1ª Reunión Nacional
Planes Complementarios de Astrofísica y Altas Energías

Plan de Recuperación, Transformación y Resiliencia
Financiado por la Unión Europea NextGenerationEU

Institute of Cosmos Sciences
EXCELENCIA MARÍA DE MAEZTU

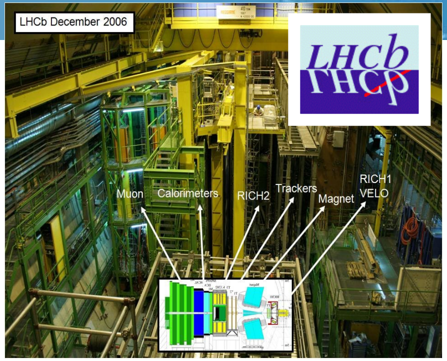
Readout ASICs for single photon detectors

UNIVERSITAT DE BARCELONA

David Gascón Fora
On behalf of many colleagues

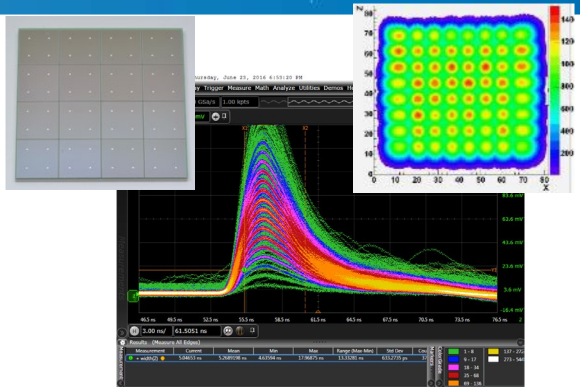
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
AGENCIA ESTATAL DE INVESTIGACIÓN
Next Generation Catalunya
Generalitat de Catalunya Departament de Recerca i Universitats

ICCUB: Photo-sensor readout in different fields

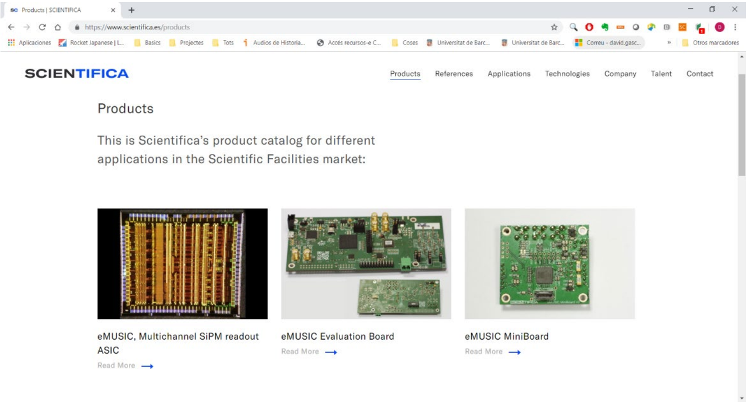


LHCb at CERN

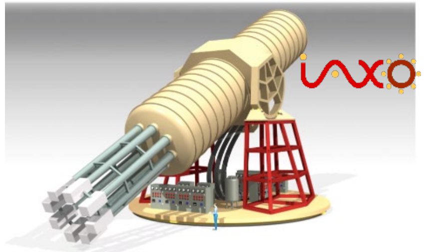
Telescope cameras



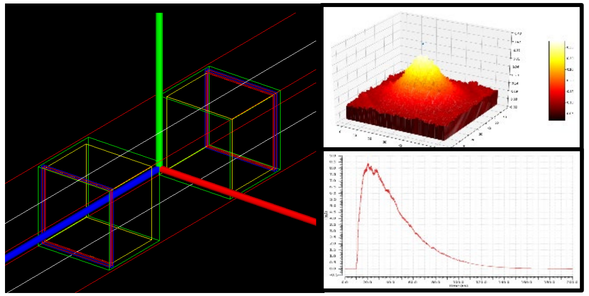
Single-Photon Sensors



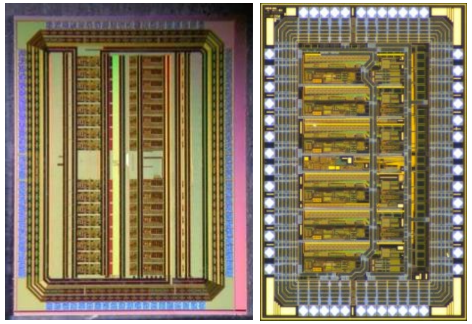
Technology Transfer



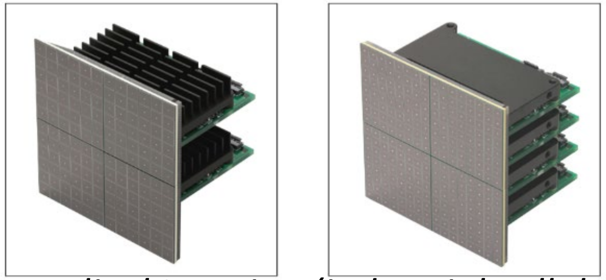
Axion and Dark Matter searches



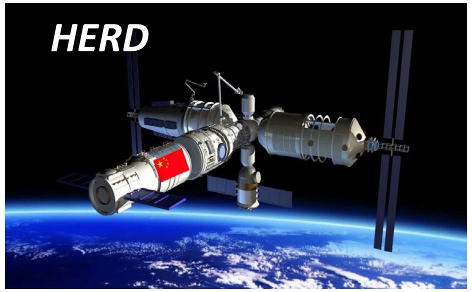
Monte Carlo simulations



Microelectronics (Chip Design)

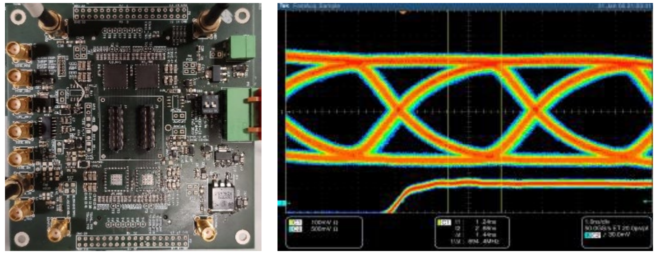


Medical Imaging (industrial collab.)



esa
European Space Agency

Space missions



Electronics

https://icc.ub.edu/research/technology-unit

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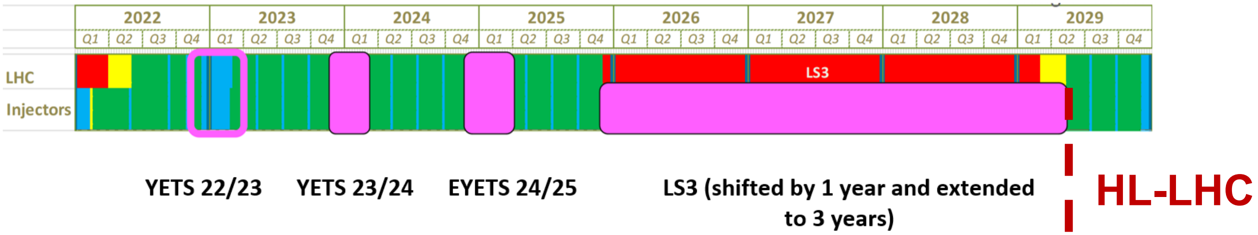
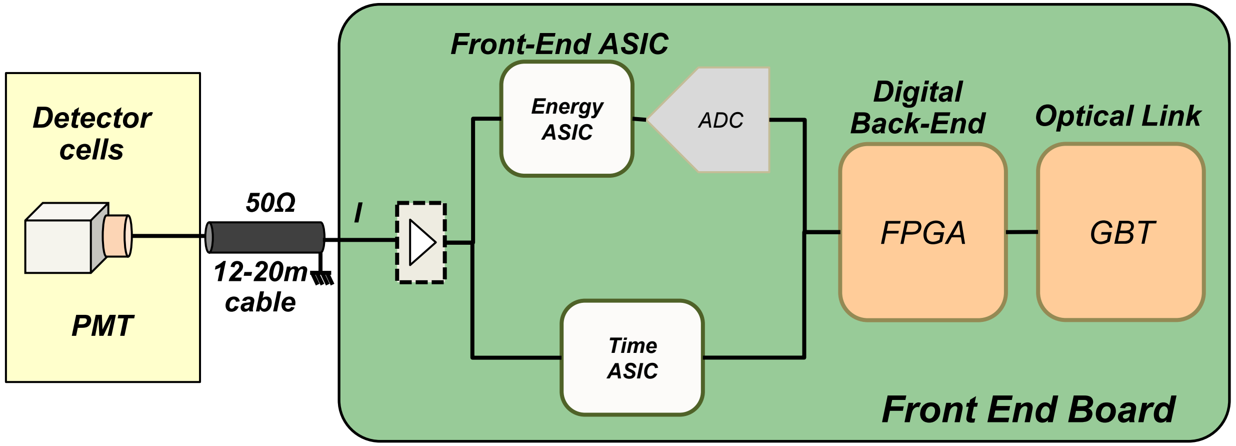
LHCb upgrade Upgrade II: PicoCal (LIA1)



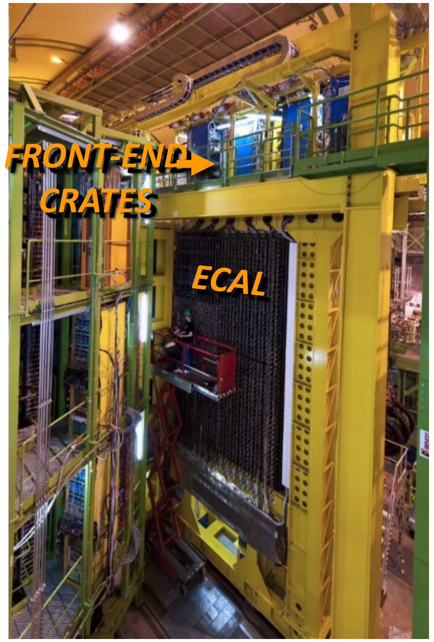


- HL-LHC: Photodetectors and FE electronics
  - **Involved in Calorimeter FE electronics since 1999**
  - **Responsible of current calorimeter front-end (ICECAL)**
  - **R&D for HL-LHC: Calorimeter, RICH and Scintillating Fiber Tracker**

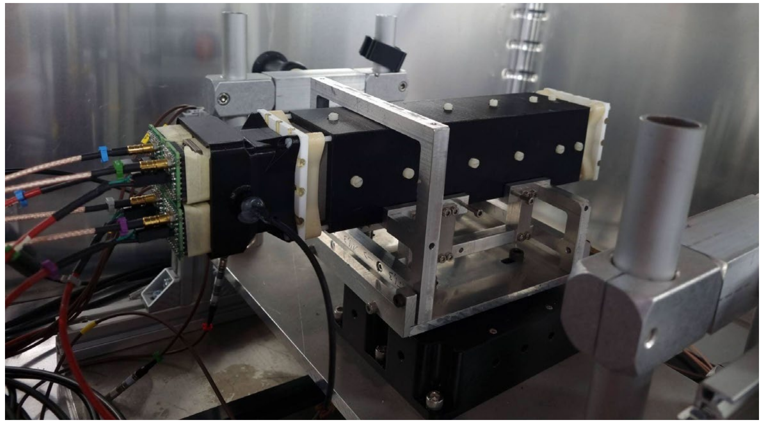
PicoCal Project: LS4 upgrade of LHCb calorimeter

