Developing flow in high-energy nuclear collisions

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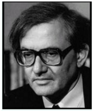
24th ZIMÁNYI SCHOOL WINTER WORKSHOP ON HEAVY ION PHYSICS

December 4th, 2024

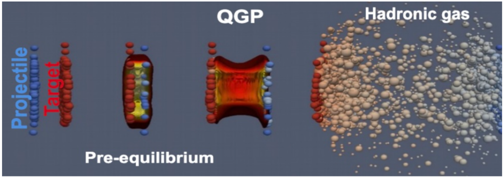


József Zimányi (1931 - 2006)

Outline:

- Introduction
  - HIC Models, Purpose of project
- Initial condition in EPOS
  - PBGRT, Core-Corona picture
- EPOS2PHSD Interface
  - Insertion procedure
- Evolution in EPOSi+PHSDe
  - Space-time evolution, Energy density evolution
- Results
  - Charged particles production, Transverse momentum spectra, Anisotropic flow
- Conclusion and Outlook

Theoretical models to study HIC:



Space-time evolution of HIC

https://webhome.phy.duke.edu/ jp401/old˙music˙manual/˙images/hic˙petersen˙bernhard.jpg

We need models concerning the various stages: initial, evolution, and hadronization.

- EPOS ✓
- PHSD ✓
- AMPT
- UrQMD
- ...

Purpose of project:

EPOSi+PHSDe : Initial distribution of matter (partons/hadrons) from EPOS (EPOSi) + Evolution of matter in PHSD (PHSDe)

Steps \ Models	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

EPOSi+PHSDe

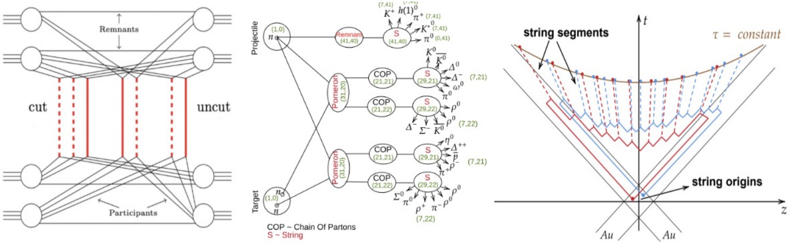
Purpose: Separate "initial" and "evolution" effects,
Study the influence of the initial conditions on observables

Initial Condition in EPOS:

Parton Based Gribov Regge Theory (PBGRT):

H. Drescher et al., Phys. Rep. 350, 93-289 (2001)

$\tau = 0$

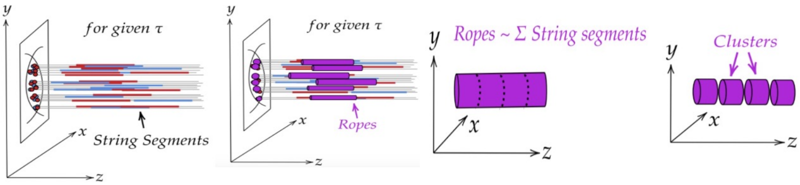


From Pomerons to string segments in AA collision

Energy loss of each string segment at given time τ:

$$P_t^{new} = P_t - f_{Eloss} \int_{\gamma} \rho dL$$

Core-Corona pre-hadrons in EPOSi+PHSDe:

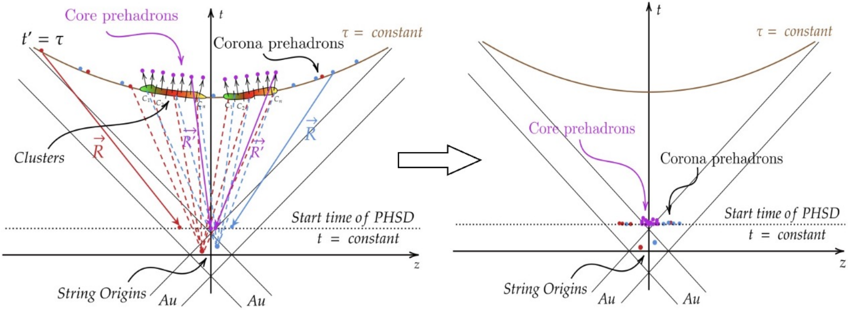


- Rope segments: overlapping of string segments
- Rope segments: longitudinal color field, consider in 3D, larger string tension and transverse momentum
- Clusters: Breaking rope segments into several pieces
- Core pre-hadrons: decay of rope segments/clusters based on Microcanonical treatment in their center of mass

