Model analysis of transverse momentum fluctuations in NICA and SPS energy range

Zvyagina A.P., Andronov E.V.

Department of Nuclear Physics Research Methods
Saint-Petersburg State University

1 December, 2022

Plan of presentation

- Motivation
- *Models EPOS, SMASH, PHSD, UrQMD*: basics of models
- Main results
- Summary

Motivation

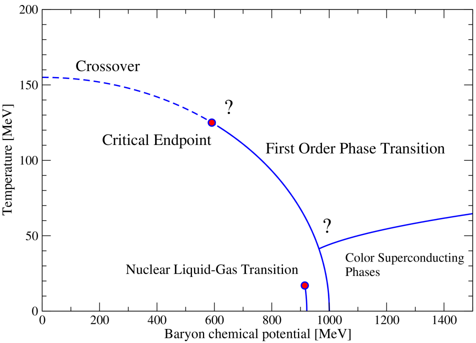

Figure 1: QCD diagram of phase transition.

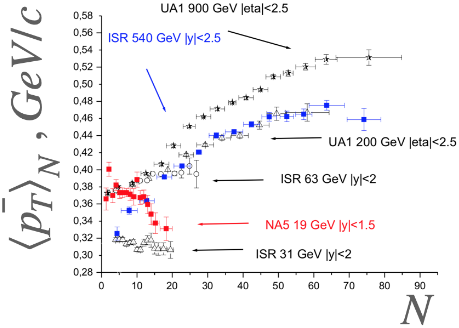

Figure 2: Results for $p_T - N$ correlations for various energies and experiments.

- transition from negative to positive correlations: good description with help of multipomeron model [N. Armesto *et al.*, Phys. of Atom. Nucl., 71. 2087-2095 (2008)]
- limit theoretical model (PYTHIA, Herwig++ and etc.)

Models

- EPOS (*Energy-conserving quantum mechanical multiple scattering approach, based on Partons (parton ladders), Off-shell remnants, and Splitting of parton ladders*). This model [K. Werneret *al.*, Phys.Rev. C74, 044902 (2006)] takes into account the multiple scattering approach based on partons and pomerons (parton ladders). The basis is a string model.
- SMASH (*Simulating Many Accelerated Strongly-interacting Hadrons*) is a relativistic hadronic transport approach [J. Weil *et al.*, arXiv:1606.06642 [nucl-th] (2017)]. Include all well-established hadrons up to a mass of $\sim$ 2 GeV as degrees of freedom.
- PHSD (*Parton-Hadron-String Dynamics*)[E. Bratkovskaya *et al.*, arXiv:1908.00451 [nucl-th] (2019)] is a microscopic off-shell transport approach for the description of strongly interacting hadronic and partonic matter in and out-of equilibrium.
- UrQMD (*Ultra-relativistic Quantum Molecular Dynamics*)[M. Bleicher et al., arXiv:hep-ph/9909407 [hep-ph] (1999).] is a microscopic model used to simulate (ultra)relativistic heavy ion collisons in the energy range from Bevalac and SIS up to AGS, SPS and RHIC.

These models have been applied to nucleus-nucleus collisions from low Super-Proton-Synchrotron (SPS) to Large-Hadron-Collider (LHC) energies in order to explore the space-time regions of 'partonic matter'.

Definitions and observables: strongly intensive quantity

$$\Sigma[p_t, N] = \frac{1}{\langle N\rangle\omega\,[p_t]}\left[\langle N\rangle\omega\,[P_t] + \langle P_t\rangle\omega\,[N]\right] \tag{1}$$

$$\Delta[p_t, N] = \frac{1}{\langle N\rangle\omega\,[p_t]}\left[\langle N\rangle\omega\,[P_t] + \langle P_t\rangle\omega\,[N] - 2\left(\langle P_T N\rangle - \langle P_T\rangle\langle N\rangle\right)\right] \tag{2}$$

[M. Gorenstein, M. Gazdzicki, Phys. Rev. C 84, 014904 (2011)]

where $P_T = \sum_{i=1}^{N} p_{T_i}$ and $\omega[p_T]$ is the scaled variance of the inclusive p_T spectrum.

