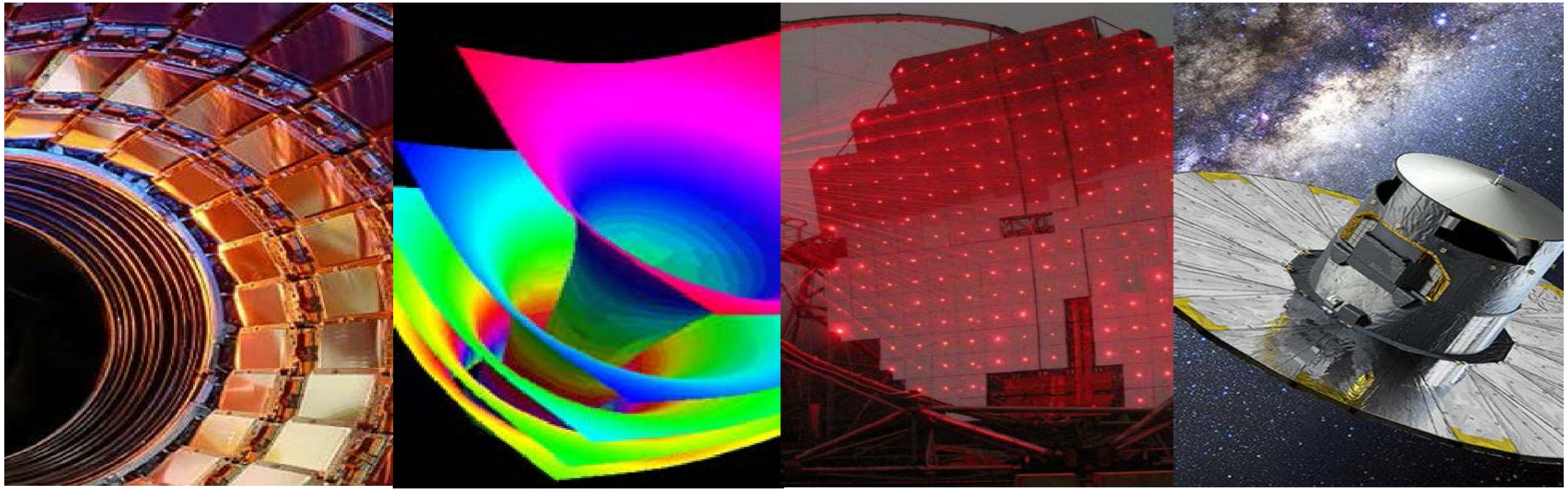
Institute of Cosmos Sciences
EXCELENCIA MARÍA DE MAEZTU



Instrumentation activities of the ICCUB Tehcnology Unit

David Gascón
Technical coordination
On behalf many ICCUB colleagues
Institute of Cosmos Sciences
Universitat de Barcelona

Winter Meeting @ ICCUB
07/02/2023

http://icc.ub.edu/technology

UNIVERSITAT DE BARCELONA

Outlook

I. **Introduction**

II. High Energy Physics

III. Ground Based Astronomy

IV. Space Projects

V. Dark Matter Searches

VI. Quantum Technologies

VII. Technology transfer

VIII. Outreach & Outlook

Introduction

- Many groups in the ICCUB are carrying research where technology is a key element
  - Development tool → new instruments for fundamental science
  - Product → transferred to scientific community or industry

- Quick overview of main current activities in:
  - Instrumentation
  - Electronics & *microelectronics*
  - Very large data processing
- for:
  - Space missions and ground instruments
  - Particle physics experiments
  - Dark matter searches
  - Quantum technologies

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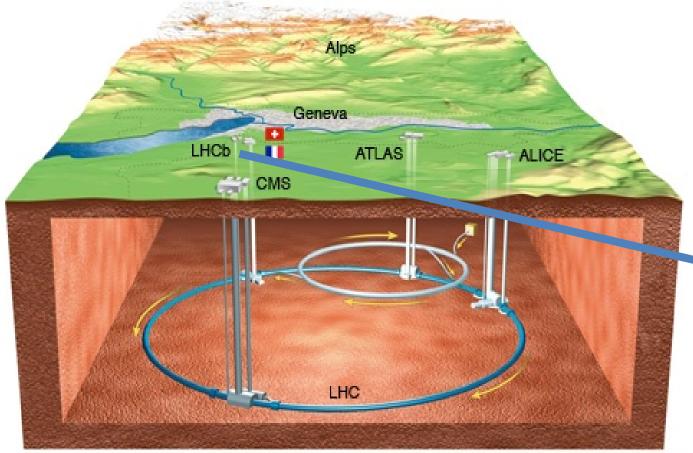
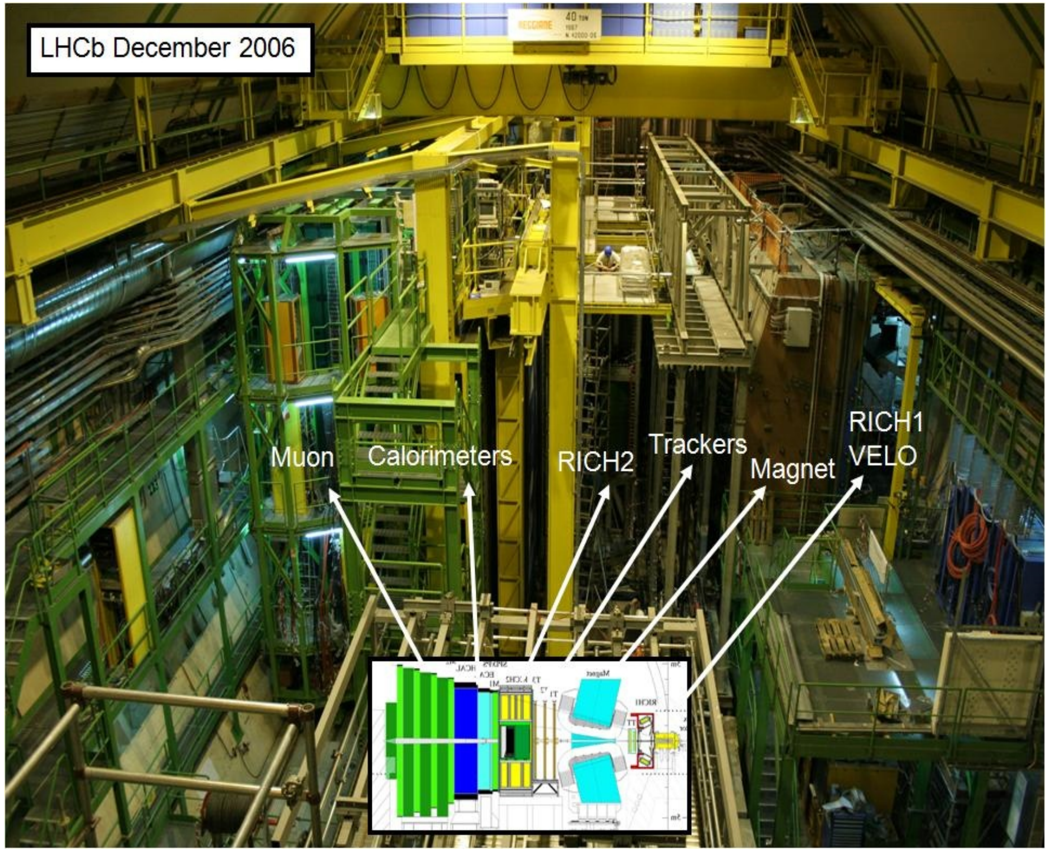
II. LHCb



- 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)
- Now working in the upgrade
  - New ASIC: ICECAL
  - 12 bit dynamic range @ 40 MHz
  - Low noise

LHCB detector at LHC (CERN)

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



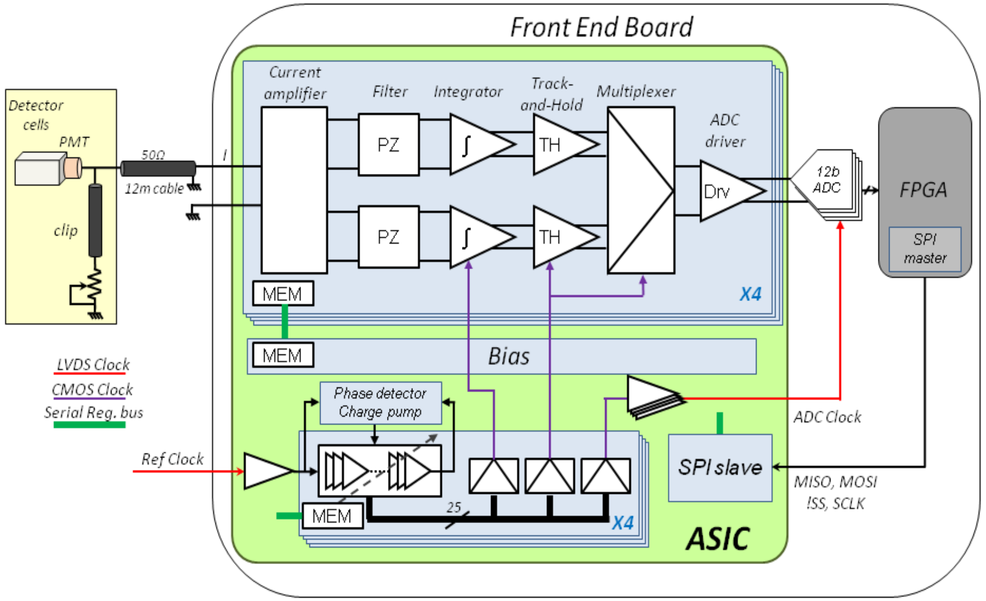
II. LHCb upgrade I

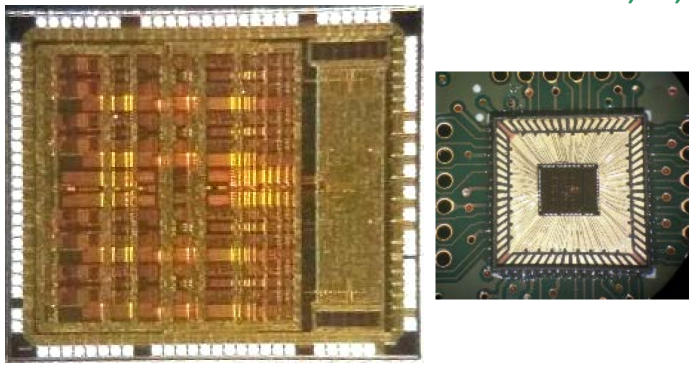
E. Picatoste, J. Mauricio, L. Garrido, E. Grauges, D. Gascon et alt.

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

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 !

