The Micro Vertex Detector of the CBM Experiment

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on behalf of the CBM-MVD Collaboration

September 1 2016 / Amfitrion I (Makedonia Palace)

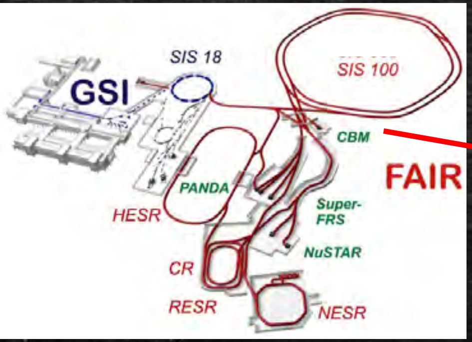
CONF12 - XIIth Quark Confinement and the Hadron Spectrum

Outline

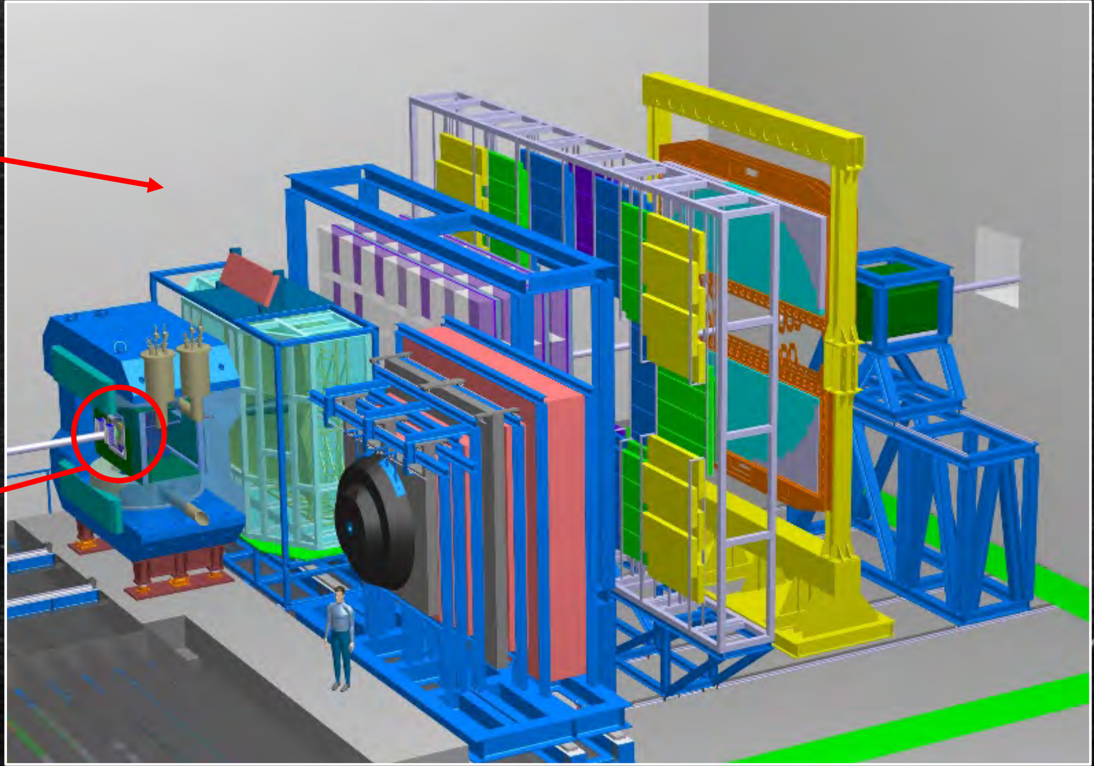
- Introduction
- Design of the MVD
- Status and Results of R&D
- Summary and Outlook

