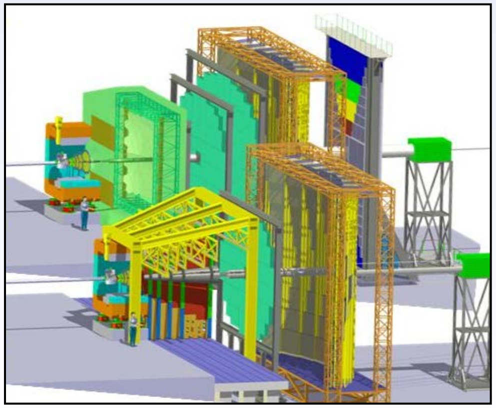
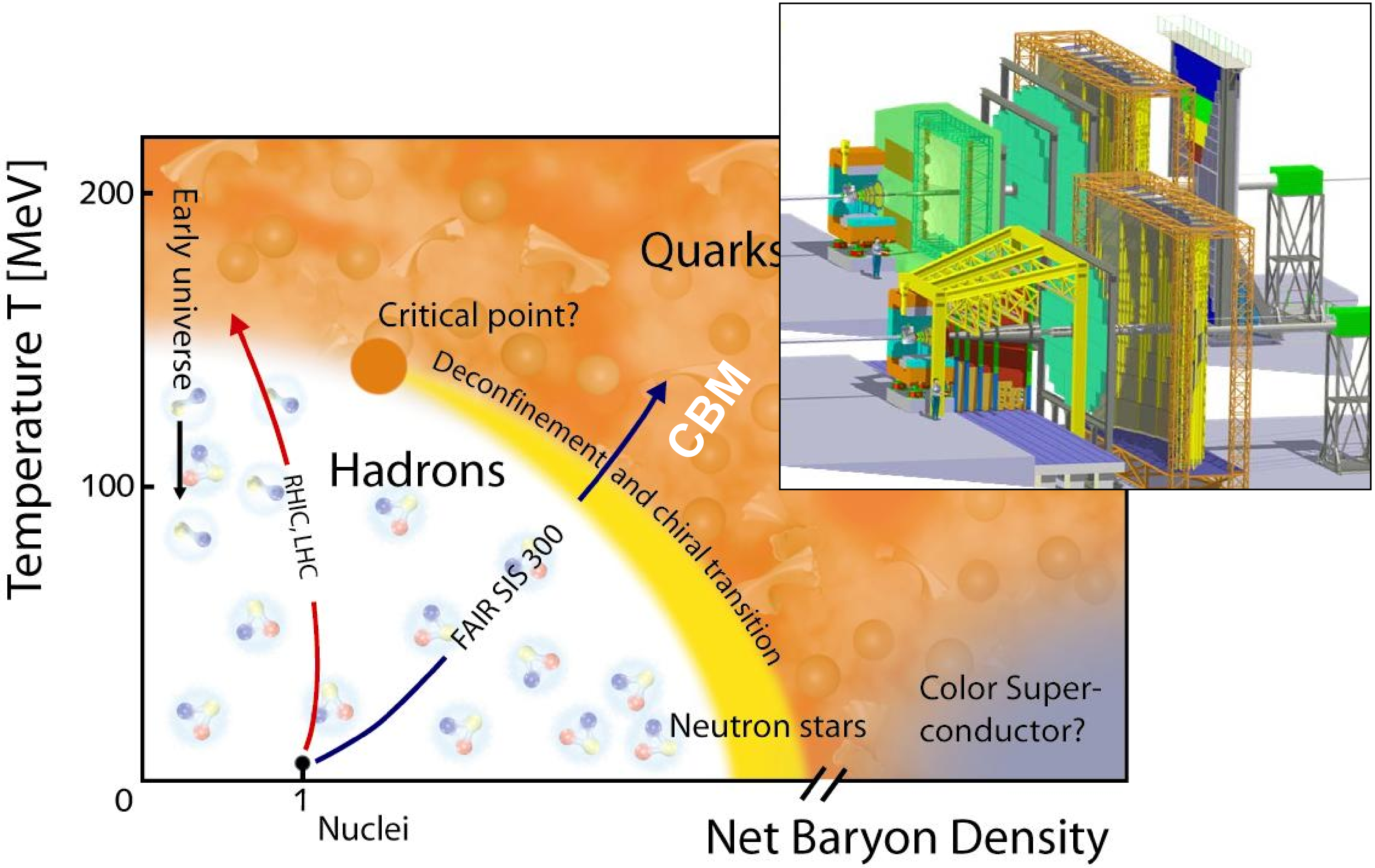
An ultra-light vertex detector for the CBM Experiment

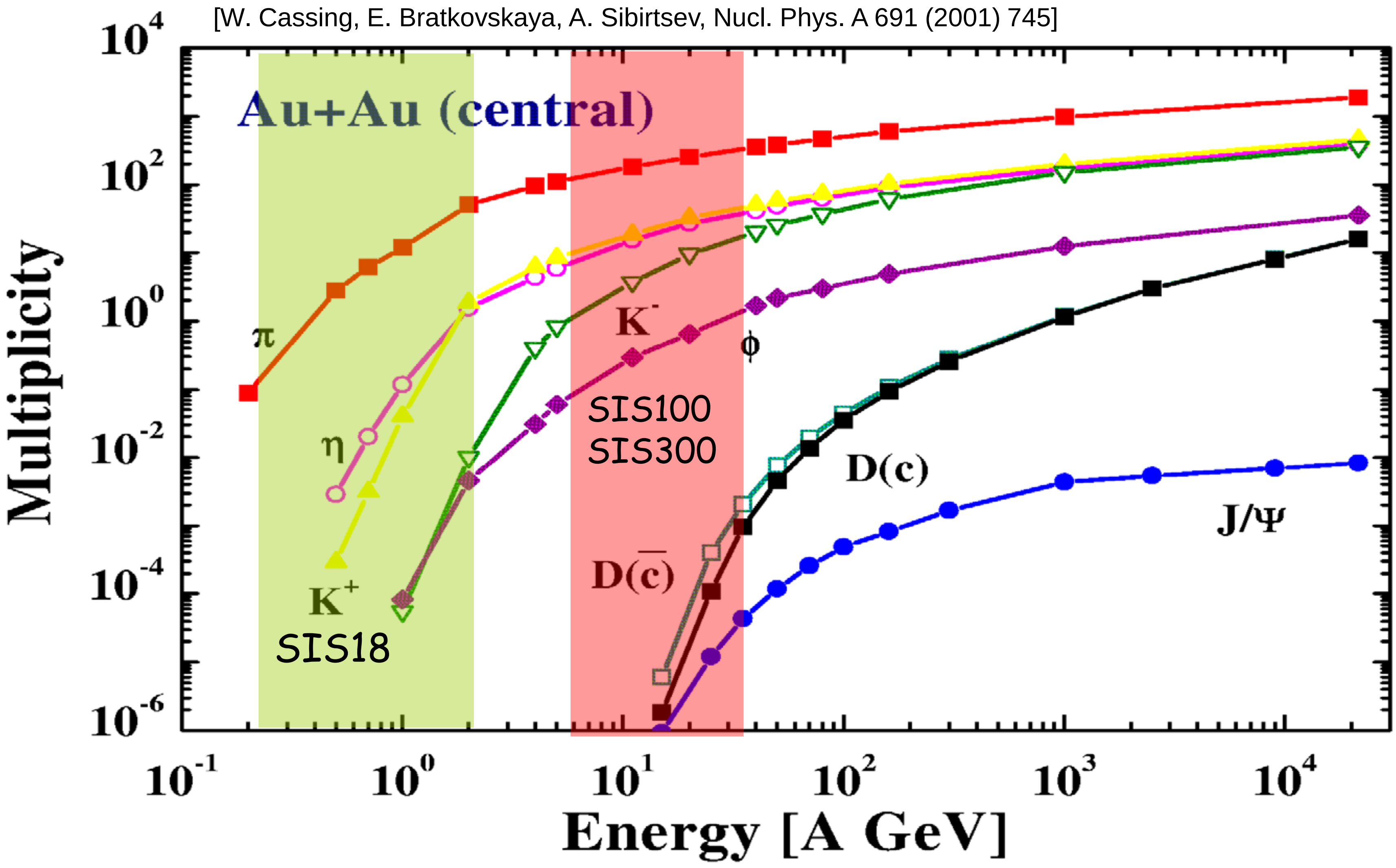
M. Deveaux, Goethe University Frankfurt and CBM
on behalf of the CBM-MVD collaboration.



Physics goals of CBM

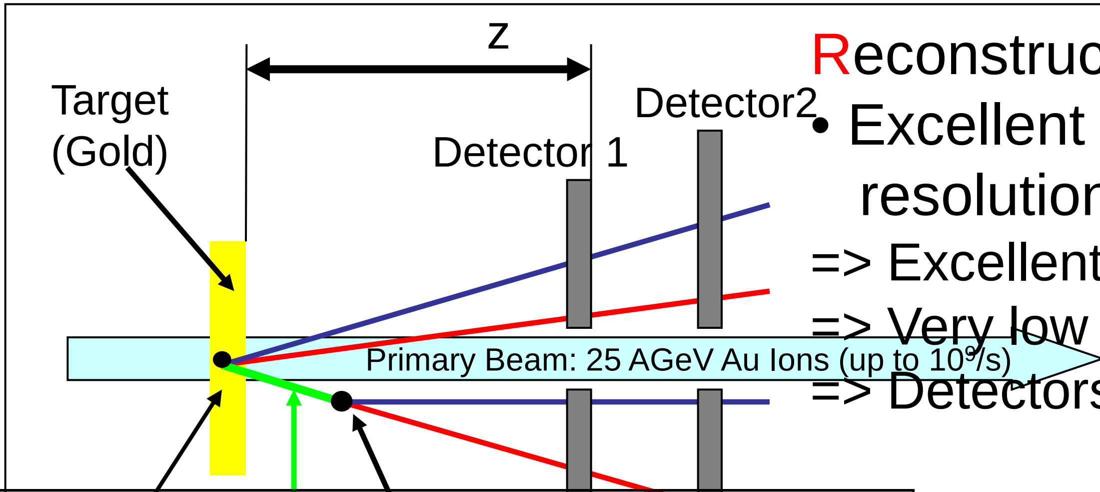


Open charm reconstruction: The challenge



A collision rate of ~10^5/s Au+Au is required

Open charm reconstruction: Concept



Reconstructing open charm requires:

- Excellent secondary vertex resolution (~ 50 µm)

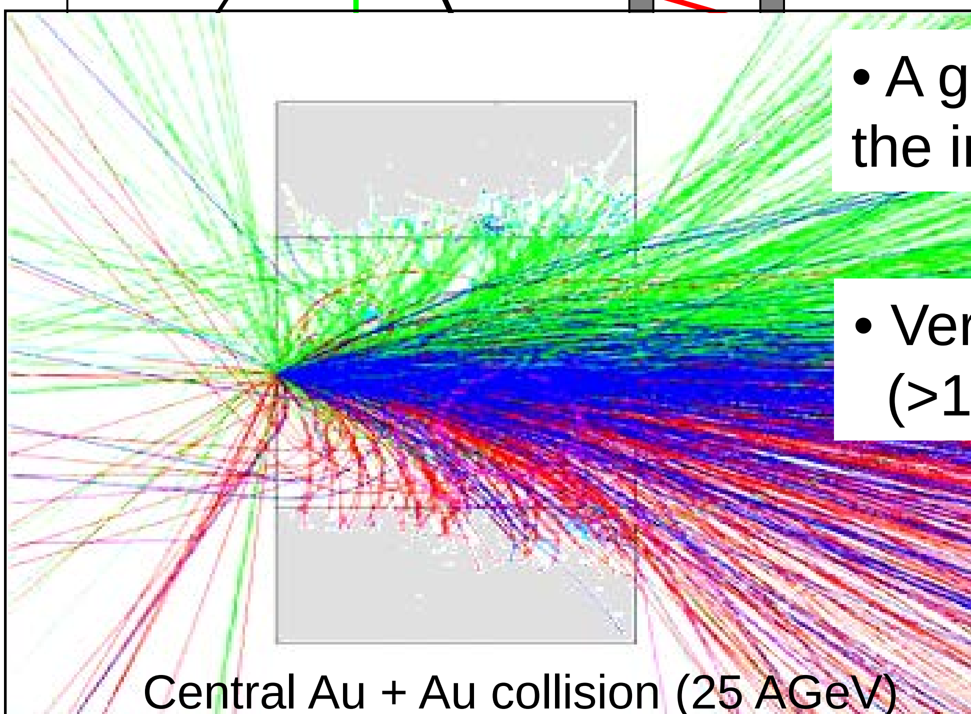
=> Excellent spatial resolution (~5 µm)

=> Very low material budget (few 0.1 % X_0)

=> Detectors in vacuum

- A good time resolution to distinguish the individual collisions (few 10 µs)

- Very good radiation tolerance ($>10^{13}$ n_{eq}/cm^2)

