Event reconstruction and selection in high-rate heavy-ion reactions in the CBM experiment at FAIR

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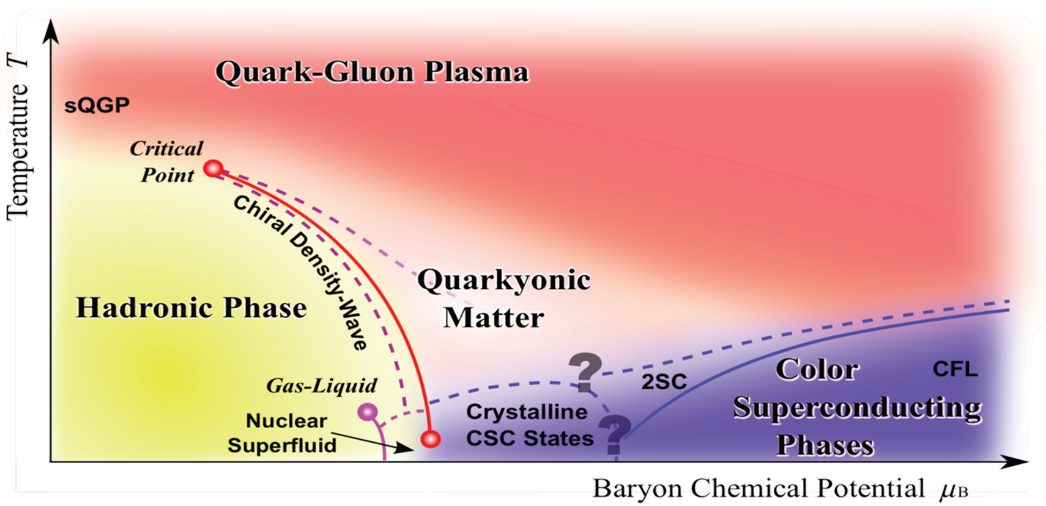
Content

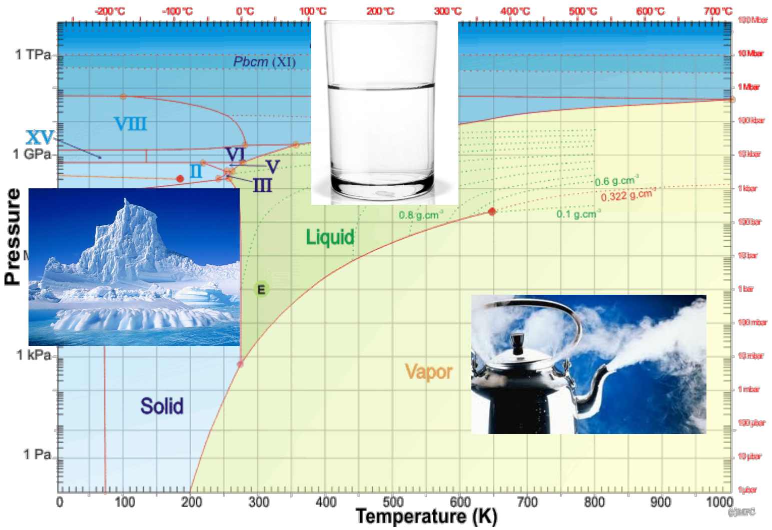
- CBM experiment: physics case and challenges.
- Event based physics observable performance:
  - strange particles;
  - dileptons;
  - open charm;
  - collective effects.
- Full event topology reconstruction.
- Time-based reconstruction:
  - time-based track reconstruction;
  - time-based track fit;
  - time-based short-lived particle reconstruction.

Tasks of the CBM experiments

Baryonic matter



Water



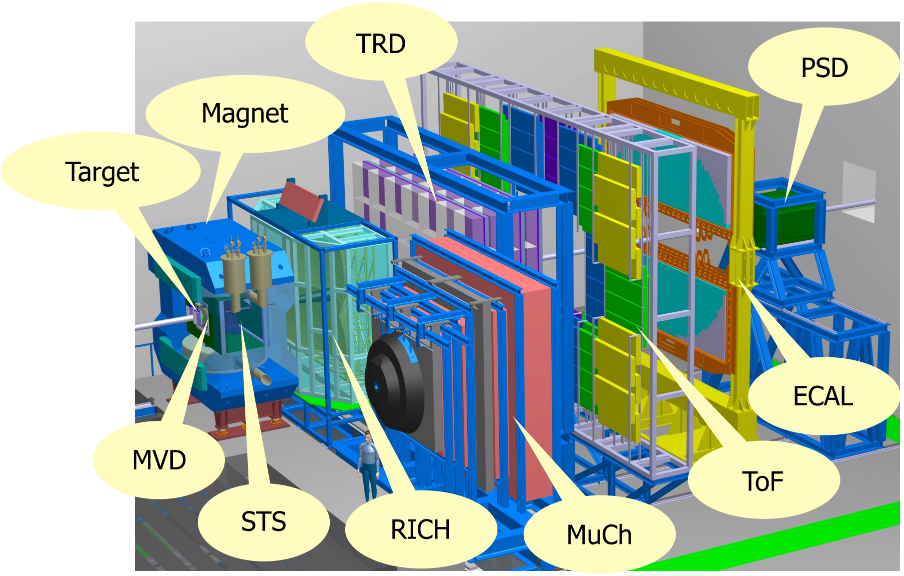
CBM physics case:

- hadronic-partonic and (or) chiral phase transition at high baryon chemical potential and search for the critical endpoint;
- equation of state of nuclear matter and degrees of freedom at these densities;
- hypernuclei and heavy multi-strange objects, if such objects exist;
- properties of hadrons in dense baryonic matter and the possible modification of them;
- charm production at threshold beam energies and charm properties in dense baryonic matter.

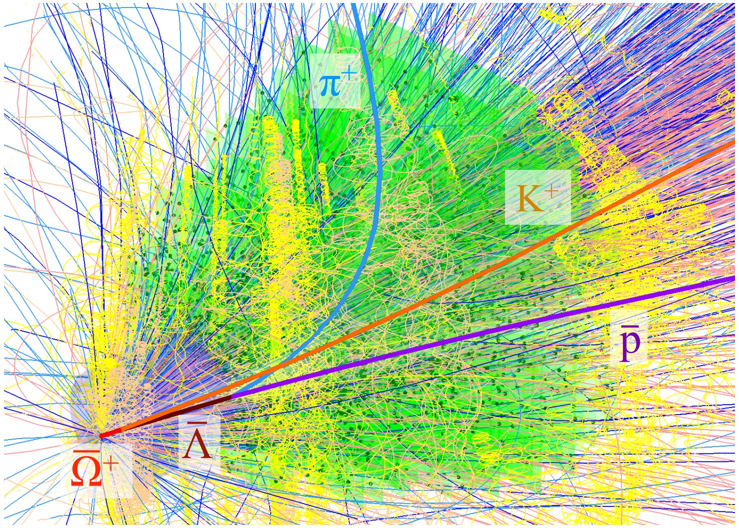
Main physics observables:

- the excitation function of yields, spectra, and collective flow of:
  - strange particles;
  - particles with charm quarks;
  - dileptons.
- in-medium mass distribution of vector mesons;
- event-by-event fluctuations of conserved quantities;
- hypernuclei, strange dibaryons and heavy multi-strange short-lived objects.

Challenges in CBM



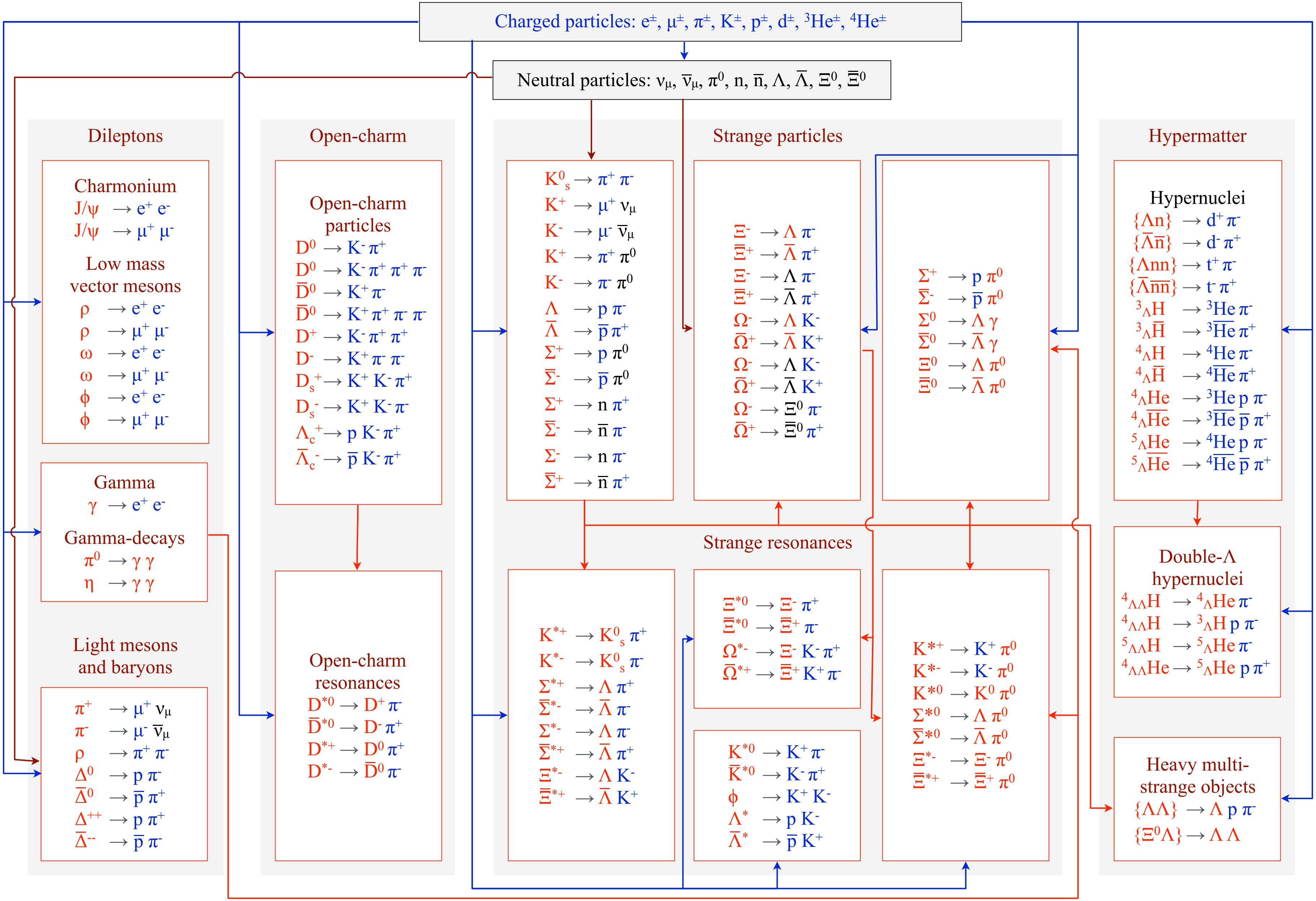
- CBM — future fixed-target heavy-ion experiment at FAIR, Darmstadt, Germany.
- 10^5-10^7 collisions per second.
- Up to 1000 charged particles/collision.
- Free streaming data.
- No hardware triggers.
- On-line time-based event reconstruction and selection is required in the first trigger level.
- Triggering is required on extremely rare probes (like one $\bar{\Omega}^+$ per 10^6 collisions).