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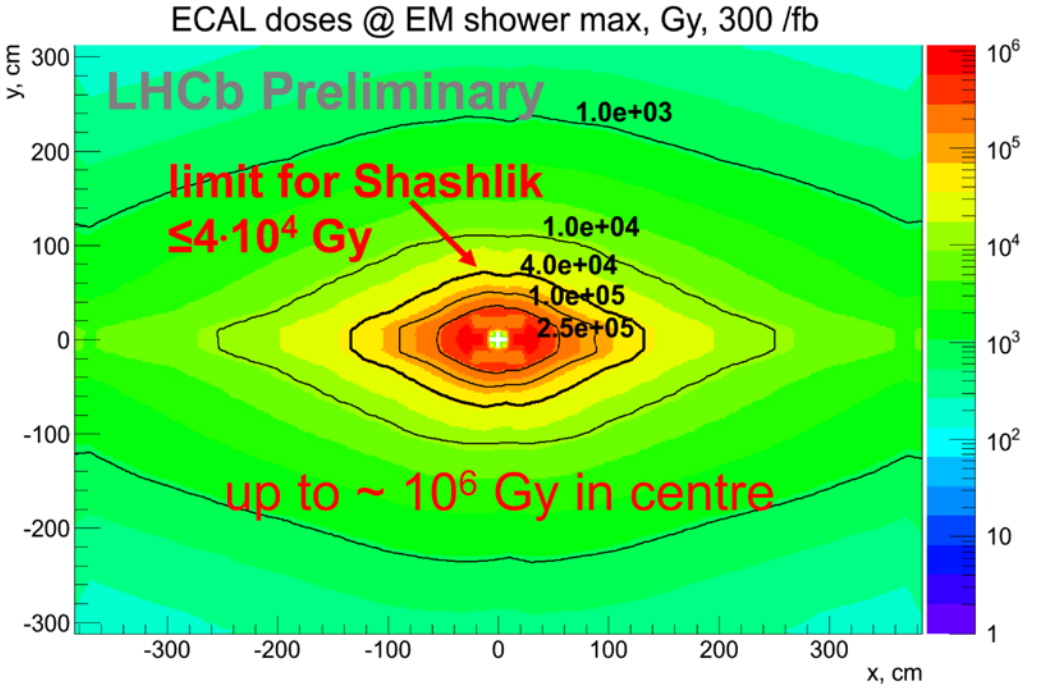
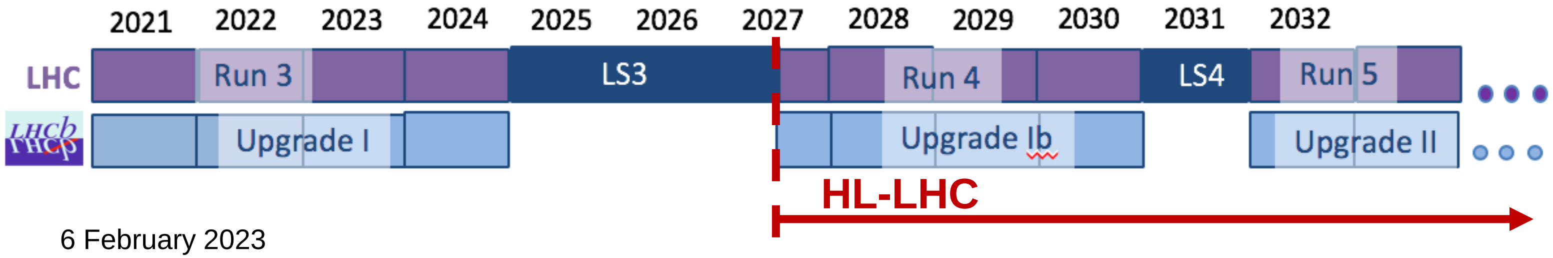
Motivation for the Upgrade II of the LHCb ECAL

Requirements for the Upgrade II: operation at L = 1-2 x 10^{34} $cm^{-2}s^{-1}$

- Sustain radiation doses up to **1 MGy** and ≤ $6 \cdot 10^{15} cm^{-2}$ for 1MeV neq/cm^2 at 300 fb^{-1}
- Keep at least current energy resolution $\frac{\sigma(E)}{E} \sim \frac{10\%}{\sqrt{E}} \oplus 1\%$
- Pile-up mitigation crucial with timing capabilities with O(15) ps precision and increased granularity to reduce occupancy
- Up to 30kch + 15kch with timing layer
- Detector R&D looks into new topology, high density absorber materials and fast rad-hard scintillator
- Schedule
  - Upgrade Ib: consolidation/enhancement phase for innermost channels and new electronics in LS3
  - (Full) Upgrade II: installation in LS4



Cell Size	Rad. Dose	Module
15mm	1MGy	SpacalW
30mm	200kGy	SpacalPb
40-120mm	<40kGy	Shashlik



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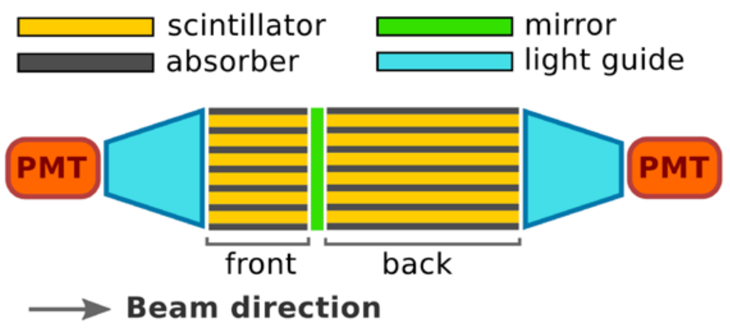
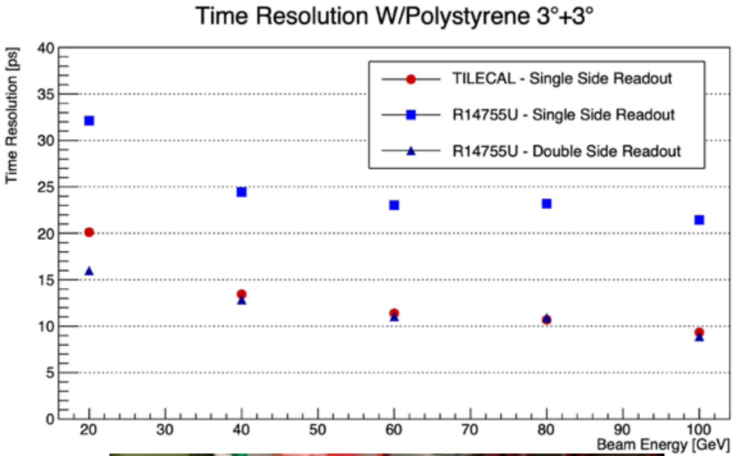
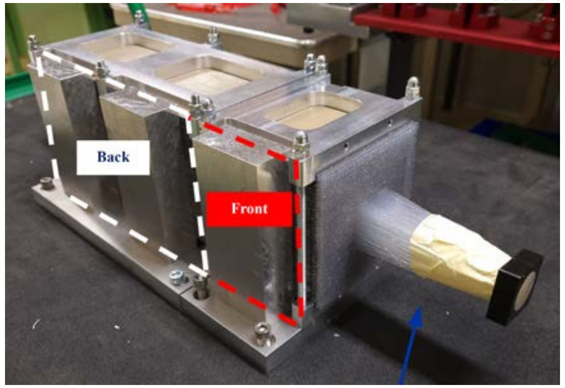
LHCb ECAL Upgrade II: channel prototypes

- SpaCal-W prototype module
  - Pure tungsten absorber with 19 g/cm^3
  - garnet crystal fibers
  - 9 cells of 1.5x1.5 cm^2 (RM ≈ 1.45 cm)
  - 4+10 cm long (7+18 X_0)
  - Reflective mirror between sections

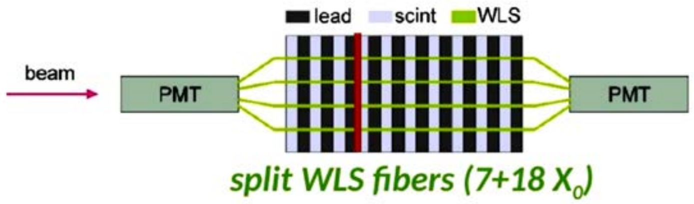


- SpaCal-Pb prototype module
  - Pb absorber + polystyrene fibers
  - 9 cells of 3x3 cm^2 (RM ~ 3 cm)
  - 8+21 cm long (7+18 X_0)
  - Reflective mirror between sections
  - Kuraray SCSF-78 fibres (1mm)

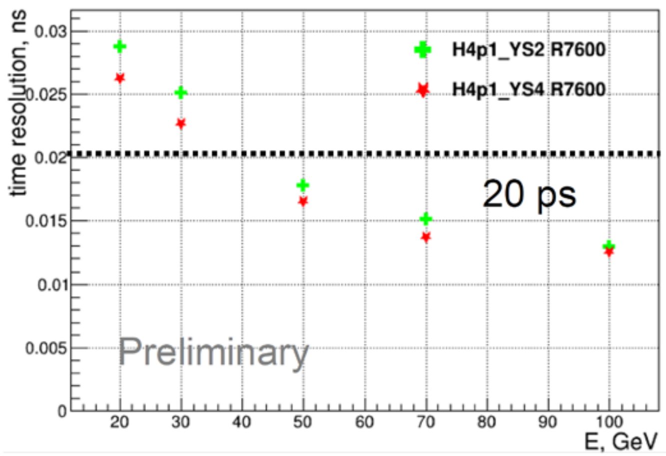




- Shashlik prototype
  - in outer part of ECAL and provide timing information
  - Split WLS fibers (7+18 X0, mirrored fiber ends)
  - Kuraray WLS YS2 and YS4

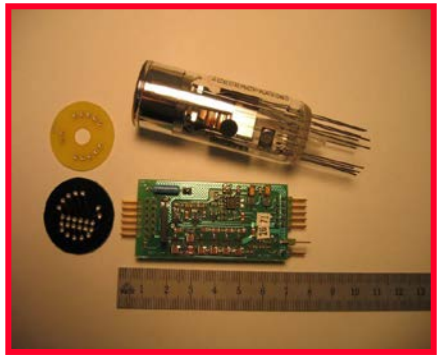


Double-sided readout (CERN SPS 2021



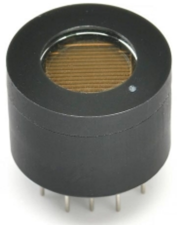
PMT Studies

R7899-20 (ECAL/HCAL)

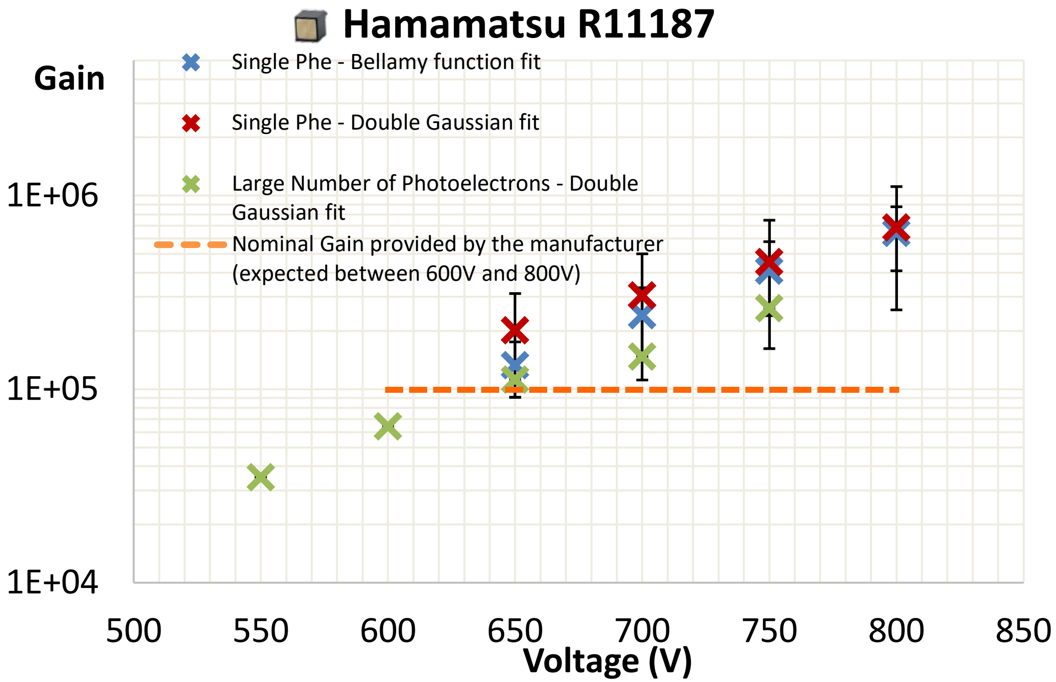


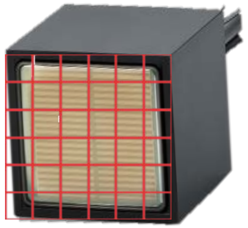
R11187 (TILECAL), R7600U-100

R14755U-100



- Gain using 1-Phe method and high N_{phe}
- Time resolution uniformity over photo-cathode and for different bias and light conditions

