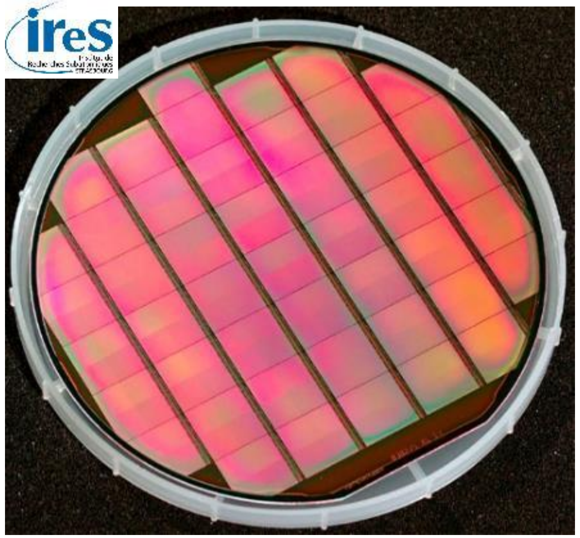
Research on CMOS MAPS at GSI/FAIR – Status and Next Step

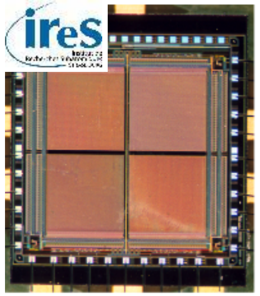
M. Deveaux, GSI



Wafer of MIMOSA-5, 1024x1024 pixel (2002)

The MIMOSA - Technology

Minimum Ionizing Particle MOS Active Pixel Sensor



MIMOSA IV

Features of the MIMOSA (I – VI) – detectors:

- Single track resolution 1.3µm - 3µm
- Typical Pixel – pitch 20µm
- Thinning potentially possible down to ~20µm
- S/N for MIPs 20 – 40
- Readout speed: 10MPixel/s (design: 40MPix/s)
- Design tested on different commercially available CMOS-Processes
- 1k€ per 10^6 Pixel (Prototype)

M.Deveaux, IPHC&GSI

21 years

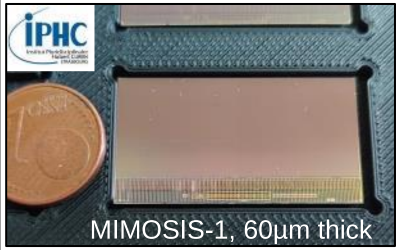
x 10^4

The MIMOSIS - technology

Mimimum Ionizing Particle MOS Active Pixel Sensor for FAIR-SIS experiments

Features of the MIMOSIS (I–II) detectors:

- Single track resolution 5-7µm
- Typical Pixel – pitch 27x30µm²
- Thinned routinely to ~60µm
- Readout speed: 103 219 MPixel/s
- 1024 x 504 pixels
- Design tested on the TJ 180 nm CMOS-Processes



Fair GmbH | GSI GmbH Dr. Michael Deveaux 3

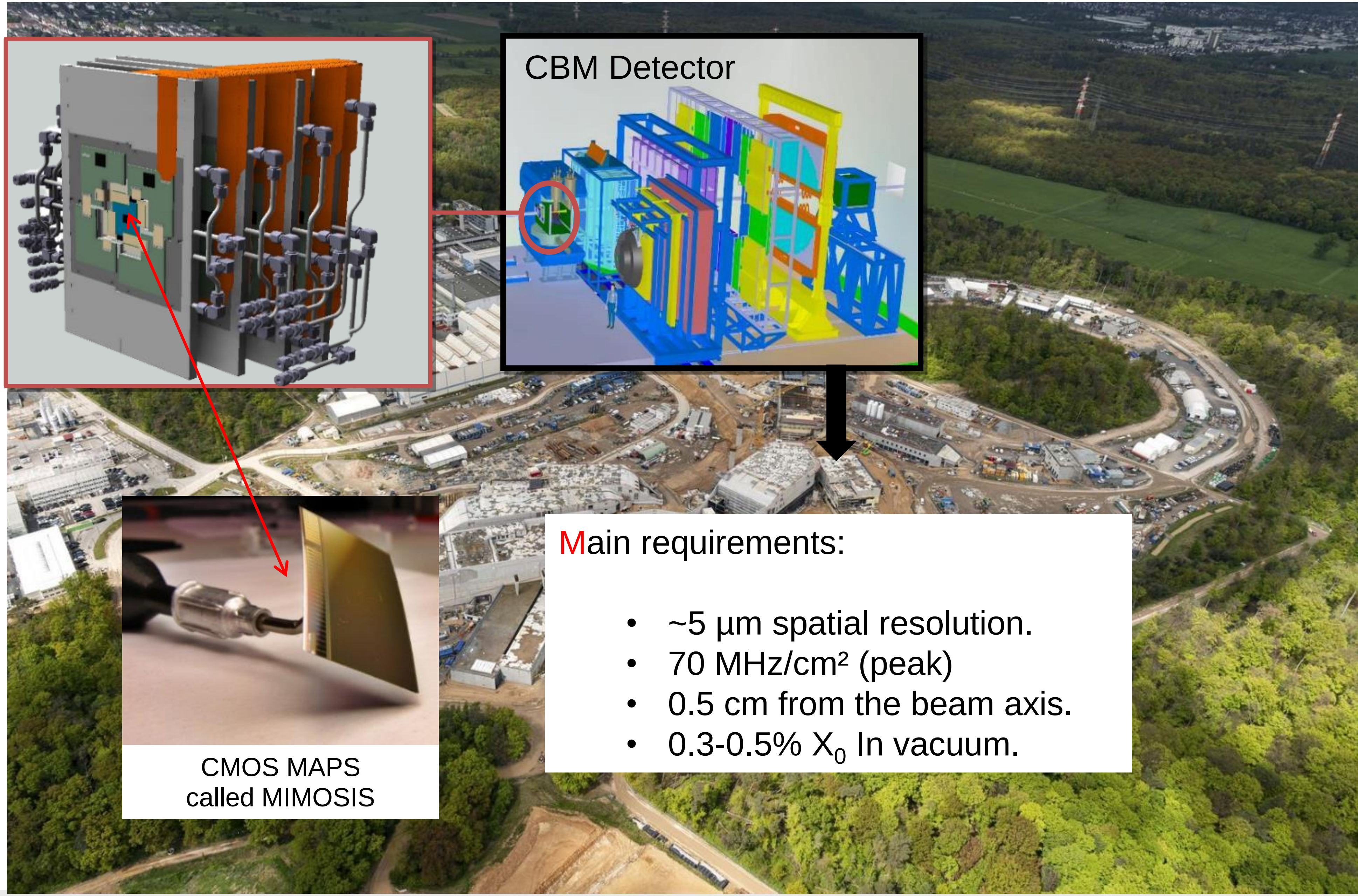
2nd CBM collaboration meeting, July 2003, GSI.