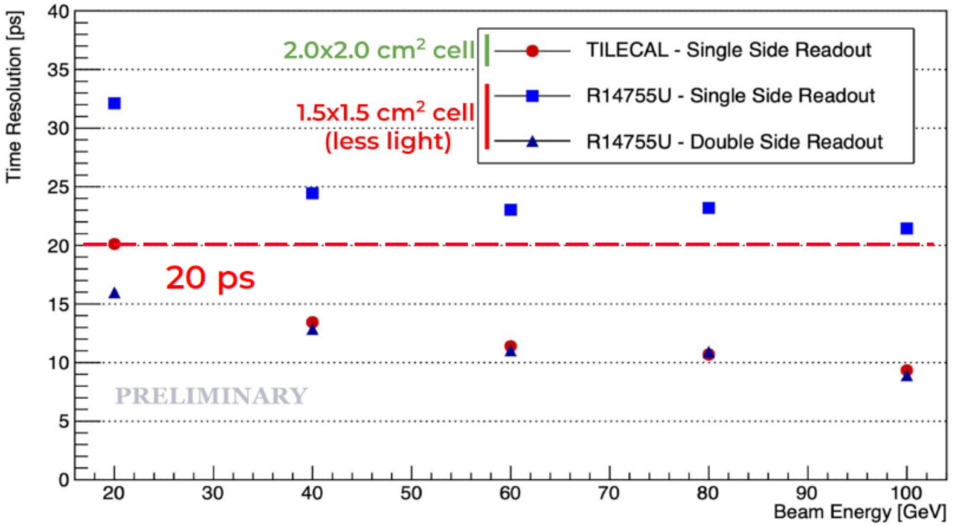
SPACAL W-Polystyrene: 10 ps @ 100 GeV

No signficant degradation after 12 m cables



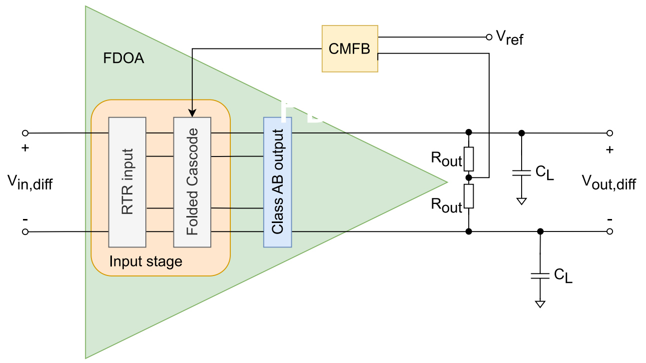
Precise Timing is critical for HL-LHC

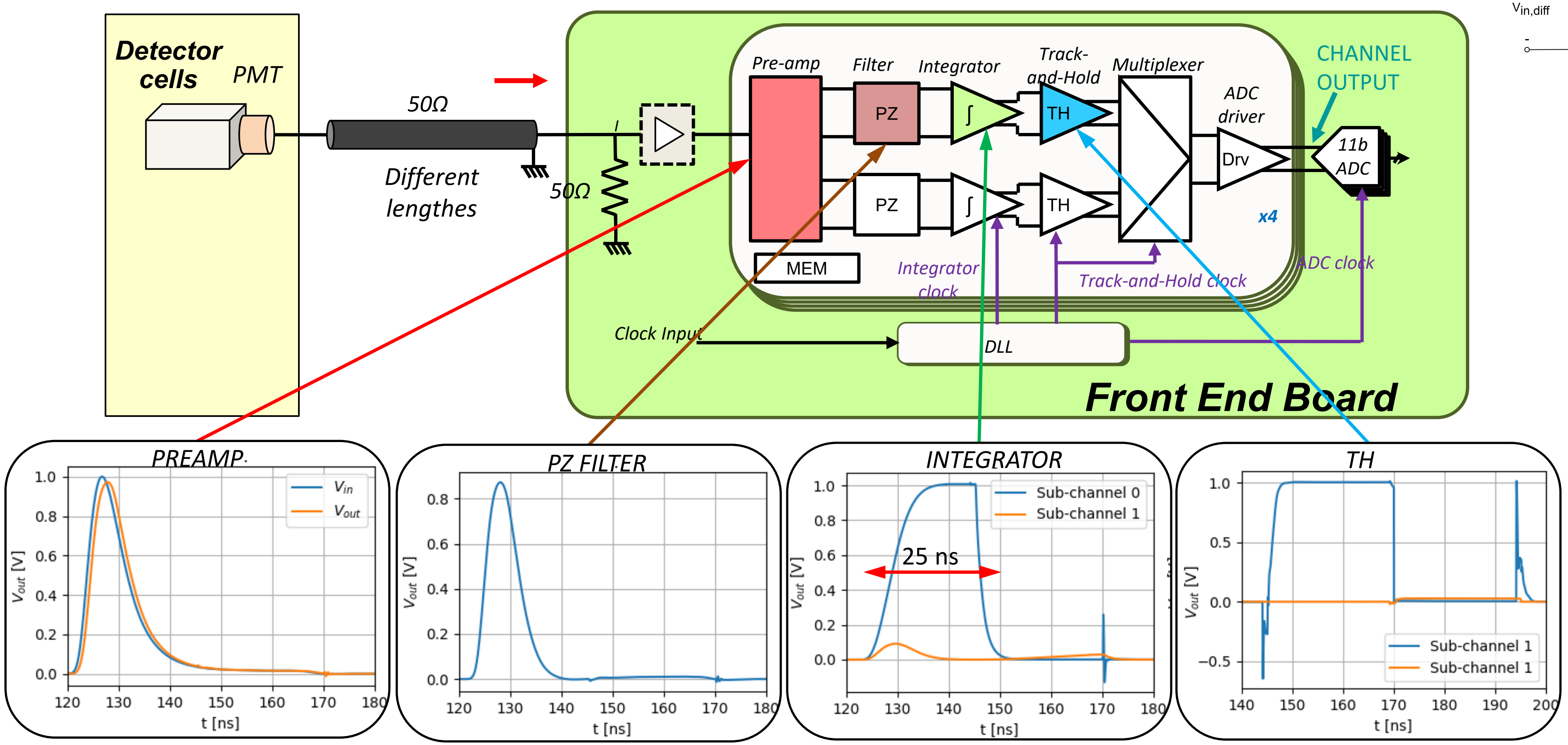




LHCb upgrade Upgrade II: PicoCal (LIA1)

- 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



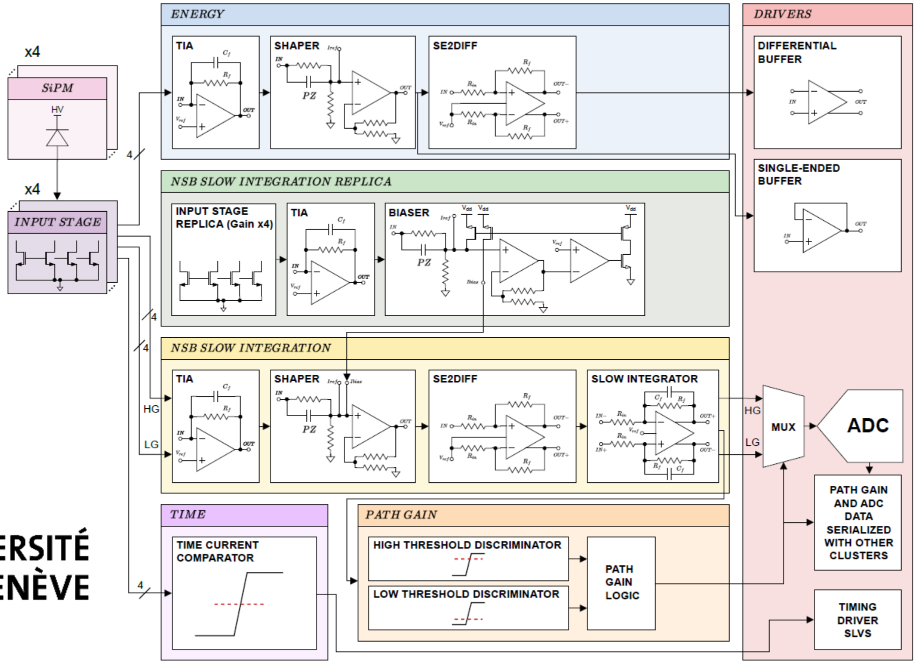


- TSMC 65nm technology
- Fully differential
- Rail-to-Rail (0-1.2 V)
- Low frequency gain > 70 dB
- GBW > 500 MHz
- PM > 65º
- SR > 0.5 V/ns
- VCM ~0.6V
- Power optimization

Cherenkov Telescope Array (LIA2)

cta cherenkov telescope array

- ICCUB has developed 3 different chips with important contributions to the cameras
  - More than 100,000 chips produced to equip 15 cameras
  - Robotic system for quality control
- In LIA2 we are contributing to the advanced SiPM camera for the Large Sized Telescope
  - Preamplifier Readout Electronics for Summing SiPMs Enhanced Circuit (PRESSEC) ASIC
    - Collaboration: ICCUB, UPC and University of Geneva
    - Submission in Q1 2025
    - Energy measurement and NSB Slow Integration



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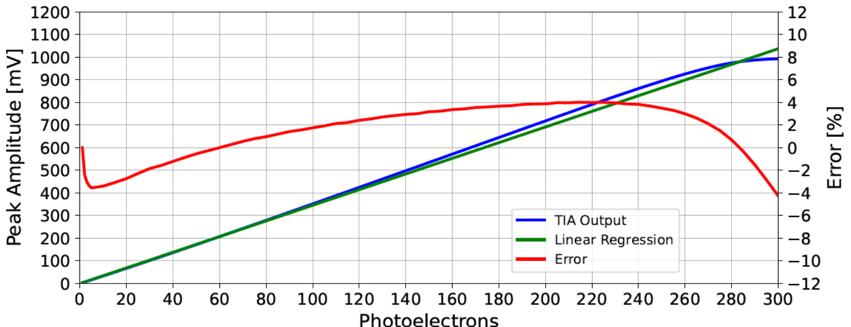


UPC

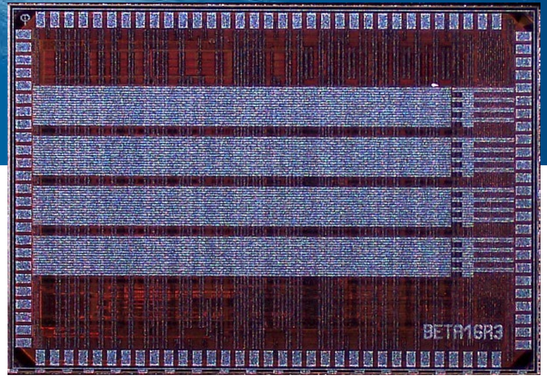
UNIVERSITÉ DE GENÈVE

HERD: BETA ASIC (LIA2)

