

# MPD PWG2 status report

Vadim Kolesnikov  
(VBLHEP, JINR)  
on behalf of the group



MPD Collaboration meeting  
JINR, Dubna, October 12-14, 2021

# Outline

---

- ❑ **PWG2 tasks**
- ❑ **Update of feasibility study results :**
  - Light hadrons
  - Hypernuclei
  - Hyperon polarization
  - Resonances
- ❑ **Summary**

## PWG2 co-conveners:

**Xianglei Zhu** (Tsinghua Univ., China) [zhux@tsinghua.edu.cn](mailto:zhux@tsinghua.edu.cn)

**Vadim Kolesnikov** (JINR, Dubna, Russia) [Vadim.Kolesnikov@cern.ch](mailto:Vadim.Kolesnikov@cern.ch)

## **PWG2 physics cases**

### ▪ **Light flavor hadron spectra, yields, and ratios**

- Energy, system size and centrality dependence of the production of charged hadrons (pions, kaons, (anti)protons).
- Extraction of transverse momentum spectra, rapidity distributions, mean multiplicities, and particle ratios.
- Nuclear modification factor, antiparticle/particle ratio, radial flow, phase diagram mapping.

### ▪ **Strangeness (hyperons and hypernuclei)**

- Analysis of strange hyperons ( $\Lambda$ ,  $\Sigma$ ,  $\Omega$ ) and their antiparticles: spectra, yields, antiparticle/particle ratio, nuclear modification factor, azimuthal anisotropy (together with PWG3).
- (Anti) $\Lambda$  polarization.
- Reconstruction of single and double hypernuclei: spectra, rapidity density, and lifetime.

### ▪ **Resonances**

- Production of  $\rho$ ,  $\phi$ ,  $K^*$ ,  $\Lambda(1520)$  etc.

### ▪ **Light nuclei**

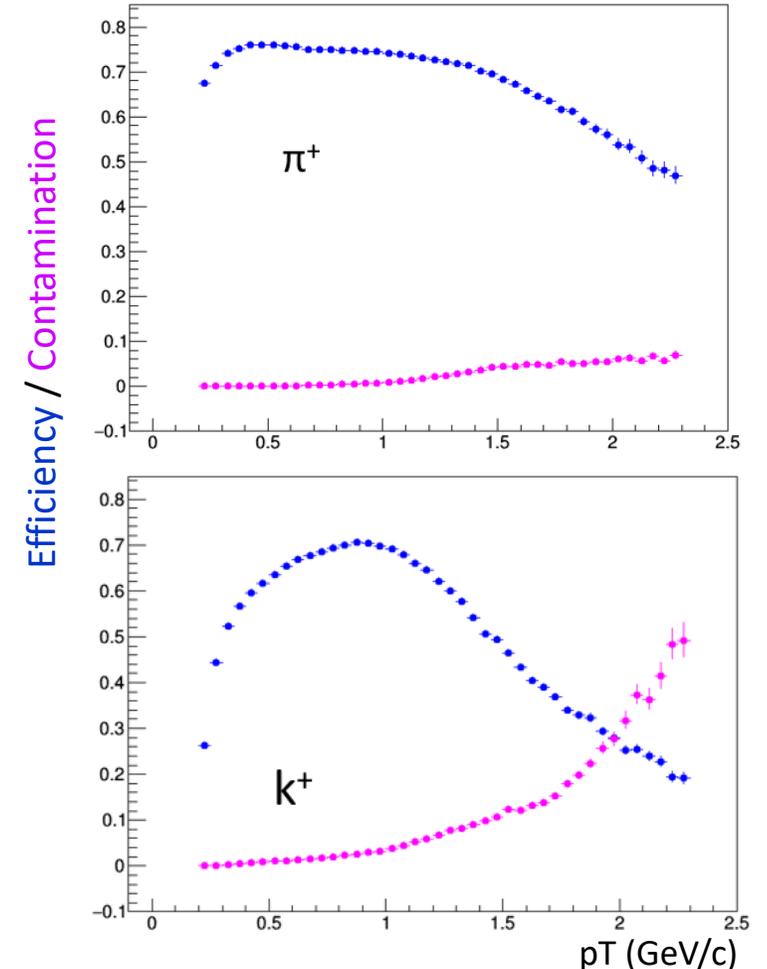
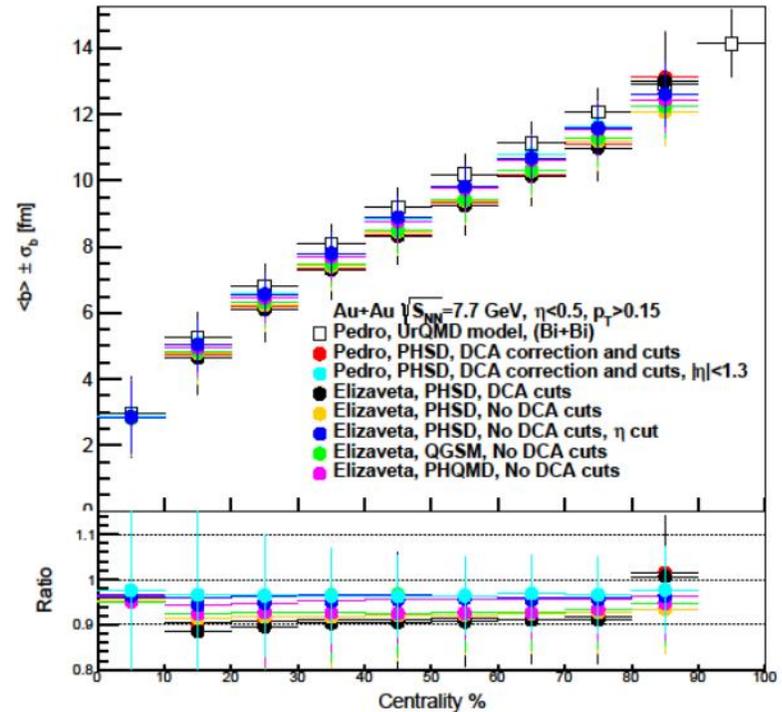
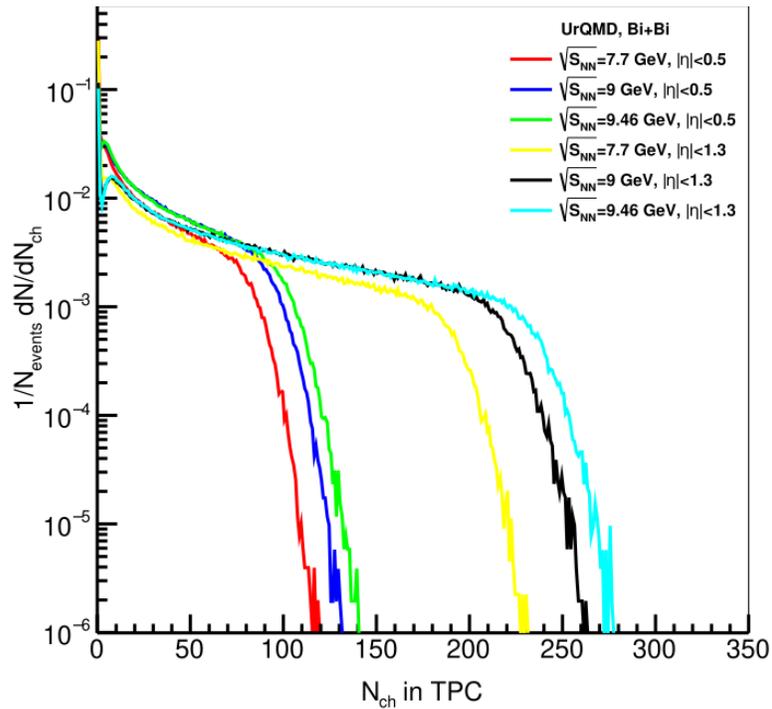
- Production of nucleon clusters (d, t,  $^3\text{He}$ ,  $^4\text{He}$ ) in various reactions (from p+p to Au+Au): spectra, yields, coalescence coefficients.



# Light hadrons : Centrality dependence of particle production

A.Aparin + team

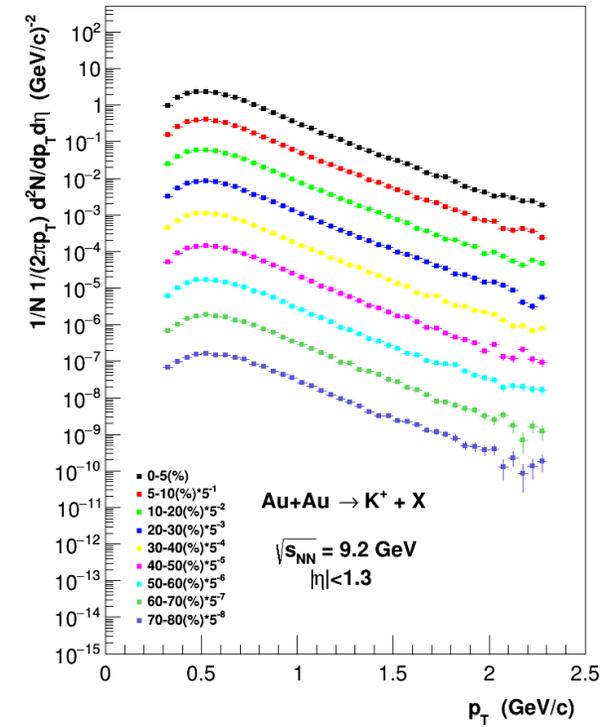
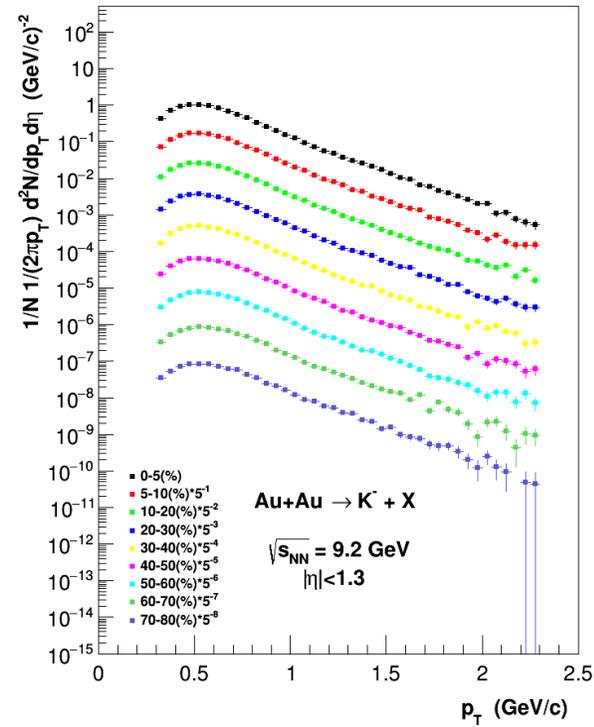
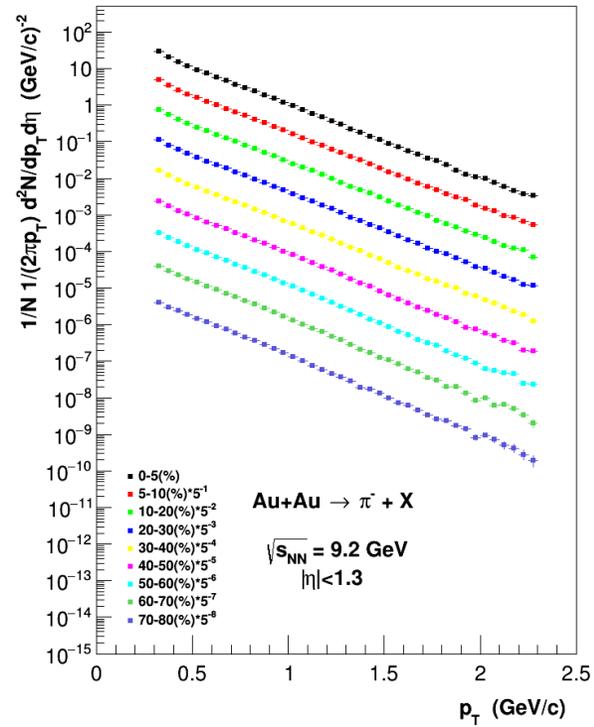
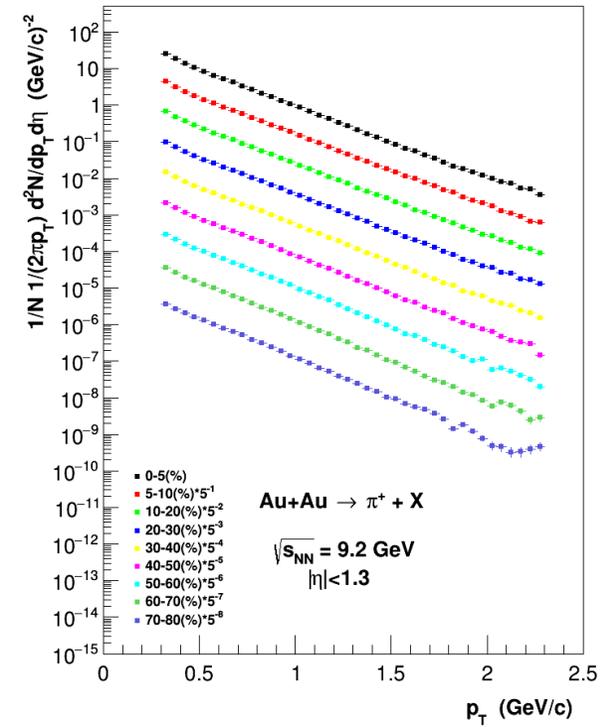
- Centrality classes were calculated based on the number of charged particles registered in TPC (PWG3-Flow group method). Results show little dependence on the model, pseudorapidity region used for track registration and collision energy
- Combined PID (dE/dx + TOF)