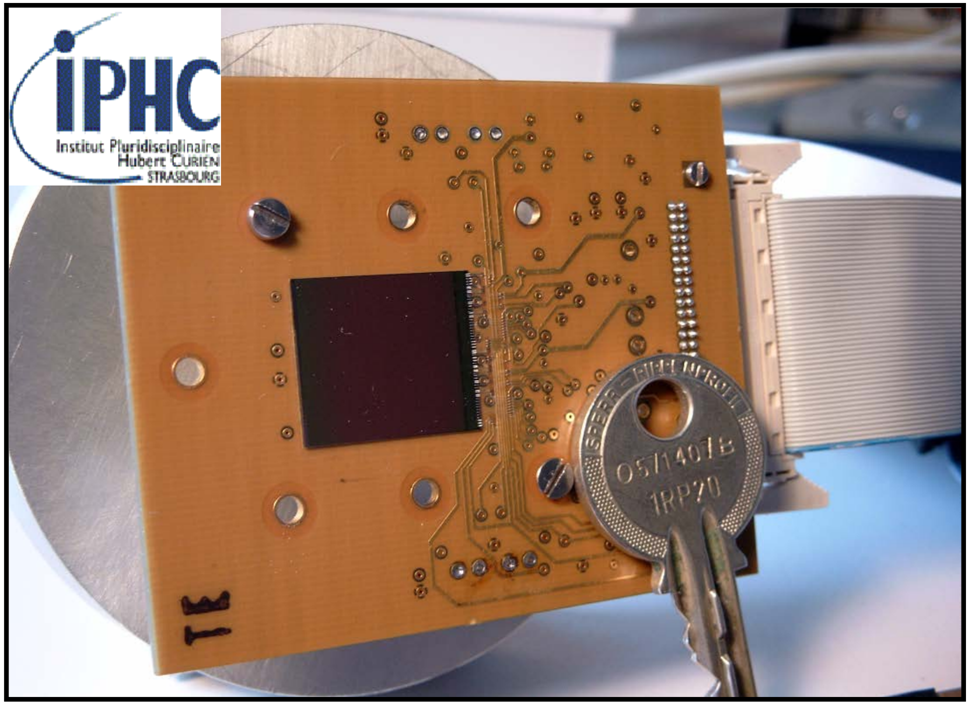


Central Au + Au collision (25 AGeV)

Requirements vs. detector performances (2003)

	Required	Hybrid pixels	CCD
Single point res. [µm]	~ 5	~ 30	~ 5
Material budget [X_0]	~ 0.3%	~ 1%	~ 0.1%
Time resolution [µs]	few 10	0.025	~100
Rad. hardness [n/cm²]	> 10^{13}	>> 10^{14}	<< 10^{10}

CMOS Monolithic Active Pixel Sensors (MAPS)

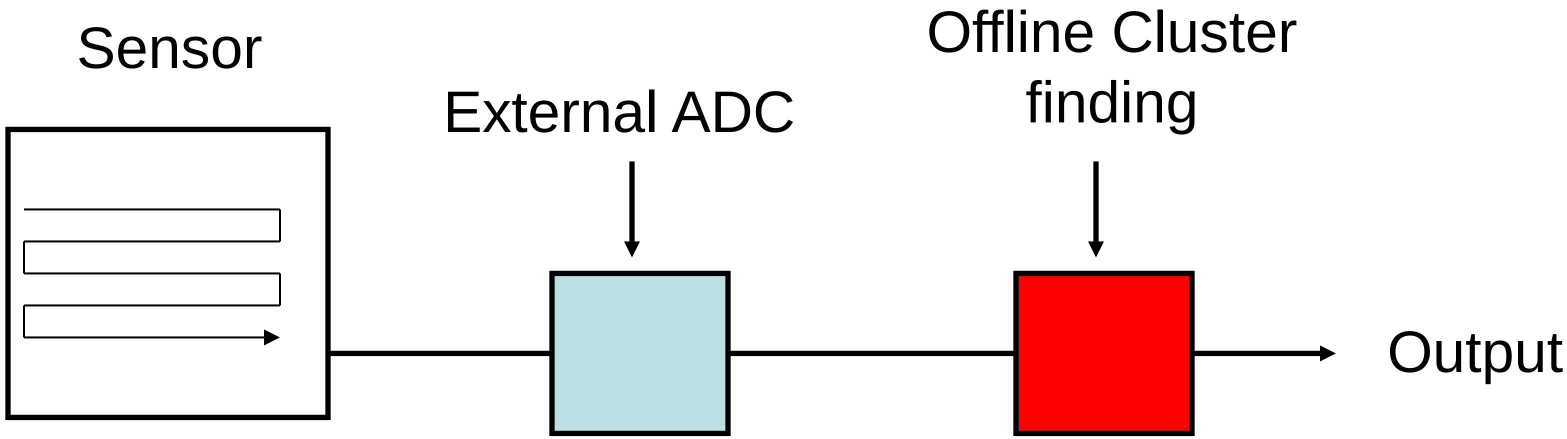


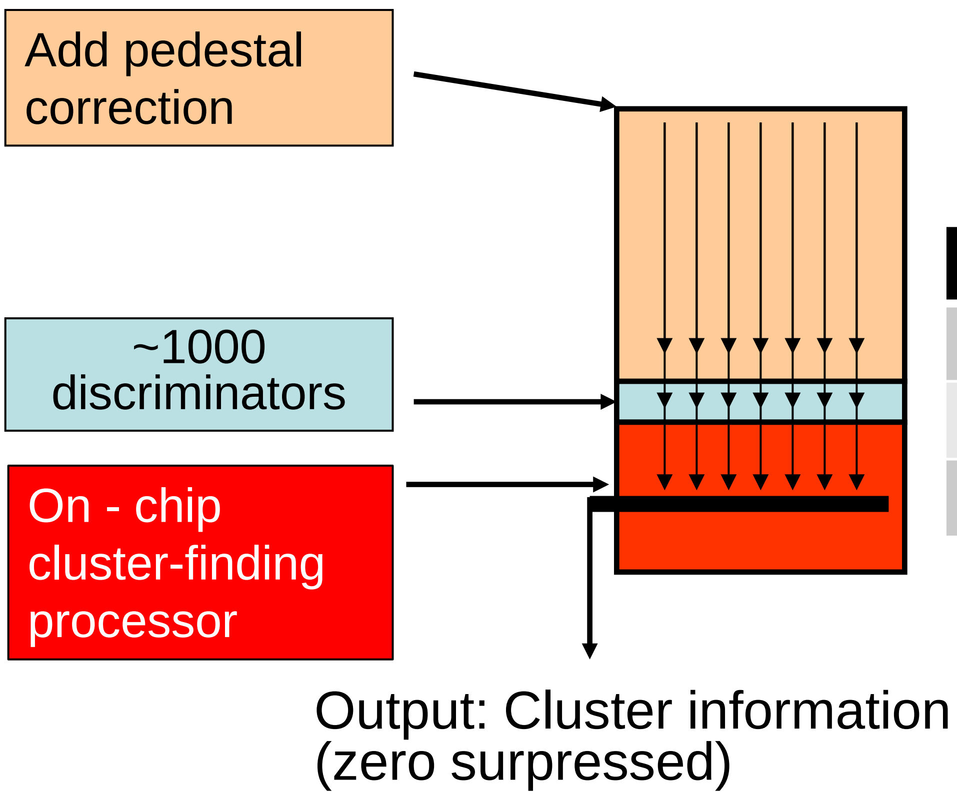
Time resolution and rad. tolerance need improvement => Perform R&D

	Required	Hybrid pixels	CCD	MAPS (2003)
Single point res. [µm]	~ 5	~ 30	~ 5	3.5
Material budget [X_0]	~ 0.3%	1%	~0.1%*	~0.05%*
Time resolution [µs]	10-100	0.025	~100	>1000
Rad. hardness [n/cm²]	> 10^{13}	>> 10^{14}	<< 10^{10}	> 10^{12}

*Sensor only

Sensor R&D: How to gain speed





Readout time	
Initially	1000 µs
2013	115 µs
Planned*	few 10 µs

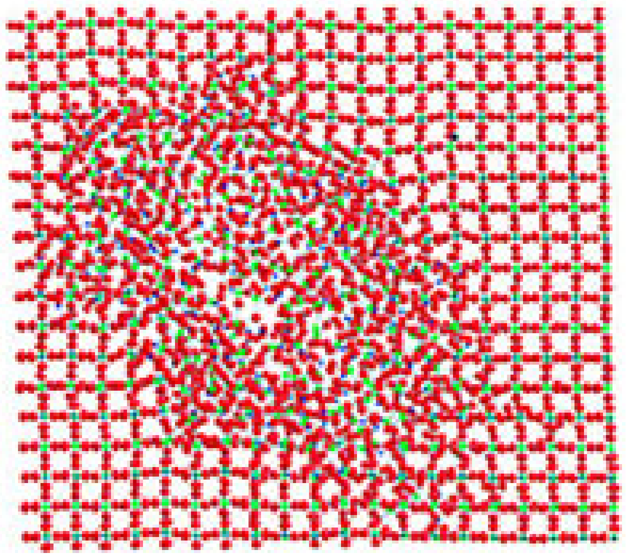
*) See Talk of Marc Winter

Radiation tolerance of MAPS

What about radiation hardness?

Ionising radiation:

- Energy deposited into the electron cloud
- May ionise atoms and destroy molecules
- Caused by charged particles and photons

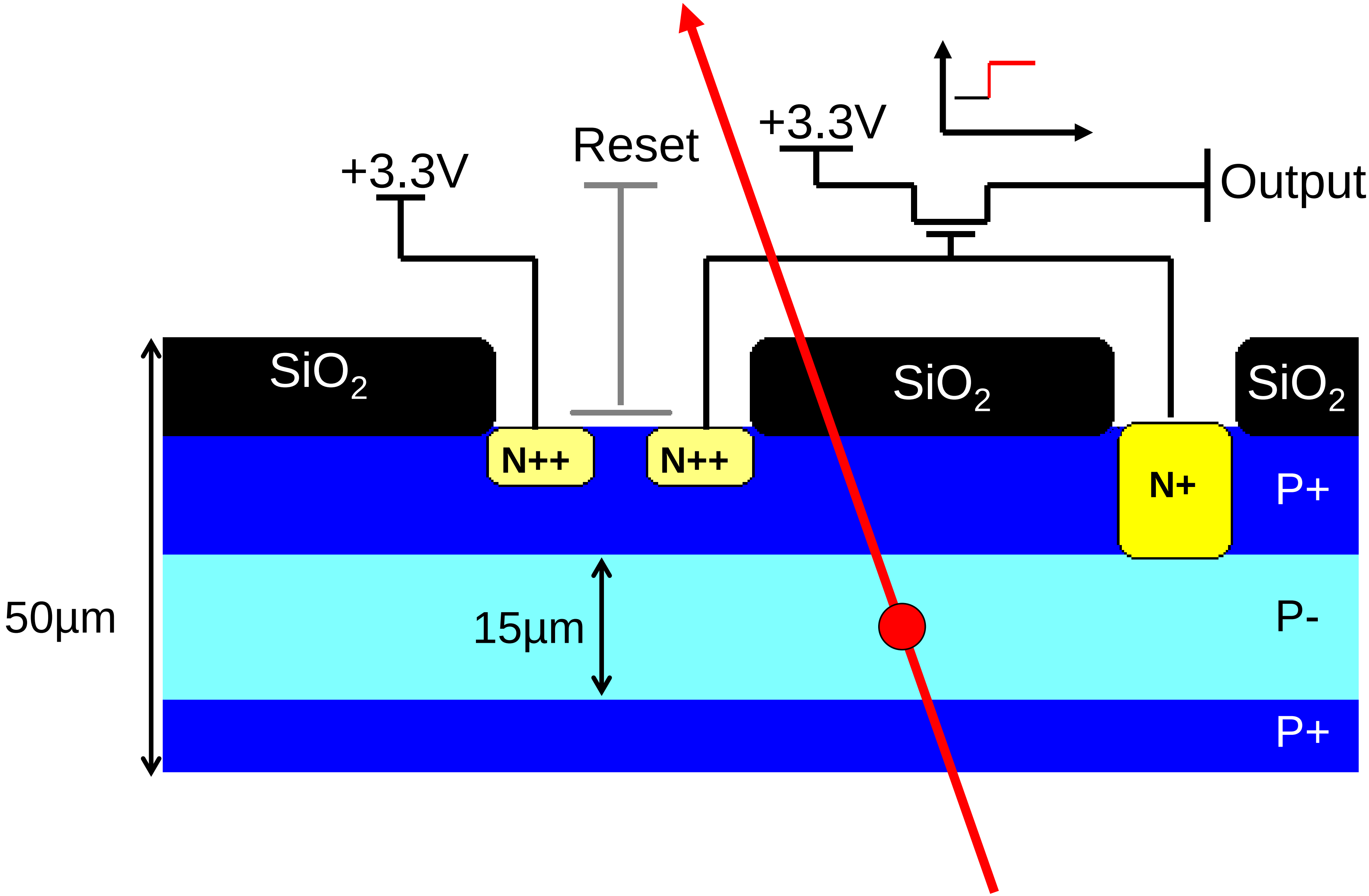


Non-ionising radiation:

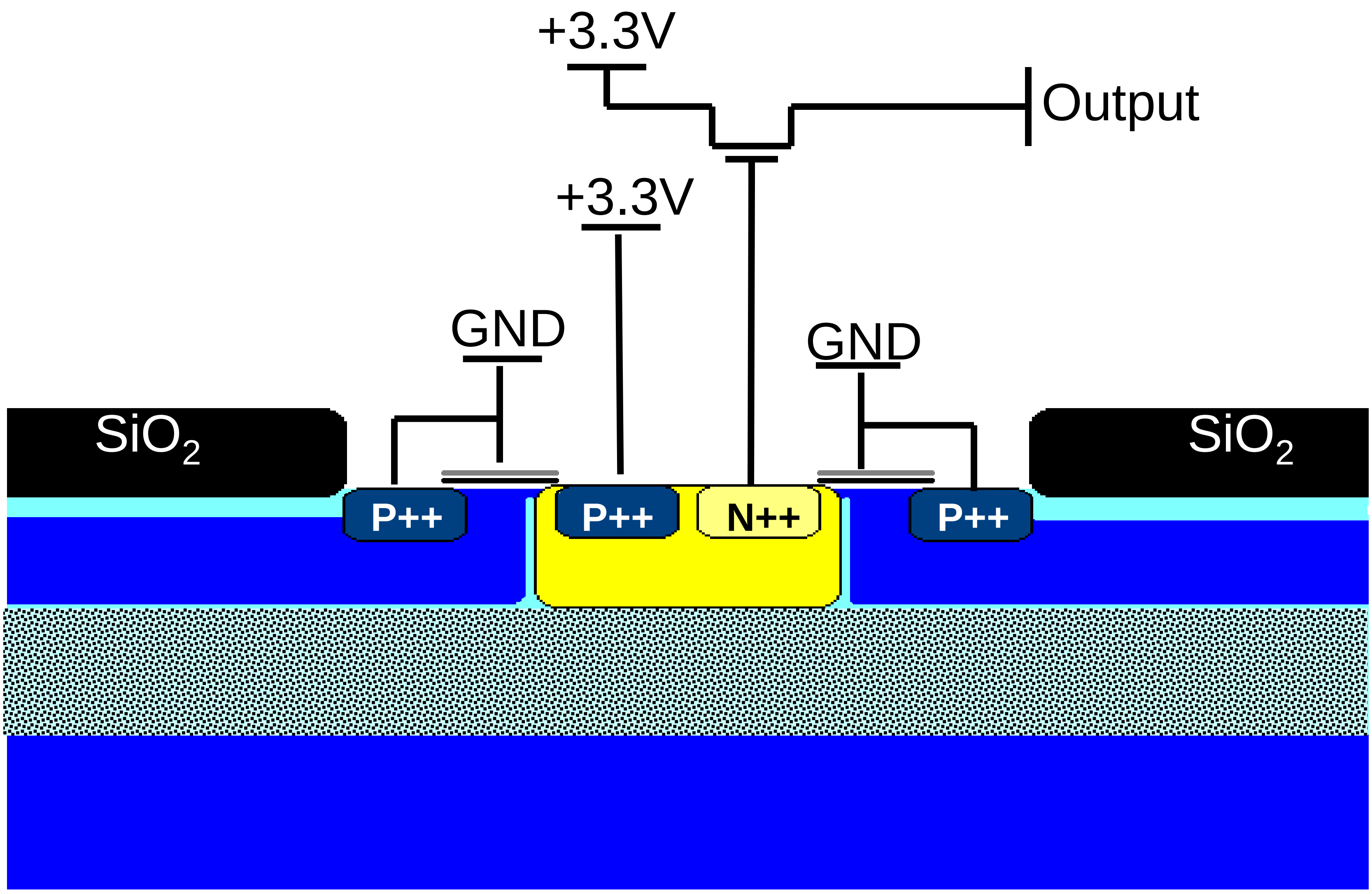
- Energy deposited into the crystal lattice
- Atoms get displaced
- Caused by heavy (fast leptons, hadrons) charged and neutral particles

Farnan I, HM Cho, WJ Weber, 2007. "Quantification of Actinide α-Radiation Damage in Minerals and Ceramics." *Nature* 445(7124):190-193.

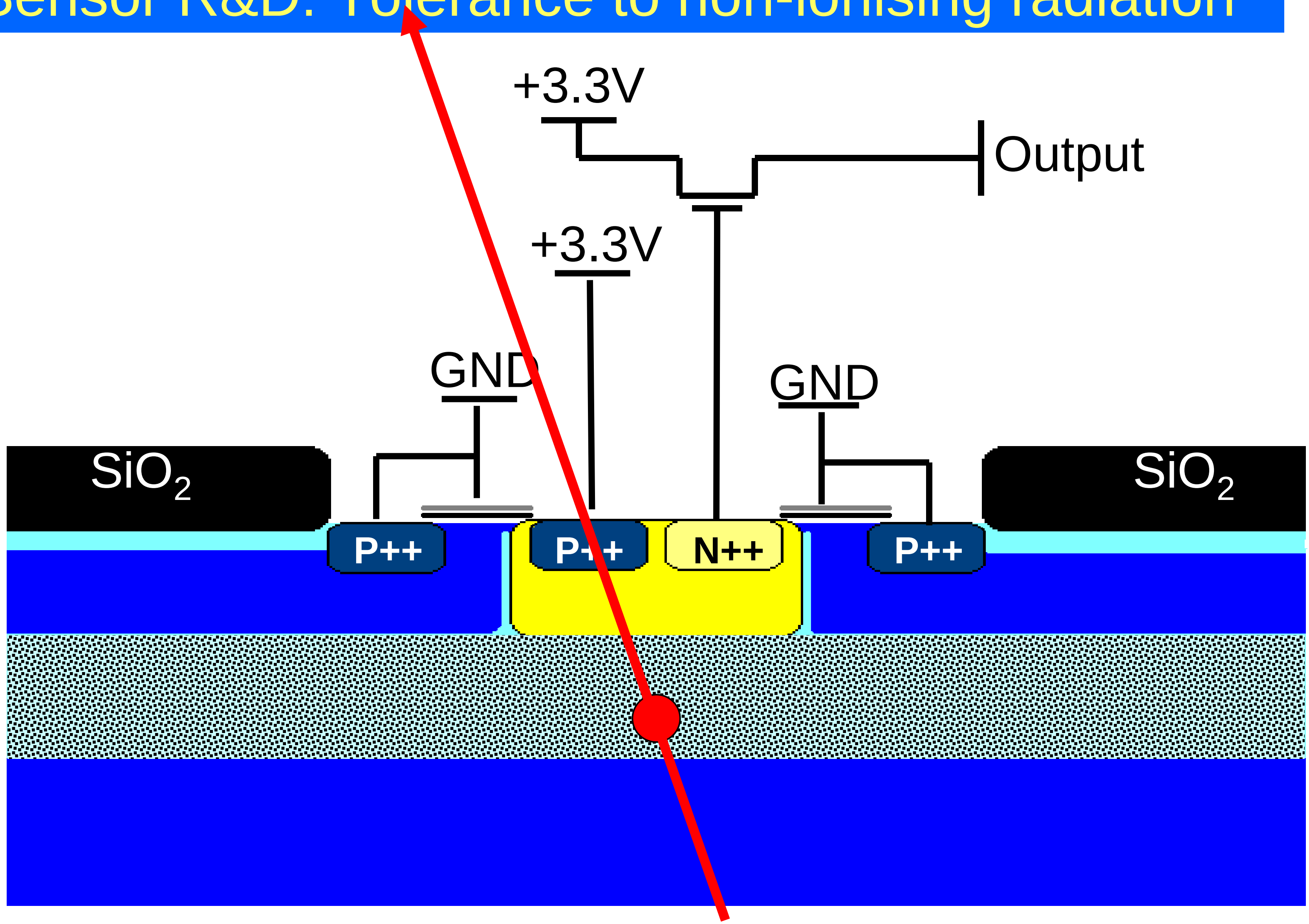
Sensor R&D: The operation principle



Sensor R&D: Tolerance to non-ionising radiation

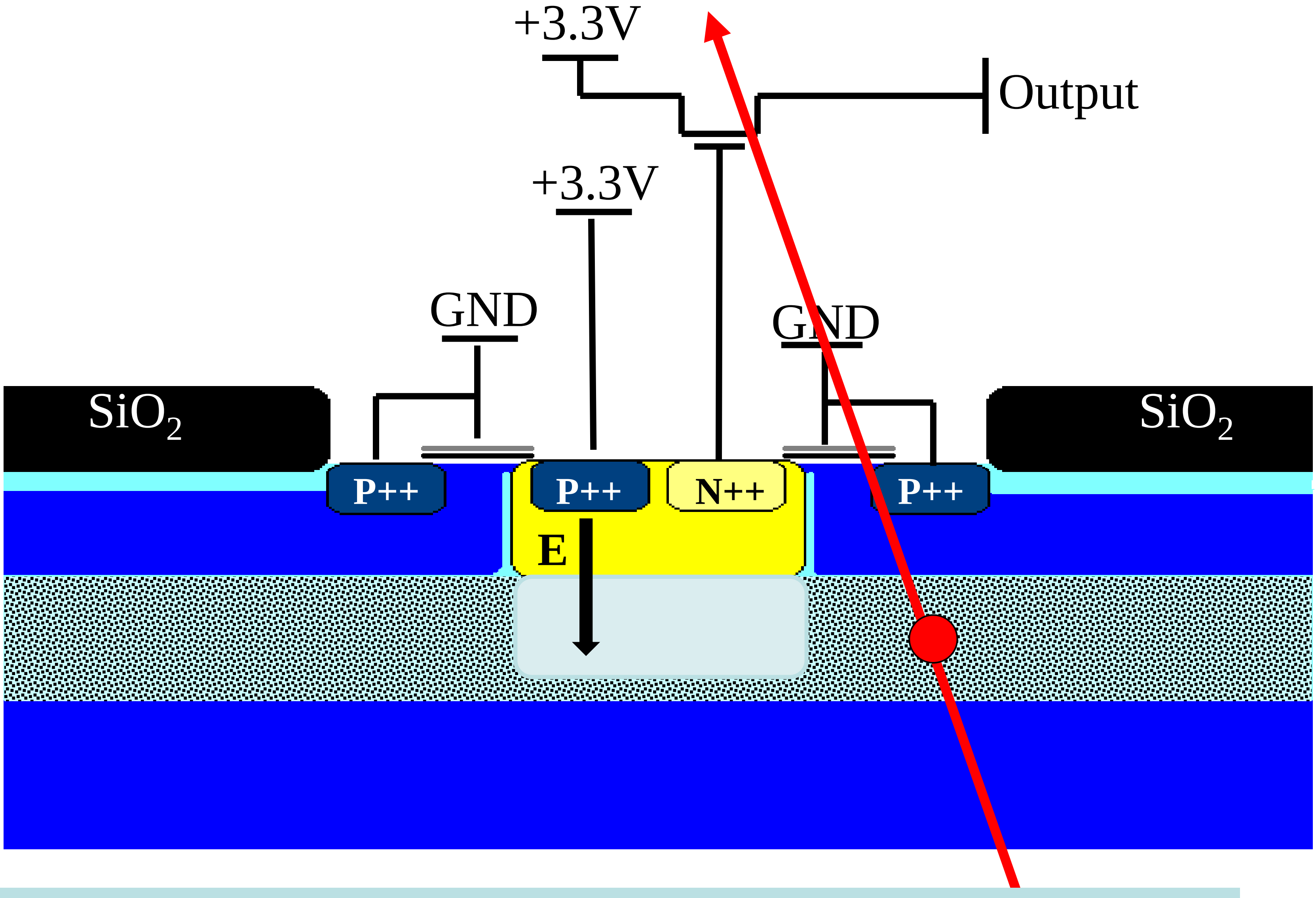


Sensor R&D: Tolerance to non-ionising radiation



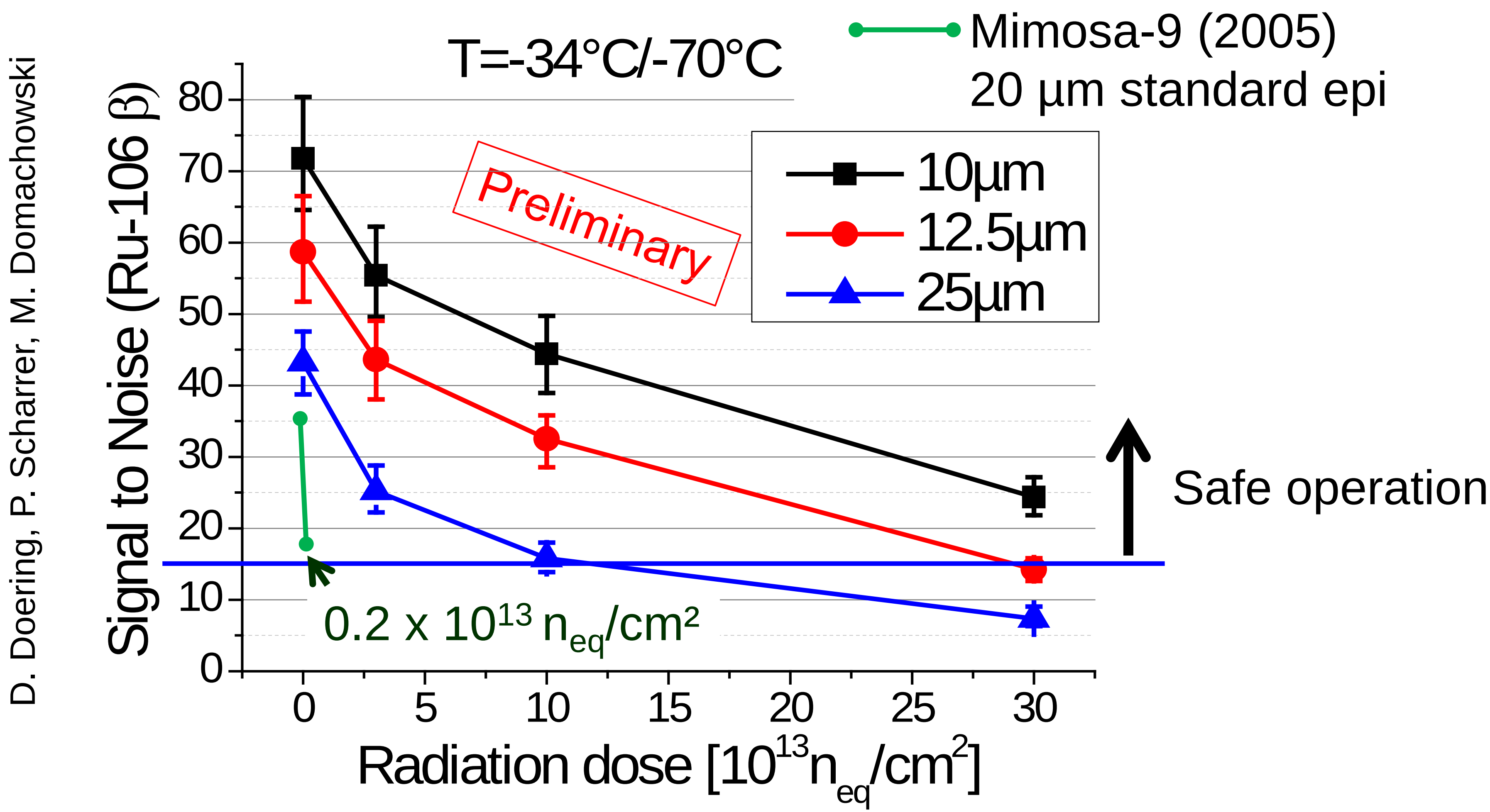
Key observation: Signal amplitude is reduced by bulk damage

