On the role of the initial stage concerning the dynamics of heavy-ion collisions using EPOS and PHSD

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From QCD to QGP:

- At low T and low $\mu_B \rightarrow$ Hadronic gas
- At low T and high $\mu_B \rightarrow$ gas of neutron
- For $T > 175 MeV \rightarrow$ QGP
- At high T and $\mu_B \rightarrow 0$, Big Bang

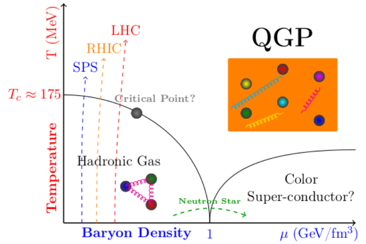


Figure: Phase diagram of nuclear matter [1].

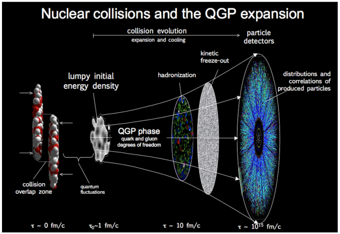


Figure: Space-time evolution of HIC.

Current Accelerators:

- SPS & LHC, CERN
- RHIC, BNL, New York

Future Accelerators:

- FAIR, Germany
- NICA, Russia

EPOS: Energy conserving multiple scattering Partons, parton ladder and strings Off-shell remnantes Saturation [2, 3].

- INITIAL CONDITION: A Gribov-Regge multiple scattering approach is employed (PBGRT).
- CORE-CORONA SEPARATION: based on momentum and density of string segments.
- VISCOUS HYDRODYNAMIC EXPANSION: Using core part and cross-over equation of state (EOS) compatible with lattice QCD.
- STATISTICAL HADRONIZATION: employing Microcanonical decay/Cooper-Frye procedure and equilibrium hadron distribution.
- FINAL STATE HADRONIC CASCADE: applying the UrQMD model.

PHSD: Parton Hadron String Dynamics [4, 5].

- INITIAL A+A COLLISION: leads to formation of strings that decays to pre-hadrons, done by PYTHIA.
- QGP FORMATION: based on local energy-density.
- QGP STAGE: evolution based on off-shell transport eqs. derived by Kadanoff-Baym eqs. with the DQPM defining the parton spectral function i.e. masses and widths.
- HADRONIZATION: massive off-shell partons with broad spectral functions hadronize to off-shell baryons and mesons.
- HADRONIC PHASE: evolution based on the off-shell transport eqs. with hadron-hadron interaction.

EPOSi+PHSDe : Employing a sophisticated EPOS approach to determine the initial distribution of matter (EPOSi) (partons/hadrons) and then using PHSD for the evolution of matter in a non-equilibrium transport approach (PHSDe).

Steps \ Models	EPOS	PHSD
Initial Conditions (i)	PBGRT	PYTHIA
Evolutions (e)	Core-Corona Separation Viscous Hydrodynamic Expansion Statistical Hadronization Final State Hadronic Cascade	QGP Formation Non-Equilibrium Parton/Hadron Evolution

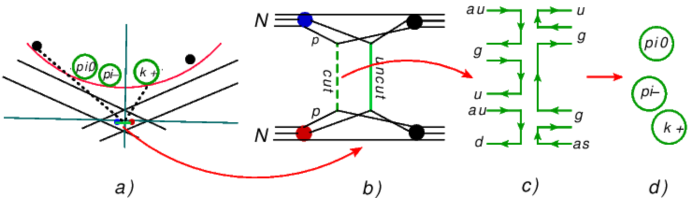
EPOSi+PHSDe

Purpose: Separate "initial" and "evolution" effects

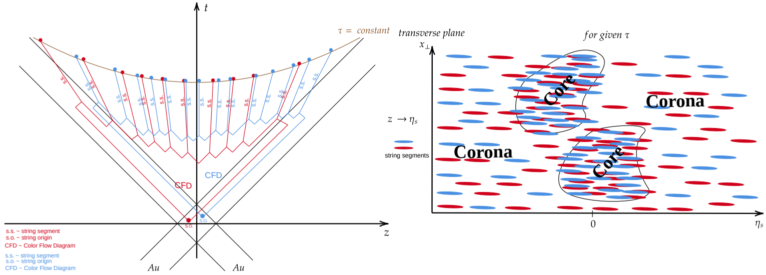
Initial Condition in EPOS:

Parton Based Gribov Regge Theory (PBGRT) [6]:

