

C3NT Workshop: Jet-soft dynamical medium interaction in high-energy heavy-ion collisions, 2026, Wuhan, China

Recent developments in EPOS4

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EPOS4: A Monte Carlo tool for simulating high-energy scatterings

Based on the requirement to have at LHC energies a formalism with multiple scatterings happening rigorously in parallel, in pp and AA collisions, we managed for the first time to get a fully selfconsistent scheme, compatible with the factorization approach, but allowing to go much beyond. Theoretical consistency (not fitting data) led to the implementation of **variable saturation scales**, where the latter depend in a well-defined way on the number of subscatterings. This has major consequences, in particular a hardening of events with increasing multiplicity.

Recent papers

2026

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EPOS4HQ

Treating heavy flavor properly

[more ...](#)

EPOS4 in short

A pedagogical overview

[more ...](#)

The basis of EPOS4

A series of four (technical) papers


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Recent papers

- "Disentangling initial-state and evolution effects in heavy-ion collisions using EPOS and PHSD"; [M. Jafarpour, V. Voronyuk, K. Werner, E. Bratkovskaya, D. Vintache, Phys. Rev. C 113, 014910 \(2026\)](#) and [arXiv:2509.05428](#)
- "Flow in small systems in the EPOS4 approach for high-energy scattering"; [K. Werner, Phys. Rev. C 113, 014911 \(2026\)](#) and [arXiv:2508.07417](#)
- "Correlations between heavy mesons and the creation of the charmonia, bottomonia, and Bc mesons in high energy pp collisions"; J. Zhao, J. Aichelin, P.B. Gossiaux, and K. Werner [arXiv:2511.08796](#)
- "Road map for the tuning of hadronic interaction models with accelerator-based and astroparticle data"; [Albrecht, J. and others, Nature Rev.Phys. \(2026\)](#) and [arXiv:2508.21796](#)

further down

The following series of four basic papers should be cited when using EPOS4

- **EPOS4 overview:** "Revealing a deep connection between factorization and saturation: New insight into modeling high-energy proton-proton and nucleus-nucleus scattering in the EPOS4 framework"; [K. Werner, Phys. Rev. C 108, 064903 \(2023\)](#) and [arXiv:2301.12517](#)
- **Internal Pomeron structure in terms of QCD (link between the multiple scattering formalism and QCD):** "Perturbative QCD concerning light and heavy flavor in the EPOS4 framework"; [K. Werner and B. Guiot, Phys. Rev. C 108, 034904 \(2023\)](#) and [arXiv:2306.02396](#)
- **Detailed and rigorous treatment of the multiple scattering formalism based on Pomerons:** "Parallel scattering, saturation, and generalized Abramovskii-Gribov-Kancheli (AGK) theorem in the EPOS4 framework, with applications for heavy-ion collisions at $\sqrt{s_{NN}}$ of 5.02 TeV and 200 GeV"; [K. Werner, Phys. Rev. C 109, 034918 \(2024\)](#) and [arXiv:2310.09380](#)
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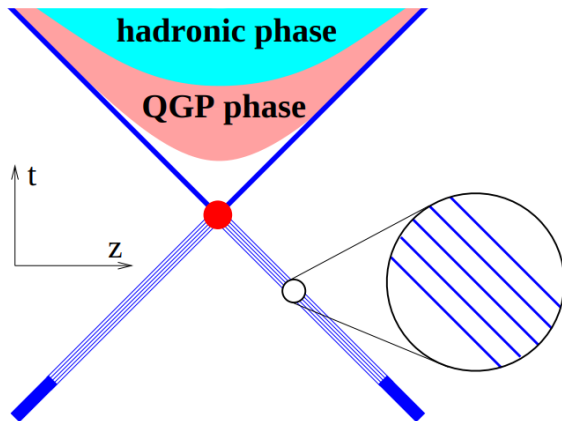
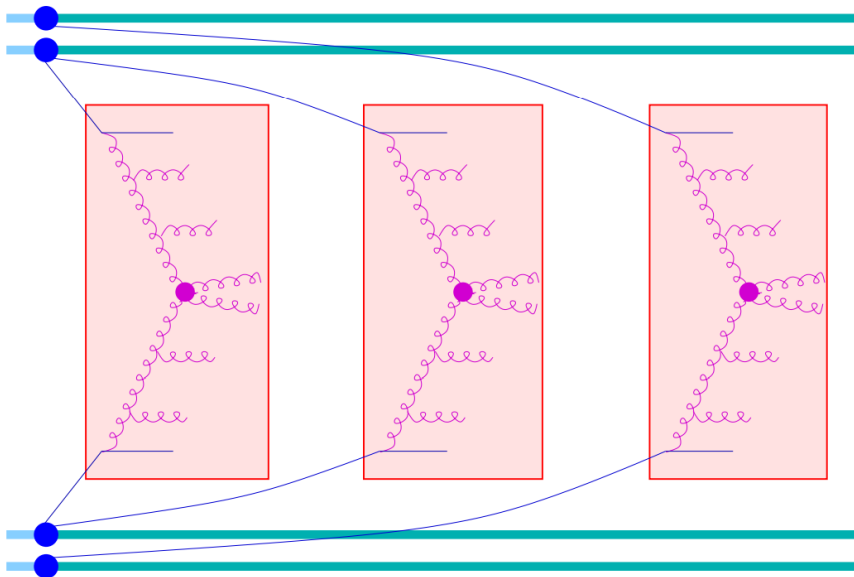


