DPG

2016, Darmstadt

"Vacuum-Compatible, Ultra-Low Material Budget MVD for the CBM Experiment : Group Report"

Michal Koziel

On behalf of CBM-MVD group.

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GOETHE UNIVERSITÄT FRANKFURT AM MAIN

CBM

HIC for FAIR Helmholtz International Center

GSI

CBM-MVD related contributions

This talk → M. Koziel: "Vacuum-Compatible, Ultra-Low Material Budget MVD for the CBM Experiment."
Monday 14:00 HK 7.1

- M. Deveaux: "On drift fields in CMOS Monolithic Active Pixel Sensors."
  Monday 14:45 HK 7.3
- Erik Krebs: "Background rejection in dilepton analysis with CBM-MVD"
  Monday 17:45 HK 10.5
- D. Doering / M.Deveaux: "Ein Röntgenspektrometer auf der Basis von hochspannungstauglichen CMOS-Sensoren mit hochdotiertem Dopiniggradienten im aktiven Medium."
  Tuesday 14:30 HK 21.2
- B. Linnik: "Status of the radiation hardness of CMOS Monolithic Active Pixels Sensors for the CBM experiment."
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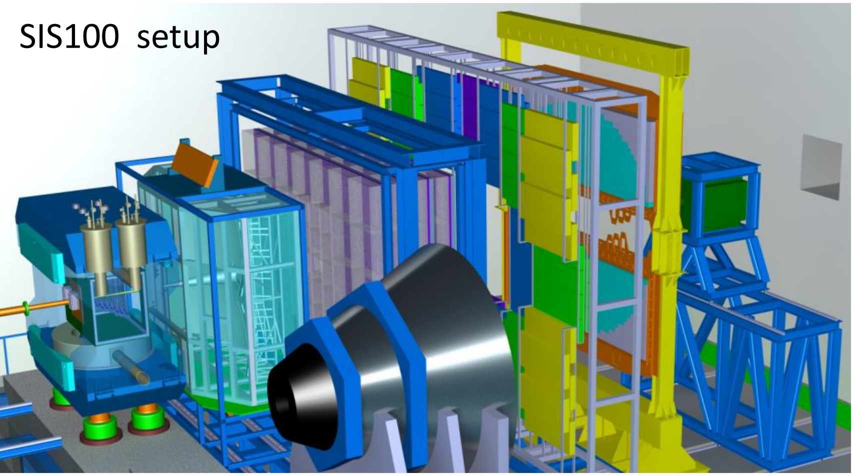
- T. Bus: "Strahlenschäden in dotiertem Silizium aufgrund Neutroneneinfangs Bor als Erweiterung des NIEL-Modells."
  Wednesday 18:30 HK 45.49
- P. Klaus: "Thin and Reliable Connectivity for the CBM-MVD"
  Thursday 18:00 HK 60.7

Outline

- The CBM-MVD: reminder
- Simulations
  - Tracking performance
  - Background rejection in dielectron analysis
- Sensor development
- PRESTO Project
- Summary

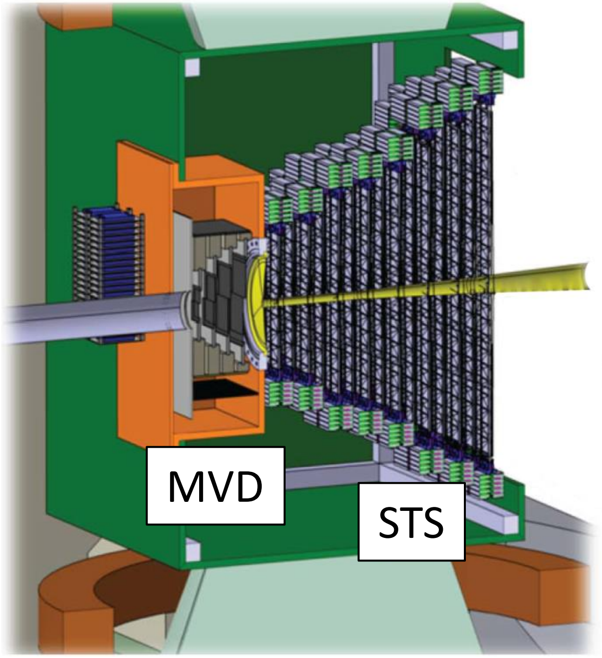
The CBM Micro Vertex Detector: Reminder p.1

SIS100 setup



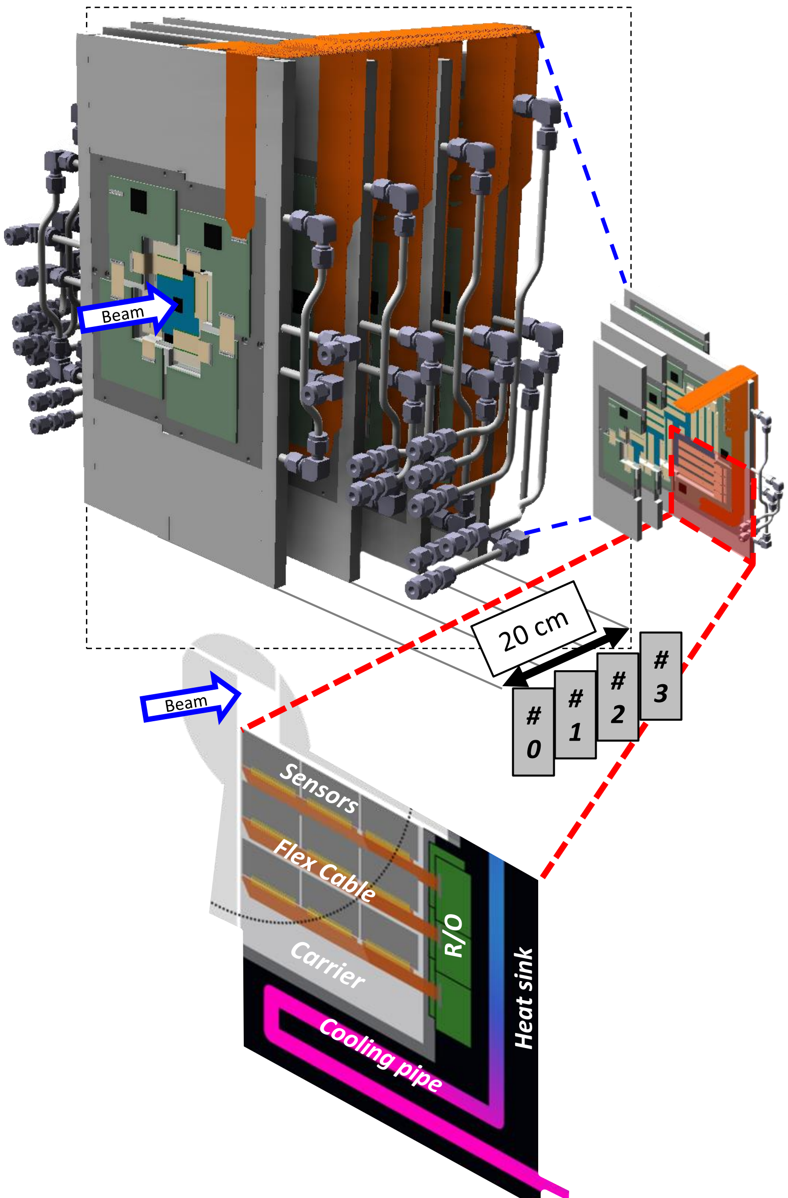
CBM-MVD :

- **Improve secondary vertex resolution (open charm)**
- **Tracking of low-momentum particles**
- **Background rejection in di-electron measurements**
- **Hosts highly granular silicon pixel sensors featuring low material budget, fast read-out, excellent spatial resolution and robustness to radiation environment.**

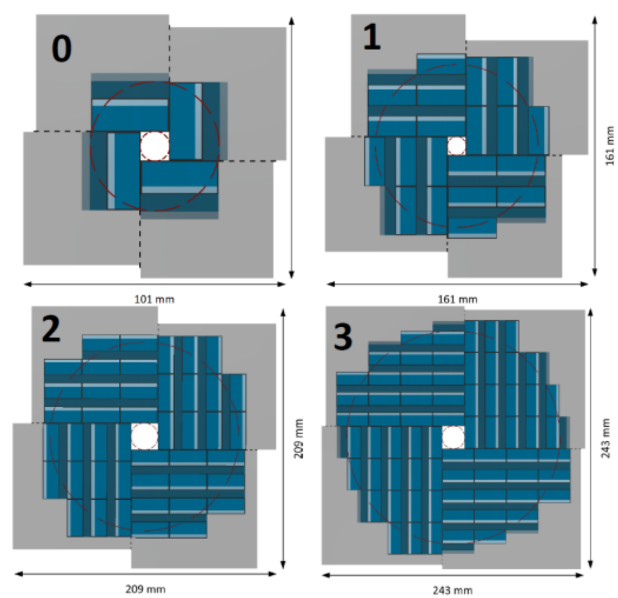


Required performances (SIS-100)	
Radiation tolerance	$> 10^{13} n_{eq}/cm^2$ & >1 Mrad
Read-out speed	> 30 kframes/s
Intrinsic resolution	5-10 µm - physics case driven
Operation in vacuum & magnetic field	
Support & cooling	Material budget ~ 0.3 % x/X_0 Double-sided sensor integration

The CBM Micro Vertex Detector: Reminder p.2

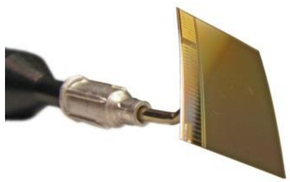


Station		Radius [mm]		Details	
No.	Distance from target [mm]	Inner	Outer	Min. # of 3x1 cm sensors	Carrier material
0	50	5.5	25	8	CVD diamond
1	100	5.5	50	36	CVD diamond
2	150	8.3	75	78	TPG
3	200	11	100	128	TPG



Minimum geometrical acceptance shown

CBM-MVD: integration challenge



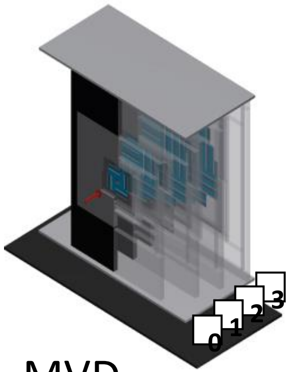
4 stations populated with sensors

- Sensor development
- Sensor commissioning

Sensor support (CVD-Diamond & TPG)

Readout & services

- R/O electronics
- Flex Print Cables (FPC)



