Scientific council
27/06/2023

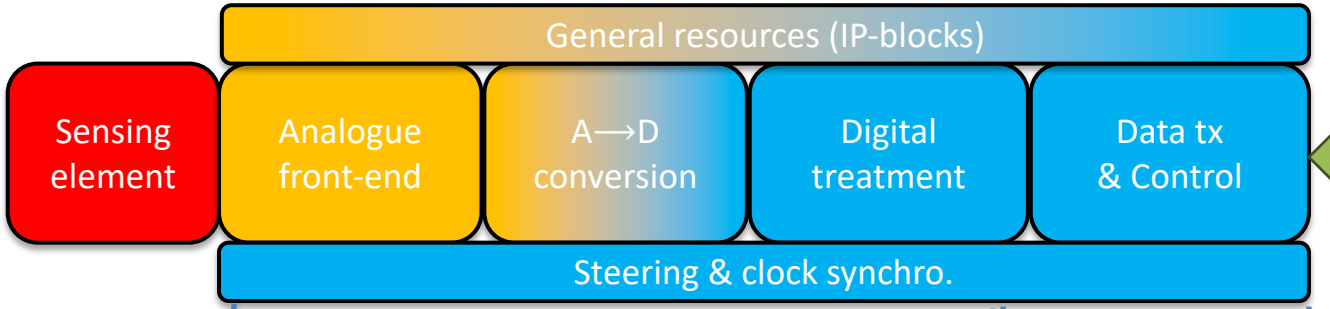
The core-facility C4Pi

for the development of CMOS-MAPS

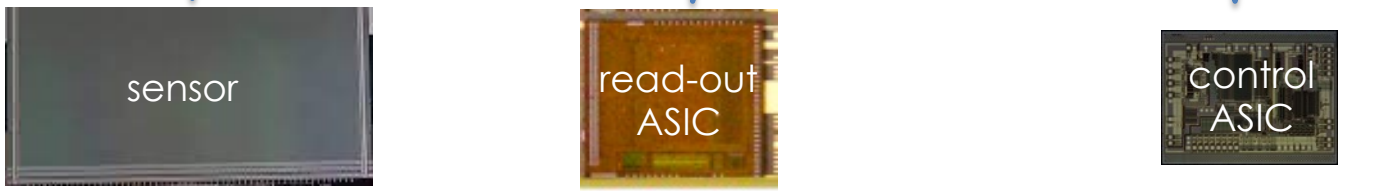
- → Missions & expertise
- → Team, equipment & network
- → Technologies
- → Internal technological R&D

