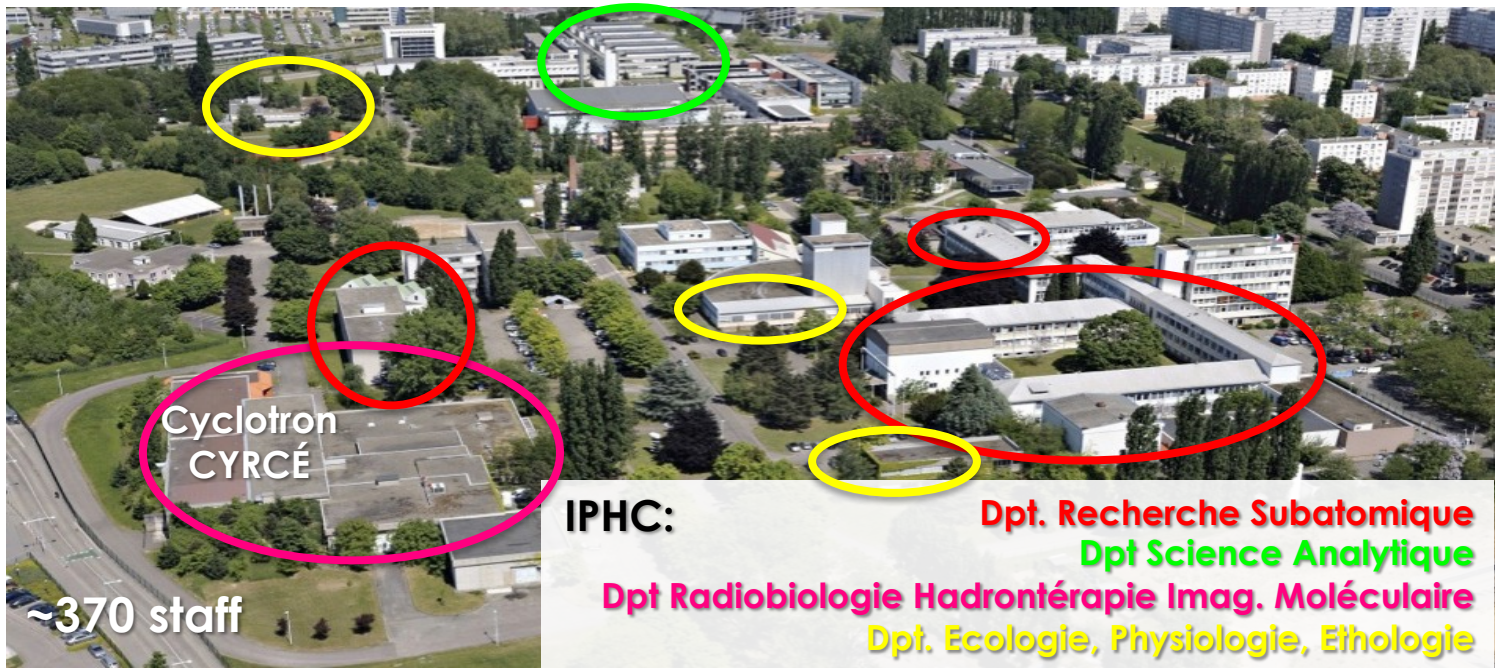
Welcome at the core-facility C4Pi

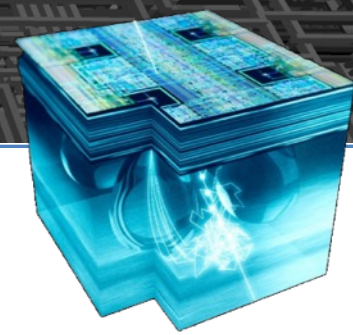


Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

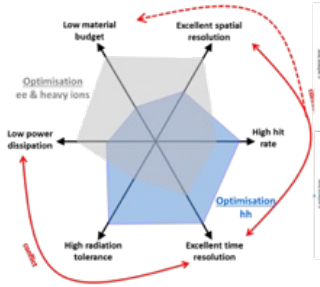
Université de Strasbourg

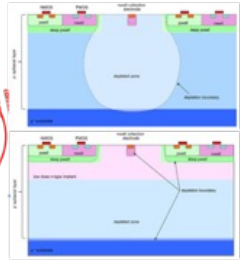
- → Expertise & missions
- → Team, infrastructure & network
- → Scientific drivers
- → Recent achievements
- → Focus on design / µ-technologies

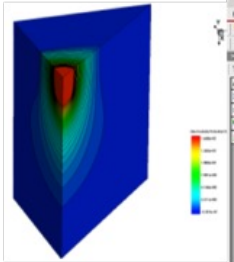
Expertise

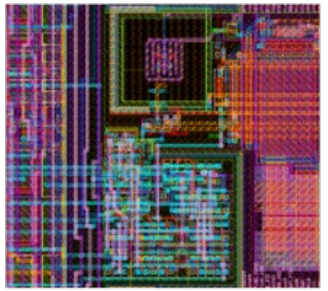


Monolithic Active Pixel Sensor in CMOS technology & detection modules







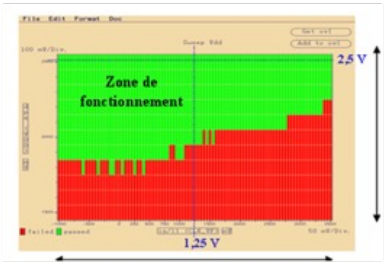


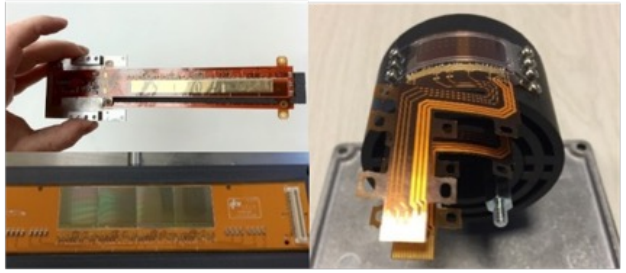
Requirements

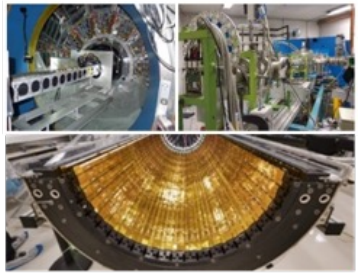
Charge collection

Front-End (analog+digital) / Functional blocs / Syst. architecture

Fab interface





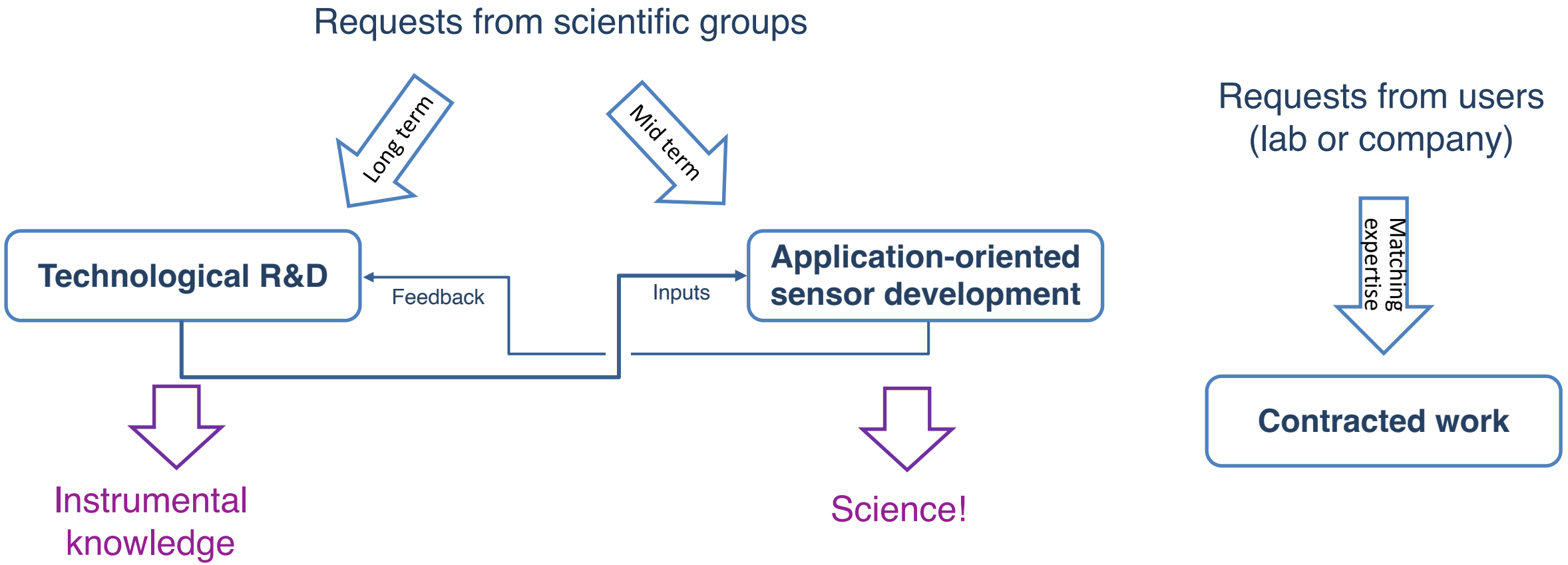


DAQ development & Tests

Integration

Construction
Installation

Missions

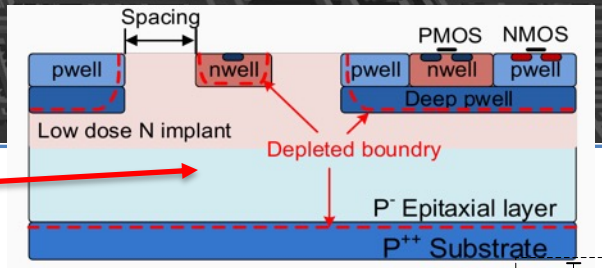


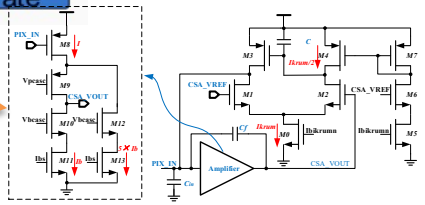
Within IN2P3
- share expertise on MAPS
- facilitate CMOS imaging technology access
- foster structured projects

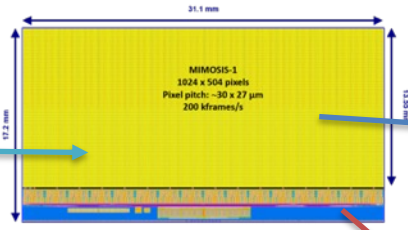
Expertise

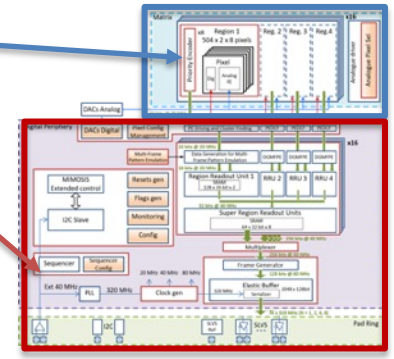
Sensitive layer	Collection node	
In-pixel analogue front-end	Bias monitoring	
Digital conversion	Digitisation	
Digital front-end & back-end	Read-out architecture	
Register Transfer Level	Top description	
Integration	Synthesis, Layout	
Design Rule Checking	Verification	
IP, component creation	Fabrication	
Test systems prototyping	DAQ, Control, data transfert systems design	
Board, flex, detection module design		
Hardware / Firmware / Software design	Test setup intergation	
IP validation	Functional tests	Physical characterisation
Laboratory tests	Beam tests	Production tests
Board/flex component population	tool design	
ASIC/wafer probe testing	Module validation	
Manual/automatic assembly	Bonding	2D/3D Metrology

