

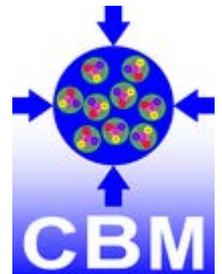
Measurement of rare probes with the Silicon Tracking System of the CBM experiment at FAIR

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Darmstadt, Germany*

for the CBM Collaboration

Quark Matter 2014 ,
Darmstadt, Germany, 19-24 May 2014



Outline

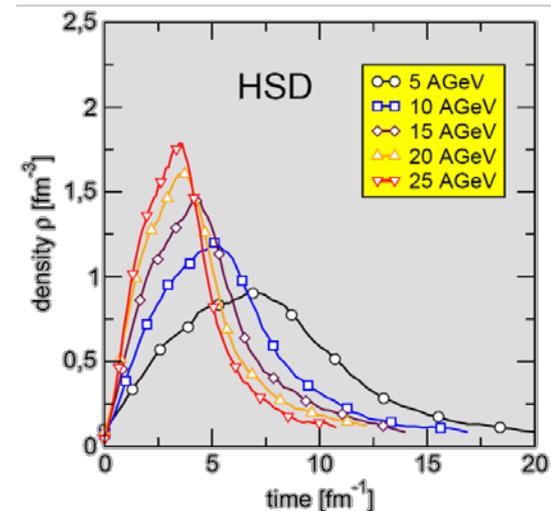
- *Compressed Baryonic Matter*
- *Meeting the experimental challenges*
- *The Silicon Tracking System*
- *On-line event reconstruction*
- *Measurement of rare probes*

The CBM Physics Program

- comprehensive program to explore the phase diagram of strongly interacting matter at highest net baryon densities and moderate temperatures:

“Compressed Baryonic Matter”

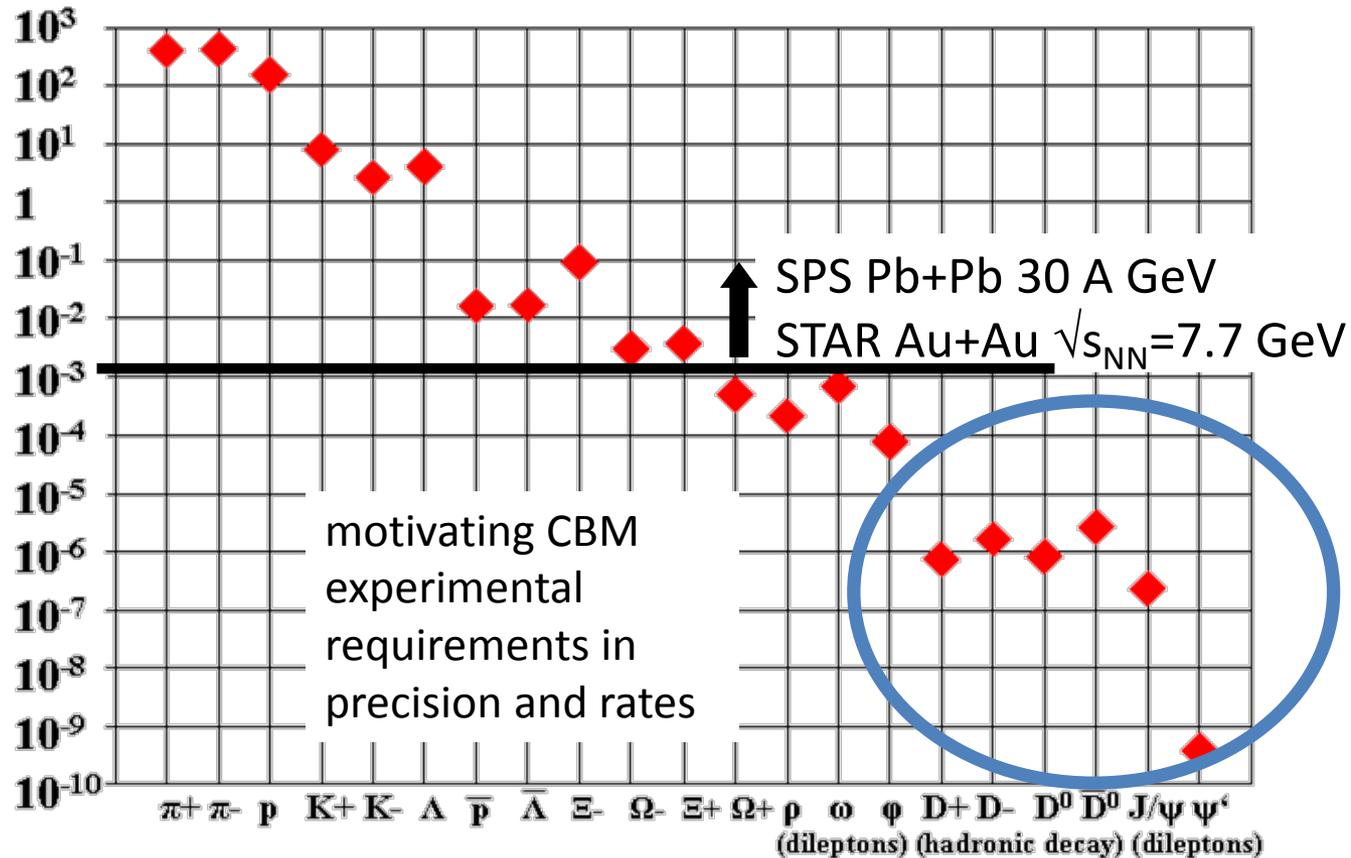
- heavy-ion collisions from 2 – 45 GeV/nucleon at FAIR
 - SIS100
 - 2 to 14 GeV/nucleon for nuclei
 - up to 29 GeV for protons
 - SIS300:
 - up to 45 GeV/nucleon for nuclei
 - up to 90 GeV for protons
 - beam extracted from SIS100/300 to the CBM experimental hall



Experimental challenges: Rare probes

particle multiplicity
 × branching ratio

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



CBM Detector – Design constraints

High interaction rates

- $10^5 - 10^7$ Au+Au collisions/sec.