- On-line reconstruction at the on-line farm with 60000 CPU equivalent cores.
- 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.

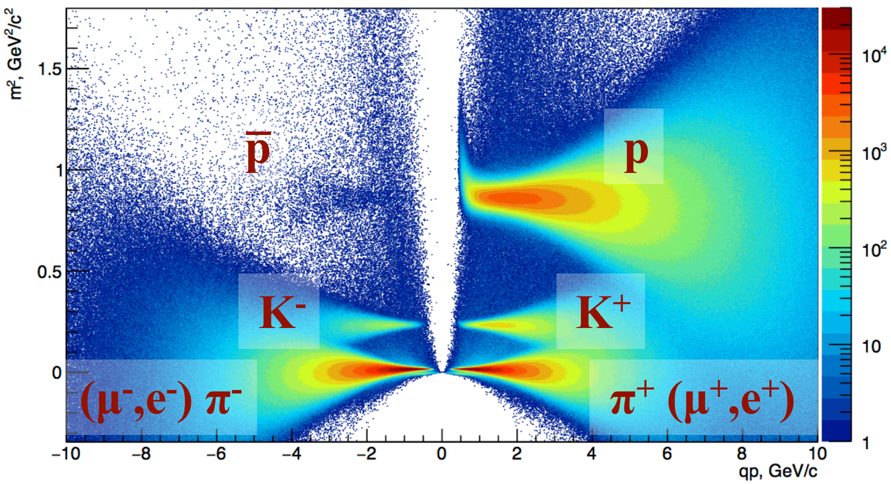
Olga Bertini, HK 9.2 Mo 17:00
Jörg Lehnert, HK 30.1 Mi 16:45

KF Particle Finder block-diagram

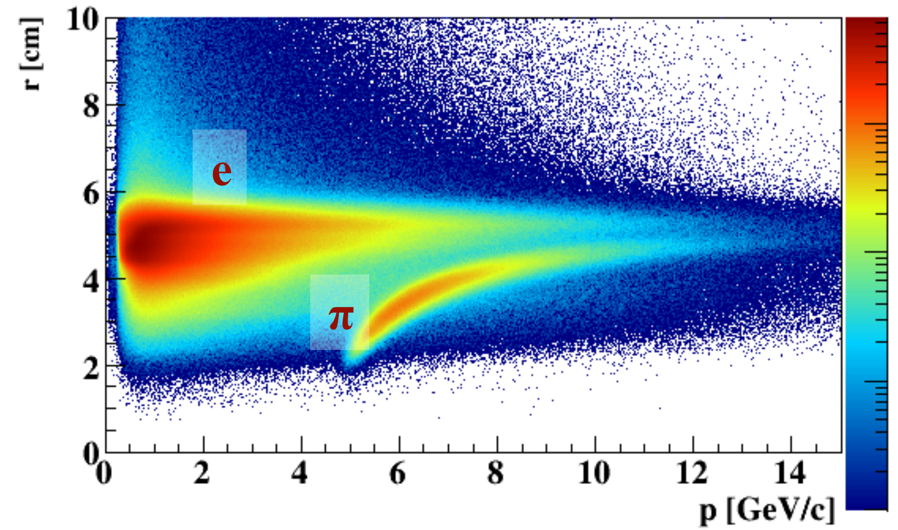


PID in CBM

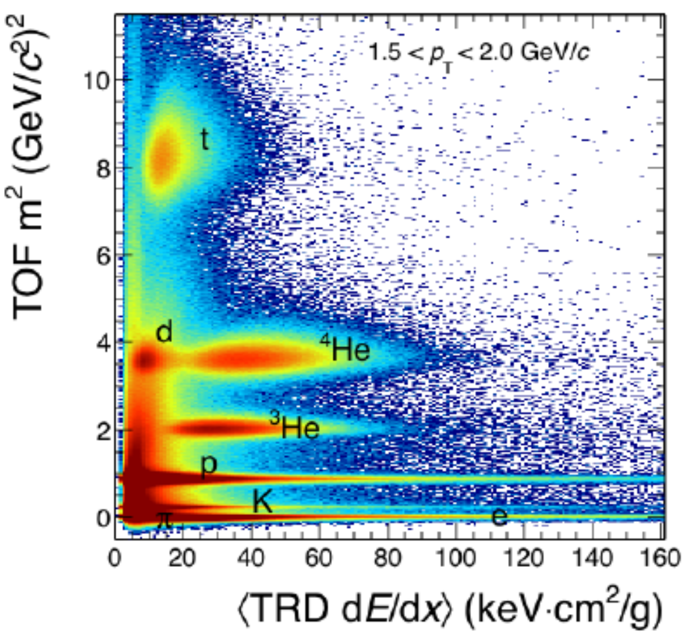
ToF: hadron identification



RICH: hadron identification



Combined ToF-TRD PID



PID detectors:

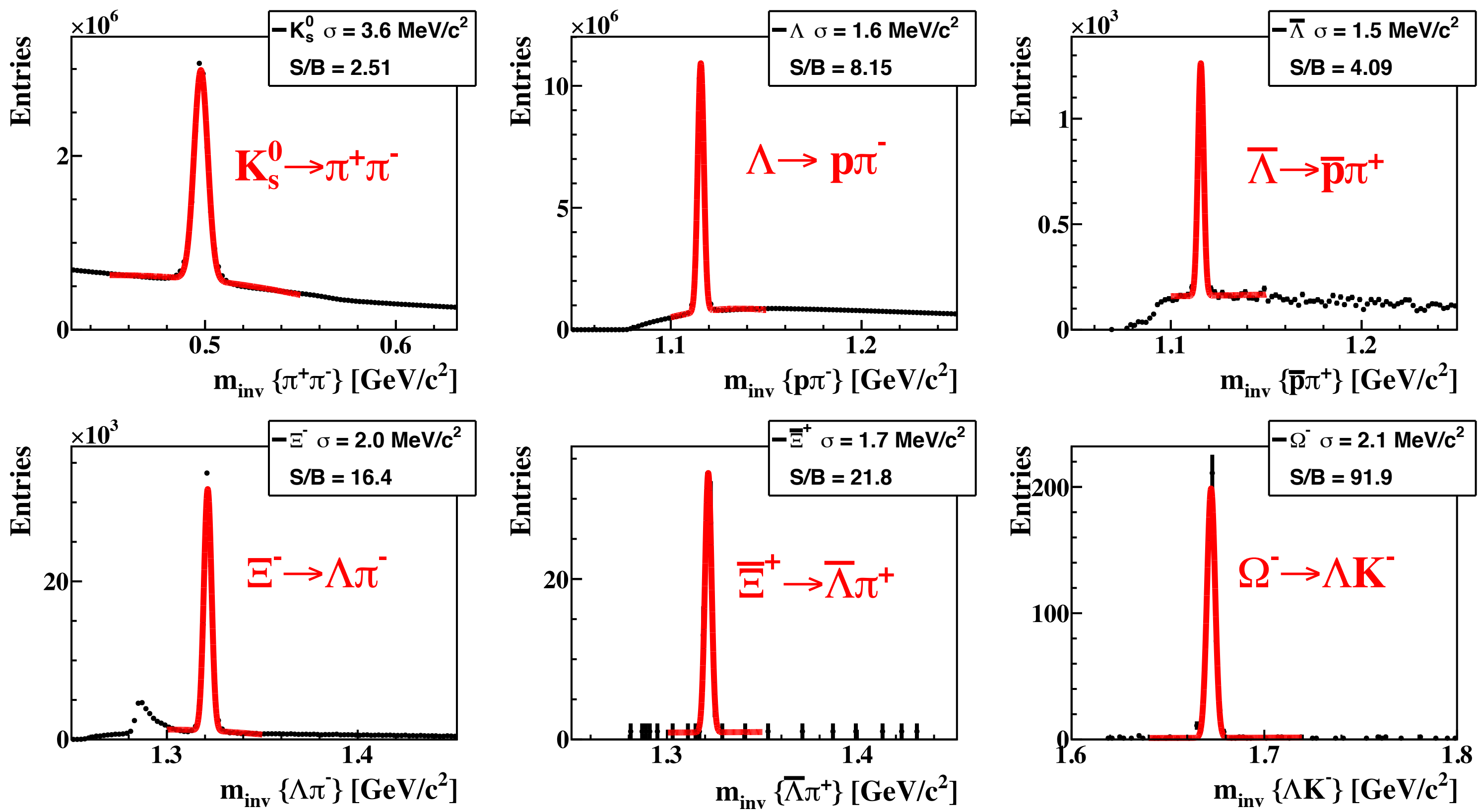
- ToF (Time of Filght) — hadron identification;
- RICH (Ring Imaging CHerenkov detector) — electron identification;
- TRD (Transition Radiation detector) — electron and heavy fragments identification.