  K. Werner, COST THOR Working Group I and II and GDRI Meeting (2018)
- Core pre-hadrons: mostly produced at low momentum and mid-rapidity regions
- Corona pre-hadrons = Corona particles

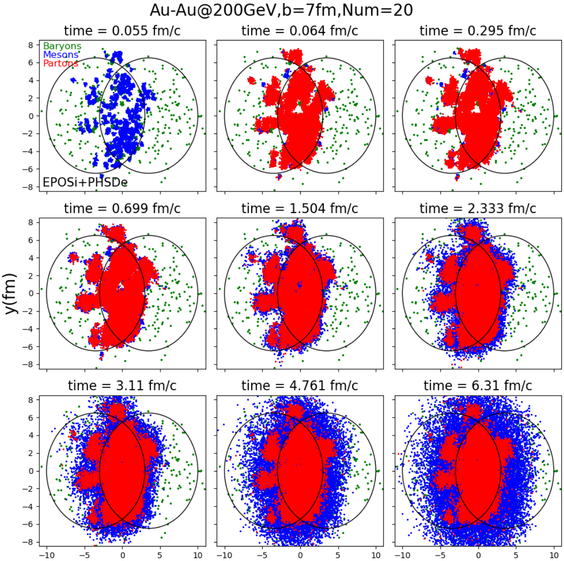
EPOS2PHSD

Extrapolation from the EPOS light cone coordinates to the PHSD cartezian coordinates:

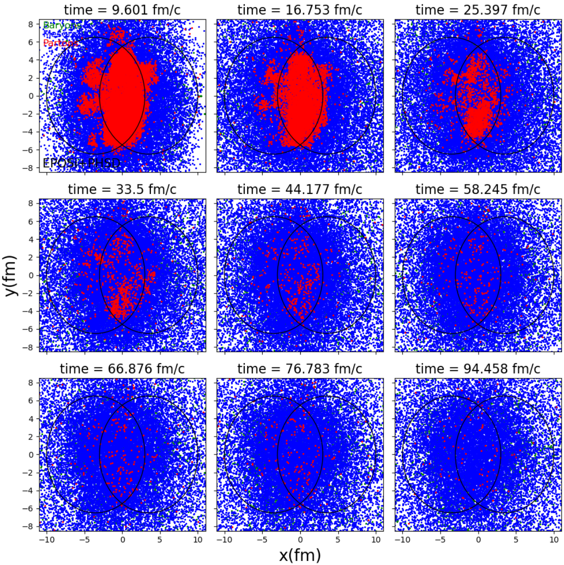


Inserting all pre-hadrons from EPOS into PHSD

Space-time evolution of HIC in EPOSi+PHSDe

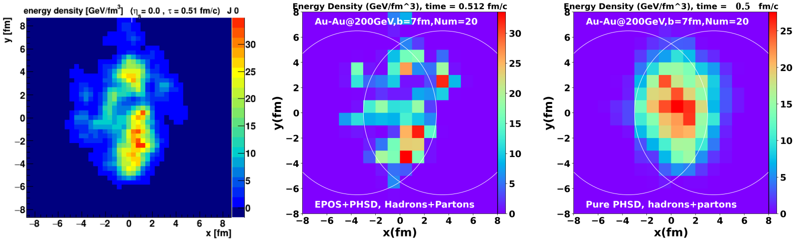


Space-time evolution of HIC in EPOSi+PHSDe



Energy density evolution in the three models

$t = 0.5$ fm/c

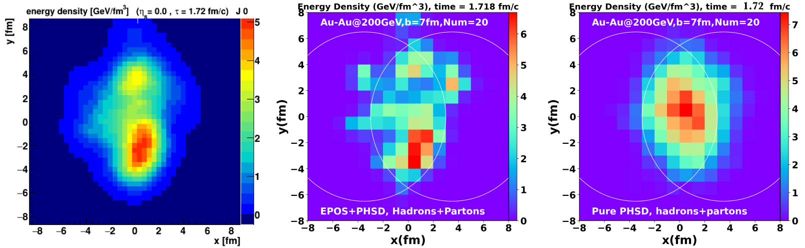


(a) EPOS (b) EPOSi+PHSDe (c) PHSD

Au-Au at 200A GeV, b=7 fm

Energy density evolution in the three models

$t = 1.7$ fm/c

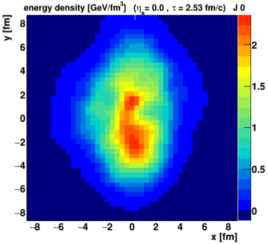


(a) EPOS (b) EPOSi+PHSDe (c) PHSD

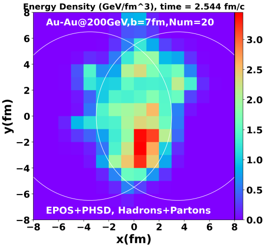
Au-Au at 200A GeV, b=7 fm

Energy density evolution in the three models

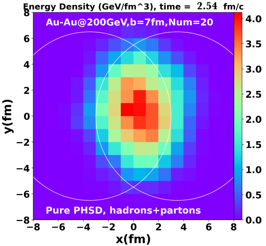
$t = 2.5$ fm/c



(a) EPOS



(b) EPOSi+PHSDe

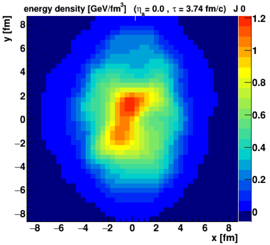


(c) PHSD

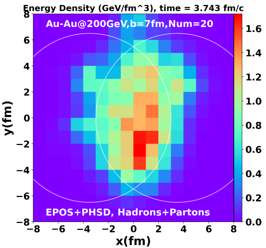
Au-Au at 200A GeV, b=7 fm

Energy density evolution in the three models

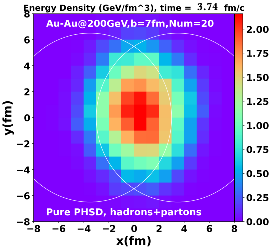
$t = 3.7$ fm/c



(a) EPOS



(b) EPOSi+PHSDe

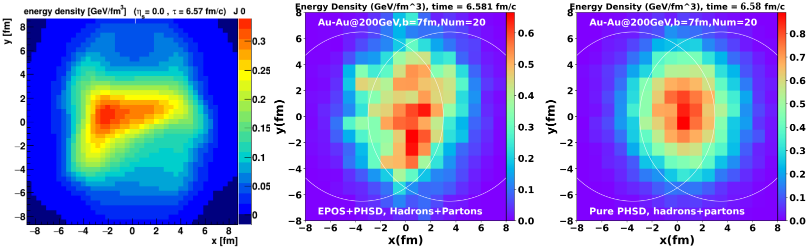


(c) PHSD

Au-Au at 200A GeV, b=7 fm

Energy density evolution in the three models

$t = 6.5$ fm/c

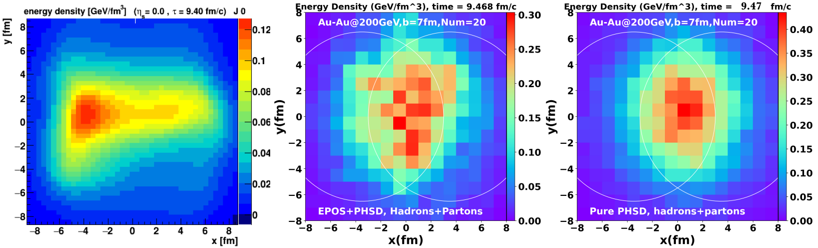