# Centrality dependent spectra of pions and kaons

*PHQMD* model  
efficiency corrected spectra

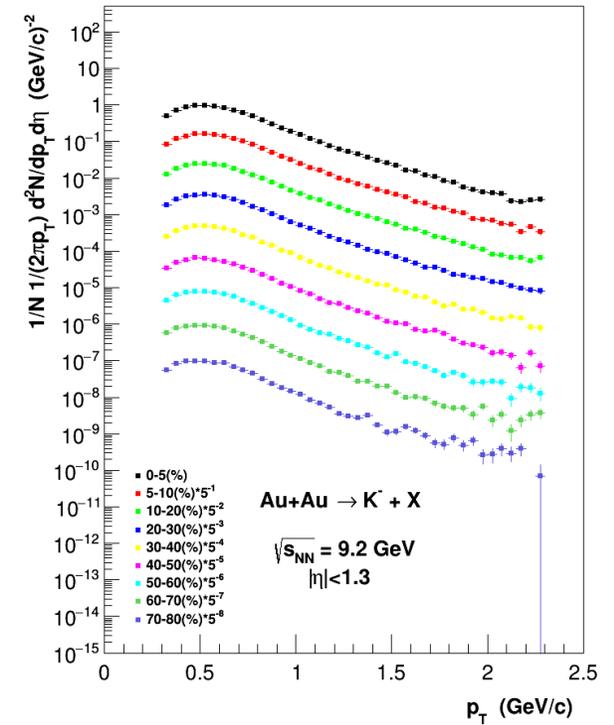
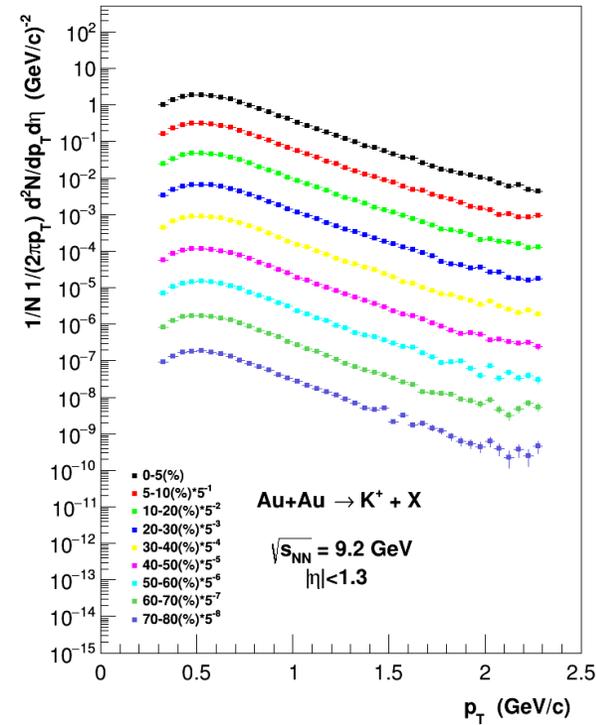
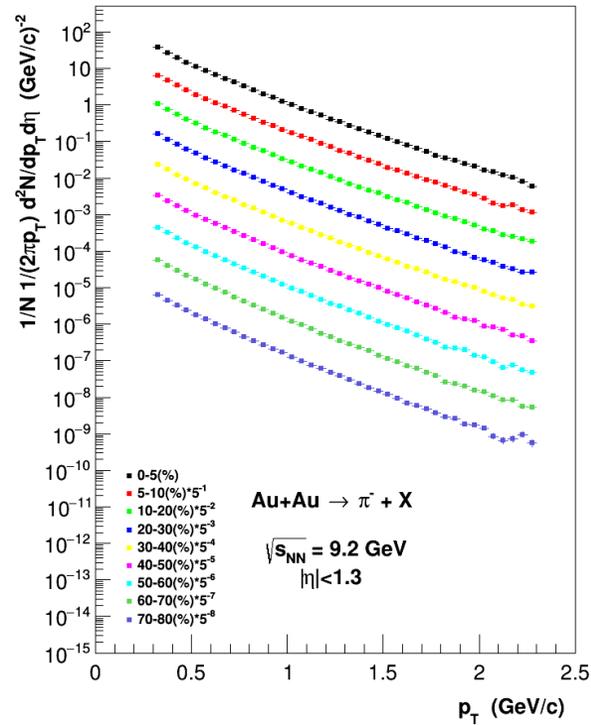
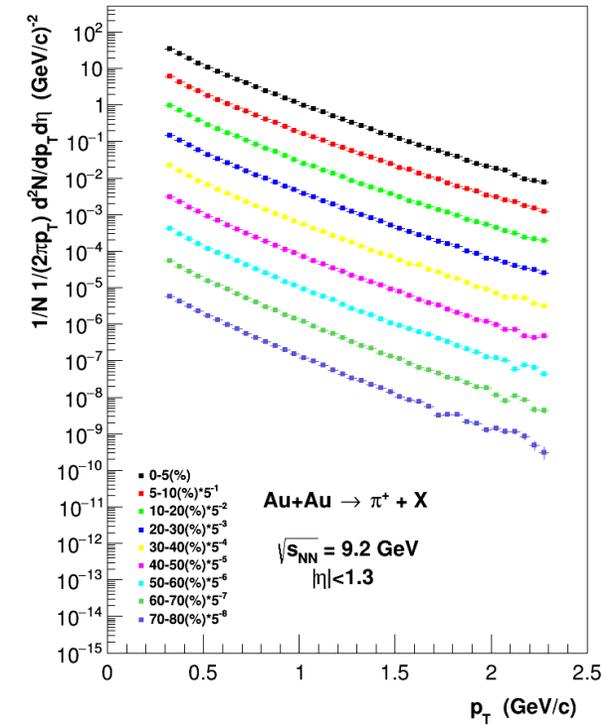
**MPD preliminary**



# Centrality dependent spectra of pions and kaons

*UrQMD* model  
efficiency corrected spectra

**MPD preliminary**



## Progress in light (hyper)nuclei

- Progress in the simulation of the cluster formation (PHQMD model)
- Reconstruction and analysis of hypernuclei in Bi+Bi collisions

# Progress in the PHQMD model

E. Bratkovskaya, J. Aichelin, V. Kireyeu, V. Voronyuk et al.

## PHQMD model

J. Aichelin, E. Bratkovskaya, A. Le Fèvre, V. Kireyeu, V. Kolesnikov, Y. Leifels, V. Voronyuk, and G. Coci, Phys. Rev. C 101, 044905



**The goal:** to develop a unified n-body microscopic transport approach for the description of heavy-ion dynamics and dynamical cluster formation from low to ultra-relativistic energies

**Realization:** combined model PHQMD = (PHSD & QMD) & SACA

### Parton-Hadron-Quantum-Molecular Dynamics

Initialization □ propagation of baryons:  
QMD (Quantum-Molecular Dynamics)

Propagation of partons (quarks, gluons) and mesons  
+ collision integral = interactions of hadrons and partons (QGP)  
from PHSD (Parton-Hadron-String Dynamics)

