DRD8

Synthèse des activités in2p3

Remarque préliminaire: les informations présentées reflètent l’état de la réflexion et des informations obtenues.

Le DRD8 est né plus tard que les autres.

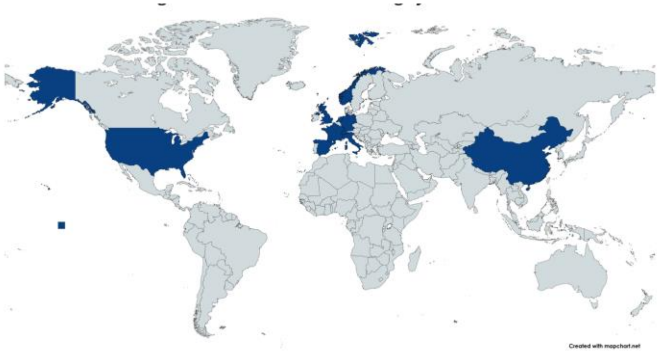
Capteurs courbes & intégration

Refroidissement par Micro-canaux

Mécanique pour les trajectographes

Many thanks to
J. Andrea, M. Barbero, J. Baudot, G. Boudoul, G. Calderini, G. Claus, J. Cogan, D. Colombet, D. Contardo, M. Goffe, F. Morel, S. Senyukov, Z. El Bitar

DRD8 introduction



- DRD8 content
  - ✓ Mechanics & Cooling for Future Vertex and Tracking Systems
  - ✓ Web page
  - ✓ Cf. Kick-off meeting after the DRD8 approval
  - ✓ Forum on Tracking Detector Mechanics 2025
    - Bristol, 16–20 Jun 2025 ⇒ DRD8 week
  - ✓ *At this stage, DRD8 doesn't foresee to have a Common Fund.*
- IN2P3 participation
  - ✓ IPHC:
    - Bent sensors for vertex detector ⇒ WP1; Project 1.1 ; M 1.1.1
  - ✓ CPPM :
    - microchannel cooling ⇒ WP3; project 3.2
    - Bent sensors for vertex detector ⇒ WP1; Project 1.1 ; M 1.1.1
  - ✓ LPNHE :
    - microchannel cooling ⇒ WP3; project 3.2
  - ✓ LAPP :
    - microchannel cooling ⇒ WP3; project 3.2
  - ✓ LPSC :
    - microchannel cooling ⇒ WP3; project 3.2
  - ✓ IJCLAb: mechanics ?
  - ✓ IP2I :
    - low mass mechanics ⇒ WP2 pour la R&D de tracker/PID layer if RH requested in the lab approved.

- **WP1: Global system design and integration**
  - Project 1.1: The Vertex Region of Future Particle Physics Experiments
  - Project 1.2: Robots in the HEP Experimental Caverns
- **WP2: Low-mass mechanics and thermal management**
  - Project 2.1: Advanced Mechanical Tracker Structures
  - Project 2.2: Characterisation of Material Properties and Database Development
- **WP3: Detector cooling**
  - Project 3.1: New Evaporative Cooling Fluids and Systems
  - Project 3.2: Microchannel Cooling Substrates
- **WP4: Design and qualification tools**
  - Project 4.1: Extended Reality (XR) Development
  - Project 4.2: Connection of Engineering Design Tools with Physics Simulation Software

- **WP1: Global system design and integration**
  - Corrado Gargiulo (CERN)
  - Fabrizio Palla (Universita & INFN Pisa (IT))
- **WP2: Low-mass mechanics and thermal management**
  - Adam Dominic Lowe (University of Oxford (GB))
  - Sushrut Karmarkar (Purdue University (US))
- **WP3: Detector cooling**
  - Bart Verlaat (CERN)
  - Oscar Augusto De Aguiar Francisco (Manchester (GB))
- **WP4: Design and qualification tools**
  - Diego Alvarez Feito (CERN)
  - Joao Batista Lopes (CERN)

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WP1: Bent sensors

IPHC, CPPM

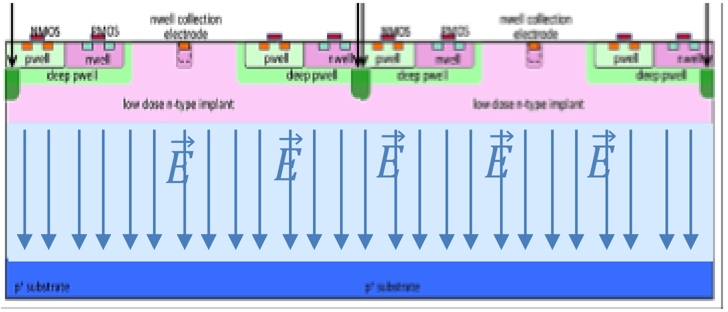
CMOS-MAPS pixel sensor

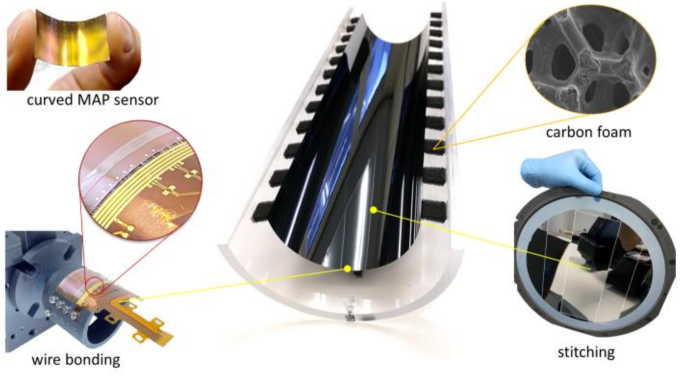
Can be thinned down to 30-50 µm

$\gtrsim$ 10 µm

10-25µm

substrate

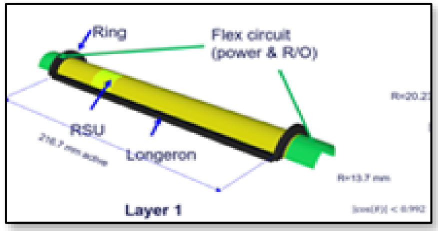




Pioneered by ALICE-ITS3

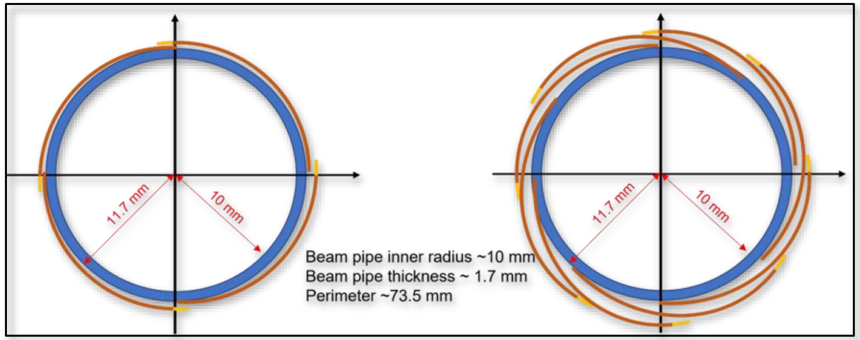
Bent sensors for a vertex detector for Higgs factories (@FCCee)

- À la CLD/ILD: 3 double ladders + discs
  - ➢ Robust but not optimized for material budget
- À la ALICE ITS-3 : 3/4 layers with stitched half cylinders
  - ➢ Fill factor not 100% per layer
  - ➢ Stitching mandatory
    - ➢ Pitch ? Power ? Yield ? Fill factor ? Bent radius ?
  - ➢ Very competitive for mat. budget but limitations (acceptance, resolution, radius ?)
- FCC-SEED: vertex detector concept for FCCee



Option 1 : single layers

Option 2 : double layers



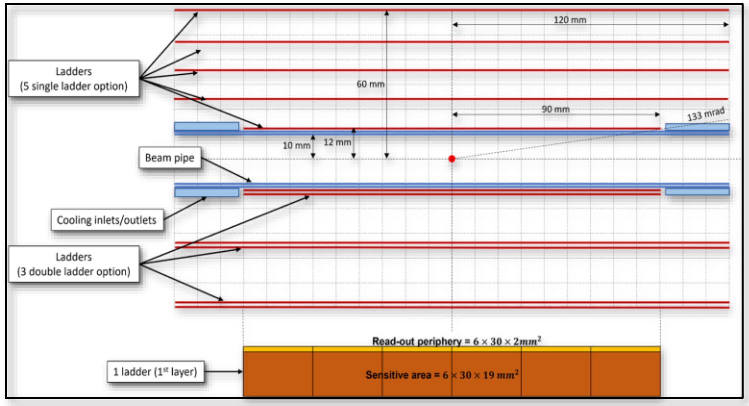
FCCee

$$\sigma_{d_0} = a \oplus \frac{b}{p \sin^{3/2}\theta}$$

$a \simeq 5\,\mu m; \quad b \simeq 15\,\mu m\,GeV$

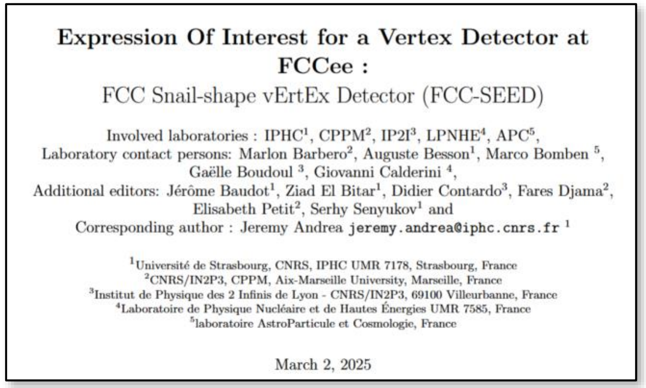
$b \sim r_0 \sqrt{material}$

$a \sim \sqrt{r_0}$



- ✓ 3rd approach between half-cylinder concepts (ALICE-ITS-3 & IDEA det. Concept) and classical approach (double sided ladders like ILD, CLICdet, CLD)
  - ▪ Based on curved sensors to minimize mat. Budget and inner radius
  - ▪ Bonding performed in the longitudinal axis
  - ▪ Compatible with/without stitching
  - ➢ Full acceptance in φ
  - ➢ Double sided can be considered.
  - ➢ Number of layers = free parameter
  - ➢ Competitive for mat. Budget. AND full azimuthal acceptance

- ✓ Ideas developed in an EoI and a supporting document
  - ▪ First kick-off workshop (~20 people) in Feb 2025



Expression Of Interest for a Vertex Detector at FCCee :

FCC Snail-shape vErtEx Detector (FCC-SEED)

Involved laboratories : IPHC[1], CPPM[2], IP2I[3], LPNHE[4], APC[5],
Laboratory contact persons: Marlon Barbero[2], Auguste Besson[1], Marco Bomben [5], Gaëlle Boudoul [3], Giovanni Calderini [4],
Additional editors: Jérôme Baudot[1], Ziad El Bitar[1], Didier Contardo[3], Fares Djama[2], Elisabeth Petit[2], Serhy Senyukov[1] and
Corresponding author : Jeremy Andrea jeremy.andrea@iphc.cnrs.fr [1]

[1]Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France
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[4]Laboratoire de Physique Nucléaire et de Hautes Énergies UMR 7585, France
[5]laboratoire AstroParticule et Cosmologie, France

March 2, 2025

Bent sensor ongoing activities (IPHC, CPPM joining)

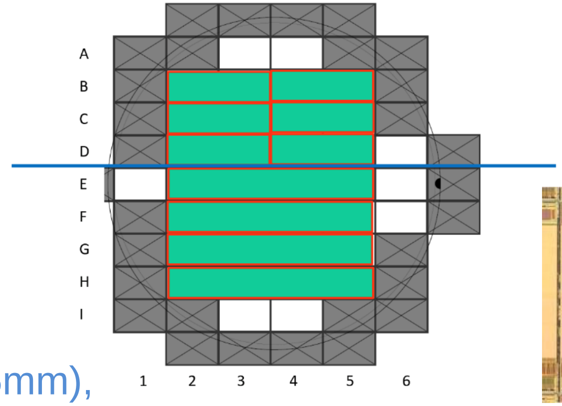
- Goal: design light and precise mechanical supports
  - ✓ Determine light material, allowing for a precise geometry,
  - ✓ Imagine a robust and "simple" assembly procedure, including integration and cable/fibre routings,
  - ✓ Allowing for an efficient (air) cooling, while other options can be explored too.
- Short/midterm plan :
  - ✓ Start the design effort,
  - ✓ Design first geometry to play with,
  - ✓ Implement it into a full simulation
- Working plan :
  - ✓ Step 1: Single sensor bending (ongoing)
    - Prepare and install sensor bending bench, with different radii options (12-15mm), and different sensor thickness (30-50 µm).
    - Practice bending with dummy sensors, then real functional on single existing sensors (MIMOSIS), perform connectivity and setup DAQ, and tests.
  - ✓ Step 2: (~2026)
    - Bending of a wafer slice (MIMOSIS), connectivity and tests,
  - ✓ Step 3: full layer demonstrator (~2026-27)
    - Move toward a larger scale demonstrator of the 1st Layer in a few years from now.