Monolithic Active Pixel Sensor in CMOS technology

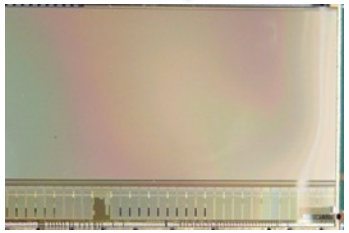
Generic detection chain

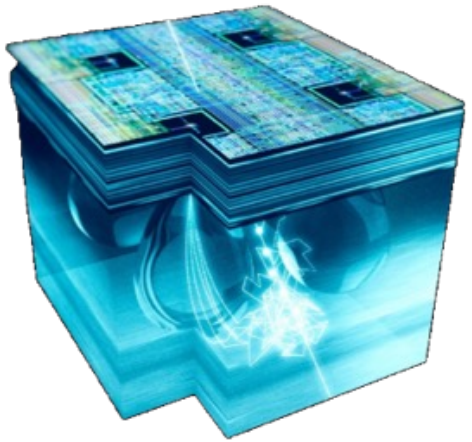


Standard implementation



Monolithic CMOS implementation



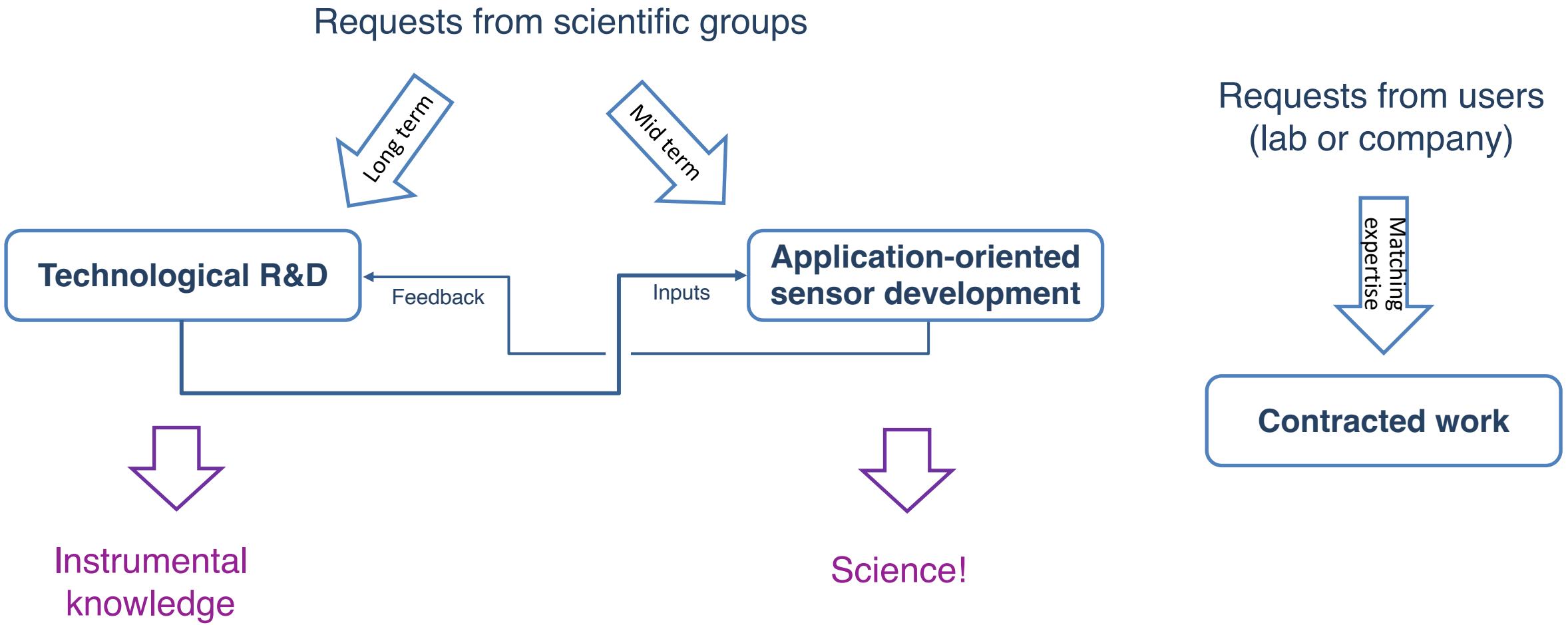


- Easier to integrate into module/detector
- For pixels: naturally small pitch & light object

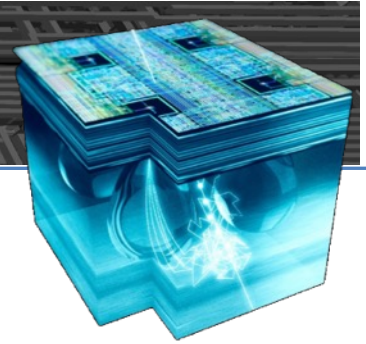
- Performance fixed at design
- Performance driven by a single technology process

Missions

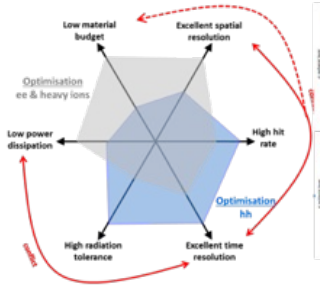
C4Pi facility born end of 2019, acknowledging specialisation of micro-electronic group in CMOS-MAPS

