Centro de Astropartículas y Física de Altas Energías

Activity Report

2020

1 Summary

The Centro de Astropartículas y Física de Altas Energías (CAPA) was started by Universidad de Zaragoza in May 2019. The fundamental objective of CAPA is the promotion of scientific research in the fields of High Energy Physics, Nuclear and Particle Physics, Astrophysics, Cosmology, Astroparticles and Theoretical Physics, as well as the technological developments associated with them. With these objectives, the Center supports the participation of its members in the unique scientific and technical infrastructures based in Aragón: the Canfranc Underground Laboratory and the Javalambre Astrophysical Observatory, and promotes, in close collaboration with Centro de Ciencias de Benasque Pedro Pascual, specialized training activities, the transfer of knowledge and scientific culture.

Currently, CAPA has 56 members from the University of Zaragoza and is supported by other 20 researchers from different entities. The research groups are being regularly funded in the framework of different national and international programs. Last year it was granted with an Advanced Grant from the European Research Council for the period 2019-2023, which represents an additional funding of 3.1 million euros.

In 2020 the whole activity of the group was very much affected by the complicated sanitary situation due to the COVID19 pandemics. However, thanks to a very active use of online facilities, the main research lines of the projects were developed in a satisfactory manner.

The research activity of the different groups has produced 126 publications in 2020 and the number of citations (6.126) has also increased with respect to previous years.

Índice General

2 About CAPA

The Centro de Astropartículas y Física de Altas Energías (CAPA) is a research institute focused on the fields of high energy physics, nuclear and particle physics, astrophysics, cosmology, astroparticles and theoretical physics, as well as the technological developments associated with them. The Center supports the participation of its members in the unique scientific and technical infrastructures based in Aragon: the Canfranc Underground Laboratory and the Javalambre Astrophysical Observatory, and promotes, in close collaboration with Centro de Ciencias de Benasque Pedro Pascual, specialized training activities, the transfer of knowledge and scientific culture.

The Center is made up of two divisions (theoretical and experimental) that address a wide variety of research lines: *direct searches of dark matter, axion physics (theory and detection), neutrino physics (double beta decay), development of new particle detector technologies, radiactivity and techniques of ultra low backgrounds, lattice gauge theories, phenomenology of the Standard Model and beyond the Standard Model, quantum field theory and applications, theory and phenomenology of quantum gravity, astrophysics and cosmology.*

2.1 Governing board

Director: Manuel Asorey
Subdirector: Igor García Irastorza
Secretary: José Manuel Carmona

2.2 CAPA Personnel

Name	**First name**	**Name**	**First name**
Alda Gallo	Jorge	Gómez Gardeñes	Jesús
Alonso Buj	José Luis	Jiménez Albericio	Javier
Amaré Tafalla	Julio César	Luzón Marco	Gloria

Name	**First name**	**Name**	**First name**
Ares Asensio	Filiberto	Martínez Pérez	María
Asensio Chaves	César	Membrado Ibáñez	Manuel
Asorey Carballeira	Manuel	Mirallas Sánchez	Héctor
Azcoiti Pérez	Vicente	Moreno Vega	Yamir
Camón Lasheras	Agustín	Núñez-Lagos	Rafael
Cariñena Marzo	José Fernando	O'Hare	Ciaran
Carmona Martínez	José Manuel	Ortigoza Paredes	Ysrael Richard
Castel Pablo	Juan Francisco	Ortiz de Solórzano	Alfonso
Cavero Peláez	Inés	Peñaranda Rivas	Siannah
Cebrián Guajardo	Susana	Pérez Marín	Carmen
Clemente Gallardo	Jesús	Pérez Torres	Miguel Ángel
Coarasa Casas	Iván	Pobes Aranda	Carlos
Cortés Azcoiti	José Luis	Puimedón Santolaria	Jorge
Dafni	Theopisti	Redondo Martín	Javier
Falceto Blecua	Fernando	Relancio Martínez	José Javier
Fernández Rañada	Manuel	Rodr íguez Vallejo	Santiago
Fernández Pacheco	Amalio	Royo Amondarain	Eduardo
Floría Peralta	Luis Mario	Ruiz Chóliz	Elisa
Follana Adín	Eduardo	Salinas Baldellou	Ana
Galán Lacarra	Javier	Sarsa Sarsa	María Luisa
García Abancens	Eduardo	Seguí Santonja	Antonio
García Esteve	José V.	Tarancón Lafita	Alfonso
García Irastorza	Igor	Vaquero Avilés-Casco	Alejandro
Gopar Sánchez	Victor Arturo	Velázquez Campoy	Luis Fernando
Gracia Bondía	José Mariano	Villar Gómez	Patricia

3 Summary of research activities

3.1 Dark matter direct searches

3.1.1 Searches for low mass WIMPs with the TREX-DM experiment at the LSC

The TREX-DM detector is based on the technology of gas time projection chambers (TPC) equipped with Micromegas readout planes of the microbulk type, i.e., built out of radiopure materials, and has as main goal the search for low mass WIMPs. The TREX-DM TPC has been designed to host 0.3 kg of argon mass at 10 bar (or, alternatively, 0.16 kg of neon). It is composed of a cylindrical vessel made of radiopure copper, with an inner diameter of 0.5 m, a length of 0.5 m and a wall thickness of 6 cm. These dimensions are set by the requirements that the vessel holds up to 10 bar of pressure, while at the same time constitutes the innermost part of the shielding. The vessel is divided into two active volumes by a central mylar cathode, which is connected to high voltage by a tailor-made feedthrough. At each side there is a 19 cm long field cage defined by a series of copper strips imprinted on a kapton substrate supported by four teflon walls.

After a first installation and commissioning phase underground that lasted until 2019, the experiment went through several data taking runs in 2020, in a stable configuration at 4 bar of pressure with Ne+isobutane gas. The performance of the detector is as expected, but the measured low-energy background is higher than predicted by the simulation-based background model. The data taken in 2020 are helping to identify the origin of this extra background. Our conclusions are that radioactive Radon gas is being emanated into the detector gas. The main emanator is the moisture filter currently used. Plans are ongoing to develop cleaner custom-made version of the filter and, in addition, to develop a radon trap that effectively reduces the level of radon in the gas. A second finding is that radon progeny contamination is present in several inner walls of the detector, consequence of past uncontrolled exposure to radon atmosphere of the said components. Mitigation actions to reduce this contamination are also being followed. Finally, another improved version of the readout plane has been designed and is currently under fabrication at CERN.

3.1.2 Searches for axions with IAXO

The International Axion Observatory IAXO is one of the most ambitious experiments to find the axion, a very light hypothetical particle that could compose

the dark matter of the Universe. Its baseline configuration relies on the axion helioscope concept, which aims at detecting the axions that are predicted to be emitted by the core of the Sun. It is based on the use of a large magnet to trigger the conversion of solar axions into photons. IAXO will go well beyond current experiments' sensitivity, in particular beyond its predecessor CAST at CERN, and will probe a large fraction of axion and ALP models. CAPA scientists have played a central role in CAST during the last two decades, and they are now leading the international IAXO collaboration (the largest collaboration on axion physics worldwide, with more that 125 scientists from more than 25 different institutions). For this currently CAPA enjoys an ERC Advanced Grant. The short-term scope of the project encompasses the realization of a first complete intermediate experimental stage, BabyIAXO, including prototypes of the IAXO magnet and detection systems. BabyIAXO will already be able to test a number of axion and ALP models that are invoked by the aforementioned astrophysical hints and therefore at this stage there is potential for discovery.

