

FROM PARTICLES TO THE COSMOS

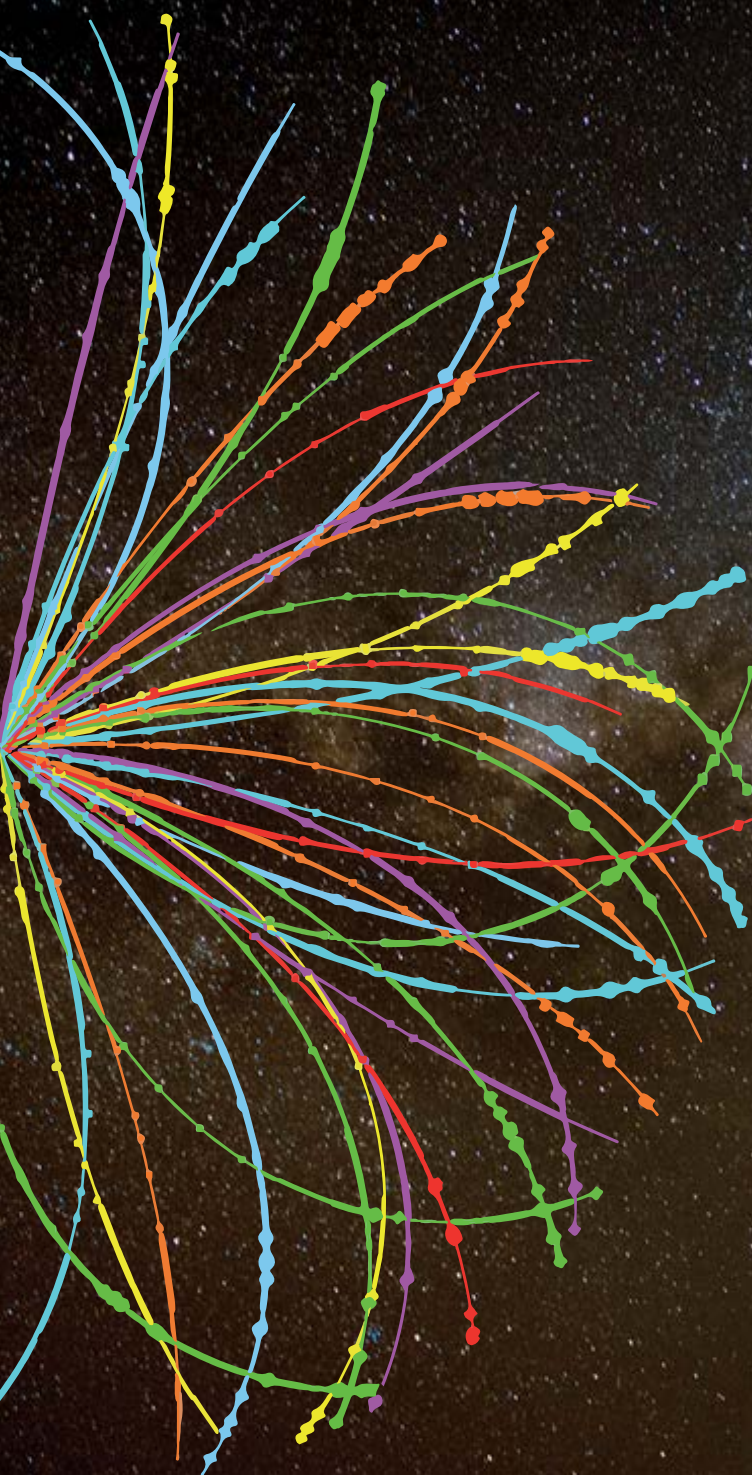
IFAE

Institut de Física
d'Altes Energies

Report
of Activities
Summary 2020

annualreport.ifae.es





FROM PARTICLES TO THE COSMOS

In 1991 the Institut de Física d'Altes Energies (IFAE) was founded as a consortium of the Generalitat de Catalunya and the Universitat Autònoma de Barcelona.

For almost 30 years we have been exploring the cosmic and high energy frontiers to address fundamental questions about our Universe.