PID detectors of CBM will allow a clear identification of charged tracks.

Viktor Klochkov, HK 2.3 Mo 17:30
Etienne Bechtel, HK 2.6 Mo 18:15

Reconstruction of strange particles

AuAu, 10 AGeV, 5M central UrQMD events, realistic PID, event-based



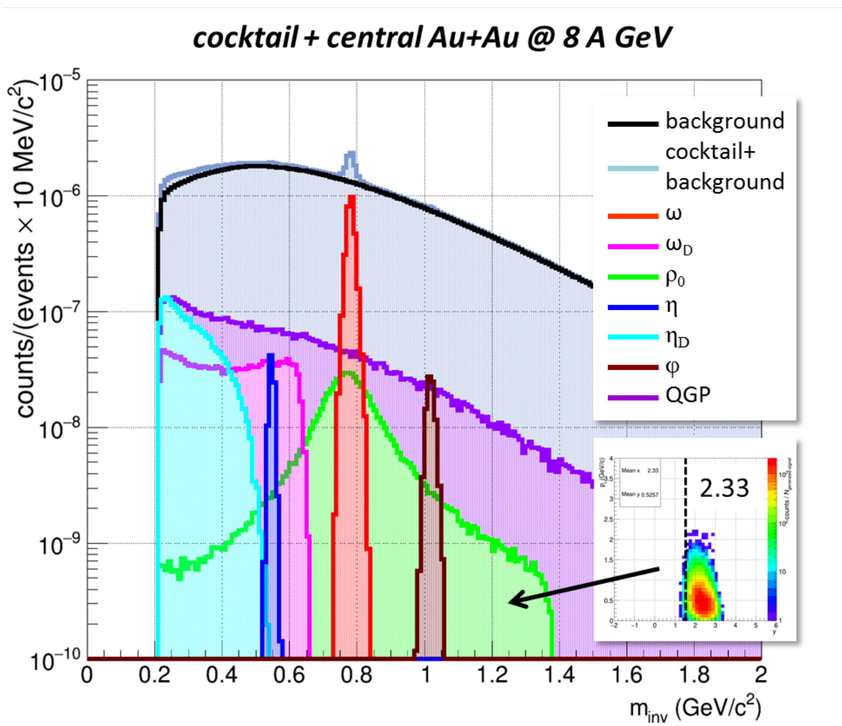
	K^0_s	Λ	$\bar{\Lambda}$	Ξ^-	$\bar{\Xi}^+$	Ω^-
ε_{method}, %	71.5	65.4	66.5	48.0	44.5	45.4
$\varepsilon_{4\pi}$, %	24.9	27.0	17.0	12.8	6.7	5.5
S/B	2.5	8.2	4.1	16.4	21.8	91.9

Mathematically correct procedures allow to collect spectra with high efficiency and signal to background ratio.

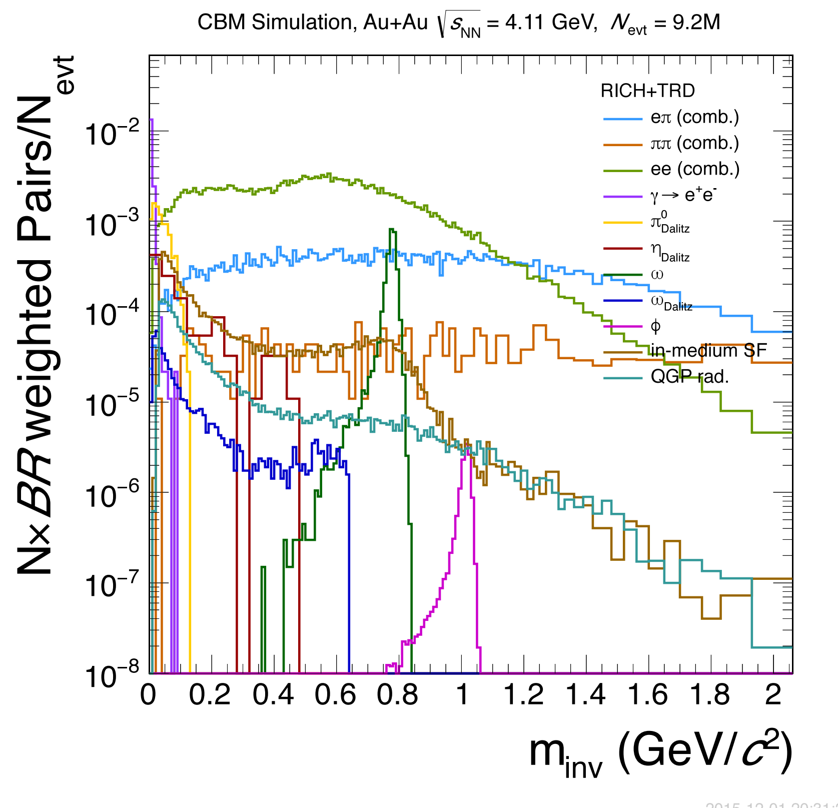
Iouri Vassiliev, HK 47.2 Do 17:15
Pavel Kisel, HK 58.3 Fr 14:45
Hamda Cherif, HK 47.8 Do 18:45

Dilepton reconstruction

Dimuon spectra for low mass vector mesons

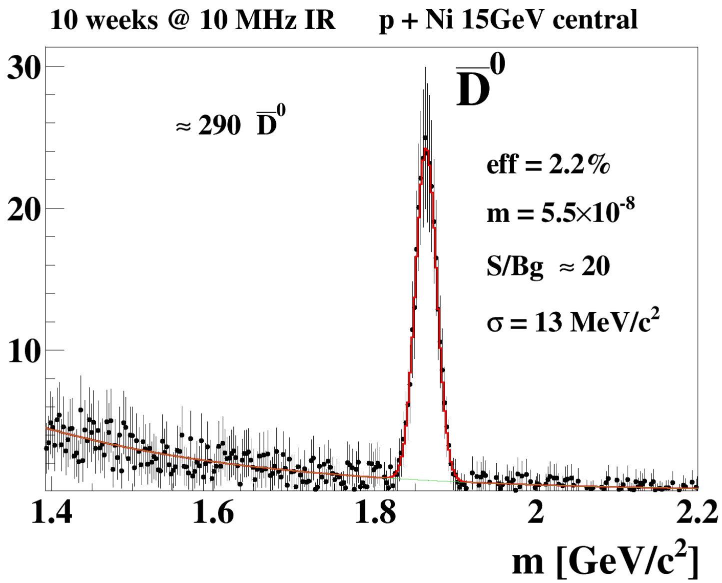


Dielectron spectra for low mass vector mesons

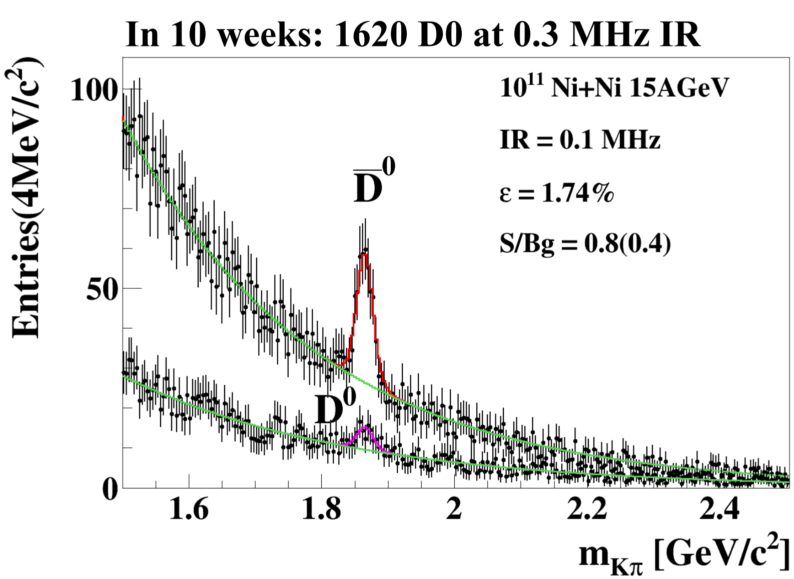


Florian Seck, HK 40.5 Do 15:00
Ievgenii Kres, HK 21.3 Di 14:45

Open charm reconstruction



	$D^0+\bar{D}^0$	D^++D^-	D_s^+	Λ_c^+
decay channel	$K^-\pi^+$	$K^-\pi^+\pi^+$	$K^-K^+\pi^+$	$p K^-\pi^+$
$M_{SM\ (J.Cleymans)}$	$4.5\cdot10^{-6}$	$2.2\cdot10^{-6}$	$1.1\cdot10^{-6}$	$3.6\cdot10^{-6}$
BR(%)	3.8	9.5	5.3	5.0
geo. acc.(%)	30	40	33	70
z-resolution (μm)	40	48	50	60
total eff. (%)	1.8	2.3	0.5	0.05
σ_m (MeV/c^2)	12	~12	~12	~12
$S/B_{2\sigma}$	0.8/0.4	-	-	-
Yield/10 weeks, 0.3 MHz IR	1620	2620	160	50