During the last year, the work towards the design of all parts of BabyIAXO has substantially progressed, together with the consolidation of the international collaboration, as well as its management structure and the adequate host environment at DESY-Hamburg. After the formal approval of the BabyIAXO project in 2019 by the DESY Physics Review Committee (PRC), the DESY directorate approved the project and preparatory actions at the host immediately started. This process culminated with the formal approval of an important budget line to cover the expenses of hosting BabyIAXO at DESY. In parallel, steady progress has been achieved with the design of all subsystems of BabyIAXO. From the conceptual design completed by the time of the DESY proposal in 2019, the project has now achieved tendering design of some of the most time-critical elements, like the magnet cold mass and cryostat, and quotations are being received by companies. At the end of 2020, an in-depth review of the magnet design by a panel of international experts, was organized by the PRC, and successfully passed. Apart from the magnet, the collaboration counts with the endorsement of the European Space Agency (ESA) to use one existing 70 cm x-ray optics (a spare optics made for the XMM x-ray astronomy mission) in one of the magnet bores. The collaboration plans to build a custom-made optics for the second bore.

The hardware work at CAPA has been focused on developing the Micromegas detectors for the focal points of BabyIAXO. A first prototype called IAXO-D0 has taken background data in the IAXO lab at CAPA, in order to gain insight on, and improve, the background level of the detector. An improved active shielding has been designed and built, to veto, in addition to cosmic muons, also the more diffi-

cult cosmic neutrons. An improved version of the detector, called IAXO-D1, has been designed and its production launched. This latter design already takes into account the mechanical environment of BabyIAXO. IAXO-D1 will be tested also underground at the Laboratorio Subterráneo de Canfranc (LSC). The comparison of the measured background on surface and in a cosmic-free environment like the LSC will help assess the cosmic muon and neutron tagging capabilities of the new shielding. In addition, the group has been operating another, earlier, prototype, dubbed IAXO pathfinder, that was re-installed in 2019 in the CAST beam line at CERN. This detector has been running with Xe instead of Ar (for the first time in CAST) and is providing invaluable operational experience for BabyIAXO. Another very active area is the software preparations for BabyIAXO. In this respect, the REST-for-physics framework, conceived at, and mostly developed at, CAPA, has been adopted as the software framework of IAXO and during 2020 has been substantially expanded and strengthened, to the point of facing its first public release in 2021. Finally, CAPA also concentrates the radiopurity efforts of the collaboration, with an active program of screening measurements for the detector groups of the collaboration. During 2020, the collaboration has finished an important paper on the BabyIAXO conceptual design, that will appear published in 2021.

CAPA also participates in the RADES project, that since a few years ago is exploring options to integrate RF-cavity-based setups, potentially sensitive to dark matter axions, in existing magnets like CAST, and, in the future, in BabyIAXO. In 2020 a second phenomenological article on the concept of filter-like structures (array of cavities coupled with irises) was published, and the first physics analysis with data taken in CAST in 2018 completed. The latter will presumably appear published in 2021. A very important milestone is a first preliminary concept of a cavity setup suitable for the geometry of the BabyIAXO magnet.

3.1.3 ANAIS-112 Experiment (LSC)

ANAIS-112 is an experiment that is being carried out in the LSC, which aims to confirm or refute the controversial result of the DAMA / LIBRA experiment, at the Gran Sasso national laboratory, which has observed an annual modulation in the detection rate compatible with that expected for WIMPs. The experiment, consisting of 112.5 kg of ultrapure sodium iodide scintillators, started data taking in August 2017 and has a high potential for dark matter discovery with five years of data if the modulation signal observed by DAMA / LIBRA is due to WIMPs.

ANAIS-112 data taking at Canfranc Underground Laboratory has been pro-

gressing smoothly along 2020, without affection from the country's alarm state and the complicated sanitary situation. ANAIS-112 duty cycle is excellent with more than 94% of live time for the full detection mass: 112.5 kg.

Moreover, we have started a collaboration to measure the seasonal variation of the neutron flux at Canfranc Underground Laboratory, HENSA-ANAIS, which started taking data underground in summer 2020.

i) ANAIS-112 annual modulation analysis status

ANAIS-112 results corresponding to two years of data were going to be presented along 2020 in some of the most important international conferences and workshops. We had been invited to Moriond, UCLA-DM, IDM2020-Vienna, DM2020-Santander, VULCANO, etc. Unfortunately, all of them were cancelled because of the COVID-pandemics.

In August 2020, three years of data were completed, starting the annual modulation analysis for the accumulated exposure. Preliminary results were presented in an invited Seminar at CIEMAT on September 2020, but more elaborated final results were ready in 2021, posted in arXiv in March 2021, producing strong impact in the field. They have been accepted for publication in Physical Review D.

ii) Na/I quenching factors measurement analysis

The measurements carried out in 2018 at Triangle Universities Nuclear Laboratory (Duke, US) on several crystals of sodium iodide made by the same provider than ANAIS crystals have been under analysis since then. In 2020, this analysis, in collaboration with researchers from Duke, Yale and Chicago Universities, has progressed and results will be ready soon. Quenching factors uncertainties are the most relevant of the possible systematic effects to be taken into consideration for the comparison between DAMA/LIBRA and other experiments using the same target. We expect these results to appear in 2021.

iii) Beyond ANAIS-112

Several lines of research are open to go beyond the present sensitivity of ANAIS-112. Two complementary lines are being followed aiming at reducing the energy threshold and improving the filtering of noise events at low energy, and at reducing the internal radioactive background of the sodium iodide crystals. First, a test-bench for testing SiPMs and searching for their application to the optical

readout of sodium iodide crystals has been setup in Zaragoza. In this line, SiPMs from DarkSide Collaboration to be used in DArT are also being tested. Second, it has been launched a new collaboration to grow ultra-pure sodium iodide crystals in underground environment at the Canfranc Underground Laboratory with our participation.

3.2 High Energy (Theory)

3.2.1 Simulation of axion strings and dark matter (DM).

We have implemented a number of extra features in the code and performed many simulations in the supercomputers of the MPG. In particular, we have worked to improve the precision on the determination of the axion-spectrum radiated by strings (still unpublished), incorporated a Schrödinger-Poisson solver for the last stage of the simulations and incorporated gravity. In 2019 we published the first simulations of Axion minicluster halos in collaboration with the Göttingen group. In 2020 we had to revise our paper to justify our choice of approximation on the initial conditions and realised that they were close to being valid so we used the improvements to study the effects of the velocities and the paper was published in Physical Review Letters. We build a collaboration with the group of D. Marsh to study the opportunities to have microlensing with the heaviest and densest halos with results expected in 2021. Late 2020, B. Schwabe joined the group, and we started to develop AMR simulations of axion strings with AMReX. We compared results of different codes in the most realistic simulations and build the necessary code to provide boosted sensitivity to string tension. Calculations continue as of 2021.

Our group supports from the theoretical side several experiments searching for the QCD axion and axion-like particles. We have continued supporting the MADMAX collaboration in the design and simulation of the booster (the most novel part), concluding with a publication.We have been present in all collaboration meetings updating the theory highlights. In parallel, we have worked together with some other groups in the evaluation of the experimental uncertainties of the solar axion flux and the scenarios in the case of a detection. The FUNK experiment has finally released its experimental results of hidden photon DM improving sensitivity over the previous existing experiments.