Sensor R&D: Tolerance to non-ionising radiation



Electric field increases the radiation hardness of the sensor
Draw back: Need CMOS-processes with low doping epitaxial layer

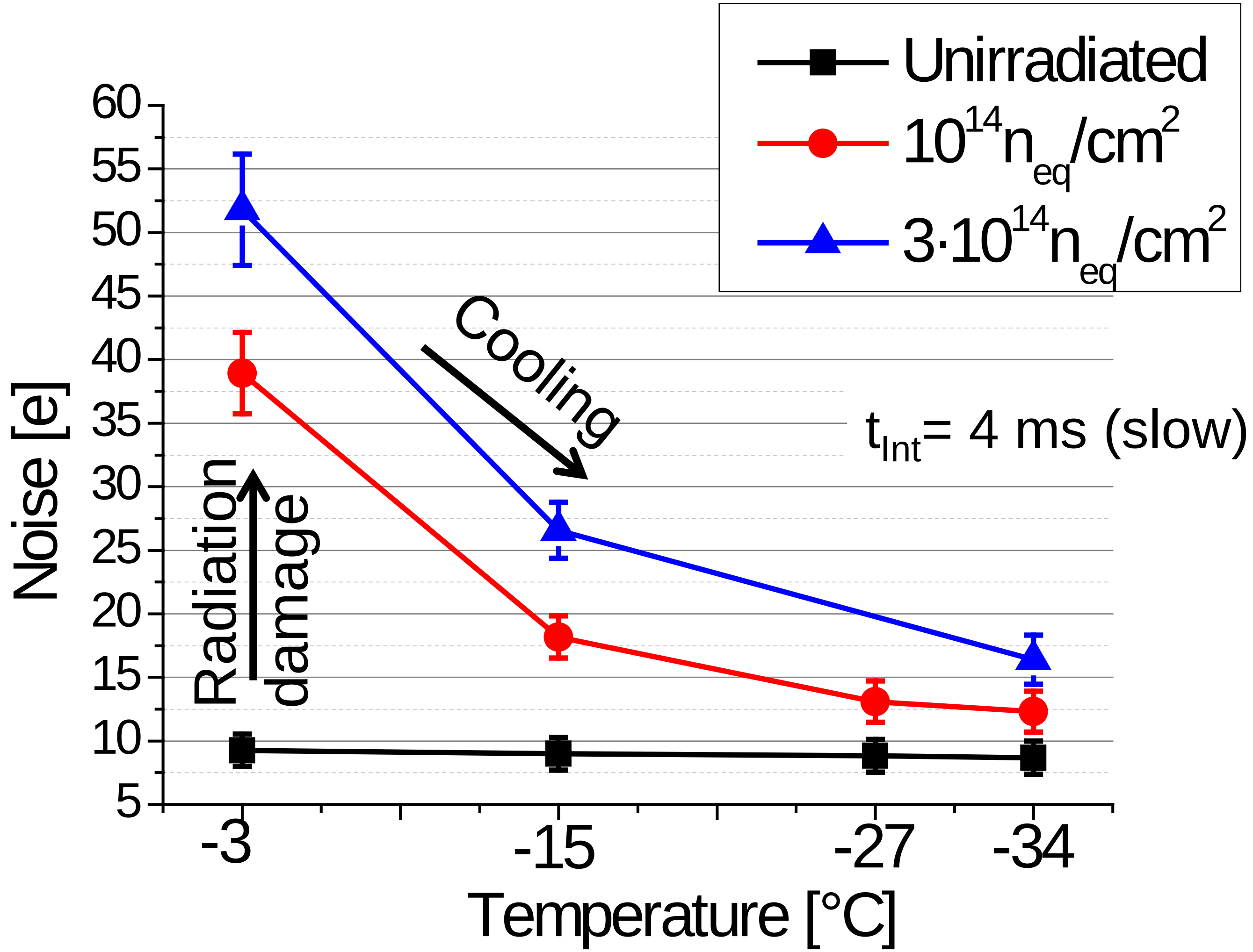
S/N of MIMOSA-18 AHR (high resistivity epi-layer)



Plausible conclusion: Radiation tolerance >10^{14} n_{eq}/cm^2 reached

- Cooling required to operate heavily irradiated sensors

Noise and cooling

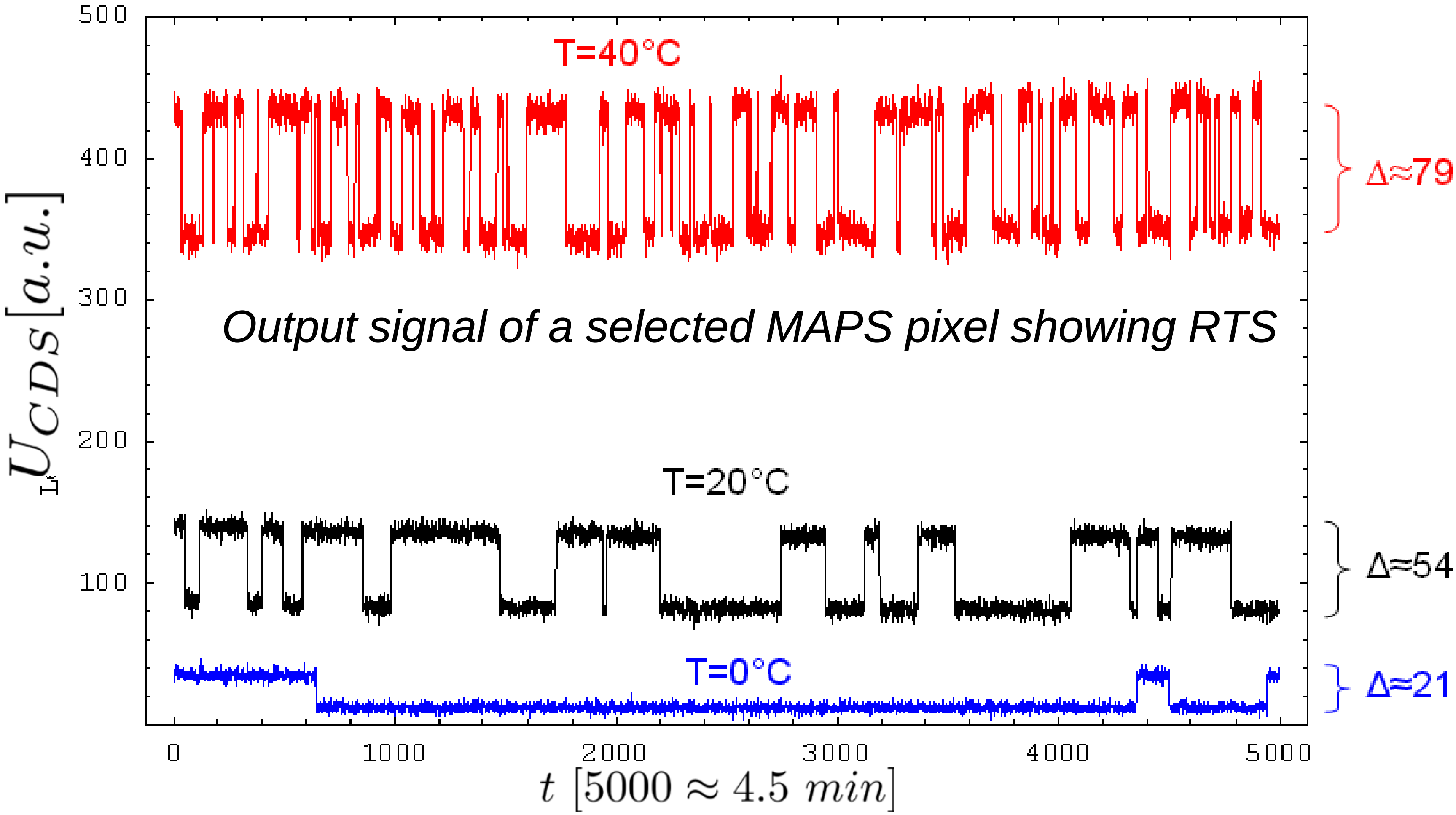


Cooling is needed to exploid the improved radiation tolerance

Alternative solution: Fast integration times help

Random Telegraph Signal

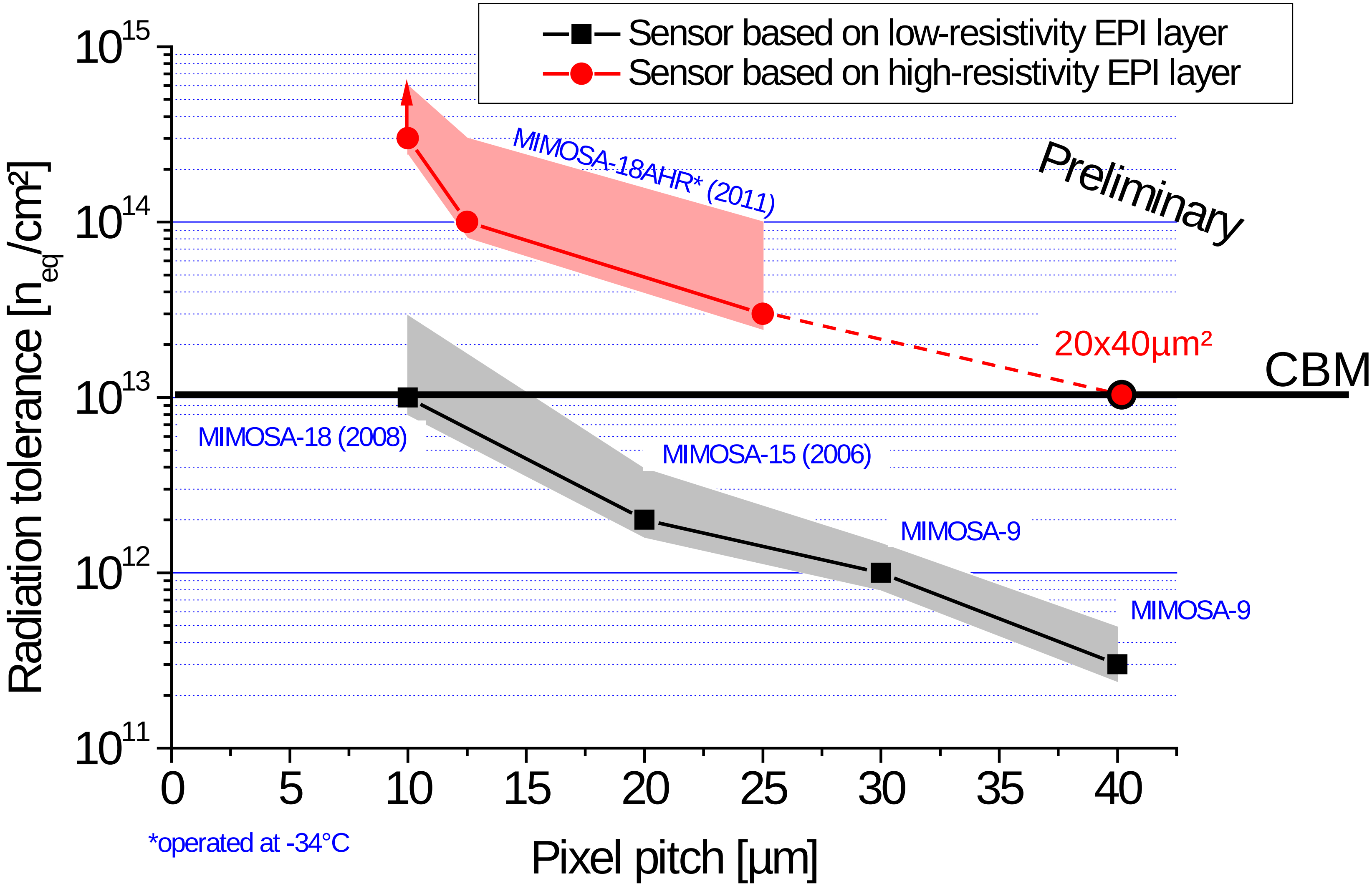
Frequency and amplitude of RTS increase with temperature*



* First observed by: G.R. Hopkinson: "Radiation Effects in a CMOS Active Pixel Sensor", IEEE-TNS Vol. 47, No. 6, P. 2480

Conclusion: RTS causes fake hits but cooling helps

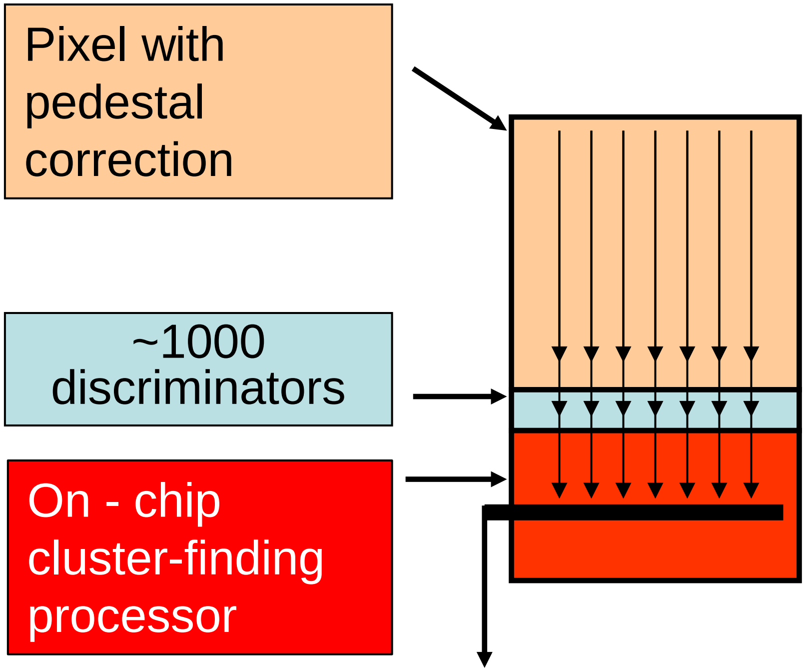
Radiation tolerance vs. pixel pitch



Non ionizing radiation tolerance depends strongly on pixel pitch
Requirements of CBM are matched.