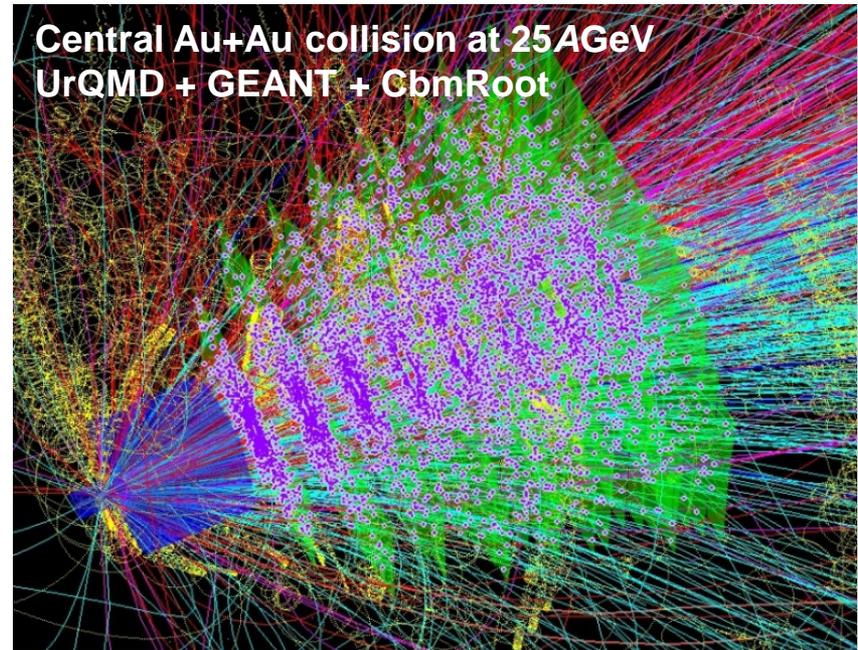
Fast and radiation hard detectors

Free streaming read-out

- time-stamped detector data
- high speed data acquisition

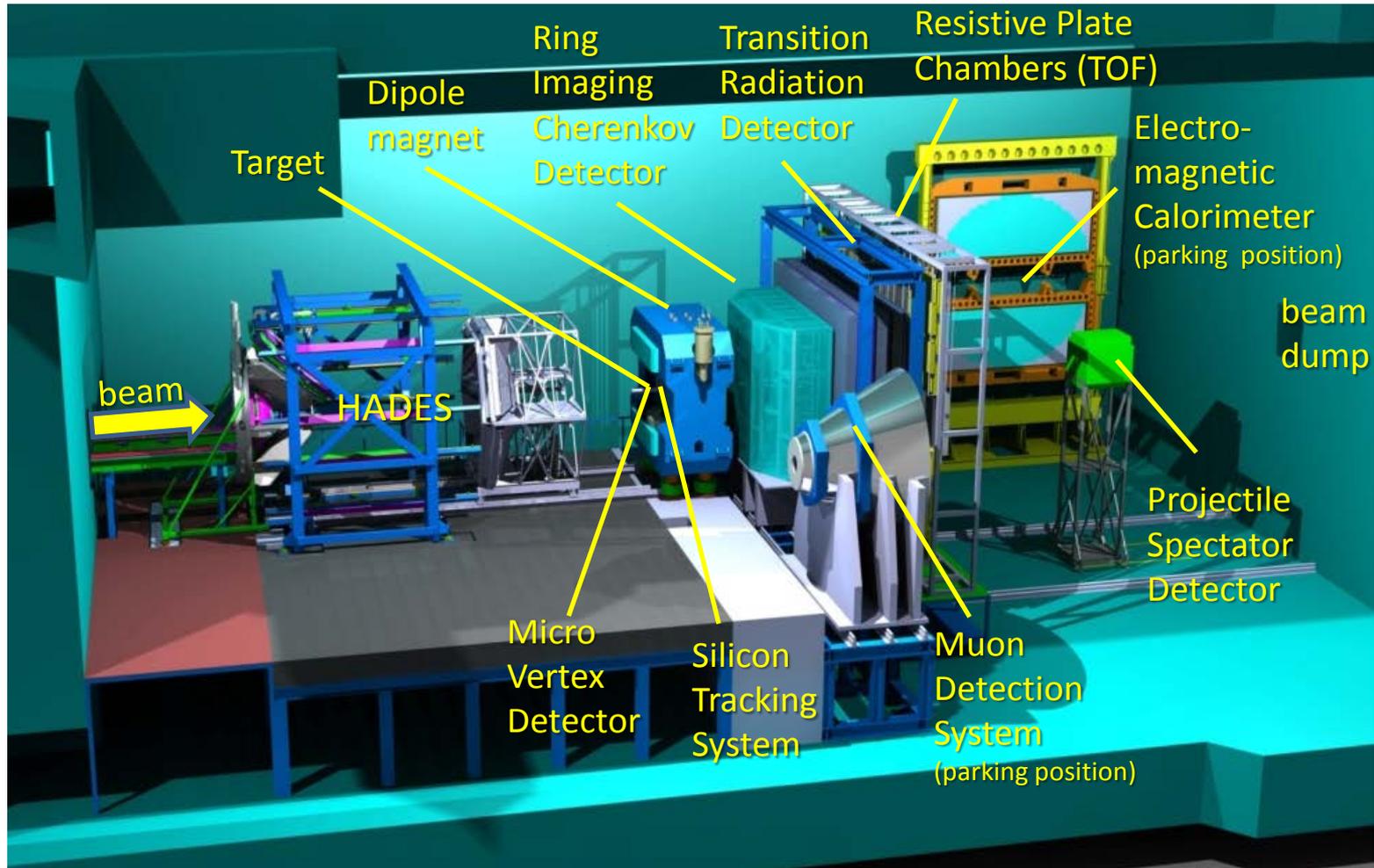
On-line event reconstruction

- powerful computing farm
- 4-dimensional tracking
- software triggers



tracks in the Silicon Tracking System

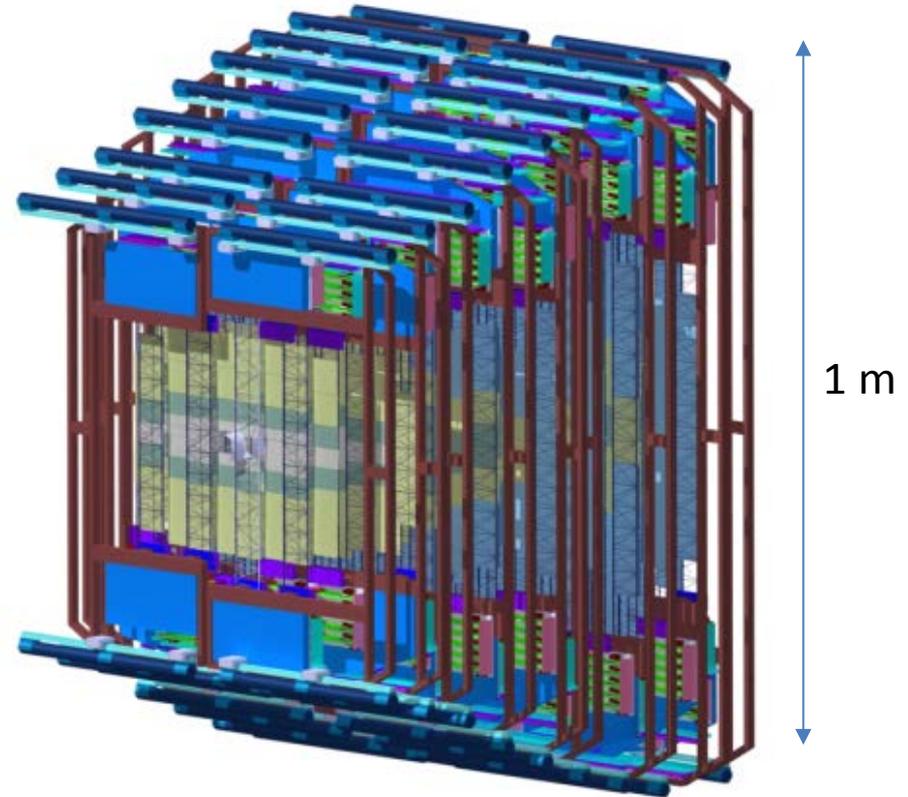
Experiment set-up



Silicon Tracking System

CBM's main tracking detector

- **large aperture**
 - from \sim center-of mass to beam rapidity
 - polar angles: $2.5 \text{ deg} < \Theta < 25 \text{ (35) deg}$
- **redundant track point measurement**
 - 8 tracking stations
 - space point resolution $\sim 25 \mu\text{m}$
- **low material budget**
 - double-sided silicon microstrip sensors
 - r/o electronics outside physics aperture;
 - $0.3\text{-}1\% X_0$ per tracking station
- **radiation tolerant silicon sensors**



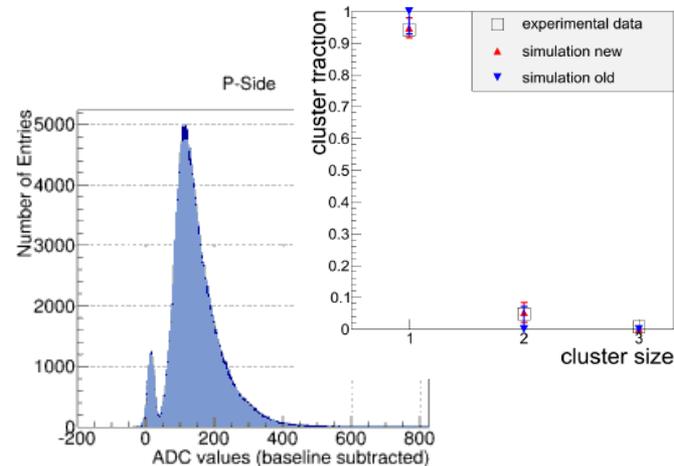
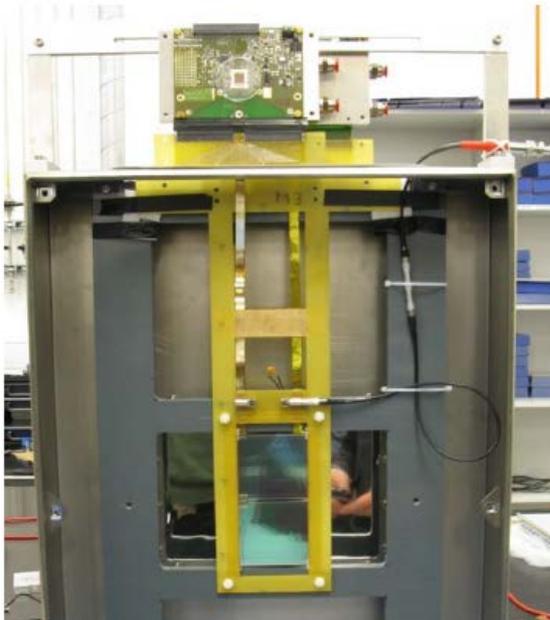
In-beam test of a prototype STS

low-mass STS module

- silicon microstrip sensors
 - double-sided, 300 μm thick
 - 1024 strips of 58 μm pitch
 - front/back side strips, 7.5 deg angle
 - radiation tolerant up to 10^{14} n/cm²
- micro r/o cables (partial read-out)
- self-triggering electronics

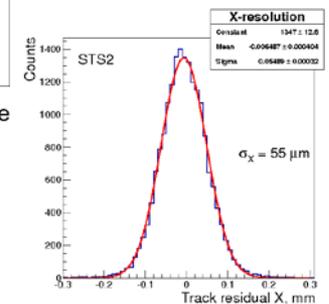


proton beam,
COSY,
Jülich



Results

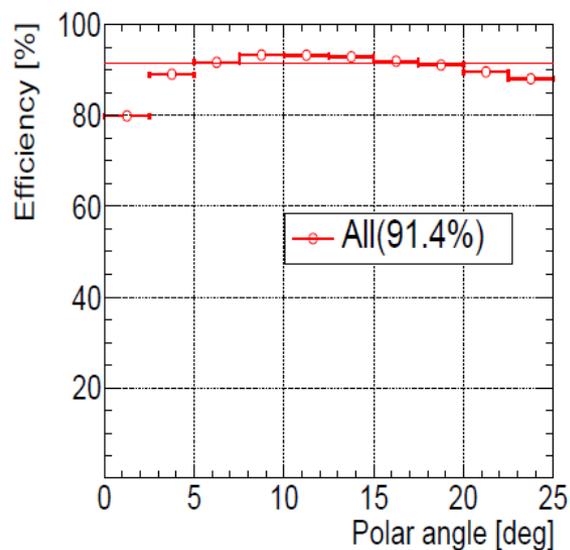
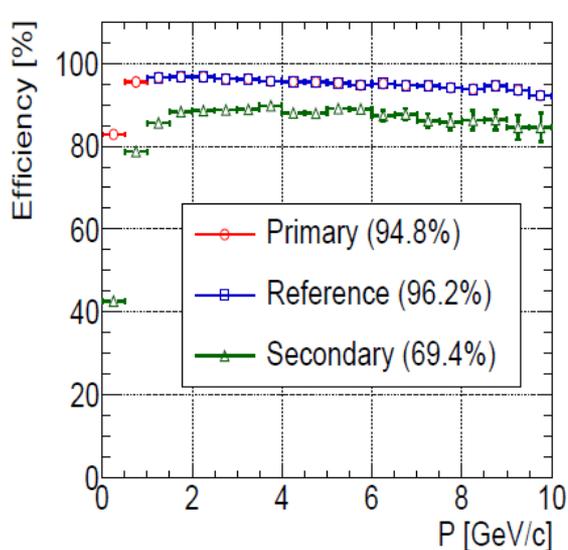
- signal amplitudes
- cluster sizes
- spatial resolution



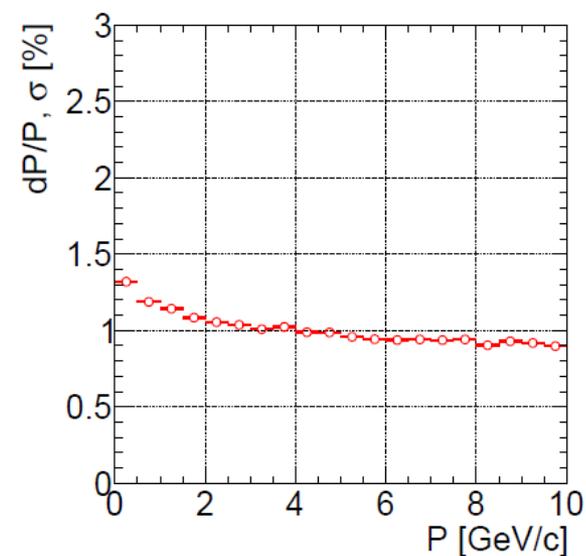
Detector performance simulations

- detailed, realistic detector model based on tested prototype components
- CbmRoot simulation framework
- using Cellular Automaton / Kalman Filter algorithms