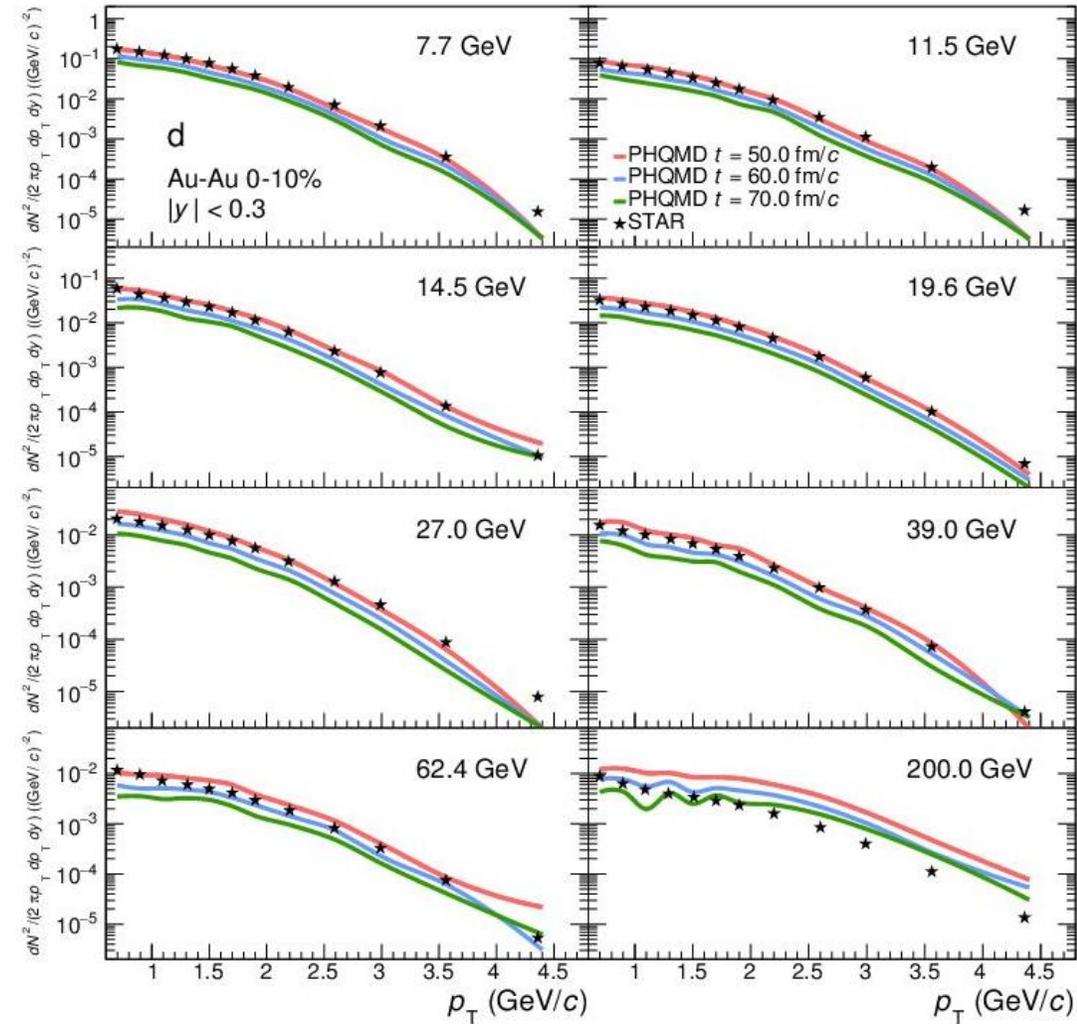
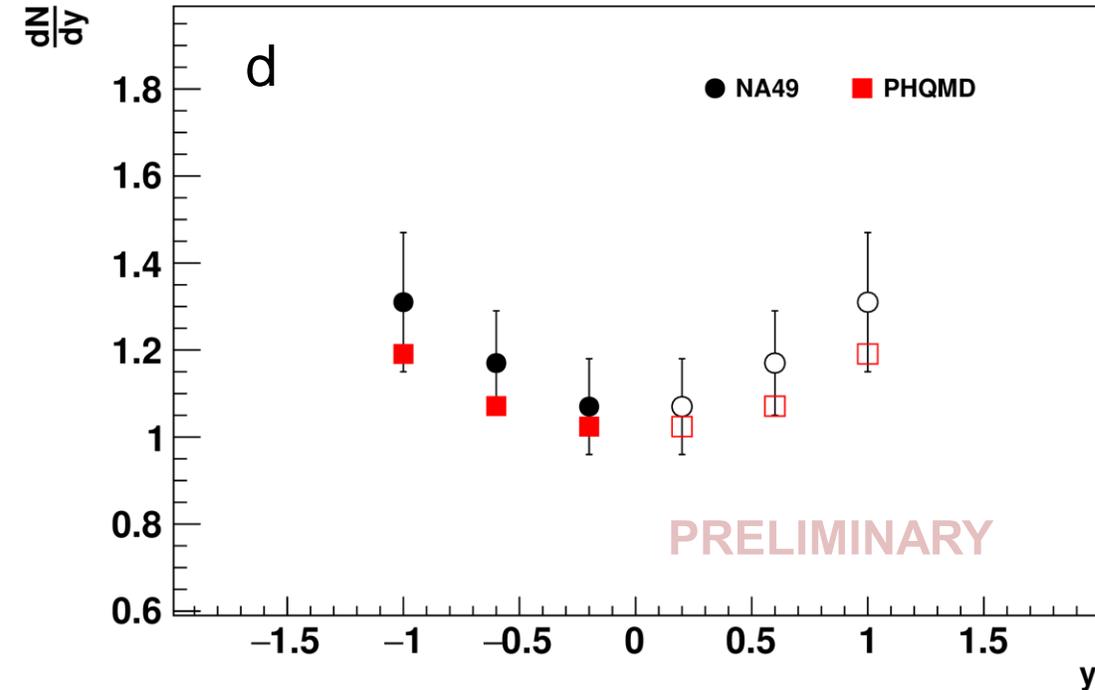
Clusters recognition:  
SACA (Simulated Annealing Clusterization Algorithm)  
vs. MST (Minimum Spanning Tree)

*PHQMD event generator is used as an input for the recent big DST production for PWG2 (40Mevents)*

# PHQMD model : predictions vs data at NICA energies (light nuclei)

[arXiv.org](https://arxiv.org) > [nucl-th](https://arxiv.org/abs/2106.14839) > arXiv:2106.14839

Pb+Pb,  $b = 0 - 5$  fm,  $\sqrt{s_{NN}} = 8.8$  GeV

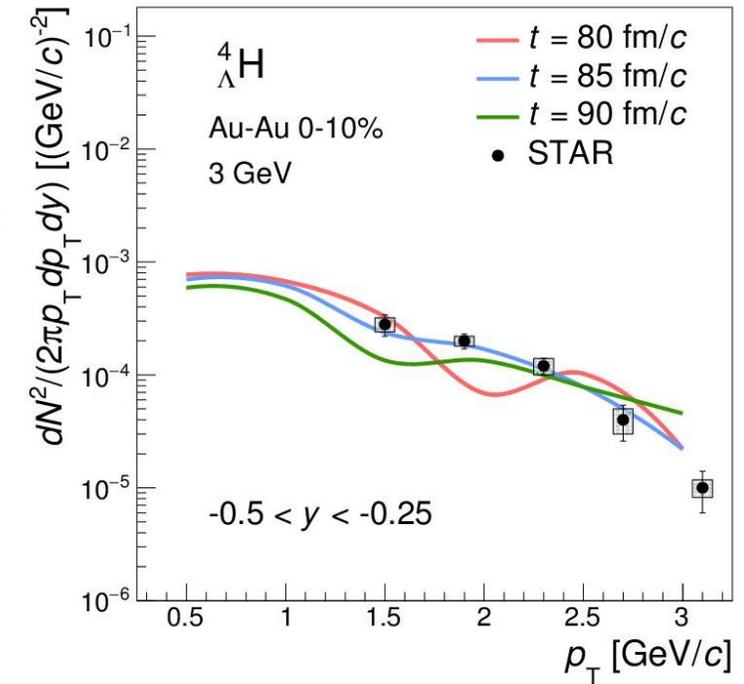
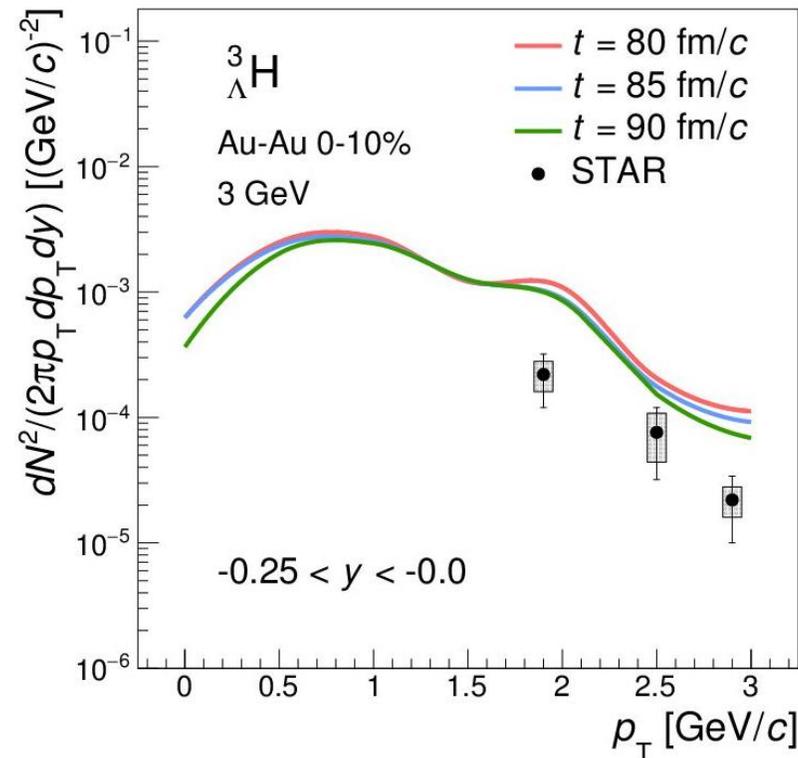
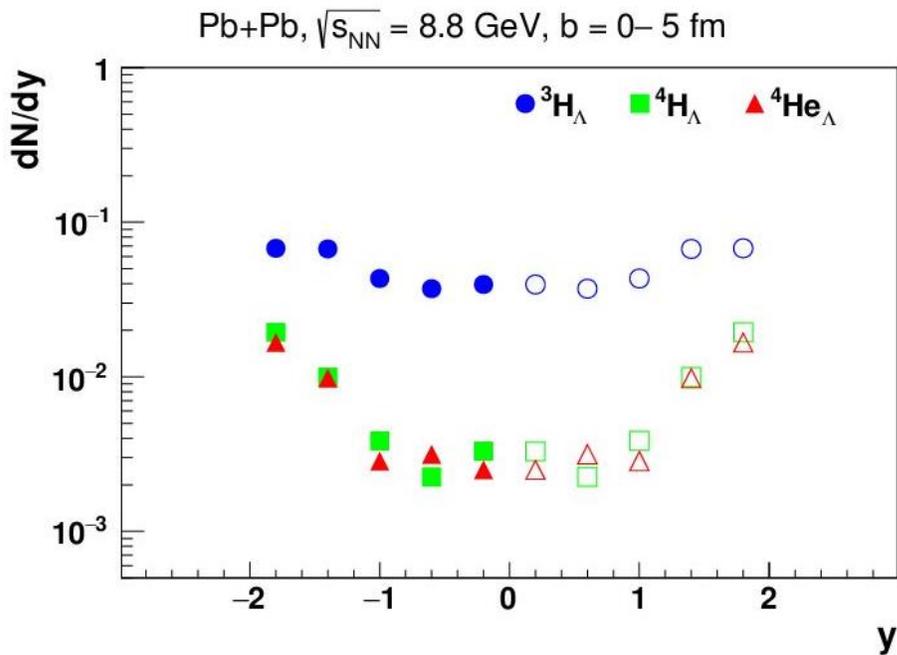


- Reasonable predictions for the yields of fragments
- Tunable parameters for nuclear matter EoS and fragment formation time
- Can be used as input for simulation of nuclei at MPD

# PHQMD model : predictions vs data at NICA energies (hypernuclei)

- PHQMD reproduces results for hypernuclei from STAR
- Is used as an input for the simulation of hypernuclei at MPD

[arXiv.org](https://arxiv.org/abs/2106.14839) > [nucl-th](https://arxiv.org/abs/2106.14839) > arXiv:2106.14839



# MPD PID performance for hypernuclei (update)

- Precise information on YN interactions: strange sector of nuclear EOS, astrophysics

