



Challenges with decay vertex detection in CBM using an ultra-thin pixel detector system

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Outline:

- The CBM experiment (a reminder)
- Requirements for the CBM vertex detector
- Technology choices and consequences
- Running conditions
- Summary and Conclusion

CBM@FAIR

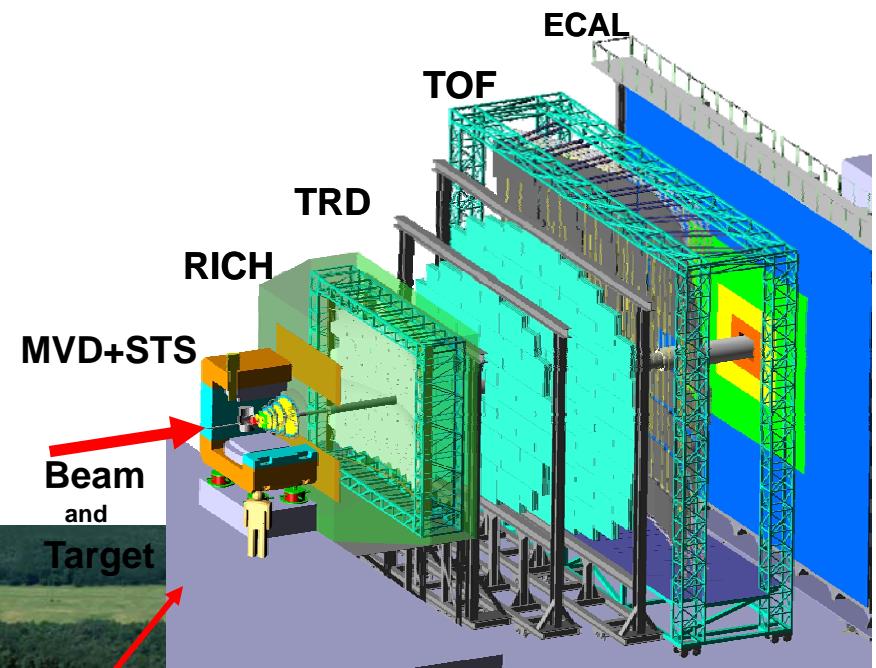
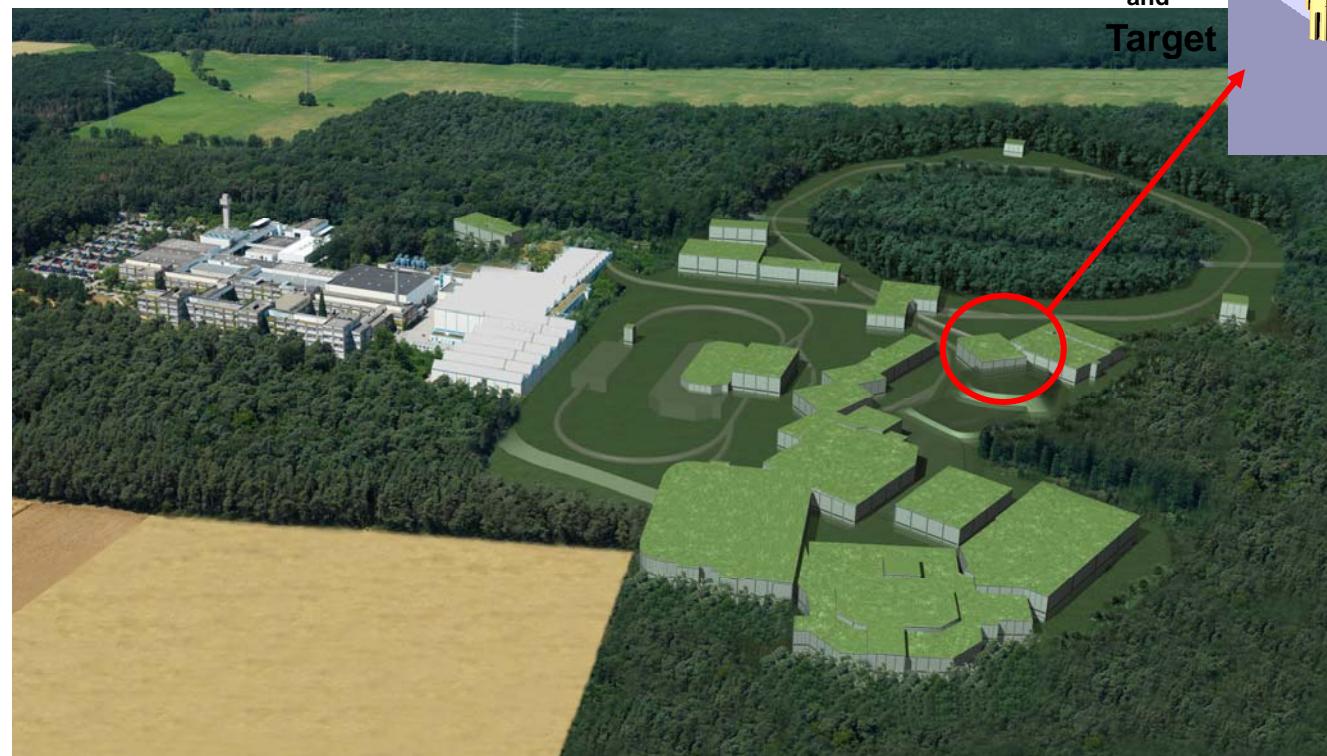
CBM:

Fixed target heavy ion experiment

10-45 AGeV beam energy

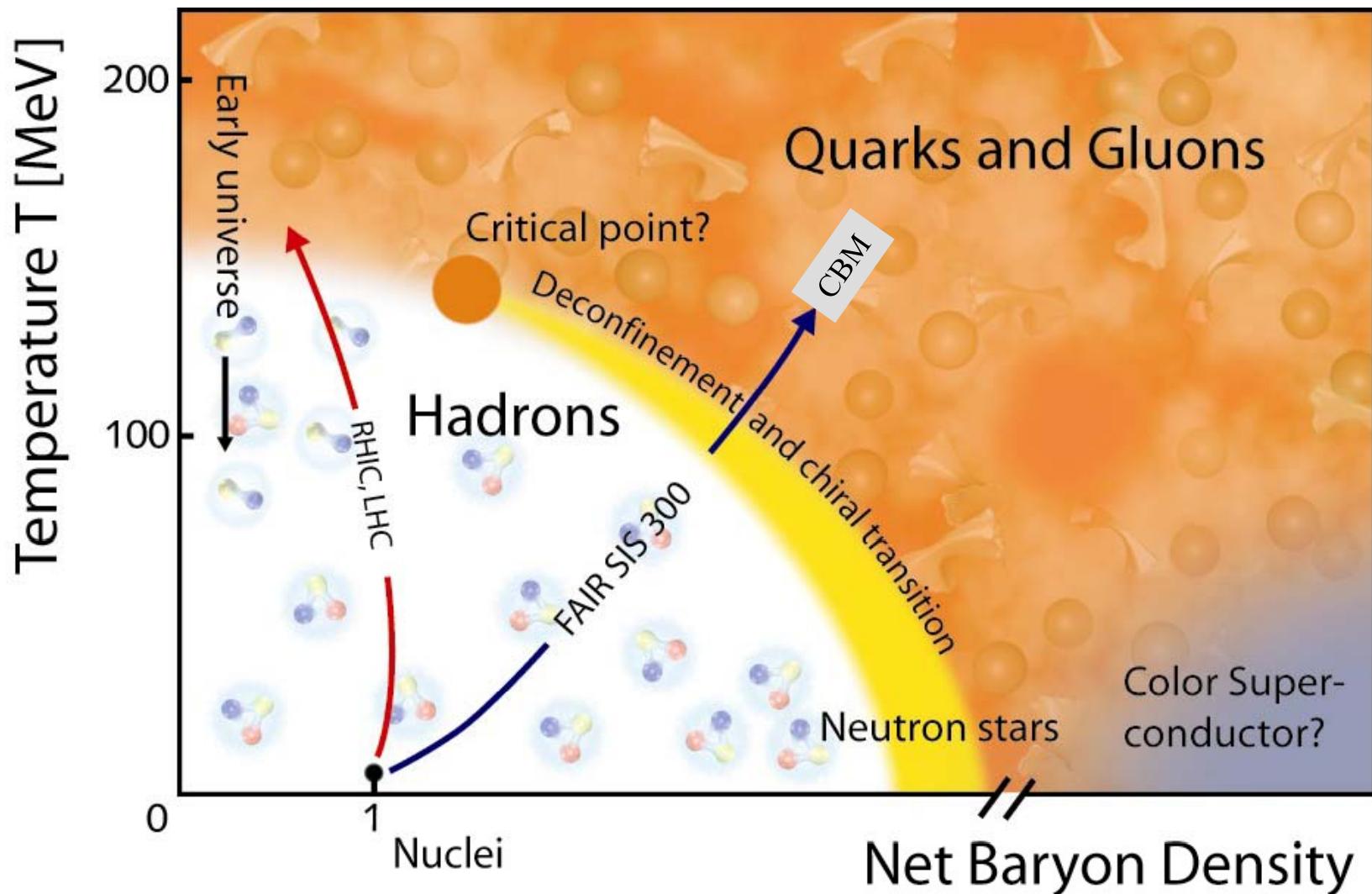
Located at GSI/FAIR, Darmstadt, Germany

First collision ~2015



The Physics case of CBM

Explore the nuclear phase diagram in the region of high net baryon density



Observables of interest

The equation-of-state at high ρ_B

- collective flow of identified hadrons
- particle production at threshold energies (open charm)

flow

Deconfinement phase transition at high ρ_B

- excitation function and flow of strangeness ($K, \Lambda, \Sigma, \Xi, \Omega$)
- excitation function and flow of charm ($J/\psi, \psi', D^0, D^\pm, \Lambda_c$)
- charmonium suppression, sequential for J/ψ and ψ' ?

charm

QCD critical endpoint

- excitation function of event-by-event fluctuations ($K/\pi, \dots$)

fluctuations

Onset of chiral symmetry restoration at high ρ_B

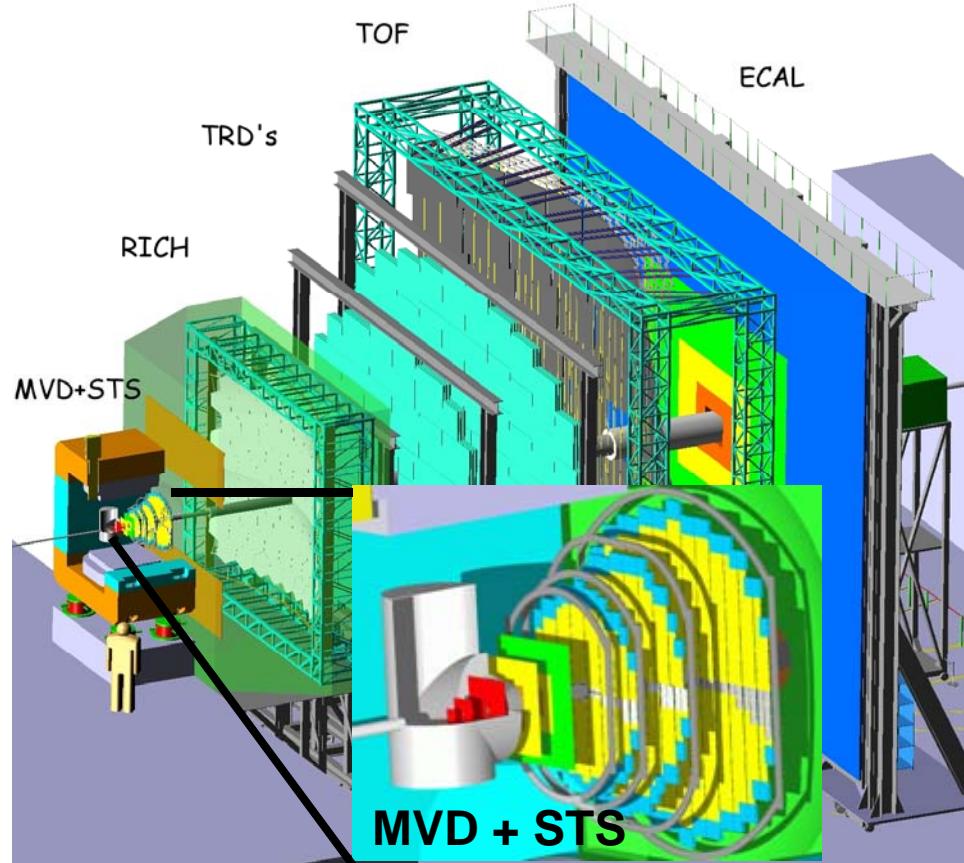
- in-medium modifications of hadrons ($\rho, \omega, \phi \rightarrow e^+e^- (\mu^+\mu^-), D$)

dileptons

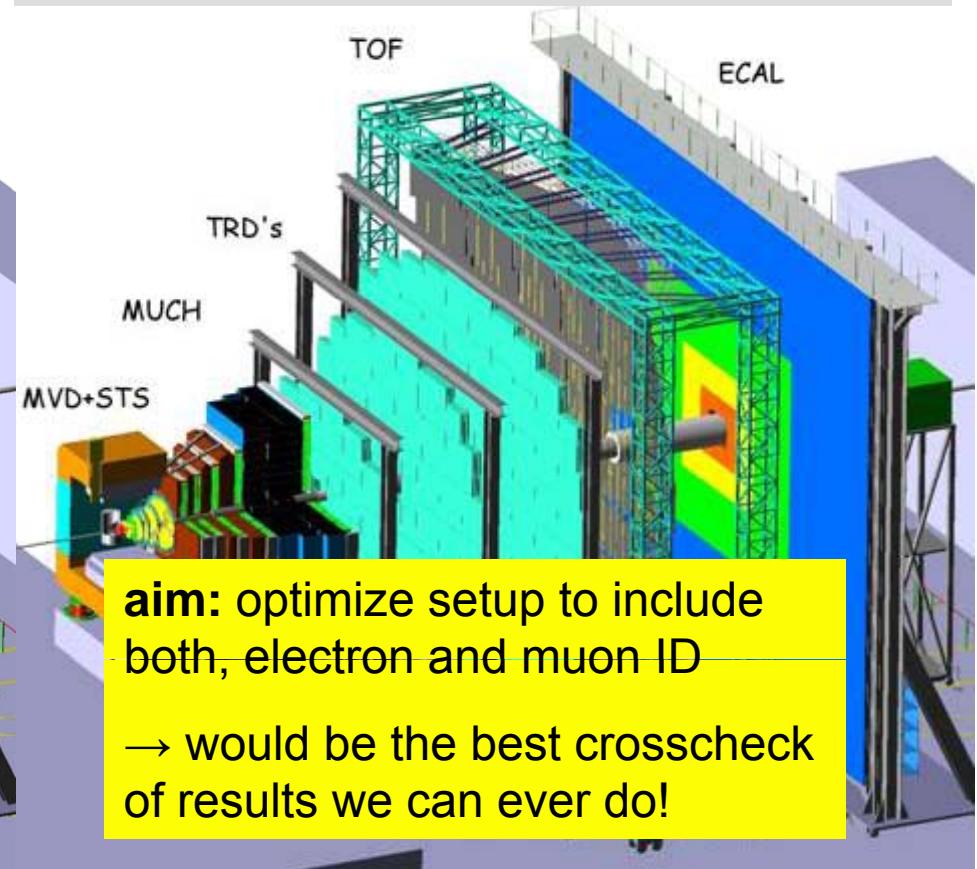
Our topic for today

Global layout of the CBM experiment

- **electron ID:** RICH & TRD
→ π suppression $\geq 10^4$



- **muon ID:** absorber + detector layer sandwich
→ move out absorbers for hadron runs



aim: optimize setup to include both, electron and muon ID
→ would be the best crosscheck of results we can ever do!

