MPD PWG2 status report

Vadim Kolesnikov

(VBLHEP, JINR)

on behalf of the group

MPD Collaboration meeting
JINR, Dubna, April 21-23, 2021

Outline

- **PWG2 tasks**
- **Update of feasibility study results :**
  - Light hadrons
  - Hyperons
  - Light nuclei
  - Hypernuclei
- **Summary**

PWG2 co-conveners:

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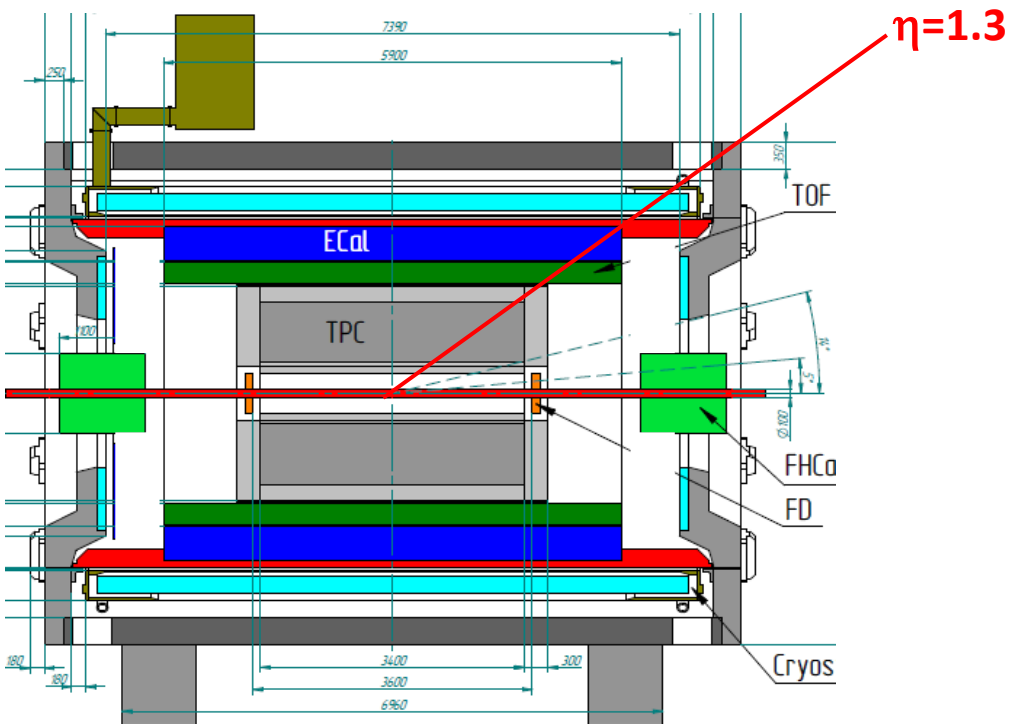
PWG2 physics cases

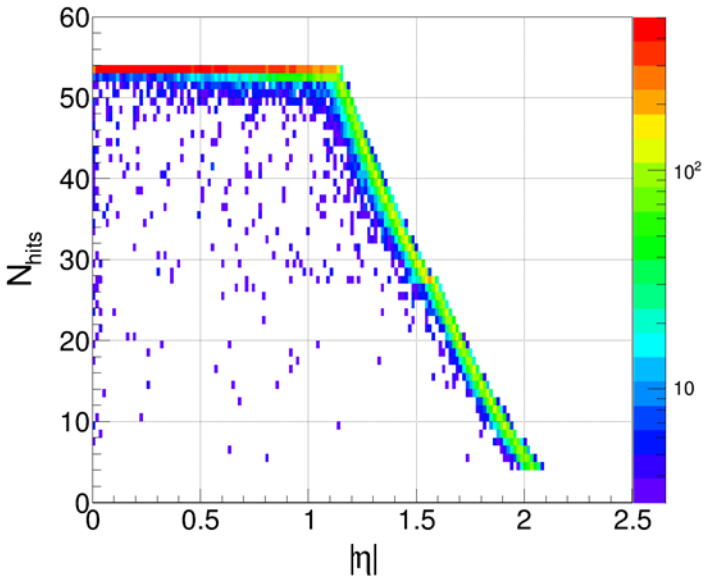
- **Light flavor hadron spectra, yields, and ratios**
  - Energy, system size and centrality dependence of the production of charged hadrons (pions, kaons, (anti)protons).
  - Extraction of transverse momentum spectra, rapidity distributions, mean multiplicities, and particle ratios.
  - Nuclear modification factor, antiparticle/particle ratio, radial flow, phase diagram mapping.
- **Strangeness (hyperons and hypernuclei)**
  - Analysis of strange hyperons (Lambda, Ksi, 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, Kstar, Lambda(1520) etc.
- **Light nuclei**
  - Production of nucleon clusters (d, t, He3, He4) in various reactions (from p+p to Au+Au): spectra, yields, coalescence coefficients.

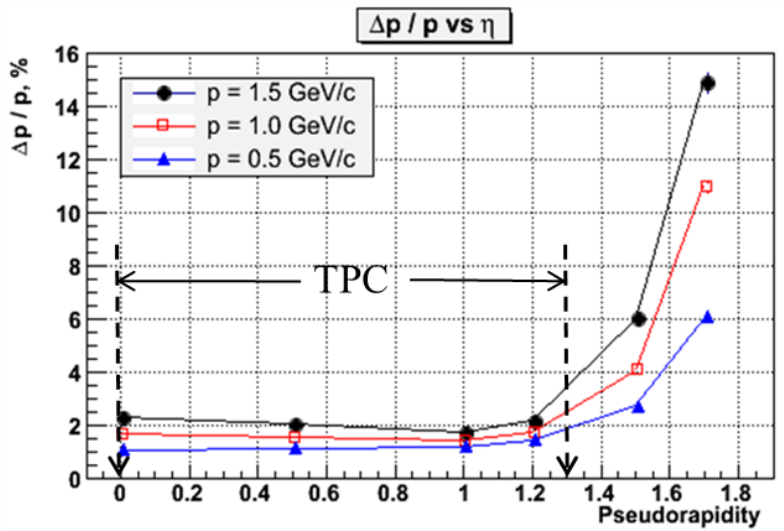
MPD setup and overall performance



MPD at Stage'1:

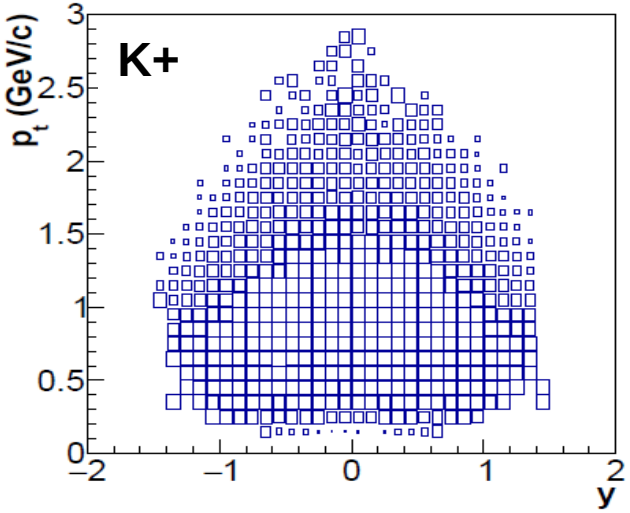
- ***TPC*** *tracking:* $|\eta|<1.6$ *(Npoints>15)*
- ***TOF & ECAL*** *coverage:* $|\eta|<1.3$
- ***PID****: TOF+dE/dx combined* $|\eta|<1.3$*, pT<3 GeV/c, limited PID* $1.3<|\eta|<1.6$ *(dE/dx)*



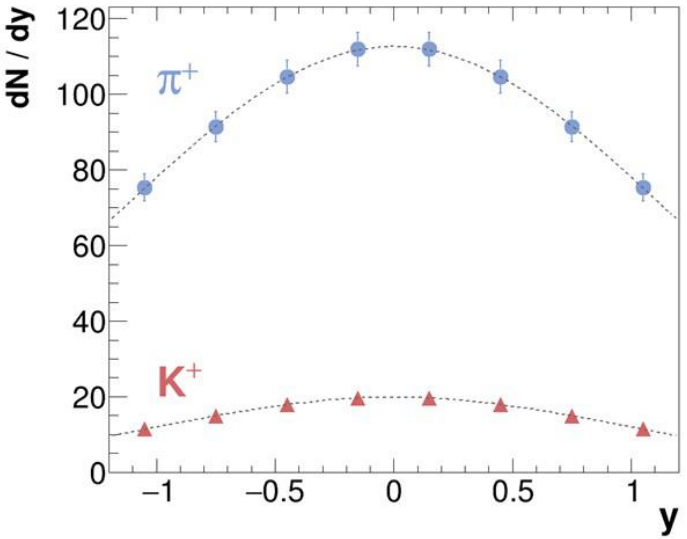


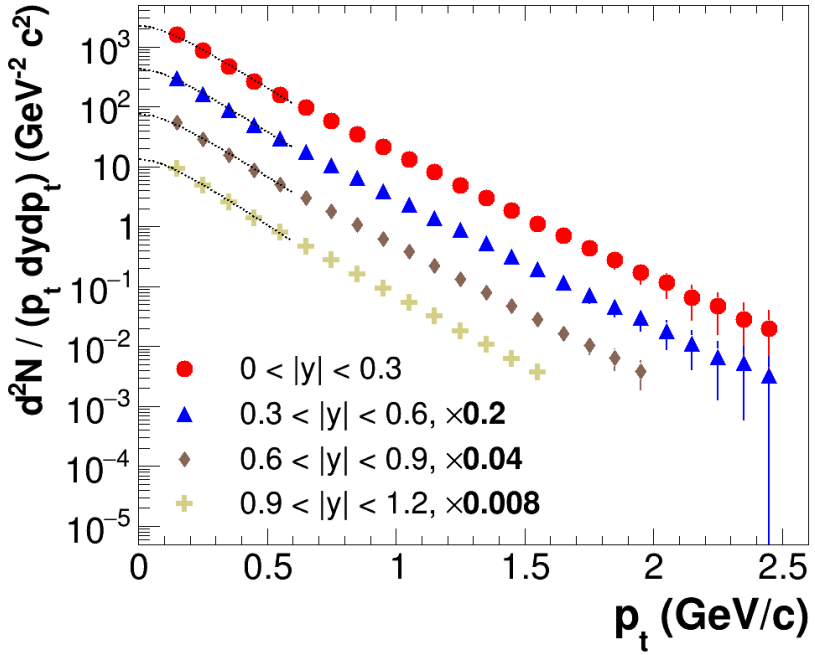
Light hadrons : spectra and yields from central Au+Au collisions