Open charm reconstruction:

- Fast tracking (STS) + decay daughter identification (ToF)
- Displaced vertex reconstruction (MVD)
- Topology reconstruction algorithm (KF Particle Finder)

Physics case at SIS100 energy:

Proton beams up to 30 GeV

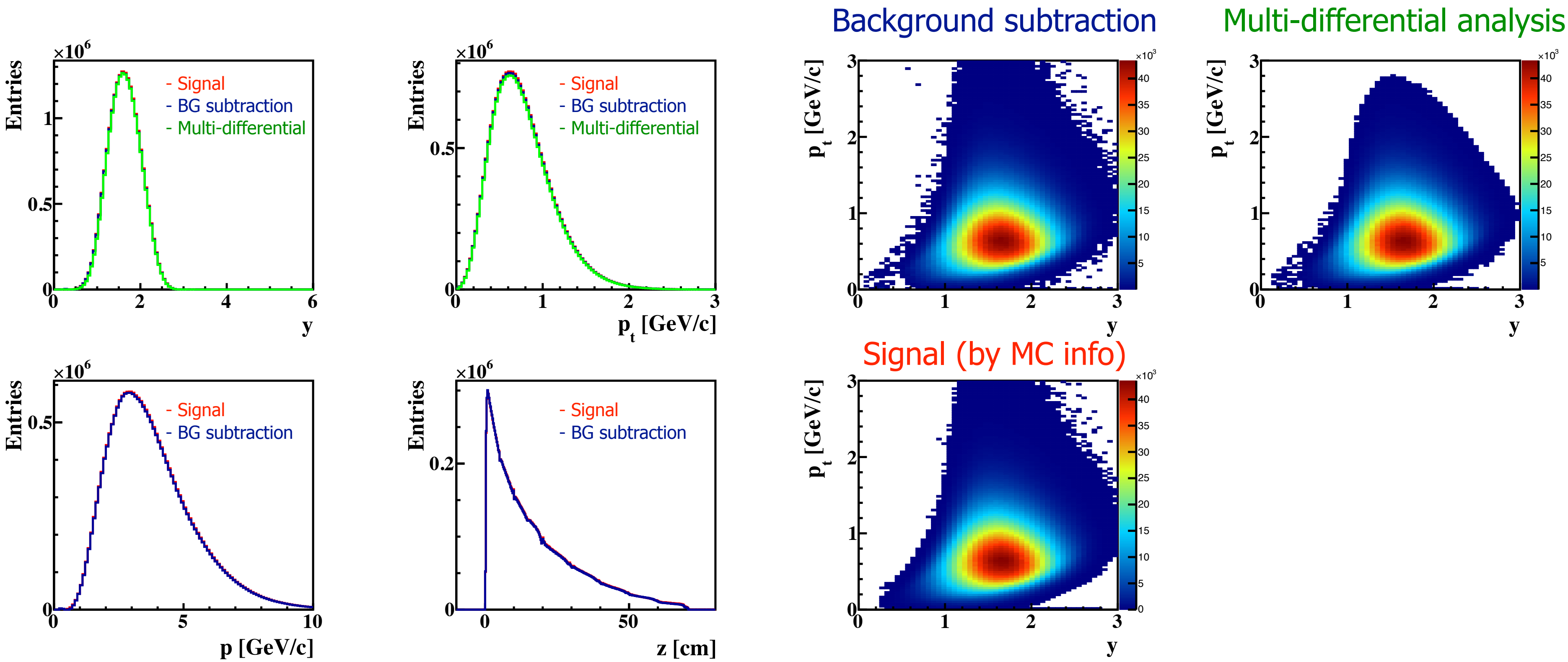
- Excitation function of charm (production mechanism)
- Charm propagation in cold nuclear matter

Light nuclei (Ni) beams up to 15 GeV

- Charm production & propagation in hot nuclear matter

Extraction of the signal spectra

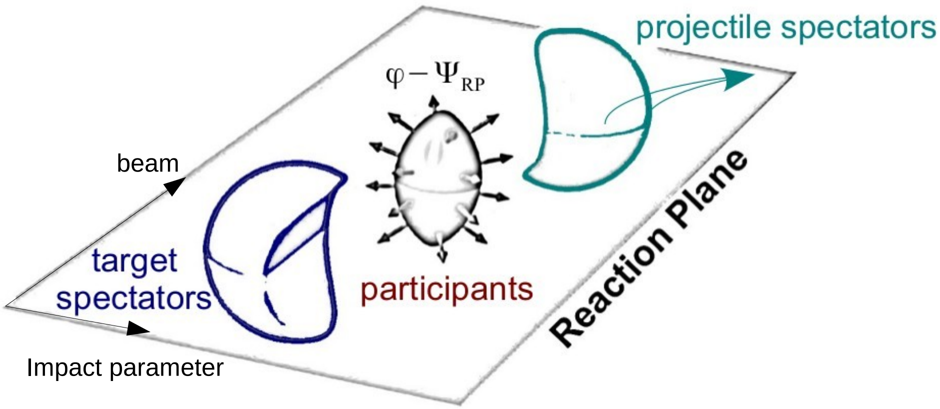
Extracted spectra for Λ hyperon in 5M central AuAu UrQMD events at 10 AGeV



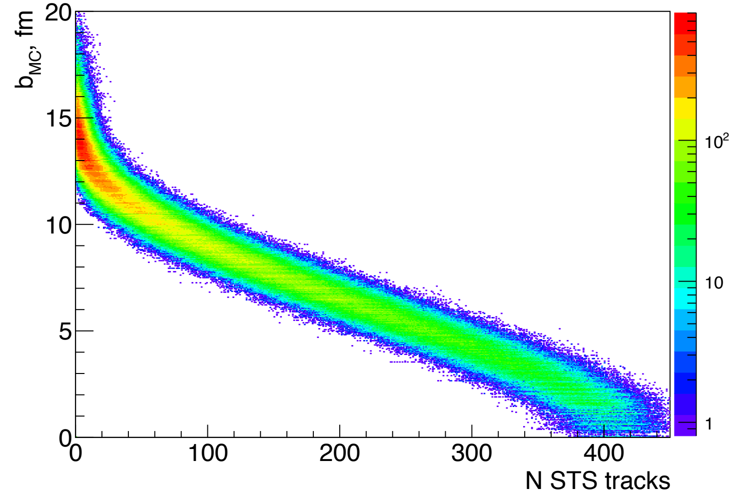
- Several independent methods for the signal spectra extraction are implemented.
- Methods show similar results.
- The signal distributions are nicely described by the extracting spectra.

Iouri Vassiliev, HK 47.2 Do 17:15
Pavel Kisel, HK 58.3 Fr 14:45

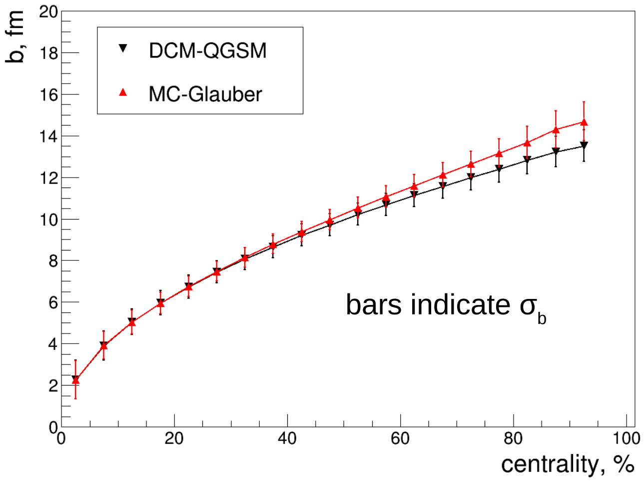
Reconstruction of collective effects



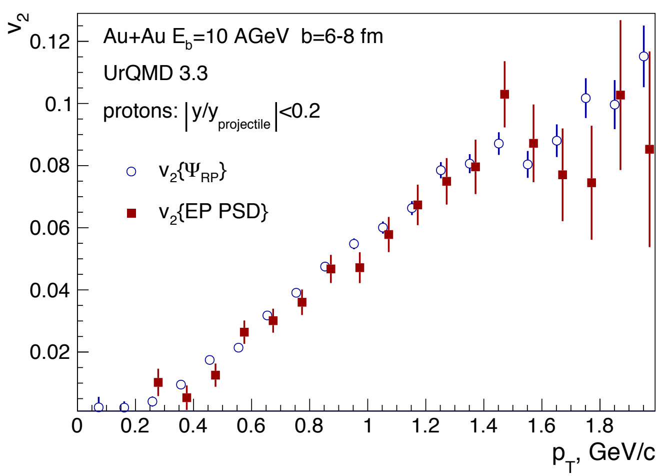
Correlation of the simulated impact parameter (b_{MC}) and track multiplicity allow reconstruction of b