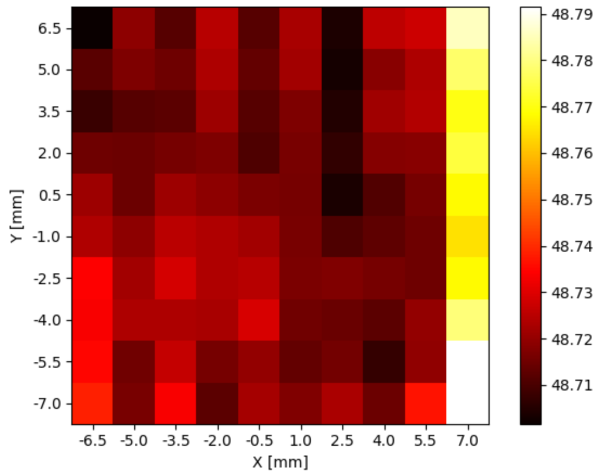


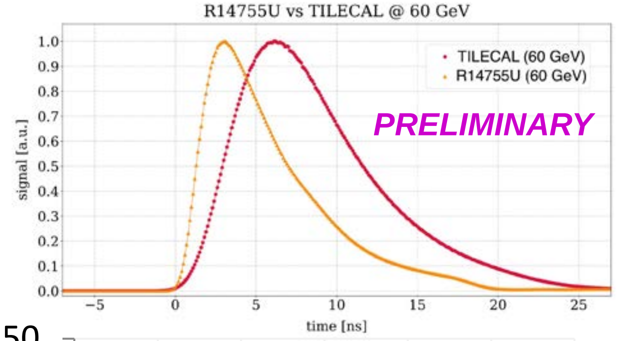


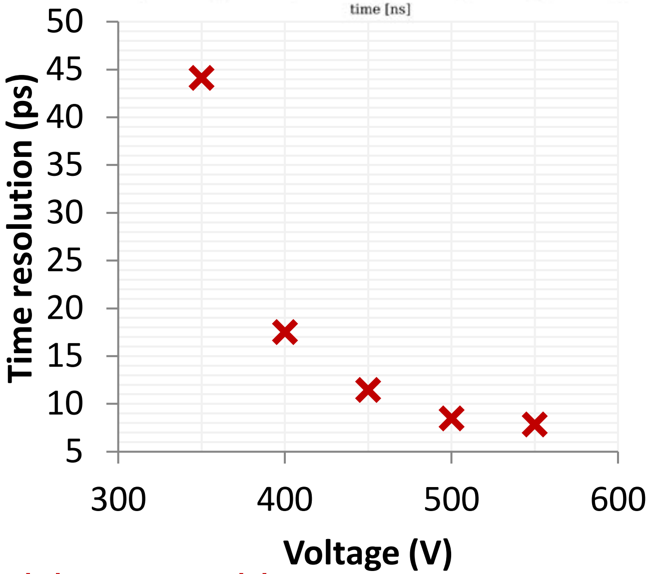
Grid of points, (laser)

Arrival time uniformity over R11187

✓ total std = 32 ps







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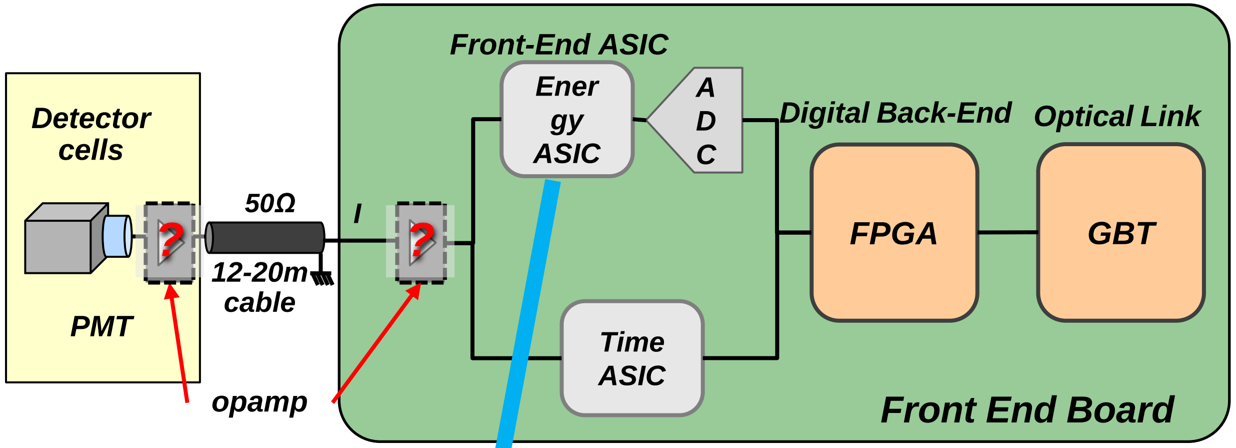
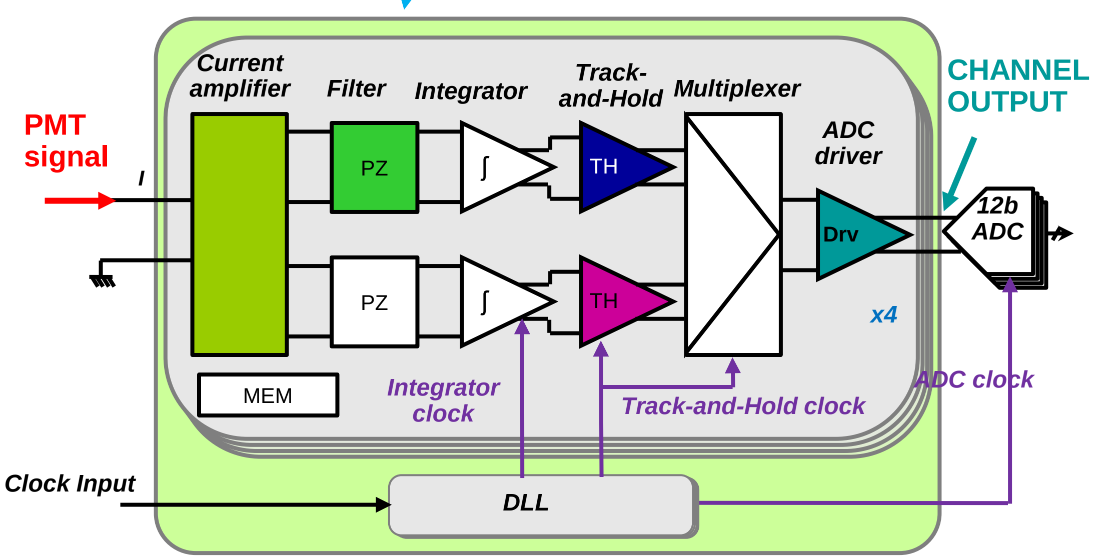
ECAL Upgrade II readout electronics

- ASIC/chipset in TSMC 65nm with separate energy and timing processing paths
- Amplifier + Shaper circuit included on the PMT base or FEB under consideration to compensate cable attenuation, improve SNR, if necessary, and reduce spill-over effort
- Energy path ASIC
  - time-interleaved double channel scheme for integrator recovery
  - dynamic range: more than 15 bits (bigain)
  - fully differential to improve noise rejection,
  - Internal digitization is under consideration but not a requirement





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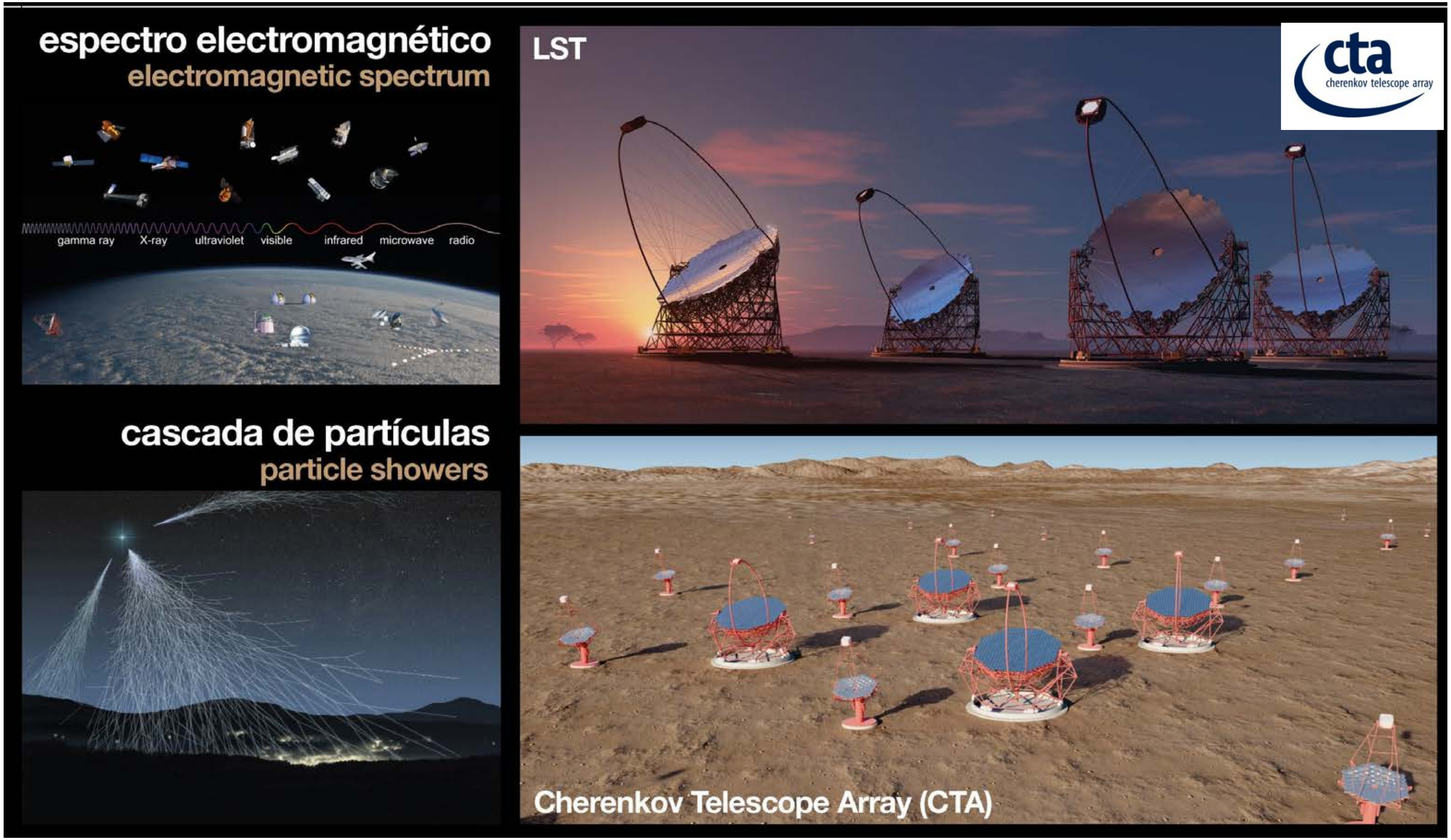
Cherenkov telescope array observatory

http://www.cta-observatory.org



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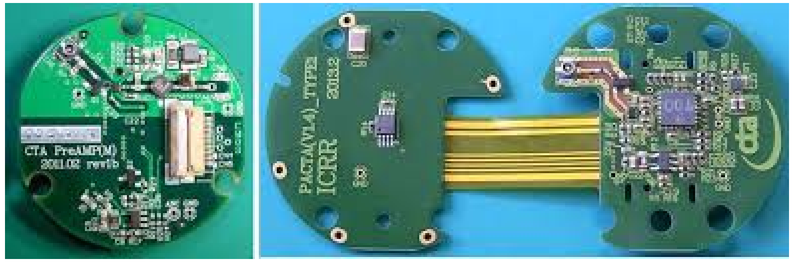
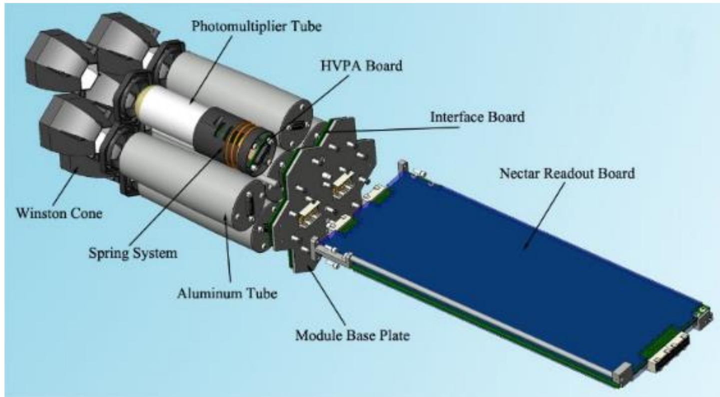
III. CTA

