Microelectronics at CNRS Nucléaire & Particules

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CNRS, IN2P3, and MI2I

CNRS in brief

National Centre for Scientific Research

- Founded in 1939
- Largest public research body in Europe and the second largest in the world
- CNRS is the only French organisation active in all scientific fields

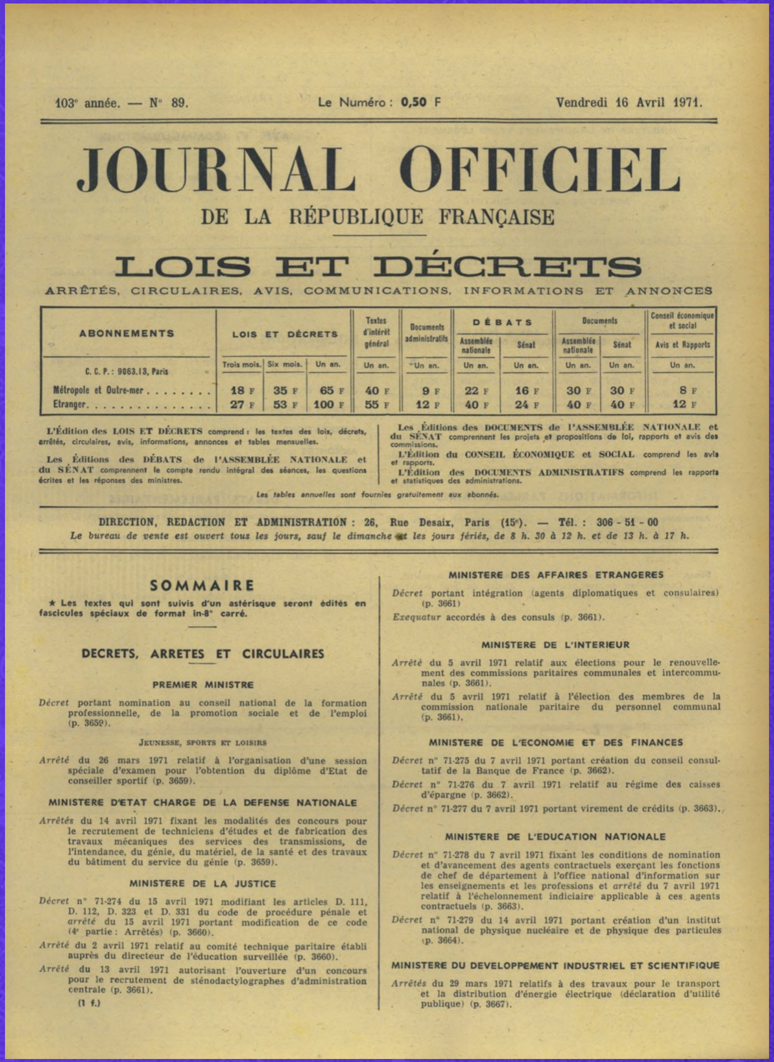
34,700 Staff members	**29,400** Scientists	**200** Different professions providing direct support for research
4 billion Budget in euros	**1100** Laboratories under CNRS supervisory authority	**80** International laboratories

cnrs BIOLOGIE
cnrs CHIMIE
cnrs ÉCOLOGIE & ENVIRONNEMENT
cnrs INGÉNIERIE
cnrs MATHÉMATIQUES
cnrs NUCLÉAIRE & PARTICULES
cnrs PHYSIQUE
cnrs SCIENCES HUMAINES & SOCIALES
cnrs SCIENCES INFORMATIQUES
cnrs TERRE & UNIVERS

CNRS Nucléaire & Particules

Originally known as IN2P3

- Founded in 1971
- Coordinates R&D in nuclear and particle physics
- Now also covers astroparticle physics



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DE LA RÉPUBLIQUE FRANÇAISE

LOIS ET DÉCRETS

ARRÊTÉS, CIRCULAIRES, AVIS, COMMUNICATIONS, INFORMATIONS ET ANNONCES

ABONNEMENTS	LOIS ET DÉCRETS			Textes d'intérêt général	Documents administratifs	DÉBATS		Documents		Conseil économique et social
						Assemblée nationale	Sénat	Assemblée nationale	Sénat	Avis et Rapports
C. C. P. : 9063.13, Paris	Trois mois.	Six mois.	Un an.	Un an.	Un an.	Un an.	Un an.	Un an.	Un an.	Un an.
Métropole et Outre-mer	18 F	35 F	65 F	40 F	9 F	22 F	16 F	30 F	30 F	8 F
Etranger.	27 F	53 F	100 F	55 F	12 F	40 F	24 F	40 F	40 F	12 F

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★ Les textes qui sont suivis d'un astérisque seront édités en fascicules spéciaux de format in-8° carré.

DECRETS, ARRETES ET CIRCULAIRES

PREMIER MINISTRE

Décret portant nomination au conseil national de la formation professionnelle, de la promotion sociale et de l'emploi (p. 3659).

JEUNESSE, SPORTS ET LOISIRS

Arrêté du 26 mars 1971 relatif à l'organisation d'une session spéciale d'examen pour l'obtention du diplôme d'Etat de conseiller sportif (p. 3659).

MINISTERE D'ETAT CHARGE DE LA DEFENSE NATIONALE

Arrêtés du 14 avril 1971 fixant les modalités des concours pour le recrutement de techniciens d'études et de fabrication des travaux mécaniques des services des transmissions, de l'intendance, du génie, du matériel, de la santé et des travaux du bâtiment du service du génie (p. 3659).

MINISTERE DE LA JUSTICE

Décret n° 71-274 du 15 avril 1971 modifiant les articles D. 111, D. 112, D. 323 et D. 331 du code de procédure pénale et *arrêté* du 15 avril 1971 portant modification de ce code (4ᵉ partie : Arrêtés) (p. 3660).

Arrêté du 2 avril 1971 relatif au comité technique paritaire établi auprès du directeur de l'éducation surveillée (p. 3660).

Arrêté du 13 avril 1971 autorisant l'ouverture d'un concours pour le recrutement de sténodactylographes d'administration centrale (p. 3661).

(1 f.)

MINISTERE DES AFFAIRES ETRANGERES

Décret portant intégration (agents diplomatiques et consulaires) (p. 3661)

Exequatur accordés à des consuls (p. 3661).

MINISTERE DE L'INTERIEUR

Arrêté du 5 avril 1971 relatif aux élections pour le renouvellement des commissions paritaires communales et intercommunales (p. 3661).

Arrêté du 5 avril 1971 relatif à l'élection des membres de la commission nationale paritaire du personnel communal (p. 3661).

MINISTERE DE L'ECONOMIE ET DES FINANCES

Décret n° 71-275 du 7 avril 1971 portant création du conseil consultatif de la Banque de France (p. 3662).

Décret n° 71-276 du 7 avril 1971 relatif au régime des caisses d'épargne (p. 3662).

Décret n° 71-277 du 7 avril 1971 portant virement de crédits (p. 3663).

MINISTERE DE L'EDUCATION NATIONALE

Décret n° 71-278 du 7 avril 1971 fixant les conditions de nomination et d'avancement des agents contractuels exerçant les fonctions de chef de département à l'office national d'information sur les enseignements et les professions et *arrêté* du 7 avril 1971 relatif à l'échelonnement indiciaire applicable à ces agents contractuels (p. 3663).

Décret n° 71-279 du 14 avril 1971 portant création d'un institut national de physique nucléaire et de physique des particules (p. 3664).

MINISTERE DU DEVELOPPEMENT INDUSTRIEL ET SCIENTIFIQUE

Arrêtés du 29 mars 1971 relatifs à des travaux pour le transport et la distribution d'énergie électrique (déclaration d'utilité publique) (p. 3667).

CNRS Nucléaire & Particules

A Unique CNRS National Institute

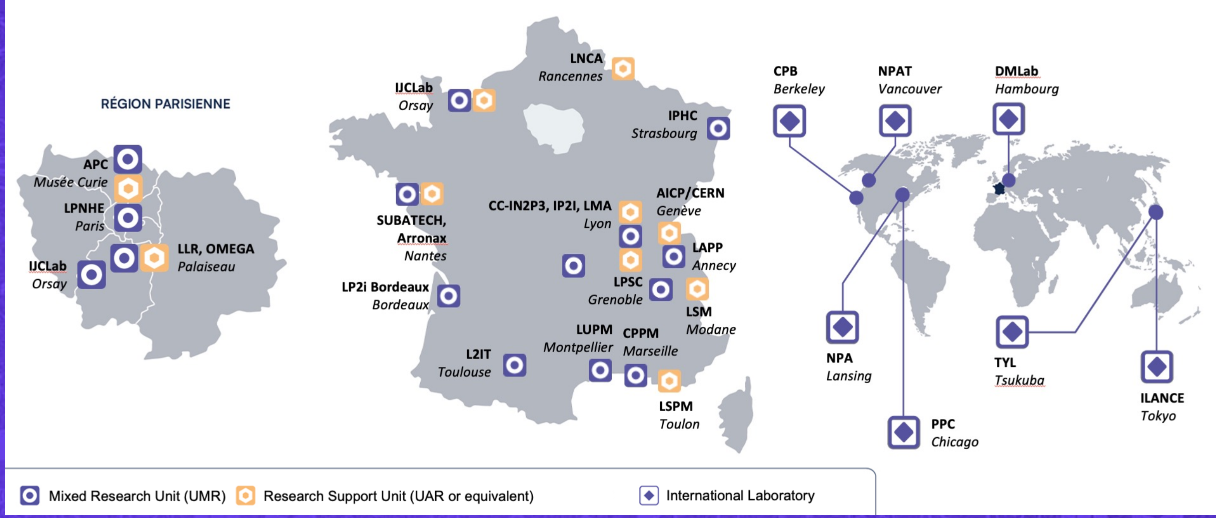
- **A reduced number of labs**
- **A large proportion of engineers and technicians**
  - **269 engineers with PhDs**

Staff (perm. & Fixed-term)	**CNRS**	**IN2P3**	**Outside CNRS**
Total	34,700	2,340	1,120
Scientists	29,400	900	850
Engineers & Technicians	5,300	1,440	270

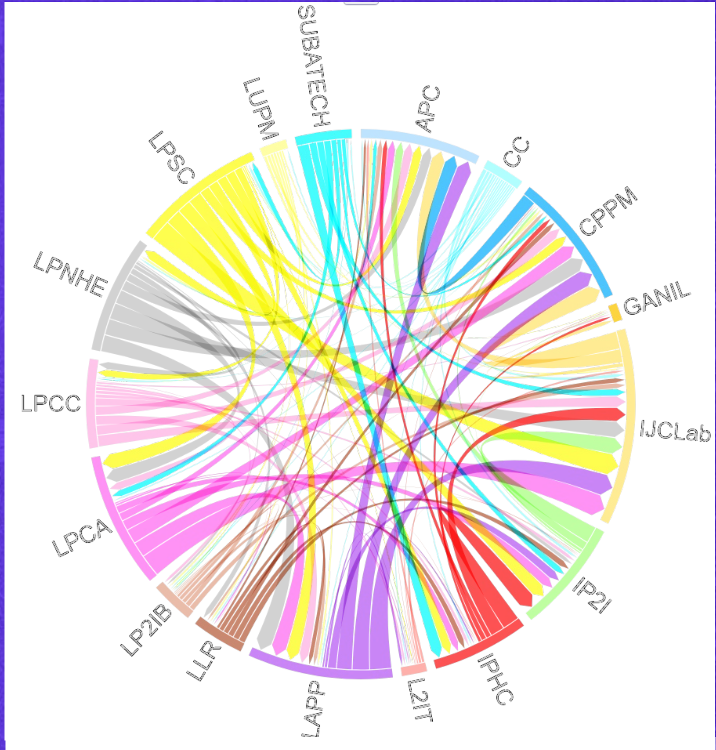
Laboratories	**CNRS**	**IN2P3**
In France	1,100	24
Aboard	85	7

CNRS Nucléaire & Particules

A Collaborative Lab Network



- Laboratories are located close to major universities
  - ➢ Spread across the entire country
- Impossible to duplicate all expertise in every location
  - ➢ Need to work together

