Perspectives of QCD phase diagram studies at high densities with the Compressed Baryonic Matter experiment at FAIR

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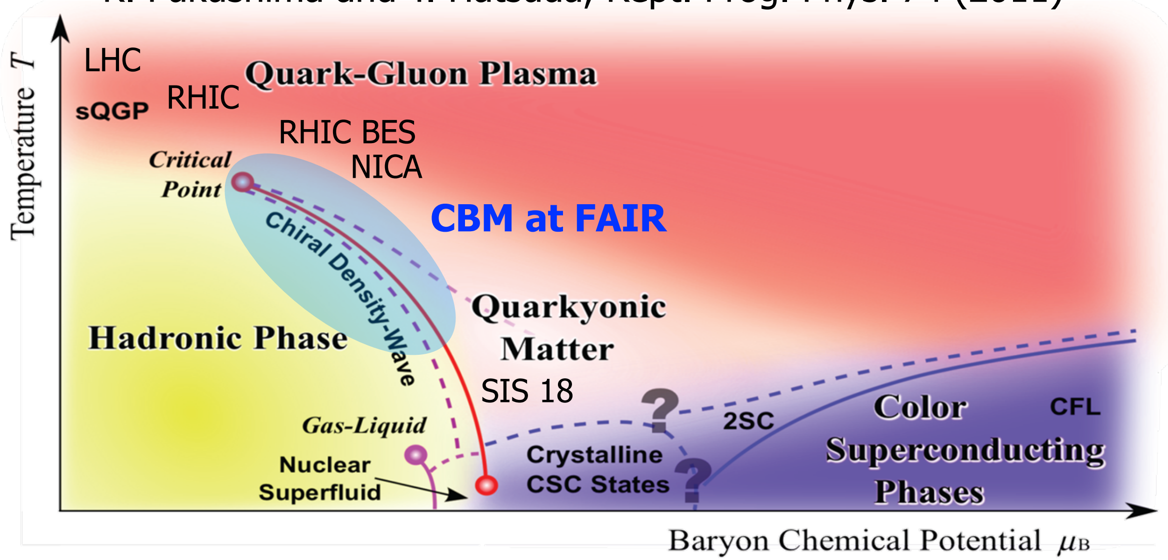
03.09.2018

Goals of the CBM experiment

K. Fukushima and T. Hatsuda, Rept. Prog. Phys. 74 (2011)

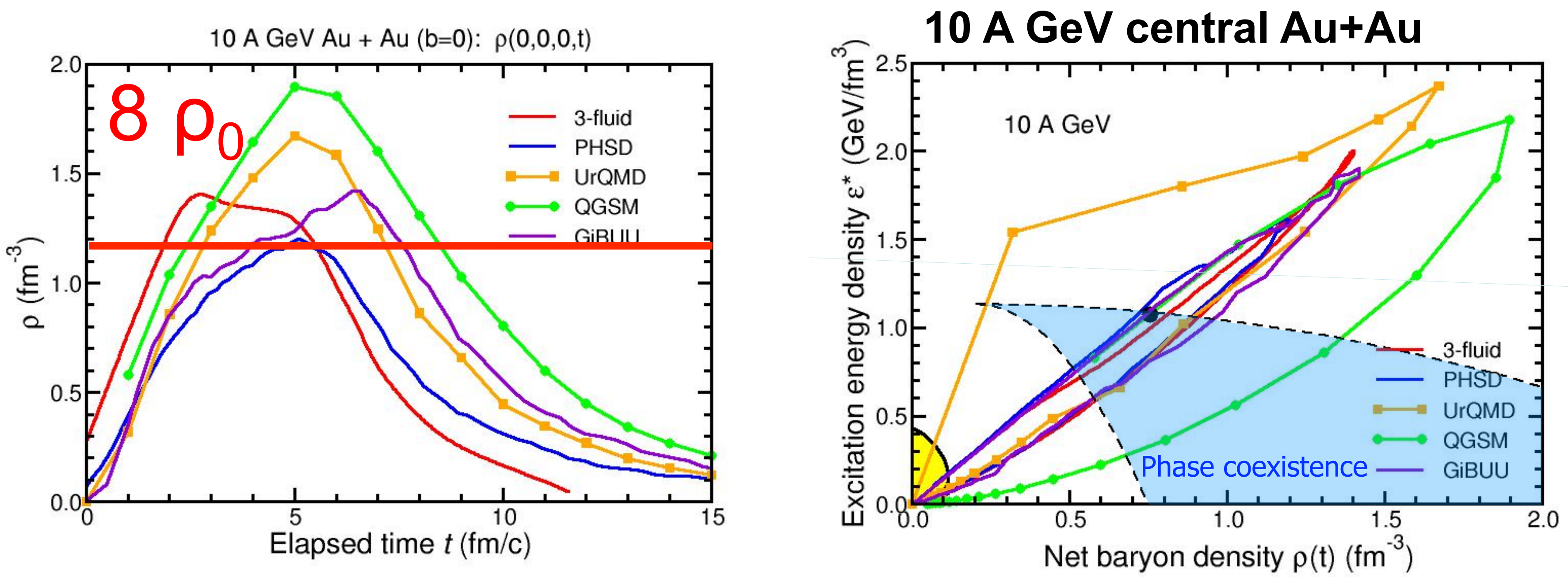


CBM aims to investigate strongly interacting matter in the region high baryonic densities ($\sqrt{s_{NN}}$ = 2.7-4.9 GeV):

- the hadronic-partonic phase transition in the region of high net baryonic densities and the critical endpoint;
- the chiral phase transition (not necessarily the same);
- the equation of state at high densities, which is important for studies of neutron stars;
- hypernuclei and heavy multi-strange objects;
- hadrons in dense baryonic matter and possible modification of their properties;
- charm production at threshold beam energies and charm properties in dense baryonic matter.

