Hybrid Model Simulation of Ultra-relativistic Heavy Ion Reactions

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outline

- Motivation
- Hybrid Model Simulation
- Transition conditions
- Preliminary results
- Summary

Motivation

Theoretic models → realistic phenomena → experimental data

Hybrid approaches:

Hannah Petersen, Marcus Bleicher,Horst Stocker (Ideal hydro+UrQMD)

Steffen A. Bass, Ulrich Heinz, Huichao Song (Viscous hydro+ hadron cascade/Boltzmann equation)

Tetsufumi Hirano, Pasi Huovinen, and Yasushi Nara (ideal hydro+JAM hadron cascade model)

Radoslaw Ryblewski and Wojciech Florkowski(ideal hydro+Landau approach)

……

Our hybrid model:

Yang-Mills Initial State +Hydro +PACIAE (parton/hadron cascade)

Sketch of the Hybrid model

Hydrodynamical model ← ***Yang-Mills initial stage***

↓ ↓

Generation of partons:q, qbar, g

↓

Hadronization

↓

Hadron rescattering

Monte Carlo Coalescence

↓

End of an event generation

Hadron cascade,as same as parton cascade above, until hadron freeze-out.

Hadron: $\pi, K, p, n, \rho(\omega), \Delta, \Lambda, \Sigma, \Xi, \Omega, J/\Psi$ and their antiparticles

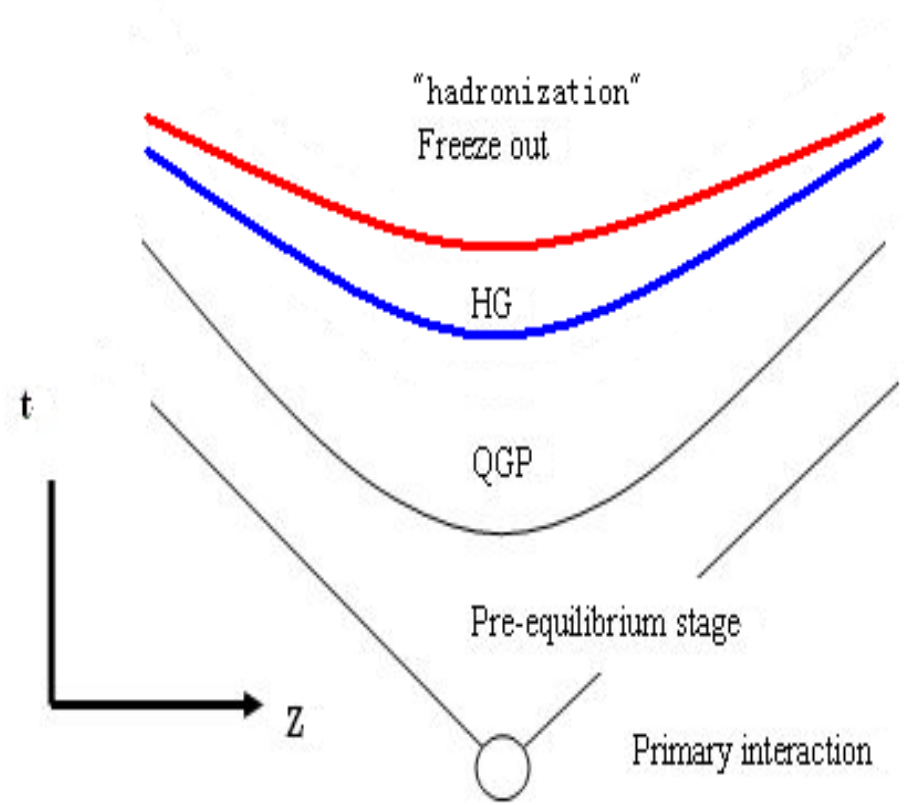
Relativistic hydrodynamics model

Relativistic Hydrodynamics is based on the **conservation laws** and the assumption of **local equilibrium**

$$N^{\mu}{}_{,\mu} = 0 \qquad T^{\mu\nu}{}_{,\mu} = 0 \quad \Rightarrow \quad [N^{\mu} d\hat{\sigma}_{\mu}] = 0 \qquad [T^{\mu\nu} d\hat{\sigma}_{\mu}] = 0$$

equation of state (EOS)

- Pre-equilibrium stage →initial state **(YM flux tube)**
- Quark Gluon Plasma → **hydrodynamics → PIC code**
- Freeze out, and simultaneously "hadronization"→ phase transition on hyper-surface→ partons/hadrons



Parton Cascade model- PACIAE

1) Parton Initialization

Original setting of the initial condition of collision system: Nucleus-nucleus (NN) collision is decomposed into parton - parton collisions, and NN collision is described by PYTHIA model. Here we create partons from hydro.

