physics (FAMN) of the University of Valencia, which has been the traditional link with the University. The first observation of the exotic nucleus ${}^8\text{He}$ was performed by IFIC researchers in 1971 through the reaction ${}^8\text{He} \rightarrow {}^4\text{He} + {}^4\text{He} + 2e^-$.

The international impact of our research activities has naturally been influenced by the social and political Spanish situation. In the period 1950-1984 IFIC survived having modest, but heroic, contributions to the physics performed at the international scale. However, after Spain re-entered CERN in 1984 the scientific activity of IFIC was boosted in both quantitative and qualitative aspects at the national and international scales.

Around the year 1985 most of the researchers of the department of Theoretical Physics of the University of Valencia joined the

¹ An excellent review article about the birth of experimental nuclear and particle physics in Spain, written by Agustín Ceba, Víctor Navarro y Jorge Velasco, was published in *Revista Española de Física* 25-2 (2011): <http://revistadefisica.es/index.php/ref/article/view/1274>

Institute and configured its final structure which benefits from the knowledge of both fields: theory and experiment. This provides an excellent atmosphere for scientific cooperation, in particular in the phenomenological and experimental areas. During the last years, it is worth mentioning the participation of IFIC in experiments at CERN (Geneva-Switzerland), GSI (Darmstadt-Germany), SLAC (Stanford-USA), FERMILAB (Chicago-USA), KEK (Japan) and others.

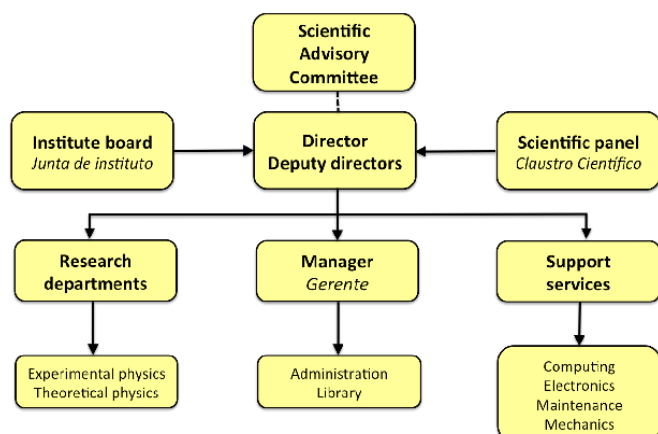
In 2005 IFIC was officially classified by the Spanish Ministry of Education and Science as a Class A institute in the list of CSIC research centres. In 2015, IFIC was awarded with the 'Severo Ochoa' accreditation as Centre of Excellence in recognition of its outstanding performance and scientific contributions at national and international level, its impact at industrial and social level, and the ability to attract scientific talent.



ORGANIZATION, SCIENTIFIC DEPARTMENTS AND SUPPORT UNITS

GOVERNING BOARD

The Scientific Panel (Claustro Científico) is the discussion forum for scientific matters of the institute. Chaired by the director, the Panel consists of the CSIC scientific personnel and the UVEG researchers affiliated to IFIC. The Institute Board (Junta de Instituto) is the governing board of IFIC. It is composed by the Director, the Deputy Directors, the Heads of the two research departments and two representatives of the IFIC personnel. The Manager of IFIC acts as secretary of the Institute Board.



Members of the International Scientific Advisory Committee:

Gustavo Branco (CTP, IST, Univ. Lisbon); William Gelletly (Univ. Surrey); F. Halzen (Univ. Wisconsin); Cecilia Jarlskog (Univ. Lund); Peter Jenni (CERN, Albert-Ludwigs-Univ. Freiburg); Antonio Masiero (Univ. Padua); Tatsuya Nakada (EPFL Lausanne); Bing-Song Zou (IHEP Beijing).

Members of the Institute Board:

Director: Nuria Rius Dionis.

Deputy Directors: Santiago Noguera Puchol (Innovation and Technology), Berta Rubio Barroso, Michel Sorel.

Manager: Ana Fandos Lario.

Heads of the research departments: Carlos Lacasta Llácer (Experimental Physics), Germán Rodrigo García (Theoretical Physics).

Personnel representatives: Teresa Cámara García (non-PhD members), Susana Cabrera Urbán (PhD members).

The Institute is situated in the Burjassot-Paterna Campus of the University of Valencia, a few kilometres from the centre of Valencia. IFIC personnel are distributed at the Science Park of the UVEG in Paterna (PCUV) and at the University departments (Atomic, Molecular & Nuclear Physics and Theoretical Physics) in Burjassot, within walking distance of each other. At the PCUV, IFIC is one of the research institutes with offices in the main University building and owns the CSIC building where all the laboratories and infrastructures are located.



SCIENTIFIC DEPARTMENTS

EXPERIMENTAL PHYSICS

Several groups of our institute participate in many of the most relevant experiments in Particle, Astroparticle and Nuclear Physics, as well as in the applications of these disciplines to other fields of Science and Technology. For instance, IFIC members are part of the international collaborations that manage the ATLAS, LHCb and MoEDAL detectors of the Large Hadron Collider (LHC) at CERN, and participate in the preparation for the future Linear Collider (ILC and CLIC) under the framework of the Linear Collider Collaboration (LCC). The group of e-Science participates in the GRID for the LHC and in other activities of distributed computing.

In Astroparticle Physics the work is focused on the neutrino telescope on the ANTARES and KM3NeT neutrino telescopes, while the Neutrino Physics group is involved in the NEXT, T2K and DUNE experiments.

In Nuclear Physics, we participate in the AGATA project, as well as in several international collaborations: NUSTAR/FAIR (Germany), ISOLDE (CERN), n_TOF (CERN) and BRIKEN (Japan).

Finally, the groups of Medical Physics carries out several activities mainly related to medical imaging and accelerator developments.

Accelerator-based Experimental High Energy Physics

This research line takes advantage of large particle accelerators to study the elementary components of matter. At present, this line is focused on two large projects: the LHC at CERN and the LCC.

IFIC members have participated in the construction of several systems of the ATLAS detector of the LHC, in the computing and data management related to the data supplied by this detector and in the development of a high gradient radio-frequency facility for future colliders and medical applications.

In the past, the scientists of this research line participated in the DELPHI experiment at the LEP accelerator of CERN, the CDF experiment at the Tevatron in Fermilab and in the BaBar experiment at the PEP-II accelerator of SLAC. Apart from ATLAS and LCC, IFIC researchers of this research line are also members of the LHCb, MoEDAL and Belle II collaborations.

Astroparticle Physics

Astroparticle Physics studies the particles coming from the cosmos in order to investigate both their properties and the Universe. The group at IFIC participates in the neutrino telescopes ANTARES and KM3NeT. The former is installed at a depth of 2500 metres in the Mediterranean seabed in the coast near Toulon (France) and it has been in operation since 2008. The latter, KM3NeT, is also being deployed in the Mediterranean Sea with an effective detection volume of several cubic kilometres.

Neutrino Physics

This research line studies the intrinsic properties of the neutrino. The group studies the phenomenon of oscillations between neutrino families, measuring the parameters that define such oscillations. It also tries to elucidate the nature of the neutrino, namely whether the neutrino is a Majorana or a Dirac fermion. IFIC leads the NEXT experiment searching for neutrino-less double beta decay, whose detection would imply that neutrinos are Majorana particles. IFIC also participates in several accelerator-based oscillation experiments: the currently operating T2K experiment in Japan, and the next-generation DUNE experiment in the United States. In the past, scientists of this line participated in the SciBooNE, K2K, HARP and NOMAD experiments.

Nuclear Physics

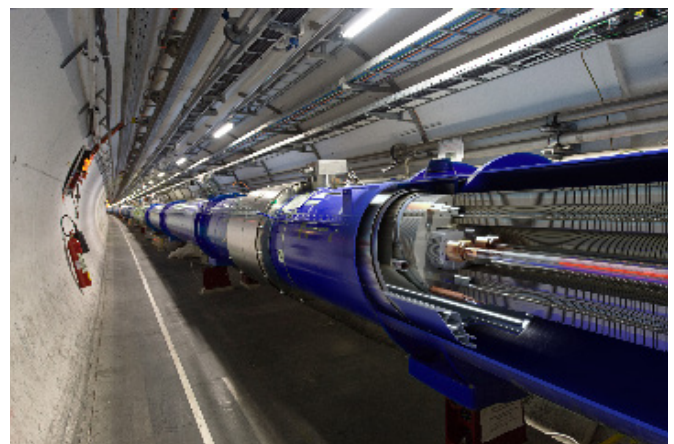
After more than a century of their discovery, atomic nuclei still keep many secrets and there is a wide variety of phenomena not fully understood yet. IFIC researchers in this line work in a broad range of studies in nuclear physics and its applications, such as gamma spectroscopy, extreme nuclear states, nuclear waste incineration or stellar nuclear reactions. Likewise, they are involved in the AGATA project and in the construction of the detectors for the large European infrastructure FAIR. Some IFIC members have participated in the HADES experiment, designed to study di-electron emission in heavy ion reactions.

GRID and e-Science

In order to satisfy the computing needs of particle physics experiments such as those of the LHC, which are providing an enormous amount of data that must be recorded and analysed, a series of initiatives at CERN and the European Union have been carried out to set up a worldwide network of computing nodes (GRID) communicating among themselves through a series of software protocols. IFIC participates in several of them with the aim of developing a model of distributed computing in Spain and in Europe. This type of development can also be interesting for the local industry and has a straightforward application to other research fields where distributed computing and communication are needed.

Medical Physics

The activities of the Medical Physics groups are devoted to the biomedical applications of particle and nuclear physics. Its research includes the development of instrumentation for medical imaging, image science (image reconstruction and algorithmics, modelling of image formation and degradation phenomena, Monte-Carlo simulations, etc.). The group activities also cover developments in particle accelerating techniques, beam instrumentation, detector developments for dose monitoring and imaging for hadron therapy.



Several groups of IFIC participate in many of the most relevant experiments in Particle, Astroparticle and Nuclear Physics, as well as in the applications of these disciplines to other fields of Science and Technology.

THEORETICAL PHYSICS

IFIC researchers cover a wide variety of topics in Theoretical Physics, such as the phenomenological aspects of the Standard Model (SM) and of theories beyond it, aspects of nuclear and many-body physics, or particle physics in astrophysics and cosmology. Both the formal aspects of Quantum Field Theory and the phenomenology of nature's fundamental interactions are investigated in the whole range of available energies both in present and future experiments. The research lines in Theoretical Physics are:

High-Energy Physics Phenomenology

The main goals of high-energy physics phenomenology are the study of the SM of the strong and electroweak interactions and the search for deviations from its predictions that could arise from new interactions expected in several of its extensions, such as supersymmetric models.

This strategy includes the precise determination of the SM parameters, couplings, masses and mixing angles, as well as the phenomenological study of possible modifications from its predictions and of new signals arising from novel processes beyond the SM, with emphasis on the potential consequences for present and future high-energy experiments. Some aspects of Quantum Information are also developed.

High-energy Theoretical and Mathematical Physics: Gravity, Black Holes, and Supersymmetry

This line investigates quantum processes in intense gravitational fields and the appearance of new space-time symmetries. The combination of Quantum Field Theory with General Relativity is studied, as well as its application to black holes (Hawking radiation) and to Cosmology (primitive universe, inflation, etc.).

The classical and quantum aspects of the modification of einsteinian gravity are also considered, as well as the use of supersymmetry and non-commutative geometries in the search for a quantum theory of gravity.

Nuclear Physics and Many-Body Theory

This line studies the interactions between hadrons and within the nuclear medium, using effective theories built from symmetries of Quantum Chromodynamics, perturbative and non-perturbative methods. Special emphasis is put on topics related to the scientific programme of PANDA and CBM of the European Laboratory FAIR and on the study of the neutrino-nucleus cross sections that are used in neutrino oscillation experiments (MiniBooNE, T2K, etc.). Some aspects of Non-linear Dynamics and Complex Systems are also treated.

Quantum Chromodynamics (QCD) and Strong Interactions

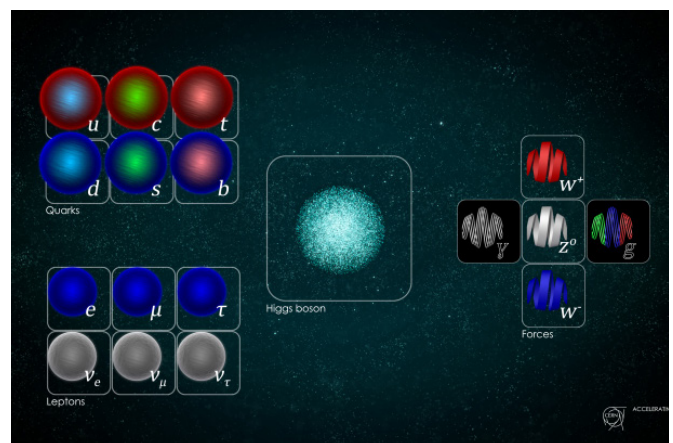
Here we study both the perturbative and non-perturbative aspects of the strong interaction, the fundamental force describing the

interactions between quarks and gluons. Several approaches are used: lattice gauge theories, effective field theories, chiral perturbation theory or phenomenological lagrangians, such as that of the resonance chiral theory.

A variety of goals are pursued, for instance, the theoretical and phenomenological study of QCD in hadron colliders, the study of the hadronic phenomenology in the resonance region, such as in the hadron decays of the tau lepton or in the semileptonic decays of the D mesons and others.

Theoretical Astroparticle Physics and Cosmology

This line covers several interdisciplinary aspects of astroparticle physics and cosmology. Among others it is worth mentioning the basic properties of neutrinos and the future experiments in this field, the origin of neutrino mass and their mixing angles, neutrinos as messengers in astrophysics and cosmology, baryogenesis and leptogenesis, ultra high-energy cosmic rays and others. Although driven by phenomenology which is thriving on the neutrino front as well as cosmology, there is space for theoretical ideas on aspects such as inflation, dark matter or dark energy.



IFIC researchers cover a wide variety of topics in Theoretical Physics, such as the phenomenological aspects of the Standard Model (SM) and of theories beyond it, aspects of nuclear and many-body physics, or particle physics in astrophysics and cosmology.

SUPPORT UNITS

Administration and Management

The Administration Service is located on the first floor of the main research building. A total of 17 people, belonging to CSIC and UVEG, manage the daily running of IFIC, as well as the budgets of many research grants. These funds are provided by different agencies at different levels (regional, national and European), each of them with its own special rules and particular conditions to manage.

At any time there are around 50 live research projects and grants, which implies the processing of a wide range of tasks as employment contracts, public calls, invoices, leaves of absence, etc. In addition, this Service deals with all sorts of matters in a community with staff belonging to two different institutions and with many nationalities.

Computing

This Unit provides a wide range of network and computing solutions for IFIC, giving support to users and projects. The service catalogue covers a wide spectrum, ranging from the installation and configuration of desktop and laptop computers to scientific computing, including the operation of computer farms with hundreds of multi-core CPUs or GPUs. Our Computing Service is more than 20 years old and has pioneered the use of new technologies, such as computer networks (FAENET), the web in the past and the GRID at present.

The computing centre houses several clusters with a total of 300 computer nodes (around 3000 cores) and 2.2 PB of disk storage, some of them using GRID technologies. More than 30 servers are constantly operating to provide email and web services, storage, resource management, user access, monitoring services, printing, databases, etc. The computing centre premises are located in a 150 m² hall with air conditioning (240 KW), technical floor and uninterruptible power supply (250 KVA).



Electronics

This Unit provides service to any IFIC research project with demands in electronics. IFIC experiments develop particle sensors that generate electronic outputs that need to be recorded. The Unit staff and equipment support these activities with design, prototyping, manufacturing, testing and validation of electronic systems.

In addition, certain sensor technologies use microelectronics, as for instance silicon particle detectors. This Unit is in charge of providing chips and silicon structures testing, as well as chip-to-sensor assembly and also the connection of their microchannels. It also offers service and developments to external companies

through contracts and agreements. This Unit makes use of two infrastructures: the general electronics laboratory (90 m², with PCB fabrication and component assembly equipment) and the clean room (80 m² in two areas, classes 10000 and 1000, ISO7 and ISO6, with X-ray inspection, flip-chip and wire-bonding machines) for support in microelectronics.



Library

IFIC's Library, part of CSIC's Library Network, is located on the first floor of the Research Building and has a collection of 2300 books both in topics of general interest and specific to our research. Its staff is responsible for managing the access to electronic journals and the book loans. The latter can be requested online, except for a selection of titles that are for on-site consultation only. IFIC members may request the purchase of books through an online application. The final decision is competence of the Library Commission.

This Service is also responsible for the inventory of theses and dissertations deposited in the library since 1954, as well as the registration of PhD theses and monographs in the general CSIC catalogue. Finally, the library staff collaborates actively in the preparation of IFIC's annual reports (CSIC and UVEG) and the tasks related to the inclusion of our scientific output in the institutional databases.



Mechanics

This Unit provides service to projects with mechanical needs, ranging from the conceptual design phase, calculation and simulation to the development of 3D models and drawings. In addition to manufacturing, we carry out measurements and tests on existing components and assemblies. We have a versatile workshop of about 200 m² that allows us to make and modify many of our prototypes in our own facilities, providing great flexibility in their development. We also have a dimensional inspection laboratory with contact and vision measuring machines.

This Service is also responsible for supervision of the design and management of the manufacturing of mechanical parts and assemblies in outside companies when they exceed our capacities.



Maintenance

This Unit is an integrated service of maintenance management, occupational safety, radiation protection, environmental and quality management of the common facilities as well as the research laboratories of the Institute. Its tasks include the preventive and corrective maintenance of facilities and laboratories, the management and logistics of the Clean Room and the Laboratory of Radioactive Sources. This Unit is also in charge of safety issues at IFIC in collaboration with the corresponding Occupational Health and Safety Services of UVEG and CSIC, including our Radioactive Facility that depends on the Radiation Protection Service of UVEG, as well as the actions in environmental management (waste disposal and energy efficiency). Finally, this Service is responsible for the implementation of quality standards in the operation of shared facilities, such as the Clean Room, according to the guidelines of our parent institutions.

282
Total Staff

219
Scientific
Personnel

24%
Women in
Scientific Staff

92
PhD Students

Scientific Staff

Algora, Alejandro
Álvarez Ruso, Luis
Baremboim, Gabriela A.
Bordes Villagrasa, José Manuel
Botella Olcina, Francisco J.
Cabrera Urban, Susana
Campanario Pallas, Francisco (*Ramón y Cajal*)
Cases Ruiz, Ramón
Castillo Giménez, M. Victoria
Cervera Villanueva, Anselmo
Costa Mezquita, M^a Jose
Díaz Medina, José
Domingo Pardo, César
Donini, Andrea
Fabbri, Alessandro
Fassi Imlahi, Farida (*Doctora vinculada*)
Fiorini, Luca
Furtado Valle, José W.
Fuster Verdú, Juan A.
Gadea Raga, Andres F.
García Figueroa, Daniel (*Ramón y Cajal*)
García García, Carmen
García Navarro, Jose Enrique
Giménez Gómez, Vicente
Gimeno Martínez, Benito
González Alonso, Martín (*GenT*)
González de la Hoz, Santiago
González Marhuenda, Pedro

Hernández Gamazo, Pilar
Hernández Rey, Juan José
Higón Rodriguez, Emilio
Hirsch, Martin K.
Lacasta Llácer, Carlos
Lledó Barrena, M^a Antonia
Llosá Llácer, Gabriela (*Ramón y Cajal*)
López Pavón, Jacobo (*GenT*)
Mariñas Pardo, Carlos (*GenT*)
Martí García, Salvador
Martin-Albo Simon, Justo (*Junior Leader*)
Martínez Vidal, Fernando
Mavromatos, Nikolaos (*Doctor vinculado*)
Mena Requejo, Olga
Mitsou, Vasiliki
Moreno Llácer, María (*Junior Leader*)
Nácher González, Enrique
Navarro Salas, José
Nieves Pamplona, Juan Miguel
Noguera Puchol, Santiago
Novella Garijo, Pau (*Ramón y Cajal*)
Olmo Alba, Gonzalo (*Ramón y Cajal*)
Oyanguren Campos, Arantza
Palomares Ruiz, Sergio (*Ramón y Cajal*)
Papavassiliou, Ioannis
Pastor Carpi, Sergio
Peñarrocha Gantes, José Antonio
Pérez Cañellas, Armando

Pich Zardoya, Antonio
Portolés Ibáñez, Jorge
Rius Dionis, Nuria
Rodrigo García, Germán
Ros Martínez, Eduardo
Rubio Barroso, Berta
Ruiz de Austri Bazán, Roberto
Ruiz Martínez, Arantxa (*Ramón y Cajal*)
Salesa Greus, Francisco (*GenT*)
Salt Cairols, José
Sanchis Lozano, Miguel Angel
Santamaría Luna, Arcadi
Sorel, Michel
Taín Enríquez, José Luis
Tórtola Baixauli, Mariam (*Ramón y Cajal*)
Valls Ferrer, Juan Antonio
Velasco González, Jorge
Vento Torres, Vicente
Vicente Vacas, Manuel
Vidal Perona, Jorge
Vijande Asenjo, Javier
Vives García, Óscar
Vos, Marcel Andre
Yahlali, Nadia
Zornoza Gómez, Juande
Zúñiga Román, Juan

Emeriti

Bernabéu Alberola, José (UV)
Ferrer Soria, Antonio (UV)

de Azcárraga Feliu, José Adolfo (UV)
Oset Báguena, Eulogio (UV)

Navarro Faus, Jesús (CSIC)

Postdoctoral Researchers

Albiol Colomer, Francisco Javier
Arnault de Mateo, Pablo
Ayet San Andrés, Samuel
Bailey, Adam
Balibrea Correa, Javier
Boronat Arévalo, Marçà
Caballero Ontanaya, Luis
Coloma Escribano, M^a Pilar
Da Silva Leite, Julio R.
de Romeri, Valentina
Escobar Ibáñez, Carlos
Esperante Pereira, Daniel
Fernández Menéndez, Pablo
Fullana Torregrosa, Esteban

Gariazzo, Stefano
González Iglesias, Daniel
Gozzini, Sara Rebecca
Husek, Tomas
Huyuk, Tayfun
Ikeno, Natsumi
Kekic, Marija
Lerendegui Marco, Jorge
Lozano Bahilo, José Julio
Mamuzic, Judita
Molina Sedgwick, Susana
Morales López, Ana Isabel
Oldengott, Isabel Mira
Orrigo, Sonja Elena Agata

Papoulias, Dimitrios
Poveda Torres, Joaquín
Ros García, Ana
Santra, Arka
Sborlini, Germán
Thakore, Tarak Nalinkumar
Toledo Sánchez, Genaro
Torres Bobadilla, William J.
Tracz, Szymon
Vale Silva, Luiz Henrique
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Salgado López, Óscar

Outreach

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García Cano, Isidoro

RESEARCH ACTIVITIES

EXPERIMENTAL PHYSICS

ACCELERATOR-BASED EXPERIMENTAL HIGH ENERGY PHYSICS

This research line comprises the activities in the LHC experiments ATLAS, MoEDAL and LHCb (which include: physics analysis, detector operation, and upgrade for the High Luminosity LHC), plus the ones related with the future colliders, accelerator and detector technology.

ATLAS EXPERIMENT

The Long Shutdown 2 (LS2) phase of the LHC accelerator involves the upgrade of the CERN accelerator complex with the goal of increasing both its energy and luminosity. Despite the LHC being in the LS2 phase, the activities in the ATLAS experiment were as frenetic as ever. The physics analyses were exploiting the full 140 fb^{-1} of data collected during the Run2. The detector and operations teams were preparing the final calibrations to reprocess the whole data set for the Run2 legacy.

ATLAS: operations

The trigger is a crucial part of the ATLAS experiment since this is the first selection applied to physics analyses. Our group members have responsibilities in the ATLAS trigger system, such as the coordination of the ATLAS trigger menu, i.e. the selection rules and corresponding pre-scaling rates to be used during the data acquisition to select the recorded events for physics analyses. A working group has been set for preparing the trigger menus of the next LHC Run3. The expected higher luminosity means more particles per beam crossing, and if the LHC energy is increased to 14 TeV, this will produce more particles per collision. Overall, more events and more data to process. Therefore, the trigger becomes more important than ever.

IFIC researchers are responsible of the off-detector electronics of the hadronic calorimeter (TileCal). The maintenance of the FE electronics required the migration to TDAQ-9 (CentOS7) and the replacement of two units of the back-end electronics (RODs), all this in preparation for the higher data rates expected in Run3.

In the tracking front, intensive tests of the track reconstruction performance were carried out in order to cope with the Run3 challenges, improving the track selection and testing the new ATLAS reconstruction software release. The bulk of the activities went to the Inner Detector alignment. As the whole Run2 data set is going to be reprocessed, a very strict and demanding alignment campaign was initiated. The goal is to produce new alignment constants valid for each luminosity block (1 minute of data taking), which must follow the movements of the detectors during the data taking, and to minimize the track parameter bias (impact parameter and transverse momentum). The latter was achieved by validating the results with large event samples of J/Ψ and Z decays to $\mu^+\mu^-$. The large events statistics allowed a novel approach (originally formulated by IFIC physicists) to constrain the radial distortions in the detector and to disentangle them from possible magnetic field biases.

The ATLAS IFIC Tier-2 was successfully operated during 2019. The IFIC Tier-2 contributed around 4% of the total ATLAS resources. The IFIC Tier-2 has the so-called Nucleus state in ATLAS, which implies significant responsibilities and larger work volume.

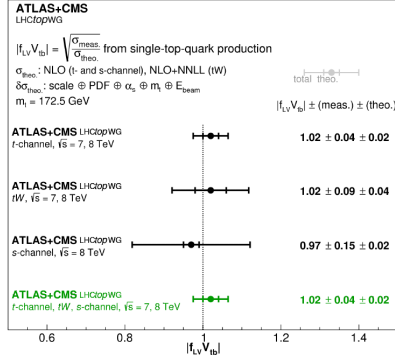
Our site is already actively participating and coordinating the emerging R&D computing activities and developing the new models needed for the Run3 and High-Luminosity LHC (HL-LHC) phases. In 2019, we worked on the integration of new components, such as High Performance Computing (HPC) resources to execute ATLAS simulation workflows. The development of new techniques to improve efficiency in a cost-effective way, such as storage and CPU federations have been studied. Improvements in data organization, management and access through storage consolidations ("data-lakes"), the use of data caches, and improving experiment data catalogues, like Event Index were carried out in 2019.

The design and deployment of new analysis facilities using GPUs together with CPUs and techniques like Machine Learning have started being implemented and considered. Our Tier-2 site contributes to significant R&D in computing: evaluating different models for improving performance of computing and data storage capacity in the High-Luminosity LHC era.