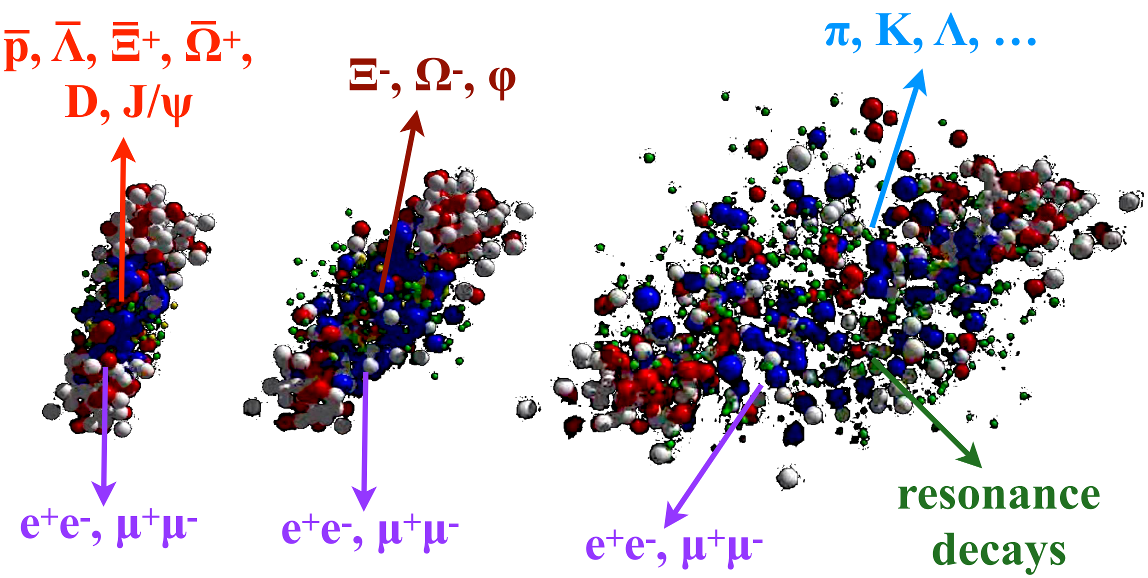
Dense matter in the laboratory

I.C. Arsene et al., Phys. Rev. C 75, 24902 (2007)



- Heavy-ion collisions at moderate beam energies are well suited to provide high net-baryon densities.
- Models predict that during the evolution of the system created matter reaches densities up to 8 times of the saturation density ρ_0. At these densities a region with the phase coexistence might be reached.

Observables



Physics cases:

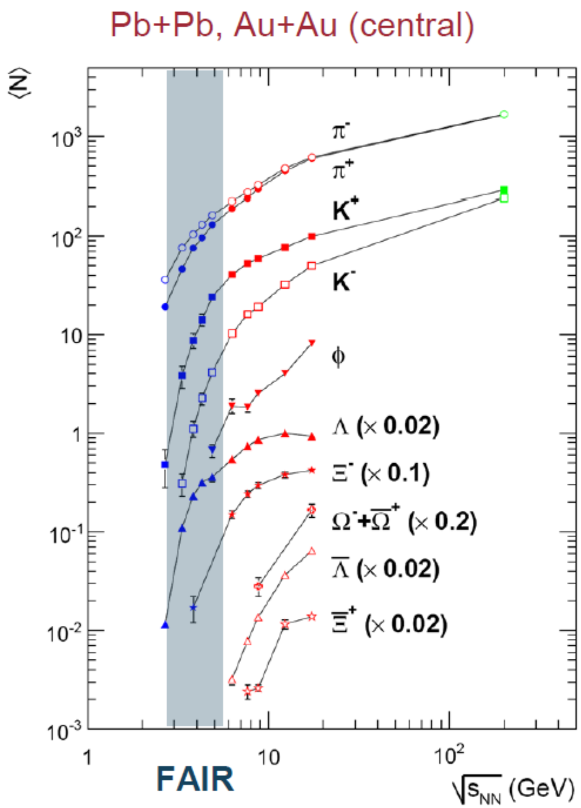
1. Equation of state of nuclear matter at high densities
2. In-medium properties of hadrons
3. Phase transitions
4. Critical endpoint
5. Chiral symmetry restoration
6. Hypernuclei, strange dibaryons and massive strange objects
7. Charm production and its properties
8. Hyperon-nucleon and hyperon-hyperon interactions

Main observables of the CBM experiment at the beam energies $\sqrt{s_{NN}}$ = 2.7-4.9 GeV:

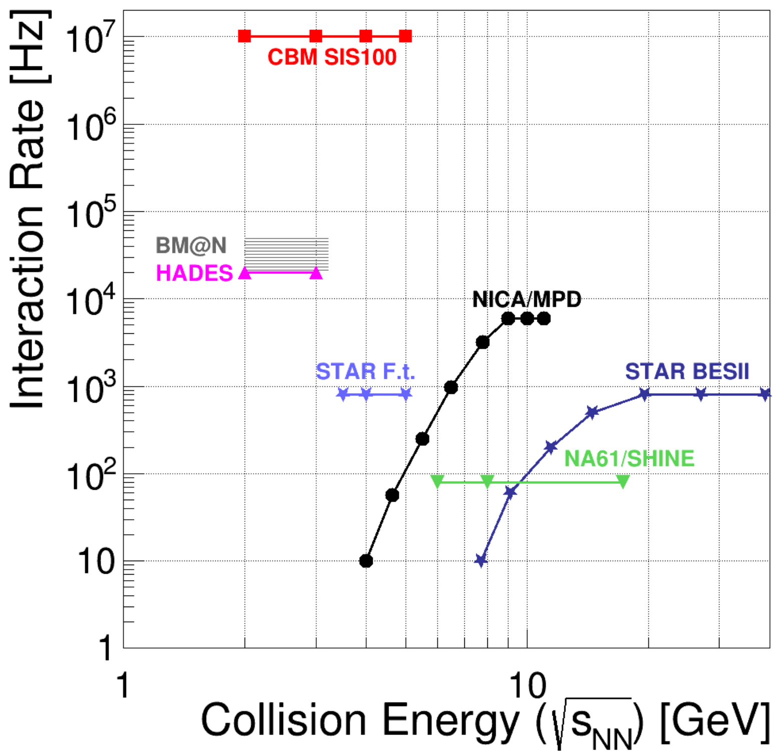
- particles containing strange or charm quarks (strange particles — Λ, Ξ, Ω, charmed D mesons, J/ψ) ; ⟶ **2,3,8**
- low mass vector mesons decaying into dilepton channel ($\rho, \omega, \varphi \rightarrow e^+e^-$, $\rho, \omega, \varphi \rightarrow \mu^+\mu^-$); ⟶ **2,3,5**
- hypernuclei, strange dibaryons and massive strange objects; ⟶ **6,8**
- excitation functions of yields, spectra, and collective flow of these particles; ⟶ **1,3**
- event-by-event fluctuations of conserved quantities like baryons, strangeness, net-charge etc. as a function of beam energy. ⟶ **3,4**