- Hard/Soft processes, Energy conservation by multiple Pomeron exchange
- Calculation of elastic/inelastic Cross-Sections (uncut ladder, soft contribution)
- Particle production [7] (cut ladder, semi-hard/hard contribution)



Core-Corona Separation in EPOS:

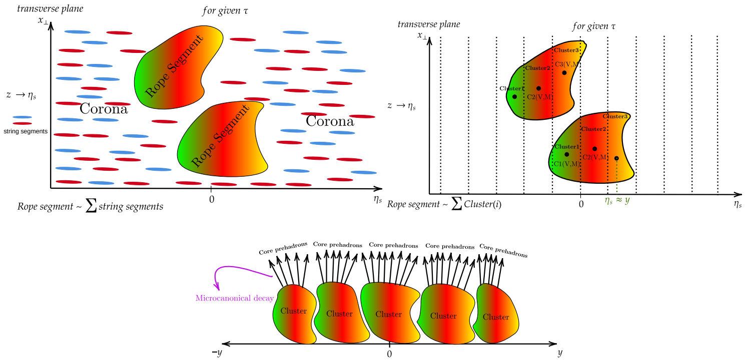


Energy loss of each string segment at given time τ:

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

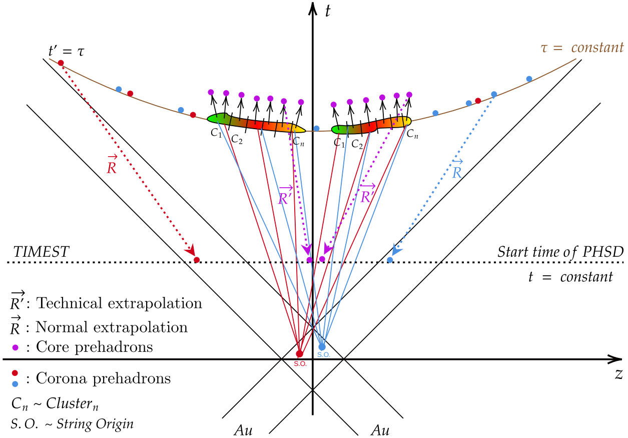
If $P_t^{new} > 0 \rightarrow$ Corona particle
If $P_t^{new} < 0 \rightarrow$ Core particle

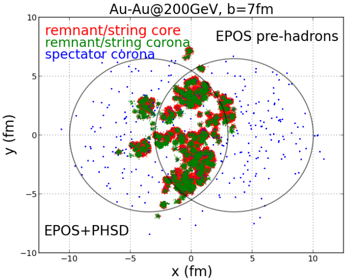
Core-Corona pre-hadrons in EPOSi+PHSDe:

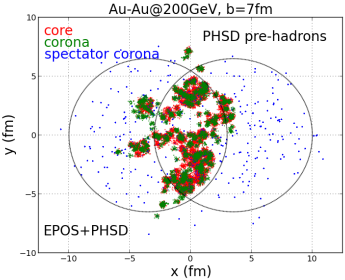


- rope segments: longitudinal color field, consider in 3D, larger string tension and transverse momentum
- Core pre-hadrons : decay of rope segments/clusters based on Microcanonical treatment [8]
- Corona pre-hadrons = Corona particles

Inserting all pre-hadrons from EPOS into PHSD:

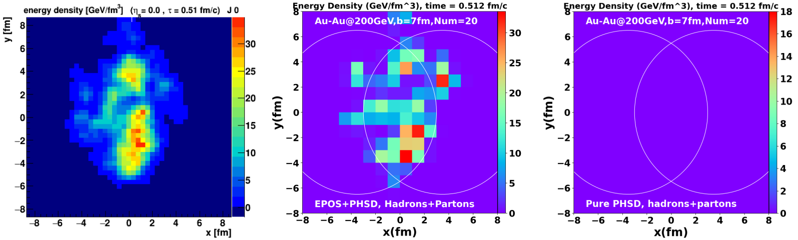






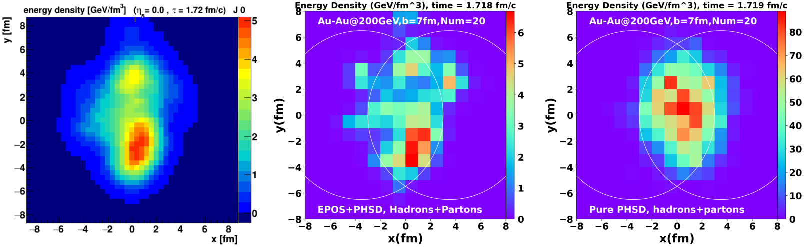
- All EPOS core/corona pre-hadrons are inserted into PHSD arrays
- Core pre-hadrons melted into QGP with respect to the melting condition ($\varepsilon > 0.5GeV/fm^3$)
- Enegy Density is computed in the Comoving frame in the three models: $T^{\mu\nu}(\vec{q}) = \int \frac{d^3p}{E} p^\mu p^\nu f(\vec{q},\vec{p}), \quad \varepsilon = T^{00}$