About 2003, the “CBM-MVD” collaboration was initiated…
… to use MAPS at a place not yet called FAIR/Darmstadt.

The “CBM-MVD” collaboration:

Sensor design.
Sensor test.
Sensor integration.
Sensor simulation.

The Micro Vertex Detector (MVD) of CBM

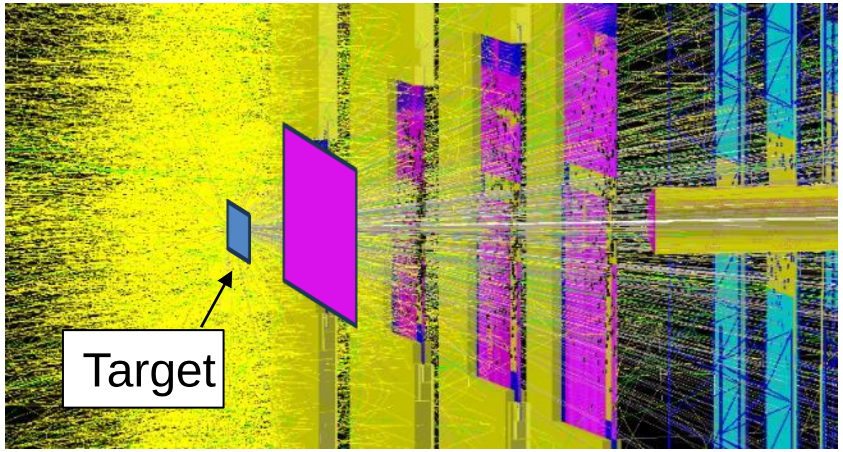


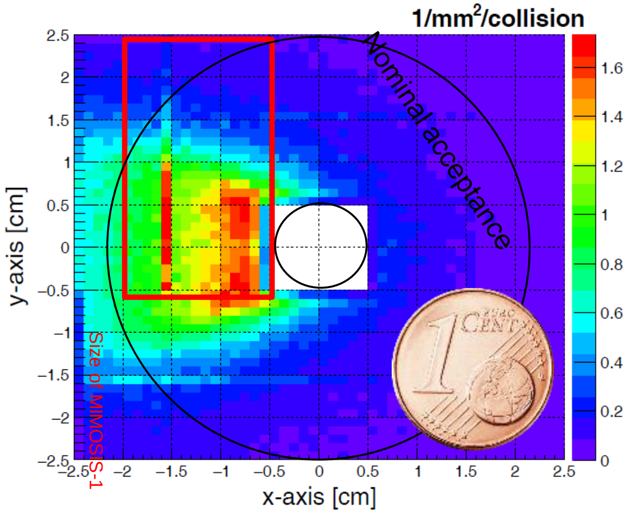
Main requirements:

- ~5 µm spatial resolution.
- 70 MHz/cm² (peak)
- 0.5 cm from the beam axis.
- 0.3-0.5% X_0 In vacuum.

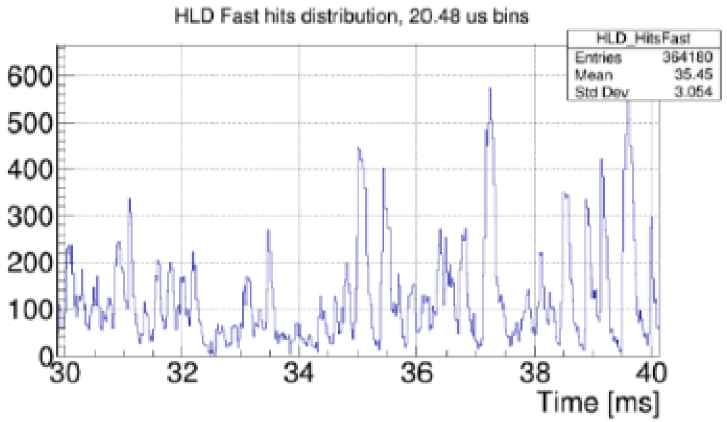
δ-electrons are kicked out by beam from target.

- δ-electrons form 90% of occupancy.
- δ-electrons create highly non-uniform radiation field.



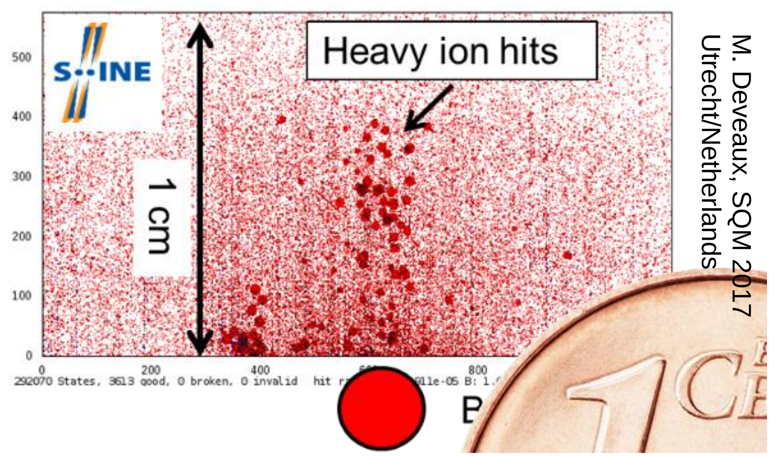


Beam intensity (SIS18-measured)



No Trigger signature => Continuous readout

- “Slow extraction” of beam on target creates beam fluctuations.
- Detector must handle significant rate peaks.



