IKF T-Lab
GEFÖRDERT VOM Bundesministerium für Bildung und Forschung
IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG
HIC for FAIR Helmholtz International Center
ADvanced MOnolithic Sensors for FAIR

JOHANN WOLFGANG GOETHE UNIVERSITÄT FRANKFURT AM MAIN

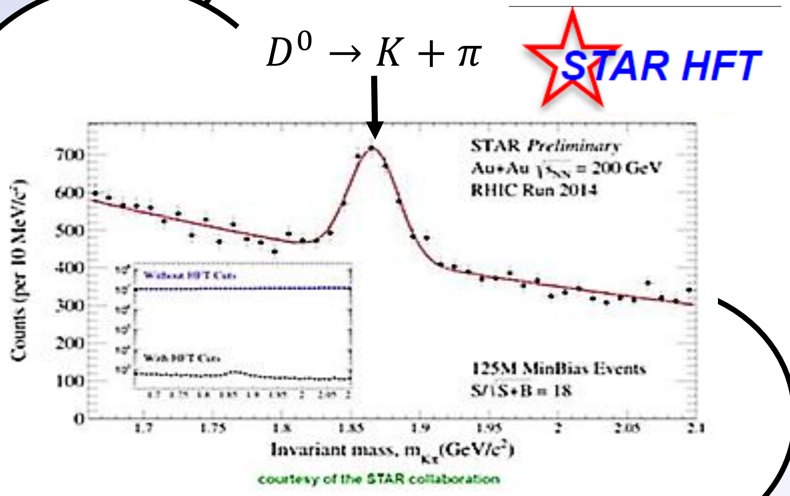
Monolithic Active Pixel Sensors

(CPS / MIMOSA – family)

M. Deveaux, Goethe University Frankfurt and CBM

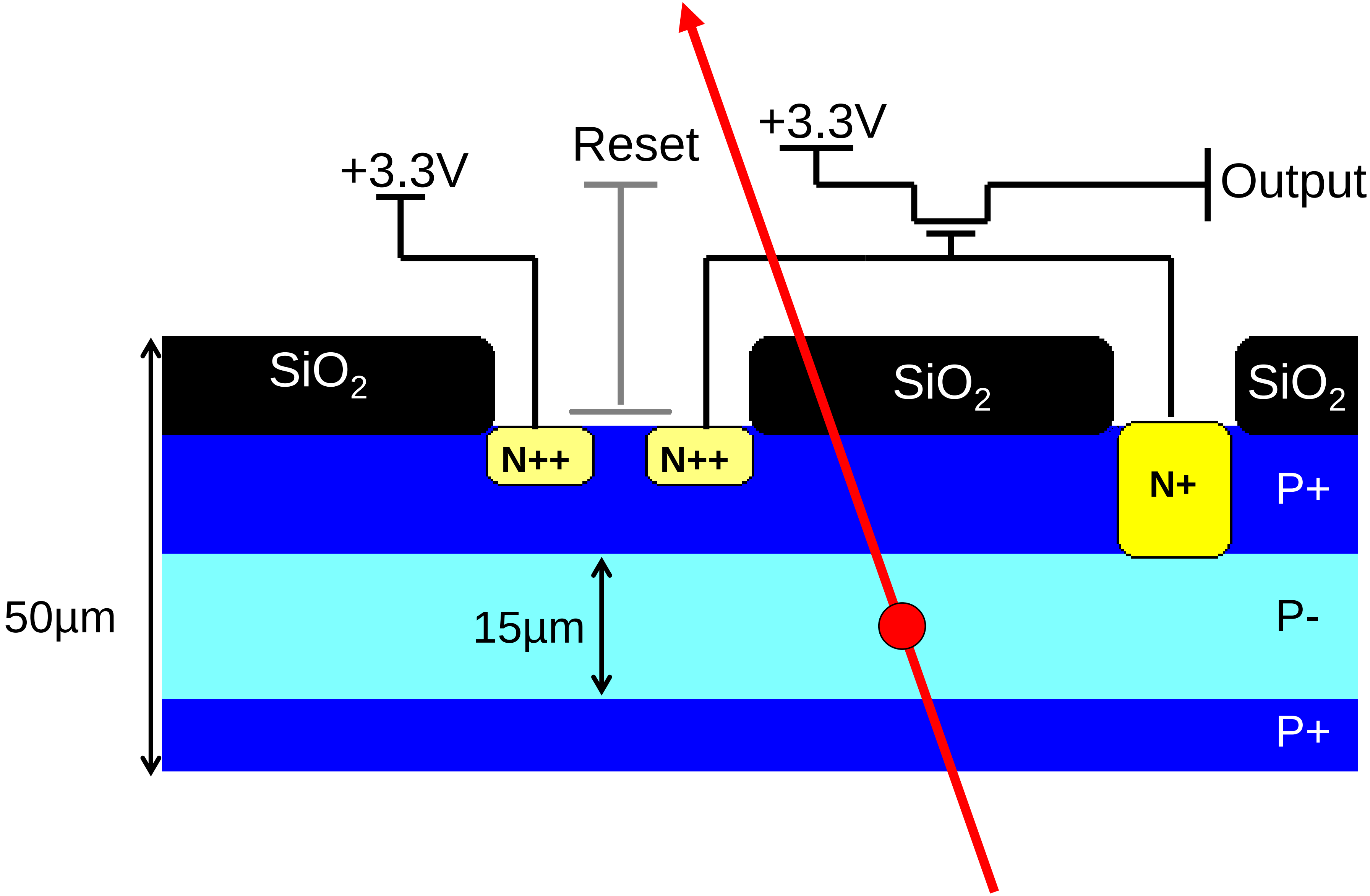
on behalf of the PICSEL group IPHC Strasbourg (Marc Winter et al.).

Institut Pluridisciplinaire Hubert CURIEN STRASBOURG



courtesy of the STAR collaboration

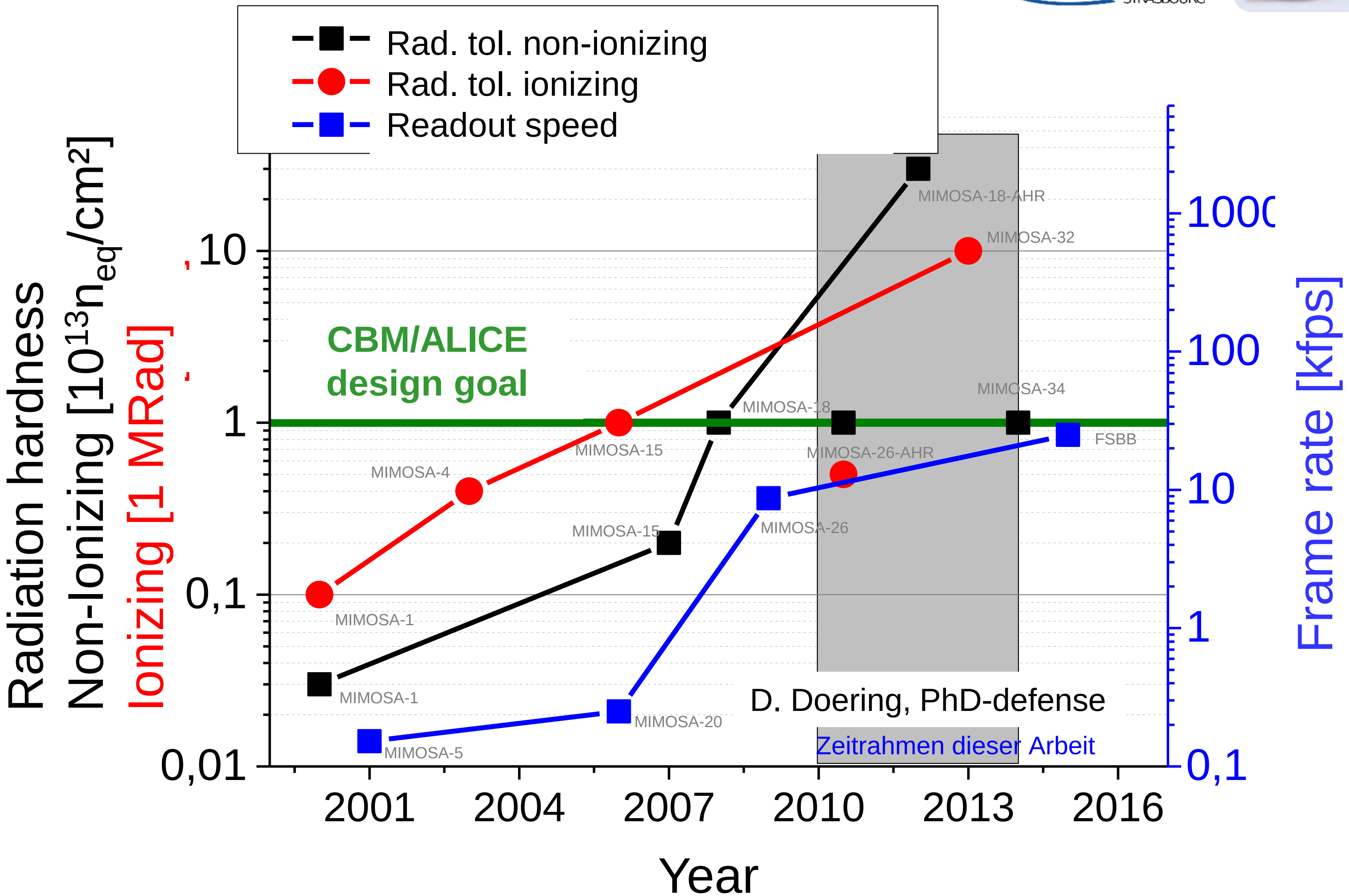
MAPS: The operation principle



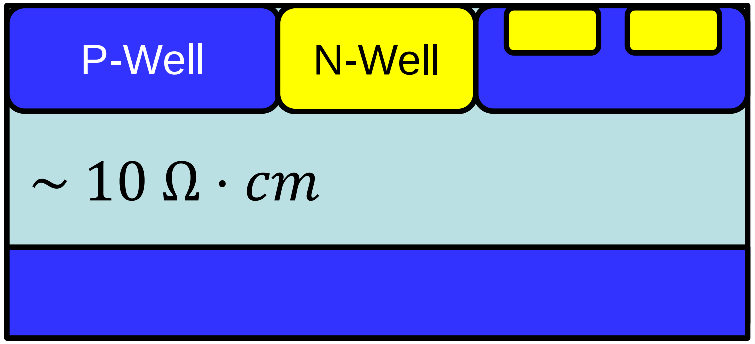
M. Deveaux, Vertex 2015, Santa Fe, 01 – 05 June 2015