Energy Density Evolution



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

Figure: Time evolution of the energy density in the x-y plane (at z=0) for Au-Au collisions at 200A GeV with an impact parameter of 7fm, for three models.



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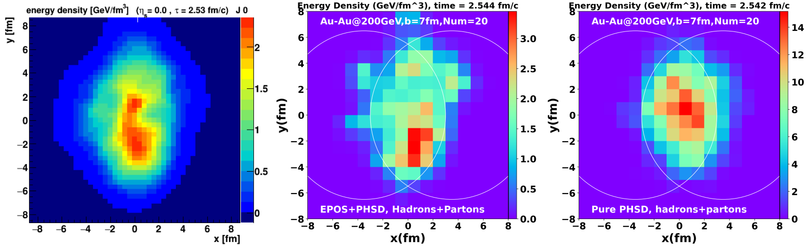

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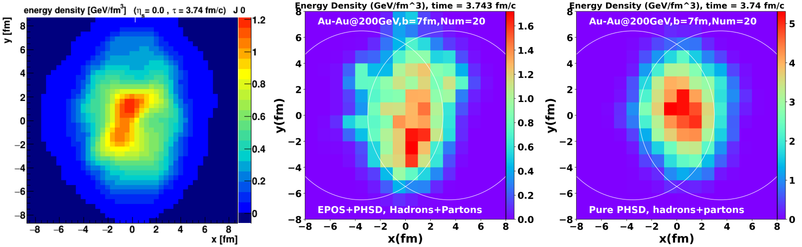
- EPOS: system expands in the longitudinal direction
- EPOSi+PHSDe: nearly identical to the EPOS
- PHSD: begins later and has more ED than others



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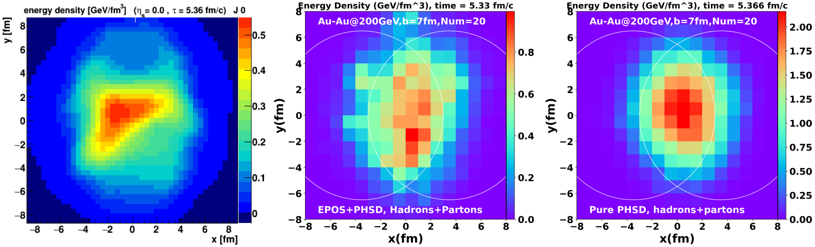

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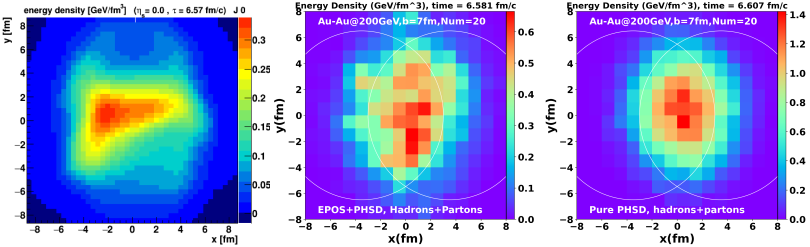

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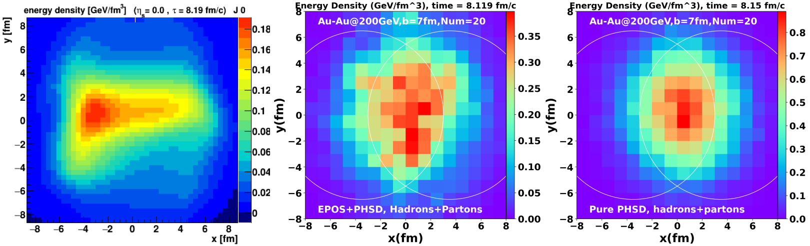