Reconstructed impact parameter is consistent with **simulated** values

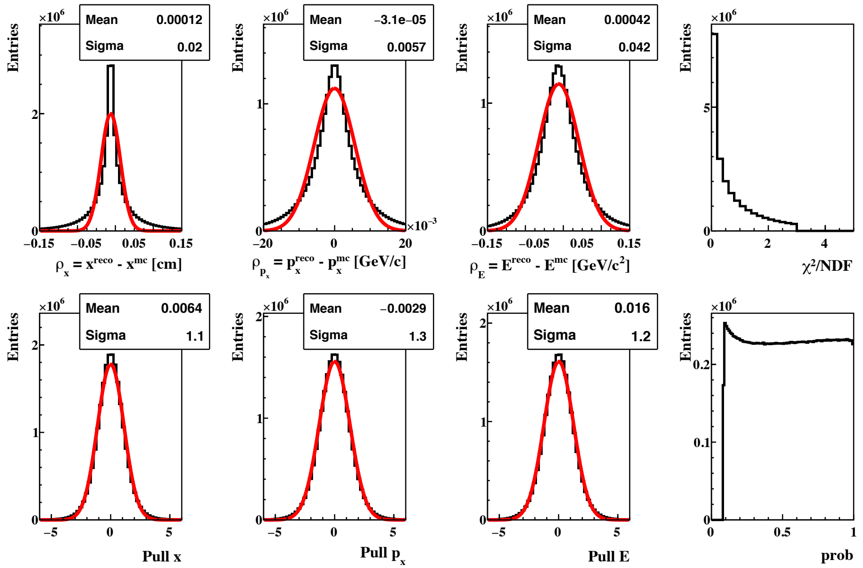


Reconstructed proton $\mathbf{v_2}$ is consistent with **simulated** values

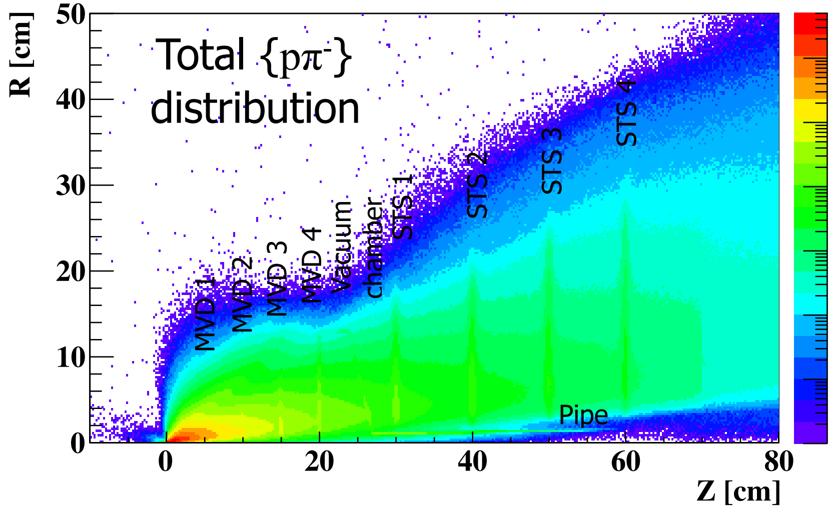


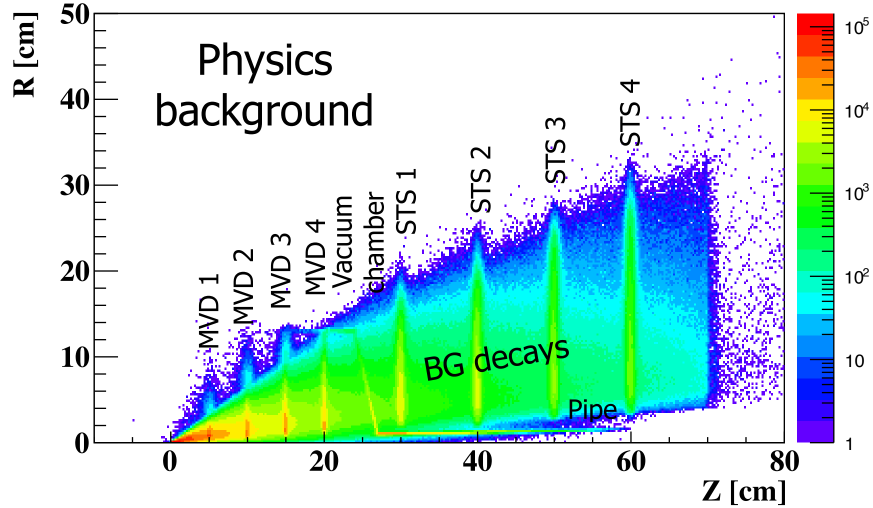
Reconstruction quality

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

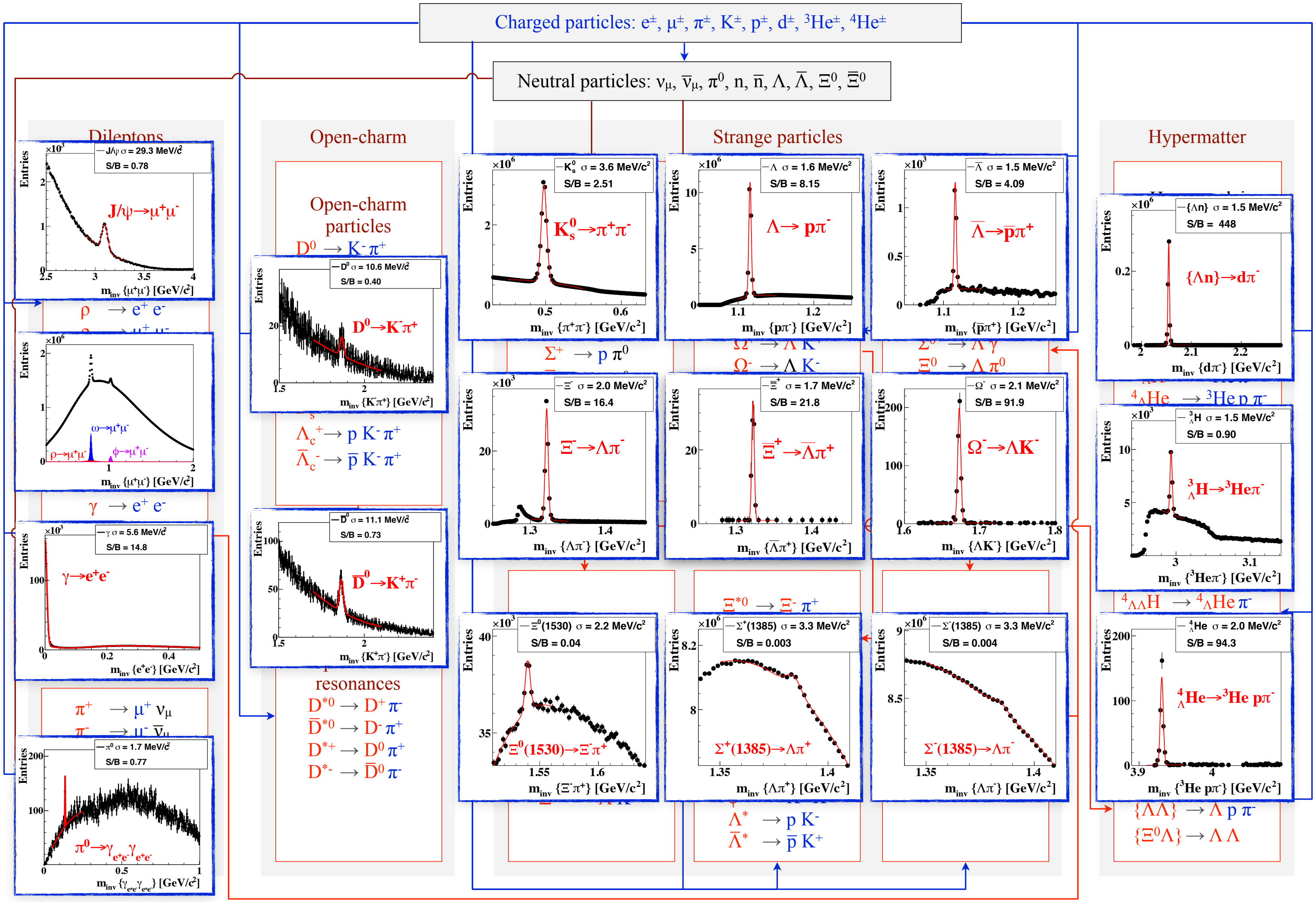


- The fit quality is demonstrated at Λ hyperon.
- Y and Z components are similar to X.
- Correct mathematics, as a result, correct pulls (unbiased, width about 1), χ^2 and flat prob (p-value) distributions.
- High quality of the reconstruction allow to perform the detector tomography.
- The vertices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



