CMOS R&D for FCCee

(in the french landscape)

HEP CMOS R&D landscape in France vs projects & DRDs

Master Projects

MP GRAM

Projet Maître GRAM
Porteur: *Auguste Besson*
Député: *Frédéric Morel*

Liens avec les DRDs

- Projet 1: Projet MIMOSIS (*A. Besson, F. Morel*)
- Projet 2: Capteurs courbes et intégration – DRD8 (*Jeremy Andrea, Eric Vigeolas*)
- Projet 3: Vertex / Octopus – DRD3 (*Serhiy Senyukov, Fadoua Guezzi Messaoud*)
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- Projet 5: R&D Amont & DRD7 (*J. Baudot, F. Morel*)
- Projet 6: Applications, Spin-off (Z. El Bitar, M. Kachiel)

FCC-Seed

Nouvelles architectures
Préamplification
Optimisation de la Puissance
Simulations TCAD/Allpix²
Architectures rapides

MP DEPHY

Projet DEPHY
Porteur: Marlon Barbero. Député: Mohsine Menouni

DRD 3 / DRD 7

- Projet 1: (resp. M. Menouni/ CPPM) Tolérance aux radiations
- Projet 2: (resp. G. Calderini / LPNHE) Pixels 4D, LGAD, interconnexions
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R&D amont:
* Tol radiation FCC-ee
* Contexte collisionneurs hadroniques
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* Soutien accès TPSCo65
* Soutien FCC-Seed
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OBELIX

- Projet 4: (resp J. Baudot / IPHC) R&D OBELIX

Upgrade Belle2

Laboratories

- APC
- CPPM
- IP2I
- IPHC
- C4PI
- LPNHE
- IRFU

FCC detectors

- Vertex detector (FCC-Seed)
- Outer tracker
- Timing / PID
- Detector optimization & software

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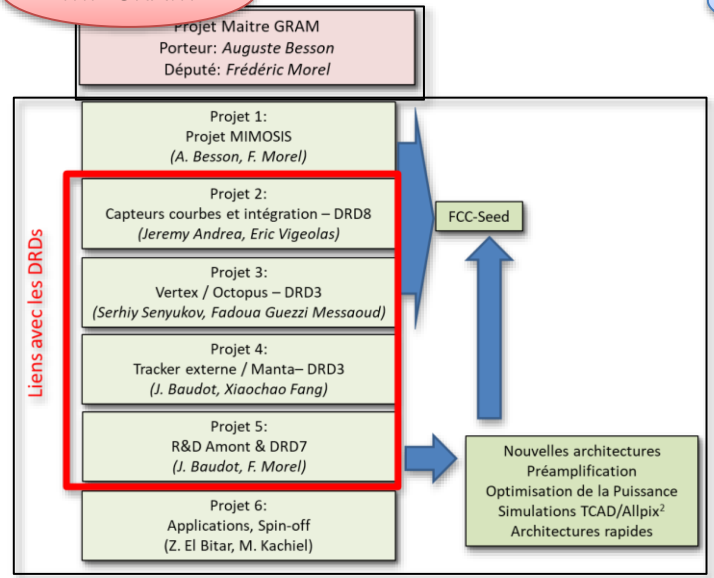

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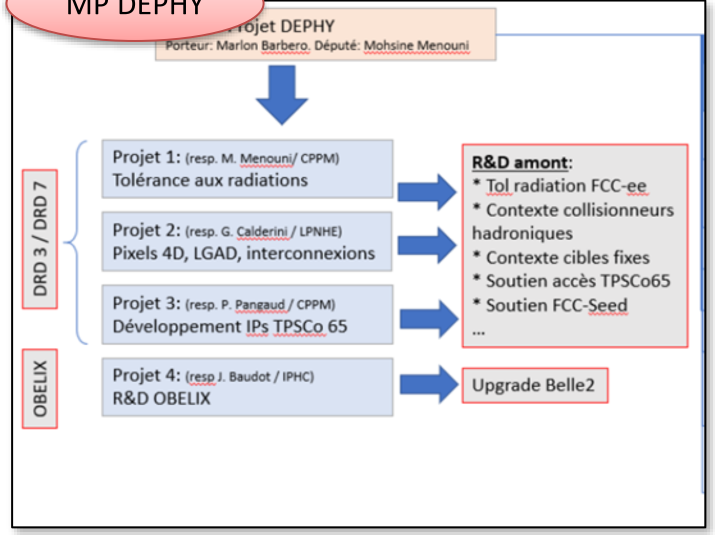

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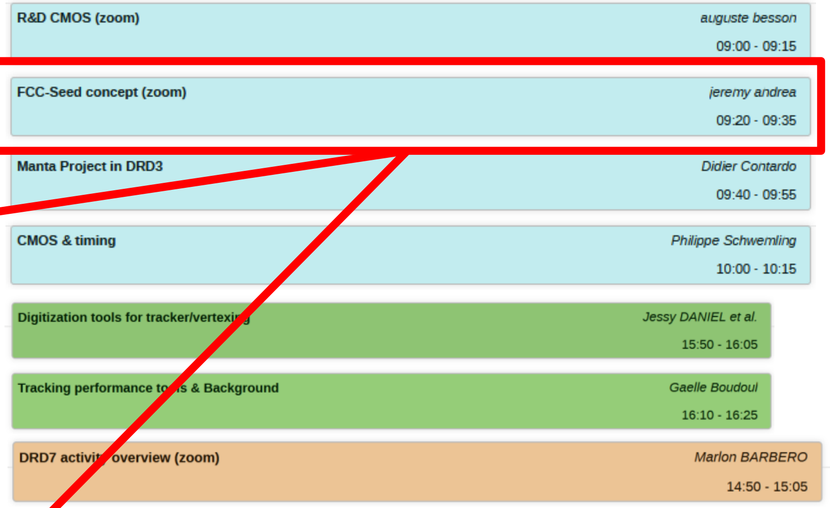

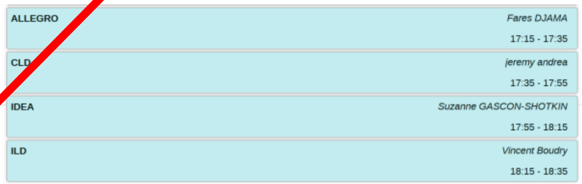

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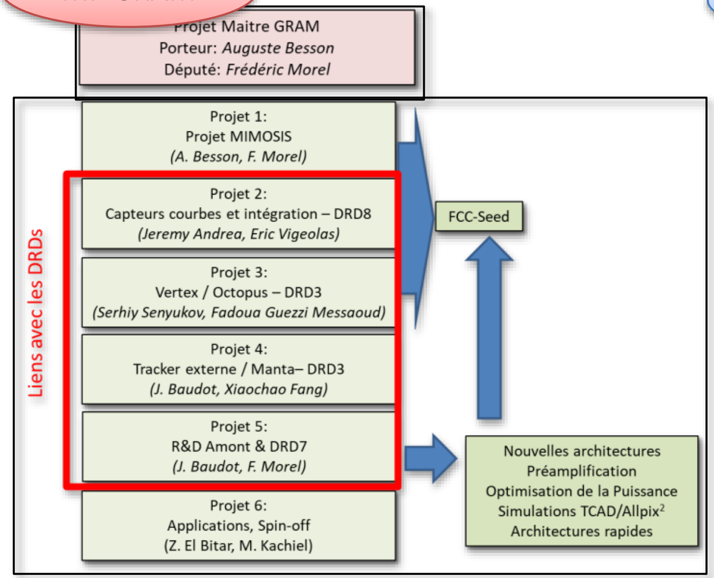

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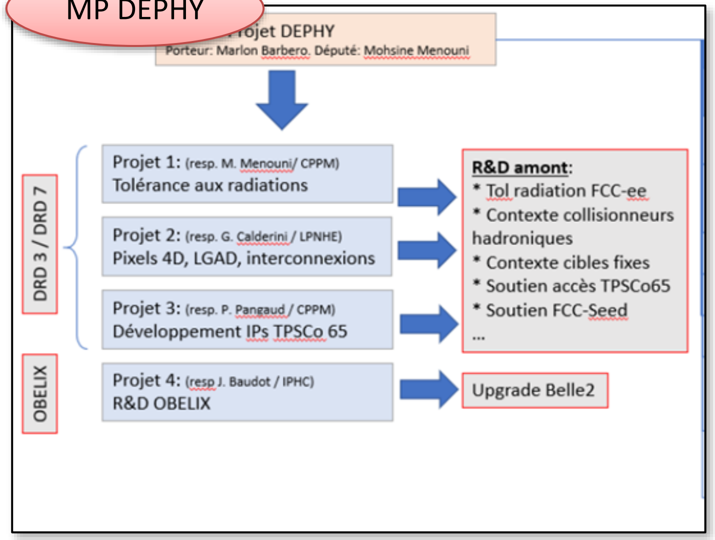

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MP GRAM — TPSCo 65 nm — Tower 180 nm

Projet Maîtr...
Porteur: Augu...
Député: Fréd...

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Upgrade Belle2

Laboratories — Tower 180 nm — TPSCo 65 nm

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- IRFU — LF 150 nm — TPSCo 65 nm

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- Vertex detector (FCC-Seed) — TPSCo 65 nm
- Outer tracker — TPSCo 65 nm
- Timing / PID — TPSCo 65 nm — LF 150 nm
- Detector optimization & software

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- LHCb (UT) — TPSCo 65 nm — LF 150 nm
- EIC tracker — TPSCo 65 nm

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FCCee requirements

- Vertex requirements
  - ✓ Data flux
    - Continuous beam ⇒ Data flux significantly higher than ILC,
    - Higher radiations doses as well, for both ionising radiation and fluence.
  - ✓ Beam pipe
    - Cooling mandatory as well as shielding,
    - Compensated by small inner radius ~12 mm
  - ✓ Challenges:
    - How to reach the targeted resolution with an adapted read-out architecture while fulfilling all the other requirements ?
    - How to propose a robust but ambitious VTX concept ? ⇒ Integration

FCCee

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

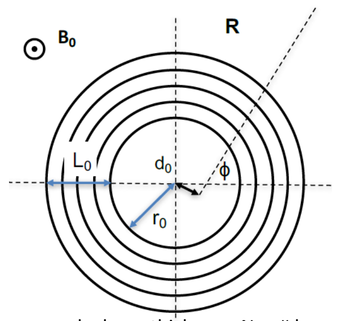
$a \simeq 5\,\mu\text{m}; \quad b \simeq 15\,\mu\text{m}\,\text{GeV}$

$b \sim r_0 \sqrt{material}$

$a \sim \sqrt{r_0}$

$$\Delta d_0|_{res.} \approx \frac{3\sigma_{r\phi}}{\sqrt{N+5}} \sqrt{1 + \frac{8r_0}{L_0} + \frac{28r_0^2}{L_0^2} + \frac{40r_0^3}{L_0^3} + \frac{20r_0^4}{L_0^4}}$$

$$\Delta d_0|_{m.s.} \approx \frac{0.0136\,\text{GeV/c}}{\beta p_T} r_0 \sqrt{\frac{d}{X_0 \sin\theta}} \sqrt{1 + \frac{1}{2}\left(\frac{r_0}{L_0}\right) + \frac{N}{4}\left(\frac{r_0}{L_0}\right)^2}$$



d = layer thickness, N = # layers

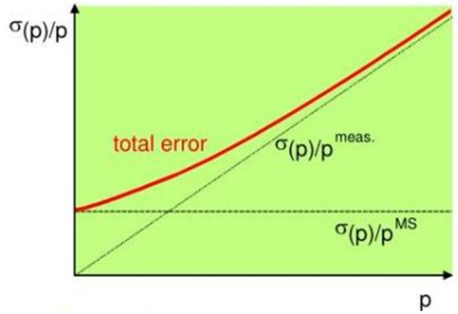
Drasal, Riegler, https://doi.org/10.1016/j.nima.2018.08.078

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	$\simeq 1.8\times10^{14}$ / 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}

- Tracker requirements
  - ✓ Maximum precision with:
    - Good spatial resolution per plane
    - Low momentum
    - High level arm
    - High B field
    - High number of layers (N)
    - Minimize material budget ⇒vLow number of layers (N)
  - ✓ Typically σ_{sp} ~5-10 μm/layer ; material ~1-2% X_0/layer
  - ✓ Challenges
    - Large surfaces ⇒ Integration & Power management
    - How to include timing / PID ?