ATLAS: precision physics measurements

We have greatly contributed to the analysis of the LHC proton-proton collisions data. The precise measurement of the couplings of the top quark, the heaviest elementary particle and with the strongest Yukawa coupling to the Higgs boson, is one of the priorities of the LHC physics program, with the IFIC-ATLAS group playing a leading role.

Following up on the cross-section measurements of top quark pair production in association with Z and W-bosons and of the first differential cross-section results in the associated production with a photon, we are now contributing to innovative differential measurements. Our group leads the studies for probing (with higher precision) the Wtb vertex (t-channel single top quark production), providing first differential measurements within a fiducial region sensitive to the three-dimensional polarisation vector.

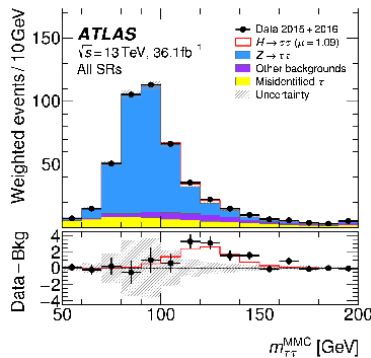


The combined $|f_{t\gamma} V_{tb}|$ value extracted from the t-channel and tW cross-section measurements at $\sqrt{s}=7$ and 8 TeV from ATLAS and CMS.

Regarding the coupling of the top quark to the Higgs boson, we have contributed to the cross-section measurement of top quark pair production in association with a Higgs boson, and developed a new analysis specifically targeting the Higgs boson decays to a pair of tau leptons combined with fully hadronic top quark decays. Our group coordinates the ATLAS effort towards the first studies probing the CP-structure of the top quark Yukawa coupling in the Higgs decay to photons. In this context, the exploration of the associated production of a single top quark with a Higgs boson is also highly motivating. We lead and coordinate the ATLAS analysis team focusing on multi-lepton final states, where the exploitation of machine learning techniques is essential to distinguish the small signal from the overwhelming backgrounds.

Since the precision of some of these LHC results is already limited by theoretical uncertainties, the team is actively involved in modelling studies, being a member of IFIC in charge of the ATLAS Top physics modelling group and of the LHC ttH/tH group. Another member is responsible for the LHC combinations of all single top related analyses, as representative of ATLAS. This work has led to the first publication of the Run-1 combination of single top cross section measurements performed in ATLAS and CMS, including the V_{tb} CKM matrix element determination.

Our group is also involved in the study of the Higgs sector. We contributed to the ATLAS measurement of the Higgs boson production properties in the final states with taus. We are also involved in the measurement of the interaction of the top quark with the Higgs boson. We also contribute to the development of machine learning algorithms to improve the analysis sensitivity and to the estimation of the background.



Distribution of the reconstructed di- τ invariant mass. The bottom panel shows the differences between observed data events and expected background. The observed Higgs-boson signal ($\mu = 1.09$) is shown with the solid red line.

Concerning the top quark mass, our group produced a world class and important result. The top quark mass measurement on 8 TeV data, using a method developed originally by IFIC, was published in 2019 [JHEP 1911 (2019) 150]. This method exploits the radiation of a hard gluon (giving rise to a jet) by a top quark before its decay. The result is:

$$m_{\text{top}}^{\text{pole}} = 171.1 \pm 0.4 (\text{stat.}) \pm 0.9 (\text{syst.})^{+0.7}_{-0.3} (\text{theo}) \text{ GeV}$$

This result has a total uncertainty approaching 1 GeV and is the most precise measurement of the top quark pole mass at the date of publication.

The involvement in studies of boosted objects in ATLAS led to the publication of the preliminary results for the charge asymmetry measurement in top quark pair production and the review paper “*Jet substructure at the Large Hadron Collider: experimental review*” in the Review of Modern Physics.

The world most -precise measurement of the top quark pole mass was made by IFIC members in ATLAS

ATLAS: new physics searches

The discovery of a Higgs boson opens the possibility that new physics (beyond the Standard Model, SM) appears in the Higgs sector. We searched for violation of lepton flavour conservation in the Higgs boson decays, for the existence of additional Higgs bosons and for heavy particles decay into two Higgs bosons. We had a prominent role in those ATLAS searches, developing multivariate analysis technique to discriminate the signal from the backgrounds. Our group has contributed to the development of techniques for the reconstruction and identification of leptons (muons, electrons and tau-leptons) with the ATLAS experiment software.

Direct searches for new physics phenomena involving top quarks in the final state are also highly motivated due to the large top quark mass. We have contributed to the first search in ATLAS for events with one top quark and large missing transverse momentum using data collected at 13 TeV center-of-mass energy, being in charge of the lepton channel analysis and of the combination with the hadronic channel. The results obtained are interpreted in the context of generic models for dark matter production and for the single production of a vector-like top quark. The group is also contributing now to the search for dark matter in the context of a two-Higgs-doublet model together with an additional pseudo-scalar mediator, which decays to the dark matter particles. New signatures are explored, where the pseudo-scalar mediator is produced in association with a single top quark.

We are strongly involved in the ATLAS searches for supersymmetric (SUSY) particles. The group has pioneered the R-parity violating (RPV) SUSY searches, the channel with two strongly-produced electron or muons and large missing transverse momentum stands out. In addition, in 2017 we searched for light higgsinos characterised by compressed spectra, a well-motivated scenario by naturalness arguments and an experimentally challenging final state. The results

offer sensitivity beyond LEP limits. Furthermore, the fully hadronic channel, in which we are also involved, provides the stronger sensitivity for many supersymmetric scenarios.

We are strongly involved in the ATLAS searches for supersymmetric (SUSY) particles, with emphasis on leptonic signatures and searches for R-parity violating models. We have made significant progress in analysing events with two electrons or muons using the full Run 2 dataset. Two orthogonal cases are studied: opposite-sign leptons, e.g. originating from Z-boson decays and same-sign leptons, characterised by small background processes. We have established collaborations with several theoretical physicists for the interpretation of the results and for seeking new physics models.

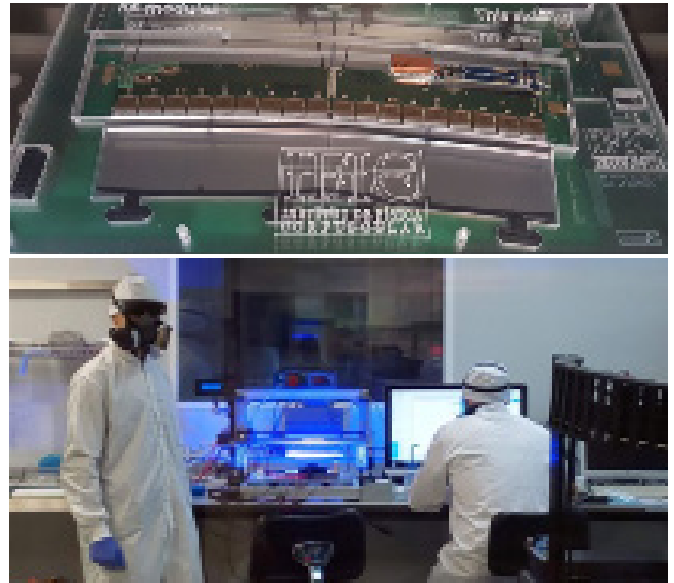
The group has also had important contributions to the HL-LHC sensitivity studies, providing an important input to the update of the European Strategy for particle physics.

ATLAS: detector upgrade

IFIC is responsible for the Upgrade of the TileCal off-detector electronics for the HL-LHC, planned to start data-taking in 2026. The TilePre-Processor (TilePPR) is the core of the HL-LHC TileCal off-detector electronics. The TilePPR prototypes are able to provide a full digitization of the calorimeter data and transmission at 40 MHz rate, withstanding an accept rate above 1 MHz. The TilePreProcessor (TilePPR) Demonstrator was installed in 2019 at the ATLAS counting room (USA15) to read out and operate the first Demonstrator module. Our group designed and validated the main components of the final version of the TilePPr for the HL-LHC: the ATCA Carrier Base Board and the Compact Processing Modules (CPMs). The Carrier passed successfully the Preliminary Design Review (PDR) in September 2019. Members of the group coordinated led the Upgrade of TileCal as Deputy Leader of the Project and coordinator of the Upgrade electronics.

IFIC is one of the leading institutes in the upgrade of the new all-silicon ATLAS tracker for the HL-LHC, the Inner Tracker (ITk), holding the role of deputy project leader and the responsibility of the services plus grounding and shielding of the detector. We have made key contributions to the design and simulation (Finite Element Analysis) of the endcap support structure, the design and optimization of the whole ITk CO₂ cooling lines, the services distribution (power, cooling, control signals and data) to modules along the whole chain (bus tapes, service modules, patch panels, etc.), the local support for the sensors and the design of the endcap sensors.

During 2019, the ITk collaboration has changed the operation mode from research and development to production and has gone through an extensive series of reviews of all the design aspects that have given us the green light to start the purchase and manufacturing of all the components of the detector. IFIC has played a critical role here given the responsibilities within the collaboration and the commitments in so many aspects of the detector. We have also been preparing the infrastructures to start the production of the detector components.



Top: an ITK strip module assembled at IFIC. The sensors are connected to 18 readout chips.

Bottom: Personnel working on the ITK strip module assembly inside the clean room.

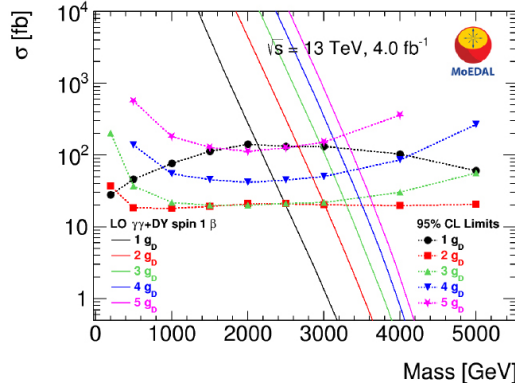
IFIC is responsible for the upgrade of the TileCal off-detector electronics of the High Luminosity LHC, and is one of the leading institutes in the upgrade of the new all-silicon ATLAS tracker for this major upgrade of LHC planned to start in 2026

MOEDAL EXPERIMENT

The IFIC team is the only Spanish participation in MoEDAL, an experiment designed to search for manifestations of new physics through highly ionising particles produced at the LHC. Its primary motivation is the quest for magnetic monopoles, yet the experiment is also sensitive to any massive, (meta-)stable, slow-moving particles with single or multiple electric charges arising in many scenarios of physics beyond the Standard Model. MoEDAL uses a (mostly) passive detector, featuring aluminium Magnetic Monopole Trapping detector volumes (MMTs), plastic Nuclear Track Detectors (NTDs) and TimePix detectors.

We are coordinating the software aspects of the experiment and we are strongly involved in the development and testing of key theoretical scenarios, such as monopole production processes and supersymmetric models. IFIC plays a leading role in the MoEDAL management by holding the Chair of the Collaboration Board.

Our group is leading the exploration of monopole production via photon fusion, which is expected to be much more abundant at LHC than the Drell-Yan process considered so far. The outcome of phenomenological aspects already studied at IFIC in the past allowed our group to carry out the first search for monopoles produced in photon fusion at the LHC. The full MMT detector, amounting to around four times more volume than in previous analyses, was exposed to proton-proton collisions during 2015-2017, representing twice as much of data than earlier searches. The MMT was scanned by a SQUID device showing no evidence for trapped monopoles, leading to the world-best limits for monopoles of high magnetic charges, up to five Dirac charges.



Cross-section upper limits set by MoEDAL for the combined $\gamma\gamma$ and Drell-Yan monopole pair production for spin-1 monopoles and different monopole masses and charges. The solid lines are cross-section calculations.

The MoEDAL group at IFIC led the first search for magnetic monopoles produced via photon fusion at LHC

LHCb Experiment

Our LHCb team has continued contributing to the program of B-decay anomalies and the study of charm baryon decays, along with the detector upgrade.

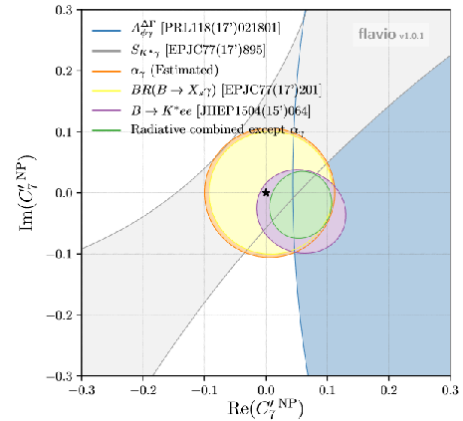
Radiative b-hadron decays, which occur in the SM via flavour changing neutral currents, are sensitive probes for new physics, although experimentally their study is very challenging. During 2019, the first measurement of CP-violating and mixing-induced observables in $B_s \rightarrow \phi\gamma$ decays has been presented. Moreover, the first experimental analysis of a radiative b-baryon decay, $\Lambda_b \rightarrow \Lambda\gamma$, has been published, along with a phenomenological study to expand these studies to other b baryons, in particular $\Xi_b \rightarrow \Xi\gamma$ decays. In parallel, experimental studies are being conducted to study charm baryon decays, whose dynamics is largely unknown despite its importance for the understanding of strong interactions and as a tool for other physics measurements. These include, among others, CP violation in the charm sector, discovered by LHCb precisely this year with charm mesons, using single and doubly Cabibbo suppressed baryonic decays.

The LHCb experiment is undergoing a detector upgrade that will provide the tools required to increase the full potential of the LHC luminosity, already during the Run 3 prior to the HL-LHC. The triggerless readout under installation will allow a fully informed and more flexible software selection that will boost the efficiency of the system, achieving an increase in data throughput for analysis, much greater than the increase in luminosity produced by the realignment of the beams. The greater enhancement of the detector is happening at the tracking stations upstream, where the Scintillating Fiber Tracker (SciFi) is being installed. This device uses plastic scintillating fibers, readout by silicon photomultipliers and cover an area of 340 m². During 2019, the assembly, installation and commissioning process has been taking place. We are part of this project through the collaboration in the design and characterization of PACIFIC, a 64-channel ASIC designed in 130nm technology to read out the light sensors. In this year, the participation extended to the collaboration in the qual-

ity control of the PACIFIC Carrier Boards, the printed circuit board hosting PACIFIC. Furthermore, the group had the chance to work onsite, where new quality control protocols were established for the installation of the detector services.

Since a good detector can only perform as such if the reconstruction, simulation and trigger have the required performances, the group also had responsibilities in the SciFi Simulation and Software group, in particular in the development of the new tracking algorithms required under the stringent computing upgrade conditions. With a computing model based on the Real Time Analysis (RTA) paradigm, the group has also contributed and taken responsibilities into the development of a new fully GPU-based implementation of the first level trigger of the upgraded detector, which highly improves the reconstruction and selection capabilities of the detector.

The group has continued exploring new ideas to extend the LHCb physics program with the upgraded detector through a fixed target program based on a tungsten target paired to a silicon or germanium bent crystal. Such a setup would provide first experimental access to magnetic and electric dipole moments of short-lived particles, like charm baryons and ultimately beauty baryons and the tau lepton, along with unique studies of production and polarization of heavy hadrons in nuclear medium. The proposal and possible scenarios are under discussion within the CERN's Physics Beyond Colliders forum and LHCb.



Constraints on New Physics given by radiative b-hadron analyses using the recent LHCb results.

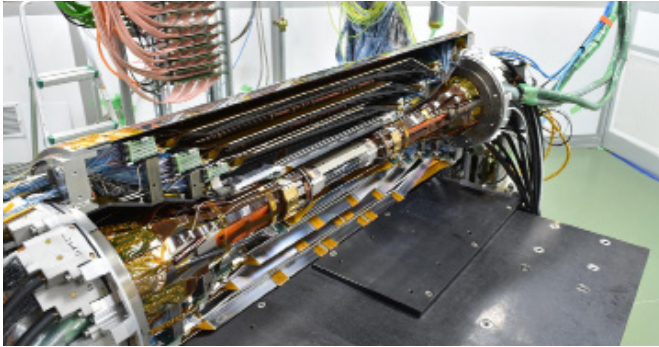
The LHCb team at IFIC has continued contributing to the program of B-decay anomalies and the study of charm baryon decays, along with the detector upgrade

Future Colliders

Our group is also deeply involved in the linear collider projects ILC (International Linear Collider, to be hosted in Japan) and CLIC (Compact Linear Collider, led by CERN) and have a representative in the ECFA (European Committee for Future Accelerators). IFIC also coordinates the Spanish network for future colliders.

2019 was an important year for future collider projects, with the main meeting for the update of the European Strategy for particle physics in Granada. The group at IFIC has made important contributions to the reports and inputs prepared by the ILC and CLIC projects. In particular to the report “*The International Linear Collider: a Global Project*”, as well as to several publications of detailed studies.

The effort in accelerator and detector R&D has been quite intense in 2019. The year 2019 saw the completion of the Belle II vertex detector and its installation in the experiment in Japan, and of course the first data from the e+e- collisions.



The Vertex detector at BELLE II experiment in KEK (Japan).

The high-gradient radio-frequency facility developed in collaboration with CERN was officially inaugurated in 2019 and is testing cavities at full capacity. A group member presented this new facility in an invited plenary talk at the Ampere conference.

In 2019 Juan Fuster was awarded the Humboldt prize. This prize is a recognition of his trajectory in particle physics and offers new opportunities for intensified collaboration with DESY and the University of Bonn.

The high-gradient radio-frequency facility at IFIC, developed in collaboration with CERN, was inaugurated in 2019, and it is testing acceleration cavities at its full capacity

Detector R&D

Our group is also involved in the RD50 Collaboration, the aim of which is to develop radiation hard semiconductor devices for very high luminosity colliders. Our activities focus in the design of Monolithic Active Sensors and the development of a data acquisition system of in collaboration with the U. of Liverpool (U.K.) and HEPHY Vienna (Austria).

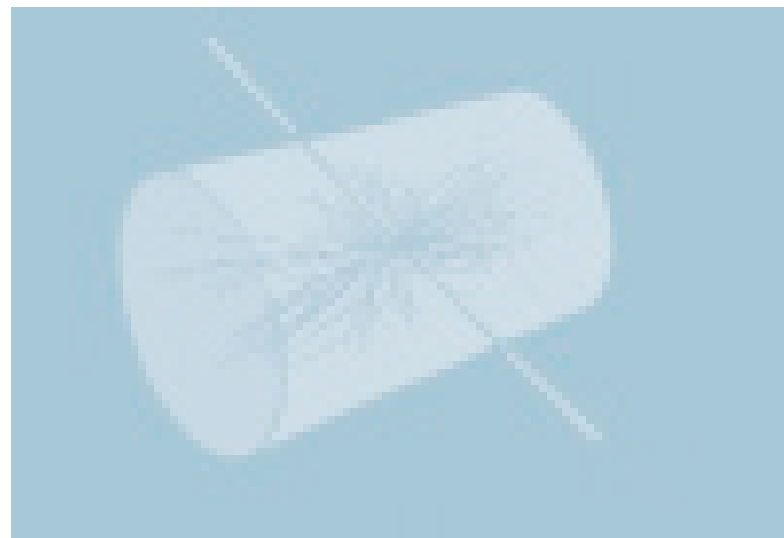
Selected publications

- > ATLAS Collaboration, *Cross-section measurements of the Higgs boson decaying into a pair of τ -leptons in proton-proton collisions at $\sqrt{s}=13$ TeV with the ATLAS detector*, Phys. Rev. D 99 (2019) 072001, DOI: <https://doi.org/10.1103/PhysRevD.99.072001>
- > ATLAS Collaboration, *Measurement of the top-quark mass in $t\bar{t}+1$ -jet events collected with the ATLAS detector in pp collisions at $\sqrt{s}=8$ TeV*, JHEP 11 (2019) 150. DOI:10.1007/JHEP11(2019)150

- > ATLAS Collaboration, *Combinations of single-top-quark production cross-section measurements and $|f_{\text{LV}}V_{\text{tb}}|$ determinations at $\sqrt{s}=7$ and 8 TeV with the ATLAS and CMS experiments*, JHEP 05 (2019) 088. DOI:10.1007/JHEP05(2019)088
- > ATLAS Collaboration, *Search for large missing transverse momentum in association with one top-quark in proton-proton collisions at $\sqrt{s}=13$ TeV with the ATLAS detector*, JHEP 05 (2019) 41. DOI:10.1007/JHEP05(2019)041
- > MoEDAL Collaboration (Acharya, B. et al), *Magnetic monopole search with the full MoEDAL trapping detector in 13 TeV pp collisions interpreted in photon-fusion and Drell-Yan production*, Phys. Rev. Lett. 123, 021802 - 7 pp, DOI: 10.1103/PhysRevLett.123.021802 [arXiv:1903.08491]
- > R. Aaij et al., LHCb collaboration, *Measurement of CP-violating and mixing-induced observables in $B_s \rightarrow \Phi \gamma$ decays*, Phys. Rev. Lett. 123 (2019) 081802.

Selected conference talks

- > R. Marco-Hernández, *Overview of CMOS sensors for future tracking detectors*, plenary session talk at Connecting the Dots and Workshop on Intelligent Trackers, 2nd-5th April 2019. Valencia (Spain).
- > V. A. Mitsou, *Magnetic monopoles at the LHC*, plenary session talk at 25th International Symposium on Particles, Strings and Cosmology (PASCOS 2019), 1-5 July 2019, Manchester, UK.
- > M. Moreno, *The Large Hadron Collider and its search for the building blocks of the Universe*, plenary session talk at XXXVIIIth Biennial Meeting of the Spanish Royal Society of Physics (RSEF), 15-19 July 2019, Zaragoza (Spain).
- > F. Carrió, *Development of the Compact Processing Module for the ATLAS Tile Calorimeter Phase-II Upgrade*, Topical Workshop on Electronics for Particle Physics, TWEPP2019. September 2019, Santiago de Compostela, Spain.
- > C. Escobar, *Inclusive $t\bar{t}$ + single top (standard modes) cross-section measurements (ATLAS+CMS)*, plenary session talk at 12th International Workshop on Top Quark Physics (TOP2019). 22-27 September 2019, Beijing (China).
- > S. González de la Hoz, *Computing activities at the Spanish Tier-1 and Tier-2s for the ATLAS experiment towards the LHC Run3 and High Luminosity (HL-LHC periods)*, 24th International Conference on Computing in High Energy and Nuclear Physics (CHEP19). 4-8 November 2019, Adelaide (Australia).
- > A. Oyanguen Campos, *Real-time data analysis model at the LHC and connections to other experiments / fields*, Plenary session talk at 24th International Conference on Computing in High Energy and Nuclear Physics (CHEP19). 4-8 November 2019. Adelaide (Australia)
- > M. Moreno, *Precision physics with top quarks*, plenary session talk at Ultimate Precision at Hadron Colliders 2019. 25 November - 6 December 2019, Paris (France).



EXPERIMENTAL ASTROPARTICLE PHYSICS

ANTARES and KM3NeT

Neutrino astronomy continues in the exciting epoch of discoveries and construction of new detectors. The scientific panorama is dominated by the observation of several cosmic neutrino signals by IceCube: a diffuse flux whose origin is still uncertain and the first identified source of high energy neutrinos (the blazar TXS 0506+056). Concerning detector construction, important steps have been taken towards KM3NeT, which will be the best neutrino detector in the world. Meanwhile, a lively activity in the analysis side continues in several fronts: to further extract the juice in the ANTARES data, to better evaluate the performance of KM3NeT and to start looking at the first KM3NeT data. Our group at IFIC has been closely involved in all of these activities.

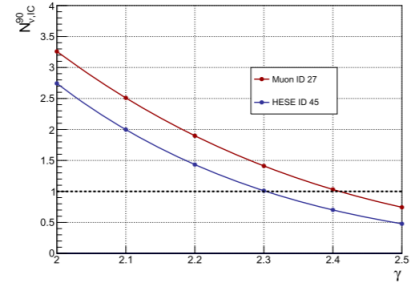
ANTARES

The ANTARES detector, installed in the deep Mediterranean Sea, has been taking data for more than a decade. These data have provided a rich harvest of scientific results, which far from being waning, it is accelerating, as a consequence of the better understanding of the detector and the maturity of the project.

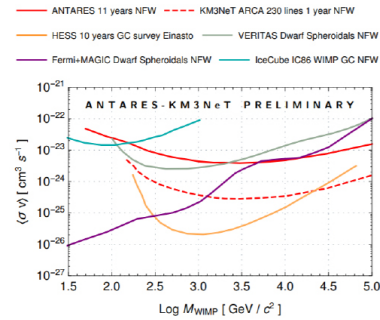
One of the big topics in the last years is multi-messenger astronomy. We are now in a particularly exciting time after the arrival of two long-expected heralds from the sky: high energy neutrinos and gravitational waves. There is a lot that we can learn from these new messengers, and much more that we can learn from them when combined with the “classical” electromagnetic observations. During 2019, the number of gravitational wave events have increased, giving new opportunities to look for correlations with other messengers. The international, “inter-signal” network of alert systems which are presently in place is ready for the new examples of such correlations and, in particular, for the next holy grail: a triple signal in electromagnetic, cosmic neutrinos and gravitational waves.

Our team is participating in this multi-messenger search. An example of this has been the search for correlations with the gamma-ray burst GRB 190114C, which emitted in very high energy gamma rays as observed by the MAGIC telescope. Offline combination of data with the IceCube detector is also an important topic of the work of our group for ANTARES. We have led the analysis to look for correlations in time and space with high energy IceCube events and the combination of data of IceCube and ANTARES to look for dark matter in the Galactic Centre. Although ANTARES can set better limits due to its location and angular resolution, at low WIMP masses, where sensitivities are similar, such a combination is worth it.

Finally, another topic in which our group has made important contributions in ANTARES is the study of non-standard interactions of neutrinos. This work was triggered by our study for KM3NeT, but soon we realised that ANTARES data offer a great opportunity to probe this sector now.



Upper limits on the expected number of IceCube events originated from a transient source emitting in a time window <0.1 s.



Limits/sensitivity on dark matter annihilation cross section for ANTARES and KM3NeT.

The IFIC group at ANTARES experiment led the combination of data of IceCube and ANTARES to look for dark matter in the Galactic Centre

KM3NeT

The year 2019 has been crucial for KM3NeT due to the deployment of additional lines of the detector up to a total of four (soon increased to seven during 2020). The data gathered with these four lines has shown the robustness of the detector and allowed us to start carrying out first analyses.

On the physics side, our group has been focused on several topics, in harmony with our work in ANTARES: studying the performance of KM3NeT for dark matter searches, studying the capability of the detector for multi-messenger astronomy and developing the tools for being part of the SNEWS alert system for supernova detection and studying neutrino properties. A good example of this is our analysis on the power of KM3NeT to look for non-standard neutrino interactions, which also triggered the use of ANTARES data to set best worldwide limits for several parameters describing such interactions, as mentioned above. Another example is our study of the performance of KM3NeT for observing neutrino decay. KM3NeT will have world-best capabilities in several of these topics thanks to its excellent angular resolution and privileged location to observe the Milky Way.

