Disentangling effects from the initial stage and the evolution stage in heavy ion collisions using EPOS and PHSD

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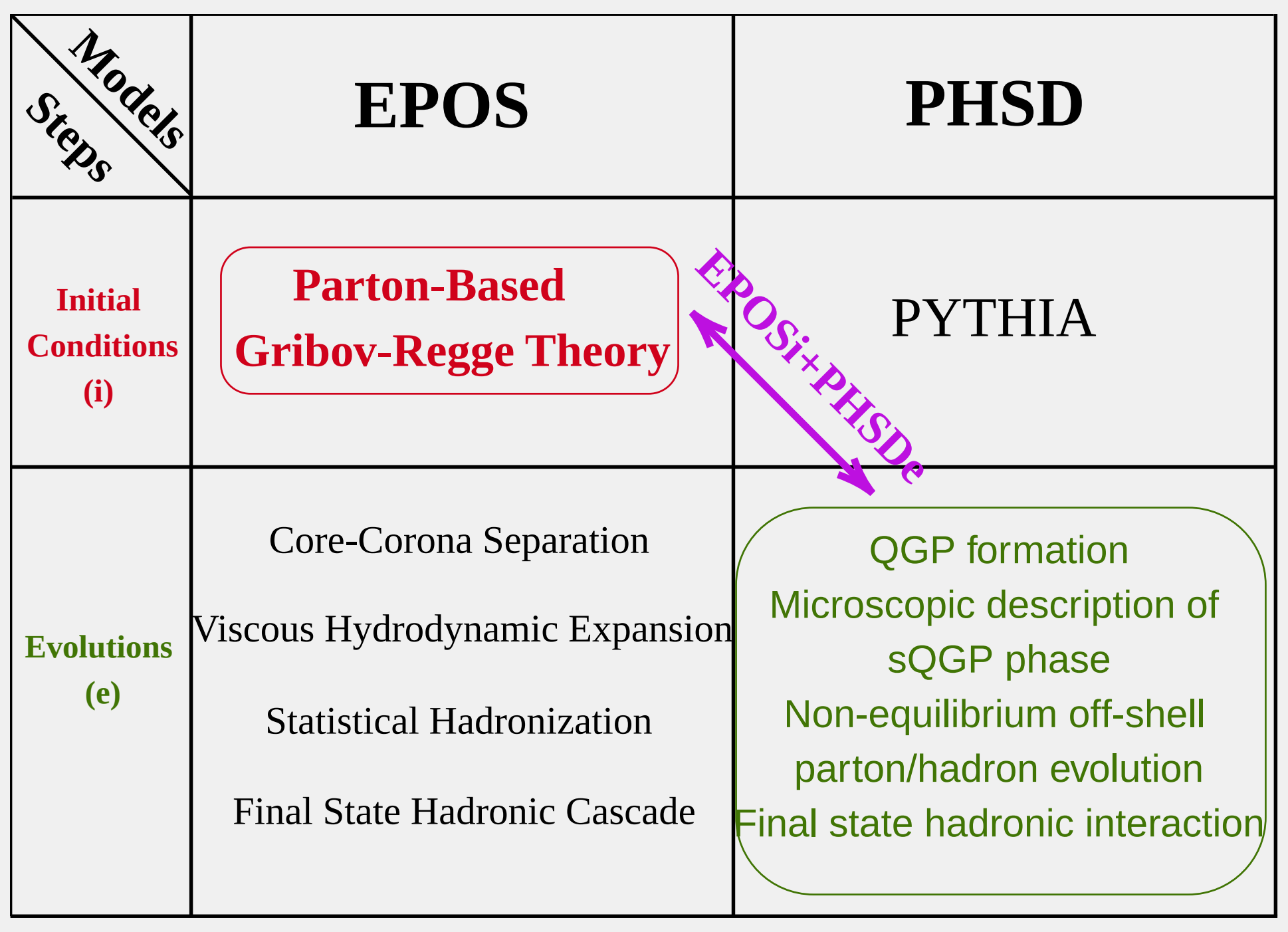
Motivation

- In ultra-relativistic HICs at RHIC and LHC a hot and dense form of matter composed of deconfined quarks and gluons, named QGP, is produced.
- The goal of experimental measurements is to investigate the QGP and to understand how it is produced, evolves, and impacts measurements.
- EPOS [1, 2] and PHSD [3, 4] are two comprehensive approaches to investigating the initial phase, time evolution, and QGP hadronization, and final hadronic interaction, see Fig. 1.

