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<tr>
<td>SA2_GRWA</td>
<td>Gravitational Wave Astronomy</td>
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<td>SA3_NUCL</td>
<td>Nuclear Physics from the Lab to Improve People’s Health</td>
</tr>
<tr>
<td>SA3_LACC</td>
<td>The structure of the nuclear many-body systems and its astrophysical and cosmological implications</td>
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INTRODUCTION

This document reports on another prolific year for our Institute, full of changes, with a big progress in terms of the strengthening of the project and with excellent scientific results. The plans included in the Maria de Maeztu Unit of excellence that, in practice, started to be implemented in mid-2018, are in a clear process of consolidation. The new researchers hired through the Global Talent program are attracting external funds and the corresponding new research activities, as well as the new Research Program in experimental detection of gravitational waves, are producing good science in international standards. During this year, another relevant action from the Maria de Maeztu proposal, the IGFAE IGNITE Program, was put in place. IGNITE funds new ideas that have the potential to become relevant research activities at the Institute and attract external funds. Three projects have been granted, all lead by junior staff researchers:

- **PHARMi: Phoswich scintillator assembly for medical imaging** (PI Pablo Cabanelas)
- **Codex-b, an experiment to unveil BSM physics searching for Long Lived Particles** (PI Xabier Cid)
- **Gas TPCs with fast timing capability (To) for the DUNE Near Detector** (PI Diego Gonzalez)

Because of one of this seed projects, the Institute has joined the DUNE collaboration in 2020. The mid-term report of the Maria de Maeztu unit of excellence was submitted in fall 2019 and we expect the report from the Spanish ministry in the near future.

A key activity for the Institute in 2019 was the application to the call from the Galician Regional Government for the Network of Research Centres of Galicia. Resolved in December 2019, for the first time IGFAE is included in this network of research centres, ensuring a much more stable future – this network is part of a long-term plan that include all Galician centres supported by the regional government, with periodical evaluations to fix the amount of funding. The strict evaluation is performed by an external committee. Our Institute was placed first in the rank of all the centres, securing the maximum possible funding (1MEuro per year until 2022). It should be noticed that joining this stable network of research centres in Galicia was one of the main objectives of many of the activities in the last years.
During 2019, a discussion about the new premises for IGFAE was also carried out and an agreement has been reached in the Governing Board of the Institute to refurnish a large surface of the Monte da Condesa building (where IGFAE is now) to fulfil our needs. The project will increase the total surface of the Institute by around an extra 70% but, most importantly, new laboratories will be built in the basement to address one of our historical deficits. Equipment for these laboratories has been also started to be bought in the last couple of years thanks to six successful projects for experimental infrastructures of the Spanish Ministry. Before the Covid19 crisis the works for the new premises were expected to start in fall 2020 but some delays are now expected. We include in the report the first ideas for the new premises that should crystalize in an actual building project expected to be developed in the second half of 2020.

We have also redefined our Responsible Research and Innovation actions in a more structured way, creating the “Labs”, that are meant to be spaces for dialog and creation aiming at new ways to communicate with society and respond to its needs. The first of these new proposals is the ArtLab, a space of dialog and research on the connection of Arts and Sciences, with several activities in 2019 and with the participation of the Galician Centre of Contemporary Art. A second “Lab”, EduLab, is being created to contribute to improve how science, and in particular Physics, is taught at schools. A third one, TechLab, is expected to be implemented in the second half of 2020. The idea behind these structures is that they are formed by members of IGFAE but also members external to the IGFAE that work together in common goals. The Institute has also increased the outreach activities with the first IGFAE Open Day where general public was invited to visit us, especially children and families. This activity was the closing of an IGFAE Science Week when plenty of activities were performed.

Special attention has been taken to diversity. We celebrated for the first time the International Masterclass on Particle Physics during the “Day of Women and Girls in Science” that very successfully gathered several tens of high school female students from Galicia. This day was appraised very highly by the participants and will, indeed, become one of IGFAE annual activities. The members of the Gender Working Group have also actively participated in meetings that help us to shape useful actions towards improving the diversity in our Institute.
We have also enlarged our group of collaborating institutions and participation in international consortia. We have already mentioned DUNE and the Galician Centre of Contemporary Art (CGAC). We have also started an important joint venture with the Galician Supercomputing Centre (CESGA) with a first action to cope with the demanding needs of computing resources of the LIGO collaboration and the local Gravitational Wave activities. This action is expected to be extended to the LHCb Collaboration and the rest of the Institute. Moreover, CESGA is designing its new supercomputer (Finisterrae III) for which several meetings to understand our needs took place. Several members of IGFAE have also receive important awards and recognitions as the nomination of Elena Ferreiro as chair of the Governing Board of the Strong2020 consortium or the ERC Advanced Grant “Yoctosecond Imaging of QCD collectivity using jet observables (YoctoLHC)” awarded in 2019 to the Institute.

Finally, it is also worth mentioning that the support of the private sector (in particular the support of Banco Santander and La Caixa Foundation) has contributed to our strategy of talent attraction and training. We have also launched, for the first time a program of summer grants to support 10 students during a summer month at IGFAE. Interestingly, the program was also open to non-STEM students that brought to IGFAE a student in Economics, interested in Innovation, and another student in Communication.

This document reports on the activities of the Institute for 2019, its scientific production and, most importantly, presents the highlights of our different Research Programs.

Carlos A. Salgado
IGFAE Director
ORGANIZATION & TEAM

The scientific research of the Institute is organized into three Strategic Research Areas (SA) with several Research Programmes (RP). While in the future these could be subject to changes following the strategy of the Institute, the configuration of Strategic Areas and Research Programs has not changed in 2019. The scientific structure is the following:

   - **SA1_LHCB**: Beyond the Standard Model with LHCB.
   - **SA1_HQCD**: Hot and dense QCD in the LHC era and beyond.
   - **SA1_STRI**: String theory and related fields.

   - **SA2_AUGE**: Extremely energetic cosmic rays & neutrinos – Large exposure experiments.
   - **SA2_GRWA**: Gravitational Wave Astronomy.
   - **SA2_NEXT**: Dark Matter and the nature of neutrinos.

SA3. Nuclear Physics from the lab to improve people’s Health. Convener: Dolores Cortina
   - **SA3_NUCL**: The structure of the nuclear many-body systems and its astrophysical and cosmological implications.
   - **SA3_LACC**: Exploitation of the Laser Laboratory for Accelerator and Applications


*Figure 1. Organization chart.*
<table>
<thead>
<tr>
<th>GOVERNING BOARD (XUNTA DE GOBERNO)</th>
<th>DIRECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Members representing U Santiago de Compostela</strong></td>
<td></td>
</tr>
<tr>
<td>Antonio López (USC Rector – GB Chair)</td>
<td></td>
</tr>
<tr>
<td>Vicente Pérez Muñuzuri (USC Vicerector for Research)</td>
<td></td>
</tr>
<tr>
<td>Máximo Plo Casasús</td>
<td></td>
</tr>
<tr>
<td><strong>Members representing Xunta de Galicia</strong></td>
<td></td>
</tr>
<tr>
<td>José Alberto Díaz de Castro (Srio.X. de Universidades)</td>
<td></td>
</tr>
<tr>
<td>Mª Jesús Tallón Nieto (Subdtora X. Promoción Científica)</td>
<td></td>
</tr>
<tr>
<td>Faustino Roura Infante (Respons. Servizo de Planificación e Estructuración de Investigación)</td>
<td></td>
</tr>
<tr>
<td>Carlos Salgado (Director)</td>
<td></td>
</tr>
<tr>
<td>Abraham Gallas (Scientific Associate Director)</td>
<td></td>
</tr>
<tr>
<td>Nestor Armesto (Executive Associate Director)</td>
<td></td>
</tr>
<tr>
<td><em>pending official appointment.</em></td>
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<tr>
<th>SCIENTIFIC ADVISORY BOARD</th>
<th>SCIENTIFIC COMMITTEE</th>
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<tbody>
<tr>
<td>Sergio Bertolucci (Università di Bologna).</td>
<td></td>
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<tr>
<td>Barbara Erazmus (Subatech, Nantes).</td>
<td></td>
</tr>
<tr>
<td>Paolo Glubelino (GSI and FAIR, Darmstadt).</td>
<td></td>
</tr>
<tr>
<td>Gabriela González (Lousiana State University).</td>
<td></td>
</tr>
<tr>
<td>Francis Hanzen (U of Wisconsin Madison).</td>
<td></td>
</tr>
<tr>
<td>Larry McLerran (Institute for Nuclear Theory de Seattle).</td>
<td></td>
</tr>
<tr>
<td>Giulia Zanderighi (Max-Planck-Institute für Physik de Munich).</td>
<td></td>
</tr>
<tr>
<td>Carlos Salgado (Director)</td>
<td></td>
</tr>
<tr>
<td>Abraham Gallas (Scientific Associate Director)</td>
<td></td>
</tr>
<tr>
<td>Elena G. Ferreiro (Convener SA1)</td>
<td></td>
</tr>
<tr>
<td>Jaime Álvarez Muñiz (Convener SA2)</td>
<td></td>
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<tr>
<td>Dolores Cortina (Convener SA3)</td>
<td></td>
</tr>
<tr>
<td>Néstor Armesto (Convener Strategies for New facilites)</td>
<td></td>
</tr>
<tr>
<td>José Ángel Hernando (SA2_NEXT)</td>
<td></td>
</tr>
<tr>
<td>Diego Martinez Santos (SA1_LHCB)</td>
<td></td>
</tr>
<tr>
<td>José Luis Miramontes (SA1_STRI)</td>
<td></td>
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<tr>
<td>Juan Saborido (SA1_LHCB)</td>
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<tr>
<td>Enrique Zas (SA2_AUGE)</td>
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<table>
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<tr>
<th>EXECUTIVE BOARD</th>
<th>MANAGEMENT UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carlos Salgado (Director)</td>
<td></td>
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<tr>
<td>Abraham Gallas (Scientific Associate Director)</td>
<td></td>
</tr>
<tr>
<td>Elena G. Ferreiro (Convener SA1)</td>
<td></td>
</tr>
<tr>
<td>Jaime Álvarez Muñiz (Convener SA2)</td>
<td></td>
</tr>
<tr>
<td>Dolores Cortina (Convener SA3)</td>
<td></td>
</tr>
<tr>
<td>Néstor Armesto (Convener Strategies for New facilites)</td>
<td></td>
</tr>
<tr>
<td>Ricardo Rodriguez. Head of Management Unit</td>
<td></td>
</tr>
<tr>
<td>Berta Mariño. Project Manager Officer.</td>
<td></td>
</tr>
<tr>
<td>Ricardo Rodríguez (Head of Management Unit)</td>
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</tr>
<tr>
<td>Berta Mariño Lavía (Project Manager Officer.)</td>
<td></td>
</tr>
<tr>
<td>Marcos Seco (Responsible Information System).</td>
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</tr>
<tr>
<td>Elena Mora (Communication Officer).</td>
<td></td>
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<tr>
<td>Ana Belén Vázquez (Administration technician).</td>
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Table 1. Governance.
Personnel

During 2019, 21 new employment contracts (29%, 6, females; 71%, 15, males) were signed to join the institute team.

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>Administrative and Technical Staff</td>
<td>8</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>Emeritus</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Postdocs</td>
<td>15</td>
<td>2</td>
<td>17</td>
</tr>
<tr>
<td>Scientific Staff</td>
<td>31</td>
<td>3</td>
<td>34</td>
</tr>
<tr>
<td>Students</td>
<td>38</td>
<td>11</td>
<td>49</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>94</td>
<td>22</td>
<td>116</td>
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</tbody>
</table>

Table 2. IGFAE Composition by professional category.

The relation of total members is in the Annex 1.

HUMAN RESOURCES

Following the strategy initiated previously, the structure of Management Unit was reinforced with two hires (100%, 2, females): a communication officer working on all inner and outer communication flows, including the design of an overall communication strategy; and a management officer with a clear orientation towards consultancy, focused on call planning and monitoring, and economic control of projects. Both positions are already critical components of the projection of IGFAE and of the construction of a solid identity of the institute, specifically by maximising the autonomy in management of all economic resources that we have access to.

Four postdoctoral fellows (100%, 4, males), all from abroad (Austria, China, Finland and USA), arrived during the year. Unfortunately, we have not been able yet to improve our gender ratio in this group.

One Global Talent Fellow (Antonio Romero) was awarded a Ramón y Cajal contract in 2019 - contract started in Jan 1st, 2020. One of the Global Talent staff members (Riccardo Borsato) was granted a “la Caixa” Junior Leader postdoctoral fellowship, signing his new contract late in the fall 2019. This success validates our strategy of recruiting young researchers through our Global
Talent program and open an interesting way for access to private funding already initiated in 2018 with the incorporation of two predoctoral students. Expectations for 2020 are excellent.

Eleven new PhD students (18%, 2, females; 82%, 9, males) initiated their scientific career at IGFAE. Funds supporting this training period come from Spanish public calls devoted to Human Resources (3 grants linked to the María de Maeztu Excellence Unit coming from the Spanish State Programme for the Promotion of Talent and its Employability in RDI, also known as FPI grants, and 2 grants from the Spanish program of university teacher training, known as FPU, and 1 grant from Xunta de Galicia, our regional government) and competitive funds of research projects.

AWARDS

**ERC- Advanced Grant to Carlos Salgado**

The European Research Council (ERC) awarded in March the IGFAE’s director, Carlos A. Salgado, a 2.5 million euros Advanced Grant to study fundamental aspects of the formation of Quark Gluon Plasma in particle colliders. Researchers from the Laboratório de Instrumentação e Física Experimental de Partículas (LIP) in Lisbon and from the University of Jyväskylä in Finland are part of the project *Yoctosecond imaging of QCD collectivity using jet observables* (YoctoLHC).

**Honourable mention of the Gravity Research Foundation to José Edelstein**

The Gravity Research Foundation awarded in May one of its Honourable Mentions to the IGFAE researcher José Edelstein. It is the second time that the American institution recognizes the work of this theoretical physicist, awarded in 2015 with another Honourable Mention. The award-winning essay based on the article *Geometric Inflation*\(^1\) presents a work which identifies a mechanism that would explain the rapid expansion of the Universe in the period known as inflation. Such Honourable Mentions was previously granted to figures such as Stephen Hawking and Roger Penrose and several Nobel prizes such as George Smoot, Gerard ’t Hooft and Frank Wilczek.

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Best PhD thesis in Experimental Particle Physics award to Julián García Peñas

The postdoctoral researcher Julián García Pardiñas was awarded in 19 July 2019 the 1st DFTP Prize (Division of Theoretical and Particle Physics) of the Royal Spanish Society of Physics (RSEF), in the modality *Best PhD thesis in Experimental Physics*, for his work supervised by IGFAE researchers Maximo Pló and Juan José Saborido. This recognition, granted in the framework of the XXXVII Biennial Meeting of the RSEF to the most outstanding works defended in Spanish universities during 2018, adds to the brilliant career of this young researcher.

Lois Peña Novo 2019 award to Carlos Salgado

On June 27, in Sotomayor, the Lois Peña Novo Foundation awarded the vital and professional career of prominent people who use Galician in their public activities. In this edition, the Director of the IGFAE Carlos Salgado received the Lois Peña Novo 2019 award for his coherence, commitment and dedication to this language in his teaching role which place him among the best scientists in his field at national and international level.

Einstein para perplejos, Prisma 2019 for the best popularization book to José Edelstein

The IGFAE researcher and USC Prof. José Edelstein was awarded the most prestigious prize in scientific culture in Spain, the “Prisma 2019” for the best science popularization book, for his work *Einstein para perplejos*, written together with the Chilean physicist Andrés Gomberoff. The “Prisma Casa de las Ciencias” Premios a la Divulgación are an initiative of the Scientific Museums in A Coruña (supported by the City Council of A Coruña).