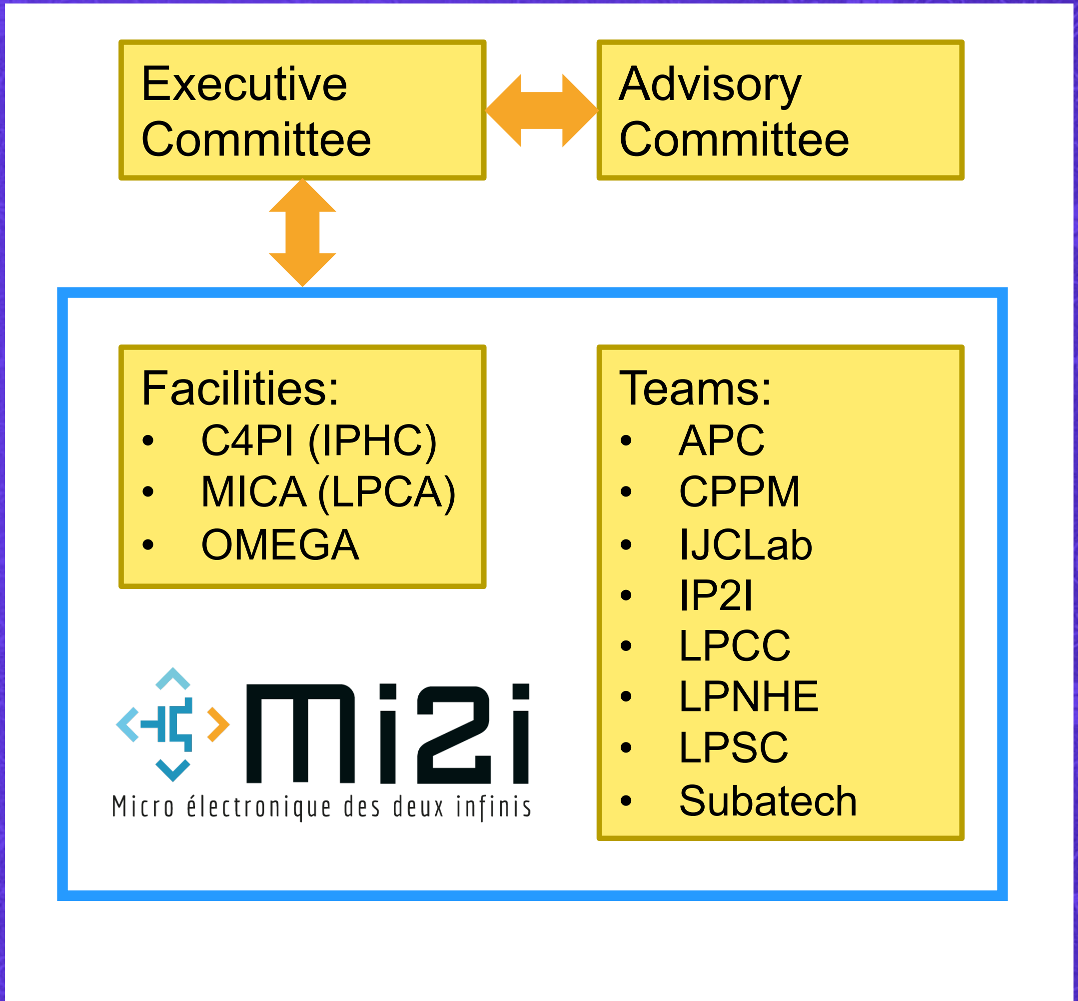


Collaboration between labs

MI2I

Microelectronics for the Two Infinities

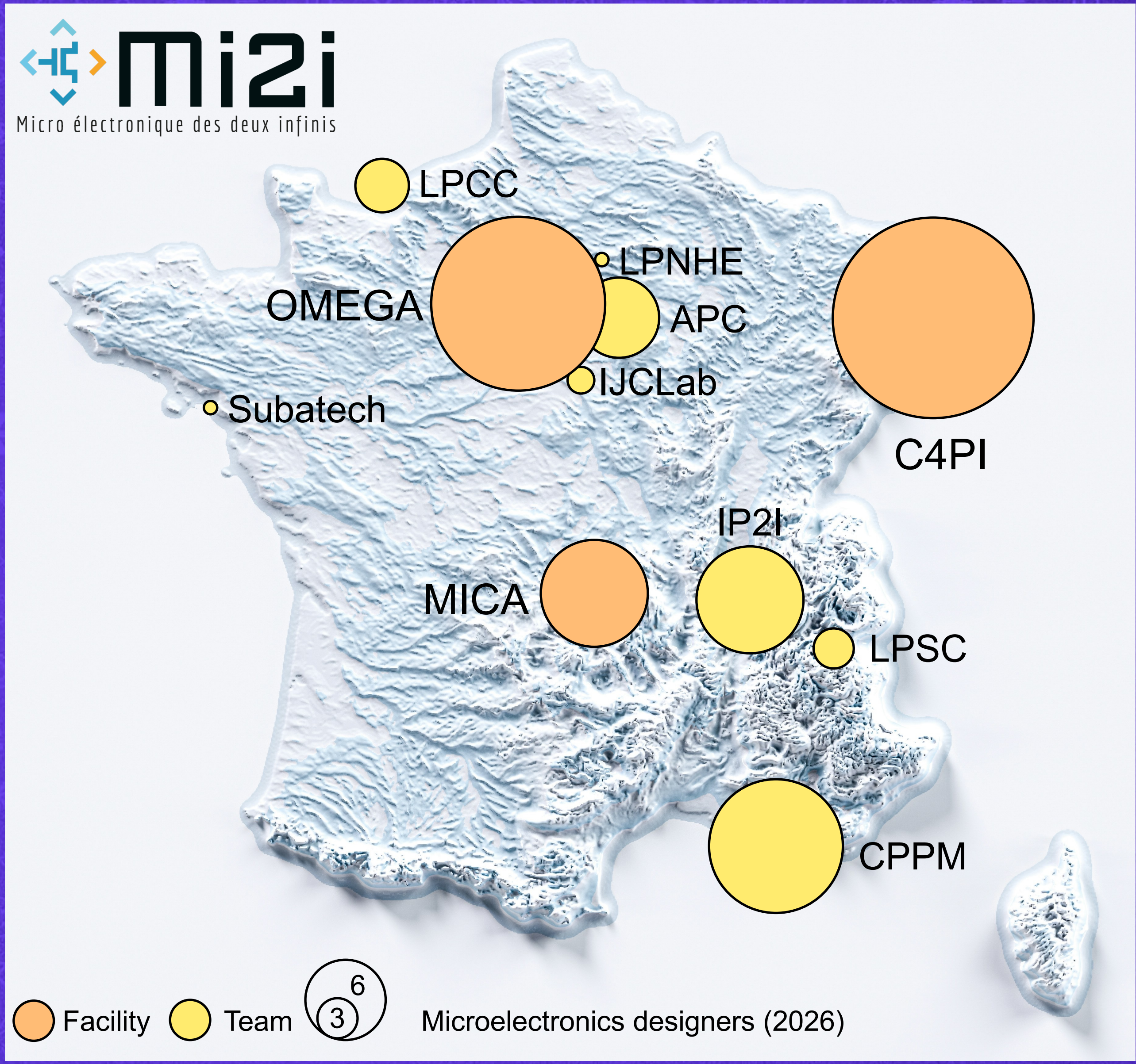
- **Federated Network**
  - ➢ **Internal single point of contact**
- **Network Actions**
  - ➢ **Communication**
  - ➢ **MI2I Days**
  - ➢ **Specific working groups (e.g., timing)**
- **Federation Actions**
  - ➢ **CNRS Microelectronics School**
  - ➢ **CAD government contract support**
  - ➢ **CAD environment development**



MI2I

Workforce

- **3 facilities**
  - **C4PI (IPHC), MICA (LPCA), OMEGA**
- **8 teams**
  - **APC, CPPM, IJCLab, IP2I, LPCC, LPNHE, LPSC, Subatech**
- **Around 80 engineers**
  - **60 in microelectronics**



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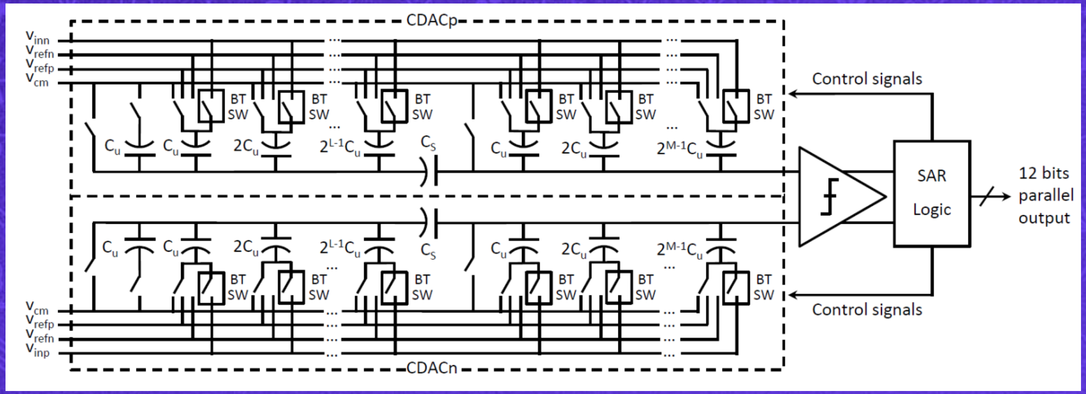
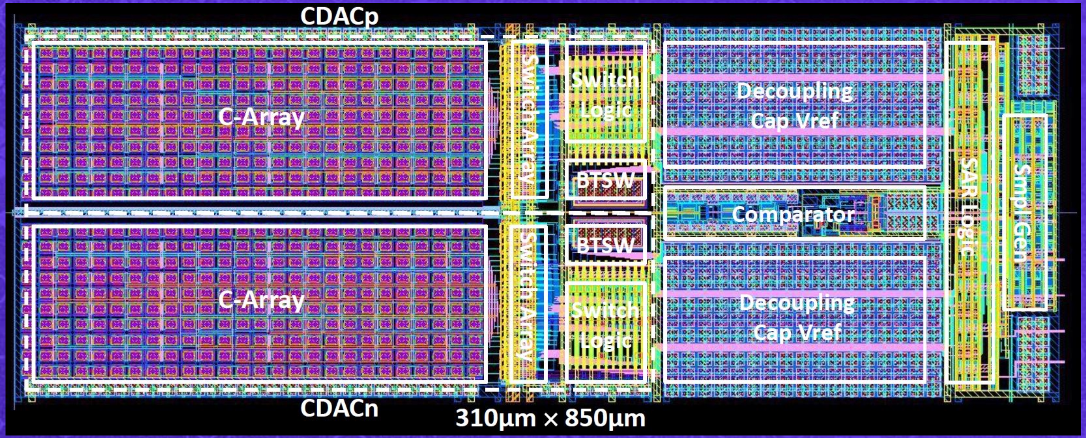
Sampling: ADC, TDC, and Waveform sampler

12bits 10MS/s ADC SAR

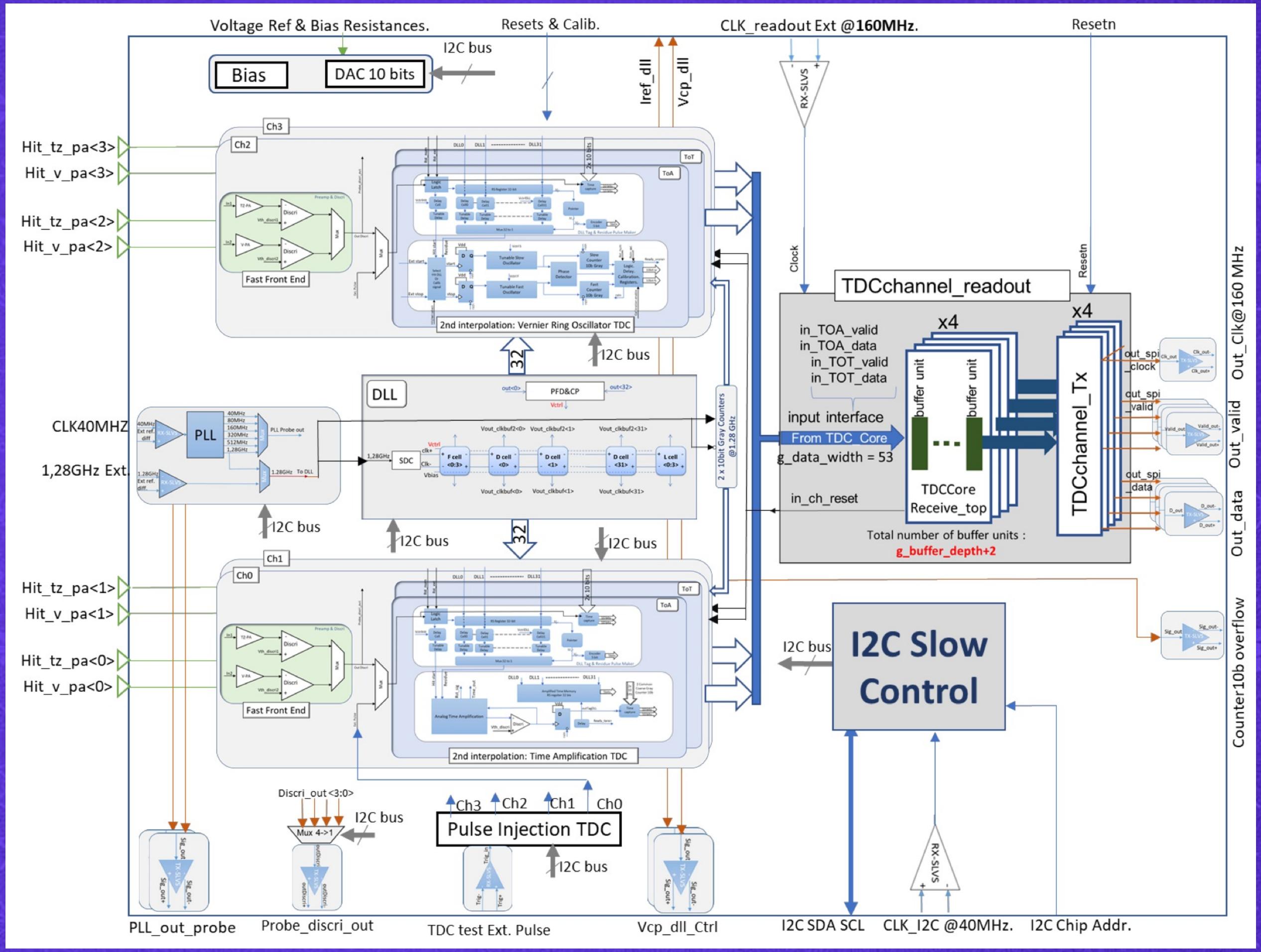




- Tower 180 nm
- IPHC[1]/LPSC[2]/APC[3] IN2P3 collaboration
  - [1]M. Kachel / [1]R. Sefri / [2]F. Rarbi / [3]F. Voisin/ [3]S. Blin
- Identified as CERN DRD 7.6 activity
  - IP for MAPS
- Compatible with high-speed/high-resolution A/D converters requirements for IN2P3 projects
  - IPHC monolithic CMOS pixels
- First version submitted in 2025

FastTime: A Multi-Channel ASIC for a Complete Fast and High-Resolution Time Measurement Chain