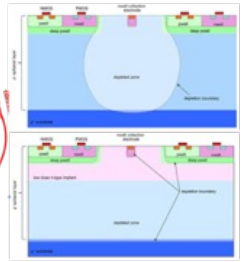


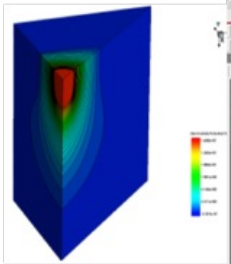
Expertise

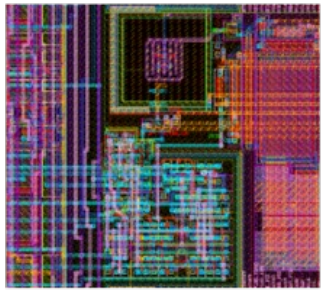


C4Pi covers the complete range of techniques required for MAPS developments







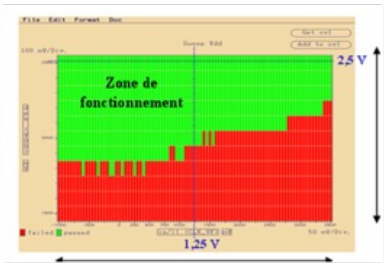


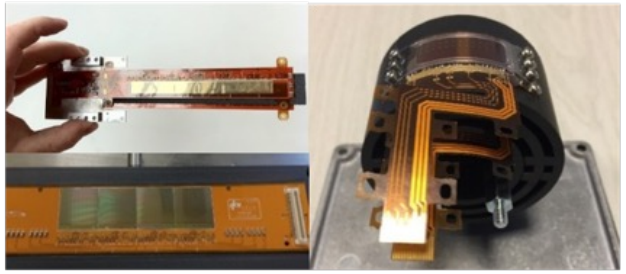
Requirements

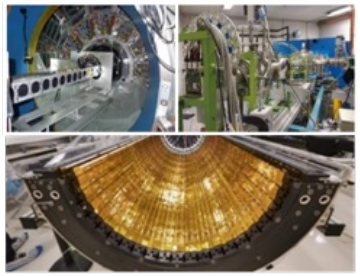
Charge collection

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

Fab interface







DAQ development & Tests

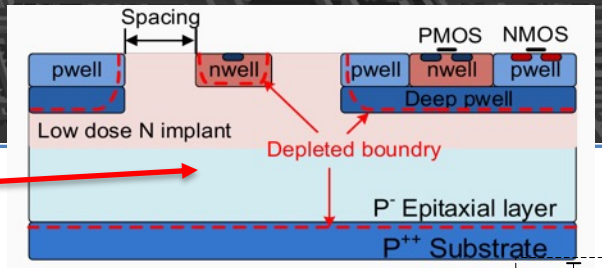
Integration

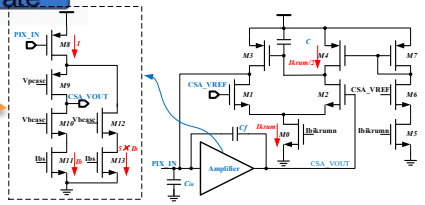
Construction
Installation

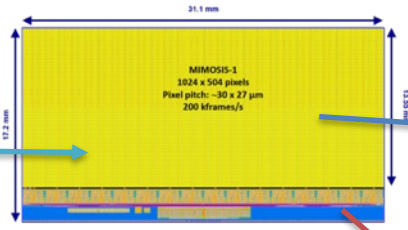
Expertise

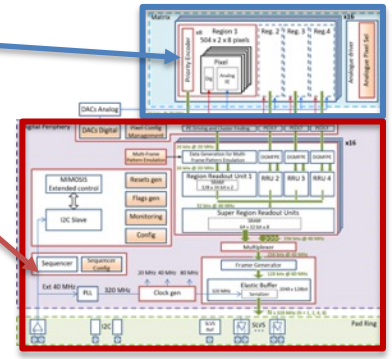
Sensitive layer	Collection node	
In-pixel analogue front-end	Bias monitoring	
Digital conversion	Digitisation	
Digital front-end & back-end	Read-out architecture	
Register Transfer Level	Top description	
Integration	Synthesis, Layout	
Design Rule Checking	Verification	
IP, component creation	Fabrication	
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