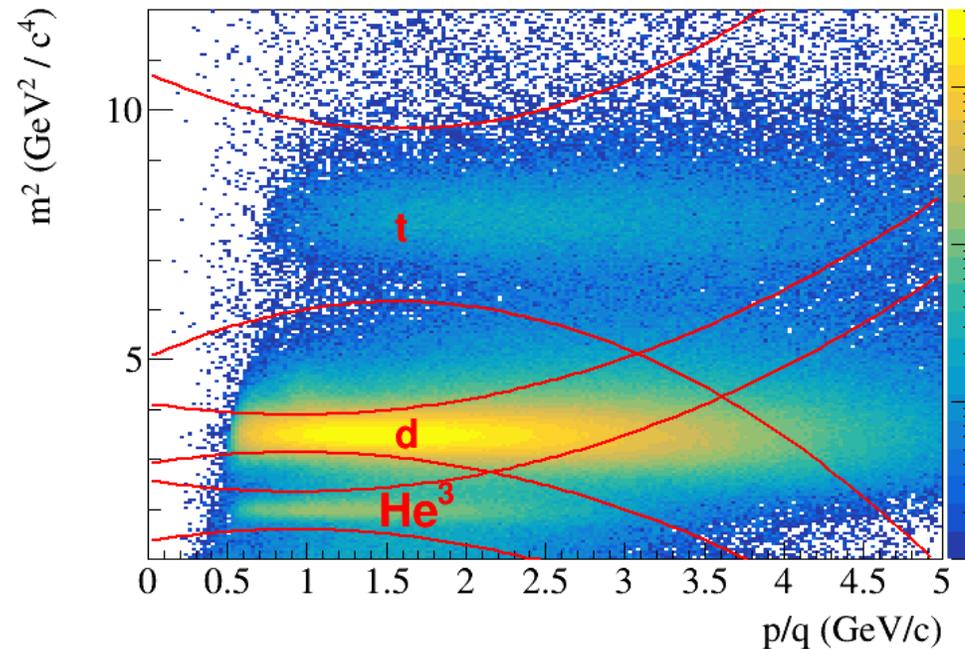
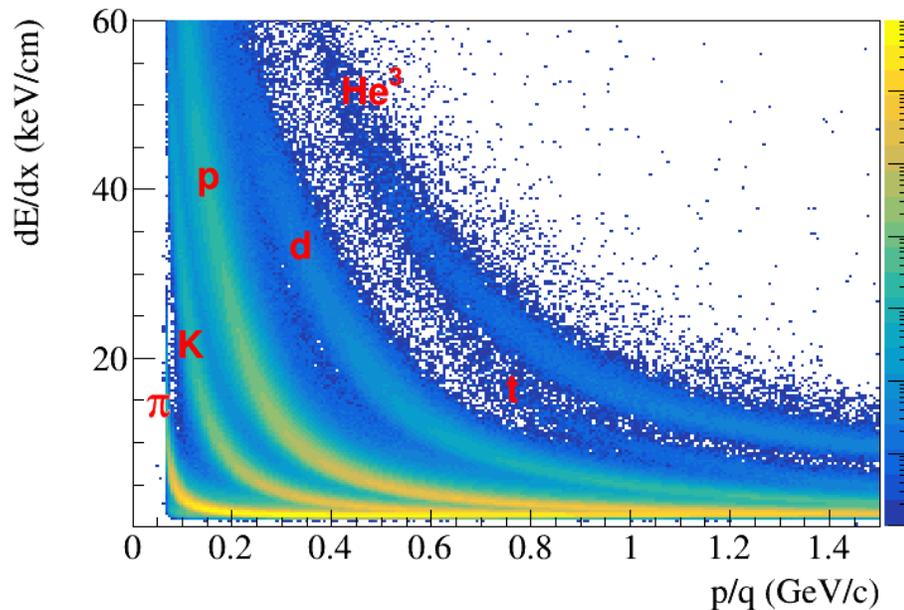
✓ 40MeV Bi+Bi at 9 GeV from the PHQMD model – the largest data set produced ever!

Many thanks to the Soft. Group and A.Moshkin for the job!

✓ Centralized DST production

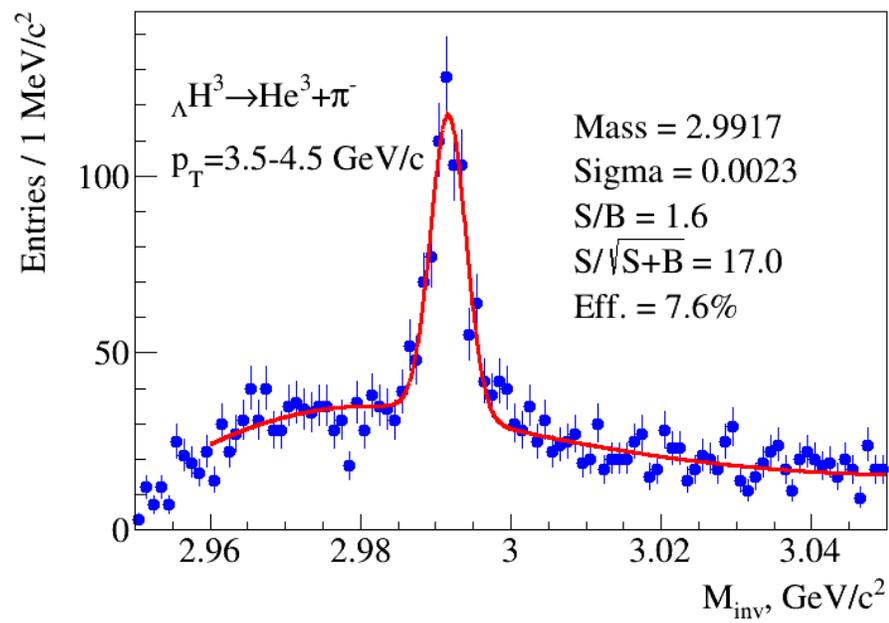
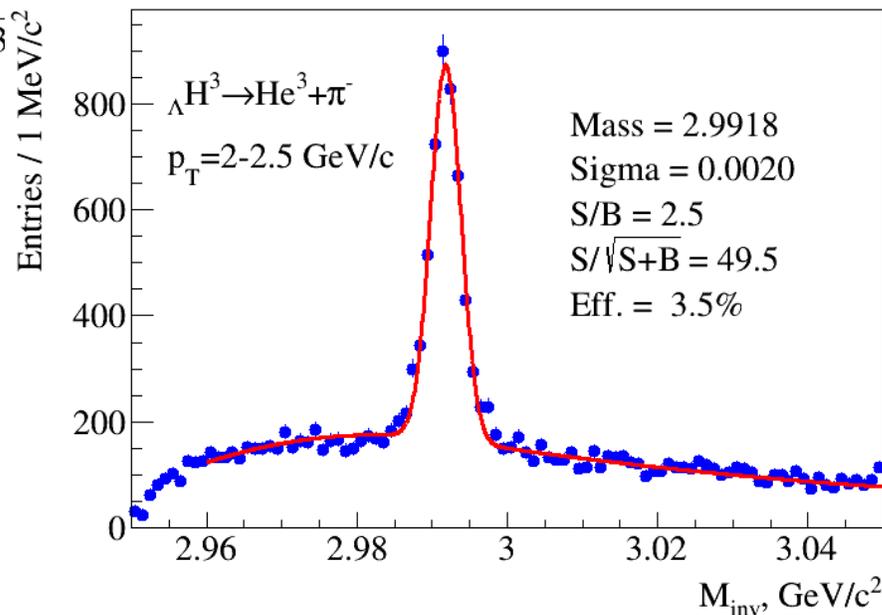
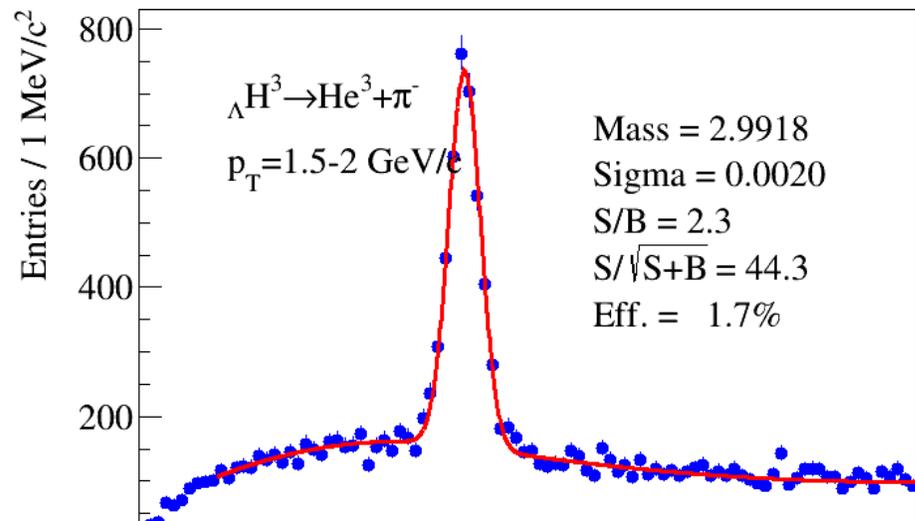
✓ MPD analysis chain

✓ Combined (dE/dx + TOF) particle ID, secondary vertexing

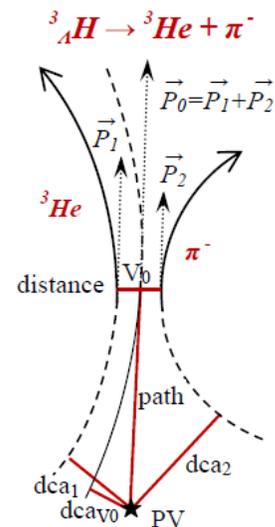


# Reconstruction of hypertritons in MPD

V.Vasendina, A.Zinchenko

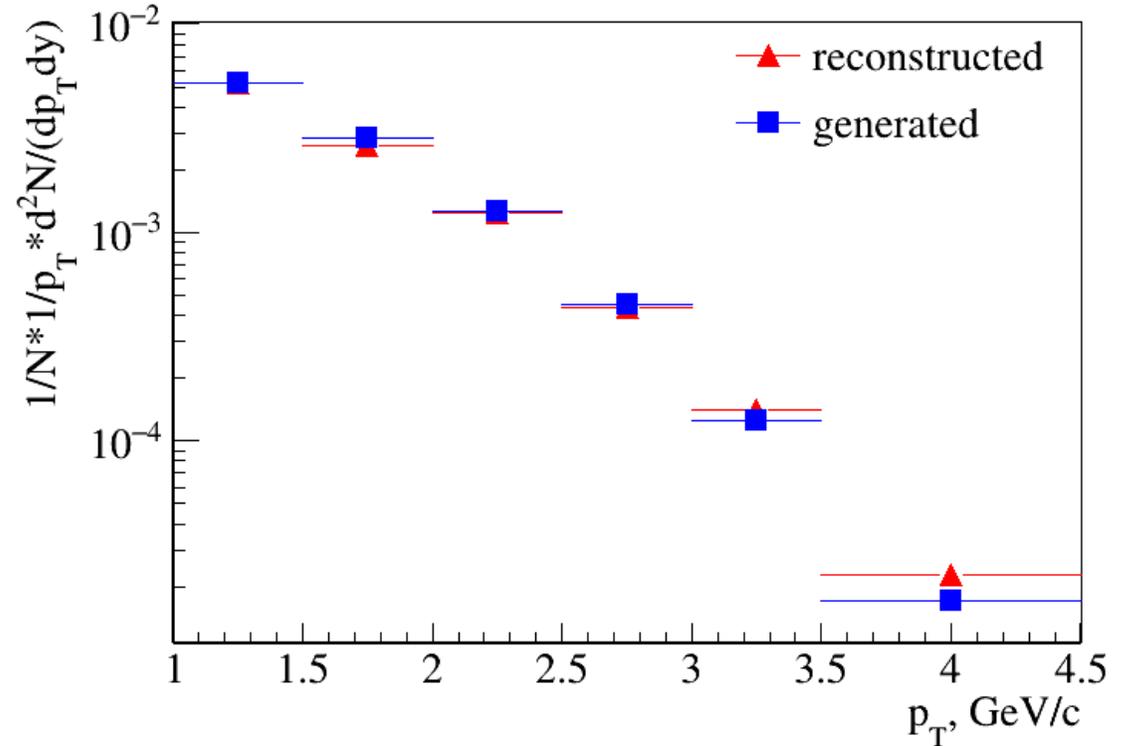
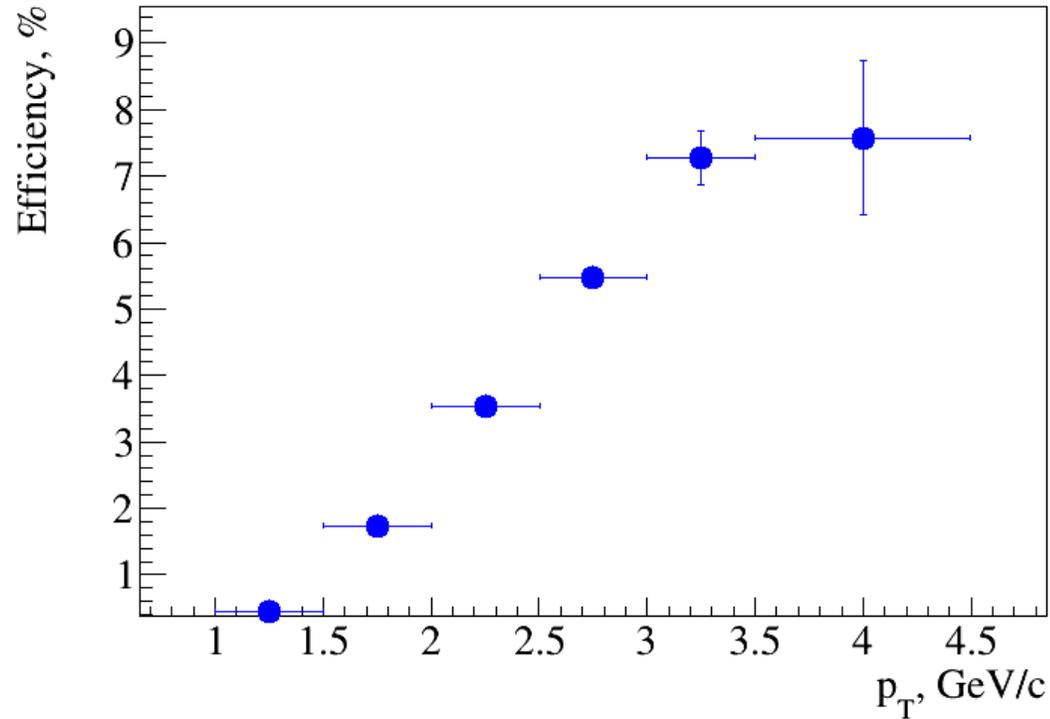


