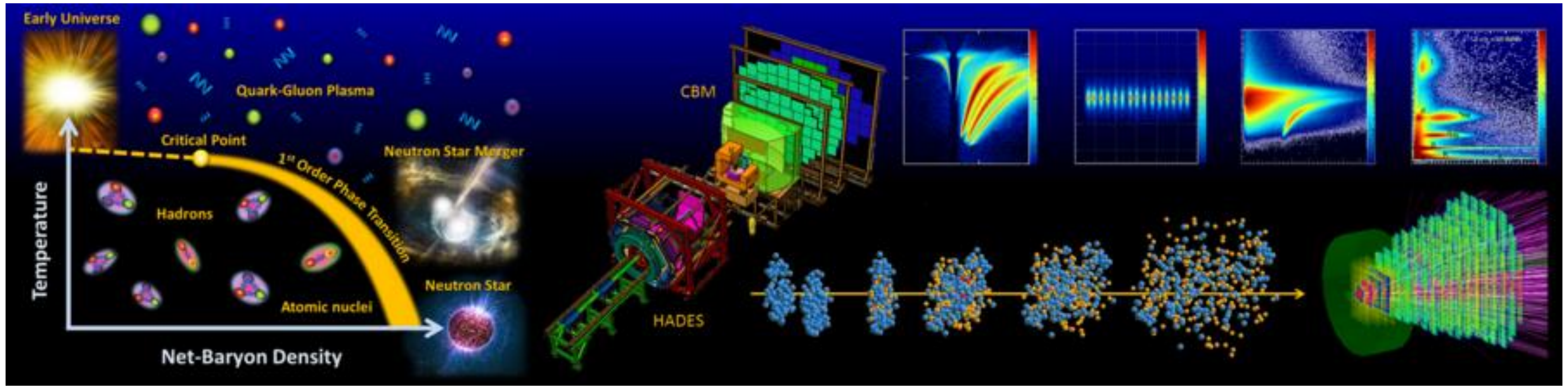
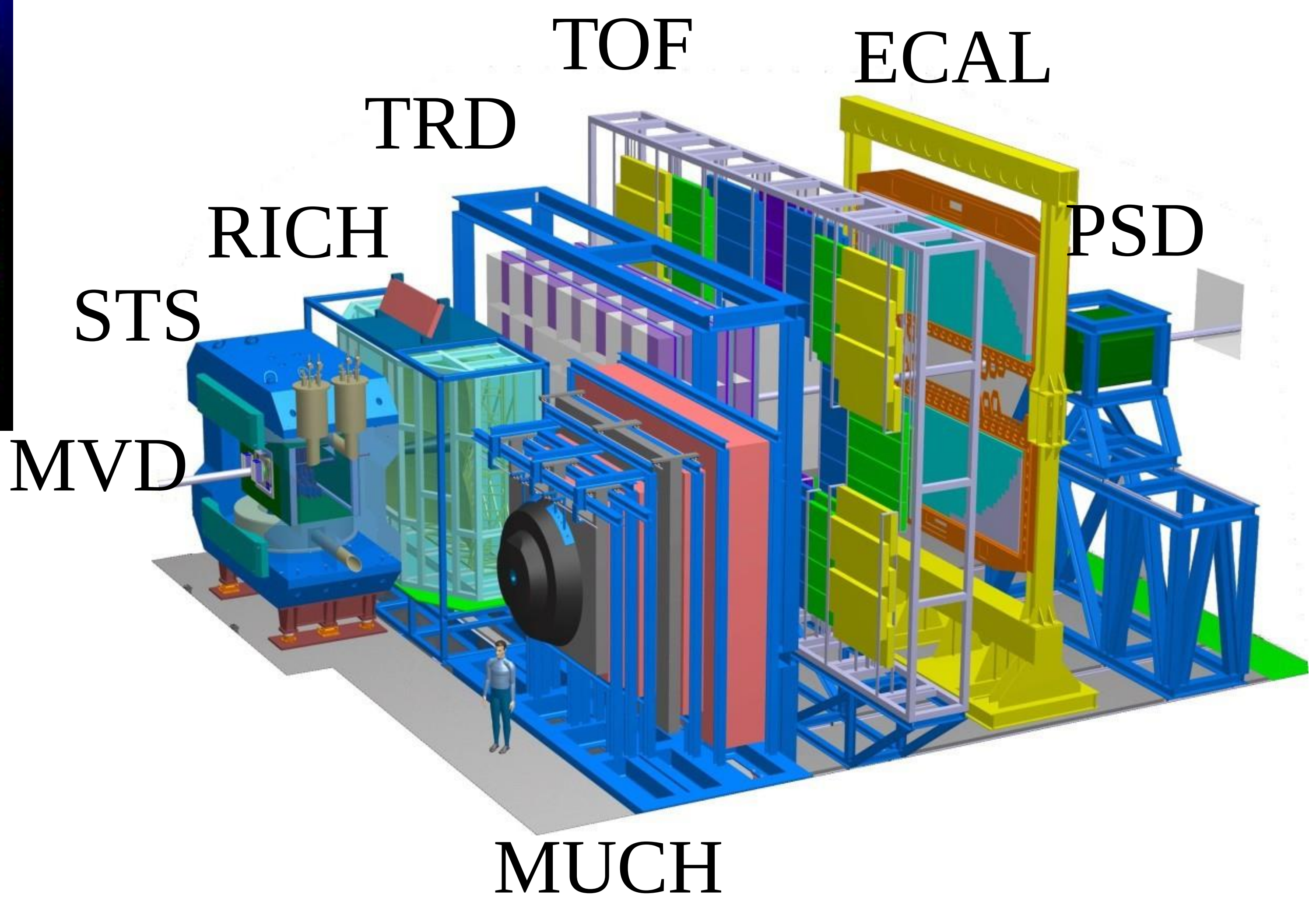
Perspectives on strangeness physics with the CBM experiment at FAIR



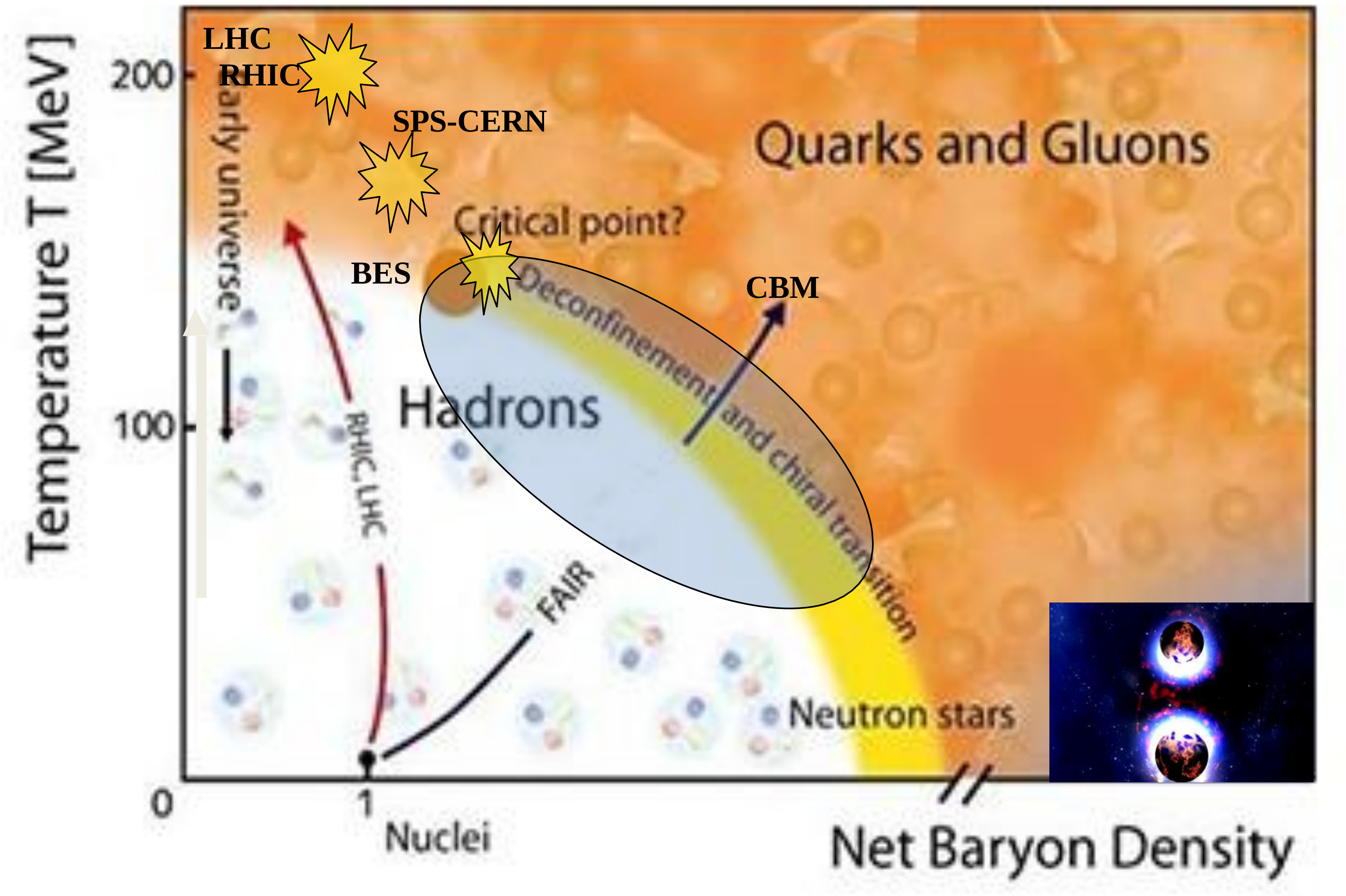
I.Vassiliev for the CBM Collaboration



- Physics case
- MSH reconstructions
- BES-I MSH measurements, models and predictions
- Tests with experimental data
- Summary

13 June 2019 Bari

Physics case: Exploring the QCD phase diagram



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!**

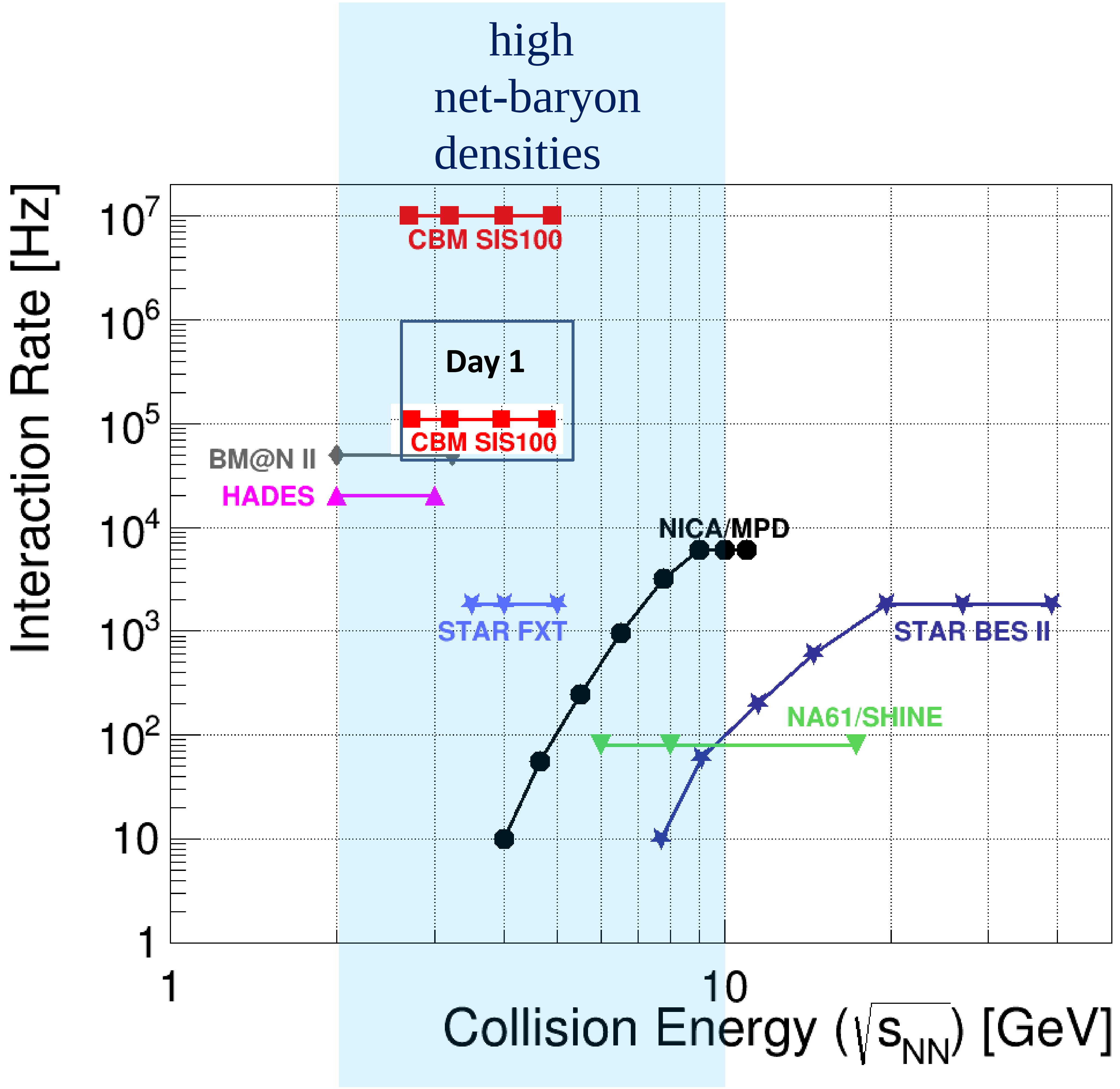
The equation-of-state at high ρ_B
collective flow of hadrons,
particle production at threshold energies:
multi-strange hyperons, hypernuclei

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…)