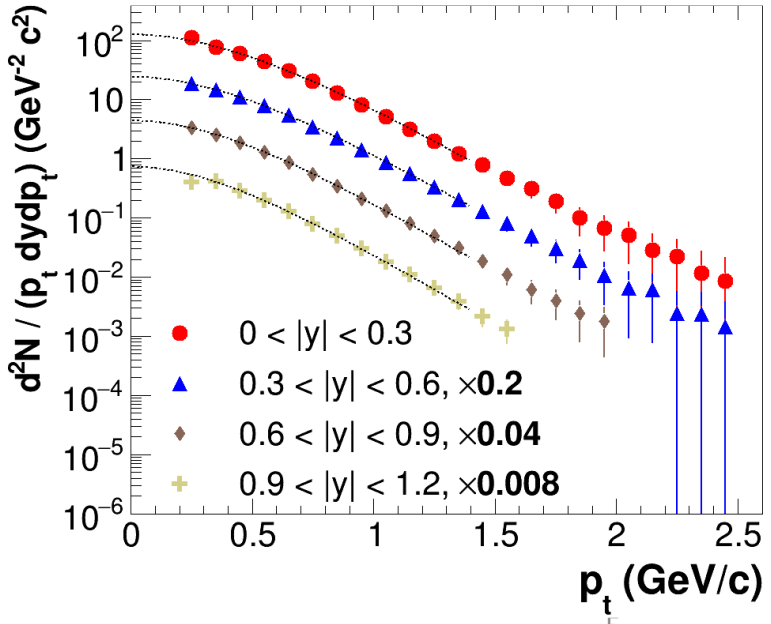
- *0-5% central Au+Au at 9 GeV from the PHSD event generator, which implements partonic phase and CSR effects*
- *Recent reconstruction chain, combined dE/dx+TOF particle ID, spectra analysis*
- *Included to the paper draft on first physics with MPD*



- MPD provides large phase-space coverage for identified pions and kaons (> 70% of the full phasespace at 9 GeV)
- Hadron spectra can be measured from p_T=0.2 to 2.5 GeV/c
- Extrapolation to full p_T-range and to the full phase space can be performed exploiting the spectra shapes (see BW fits for p_T-spectra and Gaussian for rapidity distributions)



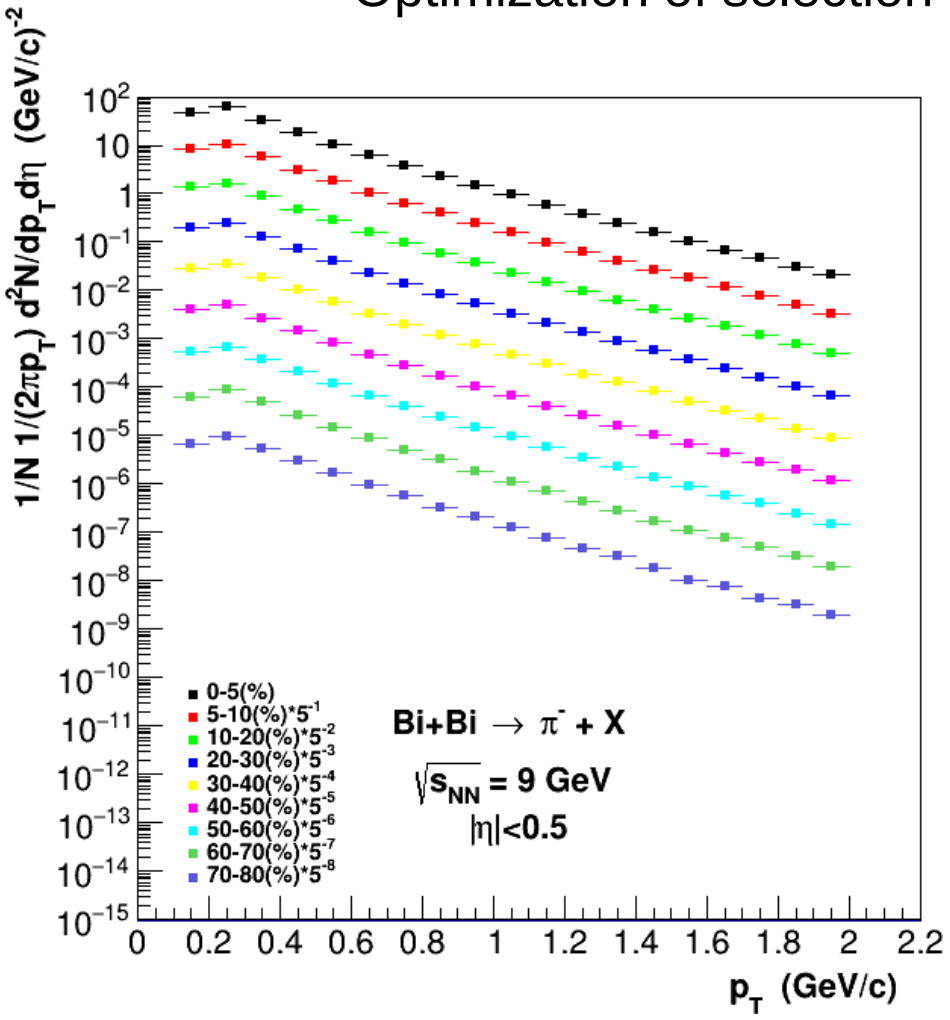


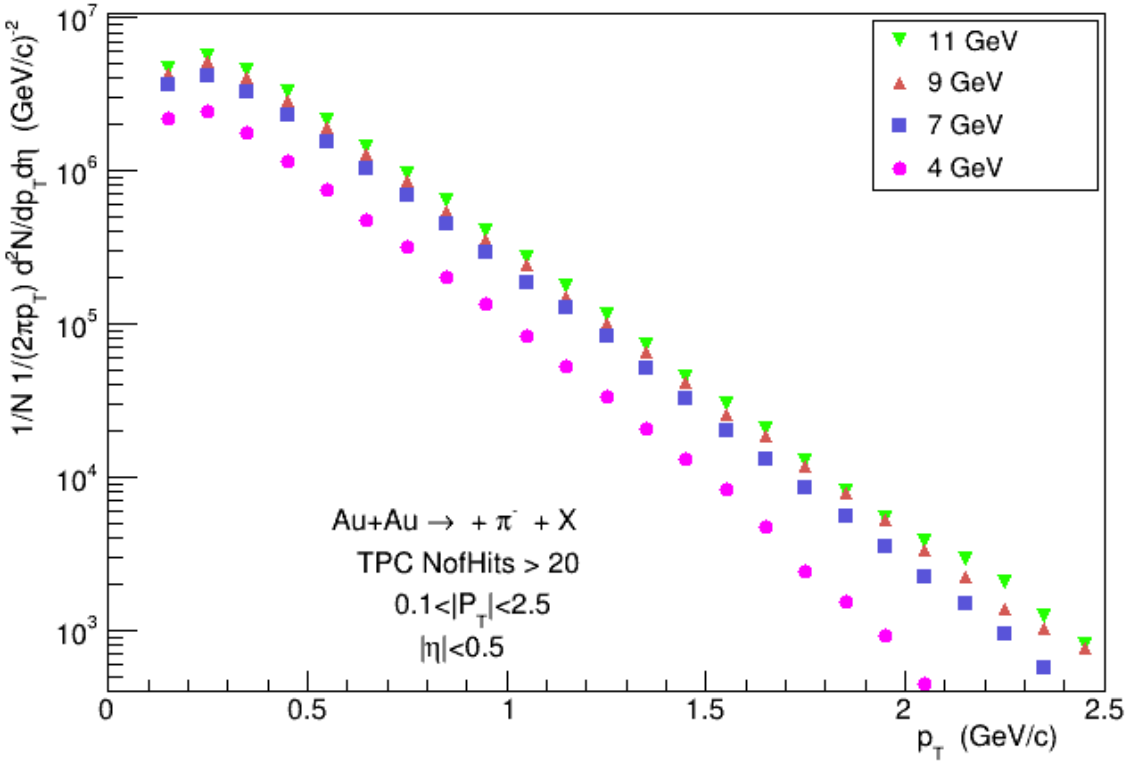


Light hadrons : Centrality dependence of particle production

A.Aparin + team

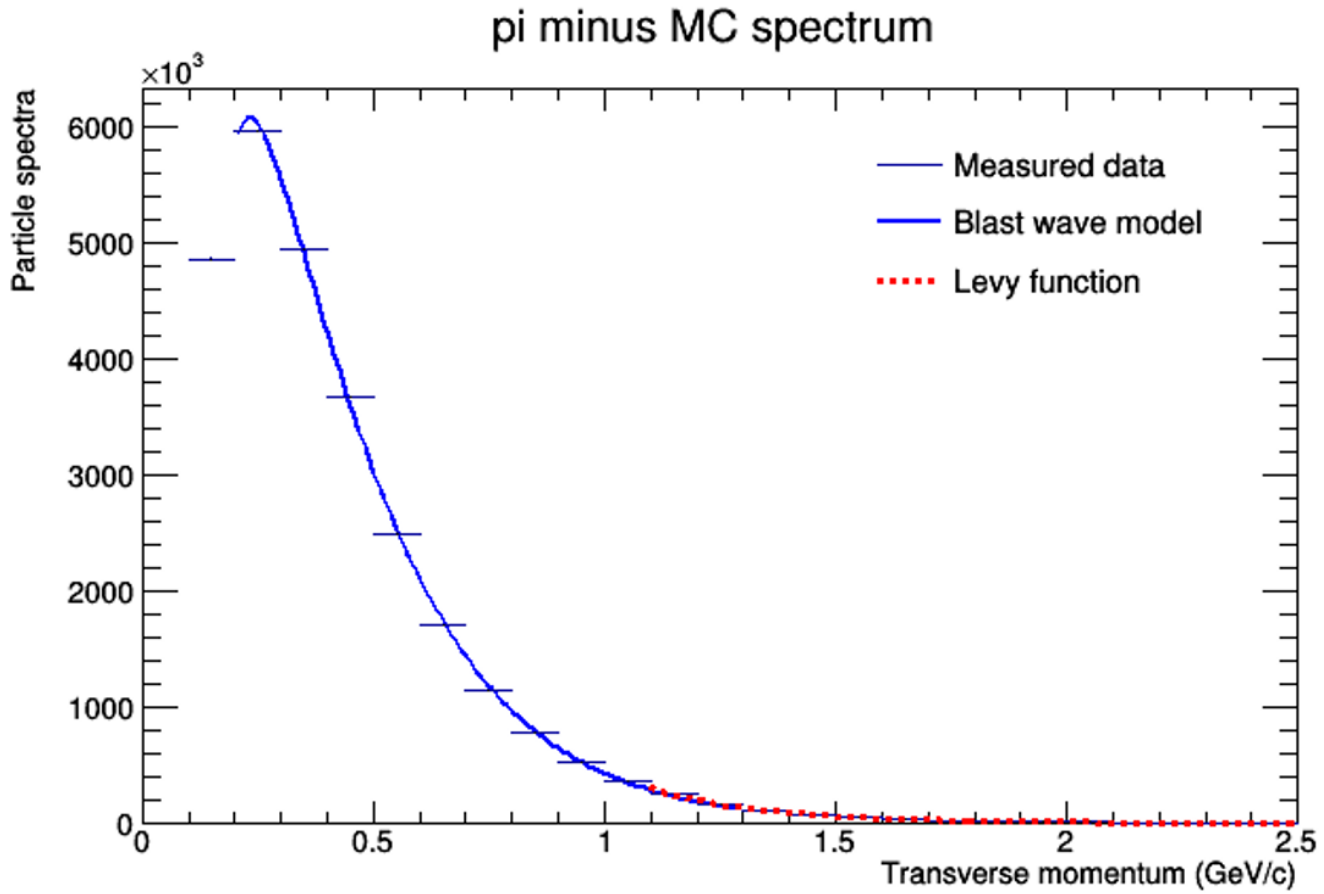
- Study of hadroproduction at several energies and centrality bins
- Optimization of selection criteria, PID, and correction coefficients





