Seminar of the MPD Collaboration
26 September 2019

Current status of hyperon reconstruction and analysis at MPD/NICA

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for the MPD collaboration VBLHEP, JINR, Dubna, Russia

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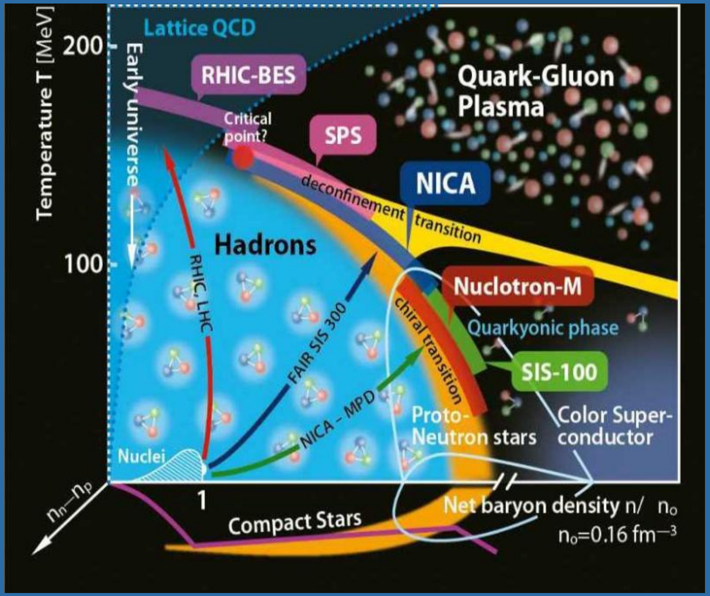
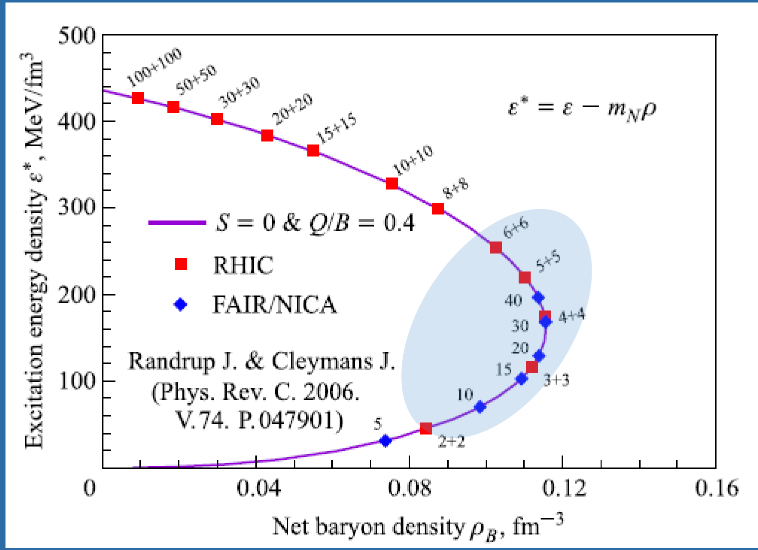
the Russian Foundation for Basic Research (RFBR):
grant No. 18-02-40060.

Outline

- MPD/NICA project:
  niche, tasks and observables
- Detector performance:
  geometry, tracking and particle identification
- Hyperon analysis in minimum bias PHSD events:
  signals, phase space, pT-slices and pT-spectra
- Hyperon reconstruction in central UrQMD events:
  new selection cut, signals, efficiency
- Summary

NICA niche for A+A collisions

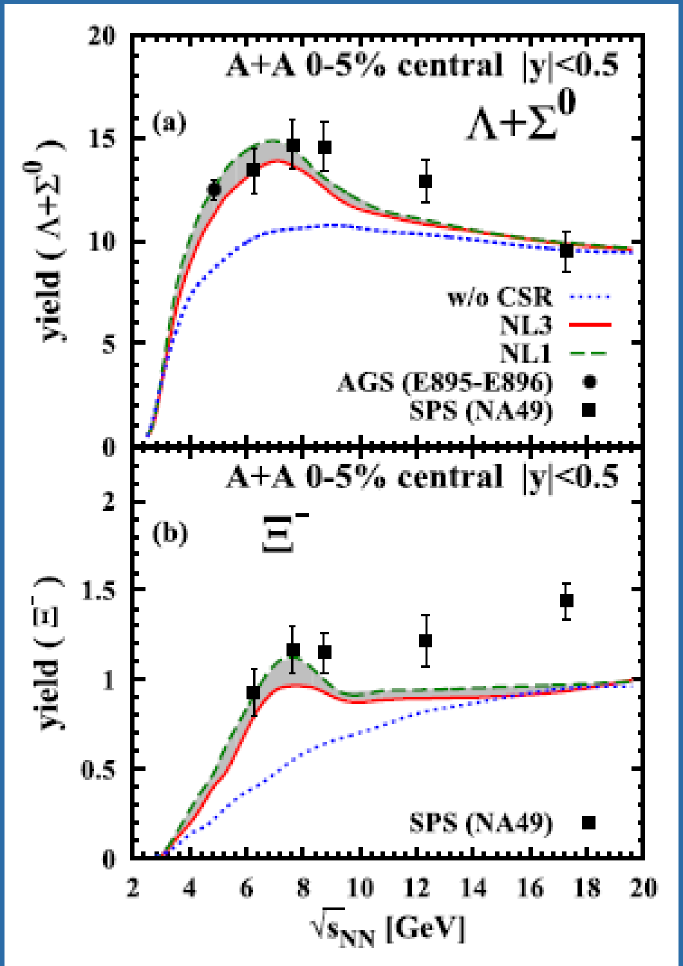




QCD matter under extreme conditions

(NICA niche – high μ_B)

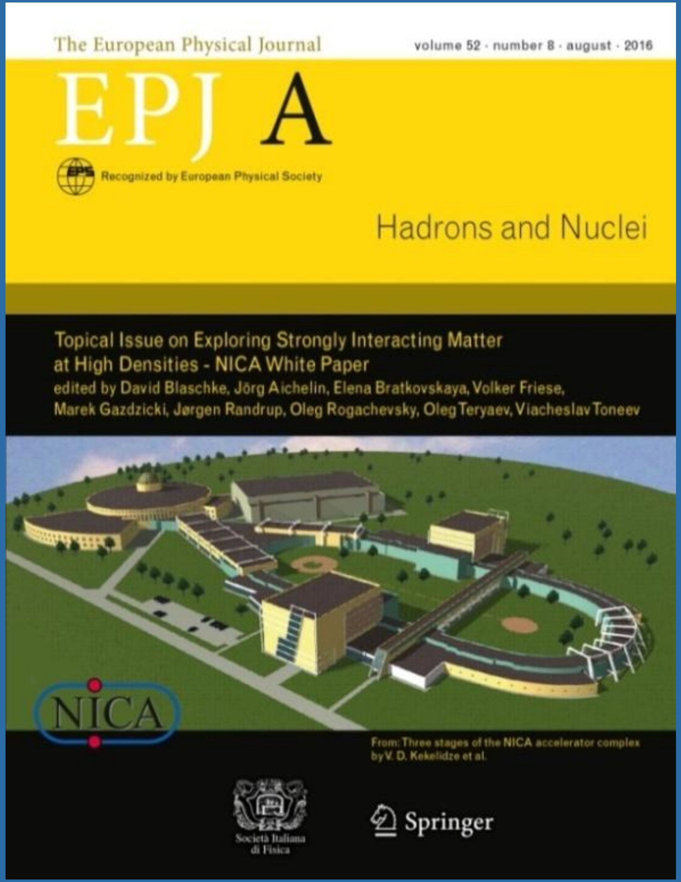
PRC 94, 044912 (2016)



- NICA (μB = [320-850] MeV) - highest net baryon density: essential to probe deconfinement and CSR
- Non-trivial energy dependence of multiple probes: strangeness production, flow, hyperon polarization
- High luminosity guarantees sufficient event rate for rare probes (hypernuclei and multistrangeness)

NICA/MPD physics. Tasks and Observables

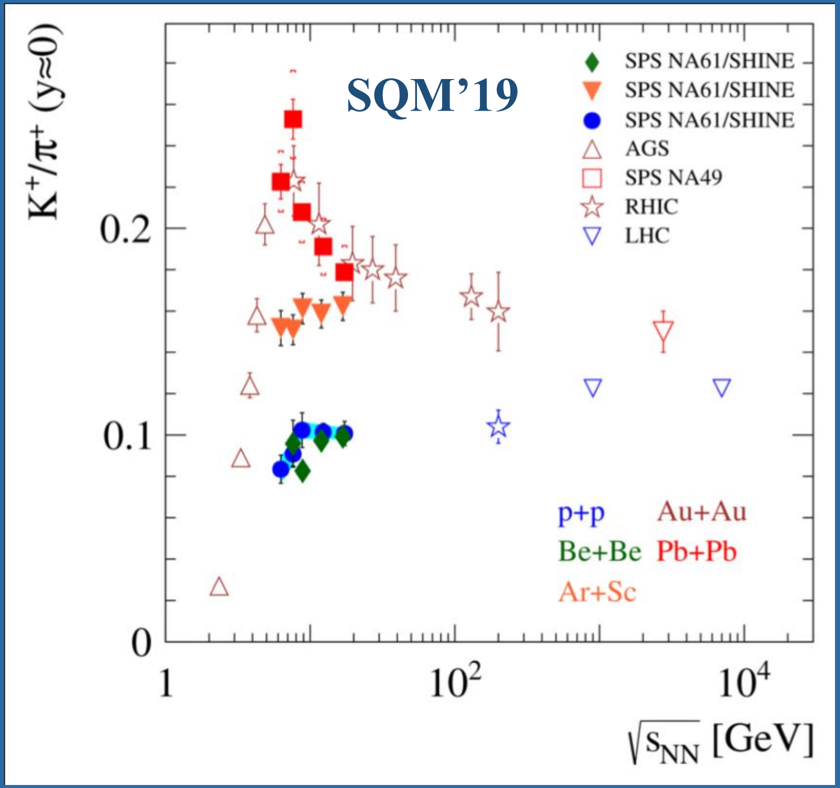
Experimental strategy: energy and system size scan to measure a variety of signals systematically changing collision parameters (energy, centrality, system size). Reference data (i.e. *p*+*p*) will be taken in the same experimental conditions