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

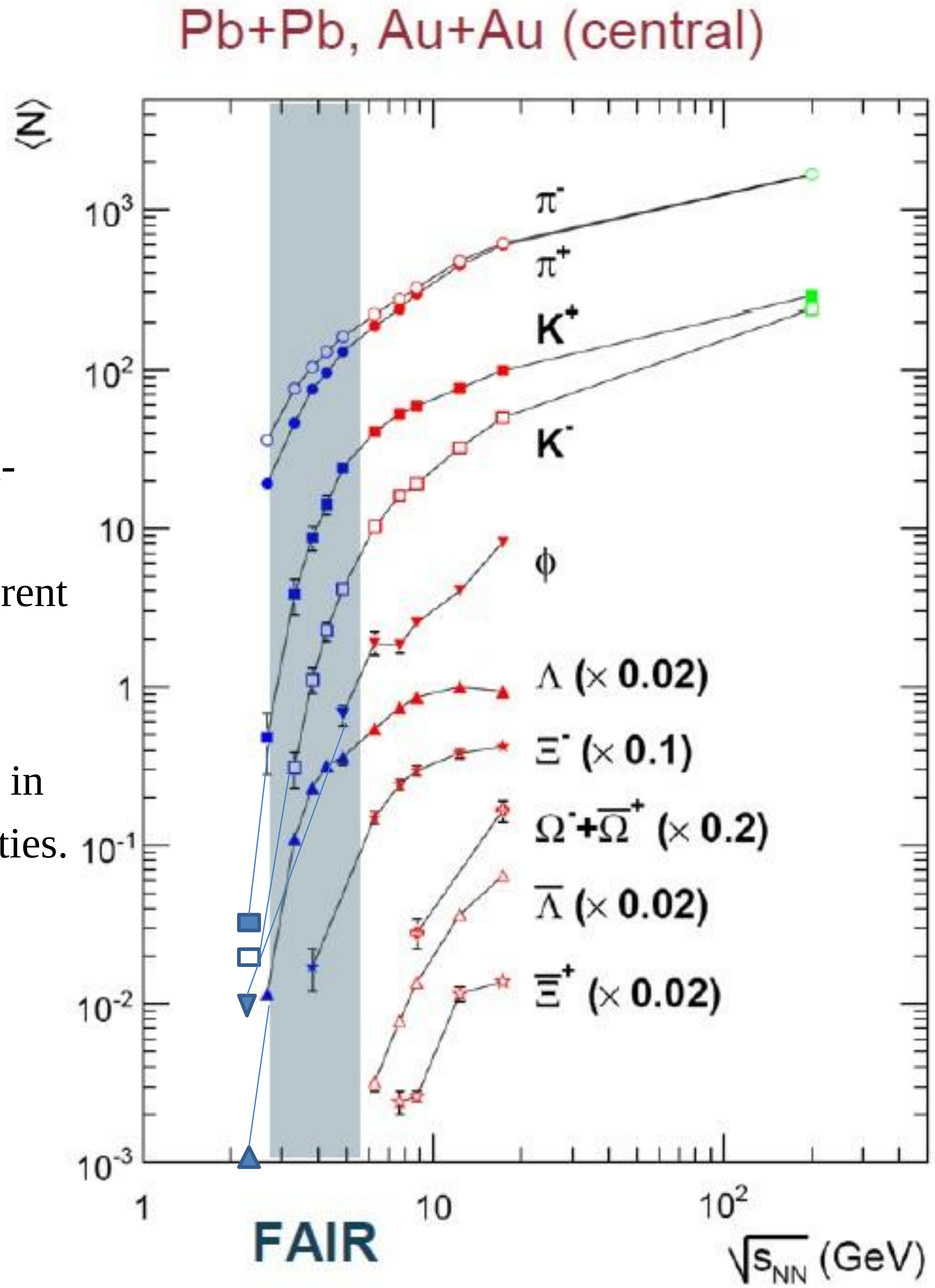
Strangeness world data

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

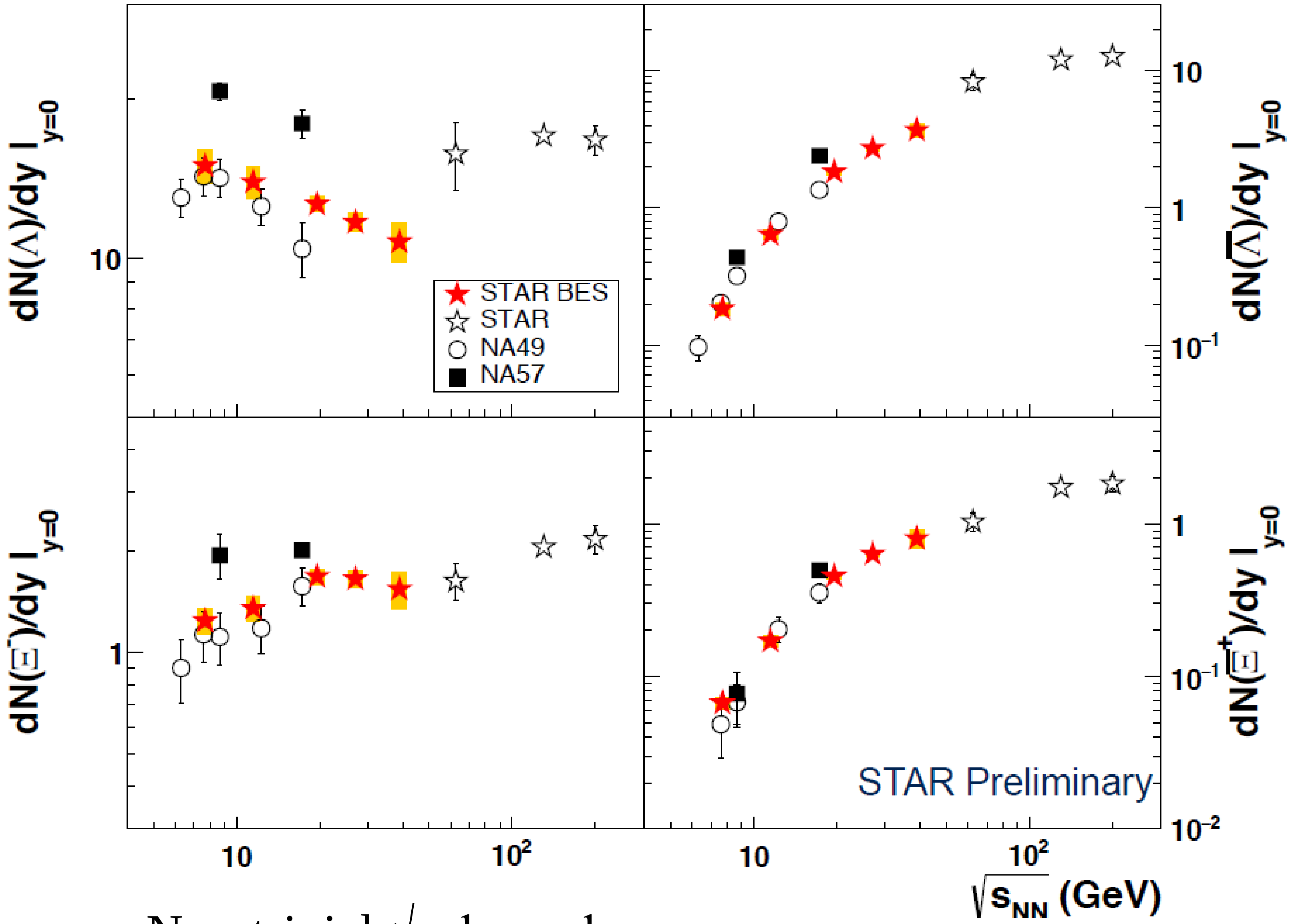
High-precision measurements of excitation functions of multi-strange hyperons in A+A collision with different mass numbers A at SIS100 energies have a discovery potential to find a signal for the onset of deconfinement in QCD matter at high net-baryon densities.

What about models?



STAR BES-I

arXiv:1906.03732v1 [nucl-ex] 9 Jun 2019



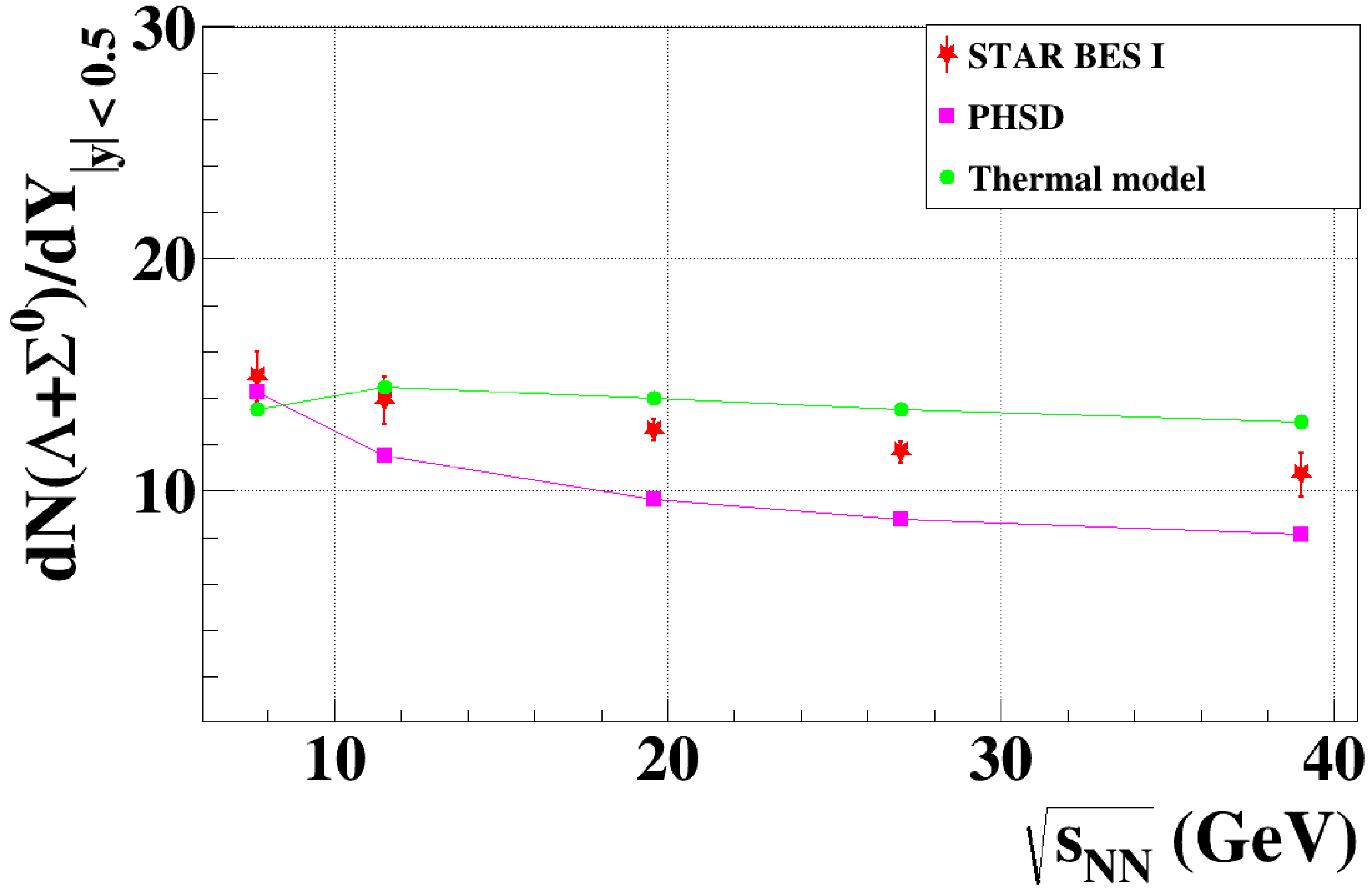
Non-trivial √s dependence of strange baryons

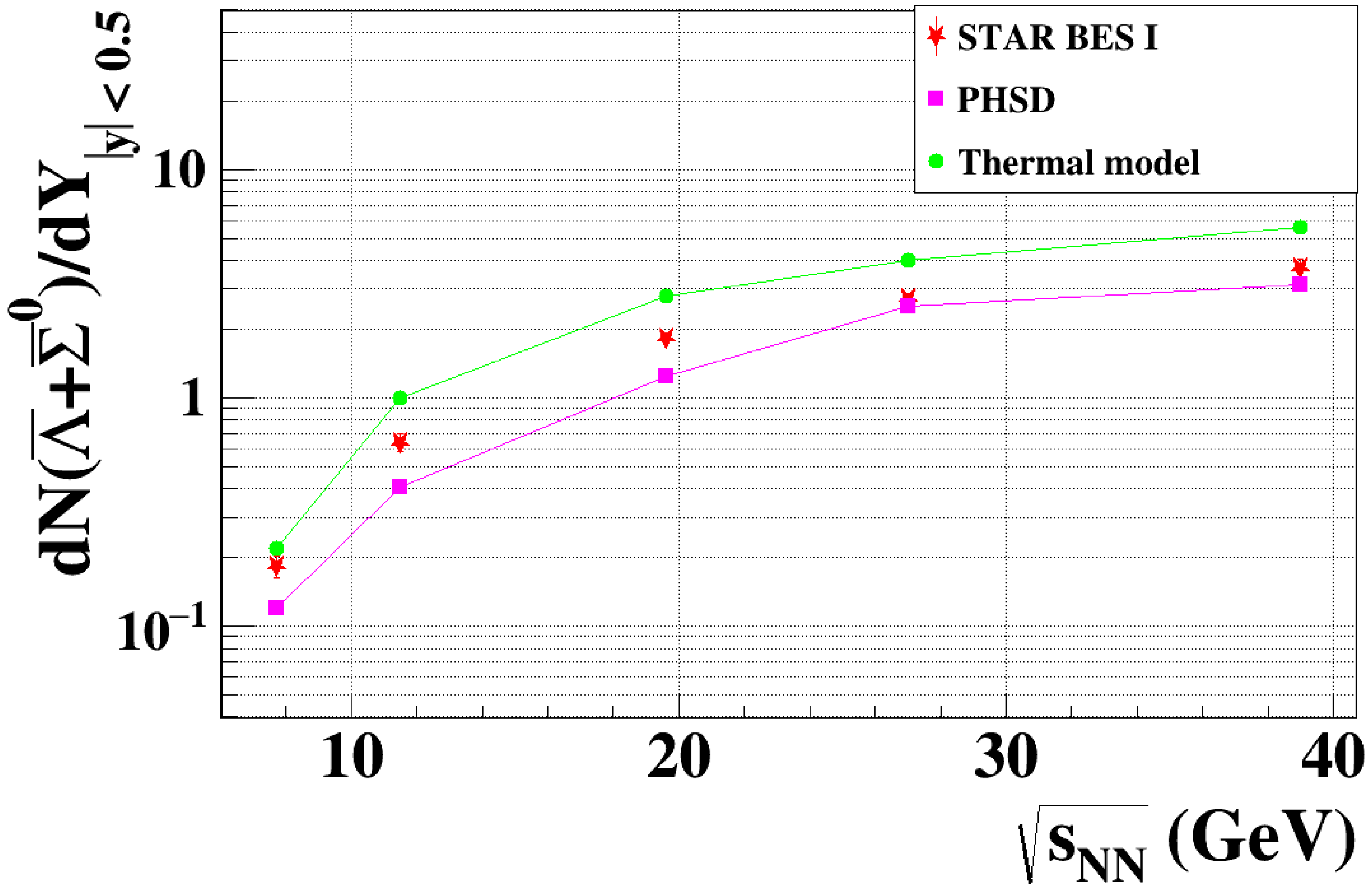
Strangeness results submitted for publication soon