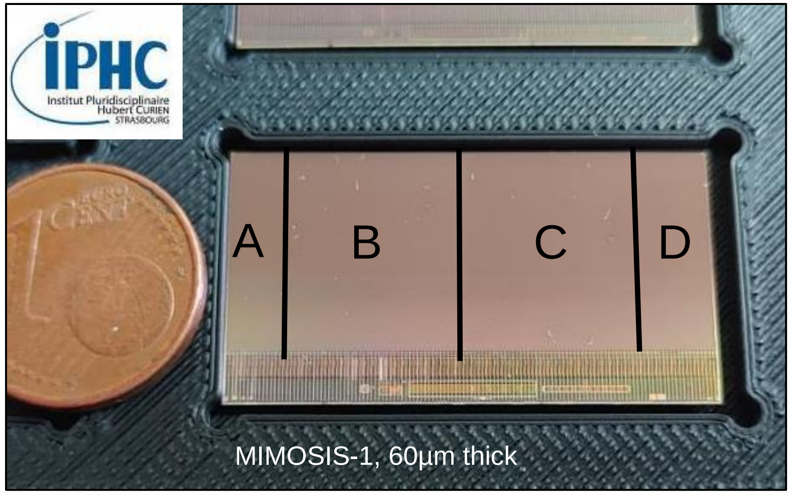
M. Deveaux, SQM 2017
Utrecht/Netherlands

Operation very close to the beam => Tolerate ions

- Significant beam halo => Need to understand integrated radiation damage
- Manage Single Event Effects up to highest LET (dE/dx >>10^4 m.i.p).

HI-physics is low momentum physics – Material budget really matters!

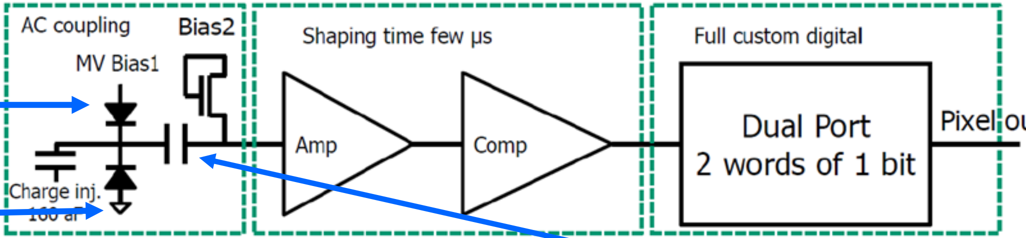
The state of the art: MIMOSIS-1 (inspired by ALPIDE)



Size: 504 x 1024 pixels (27x30µm²), 5µs time binning
Full integrated: 20 MHz/cm² (80 MHz/cm² for 35µs), ~70mW/cm²
Fully depleted: >20V top bias

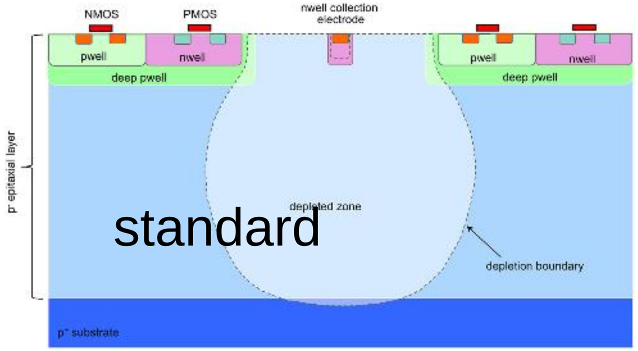
>20V HV top bias

Back bias possible.
P-Well bias (ALPIDE) possible

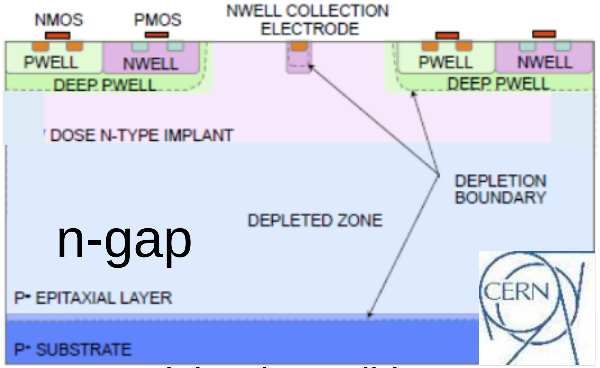


Capacitor blocks HV

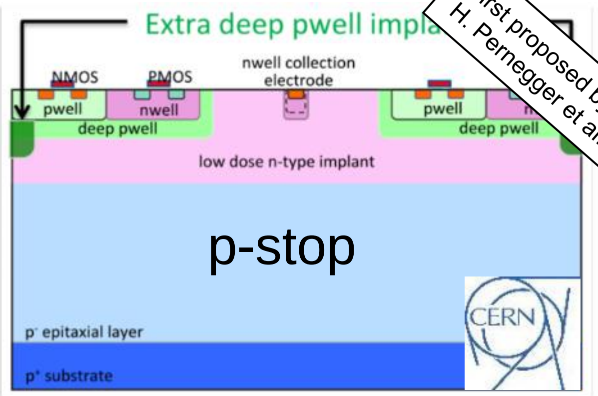
Most likely Fully Depleted



Standard



Rad. hard, candidate 2



Rad. hard, candidate 1

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

MIMOSIS-1: 25 µm epitaxial layer. MIMOSIS-2.1: 25µm + 50µm epitaxial layer => stay tuned.