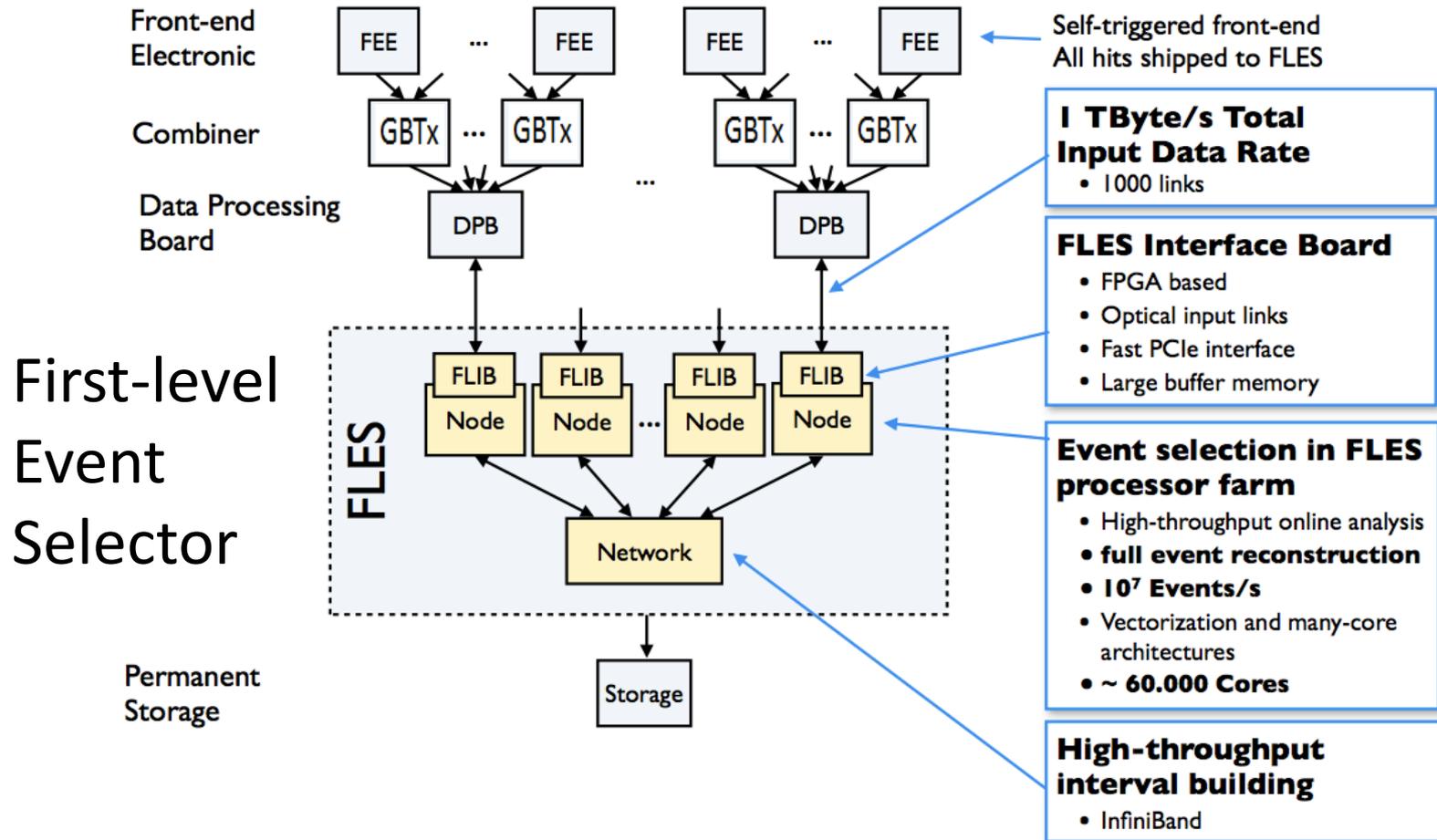
track reconstruction efficiency



momentum resolution



CBM online data flow



On-line event reconstruction

- There is no a-priori event definition possible:
 - no simple trigger signatures: e.g. $J/\psi \rightarrow e^+e^-$ and $D,\Omega \rightarrow$ charged hadrons.
 - extreme event rates set strong limits to trigger latency.
 - therefore data from all detectors come asynchronously.
 - events may overlap in time.
- The classical DAQ task of „event building“ is now rather a „time-slice building“. Physical events are defined later in software.
- Data reduction is shifted entirely to software:
 - Complex signatures involve secondary decay vertices; difficult to implement in hardware.
 - maximum flexibility w.r.t. physics.
- The system is limited only by the throughput capacity and by the rejection power of the on-line computing farm.

Steps of event reconstruction

1. Time-slice sorting of detector hits:

First step in “pre-event” definition.

2. Track finding – Cellular Automaton:

Which hits in the detector layers belong to the same track?

- large combinatorial problem
- well to be parallelized
- applicable to many-core CPU/GPU systems

3. Track fitting – Kalman Filter:

Optimization of the track parameters.

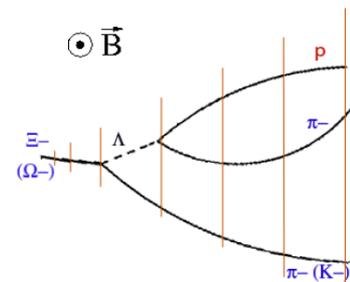
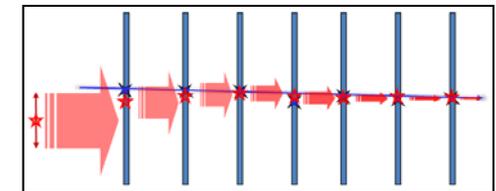
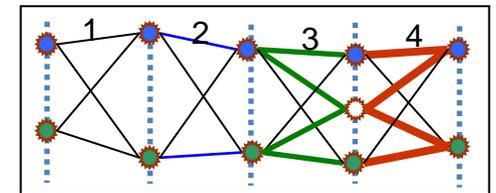
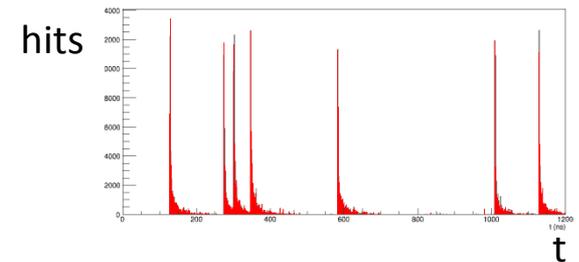
- recursive least squares method, fast

4. Event determination

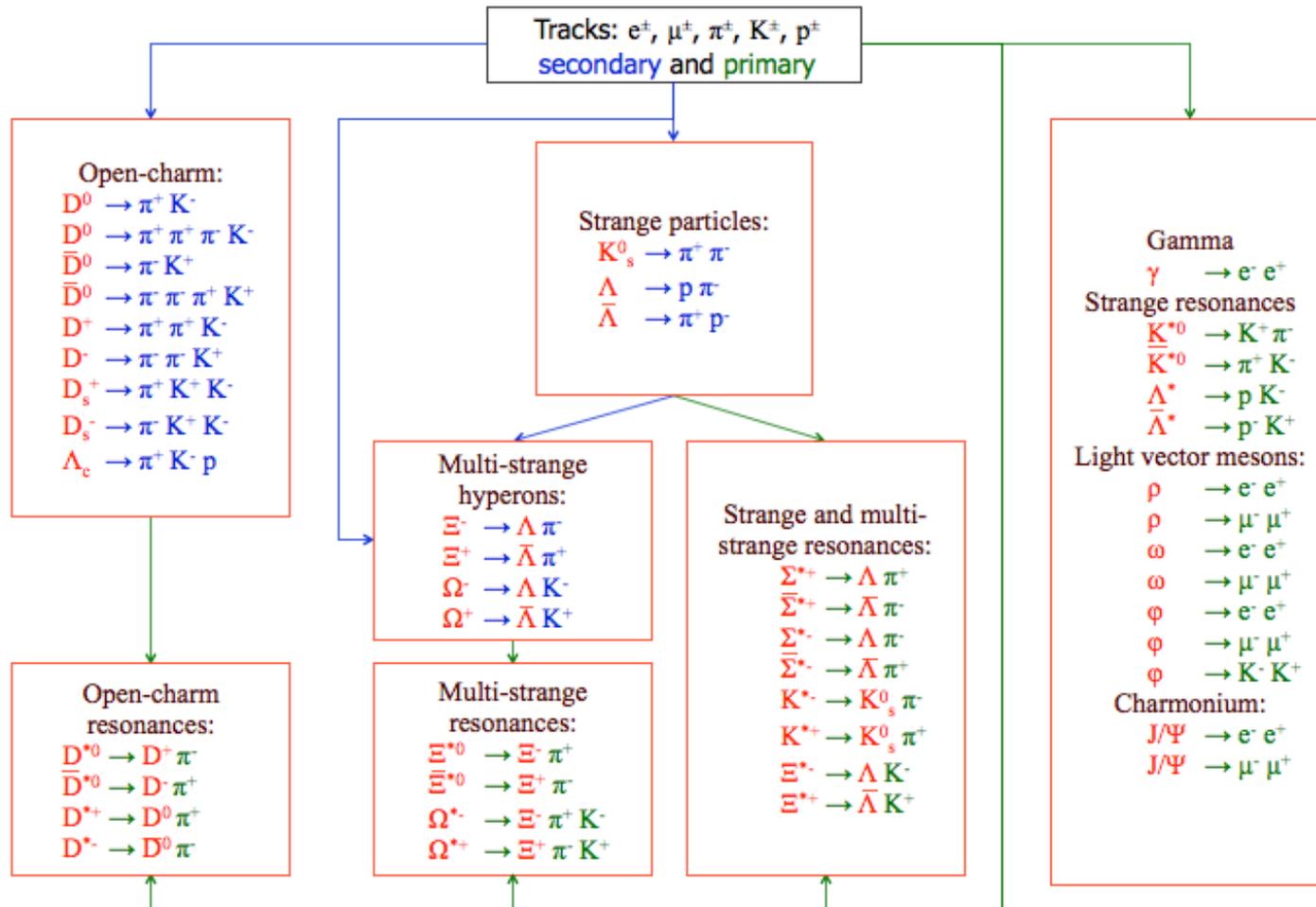
Which tracks belong to same interaction?

5. Particle finding:

Identify decay topologies and other signatures.