3.2.2 Lattice QCD simulations

Our group has been working on several aspects of this line of research in 2020. We explored the possibility of improving on a purely gluonic determination of the strong coupling constant, based on the calculation of the gluon and ghost propagators on the lattice, using very large lattices made public by the MILC collaboration. This preliminary work was included in a PhD thesis. We continued to work on the interplay between topology and QCD. In particular, we introduced a possible mechanism, different from Goldstone's theorem, based on the anomalous axial U(1) symmetry, to produce massless bosons in the chiral limit which will appear in a publication in early 2021. We also continue with our long term project to study QCD with a theta term. We have implemented a geometric formulation for the topological charge and are testing it to check how it compares with more usual formulations. We also continue our study of non standard phases in quantum field theory models.

3.2.3 Lepton-flavour universality

The experimental measurements on flavour physics, in tension with Standard Model predictions, exhibit large sources of lepton-flavour universality violation. We have performed an analysis of the effects of the global fits on the Wilson coefficients assuming a model independent effective Hamiltonian approach, by including a set of different scenarios in which the new physics contributions to the Wilson coefficients are present in one, two or three of the Wilson coefficients at a time. We have compared the results of a global fit with respect to two cases: the Standard Model and the more general case in which new physics modifies three independent Wilson coefficients. The last mentioned scenario is the favoured one for explaining the tension between Standard Model predictions and B-physics anomalies, but a specific more restricted scenario can provide similar goodness with a smaller set of free parameters. An analysis of the implications of leptoquark models is in progress.

3.2.4 UV completion of gauge theories with higher derivatives

High derivatives can dramatically change the behaviour of gauge theories at high energies. We have explored the effects of UV completions of gauge theories by means higher derivative terms.

The requirement of asymptotic freedom imposes very stringent constraints that are only satisfied by a small family of higher derivative theories. If the number of

derivatives is large enough ($n > 4$), the theory is strongly interacting both at the extreme infrared and ultraviolet regimes, whereas it remains asymptotically free for a low number of extra derivatives ($n \leq 4$). In all cases the theory improves its ultraviolet behaviour leading in some cases to ultraviolet finite theories with vanishing β-function. The usual consistency problems associated to the presence of extra ghosts in higher derivative theories may not harm asymptotically free theories because in that case the effective masses of such ghosts are running to infinity in the ultraviolet limit.

3.2.5 Quantum gravity phenomenology

From a theoretical perspective we have explored different possible implications of a theory of quantum gravity, including the modification of the notion of spacetime for a multiparticle system, the locality of interactions, the relation between a deformation of the kinematics and a nontrivial geometry of momentum space, or the modification of the transition from a classical to a quantum theory.

From a phenomenological perspective we have proposed the emergence of a new energy scale much lower than the energy scale of the classical theory of gravity (Planck scale) as a low energy footprint of quantum gravity fluctuations and we have taken the first steps in studying the possible observable effects of this new scale in the transparency of the universe to very high energy gamma rays.

3.3 Astrophysics and cosmology

i)Type Ia SNe progenitors.

We have continued our radio follow-up of nearby (D $<$ 25 Mpc), newly discovered thermonuclear runaway supernovae (aka Type Ia Sne), aimed at shedding light on their progenitor scenario. We obtained some of the deepest radio luminosity limits of SNe Ia ever. Those limits allow us to rule out many single-degenerate scenarios (i.e., involving the explosion of a white dwarf with a *normal*, non-degenerate star as a companion in a binary system), which would seem to favor a double-degenerate scenario, where the white dwarf explodes in a system whose companion star is also another white dwarf. However, the microphysics involved is still relatively poorly constrained, and the conclusions heavily depend on it, mainly via the postshock magnetic energy density. Those results have been published partially in several Atels (Astronomers' telegrams) and an ApJ 2020 paper.

We continue to be successful in getting observing time from state-of-the-art radio interferometer facilities across the world, including the e-MERLIN network in UK, the EVN in Europe and Asia, the ATCA in Australia, and the GMRT in India.

ii) The future of transient studies with the European VLBI Network

Members of CAPA were asked to coordinate the chapter on transient studies with the European very-long-baseline interferometry (VLBI) network, aimed at building up a roadmap for the decade 2020-2030 with this array. Members of CAPA also wrote the section on core-collapse supernovae and Type Ia SNe. Probing star-planet interaction with radio observations. Our group has started a new line of research, aimed at unveiling exoplanets via radio observations. We have been successful in getting competitive time from the most sensitive radio interferometer at cm-wavelengths, the recently finished MeerKAT array in South Africa. Our approved project is for observations of the most nearby star-planet system, Proxima–Proxima b. The observations were approved last December 2020, and have just been carried out in April 2021.

3.4 Other activities

Members of the research team took part on the collaborative effort MECHANICAL VENTILATOR MILANO aiming at designing a simple ventilation system for mass scale production in order to fight the shortage of ventilators in health care produced by the COVID-19 pandemicss.

4 New research grants

This section includes the projects leaded by CAPA members that obtained grants from different funding agencies via competitive programs.

4.1 New grants in 2020

1. **El experimento ANAIS-112 y nuevas líneas de investigación para la detección de sucesos poco probables en el Laboratorio Subterráneo de Canfranc**. Agencia Estatal de Investigación PID2019-104374GB-I00 (2020-2023). IP: María Luisa Sarsa (CAPA) y María Martínez (CAPA).

2. **Actividades de coordinación de la construcción de BabyIAXO, construcción de los detectores de rayos-X del experimento y contribuciones relacionadas**. Agencia Estatal de Investigación PID2019-108122GB-C31. IP: Igor G. Irastorza (CAPA) y Gloria Luzón (CAPA).

3. **Grupo Teórico de Altas Energías**, Grupo de Referencia DGA-FSE, 2020-E21-17R (2020-2022, 17 investigadores). IP: Manuel Asorey (CAPA).

4. **Física Nuclear y Astropartículas**, Grupo de Referencia DGA-FSE, 225352 E27-20R (2020-2022, 18 investigadores). IP: Gloria Luzón (CAPA).

5. **Nanosistemas con potenciales aplicaciones en Seguridad y Defensa**, Centro Universitario de la Defensa, CUD20-02 (2021). IP: Inés Cavero (CAPA).

6. **Respirador MVM-Aragón**, U. de Zaragoza OTRI 2020/0273 COVID19-IT3. IP: Gloria Luzón (CAPA).

4.2 Other current research grants

- Research Networks

  1. **Red CONSOLIDER "MultiDark"** – MINECO FPA2017-90566-REDC (2018 – 2020). IP: Carlos Muñoz, Universidad Autónoma de Madrid. (María Luisa Sarsa, CAPA).

  2. **Red temática de física de partículas** – MINECO FPA2017-90714-REDT (2018 – 2021). IP: Igor G. Irastorza, CAPA.

  3. **LATTICENET: Red Española de Lattice Gauge theory** – RED2018/102504-T. IP: Vicente Azcoiti, CAPA.

  3. **RENATA: Red Nacional Temática de Astropartículas** – RED2018/102661-T. IP: Carlos Delgado, CIEMAT. (Javier Redondo, María Martínez, CAPA).

- International Grants

  1. **Towards the detection of the axion with the International Axion Observatory**, European Research Council Advanced Grant (2018–2023). IP: Igor G. Irastorza, CAPA.

  2. **Quantum gravity phenomenology in the multi-messenger approach** – European Cooperation, COST Action CA18108 (2019–2023). IP ("Action Chair"): José M. Carmona, CAPA.