Table 3: Barrel dimensions (single and double sided option)

Layer	1	2	3	4	5
Radius (mm)	12-13	24	36	48	60
Zmax (mm)	90	120	120	120	120
Perimeter (mm)	75	151	226	302	377
# Chips per ladder	6	8	8	8	8
# ladders	4	8	12	16	20

Layer	1-2	3-4	5-6
Radius (mm)	12-13	35-36	59-60
Zmax (mm)	90	120	120
Max perimeter (mm)	82	226	377
# Chips per ladder	6	8	8
# ladders	4	12	20

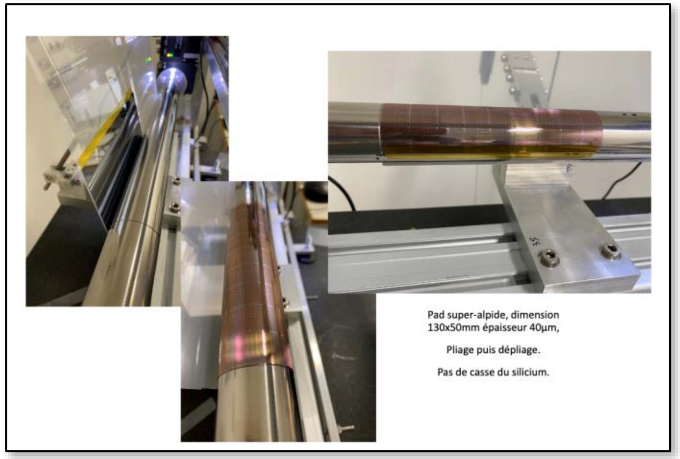
Single chip dimension	$30 \times 22.2\ mm^2$
Sensitive area chip dimension	$30 \times 19.2\ mm^2$



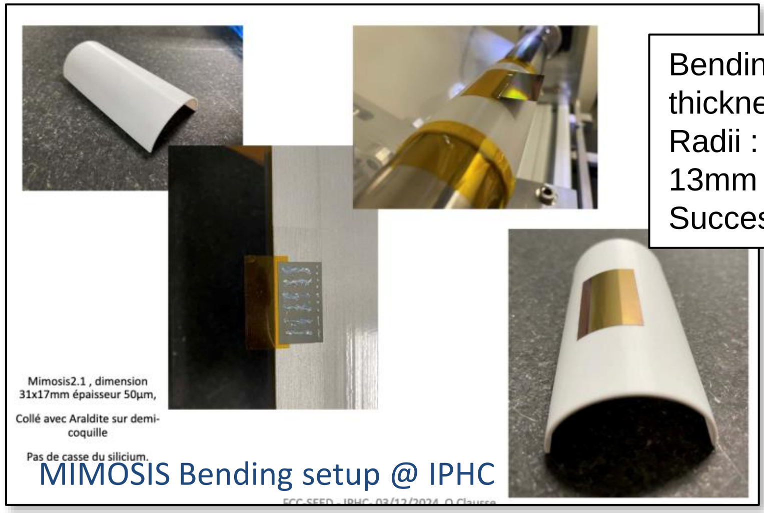
Parameter	Value
Technology	TowerJazz 180 nm
Epi layer	~25 µm
Epi layer resistivity	$> 1k\Omega cm$
Sensor thickness	60 µm
Pixel size	26.88 µm × 30.24 µm
Matrix size	1024 × 504 (516096 pix)
Matrix area	≈ 4.2 cm²
Matrix readout time	5 µs (event driven)
Power consumption	40-70 mW/cm²

Bent sensors for FCCee

- Bent sensors pioneered by Alice ITS-3
  - ➢ IPHC experienced learned on SUPERALPIDE



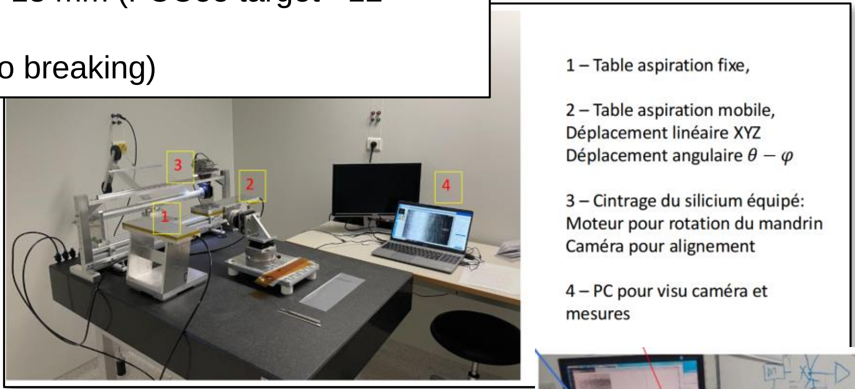
SUPERALPIDE Bending setup @ IPHC

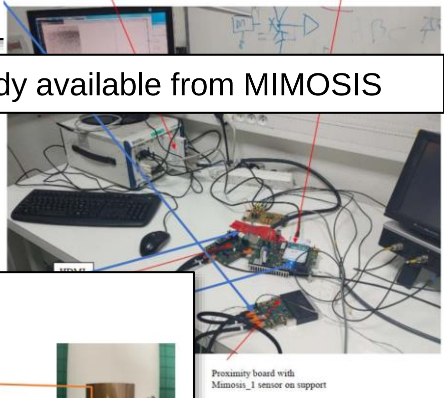


MIMOSIS Bending setup @ IPHC

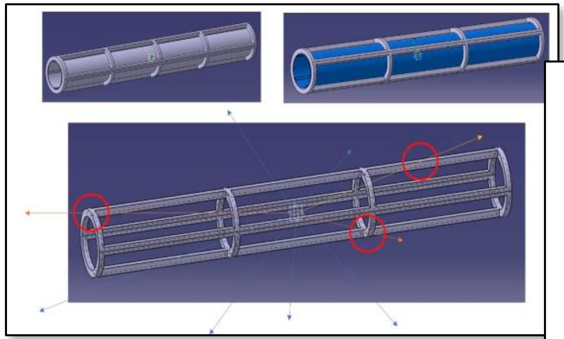
- IPHC: working program dedicated to bend sensor with MIMOSIS
  - ➢ e.g. functional tests @ R = 12 mm

Bending tests of Mimosis 2.1 (31x17mm), thickness of 40-50 microns.
Radii : 15 and 18 mm (FCCee target ~12-13mm
Successful (no breaking)

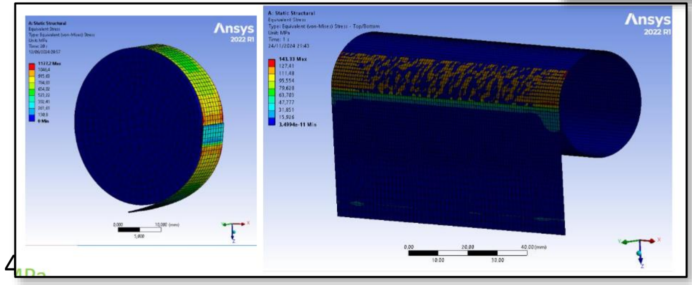


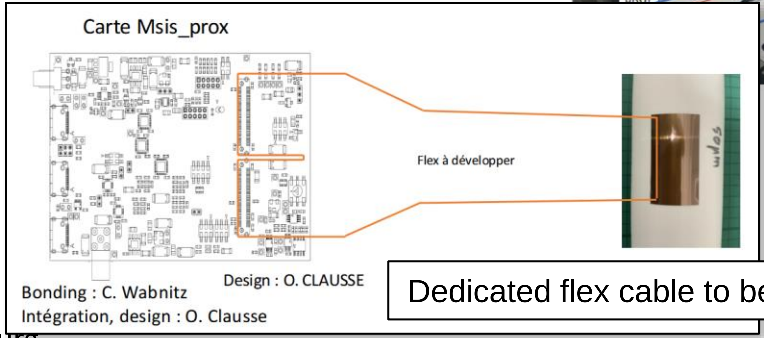


Test bench already available from MIMOSIS



Simulation en mécanique non linéaire et thermofluidique
(Ansys Workbench ou Comsol Multiphysics)
CAO via 3DExperience
Avec optimisation topologique
Apprenti ingénieur en Mécanique 2025-2028