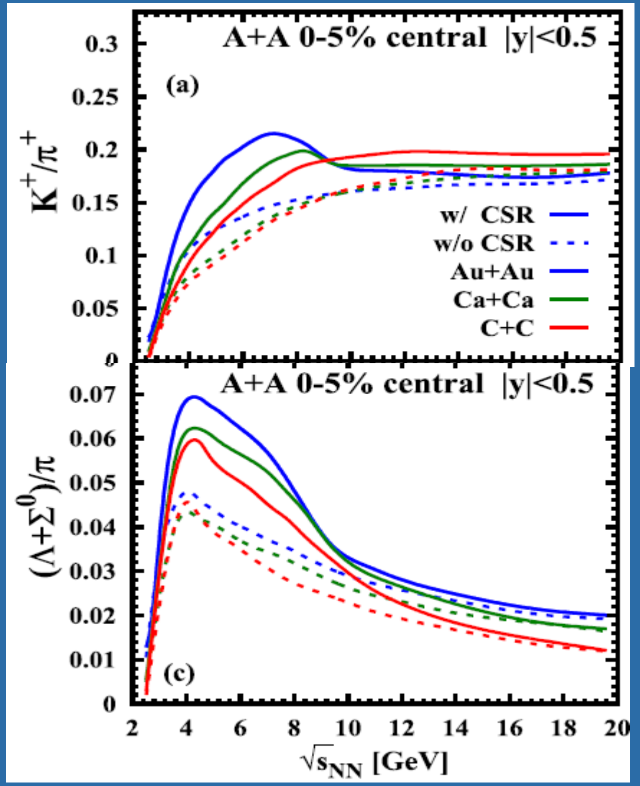
- *Bulk properties, EOS*
  particle yields & spectra, ratios, femtoscopy, flow
- *In-Medium modification of hadron properties*
  dileptons and resonances
- *Deconfinement (chiral) phase transition at high* r_B
  strangeness, Chiral Magnetic (Vortical) effect
- *QCD Critical Point*
  event-by-event fluctuations and correlations
- *YN, YY interactions in nuclear matter*
  hypernuclei

NICA/MPD physics cases: strangeness

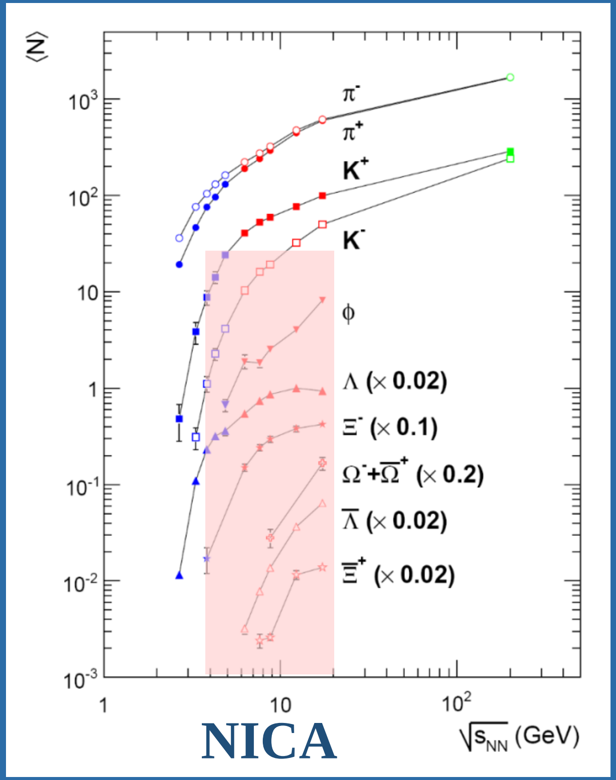
- Excitation function of hadrons, including strangeness (yields, spectra, and ratios)
- Nuclear matter EOS, in-medium effects, and chemical equilibration can be probed
- Hyperons sensitive to early stage and phase transformations in QCD medium
- Non-monotonic strangeness-to-entropy ratio seen in heaviest systems (phase transformation?)



System size of the energy dependence is not fully understood



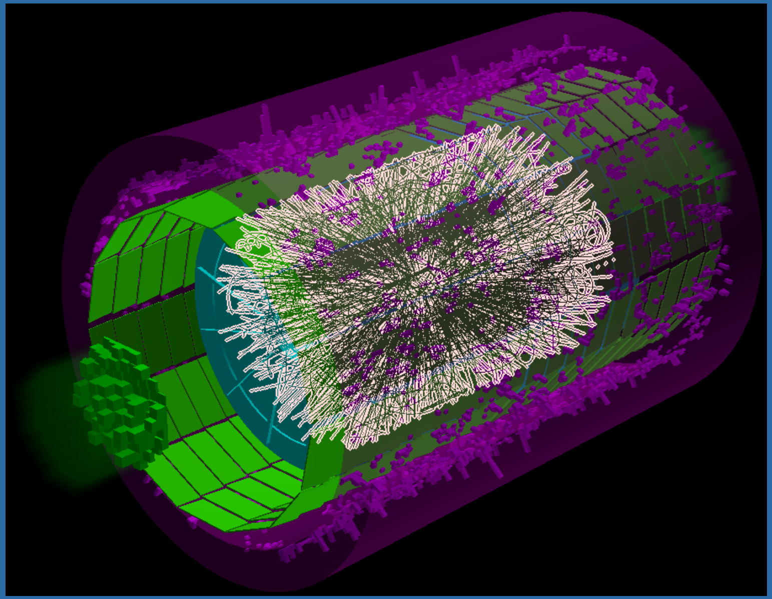
Theory predicts the largest effect for the hadron ratios due to CSR in dense matter

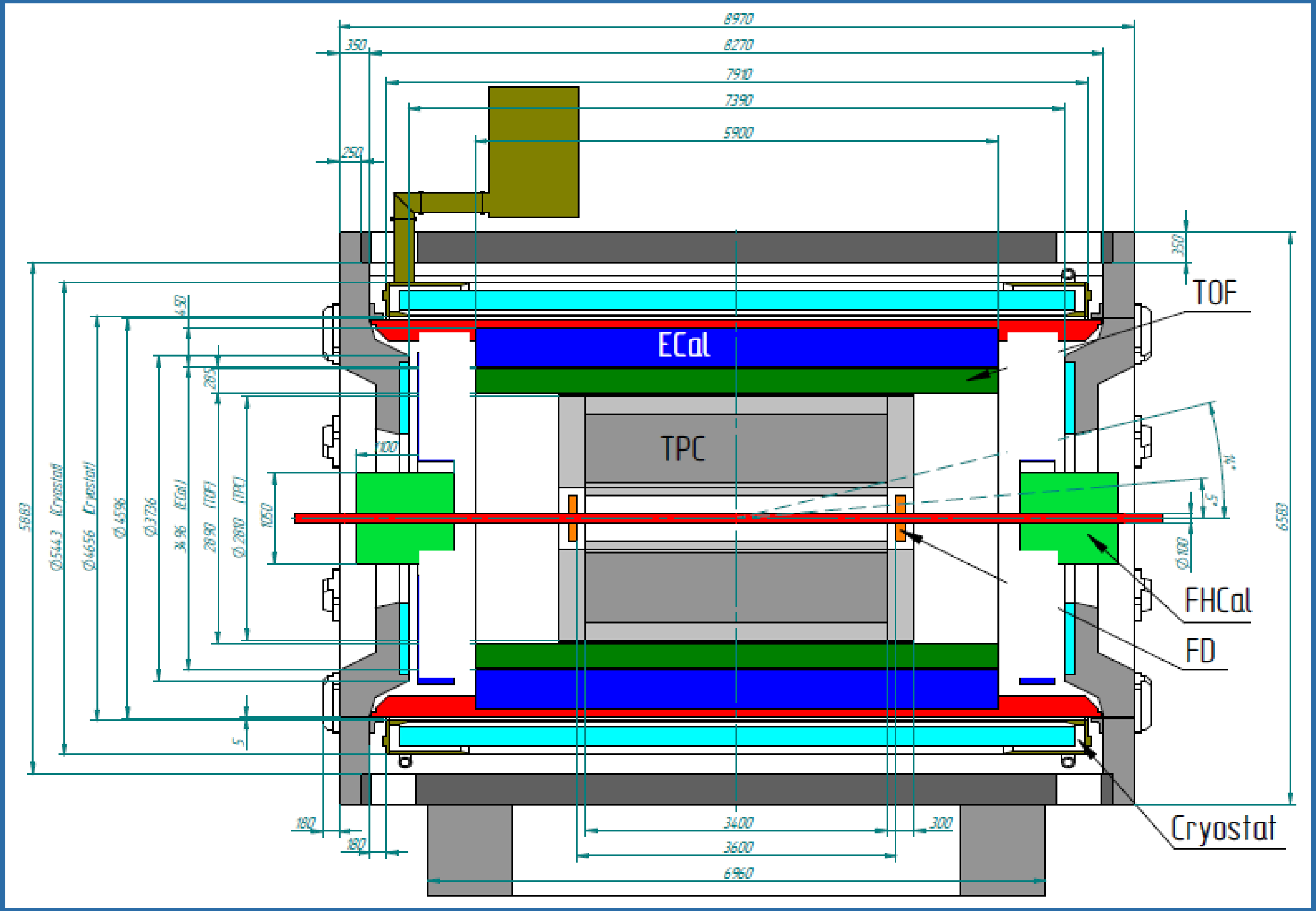


Lack of data on multistrangeness in different collision systems at NICA energies!