Light hadrons : work in progress

- Implementation of the code for centrality determination from the flow group
- Preparation of fitting class for momentum spectra (5 fit functions : BW, Levy etc..)
- Calculate spectra, rapidity distributions, ratios, nuclear modification factors, etc. for PIDed hadrons



Levy function

$$\frac{d^2N}{2\pi p_T dp_T d\eta} \propto (1+\frac{p_T}{nT})^{-n}$$

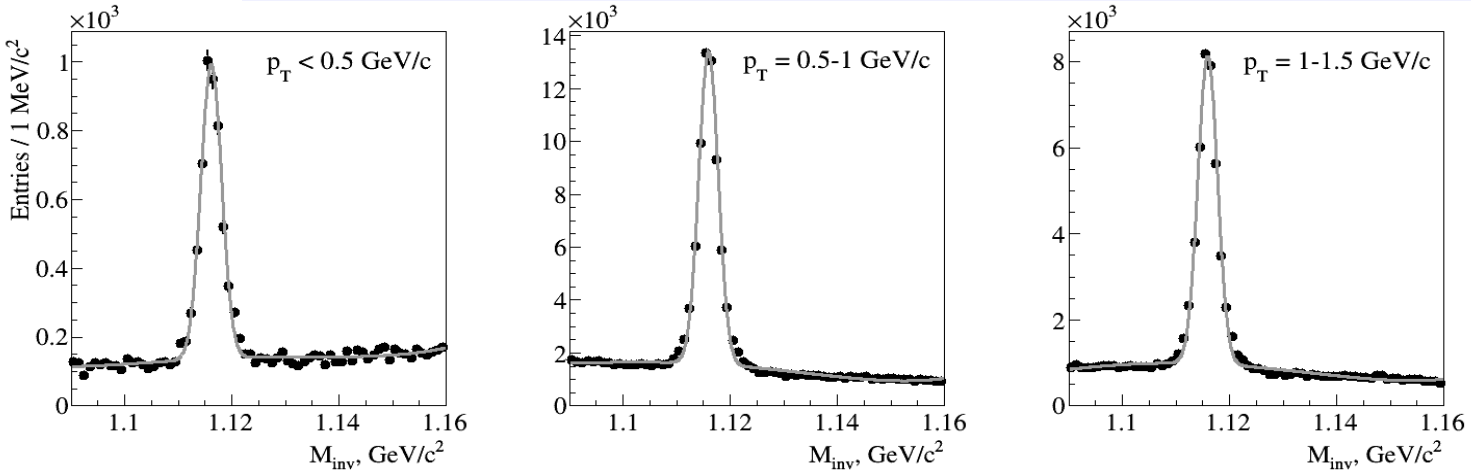
Blast-wave function

$$\frac{d^2N}{2\pi p_T dp_T d\eta} \propto \int_0^R r dr m_T I_0\left(\frac{p_T \sinh\rho(r)}{T}\right) \times K_1\left(\frac{p_T \cosh\rho(r)}{T}\right)$$

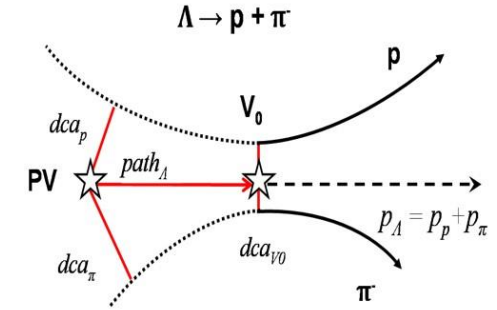
News on hyperon production

Hyperon reconstruction in MPD

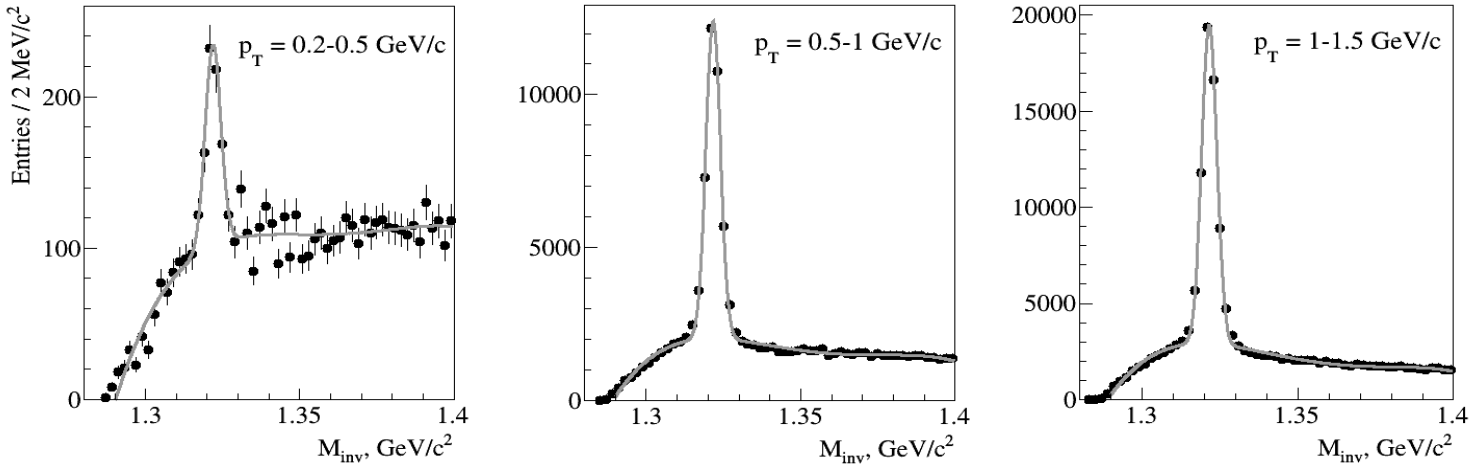
- *Generator: 8M Au+Au @ 11 GeV (PHSD)*
- *Detectors: MPD Satge'1 configuration, $|\eta|< 1.3$*
- *Track reconstruction and PID (dE/dx+TOF)*
- *Secondary vertex finding technique with a set of topological cuts*



Invariant mass spectra of $(\bar{p}, \pi^+)$ pairs in several transverse momentum intervals.



PV *- primary vertex*
V0 ***-*** *vertex of decay*
dca- *distance of closest approach*
path *– decay length*

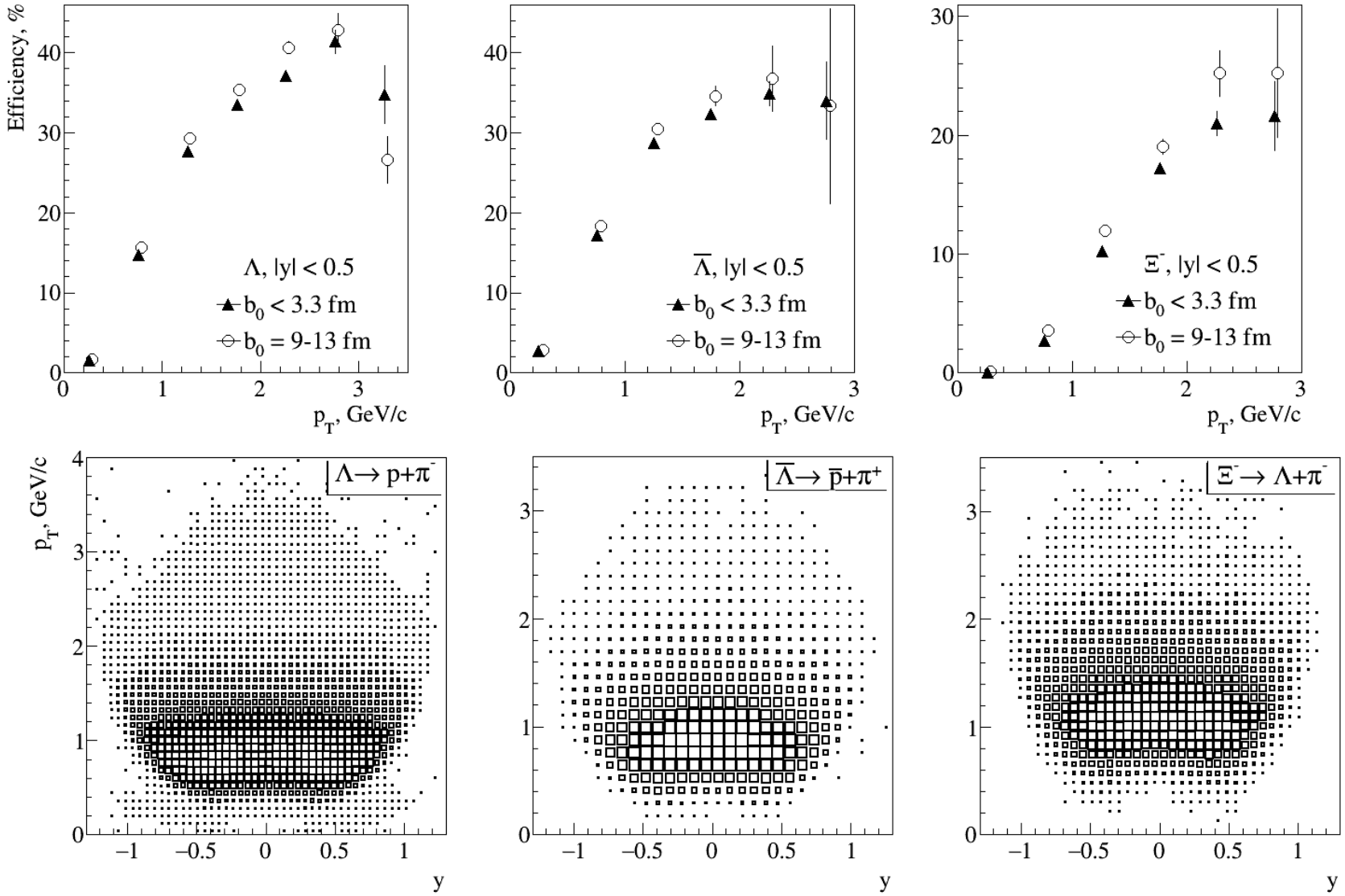


Invariant mass spectra of (Λ, π^-) pairs in several transverse momentum intervals.