(a) EPOS (b) EPOSi+PHSDe (c) PHSD

Au-Au at 200A GeV, b=7 fm

Energy density evolution in the three models

$t = 9.4$ fm/c

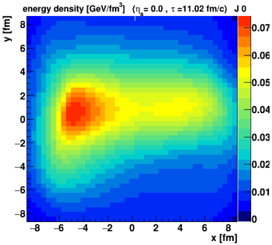


(a) EPOS (b) EPOSi+PHSDe (c) PHSD

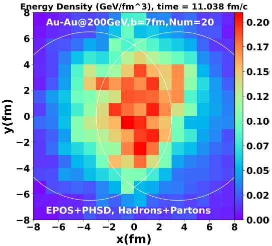
Au-Au at 200A GeV, b=7 fm

Energy density evolution in the three models

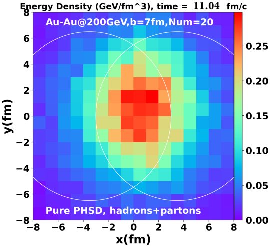
$t = 11$ fm/c



(a) EPOS



(b) EPOSi+PHSDe

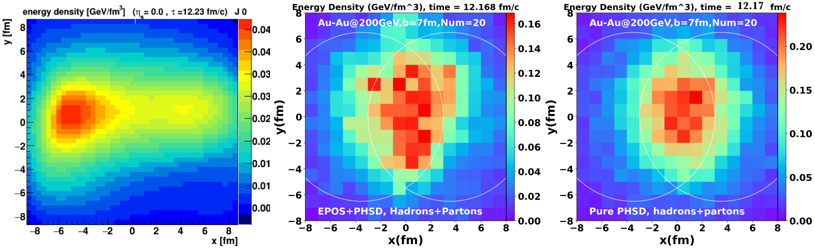


(c) PHSD

Au-Au at 200A GeV, b=7 fm

Energy density evolution in the three models

$t = 12.2$ fm/c

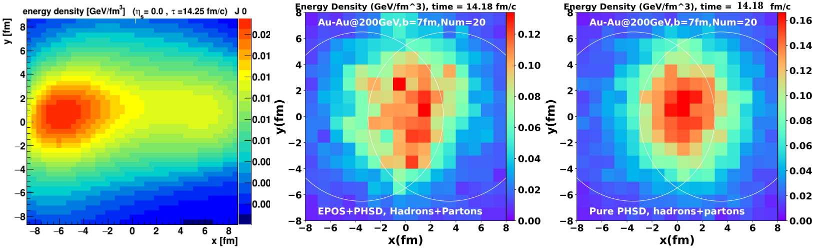


(a) EPOS (b) EPOSi+PHSDe (c) PHSD

Au-Au at 200A GeV, b=7 fm

Energy density evolution in the three models

$t = 14.2$ fm/c

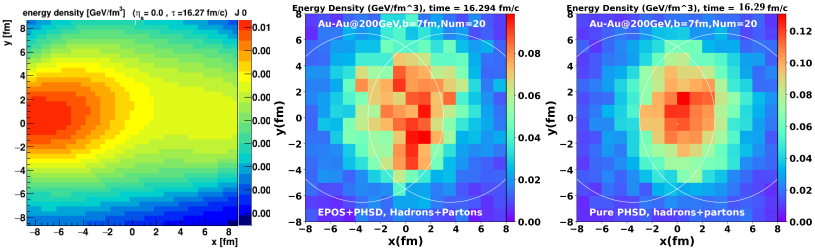


(a) EPOS (b) EPOSi+PHSDe (c) PHSD

Au-Au at 200A GeV, b=7 fm

Energy density evolution in the three models

$t = 16.2$ fm/c



(a) EPOS (b) EPOSi+PHSDe (c) PHSD

- EPOS has a strong transverse expansion and evolves asymmetric (driven by matter gradients), leading to larger transverse momentum, and flow harmonics.
- EPOSi+PHSDe and pure PHSD show more symmetric expansion in the transverse plane than pure EPOS.

