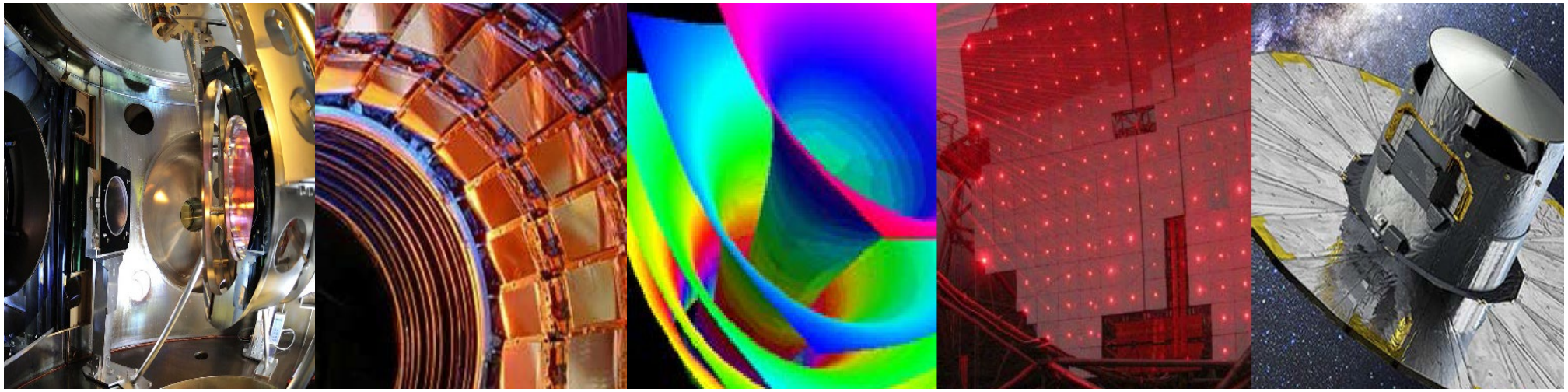
Institute of Cosmos Sciences

EXCELENCIA MARÍA DE MAEZTU



Instrumentation activities of the ICCUB Technology Unit

David Gascón

Technical coordination

On behalf of many ICCUB colleagues

Institute of Cosmos Sciences

Universitat de Barcelona

Winter Meeting @ ICCUB
07/02/2024

http://icc.ub.edu/technology

UNIVERSITAT DE BARCELONA

Outlook

I. Introduction

II. High Energy Physics

III. Ground Based Astronomy

IV. Space Projects

V. Axions and DM Searches

VI. Quantum Technologies

VII. Technology R&D

VIII. Outreach & Outlook

Introduction

- The Technology Unit is a transversal unit that:
  1) Provides technological support → new instruments for fundamental science
  2) Performs technological R&D → future impact in science and beyond
  3) Transfers Technology → industrial collaborations and societal impact

- Quick overview of main current activities in:
  - Instrumentation (detectors, electronics & *microelectronics)*
  - Software & data processing (Jordi's talk)
- for:
  - Space missions
  - Ground instruments
  - Particle physics experiments
  - Dark matter searches
  - Quantum technologies

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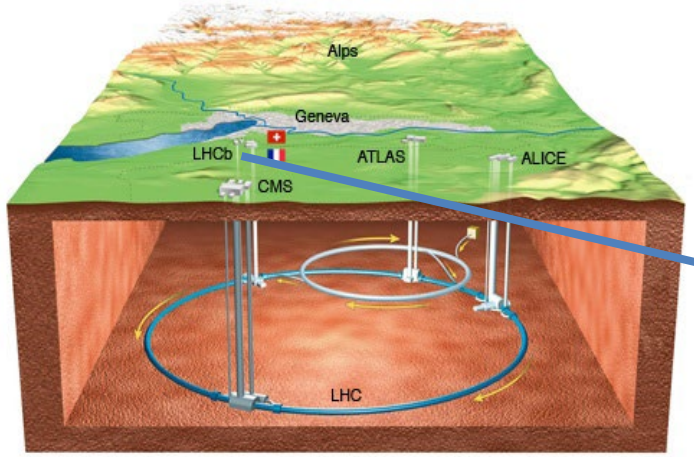
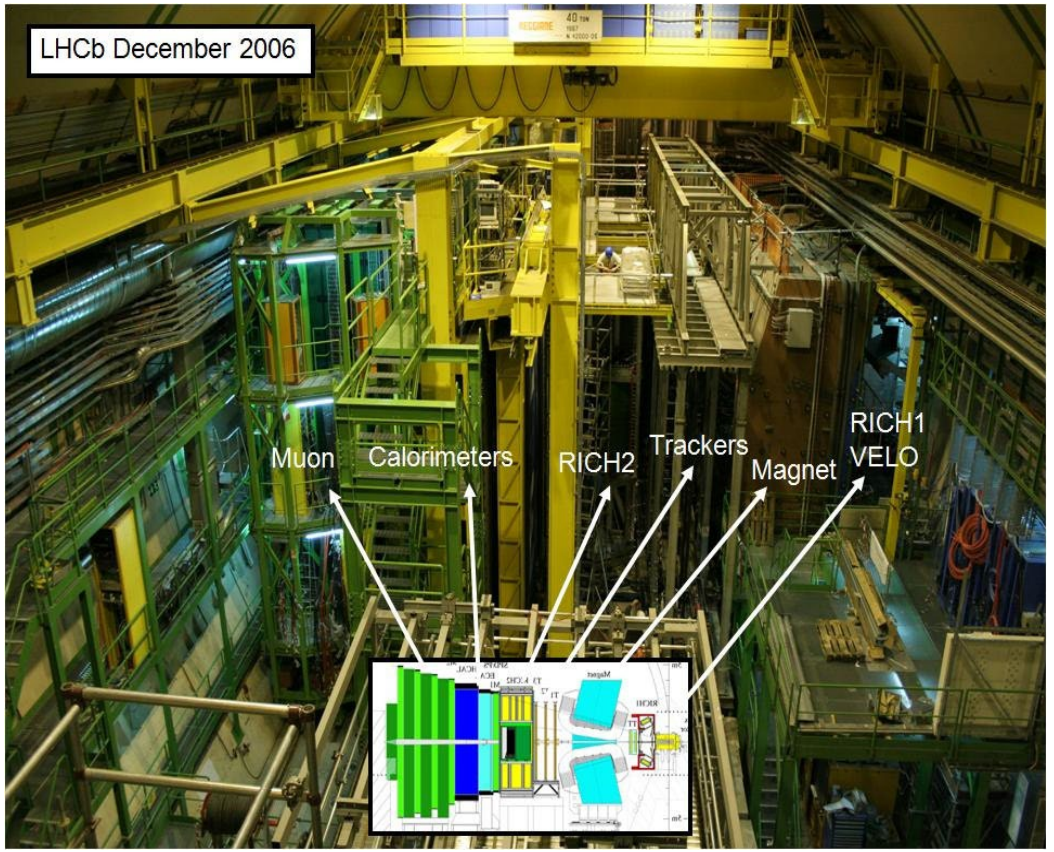
II. LHCb



LHCB detector at LHC (CERN)

http://lhcb-public.web.cern.ch/lhcb-public/

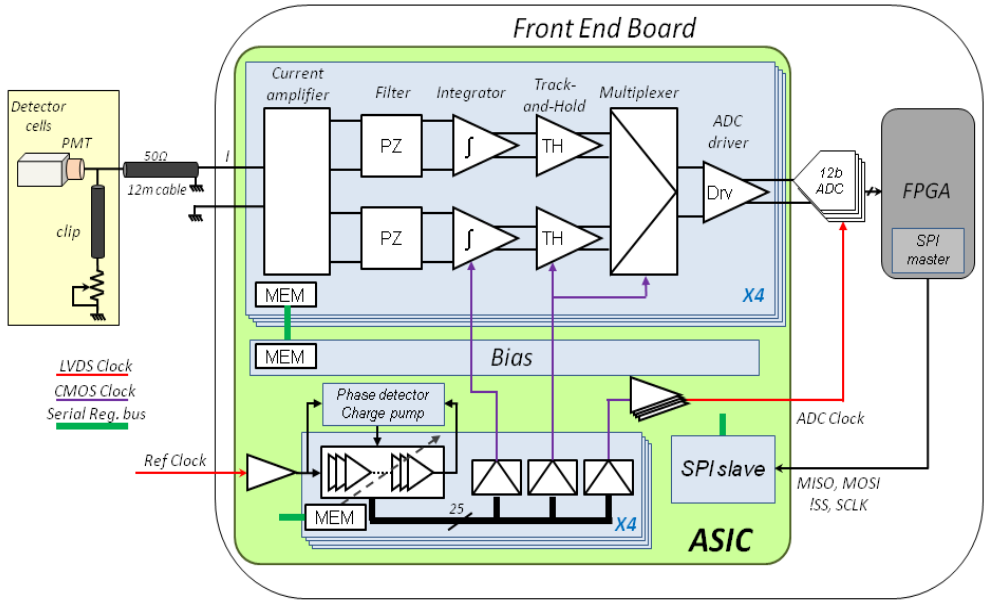


- Design of the Front End electronics of the first detector of the calorimeters:
  - 100 acquisition cards of 64 ch
  - 800 ASICs (8 ch)
  - Slow control system
  - High speed links (2.5 GB/s)
- Front end electronics of upgraded calorimeter
  - New ASIC: ICECAL
  - 12 bit dynamic range @ 40 MHz
  - Low noise

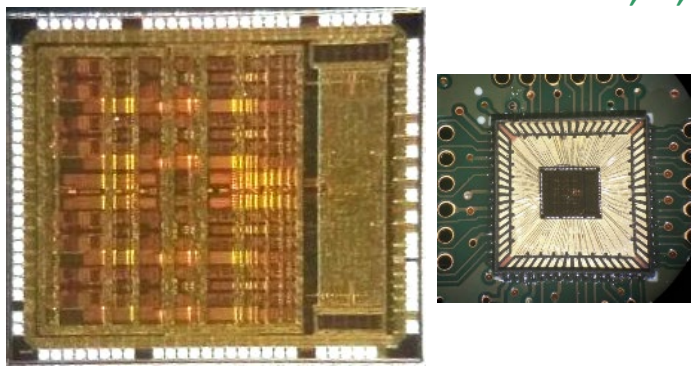
II. LHCb upgrade I

- In 2022: phase I upgrade completed!
  - Luminosity increased by a factor 5
  - ICCUB: responsible of new FE for the complete calorimeter system
  - ICECAL chip designed, produced and validated (beam & rad tests)

E. Picatoste, J. Mauricio, L. Garrido, E. Grauges, R. Vazquez, C. Marin, D. Gascon et alt.



IEEE TNS, 59, 2012
JINST, 7, 2012

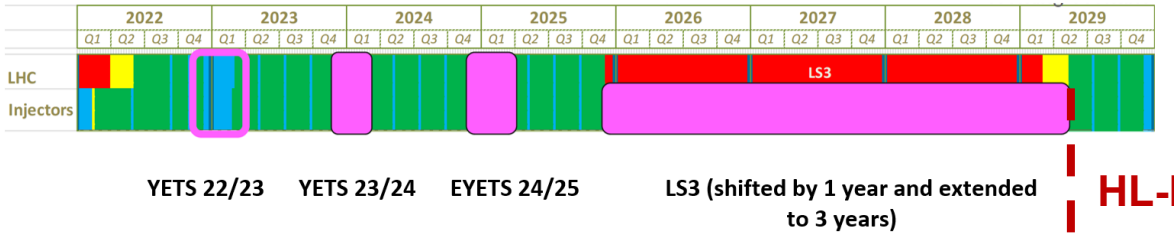


ICECALv3 chip:
SiGe BiCMOS 0.35um
AMS 10.5 mm^2
12 bit resolution @ 40 MS/s

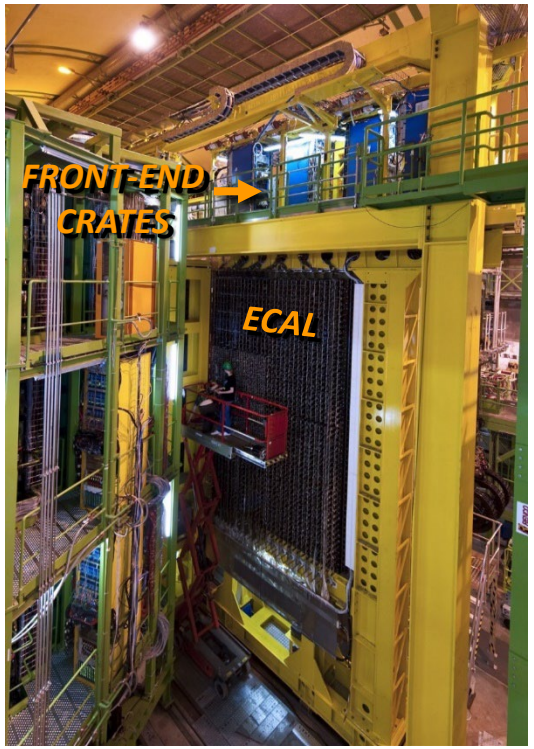
- FE electronics installed and commissioned !