- ◆ PV – primary vertex
- ◆  $V_0$  – vertex of hyperon decay
- ◆ dca – distance of the closest approach
- ◆ path – decay length



# Hipertritons in Bi+Bi collisions : efficiency and pT-spectrum

- 40M Events BiBi at 9.2 GeV,  $|y| < 1$ , no centrality selection

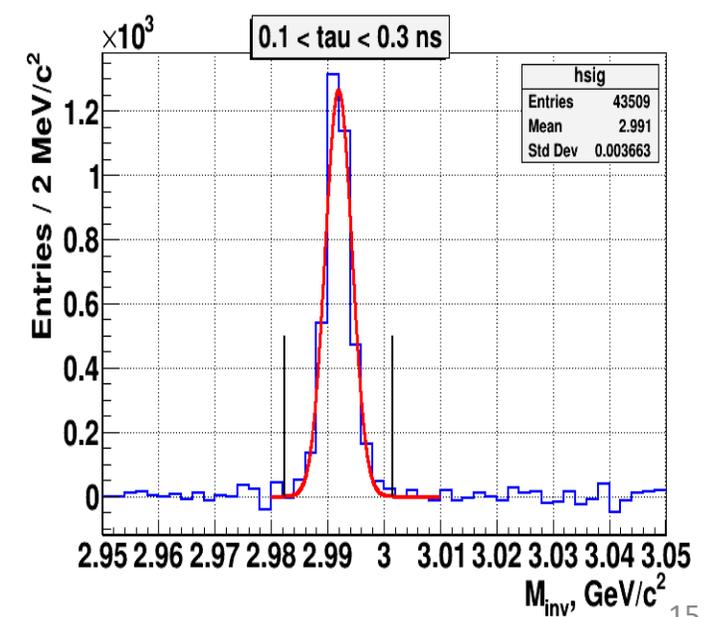
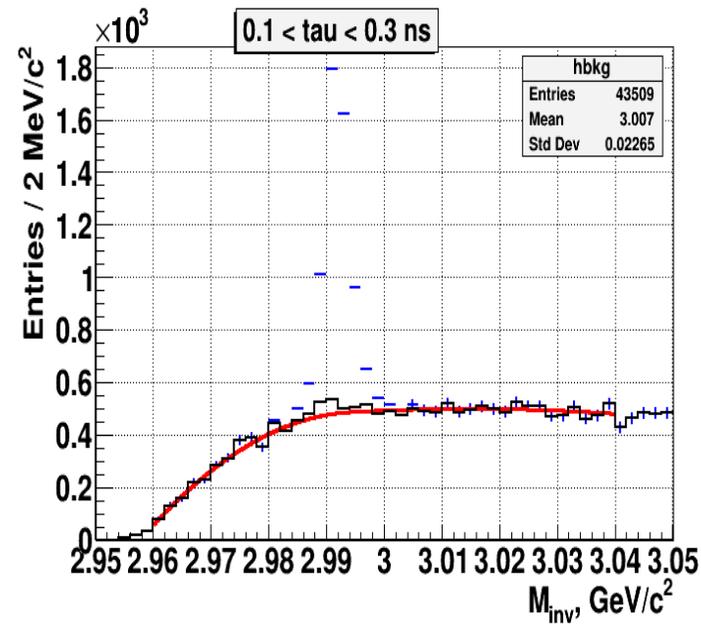
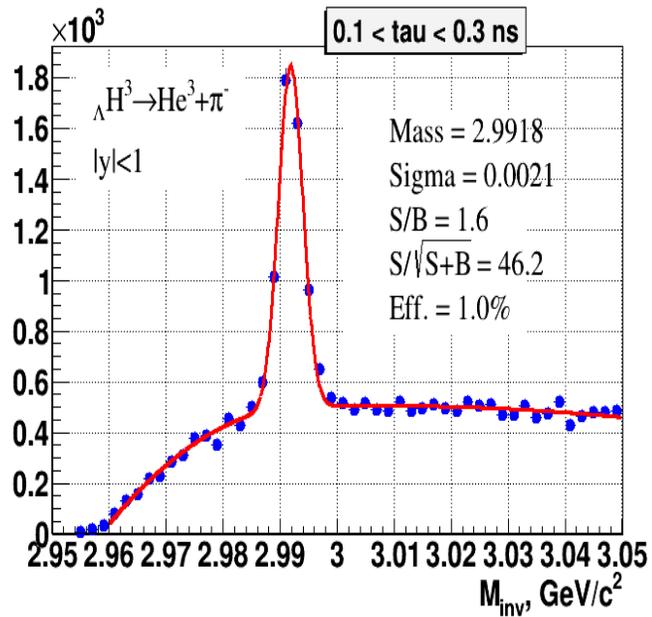
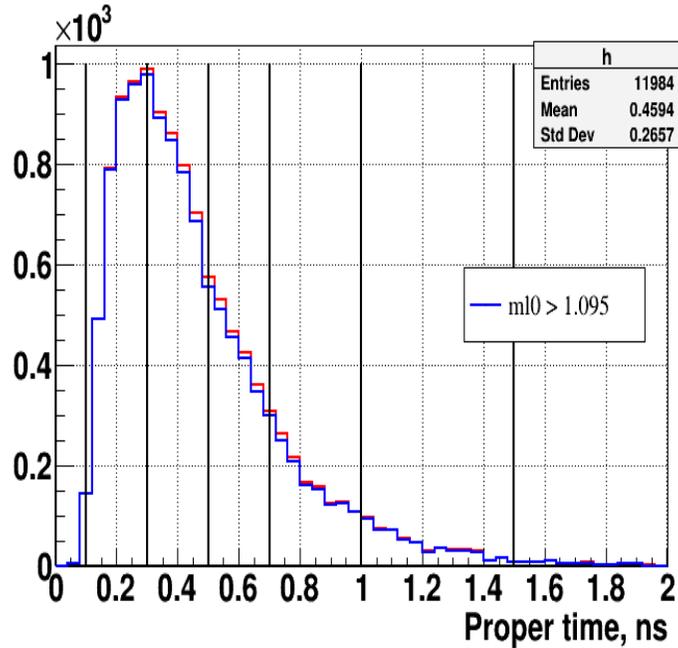


- Invariant spectrum is reconstructed up  $p_T = 4.5$  GeV/c
- Rapidity density can be obtained in minbias Bi+Bi collisions

# Hyperon lifetime measurements

- Hyperon lifetime puzzle in HIC affects Y-N interactions in the medium and requires additional measurements
- Results in a broad region of  $c\tau$  also requires large data sets

$$c\tau = cML/p \text{ (c-speed of light, M-hypertriton mass, L-track length)}$$



# H3L lifetime (old vs new production)

## Old production

15 Mevents, Au+Au at 9 GeV,  $b < 16$  fm

$$\tau = [0.2 - 1.0] \text{ ns}$$

$$p1 = 259 \pm 19 \text{ ps (7\%, 2\%)}$$

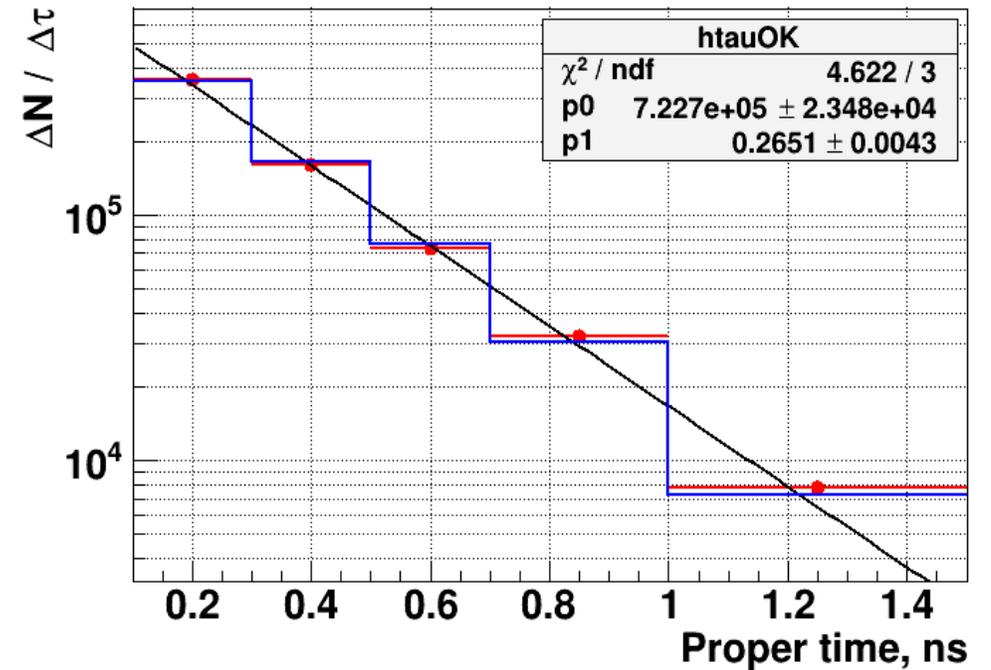
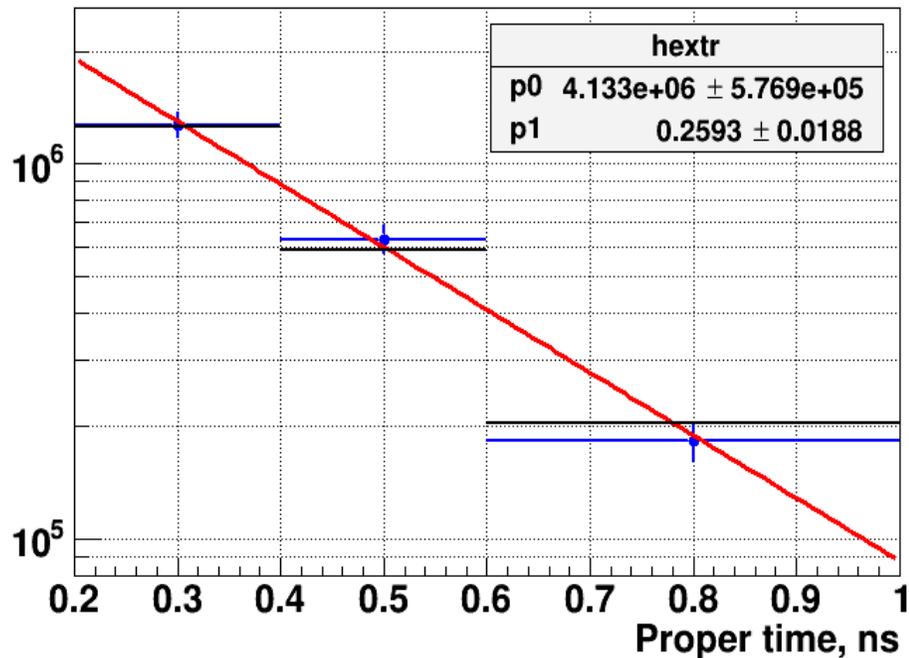
## New production