The Compressed Baryonic Matter Experiment and its Micro Vertex Detector

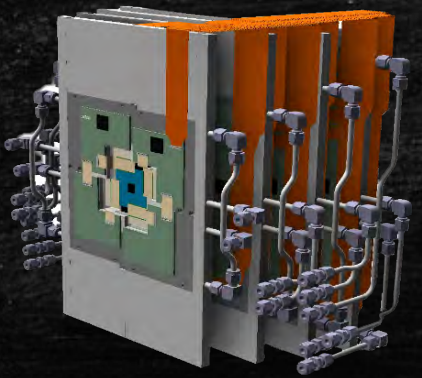
FAIR @ Darmstadt, Germany



The fixed-target CBM experiment

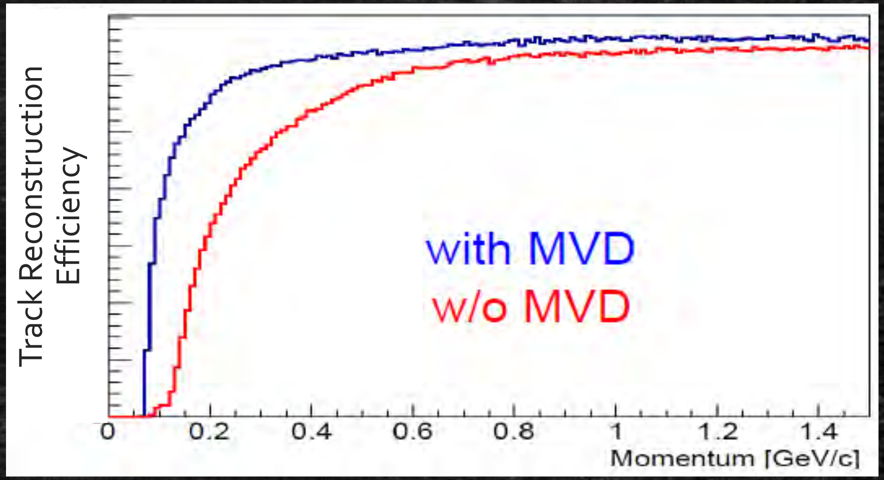


The CBM - MVD



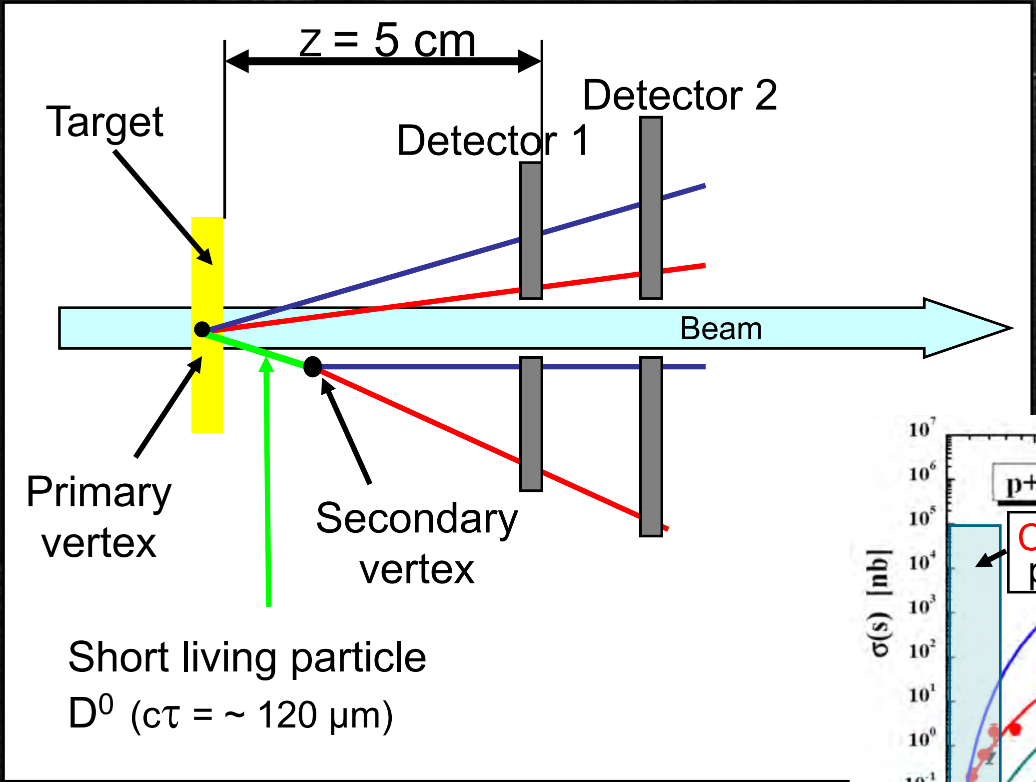
The Mission of the Micro Vertex Detector

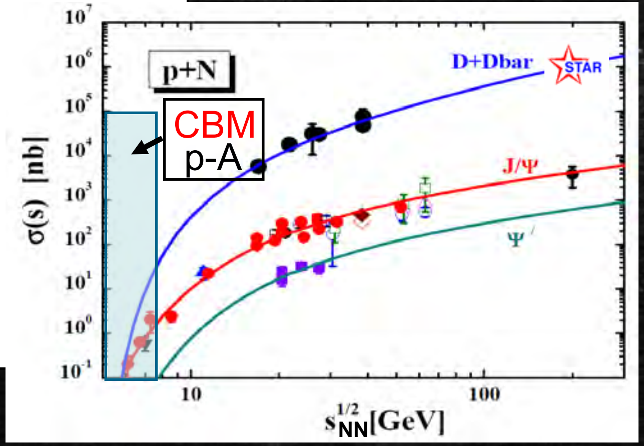
1) Reconstruction of open-charm particles in p-A collisions
2) Light vector mesons: Conversion pair suppression
3) Multi-strange particles and hyperons
4) Low momentum tracking



Design Considerations for the MVD

Design driven by open charm reconstruction (historically the primary mission):





Need excellent sec. vertex resolution (~ 50 μm)

- Very good spatial resolution (~ 5 μm)
- Very thin detector stations (avoid multiple scattering)
- Detector must run in target vacuum

Very rare probes:

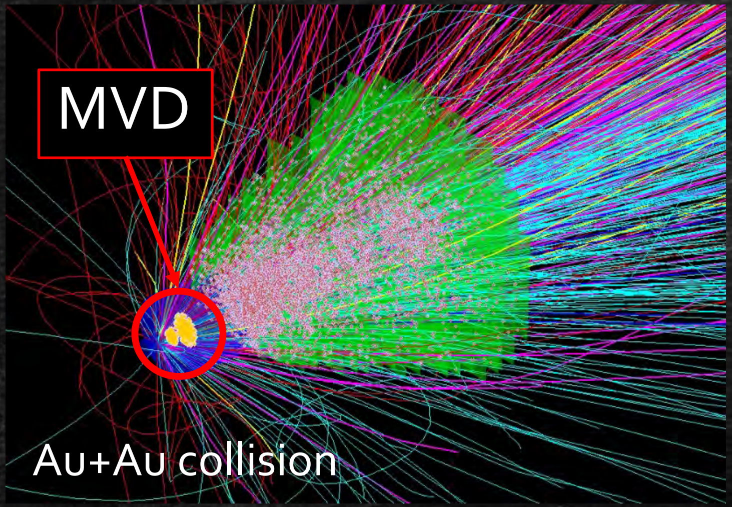
- High collision rate

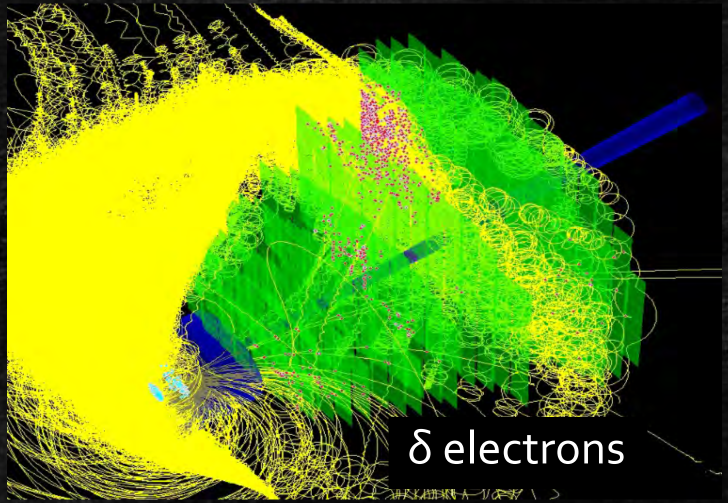
⇒ Good radiation hardness

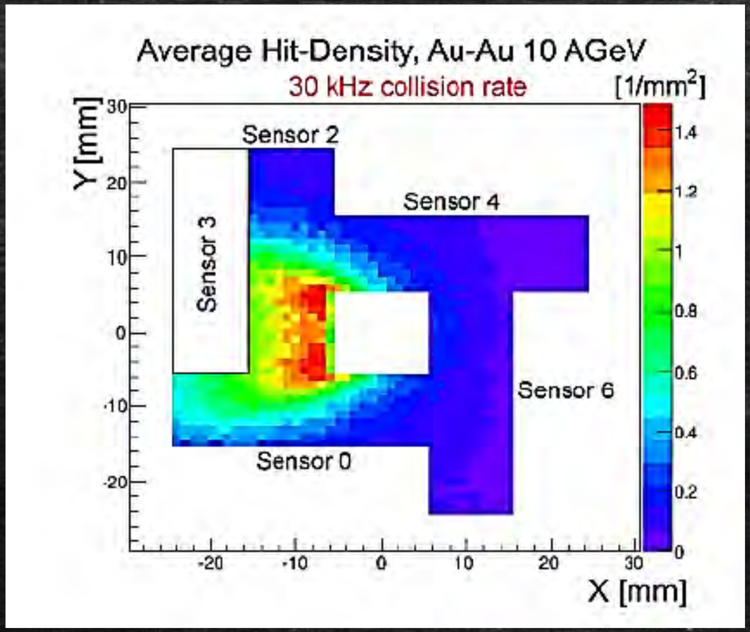
⇒ High rate capability

Need unique combination of high resolution and high rate.

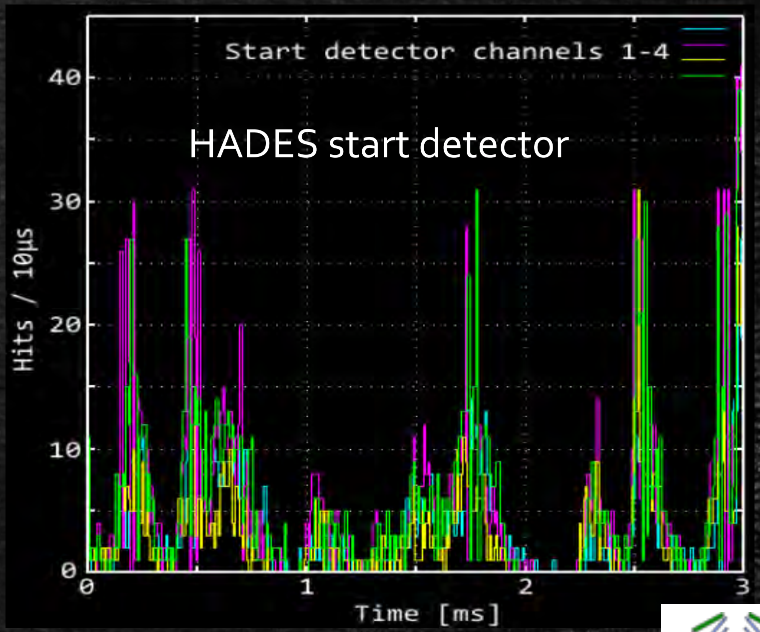
Requirements: Rates and Radiation







Rates at first station (10% peak rate)



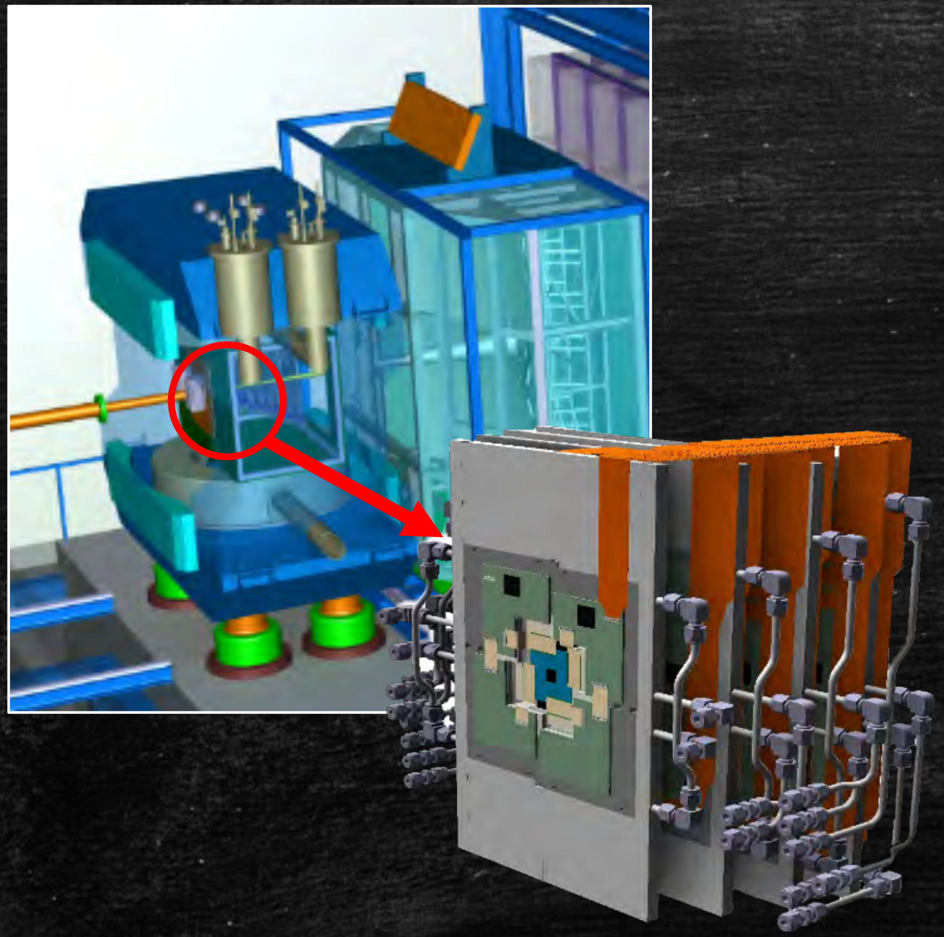
Beam fluctuations @SIS18

Hit rate: 7.5 x 10^7 hits/cm² (peak)
Radiation damage (per run):
~ 3 x 10^{13} n_{eq}/cm²
~ 3 Mrad

~ 10 times higher than ALICE ITS

→ need for dedicated sensor

MVD - Fundamental Design Idea



Aim for high **collision rate capability**

⇒ 10^5 Au+Au collisions per second

⇒ 10^7 p-A collisions per second

Aim to **contribute to tracking**

⇒ 4 planar detector stations

Aim for **good sec. vertex resolution**

⇒ Operate in target vacuum

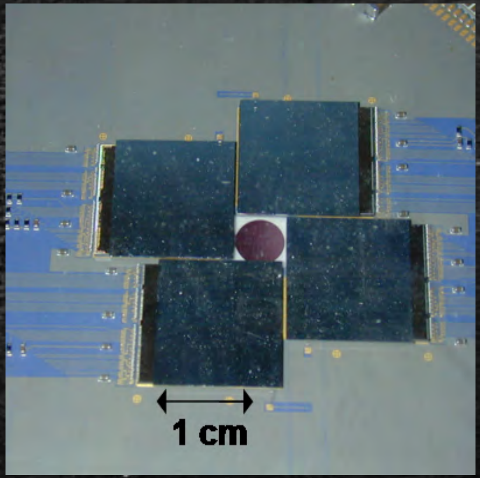
⇒ First station 5 cm from target

⇒ Silicon pixel (~ 5 µm resolution)