II. LHCb upgrade Upgrade II: PicoCal

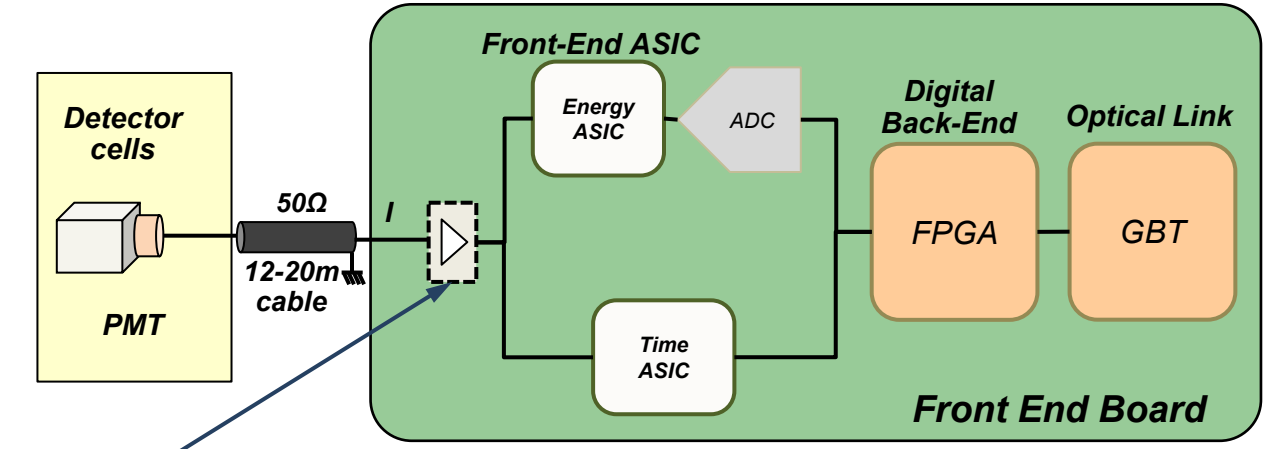
Exp. High Energy Physics group and Technology Unit

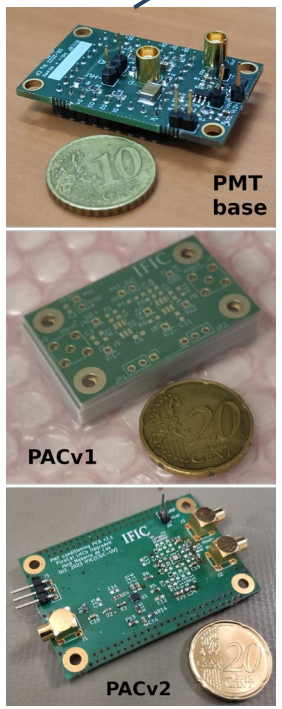


- HL-LHC: R&D on Photodetectors and FE electronics
  - Calorimeter, RICH and Scintilalting Fiber Tracker

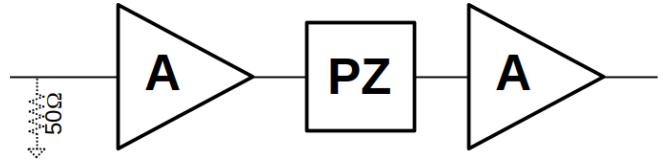


- ASIC/chipset in TSMC 65nm with separate energy and timing processing paths
  - Energy ASIC (ICECAL65) designed by ICCUB with UPC and IFIC
  - Timing ASIC (SPIDER) designed by IJC Lab, LPCA,IP2I, LPC Caen





COTS conditioning circuit



- Boost SNR and adapt dynamic ranges
- Two stage amplifier based on COTS
  - acquisition stage to boost SNR (low noise)
  - pole-zero cancellation network for shaping
  - driving stage to adapt to ASICs input ranges
- Designs: PMT base, PACv1, PACv2
- Tested at test beams

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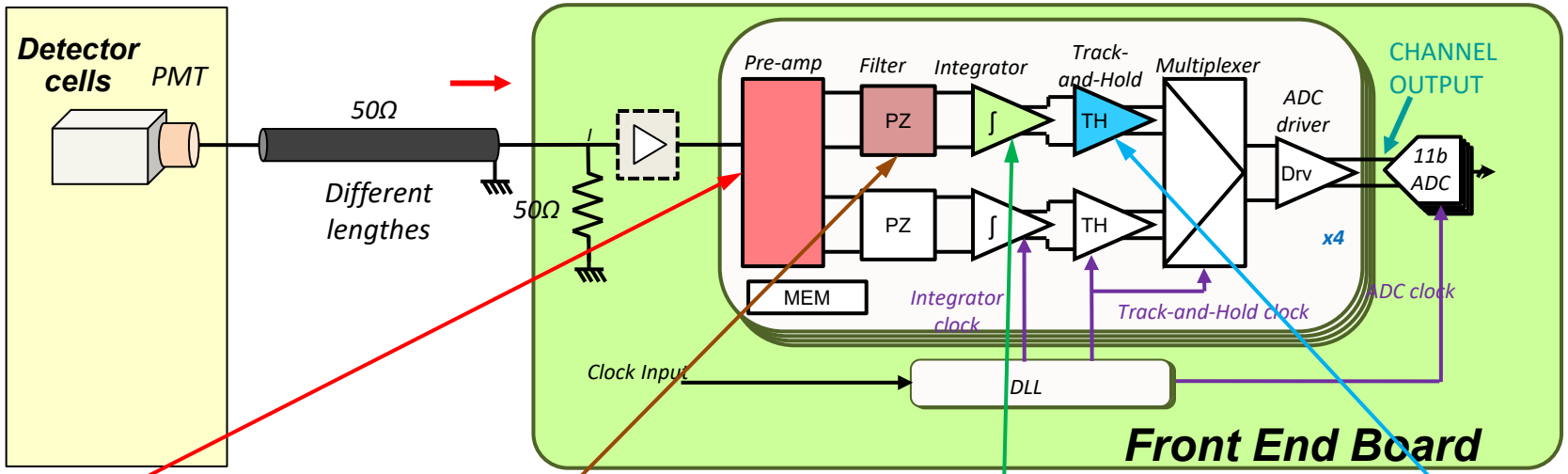
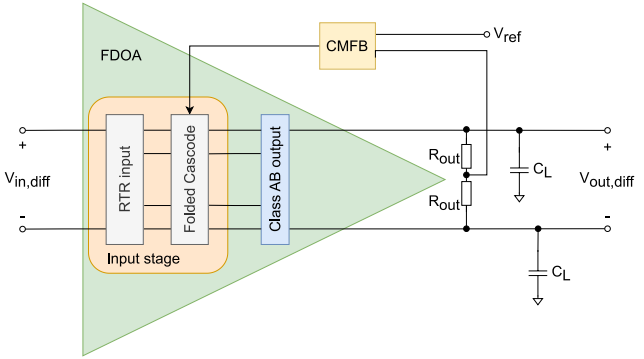
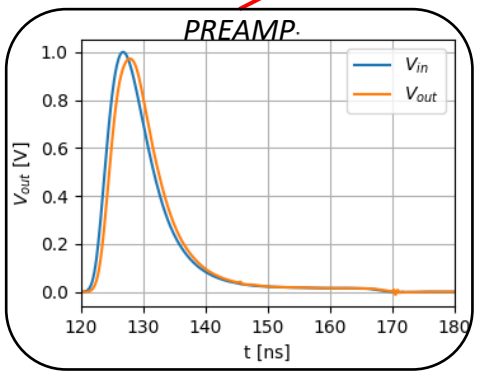
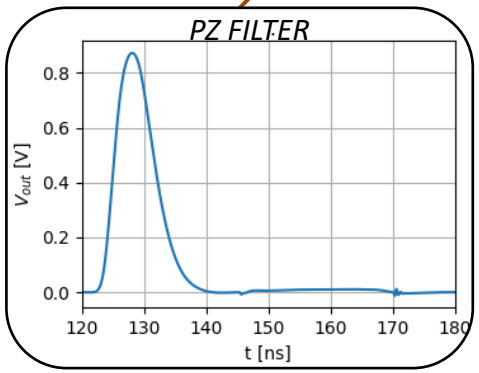
II. LHCb upgrade Upgrade II: ICECAL65 design

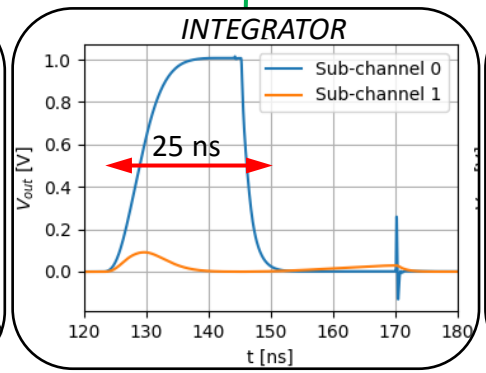
- ICECAL65 chip being designed for PicoCal (ICCUB, UPC, IFIC)
  - Time-interleaved double channel scheme for integrator recovery
  - 2 gains to cover the large dynamic range

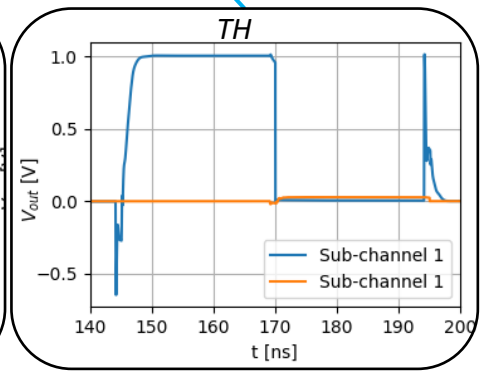












- TSMC 65nm technology
- Fully differential
- Rail-to-Rail (0-1.2 V)
- Low frequency gain > 70 dB
- GBW > 500 MHz
- PM > 65º
- SR > 0.5 V/ns
- VCM ~0.6V
- Power optimization