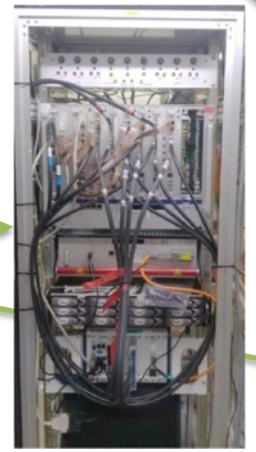
TOOLS & Foundry support

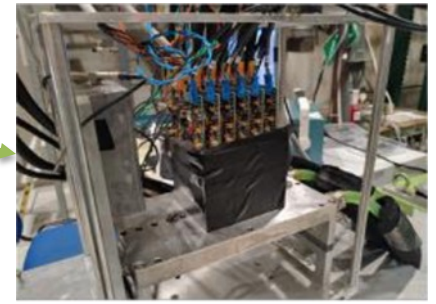


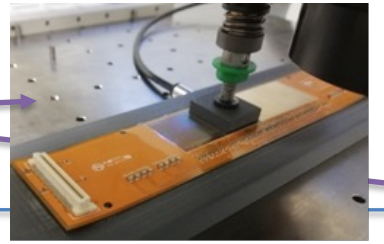


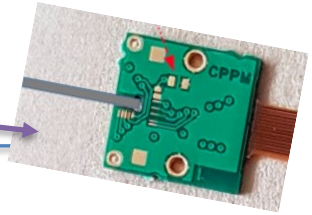




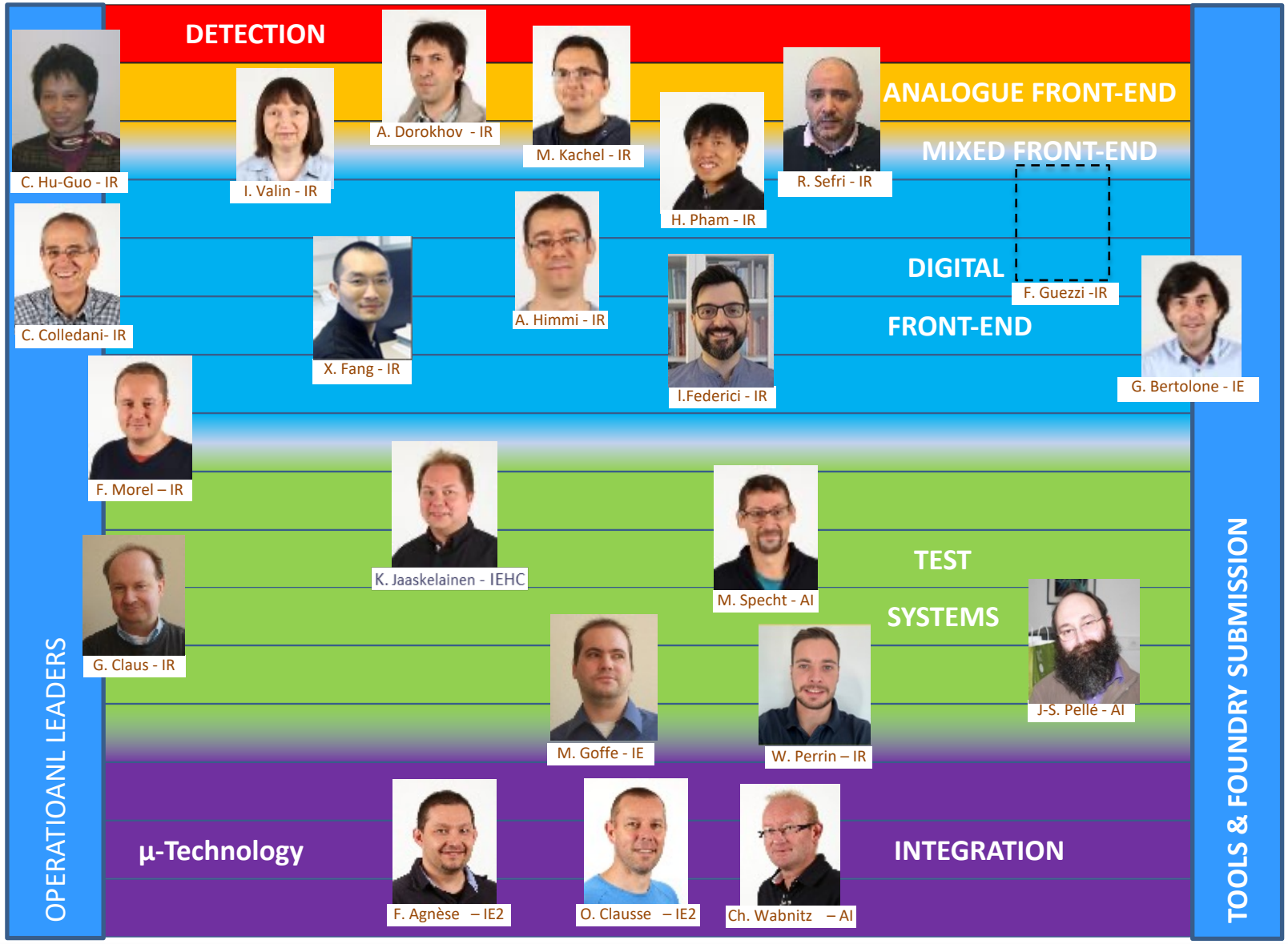








Team

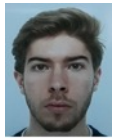


- **PhD**


J. Soudier – Doc3


C. Lemoine (CERN) – Doc2


H. Shamas – Doc1


E. Sacchetti – Doc1

- **Masters**

C. Antony, G. Morel, N. Vergara – M2 microelectronics

N. Favriou – M2 physics

- **Bachelors**

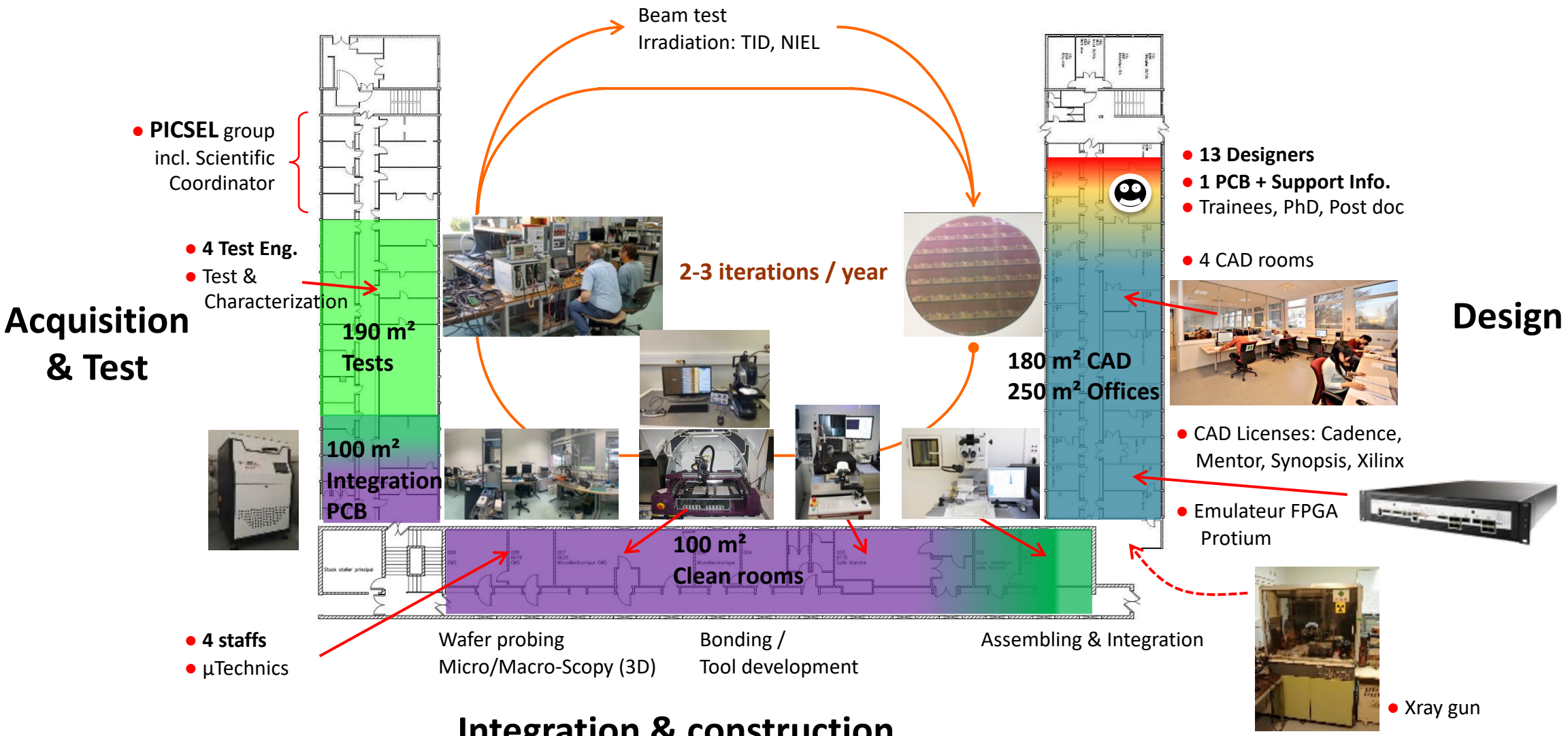
M. Grau – L2 electronics

- **Apprentices**

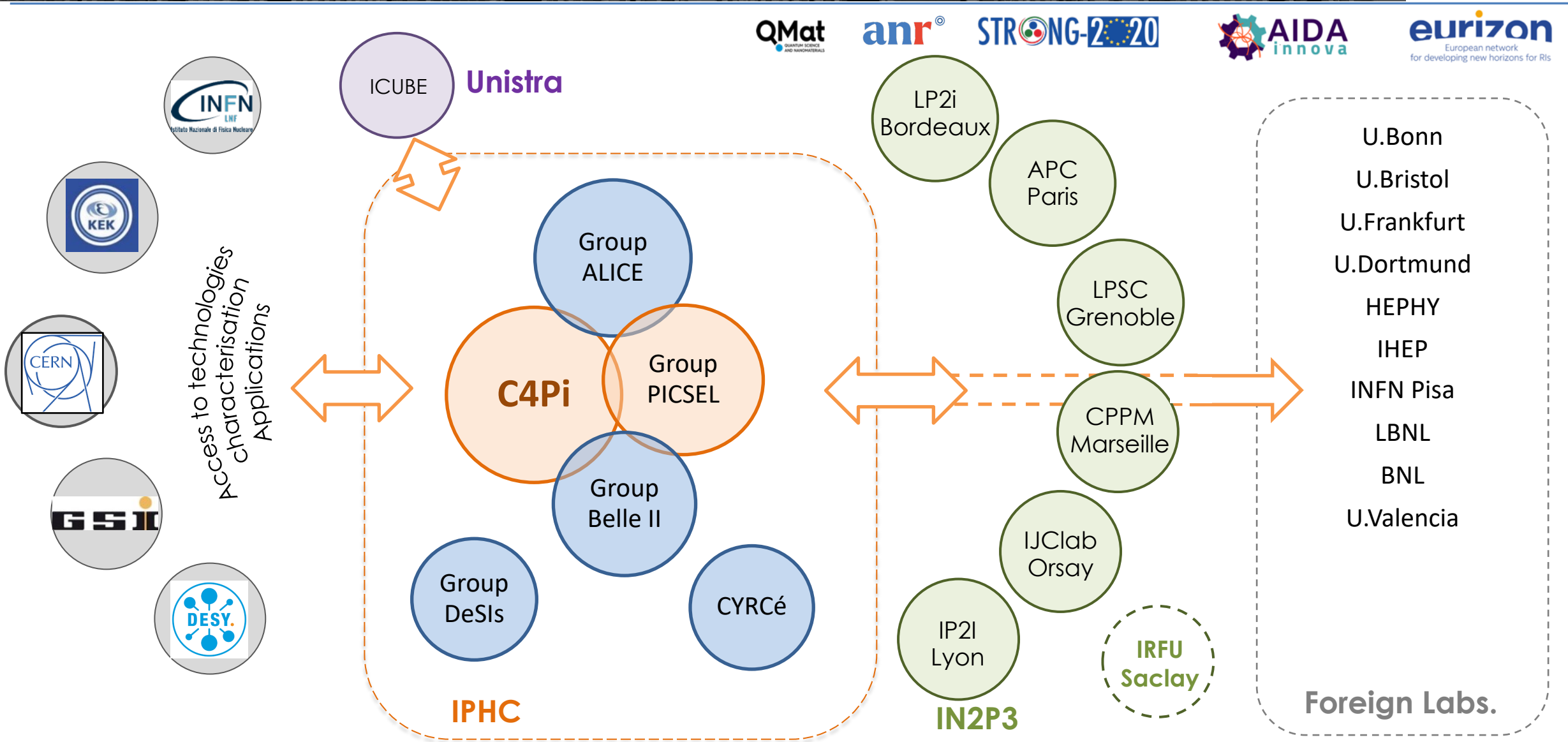

B. Faechtig – LPro1


T.Jacques – BUT3

Infrastructure



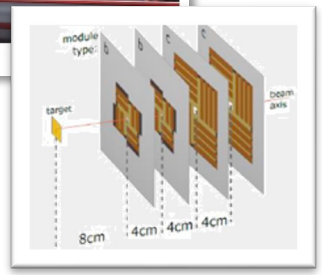
Network


QMat
anr
STRONG-2020
AIDA innova
eurizon
European network for developing new horizons for RIs
INFN
KEK
CERN
GSI
DESY.
ICUBE
Unistra
Access to technologies
characterisation
Applications
Group ALICE
C4Pi
Group PICSEL
Group Belle II
Group DeSIs
CYRCé
IPHC
LP2i Bordeaux
APC Paris
LPSC Grenoble
CPPM Marseille
IJClab Orsay
IP2I Lyon
IRFU Saclay
IN2P3
U.Bonn
U.Bristol
U.Frankfurt
U.Dortmund
HEPHY
IHEP
INFN Pisa
LBNL
BNL
U.Valencia
Foreign Labs.

Scientific drivers & commitments

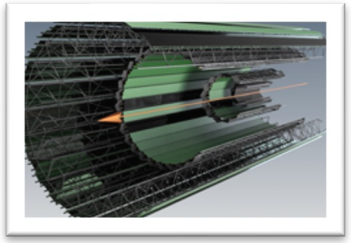
Future ee coll.
Update ~2026

- CE-65 & SPARC programs for vertex (VTX) and tracker