IFAE

Institut de Física
d'Altes Energies



EXCELENCIA
SEVERO
OCHOA

BIST

Barcelona Institute of
Science and Technology

IFAE AT A GLANCE



founded in **1991**

150 people

three **divisions**: theory, experimental, technical; and administration

basic research in fundamental physics and
applied research in instrumentation, medical applications, and quantum computing technologies

research lines: Particle Physics, Astroparticle Physics, Cosmology, Medical Imaging, Physics Instrumentation and Quantum Computing Technologies

one large **engineering** group (30+ engineers and technicians)

collaboration in **10 international experiments** in high impact / leadership positions (ATLAS, MAGIC, DES, T2K, PAU, CTA, DESI, Euclid, LSST, Virgo)

facilities: chip packaging & assembly, clean rooms, shielded room, electronics labs, optical lab, quantum computing technologies lab, mechanical workshop (300 m²)

one data-processing centre: **PIC** (LHC Tier-1)

member of **Barcelona Institute of Science and Technology**

twice awarded with the **Severo Ochoa** accreditation of excellence (2012, 2016)



SCIENCE AT IFAE

At IFAE we conduct experimental and theoretical research at the frontiers of fundamental physics, namely in Particle Physics, Astrophysics and Cosmology.

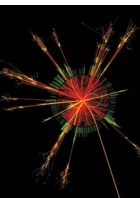
We are involved in the ATLAS project at the LHC, the T2K neutrino experiment in Japan, the MAGIC telescopes in La Palma, the Dark Energy Survey project in Chile, the Cherenkov Telescope Array in La Palma and Chile, the Virgo interferometer, among others.

We focus our research on the hottest topics in fundamental physics from particles to the cosmos.

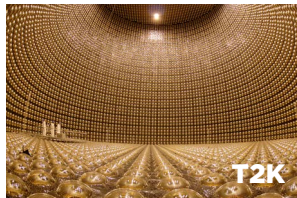
HIGGS PHYSICS
ANTIMATTER
DARK **MATTER**
DARK **ENERGY**
EXTREME **UNIVERSE**

EXPERIMENTAL division

PARTICLE
PHYSICS



ATLAS



T2K

ASTROPARTICLES



MAGIC



CTA



Virgo

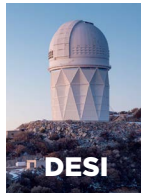
COSMOLOGY



DES



PAU



DESI

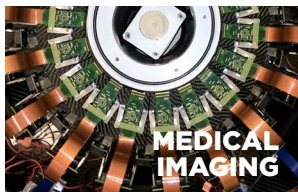


Euclid



LSST

APPLIED
PHYSICS



MEDICAL
IMAGING



QUANTUM
COMPUTING
TECHNOLOGIES

THEORY division

STANDARD
MODEL

$$\vec{p} = (p_x, p_y)$$
$$\vec{v} = \left(\frac{p_x}{m}, \frac{p_y}{m} \right)$$
$$E = \sqrt{p^2 c^2 + m^2 c^4}$$
$$E = \gamma m c^2$$
$$\gamma = \frac{1}{\sqrt{1 - \beta^2}}$$
$$\beta = \frac{v}{c}$$

BEYOND THE
STANDARD
MODEL



ASTROPARTICLES
& COSMOLOGY





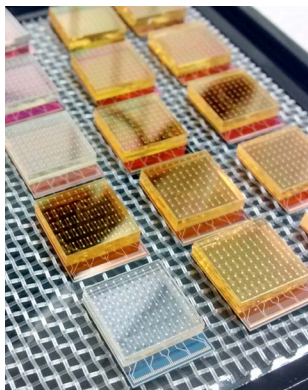
TECHNOLOGY AT IFAE

At IFAE we work at the cutting edge of detector technology, developing pixel detectors for High Energy Physics, telescope cameras, detectors for medical imaging and quantum computing technologies.

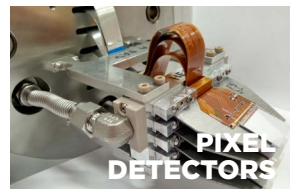
Our facilities include a microelectronics laboratory with state-of-the-art packaging and assembly technologies, clean rooms, a data center, a mechanical workshop, electronics labs, an optical room, a shielded room and a quantum computing technologies lab.