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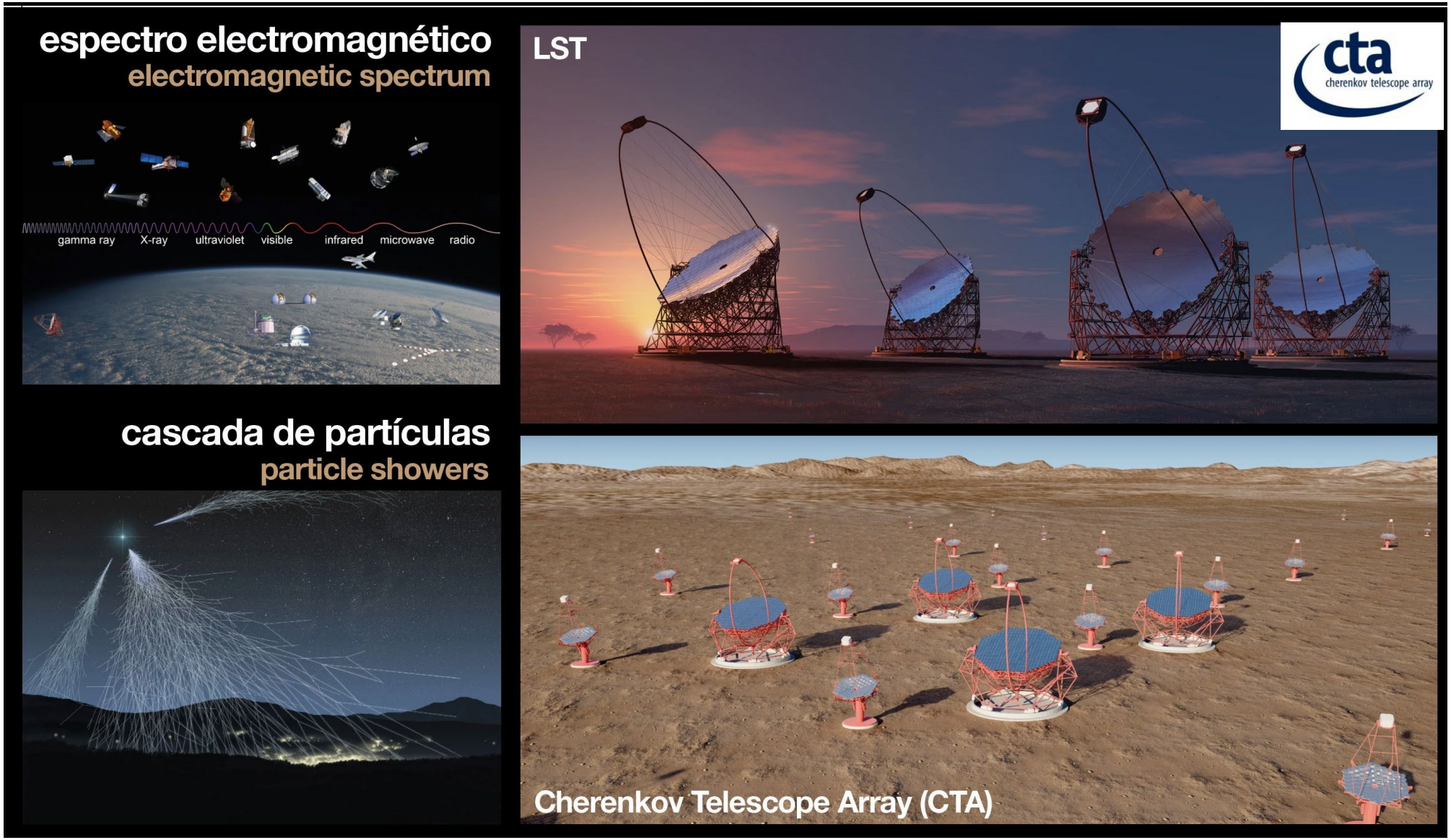
III. CTA

Cherenkov telescope array observatory

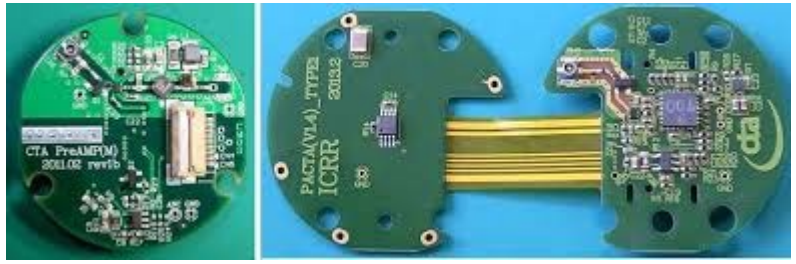
http://www.cta-observatory.org

High Energy Astrophysics group and Technology Unit

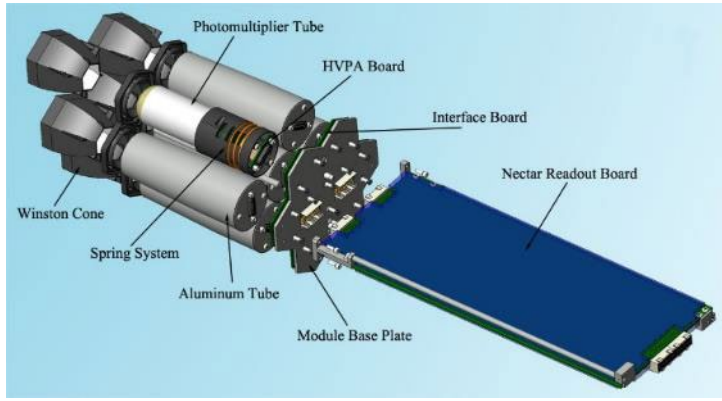


III. CTA

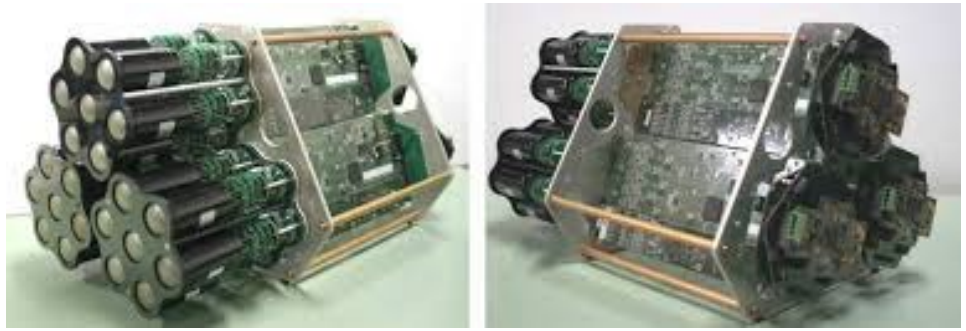
- **ICCUB has developed 3 different chips with important contributions to the cameras**
  - DragonCAM for LSTs
  - NECTArCAM for MSTs
  - **More than 100,000 chips produced to equip 15 cameras**



ICRC 2013



NIMA, 639, 2011



SPIE, 9151, 2014

A. Sanuy, J. Mauricio, M. Ribó, J. M. Paredes, V. Bosch, P. Bordas, D. Gascon et alt.

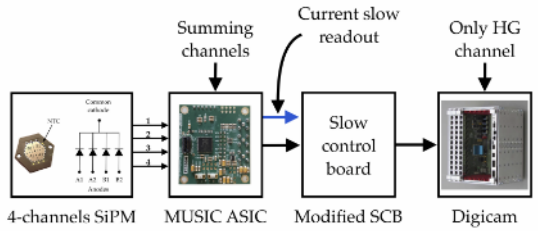
III. CTA

- In the short and mid-term we plan to consolidate our contribution to the CTA cameras:
  - We are completing the quality control of ASICs for additional LST cameras
  - Contributing to the commissioning of the cameras in the North site at La Palma

- SSTs cameras and LSTs/MSTs (long term) upgrades will be based in SiPMs
  - MUSIC chip was the first step in this direction
  - New versions with enhanced performances and additional functionalities
    - Collaboration with UPC
    - HORIZON INFRA-TECH proposal to be submitted soon to the EC

A. Sanuy, J. Mauricio, M. Ribó, J. M. Paredes, V.Bosch, S. Gomez, P. Bordas, O. de La Torre, A. Espinya, D. Gascon et alt.

Integrating MUSIC in the camera



- 1 output channel per pixel ⟹ 1 MUSIC to sum the 4 anodes of a single pixel ⟹ 1 MUSIC per pixel ⟹ expensive, power consuming
- Currently DC coupled → MUSIC is AC coupled ⟹ we have to use the slow readout current to monitor baseline shifts
- SCB needs to be modified to readout slow integration output

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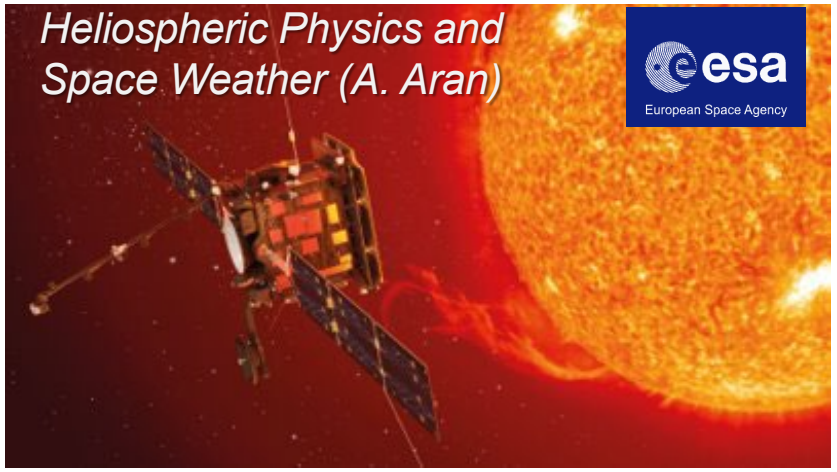
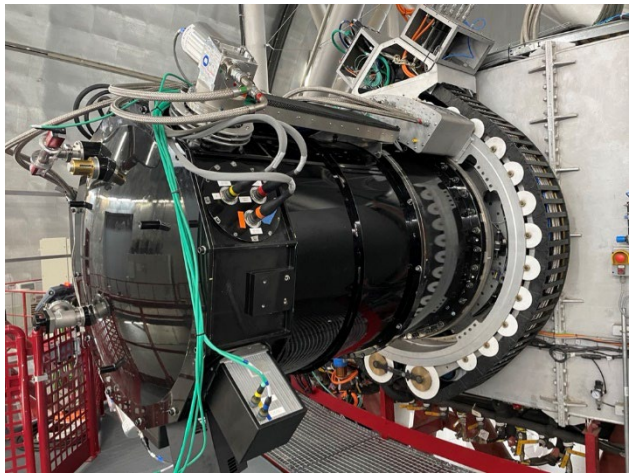
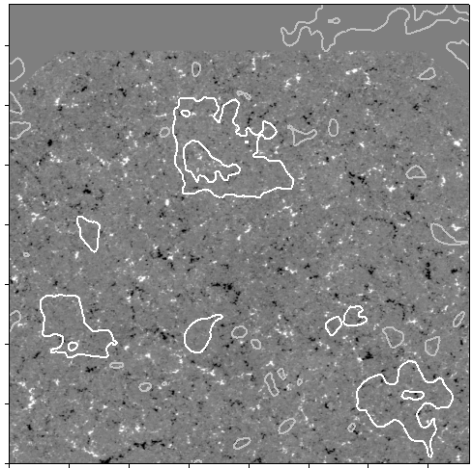
IV. Solar Orbiter, MIRADAS, Ariel

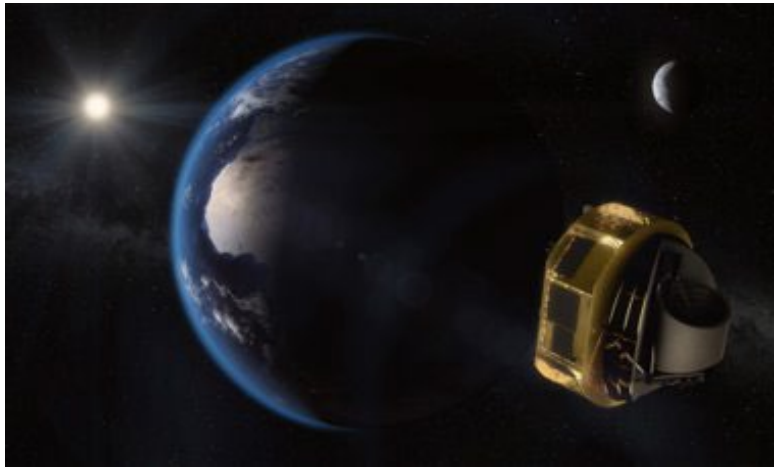
Electronics Dept & Technology Unit : J. M. Gomez, J. Ateca, A. Casas, P. Lopez, C Serre et alt.

- Solar Orbiter: Launched 2021, first results available
  - Image stabilisation System
- Ariel: To be launched 2029
  - Telescope Control Unit
  - Preliminary Design Review completed
- MIRADAS: First test light 2022
  - Full operation expected during 2024.