In addition to our contributions to physics analyses, the IFIC group has an important role in the detector design and construction, in particular in the main electronics elements (the Central Logic Board and the Power Board) and the so-called nanobeacons, used for in situ time calibration. We are also setting up our labs to become a node for base integration of detector lines, which will

have an enormously beneficial impact in the deployment of the detector, as recognised by the KM3NeT Collaboration. Additional contributions from our group include the roles of coordinators of the Dark Matter and Exotics Working Group and the Electronics Working group.

Selected publications

- > ANTARES Collaboration (A. Albert et al), *ANTARES neutrino search for Time and Space correlations with IceCube High-Energy neutrino events*, The Astrophysical Journal, 879:108 (2019).
- > ANTARES Collaboration (A. Albert et al), *Search for Multi-messenger Sources of Gravitational Waves and High-energy Neutrinos with Advanced LIGO during its first Observing Run*, ANTARES and IceCube, Astrophys.J. 870 (2019) no.2, 134.
- > ANTARES Collaboration (A. Albert et al), *Measuring the Atmospheric Neutrino oscillation parameters and constraining the 3+1 neutrino model with ten years of ANTARES data*, J. High Energy. Phys. (2019) 2019: 113.
- > KM3NeT Collaboration (S. Aiello et al), *KM3NeT front-end and readout electronics system: hardware, firmware and software*, J. Astron. Telesc. Instrum. Syst. 5(4), 046001 (2019)
- > KM3NeT Collaboration (S. Aiello et al), *Sensitivity of the KM3NeT/ARCA neutrino telescope to point-like neutrino sources*, Astroparticle Physics 111 (2019) 100.

Selected conference talks

- > R. Gozzini, *Searches for dark matter with the ANTARES and KM3NeT neutrino telescopes*, International Cosmic Ray Conference ICRC2019, July 2019, Madison, USA.
- > G. Illuminati, *Latest Results from the ANTARES Neutrino Telescope and Prospects for KM3NeT/ARCA*, Rencontres de Blois on Particle Physics and Cosmology, June 2019, Blois, France.
- > T. Thakore, *Oscillation Physics with KM3NeT-ORCA*, 27th Workshop on Weak Interactions and Neutrinos WIN2019, June 2019, Bari, Italy.
- > J. D. Zornoza, *Neutrino astronomy with ANTARES*, CIEMAT Seminar Series, January 2019, Madrid, Spain.
- > J. J. Hernández-Rey, *Searches for dark matter with the ANTARES and KM3NeT neutrino telescopes*, New windows to the Universe: gravitational waves and multi-messengers (1st International School on Particle Physics and Cosmology), July 2019, Santander, Spain.

EXPERIMENTAL NEUTRINO PHYSICS

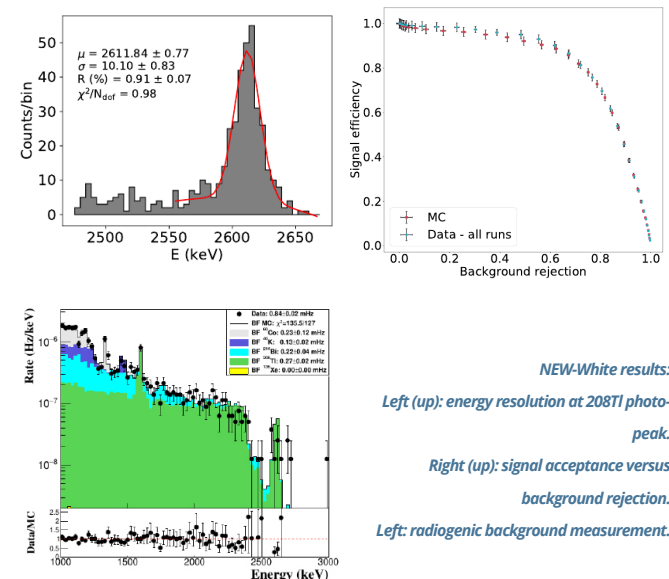
Addressing the major open questions in the field of massive neutrinos, the experimental Neutrino Physics group at IFIC has continued delivering significant contributions to the NEXT, T2K and DUNE experiments during 2019.

NEXT: technology validation and background measurement with NEXT-White

The NEXT collaboration searches for the neutrino-less double beta decay ($\beta\beta 0\nu$) with gas-xenon high-pressure TPCs. These detectors offer an excellent compromise between energy resolution, background rejection, and scalability. NEXT-White is the first large-scale demonstrator implementing the NEXT technology, and it has been in operation since late 2016 in the Laboratorio Subterráneo de Canfranc.

During 2019, NEXT-White has been operated for the first time with xenon enriched in ^{136}Xe and most of the goals of the physics program of this detector have been achieved. An energy resolution of 1% FWHM at ~ 2600 keV (slightly above the $Q_{\beta\beta}$ of ^{136}Xe , 2458 keV) has been measured, obtaining a world-leading result for xenon-based detectors. The background rejection capabilities relying on the topological information of the events have also been studied, reaching a background suppression of $\sim 80\%$ for energies around 1600 keV. Finally, the radiogenic backgrounds have been measured, allowing for an estimation of the backgrounds in the $\beta\beta$ decay searches. The IFIC members have led or significantly contributed to these analyses, which have been published in JHEP.

Although a first measurement of the 2ν mode of the $\beta\beta$ decay is expected for 2020, a preliminary result has been released in mid 2019. In parallel to the NEXT-White operation and data analysis, the IFIC members have conducted a data taking campaign with the NEXT-DEMO++ detector at IFIC, with the goal of exploring different gas mixtures.



NEXT-White results:

Left (up): energy resolution at 2081 photo-peak.

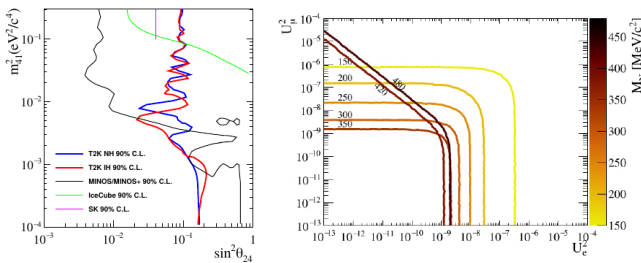
Right (up): signal acceptance versus background rejection.

Left: radiogenic background measurement.

T2K: physics beyond the 3-neutrino paradigm

T2K is a long-baseline neutrino oscillation experiment, offering the current best sensitivity to the CP violation in the leptonic sector and precise measurements of the oscillation parameters in the so-called atmospheric sector.

During 2019, the members of the Experimental Neutrino Physics group have continued with their responsibilities in detector operation and calibration, as well as in oscillation analyses and new physics searches with the T2K near detector. While collecting new data to improve the measurement of the CP-violating phase δ_{CP} , T2K has published in 2019 results on the search for light sterile neutrinos in Super-Kamiokande and on the search for heavy neutrinos in the near detector ND280. The IFIC group has played an important role in the latter, as chair of the New Physics group.



T2K published limits on the search of light sterile (left) and heavy neutrinos (right).

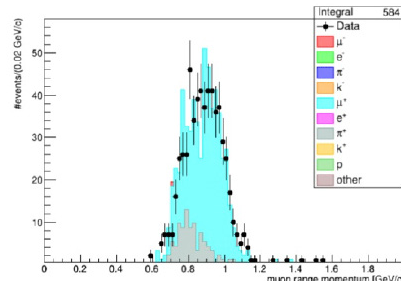
DUNE

The Deep Underground Neutrino Experiment (DUNE), based on the Liquid Argon Time Projection Chamber (TPC) technology, will be far superior to the current generation of experiments (T2K and NOvA) in terms of sensitivity to the leptonic CP violating phase and the neutrino mass hierarchy.

2019 has been a crucial year for DUNE, with the successful operation of the first of its prototypes, ProtoDUNE-SP, at CERN, and the publication of the Technical Design Report (TDR). In collaboration with IFIC's Electronics and Mechanics Support Units, the group built in 2018 a device to measure with a precision of 3 mK the temperature gradient across the 8 m height of the liquid argon volume. Having ProtoDUNE-SP the largest cryostats ever constructed for a TPC, this system is crucial for both the correct functioning of the TPC and for physics. During 2019 IFIC's neutrino group has been in charge of the analysis of the ProtoDUNE-SP temperature data and its comparison with computational fluid dynamics simulations, crucial to predict the liquid argon purity across the entire cryostat.

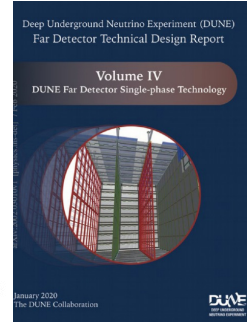
On the other hand, IFIC has participated in the analysis of the test beam data collected during 2018, with the selection of muon, kaon and proton stopping samples, which will help in understanding the detector performance. The DUNE collaboration is about to publish the first article on ProtoDUNE-SP. IFIC has been heavily involved in the preparation of the TDR, both in the Cryogenics Instrumentation and Slow Controls chapter of the DUNE Far Detector

tor Single-Phase Technology volume (we are technical coordinators of this consortium), and in the Photon Detection System for the DUNE Far Detector Dual-Phase Technology volume (we are TDR editors of this consortium). This has been a crucial milestone for the success of the project, which will enter soon its final prototyping phase, with the second run of ProtoDUNE-SP, foreseen for the end of 2021, and soon after the construction phase.



Left: Momentum measured by range for 1 GeV stopping muons in ProtoDUNE-SP.

Right: Cover of the fourth volume of the DUNE TDR.



Selected publications

- > NEXT Collaboration (Novella, P. et al), *Radiogenic Backgrounds in the NEXT Double Beta Decay Experiment*, JHEP 10 (2019) 051, DOI:10.1007/JHEP10(2019)051 [arXiv:1905.13625]
- > NEXT Collaboration (Ferrario, P. et al), *Demonstration of the event identification capabilities of the NEXT-White detector*, JHEP 10 (2019) 052, DOI:10.1007/JHEP10(2019)052 [arXiv:1905.13141]
- > NEXT Collaboration (Renner, J. et al), *Energy calibration of the NEXT-White detector with 1% resolution near $Q\beta\beta$ of ^{136}Xe* , JHEP 10 (2019) 230, DOI:10.1007/JHEP10(2019)230 [arXiv:1905.13110]
- > T2K Collaboration (Abe, K. et al), *Search for heavy neutrinos with the T2K near detector ND280*, Phys. Rev. D 100 (2019) 5, 052006, DOI:10.1103/PhysRevD.100.052006 [arXiv:1902.07598]
- > DUNE Collaboration (Abi, B. et al), *The DUNE Technical Design Report*. Volume 1: <https://arxiv.org/abs/2002.02967>. Volume 2: <https://arxiv.org/abs/2002.03005>. Volume 3: <https://arxiv.org/abs/2002.03008>. Volume 4: <https://arxiv.org/abs/2002.03010>

Selected conference talks

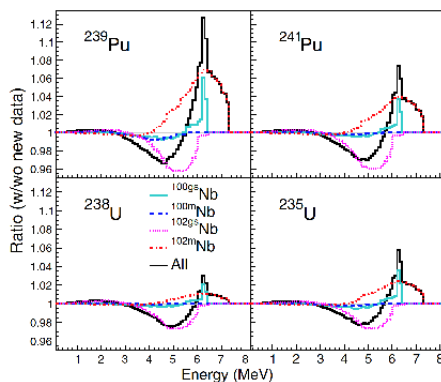
- > J. M. Benlloch, *The NEXT experiment for neutrinoless double beta decay searches*, TAUP 2019, September 2019, Toyama, Japan.
- > P. Novella, *NEXT: results from NEXT-White*, EPS-HEP 2019, July 2019, Ghent, Belgium.
- > N. López March, *The NEXT-DEMO++ detector: R&D for low diffusion mixtures*, LIDINE 2019, August 2019, Manchester, London.
- > A. Cervera, *The DUNE Experiment*, CERN colloquium, January 2019, Geneva, Switzerland
- > M. Antonova, *Proposal for the joint neutrino oscillation analysis using data from the T2K and reactor experiments within the VALOR framework*, Invisibles'19 workshop of Neutrinos, Dark Matter and Dark Energy, Valencia, Spain.

EXPERIMENTAL NUCLEAR PHYSICS

The experimental Nuclear Physics activity at IFIC is carried out by two groups, the Gamma and Neutron Spectroscopy group and the AGATA group.

The research of the Gamma and Neutron Spectroscopy Group covers aspects of nuclear structure, astrophysics, applications and the development of instrumentation. One of the most important results of the group this year is related to the application of the total absorption gamma spectroscopy technique (TAGS) to the study of beta decays that have a large impact on the prediction of the antineutrino spectrum from reactors. In the work of V. Guadilla et al. (*PRL* 122.042502), a study of the beta decays of $^{100,100m,102,102m}\text{Nb}$ has been published. Nb decays were poorly known and in fission, isomers of each isotope are produced as fission products. The measurements were very challenging due to the similarity of the half-lives and the low excitation energy of the isomers, which makes the separation of the individual beta decays a very difficult task. The experiment required a combination of purification techniques and the use of the JYFL Penning trap to separate the contribution of the different isomers. In the measurements, the total absorption spectrometer DTAS, developed by our group for the DESPEC experiment (FAIR), was used at the IGISOL IV facility of the Univ. of Jyväskylä (Finland) for the very first time.

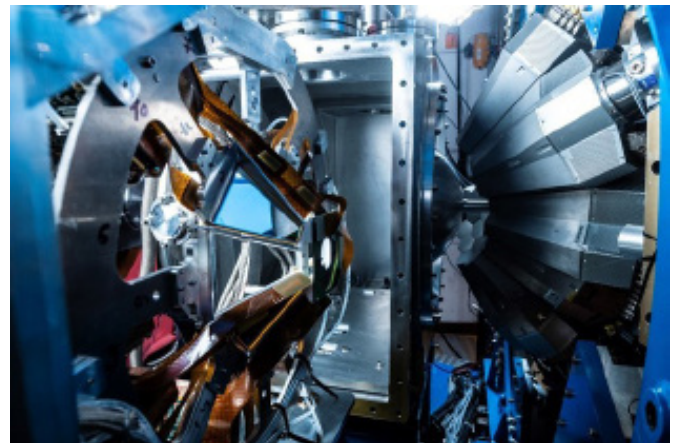
The new TAGS decay data on the Nb isotopes made a very important contribution to the new summation calculations of the antineutrino spectrum presented in M. Estienne et al. (*PRL* 123.022502). The new summation calculations presently provide the best description available for the antineutrino spectrum in reactors in the region of the maximum flux (2-5 MeV). The results are comparable in quality in the full energy range with the Huber-Mueller model, which is considered the standard in the field. This work also shows the relevance of the total absorption measurements in summation calculations. The successive incorporation of TAGS data reduces the gap between the summation model and experiment to approximately 2%, thus raising doubts about the existence of the reactor antineutrino anomaly.



The new TAGS decay data on the Nb isotopes made a important contribution to the new summation calculations of the antineutrino spectrum in reactors in the region of the maximum flux.

Another relevant result of the group is related to the development of analysis techniques and instrumentation. In A. Tolosa et al. NIM A 925.133 the BRIKEN setup at RIKEN (Japan) is described in detail, and some selected results demonstrating its performance for the measurement of half-lives and β -delayed neutron emission probabilities are presented. This setup is one of the most efficient moderated ^3He neutron detector arrays ever built. In the article, the methodology followed in the analysis of the data is described in detail and particular emphasis is placed on the correction of the accidental neutron background.

2019 has been a decisive year for the CERN n_TOF experiment, where our group is very actively involved since its foundation 20 years ago. A new high-performance spallation source has been designed and will enter operation after LS2 in 2021. Additionally, a brand new experimental area, so-called NEAR, is being planned for the next data-taking period. NEAR, once fully developed, will provide the largest quasi-stellar Maxwellian neutron fluxes worldwide. Together with the neighbouring ISOLDE facility, it will become possible to conduct first direct activation measurements on several radioactive samples of astrophysical interest, that could not be measured to date. In this respect, a pilot experiment at SARAF LiLiT has delivered neutron density constraints for Thermally-Pulsing AGB-Stars after the measurement of the $^{147}\text{Pm}(n,\gamma)$ reaction using only 56 micrograms of sample material. Concomitant developments for future TOF experiments using the novel system i-TED at CERN have been also accomplished by developing advanced position-reconstruction algorithms for very large monolithic crystals with SiPM readout. i-TED represents the core detection system of the HYMNS ERC project, and it will begin operation at CERN n_TOF in 2021.



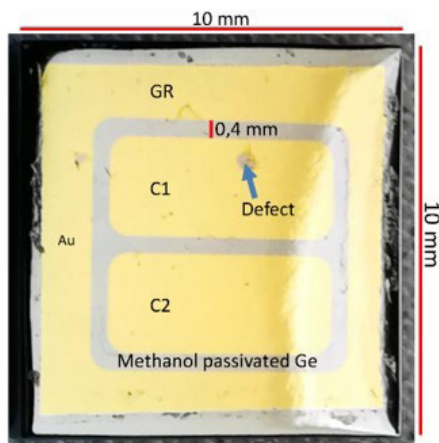
The experimental activity of the AGATA group in 2019 has been mainly performed at GANIL using the radioactive ion beams of SPIRAL 1 and with the AGATA array coupled to the light charged particle detector MUGAST. MUGAST includes an early implementation of the GRIT/TRACE Si detector array, being built with the contribution of several groups in Spain including the AGATA group at IFIC. The experimental setup is shown in the figure above. The study of unbound states in ^{15}F , the single particle shell structure of ^{46}Ar or the determination of the $\alpha+^{15}\text{O}$ radiative capture rate, a reaction of interest for the breakout from the Hot-CNO cycle to the rp-process, are examples of the experiments with contributions from our group.

Regarding progress on the analysis of experiments performed in previous years, Rosa M. Perez Vidal defended her thesis on the study of the seniority conservation along the $N=Z$ line, in the vicinity of ^{100}Sn , with lifetime techniques.

The AGATA group of IFIC in collaboration with the TEDRA group at the ETSE-University of Valencia is developing part of the pre-processing electronics for Phase 2 of AGATA starting in 2021. The goal in 2019 was to prove the concept of the time multiplexing of the data flow as well as defining the pre-processing hardware. The time multiplexing of the data flow has been implemented for a complete AGATA detector channel in the IDM concentrator board, designed and constructed in early 2019 and successfully tested in the second half of the year.

During 2019 the AGATA group has been working on detector technology developments in the framework of the ENSAR2-PSeGe JRA fund of the EU Horizon 2020 programme. The goal of the work is to develop a technology to build segmented p-type HP-Ge detectors without using Li n-contacts. This development will allow one to build segmented p-type detectors that can undergo the annealing process and therefore recover the performance loss due to radiation damage (in particular by neutrons). The work is being performed in collaboration with the Department of Physics and the University of Padova Italy. The year 2019 concluded with the production of several small segmented p-type detectors. The technology used, Thermal Laser Annealing following deposition of antimony by sputtering, has been used for the first time for the production of functional HP-Ge detectors.

In future this technology will allow one to build p-type HP-Ge segmented Coaxial detectors for AGATA, improving the performance of the segmented contacts under neutron radiation bombardment. This work will be part of the PhD thesis of S. Bertoldo in the University of Valencia.



The AGATA group of IFIC, in collaboration with the TEDRA group at the ETSE-University of Valencia, is developing part of the pre-processing electronics for Phase 2 of AGATA starting in 2021

Selected publications

- > V. Guadilla et al., *Large impact of the decay of Niobium isomers on the reactor antineutrino summation calculations*, Physical Review Letters 122, 042502 (2019)
- > M. Estienne et al., *Updated summation model: an improved agreement with the Daya Bay antineutrino fluxes*, Physical Review Letters 123, 022502 (2019)
- > A. Tolosa et al., *Commissioning of the BRIKEN detector for the measurement of very exotic β -delayed neutron emitters*, Nuclear Inst. and Methods in Physics Research, A 925, 133 (2019)
- > C. Guerrero et al., *The s-process in the Nd-Pm-Sm region: Neutron activation of ^{147}Pm* , Phys.Lett.B, 797, 134809 (2019)
- > V. Babiano et al., *Gamma-ray position reconstruction in large monolithic $\text{LaCl}_3(\text{Ce})$ crystals with SiPM readout*, NIM-A, 931, 1 (2019)
- > D. Ralet et al, *Evidence of octupole-phonons at high spin in Pb-207* , Physics Letters B 797 (2019) 134797
- > A. Gottardo et al., *New spectroscopic information on $\text{Tl-211}, \text{Tl-213}$: A changing structure beyond the $N=126$ shell closure*, Physical Review C 99 (2019) 054326

Selected conference talks

- > J. L. Taín, *The BRIKEN project: extensive new beta- delayed neutron measurements for Astrophysics*, invited talk at Michigan State University (USA), February 2019.
- > B. Rubio, *Using Isospin symmetry to understand proton rich nuclei*, invited talk at 42nd Symposium on Nuclear Physics, Cocoyoc, Mexico, January 2019.
- > C. Domingo Pardo, *Review and new concepts for neutron-capture measurements of astrophysical interest*, Nuclear Physics in Astrophysics IX, Int. Conference, September 2019.
- > A. Algora, *Complementary techniques for studying the beta decay of very exotic nuclei*, invited talk at RIBF Users Meeting 2019, RIKEN, Japan, September 2019.
- > E. Nacher, *Total Absorption Spectroscopy along the $N=Z$ line: nuclear shapes and astrophysical interest*, invited talk at ISTROS 2019 (Isospin, Structure, Reactions and energy Of Symmetry), October 2019, Slovakia.
- > A. Gadea, *Performance and Recent Results with the Advanced GAMMA Tracking Array (AGATA)*, Invited contribution to Nuclear Structure and Dynamics - NSD2019, Venice, Italy, May 2019.



The research topics of this research line include mainly the Spanish ATLAS Tier-2 goals. It also includes several generic activities devoted to the application of Distributed Computing and to improve the performance of the physics analysis work:

- **Delivery of the committed resources for 2019** (in April). 2019 has been the third year funded by the project FPA2016-75141-C2-1-R of the Spanish HEP Program. During this year, the Tier-2 IFIC site has provided 32130 HS06 and 3089 TB of disk. The efficiency of the whole Tier-2 has been of about 98% (and in particular the IFIC part had a very good performance).

– On 17th and 18th January the **Second IFIC Scientific Projects Days** took place and our group presented a talk about the ‘GRID Tier-2 of the ATLAS Experiment’.

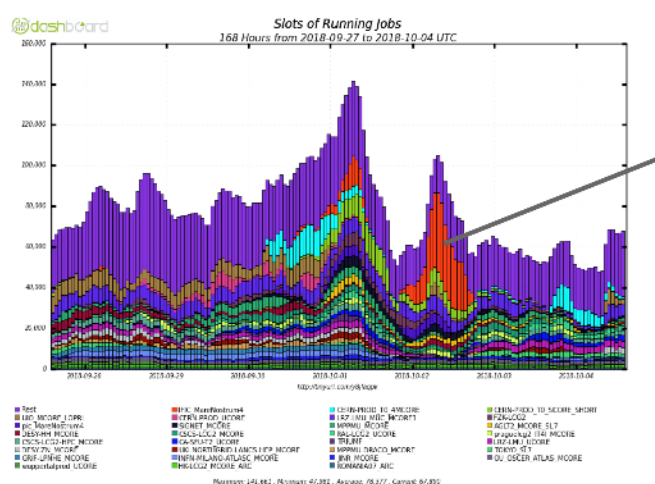
We have progressed in the main objectives of the project:

a) Taking into account the need of computing power in the near future our group has continued the exploration of conventional ATLAS production analysis pipelines and workflows on opportunistic resources, mainly HPC infrastructures (MareNostrum, Lusitania, etc) with a total of 7 million CPU hours and more than 100 Million of events of a complete simulation of the detector. The ATLAS Event Service has been consolidated as the new computing framework to exploit these resources. In particular, the new framework has been commissioned by developing several analysis tools to compare the performance of event service with respect to the standard framework. The monitoring tools for the computing shifters in order to facilitate a prompt identification of problems have been applied.

b) Monitoring of Frontier servers. Frontier servers, composed of Tomcat servers and Squid servers caching frequently used data, handle the access of ATLAS jobs to Conditions data in a parallel and distributed way. The monitoring system developed during the previous years based on the ELK stack (Elasticsearch, Logstash and Kibana) has been improved to store precise information of the SQL queries submitted to the Oracle conditions DB. This additional information has provided vital clues to understand the caching efficiency of the Frontier system and to pinpoint particularly demanding physics tasks and queries that caused failures in the Frontier servers. The monitoring system has proven so successful that it has been also adopted by the CMS collaboration under the management of the IFIC group. The Kibana dashboard has been also modified and improved to present the most relevant information in a simple visual way; a replicated Dashboard was set up for the CMS servers as well.

c) **Application of Machine Learning Methods methods for Physics Analysis in ATLAS.** The studies performed in 2018, which gave rise to one TFG and one TFM, were summarised in a contribution to the CTD/WIT workshop held in April 2019 in Valencia. Several further analyses with Neural Networks and other ML techniques were reported in another TFM defended in October 2019. In the last months of the year we established the first contacts in order to become part of the ATLAS Physics Analysis Group dealing with $t\bar{t}$ resonances with the goal of applying our previous experience on ML to this topic.

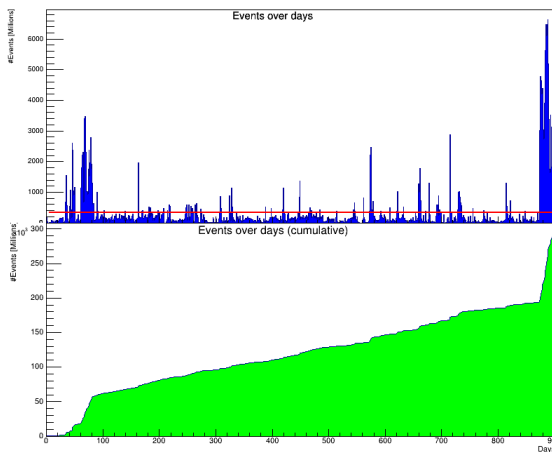
d) **Opportunistic usage of HPC.** The use of opportunistic resources is needed to accommodate the current requirements and especially for the future HL-LHC. Specifically, computing power of RES (Spanish Supercomputing Network) has been granted: 7 Mhours CPU in Lusitania II and Mare Nostrum 4 in 5 requests. CPU time has been consumed successfully in a short period of time and you can see the peak of MN4 leading the ATLAS production when the MN4 resources were launched. This work is a valuable contribution to the ATLAS community, given that it is a subject of study at present, in anticipation of the high CPU requirements during HL-LHC.