MVD: Micro Vertex Detector, **STS:** Main Silicon Tracking System

RICH + TRD: electron identification, **TOF:** Time of Flight system for hadron identification, **MUCH** Muon detector (replacing the RICH), **ECAL**

The open charm challenge

$D^\pm : c\tau \sim 312 \mu\text{m}$

$D^+ \rightarrow K^- \pi^+ \pi^+ (9.5\%)$

$D^0 : c\tau \sim 123 \mu\text{m}$

$D^0 \rightarrow K^- \pi^+ (3.8\%)$

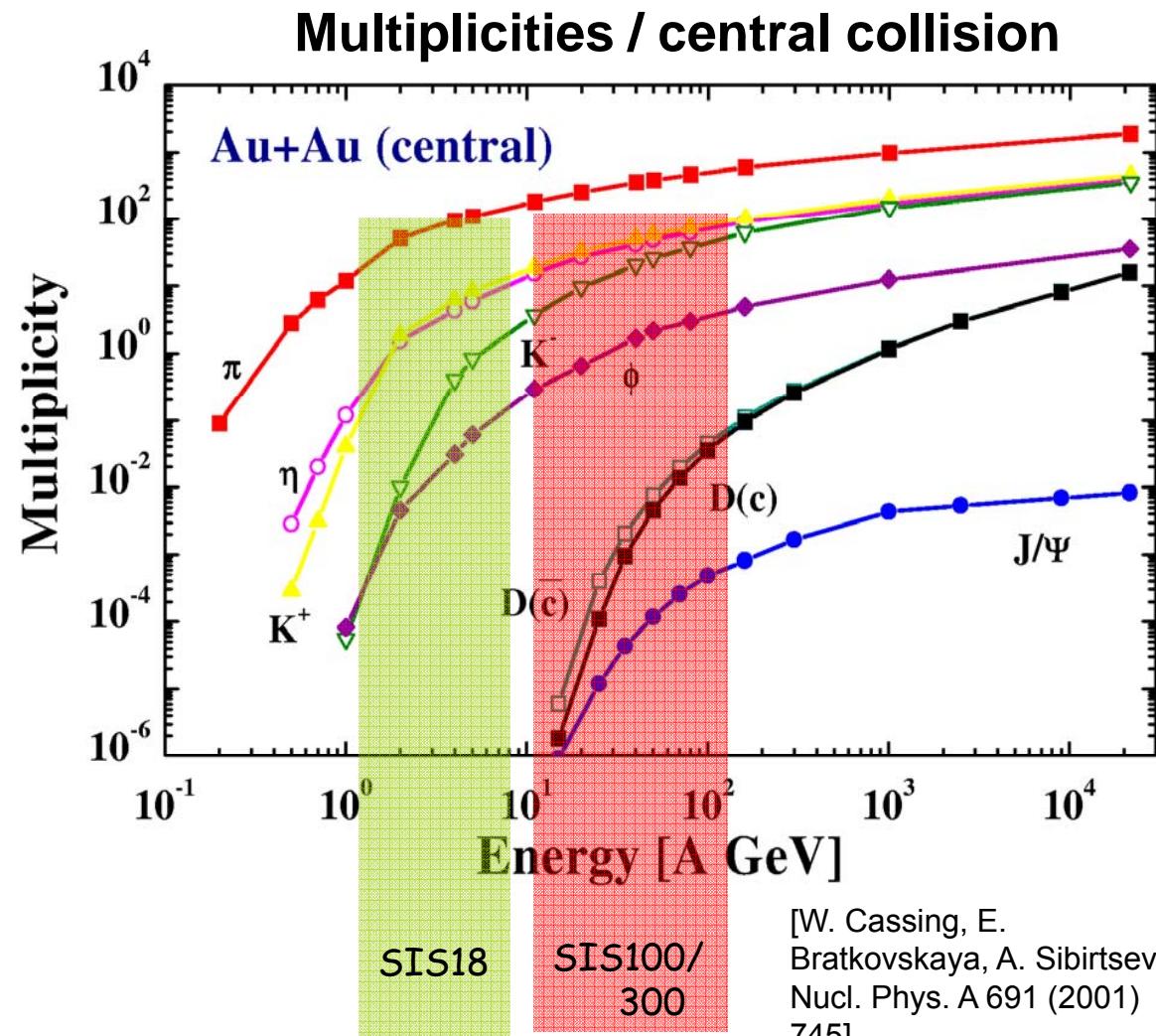
$D^0 \rightarrow K^- \pi^+ \pi^+ \pi^- (7.5\%)$

$D_{s}^\pm : c\tau \sim 150 \mu\text{m}$

$D_s^+ \rightarrow K^+ K^- \pi^+ (5.3\%)$

$\Lambda_c^+ : c\tau \sim 60 \mu\text{m}$

$\Lambda_c^+ \rightarrow p K^- \pi^+ (5.0\%)$



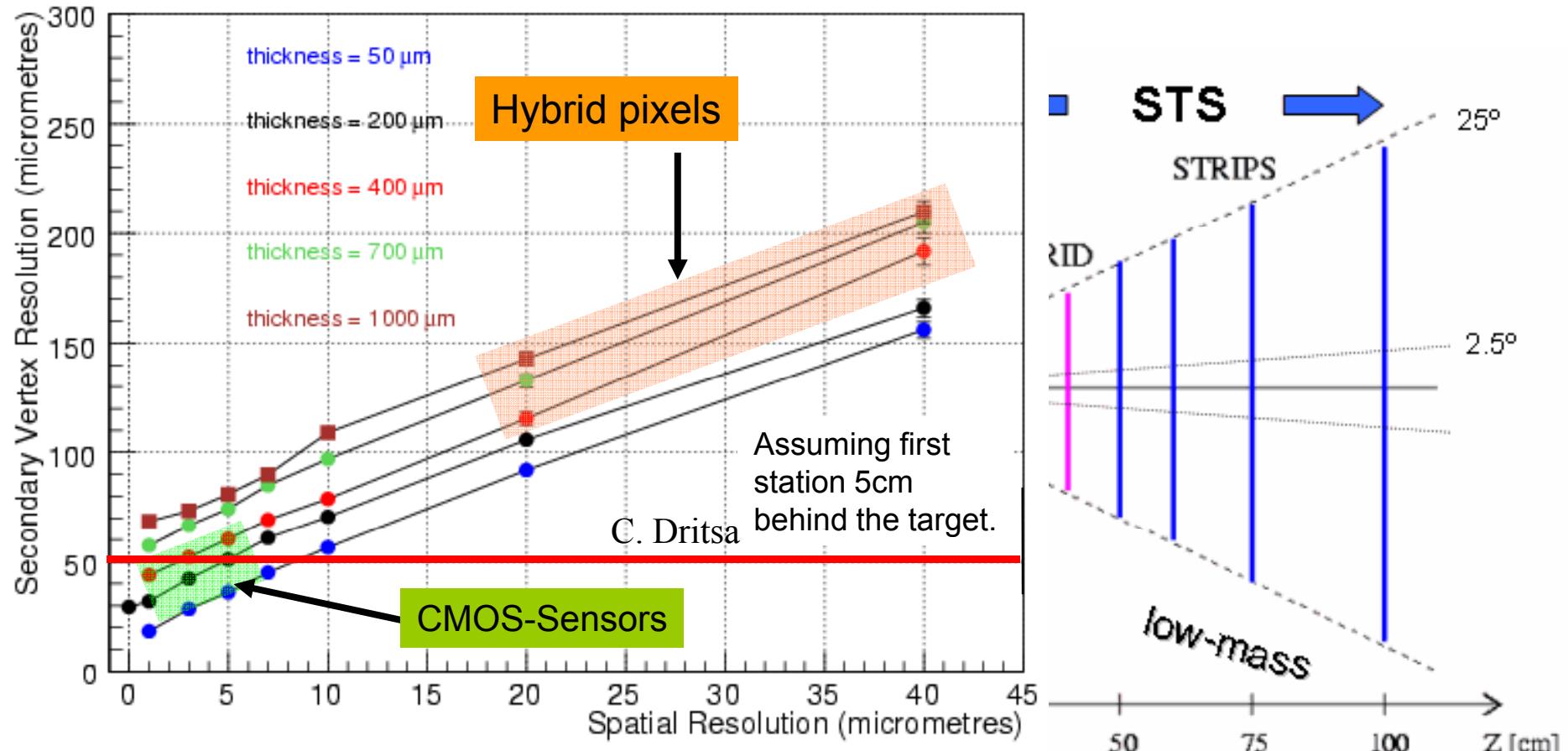
High interaction rate required => CBM is designed as fixed target experiment

Beam intensity provided by SIS300: Up to 10^9 ions/s (slow extraction)

Needs excellent secondary vertex resolution $\sim 50 \mu\text{m}$

How to get the resolution

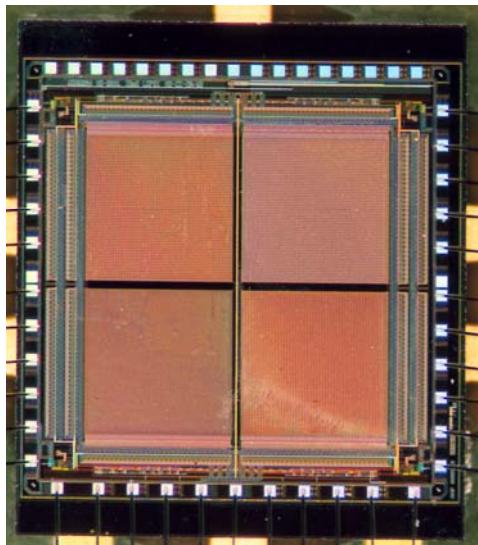
Simulation of the sec. vtx resolution of the MVD



Sec. vtx. resolution demands for thin sensors like CMOS-Sensors (MAPS)

Can't tolerate material of the beam pipe. Vertex detector must be placed in (moderate) vacuum.

Minimum Ionizing Particle MOS Active Pixel Sensor



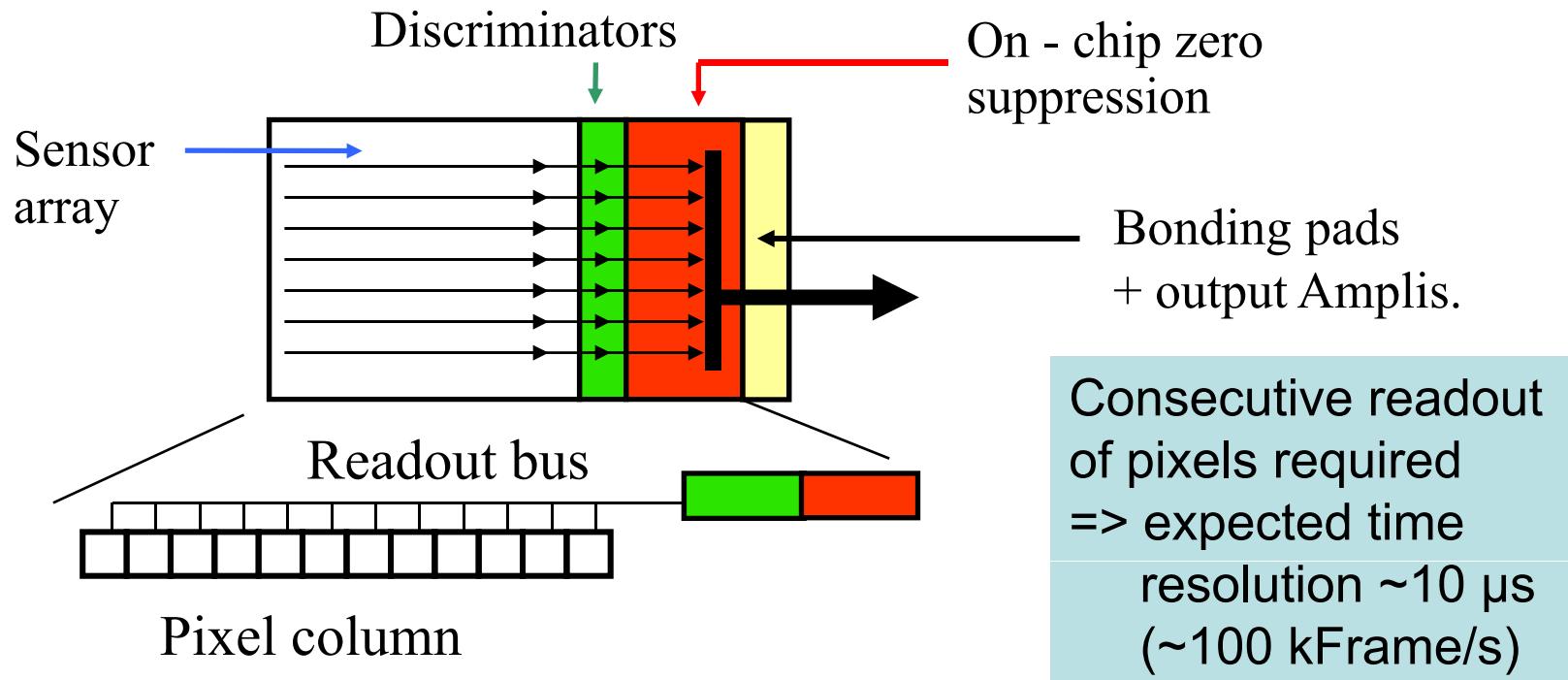
MIMOSA IV

Features of the MIMOSA – detectors:

- Single point resolution $1.5\mu\text{m} - 2.5\mu\text{m}$
- Pixel – pitch $10 - 40 \mu\text{m}$
- Thinning achieved $50 - 120\mu\text{m}$
- S/N for MIPs $20 - 40$
- Radiation hardness: $1\text{MRad} ; 1 \times 10^{13} n_{\text{eq}}/\text{cm}^2$
- Time resolution $\sim 20 \mu\text{s}$ (massive parallel readout)

We follow the R&D for SoI-Detectors and 3D-VLSI-detectors

The time resolution of MAPS vs. collision rate



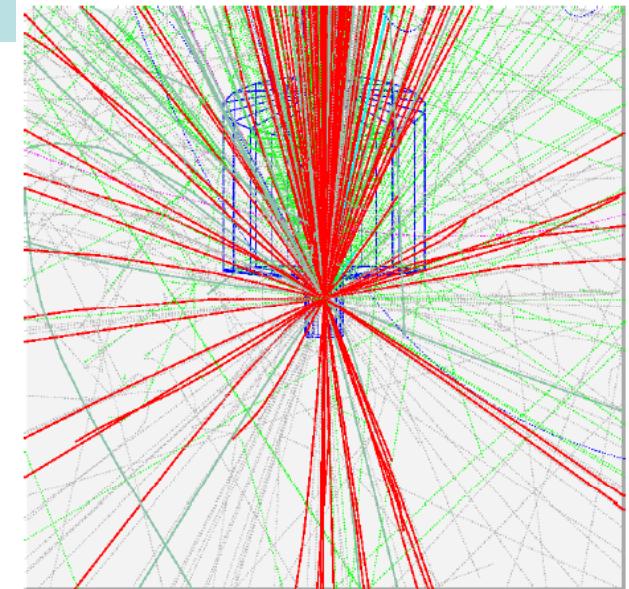
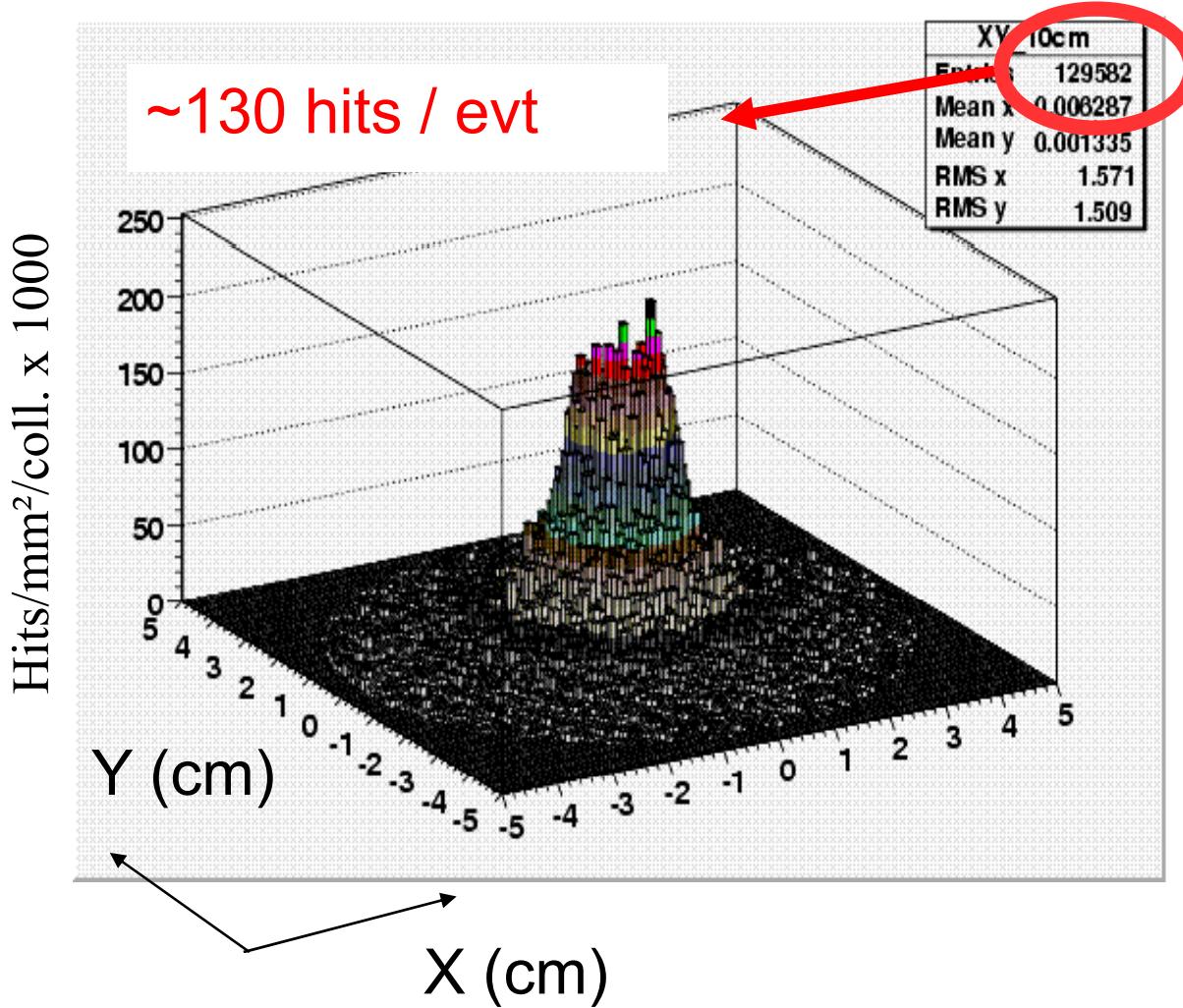
Expected collision rates:

Up to 10^9 heavy ions / sec (up to uranium @ 35 AGeV)
1% - target => Up to 10^7 collisions / s

Expect pile up of nuclear collisions in the vertex detector

Running conditions (1)

Average hit density from nuclear collisions (@ 10cm)

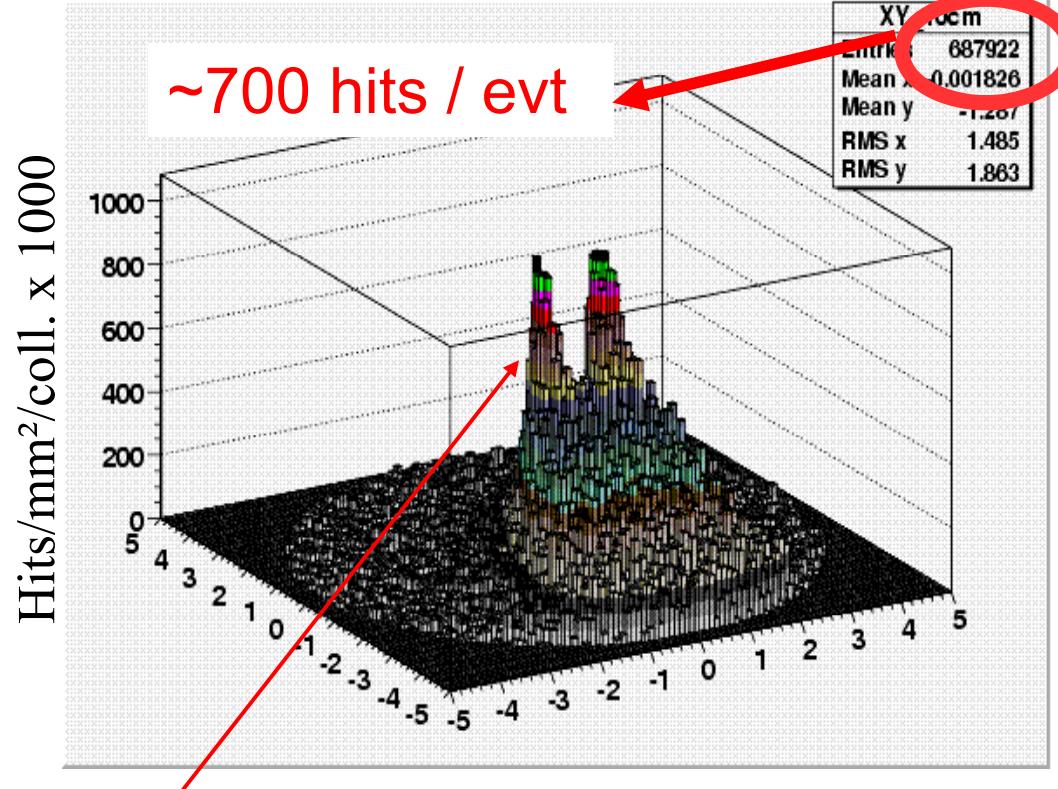


Typical non-central
collision

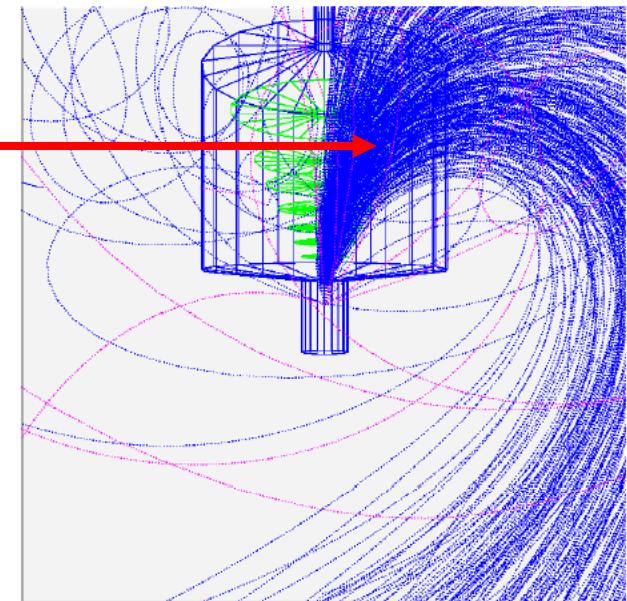
Running conditions (1)

Mean hit density from nuclear collisions (@ 10cm)

Incl. delta electrons from the target



Hot spots up to 1 hit / evt / mm²

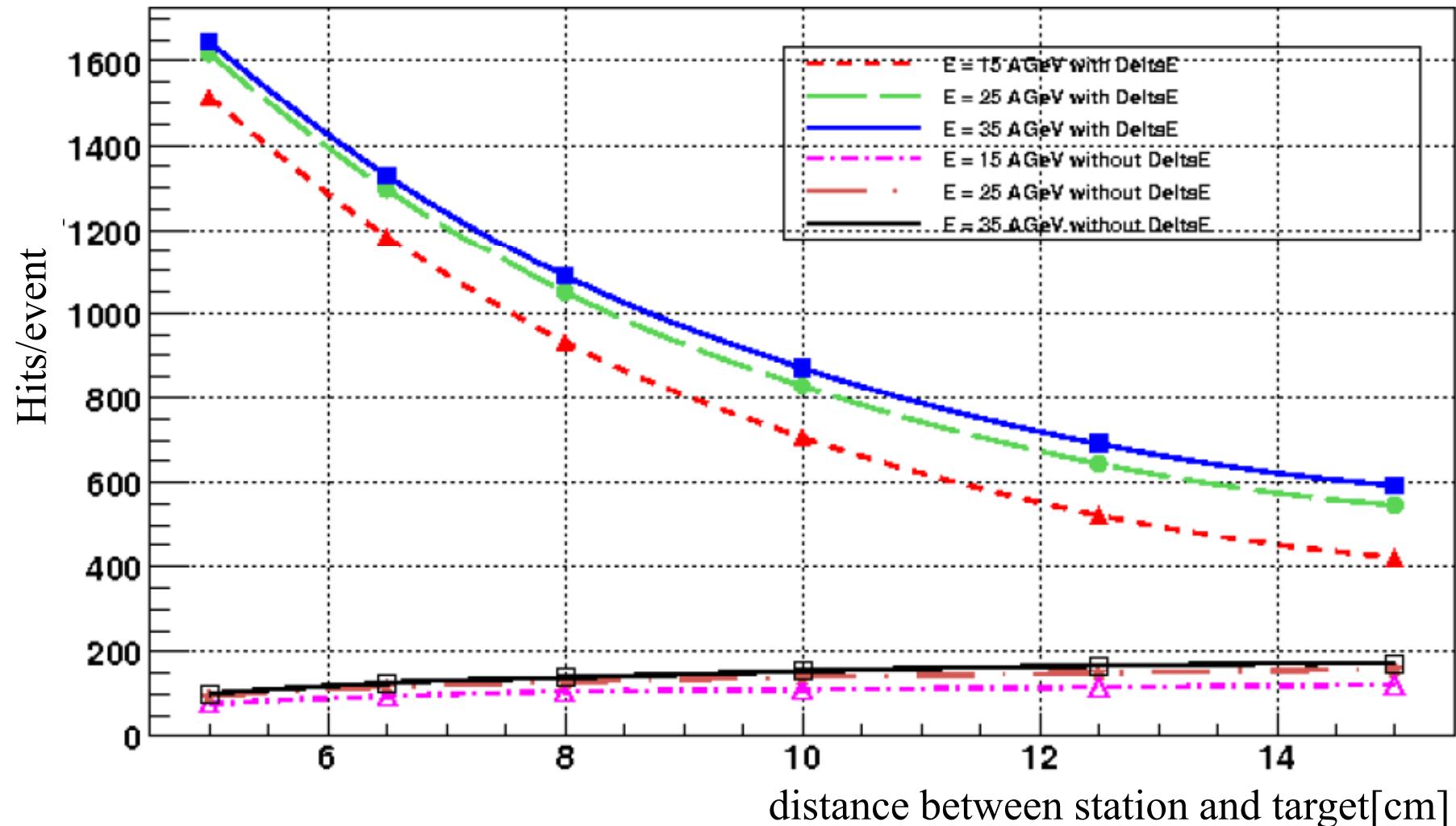


Rate	Hits (Max.)
100 kHz =>	0.7k (1/mm ²)
1 MHz =>	7k (10/mm ²)
10 MHz =>	70k (100/mm ²)

Adapt beam to abilities
of the detector!