Rate capabilities

C. Blume, J. Phys. G 31 (2005) S57



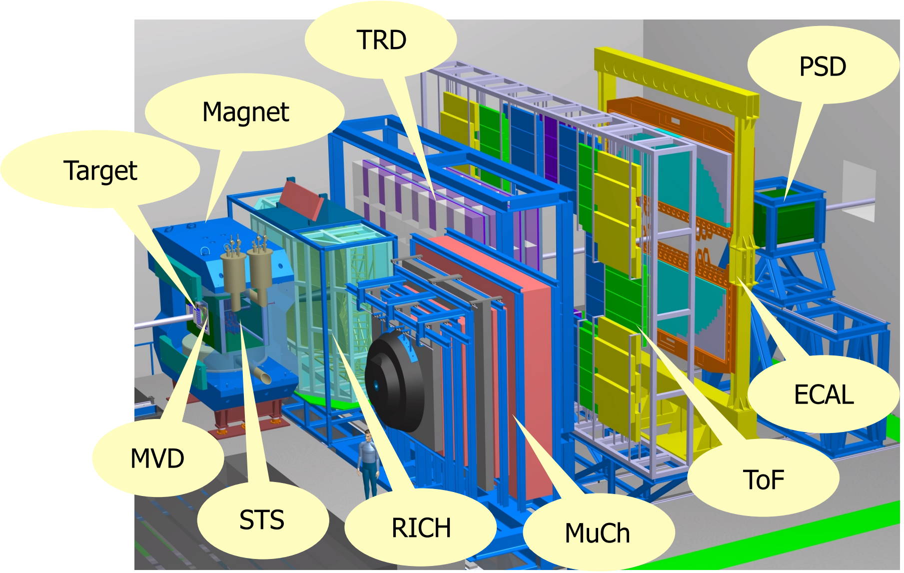
T. Ablyazimov et al., Eur. Phys. J. A 53 (2017) no.3, 60



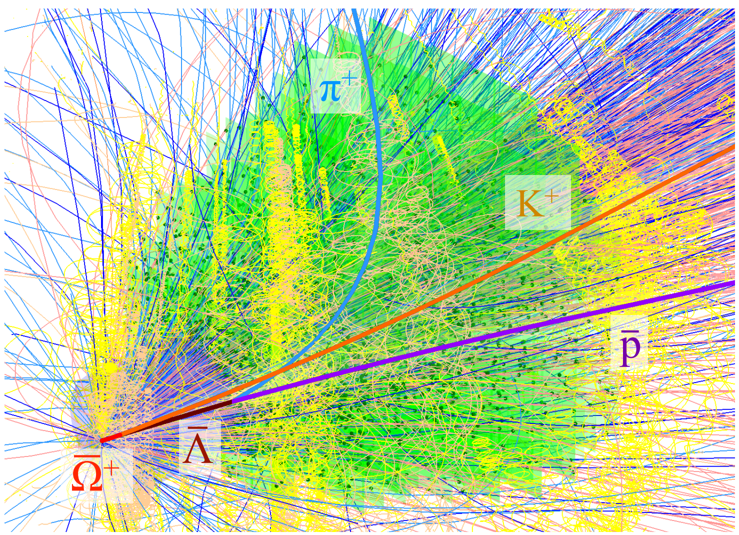
- CBM will perform comprehensive high precision measurements of observables which are produced rarely.
- Multi-differential studies of rare probes down to 1 particle per million events will require unprecedented statistics.
- In order to collect enough statistics CBM will operate with the interaction rates of up to 10 MHz.

Challenges in CBM

CBM experimental setup



Central AuAu UrQMD event with $\bar{\Omega}^+$ decay highlighted



No hardware trigger possible

- A fixed-target experiment with a forward geometry — high track density.
- Up to 1000 charged particles/collision.
- 10^5-10^7 collisions per second.
- No hardware triggers — free streaming data.
- On-line time-based event reconstruction is required with selection of extremely rare probes (like one $\bar{\Omega}^+$ per 10^6 collisions).

- On-line reconstruction at the dedicated high performance computing farm (GSI Green IT Cube).
- High speed and efficiency of the reconstruction algorithms are required.
- The algorithms have to be highly parallelised and scalable.
- CBM event reconstruction: Kalman Filter and Cellular Automaton.

The detector system of CBM

Tracking system:

- Silicon Tracking System (STS) — main tracking system; fast double sided microstrip sensors;
- Micro Vertex Detector (MVD) — reconstruction of displaced vertices; MAPS pixel detectors with precision of about 5 μm.

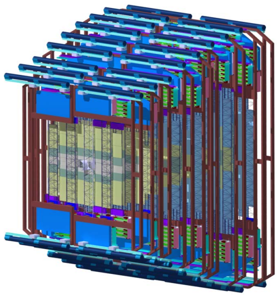
Particle identification detectors:

- Ring Image Cherenkov Detector (RICH) — separation of electrons and pions; gaseous RICH;
- Transition Radiation Detector (TRD) — separation of electrons and pions, dE/dx for light nuclei;
- Muon Chambers (MuCh) — identification of muons; set of absorbers followed by GEM detectors;
- Time Of Flight (TOF) — identification of hadrons; fast MRPC sensors.

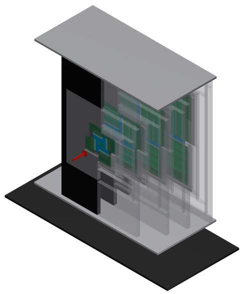
Detector for event characterisation:

- Projectile spectator detector (PSD) — forward calorimeter; determination of the reaction plane, collision centrality.