Results

Comparing bulk matter observables for Au-Au@200 GeV/A :

- Charged particles production (Pseudorapidity dependence)
- Transverse momentum spectra
- Anisotropic flow
    - Elliptic flow v_2

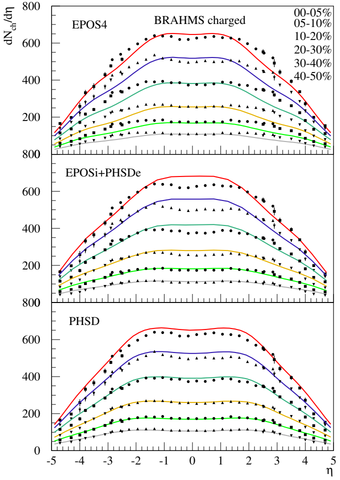
in

EPOS, EPOSi+PHSDe, and PHSD

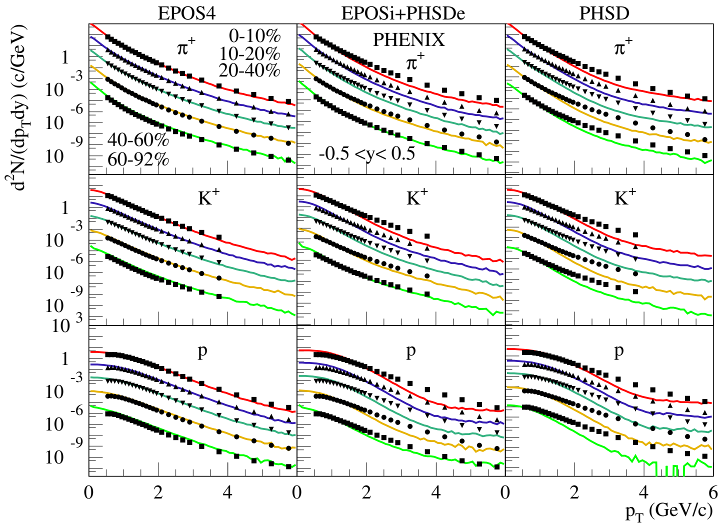
Charged particles production: pseudorapidity dependence

- EPOS: produces reasonably charged particles
- EPOSi+PHSDe: produces more charged particles at $|\eta| < 1.5$ in $0 - 30\%$
- PHSD: produces well the real data and the η shapes

BRAHMS data: PRL 88, 202301 (2002)



Transverse momentum spectra for Au-Au at 200A GeV



Anisotropic Flow

Event Plane method:

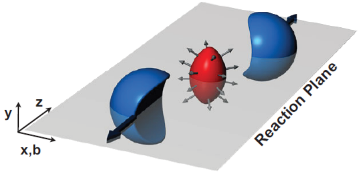
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}(1+\sum_{n=1}^{\infty} 2v_n cos(n(\phi - \Psi_{EP})))$$

$$v_n(p_t, y) =< cos(n(\phi - \Psi_{EP})) >$$

v_2 = elliptic flow, v_3 = triangular flow, v_4 = quadrangular flow

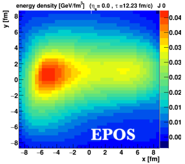
Ψ_{EP} = Event Plane angle

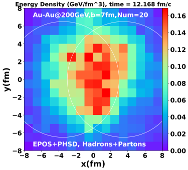
PLB 659, 537-541 (2008)