  - Vertex sensor to renew reference planes of beam telescope
  - Tracker sensor in synergy with ALICE3



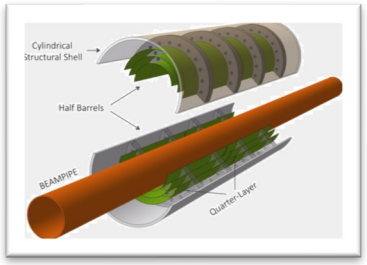
CBM
⟶ ~2028

- MIMOSIS & CE-18 programs for vertex (MVD)



Belle II
⟶ ~2029

- OBELIX program for vertex upgrade(VTX)



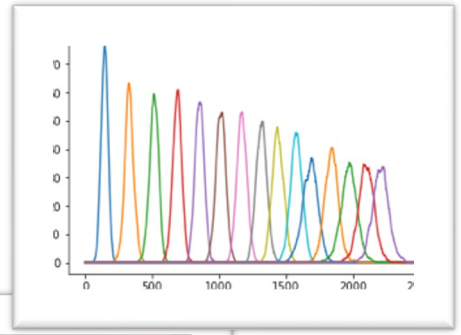
ALICE
⟶ 2027
⟶ 2033

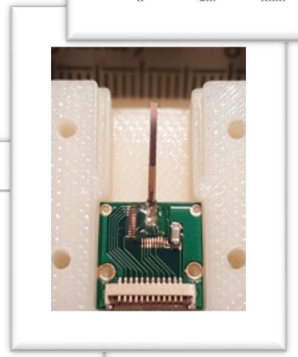
- MOSS/MOSAIX program for new vertex ITS3
- Common R&D CE-65 for tracker ALICE3

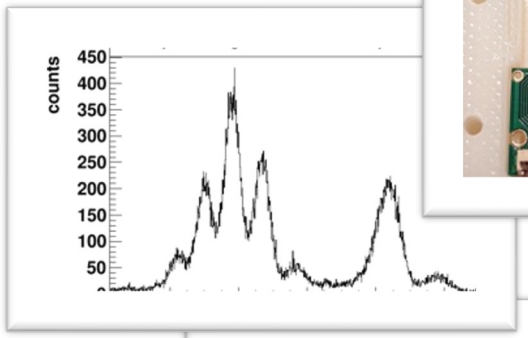
Sensor comparison

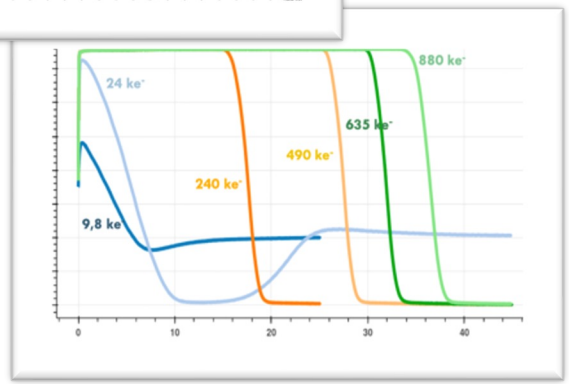
Scientific drivers & commitments

Applications









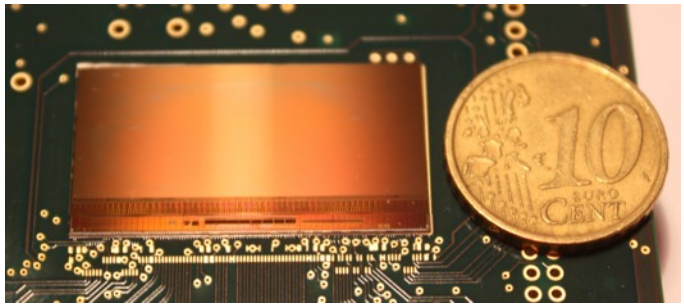
- **Monolithic-Imager**
  multi-purpose with analogue output: dosimetry/spectroscopy
  back-side illumination for sensitivity to very-low penetrating quanta

- **TIIMM / TIXX**
  Ion tracking & identification (through ΔE)
  Signal digitized (ToT) with 10^4 dynamic

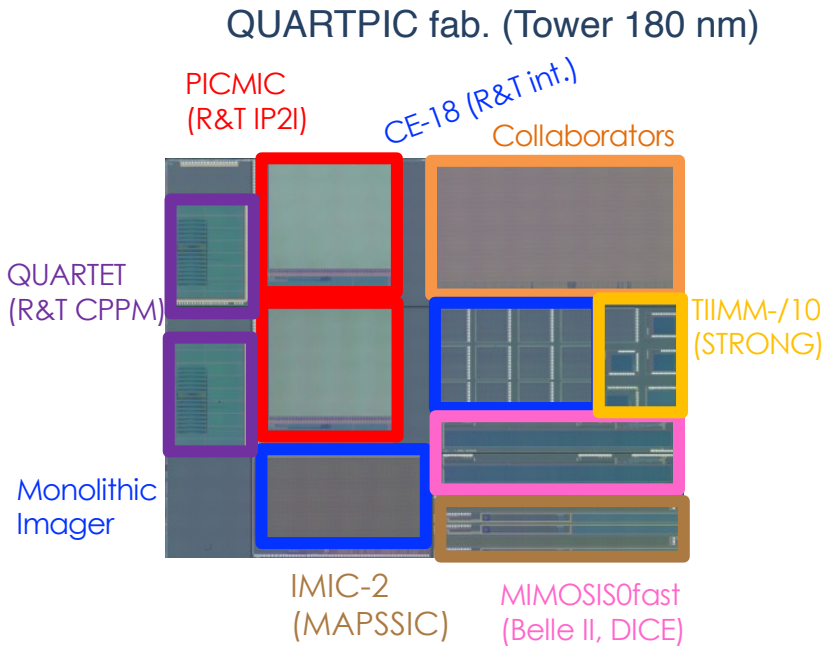
- **IMIC**
  ß imaging in awake rodents brain
  ALPIDE made a needle

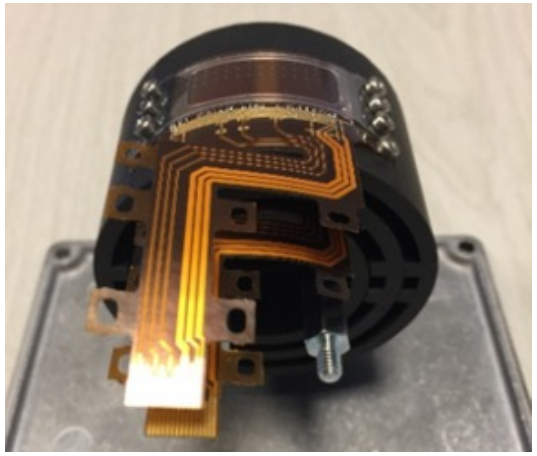
- **MIMOSIS**
  – Various applications possible in spectroscopy

Recent achievements

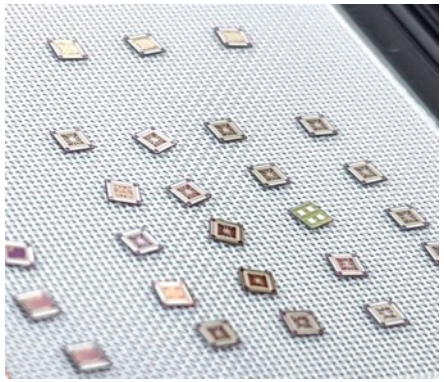


MIMOSIS sensor

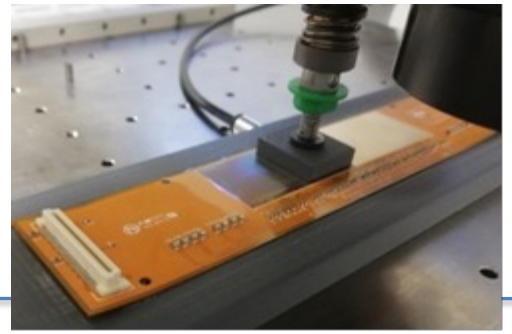




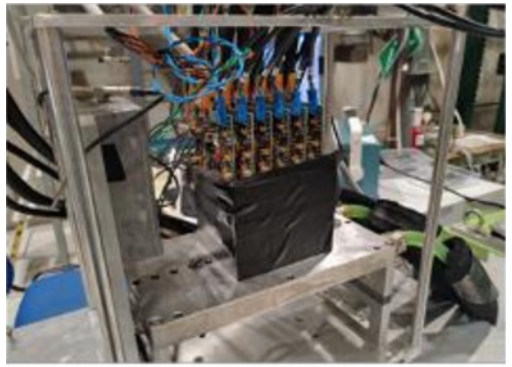
Bended sensors



New TPSCo 65 nm proc.