FRONT-END ELECTRONICS
GRID COMPUTING
CONTROL SYSTEMS
CRYOGENICS
READ-OUT ELECTRONICS
DETECTORS

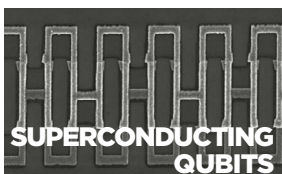
TECHNOLOGIES



**SOLID STATE
DETECTORS**



**PIXEL
DETECTORS**



**SUPERCONDUCTING
QUBITS**



**GAS
DETECTORS**

DATA CENTER

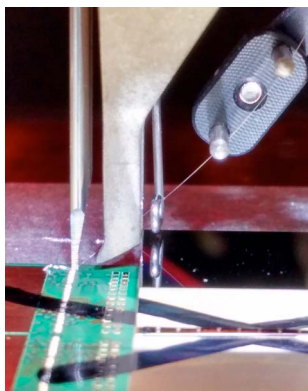


**GRID
COMPUTING**

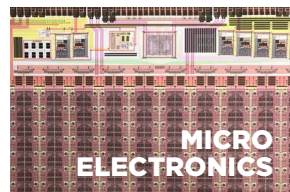


**SCIENTIFIC-DATA
CENTER**

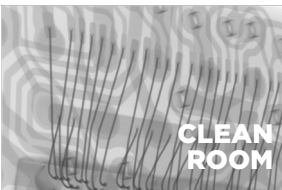
ENGINEERING



ELECTRONICS



**MICRO
ELECTRONICS**



**CLEAN
ROOM**

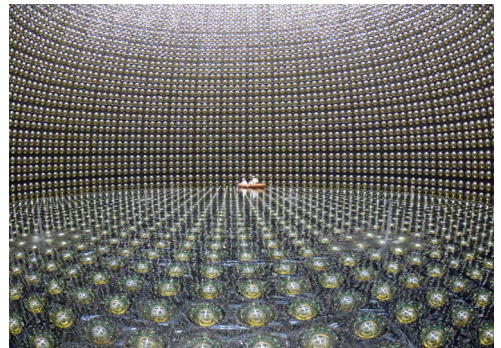


**MECHANICAL
WORKSHOP**

HIGHLIGHTS OF THE YEAR

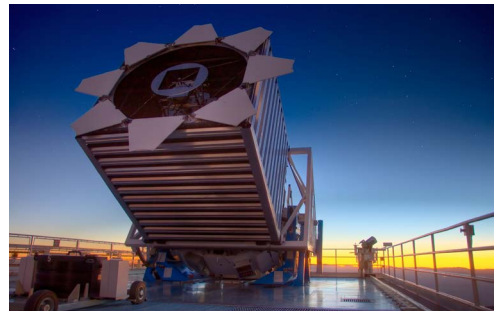
T2K RESULTS RESTRICT POSSIBLE VALUES OF NEUTRINO CP PHASE

The T2K Collaboration published new results showing the strongest constraint yet on the parameter that governs the breaking of the symmetry between matter and antimatter in neutrino oscillations, called δ_{cp} phase. For the first time, T2K has disfavored almost half of the possible values of δ_{cp} at the 99.7% (3σ) confidence level, and is starting to reveal a basic property of neutrinos that has not been measured until now. These results, using data collected through 2018, were published in Nature.



FINAL COSMOLOGICAL RESULTS FROM SDSS

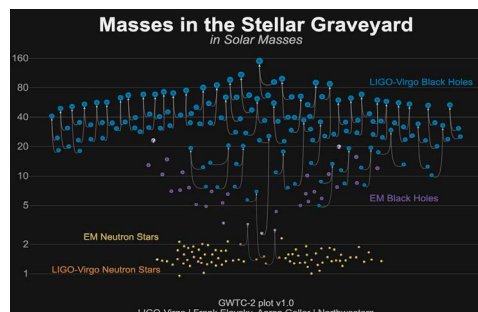
After 20 years of operations, the Sloan Digital Sky Survey (SDSS) published in 2020 its final cosmological analysis, a publication co-led by Andreu Font-Ribera (IFAE). The 3D maps of over two million galaxies and quasars from SDSS have been used to provide exquisite measurements of the expansion rate of the universe over the last 11 billion years, using a technique known as Baryon Acoustic Oscillations (BAO). These BAO



measurements provide by themselves a confirmation of the existence of dark energy (detected at 8-sigma), and improve by an order of magnitude the constraints on the curvature of the Universe.

OVER 100 BLACK HOLES DETECTED BY VIRGO AND LIGO IN THE FIRST RUN OF 2019

The classification and definitive analysis of the 39 events detected by Virgo and LIGO in the third observation period was published in 2020. Events included: 36 mergers of black holes; a likely merger of a binary system of neutron stars; and two systems that were most likely composed of a black hole and a neutron star. The catalogue provided, for the first time, a complete picture of the extraordinarily large number of recorded gravitational-wave signals and their sources. It represents a wealth of observations and data on the physics of black holes, barely imaginable until only a few years ago.