MultiPurpose Detector for A+A collisions @ NICA

Au+Au collision in MPD

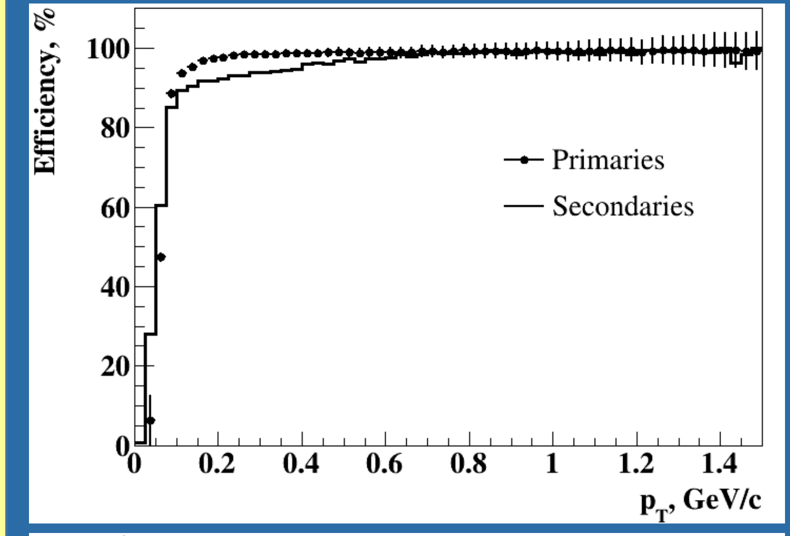


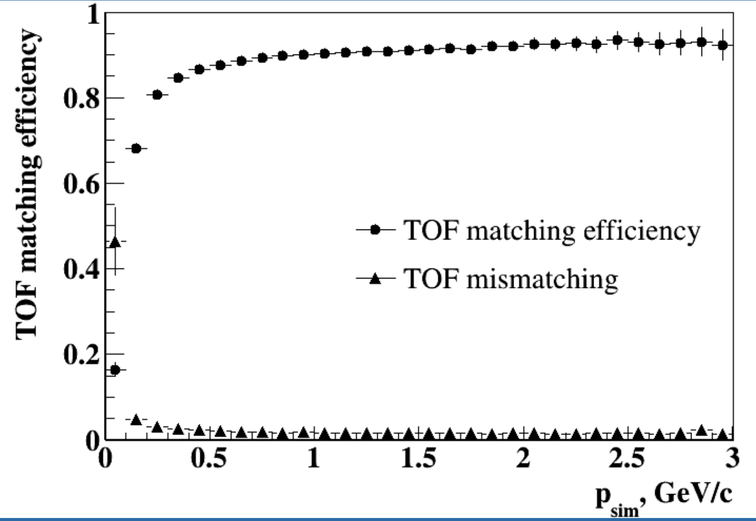


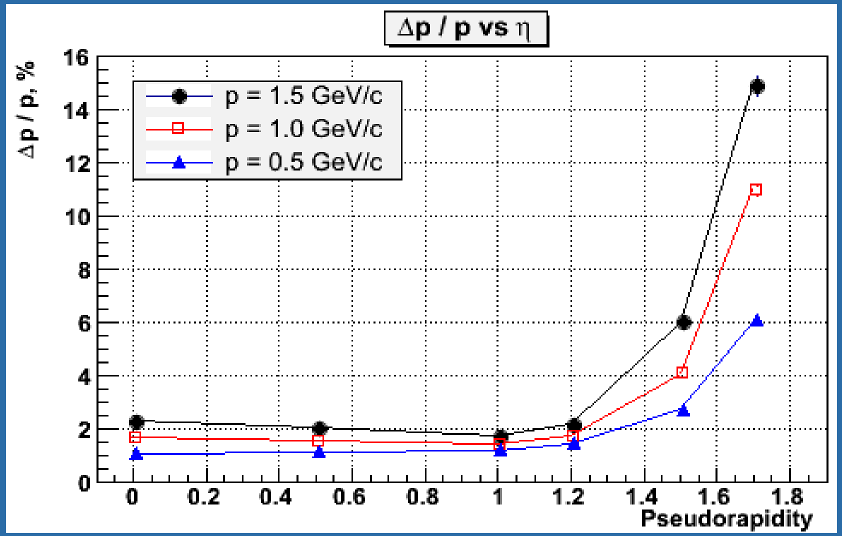
Magnet: 0.5 T superconductor
Tracking: TPC, ECT, IT
ParticleID: TOF, ECAL, TPC
T0, Triggering: FFD
Centrality, Event plane: FHCAL

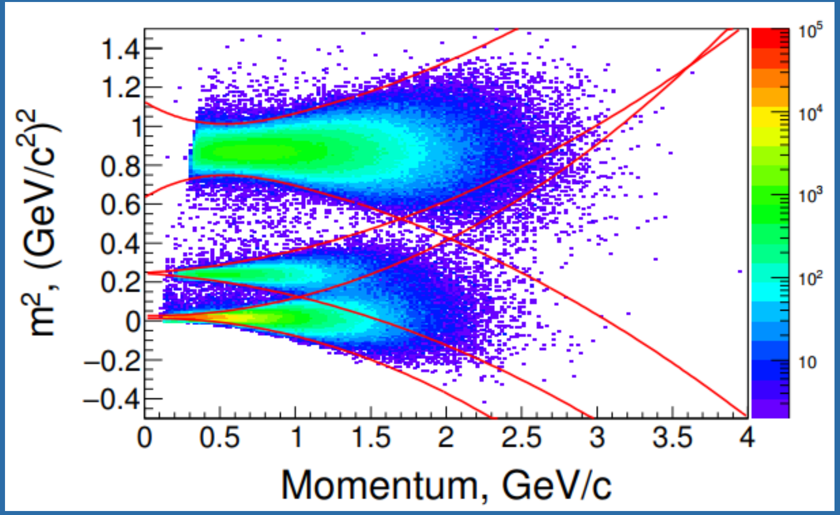
MPD tracking & PID performance

Based on realistic event simulation within the MPDRoot framework

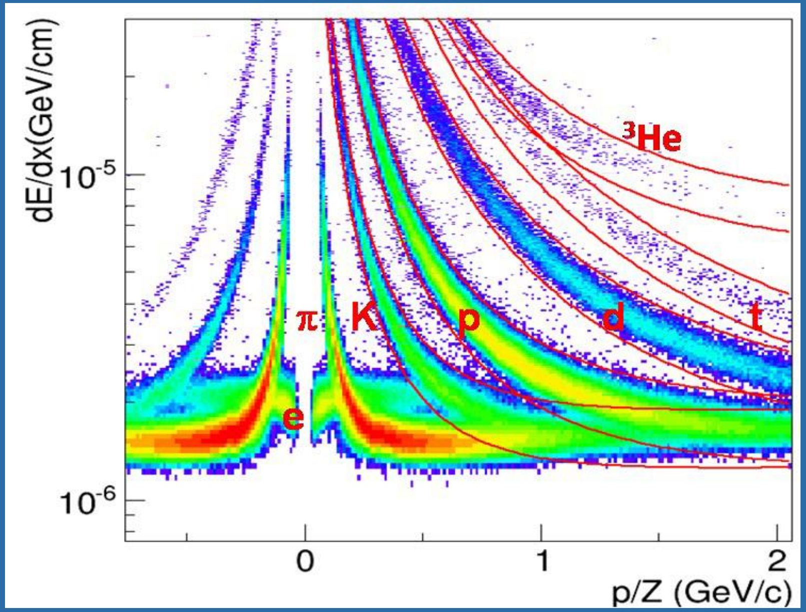








- High tracking efficiency over the reaction phase-space
- Good vertexing
- Combined (*dE/dx*+TOF) PID for hadrons provides *p/K* up to 2 GeV/c and *K/p* up 3 GeV/c



Papers

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METHODS
OF PHYSICAL EXPERIMENT

Evaluation of the MPD Detector Capabilities for the Study of the Strangeness Production at the NICA Collider[1]

M. Ilieva[a], V. Kolesnikov[a], Yu. Murin[a], D. Suvarieva[a], V. Vasendina[a], A. Zinchenko[a, *], E. Litvinenko[b], and K. Gudima[c]

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Abstract—One of the main tasks of the NICA/MPD physics program is the study of the strangeness production in nuclear collisions. In this paper the MPD detector performance is presented for measurements of K_S^0-mesons, $\Lambda(\bar{\Lambda})$-hyperons and hypertritons in central Au + Au collisions at NICA energies.

DOI: 10.1134/S1547477115010136

1. INTRODUCTION

The primary goal of the NICA (Nuclotron-based Ion Collider fAcility) heavy-ion program [1] is the study of the properties of nuclear matter under extreme conditions. At sufficiently high temperature

detecting both the hadronic (π, K, p, Λ, Ξ, Ω) and non-hadronic (e, γ) probes.

Study of (anti)hyperon production is of particular interest because of several reasons. First of all, the strangeness enhancement in heavy-ion collisions rela-

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COMPUTER TECHNOLOGIES
IN PHYSICS

Reconstruction of Multistrange Hyperons with the MPD Detector at the NICA Collider: a Monte Carlo Feasibility Study[1]

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Abstract—One of the main tasks of the NICA/MPD physics program is a study of strangeness production in nuclear collisions. In this paper the MPD detector performance for measurements of Λ, Ξ^- and Ω^- hyperons and their antiparticles $\bar{\Lambda}$, $\bar{\Xi}^+$ and $\bar{\Omega}^+$ in central Au+Au collisions at NICA energies is presented.

DOI: 10.1134/S1547477115040160

1. INTRODUCTION

The main goal of studying heavy-ion collisions is to explore the properties of nuclear matter under extreme density and temperature conditions. Lattice QCD cal-

that from a hadron gas (HG). The enhancement of the strangeness was experimentally observed at SPS [5] and RHIC [6], and it is more pronounced for hyperons with larger strangeness content (cascades and omegas). However, in order to prove or rule out the

METHODS
OF PHYSICAL EXPERIMENT

Towards a Realistic Monte Carlo Simulation of the MPD Detector at NICA[1]

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Abstract—During the preparation of the physics program of any experiment it is very important to perform a realistic simulation of the detector, i.e. to describe real detector effects with as many details as possible. In this paper the current status of such a simulation of the MPD TPC (Time Projection Chamber) is demonstrated, including description of relevant processes. Data reconstruction approaches are also presented along with the main results on detector performance.

DOI: 10.1134/S1547477119010084

1. INTRODUCTION

The NICA heavy-ion program is aimed at the experimental investigation of the nuclear matter prop-

needs to measure particle production practically up to the fragmentation region.

In order to fulfill the NICA physics program goals

Accepted for publication

Perspectives of multistrange hyperon study at NICA/MPD from realistic Monte Carlo simulation

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Abstract

One of the main tasks of the NICA/MPD physics program is a study of strangeness production in nuclear collisions. In this paper the MPD detector performance for measurements of multistrange hyperons in Au+Au collisions at NICA energies is presented based on the analysis of realistically simulated data samples. Perspectives of the studies on the strangeness production at the experiment start-up are evaluated.

The investigation has been performed at the Laboratory of High Energy Physics, JINR

Data set

- **Generators:** PHSD, Au+Au @ 11 GeV, min. bias, 8M events (~6 hours of running time at starting luminosity - 1/20 of design value)

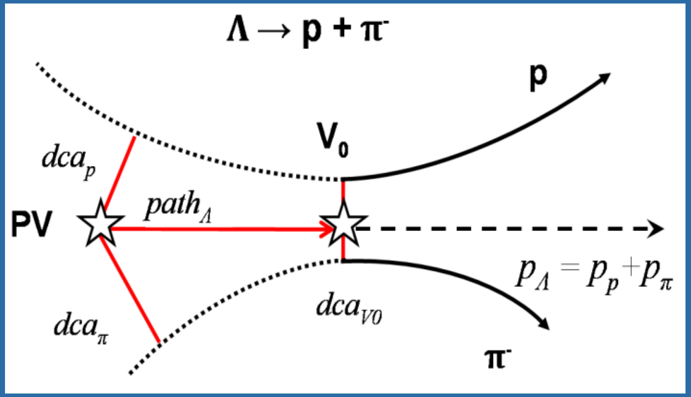
  UrQMD, Au+Au @ 9 GeV central, 40k events
- **Detectors:** start version of MPD with up-to-date TPC & TOF
- **Cluster / hit reconstruction:** precluster finder *(group of adjacent pixels in time bin – pad space*) ; hit finder *("peak-and-valley" algorithm either in time bin – pad space (for simple topologies) or in time-transverse coordinate pixel space after Bayesian unfolding (for more complicated topologies))*→ COG around local maxima
- **Track reconstruction:** two-pass Kalman filter with track seeding using outer hits (*1st pass*) or leftover inner hits (*2nd pass*)
- **Track acceptance criterion:** $|\eta| < 1.3$, $N_{hits} \geq 10$
- **Particle Identification:** dE/dx in TPC & β in TOF
- **Vertex reconstruction: Kalman filter based formalism working on MpdParticle objects**