---

2 Search for flavour anomalies at LHCb: decay-time-dependent CP violation in $B_s \rightarrow K\pi(\bar{K}\pi)$ and Lepton Universality in $B_0 \rightarrow D(\bar{\psi})v$.
to reward the dissemination of scientific culture, and to support all professionals working in this field.

**FINANCES**

This report briefly explains our financial results from several points of view.

**Fundraising**

The total funds raised during 2019 has been **6,929,684€** (total amount of the raised funds, not only for 2019), with **28 new projects, institutional agreements, and contracts**. Most of the overall funding comes from competitive calls at the regional (50%), national (22%) and international (28%) levels. Four of our researchers obtained projects from the European Commission amounting **1,925,188€**, one of them being the ERC Advanced Grant of Carlos Salgado.

![Figure 5. Total funds raised during 2019.](image)

<table>
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<tr>
<th>TITLE</th>
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<th>FINANCED</th>
<th>START DATE</th>
<th>END DATE</th>
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<tbody>
<tr>
<td>Acciones centros singulares de investigación: programa de portas abiertas IGFAE. Convenio acciones I+D.</td>
<td>Salgado López, C.</td>
<td>Xunta Galicia</td>
<td>1/1/2019</td>
<td>12/31/2020</td>
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<tr>
<td>Mantenimiento y renovación de infraestructuras científico-técnicas básicas de interés general: Tier3 LIGO e intercomunicación Tier2 e Tier3.</td>
<td>Salgado López, C.</td>
<td>Xunta Galicia</td>
<td>1/1/2019</td>
<td>12/31/2020</td>
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<tr>
<td>Actualización de computación en el CPD del IGFAE. Infraestructuras 2019</td>
<td>Salgado López, C.</td>
<td>AEI</td>
<td>11/20/2019</td>
<td>12/31/2020</td>
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<tr>
<td>Descripción</td>
<td>Autor</td>
<td>Institución</td>
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<td>Fecha Fin</td>
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<td>Acuerdo confidencialidad “Potenciales actividades comerciales e industriales de SENRA”</td>
<td>Cortina Gil, MªD.</td>
<td>ESTAÑOS Y SOLDADURAS SENRA, SLU</td>
<td>4/12/2019</td>
<td>4/11/2029</td>
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<td>Acuerdo confidencialidad “Potenciales actividades comerciales e industriales de SENRA”</td>
<td>Cortina Gil, MªD.</td>
<td>CINDEGAL, SLU</td>
<td>4/12/2019</td>
<td>4/11/2029</td>
</tr>
<tr>
<td>Convenio GAIN e Universidades para o fomento da actividade investigadora beneficiarios de ERC</td>
<td>Salgado López, C.</td>
<td>AXENCIA GALEGA DE INNOVACION (GAIN)</td>
<td>1/1/2019</td>
<td>12/31/2020</td>
</tr>
<tr>
<td>Axudas para a acreditación, estruturación e mellora de centros de investigación do SUG. 2019</td>
<td>Salgado López, C.</td>
<td>Xunta Galicia</td>
<td>12/1/2019</td>
<td>11/30/2022</td>
</tr>
<tr>
<td>Consolidación e estruturación 2018 GPC GI-2070 Fisica Corpuscular e aplicaciones (FICA)</td>
<td>Fernandez Dominguez, B.</td>
<td>Xunta Galicia</td>
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<tr>
<td>The strong interaction at the frontier of knowledge: fundamental research and applications (STRONG2020)</td>
<td>González Ferreiro, E.</td>
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<td>Heavy ion collisions: collectivity and precision in saturation physics (HIEIC)</td>
<td>Armesto Pérez, N.</td>
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<td>Yoctosecond imaging of QCD collectivity using jet observables (YOCTOLHC)</td>
<td>Salgado López, C.</td>
<td>EUROPEAN COMMISSION</td>
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<td>Supplying accurate nuclear data for energy and non-energy applications (ISANDA)</td>
<td>Bentliure Anaya, J.F.</td>
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<td>Calibración, veto de muones y offline en next (CALMU). Retos 2018</td>
<td>Hernando Morata, J.A.</td>
<td>AEI</td>
<td>1/1/2019</td>
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<td>Datos nucleares para estructura y dinámica nuclear. Generación del conocimiento 2018</td>
<td>Fernandez Dominguez, B.</td>
<td>AEI</td>
<td>1/1/2019</td>
<td>12/31/2021</td>
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<td>Puesta en marcha y primeros experimentos en r3b. Generación del conocimiento 2018</td>
<td>Cortina Gil, MªD.</td>
<td>AEI</td>
<td>1/1/2019</td>
<td>12/31/2021</td>
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<tr>
<td>Explorando sectores oscuros en LHCB. Europa investigación 2019</td>
<td>Cid Vidal, Xabier</td>
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<td>5/31/2021</td>
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<tr>
<td>Busca de nova física no experimento LHCB do CERN.</td>
<td>Romero Vidal, Antonio</td>
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<td>Study of the structure of exotic nuclei</td>
<td>Fernandez Dominguez, B.</td>
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<td>Servizo medida de radón e outros parámetros radiactivos.</td>
<td>Cortina Gil, MªD.</td>
<td>INNOVACIONES TECNOLOGICAS RADÓN.</td>
<td>1/1/2019</td>
<td>12/31/2020</td>
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</table>
Active Projects

Our researchers are working in 48 ongoing projects with that amount, for this year, to **2,994,985€**. The complete list of ongoing projects is included in Annex 2.

![Figure 6. Actives projects & agreements 2019.](image)

The annual budget has increased from 2,631,529€ up to 2,994,985€ since last year (+13.8%). The next figure shows the type of activity with an impact in the increase of the budget.
RESEARCH OUTPUTS

Publications

144 articles were published in Scopus Journals (83% of the total publications) and 69% in the first decile (D1), more than 85% of the scientific production of the IGFAE is in the first quartile (Q1) Journals classified in the High Energy Physics and other Areas of the Scopus database. The average Scopus CiteScore of the published articles was 9.42.

The complete list of publications is provided in Annex 3, including articles, erratums and proceedings.

Theses

<table>
<thead>
<tr>
<th>Title</th>
<th>Student</th>
<th>Tutors</th>
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<td>Studies on the composition and energy of secondary cosmic rays with the Tragaldabas detector</td>
<td>Yanis Fontenla Barba</td>
<td>Cabanelas Eiras, Pablo</td>
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<td>Garzón Heydt, Juan Antonio</td>
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<td>Holography, dualities, and D-branes</td>
<td>José Manuel Penín Ascariz</td>
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<td>Long Time Dynamics of Resonant Systems</td>
<td>Anxo Fariña Biasi</td>
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<td>Quasi-Free Scattering of Light Neutron-Deficient Nuclei</td>
<td>Juan Manuel Boillos Betete</td>
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<td>New physics implications and searches at LHCb</td>
<td>Miriam Lucio Martínez</td>
<td>Martinez Santos, Diego</td>
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<td>Cid Vidal, Xabier</td>
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<td>Study of the B_0→π^+π^−(892)K^+K^− decays with an amplitude analysis of B_0→(π^+π^−)(K^+π^−) decays</td>
<td>Maria Vieites Díaz</td>
<td>Santamarina Rios, Cibrán</td>
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<td>Pló Casasús, Máximo Tomás</td>
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ALLIANCES & NETWORKS

During 2019 IGFAE has maintained and strengthened its long-term alliances with other international research centres, experimental collaborations, research institutions and universities, as well as has participated in training and Doctorate networks.

Alliances with international centres:

In the field of High-Energy Physics, IGFAE has maintained in 2019 a 30-years old close scientific relationship with CERN (European Organization for Nuclear Research) in Geneva, Switzerland. Members of IGFAE have participated in several experiments at CERN in the past, such as NA36, SMC, Dirac and ALICE among others. In 2019 IGFAE has kept its participation in nTOF, ISOLDE and most prominently the LHCb experiment, with the LHCb group at IGFAE being the third largest LHCb group in terms of number of researchers and engineers. More than half of IGFAE researchers have spent long stays at CERN working on these experiments. IGFAE also maintains strong contacts with the Theory Division at CERN.

In Nuclear Physics, IGFAE has maintained in 2019 its strong and sustained presence in international research centres such as GANIL (Grand Accélérateur National d’Ions Lourds) in Caen (France), as well as GSI (Helmholtz Centre for Heavy Ion Research) and in the Facility for Antiproton and Ion Research in Europe (FAIR) in Darmstadt (Germany). The presence of IGFAE is strongest in the R3B experiment in which our Institute has had an important participation in its construction and has maintained a leadership position – the current spokesperson of R3B is Prof. D. Cortina of IGFAE. IGFAE is also a founding member of the NEXT collaboration, an experiment located at the LSC (Laboratorio Subterráneo de Canfranc) in Huesca, Spain, aiming at deciphering the Dirac or Majorana nature of neutrinos.

In the field of Astroparticle Physics, IGFAE is one of the founding members of the Pierre Auger Observatory in Malargüe (Argentina), the largest and most precise ultra-high energy cosmic ray detector in the world. The Observatory was proposed by Prof. J. Cronin (Nobel Prize awardee in Physics in 1980) and Prof. A. Watson, both close collaborators of IGFAE. In 2019 members of IGFAE have continued their contributions to the search for ultra-high energy neutrinos and multi-messenger astronomy with Auger.

Since 2018 IGFAE is a member of the LIGO Collaboration that has discovered gravitational waves (GW) in 2015, a discovery that has opened a new window to the Universe (Nobel Prize in Physics in 2017) and has started the era of Multi-messenger Astronomy with gravitational waves. A
member of IGFAE is one of the main developers of one of the principal analysis pipelines to search for GW from Compact Binary Coalescence events.

**Cooperation with research centres and universities:**

- IGFAE has also maintained and fostered in 2019 stable collaborations with many research centres such as École Polytechnique (Paris, France), NIKHEF (Holland), INFN (Italy), LBNL, JPL and Fermilab (USA), or INP and NCBJ (Poland); and universities such as Jyvaskyla (Finland), Leeds (England), Wuppertal (Germany), St. Petersburg (Russia), Swansea (Wales) or Connecticut and Penn State (USA) among many others.

- IGFAE has started a strategic alliance with Laboratório de Instrumentação e Física Experimental de Partículas (LIP), the centre that coordinates Particle Physics in Portugal, an alliance that has been fostered in 2019 with the celebration in Santiago of the 2nd edition of the Joint Workshop LIP/IGFAE to consolidate the long tradition of scientific cooperation between researchers from both institutes.

- An important alliance has also been established in 2019 with the Supercomputing Centre of Galicia, where the computing cluster TIER3 of LIGO will be installed.

- IGFAE is also a member of the Severo Ochoa and Maria de Maeztu Alliance (SOMMa), the alliance of all research centres and units with SOMM accreditation. SOMMa is becoming an important interlocutor with the Spanish science authorities.

IGFAE has also started an alliance with the Galician Centre for Contemporary Art (CGAC), as part of IGFAE’s ArtLab initiative, one of the initiatives to boost the Responsible Research and Innovation of the Institute.

**Research networks:**

- IGFAE participates in the INFRAIA STRONG2020, both in the Steering Committee and Executive Board (Carlos Salgado) and in two Networking Activities: NA2-Small-x: Physics at the LHC and future DIS experiments with N. Armesto as spokesperson, and JRA2-FTE@LHC: Fixed Target Experiments at the LHC (Elena Ferreiro who is also chairperson of the STRONG2020 Governing Board).

- IGFAE participates in the Marie Sklodowska Curie Research and Innovation Staff Exchange (RISE) Heavy ion collisions: collectivity and precision in saturation physics (HIEIC) (N. Armesto) with researchers from NCBJ (Poland), Ben-Gurion University (Israel) and UConn (USA).
Training and Doctorate networks:

- IGFAE participates in the "International Doctorate Network in Particle Physics, Astrophysics and Cosmology (IDPASC)". An interdisciplinary network of research institutes with the aim of forming new high-level experts in the fields of Particle Physics, Astroparticle Physics and Cosmology. In 2019 some IGFAE PhD students attended schools organized by IDPASC, and some IGFAE senior members taught at other schools such as the 5th IDPASC/LIP PhD student Workshop.
- IGFAE has also subscribed in 2019 a new agreement of ISAPP – International School on Astroparticle Physics European Doctorate School, a network of 37 European Institutions with the purpose of organizing a common curriculum in Astroparticle Physics at the level of a Doctorate School with specialized courses on Astroparticle Physics. Bilateral and multilateral student exchanges concerning research activities focused on thesis preparation are also foreseen.

RESEARCH ACTIVITY: STRATEGIC AREAS (SA)

SA1 – THE STANDARD MODEL TO THE LIMITS

Our Institute works actively in the study of the Standard Model (SM) of particle physics, the best physics theory we currently have for explaining the microscopic reality. Our research plays a fundamental role in this broad field, which includes the search for new physics beyond the Standard Model (SM) using the LHCb experiment (SA1_LHCb), the study of the Quantum Chromodynamic (QCD) matter at extreme conditions (SA1_HQCD) and the investigations on string theory from both formal and applied points of view (SA1_STRI).

SA1_LHCb: Beyond the Standard Model with LHCb

The LHCb experiment completed very successfully its data taking in 2018 and the installation period of the Upgrade phase-I has already started in 2019. The upgraded detector will be able to read out all sub-detectors at 40 MHz and to select physics events of interest by means of a pure software trigger at the bunch crossing rate of the LHC. This capability will allow the experiment to collect data with high efficiency at a luminosity of 2×10^{33} \text{cm}^{-2}\text{s}^{-1}. Flavour-physics measurements will be performed with much higher precision than was possible with the previous detector, and across a wider range of observables. The flexibility inherent in the new trigger scheme will also allow the experiment to further diversify its physics programme into important areas beyond flavour.
The Upgrade was proposed in the Letter of Intent \(^3\) in 2011, and its main components and cost-envelope were defined in the Framework TDR\(^4\) one year later. Technical Design Reports (TDRs) have been written for all sub-detector systems as well as for the Software and Computing and the Computing Model and approved by the Research Board at CERN.

Researchers from the IGFAE are involved in the upgrade of the LHCb vertex sub-detector (VELO, Vertex Locator\(^5\)), and the high-level trigger (HLT) since 2008 and 2014 respectively. Concerning the VELO, considerable progress has been made this year. All the ancillary systems for this sub-detector are installed in the cavern, have been already commissioned, or are being commissioned at the time of the writing of this report. The production of the detector modules has started. The installation of this sub-detector was foreseen for May next year (see Figure 8).

![Figure 8. Artistic view of the VELO sub-detector, detail of the detector modules.](image)

For the vertex sub-detector (VELO) the researchers at the IGFAE completed a first version of the readout firmware, the FPGA clustering algorithms, and the Time and Fast Control system (TFC) for the back-end electronics. In addition, 320 High-speed data links were assembled and certified, along with 190 High Voltage cables produced and tested, and the assembly of the Optical Power Boards and the Feedthroughs (see Figure 9). Finally, integration tests were performed for the VELO readout chain and a complete VELO slice with cooling, RO electronics, LV and HV systems, and detector monitoring. Finally, researchers from IGFAE organised several

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Figure 9. Assembly of Optical Power Boards, production of High Voltage cables, High-Speed data links

One of the main characteristics of the LHCb upgrade is the full software trigger. The possibility of an HLT based on GPUs instead of CPUs can significantly improve the farm’s computing power per euro at any of the LHCb upgrade phases. IGFAE contributes to the development of VELO clusterization algorithms, muon identification algorithms, and track matching algorithms using GPU’s. The efforts in the trigger for strangeness decays for the LHCb upgrade progressed smoothly. A fully GPU-based implementation of the first level trigger for the upgrade of the LHCb detector, has been completed and published (Allen: A high level trigger on GPUs for LHCb) (arXiv:1912.09161v2, Computing and Software for Big Science 4, 7 (2020). Allen is the first complete high-throughput GPU trigger proposed for a HEP experiment.

Since 2018, the reconstruction and trigger tasks of LHCb are organized in a subdetector-like working group called Real Time Analysis (RTA). IGFAE became part of the Spanish commitment to RTA.