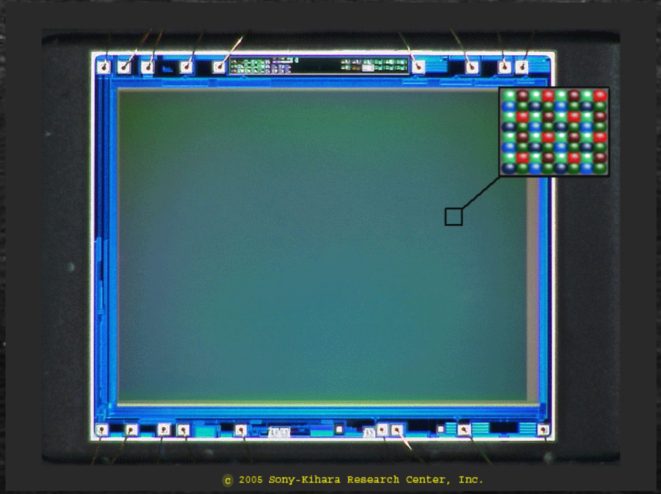
⇒ Thin stations

- ~ 0.3 % X_0 (first station)
- ~ 0.5 % X_0 (other stations)

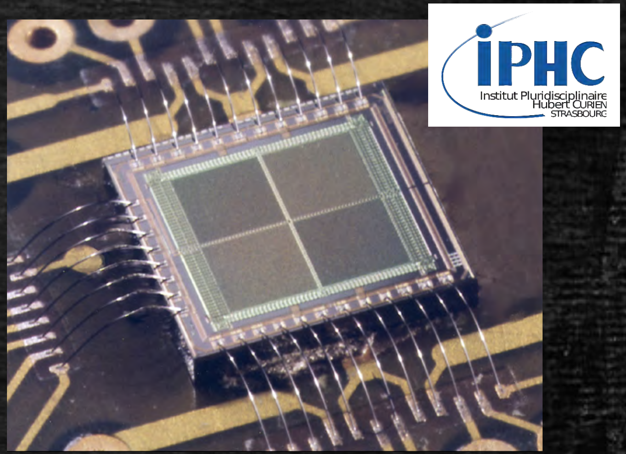
Sensor Technology Choice



Hybrid pixels



CCD

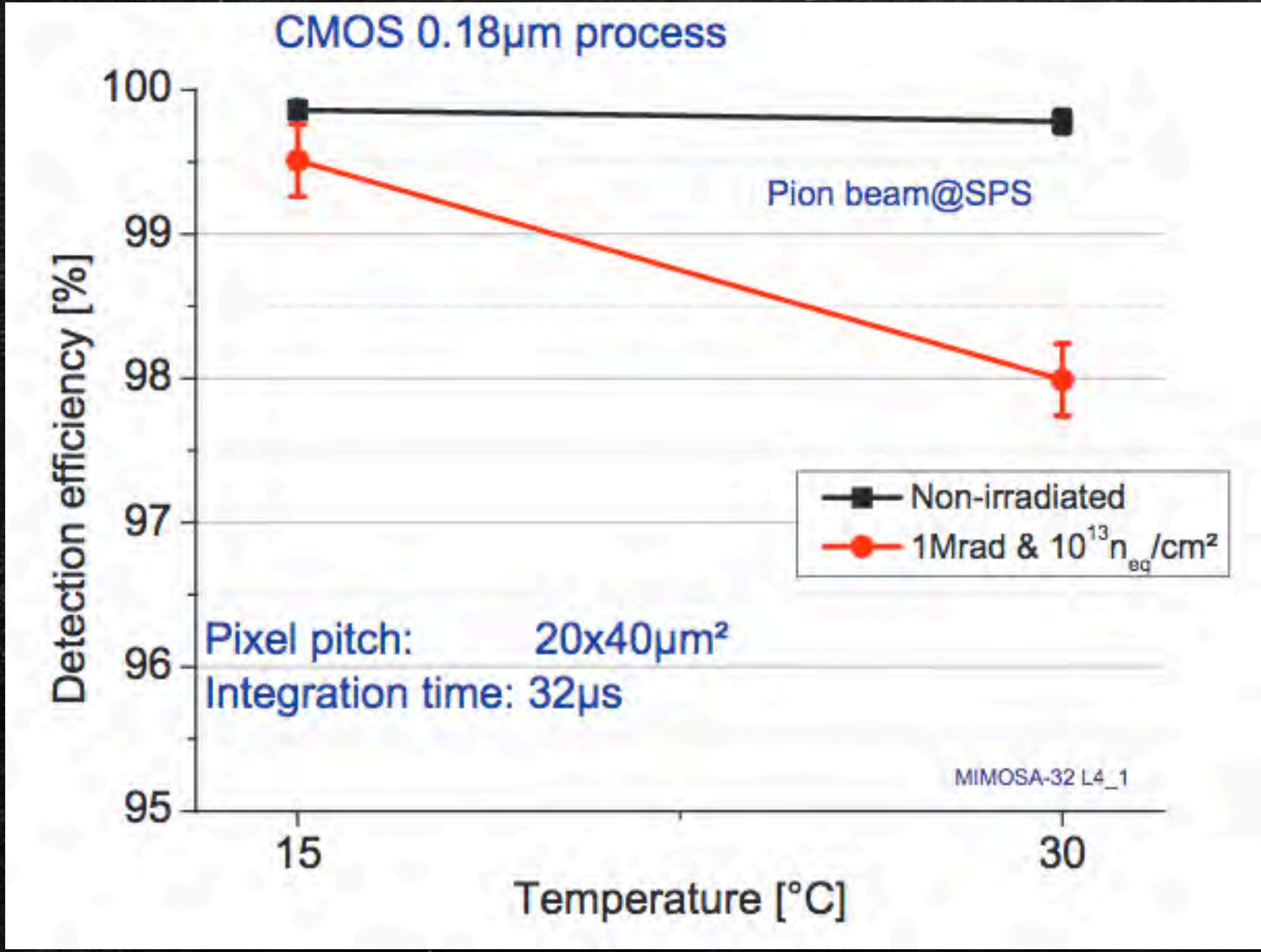


CMOS (MAPS)