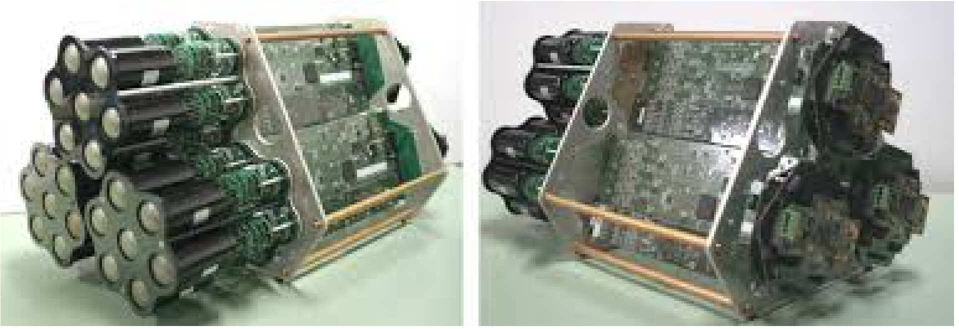
- **ICCUB has developed 3 different chips with important contributions to the cameras**
  - DragonCAM for LSTs
  - NECTArCAM for MSTs
  - **More than 30,000 chips produced to equip 5 cameras**
    - **Around 10-15 more cameras to be build**



ICRC 2013



NIMA, 639, 2011



SPIE, 9151, 2014

A. Sanuy, J. Mauricio, M. Ribó, J. M. Paredes, D. Gascon et alt.

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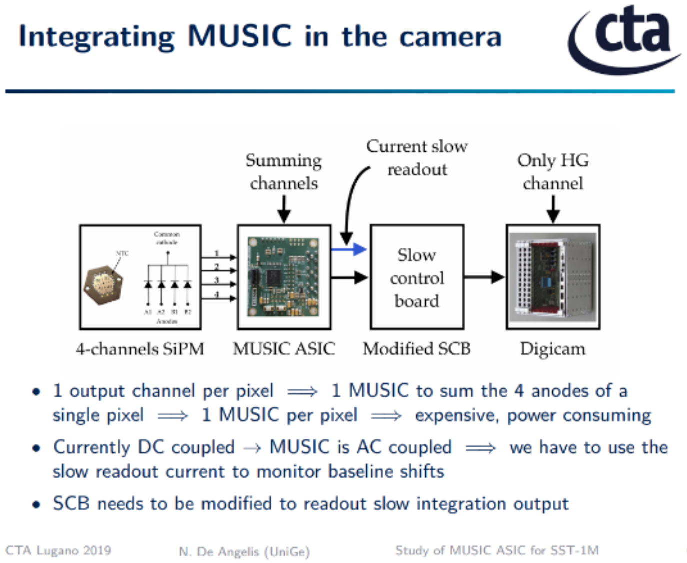
III. CTA

- In the short and mid-term we plan to consolidate our contribution to the CTA cameras:
  - Working in the production and quality control of the PACTA, ACTA and L0 trigger ASICs for 15 NECTAr MST cameras
  - Preparing the production of ASICs for additional LST cameras
  - Contributing to the installation and 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

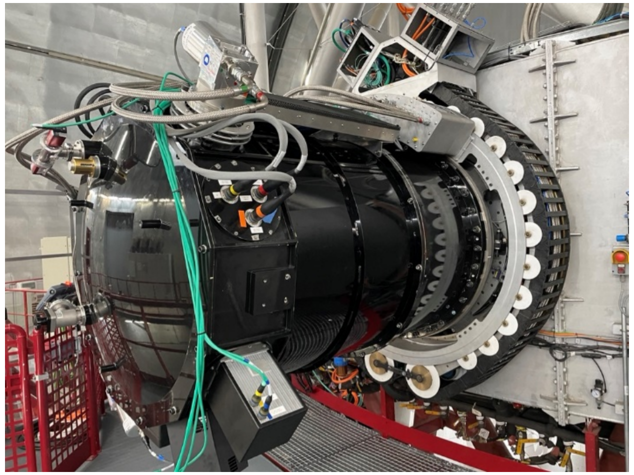


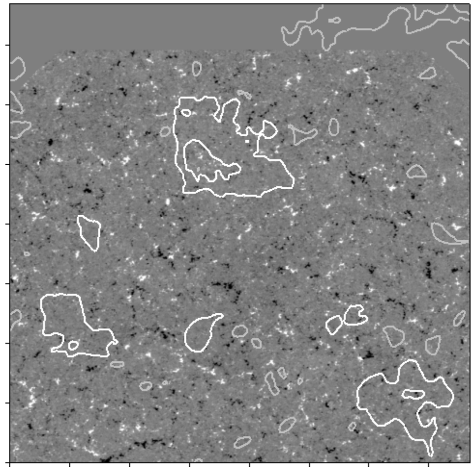
A. Sanuy, J. Mauricio, M. Ribó, J. M. Paredes, S. Gomez, A. Casajus, O. de La Torre, A. Espinya, D. Gascon et alt.

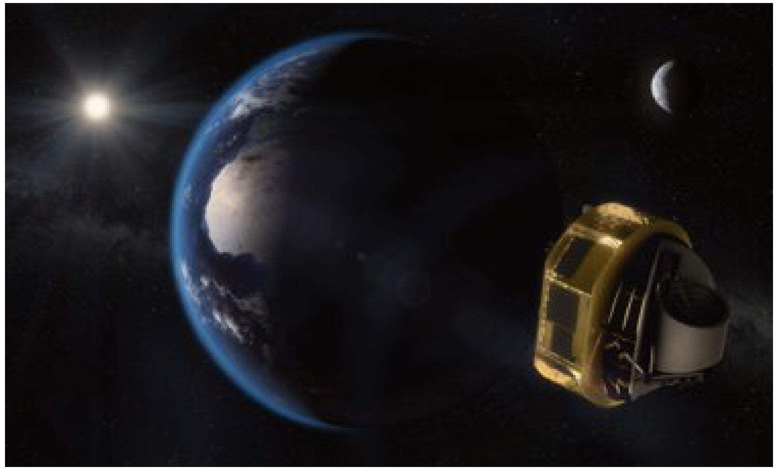
Institute of Cosmos Sciences

Solar Orbiter, MIRADAS, Ariel

- Solar Orbiter: Launched 2021, first results available
  - Image stabilisation system being used in the first studies
- MIRADAS: First test light 2022
  - Solving detected issues
- Ariel: To be launched 2029
  - Telescope Control Unit preparing for the Preliminary Design Review







J. M. Gomez, J. Ateca, A. Casas, P. Lopez, C Serre et alt.

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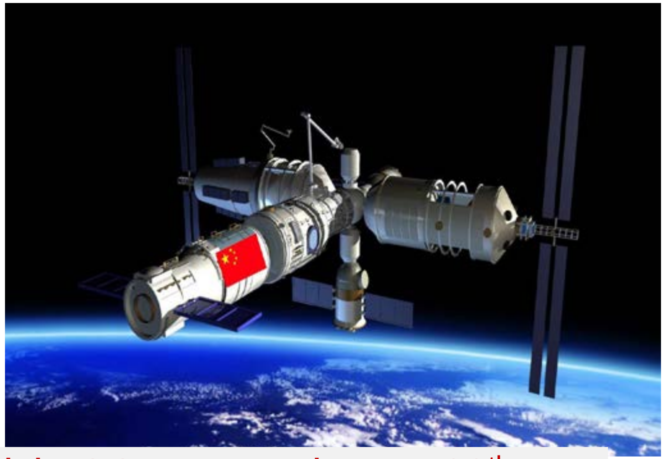
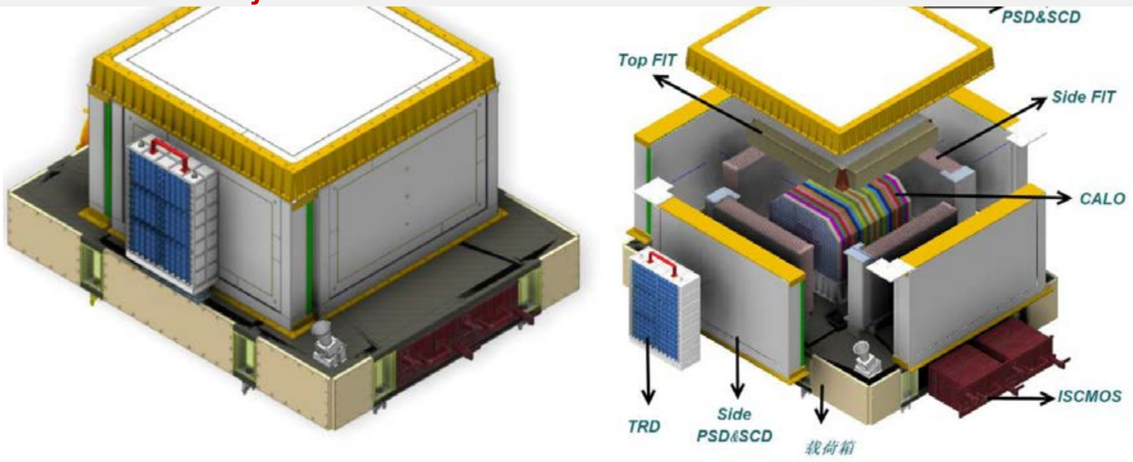
IV. HERD

- 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 PI and Chinese delegation will visit ICCUB on February 28th
You are welcome to join fro scientific discussion!