The year 2019 has been highly successful for the LHCb physics output, with 45 papers published in high impact journals (Nature Physics, Physical Review Letters, Journal of High Energy Physics, etc.) More than 504 scientific publications already published. According to the SCOPUS database, more than 95% of the articles have been published in “first decil” category journals.
The main physics analysis research lines at IGFAE are: measurement of observables sensitive to lepton universality violation in b-hadron decays, measurement of CP-violating observables in B decays, the study of rare decays of mesons with b and s quarks, dark matter searches, and measurement of observables in proton-lead collisions.

The publications below were entirely made or have significant contribution by IGFAE members at LHCb during 2019:

**Lepton Universality tests in B decays:**


**CP violating observables in B decays:**

- Study of the $B^0 \rightarrow \rho(770)^0 K^-(892)^0$ decay with an amplitude analysis of $B^0 \rightarrow (\pi^+\pi^-)(K^+\pi^-)$ decays, arXiv:1812.07008, JHEP05 (2019) 026.
- Amplitude analysis of the $B^0_{(s)} \rightarrow K^{-0}\bar{K}^{-0}$ decays and measurement of the branching fraction of the $B^0 \rightarrow K^{-0}\bar{K}^{-0}$ decay, arXiv:1905.06662, JHEP07 (2019) 032.

**Rare decays:**

- Strong constraints on the $K^0_s \rightarrow \mu^+\mu^-$ branching fraction, arXiv:2002.08229.

**Dark matter searches:**


**Proton-Lead collisions:**

- Nuclear Modification Factor of Charged Primary Particle Spectra in pPb/Ppb/pp Collisions at 5 TeV. In preparation.

In addition, the following PhD theses were brilliantly defended by IGFAE-LHCb students:

- Study of the $B^0 \rightarrow \rho(770)^0 K^-(892)^0$ decay with an amplitude analysis of $B^0_s \rightarrow (\pi^+\pi^-)(K^+\pi^-)$ decays. **Maria Vieites Diaz**, 27/03/2019. Now at EPFL.

New research initiatives are being started by Dr. Cid Vidal, for instance the experiment Codex-b. This is a proposed new experiment to be located in the LHCb cavern, providing sensitivity to long-lived particles (LLPs) that cannot be reconstructed by standard LHC detectors. This initiative has received one of the IGFAE Ignite projects.

Concerning **scientific management** the IGFAE researchers were very active during 2019. Dr. Cid Vidal has been involved in the management of different working groups beyond LHCb. In particular, he has been one of the coordinators of the WG of the BSM HL-LHC and is currently one of the coordinators of the WG of the DM LHC. Regarding the first, he was in charge of establishing the physical motivations for HL and HE-LHC in relation to direct searches. The second is responsible for coordinating the efforts of LHC collaborations and the theoretical community in physics related to dark matter searches. Apart from these two aspects, Dr. Cid Vidal has also participated in the LLP LHC working group, which coordinates the LHC’s efforts in the area of LLPs. Dr. Jeremy Dalseno is the convener of the BnoC working group at LHCb, dedicated to the study of B-meson decays to final particles with no net content in charm flavour.

Dr Antonio Romero finished in March 2019 his term as sub-convenor of the Semileptonic Tauonic decays. For the instrumentation part of the scientific project, Dr. Lemos Cid, is the VELO DAQ and firmware coordinator, and Prof. Gallas Torreira holds the position of the collaboration chair of the VELO project.

In regards the **organization of scientific conferences:**

• Organization of the sixth edition of the Topical Workshop on Electronics for Particle Physics (TWEPP), held in Santiago de Compostela between September 2 and 6, 2019. [https://igfae.usc.es/twepp2019/](https://igfae.usc.es/twepp2019/)

• During 2019 we were working on the organization of the 2020 edition of the Conference on Flavour Physics and CP Violation (FPCP 2020), that was held online due to the COVID-19 restrictions. [https://igfae.usc.es/igfae/fpcp2020/](https://igfae.usc.es/igfae/fpcp2020/)

Finally, the group was engaged with great dedication to **science dissemination tasks** during 2019, both giving talks and conferences in secondary and high school institutes and organizing specific events at the IGFAE’s premises. In this sense, the organization of the Summer Scientific Campus and the “Master Class” in particle physics for secondary school students stand out.
There is also an organized outreach activity within the framework of IGFAE, for which they were partly responsible.

**SA1_HQCD: Hot and dense QCD in the LHC era and beyond**

The study of the QCD matter at high temperatures and densities constitutes the main interest of the QCD phenomenology group at IGFAE. Under these extreme conditions, all hadronic matter is in a universal form, generically known as the Quark Gluon Plasma (QGP), which is also the state of the universe right after the Big Bang. The main goal of our research work is the characterisation of this new form of matter. To do so, we have continued our activities on different lines, which include heavy-ion collisions, high-energy QCD and the description of strongly interacting matter in effective models like Skyrme.

Some highlights during 2019 are the following:

Concerning the use of **hard probes as jet quenching and quarkonia** for characterising the QGP, they have been studied in:

- Jet quenching as a probe of the initial stages in heavy-ion collisions, Phys. Lett. B 803 (2020) 135318
- Jet quenching tests of the QCD Equation of State, arXiv:1911.01309

Central in this point is the proposed use of jet quenching to study the initial stages of a heavy ion collisions, which is the main topic of the ERC Advanced Grant “Yoctosecond Imaging of QCD collectivity using jet observables (YoctoLHC)” granted to Carlos Salgado.

We have also pursued the study of the **initial states** of the collision in the Color Glass Condensate effective theory for high energy QCD, in

Our group is also heavily involved in the elaboration of physics cases for future experiments. In particular, during 2019 the group has been involved in the elaboration of the Conceptual Design Report of the Future Circular Collider in Eur.Phys.J. C79 (2019) no.6, 474 (FCC-AA, FCC-ee, FCC-hh in Eur.Phys.J.ST 228 (2019) no 2, 4 and 5), on the study of the physics opportunities with fixed target experiments at the LHC (AFTER@LHC), and at the LHeC (Phys.Rev.D 100 (2019) 7, 074022). Moreover, there are still publications related to our ancient collaboration with ALICE experiment.

Néstor Armesto is member of the board of the LHeC and Elena G. Ferreiro is institutional board member from European institutions of the Electron Ion Collider.

Finally, the applications of the effective Skyrme model and its soliton solutions are developed in

- BPS soliton-impurity models and supersymmetry, JHEP 07 (2019) 164
- Solvable self-dual impurity models, JHEP 07 (2019) 150
- The $\phi^4$ model with the BPS preserving defect, JHEP 03 (2019) 131

As mentioned above, the members of this group have important roles in different activities, as the nomination of Elena Ferreiro as chair of the Governing Board of the Strong2020 consortium, where Carlos Salgado is member of the Executive Board and Nestor Armesto being leader of one of the Working Packages, or the ERC Advanced Grant “Yoctosecond Imaging of QCD collectivity using jet observables (YoctoLHC)” awarded in 2019 to Carlos Salgado.

**SA1_STRI: String theory and related fields**

Last but not least, the IGFAE theory group has performed research in more formal areas of particle physics, with a strong interest in String Theory. String Theory gives a fruitful framework to explore interesting problems in high-energy physics; most notably, putting together General Relativity and Quantum Mechanics in a consistent manner. One of its most robust ideas is the AdS/CFT correspondence, a holographic duality relating Quantum Field Theory with gravity in higher dimensions. It became by now a powerful tool to describe strongly coupled phenomena ranging from quantum field theories to lower dimensional condensed matter problems. A key aspect of this duality is the appearance of integrable structures. Furthermore, albeit less explored, the AdS/CFT correspondence can be used to understand space-time as an emergent concept and, in particular, to shed some light into a central problem in physics: how to go from General Relativity to Quantum Gravity. Our group is focused on these issues along three lines of
research:

**Holographic tools for strongly coupled quantum systems**

The group has a wide experience in the uses of the AdS/CFT correspondence to tackle strongly coupled quantum systems. We have studied in the past year the low-energy modes in anisotropic holographic fluids [Nucl. Phys. B940 (2019) 264], the flow of information in strongly coupled so-called ABJM theory [JHEP 1901 (2019) 232], the gravity dual of a multilayer system [JHEP 1903 (2019) 064], the geometry of supersymmetric probes in warped AdS6 [JHEP 1910 (2019) 021], the spin-2 excitations arising in Gaiotto-Maldacena conformal field theories [JHEP 1910 (2019) 231] and the introduction of holographic fundamental matter in multilayered media [JHEP 1912 (2019) 038].

We have also used holographic tools to deal with time dependent processes in strongly coupled systems, which are mapped to dynamical gravitational problems demanding numerical simulation. We investigated the case of gravitational wave driving of a gapped holographic system [JHEP 1905 (2019) 161] and that of the energy returns in global AdS4 [Phys. Rev. D100 (2019) 024008]. A broader family of confined (completely resonant) systems whose mildly non-linear wave dynamics was studied are the solvable cubic resonant systems [Commun. Math. Phys. 369 (2019) 433] and the complex plane representations and stationary states in cubic and quintic resonant systems [J. Phys. A52 (2019) 435201].

**Integrability in String Theory and the AdS/CFT correspondence**

The group is well recognised for its contributions in the application of integrability to the study of the AdS/CFT correspondence. Integrability was found in both sides of the AdS/CFT correspondence and provided new tools to investigate non-perturbatively the conjectured duality. The success of the methods provided by integrability in the AdS/CFT correspondence motivated substantial activity in exploring deformations of string sigma-models that preserve integrability, and in the development of new strategies to obtain exact results in those cases. We have studied in the past year the marginal deformations of WZW models and its relation to the classical Yang–Baxter equation [J. Phys. A52 (2019) 225401], the two-loop conformal invariance for Yang-Baxter deformed strings [arXiv:1910.02011] and the classical spectral curve of the AdS5×S5 lambda-deformed superstring [arXiv:1909.02618].

**From General Relativity to Quantum Gravity**

This line of research is younger than the other two and currently explores consistence conditions
on local Lorentz invariant gravity Lagrangians. We have studied in the past year the validity of T-duality equivalences beyond string theory by analysing the invariance of the temperature and entropy of black holes [JHEP 1905 (2019) 082]. While studying higher-curvature gravity actions we realized that there is a family with remarkable properties: (i) just gravitons in vacuum, (ii) non-hairy black holes and, most interestingly, (iii) a well-behaved cosmology with a mechanism of geometric inflation deserving further study. We were able to explore the all-orders case [arXiv:1812.11187] finding the possibility of cosmic inflation without the need of an inflaton field [Int. J. Mod. Phys. D28 (2019) 1944008].

SA2 – COSMIC PARTICLES AND FUNDAMENTAL PHYSICS

SA2_NEXT: Dark Matter and the nature of neutrinos

During 2019, the NEXT collaboration has successfully operated the NEXT detector at the Canfranc Underground Laboratorio in Spain. NEXT is an international collaboration mostly from Spain and USA and whose objective is the construction of the NEXT-100 detector. This detector will allow us to search for a hypothetical, very rare decay, a double-beta neutrino-less decay in 136Xe nuclei. In case this decay is realized in Nature, the neutrino will be its own antiparticle, a discovery that will have profound consequences for Particle Physics and Cosmology. NEW is a large prototype, half the size of NEXT-100 that has been successfully operated in 2019 with very small number of sparks and no leaks.

During 2019 we have taken long periods of data with enriched Xe what was exceptional in the past, i.e. to take a million of Kr events for calibration, has become now daily routine. We have taken data with external sources and estimated the energy resolution (better than 1% at the relevant energy range - JHEP 10 (2019) 230). We have measured that the signal can be discriminated with a 90% efficiency with respect to the background UHEP 10 (2019) 052, better than the expectations. We have also measured the radio-purity level of the detector UHEP 10 (2019) 051. In the last Scientific Committee of the Laboratory, in November, we have presented a new reconstruction of electron trajectories, based on image algorithms, which allow us to reduce the background by a factor 2 while keeping the same signal efficiency. We have performed the measurement of the half-live of the double beta decay with neutrinos of 136Xe, which demonstrated that we will be able to measure the hypothetical decay with no-neutrinos. These results will be published soon.

The goal of the collaboration has now switched to the commissioning of the NEXT-100 detector to be installed at Canfranc in 2020. The NEXT group in Santiago has had a crucial contribution in
the determination of the energy resolution and the half-life of the double-beta decay with neutrinos of 136Xe, and it is now participating in the studies of the performance of the future NEXT-100 detector.

R&D on gaseous detectors for Rare Event Searches and new lab

Year 2019 marked the start of the experimental activity at the new gaseous detector lab of IGFAE. The lab is equipped with several setups namely, ‘Nausicaa’ (Nuclei with A under Uranium Studied In a Chamber with Accurate A-discrimination) an Optical Time-Projection Chamber (OTPC) that serves as technological demonstrator for nuclear and neutrino physics experiments, and applied research, as well as two other systems (N0, N2) devoted to the characterization of new scintillating structures and mixtures, respectively, for next-generation OTPC-based experiments. Currently, these are devoted to R&D for NEXT and the DUNE near detector (‘IGNITE’ project of IGFAE).

The main technological/scientific milestones achieved in 2019 are: (A) First $\alpha$-tracks observed in Nausicaa-OTPC after equipping it with large-area FAT-GEMs coupled to a CMOS camera. (B) Proof of principle of two new amplification structures: (B1) FAT-GEMs (Field-Assisted Transparent Gas Electroluminescence Multipliers), rugged scintillating structures that can be easily tiled, designed at IGFAE for the NEXT experiment in collaboration with CERN workshops. Operation in high pressure Xe (10 bar) was demonstrated at an energy resolution below the NEXT goal (0.9% at $Q_{\beta\beta}=2.45$ MeV, FWHM) for an optical gain comparable to the one achieved in the experiment ($m = 100\, \text{ph/e/cm/bar}$) - see Fig. 2 & arXiv:1907.03292. (B2) LT-RPWell (Low-Temperature, Resistive Plate Well): this charge-multiplication structure is spark-protected through specially developed iron oxide ceramics that can withstand operation at the temperature of Liquid Xe (-108.1°C) (JINST 14 (2019) no.10, P10014). A gain slightly below $m=10^6$ was achieved at cryogenic conditions, demonstrating single-photon sensitivity (Fig.2-left). (C) Time-resolved study of broad-band scintillation of Xe/Ar under irradiation from $\alpha$-particles and $\beta$-electrons. There is still a large uncertainty on the primary scintillation yields of electrons (up to a factor of 4) and no measurements of charge recombination or scintillation outside the conventional VUV-band. We have designed a setup to address these goals. The data is in the final stage of the analysis with preliminary results on the P-dependence of the scintillation in the 250-400nm band - see Fig. 2. (D) Re-factorization of the industry-standard simulation code Magboltz, into Python (Pyboltz) in collaboration with Univ. of Texas Arlington, and the Magboltz developer (S. Biagi) (arXiv:1910.06983). This effort will be central to the simulation of the properties of next-generation OTPCs in forthcoming years.
As of today, the experimental efforts concentrate primarily on the development of new scintillating gas mixtures for the Near Detector of DUNE, in collaboration with Spanish, Portuguese, American and British Univs. with synergies with other R&D lines and experiments.

Figure 10. Photograph of one of the FAT-GEM samples and schematic drawing of the fabrication procedure.