2) Parton Evolution (Parton Scattering)

$2 \rightarrow 2$ Leading-Order (LO-) pQCD differential cross sections.

3) Hadronization

String Fragmentation (SF) model, and Coalescence model.

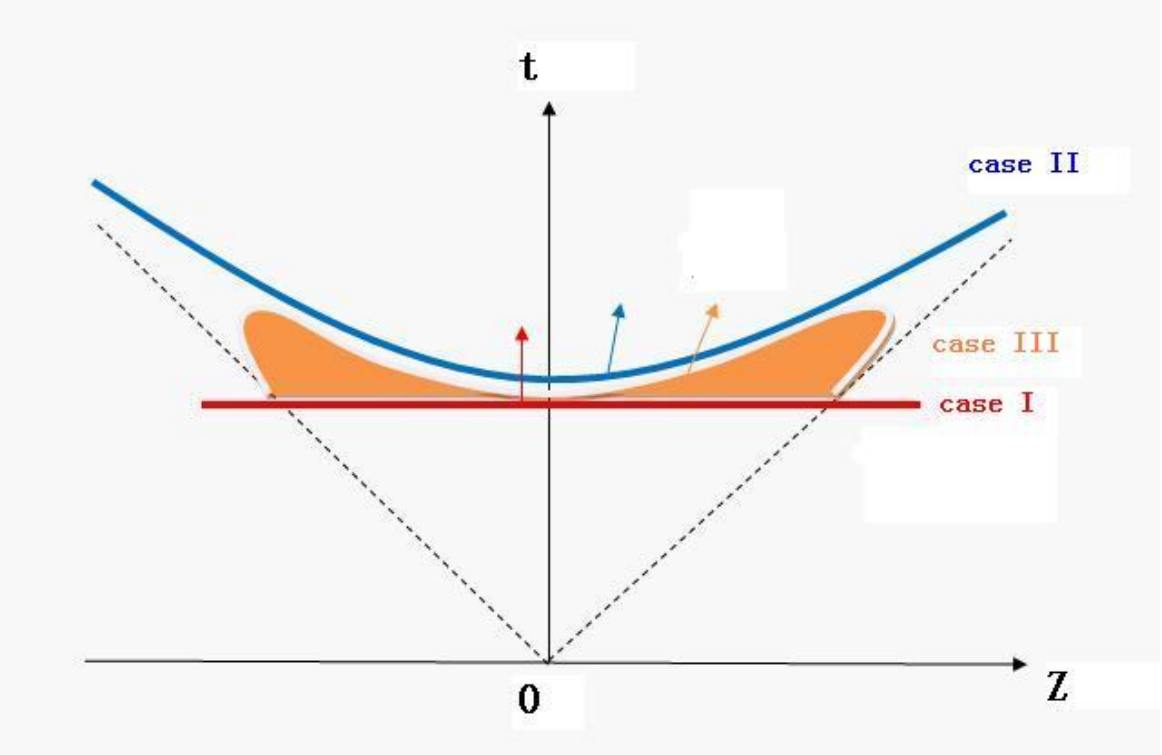
4) Hadron Evolution (Hadron Rescattering)

Usual two-body collision model.

Transition hyper-surface in hydrodynamics

Conservation laws should be satisfied across the transition hyper surface. There are three cases:

$$[N^{\mu} d\sigma_{\mu}] = 0;$$
$$[T^{\mu\nu} d\sigma_{\mu}] = 0;$$
$$[S^{\mu} d\sigma_{\mu}] \geqslant 0,$$



