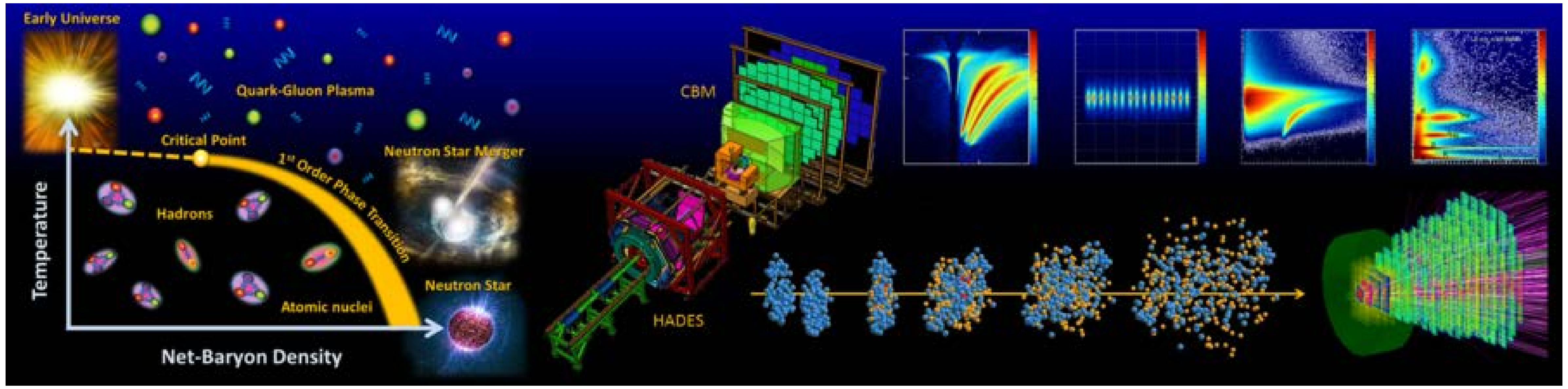
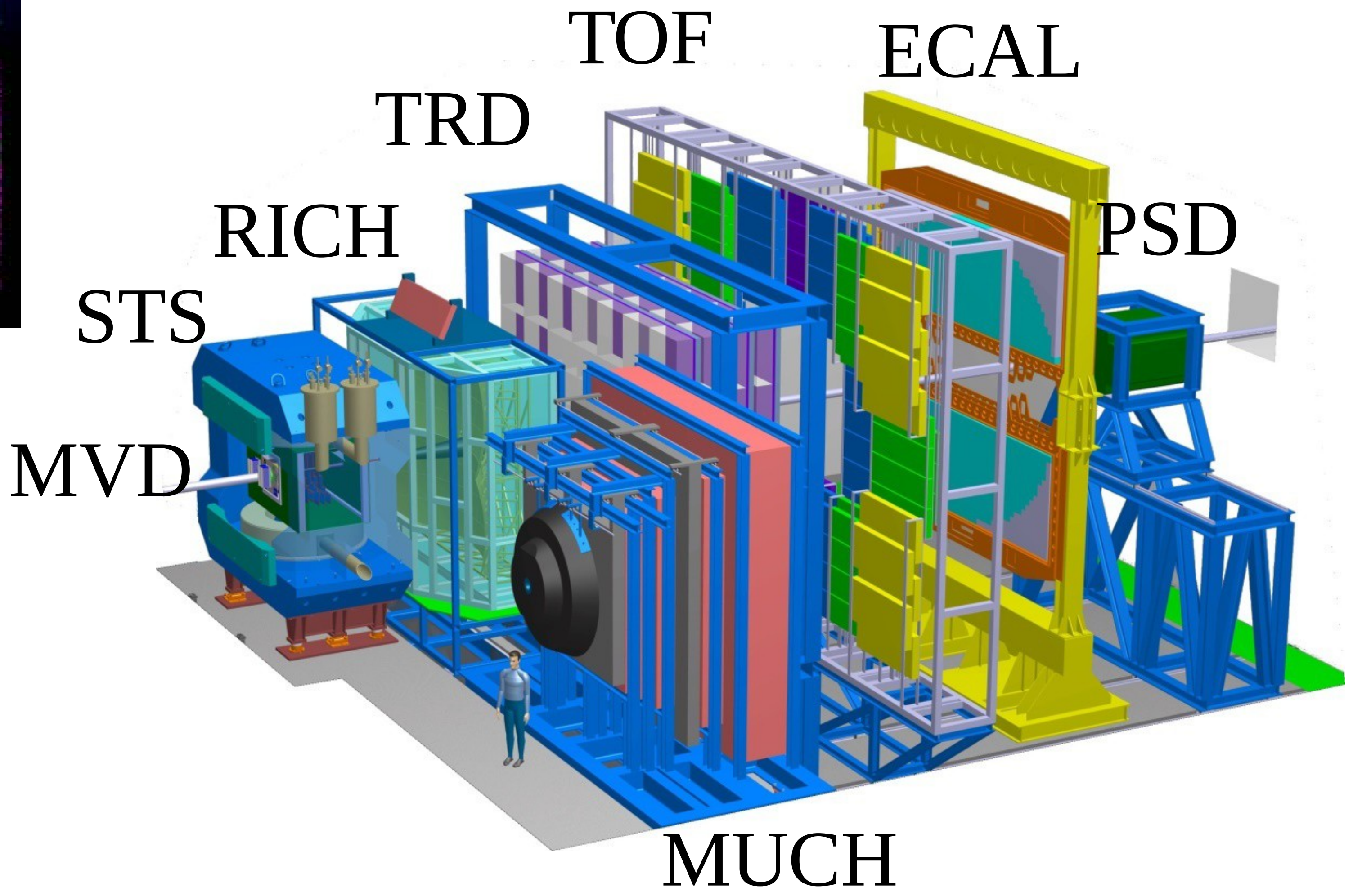
The CBM hadron program (Day-1)



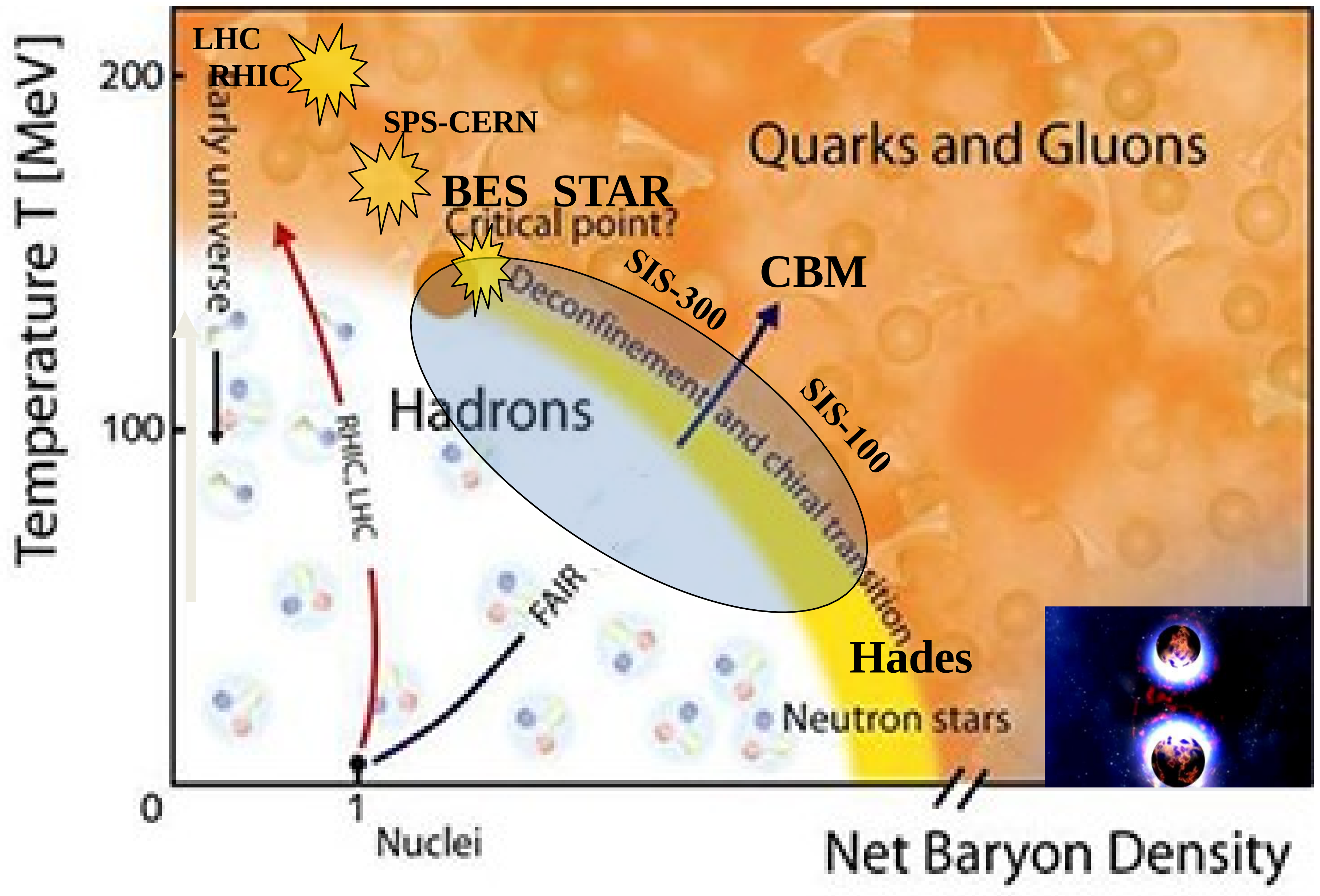
I.Vassiliev for the CBM Collaboration



- **Physics case**
- **Multi strange hyperons**
- **Tests with STAR data**
- **Hypernuclei**
- **Summary**

February 2019 Darmstadt

Physics case: Exploring the QCD phase diagram



The equation-of-state at high ρ_B
collective flow of hadrons,
particle production at threshold energies:
multi-strange hyperons, hypernuclei

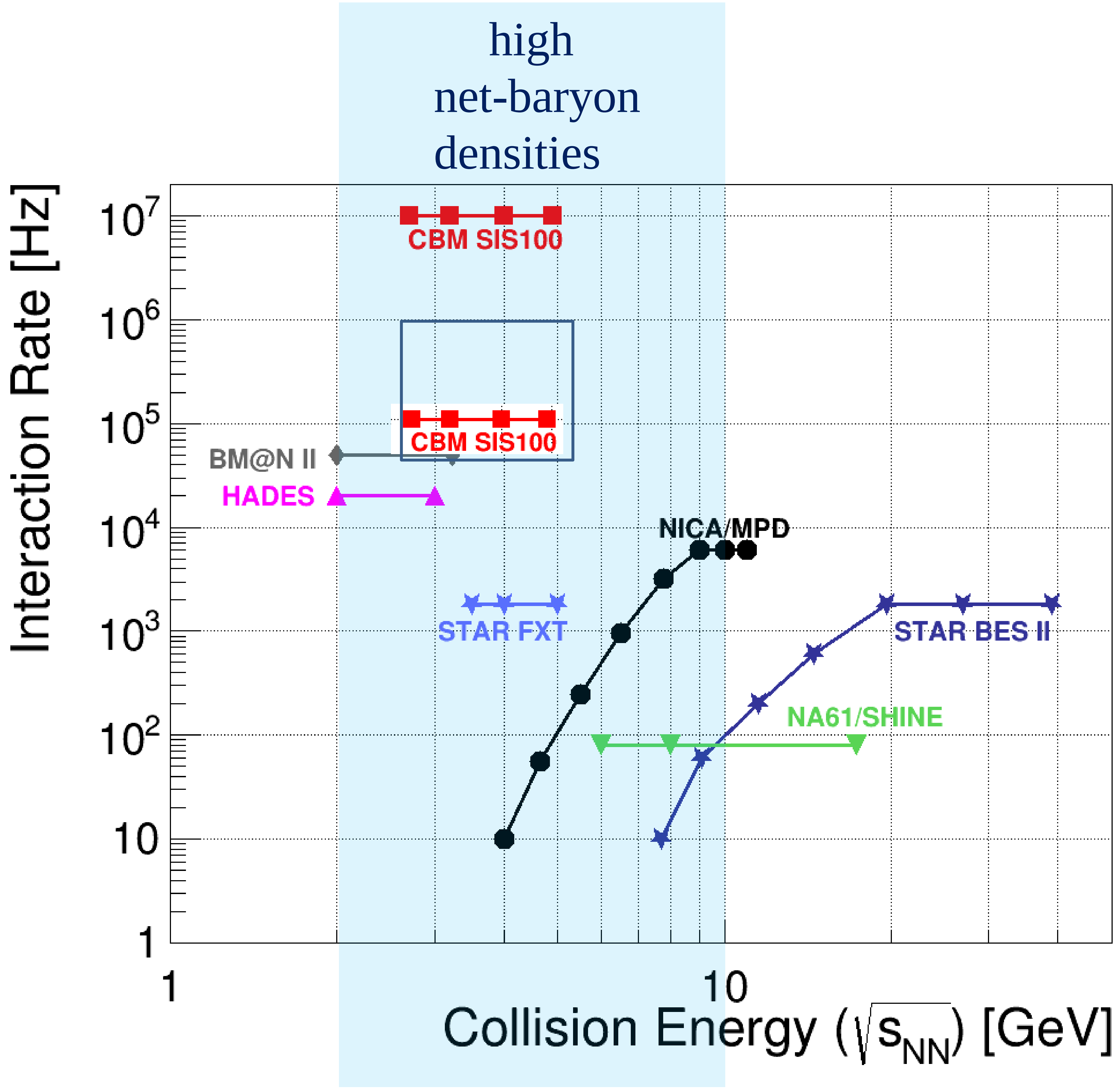
Deconfinement phase transition at high ρ_B
excitation function and flow of
strangeness (K, Λ, Σ, Ξ, Ω and φ)

Chiral symmetry restoration at high ρ_B
in-medium modifications of hadrons (ρ)
excitation function of **multi-strange (anti)hyperons**

QCD critical endpoint
excitation function of event-by-event fluctuations
(π, K, p, Λ, Ξ, Ω…)

Projects to explore the QCD phase diagram at large μ_B:
RHIC (**STAR**) beam energy-scan, **HADES**, NA61@SPS,
MPD@NICA: bulk observables
CBM: bulk and **rare observables, high statistic!**

Experiments exploring dense QCD matter

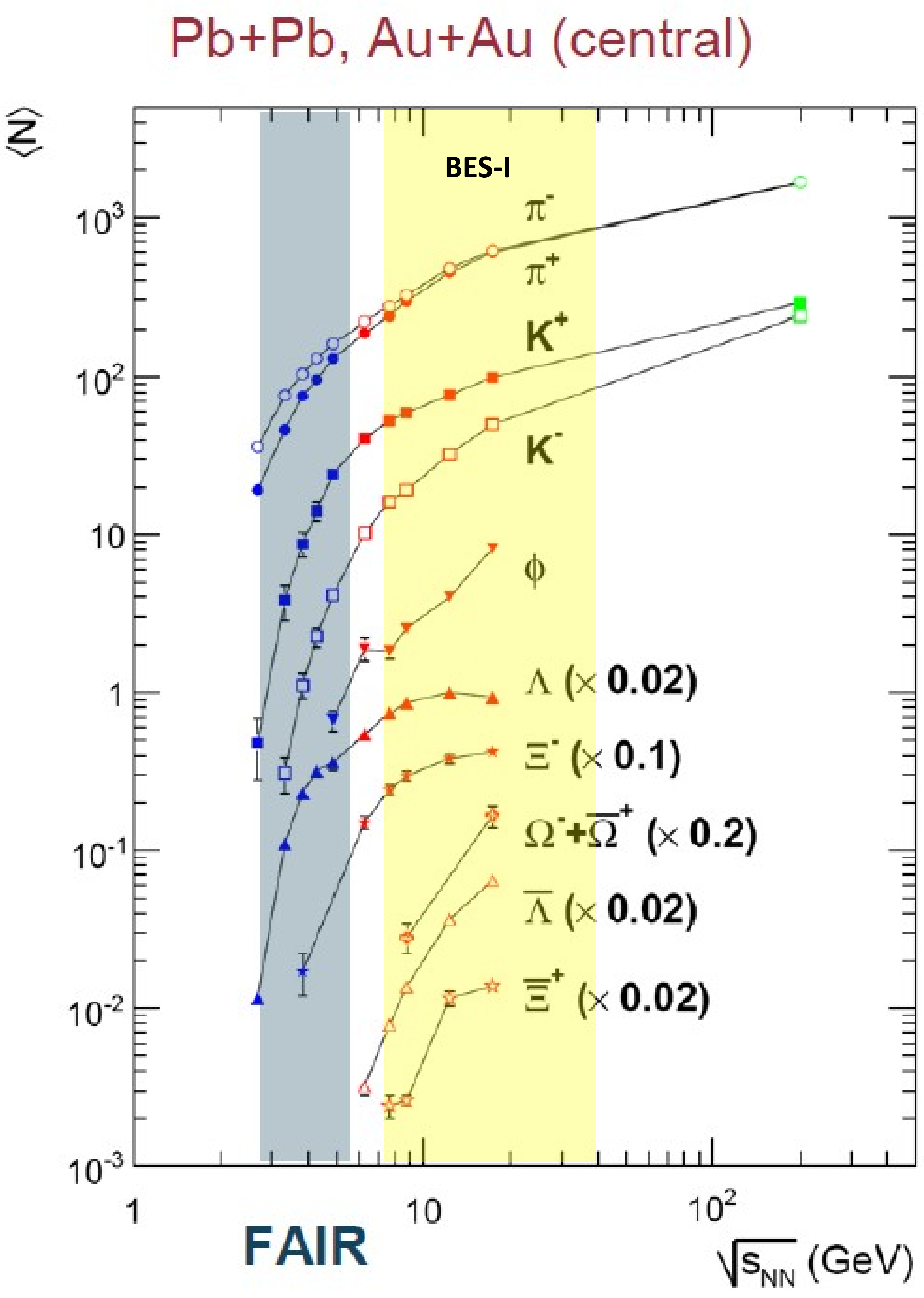


CBM:

***unprecedented* (high) rate capability**

- determination of (displaced) vertices with high resolution (≈ 50 µm)
- identification of leptons and hadrons
- fast and radiation hard detectors
- self-triggered readout electronics
- high speed data acquisition and
- online event selection
- powerful computing farm *and 4D tracking*
- software triggers

Strangeness world data (before BES-I)



No data available at FAIR energy

In the AGS (SIS100) energy range, only about 300 Ξ^- hyperons have been measured in Au+Au collisions at 6AGeV