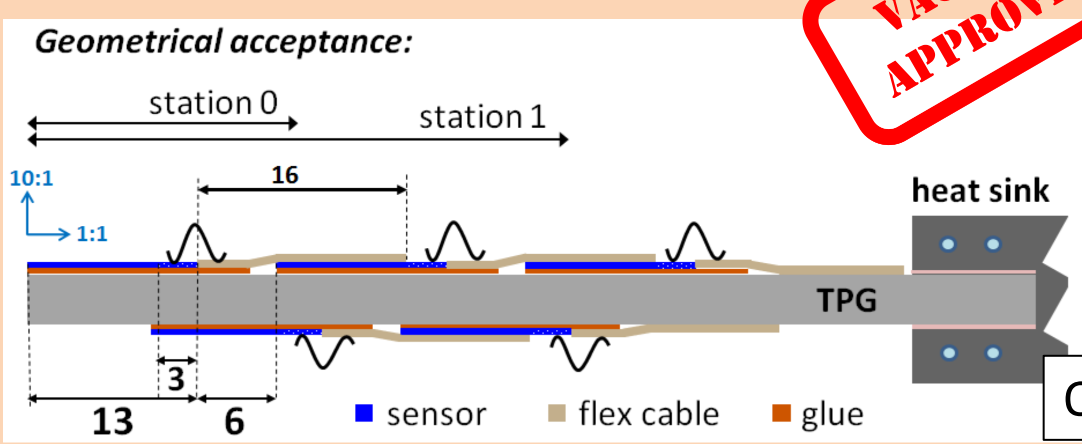
MVD mechanics

- Jigs
- Dispensing tools
- Procedure

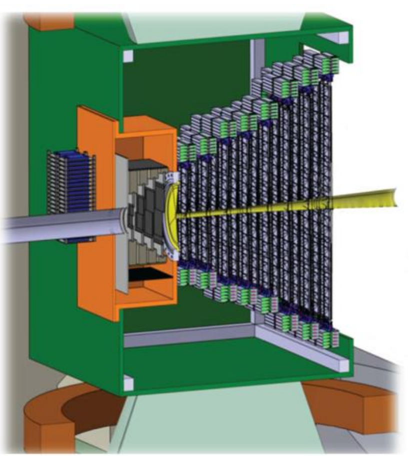
INTEGRATION

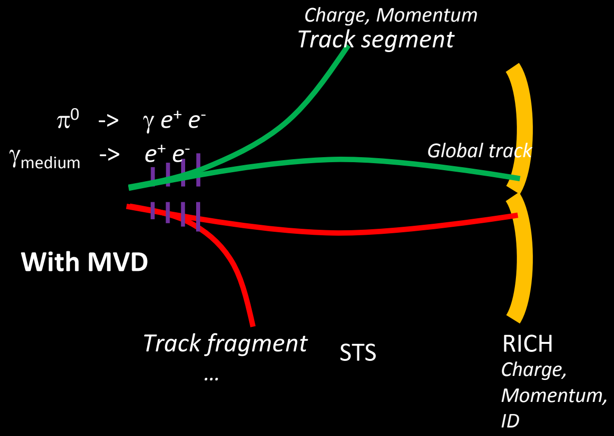
- Quality assessment
- Metrology
- Alignment

VACUUM APPROVED



QUADRANTS



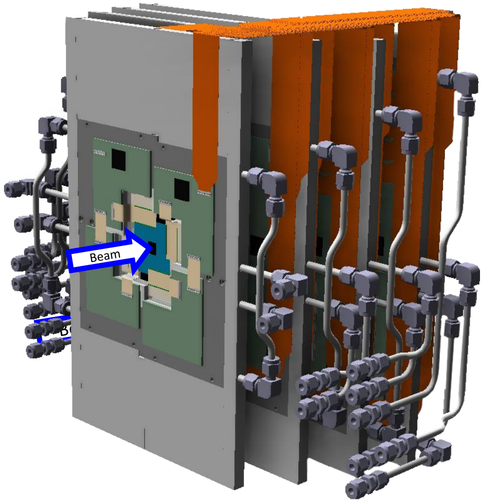


SIMULATIONS

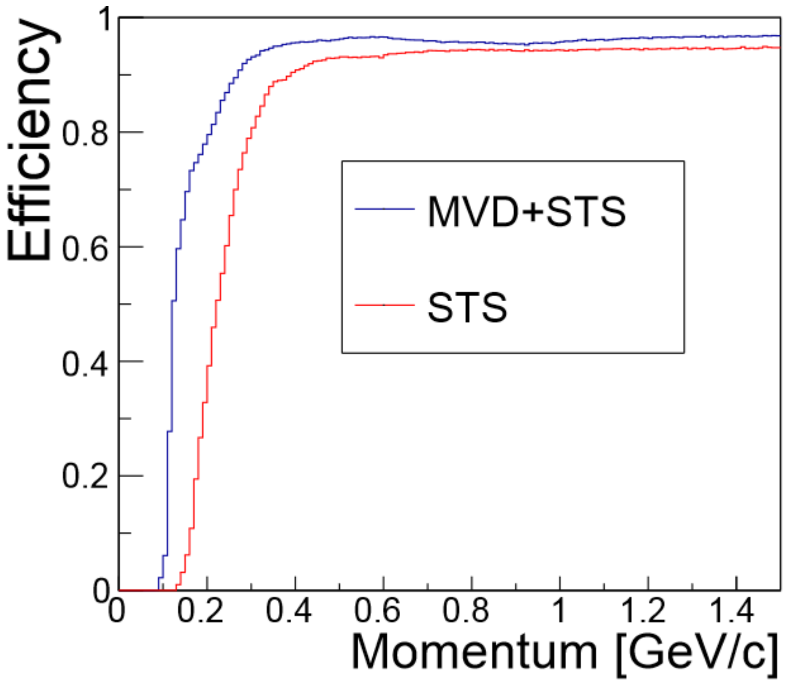
Performance
&
Physics Case Studies

Erik Krebs: "Background rejection in dilepton analysis with CBM-MVD"
Monday 17:45 HK 10.5

MC simulations => MVD+STS tracking capability



FAIRROOT



Monte Carlo simulations

Setup = 4 MVD + 8 STS stations

Primary tracks considered

Studied:

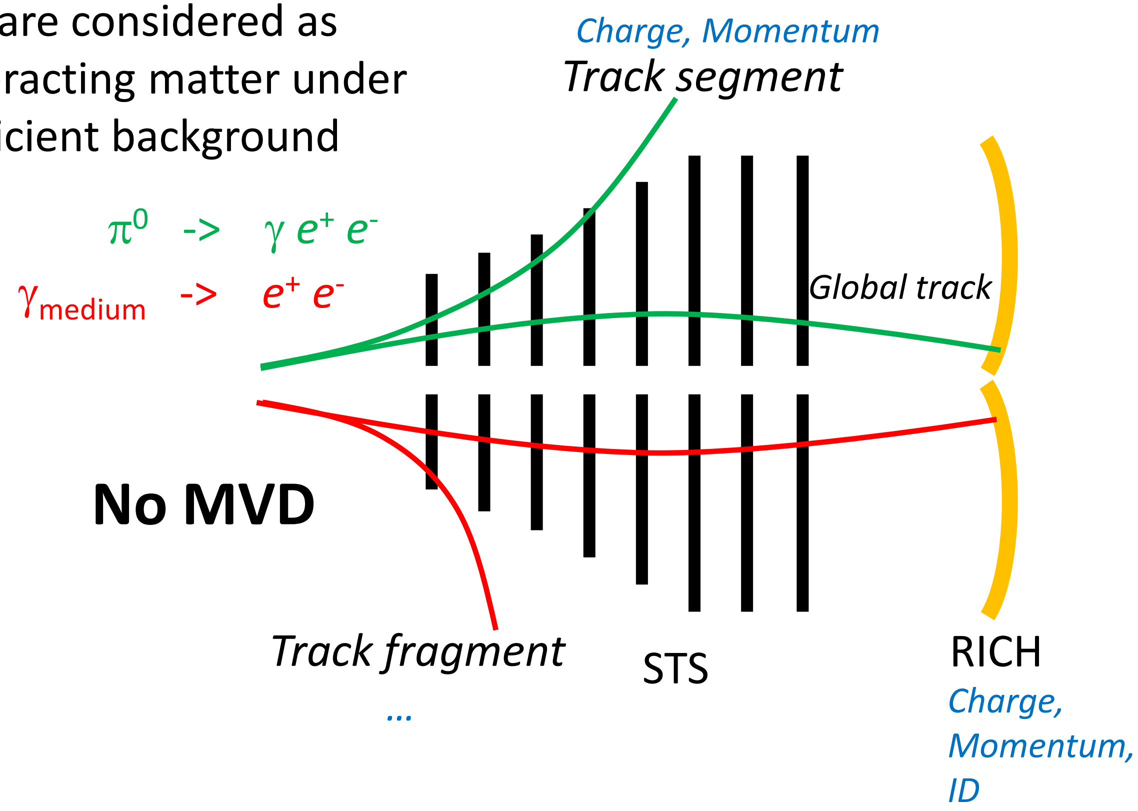
- Impact parameter resolution
- Momentum resolution
- Tracking efficiency
- For particles with momentum smaller than 0.5 GeV/c

Conclusion: MVD improves the CBM tracking capability due to added value, that is spatial resolution and geometrical acceptance.

Background rejection with MVD

The light vector mesons ρ, ω and ϕ are considered as excellent probes of the strongly interacting matter under extreme conditions… but rare -> efficient background rejection.

Single electron or positron tracks from incompletely detected γ-conversions and Dalitz decays of π^0 -mesons are the most abundant source contributing to the combinatorial background.