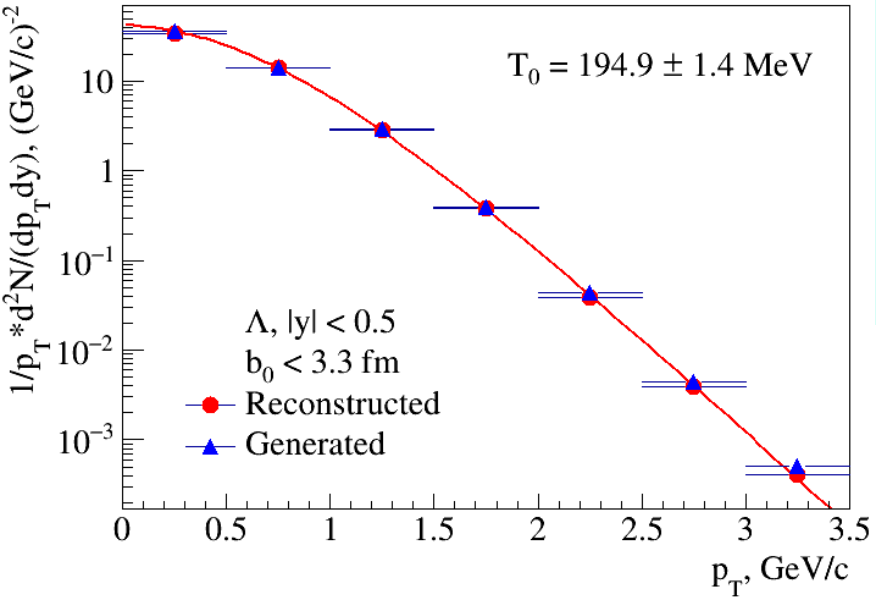
Hyperon production with MPD and ahtihyperon-to-hyperon ratio

J. Drnoyan, V. Vasendina, A. Zinchenko, A. Mudrokh

- (ani)Hyperon production studied in centrality selected Au+Au (MC centrality binning)
- Spectra and yields are obtained in a broad phase-space region

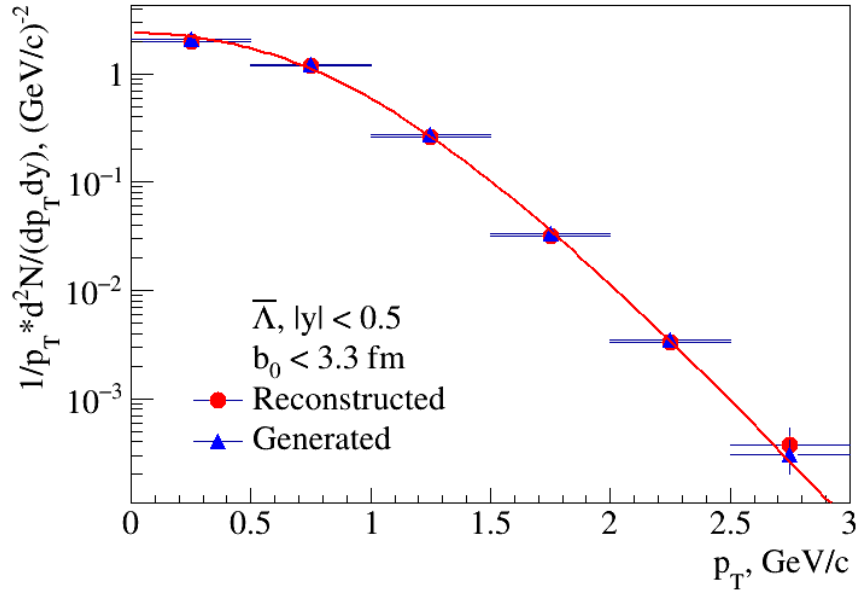


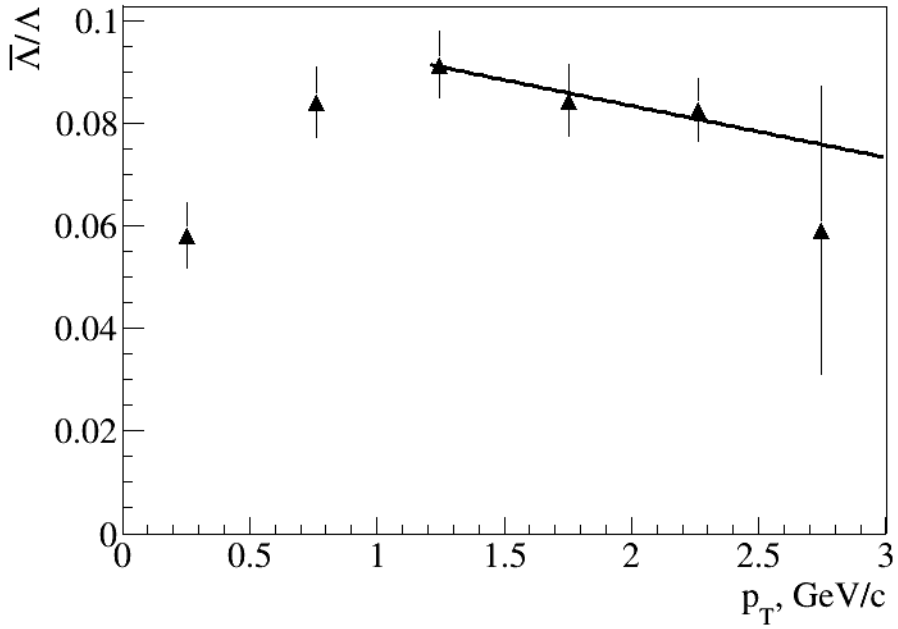
(anti)Hyperon spectra and ratio



- With hyperon production we can address bulk properties, phase transition as well as critical phenomena.
- Antibaryon-to-baryon ratio at intermediate momenta (pT >~ 1 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).*

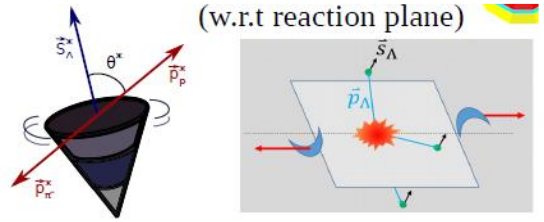
- Full corrected spectra of hyperons (including feeddown)
- Midrapidity spectra up to pT=3-3.5 GeV/c. Good results of closure tests
- **But the error in the slope of the antiL/L–ratio for 10^7 events is too large, - a 10–100-time bigger data set is needed**





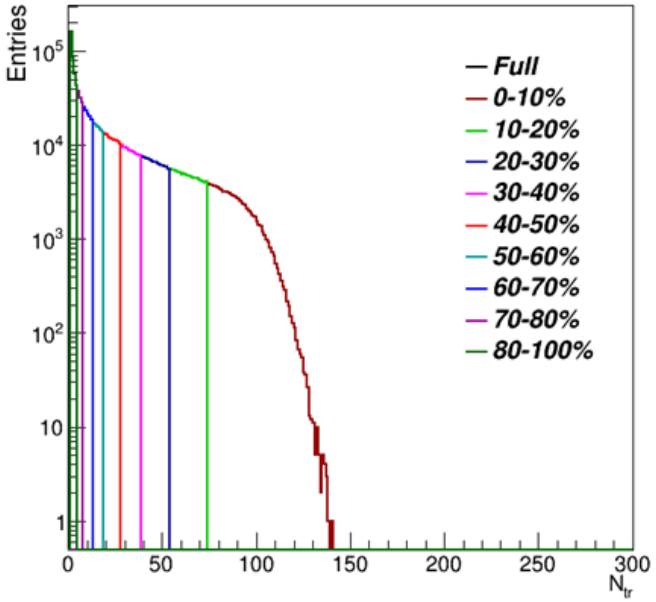
Global hyperon polarization (ongoing analysis)

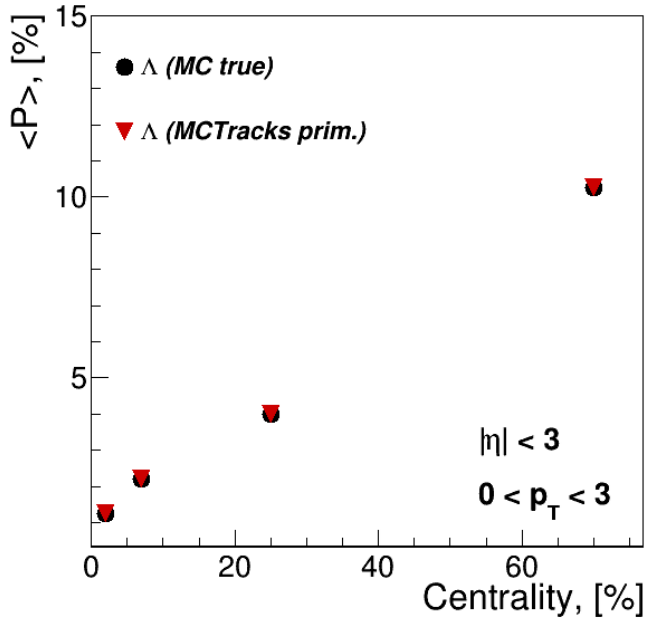
- Rising polarization signal for hyperons toward NICA energies
- Connecting to intrinsic properties of the medium

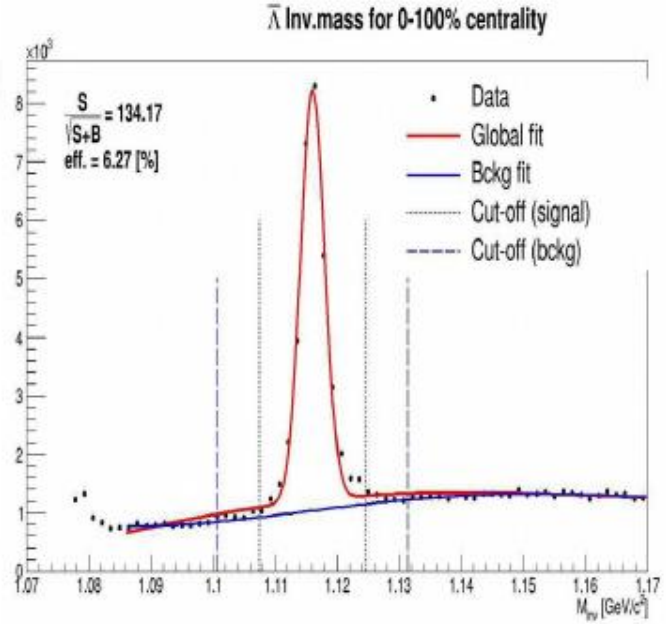


- 1.5M Minbias Au+Au at 7.7 GeV (PHSD)
- Global hyperon polarization modelled via thermodynamic (Becattini) approach
- Centrality estimated through multiplicity in TPC (MC-Glauber, P.Parfenov)
- Event plane angle measured through FHCal

$$\overline{P}_{\Lambda/\bar{\Lambda}} = \frac{8}{\pi\alpha}\frac{1}{R^1_{\mathrm{EP}}}\left\langle \sin(\Psi^1_{\mathrm{EP}} - \phi^*_p)\right\rangle$$







- Fixed transfer of Polarization vector from PHSD model to the MPD simulation (MCTracks)
- Estimated transfer of polarization to the secondary Lambda (needs to be corrected)

See talk «Vorticity and Polarization in HIC» for details (23.04 17:45)