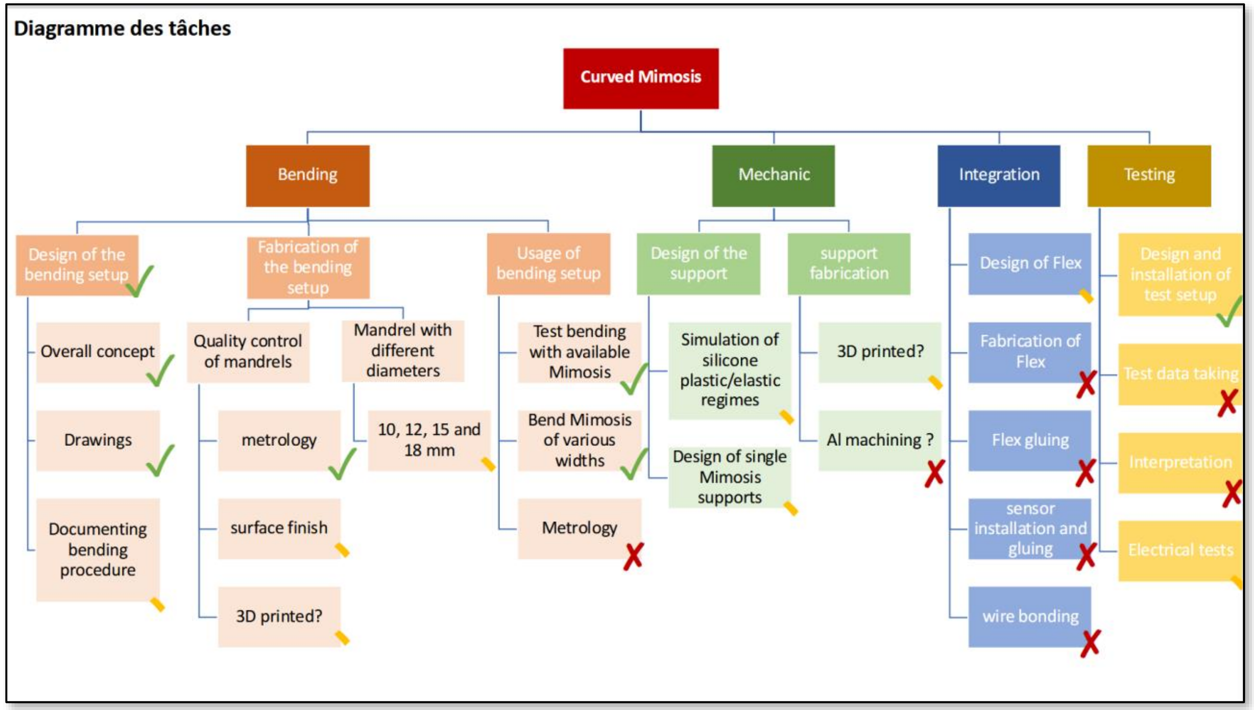


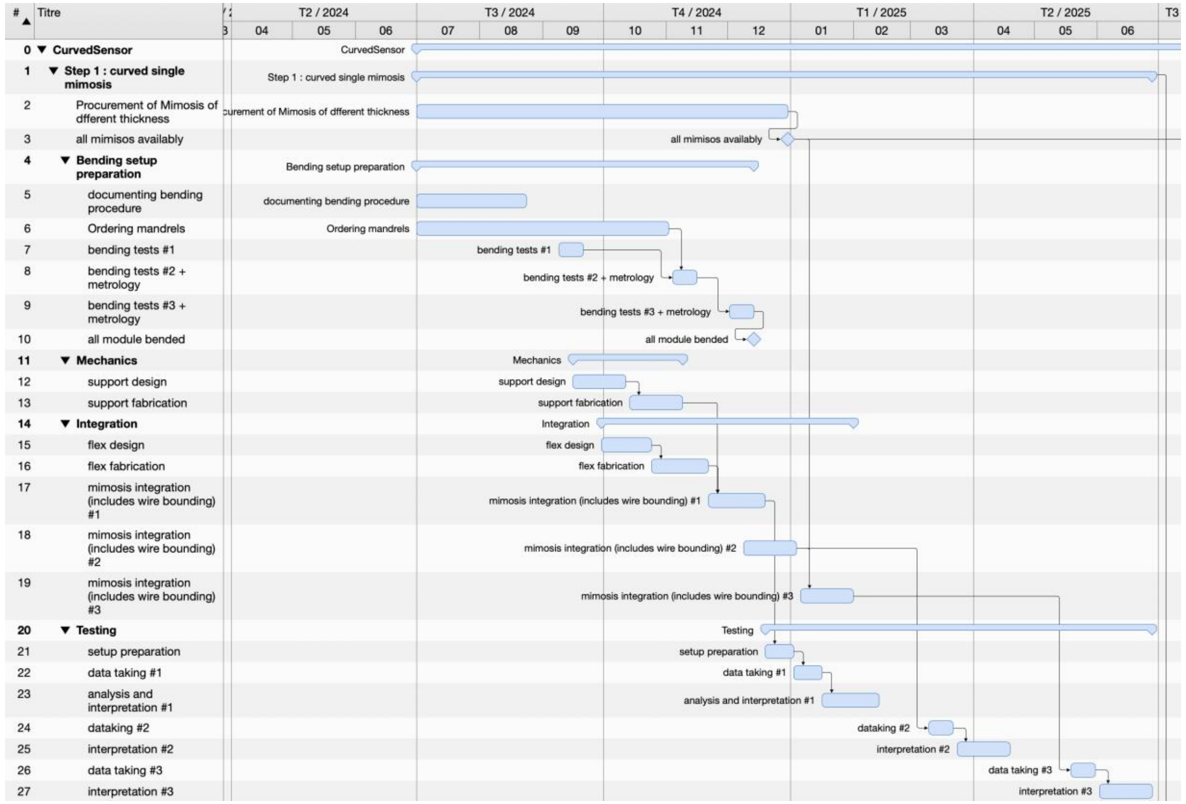
Dedicated flex cable to be developped

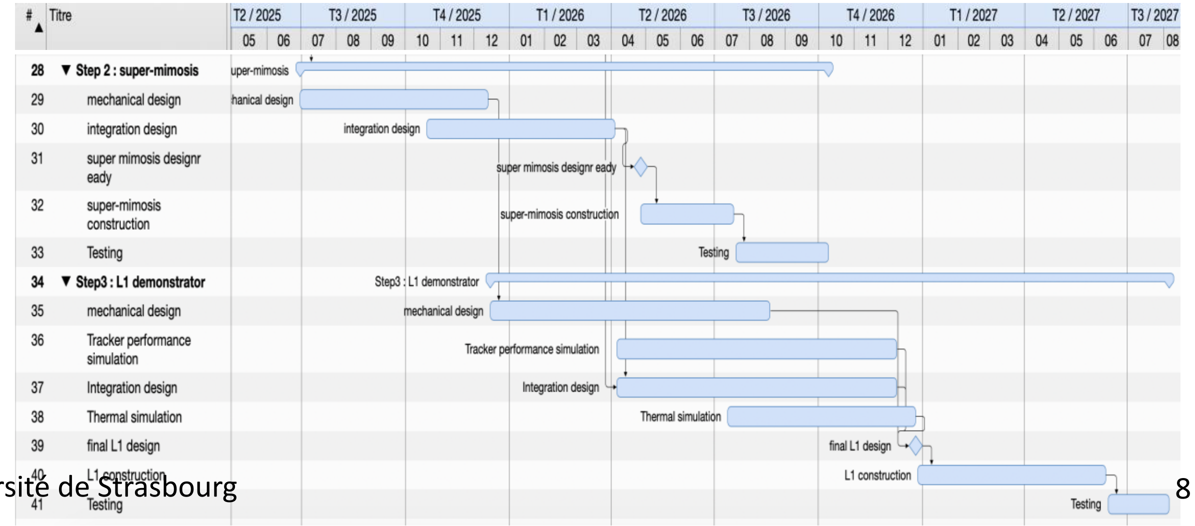
CPPM: Thin sensor / DRD8 mechanical prospects

- Possible goals:
  - ✓ Development of module loading, integration tool and processes → focus on thin curved monolithic sensors
  - ✓ Performances measurements and simulation:
    - Thermal figure of merit
    - Thermomechanical stabilities
    - Geometrical 3D scanning and accuracies (production and placement)
  - ✓ Design, simulations and prototyping of thin mechanical structures
  - ✓ Development of novel laser welding of cooling services
- Resources:
  - ✓ RH: 2 FTE.months / year (E. Vigeolas / JP Logier / M. Niclas / M. Barbero / E. Petit)
  - ✓ Budget 2025-2027: ~5 k€ / year (DEPHY?)

Project already structured (J. Andrea)







Bent sensors: Connexion to Proposal for DRD8 (Oct. 2024)

Project 1.1: The Vertex Region of Future Particle Physics Experiments

- IPHC Strasbourg: Vertex detector design and prototyping. Based on curved MAPS sensors, covering for integrations aspects: mechanics, services (power+data transmission) and cooling

Milestones and Deliverables

Label	Topic	Month	Description
M1.1.1	Curved and tilted sensors	12	Demonstrate curved and tilted sensors bringing the first hit point closer to the interaction point.
D1.1.1	Carbon beam pipe	24	Deliver an ultra-thin vacuum beam pipe (carbon, beryllium, Albemet) for primary and secondary vacuum compatible with vacuum operational requirements.
M1.1.2	Retractable detectors	36	Develop a design for a retractable vertex detector with minimum material budget that could withstand the primary and secondary vacuum.
D1.1.2	Mock-up & integration	36	Delivery of a mock-up of the interaction region with integration of vertex detector and services.

Table 1: Summary of available and required resources for WP1 Project 1.

Institute	**Effort [FTE/year]**		**Material budget [kCHF]**	
	available	**required**	**available**	**required**
CERN	1.0	1.0	100	100
IHEP/CAS	0.5	1.0	50	100
GSI Darmtadt	0.2	0.4	0	10
INFN Pisa	0.5	1.0	50	90
INFN Perugia	0.5	0.5	0	30
INFN Frascati	0.5	1.0	100	500
Nikhef	0.5	1.0	20	50
IPHC Strasbourg	3.0	4.0	10	10
IFIC Valencia	0.5	1.0	300	300
University of Geneva	0.5	0.5	10	10
University of Liverpool	0.5	1.0	0	50
University of Oxford	0.5	1.0	0	100
University of Bristol	0	0.5	0	100
University of Freiburg	0.5	1.0	10	30
Total	**9.7**	**15.4**	**650**	**1530**

+ CPPM joining

Tasks INTEGRATION	Name	Q3/24	Q4/24	Q1/25	Q2/25	Q3/25	Q4/25	Q1/26	Q2/26	Q3/26	Q4/26	Q1/27	Q2/27	Q3/27	Q4/27	total ETP (mois)
Coordination scientifique	Jeremy Andrea	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%					9
Coordination technique	tbd	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%					6
sensor cutting	Mathieu Goffe	10%	10%		5%		5%		5%		5%		5%			1,35
	Gilles Claus															0
Bending setup	Frank Agnese	20%	20%							20%	20%			20%	20%	3,6
	Olivier Clausse	20%	20%							20%	20%			20%	20%	3,6
Mechanicl supports	Frank Agnese	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	2,52
	Olivier Clausse (Meca, Flex,PCB)	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%	6,72
	ingé par alternance					50%	50%	50%	50%	50%	50%					9
	permanent STM	10%	10%	20%	20%	20%	20%	20%	20%	20%	20%					5,4
Integration + Functionnal tests	Frank Agnese	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	2,52
	Olivier Clausse	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	2,52
Conseil for Tests / Char / integration	Mathieu Goffe			20%	20%		20%	20%		30%	30%			30%	30%	6
Conseil for Tests / electronic design	Gilles Claus (support + dev DAQ)			35%												1,05
Test / Char	Serhiy Senyukov			20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	7,2
Test bench integ, SW dev	Jean-Sebastien PELLE		5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	1,95
DAQ upgrades / Conseil SW	Gilles Claus		15%	70%								35%				3,6
DAQ fw dev	Kimmo Jaaskelainen											105%				3,15
Conseil for flex design	Kimmo Jaaskelainen			35%												1,05
Conseil for SW dev	Matthieu Specht			35%								35%				2,1
CPS bonding, PCB assembly, etc …	Christophe Wabnitz			35%								35%				2,1
	Temps global estimé pour ces personnes affecté sur Q1/25 et Q1/27															68,43
Project duration [Month] (step 1,2,3)	42															
1 ETP [Month] (1 an - 46 J congés)	9,7															
1 ETP [Month] sur durée projet	33,95															

Total RH	total ETP (mois)	ETP %
Jeremy Andrea	9	26,5
tbd - Coordination	6	17,7
Frank Agnese	8,64	25,4
Olivier Clausse	12,84	37,8
Christophe Wabnitz	2,1	6,2
Serhiy Senyukov - Test / Char To be confirmed	7,2	21,2
ingé par alternance	9	26,5
permanent STM	5,4	15,9
Mathieu Goffe	7,35	21,6
Gilles Claus	4,65	13,7
Jean-Sebastien PELLE	1,95	5,7
Matthieu Specht	2,1	6,2
Kimmo Jaaskelainen	4,2	12,4
		0,0
Serhiy Senyukov (potentiel)	13,2	38,9
Total Test	20,3	59,6
Total uTec	23,6	69,5
Total RH Technics : Test + uTec	43,8	**129,1**
Total RH Technics : Test + uTec + PICSEL	57,0	**168**

GRAM - Tâche 2:
Capteurs courbes et intégration ⇒DRD8
(Jeremy Andrea, G. Claus)
~60 ETP-mois

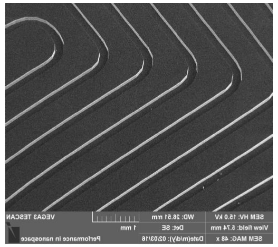
+ CPPM: 6 ETP.mois

- ✓ Budget from GRAM
  - GRAM Budget 2025 request: 10 keuros ⇒ rising project (mechanics added) ~15 keuros/yr on 2025-27
    - – Mandrell, flex cable, bonding, connectors, tests
  - + apprentice on mechanics to be supported by IPHC/GRAM/IN2P3: 9 keuros/yr for 3 years (2025-28)
- ✓ Budget from DEPHY ?
  - 5 k€ / year ?