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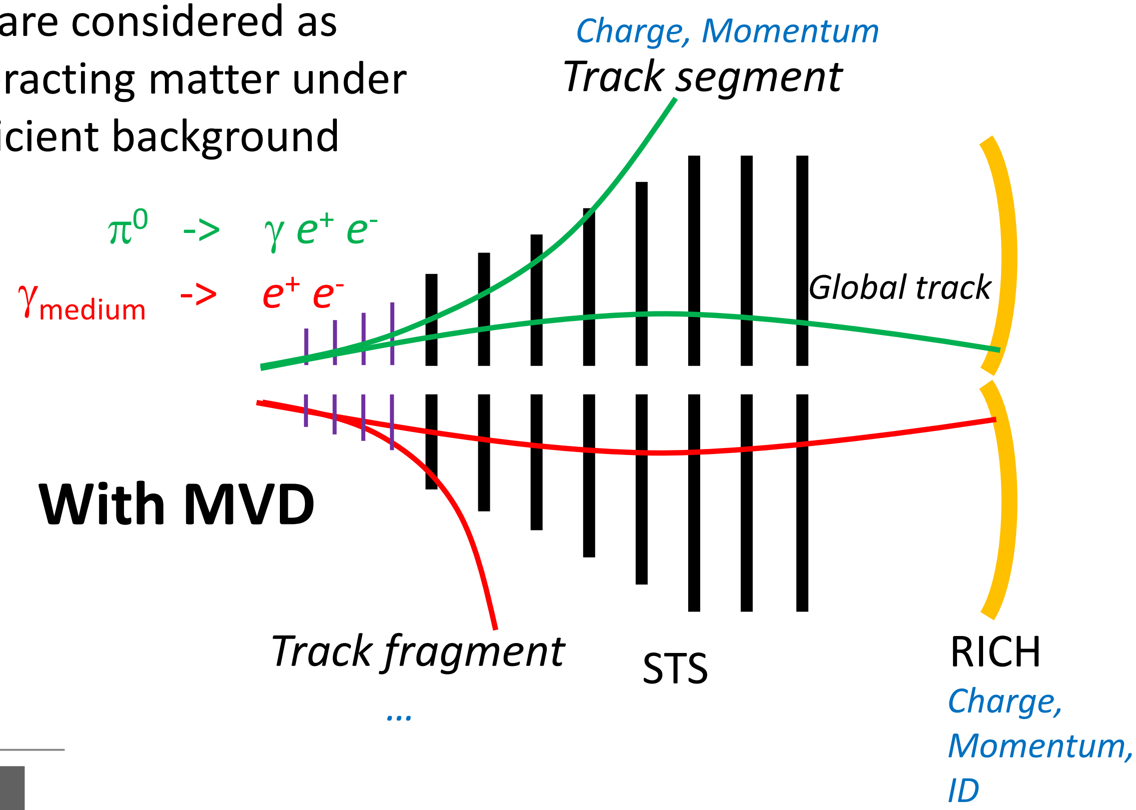
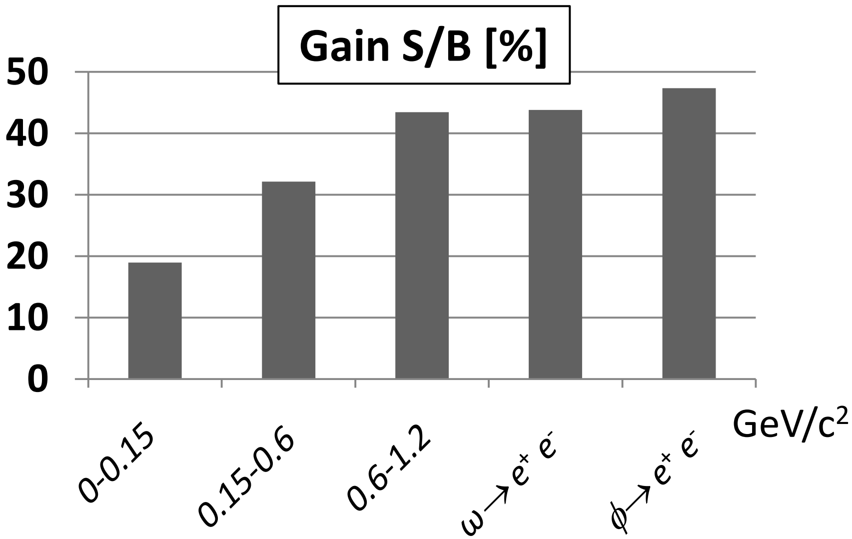
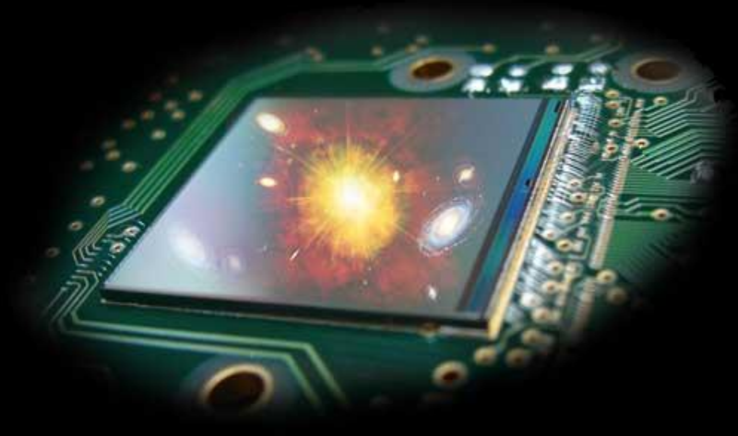




Tracking of low momentum tracks, helps to suppress background (mainly from conversion) as being e.g. well established by HADES collaboration.



SENSOR DEVELOPMENT

- **M. Deveaux:** **"On drift fields in CMOS Monolithic Active Pixel Sensors."**
  Monday 14:45 HK 7.3
- **D. Doering / M.Deveaux:** **"Ein Röntgenspektrometer auf der Basis von hochspannungstauglichen CMOS-Sensoren mit hochdotiertem Dopiniggradienten im aktiven Medium."**
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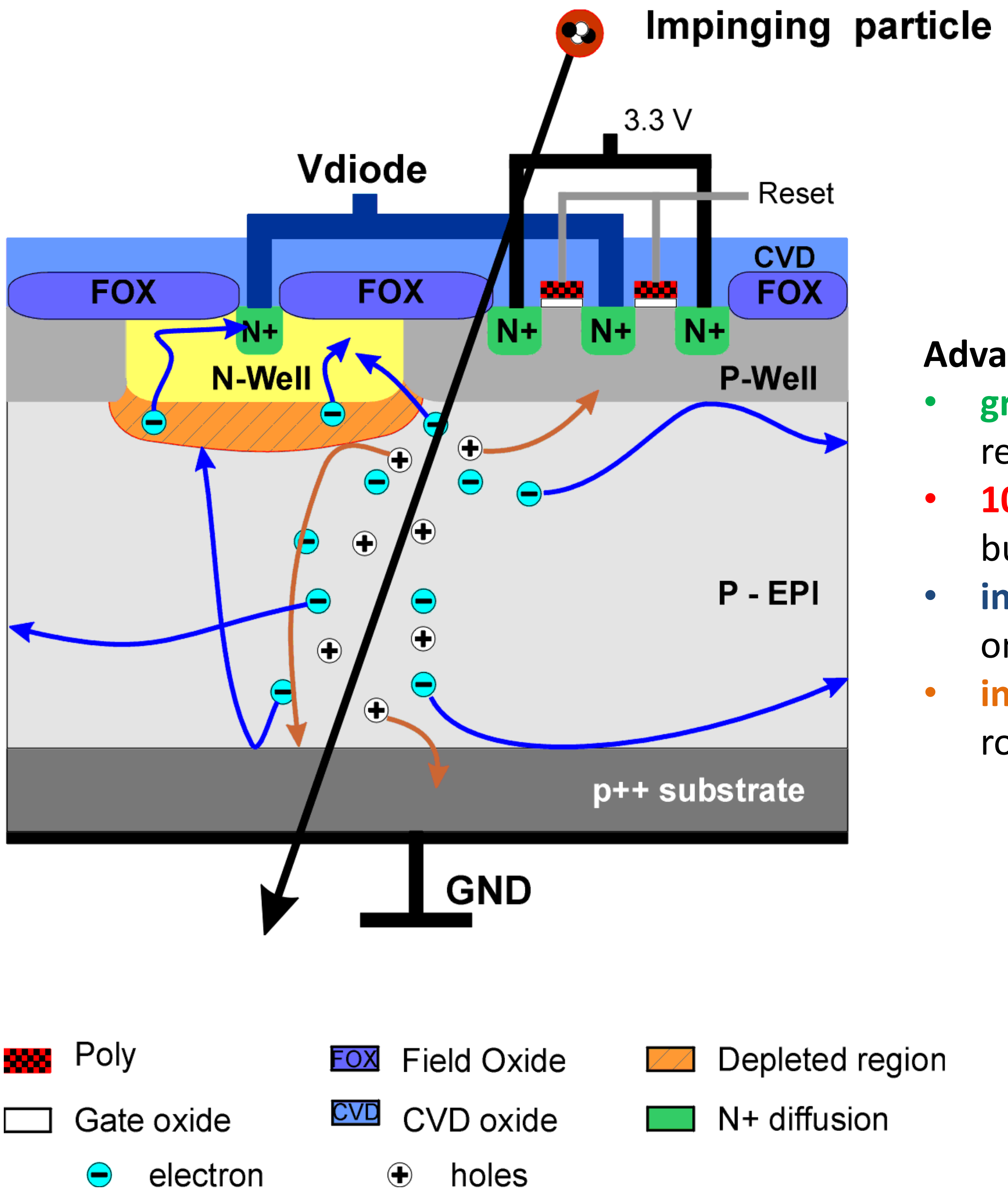
CMOS Pixel Sensors (CPS)

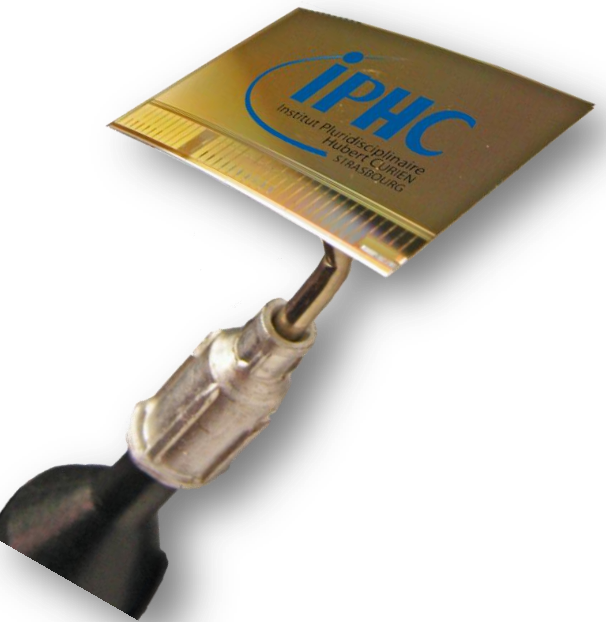


Advantages of CMOS sensors:

- **granularity**: pixels of 10×10 µm, high spatial resolution
- **10-20 µm thick sensing volume:** low material budget (typically 50 µm Si)
- **in-chip signal processing:** compact sensors with on-board intelligence, e.g. data sparsification
- **in addition:** cost, multi-project run frequency, room temperature operation, potentially HR EPI

CBM-MVD sensor specification

PRELIMINARY !!!

