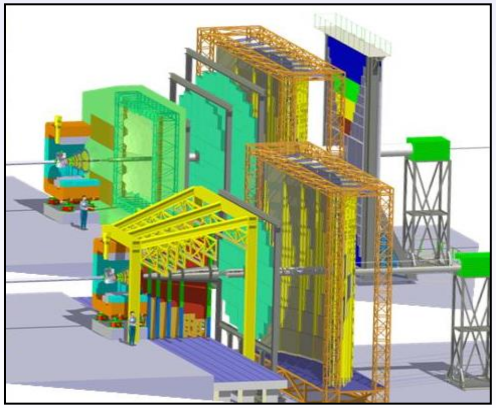
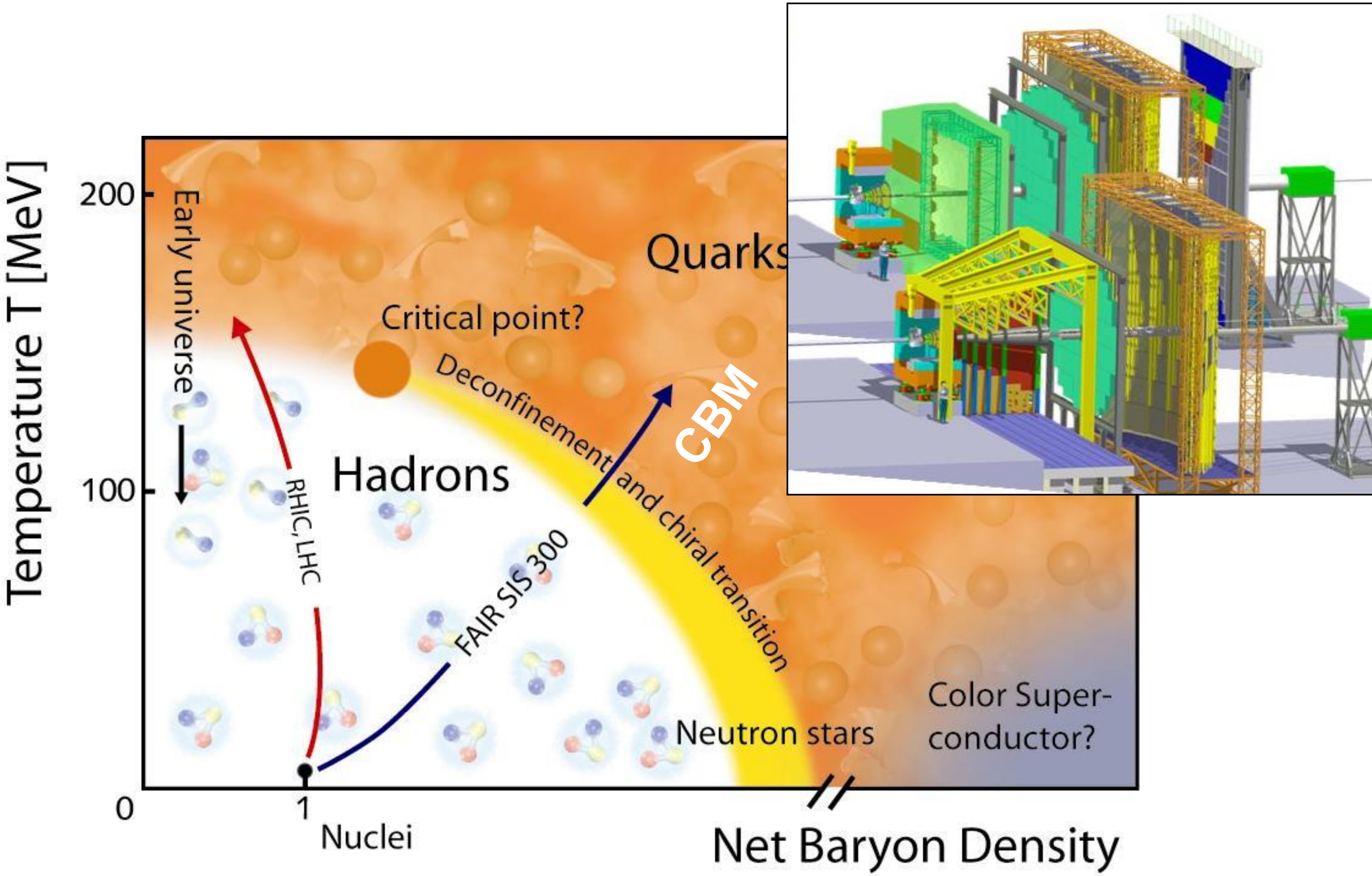
The silicon detector systems of the Compressed Baryonic Matter Experiment at FAIR

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



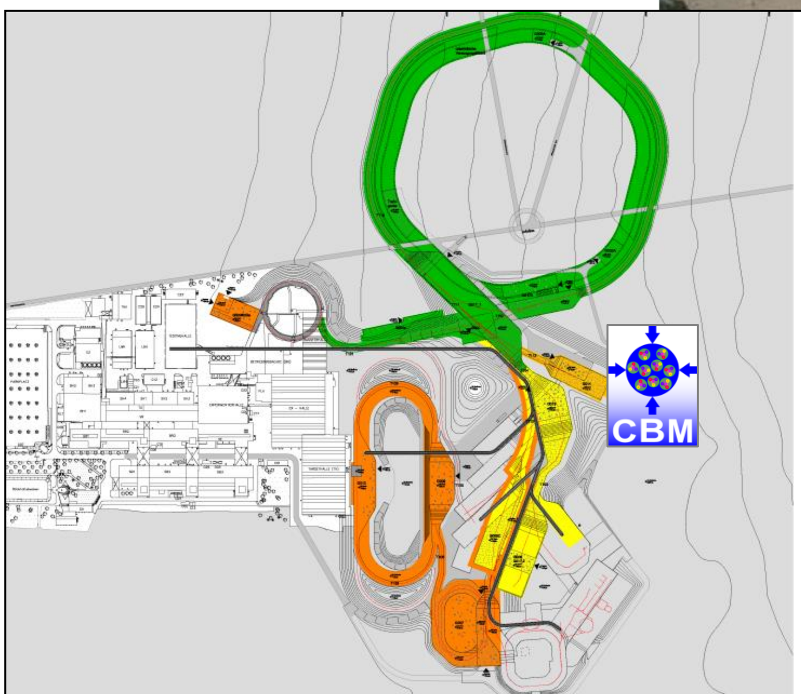
What is CBM?



CBM is a heavy ion experiment to scan the phase diagram of hadronic matter for phase transitions and much more…

Realization of FAIR

Facility for Anti-Proton and Ion Research, former GSI, Darmstadt



civil construction started 2012
commissioning: 2018

The strategy of CBM

Poor theory guidance, physics signatures not clear
=> Build “universal detector” as known from LHC

Hadron spectrometer

Di-Electron spectrometer

Di-Muon spectrometer

@ SPS (40-156 AGeV)

Universal detector

@ FAIR (10-40 AGeV)

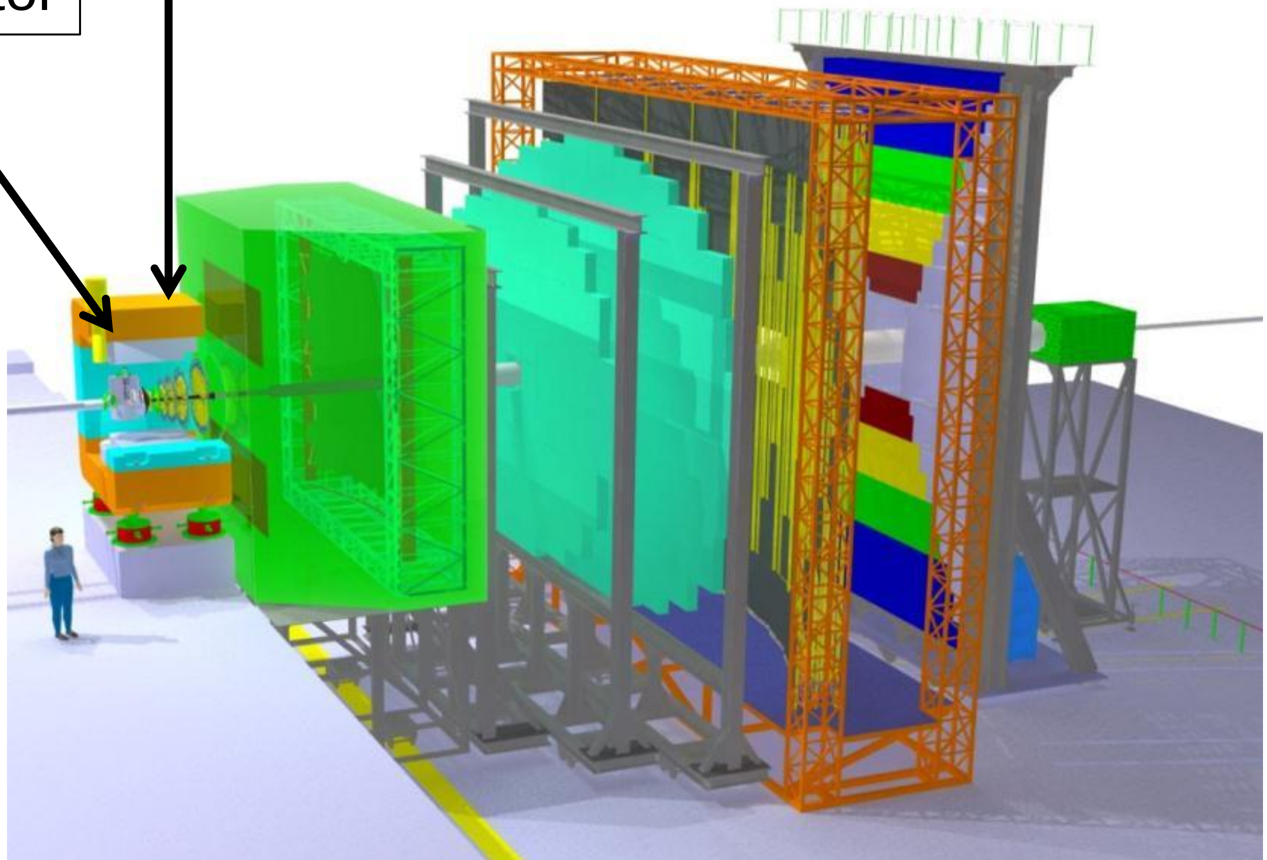
- ✓ Intrinsically retundant => May spot systematic errors
- ✓ Comparable measurements => Eases physics interpretation
- ✓ Complementary to SPS, RHIC, LHC experiments