Performances of MAPS

Material budget: 0.05% X_0
Spatial resolution: ~ 3-5 µm

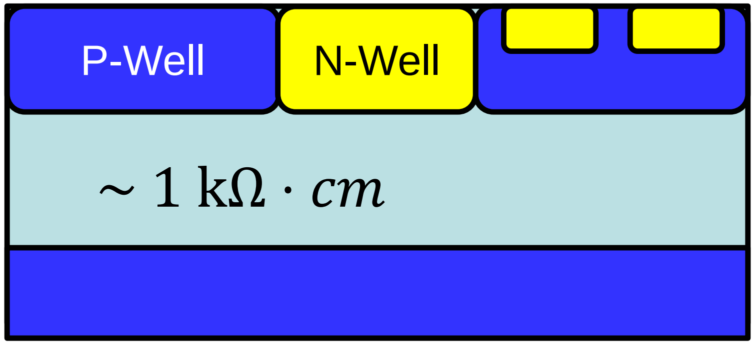


Generations of CMOS-processes



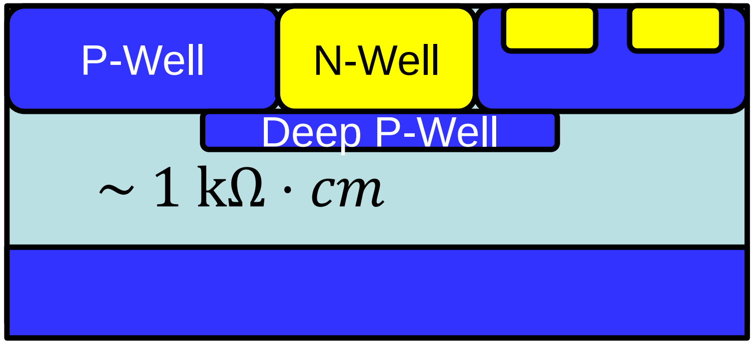
Generation 1: Twin-Well

- NMOS only
- Charge collection by diffusion



Generation 1a: Twin-Well

☺ - Charge collection by drift

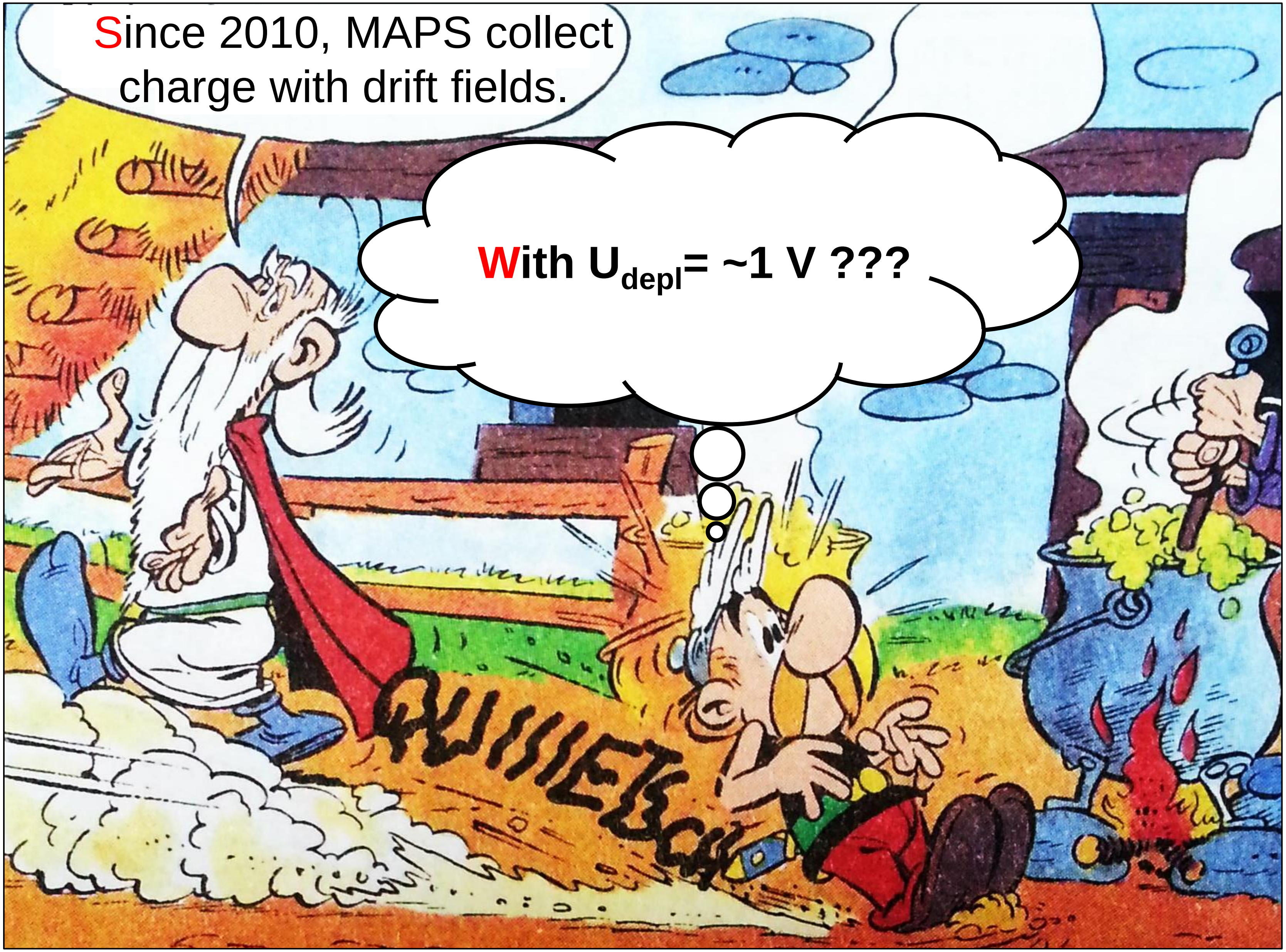


Generation 2: Quad-Well

☺ Full CMOS

☺ Depletion possible

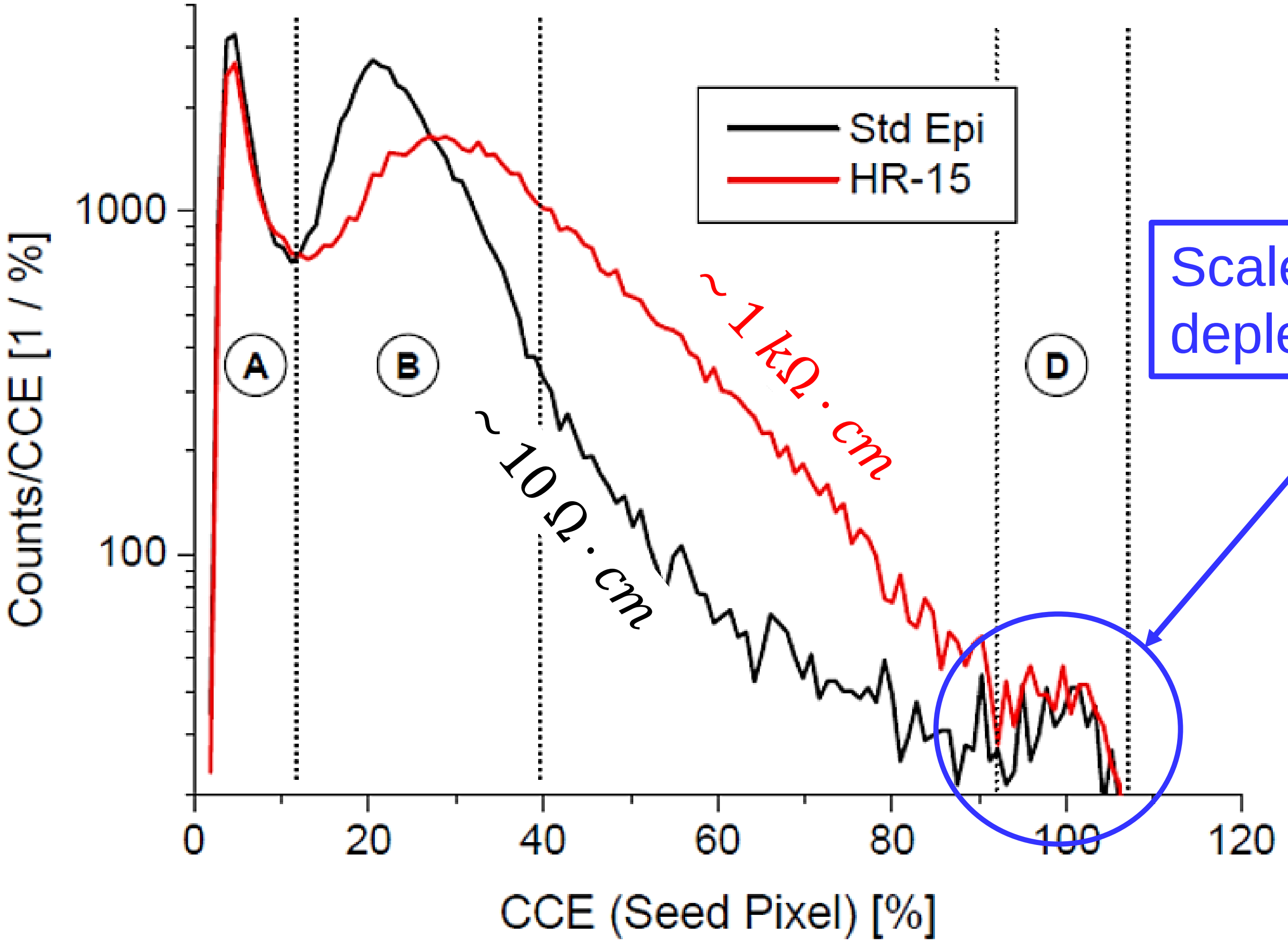
2.5D VLSI integration
(„two tiers“ on one wafer)


Since 2010, MAPS collect charge with drift fields.
With U_{depl}= ~1 V ???