Number of jobs running at different ATLAS sites. In red there are the jobs running at MareNostrum 4 (MN4).

During 2019 the Tier-2 IFIC site has provided 32130 HS06 and 3089 TB of disk. The efficiency of the whole Tier-2 has been about 98%, and in particular the IFIC part had a very good performance

e) **The ATLAS Event Index Project.** We have continued our duties with the ATLAS Event Index Project, where our group is in charge of the data collection and coordinates the data taking. During 2019 we have considerably increased the number of processed events. We are developing and testing a new Event Index based on HBase and Phoenix. This new Event Index will surpass the actual one optimizing the key of the events. This will improve the data storage, moreover, it will significantly improve the performance of the system for the most common use cases. It will also add a layer of granularity and flexibility compared to the current system. This will satisfy the demanding requirements of data generation during Run 3.



Number of processed events/day (top) and cumulative (bottom) since the start of the current supervisor until the end of November 2019.

One of the advances during this year has been the implementation of HBase/Phoenix in the EI framework. Data in HBase can be organised in large tables, with one row per event and one column per event property. A number of tests have been performed, loading ATLAS Event Index data to HBase via Phoenix and then running Phoenix queries on the loaded data. The results are encouraging: single event picking works in 30 ms and full dataset queries run in 6-10 seconds.

Selected publications

- > A. Fernández, D. Barberis, J. Sánchez, C. García, S. Gonzalez de la Hoz, J. Salt on behalf of the ATLAS Collaboration, *Distributed Data Collection for the Next Generation ATLAS EventIndex project*, Proceedings de la Conferencia 23th International Conference on Computing in High Energy and Nuclear Physics (CHEP18) EPJ Web of conference 214, 04010 (2019); ATL-SOFT-PROC-2018-039
- > D. Barberis, E. Alexandrov, I. Aleksandrov, Z. Baranowski, G. Dimitrov, A. Fernández Casani, E. Gallas, C. García Montoro, S. González de la Hoz, J. Hrivnac, A. Iakovlev, A. Kazymov, M. Mineev, F. Prokoshin, G. Rybkin, J. Sánchez, J. Salt, P. Vasileva, M. Villaplana on behalf of the ATLAS Collaboration, *The ATLAS EventIndex and its evolution towards LHC Run3 project*, Proceedings of the 19th International Workshop on Advanced Computing and Analysis Techniques in Physics Researches (ACAT19): ATL-COM-SOFT-2019-33; ATL-SOFT-PROC-2019-003
- > D. Barberis, E. Alexandrov, I. Aleksandrov, Z. Baranowski, G. Dimitrov, A. Fernández Casani, E. Gallas, C. García Montoro, S. González de la Hoz, J. Hrivnac, A. Iakovlev, A. Kazymov, M. Mineev, F. Prokoshin, G. Rybkin, J. Sánchez, J. Salt, P. Vasileva, M. Villaplana on behalf of the ATLAS Collaboration, *The ATLAS EventIndex for LHC Run3*, Proceedings of 27th International Symposium on Nuclear Electronics & Computing (NEC19): ATL-SOFT-PROC-2019-009, CEUR-WS Vol 2507 pag 30-35
- > D. Barberis, F. Prokoshin, E. Alexandrov, I. Aleksandrov, Z. Baranowski, L. Canali, D. Gancho, A. Fernandez, E. Gallas, C. García, S. González de la Hoz, J. Hrivnac, A. Iakovlev, A. Kazymov, M. Mineev, G. Rybkin, J. Sánchez, J. Salt, P. Vasileva on behalf of the ATLAS Collaboration, *The ATLAS Event Index and its evolution based on Apache Kudu storage*, 8th International Conference "Distributed Computing and Grid-technologies in Science and Education". (Grid2018) ATL-COM-SOFT-2018-115, CEUR Workshop Proceeding, vol 2267, pag 18-25, ISSN 1613-0073

Selected conference talks

- > S. González de la Hoz, C. Acosta-Silva, J. Aparisi Pozo, J. Del Peso, A. Fernández Casani, J. Flix, E. Fullana Torregrosa, C. Garcia montoro, J. Lozano Bahilo, A. del Rocio Montiel, G. Merino, A. Pacheco Pages, J. Sánchez Martínez, J. Salt, A. Vedaee on behalf of the ATLAS Collaboration, *Computing activities at the Spanish Tier-1 and Tier-2s for the ATLAS experiment towards the LHC Run3 and High Luminosity (HL-LHC periods)*, talk given at Computing High Energy and Nuclear Physics (CHEP19), 4-8 November 2019 Adelaide (Australia). ATL-SOFT-PROC-2020-004 and ATL-SOFT-SLIDE-2019-793.
- > J. Salt, S. González de la Hoz, M. Villaplana, S. Campos on behalf of the ATLAS Collaboration, *Comparison of different ML methods applied to the classification of events with $t\bar{t}$ in the final state at the ATLAS experiment*, REF. REVISTA/LIBRO: Proceedings de la Conferencia (id 11), Connecting The Dots / Intelligent Trackers 2019 (CTD/WIT 2019): ATL-COM-SOFT-2019-019.
- > J. Salt, *Plans of the WLCG for Run 3 and HL-LHC era*, invited talk at XI CPAN days, 21-23 October 2019, Oviedo (Spain).



MEDICAL APPLICATIONS

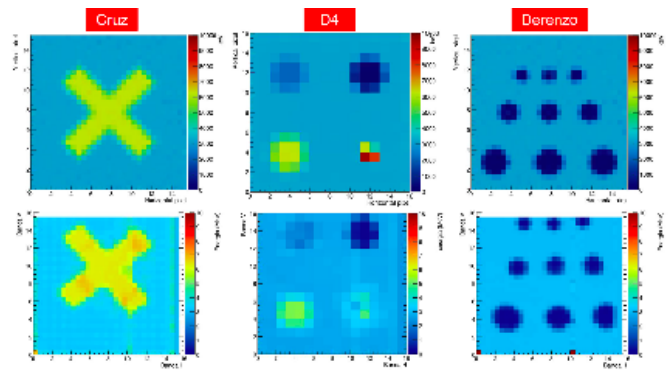
Several IFIC groups work on physics developments for different medical applications, focusing on different aspects from instrumentation to data analysis, modelling, image processing and artificial intelligence.

The **IRIS medical physics group** works on the development of a Compton telescope for hadron therapy treatment monitoring. The system is composed of three planes of LaBr_3 crystals coupled to Silicon photomultipliers (SiPMs) as photodetectors and it aims at detecting the distribution of prompt gamma rays emitted by the tissue after therapeutic irradiation with proton or Carbon ion beams.

The activities during 2019 have been mainly focused on the performance improvement of the system. A third version of the prototype, MACACO III, has been set up employing new components (crystals and photodetectors) and upgraded readout electronics. The AliVATA readout system, developed by the group and transferred for commercialization allows operation of the three detector planes with one board and improves the readout speed. The combination of the enhanced system performance with the image reconstruction algorithms previously developed has yielded unprecedented results in system spatial resolution and accuracy. In addition, an alternative prototype based on the PETsys TOFPET2 ASIC is under development for timing resolution improvement, with very promising results.

Detailed simulations employing GATE have also been implemented, reproducing the interaction of protons of therapeutic energies in a phantom, which are being employed for system optimization and background identification studies. A collaboration with the University Claude Bernard of Lyon has been initiated for system optimization and further applications beyond hadron therapy. In addition, the group has started the implementation and demonstration of the functionality of a new high spatial resolution probe for Positron Emission Tomography (PET). Combined measurements using the probe and PET scanners will be obtained by carrying out tests to position the probe and synchronise its signal with the scanner. The probe will benefit whole-body PET scanners by improving the spatial resolution in specific areas.

The **Gamma and Neutron Spectroscopy group** has worked in two lines related to proton therapy. The first one is the design and construction of a prototype for a proton tomography scanner based on double-sided silicon-strip detectors and phoswich scintillators, within the PRONTO-CM project. Following this line, they have performed the first experiment to adjust the system at CMAM (Madrid) with low-energy proton beams, and obtained the first 2D images in preparation of the next run with high-energy protons that will take place at KVI (Groningen) in 2020. The second line regards the development, in collaboration with UPC (Barcelona), of the LINrem neutron dosimeter with online capability for use during irradiations at proton-therapy centres. The first prototype was successfully deployed at the Westdeutschen Protonentherapiezentrum Essen (WPE) and the preliminary analysis shows good agreement with EURADOS benchmarks (Master thesis at UPC). A new improved prototype will be tested soon.



Upper row: Monte Carlo simulations (Geant4) of some different phantoms for a test beam of the tracking detectors of the PRONTO-CM project.

Lower row: actual measurement of those phantoms with 10 MeV protons at CMAM (Madrid).

The objectives of the **42 is the answer group** are providing tools and devices to improve the three 'P' associated to medicine which are Precision, Personalized, and Predictive. The main focus in recent years has been dose reduction while keeping or improving precision.

The group is using deep artificial intelligence to improve and enhance in the diagnostic area, in which they are developing devices to improve rachis X-ray detection combining 3D enhanced planar devices to provide 3D models of the spine. These devices aim to reduce the dose in CT scan, and enhance prediction and tracking of scoliosis.

Other aspects of their work include pure machine learning to track, segment and classify brain tumors using MRI. This kind of techniques are called virtual biopsies, as far as provide a large range of information from MRI in tumor lesion classification. Good tumor lesion identification is crucial for precision radiotherapy techniques such as proton-therapy. Localization of the patient lesion and its correct placement in the accelerator device is a must to have. Providing tools to identify dose deposition and how this dose is located in patient coordinates requires a good inter-device localization framework. In this area we have been working with a medical company to improve both aspects.

The **PETALO group** is developing a PET scanner prototype based on liquid xenon, with the scintillation signal read out by silicon photomultipliers (SiPMs). The excellent scintillator properties of liquid xenon allow for the possibility of building a PET scanner with Time-of-Flight capabilities, which results in a drastic improvement in the quality of the image in less time. The group has designed a first prototype, which is an aluminium box, filled with liquid xenon and instrumented with two opposite planes of SiPMs. In the middle, a Na-22 source producing two back-to-back high energy photons will allow for the measurement of the principal characteristics of the technology, namely the energy, position and time resolution. Since xenon needs cryogenic temperatures (around 161 K) to be liquid at atmospheric pressure, a cryostat had to be designed and built, together with a recovery tank necessary to evacuate xenon in case of overpressure, and a cryogenic bottle for normal recovery. At the same time, tests of samples of the sensors to be used have been carried out in a dedicated, cold set-up, to evaluate their response at the liquid xenon temperature. Since the liquid xenon scintillation

light is in the VUV range, specific sensors with an enhanced photo-detection efficiency in that range are used, or conventional SiPMs coupled to a wavelength shifter material can be employed.

From the point of view of the electronics, all the components have been designed ad hoc, following the requirements given by a detailed simulation of the thermal conductivity of the system. The full DAQ system has been also designed, using TOFPET2 asics by PETsys to digitize the signal from SiPMs. The prototype has been assembled and will start working in 2020.

In parallel with the design and construction of the prototype, the PETALO group has written software tools for simulation, reconstruction and analysis and carried out an intense campaign of Monte Carlo simulations, to guide the decisions on the prototype design. Moreover, the performance of a full-body PET scanner has been also studied, in particular applying image reconstruction algorithms to the Monte Carlo simulation of a body-size PET. The complete response of the SiPMs, including electronics effects is simulated, and a reconstruction algorithm based on Maximum Likelihood Expectation Maximization (MLEM) is applied to provide the reconstructed image.

The **Medical Physics Group** (UV-La Fe) is active in different fields, including clinical medical physics, radiological protection, Monte Carlo simulations with different codes (MCNP, PENELOPE and GEANT4), experimental dosimetry, brachytherapy and conceptual design and development of electronic instrumentation for medical physics applications. The main field of interest at this moment is experimental dosimetry with passive detectors (currently working mainly with TLD and OSL). The studies on this topic are focused on two areas: personal dose monitoring and multi-centre dosimetry audit of radiotherapy. The group also works on the design of specific shieldings and/or applicators to reduce the peripheral dose to the patients receiving radiation therapy. Brachytherapy physics research is focused on the development and implementation of tools and techniques for precision on dose calculations and delivery. Research is ongoing in the treatment of skin, cervix, vagina and prostate cancers using both low dose-rate (LDR) seed implant brachytherapy, high dose rate brachytherapy and electronic brachytherapy techniques.

IFIC groups work on physics developments for different medical applications, focusing on different aspects from instrumentation to data analysis, modelling, image processing and artificial intelligence

Selected publications

- > F. Albiol, A. Corbi and A. Albiol, *Densitometric Radiographic Imaging With Contour Sensors*, in IEEE Access, vol. 7, pp. 18902-18914, 2019, doi: 10.1109/ACCESS.2019.2895925.
- > G. Llosá, *SiPM-based Compton cameras*, Nucl. Inst. and Meth. A. 962 (2019) 148-152.
- > A. Ros, L. Barrientos, J. Barrio, A. Etxebeste, C. Lacasta, E. Muñoz, J. F. Oliver, J. Roser, G. Llosá, *Evaluation of LFS continuous scintillation crystals for PET*, Nucl. Inst. and Meth. A. Vol 936, p39-40, 2019.
- > A. Etxebeste, J. Barrio, José Bernabéu, C. Lacasta, G. Llosá, E. Muñoz, A. Ros and Josep F Oliver, *Study of Sensitivity and Resolution for Full Ring PET Prototypes based on Continuous Crystals and analytical modeling of the light distribution*, Phys. Med. Biol. 64 (2019) 035015.

Selected conference talks

- > J. Vijande, *The Role of Monte Carlo in the Validation and Commissioning of Advanced Dose Calculation Algorithms*, 2019. Invited talk at ICCR & MCMA 2019: INTERNATIONAL CONFERENCE ON THE USE OF COMPUTERS IN RADIOTHERAPY AND THE INTERNATIONAL CONFERENCE ON MONTE CARLO TECHNIQUES FOR MEDICAL APPLICATIONS.
- > J. Renner, J.M. Benlloch-Rodríguez, J.V. Carrión, R. Gadea, V. Herro-Bosch, M. Kekic, C. Romo-Luque, P. Ferrario and J.J. Gómez-Cadenas, *Processing of Compton events in the PETALO readout system*, 2019 IEEE Nuclear Science Symposium (NSS) and Medical Imaging Conference (MIC), DOI: 10.1109/NSS/MIC42101.2019.9059979 [arXiv: 2001.04724].
- > A. Ros, L. Barrientos, J. Barrio, J. Bernabéu, M. Borja-Lloret, P. Denooven, A. Etxebeste, C. Lacasta, R. Marco, E. Muñoz, J. F. Oliver, I. Ozoemelum, J. Roser, C. Senra, C. Solaz and G. Llosá, *Performance characterisation of MACACO II, a second prototype of a Compton telescope*, Talk at 6th International Conference on Advancements in Nuclear Instrumentation Measurements and their Applications, ANIMMA, 2019, 17-21 Jun 2019, Portoroz, Slovenia.
- > Gabriela Llosá, L. Barrientos, J. Barrio, M. Borja-Lloret, A. Esteban, C. Lacasta, R. Marco, E. Muñoz, J.F. Oliver, A. Ros, J. Roser, C. Solaz, R. Viegas, *Upgrade of a Compton telescope for Hadron Therapy Treatment Monitoring*, Talk at MEDAMI 2019, Valencia (Spain), 15-17 May 2019. Valencia, Spain.
- > G. Llosá, L. Barrientos, M. Borja-Lloret, A. Esteban, C. Lacasta, R. Marco, E. Muñoz, J. F. Oliver, A. Ros, J. Roser, C. Solaz, R. Viegas, *MACACO II results and further upgrades*, Talk at XI CPAN days, 21-23 Oct 2019, Oviedo, Spain.

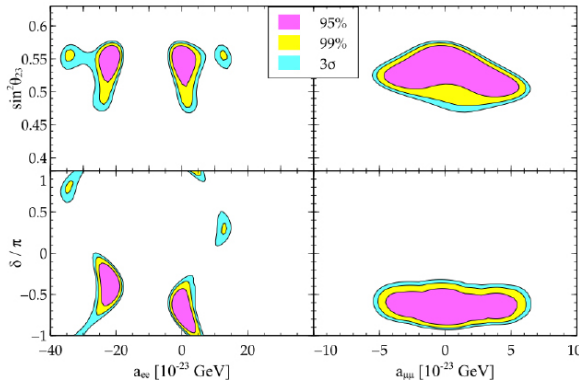


THEORETICAL PHYSICS

HIGH-ENERGY PHYSICS PHENOMENOLOGY

CPT and Lorentz violating interactions explored with neutrinos

Neutrinos can push our search for new physics to a whole new level. What makes them so hard to be detected, what allows them to travel humongous distances without being stopped or deflected allows to amplify Planck suppressed effects (or effects of comparable size) to the level we can measure or bound in DUNE. In this work, the sensitivity of DUNE to CPT and Lorentz-violating interactions was analyzed in a framework that allows a straightforward extrapolation of the bounds obtained to any phenomenological modification of the dispersion relation of neutrinos.



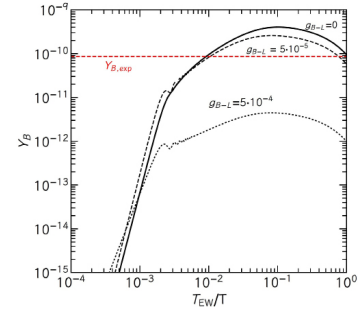
DUNE sensitivity to the diagonal CPT-violating parameters a_{ee} and $a_{\mu\mu}$ and the oscillation parameters θ_{23} and δ .

Cosmological domain walls may form if global lepton number gets spontaneously broken after inflation

Researchers from IFIC have shown that if global lepton number symmetry is spontaneously broken in a postinflation epoch, then it can lead to the formation of cosmological domain walls. This happens in the well-known “Majoron paradigm” for neutrino mass generation. Some realistic examples that allow spontaneous lepton number breaking to be safe from such domain walls were also proposed.

Leptogenesis and dark matter from neutrino oscillations

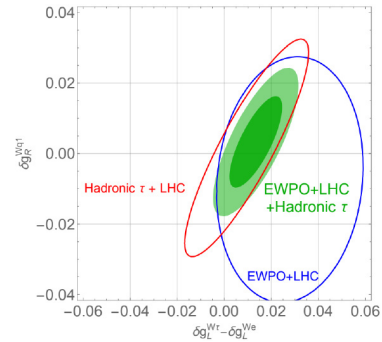
An extension of the Standard Model with Majorana singlet fermions in the 1-100 GeV range can give rise to a baryon asymmetry at freeze-in via the CP-violating oscillations of these neutrinos: this is the well known ARS mechanism. In this paper, IFIC researchers consider possible extensions of the minimal ARS scenario that can account not only for successful leptogenesis but also explain other open problems such as dark matter. An extension in the form of a weakly coupled B-L gauge boson, an invisible QCD axion model, and the singlet majoron model can simultaneously account for dark matter and the baryon asymmetry.



Baryon asymmetry Y_B as a function of temperature T relative to the electroweak phase transition one, for various (B-L) gauge couplings.

Hadronic tau decays offer new physics probes complementary to LHC measurements

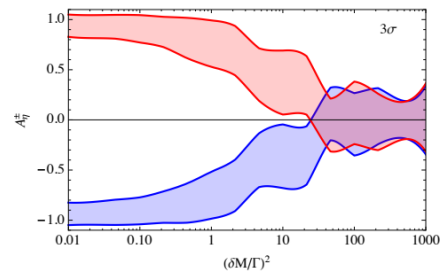
The sensitivity of hadronic τ decays to nonstandard interactions was analysed by a team containing IFIC researchers. The analysis, performed within the model-independent framework of the standard model effective field theory, found unexpected powerful new physics probes. The resulting bounds are complementary to the ones from electroweak precision observables and measurements at the LHC, and their full combination puts tighter constraints on lepton universality violation in the gauge boson-lepton vertex corrections.



Bounds on the vertex corrections to W boson couplings after combining input from the LHC with hadronic tau decays.

Majorana vs Pseudo-Dirac neutrino character at the ILC

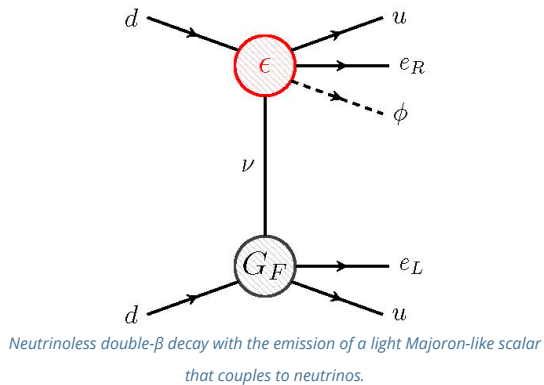
Neutrino masses could originate in seesaw models testable at colliders, with light mediators and an approximate lepton number symmetry. The minimal model of this type contains two quasi-degenerate Majorana fermions forming a pseudo-Dirac pair. The production of these neutral heavy leptons was considered at the ILC, where their displaced decays provide a golden signal: a forward-backward charge asymmetry. This observable can constrain the mass splitting to values much lower than current bounds from neutrinoless double beta decay and natural loop corrections.



For the A_{η}^- forward-backward asymmetry for the charged lepton l in red, and for the A_{η}^+ forward-backward asymmetry for the charged lepton \bar{l} in blue

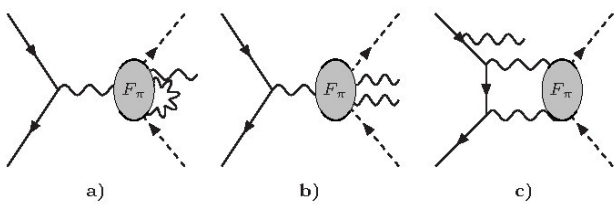
A novel mode of neutrinoless double- β decay was proposed

Researchers from IFIC presented a novel mode of neutrinoless double- β decay with emission of a light Majoron-like scalar particle. Future double- β decay searches were found to be sensitive to new physics scales of the order of 1 TeV and a light scalar with a mass below 0.2 MeV, based on ordinary double- β decay Majoron searches. The angular and energy distributions can deviate considerably from that of two-neutrino double- β decay, which is the main background. Possible ultraviolet completions where such mode can take place were also identified.



The a_μ anomaly may hint at new physics

IFIC researchers address the question of whether the almost four standard deviations difference between theory and experiment for the muon anomalous magnetic moment a_μ can be explained as a higher-order Standard Model perturbation effect in the pion form factor measurements. They calculated the last radiative corrections for the extraction of the pion form factor, which were believed to be substantial enough to explain the data within the Standard Model. These corrections were too small to diminish existing discrepancies in the determination of the pion form factor for different kinematical configurations of low-energy BABAR, BESS-III and KLOE experiments.



Representative final-state radiation and two-virtual-photon diagrams discussed which describe the radiative corrections to the $e^+e^- \rightarrow \pi^+\pi^-\gamma$ process.

Hints for new physics may have been observed in $b \rightarrow c \tau \nu$ transitions

A group of researchers from IFIC have performed a general model-independent analysis of $b \rightarrow c \tau \nu$ transitions, including measurements of the popular $R(D)$ and $R(D^*)$ ratios. As a result of this analysis, a global fit to a general set of Wilson coefficients of an effective low-energy Hamiltonian was obtained, which in turn allowed the authors to interpret the experimental results in terms of hypothetical new-physics mediators.

Selected publications

- > G. Barenboim, M. Masud, C. A. Ternes, M. Tórtola, *Exploring the intrinsic Lorentz-violating parameters at DUNE*, Phys. Lett. B 788 (2019) 308-315 – 8pp, DOI: 10.1016/j.physletb.2018.11.040 [arXiv:1805.11094].
- > G. Lazarides, M. Reig, Q. Shafi, R. Srivastava, J.W.F. Valle, *Spontaneous breaking of lepton number and the cosmological domain wall problem*, Phys. Rev. Lett. 122 (2019) 151301 – 5pp, DOI: 10.1103/PhysRevLett.122.151301 [arXiv:1806.11198].
- > A. Caputo, P. Hernandez, N. Rius, *Leptogenesis from oscillations and dark matter*, Eur. Phys. J. C 79 (2019) 7, 574 – 14pp, DOI: 10.1140/epjc/s10052-019-7083-y [arXiv:1807.03309].
- > V. Cirigliano, A. Falkowski, M. González-Alonso, A. Rodríguez-Sánchez, *Hadronic tau decays as New Physics probes in the LHC era*, Phys. Rev. Lett. 122, 221801 (2019) – 7pp, DOI: 10.1103/PhysRevLett.122.221801 [arXiv:1809.01161].
- > P. Hernández, J. Jones-Pérez and O. Suarez-Navarro, *Majorana vs Pseudo-Dirac Neutrinos at the ILC*, Eur. Phys. J. C 79 (2019) 3, 220 – 16pp, DOI: 10.1140/epjc/s10052-019-6728-1 [arXiv:1810.07210].
- > R. Cepedello, F.F. Deppisch, L. González, M. Hirsch, *Neutrinoless Double Beta Decay with Non-standard Majoron Emission*, Phys. Rev. Lett. 122 (2019) 181801 – 6pp, DOI: 10.1103/PhysRevLett.122.181801 [arXiv:1811.00031].
- > F. Campanario, H. Czyż, J. Gluza, T. Jeliński, G. Rodrigo, S. Tracz, D. Zhuridov, *Standard model radiative corrections in the pion form factor measurements do not explain the a_μ anomaly*, Phys. Rev. D 100 (2019) 7, 076004 – 5 pp, DOI: 10.1103/PhysRevD.100.076004 [arXiv:1903.10197].
- > C. Murgui, A. Peñuelas, M. Jung, A. Pich, *Global fit to $b \rightarrow c \tau \nu$ transitions*, JHEP 09 (2019) 103 – 44pp, DOI: 10.1007/JHEP09(2019)103 [arXiv:1904.09311].