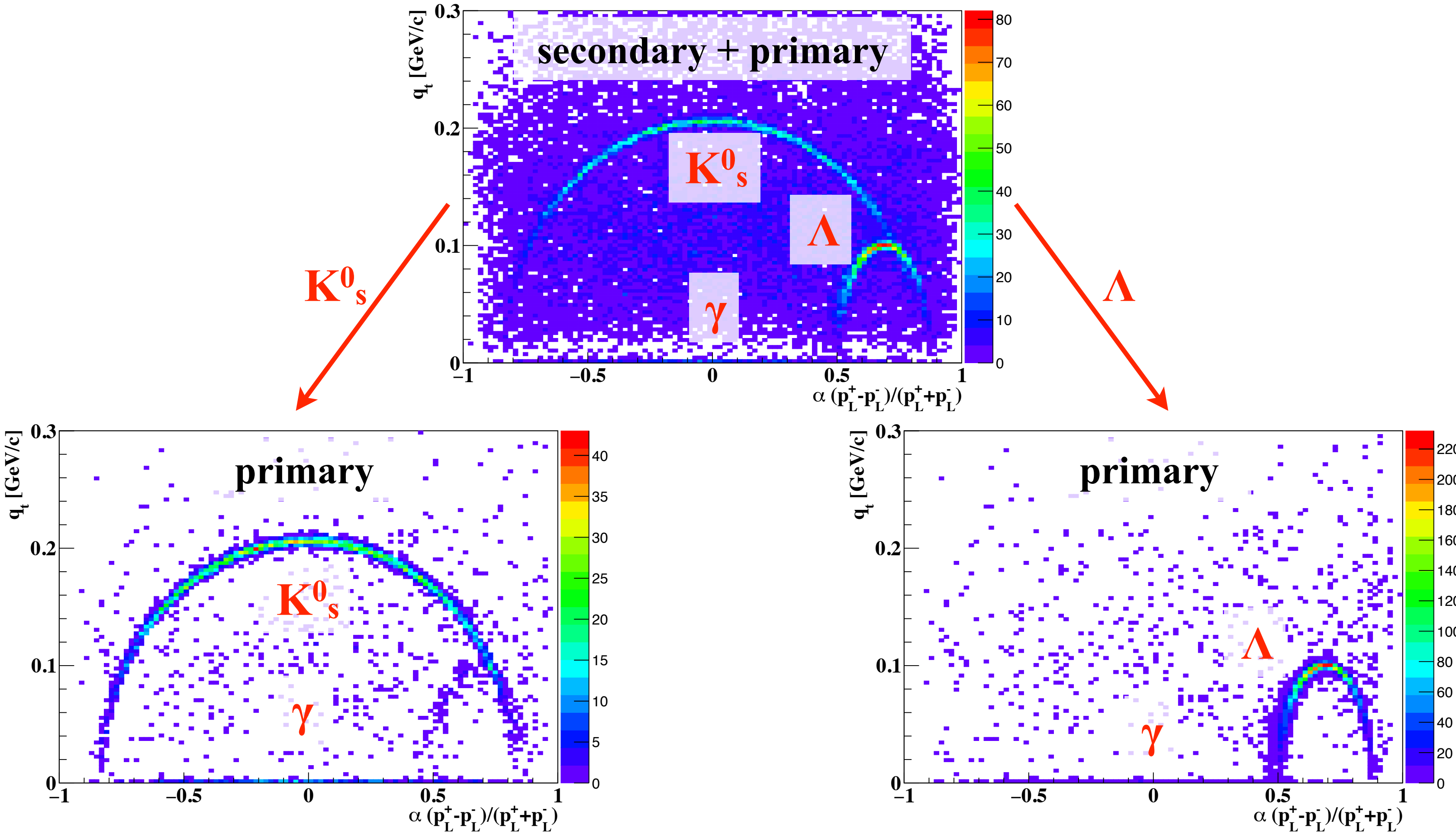


Physics coverage



Main physics observables are covered by the event based CBM reconstruction

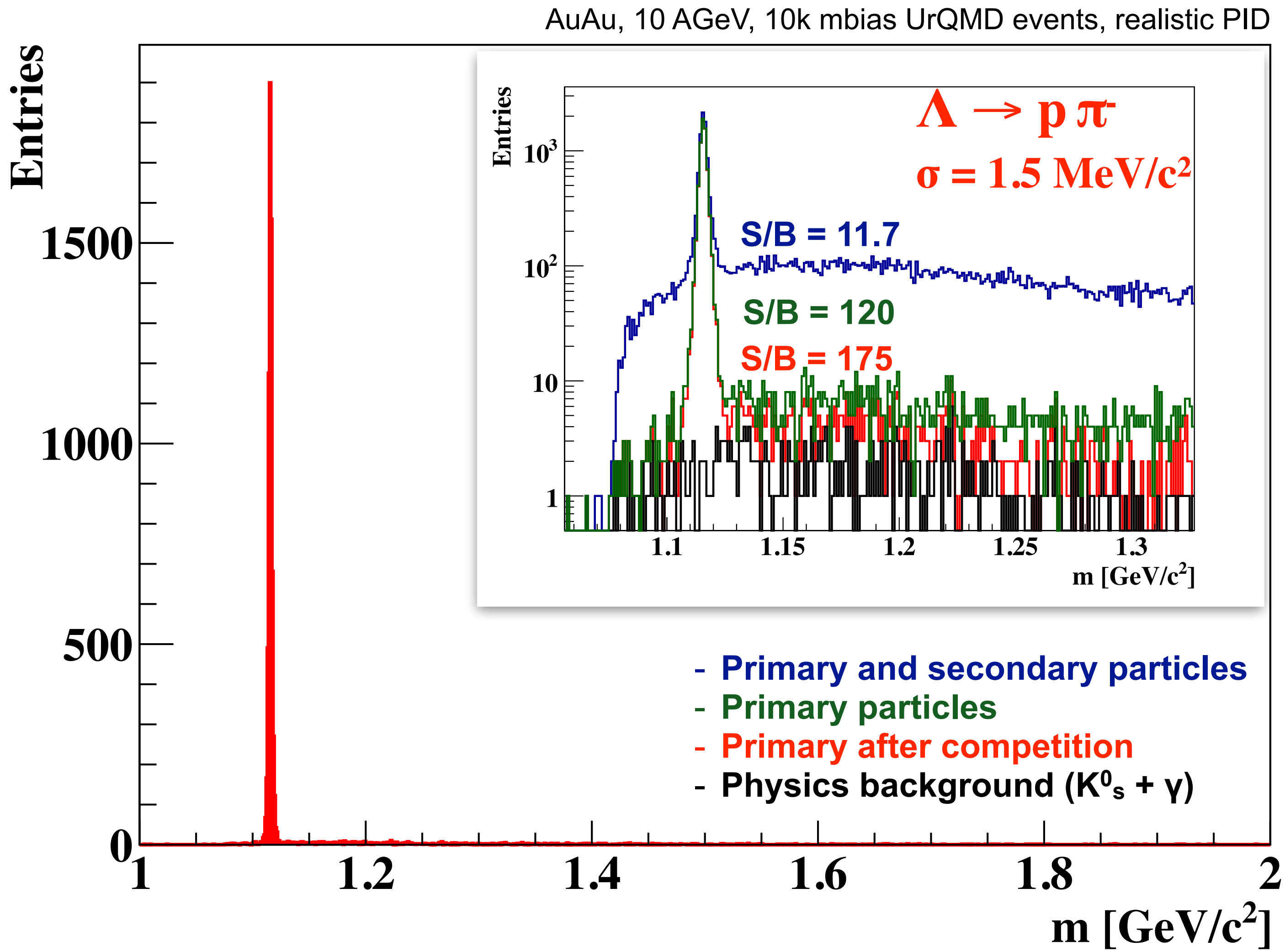
Competition between particle candidates



AuAu, 10 AGeV, 10k mbias UrQMD events, realistic PID

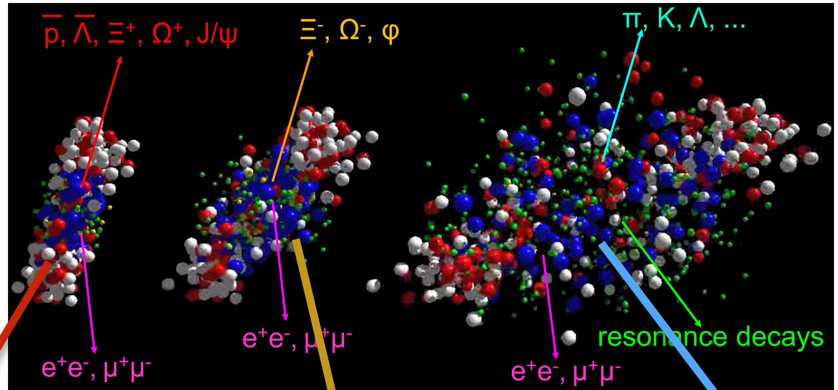
- Idea: full event topology reconstruction in CBM.
- Primary particles are of the main physics interest.
- For reduction of the background a competition between K^0_s and Λ candidates is organized based on the topology reconstruction and mass hypothesis.

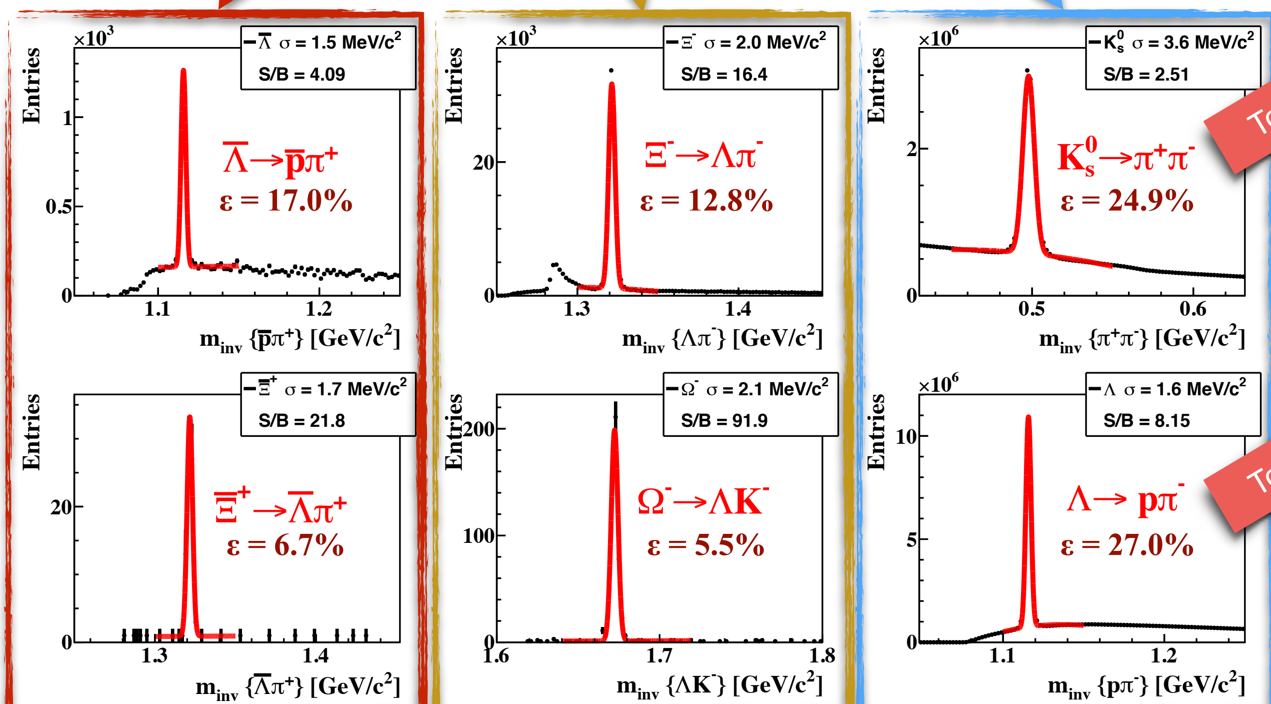
Competition between K^0_s and Λ: Λ spectrum



- Topological cut allow to decrease the combinatorial background several times.
- Dominant background — misidentified K^0_s and γ.
- Competition between K^0_s and Λ candidates is organized: if both candidates are constructed and at least one lies within 3σ from the corresponding peak, only the closest candidate is stored.