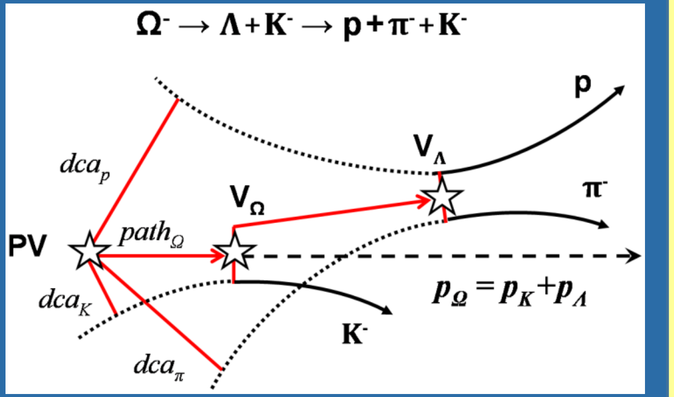
Analysis goals and Event topology

Goals:

- Secondary Vertex Reconstruction algorithms development for multistrangeness analysis
- Optimization of selection criteria in *pT* and centrality
- Analysis macros for invariant spectra reconstruction
- Estimates of MPD efficiency and expected event rates
- Publications with results of the study (supported by a RFBR Grant for 2019-21)

Analysis method:
Secondary Vertex Finding Technique



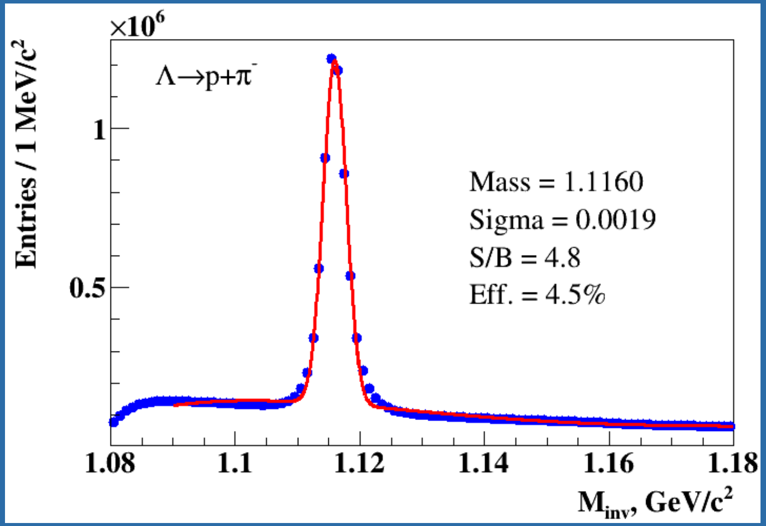


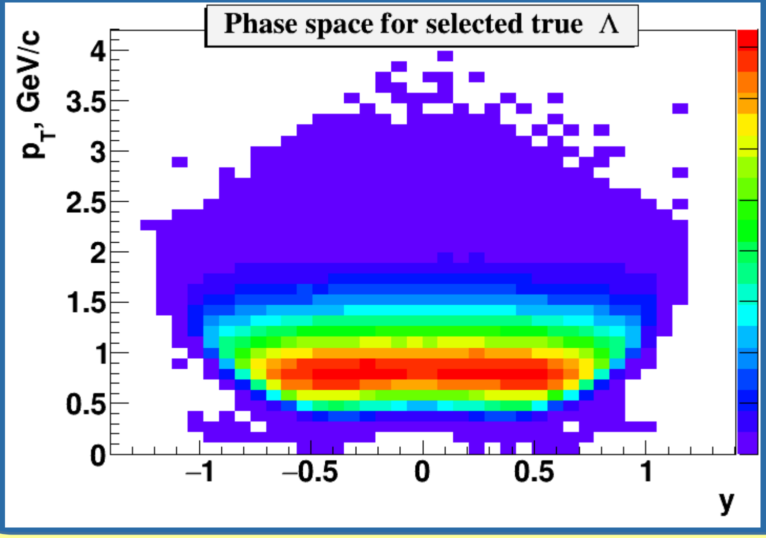
Event topology:

- PV – primary vertex
- V_0 – vertex of hyperon decay
- dca – distance of the closest approach
- path – decay length

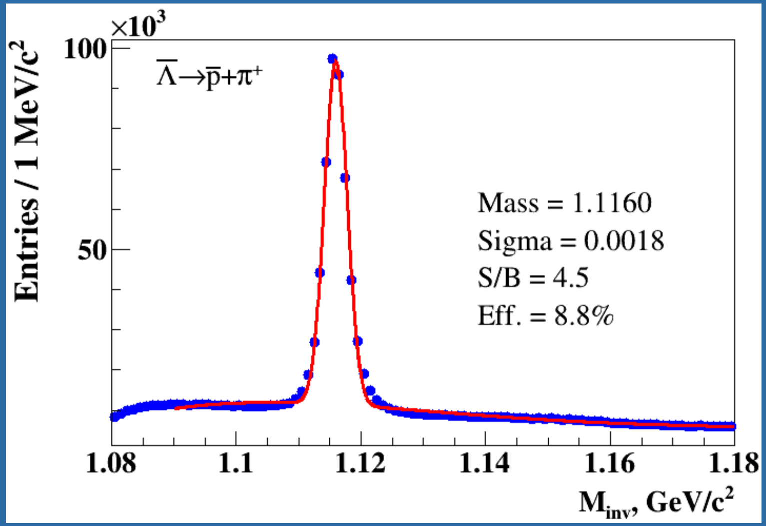
Λ, Λ_{bar}, Ξ^- reconstruction and Phase space (PHSD)