WP3: Microchannel cooling

LPNHE, CPPM, LAPP, LPSC/LEGI

Currently in DRD7 ⇒ expected to move (at least partly) to DRD8

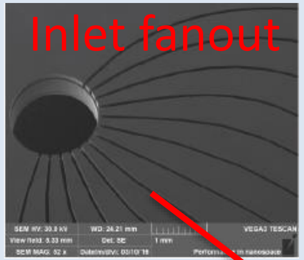


- Very good heat transfer ratio
(heat transferred per unit area per kelvin)
- Mat. Budget
- Can target localized areas

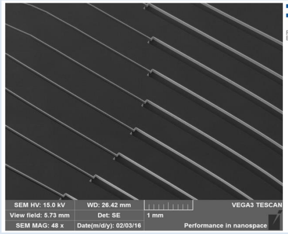
Advanced mechanics

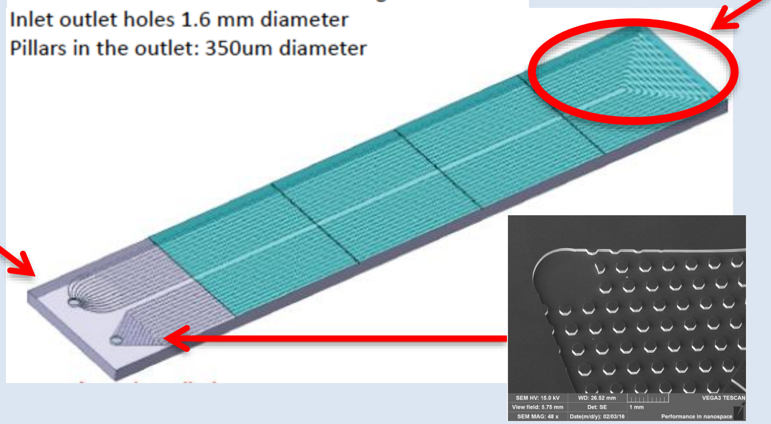
1.Microchannel blocks for cooling at future detectors

Prototypes produced by LPNHE with FBK and IEF Orsay

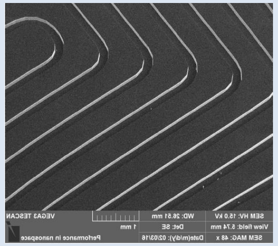


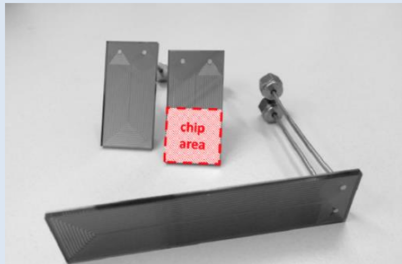
13 channels 200x120 um
Silicon walls 500um
Inlet restrictions 60x120um: same lenght 6mm for all
Inlet outlet holes 1.6 mm diameter
Pillars in the outlet: 350um diameter





Details of the channel design

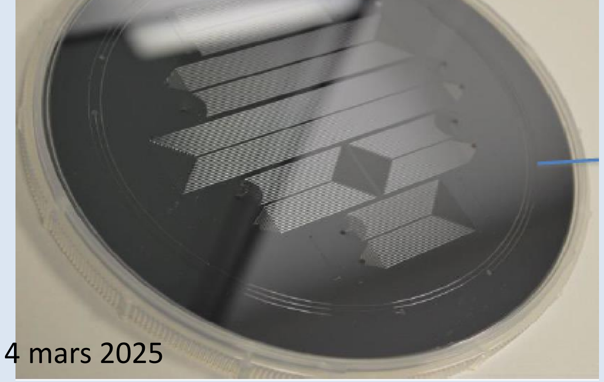


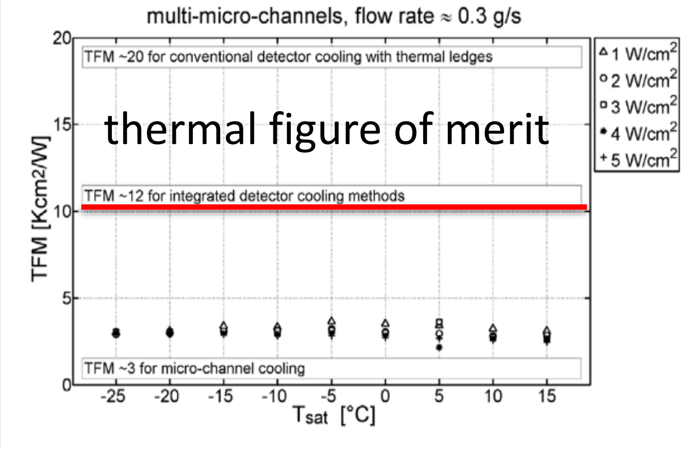


Connected & tested @ CERN

Channel size modulation to control CO_2 boiling

D.Hellenschmidt et al,
Nucl. Instrum. Meth. A 958 (2020) 162535

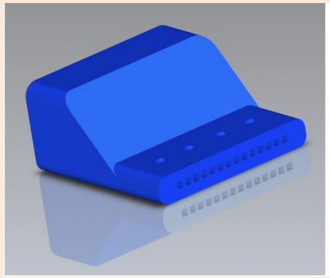


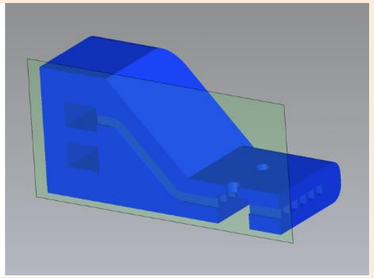


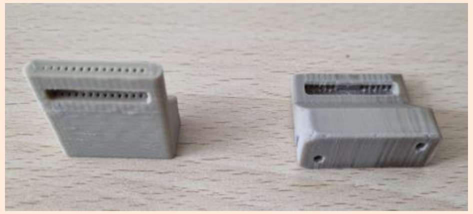
Values of TFM obtained down to 3!

Interconnectivity for micro-tubes

Prototypes produced by LPNHE & Pisa

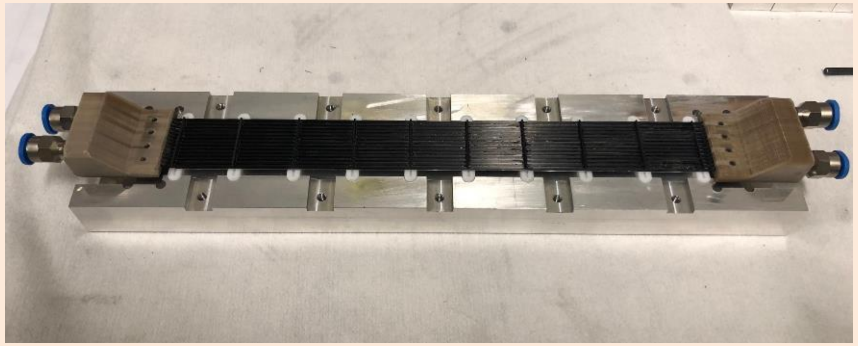






Y. Orain - LPNHE (peek - **thermoplastique**)

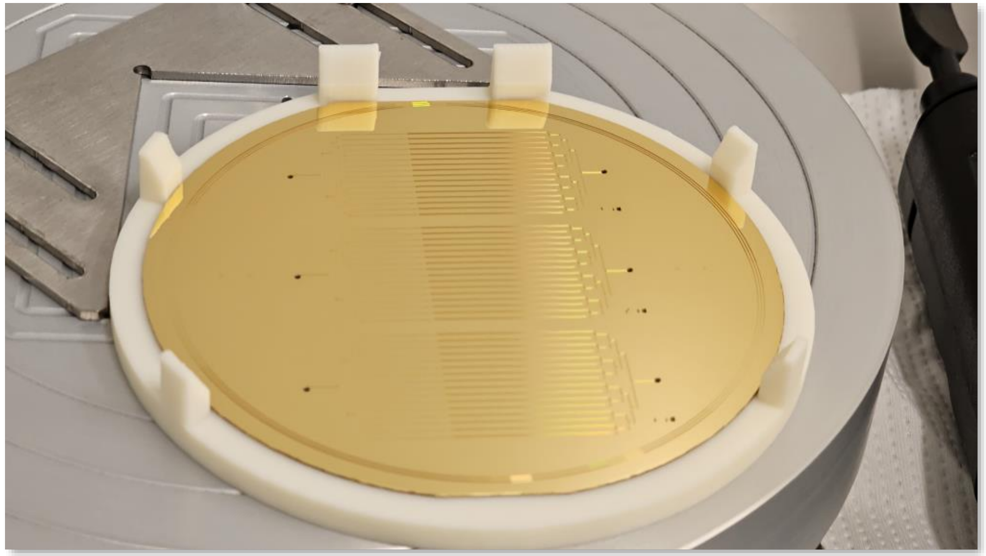
INFN Pisa (ceramic)

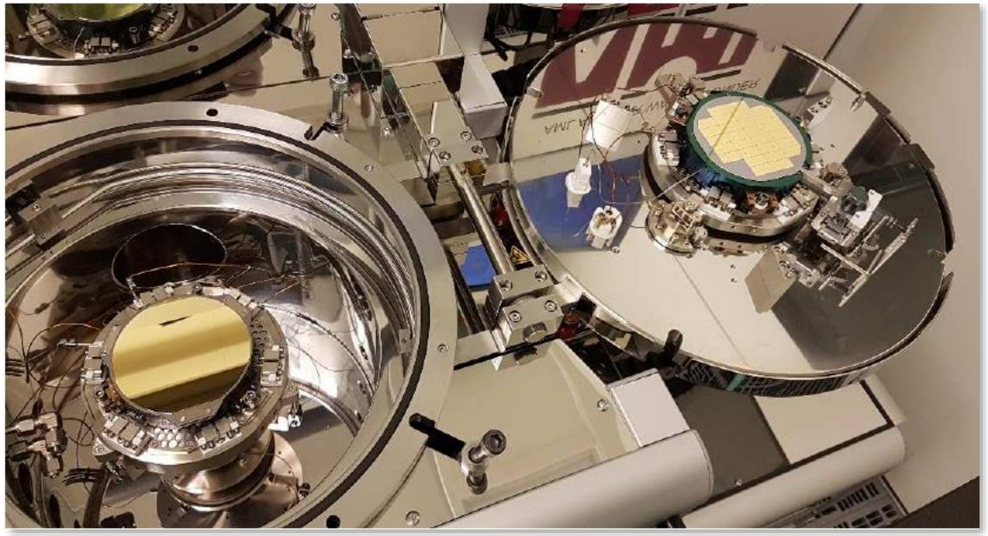


Short stave demonstrator

Micro-cooling @ CPPM : fabrication process

- Aim : Develop a low cost fabrication process for silicon cooling plates with micro-channels
- Focus :
  - ✓ Bond etched wafer and cover in a hyperbar chamber at room temperature with thin intermediate Au layers
  - ✓ Investigate fluidic connector bonding
- Currently : Characterize bond quality with acoustic imaging and high pressure test on dedicated micro-structures
- Goal : Produce functional cooling plates in 2025 and 2026 and characterize their thermal performances
- Context :
  - ✓ In2p3 R&T project
  - ✓ Participation in DRD7 & DRD8





Micro-cooling @ LEGI : cooling plate efficiency and simulation of boiling flow

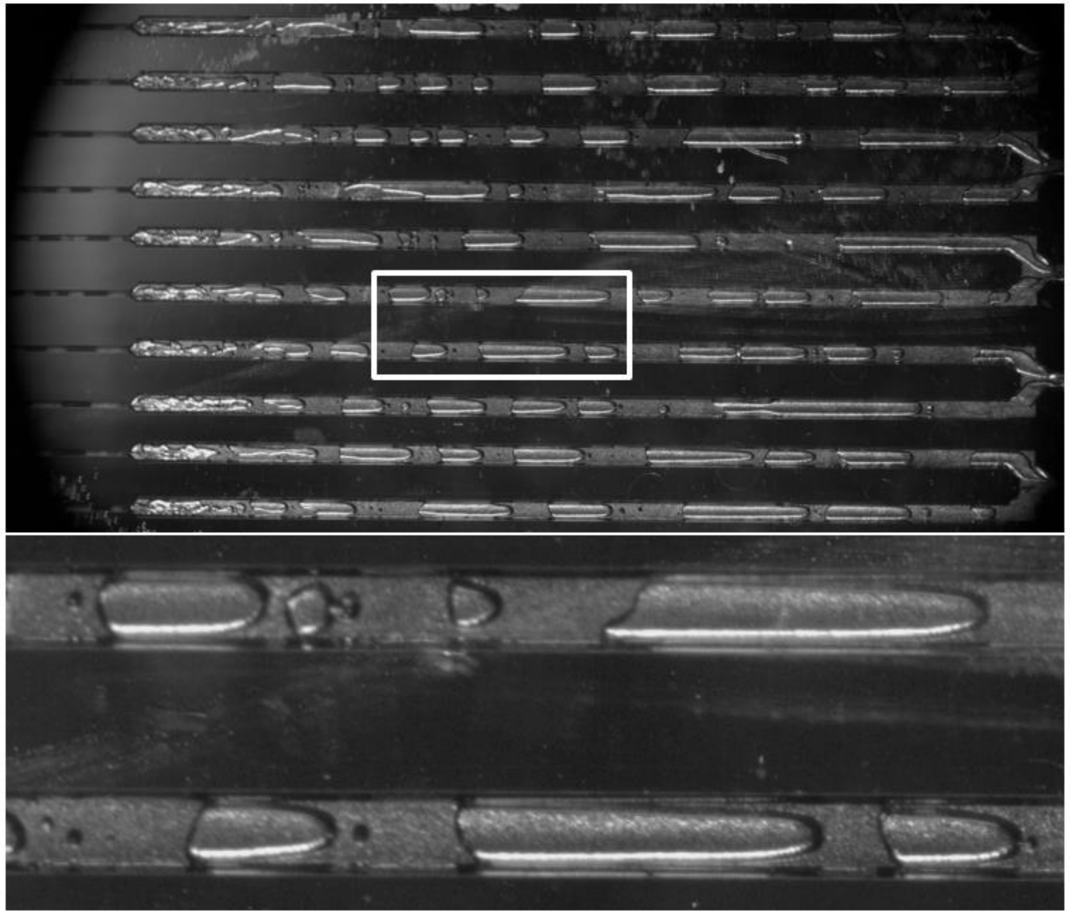
- Aim : Design of efficient cooling plates with micro-channels and simulation of boiling flow