Figure 12. Energy resolution vs reduced electric field across the structure, indicating the NEXT goal as a dashed line. The maximum field achieved (about 3kV/cm/bar at 10bar), limited by the setup and not the FAT-GEM itself, translates into an optical gain of around 500ph per electron, at the same level as the one achieved by the NEXT experiment with conventional meshes

Figure 11. Preliminary results of the ratio of 2nd to 3rd continuum (VUV/UV bands) as a function of pressured, measured for the first time for $\beta$-electrons in Xe.
The Pierre Auger Observatory located in Malargüe, Mendoza (Argentina) is the world’s largest ground-based air-shower array for the detection of Ultra-High-Energy (UHE) Cosmic Rays (CR) and UHE neutrinos with energies in excess of 1 EeV (1018 eV). The Astroparticle Physics group at IGFAE has been involved in the Observatory since its early years. In 2019, the Auger Collab. presented its latest results on the energy spectrum, composition, and arrival directions of the UHECR at the 36th International Cosmic Ray Conference in Madison, Wisconsin, USA. Also, and for the first time, the fluctuations in the number of muons in inclined air showers above 4 EeV have been obtained, a result in which IGFAE members participated directly. The search for UHE neutrinos with the surface detector stations of the Observatory, a direct responsibility of IGFAE members, was another key result. With Auger data we have obtained stringent upper limits to the neutrino flux [JCAP 10 (2019) 022] and shown that Auger has an unmatched sensitivity to sources of UHE neutrinos from a large fraction of the sky [JCAP 11 (2019) 004]. Auger is a key Observatory in MultiMessenger Astronomy (MMA) activities at UHE [Front. Astron. Space Sci. 6, 24 (2019) – a review paper also led by IGFAE members]. Regarding MMA activities, in 2019 IGFAE has exploited Auger data to search for UHE neutrinos in coincidence with the Gravitational Wave
(GW) candidate events detected in run O3 of LIGO and Virgo GW detectors. In Nov. 2019 about 300 scientists and guests from all over the world celebrated the 20th anniversary of the Pierre Auger Observatory with a ceremony and a scientific symposium in Argentina, where the potential of the upgraded AugerPrime Observatory, under deployment, and which will play a leading role in the field for the next decade was stressed.

In 2019 IGFAE’s Astroparticle Physics group has also been strongly involved on the planning and design of the Tau Airshower Mountain-Based Observatory (TAMBO) an array of particle detectors in a deep valley for the observation of the tau neutrino component of the astrophysical neutrino flux in the 1 – 100 PeV (Astro2020: Decadal Survey on Astronomy and Astrophysics, Bull. of the American Astron. Soc., 51, 7, 046 (2019)). IGFAE has also take part in the development of the Beamforming Elevated Array for Cosmic Neutrinos (BEACON), a mountain-based detector consisting on an antenna array viewing a large area of ground in the search for radiopulses from the decay of tau leptons induced by Earth-Skimming tau neutrinos (Astro2020: Decadal Survey on Astron. & Astrophys., Bull. of the American Astron. Soc., 51, 7, 191 (2019)). IGFAE members have also taken a leading role in ruling out the interpretation of the anomalous ANITA events as being produced in decays of tau leptons in the atmosphere (PRD 99, 063011, 2019), in strong tension with the absence of candidates in IceCube and Auger. IGFAE has also participated in the scientific review of the Radio Upgrade of the Pierre Auger Observatory that in 2019 became an integral part of the AugerPrime upgrade. This detector features a SALLA antenna on top of each Auger Cherenkov stations with the aim of detecting radio emission mainly from inclined showers that, in combination with the detection of the muonic component, provides information on composition of UHECR.
Lower-energy cosmic-ray detectors

The LabCAF group at IGFAE is involved in the TRASGO project, a new standard of cosmic-ray detectors with improved capabilities for monitoring, calibration and reconstruction. Three TRASGO detectors are operative and two more under development as part of the Stratos project, in collaboration with the Hydronav company: (1) Tragaldabas, running at the Univ. of Santiago de Compostela; (2) MuTT, devoted to industrial tomography of cargo containers using cosmic rays; (3) Tristan, designed to complement detectors that are part of the ORCA (Observatorio de Rayos Cósmicos Antártico), being installed in the Spanish Antarctica Juan Carlos I base in the Livingston island. These devices are devoted to activities in solar and space-weather physics, atmospheric effects on cosmic-rays, muon tomography, and the analysis of the short-range structure on the front-side of Extended Air Showers. During 2019 the monitoring, reconstruction and simulation tools of the Tragaldabas detector have been improved. Tristan gathered cosmic ray data in a two-way journey between Vigo (42ºN) in Spain, and Punta Arenas (53ºS) in Chile, under the effect of different atmospheric profiles and magnetic rigidity thresholds. Analysis of the data is being done.

During more than one month, Tristan has been taking data at the Univ. of Santiago in coincidence with Tragaldabas in order to cross-calibrate both detectors. In Nov. 2019 Tristan has been installed in the oceanographic vessel BIO HESPERIDES (see Fig.) and will take data in the trip between Spain and the Juan Carlos I base, where it will be installed as a station of the ORCA observatory. An array of 4 SALLA radio antennas has been installed on the roof of the Physics building, on top of the Tragaldabas detector to complement the measurements of bundles of particles belonging to high-energy extended air showers with the measurement of the radio pulse produced during the shower development. The calibration of the SALLA antennas has just started. A wide range of simulations have been performed to understand the response of the array to primary cosmic-ray showers of different energies, core positions and zenithal and azimuthal angles.
SA2_GRWA: Gravitational Wave Astronomy

The IGFAE Gravitational Wave (GW) Astronomy group was established in October 2018 with funds from IGFAE’s Maria de Maeztu award, currently with 5 members (group leader T. Dent, postdoctoral researcher G. Davies, FPI doctoral student V. Villa, faculty E. Zas and J. Alvarez). The group is a member of the LIGO collaboration, and thanks to this membership has access to data from the Virgo detector and will have access to KAGRA data when the detector is brought online in the near future. The main group research activity is analysis of data from the Advanced GW detector network, specifically the search for mergers of binary systems of black holes and neutron stars, and the interpretation of search results, including low latency followup of candidate events for possible high-energy neutrino emission, as well as study of the population properties of binary black hole mergers. The final LIGO-Virgo collaboration (LVC) binary merger search and population results from the second observing run, with significant contributions from the group leader (T. Dent), were released at the end of 2018 [Phys. Rev. X 9, 031040 (2019); Astrophys. J. Lett. 882, L24 (2019)]; a review article on LVC data analysis and noise properties appeared during 2019 with T. Dent as internal reviewer [arXiv:1908.11170].

The ongoing O3 observing run is the most sensitive to date to GW signals: unlike in previous runs, 3 detectors have been active from the beginning, with Virgo sensitivity a factor of a few below that of LIGO (see Figure). The IGFAE GW group has played a leading role in adapting and optimizing the PyCBC search pipeline for current multi-detector observations: this improved search has been demonstrated in a re-analysis of O2 open data [arXiv:1910.05331] which identified or confirmed several binary black hole mergers not previously published by LVC. Some aspects of the multi-detector search are, or will be deployed in LIGO-Virgo low-latency
public alerts for followup of GW candidates by electromagnetic observations (see https://gracedb.ligo.org/superevents/public/O3/).

The group has recently acquired hardware for a planned high throughput computing cluster: 1150 AMD cores have been delivered at a cost of 170,000 euros funded by Xunta de Galicia. The cluster will be used for production of final O3 observational results and subsequently for prototyping and testing of upgraded analyses for the upcoming O4 and future runs reaching the Advanced network design sensitivity, with up to hundreds of GW signals per year detected.

**SA3 - Nuclear Physics from the Lab to Improve People’s Health**

The strategy of the nuclear physics scientific area at IGFAE covers a broad spectrum of experimental activities from fundamental research, up to development of societal applications, namely in the field of human health. The implementation of this strategy is based on two research programs: the structure of the nuclear many-body systems and its astrophysical and cosmological implication and the exploitation of the Laser Laboratory for Accelerator and Applications.

During the reporting period:

- We have participated in 10 international conferences and workshops.
- We have contributed to 18 SCI publications.
- We are involved in the organization of the International Conference on Direct Reactions with Exotic Beams (DREB) 29 June to 3 July 2020 (https://indico.cern.ch/event/812362/) with an expected attendance of 150 people. Due to the Covid-19 crisis this event has been postponed to 2022.
• We won a bid to host the European Nuclear Physics Conference in 2021 EuNPC organized by the Nuclear Physics Board of the EPS with an expected attendance of 300 people.
• We have defended one PhD work and a two Master thesis. 6 PhD students have been working with us in 2019 in the different research programs (4 in RP 6 and 2 in RP 7). 4 new PhD positions and 2 post-docts will join the team along 2020 (2 PhD in RP6 and 2 PhD and 2 Postdocs in RP7)

In the following we present the scientific highlights of the activity performed in 2019.

**SA3_NUCL:** The structure of the nuclear many-body systems and its astrophysical and cosmological implications

IGFAE pursuies the study of the structure and dynamics of the nuclear many-body systems. Our activity concentrates on the following topics:

**Experiments at high energy facilities. Contribution to R3B/FAIR experiment**

In accordance with the IGFAE’s scientific strategy we have aligned our work with the worldwide largest Nuclear Physics Facility FAIR (https://fair-centre.eu/). We develop an outstanding scientific program based on the study of nuclear reactions induced by exotic projectiles at relativistic energies together with a relevant contribution to the instrumentation associated to the R3B experiment. R3B FAIR Phase 0 2019 experimental campaign was successfully conducted from February to May 2019. Engineering runs of FAIR Phase 0 2020 have been conducted along November and December 2019. They have been crucial to test all the new equipment installed in the R3B cave during this year.

The strategy of the R3B experimental campaign for 2019-21, the status of the on-going data sorting and the organization of the 2021 campaign was deeply discussed during our annual meetings (May and October 2019 in Darmstadt) with strong participation of the USC group.

We highlight the following activities:
• We are deeply engaged with the construction and exploitation of the CALIFA calorimeter for the R3B experiment. Major milestone has been achieved in 2019 with the installation of CALIFA in R3B FAIR (October-December 2019).

• We have participated in the design and construction of the silicon tracker prototype that has been installed in the target area for FAIR Phase 0 2020 experimental campaign (May-December 2019).

• We have been also working on the installation of the tracking gas detectors that will be used in the next R3B FAIR Phase 0 campaign (October-December 2019).

• P Cabanelas was awarded with one of the projects from the IGFAE internal call IGNITE (December 2019). His research project aims to translate the technology and knowledge acquired with CALIFA to societal applications, in particular the development of novel detector system for PET.

• We took part in the first R3B FAIR Phase 0 campaign conducted from February to May 2019.

• We are deeply committed with the preparation (physics definition, hardware and instrumentation and data analysis and simulation software development) of the R3B FAIR Phase 0 2020 experimental campaign (February –May 2020). As mentioned above and due to the Covid-19 crisis, this experimental campaign has not been 100% completed.

  o Development of software and simulation environment R3BRoot (Elisabeth Galiana PhD expected in February 2021).

  o Neuronal network algorithm developments for high –energy CALIFA event reconstruction (Gabriel García Master Thesis July 2019).

• We have a leading role (JB) in the quasi-free fission induced experimental campaign scheduled for April 2020. We have opened 2 PhD positions (confirmed in May 2020) to reinforce our participation in the R3B Physics program.
• We progress in the data sorting and interpretation of experiments performed within the past years (Juan M. Boillos PhD defended in May 2019 and Manuel Feijoo PhD expected in December 2021).

• We are in charge of the organisation of the International Conference on Direct Reactions with Exotic Beams (DREB) that was scheduled in Santiago from 29 of June to 3 of July 2020 (and finally postponed to the same date in 2022).

In this activity, we have published 6 papers and participated in several workshops and attended 5 conferences (D. Cortina got a plenary talk in the largest Nuclear Physics conference INPC2019) and doctoral schools. One student defended his PhD (JMB, May 2019), we have 2 other PhD on going, plus 2 new FPI PhD students (A. Graña and A. Bembibre) that will start in September 2020.

Experiments with stable and radioactive nuclei at low-energy facilities

The work in focuses mainly on fundamental studies of the structure and dynamics of the nuclei studied using active targets and fission. We highlight the activities leaded by IGFAE

• We have submitted (B. Fernández) a Letter of Intent to the Experiments Evaluation Committee to take ACTAR TPC to the TRIUMF laboratory (Canada) in July 2019 and an experiment aiming at studying shell effects at the edge of the proton drip-line with ACTAR TPC was approved.

• A proposal to study the spin-orbit origin of the Z=6 shell gap in neutron-rich carbon isotopes with ACTAR TPC (BF) was accepted by the Programme Advisory Committee from GANIL (France). This is part of the PhD work of J. Lois and D. Regueira.

• We have published a NIM paper summarising the simulated response of the ACTAR TPC device performed with the ACTARSim framework.
• We have submitted a Letter of Intent with AT-TPC (American partner on active targets) to perform the spectroscopy of nuclei at the proton drip line using radioactive beams from the newly develop facility FRIB.

• We are in charge of the coordination of the current fission experimental campaign at VAMOS/GANIL (MC) and we have published our results in Phys. Rev Letters and Phys. Rev. C

• We are on charge of the coordination of the current fission experimental campaign at VAMOS/GANIL (MC)

• We have established a new collaboration with LNL-IFN (Legnaro) to widen the possibilities for fission studies and the connections to other setups. A new experimental proposal “Fusion-fission and quasi-fission at PRISMA with a 208Pb beam” (Spokespersons: M. Caamano (USC), D. Ramos (GANIL), A. Gottardo (LNL), J.J. Valiente-Dobon (LNL)) endorsed by the LNL Physics Advisory Committee in March 2019.

• We have started the design and construction of a new fission chamber to be used in the n_TOF facilities at CERN. The construction is being done in collaboration with the Cima group at the University of Vigo.

In this activity, we have published 12 papers (3 as first authors in NIMA, Phys. Rev.C and Phys. Rev. Letters) and attended 5 international conferences Nuclear Data 2019 (China), HIAS (Australia), Nuclear Structure and Dynamics (Italy), Gordon Conference (US) and INPC2019 (UK). We have at this moment 4 PhD works on going.

SA3_LACC: Exploitation of the Laser Laboratory for Accelerator and Applications

The scientific program led by IGFAE at the Laser Laboratory for Acceleration and Applications (L2A2) focuses on the development of technologies related to laser-particle acceleration and their used in medical applications. In particular we are working in two initiatives: new laser-driven X-ray sources to develop advanced imaging techniques (LaseX), and the laser-driven production of radioisotopes for PET imaging (LaserPET). The main achievements in these two projects along 2019 are the following:
LaseX

We summarise 2019 highlights for the L2A2 laser induced x-ray source

- Collaboration with the Universidad Complutense established with the goal of improving the image quality of the X-ray source.

- The company Sedecal S.L got interested on the IGFAE Lasser induced X-ray source. A common research program to apply this technology to medical imaging was submitted to the Retos Colabora program call (October 2019 and approved in June 2020 – a new PhD work will be partially covered with these funds).

LaserPET

The main scientific achievements in 2019 in the L2A2 proton source and LaserPet experiment are:

- Successful production of 1.5 MeV protons in continuous multi-shot mode achieved (May 2019)

- The Technical design of novel a Plasma-mirror to improve the proton production for the ELI-ALPS international facility was approved by February 2019 and the construction is presently in progress.

- A collaboration with the I3M (Instituto de Instrumentación para Imagen Médica) del CSIC-UPValencia and IDICHUS was established to investigate the use of laser-accelerated ions in radio therapy. This research program was granted in the Retos Investigación call 2019.

- A collaboration with the University of Sevilla and the Centro Nacional de Aceleradores
(CAN) was established to investigate the use of laser induced neutron sources.

- A new beam-line for ion- acceleration granted in the Research Infrastructure call.
- We had an important number of long stay visitors attracted by the use of L2A2 facility.
  - Universidad Autónoma de México: Ramiro Contreras and Jesús Delgado
  - Universidad Politécnica de Valencia: Michael Seimetz
  - Universidad de Salamanca: Camilo Ruiz
  - Universidad de Sevilla: Carlos Guerrero y Mª Ángeles Millán
  - Liverpool University: Natasha Khan

In this activity, we have published 1 paper, 2 more are submitted. We have contributed to 3 International Conferences. Two PhD works are on-going (LM and JP). An FPI contract for a new PhD student (A. Bembibre) was recently approved (June 2020) and another PhD (A. Coathup) student will be partially funded with the Retos research project approved also in June 2020. We also succeed in the attraction of young talent: a new postdoc (R. Contreras) funded with an IGFAE internal call and another one funded with the prestigious La Caixa Junior Leadership postdoctoral program (A. Alejo) will join our team along 2020, reinforcing existing research lines and surely opening new research activities.