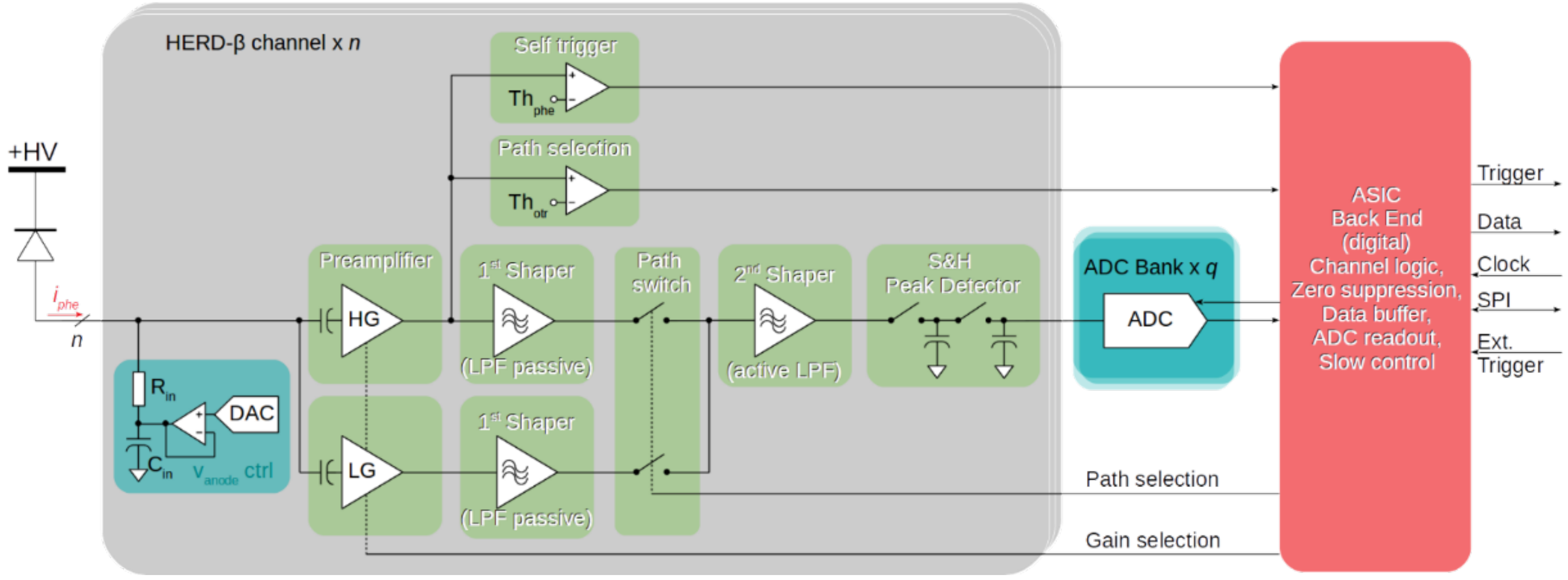
- HERD will be unique
  - No other planned or approved mission with comparable scientific capabilities
- Flagship scientific experiment on the Chinese Space Station (CSS)
- Out key contribution is ***Beta ASIC*** for Fiber Tracker and PSD subdetectors



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

IV. HERD

Beta ASIC



- Readout based on SiPM
- Good MIP resolution and high dynamic range
- A low power high dynamic range ASIC is required

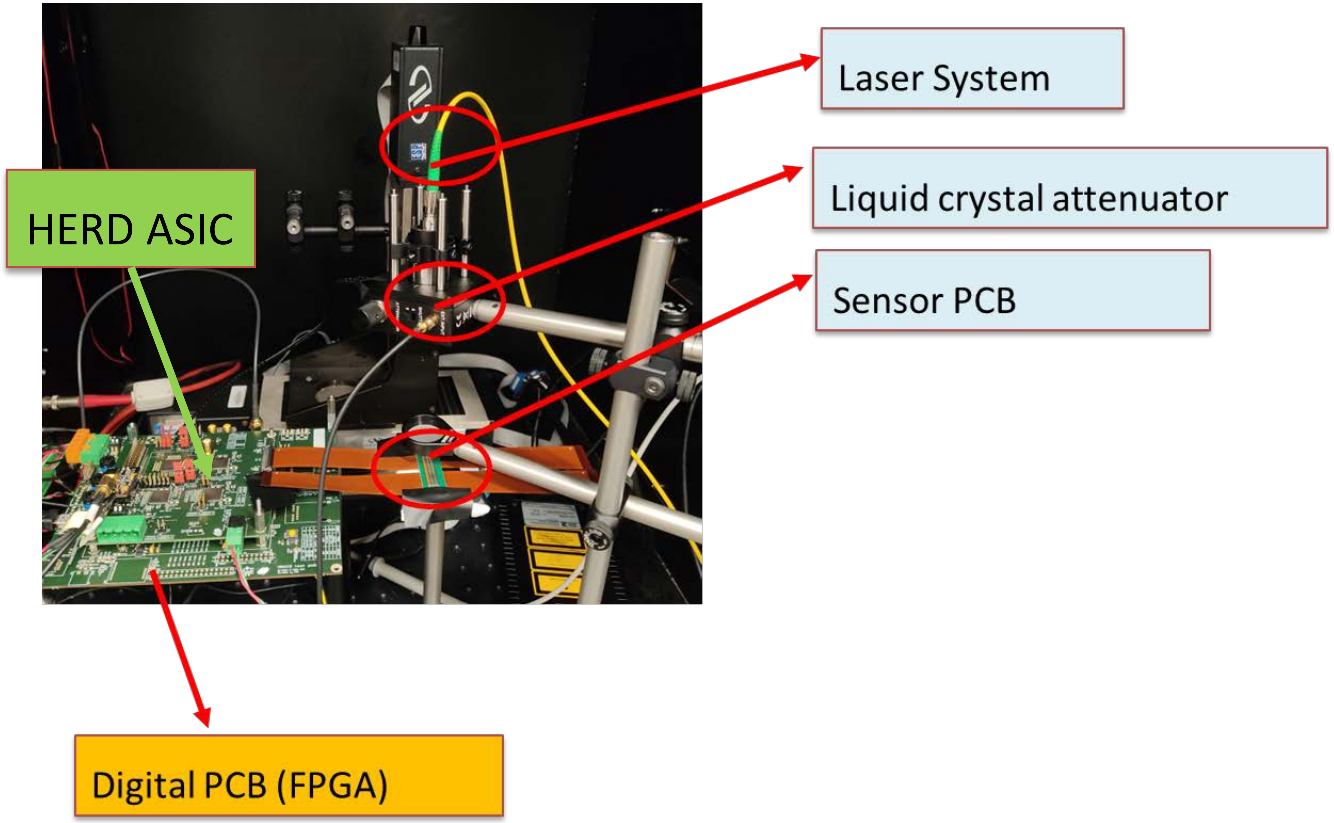
Item	Value
Energy range (e/γ)	10 GeV - 100 TeV (e); 0.5 GeV - 100TeV (γ)
Energy range (CR)	30 GeV - PeV
Angular resolution	<0.6° @1GeV, 0°
Charge measurement	Z=1 to 26
Charge resolution	0.15c.u.@Z=1, 0.2c.u.@Z=6
Energy resolution (e)	<1.5%@200GeV
Energy resolution (p)	<22%@400GeV
e/p separation	>3*10^5@effi. 90% 100GeV e-
G.F. (e)	>3m^{2}sr @200 GeV
G.F. (p)	>2m^{2}sr @100 TeV

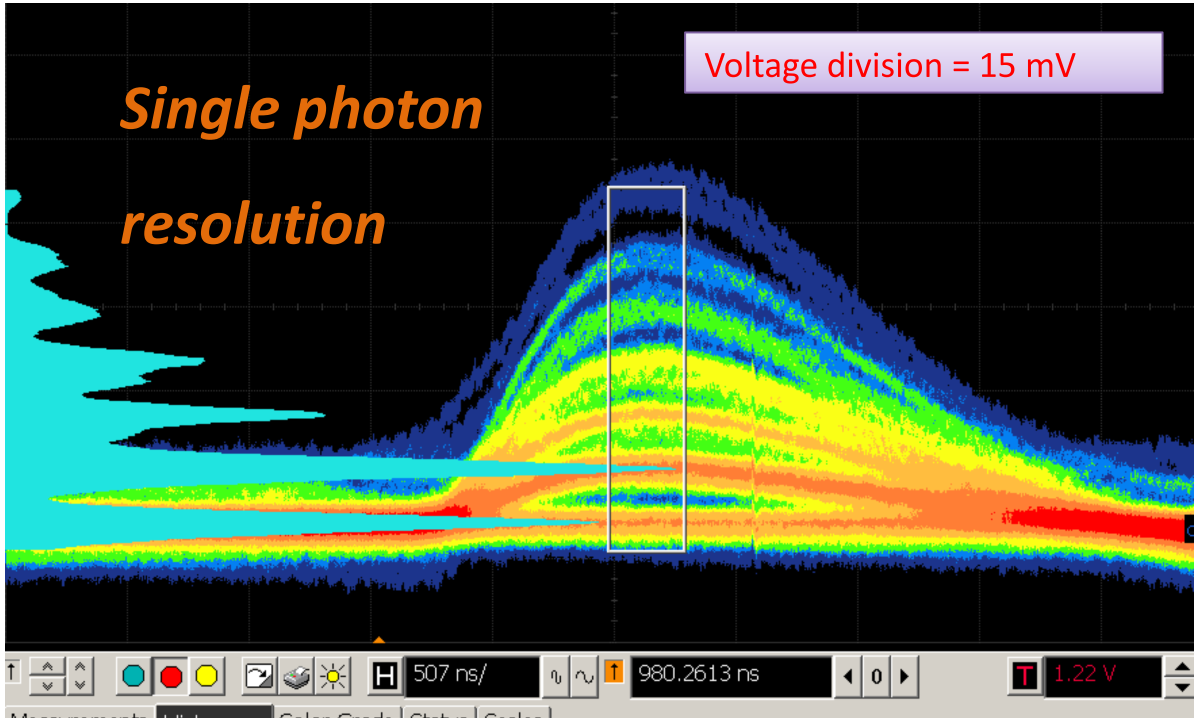
SCD	Charge Reconstruction
PSD	Charge Reconstruction γ Identification
FIT	Trajectory Reconstruction Charge Identification
CALO	Energy Reconstruction e/p Discrimination
TRD	Calibration of CALO response for TeV protons

IV: BETA - ASIC

- ✓ 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





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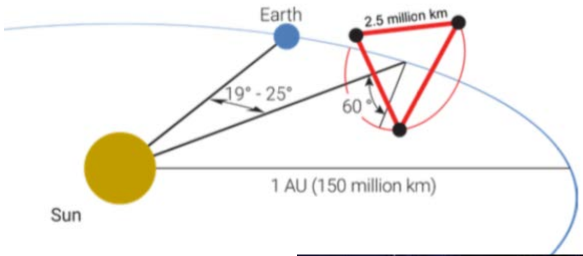
IV. LISA

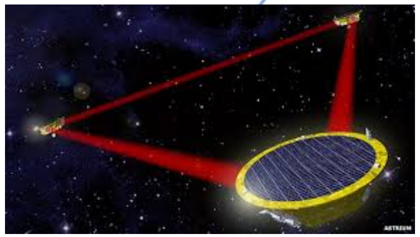
Control and diagnostic PI : M Nofrarias (IEEC-ICE)

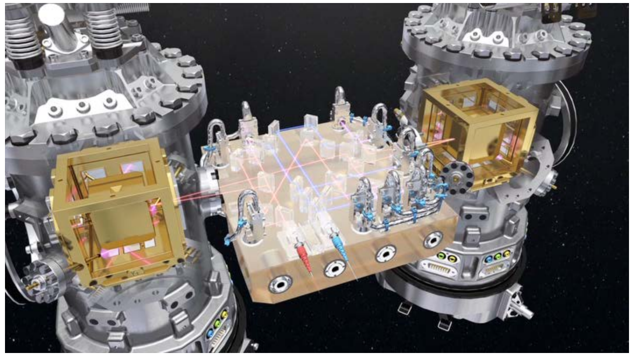
Institut d'Estudis Espacials de Catalunya

- LISA is the concept selected for ESA L3 mission slot (2034)
  - Constellation of 3 satellites in heliocentric orbit
  - Space-craft are drag-free
    - Test mass (TM) inside which is in nominal free fall
  - Differential arm-length measured by laser interferometry
- High energy environment responsible for test-mass charging
  - Affects the capacitive control of the test masses: acceleration noise
- ICCUB contribution to common IEEC project
  - Monte Carlo simulation
    - To understand better the effective TM charging
  - Study radiation monitor for LISA mission
    - Transversal project within ICCUB: space weather, interaction of radiation with matter, particle physics, technology unit
  - Also, possible contribution to integration of readout electronics of new concept miniaturized magnetometer with a very low noise floor
    - IEEC's MELISA project