Case 1: Isochronous transition, *t = Constant*. $d\sigma^{\mu} = (1,0,0,0)$

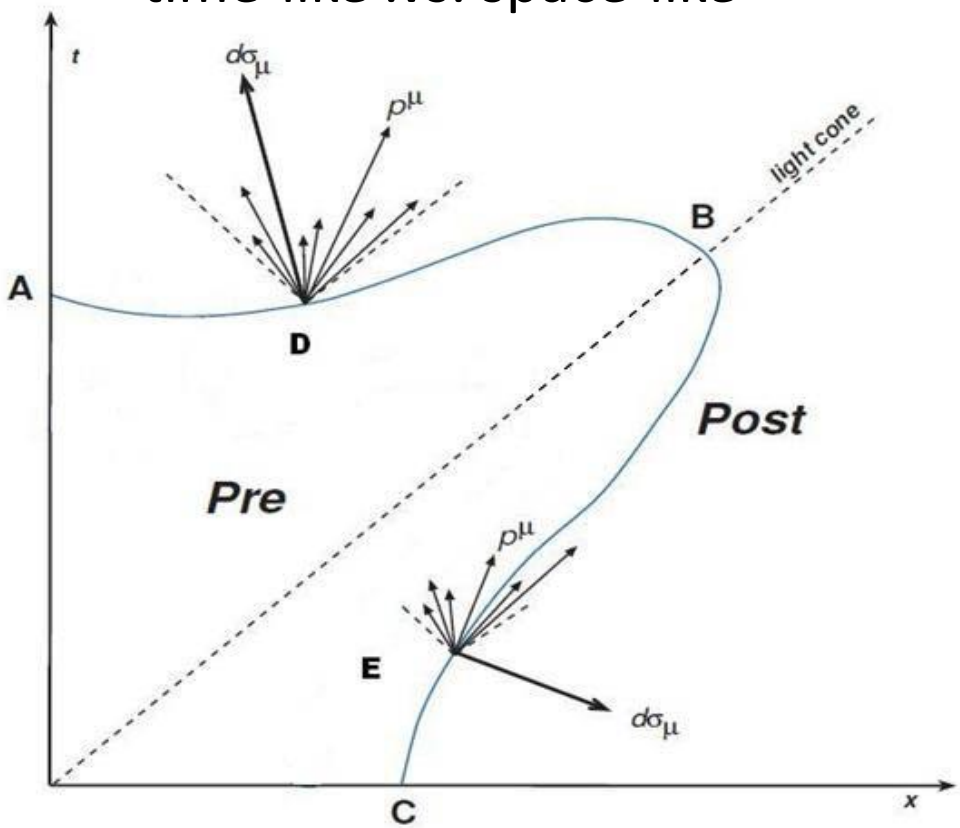
Case 2: Transition on the hyperboloid, τ=Constant. $d\sigma^{\mu} = \gamma_{\sigma}(1,0,0,v_{\sigma})$

Case 3: Realistic and complex condition. $d\sigma^{\mu} \rightarrow different \quad in \quad every \quad cell$

[Berndt Schlei]

Transition on Freeze out Hyper-surface

time-like .vs. space-like



$$[N^\mu d\sigma_\mu] = 0;$$
$$[T^{\mu\nu} d\sigma_\mu] = 0;$$
$$[S^\mu d\sigma_\mu] \geqslant 0,$$

$$j = N^\mu d\sigma_\mu$$
$$A^\mu = T^{\mu\nu} d\sigma_\nu$$

•We use the Cooper-Frye formula:

$$E\frac{dN}{d^3p} = \int_\sigma f(x,p)\, p^\mu d\sigma_\mu$$

Generating the phase space distribution of non-interacting particles

When space-like FO surface

$$p^\mu d\sigma_\mu > or < 0$$

When time-like FO surface $p^\mu d\sigma_\mu > 0$

Simple Solution for Eequilibrated Final State

Conserved energy momentum current, baryon current:

$$A^{\mu} = T^{\mu\nu} d\sigma_{\nu} = w u^{\mu} u^{\nu} d\sigma_{\nu} - P g^{\mu\nu} d\sigma_{\nu}$$

$$j = N^{\mu} d\sigma_{\mu} = n u^{\mu} d\sigma_{\mu}$$

Simple solution for the final state in equilibrium:

$$A^{\mu} A_{\mu} = (e - P) A^{\mu} d\sigma_{\mu} + e\, P\, (d\sigma^{\mu} d\sigma_{\mu})$$

+ EoS

- Special case for baryon free matter with EoS as: P=e/3

$$d\hat{\sigma}^{\mu} d\hat{\sigma}_{\mu}\, e^2 + 2\, a^{\mu} d\hat{\sigma}_{\mu}\, e - 3\, a^{\mu} a_{\mu} = 0$$