Selected talks

- > H. Gisbert, *Status of ϵ/ϵ in the Standard Model*, Electroweak session of the 54rd Rencontres de Moriond, March 2019, La Thuile, Italy.
- > P. Hernández, *2019 Outstanding questions in particle Physics*, CERN Council Open Symposium on the Update of European Strategy for Particle Physics, May 2019, Granada, Spain.
- > A. Santamaria, *Dynamical electroweak symmetry breaking and exotic scalars*, 7th RISE Collaboration workshop: NonMinimalHiggs, May 2019, Helsinki, Finland.
- > A. Melis, *$N1+N2$ -leptogenesis in $\Delta(27)$ with a universal texture zero*, FLASY2019: 8th Workshop on Flavor Symmetries and Consequences in Accelerators and Cosmology, July 2019, Hefei, China.
- > J.W.F. Valle, *Neutrino pathways to new physics*, XXV International Symposium on Particle physics, String theory and Cosmology (PASCOS 2019), July 2019, Manchester, United Kingdom.
- > A. Vicente, *Theory status and implications of $RK^{(*)}$* , 18th International Conference on B-Physics at Frontier Machines (Beauty 2019), September-October 2019, Ljubljana, Slovenia.
- > A. Peñuelas, *Global fits to $b \rightarrow c \tau \nu$ data*, Implications of LHCb measurements and future prospects, October 2019, CERN, Geneva, Switzerland.
- > P. Hernández, *2019 Madrid Reflections on the SM and Beyond*, International Workshop on Baryon and Lepton Number Violation (BLV 2019), October 2019, Madrid Spain.

HIGH-ENERGY THEORETICAL PHYSICS: QUANTUM BLACK HOLES, SUPERGRAVITY, AND COSMOLOGY

The year 2019 has brought some new members to our group: Andreu Sales Masó Ferrando and Pau Beltran Palau, who are doing their Ph.D. under the supervision of Gonzalo J. Olmo and J. Navarro-Salas, respectively.

The most relevant activity organized by our group in 2019 was the International Conference GR22-Amaldi13, which took place in Valencia on the week of July 7-12, 2019. This conference is the most important and representative in the area of relativity, gravitation and gravitational waves worldwide. The conference has had 957 delegates, doubling the number of the previous edition (New York, 2016). The participants came from 51 different countries, and of the total number of attendees, 809 came from outside Spain. The event was co-organized with the group of J.A. Font (Astronomy and Astrophysics Department) and numerous other groups of Spanish institutions coordinated by the Red Temática de Relatividad y Gravitación.

Our group member Gonzalo J. Olmo participated in the social programme of the meeting in an open discussion on the British expeditions of 1916 to Sobral (Brazil) and Principe Island. This activity took place at the Botanical Garden of the University of Valencia and had Isabel Cordero Carrión (UV) as moderator and Prof. Luís C.B. Crispino (UFPa, Brazil) as guest speaker, who is a renowned expert on this topic.



From left to right: Isabel Cordero, Gonzalo J. Olmo, and Luis C.B. Crispino.

Besides the GR22-Amaldi13 meeting, as coordinators of the Red Temática de Relatividad y Gravitación, we have supported this year other important meetings, such as the Iberian Gravitational Waves Meeting (Santiago de Compostela), Iberian Cosmology Meeting (Bilbao), Spanish-Portuguese Relativity Meeting (Valencia), and the IPARCOS School on Gravitational Waves (Madrid).

The PhD thesis of Adrián del Río, [*Quantum aspects originated by Gravitation: from Cosmology to Astrophysics*; Supervisors: J. Navarro-Salas and I. Agullo; University of Valencia-IFIC] was awarded the prestigious Bergmann-Wheeler Thesis Prize by the International Society for General Relativity and Gravitation (ISGRG) for the best PhD thesis in the broad area encompassing all approaches to quantum aspects of gravity. Only 1 thesis every 3 years is rewarded. The ceremony took place during the GR22 conference.

The PhD thesis of Adrián del Río supervised by J. Navarro-Salas and I. Agullo was awarded the prestigious Bergmann-Wheeler Thesis Prize by the International Society for General Relativity and Gravitation (ISGRG). Only 1 thesis every 3 years is rewarded.



Our research activity this year has led to important progress in the correspondence of modified gravity with General Relativity, having worked out several explicit examples with scalar fields and electromagnetic fields. We have also investigated the coupling of modified gravity theories to global monopoles, non-linear sigma models, and Lorentz symmetry breaking fields (bumblebee), the impact of modified gravity on the minimum mass for sustained hydrogen burning in main sequence stars, and some conceptual issues related to the notions of proper time associated to theories with non-metricity and the gauge dependence of some curvature divergences in the metric-affine formulation.

A detailed analytical analysis of how backreaction effects modify classical rotating black holes and naked singularities in 2+1 dimensions has been carried out by our group. We discussed (for the full BTZ solutions) the role of quantum effects in connection with the cosmic censorship conjecture. We have also focused on the late time particles created by black holes (Hawking radiation), explicitly computing the next to leading order term, and continued our investigations on the electromagnetic duality anomaly and its implications in chiral astrophysical systems. Further analysis on the physical meaning of the axial anomaly in connection to particle creation phenomena and adiabatic invariance has been done. As a bonus, we improved our understanding of the renormalization group flow in curved spacetime using the adiabatic scheme for renormalization.

Using simple toy models, we have studied the phonons created by acoustic black holes (analog Hawking radiation) and showed that in the interior, due to anomalous scattering, the emitted spectrum is not thermal. In a more mathematical setting, we completed the study of the quantization of superconformal spaces in terms of the Segre embedding from the point of view of quantum groups.

We have studied the phonons created by acoustic black holes (analog Hawking radiation) and showed that in the interior, due to anomalous scattering, the emitted spectrum is not thermal.

Selected publications

- > Adria Delhom, Gonzalo J. Olmo, and Emanuele Orazi, *Ricci-Based Gravity theories and their impact on Maxwell and nonlinear electromagnetic models*, JHEP 11 (2019) 149.
- > Marc Casals, Alessandro Fabbri, Cristián Martínez, Jorge Zanelli, *Quantum-corrected rotating black holes and naked singularities in (2+1)-dimensions*, Phys. Rev. D99 (2019) 10, 104023
- > R. Fiorese, E. Latini, M. A. Lledó, F. A. Nadal, *The Segre embedding of quantum conformal superspace*, Adv. in Theor. and Math. Phys. Vol. 22, 1907-1968 (2019).
- > P. Beltrán-Palau, A. Ferreira, J. Navarro-Salas and S. Pla, *Breaking of adiabatic invariance in the creation of particles by electromagnetic fields*, Phys. Rev. D100, 085014 (2019).
- > A. Ferreira and J. Navarro-Salas, *Running coupling from adiabatic regularization*, Phys. Lett. B792, 81 (2019).

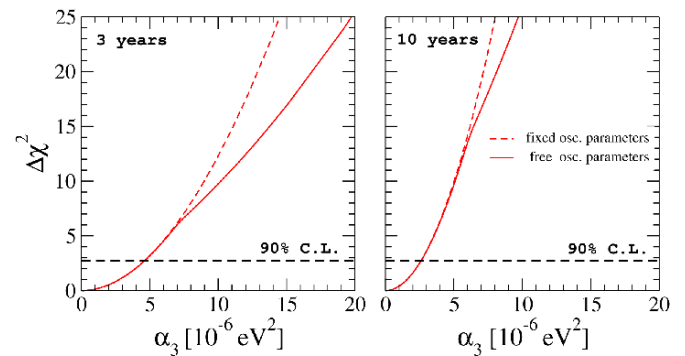
Selected talks

- > G.J. Olmo, *Particle creation by wormholes*, V Amazonian Symposium in Physics, November 18-22, Belém, Brazil.
- > G.J. Olmo, *Exotic compact objects in Ricci-based gravity theories*, October 7-12, Tuzla, Bosnia-Herzegovina.
- > G.J. Olmo, *Using GR to explore modified gravity effects*, 1st PUICGC, January 27-31, Lahore (Pakistan).
- > Fabbri, *Hawking radiation in Bose-Einstein condensates*, Seminar/Lecture within the course 'Advanced QFT', Master in Theoretical Physics, December 19, Univ. Bologna, Italy.
- > J. Navarro-Salas, *Particle creation, quantum anomalies, and gravity*, VI Amazonian Workshop on Black Holes and Analogue Models of Gravity, June 10-14, Federal University of Pará, Brazil.

THEORETICAL ASTROPARTICLE PHYSICS AND COSMOLOGY

The research topics of this line include cosmic rays, neutrinos, dark matter, dark energy and inflationary theories, involving as well international collaborations devoted to the study of neutrino oscillations and CP violation searches (Deep Underground Neutrino Experiment, DUNE), direct detection of relic neutrinos (PTOLEMY) and the role of dark matter, neutrinos and dark energy in the context of 21cm observations using the future Square Kilometer Array (SKA) Telescope.

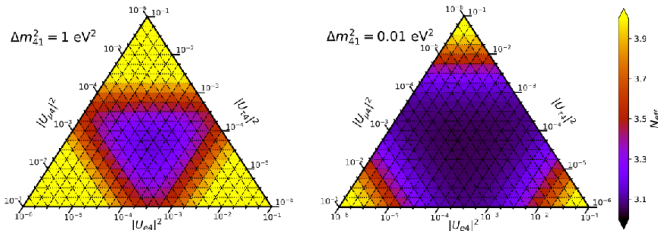
One of the topics of this research line is the study of the implications of non-standard neutrino physics for terrestrial experiments and astrophysical or cosmological observations. For instance, in 2019 IFIC authors have carried out several analyses that explore scenarios beyond the well-known three-flavour neutrino oscillation framework. One of them concerns the possibility that the heaviest neutrino mass state decays into a sterile neutrino and, depending on the model, a scalar or a Majoron. It is shown that the forthcoming ORCA experiment, part of the KM3NeT deep sea installation, will improve the sensitivity on this decaying scenario, finding that it could improve the current bounds coming from oscillation experiments. This study is a nice example of the collaboration among researchers from our institute's experimental and theoretical departments.



Sensitivity of the forthcoming ORCA experiment to the neutrino decay constant $\alpha_3 = \tau_3/m_3$

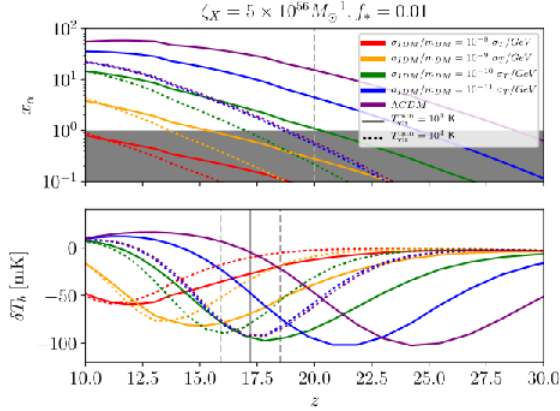
A few anomalies found in some short-baseline oscillation experiments could indicate the presence of an additional light neutrino at the eV mass scale that mixes with the three ordinary active states. This so-called 3+1 scheme would have profound implications for the early Universe and it is severely limited by present cosmological observations. IFIC researchers have presented an analysis of the cosmological evolution of neutrinos taking into account, for the first time, the full 4x4 mixing matrix. The degree of thermalisation of the sterile state was calculated in terms of the effective number of neutrinos (N_{eff}) and its dependence on the three additional mixing angles ($\theta_{14'}$, $\theta_{24'}$, $\theta_{34'}$) is discussed. These results are relevant for fixing the contribution of a fourth light neutrino species to the cosmological energy density, whose value is very restricted by the final Planck observations.

IFIC researchers have presented an analysis of the cosmological evolution of 3+1 sterile neutrino models taking into account, for the first time, the full 4x4 mixing matrix.



Contribution of neutrinos to the cosmological energy density (N_{eff}) in the 3+1 case for two different values of the mass-squared difference.

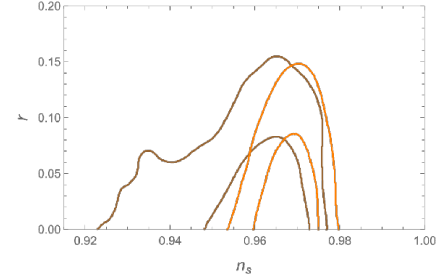
Researchers at IFIC also look for the effects of scattering of dark matter particles with massless or very light Standard Model particles, such as photons or neutrinos. These interactions would produce a suppression of the matter fluctuations at small scales and of the number of low mass haloes. These interacting dark matter (IDM) scenarios may lead to imprints in the cosmological 21cm signal from the hyperfine transition of the hydrogen, delaying the absorption features of the signal due to collisional damping effects. The astrophysical conditions under which the current constraints on the IDM scattering cross section could be improved due to its impact on the 21 cm signal have been explored. An explicit comparison to the warm dark matter (WDM) scenario, which presents a similar delay in the astrophysical processes, is also presented, complementing other efforts from IFIC scientists in the search for the dark matter nature.



Suppression in the Lyman- α coupling coefficient (top) and the delay in the brightness temperature of the 21 cm signal (bottom), for different values of the cross section of the IDM scattering.

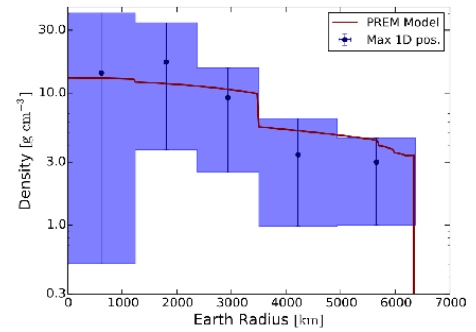
Scientists at IFIC also focus on early Universe physics. The precision of cosmological data has moved us from testing generic predictions of the inflationary paradigm to selecting individual models of inflation. Inflation is governed exclusively by two parameters. Therefore, extreme care is demanded when extracting these two numbers from data. While in the conventional picture, inflation models are becoming somewhat constrained, the presence of new neutrino interactions enlarges the range of allowed values of these two numbers and therefore enlarges the number of models and changes the selection criteria. By ignoring this possibility, we are missing important regions of cosmological parameter space. We cannot do more than guess the huge number of appealing and interesting inflation models that were not even considered because they predict a spectral index outside the

region obtained when neutrino interactions are neglected. Besides, the existence of these neutrino interactions can be experimentally tested and searched for in astrophysical experiments that are running now. Thus, maybe in the near future, astrophysical experiments will shed a new light on the way we analyze inflation.



One and two sigma allowed regions in the (tensor-to-scalar ratio r , spectral index n_s) space for the interacting (dark brown) and non-interacting (light brown) modes.

The first tomography of the Earth using neutrinos was performed by IFIC researchers and has been published in Nature Physics this year. Cosmic-ray interactions with the atmosphere produce a flux of neutrinos in all directions with energies extending above the TeV scale. Nevertheless, the Earth is not a fully transparent medium for neutrinos with energies above a few TeV. Since the amount of absorption depends on energy and distance traveled, studying the distribution of the TeV atmospheric neutrinos passing through the Earth offers an opportunity to infer its density profile. This had never been done before due to the lack of relevant data. Now, using public data from the IceCube South Pole neutrino observatory, and in a way completely independent of gravitational measurements, the first one-dimensional Earth's density profile has been obtained, relying on purely weak-interaction effects. These results demonstrate, for the first time using actual data, the feasibility of this approach to study the Earth's internal structure, which is complementary to traditional geophysics methods.



Density profile of the Earth with one-year IC86 data, with 68% error bars. PREM density profile in red.

The first tomography of the Earth using neutrinos was performed by IFIC researchers and has been published in 'Nature Physics' in 2019. Using public data from the IceCube South Pole neutrino observatory, and in a way completely independent of gravitational measurements, the first one-dimensional Earth's density profile was obtained, relying on purely weak-interaction effects.

Selected publications

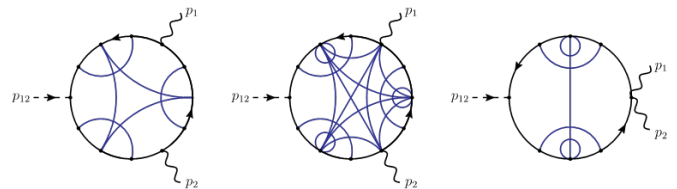
- > P. F. de Salas, S. Pastor, C. A. Ternes, T. Thakore and M. Tórtola, *Constraining the invisible neutrino decay with KM3NeT-ORCA*, Phys. Lett. B789, 472-479, DOI: 10.1016/j.physletb.2018.12.066 [arXiv:1810.10916].
- > S. Gariazzo, P. F. de Salas, and S. Pastor, *Thermalisation of sterile neutrinos in the early universe in the 3+1 scheme with full mixing matrix*, JCAP 07, 014, DOI: 10.1088/1475-7516/2019/07/014 [arXiv:1905.11290].
- > L. Lopez-Honorez, O. Mena, P. Villanueva-Domingo, *Dark Matter microphysics and 21 cm observations*, Phys. Rev. D99, 02352, DOI: 10.1103/PhysRevD.99.023522 [arXiv:1811.02716].
- > G. Barenboim, P. B. Denton and I. M. Oldengott, *Constraints on inflation with an extended neutrino sector*, Phys. Rev. D99, 083515, DOI: 10.1103/PhysRevD.99.083515 [arXiv:1903.02036].
- > A. Donini, S. Palomares-Ruiz and J. Salvado, *Neutrino tomography of Earth*, Nature Phys. 15, 37-40, DOI: 10.1038/s41567-018-0319-1 [arXiv:1803.05901].

Selected talks

- > A. Donini, *Neutrino tomography of Earth*, European Geoscience Union (EGU) General Assembly, April 2019, Vienna, Austria.
- > S. Gariazzo, *Relic neutrinos: clustering and consequences for direct detection*, 27th Int. Workshop on Weak Interactions and Neutrinos (WIN 2019), June 2019, Bari, Italy.
- > S. Pastor, *Active-sterile neutrino oscillations in the early Universe with the complete mixing matrix*, 16th Int. Conference on Topics in Astroparticle and Underground Physics (TAUP 2019), September 2019, Toyama, Japan.
- > S. Witte, *Probing the neutrino mass mechanism with the CMB*, 4th IBS-Multidark-IPPP workshop, October 2019, Daejeon, Korea.
- > M. Tórtola, *The global three-neutrino picture before DUNE*, XI Jornadas CPAN, October 2019, Oviedo, Spain.

QCD AND STRONG INTERACTIONS

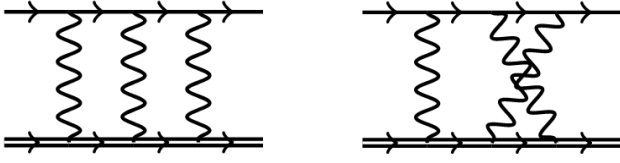
This research line is devoted to the study of the fascinating properties of Quantum Chromodynamics (QCD), the quantum field theory that best describes the strong interactions between quarks and gluons, the fundamental components of protons, neutrons and many other hadrons. QCD explains with incredible detail a multitude of intriguing physical effects on a wide range of energy scales, ranging from the nuclear force at low energies to the hard-scattering processes taking place at high-energy colliders. The strong interactions are ubiquitous at hadron colliders like the CERN's Large Hadron Collider (LHC), and, therefore, their accurate study is essential for precision measurements and searches for new physics beyond the Standard Model. In order to provide a comprehensive description, various approaches are considered such as perturbative and non-perturbative methods, lattice gauge theories, effective field theories, chiral perturbation theory, and phenomenological models. Furthermore, theoretical techniques developed in QCD find also applications to the study of gravity.



Two-loop Feynman diagrams describing the decay of the Higgs boson to a pair of photons through a closed loop of top quarks or hypothetical charged scalars.

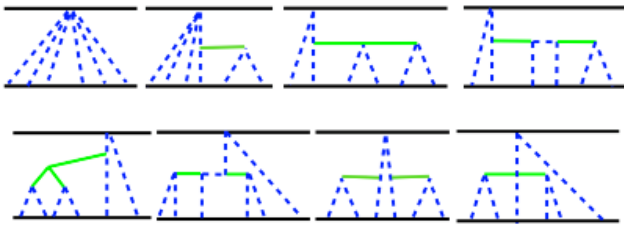
Theoretical predictions for the high-energy scattering processes taking place at high-energy colliders are primarily based on the perturbative approach in quantum field theory. The accuracy of these predictions is, however, limited by our ability to reach higher orders of the perturbative series in powers of the interaction couplings. The lowest order (leading order LO), which is typically described by Feynman tree diagrams, delivers a very crude and uncertain approximation. In order to achieve trustable theoretical predictions, it is compulsory to include the quantum fluctuations that are encoded by Feynman diagrams with closed circuits, also called loops.

One of the main obstacles, yet an open problem, remains in the evaluation of multi-loop scattering amplitudes. It is then for the above-mentioned issues that efficient techniques are being developed. Among them, the loop-tree duality method (LTD) proposed by IFIC's researchers. Unlike the traditional approaches, LTD is aimed at formulating quantum field theories directly in the four physical space-time dimensions. Remarkably, it also offers many potential advantages with respect to the Feynman representation regarding numerical evaluations and the characterization of the causal behavior of scattering reactions. The two-loop scattering amplitudes describing the decay of the Higgs boson to a pair of photons through a closed loop of top quarks and charged scalars as intermediate quantum states have been recently completed within this approach.



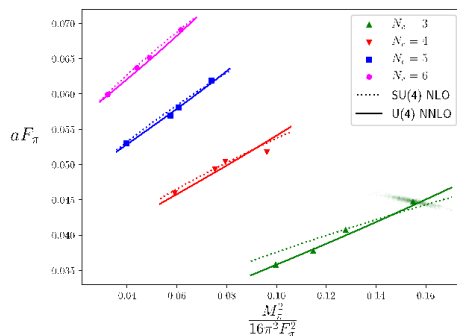
Representative two-loop Feynman diagrams contributing to μ -e scattering.

Along the several research lines, decomposing multi-loop scattering amplitudes through integral relations has also been elaborated by now working at integrand level. This new approach, based on integrand reduction methods, is currently applied to muon-electron elastic scattering at third order in the perturbative expansion (NNLO). Since the NNLO contributions require several pieces to provide a full theoretical prediction, one focuses on the interference between the two-loop and the Born amplitude, whose reduction and evaluation of Feynman integrals is done by means of the application of integration-by-parts identities and the method of differential equations, respectively.



Five-loop Feynman diagrams describing post-Newtonian contributions in General Relativity.

Although the strong and the gravity interactions appear to be very different, they are actually closely interconnected. Theoretical techniques developed to describe scattering amplitudes in perturbative QCD are now being used to predict post-Newtonian (PN) corrections to the Newton's potential. These corrections account for deviations of the Newton's potential due to General Relativity. The PN corrections started with the computation at first order performed by Einstein, Infeld and Hoffmann and recently went up to fourth order. Fifth order contributions are particularly important due to spin-independent size effects. This calculation has been carried out in the static limit by IFIC's researchers. In order to perform this evaluation, sophisticated tools to evaluate five-loop Feynman diagrams have been pushed forward.



Chiral dependence of the pion decay constant for varying number of colors.

The focus of the research based on Lattice Field Theory is on the calculation of low energy hadronic observables, such as masses, decay constants, and matrix elements. One of the main challenges is the connection between the finite-volume quantities computed on the lattice to the infinite volume observables. Hence, it has focused on two main goals. Firstly, the scaling of the pion mass and decay constant with the number of colors. With this, the scaling of the low energy constants of the chiral Lagrangian was calculated with the number of colors. Likewise, the chiral dependence of the decay constant for varying number of colors was computed. Secondly, the development and implementation of the formalism that relates the three-particle spectrum on the lattice to the infinite volume three-particle scattering amplitude. By means of this formalism, the extraction of the three-pion scattering amplitude at maximal isospin was straightforwardly carried out.

Furthermore, it has also been studied that skyrmion matter at low density is stable in an inhomogeneous phase where skyrmions condensate into lumps, while the remaining space is mostly empty. It was shown that skyrmion matter shares common properties with standard nuclear matter developing a skin and leading to a binding energy equation, which resembles the Weizsäcker mass formula. On top of this study, it was noticed that although the mass of the heavy-quark meson Upsilon(10860) is close to that of the conventional 5s quark model bottom-antibottom state, its decay properties point out to a non-conventional nature. It was shown that a good description of these properties, mass, leptonic decay width and dipion transitions, can be obtained under the assumption that it is a mixing of the conventional 5s quark model state with the lowest P-wave hybrid state.

The post-Newtonian (PN) corrections started with the computation at first order performed by Einstein, Infeld and Hoffmann and recently went up to fourth order. Fifth order contributions are particularly important due to spin-independent size effects. This calculation has been carried out in the static limit by IFIC's researchers.

Selected publications

- > S. Foffa, P. Mastrolia, R. Sturani, C. Sturm and W. J. Torres Bobadilla, *Static two-body potential at fifth post-Newtonian order*, Phys. Rev. Lett. 122 (2019) no.24, 241605.
- > F. Driencourt-Mangin, G. Rodrigo, G. F. R. Sborlini and W. J. Torres Bobadilla, *Universal four-dimensional representation of $H \rightarrow \gamma\gamma$ at two loops through the Loop-Tree Duality*, JHEP 02 (2019), 143.
- > J. J. Aguilera-Verdugo, F. Driencourt-Mangin, J. Plenter, S. Ramírez-Urbe, G. Rodrigo, G. F. R. Sborlini, W. J. Torres Bobadilla and S. Tracz, *Causality, unitarity thresholds, anomalous thresholds and infrared singularities from the loop-tree duality at higher orders*, JHEP 12 (2019), 163.
- > T. D. Blanton, F. Romero-López and S. R. Sharpe, *Implementing the three-particle quantization condition including higher partial waves*, JHEP 1903 (2019) 106.
- > P. Hernández, C. Pena and F. Romero-López, *Large N_c scaling of meson masses and decay constants*, Phys. J. C 79 (2019) no.10, 865.

- > D. Binosi, L. Chang, M. Ding, F. Gao, J. Papavassiliou and C. D. Roberts, *Distribution Amplitudes of Heavy-Light Mesons*, Phys. Lett. B 790, 257-262 (2019).
- > S. S. Xu, Z. F. Cui, L. Chang, J. Papavassiliou, C. D. Roberts and H. S. Zong, *New perspective on hybrid mesons*, Eur. Phys. J. A 55, no.7, 113 (2019).
- > R. Bruschini, P. González, *Quark model description of $\psi(4260)$* , Phys. Rev. C99 (2019) 045205-045213.
- > B. Park, W. Paeng, V. Vento, *The Inhomogeneous Phase of Dense Skyrmion Matter*, Nucl.Phys. A989 (2019) 231-245.