$\Delta[p_T, N] = \Sigma[p_T, N] = 1$ - for independent particle production model, $\Delta[p_T, N] = \Sigma[p_T, N] = 0$ in the absence of fluctuations.

Also, another strongly intensive quantity is introduced for analysis [M. Cody, S. Gavin, B.Koch et al., arXiv:2110.04884 [nucl-th]]:

$$\langle N\rangle D[p_t, N] = \frac{1}{\langle N\rangle}\left[\left(\langle P_T N\rangle - \langle P_T\rangle\langle N\rangle\right) - \langle P_t\rangle\omega\,[N]\right] \tag{3}$$

Definitions and observables: cumulants

The n-particle p_T correlator in one event is defined as

$$C_n = \frac{\sum_{i_1 \neq \ldots \neq i_n} \omega_{i_1} \ldots \omega_{i_n} (p_{T,i_1} - \langle\langle p_T \rangle\rangle) \ldots (p_{T,i_n} - \langle\langle p_T \rangle\rangle)}{\sum_{i_1 \neq \ldots \neq i_n} \omega_{i_1} \ldots \omega_{i_n}} \tag{4}$$

$$C_2 = \frac{\overline{p}_{11}^2 - \overline{p}_{22}}{1 - \tau_1} \tag{5}$$

$$C_3 = \frac{\overline{p}_{11}^3 - 3\overline{p}_{22}\overline{p}_{11} + 2\overline{p}_{33}}{1 - 3\tau_1 + 2\tau_2} \tag{6}$$

$$K_2 = \frac{\langle C_2 \rangle}{\langle\langle p_T \rangle\rangle^2}, \tag{7}$$

$$K_3 = \frac{\langle C_3 \rangle}{\langle\langle p_T \rangle\rangle^3}, \tag{8}$$

[Bhatta S. *et. al.* Phys. Rev. C 105, 024904]

Results for strongly intensive observables

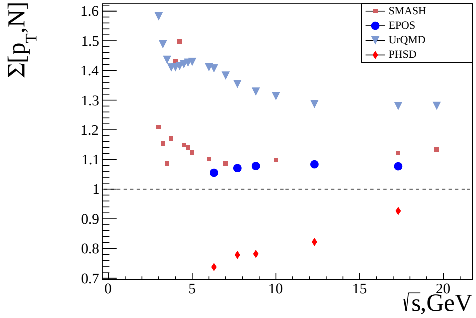

Figure 3: Dependence of $\Sigma[p_T, N]$ on beam energy for proton-proton collisions.

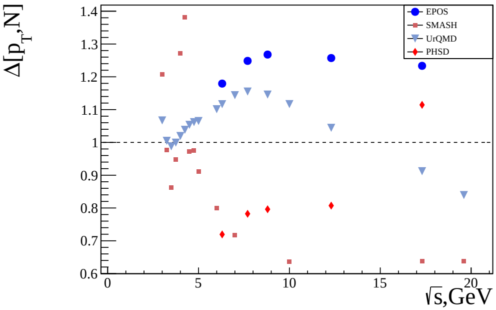

Figure 4: Dependence of $\Delta[p_T, N]$ on beam energy for proton-proton collisions.

- The resonances-to-strings transition in models produce a "wave", which is observed on the figures of the $\Sigma[p_T, N]$ and $\Delta[p_T, N]$ on energy collisions
- For various models, this transition from resonances to strings occurs with various energies

Results for strongly intensive observables

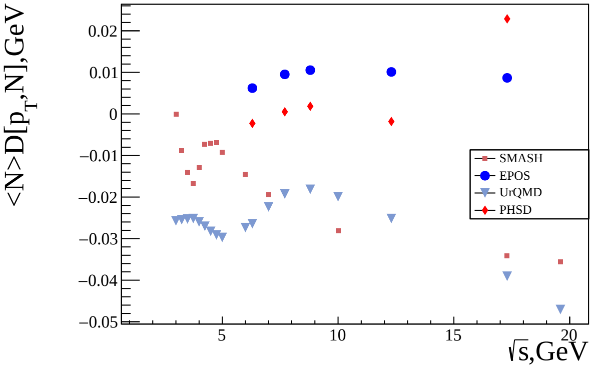

Figure 5: Energy dependence of $\langle N \rangle D[p_t, N]$.