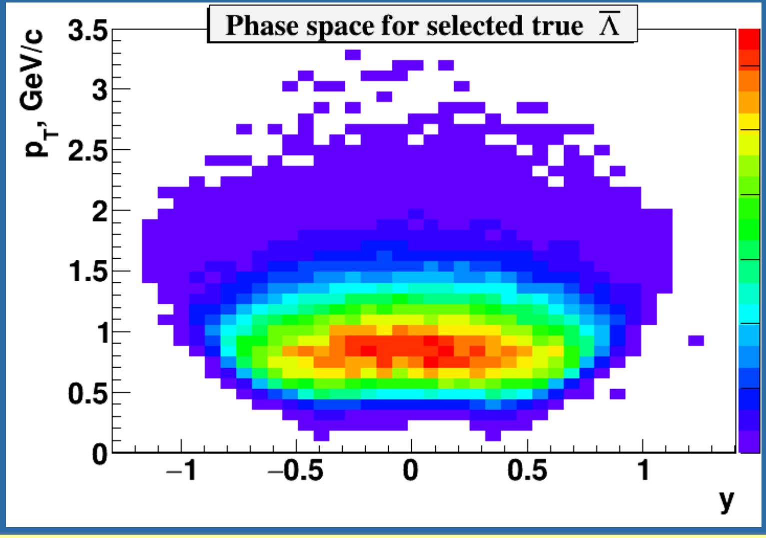
Eff. (for |*y*|<0.5) =10.4%



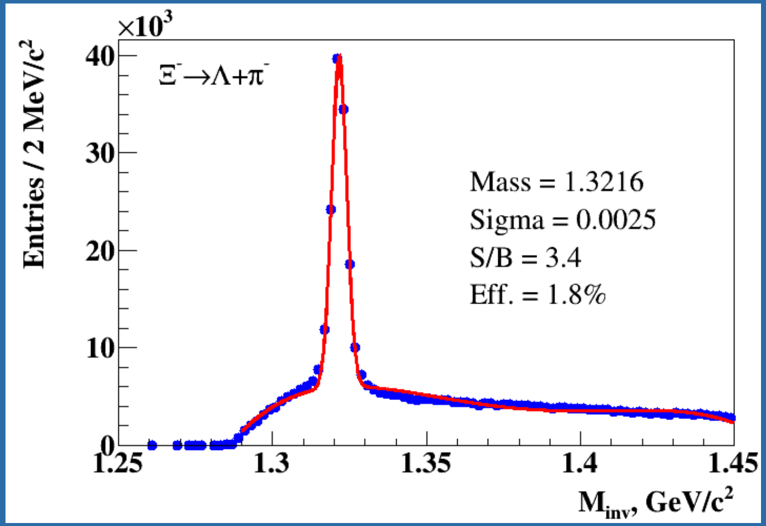


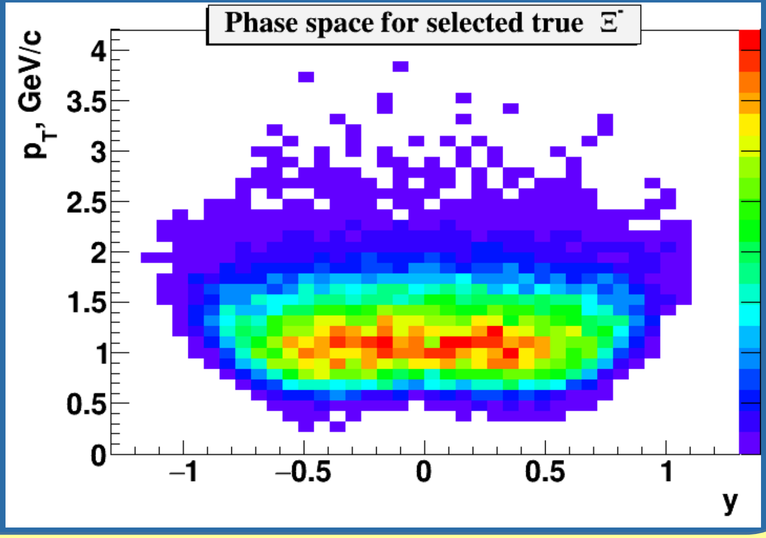
Eff. (for |*y*|<0.5) =14.1%





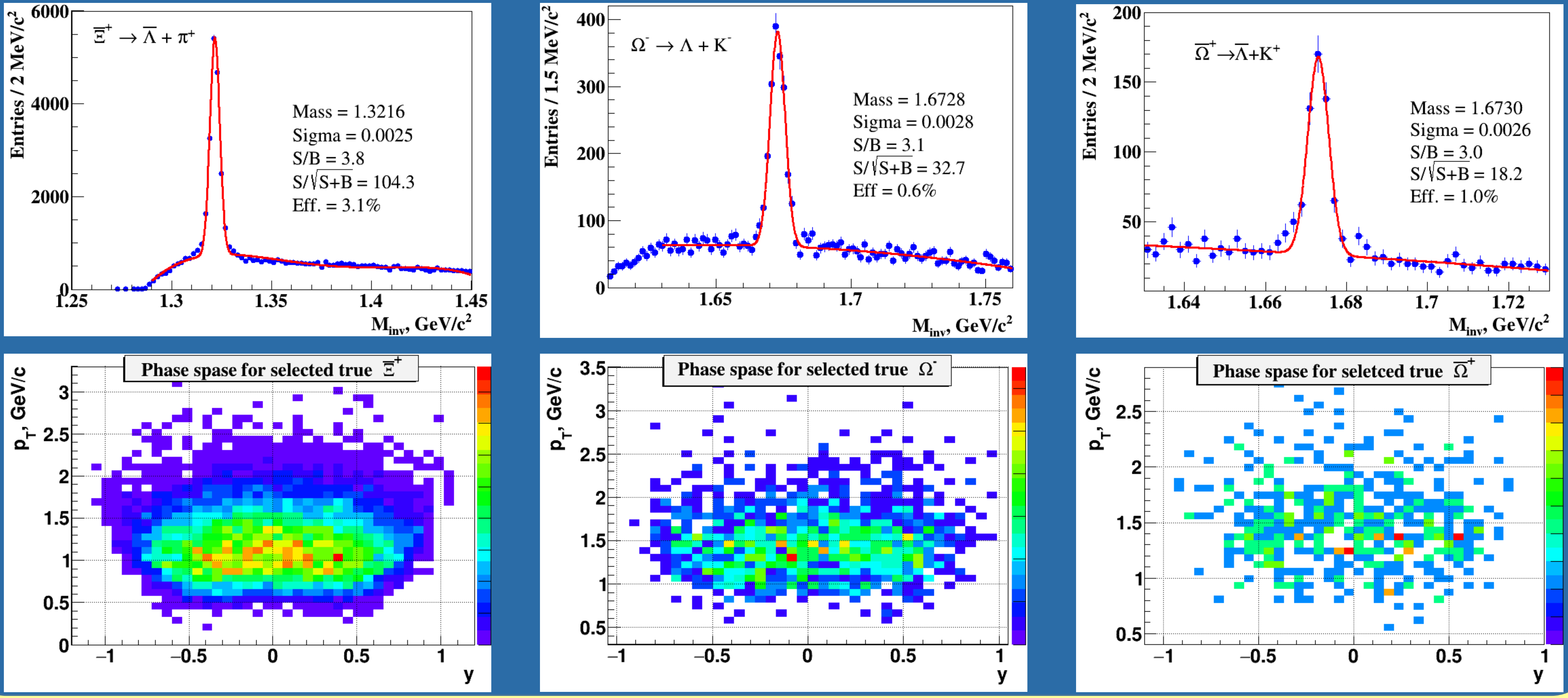
Eff. (for |*y*|<0.5) =3.6%





Ξ^+, Ω^-, Ω^+ reconstruction and Phase space (PHSD)

Eff. (for $|y|<0.5$) =4.7% | Eff. (for $|y|<0.5$) =1.1% | Eff. (for $|y|<0.5$) =1.5%

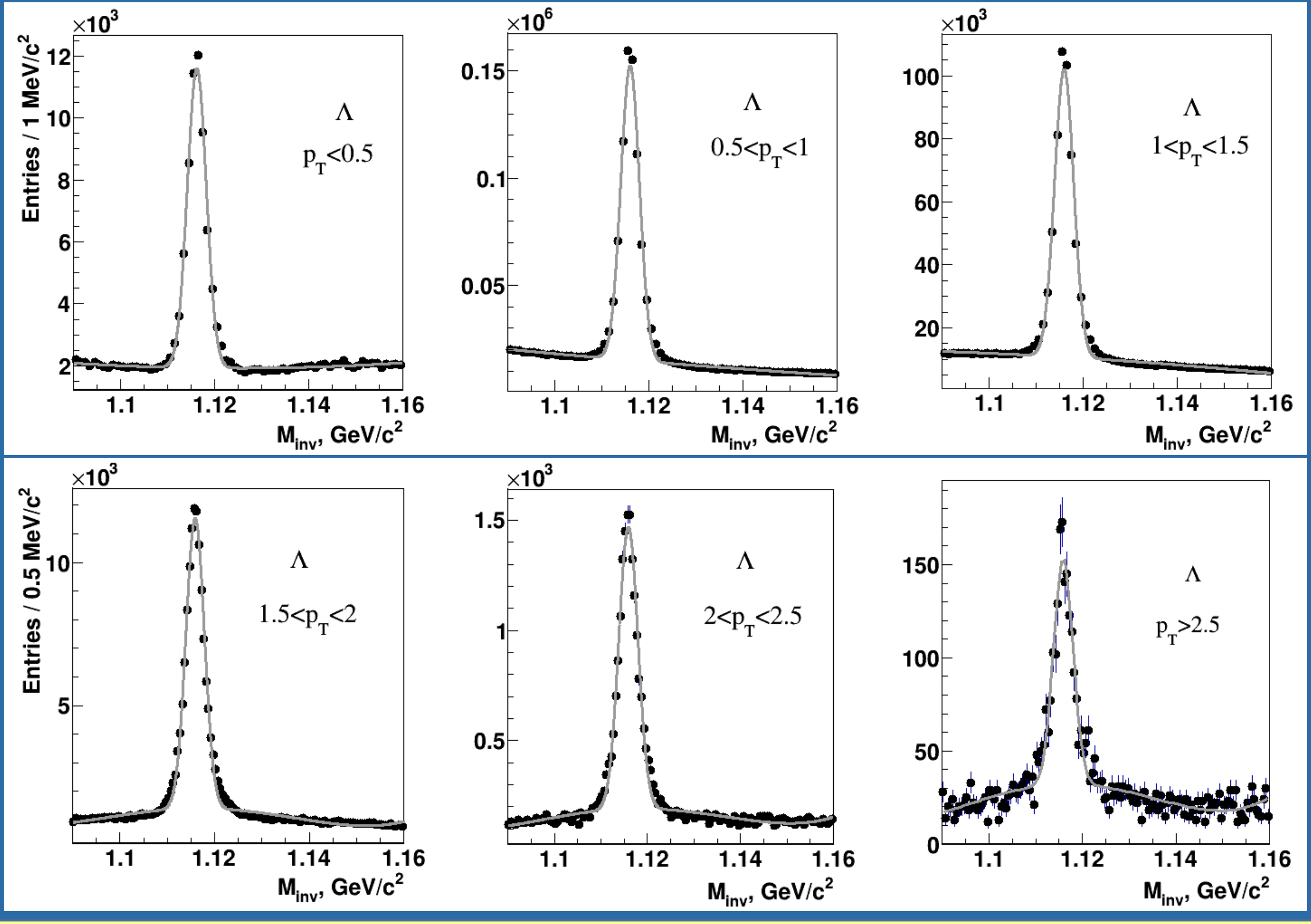


Ξ^+, Ω^-, Ω^+ reconstruction efficiency and yields (PHSD)

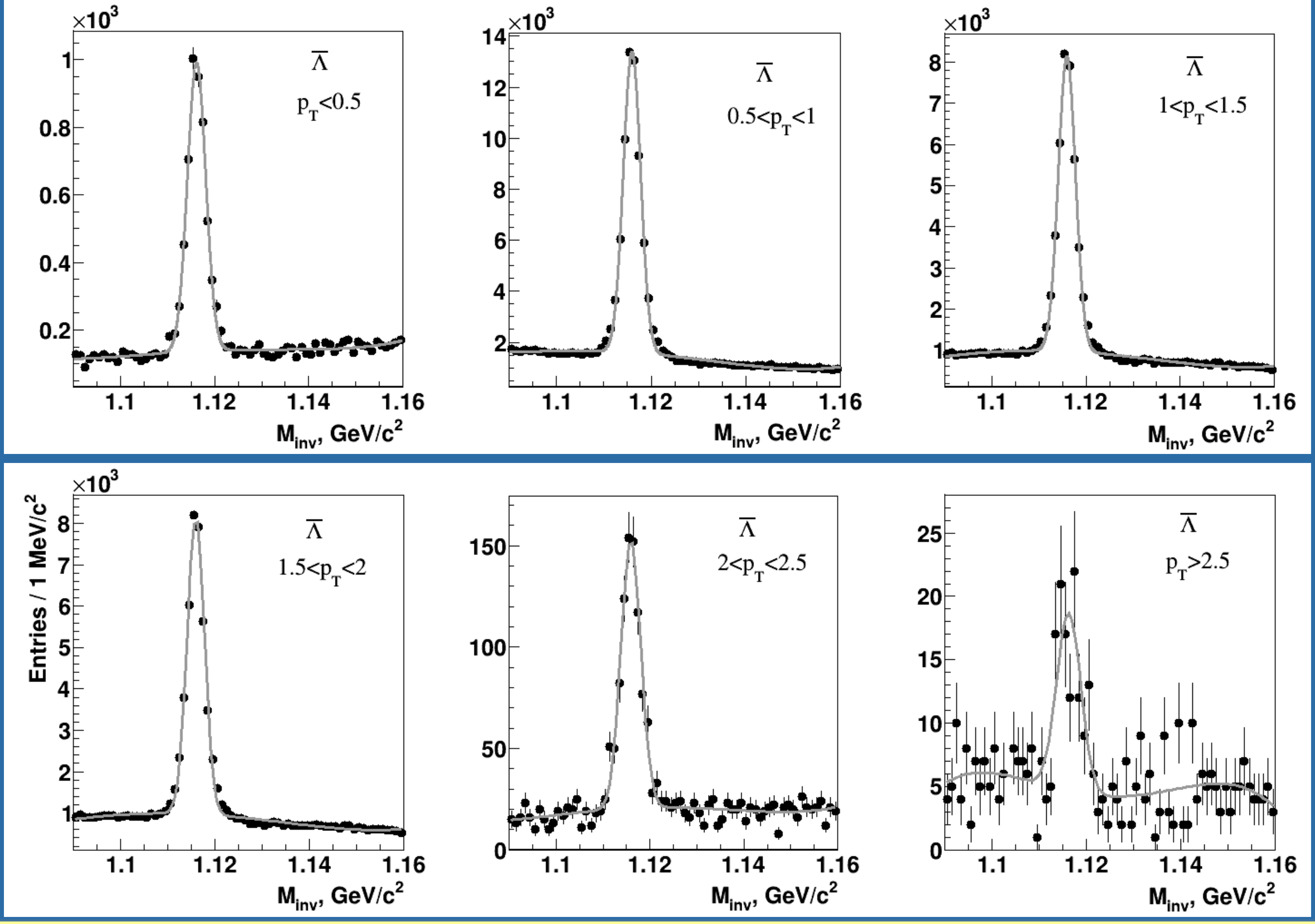
Table 2: Factors affecting multistrange hyperon reconstruction efficiency.