Hadron Spectrometer

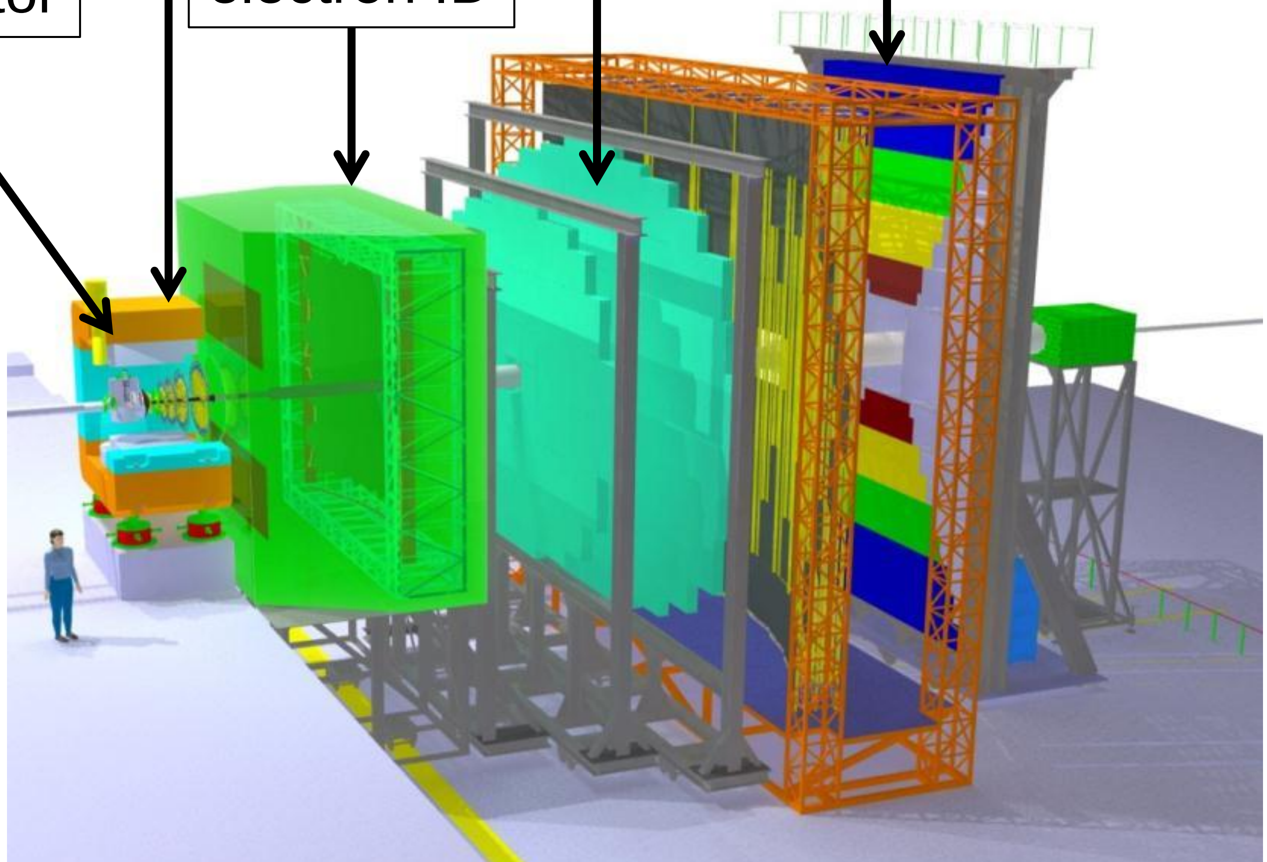
STS Strip Tracker

TOF Hadron ID

MVD Pixel Vtx Detector



Electron Spectrometer



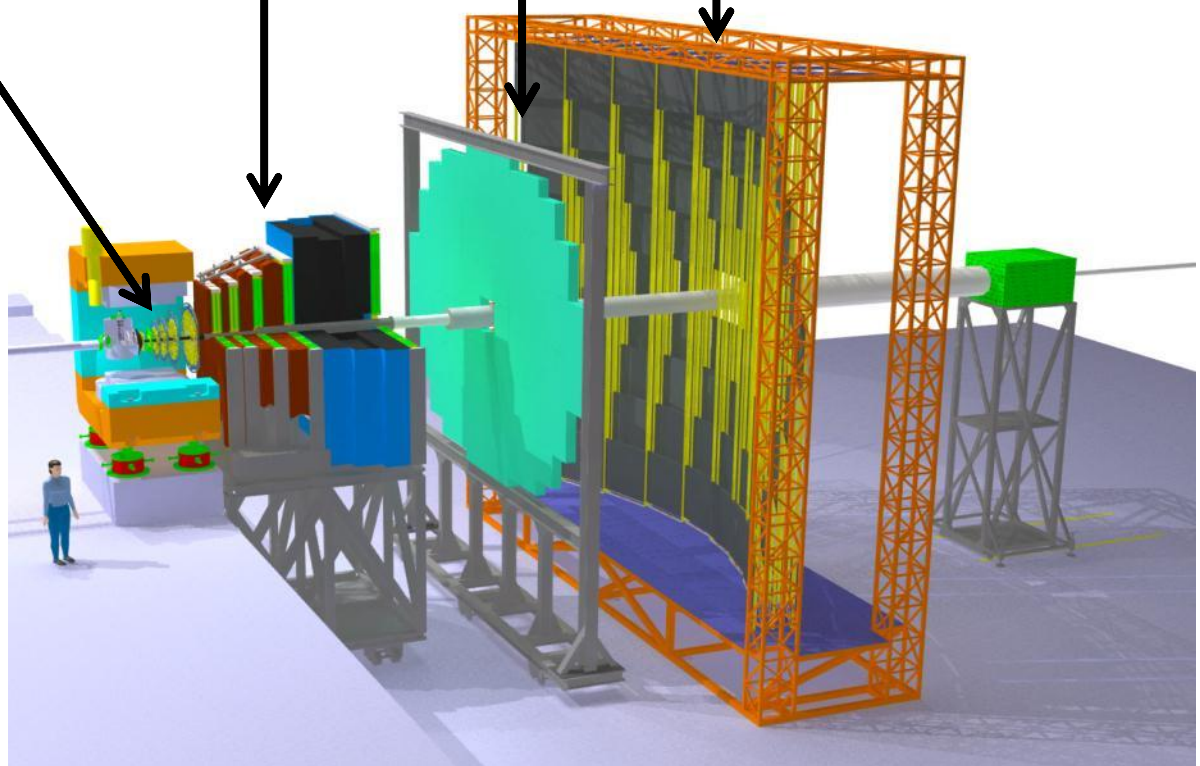
Muon Spectrometer

TRD, tracking

STS Strip Tracker

MUCH, CMS like instrumented hadron absorber

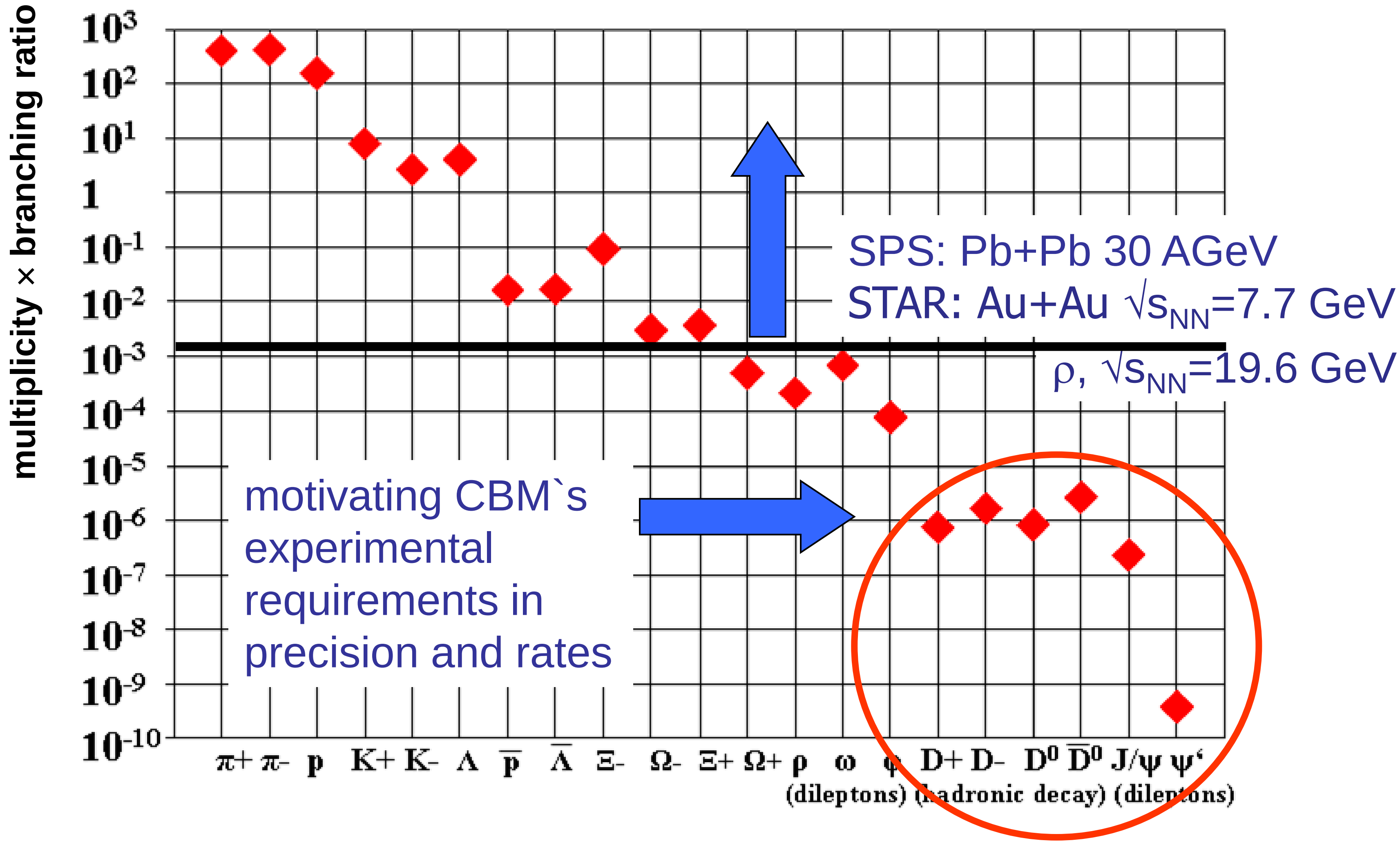
TOF – Fast hadron rejection



The measurement challenge

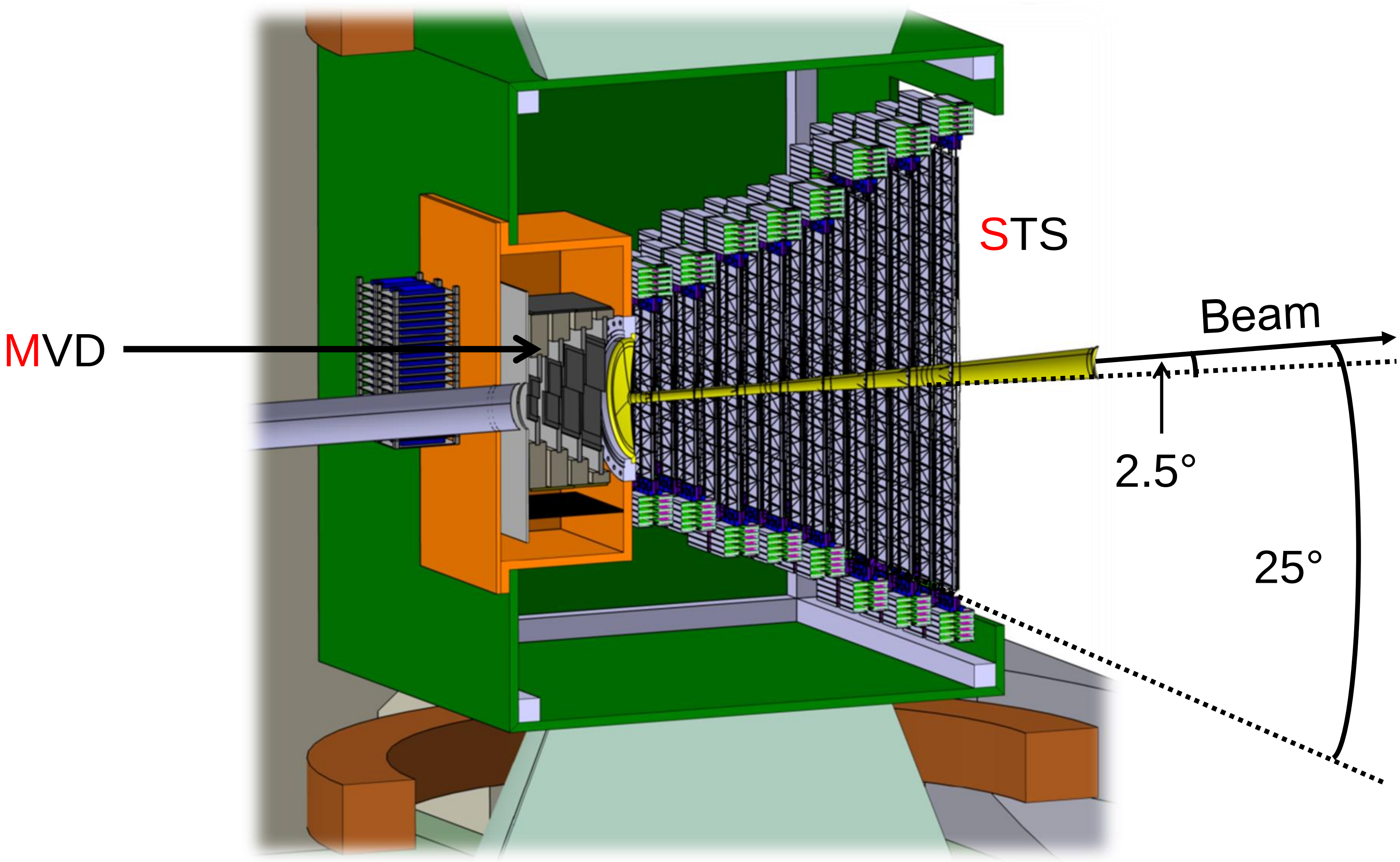
J. Heuser, QM2012

minimum bias Au+Au collisions at 25 AGeV
(from HSD and thermal model)

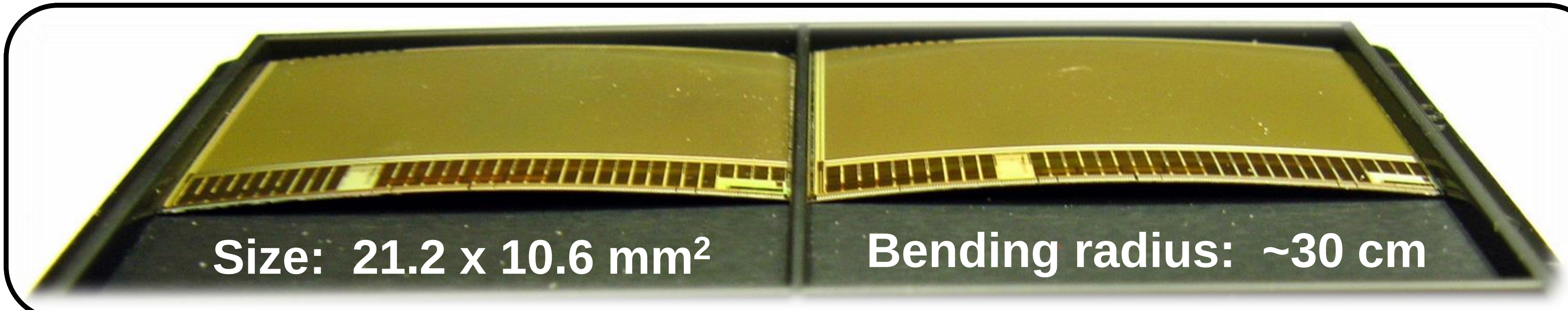


Needs very light and fast silicon and vertex detectors
Need very high collision rates: $10^5 - 10^7$ /s (Au-Au)