Radiation tolerance of MAPS

Sensor R&D: Tolerance to ionising radiation



Output: Cluster information (zero surpressed)

Imagers (0.35µm):

Tolerate 1-2 MRad if cooled.

Fast pixels are so far vulnerable:

- More transistors
- No space for radiation tolerant layout in 0.35µm CMOS.

$\Rightarrow$ Current tolerance: 0.5 MRad

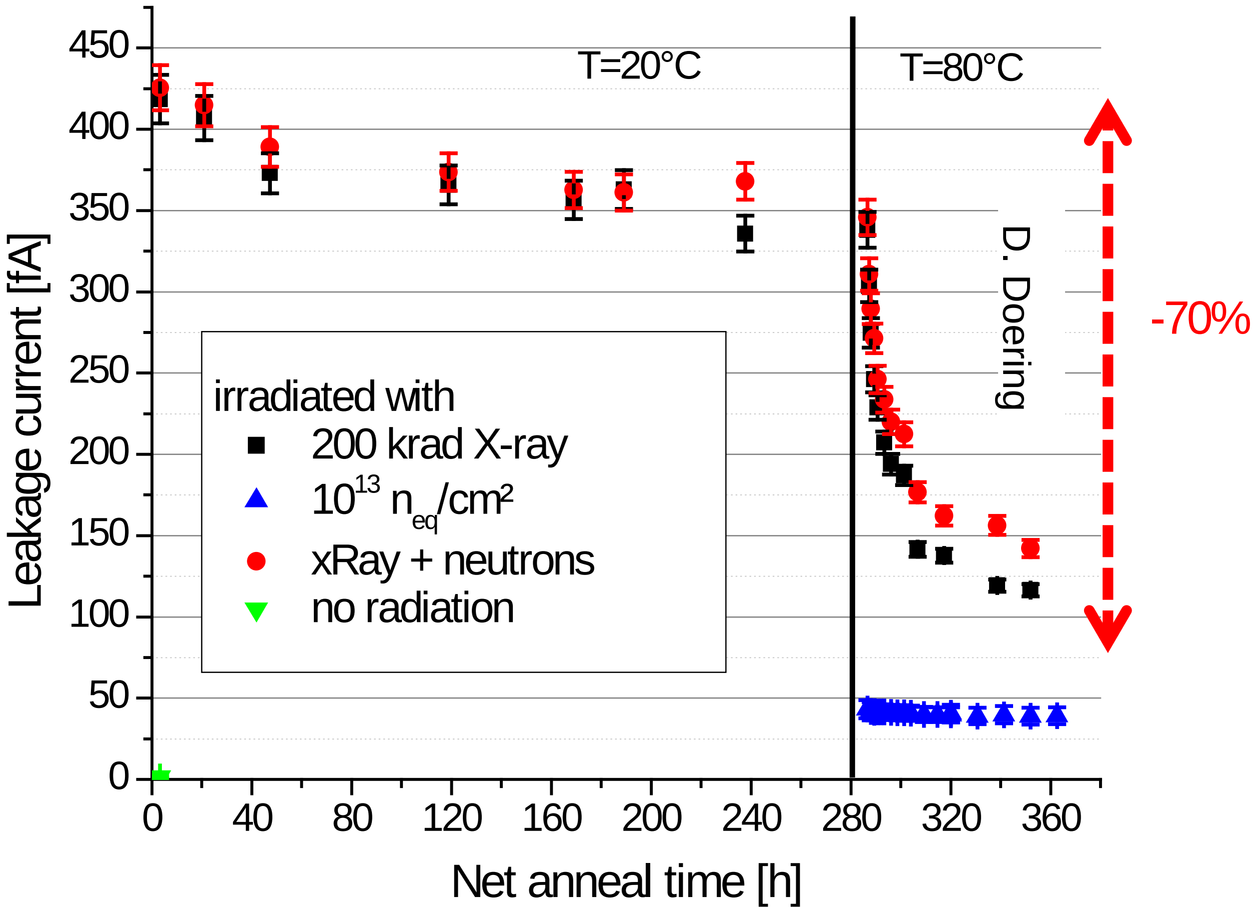
M. Koziel, PhD

Progresses with 0.18 µm CMOS process

$\Rightarrow$ Seems radiation tolerant to 10 Mrad

$\Rightarrow$ Results shown by Marc Winter were confirmed

Tolerance to ionising radiation - Annealing



MIMOSA-19 imager

Ionizing radiation increases leakage current of diodes

Annealing alleviates ionizing radiation damage substantially

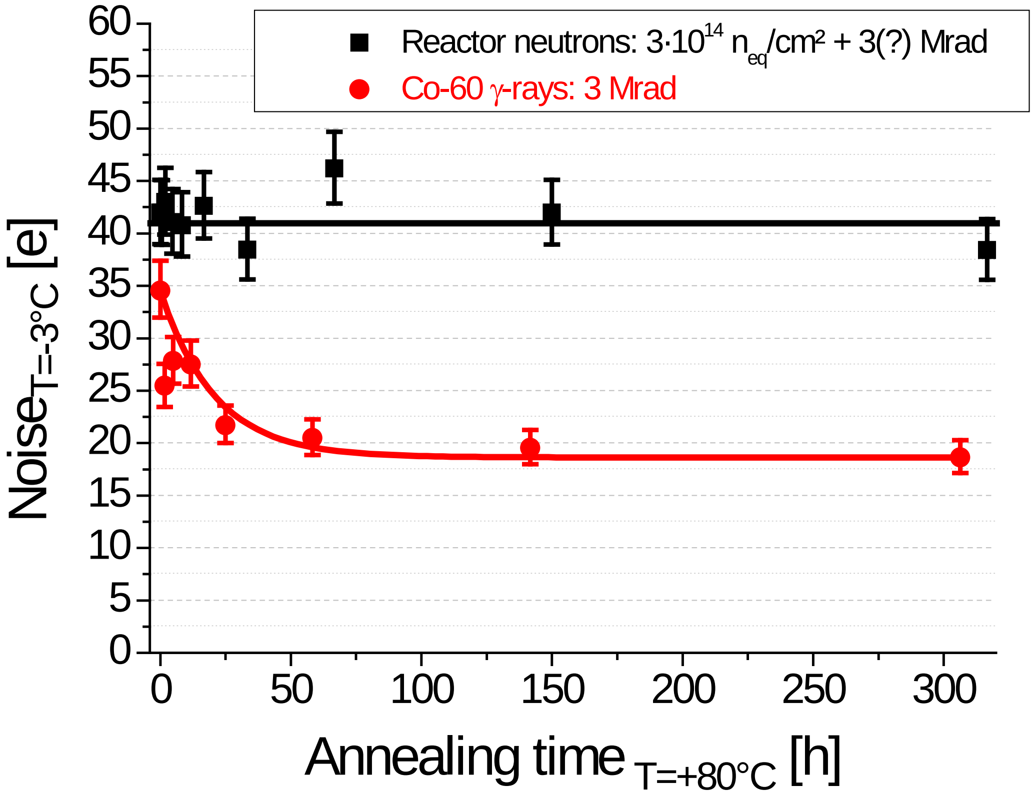
No indication for reverse annealing => Recover detector on the fly(?)

Just opening a bracked

(...

Separation of ionizing and non-ionizing doses

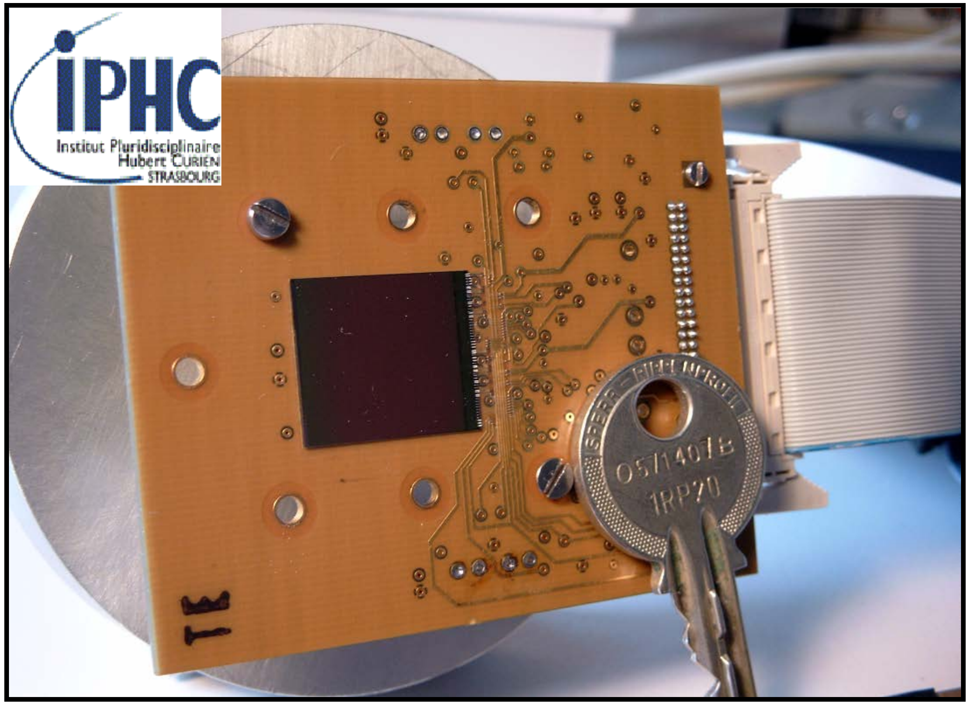
Reactor neutrons are polluted with parasitic gamma rays.
Does this have an impact on the measurements?



Effect of gamma rays is reduced due to annealing.
Apparently, reactor neutrons dominated.

...)

Performances of MAPS (2013)



All requirements demonstrated with dedicated sensors.

Next step: Do it with ONE sensor

Remaining issues:
- Factor 2-3 in readout speed
- Extend internal bandwidth by factor of 5

⇒ In reach of 0.18 µm CMOS technology

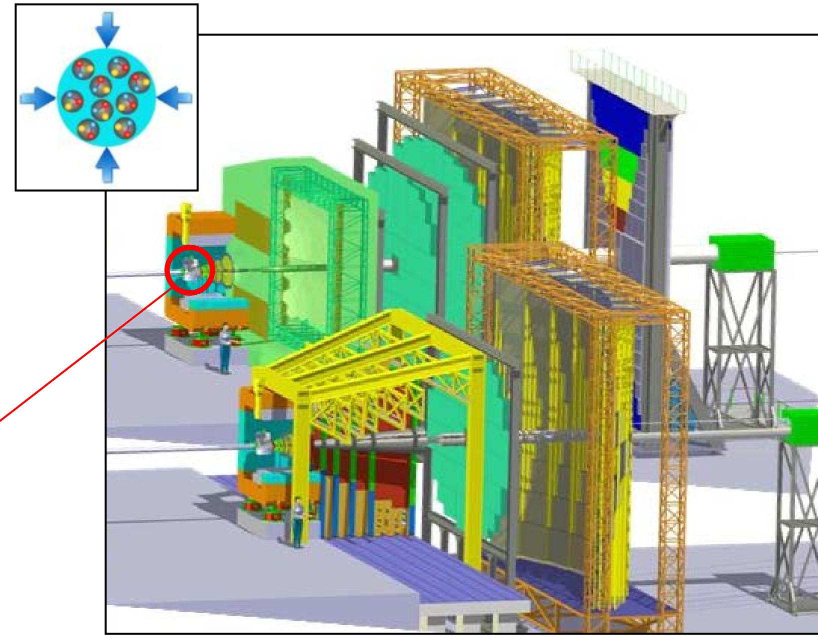
	Required	Hybrid pixels	CCD	MAPS** (2013)
Single point res. [µm]	~ 5	~ 30	~ 5	3.5
Material budget [X_0]	~ 0.3%	1%	~0.1%*	~0.05%*
Time resolution [µs]	few 10	0.025	~100	32
Rad. hardness [n/cm²]	> 10^{13}	>> 10^{14}	<< 10^{10}	> 3×10^{14}

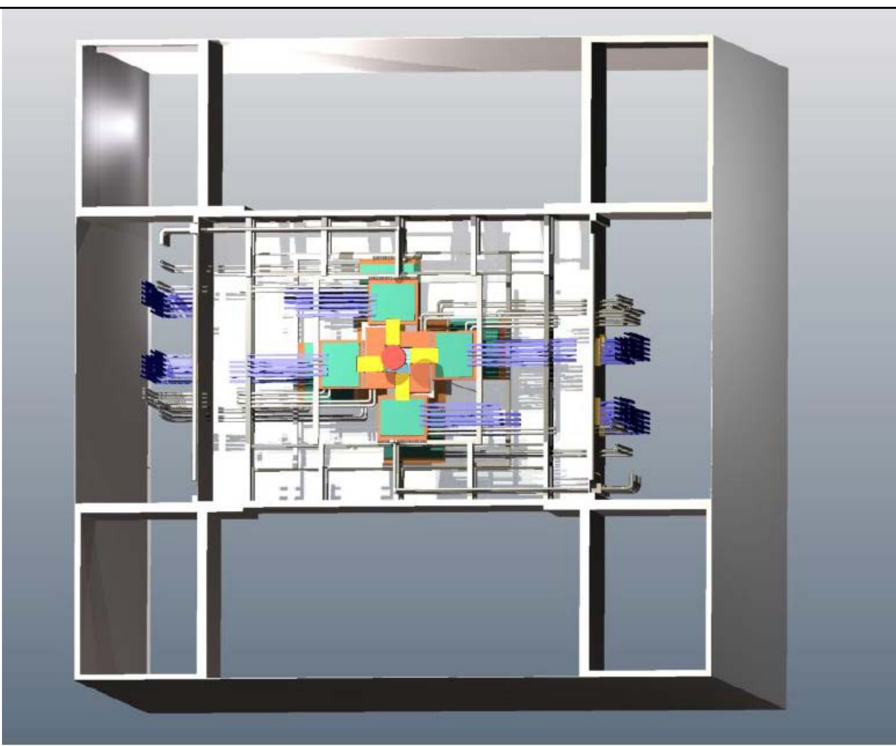
** Best of specialized sensors *Sensor only

System integration – An MVD for CBM

Aim for thickness of 0.3% X_0
(=0.3 mm Si equivalent)

How to fix the sensors?