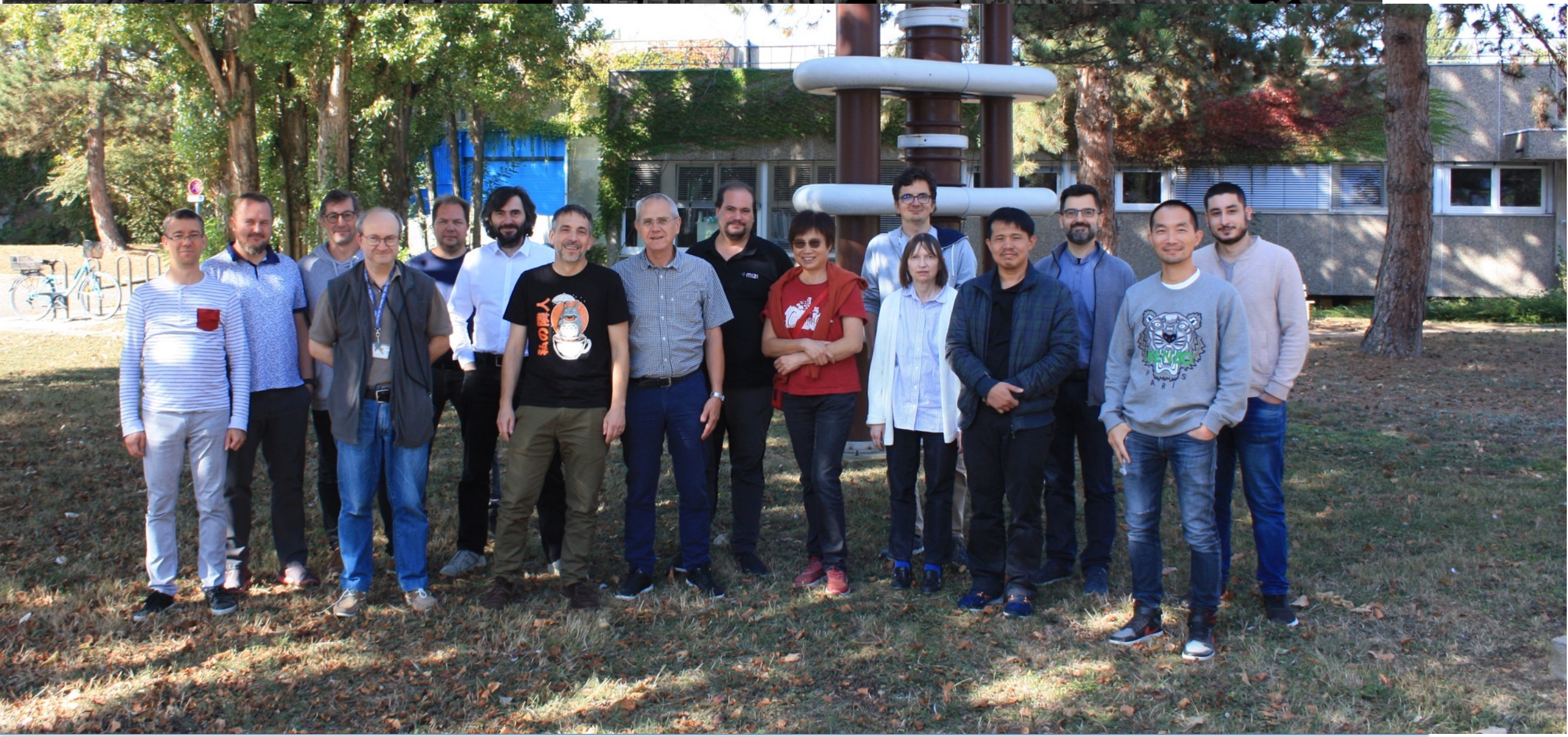


FOOT
module



New beam telescope

Part of the Strasbourg technical team developing MAPS (Oct.23)



Focus on micro-technology activities

CMOS technologies

- Maintaining access to processes costs resources → **limited nb of CMOS processes** handled at C4Pi
- C4Pi strategy: **mainstream processes** → fabrication robustness guaranteed

MIMOSA-1, 1999, AMS 600 nm

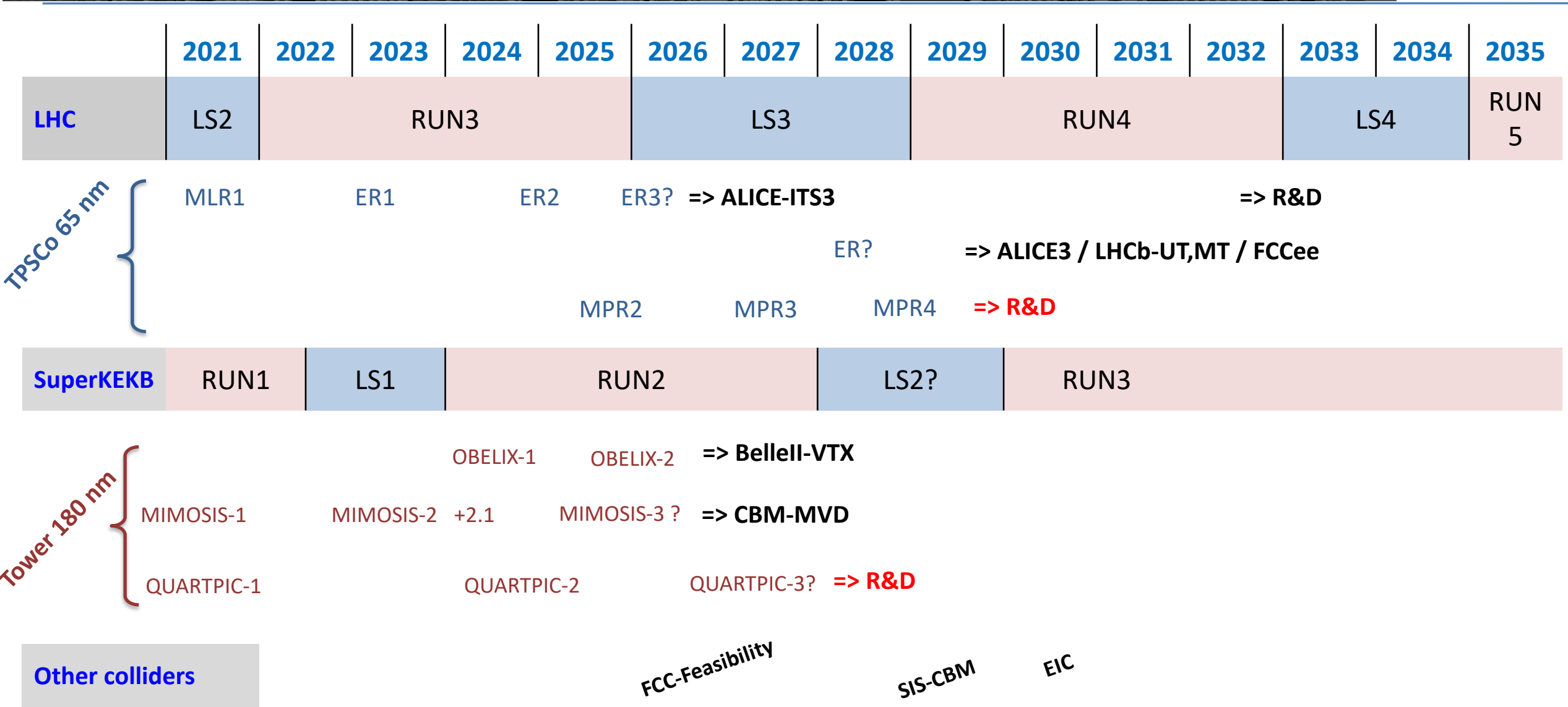
- AMS 350 nm
  - **2004**-2011
  - MIMOSA-26
  - MIMOSA-28
- XFAB 350 nm
  - ALPHABeast for DeSis 2022

- Tower 180 nm
  - Since **2011**
  - CE-18 + others for R&D
  - ALPIDE for ALICE-ITS2
  - MIMOSIS for CBM-MVD
  - OBELIX-1 for Belle II-VTX
  - TIIX for STRONG EU-project
- TPSCo 65 nm
  - Since **2020**
  - MOSS for ALICE-ITS3
  - CE-65 series for R&D
  - **Main choice for ECFA-DRDs**

Current processes

C4Pi proposal to ECFA-DRD7 for 180 nm contact-point (2024-27)

Roadmap on Tower technologies



Internal technological R&D

Scientific applications ⟶ R&D @ C4Pi with general trend = maximise CMOS-MAPS potential

- R&D = upstream advances (+ PhD / Master student)

Amplification in silicon

- Low gain <10, get rid of analogue front-end

=> Reduce pixel pitch, reduce power dissipation, increase sensitivity

- Start with Tower 180 nm, then switch to 65 nm
- Programmed financed by French ANR / DRD3: Tower, Icube, CPPM, CERN

Read-out architecture

- Explore asynchronous logic (entirely event driven)

=> Increase versatility (hit-rate, area), decrease power

- Within TPSCo 65 nm R&D: DRD3/DRD7

Intelligence on sensor

- Embedded processor and artificial intelligence

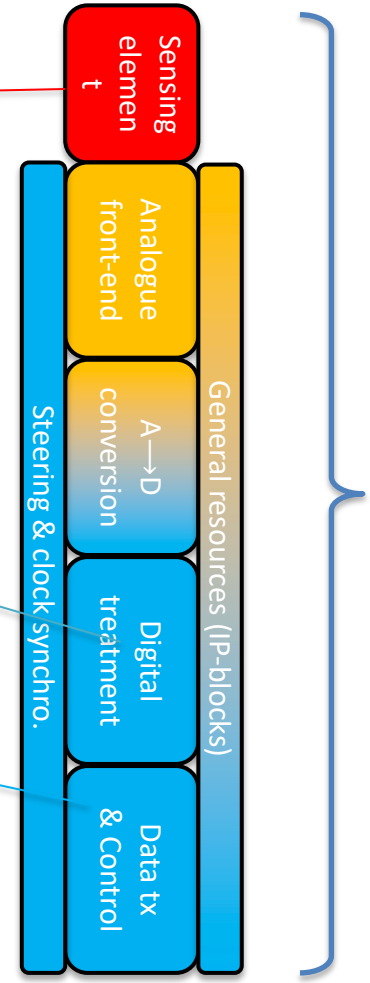
=> Data reduction, ease control/calibration against granularity curse