Factor	Efficiency, %		
	$\bar{\Xi}^+ \to \bar{\Lambda} + \pi^+$	$\Omega^- \to \Lambda + K^-$	$\bar{\Omega}^+ \to \bar{\Lambda} + K^+$
Branching ratio	62.4	41.6	42.8
p and $\pi(K)$ at $\lvert\eta\rvert < 1.3$	27.6	14.4	18.8
p and $\pi(K)$ at $\lvert\eta\rvert < 1.3$ and $p_T > 0.05$ GeV/c	24.9	13.3	17.4
p and $\pi(K)$ at $\lvert\eta\rvert < 1.3$ and $p_T > 0.1$ GeV/c	15.3	9.3	12.6
p and $\pi(K)$ at $\lvert\eta\rvert < 1.3$ and $p_T > 0.2$ GeV/c	2.8	2.3	3.4
Reconstructed p and $\pi(K)$ at $\lvert\eta\rvert < 1.3$	14.0	6.7	8.9
Reco + PID	13.2	6.3	8.3
Reco + PID + sel. at maximum siginificance	3.1	0.6	1.0

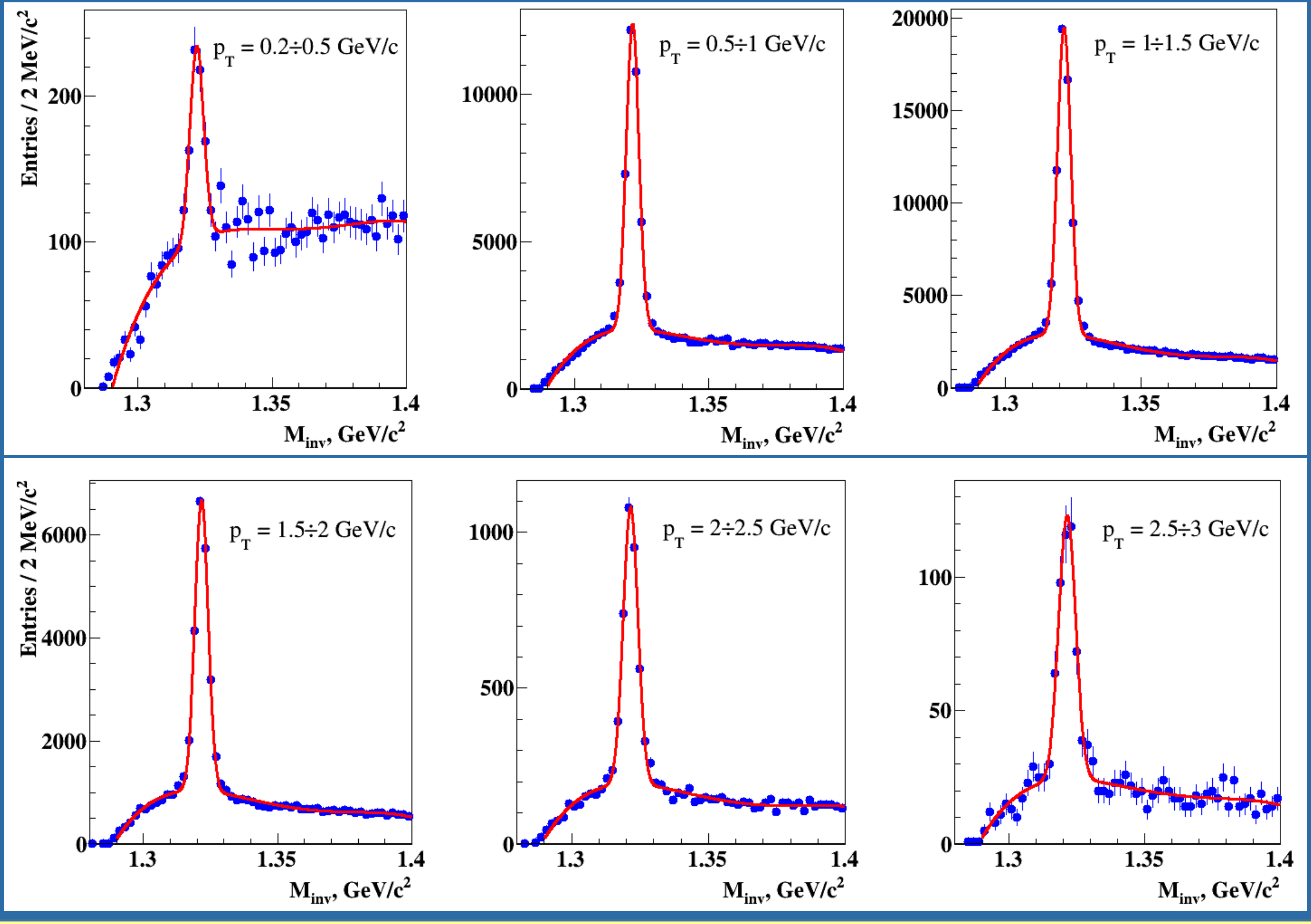
p_T dependence of Λ for all centralities (PHSD 2M)



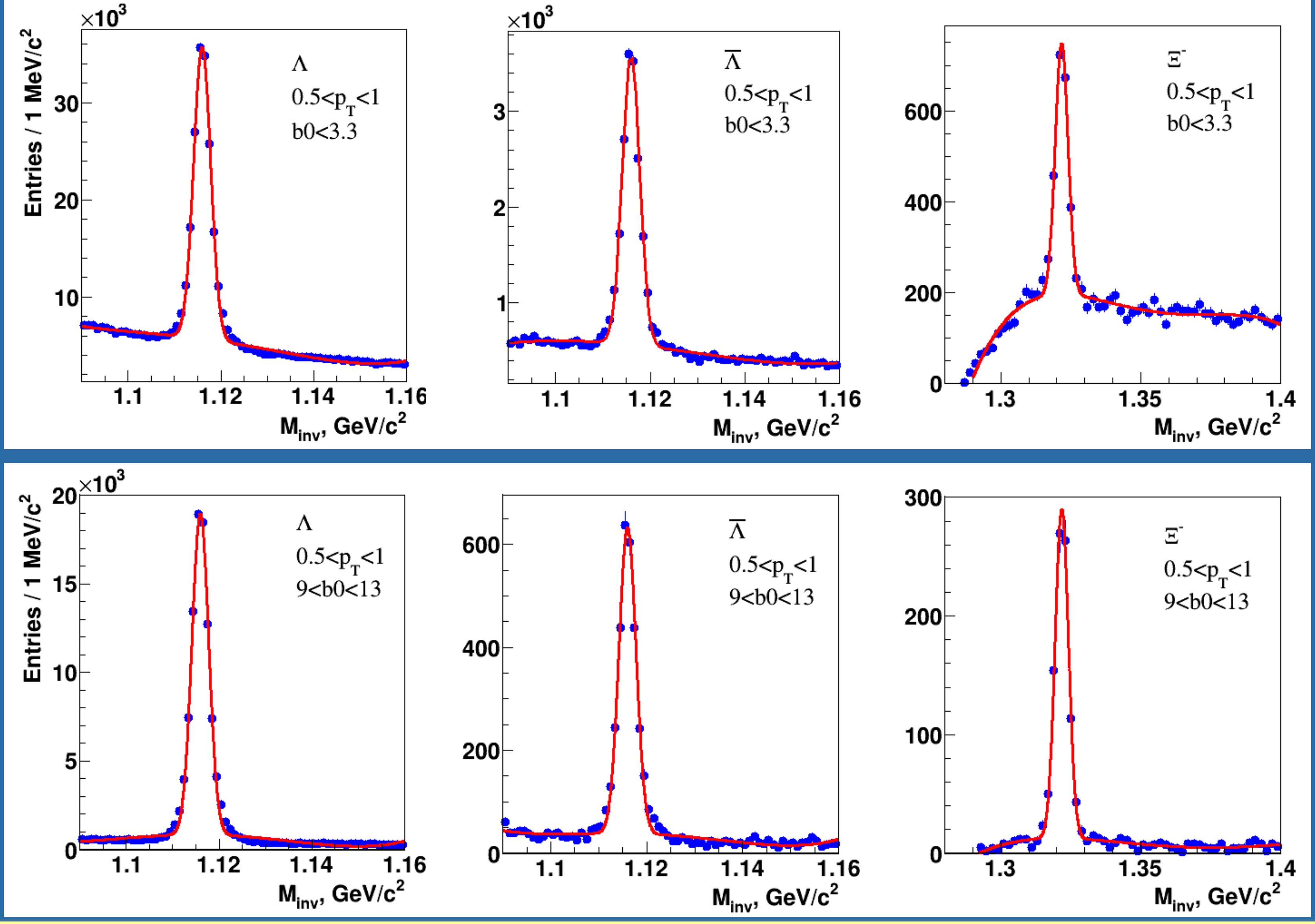
p_T dependence of Λ_{bar} for all centralities (PHSD 2M)



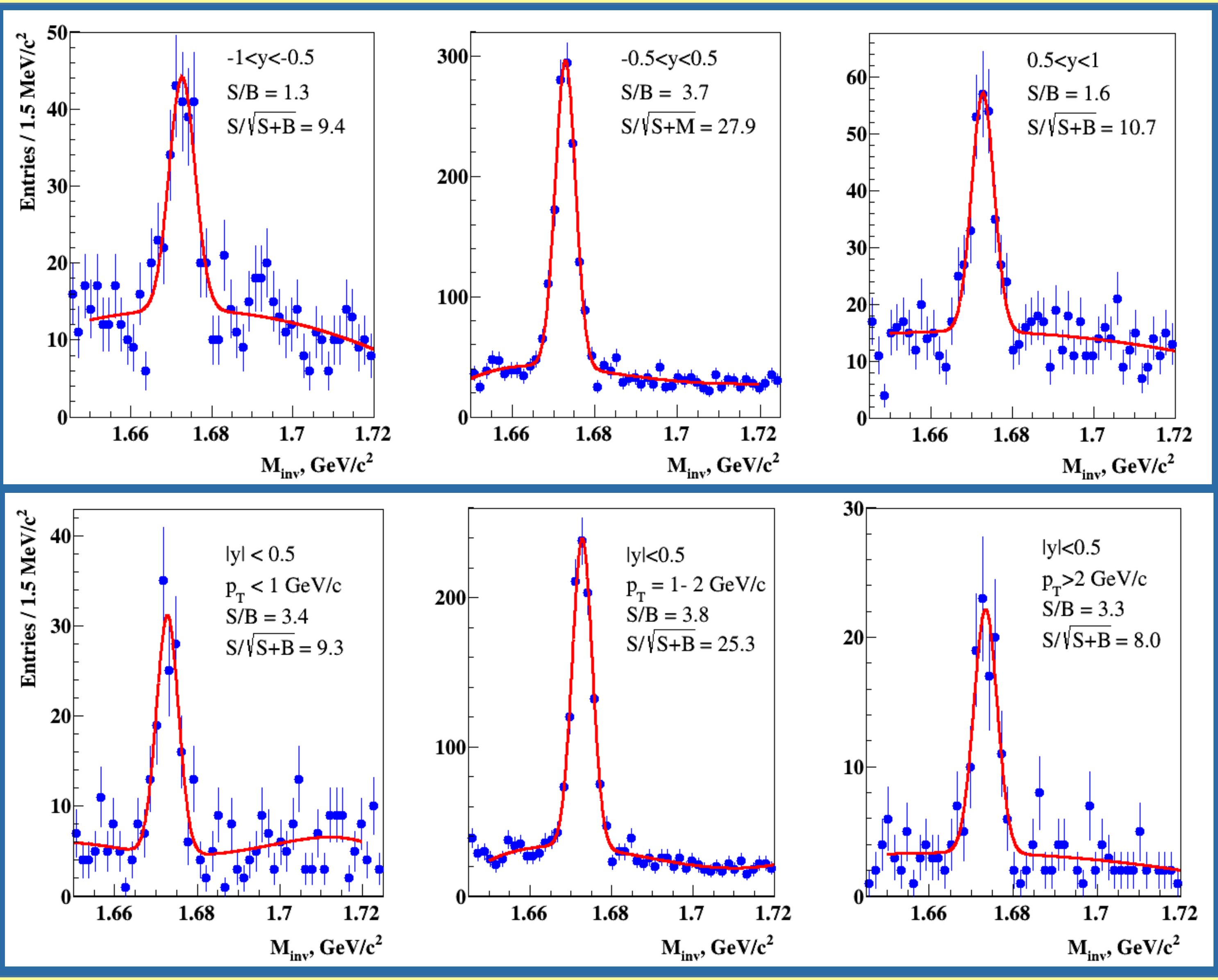
p_T dependence of Ξ^- for all centralities (PHSD)



p_T dependence for different centralities (PHSD 2M)