Progress in light (hyper)nuclei

- Progress in the simulation of the cluster formation : models and afterbunners
- Study of light production : PID, yields and ratios
- Reconstruction of hypernuclei

Progress in the PHQMD model

E.Bratkovskaya, J. Aihelin, 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

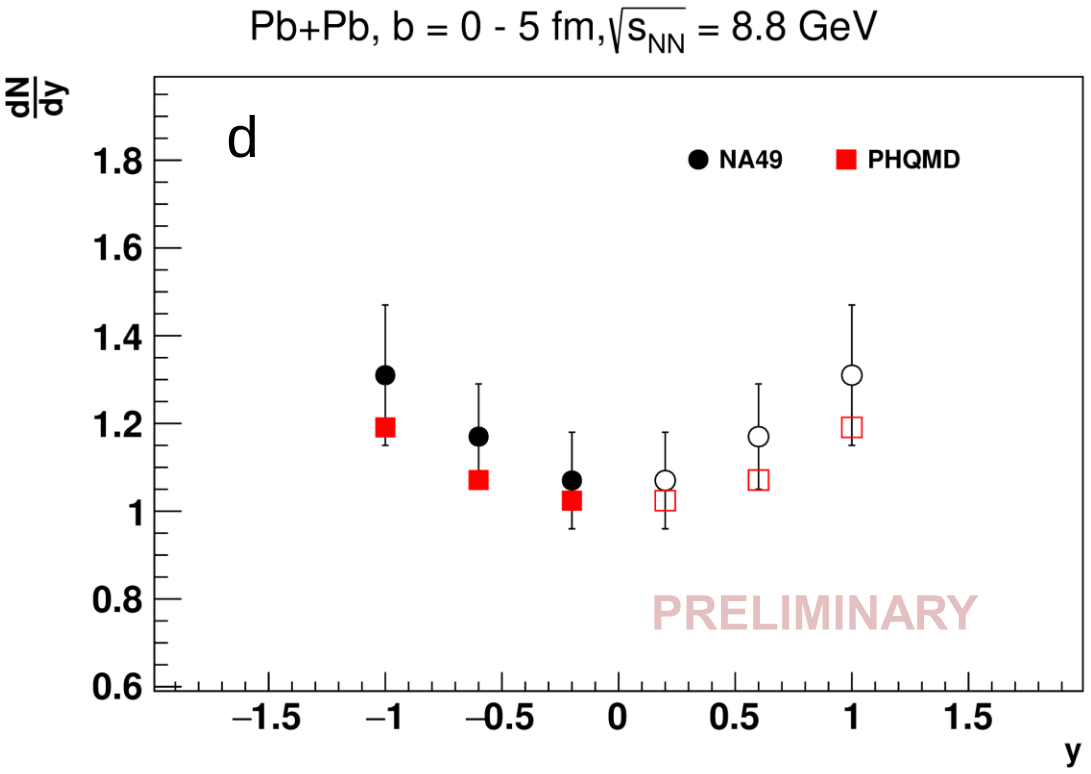
Parton-Hadron-Quantum-Molecular Dynamics

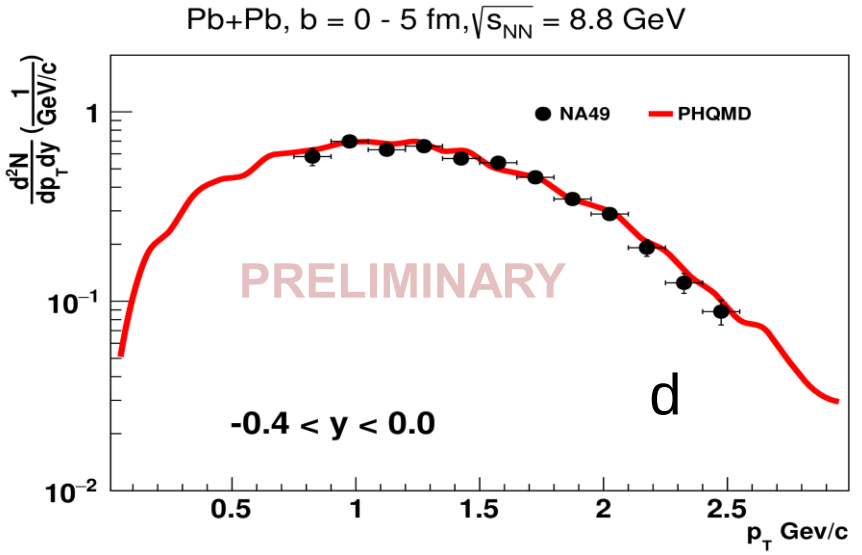
Initialization propagation of baryons:
QMD (Quantum-Molecular Dynamics)

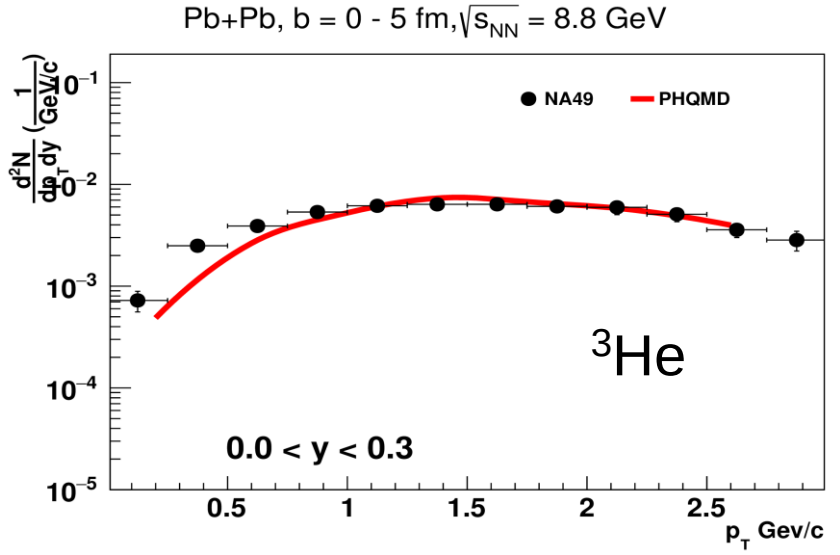
Propagation of partons (quarks, gluons) and mesons
+ collision integral = interactions of hadrons and partons (QGP)
from PHSD (Parton-Hadron-String Dynamics)

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

PHQMD model : predictions vs data at NICA energies





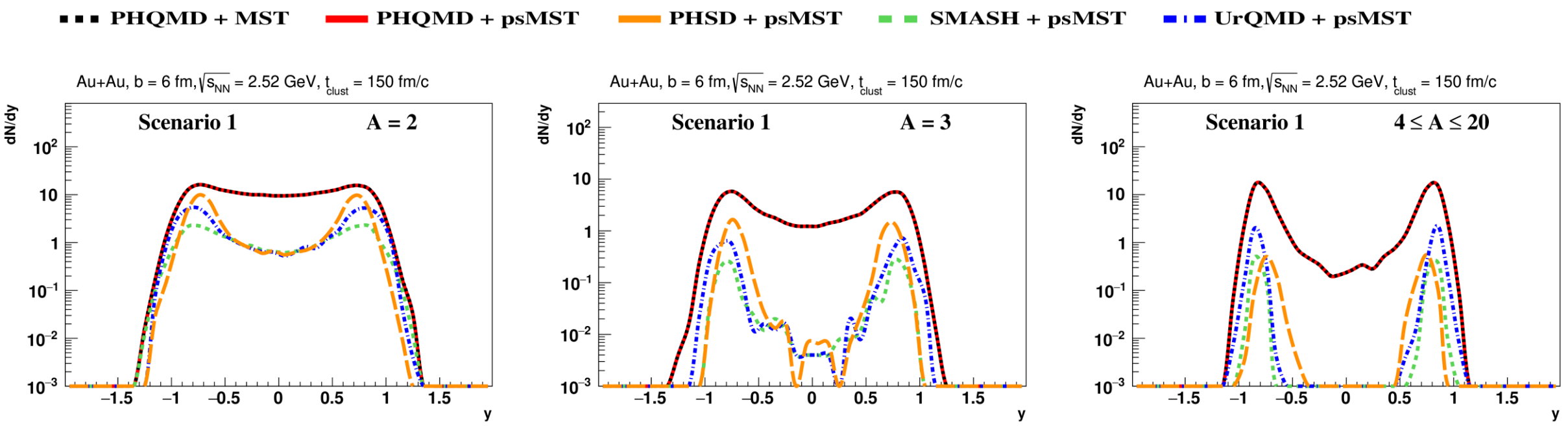


- Reasonable predictions for the yields of fragments
- Tunable parameters for nuclear matter EoS and fragment formation time
- Can be used as input for simulation of hypernuclei at MPD

If you do not like, however, the PHQMD model, then..

V. Kireyeu

The **phase-space Minimum Spanning Tree (psMST)** is based on the idea of the **MST** algorithm for searching bound nucleon systems (clusters and hypernuclei) in dense hadronic matter. **psMST is a model-independent library** and thus can be linked to **ANY** transport approach propagating hadrons. *arXiv:2103.10542*

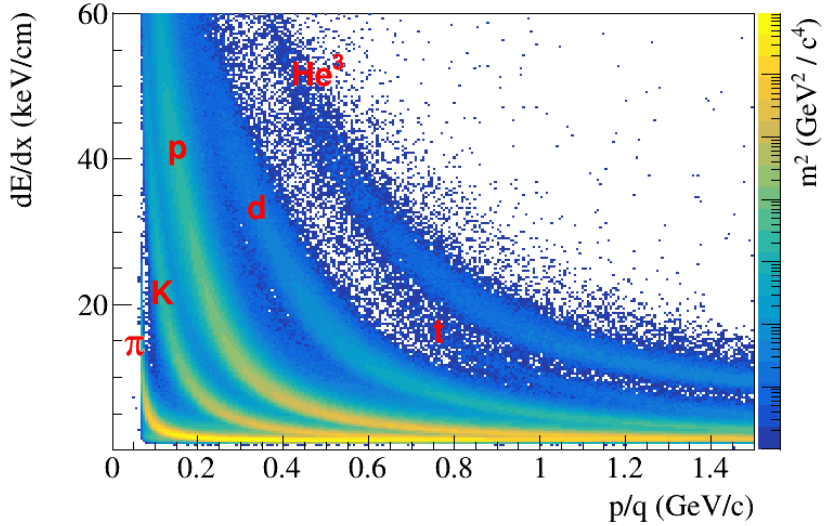


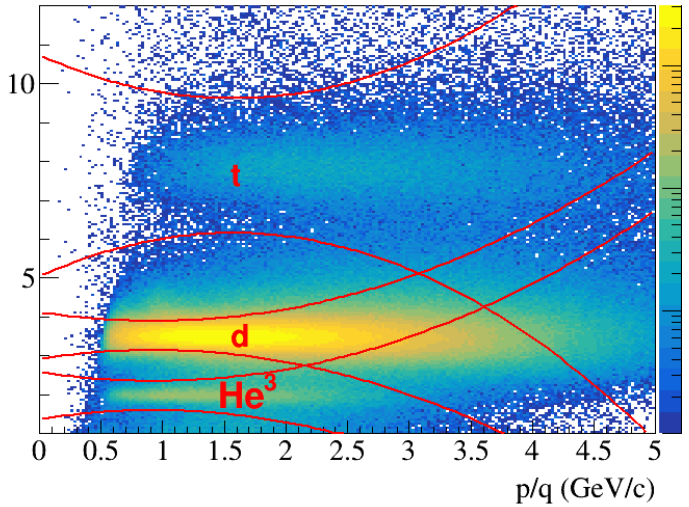
Rapidity distributions of clusters with the mass number **A = 2** (left plot), **A = 3** (central plot) and **4 ≤ A ≤ 20** (right plot) in semi-peripheral Au+Au collisions at $\sqrt{s_{NN}}$ = 2.52 GeV.