CBM-MAPS consume <1W/cm²

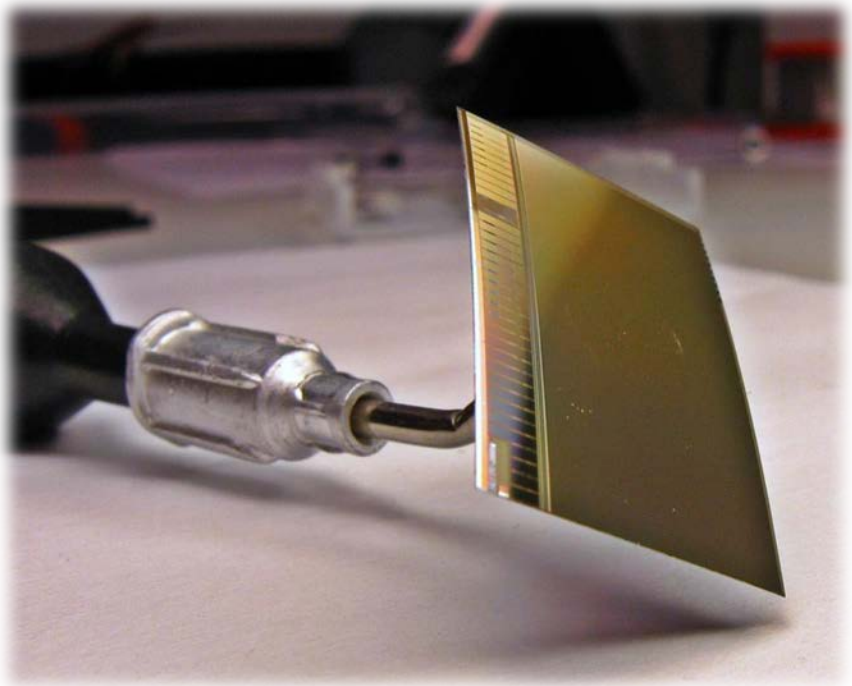
How to bias?
How to evacuate heat? …

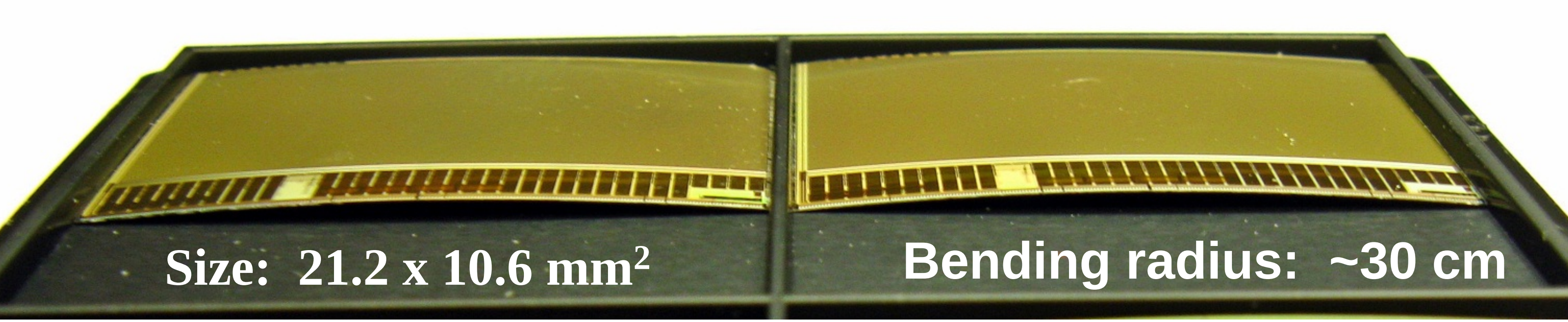
…without material … in vacuum?

Integration of the sensors

The integration challenge:

Integrate 50µm thick and bended silicon foils on a diamond support

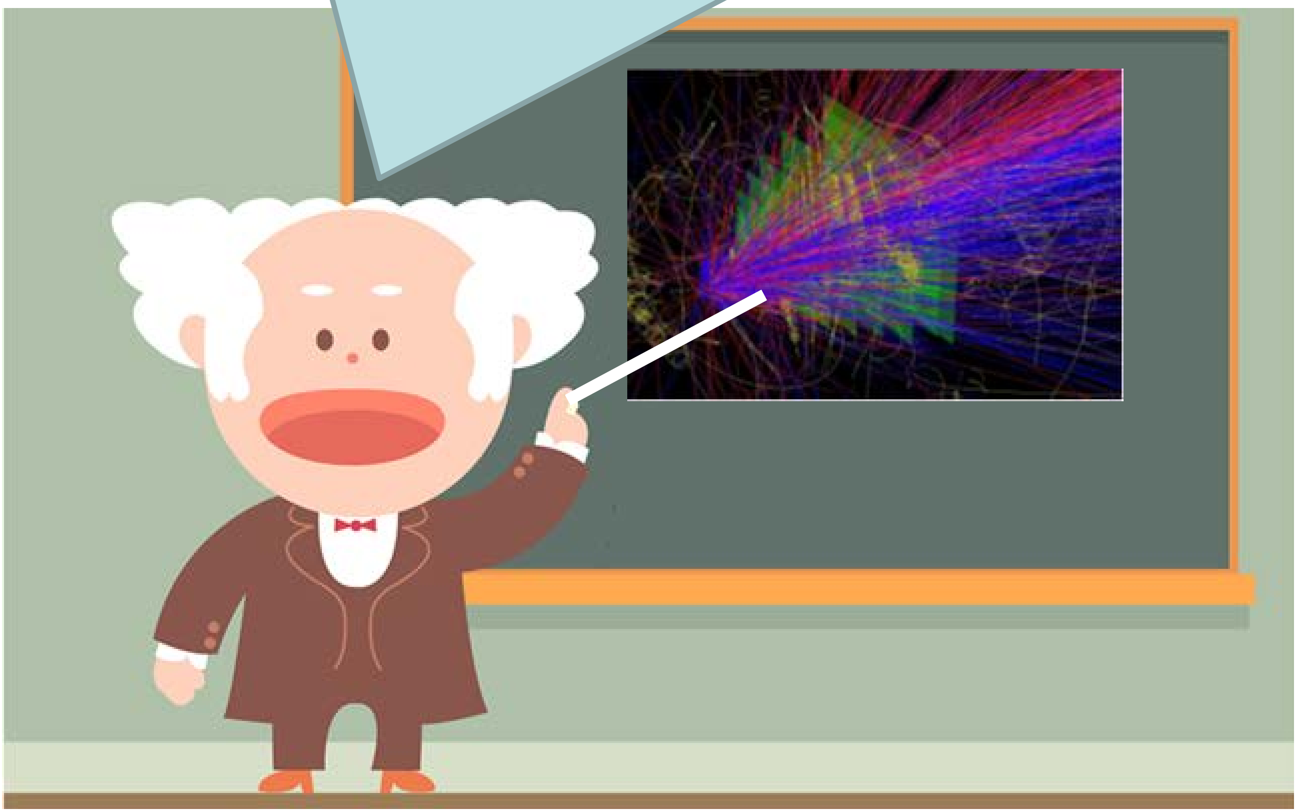




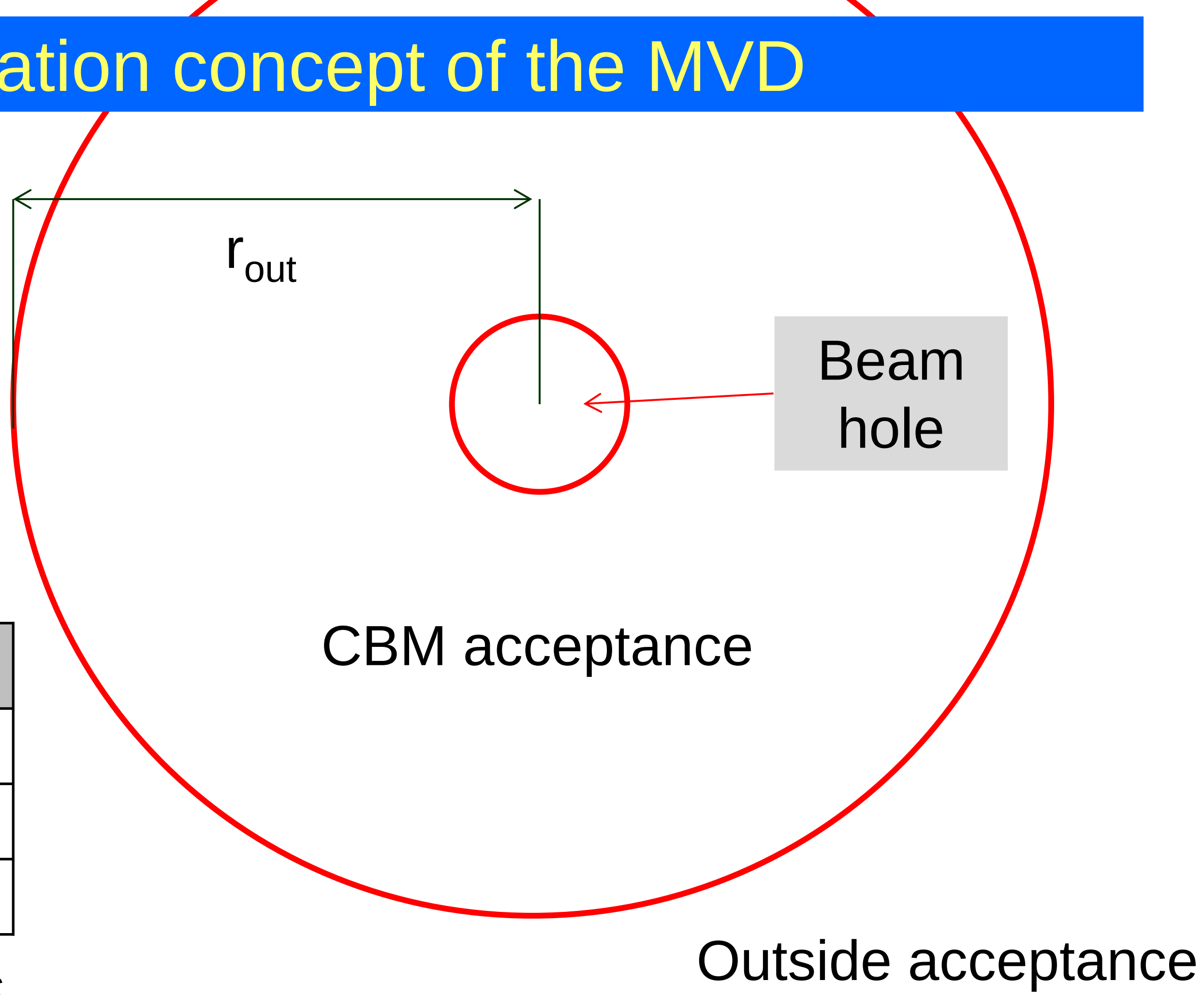
Naïve approach for system integration

Again, this structure will be fixed with

the novel ***Anti Gravitation Glue™***.