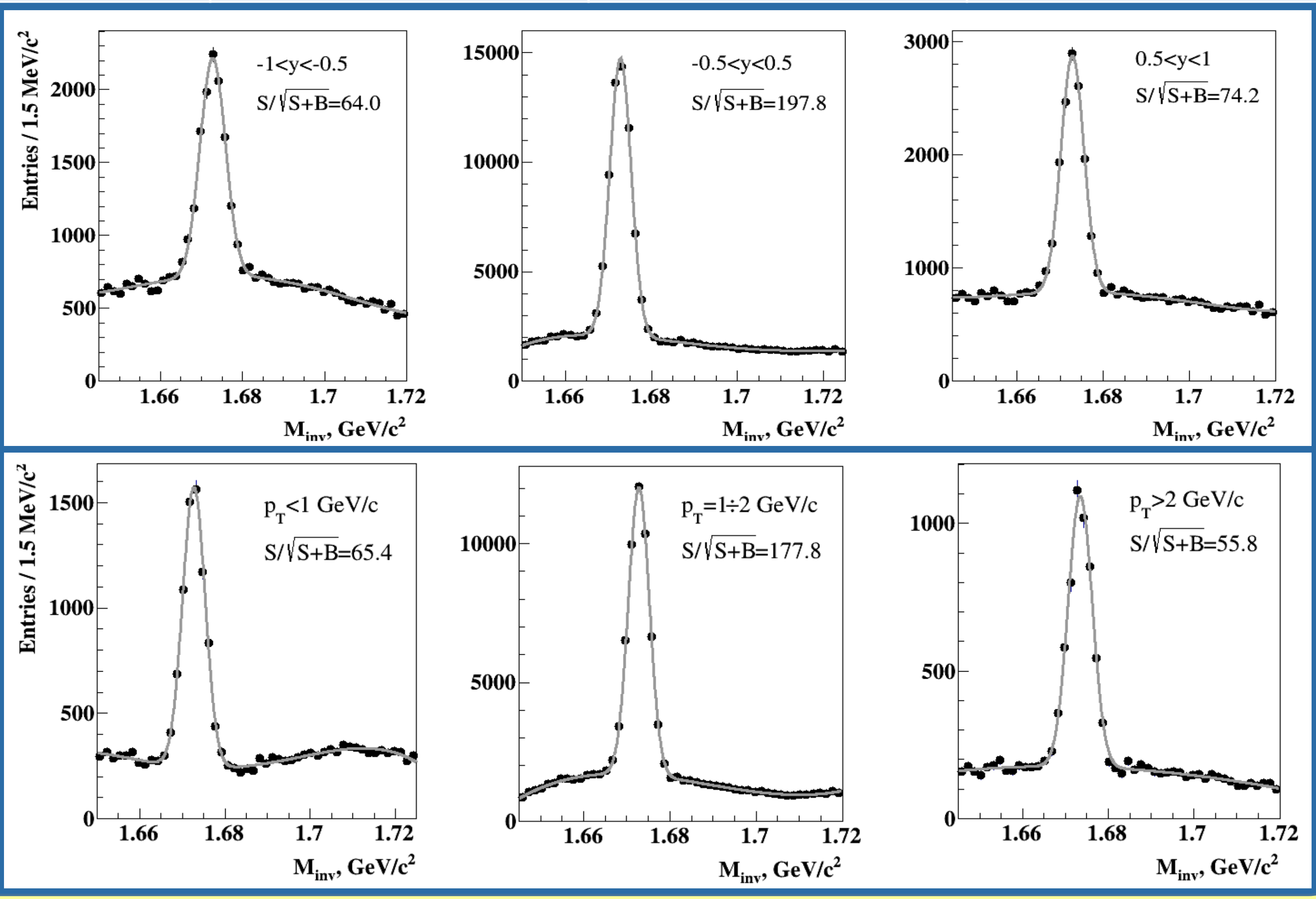
Ω^- hyperon: y & p_T dependence (PHSD)



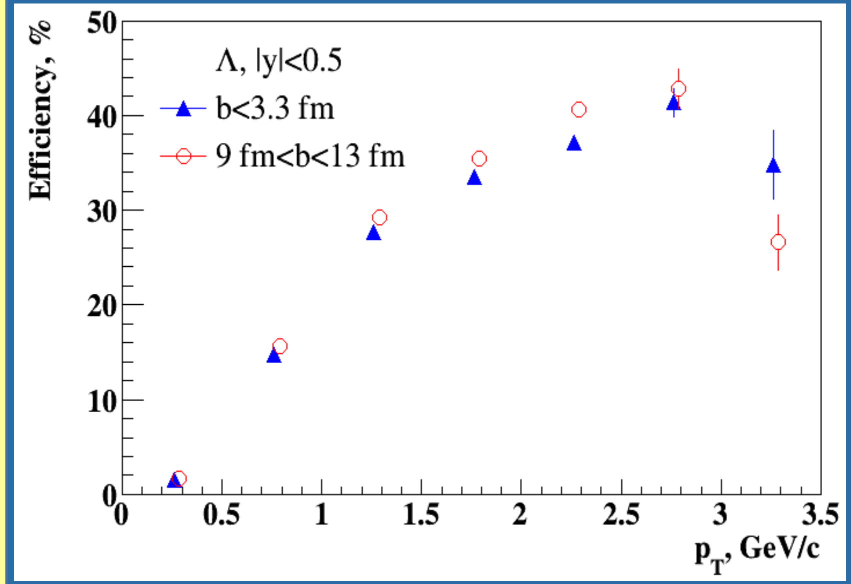
Ω^- hyperon: y & p_T dependence (PHSD)

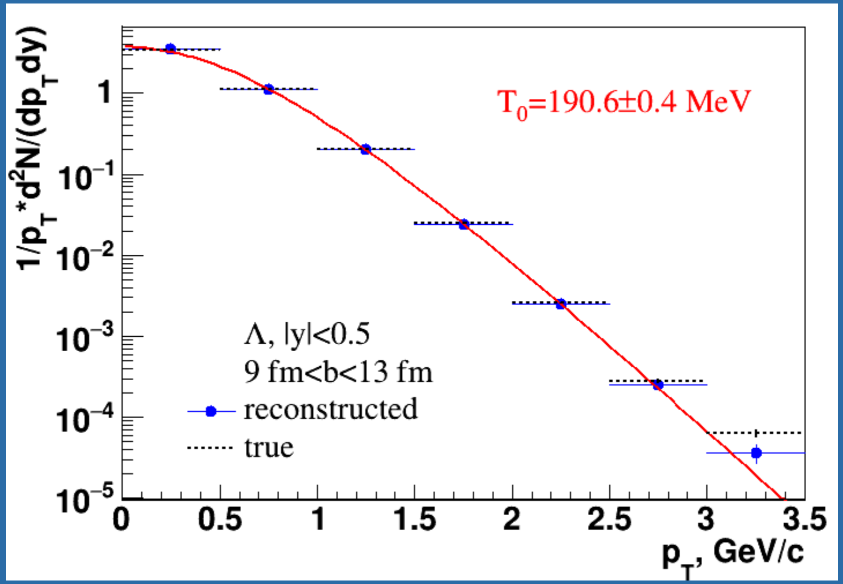
Particle	$\Xi^+_{bar} \rightarrow \Lambda_{bar} + \pi^+$	$\Omega^- \rightarrow \Lambda + K^-$	$\Omega^+ \rightarrow \Lambda_{bar} + K^+$
Expected yield	7.2×10^5	7.4×10^4	2.3×10^4

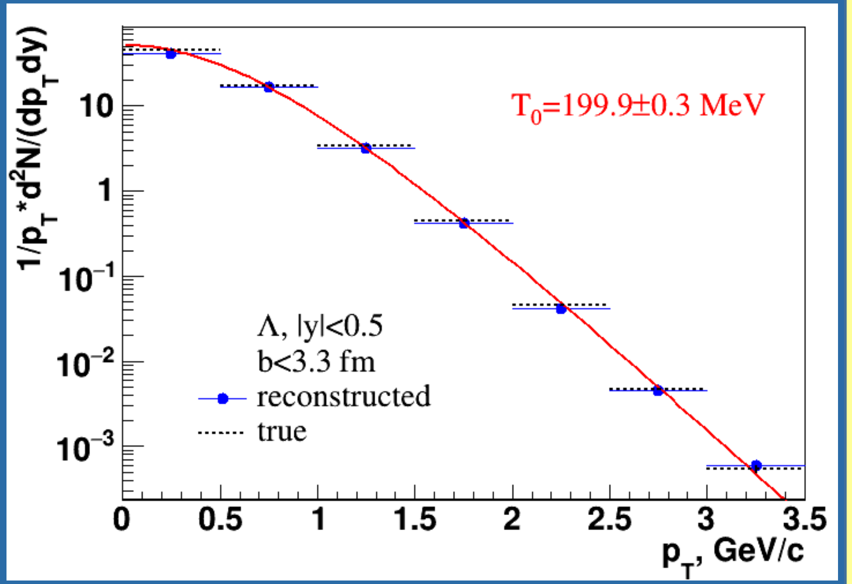
Expected multistrange hyperon yields in minimum bias *Au+Au* collisions for 2 weeks of running time.



Λ reconstruction: efficiency and *pT* spectrum (PHSD)



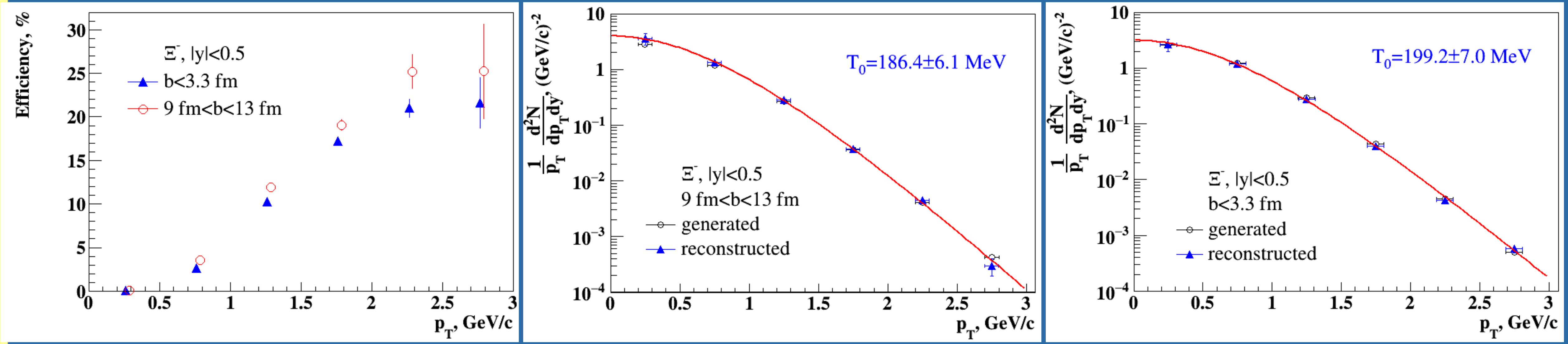




Efficiency of true *Λ* in p_T and *b* bins for |*y*|<0.5: (reco & select *Λ*) / (all gen *Λ*)

Reconstructed spectrum: fit of selected *Λ* in each bin (Gauss ± 3*σ*) / Eff.