Several Scenarios realize a sophisticated selection of space and momentum information in the formation of bound states.
“Scenario 1” corresponds to the full compatibility mode of the psMST with the original MST procedure from the PHQMD release.

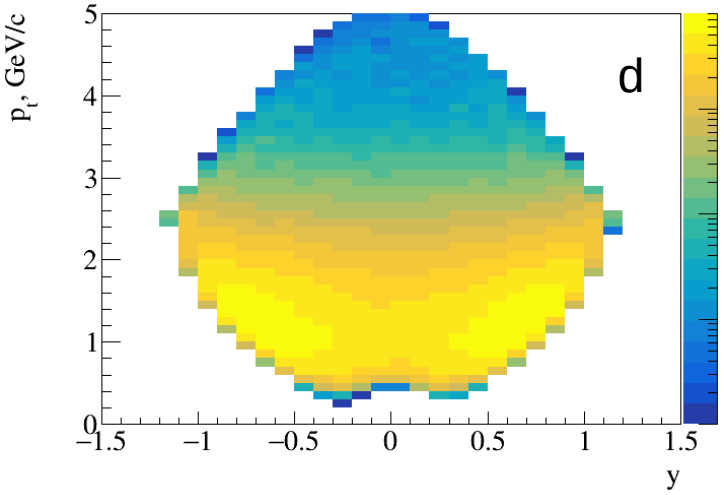
MPD PID performance for light nuclei

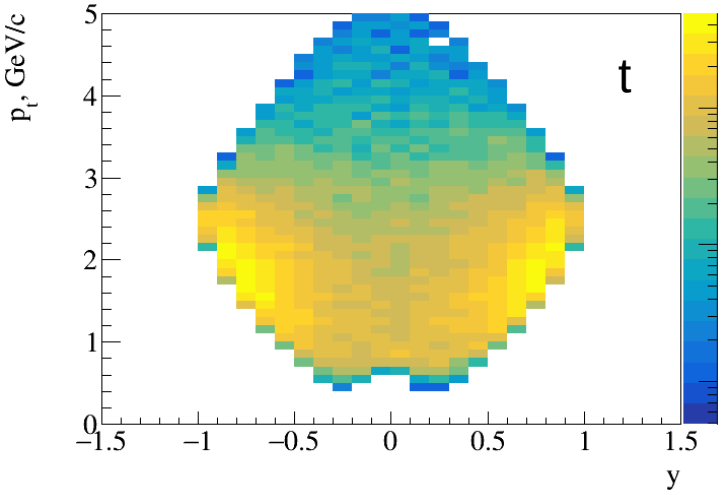
A.Mudrokh





- **Bi+Bi events from the PHQMD model**
- **Combined (dE/dx+TOF) PID**

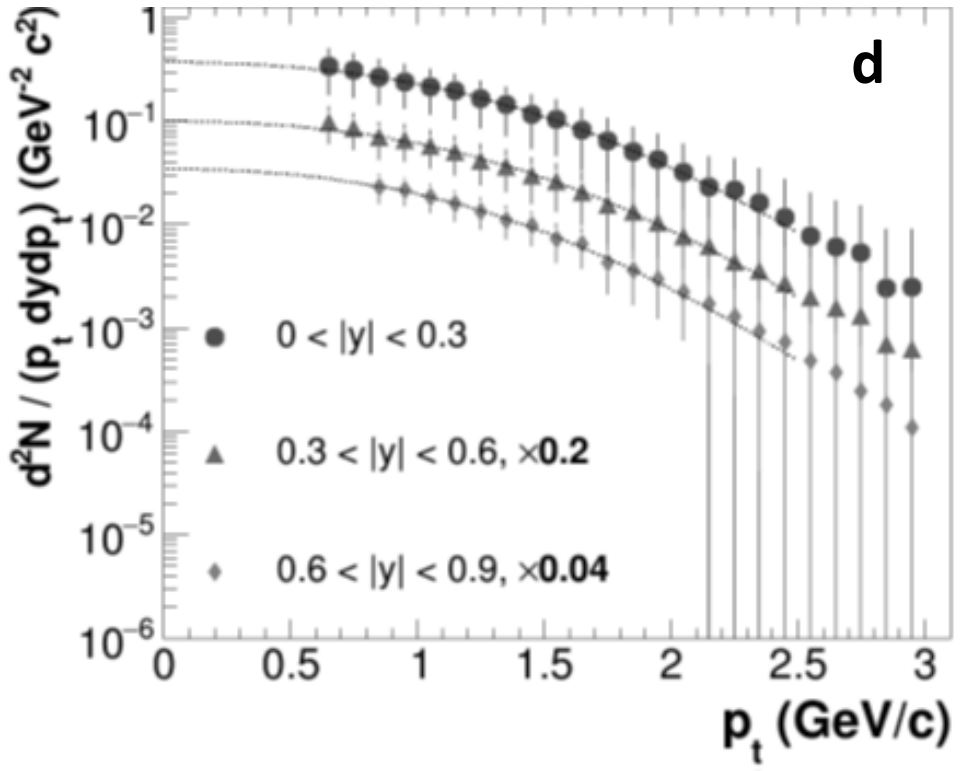


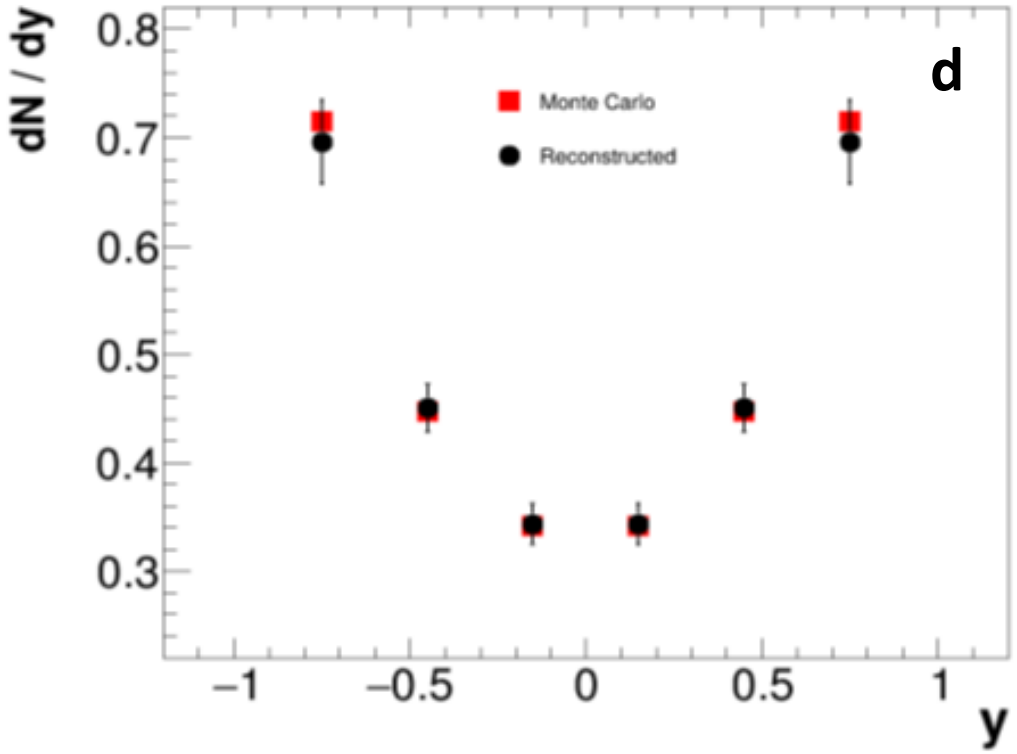


- MPD phase-space for deuterons and tritons (TPC+TOF)

Yields of light nuclei in Bi+Bi

- At NICA energies a sizeable fraction of the total baryon number is contained in nucleon clusters
- Production of light nuclei allows addressing reaction dynamics and EOS, momentum-space correlations and CEP





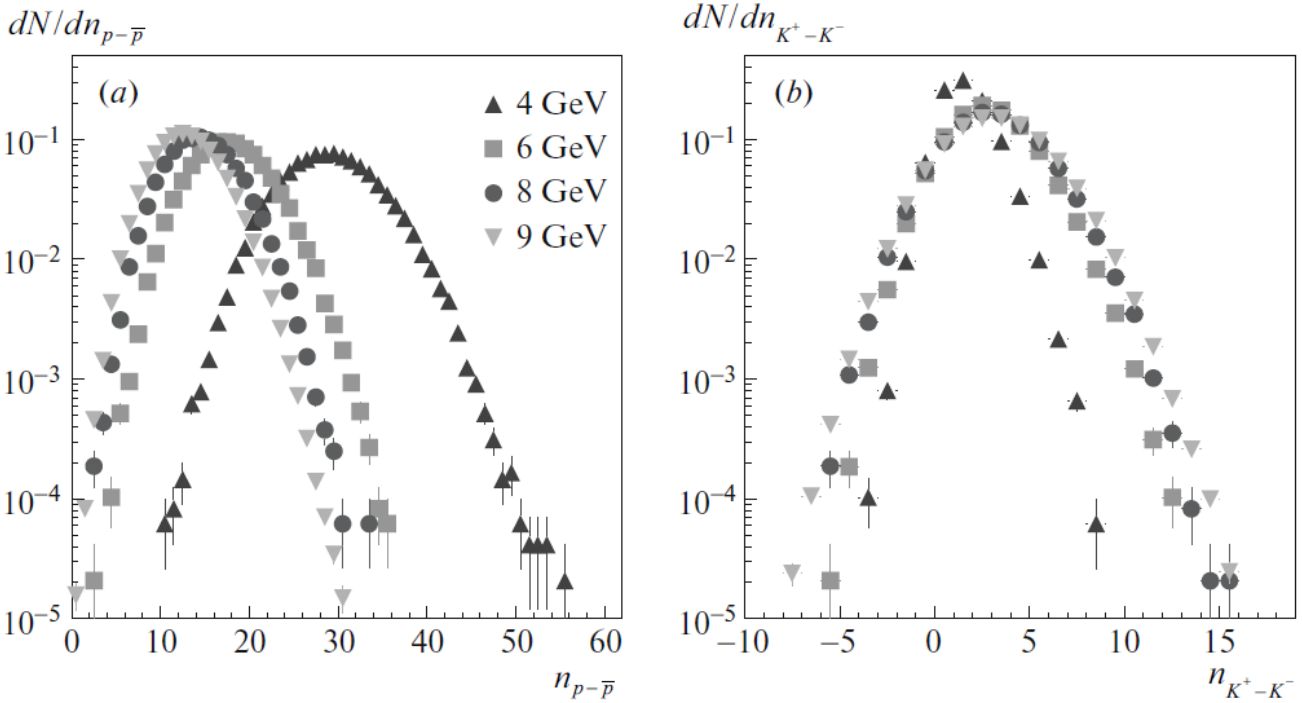
✓ Low pT-range is populated by spallation in the MPD material (pT-cutoff is larger than expected)