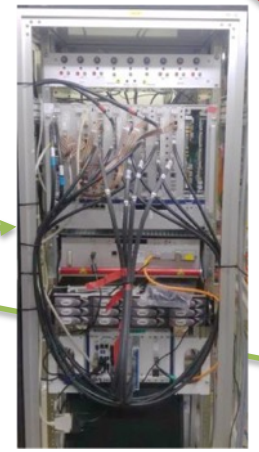
TOOLS & Foundry support

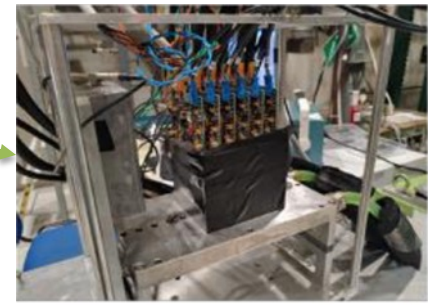


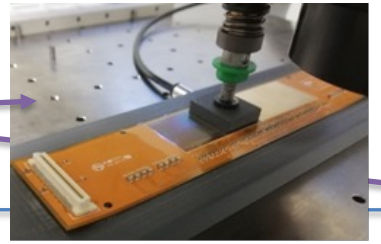


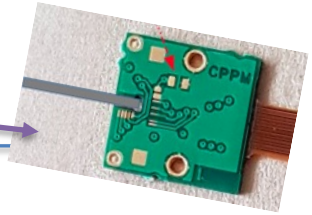




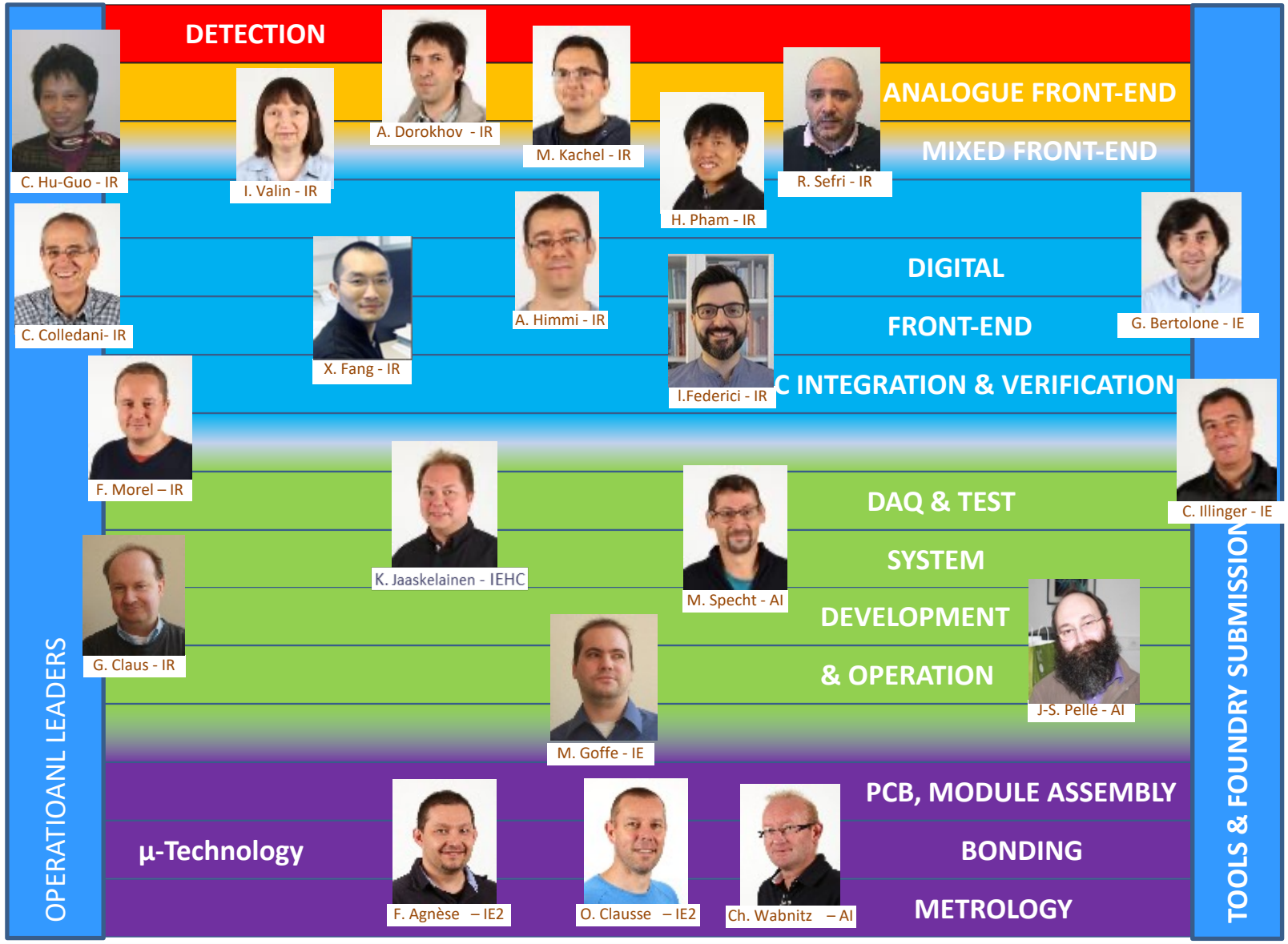








Team



- **PhD students**


J. Soudier – Doc2


C. Lemoine (CERN) – Doc1

+2 positions starting in 2023

- **Master students**

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

N. Favriou – M2 physics

- **Bachelor students**

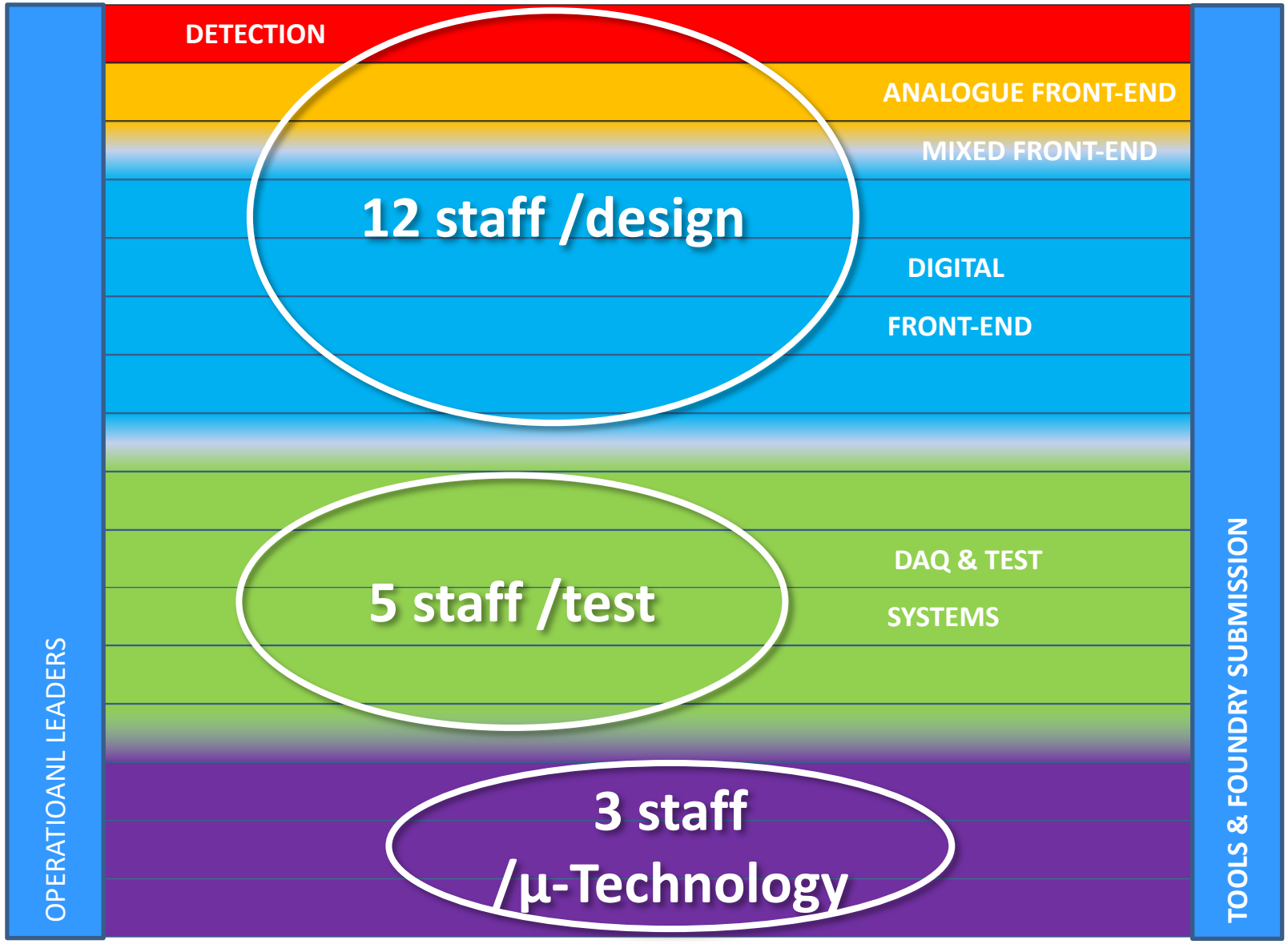
M. Grau – L2 electronics

- **Apprentices**


B. Faechtig – LPro1


T.Jacques – BUT3

Team



- Design work
  - ~4 FTE for large project
  - ~1.5 FTE for R&D (staff+student)