COSMIC CATAclySM ALLOWS PRECISE TEST OF GENERAL RELATIVITY

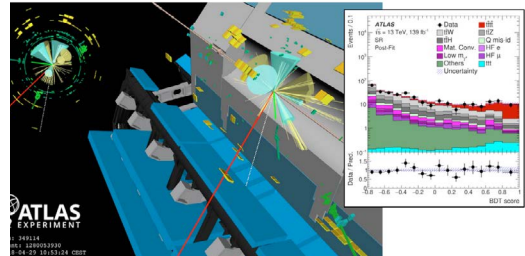
The MAGIC telescopes detected the first Gamma Ray Burst at very high energies. This was the most intense gamma-radiation ever obtained from such a cosmic object. But the GRB data had more to offer. With further analysis, the MAGIC scientists could confirm that the observation is consistent with the hypothesis that the speed of light in vacuum is constant - no evidence of a dependence with energy was found. So, like many other tests, GRB data also corroborate Einstein's theory of General Relativity. The study was published in Physical Review Letters.



EVIDENCE OF SPECTACULAR FOUR-TOP-QUARK PRODUCTION AT THE LHC

In July 2019 the ATLAS Collaboration reported strong evidence for the production of four top quarks, a milestone reached by studying events with two same-charge leptons or three leptons, plus additional jets originating from the bottom quarks. The signal significance amounts to 4.3 standard deviations (s.d.), for an expected significance of 2.4 s.d. in the SM.

The IFAE-ATLAS team has not only contributed to this result, but is also completing a search for this process in a complementary channel featuring only one lepton or two opposite-charge leptons.



THE BARCELONA RAMAN LIDAR STARTS A ONE-YEAR TESTING PERIOD AT THE LST1 SITE

In December 2020 the LIDAR was shipped to La Palma for a one-year pathfinder testing period at the ORM within the LST1 site. The commissioning of the LIDAR in Barcelona was deemed completed after being able to re-aluminize its 1.8m mirror. This one-year test during 2021 shall demonstrate that the LIDAR on-site performance and endurance fulfil the CTA requirements.



3D PIXEL SENSORS FOR THE HL-LHC

After IFAE demonstrated the radiation hardness capabilities of 3D sensors (which surpass any other sensing technology), ATLAS selected these sensors for the innermost layer of the pixel tracker for the high-luminosity LHC era. IFAE is now in the process of qualifying its assembly line to produce 3D modules for the first barrel layer of the ITk pixel detector.



DEEP DETECTION, NEW IFAE SPIN-OFF

In November 2020, IFAE became a partner of the company Deep Detection S.L. Deep Detection offers new industrial inspection solutions combining X-ray detection and artificial intelligence thanks to a multispectral X-ray camera that includes a photon-counting technology capable of detecting hitherto undetectable foreign bodies, such as plastics, wood or bones. Its first applications focus on the food security sector.



**Deep
Detection**

deepdetection.tech

QILIMANJARO QUANTUM TECH PIONEERS QUANTUM COMPUTING IN EUROPE

Qilimanjaro Quantum Tech SL, a spin-off of the University of Barcelona (UB), the Barcelona Supercomputing Center (BSC), and IFAE, was presented in 2020.

Qilimanjaro's integrated hardware & software team focuses on coherent quantum annealing high-quality qubit architectures to deliver scalable app-specific fully quantum processors and algorithmic services in a short timeframe.



qilimanjaro.tech

PIC JOINS THE SPANISH SUPERCOMPUTING NETWORK AS A DATA SERVICE NODE

In September 2020 PIC joined the Spanish Supercomputing Network (RES) as one of the nine nodes of the new Data Service. RES was created in March 2007 by the Spanish Ministry of Education and Science and it is recognized as a "Singular Scientific and Technical Infrastructure (ICTS)" since 2014, as it is a unique infrastructure in its field, with public ownership and open to competitive access. The first RES call for Data projects opened at the end of 2020 and further calls are expected annually.