Running conditions

integrated Hits/Event without Absorber



The occupancy is dominated by delta electrons generated in the target.
Handling them needs detector with very high granularity

Running conditions and consequences

Occupancy estimate:

Pixel pitch: $\sim 15 \mu\text{m} \Rightarrow 4.4\text{k pixel /mm}^2$

Assume collision rate of $\sim 1\text{MHz}$ for the first years + 5 fired pixels / hit:

$\Rightarrow 1.2\% \text{ occupancy @ } 10\text{cm}$

$\Rightarrow 4.0\% \text{ occupancy @ } 5\text{cm}$

Data flow estimate:

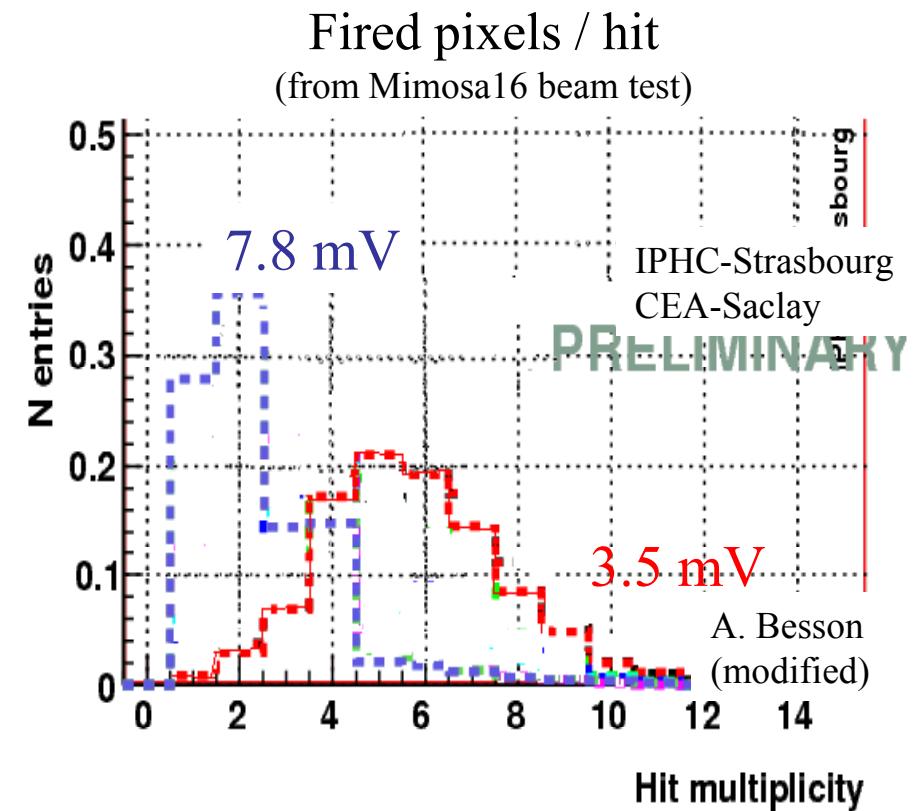
Assume on-chip zero suppression:

40-80 bit/cluster (including addresses)

1 MHz collision rate

$\Rightarrow \sim 5\text{-}10 \text{ GB/s @ } 10 \text{ cm}$

$\Rightarrow \sim 8\text{-}16 \text{ GB/s @ } 5 \text{ cm}$



Tracking?

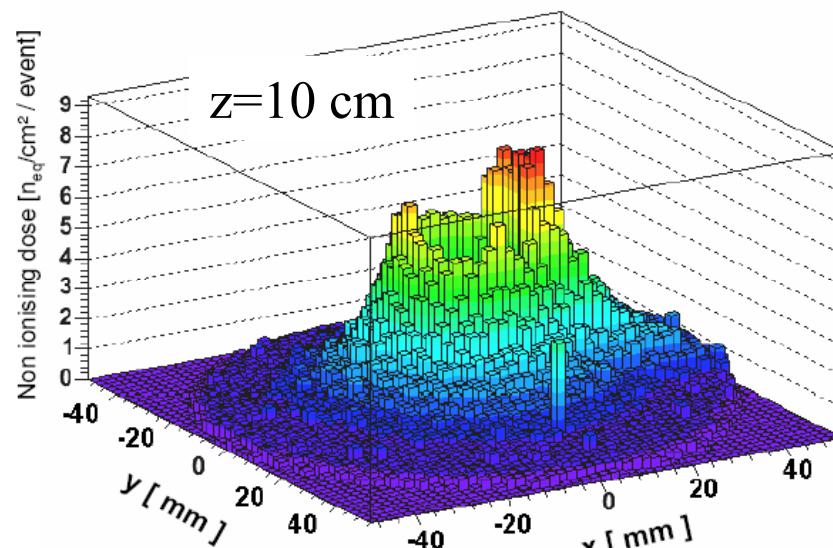
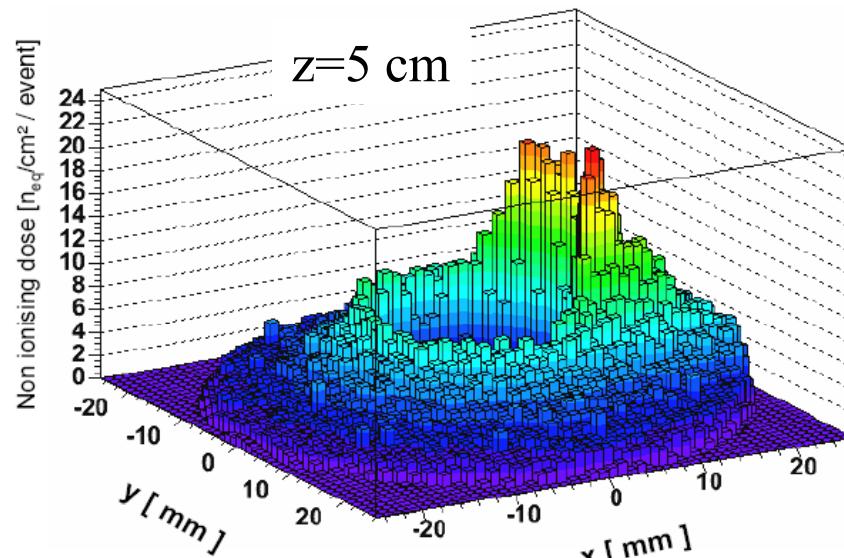
- Start in fast detectors of the STS,
- Extrapolate tracks to the MVD.

Validated excluding Delta-electrons

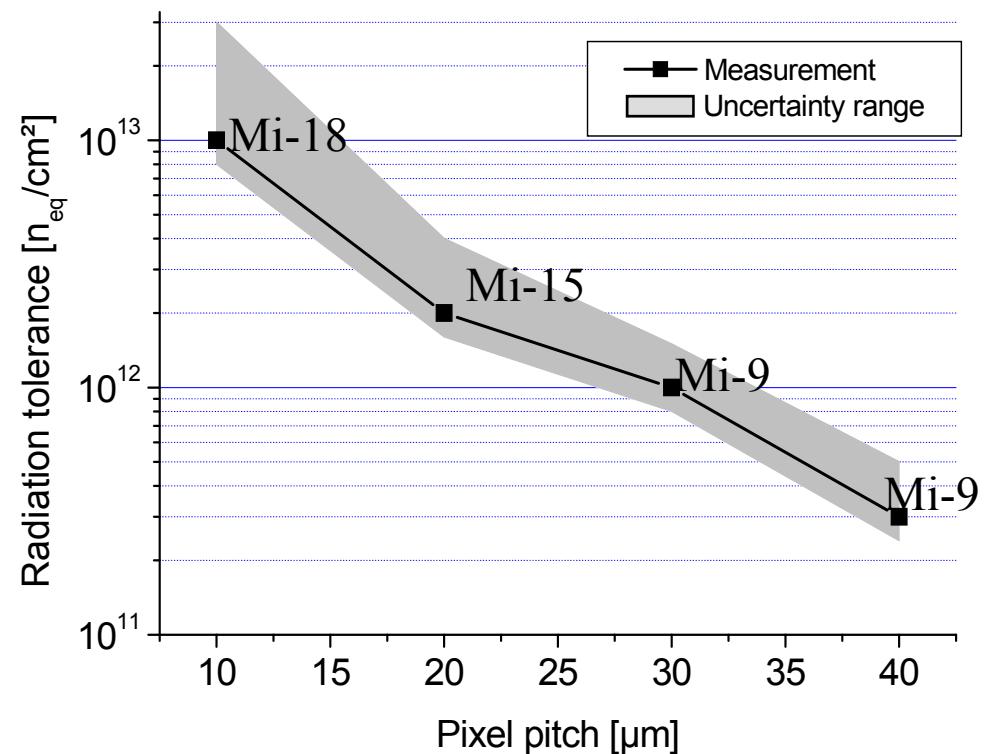
To be confirmed accounting for them

Radiation dose and tolerance

Full collision rate => few 10^{15} $n_{eq}/year$

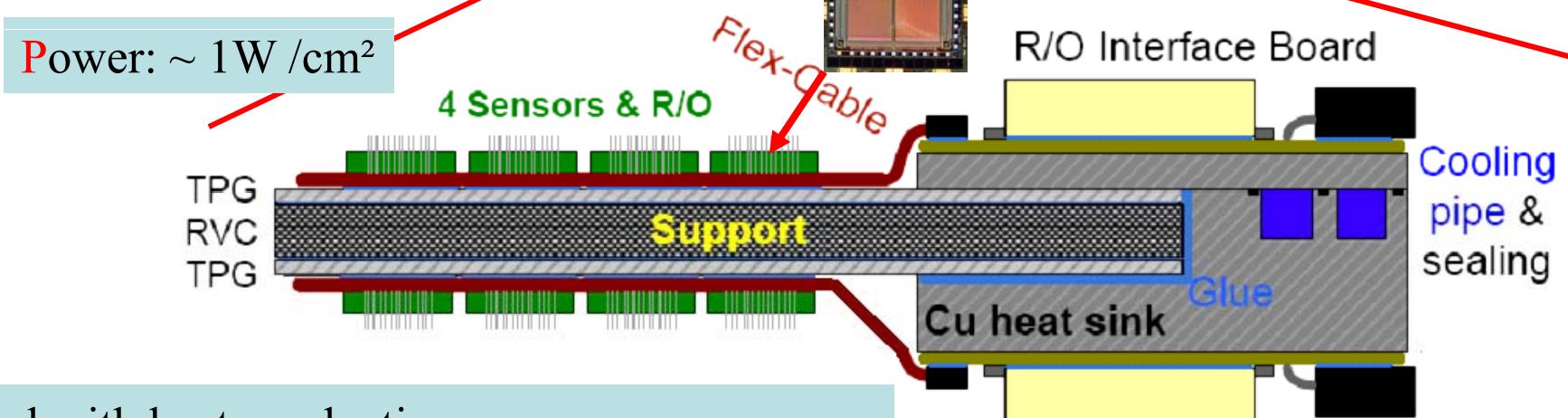
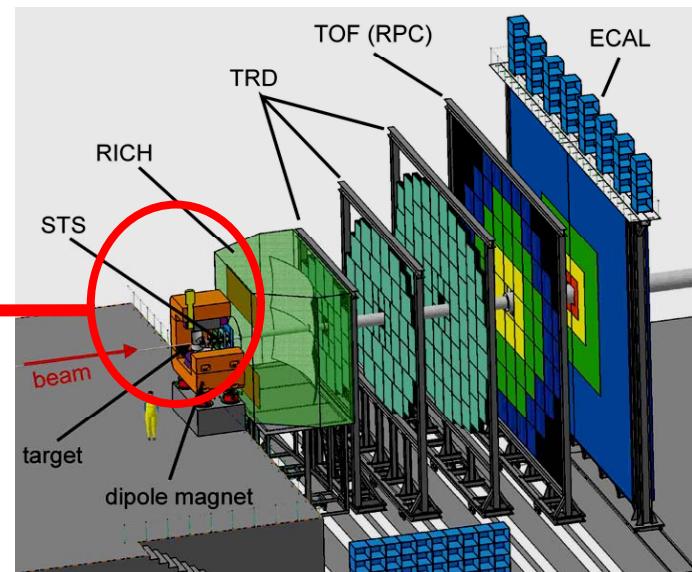
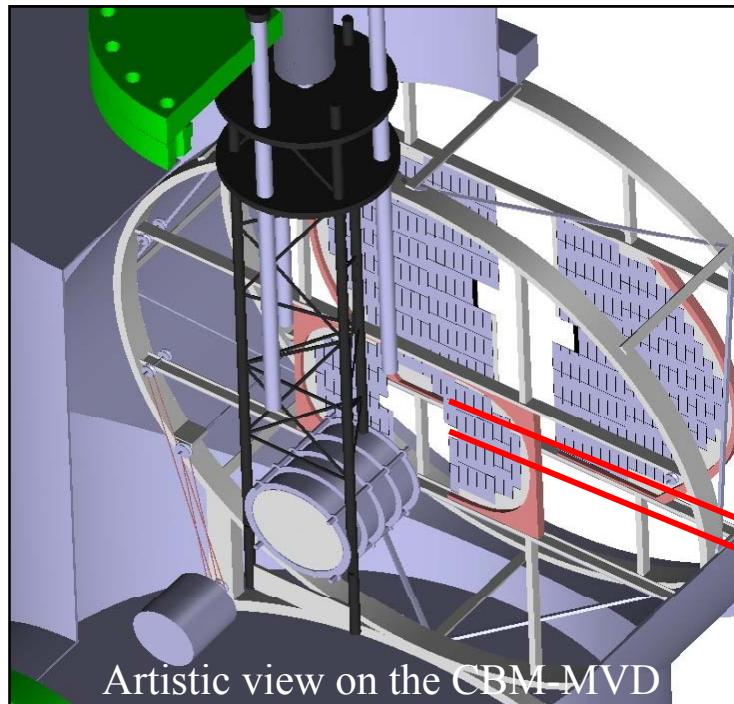


Radiation tolerance of MAPS



Assumption today:
 Detector may tolerate $10^{13} n_{eq}/\text{cm}^2$
 \Rightarrow two weeks beam on target (1 MHz)
 $\sim 5 \times 10^{11}$ coll. @ 5 cm
 $\sim 1 \times 10^{12}$ coll. @ 10 cm
 \Rightarrow Replace detector after one beam time