Sensor performance: New and after 5 MRad + $10^{14} n_{eq}/cm^2$

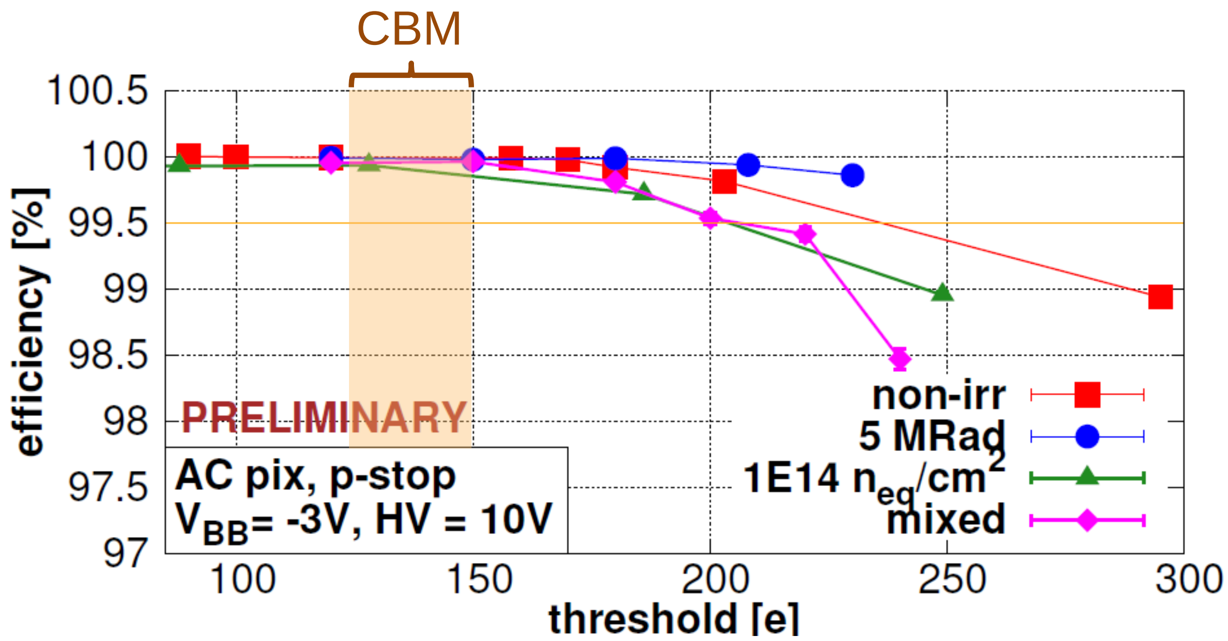
Best performing pixel: AC P-stop

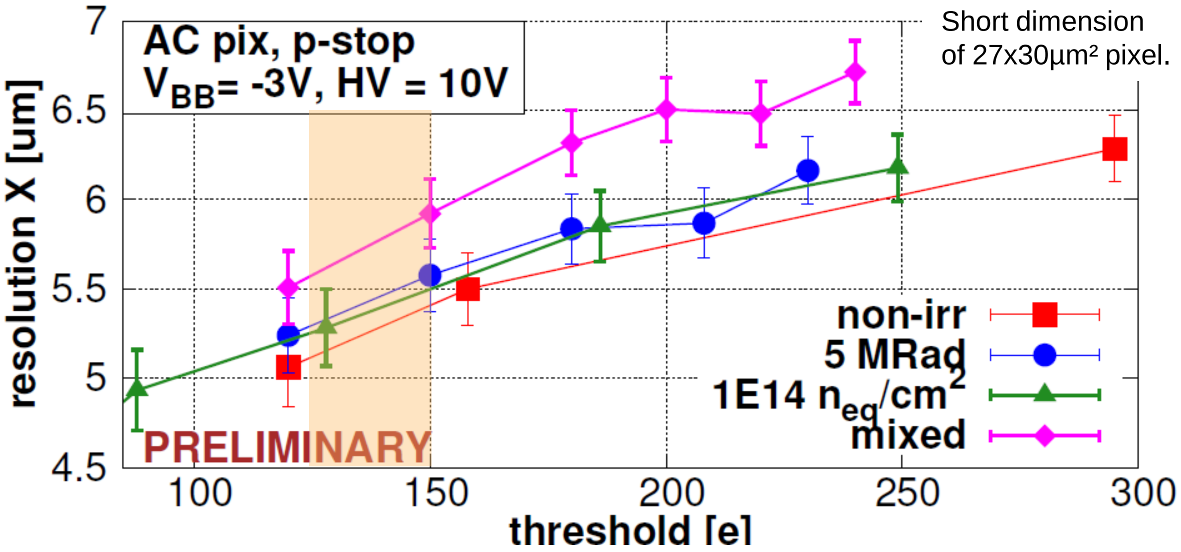
Efficiency >99% (end of life-time).

Dark rate (not shown):

- Marginal before irradiation.
- $<10^{-6}$ after irradiation.

Spatial resolution: ~6 µm





Short dimension of 27x30µm² pixel.

Conclusion on sensor performance:

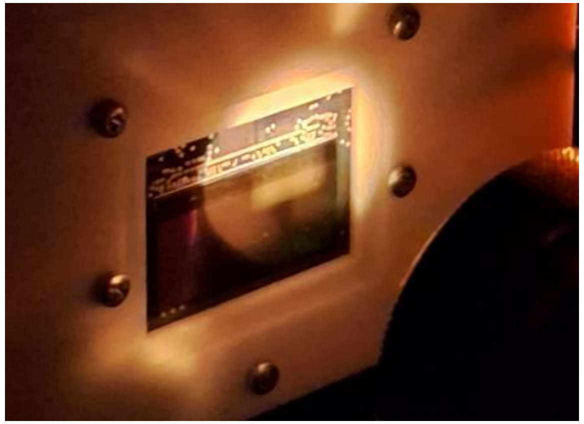
- All pixels work excellent before irradiation.
- P-stop AC pixel most radiation hard, matches requirements of CBM.

Test and integration work at GSI/Uni-Frankfurt

MIMOSIS-2 SEE tests with ~5 AMeV heavy ion beam.

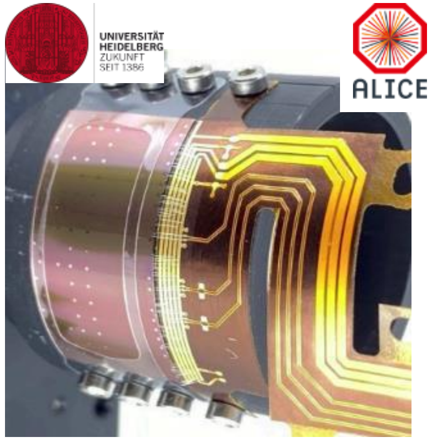
- ✓ Working bit-flip recovery.
- ✓ No latch-up <50 MeV cm²/mg.