European Space Agency





D. Guberman, D. Mazzanti, D. Sanchez, L. Garrido, A. Aran, F. Salvat, A. Herms, D. Gascon et alt.

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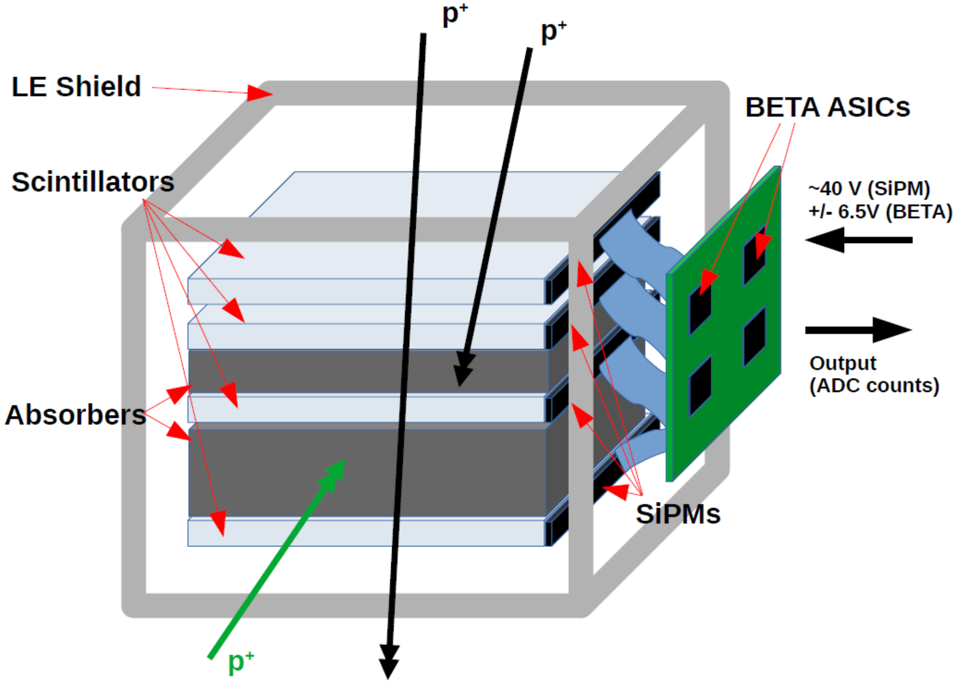
Excelencia María de Maeztu

IV. LISA: radiation monitor based on BETA - ASIC

- 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)

D. Guberman, D. Mazzanti, D. Sanchez, L. Garrido, A. Aran, F. Salvat, A. Herms, D. Gascon et alt.

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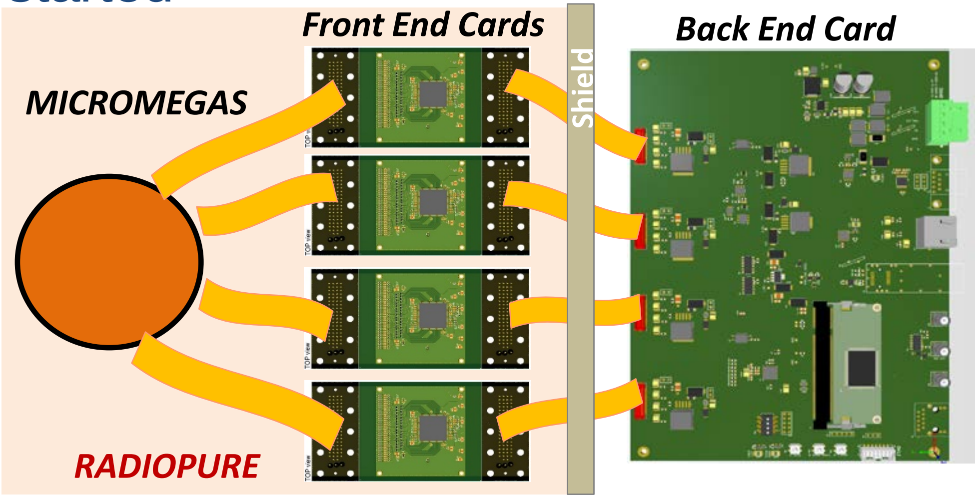
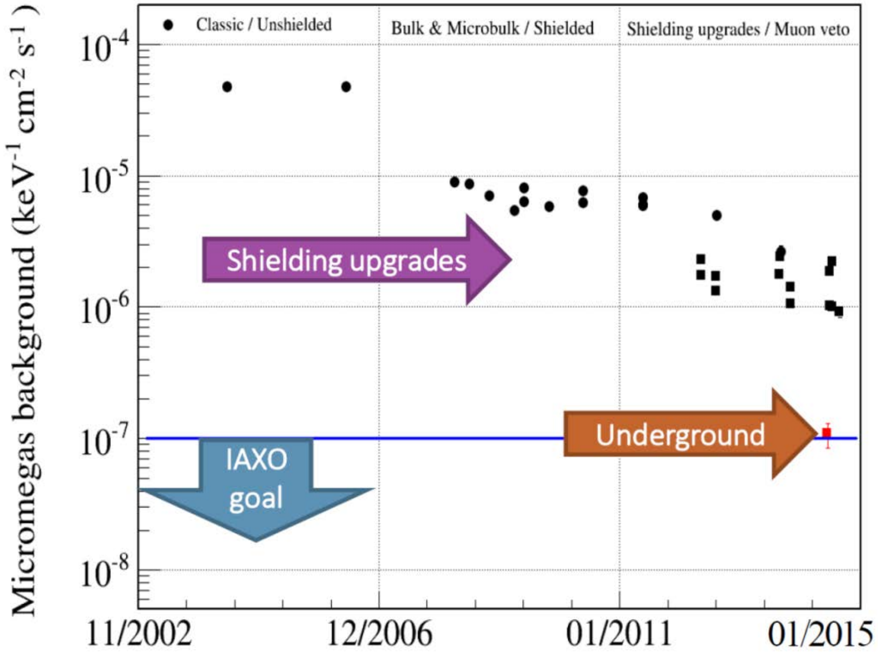
V. Axion searches

- 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
  - Radiopurity simulations
    - Detector + electronics
  - Front end electronics redesign (based on ARC from Saclay)
    - Move ASIC to Front End as close as possible to the detector
    - Back End with FPGA and ADC separated by extra shielding
  - Production phase started

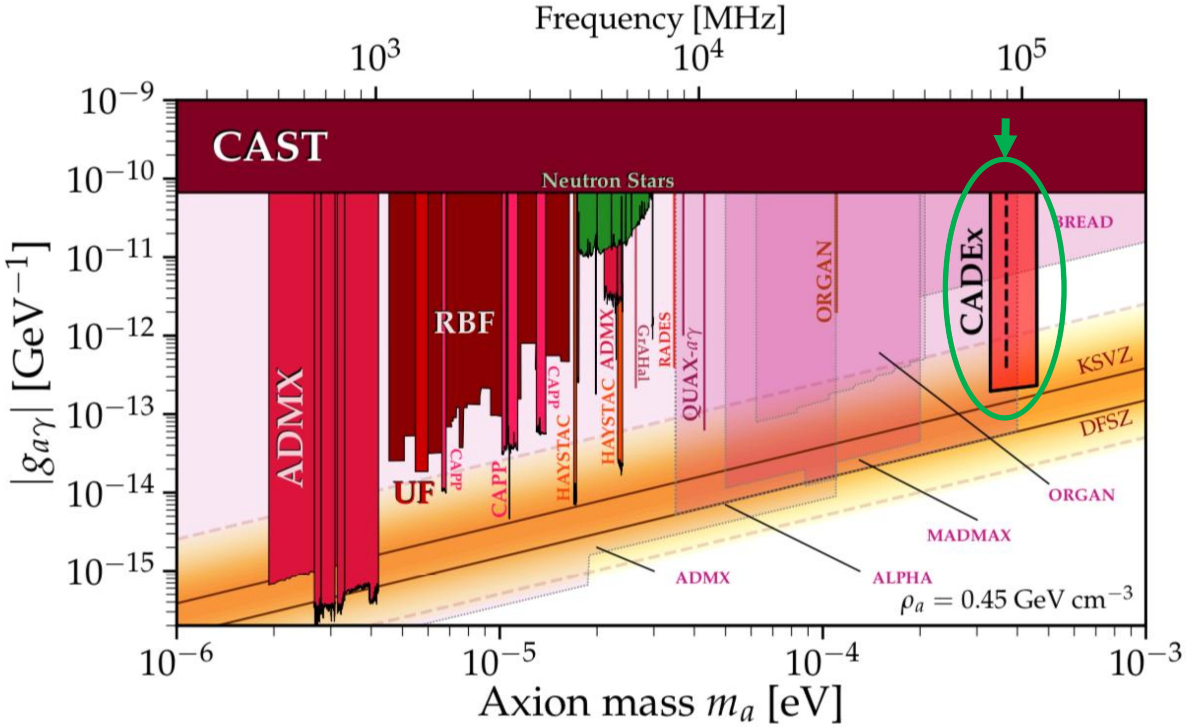


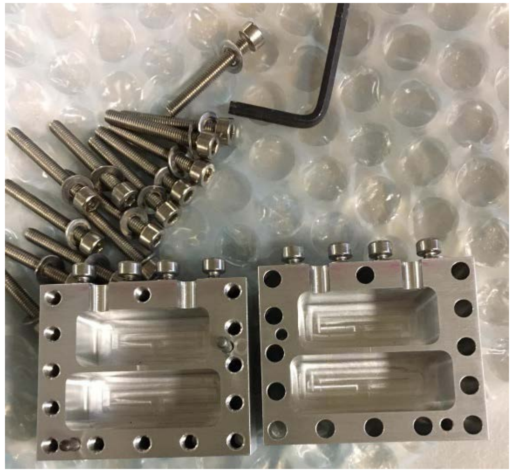


E. Picatoste, C. Cogollos, J. Miralda et alt.

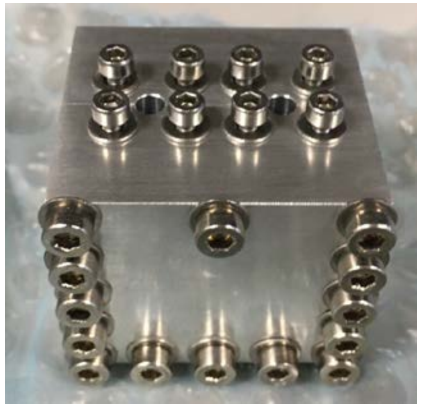
V. Axion searches

- ICCUB is involved both in helioscope and haloscope @ IAXO
- R&D on RF cavities
  - o CADEx collaboration
  - o Experimented hosted at LSC
  - o Implement KIDs technologies/detectors for Axion research at 90 GHz
  - o First RADES detector with qubits designed and produced





Cavity for qubit



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

Outlook

I. Introduction
II. High Energy Physics
III. Ground Based Astronomy
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V. Dark Matter Searches
VI. Quantum Technologies
VII. Technology transfer
VIII. Outreach & Outlook

VI. Quantum Technologies

We are working on two main projects:

1) **Development of an entangled photon source + Portable Bell Test**
Jose Maria Gomez Cama, Bruno Julia Diaz

Uses:
- Bell test for future entangled photon sources
- Future academic laboratory
- Science popularisation

2) **Start a lab on Quantum communications**
Jose Maria Gomez Cama, Marti Duocastella, Bruno Julia Diaz (PI)

Goals:
- Develop solid state entangled photon sources
- Prepare them for possible ground or satellite use.

Planes Complementarios

Comunicación cuántica

Outlook

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VII. Our approach: a new hybrid photosensor

- 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

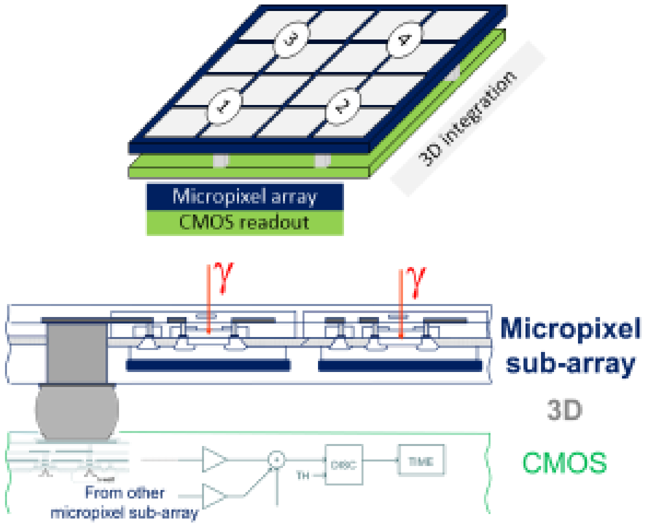
J. Mauricio, R. Manera S. Gomez,
A. Sanuy, D. Gascon et alt @ ICCUB
J. M. Fernandez-Tenllado, M. Campbell,
R. Ballabriga et alt. @ CERN

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.