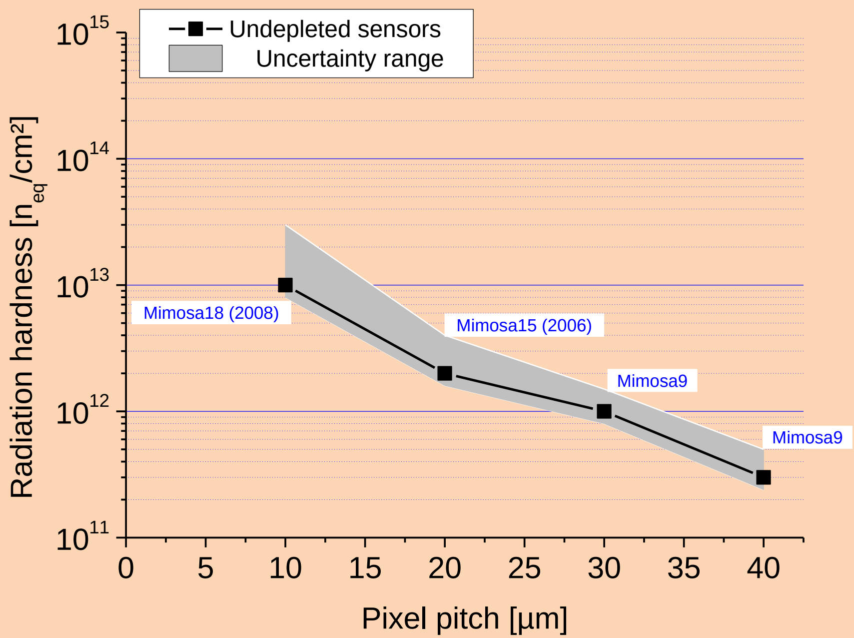


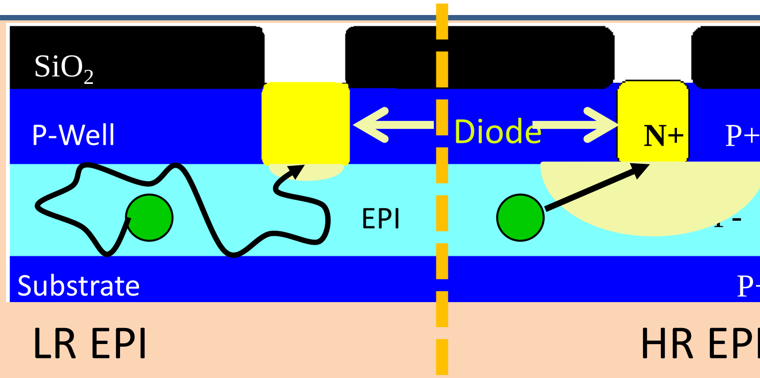
PARAMETER	Baseline
Spatial resolution	~ 5 µm
Maximum power dissipation (full occupancy) [mW/cm²] ➔ Reduced rate, Station 2-3 ➔ Full rate, Station 0-1	< 200 < 350
Pixel pitch	~30 x 30 µm²
Operation temperature [°C]	-40 to +30
Operation temperature gradient on sensor [K/cm]	5
Radiation doses $[n_{eq}/cm^2]$ @ -20°C @+30°C	3×10^{13} 1×10^{13}
Radiation doses [Mrad] @ -20°C @+30°C	3 Mrad 1 Mrad
Radiation doses [HI/cm²]	10^{10} ? High uncertainty
Radiation dose (gradient)	100%
Readout time (µs)	~10
Average hit rate (1/mm²/s)	1.5×10^5
Peak hit rate (1/mm²/s)	7×10^6
Maximum Data rate (Gbps/cm²)	~1.6
Minimum Data rate (Gbps/cm²)	0.16
Encoding	24bit/hit

PARAMETER	Baseline
Efficiency ➔ New ➔ End of lifetime	> 99% ~99%
Fake hit rate ➔ New ➔ End of lifetime	10^{-5} 10^{-4}
Data interface	320 Mbps
Minimum number of data lines/sensor	
I/O Standard	GBT-comp.
Bonding technology	Wedge
Bias voltage mismatch tolerance	0.3V
Variation in currents	5%
Slow control	
Clock down	Factor 2 (Uncertain)
Sensor surface (sensitive)	3 x 1 cm²
Sensor surface (insensitive)	3 x 0.3 cm²
Thickness	50 µm
ESD - Protection	
Pads for probe testing	
Unique ID for sensors	
Alignment markers	
Temperature sensor	

How to improve radiation tolerance of CPS

How to improve the non-ionizing hardness:



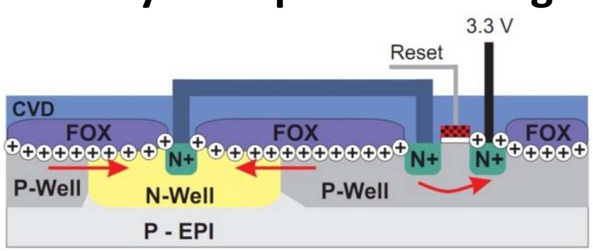


Aim for a larger depletion zone !!!

- Diffusion -> drift in electric field
  - Doping profile
  - Higher depletion voltage

Calls for CMOS processes providing a High Resistivity epitaxial layer.

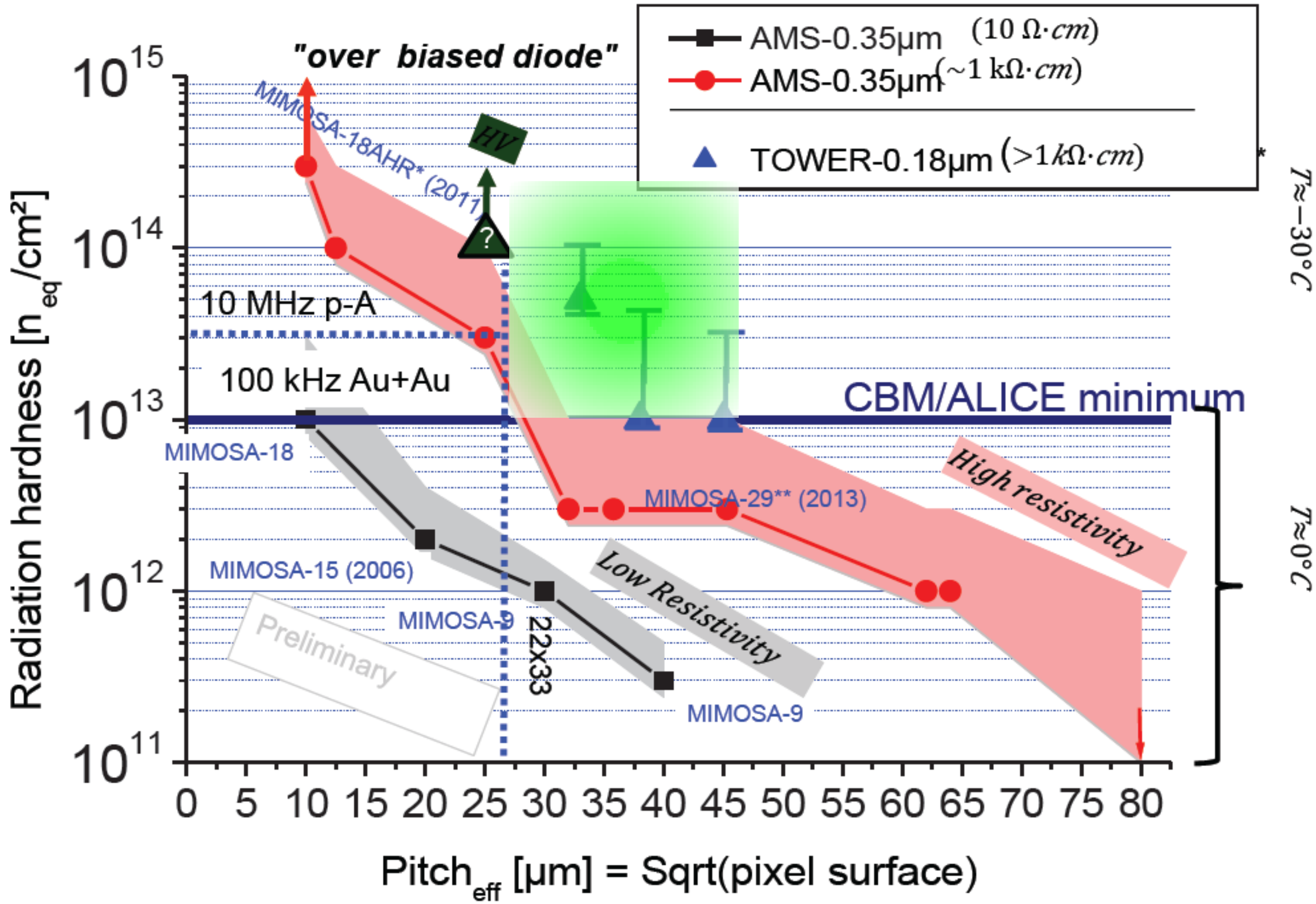
The way to improve ionizing hardness:



Investigate processes with small feature size, 0.18 µm and below.

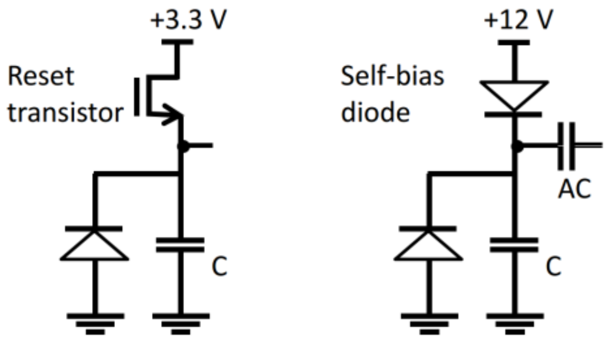
Radiation hardness: 2015 achievements

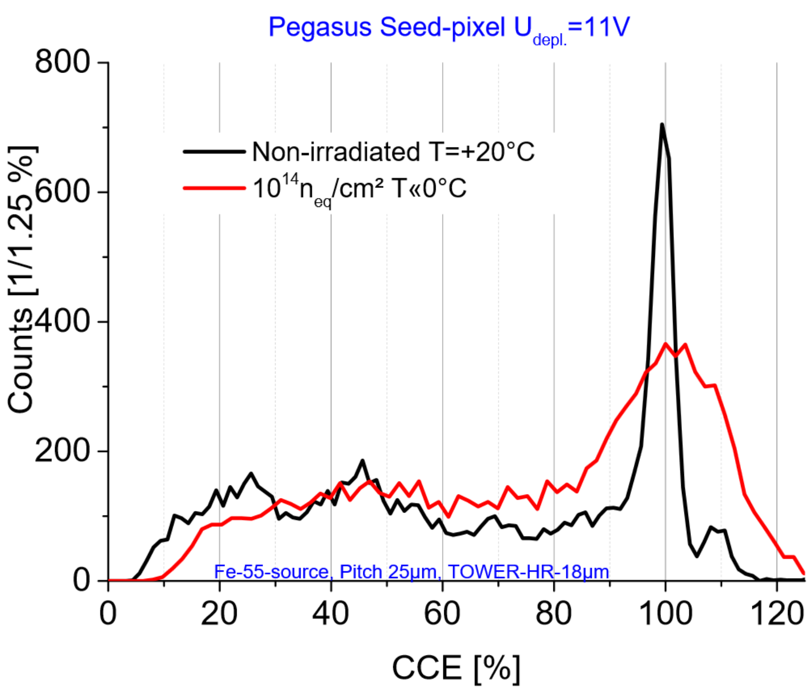
Aim: investigate the radiation hardness of the JAZZ-TOWER 0.18 µm CMOS process
Key point: a high-resistivity (> 1kΩ*cm) EPI (HR-EPI) layers with different doping profiles
Outcome: top radiation tolerance for HR-EPI featuring gradient doping profile (publication during write-up)



Radiation hardness: 2015 achievements

Towards fully-depleted CMOS pixel sensors: PEGASUS sensor





Aim: Design, manufacture and study the sensor with pixels powered from higher (~12.5 V) than standard (0.6-2.8 V) bias voltage.