40 Mevents, Bi+Bi at 9.2 GeV,  $b < 12$  fm

$$\tau = [0.1 - 1.5] \text{ ns}$$

$$p1 = 265 \pm 4 \text{ ps (2\%, 1\%)}$$

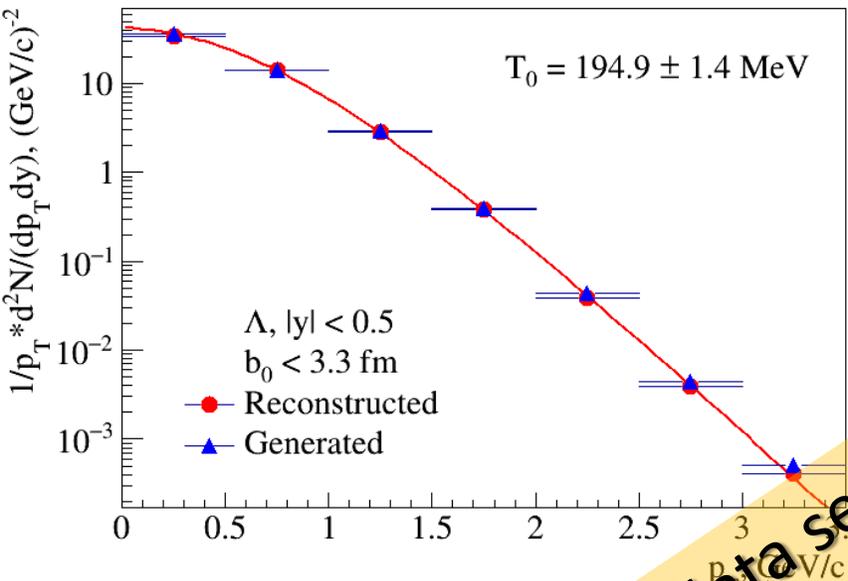
Fit:  $dN/d\tau = p0 \cdot \exp(-\tau/p1)$ ,  $p1$  - lifetime



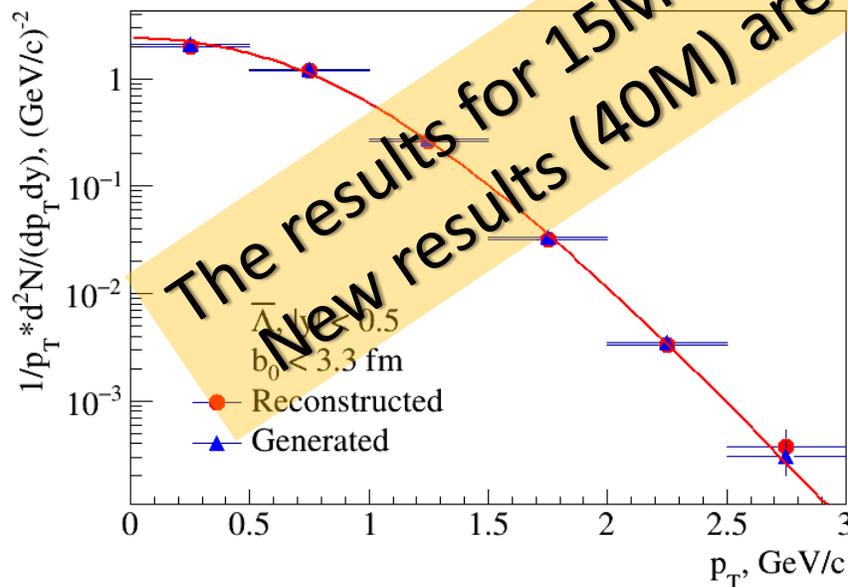
**Several analyses with the recently produced 40M data sample are ongoing:**

- ❖ Performance study for  $\Lambda$ H<sup>4</sup> and  $\Lambda$ He<sup>4</sup>
- ❖ Hyperon production and antihyperon-to-hyperon ratio at high-pT

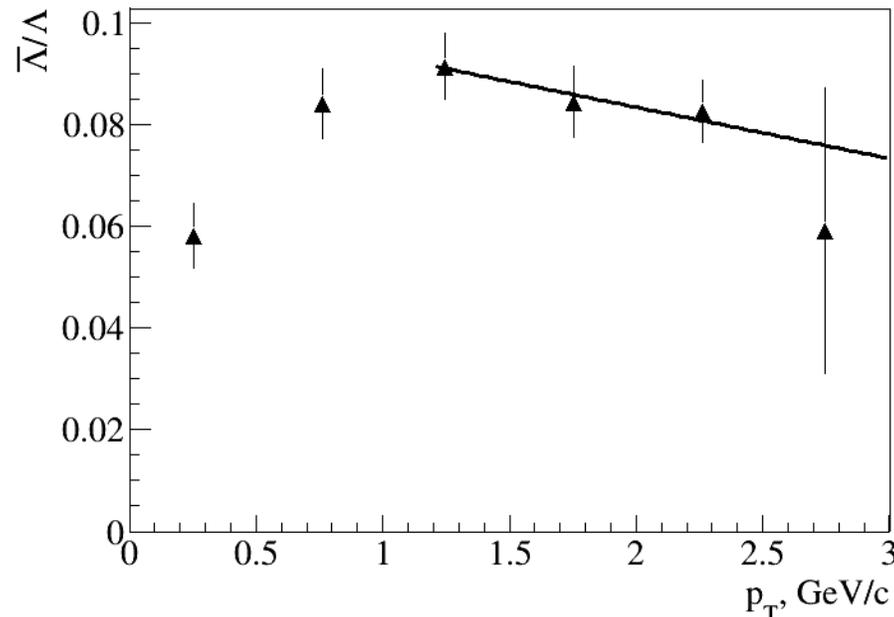
# (anti)Hyperon spectra and ratio



- With hyperon production we can address bulk properties, phase transition as well as critical phenomena.
- Antibaryon-to-baryon ratio at intermediate momenta ( $p_T > \sim 1 \text{ GeV}/c$ ) can be sensitive to CEP (a falling trend in contrast to a constant behavior in the scenario without CEP) - *Askawa, et al., Phys. Rev. Lett. 101, 122302 (2008)*.



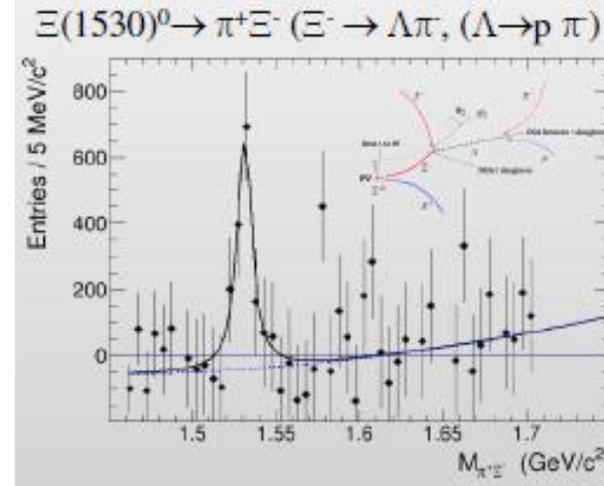
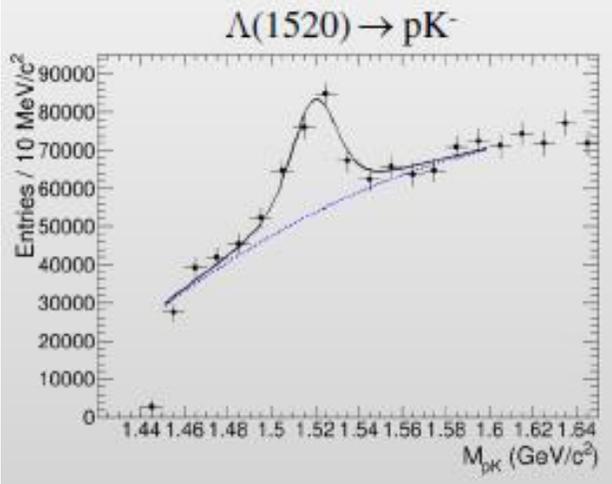
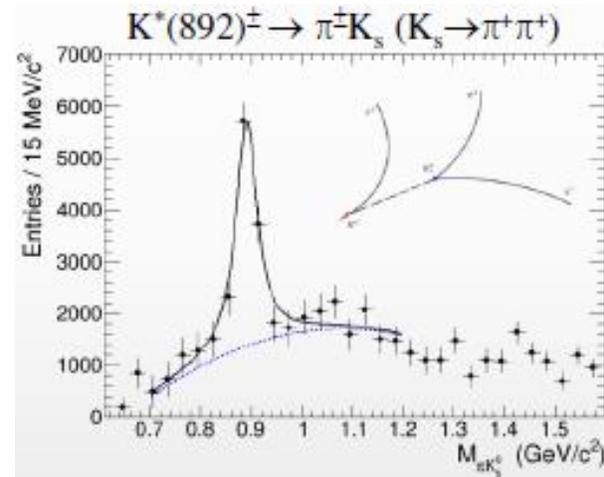
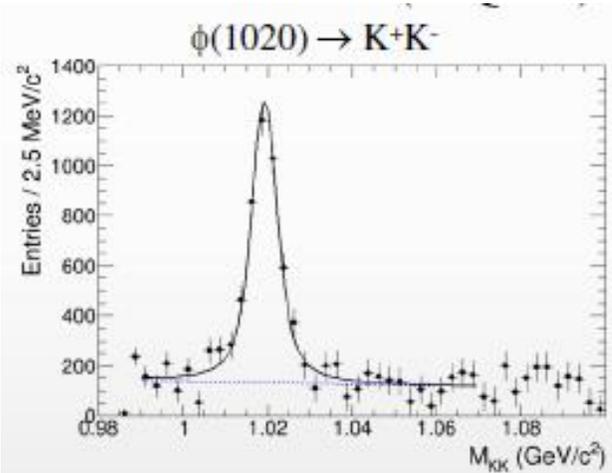
- Full corrected spectra of hyperons (including feeddown)
- Midrapidity spectra up to  $p_T=3-3.5 \text{ GeV}/c$ . Good results of closure tests
- **but the error in the slope of the antiL/L-ratio for  $10^7$  events is too large, - a 10–100-time bigger data set is needed**