The main idea to combine EPOS and PHSD

- Combining the initial EPOS phase (EPOSi) with the evolution from PHSD (PHSDe), resulting in the **EPOSi+PHSDe**, see Fig. 1.
- **Comparing EPOSi+PHSDe and pure EPOS:**
  - Two models that have different evolutions but the same initial conditions.
- **Comparing EPOSi+PHSDe and pure PHSD:**
  - Two models that have different initial conditions but the same evolution.
- **The main goal of this study:**
  - **Separate "initial" and "evolution" effects.**
  - **Investigate the influence of the initial conditions on observables.**



Models / Steps	EPOS	PHSD
Initial Conditions (i)	**Parton-Based Gribov-Regge Theory**	PYTHIA
Evolutions (e)	Core-Corona Separation Viscous Hydrodynamic Expansion Statistical Hadronization Final State Hadronic Cascade	QGP formation Microscopic description of sQGP phase Non-equilibrium off-shell parton/hadron evolution Final state hadronic interaction

Figure 1. The EPOS and PHSD stages to investigate the entire space-time evolution of matter in HICs. The new approach is called EPOSi+PHSDe since it integrates the initial conditions of EPOS (EPOSi) with the evolution of matter in a non-equilibrium transport approach (PHSDe).

Energy density evolution in different simulations

To see the differences between these three models, EPOS, EPOSi+PHSDe, and PHSD, we study the radial expansions via energy density evolutions using the energy-momentum tensor:

$$T^{\mu\nu}(\vec{q}) = \int \frac{d^3p}{E} p^\mu p^\nu f(\vec{q}, \vec{p}),$$

where $\vec{q}$ is a position vector, $\vec{p}$ indicates a momentum vector, and f denotes the phase space density for a given time. The energy density is given as T^{00} in the comoving frame, see the evolutions in Fig. 2.

- **Time $<$ 3 fm/c:**
  - Similar energy density profiles of EPOS and EPOSi+PHSDe due to similar initial conditions.
  - The evolution of the shape of energy density in pure PHSD is different, although it is comparable in magnitude to the other models.
- **Time $>$ 3 fm/c:**
  - EPOS in the hydro phase has a strong transverse expansion and evolves in an asymmetric fashion, which leads to larger transverse flows.
  - EPOSi+PHSDe and pure PHSD show more symmetric expansion in the transverse plane than pure EPOS, which affects observables like transverse momentum and elliptic flow.