It could have applications in medical imaging by enabling real time PET (Positron Emission Tomography), LIDAR, fluorescence lifetime imaging, homeland security and IOT / vision systems.

Our project is coordinated by the University of Barcelona **in partnership with** CERN.

It is part of wider collaborative effort involving sensor and ASIC design, 3D integration, module and applications with additional collaborators: CEA, EPFL, FBK, IFAE, LAL and University of Geneva.

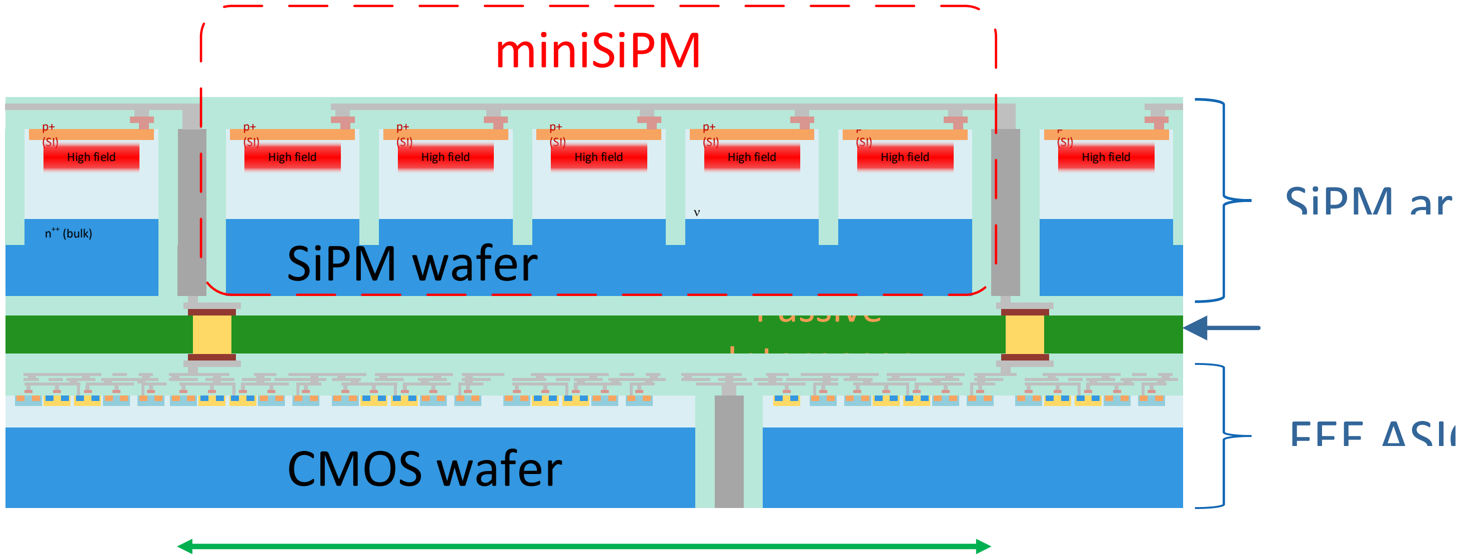
Contact email dgascon@fqa.ub.edu

ICCUB Institute of Cosmos Sciences — Excelencia María de Maeztu

VII. Our approach: a new hybrid photosensor

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

- 2.5D and 3D Integration
  - Photon Detection Module (PDM) in which SiPMs with TSVs down to 1 mm pitch
  - Connected to the readout ASIC on the opposite side of a passive interposer



1 - 3 mm interconnection pitch

Integrated Photon Detection Module

Core partners:

Jožef Stefan Institute

FONDAZIONE BRUNO KESSLER

ICCUB Institut de Ciències del Cosmos

CERN

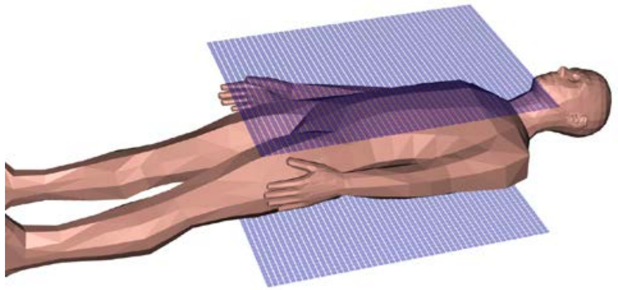
MGH 1811 MASSACHUSETTS GENERAL HOSPITAL

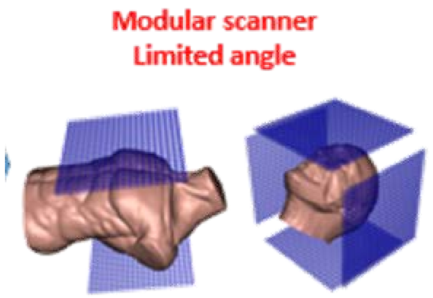
ONCO VISION

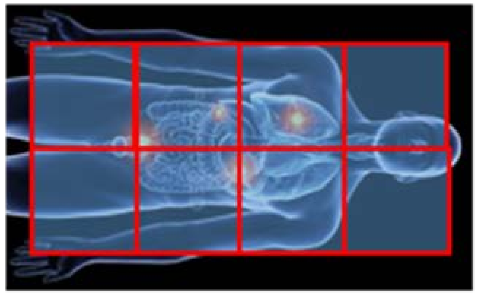
Hybrid SiPM module being developed for ultimate timing performance in ToF-PET

VII. Towards a new ToF-PET scanner concept

- The 2.5D integrated PDM will be the basis of a 30x30 cm2 ToF-PET panel, which will be used to build limited-angle ToF-PET systems, for brain PET, Cardiac PET and full-body scanners.
- We expect very good timing performance, supported by preliminary measurements achieved with NUV-HD SiPMs coupled to FastIC ASIC.







Application of the PDM to build large panes used in new, limted-angle PET applications: Brain Pet, Cardiac PET, wi

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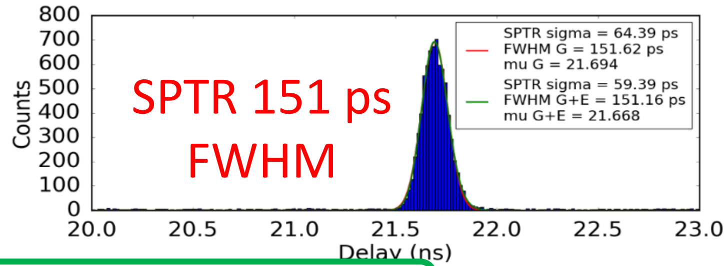
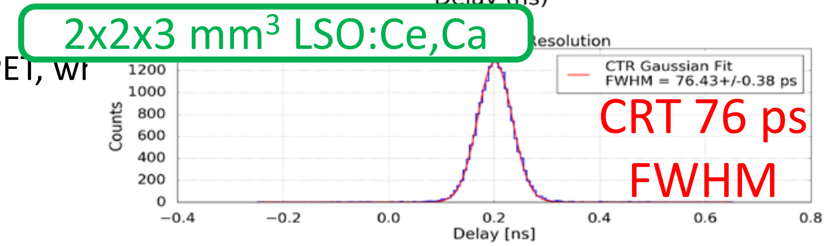
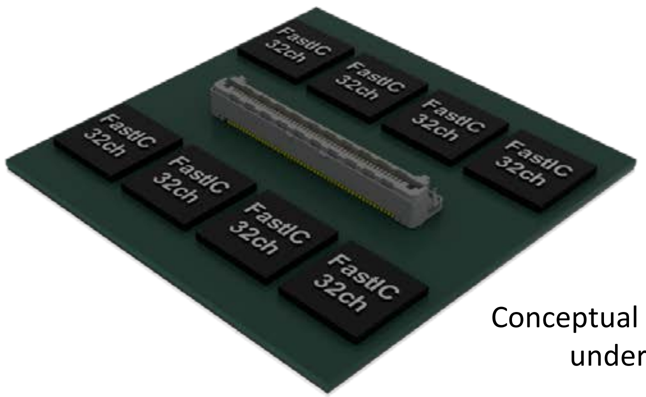
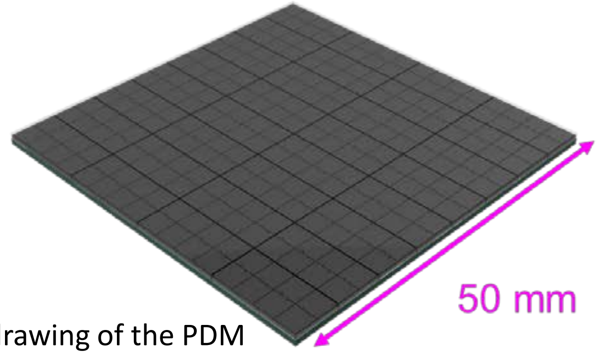
CERN







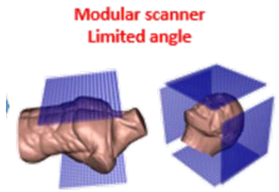


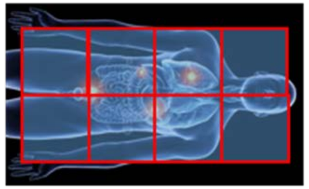
Conceptual drawing of the PDM under development

SPTR and CRT measured at FBK NUV-HD-SiPMs read by the FastIC ASIC developed by ICCUB.
Sensor: NUV-HD-LFv2 SiPMs, 3x3 mm^2
Scintillator: 2x2x3 mm^3 LSO:Ce,Ca
Power consumption: 3 mW / channel

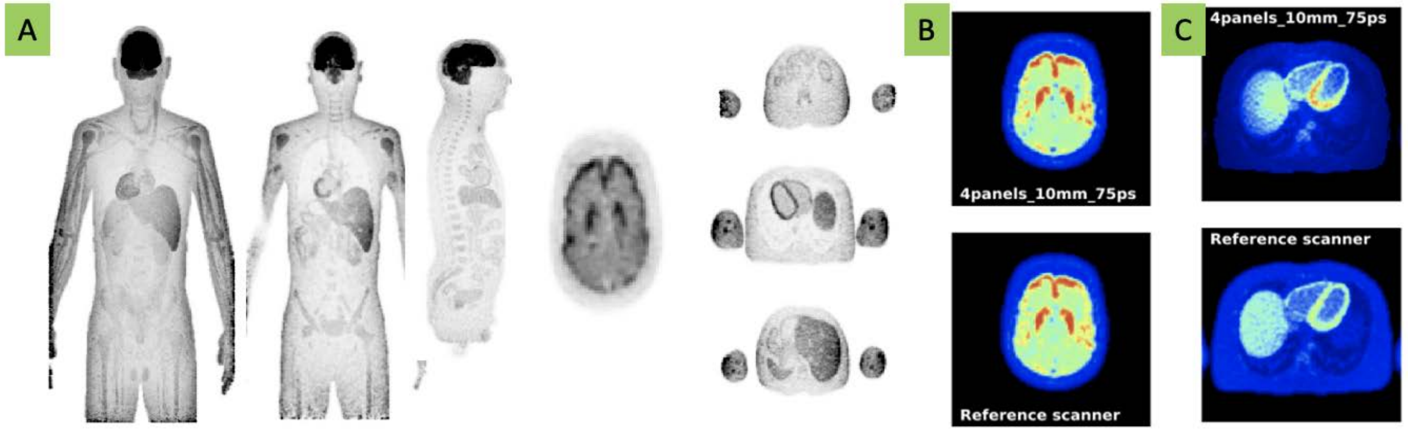
VII. Towards a new ToF-PET scanner concept