Figure 1: Space-time picture of hadronic scatterings.

The red dot (in EPOS4):



crucial role of saturation

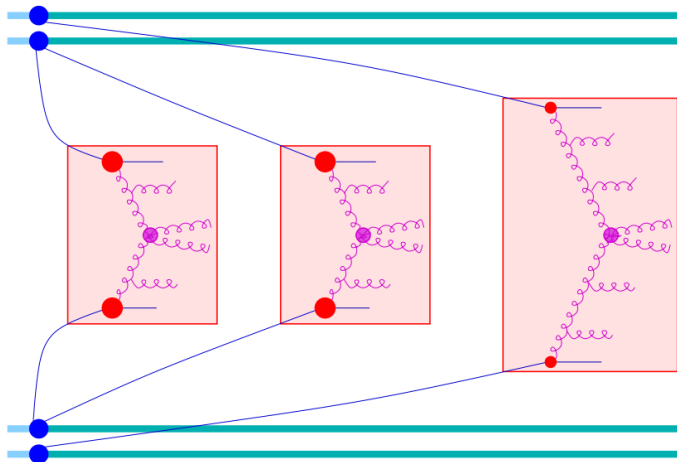


Figure 13: Sketch of the “compensation” of smaller energies (red box sizes) by larger saturation scale values (red dots).