See J.Rico plenary talk

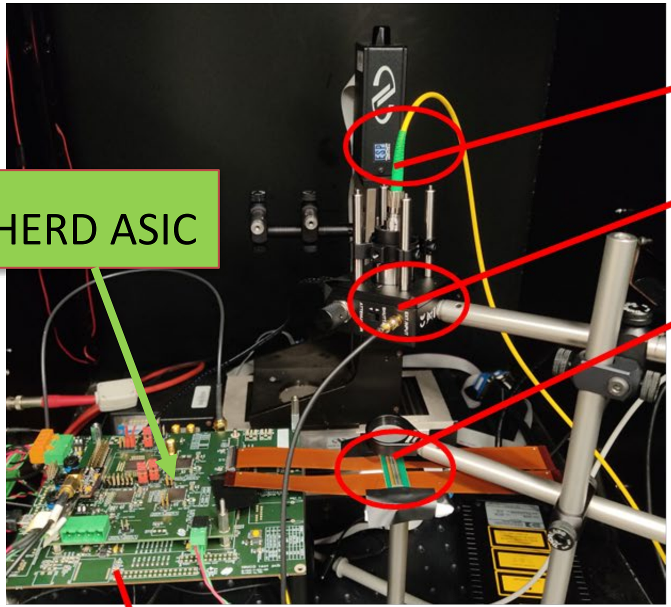
- ✓ Channels: 16 (PSD) or 64 (FIT)
- ✓ Event rate : 10 kHz max
- ✓ Configurable preamplifer gain: 4 bits
- ✓ Tunable shaping time: 300 ns to 1.5 us
- ✓ Trigger output: < 250 ps time resolution

- ✓ 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 – 9 mm^2

HERD ASIC

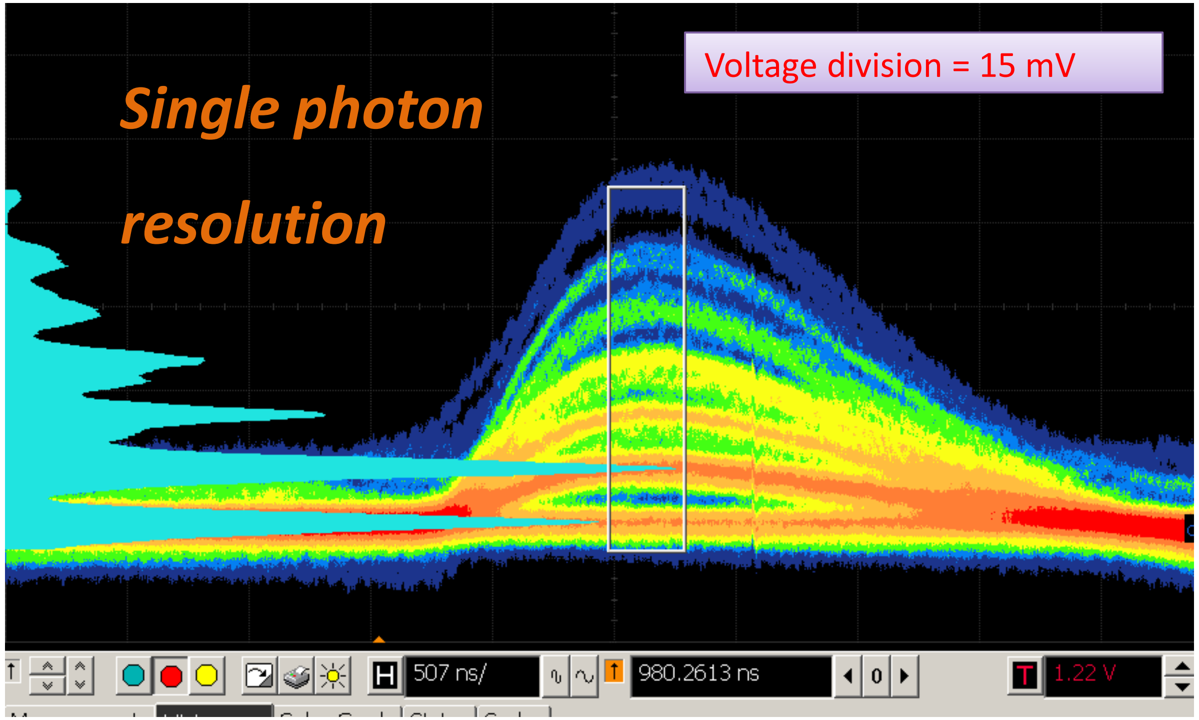


Laser System

Liquid crystal attenuator

Sensor PCB

Digital PCB (FPGA)



Sanmukh, A.. et al. Low-power SiPM readout BETA ASIC for space applications. NUCL SCI TECH 35, 59 (2024). https://doi.org/10.1007/s41365-024-01419-z

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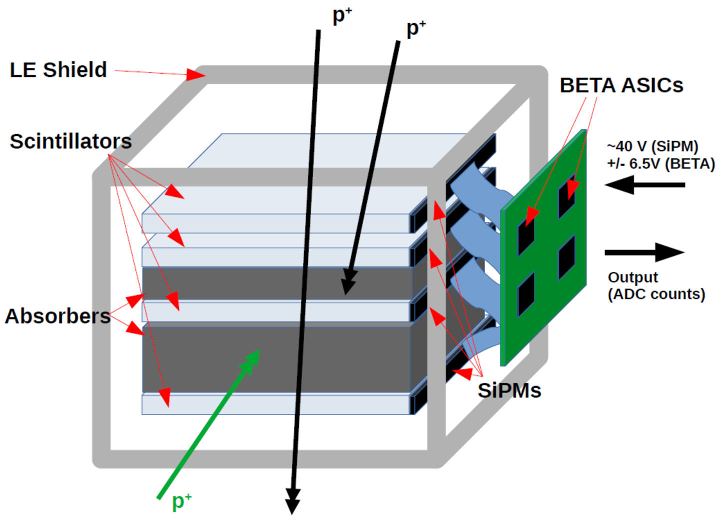
Other space instruments based on BETA ASIC

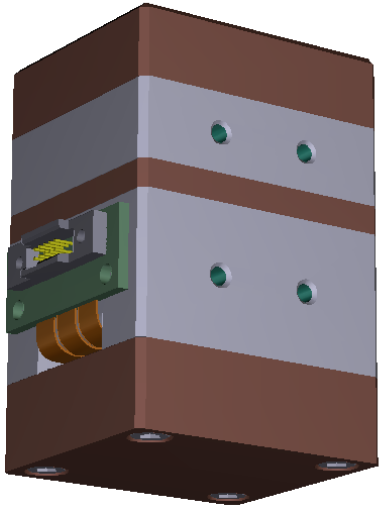
See M. Nofrarias plenary talk

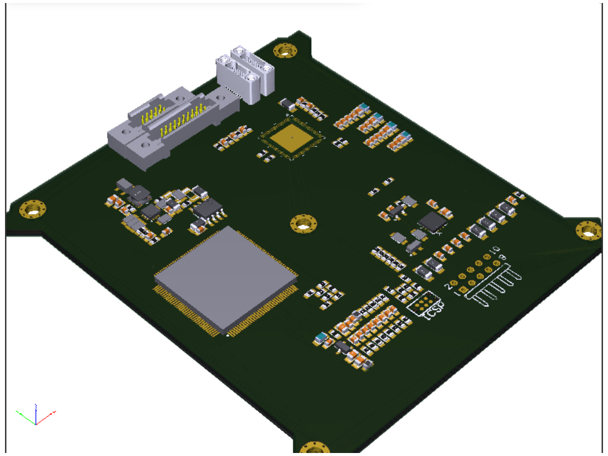
- A radiation monitor based on BETA-ASIC is being developed for LISA mission
  - IEEC project (LIA3)



- 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
  - APT/ADAPT, GENEO-02 et alt

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Excelencia María de Maeztu

R&D: Towards a new vertically integrated sensor

- *FastIC collaboration: ICCUB (Univ. Barcelona) and CERN microelectronics section*
  - https://ep-news.web.cern.ch/content/fastic-and-fasticpix-developments
  - FastIC chip family: FastIC, FastIC+ and FastRICH
  - ATTRACT project to explore new sensor architecture

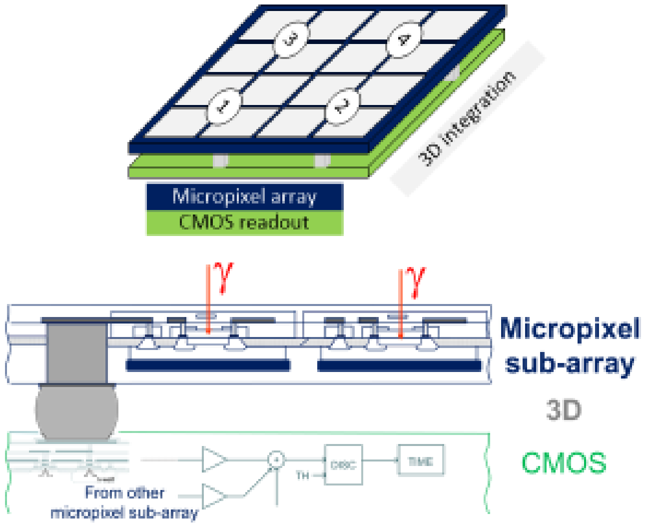
J. Mauricio, R. Manera S. Gomez, A. Sanuy, D. Gascon et alt @ ICCUB
J. M. Fernandez-Tenllado, M. Campbell, R. Ballabriga et alt. @ CERN

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.