Topic	CBM wish list	Hybrid Pixels	CCD	CMOS PS (MAPS) 2003
Single point resolution	~ 5 µm	~ 30 µm	~ 5 µm	1.5 µm
Material budget	Few 0.1 % X_0	~ 1 % X_0	~ 0.1 % X_0	~ 0.1 % X_0
Time resolution	~ 10 µs	~ 25 ns	~ 100 µs*	~ 1 ms
Radiation hardness	~ 10^{15} n_{eq}/cm^2	> $10^{14} n_{eq}$	~ 10^{10} n_{eq}*	~ 10^{12} n_{eq}

CMOS Pixel Sensors (MAPS): the most promising sensor technology in 2003

Sensor R&D Progress With CMOS PS (MAPS)



Progress made possible by

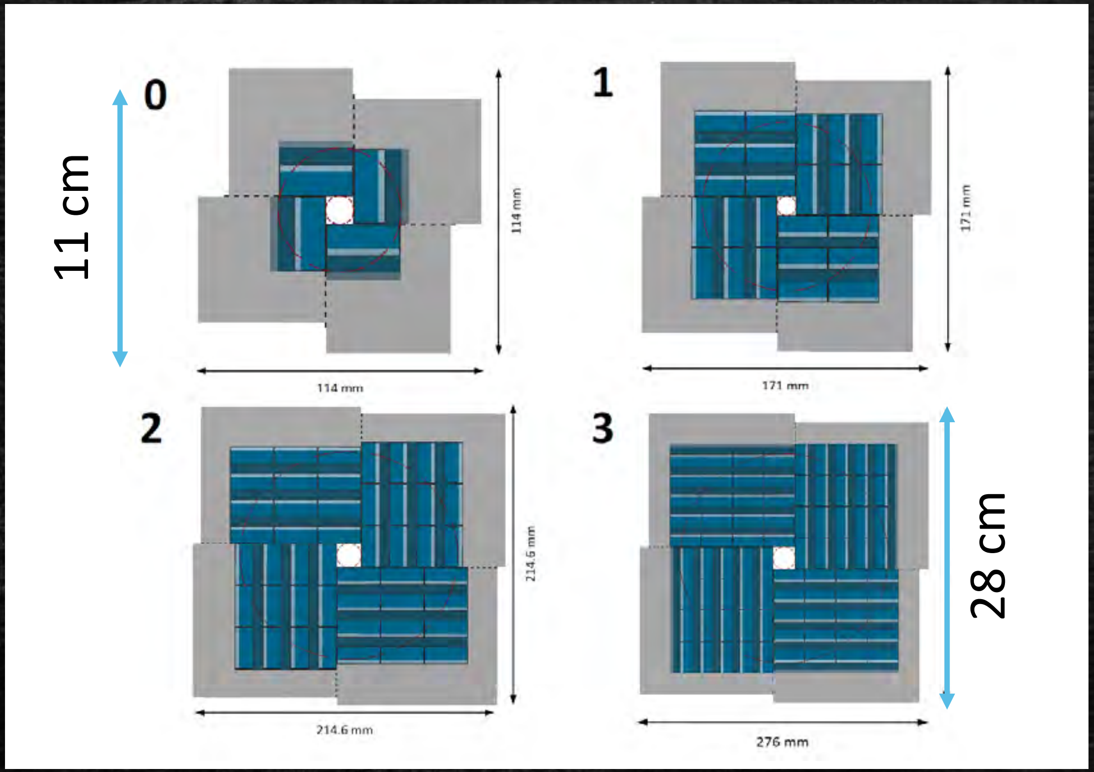
- Hi-Resistivity EPI Layer
- Newer 180 nm TowerJazz CMOS chip production process
- Cooling mandatory for rad.hard.

CMOS (MAPS) used in science so far:

EUDET STAR ALICE NA61/SHINE

The requirements of CBM can be reached using CMOS PS (MAPS) sensors.

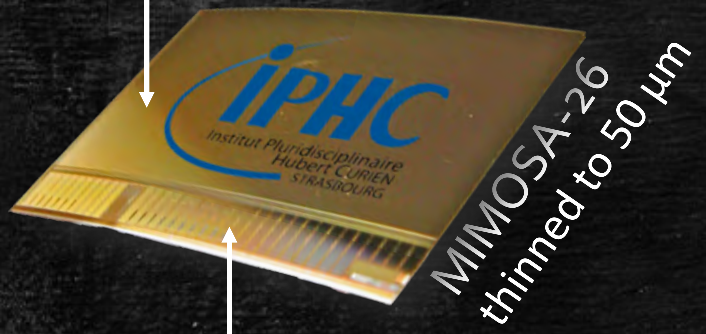
Detector Stations



- Total number of four stations
- No. of sensors per station:
  8 / 40 / 84 / 160
- Front- and back side equipped with sensors
- Carrier material (grey):
  - CVD diamond (first two stations)
  - TPG (next two stations)

Detector Composition and Integration

Sensing matrix
- 18.4 x 18.4 µm² pixel pitch
- 1152 x 576 pixel
- 119.2 µs integration time



Read-out area w/ integrated DAQ
- Threshold Voltages
- Signal discrimination
- Digital data pre-processing
- Slow control

Detector Composition/ Cross Section:

Holding structure to evacuate heat (no air cooling in vacuum)