Particle finder



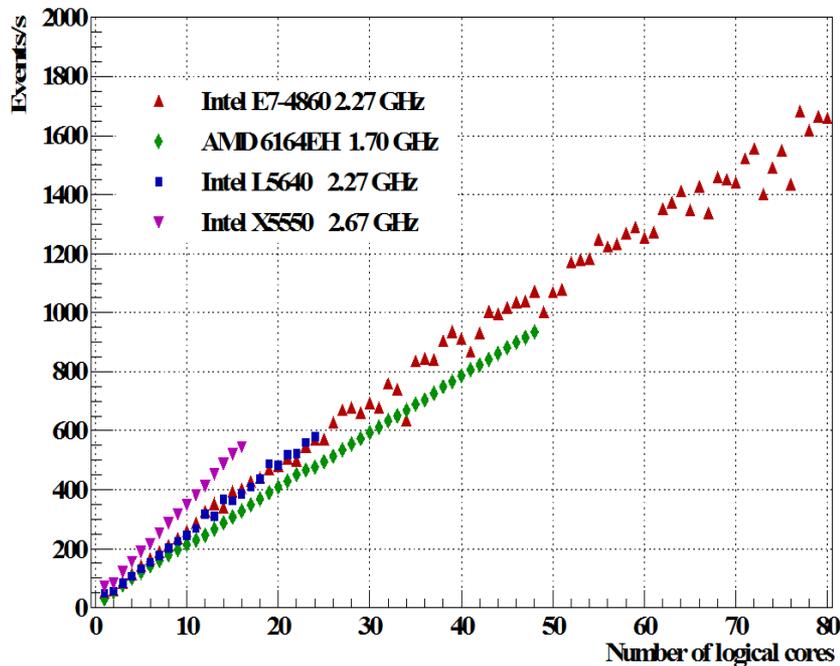
Parallelization of event reconstruction

On “event” level:

- reconstruction with independent processes
- Exploit many-core systems with multi-threading: 1 thread per logical core, 1000 events per core.

On “task” level:

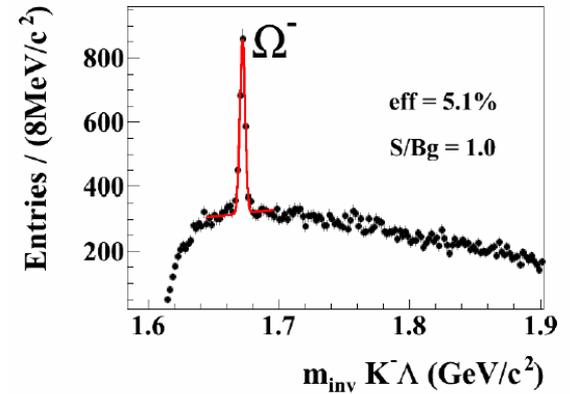
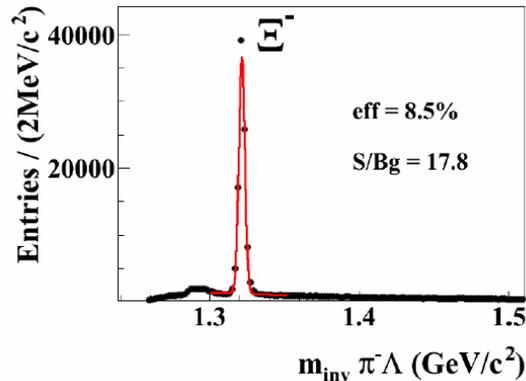
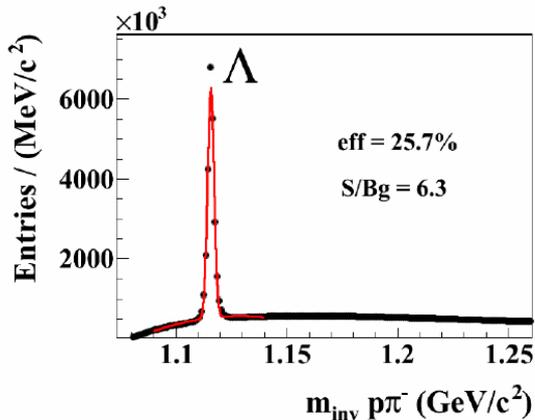
- digitizer, finder, fitter, analysis tasks: current readiness of parallelization
- employing different computing techniques and architectures



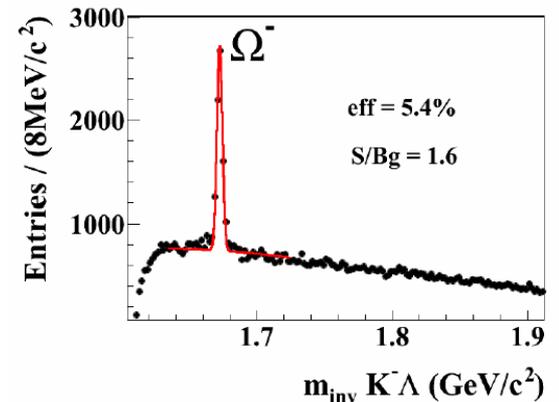
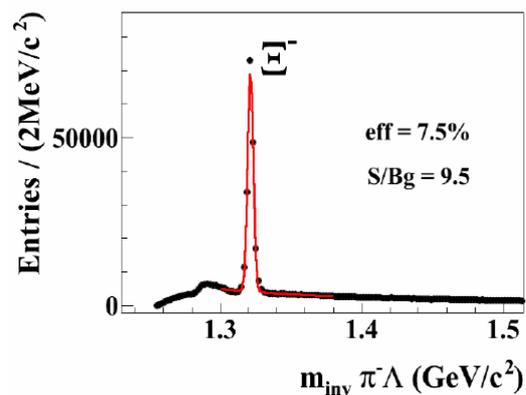
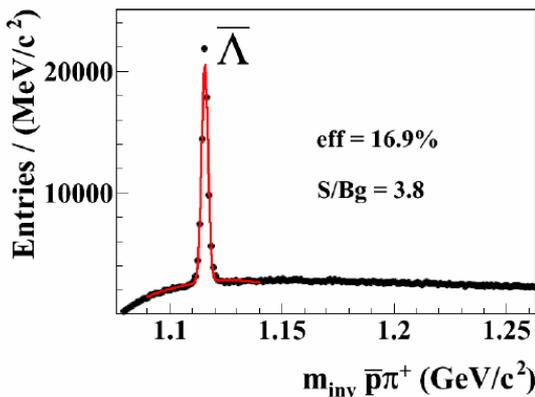
Algorithm	Vector SIMD	Multi Threading	CUDA	OpenCL CPU/GPU
Digitizers				
STS KF Track Fit	✓	✓	✓	✓/✓
STS CA Track Finder	✓	✓		
MuCh Track Finder	✓	✓	✓	
TRD Track Finder	✓	✓	✓	
RICH Ring Finder	✓	✓		✓/✓
Vertexing (KF Particle)	✓	✓		
Off-line Physics Analysis	✓			
FLES Analysis and Selection	✓	✓		

Performance of hyperon measurement

$5 \cdot 10^6$ central Au+Au collisions, 10 AGeV



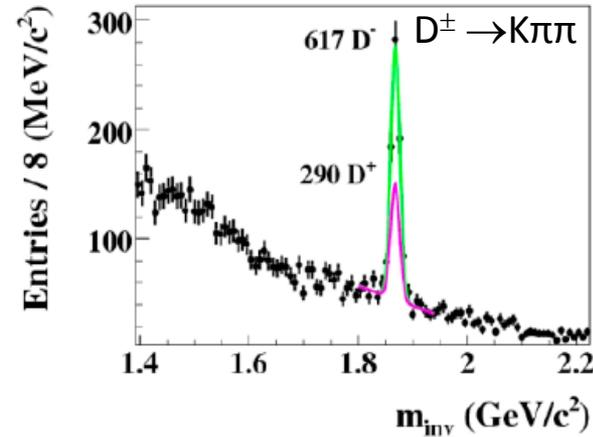
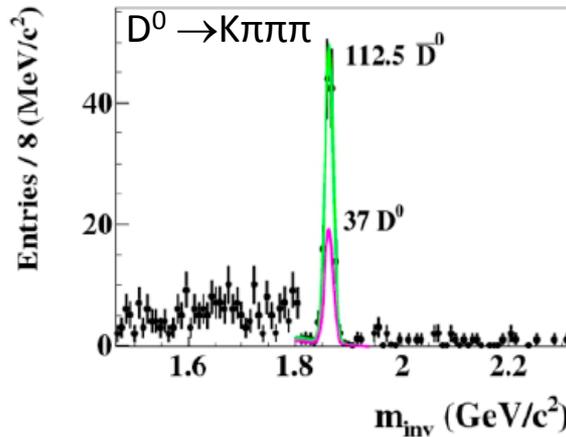
$5 \cdot 10^6$ central Au+Au collisions, 25 AGeV



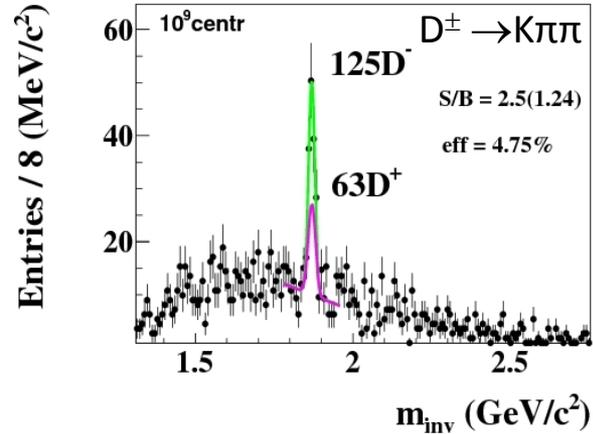
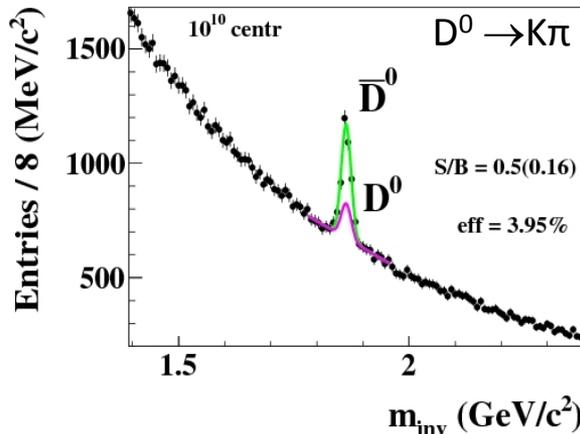
Performance of open charm measurement

p+C collisions, 30 GeV (SIS100)

10^{12} centr.