The Micro Vertex Detector

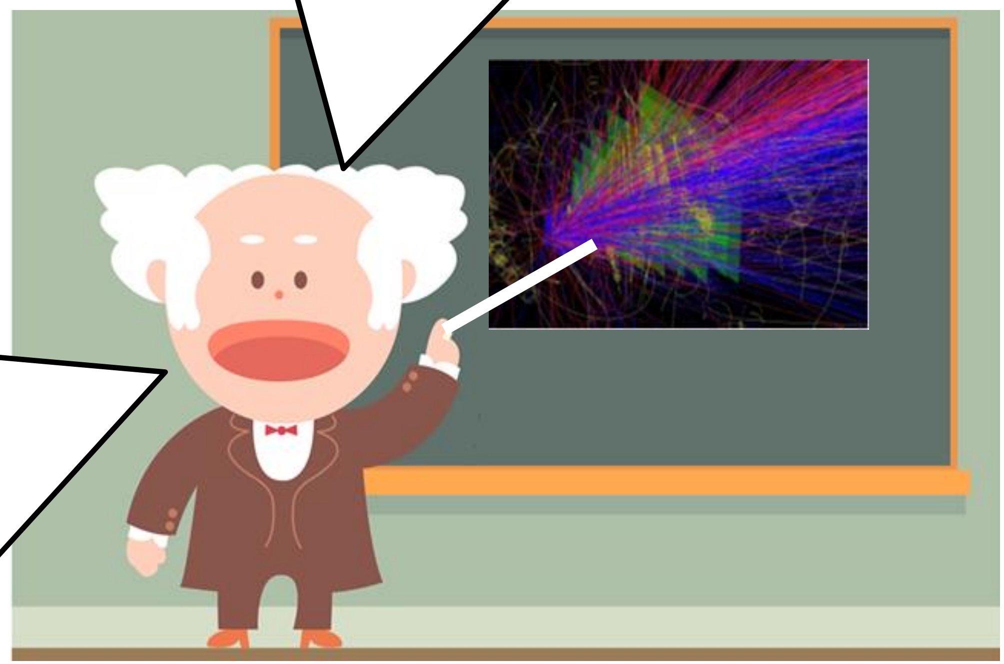


Requirements on the CBM Vertex Detector

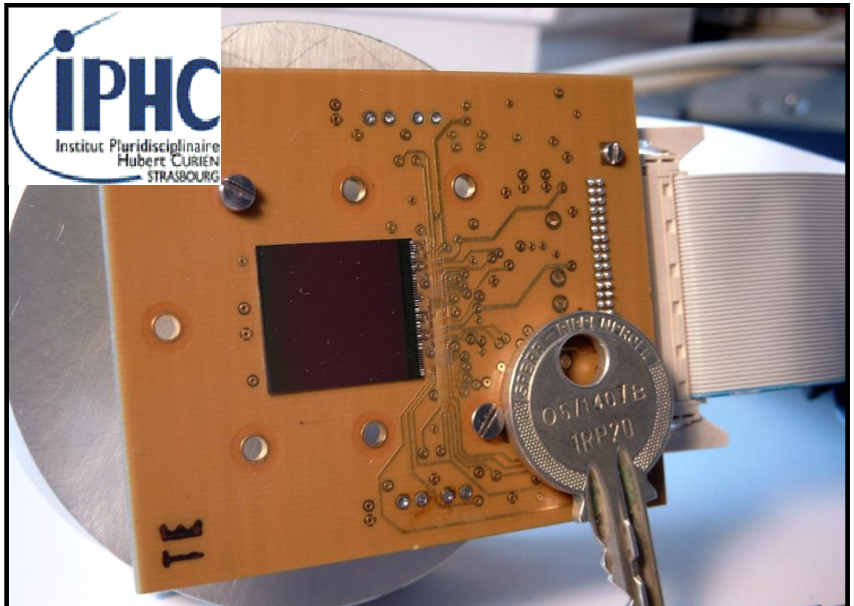


The CBM – MVD should

- Have 3-4 layers
- ~0.3% X_0 (first station)
- ~0.5% X_0 (other stations)
- Handle ~10^5 Au-Au coll/s
- ~40 hits/mm², ~10^8/cm²/s
- Operate in target vacuum
- Cooling <1 W/cm²



Performances of MAPS (2013)



Learn more: Talk of Marc Winter

All requirements demonstrated with dedicated sensors.

Next step: Do it with ONE sensor

Remaining issues:

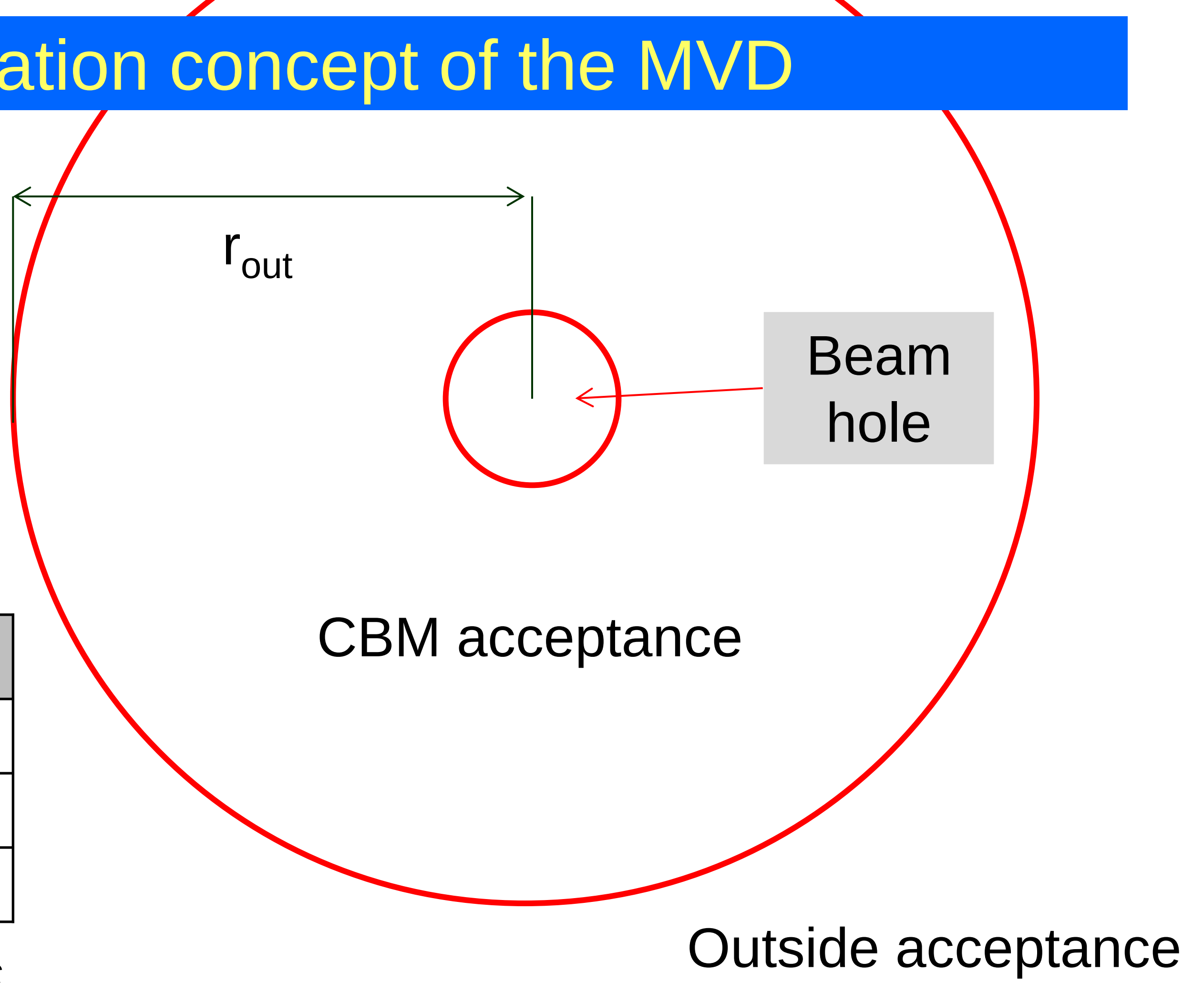
- Factor 2-3 in readout speed
- Extend internal bandwidth by factor of 5