(…

Drift fields in undepleted MAPS (Observation 2010)

MIMOSA-26 (AMS 0.35) illuminated with ^{55}Fe



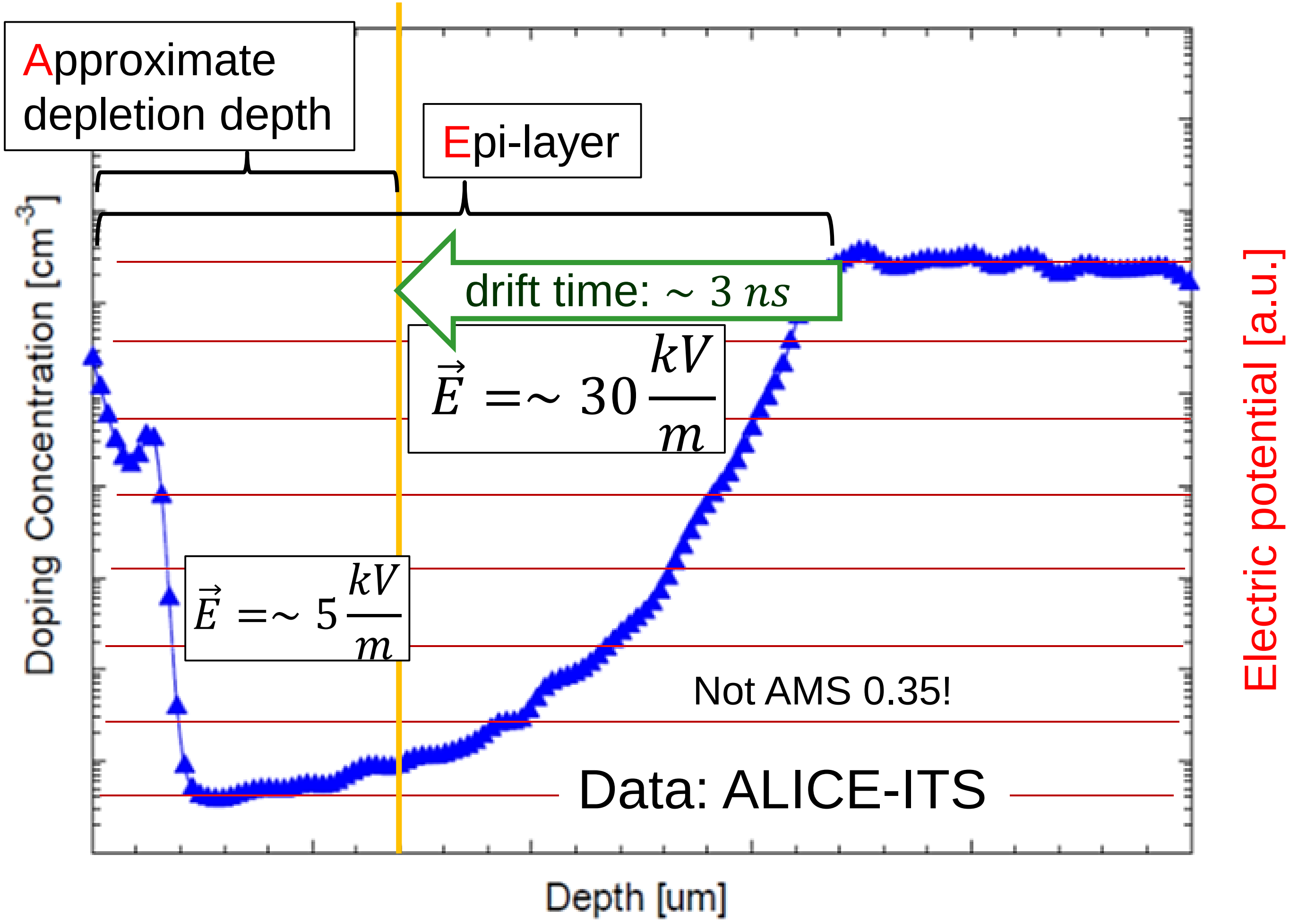
Scales with depleted volume

M. Deveaux et al., 2011 JINST **6** C02004 doi:10.1088/1748-0221/6/02/C02004

- Depleted volume not significantly changed.
- CCE and radiation hardness improved.

⇒ „Unknown beneficial effect“

Drift fields in undepleted MAPS



Buildt in potential:

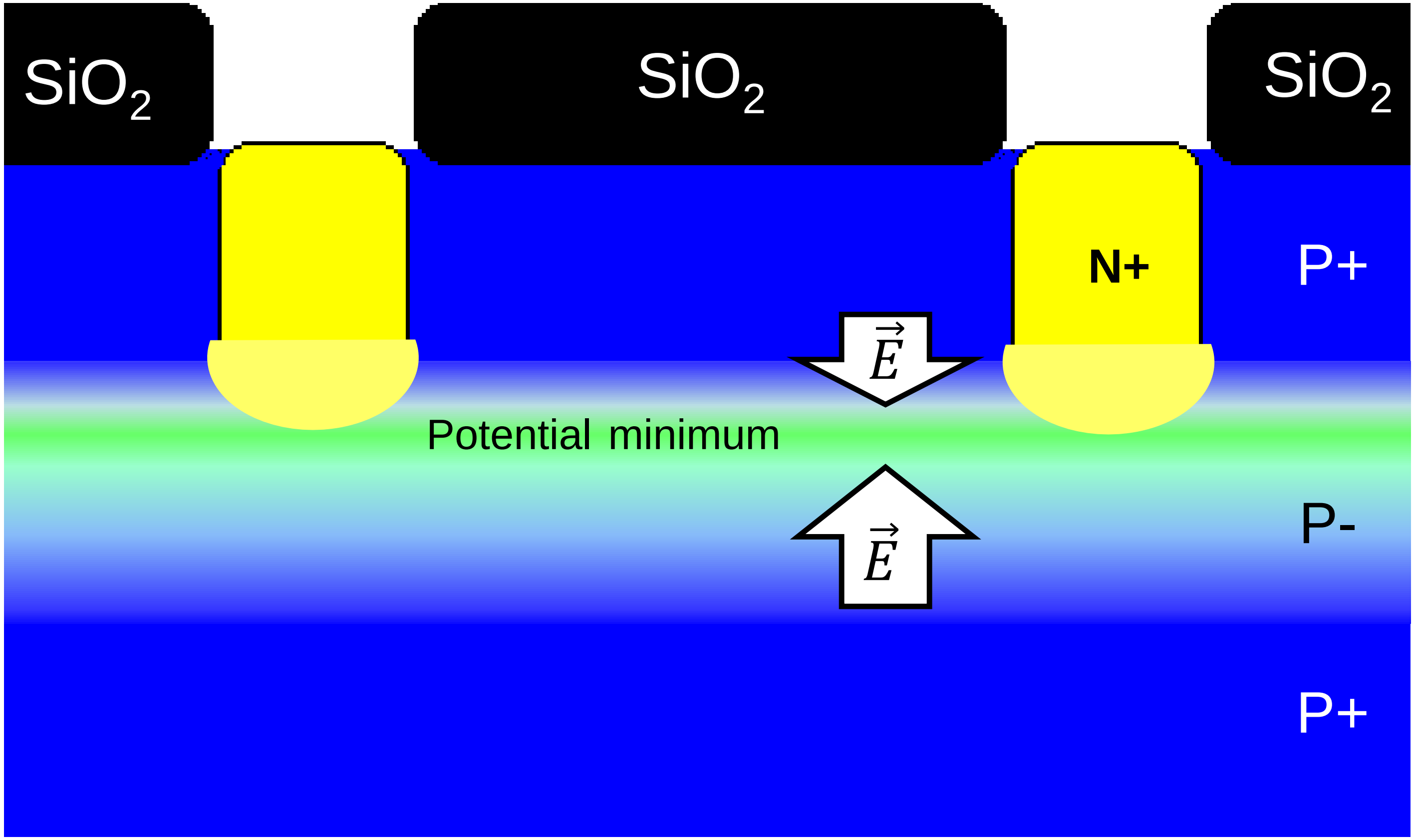
$$V = \frac{k\,T}{e}\ln\left(\frac{N_{subst}}{N_{epi}}\right)$$

G. Deptuch, PhD, Eq. 4-19
ULP Strasbourg (2002)

Back of the envelope calculation:

- Doping gradients create sizable drift fields in epi-layer.
- Electrons reach potential minimum in << 10 ns by drift.