- TSMC 130 nm
- IN2P3 collaboration: IJCLab, IP2I, LP2IB, LPC, LPCA, OMEGA
- Targeted resolution: ~1 ps
- Targeted input charge: ~1 pC
- ToA and ToT measurments
- DLL @ 24 ps
- 1st stage interpolation:
  - ➢ Residue pulse maker
- 2nd stage interpolation:
  - ➢ Vernier ring oscillator TDC
  - ➢ Time amplification TDC
- Front-end:
  - ➢ Trans-Impedance preamplifier
  - ➢ Voltage Preamplifier



PLAS : PipeLined Asymmetric Switched Capacitor Array for GRIT experiment (Nuclear Physics)

- PLAS_v2 ➔ Measured resolution 8 bits in TSI 180nm CMOS (no more available)
  - Designed by IFIC Valencia.
- PLAS_v3 ➔ XFAB XH018 technology, submission in oct. 2026
  - Redesign by LPC Caen.
- Target resolution : 10 bits (noise expected below 340 µVrms with FS=1,2V)
- Sampling Features:
  - 32 inputs with independent trigger
  - Samples at 200 MHz (Write Clock=100MHz)
  - 224 samples captured per pulse
    - 32 before trigger (pre-trigger samples)
    - 192 after trigger (post-trigger samples)
  - No deadtime
- Reading Features:
  - 8 output queue slots
  - Single differential analog output
  - Serial readout at 50 MHz (Read Clock)
  - Needs external ADC
  - Designed for triggerless readout

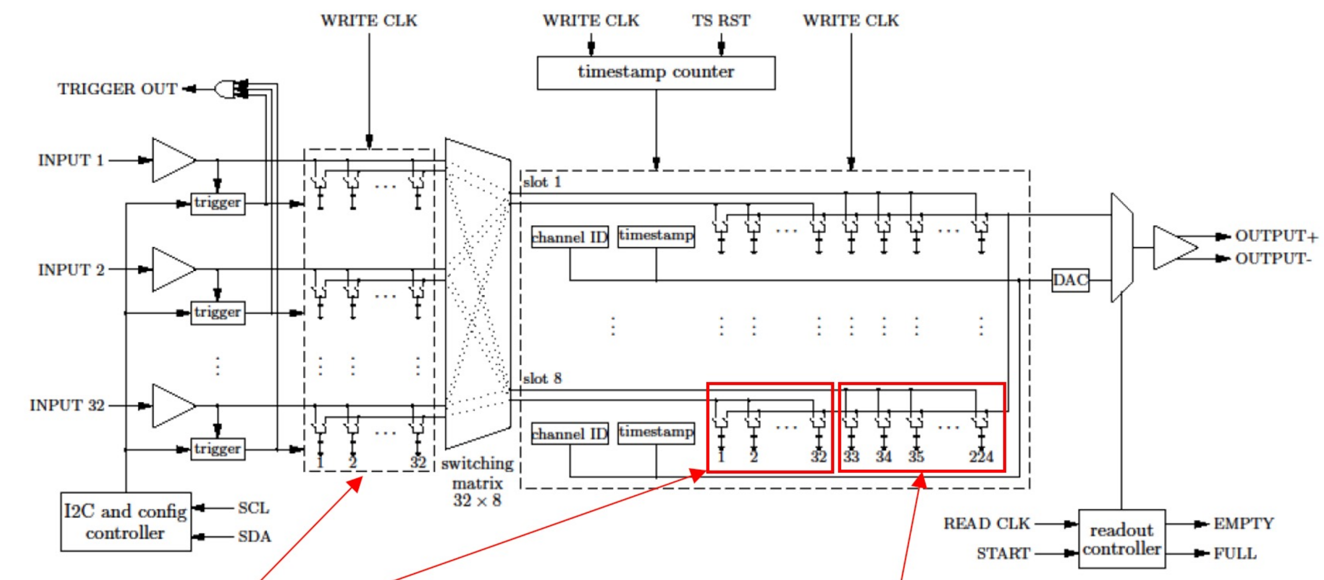
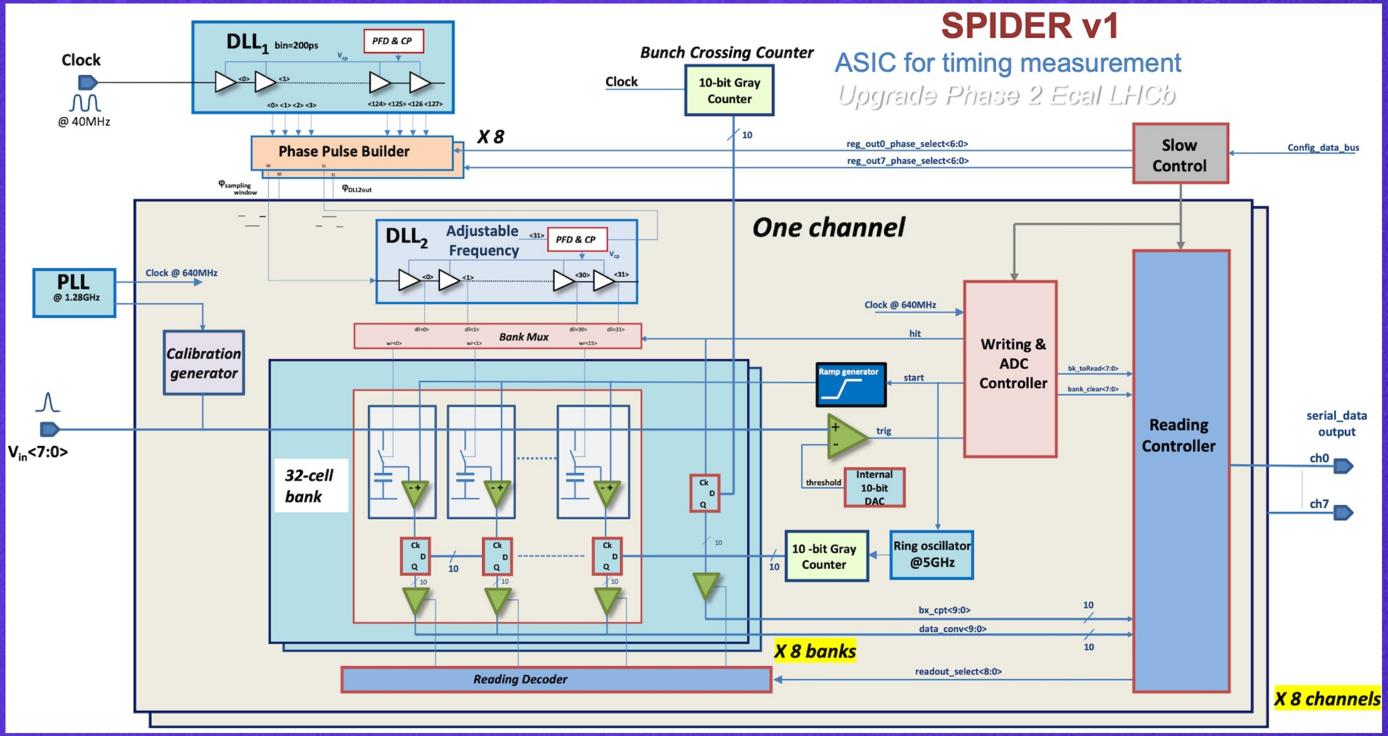


Figure 1. PLAS functional block diagram.

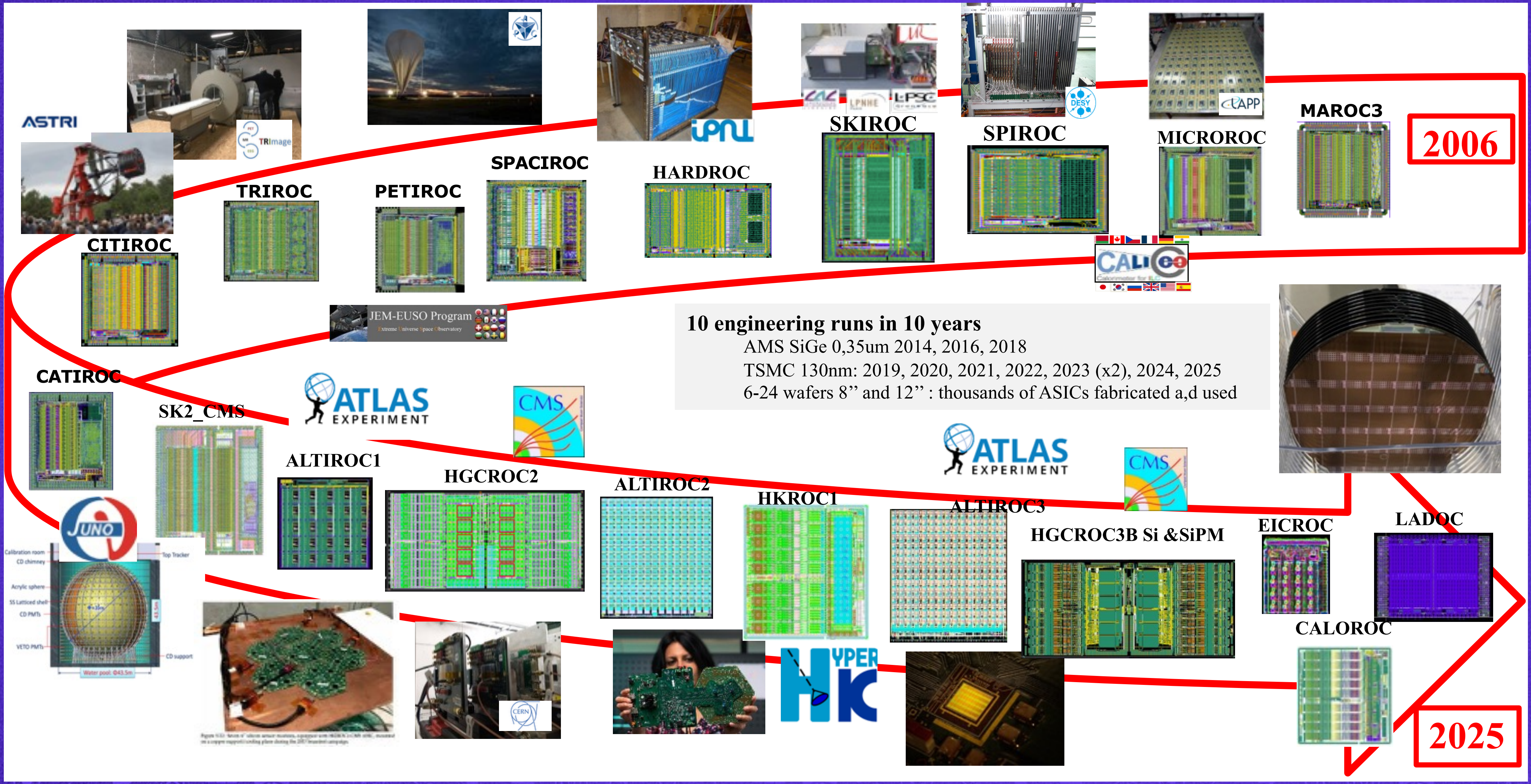
SPIDER: a Waveform Digitizer ASIC for picosecond timing in LHCb PicoCal

- TSMC 65 nm
- IN2P3 members: IJCLab, IP2I, LPC, LPCA
- 2 self-triggered channels (V0), targeting 8 on V1
- Sampling period 50ps to 600ps
- Adjustable sampling window w.r.t LHC clock
  - + trigger enable window
  - 32-sample waveform
- Analog bandwidth compatible with rise time ~250ps
- Noise < 0.5mV
- 10-bit conversion (range 0-800 mV)
- Max conversion time 200ns, optimized for positive pulses
- 8-bank derandomization buffer
  - Simultaneous writing, conversion (1 or several banks) and readout
  - Rotating FIFO
- Peak finder: allows to read a portion (e.g. 8 samples rising edge) => reduce extraction time



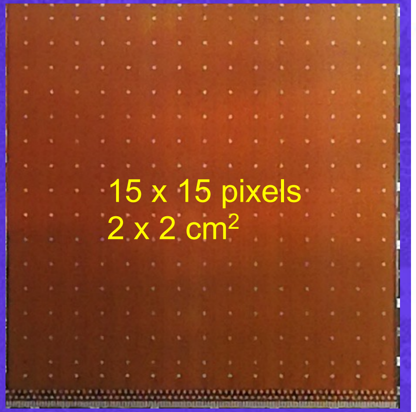
3 Calorimetry

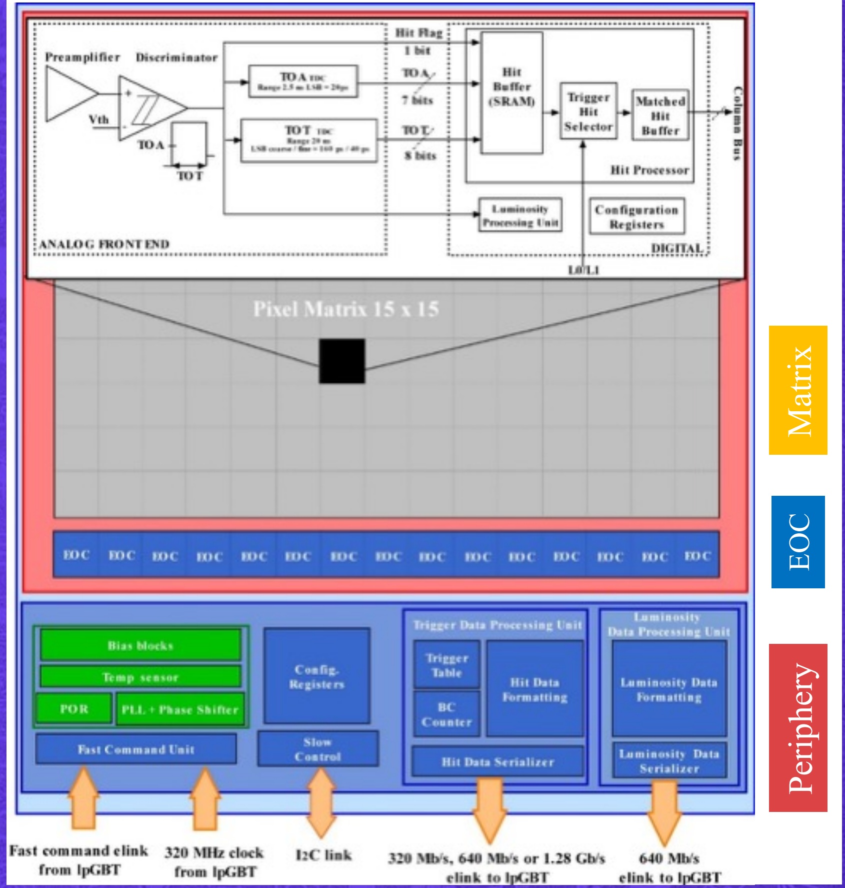
OMEGA: ASICs fabricated and installed 2006-2025