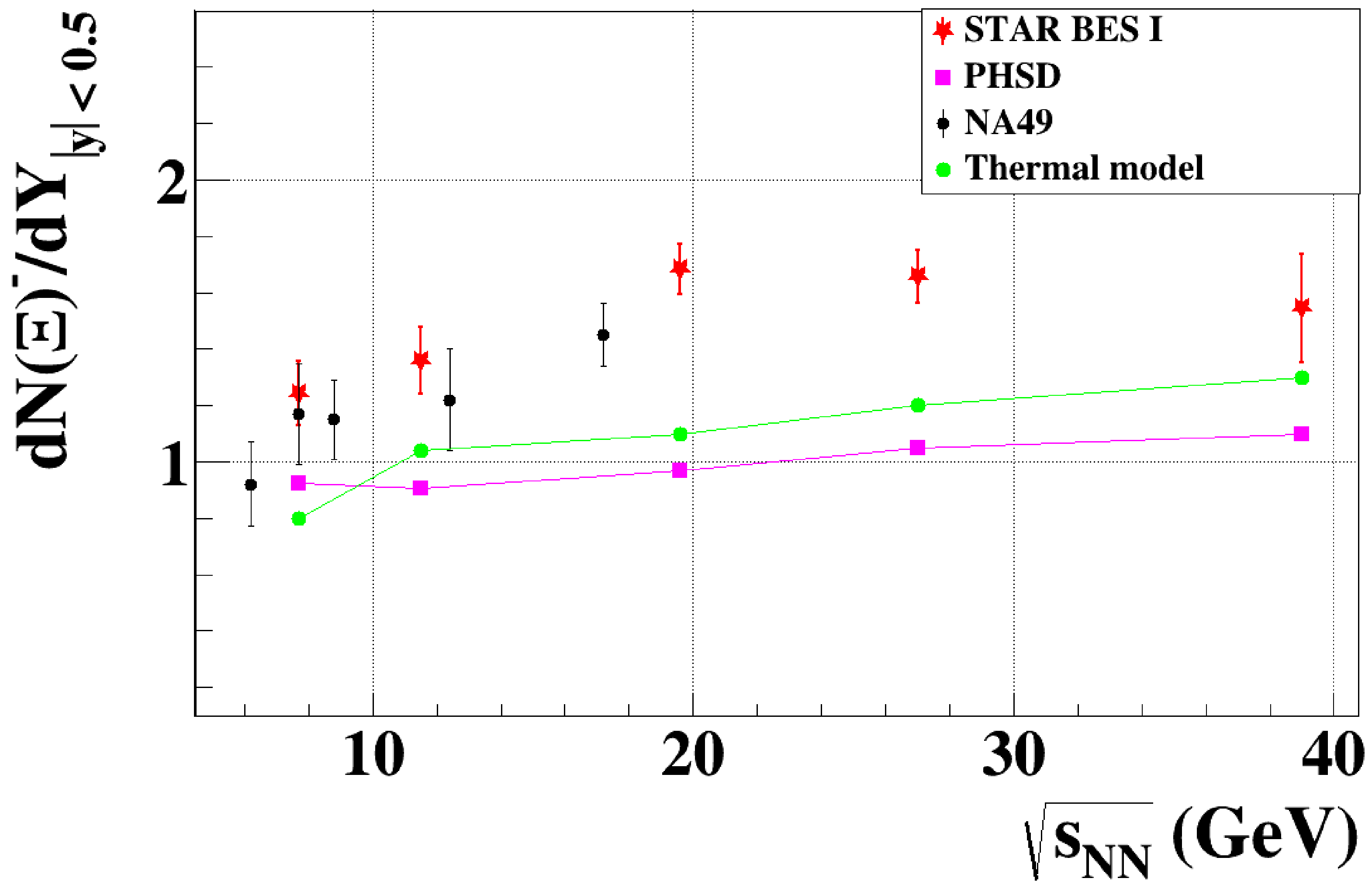
$\Omega^{\pm}$ (!)

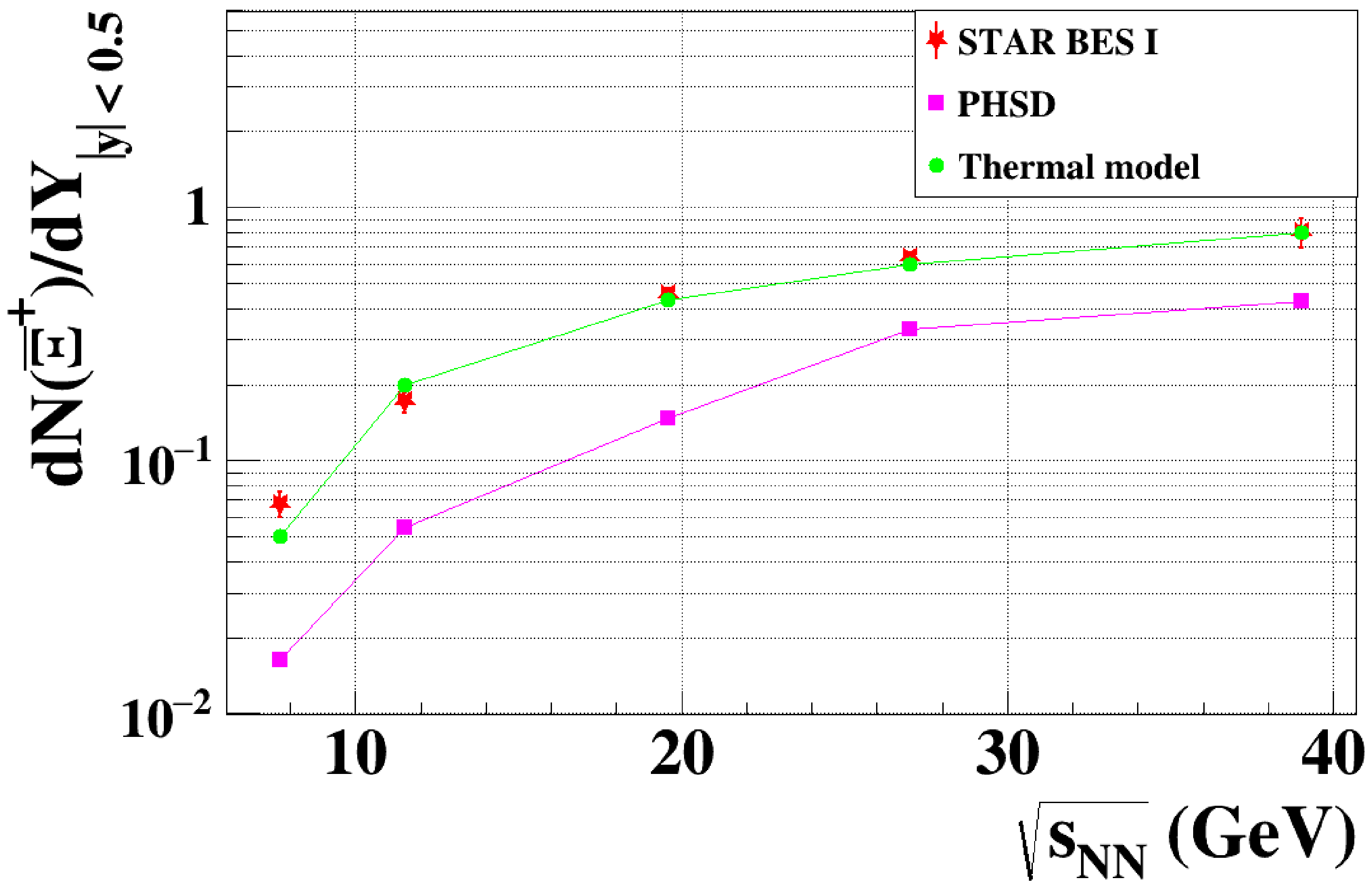
Helen Caines
EMMI Workshop
GSI February 2019

MSH measurements and models









* STAR BES data by Helen Caines EMMI Workshop GSI February 2019

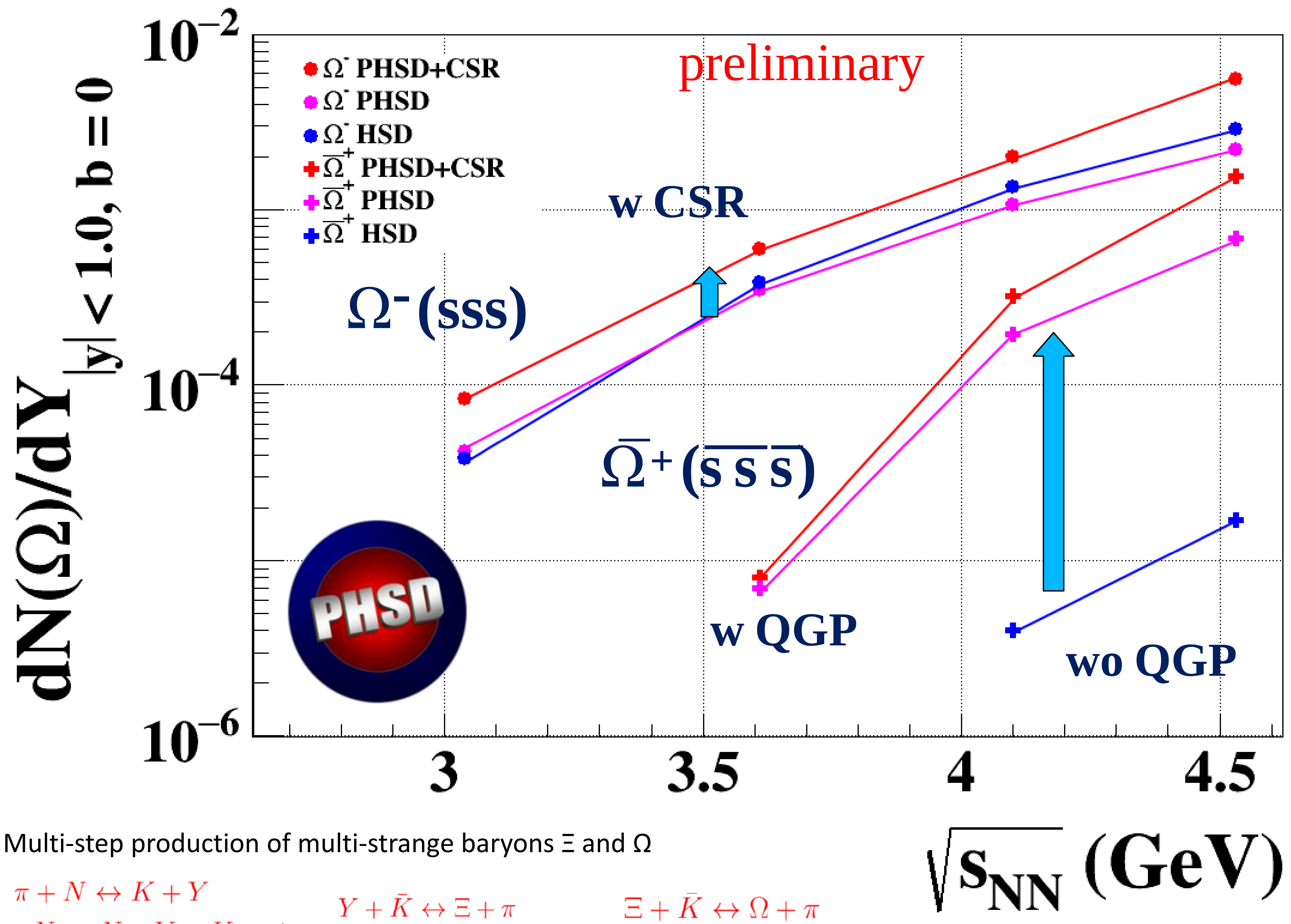
– Thermal model by A. Andronic 32 CBM week

-- PHSD by P.Moreau SQM 2015

- Very reasonable agreement by both models
- More strangeness needed (PHSD)

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

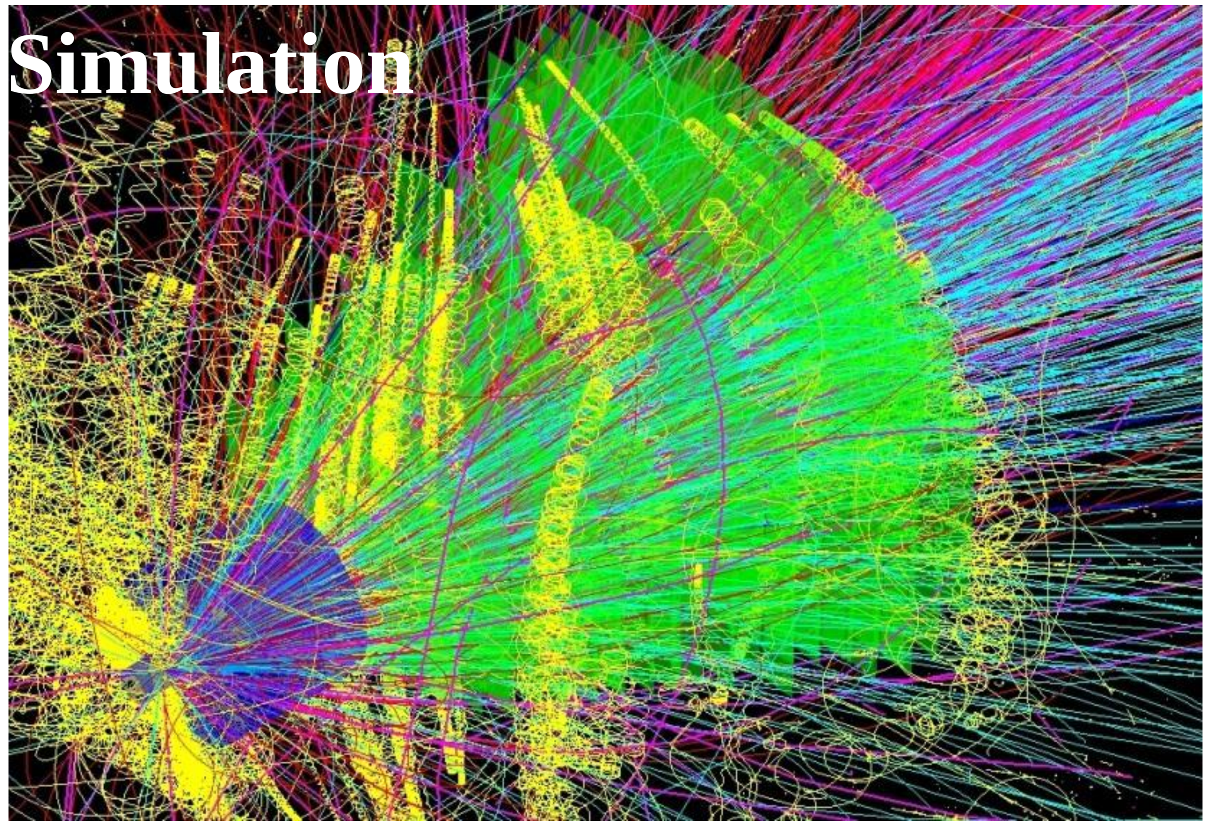
$$\pi + N \leftrightarrow K + Y \quad N + N \leftrightarrow N + Y + K \quad N + \bar{K} \leftrightarrow Y + \pi$$
$$\Rightarrow \quad Y + \bar{K} \leftrightarrow \Xi + \pi \quad Y + Y \leftrightarrow \Xi + N$$
$$\Rightarrow \quad \Xi + \bar{K} \leftrightarrow \Omega + \pi \quad \Xi + \Xi \leftrightarrow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