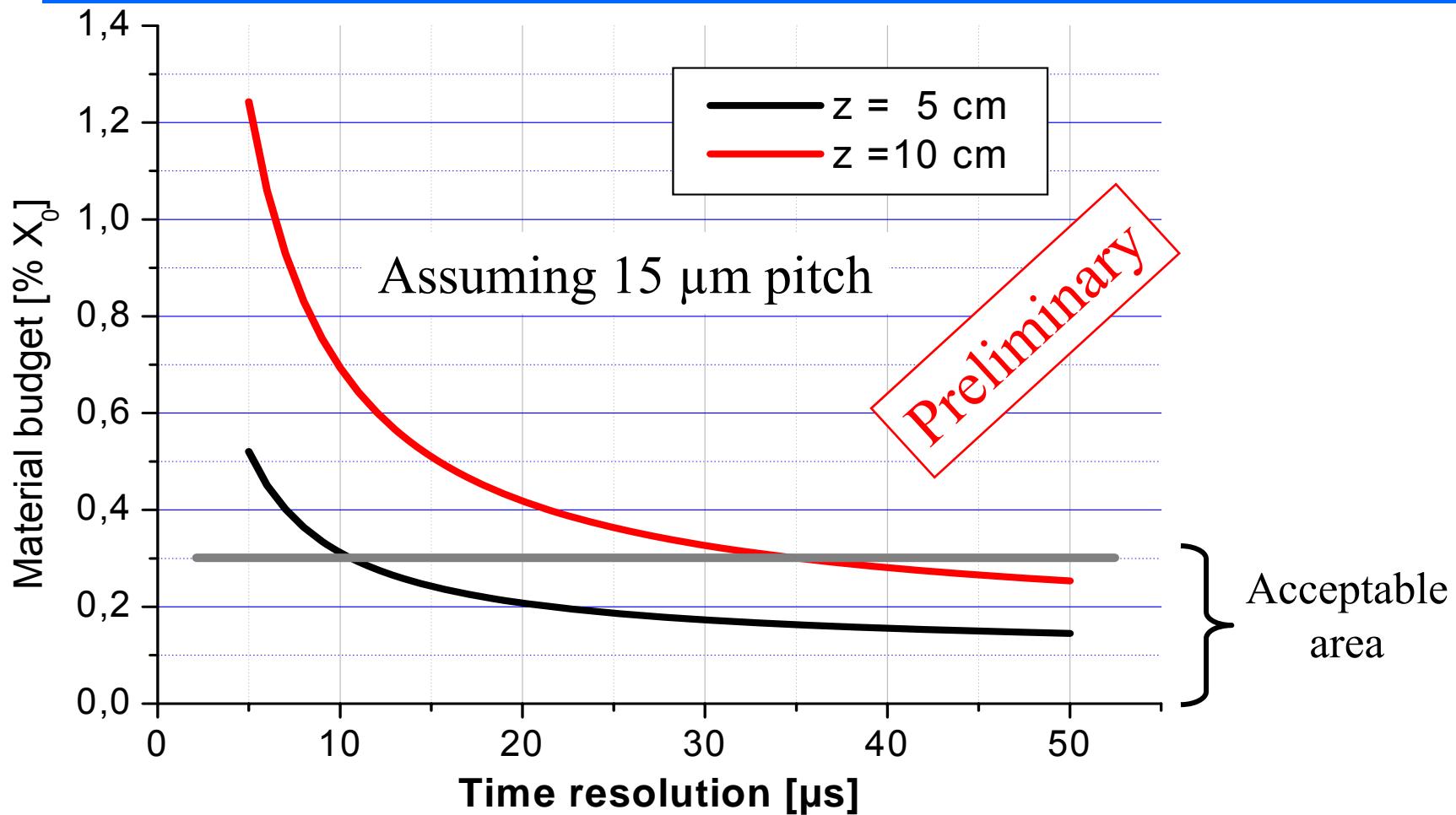
How it might look like



Cool with heat conduction:

TPG - ~ 1400 W/(m K), 3-4 times better than Cu

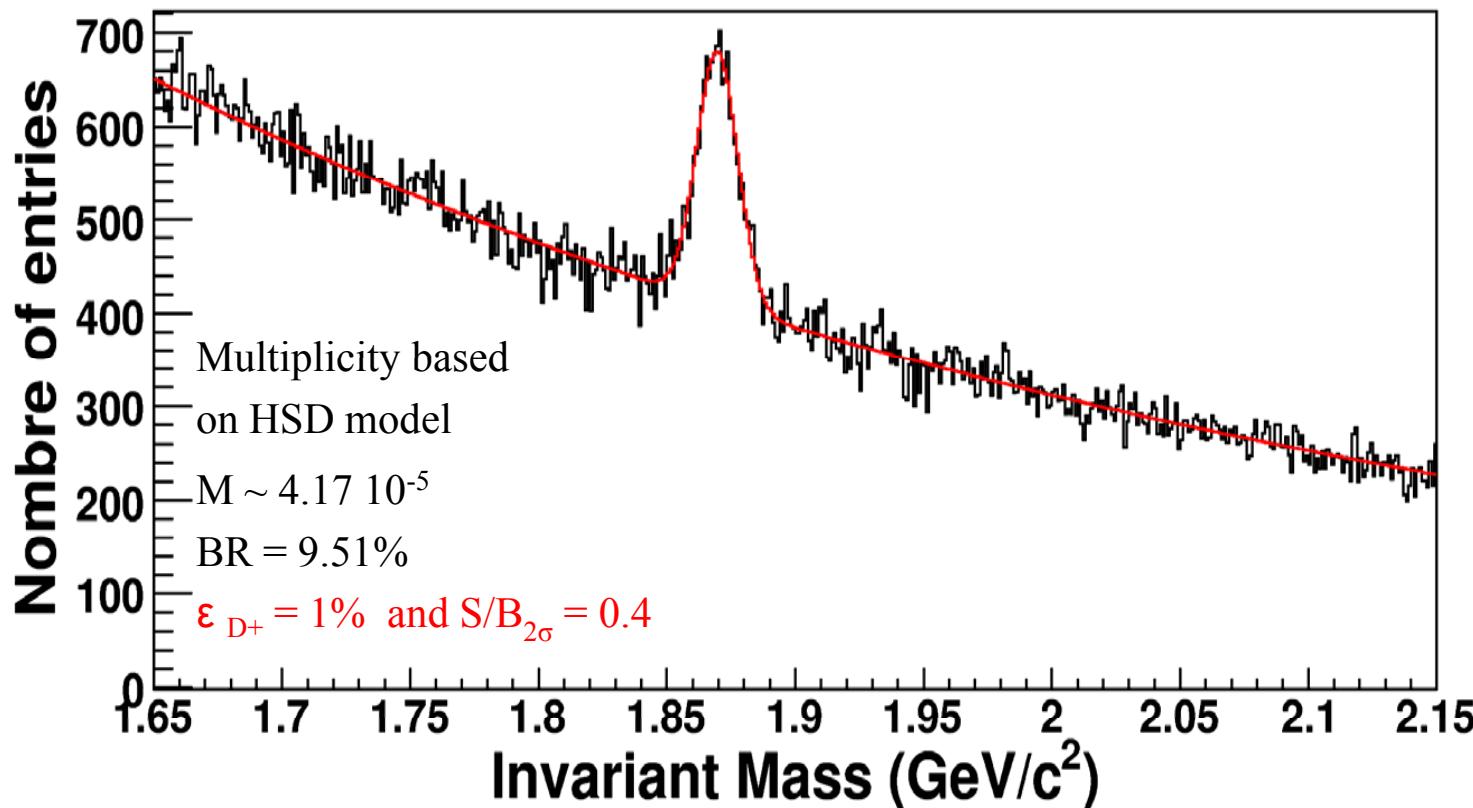
Material budget?



More speed needs more power => More material for cooling & cables
Larger diameter needs more pixels => Even more power & cables
Larger diameter needs longer ways for heat conduction => More material

Time resolution might need fine tuning accounting for material budget

Some simulation results (25 AGeV)



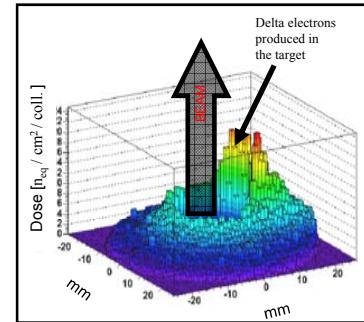
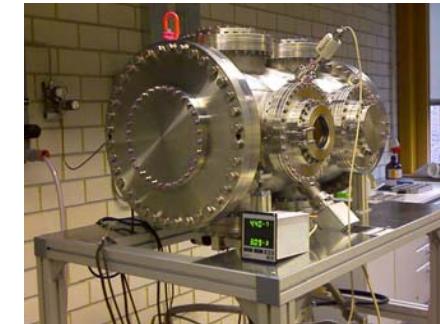
We expect $\sim 5k$ (up to few 10k) reconstructed D^+ within 2 weeks of measurement (10^{12} coll. at 10^6 coll./s, 25 AGeV). λ_C can be seen.

Expect better results for 35 AGeV (higher multiplicities)

But: Material budget of the detector must not exceed $\sim 0.3\% X_0$ per layer

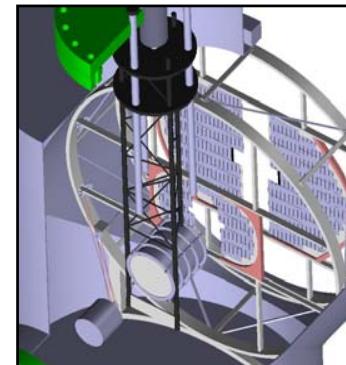
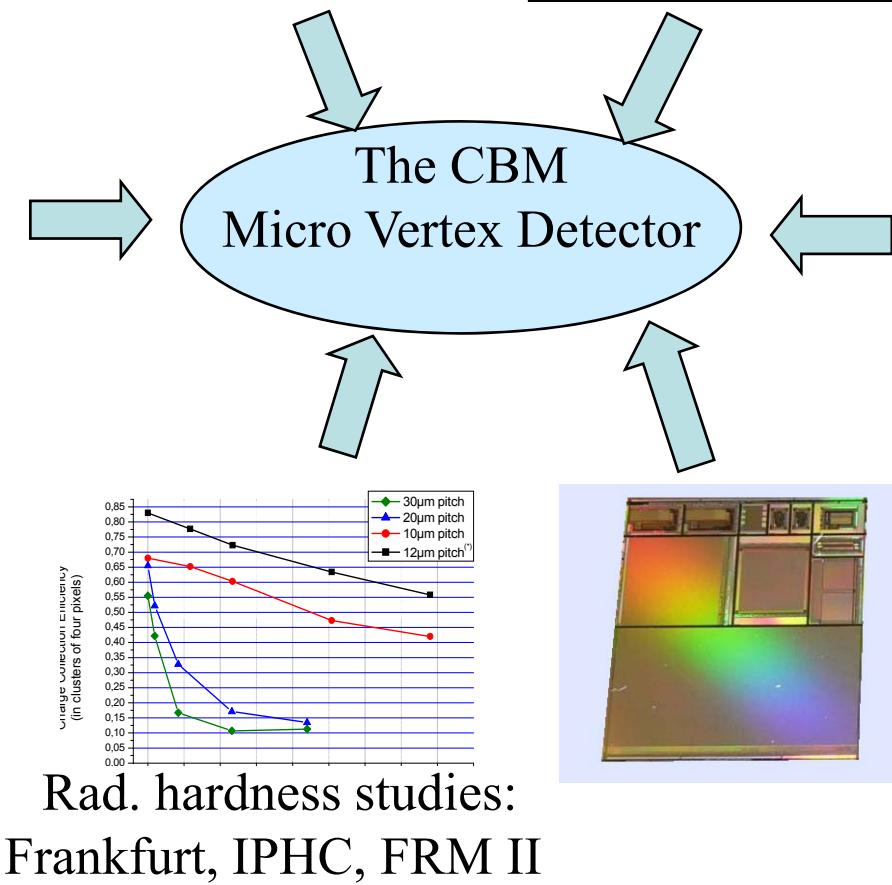
Research lines for the MVD

Mechanical system
integration R&D
@ Frankfurt



Simulation studies
@ GSI + IPHC

Electronic system
integration R&D
@ Frankfurt



Design studies

MAPS R&D
@ IPHC

Summary and conclusion

The CBM experiment aims for a first time to measure open charm being emitted from heavy ion collisions at beam energies between 10 and 45 AGeV

This requires a vertex detector with:

- very low material budget ($\sim 0.3\% X_0/\text{layer}$)
- good radiation hardness (minimum $10^{13} \text{ n}_{\text{eq}}/\text{cm}^2$, optimal $> 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$)
- good time resolution (minimum $\sim 10\mu\text{s}$, optimal $< 100 \text{ ns}$)
- good spatial resolution ($\sim 5 \mu\text{m}$ or better)
- vacuum compatible design and cooling

Currently we consider CMOS sensors (by IPHC) as baseline technology
Excessive R&D seems required to match the needs

R&D on radiation hardness of CMOS sensors and detector integration have started (KIT and Goethe University Frankfurt)

We will presumably proceed in two phases:

- A CMOS sensor based detector operating roughly 2015 (min. performance)
- A novel technology based detector operating few years later

We are open to alternative technologies, advices and collaborators.

The CBM collaboration

China:

CCNU Wuhan
USTC Hefei

Croatia:

RBI, Zagreb

Cyprus:

Nikosia Univ.

Czech Republic:

CAS, Rez
Techn. Univ. Prague

France:

IPHC Strasbourg

Germany:

Univ. Heidelberg, Phys. Inst.
Univ. HD, Kirchhoff Inst.
Univ. Frankfurt
Univ. Kaiserslautern

Univ. Mannheim

Univ. Münster

FZ Rossendorf

GSI Darmstadt

Hungary:

KFKI Budapest
Eötvös Univ. Budapest

India:

VECC Kolkata
SAHA Kolkata
IOP Bhubaneswar
Univ. Chandigarh
Univ. Varanasi
IIT Kharagpur

Korea:

Korea Univ. Seoul
Pusan National Univ.