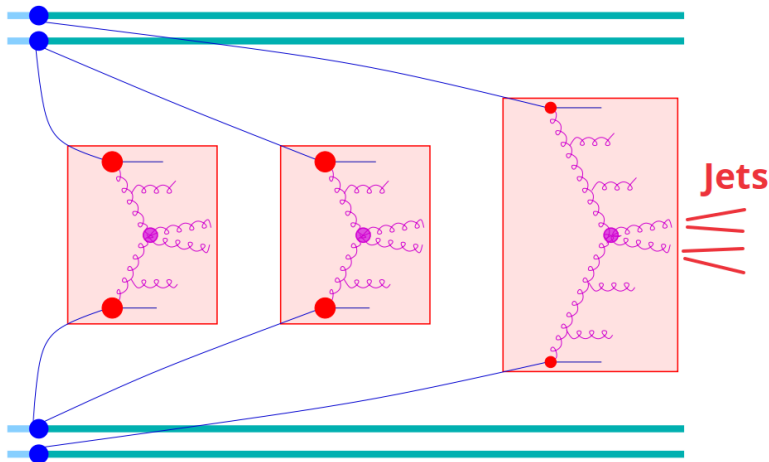
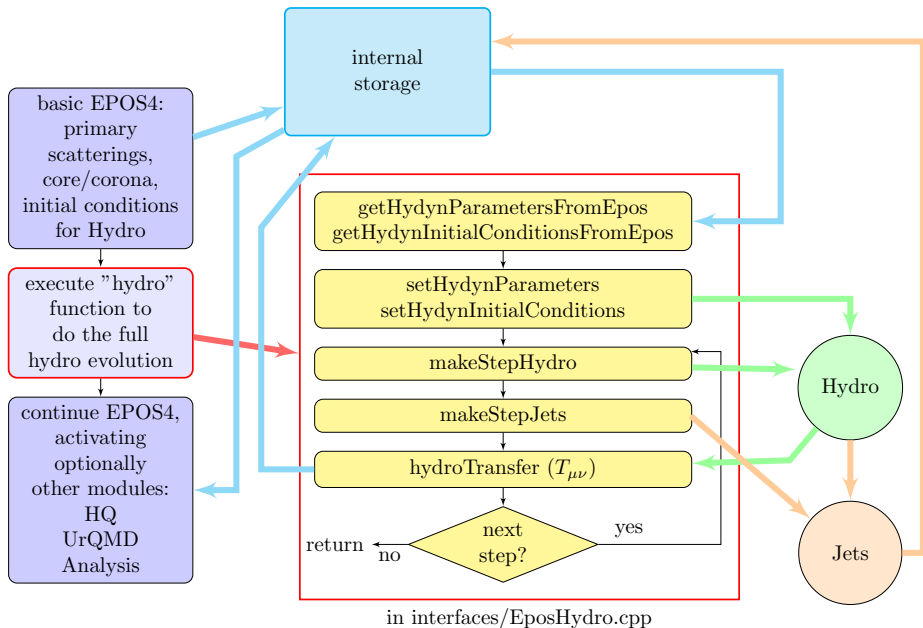
crucial role of saturation

Figure 13: Sketch of the “compensation” of smaller energies (red box sizes) by larger saturation scale values (red dots).

What about jet-medium interaction?



Analyzing heavy ion results using EPOS and PHSD

based on

"Disentangling initial-state and evolution effects in heavy-ion collisions using EPOS and PHSD"; M. Jafarpour, V. Voronyuk, K. Werner, E. Bratkovskaya, D. Vintache, *Phys. Rev. C* 113, 014910 (2026) and arXiv:2509.05428

in collaboration with

M. Jafarpour, V. Voronyuk, E. Bratkovskaya, D. Vintache

EPOS and PHSD

In both models, one has (at high energy) a clearly defined initial stage (i) and evolution stage (e)

$$\text{EPOS}_i + \text{EPOS}_e$$
$$\text{PHSD}_i + \text{PHSD}_e$$

Idea: Mix it

$$\text{EPOS}_i + \text{PHSD}_e$$

In more detail

EPOS¹:

The initial phase **EPOSi** amounts to an S-matrix approach for instantaneous parallel scatterings

whereas

the following dynamics **EPOSe** has been realized by assuming that a fast equilibration occurs followed by a hydrodynamical evolution

¹<https://klaus.pages.in2p3.fr/epos4/highlights/concepts.html> (qualitative discussion)
<https://klaus.pages.in2p3.fr/epos4/highlights/basis.html> (all details)

PHSD²:

The initial high energy nucleon nucleon scatterings and the string formation **PHSDi** is based on the LUND string model using the Pythia event generator in the initial phase

whereas

the evolution **PHSDe** is based on a microscopic covariant dynamical approach for strongly interacting systems using Kadanoff-Baym equations in the semi-classical limit.

²W. Cassing and E. L. Bratkovskaya, Phys. Rev. C 78, 034919 (2008), arXiv:0808.0022 [hep-ph].

W. Cassing and E. L. Bratkovskaya, Nucl. Phys. A 831, 215 (2009), arXiv:0907.5331 [nucl-th].

W. Cassing, Eur. Phys. J. ST 168, 3 (2009), arXiv:0808.0715 [nucl-th].

E. L. Bratkovskaya, W. Cassing, V. P. Konchakovski, and O. Linnyk, Nucl. Phys. A 856, 162 (2011), arXiv:1101.5793 [nucl-th].