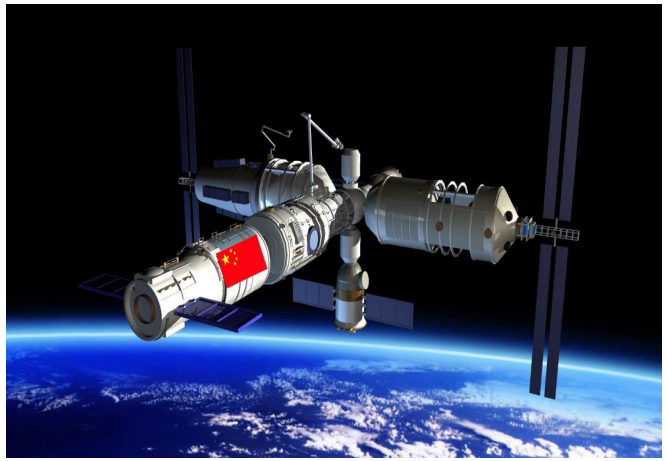




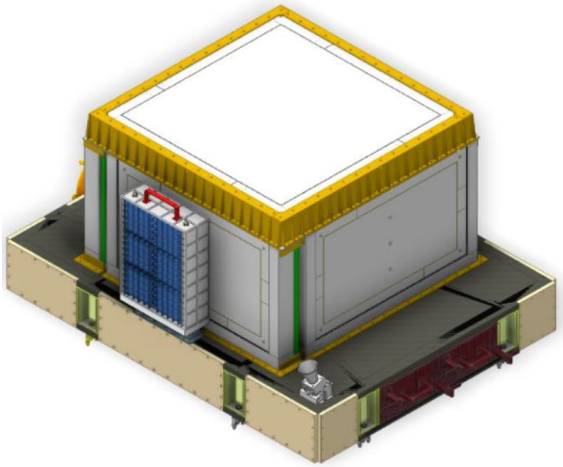


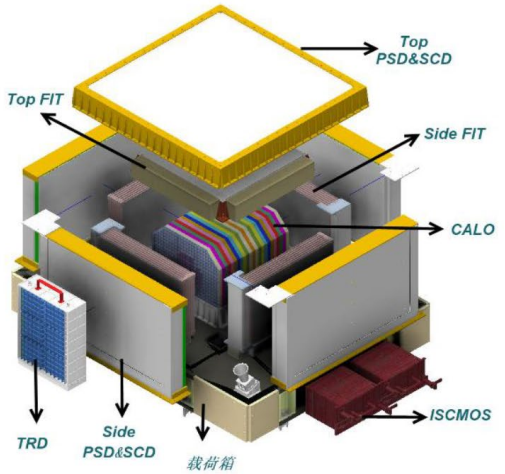
IV. HERD

- The High Energy cosmic-Radiation Detection (HERD) experiment is proposed to understand key problems in fundamental physics:
  - to search for signatures of the annihilation/decay products of DM
  - to measure precisely the energy spectra and composition of primary cosmic rays up to the cosmic rays 'knee' structure
  - to make wide FoV monitoring of the high energy gamma-ray sky



- HERD will be unique
  - No other planned or approved mission with comparable scientific capabilities
- Flagship scientific experiment on the Chinese Space Station (CSS)
- Our key contribution is ***Beta ASIC*** for Fiber Tracker and PSD subdetectors
  - With IFAE we provide full readout & trigger





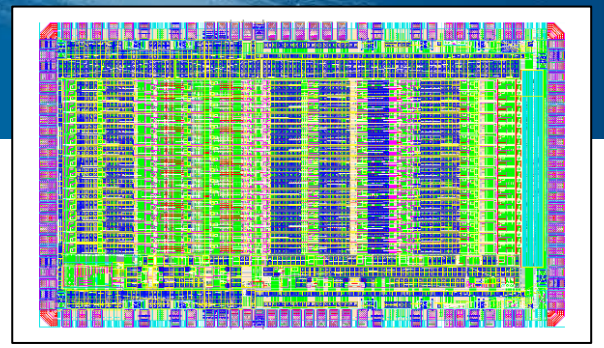
A. Sanmukh, J. Mauricio, A. Comerma, D. Guberman, S. Gomez, A. Sanuy, P. Bordas, D. Gascon et alt.

IV: BETA - ASIC

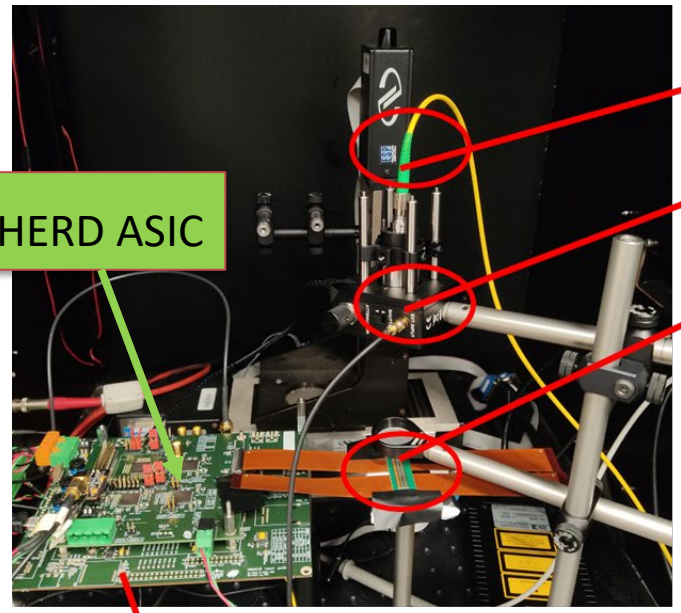
High Energy Astrophysics, Exp. High Energy Physics groups and Technology Unit

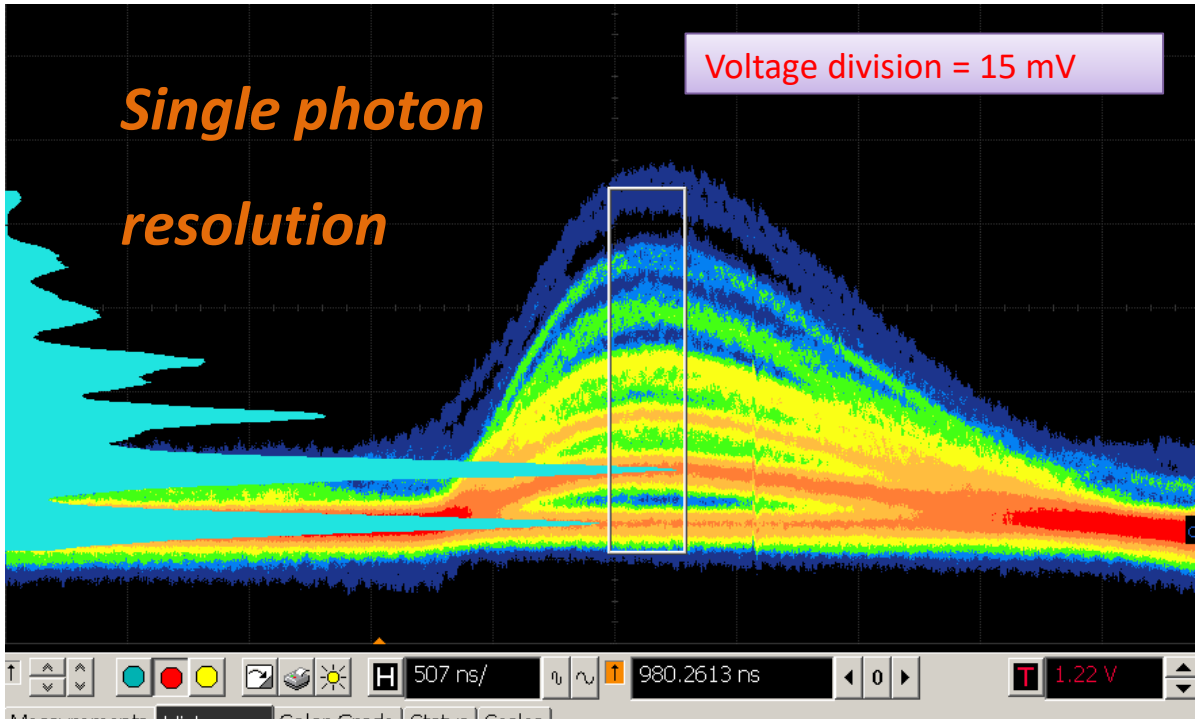
- ✓ Channels: 16 (FIT version: 64 ch)
- ✓ Event rate : 10 kHz max
- ✓ Configurable preamplifer gain: 4 bits
- ✓ Tunable shaping time: 230 ns to 1.5 us
- ✓ Trigger output: < 250 ps time resolution

- ✓ Single photon resolution: SNR >10
- ✓ Dual path: automatic gain switching
- ✓ On chip ADC: Wilkinson11 bit + 1bit (path sel)
- ✓ Dynamic Range : 15 bit
- ✓ Slow Digital Control : I2C
- ✓ Power Budget : <1 mW/ch



16 ch - 130 nm CMOS – 7 mm^2





A. Sanmukh, J. Mauricio, A. Comerma, D. Guberman, S. Gomez, A. Sanuy, D. Gascon et alt.

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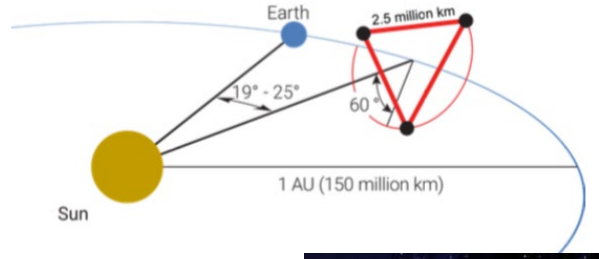
IV. LISA

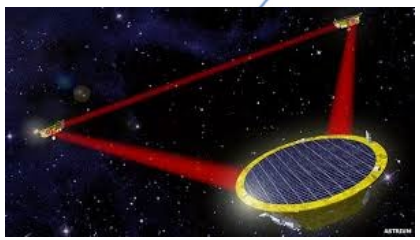
Control and diagnostic PI : M Nofrarias (IEEC-ICE)

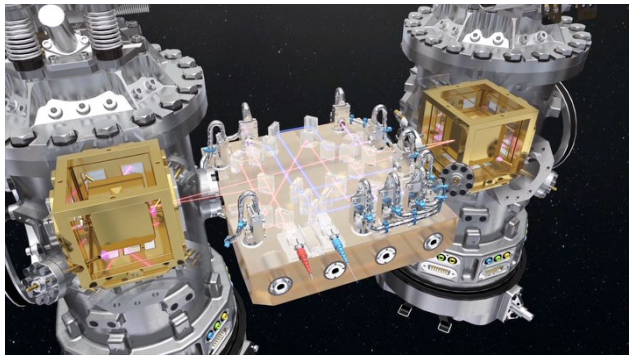
IEEC Institut d'Estudis Espacials de Catalunya

- LISA has bee recently adopted by ESA
  - Constellation of 3 satellites in heliocentric orbit
- Radiation environment -> test-mass charging
  - Affects the capacitive control of the test masses: acceleration noise
- ICCUB contribution to coordinated IEEC project
  - Monte Carlo simulation
    - To understand better the effective TM charging
  - Developing a radiation monitor for LISA mission



esa European Space Agency





Many ICCUB groups and Technology Unit: D. Guberman, A. Sanuy, R. Català, A. Espinya, D. Mazzanti, M. Orta, L. Garrido, A. Aran, F. Salvat, A. Herms, D. Gascon et alt.