Norway:

Univ. Bergen

Poland:

Krakow Univ.
Warsaw Univ.
Silesia Univ. Katowice
Nucl. Phys. Inst. Krakow

Portugal:

LIP Coimbra

Romania:

NIPNE Bucharest

Russia:

IHEP Protvino
INR Troitzk
ITEP Moscow
KRI, St. Petersburg

Kurchatov Inst. Moscow

LHE, JINR Dubna

LPP, JINR Dubna

LIT, JINR Dubna

MEPHI Moscow

Obninsk State Univ.

PNPI Gatchina

SINP, Moscow State Univ.

St. Petersburg Polytec. U.

Ukraine:

Shevchenko Univ., Kiev

46 institutions

> 400 members

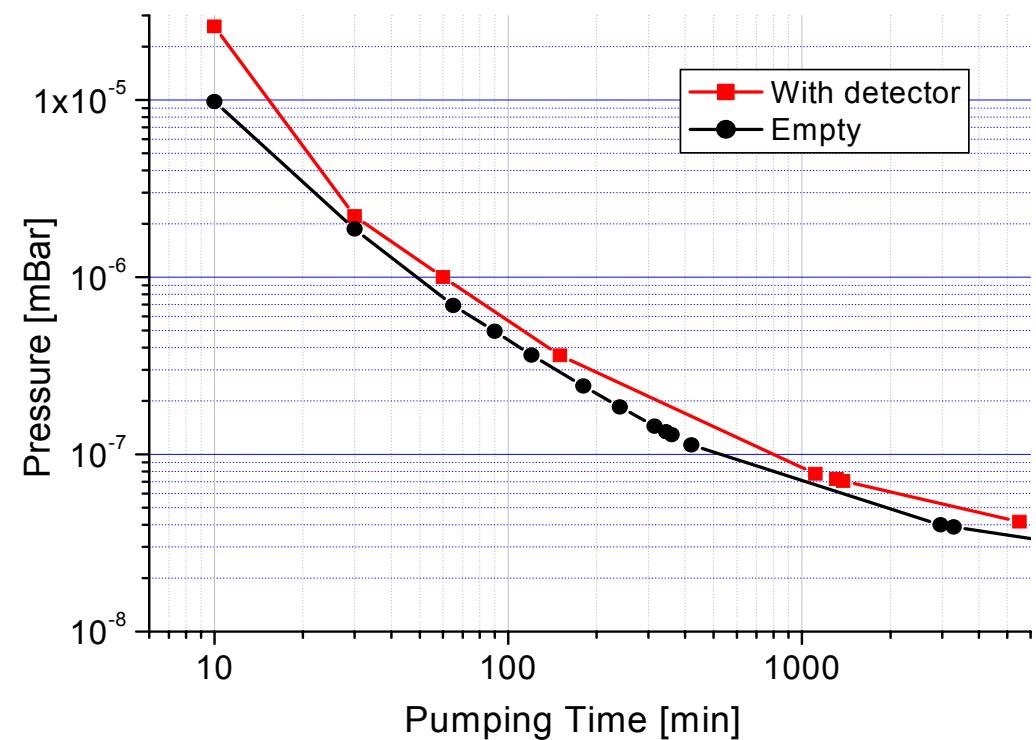
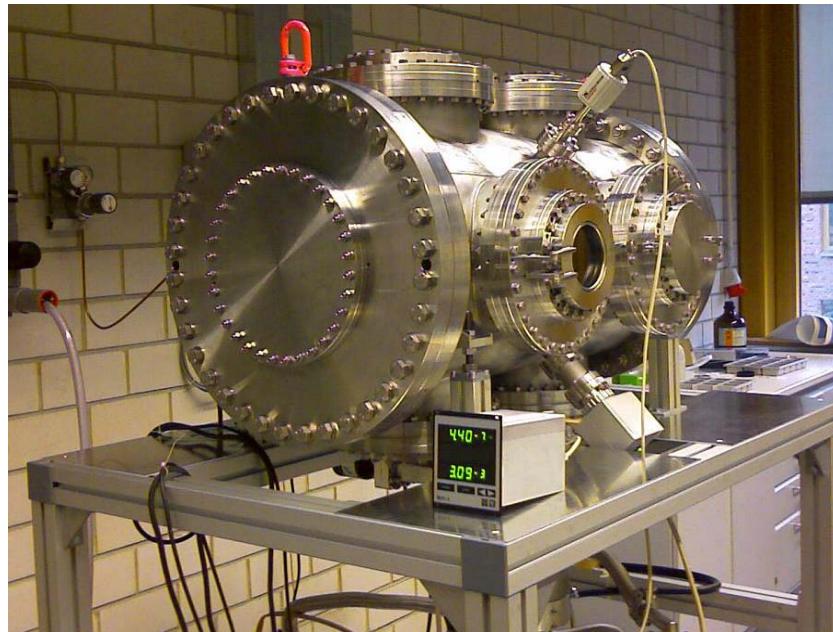


Strasbourg, September 2006

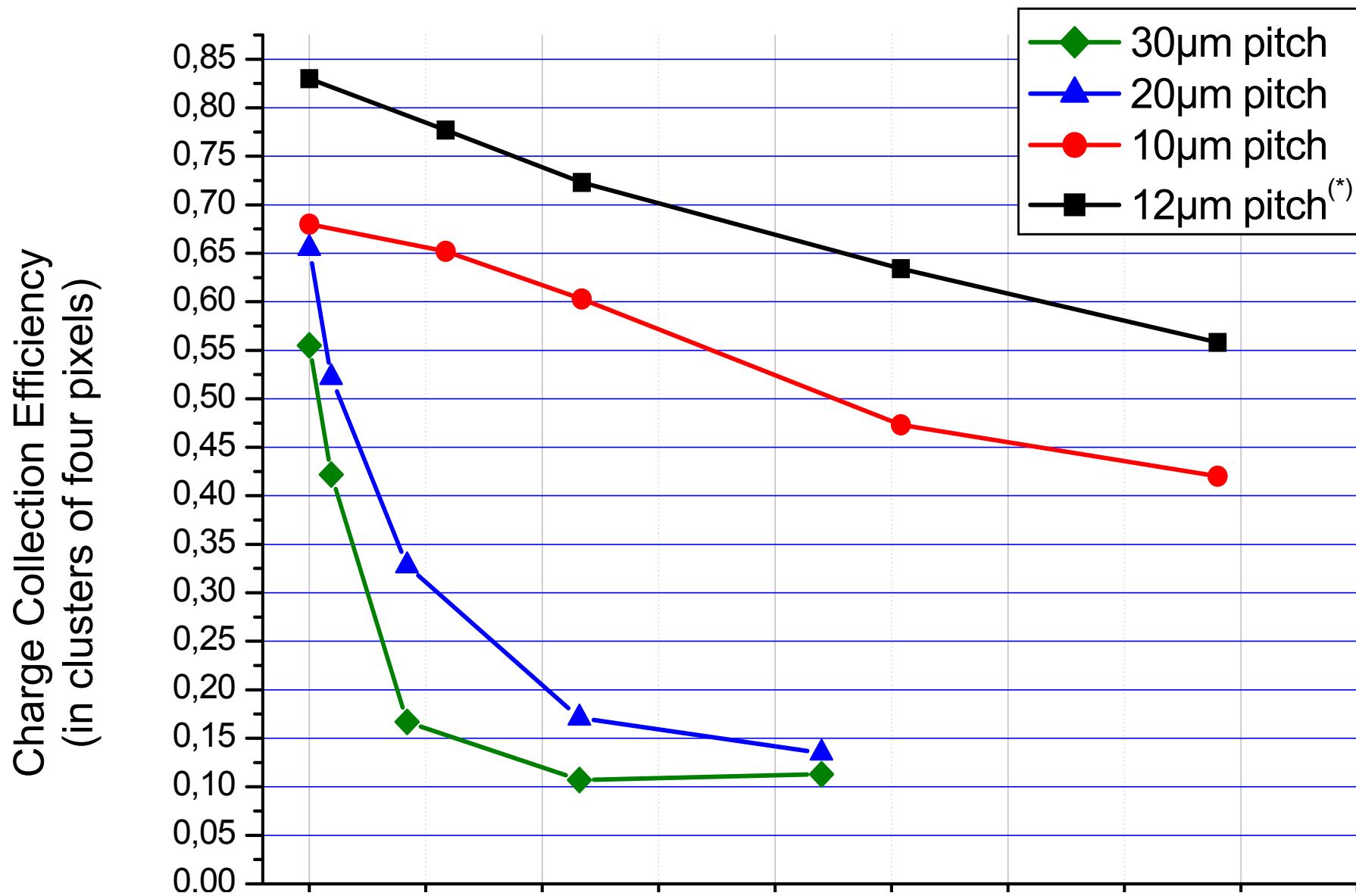
Backup

First vacuum compatibility tests

High-tech prototype ladder for vacuum tests (silicon glued on TPG)



Radiation hardness of MAPS



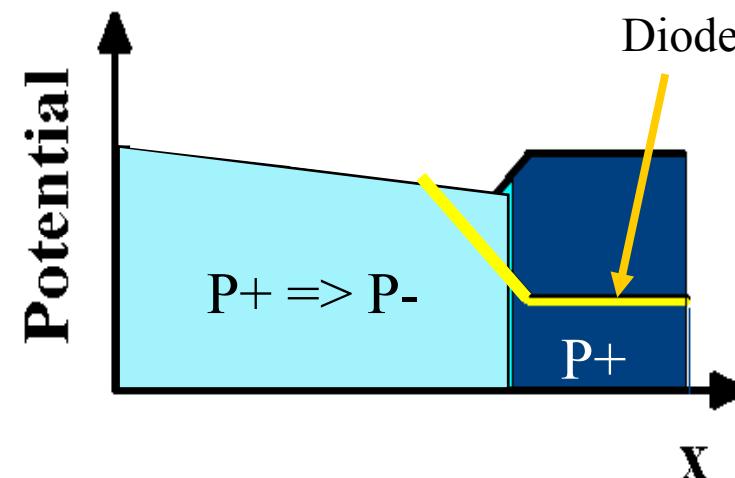
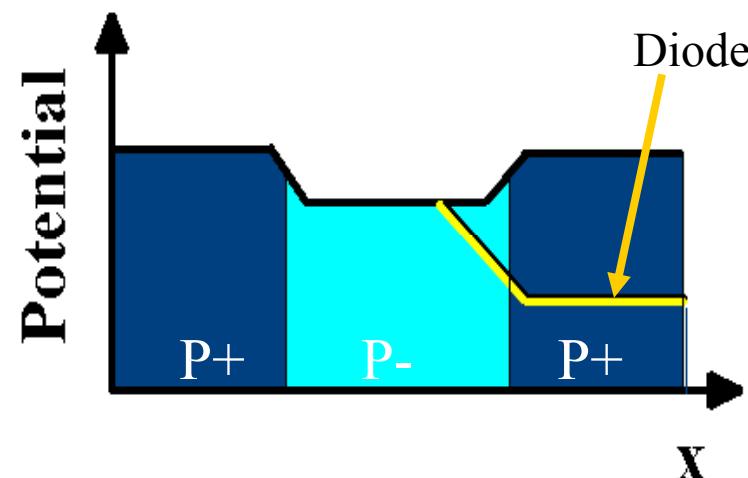
Outlook Radiation hardness

Non-ionizing radiation hardness:

Limitation:

Slow charge collection in the sensor + reduced lifetime of signal electrons

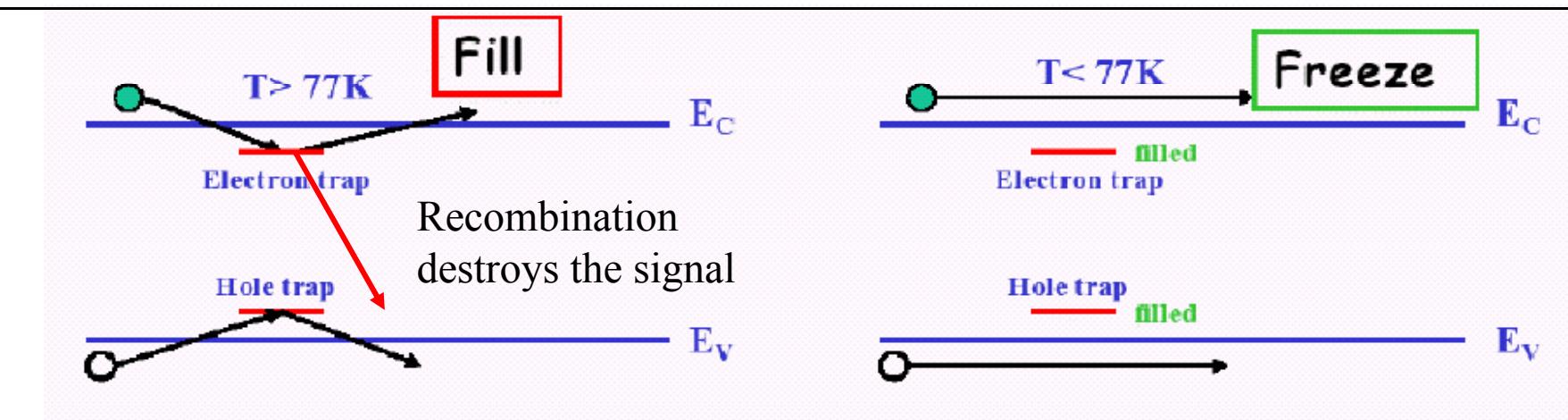
Approach (1): Speed up charge collection:



Pixel with gradient doping.
Attractive build in potential?