$$\frac{\sigma_{p_T}}{{p_T}^2} \sim 2 \times 10^{-5} GeV^{-1}$$



for N equidistant measurements
(R.L. Gluckstern, NIM 24 (1963) 381)

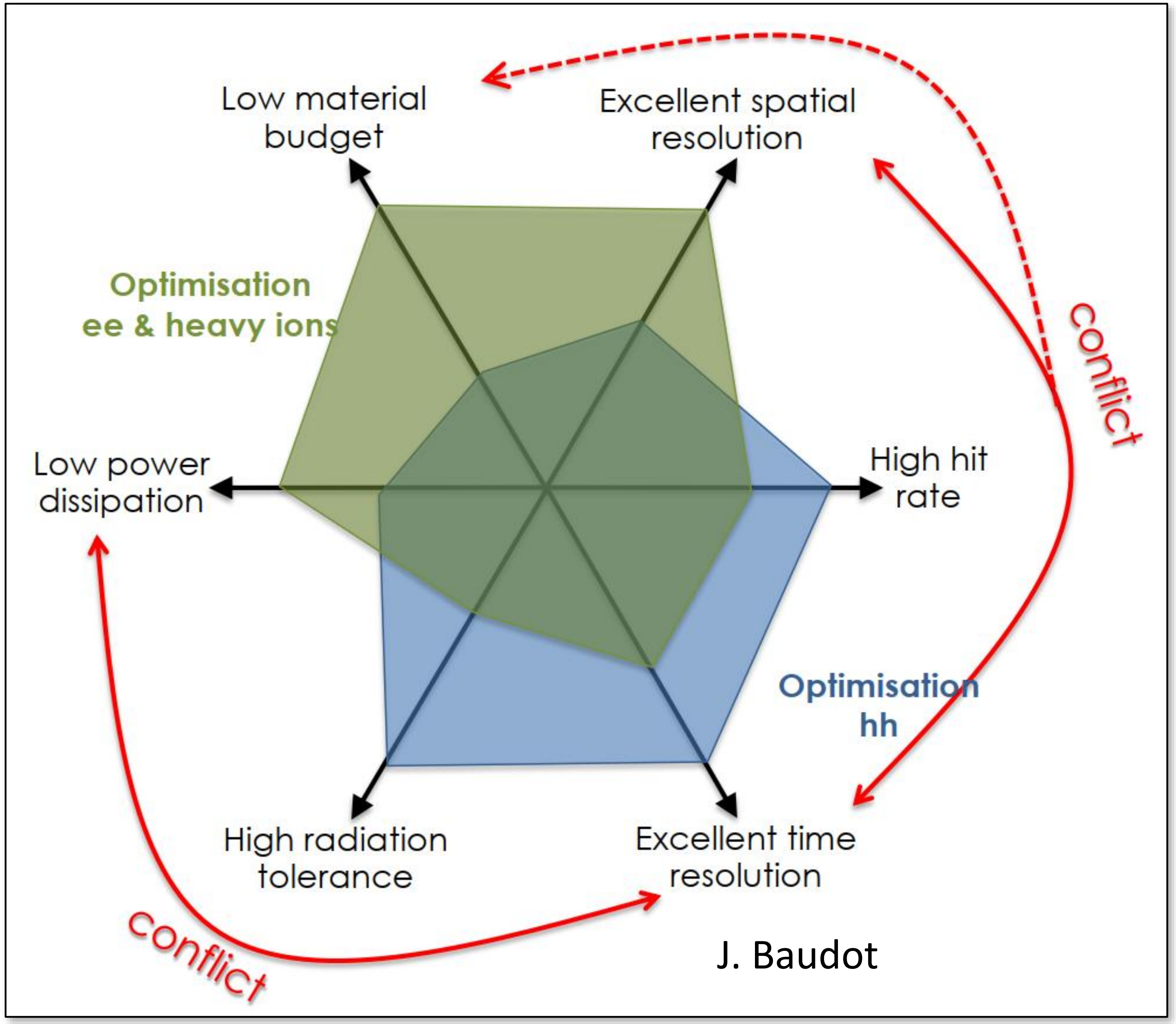
	thickness (mm)	Mat. Budget (X/X_0 %)
Beam pipe[1]		
Au	0.005	0.16%
AlBeMet162[2]	0.35	0.14%
Paraffin	1.0	0.18%
AlBeMet162[2]	0.35	0.14%
Total beam pipe	1.705	0.61%
Single layer		
Silicon sensor	0.050	0.05%
Cables, flex and support		$\simeq$ 0.10%
Material per layer		$\simeq$ 0.15%

[1] described in [6]
[2] 62% Be and 38% Al alloy

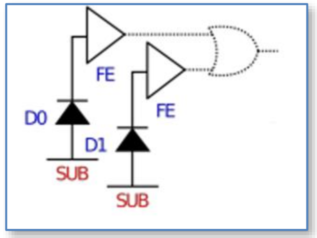
$$\frac{\Delta p_T}{p_T}\Big|_{m.s.} \approx \frac{0.0136\,\text{GeV/c}}{0.3\beta B_0 L_0} \sqrt{\frac{d_{tot}}{X_0 \sin\theta}} \qquad \frac{\Delta p_T}{p_T}\Big|_{res.} \approx \frac{12\,\sigma_{r\phi}\, p_T}{0.3\, B_0 L_0^2} \sqrt{\frac{5}{N+5}}$$

[6] A. Novokhatski et al. Estimated heat load and proposed cooling system in the FCC-ee Interaction region beam pipe. In *Proc. IPAC'23*, number 14 in International Particle Accelerator Conference, pages 260–263. JACoW Publishing, Geneva, Switzerland, 2023.

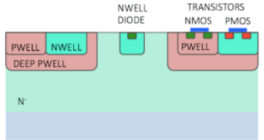
Conflicting parameters

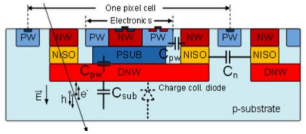


Main axis of R&D

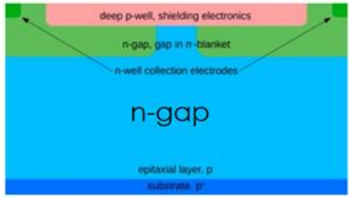


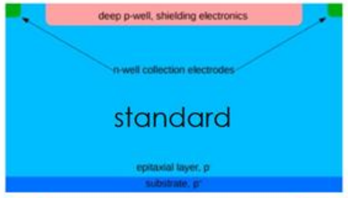
- Smaller features sizes
- Small diodes / large diodes

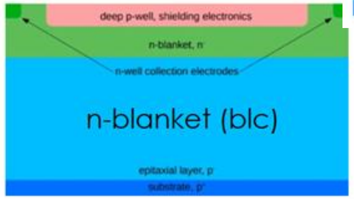


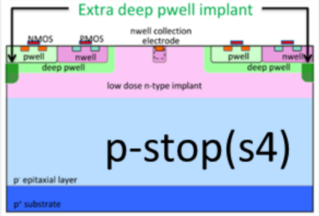


- Sensitive volume



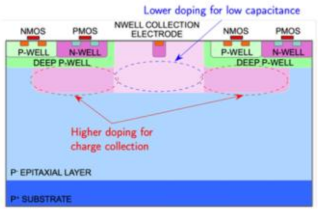


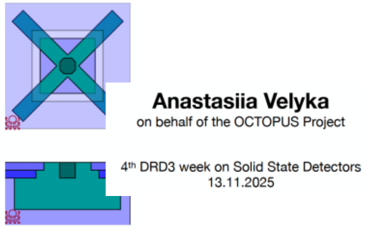




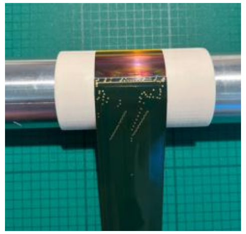
- C.Lemoine (PhD CERN-IPHC) JINST 19 (2024) 02, C02033

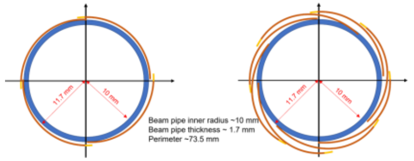
=> Heterogeneous n-implant dose



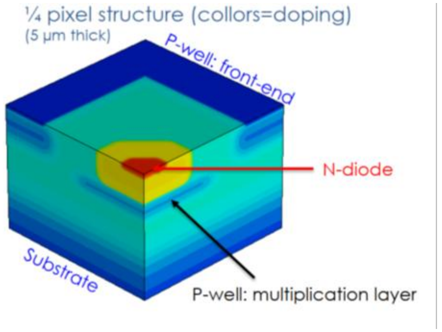


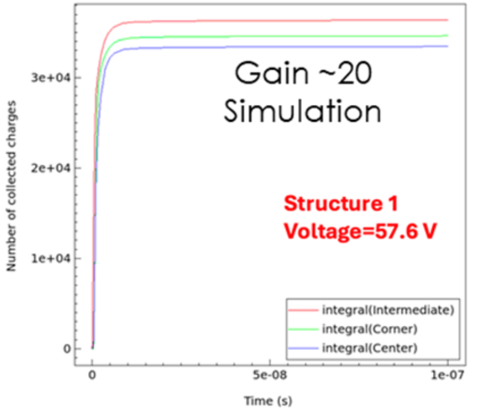
- Integration and mat. Budget optimization
  - ✓ Stitching
  - ✓ Bent sensors
    - FCC-Seed concept and DRD8





- In pixel and in matrix circuits
  - ✓ Amplification, digitization
  - ✓ Read-out architecture
    - Asynchronous read-out (SPARC ⇒ OCTOPUS/MANTA)
    - Pixel grouping (MANTA)
- Peryphery circuit
  - ✓ powering, multiplexing, configuration, control, outputs
- Preamplification
  - ✓ ANR APICS (IPHC, CPPM, icube)
    - Proto tested in 2026
  - ✓ DRD3-CASSIA
  - ✓ CACTUS (IRFU)





- Pitch reduction (spatial resolution) ⇒ OCTOPUS
  - ✓ Global effort on the footprint
- Power reduction, large surfaces
- Timing ⇒ CACTUS, MANTA

Tower 180 nm

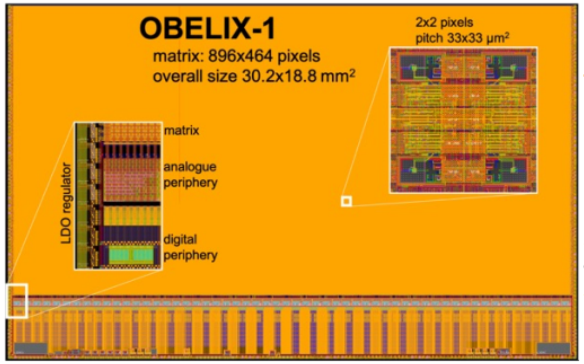
Recent application: OBELIX

IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

- Goals
  - Match **Belle II** upgraded vertex requirements

Pitch	30 to 40 µm
Signal digits	1 to few bits
Integration	50 to 100 ns
Average hit	120 MHz/cm²
Triggered read-out	30 kHz, latency 10 µs

Power	200-300 mW/cm²
TID **NIEL fluence**	~1 MGy ~5.10^{14} n_{eq}/cm²
Temperature	room+
Time stamping	~5 ns
Track triggering	Low latency out