⇒ In reach of today's 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}	> $3x10^{14}$

** Best of specialized sensors *Sensor only

Integration concept of the MVD



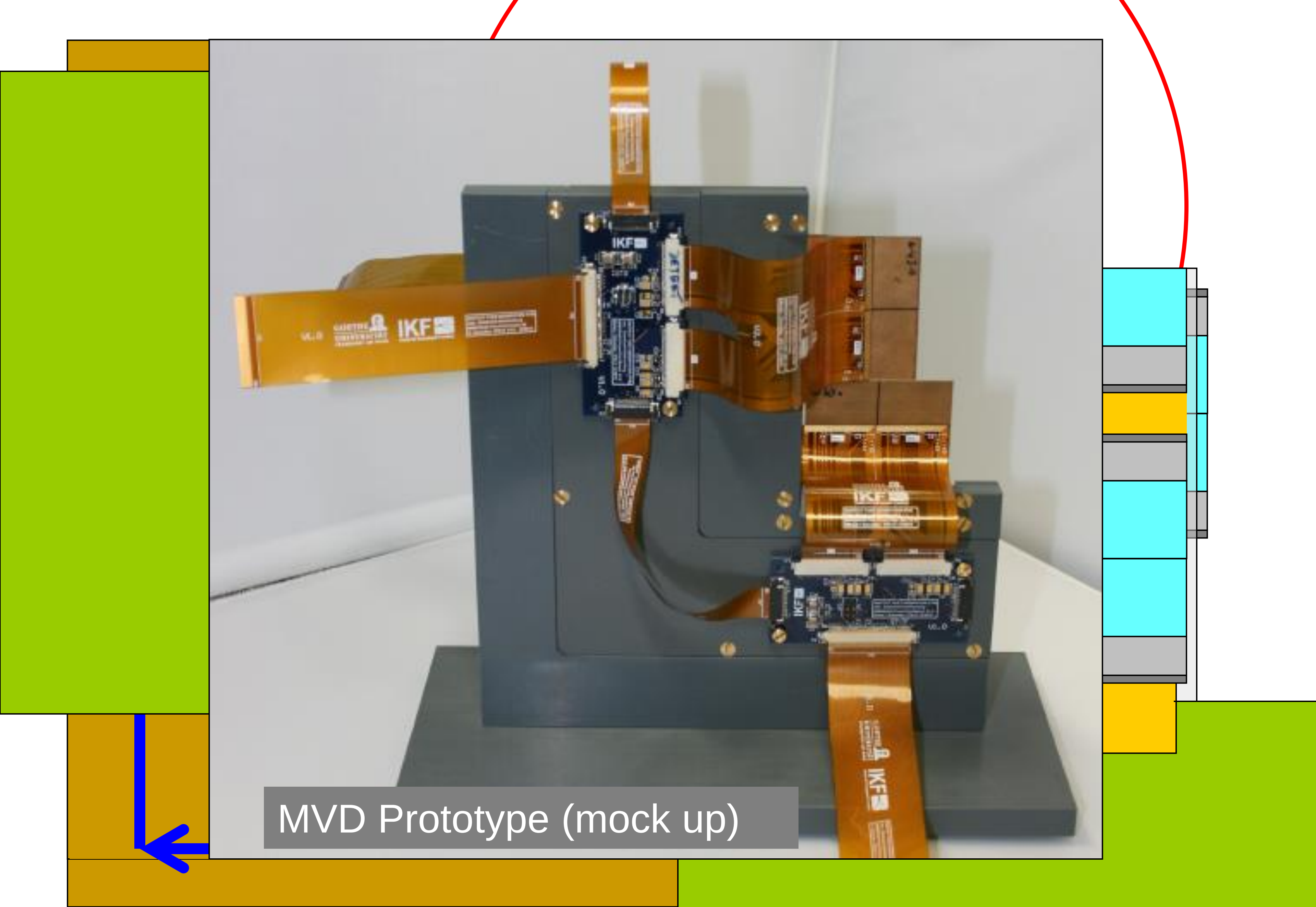
z[cm]	r_{out}	r_{in}
5	2.5	0.55
10	5.0	0.55
15	7.5	0.75

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

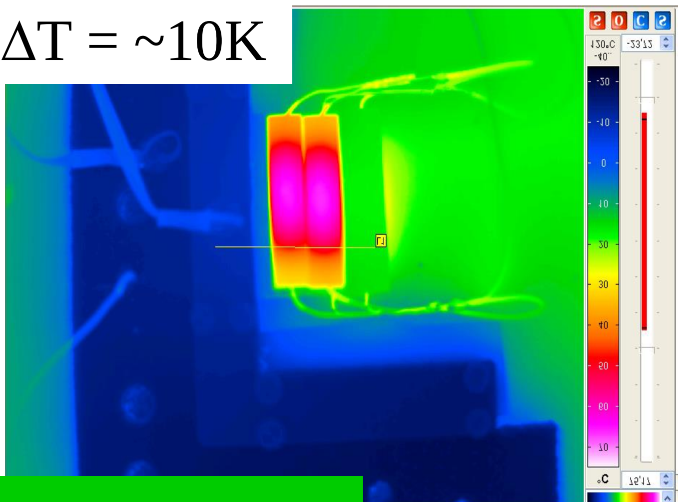


MVD Prototype (mock up)

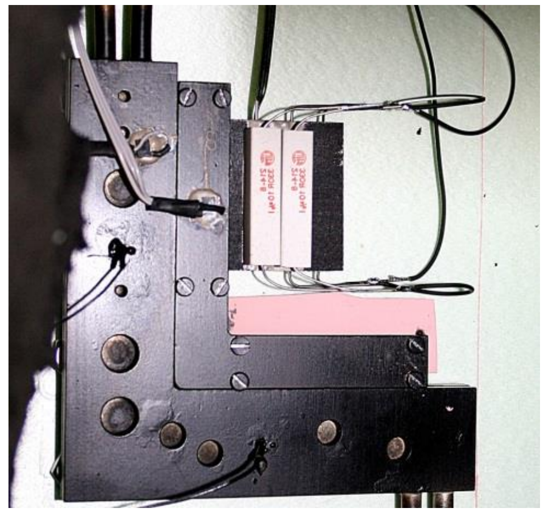
Validation of the cooling concept

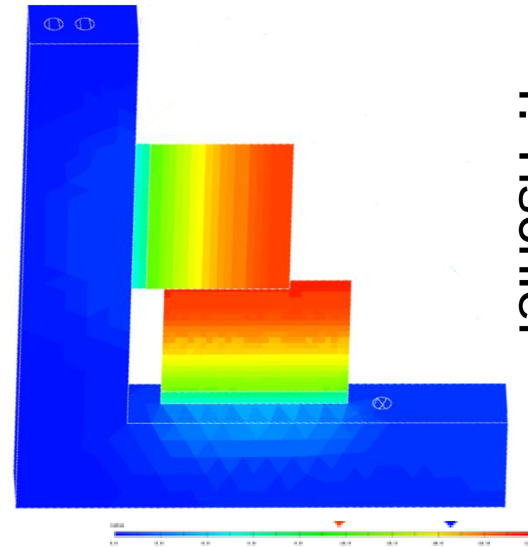
Aim: Validate the cooling concept with TPG

ΔT = ~10K



25 W / 16 cm²





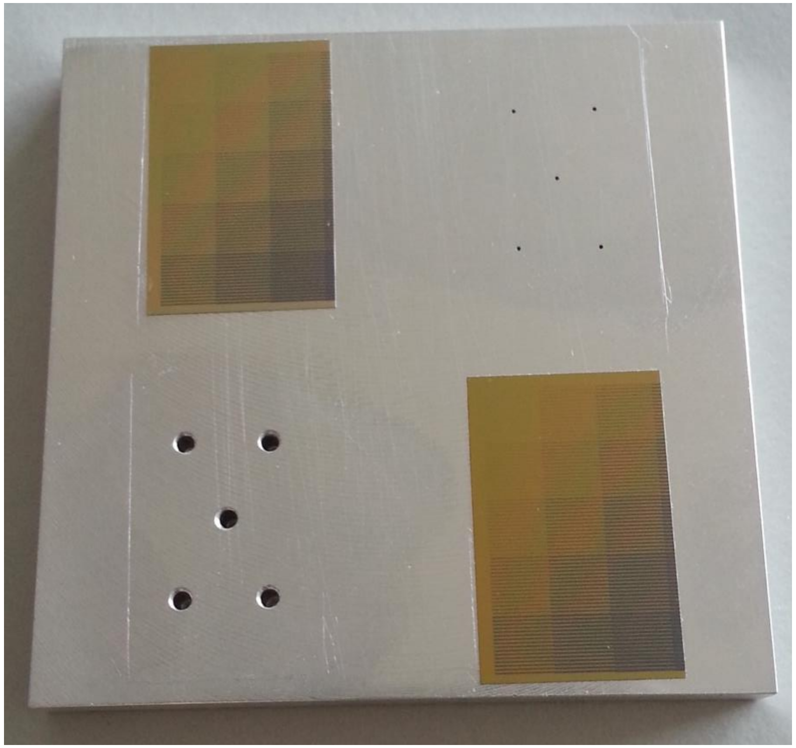
T. Tischler

Observation:

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

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

Vacuum compatibility



First tests on vacuum:

- Goal: Absence of air

Issues:

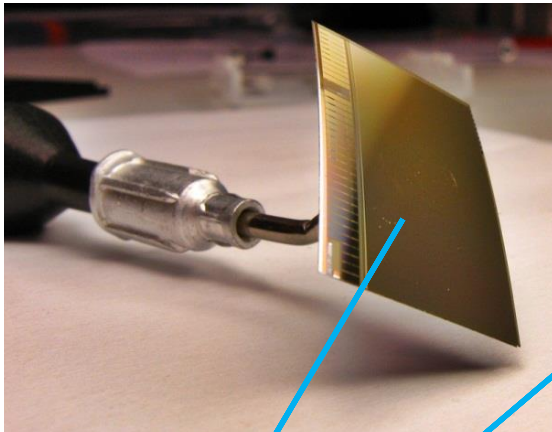
- Outgasing
- Mech. stress due to cavities