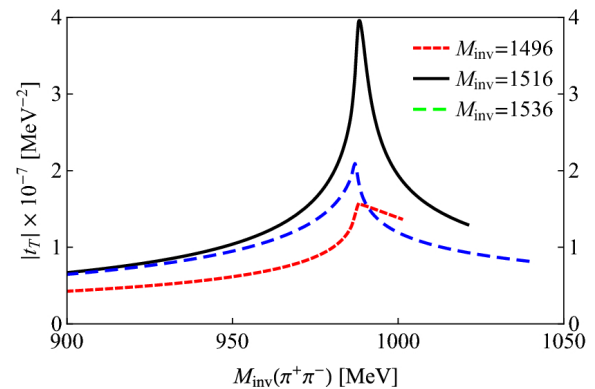
Selected talks

- > W. J. Torres Bobadilla, *Loops from trees in four space-time dimensions*, RADCOR2019, Avignon, France, 9-13 September 2019.
- > W. J. Torres Bobadilla, *Recent advances in the $\mu^- e$ scattering amplitude at NNLO in QED*, European Physical Society Conference on High Energy Physics - EPS-HEP2019 - 10-17 July, 2019 Ghent, Belgium.
- > G. Rodrigo, *Summary talk*, Workstop/Thinkstart 3.0 Paving the way for alternative NNLO strategies. Galileo Galilei Institute, Florence, Italy, 4-6 November 2019.
- > J. Papavassiliou, *Threading the needle with Schwinger-Dyson equations*, Continuum Functional Methods for QCD at New Generation Facilities, 07-10 May, 2019 – The European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) - Trento, Italy.
- > F. Romero-López, *Meson interactions at large N_c from Lattice QCD*, 37th International Symposium on Lattice Field Theory - Lattice2019, 16-22 June 2019. Wuhan, China.
- > P. González, *Quark model explanation of Upsilon(10860)*, HADRON 2019: XVIII International Conference on Hadron Spectroscopy and Structure. Guilin (China), August 17-21, 2019.

EFFECTIVE FIELD THEORIES IN HADRON AND NUCLEAR PHYSICS

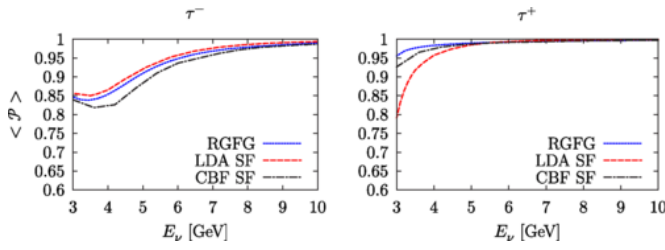
The discovery of a large number of exotic hadrons, which do not fit the expectations of the until then very successful quark model, as well as the unprecedented statistical precision obtained by LHCb, BESIII and other experiments (e.g. GlueX), have led to the renaissance of hadron spectroscopy. These discoveries have mostly occurred in the open and hidden charm and bottom sectors, but some of them are also in the light quark sector. Among various explanations of the internal structure of these excitations, hadronic molecules, being analogues of light nuclei, pentaquarks, tetraquarks and glueballs naturally emerge. The description and classification of all these exotic states and their interactions requires the combination of Effective Field Theories and analytic/dispersive methods. Among other studies, we have described the recent three pentaquark states reported by the LHCb Collaboration and predicted heavy-quark spin and SU(3) flavor partners and given a robust molecular interpretation for some of the new Ξ_b and Ξ_c resonances observed by Belle and LHCb.

We have also paid a special attention to triangle singularities, which stem from mechanisms represented by a triangle loop Feynman diagram, when all the intermediate particles can be put on shell and are parallel, and, in addition, represent a process that can occur at the classical level (Coleman Norton theorem). The subject has become topical because in the search of new resonances there is the danger to misidentifying a triangle singularity as a new resonance.



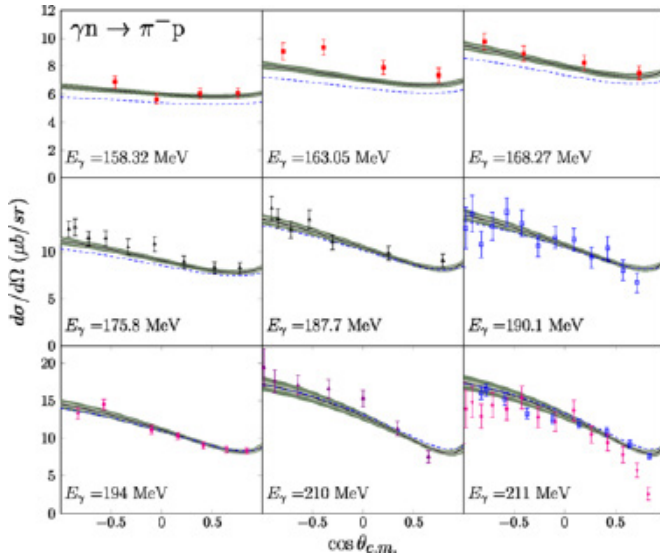
Triangle singularity contribution to the $\pi^+ \pi^-$ spectrum in the reaction $J/\psi \rightarrow K^* K_f^0(980) \rightarrow K^* K \pi^- \pi^+$ for different invariant masses of the K_f^0 pair.

In addition, the response of complex nuclei to electroweak probes has been also investigated using the hadronic effective formulation together with many-body field theory techniques, with direct impact on current and future neutrino experiments. The precision goals of oscillation experiments call for an improvement in our ability to describe neutrino scattering with nucleons and a variety of complex nuclei such as carbon, oxygen, iron or argon. Within our effective model of nuclear dynamics, we have studied exclusive final state hadron observables from neutrino-nucleus multi-nucleon knockout and the polarization of τ in quasielastic (anti-)neutrino scattering.



Degree of polarization of τ^- (left) and τ^+ (right) as a function of the incoming neutrino energy for various nuclear models for $\nu_\tau/\bar{\nu}_\tau$ scatters off ^{16}O .

Using the powerful tool of covariant baryon chiral perturbation theory, we have also undertaken detailed studies of the axial properties of baryons, the electroweak properties of the $N\Delta(1232)$ transition current and pion production.



Angular cross section for the $\gamma n \rightarrow \pi^- p$ channel at various energies.

We have investigated the response of asymmetric nuclear matter excited by an isospin flip probe at zero and finite temperatures using linear response theory. This study represents a step towards a realistic description of neutrino transport properties in dense matter, which play a crucial role in several astrophysical scenarios such as supernovae explosions, neutron star mergers or the evolution of protoneutron stars.

We finally mention the participation in the organization of the Workshop Neutrini and nuclei, challenges and opportunities for nuclear theory (ECT*) in Trento in May 2019.

We have described the recent three pentaquark states reported by the LHCb Collaboration, predicted heavy-quark spin and SU(3) flavour partners and given a robust molecular interpretation for some resonances observed by Belle and LHCb.

Selected publications

- > C.-W. Xiao, J. Nieves and E. Oset, *Heavy quark spin symmetric molecular states from $D^-\Lambda_c^{(*)}$ $\Sigma_c^{(*)}$ and other coupled channels in the light of the recent LHCb pentaquarks*, Phys. Rev. D 100 (2019) 014021 – 6pp.
- > W.-H. Liang, H.-X. Chen, E. Oset and E. Wang, *Triangle singularity in the $J/\psi \rightarrow K^+ K^- f_0(980)$ decays*, Eur. Phys. J. C 79 (2019) 411 – 11pp.
- > G. H. Guerrero Navarro, M. J. Vicente Vacas, A.N. H. Blin and D.-L. Yao, *Pion photoproduction off nucleons in covariant chiral perturbation theory*, Phys. Rev. D 100 (2019) 094021 -19pp.
- > D.-L. Yao, L. Alvarez-Ruso and M. J. Vicente Vacas, *Neutral-current weak pion production off the nucleon in covariant chiral perturbation theory*, Phys. Lett. B 794 (2019) 109 – 5pp.
- > J. E. Sobczyk, N. Rocco and J. Nieves, *Polarization of Tau in Quasielastic (Anti)Neutrino Scattering: The Role of Spectral Functions*, Phys. Rev. C 100 (2019) 035501 – 14pp.

Selected talks

- > E. Oset, *Pentaquark states, Implications of LHCb measurements and future prospects*, October 2019, CERN, Suiza.
- > J. Nieves, *Theoretical review of heavy-light spectroscopy*, 18th International Conference on Hadron Spectroscopy and Structure (HADRON2019), August 2019, Guilin, China.
- > J.E. Sobczyk, *Tensions in neutrino-nucleus modeling*, International Workshop on Neutrino Factories (NuFACT 2019), August 2019, Daegu, South Korea.
- > M.J. Vicente-Vacas, *Hadron and Nuclear Physics and Neutrinos*, Hadronic Contributions to New Physics Searches 2019, October 2019, Puerto de la Cruz, Tenerife.
- > L. Alvarez-Ruso, *Baryon spectrum in neutrino-induced reactions*, 12th International Workshop on the Physics of Excited Nucleons (NSTAR2019), June 2019, Bonn, Germany

IFIC 2019 AWARDS AND APPOINTMENTS

Astrid Hiller Blin y Cristian Bosch Serrano have obtained the extraordinary doctoral award by the University of Valencia for the academic year 2017-2018. Astrid Hiller Blin carried out her thesis on the electroweak properties of hadrons at low energies under the direction of Manuel José Vicente Vacas. Cristian Bosch Serrano carried out an exploration on physics beyond the Standard Model after the discovery of the Higgs at the LHC under the direction of Gabriela Barenboim. More details here.

José Wagner Furtado Valle was awarded the 2018 "Premio México de Ciencia y Tecnología". This is the highest award granted by the Mexican government to distinguished scientists from Central America, South America, the Caribbean, Spain and Portugal. The award recognises the career of José Valle, one of the most cited scientists in high-energy physics in Spain who has made important contributions to neutrino physics. In addition, the researcher carries out intense work to strengthen cooperation between scientists in Latin America and Europe. The award was delivered by the President of Mexico, Andrés Manuel López Obrador, and by the General Director of the National Council of Science and Technology of Mexico (Conacyt), Elena Álvarez-Buylla. More details here and here.

Juan Fuster Verdú has obtained the Humboldt Research Award, one of the most prestigious awards given in Germany to recognise the awardees' academic achievements and to foster collaboration with colleagues in Germany. The award recognises Fuster's contributions to the knowledge of the heaviest known elementary particle, the top quark, through the development of new experimental techniques that are applied in the largest particle accelerator in the world, the CERN LHC, and serve as foundation for future accelerators. More details here.

Adrián del Río was awarded the Bergmann-Wheeler Thesis Prize for outstanding PhD thesis in the broad area of quantum gravity, by the International Society for General Relativity and Gravitation (ISGRG). His thesis, directed by IFIC researcher José Navarro Salas and by Iván Agulló Ródenas, from Louisiana State University (USA), proposes that, from the point of view of quantum physics, the polarisation of light changes when it passes through environments with intense gravity such as the collision of two black holes. The award is considered the most prestigious worldwide for doctoral theses in the area of gravitation. More details here.

Juan Nieves was appointed spokesperson of the joint research activity "JRA7-HaSP: Light-and heavy-quark hadron spectroscopy", within the project STRONG-2020, "The strong interaction at the frontier of knowledge: fundamental research and applications".

The project received 10 MEUR from the European Union's Horizon 2020 research and innovation programme. The Consortium includes institutions from 36 countries. More details here.

Juan Fuster Verdú was appointed Institutional Coordinator of CSIC in the Valencian Community, replacing José Pío Beltrán Porter. The appointment ceremony was held at the Casa de la Ciencia of CSIC in Valencia and was attended by Rosa Menéndez, president of CSIC, as well as directors and managers of research centres of the Valencian Community, and other prominent personalities of the University of Valencia, the Polytechnic University of Valencia, the Jaume I University, the Miguel Hernández University and the Valencian Innovation Agency, among others. More details here.

Pablo Roig Garcés has obtained the "Premio de Investigación 2019 para científicos jóvenes de la Academia Mexicana de Ciencias", in the area of exact sciences. Roig received his doctorate from the University of Valencia with a thesis carried out at IFIC under the direction of Jorge Portolés Ibáñez. Currently, he is a researcher at the Department of Physics at Cinvestav, one of the main scientific institutions in Mexico. The award recognises Roig's "outstanding scientific career" and his contributions to the study of the decay properties of particles known in the Standard Model as a tool to search for new physics. More details here.

Berta Rubio was appointed co-spokesperson of NUSTAR, one of the future research lines at FAIR. NUSTAR is a scientific collaboration with 700 members and 170 institutions that forms one of the pillars of FAIR, the future facility for nuclear physics research being built in Darmstadt (Germany). More details here.

Pilar Hernández was appointed member of the CERN Scientific Policy Committee. This committee was created at the foundations of CERN in 1954 as an advisory body to establish the scientific objectives of the laboratory, and is composed of highly renowned scientists worldwide. The appointment is for three years (2020-2023). More details here.

392 ARTICLES IN INDEXED JOURNALS (ONLY DOCUMENT TYPE ARTICLE OR REVIEW). SEE ANNEX FOR FULL LIST OF PUBLICATIONS.

95.1% IN FIRST QUARTILE JOURNALS (JCR-WOS OR CITESCORE-SCOPUS, 2019)

TOP 5 JOURNALS (BY IMPACT FACTOR, JCR-WOS) WITH IFIC AUTHORS

Review of Modern Physics (IF 45.0)	1
Nature Physics (IF 19.3).....	1
Reports on Progress in Physics (IF 17.0).....	1
Progress in Particle and Nuclear Physics (IF 13.4).....	1
Physical Review Letters (IF 8.4).....	37

TOP 5 JOURNALS (BY NUMBER OF PAPERS) WITH IFIC AUTHORS

Physical Review D (IF 4.8).....	92
Journal of High Energy Physics (IF 5.9).....	69
European Physical Journal C (IF 4.4).....	47
Physics Letters B (IF 4.4).....	47
Physical Review Letters (IF 8.4).....	37

412 CONTRIBUTIONS TO NATIONAL AND INTERNATIONAL CONFERENCES

79 SEMINARS ORGANIZED

12 'SEVERO OCHOA' COLLOQUIA

10 PHD THESIS WITH
IFIC SUPERVISORS

8 THEORETICAL

2 EXPERIMENTAL

28 MASTER PROJECTS

17 THEORETICAL

11 EXPERIMENTAL

TRAINING

Teaching Activities

The members of IFIC with positions at the University of Valencia are mainly involved in its Degree in Physics, although they also teach in Chemistry and Engineering. At the postgraduate level, IFIC participates in two of the Master's Degrees offered by the UVEG: Master in Advanced Physics and Master in Medical Physics. In the former, we are responsible for two of the four specialities: Theoretical Physics and Nuclear & Particle Physics. The Gamma Spectroscopy group participates in the inter-university Master in Nuclear Physics, where six Spanish universities, CIEMAT and CSIC are involved. Finally, a large number of PhD students carry out their research work in our institute, many of them from foreign countries.

In addition, IFIC researchers often teach at international schools for PhD students. Some of the series include the International Doctorate Network in Particle Physics, Astrophysics and Cosmology (IDPASC), the International School of AstroParticle Physics (ISAPP), the European School of High-Energy Physics or the Taller de Altas Energías (TAE).

PhD Theses

Theoretical Physics

Noncanonical approaches to inflation

Héctor Ariel Ramírez Rodríguez

Advisor: Olga Mena Requejo

10 May, University of Valencia

TESEO: 1773585

Four-dimensional representation of scattering amplitudes and physical observables through the application of the Loop-Tree Duality theorem

Felix Driencourt-Mangin

Advisors: Germán Rodrigo and Germán F. R. Sborlini

12 June, University of Valencia

TESEO: 1784688

Lepton flavor violation phenomenology beyond the Standard Model

María Paulina Rocha Morán

Advisors: Manuel Drees and Avelino Vicente Montesinos

30 August, University of Bonn (Germany)

Phenomenological applications in CP-violating systems in the SM and beyond

Héctor Gisbert Mullor

Advisor: Antonio Pich Zardoya

18 October, University of Valencia

TESEO: 1808808

Breaking of discrete symmetries and global lepton number in neutrino physics

Alejandro Segarra Tamarit

Advisors: José Bernabéu Alberola y Jose Peñarrocha Gantes

21 October, University of Valencia

TESEO: 1812633

Effective theory approaches to heavy meson resonances based on non-perturbative low energy two-meson dynamics

Pedro Fernández Soler

Advisors: Eulogio Oset Báguena, Juan Nieves Pamplona and Miguel Albaladejo Serrano

6 November, University of Valencia

TESEO: 1819842

Nuclear effects in neutrino-nucleus interactions: the role of spectral functions

Joanna Sobczyk

Advisor: Juan Nieves Pamplona

17 December, University of Valencia

TESEO: 1834791

Quantum walks: background geometry and gauge invariance

Iván Márquez Martín

Advisors: Armando Pérez Cañellas, Giuseppe Di Molfetta and Pablo Arrighi

27 December, University of Valencia

TESEO: 1833300

Experimental Physics

Development of a reconfigurable multi-plane Compton telescope for hadrontherapy dose monitoring

Enrique Muñoz Albaladejo

Advisors: Gabriela Llosá and Josep F. Oliver

2 December, University of Valencia

TESEO: 1822191

Collectivity along N=50: Nuclear Structure studies on the neutro-magic nuclei ^{92}Mo and ^{94}Ru with AGATA and VAMOS++

Rosa María Pérez Vidal

Advisors: Andrés Gadea Raga and César Domingo Pardo

20 December, University of Valencia

TESEO: 1835319

Master's Final Projects

Experimental Physics

Contribución al desarrollo de un veto de rayos cósmicos para el monitor de tritio del proyecto TRITIUM

Ana Bueno Fernández

Advisors: Nadia Yahlali and José Díaz Medina

Simulations of scintillating fibers in GEANT4 to measure "dark current" in high-gradient accelerators

Ana Catalán Benavent

Advisor: Marçà J. Boronat Arévalo

Data analysis in the PROTO-DUNE-SP liquid argon detector at CERN

Francisco Chacón Rubio

Advisor: Anselmo Cervera Villanueva

Search for secluded dark matter with the ANTARES and KM3NeT neutrino telescopes

Cristina Lagunas Gualda

Advisors: Rebecca Gozzini and Juan de Dios Zornoza Gómez

Construcción del módulo TRITIUM-2-IFIC del monitor TRITIUM y análisis

de datos

Marcos Llanos Expósito

Advisors: José Díaz Medina and Nadia Yahlali

BETIOP-I, primer prototipo de sonda beta intraoperatoria para cirugía oncológica: estudio preliminar

Mireia Simeó Vinaixa

Advisor: Nadia Yahlali Haddou

Sensitivity of NEXT to Xe-124 double electron capture

Myriam Martínez Vara

Advisor: Michel Sorel

Introduction to point-like neutrino source search algorithms using ANTARES data

Samuel Hassanasia Arencibia

Advisors: Juan de Dios Zornoza and Juan Zúñiga

Machine Learning algorithms in dark matter searches

Sergio Alves Garre

Advisors: Rebecca Gozzini and Juan de Dios Zornoza Gómez

Neutrino decay

Víctor Carretero Cuenca

Advisors: Tarak Thakore and Juan Zúñiga

Trigger and background rejection improvements in the search for neutral long-lived particles decaying in the ATLAS hadronic calorimeter for Run 3

Victoria Sánchez Sebastián

Advisors: Santiago González de la Hoz and Emma Torró Pastor

Theoretical Physics

$B \rightarrow D^{()} l \nu$ Decay in the heavy quark effective theory*

Arantxa Tymowska

Advisor: Antonio Pich Zardoya

Moments dipolars electromagnètics del leptó τ a l'LHC i a l'SPS

Andreu Negre Simó

Advisor: Fernando Martínez Vidal

Teleparallel Palatini theories: torsion formulations of gravity

Antonio Ferrer Sánchez

Advisors: Gonzalo Olmo and M^a Antonia Lledó

Cálculo a segundo orden en loops de una teoría Φ^3 sin masa

Daniel Diaz Anichtchenko

Advisor: Ioannis Papavassiliou

Funcional approach to Effective Field Theories

David Albadea Jordán

Advisor: Pilar Hernández Gamazo

Topological aspects of Shwinger Model on the lattice

David Cascales Picó

Advisor: Pilar Hernández Gamazo

Extensión mínima del Modelo Estándar: $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)'$

David Díaz Calderón

Advisor: Antonio Pich Zardoya

Constraining theories of gravity through astrophysical data: Λ CDM vs Mond and External Field Effect

Jaime de Cabo Martín

Advisor: Gonzalo Olmo

Neutrino non-standard interactions from an Effective Field Theory point of view

Jorge Terol Calvo

Advisors: Mariam Tórtola and Avelino Vicente

Estudi de la desintegració semileptònica $\Lambda_b \rightarrow \Lambda_c l \nu_l$ $l=e,\mu,\tau$

Neus Penalva Martínez

Advisor: Juan M. Nieves Pamplona

Internal structure of black holes

Pablo Burbano Hernández

Advisor: Gonzalo Olmo

Física de sabor más allá del Modelo Estándar

Pablo Escribano Valiente

Advisor: Avelino Vicente Montesinos

Quantum Field Theory in classical backgrounds: Yukawa interactions and cosmic preheating

Sergi Nadal Gisbert

Advisor: José Navarro Salas

Quantum cellular automata for simulation of Quantum Field Theory in (2+1) dimensions

Vicente Pina Canelles

Advisors: Armando Pérez Canyellas and Pablo Arnault de Mateo

Estudio de la dispersión elástica de neutrinos con núcleos. Experimento COHERENT

Andrea Satorre Antón

Advisors: Manuel Vicente Vacas and Luis Álvarez

Modified dispersion relations and the anomalies in neutrino oscillation experiments

Pablo Martínez Miravé

Advisors: Mariam Tórtola and Gabriela Barenboim

One loop effective theory for the vMSM model with heavy inflatons

Víctor Bresó Plá

Advisor: Jorge Portolés

Technical Training

The members of **IFIC have trained 13 students from technical areas** such as Electronic Engineering or Industrial Engineering during 2019, through a fruitful collaboration with ADEIT, the University-Business Foundation of the University of Valencia. In 2019, **10 technicians were working at IFIC** within the national programme for recruiting Technical Support Personnel (PTA). Moreover, **5 young technicians under 25 have worked at IFIC in 2019** within 'Garantía Juvenil' programme.

CONFERENCES, SEMINARS AND COLLOQUIA

Conferences and Meetings

IFIC researchers present their results in the main international conferences and workshops. **A total of 412 contributions were presented in 2019:** 396 talks (4 invited, 52 plenaries) and 16 posters. Here we highlight conferences and workshops organized by IFIC members in Valencia or elsewhere:

5th Workshop on Flavour Physics in the LHC Era: New physics with heavy mesons and baryons. 23-25 January, Valencia.

CERN Council Open Symposium on the Update of European Strategy for Particle Physics. 13-16 May, Granada.

1st ARTEMISA Mini-workshop on Machine Learning. 29 May, Valencia.

Invisibles19 Workshop. 10-14 June, Valencia.



Kick-Off Meeting of the Radio-Frequency Laboratory of the Medical Physics Facility (IFIMED) at IFIC. 25 June, Valencia.



22nd International Conference on General Relativity and Gravitation. 13th Edoardo Amaldi Conference on Gravitational Waves. 7-12 July, Valencia

PARTICLEFACE WG1 Meeting - WorkStop/ThinkStart 3.0: paving the way to alternative NNLO strategies. 4-6 November, Florence (Italy).

Total Absorption Spectroscopy: present and near future. 16-19 December, Valencia.

GenT workshop on Precision probes of New Physics. 16-19 December, Valencia.

Quantum walks and quantum information. 20 December, Valencia.

Meeting on Artificial Intelligence at IFIC. 20 December, Valencia.

IFIC Colloquia

The colloquium series "Severo Ochoa" brings the world leading experts to Valencia to present a vision of their area of science. Lectures are primarily devoted to particle, astroparticle and nuclear physics, but also explore other areas of science. Colloquia are open to scientists of other research institutes and to personnel and students of the science faculties. The outreach department shares recordings of the lectures on the institute's YouTube channel. **In 2019, IFIC celebrated 12 Severo Ochoa Colloquia.** Organisers: Germán Rodrigo, Mariam Tórtola and Marcel Vos.

Barbara Sciascia: *"Flavour physics, why do we care? An experimental review"*. January, 16th.

Nazila Mahmoudi: *"Flavour physics: Rare B decays and search for new physics, a theoretical review"*. January, 24th.

David Nygren: *"The Art of Experiment and the Pace of Discovery in Particle Physics"*. February, 14th.

José Manuel Fernández de Labastida: *"El Consejo Europeo de Investigación"*. March, 28th.

Geraldine Servant: *"From the Higgs to Cosmology"*. March, 28th.

Bernd Grambow: *"Scientific research addressing the problem of nuclear legacy"*. May, 9th.

Jonathan Butterworth: *"Off the map? Making and communicating the case for particle physics after the Higgs"*. May, 23th.

Maia García Vergniory: *"The Topological Periodic Table of Materials"*. June, 20th.

Yvone Y. Y. Wong: *"Neutrino Cosmology"*. October, 17th.

Andreu Climent: *"Ciencia en el Parlamento"*. October, 31th.

Daniel Ramón Vidal: *"Del laboratorio a la empresa: la experiencia de Biopolis S.L."*. November, 7th.

Peter Jenni: *"The Long Journey to the Higgs Boson and Beyond: Some History of ATLAS and the LHC"*. December, 5th.

Seminars

Seminars are more specific research talks given by an invited speaker, usually connected to one of the IFIC research groups. Some of them are more informal talks followed by a discussion session, such as those within Student Seminars series. **In 2019 we hosted a total of 79 seminars** (some of them webinars). The complete list can be found at the IFIC's Indico webpage. Coordinator: Andrea Donini.

TECHNOLOGY TRANSFER

In 2018, the Valencian Innovation Agency (AVI) endowed the most significant research institutes of the Valencian Community, including the IFIC, with a Scientific Unit for Business Innovation (UCIE). IFIC's UCIE is made up of four innovation agents and an external advisor. IFIC provides the administrative support of the UCIE.

UCIEs' objective is to transform the generated and accumulated knowledge in the institutes into innovations, facilitating its effective transfer through the granting of licenses, the creation of companies, the collaboration with companies and technological institutes in R+D+I projects, the personnel exchanges and other forms of management of the created knowledge.

To bring IFIC research results closer to the industrial environment, UCIE implements two strategies. The first one is to develop specific actions to support groups with technological impact and transfer potential, by taking research results to a more advanced stage of development and/or reorienting lines of research when necessary. The second one consists of establishing contacts and collaborations with the rest of the Valencian R+D+I system agents providing them with the necessary technical support to achieve an effective transfer of the technologies generated at IFIC.

Within this framework, during 2019 UCIE has developed its activity along the following lines:

Actions aimed at reinforcing internally and externally the impact of the IFIC UCIE:

The UCIE has increased IFIC's presence in the innovation scenario by means of contacts with technological institutes, research institutes working on technological subjects, companies, and business associations.

Through the UCIE, IFIC has been present at local, national and international technological forums and meetings:

- > INNOVAPOLI presentations. Some possible fields of collaboration in ICT, digitalization, resource management and water treatment have been identified.