Au+Au collisions, 25 AGeV (SIS300)



Conclusions

- CBM: focus on rare probes to investigate “Compressed Baryonic Matter” in a dedicated experimental facility
- consequent application of new paradigms for detectors, read-out, on-line event determination and analysis
- Technical Design Reports for most of the detector systems approved/submitted/under compilation
- among those the STS as the main tracking device
- TDR for on-line computing in progress
- simulation studies show expected performance
- construction of CBM components have started
- commissioning in CBM cave expected in 2018



<http://repository.gsi.de/record/54798>

The CBM Collaboration

12 countries, 56 institutions, 516 members

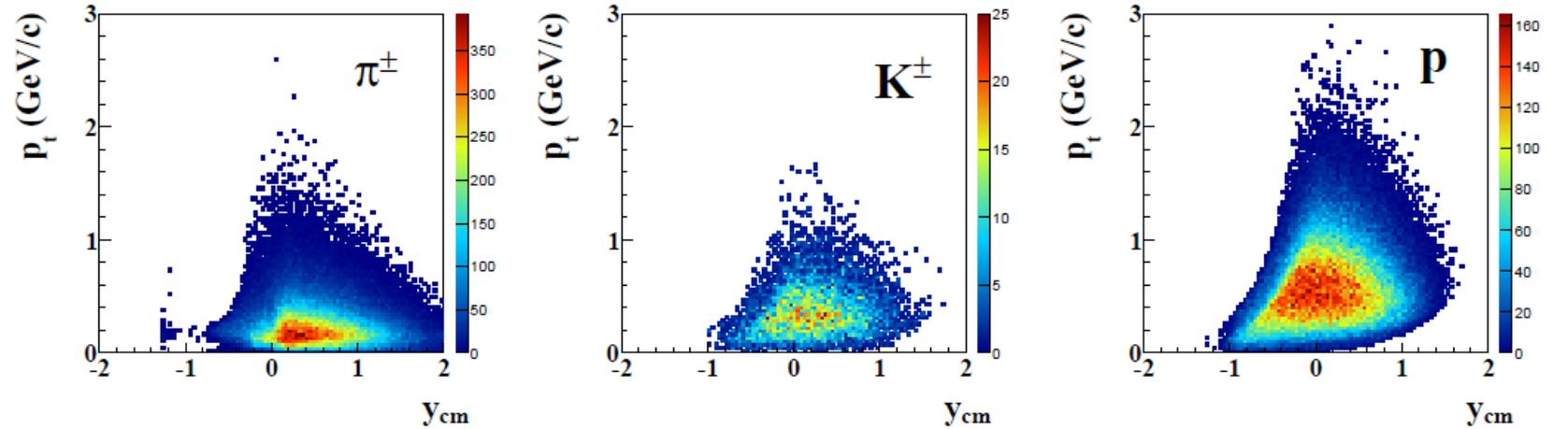
<http://www.fair-center.eu/for-users/experiments/cbm.html>