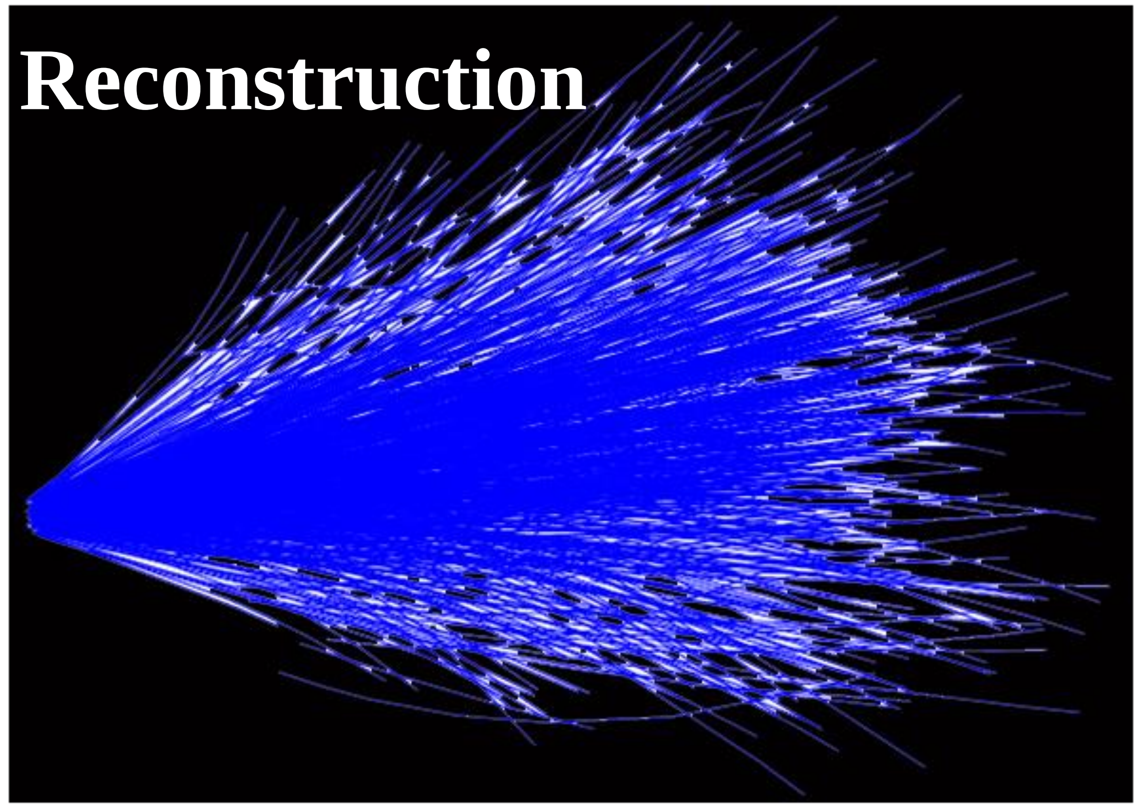
Chiral symmetry restoration (CSR) change the flavor decomposition – more s-sbar pairs produced.

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

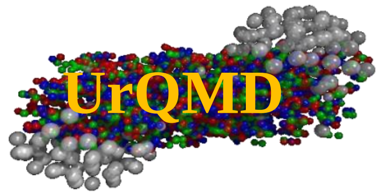
- Presence of QGP significantly increase yield of Ω^+ at FAIR energy
- CSR effect increase yield of Ω^- and Ω^+ at FAIR energy

Performance of the CBM track finder



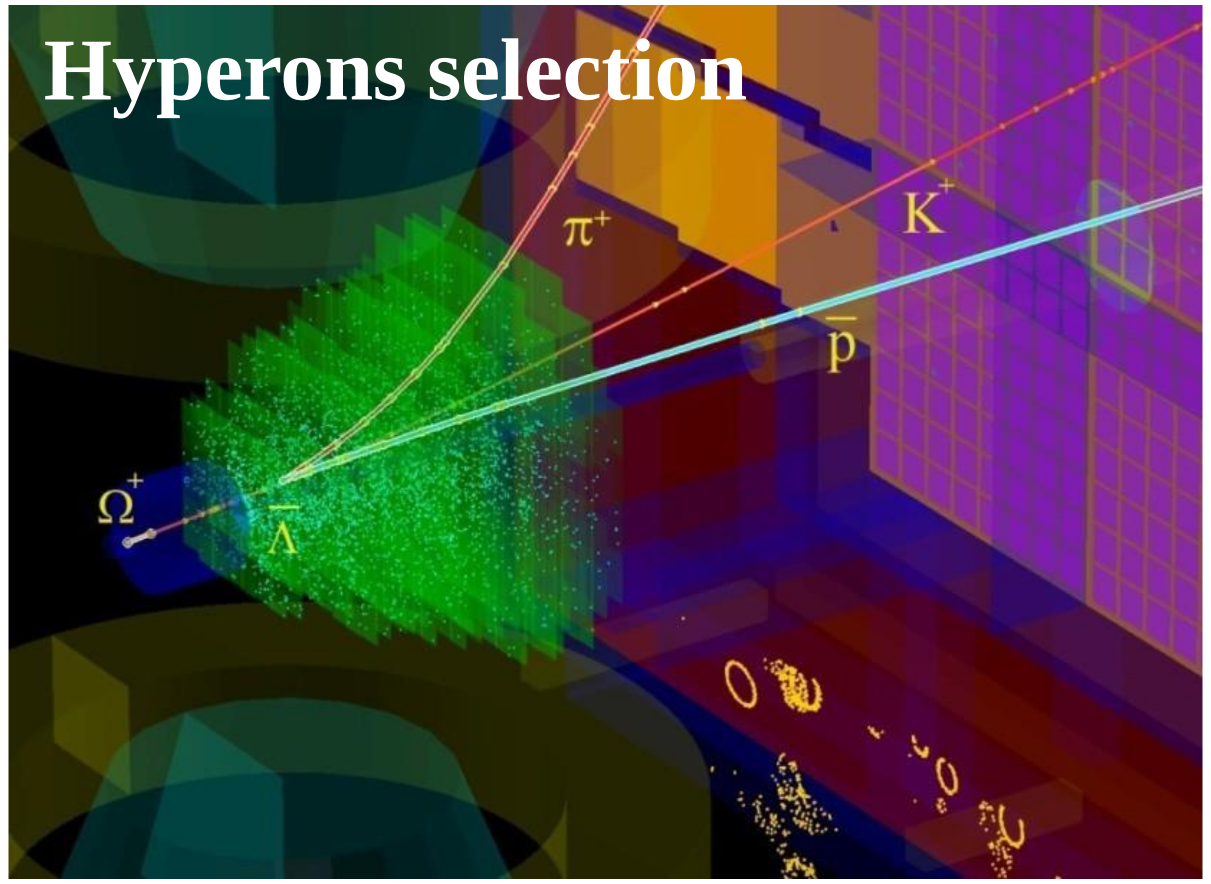


AuAu 10 AGeV/c
165 π
170 p
26 K
15 Λ
20 K_S^0
0.3 Ξ^-



PHSD

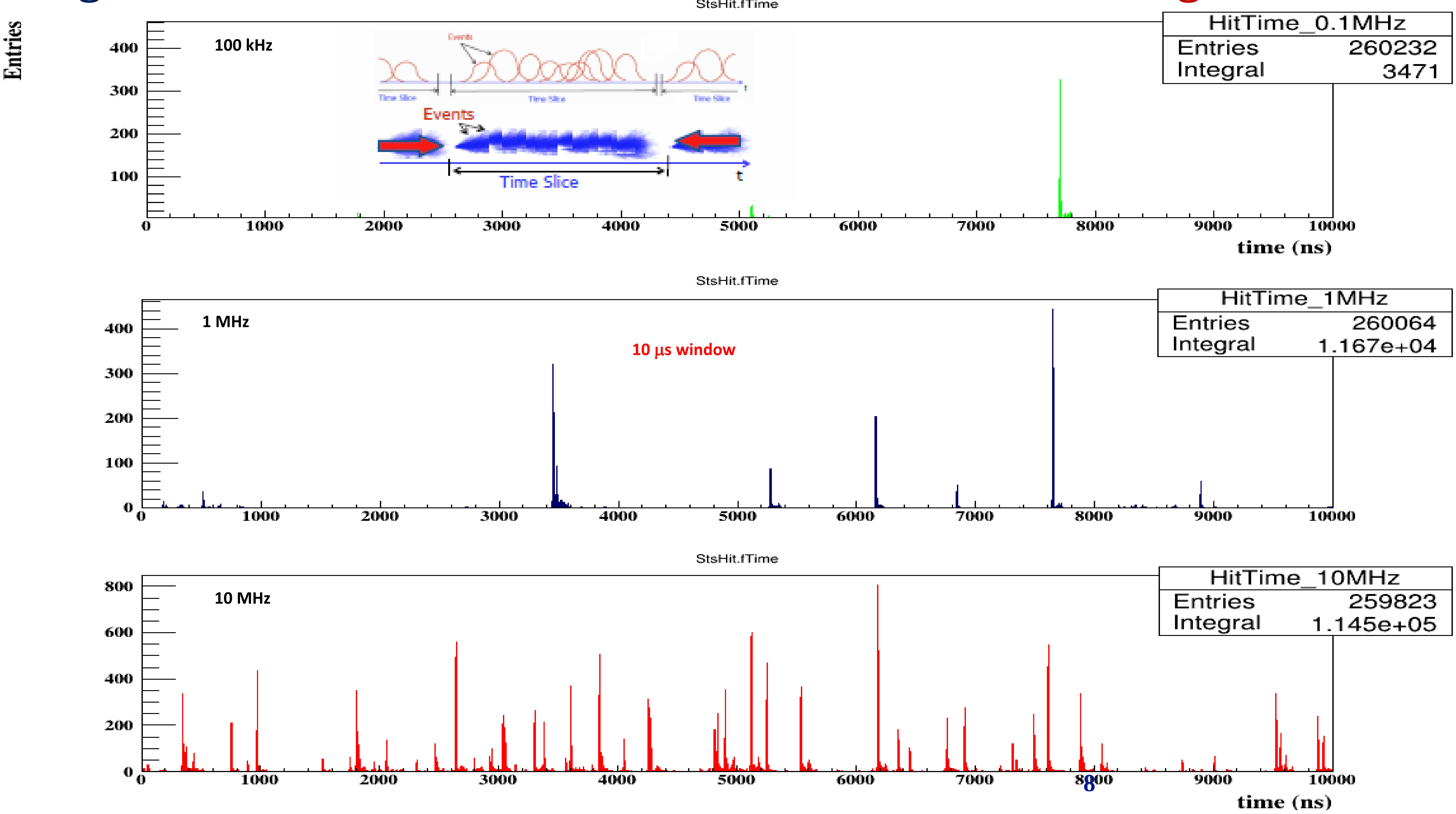
2 models



- 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: event reconstruction with 4D tracking



4D Track Finder in CBMROOT

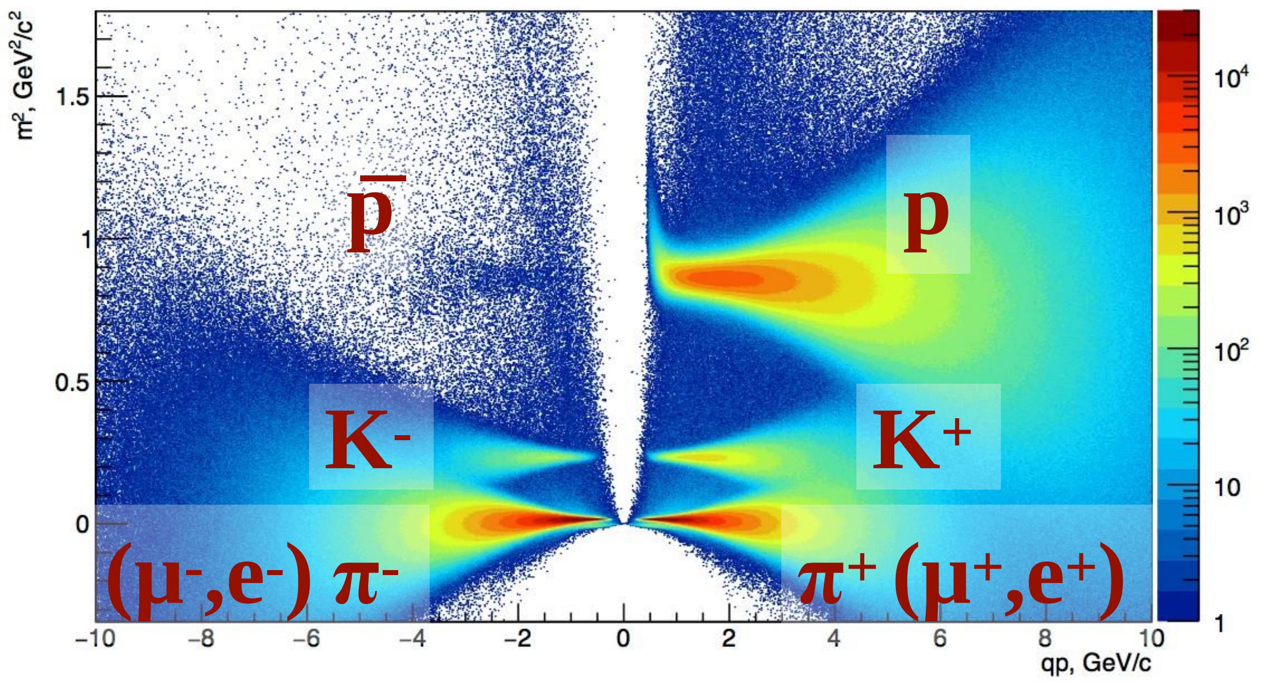
100 AuAu 10 AGeV mbias events

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

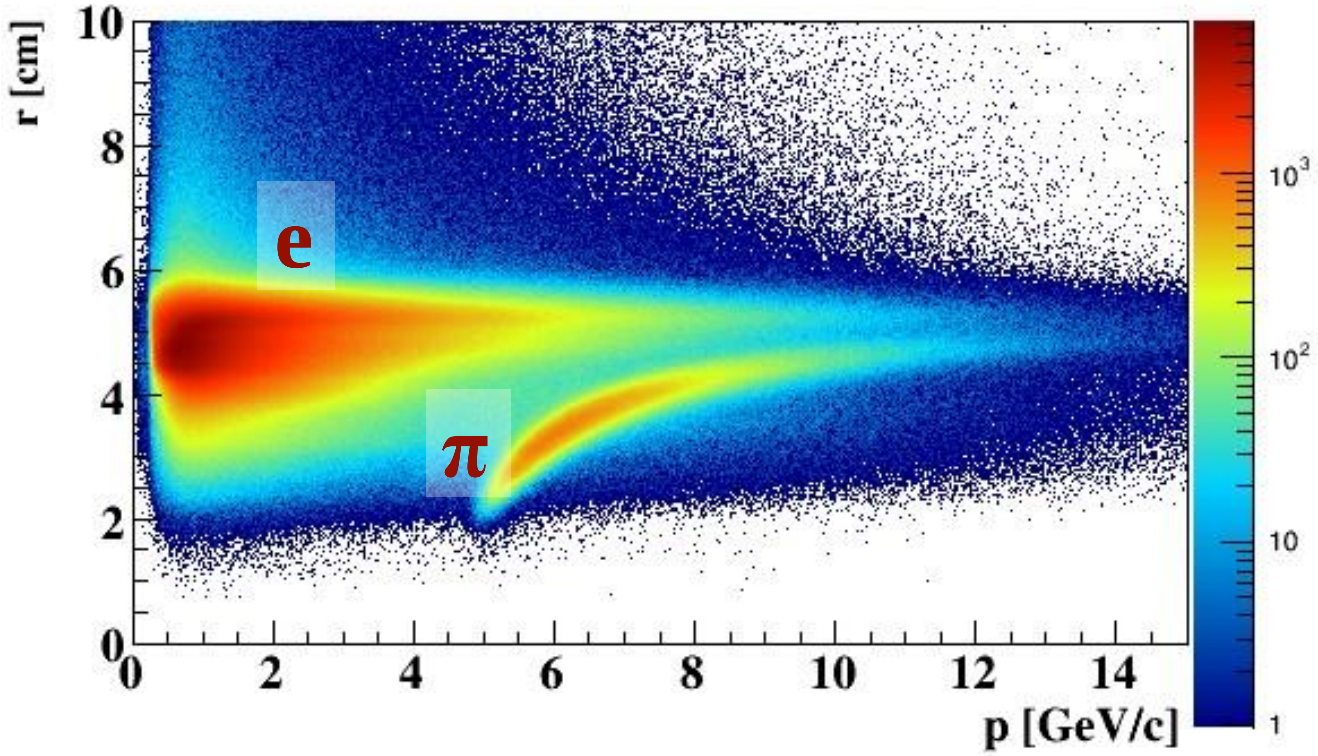
Timeslices from CBMROOT
Timebased digitisation, cluster and hit finder