- > Conference: "Soluciones tecnológicas. Nuevas oportunidades de mercado en la Comunidad Valenciana" organized by the UCIEs' and AVI's Innovation Agents, Valencia, December 12, 2019.

- > Meeting on "Cybersecurity in critical environments" within the ISACA VALENCIA Events, Valencia, June 20, at the Valencia Chamber of Commerce, including a conference of Francisco Albiol (IFIC) about "Bigdata en Infraestructuras críticas".

- > Meeting "Retos Tecnológicos en la Industria de la Ciencia" organized by INDUCIENCIA and CDTI, Madrid, December 5, including a conference of Juan Fuster (IFIC) on the subject "OPORTUNIDADES, RETOS Y CASOS DE ÉXITO EN ACELERADORES/F. PARTÍCULAS".

- > Meeting "ILO Industrial Opportunities Days", Instituto Nazionale di Astrofisica, Nápoles, June 6-7.

- > GLOBAL INNOVATION FORUM. WTA-GIF-Unesco. Daejeon, Korea, October 21-22. Francisco Javier Cáceres (IFIC) was the chairperson of one parallel session (START-UPS FROM BASIC SCIENCE).

An in-depth study on the IFIC's potential for transferring results has been carried out by a prestigious external advisor, Francisco Javier Cáceres Núñez. This study analyses the scientific and social environment of the IFIC, and the legal conditions raised by being defined as a mixed center of the CSIC and the University of Valencia. It also includes a section of interviews with 21 professionals, researchers and heads of technical services from the IFIC, as well as 6 senior officials involved in the transfer of technology from the UV, the CSIC, the UV Science Park and the CEV. In addition, models used in different national and international organizations for Innovation and Technology Transfer from basic science centers to society are examined. Finally, it concludes with a specific analysis of the weaknesses, challenges, strengths and opportunities, as well as specific proposals for the work of the UCIE in the short term, 2020, and the medium and long terms. The work plan defined, already started, will be developed mainly throughout 2020. The main elements addressed have been:

- > A detailed review of the current situation of the IFIC in general as well as in relation to Innovation and Technology Transfer.

- > Identification of the main nearby Innovation agents with whom there is the possibility of collaborating and providing close support (innovative fabric).

- > Identification of the potential priorities of the Valencian Community (AVI, RIS3 actions, company programs...) as possible priorities to guide the innovation actions of the UCIE.

- > Identification and characterization of the capacities and potential of IFIC, in view of its structuring (structuring of the offer)

- > The gradual participation of UCIE in external diffusion and training programs.

- > The organization of a training program for IFIC staff on topics related to Innovation and technology transfer.

- > The drafting of an executive action plan for 2020.

In 2019, UCIE started the organisation of IFIC's technological offer. Presentation sheets were prepared on IFIC's technological capabilities in order to structure an offer portfolio. The means of presenting this offer on different formats have also been addressed and the creation of a UCIE website has been started.

Training actions carried out:

- > Participation in AVI training courses.

> Course aimed at IFIC master's and doctoral students on "Innovation in the area of particle physics". March 25-27, 2019, IFIC. Professors: Francisco Albiol Colomer (IFIC) and M^a José Sales Montoliu (CEO of MODELIZA) (<https://indico.ific.uv.es/event/3666/>).

UCIE prepared also a training courses planning for researchers to be held through 2020.

Specific actions to support groups with technological potential and impact which were under the AVI agreement of 2019:

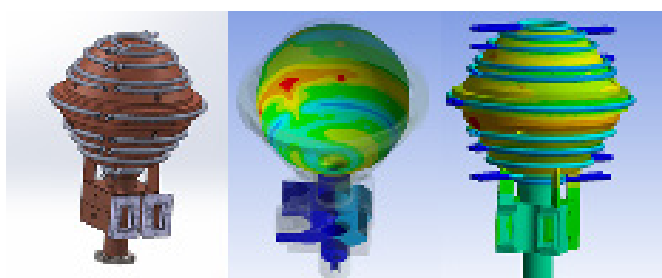
Along 2019, four singular innovation activities were funded: HGRF, NOTAC, LARAM, BioLight. Their respective progress during 2019 is summarized below.

HGRF. High Gradient Radio Frequency Facility.

The construction of an S-band High Gradient RF facility at IFIC has been completed and the laboratory has already started operations. The goal of this facility is to perform R+D with normal-conducting RF technology for accelerators. This R&D will help to design more compact linear accelerators, at a lower construction cost and with smaller size. This can have a positive impact on hadrontherapy facilities based on linear accelerators, as well as on industrial applications, such as cargo scanning, or scientific applications like free-electron lasers and Compton sources.

The radiation shielding necessary for running the facility up to medium power has already been designed, built and installed, and the first tests with an accelerator RF cavity have been performed. An upgrade in the radiation shielding, necessary in order to perform the full power tests, it is already under study and design.

In addition, the High Gradient RF group has upgraded its previous design of a RF pulse compressor improving its manufacturability and cooling system. The group has also manufactured 2 units of a RF wave-guide for 3 GHz in collaboration with a Valencian company. The aim is to transfer the group's knowledge and capabilities to Valencia's industry. The design of new wave-guide



RF components, such as bends or a hybrid combiner are being developed as well.

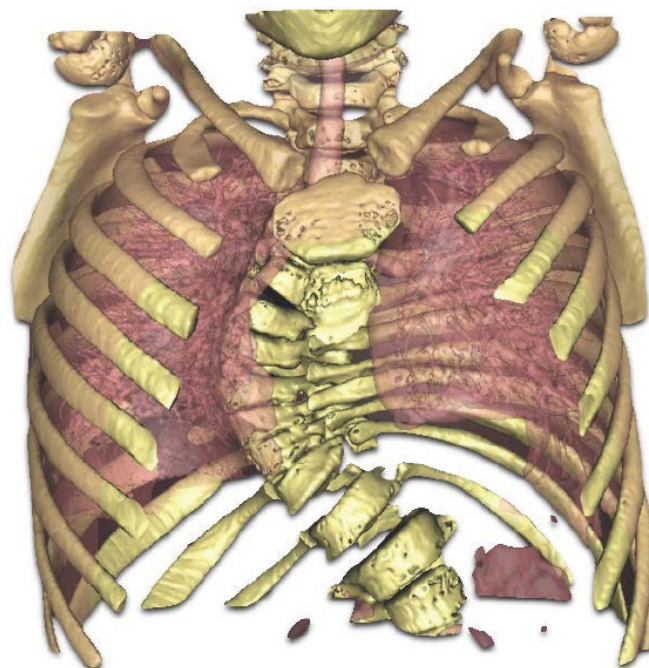
NOTAC. Tool for 3-D Image Reconstruction of the Spine in Idiopathic Scoliosis Patients.

This project aims at achieving a three-dimensional reconstruction of the spine of idiopathic scoliosis patients, using a patented 3D reconstruction technology.

This reconstruction presents several modeling and machine learning challenges. The reconstruction and segmentation of the organs is of utmost importance for all medical physical treatments that require the location of these organs.

In particular, the use of IFIC's patent for correcting the projective image allows incorporating techniques that can later be used in accelerators for the treatment and localization of lesions. For instance, treatments such as medulloblastoma or neuroblastoma using radiotherapy are eminently pediatric treatments requiring a complete irradiation of the central nervous system, which also includes spinal irradiation. Localization and irradiation methods based on the project results will allow to improve these treatments, particularly when both pathologies converge.

The project, funded by the Valencian Innovation Agency, has led to a clinical collaborative effort with a private company. In addition, IFIC has applied for a CDTI project in collaboration with Hospital Politécnico y Universitario La Fe, and the Instituto de Biomecánica de Valencia (IBV).



In 2019, the Scientific Unit for Business Innovation (UCIE) started the organisation of IFIC's technological offer. Four singular innovation activities were funded: HGRF, NOTAC, LARAM and BioLight.

LARAM. *Laboratorio de Radioactividad Ambiental.*

The international project TRITIUM ended its execution period in June. New improvements and perspectives emerged and a new project, named TRITIUM++, was presented to the SUDOE program of the EU.

Several automatic sensors prototypes for real-time monitoring of low radioactive levels of tritium in water of nuclear power plants were designed and constructed. The effort towards the implementation and fine tuning of prototypes in a real environment still continues.

LARAM maintains its contracts and agreements with the Generalitat Valenciana for the quality control of the Environmental Radiological Surveillance Plan (PVRA) of Cofrentes nuclear power plant, and for the development of the Radiological and Nuclear Emergency Plan of the Comunidad Valenciana. The laboratory also remains involved in the REM program in agreement with the Spanish Nuclear Safety Council (CSN).

The laboratory certificate complying with ISO/IEC 17025 is extended to include radon in drinking water. The laboratory carried out dissemination activities in order to make possible the adaptation of local companies to the radon legislative changes and technological futures. These activities have been completed with the creation of a website: www.radonlaram.es. In addition, during this year, LARAM has measured radon gas at the Spanish hydroelectric underground plants of Iberdrola Company under a contract to guarantee the radiological safety of workers.

BioLight. *Measurement of Light Emitted by Biological Samples.*

Continuing with the work done in the BioLight project started in the previous year, the IRIS group, in collaboration with a Valencian biotechnology company, has worked on the improvement of the experimental setup for the detection of light from biological samples. The results obtained in the experiments related to the measurement of light emission induced by the application of different chemical agents, were of interest to the company and led to the drafting and signature of an R&D contract to address the study of laser-induced light emission.

Preparing the year 2020, work has been done to recover the BRAINVECTOR project. This project, initiated within the 2018 agreement in collaboration with AIMPLAS, was not included in the 2019 agreement due to unforeseen causes. Moreover, five new projects with that company will be included next year.

UCIE's Innovation Agents have been involved in the preparation of 3 applications submitted to the CDTI and another 3 submitted to the AVI.

ARTIFICIAL INTELLIGENCE

IFIC's researchers have been using machine learning techniques (ML) for their data analyses since some time. However, there was a lack of coordination among the different groups using these techniques and gradually the feeling that this state of affairs should be changed grew up. The calls of the Conselleria d'Educació, Investigació, Cultura i Esport of the Generalitat Valenciana (GVA) for the acquisition of infrastructures and large equipment (PO FEDER 2014-2020) were a good opportunity to present a common proposal in this area. The fact that the applications had to be casted in the form of research projects decisively spurred IFIC researchers to join forces and make an application related to artificial intelligence. Under the shared goal of setting up a GPU-based computing platform, the application gathered a great deal of IFIC's activities linked to machine learning and big data analytics, both in fundamental and applied research.

In 2018, IFIC's proposal was positively evaluated and a budget of 1 M€ was granted. Due to the late resolution of the call and the red tape associated with the process of tendering and procurement, the first equipment could only be installed at the very end of 2018. It consisted of one server with 4 GPUs NVIDIA's Tesla Volta 100 (a.k.a. V100) and two servers with 1 V100 GPU each. In addition, two user interfaces with 1 GPU NVIDIA Pascal for testing purposes were installed. These machines included also two Intel Xeon CPUs. Five disk servers with a total of 240 TB were also installed. Thanks to the skillfulness of the personnel of IFIC's computing centre, the system was up and running in a very short time. The news was announced in the websites of IFIC and the University of Valencia [1] and appeared in some media outlets [2].

The platform was installed under the umbrella of CentOS, with a batch system managed by HTCondor and the disk servers under the control of Lustre. The relevant systems for accounting and monitoring (Ganglia, Nagios) were also installed together with specific software for AI and ML (NVIDIA's CUDA and cuDNN, Google's Tensorflow and GNU's GCC). During the first semester of 2019, the system was operated on a beta-testing basis, while the webpage of the platform ready to process applications was set up [3] and a twiki-supported documentation website was produced [4]. In parallel, an Advisory Committee (AC) was established to advise and guide the responsible scientist in charge of the platform. The members of the AC span most of the activities in AI of the institute, such as theoretical and experimental physics, GRID computing and computing in general, and applications for the society, in particular those related to medical diagnosis and treatment. The infrastructure was dubbed "Artemisa", after the Greek deity of "wilderness".

The first call for applications to use Artemisa was opened in May 2019. Fourteen research groups applied. After evaluation by the AC all applications were approved. The projects contained a variety of topics, most of them related to the research in physics carried out at IFIC. A second call was opened in October 2019. In this case, the AC decided that some special applications from the University of Valencia at large would also be accepted, even though a general announcement of the call was not made. A similar number of applications were received, this time including new subjects, such as those related to neuroimage and the visual brain and satellite monitoring of Earth's vegetation.



Photo collage of the equipment that composes Artemisa. Top left and bottom right: GPU units; Top centre: storage disks; Top right and bottom left: network switcher cables.

In parallel, the "1st ARTEMISA Mini-workshop on Machine Learning" was held in May at IFIC [5]. In this workshop, the Artemisa infrastructure was introduced and several IFIC's groups presented their activities in AI and Big Data analytics.

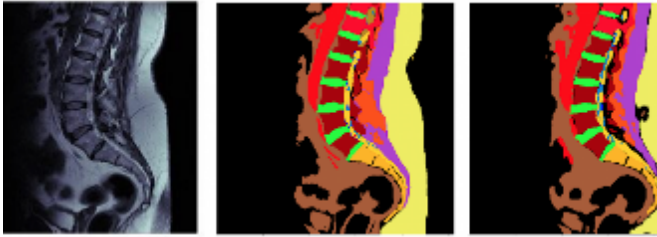
Likewise, with the aim of bolstering the collaboration in modern data reconstruction, computing and machine learning technologies across different physics communities, IFIC created the Computing Challenges network (COMCHA) [6]. It includes at present about 100 researchers from a variety of fields, but whose main interests lay in particle, astroparticle, nuclear, medical and applied physics. The network provides a forum for discussion and allows for the exchange of new technologies across experiments and research groups. It also aims to train students and help in capacity building. The first COMCHA school, organized by IFIC and La Salle - Universidad Ramón Llull, was held in October 2019 [7]. It included dedicated lectures on Artificial Intelligence and Machine Learning, and hands-on programming with new GPUs platforms. COMCHA provides its participating members a means to collaborate at national and international levels, and works with peers such as the HEP software foundation (HSF) [8].

IFIC had a strong participation in the "Jornadas del CSIC de identificación de competencias en Inteligencia Artificial", held in November 2019, with contributions related to DarkMachines, ANTARES/KM3NeT, NEXT/PETALO, Machine Learning for Medical Applications and AI for particle physics in accelerators [9]. Several IFIC members started to contribute to the "White Paper on Artificial Intelligence, Robotics and Data Science", CSIC's Strategic Roadmap, in particular in the areas of Machine Learning and Data Science, and of Low-Power Sustainable Hardware for AI.



Front view of Artemisa (the three rightmost racks). The rack in the centre (open door) contains the GPU units

At the end of 2019, the new tender procedure was finalised and the new purchased equipment was integrated in the Artemisa infrastructure. As of December 2019, the system consisted of 22 servers with 1 GPU NVIDIA V100 each (plus two CPUs Intel Xeon each), one server with 4 GPU NVIDIA V100 and two User Interfaces with one GPU Pascal each. The disk space was increased to 480 TB over five servers.



Low back pain (LBP) is a very prevalent pathology and a frequent cause of disability. A multidisciplinary group uses Artemisa for their studies of lumbar magnetic resonance imaging (MRI).

This is already an impressive platform that allows us to face computing intensive projects in Artificial Intelligence, while providing an exceedingly useful facility for the Spanish research community at large.

***Artemisa is co-funded by the European Union
through the 2014-2020 FEDER Operative Programme of
Comunitat Valenciana, project IDIFEDER/2018/048***

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<https://twiki.ific.uv.es/twiki/bin/view/Main/ComCha>
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<https://hepsoftwarefoundation.org/>
- [9] "Jornadas CSIC de identificación de competencias en Inteligencia Artificial", November 2019, Bellaterra, Barcelona:
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OUTREACH

IFIC participates and organises many activities of science dissemination that would not be possible without an active involvement of the members of the Institute. These activities range from public talks outside our facilities to opening the doors of our laboratories, and are aimed both at the general public and the educational community. Four people at IFIC coordinated and conducted these activities in 2019: Isidoro García, who manages our web, as well as our relation with journalists and press offices of other institutions, and Alberto Aparici, who deals with activities and materials aimed at students and the general public, and Enrique Nácher and Olga Mena, as scientists involved in the coordination and development of the outreach activities.

Outreach materials

Entre cientIFIC@s, the outreach blog of IFIC

Our outreach blog, *Entre cientIFIC@s*, is a platform where the members of IFIC can publish texts aimed at the general public. These texts can be about their research or about broader topics in physics or even the history of science. In 2019 we produced three pieces, from the birth of the neutrino to the LHCb experiment, including a special article on the 2019 Physics Nobel Prize to Jim Peebles.

The blog has an editorial board that receives the candidate texts and revises them before publishing, to ensure mostly that the format is consistent and there is a good image-to-text ratio. This board is formed by Alberto Aparici, Avelino Vicente and Luis Álvarez. Apart from them, in 2019 Stefano Gariazzo and Carlos Sánchez also contributed to the blog actively.



El nacimiento del neutrino

Los neutrinos siguen siendo a día de hoy objeto de intenso estudio tanto teórico como experimental. La historia de su nacimiento nos conduce a principios del siglo XX, una época de apasionantes descubrimientos.



Avelino Vicente
22 marzo, 2019
Física de partículas
FÍSICA, NEUTRINOS

El **neutrino** es sin duda la partícula más misteriosa del Modelo Estándar. Interacciona tan débilmente con el resto de partículas que resulta realmente muy difícil de detectar, lo que ha hecho que en la actualidad sigamos intentando averiguar muchas de sus propiedades. En este artículo hablaremos de los problemas experimentales que dieron lugar a que se postulase su existencia. Veámoslos uno a uno, como es habitual en ciencia: nos

ENTRADAS RECIENTES

- Agujeros negros y un Nobel de Física "suroccidental"
- Un colí de partículas
- ¿Es finita todo lo que vemos?
- El universo brinca (II): el ensanchamiento de las estrellas
- Simetría: Una de las herramientas más poderosas de la física

Science communication Colloquia

Among outreach materials we also consider IFIC's "Severo Ochoa" Colloquia. The list of the 12 colloquia offered in 2019 can be found in the section "Conferences, seminars and colloquia" of this report. The colloquia are recorded and publicly available on IFIC's YouTube channel. Directly related to outreach, we highlight the colloquium by Jonathan Butterworth, "Off the map? Making and communicating the case for particle physics after the Higgs", which took place in May 2019. Colloquium organizers during 2019 were Germán Rodrigo, Mariam Tórtola and Marcel Vos.

Books

Pedro González, *"La naturaleza de la llum. Breu història bibliogràfica"* (Publicacions de la Universitat de València).

Public Lectures

CPAN talks at High Schools

The Centro de Partículas, Astropartículas y Nuclear (CPAN) encourages its member institutions to offer outreach talks to local high schools and coordinates their organisation. In 2019 IFIC offered 36 such talks on three different topics: LHC physics, astroparticles and nuclear physics research, see more at <https://indico.ific.uv.es/event/3468/>.

Other public talks

Several IFIC members contributed in 2019 with 11 public talks covering a wide range of topics, from accelerator physics to black holes. IFIC speakers included Alberto Aparici, Miguel Escudero, Anabel Morales, Antonio Pich, Judith Plenter, Mario Reig, Joan Ruiz, Alejandro Segarra, Christoph Ternes and Avelino Vicente. Various talks were given at the E3F Summer School of the Faculty of Physics of the University of Valencia, as well as in other events such as the "XXV Ciclo de Conferencias de Astronomía y Cosmología Carlos Sánchez Magro", "Hay Vida en Martes" by Fundación Telefónica, and the opening day of the Centro de Astropartículas y Física de Altas Energías (CAPA) of the University of Zaragoza.

Outreach Activities

Guided tours for students

The institute offers guided tours to our facilities for groups of students interested in particle physics. These tours, usually spanning a whole morning, include a talk introducing some particle physics concepts and the research lines of IFIC, followed by a visit to our outreach material in the experimental building (cloud chamber, ATLAS Lego model, LHC photocall). After a break for coffee and food the tour continues with visits to two of our laboratories.

The available labs for the tours are ANTARES/Km3NET, NEXT, Nuclear Astrophysics, Gamma and Neutron Spectroscopy, Nuclear Reactions, ATLAS-Silicon Lab, ATLAS-Tile Calorimeter, Future Colliders, Radiofrequency Laboratory, Medical Imaging and GRID-Computing Centre. Alberto Aparici is the main responsible and coordinator for these visits, and usually he also plays the role of maître-de-cérémonie, but each laboratory provides one or two people who can share their expertise with the students during their visit to the labs. Thirty-six members of IFIC contributed to the tours throughout the year.



The total number of visiting schools in 2019 was thirty-two, from towns all over our region, mainly from the province of Valencia, but also including Muro de Alcoy from Alicante and Castellón de la Plana. Some visits were arranged together with the local delegation of CSIC in the Valencian Community, which sponsors the program Con Ciencia Sé to connect CSIC research centers and high schools. We were also pleased to host some special visits during this year. We received four groups of degree students of Universitat de València, two from the Degree in Physics, one from Electronics Engineering and one from the Degree in Journalism. The ES-TALMAT programme, devoted to promoting mathematical talent, visited the institute with a group of 65 students. In summer we also hosted the two groups of students within the VLC/Campus programme and one group of High School #1517 from Moscow, whose visits have already become a tradition. Besides these, we were also pleased to host two groups of senior people: a group from the senior programme of Florida Universitària and a group from Universidad Europea de Valencia. As we also mention below, we received in addition a group of high school teachers as part of our programme of particle physics outreach for teachers. Overall, in 2019 we hosted 696 visitors.

International Masterclasses: Hands On Particle Physics

Every year since 2005 CERN promotes the organisation of the Hands On Particle Physics International Masterclasses, a series of events that gather together high school students from all over the world to learn about particle physics by analysing real data from the experiments at CERN. IFIC participates since the very beginning, and in 2019 hosted several masterclasses, related to the ATLAS experiment, LHCb and Minerva experiments.

The participating students, accompanied by their teachers, gather at the Campus and spend the rest of the day together. The schedule of a masterclass includes several talks introducing basic concepts of the Standard Model and of experimental particle physics, and then a practical exercise analysing real data from the experiments.

After the exercise the group prepares for lunch, and in the afternoon the obtained results are discussed and interpreted. The masterclass comes to an end with a videoconference where the students can share their results with other participants in different countries that have worked through the same exercise. One or two experts at CERN and Fermilab act as masters of ceremonies and discuss how the results change when more data are put together.

Particle Physics Programme for high school teachers

Starting in 2016, IFIC sponsors a programme aimed at the teaching community of Comunitat Valenciana. Teachers in Spain have the opportunity to attend courses to update their background, but the number of courses focused on Physics is scarce. Together with the Department of Science Teaching of Universitat de València and CEFIRE, the government body that regulates such courses, IFIC offered in 2019 a 30-hour programme from February 4th until March 6th, to improve the teachers' training in particle physics and cosmology and to discuss how to translate that knowledge into the classrooms. The call for applications was a complete success.

The course was held in the Faculty of Physics, which kindly provided a classroom for the course. It included two sessions devoted to teaching techniques specific to particle physics, and two introductory lectures to relativity and quantum physics. Then several sessions followed which focused on particular topics: nuclear physics, accelerator physics, imaging techniques for medicine and neutrino physics. A special session described homemade particle physics experiments that can be used in the classroom, and the programme ended with a visit to the laboratories of the institute. Nine members of IFIC were involved in the different sessions that comprise the programme. The full programme can be found at <https://indico.ific.uv.es/event/3607/timetable/>

Open Day of the Scientific Park of the University of Valencia: Expociència 2019

Every year, around the end of May, the Parc Científic of the Universitat de València organises Expociència, an open door day in the context of which demonstrations are performed and science outreach activities are offered to the public. The 2019 edition received 4700 visitors. In 2019 IFIC contributed with several activities: "*Telescopios de neutrinos: observando el universo desde las profundidades del mar*", "*Cocinando en el Ártico*", "*ATLAS, un gigante para atrapar partículas*", "*¿Somos radiactivos?*", "*¿Busca todas las contribuciones!*".

Experimenta

Every year the Faculty of Physics of Universitat de València organises the Experimenta Exhibition-Contest, an event aimed at high school students for which they develop a project in basic science or technology with the help of their teachers. The projects are exhibited in a public session where the students themselves explain the science within, and then they are evaluated by a jury and four winners are selected. The 2019 edition attracted 5000 visitors. IFIC was involved as part of the organising committee, several members of the institute served as jurors during the contest phase of the event, and several others helped in organisational tasks and logistics.



Pint of Science

Pint of Science is an international festival that aims at transforming pubs into public forums of science discussion. In 2019, 73 cities in Spain, and more than 400 cities over the world, joined the festival, with hundreds of science talks for the general public on May 20, 21 and 22. IFIC scientists had a notable participation, both giving talks as well as organizing the festival in some cities.

Olga Mena and Judith Plenter participated in Valencia on May 21, at the Beers and Travels Bar. Olga spoke of the matter and energy that are still invisible and unknown in the universe, and how they shape its future. She also spoke about the other 'invisibles' of cosmology: women. Judith gave a talk entitled "*Lecturas de Mujeres Científicas*".

In Alcoy, Juan Fuster participated on May 20 in the session "*De lo más grande a lo más pequeño*" with the conference "*Lo pequeño es hermoso*". In Castellón, Mariam Tórtola gave the talk "*Neutrinos: Las partículas rebeldes del Modelo Estándar*", and Alberto Aparici contributed with "*La búsqueda del Planeta Nueve*", within the session "*Viajamos desde planetas a los átomos*" on May 22 at The Temple Bar. In Seville, IFIC researcher Nuria Rius gave the talk "*Los invisibles*", on May 20 at the Bulebar Café, within the session "*De los átomos a las galaxias*".

In addition, IFIC members Avelino Vicente and Alberto Aparici were part of the organization of the festival in the city of Sagunto, and the predoctoral researchers Óscar Estrada and Clara Remón organized, for the first time, the event in Alzira.