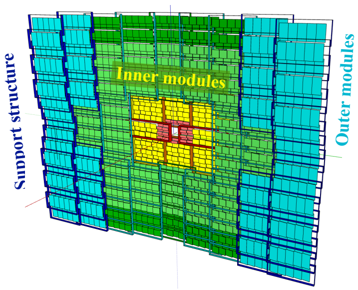
STS



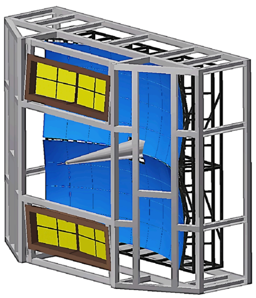
MVD



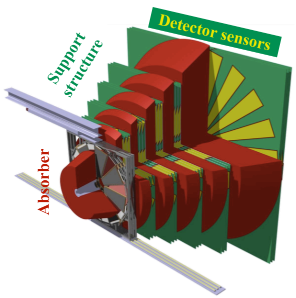
TOF



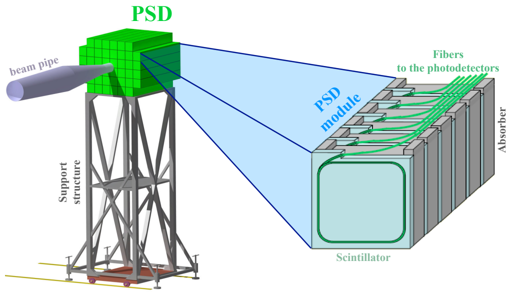
RICH



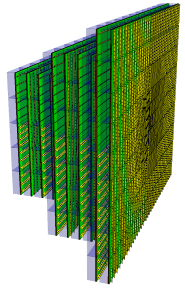
MuCh



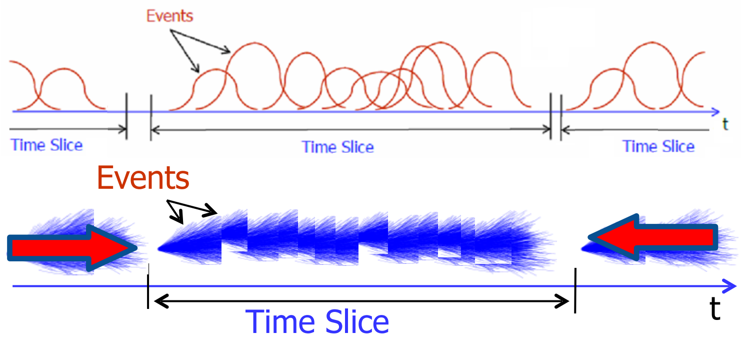
PSD



TRD

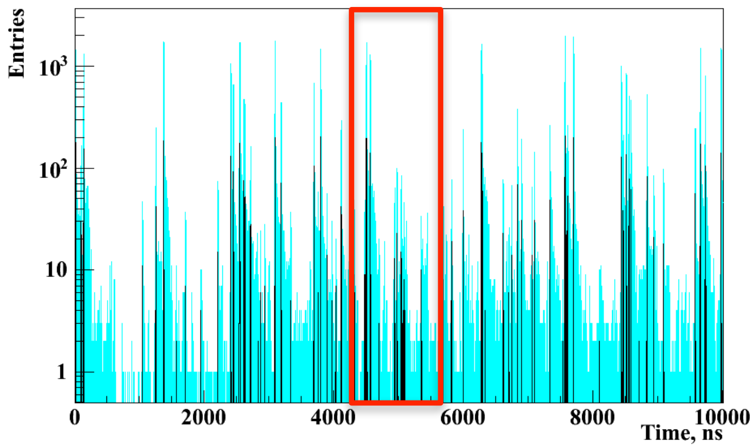


Time based reconstruction in CBM

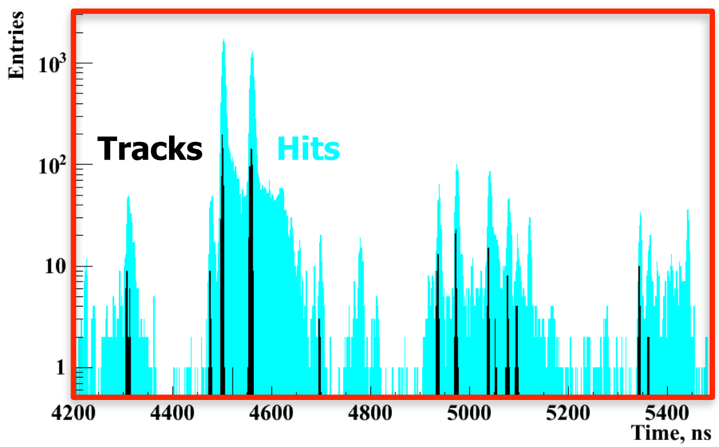


- The beam will be continuous (no bunch structure).
- Detector hits will be marked with a time stamp.
- Events in the selected time window (time slice) will overlap in time.
- Reconstruction will be in 4D (x,y,z,t).
- Reconstruction of time slices rather than events will be needed.
- Events will be defined based on the reconstructed tracks.