V. P. Konchakovski, E. L. Bratkovskaya, W. Cassing, V. D. Toneev, and V. Voronyuk, Phys. Rev. C 85, 011902 (2012), arXiv:1109.3039 [nucl-th].

T. Song, H. Berrehrh, D. Cabrera, J. M. Torres-Rincon, L. Tolos, W. Cassing, and E. Bratkovskaya, Phys. Rev. C 92, 014910 (2015), arXiv:1503.03039 [nucl-th].

E. L. Bratkovskaya, A. Palmese, W. Cassing, E. Seifert, T. Steinert, and P. Moreau, J. Phys. Conf. Ser. 878, 012018 (2017).

O. Linnyk, E. L. Bratkovskaya, and W. Cassing, Prog. Part. Nucl. Phys. 87, 50 (2016), arXiv:1512.08126 [nuclth].

P. Moreau, O. Soloveva, L. Oliva, T. Song, W. Cassing, and E. Bratkovskaya, Phys. Rev. C 100, 014911 (2019), arXiv:1903.10257 [nucl-th].

Our aim

EPOSi+PHSDe

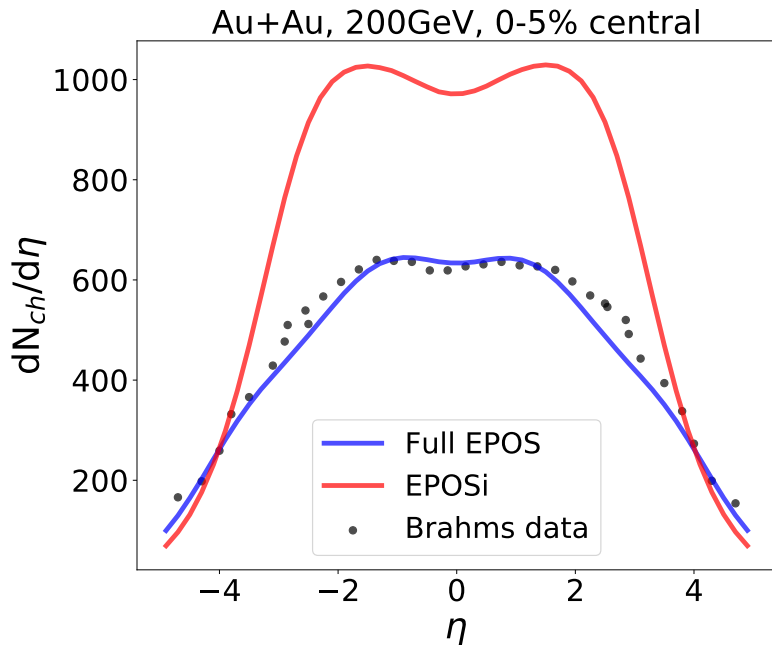
Let's look at **EPOSi**. In short:

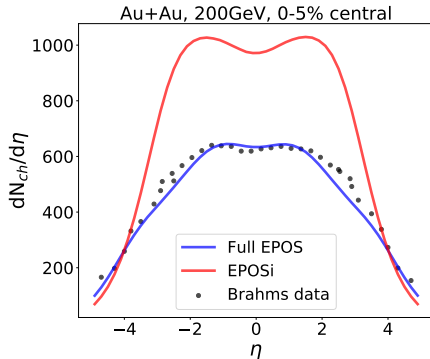
Pomerons => Parton chains => kinky strings
=> string segments

First test:

Count the segments (prehadrons), compare with data

Prehadrons, from string fragmentation, have per def hadron properties, in particular charge, so we can check charged particles





Taking this EPOSi and implement these prehadrons into PHSD for the evolution (EPOSi+PHSDe) ...

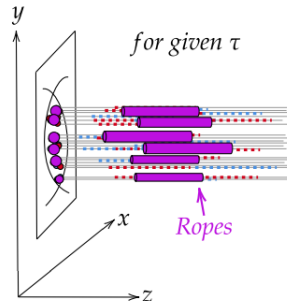
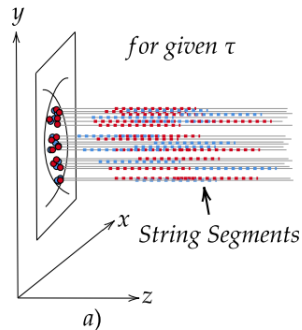
- it will not work at all,**
- the multiplicity will not be reduced as in the EPOSe (hydro) case,**
- the multiplicity will be way too high!**

EPOSi+PHSDe does not work. We switch to

EPOSir+PHSDe

by introducing ropes.