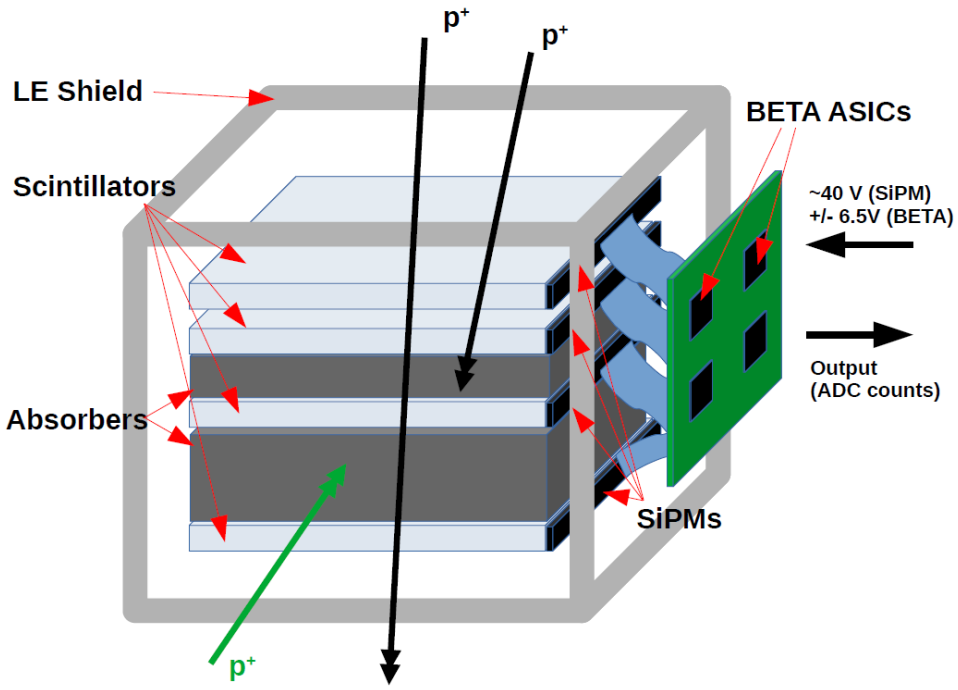
ICCUB Institute of Cosmos Sciences EXCELENCIA MARÍA DE MAEZTU

IV. LISA: radiation monitor based on BETA - ASIC

IEEC Institut d'Estudis Espacials de Catalunya

- A radiation monitor based on BETA-ASIC is proposed

Baseline design



- Plastic scintillators + SiPMs for particle detection
- High-density absorbers for achieving some energy resolution
- Shield for blocking low-energy particles (as in LPF-RM)
- SiPM readout with the BETA ASIC

  → Can read up to 16/64 SiPMs per chip. Digital output with a few mW/channel

- Other missions and CubeSat projects are considering BETA chip (NUSES et alt)

Many ICCUB groups and Technology Unit: D. Guberman, A. Sanuy, R. Català, A. Espinya, D. Mazzanti, M. Orta, L. Garrido, A. Aran, F. Salvat, A. Herms, D. Gascon et alt.

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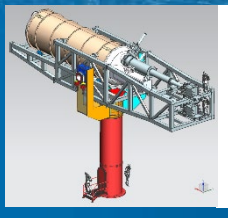
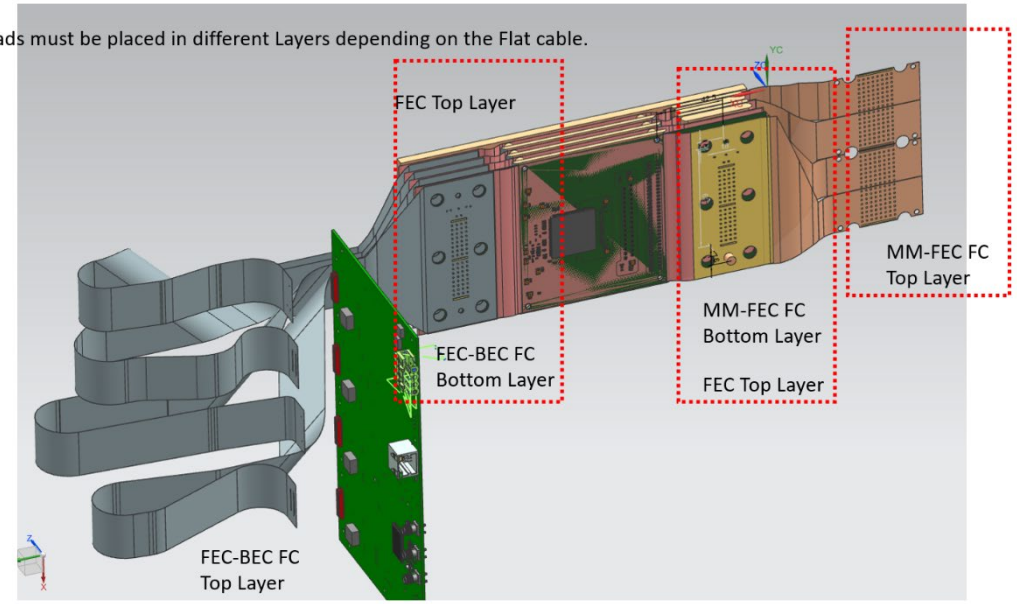
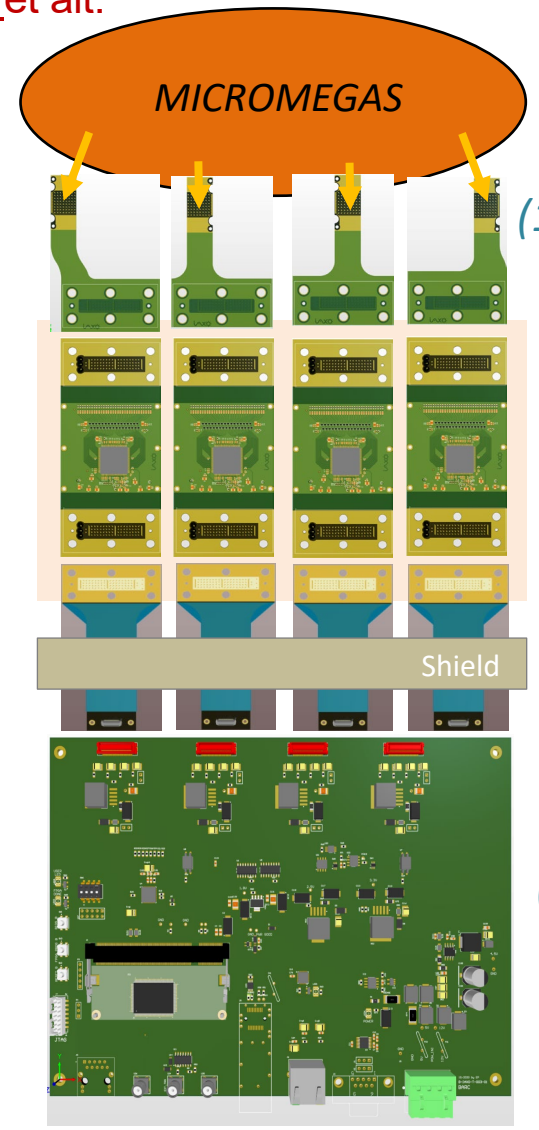
V. Axions and DM searches: IAXO



E. Picatoste, S. Ahyoune, C. Cogollos, J. Sieiro, J. Miralda et alt.



- ICCUB is involved both in helioscope and haloscope @ IAXO
- Developing a radiopure version of the FE electronics
  - Collab. with UniZar & CEA/Irfu
  - Improve SNR → improve sensitivity
  - New front-end electronics being produced (1-4)



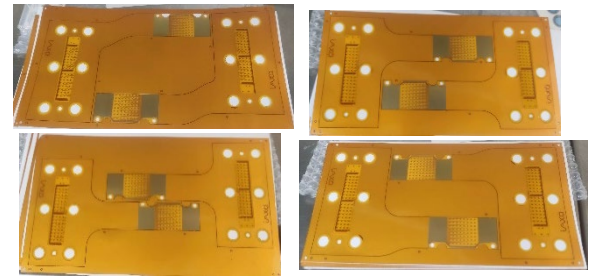
x16

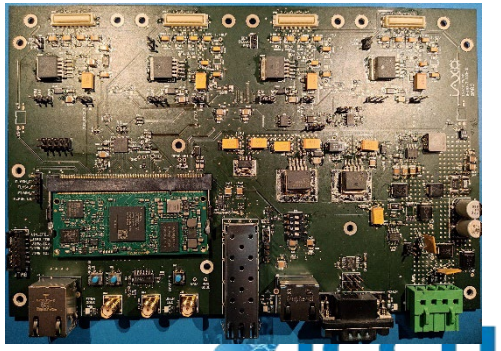
(1) Micromegas to FEC

(2) FEC

(3) FEC to BEC

(4) BEC





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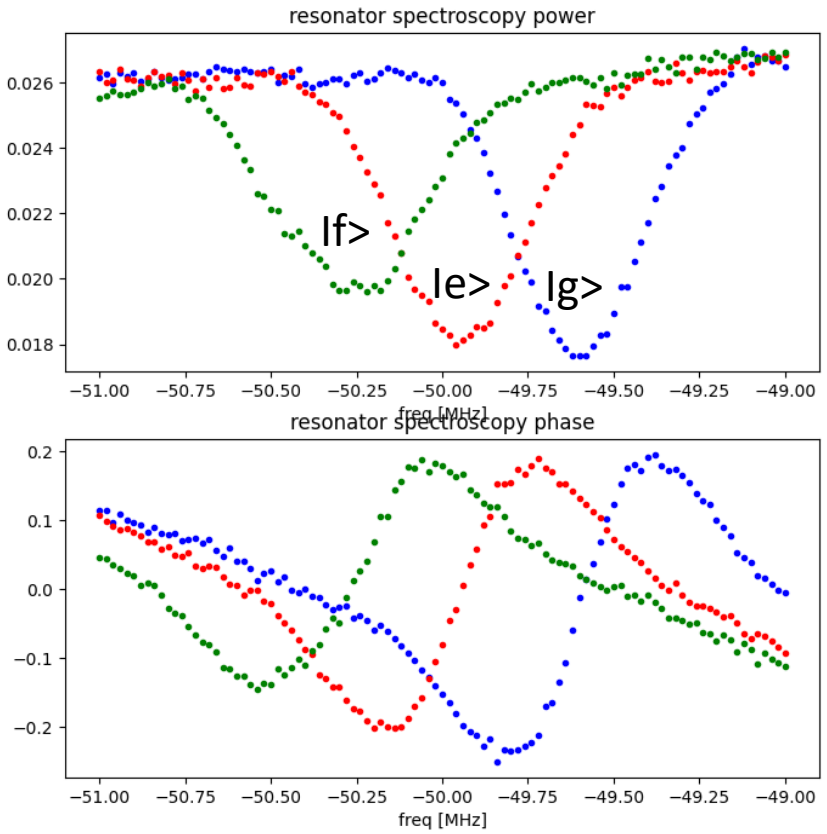
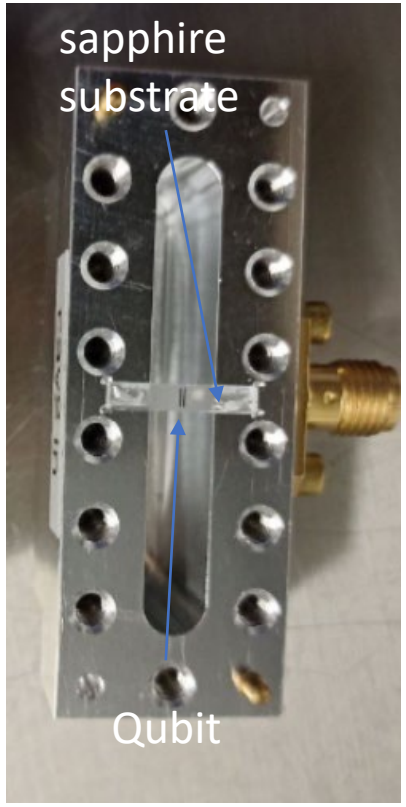
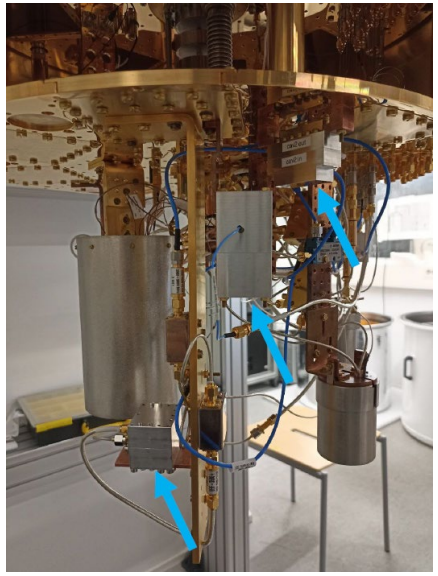
V. Axions and DM searches: Haloscope detection experiments for axion-like dark matter using quantum photon counters.