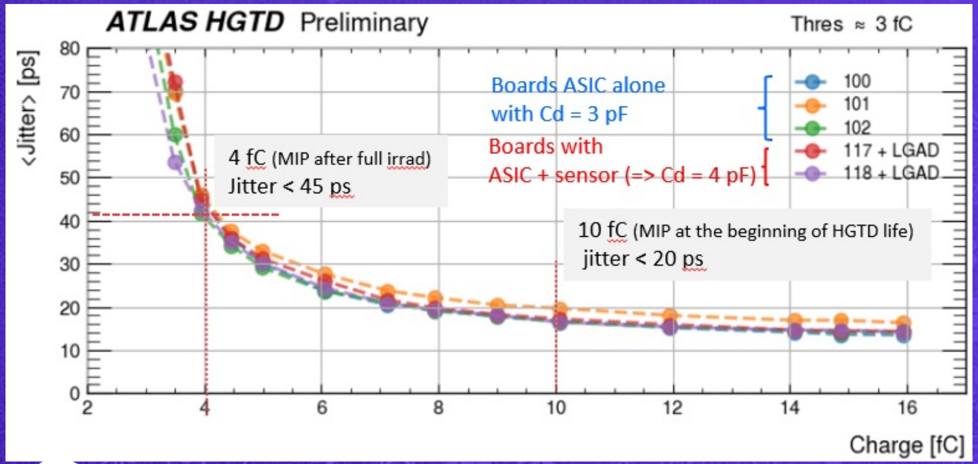


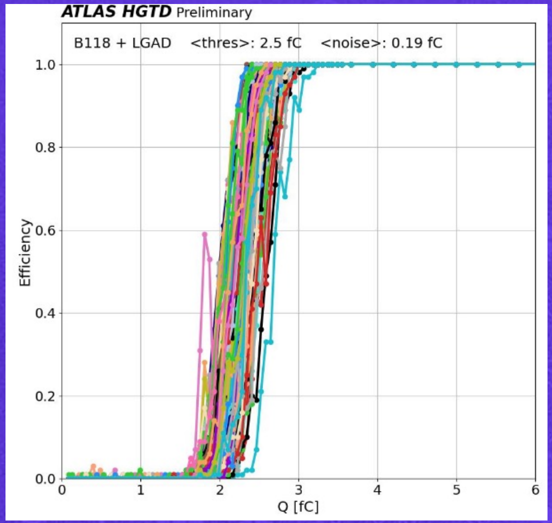
ATLAS HGTD: ALTIROC

- **ALTIROC: Atlas Lgad Timing Integrated ReadOut Chip**
  - ➢ **20 ps silicon timing detector for jet id and pileup rejection**
  - ➢ **Active radius from 120 mm (η = 4) to 640 mm (η =2.4)**
  - ➔ **2.5 e15 neq/cm2 and 200 Mrad at the end of HL-LHC (4000/fb)**
  - ➢ **Readout of 225 (1.3 mm)² LGAD sensors (Cd= 4 pF)**
  - ➢ **1 GHz preamp & discriminator + 20 ps TDC to measure ToA & ToT**
  - ➢ **225 wafers produced in 2025**



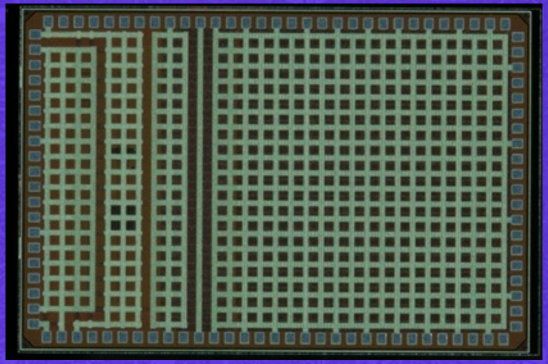




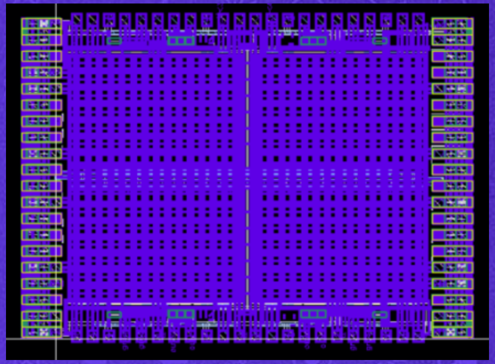


ATLAS: LArg Calorimeter Upgrade

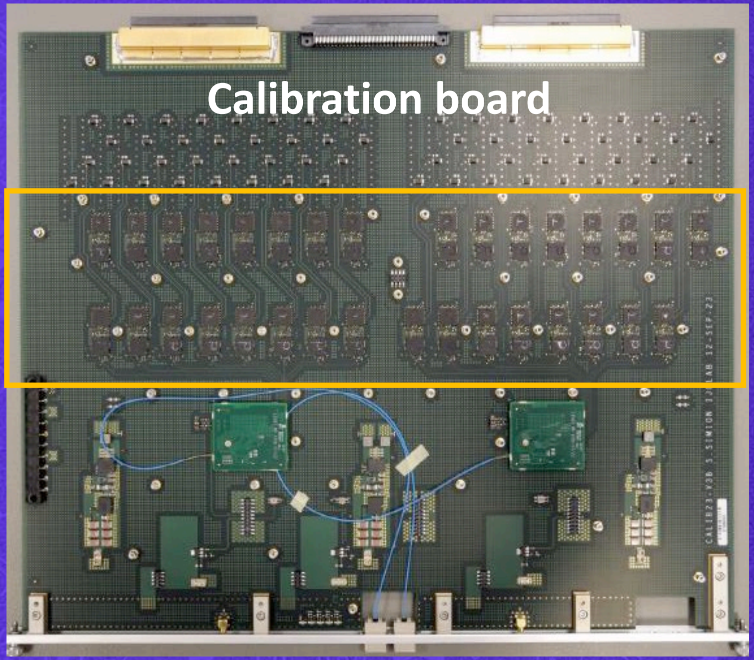
- LADOC (Liquid Argon DAC Output Chip)
  - Provides 0.1% accuracy current over 16 bits dynamic range for calibration of LAr Electromagnetic Calorimeter
  - Maximum current 320 mA
  - 6000 chips fabricated in 2025 in ATLAS/EIC combo run
- CLAROC (Calibration Liquid Argon Output Chip)
  - Provides a fast pulse similar to liquid argon signal up to - 7.5 V in 50 Ω
  - Technology XFAB SOI 180nm, 6000 chips fabricated in 2024

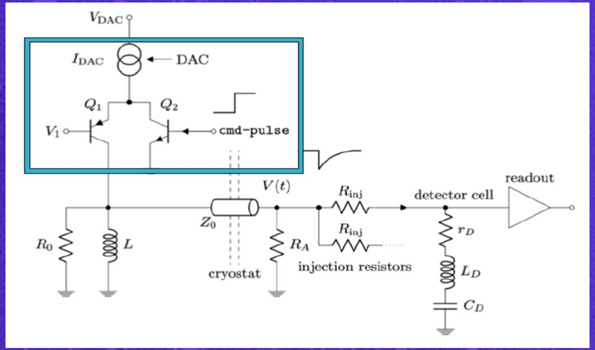


LADOC layout

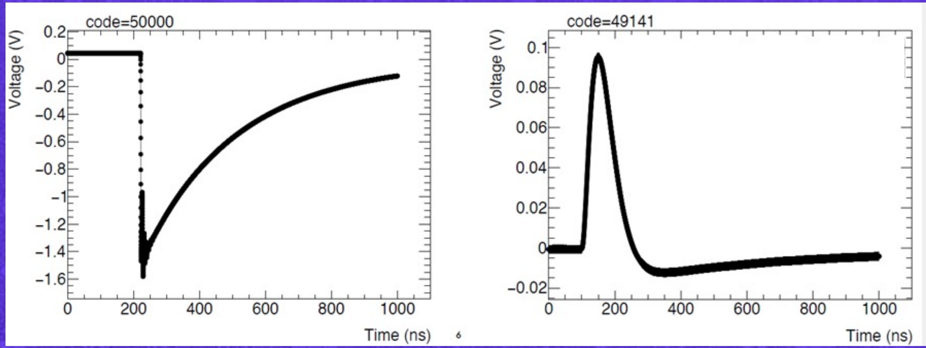


CLAROC layout



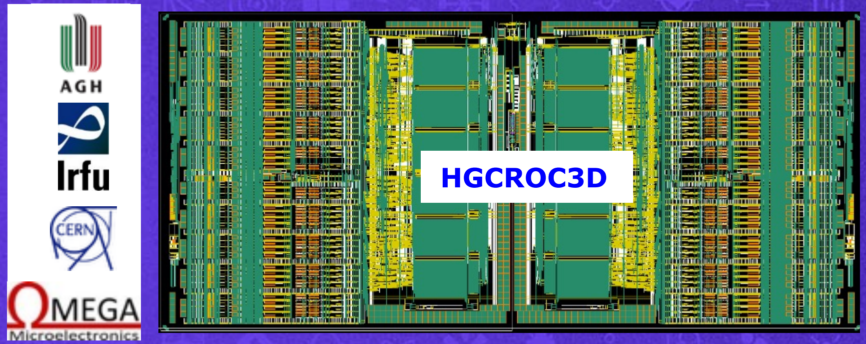


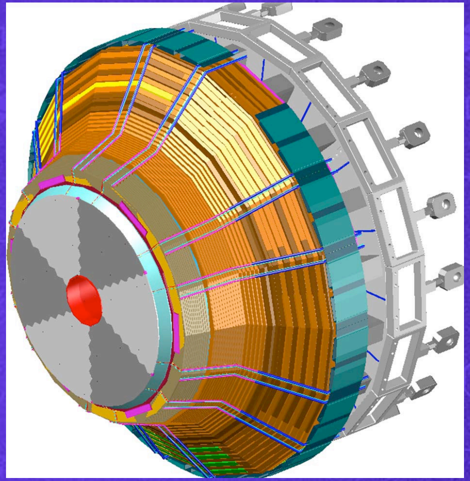
Calibration principle



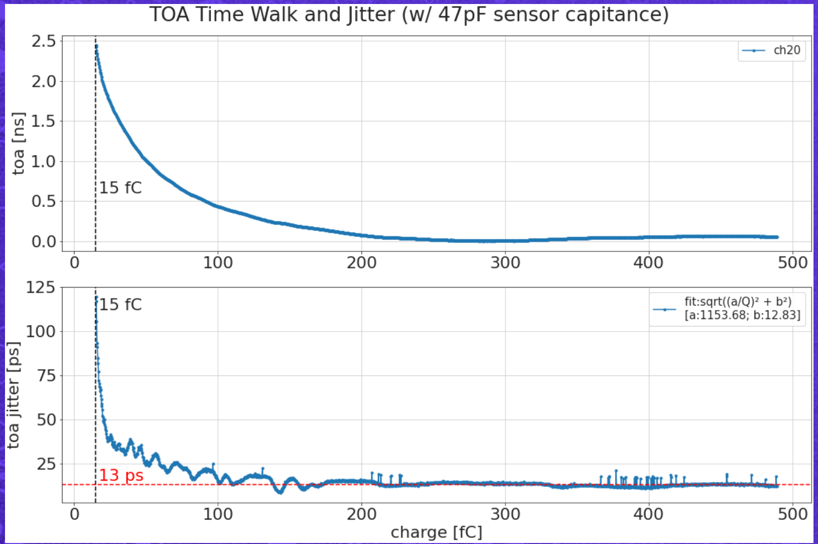
Pulse before and after shaping

CMS: HGCAL

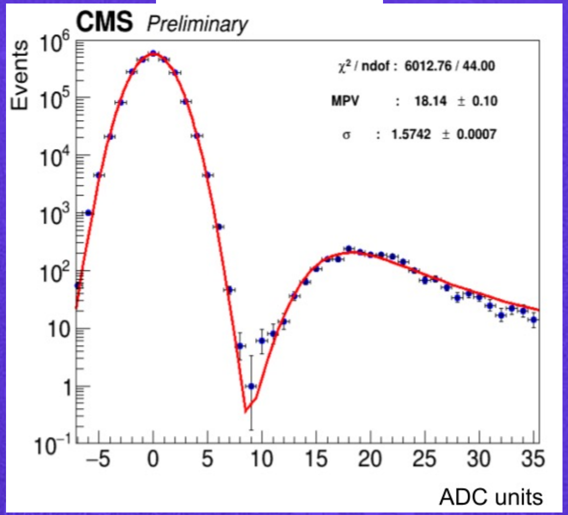


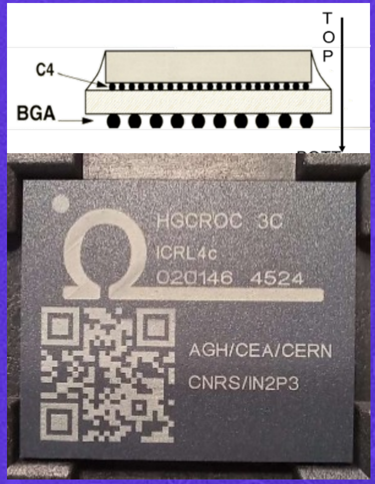


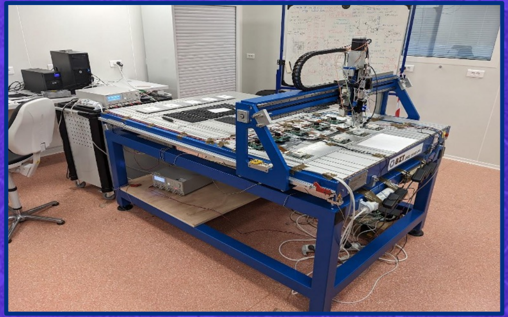
- HGCROC (High Granularity Calorimeter ReadOut Chip)
  - Calorimeter readout of PIN diodes and SiPMs of new HGCAL end cap calo
  - 0.1 MIP to 2000 MIPs digitization with 10bit ADC and ToT, 20 ns peaking time
  - 20 ps timing measurement with 3 ns time walk
  - 200 Mrad radiation hardness
  - 72 channels, 15 mW/channel, C4 bumping, BGA package
  - 120 000 chips produced in 2025