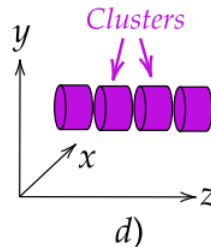
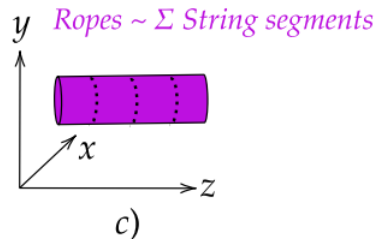
Idea: overlapping strings produce too many hadrons, they should not decay independently, but via ropes (old idea)

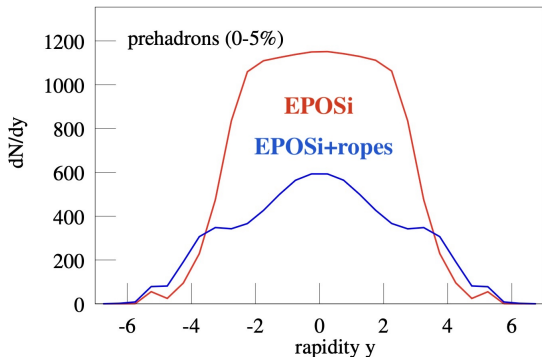


We construct connected objects from overlapping string segments (of irregular geometry)

cut into segments of given longitudinal width (discretization)

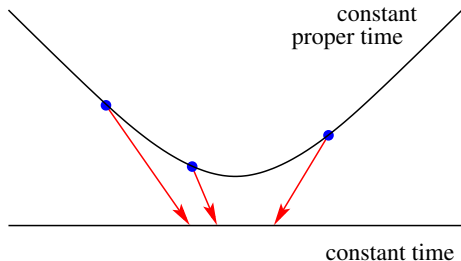
Each rope segments (called cluster) decays via microcanonical decay in its center of mass, with a subsequent boost back into the lab system.





Considerable
reduction
of the number
of prehadrons

Inserting prehadrons into
PHSD: extrapolation back
to constant PHSD start time
... and PHSD takes over



In the following, we compare

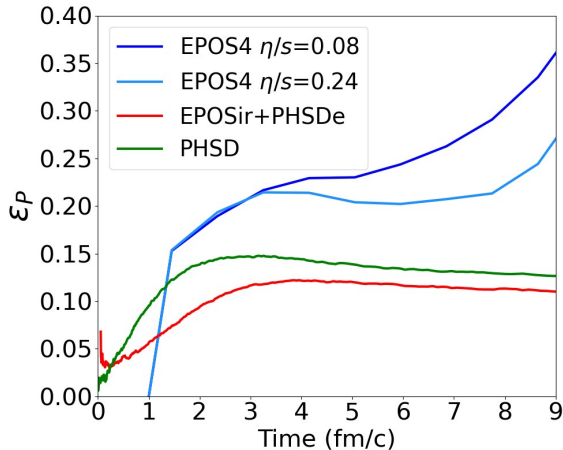
$$\text{EPOS} = \text{EPOS}_i + \text{EPOS}_e$$

$$\text{EPOSPHSD} = \text{EPOSPHSD}_i + \text{PHSD}_e$$

$$\text{PHSD} = \text{PHSD}_i + \text{PHSD}_e$$

Let's look at the momentum eccentricity
(summed over all cells) at $z = 0$ (longitudinal coordinate)