=> Expertise is shared among projects

- Mostly focused on MIMOSIS
- Evolution toward multi-projects

- Each staff specialised
- Participation of all to all projects

Equipment

Beam test
Irradiation: TID, NIEL

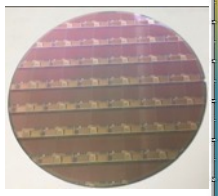
- **PICSEL** group incl. Scientific Coordinator
- **5 Test Eng.**
- Test & Characterization

Acquisition & Test

190 m² Tests

100 m² Integration PCB

2-3 iterations / year

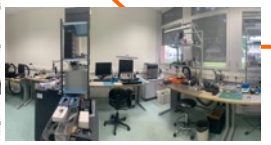


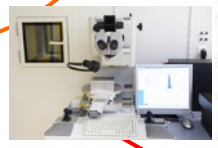
180 m² CAD
250 m² Offices

- **12 Designers**
- **1 PCB + Support Info.**
- Trainees, PhD, Post doc
- 4 CAD rooms

Design

- CAD Licenses: Cadence, Mentor, Synopsis, Xilinx
- Emulateur FPGA Protium





100 m² Clean rooms

- **3 staffs**
- µTechnics

Wafer probing
Micro/Macro-Scopy (3D)

Bonding /
Tool development

Assembling & Integration

- Xray gun

Integration & construction

Technological risks

Staff

- Expertise in bonding: 1 person → training plan for colleague + recruitment plan
  - Used by all projects + strong point of contracted works

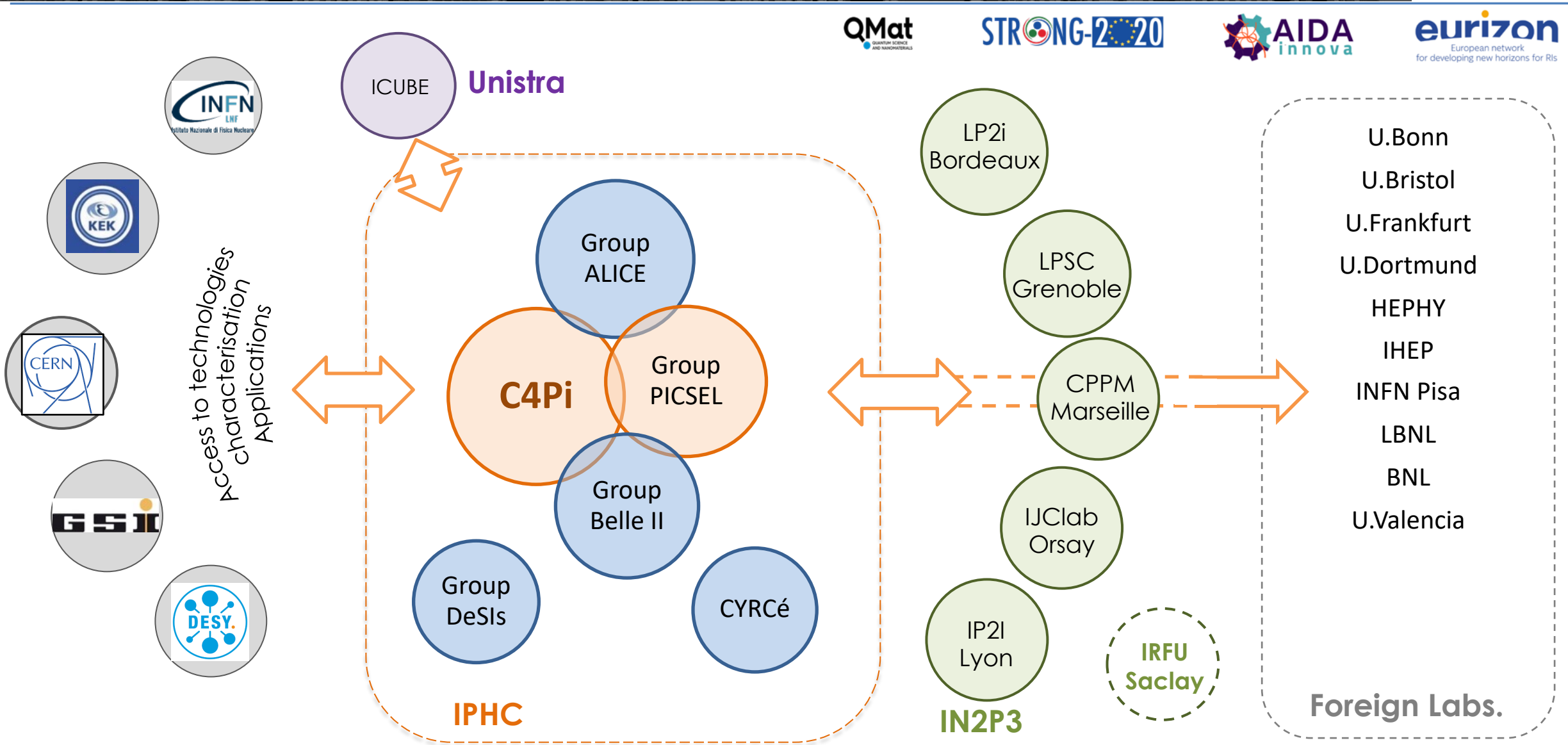
CMOSS process

- Access to TPSCo 65 nm → Tower 180 nm in case of failure → Major international issue if 2nd failure

Equipment

- Bonding machine → 150 k€ in case of failure
  - Used by all projects + strong point of contracted works
- Probe station too old for production & 12" → 350 k€ budget under planning
  - Important for MIMOSIS distribution (solution in Frankfurt)
  - Key for Belle II production (solutions with VTX partners)
  - Asset for R&D with TPSCo 65 nm
- Automatic placement machine → 150 k€ in case of failure
  - Key for Belle II production (solutions with VTX partners)

Network


QMat
STRONG-2020
AIDA innova
eurizon
European network for developing new horizons for RIs
ICUBE
Unistra
INFN
KEK
CERN
GSI
DESY.
Access to technologies
characterisation
Applications
Group ALICE
C4Pi
Group PICSEL
Group Belle II
Group DeSIs
CYRCé
IPHC
LP2i Bordeaux
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.