(work in progress)



Test of bent ALICE and 65nm TPSCo prototypes:

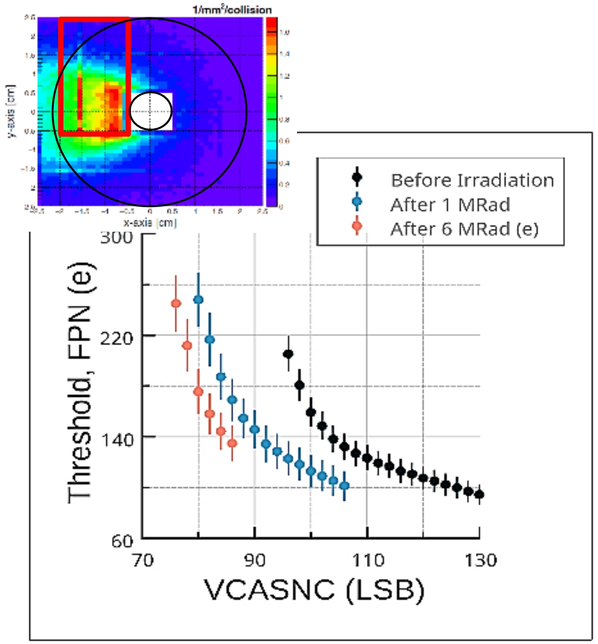
The GSI ALICE group.



Test of differential rad. damage:

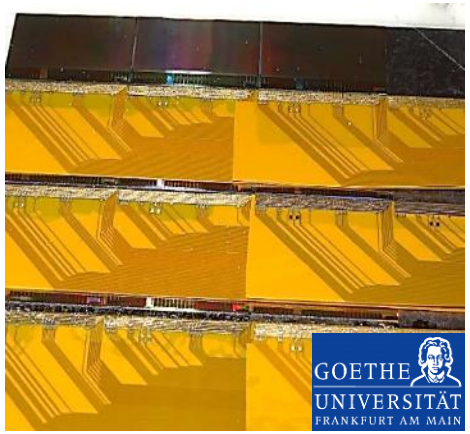
- ✓ Issues finding common working point at differential rad. damage.
- ✓ Effect saturates: Pre-condition by irradiating with ~1 MRad.

(work in progress)



Integration :

- ✓ Vacuum compatible detector stations with 0.3 - 0.5% X_0.
- ✓ High speed DAQ (CBM)



Toward the future: MAPS at GSI/FAIR

Status

Completed
Under preparation
Considered

ALICE ITS3:
Vertex detector
(S. Masciocchi et al.)

ALICE 3:
Outer tracker

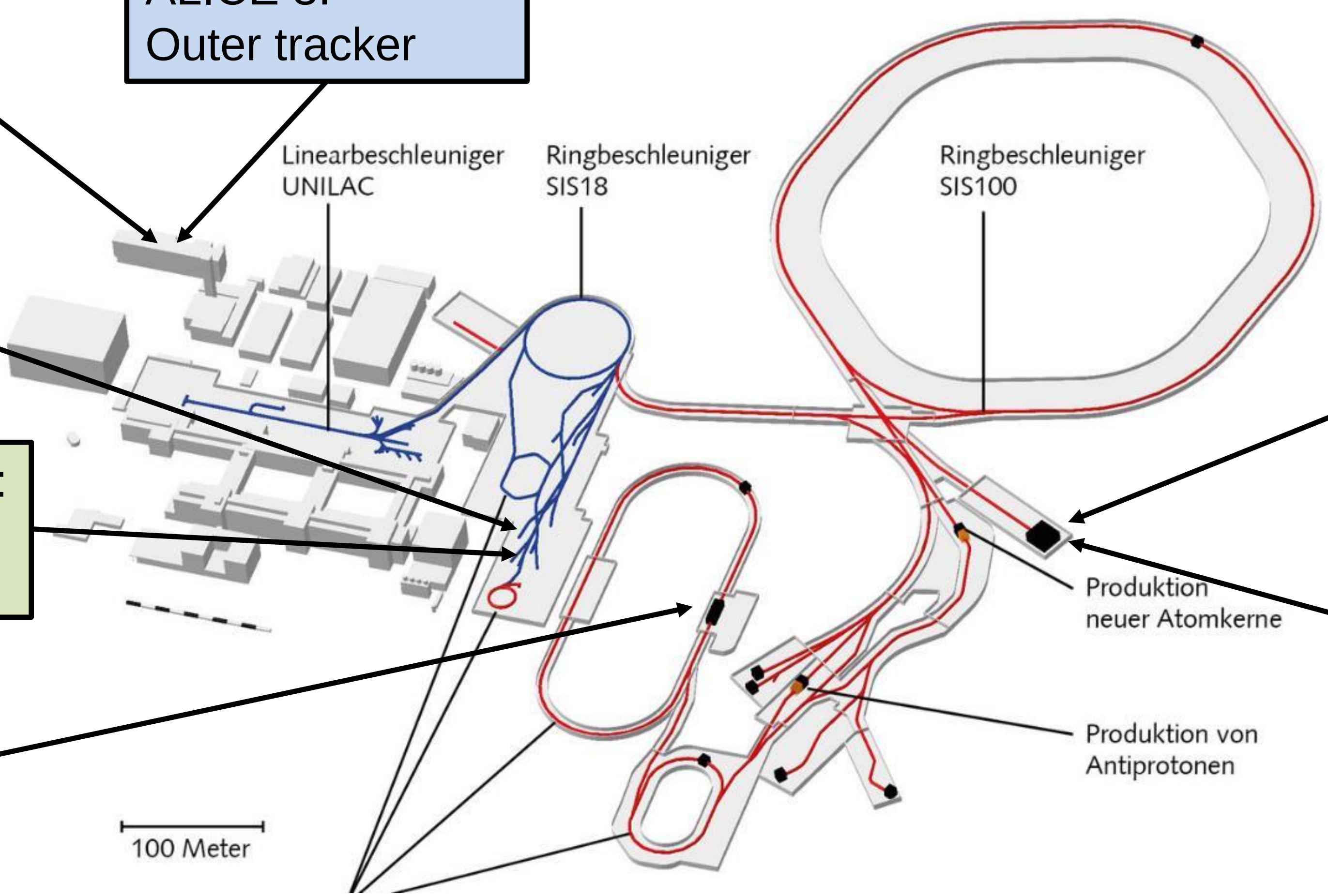
R3B:
Si – Tracker
(O. Kiselev et al.)