Spectroscopy of a sapphire transmon qubit, examining the power and phase of the three states |g⟩ (0 photons) , |e⟩ (1 photon), and |f⟩ (2photons)



Transmon qubit on a sapphire substrate installed in the cavity



Three different cavities with transmon qubits installed in the fridge (T=10 mK).

Fridge Bluefors

This work is in collaboration with Aalto University- Helsinki

S. Ahyoune, E. Picatoste, C. Cogollos, J. Sieiro, J. Miralda et alt.

Outlook

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IV. Space Projects

V. Axions and DM Searches

VI. Quantum Technologies

VII. Technology R&D

VIII. Outreach & Outlook

Quantum Communications Group

Team

Bruno Julia Díaz - Dept. Quantum Physics and Astrophysics and ICCUB
José María Gómez Cama - Dept. of Biomedical Engineering and ICCUB
Martí Duocastella - Dept. of Applied Physics
Raul Lahoz Sanz - PhD student
Lidia Lozano Martín - PhD student
Adrià Brú i Cortés - Undergrad Physics and Electronics engineering

https://quantumcomms.fqa.ub.edu/

QCommsUB

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Plan de Recuperación, Transformación y Resiliencia
Next Generation Catalunya
Generalitat de Catalunya Departament de Recerca i Universitats

VI. Quantum technologies

WP1) Enhanced production of single and entangled photon from quantum dots
WP2) Characterization of their entanglement properties by means of a versatile Bell test.

Current funding from Planes Complementarios de Comunicaciones Cuánticas (until Sep 2025)

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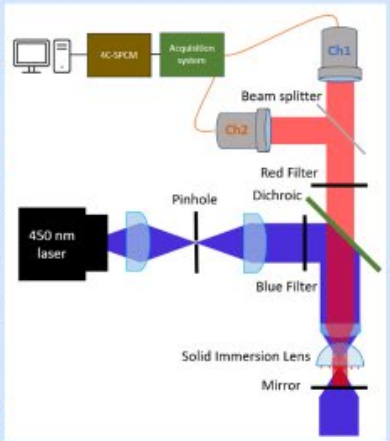
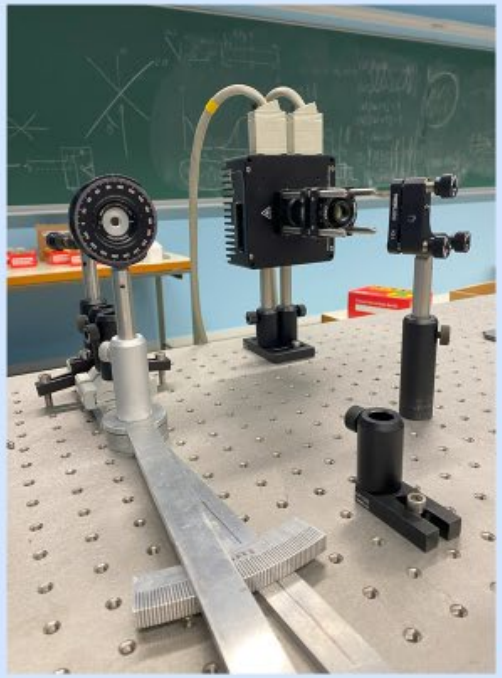
https://quantumcomms.fqa.ub.edu/

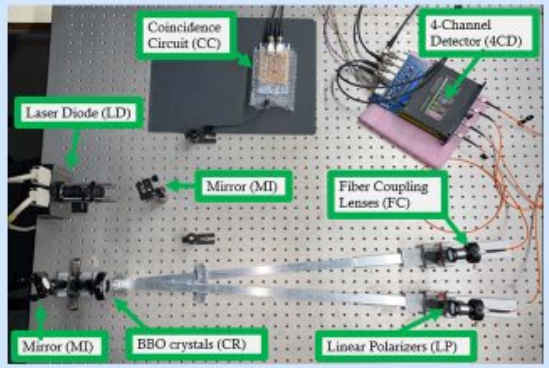
VI. Quantum technologies



Photon antibunching experiment



Bell test for entangled photons



QCommsUB

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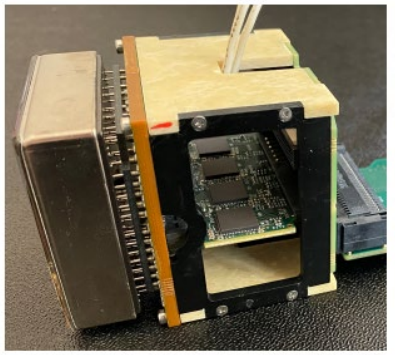
VII. Our approach: a new hybrid photosensor

J. Mauricio, R. Manera S. Gomez,
A. Sanuy, D. Gascon et alt @ ICCUB
J. M. Fernandez-Tenllado, M. Campbell,
R. Ballabriga et alt. @ CERN

- FastIC collaboration with CERN microelectronics section
  - https://ep-news.web.cern.ch/content/fastic-and-fasticpix-developments
  - FastIC chip baseline for LHCb RICH upgrades (Ib and II, LS3-LS4)
  - ATTRACT project to explore new sensor architecture

FastIC is used in LHCb RICH upgrade test beams

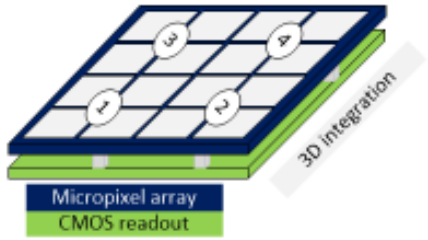


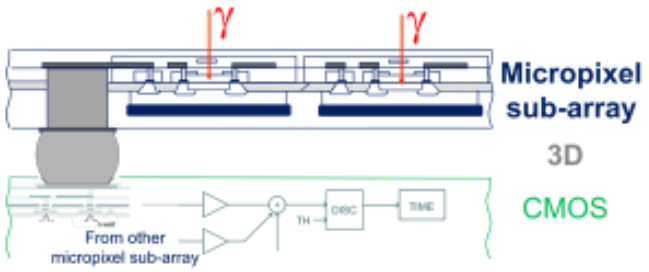
DEVELOPING BREAKTHROUGH TECHNOLOGIES FOR SCIENCE AND SOCIETY

ATTRACT

FastICPix: Integrated Signal Processing for a New Generation of Active Hybrid Single Photon Sensors with Picosecond Time Resolution

The Idea is to combine actively the signal of small micropixel sub-arrays based on the fastest single photon sensor technologies with ultrafast readout electronics using 3D integration.





- Applications:
  - Fundamental science
  - Medical Imaging
  - Quantum communications

And FastRICH spin-off will enable LHCb RICH upgrade

Deeply involved in ECFA's Detector R&D (DRD) program:
PID & photodetectors, calorimetry and electronics

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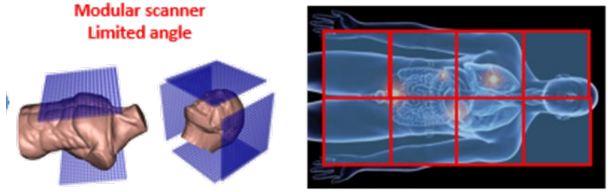
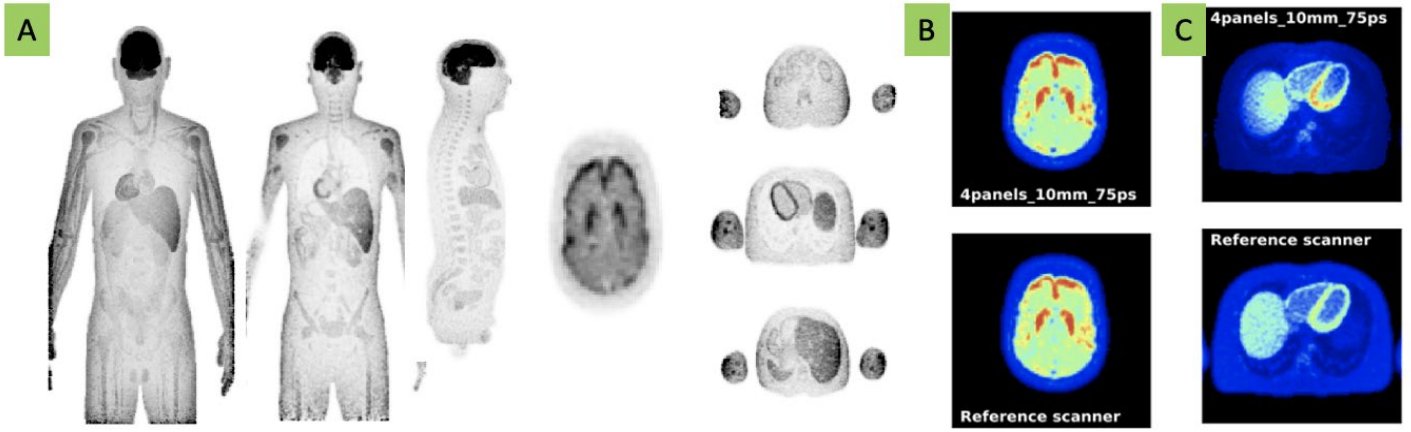
VII. Towards a new ToF-PET scanner concept

- The **PETVision** Project was approved! Call: **Horizon EIC 2022 Pathfinder-open**.
  - 5-year project started in September 2023
- The aim of PetVision is to leverage on vertical integration techniques to build a modular ToF-PET scanner, with next-generation performance and affordable cost.



Partner	PI	Country
JSI	Rok Pestotnik	SI
FBK	Alberto Gola	IT
ICCUB	David Gascon	ES
Oncovision	Jorge Alamo	ES
CSIC	Jose Maria Bennloch	ES
TUM-MED	Wolfgang Weber	DE
Yale	Georges El Fakhri	USA



Simulation of the capability of the proposed planar TOF PET imager: Reconstructed Image (3mm slices) of an XCAT digital phantom acquired by two 120x60cm^2 panel detectors (above and below the patient) assuming 100 ps TOF resolution and 10 mm scintillator thickness (A) and with small 4 panel system used to image head (B) and torso (C)

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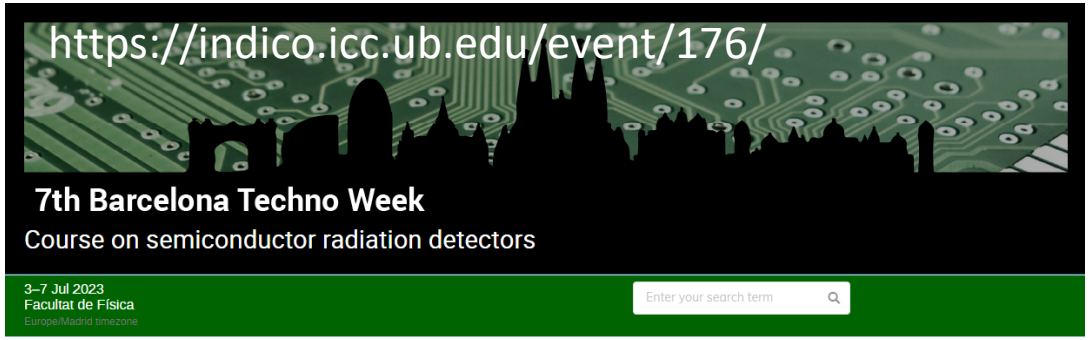
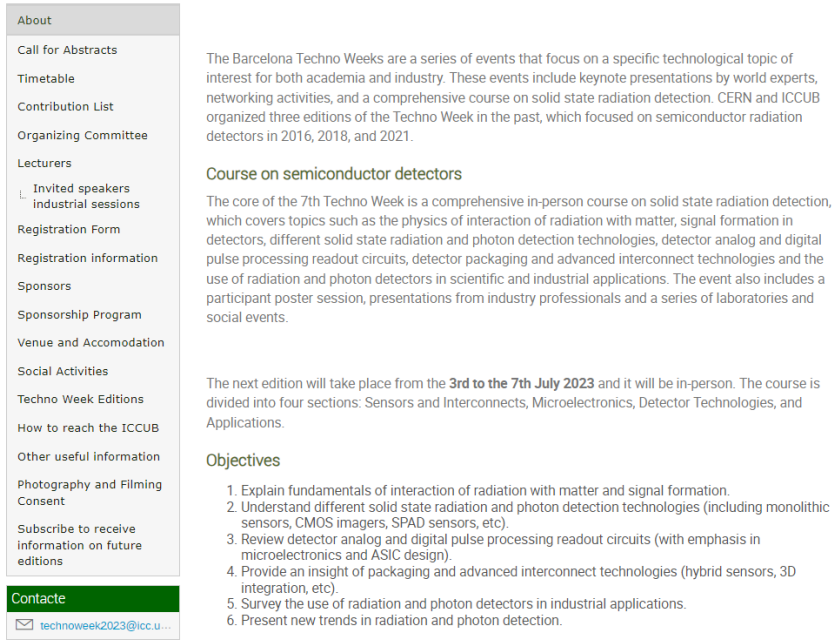
VIII. Barcelona Techno Week

E. Pallarés, A. Argudo, R. Ballabriga (CERN), S. Gomez, E. Picatoste, J. Mauricio, A. Sanuy, D. Guberman, D. Gascon et alt.