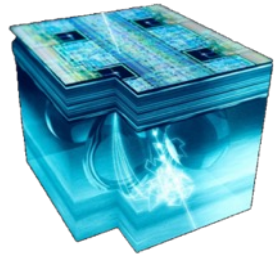
Prototyping

- Develop full simulation chain from Physics to Final performance

=> Prediction at early stage of development for better design choices

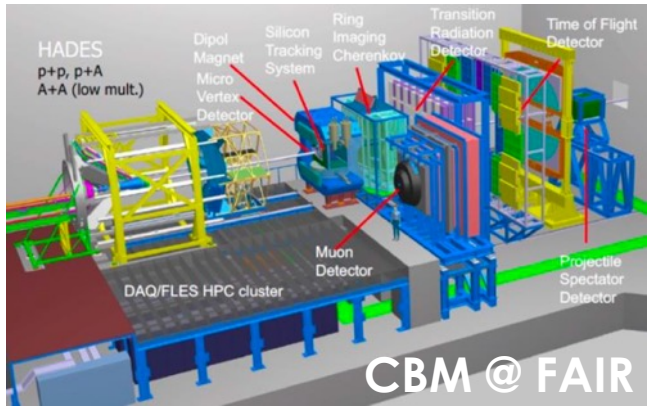
- Within DRD7





Direct application: CBM-MVD

- ## MIMOSIS sensor
  - Match CBM vertex requirements & achieve step forward / Higgs-Factories
    combine position res. (~5µm) & low-power (<100 mW/cm²) & high hit-rate (>50 MHz/cm²)
  - Specificity of CBM collisions: 100 kHz Au+Au @ 11 AGeV and 10GHz p+Au @ 30 AGeV
    => large hit-rate fluctuation & operation in vacuum

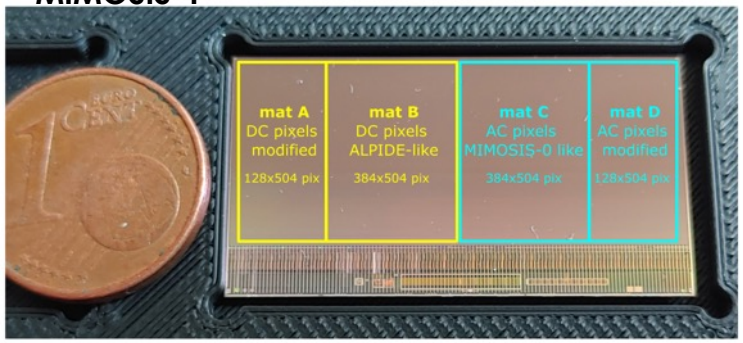


Full specs for MIMOSIS sensor

Position resolution	~5 µm
Time resolution / continuous r.o.	~5 µs
Power dissipation	<100 - 200 mW/cm²
Hit rate (average/50 µs peak)	20/70 MHz/cm²
Material budget / layer	0.05 % X_0
Operation temp in **vacuum**	- 40°C to +30°C
Radiation* (non-ionizing)	~ 7x10¹³ n_{eq}/cm²
Radiation* (ionizing)	~ 5 Mrad
Radiation gradient	100 %
Heavy Ions-tolerance	10 Hz/mm²

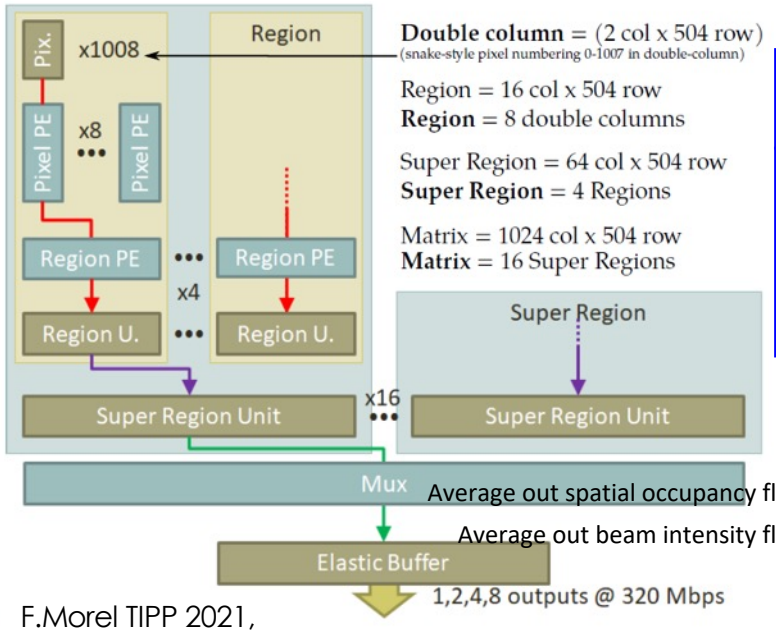
* No safety factor

MIMOSIS-1



Parameter	Value
Technology	TowerJazz CIS 180 nm
Epitaxial layer	~25 µm thick, > 1kΩ·cm
Sensor thickness	300 µm or 60 µm
Pixel size	26.9 µm × 30.2 µm
Pixel array	1024 × 504 pixels
Sensitive area	≈4.2 cm²
Array readout time	≈5 µs
Power consumption	< 100 mW/cm²

Full digital on top design



ALPIDE-like matrix
Modified process
10.1016/j.nima.2017.07.046

Average out spatial occupancy fluctuation

Average out beam intensity fluctuation

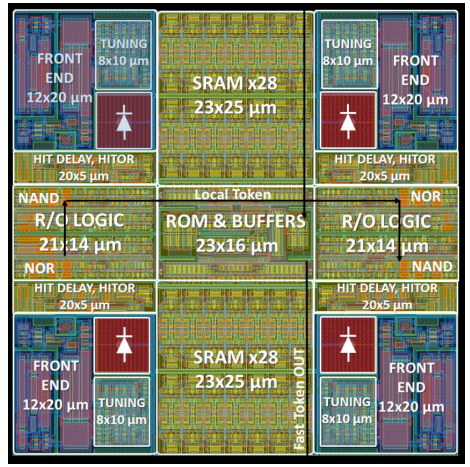
F.Morel TIPP 2021,
https://indi.to/Vf5Vs

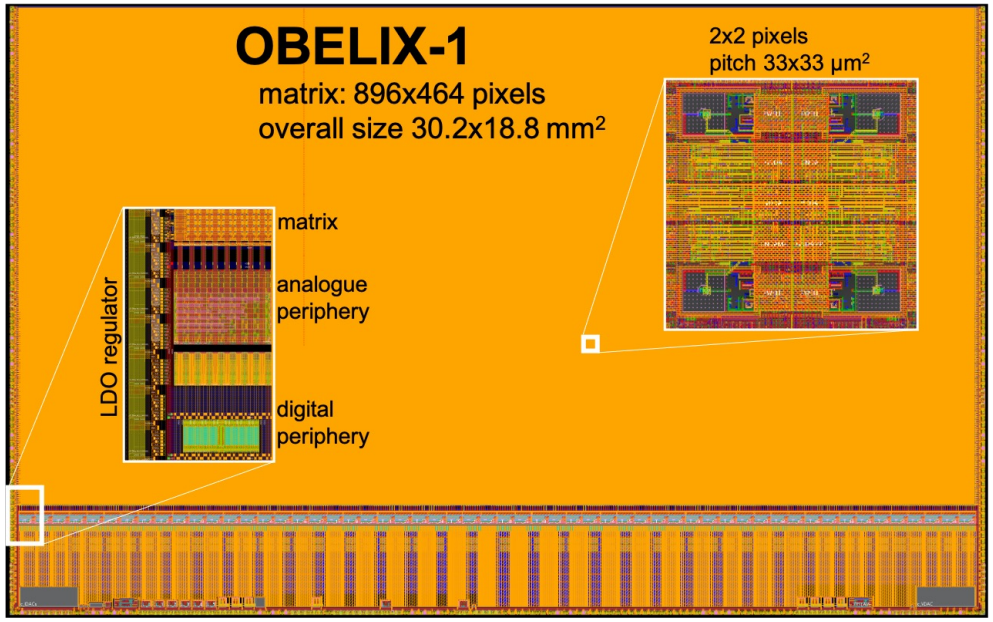
- ## MIMOSIS sensors
  - MIMOSIS-1 (2020)
  - MIMOSIS-2 (submitted 2022)
  - Final MIMOSIS-3

Direct application: Belle II-VTX

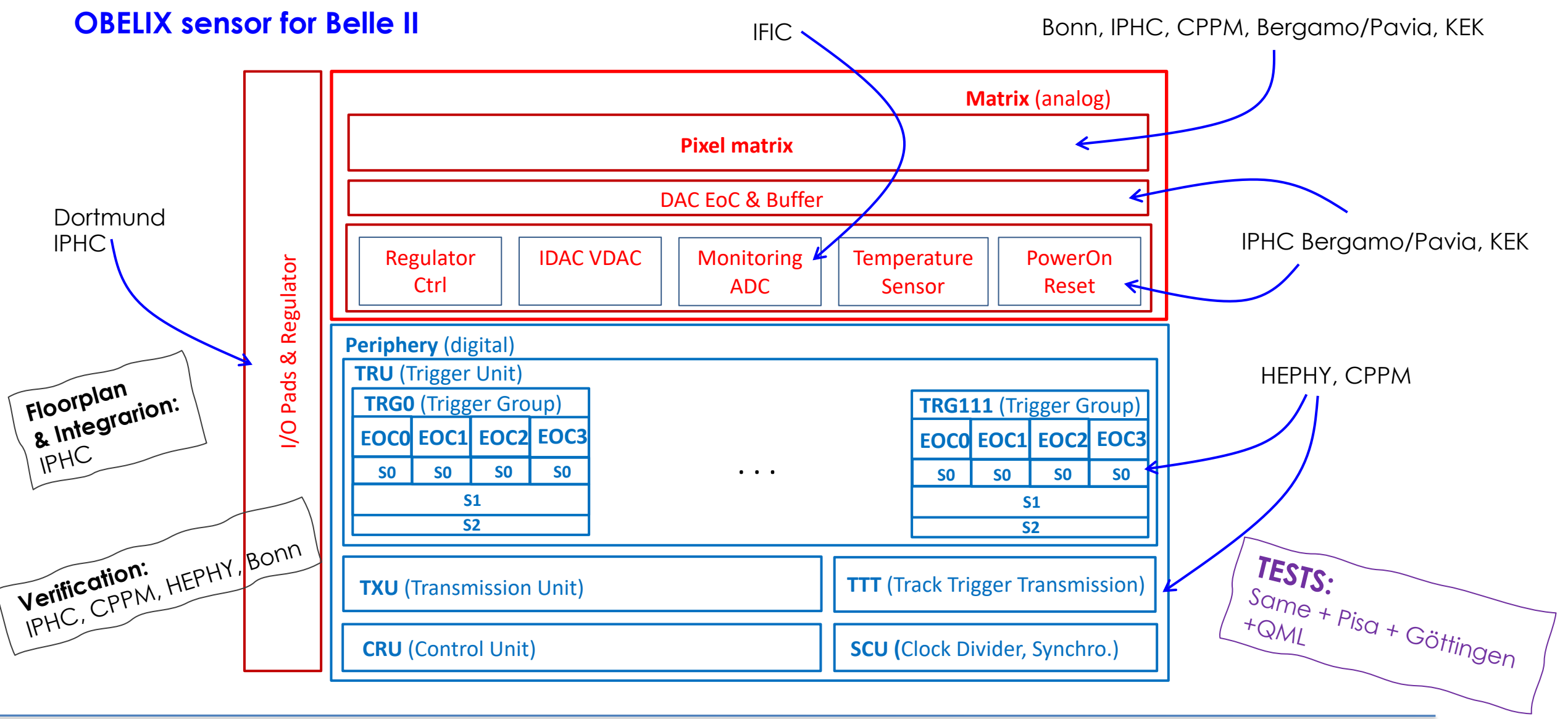
- OBELIX sensor
  - Dedicated sensor for the upgrade of the VTX
  - Based on TJ-MONOPIX-2 (Tower 180 nm)
    - C. Bespin VCI 2022 https://indi.to/5BR2P
  - Collaboration between
    - Bergamo, Bonn, Dortmund, Gottingen, KEK-Tsukuba, Marseille, Pavia, Strasbourg*, Valencia and Vienna
  - Specifications
    - Larger matrix / TJ-MONOPIX2: 896x464 pixels
    - Triggered @ 30 kHz with up to 10 µs delay
      - ✓ Maximum hit rate 120 MHz/cm2
    - Time binning 100 ns
      - ✓ Additional precision ~3ns @ low multiplicity (~10 MHz/cm^2)
    - LDO regulator for voltage supply
    - Power budget 170-200 mW/cm^2
    - Exploratory feature to input trigger
      - ✓ Fast ouput (~100 ns) with coarse granularity