100 AuAu mbias events at 10 AGeV at 10^7 Hz

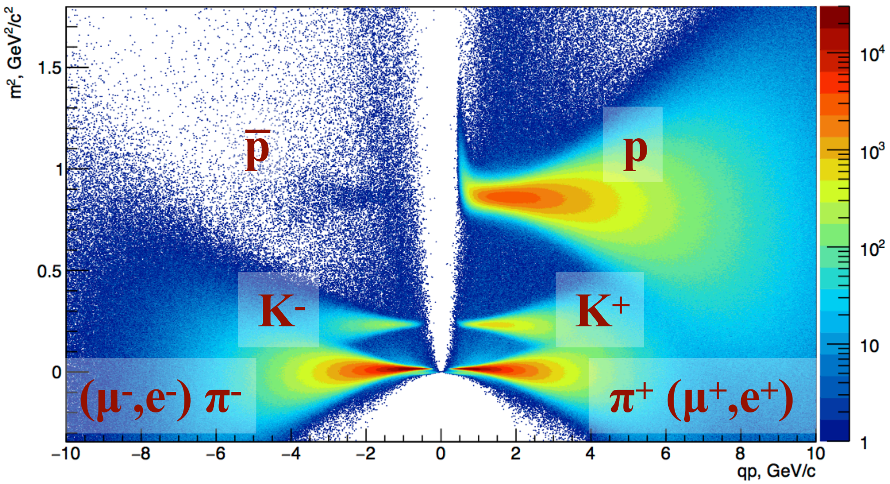


Reconstructed tracks - zoom

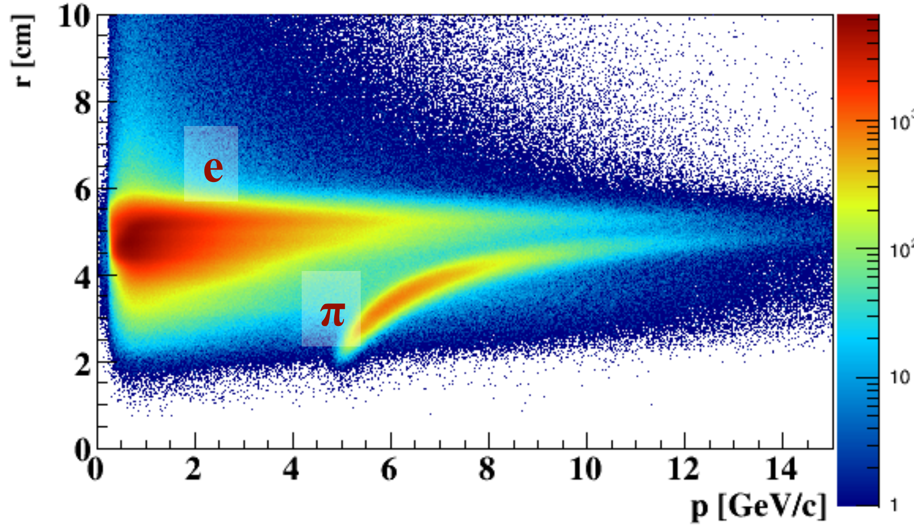


Reconstructed tracks clearly represent groups, which correspond to the original events central AuAu events, 10 AGeV