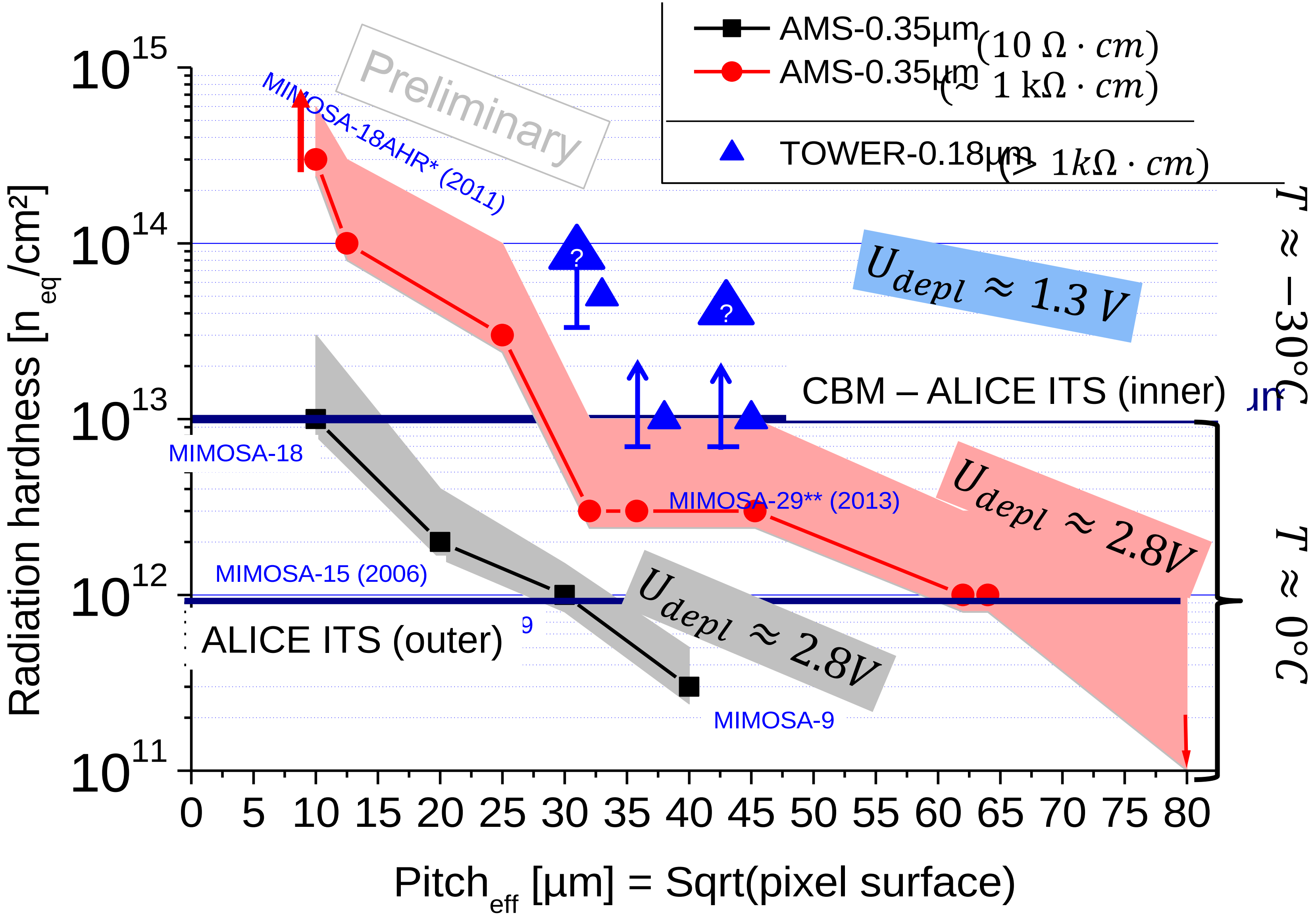
Drift fields in undepleted MAPS



- Vertical movement guided by fields over full depth.
- Lateral movement constrained by fields.

Depletion is not needed to apply fields.

Established knowledge on radiation tolerance

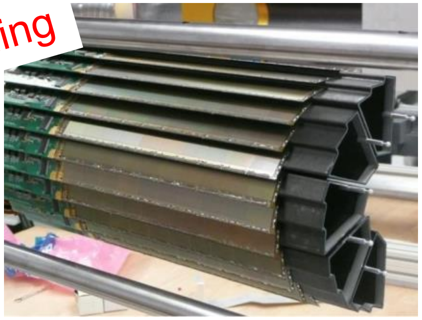


Sensors: IPHC Strasbourg
M. Deveaux, D. Doering, B. Linnik, S. Strohauer, CBM/IKF Frankfurt

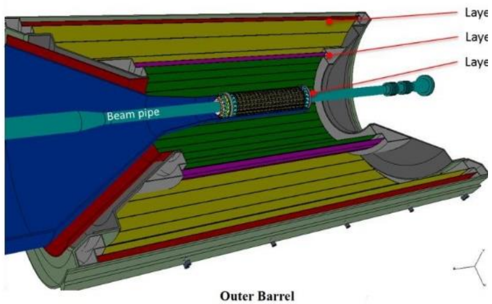
. . .)