TJ-Monopix2 pixel





Example of distributed design



OBELIX design status

Analogue

- Matrix quasi-complete
  - Operating Std and HV flavours together:
    Hung working on duplicating biases
  - Pulse signal amplitude:
    new buffer from Kishishita to be integrated in layout soon
  - Test columns (1 column per flavour):
    Pavia simulating to introduce new monitoring points
  - General monitoring:
    ADC by Jose moving well (could be in time)
    multiplexing by Hung well
- LDO
  - Real person power issue => being worked on

Simulation

- Lot of work done by Roua
- Need a dedicated meeting to "wrap-up"

Digital

- Quasi-complete since some time wrt code
  - Still adaptation needed with
- Big think now is implementing the layout
  - Danwei's work

Floorplan

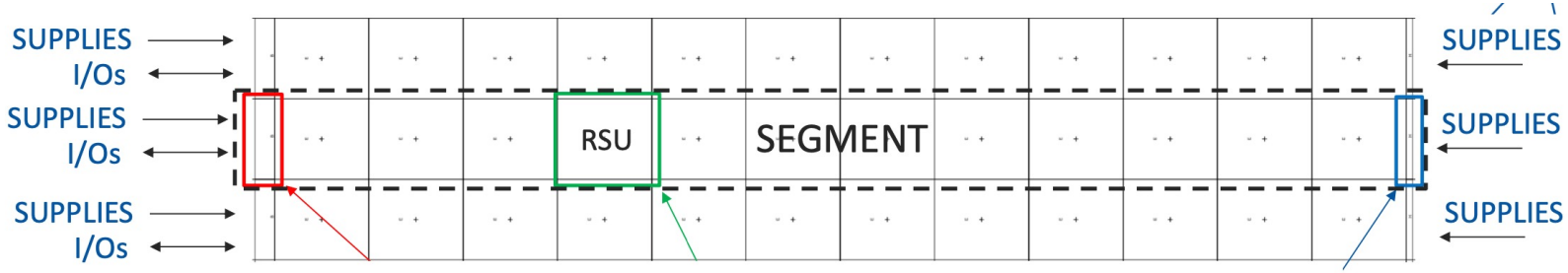
- Continuous effort by Kader
- Will be the last part after the rest is done

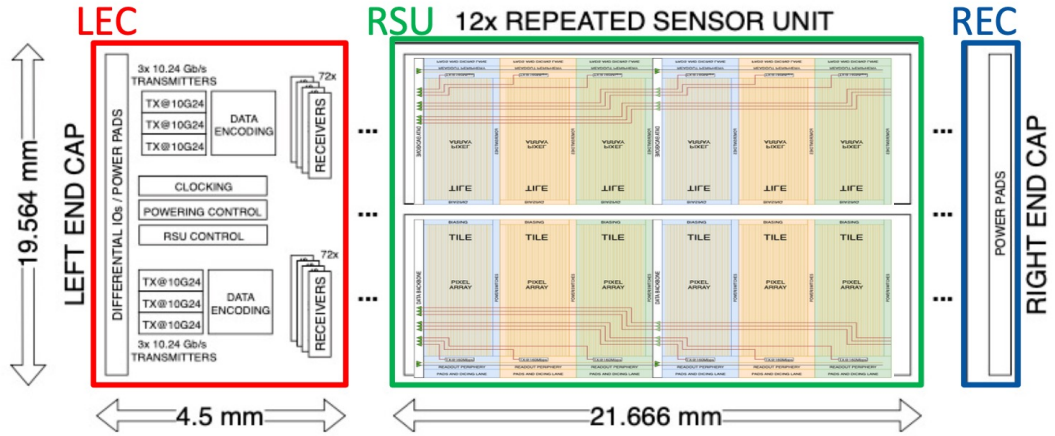
Verification

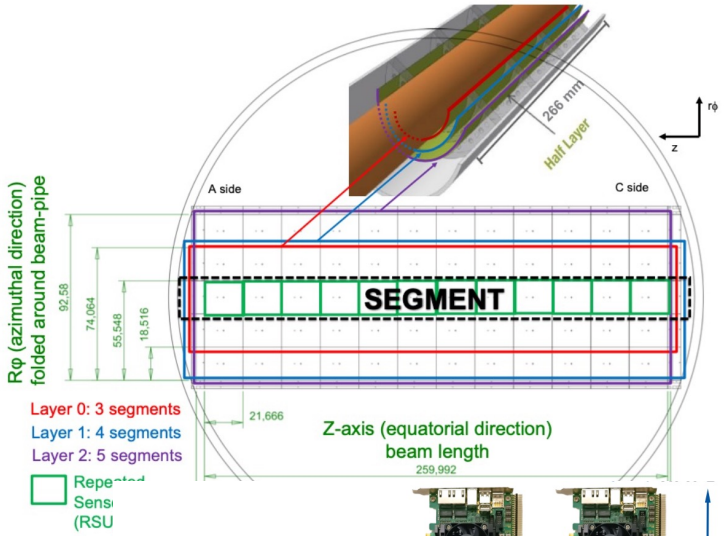
- UVM (Luca):
  - first step on registers achieved
  - Top-funcitonality on-going
- Cocotb:
  - Max has initial tests
  - Possibly need manpower to extend them

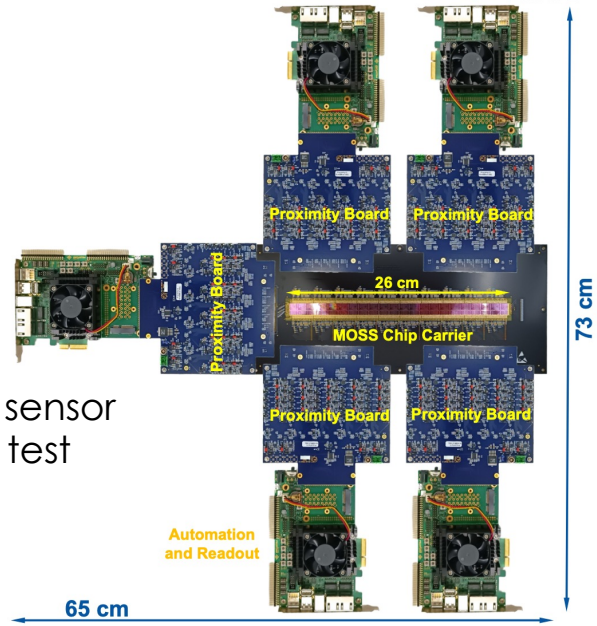
Direct application: ALICE-ITS3

- MOSAIX sensor
  - Dedicated sensor for ITS3
  - Based on MOSS (TPSCo 65 nm)
    - developed with MLR1-ER1
  - Collaboration lead by CERN-ALICE
    - C4Pi have the responsibility of pixel array integration









MOSS sensor under test

DRDs prospect for sensors in TPSCo 65 nm

- Already a lot known from MLR1+ER1 runs
  - Techno performance with CE-65, APTS, DPTS
  - Still completed this year (including tests at AR-TestBeam)
  - Yield of stitched sensor MOSS
- Additional prototypes in ER2
  - APTS with pitch up to 50 µm
  - SPARC with asynchronous read-out
  - 1st version of MOSAIX

	ALICE ITS3	ALICE3 vertex	FCCee vertex	ALICE3 OT-ML	LHCb UT	FCCee tracker
Data taking in	2029	2035	>2040	2035	2035	>2040
Spatial res. (µm)	~5	2.5	3	10	pitch O(30)	10
Mat. budget (%X0)	0.05	0.1	0.15	1	0.3?	<1?
Hit rate (MHz/cm^2)	~10	100	50	0.06-1.7	160	<10
Time figure (ns)	1000	100 (RMS)	1000	100 (RMS)	O(1)	10^2-10^3
Power (mW/cm^2)	20	70	20	20	100-300	50
Rad.hard. (kGy) (n_{eq}/cm^2)	3 3×10^{12}	3000 1×10^{16}	20 5×10^{11}	2 - 50 ~6×10^{12} – 2×10^{14}	2400 3×10^{15}	20 5×10^{11}

DRDs prospect for sensors in TPSCo 65 nm

Fine pitch

- Main goal = position resol. ≲3 µm
- Other features:
  - Timing merit 1 to few 100 ns
  - Hit rate range 50-100 MHz/cm^2
  - Power < 70 mW/cm^2
  - NIEL tolerance 10^{14} n_{eq}/cm^2 (?)
  - Size not critical (reticule OK)
- Realisation:
  - Pitch 15-20 µm
  - Binary output
  - Read-out architecture to be decided
- Projects interested:
  - Future e+e- colliders (>> 2040)
  - ALICE-3 IRIS layers inside beam pipe (2033)
  - test-beam reference plane (2028)

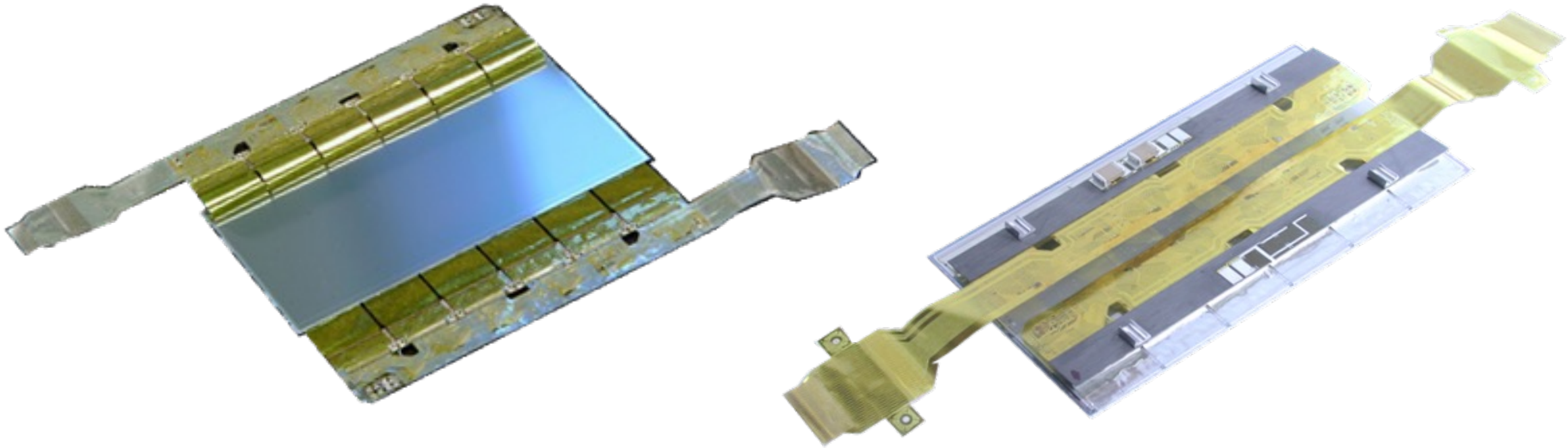
Tracking over large area

- Main goal = power dissipation ~20 mW/cm^2
- Other features:
  - Timing merit 1 ns
  - Position resol. 10 µm
  - Hit rate & Radition tolerance => large range
- Realisation:
  - Pitch 25 to 30 µm
    - 50 µm made from merging 4x 25 µm pixels
  - Digitised output (3-6? Bits) like ToT or very small ADC
  - Optional: time resolution 10-100 ps with TDC outside matrix
  - Asynchronous read-out architecture
    - Should provide 25 ns tagging
- Project interested:
  - Future e+e- collider (>>2040)
  - ALICE-3 tracker (2033)
  - LHCb upstream tracker (2033)
  - Fixed target experiments
  - Calorimeters