Particle identification with PID detectors

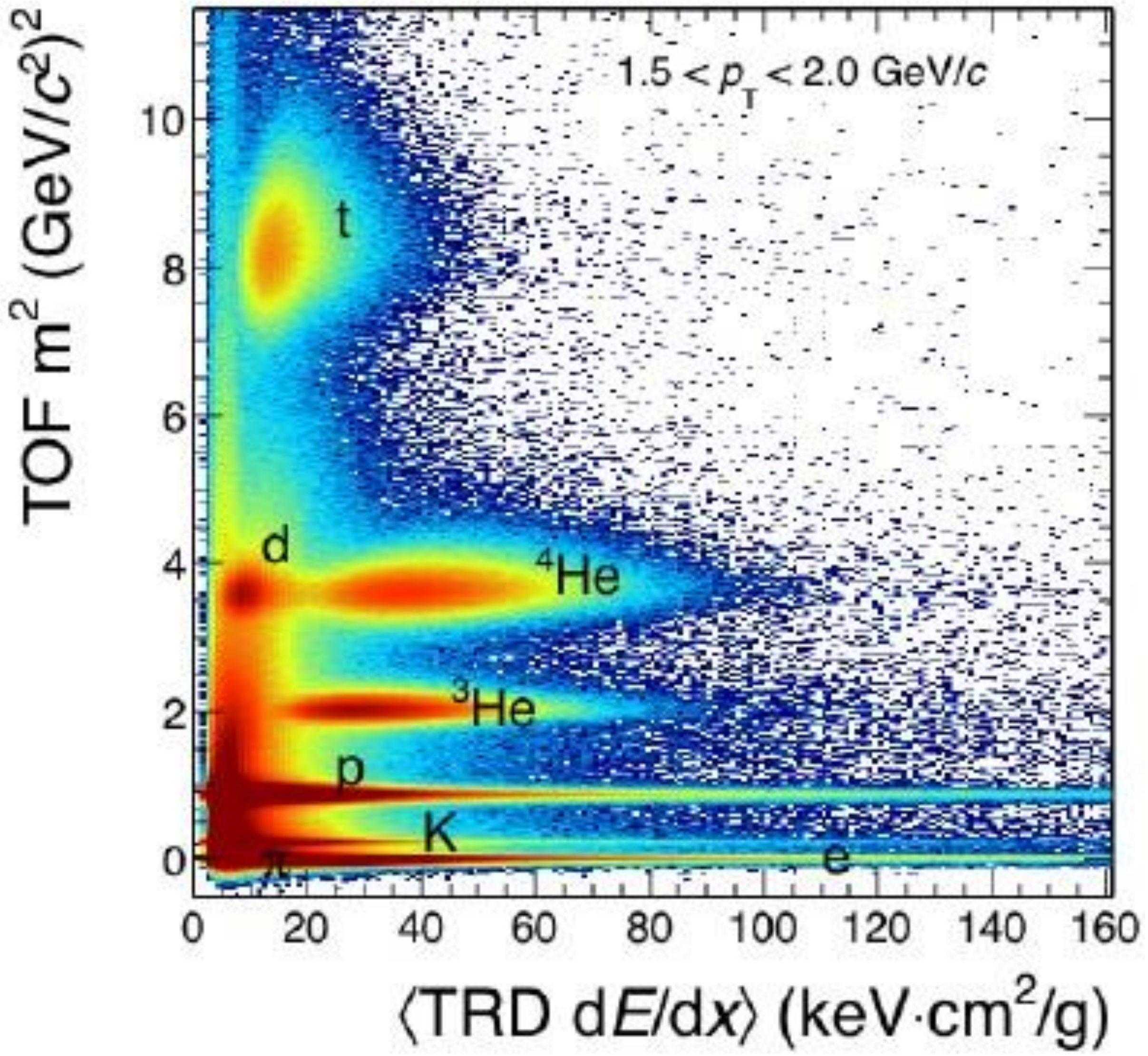
ToF: hadron identification



RICH: electron identification



TRD: d-He separation

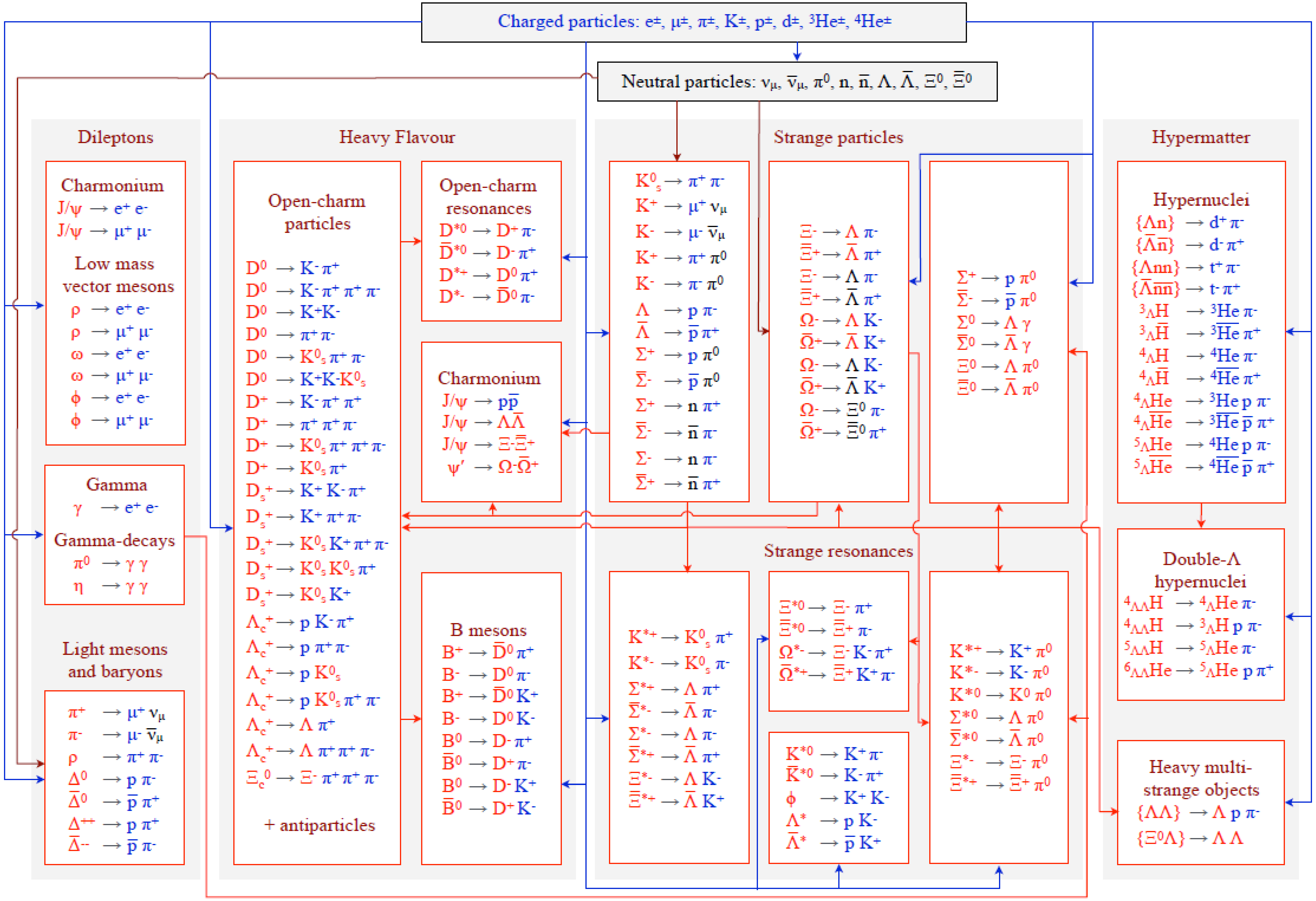


PID detectors:

- 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.

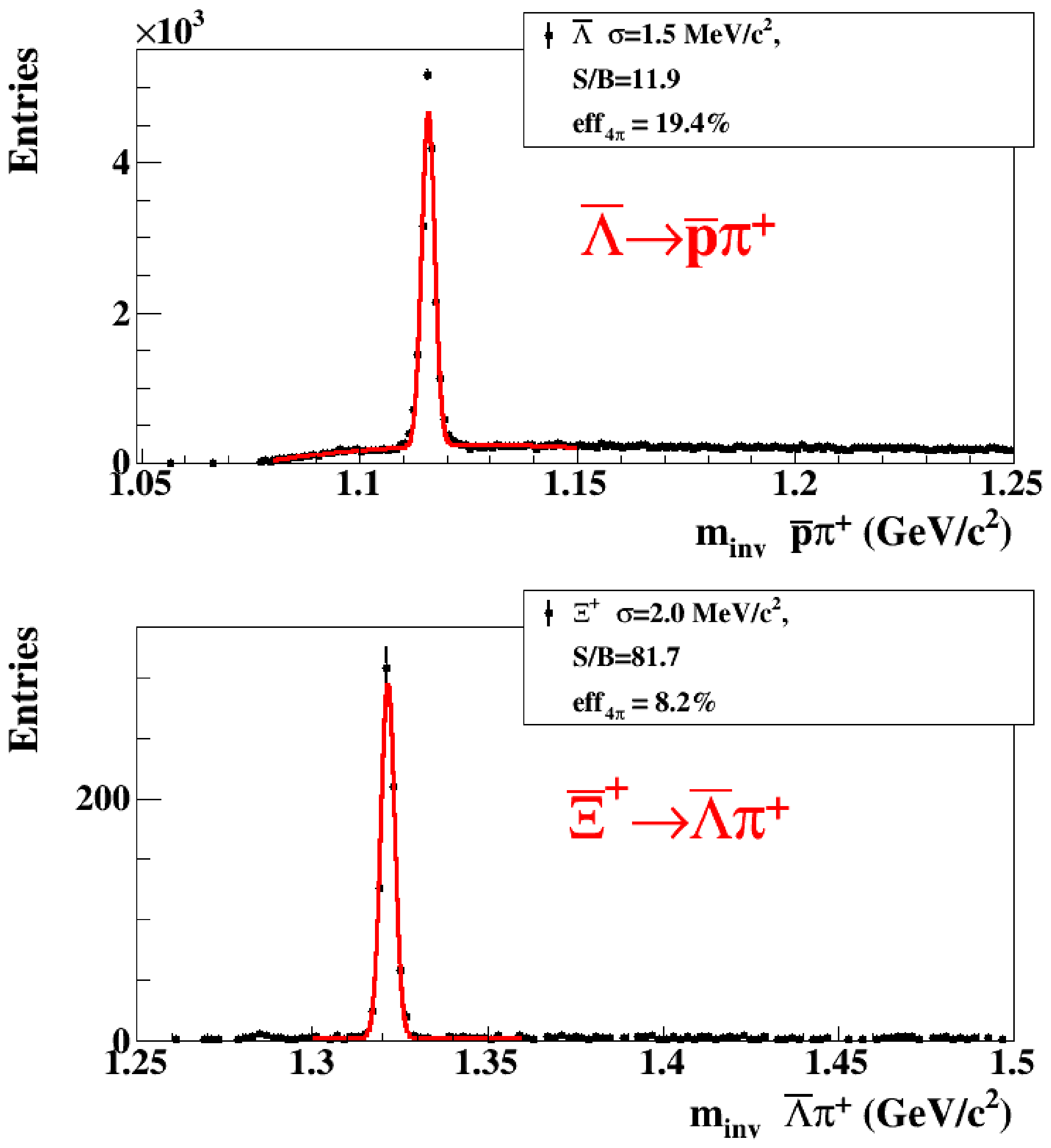
KF Particle Finder for the CBM Experiment

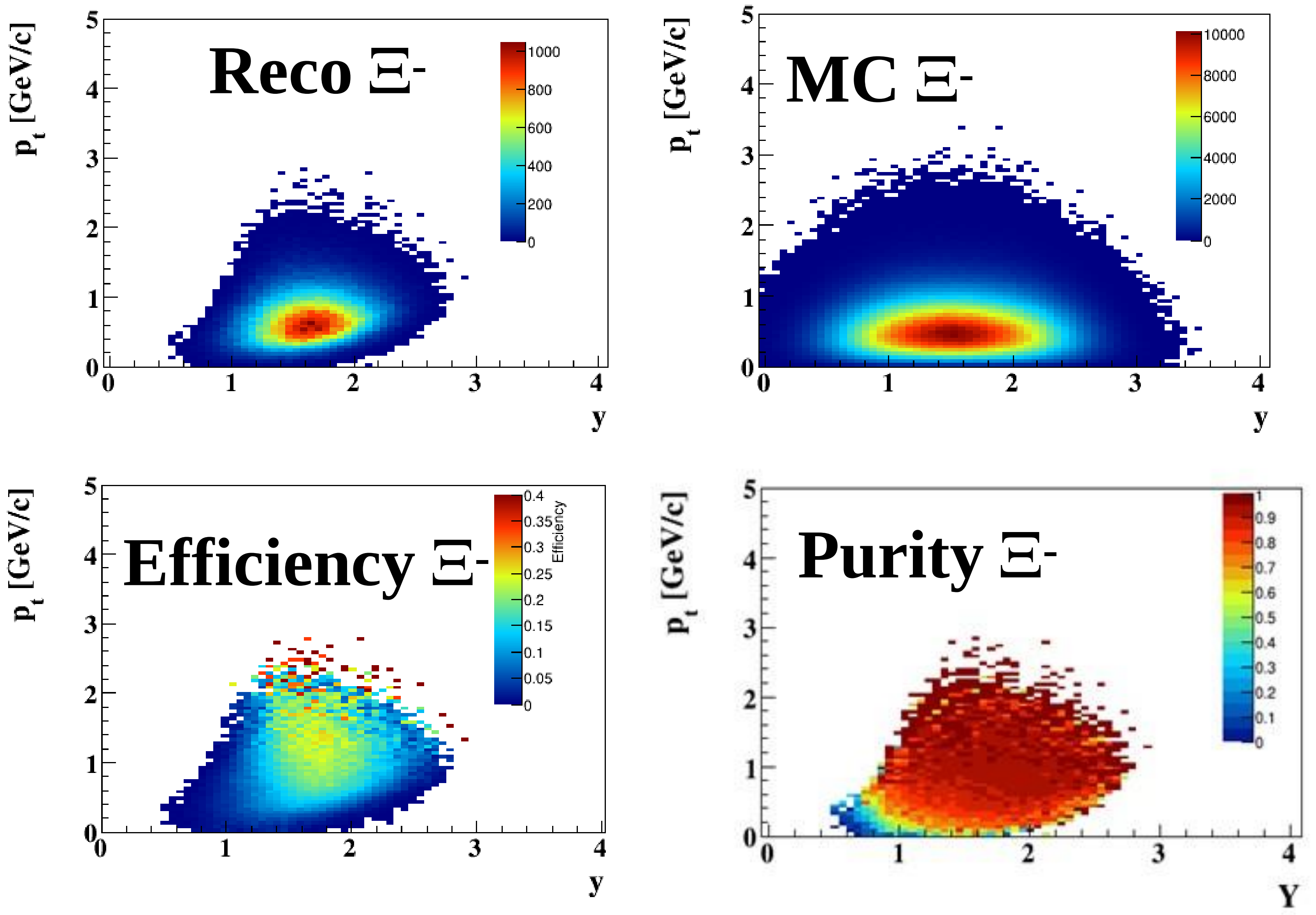


- More than 150 decays. All decays are reconstructed in one go.
- Based on the Kalman filter method - mathematically correct parameters and their errors.
- KF Particle Finder is successfully tested in STAR and allows to reconstruct up to 2 times more signal.
- STAR developments are fully merged with the KF Particle Finder repository.