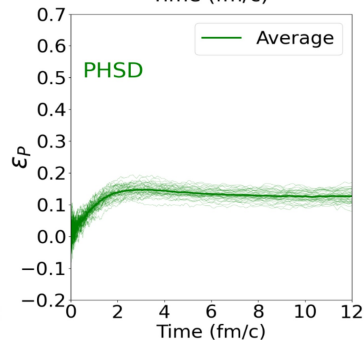
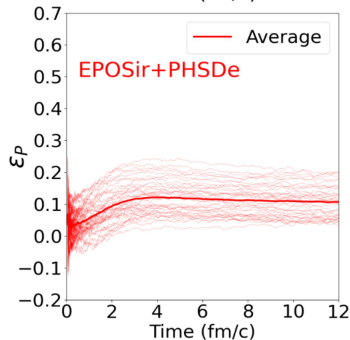
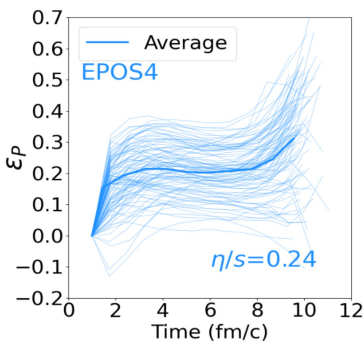
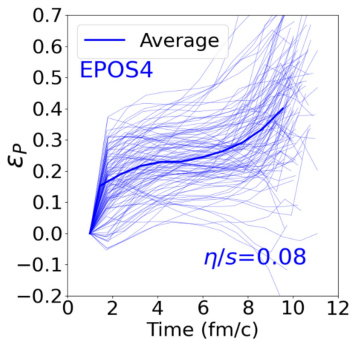
$$\epsilon_p = \frac{\sum \epsilon v_{\perp}^2 \cos(2\phi)}{\sum \epsilon v_{\perp}^2}$$



Au+Au 200 GeV,
 $b=7\text{fm}$
averaged over events

significant differences

Here we show “flow asymmetry”. A large value is a consequence of a initial asymmetry in space + a strong radial flow.



Au+Au
200 GeV,
b=7fm
event-by-
event

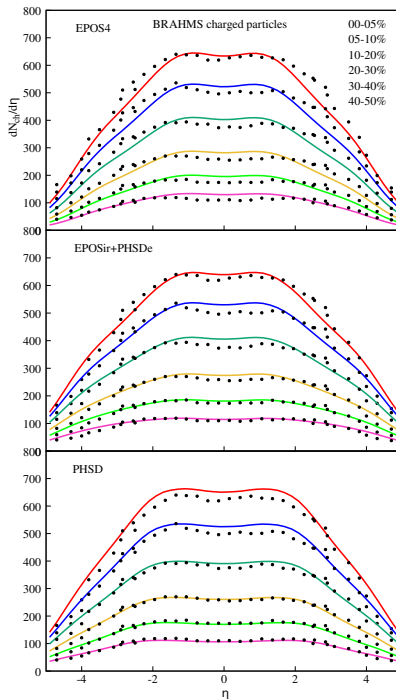
**significant
differences
concerning
fluctuations**

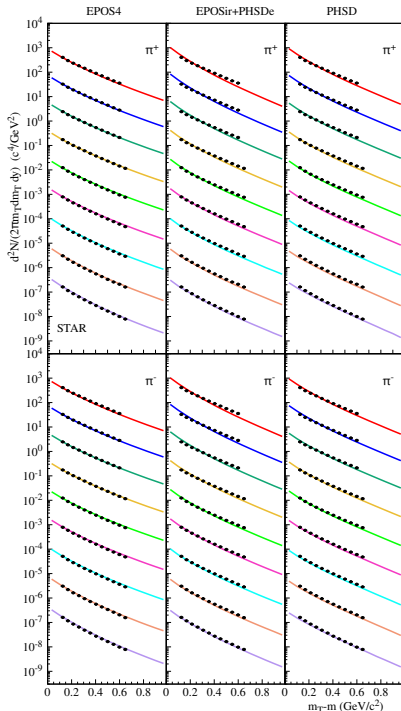
Comparing with data

Pseudorapidity distributions

Au+Au 200 GeV
different centralities

not bad ...