Focus on test & setup activities

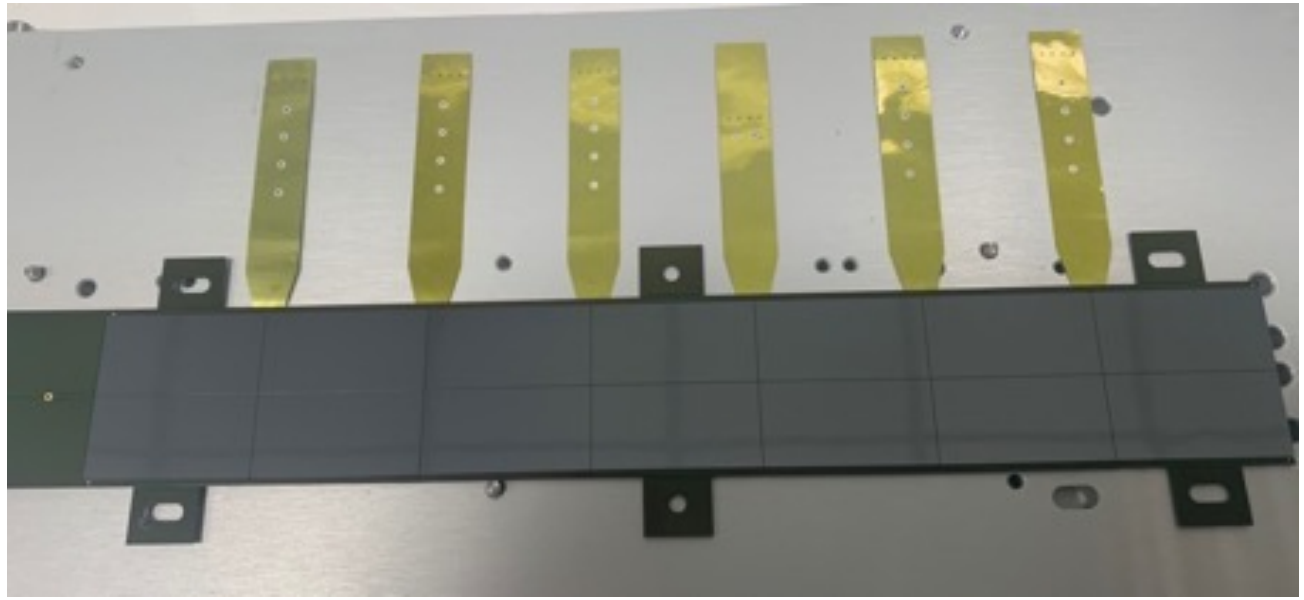
Focus on integration activities

ALICE ITS1 production: 200 modules in 2005

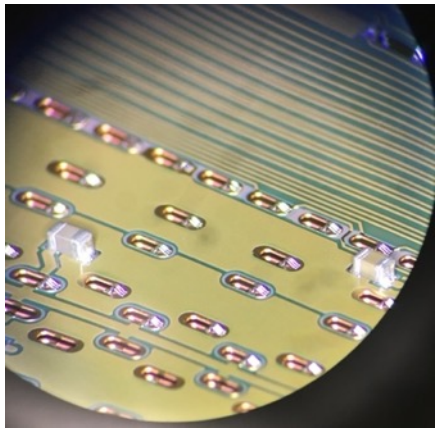


Double Sided Silicon Strip Detector (DSSD) 6x128 strips / side
=> TAB bonding used to wrap ASIC ontop of sensors

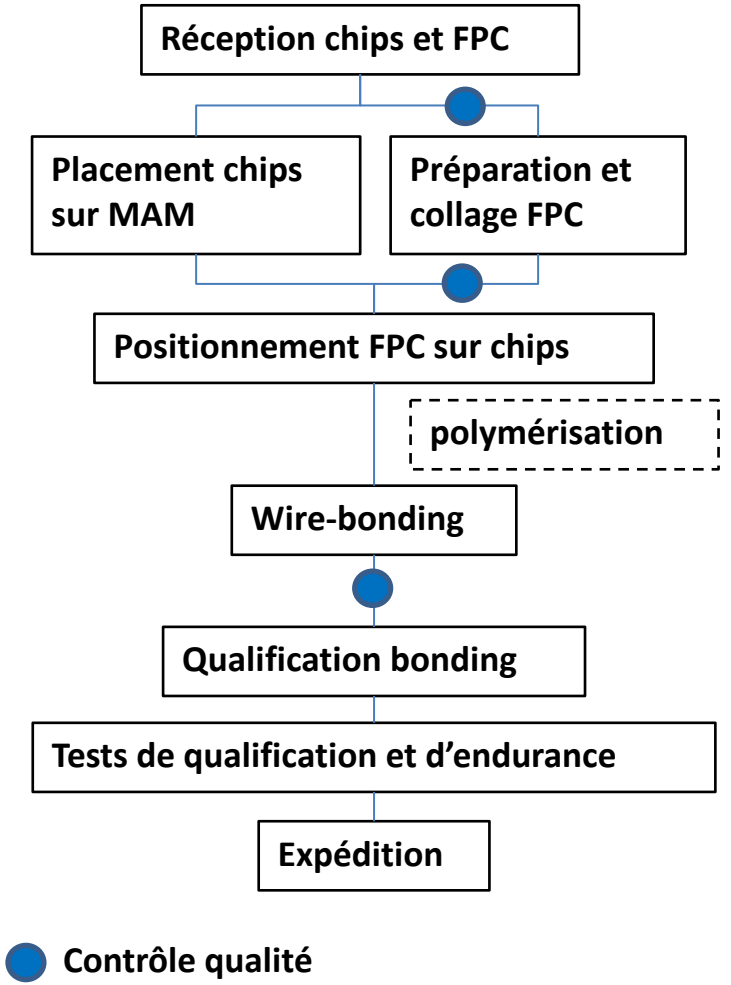
ALICE ITS2 production: 500 modules in 2017-19



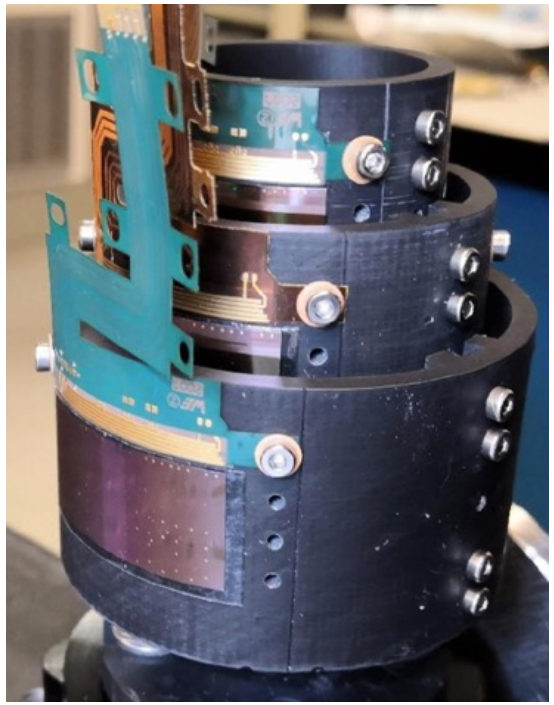
2 rows of 7 ALPIDE sensors (15x30mm, ép. 100um)



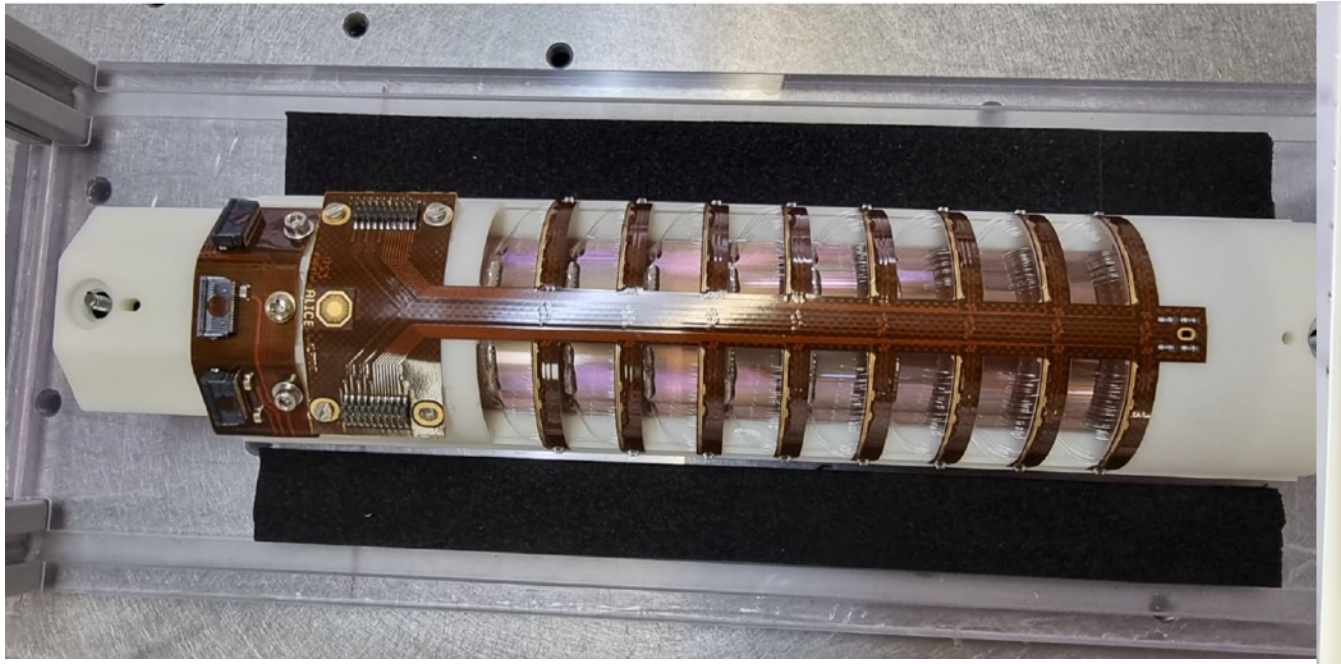
3 bonds / pads



ALICE R&D ITS3 since 2019: bended sensors



1er bended mini-tracker
Radii: 18, 24, 30mm



2x9 capteurs de 15x30mm, épaisseurs 50um
montés sur exosquelette
Rayon de courbure de 18mm.
En cours : ép. 30um