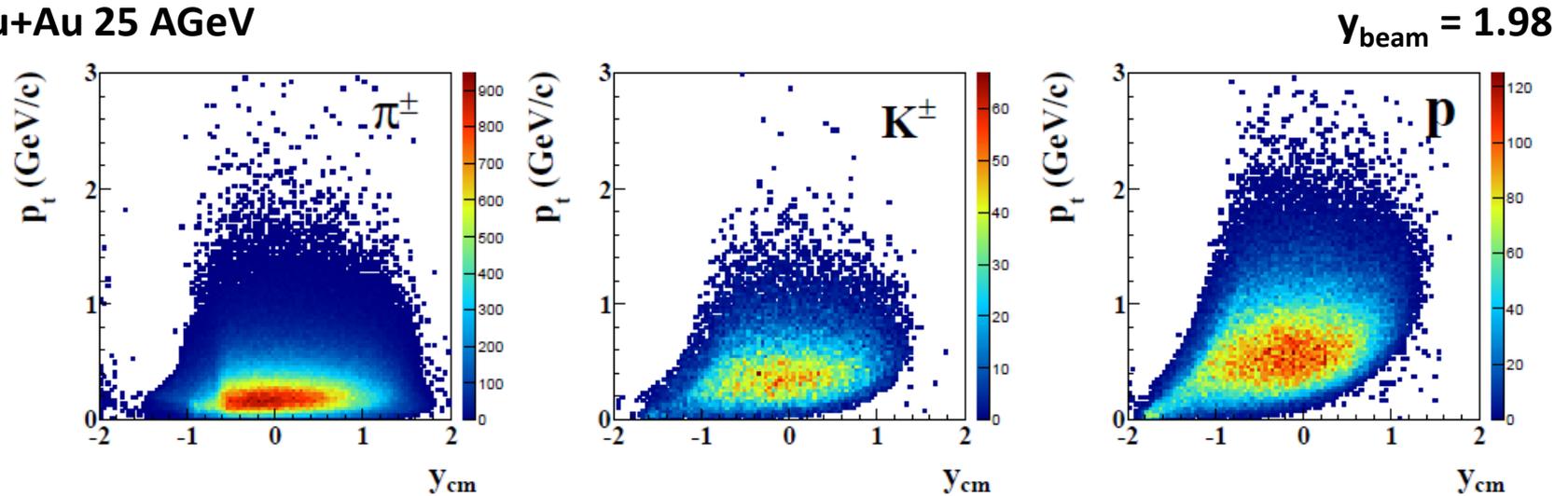
Backup slides

Detector acceptance

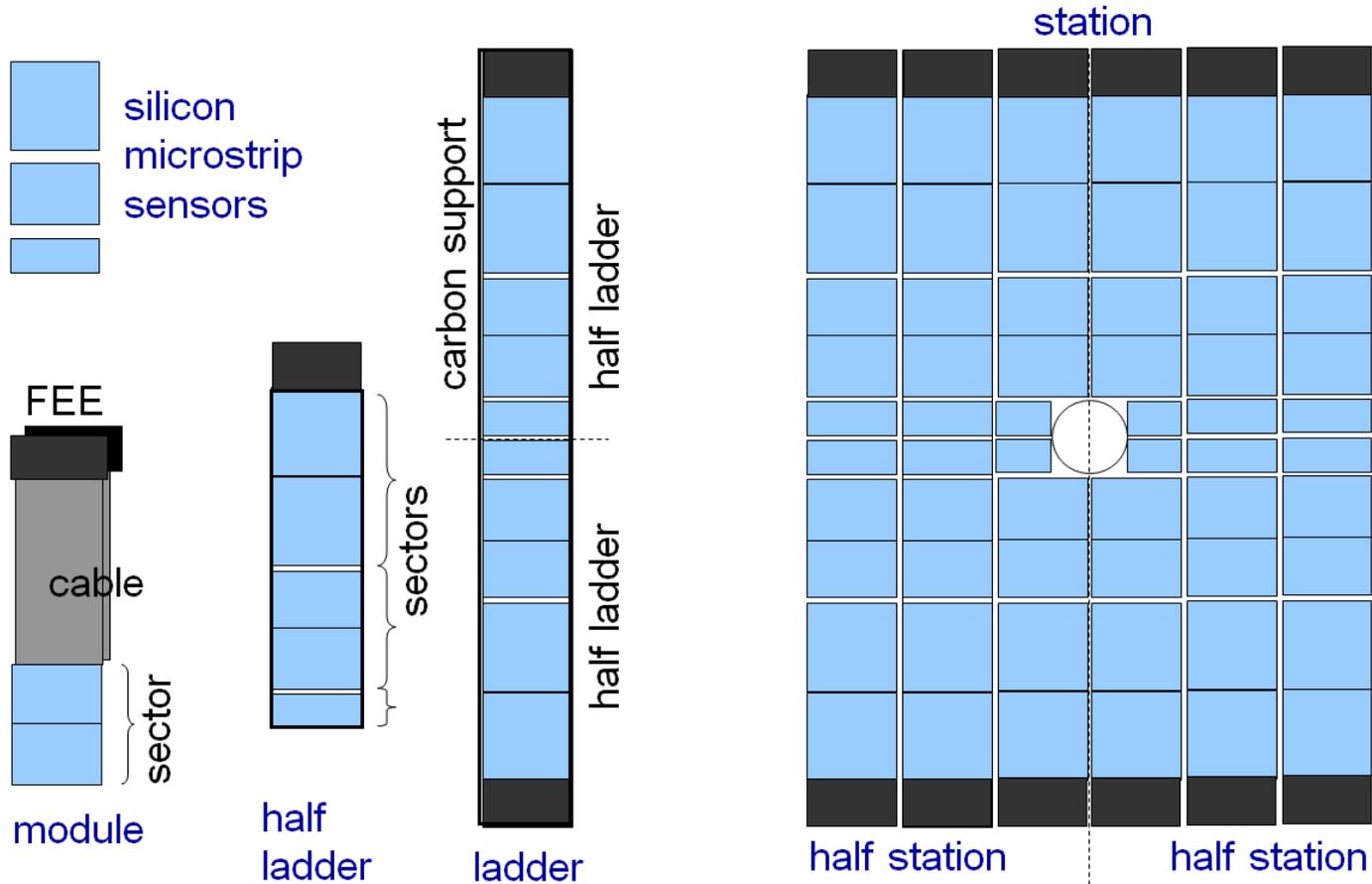
Au+Au 6 AGeV



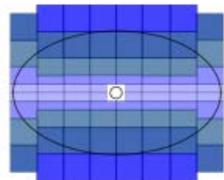
Au+Au 25 AGeV



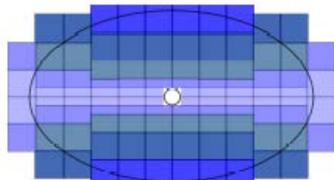
STS Detector Concept



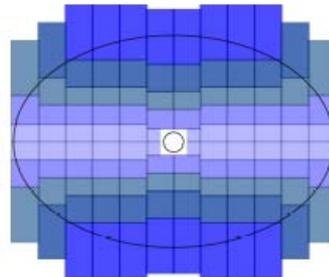
STS stations - layout



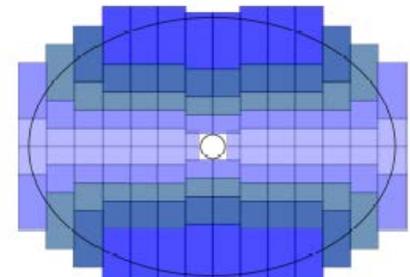
station 1



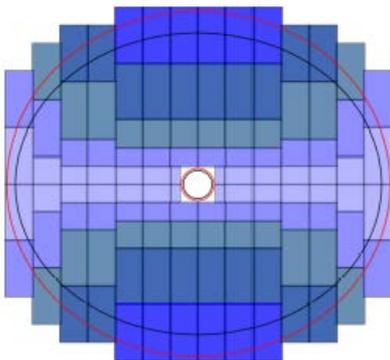
station 2



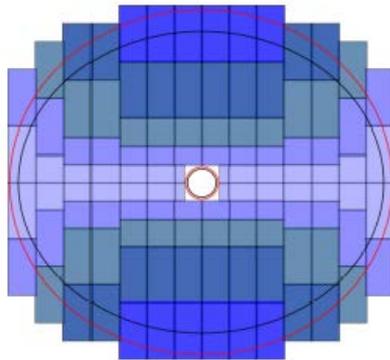
station 3



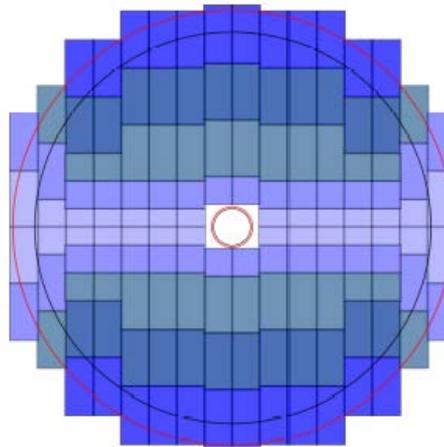
station 4



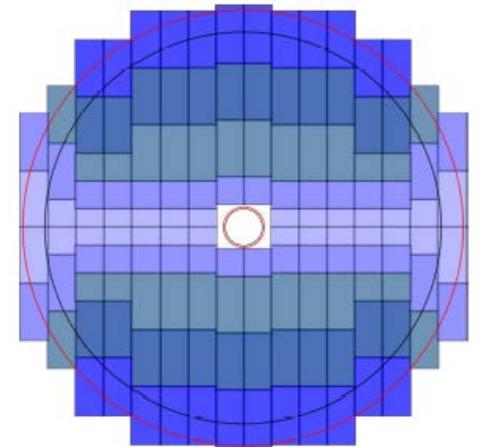
station 5



station 6

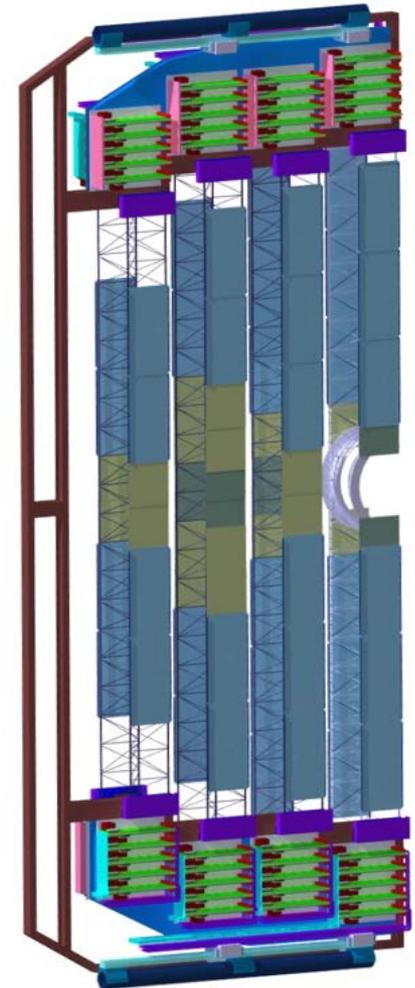
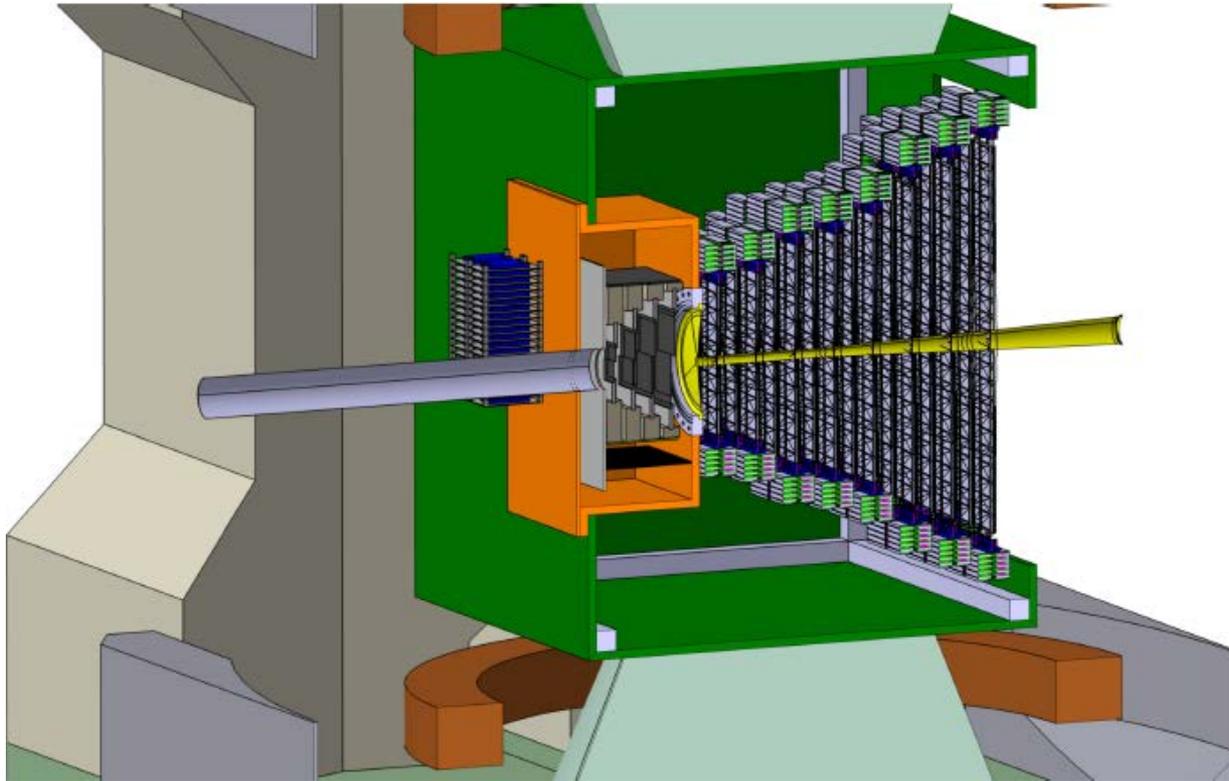


station 7

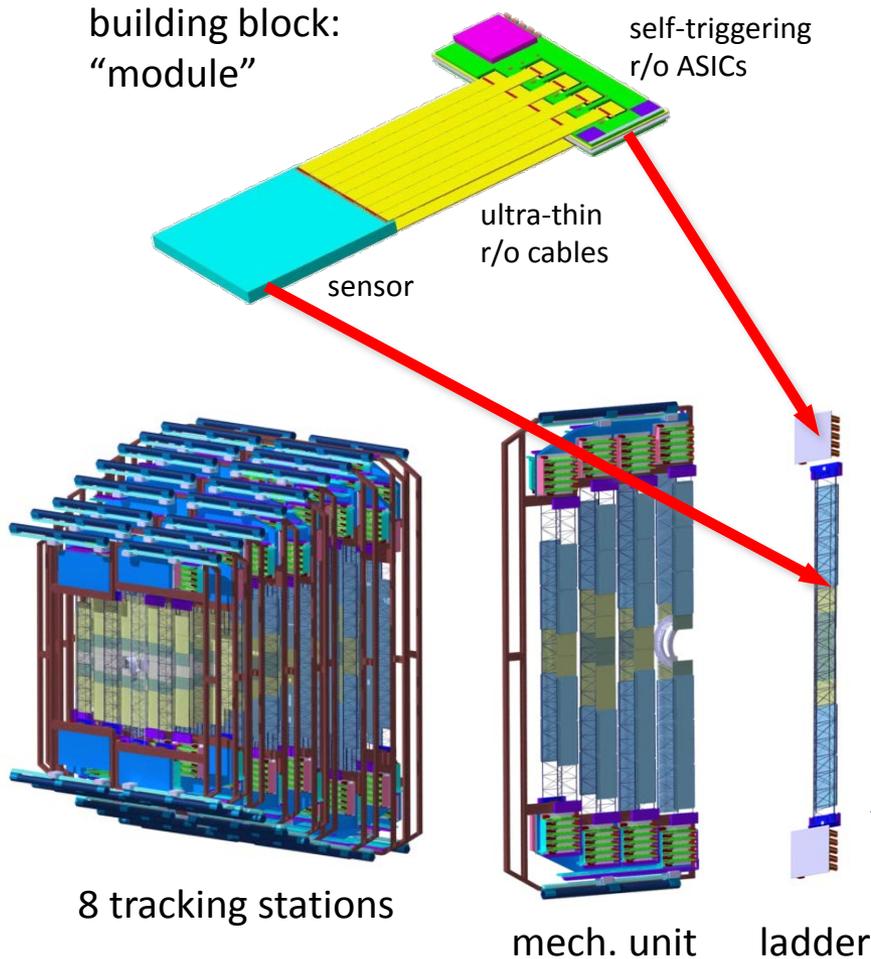


station 8

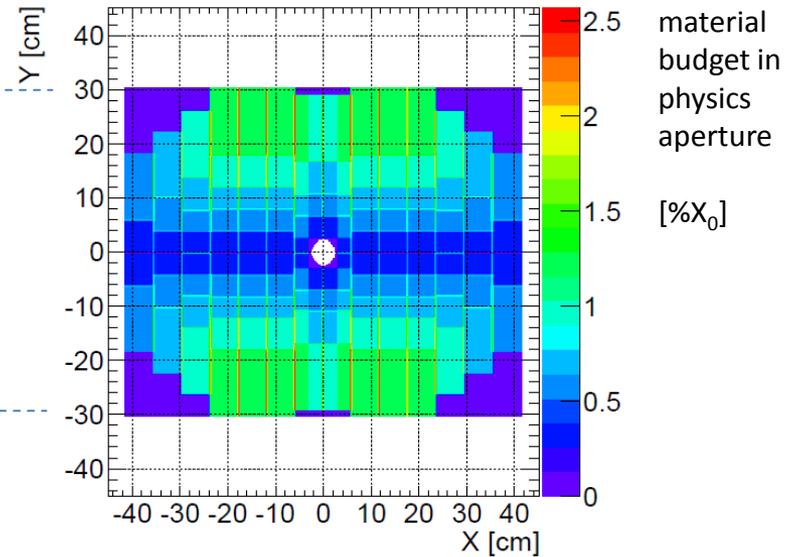
STS – system engineering



STS integration concept

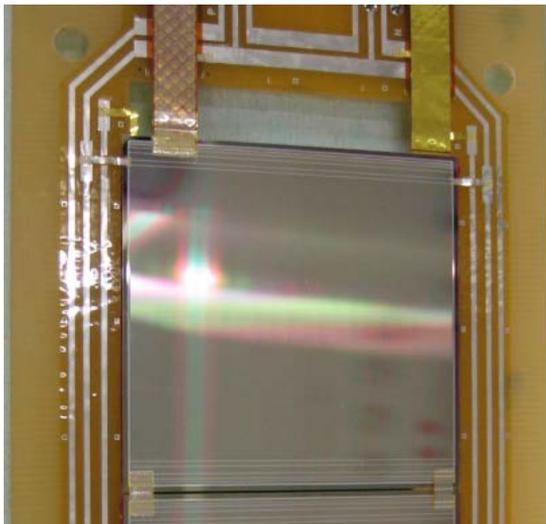


- 8 stations, volume 2 m³, area 4 m²
- 896 detector modules
 - 1220 double-sided microstrip sensors
 - ~ 1.8 million read-out channels
 - ~ 16 000 r/o STS-XYTER ASICs
 - ~ 58 000 ultra-thin r/o cables
- 106 detector ladders with 4-5 modules
- power dissipation: 42 kW (CO₂ cooling)