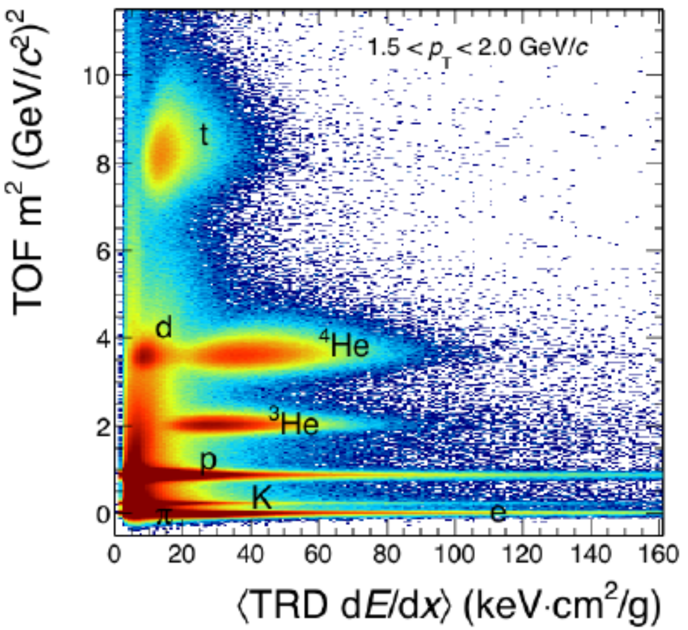
ToF: hadron identification



RICH: electron identification



Combined ToF-TRD identification

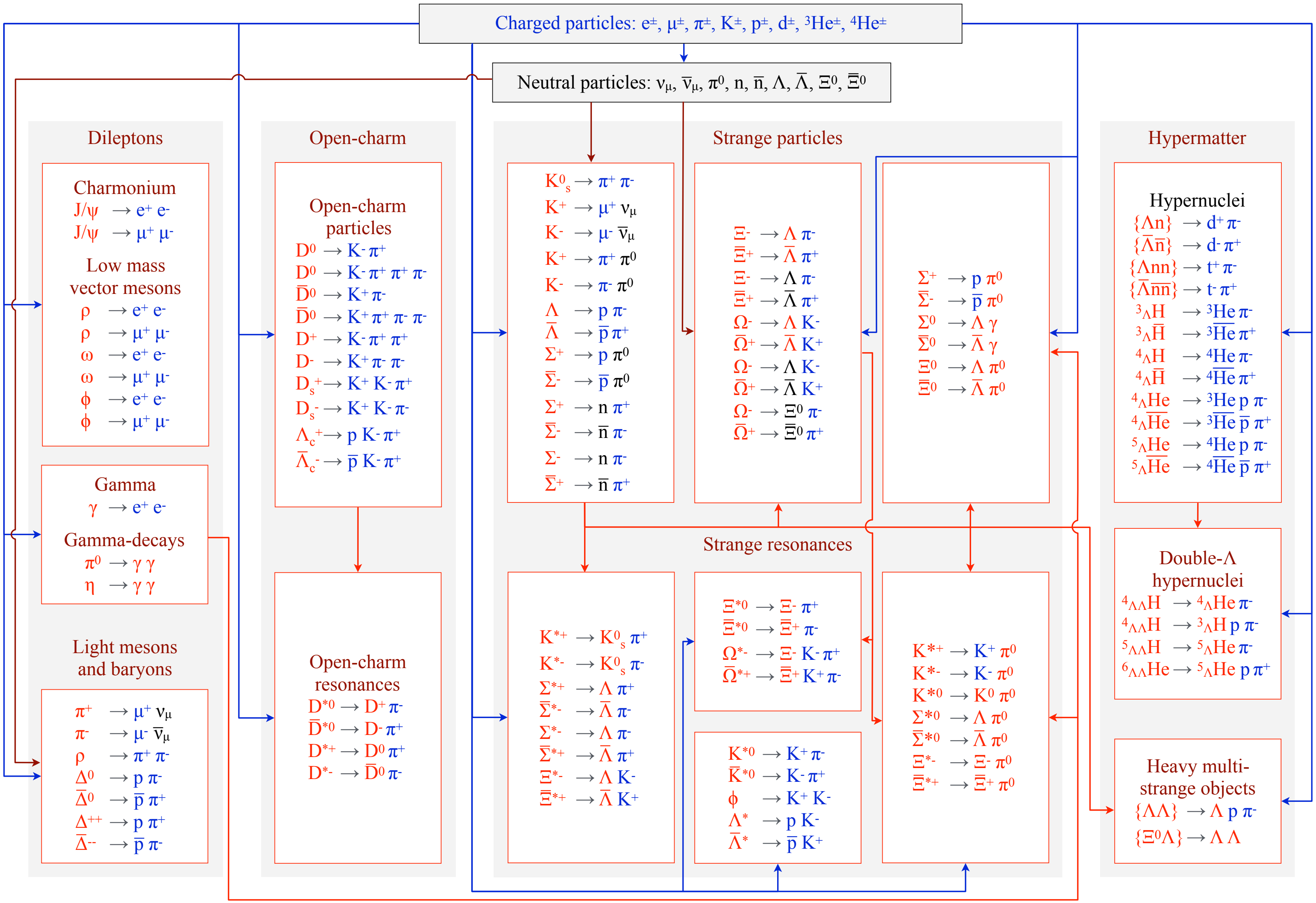


Particle identification (PID) detectors:

- ToF (Time of Filght) — hadron identification;
- RICH (Ring Imaging CHerenkov detector) — electron identification;
- TRD (Transition Radiation detector) — electron and light nuclei identification.

Particle identification detectors of CBM will allow a clear identification of charged particle.

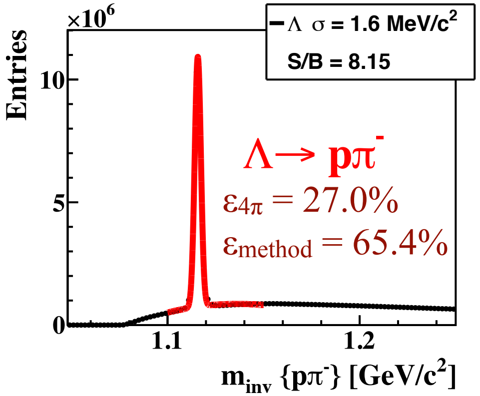
Reconstruction of short-lived particles with KF Particle Finder

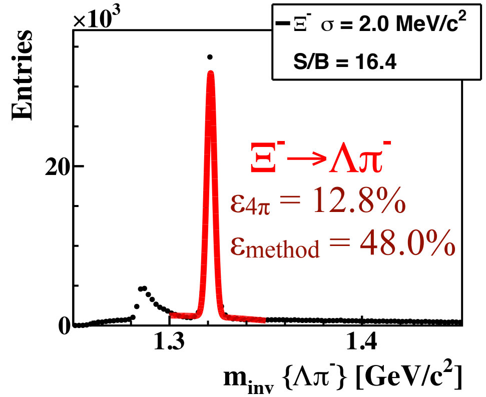


- The package is being designed for online operation.
- It is based on the Kalman filter mathematics.

Event based reconstruction (3D)

AuAu, 10 AGeV, 5M central UrQMD events, realistic PID

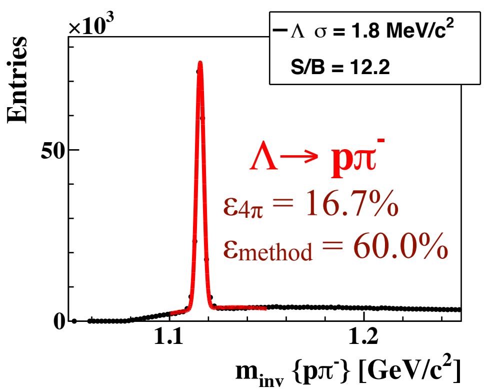


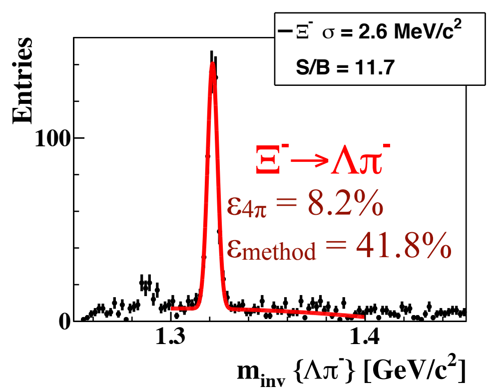


- Event based approach is standard in HEP.
- Full detector setup is used.
- CBM allows reconstruction of particles with high efficiency and signal to background (S/B) ratio.

Time based reconstruction (4D)

10 MHz, AuAu, 10 AGeV, 300k mbias UrQMD events, ideal PID



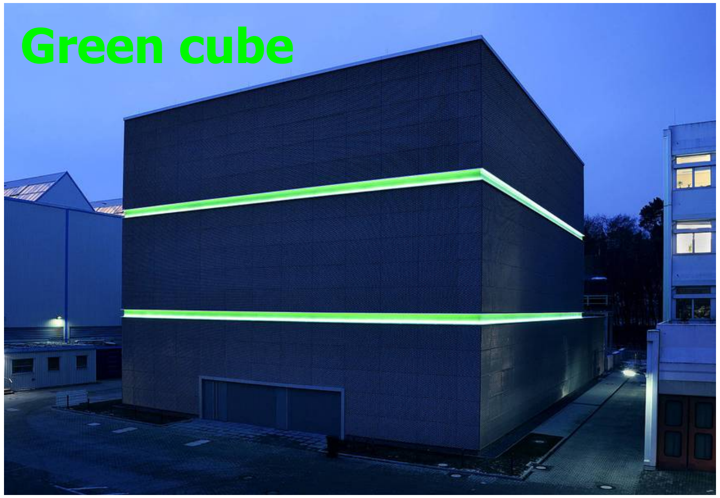


- Time based (4D) reconstruction required by CBM is under development.
- First version with STS and ideal Monte Carlo PID is ready.
- It is stable up to the highest interaction rates.
- PID detectors are being added to the 4D reconstruction scheme.
- Multi primary vertex procedure is in progress.