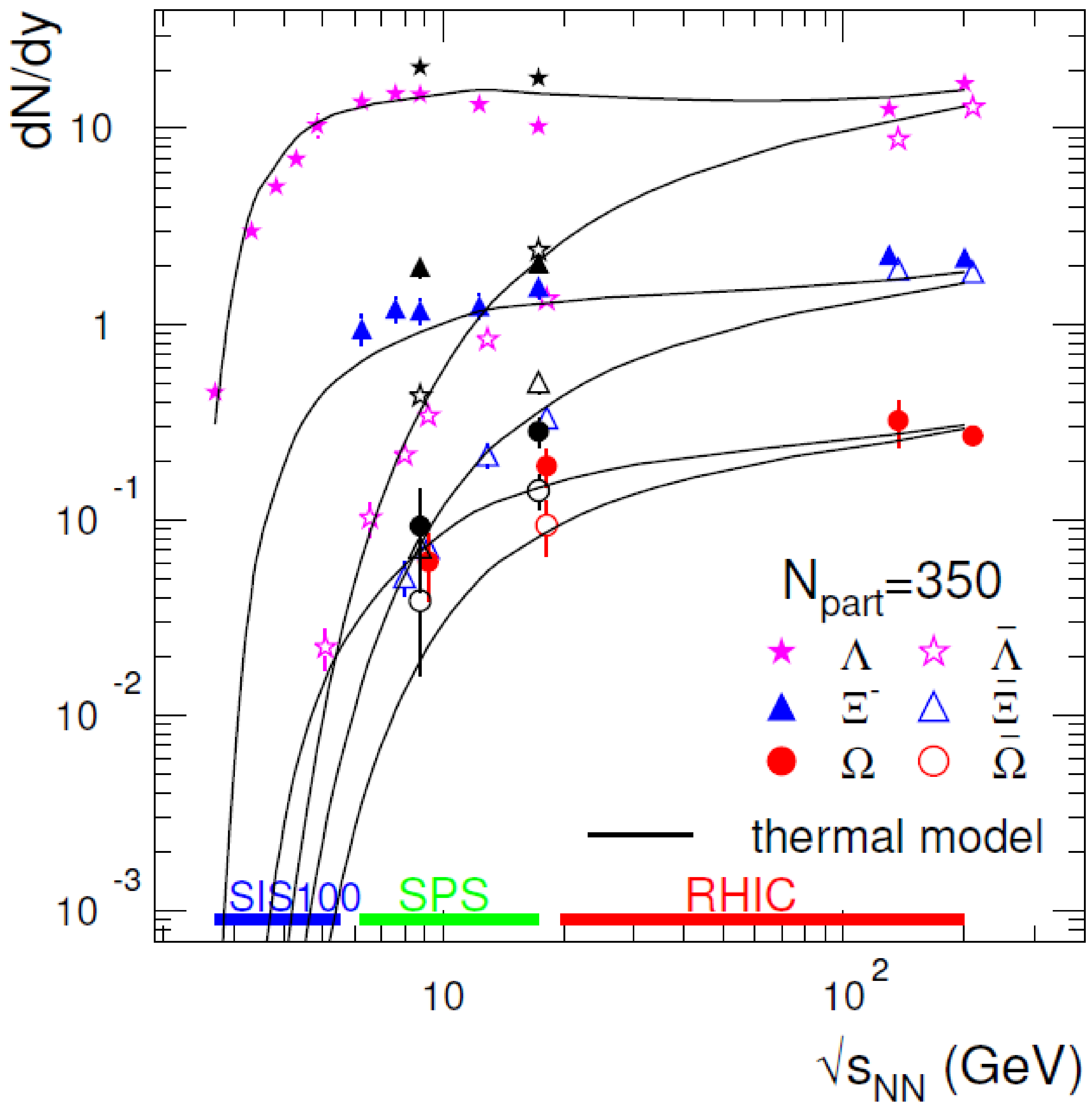
High-precision measurements of excitation functions of multi-strange hyperons in A+A collision with different mass numbers A at SIS100 energies have a discovery potential to find a signal for the onset of deconfinement in QCD matter at high net-baryon densities.

Thermal model at CBM/FAIR

Predictions

A. Andronic

32 CBM Collaboration meeting, GSI Oct 2018



- confirm significantly lower T values (energy dependence)
  (need confident treatment of canonical suppression of strangeness)
  recall: many observables change rapidly in the SIS-100 energy regime
- how is chemical equilibration (if confirmed) achieved?
  (in a deconfined phase, as at higher energies?)
- what do we learn about hadronization? (a deep mystery of nature)
  (very rare hadrons, like Ω; complex objects like d, ${}^{3}_{\Lambda}$H)

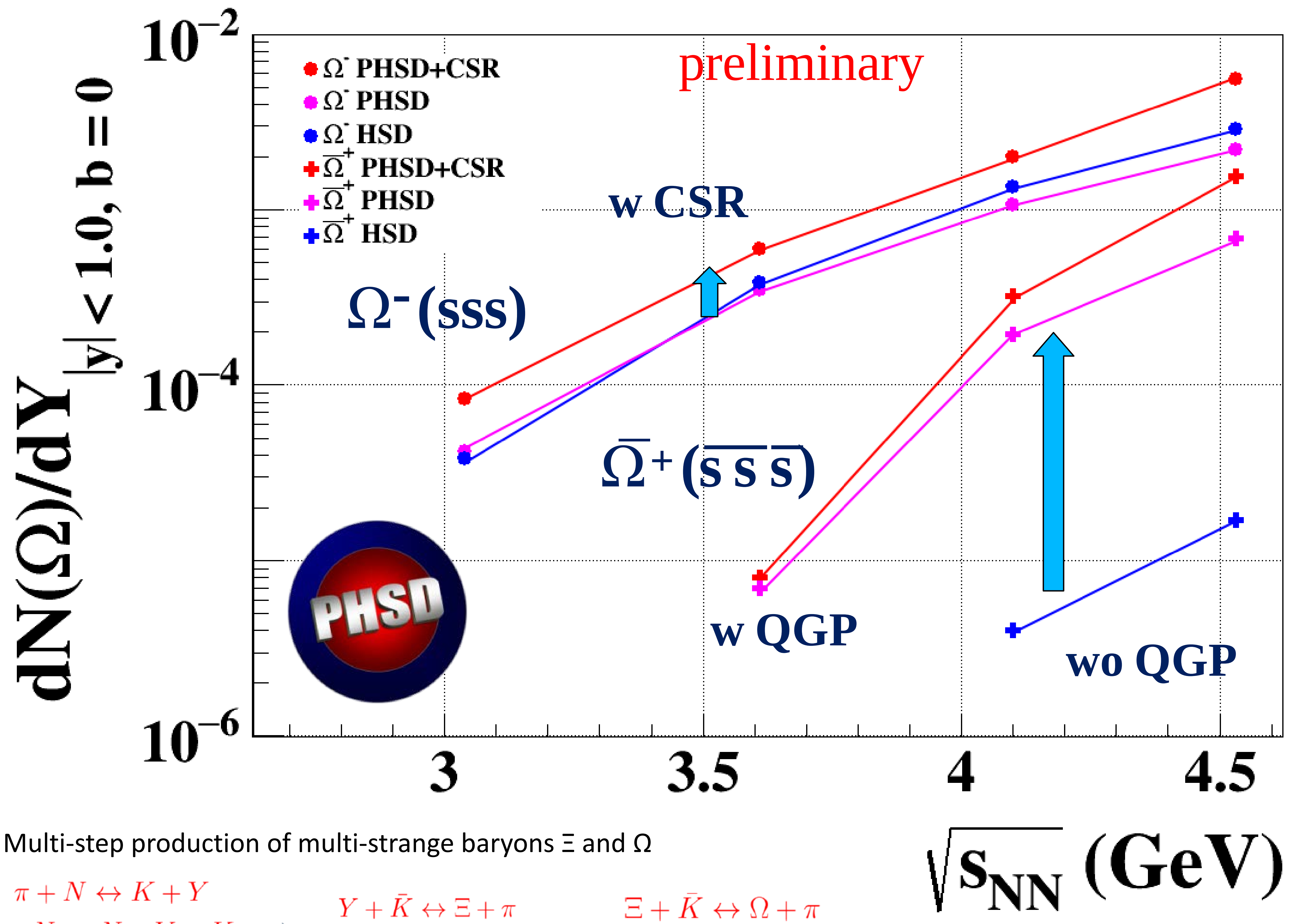
Example:

$dN/dy|_{y=0}$ yields at 8 AGeV:

Λ: 9.0	$\bar{\Lambda}$: $1.4 \cdot 10^{-3}$
Ξ^-: 0.27	$\bar{\Xi}^+$: $3.2 \cdot 10^{-4}$
Ω^-: $5.4 \cdot 10^{-3}$	$\bar{\Omega}^+$: $5.4 \cdot 10^{-5}$

PHSD model at CBM/FAIR
QGP and Chiral symmetry restoration

“Chiral symmetry restoration versus deconfinement in heavy-ion collisions at high baryon density”
W. Cassing, A. Palmese, P. Moreau, and E. L. Bratkovskaya Phys.Rev. C93 (2016), 014902, arXiv:1510.04120 [nucl-th]



Multi-step production of multi-strange baryons Ξ and Ω

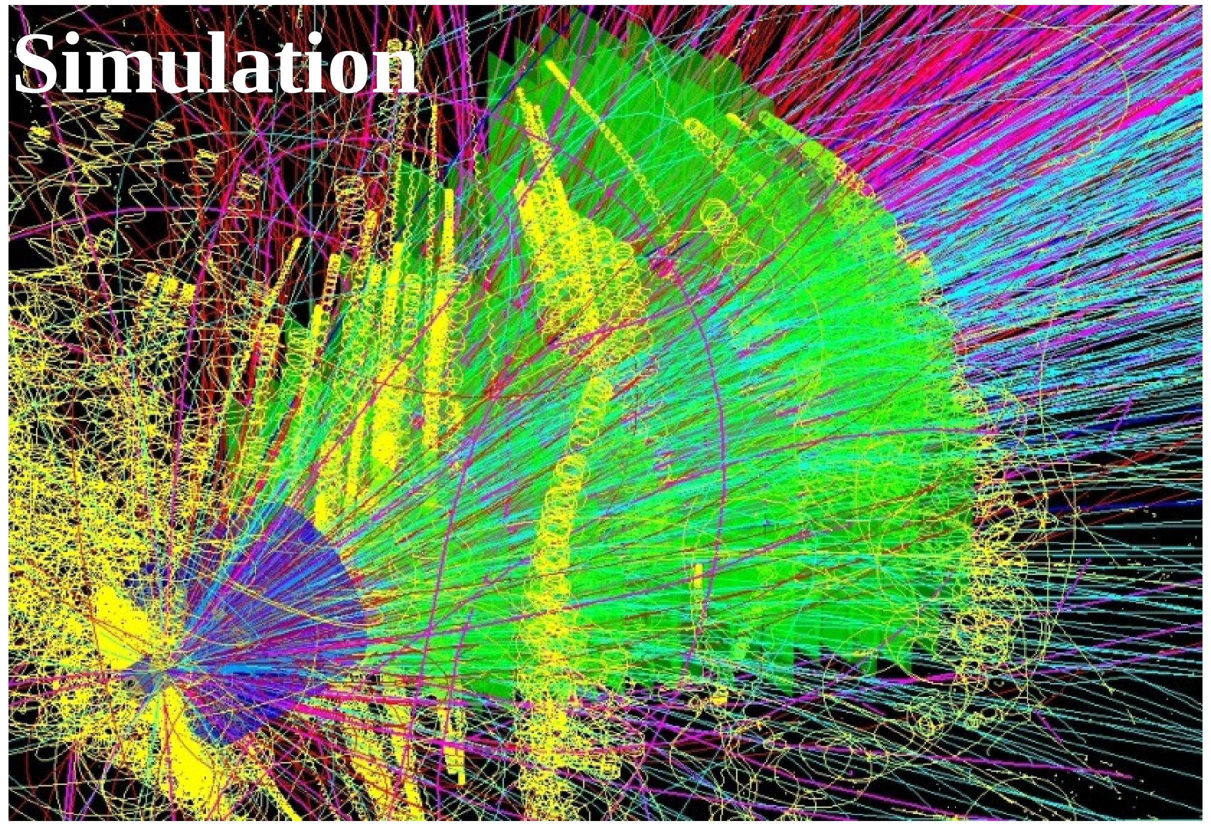
$\pi + N \leftrightarrow K + Y$
$N + N \leftrightarrow N + Y + K$
$N + \bar{K} \leftrightarrow Y + \pi$
⇨
$Y + \bar{K} \leftrightarrow \Xi + \pi$
$Y + Y \leftrightarrow \Xi + N$
⇨
$\Xi + \bar{K} \leftrightarrow \Omega + \pi$
$\Xi + \Xi \leftrightarrow \Omega + Y$

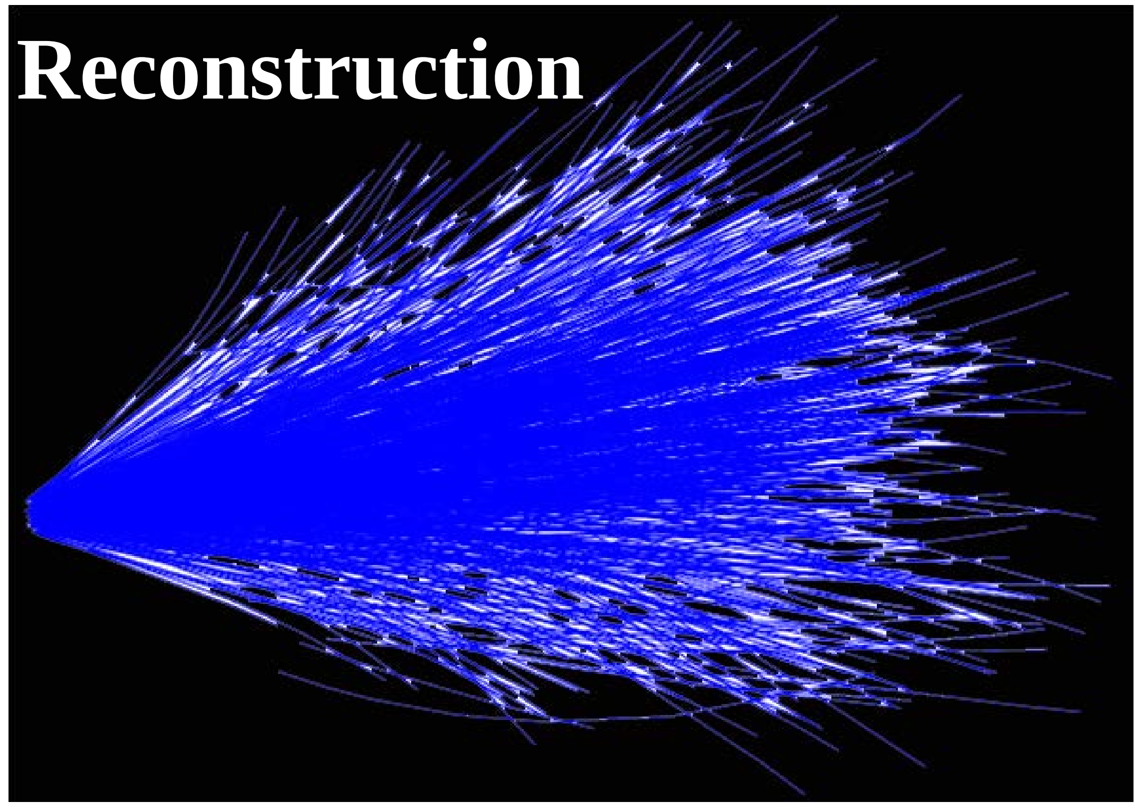
Chiral symmetry restoration (CSR) change the flavor decomposition – more s-sbar pairs produced.

Droplets of QGP allow to interact s-sbar quarks and create more multi-strange (anti)baryons.

- Presence of QGP significantly increase yield of Ω^+ at FAIR energy
- CSR effect increase yield of Ω^- and Ω^+ at FAIR energy