✓ BW fits describe the shape of spectra quite well, allowing precise integration and yield estimates

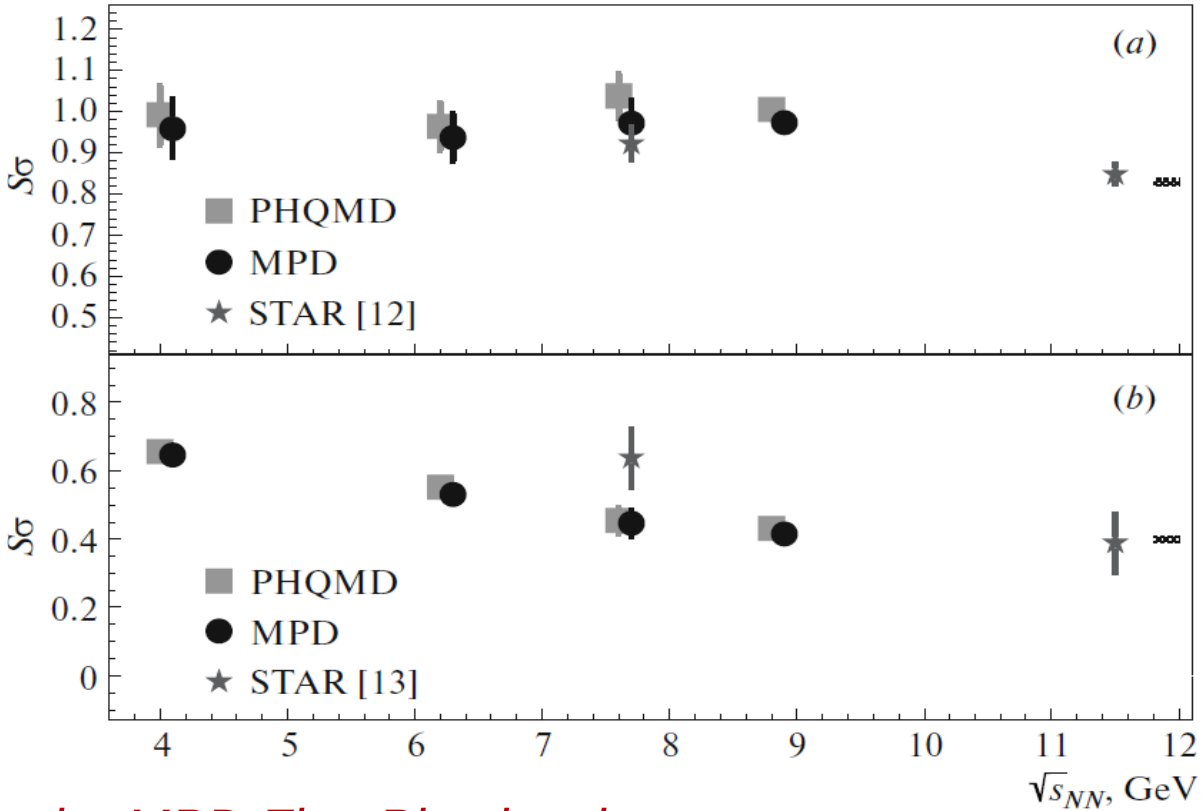
Net-proton and net-kaon event-by-event fluctuations

- Cumulant ratios are directly compared to susceptibilities, which diverge in the proximity of CEP

- $5 \cdot 10^4$ 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 Sσ for net-protons (a) and net-kaons (б)

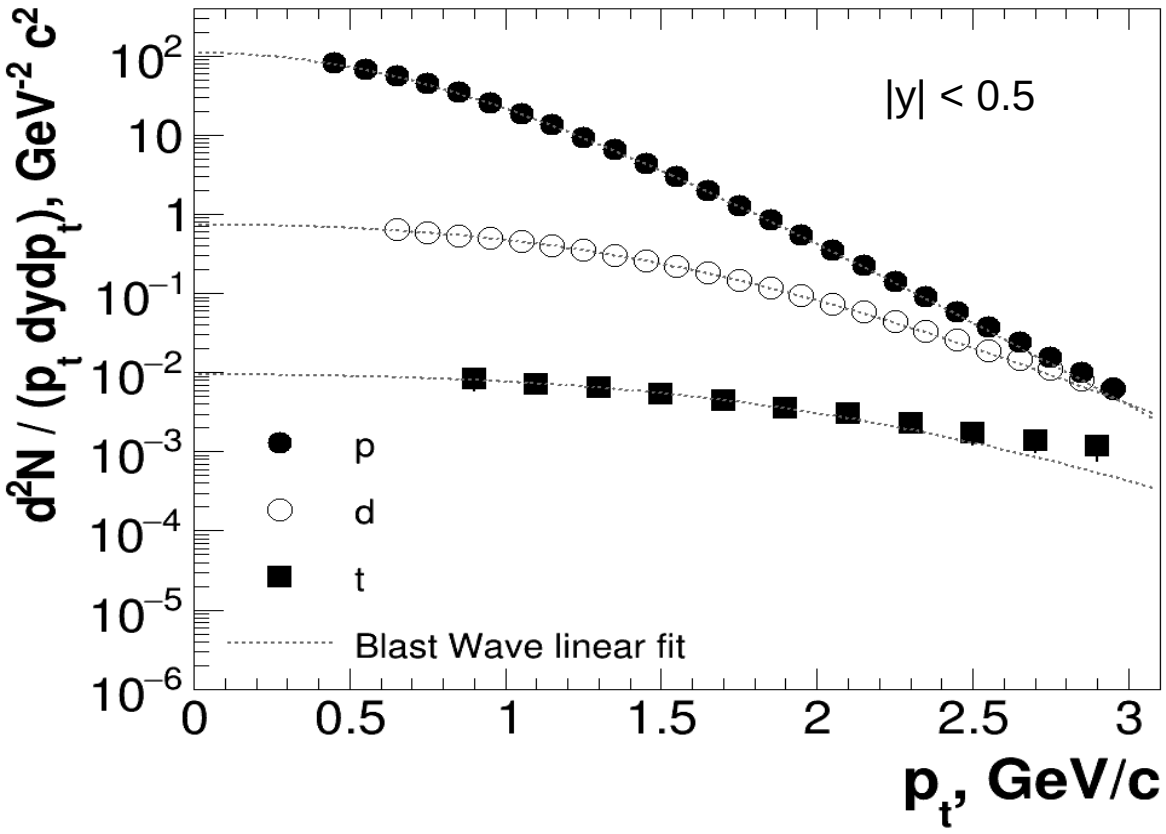


Results on Ev-by-Ev fluctuations are included in the MPD First Physics document

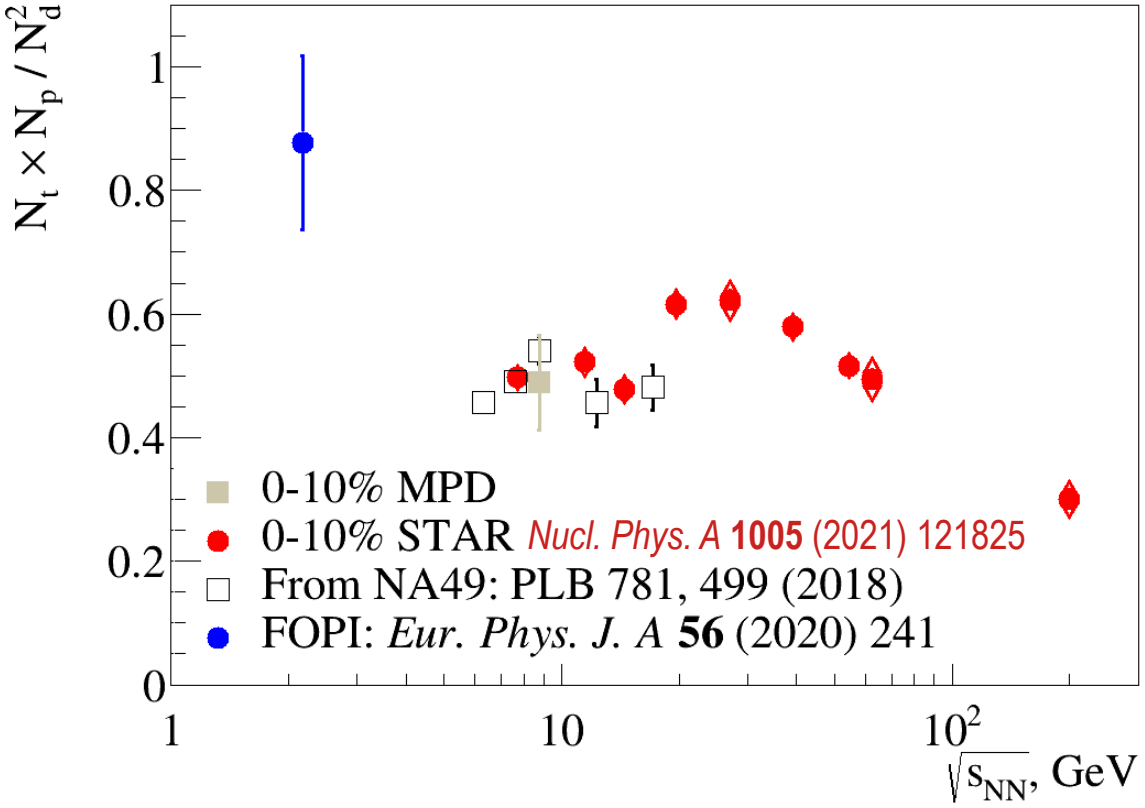
More on CEP search : yields of light nuclei and density fluctuations

- A peak structure in the excitation function of relative neutron density fluctuations as a probe of the QCD phase diagram structure
- Peaks in the O_{pdt} – ratio due to spinodal instability for the 1st order PT and/or CEP

K.J. Sun, et al, Phys. Lett. B 781, 499 (2018)