Outlook Radiation hardness

Approach (2): Restore lifetime of electrons



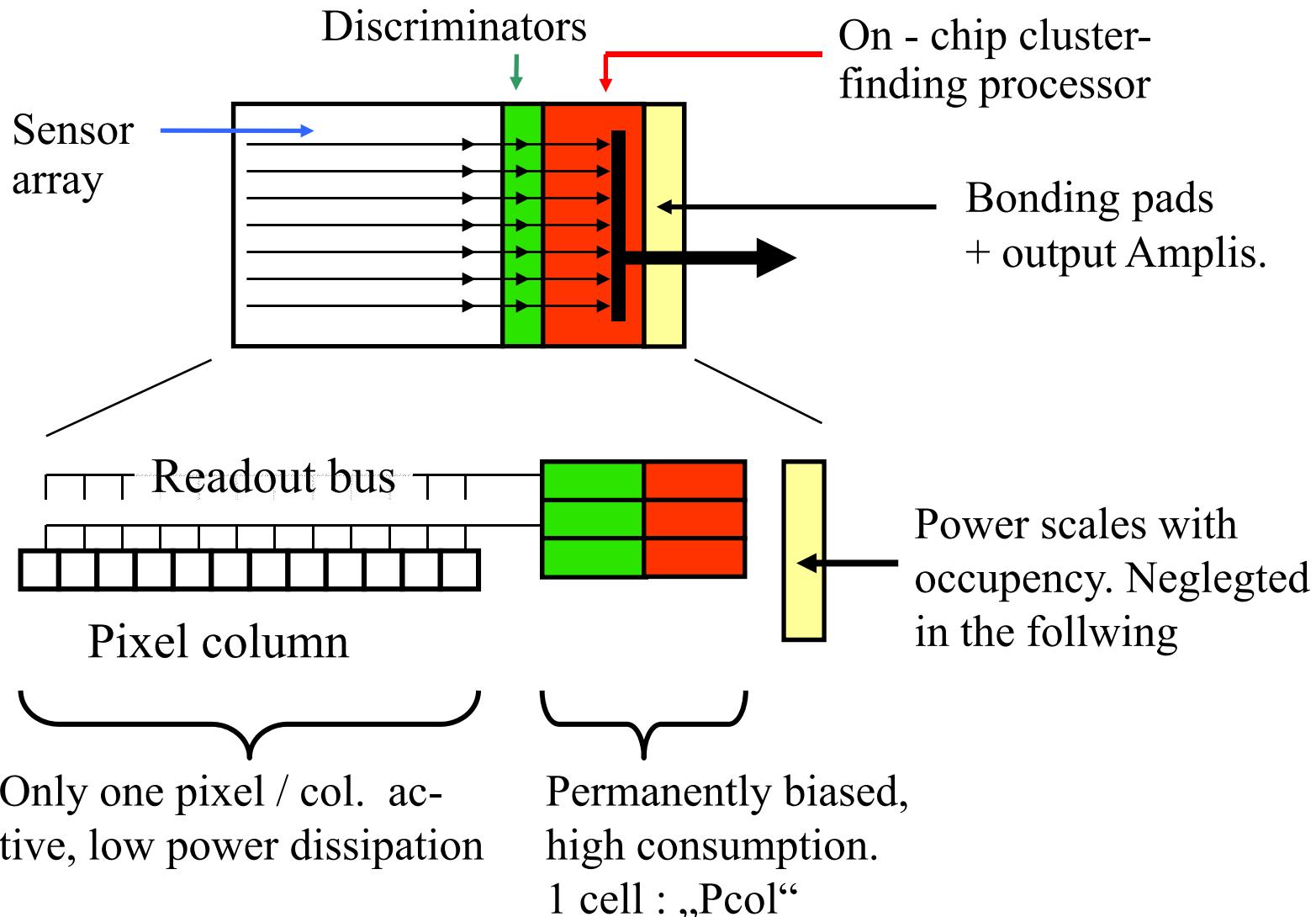
If the Si is cold enough, once the trap is filled, it remains filled

T(K)	300	150	100	77	60	55	50	48	47	46
τ_d	3.7 ns	3.9 μs	4 ms	2 s	1.22 hrs	1.2 days	53 days	302 days	2.1 years	5.47 years

X. Rouby RESMDD Florence Oct. 11, 2006
On behalf of CERN RD39 Collaboration

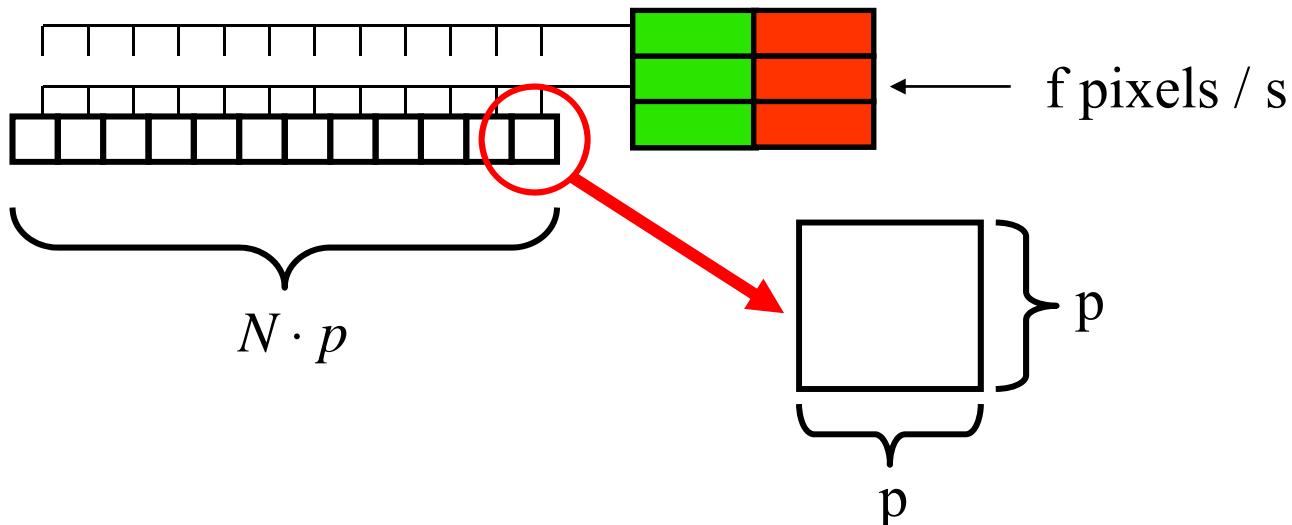
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The power dissipation of MAPS



Basic assumption: Power scales with number of the end of column logics (discriminator + cluster finding processor)

The power dissipation of MAPS



$$t_{Int} \approx 10\mu s$$

$$f \approx 5 \dots 10 MHz$$

$$P_{Col} \approx 0.5 mW$$

Time resolution of MAPS

Readout freq. (Pixels / time)

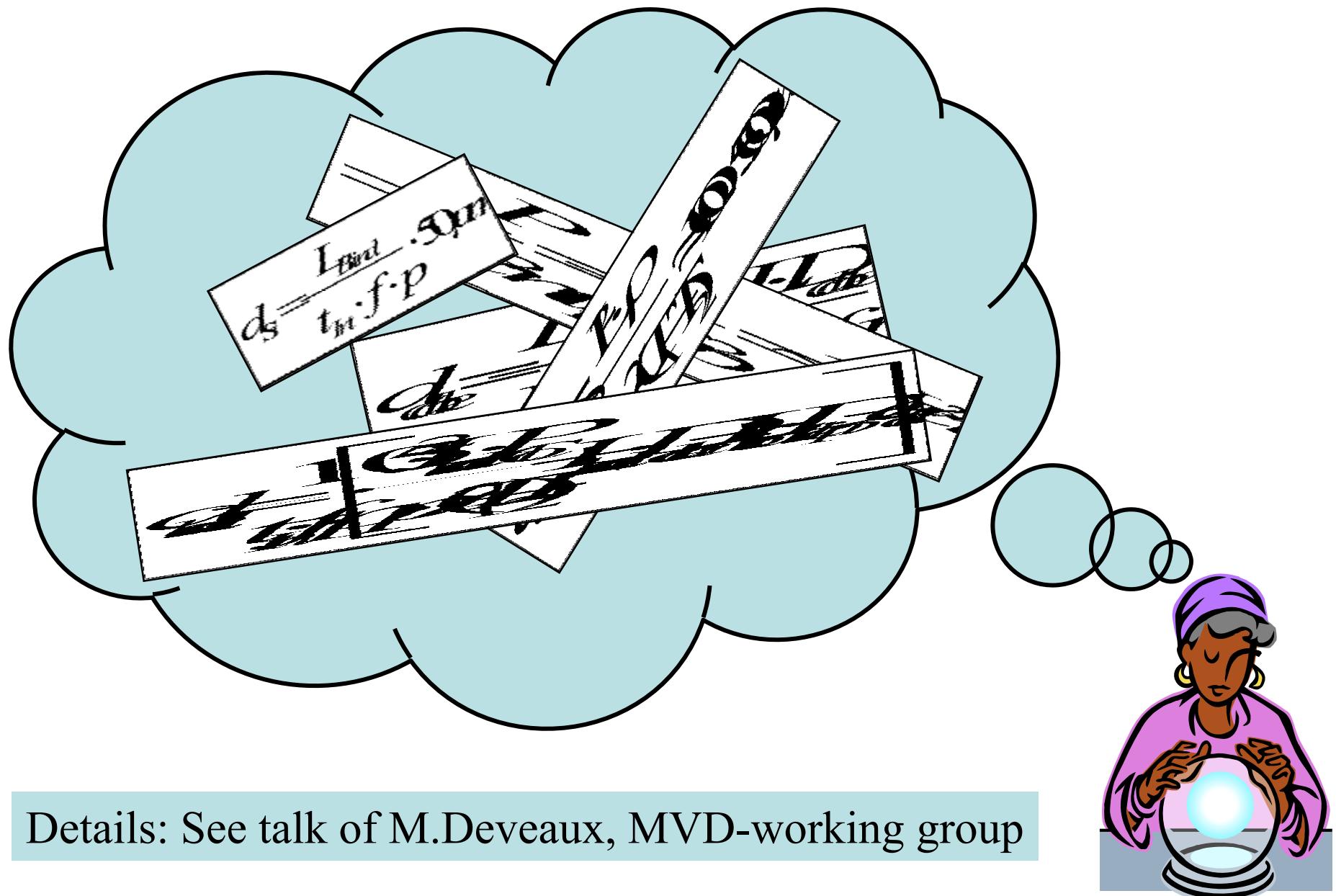
Power of one logic cell

The surface of one column is: $S = N \cdot p^2$

With: $N = t_{Int} \cdot f$ pixels

$$\Rightarrow \rho = \frac{P}{cm^2} = \frac{P_{Col}}{t_{Int} \cdot f \cdot p^2} = \sim 1 W/cm^2$$

The material buget of the MVD



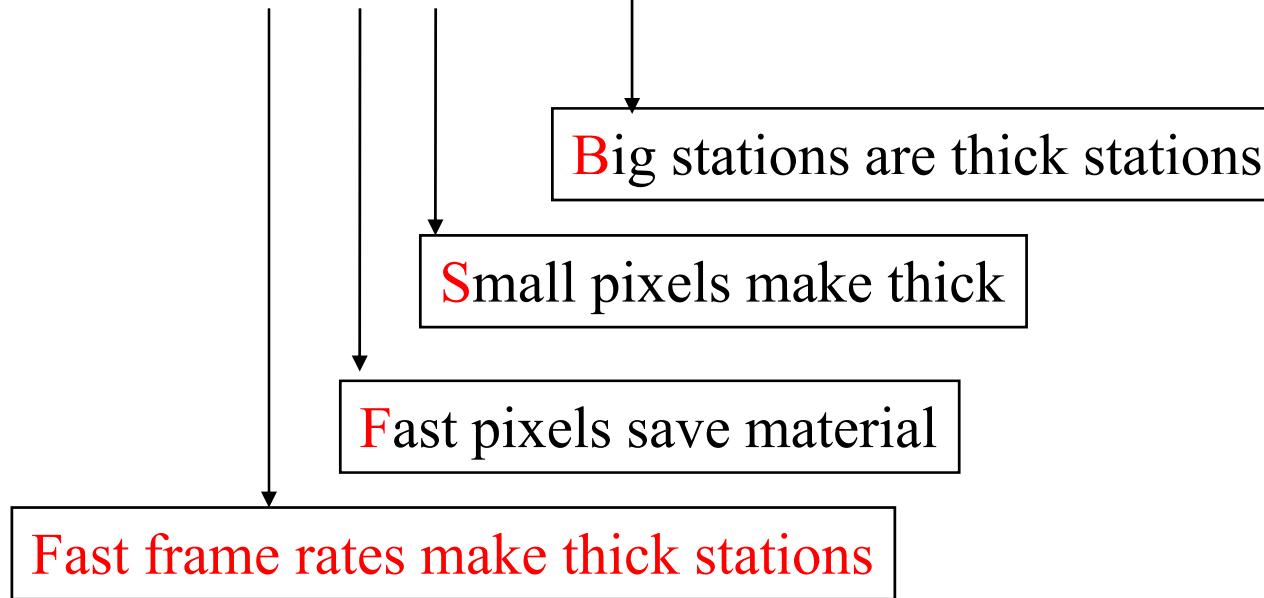
Details: See talk of M.Deveaux, MVD-working group

Correlations of the thickness

$$d_{ladder} = d_{cool} + d_{cable} + d_{Si} + d_{others}$$

$$d_{ladder} = \frac{1}{t_{Int} \cdot f \cdot p} \cdot [C_1 \cdot L_{ladder}^2 + C_2 \cdot L_{ladder} + C_3]$$

(Simplified)