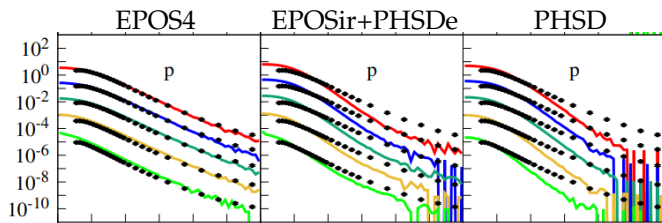
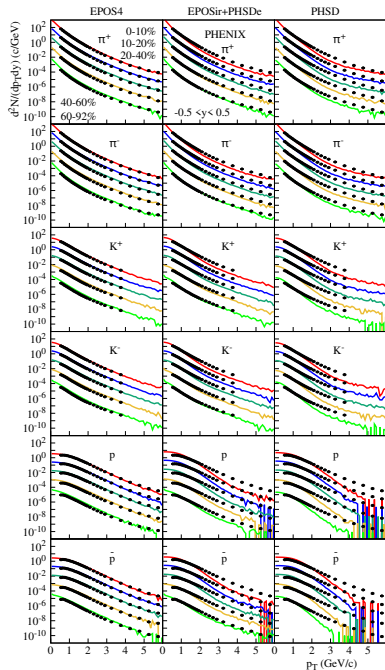
Transverse mass distributions

Au+Au 200 GeV
different centralities
pions (range 0 - 1 GeV/c^2)

Looking at this and more comparisons, also at different rapidities,

BUT always at low p_T or m_T :

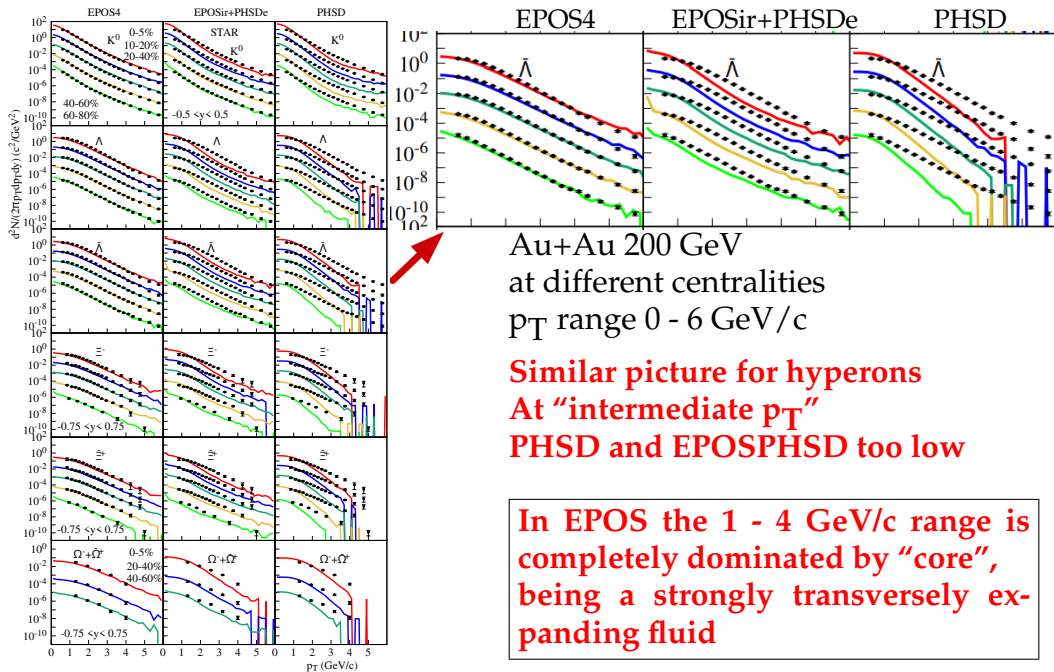
agreement with data and among the three models.