$O_{pdt}=(N_pN_t)/(N_d^2)$



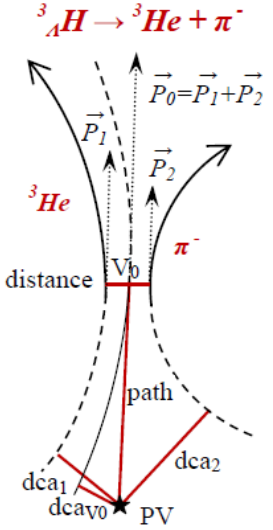
Reconstruction of hypernuclei in MPD

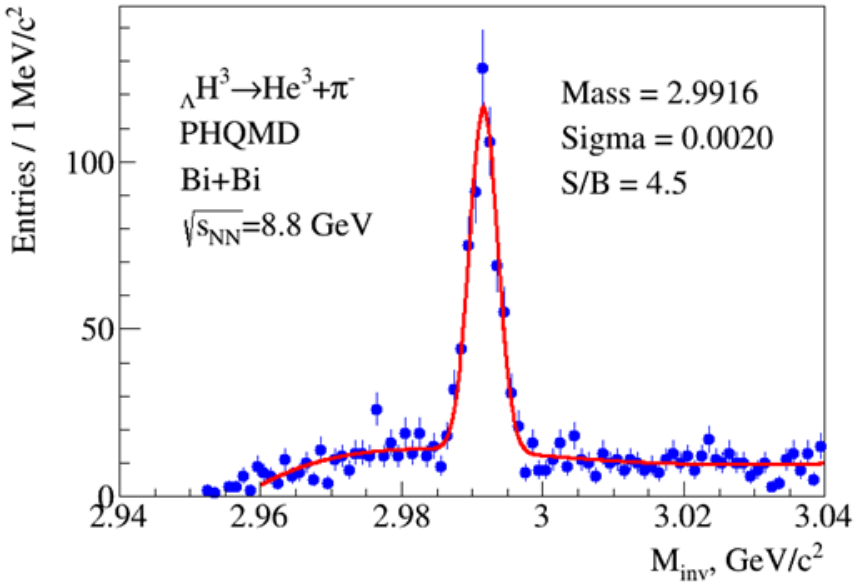
V.Vasendina, A.Zinchenko, D.Drnoyan

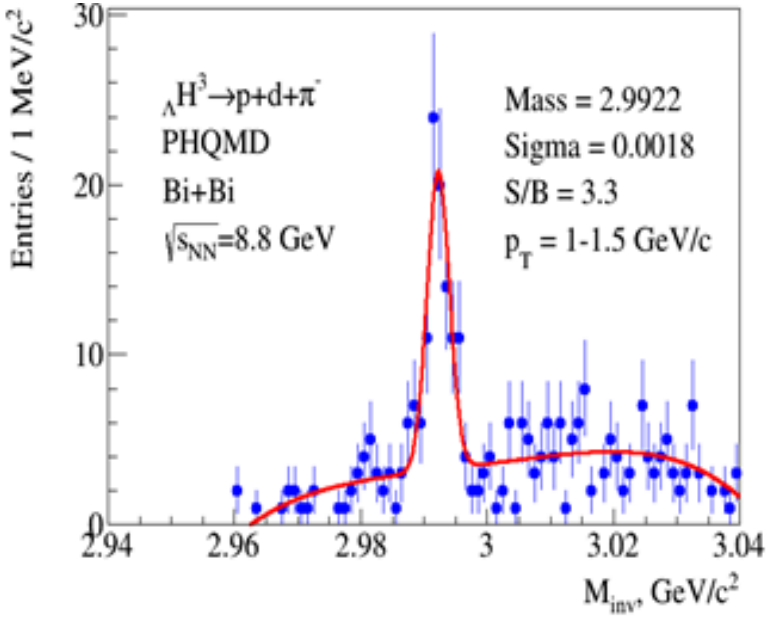
- **Precise information on YN interactions: strange sector of nuclear EOS, astrophysics**

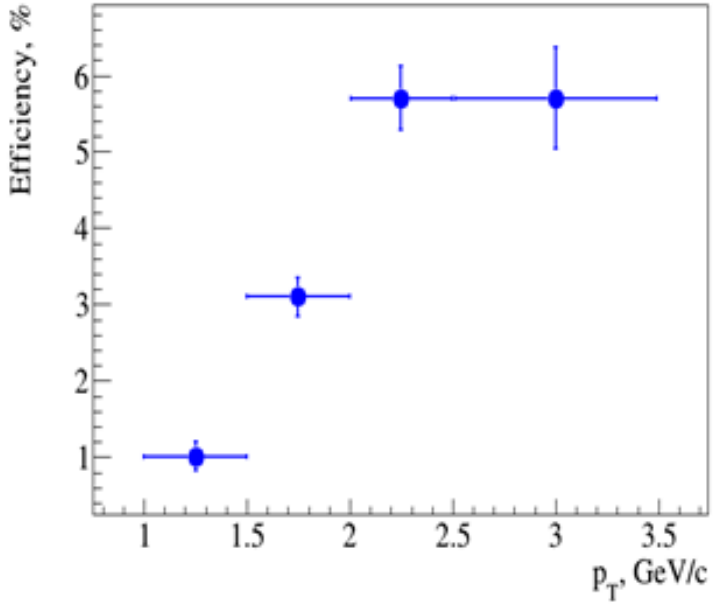
- ✓ 15Mevent Bi+Bi at 9 GeV from the PHQMD model
- ✓ Centralized DST production (A.Moshkin)
- ✓ MPD analysis chain (reco, PID, secondary vertexing)

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





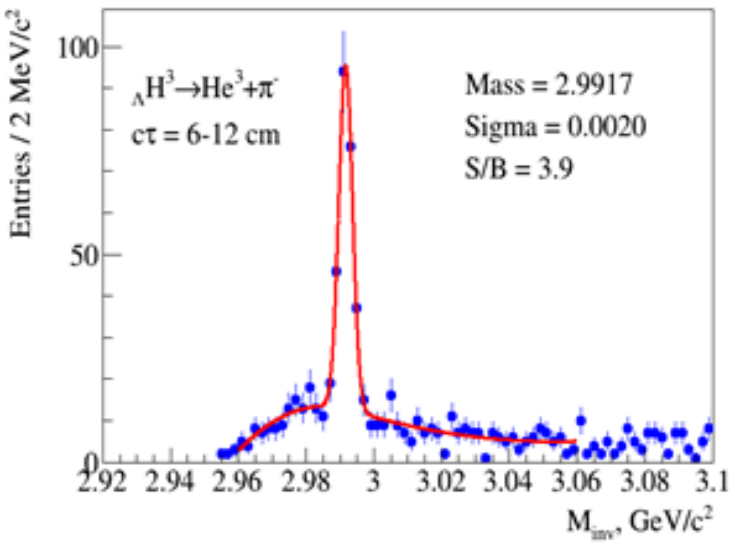


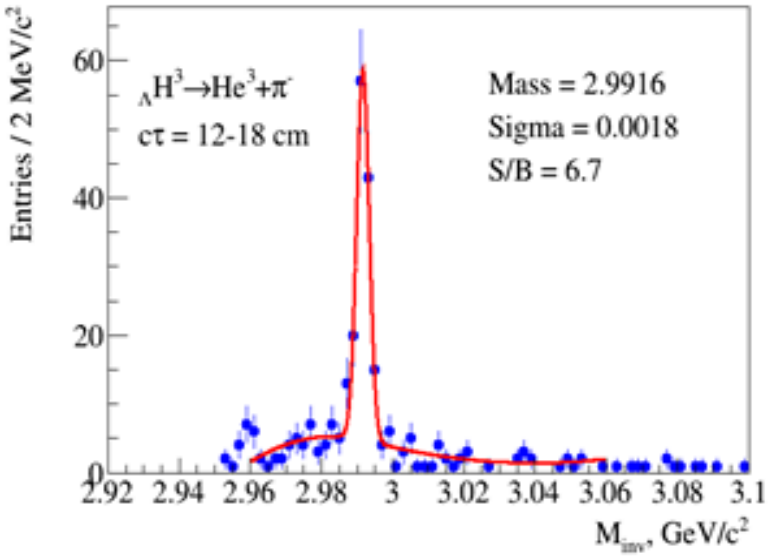


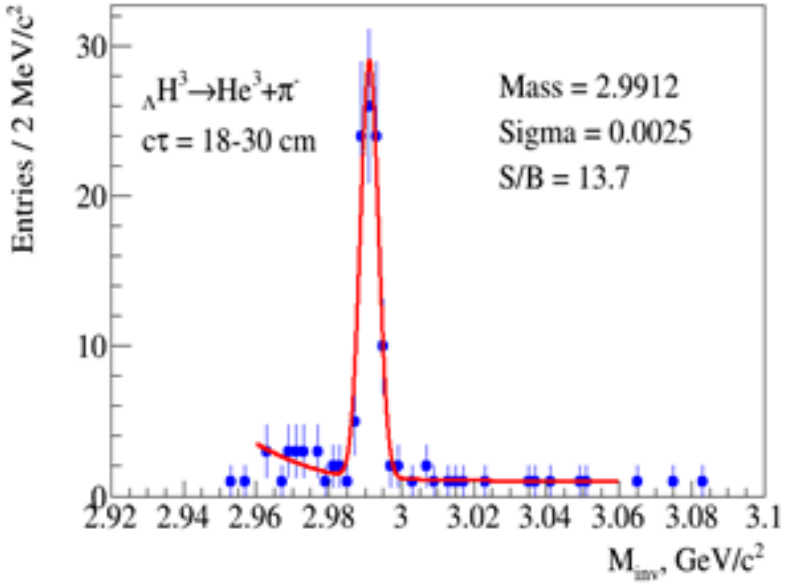
Hyperon lifetime measurements

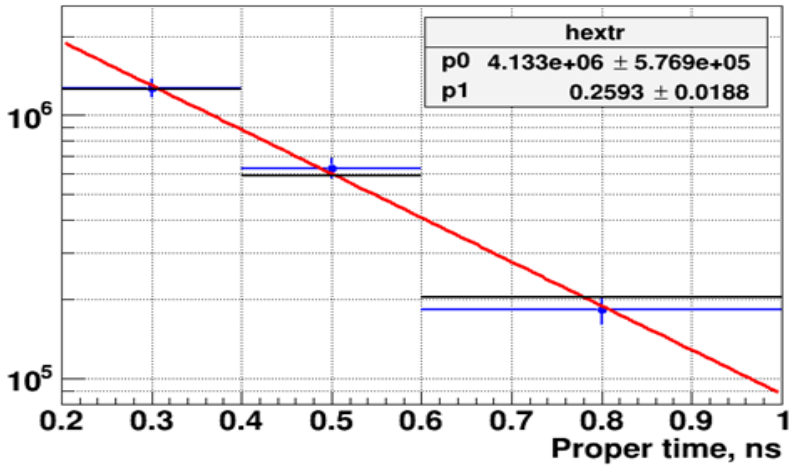
- Hyperon lifetime puzzle in HIC affects Y-N interactions in the medium and requires additional measurements
- Results in a broad region of cτ also requires large data sets

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









Fit: $dN/d(c\tau) = p0*\exp(-c\tau/p1)$

- A current estimate for P1 = 259 +/- 19 ps (~7%)
- Better estimates for the accuracy in the lifetime measurements requires a larger statistics and a broader range.

Summary

- **MPD physics simulation within PWG2 is ongoing**

  Steady progressing : Hadron spectra, *Multistrangeness, (Hyper)nuclei, Resonances*

- **In plans : extend analysis activities with larger data sets and solving existing problems**

Thank you for your attention!