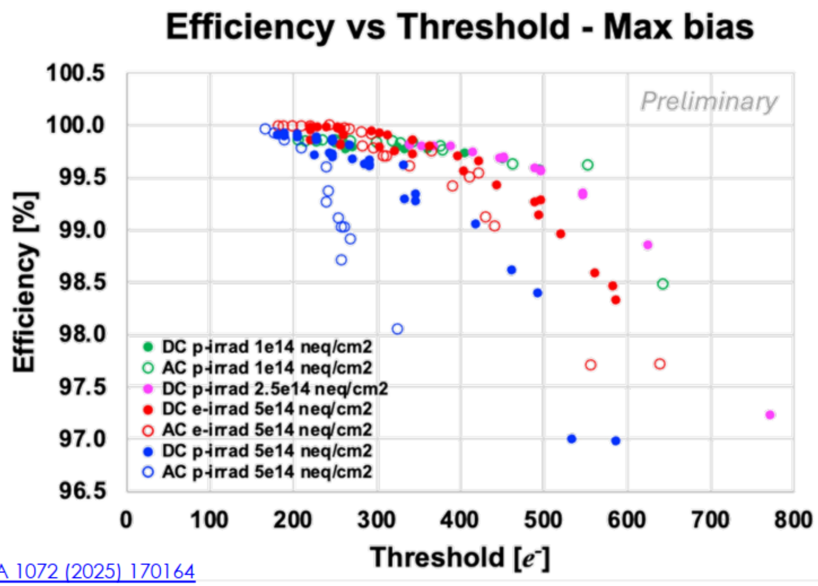


Tower CIS 180 nm modified process

1st submission end-2025

VTX collaboration:
Austria, China, France, Germany, Italy, Spain, Japan

- Forerunner: TJ-Monopix2
  - Bonn, CERN, CPPM, CEA-IRFU 10.1016/j.nima.2020.164403
  - Dvpd for ATLAS-ITK => radiation tolerance @ neg.T
  - Column-drain read-out from ATLAS FE-I3



NIM A 1067 (2024) 169659 NIM A 1072 (2025) 170164

J. Baudot - Next generation of CMOS-MAPS in France - Bi-national conf on detector R&D, 18/11/2025 11

Triggering
Radiation tolerance

Tower 180nm: MIMMOSIS for CBM-MVD

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

J. Andary,[a] B. Arnoldi-Meadows,[a] O. Artz,[a] J. Baudot,[b] G. Bertolone,[b] A. Besson,[b] N. Bialas,[a] R. Bugiel,[b] G. Claus,[b] C. Colledani,[b] H. Darwish,[a,b] M. Deveaux,[c] A. Dorokhov,[b] G. Dozière,[b] Z. El Bitar,[b] I. Fröhlich,[a,c] M. Goffe,[b] F. Hebermehl,[a] A. Himmi,[b] C. Hu-Guo,[b] K. Jaaskelainen,[b] O. Keller,[f] M. Koziel,[a] F. Matejcek,[a] J. Michel,[a] F. Morel,[b] C. Müntz,[a] H. Pham,[b] C.J. Schmidt,[c] S. Schreiber,[a] M. Specht,[b] D. Spicker,[a] J. Stroth,[a,c,d] I. Valin,[b] R. Weirich,[a] Y. Zhao[b] and M. Winter[e]

[a] *Goethe-Universität Frankfurt, Germany*
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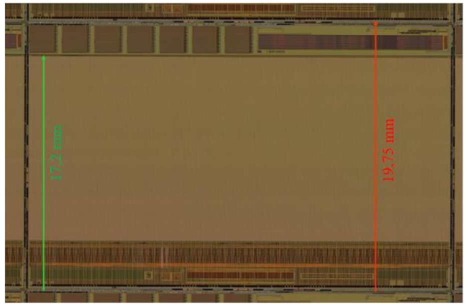
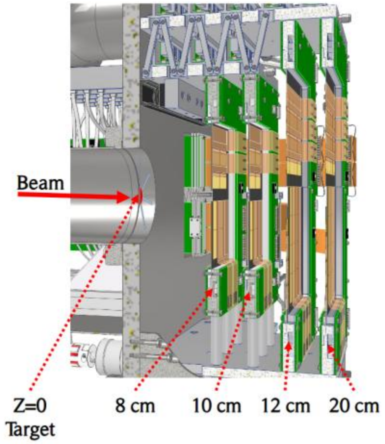
[c] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany*
[d] *Helmholtz Forschungsakademie Hessen für FAIR, Germany*
[e] *IJCLab, UMR9012 – CNRS / Université Paris-Saclay / France*
[f] *Facility for Antiproton and Ion Research in Europe GmbH, Germany*

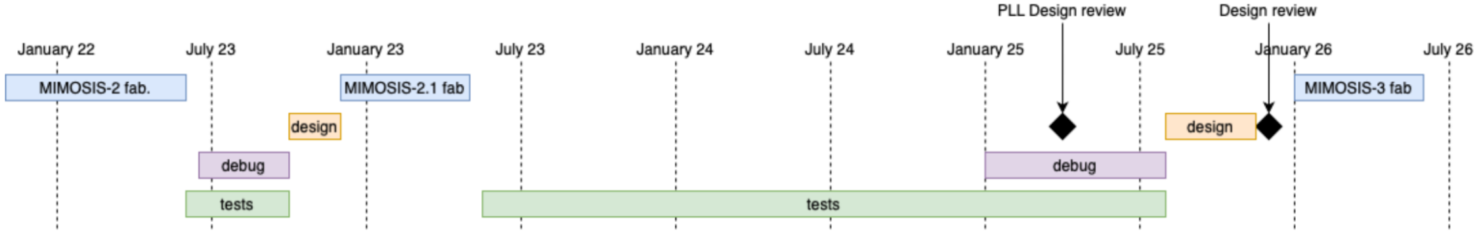
- Specifications (4 cm^2)
  - ✓ Will equipe le MVD de CBM@ FAIR
  - ✓ « 5µm - 5µs » + comparable flux to FCCee
  - ✓ Higgs factory demonstrator (closest sensor to specifications)
  - ✓ other applications considered (e.g. exp. FOOT, Integration tests)
- Timeline
  - ✓ 2023-24: Tests of Mimosis-2.1
    - Performances beyond requirements
  - ✓ 2025: test DAQ CBM: 3 identified problems:
    - Powering; sync. ; PLL ⇒ fixes for MIMOSIS-3
  - ✓ Submission MIMOSIS-3 (final sensor): 2025/26
  - ✓ Utilisation pour les activités capteurs courbes



Parameter	Value
Technology	TowerJazz 180 nm
Epi layer	$\sim 25\,\mu m$
Epi layer resistivity	$> 1 k\Omega cm$
Sensor thickness	$60\,\mu m$
Pixel size	$26.88\,\mu m \times 30.24\,\mu m$
Matrix size	1024×504 (516096 pix)
Matrix area	$\approx 4.2\,cm^2$
Matrix readout time	$5\,\mu s$ (event driven)
Power consumption	40-70 mW/cm^2

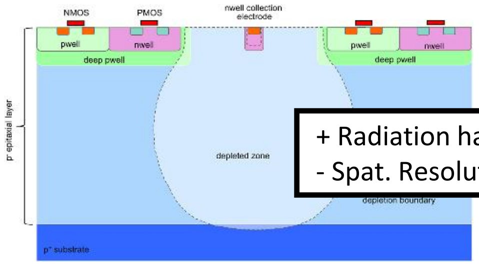


Physics parameter	Requirements
Spatial resolution	~ 5 um
Time resolution	~ 5 us
Material budget	0.05% X_0
Power consumption	< 100 – 200 mW/cm^2
Operation temperature	- 40 ^oC to 30 ^oC
Temp gradient on sensor	< 5K
Radiation tol* (non-ion)	~ 7 x 10^{13} n_{eq}/cm^2
Radiation tol* (ionizing)	~ 5 MRad
Data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

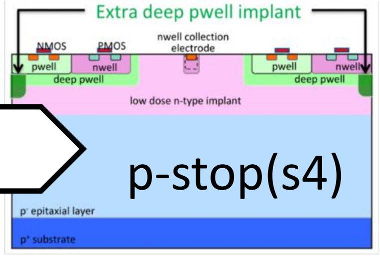


MIMOSIS-2.1 results to chose the final pixel in MIMOSIS-3

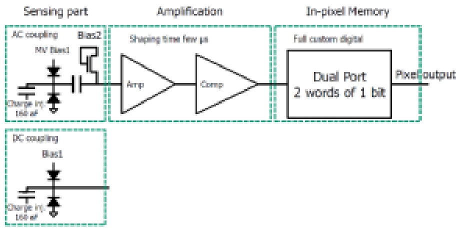
First proposed by W. Snoeys et al.
H. Pernegger et al., 2017 JINST 12 P06008



+ Radiation hardness
- Spat. Resolution

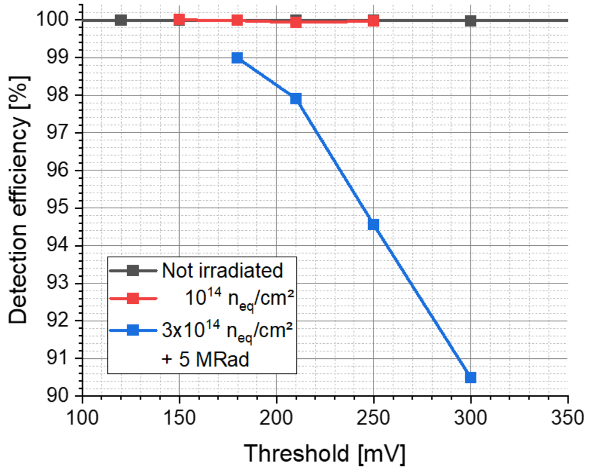


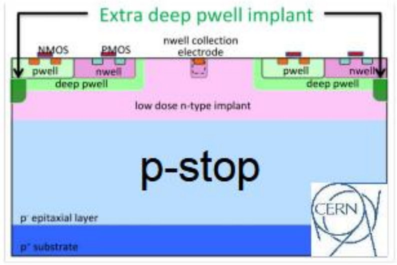
MIMOSIS-2.1: 25µm OR 50µm epitaxial layer



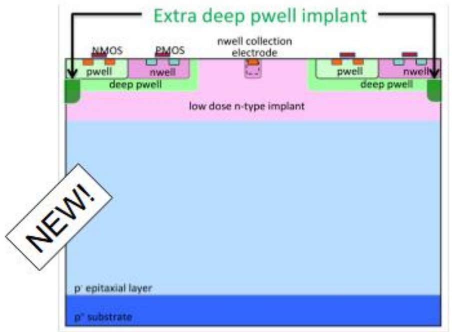
- DC pixel – limited rad. hardness.
- AC Pixel – more biasing lines.

Detection efficiency MIMOSIS-2.1
p-stop 50 µm

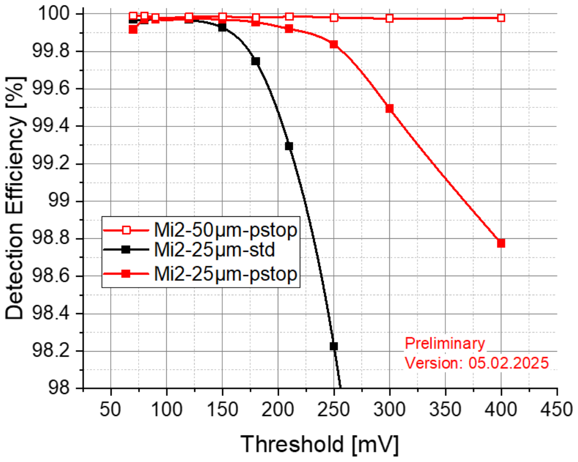




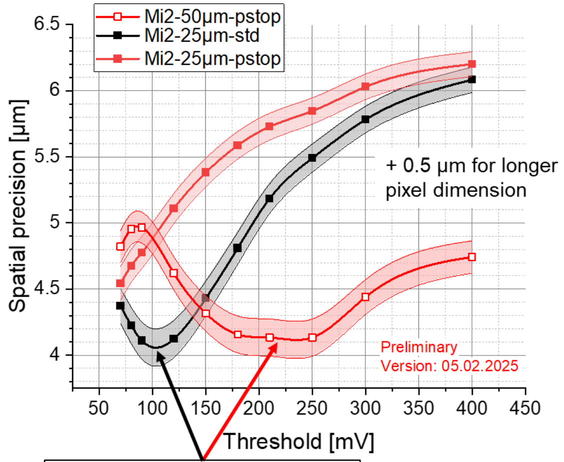
Rad. hard, candidate 1



25 µm & 50 µm epi thicknesses



Dark rate typically <10^{10}/pixel (2 Hz/cm²) driven by individual hot pixels.