FIRST (^{12}C-therapy):
Si – Tracker
(M. Durante? et al.)

PANDA:
Vertex Detector
(L. Schmidt)

CBM:
MVD
(J. Stroth et al.)

CBM:
MVD (upgrade)
STS (upgrade)
(M. Teklishyn, M. Deveaux)



Sensors used:
MIMOSA-28
MIMOSIS
ALPIDE
New sensors

} Each great but not cross compatible.

GSI/FAIR groups try to support 3+ independent technology flavors from different sources.
=> Even more in the future?

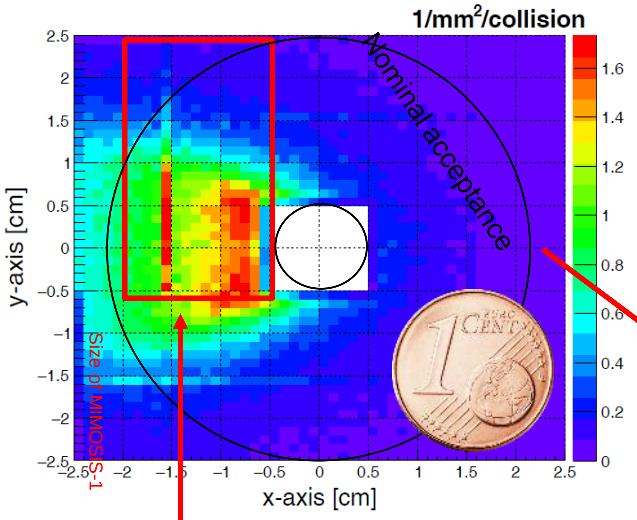
Many applications, many devices?

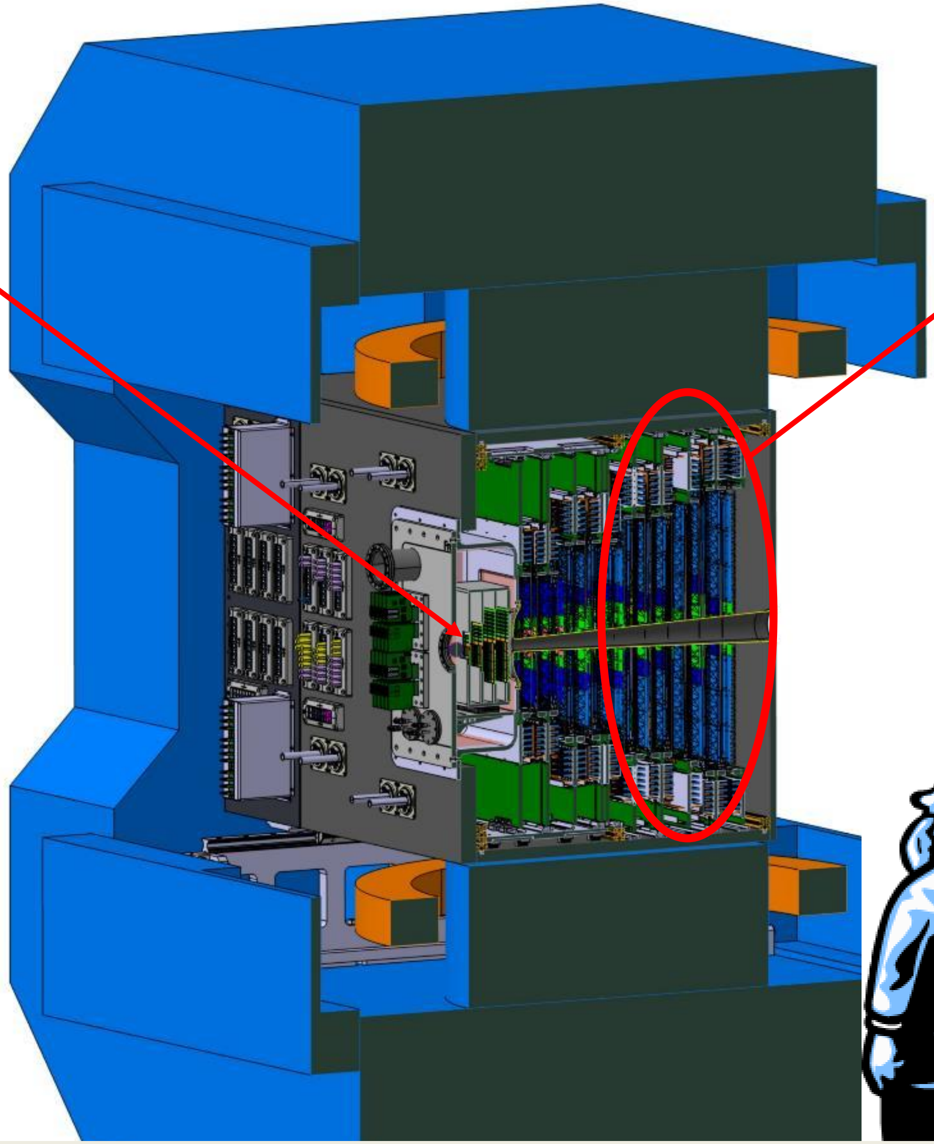
$$\Sigma$$

$$\approx$$

Given the limited resources of GSI:
Try to develop one flexible standard technology suited for multiple purposes rather than too many customized solutions.

Thinking about flexible standard technology





Determines the requirements on rates.

Need high rate sensors.

Small surface => few W power
=> Cooling easy.