Multi Strange particle reconstruction performance

5M central AuAu collisions 10AGeV/c

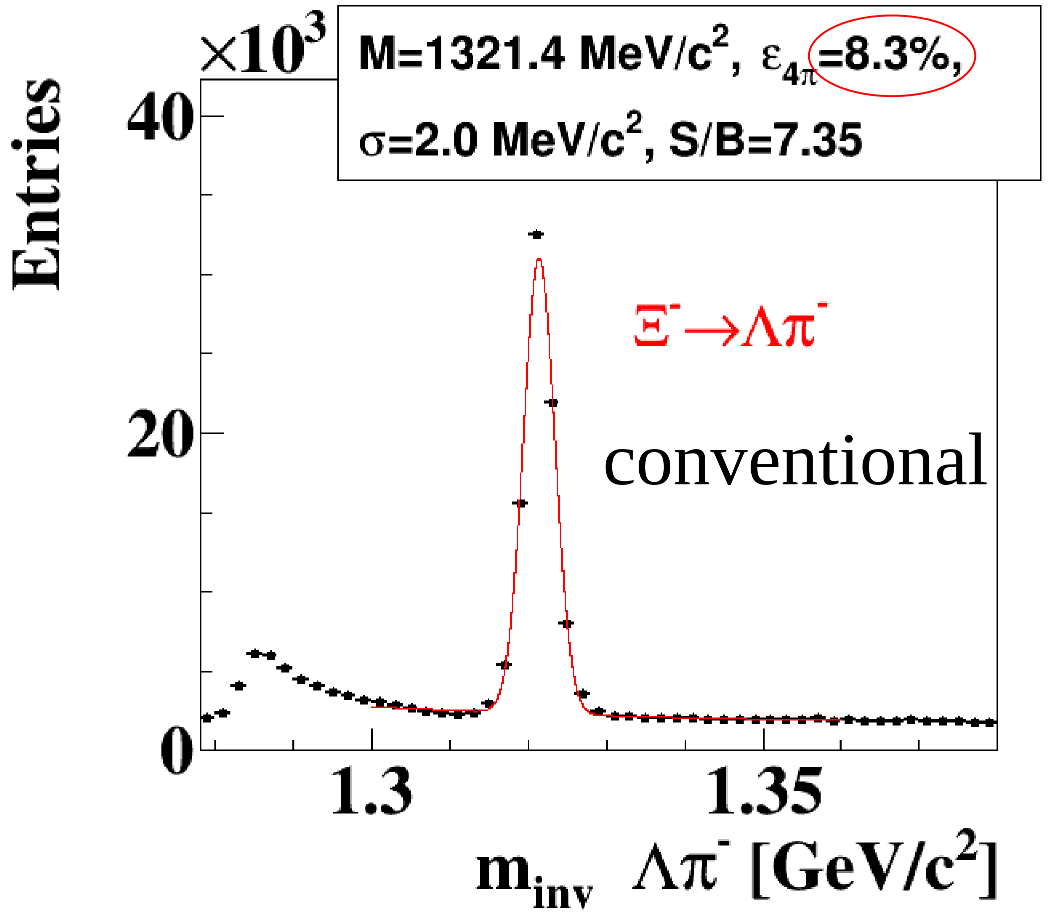


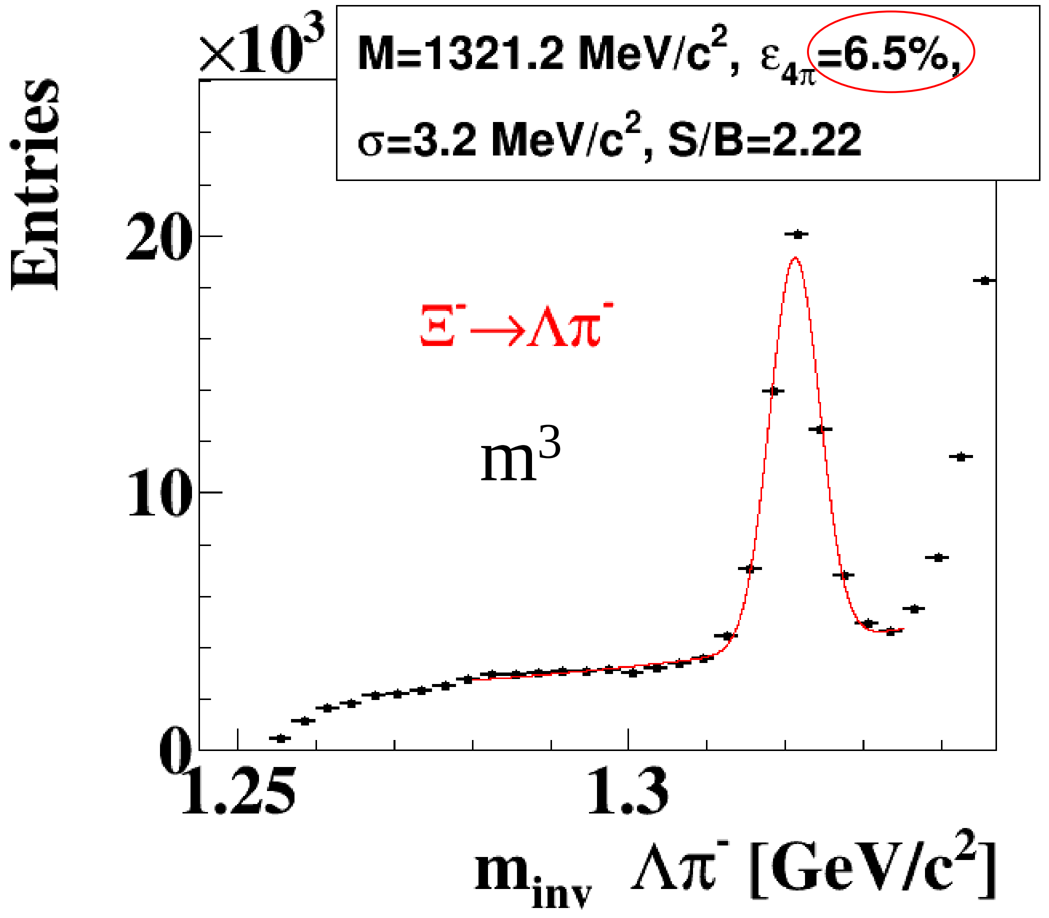


- CBM will allow clean reconstruction of **rare strange probes** with high efficiency and high statistics.
- Tools for the **multi-differential physics analysis** are prepared.