  3. **InvisiblesPlus** – European Cooperation, MSCA-RISE Action 690575 (2016–2020). IP: Belén Gavela (IFT, Madrid) (José M. Gracia, CAPA).

4. **Connecting insights in fundamental physics** – FUNDAMENTAL-CONNECTIONS, COST Action CA1510.8 (08/04/2016-07/04/2020). IP: A. Weiler (TUM, Munich) (Manuel Asorey is member of the Management Committee).

5. **Large area high-granularity segmented-mesh microbulk for future rare event searches**, RD51 CERN competitive call (2020-2022) IP: Javier Galán

- Nacional Grants

  1. **Búsquedas de materia oscura en la frontera de baja masa**, – MINECO FPA2016-76978-C3-1-P (2016–2020). IP: Igor G. Irastorza, CAPA.

  2. **Comprobación de la señal de DAMA/LIBRA con ANAIS-112 en el Laboratorio Subterráneo de Canfranc** – MINECO/FEDER FPA2017-83133-P (2018–2020). IP: María Luisa Sarsa, CAPA.

  5. **Más allá de los modelos estándar: simetría, gravedad y materia oscura** – MINECO/FEDER, PGC2018-095328-B-I00 (2019–2021). IP: Eduardo Follana and Javier Redondo, CAPA.

  6. **Interacción Física-Tecnología-Matemáticas: métodos geométricos modernos** – MINECO/FEDER, PGC2018-098265-B-C31 (2019–2021). IP: Eduardo Martínez (UZ) (José F. Cariñena, CAPA).

  7. **Sistemas basados en nanoestructuras metálicas con potenciales aplicaciones en Seguridad y Defensa** – Centro Universitario de la Defensa, CUD19-11 (2020). IP: Inés Cavero, CAPA.

  8. **Campos cuánticos string-locales** – Universidad de Costa Rica, 820–B8–225 (2018–2020). IP: Joseph C. Várilly (José M. Gracia, CAPA).

5 Grants for outreach activities

Some outreach grants with participation of CAPA members also obtained public support during 2020. The main objective of these activities was the promotion of scientific culture.

1. **Activities of Unidad de Cultura Científica de la Universidad de Zaragoza**.FECYT. Ref.: FCT-19-14956 (Programa de Cultura Científica y de la

Innovación). July 2020 - June 2021 IP: Vicerrectorado de Investigación (Universidad de Zaragoza).

2. **Hola, somos científicas II**. FECYT. Ref.: FCT-18-13366 (Programa de Cultura Científica y de la Innovación) April 2019 - June 2020 IP: María Elisabet Pires Ezquerra (Universidad de Zaragoza).

3. **Actividades de divulgación de la UCC de la Universidad de Zaragoza** FECYT. Ref.: FCT-18-13648 (Programa de Cultura Científica y de la Innovación). April 2019 - June 2020 IP: Vicerrectorado de Investigación (Universidad de Zaragoza).

4. **II Marathon de Astropartículas. Detectores de rayos cósmicos en colegios de ámbito nacional**. FECYT. Ref.: FCT-18-13747 (Programa de Cultura Científica y de la Innovación) April 2019 - June 2020 IP: María Dolores Rodríguez Frías (Universidad de Alcalá).

6 Publications

6.1 Publications in refereed journals (2020)

In an annex we include the publications of CAPA members that appeared in scientific journals indexed in the Web of Science (WoS) database of *Clarivate Analytics* in 2020. In total, 122 publications, without conference contributions. Figure 1 illustrates in a graphic the journals where the publications appeared. The journals with more publications of CAPA members are *Journal of High Energy Physics* (22), *European Physical Journal C* (17), *Physical Review D* (14), *Physics Letters B* (10), *Physical Review Letters* (9), all of them Q1 within their categories in 2019 according to the Journal Citation Reports (JCR) database.

6.2 Quality indicators of scientific production over the last 10 years)

The total number of publications of CAPA members in the last 10 years is 871, according to the WoS databas. Those papers received 19.541 citations, with a mean of 22.44 citations/article and h-index of 61. Figure 2 shows the evolution of the number of publication and citations along the last 10 years according to the same database.

Figura 1: Graphics representing journals where the articles of CAPA members were published in 2020, according to the WoS database.

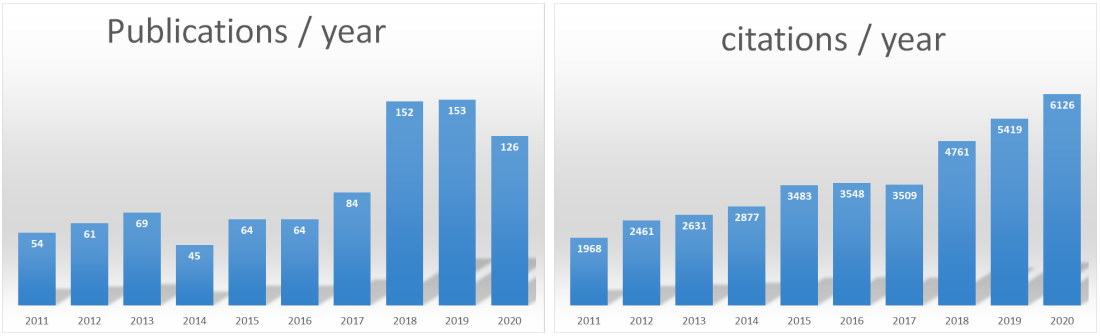

Figura 2: Left: CAPA members publications along the last 10 years. Right: evolution of citations of CAPA members papers along the last 10 years.

7 Organization of conferences, workshops and congresses

- COST First Annual Conference, Marrc 2020, U. de Granada. Co-organized by: José M. Carmona, CAPA.
  `https://indico.capa.unizar.es/event/2/`
- "Dark Matter 2020", IFCA, Santander, June 2020 (delayed due to COVID19 pandemics). Members of CAPA in the Scientific Organizing Committee: María Luisa Sarsa.
- "Latin-American Conference on High Energy Physics: Particles and Strings III", La Habana, Julio 2020 (delayed due to COVID19 pandemics). Organized by: Siannah Peñaranda, CAPA.
- Workshop on feebly-interacting particles, CERN, August-September 2020. CAPA member in the Organizing Committee: Igor G. Irastorza, CAPA.
- IV International Workshop on Information Geometry, Quantum Mechanics and Applications, Universidad Carlos III, February 2020. CAPA member in the Organizing Committee: Manuel Asorey.
- XV EITA Research Meeting in Approximation Theory Zaragoza (online), 5-6 November 2020 Co-organized by Luis Velázquez
  `http://eventos.unizar.es/go/xveita2020`
- XLVIII International Meeting on Fundamental Physics 2021, organized by CAPA and originally planned for June 2020 in Centro de Ciencias de Benasque Pedro Pascual (postponed to September 2021 due to COVID19 pandemics).
- Saturnalia 2020, 21-22 December 2020, CAPA (online). Organized by Javier Redondo and Siannah Peñaranda, CAPA.
  `https://indico.capa.unizar.es/event/12/`

8 Seminars and colloquia

8.1 *Martes Cuantico* seminars

- *Inteligencia Artificial y Ética*, José Ignacio Latorre (U. de Barcelona), 13

January 2020.

- *Huygens, la Helena de la geometría y el aprisionamiento del tiempo*, Carlos Farina (Universidade Federal do Rio de Janeiro), 3 March 2020.