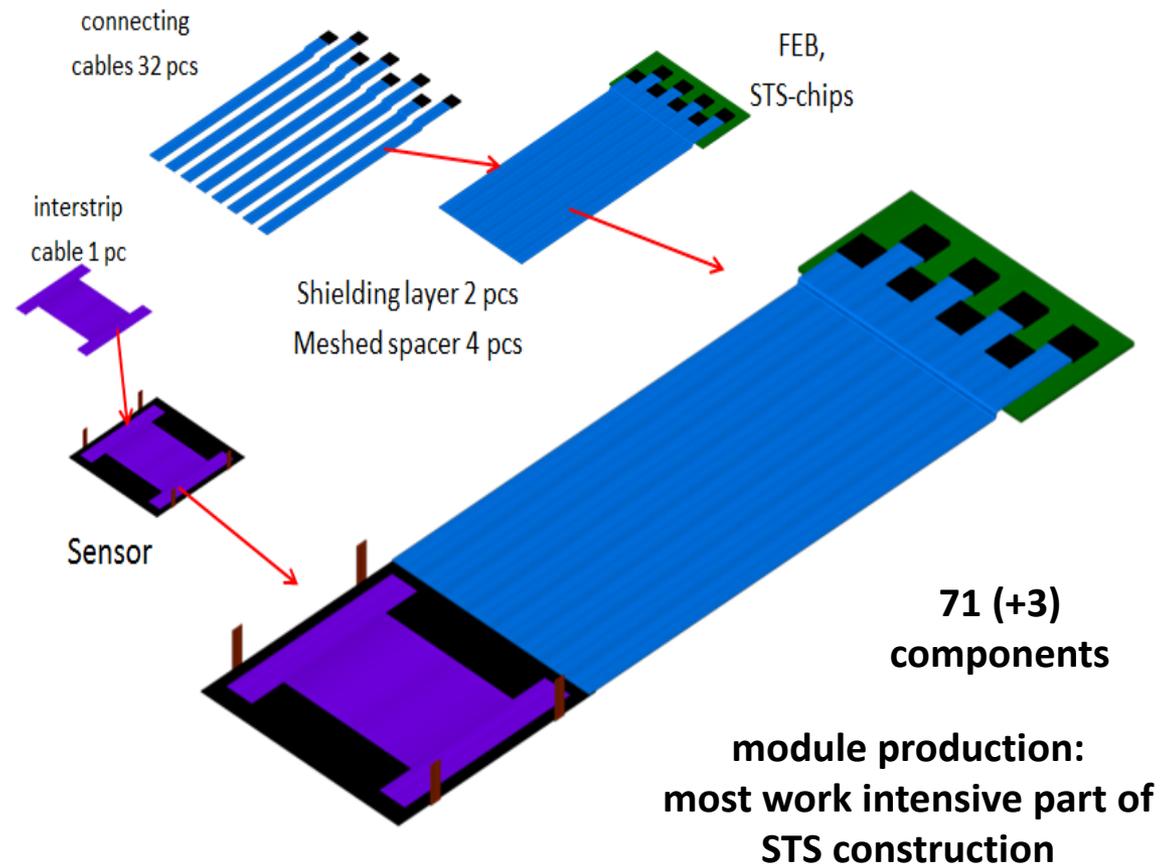
Development of detector components

Silicon microstrip sensors

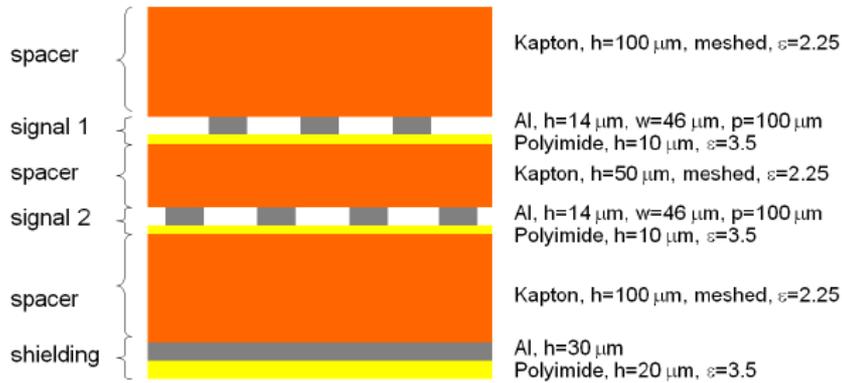


- 300 μm thick, n-type silicon
- double-sided segmentation
- 1024 strips of 58 μm pitch
- strip length 6.2/4.2/2.2 cm
- angle front/back: 7.5 deg
- read-out from top edge
- rad. tol. up to $10^{14} n_{\text{eq}}/\text{cm}^2$

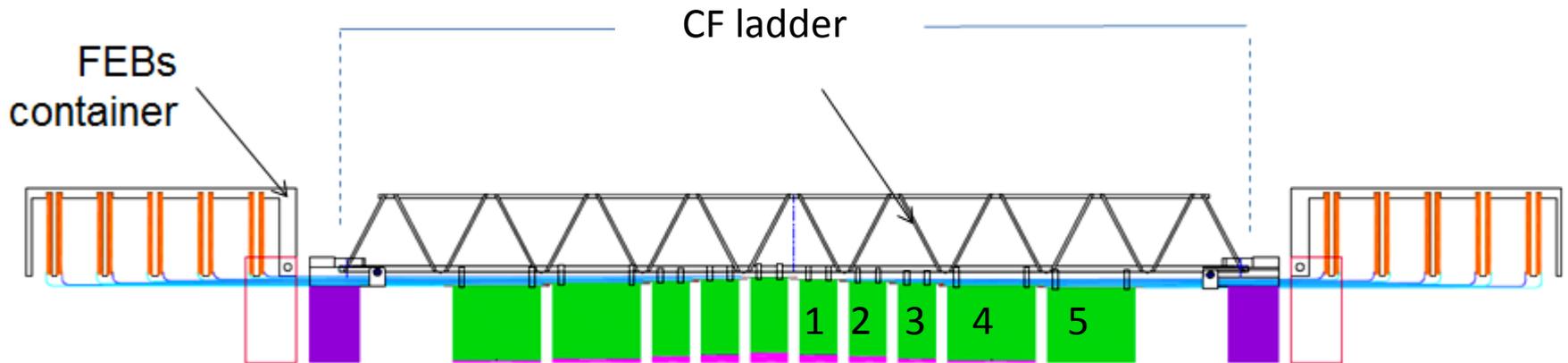
Detector module



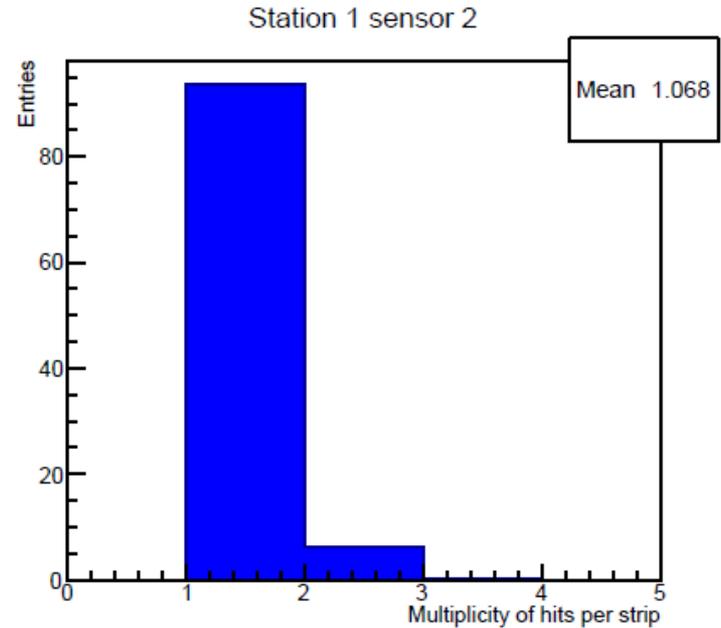
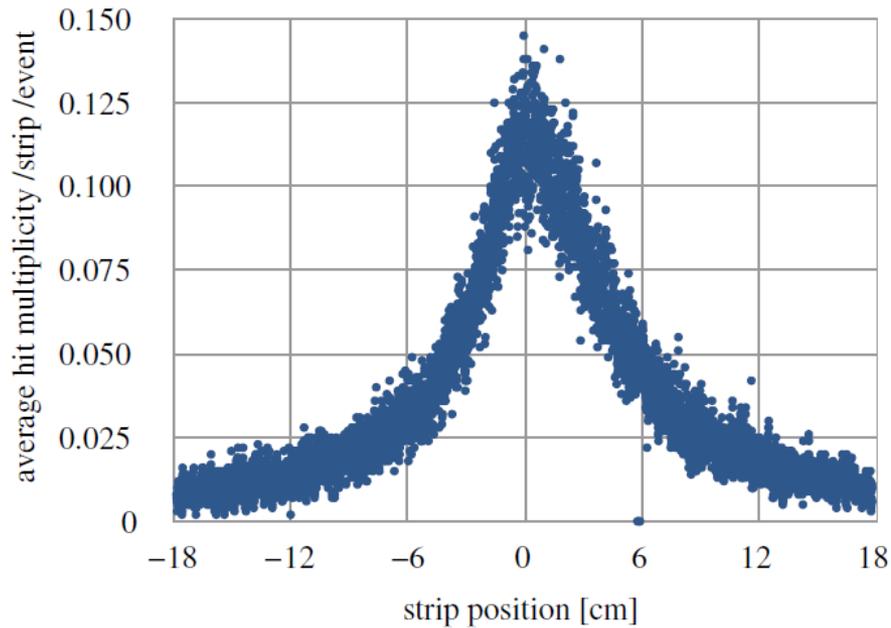
Material budget