Multi strange hyperons reconstruction with missing mass method

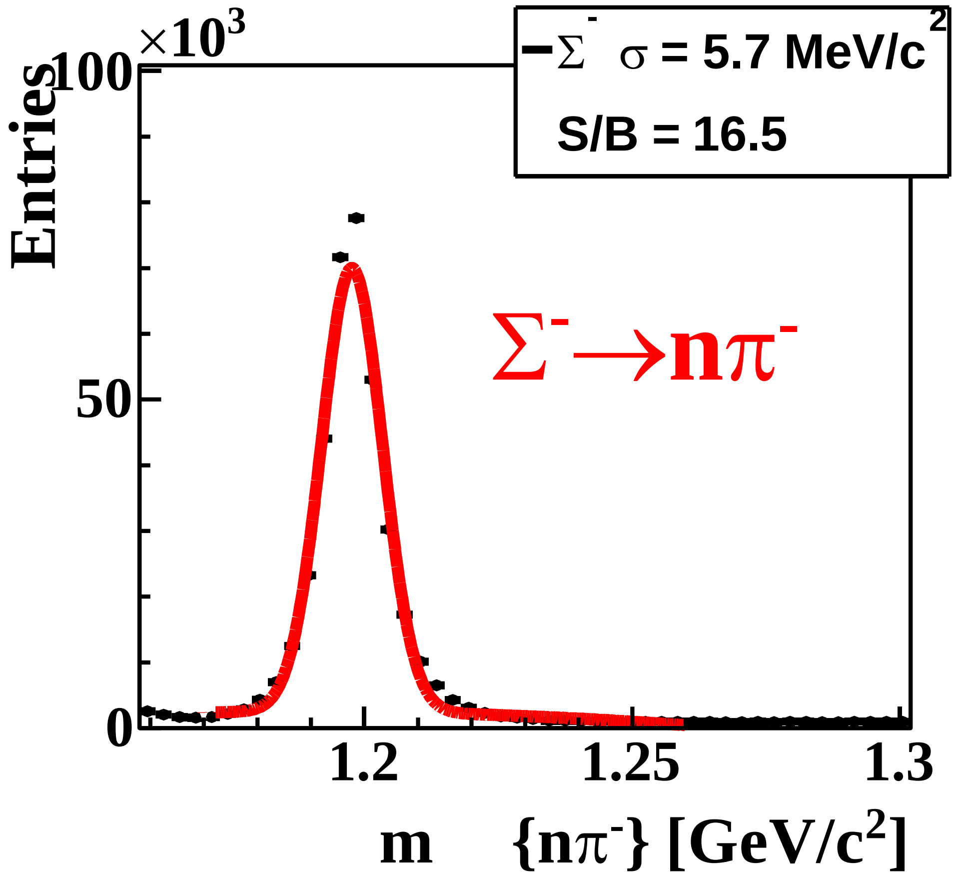
5M central AuAu collisions 10AGeV/c

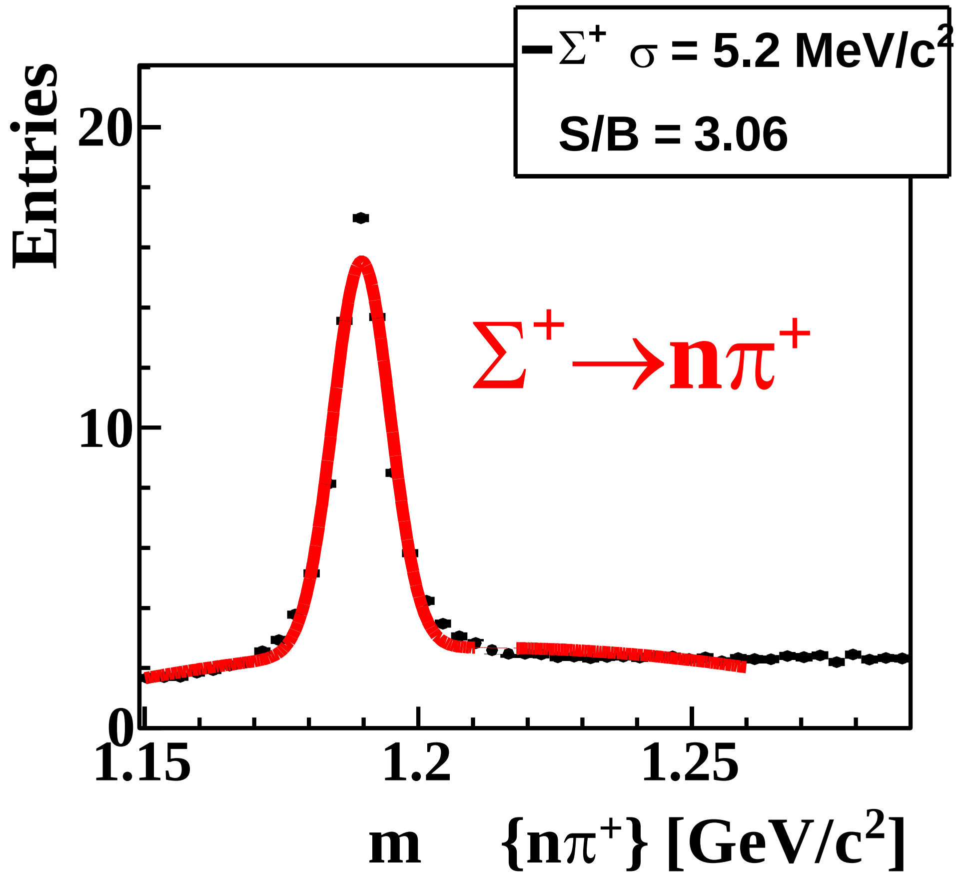


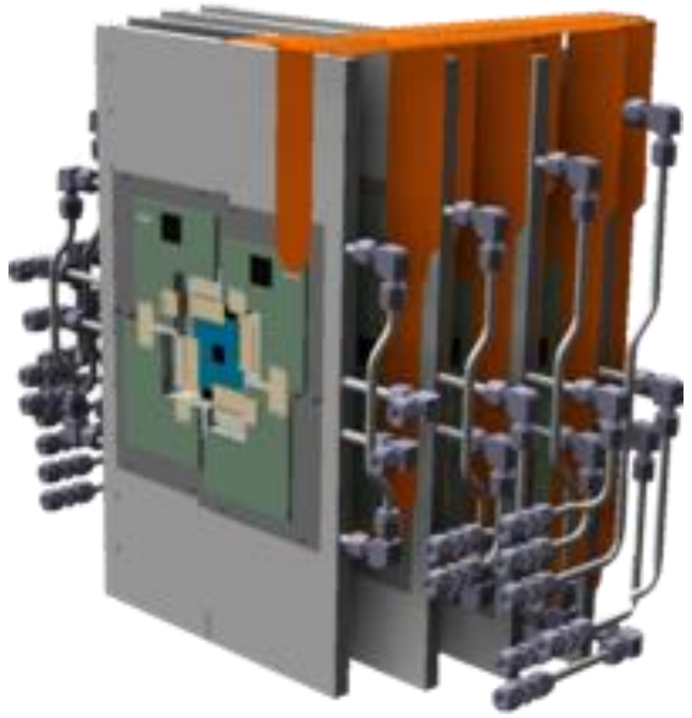


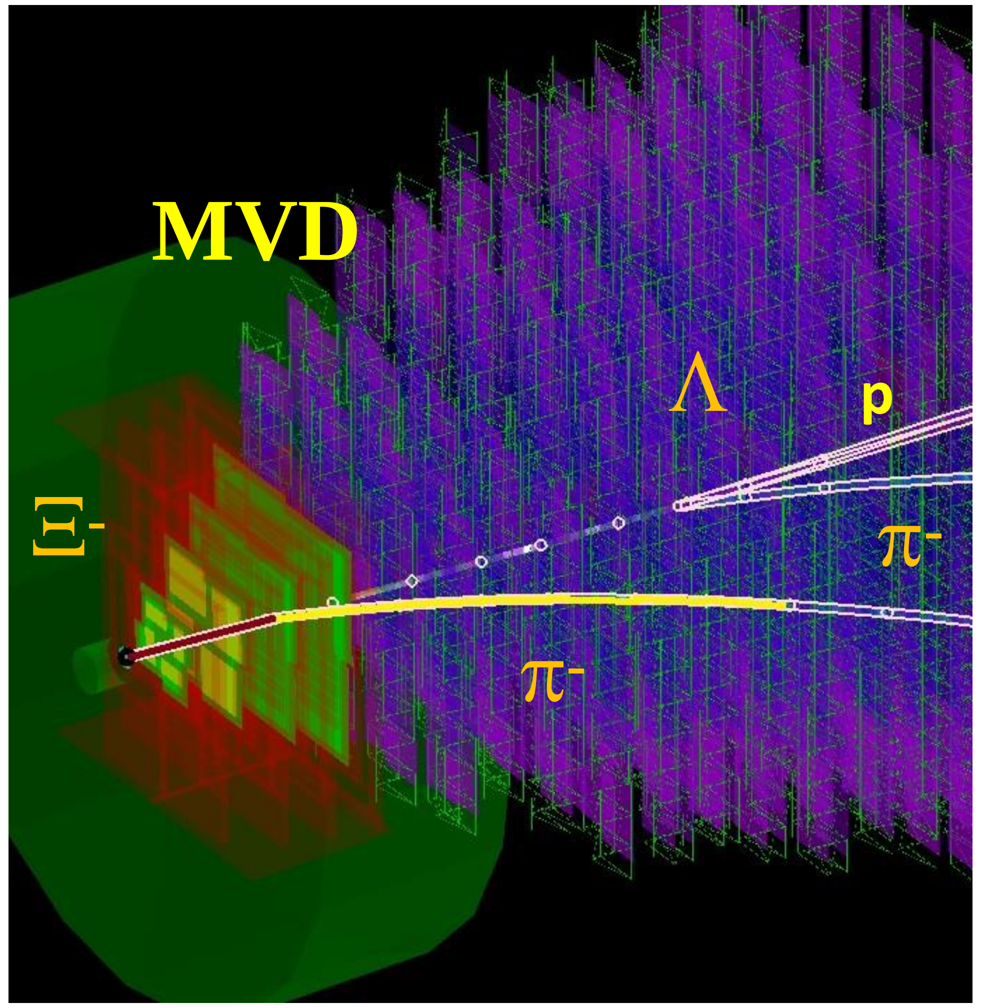
- Comparable efficiencies, better control over the systematic errors
- Σ+ and Σ- physics: completes the picture of strangeness production

$^{3}_{\Lambda}H \rightarrow {}^{3}He\,\pi^-$	$^{4}_{\Lambda}H \rightarrow {}^{4}He\,\pi^-$	$^{4}_{\Lambda}He \rightarrow {}^{3}He\,p\,\pi^-$
$d\,p\,\pi^-$	$t\,p\,\pi^-$	$d\,p\,p\,\pi^-$
$p\,p\,n\,\pi^-$	$d\,d\,\pi^-$	$p\,p\,p\,n\,\pi^-$
$t\,\pi^0$	$^{3}He\,n\,\pi^-$	$^{4}He\,\pi^0$
	$p\,p\,n\,\pi^-$	$d\,d\,\pi^0$
		$t\,p\,\pi^0$

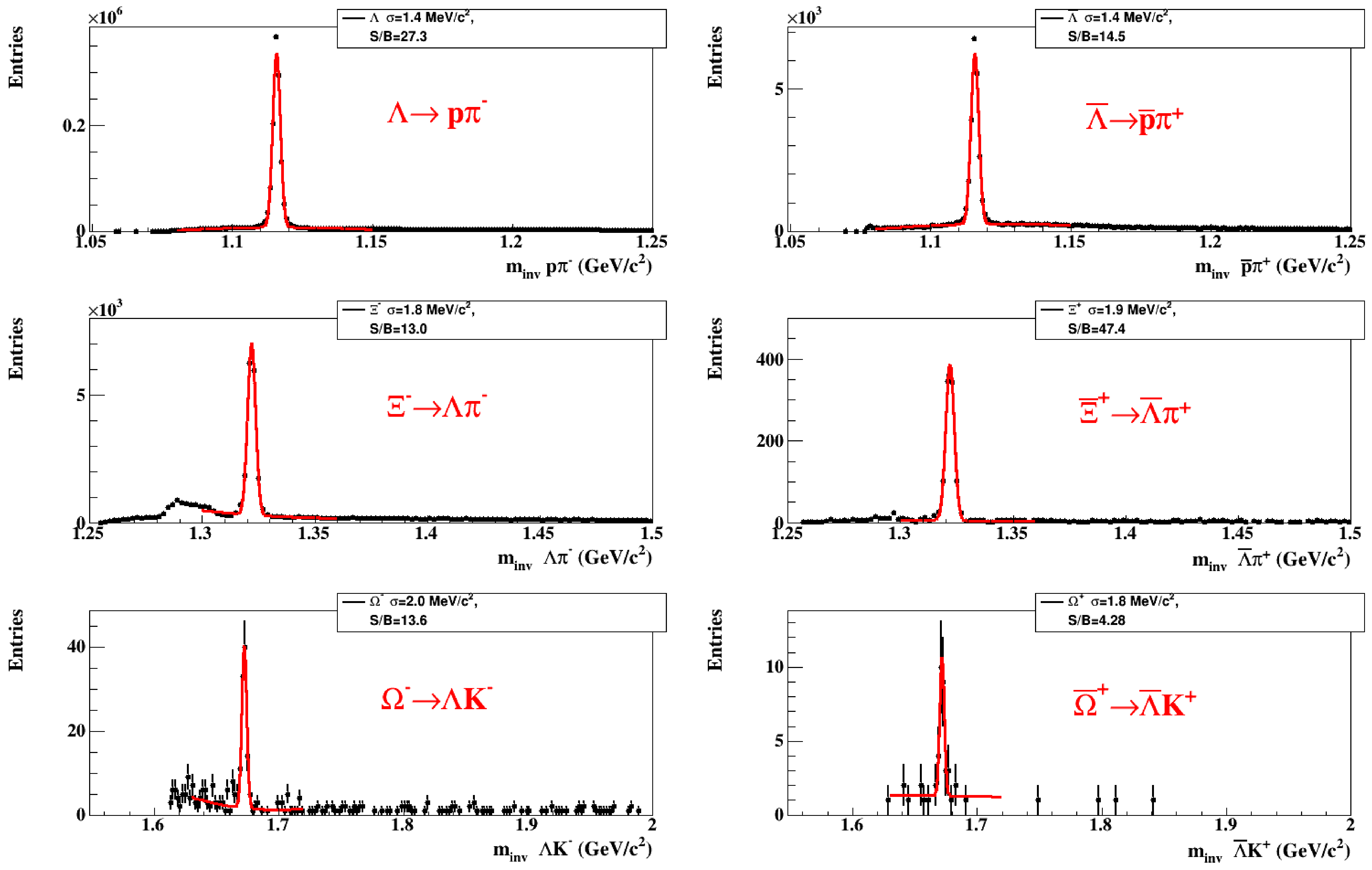




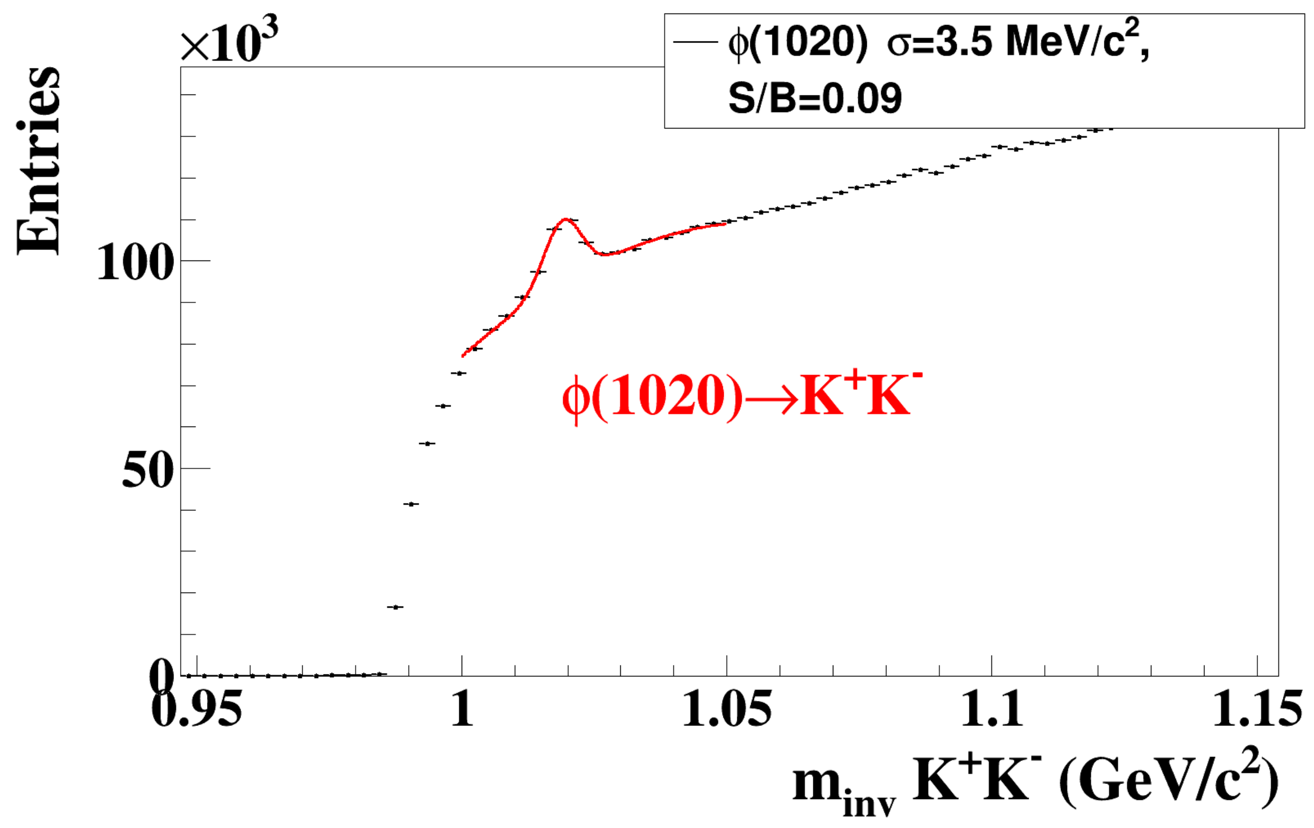




CBM KFParticle Finder test @ STAR 4.4M Au+Au events sqrt(s) = 7.7



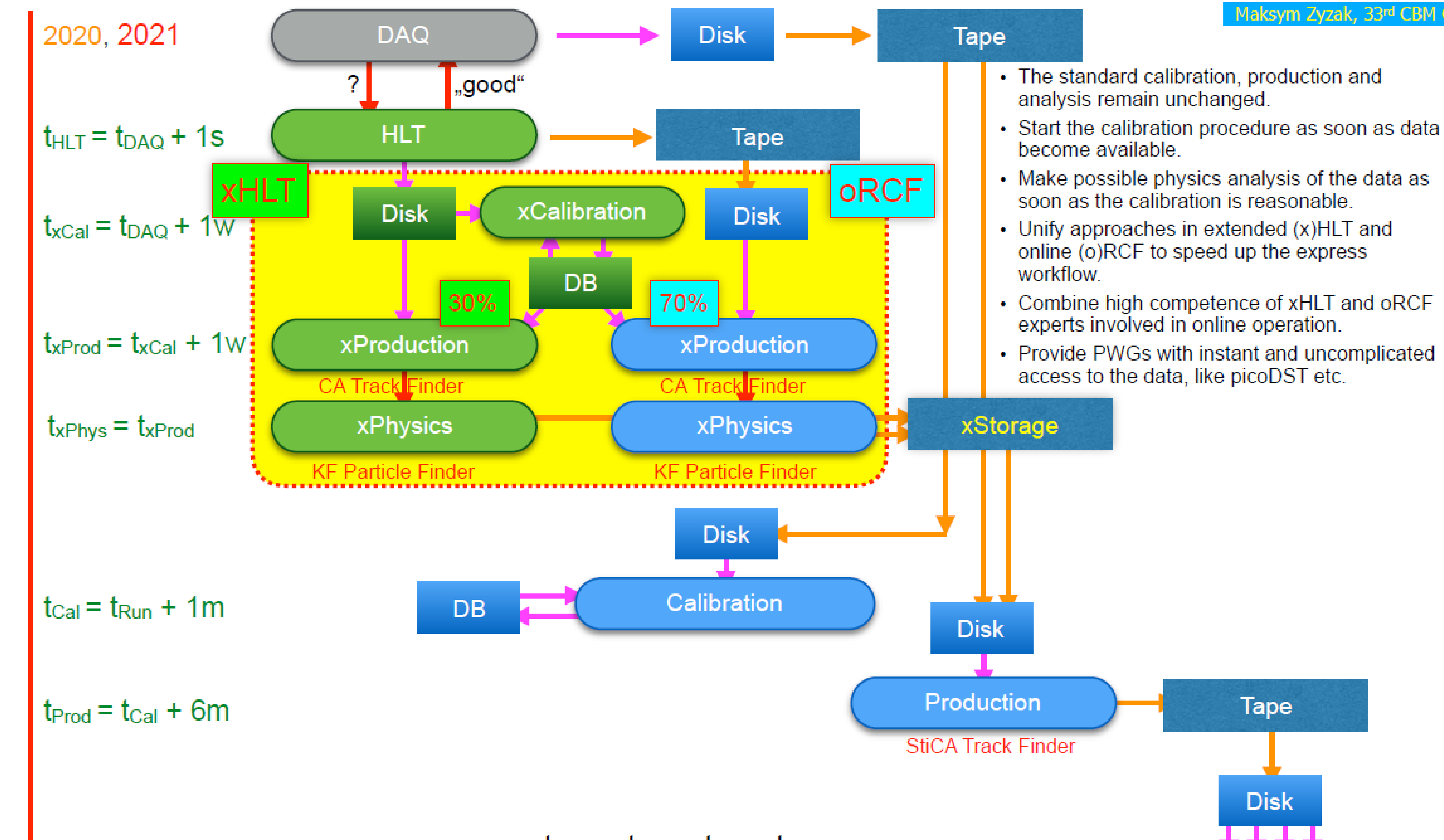
all centralities, no cuts on rapidity



- 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.