8.2 CAPA seminars

- Filiberto Ares (International Institute of Physics, Natal, Brasil), January 2020.

- "Local and nonlocal models of quantum gravity", Ilya L. Shapiro (Universidade Federal de Juiz de Fora, Brasil), 5 February 2020.

- "Anomaly-induced effective action of gravity and some important applications". Ilya L. Shapiro (Universidade Federal de Juiz de Fora, Brasil), 5 Febrero 2020.

- Kenaichi Saikawa (U. de Kanazawa), February 2020.

- "Twisted Torus bundle and U(1) symmetries of the Supermembrane theory in a constant flux background", María Pilar García del Moral (U. de Antofagasta, Chile), 13 February 2020.

- Patricia Abrantes y Yuri Muniz (Universidade Federal do Rio de Janeiro), February 2020.

- Patricia Vitale (Università degli Studi di Napoli Federico II), March 2020.

- P. Abrahantes y Y. Muniz (Universidade Federal do Rio de Janeiro, Brasil), Mars 2020.

- Bodo Schwabe (Universität Göttingen), September 2020.

8.3 CAPA colloquia

- J. M. Senovilla, U. del País Vasco: "Hoyos negros y singularidades: Nobel de Física", 26 November 2020.

9 Training activities

9.1 Ph.D. theses

1. José Manuel Relancio: "Beyond special relativity and the notion of spacetime", *cum laude*, April 2020. Supervisors: José L. Cortés (CAPA) and José M. Carmona (CAPA).

9.2 Master theses

1. Luis A. Obis: "Estudio de fondo y señal en BabyIAXO", matrícula de honor, Julio 2020. Supervised by: Javier A. Galán (CAPA) and Gloria Luzón (CAPA).

2. David Díez: "Análisis de una señal de WIMPs de baja masa en el experimento TREX-DM", 2020. Supervised by: Igor G. Irastorza, CAPA.

3. Fernando Ezquerro Sastre: "Energía Casimir en teorías gauge no abelianas", 2020. Supervised by: Manuel Asorey, CAPA.

9.3 New Master in Physics of the Universe

In 2020, Zaragoza University approved a new master entitled *Física del Universo: Cosmología, Astrofísica, Partículas y Astropartículas*. The master was launched by CAPA, Centro de Estudios de Física del Cosmos de Aragón and Laboratorio Subterráneo de Canfranc, with the collaboration of Centro de Ciencias de Benasque Pedro Pascual. It will start in the academic year 2021/2022 and it will be taught both in English and Spanish promoting the training of students in the following research areas:

- Direct dark matter detection
- Modelling dark matter in galaxies
- Axions physics: theory and detection
- Neutrino physics: doble beta decay and neutrino mass
- Radioactivity and low background techniques
- Development of particle detectors

- Lattice gauge theories
- Field theory applications in quantum information and topological materials
- Standard model phenomenology and beyond Standard Model physics
- Theory and phenomenology of quantum gravity
- Cosmology and galaxy evolution

10 Outreach activities

10.1 Group activities

- *"Maratón de astropartículas 2020"*: planetario de Huesca, february 2020. Organized by María Luisa Sarsa and María Martínez within activities related to FECYT grant "Maratón de Astropartículas" and with the participation of CAPA members: Susana Cebrián, Alfonso Ortiz, David Cintas and Iván Coarasa.

  Documentary projection:

  - "Phantom of the Universe",

  - "Visita virtual al Laboratorio Subterráneo de Canfranc"

  Public talks:

  - Un cazador de neutrinos en el Polo Sur, por Carlos Pobes, CAPA

  - Detectando la radiación cósmica, Luis del Peral, U. Alcalá

  - ¿Qué se investiga en el Laboratorio Subterráneo de Canfranc? Carlos Peña-Garay, LSC

  - ¿Sopla el viento de materia oscura en el Pirineo? María Luisa Sarsa, CAPA

- *"Noche Europea de lxs investigadorxs"*, online, november 2020. Within the programmed activities by CPAN and CIEMAT for *la noche de los investigadores*, which due to COVID19 pandemics went online. It included a virtual visit to Laboratorio Subterráneo de Canfranc which besides the participation of people from LSC and researchers from CIEMAT counted with the participation of different CAPA members: Susana Cebrián, Gloria Luzón, Theopisti Dafni y María Martínez.

- "Dark matter day", October 2020. Usually this event organized by CAPA was held at Universidad de Zaragoza including a gymkhana open to all ages. This year due to the COVID19 pandemics it was replaced by a "Twitter takeover": sending Twitter messages from CAPA and ANAIS, TREX-DM and IAXO experiments with images and short videos.

- *"Hands on CERN"*, March 2020, within an international initiative leaded by CERN the activity was aimed to bring particle physics closer to high school students. The activity was carried out at Facultad de Ciencias of Universidad de Zaragoza.

10.2 Lectures

- Lecture: "De los núcleos atómicos a las galaxias: logros de científic@s", Barbastro, Aula Magna. (María Luisa Sarsa, CAPA).

- Lecture of Academia Nacional de Ciencia de Costa Rica: "El premio Nobel de Física 2020", November 2020. (José M. Gracia, CAPA).

10.3 Outreach publications

- Maratón de Astropartículas 2020, Digital magazine conCIENCIAS # 25, Facultad de Ciencias, May 2020, Universidad de Zaragoza (María Martínez and María Luisa Sarsa, CAPA).

- "Muerte por materia oscura", Revista Española de Física, section "Temas de Física", June 2020 (María Luisa Sarsa, CAPA).

10.4 Other outreach activites

- Performance with the stand up scientist group RISArchers: 11/02/2020, Mercado Central de Zaragoza, within the organized activities of UZ to celebrate the International Day of Women and Girls in Science (María Luisa Sarsa).

- "La ciencia que se cuenta", May 2020, initiative of Unidad de Cultura Científica de la Universidad de Zaragoza (María Luisa Sarsa). 2 minutes recording broadcasted on Twitter. (online: `https://twitter.com/i/status/1263030838196867073`)

- Chapter 89 of podcast "La tengo pequeña": ¿Cómo se demuestra una materia que ni se ve, ni se siente y ni se oye? Bienvenidos al fascinante mundo de la "materia oscura" (María Luisa Sarsa, ANAIS, experiment). 22/05/2020 (online `link`)

- Twitter campaign in February 2020 commemorating the International Day of Women and Girls in Science (11/02/2020), highlighting the achievements of female scientists, in the framework of the COST Acion CA18408. Coordinated by José Manuel Carmona (CAPA) and Mariam Tortola (CSIC).

11 Research stays

11.1 CAPA members

- Vicente Azcoiti, Laboratori Nazionale del Gran Sasso, INFN, Italy. January 2020.

- José M. Gracia, Universität Göttingen, Germany. January 2020.

- Eduardo Follana, University of Glasgow, United Kingdom. January-February 2020.

11.2 Guest visitors

- José Ignacio Latorre, UB, Barcelona. January 2020.

- Ilya Shapiro, Universidade Federal da Luz da Fora, Brasil. February 2020.

- Carlos Farina, Universidade Federal do Ro de Janeiro. February-March 2020.

- Maria Pilar Garcia del Moral, U. Antofagasta, February-March 2020.

- Patrizia Vitale, Universitá degli Studi di Napoli Federico II, Italia, March 2020.

- Bodo Schwabe, Universität Göttingen, Alemania. September 2020.