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)

Internal technological R&D

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

- "internal" R&D = upstream advances (+ PhD / Master student)
- Not necessarily only internal

Amplification in silicon

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

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

Read-out architecture

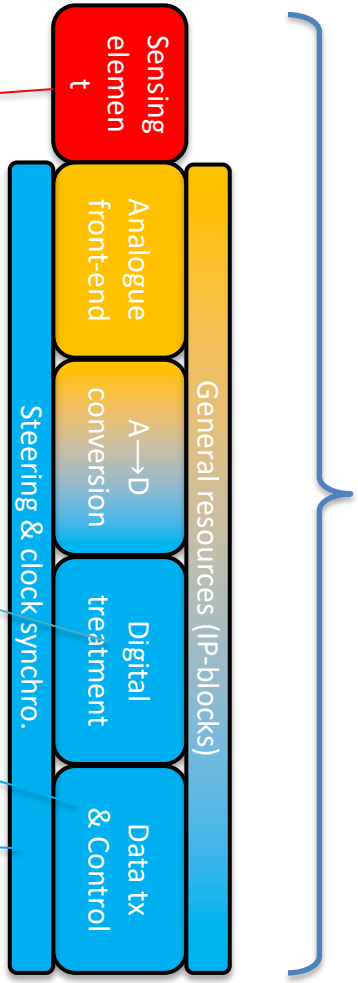
- Explore asynchronous logic (entirely event driven)
- Increase versatility (hit-rate, area), decrease power

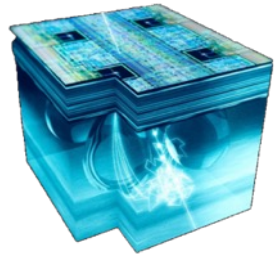
Intelligence on sensor

- Embedded processor and artificial intelligence
- Data reduction, ease control/calibration against granularity curse