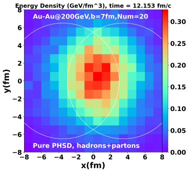


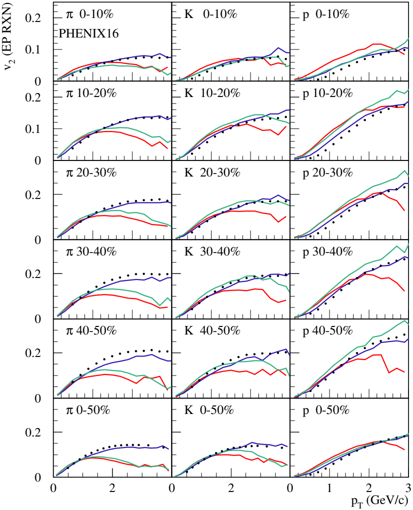
- Collision geometries and fluctuations of the initial state → anisotropic QGP matter in AA
- Initial spatial anisotropy → momentum anisotropy
- Elleptic flow: how the flow is not uniform

Elliptic flow for Au-Au at 200A GeV







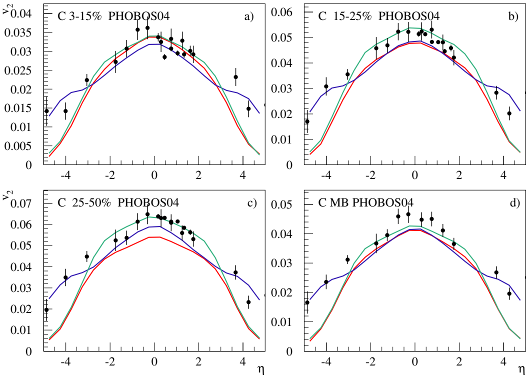


EPOS, EPOSi+PHSDe, PHSD

Elliptic flow : pseudorapidity dependence

- The flow is smallest at most central collisions
- At mid-pseudorapidity: PHSD has more flow than others
- At large $|\eta|$: EPOS has more flow than others

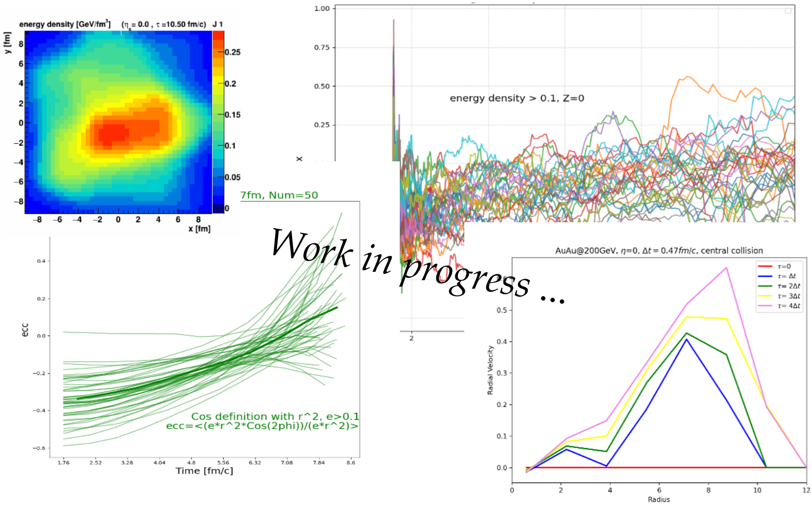
PHOBOS data: PRC 72, 051901 (2005)



EPOS, EPOSi+PHSDe, PHSD

Summary and Conclusion

- Combining two separate HIC models successfully.
- EPOSi+PHSDe: initial phase state from EPOS + matter evolution from PHSD
- The main distinctions between EPOS and PHSD are related to their "evolutions", while an "initial condition" has a minor role.
- 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.



Work in progress ...

EPOS4 Published

https://klaus.pages.in2p3.fr/epos4

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

from electron-positron annihilation up to heavy ion collisions

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Me, mahbobeh.jafarpour@subatech.in2p3.fr

Thanks for your time