MIP in detector

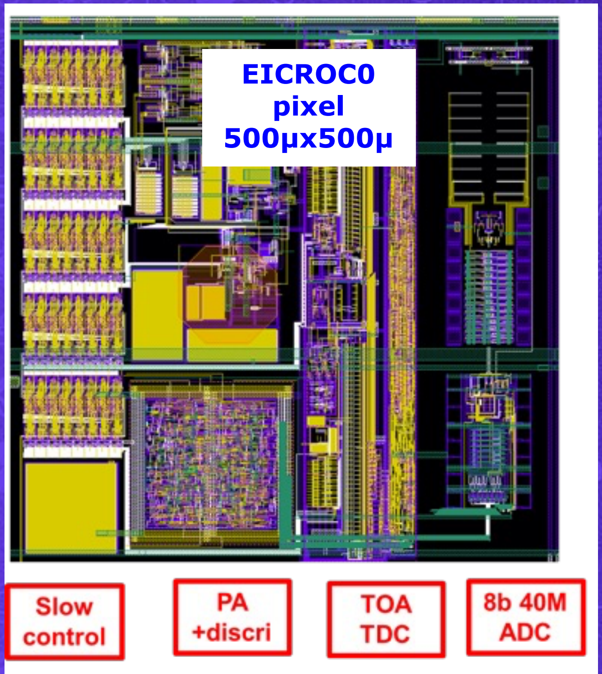




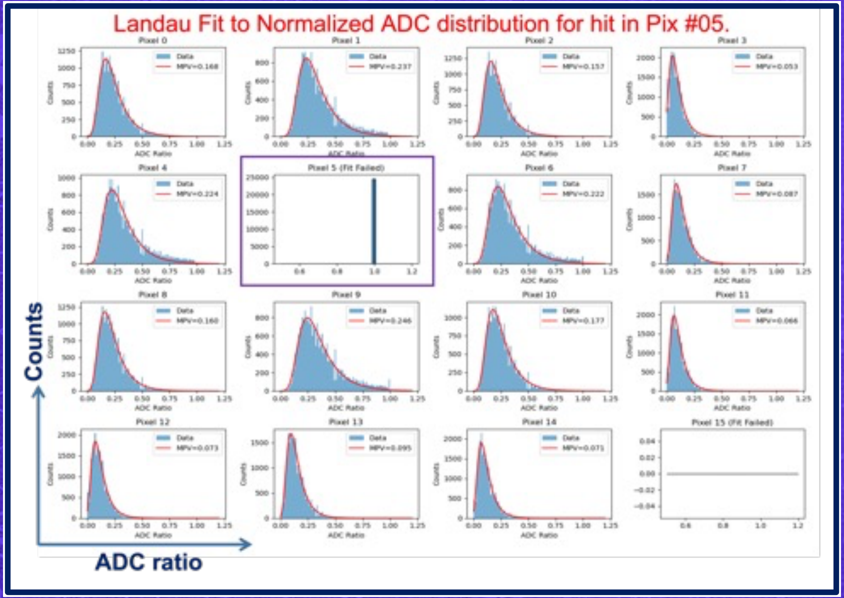


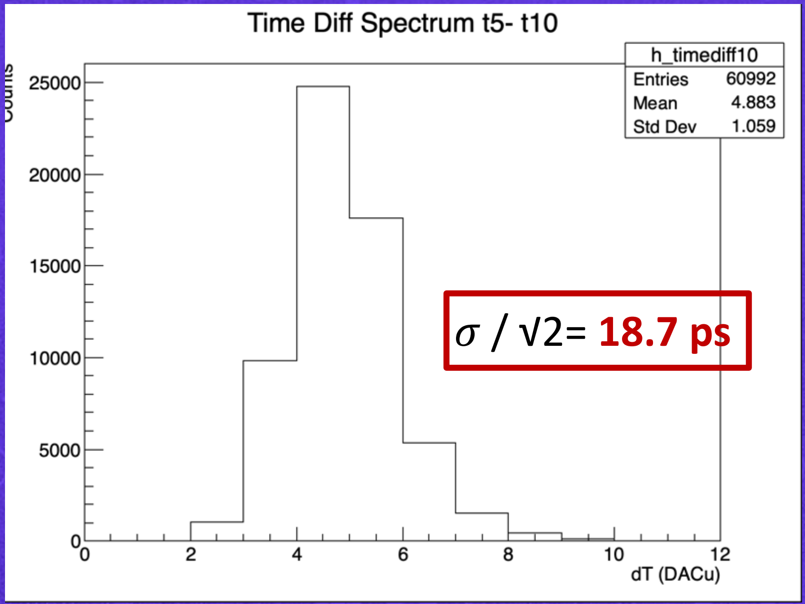
EIC: EICROC AC-LGAD readout

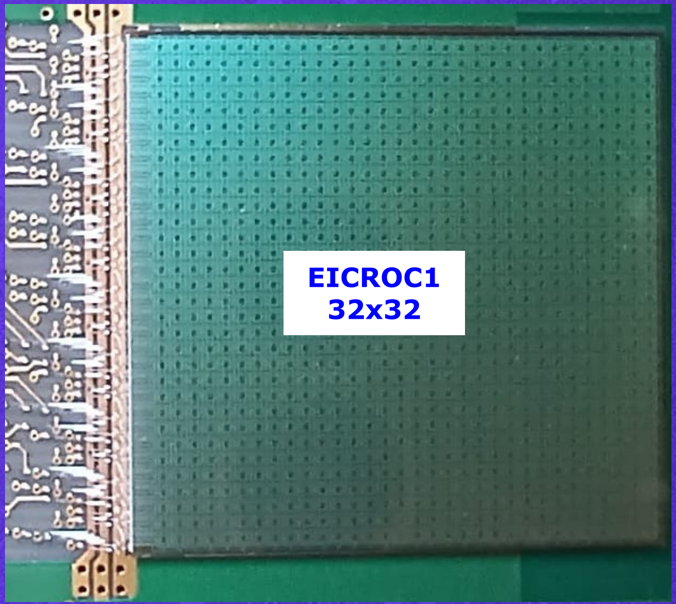
- EICROC (EIC ReadOut Chip)
  - ➢ Reads out 1024 pixels (500 µm²) of AC-LGAD for ToF detector (2 cm² sensors)
  - ➢ 8-bit 40MHz ADC for position measurement down to 20 µm
  - ➢ 20 ps TDC for timing measurement down to 20 ps
  - ➢ 4x4 prototype in 2023, 32x32 in 2025, final chip DoT in 2027 (LPC Clermont-Ferrand)



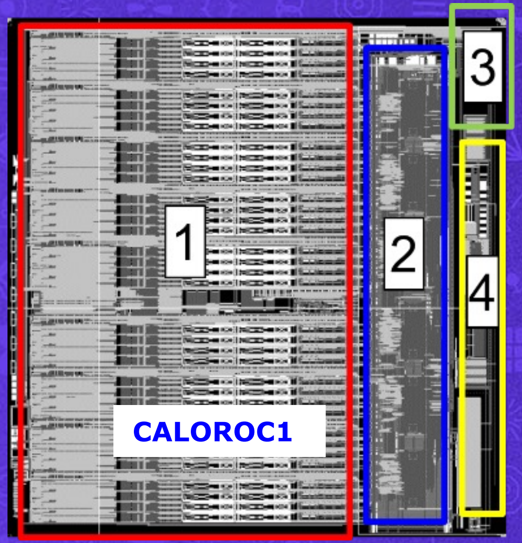
Refer to OMEGA's talk



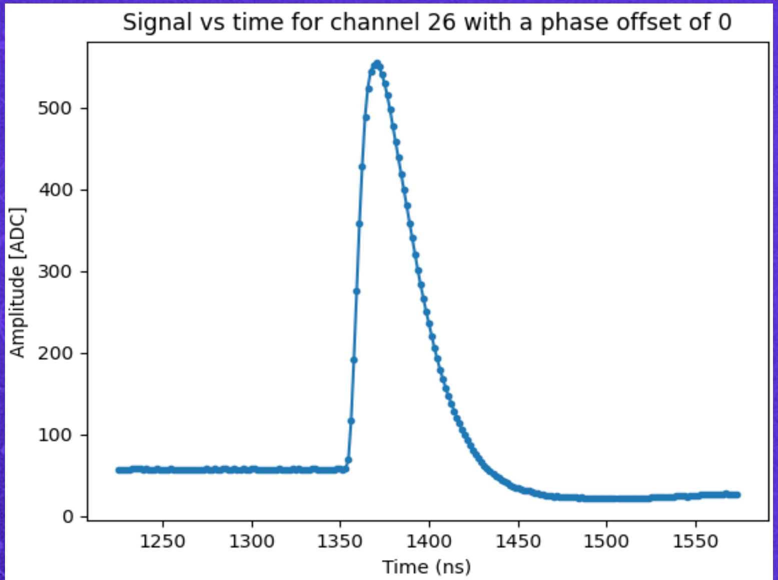


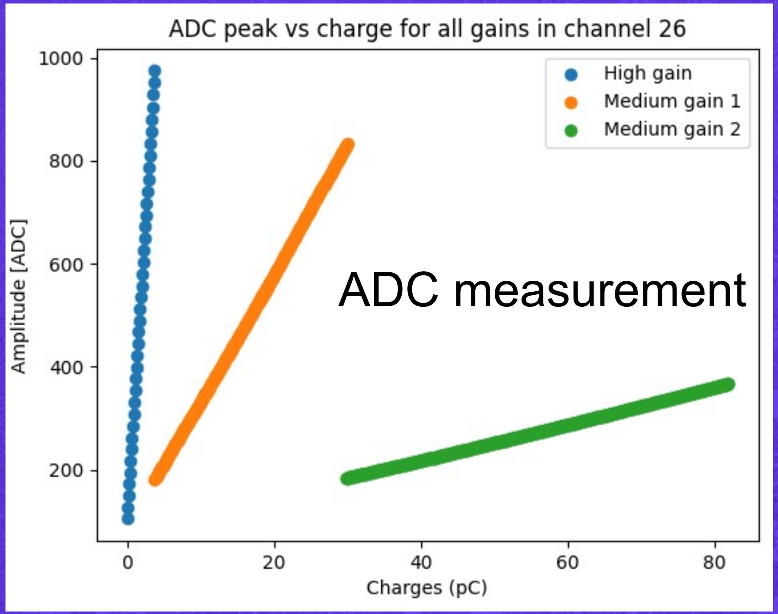


EIC: CALOROC SiPM readout



- CALOROC : SiPM readout for EIC calorimeter
  - 36 channels of charge and time measurement for SiPM up to 10 nF
  - Streaming readout : auto-trigger and zero-suppress
  - 4 gains
  - 20 ps timing
  - 12 mW/ch
- Variant for DRD6 and Allegro LAr calorimeter