12 Collaborations with other centers and entities

12.1 International collaborations

- **Aproximación Constructiva: Análisis, Algoritmos y Aplicaciones**, MINECO/FEDER (2018–2021). Participant entities: U. de Almería, U. de Zaragoza, University of California at Berkeley, Baylor University. IP: D. Andrei Martínez. (Luis Velázquez, CAPA).

12.2 National collaborations

- **Polinomios Ortogonales: Métodos Analíticos y Funcionales, Aplicaciones clásicas y cuánticas**, JUNTA DE ANDALUCÍA/FEDER/UAL (2019–2021). Participant entities: U. de Almería, U. de Zaragoza. IP: D. Juan J. Moreno. (Luis Velázquez, CAPA).

13 Editorial boards and scientific committees

13.1 Editorial boards

- *Reports on Mathematical Physics*, *International Journal of Geometric Methods in Modern Physics*, *Advances in Mathematical Physics*, *ISRN Mathematical Physics*, *Frontiers in Physics* (Mathematical Physics), *Symmetry*. (José F. Cariñena, CAPA).

  Frontiers of Mathematical Physics, *Symmetry*, *International Journal of Modern Physics A*, *Modern Physics Letters A* (Manuel Asorey, CAPA).

- Guest editors of *Symmetry* (José L. Cortés and José M. Carmona, CAPA).

- Topic Editorial Board of *Symmetry* (Inés Cavero, CAPA).

13.2 Scientific committees

- Evaluation of research INFN (Italy) projects (Manuel Asorey and José M. Carmona, CAPA).

- Evaluation of research projects for the Croatian Science Foundation (Croacia) (José M. Carmona, CAPA).
- "APPEC Committee for direct detection of dark matter" (Susana Cebrián, CAPA).
- Evaluation Committee of Ramón y Cajal 2019 program, FIS-RyC-219,AEI (María Luisa Sarsa and Siannah Peñaranda, CAPA).
- Programa de doctores de excelencia de la Generalitat valenciana, subdivisión de coordinación y evaluación (Siannah Peñaranda, CAPA).
- Agencia de Calidad Universitaria de Galicia (Igor G. Irastorza, CAPA).
- Consejo Académico del Instituto de Estudios Avanzados de la Universidad de Costa Rica (UCREA) (José M. Gracia, CAPA).
- Evaluator of Italy research system: ANVUR (Manuel Asorey, CAPA)
- Evaluator of Agencia FONDECYT CONCYTEC (Perú) (Manuel Asorey, CAPA)
- Projects review of European Research Council (ERC) (Igor G. Irastorza, CAPA).
- Board of mock interviews to candidates of ERC grants(Igor G. Irastorza, CAPA).
- Review of the postdoctoral program Lisa Meitner (Austrian Science Fund.) (Igor G. Irastorza, CAPA).

14 Report of activities of the Laboratorio de Bajas Actividades (LABAC)

The LABAC Radioactivity Measurement Service offers to the university community and other research centers and companies, facilities that allow the radiological characterization of organic and inorganic samples. Since February 2019, LABAC has accreditation by ENAC N^0 1324 / LE2490 for the measurement of total alpha and total beta activity in drinking and continental waters, according to the UNE-EN ISO / IEC 17025 standard. In 2020, the corresponding follow-up auditor was superseded and the following analyses were carried out:

1. Analysis carried out for the Food Safety and Environmental Health Service of the Government of Aragón. A total of 42 samples were analyzed. The measurements carried out were determination of the total alpha activity index (9 samples), determination of the total beta activity index (9 samples) and determination of the radon concentration (24 samples).

2. Analysis performed for the Nuclear Safety Council (CSN) according to the sampling program established in the Agreement with the University of Zaragoza on an Environmental Radiological Surveillance Program (Network of Sampling Stations). During the 2019-2020 sampling campaign, LABAC has participated in the following intercomparisons exercises:

   - CSN-CIEMAT Intercomparison Exercise (2019-2020) in drinking water and marine water.
   - Intercomparison Exercise of Continuous Measurement Equipment of radon concentration in air under different environmental conditions. Nuclear Safety Council (CSN) and the Universitat Politécnica de Catalunya (UPC).
   - Intercomparison Exercise CSN-CIEMAT (2020) in two soil samples.

3. Radiologic Environment Control in the Laboratorio Subterráneo de Canfranc (LSC). During 2020, the following studies have been carried out: analysis of physical-chemical-physical parameters (20 samples / 11 parameters) and microbiological parameters (20 samples / 3 pairs)), determination of the indices of total alpha and beta activity in water samples from different locations (28 samples), gamma spectrometry analysis of atmospheric filters and cartridges of active carbon for the determination of I-131 (3 samples) and control of the concentration of Radon continuously by using Alphaguard portable equipment (6 locations/month). In addition, the measurement of equivalent environmental dose H*(10) has been carried out by using two Panasonic UD-802A thermoluminescent dosimeters (TLD) in 60 samples.

15 Other activities

- Participation in the organization of Olimpiada Aragonesa de Física (María Luisa Sarsa, CAPA).
- Elaboration of questionnaire for the access exam for sanitary specialization in Radiofísica Hospitalaria, 2020. (Siannah Peñaranda, CAPA).

16 Incorporation of new members

During 2020 CAPA incorporated the following new members:

- Ph.D. students: David Cintas Casas, David Martínez Crespo, Luis Antonio Obis Aparicio, Óscar Pérez Lázaro, Fernando Ezquerro Sastre.
- Post-doctoral researchers: Konrad Altenmüller.

A Appendix: Publications

1. Aaboud, M. *et al.* A search for the Zγ decay mode of the Higgs boson in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *Physics Letters B* **809** (2020).
2. Aaboud, M. *et al.* ATLAS data quality operations and performance for 2015-2018 data-taking. *Journal of Instrumentation* **15** (2020).
3. Aaboud, M. *et al.* Combined measurements of Higgs boson production and decay using up to 80 fb^{-1} of proton-proton collision data at $\sqrt{s}$=13 TeV collected with the ATLAS experiment. *Physical Review D* **101** (2020).
4. Aaboud, M. *et al.* Fluctuations of anisotropic flow in Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV with the ATLAS detector. *Journal of High Energy Physics* **1** (2020).
5. Aaboud, M. *et al.* Higgs boson production cross-section measurements and their EFT interpretation in the 4l decay channel at $\sqrt{s}$=13 TeV with the ATLAS detector. *European Physical Journal C* **80** (2020).
6. Aaboud, M. *et al.* Measurement of Azimuthal Anisotropy of Muons from Charm and Bottom Hadrons in pp Collisions at $\sqrt{s}$=13 TeV with the ATLAS Detector. *Physical Review Letters* **124** (2020).
7. Aaboud, M. *et al.* Measurement of long-range two-particle azimuthal correlations in Z-boson tagged pp collisions at root s=8 and 13 TeV. *European Physical Journal C* **80** (2020).
8. Aaboud, M. *et al.* Measurement of the transverse momentum distribution of Drell-Yan lepton pairs in proton-proton collisions at $\sqrt{s}$=13TeV with the ATLAS detector. *European Physical Journal C* **80** (2020).
9. Aaboud, M. *et al.* Measurements of the Higgs boson inclusive and differential fiducial cross sections in the 4l decay channel at root s=13 TeV. *European Physical Journal C* **80** (2020).
10. Aaboud, M. *et al.* Measurements of the production cross-section for a Z boson in association with b-jets in proton-proton collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *Journal of High Energy Physics* **7** (2020).
11. Aaboud, M. *et al.* Measurements of top-quark pair spin correlations in the e mu channel at $\sqrt{s}$=13 TeV using pp collisions in the ATLAS detector. *European Physical Journal C* **80** (2020).