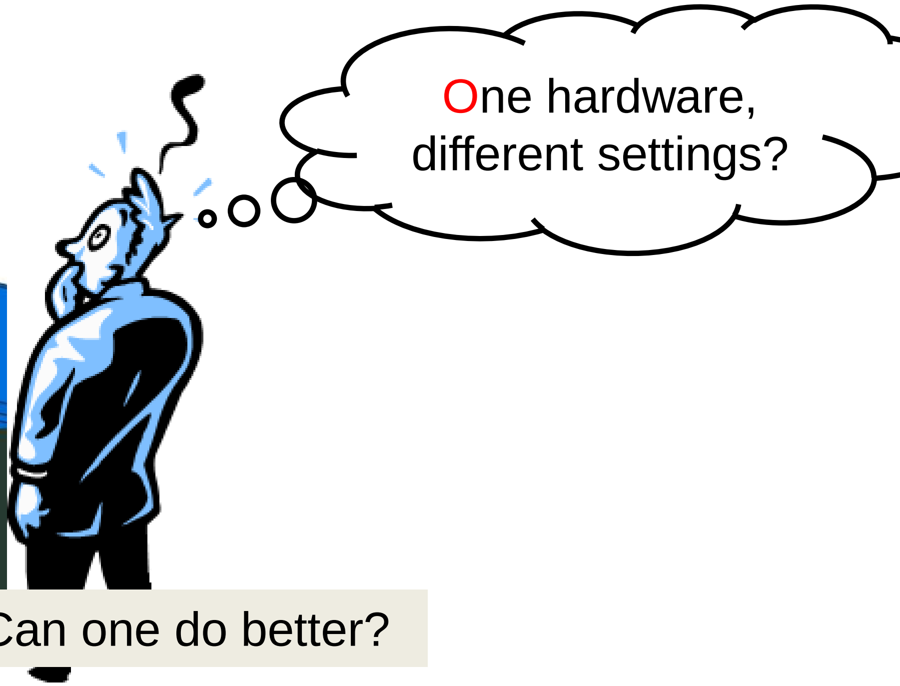
High rate, high power.

Determines requirements on cooling.

Need low power sensors.

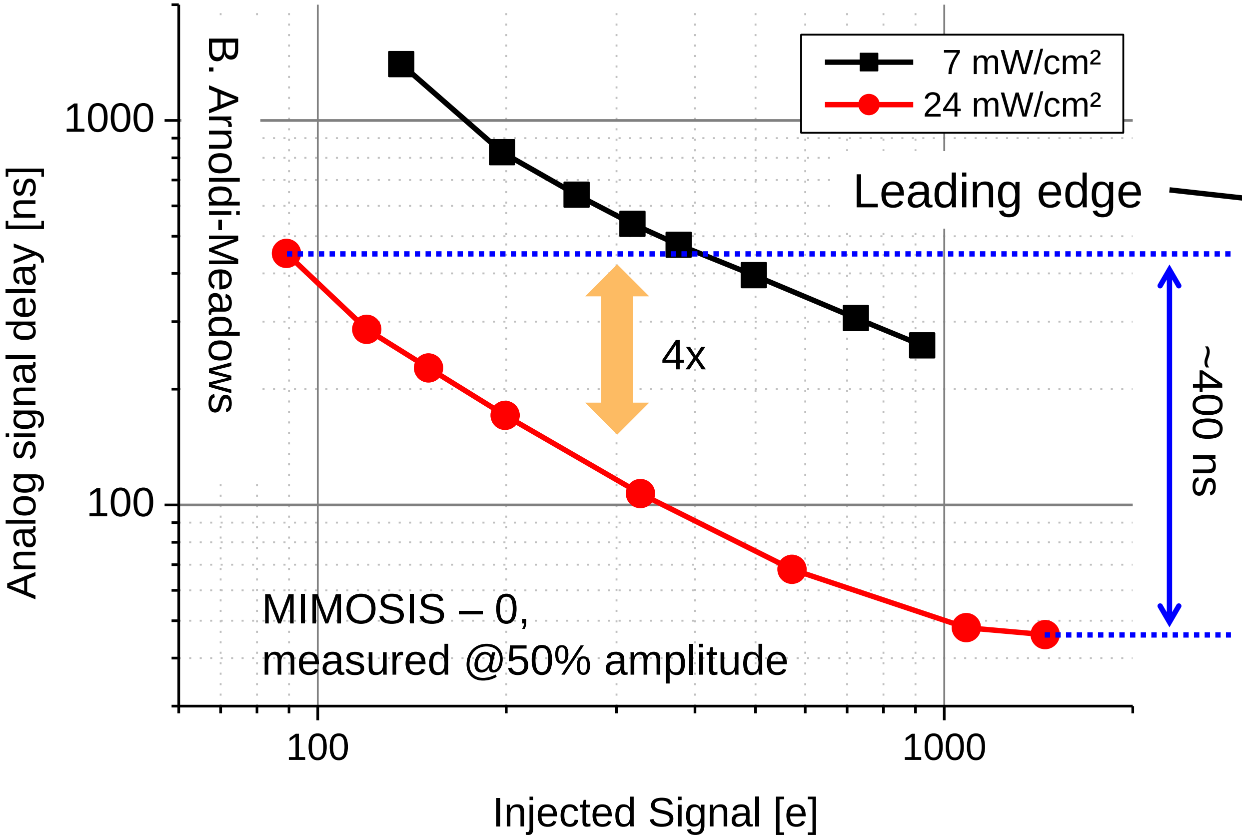
Big surface => few kW power
=> Cooling difficult