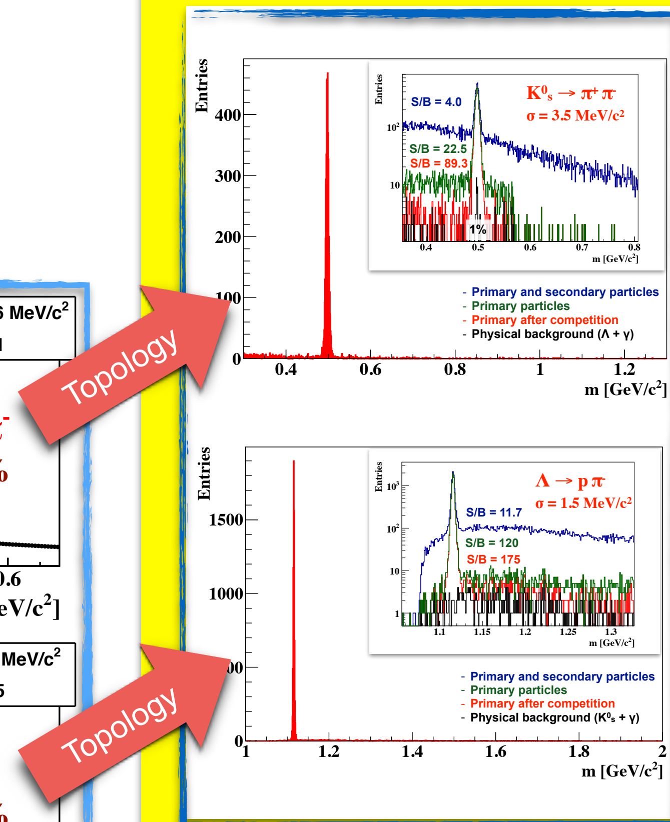
Full event topology reconstruction for physics analysis





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

Full event topology reconstruction



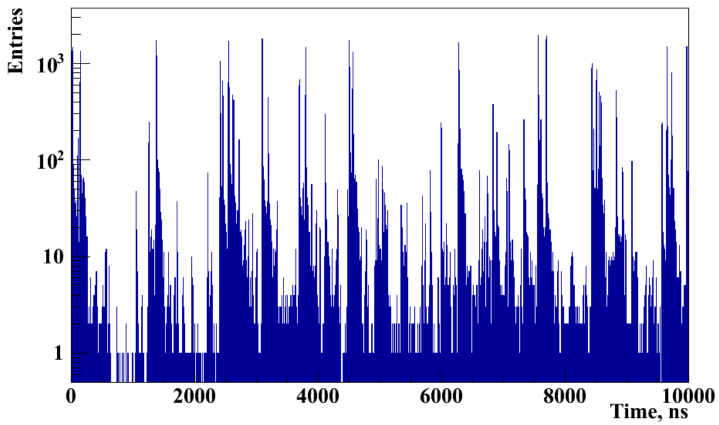
AuAu, 10 AGeV, 10K mbias UrQMD events, realistic PID

Full event topology reconstruction → clean probes of collision stages.

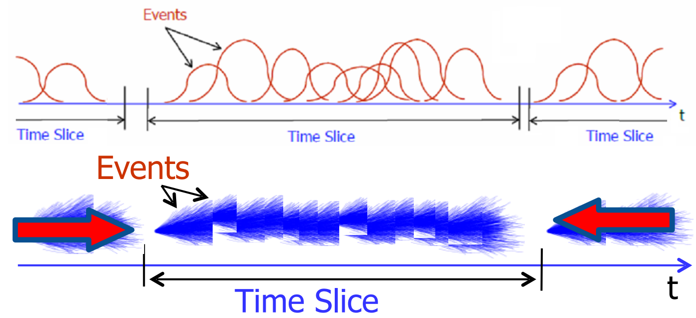
Time-based event reconstruction

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

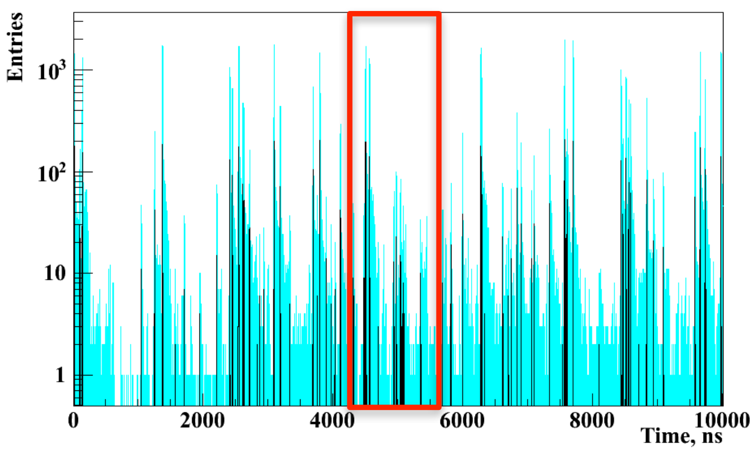
Input hits



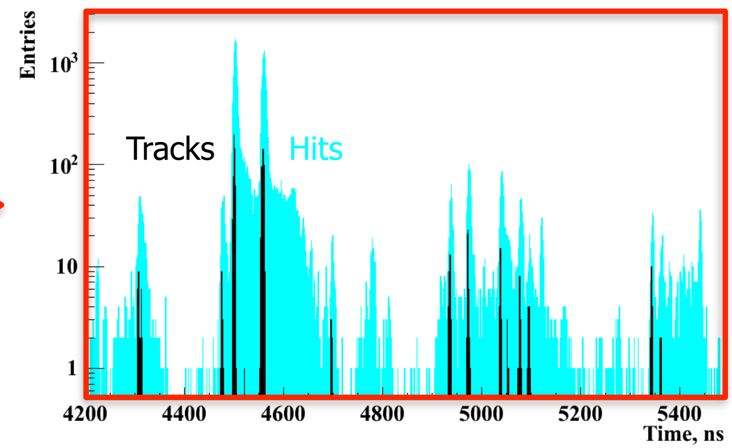
- The beam will have no bunch structure, but continuous.
- Free streaming data.
- Measurements in this case will be 4D (x,y,z,t).
- Reconstruction of time slices rather than events will be needed.



Reconstructed tracks



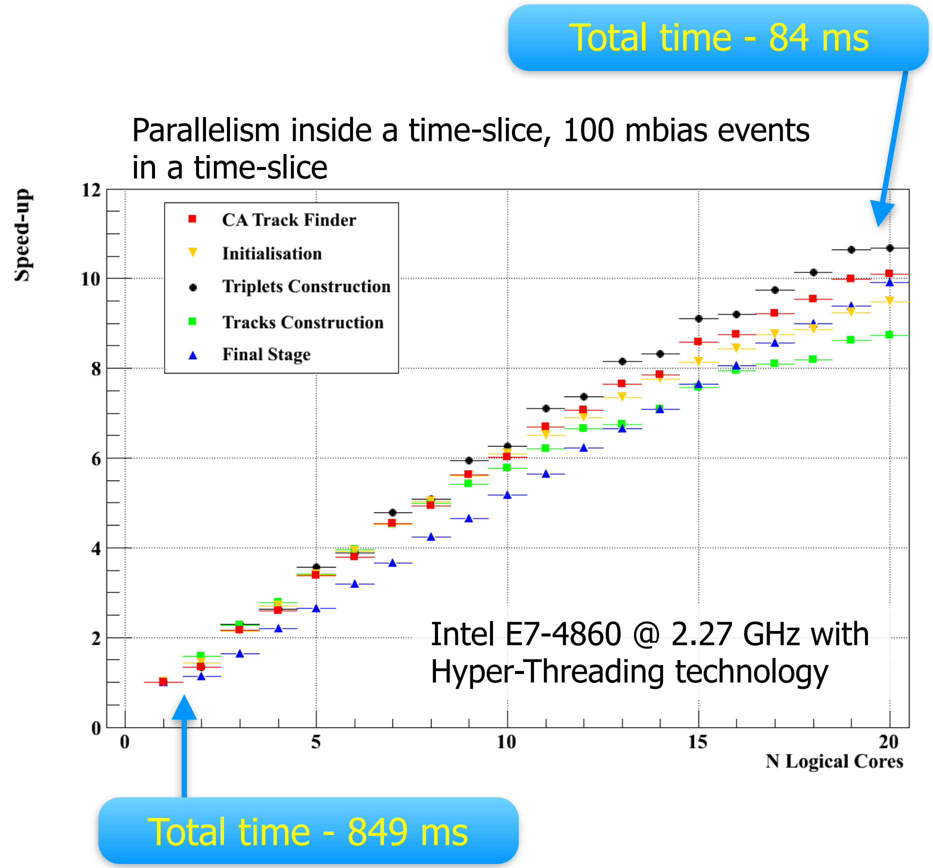
Reconstructed tracks - zoom



Reconstructed tracks clearly represent groups, which correspond to the original events