Performance of the CBM track finder

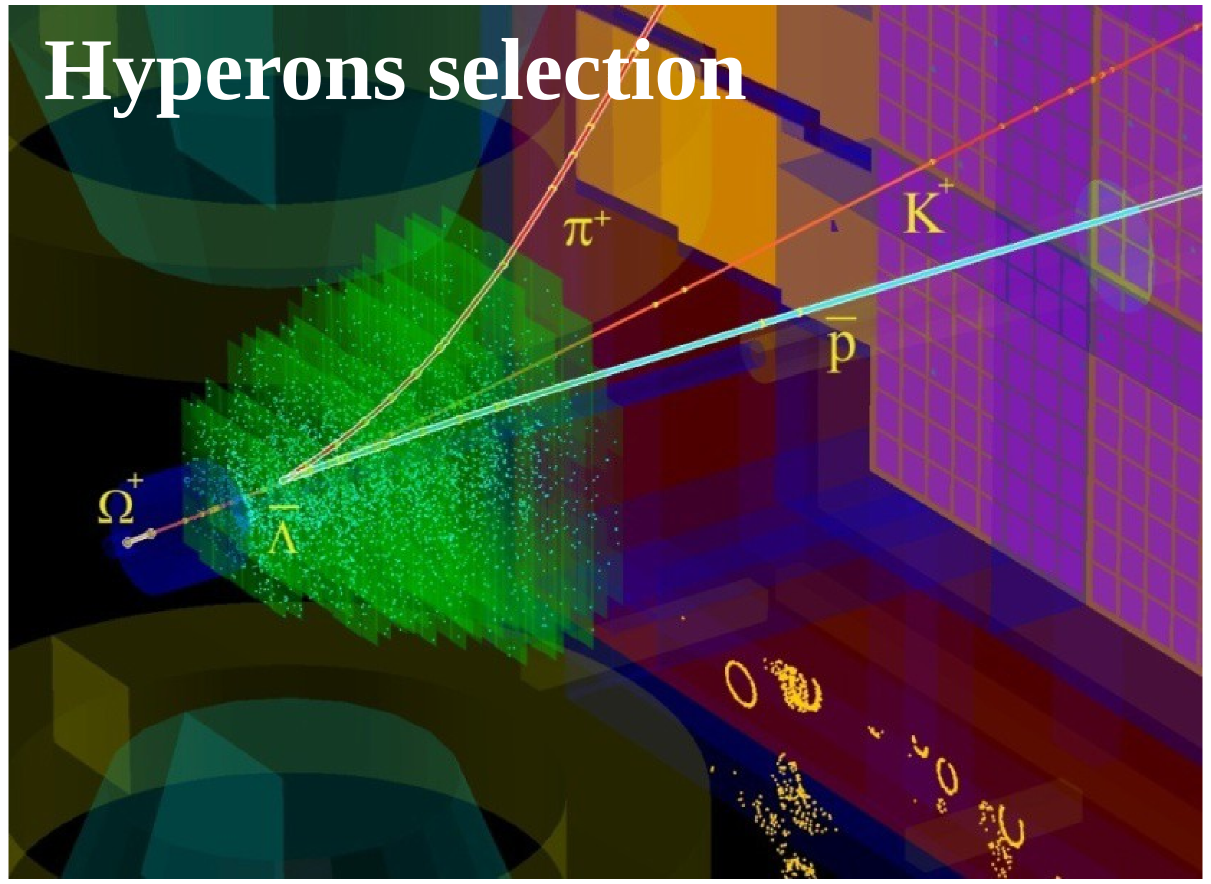




AuAu 10 AGeV/c
165 π
170 p
26 K
15 Λ
20 K_S^0
0.3 Ξ^-

UrQMD

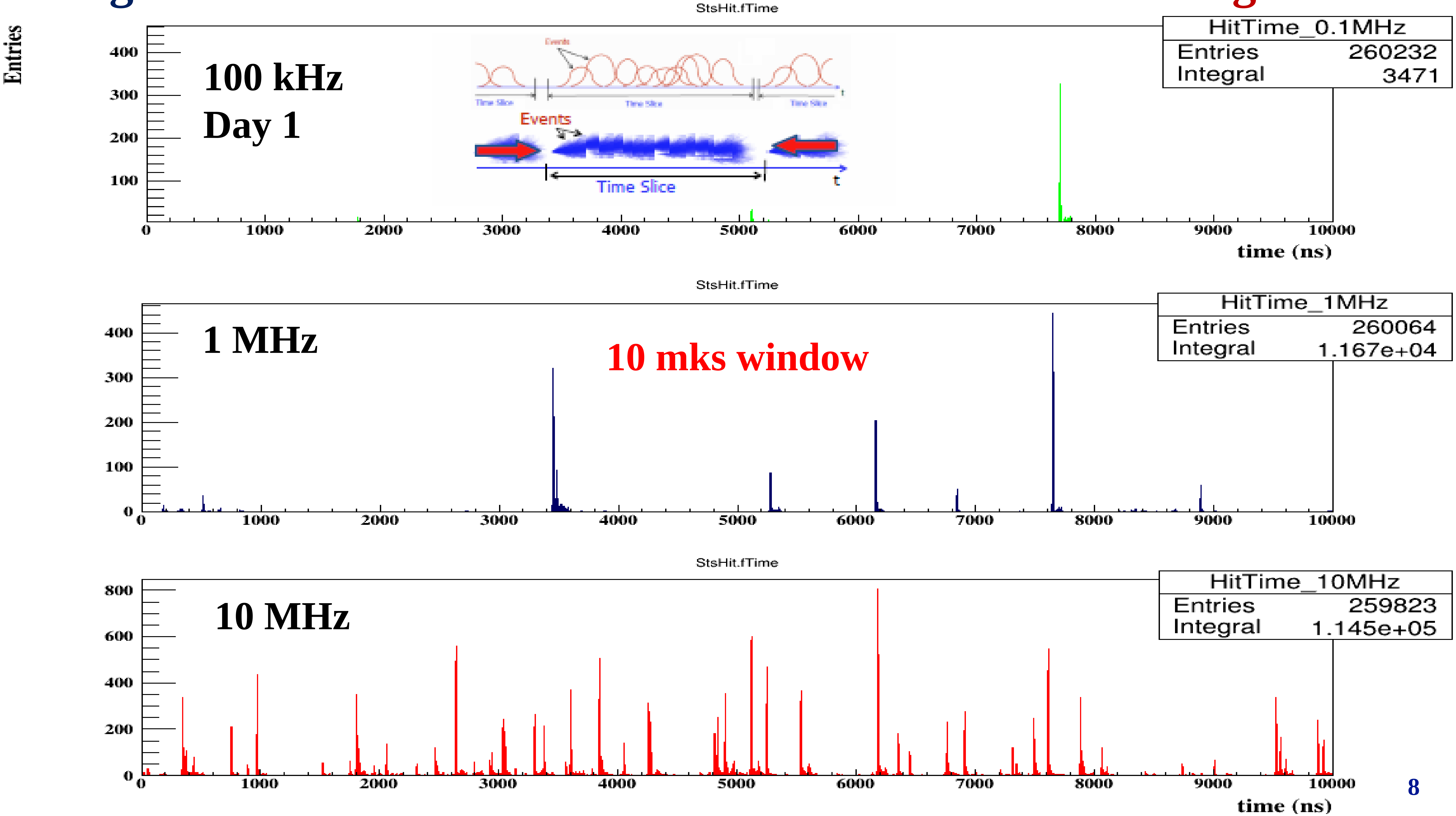
PHSD



- For studies several theoretical models like UrQMD and PHSD are used.
- Track finder is based on the Cellular Automaton method.
- High efficiency for track reconstruction of more then **92%**, including fast (more then 90%) and slow (more then 65%) secondary tracks.
- Time-based track finder is developed, efficiency is stable with respect to the interaction rate.
- Low level of split and wrongly reconstructed (ghost) tracks.

minimum bias : 6ms/core track finder, 1 ms/core particle finder

High rate scenario: MSH reconstruction with 4D tracking



4D Track Finder in CBMROOT

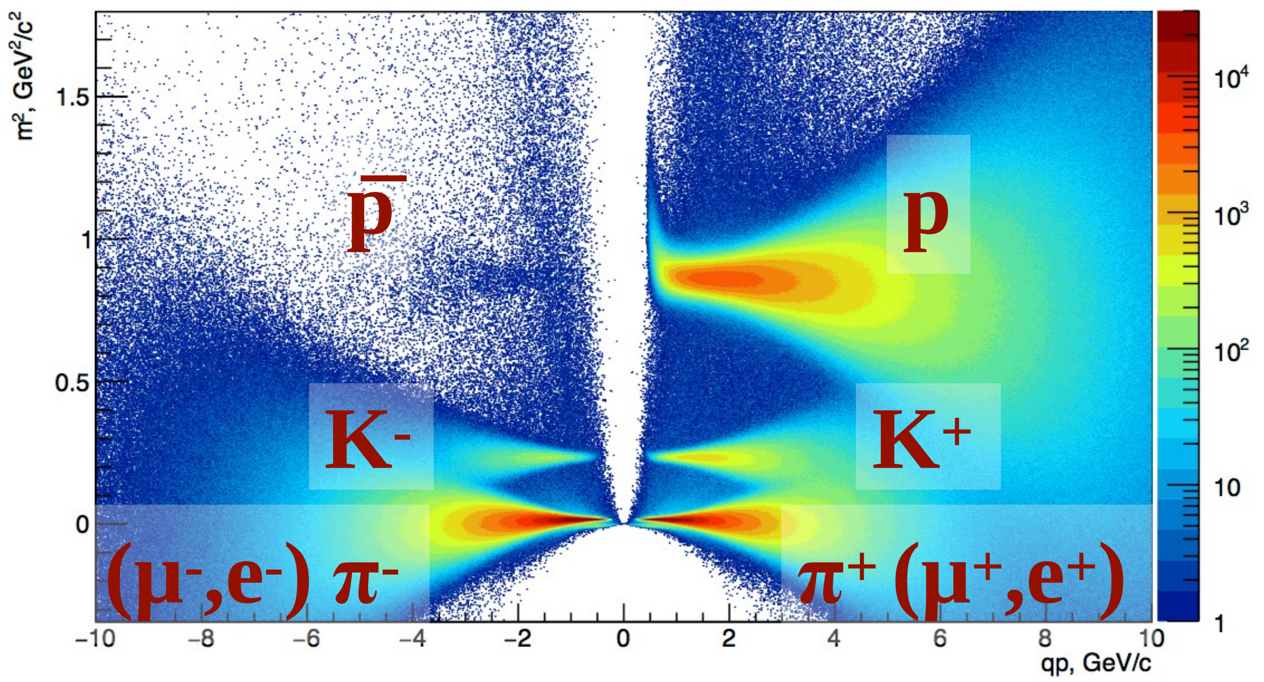
100 AuAu 10 AGeV mbias events

Efficiency, %	3D	0.1 MHz	1 MHz	10 MHz
All tracks	92.5 %	93.8 %	93.5 %	91.7 %
Primary high-p	98.3 %	98.1 %	97.9 %	96.2 %
Primary low-p	93.9 %	95.4 %	95.5 %	94.3 %
Secondary high-p	90.8 %	94.6 %	93.5 %	90.2 %
Secondary low-p	62.2 %	68.5 %	67.6 %	64.3 %
Clone level	0.6 %	0.6 %	0.6 %	0.6 %
Ghost level	1.8 %	0.6 %	0.6 %	0.6 %
True hits per track	92%	93 %	93 %	93%
Hits per MC track	7.0	7.0	6.97	6.70

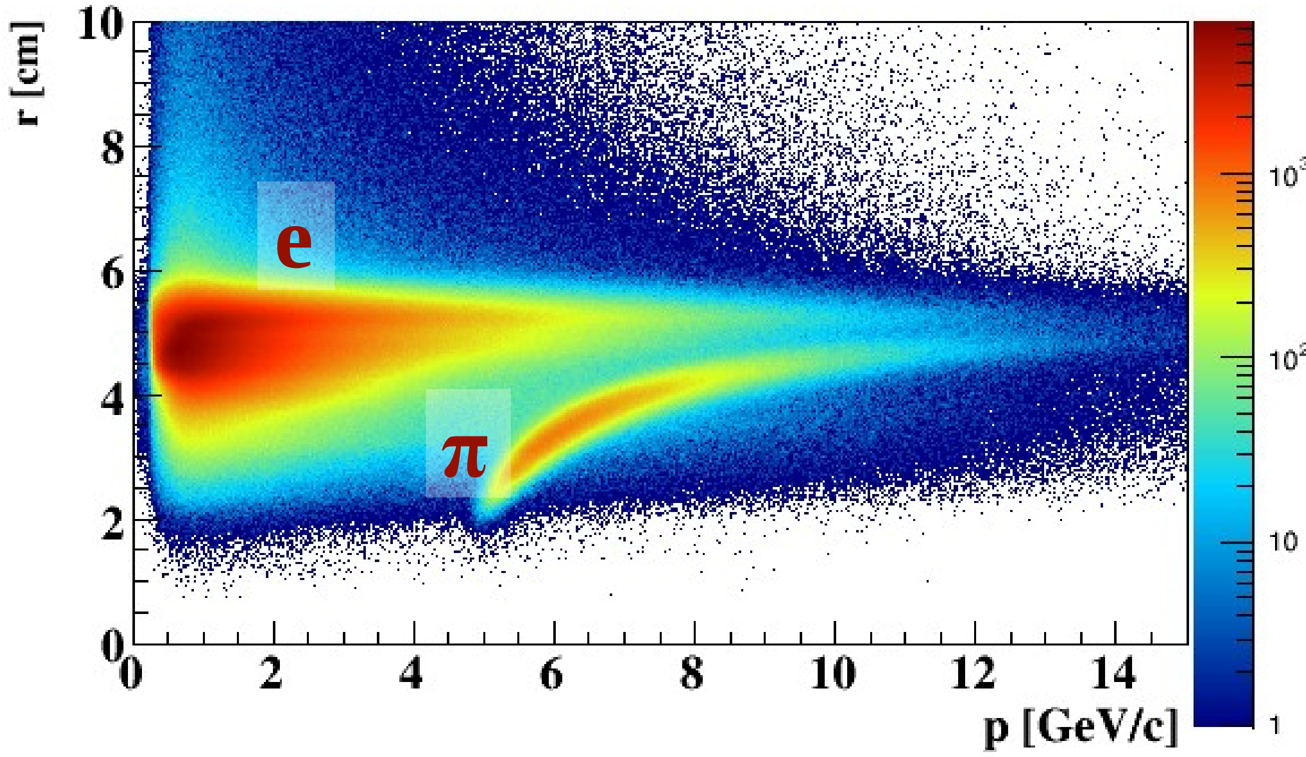
Timeslices from CBMROOT
Timebased digitisation, cluster and hit finder

Particle identification with CBM

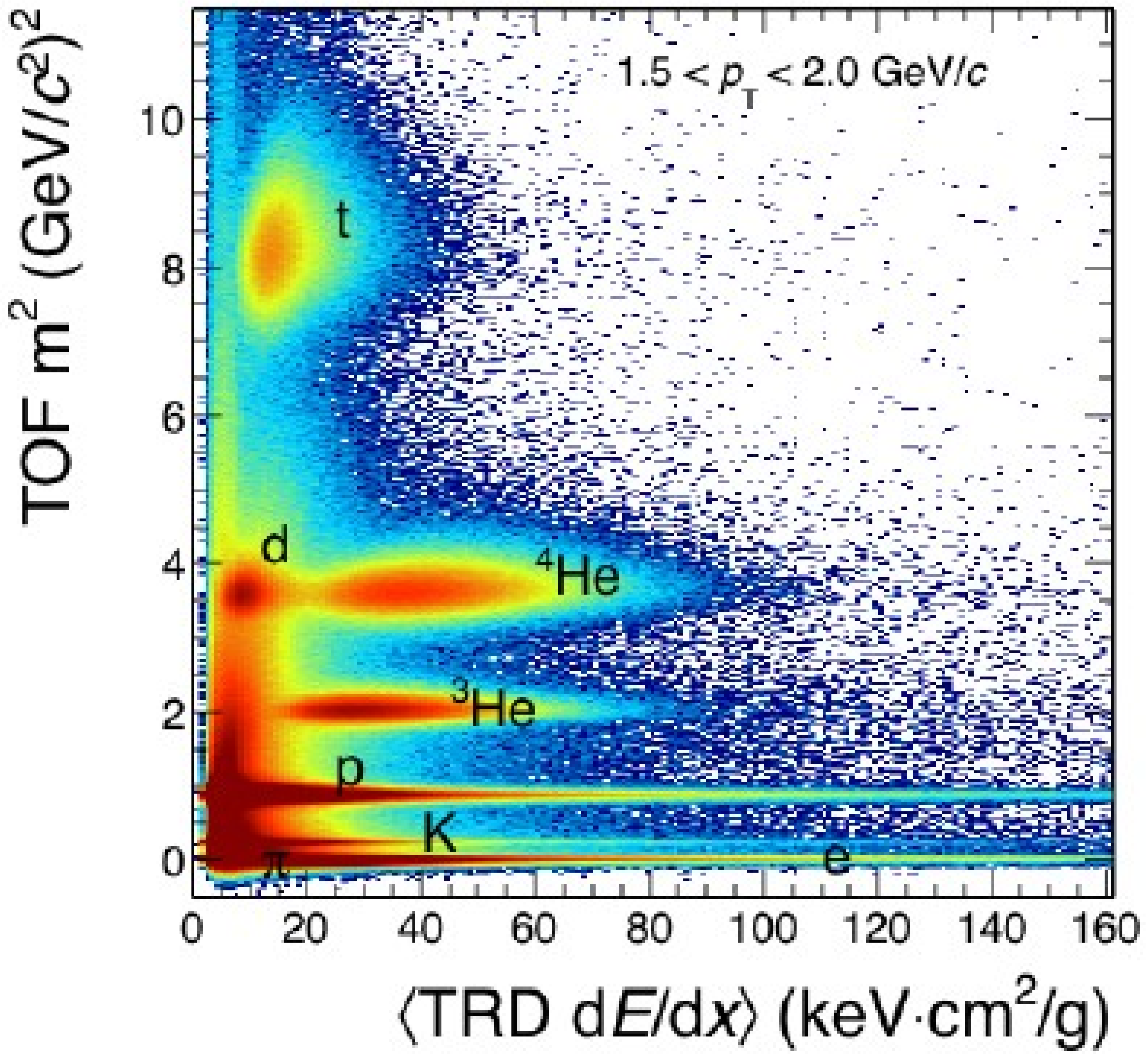
ToF: hadron identification



RICH: electron identification



TRD: d-He separation



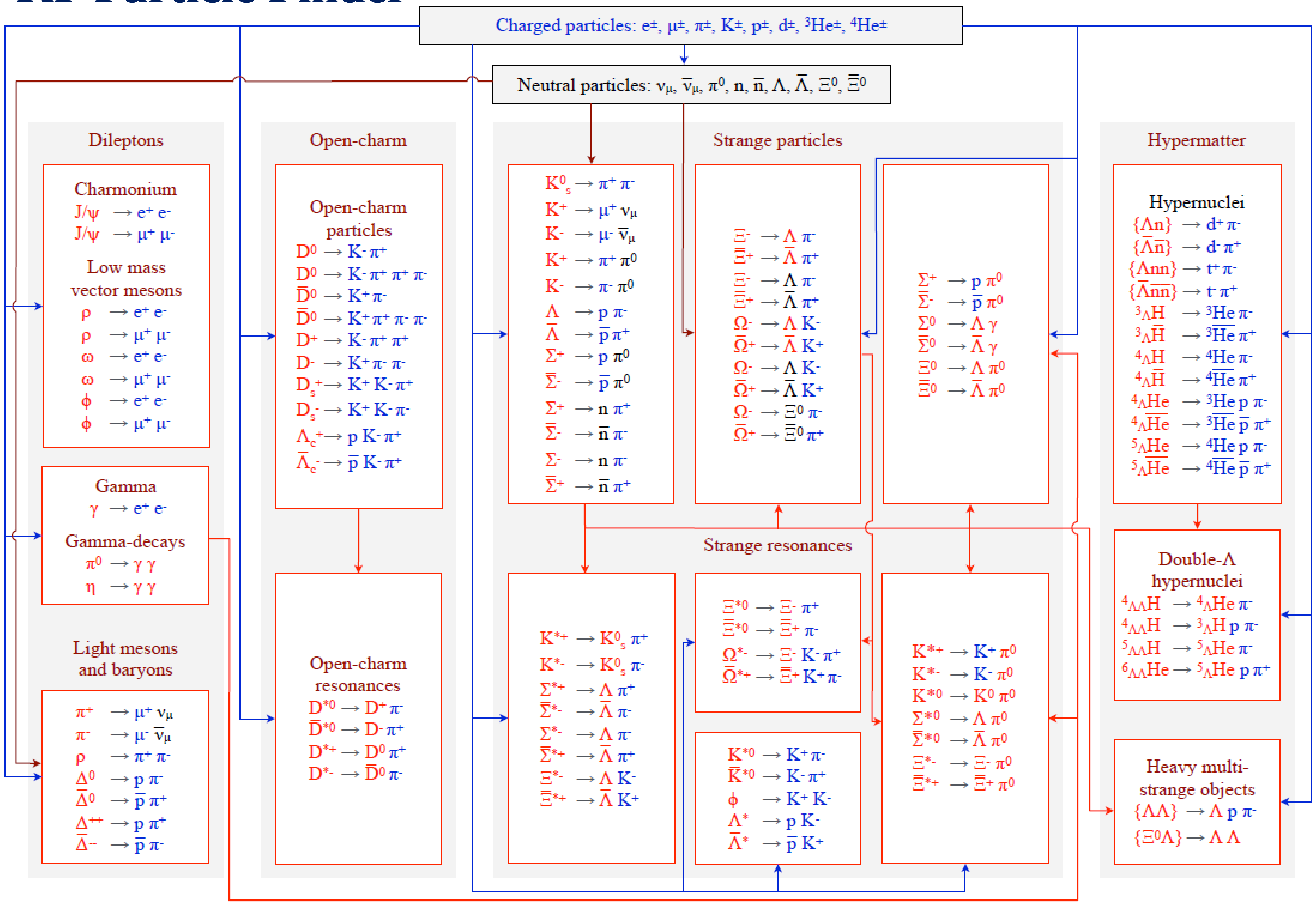
PID detectors:

- 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.