Summary and outlook

- The mission of the CBM experiment is to investigate the phase diagram of strongly interacting matter in the region of the high densities ($\sqrt{s_{NN}}$ = 2.7-4.9 GeV).
- The key feature of CBM is a high rate capability required for the measurement of rare observables.
- The CBM strategy for data readout and event selection is based on free streaming frontend electronics.
- Fast and scalable algorithms will allow efficient online reconstruction and selection of events.
- First version of the time based reconstruction in the tracking system is available. Implementation of the full time based reconstruction scheme is in progress.
- Performance studies for a wide set of observables show unprecedented capabilities of the CBM experiment for the exploration of highly compressed baryonic matter.

FAIR, SIS100

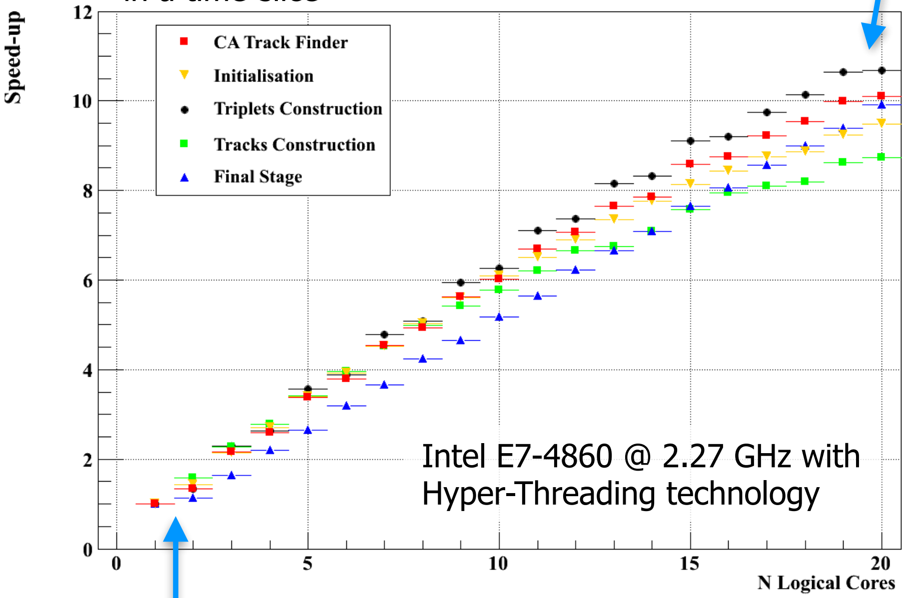


4D track reconstruction with the CA Track Finder

Efficiency	3D	4D, 10 MHz
All tracks	92.5	91.7
Primary, high p	98.3	96.2
Primary, low p	93.9	94.3
Secondary, high p	90.8	90.2
Secondary, low p	62.2	64.3
Clone level	0.6	0.6
Ghost level	1.8	0.6

Total time - 84 ms

Parallelism inside a time-slice, 100 mbias events in a time-slice

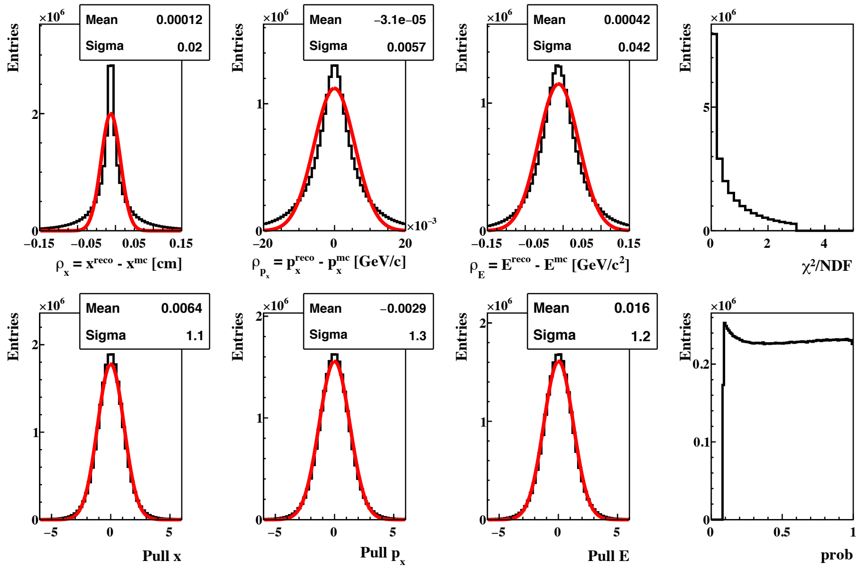


Total time - 849 ms

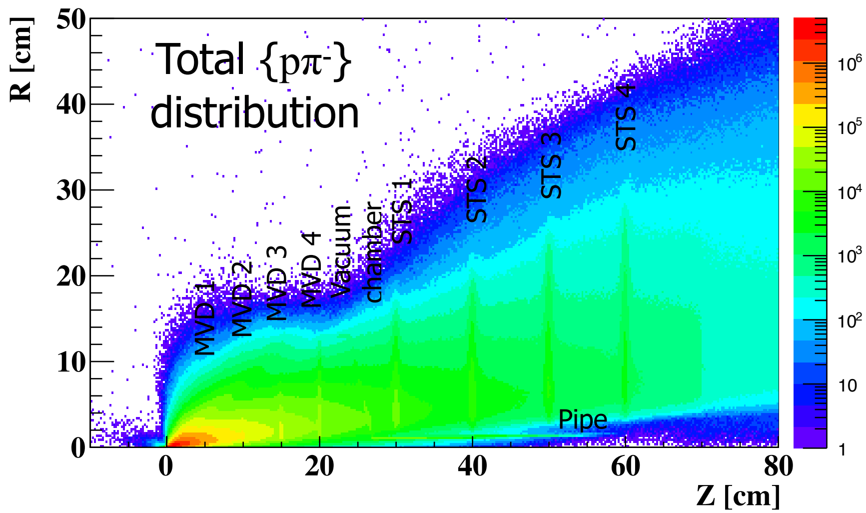
- The full chain for the time-based simulation and reconstruction is implemented for the STS detector.
- The 4D CA track finder is developed.
- The 4D CA track finder shows practically the same efficiency as the 3D track finder.
- It is fast and scalable.