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

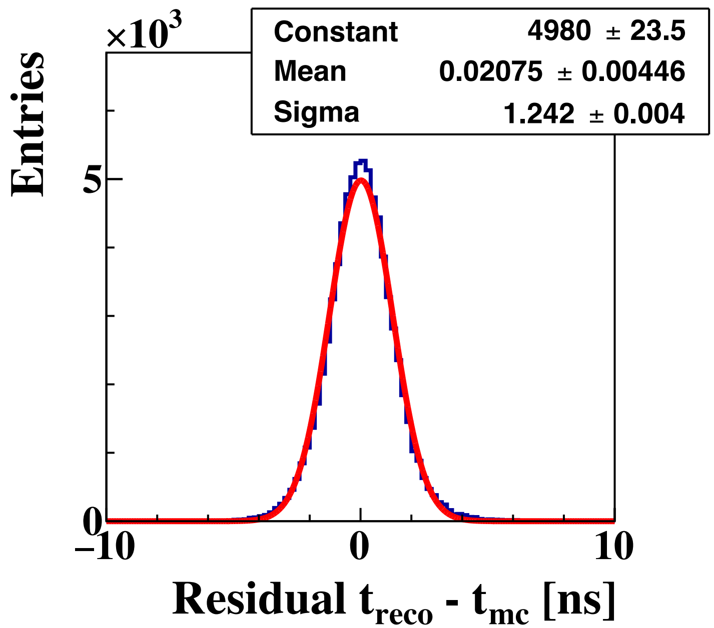


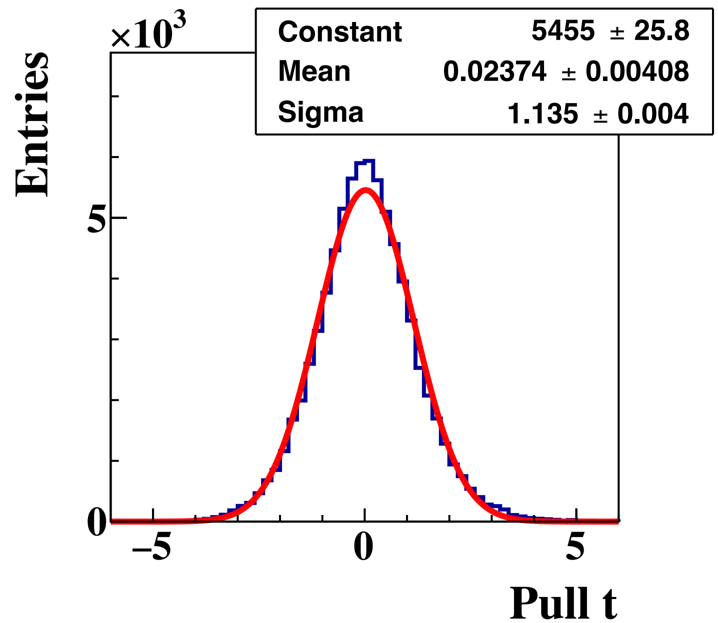
- The full chain for the time-based simulation and reconstruction is implemented for the STS detector.
- The 4D CA track finder is developed.
- The 4D CA track finder shows practically the same efficiency as the 3D track finder.
- It is fast and scalable.

Valentina Akishina, HK 12.5 Di 12:15

4D track fit

$$(x, y, t_x, t_y, q/p) \rightarrow (x, y, t_x, t_y, q/p, t)$$





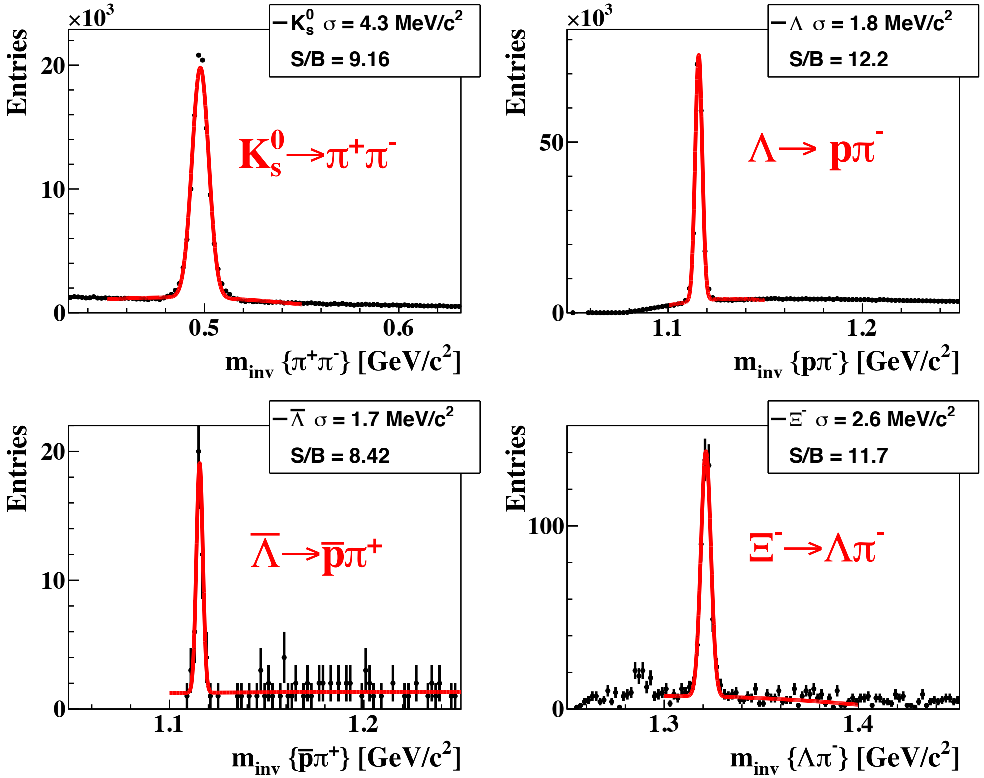
Time is added to the track fit:

- The vector of parameters and its covariance matrix are extended with time.
- Propagation and Kalman filter are extended to take time into account.
- Fit shows correct results: high resolution and pulls close to 1.

Valentina Akishina, HK 12.5 Di 12:15

4D physics analysis

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



		K0s	Λ	$\bar{\Lambda}$	Ξ^-
3D	ε_{method}, %	68.6	61.2	67	46.7
	$\varepsilon_{4\pi}$, %	20.7	19.4	28	10.5
	S/B	10.6	23.7	12.7	21.8
0.1 MHz	ε_{method}, %	68.5	62.0	62	45.2
	$\varepsilon_{4\pi}$, %	21.1	20.6	32	11.7
	S/B	9.8	12.9	10	14.2
1 MHz	ε_{method}, %	67.5	60.9	59	46.0
	$\varepsilon_{4\pi}$, %	19.4	18.7	26	10.6
	S/B	9.3	12.5	10	12.3
10 MHz	ε_{method}, %	66.8	60.0	64	41.8
	$\varepsilon_{4\pi}$, %	17.6	16.7	28	8.2
	S/B	9.2	12.2	8	11.7

- 4D reconstruction chain from hit production to physics analysis level is established.
- Ideal (Monte Carlo) PID is used for track identification.
- Particle reconstruction performance is stable up to 1 MHz interaction rate.
- Investigation of the events overlapping in time is in progress.
- Extreme case of 10 MHz interaction rate will require further include of the information from fast detectors (ToF) and multi primary vertex analysis.

Valentina Akishina, HK 12.5 Di 12:15

Summary and outlook

- Reconstruction on the event-by-event level in CBM is fully established.
- Main physics observables are covered, reconstruction procedures demonstrate high quality.
- Full event topology reconstruction is under development.
- Time-based 4D track finder, track fitter and event builder are further developed.
- 4D reconstruction is efficient, fast and scalable.
- Time-based physics analysis is under development.
- Time-based PID and multi primary vertex analysis are in progress.

Reconstruction related talks

Talks:

- HK 2.3 Mo 17:30 Viktor Klochkov, “Performance of charged pions, kaons, protons and their anti-particles identification in the CBM experiment”
- HK 2.6 Mo 18:15 Etienne Bechtel, “Performance studies for electron measurement with the CBM-TRD”
- HK 9.5 Mo 18:00 Hanna Malygina, “Hit position error estimation for the CBM Silicon Tracking System”

- HK 12.2 Di 11:30 Artemiy Belousov, “Geometry independent Kalman filter based track fit”
- HK 12.5 Di 12:15 Valentina Akishina, “Performance of 4-Dimensional Cellular Automaton Track Finder in CBM”
- HK 21.3 Di 14:45 Ievgenii Kres, “Reconstruction of neutral pions at CBM-RICH detector via conversion”
- HK 33.3 Mi 17:30 Timur Ablyazimov, “Time based track reconstruction in the CBM experiment”
- HK 33.4 Mi 17:45 Grigory Kozlov, “Speed up approaches in the Cellular Automaton (CA) track finder”
- HK 40.5 Do 15:00 Florian Seck, “Thermal dilepton emission as a fireball probe”
- HK 47.2 Do 17:15 Iouri Vassiliev, “Multi-strange Hyperons and Hypernuclei reconstruction at the CBM experiment”
- HK 47.8 Do 18:45 Hamda Cherif, “Online reconstruction of multi-strange hyperons with the CBM experiment”
- HK 58.3 Fr 14:45 Pavel Kisel, “Reconstruction of short-lived particles with neutral daughter by the missing mass method”

Posters:

- HK 27.24 Di 16:45 Daniel Giang, Frankfurt University, “Performance studies for J/Psi measurements in p+A collisions with CBM”
- HK 27.24 Di 16:45 Susovan Das, Tübingen University, “Track-based Misalignment Corrections for the CBM Silicon Tracking Detector”