Despite this intensive and successful program, the operation of the laser facility along 2019 has been rather unstable. A couple of technical failures together with an un-efficient management of the L2A2 facility has resulted in around 6 months operation of the low energy laser beam for the X-ray source but only one week for the high-energy proton source, compromising seriously the future of all the research program above described.

**HORIZONTAL LINE: STRATEGIES FOR NEW FACILITIES**

2019 was an important year for the strategic decisions at IGFAE, both with respect to the global strategies in Particle Physics and for decisions taken at the level of the Institute.

On the global side, 2019 was a crucial year for the European Strategy for Particle Physics Update, launched by CERN in 2017 and that resulted in a decision and final document that has been endorsed by the CERN Council (where all CERN members states are represented and vote) in
June 2020. This new strategy document is intended to guide European actions on Particle Physics for the period 2020-2027 and will greatly constrain the world-wide agenda. A key item was the Town Meeting in Granada in May 2019, where numerous discussions took place. Members of IGFAE (Néstor Armesto) contributed to the discussion at a scientific level and are authors of the corresponding Briefing Book. The main outcomes of the conference were: (i) the lack of theoretical guidance on where new physics can be manifested calls for a wide physics search programme; (ii) the technical requirement of strong R&D on high-field superconducting magnets for hadronic colliders, with the goal of 16 T magnets requiring at least 25 years; (iii) the different electron-positron colliders were analysed with no clear conclusions of the cost-benefit analyses due to the possibilities that they can be built in Asia.

Five scenarios have been proposed that involve different options and extend to 2090. Due to this lack of clear conclusions, IGFAE has decided to keep the efforts on Particle Physics concentrated on the upgrades of the existing LHC at CERN while waiting for the next one-two years before making decisions to explore other possibilities for the future.

On the local side, the IGNITE program supported by Maria de Maeztu funds, was launched to support three actions (led by Diego González, Xabier Cid and Pablo Cabanelas respectively) with around 100,000 EUR each. First, we decided to explore the possibilities for entering a large neutrino experiment in the USA, DUNE, collaborating on the development of gaseous subdetectors for the Near Detector. Pending the national decision to enter DUNE, this action would allow to join the experiment with a participation on hardware. The second IGNITE action went to join an experiment at the LHC linked to LHCb were IGFAE has already a strong participation. This new small experiment, CODEX-b, will search for new physics beyond the standard model with long-lived particles. Finally, the third action is focused on the development of detectors for PET.
SCIENCE & SOCIETY

Communication and scientific dissemination are one of our priorities since the foundation of the institute. One of our main objectives is to foster STEM careers (in science, technology, engineering, and mathematics) among students, obviously focusing on Physics, as well as to return to society the knowledge generated in our scientific activity, largely financed by public funding.

Following the path of previous years, the outreach activities in which the IGFAE research staff participated increased and diversified, using all available channels to reach society. In 2019 we organized or participated in more than 80 activities, with an estimated direct audience of 4000 people. Apart from talks in schools, high schools and universities, some other highlighted events were the first edition of ArtLAB with the exhibition Cosmoloxías; the 2nd Science Week - including the first Open Day Ciencia Singular; the USC Innovation Faire; and the Summer Fellowships.

Facts & Figures:

- Nearly 100 impacts in media.
- 200 new followers and 153 tweets in 2019.
- 94 new items in our website.
- New LinkedIn account.
- More than 80 outreach activities.
Outreach Activity

International Masterclass in Particle Physics (LHICMC19)

On April 5, IGFAE hosted a Masterclass in Particle Physics, inviting around 60 Galician high school students to participate. The students took a day off from school to analyse data of the CMS experiment at the Large Hadron Collider (LHC) under the supervision of IGFAE scientists. At the end of the day, the students discussed the obtained results in a video conference with Fermilab, USA, and the other participating institutes from around the world, giving the experience of working in an international collaboration, which is part of CERN’s everyday life.

The Masterclass at IGFAE is part of an annual program called International Masterclasses. Scientists at about 210 universities and laboratories host Masterclasses at their home institutions. The Masterclasses this year are organized from February to April in more than 50 countries worldwide.

Scientific Summer Campus (FECYT)

Every year in July, members of the Department of Particle Physics of the University of Santiago de Compostela (USC) and the Galician Institute of High Energy Physics (IGFAE) participate in the Summer Scientific Campus through the program “A Ponte entre o Ensino Medio a USC”. The campus is organized by the Spanish Foundation for Science and Technology (FECYT) and the Ministry of Education, Culture and Sports, with the support of the Obra Social “la Caixa”.

The purpose of this program is to promote the interest of students in 4th year of secondary school and 1st year of Bachillerato in Spain for science, technology and innovation, and
encourage access to scientific-technical qualifications. The project presented is “Looking for the particles produced in the greatest accelerator in history”, aimed to put students in contact with the science developed at the Large Hadron Collider (LHC) at CERN, the largest particle accelerator in the world. In the campus, 32 students carry out tasks like those of the scientists working in the LHC experiments: particle detection, data collection and analysis or interpretation and presentation of results.

**Summer Fellowships**

IGFAE launched the 1st edition of the Summer Fellowships for research initiation, offering 10 grants (2 for no-STEM studies) aimed at undergraduate students interested in having their first research experience. Applicants enjoyed a hands-on extracurricular internship and were assigned a research project belonging to one of the research fields of the IGFAE under the supervision of a senior researcher. The students gained knowledge and know-how in the thematic area and had the opportunity to assist to all scientific and the educational activities offered in the centre.

**2nd Science Week 2019: Particle Accelerators**

IGFAE organized its 2nd Science Week (Semana da Ciencia) from 11th to 16th November 2019. From Monday to Saturday various outreach and educational events took place in Santiago de Compostela, including the first open day “Ciencia Singular” jointly organized among the 4 Singular Research Centres of the USC (CiTIUS, CiQUS, CiMUS and IGFAE). This year the topic was particle accelerators since it is the 90 anniversaries of the first cyclotron developed by Ernest Lawrence.
Conference

Monday 11th: public conference *The Large Hadron Collider: a marvel of technology* by Lyn Evans, former LHC-project leader at CERN. More than 300 people attended the event at Auditorio ABANCA, in Santiago de Compostela.

Tuesday 12th: public conference *Physics in concert with the arts* by Ágnes Mócsy, at the Centro Galego de Arte Contemporánea (CGAC). Around 80 people participated. [see ArtLab section](#).

Wednesday 13th: *Accelerated NerdNite* at Nave de Vidán, an informal gathering to learn and discuss on particle accelerators in a short talk format and relaxed atmosphere. Four IGFAE researchers gave talks to an audience of 100 people who filled to room.

Thursday 14th: award ceremony of the 2nd IGFAE Science Communication Contest at the Faculty of Physics. The contest is composed of three categories: scientific monologues (1 participant); experiments, demonstrators, web or app (3 participants); and outreach article (9 participants).

Friday 15th: colloquium

Minorities in Science: friendly conversations about equity and inclusion over wine and beer by Ágnes Mócsy [see Gender Group section](#).

Saturday 16th: IGFAE opened its doors to the citizenship of Santiago de Compostela in its first open day *Ciencia Singular*. More than 120 (85 adults and 42 children) visited the Institute from 10:00 to 20:00 in 4 slots filled with outreach talks, demonstrators, tours to the Laser Laboratory for Acceleration and Applications (L2A2), and educative workshops for kids.
Figure 30. Poster of the Open Days "Ciencia Singular".

Figure 31. Workshops and talks during the Open Days "Ciencia Singular".
Gender Working Group

Masterclass "Day of Women and Girls in Science"

At IGFAE, we believe it is essential to promote the full and equitable access and participation of all people in science. Moved by this same principle, on February 11, 2019 we joined the “International Day of Women and Girls in Science”, proclaimed by the General Assembly of the United Nations (UN). We organized a Masterclass aimed at high school students, born as a result of the IGFAE’s collaboration with the “International Physics Dissemination Group” (promoters of the initiative) and CERN (European Organization for Nuclear Research). During the day, around 50 females students of the SEK International School in Poio (Pontevedra) got closer to the work of the researchers of the institute, a series of introductory talks on particle physics were given and a practical exercise was carried out with real data from CERN, whose results were discussed by videoconference with CERN and other European centres.

Minorities in Science: friendly conversations about equity and inclusion

On Friday 15th, Ágnes Mócsy, theoretical physicist at Pratt Institute (NY), filmmaker and communicator, gave a talk at O Besbello – Bar cultural in the oldtown of Santiago de Compostela. It was an engaging and respectful a conversation about implicit bias, identity threat, meritocracy, and gender, facilitating inquiry and self-expression, while also demonstrating conscientiousness in understanding how others’ viewpoints and experience may be different from our own.
Activity of the “Labs”

Labs are the tools we are developing to improve our Responsible Research and Innovation strategy. These new structures, still in the process to be designed and implemented, try to gather in the same space for dialog IGFAE researchers with external stakeholders. We are planning for three of these Labs, some of which with some activity already in 2019.

ArtLAB:

The first of these spaces is ArtLAB, created in March 2019. This ambitious programme aims to push forward and explore the boundaries between art and science, physics, inviting artists whose work can promote discussion and reach the general public in a different, creative way.

“Cosmoloxías”

The first initiative of ArtLAB was Irene Dubrosky’s exhibition “Cosmoloxías”, a series of cartographic works inspired by the Universe which evoke the real maps that try to explain its origin. The exhibition, that took place in the oldtown of Santiago de Compostela for two weeks, made the headlines of the local media such as La Voz de Galicia, GCiencia o Compostela24horas.

The first edition of ArtLAB also included a colloquium between the audience and renowned representatives of both sides: Agustín Fernández Mallo (writer), José Edelstein (physicist and writer), Elena Vázquez Cendón (Dean of Mathematics at the University of Santiago), Uxía (one of
the most relevant singers in Galicia), David Crooks (painter and physicist), Ainhoa Apestegui (journalist) and Irene Dubrovsky (visual artist). The 2nd edition of ArtLAB is expected for late 2020.

Figure 36. Irene Dubrovsky (left) and colloquium between artist and scientists (right).

Conference Physics in concert with the arts

Ágnes Mócsy gave a public talk at the Centro Galego de Arte Contemporânea (CGAC) on Tuesday 12th, November 2019. She explored the complex and sometimes unexpected relationship that physics and arts share to find opportunities for new and richer narrative forms about science, as well as unconventional educational approaches.

Figure 37. Ágnes Mócsy, Santiago Olmo (Director of CGAC) and Carlos Salgado.

EduLab

We are currently working on teacher training and content updating in secondary schools. Another example, the Stembach Program is oriented to encourage a vocation in Science and Technology: an extra non-curricular student subject with specific topics, and development of a research project with a tutor. The tutoring is shared between a professor from the secondary school and a professor from the University. During 2019 we have also helped in the design and organization of a training course in Particle Physics through the official center for teachers’ training CAFI.
TechLab

TechLAB, the third laboratory to transfer part of our scientific-technological activity to the public. During 2019:

Workshop: From the lab to improve people’s health

It was held during the 45th Annual meeting of the Spanish Nuclear Society (SNE) in 23-28 September in Vigo. On Wednesday 25, IGFAE researchers Manuel Feijoo, Xabier García and Juan Peñas organized the workshop *From the lab to improve people’s health*. The objective was to show the participants, both from science and company sector, how nuclear physics could be useful to produce PET radioisotopes for medical purposes using a laser instead of conventional accelerators. The workshop was complemented with some practical demonstrations of some targeting techniques, micrometric positioning or image reconstruction that are used as auxiliaries in this area of research of the Institute.

Other activities

USC Innovation Faire

On November 27 and 28, IGFAE participated in the 2nd edition of the USC Innovation Faire ad Cidade da Cultura, a university recruitment event aimed at Bachillerato students. The first day, IGFAE researcher Néstor Armesto gave the talk *Dos fundamentos ás aplicacións: para qué sirve a Física de Partículas?* to an audience of around 100 students. The second day, Pablo Baladrón, Alexandre Brea, Adrián Casais and Miguel Ramos deployed the experiment *As cores da luz: análise de espectros atómicos* to explain the quantum nature of matter using a mercury lamp and a diffraction grating.
Public talks

Gabriela González: Einstein, buratos negros e ondas gravitacionais

In 8 March 2019, coinciding with the International Women’s Day, the astrophysicist and former spokesperson of LIGO collaboration, Gabriela González, gave the public talk *Einstein, buratos negros e ondas gravitacionais* at the Faculty of Communication Sciences of the USC. Gabriela was one of four LIGO scientists present for the announcement that the first direct gravitational wave observation had been detected in September 2015.

José Edelstein: Stephen Hawking, in memoriam

IGFAE researcher José Edelstein gave the public conference *Stephen Hawking, in memoriam*, one year after the death of one of the most brilliant scientists in history. It was held at the Faculty of Physics of the USC.

José Edelstein: a cen anos da eclipse na que Einstein ensombreceu a Newton

On the occasion of the centenary of the total solar eclipse in which was verified one of the predictions of Albert Einstein’s General Theory of Relativity for the first time, IGFAE researcher José Edelstein gave a public talk in 29 May at the ABANCA Obra Social Centre (Plaza de Cervantes) in Santiago de Compostela.

Bernard Schutz: How gravitational waves made human evolution possible?
Within the framework of the 9th Iberian gravitational Waves Meeting (IGWM2019) organized by IGFAE in June in Santiago de Compostela, the Director Emeritus of the Max-Planck Institute for Gravitational Physics – Albert Einstein Institute and professor at the University of Cardiff, Bernard F. Schutz, gave the public talk *How gravitational waves made human evolution possible?* on June 3rd, in the Aula Magna of the Faculty of Physics of the USC.

**EDITIONS**

*Unha breve historia do tempo*

In February, the best-seller *A brief history of time* by Stephen Hawking was included in Clásicos do Pensamento Universal, a collection jointly published by USC and the BBVA Foundation since 2002. The professors of the Faculty of Physics José Edelstein and Jorge Mira, the latter also as translator, prologued the translation into Galician.

*Ciencia y un gran paso para la humanidad*

The book *Ciencia y un gran paso para la humanidad* (2019) discovers the Spanish contribution to the Conquest of the Moon as well as other scientific “great steps”. The book consists of twenty-eight chapters written by reputed scientists, who under the premise of “great steps for humanity” draw us a very interesting historical-scientific panorama. IGFAE researcher Bernardo Adeva wrote the chapter *El LHC: acelerador de partículas, acelerador del conocimiento*. It is available under a Creative Commons license.

**IMPACT IN MEDIA AND SOCIAL NETWORKS**

In 2019, our presence in the media, either online or in print, was continuous. Some milestones helped to achieve a greater audience: the ERC Advanced Grant to Carlos Salgado, the
appointment of Elena G. Ferreiro as chair of the governing board of STRONG-2020, the installation of the CALIFA detector at FAIR, diverse piece of news related to gravitational waves and the Open Day Ciencia Singular. IGFAE activities and new items caught the attention of several radio and television programs and made the headlines in the leading media more than 90 times.