Applications of MAPS

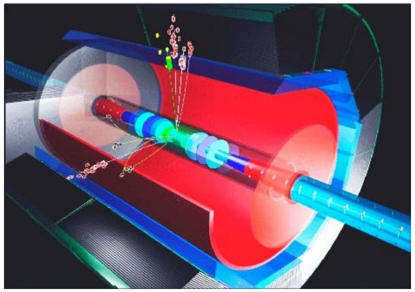
running



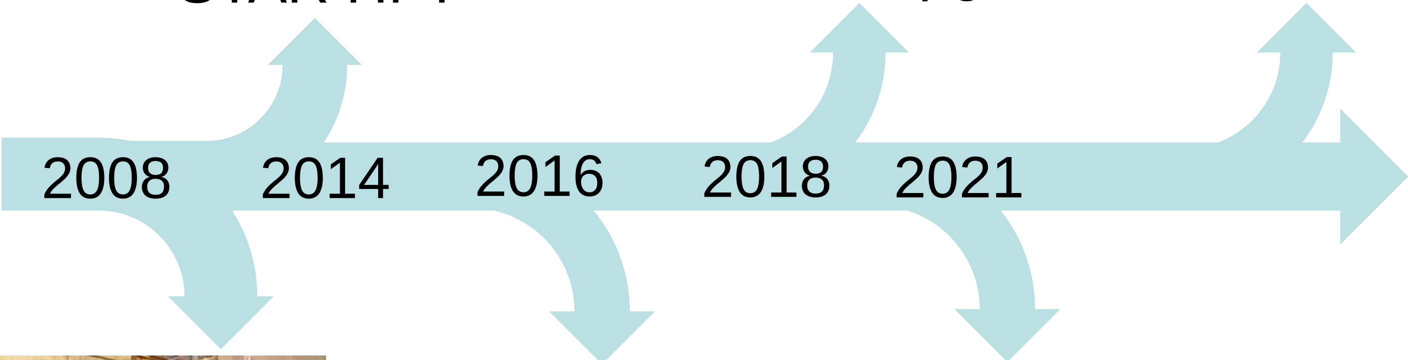
STAR HFT



ALICE ITS upgrade



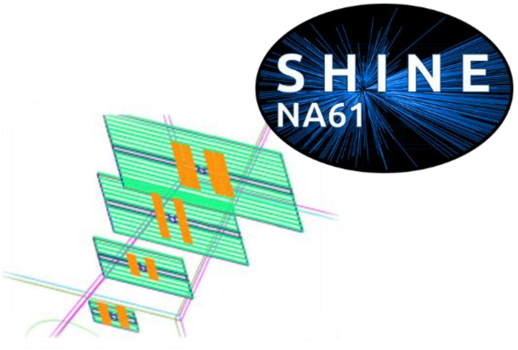
ILC



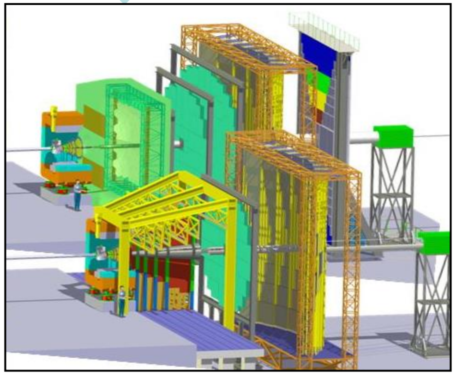
2008 2014 2016 2018 2021

running

EUDet Telescope

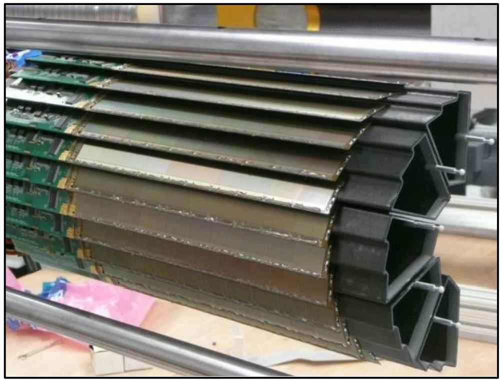


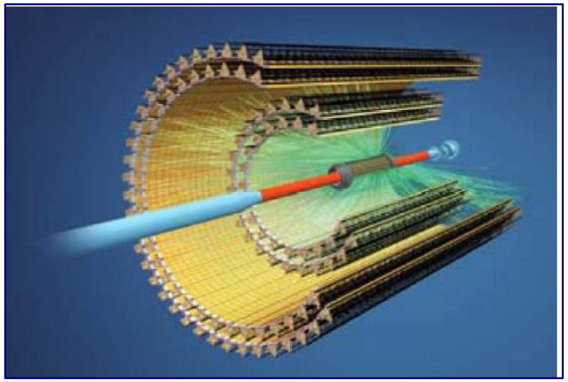
NA61 SAVD



CBM - MVD

From STAR to ALICE

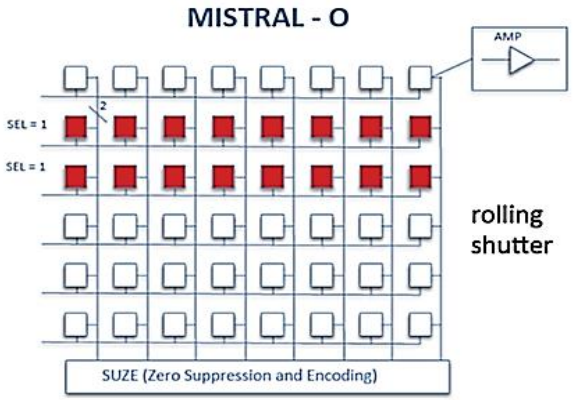




Introduction to project: Monika Kofarago’s talk

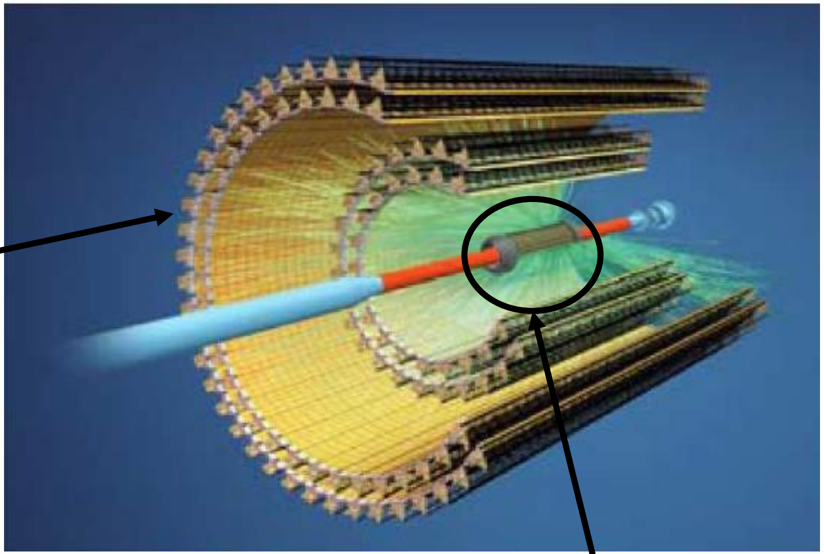
	STAR-PXL	ALICE ITS Outer	ALICE ITS Inner
Spat. Res. [µm]	<4µm	<10µm	<5µm
R.O. time [µs]	<200 µs	< 30 µs	< 30µs
Dose [kRad]	150 kRad	100 kRad	2.7 MRad
Fluency $\left[\frac{n_{eq}}{cm^2}\right]$	$3 \cdot 10^{12}$	$1 \cdot 10^{12}$	$1.7 \cdot 10^{13}$
T [°C]	30-35	30	30
Power $\left[\frac{mW}{cm^2}\right]$	160	<100	<300
Area [m²]	0.15	10	0.17

Toward Sensors for the ITS => Exploit 0.18µm (Gen 2)



Pixel pitch	36µm x 64µm
Event time resolution	~20µs
Power consumption(*)	~~97mW/cm^2~~
Dead area	1.7 mm x 30mm

80mW/cm^2



Goal: Early available and reliable solution

⇒ **Conservative design based on STAR-PXL**

⇒ Big pixels (low power, high speed)

⇒ Moderate rad. hardness ok.

⇒ Moderate (~10µm) resolution ok.

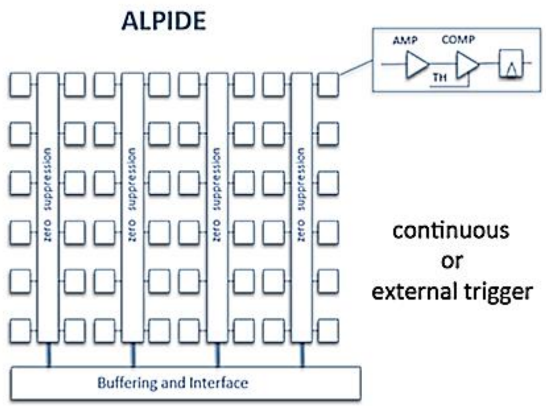
Goal: High performance, accept risks

⇒ **Agressive design**

⇒ Discrimination on pixel

⇒ Asynchronous readout concept

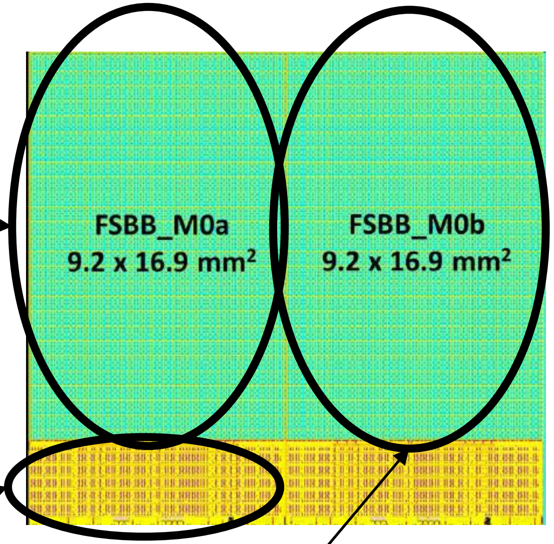
Monika Kofarago's talk



Pixel pitch	28µm x 28µm
Event time resolution	<2µs
Power consumption	39mW/cm^2
Dead area	1.1 mm x 30mm

Going MISTRAL: The FSBB-M0

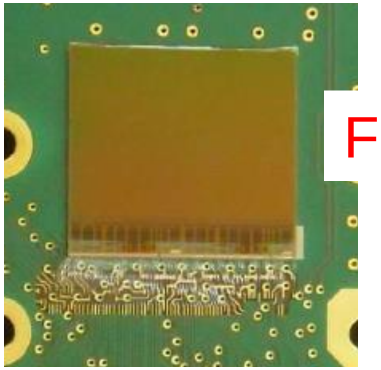
- 416x416 pixels,
- 22 x 33 µm^2 pitch
- 13.7 x 9.2 mm^2 sensitive area
- 40µs readout time



- on-chip CDS, discriminator
- 2 x 320 Mbps output bus
- integrated JTAG, regulators

Two versions, vary:
- sensing node
- input transistor or pre-amp.

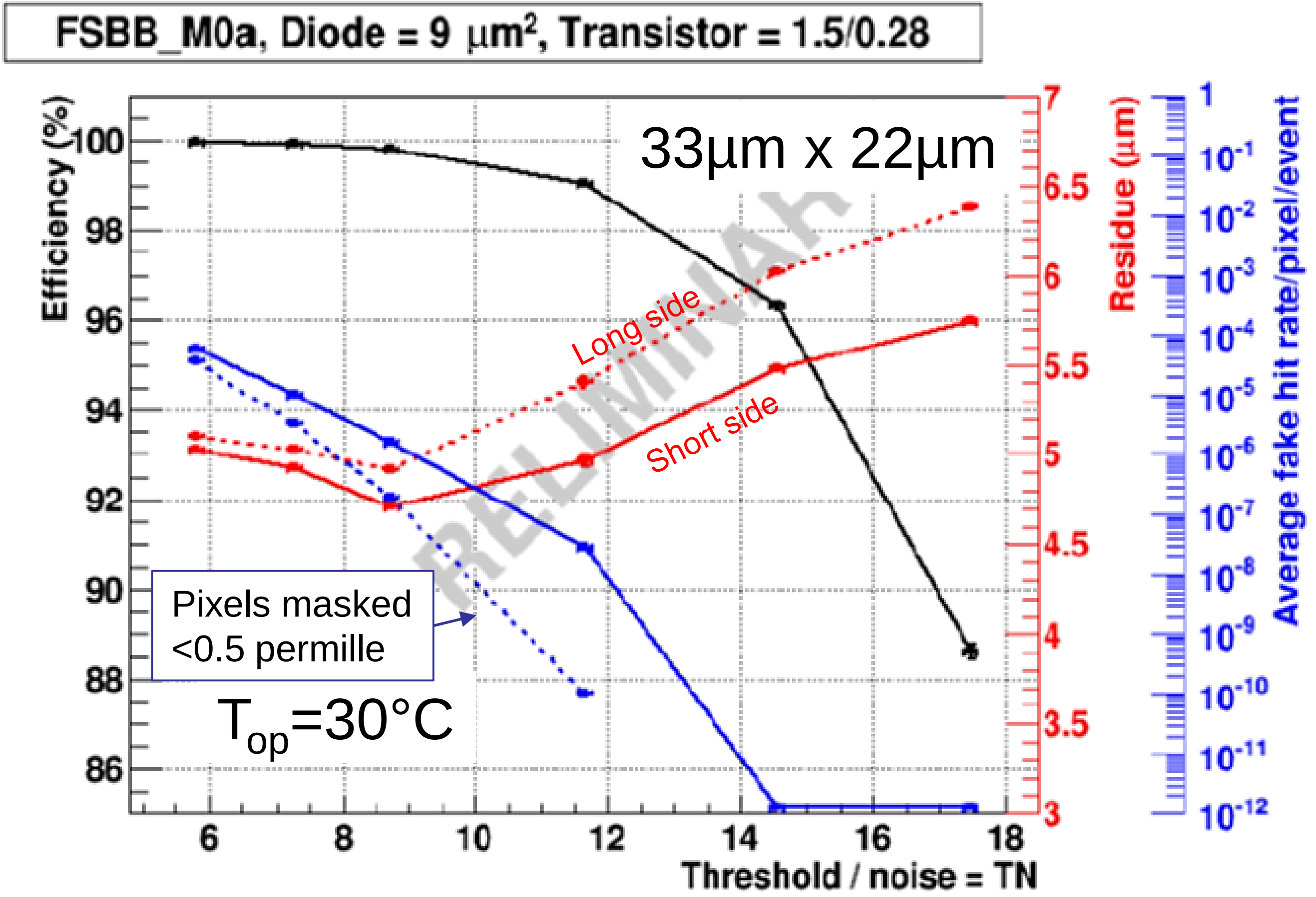
Not yet optimized for:
- pixel dimensions
- readout speed
- in-pixel circuitry & discri
- power consumption
- pads over pixels …