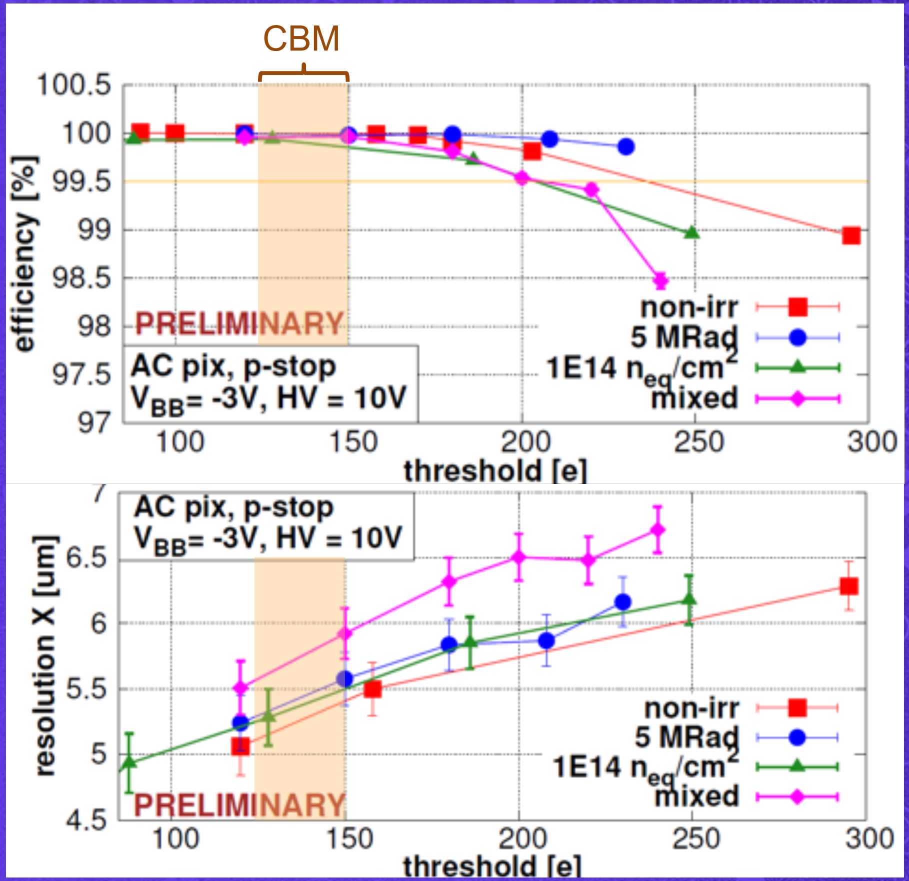


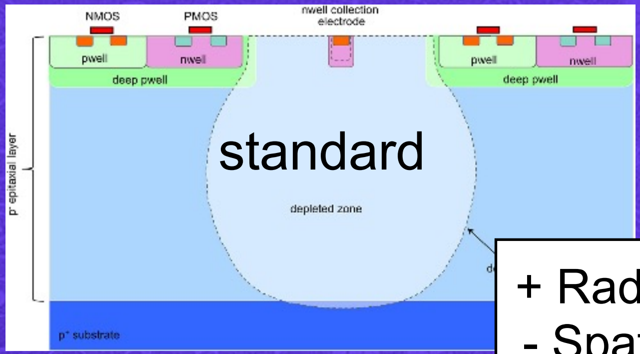
3

Vertexing & Tracking

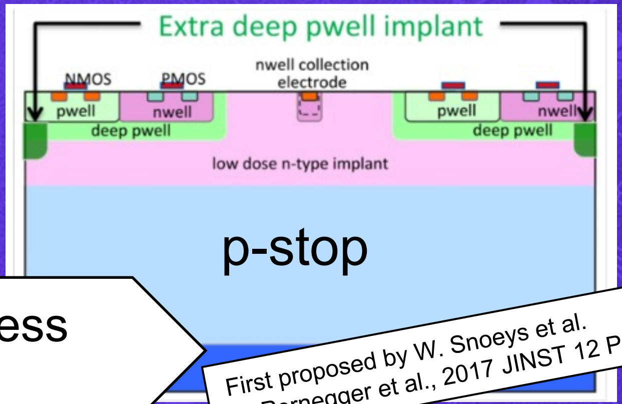
CBM-MVD: MIMOSIS

- Based on ALPIDE architecture
  - New readout to sustain space and time variations
  - Matrix dimension: 1024 col. X 504 row
  - Pixel dimension: 26.88 µm (height) x 30.24 µm (width)
  - 2 front-end variants AC and DC
  - Integration time: 5 µs
  - Tower 180 nm with modified process
  - Designed by IPHC
- MIMOSIS-3:
  - Production Readiness Review on 03/26
  - System Improvement in Progress





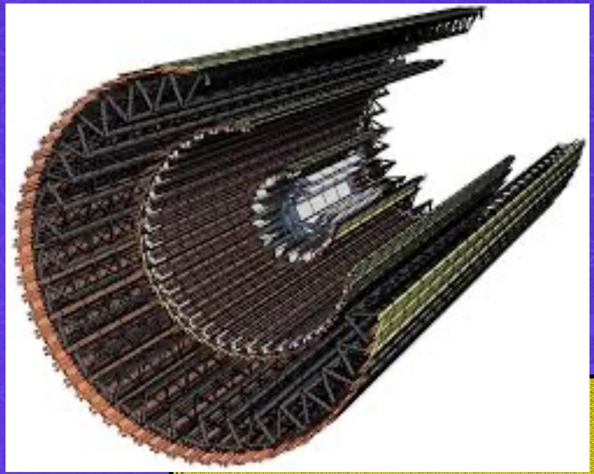
+ Radiation hardness
- Spat. Resolution



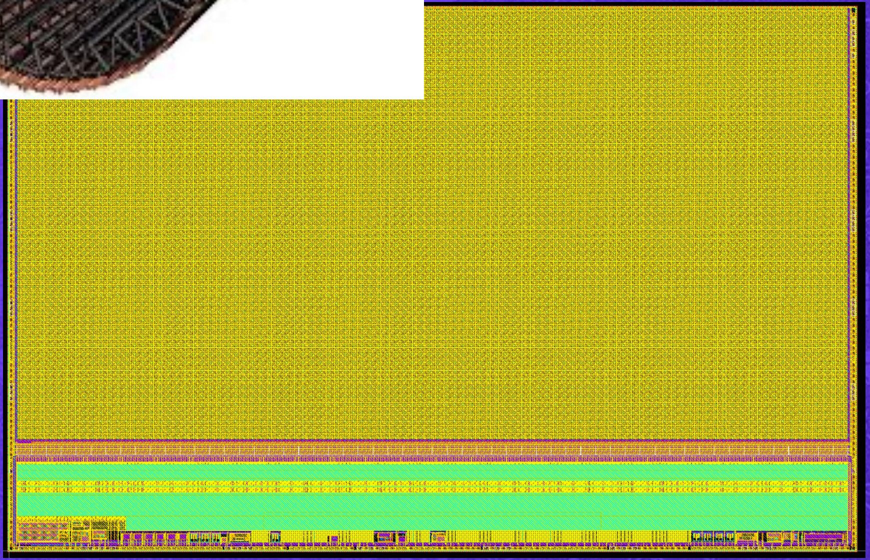
First proposed by W. Snoeys et al.
H. Pernegger et al., 2017 JINST 12 P06008

OBELIX: A Dedicated MAPS for Belle II experiment

- Tower 180 nm
- IN2P3 members: CPPM, IPHC
- Dedicated MAPS for Belle II vertex detector upgrade
- Based on TJ-Monopix2
- Digital-on-Top flow integration
- Matrix of 464x896 pixels (33.04x33.04 μm^2)
  - Column-drain with data-driven readout
  - 21.1 MHz timestamping clock for ToA and ToT
- On-chip LDO regulation for all power domains
- New digital periphery to cope with Belle II trigger:
  - Two-level data buffering & trigger management
  - Trigger output for L1
  - High precision time stamping at low hit rate

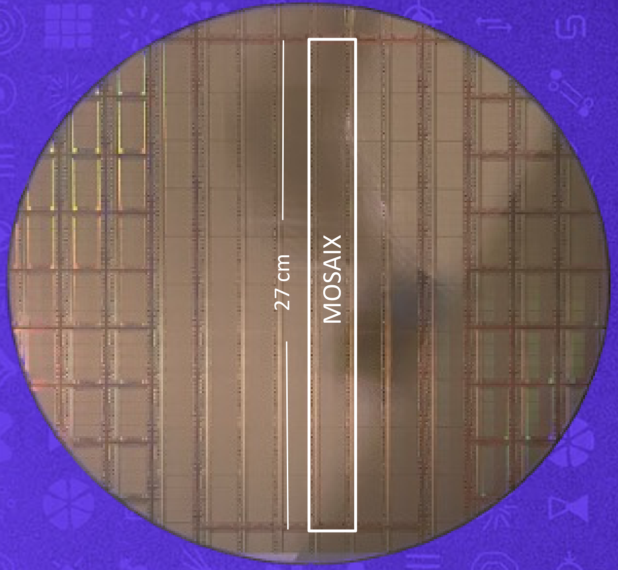


ladders ~ 160
sensors ~ 2500

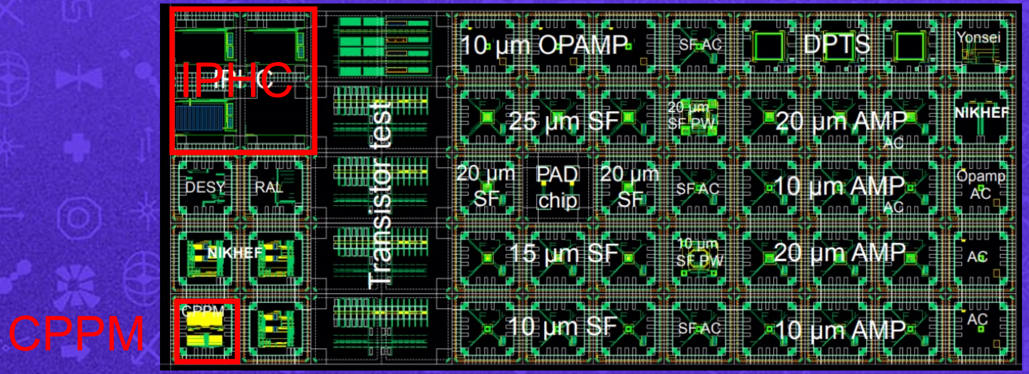


Refer to H. Pham's talk

TPSCo 65nm: from baby steps to MOSAIX



- MLR1: 55 different chips to explore the technology
  - IPHC: CE_65v1 to explore charge collection
  - CPPM: Ring oscillator for radiation study on standard cells
- ER1: stitching exploration focus on ALICE-ITS3 (MOSS/MOST)
  - IPHC:
    - New version of CE_65v2 (chiplet)
    - Matrix implementation and biasing for MOSS (large scale sensor)
- ER2: first prototype of the final sensor for ALICE-ITS3 (MOSAIX)
  - IPHC:
    - SPARC for asynchronous readout (see next slide)
    - Matrix implementation and biasing for MOSAIX
  - CPPM:
    - New version of ring oscillator (chiplet)

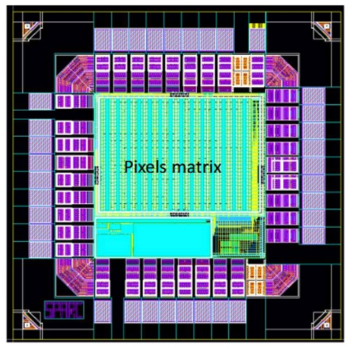


MLR1

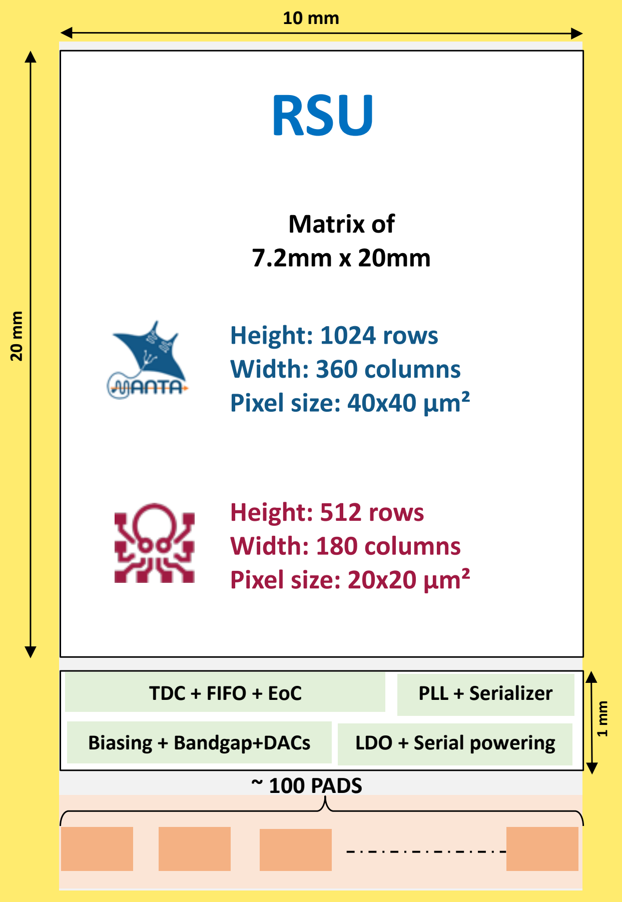
ITS3 Qualification Model

DRD 3: MANTA & OCTOPUS

- Technology: TPSCo 65 nm
- Asynchronous readout derived from SPARC
  - IPHC, CEA-Irfu, ICube (University of Strasbourg & CNRS Ingénierie)
  - ToA and ToT on matrix periphery
  - Time resolution of few nanoseconds
  - First test seems promising
- MANTA:
  - For tracking applications
  - Diode pitch (20 µm) ≠ Pixel pitch (40 µm) ➔ Pixel grouping Ana./Dig.
  - Fast OR and high-resolution time stamping: ~70 ps
  - IN2P3 members: IP2I, IPHC, LPNHE, LPSC
- OCTOPUS:
  - For vertexing applications
  - Pixel pitch (20 µm)
  - Increase spatial resolution with ToT measurement
  - IN2P3 members: APC, CPPM, IPHC