Figure 43. Some newspaper covers and pieces of news in media websites.
## Annex 1: Personnel IGFAE

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<td>Xuna</td>
<td>John</td>
<td>Students</td>
<td>Outros</td>
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<td>Zas Arregui</td>
<td>Enrique</td>
<td>Scientific staff</td>
<td>Catedrático de Universidade</td>
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## ANNEX 2: ONGOING PROJECTS

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<th>TITLE</th>
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<tr>
<td>Convenio de colaboración entre a conselleria de cultura, educación e ordenación universitaria e a universidade de santiago de compostela e a universidade de vigo para completar as axudas ao persoal investigador principal no programa starting grants.</td>
<td>Martínez Santos, D.</td>
<td>Xunta de Galicia</td>
<td>1/1/2016</td>
<td>12/31/2019</td>
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<tr>
<td>Búsquedas de nueva Física con el experimento mejorado LHCb del CERN. EXCELENCIA 2017</td>
<td>Gallas Torreira, A.</td>
<td>AEI</td>
<td>1/1/2018</td>
<td>12/31/2020</td>
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<td>Vázquez P.</td>
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<td>Equipo de espectroscopia gamma de alta resolución para la determinación radiológica de muestras ambientales sólidas</td>
<td>Salgado López, C.</td>
<td>AEI</td>
<td>1/1/2018</td>
<td>12/31/2019</td>
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<tr>
<td>Laboratorio de microelectrónica para instrumentación en física de partículas y astrofísica</td>
<td>Salgado López, C.</td>
<td>AEI</td>
<td>1/1/2018</td>
<td>12/31/2019</td>
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<tr>
<td>Taller mecánico de alta precisión para desarrollo yfabricación de instrumentación del igfae</td>
<td>Salgado López, C.</td>
<td>AEI</td>
<td>1/1/2018</td>
<td>12/31/2020</td>
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<tr>
<td>Estacion terrestre para monitorizacion continua de la temperatura de la estratosfera mediante la medida de flujo direccional de rayos cosmicos (stratos) ] conecta pemere 2018</td>
<td>Garzón Heydt, J.P.</td>
<td>DIGAFER, S.A.</td>
<td>10/1/2018</td>
<td>9/30/2021</td>
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<td>Acuerdo confidencialidad “posible acción comercial y posterior estudio técnico consistente en el análisis de la normativa aplicable apotenciales actividades comerciales e industriales de senra”</td>
<td>Cortina Gil, Mª D.</td>
<td>ESTAÑOS Y SOLDADURAS SENRA</td>
<td>4/11/2019</td>
<td>8/31/2022</td>
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<td>Acuerdo confidencialidad “posible acción comercial y posterior estudio técnico consistente en el análisis de la normativa aplicable apotenciales actividades comerciales e industriales de senra”</td>
<td>Cortina Gil, Mª D.</td>
<td>CINDEGAL</td>
<td>4/11/2019</td>
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<td>Plasma mirrors for high-power high-repetition rate laser pulses</td>
<td>Benlliure Anaya, J.F.</td>
<td>ELI-HU NON-PROFIT LTD</td>
<td>12/1/2017</td>
<td>5/1/2021</td>
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<td>Convenio de colaboración entre gain e universidades para fomento actividade investigadora do persoal universitario beneficiario do erc</td>
<td>Salgado López, C.</td>
<td>AXENCIA GALEGA DE INNOVACION (GAIN)</td>
<td>1/1/2019</td>
<td>12/31/2020</td>
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<tr>
<td>Becas de doctorado inphinit para estudios de doctorado en centros de investigación españoles de excelencia.</td>
<td>Salgado López, C.</td>
<td>FUNDACION BANCARIA LA CAIXA</td>
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<td>Bolsas de verán 2019 igfae.</td>
<td>Salgado López, C.</td>
<td>Xunta de Galicia</td>
<td>1/1/2019</td>
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<tr>
<td>Consolidación e estruturación 2017 gpc gi-1493 grupo experimental de núcleos e partículas (genp)</td>
<td>Benlliure Anaya, J.F.</td>
<td>Xunta de Galicia</td>
<td>1/1/2017</td>
<td>12/31/2020</td>
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<tr>
<td>Consolidación e estruturación 2017 gpc gi-2039 teoría e fenomenología de partículas, astropartículas, campos e cordas (teofpacc)</td>
<td>Miramontes Antas, J.L.</td>
<td>Xunta de Galicia</td>
<td>1/1/2017</td>
<td>12/31/2020</td>
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<td>Consolidación e estruturación 2017 modalidade d (excelencia)</td>
<td>Salgado López, C.</td>
<td>Xunta de Galicia</td>
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<td>Consolidación e estruturación 2017 modalidade d (excelencia)</td>
<td>Gónzalez Díaz, D.</td>
<td>Xunta de Galicia</td>
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<td>12/31/2021</td>
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<td>Consolidación e estruturación 2018 gpc gi-2070 física corpuscular e aplicaciones (fica)</td>
<td>Fernandez Dominguez, B.</td>
<td>Xunta de Galicia</td>
<td>1/1/2019</td>
<td>12/31/2020</td>
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<tr>
<td>Consolidación e estruturación 2018 gpc gi-1490 grupo de física de altas enerxías (gaes)</td>
<td>Saborido Silva, J.J.</td>
<td>Xunta de Galicia</td>
<td>1/1/2019</td>
<td>12/31/2021</td>
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<tr>
<td>Novos enfoques na procura de física alén do modelo estándar co-experimento LHC - modalidade c. Proxectos de excelencia - consolidación e estruturación 2018</td>
<td>Cid Vidal, X.</td>
<td>Xunta de Galicia</td>
<td>1/1/2018</td>
<td>12/31/2022</td>
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<tr>
<td>Axudas para a acreditación, estruturación e mellora de centros de investigación do sug</td>
<td></td>
<td>Xunta de Galicia</td>
<td>12/1/2019</td>
<td>10/30/2022</td>
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<tr>
<td>European nuclear science and application research 2 (ensar2)</td>
<td>Alvarez Pol, H.</td>
<td>EUROPEAN COMMISSION</td>
<td>3/1/2016</td>
<td>8/31/2020</td>
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<td>Heavy ion collisions: collectivity and precision in saturation physics (hiheic)</td>
<td>Armesto Pérez, N.</td>
<td>EUROPEAN COMMISSION</td>
<td>6/1/2019</td>
<td>5/31/2023</td>
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<tr>
<td>Supplying accurate nuclear data for energy and non-energy applications (sanda)</td>
<td>Benlliure Anaya, J.F.</td>
<td>EUROPEAN COMMISSION</td>
<td>9/1/2019</td>
<td>8/31/2023</td>
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<td>The strong interaction at the frontier of knowledge: fundamental research and applications (strong-2020)</td>
<td>González Ferreiro, E.</td>
<td>EUROPEAN COMMISSION</td>
<td>6/1/2019</td>
<td>5/31/2023</td>
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<td>Yoctosecond imaging of QCD collectivity using jet observables (yoctolhc)</td>
<td>Salgado López, C.</td>
<td>EUROPEAN COMMISSION</td>
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<td>9/30/2024</td>
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<tr>
<td>Análisis de las partículas más energéticas de la naturaleza: el observatorio pierre auger. Excelencia 2017</td>
<td>Zas Arregui, E.</td>
<td>AEI</td>
<td>1/1/2018</td>
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<td>Búsqueda de nueva física con el experimento mejorado lhcb del cern. Excelencia 2017</td>
<td>Martinez Santos, D.</td>
<td>AEI</td>
<td>1/1/2018</td>
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<td>Calibración, veto de muones y offline en next (calmu) - retos 2018</td>
<td>Hernando Morata, J.A.</td>
<td>AEI</td>
<td>1/1/2019</td>
<td>12/31/2021</td>
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<td>Datos nucleares para estructura y dinámica nuclear - generación del conocimiento 2018</td>
<td>Fernandez Dominguez, B.</td>
<td>AEI</td>
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<td>12/31/2021</td>
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<td>Deseño, construcción e posta a punto dun sensor baseado en tecnoloxía de si para o seu emprego como monitor radón, en colaboración co cmn-csic, no marco da actividade de investigación 2016-pn011, co título: ‘desarrollo de un sistema de control automático</td>
<td>Cortina Gil, Mª D.</td>
<td>AEI</td>
<td>3/7/2016</td>
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<td>Estudios de canales de integraciones raras de partículas conteniendo un quark s con datos de lhcb</td>
<td>Chobanova, V.</td>
<td>AEI</td>
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<td>Explorando sectores oscuros en lhcb - europa investigación 2019</td>
<td>Cid Vidal, X.</td>
<td>AEI</td>
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<td>Holografía, gravitación y teorías gauge. Excelencia 2017</td>
<td>Miramontes Antas, J.L.</td>
<td>AEI</td>
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<td>Puesta en marcha y primeros experimentos en r3b - generación del conocimiento 2018</td>
<td>Cortina Gil, Mª D.</td>
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<td>Ocdd a alta temperatura y densidad desde escalas pequeñas a grandes. Excelencia 2017</td>
<td>Salgado López, C.</td>
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<td>Refuerzo del papel lhcb como uno de los principales experimentos actuales en física de partículas. Trabajo en el área de machine learning. Realización de actividades de docencia y divulgación.</td>
<td>Cid Vidal, X.</td>
<td>AEI</td>
<td>1/1/2018</td>
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<td>Study of the structure of exotic nuclei</td>
<td>Fernandez Dominguez, B.</td>
<td>USC</td>
<td>7/30/2019</td>
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<td>Servizo de medida de radón e outros parámetros radiactivos en mostras ambientais</td>
<td>Cortina Gil, Mª D.</td>
<td>QUIRON PREVENCIÓN SL</td>
<td>1/1/2016</td>
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<td>Servizo de medida de radón e outros parámetros radiactivos en mostras ambientais</td>
<td>Cortina Gil, Mª D.</td>
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<td>Servizo de medida de radón e outros parámetros radiactivos en mostras ambientais</td>
<td>Cortina Gil, Mª D.</td>
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<td>Servizo de medida de radón e outros parámetros radiactivos en mostras ambientais</td>
<td>Cortina Gil, Mª D.</td>
<td>BIOTECNICAS APLICADAS, S.L.</td>
<td>1/1/2016</td>
<td>12/31/2020</td>
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<td>Programa científico do instituto galego de física de altas enerxias igfai. Contrato programa igfai</td>
<td>Salgado López, C.</td>
<td>USC</td>
<td>1/1/2019</td>
<td>12/31/2019</td>
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<td>Unidades de excelencia &quot;maría de maeztu&quot;</td>
<td>Salgado López, C.</td>
<td>AEI</td>
<td>1/7/2017</td>
<td>30/06/2021</td>
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</table>
ANNEX 3: PUBLICATIONS

1. **Title:** Validation of the radiation shielding for the Laser Laboratory for Acceleration and Applications
   Authors: Benlliure J., Cortina-Gil D., Llerena J.J., Ruiz C.
   IGFAE Authors: Benlliure, J.; Cortina-Gil, D.
   Research Program: SA3_NUCL, SA3_LACC
   DOI: 10.1016/j.nima.2018.10.217

2. **Title:** Observation of Two Resonances in the \( \Lambda b_0 \pi^\pm \) Systems and Precise Measurement of \( \Sigma^+_b \) and \( \Sigma^{*_b}_+ \) Properties
   Authors: Aaij, R. et al.
   Research Program: SA1_LHC
   DOI: 10.1103/PhysRevLett.122.012001

3. **Title:** Measurement of the Charm-Mixing Parameter \( \gamma_{CP} \)
   Authors: Aaij, R. et al.
   Research Program: SA1_LHC
   DOI: 10.1103/PhysRevLett.122.011802

4. **Title:** Electroluminescence TPCs at the thermal diffusion limit
   Authors: Henriques, C.A.O. et al.
   IGFAE Authors: Gonzalez-Díaz, D.; Hernando Morata, J.A.; Martinez-Lema, G.; Palmeiro, B.
   Reference: JHEP 1(2019)27
   Research Program: SA2_NEXT
   DOI: 10.1007/JHEP01(2019)027

5. **Title:** Properties of the CsI(Tl) detector elements of the CALIFA detector
   Authors: Kniazev, A. et al.
   IGFAE Authors: Alvarez-Pol, H.; Cabanelas, P.; Cortina-Gil, D.; Feijoo, M.; Galiana, E.
   Research Program: SA3_NUCL, SA3_LACC
   DOI: 10.1016/j.nima.2019.06.045

6. **Title:** Commissioning of the ACtive TARget and Time Projection Chamber (ACTARTPC)
   Authors: Mauss, B. et al.

---

6 This appendix includes articles, proceedings and erratums.
7. **Title:** Charged particle timing at sub-25 picosecond precision: The PICOSEC detection concept  
Authors: Iguaz, F.J. et al.  
IGFAE Authors: Gonzalez-Diaz, D.  
Research Program: SA2_NEXT  
DOI: 10.1016/j.nima.2019.06.070

8. **Title:** Quasi-free neutron and proton knockout reactions from light nuclei in a wide neutron-to-proton asymmetry range  
Authors: Holl, M. et al.  
IGFAE Authors: Alvarez-Pol, H.; Benlliure, J.; Boillos, J.M.; Caamano, M.; Cortina-Gil, D.  
Research Program: SA3_NUCL, SA3_LACC  
DOI: 10.1016/j.physletb.2019.06.069

9. **Title:** Identical pion intensity interferometry in central Au + Au collisions at 1.23A GeV  
Authors: Adamczewski-Musch, J. et al.  
IGFAE Authors: Garzon, J.A.  
Research Program: SA3_NUCL  
DOI: 10.1016/j.physletb.2019.06.047

10. **Title:** Blip glitches in Advanced LIGO data  
Authors: Cabero, M. et al.  
IGFAE Authors: Dent, T.  
Reference: Classical Quantum Gravity 36(2019)155010  
Research Program: SA2_GRWA  
DOI: 10.1088/1361-6382/ab2e14

11. **Title:** BPS soliton-impurity models and supersymmetry  
Authors: Adam C., Queiruga J.M., Wereszczynski A.  
IGFAE Authors: Adam, C.  
Reference: JHEP7(2019)164  
Research Program: SA1_HQCD  
DOI: 10.1007/JHEP07(2019)164

12. **Title:** Solvable self-dual impurity models  
Authors: Adam C., Oles K., Queiruga J.M., Romanczukiewicz T., Wereszczynski A.  
IGFAE Authors: Adam, C.  
Reference: JHEP7(2019)150  
Research Program: SA1_HQCD  
DOI: 10.1007/JHEP07(2019)150

13. **Title:** Spectral Walls in Soliton Collisions  
Authors: Adam C., Oles K., Romanczukiewicz T., Wereszczynski A.  
IGFAE Authors: Adam, C.  
Research Program: SA1_HQCD
14. **Title:** Measurement of the Mass Difference between Neutral Charm-Meson Eigenstates  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCBD  
DOI: 10.1103/PhysRevLett.122.231802

15. **Title:** Observation of an Excited Bc+ State  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCBD  
DOI: 10.1103/PhysRevLett.122.232001

16. **Title:** Observation of a Narrow Pentaquark State, Pc (4312)+, and of the Two-Peak Structure of the Pc (4450)+  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCBD  
DOI: 10.1103/PhysRevLett.122.222001

17. **Title:** String percolation in AA and p+p collisions  
Authors: Bautista I., Pajares C., Ramírez J.E.  
IGFAE Authors: Pajares, C.; Ramírez, J.E.  
Reference: Rev. Mex. de Fis.65(2019)197  
Research Program: SA1_HQCD  
DOI: 10.31349/RevMexFis.65.197

18. **Title:** Observation of CP Violation in Charm Decays  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCBD  
DOI: 10.1103/PhysRevLett.122.211803
19. **Title:** New spectroscopic information on Tl 211,213: A changing structure beyond the N=126 shell closure  
Authors: Gottardo, A. et al.  
IGFAE Authors: Benlliure, J.  
Research Program: SA3_NUCL, SA3_LACC  
DOI: 10.1103/PhysRevC.99.054326

20. **Title:** Marginal deformations of WZW models and the classical Yang-Baxter equation  
Authors: Borsato, R., Wulff, L.  
IGFAE Authors: Borsato, R.  
Research Program: SA1_STRI  
DOI: 10.1088/1751-8121/ab1b9c

21. **Title:** Gravitational wave driving of a gapped holographic system  
Authors: Biasi A., Mas J., Serantes A.  
IGFAE Authors: Biasi, A.; Mas, J.  
Reference: JHEP5(2019)161  
Research Program: SA1_STRI  
DOI: 10.1007/JHEP05(2019)161