FSBB

Detection performances of the FSBB

CERN-SPS, 120 GeV/c $\pi^- + \mu^-$,
2.5 – 100kHz trigger rate



FSBB_M0a, Diode = 9 µm², Transistor = 1.5/0.28

33µm x 22µm

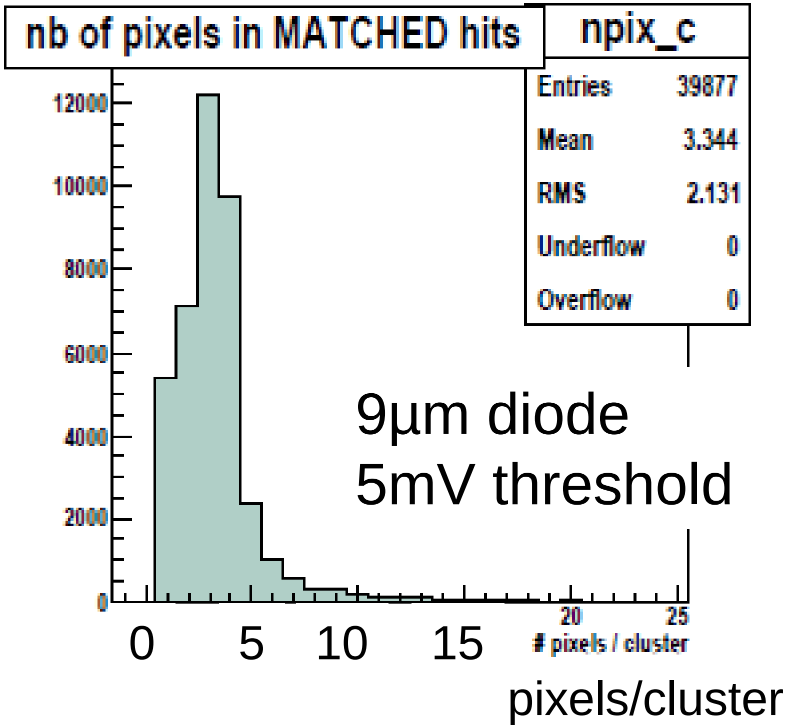
Pixels masked <0.5 permille

T_{op}=30°C

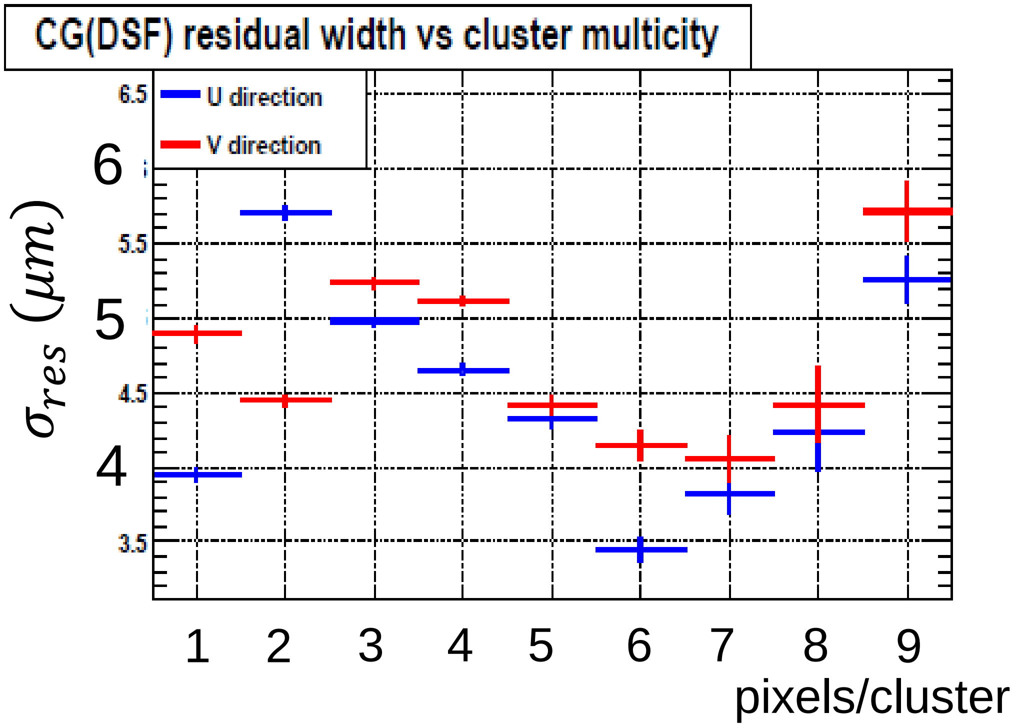
Telescope:
6 x FSBB-M0
50µm thick

Excellent performance:
Detection efficiency: $\epsilon_{det} > 99\%$ @ dark rate $< 10^{-5}$
Spatial resolution $\sigma_{sp} < 5\mu m$

Spatial resolution vs. cluster size



9µm diode
5mV threshold



Spatial resolution mostly independent of # pixels / cluster.

Conclusion from results of FSBB:

- Sensor matches ALICE ITS requirements.
- Still needed:
    - More speed, bigger pixels
    - Adapt to ALICE integration concept

Toward bigger pixels – M22THR (b5-b8)

On chip:

- Pixels + Discriminator

Pixel pitch:

- $36 \times 62.5 \mu m^2$ and $39 \times 50.8 \mu m^2$

Pixel diodes:

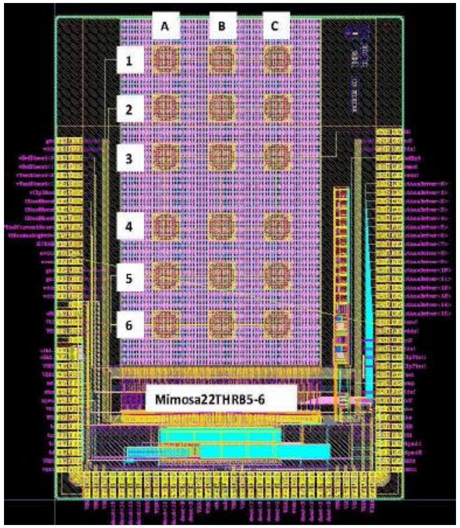
- $2.2 / 4.8 / 7.4 / 14.8 \mu m^2$

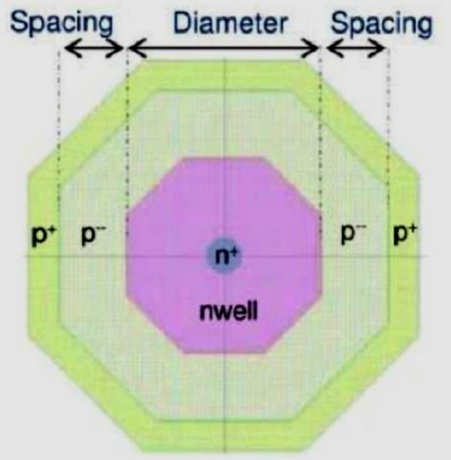
Various options of pre-amplifyers

Various clamping capacitors

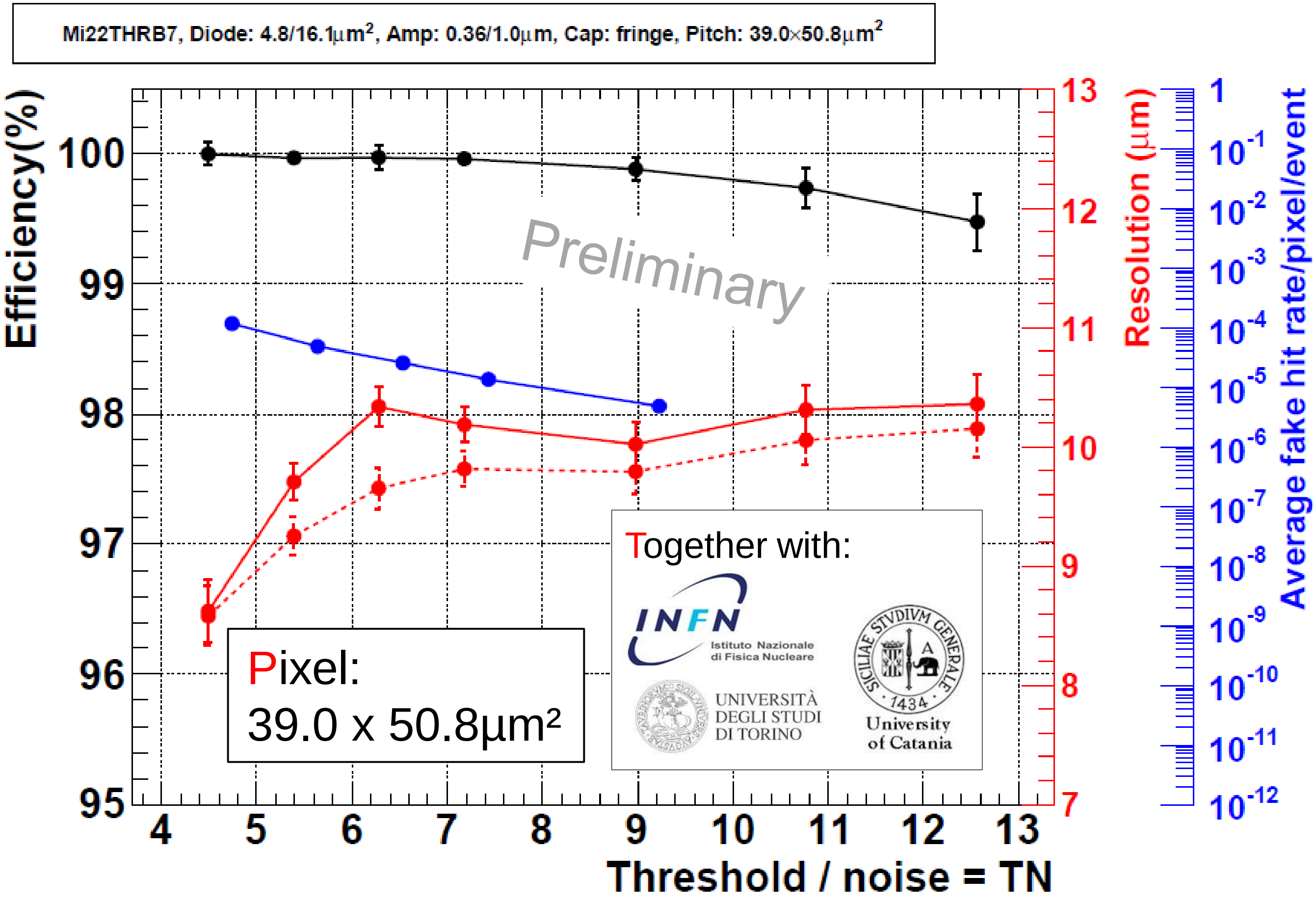
Bonding pads WITHIN the pixel matrix (using ML5 and ML6)

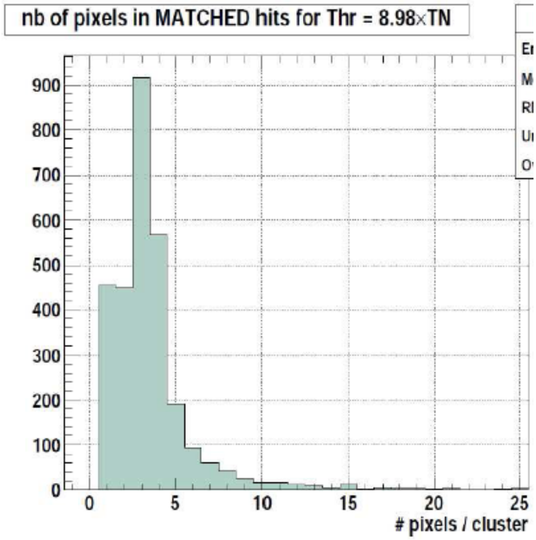
=> Beam test at LNF/BTF (500 MeV electrons)





Toward bigger pixels – M22THR (b5-b8)



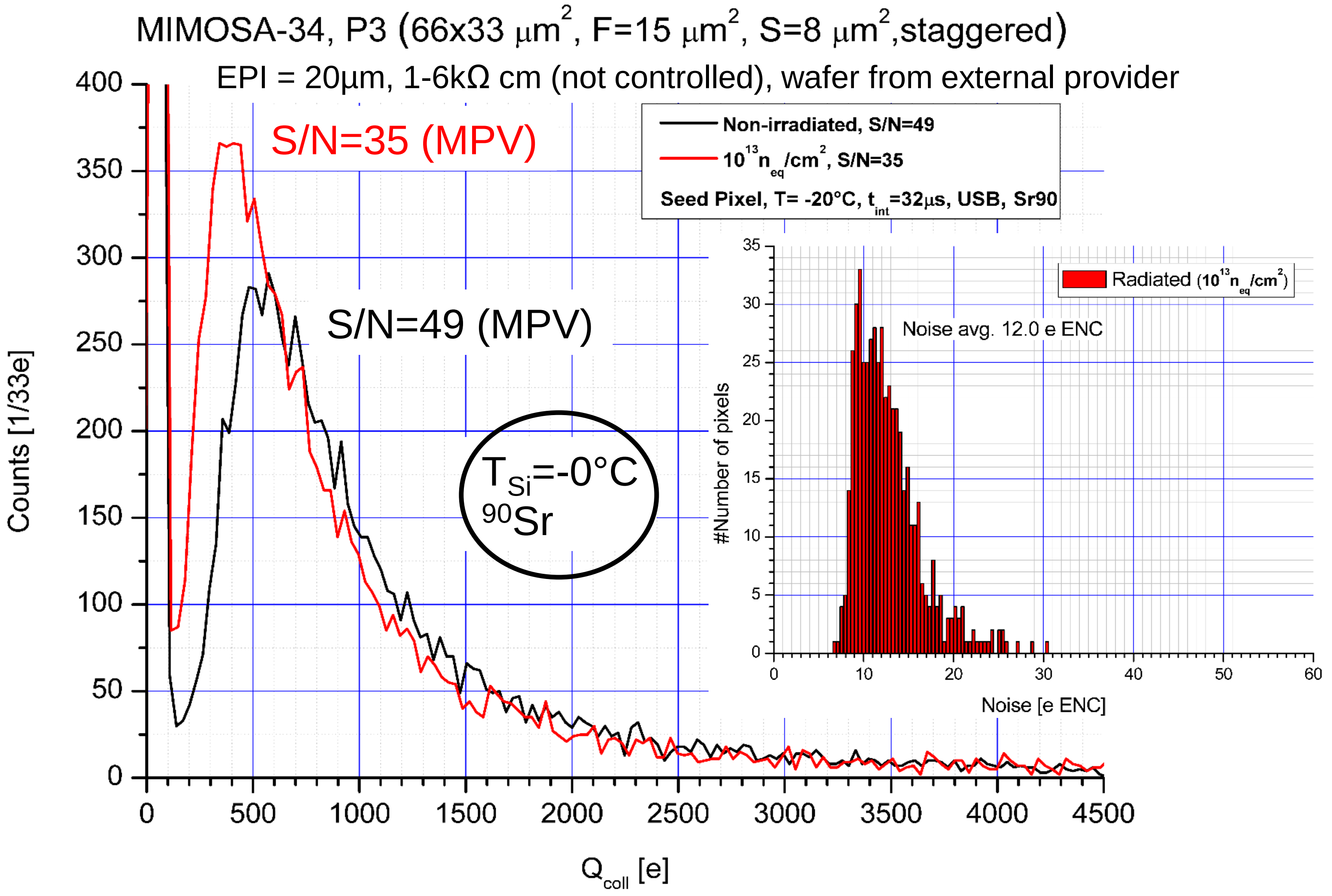


Performances match requirements for ALICE-ITS outer layer.

Next steps:

- Check radiation tolerance (once more, relaxed requirements)
- Build final prototype sensor (MISTRAL-O = 3x FSBB)

Tolerance to bulk damage


MIMOSA-34, P3 (66x33 μm^2, F=15 μm^2, S=8 μm^2,staggered)

EPI = 20µm, 1-6kΩ cm (not controlled), wafer from external provider

Looks promising (note: 10 x ITS outer layer requirement):

- To be confirmed: T= +30°C, smaller depletion voltage (0.7V instead of 1.3V).

Seems better than new MIMOSA-26 with LR epitaxial layer (EU-Det).

From FSBB to MISTRAL – O, final prototype

Area: 13.5 x 29.95 mm^2
Pixels: 832 colls x 208 pixels
Pixel pitch: 36 x 65 µm^2 => ~10 µm resolution