Passive part of sensors covered by opposite sensor

Very thin cables power and steer sensors

Prototyping Timeline

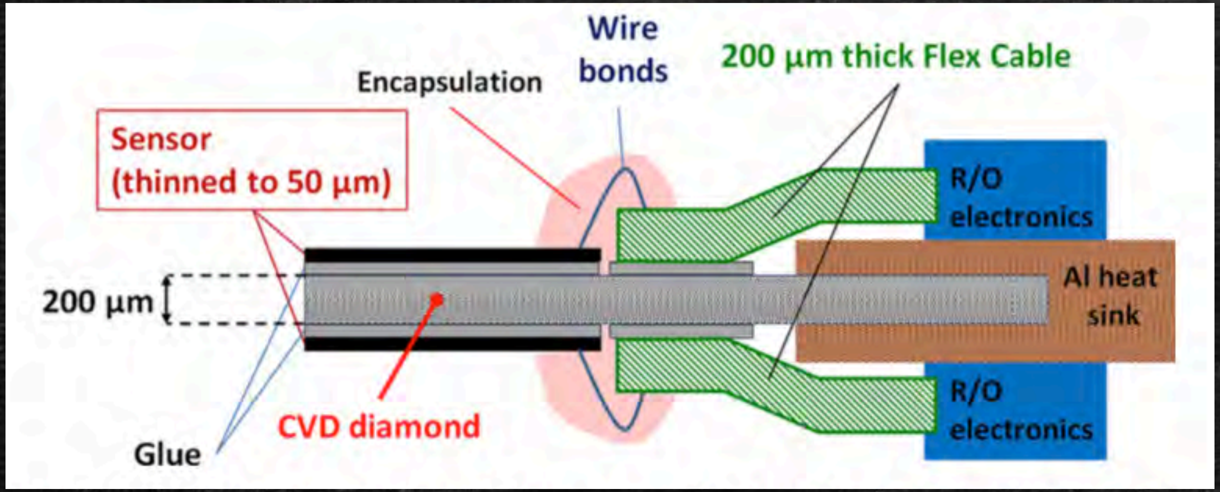
2009
"MVD Demonstrator"
4 x Mimosa-20 on
TPG-RVC sandwich

2012
"MVD Prototype"
4x Mimosa-26 on
CVD diamond

2015
"PRESTO" Precursor of
the Second Station on
bare TPG

Design Validation: Prototype 2012

Prototype cross section



Tested at CERN –SPS with π^- beam

Validated concepts:

- Double-sided integration
- Low material budget w/ thinned sensors
- Bonding technology to connect the sensors
- CVD diamond as carrier material

Important design choices validated ✓

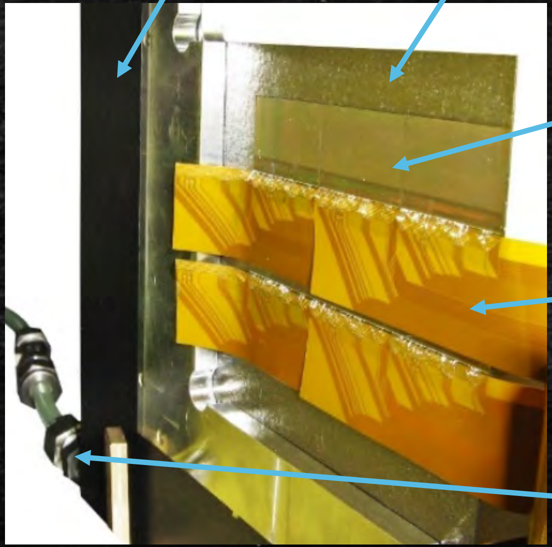
M. Koziel, et al., Nuclear Instruments & Methods in Physics Research A (2013) http://dx.doi.org/10.1016/j.nima.2013.07.041

Design Validation: PRESTO 2015

„PRESTO" – PREcursor of the Second sTatiOn

Liquid cooled Al-heat sink (easy unless you have to do it)

TPG holding structure,
high heat conductivity, low Z
(test thermal management)



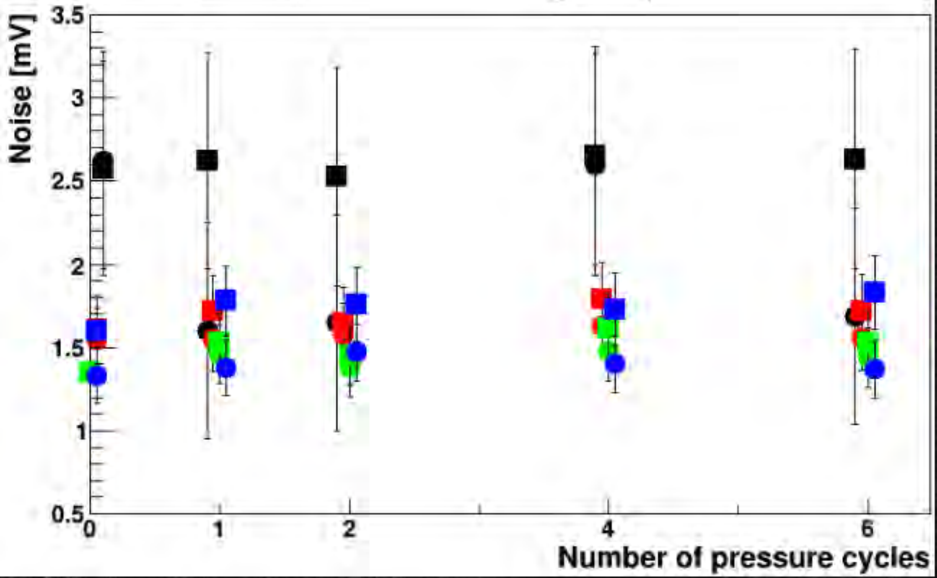
50µm thin MIMOSA-26 sensor prototypes
(test placing, bonding, gluing)

Micro cables
(test data transmission, noise etc)