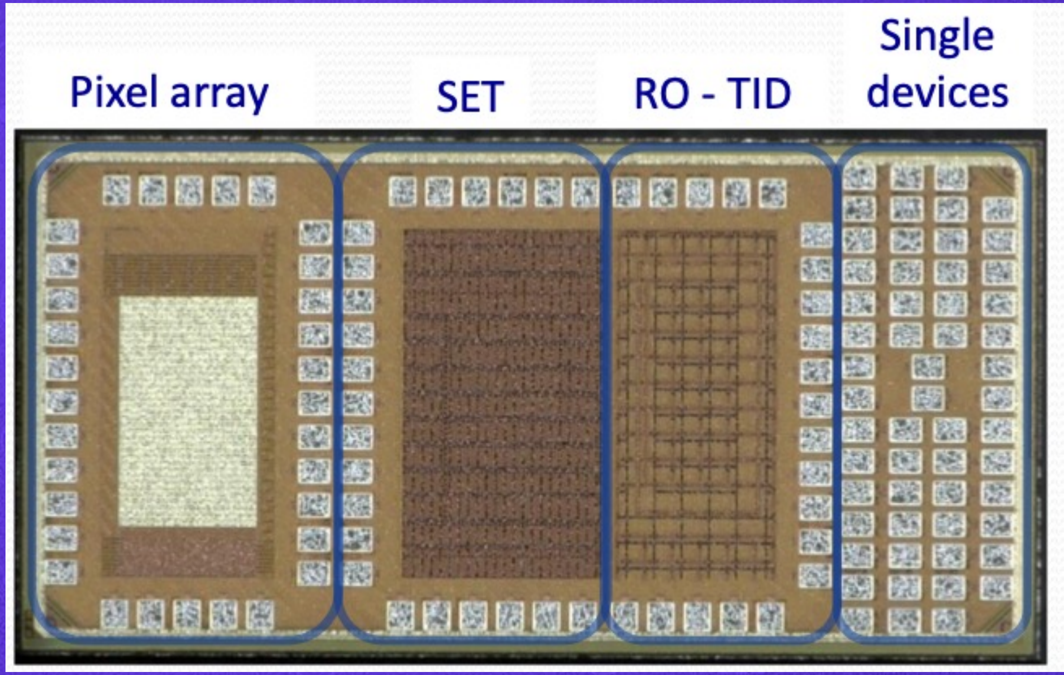
SPARC layout



MANTA1 & OCTOPUS1 schematic

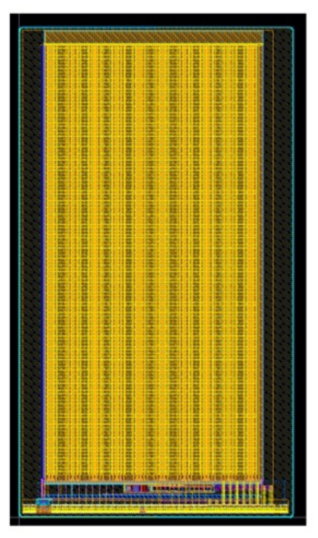
28 nm electronics developments for future pixel detectors

- TSMC 28 nm
- Exploring 4D tracking in future experiments using hybrid technologies
  - ➢ High spatial resolution
  - ➢ High time precision
  - ➢ Very high radiation tolerance
- Led by CPPM
- R&D activities on:
  - ➢ SEE/SET testing
  - ➢ Ring Oscillator Design
  - ➢ Analog FE pixel array



MAPS spin-off in Tower 180 nm

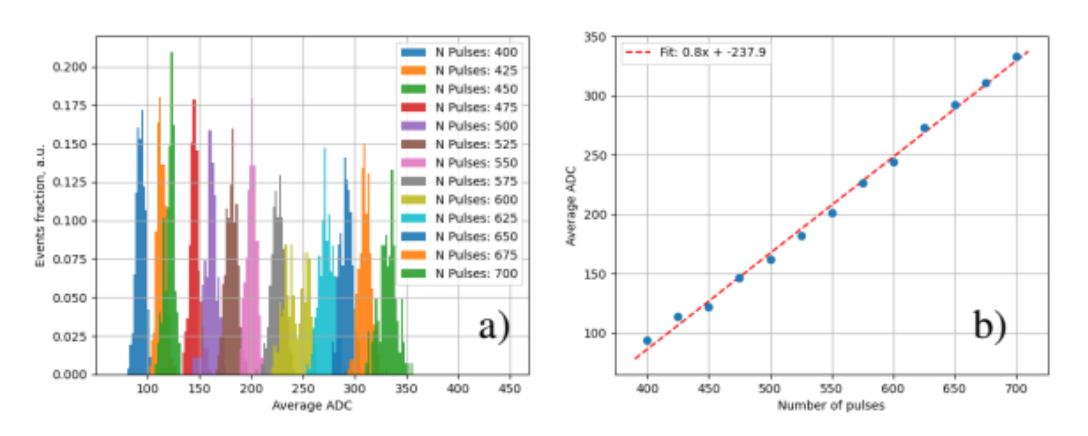
- **IMPACT:**
  - ➢ Ion identification ➔ proj. EU “Philm” in Hadron-2030
  - ➢ Need of ADC SAR 12bits 10MS/s: see previous slide
- **Spatial dosimetry:**
  - ➢ Developed inside LabCOM LAMAPS (IPHC and Weeroc)
  - ➢ Collaboration contract with CNES



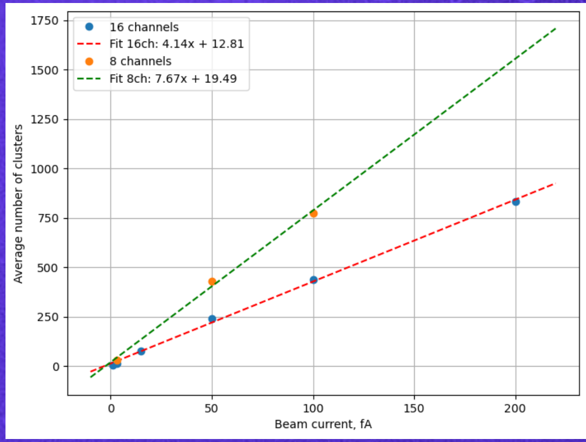
IMPACT layout

CNES DAQ – CubeSat format

Lab test with laser



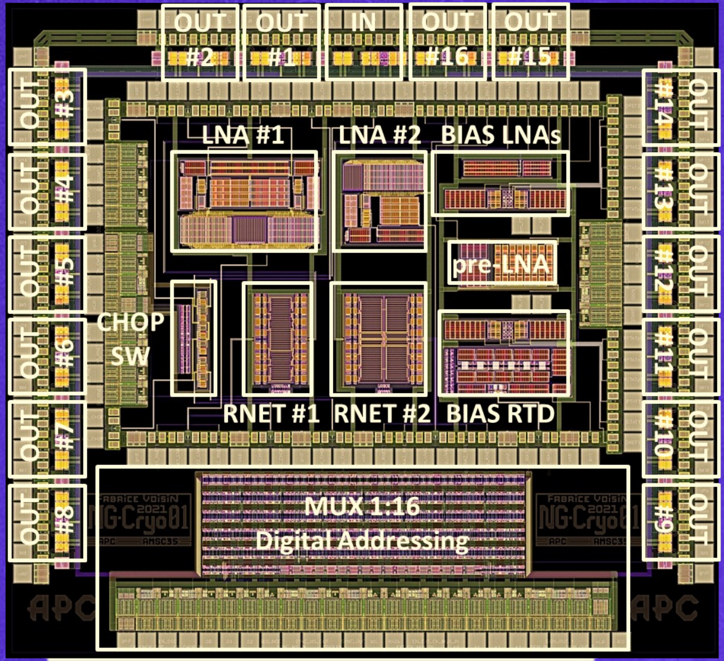
Proton beam — CYRCé

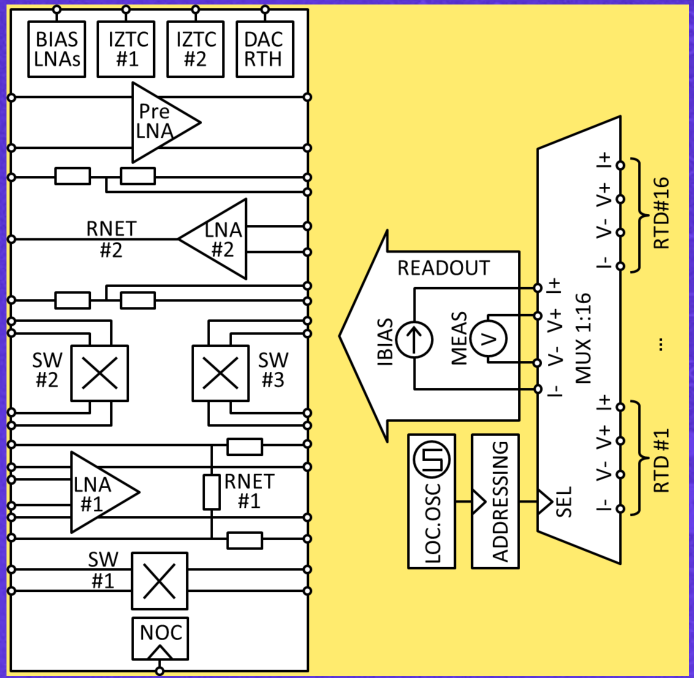


4

Cryogenics & space applications

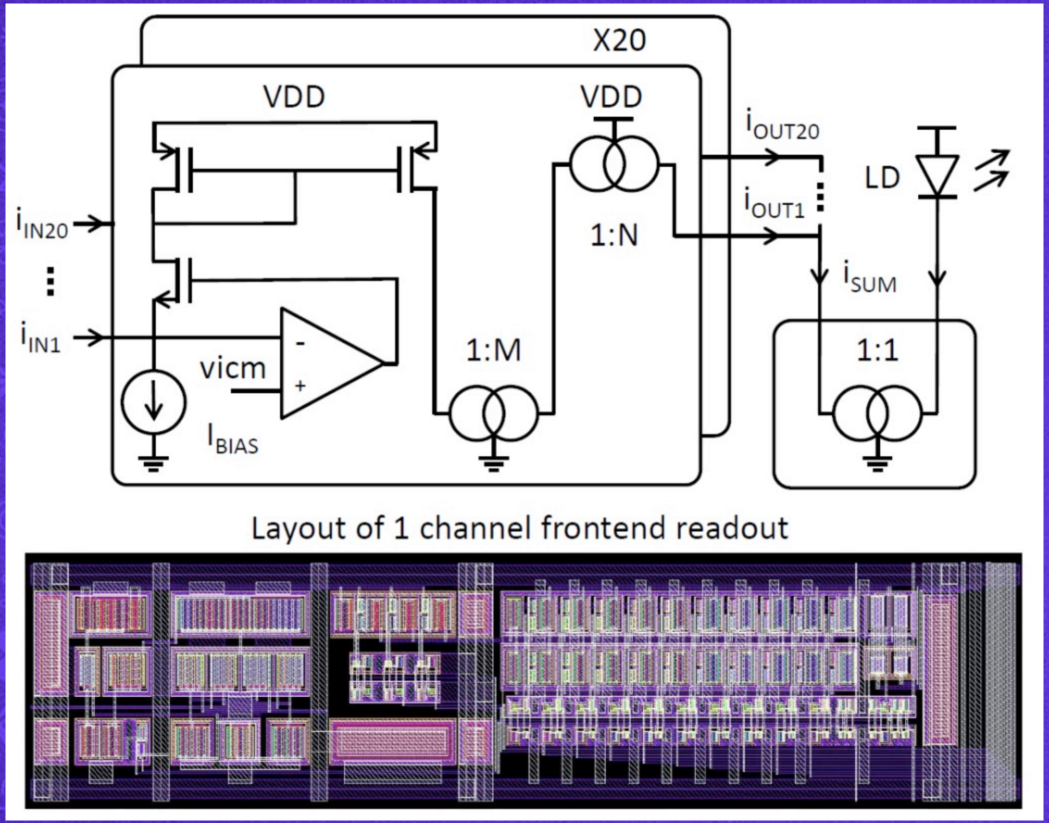
R&T IN2P3 NGCryo





- Project larger than microelectronics
  - ➢ Designed at APC
- Simplify cryostat thermometry procedure in the sub-kelvin range
- Reduce the number of wires needed for in-situ thermometer measurements
- Cryogenic ASIC in AMS CMOS 350nm technology (2022), integrating multiplexing function and test architectures for the readout of thermometers operating at 300mK

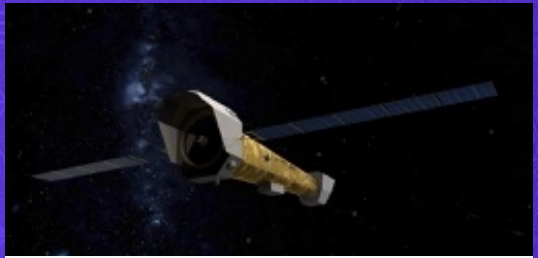
ANR SOFIC

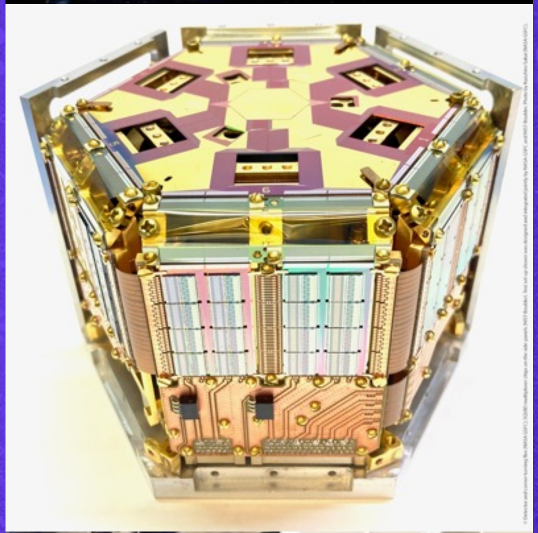


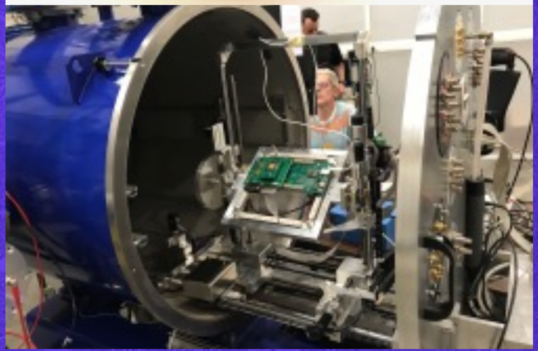
- Readout chain of the DUNE neutrino detection experiment photodetection system
- Multi-channel ASIC in AMS CMOS 350nm technology, operating at cryogenic liquid argon temperature (90K)
- Optical fiber readout and transmission of signals from SiPMs detectors (20x channels)
- Submission expected by the end of 2026
  - Designed at APC