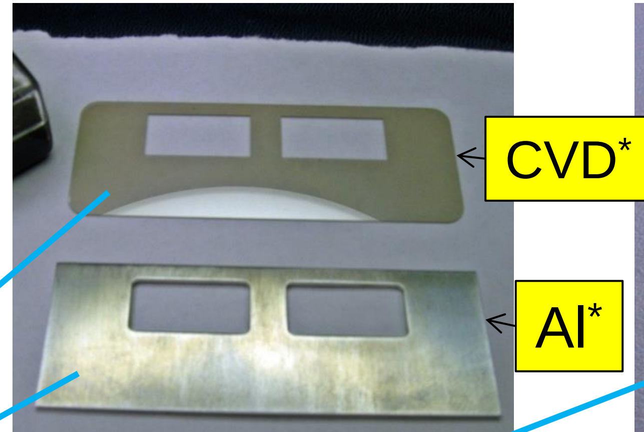
Observations with 50µm dummies:

- No significant outgasing (test not very sensitive)
- Cavities of ~0.5mm can be tolerated

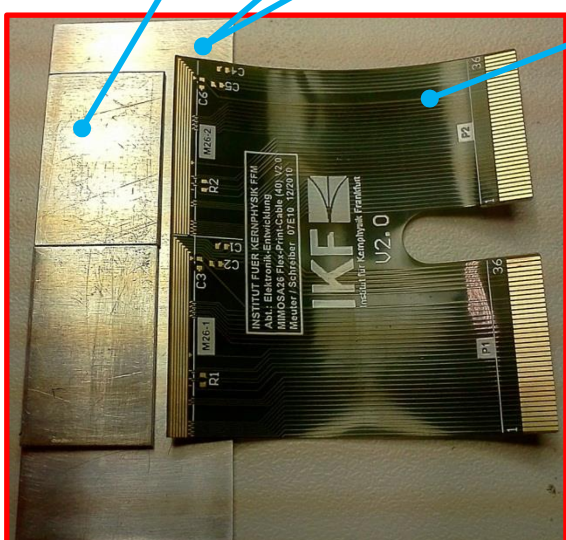
Study in progress, so far no problems

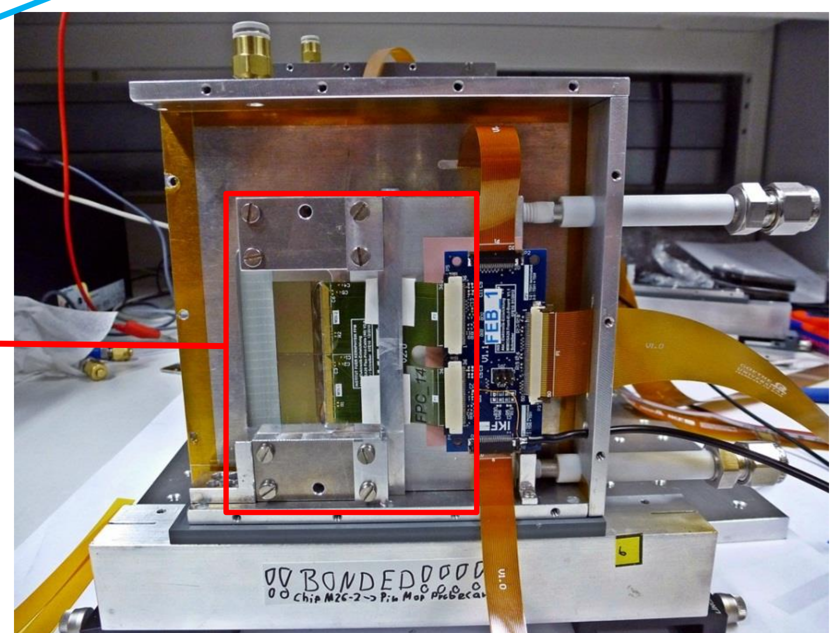
The CBM-MVD prototype



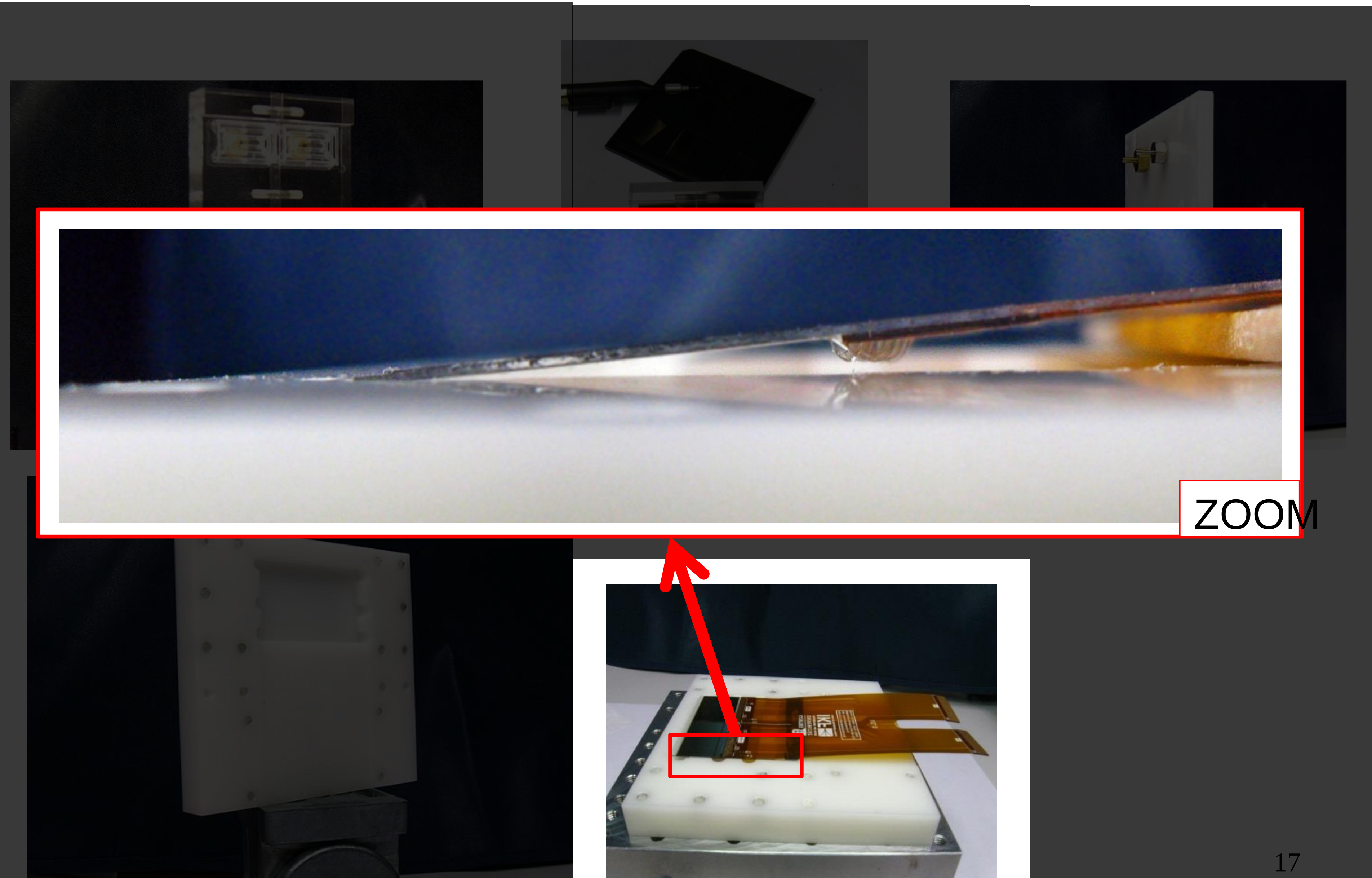


*) CVD and Al with cut-outs were tested for the reference plandes of the telescope. The prototype bases on a 100% filled CVD layer.





Tools



M. Deveaux

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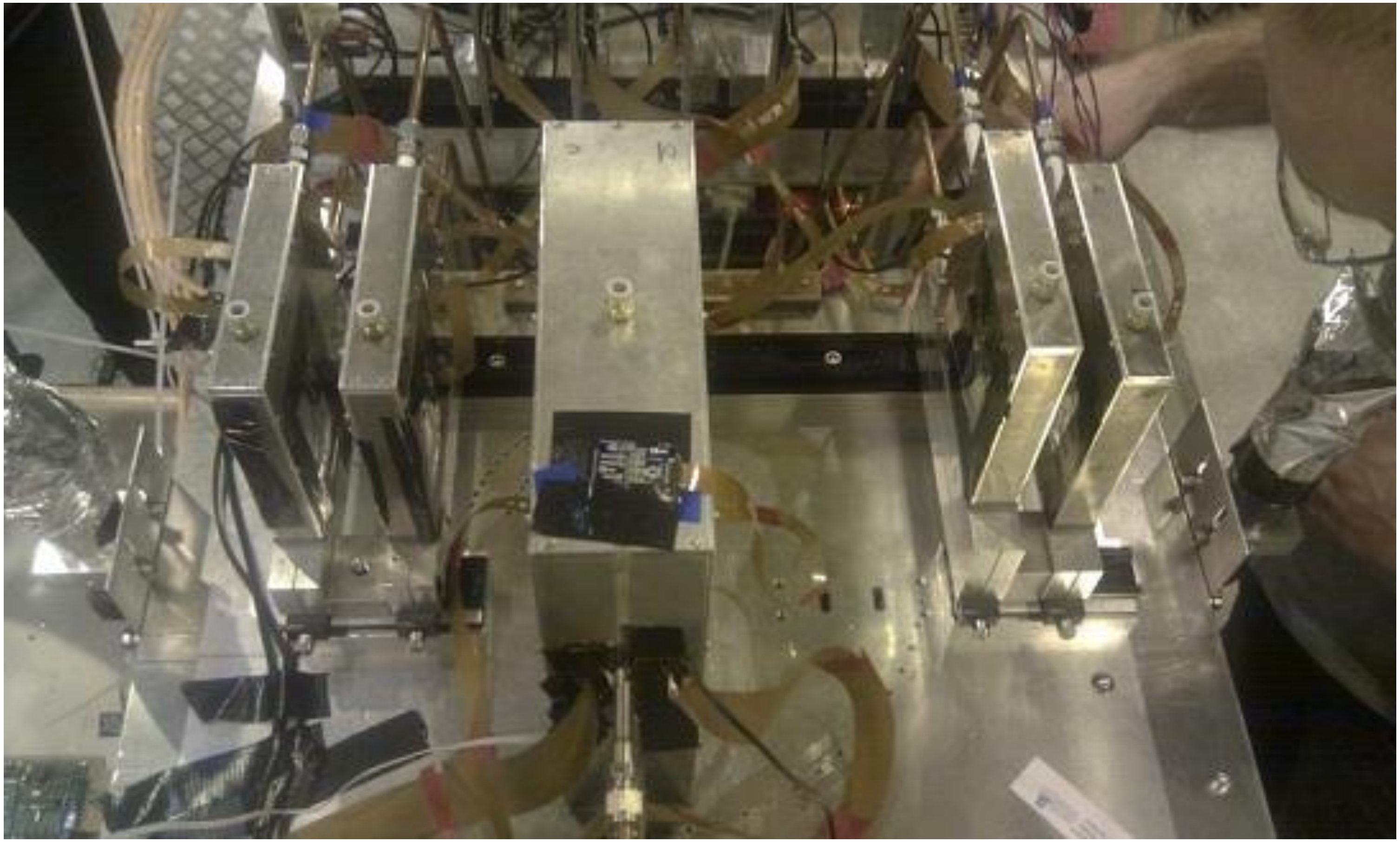
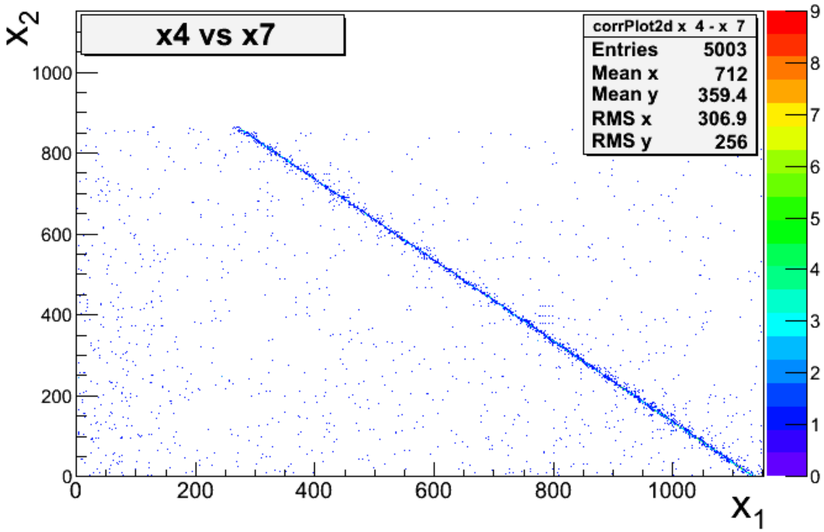
Prototype: Beam test setup