- **Barcelona Techno Week:** a series of meeting point events between academia and industry, organized around a technological topic of interest for both worlds
  - 7 editions
  - Topics: semiconductors detectors, nanosatellites, cloud computing
- Last edition on 2023
  - More than 60 students
  - Nearly 80 attendees in total
  - Industrial participation





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VIII. Future plans

- Consolidate our contributions to instrumentation of key scientific projects:
  - LHCb & DRD, CTA/HERD, LISA, ARIEL, Axion searches, …
- Reinforce our position as reference centre for single photon sensors and integrated readout
  - New infrastructures for vertical integration: sensor and integrated readout
    - Microprobe automatic station
    - Flip-chip and bump bonding
    - Clean room for integration and test

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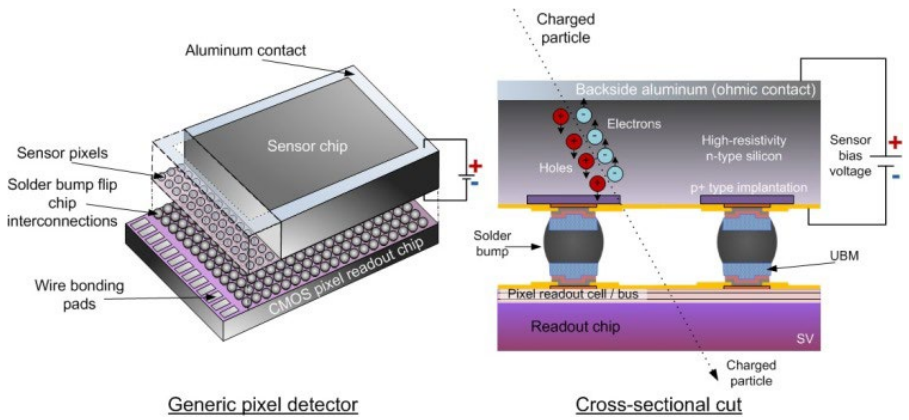

Generic pixel detector | Cross-sectional cut

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VIII. Future plans

- Boost internal cooperation of our R&D lines and resources
  - Application of our photodetector know-how in quantum & space technologies
  - Application of quantum technologies to detectors (also part of DRD effort)
  - Consolidate instrumentation contribution in key GW projects: LISA and ET
- Exploit further synergies and complementarity with other institutes :
  - IEEC, ICFO, IFAE, BSC/UPC, IBEC, etc
- Increase scientific and industrial external collaborations
  - Key role in ECFA's DRD effort
  - New collaboration in Time-of-Flight Mass Spectrometry
  - New col. to develop rad-hard electronics for fusion reactors (DEMO/DONES)

Thanks a lot for your attention !!!

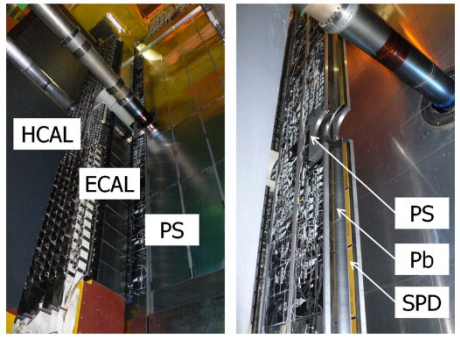
http://icc.ub.edu/technology

Thanks a lot for materials and contributions to our colleagues !!

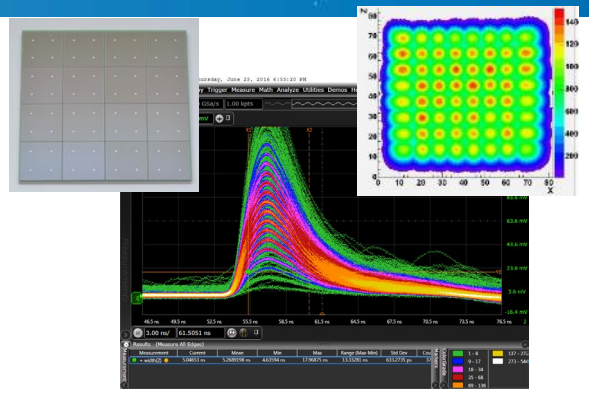
dgascon@fqa.ub.edu **jportell@fqa.ub.edu**

II. Activities in instrumentation

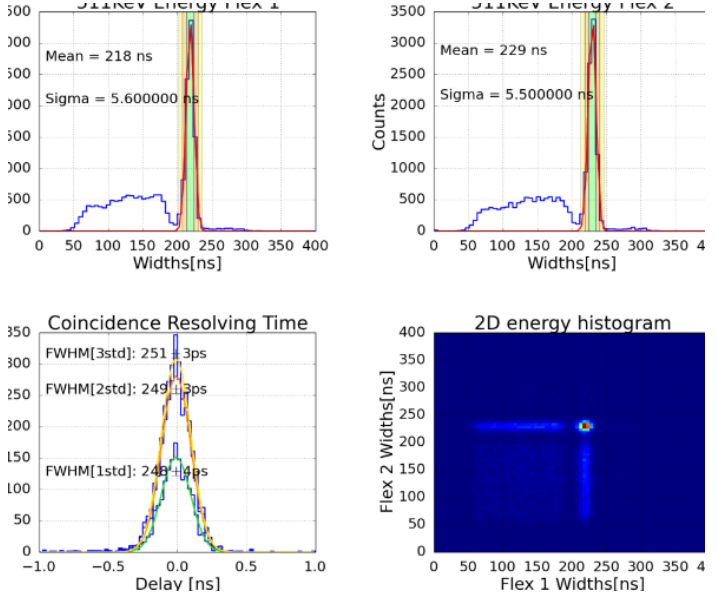
Telescope cameras



Particle detectors at CERN

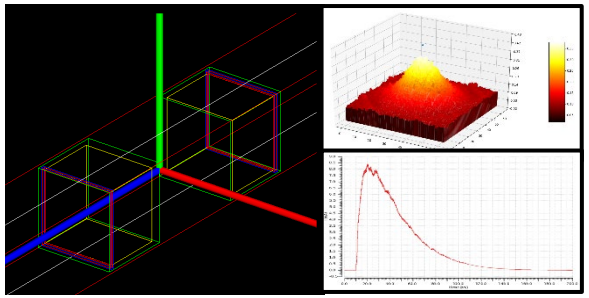


Single-Photon Sensors

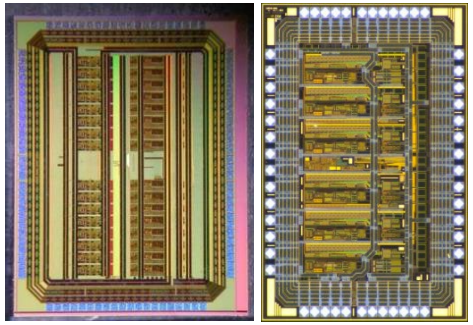


Positron Emission Tomography with Time-of-Flight (ToF-PET)

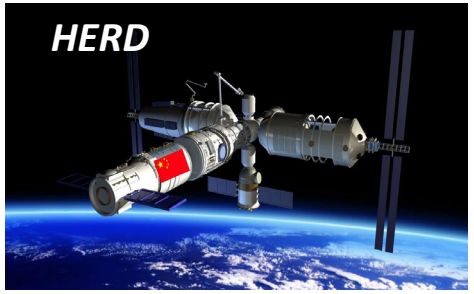
Axion and Dark Matter searches



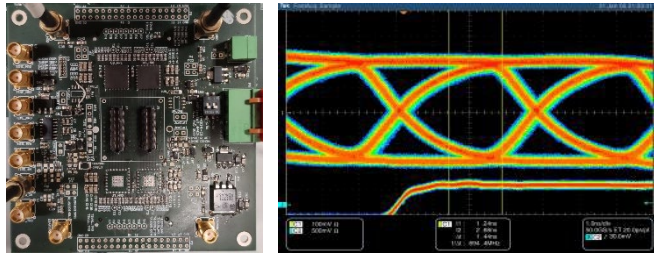
Monte Carlo simulations



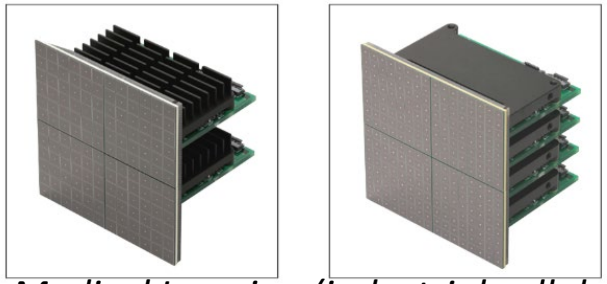
Microelectronics (Chip Design)



Space missions



Electronics



Medical Imaging (industrial collab.)