Functional blocks

Sensor Bending

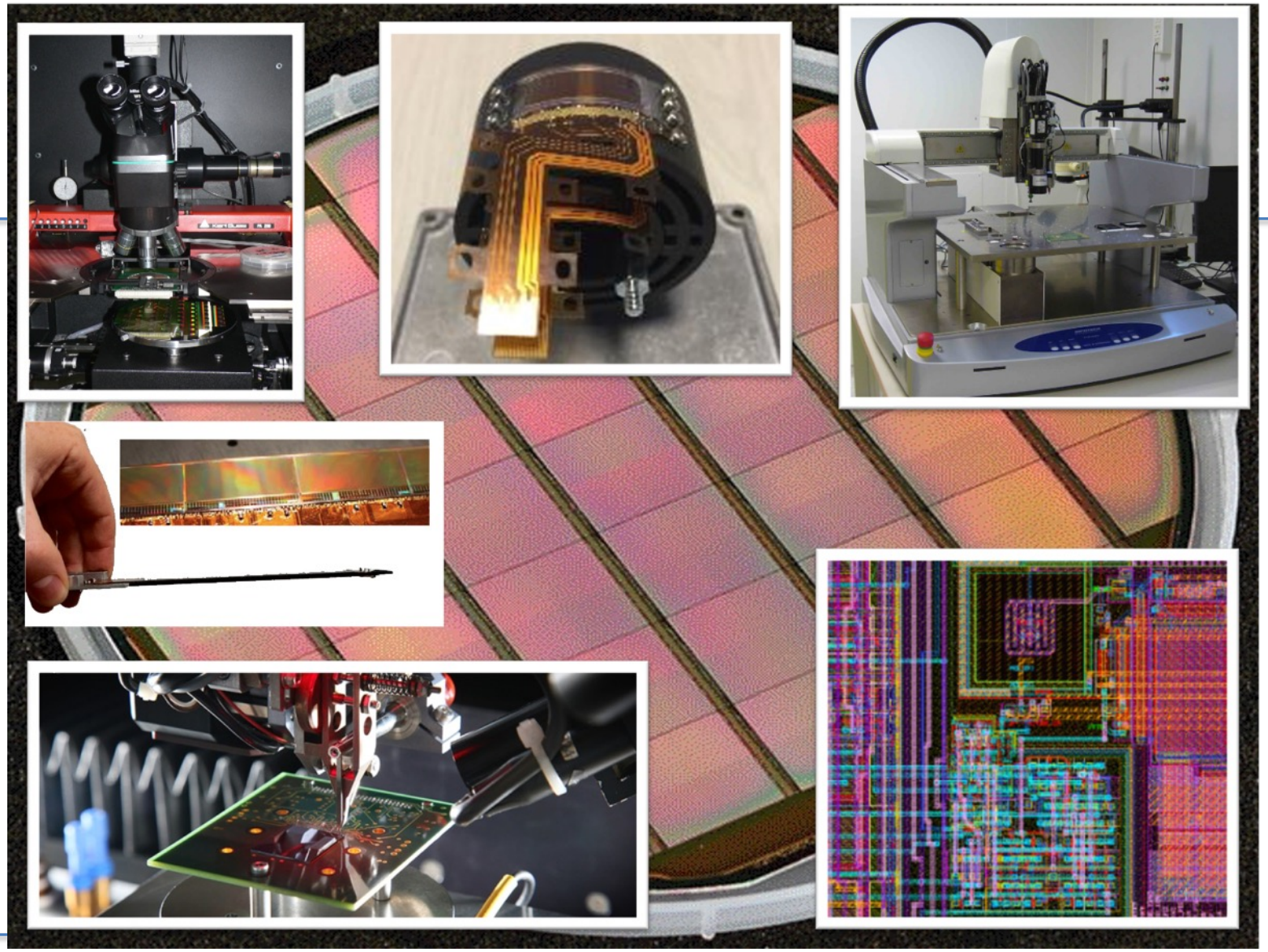




Main activity at C4Pi generated by scientific group requests

Let's listen to their programs

Supplementary slides



C4Pi : Centre de Compétences de Capteurs CMOS à Pixels Intégrés

Comité de Pilotage

Direction de la Plateforme C4Pi

Responsable Opérationnelle (RO)
Coordinateur Scientifique (CS)
Responsable Opérationnelle Adjoint (ROJ)
Responsable Qualité (RQ)

Plateau technique de prestations de services en microtechniques

Déploiement & Mise en œuvre des systèmes de détection sur sites expérimentaux

Support CAO, Dkit, Submissions PROTIUM: vérification ASICs pour validation logicielle

Microtechnique (µT)

- Micro-connectique
- Routage & Montage des PCB
- Assemblage automatisé
- Conception des PCB
- Test de microcircuit & capteurs sous point
- Métrologies
- Intégration de détecteurs
- Procédure Qualité

Test-Caractérisation (TC)

- Développement PCB
- Développement Software
- Développement FPGA
- Conception & Intégration des bancs de test
- Conception de systèmes DAQ
- Caractérisation des ASIC
- Caractérisation des capteurs
- Test irradiations & faisceaux
- Intégration des détecteurs sur sites des expériences

Conception Microélectronique (µE)

Analogue & Mixte

- Physique semi-conducteur: Conception des éléments de détection (TCAD)
- Conception électronique very Front End intégré
- Conception de briques de base (Analogique, Numérique et Mixte)