Multi strange particles reconstruction in the CBM Experiment

KF Particle Finder



More than 100 decays.

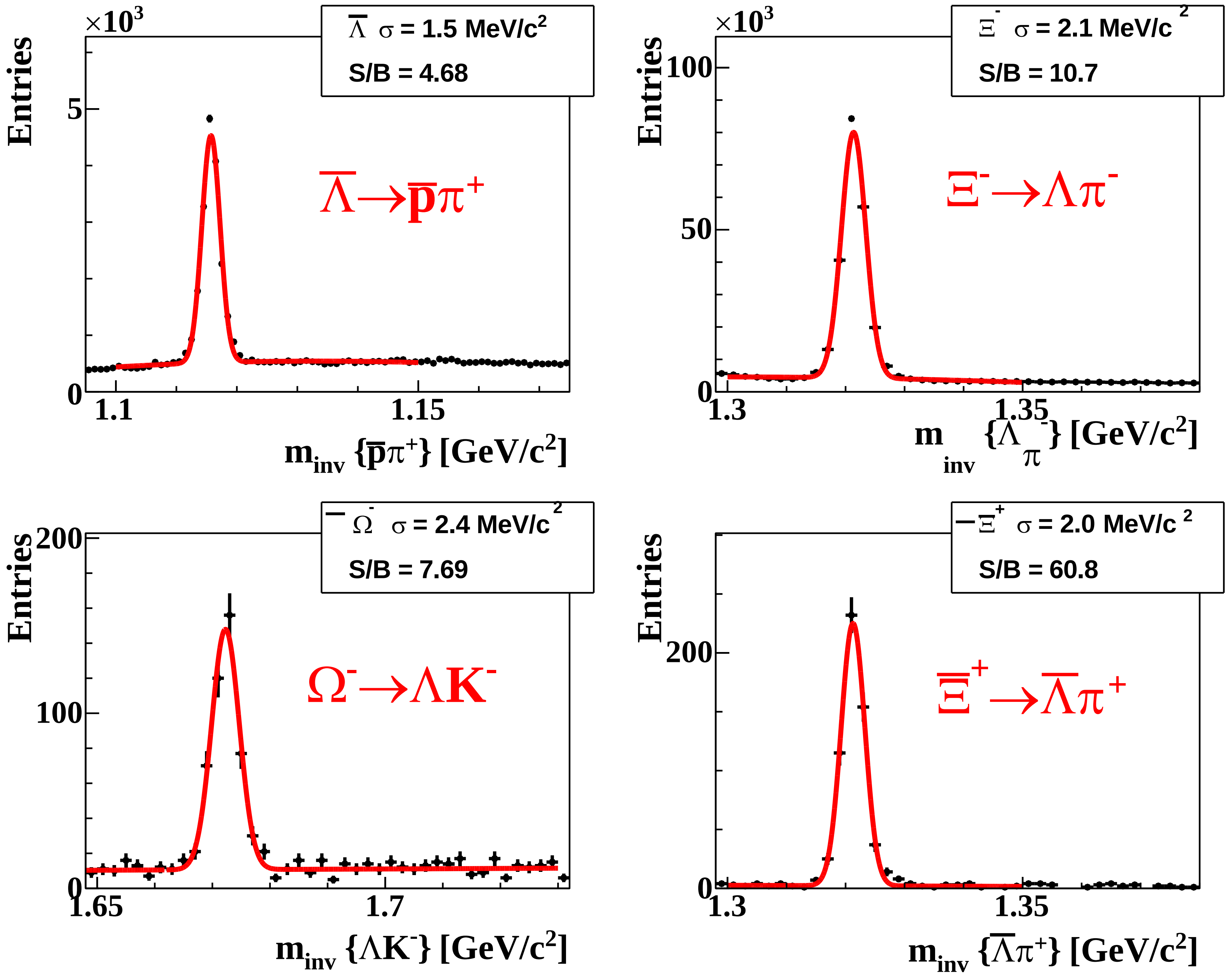
All decays are reconstructed in one go.

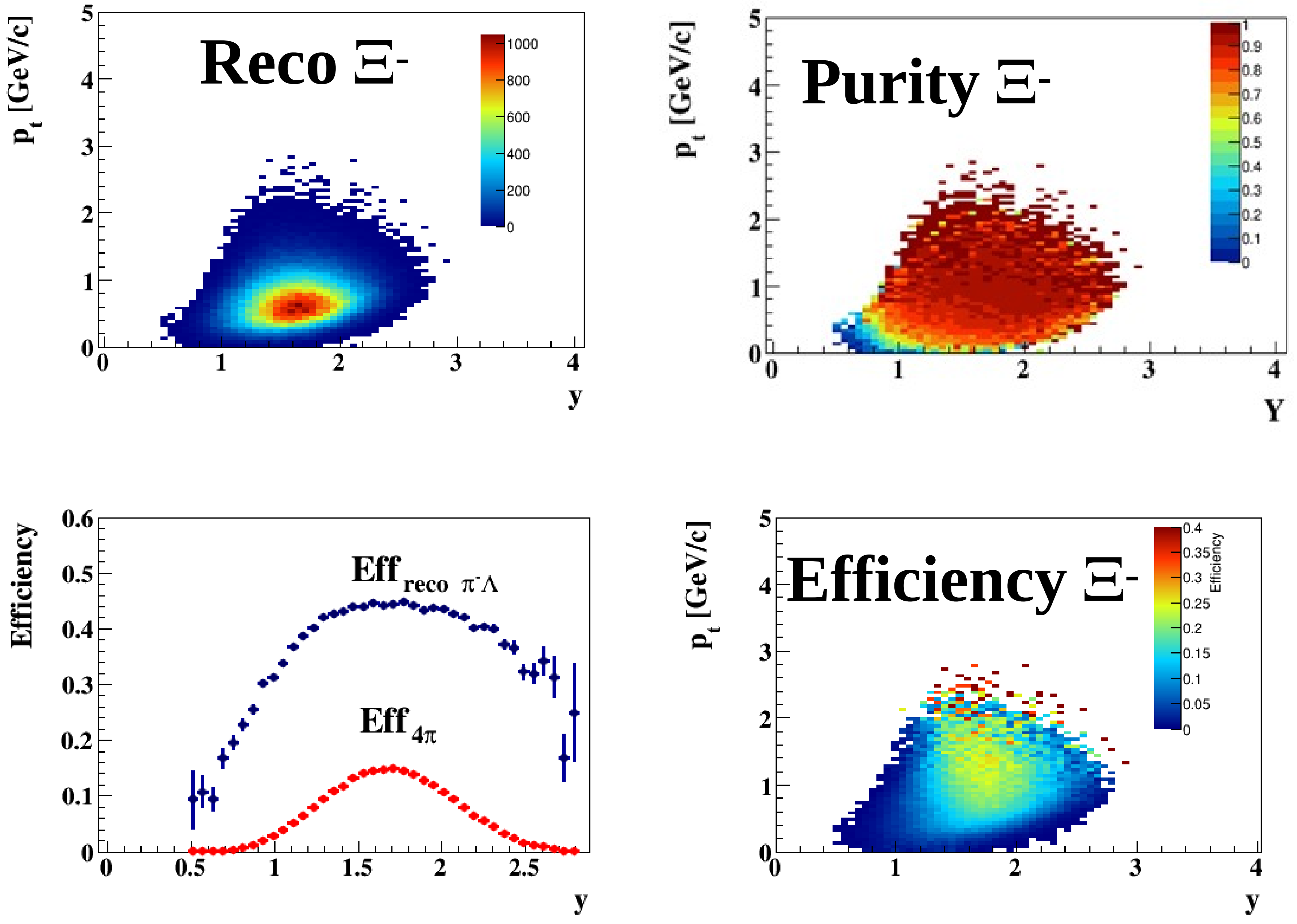
Based on the Kalman filter method - mathematically correct parameters and their errors.

Available in and approbated within STAR, ALICE, PANDA.

Multi Strange particle reconstruction performance

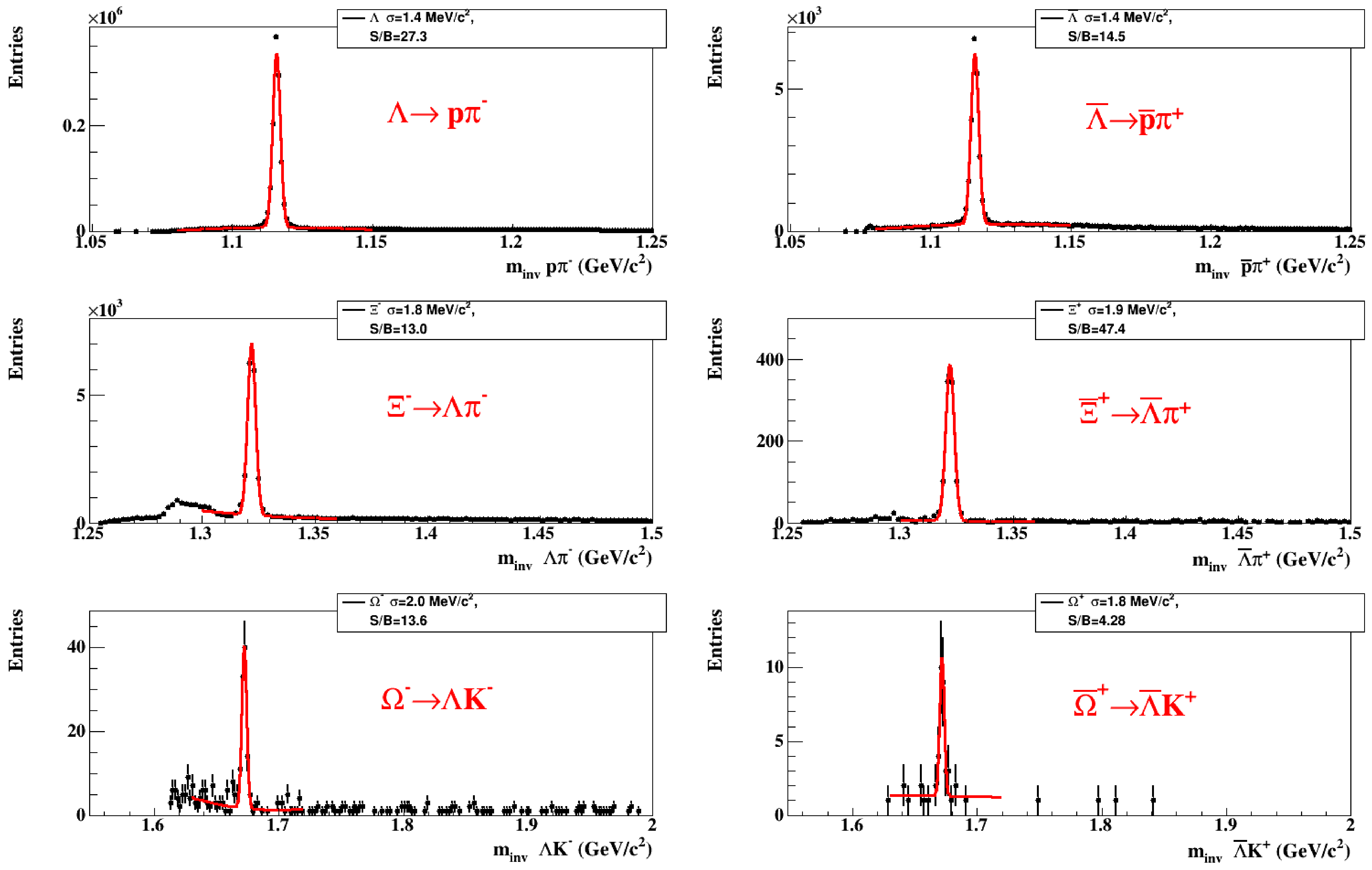
5M central AuAu collisions 10AGeV/c



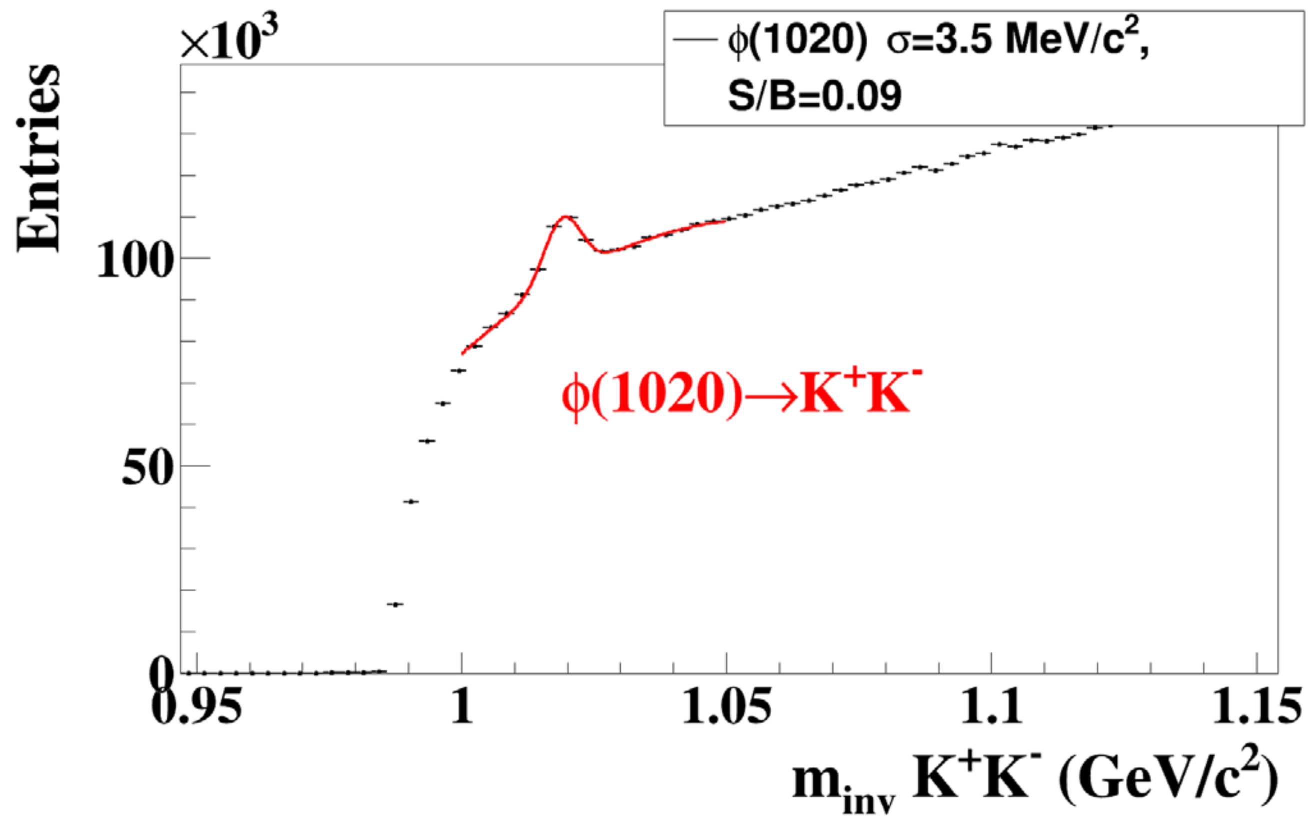


- CBM will allow clean reconstruction of rare strange probes with high efficiency and high statistics.
- Tools for the multi-differential physics analysis are prepared.

Testing tools in real environment @ STAR 4.4M Au+Au events sqrt(s) = 7.7



all centralities, no cuts on rapidity



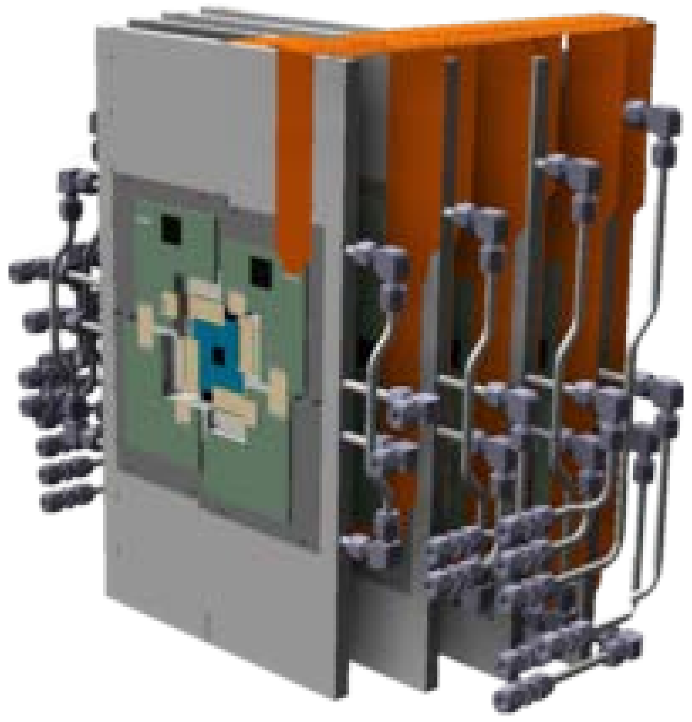
CBM+STAR Team:
M. Zyzak
Yu. Fisyak
I. Kisel
I. Vassiliev
A. Tang
H. Ke

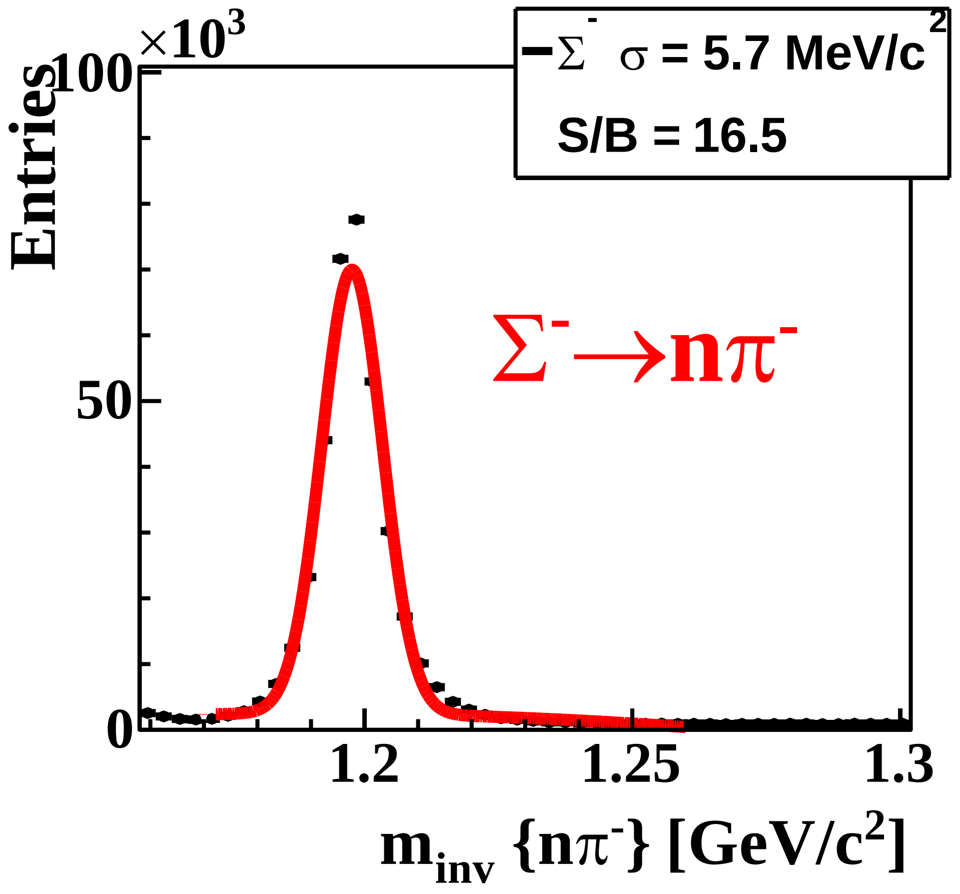
- CBM KF Particle Finder is successfully applied to the STAR data in a wide energy range.
- STAR data are excellent platform to test and improve our reconstruction software.