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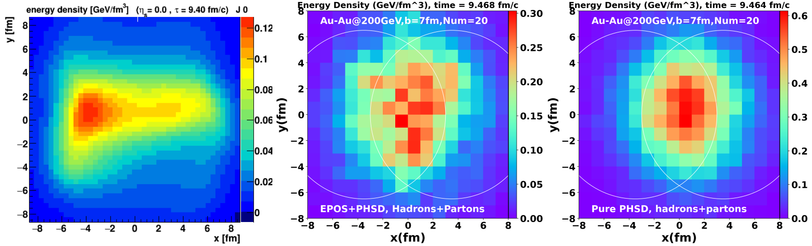

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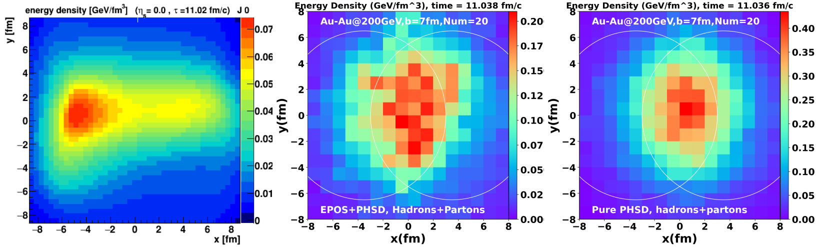

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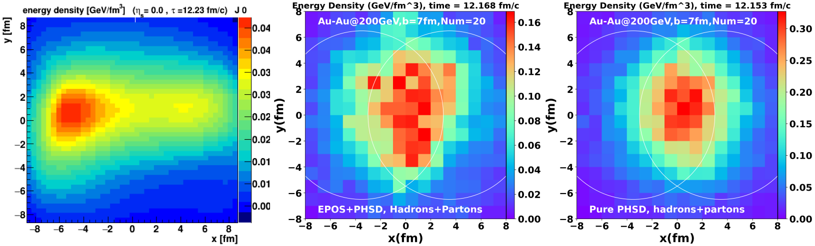

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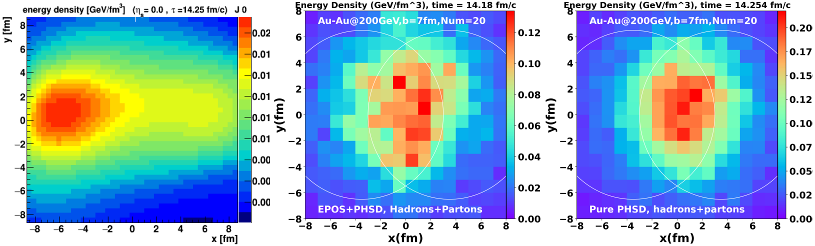

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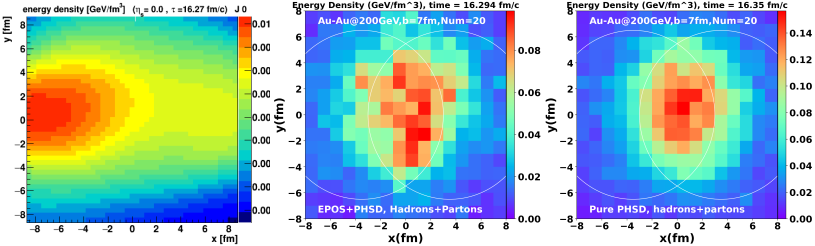

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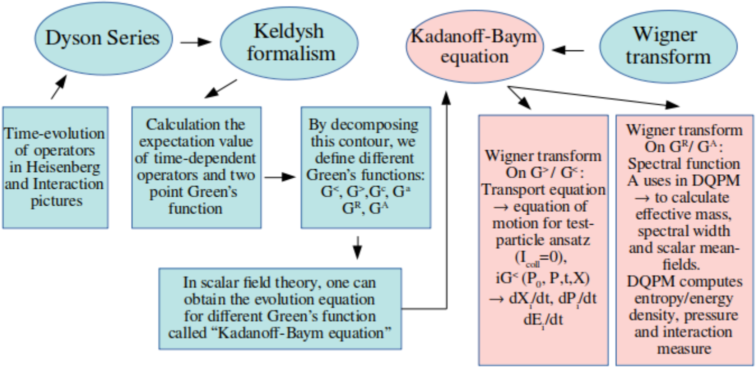
Figure: Time evolution of the energy density in the x-y plane (at z=0) for Au-Au collisions at 200A GeV with an impact parameter of 7fm, for three models.