- The **PETVision** Project was approved! Call: **Horizon EIC 2022 Pathfinder-open**.
  - 5-year project starting in September 2023
- The aim of PetVision is to leverage on 3D / 2.5D 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
MGH	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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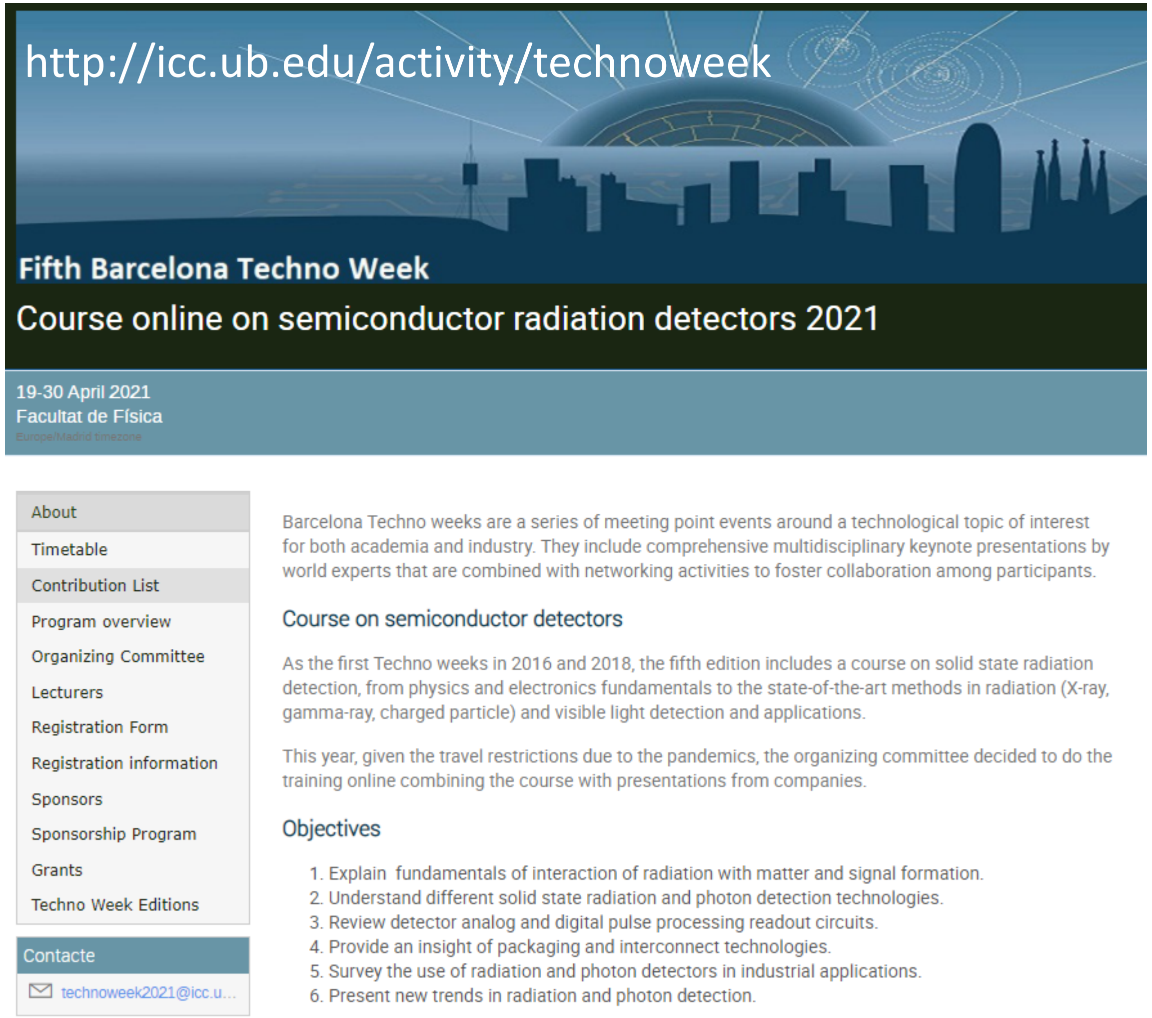
VIII. Barcelona Techno Week

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
  - 4 editions
  - Topics: semiconductors detectors & nanosatellites
- Last edition on 2021 (online)
  - More than 100 students
  - Nearly 150 attendees in total
  - Industrial participation
- *July 2023: back to presential:* ***you are welcome !***



ams Sensing is life.

πtec

CERN Knowledge Transfer *Accelerating Innovation*

Direct Conversion A VAREX IMAGING COMPANY

HAMAMATSU PHOTON IS OUR BUSINESS

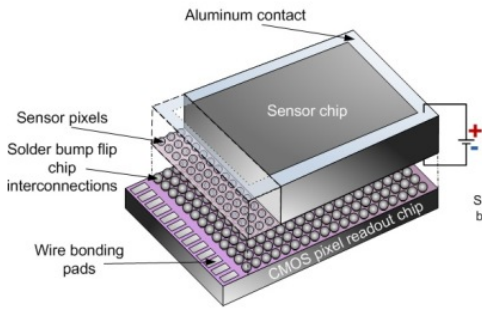
ICCUB Institute of Cosmos Sciences

EXCELENCIA MARÍA DE MAEZTU

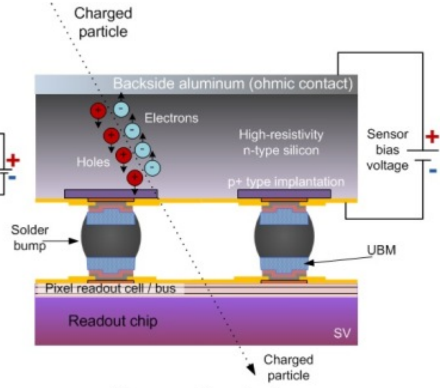
VIII. Future plans

- Consolidate our contributions to instrumentation of key scientific projects:
  - LHCb, CTA, LISA, IAXO, LISA, ARIEL and ET?

- Reinforce our position as reference centre for single photon sensors and readout
  - New infrastructures for vertical integration: sensor and integrated readout
    - Microprobe automatic station
    - Flip-chip and bump bonding
    - Clean room for integration and te



Generic pixel detector



Cross-sectional cut

VIII. Future plans

- Boost internal cooperation of our R&D lines and resources
  - Examples
    - Application of our photosensor technologies in quantum technologies
    - Application of quantum technologies for dark matter and scientific applications
- Increase scientific and industrial external collaborations
  - Example: New potential collaboration in Time-of-Flight Mass Spectrometry
- Training and outreach
  - New Techno Weeks
  - Participation in Masters: Astrophysics and Particle Physics and Quantum Science and Technology
    - In preparation “Semiconductor Engineering and Microelectronics Design”

Thanks a lot for your attention !!!

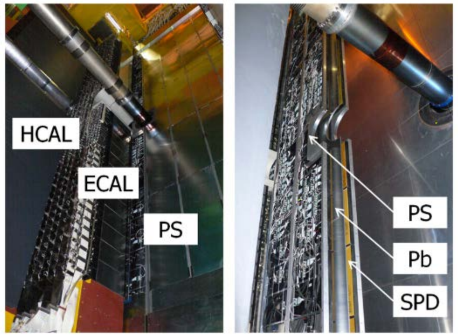
http://icc.ub.edu/technology

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

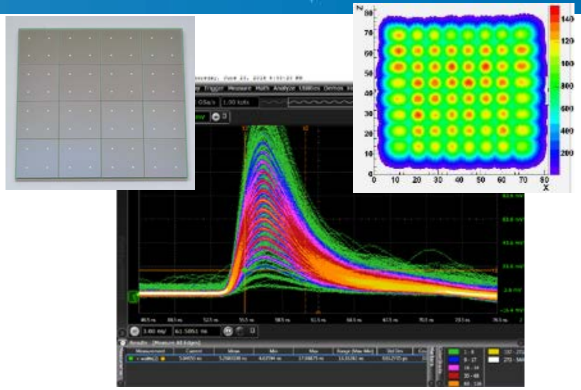
dgascon@fqa.ub.edu **jportell@fqa.ub.edu**

II. Activities in instrumentation

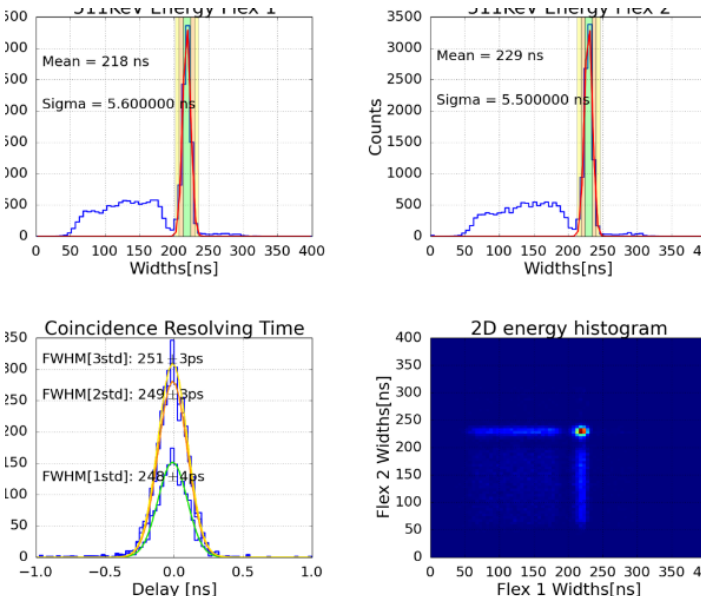
Telescope cameras



Particle detectors at CERN

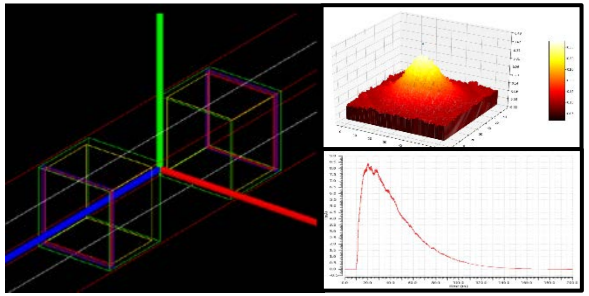


Single-Photon Sensors

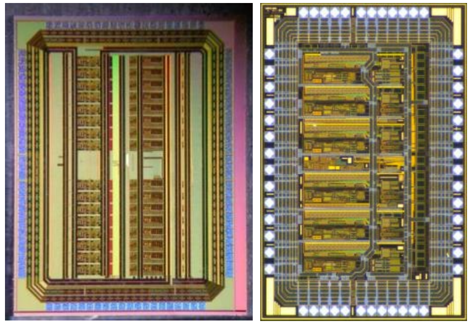


Positron Emission Tomography with Time-of-Flight (ToF-PET)

Axion and Dark Matter searches



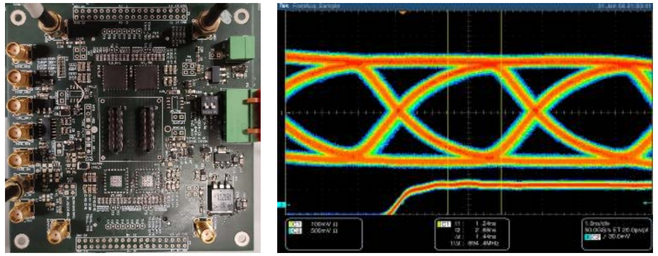
Monte Carlo simulations



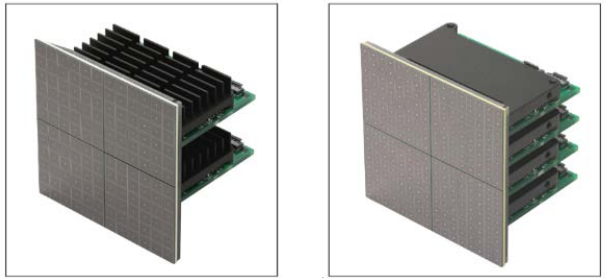
Microelectronics (Chip Design)

Space missions

esa European Space Agency



Electronics



Medical Imaging (industrial collab.)

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