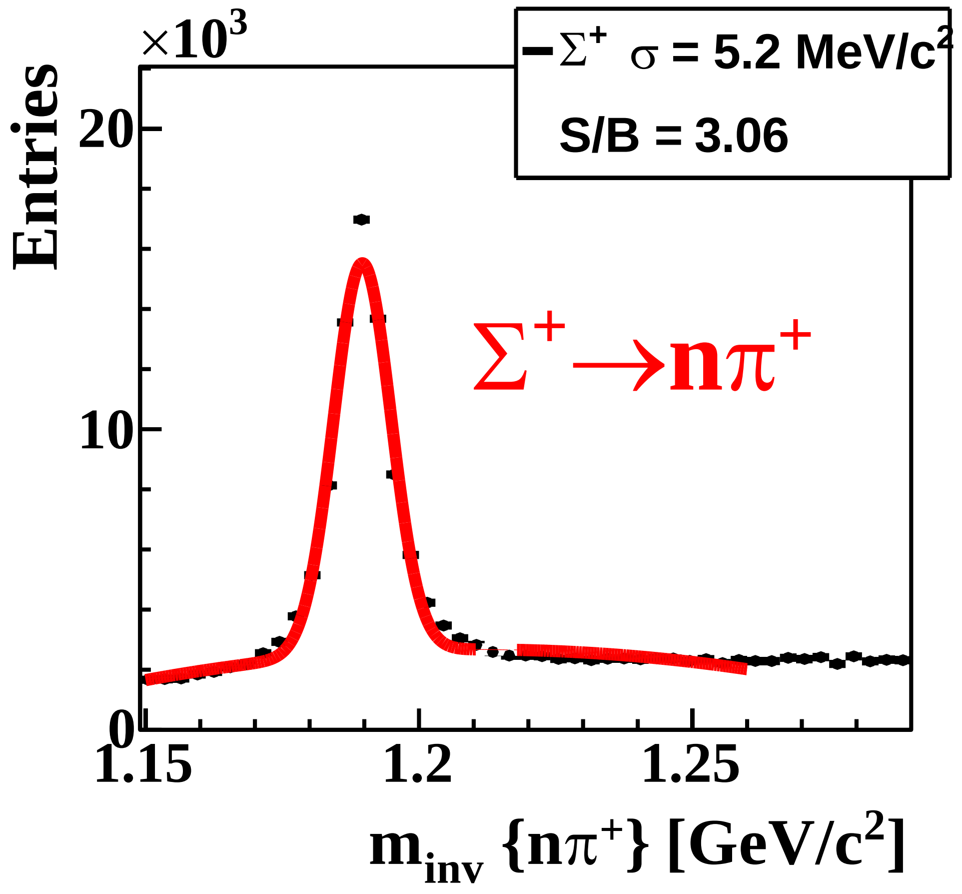
M^3 - Missing Mass Method

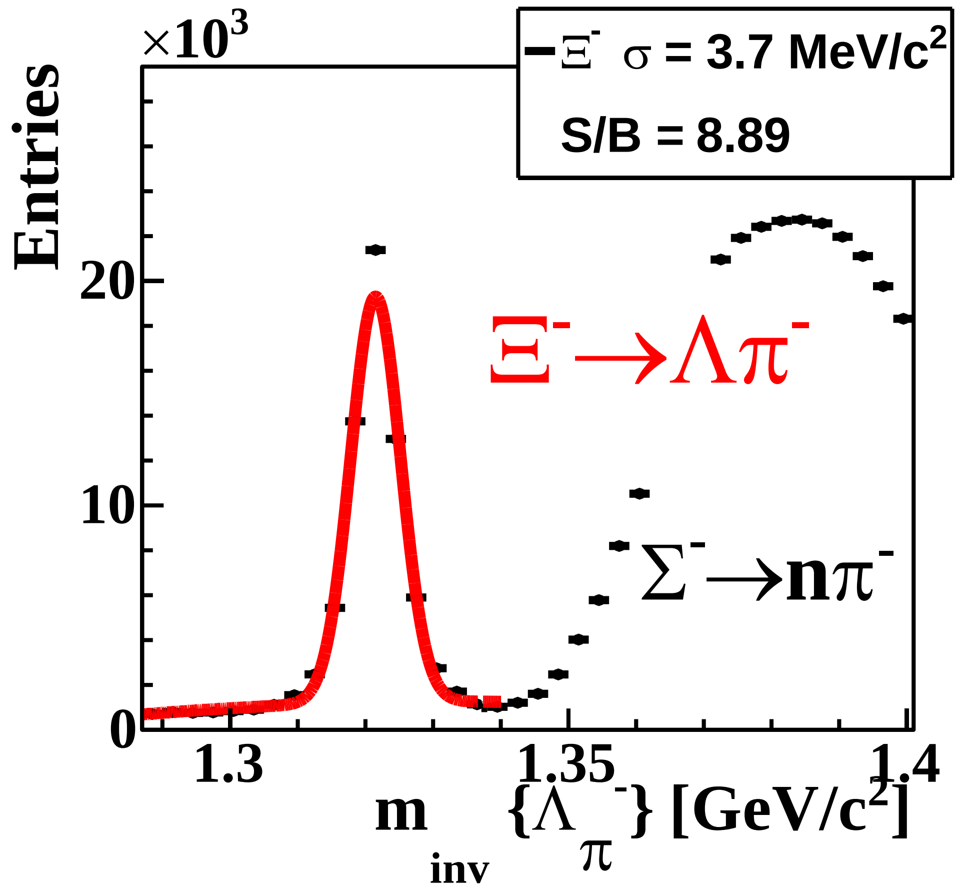
5M central AuAu collisions 10AGeV/c

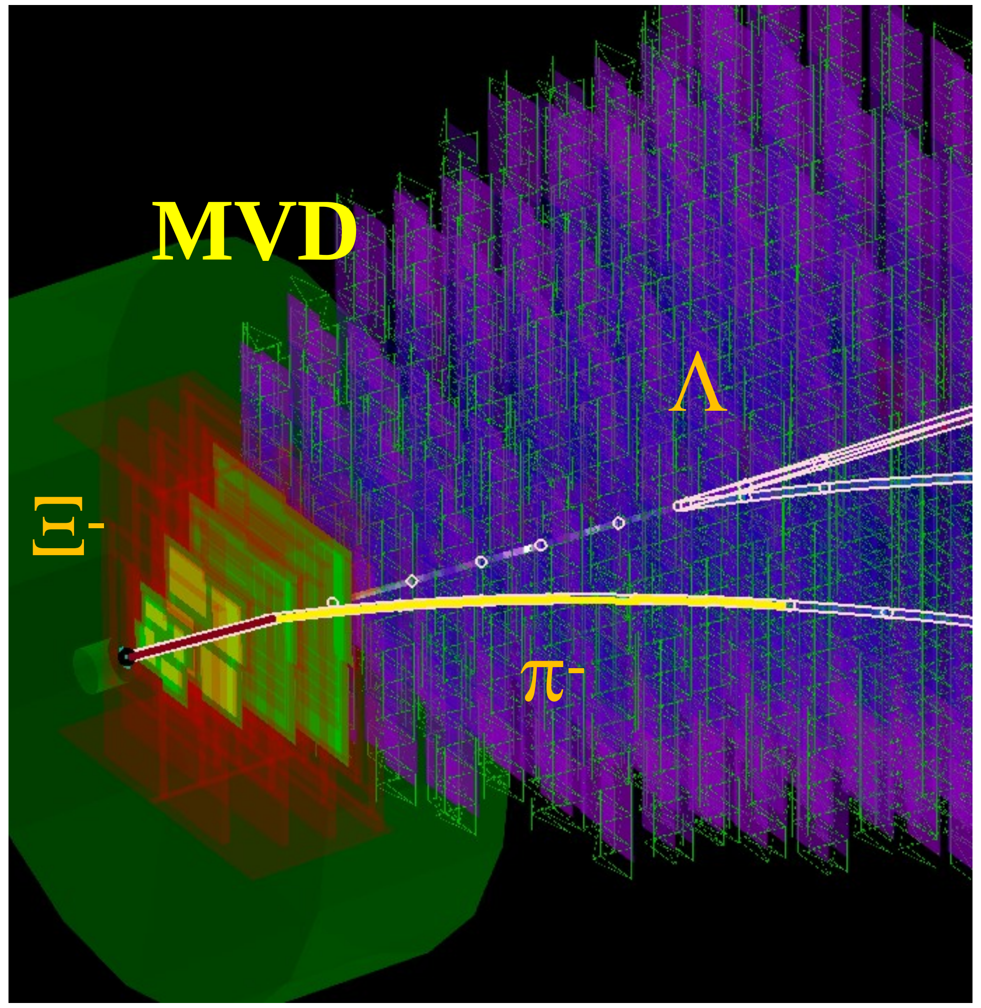
P. Kisel





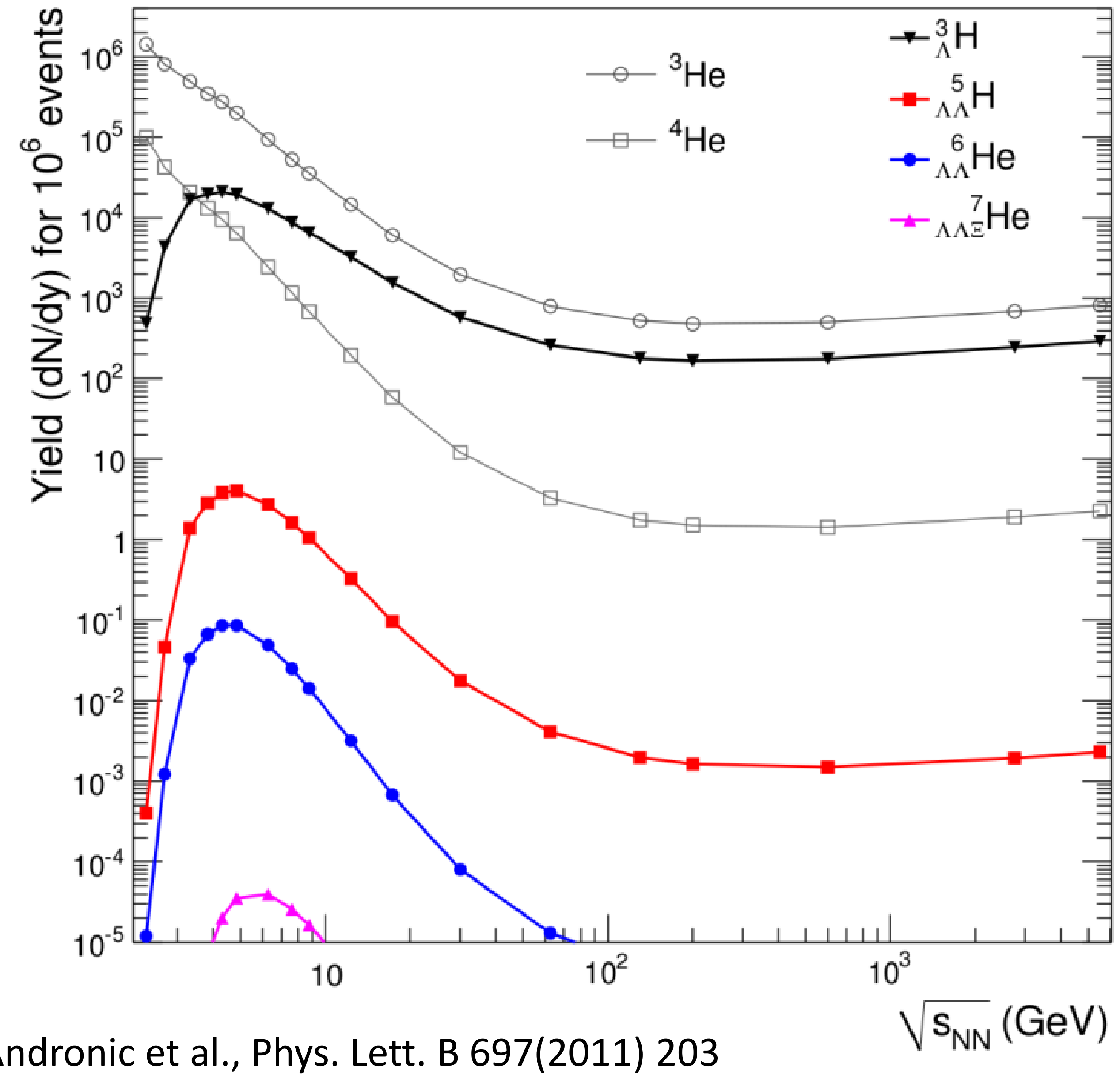






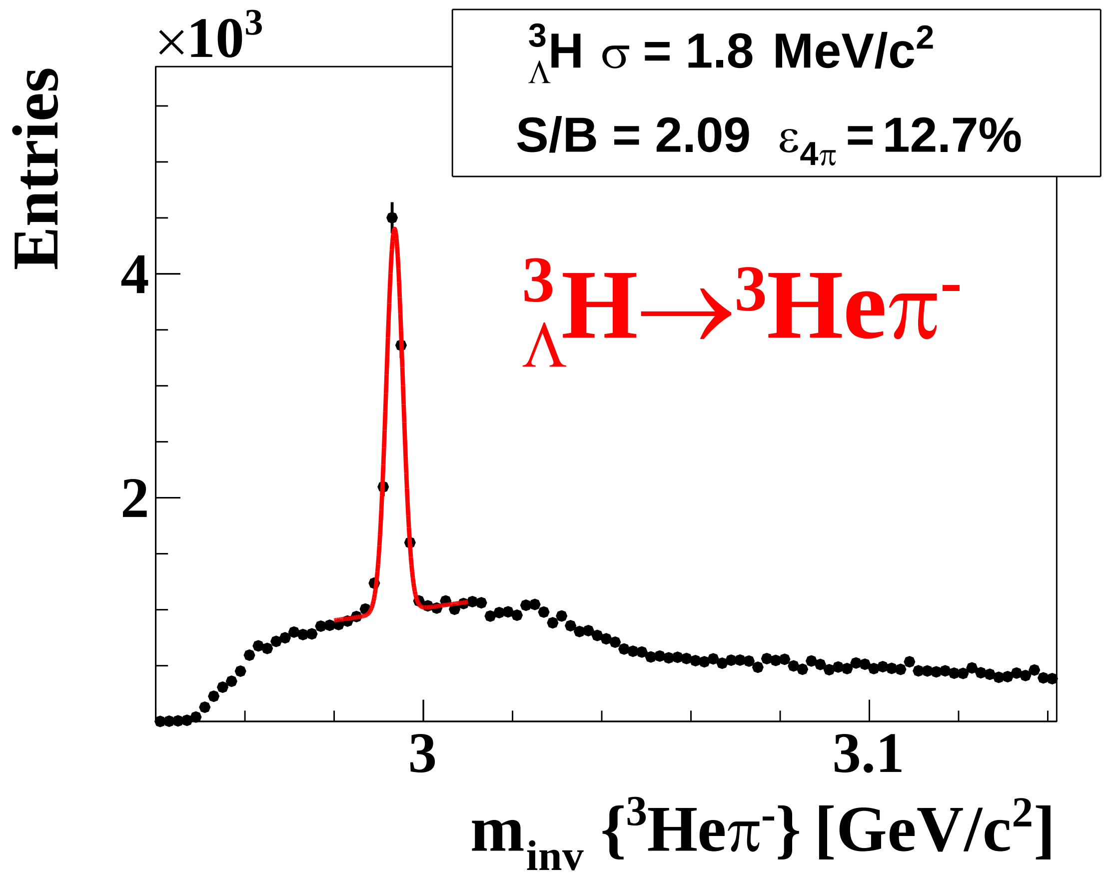
- Σ^+ and Σ^- physics:
  - completes the picture of strangeness production: abundant particles, carry out large fraction of strange quarks;
  - reconstruction of resonances, like $\Lambda(1405)$;
  - reconstruction of hypothetic particles, like H-dybarion.
- Having high acceptance for Σ hyperons CBM is capable to reconstruct them by the **Missing Mass Method**.
- The method provides also independent way for reconstruction of Ξ and Ω hyperons, that will allow systematics study.