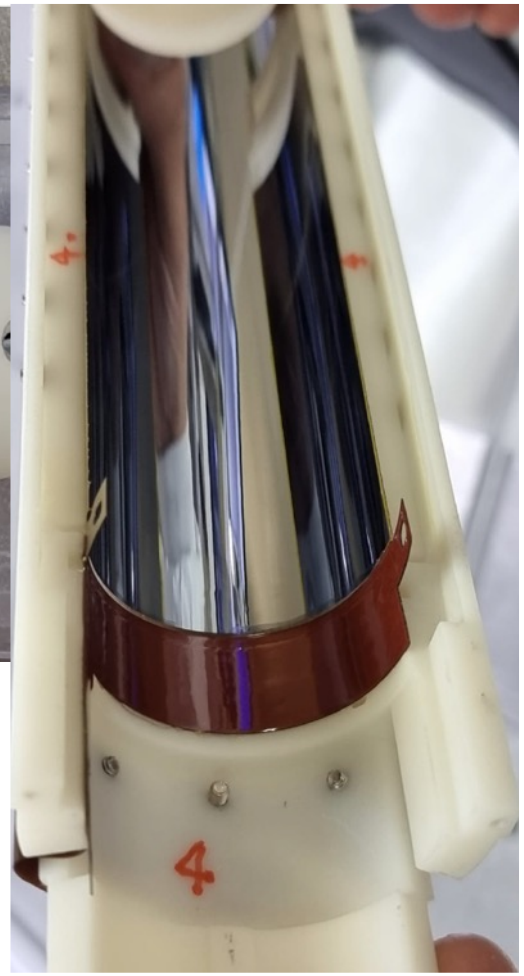
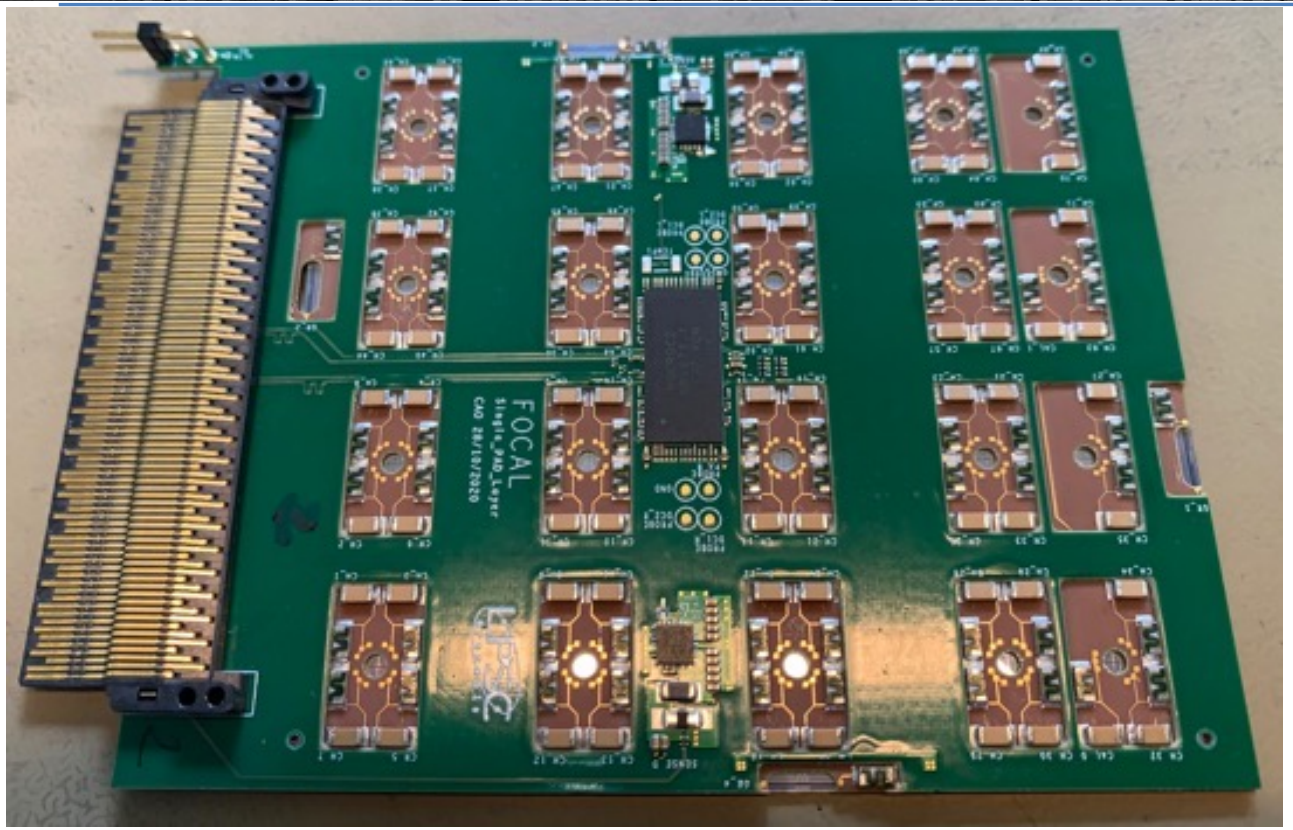


Illustration of specific bonding service



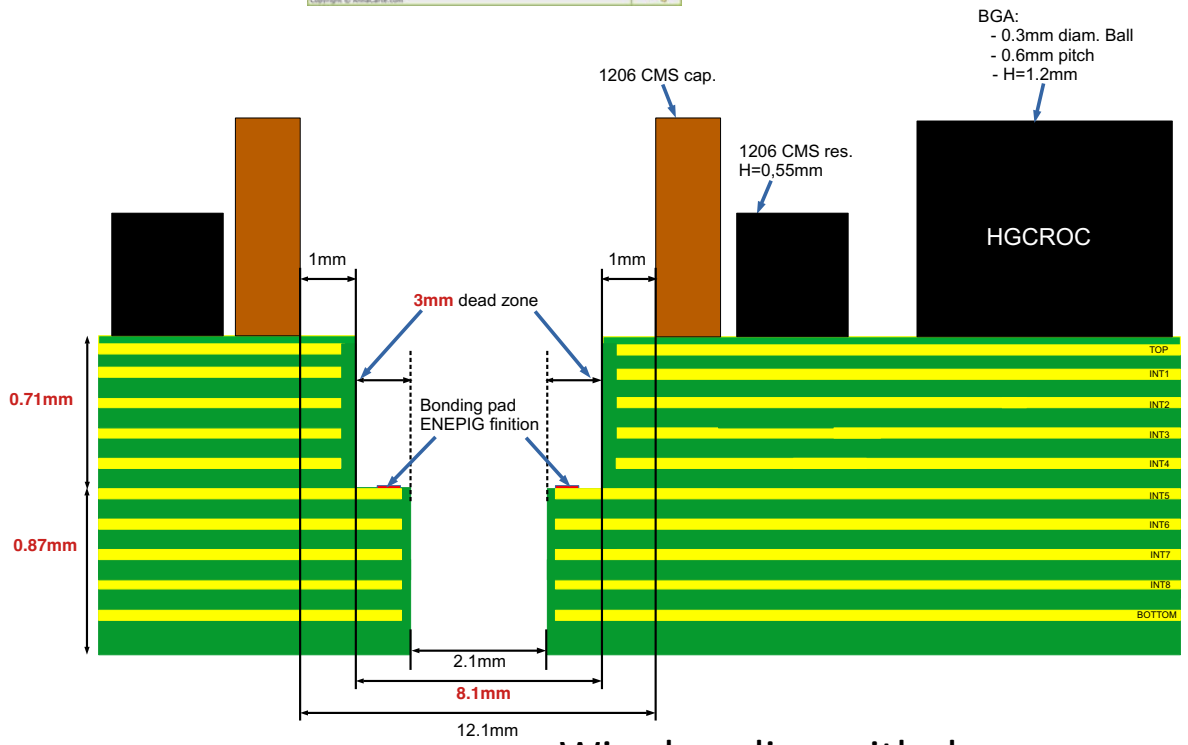
<u>LPSC</u> – ALICE FoCAL

Détecteur Silicium : 9x8 pixels de 1cm x 1cm

Démonstrateur : 18 cartes

Final ? : 396 PCB de 45 x 8 (5 capteurs) (soit 1980 capteur silicium).

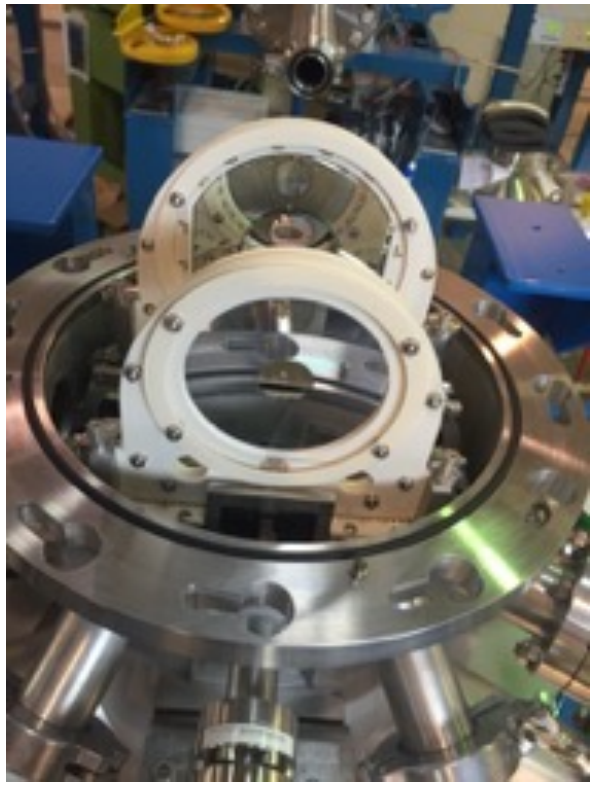
Strasbourg : EOST, ICS, I3
Bordeaux : IMS
Clermont- Fd : LPC
Grenoble : LPSC
Lyon : IPNL
Marseille : LAM
Nantes : SUBATECH/IMT
Paris : OMEGA, IPNO



Wire bonding with deep-access

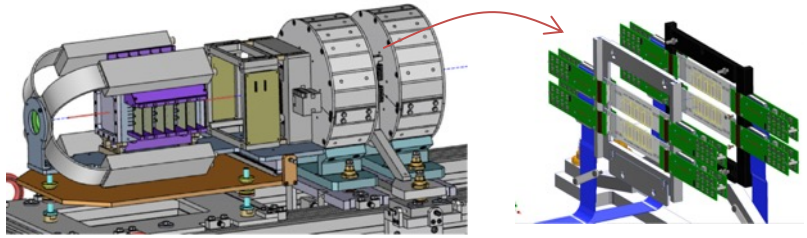
Other achieved or on-going projects

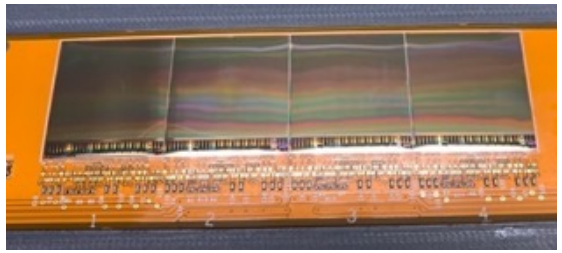
STELLA : 2015 (DSSD for nuclear physics)



Collab. : GANIL, IJCLab, Univ. York (UK), Univ. Surrey (UK), Obs. Genève

FOOT (INFN): 2021-23
Measurement of nuclear cross-sections of interest for Carbon-therapy



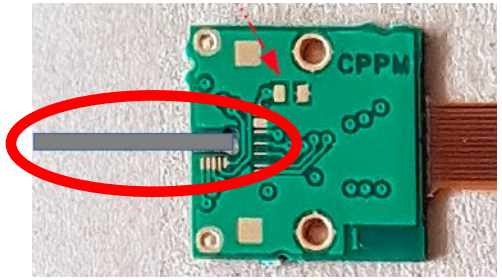


Module de détection
Capteur MIMOSA 28 20 x 20 mm
Epaisseur 50um

Cross-section module de détection

MAPSSIC: 2023
Implantable ß-probe for neuro-imaging

IN2P3 : CPPM, IJCLAB ; INSB : Lyon Neuroscience, NeuroPSI



2 capteurs CMOS (12x0,65mm, ép. 200um) collés dos à dos.