12. Aaboud, M. *et al.* Performance of electron and photon triggers in ATLAS during LHC Run 2. *European Physical Journal C* **80** (2020).

13. Aaboud, M. *et al.* Reconstruction and identification of boosted di-tau systems in a search for Higgs boson pairs using 13 TeV proton-proton collision data in ATLAS. *Journal of High Energy Physics* **11** (2020).

14. Aaboud, M. *et al.* Search for $t\bar{t}$ resonances in fully hadronic final states in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *Journal of High Energy Physics* **10** (2020).

15. Aaboud, M. *et al.* Search for a scalar partner of the top quark in the all-hadronic $t\bar{t}$ plus missing transverse momentum final state at $\sqrt{s}$=13 TeV with the ATLAS detector. *European Physical Journal C* **80** (2020).

16. Aaboud, M. *et al.* Search for dijet resonances in events with an isolated charged lepton using $\sqrt{s}$=13 TeV proton-proton collision data collected by the ATLAS detector. *Journal of High Energy Physics* **6** (2020).

17. Aaboud, M. *et al.* Search for direct production of electroweakinos in final states with missing transverse momentum and a Higgs boson decaying into photons in pp collisions at root s=13 TeV with the ATLAS detector. *Journal of High Energy Physics* **10** (2020).

18. Aaboud, M. *et al.* Search for displaced vertices of oppositely charged leptons from decays of long-lived particles in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *Physics Letters B* **801** (2020).

19. Aaboud, M. *et al.* Search for electroweak production of charginos and sleptons decaying into final states with two leptons and missing transverse momentum in root s=13 TeV pp collisions using the ATLAS detector. *European Physical Journal C* **80** (2020).

20. Aaboud, M. *et al.* Search for heavy diboson resonances in semileptonic final states in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *European Physical Journal C* **80** (2020).

21. Aaboud, M. *et al.* Search for Higgs Boson Decays into a Z Boson and a Light Hadronically Decaying Resonance Using 13 TeV pp Collision Data from the ATLAS Detector. *Physical Review Letters* **125** (2020).

22. Aaboud, M. *et al.* Search for light long-lived neutral particles produced in pp collisions at $\sqrt{s}$=13 TeV and decaying into collimated leptons or light hadrons with the ATLAS detector. *European Physical Journal C* **80** (2020).

23. Aaboud, M. *et al.* Search for new non-resonant phenomena in high-mass dilepton final states with the ATLAS detector. *Journal of High Energy Physics* **11** (2020).

24. Aaboud, M. *et al.* Search for new phenomena in final states with large jet multiplicities and missing transverse momentum using $\sqrt{s}$=13 TeV proton-proton collisions recorded by ATLAS in Run 2 of the LHC. *Journal of High Energy Physics* **10** (2020).

25. Aaboud, M. *et al.* Search for pairs of scalar leptoquarks decaying into quarks and electrons or muons in $\sqrt{s}$=13 TeV pp collisions with the ATLAS detector. *Journal of High Energy Physics* **10** (2020).

26. Aaboud, M. *et al.* Search for the HH -¿ $b\bar{b}b\bar{b}$ process via vector-boson fusion production using proton-proton collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *Journal of High Energy Physics* **7** (2020).

27. Aaboud, M. *et al.* Transverse momentum and process dependent azimuthal anisotropies in $\sqrt{s_{NN}}$=8.16 TeV p plus Pb collisions with the ATLAS detector. *European Physical Journal C* **80** (2020).

28. Aaboud, M. *et al.* Z boson production in Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV measured by the ATLAS experiment. *Physics Letters B* **802** (2020).

29. Aad, G. *et al.* Alignment of the ATLAS Inner Detector in Run 2. *European Physical Journal C* **80** (2020).

30. Aad, G. *et al.* Combination of searches for Higgs boson pairs in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *Physics Letters B* **800** (2020).

31. Aad, G. *et al.* Combination of the W boson polarization measurements in top quark decays using ATLAS and CMS data at $\sqrt{s}$=8 TeV. *Journal of High Energy Physics* **8** (2020).

32. Aad, G. *et al.* CP Properties of Higgs Boson Interactions with Top Quarks in the $t\bar{t}$H and tH Processes Using H -¿ $\gamma\gamma$ with the ATLAS Detector. *Physical Review Letters* **125** (2020).

33. Aad, G. *et al.* Determination of jet calibration and energy resolution in proton-proton collisions at s=8 TeV using the ATLAS detector. *European Physical Journal C* **80** (2020).

34. Aad, G. *et al.* Dijet Resonance Search with Weak Supervision Using $\sqrt{s}$=13 TeV pp Collisions in the ATLAS Detector. *Physical Review Letters* **125** (2020).

35. Aad, G. *et al.* Evidence for $t\bar{t}t\bar{t}$ production in the multilepton final state in proton-proton collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *European Physical Journal C* **80** (2020).

36. Aad, G. *et al.* Evidence for electroweak production of two jets in association with a Z gamma pair in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *Physics Letters B* **803** (2020).

37. Aad, G. *et al.* Measurement of azimuthal anisotropy of muons from charm and bottom hadrons Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV with the ATLAS detector. *Physics Letters B* **807** (2020).

38. Aad, G. *et al.* Measurement of differential cross sections for single diffractive dissociation in $\sqrt{s}$=8 TeV pp collisions using the ATLAS ALFA spectrometer. *Journal of High Energy Physics* **2** (2020).

39. Aad, G. *et al.* Measurement of isolated-photon plus two-jet production in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *Journal of High Energy Physics* **3** (2020).

40. Aad, G. *et al.* Measurement of soft-drop jet observables in pp collisions with the ATLAS detector at $\sqrt{s}$=13 TeV. *Physical Review D* **101** (2020).

41. Aad, G. *et al.* Measurement of the $t\bar{t}$ production cross-section in the lepton plus jets channel at $\sqrt{s}$=13 TeV with the ATLAS experiment. *Physics Letters B* **810** (2020).

42. Aad, G. *et al.* Measurement of the azimuthal anisotropy of charged-particle production in Xe+Xe collisions at $\sqrt{s_{NN}}$=5.44 TeV with the ATLAS detector. *Physical Review C* **101** (2020).

43. Aad, G. *et al.* Measurement of the Lund Jet Plane Using Charged Particles in 13 TeV Proton-Proton Collisions with the ATLAS Detector. *Physical Review Letters* **124** (2020).

44. Aad, G. *et al.* Measurement of the tt production cross-section and lepton differential distributions in e mu dilepton events from pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *European Physical Journal C* **80** (2020).

45. Aad, G. *et al.* Measurement of the $Z(\rightarrow \ell^+\ell^-)\gamma$ production cross-section in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *Journal of High Energy Physics* **3** (2020).

46. Aad, G. *et al.* Measurements of inclusive and differential cross-sections of combined $t\bar{t}$ and tW gamma production in the e μ channel at 13 TeV with the ATLAS detector. *Journal of High Energy Physics* **9** (2020).

47. Aad, G. *et al.* Observation and Measurement of Forward Proton Scattering in Association with Lepton Pairs Produced via the Photon Fusion Mechanism at ATLAS. *Physical Review Letters* **125** (2020).

48. Aad, G. *et al.* Observation of the associated production of a top quark and a Z boson in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *Journal of High Energy Physics* **7** (2020).