- Focus :
  - Experimental flow regime and heat transfer characterization
  - Direct numerical simulation of boiling flow in microchannels
  - Investigate the coupling between flow and thermal cooling efficiency

- Currently : integration of thermal sensors and electrical heating onto the microfluidic to improve wall temperature measurement accuracy

- Goal : To identify a design that insures a homogeneous and efficient cooling, to propose a modelling approach in order to simplify chip design

- Context :
  - In2p3 R&T project
  - Participation in DRD7 & DRD8



In2p3 « microcanaux » R&T in DRD7 & 8

Available resources

projet "R&T Microcanaux” Ventilation DRD8 vs DRD7.4

Ingenieurs (FTE.month)		2025	2026	2027
DRD7.4c	CPPM	3	3	
DRD7.4c	LAPP			
DRD7.4c	LPNHE			
DRD7.4c	LPSC	1	1	

Physicists (FTE.month)		2025	2026	2027
DRD7.4c	CPPM	6	6	
DRD7.4c	LAPP	0,2	0,2	
DRD7.4c	LPNHE	1,3	1,3	
DRD7.4c	LPSC			

Ressources		2025	2026	2027
DRD7.4c	CPPM	8,3		
DRD7.4c	LAPP			
DRD7.4c	LPNHE	1		
DRD7.4c	LPSC	2,7		

Ingenieurs (FTE.month)		2025	2026	2027
DRD8	CPPM	0,8	0,8	
DRD8	LAPP			
DRD8	LPNHE	9	4	
DRD8	LPSC	4	4	

Physicists (FTE.month)		2025	2026	2027
DRD8	CPPM	1,5	1,5	
DRD8	LAPP	0,8	0,8	
DRD8	LPNHE	5,2	5,2	
DRD8	LPSC			

Ressources		2025	2026	2027
DRD8	CPPM	2,1		
DRD8	LAPP			
DRD8	LPNHE	4		
DRD8	LPSC	10,8		

LPNHE:

G. Calderini   10% -> 4 mois 2025-2027
S. Beaucheron 15% 26-27 (CR) -> 4 mois
N Garroum 10% (IR) -> 4 mois (intérêt confirmé mais FTE tbc)
Y. Orain 10% IE -> 4 mois
Y. Khwaira 6 mois

Microchannels: Connexion to Proposal for DRD8 (Oct. 2024)

Project 3.2: Microchannel Cooling Substrates

- CPPM (Aix Marseille Univ, CNRS/IN2P3) - *French Collaboration*[1]: Experience in the assembly, testing, and validation of silicon detectors in general (ATLAS) and in the development of micro-channel cooling plates. Recently, the development of bonding processes at room temperature in collaboration with the micro-fabrication CNRS laboratory FEMTO-ST.
- Laboratoire d'Annecy de Physique des Particules (LAPP) - *French Collaboration*[1]: Experience in CO_2 microchannels heat exchanger studies, thermal and mechanical simulations, characterisation and measurement on bi-phase CO_2 cooling test bench.
- LEGI - *French Collaboration*[1]: Experience in numerical modelling to simulate the flow of bi-phase coolant inside micro-channels. Microchannel heat exchanger production (etching, anodic silicon/Pyrex bonding and connectors brazing)
- Laboratoire de physique nucléaire et des hautes énergies (LPNHE) - *French Collaboration*[1]: Experience in assembly, construction and characterization of silicon pixel modules, design of micro-channel cooling plates and interconnections.

Milestones and Deliverables

Label	Topic	Task	Month	Description
D3.2.1	New round of 3D printing prototypes exploring different geometries	T4	9	
M3.2.1	Ceramics feasibility tests	T3	15	Public note or paper
M3.2.2	Prototypes bonded with thermo-compression or hyperbaric process characterisation	T2	18	
M3.2.3	3D printing	T4	24	Public note or paper
D3.2.2	Fluidic and thermal results from integrated system	T1	27	
M3.2.4	Bi-phase CO_2 thermo-fluidic models	T2	36	Bi-phase CO_2 Thermo-fluidic models development for microchannels/nuclear and annular flows. Heat exchanger characterisation and interconnections

Table 6: Summary of available and required resources for WP3 Project 2.

Institute	Effort [FTE/year]		Material budget [kCHF]	
	available	required	available	required
University of Manchester	1.0	1.5	30	90
French Collaboration	1.0	1.5	45	105

WP2: Mechanics for tracker (FCCee)

IP2I

Expression of interest IP2I-Lyon – DRD8

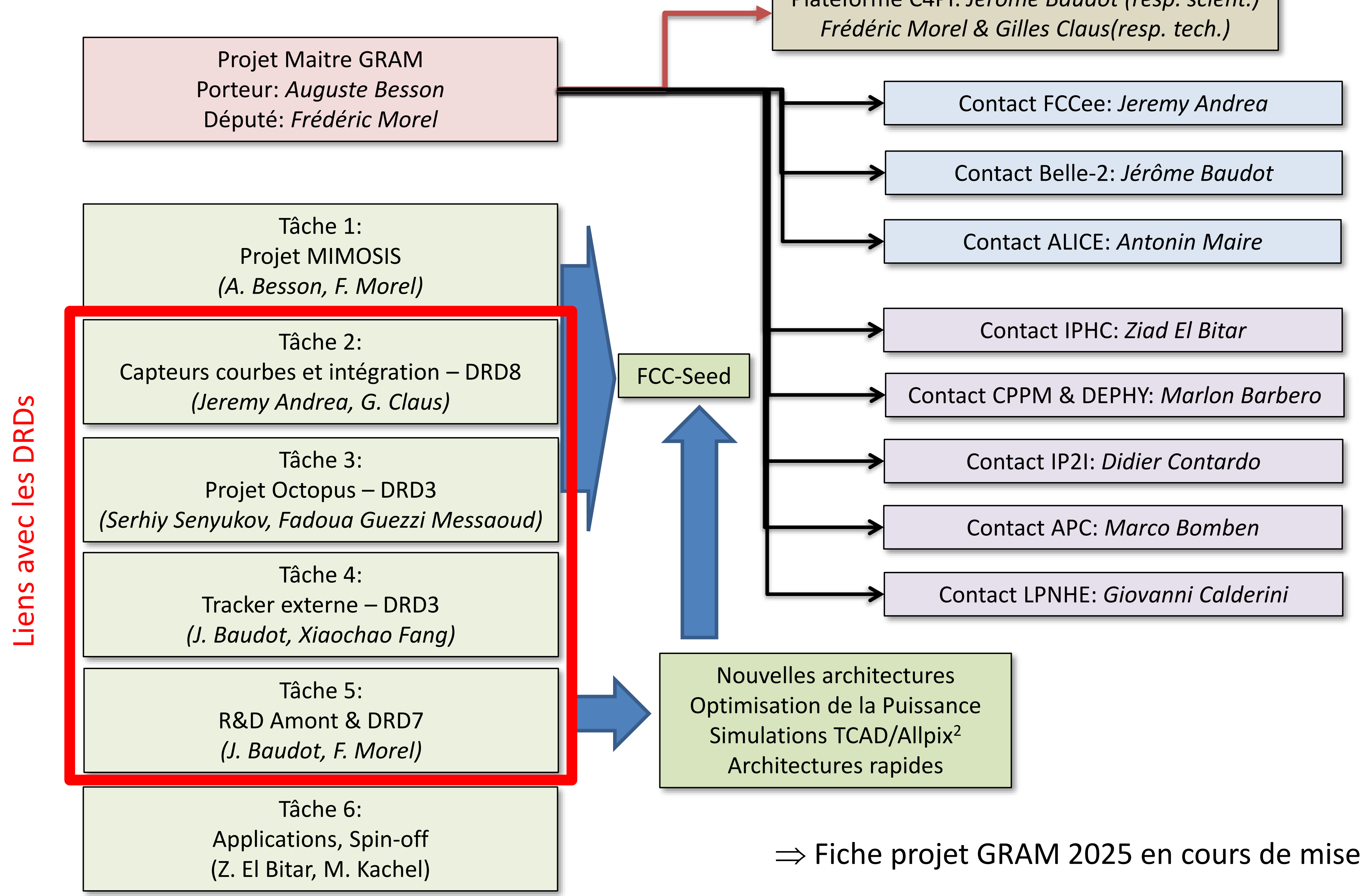
- Expression of interest submitted to ESPPU :
  - ✓ *Towards Time of Flight MCMOS tracking layers for a detector at FCC-ee (IRFU-IP2I)*
    - Developments of MCMOS sensors (fast timing and high spatial resolution)
  - ✓ Preparing R&D towards ultra-light, precise and stable mechanical structures for a tracking system at FCC-ee → *DRD8*
- Synergies :
  - ✓ CMOS-MAPS devpt, Simulations & physics performances, FCC-SEED
- Short-mid term :
  - ✓ Simulation of the impact of hardware introduced by 5D layers on the track reconstruction performance depending on their number and thermal consumption their radius
  - ✓ Study of in a simplified mechanical configuration
    - evaluation of cooling needs and their effect on the quantity of material depending on the dissipated power
    - minimizing the quantity of material with structures made from new materials and modern manufacturing techniques (orthotropic materials, additive manufacturing, etc.)
- Medium and long-term objectives
  - ✓ Mechanical configurations CAD modelling
  - ✓ Preparation of models and prototypes
  - ✓ Development of an end-to-end / digital twin approach from design to system integration
- Ressources
  - ✓ No specific request in the context of DRD8 at this stage
  - ✓ However, travel budget will very likely be requested in 2026 (to be quantified, it depends on the IP2I technical ressources allocation, under discussion)