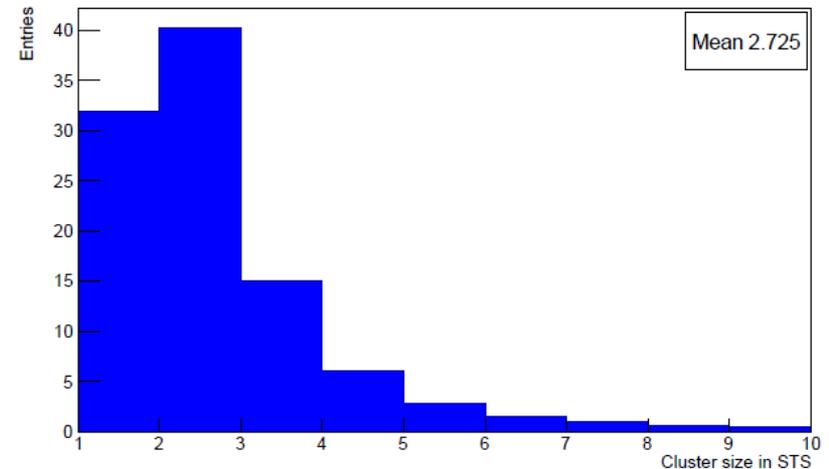
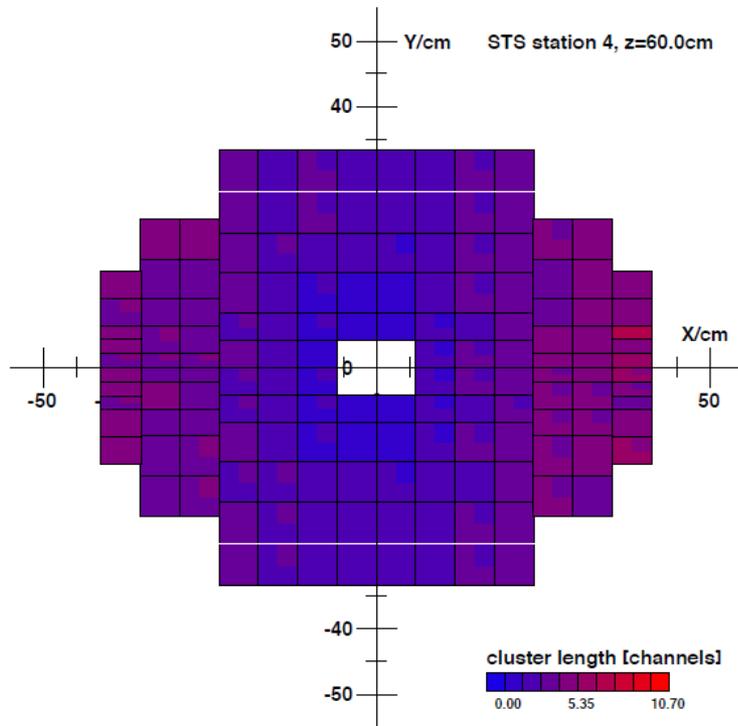
sector	1	2	3	4	5
per sector, % X_0	0.3	0.3	0.3	0.3	0.3
per cable pair, % X_0	0	2×0.11	4×0.11	6×0.11	8×0.11
sector+cables, % X_0	0.3	0.52	0.74	0.96	1.18



Detector occupancy



Cluster size: Number of strips firing per particle

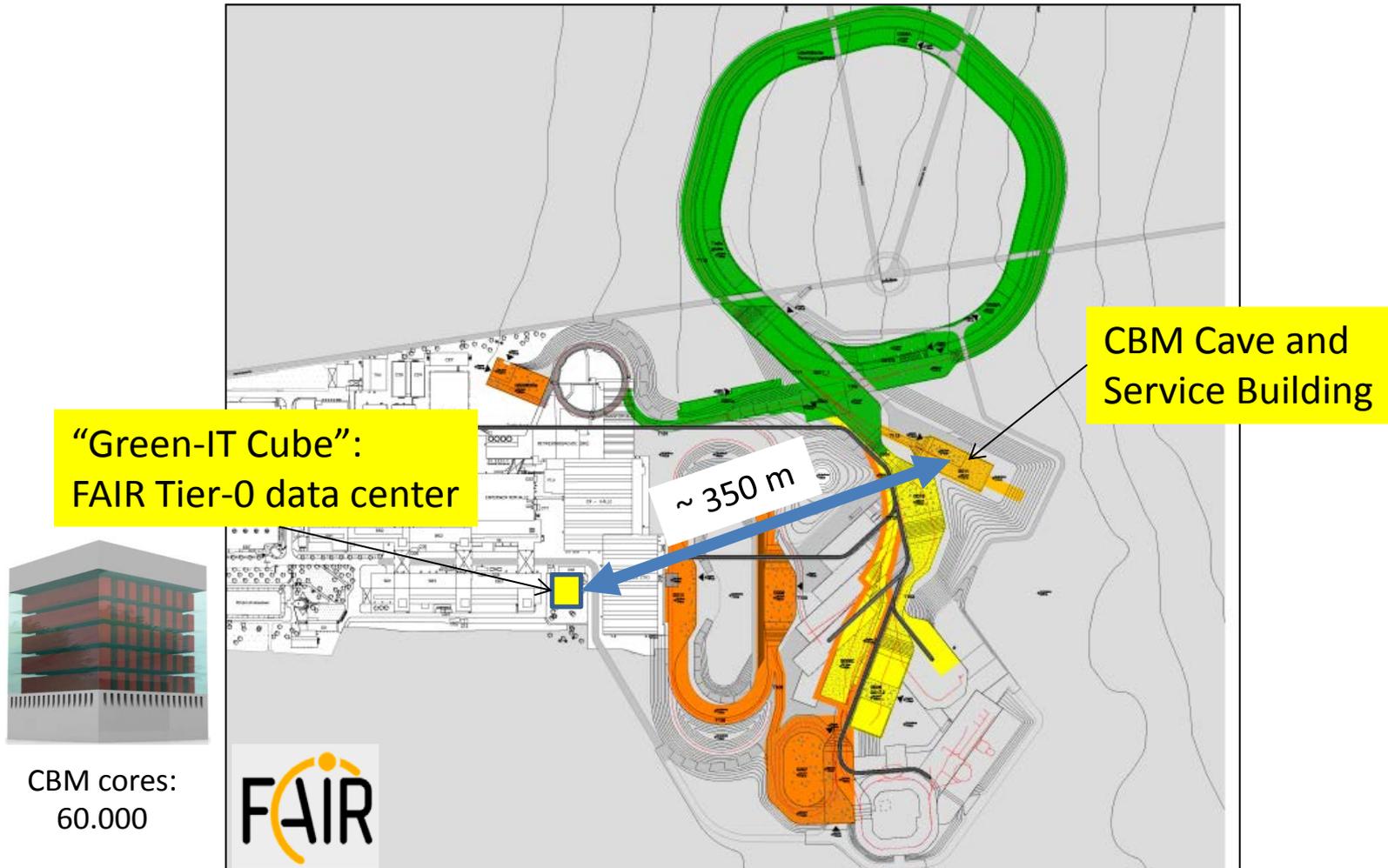


FAIR – start version



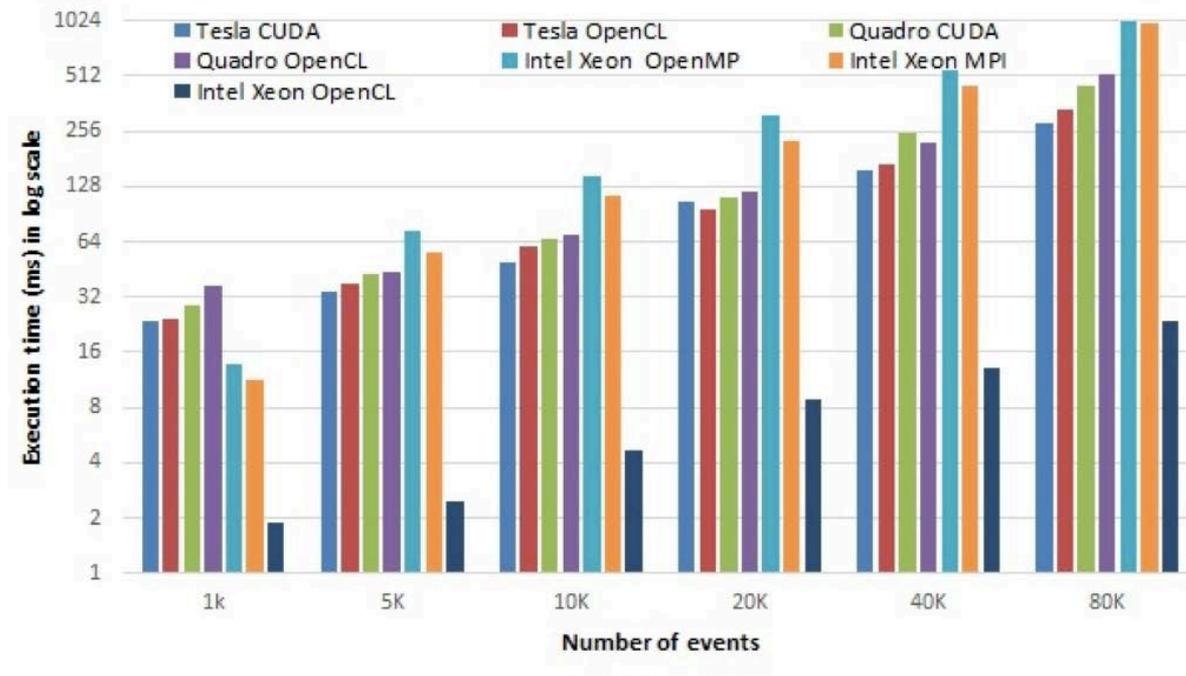
- Modul 0**
SIS100
- Modul 1**
CBM,
APPA
- Modul 2**
Super-FRS
- Modul 3**
Antiproton-
target, CR,
p-Linac,
HESR

CBM cave and FLES location



Muon trigger studies

- Investigation on several CPU / GPU architectures.
- Strong differences between different computing paradigms on same architecture.



CBM @ QM 2014

Presentations:

- The physics program of FAIR (*S. Chattopadhyay et al.*)
- Measurements of dileptons with the CBM-Experiment at FAIR (*C. Höhne et al.*)
- Measurement of rare probes with the Silicon Tracking System of the CBM experiment at FAIR (*J. Heuser et al.*)

Posters :

- Concept and performance of the Silicon Tracking System for the CBM experiment at FAIR (*M. SINGLA et al.*)
- Development of prototype components for the Silicon Tracking System of the CBM experiment at FAIR (*P. Ghosh et al.*)
- System integration of the Silicon Tracking System for the CBM experiment at FAIR (*T. Balog et al.*)
- A Muon Detection System for the CBM experiment at FAIR (*A.K. Dubey*)
- Determination of tolerances of mirror displacement and radiator gas impurity for the CBM RICH detector (*T. Mahmoud*)
- The CBM-RICH detector (*J. Kopfer*)
- Development of the photon detection system for the CBM RICH (*C. Pauly*)
- Low-mass di-electron reconstruction at the CBM experiment (*E. Lebedeva*)