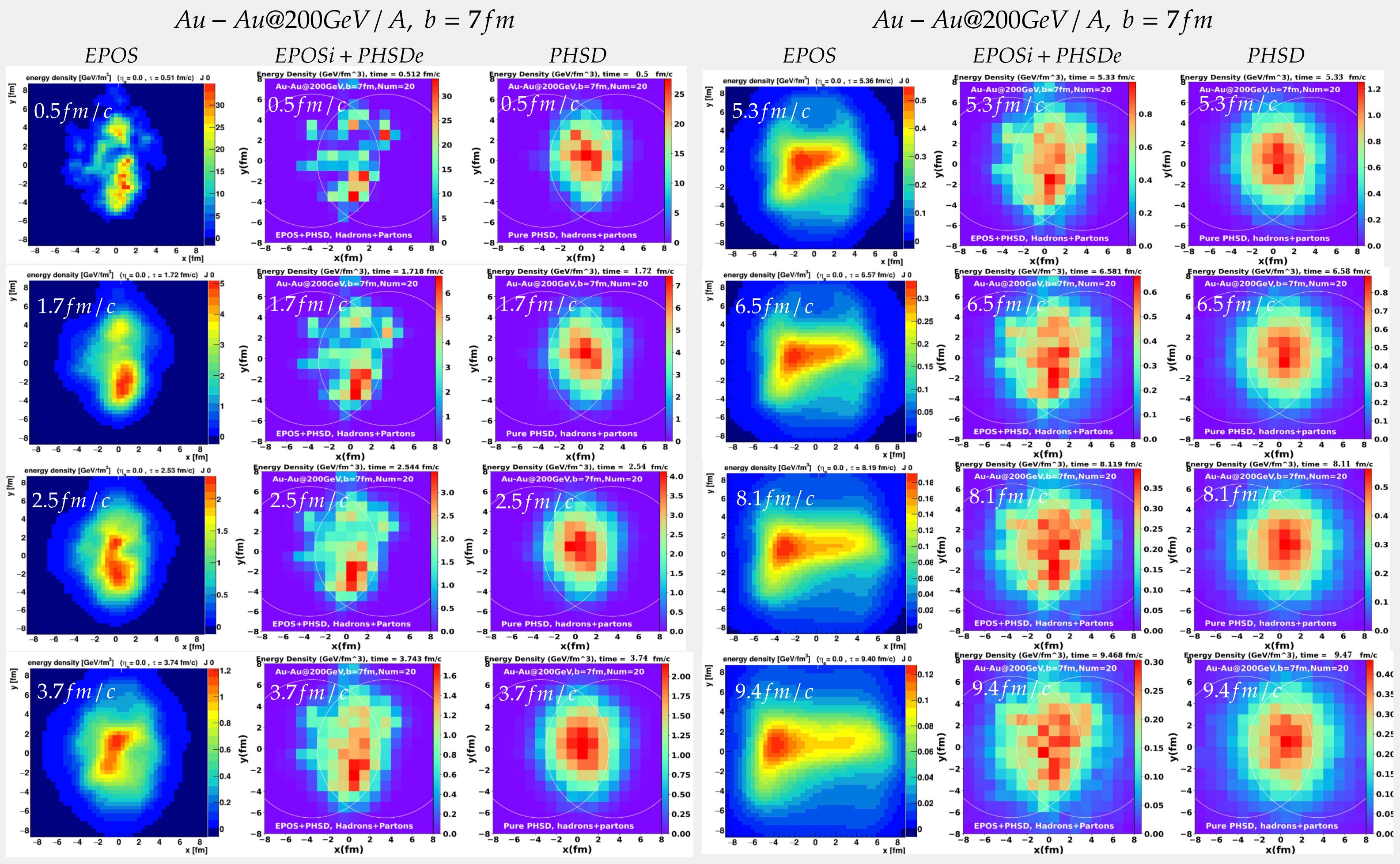


Figure 2. Time evolution of the energy density in the transverse plane ($x - y$ coordinates), the longitudinal coordinate z being zero, in Au-Au collisions at 200 AGeV, for an impact parameter of 7 fm. We show results for EPOS (left column), EPOSi+PHSDe (middle column), and PHSD (right column). The rows refer to different times.

Bulk Matter Observables

- **Transverse momentum distributions** (Fig. 3):