Linked to DRD4 and DRD7

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

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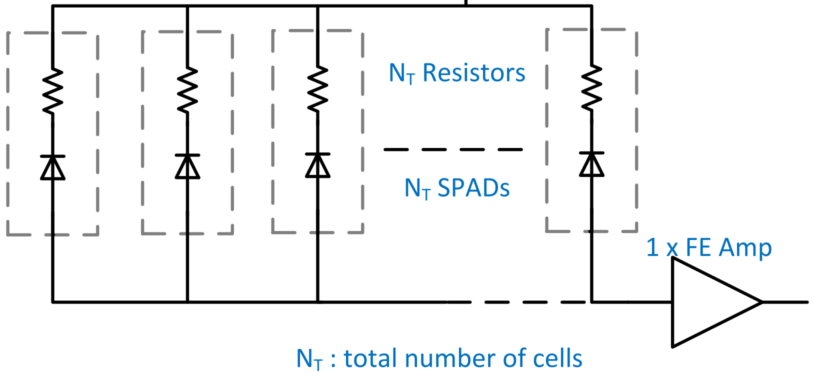
R&D: Our approach to solid state single photon sensor

- FastICpix: try to exploit optimal segmentation
  - Optimization for a given <u>*power budget !*</u>
  - Investigation of new circuit topologies
  - 3D integration

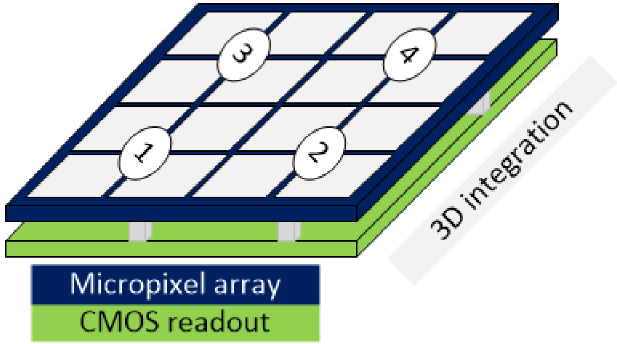
Electronic noise jitter < 1 ps for next generation of detectors based on prompt light

Time tagging of first(s) photons

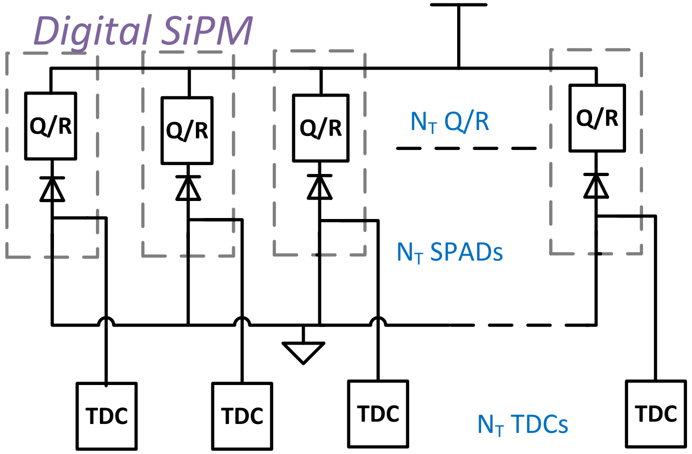
Analog SiPM



Optimal and adaptable segmentation: with <u>hybrid</u> detector



Digital SiPM

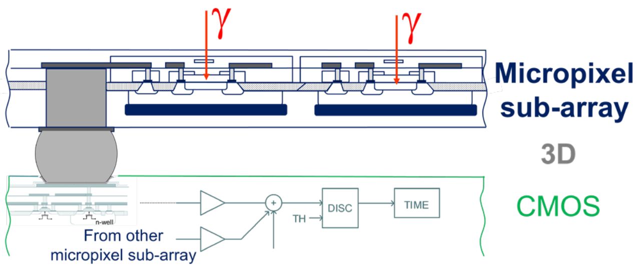


Q/R: Quenching and recharge circuit

Pros
- Simplicity
- High Fill Factor (PDE)

Cons
- Large capacitance degrades timing
- Xtalk deagrades timing

No segmentation



Pros
- Individual photon timing available

Cons
- Complexity (cost and power)
- Fill factor degradation
- Xtalk degrades timing

Maximum segmentation

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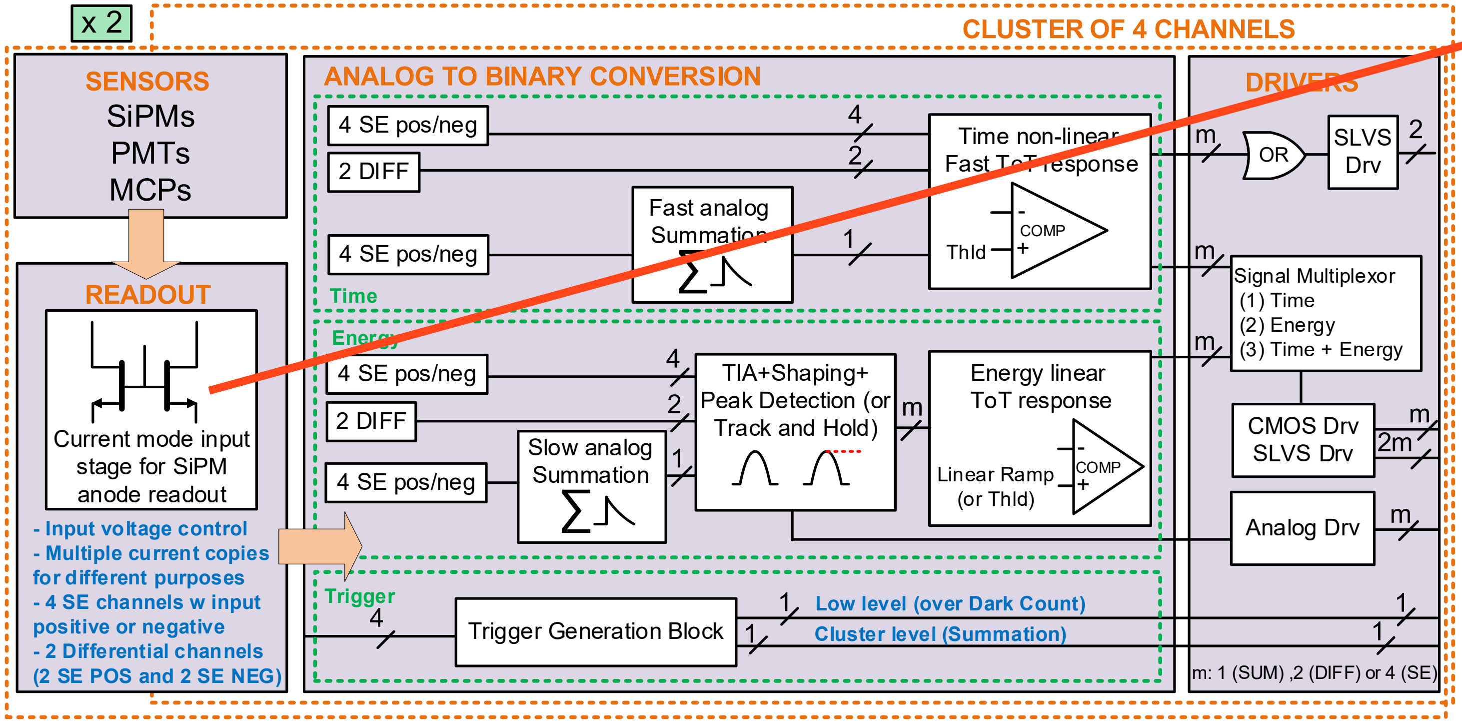
FastIC architecture

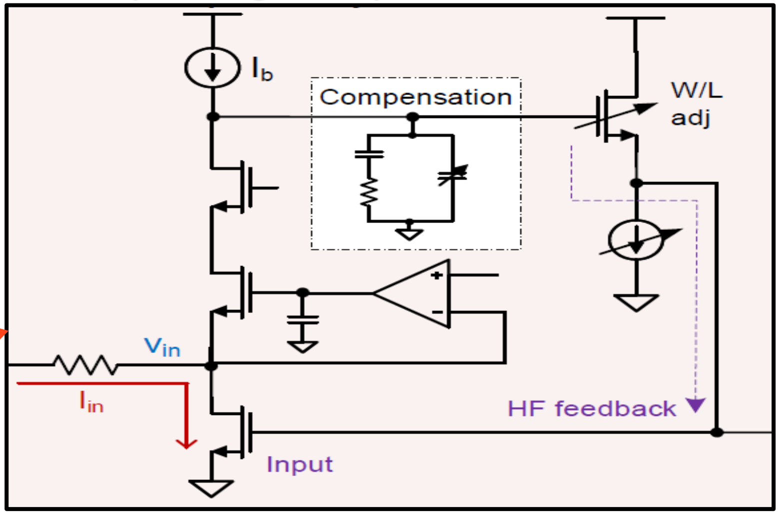
- FASTIC current mode 8ch ASIC.
  - Multiporpose: particle physics, medical imaging, ToF detectors
  - Compatible with SiPMs, PMTs, MCPs
  - Designed to cope with capacitance from few pF to nF
  - Large dynamic range: single photon to 1000s

– Fast current mode input stage

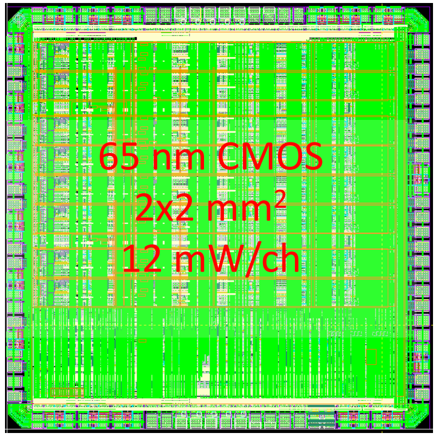
– Current mode comparator for timing

Input stage "amplifier" < 3 mW/ch





Based on HRFlexToT ASIC



Collaboration of the ICCUB (Univ. Barcelona) and CERN-MIC

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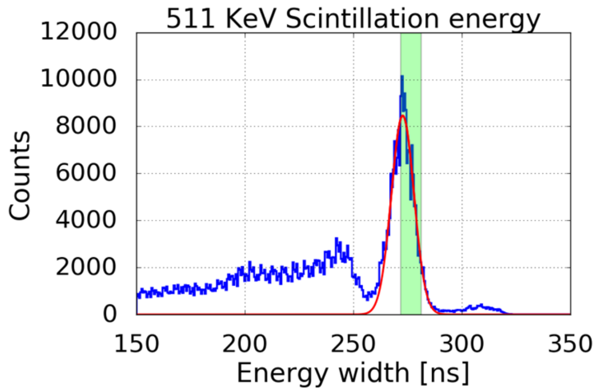
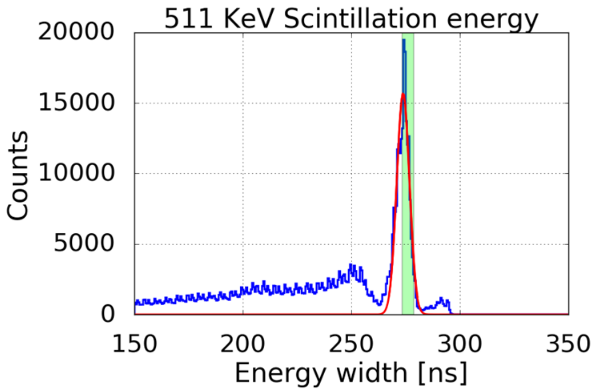
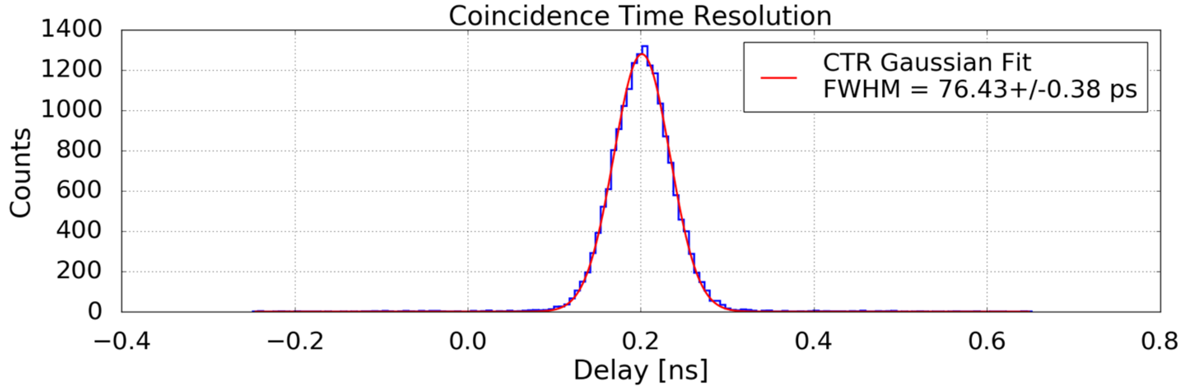
FastIC performance

- **Sensor:** FBK-NUVHDLFv2b 3x3 mm², 40 pixel pitch.
- **Crystal:** LSO:Ce Ca 0.2% of 2x2x3 mm³.