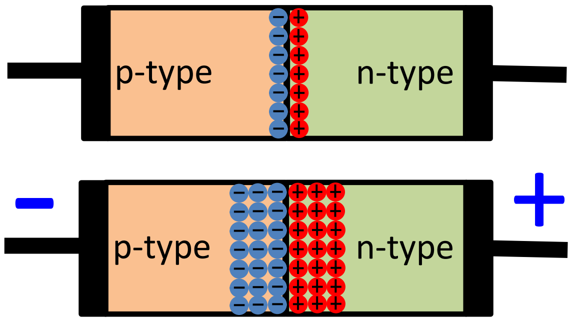
Outcome: High bias voltage increases the size of the depleted volume to almost (?) full epitaxial layer thickness.

D.Doering et al.,"CMOS-sensors for energy-resolved X-ray imaging"

http://dx.doi.org/10.1088/1748-0221/11/01/C01013

Why we do not deplete CMOS Pixel Sensors ?

Theory



$$d = \sqrt{\frac{2\varepsilon\varepsilon_0}{e} + \left(\frac{1}{N_A} + \frac{1}{N_D}\right)(U_{bi} - U)} \quad \sim \sqrt{U_{depl}}$$

$N_A = 10^{18} / cm^3$

$N_D = 10^{12} / cm^3$

$U_{depl} = -0.6\ V$

⇒ $d = 30\ \mu m$

...but full CMOS HR-EPI depletion at 0.6 V never observed...

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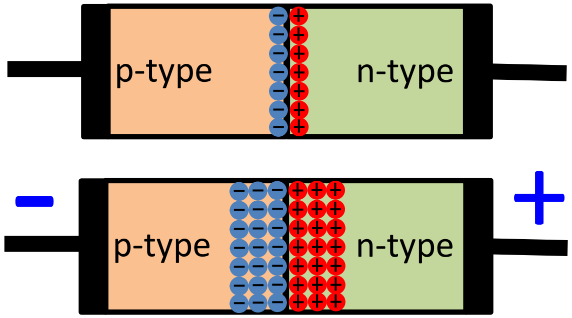

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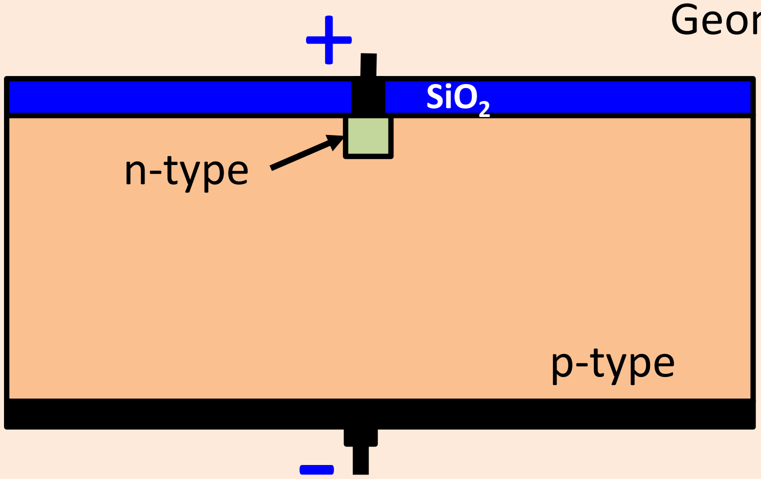
Reality

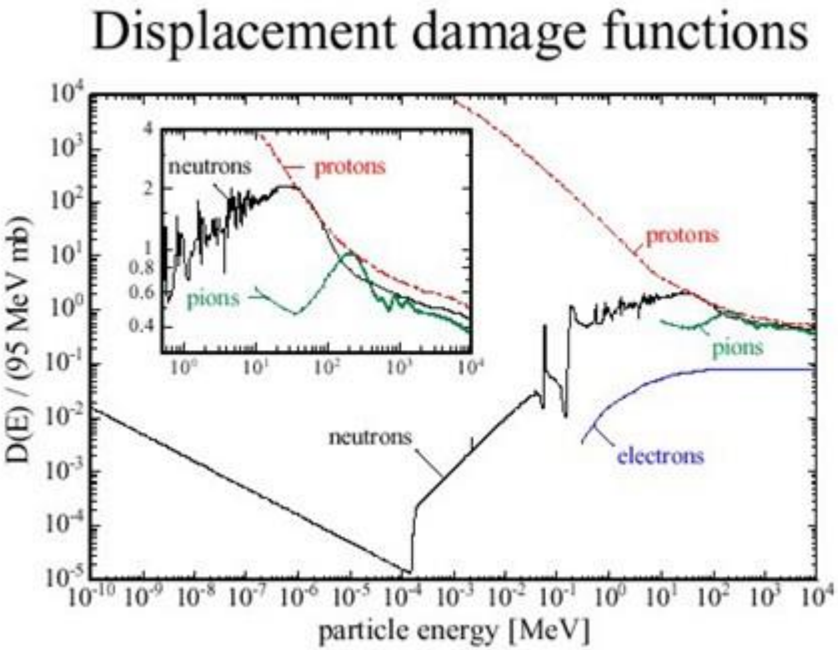
Geometry of a real pixel does not fit



⇒ $d_{CMOS} \sim \sqrt[6]{U_{depl}}$

M. Deveaux: "On drift fields in CMOS Monolithic Active Pixel Sensors."
Monday 14:45 HK 7.3

On the NIEL scaling for low-energy neutrons



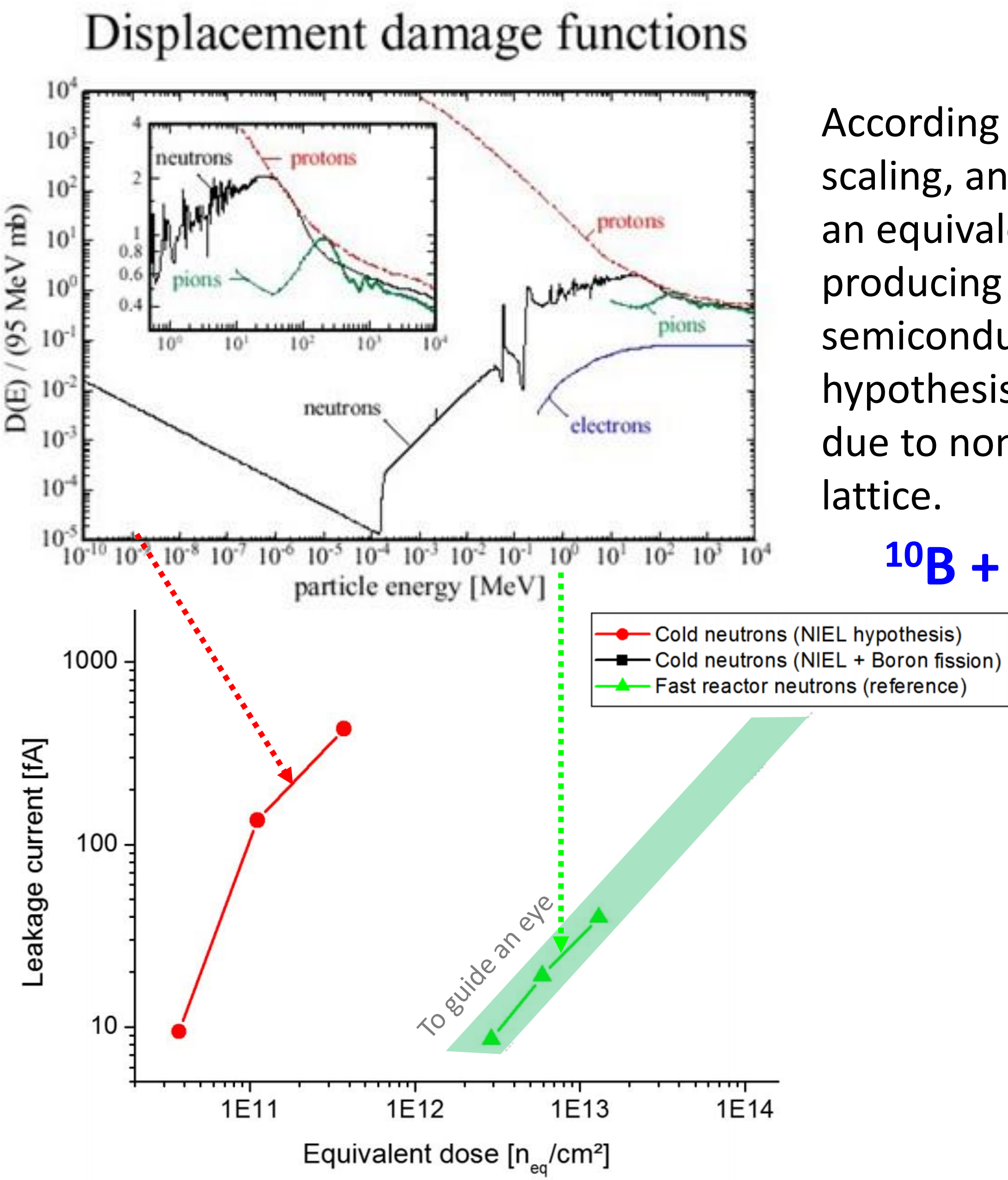
According to NIEL (non-ionizing energy loss) scaling, any particle fluence can be reduced to an equivalent 1 MeV neutron fluence producing the same bulk damage in a specific semiconductor. The scaling is based on the hypothesis that generation of bulk damage is due to non-ionizing energy transfers to the lattice.