# Progress in the study of resonances

V. Riabov + team

- AuAu at 11 GeV (UrQMD) after mixed-event background subtraction

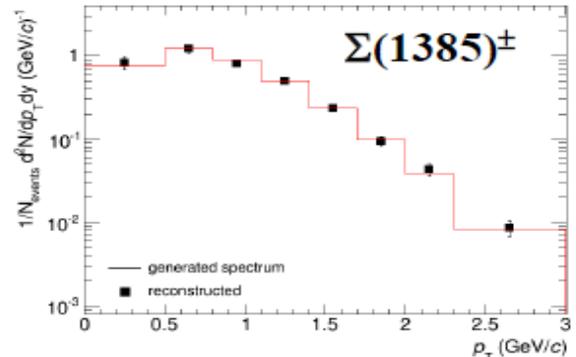
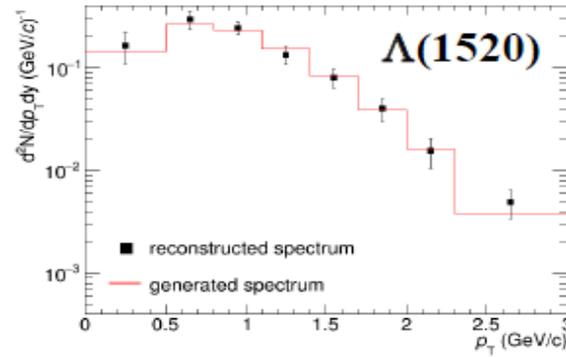
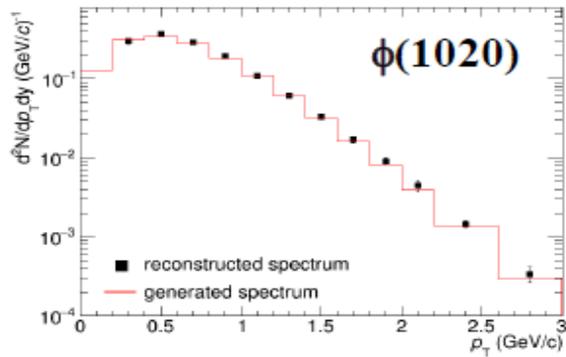
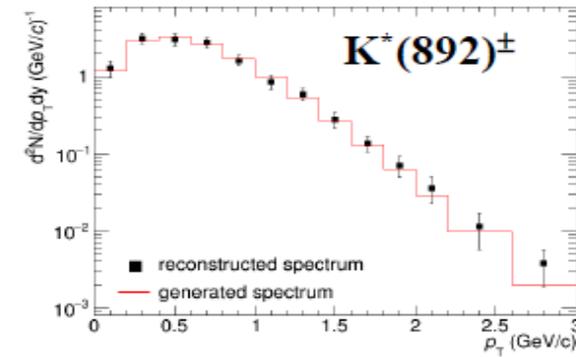
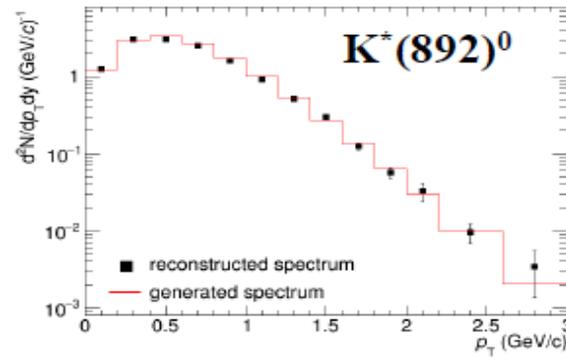
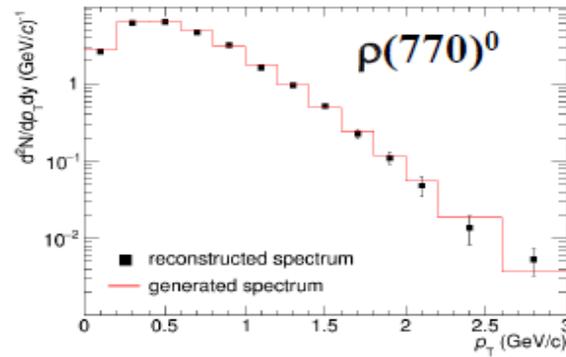


- MPD is capable to reconstruct resonances in HIC by means of combined dE/dx+TOF information
- Second vertex decay technique is required for weakly decaying resonances

# Resonances in Bi+Bi reactions

D. Ivanishchev for MPD, Nucleus-2021

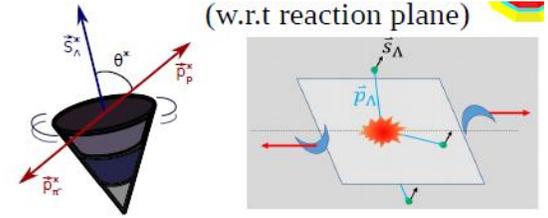
- ❖ UrQMD v.3.4: BiBi@9.2 (5M events)
- ❖ Full chain simulation and reconstruction,  $p_T$  ranges are limited by the possibility to extract signals,  $|y| < 1$



- ❖ Reconstructed spectra match the generated ones within uncertainties
- ❖ First measurements for resonances will be possible with accumulation of  $\sim 10^7$  Bi+Bi@9.2 events
- ❖ Measurements are possible starting from  $\sim$  zero momentum  $\rightarrow$  sample most of the yield, sensitive to possible modifications
- ❖ Measurements of  $\Xi(1530)^0$  are very statistics hungry

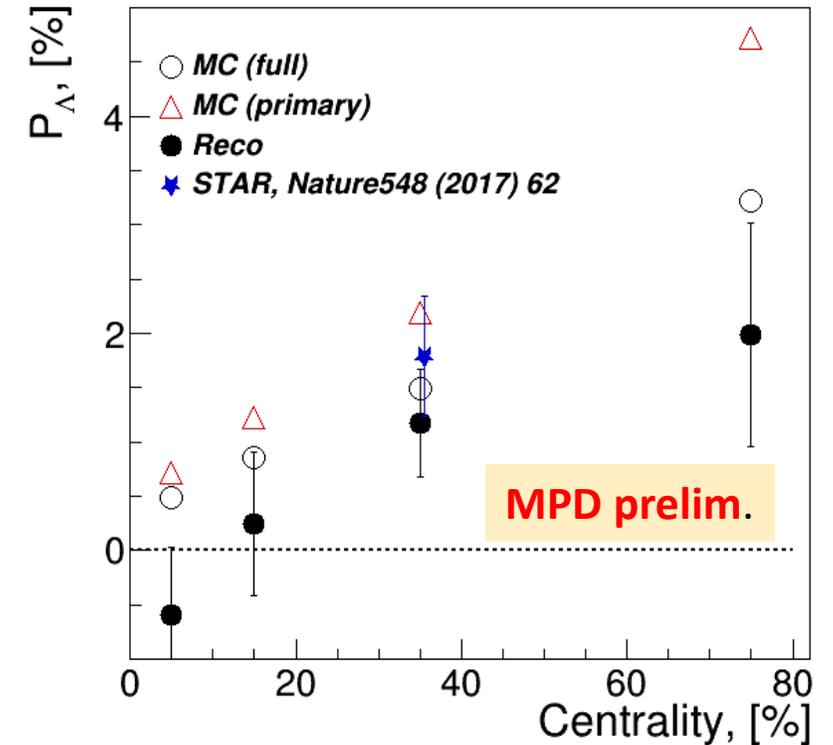
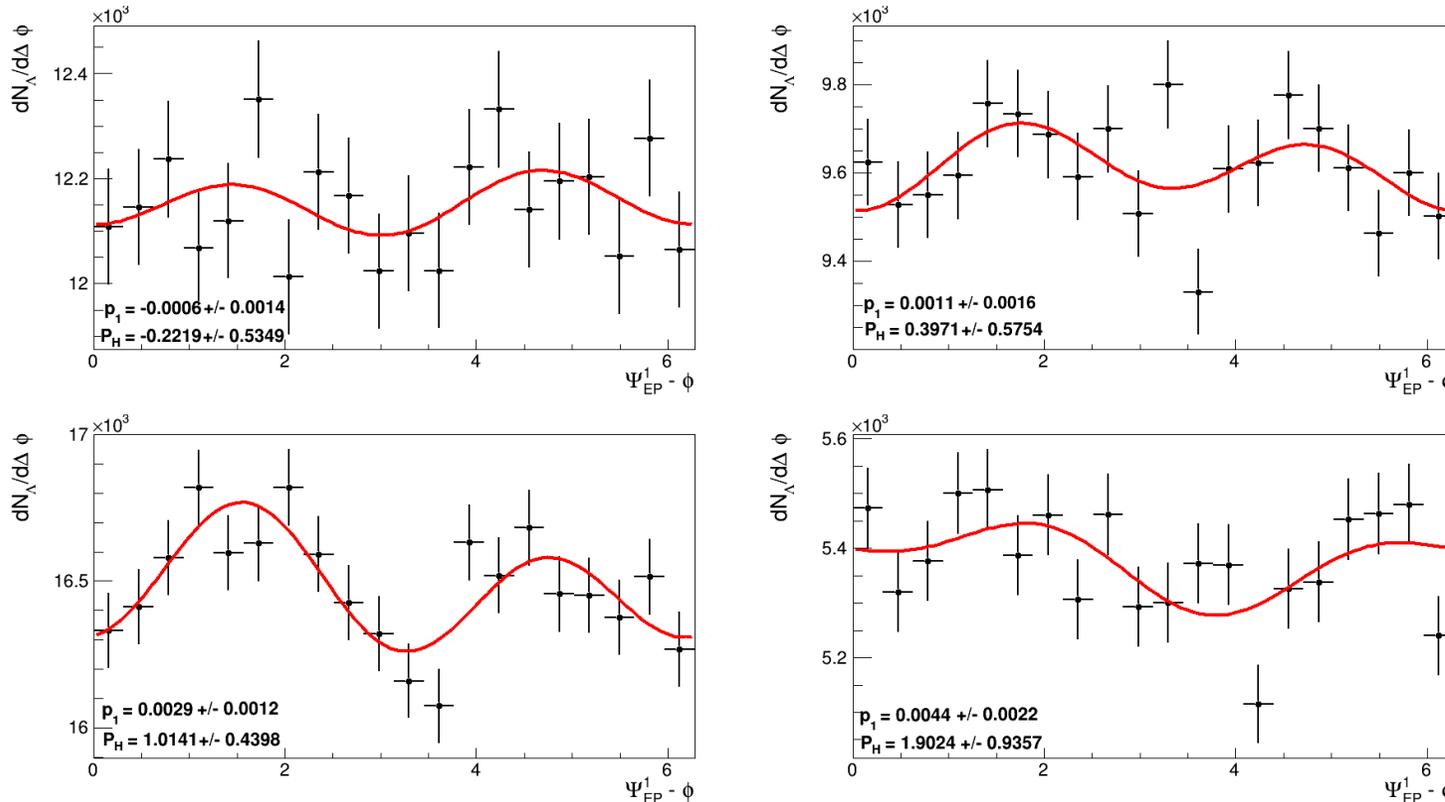
# Global hyperon polarization (ongoing analysis)

E.Nazarova



- Minbias Au+Au at 7.7 GeV (PHSD)
- Global hyperon polarization modelled via thermodynamic (Becattini) approach
  - Transfer of hyperon polarization vector from generator data (PHSD) to MPD simulation (MCTracks)
  - Transfer of polarization during hyperon decays (feed-down)
- Centrality estimated through multiplicity in TPC (MC-Glauber, P.Parfenov)
- Event plane angle measured through FHCAL