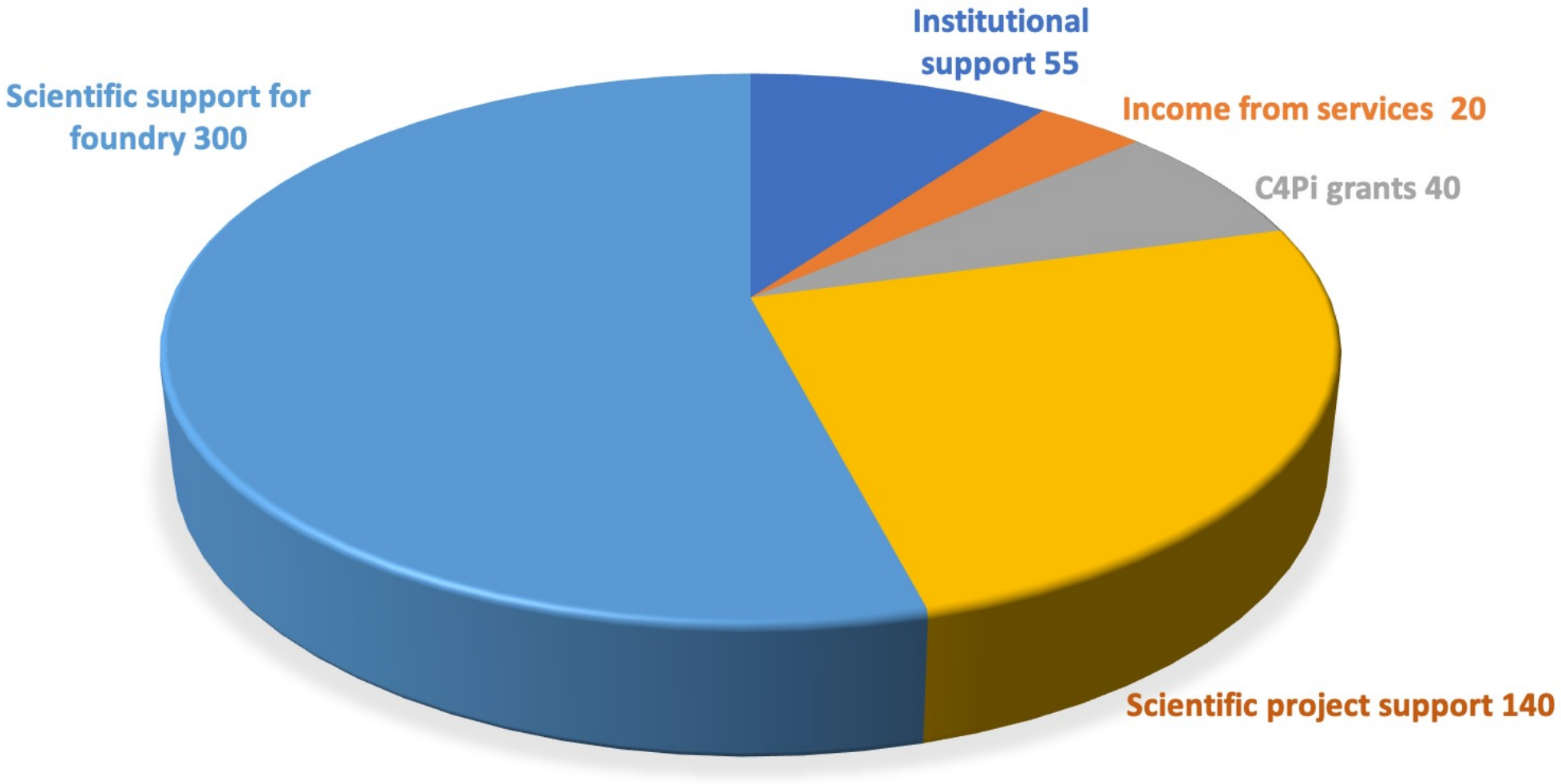
Digital & Intégration

- Modélisation & Description HDL & test fonctionnel
- Synthèse, routage
- Analyse de timing, de puissance
- Vérification haute niveau UVM
- Intégration et Vérification (DRC, LVS, IR drop)

Collaborations nationales & internationales, Groupes scientifiques & Supports de l'IPHC (RH, Finances, STI, …)

2023

Average yearly budget (k€)

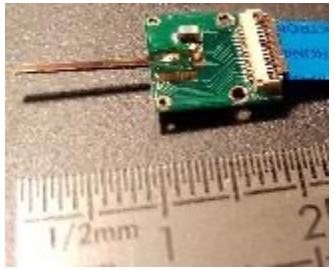


Note: Services, grants, foundry fluctuate

"Other" projects, aside collider physics

MAPSSIC

- Intracerebral β+ probe for awake and free rodents
- Collab. CPPM, IJClab, IPHC, CERMEP
- Design of needle-shape sensor + Probe assembly

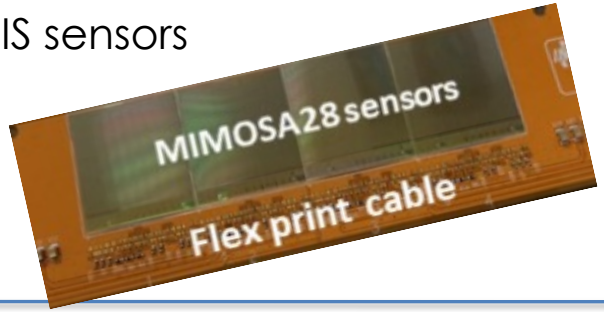


STRONG, TIIMM / TIIX

- Tracking and Ion identification with minimal material budget
- Collab. GSI, INFN-LNF, IPHC, IP2I
- Design of TIIM and TIIX demonstrator sensors
  - E_{loss} dynamic: 5 keV to 5 MeV
  - In-pixel digitisation with Time-over-Threshold technique

FOOT

- Doubly-differential nuclear cross-sections for hadrontherapy
- Collab. INFN-LNF, IPHC-DeSIS,
- Provider of MIMOSA-28 / MIMOSIS sensors
- Assembly of tracker
  - Light double-sided 8x8 cm^2 plane



Monolithic Imager

- All-purpose analogue-output sensor with 20 µm pixels

=> Proton spectroscopy for diagnostic of ion acceleration in plasma (with LP2I)

=> Electron/proton separation in space radiation (with Weeroc & CNES)

=> X-ray spectroscopy (with TüB)

Large CMOS Monolithic Active Pixel Sensors

Sensor	MIMOSA26/28	ALPIDE	MIMOSIS-2	TJ-MONOPIX2	MALTA-2	LF-MONOPIX2	ARCADIA MD2	ATLASPix-3	MuPix10
Date	2008/10	2015-17	2023	2021	2021	2021	2021	2019	2020
Labo/Collab	IPHC	CERN+	IPHC	CERN-Bonn+	CERN+	Bonn-CERN+	INFN	KIT+	KIT+
Techno	AMS-350 nm	TJ-180 nm	TJ-180 nm	TJ-180 nm	TJ-180 nm	LF-150 nm	LF-110 nm	TSI 180 nm	TSI 180 nm
Pixel pitch (μm^2)	18.4x18.4 20.7x20.7	29x27	30x27	33x33	36.4x36.4	150x50	25x25	150x50	80X81
#Columns x #Rows	1152x576 960/928	1024x512	1024x504	512x512	256x512	56x340	512x512	132x372	256x250
Sensitive area (mm^2)	21.2x10.6 19.7x19.2	27.5x15.0	31.0x13.6	16.9x16.9	10x20	8.4x17	12.8x12.8	19.8x18.6	20.5x20.0
Time Stamp (ns)	112/ $x10^3$	5000	5000	25	25	25	?	25	20
Trigger latency (µs)	Continuous r.o.	Contin./Trig. 2	Continuous	Global shutter	Global shutter	Continuous	?	25	?
Output charge (bits)	1	1	1	7		6	?	7	5
Bandwidth (Mbits/s)	180	1200	3200	320	1300		2000	1300	?
Power (mW/cm^2)	300/150	18-35	~50	O(200)	>70		O(20) ?	150	4.6 µW/pixel
Hit rate (Mhz/cm^2)	O(0.1)	<10	15-70	>100	>100	>100	>100	>100	?
TID kGy	2	27	100	1000	1000		?	1000	?
Fluence (x $10^{13} n_{eq}.cm^{-2}$)	0.1	1.7	10	300	300	100	?	100	100