$^{10}B + n \Rightarrow Li + \alpha + 3MeV$ **?**

Radiation from this process to be considered

No problem if P-doping << $10^{15}cm^3$

On the NIEL scaling for low-energy neutrons



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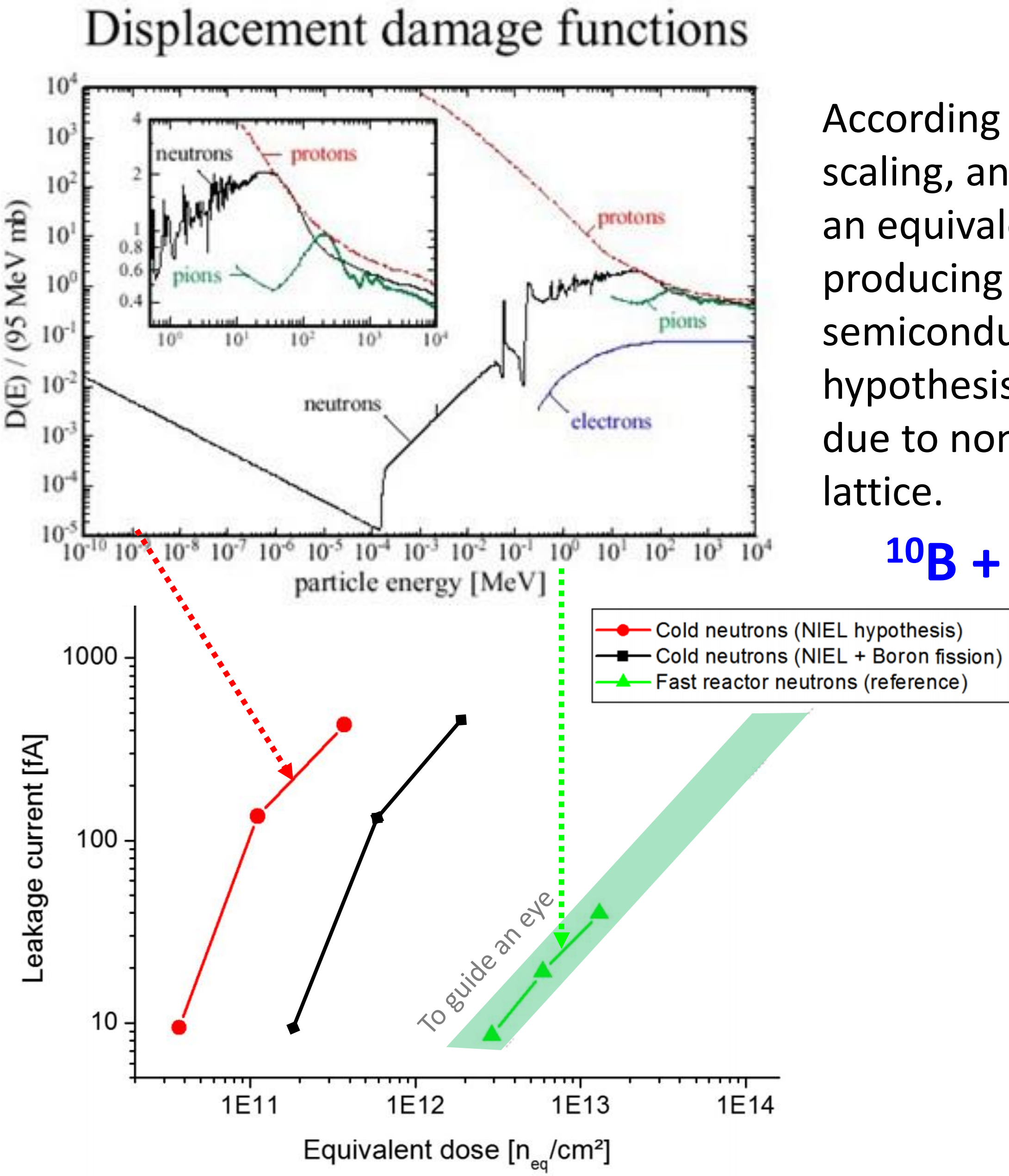

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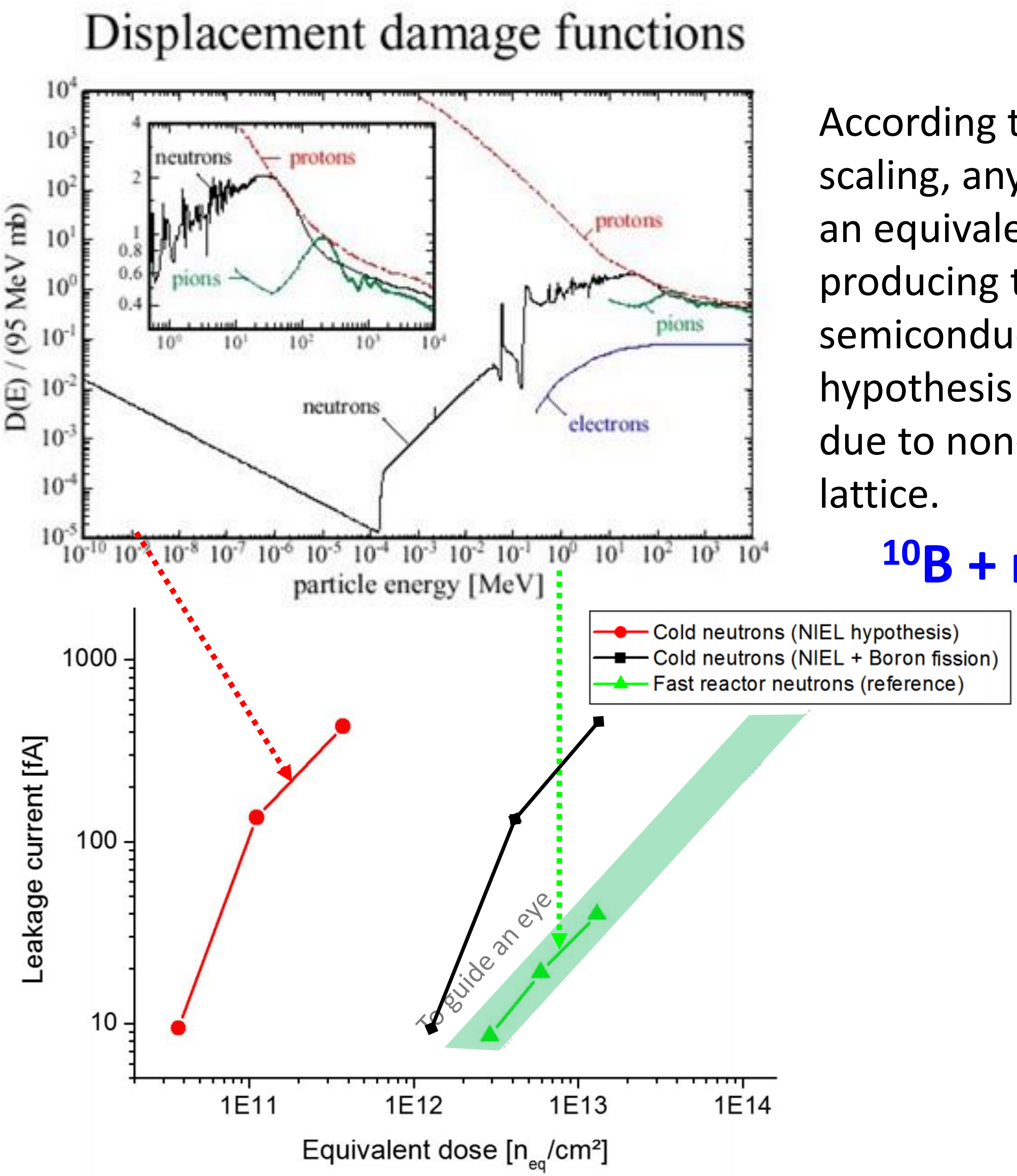

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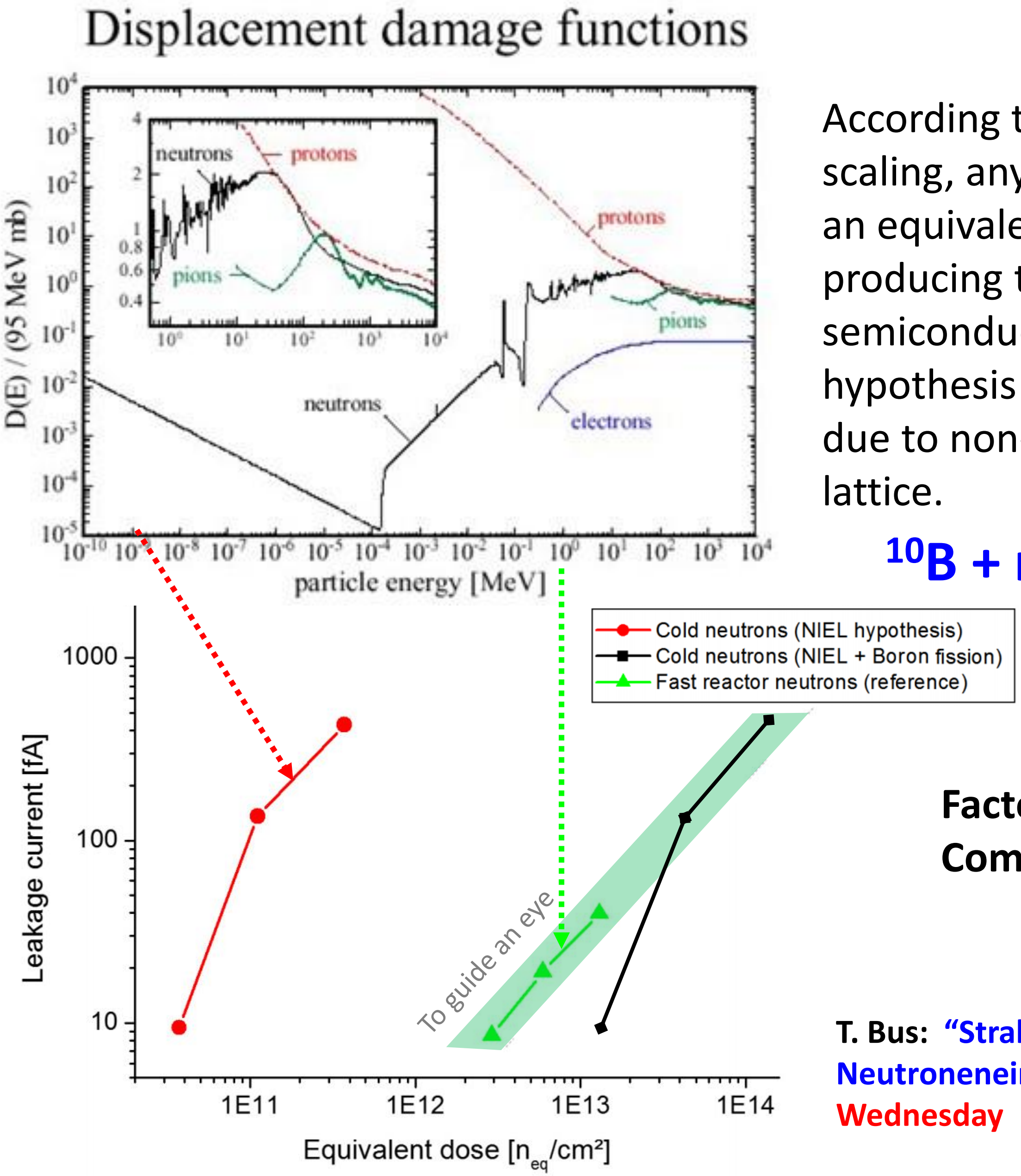