Testing CBM algorithms online: STAR express analysis

Maksym Zyzak, 33rd CBM Collaboration Meeting, Darmstadt



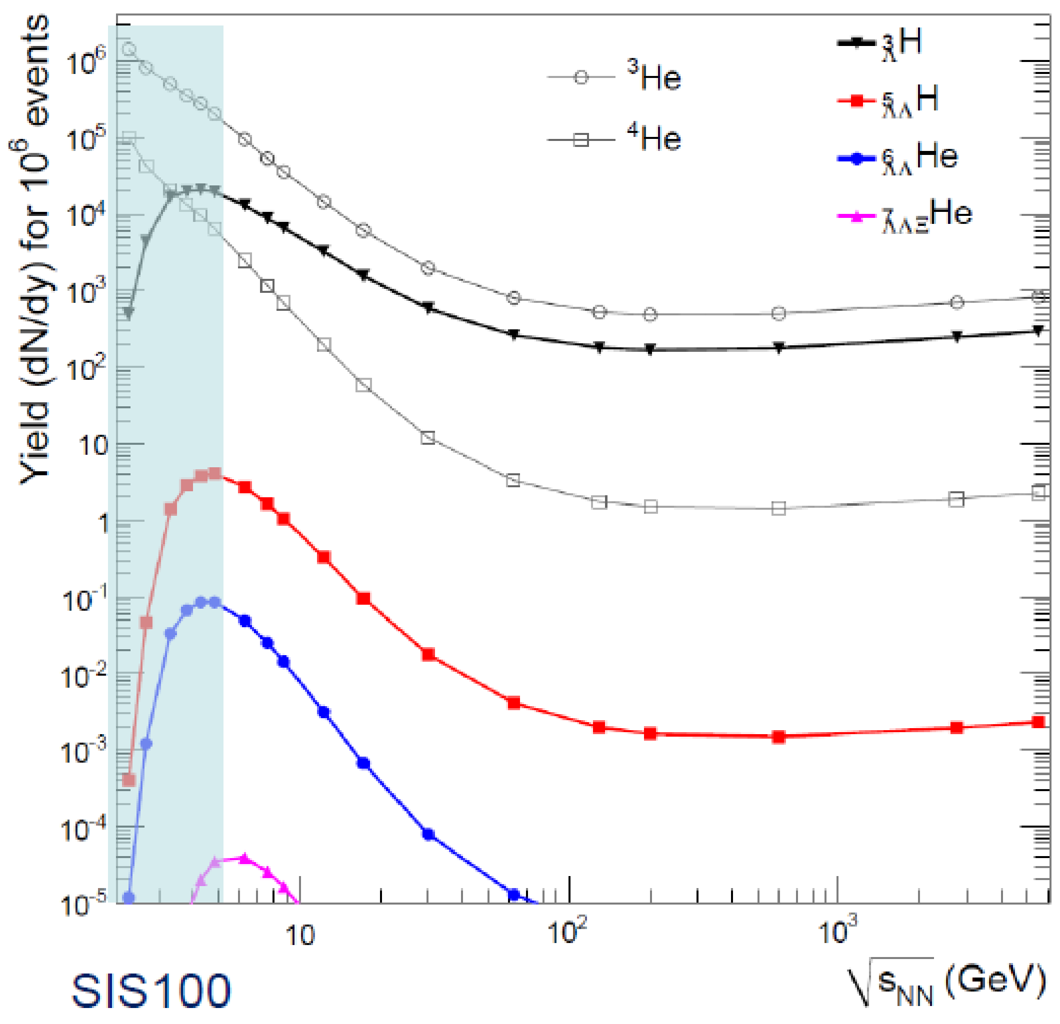
- The standard calibration, production and analysis remain unchanged.
- Start the calibration procedure as soon as data become available.
- Make possible physics analysis of the data as soon as the calibration is reasonable.
- Unify approaches in extended (x)HLT and online (o)RCF to speed up the express workflow.
- Combine high competence of xHLT and oRCF experts involved in online operation.
- Provide PWGs with instant and uncomplicated access to the data, like picoDST etc.

t_{Run} t_{Cal} t_{Prod} t_{Phys}

t^{BES-II} = 2021 + 6 m + 1 m + 6 m + 6 m = 1÷2 y = 2021÷2022

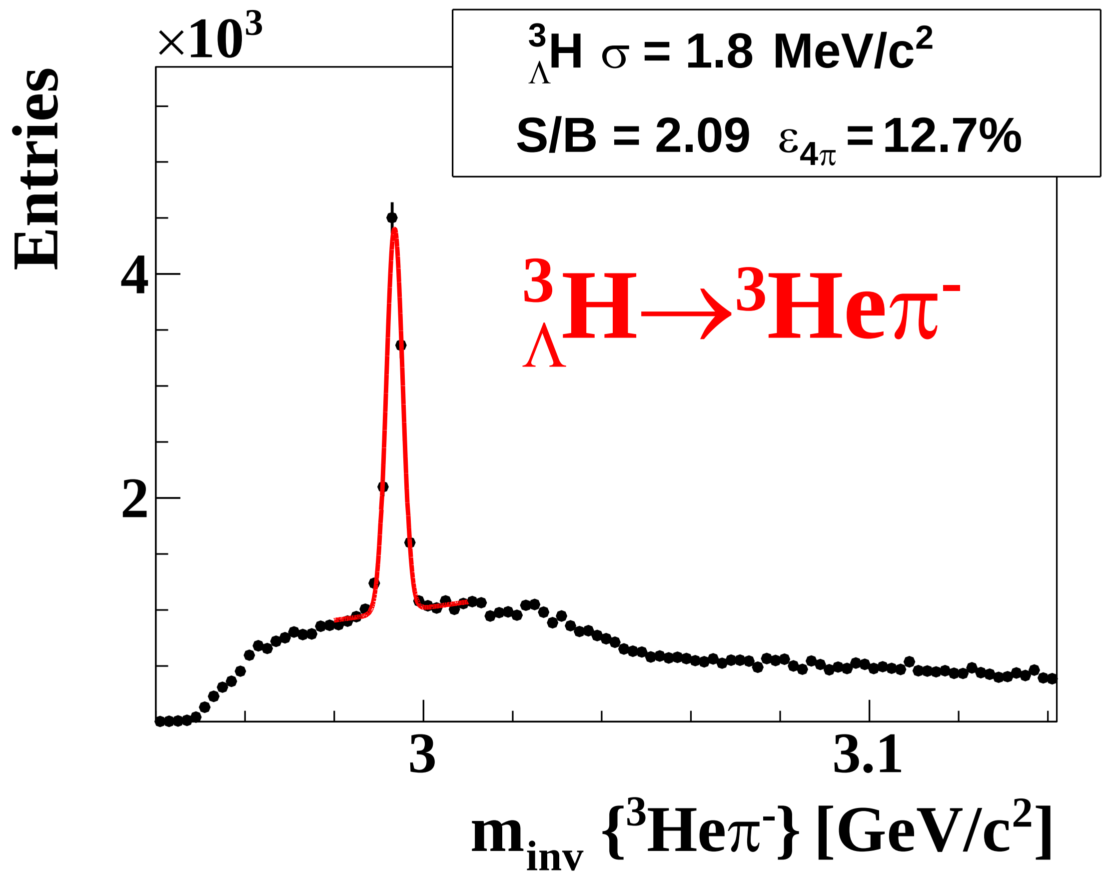
t_{BES-II} = 2021 + 6 m + 2 m + 1 y + 1 y = 2÷3 y = 2023÷2024

Hypernuclei production in A+A collisions

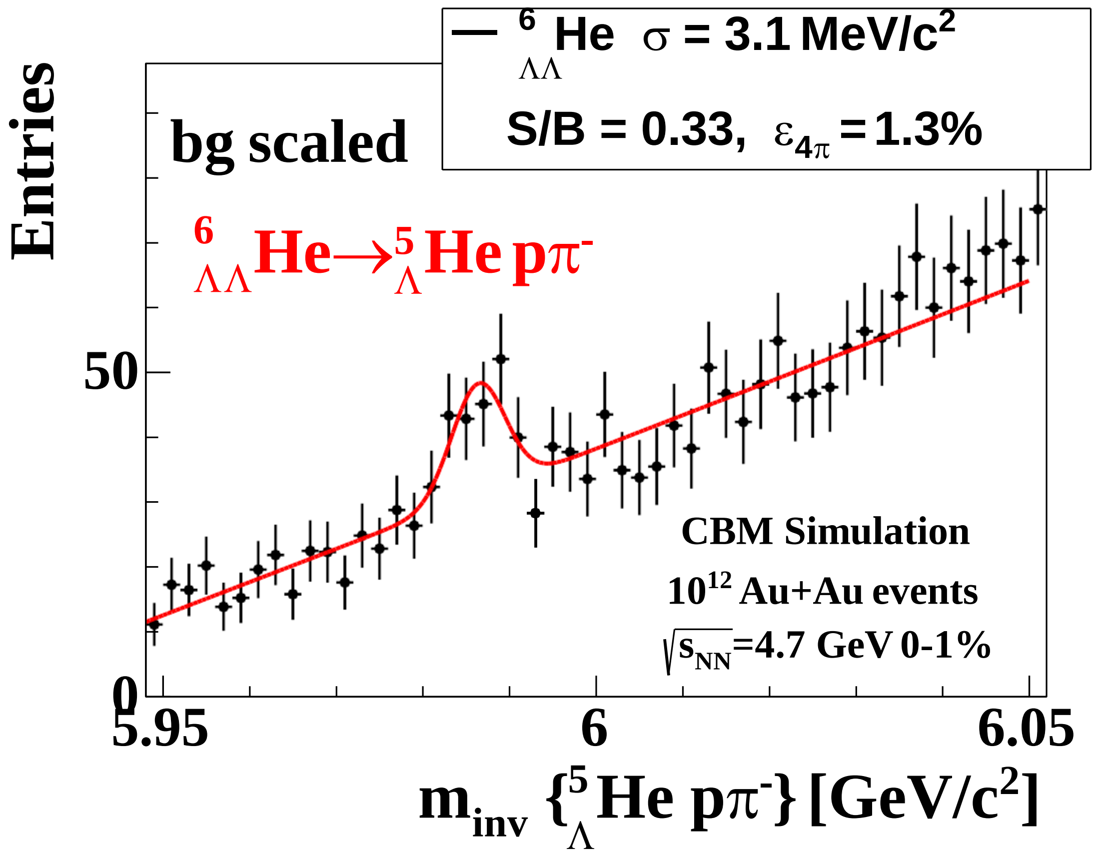


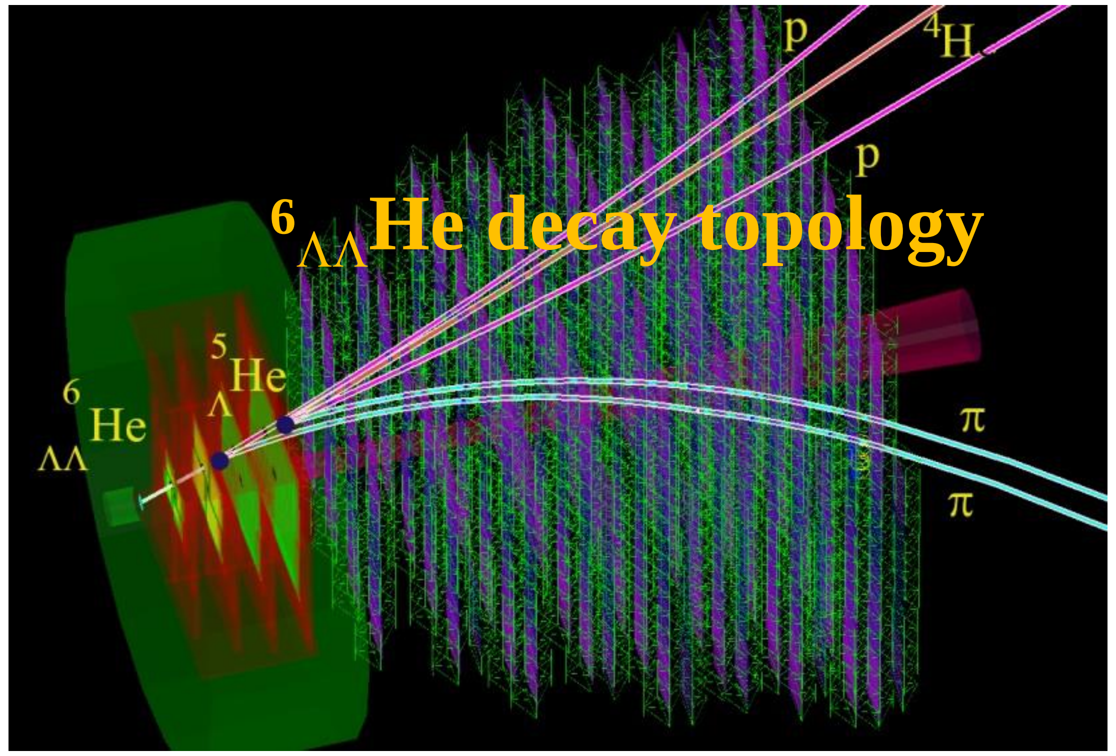
A. Andronic et al., Phys. Lett. B697 (2011) 203

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.

Day-1: 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)	$5.1 \cdot 10^{-3}$	0.041	$\bar{p}\pi^+$	0.64	19.7	$1.2 \cdot 10^{8}$	$1.0 \cdot 10^{9}$	**0.1**
Ξ^- (1321)	0.11	0.36	$\Lambda\pi^-$	1	9.9	$2.0 \cdot 10^{9}$	$7.0 \cdot 10^{9}$	**0.1**
Ξ^+ (1321)	$1.8 \cdot 10^{-3}$	$1.5 \cdot 10^{-2}$	$\bar{\Lambda}\pi^+$	1	8.7	$3.0 \cdot 10^{7}$	$2.5 \cdot 10^{8}$	**0.1**
Ω^- (1672)	$6.8 \cdot 10^{-4}$	$4.4 \cdot 10^{-3}$	ΛK^-	0.68	4.4	$4.0 \cdot 10^{6}$	$2.6 \cdot 10^{7}$	**0.1**
Ω^+ (1672)	$1.4 \cdot 10^{-5}$	$2.6 \cdot 10^{-3}$	$\bar{\Lambda} K^+$	0.68	3.9	$7.0 \cdot 10^{4}$ (0 w/o QGP?)	$1.4 \cdot 10^{7}$	**0.1**
$^{3}_{\Lambda}H$ (2993)	$4.2 \cdot 10^{-2}$	$3.8 \cdot 10^{-2}$	$^{3}He\pi^-$	0.25	12.7	$2.7 \cdot 10^{8}$	$2.5 \cdot 10^{8}$	**0.1**
$^{4}_{\Lambda}He$ (3930)	$2.4 \cdot 10^{-3}$	$1.9 \cdot 10^{-3}$	$^{3}Hep\pi^-$	0.32	11.4	$1.7 \cdot 10^{7}$	$1.4 \cdot 10^{7}$	**0.1**
$^{5}_{\Lambda\Lambda}He$(5047)		$5.0 \cdot 10^{-6}$	$^{3}He2p2\pi$	0.01	3	15	250	**0.1**
$^{6}_{\Lambda\Lambda}He$(5986)		$1.0 \cdot 10^{-7}$	$^{4}He2p2\pi$	0.01	1.2			**0.1**

Summary

- CBM detector is an excellent device 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.