$t_{Int} \approx 10\mu s$

Time resolution of MAPS

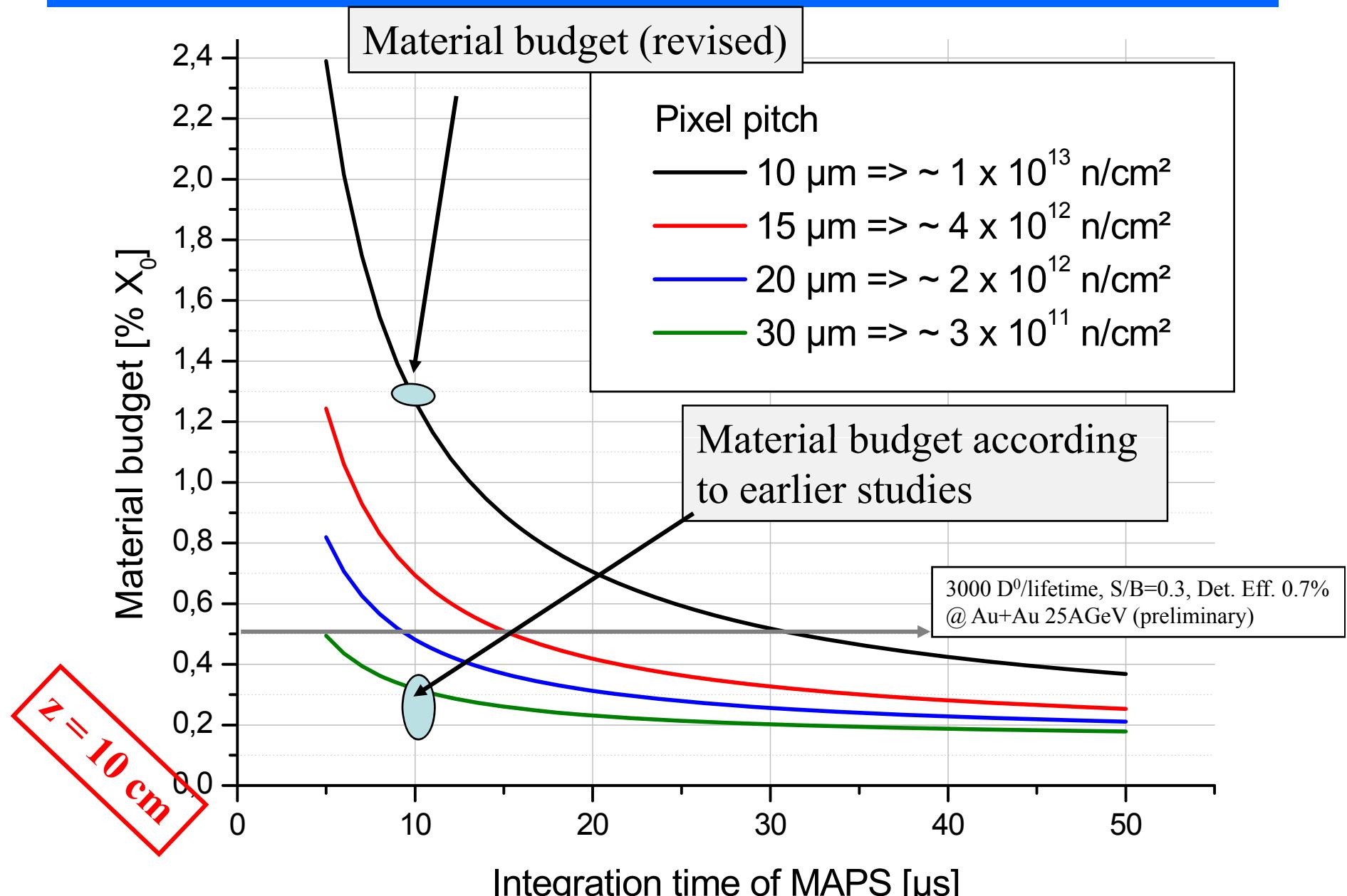
$f \approx 5 \dots 10 MHz$

Readout freq. (Pixels / time)

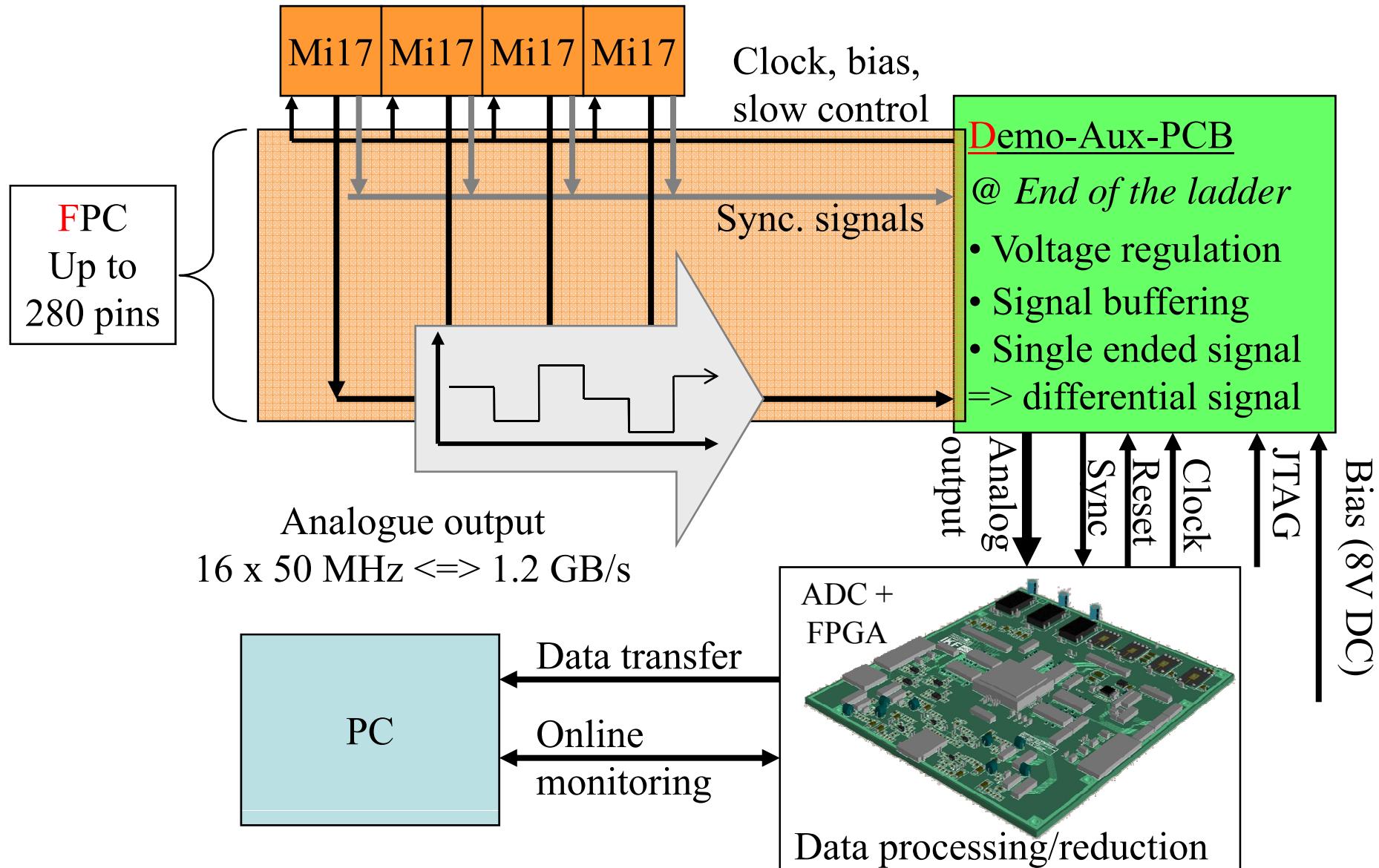
$p \approx 10 \dots 30 \mu m$

Pixel pitch

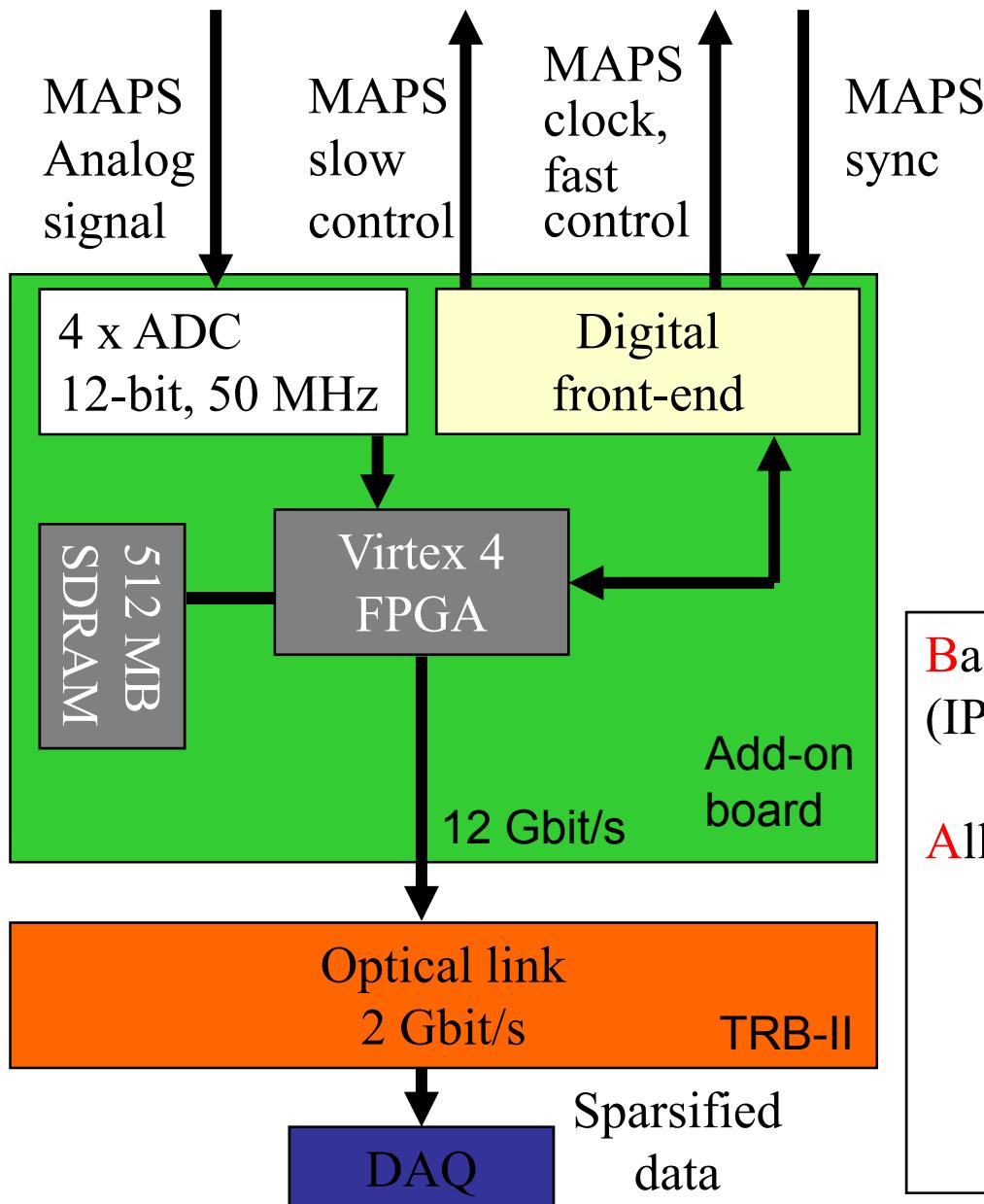
Correlation of thickness



Electronic system integration studies (Readout concept)



How to study things more in detail => R&D in Frankfurt



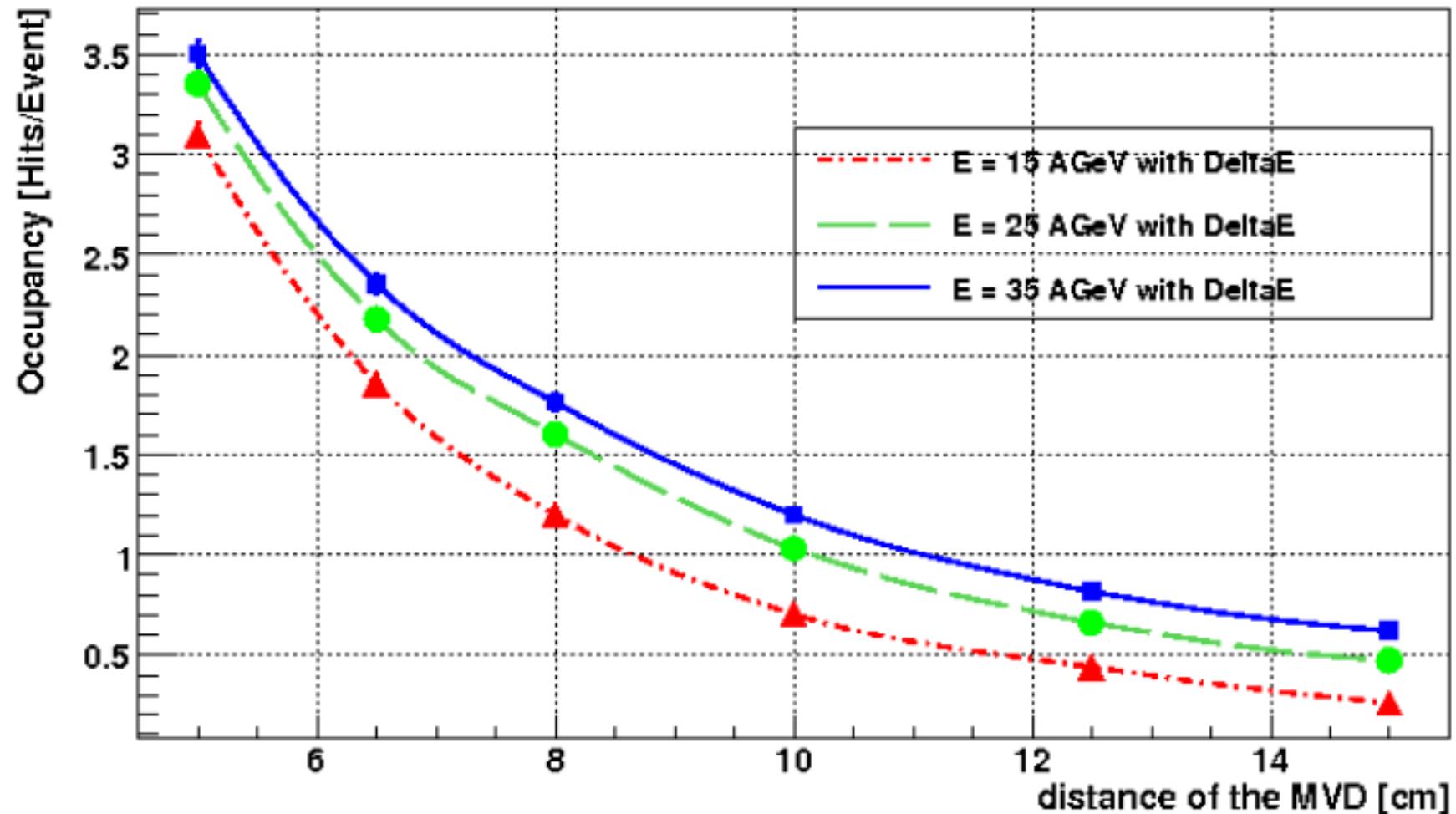
Bases on existing USB-FPGA board
(IPHC, Strasbourg)

Allows for:

- FPGA-based data sparsification (CDS, clustering, data compression)
- Pipeline readout of MIMOSA-17 (~ 1 ms time resolution) without dead time

Running conditions

Occupancy of the Hotspots without Absorber



Needs still to be scaled with pile – up (up to factor 100)