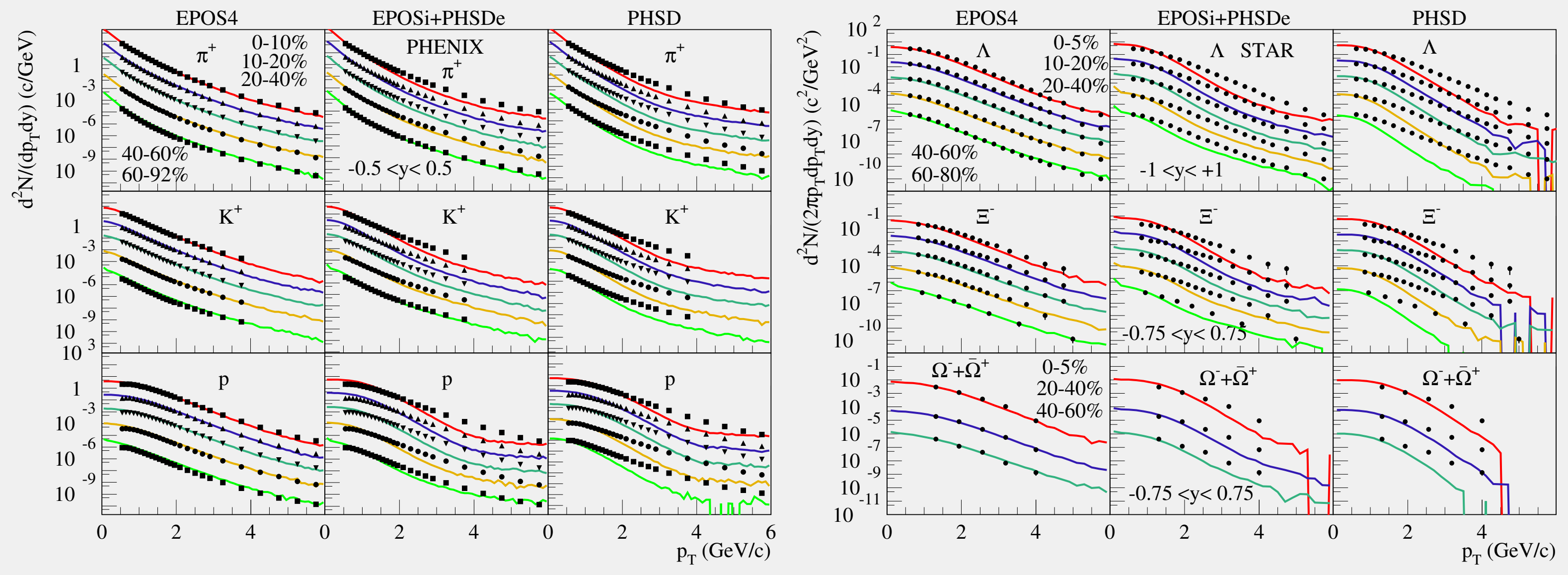


Figure 3. Transverse momentum distributions of identified particles in different simulations compared to PHENIX data (symbols) [5] and STAR data (symbols) [6]. The simulations have been done for Au-Au at 200GeV/A.

- **Flow harmonics v_2 and v_3** (Fig. 4):