Optimal number of fired pixels/particle (about 2.5)

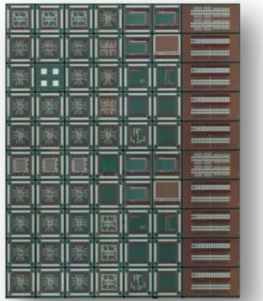
Chosen baseline : p-stop; 50 µm epi; AC pixel; amincis à 70 µm

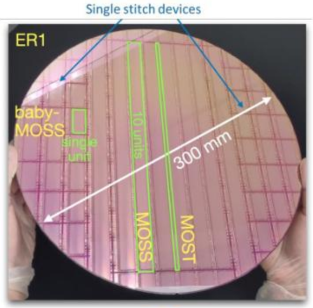
TPSCo 65nm

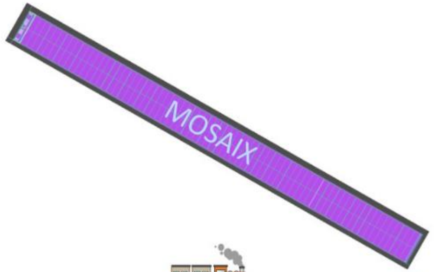
Timeline

W. Snoeys at DRD7 Week

EP R&D







(OCTOPUS/MANTA)

MPR2

Shared engineering run

WP 1.2 "rail"

ALICE "rail"

MPR3 (~2028-29)

MLR1 (Multy-Layer Reticle, Dec 2020):

Learn about the technology, characterize pixels, transistors and building blocks

1.5 x 1.5 mm^2 test chips

>50 chiplets from: DESY, IPHC, RAL, NIKHEF, CPPM, Yonsei, CERN

CE_65v1

ER1 (Engineering Run, Dec. 2022):

Prove we can design wafer-scale stitched sensors

MOSS (1.4 x 25.9 cm)

MOST (0.25 x 25.9 cm)

Hybrid-To-Monolithic (H2M)

51 chiplets from: DESY, IPHC, RAL, NIKHEF, SLAC, INFN, CERN

CE_65v2

ER2 (August 2025):

Full-scale stitched sensor prototype for ALICE ITS3

MOSAIX (1.9 x 26.6 cm)

~30 chiplets from: IPHC, SLAC, CPPM, BNL, INFN, Universität Heidelberg, CERN

Submitted, approved for mask making SPARC ered, wafers not yet in the line.

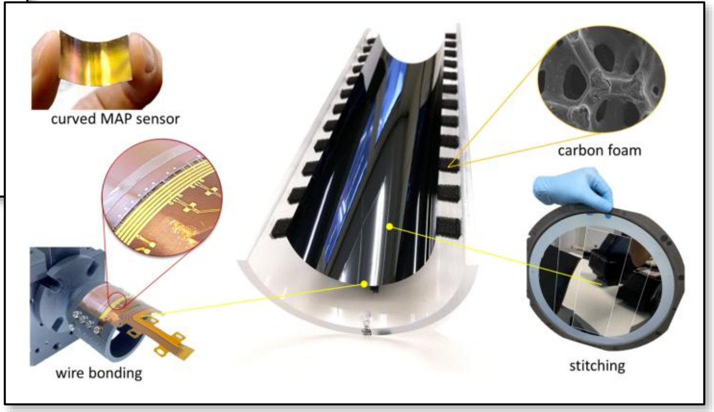
ER3 (2026):

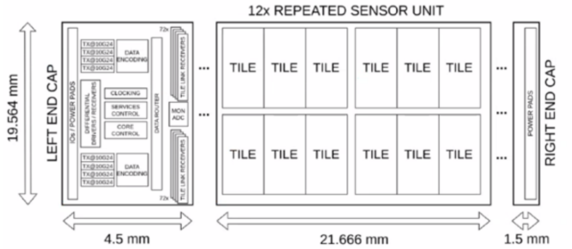
Stitched sensor production for ITS3 (ALICE-specific)

chiplets

- OCTOPUS
  - ✓ Vertex for e+e-
- MANTA
  - ✓ Outer trackers
  - ✓ Cf. D. Contardo talk

ALICE ITS-3

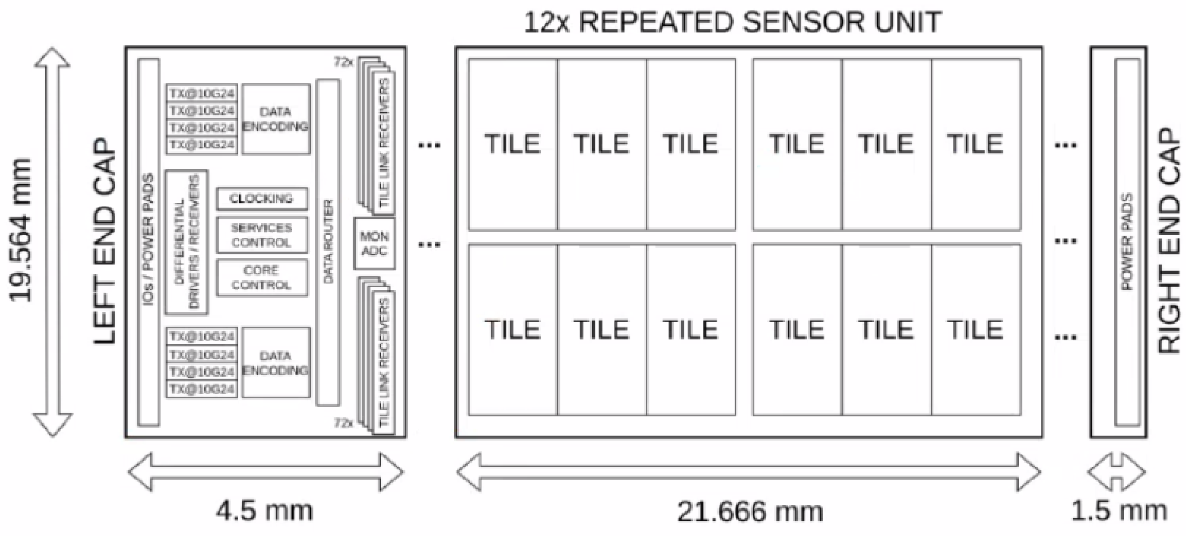




- Tape-out : 2025-07-14
- Delivery : 2026-01/02
- Pad Wafers : ≈2025-11-26

(i.e. MOSAIX, baby MOSAIX + chiplets)

ALICE ITS-3



- Tape-out : 2025-07-14
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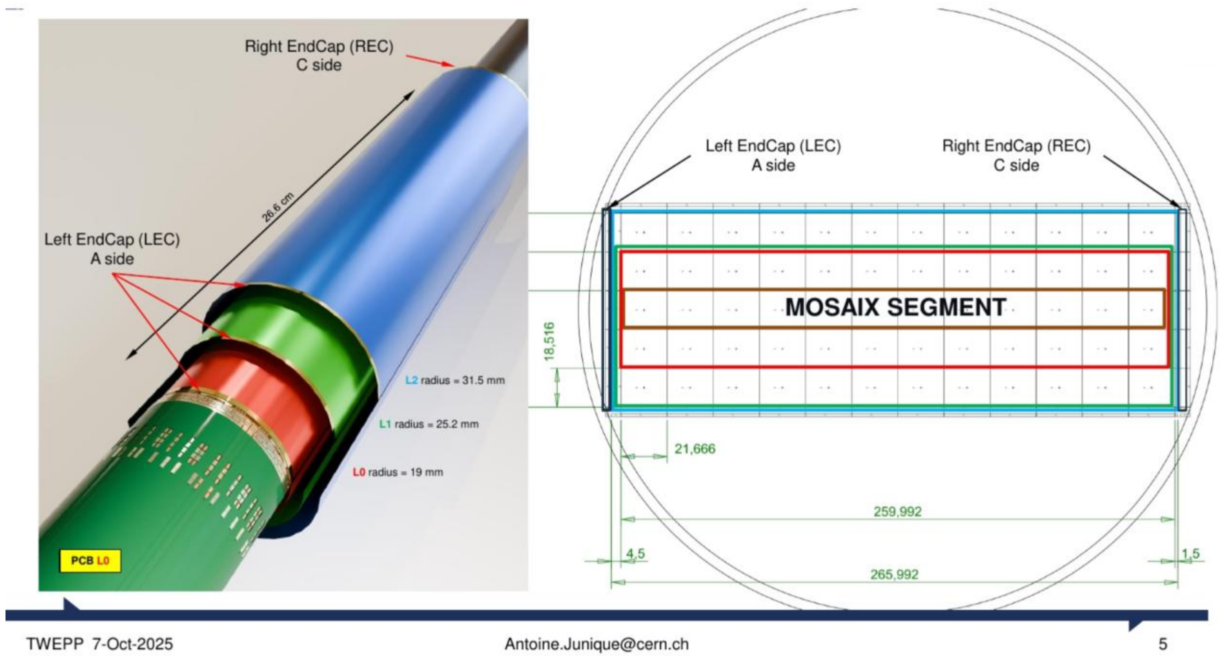
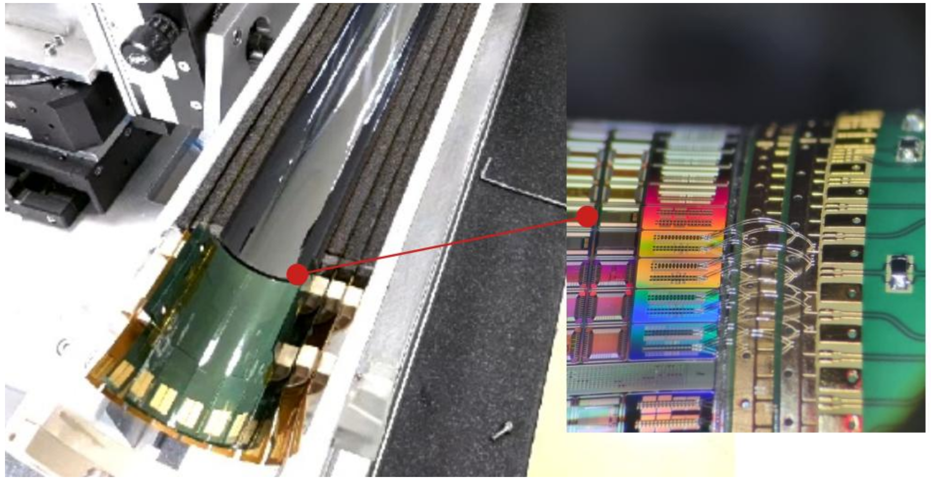
- Pad Wafers : ≈2025-11-26
  (i.e. MOSAIX, baby MOSAIX + chiplets)

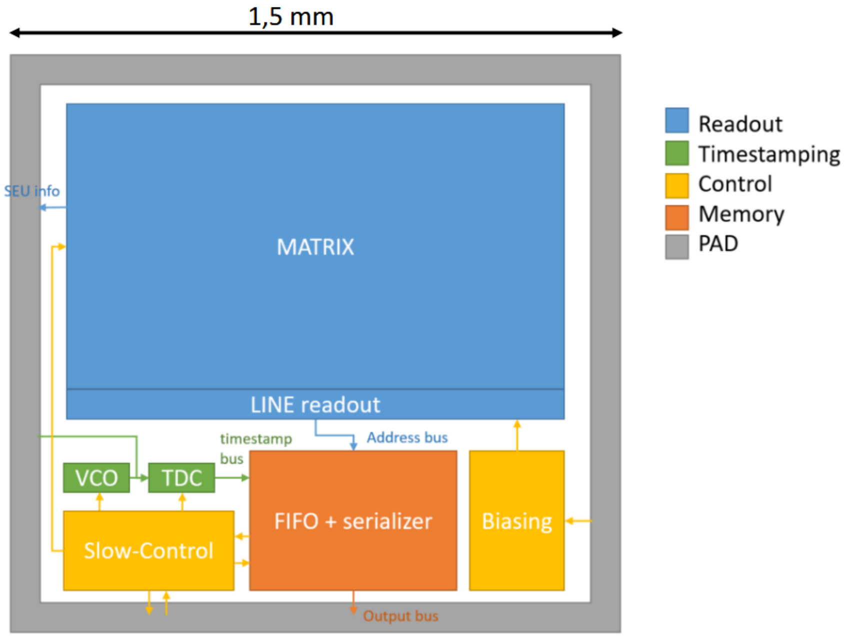




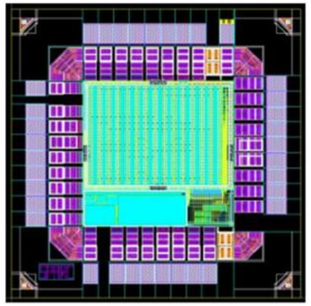
Engineering model

A. Junique,
M. Imhoff
+ WP5 Mechanics

SPARC sensor (IPHC, IRFU)