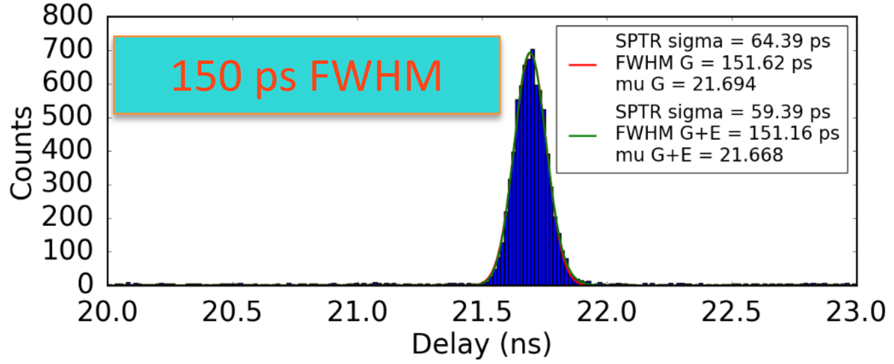




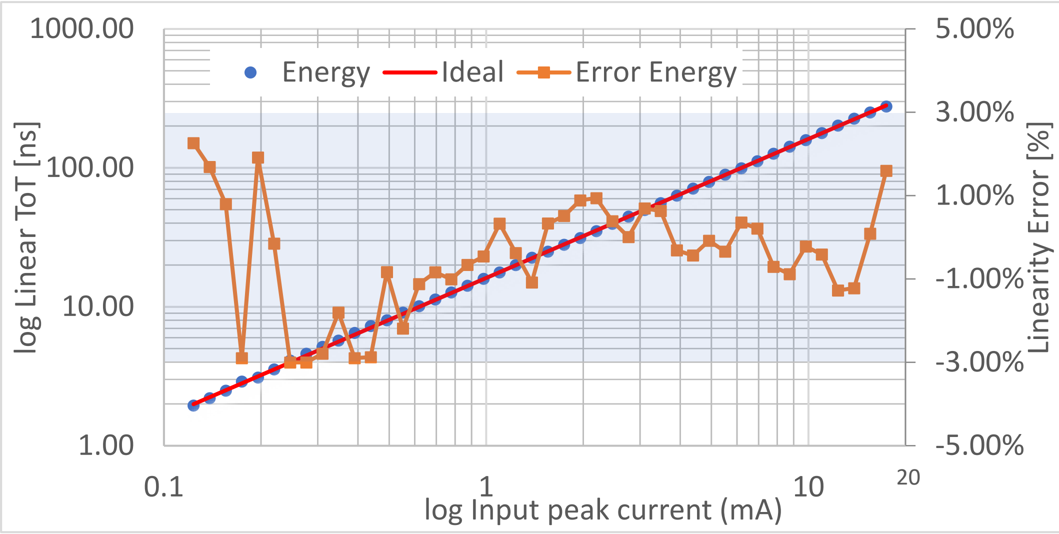
FWHM = 76 ps

Input "amplifier" < 3 mW/ch
Complete signal processing < 12 mW/ch

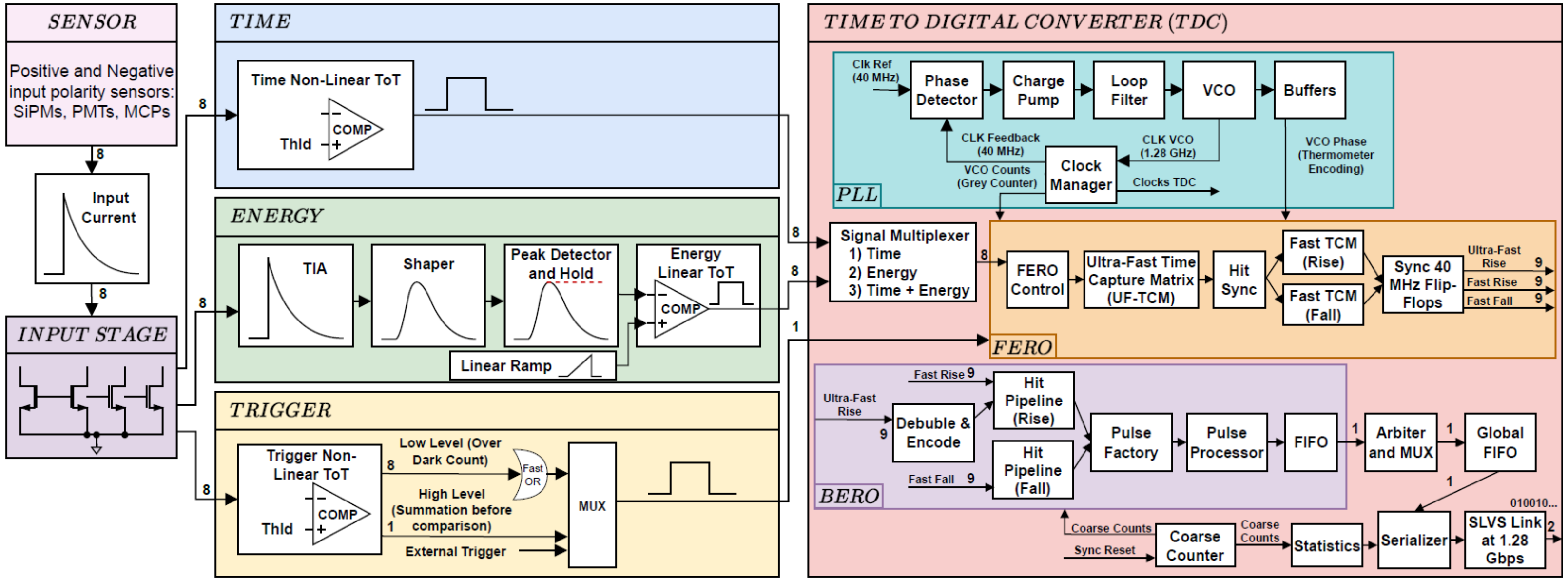
- **SPTR with** FBK-NUVHDLFv2b 3x3 mm²



- **Linearity error is below 3%**

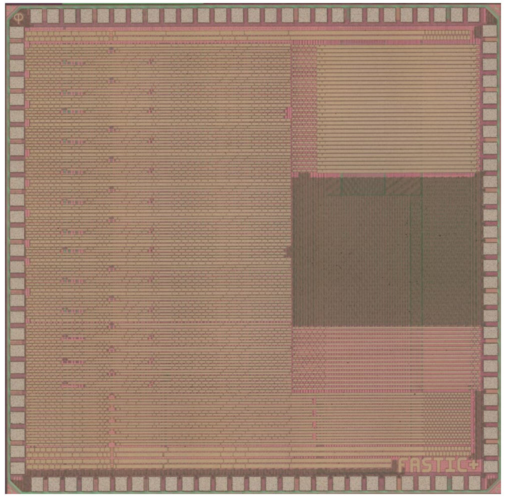


FastIC+ status



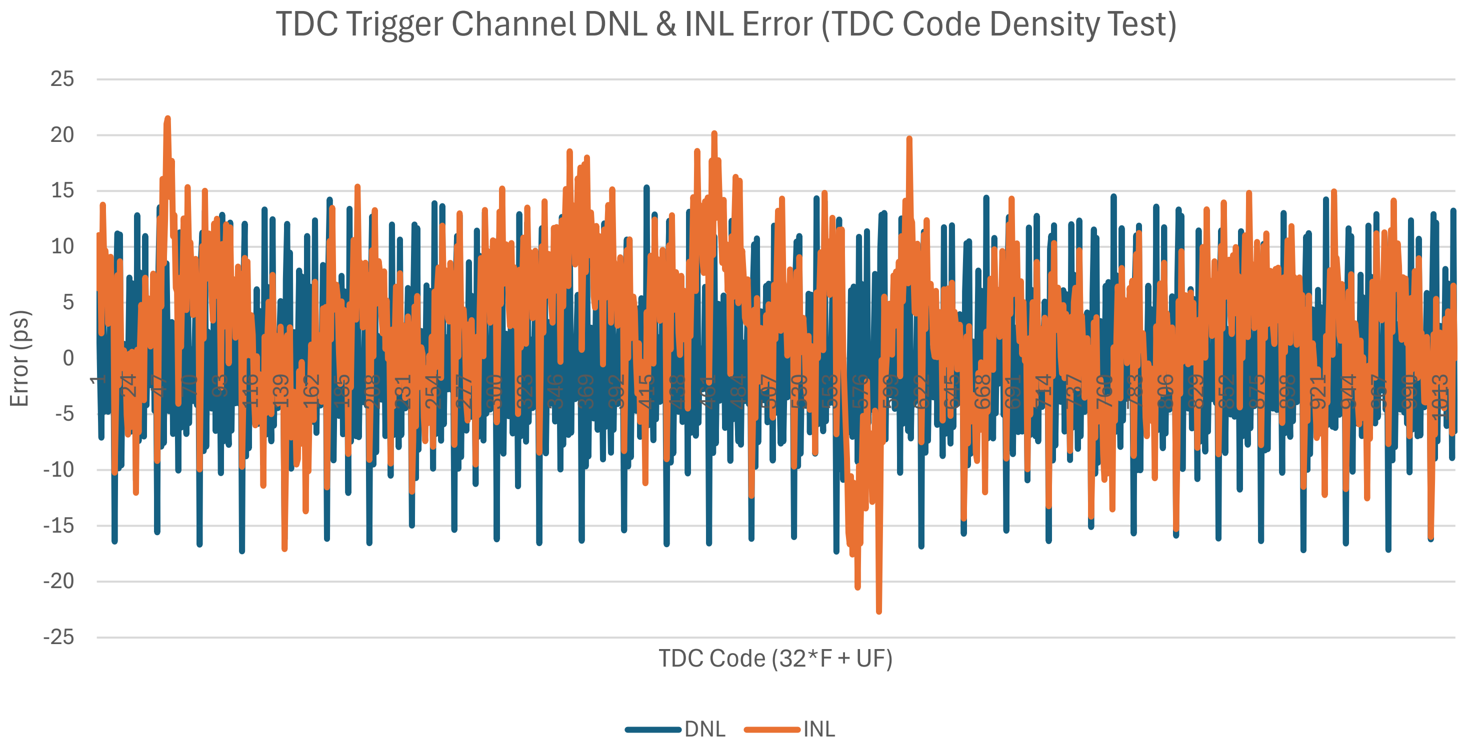
- **A 25 ps time bin TDC is added to FastIC**