Low-Noise ASICs for Space Cryogenic Detector Readout

- **Mission context - ATHENA / X-IFU Warm Front-End Electronics (WFEE)**
  - ➢ ESA ATHENA mission, X-IFU instrument, 32 multiplexed readout channels, 1536 superconducting microcalorimeters @ 50 mK
  - ➢ Cryogenic readout : SQUID Time domain multiplexing
  - ➢ APC responsibility: warm (300 K) front end electronics WFEE
    - ➔Target instrument: ~2.5 eV energy resolution @ 6 keV over 1536 detector : Xray spectro-imager
- **WFEE ASIC functions**
  - ➢ Differential low-noise LNAs
    - < 1 nV/√Hz input noise
    - Tens of MHz bandwidth
  - ➢ Low-noise programmable DACs for TES & SQUID biasing
    - Low 1/f noise
    - Thermal drift compensation
    - Radiation robustness up to 200 krad and 120 MeV/mg/cm^2

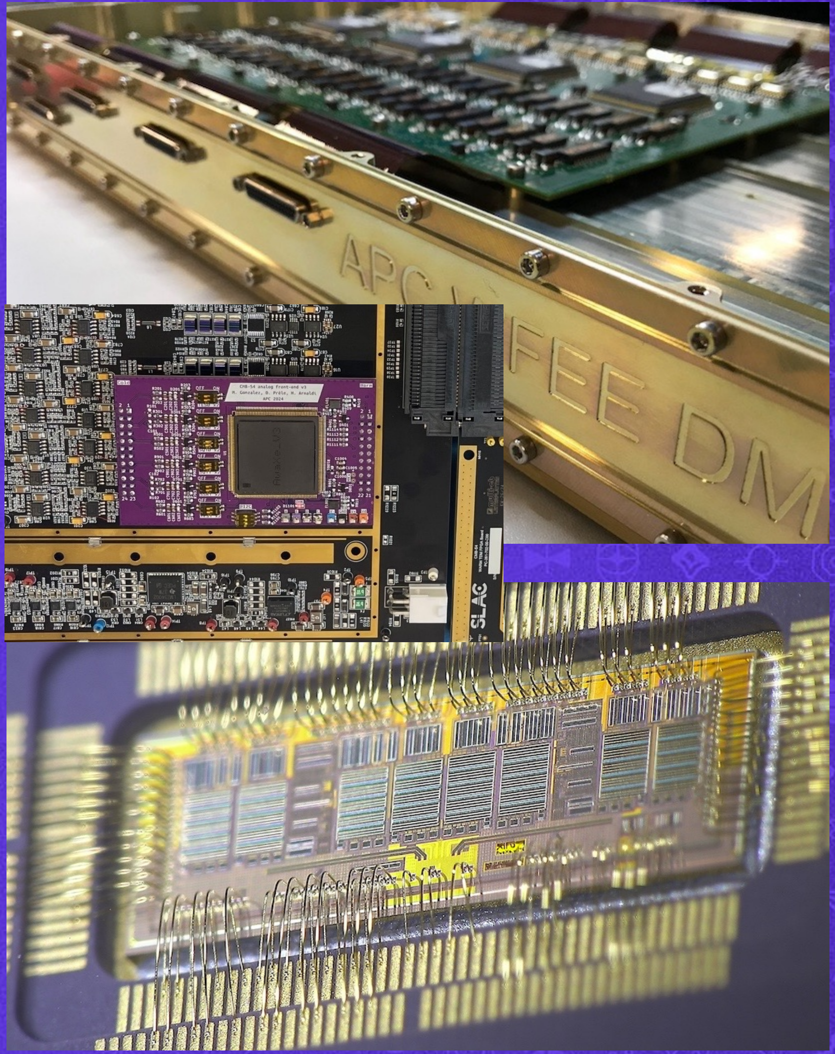






AwaXe ASIC Family Evolution
Athena Warm ASIC for X-IFU Electronics

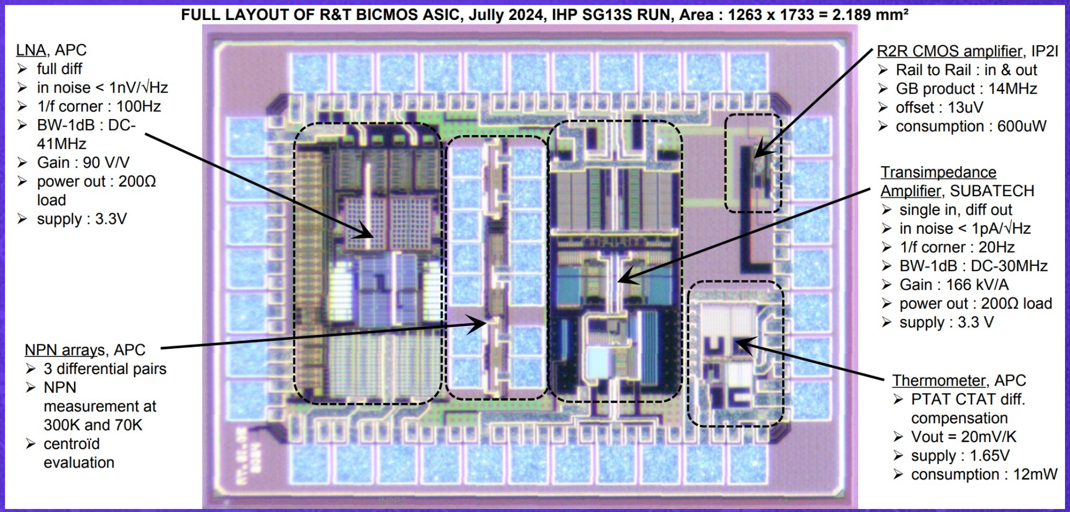
- **2020 — AwaXe_v3 (AMS 350 nm BiCMOS SiGe)**
  - ➢ Used in WFEE DM1 / DM2 (16 channels delivred to CNES & SRON):
  - ➢ https://x-ifu.irap.omp.eu/fr/announcement/successful-coupling-of-the-x-ifu-warm-front-end-electronics-demonstrator-at-sron
  - ➢ Also deployed for CMB-S4 electronics at SLAC : see CMB-S4 SiGe ASIC-based daughter board for low-temperature detectors front-end analog readout L. H. Arnaldi, M. Gonzalez, D. Prêle, S. Chen, et al. doi.org/10.1117/12.3020728
  - ➢ See datasheet :
    https://apc.u-paris.fr/~prele/datasheet_AwaXe_v3.pdf
- **2021–2025 — AwaXe_vEM / v4 / v5 / v6 (ST 130 nm BiCMOS SiGe)**
  - ➢ Engineering models back-up - Long-term technology sustainability (?)
- **2025–2027 — AwaXe_TLH (last run AMS 350 nm BiCMOS SiGe)**
  - ➢ Redundant AMS implementation
  - ➢ Modular architecture (LNA separated from DACs)
  - ➢ TMR on digital
  - ➢ Offset compensations



5 Other Topics

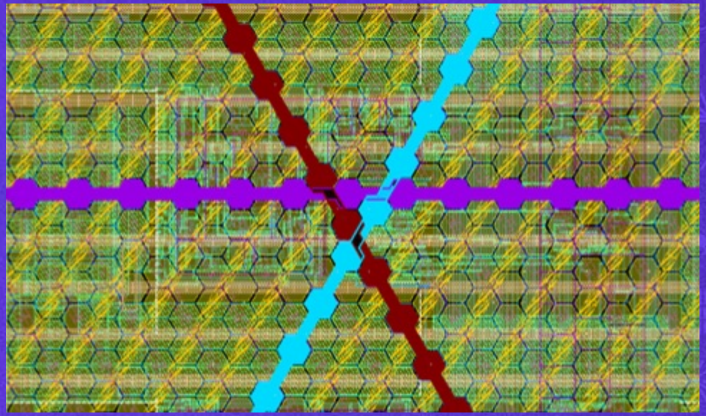
R&T BiCMOS Project

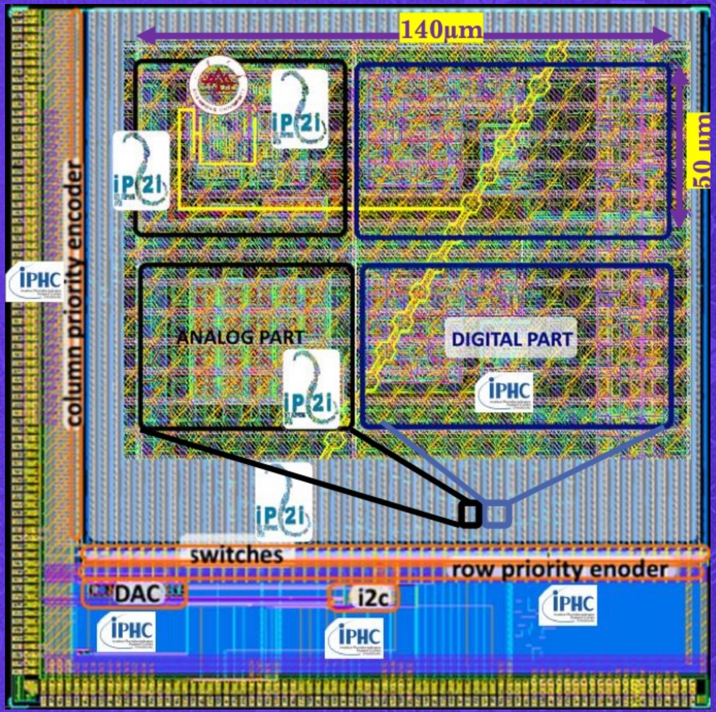
- **Applications:**
  - ➢ **cryogenic detectors, silicon detectors, TPCs and radio-frequency instrumentation**
- **Designed at APC, IP2I, SUBATECH**
- **Project objectives:**
  - ➢ **Identify and characterize several alternative BiCMOS/CMOS technologies with a node size > 130 nm**
  - ➢ **specific front-end applications requiring high dynamics, low flicker noise, high gain-bandwidth product, and performance at cryogenic temperatures**
  - ➢ **Long-term MPW production availability and low-cost access are also required**
  - ➢ **Perform cross-comparison of CMOS and BiCMOS technologies**
- **Main achievements:**
  - ➢ **IHP SiGe SG13S (130 nm) validated**
  - ➢ **XFAB XH180 (180 nm) under validation**
  - ➢ **Design and characterization of reusable analog building blocks**
    - **low-noise LNAs**
    - **Transimpedance amplifiers**
    - **Rail-to-rail CMOS amplifiers**
    - **Cryogenic thermometers**
    - **Current conveyor**
    - **Charge preamplifier**

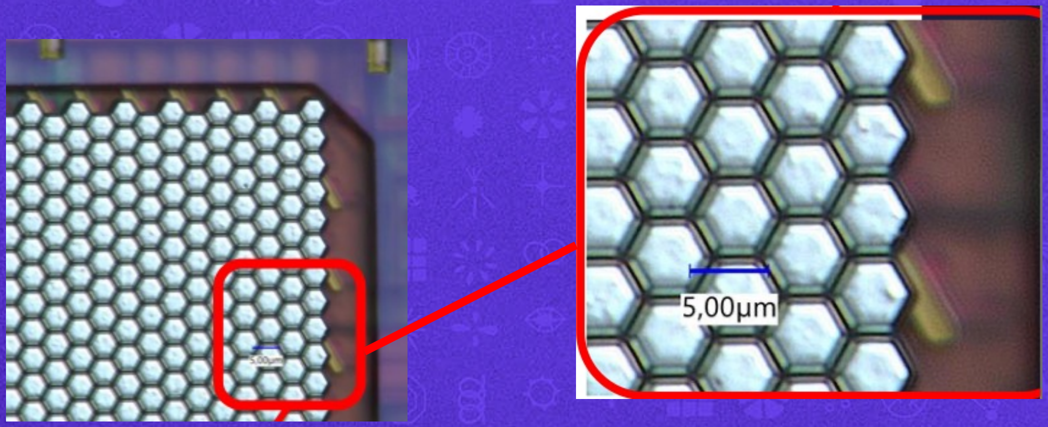


PICMIC: Tri-axis 5µm hexagon pixel-strip matrix

- Tower 180 nm
- IN2P3 members: IP2I, IPHC (for first prototype)
- ASIC dedicated to direct readout of MCP or NCP
- Matrix for PICMIC-0
  - 53 rows by 128 columns
  - Active readout cell
    - Size: 140x50 µm²
    - Channels: 2556
- Coincidence between a timing sensor and a position sensor
  - Time resolution: picoseconde
  - Spatial resolution: Micrometer
- 2nd prototype is submitted







6 Summary

Evolution of ASIC Design: Challenges and Collaboration

- Context
  - Similar presentation by C. Colledani at TWEPP 2014 (Aix-en-Provence)
- Key Challenges in Modern ASIC Design
  - Increased Complexity: ASICs are now more expensive, technically challenging, complex to design, and aggressive schedule
  - Shift in Design Ownership: The era of a single analogue designer creating an ASIC is over
- The Need for Multidisciplinary Teams:
  - Analogue designers
  - Digital implementation designers
  - RTL designers
  - Verification designers
  - Legal experts
  - Customs experts
  - Finance controller
  - Tests and characterisation experts → This is a real bottleneck

World is more complex

- Collaboration is key to addressing these challenges
  - MI2I is one building block of the response for CNRS Nucléaire & Particules
  - A broader response beyond CNRS Nucléaire & Particules is needed:

    Hub proposal by WG 7.7 of the DRD7 collaboration for example