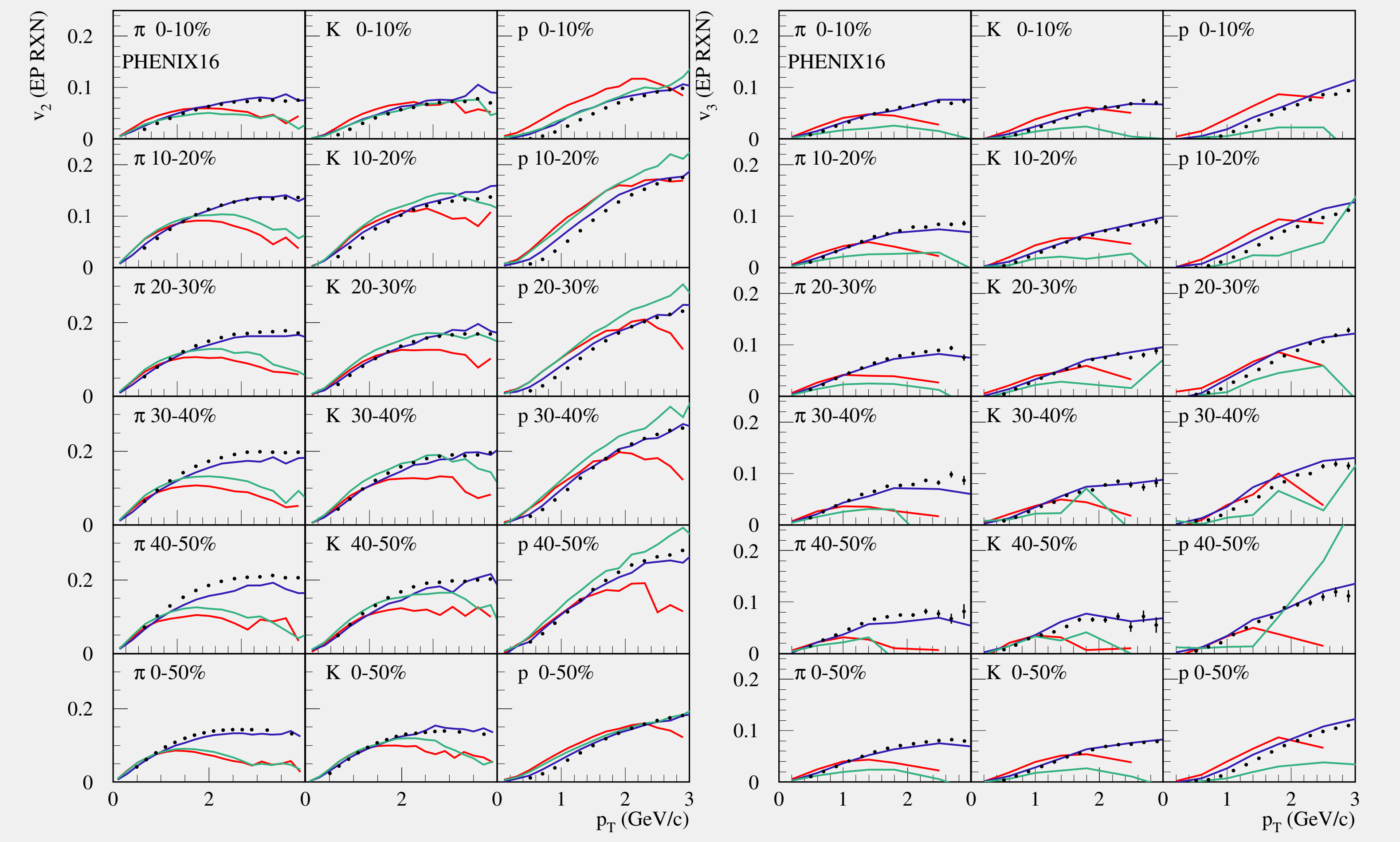


Figure 4. Elliptical flow v_2 and Triangular flow v_3 coefficients of identified particles for EPOS (blue curve), EPOSi+PHSDe (red curve), and PHSD (green curve), for AuAu collisions at 200 GeV/A, as the function of the transverse momentum p_T, for different centrality ranges, compared to PHENIX data (points) [7].

- EPOS simulations are quite close to the data for low and intermediate p_T. Intermediate p_T are strongly affected by hydrodynamic flow, and the effect increases with particle mass.
- EPOSi+PHSDe and PHSD simulations are close to the data at small p_T ($<$ 1 GeV/c) while at intermediate p_T values (1 GeV/c $< p_T <$ 5 GeV/c), in particular at central collisions, the data are underestimated and the deviation increases with particle mass.

- **The "collective push" from radial flow in EPOS during the hydro phase is much stronger compared to the transverse pressure in EPOSi+PHSDe and PHSD generated by partonic scattering and potential interaction in the quasiparticle picture.**

Conclusion

- **The initial conditions from pure EPOS (and similar in EPOSi+PHSDe), based on Parton Based Gribov Regge Theory (PBGRT), show more asymmetric energy density profile in coordinate space than the profile based on PYTHIA strings initial conditions in the PHSD.**
- **Hydrodynamic expansion in EPOS converts the initial asymmetric shape of energy density to a larger transverse flow more effectively (especially for larger p_T) than the microscopic partonic interactions based on DQPM as used in pure PHSD and EPOSi+PHSDe.**

References

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