- **Back from foundry few weeks ago**
  - Dimension: 3x3 mm^2
  - Technology: TSMC 65 LP
  - Metal stack: 9M + AP
  - Quantity: 10 units (QFN64)
    - For internal use only
    - Standard package will be QFN88
  - Very preliminary measurements!!!
    - THE CHIP IS MEASURED IN A SOCKET (INDUCTANCES)



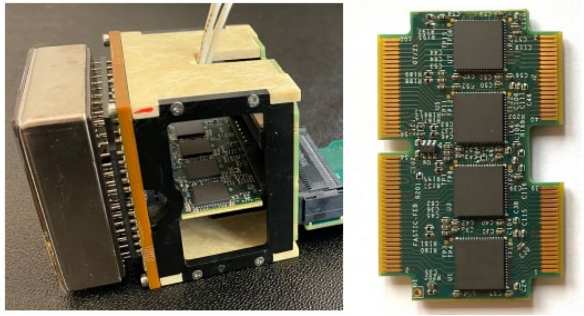
FastIC+ status

- **FastIC+ is alive and kicking ☺**
  - QFN88 packaging has been already asked
- **Quite promising TDC performance:**
  - Jitter < 12 ps
  - DNL < 6 ps
  - INL < ± 22 ps
  - TDC Power Consum.: 24.6 mW
    - ~3 mW/ch
- **No big issues have been identified for the moment**
- **Very preliminary:**
  - The chip has been tested in a socket in a sub-optimal (compatible) package.
  - Not tested in an optical setup yet.
  - No fine parameter tuning to obtain the best timing resolution.



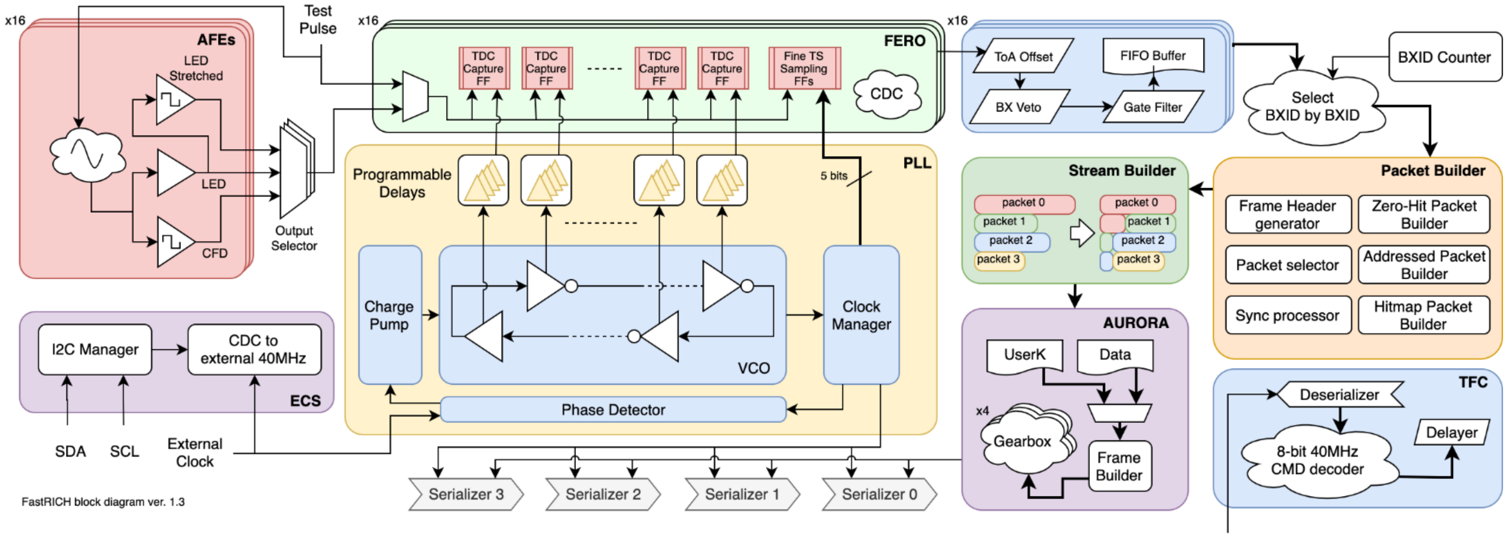
Spin-back from R&D: FastRICH (LIA1)

- FastIC is used in LHCb RICH upgrade test beams
  - Readout and DAQ electronics developed by LHCb RICH groups



See: F. Keizer, “A novel fast-timing readout chain for LHCb RICH LS3 and prototype beam tests”, NIMA, Vol. 1055, 2023, https://doi.org/10.1016/j.nima.2023.168475.

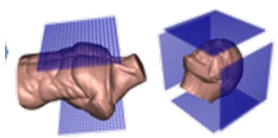
- FastRICH: a dedicated 16 ch ASIC for RICH upgrade in LS3
  - Optimized for single photon detection
  - Compatible with PMTs and SiPMs
  - CFD to deal with time walk @ high rates
  - Nearly the same PLL and TDC blocks integrated in FastIC+
  - Technology: TSMC 65 LP
  - Schedule: submission during 2024

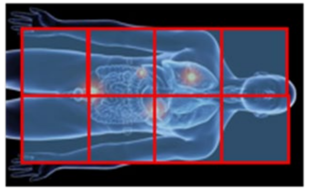


More information on: https://fastrich.docs.cern.ch/

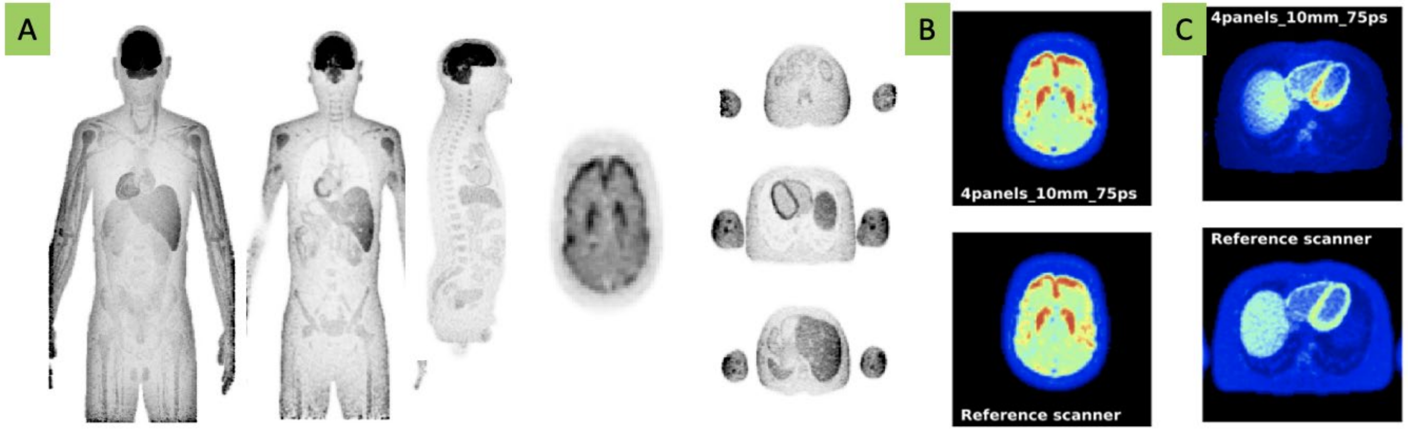
Tech Transfer: Towards a new ToF-PET scanner concept

- 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)

New vertical integration facilities

- Different facilities for electrical and optical characterization
  - Picosecond laser, micro-positioning systems, GS/s acquisition, thermal chamber, etc
- New infrastructures for vertical integration: sensor and integrated readout
  - Under preparation
    - Microprobe automatic station
    - Flip-chip and bump bonding
    - Clean room for integration and test

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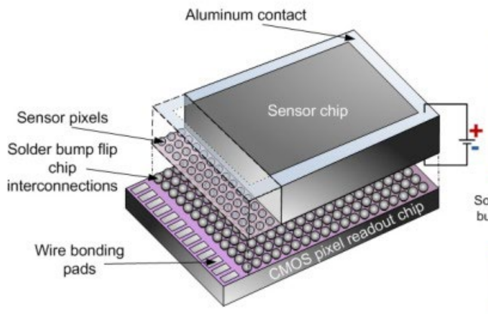
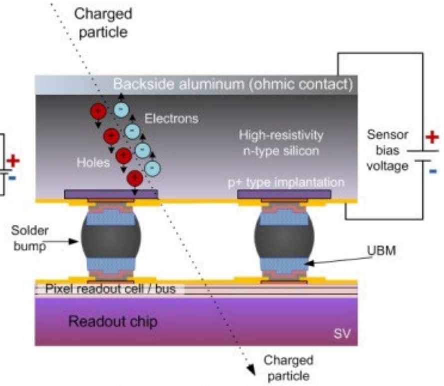


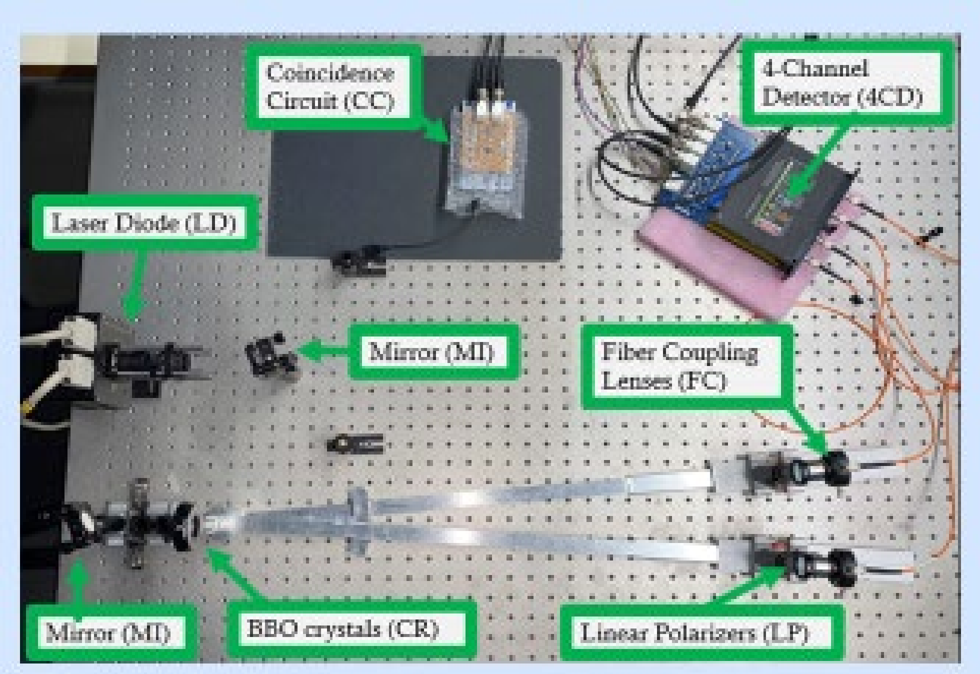
Generic pixel detector



Cross-sectional cut

Summary

- Try to define a coherent technology development plan with impact in different areas (LIAs 1,2 and 3 for the moment)
- Contributions to experiments, missions and upgrades
- Seed activities for ECFA's DRD program
  - Involved in DRD4, DRD6 an DRD7
    - Leading Fast Timing and Readout Electronics Task in DRD4.1
- Technology Transfer of our technology
  - Impact on medical imaging
  - New activity on quantum communications