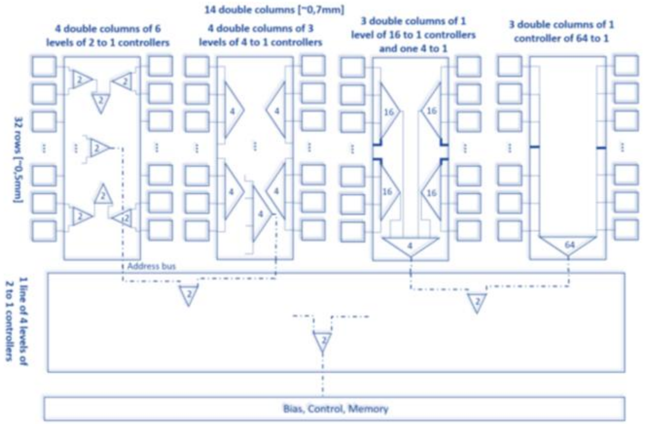


- SPARC 1st prototype for asynchronous readout
  - ✓ Asynchronous Prority Arbiters (APA)

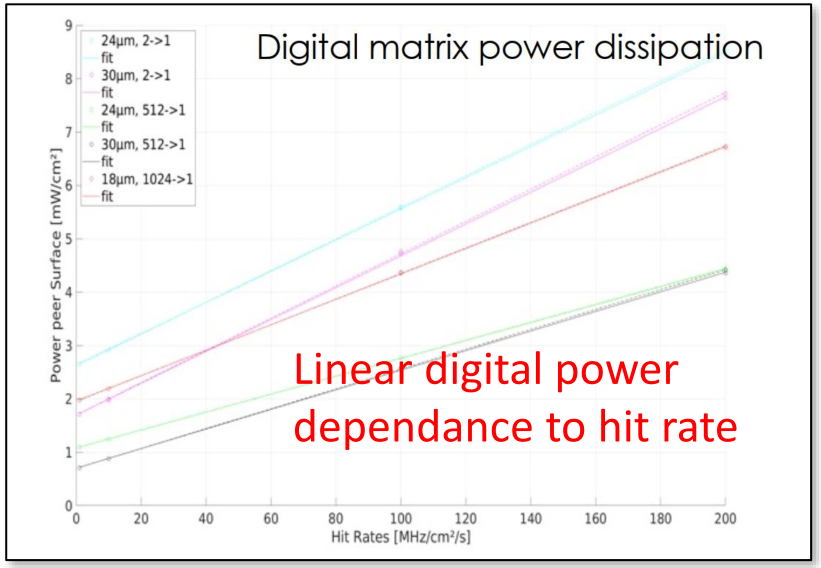


1.5×1.5 mm²

- Pixel matrix: 32 × 28
- Pixel pitch: 24 × 16 µm²
- Pixel front-end: DPTS-like (CERN)
- FPA tree types: 2:1, 4:1, 16:1, 64:1
- Power dissipation: 5 mW/cm²
- Mean readout time: 6.3 ns
- Designed by: IPHC, IRFU
- Submission: summer 2025 (ER2)
- Test system in preparation for 2026



S. Senyukov (CNRS-IN2P3-IPHC) Second FCC Italy & France workshop (5 Nov 2024) 10



Back from foundry end 2025 ⇒ to be tested in 2026by group of partners (Belle-2, OCTOPUS, etc.)

https://octopus.web.cern.ch/

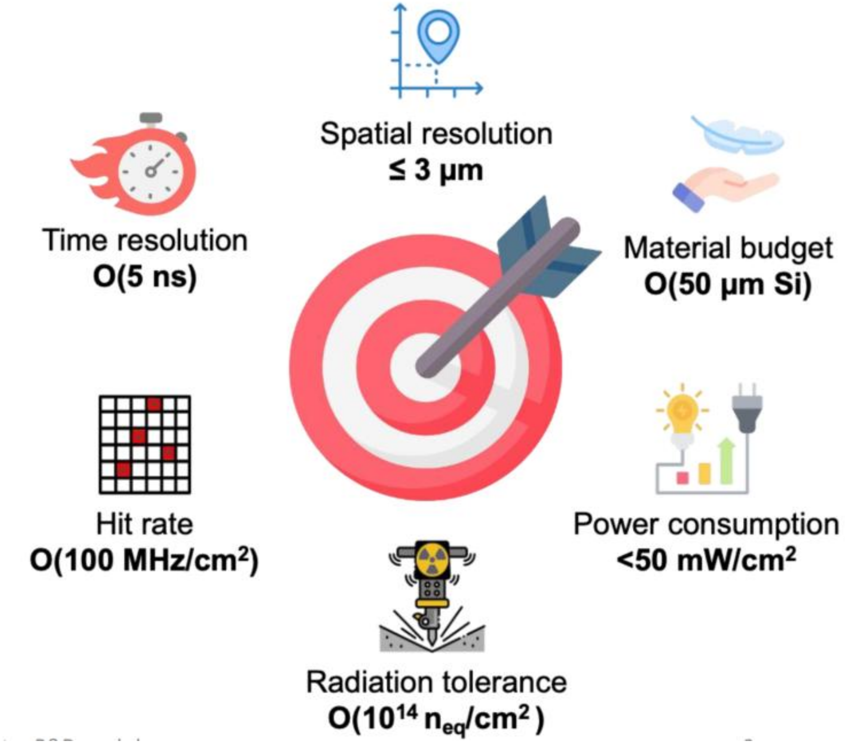
DRD3: Octopus project

WP1: Simulations
A. Ilg, A. Velyka

WP2: ASIC design
F. Guezzi, L. Huth, S. Senyukov

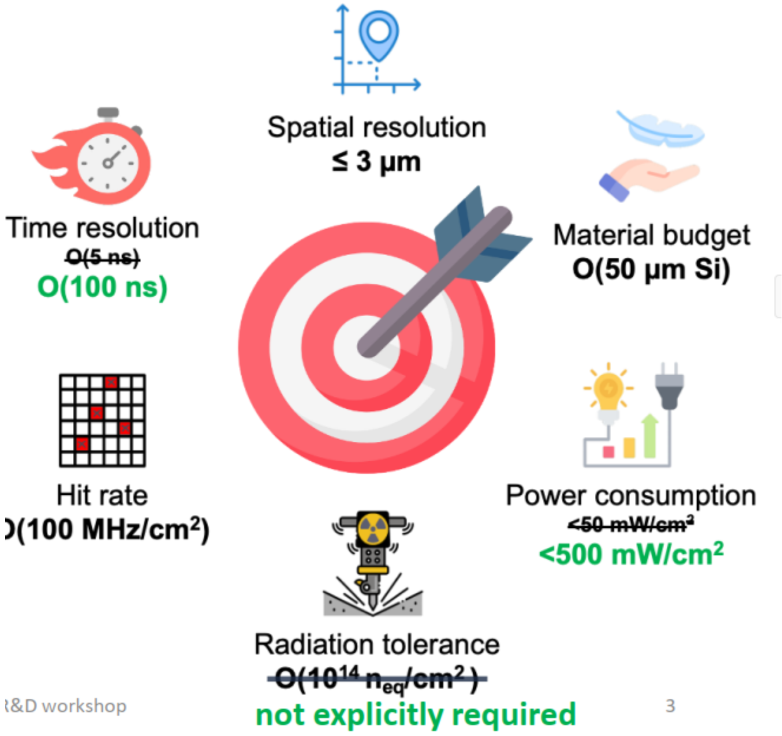
WP3: Data Acquisition
Y. Otarid

WP4: Testing and characterization
F. King, M. Franks



Final goals

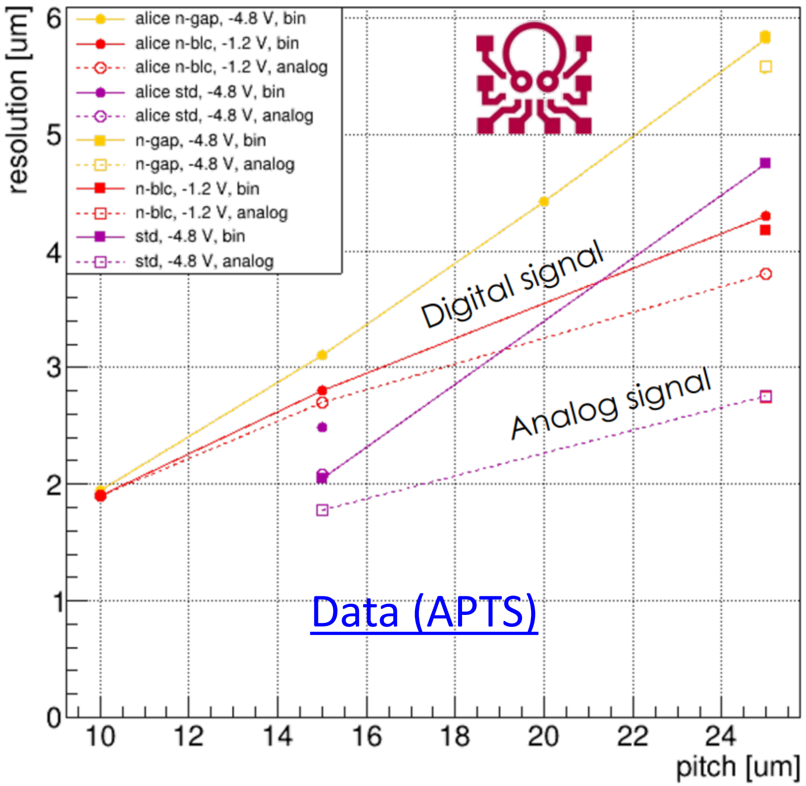
Institute	Main areas of contribution
APC Paris	Simulations, testing
University of Bonn	ASIC design, testing
CPPM Marseille	ASIC design
NIKHEF	Testing, DAQ
CERN	Testing, DAQ, ASIC design support
DESY	ASIC design, testing, DAQ, simulations
ETH Zurich	ASIC design, testing
CTU Prague	ASIC design, DAQ, testing
GSI Darmstadt	Simulations, testing
MBI Vienna	DAQ, testing, ASIC design
IPHC Strasbourg	ASIC design, testing
University of Oxford	Powering, integration, testing
University of Zurich	Testing, DAQ, simulations



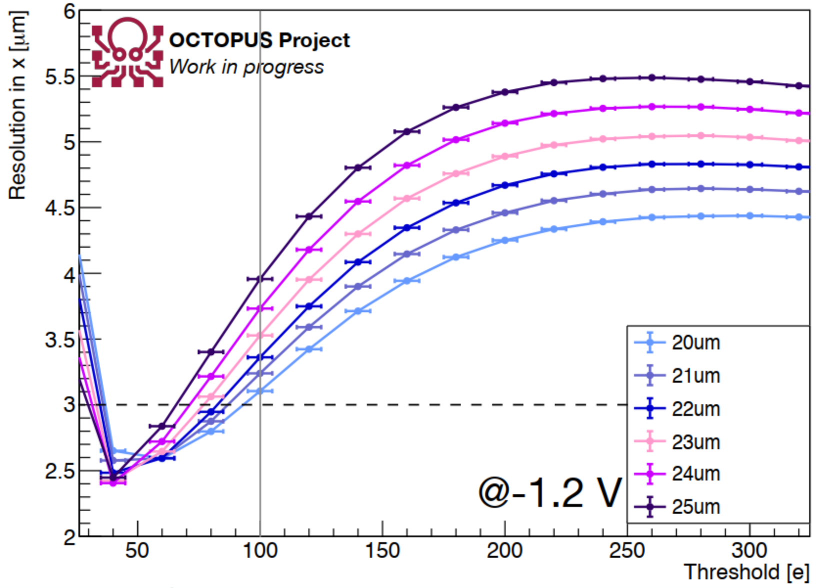
Intermediate goal
(beam telescopes)