DRD8 Summary

- Work on evaluating RH : preliminary results
  - ✓ Microchannels: to be shared between DRD7 / 8
    - LPNHE : ~23 ETP.mois
    - CPPM : ~5 ETP.mois
    - LAPP :1.6 ETP.mois
    - LPSC: 8 ETP.mois
  - ✓ Bent sensors: 2024-27
    - IPHC: 60 ETP.mois (including apprentice)
    - CPPM: 6 ETP.mois
  - ✓ Mechanics for tracker
    - IP2I: tbd
- Work on evaluating funding resources for DRD8 has begun
  - ✓ Microchannels: currently funded by in2p3 & AIDAInnova
    - ongoing
  - ✓ Bent sensors: currently funded by GRAM
    - GRAM Budget 2025 request: 10 keuros
      - $\Rightarrow$ rising project (mechanics added) ~15 keuros/yr on 2025-27
      - Mandrell, flex cable, bonding, connectors, tests
    - + apprentice on mechanics to be supported by IPHC/GRAM/IN2P3: 9 keuros/yr for 3 years (2025-28)
  - ✓ Mechanics for tracker
    - ongoing

backup

Proposition Organigramme GRAM 2025



⇒ Fiche projet GRAM 2025 en cours de mise à jour

DRD3 WP1 projects

Contact person	Project title	Technology	Research Goal	Target applications
Simon Spannagel	Octopus – Fine-pitch CMOS pixel sensors with precision timing for vertex detectors at future Lepton-Collider experiments and beyond	TPSCo 65 nm	RG1, RG3	FCCee, vertex
Didier Contardo	TPSCo 65 nm MCMOS with high precision timing	TPSCo 65 nm	RG2, RG3	FCCee, tracker, pre-shower
Heiko Augustin	Evaluation of new presses option(s) for large fill-factor HVCMOS sensors (Xfab) and Internal Gain Layer for HVCMOS sensors	Xfab/IHP SiGe	RG2	PSI, tracker
Philippe Schwemling	Towards large electrode CMOS sensors with intrinsic amplification for ultimate timing performance	LF 150 nm	RG2	Tracker
Heinz Pernegger	CASSIA – CMOS Active SenSor with Internal Amplification	TJ 180 nm	RG2	Generic R&D
Artur Apresyan	Development of Ultra Fast-Time Low Mass Tracking Detectors	US vendor	RG2, RG3	Tracker
Caternia Vernieri	MAPS developments at SLAC	TPSCo 65 nm	RG3	FCCee, tracker, calo
Yiming Li	Development of HVCMOS sensors using 55 nm process	SMIC 55 nm	RG3, RG4	HL-LHC, FCCee, tracker
Carlos Solans	Radiation hard read-out architectures	TJ 180 nm	RG3, RG4	HL-LHC, tracker
Jerome Baudot	Versatile CMOS pixel sensor suited for future trackers	TPSCo 65 nm	RG4 (RG4)	Tracker
Alexander Dierlamm	Monolithic sensors, fast electronics, and silicon photonics for future tracking detectors	IHP SiGe	RG3 (RG4)	FCCee, tracker
Eva Vilella	Thin monolithic High Voltage CMOS sensors with excellent radiation tolerance	LF 150 nm	RG4	HL-LHC, tracker
Uli Parzefall	MASSATI – Monolithic Active Strip Sensors for Applications in future Tracking detectors & medical Imaging	LF 150/110 nm	RG5	Tracker
Attilio Andreazza	HV-CMOS Multi-chip integration for large area silicon trackers	180/150 nm	RG5	FCCee. Tracker
Xin Shi	CMOS Strip Chip for Future Tracking Detector	CSMC 180 nm	RG5	CEPC, tracker
Attilio Andreazza	Arcadia	LF 110 nm		
Alessandro Tricoli	Development of Ultra-Fast-Time Low Mass Tracking Detectors			

Submitted to CDS; switched to common fund project

Research goals DRD3 WG1

<table>
<tr><th colspan="2">DRD3 WG1 Monolithic silicon sensors</th><th colspan="4">Assess technology performance for each RG - handle technical solution options for strategic programs of LS4 time scale</th><th>Toward 4D-tracking for future colliders</th></tr>
<tr><td rowspan="4">Research Goals</td><td>Timeline</td><td>2024</td><td>2025</td><td>2026</td><td>2027</td><td>≳ 28</td></tr>
<tr><td>Technologies</td><td colspan="5">Foundry submissions and Milestonses (MS)</td></tr>
<tr><td>TPSCo (TJ) 65 nm</td><td>design MPW1.1</td><td>submit MPW1.1
Q4-2025 (MLR2)</td><td>evaluate MPW1.1
design MPW1.2</td><td>submit MPW1.2
Q2-2027 (MLR3)</td><td rowspan="2">evaluate MPW1.2 (TJ 65 nm),
design/submit/evaluate
MPW1.3-1.n (all technologies)
(possibly including in common submissions
ER designs for dedicated experiments)</td></tr>
<tr><td>TJ/AMS 180 nm, LFoundry 110/150 nm, IHP 130 nm</td><td>design MPW1.1
submit MPW1.1 Q4-2024</td><td>evaluate MPW1.1
design MPW1.2</td><td>submit MPW1.2 Q1-2026</td><td>evaluate MPW1.2</td></tr>
<tr><td rowspan="2">RG1
Position precision</td><td>TPSCo (TJ) 65 nm</td><td colspan="2">electrode size/shape/pitch, process variants
12” ER splits, thin epitaxial layer, stitching
optimized for high channel density (low pitch)</td><td rowspan="2">MS1
establish position precision versus technology, channel configuration and readout mode</td><td rowspan="2">MS6
handle technical solutions for Vertex Detector (ALICE-3, LHCb-</td><td rowspan="2"></td></tr>
<tr><td>TJ/AMS 180 nm, LFoundry 110/150 nm, IHP 130 nm</td><td colspan="2">electrode size/shape/pitch, wafer type/thickness, process variants
8” ER or MLM splits</td></tr>
</table>

DRD3 effort

Table 10: Summary of existing and to be requested resources.

Project	**Effort [FTE/year]**		**Material budget [kCHF]**	
	available	**required**	**available**	**required**
Project 1.1	9.7	15.4	650	1530
Project 1.2	3.0	4.0	120	220
Project 2.1	7.7	13.0	190	500
Project 2.2	4.5	8.5	85	245
Project 3.1	3.0	4.5	30	200
Project 3.2	5.5	10.5	285	1030
Project 4.1	0.4	1.7	0	80
Project 4.2	1.5	4.7	0	20
Grand total	**35.3**	**62.3**	**1360**	**3825**

Spatial resolution per layer	$\simeq 3$	μm
Pixel pitch	14-20	μm [1]
read-out time	$\simeq 500$	ns [2]
Power dissipation	$\simeq 20-50$	mW/cm^2
Sensor thickness	$40-50$	μm [3]
Safety factor on particle rate	3	[4]
Maximum Hit rate	75 / 25	MHz/cm^2 [5]
Maximum Hit rate	22.5×10^{-3} / 7.5×10^{-3}	$hits/mm^2/BX$ [5]
Assumed cluster multiplicity	5	
Fired pixel rate	375 / 125	MHz/cm^2 [5]
Fired pixel rate	0.33 / 0.11	$fired\ pixels/mm^2/BX$ [5]
Occupancy/pixel/read-out	3.45×10^{-3} / 1.15×10^{-3}	$/pixel/readout$ [5]
Ionising radiation (1^{st} layer)	30 / 10	$MRad/year$ [5] [6]
Corresponding Fluence	$\simeq 1.8 \times 10^{14}$ / 6×10^{13}	$n_{eq(1\ MeV)}/year$ [5] [7]

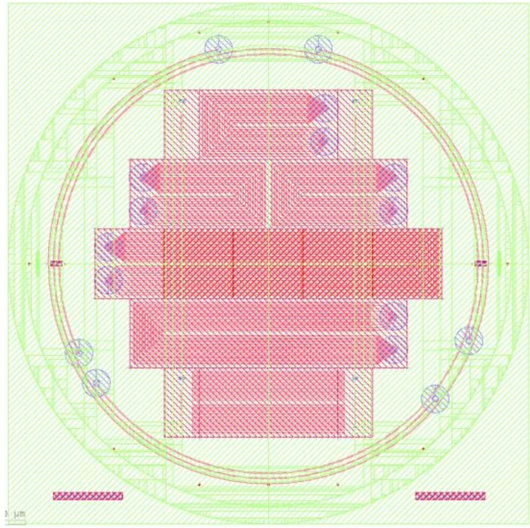
[1] Depending on charge sharing/encoding
[2] Compromise between power dissipation and pile-up at $\sqrt{s} = 91\ GeV$
[3] To allow bending
[4] due to beam background uncertainties estimates
[5] With / without safety factor
[6] assuming beam running 180 days/year, and average incident angle of $\simeq 70^o$.
[7] assuming NIEL factor of 5×10^{-2}

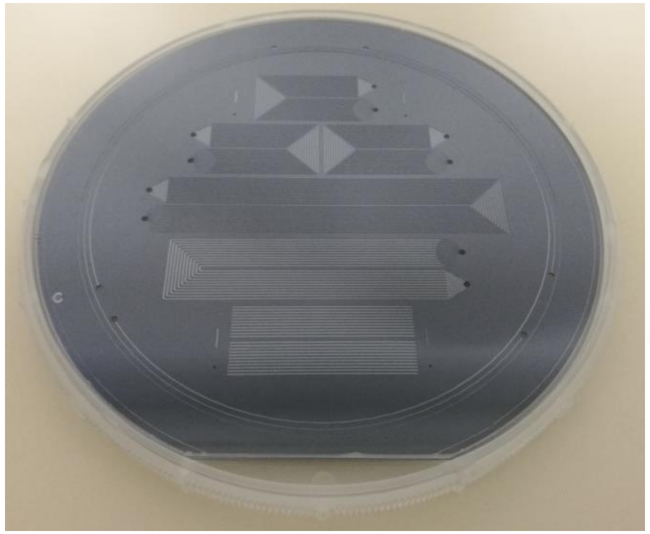
Micro-channel structures originally developed following two axes:
- develop cooling blocks for demonstrator suitable with our ATLAS ITk silicon modules
- develop structures able to study the evaporative behaviour of CO_2 in channels and compare with models

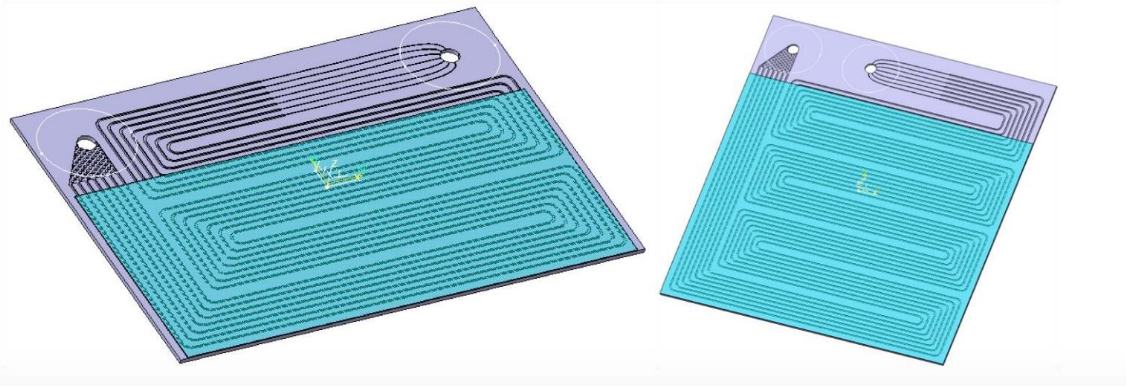
A few runs have been made in collaboration with FBK Trento, to build single-chip and multi-chip substrates to be used to measure the thermal performance when loaded with ITk modules

Activity funded by AIDA-2020/AIDAInnova and IN2P3 projects

"Snake" design microchannel cooling unit size		
Design	Width [mm]	Height [mm]
Single	30.0	30.0
Double	30.0	41.3
Quad	42.4	48.0