- EPOS: strong transverse expansion leads to more transverse flows
- EPOSi+PHSDe: less transverse expansion than EPOS, same forms as pure PHSD
- PHSD: more ED than others and expands spherically

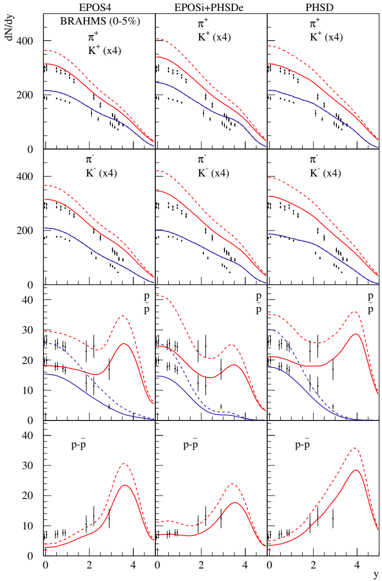
Dynamical description of strongly interacting system in PHSD

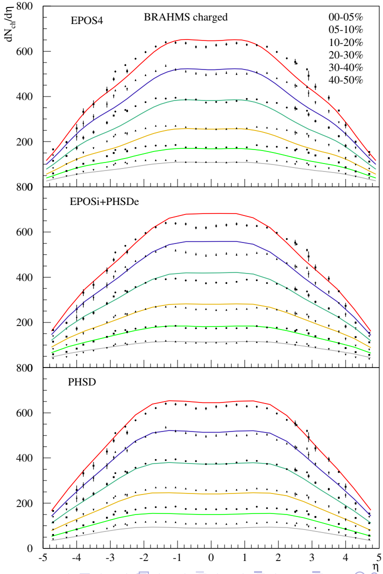


RESULTS

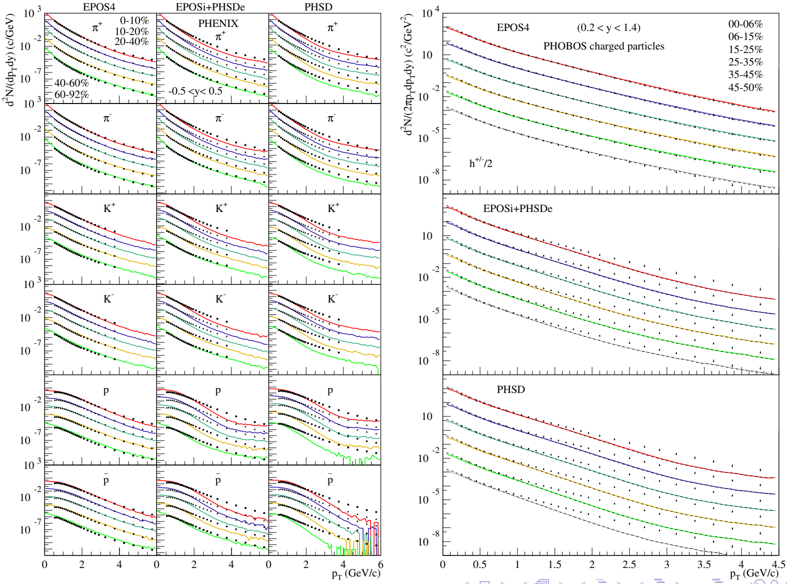
Comparing the
Particle Production, Transverse Momentum (p_T), Anisotropic Flow (v_2 and v_3) for Au-Au@200GeV
With different simulations:
EPOSi+PHSD, EPOS, and pure PHSD

Charged Particle Production: Au-Au@200GeV





Transverse Momentum spectra: Au-Au@200GeV



Anisotropic Flow

Event Plane method, Fourier series:

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

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

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

Ψ_{EP} = Event Plane angle [9].