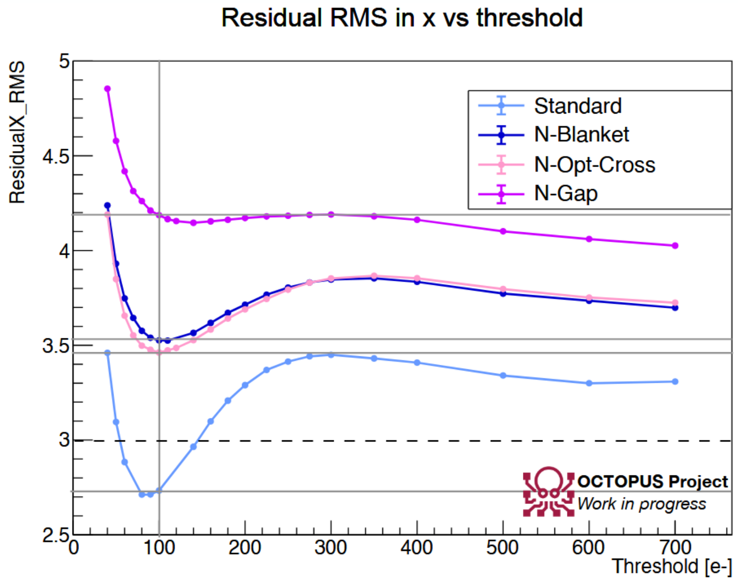
The spatial resolution challenge

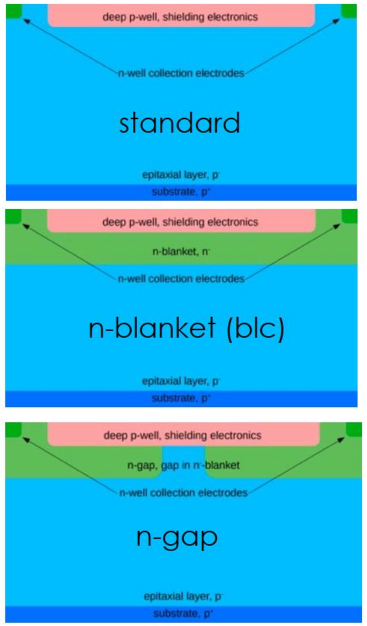
Geo	Process	Pitch(um)	HV(V)	Sp. Res.(um) (telescope resolution subtracted)
SQ	GAP	22.5	10	~5.1
SQ	GAP	18	10	~4.1
SQ	GAP	15	10	~3.2
SQ	STD	22.5	10	~2.4
SQ	STD	18	10	~1.8
SQ	STD	15	10	~1.3

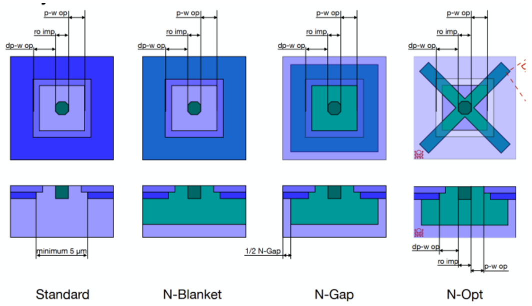


Simulation, Standard, analog read-out





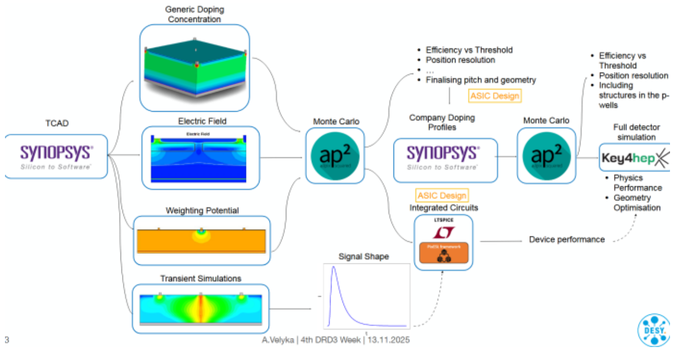


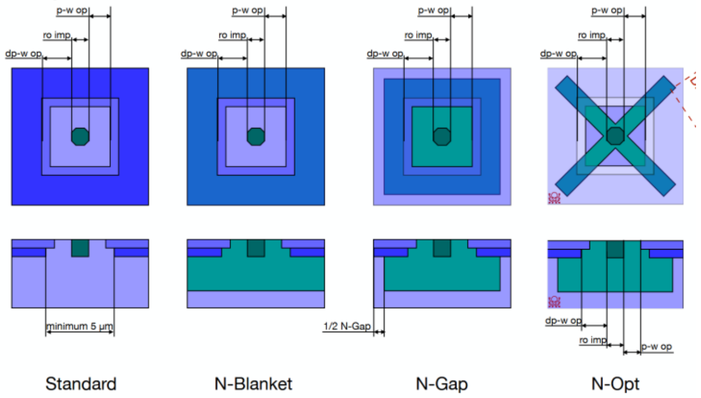


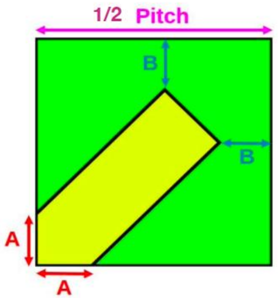
Goal :
optimize the design to guarantee 3 μm spatial resolution
vs efficiency and pitch

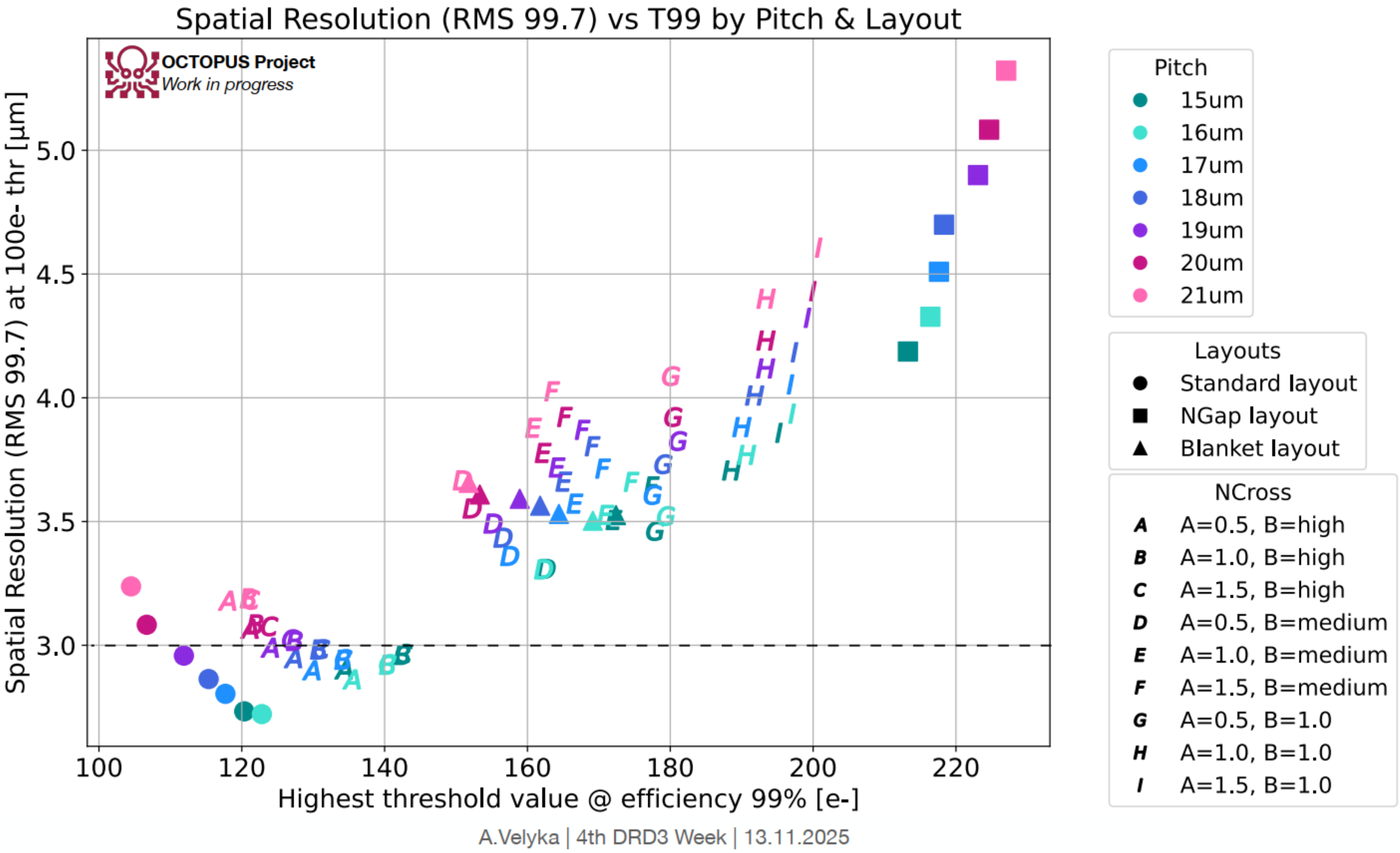
OCTOPUS: Spatial resolution optimization

- [See Velyka (DRD3)]





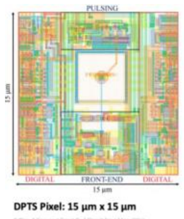


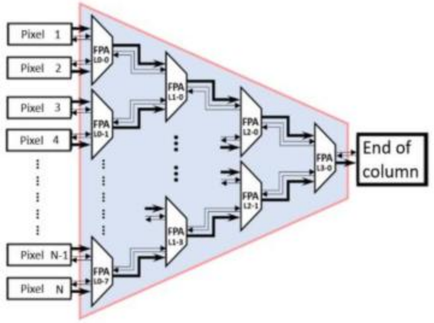


Idea: improve the homogeneity of the response

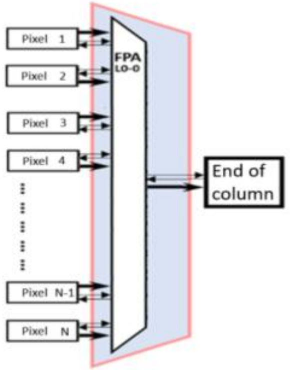
OCTOPUS Asynchronous read-out

- Front-end from DPTS/MOSS (ALICE-ITS3)
  - ✓ Compact footprint
- Asynchronous Priority Arbiter from SPARC
  - ✓ Architecture shared with MANTA
  - ✓ Pixel pitch optimization
- Readout
  - ✓ Various options of column merging under study
  - ✓ In chip lpGBT logic
  - ✓ Expected data rate 10 Gb/s/cm^2
- Time stamp
  - ✓ Rising / falling edge
  - ✓ Time stamping via TDC end of column (ToA + ToT)
  - ✓ Time walk correction
  - ✓ ToT used for charged measurement ⇒ spatial resolution

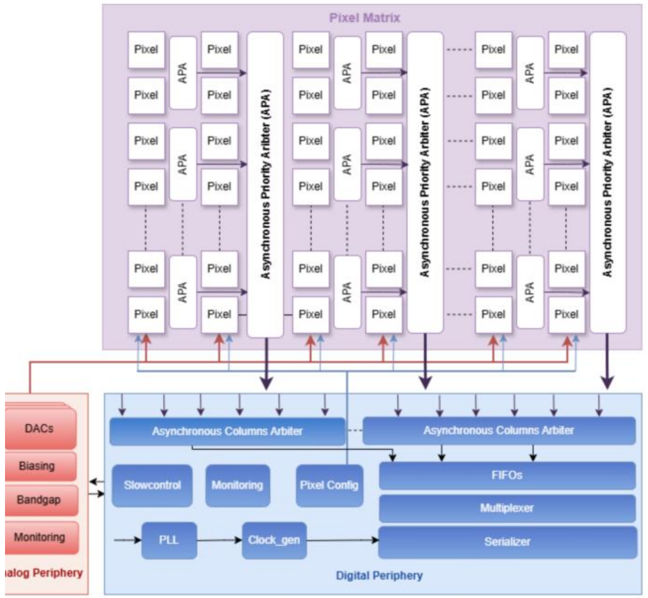




Bandwidth ↑
Footprint ↓



Bandwidth ↓
Footprint ↑



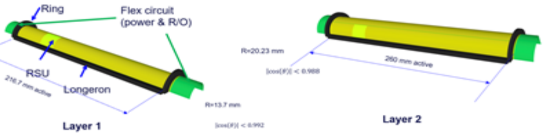
Summary

- Tower 180 nm still active
  - ✓ Know how maintained with intermediate projects to be installed in experiments (CBM, Belle-2, etc.)
- Integration:
  - ✓ ALICE-ITS3 for stitching and bent sensors
  - ✓ Integration for FCCee R&D: cf. next talk by J. Andrea
- CMOS R&D for FCCee is fully integrated to DRD3/7/8 framework
  - ✓ OCTOPUS & MANTA are the main driving projects for VERTEX/Outer Tracker
  - ✓ Synergies (to save person power & costs)
  - ✓ Submission line in DRDs defined by MPR2 / MPR3 submission
  - ✓ ALICE ITS-3: ER2/ER3 line
- OCTOPUS
  - ✓ SPARC prototype will allow to explore/test the Asynchronous readout (APA)
  - ✓ First OCTOPUS prototype to be submitted in MPR2 (2027) $\Rightarrow$ (cm^2)
  - ✓ Strong connexion to FCCee through simulations (see other talks today)
- Blue sky R&D
  - ✓ e.g. preamplification in the pixel could be a game changer