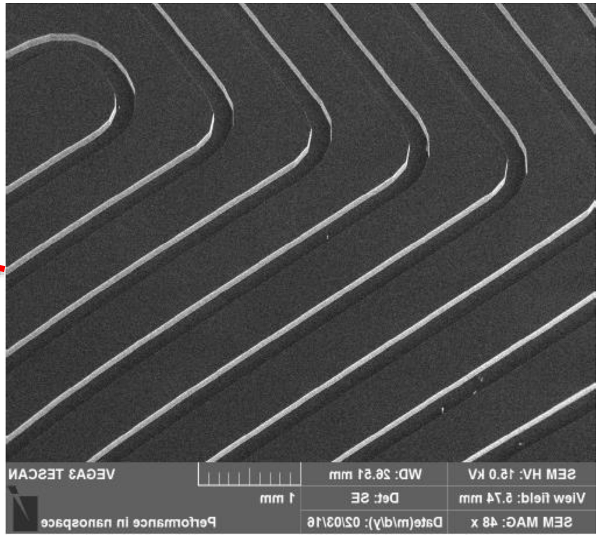


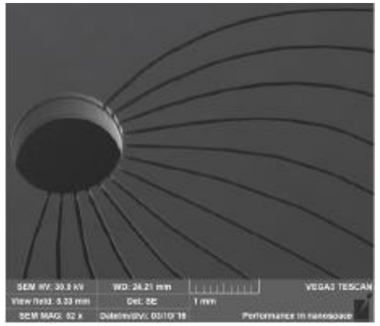




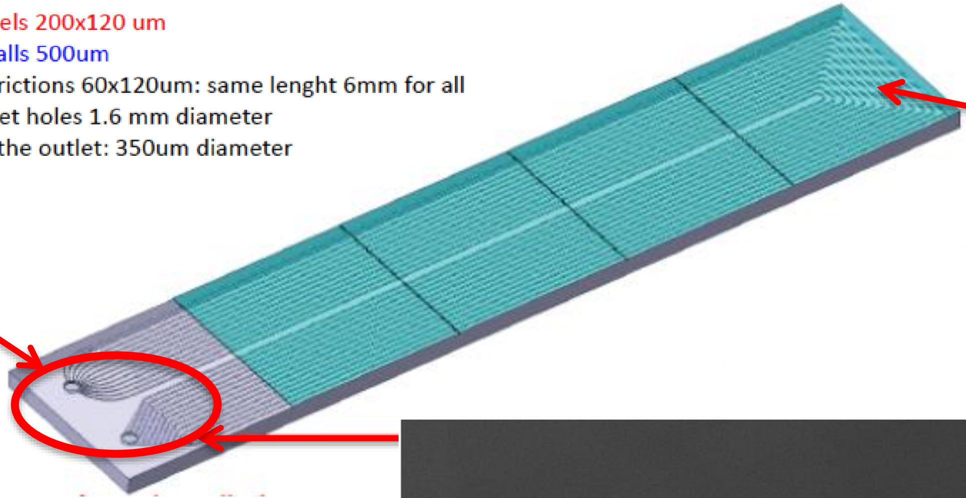
Prototypes produced by LPNHE with FBK

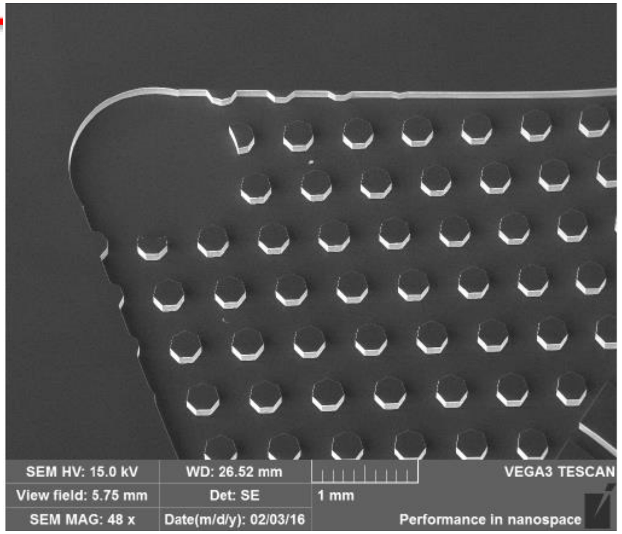
Details of the channel design



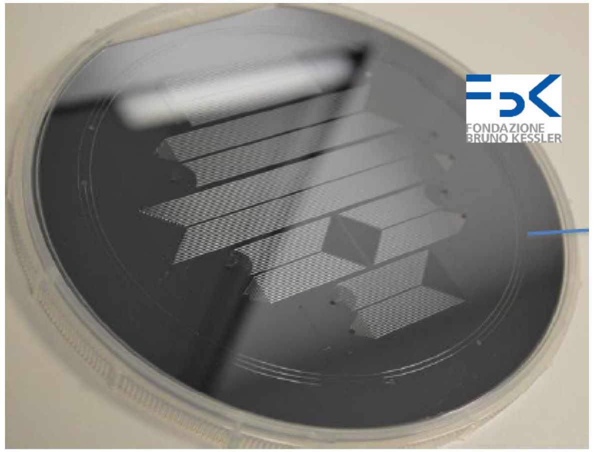


13 channels 200x120 um
Silicon walls 500um
Inlet restrictions 60x120um: same lenght 6mm for all
Inlet outlet holes 1.6 mm diameter
Pillars in the outlet: 350um diameter

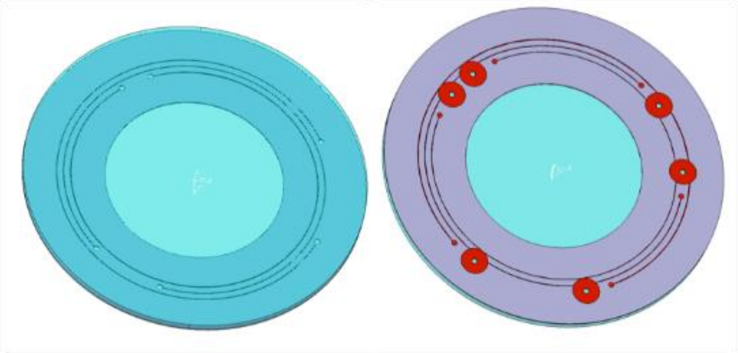




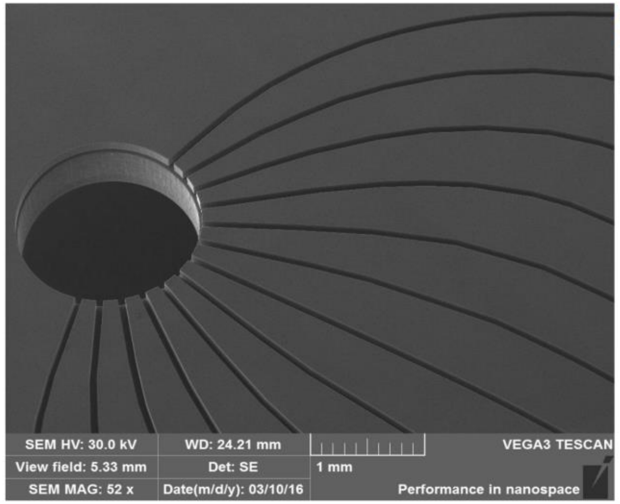
D.Hellenschmidt et al,
Nucl. Instrum. Meth. A 958 (2020) 162535



Long channels running around the border for better evaporation studies

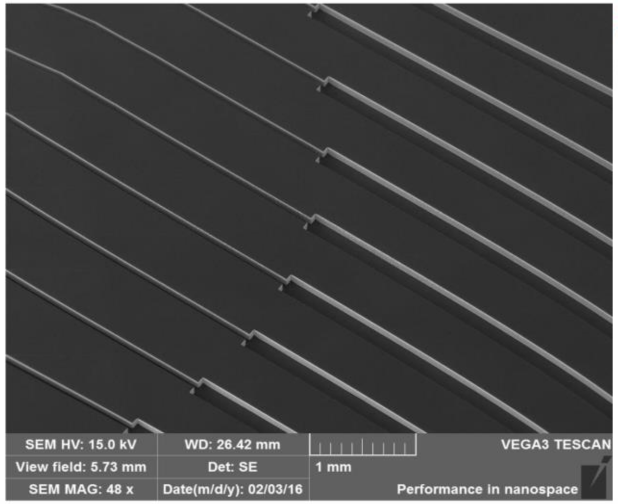


Inlet fanout



FONDAZIONE BRUNO KESSLER

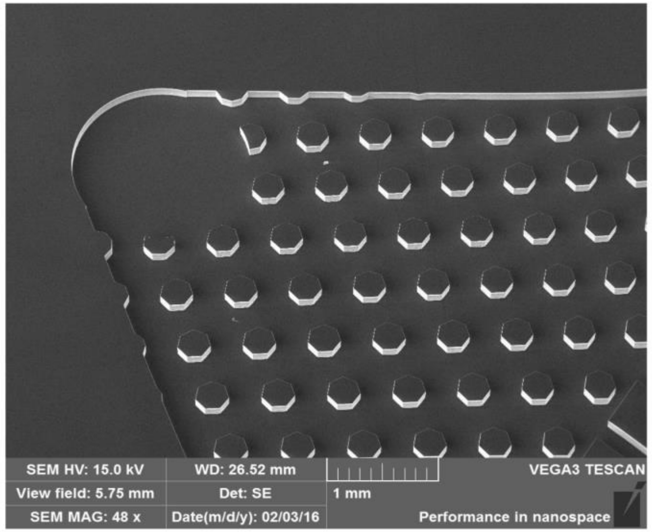
Channel size modulation to control CO2 boiling



FONDAZIONE BRUNO KESSLER

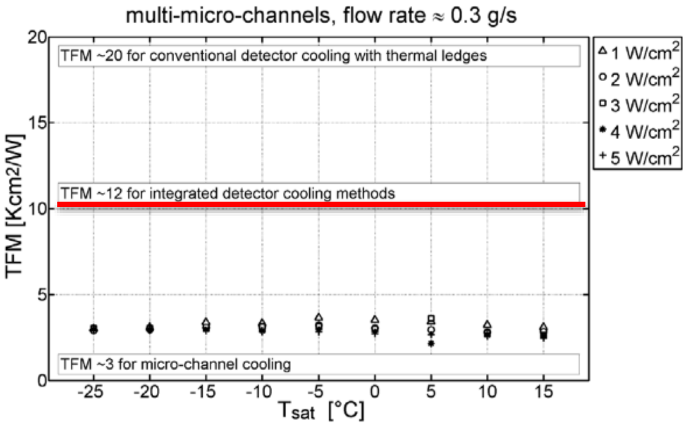
Connected et tested at CERN EP-DT (P. Petagna)

Detail of the outlet; pillars to reduce the surface (force) on the glass cover



FONDAZIONE BRUNO KESSLER

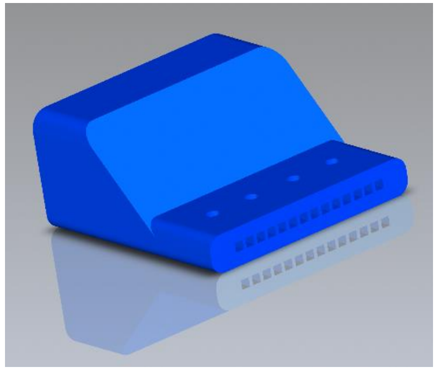
D.Hellenschmidt et al,
Nucl. Instrum. Meth. A 958 (2020) 162535

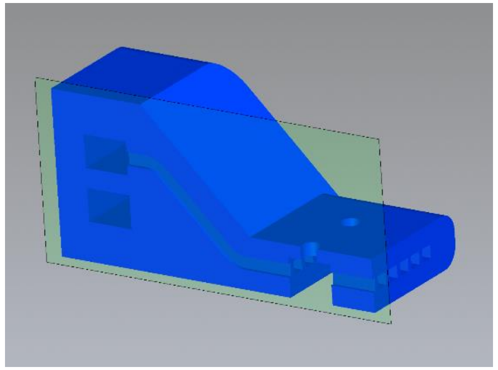


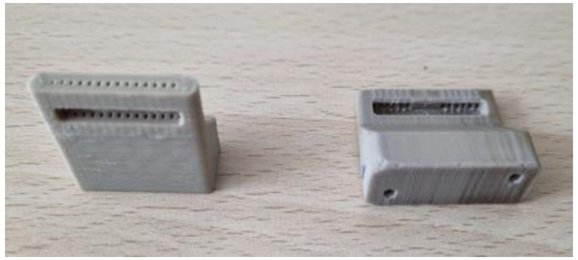
Values of TFM obtained down to 3!

Alternative microchannel technique in AIDAInnova (collaboration with INFN PISA)

Use of carbon fiber pipes: length is less of a limitation with respect to silicon channels (wafer size)





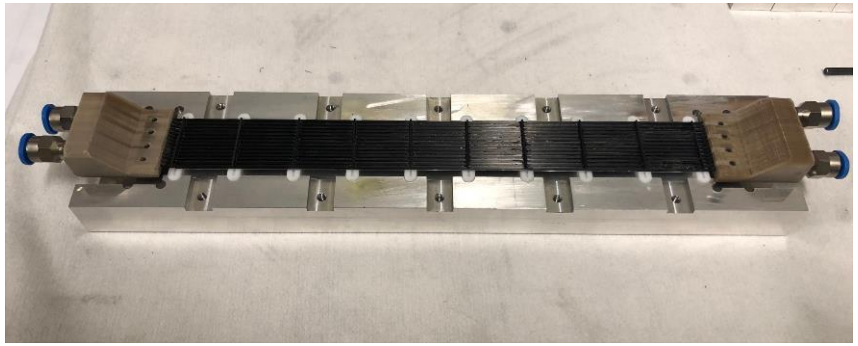


LPNHE Paris
(peek)

INFN Pisa
(ceramic)

Design and development of interconnection blocks
Due to internal complex structure, parts in peek printed in 3D with printer at LPNHE (in draft print mode, to test the structure)

The blocks in peek have not performed well during tests with liquid coolant, with leaks at pressures of some bars, this has been tracked to be due to the material deposition sequence.