Performances:

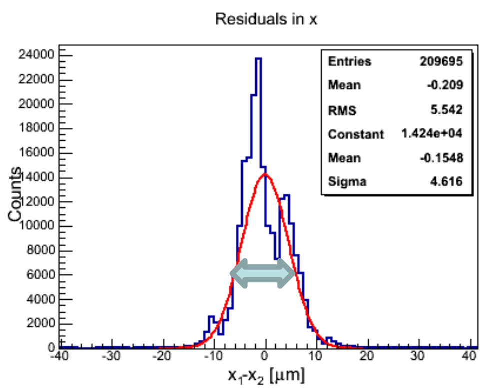
- Up to 10 MIMOSA-26 running @10k frames/s, 3.5µm resolution.
- Free-running, scalable DAQ based on HADES TRB – 100 MB/s.
- Actively cooled prototype (<0.3% X_0)
- Passively cooled telescope arms (0.05% X_0)

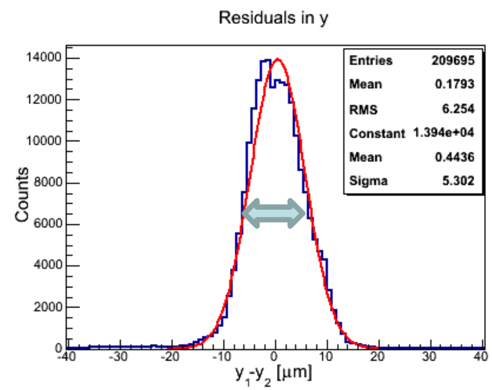
Some first results



Result so far for the DUT:

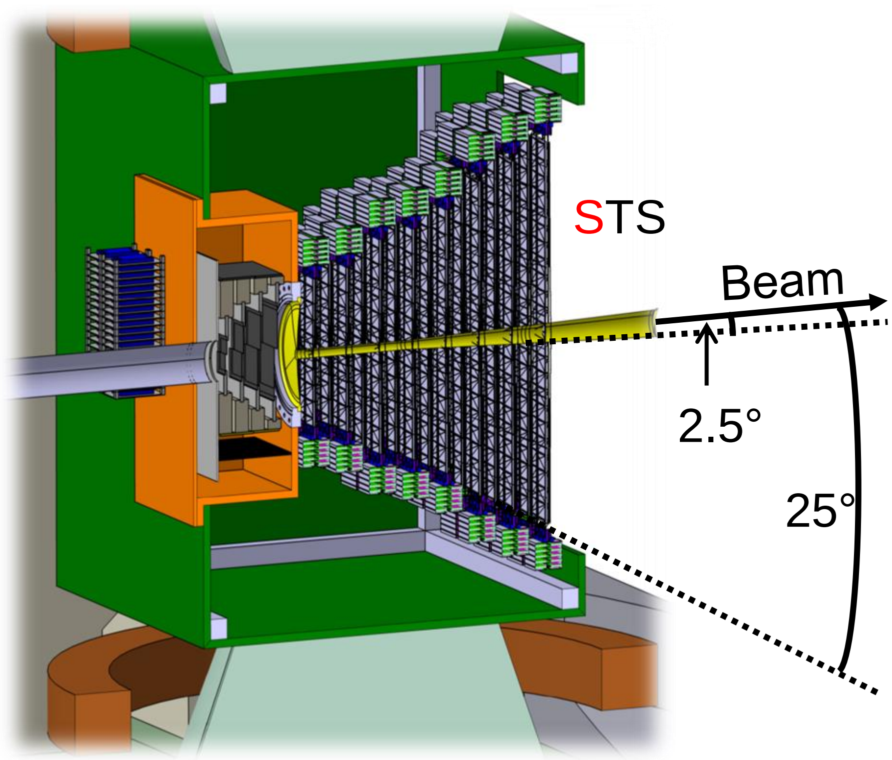
σ_x= 3.3 µm
σ_y= 3.7 µm





All performance plots very promising, analysis is being continued

The Silicon Tracking System



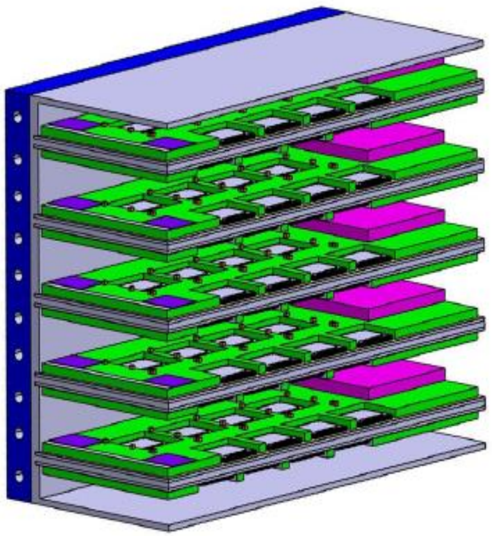
Requirements:

- dp/p ~ 1%
- 95% track eff. (> 1 GeV)
- 10 MHz Au-Au
  - Self triggered
  - 20 ns shaping time
- < $10^{14} n_{eq}/cm^2$ per year

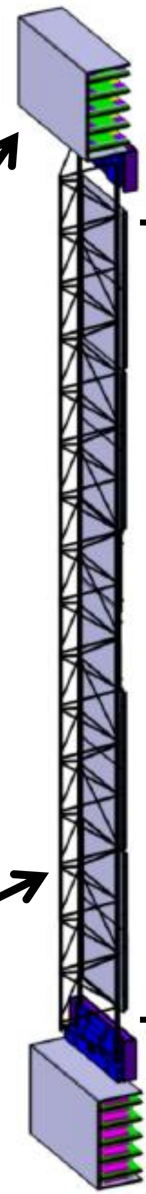
Solution:

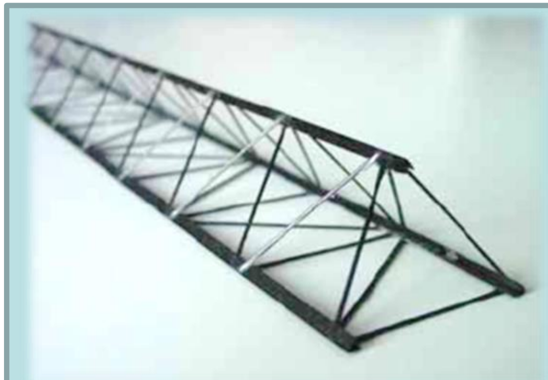
- 8 silicon strip stations
- $X_{Station}$ = ~1% X_0
- Electronics outside acceptance

The Silicon Tracking System



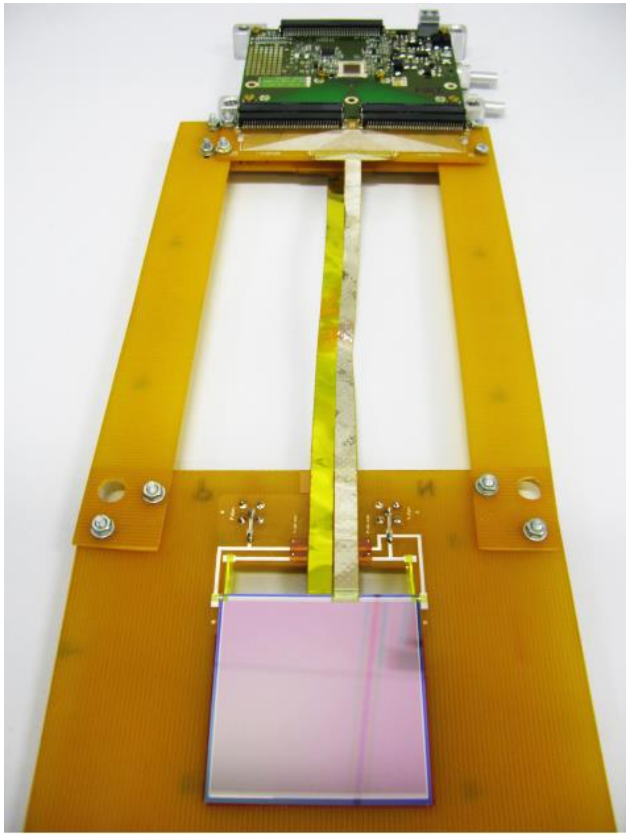
Front-end electronics





Carbon fibre ladder

CBM Accep- tance



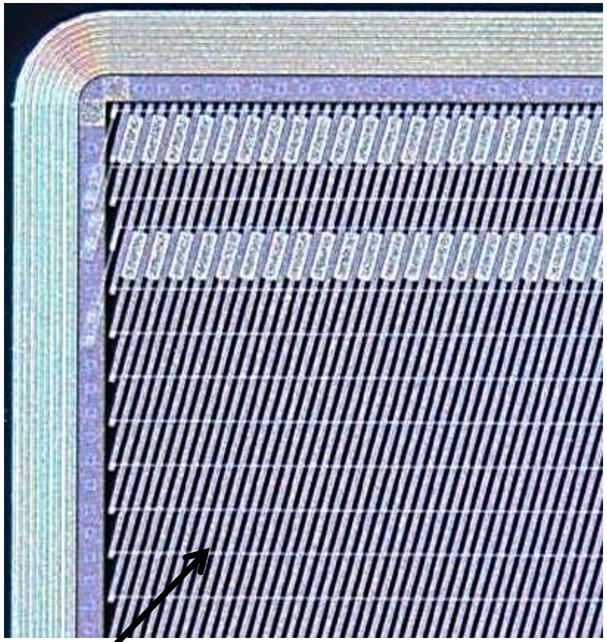
Silicon Strip Sensors + Ultra-thin cables