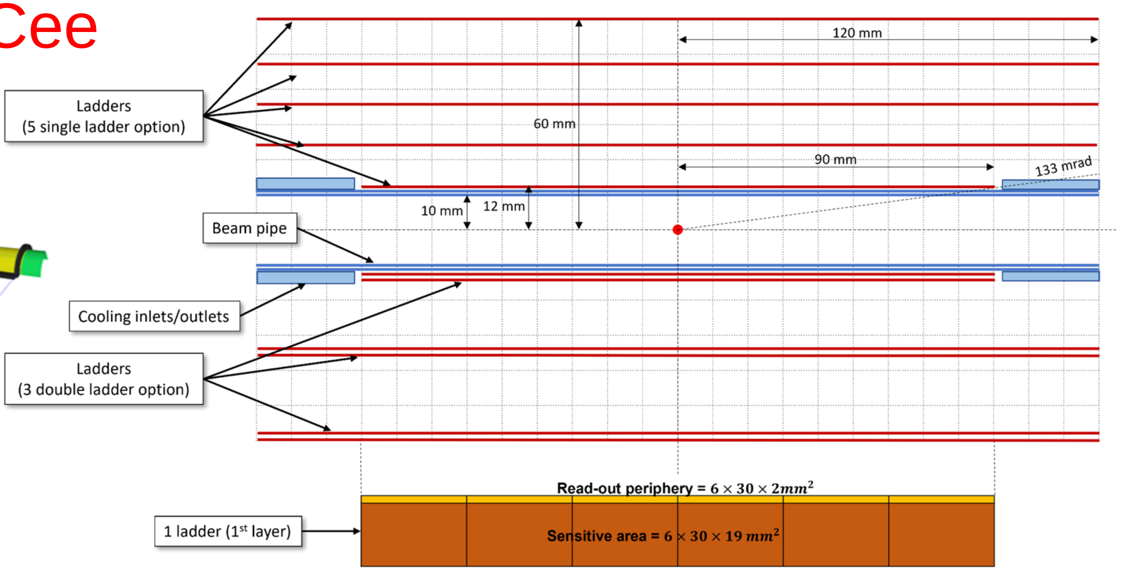
Back up

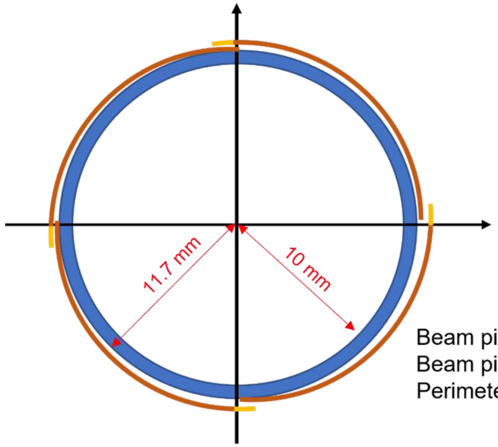
SEED: a vertex detector for FCCee

- 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 ?)



- Alternative Proposal: SEED concept = bent ladders
  - ➢ Stitching or not stitching
  - ➢ Radius approaching constant value
  - ➢ Full acceptance in φ
  - ➢ Double sided can be considered.
  - ➢ Number of layers = free parameter
  - ➢ Competitive for mat. Budget. AND full azimuthal acceptance





Beam pipe inner radius ~10 mm
Beam pipe thickness ~ 1.7 mm
Perimeter ~73.5 mm

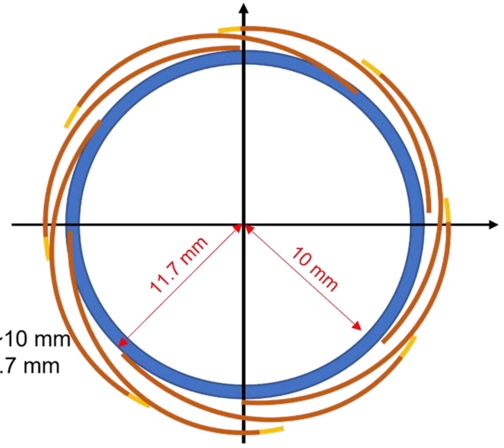
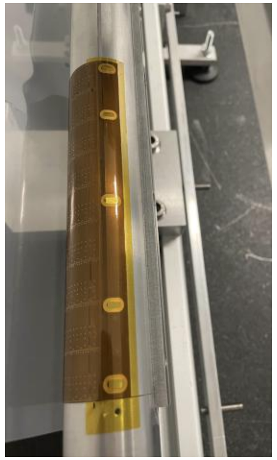


Table 3: Barrel dimensions (single and double sided option)

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			$30 \times 19.2\ mm^2$

Bending setup @ IPHC

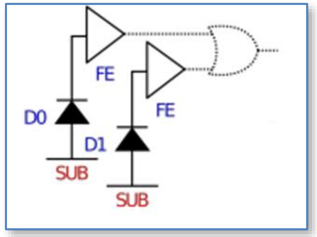


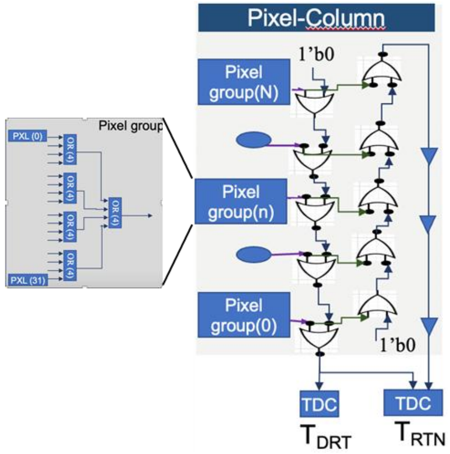
- Bent sensors pioneered by Alice ITS-3,
  - ➢ program dedicated to bent sensor with MIMOSIS
  - ➢ e.g. functional tests @ R = 12 mm

Manta

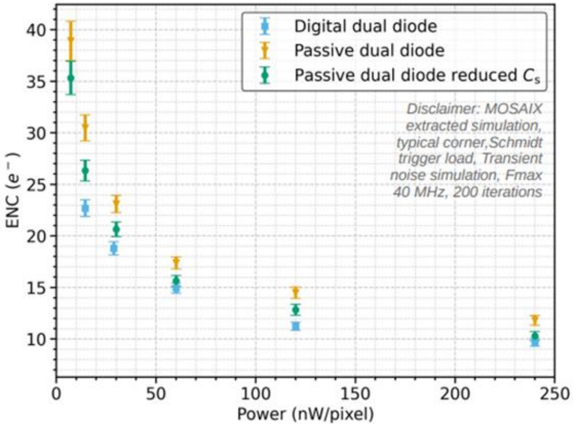
	ALICE3 OT	Belle II trk	CBM STS	LHCb UT	FCCee trk
Position resolution	10 µm	<15 µm	>10 µm	~10 µm	5-10 µm
Hit rate (MHz/cm²)	0.03 to 0.6	<1	>10	<60	<1
Data rate (Gb/s)			8	20	
Time stamping (ns)	100	~1	~10	~1	<1000?
Triggering	no	yes	no	no	?
Power	20-40	<50	50	200	~20?
TID (kGy)	17	10?	170	2500	TBD
NIEL	6×10^{13}	10^{11}?	few 10^{14}	4×10^{15}	TBD

- Projet DRD3 visant les trajectographes du futur
- Cahier des charges commun:
  - ✓ Résolution spatiale ~10 µm ;
  - ✓ Puissance modérée
  - ✓ Possibilité de grandes surfaces (55m² pour ALICE3 ML+OT)
  - ✓ Résolution temporelle via ToT
    - Mesure fine (<100 ps) avec TDC en bas de colonne de pixels (IP2I)
  - ✓ Fake Hit rate
- Stratégie et synergies
  - ✓ Même architecture de lecture qu'OCTOPUS (APA)
  - ✓ Versatilité de l'architecture ⇒ Ajustement sur la Puissance
- Status
  - ✓ En cours de structuration (meetings réguliers); Design a débuté
    - Assignation des tâches design, en cours (peu de designers hors Fr pour MANTA)
    - Pixel grouping (Johannes Hensler, Heidelberg + Andrei Dorokhov, IPHC)
    - Grouping passif (simple connexion des diodes < pixel grouping au niveau numérique
    - Optimisation puissance (solution CERN W. Snoeys ?)
- Points d'attention
  - ✓ Alternative pour ALICE3 OT MOSAIX proposé par le CERN ?
  - ✓ Organisation interne MANTA: conciliation entre un Timing < 20 ps vs. < 1 ns (maintenir la compatibilité entre les 2 options, difficile)
  - ✓ Poids des différentes applications exp = mouvant
  - E.g. ALICE3 OT (~55m²) ≠ LHCb UP (~0.1 m², plus petit que le MFT ALICE2), etc..
  - Échelles de temps





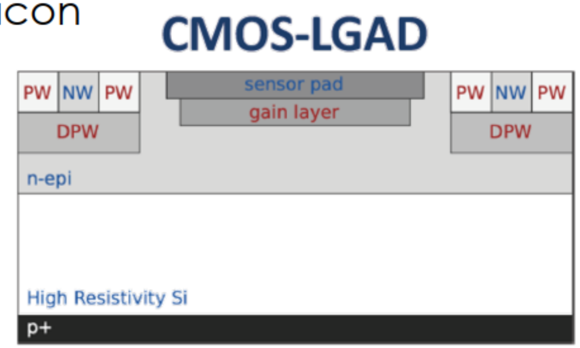
- 18 institutions, 8 countries
  - Conveners: Michael Deveaux, Antonin Maire
- Designers from:
  - HEPHY, Vienna
  - IP2I, Lyon
  - IPHC, Strasbourg
  - IRFU, Saclay
  - LPNHE, Paris
  - SLAC, Stanford
  - Uni Barcelona
  - Uni/INFN Bergamo/Pavia



WP design converners:
- Mokrane DAHOUMANE (IP2I Lyon)
- Xiaochao FANG (IPHC Strasbourg)
- Gianluca TRAVERSI (University Bergamo)
- Michael DEVEAUX (GSI)

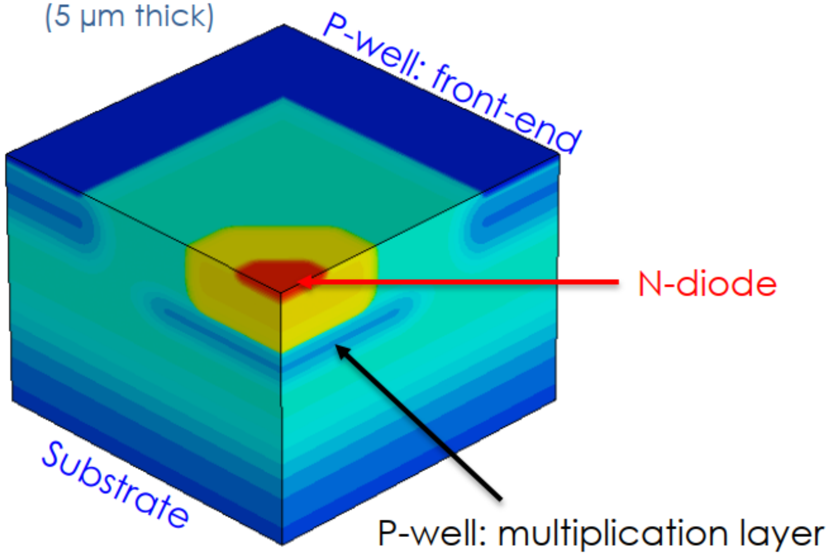
Intrinsic amplification

- Provide charge amplification in silicon
  - Linear regime with gain x10-30
- Inspired by LGAD structures
- Pursued in various technologies:
  Tower 180 nm (CASSIA/DRD3),
  IHP 130 nm (Geneve)
  LF 150 nm (CACTUS @ IRFU),
  LF 110 nm (ARCADIA, INFN)