Single and double hypernuclei production in A+A collisions at CBM/FAIR

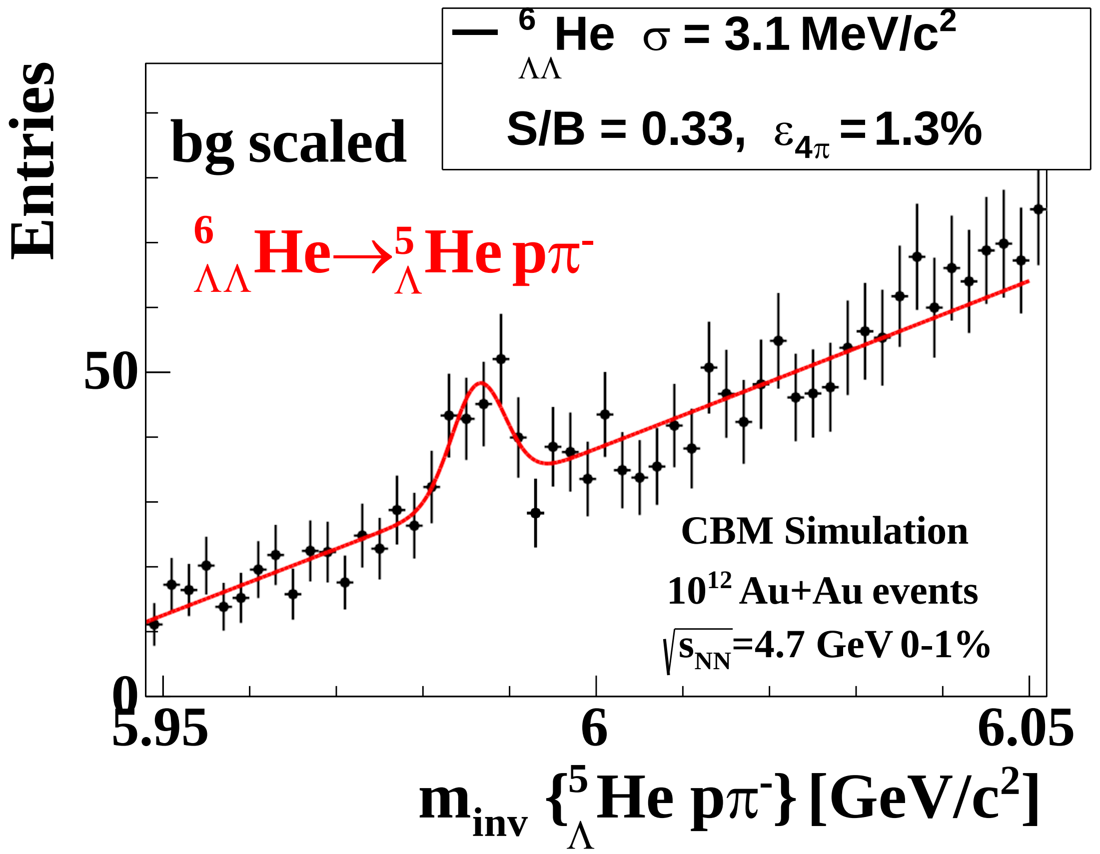


A,Andronic et al., Phys. Lett. B 697(2011) 203

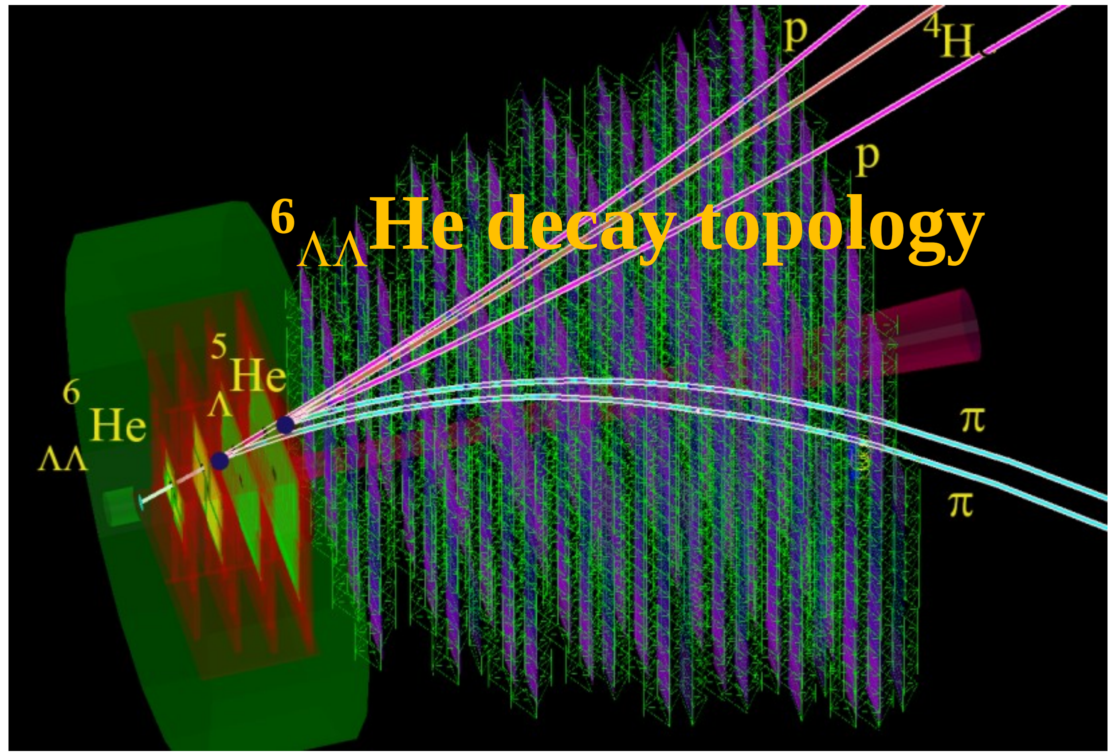
5M mbias events Au+Au at 10AGeV/c
50 sec at 0.1MHz IR (1.8 k/sec)



Expected collection rate: ~60 $^6_{\Lambda\Lambda}He$ in 1 week at **10MHz IR** (not day-1)



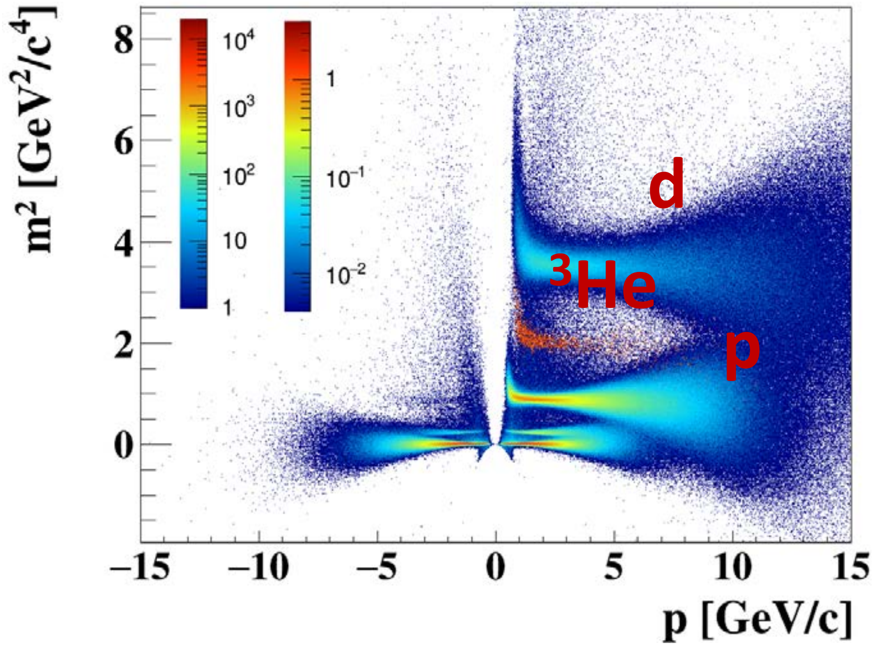
- According to the current theoretical predictions CBM will be able to perform comprehensive study of hypernuclei, including:
  - precise measurements of lifetime;
  - excitation functions;
  - flow.
- It has a huge potential to register and investigate double Λ hypernuclei.

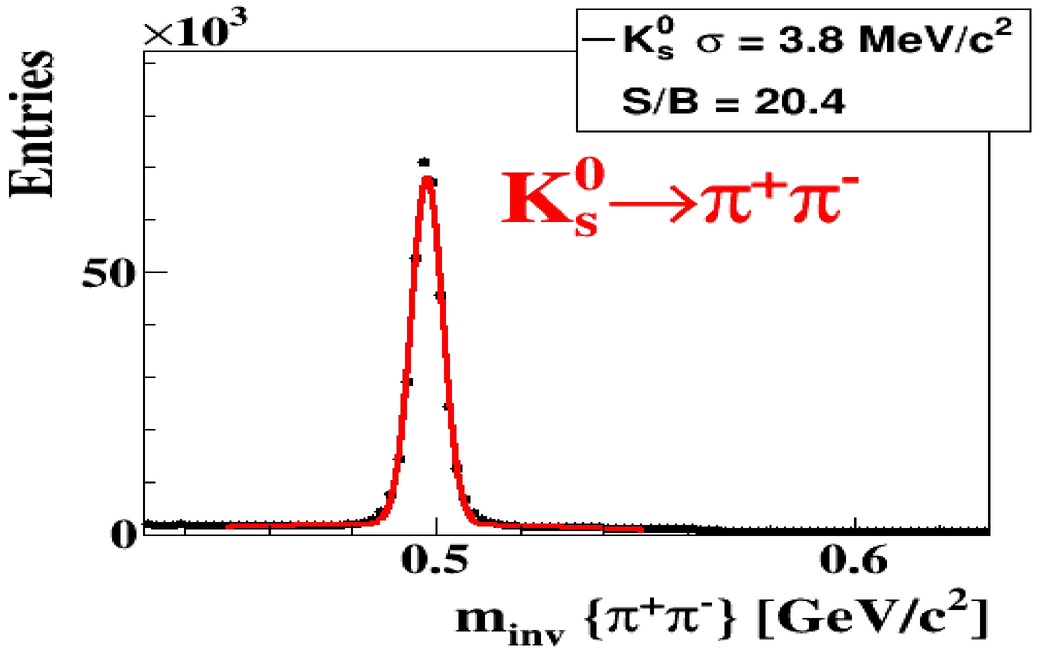


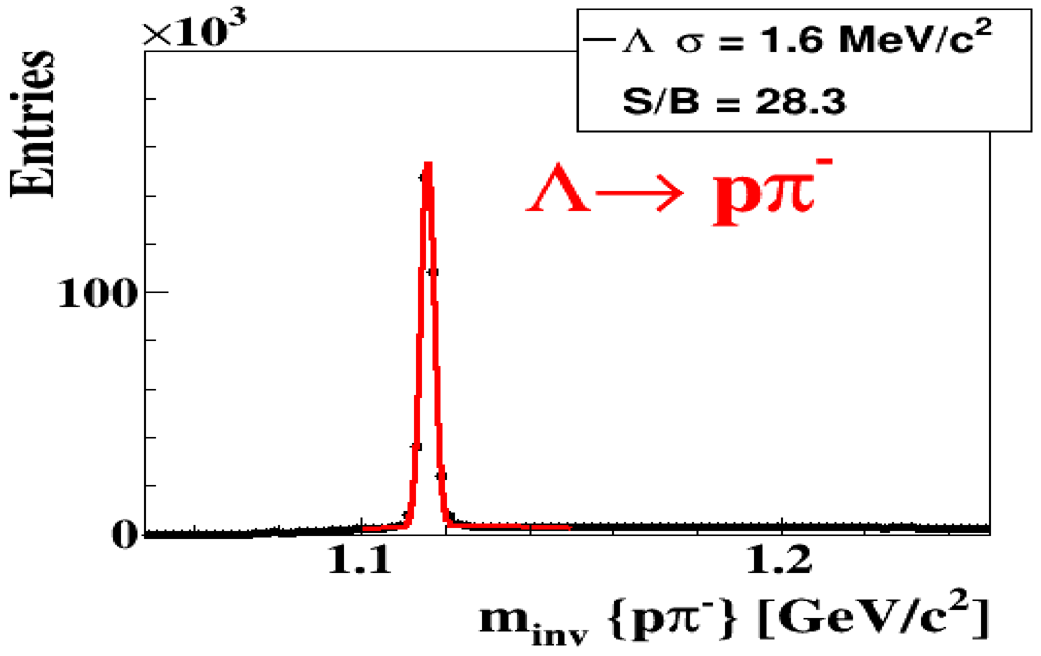
What about the fragments? Background produced by d, t, ^{3}He, ^{4}He

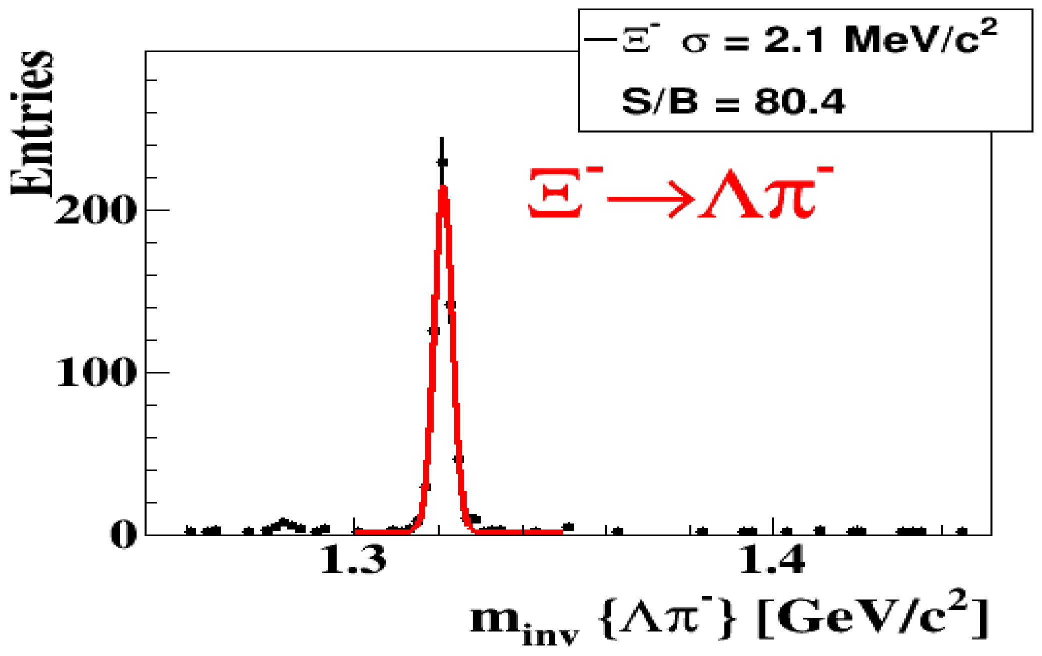
Dubna Cascade Model (DCM) with CBM detector
5M mbias C + C collisions about 50 sec of data taking assuming 10^5 IR

A.S.Botvina, K.K.Gudima, J.Pochodzalla.
Production of hypernuclei in peripheral relativistic ion collisions.
Phys. Rev. C , v. 88, p. 054605, 2013.