Ξ^- reconstruction: efficiency and pT spectrum (PHSD)

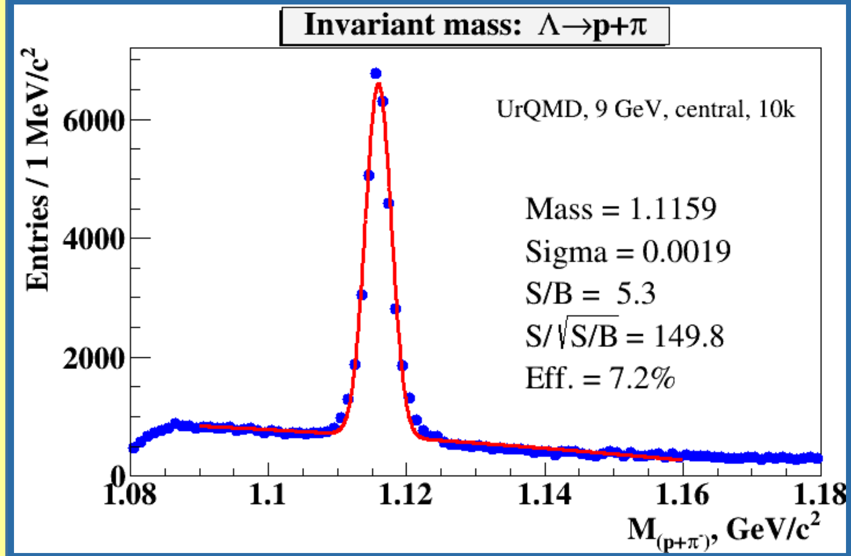


Efficiency of true Ξ^- in p_T and b bins for $|y|<0.5$: (reco & select Ξ^-) / (all gen Ξ^-)

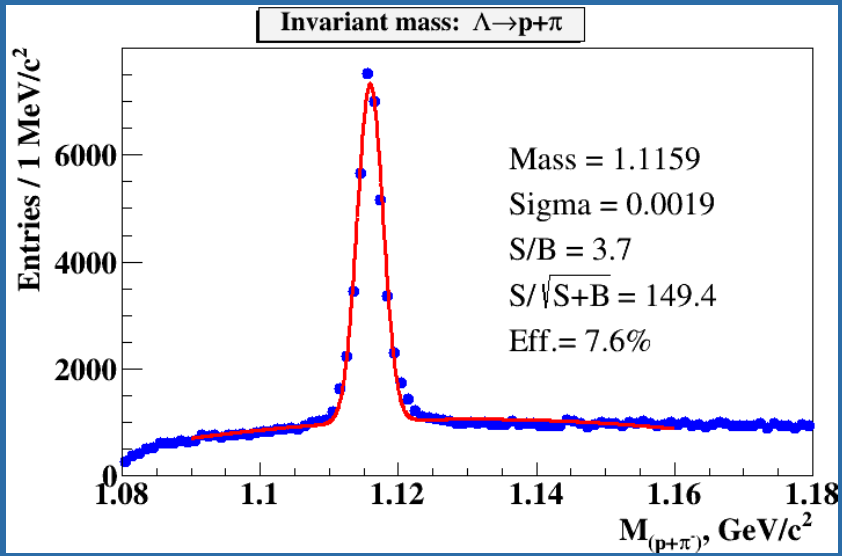
Reconstructed spectrum: fit of selected Ξ^- in each bin (Gauss $\pm$ 3σ) / Eff.

Λ reconstruction: standard cuts vs parameter ω (UrQMD)

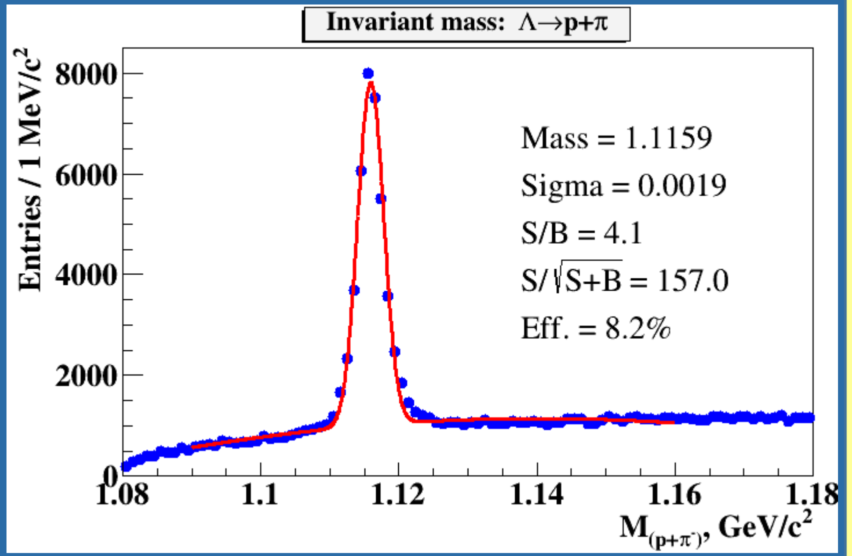
UrQMD, central, *Au+Au* @ 9 GeV, 10k events



Standard cuts



With parameter *ω1*

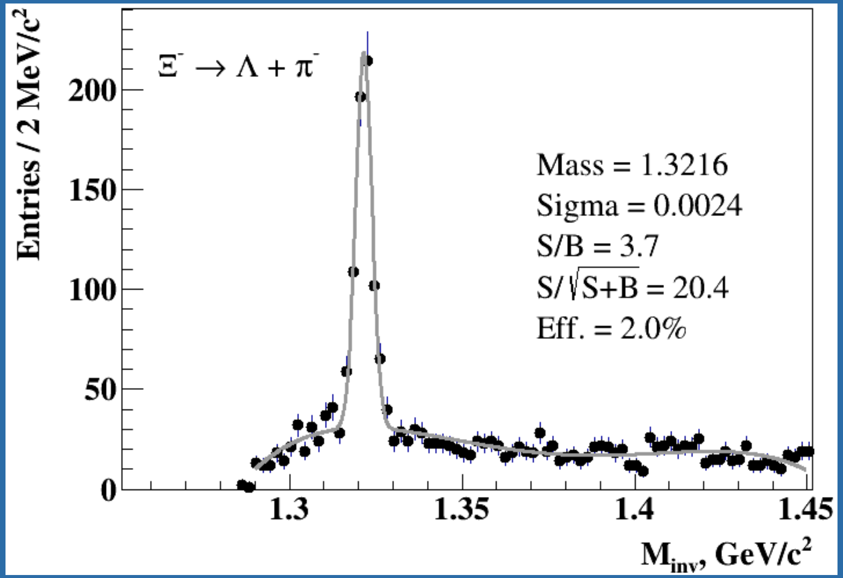


With parameter *ω2*

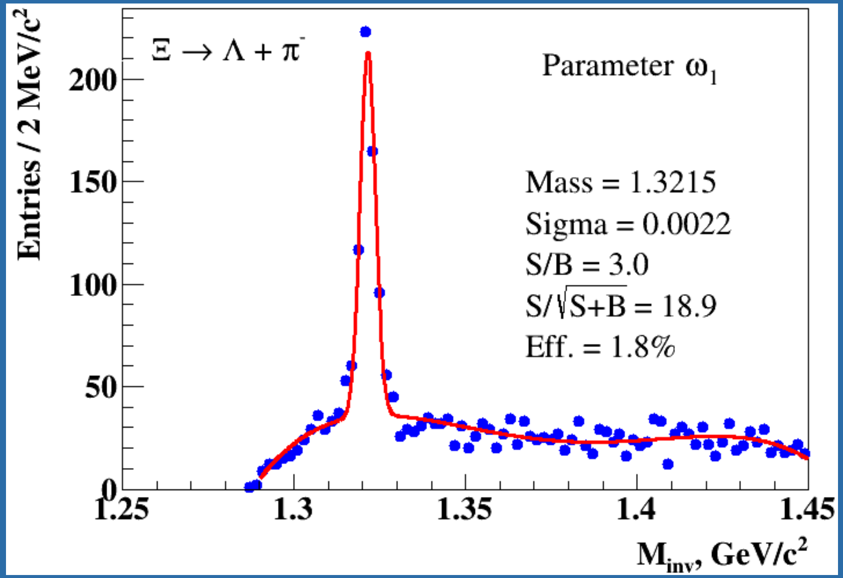
$$\omega_1 = \ln \frac{dca_\pi \cdot dca_p}{dca_\Lambda^2 + dca_{V0}^2}, \qquad \omega_2 = \ln \frac{\sqrt{\chi_\pi^2 \cdot \chi_p^2}}{\chi_\Lambda^2 + \chi_{V0}^2}.$$

Ξ^- reconstruction: standard cuts vs parameter ω (UrQMD)

UrQMD, central, *Au+Au* @ 9 GeV, 40k events



Standard cuts for Ξ^- and secondary Λ



Standard cuts for Ξ^- and parameter $\omega 1$ for secondary Λ

Λ and Ξ^- reconstruction efficiency (UrQMD)

Table 1: Factors affecting hyperon reconstruction efficiency.

Factor	Efficiency, %	
	$\Lambda \rightarrow p + \pi^-$	$\Xi^- \rightarrow \Lambda(p\pi^-) + \pi^-$
Branching ratio	63.4	63.3
p and π^- at $\|\eta\| < 1.3$	30.4	26.8
p and π^- at $\|\eta\| < 1.3$ and $p_T > 0.05$ GeV/c	28.7	24.3
p and π^- at $\|\eta\| < 1.3$ and $p_T > 0.1$ GeV/c	22.4	14.6
p and π^- at $\|\eta\| < 1.3$ and $p_T > 0.2$ GeV/c	8.8	2.9
Reconstructed p and π^- at $\|\eta\| < 1.3$	22.4	15.5
Reco + PID	21.3	14.5
Reco + PID + selection at maximum siginificance	7.2	2.0

Hyperon-related activity (past, present and future)

- Λ hyperon global polarization – feasibility evaluation – A.Kechechyan – needs event generator
- Λ hyperon local polarization – D.Suvarieva for BM@N – needs event generator
- Σ^0 reconstruction – N.Geraksiev – inconclusive (not very optimistic)
- Hyperon flow – N.Geraksiev – ongoing – needs high statistics: faster MC – fast digitizer (machine learning, cluster shape library); better signal selection (machine learning)
- Hyperons with ITS – V.Kondratiev, Yu.Murin
- Hyperon reconstruction framework (Particle Finder) – N.Geraksiev

Summary

- Hyperon-related activity is ongoing
- Some analyses require dedicated event generators
- Statistics is an issue for multistrange hyperons – future developments might help

Thank you for attention!