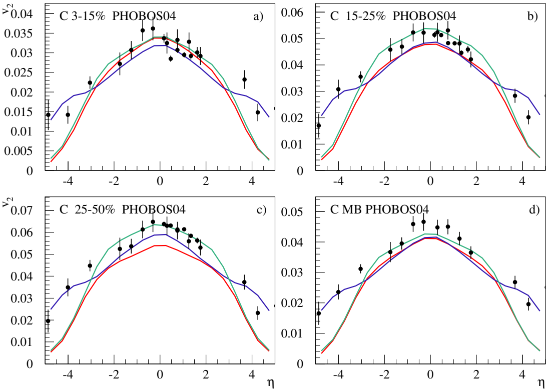


Figure: EPOS, EPOSi+PHSD, pure PHSD

Flow behavior v_2, and v_3: Au-Au@200GeV

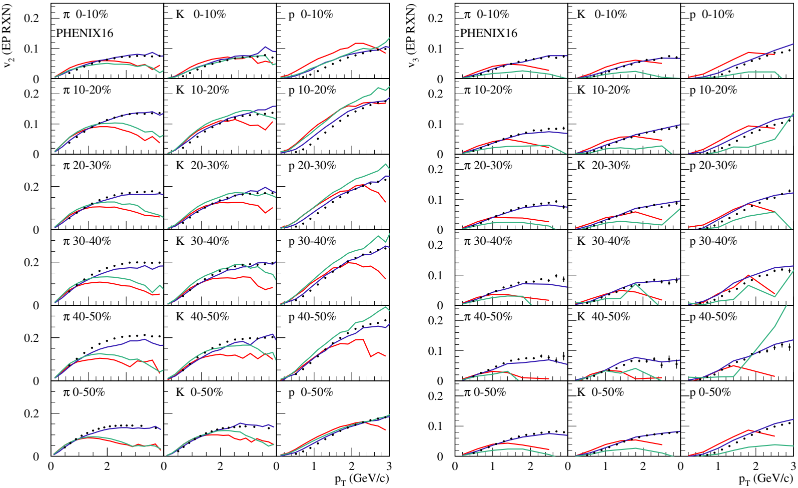


Figure: EPOS, EPOSi+PHSD, pure PHSD

Summary and Conclusion:

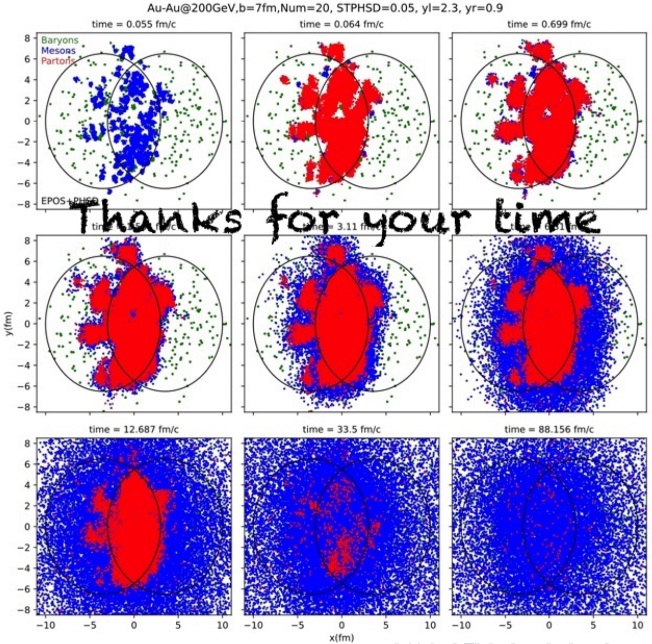
- Two different HIC models were successfully combined
- Comparison of space-time and energy density evolution by EPOSi+PHSDe with pure EPOS and pure PHSD
- Comparing observables like charged particles production, p_T, v_2, v_3 in three different frameworks
- High p_T part has not been improved yet by EPOSi+PHSDe
- The distinctions between EPOS and PHSD are related to their "evolutions"
- In EPOSi+PHSDe and pure PHSD, the partons do not interact strongly enough to produce something equivalent to "strong pressure gradiants", which are reasonable to the transverse flow in EPOS
- The partonic scatterings do not provide sufficient "thermalization" in EPOSi+PHSDe

Current work:

- Investigation of dilepton production in EPOSi+PHSDe compared to pure PHSD.

Outlook:

- Employing the early hydrodynamical evolution from EPOS (EPOSh), then use the PHSD evolution (PHSDe) to study the production of particles in higher p_T.
- Checking the heavy-flavor particle behavior in EPOSi+PHSDe and comparing the results with two other models.
- Comparing EPOSi+PHSDe with different ranges energies from RHIC to LHC for various systems like p-p and Au-Au.
- Studying the inclusive photon yield in EPOSi+PHSDe compared to pure PHSD.


Au-Au@200GeV,b=7fm,Num=20, STPHSD=0.05, yl=2.3, yr=0.9
time = 0.055 fm/c
time = 0.064 fm/c
time = 0.699 fm/c
Baryons
Mesons
Partons
EPOS+PHSD
time = 3.11 fm/c
time = 12.687 fm/c
time = 33.5 fm/c
time = 88.156 fm/c
y(fm)
x(fm)
Thanks for your time

References I

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