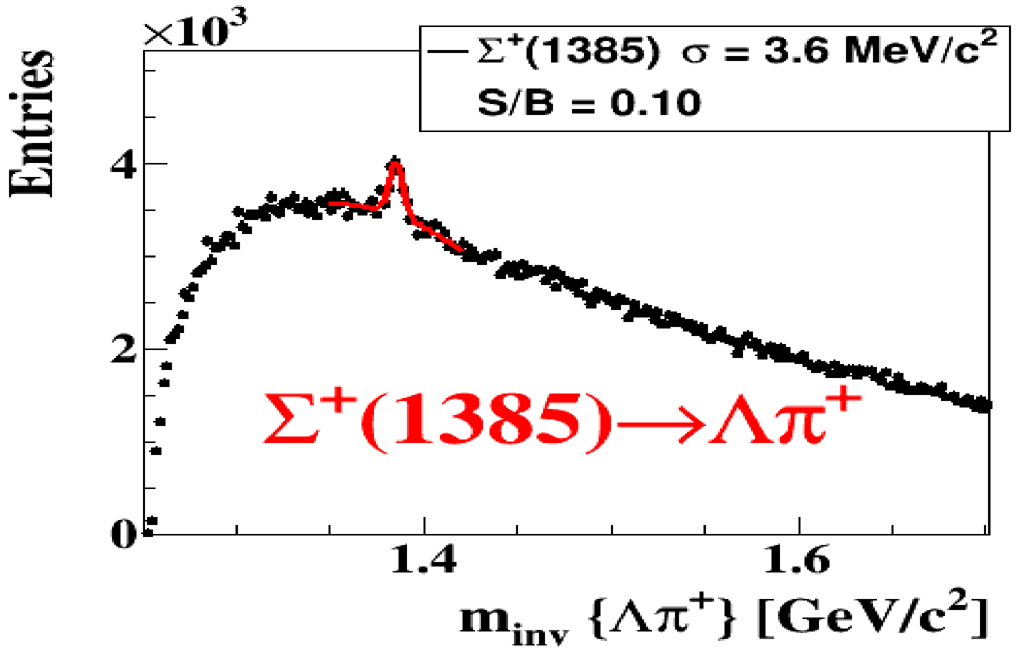


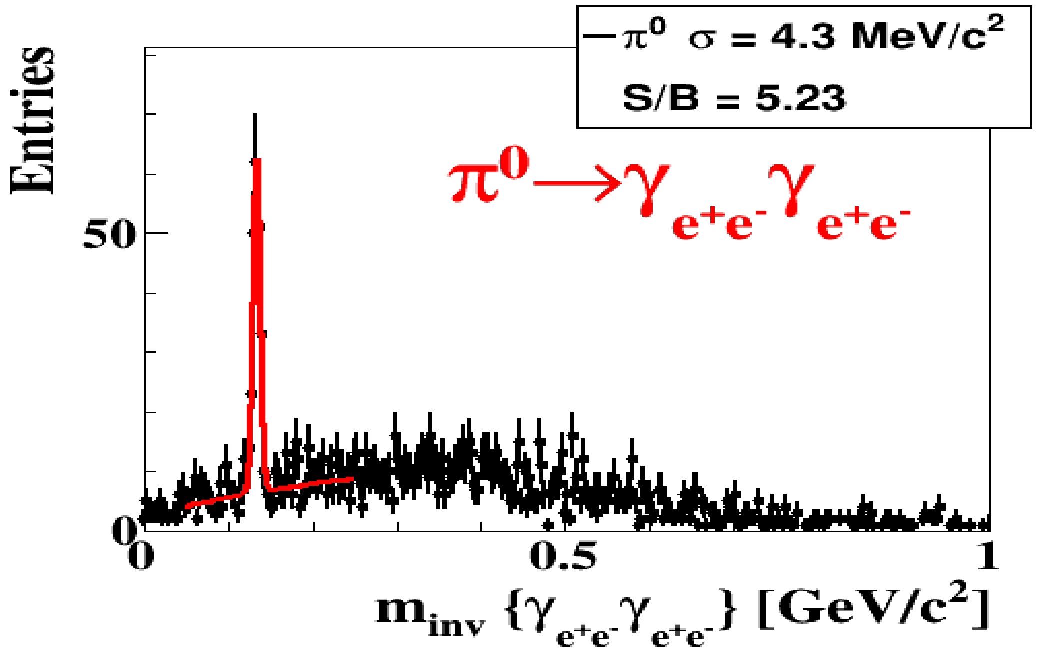


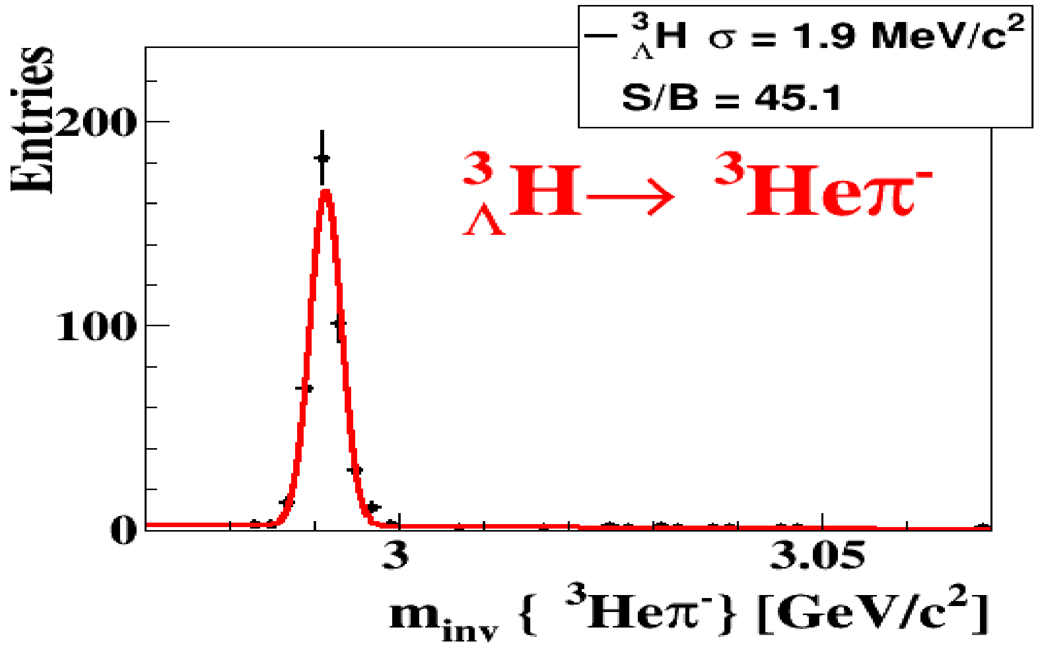




Λ N, ΛNN, $^4{}_\Lambda$H and $^4{}_\Lambda$He

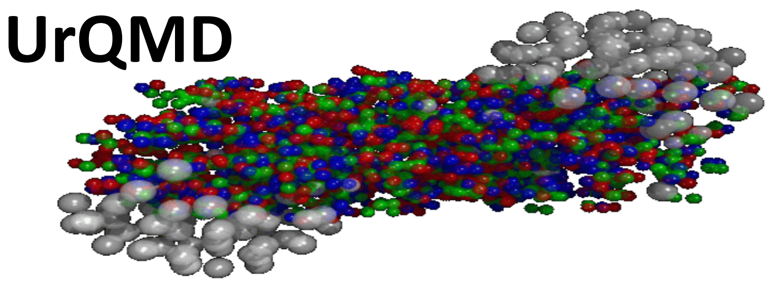






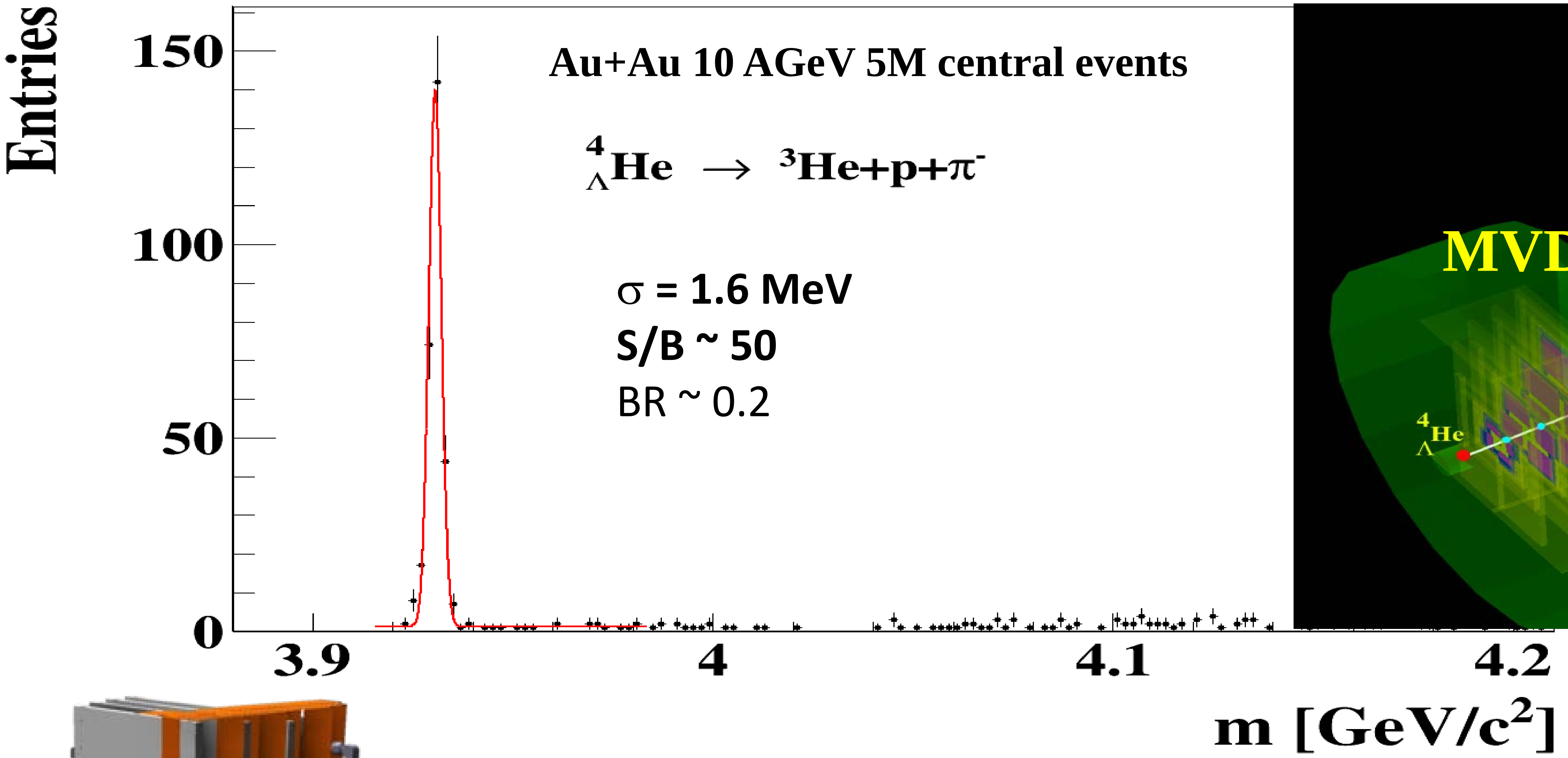
DCM Au + Au collisions at CBM energies are generated and ready to simulations

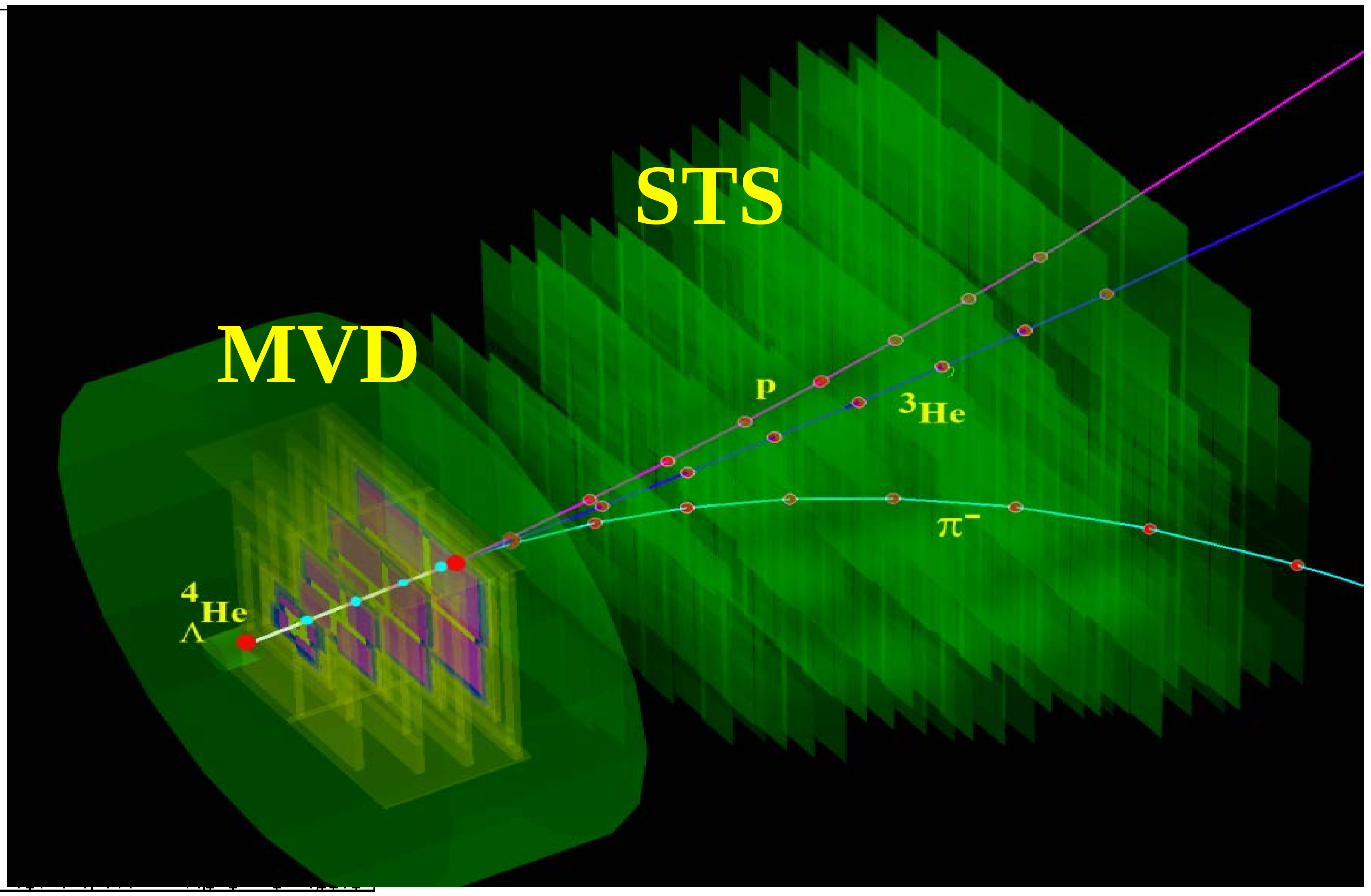
M^3 – new tool for Hypernuclei reconstruction

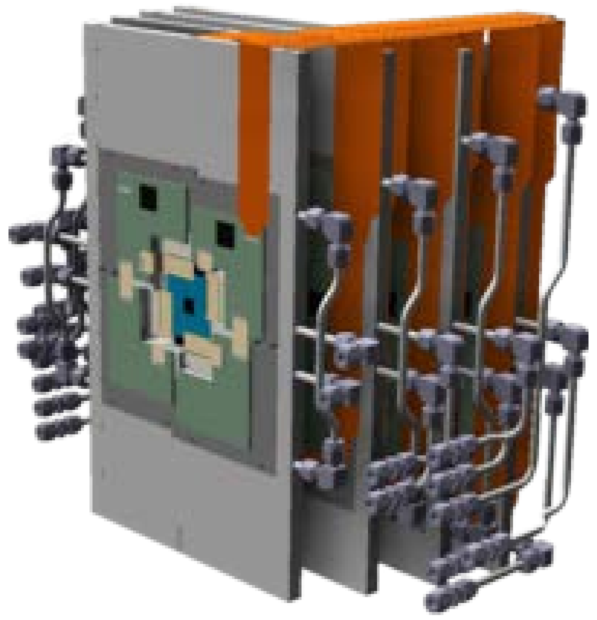


Multiplisity: J. Steinheimer et al., Phys. Lett. B**714**, 85, (2012)

3 prong detached vertex is good signature of ${}^{4}_{\Lambda}$He decay







New decay channels with neutrals: ${}^{4}_{\Lambda}H \rightarrow d + p + \pi^{-} + n$

Day 1 at CBM: Expected particle yields
Au+Au @ 6, 10 AGeV

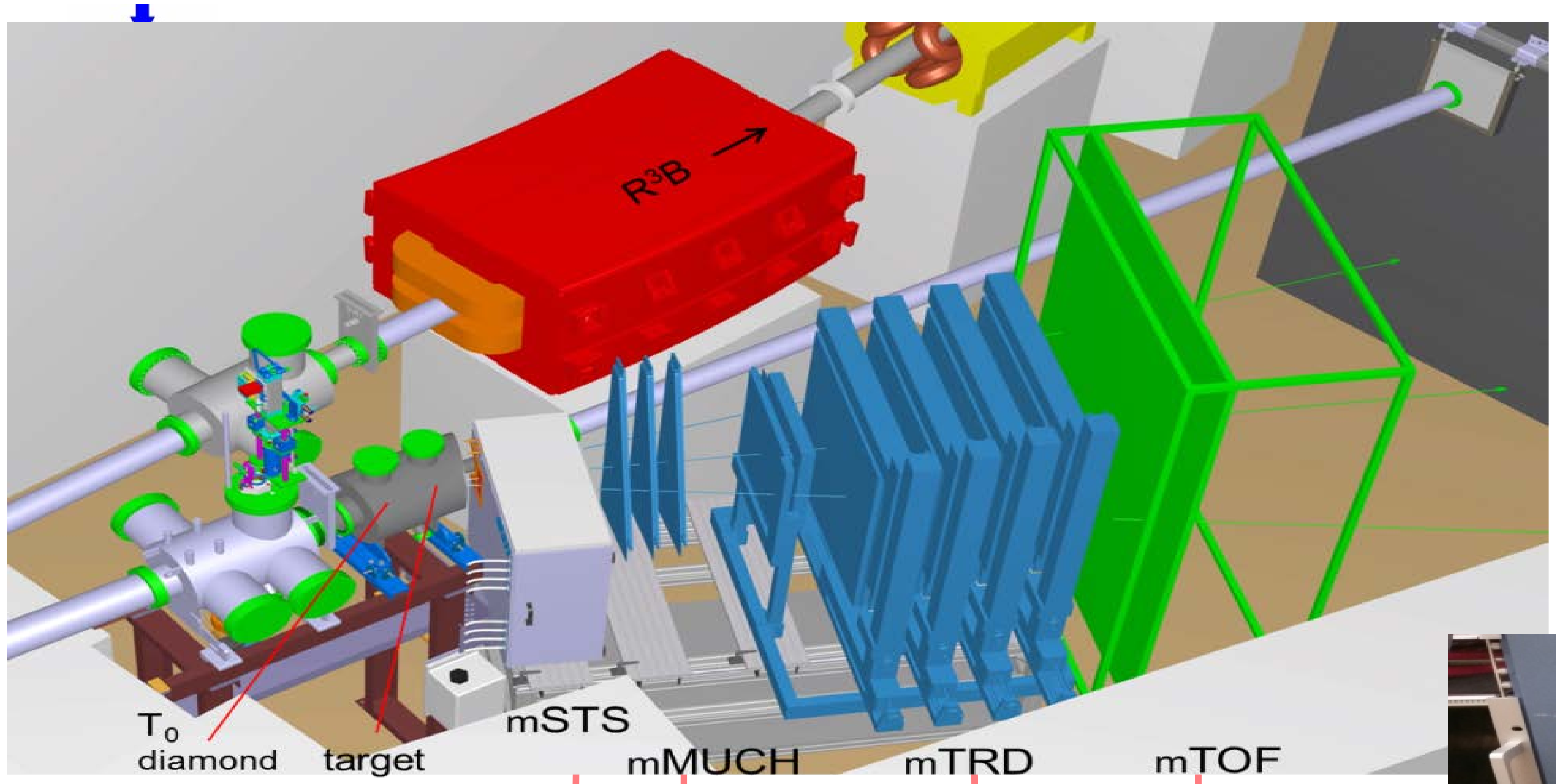
Particle (mass MeV/c^2)	Multiplicity central ev. 6 AGeV	Multiplicity central ev. 10 AGeV	decay mode	BR	ε (%)	yield in 90 days 6AGeV	yield in 90 days 10 AGeV	IR MHz
$\bar{\Lambda}$ (1115)	$4.6\cdot10^{-4}$	0.034	$\bar{p}\pi^+$	0.64	19.7	$1.1\cdot10^{7}$	$8.3\cdot10^{8}$	**0.1**
Ξ^- (1321)	0.054	0.222	$\Lambda\pi^-$	1	9.9	$1.0\cdot10^{9}$	$4.3\cdot10^{9}$	**0.1**
Ξ^+ (1321)	$3.0\cdot10^{-5}$	$5.4\cdot10^{-4}$	$\bar{\Lambda}\pi^+$	1	8.7	$5.0\cdot10^{5}$	$9.1\cdot10^{6}$	**0.1**
Ω^- (1672)	$5.8\cdot10^{-4}$	$5.6\cdot10^{-3}$	ΛK^-	0.68	4.4	$3.4\cdot10^{6}$	$3.3\cdot10^{7}$	**0.1**
Ω^+ (1672)	-	$7\cdot10^{-5}$	$\bar{\Lambda}K^+$	0.68	3.9	0 (QGP?)	$3.8\cdot10^{5}$	**0.1**
${}^3_\Lambda H$ (2993)	$4.2\cdot10^{-2}$	$3.8\cdot10^{-2}$	${}^3He\pi^-$	0.25	12.7	$2.7\cdot10^{8}$	$2.5\cdot10^{8}$	**0.1**
${}^4_\Lambda He$ (3930)	$2.4\cdot10^{-3}$	$1.9\cdot10^{-3}$	${}^3He p\pi^-$	0.32	11.4	$1.7\cdot10^{7}$	$1.4\cdot10^{7}$	**0.1**
${}^5_{\Lambda\Lambda}He$(5047)		$5.0\cdot10^{-6}$	${}^3He2p2\pi$	0.01	3	15	250	**0.1**
${}^6_{\Lambda\Lambda}He$(5986)		$1.0\cdot10^{-7}$	${}^4He2p2\pi$	0.01	1.2			**0.1**