ARCADIA (INFN), [MadPiX LHCP2025]

¼ pixel structure (collors=doping)
(5 µm thick)



Goal with APICS French project

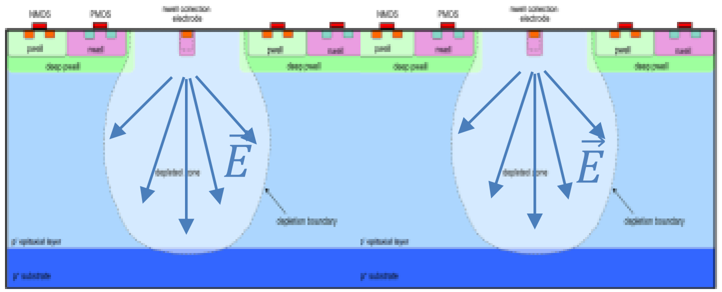
- CPPM, Icube, IPHC
- Drive discriminator 'directly' from sensing node
  - No more front-end amplifier => smaller pitch (10-15 µm) & power
- Start with Tower 180 nm → deploy with TPSCo 65 nm
- Within DRD3-CASSIA project
  - larger pitch studied for time resolution

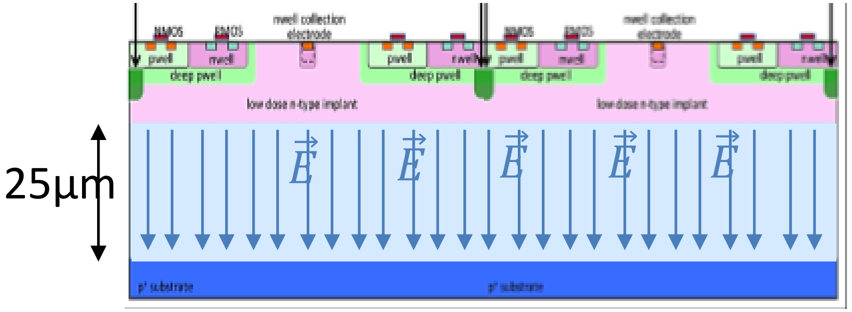
- TCAD simulation prediction: ~Volts at sensing node output
- Validated by first prototype measurements

=> See Andrei Dorokhov presentation after break

MIMOSIS (CBM-MVD) & options for sensing elements

Process modification: Standard? P-stop? N-Gap?





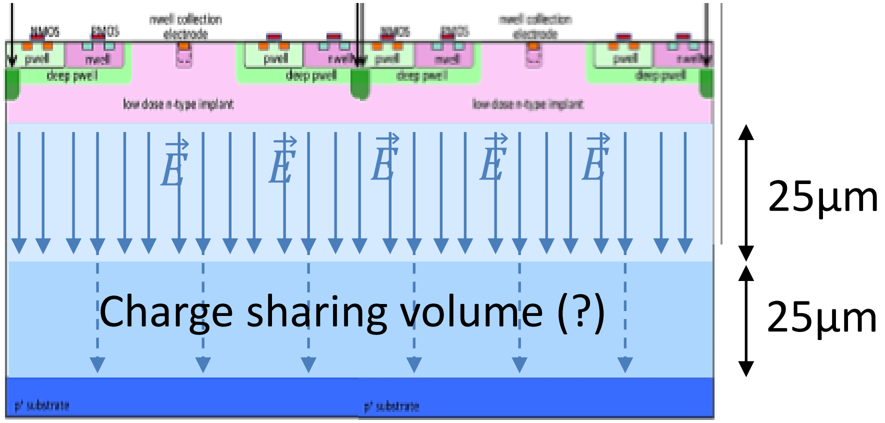
$\sigma = 4 - 5$ µm
> 3 x $10^{13} n_{eq}/cm^2$

Spatial resolution
Rad. hardness

$\sigma = 5 - 7$ µm
> 30 x $10^{13} n_{eq}/cm^2$

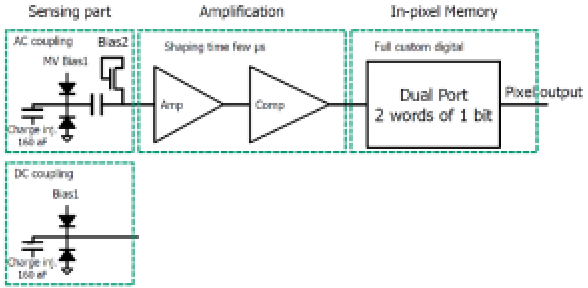
Process options inherited from ALPIDE

25 or 50 µm epi?



- Better spatial res. at given rad. tolerance?
- Higher S/N => Robustness to external noise?
- Nuclear fragment ID by dE/dx?

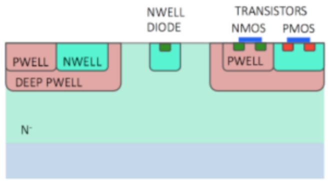
AC? DC? pixel

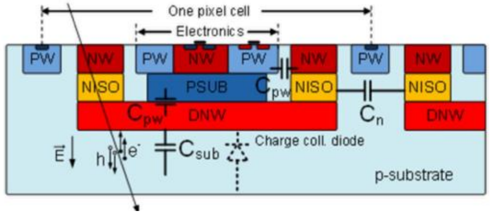


- DC pixel – limited rad. hardness.
- AC Pixel – more biasing lines.

W. Snoeys et al., NIM-A Vol.871 (2017) 90–96.
Munker, Vertex 2018, Status of silicon detector R&D at CLIC

Small / large collection electrodes

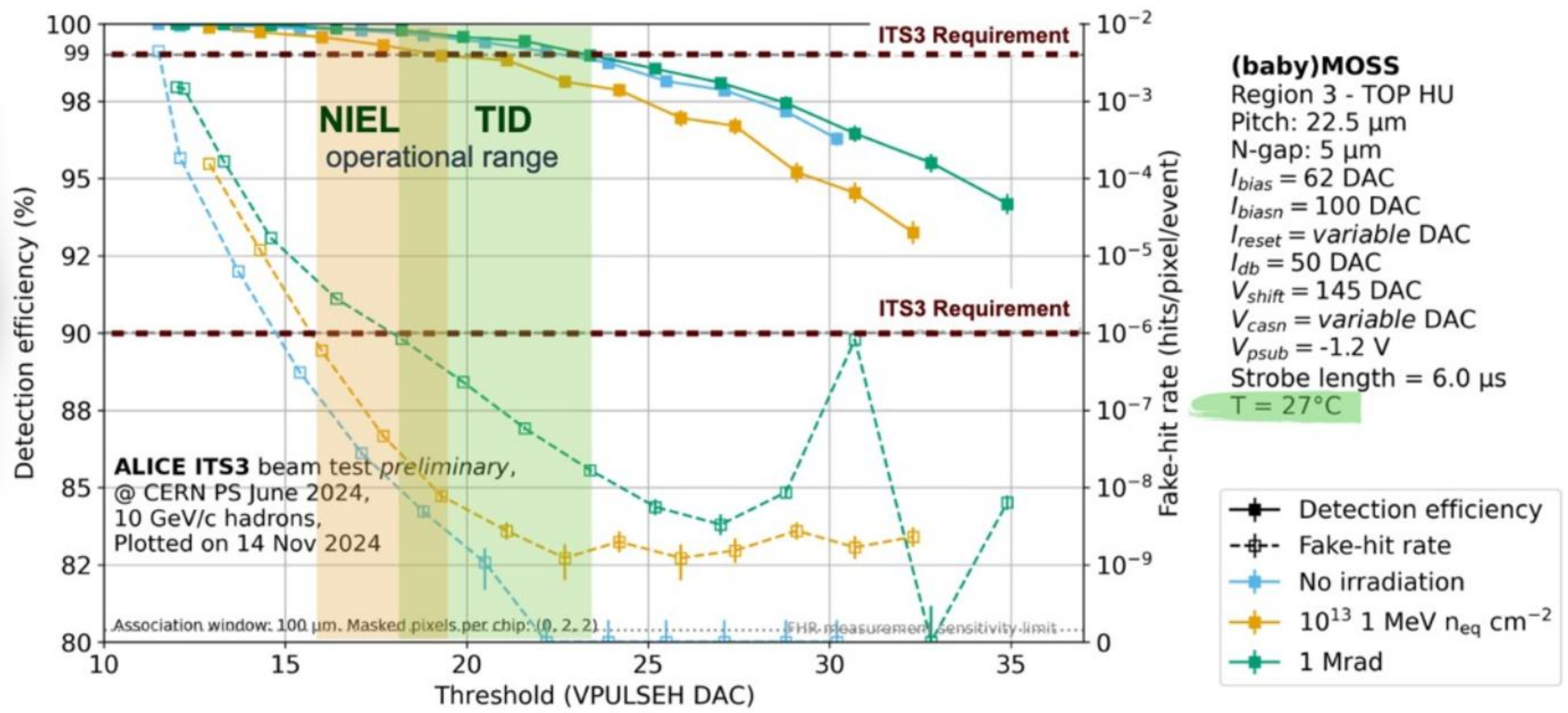




- Small electrodes
  - Small sensor capacitance
  - Reduced noise & Power
  - Less cross-talk

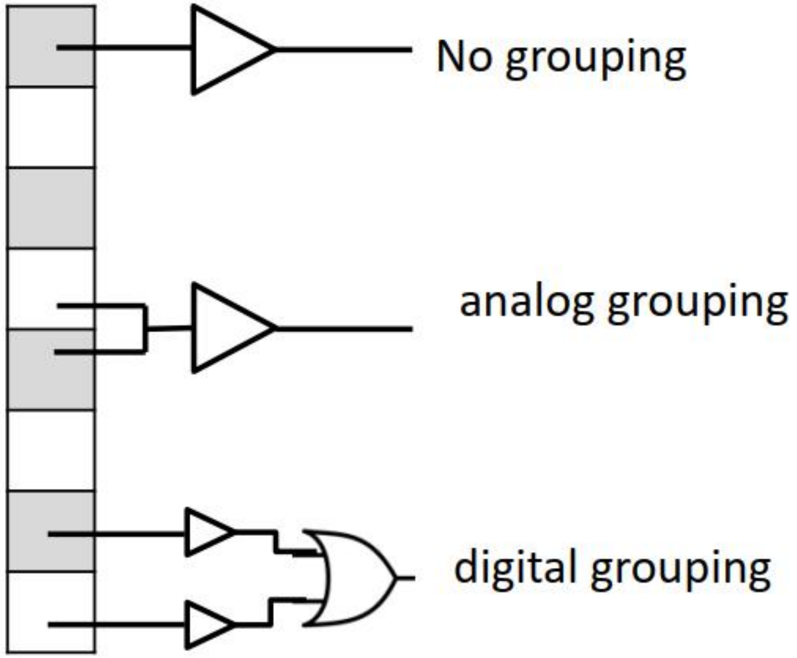
- Large collection electrodes
  - Large sensor capacitance
  - Large “natural” depletion volume
  - Higher radiation tolerance

Sensor	MIMOSA26/28	ALPIDE	MIMOSIS-1	TJ-MONOPIX2	MALTA-2	LF-MONOPIX2	ARCADIA MD2	ATLASPix-3	MuPix10
Date	2008/10	2015-17	2021	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	**3800**
Power (mW/cm^2)	300/150	18-35	~50	O(200)	>70		O(20) ?	150	<350
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



MOSS Detection efficiency and fake-hit rate

Pixel grouping



Power	Footprint
S/N	Spat. res.

Power ?	Footprint
S/N ?	Spat. res.

Power	Footprint
S/N	Spat. res.