The STS-Sensors

Double sided p-n-n strip detectors

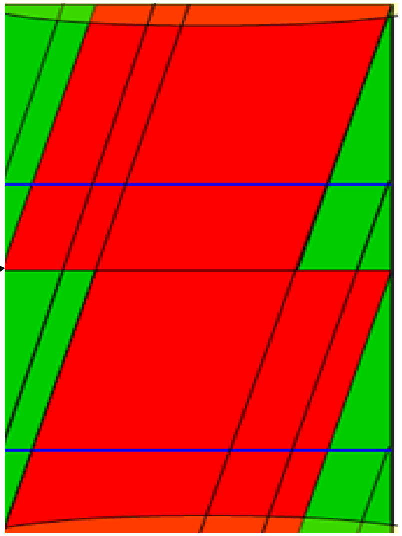
- 300 µm silicon
- 7.5° stereo angle, 58µm pitch
- 6.2 cm wide, 1024 strips
- Strip length: 2cm, 4cm, 6 cm
- AC coupled read-out

- Few 100V operation voltage
- $10^{14} n_{eq}/cm^2$ rad. tolerance



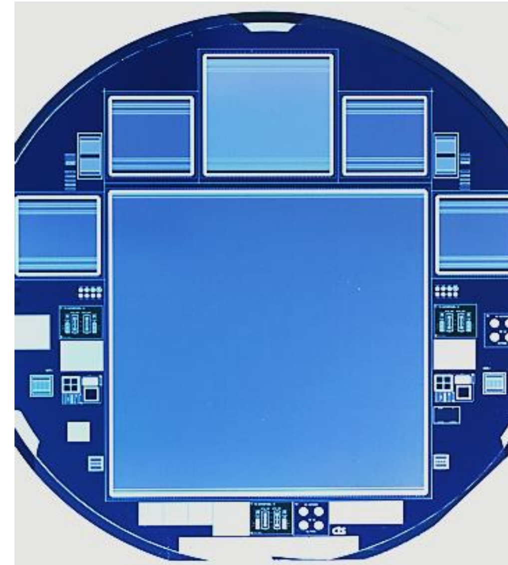
Strips reaching the border are continued on the other side

⇒ Needs double metal layer or external cable



The STS-Sensors

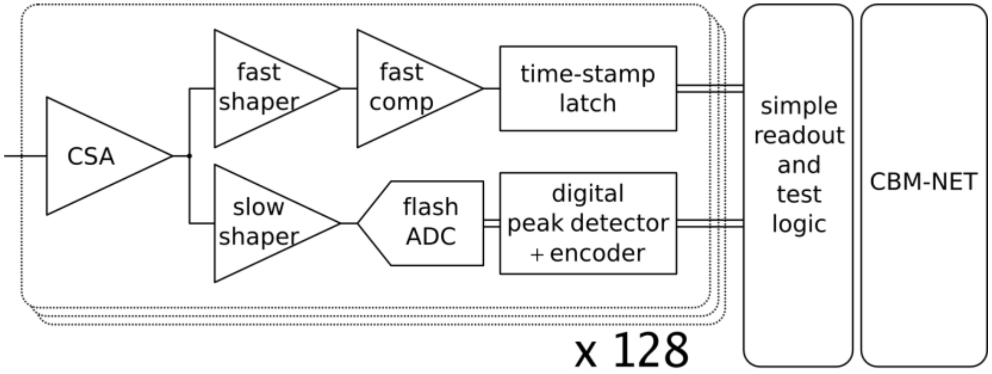
Under study: replacement of 2nd metal layer by cable



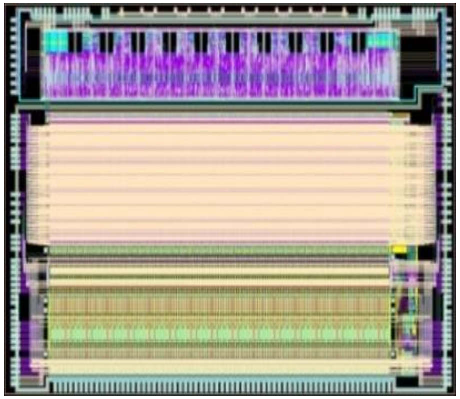
Prototype	Year	Vendor	Processing	Size [cm²]	Description
CBM01	2007	CiS	double-sided	5.5 × 5.5	±7.5 deg
CBM03	2010	CiS	double-sided	6.2 × 6.2	±7.5 deg
CBM03’	2011	CiS	Single/CBM03	6.2 × 6.2	test for CBM05
CBM05	2013	CiS	double-sided	6.2 × 6.2	7.5/0 deg full-size
CBM05H4	2013	Hamamatsu	double-sided	6.2 × 4.2	7.5/0 deg full-size
CBM05H2	2013	Hamamatsu	single-sided	6.2 × 2.2	7.5/0 deg full-size

Readout: STS-XYter

- Derived from N-XYter
- Self triggered
- Intelligent back end
- Two level discriminator



fast ⇔ low noise ⇔ low power dissipation



design V1.0 @ AGH Kraków

UMC 180 nm CMOS

produced 2012

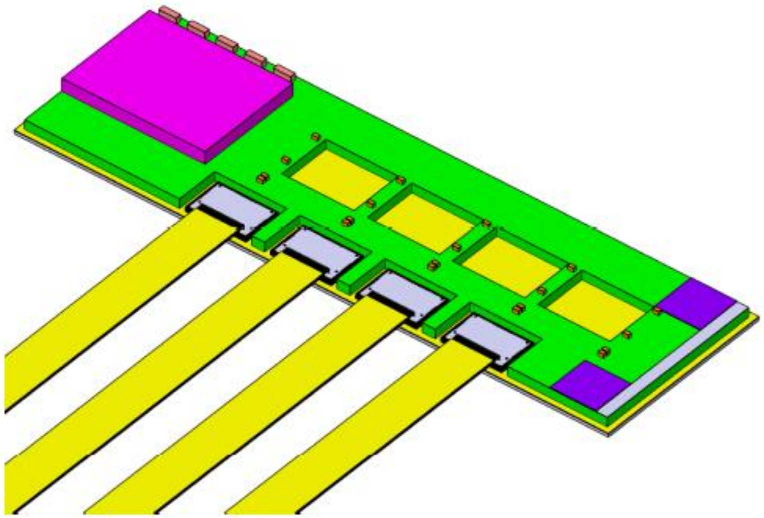
die size 6.5 mm × 10 mm

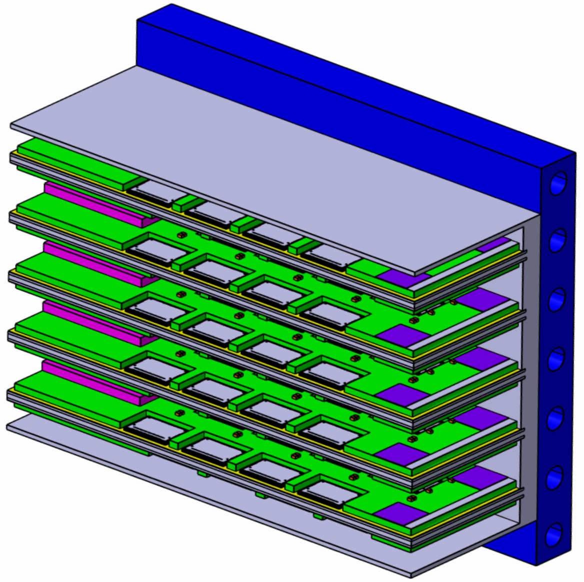
Channels, pitch	128 + 2 test
Channel pitch	58
Input signal polarity	+ and -
Input current	10 nA
Noise at 30 pF load	900 e^-
ADC range	16 fC, 5 bit
Clock	250 MHz
Power dissipation	< 10 mW/channel
Timestamp resolution	< 10 ns
output interface	4 × 500 Mbit/s LVDS

Interation concept

FEE outside acceptance

- 8 STS-XYter per FEE-board
- Floating electronics
- Connection to sensor:
  Micro-cable, tab bonding
- Data: Optical links