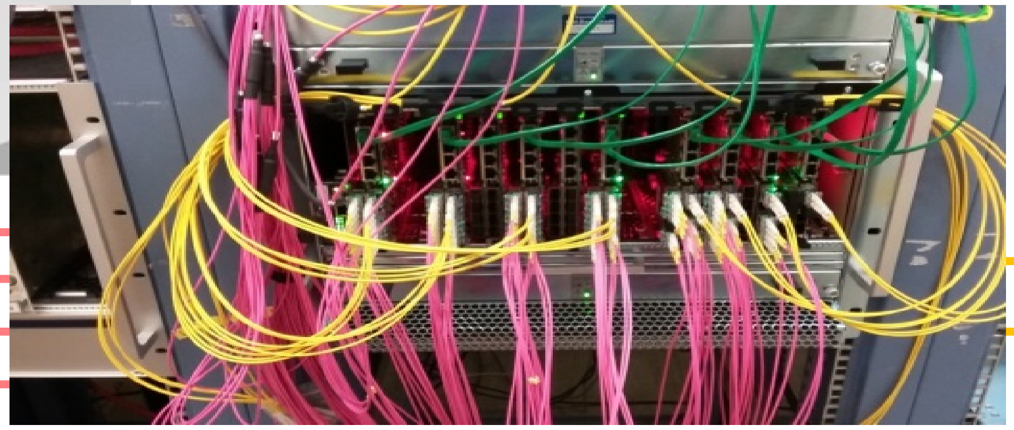
C.Sturm, mCBM

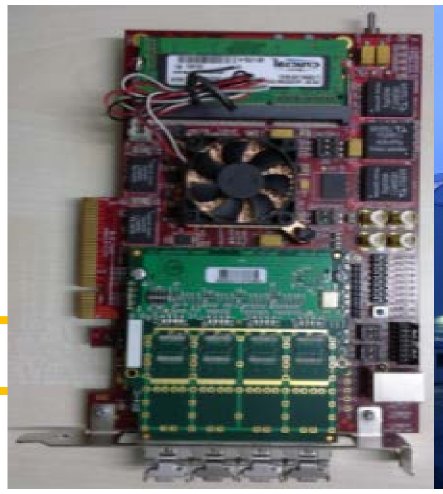
mCBM@SIS18

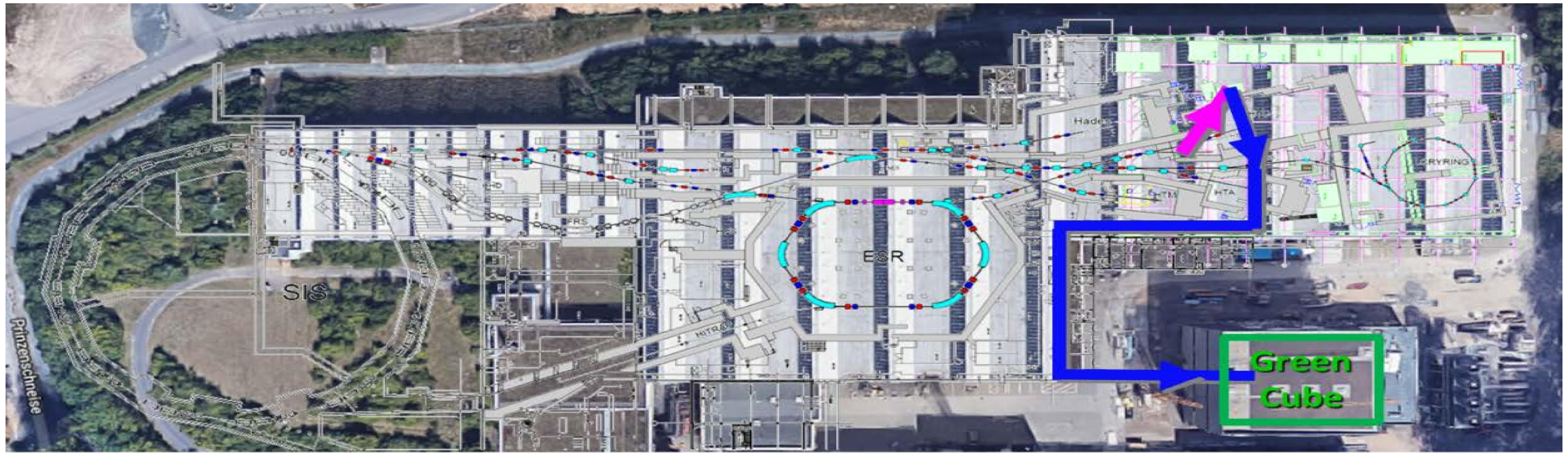
A CBM full system test-setup
for high-rate nucleus-nucleus collisions at GSI/FAIR

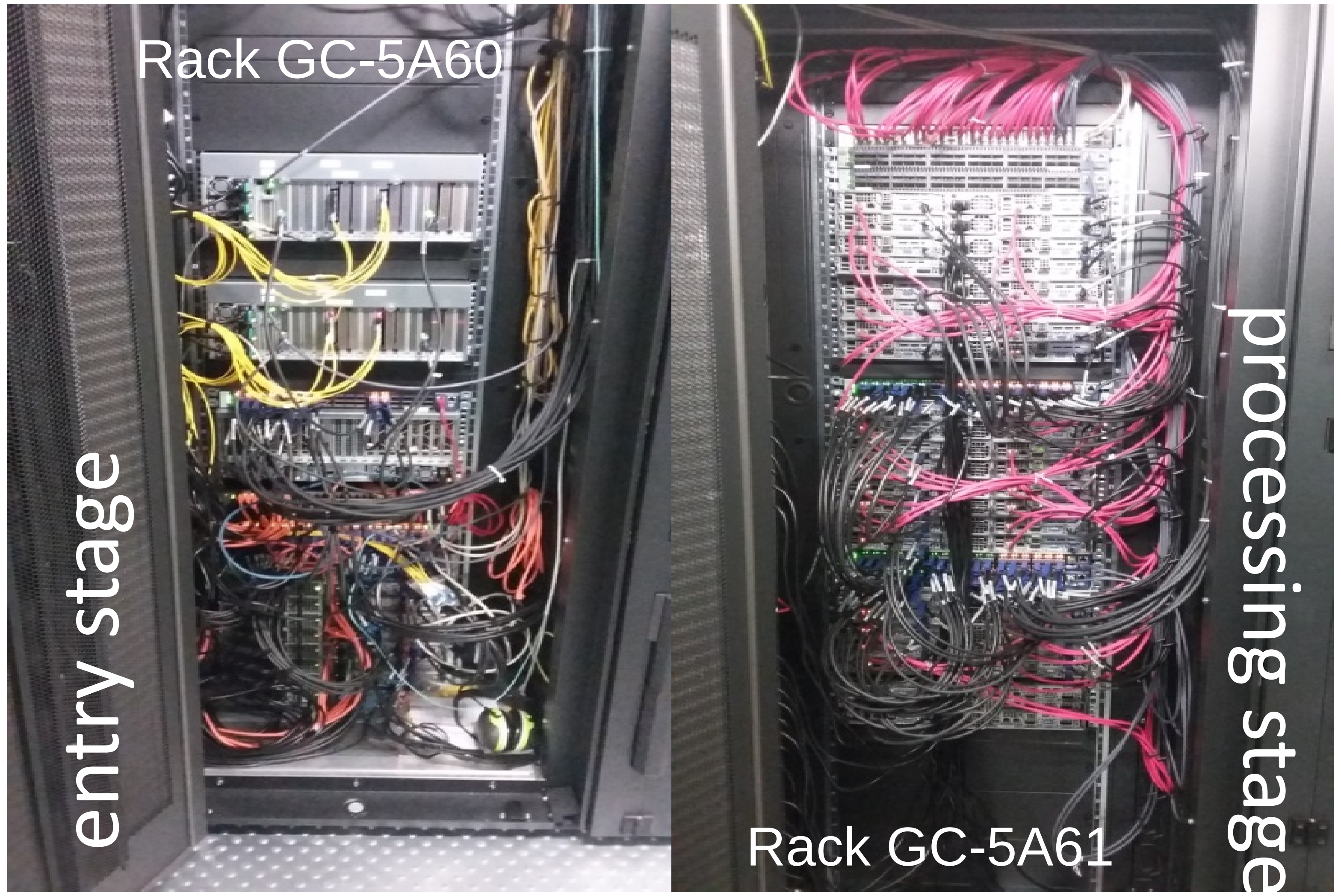
- CBM prototype detector systems
- free streaming read-out and data transport to the mFLES
- up to 10 MHz collision rate
- first commissioning beam in December 2018





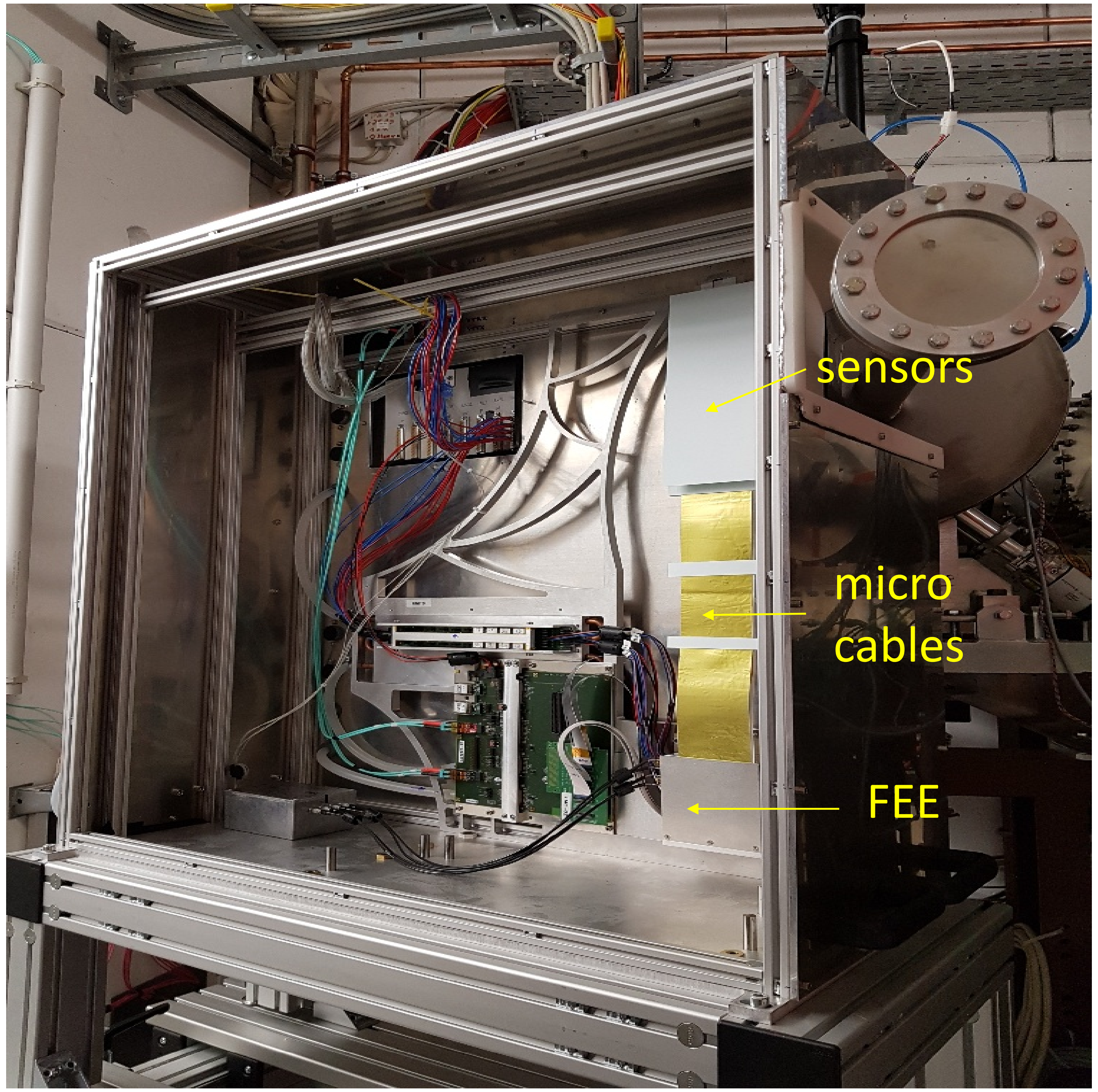




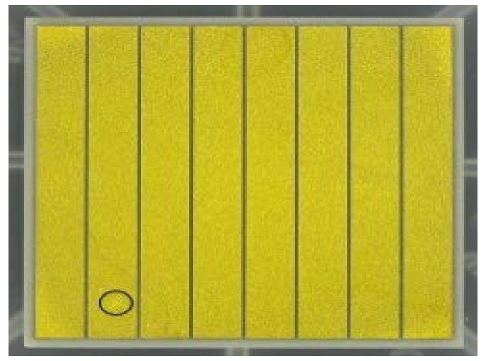


mCBM subsystems in Nov. / Dec. 2018

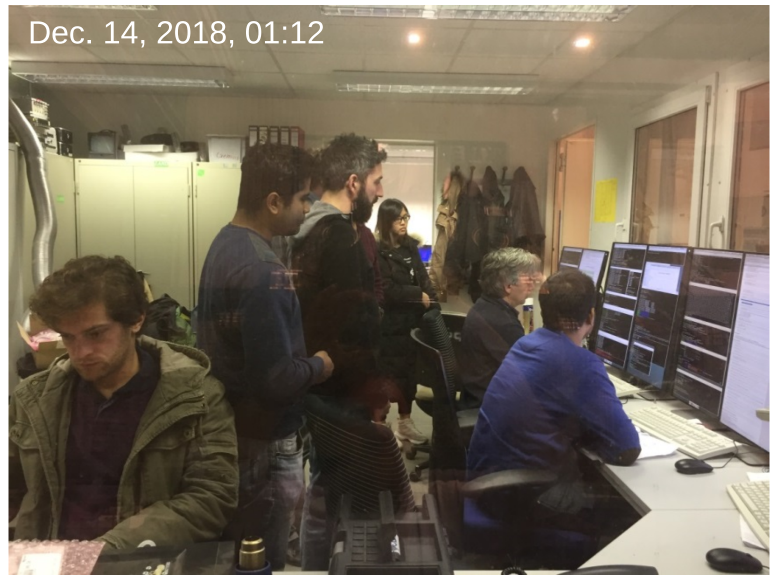
mSTS (GSI)



T0 diamond (GSI)



mMUCH (VECC)



mTOF modules (HD)

Summary

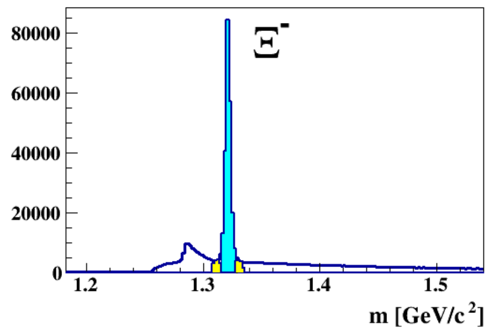
- CBM detector will allow to measure not only bulk observables, but strangeness, hypernuclei and other rare probes with high statistic.

- The CBM experiment will provide multidifferential high precision measurements of strange hadrons including multi-strange (anti)-hyperons.

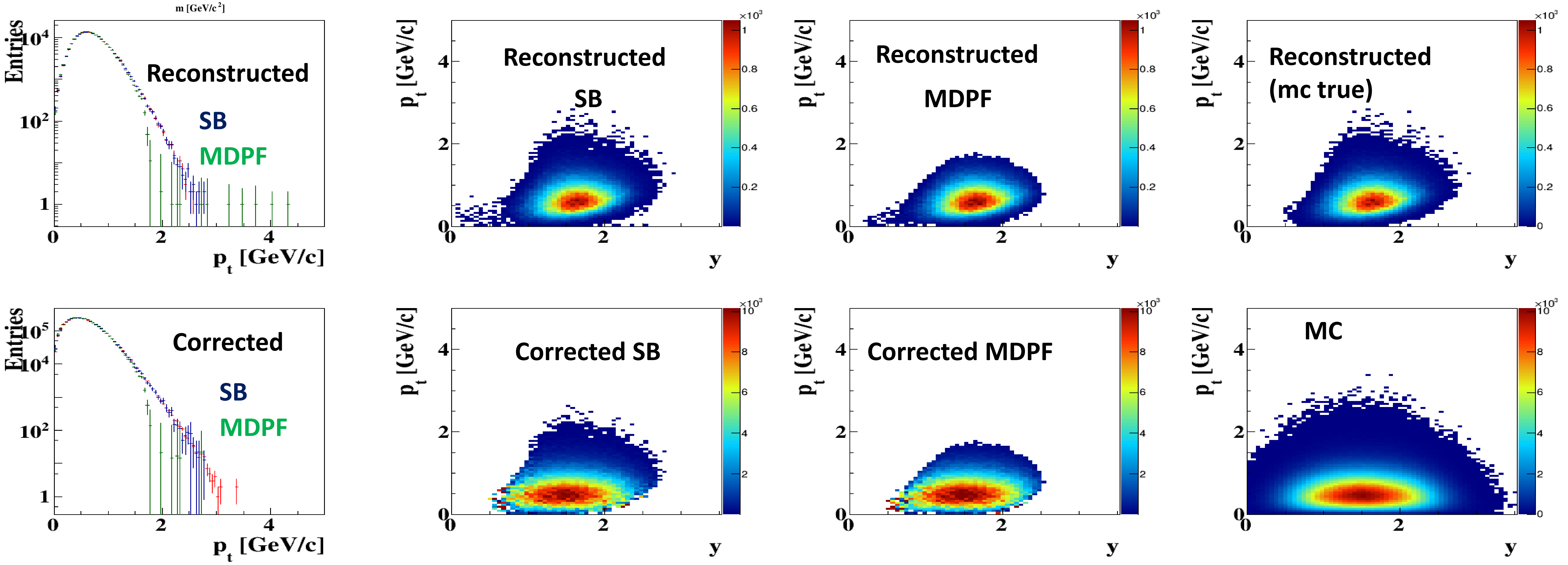
- High precision measurements of excitation functions of multi-strange hyperons in A+A collision with different mass numbers A at SIS100 energies have a discovery potential to find a signal for the onset of deconfinement in QCD matter at high net-baryon densities

- The discovery of (double-) Λ hypernuclei and the determination of their lifetimes will provide information on the hyperon-nucleon and hyperon-hyperon interactions, which are essential ingredients for the understanding of the nuclear matter EoS at high densities, and, hence, of the structure of neutron stars.

Strange particle reconstruction performance



Two different methods:
Multi Differential Polinomial Fit & Side Bands



- CBM will allow clean reconstruction of rare strange probes with high efficiency and high statistics.
- Tools for the multi-differential physics analysis are prepared.