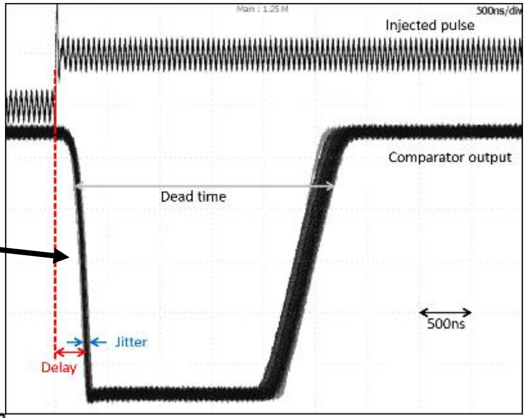
Low rate, low power sensors

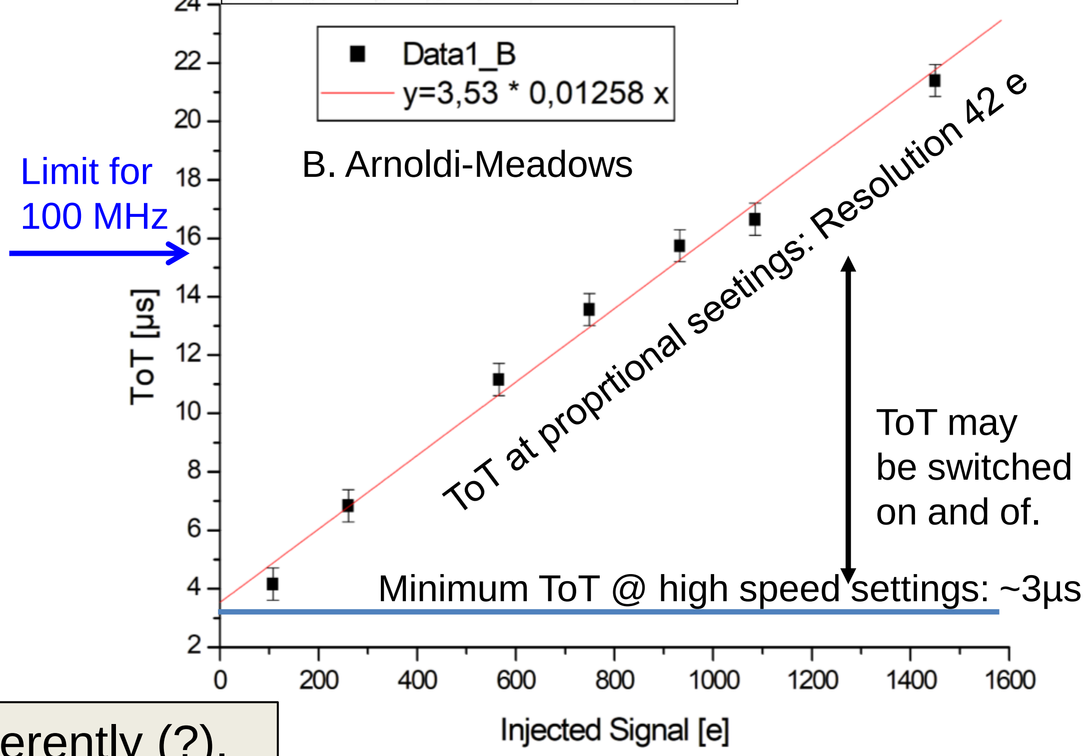


Standard solution: Use different technologies (e.g. pixels, strips). Can one do better?

One hardware, different settings: MIMOSIS-0 (analog output)







Using the ALPIDE/MIMOSIS-FEE, slow control allows to:

- Tune small Time-Walk vs. low power.
- Tune linear ToT vs. short pulse.

=> 400ns (25 ns with ToT) feasible with 5µs front-end if steered differently (?).
Exploiting this may allow for flexible hardware with multiple use cases.

Summary and conclusion

GSI, IPHC and Goethe University Frankfurt are developing MIMOSIS:

- ✓ Fully depleted, $>10^{14} n_{eq}/cm^2$.
- ✓ 5 µm spatial resolution.
- ✓ 5 µs time binning.
- ✓ 20 MHz/cm² (80 MHz/cm² peak).
- ✓ Proven tolerance to heavy ion impacts.

Sensor design far advanced, expect final sensor within 2 years.

GSI intends to find partners to develop (at best):

- One sensor with tunable performance (power vs. rate).
- An integration toolset (DAQ, mechanics, software)…

…suited for multiple applications and small teams of end users at and beyond FAIR.

Guess-timate of sensor requirements (to be scrutinized)

Thanks to:

IPHC, Uni-Frankfurt, GSI (CBM-MVD) collaboration:
Julio Andary[1], Benedict Arnoldi-Meadows[1], Ole Artz[1], Jérôme Baudot[2], Grégory Bertolone[2], Auguste Besson[2], Norbert Bialas[1], Roma Bugiel[2], Gilles Claus[2], Claude Colledani[2], Hasan Darwish[1,2,3], Michael Deveaux[3], Andrei Dorokhov[2], Guy Dozière[2], Ziad El Bitar[2], Ingo Fröhlich[1,3], Mathieu Goffe[2], Fabian Hebermehl[1], Abdelkader Himmi[2], Christine Hu-Guo[2], Kimmo Jaaskelainen[2], Oliver Michael Keller[6], Michal Koziel[1], Franz Matejcek[1], Jan Michel[1], Frédéric Morel[2], Christian Müntz[1], Hung Pham[2], Christian Joachim Schmidt[3], Stefan Schreiber[1], Matthieu Specht[2], Dennis Spicker[1], Joachim Stroth[1,3,4], Isabelle Valin[2], Yue Zhao[2], Roland Weirich[1] and Marc Winter[2,5]

[1]Goethe-Universität Frankfurt, Germany, [2]Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France
[3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, [4]Helmholtz Forschungsakademie Hessen für FAIR,
[5]IJCLab, UMR9012 – CNRS / Université Paris-Saclay / Université de Paris, France, [6] FIAR GmbH,Germany

ALICE@GSI: Silvia Masciocchi et al.

	MIMOSIS	CBM tracker upgrade	CBM vertex upgrade
Spat. res.	~5 µm	~10 µm	~5 µm
Time res.	5 µs	25 ns	few 100 ns
Rad. hard.	$> 3 \times 10^{14}\ n_{eq}$ > 5 MRad	Few $10^{14}\ n_{eq}$ ~10 MRad	few $10^{14}\ n_{eq}$ few 10 MRad
Rate MHz/cm²	(20/80) (mean/peak)	(20/60) (mean/peak)	(60/180) (mean/peak)
Readout	8 x 320 Mbps	8 x 320 Mbps	~ 8 x 1 Gbps
Power	~70 mW/cm²	~ 50 mW/cm²	<100 mW/cm²

M. Deveaux, educated guess