49. Aad, G. *et al.* Operation of the ATLAS trigger system in Run 2. *Journal of Instrumentation* **15** (2020).

50. Aad, G. *et al.* Performance of the ATLAS muon triggers in Run 2. *Journal of Instrumentation* **15** (2020).

51. Aad, G. *et al.* Performance of the missing transverse momentum triggers for the ATLAS detector during Run-2 data taking. *Journal of High Energy Physics* **8** (2020).

52. Aad, G. *et al.* Performance of the upgraded PreProcessor of the ATLAS Level-1 Calorimeter Trigger. *Journal of Instrumentation* **15** (2020).

53. Aad, G. *et al.* Search for chargino-neutralino production with mass splittings near the electroweak scale in three-lepton final states in $\sqrt{s}$=13 TeV pp collisions with the ATLAS detector. *Physical Review D* **101** (2020).

54. Aad, G. *et al.* Search for direct production of electroweakinos in final states with one lepton, missing transverse momentum and a Higgs boson decaying into two b-jets in pp collisions at root s=13 TeV with the ATLAS detector. *European Physical Journal C* **80** (2020).

55. Aad, G. *et al.* Search for direct stau production in events with two hadronic tau-leptons in $\sqrt{s}$=13 TeV pp collisions with the ATLAS detector. *Physical Review D* **101** (2020).

56. Aad, G. *et al.* Search for flavour-changing neutral currents in processes with one top quark and a photon using 81 fb^{-1} of pp collisions at $\sqrt{s}$=13 TeV with the ATLAS experiment. *Physics Letters B* **800** (2020).

57. Aad, G. *et al.* Search for Heavy Higgs Bosons Decaying into Two Tau Leptons with the ATLAS Detector Using pp Collisions at $\sqrt{s}$=13 TeV. *Physical Review Letters* **125** (2020).

58. Aad, G. *et al.* Search for heavy neutral Higgs bosons produced in association with b-quarks and decaying into b-quarks at $\sqrt{s}$=13 TeV with the ATLAS detector. *Physical Review D* **102** (2020).

59. Aad, G. *et al.* Search for Heavy Resonances Decaying into a Photon and a Hadronically Decaying Higgs Boson in pp Collisions at $\sqrt{s}$=13 TeV with the ATLAS Detector. *Physical Review Letters* **125** (2020).

60. Aad, G. *et al.* Search for Higgs boson decays into two new low-mass spin-0 particles in the 4b channel with the ATLAS detector using pp collisions at $\sqrt{s}$=13 TeV. *Physical Review D* **102** (2020).

61. Aad, G. *et al.* Search for long-lived neutral particles produced in pp collisions at $\sqrt{s}$=13 TeV decaying into displaced hadronic jets in the ATLAS inner detector and muon spectrometer. *Physical Review D* **101** (2020).

62. Aad, G. *et al.* Search for long-lived, massive particles in events with a displaced vertex and a muon with large impact parameter in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. *Physical Review D* **102** (2020).

63. Aad, G. *et al.* Search for Magnetic Monopoles and Stable High-Electric-Charge Objects in 13 Tev Proton-Proton Collisions with the ATLAS Detector. *Physical Review Letters* **124** (2020).

64. Aad, G. *et al.* Search for new resonances in mass distributions of jet pairs using 139 fb^{-1} of pp collisions at $\sqrt{s}$=13TeV with the ATLAS detector. *Journal of High Energy Physics* **3** (2020).

65. Aad, G. *et al.* Search for resonances decaying into a weak vector boson and a Higgs boson in the fully hadronic final state produced in proton - proton collisions at root s=13 TeV with the ATLAS detector. *Physical Review D* **102** (2020).

66. Aad, G. *et al.* Search for squarks and gluinos in final states with same-sign leptons and jets using 139 fb^{-1} of data collected with the ATLAS detector. *Journal of High Energy Physics* **6** (2020).

67. Aad, G. *et al.* Search for top squarks in events with a Higgs or Z boson using 139 fb^{-1} of pp collision data at root s=13 TeV with the ATLAS detector. *European Physical Journal C* **80** (2020).

68. Aad, G. *et al.* Searches for electroweak production of supersymmetric particles with compressed mass spectra in $\sqrt{s}$=13 TeV pp collisions with the ATLAS detector. *Physical Review D* **101** (2020).

69. Aad, G. *et al.* Searches for lepton-flavour-violating decays of the Higgs boson in $\sqrt{s}$=13 TeV pp collisions with the ATLAS detector. *Physics Letters B* **800** (2020).

70. Aad, G. *et al.* Test of CP invariance in vector-boson fusion production of the Higgs boson in the H $\rightarrow \tau\tau$ channel in proton-proton collisions at $\sqrt{s}$=13TeV with the ATLAS detector. *Physics Letters B* **805** (2020).

71. Aalseth, C. E. *et al.* Design and construction of a new detector to measure ultra-low radioactive-isotope contamination of argon. *Journal of Instrumentation* **15** (2020).

72. Aleta, A., de Arruda, G. F. & Moreno, Y. Data-driven contact structures: From homogeneous mixing to multilayer networks. *Plos Computational Biology* **16** (2020).

73. Aleta, A., Hu, Q., Ye, J., Ji, P. & Moreno, Y. A data-driven assessment of early travel restrictions related to the spreading of the novel COVID-19 within mainland China. *Chaos Solitons & Fractals* **139** (2020).

74. Aleta, A. & Moreno, Y. Evaluation of the potential incidence of COVID-19 and effectiveness of containment measures in Spain: a data-driven approach. *Bmc Medicine* **18** (2020).

75. Aleta, A. *et al.* Modelling the impact of testing, contact tracing and household quarantine on second waves of COVID-19. *Nature Human Behaviour* **4,** 964 (2020).

76. Alonso, J. L., Bouthelier, C., Castro, A., Clemente-Gallardo, J. & Jover-Galtier, J. A. Entropy and canonical ensemble of hybrid quantum classical systems. *Physical Review E* **102** (2020).

77. Alvarez Melcon, A. *et al.* Scalable haloscopes for axion dark matter detection in the 30 mu eV range with RADES. *Journal of High Energy Physics* **7** (2020).

78. Alves, L. G. A., Aleta, A., Rodrigues, F. A., Moreno, Y. & Amaral, L. A. N. Centrality anomalies in complex networks as a result of model over-simplification. *New Journal of Physics* **22** (2020).

79. Arenas, A. *et al.* Modeling the Spatiotemporal Epidemic Spreading of COVID-19 and the Impact of Mobility and Social Distancing Interventions. *Physical Review X* **10** (2020).

80. Asorey, M. & Santagata, A. The critical transition of Coulomb impurities in gapped graphene. *Journal of High Energy Physics* **8** (2020).

81. Azzolini, O. *et al.* CUPID-0: A double-readout cryogenic detector for Double Beta Decay search. *Nuclear Instruments & Methods A* **958** (2020).

82. Azzolini, O. *et al.* Search for neutrinoless double beta decay of ^{64}Zn and ^{64}Zn with CUPID-0. *European Physical Journal C* **80** (2020).

83. Bauza, F., Soriano-Panos, D., Gomez-Gardenes, J. & Floria, L. M. Fear induced explosive transitions in the dynamics of corruption. *Chaos* **30** (2020).

84. Bauza, F. *et al.* Analyzing the potential impact of BREXIT on the European research collaboration network. *Chaos* **30** (2020).

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