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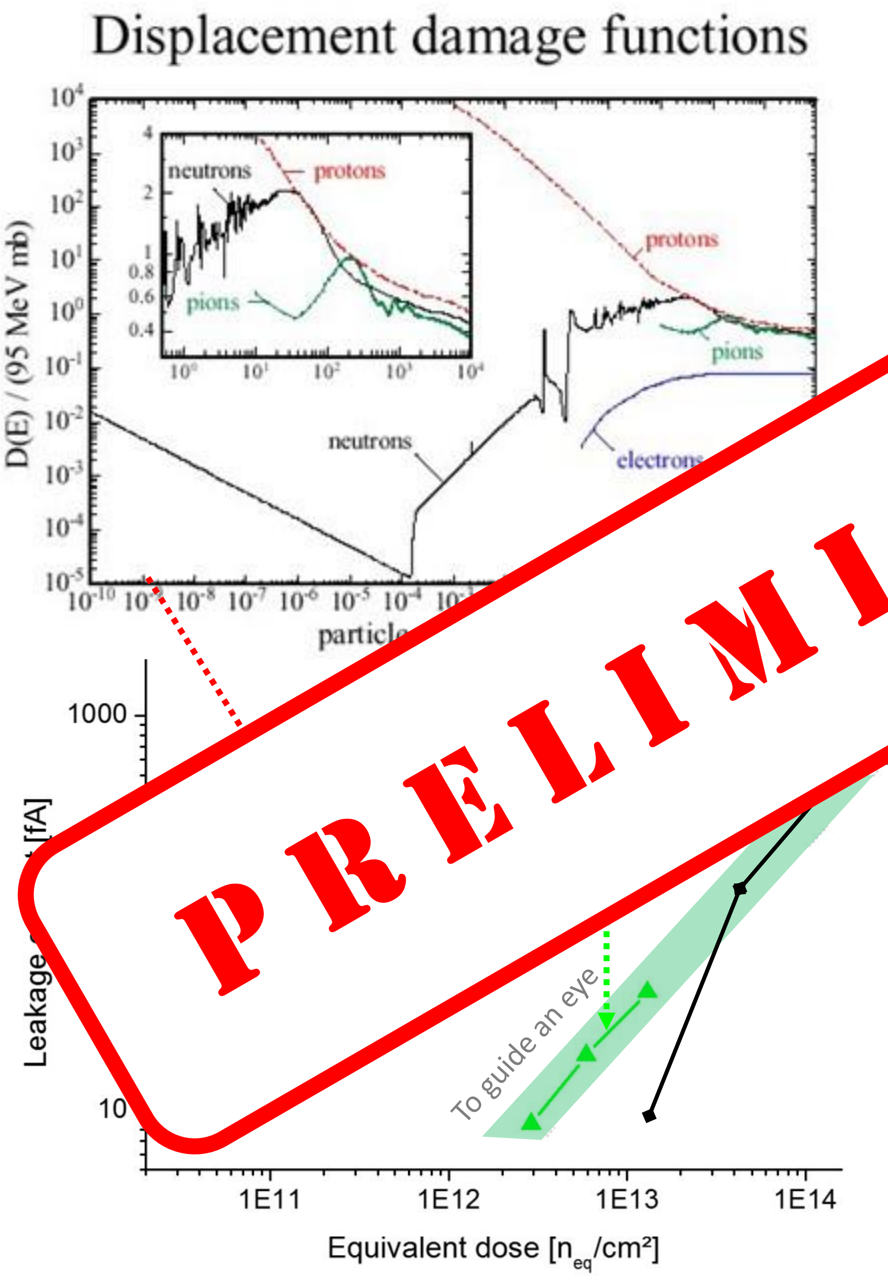
$^{10}B + n \Rightarrow Li + \alpha + 3MeV$

!

Factor of ~500 !!!
Compatible with P-doping of $10^{18}/cm^3$

T. Bus: "Strahlenschäden in dotiertem Silizium aufgrund Neutroneneinfangs Bor als Erweiterung des NIEL-Modells."
Wednesday 18:30 HK 45.49

On the NIEL scaling for low-energy neutrons



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... => Li + α +3MeV

!

...s)
...ron fission)
...s (reference)

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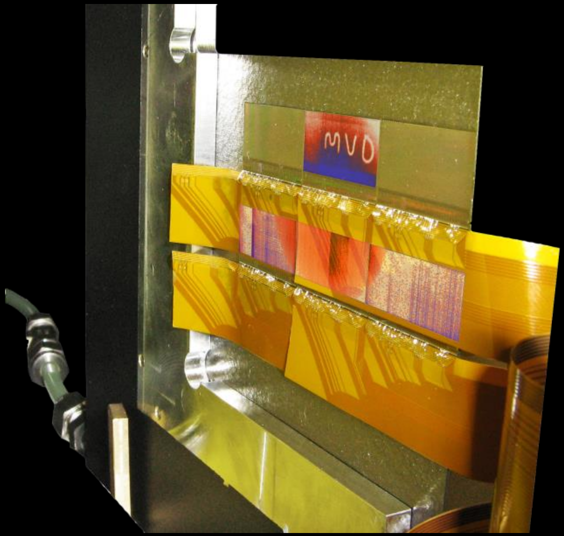


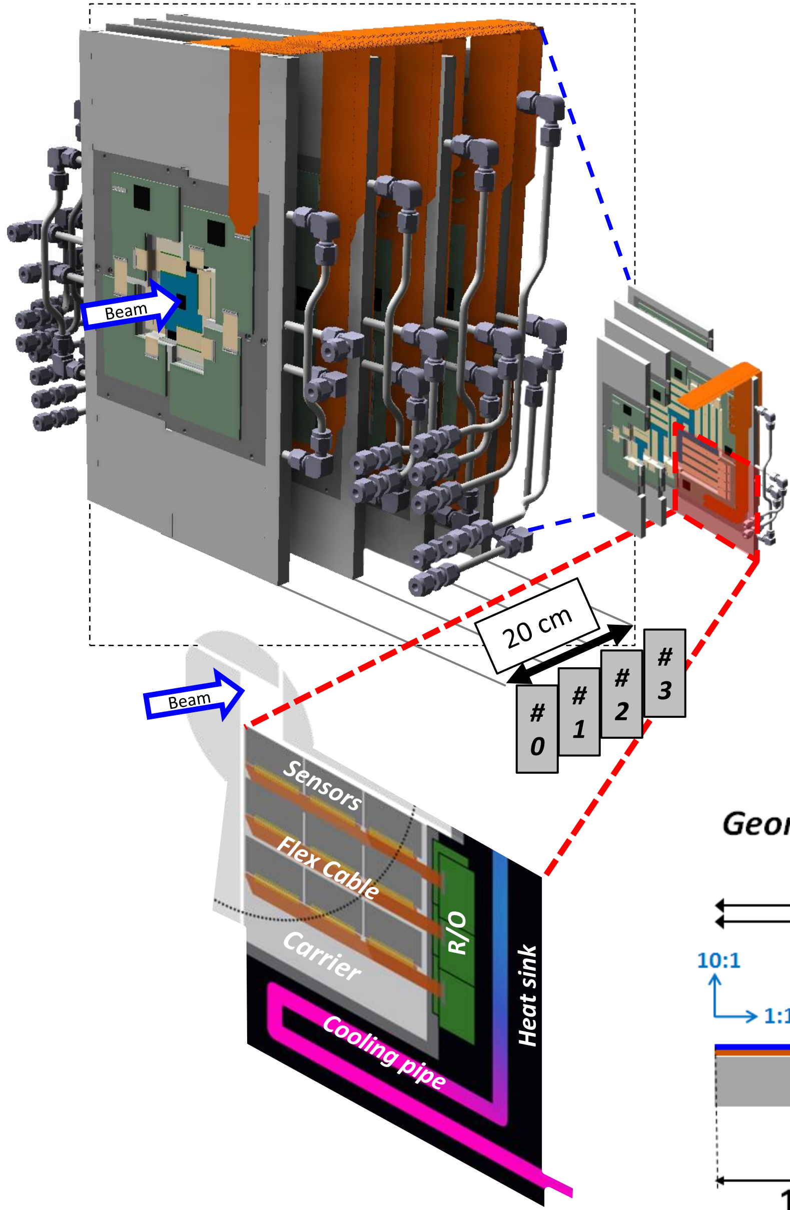
PRESTO Project

P. Klaus, M.Wiebusch et al., "Prototyping the read-out chain of the CBM Micro Vertex Detector"
Accepted for publication

M.Koziel et al., "Vacuum-Compatible, Ultra-Low Material Budget Micro Vertex Detector of the Compressed Baryonic Matter Experiment at FAIR"
In preparation

P. Klaus: "Thin and Reliable Connectivity for the CBM-MVD"
Thursday 18:00 HK 60.7

PRESTO: PREcursor of the Second sTatiOn



What's that ?

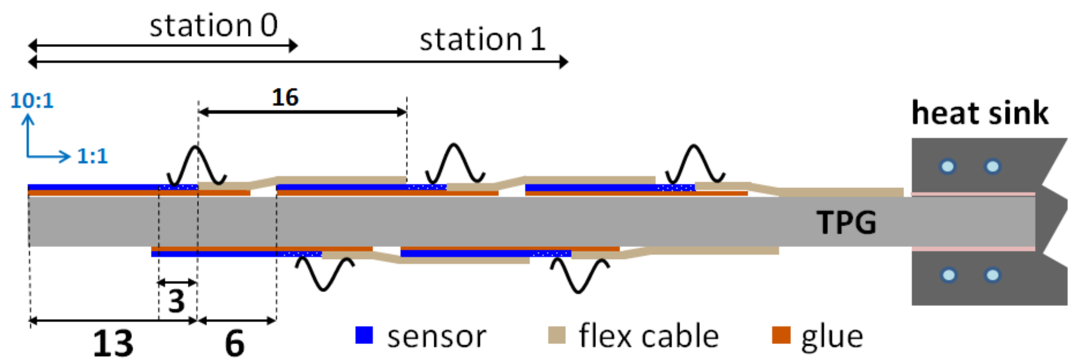
15 MIMOSA-26 sensors integrated on both sides of a 8 × 8 cm^2 350 µm thin TPG carrier

- 9 on the front in a 3 × 3 arrangement
- 6 sensors on the back in a 2 × 3 arrangement
- Support **size of MVD station #1**
- **Complexity ~ of MVD station #2**
- Sensors are connected with the DAQ system employing new flex cables (10 FPCs / PRESTO)

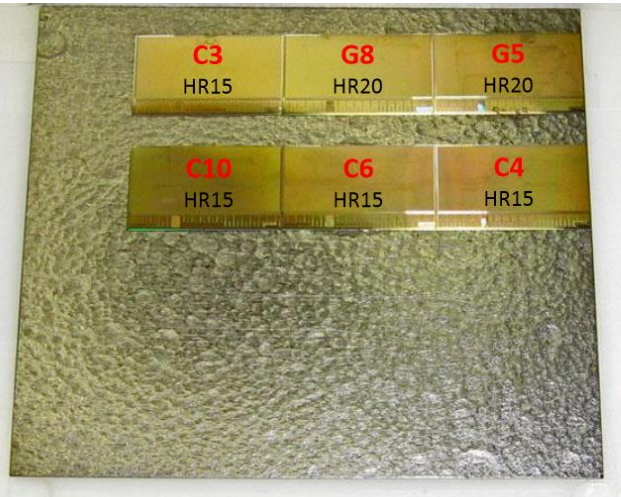
Motivation:

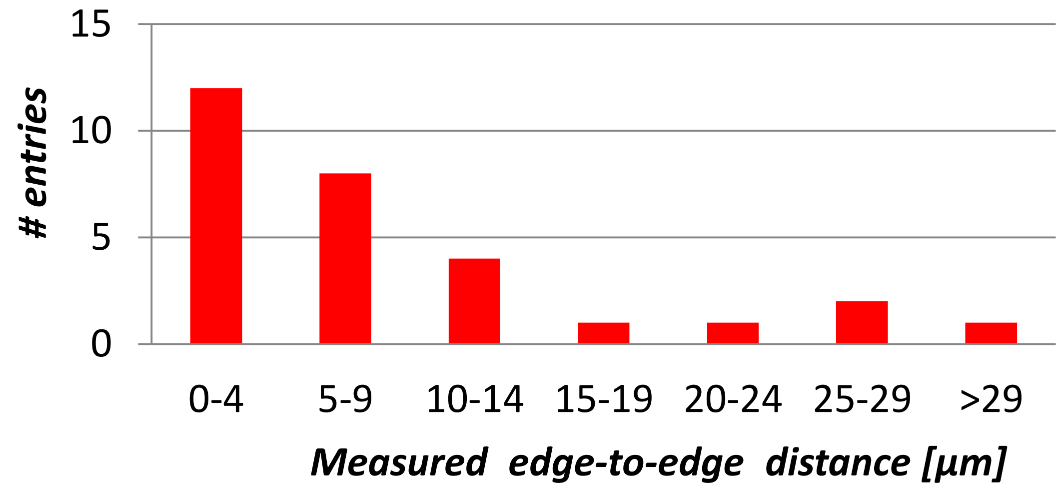
2nd phase of prototyping (1st step, station "0" oriented) aiming for 2-sided, vacuum compatible, quadrant integration.