Integration concept of the MVD



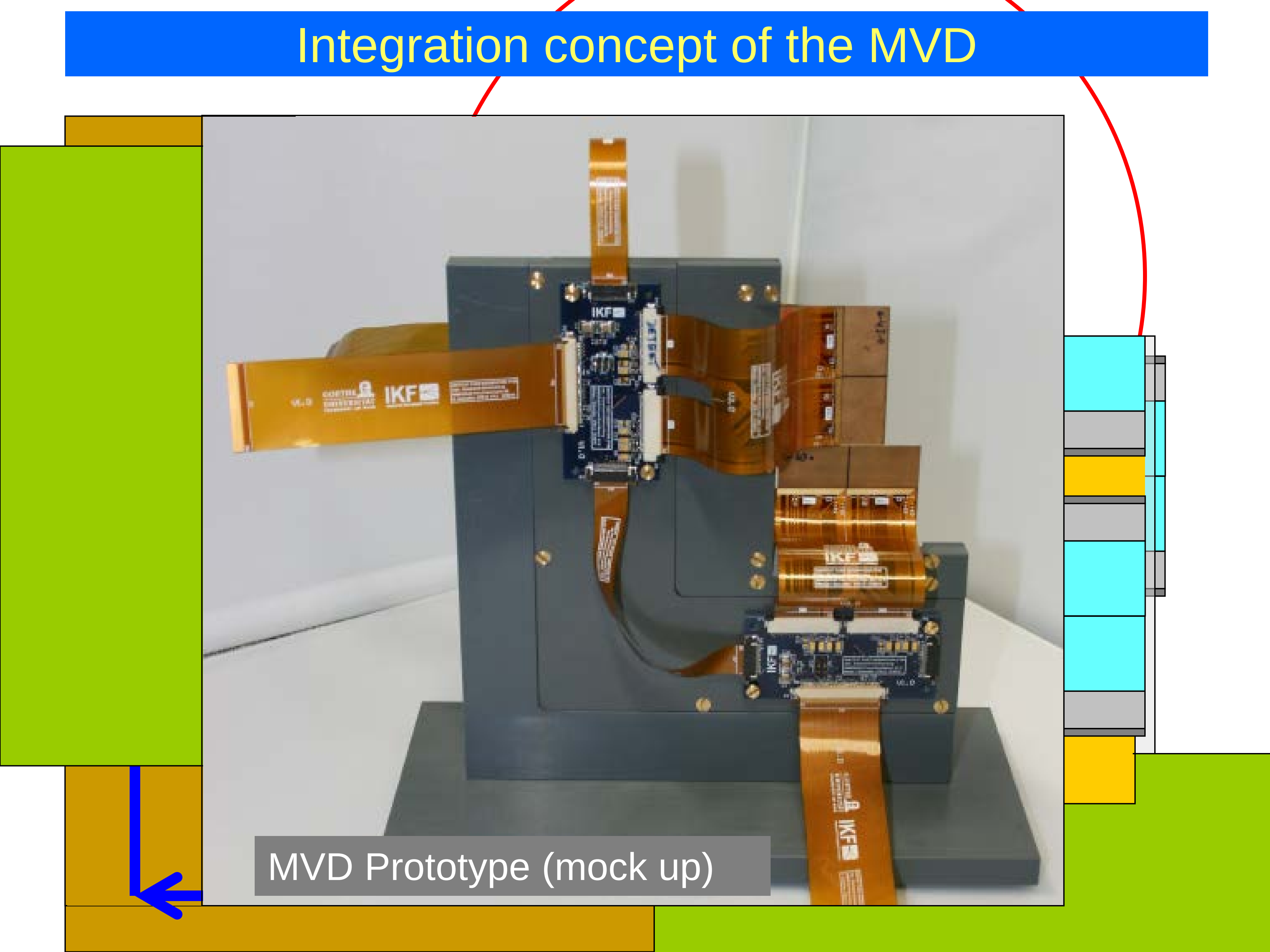
z[cm]	r_{out}	r_{in}
5	2.5	0.55
10	5.0	0.55
15	7.5	0.75

Geometry of MVD-stations

Vacuum operation requires light and actively cooled device.

- Use cooling support from diamond to move heat out of acceptance
- Put heat sink and FEE outside acceptance

Integration concept of the MVD

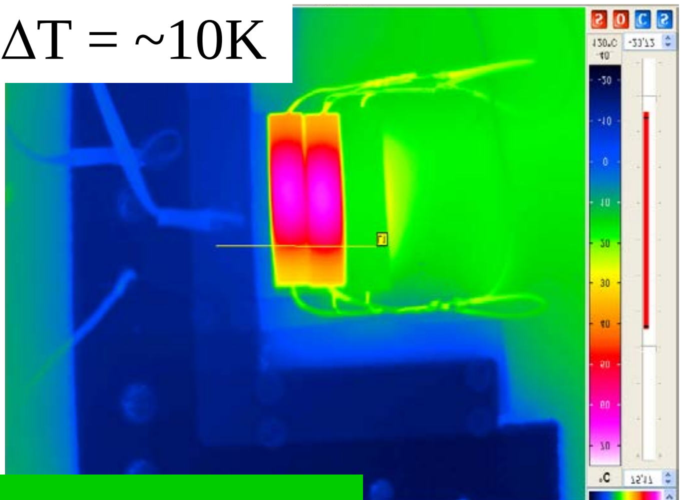


MVD Prototype (mock up)

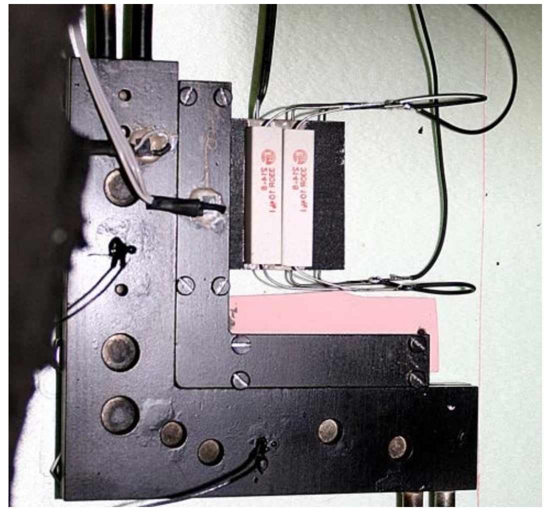
Validation of the cooling concept

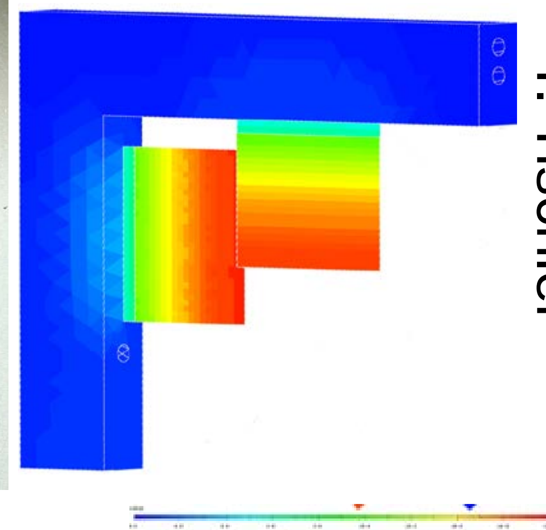
Aim: Validate the cooling concept with TPG

$\Delta T = \sim 10K$



25 W / 16 cm²





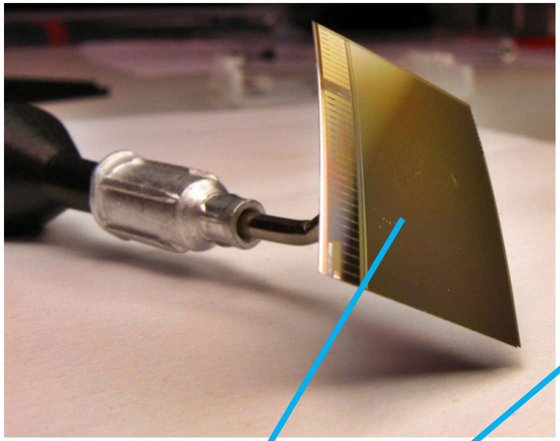
T. Tischler

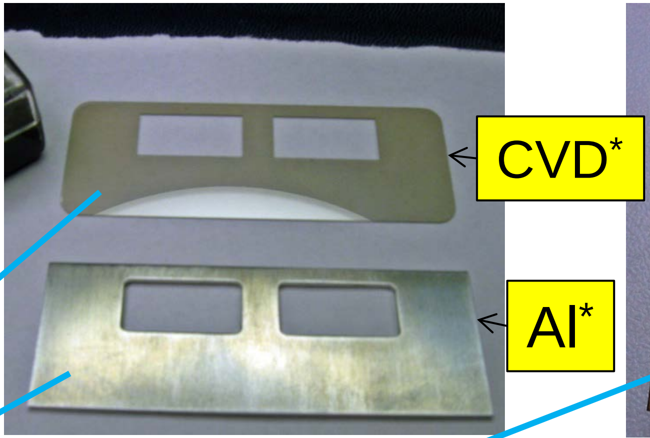
Observation:

- Temperature gradient on the station appears acceptable
- A 150 µm CVD diamond support might be sufficient for station 1
- Diamond => liquid heat transport needs optimization

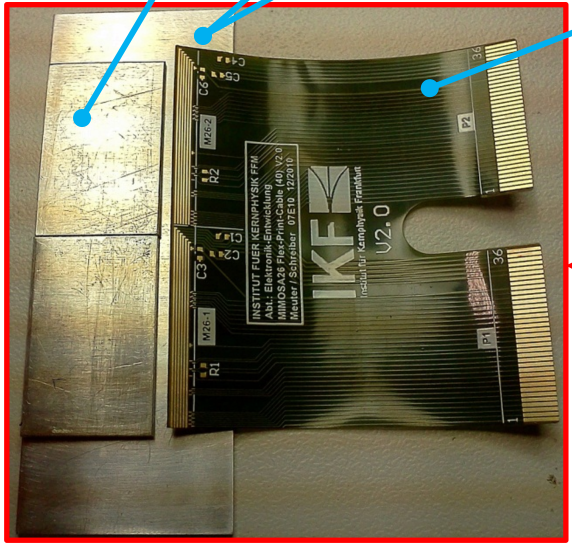
Vacuum compatible cooling concept for 1W/cm² seems robust.

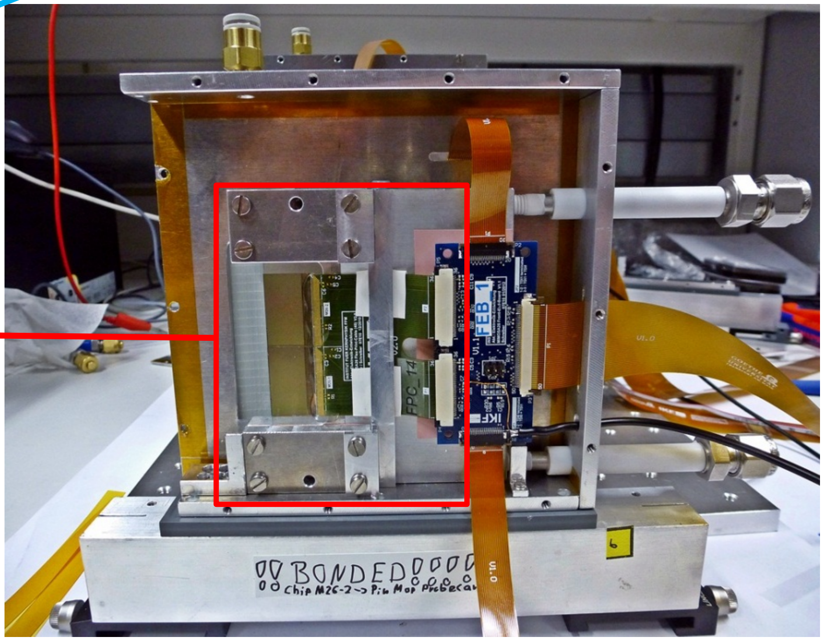
The CBM-MVD prototype



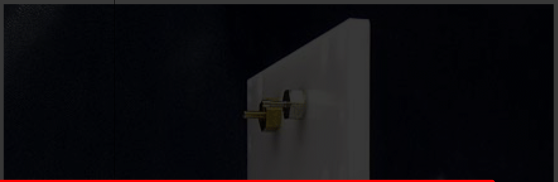


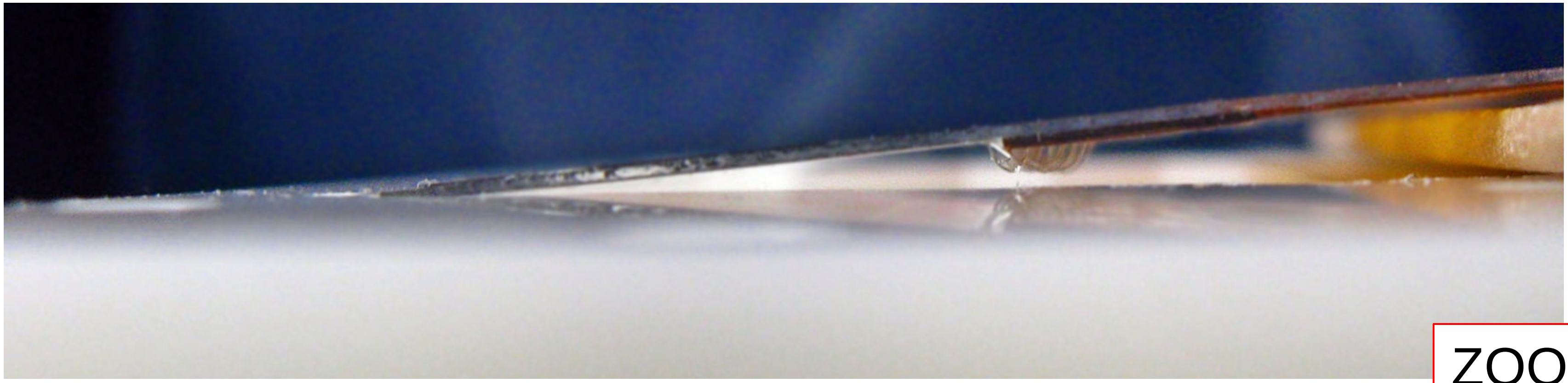
*) CVD and Al with cut-outs were tested for the reference plandes of the telescope. The prototype bases on a 100% filled CVD layer.