22. **Title:** T-duality equivalences beyond string theory  
Authors: Edelstein J.D., Sfetsos K., Sierra-García J.A., López A.V.  
IGFAE Authors: Edelstein, J.D.  
Reference: JHEP5(2019)82  
Research Program: SA1_STRI  
DOI: 10.1007/JHEP05(2019)082

23. **Title:** Determination of cosmic-ray primary mass on an event-by-event basis using radio detection  
Authors: Carvalho W.R., Jr., Alvarez-Muñiz J.  
IGFAE Authors: Alvarez-Muniz, J.  
Research Program: SA2_AUGE  
DOI: 10.1016/j.astropartphys.2019.02.005

24. **Title:** The Color Glass Condensate density matrix: Lindblad evolution, entanglement entropy and Wigner functional  
Authors: Armesto N., Dominguez F., Kovner A., Lublinsky M., Skokov V.V.  
IGFAE Authors: Armesto, N.  
Research Program: SA1_HQCD  
DOI: 10.1007/JHEP05(2019)025

25. **Title:** A compensated multi-gap RPC with 2 m strips for the LEPS2 experiment  
Authors: Watanabe, K. et al.  
IGFAE Authors: Gonzalez-Díaz, D.  
Research Program: SA2_NEXT  
DOI: 10.1016/j.nima.2019.02.014
26. **Title:** Prominence of Pairing in Inclusive \((p,2p)\) and \((p,\text{pn})\) Cross Sections from Neutron-Rich Nuclei  
Authors: Paul, N. et al.  
IGFAE Authors: Rodriguez-Sanchez, J.L.  
Research Program: SA3_NUCL  
DOI: 10.1103/PhysRevLett.122.162503

27. **Title:** Digging the population of compact binary mergers out of the noise  
Authors: Gaebel, S.M., Veitch, J., Dent, T., Farr, W.M.  
IGFAE Authors: Dent, T.  
Research Program: SA2_GRWA  
DOI: 10.1093/mnras/stz225

28. **Title:** First Measurement of Charm Production in its Fixed-Target Configuration at the LHC  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1103/PhysRevLett.122.132002

29. **Title:** Comprehensive analysis of anomalous ANITA events disfavors a diffuse tau-neutrino flux origin  
Authors: Romero-Wolf, A. et al.  
IGFAE Authors: Alvarez-Muniz, J.; Zas, E.  
Research Program: SA2_AUGE  
DOI: 10.1103/PhysRevD.99.063011

30. **Title:** Gravity dual of a multilayer system  
Authors: Jokela, N., Penin, J.M., Ramallo, A.V., Zoakos, D.  
IGFAE Authors: Penin, J.M., Ramallo, A.V.  
Reference: JHEP3(2019)64  
Research Program: SA1_HQCD, SA1_STRI  
DOI: 10.1007/JHEP03(2019)064

31. **Title:** Low-energy modes in anisotropic holographic fluids  
Authors: Itsios, G., Jokela, N., Järvelä, J., Ramallo, A.V.  
IGFAE Authors: Ramallo, A.V.  
Research Program: SA1_STRI  
DOI: 10.1016/j.nuclphysb.2019.01.018

32. **Title:** Effective-field-theory arguments for pursuing lepton-flavor-violating K decays at LHCb  
Authors: Borsato, M., Gligorov, V.V., Guadagnoli, D., Martinez Santos, D., Sumensari, O.  
IGFAE Authors: Borsato, M.; Santos, D.M.  
Research Program: SA1_LHCB  
DOI: 10.1103/PhysRevD.99.055017
33. **Title:** Insight into excitation energy and structure effects in fission from isotopic information in fission yields  
Authors: Ramos, D. et al.  
IGFAE Authors: Benlliure, J.; Caamano, M.; Cortina-Gil, D.; Fernandez-Dominguez, B.  
Research Program: SA3_NUCL, SA3_LACC  
DOI: 10.1103/PhysRevC.99.024615

34. **Title:** Quarkonium: a theory overview  
Authors: Ferreiro E.G.  
IGFAE Authors: Ferreiro, E.G.  
Research Program: SA1_HQCD  

35. **Title:** Unveiling the yoctosecond structure of the QGP with top quarks  
Authors: Apolinário L., Milhano G., Salgado C.A., Salam G.  
IGFAE Authors: Salgado, C.A.  
Research Program: SA1_HQCD  
DOI: 10.1016/j.nuclphysa.2018.11.014

36. **Title:** Thermal behavior and entanglement in Pb-Pb and p-p collisions  
Authors: Feal X., Pajares C., Vazquez R.A.  
IGFAE Authors: Pajares, C.; Vazquez, R.A.  
Research Program: SA1_HQCD, SA2_AUGE  
DOI: 10.1103/PhysRevC.99.015205

37. **Title:** Transverse spectrum of bremsstrahlung in finite condensed media  
Authors: Feal X., Vazquez R.A.  
IGFAE Authors: Vazquez, R.A.  
Research Program: SA1_HQCD, SA2_AUGE  
DOI: 10.1103/PhysRevD.99.016002

38. **Title:** Information flows in strongly coupled ABJM theory  
Authors: Balasubramanian V., Jokela N., Pönni A., Ramallo A.V.  
IGFAE Authors: Ramallo, A.V.  
Research Program: SA1_STRI  
DOI: 10.1007/JHEP01(2019)232

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Authors: Centis Vignali, M. et al.  
IGFAE Authors: Otero Ugobono, S.  
Research Program: SA1_LHCB  
DOI: 10.1016/j.nima.2019.162405
40. **Title:** Quasi-free proton knockout from 12C on carbon target at 398 MeV/u  
Authors: Panin,V. et al.  
IGFAE Authors: Alvarez-Pol, H.; Cortina-Gil, D.  
Research Program: SA3_NUCL, SA3_LACC  
DOI: 10.1016/j.physletb.2019.134802

41. **Title:** Measurement of the CP-violating phase $\phi_s$ from $B_s \to J/\psi \pi^+ \pi^-$ decays in 13 TeV pp collisions  
Authors: Aaij,R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1016/j.physletb.2019.07.036

42. **Title:** Inclusive cross sections for one- and multi-nucleon removal from Sn, Sb, and Te projectiles beyond the N = 82 shell closure  
Authors: Vaquero,V. et al.  
IGFAE Authors: Rodriguez-Sanchez, J.L.  
Research Program: SA3_NUCL  
DOI: 10.1016/j.physletb.2019.06.035

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Authors: Aaij,R. et al.  
Reference: JHEP8(2019)41  
Research Program: SA1_LHCB  
DOI: 10.1007/JHEP08(2019)041

44. **Title:** Search for the rare decay $B^+ \to \mu^+ \mu^- \mu^+\nu\mu$  
Authors: Aaij,R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1140/epjc/s10052-019-7112-x

45. **Title:** Updated measurement of time-dependent CP-violating observables in $B_s0 \to J/\psi K^+ K^-$ decays  
Authors: Aaij,R. et al.  
46. **Title:** First Observation of the Radiative Decay $\Lambda b_0 \rightarrow \Lambda \gamma$
**Authors:** Aaij, R. et al.
**Research Program:** SA1_LHC
**DOI:** 10.1103/PhysRevLett.123.031801

47. **Title:** Strong Absorption of Hadrons with Hidden and Open Strangeness in Nuclear Matter
**Authors:** Adamczewski-Musch, J. et al.
**IGFAE Authors:** Garzon, J.A.
**Research Program:** SA3_NUCL
**DOI:** 10.1103/PhysRevLett.123.022002

48. **Title:** Solvable Cubic Resonant Systems
**Authors:** Biasi, A., Bizoń, P., Evnin, O.
**IGFAE Authors:** Biasi, A.
**Research Program:** SA1_STRI
**DOI:** 10.1007/s00220-019-03365-z

49. **Title:** Measurement of the $^{235}\text{U}(n, f)$ cross section relative to the $^{6}\text{Li}(n, t)$ and $^{10}\text{B}(n, \alpha)$ standards from thermal to 170 keV neutron energy range at n_TOF
**Authors:** Amaducci, S. et al.
**IGFAE Authors:** Caamano, M.; Duran, I.; Fernandez-Dominguez, B.
**Research Program:** SA3_NUCL
**DOI:** 10.1140/epja/i2019-12802-7

50. **Title:** Amplitude analysis of the $B(s)0 \rightarrow K^*0 K^{-}0$ decays and measurement of the branching fraction of the $B \rightarrow K^*0 K^{-}0$ decay
**Authors:** Aaij, R. et al.
**Reference:** JHEP 7(2019)32
**Research Program:** SA1_LHC
**DOI:** 10.1007/JHEP07(2019)032
51. **Title:** Near-threshold $D(\text{Formula presented.})$ spectroscopy and observation of a new charmonium state  
Authors: Aaij, R. et al.  
Reference: JHEP7(2019)35  
DOI: 10.1007/JHEP07(2019)035

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Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
DOI: 10.3847/1538-4357/ab20cb

53. **Title:** Tests of General Relativity with GW170817  
Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
DOI: 10.1103/PhysRevLett.123.011102

Authors: Abada, A. et al.  
IGFAE Authors: Armesto, N.; Salgado, C.A.  
DOI: 10.1140/epjst/e2019-900088-6

Authors: Abada, A. et al.  
IGFAE Authors: Armesto, N.; Salgado, C.A.  
DOI: 10.1140/epjst/e2019-900087-0

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Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
DOI: 10.1103/PhysRevD.99.122002

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Authors: Adamczewski-Musch, J. et al.  
IGFAE Authors: Garzon, J.A.  
Research Program: SA3_NUCL
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Authors: Aaij, R. et al.  
Reference: JHEP6(2019)114  
Research Program: SA1_LHCB  
DOI: 10.1007/JHEP06(2019)114

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Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1140/epjc/s10052-019-6698-3

60. **Title:** FCC Physics Opportunities: Future Circular Collider Conceptual Design Report Volume 1  
Authors: Abada, A. et al.  
IGFAE Authors: Armesto, N.; Salgado, C.A.  
Research Program: SA1_HQCD  
DOI: 10.1140/epjc/s10052-019-6904-3

Authors: Abada, A. et al.  
IGFAE Authors: Armesto, N.; Salgado, C.A.  
Research Program: SA1_HQCD  
DOI: 10.1140/epjst/e2019-900045-4

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Authors: Chatillon, A. et al.  
IGFAE Authors: Alvarez-Pol, H.; Benlliure, J.; Caamaño, M.; Cortina-Gil, D.; Fernandez-Dominguez, B.; Rodriguez-Sánchez, J.L.  
Research Program: SA3_NUCL, SA3_LACC  
DOI: 10.1103/PhysRevC.99.054628

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Authors: Konczykowski, P. et al.  
IGFAE Authors: Alvarez-Pol, H.; Caamaño, M.; Fernandez-Dominguez, B.  
Research Program: SA3_NUCL  
DOI: 10.1016/j.nima.2019.02.013
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Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1103/PhysRevLett.122.191803

65. Title: Observation of $B(s)_0 \rightarrow J/\psi p\bar{p}$ Decays and Precision Measurements of the $B(s)_0$ Masses  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1103/PhysRevLett.122.191804

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Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
Research Program: SA2_GRWA  
DOI: 10.1103/PhysRevD.99.104033

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Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1103/PhysRevLett.122.191801

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Authors: Perez-Loureiro, D. et al.  
IGFAE Authors: Alvarez-Pol, H.; Benlliure, J.; Rodriguez-Sanchez, J.L.  
Research Program: SA3_NUCL, SA3_LACC  
DOI: 10.1103/PhysRevC.99.054606

69. Title: Prospects for measurements with strange hadrons at LHCb  
Authors: Alves, A.A., Jr. et al.  
IGFAE Authors: Alves, A.A., Jr.; Brea Rodriguez, A.; Casis Vidal, A.; Chobanova, V.; Vidal, X.C.; Dalseno, J.; Lucio Martinez, M.; Santos, D.M.; Ramos Pernas, M.  
Research Program: SA1_LHCB  
DOI: 10.1007/JHEP05(2019)048
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**Authors:** Aaij, R. et al.

**IGFAE Authors:** Adeva, B.; Alves, A.A., Jr.; Boente García, O.; Borsato, M.; Chobanova, V.; Vidal, X.C.; Dalseno, J.; Fernandez Prieto, A.; Gallas Torreira, A.; García Pardinas, J.; García Plana, B.; Lucio Martínez, M.; Santos, D.M.; Plo, M.; Prouvre, C.; Ramos Pernas, M.; Romero Vidal, A.; Saborido Silva, J.J.; Santamarina Rios, C.; Vazquez Regueiro, P.; Vieites Díaz, M.


**Research Program:** SA1_LHC

**DOI:** 10.1103/PhysRevD.99.092009

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**Authors:** Aaij, R. et al.

**IGFAE Authors:** Adeva, B.; Alves, A.A., Jr.; Boente García, O.; Borsato, M.; Chobanova, V.; Vidal, X.C.; Dalseno, J.; Fernandez Prieto, A.; Gallas Torreira, A.; García Pardinas, J.; García Plana, B.; Lucio Martínez, M.; Santos, D.M.; Plo, M.; Prouvre, C.; Ramos Pernas, M.; Romero Vidal, A.; Saborido Silva, J.J.; Santamarina Rios, C.; Vazquez Regueiro, P.; Vieites Díaz, M.

**Reference:** JHEP5(2019)26

**Research Program:** SA1_LHC

**DOI:** 10.1007/JHEP05(2019)026

72. **Title:** First Measurement of the Hubble Constant from a Dark Standard Siren using the Dark Energy Survey Galaxies and the LIGO/Virgo Binary-Black-hole Merger GW170814

**Authors:** Soares-Santos, M. et al.

**IGFAE Authors:** Dent, T.


**Research Program:** SA2_GRWA

**DOI:** 10.3847/2041-8213/ab14f1

73. **Title:** Low-latency Gravitational-wave Alerts for Multimessenger Astronomy during the Second Advanced LIGO and Virgo Observing Run

**Authors:** Abbott, B.P. et al.

**IGFAE Authors:** Dent, T.

**Reference:** Astrophys. J. 875(2019)161

**Research Program:** SA2_GRWA

**DOI:** 10.3847/1538-4357/ab0e8f

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**Authors:** Abbott, B.P. et al.