In our calculations, it was revealed $D \neq 0$ that was predicted by the model PYTHIA/Angantyr simulations of proton-proton $(p + p)$ and nucleus-nucleus $(A + A)$ collisions [**M. Cody *et al.*, arXiv:2110.04884 [nucl-th]**].

Results for second and third order cumulants

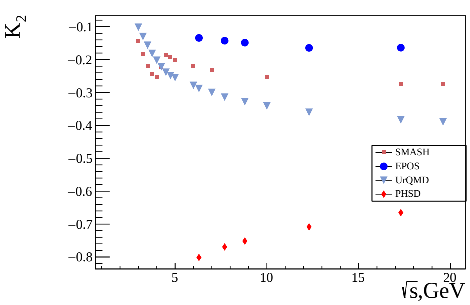

Figure 6: Dependence of the second-order cumulant for the transverse momentum in proton-proton collisions.

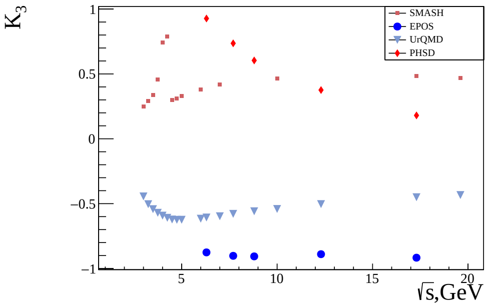

Figure 7: Dependence of the third-order cumulant for the transverse momentum in proton-proton collisions.

- In HIJING models κ_2 and κ_3 have positive means at high energies [S. Bhatta *et al.*, Phys. Rev. C 105, 024904].
- At low energies κ_2 has only negative values, κ_3 has both positive (SMASH, PHSD) and negative(UrQMD, EPOS) values

Summary

The key findings are:
• significant discrepancies between predictions of EPOS, SMASH, PHSD and UrQMD models are observed indicating that data on $p+p$ collisions from the NICA experiment, which will be obtained in the future, will limit the prediction of this models, as well as clarify the results obtained.
• in the figures of the dependence of $\Sigma[p_T, N]$, $\Delta[p_T, N]$,$\langle N\rangle D[p_T, N]$ on energy appear a "wave" that is caused by the resonance-to-string transition.
• non-trivial p_T cumulants collision energy dependence predicted by the models for a 'baseline' $p+p$ reaction emphasizes difficulties in interpreting future results for $A+A$ collisions and requires further investigations.
• At low energies κ_2 has only negative values for all models, κ_3 has both positive (SMASH, PHSD) and negative(UrQMD, EPOS) values. This means that future NICA experiments will make an important contribution to the study of these quantities.

Thank you for your attention!

Back-up

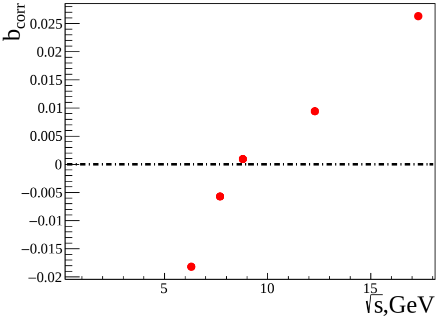

Figure 8: Dependence on energy of the $p_t - N$ coefficient correlation in proton-proton collisions for EPOS model.

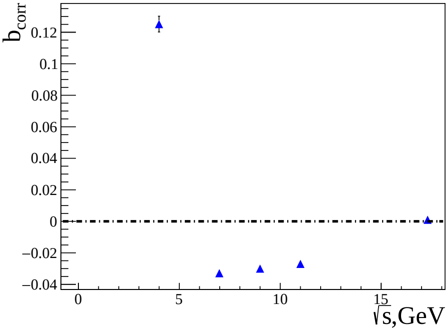

Figure 9: Dependence on energy of the $p_t - N$ coefficient correlation in proton-proton collisions for SMASH model.