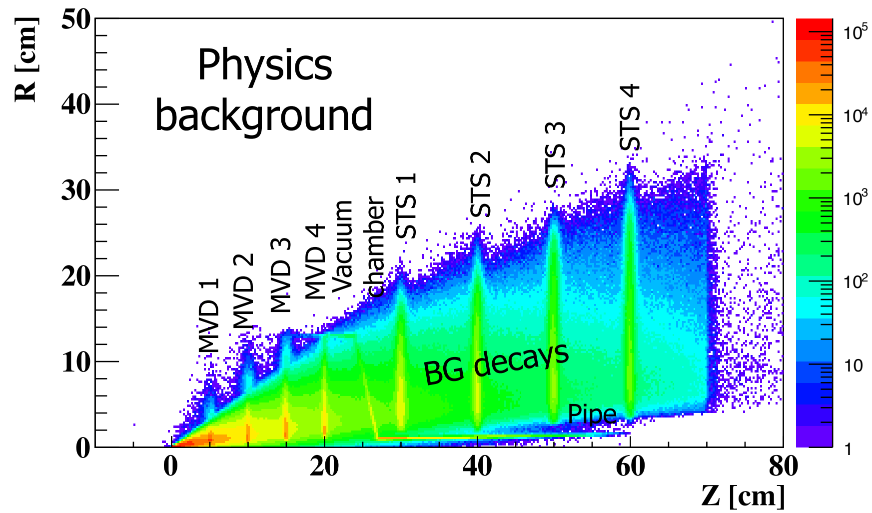
Reconstruction quality

AuAu, 10 AGeV, 5M central UrQMD events, realistic PID

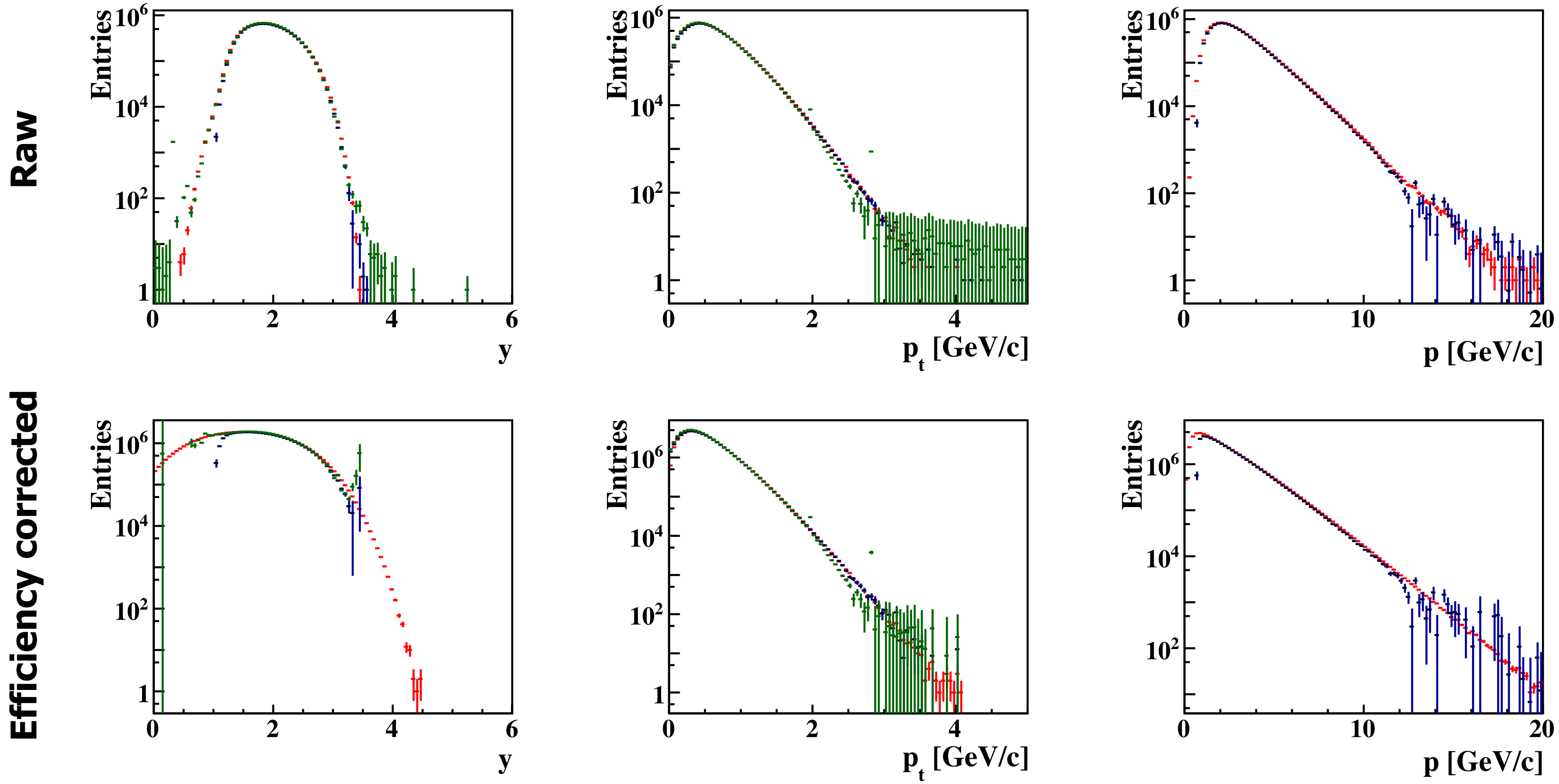


- The fit quality is demonstrated at Λ hyperon.
- Y and Z components are similar to X.
- Correct mathematics, as a result, correct pulls (unbiased, width about 1), χ^2 and flat prob (p-value) distributions.
- High quality of the reconstruction allow to perform the detector tomography.
- The vertices on the stations are due to the interaction of the primary particles with the material.





Extraction of the signal spectra



5M central AuAu UrQMD events at 10 AGeV

- Results are shown at the example of $K^0_s \rightarrow \pi^+\pi^-$.
- Several independent methods for the signal spectra extraction are implemented, results are in a good agreement.
- Implemented methods allow to reconstruct signal spectra (Side bands and Background fit) reproducing the shape of distributions obtained from the reconstructed signal particles (Reco Signal).
- Efficiency corrected spectra reproduce the MC Signal distributions.