esa European Space Agency

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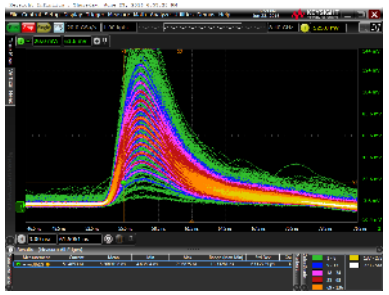
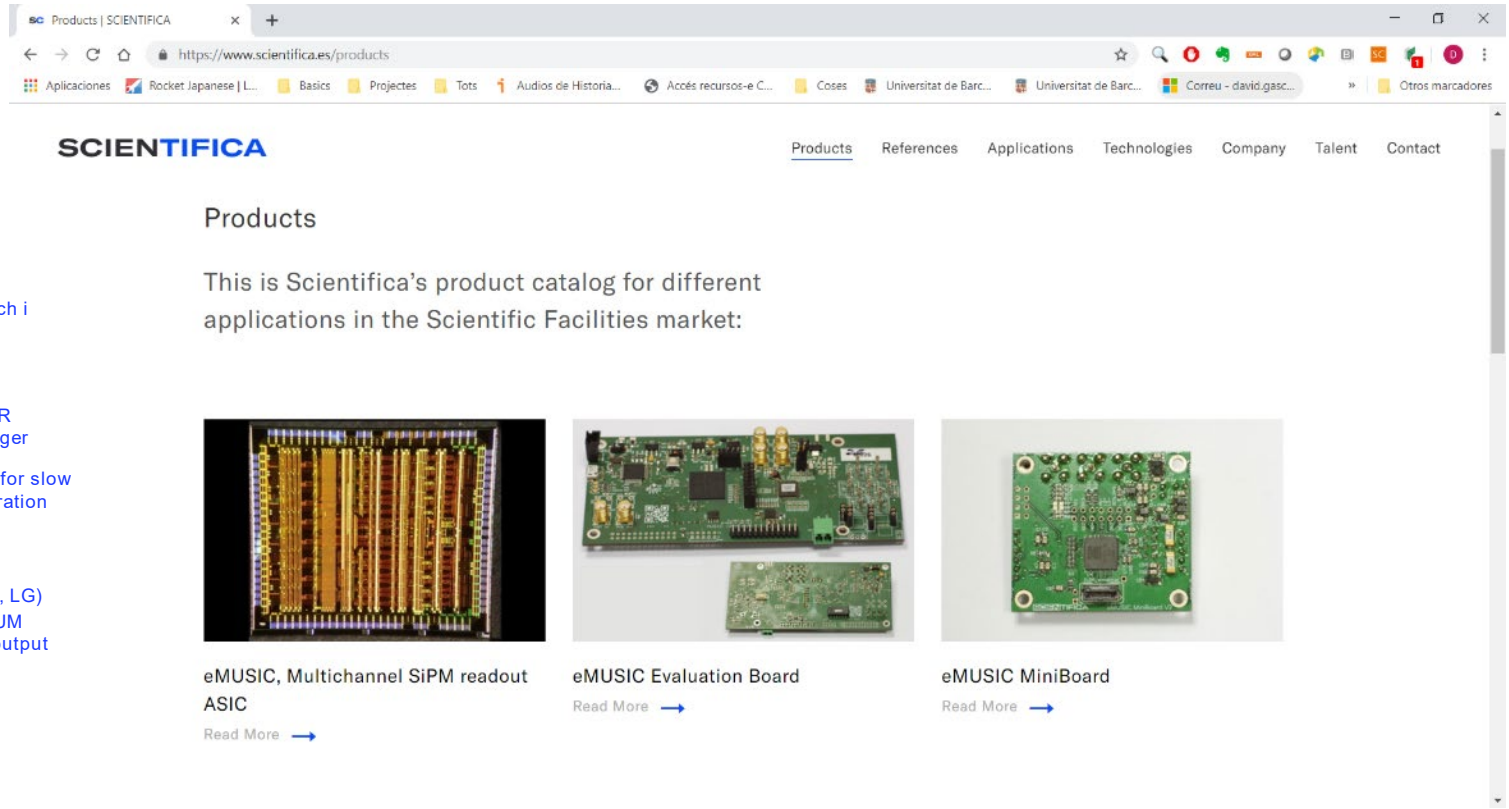
VII. Technology transfer

- Technology protected by patent and commercialized
  - Licensed to Scientifica international
  - Chip and evaluation boards are commercially available
  - Part of wider collaboration agreement

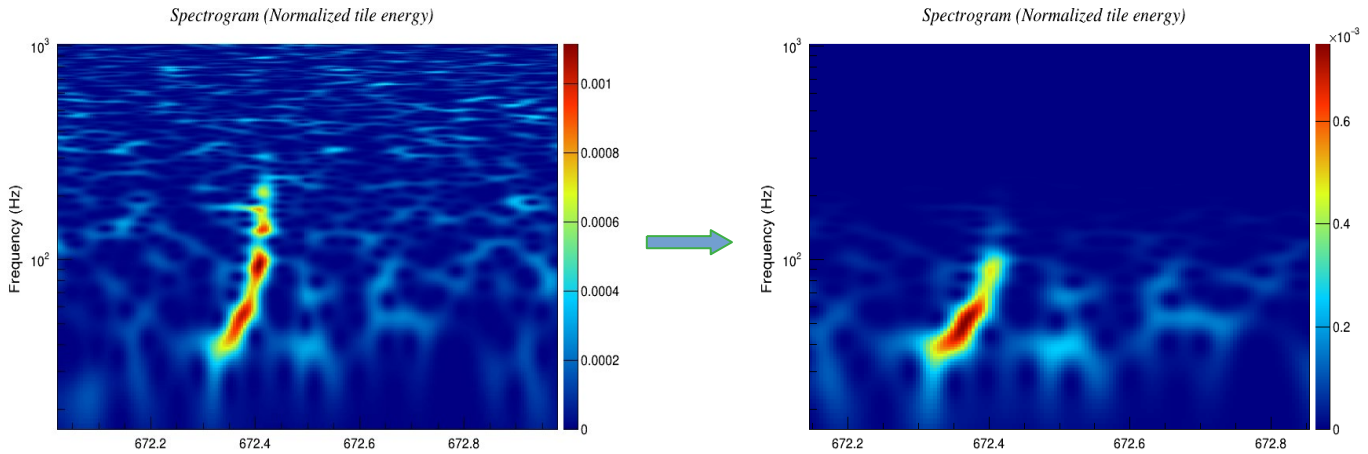


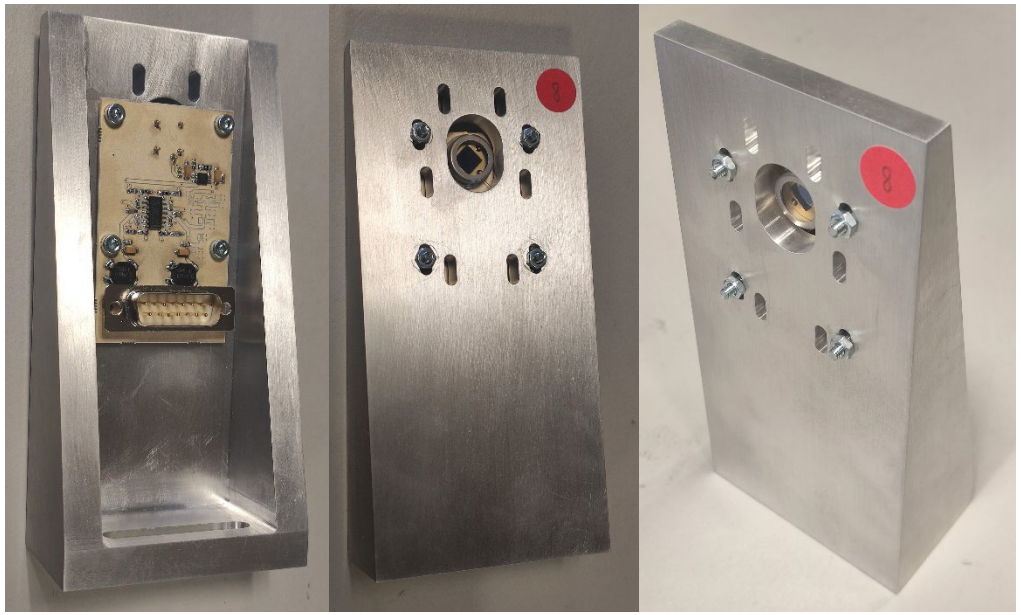


Software/Computing + Instrumentation: **Virgo**

- ICCUB is full member of Virgo since July 2019
  - Now 11 members, will add 3 this year. Contributions on: Computing, Instrumentation, Data analysis, Science, Outreach
- **Computing**:
  - Quite in stand-by (our expert left, now waiting for new manpower to arrive: COVID + India…)
  - So far: Computing Model revision, migration to modern software tools (CMake + Conda, Git)
  - Soon: Low-latency end-to-end test facility and off-site porting, support to pipelines development, data handling improvements…
- **Instrumentation**:
  - Quantum Noise Reduction:
    2D Position Sensitive Devices + electronics + mechanics + test
    (to be operated in **vacuum** → outgassing tests)
- **Data analysis**:
  - rROF-based de-noising algorithm integrated in the Bursts (cWB) pipeline

(see GW presentation by R. Emparan/M. Gieles)





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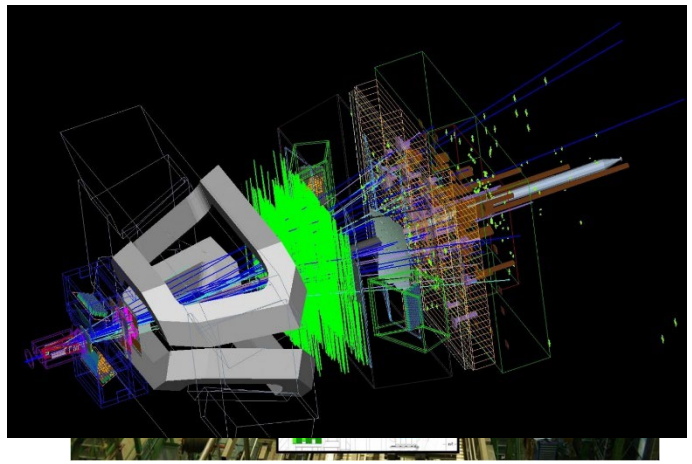
II. Activities in instrumentation

Part of the *ICCUB technology unit* (*TU* has 2 sections: instrumentation/electronics and software/data processing)
Enabling key contributions on instrumentation to ICCUB to *high impact collaborations*:

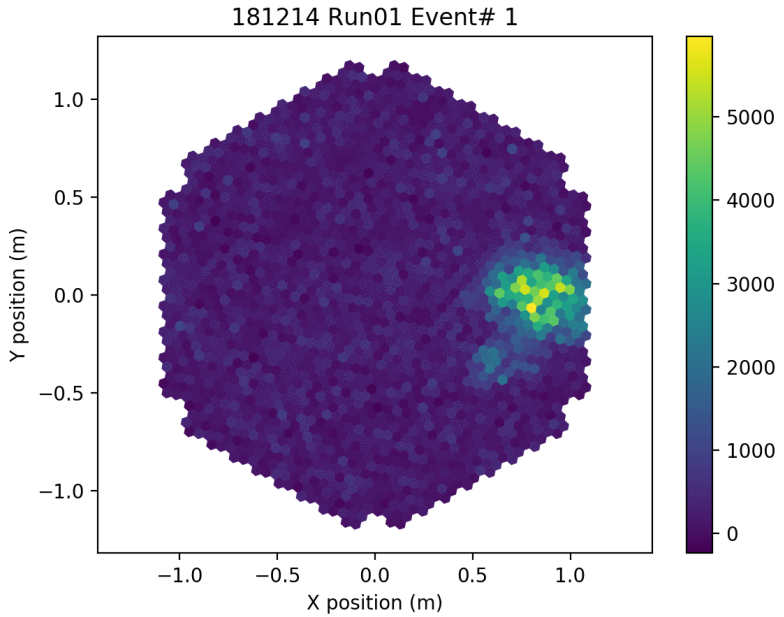
- Particle physics: LHCb, IAXO
- Ground instruments: CTA, VIRGO
- Space missions: LISA (ESA-L3), HERD

Close coordination other ICCUB research groups and Electronics Department (Solar Orbiter, Ariel and others)
Technological R&D: photosensors, medical imaging and quantum technologies

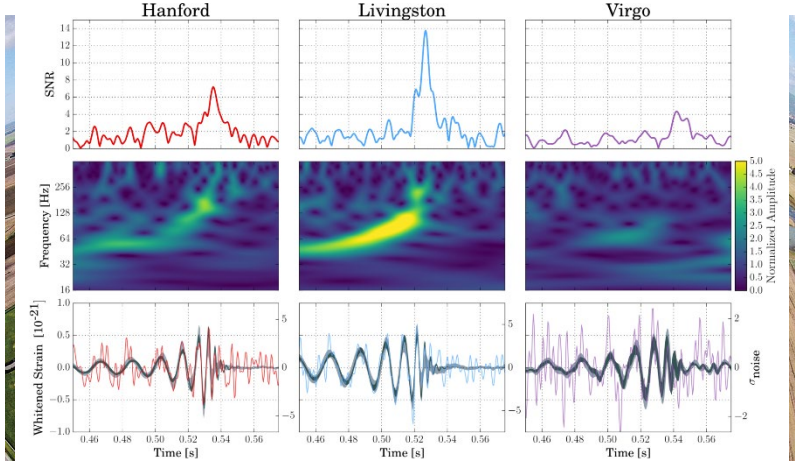
LHCb detector at LHC (CERN) with the Experimental Particle Phsyics group



Cherenkov Telescope Array with the High Energy Astrophysics group



VIRGO gravitational wave detector involves many groups and the 2 sections of the TU



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