Int. time: 20.8µs
Data link: 320 Mbps

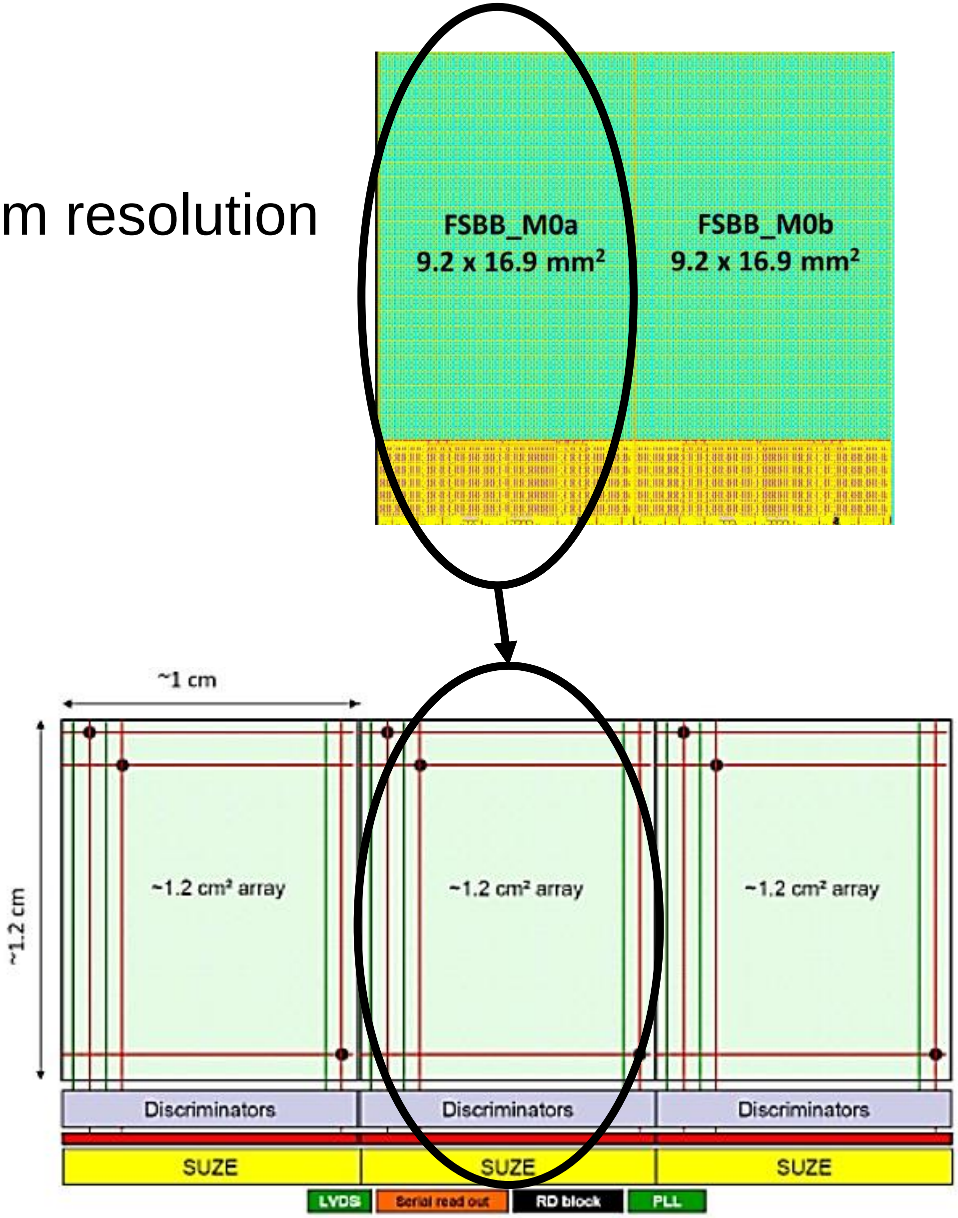
Integrated:

- Slow control ALICE-ITS style
- Voltage generation
- Data concentrator
  (multiplexes data from
  other sensors).

Epi-layers:

- 5 layers
- 18-30 µm thick
- 1 – 8 kOhm cm

Submission: End of July 2015
Test: Until Q1 2016

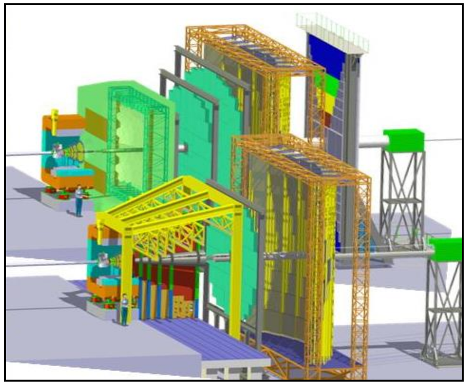


Outlook: CBM@SIS100

Mission:

Open charm from 30 GeV p-A (10 MHz),
Low momentum tracker for 1-12 AGeV A-A (30-100 kHz)

Beam on target: 2021 (estimate from May 2015)



Sensor properties	MISTRAL - O	MIMOSIS-100 (preliminary)
Active surface	13.5 x 29.95 mm²	~ 10 x 30 mm²
Pixels	832 colls x 208 pixels	~ 1500 colls x 300 pixels
Pixel pitch	36 x 65 µm² →	22x33 µm ²
Integration time	20.8 µs	30 µs
Data rate	320 Mbps	> 6x 320 Mbps
Rad tol. (non-io)	$>10^{12}$ n_{eq}/cm^2	$>3 \times 10^{13}$ n_{eq}/cm^2
Rad tol (io)	> 100 kRad	> 3 MRad
Operation Temperature	+30°C →	-20°C in vacuum

In reach of slightly modified FSBB

Toward ILC: IBISCUS

ILC Bunch Identifying Sensor Compatible with Ultraprecise Spatial resolution

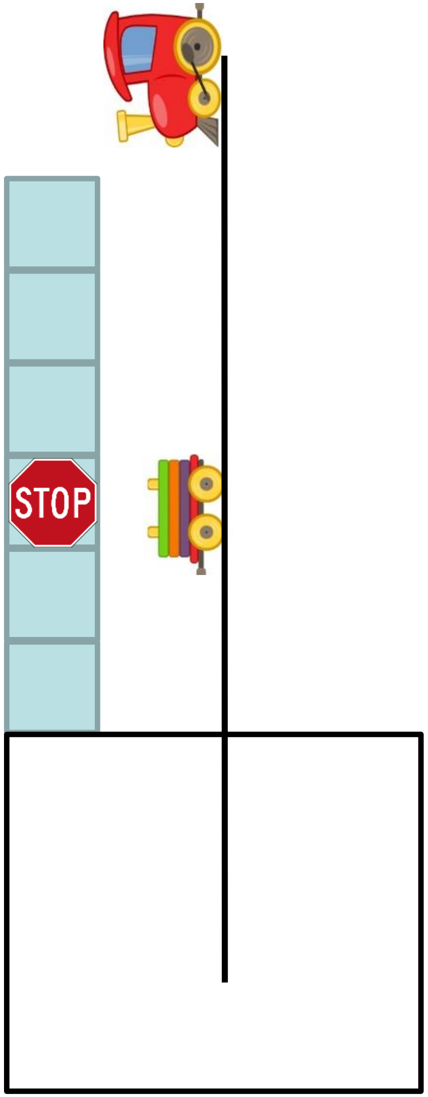
See Marcel Stanitzki's talk

Challenge:

- Combine 1ms time resolution with 3µm spatial resolution (track seeding in VTX).
- Needs small pixels, too small for ALPIDE in-pixel logic in 0.18µm.

Idea: Move time stamping to the border of the matrix:

- Discriminate on pixel.
- Connect ~ 2k pixels with token ring (expect some 100ns per scan).
- Add address of fired pixels to token.
- Accumulate data for 1ms into buffer outside pixel matrix.
- Create time stamp for data in this buffer.



Status:

- So far a concept.
- Design being started.

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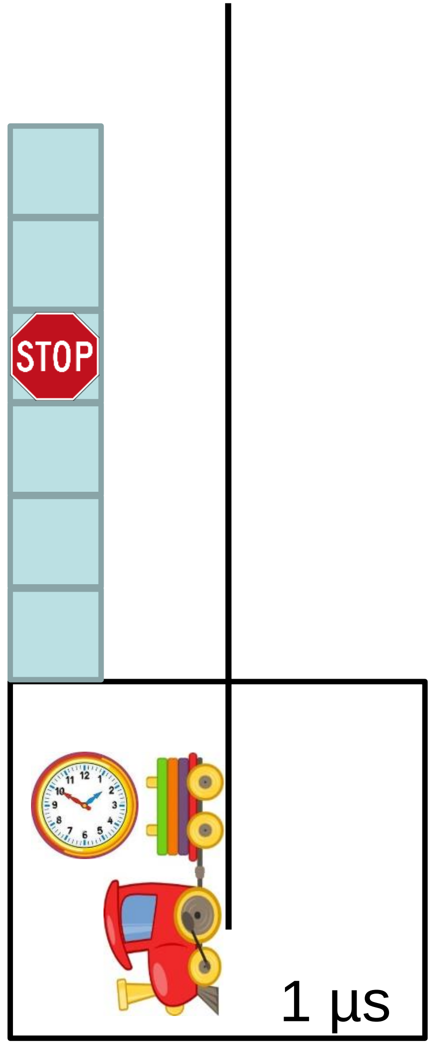

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Summary and Conclusion

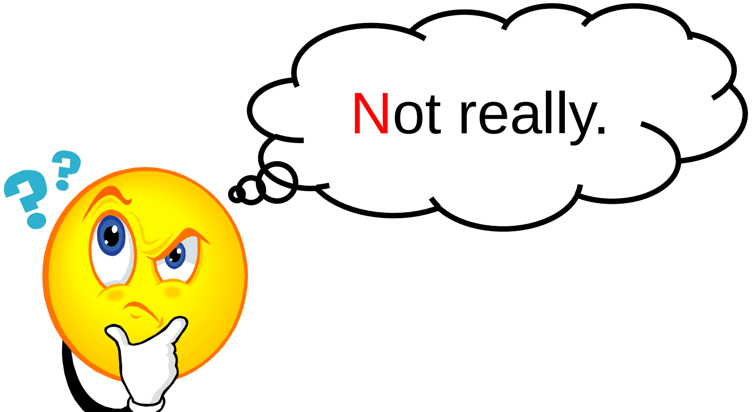
Substantial experience has been collected with running STAR-PXL to prove that MAPS provide added value to physics.

New CMOS sensor technology was validated (Tower 0.18µm)

- Close to fully expoit the potential of the CPS technology
- Expected to provide 1-2 orders of magnitude in performances as compared to STAR-PXL
- Allows to integrate a fast signal processing electronics in small pixels as needed for applications *requirering* fast readout.
- Allows for low power and opens the possibility to equip sizable trackers.
- Expect prototype for ALICE-ITS (MISTRAL-O) tested until Q1 2016.

Next step: Adressing the requirements of CBM (high collision rate and vacuum), long term goal ILC vertexing with 1µs integration time + 3µm precision (track seeding, bunch tagging).

„MAPS collect their signal charge by thermal diffusion.“



Not really.