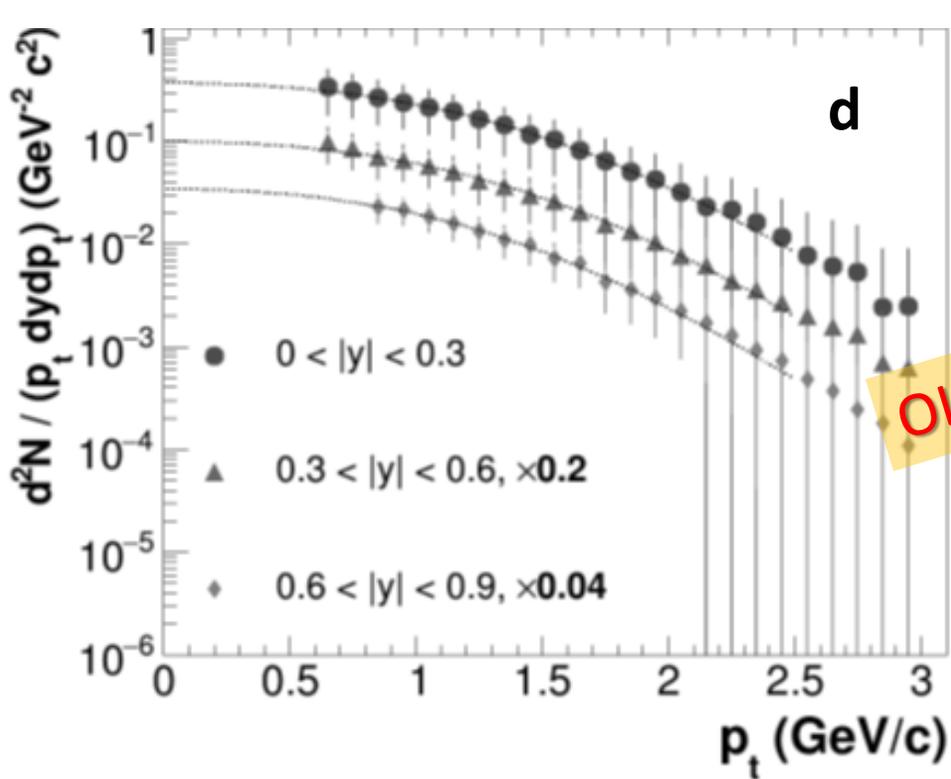
$$\bar{P}_{\Lambda/\bar{\Lambda}} = \frac{8}{\pi\alpha} \frac{1}{R_{EP}^1} \langle \sin(\Psi_{EP}^1 - \phi_p^*) \rangle$$



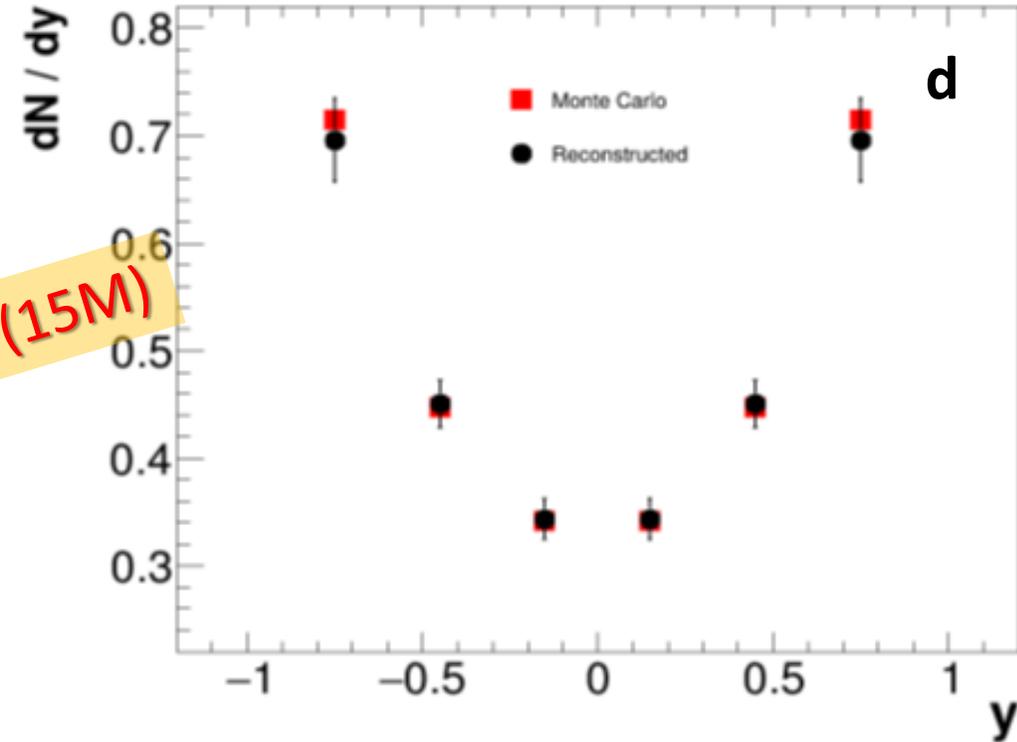
*More details in the talk E.Nazarova today*

# Yields of light nuclei in Bi+Bi

- Little progress since April
- Additional tests of light nuclei (t, He3, He4) production and propagation in material



OLD results (15M)

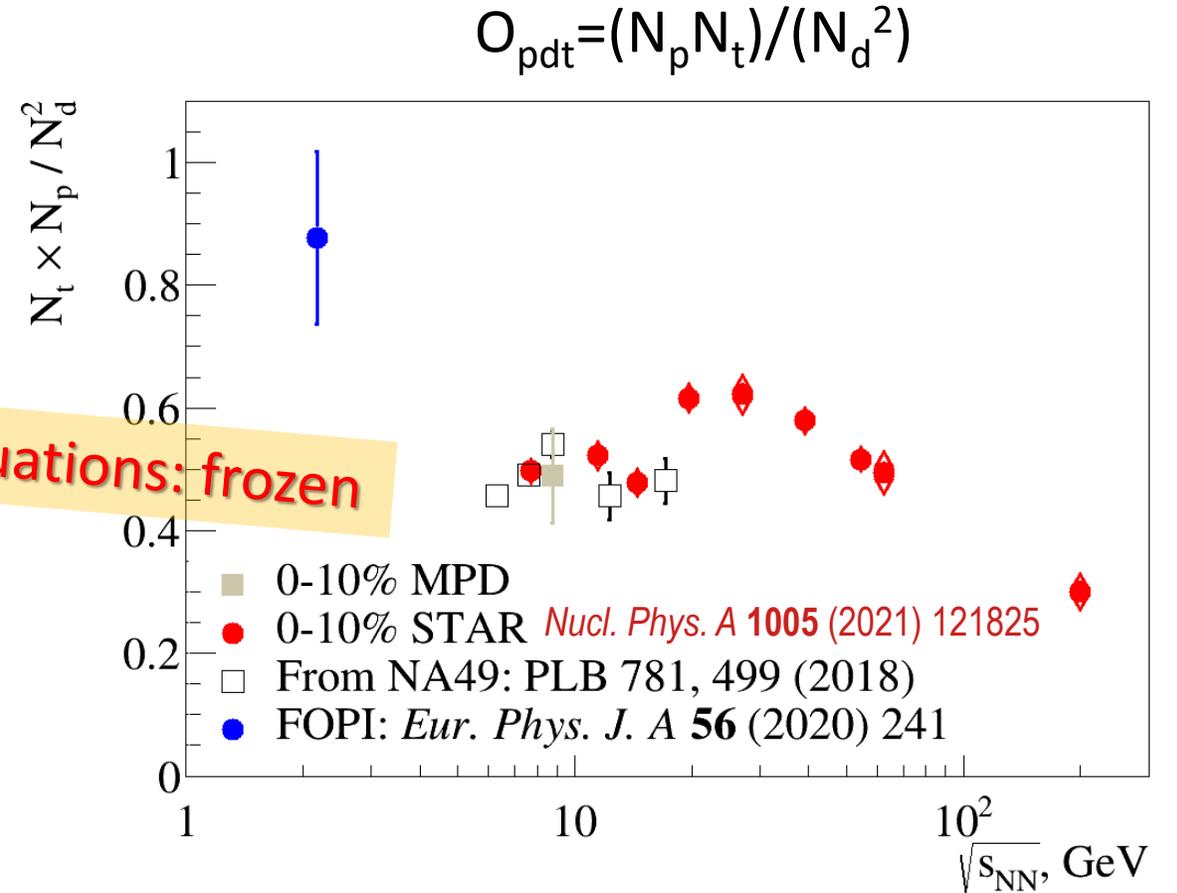
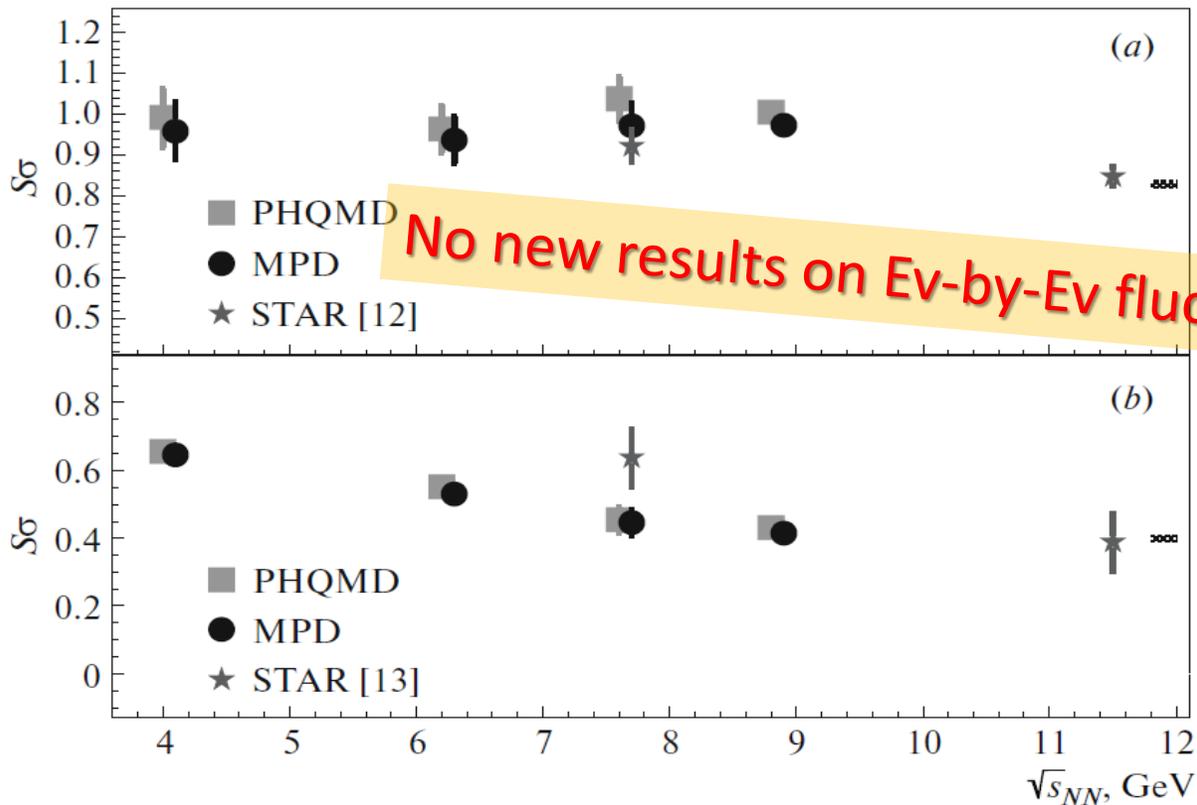


- ✓ Low  $p_T$ -range is populated by spallation in the MPD material ( $p_T$ -cutoff is larger than expected)
- ✓ BW fits describe the shape of spectra quite well, allowing precise integration and yield estimates

# Event-by-event fluctuations (net-protons, net-kaons, density fluctuations)

- $5 \cdot 10^4$  central Au+Au events at  $\sqrt{s} = 4, 6.2, 7.6$  and  $12.3$  GeV and  $10^6$  central Au+Au events at  $8.8$  GeV (PHSD)
- Recent reco chain,  $dE/dx+TOF$  combined PID
- Set of track quality cuts, DCA cut to suppress secondaries

effective skewness  $S\sigma$  for net-protons (a) and net-kaons (b)



# Summary

- MPD physics simulation within PWG2 is ongoing  
Steady progressing : *Hadron spectra, (Hyper)nuclei, Resonances*  
**The goal** – finish analyses and prepare materials for the “MPD Performance Paper 2”
- **Further actions/plans** : narrow focus to 1-Day observables (**light hadrons, hyperons and resonances can be studied in a 10M data set**), pay more attention to developing/standardization official event/track selection criteria, particle ID methods, efficiency corrections, and unification of the analysis code to MPD standards.

***Thank you for your attention!***