Thanks a lot for your attention !!!

http://icc.ub.edu/technology

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

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
AGENCIA ESTATAL DE INVESTIGACIÓN
Next Generation Catalunya
Generalitat de Catalunya Departament de Recerca i Universitats

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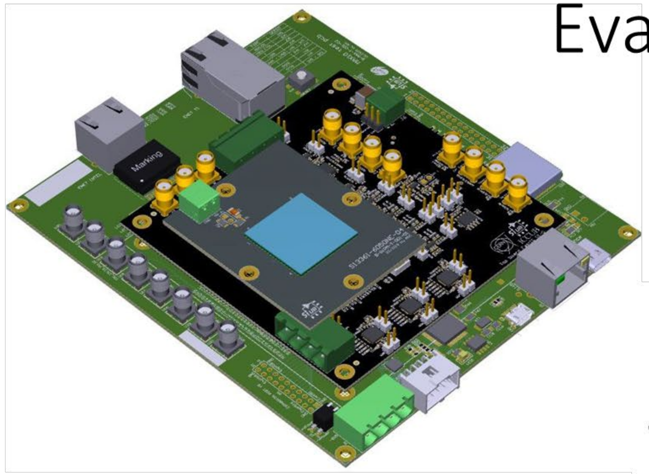
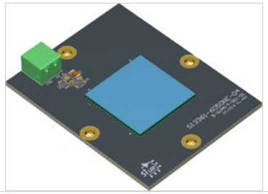
FastIC support and evaluation boards

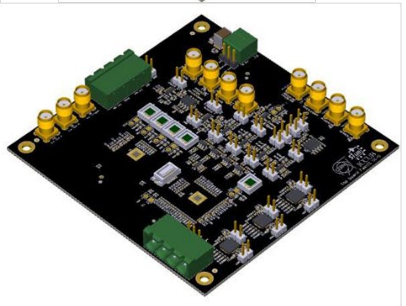
Evaluation system



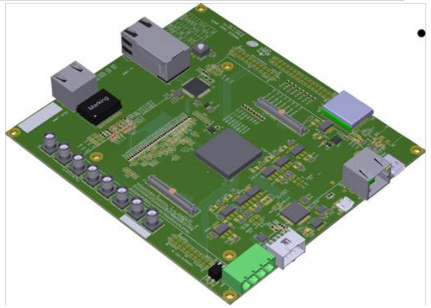
- Aims of the evaluation system:
  - Basic operational test & debug ASIC functionalities
  - Initial electrical characterization and linearity analysis.
  - Initial benchmark i.e. evaluate the FastIC chip by comparison
    - With respect previous designs (NINO, HRFlexTOT)
    - Using reference SiPM sensor:
      - Hamamatsu S13360-3050CS
      - FBK NUV-HD
  - Interface with other sensor based on adaptor board
  - Signal acquisition:
    - FPGA-based TDC (45ps time bin)
    - Differential sLVS link to external system



- Custom sensor board



- FastIC generic board
  - 2 FastICs on QFN64 (16 channels)
  - Reference SiPM sensors included
  - The board can be used stand alone



- FPGA board
  - FPGA board for slow control, acquisition and additional biasing.
  - Multichannel TDC is implemented in the FPGA (45ps time bin)

- **Documentation, software and support available at**
  - **https://icc-ub.gitlab.io/instrumentation/documentation/index.html?page=fastic**
  - **Contact: fastic_support@fqa.ub.edu**

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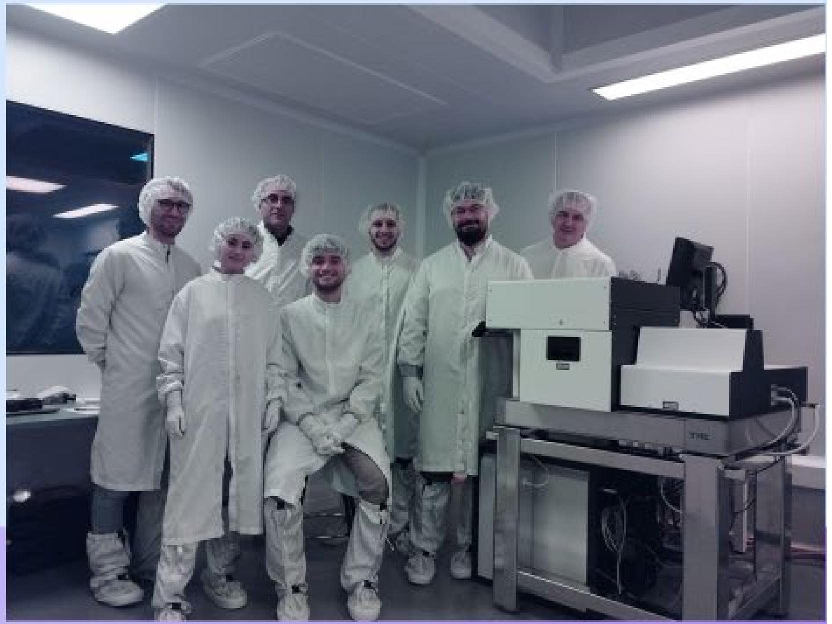
VI. Quantum technologies

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/

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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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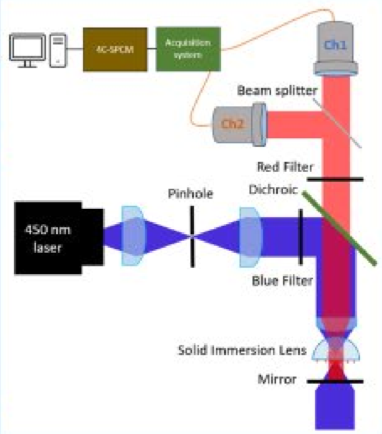
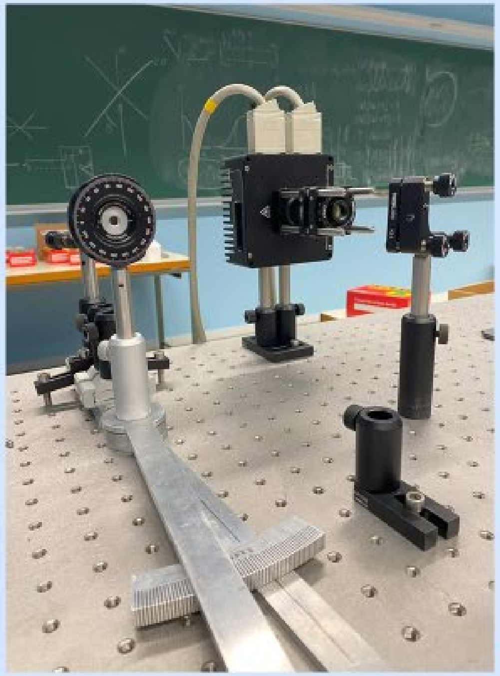
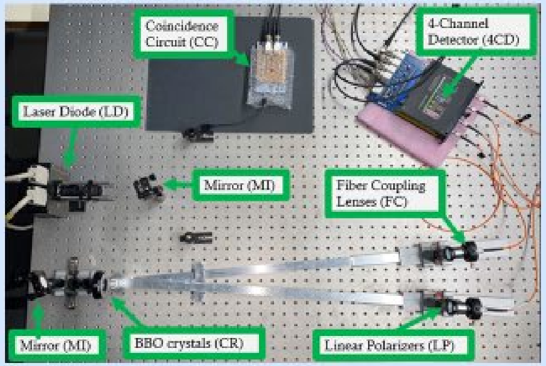
VI. Quantum technologies