**IGFAE Authors:** Dent, T.


**Research Program:** SA2_GRWA

**DOI:** 10.3847/1538-4357/ab113b

75. **Title:** Search for Gravitational Waves from a Long-lived Remnant of the Binary Neutron Star Merger GW170817

**Authors:** Abbott, B.P. et al.

**IGFAE Authors:** Dent, T.


**Research Program:** SA2_GRWA
Title: Model-Independent Observation of Exotic Contributions to $B_0 \rightarrow j \psi K^+ \pi^-$ Decays
Authors: Aaij, R. et al.
Research Program: SA1_LHCB
DOI: 10.1103/PhysRevLett.122.152002

Title: Observation of the doubly Cabibbo-suppressed decay $\Xi_c^+ \rightarrow p\phi$
Authors: Aaij, R. et al.
Reference: JHEP4(2019)84
Research Program: SA1_LHCB
DOI: 10.1007/JHEP04(2019)084

Title: Dalitz plot analysis of the $D^+ \rightarrow K^- K^+ K^+$ decay
Authors: Aaij, R. et al.
Research Program: SA1_LHCB
DOI: 10.1007/JHEP04(2019)063

Title: Search for Transient Gravitational-wave Signals Associated with Magnetar Bursts during Advanced LIGO’s Second Observing Run
Authors: Abbott, B.P. et al.
IGFAE Authors: Dent, T.
Research Program: SA2_GRWA
DOI: 10.3847/1538-4357/ab0e15

Title: Measurement of $^{73}$Ge($n,\gamma$) cross sections and implications for stellar nucleosynthesis
Authors: Lederer-Woods, C. et al.
IGFAE Authors: Caamano, M.; Duran, I.; Fernandez-Domínguez, B.
Research Program: SA3_NUCL
DOI: 10.1016/j.physletb.2019.01.045

Title: Neutron skin and signature of the $N = 14$ shell gap found from measured proton radii of $17$–$22N$
Authors: Bagchi, S. et al.
IGFAE Authors: Cortina-Gil, D.
Research Program: SA3_NUCL, SA3_LACC
82. **Title:** Measurement of the average shape of longitudinal profiles of cosmic-ray air showers at the Pierre Auger Observatory  
Authors: Aab, A. et al.  
Research Program: SA1_HQCD, SA2_AUGE  
DOI: 10.1088/1475-7516/2019/03/018

83. **Title:** The $\phi^4$ model with the BPS preserving defect  
Authors: Adam C., Romanczukiewicz T., Wereszczynski A.  
IGFAE Authors: Adam, C.  
Reference: JHEP3(2019)131  
Research Program: SA1_HQCD  
DOI: 10.1007/JHEP03(2019)131

84. **Title:** First Measurement of a Long-Lived $\pi^+\pi^-$ Atom Lifetime  
Authors: Adeva, B. et al.  
IGFAE Authors: Adeva, B.; Plo, M.; Romero Vidal, A.; Saborido Silva, J.J.  
Research Program: SA1_LHCB  
DOI: 10.1103/PhysRevLett.122.082003

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Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1103/PhysRevD.99.052006

86. **Title:** Measurement of $B^+$, $B_0$ and $\Lambda_b$ production in pPb collisions at $s_{NN}=8.16$ TeV  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1103/PhysRevD.99.052011

87. **Title:** Measurement of the branching fractions of the decays $D^+ \rightarrow K^- K^+ K^+$, $D^+ \rightarrow \pi^- K^+ K^+$ and $D^+ \rightarrow \pi^- K^+ K^+$  
Authors: Aaij, R. et al.  
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Authors: Aaij, R. et al.
Reference: JHEP3(2019)176
Research Program: SA1_LHCB
DOI: 10.1007/JHEP03(2019)176

89. **Title**: Relative particle yield fluctuations in Pb–Pb collisions at $\sqrt{s_{NN}}=2.76$TeV
Authors: Acharya, S. et al.
IGFAE Authors: Ferreiro, E.G.
Research Program: SA1_HQCD
DOI: 10.1140/epjc/s10052-019-6711-x

90. **Title**: A fixed-target programme at the LHC for heavy-ion, hadron, spin and astroparticle physics: AFTER@LHC
Authors: Kikola, D. et al.
IGFAE Authors: Ferreiro, E.G.
Research Program: SA1_HQCD
DOI: 10.1016/j.nuclphysa.2018.09.063

91. **Title**: Search for CP violation through an amplitude analysis of $D^0 \to K^+ K^- \pi^+ \pi^- \pi^+$ decays
Authors: Aaij, R. et al.
Research Program: SA1_LHCB
DOI: 10.1007/JHEP02(2019)126

92. **Title**: Prompt $\Lambda_c^+ +$ production in pPb collisions at $\sqrt{s_{NN}}=5.02$ TeV
Authors: Aaij, R. et al.
Research Program: SA1_LHCB
DOI: 10.1007/JHEP02(2019)102

93. **Title**: Study of multi-neutron emission in the $\beta$-decay of $^{11}$Li
Authors: Delaunay, F. et al.
IGFAE Authors: Fernandez-Dominguez, B.
94. **Title**: Cross section measurements of $^{155,157}$Gd$(n, \gamma)$ induced by thermal and epithermal neutrons
Authors: Mastromarco, M. et al.
IGFAE Authors: Caamano, M.; Duran, I.; Fernandez-Dominguez, B.
Research Program: SA3_NUCL
DOI: 10.1140/epja/i2019-12692-7

95. **Title**: Cosmic inflation without inflaton
IGFAE Authors: Edelstein, J.D.
Research Program: SA1_STRI
DOI: 10.1142/S0218271819440085

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Authors: Aaij, R. et al.
Research Program: SA1_LHCb
DOI: 10.1103/PhysRevLett.123.211801

97. **Title**: Universal Relaxation in a Holographic Metallic Density Wave Phase
Authors: Amoretti A., Areán D., Goutéraux B., Musso D.
IGFAE Authors: Musso, D.
Research Program: SA1_STRI
DOI: 10.1103/PhysRevLett.123.211602

98. **Title**: Extracting the spectral signature of a clustering in Ti 44,48,52 using a continuous wavelet transform
Authors: Bailey, S. et al.
IGFAE Authors: Fernandez-Dominguez, B.
Research Program: SA3_NUCL
DOI: 10.1103/PhysRevC.100.051302

99. **Title**: Data-driven estimation of the invisible energy of cosmic ray showers with the Pierre Auger Observatory
Authors: Aab, A. et al.
Research Program: SA1_HQCD, SA2_AUGE
DOI: 10.1103/PhysRevD.100.082003
100. Title: Inclusive diffraction in future electron-proton and electron-ion colliders  
Authors: Armesto N., Newman P.R., Stomiński W., Staśto A.M.  
IGFAE Authors: Armesto, N.  
Research Program: SA1_HQCD  
DOI: 10.1103/PhysRevD.100.074022

101. Title: Search for Subsolar Mass Ultracompact Binaries in Advanced LIGO's Second Observing Run  
Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
Research Program: SA2_GRWA  
DOI: 10.1103/PhysRevLett.123.161102

102. Title: Measurement of the Ge 70 (n,γ) cross section up to 300 keV at the CERN n-TOF facility  
Authors: Gawlik, A. et al.  
IGFAE Authors: Caamano, M.; Duran, I.; Fernandez-Dominguez, B.  
Research Program: SA3_NUCL  
DOI: 10.1103/PhysRevC.100.045804

103. Title: Observation of New Resonances in the Λb0 π+π- System  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1103/PhysRevLett.123.152001

104. Title: Diffusion and universal relaxation of holographic phonons  
Authors: Amoretti, A., Aréan, D., Goutéraux, B., Musso, D.  
IGFAE Authors: Musso, D.  
Reference: JHEP10(2019)068  
Research Program: SA1_STRI  
DOI: 10.1007/JHEP10(2019)068

105. Title: Supersymmetric probes in warped AdS6  
Authors: Penin, J.M., Ramallo, A.V., Rodriguez-Gómez, D.  
IGFAE Authors: Penin, J.M.; Ramallo, A.V.  
Reference: JHEP10(2019)021  
Research Program: SA1_STRI  
DOI: 10.1007/JHEP10(2019)021

106. Title: A search for Ξcc++ → D+pK− π + decays  
Authors: Aaij, R. et al.  
107. **Title:** Energy calibration of the NEXT-White detector with 1% resolution near Qββ of 136Xe  
Authors: Renner, J. et al.  
IGFAE Authors: Gonzalez-Díaz, D.; Hernando Morata, J.A.; Martinez-Lema, G.; Palmeiro, B.; Renner, J.  
Research Program: SA2_NEXT, SA3_NUCL  
DOI: 10.1007/JHEP10(2019)230

108. **Title:** Demonstration of the event identification capabilities of the NEXT-White detector  
Authors: Ferrario, P. et al.  
IGFAE Authors: Gonzalez-Díaz, D.; Hernando Morata, J.A.; Martinez-Lema, G.; Palmeiro, B.; Renner, J.  
Reference: JHEP10(2019)052  
Research Program: SA2_NEXT, SA3_NUCL  
DOI: 10.1007/JHEP10(2019)052

109. **Title:** Radiogenic backgrounds in the NEXT double beta decay experiment  
Authors: Novella, P. et al.  
IGFAE Authors: Gonzalez-Díaz, D.; Hernando Morata, J.A.; Martinez-Lema, G.; Palmeiro, B.; Renner, J.  
Reference: JHEP10(2019)051  
Research Program: SA2_NEXT, SA3_NUCL  
DOI: 10.1007/JHEP10(2019)051

110. **Title:** Probing dense baryon-rich matter with virtual photons  
Authors: Adamczewski-Musch, J. et al.  
IGFAE Authors: Garzon, J.A.  
Research Program: SA3_NUCL  
DOI: 10.1038/s41567-019-0583-8

111. **Title:** Search for Eccentric Binary Black Hole Mergers with Advanced LIGO and Advanced Virgo during Their First and Second Observing Runs  
Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
Research Program: SA2_GRWA  
DOI: 10.3847/1538-4357/ab3c2d

112. **Title:** Search for intermediate mass black hole binaries in the first and second observing runs of the Advanced LIGO and Virgo network  
Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
Research Program: SA2_GRWA  
DOI: 10.1103/PhysRevD.100.064064
113. **Title:** Transport coefficients from in-medium quarkonium dynamics  
Authors: Brambilla N., Escobedo M.A., Vairo A., Vander Griend P.  
IGFAE Authors: Escobedo, M.A.  
Research Program: SA1_HQCD  
DOI: 10.1103/PhysRevD.100.054025

114. **Title:** Binary Black Hole Population Properties Inferred from the First and Second Observing Runs of Advanced LIGO and Advanced Virgo  
Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
Research Program: SA2_GRWA  
DOI: 10.3847/2041-8213/ab3800

115. **Title:** GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs  
Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
Research Program: SA2_GRWA  
DOI: 10.1103/PhysRevX.9.031040

116. **Title:** Directional limits on persistent gravitational waves using data from Advanced LIGO’s first two observing runs  
Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
Research Program: SA2_GRWA  
DOI: 10.1103/PhysRevD.100.062001

117. **Title:** Search for the isotropic stochastic background using data from Advanced LIGO’s second observing run  
Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
Research Program: SA2_GRWA  
DOI: 10.1103/PhysRevD.100.061101

118. **Title:** Hadroproduction of neutral $K^*$-mesons up to LHC energies  
Authors: Arakelyan G.H., Merino C., Shabelski Y.M.  
IGFAE Authors: Merino, C.  
Research Program: SA1_HQCD  
DOI: 10.1140/epja/i2019-12832-1

119. **Title:** Effect of non-eikonal corrections on azimuthal asymmetries in the color glass condensate  
Authors: Agostini P., Altinoluk T., Armesto N.  
IGFAE Authors: Armesto, N.  
Research Program: SA1_HQCD  
DOI: 10.1140/epjc/s10052-019-7315-1
120. **Title:** Observation of the $\Lambda b_0 \to \chi c_1$ (3872) $pK^-$ decay  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1007/JHEP09(2019)028

121. **Title:** Measurements of CP asymmetries in charmless four-body $\Lambda b_0$ and $\Xi b_0$ decays  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1140/epjc/s10052-019-7218-1

122. **Title:** First Direct Measurement of Isotopic Fission-Fragment Yields of U 239  
Authors: Ramos, D. et al.  
IGFAE Authors: Alvarez-Pol, H.; Caamano, M.; Fernandez-Dominguez, B.; Galiana, E.  
Research Program: SA3_NUCL  
DOI: 10.1103/PhysRevLett.123.092503

123. **Title:** Measurement of $b$ hadron fractions in 13 TeV $pp$ collisions MEASUREMENT of $b$ HADRON FRACTIONS in 13 TeV ... AAIJ et al.  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1103/PhysRevD.100.031102

124. **Title:** Measurement of CP -Violating and Mixing-Induced Observables in $Bs_0 \to \phi$ Decays  
Authors: Aaij, R. et al.  
Research Program: SA1_LHCB  
DOI: 10.1103/PhysRevLett.123.081802
125. **Title:** Area covered by disks in small-bounded continuum percolating systems: An application to the string percolation model  
Authors: Ramirez J.E., Pajares C.  
IGFAE Authors: Pajares, C.; Ramirez, J.E.  
Research Program: SA1_HQCD  
DOI: 10.1103/PhysRevE.100.022123

126. **Title:** Electron drift and longitudinal diffusion in high pressure xenon-helium gas mixtures  
Authors: McDonald, A.D. et al.  
IGFAE Authors: Gonzalez-Diaz, D.; Hernando Morata, J.A.; Martinez-Lema, G.; Palmeiro, B.; Renner, J.  
Research Program: SA2_NEXT, SA3_NUCL  
DOI: 10.1088/1748-0221/14/08/P08009

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Research Program: SA1_LHCB  
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IGFAE Authors: Armesto, N.  
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Authors: Blaizot J.-P., Dominguez F.  
IGFAE Authors: Dominguez, F.  
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Authors: Kordas, K. et al.  
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Authors: Scharenberg R.P., Srivastava B.K., Pajares C.  
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Authors: Aaij, R. et al.  
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Authors: Aaij, R. et al.  
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Authors: Abbott, B.P. et al.  
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Authors: Gran U., Jokela N., Musso D., Ramallo A.V., Tornsò M.  
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Authors: Musso D.  
IGFAE Authors: Musso, D.  
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Authors: Aaij, R. et al.  
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Authors: Aaij, R. et al.  
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142. **Title:** Tests of general relativity with the binary black hole signals from the LIGO-Virgo catalog GWTC-1  
Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
143. **Title:** Search for Gravitational-wave Signals Associated with Gamma-Ray Bursts during the Second Observing Run of Advanced LIGO and Advanced Virgo  
Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
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Authors: Bagnaschi, E. et al.  
IGFAE Authors: Lucio Martinez, M.; Santos, D.M.  
Research Program: SA1_LHCb  
DOI: 10.1140/epjc/s10052-019-7382-3

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Authors: Aab, A. et al.  
Research Program: SA1_HQCD, SA2_AUGE  
DOI: 10.1088/1475-7516/2019/10/022

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Authors: Itsios G., Penín J.M., Zacarías S.  
IGFAE Authors: Penin, J.M.  
Reference: JHEP10(2019)231  
Research Program: SA2_AUGE  
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Authors: Dalseno J.  
IGFAE Authors: Dalseno, J.  
Reference: JHEP10(2019)191  
Research Program: SA1_LHCb  
DOI: 10.1007/JHEP10(2019)191

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Authors: Biasi A., Bizoń P., Evnin O.  
IGFAE Authors: Biasi, A.  
Research Program: SA1_STRI  
DOI: 10.1088/1751-8121/ab4406

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Authors: Alvarez Navarro E., Diaz B., Garcia-Ariza M.A., Ramirez J.E.  
IGFAE Authors: Ramirez, J.E.  
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Authors: Arbey A., Hurth T., Mahmoudi F., Martinez Santos D., Neshatpour S.  
IGFAE Authors: Santos, D.M.  
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Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
Research Program: SA2_GRWA  
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Authors: Castro-Villarreal P., Ramirez J.E.  
IGFAE Authors: Ramirez, J.E.  
Research Program: SA1_HQCD  
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Authors: Abbott, B.P. et al.  
IGFAE Authors: Dent, T.  
Research Program: SA2_GRWA  
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Authors: Aaij, R. et al.  
IGFAE Authors: Santos, D.M.; Prouvre, C.; Ramos Pernas, M.  
Research Program: SA1_LHCB  
DOI: 10.1088/1748-0221/14/04/P04013

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Authors: Aab, A. et al.  
Research Program: SA1_HQCD, SA2_AUGE  
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Authors: Kampert K.-H., Alejandro Mostafa M., Zas E., The Pierre Auger Collaboration  
IGFAE Authors: Zas, E.
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Authors: Guo Y., Dong L., Pan J., Moldes M.R.  
IGFAE Authors: Moldes, M.R.  
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Authors: Vidal X.C., Ilten P., Plews J., Shuve B., Soreq Y.  
IGFAE Authors: Vidal, X.C.  
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Authors: Akiba, K. et al.  
IGFAE Authors: Vidal, X.C.; Gallas Torreira, A.; Garcia Pardinas, J.; Vieites Diaz, M.  
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Authors: Vidal X.C., Mariotti A., Redigolo D., Sala F., Tobioka K.  
IGFAE Authors: Vidal, X.C.  
Reference: JHEP1(2019)113  
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Authors: Bifani S., Descotes-Genon S., Vidal A.R., Schune M.-H.  
IGFAE Authors: Romero Vidal, A.  
Research Program: SA1_LHCB  
DOI: 10.1088/1361-6471/aaf5de
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