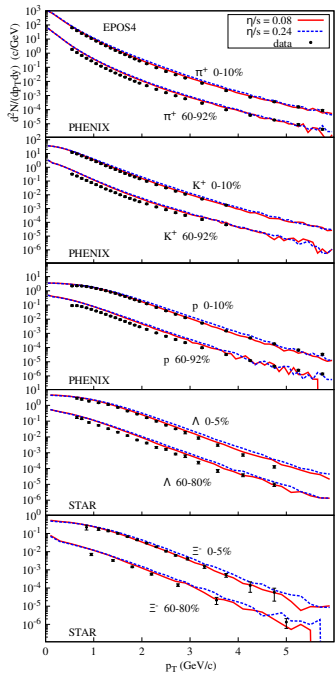


Transverse momentum distributions

Au+Au 200 GeV
at different centralities
 p_T range 0 - 6 GeV/c

Big differences at "intermediate p_T "
PHSD and EPOSPHSD similar





In EPOS4 a small value of η/s (0.08) is used. Does this “make the effect” ?

**We compare η/s 0.08 and 0.24
for p_T spectra in AuAu at 200 GeV.**

Very little η/s dependence.

Elliptic flow

Event plane method

$$v_2 = \langle \cos [2(\phi - \Psi_{EP})] \rangle$$

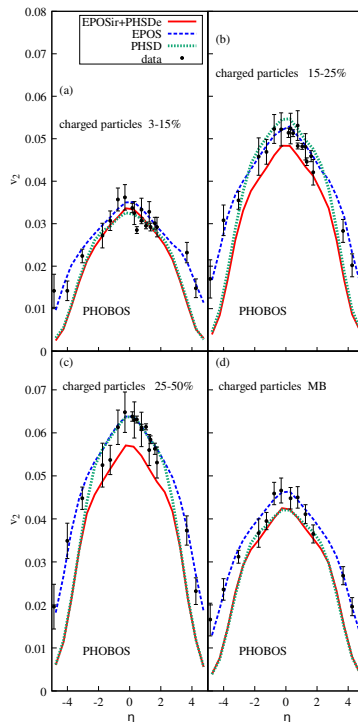
(old method, but we use the same as in experiment)

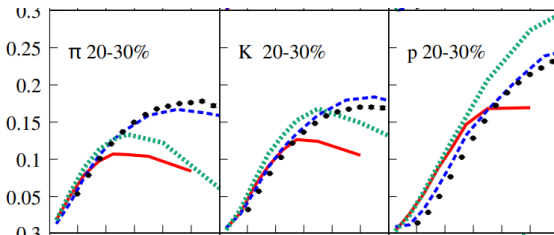
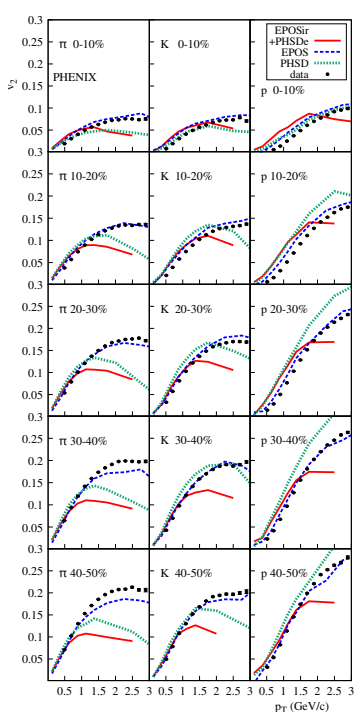
Plotted: v_2 vs pseudorapidity η

EPOSPHSD and PHSD a bit narrow

EPOSPHSD too low

But altogether reasonable agreement with data for all





Differential elliptic flow $v_2(p_T)$
 Au+Au 200 GeV
 p_T range 0 - 3 GeV/c

**For $p_T > 1$ GeV/c:
 PHSD and EPOSPHSD too low
 PHSD for protons too high**

**In EPOS the 1 - 4 GeV/c range is
 completely dominated by "core",
 strong transverse flow**

Summary

- Studying radial expansions via momentum eccentricities ε_P : the system in EPOSir+PHSDe and PHSD expands slowly in transverse direction and ε_P even decreases finally.
- **But ε_P in EPOS increases very strongly (with large fluctuations) at very early times and continues growing.**
- **Consequence: underestimation by EPOSir+PHSDe (similar to PHSD) of the intermediate and high p_T range of hadron spectra and flow coefficients.**
- **The “hydrodynamical radial push” seems to be needed to describe the experimental data at intermediate p_T .**

Thank you