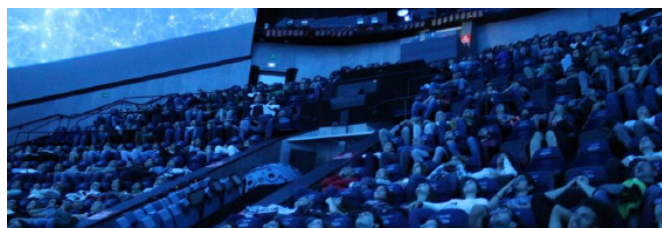


European Researchers' Night

September 27th was the chosen day to celebrate the European Researchers' Night, a Europe-wide event sponsored by the European Commission which aims to bring together researchers and citizens. Valencia joined the initiative and Berta Rubio from IFIC gave a talk about Nuclear Physics and the origin of elements in the Universe

Dark Matter Day

IFIC joined the initiative of the Interactions Collaboration to promote public knowledge of the physics of dark matter and the many efforts devoted to elucidate its nature. Three events were organized within this framework. On October 18, a talk about dark matter by video-conference halfway between Valencia and Tenerife was held. IFIC researchers Alberto Aparici and Avelino Vicente in Valencia, and Héctor Socas and Jose Alberto Rubiño from the Instituto de Astrofísica de Canarias (IAC) in the Museum of Science and Cosmos (MCC) of Tenerife talked about dark matter from the points of view of particle physics and astrophysics. On October 29, at the Hemisfèric of the City of Arts and Sciences in València, the movie '*Phantom of the Universe*', in whose production IFIC participated, was screened. The screening was preceded by an introductory talk by Olga Mena. On October 31, an activity similar to the one held in València was also organized at the Planetari de Castelló, with a talk by IFIC researcher Sergio Pastor.



International Day of Women and Girls in Science

Olga Mena and Mariam Tórtola participated in the conference cycle "*Dones i ciència*" at the Jardí Botànic of Valencia on February, 12-15, in celebration of the International Day of Women and Girls in Science. This event was part of the global initiative led by the 11defebrero.org platform. The artist Ana Beltrán Porcar crafted a painting inspired by the content of the scientific talks. Mariam Tórtola also participated in a round table entitled "Aprofitar tot el talent. Polítiques d'igualtat i ciència", which took place on February 14.

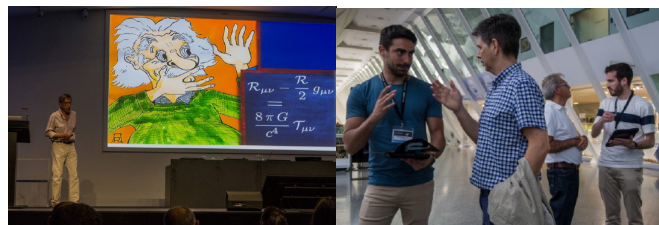
Outreach activities in the context of meetings and projects

INVISIBLES 19 workshop

Álvaro de Rújula gave a public talk at the Ciudad de las Artes y las Ciencias. Álvaro de Rújula is one of the most important theoretical physicists of the world, researcher at CERN since 1997 and one of the leading members of the team responsible for starting up the Large Hadron Collider. His talk was titled "*Einstein, the vacuum and nothing*".

Before the outreach talk, an interactive activity called "*Ghosts in the Universe*" took place at Calle Menor within the Museo de las Ciencias. During this activity, over 100 participants of diverse ages were able to "see" the elusive neutrinos using the "*NeutrinoScope*", a mobile app that allows the user to see the neutrinos produced from different sources. Moreover, the participants were able to play the videogame called NuOdyssey, in which they had to help a neutrino travel to the detector by interacting with neutrons, protons and electrons.

Also, as part of the Invisibles 19 Workshop Outreach Programme, there was the Arquímedes Opera at the Hemisfèric. The Opera describes the life of the hellenistic polymath (physicist, mathematician and engineer) from his childhood until the end of his life, based on the Greek historian Plutarch's biography of the Roman general Marcellus. The selected scenes combined electroacoustic music and synchronized video images, vocal soloists and mimes showing physical and mathematical concepts that Archimedes developed and applied to mechanical and pneumatic machines. The director adds some artistic licenses towards the end: shortly before dying, Archimedes imagines present-day physics, mathematics and cosmology (Feynman diagrams, string theory, the Big Bang, the multiverse, etc.).



IFIC in the media

In 2019 IFIC participated in the production of more than 150 pieces for several media, from newspapers to television. Some of them were produced directly by members of IFIC and others were the result of interviews or press releases issued by the outreach office of the institute.

Written articles

Some of the press releases produced in 2019 reached the media, either on physical paper or online. Results by IFIC researchers were also the subject of 29 newspaper articles. The articles were published in the following media: Europa Press, Las Provincias, El Periòdic, Levante, Valencia Plaza, ABC, 20 Minutos, Scientific American, Cadena SER and Bolsa Manía.

Articles authored by IFIC members

Antonio Pich contributed two articles: *“Cincuenta años de modelo estándar”* in the Revista Española de Física and *“Sin ciencia no hay innovación”* in Investigación y Ciencia.

Radio pieces

José Navarro, Avelino Vicente and especially Alberto Aparici contributed to 123 radio pieces in the following media: Onda Cero, Coffee Break: Señal y Ruido, CV Ràdio, El gato de Turing and Radio Esport. In particular, Alberto Aparici organised 36 issues of *La Brújula de la Ciencia* and 48 issues of *Aparici en Órbita* in Onda Cero.

TV and audiovisual pieces

Alberto Aparici also contributed to Antena 3 Noticias with *“On the interstellar asteroid Oumuamua and its possible artificial origin”*. As mentioned above, IFIC also produced the recordings of the 12 Severo Ochoa Colloquia in 2019, available at the YouTube channel of the institute.

YOUNG RESEARCHERS, GENDER AND DIVERSITY

The office for Young Researchers, Gender and Diversity of IFIC has continued its activity with the organization of several activities during its second year of life. At the beginning of the year 2019, an informal meeting in the format *"Coffee and cake"* was held with Prof. Barbara Sciascia, from the Laboratori Nazionali di Frascati and young researchers at IFIC. Several topics, ranging from how to deal with gender issues to the worries and requests of these young scientists were covered. The feedback from this meeting was communicated to IFIC management. The list of concrete measures included the policy of inserting a summary in English for all emails sent to the general IFIC list, creation of an email list for PhD students or the participation of a PhD students' representative in the IFIC Board meetings.

This office has also provided relevant input for the creation of the *"Welcome Pack"*, a collection of basic information to newcomers to IFIC (many of whom are young postdocs or starting PhD students).

The International Day for Women and Girls in Science was celebrated with the projection of the film *"Contact"*, open to IFIC members and their families. After the film, a round table discussion was held among the attendants. Moreover, an International Master Class for Girls was held at IFIC (not organized by JIGD, but by young IFIC female researchers), with the participation of 74 high-school female students. Other activities related to this day with participation of IFIC members included talks at the Botanical Garden and the participation in a round table organized in Madrid by CIEMAT on Science and Equal Opportunities.



Masterclass for girls organized on the International Day of Women and Girls in Science.

Concerning the topic of diversity in our field, it should be mentioned that the Office JIGD supported the celebration of the LGTB-STEM Day (July 5th).

Other activities related to these topics, organized externally with the support of the JIGD office, have been the two meetings on young researchers and employability held at IFIC. In the first one, three former IFIC members now working outside physics research shared their experience. In the second meeting, eleven companies (national and international), gathered with young IFIC researchers.



Meeting on young researchers and employability at IFIC.

In November 2019, the two-year mandate of Arantza Oyanguren and Juande Zornoza ended, and they were been replaced by Mariam Tórtola and Enrique Nácher.

The office for Young Researchers, Gender and Diversity of IFIC has provided relevant input for the creation of the 'Welcome Pack', a collection of basic information to newcomers to IFIC (many of whom are young postdocs or starting PhD students).

FUNDING

In this section we list all research grants that were active during the whole or part of 2019, funded by European Union (EU), national (NP), regional (CCAA) or other agencies.

PROJECTS BY SOURCE

<u>NATIONAL</u>	4,102,951 €
<u>REGIONAL</u>	1,675,828 €
<u>OTHERS</u>	399,740 €
<u>TECHNOLOGY TRANSFER</u>	279,180 €
<u>EUROPEAN</u>	130,500 €
<u>TOTAL</u>	6,588,199 €

PERSONNEL BY SOURCE

<u>REGIONAL</u>	2,263,995 €
<u>NATIONAL</u>	1,585,007 €
<u>OTHERS</u>	689,400 €
<u>TOTAL</u>	4,538,402 €

TOTAL INCOME* 11,126,601 €

* The income values refer to the total amount awarded to new research projects and personnel contracts during 2019.

NATIONAL PLAN PROJECTS

Refrigerador CO₂ y Cámara Infrarrojos para sala blanca del IFIC

Ref. EQC2019-005693-P

PI: Carlos Lacasta Llácer

138,919 € (Jan 2019 – Dec 2021)

Laboratorio de Certificación Electro-Óptica (CEOLAB)

Ref. EQC2019-006066-P

PI: César Domingo Pardo

399,639 € (Jan 2019 – Dec 2021)

Infraestructura de Cálculo de 87 nodos con 3480 cores y 16,7 TB Ram. Almacenamiento con capacidad de 1200 TB

Ref. EQC2019-006074-P

PI: José Fco. Salt Cairols

814,885 € (Jan 2019 – Dec 2021)

Buscando pistas de nueva física de altas energías en el LHC/ATLAS y en colisionadores e+e: Alta precisión y búsquedas directas

Ref. PGC2018-094856-B-100

PI: Juan Antonio Fuster Verdú

181,500 € (Jan 2019 – Dec 2021)

Construcción y operación del detector NEXT-100

Ref. RTI2018-095979-B-C42

PI: Michel Sorel

493,680 € (Jan 2019 – Dec 2021)

Contribución a la operación del Experimento ATLAS del Detector Interno de Trazas, del Calorímetro Hadrónico y a su Programa de Física

Ref. RTI2018-100863-B-100

PI: Salvador Martí García

1,188,220 € (Jan 2019 – Dec 2021)

Física Fundamental y Astronomía Multimensajero con telescopios de neutrinos

Ref. PGC2018-096663-B-C41

PI: Juan de Dios Zornoza Gómez

744,150 € (Jan 2019 – Dec 2021)

Upgrade del detector ATLAS: electrónica del Tile Calorimeter y explotación del Programa de Física

Ref. RTI2018-094270-B-I00

PI: Luca Fiorini

940,170 € (Jan 2019 – Dec 2021)

Experimentos de estructura Nuclear y Astrofísica con haces radioactivos y neutrones y aplicaciones

Ref. FPA2017-83946-C2-1-P

PI: José Luis Taín Enríquez

217,800 € (Jan 2018 – Dec 2019)

Estudios contemporáneos teóricos y experimentales de estructura nuclear, construcción y I+D instrumentales para AGATA, un instrumento para Hispec/Fair

Ref. FPA-2017-84756-C4-1-P

PI: Andrés Gadea

121,000 € (Jan 2018 – Dec 2020)

Búsqueda de nueva física con sabor con el experimento LHCb del CERN

Ref. FPA2017-85140-C3-3-P

PI: María Aranzazu Oyanguren Campos

229,900 € (Jan 2018 – Dec 2019)

Apoyo a Centros Excelencia Severo Ochoa

Ref. SEV-2014-0398

PI: Juan J. Hernandez Rey

4,000,000 € (Jul 2015 – Jun 2019)

Red Española de Física del Sabor

Ref. FPA2016-81784-REDt

PI: Arantza Oyanguren

20,000 € (Jan 2017 – Jun 2019)

Hacia un genuino TIER-2 federado español de ATLAS para afrontar el reto de la gestión y procesado del Big Data del LHC

Ref. FPA2016-75141-C2-1-R

PI: Santiago González de la Hoz

925,650 € (Dec 2016 – Dec 2019)

Física de Oscilaciones de neutrinos en el IFIC y la UAM

Ref. FPA2016-78417-C2-1-P

PI: Anselmo Cervera Villanueva

195,000 € (Dec 2016 – Dec 2019)

Teorías efectivas en física nuclear y de hadrones

Ref. FIS2017-84038-C2-1-P

PI: Juan Nieves Pamplona

102,850€ (Jan 2018 – Dec 2020)

Física de Partículas en el LHC y las factorías de sabor

Ref. FPA2017-84445-P

PI: Antonio Pich Zardoya

217,800 € (Jan 2018 – Dec 2020)

Física Nuclear y de hadrones a energías intermedias

Ref. FIS2017-84038-C2-2-P

PI: Manuel Vicente Vacas

72,600 € (Jan 2018 – Dec 2020)

Partículas elementales: El Modelo Estándar y sus extensiones

Ref. FPA2017-84543-P

PI: Óscar Manuel Vives

193,600 € (Jan 2018 – Dec 2020)

Astropartículas y física de altas energías

Ref. FPA2017-85216-P

PI: Jose Furtado Valle

127,050 € (Jan 2018 – Dec 2020)

Sabor y Origen de la materia

Ref. FPA2017-85985-P

PI: Pilar Hernández Gamazo

157,300 € (Jan 2018 – Dec 2020)

Campos cuánticos y gravitación
Ref. FIS2017-84440-C2-1-P
PI: Gonzalo Olmo Alba
60,500 € (Jan 2018 – Dec 2020)

Gravedad, Quiralidad de fotones y emisión estimulada
Ref. FIS2017-91161-EXP
PI: José Navarro Salas
36,300 € (Jan 2018 – Jun 2020)

Investigación de técnicas Compton para aplicaciones médicas
Ref: FPA2017-85611-R
PI: José Bernabéu Alberola
60,500 € (Dec 2018 – Dec 2020)

Redes de Excelencia
Ref: FPA-2017-90687-REDC
PI: Antonio Pich Zardoya
30,000 € (Dec 2018 – Dec 2020)

Red Española de Relatividad y gravitación
Ref. FIS2016-81770-REDT
PI: Gonzalo Olmo Alba
18,500 € (Jan 2017 – Jun 2019)

Física Hadrónica Interacciones fundamentales y física nuclear
Ref: FPA2016-77177-C2-1-P
PI: Pedro González Marhuenda
78,650 € (Dec 2016 – Dec 2019)

EUROPEAN PROJECTS

SANDA. Supplying Accurate Nuclear Data for energy and non-energy Application
NFRP-2018 Ref. 847552
PI: Alejandro Algora
48,999 € (Sep 2019 – Aug 2023)

STRONG-H2020. The strong interaction at the frontier of knowledge:- fundamental research and applications
H2020-INFRAIA-2018-1 Ref. 824093
PI: Santiago Noguera Puchol
81,500 € (Jun 2019 – May 2023)

CompactLight
H2020-INFRADEV-2017-1 Ref. 777431
PI: Juan A. Fuster Verdú
80,000 € (Jan 2018 – Dec 2020)

ENCORE
H2020-MSCA-IF-2017 Ref. 796941
Fellow: Stefano Gariazzo
IFIC PI: Sergio Pastor Carpi
158,121 € (April 2018 – March 2020)

A positron emission tomography apparatus based on liquid xenon with time of flight applications - PETALO

ERC-2017-STG Ref. 757829
PI: Anselmo Cervera
224,856 € (July 2018 – June 2023)

A positron emission tomography apparatus based on liquid xenon with time of flight applications - PETALO
ERC-2017-STG Ref.757829
PI: Pilar Hernández Gamazo
306,250 € (July 2018 – June 2023)

Towards the NEXT generation of neutrinoless double beta experiments
ERC-2013-ADG Ref. 284518
PI: Juan J. Gómez Cadenas
2,791,776 € (Feb 2014 – Jan 2019)

Advanced European Infrastructures for Detectors at Accelerators (AIDA)-2020
H2020-INFRAIA-2014-2015 Ref. 654168
IFIC PI: Marcel A. Vos
93,396.22 € (May 2015 – Apr 2019)

Europe-Japan Accelerator Development Exchange Programme (E-JADE)
H2020-MSCA-RISE-2014 Ref. 645479
IFIC PI: Ángeles Faus Golfe
63,000 € (Jan 2015 – Dec 2019)

European Nuclear Science and Applications Research (ENSAR2)
H2020-INFRAIA-2014-2015 Ref. 654002
IFIC PI: Andres Gadea Raga
159,625 € (Mar 2016 – Feb 2020)

Optimization of Medical Accelerators (OMA)
H2020-MSCA-ITN-2015 Ref. 675265
IFIC PI: Juan Fuster Verdú
247,872.96 € (Feb 2016 – Jan 2020)

INVISIBLESPLUS
H2020-MSCA-RISE-2015 Ref. 690575
IFIC PI: Pilar Hernández Gamazo
198,500 € (Feb 2016 – Jan 2020)

ELUSIVES
H2020-MSCA-ITN-2015 Ref. 674896
IFIC PI: Pilar Hernández Gamazo
454,402.92 € (Apr 2016 – Mar 2020)

TRITIUM
Ref. SOE1/P4/EO214
IFIC PI: Jose Diaz Medina
281,304.16 € (Jul 2016 – Jul 2019)

High-sensitivity Measurements of key stellar Nucleo-synthesis reactions
ERC-2015-CoG Ref. 681740
PI: César Domingo Pardo
1,886,558 € (Jun 2016 – May 2021)

INVISIBLESPLUS
H2020-MSCA-RISE-2015 Ref. 690575

IFIC PI: Olga Mena Requejo
103,220 € (Feb 2016 – Jan 2020)

Developing new world-class research infrastructures Astroparticle and Oscillations Research with Cosmics in the Abyss (ARCA and ORCA)

H2020-INFRADEV-2016-2 Ref. 739560

IFIC PI: Juan de Dios Zornoza Gómez

251,250 € (Jan 2017 – Dec 2019)

Commissioning, first tests and upgrade of a highpower S-Band Radio Frequency (RF) sustem for +D of high-gradient normal- accelerating cavities in breakdown science and RF conditioning - HGRF

H2020-MSCA-IF-2016 Ref. 750871

PI: Daniel Esperante

170,121.60 € (May 2017 – May 2019)

Molecule for low diffusion TPCs for rare event searches - MELODIC

H2020-MSCA-IF-2016 Ref. 740055

PI: Neus López March

159,126 € (Sep 2017 – Sep 2019)

Unraveled new physics at the LHC through the precision frontier

Ref. CA16201

PI: Germán Rodrigo García

560,000 € (Oct 2017 – Sep 2021)

REGIONAL PROJECTS

Estimación de dosis en terapia hadrónica

Ref. AICO/2019/070

PI: Carlos Lacasta Llácer

39,957 € (Jan 2019 – Dec 2020)

Desarrollo de dosimetría de precisión en radioterapia

Ref. AICO/2019/132

PI: Javier Vijande Asenjo

33,000 € (Jan 2019 – Dec 2020)

Desrrollos tecnológicos e instrumentales para AGATA

Ref. PROMETEO/2019/005

PI: Andrés Gadea Raga

276,677 € (Jan 2019 – Dec 2022)

Search for new physics at LHC with the ATLAS detector

Ref. PROMETEO/2019/006

PI: M. Carmen García García

262,885 € (Jan 2019 – Dec 2022)

Núcleos exóticos y Astrofísica Nuclear

Ref. PROMETEO/2019/007

PI: Berta Rubio Barroso

309,782 € (Jan 2019 – Dec 2022)

Sabor y origen de la materia

Ref. PROMETEO/2019/083

PI: Nuria Rius Dionis

254,928 € (Jan 2019 – Dec 2022)

Estudios perturbativos y no perturbativos del modelo estandar y sus extensiones

Ref. PROMETEO/2019/087

PI: Arcadi Santamaría Luna

241,434 € (Jan 2019 – Dec 2022)

Reto en física de sabor: el EXPERimento Desafía la Teoría (EXPEDITE)

Ref. PROMETEO/2019/113

PI: Francisco José Botella Olcina

213,065 € (Jan 2019 – Dec 2022)

Colaboracion IFIC-experimento MOEDAL en el acelerador LHC del CERN

PI: Vasiliki Mitsou

30,000 € (Jan 2019 – Dec 2019)

Infraestructuras y Equipamiento. Machine learning y big data en física de partículas y sus aplicaciones a los retos de la sociedad

Ref. IDIFEDER/2018/048

PI: Juan José Hernández Rey

999,860 € (Jan 2018 – Oct 2020)

Astroparticulas y física de Altas Energías

Ref. PROMETEO/2018/165

PI: Mariam Tórtola Baixauli

336,597 € (Jan 2018 – Dec 2021)

Física de precisión a altas energías: el LHC y futuros colisionadores

Ref. PROMETEO/2018/060

PI: Juan Fuster Verdú

252,960 € (Jan 2018 – Dec 2021)

Búsqueda de Nueva Física a través del Sabor

Ref. SEJI/2018/033

PI: Avelino José Vicente Montesinos

208,167 € (Jan 2018 – Dec 2020)

Sistema de Adquisición de datos multidetector

Ref. UV-INV-PROVAL17-720859

PI: Gabriela Llosá Llácer

44,873 € (Sep 2018 – Sep 2019)

Desarrollo de nuevas tecnologías basadas en el xenón

Ref. PROMETEO/2016/120

PI: Juan José Gómez Cadenas

300,375 € (Jan 2016 – Dec 2019)

Precise phenomenology in the LHC ERA

Ref. SEJI/2017/019

PI: Francisco Campanario Pallas

182,156.80 € (Jan 2017 – Dec 2019)

Aspectos Teóricos y observacionales de la estructura geométrica del Espacio Tiempo

Ref. SEJI/2017/042

PI: Gonzalo Olmo Alba

182,044.50 € (Jan 2017 – Dec 2019)

Aprendizaje profundo en análisis de detectores en física

Ref. SEJI/2017/011
Pl: Joshua Edward Renner
207,568.40 € (Jan 2017 – Dec 2019)

Nuevas interacciones en la frontera de altas energías

Ref. PROMETEO/2017/053
Pl: Antonio Pich Zardoya
392,000 € (Nov 2017 – Oct 2021)

De la física del LHC a las claves del universo primordial en la era de los datos

Ref. PROMETEO/2017/033
Pl: Gabriela Barenboim Szuchman
381,625 € (Nov 2017 – Oct 2021)

OTHER PROJECTS

Impulso a la estrategia de comunicación, divulgación y networking del IFIC

Ref. 201950E066
Pl: Juan José Hernández Rey
300,000 € (May 2019 – May 2022)

Equipamiento para microsoldería electrónica

Ref. FAS-19-0030
Pl: José Bernabéu Verdú
89,740 € (Jan 2019 – Dec 2020)

INCONI-Intercomparison of Compton cameras for nuclear imaging

Ref. PIC2018FR0032
Pl: Gabriela Llosá Llácer
10,000 € (Jan 2019 – Dec 2021)

Apoyo a la Creación de una Unidad Científica de innovación Empresarial en el Instituto de Física Corpuscular

Ref. 201850E066
Pl: Juan Fuster Verdú
144,000 € (May 2018 – April 2021)

Parity violations and metric-affine gravity

Ref. I-LINK1215
Pl: Gonzalo Olmo Alba
20,000 € (Jan 2018 – Dec 2019)

Geometry and Quantum Simulation

Ref. PICS2017
Pl: Armando Pérez Cañellas
10,000 € (March 2018 – Dec 2020)

Participación en el proyecto ATLAS: Operación del detector, análisis de datos y actualización del detector para la fase de alta luminosidad

Ref. PIE 201650E004
Pl: Carmen García García
96,100 € (Jan 2016 – Dec 2019)

Particle Physics at the LHC in the crossroad

Ref. 2017 50 E021
Pl: Germán Rodrigo García
113,871 € (Jan 2017 – Dec 2019)

Impulso a las nuevas fases de los experimentos del IFIC (ATLAS upgrade, Km3Net Fase 2,0, NEXT 100, DUNE, IFIMED)

Ref. 2017050E070
Pl: María José Costa Mezquita
130,200 € (Jan 2017 – Jun 2020)

Búsqueda de Nueva Física en los Experimentos ATLAS y MoEDAL del LHC en el CERN

Ref. IN[17]_CBB_FIS_0014
Pl: Vasiliki Mitsou
39,999 EUR (Sep 2017 – Mar 2019)

TECHNOLOGY TRANSFER PROJECTS

Creación de una Unidad Científica de Innovación Empresarial en el IFIC

Ref. 20180228
Pl: Juan Fuster Verdú
250,000 € (Jan 2019 – Dec 2019)

Contrato licencia exclusiva de software "predicciones para el sector eléctrico"

Ref. 20162171
Pl: Francisco Albiol Colomer
7,073 € (Apr 2016 – Apr 2021)

Correlación de la emisión espontánea e inducida de fotones en aneuploidia del embrión o Diagnóstico no-invasivo embrionario por emisión fotónica

Ref. 20194656
Pl: Gabriela Llosá Llácer
11,574 € (May 2019 – Oct 2019)

FACIEM 3D

Ref. 20177060
Pl: Francisco Albiol Colomer
7,811 € (Jul 2017 – Dec 2019)

CAV2.0: Estudio de mejoras para el sistema de valoración CAV

Ref. 20192416
Pl: Francisco Albiol Colomer
2,722 € (Mar 2019 – May 2019)

Study potential upgrades for the high-gradient S-band test facility

Ref. 20185988
Pl: Juan Fuster Verdú
166,000 € (June 2018 – June 2020)

Contrato de licencia exclusiva de la patente 201231243 "Dispositivo y procedimiento de obtencion de imágenes desitométricas de objetos mediante combinacion de sistemas radiológicos"

Ref. 20132089
Pl: German Rodrigo Garcia
6,171 € (May 2013 – Jul 2032)

Contrato de Apoyo tecnológico entre el CSIC e IST "FACIEM-3D"

Ref. 20177060
Pl: Francisco Albiol Colomer
23,437.70 € (Jan 2017 – Dec 2019)

ANNEX: PUBLICATIONS

EXPERIMENTAL PHYSICS

AGATA Collaboration

IFIC authors: Domingo-Pardo, C.; Gadea, A.; Perez-Vidal, R.M.

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IFIC authors: Barrios-Marti, J.; Coleiro, A.; Colomer, M.; Gozzini, R.; Hernandez-Rey, J.J.; Illuminati, G.; Khan-Chowdhury, N.R.; Lotze, M.; Thakore, T.; Zornoza, J.D.; Zuñiga, J.

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Run, ANTARES, and IceCube, Astrophys. J. 870, 134 - 16pp,
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<http://arxiv.org/abs/1810.10693>

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IFIC authors: Alvarez Piqueras, D.; Aparisi Pozo, J.A.; Bailey, A.J.; Baranco Navarro, L.; Cabrera Urban, S.; Castillo, F.L.; Castillo Gimenez, V.; Cerda Alberich, L.; Costa, M.J.; Escobar, C.; Estrada Pastor, O.; Ferrer, A.; Fiorini, L.; Fullana Torregrosa, E.; Fuster, J.; Garcia, C.; Garcia Navarro, J.E.; Gonzalez de la Hoz, S.; Gonzalvo Rodriguez, G.R.; Higon-Rodriguez, E.; Jimenez Pena, J.; Lacasta, C.; Lozano Bahilo, J.J.; Madaffari, D.; Mamuzic, J.; Marti-Garcia, S.; Melini, D.; Miñano, M.; Mitsou, V.A.; Rodriguez Bosca, S.; Rodriguez Rodriguez, D.; Ruiz-Martinez, A.; Salt, J.; Santra, A.; Soldevila, U.; Sanchez, J.; Valero, A.; Valls Ferrer, J.A.; Vos, M.

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