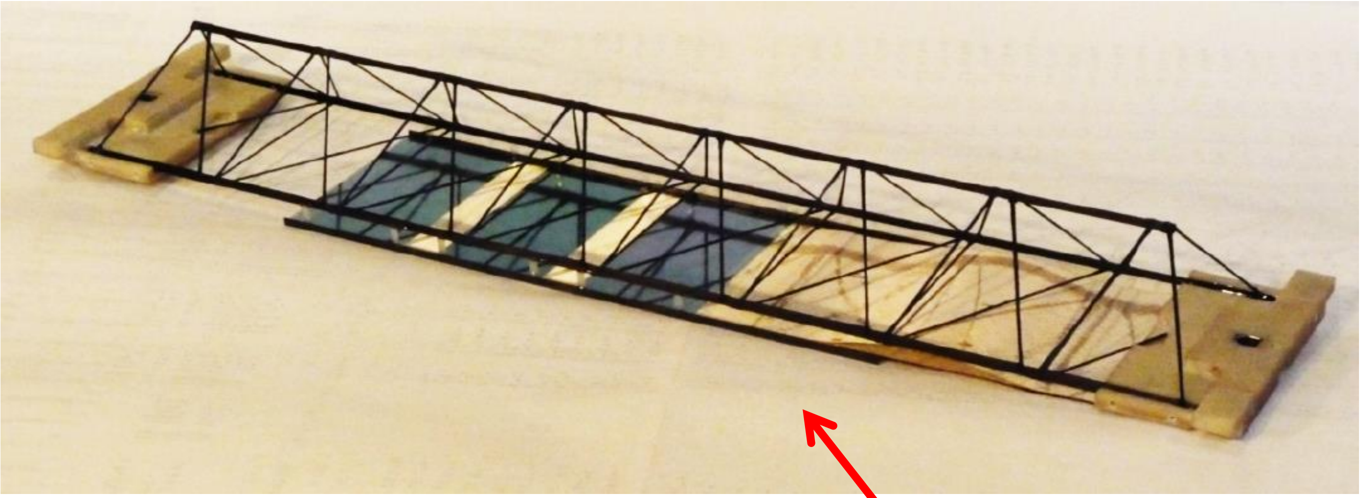


FEE boxes:
10 boards
200W power

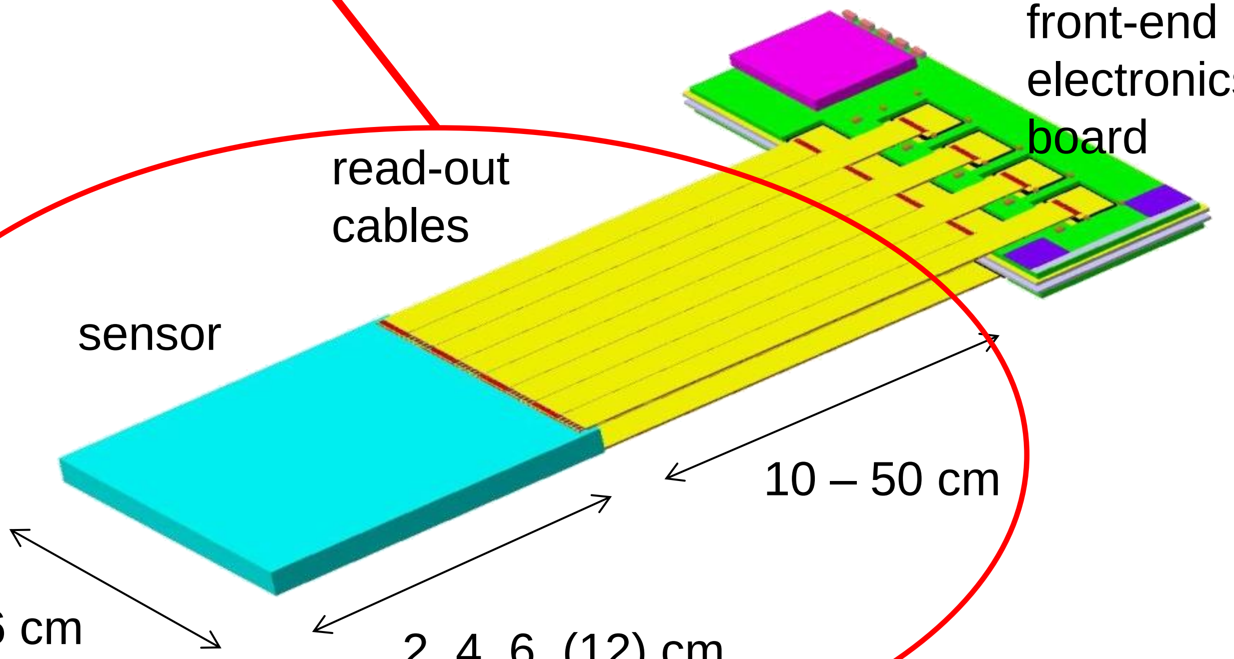
Cooling concept:
FEE-Boxes: CO_2 cooling (42kW)

Sensors: Gas cooling

Ladder – Mechanical Prototype

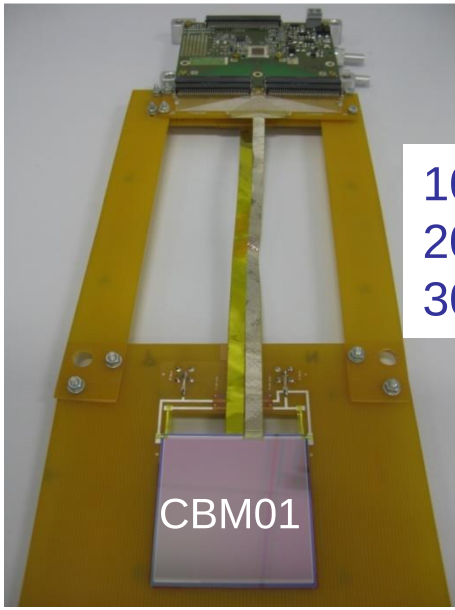


module –
building block
of STS



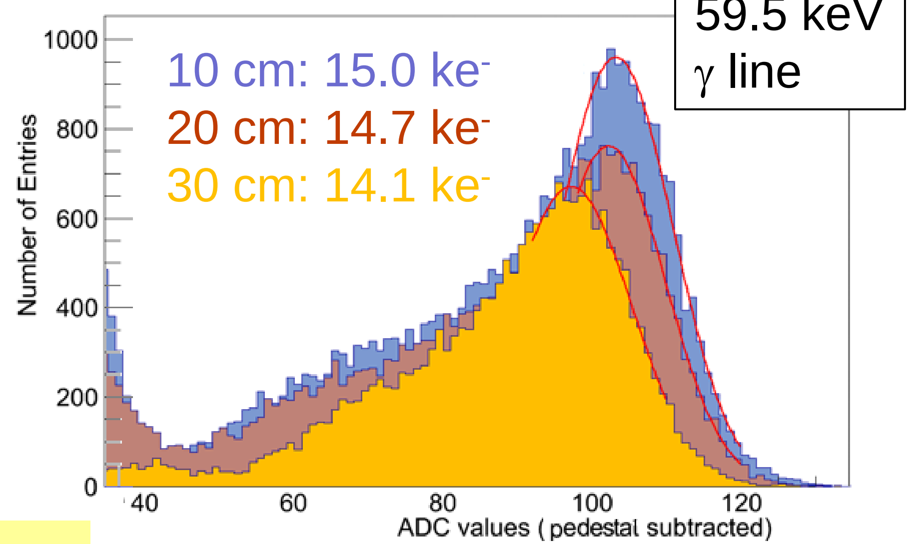
Some test results

n-XYTER FEB

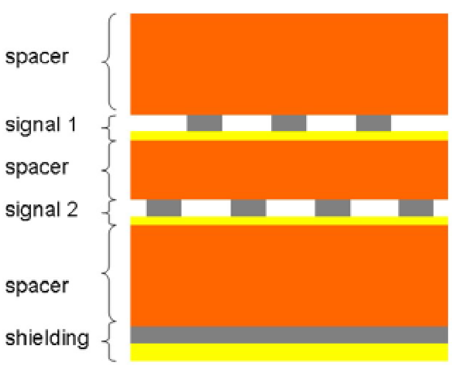


10 cm
20 cm
30 cm

ADC spectrum, ^{241}Am source

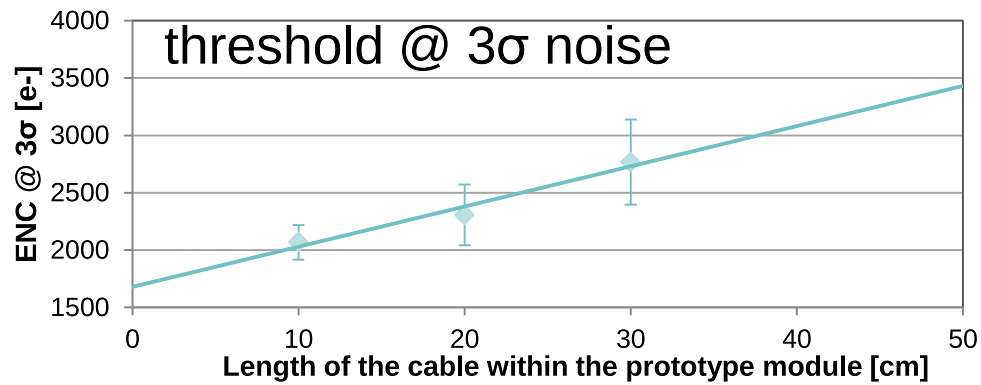


$S/N_{MIP} \sim 20$



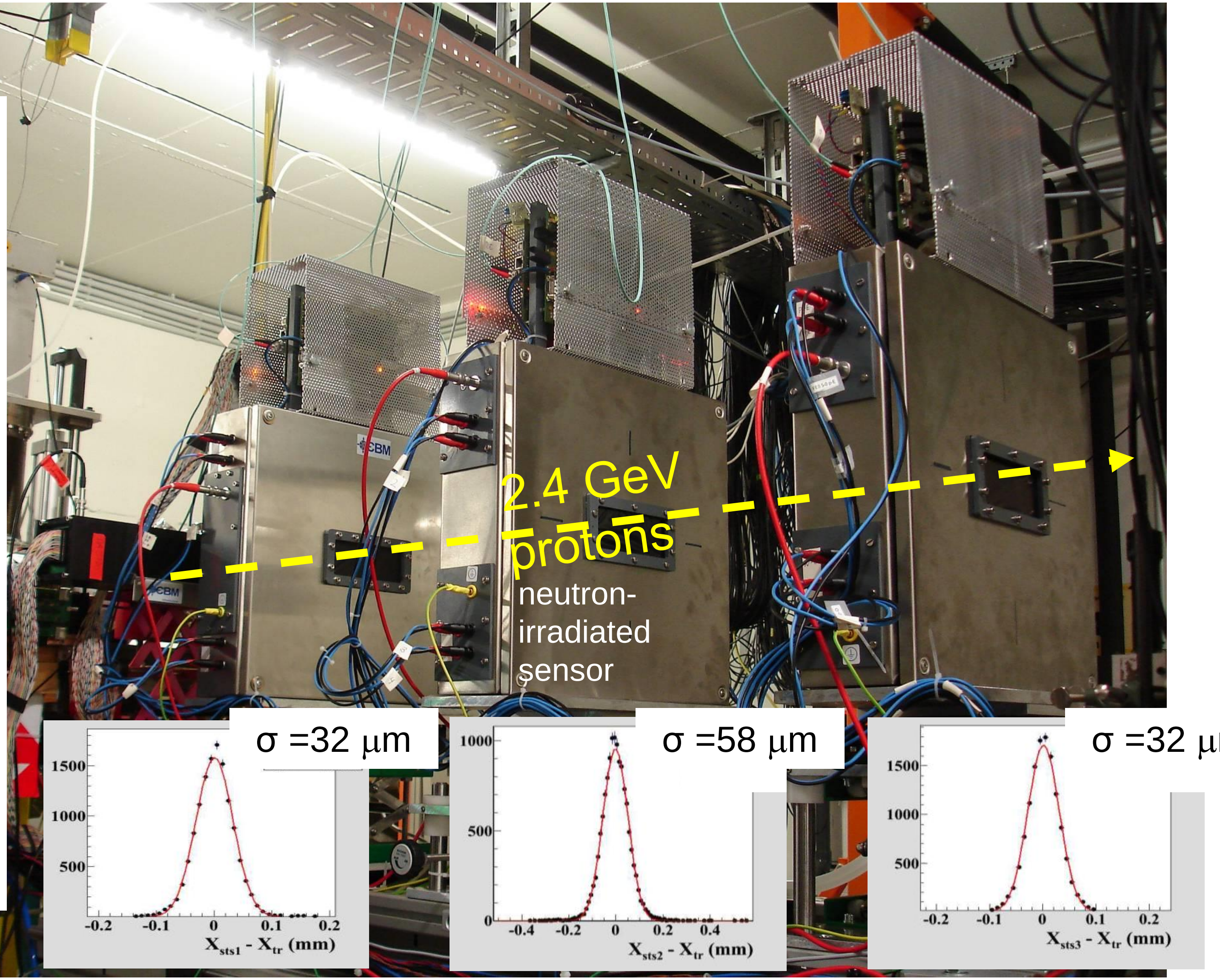
read-out cable,
Al-Polyamide

thickness
0.1% X_0



Some test results

- silicon microstrip sensors
- self-triggering front-end electronics
- DAQ
- DCS
- online monitoring
- tracking



Summary and conclusion

CBM
- is a next generation fixed target heavy ion experiment at FAIR
- aims for rare e+/e-, μ+/μ- and hadronic probes (incl. open charm)

The MVD
- Operate at ~10^5 Hz (Au-Au) or ~10^7 Hz (p-A)
- 3-4 vacuum compatible stations based on diamond support
- 0.3-0.5% X_0
- Sensors: CMOS Monolithic Active Pixel Sensors

The STS
- Operate at up to ~10^7 Hz (Au-Au)
- 8 Stations, carbon fibre support
- <1% X_0, FEE outside acceptance

Prototypes were sucessfully tested,
- aim for production readiness mid 2015,
- production 2015-17,
- commissioning/first operation 2017-18

CBM Technical Design Reports approved