Vacuum compatible coolant pipes

PRESTO – Results Vacuum

„PRESTO" – PREcursor of the Second sTatiOn

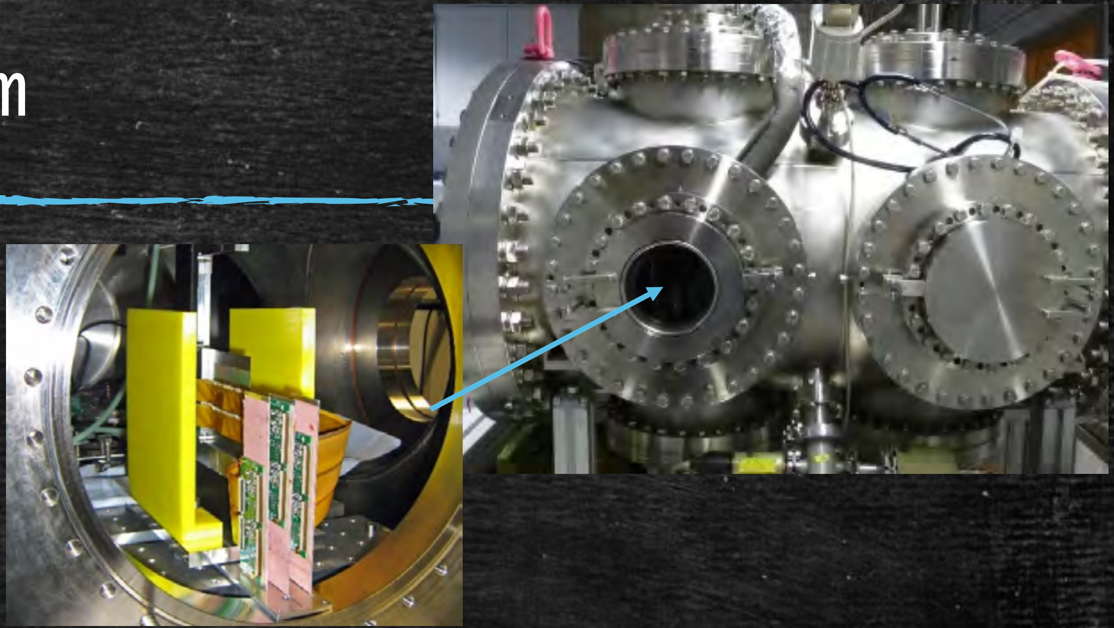


Sensor Section (Bank):

- *A*
- *B*
- *C*
- *D*

○ Temporal noise

□ Fixed-pattern noise



- Successful operation of the sensors in vacuum
- Gluing method with radiation hard glue demonstrated to be vacuum compatible

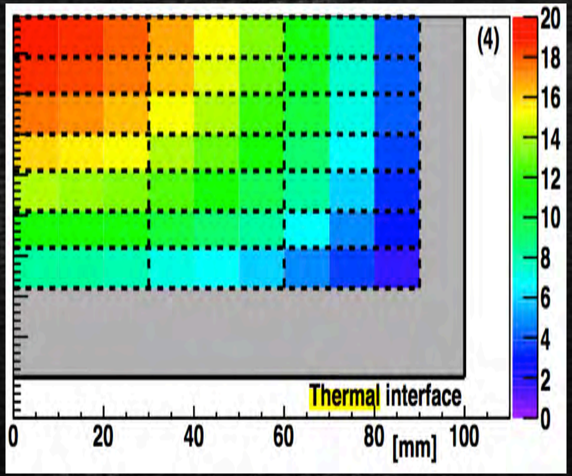
- **Vacuum Suitability and Compatibility ✓**
  No performance loss observed after several pressure cycles @ 10^{-4} mbar

M. Koziel, et al., Nuclear Instruments & Methods in Physics Research A (2016) http://dx.doi.org/10.1016/j. nima.2016.05.093

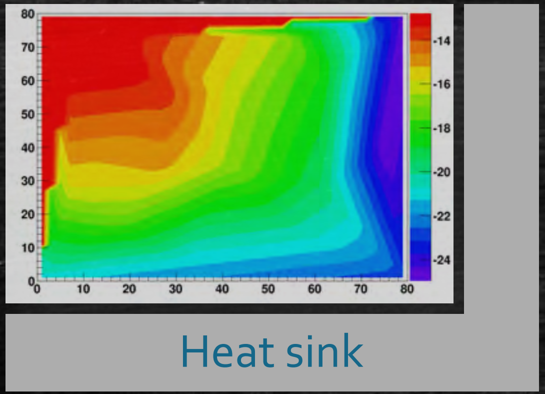
PRESTO – Results Cooling

„PRESTO" – PREcursor of the Second sTatiOn

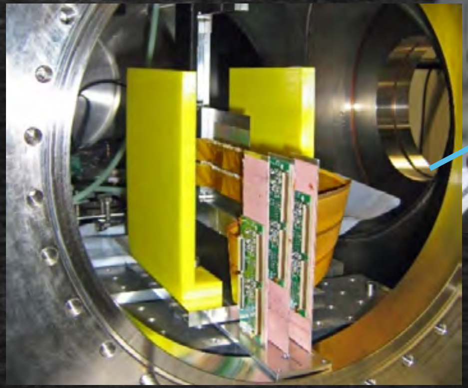
Simulation

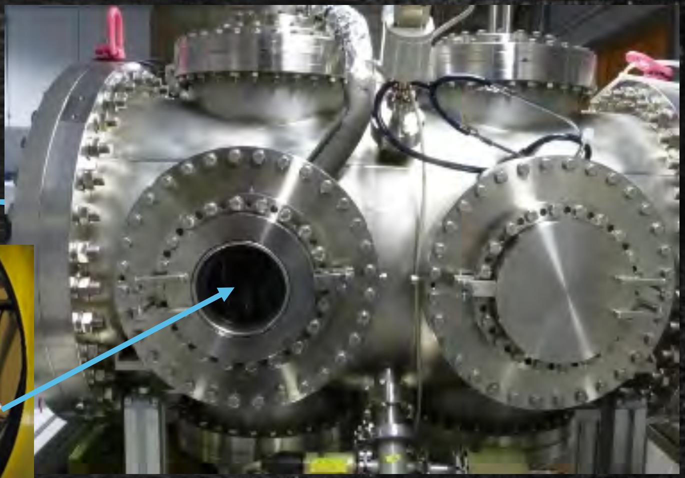


Measurement (Pt100 sensors)



The gradients are in good agreement





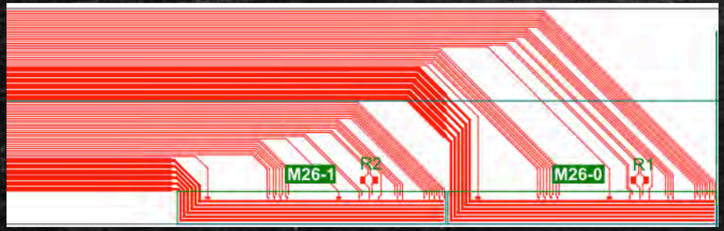
Our cooling system Huber CC-405 can provide temperatures from - 50 °C to 30 °C

- Our prior thermal simulations were verified by our measurements .
- CVD diamond & TPG were validated as suitable carrier materials.

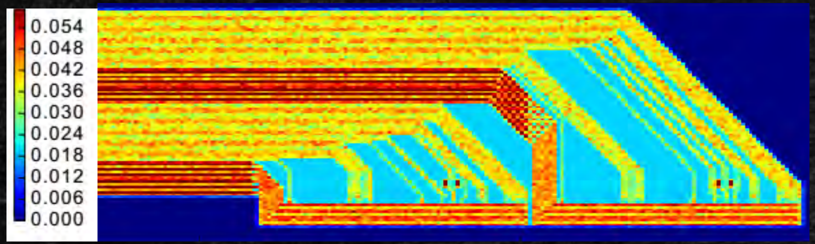
The performance is very promising. A thermal mockup system for the entire MVD is planned.