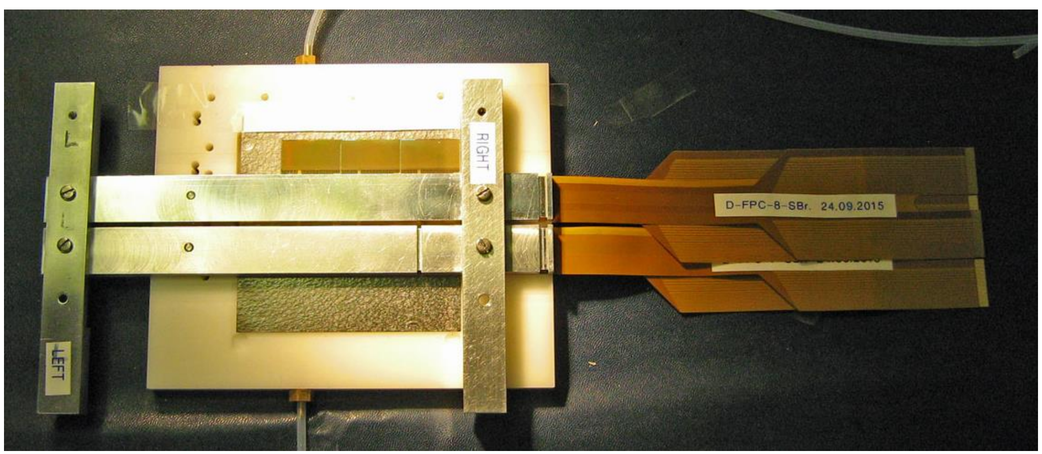
Geometrical acceptance:

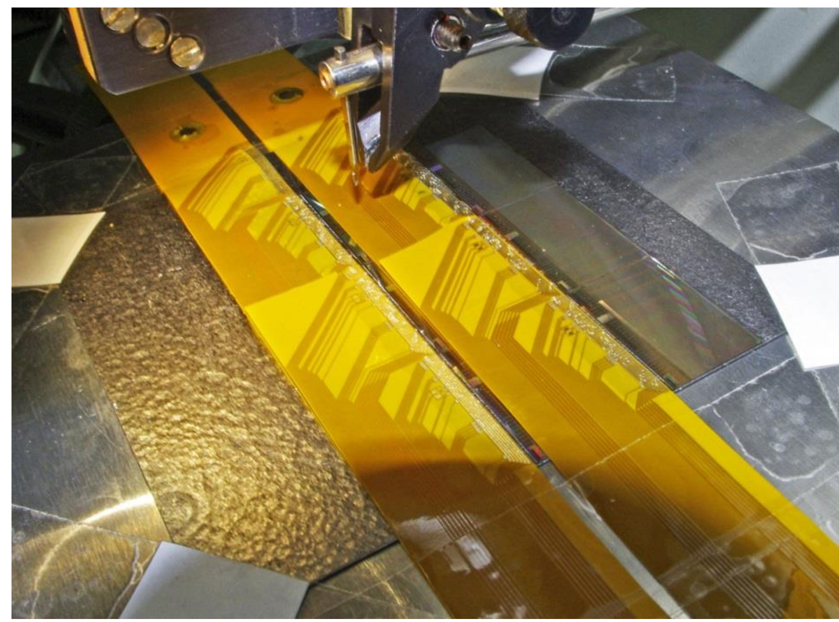


PRESTO: construction

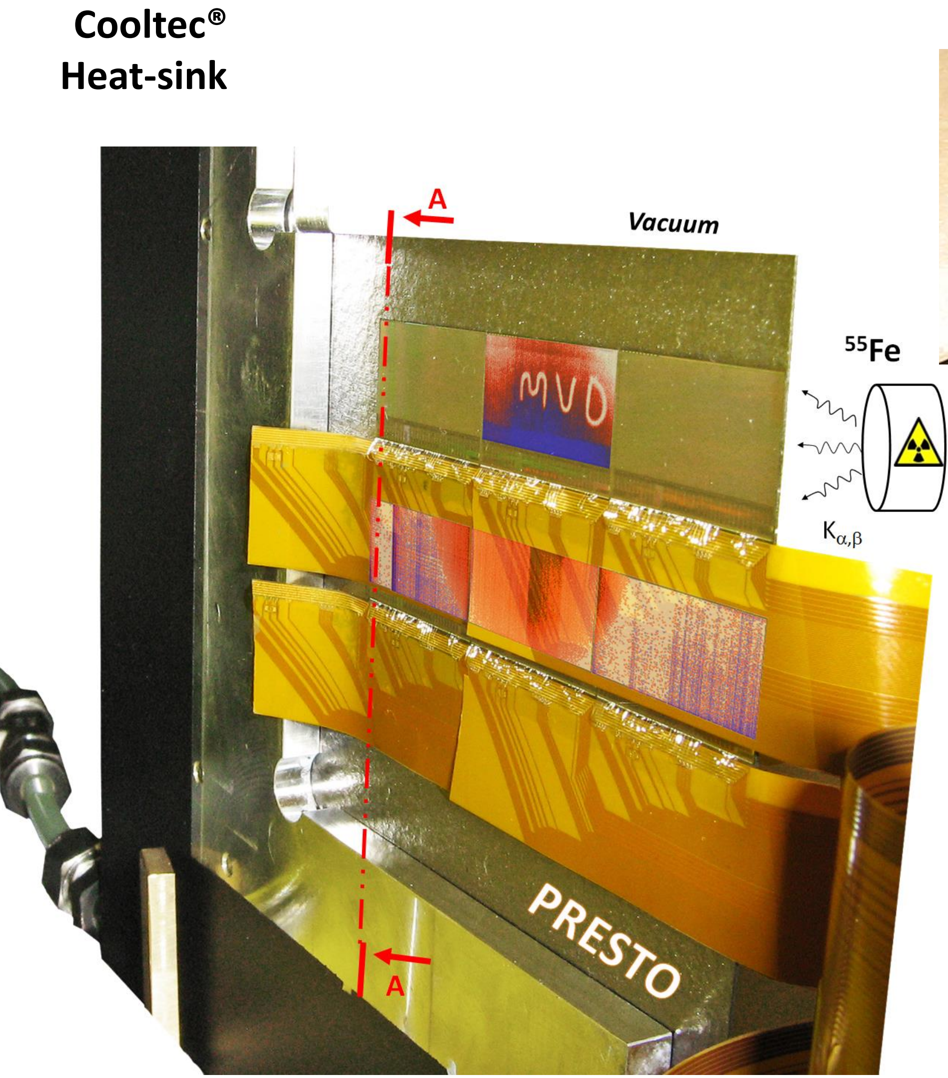


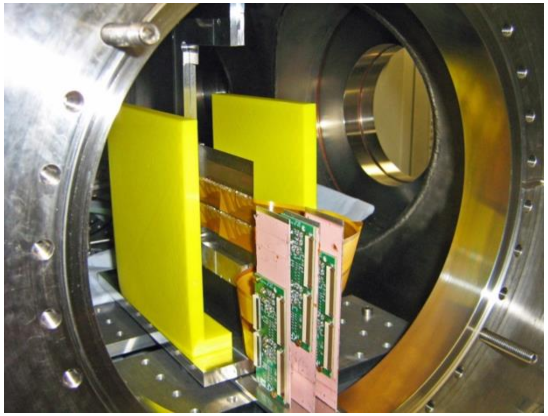


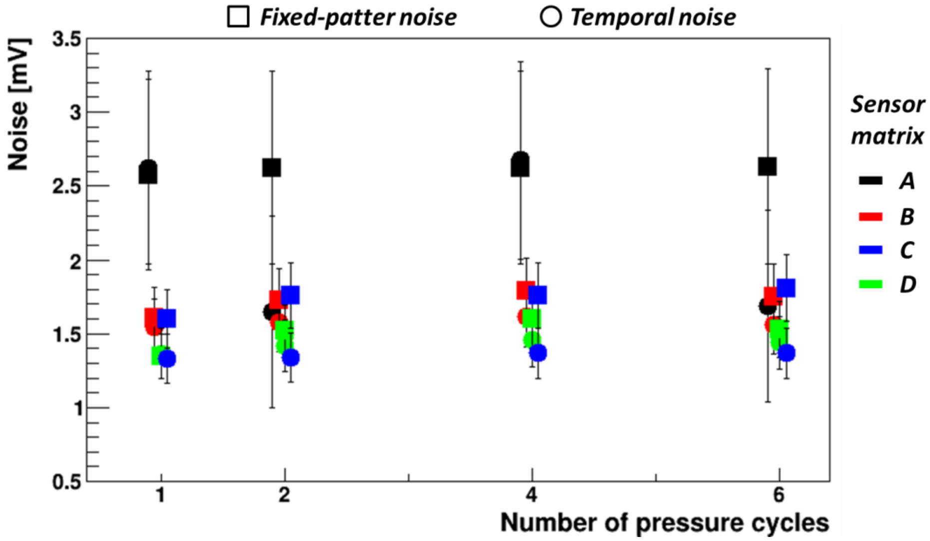




PRESTO: vacuum compatibility







No change in sensor performance after several pressure cycles (atmospheric – 10^{-4} mbar)

Accomplished MVD-related PhDs: 2015

Dennis Doering

"Untersuchungen zur Verbesserung
der Strahlenhärte von CMOS-Sensoren
zum Einsatz in Vertexdetektoren
von Schwerionenexperimenten."

Tobias Tischler

*"Mechanical Integration of the Micro
Vertex Detector for the CBM experiment."*

Borislav Milanovic

*"Development of the Readout Controller
for the CBM Micro Vertex Detector."*

SUMMARY:

Thank you for your attention…

- Wide range of activities towards the CBM-MVD
- PRESTO project
  - proves that one can built a vacuum compatible device based on a bare TPG carrier and employing ultra-thin, but industrial flex cable.
  - Construction of the second side is ongoing (last R&D step before MVD production)
- MVD: flexibility to adopt to physics case
- Sensors implemented in Jazz-Tower CMOS process seems to meet radiation tolerance requirements
- Technical specification of the MVD sensor in advance stage, synergy with other experiments, mainly STAR (running!) and ALICE upgrade