New prototypes printed at DEMCON Bond 3D (NL) (specialized company for peek)
- under test

New run also at Novadditive (Tarbes, France) (ceramics: alumine)
- at the company

New run with the new 3D printer at LPNHE

MIMOSIS Sensor

Supported by Bundesministerium für Bildung und Forschung (05P19RFFC1)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072

- MIMOSIS sensor for CBM-MVD @ FAIR
  - ✓ Based on ALPIDE architecture
    - Multiple data concentration steps
    - Elastic output buffer
    - 8 x 320 Mbps links (switchable)
    - Triple redundant electronics
  - ✓ A milestone for Higgs factories
    - « 5 µm / ≤5 µs » + enhanced bandwidth
    - Improve radiation hardness

Physics parameter	Requirements
Spatial resolution	~ 5 um
Time resolution	~ 5 us
Material budget	0.05% X_0
Power consumption	< 100 – 200 mW/cm^2
Operation temperature	- 40 °C to 30 °C
Temp gradient on sensor	< 5K
Radiation tol* (non-ion)	~ 7 x 10^{13} n_{eq}/cm^2
Radiation tol* (ionizing)	~ 5 MRad
Data flow (peak hit rate)	@ 7 x 10^5 / (mm^{2}s) > 2 Gbit/s

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[f] Facility for Antiproton and Ion Research in Europe GmbH, Germany

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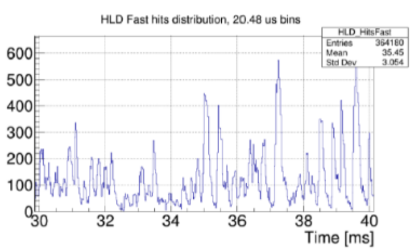
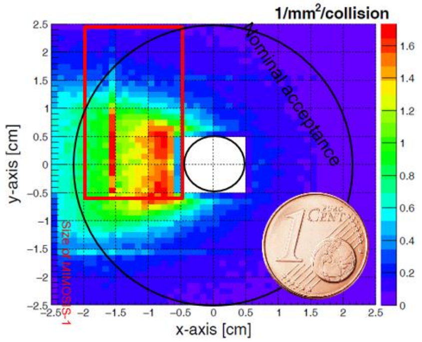
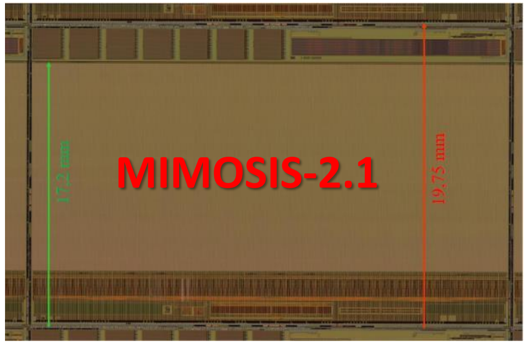
Requirements already achieved with MIMOSIS-1

kHz modulation ON





Parameter	Value
Technology	TowerJazz 180 nm
Epi layer	∼ 25 µm
Epi layer resistivity	> 1kΩcm
Sensor thickness	60 µm
Pixel size	26.88 µm × 30.24 µm
Matrix size	1024 × 504 (516096 pix)
Matrix area	≈ 4.2 cm^2
Matrix readout time	5 µs (event driven)
Power consumption	40-70 mW/cm^2



MIMOSIS-0 (2018)
- Demonstrate pixel concept.
- Demonstrate zero suppression.
- Demonstrate readout concept.

MIMOSIS-1 (2020)
- Full dimension sensor
- Add buffer structure.
- SEE hardening 1/2

MIMOSIS-2 (Q2/2023) Major issues
- On-chip pixel grouping.
- Final pixels.
- SEE hardening 2/2
- MIMOSIS-2.1

MIMOSIS-2.1 (Q4 2023)
- = M-2 corrected
- Delivered May 2024
- Tested in beam in July-September 2024

MIMOSIS-3
- Final sensor for mass production
- Submission in 2025

Octopus FTE ~170 ETP mois (2024-2028)

- IPHC

(in line with the IPHC scientific council of 2023 and GRAM plans)

task OCTOPUS	name	2024				2025				2026				2027				2028				total ETP (mois)
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Coordination scientifique	Auguste Besson	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	3,00
Coordination scientifique	Jérôme Baudot	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	3,00
Coordination scientifique	Marlon Barbero	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	3,00
Coordination technique WP2	Fadoua Guezzi				50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	25,50
Coordination technique WP2	Serhiy Senyukov				50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	25,50
Coordination technique	Frédéric Morel				10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	5,10
Design Octopus-1 (MPR2)	Fadoua Guezzi				50%	50%	50%	50%	50%	50%	50%											10,50
	Andrei Dorokhov				10%	30%	30%	30%	30%	30%	30%											5,70
	Isabelle Valin					10%	10%	30%	30%	30%	30%											4,20
	Gregory Bertolone					30%	30%	30%	30%	30%	30%											5,40
	Liana Wassouf							70%	70%	70%	70%											8,40
	Mohsine Menouni							25%	25%	25%	25%											3,00
	Patrick Pangaud									25%	25%											1,50
fabrication Octopus-1 (MPR2)	Gregory Bertolone							10%			10%	10%										0,90
																						0,00
Octopus-1 microtec.	Olivier Clausse												5%									0,15
	Christophe Wabnitz												10%	10%								0,60
Octopus-1 tests	Gilles Claus													25%								0,75
	Mathieu Goffe													25%								0,75
	Kimmo Jaaskelainen													25%								0,75
	Matthieu Specht												100%	25%								3,75
	Pierre Barrillon												50%	50%								3,00
	D. Fougeron/P. Breugnon												50%	50%	50%	50%						6,00
Design Octopus-2 (MPR3)	Fadoua Guezzi											50%	50%	50%	50%	50%	50%	50%	50%			12,00
	Andrei Dorokhov												10%	30%	30%	30%	30%	30%	30%			5,70
	Isabelle Valin													10%	10%	30%	30%	30%	30%			4,20
	Gregory Bertolone													30%	30%	30%	30%	30%	30%			5,40
	Liana Wassouf													70%	70%	70%	70%	70%	70%			12,60
	Mohsine Menouni												25%	25%	25%	25%						3,00
	Patrick Pangaud														25%	25%						1,50
fabrication Octopus-2 (MPR3)	Gregory Bertolone															10%			10%	10%		0,90
																						0,00
Octopus-2 microtec.	Olivier Clausse																					0,00
	Christophe Wabnitz																					0,00
																						0,00
Octopus-2 tests	tbd																					0,00
	tbd																					0,00
	tbd																					0,00
	tbd																					0,00
TOTAL		15%	15%	15%	185%	245%	245%	370%	360%	385%	395%	185%	425%	550%	415%	445%	335%	335%	345%	135%	125%	165,75

Total RH	total ETP (mois)
Auguste Besson	3,00
Jérôme Baudot	3,00
Marlon Barbero	3,00
TOTAL physicists	9,00
Fadoua Guezzi	48,00
Serhiy Senyukov	25,50
Frédéric Morel	5,10
Isabelle Valin	8,40
Andrei Dorokhov	11,40
Gregory Bertolone	12,60
Liana Wassouf	21,00
Mohsine Menouni	6,00
Patrick Pangaud	3,00
Mathieu Goffe	0,75
Gilles Claus	0,75
Jean-Sebastien PELLE	0,00
Matthieu Specht	3,75
Kimmo Jaaskelainen	0,75
Pierre Barrillon	3,00
D. Fougeron/P. Breugnon	6,00
Olivier Clausse	0,15
Christophe Wabnitz	0,60
TOTAL IT	156,75
GRAND TOTAL	165,75

~ 165 ETP.mois over 4 years

~8 IT with significant involvement

- CPPM: currently joining, about 20 ETP.mois over 3 years (design + tests)
  - M. Barbero, M. Menouni, P. Barrillon, D. Fougeron, P. Pangaud
- APC: M. Bomben: 0.1 FTE ~ 4-5 ETP mois over 4 years (simulation)

- Needs: current proposal is conservative
  - ➢ Post-doc for tests ?
  - ➢ Designers slightly understaffed, to be completed by collaborators

Versatile tracker

task TRACKER	name	2024				2025				2026				2027				2028				total ETP (mois)
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Coordination scientifique	Jérôme Baudot	0%	0%	0%	5%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	4,95
Coordination technique	tbd				0%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	4,80
Coordination technique					0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0,00
design tracking	Xia Chao					50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	24,00
	Luca Federici					10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	4,80
	Andrei Dorokhov					10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	4,80
	Isabelle Valin					20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	9,60
fabrication (MPR2)	Gregory Bertolone											10%	10%									0,60
microtec.	Olivier Clausse													10%								0,30
	Christophe Wabnitz													10%								0,30
Tests	Mathieu Goffe													5%								0,15
	Matthieu Specht													5%								0,15
	Gilles Claus													5%								0,15
	Kimmo Jaaskelainen													5%								0,15
TOTAL		0%	0%	0%	5%	110%	110%	110%	110%	110%	110%	120%	120%	150%	110%	110%	110%	110%	110%	110%	110%	54,75

Total RH	total ETP (mois)
Jérôme Baudot	4,95
TOTAL physicists	4,95
Xia Chao	24
Luca Federici	4,8
Andrei Dorokhov	4,8
Isabelle Valin	9,6
Gregory Bertolone	0,6
tbd	4,8
Olivier Clausse	0,3
Christophe Wabnitz	0,3
Mathieu Goffe	0,15
Matthieu Specht	0,15
Gilles Claus	0,15
Kimmo Jaaskelainen	0,15
TOTAL IT	49,80
GRAND TOTAL	54,75

- Resources w.r.t. DRD proposal
  - ✓ Under discussion

WG4 research goals <2027

	Description
RG 4.1	Flexible CMOS simulation adaptable to different technology nodes and development of connections between tools for device-level simulation and electronic circuit design/validation
RG 4.2	Implementation of newly measured semiconductor properties into TCAD and MC simulations tools
RG 4.3	Definition of benchmark for validating the radiation damage models with measurements and different benchmark models.
RG 4.4	Developing of bulk and surface model for $10^{16}\text{cm}^{-2} < \Phi_{eq} < 10^{17}\ \text{cm}^{-2}$
RG 4.5	Collate solutions from different MC tools and develop an algorithm to include adaptive electric and weighting fields

Table 9: WG4 research goals in the period 2024 - 2026

R&D Amont

task	name	2024				2025				2026				2027				2028				total ETP (mois)
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Coordination scientifique	Jérôme Baudot	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	3
Coordination technique	Frédéric Morel	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	6
Coordination technique	Andrei Dorhokov	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	6
Coordination technique	Maciej Kachel	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	6
R & D amont	Andrei Dorhokov	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	3
	Luca Federici	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	6
	Hung Pham	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	6
	Abdelkader Himmi	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	6
	Rachid Sefri	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	6
PhD	Jean Soudier	100%	100%																			6
PhD	Elio Sacchetti	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%											30
PhD	Hasan Shamas	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%											30
fabrication (ER2)	Gregory Bertolone					10%																0,3
sparc microtec	Christophe Wabnitz								10%													0,3
PCB	Matthieu Specht							30%														0,9
test SPARC	Gilles Claus					10%	10%		10%													0,9
	Mathieu Goffe								30%													0,9
	Kimmo Jaaskelainen																					0
	Matthieu Specht					20%	20%		10%													1,5
	Willy Perrin					100%	100%		100%													9
TOTAL		380%	380%	280%	280%	420%	410%	310%	440%	280%	280%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	127,80

Total RH	total ETP (mois)
Jérôme Baudot	3
TOTAL physicists	3,00
Frédéric Morel	6
Andrei Dorhokov	9
Luca Federici	6
Hung Pham	6
Abdelkader Himmi	6
Rachid Sefri	6
Maciej Kachel	6
Jean Soudier	6
Elio Sacchetti	30
Hasan Shamas	30
Gregory Bertolone	0,3
Christophe Wabnitz	0,3
Gilles Claus	0,9
Mathieu Goffe	0,9
Kimmo Jaaskelainen	0
Matthieu Specht	2,4
Willy Perrin	9
TOTAL IT	124,80
GRAND TOTAL	127,80

- Includes

Nouvelles architectures
Optimisation de la Puissance
Simulations TCAD/Allpix^2
Architectures rapides

- Resources w.r.t. DRD proposal
  - ✓ Under discussion