Material Budget Simulation: Cables

Crucial contribution to material: cables
=> need precise simulation model



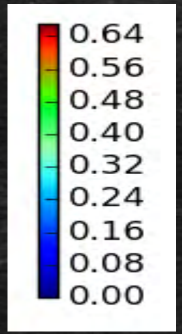
1) Design cable



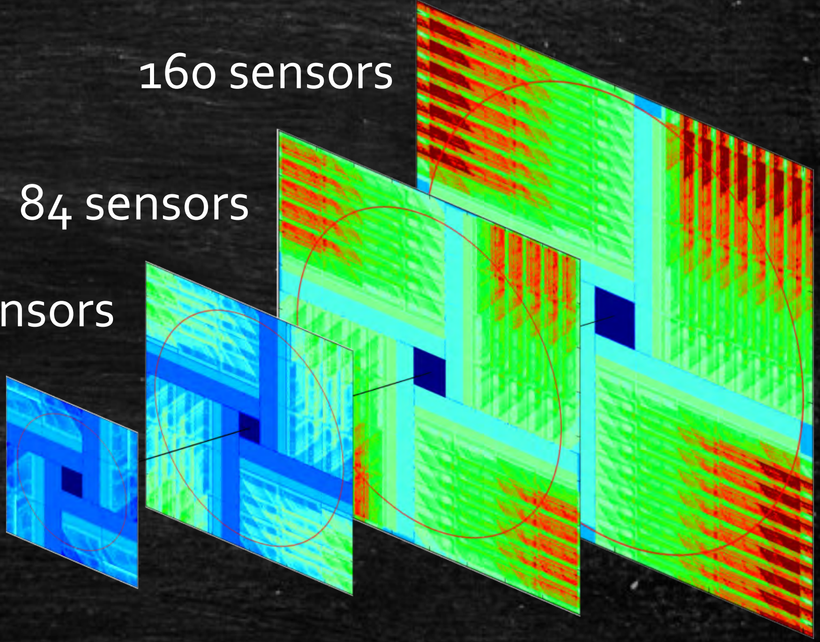
2) Create Simulation

3) Combine with full detector CAD model

x/X_0 [%]



Blue ≤ 0.3 X_0 (goal 1st station)
Green ≤ 0.5 X_0 (goal other stations)

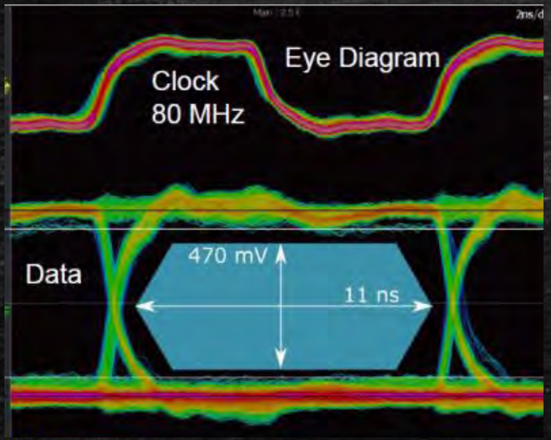


Detailed material simulation

Requirements met with copper technology (locally +20% => OK)

Data Acquisition and Front-End Electronics

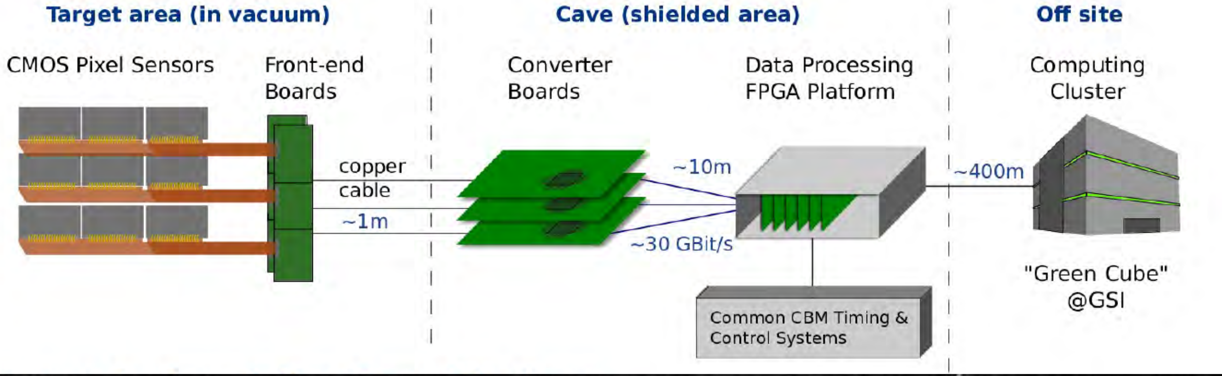
Reliable digital transmission



via the ultra-thin single-layer FPC cable

Precursor Implementation / Current Hardware

Schematic Representation of the Full MVD Read-out Chain



Read-out chain thoroughly tested and continuously updated

P. Klaus, et al., Journal of Instrumentation, Volume 11, March 2016 DOI: 10.1088/1748-0221/11/03/C03046

JINST

Summary & Conclusion

The CBM-MVD will help reconstructing rare probes

Requirements:
- Outstanding vertex resolution
  - ⇒ Low material budget
  - ⇒ excellent spatial resolution
  - ⇒ Vacuum operation
- Extreme rate capability
  - ⇒ Outstanding count rates
  - ⇒ High radiation tolerance

Concept:
- Dedicated CMOS - MAPS
- Cooling by heat conduction
- Ultra light cables

Status:
- Sensor R&D with IPHC on good track ✓
- Integration concept validated with our prototypes:
  - Material budget ✓
  - Vacuum operation and cooling ✓
  - Sensor integration ✓
  - Sensor readout ✓

Feasibility demonstrated with three generations of prototypes.

The CBM-MVD Collaboration

- AG Prof. Dr. Joachim Stroth (Goethe University FFM)

Group of Prof. Marc Winter (IPHC Strasbourg)

iPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

Tobias Bus, Michael Wiebusch, Erik Krebs, **Joachim Stroth**, Christian Müntz
Gisa Kretzschmar, Philipp Klaus, Dennis Doering, Benjamin Linnik, Samir Amar-Youcef
Qiyan Li, Michal Koziel, Michael Deveaux, Tobias Tischler, Philipp Sitzmann
Not present: Jan Michel

Thank you for your attention!