Photon antibunching experiment

Bell test for entangled photons





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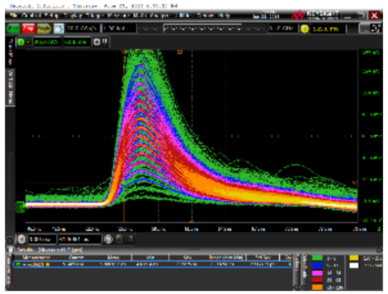
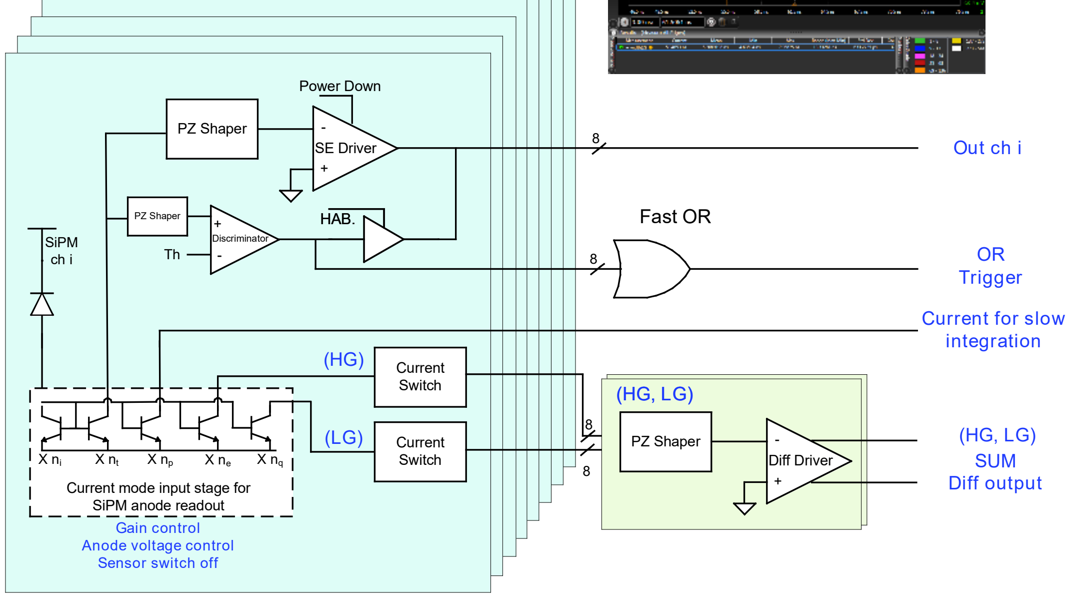
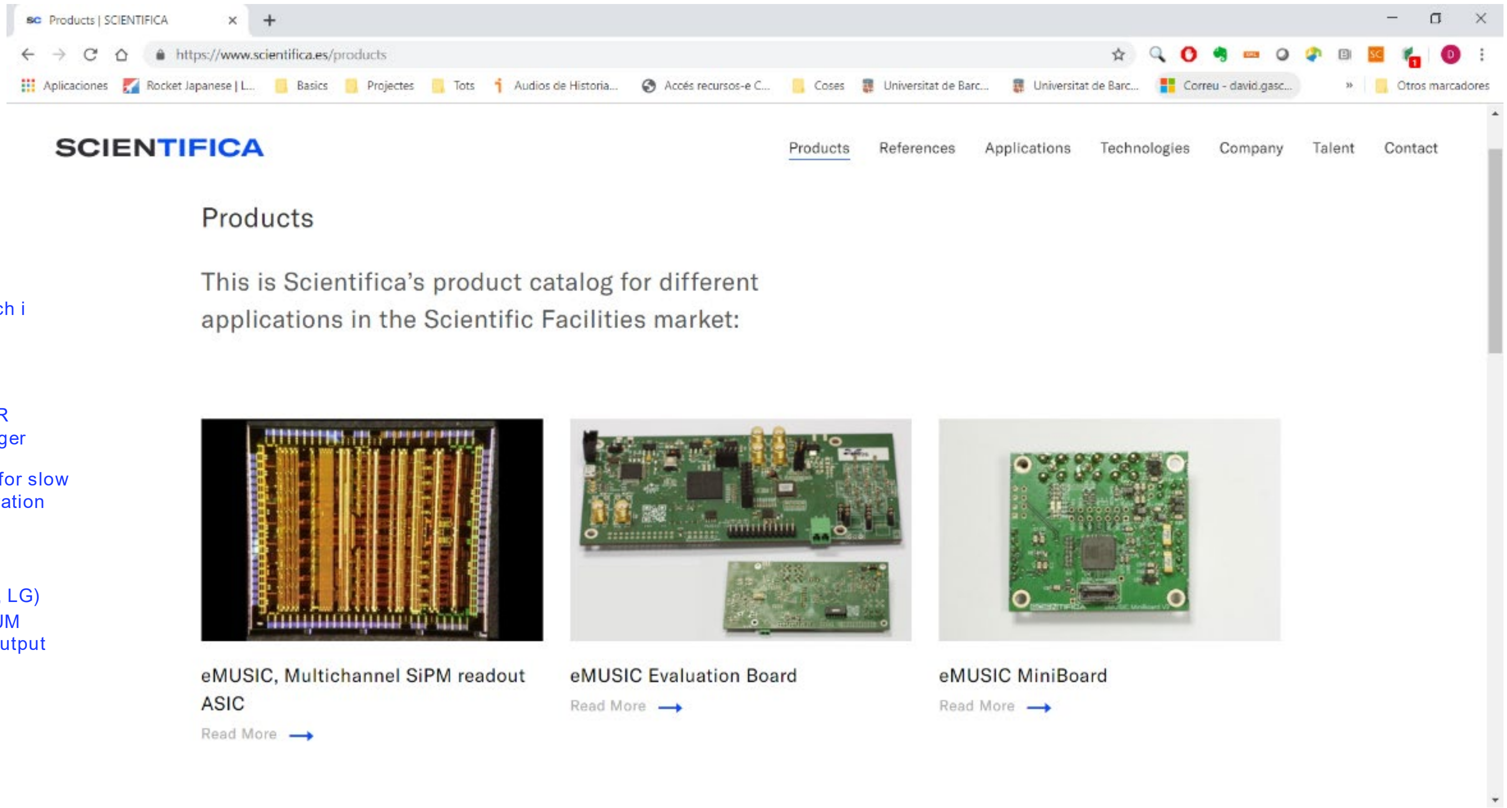
VII. Technology transfer

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





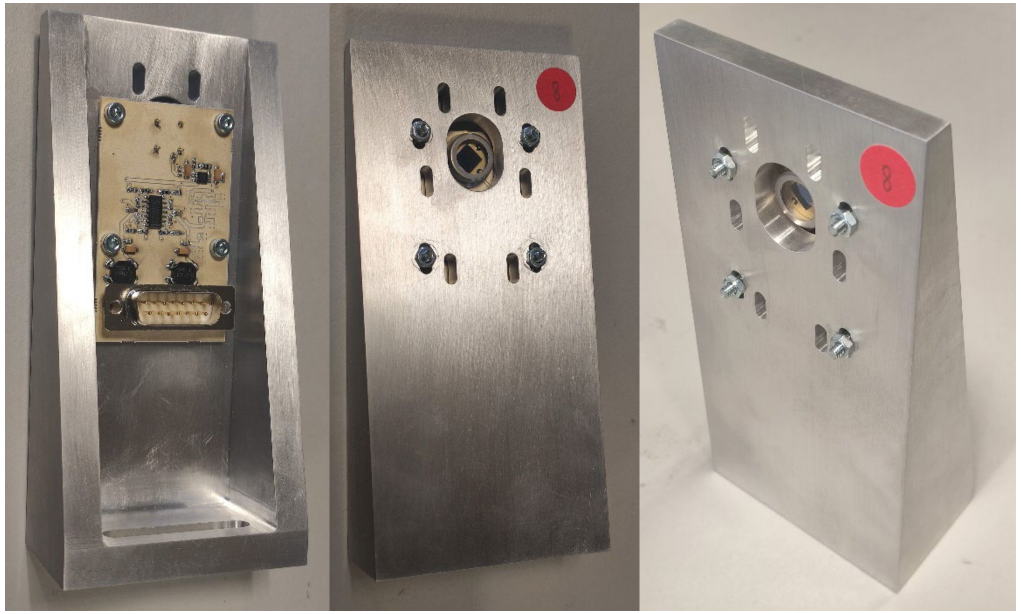


Software/Computing + Instrumentation: **Virgo**

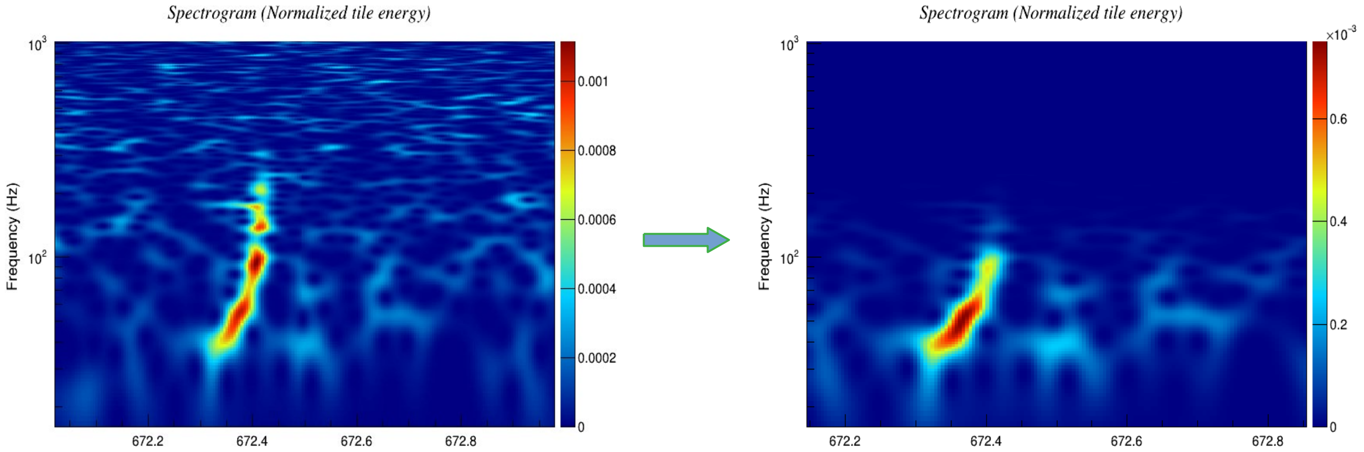
- ICCUB is full member of Virgo since July 2019
  - Now 11 members, will add 3 this year. Contributions on: Computing, Instrumentation, Data analysis, Science, Outreach

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

- **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



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II. Activities in instrumentation

Part of the *ICCUB technology unit* (*TU* has 2 sections: instrumentation/electronics and software/data processing)

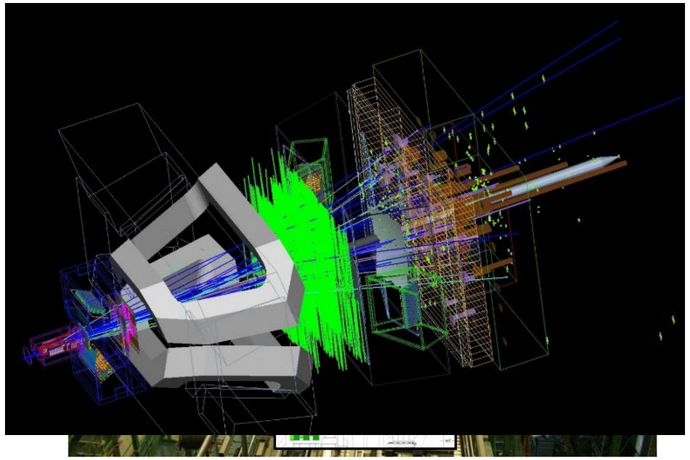
Enabling key contributions on instrumentation to ICCUB to *high impact collaborations*:

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

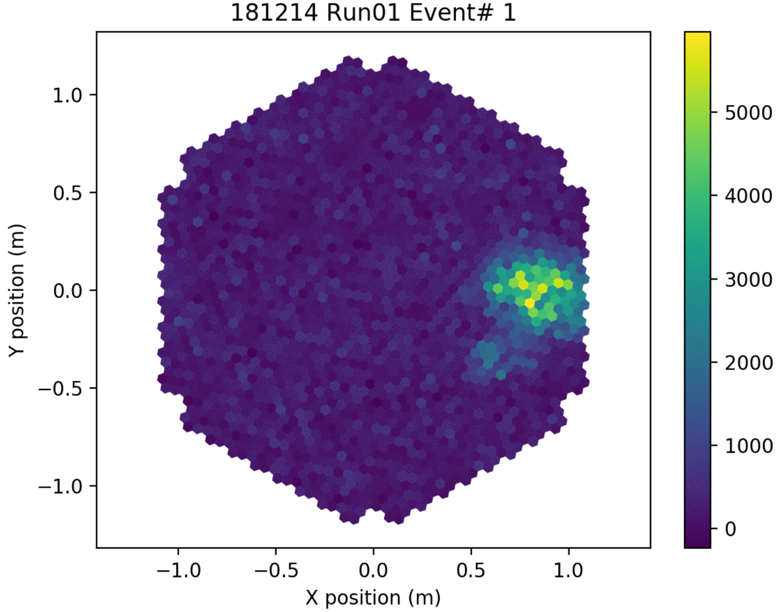
Close coordination other ICCUB research groups and Electronics Department (Solar Orbiter, Ariel and others)

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