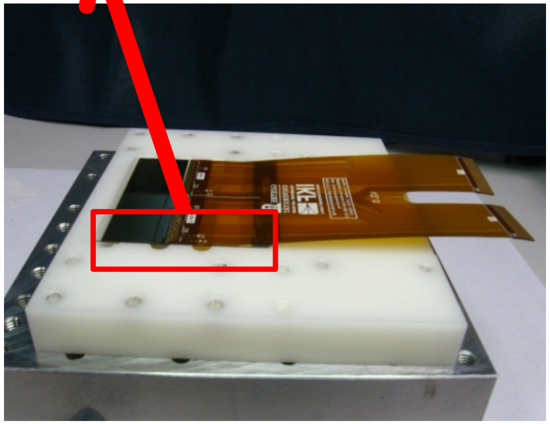




Tools







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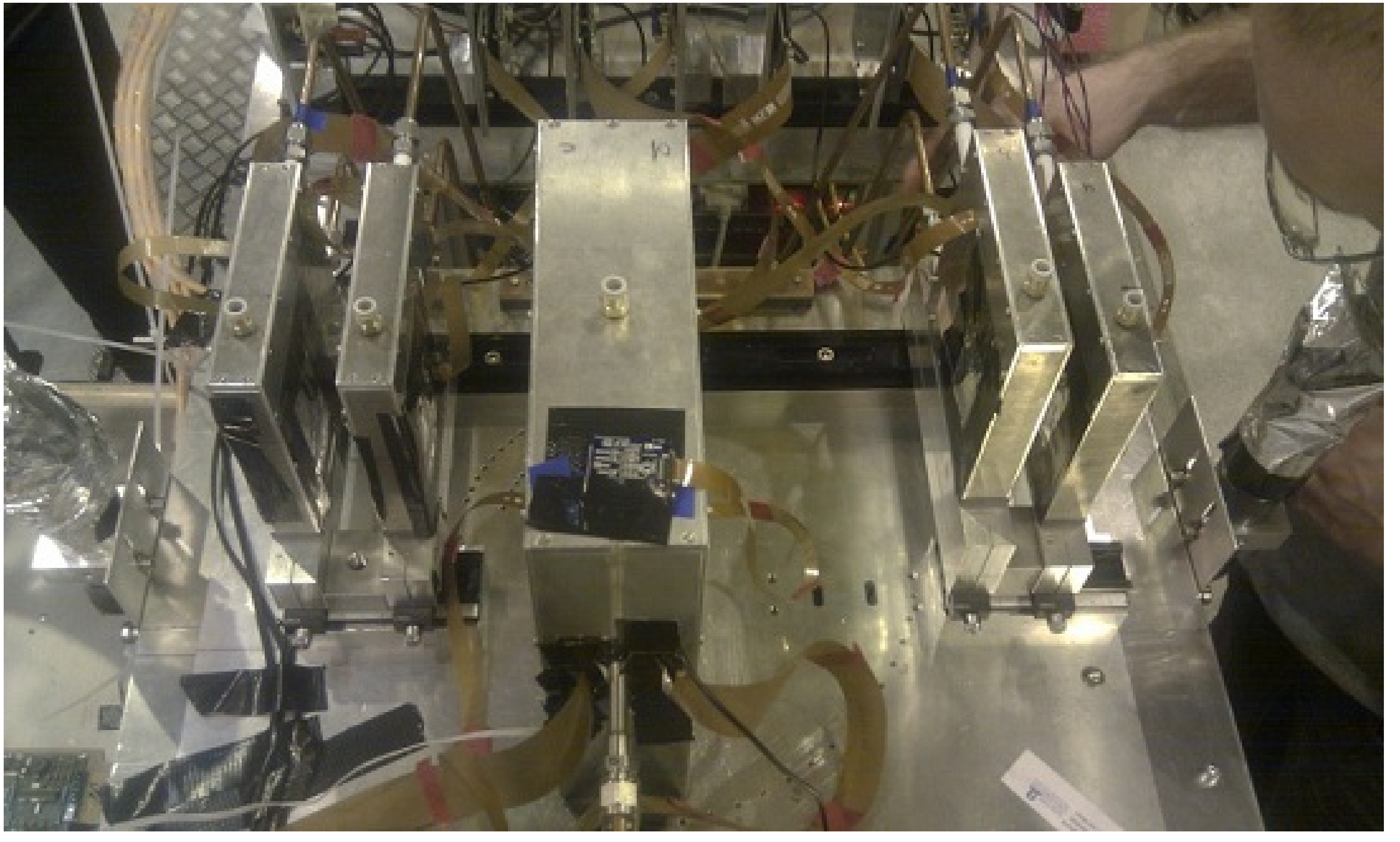
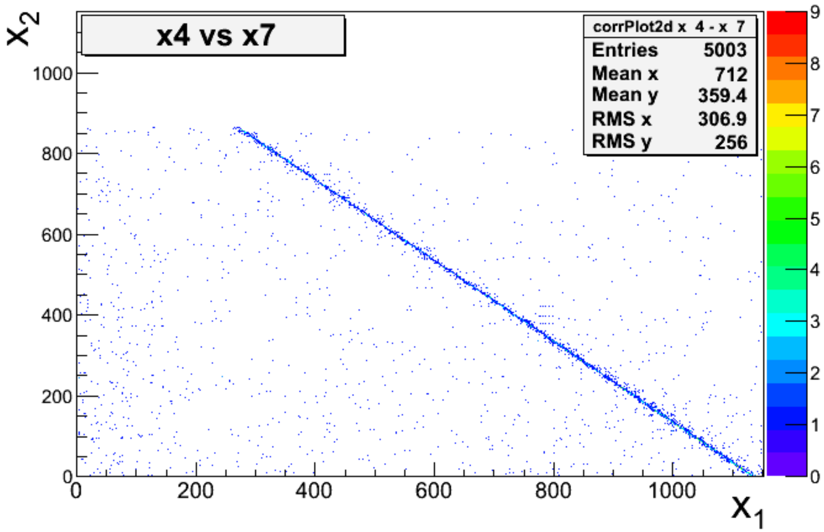
Prototype: Beam test setup



Ambitioned performances:

- Up to 10 MIMOSA-26 running @10k frames/s, 3.5µm resolution.
- Free-running, scalable DAQ based on HADES TRB – 100 MB/s.
- Actively cooled prototype (<0.3% X_0)
- Passively cooled telescope arms (0.05% X_0)

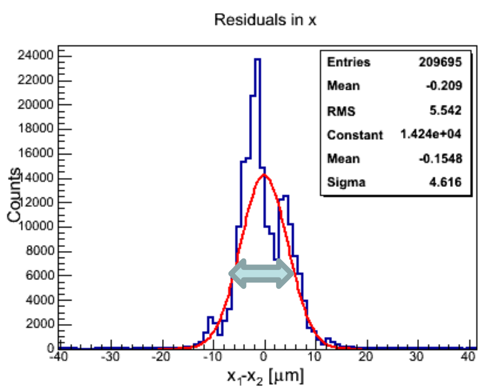
Some first results

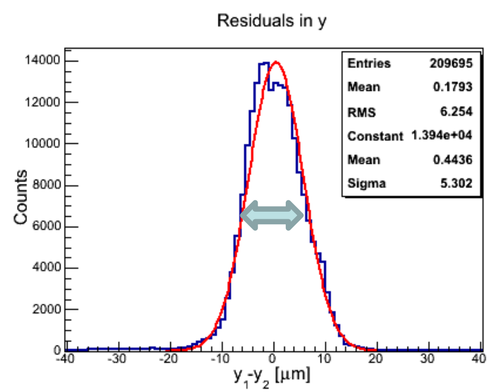


Result so far for the DUT:

σ_x= 3.3 µm

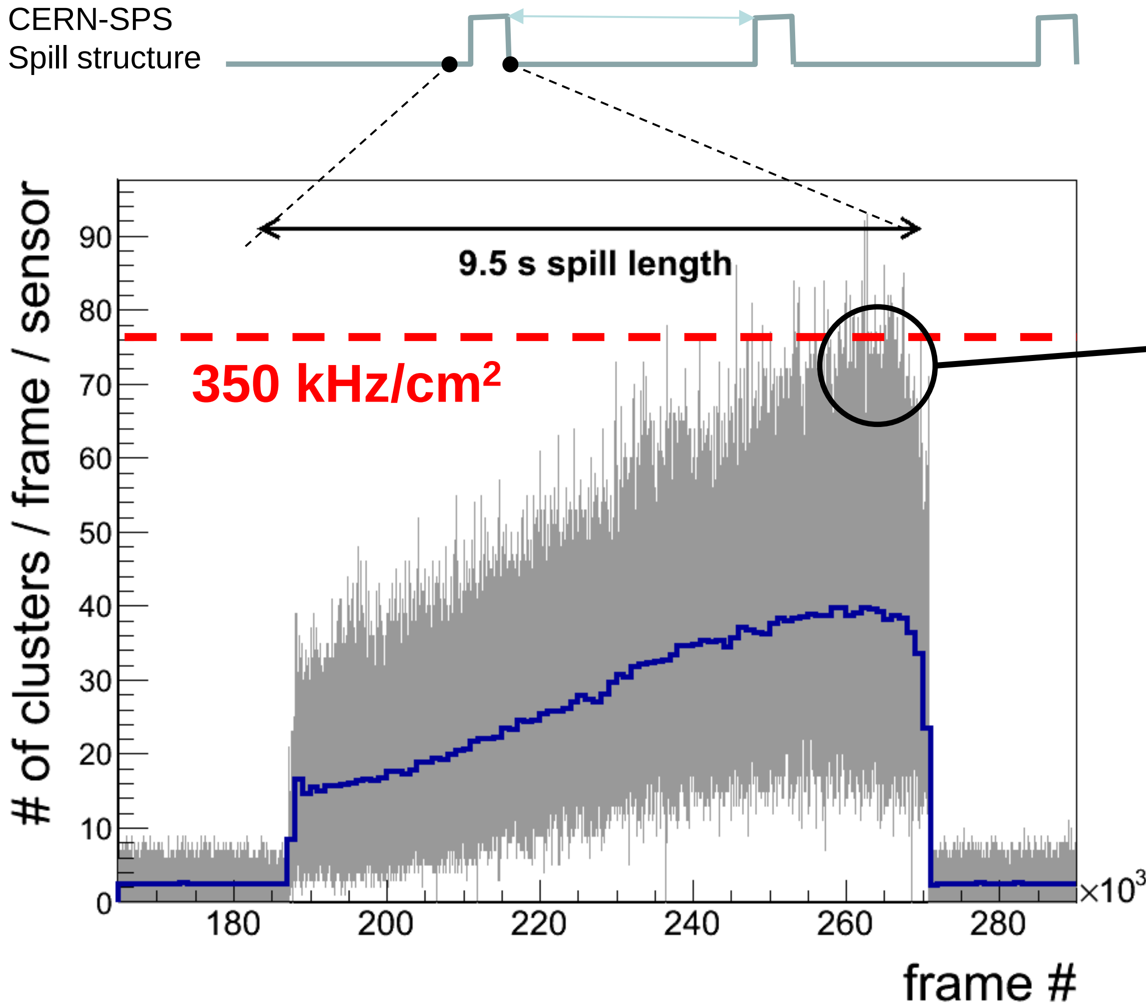
σ_y= 3.7 µm

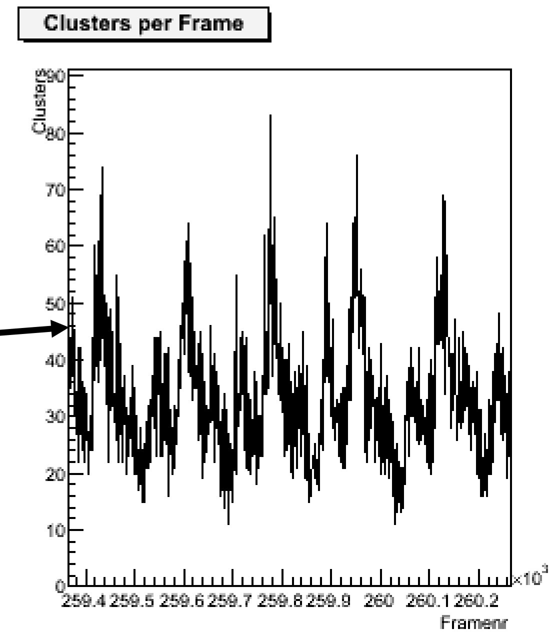


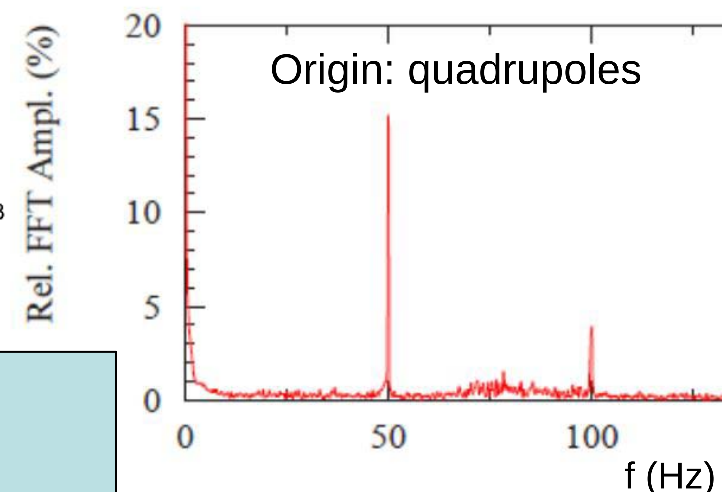


All performance plots very promising, analysis is being continued

Stability of the readout







Peak fluence: ~350 kHz/cm ^{2} (limited by CERN safety limits)

Summary

The CBM-Experiment

- CBM will be a heavy ion experiment located at FAIR
- The MVD bases on CMOS-MAPS (CPS) and is to measure open charm particles

Integration concept for the CBM-Micro Vertex Detector:

- Host MAPS on a vacuum compatible diamond cooling support
- Readout with ultra thin flex print cables
- Build local DAQ based on HADES TRB

Results of prototyping:

- Handling of sensors successful (close to 100% yield)
- Readout system operated stable at highest rates applied
- Preliminary results compatible with IPHC-results

Next steps:

- Demonstrate vacuum operation
- Prepare TDR