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SCIENTIFIC OUTPUT IN 2020

223

NUMBER
OF INDEXED
JOURNAL
ARTICLES

87%

% ARTICLES
IN FIRST QUARTILE
JOURNALS

5.41

AVERAGE
JOURNAL
IMPACT
FACTOR (IF)

TOP 5 JOURNALS (BY IF) WHERE IFAE PUBLISHED IN 2020

	NUMBER OF ARTICLES
Nature	1
Physics Reports	1
Physical Review X	1
Physical Review Letters	13
Astrophysical Journal letters	4

TOP 5 JOURNALS WHERE IFAE PUBLISHED MOST FREQUENTLY IN 2020

Physical Review D	35
Monthly Notices of the Royal Astronomical Society	34
Journal of High Energy Physics	30
European Physical Journal C	21
Astronomy & Astrophysics	18

DOCTORAL THESES: 7

NUMBER OF PRESENTATIONS AT INTERNATIONAL CONFERENCES: 73

HUMAN RESOURCES IN 2020



EXPERIMENTAL DIVISION

21

FACULTY

21

POST-DOCTORAL
RESEARCHERS

38

DOCTORAL
STUDENTS

THEORY DIVISION

10

FACULTY

10

POST-DOCTORAL
RESEARCHERS

9

DOCTORAL
STUDENTS

TECHNICAL SERVICES

30

20

PIC

RESEARCH SUPPORT

12

PROJECTS IN 2020

20

MINISTERIO DE
ECONOMÍA Y
COMPETITIVIDAD

15

EUROPEAN
COMMISSION

5

AGÈNCIA DE
GESTIÓ D'AJUTS
UNIVERSITARIS I
DE RECERCA

4

FUNDACIÓ
BANCARIA
LA CAIXA

2

BIST

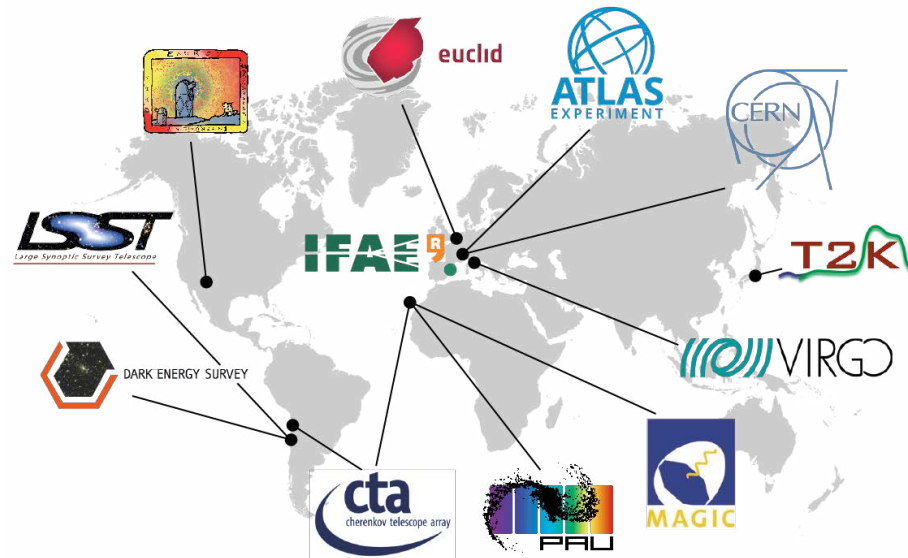
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FEDER

1

FECYT

INTERNATIONAL COLLABORATIONS



TECHNOLOGY TRANSFER IN 2020



IFAE performs frontier research in particle physics, astrophysics, and cosmology, fields of knowledge requiring advanced engineering, electronics and software technologies not existing in the market. IFAE research & engineering teams develop their own technology, transferring it to industry by means of joint ventures, partnerships, R&D agreements, technical services based on singular scientific infrastructures, training sessions, consultancy, licensing and spin-off creation. The KTT unit at IFAE promotes the valorisation and exploitation of new technological solutions for societal and industrial challenges, by increasing its technology readiness level to finally transfer it to the market.

614k€

COMPETITIVE FUNDS
FROM COLLABORATIVE
RESEARCH AND
INNOVATION ACTIONS
WITH PRIVATE SECTOR

224k€

NON COMPETITIVE FUNDS
COMING FROM ENGINEERING
PROJECTS AND SERVICES
OFFERED TO
EXTERNAL ENTITIES

35k€

COMPETITIVE FUNDS FOR
THE VALORISATION OF NEW
TECHNOLOGIES

50k€

ENTREPRENEURSHIP

2

PRIORITY PATENT
APPLICATIONS
FILED

2

NEW SPIN-OFFS
PARTICIPATED BY
IFAE

2

PATENTS
GRANTED



Institut de Física d'Altes Energies
Edifici Cn
Universitat Autònoma de Barcelona (UAB)
E-08193 Bellaterra (Barcelona)
Spain
www.ifae.es
@_ifae

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