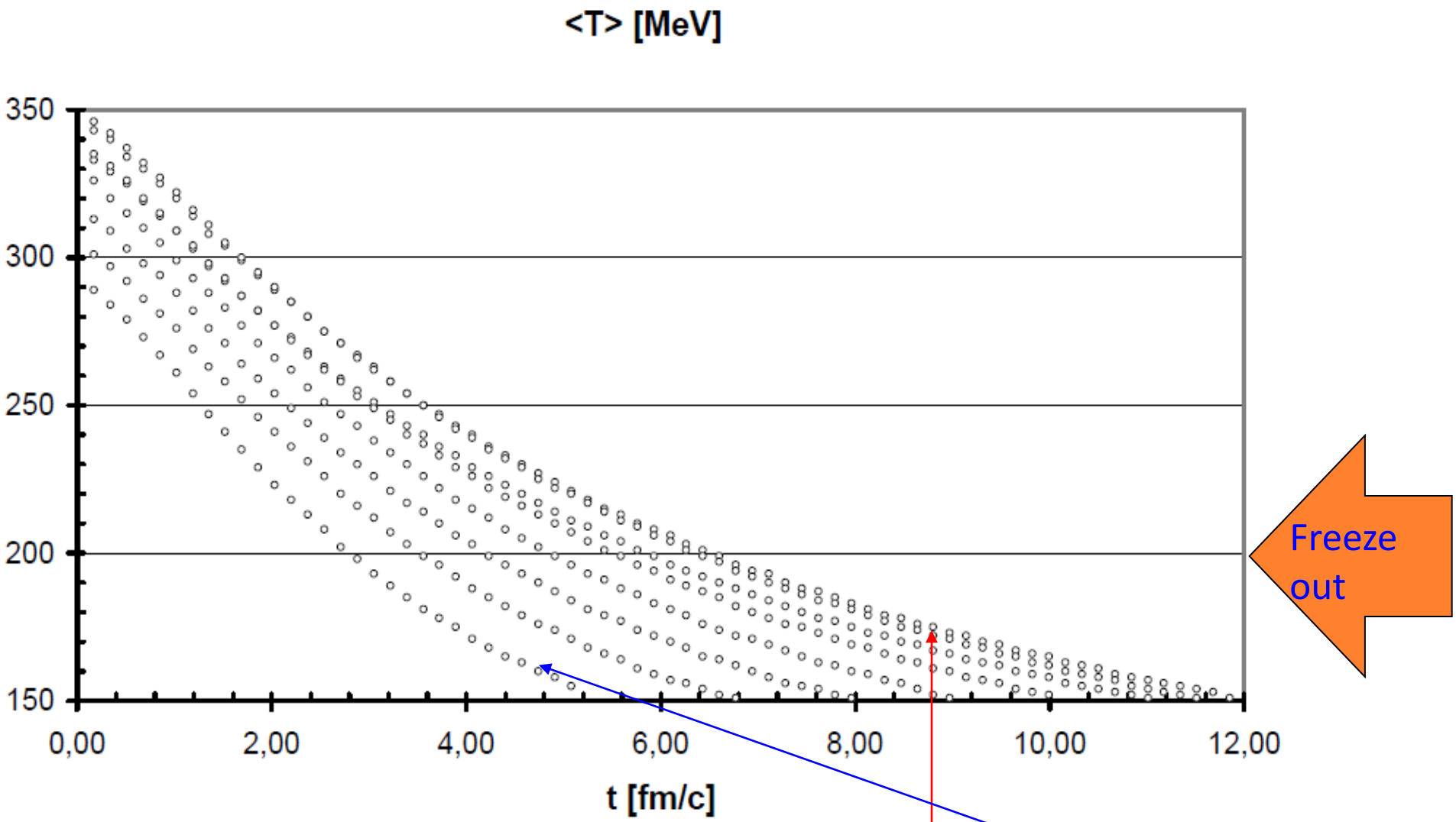
$$u^{\mu} = d\hat{\sigma}^{\mu} \quad a^{\mu} = A^{\mu} / D$$

Case for finite baryon current, and with an EoS as: P=P(n,e)

$$\frac{e + P}{n^2} = \frac{1}{j^2} \left[\mathbf{A}^{\mu} d\sigma_{\mu} + P (d\sigma^{\mu} d\sigma_{\mu}) \right]$$

Phy. Rev. C81, 064910(2010)

Freeze Out Transition Time



Average temperature versus time in Au+Au collisions at 65+65 AGeV, for impact parameters, b = 0, 0.1, 0.2, … 0.7 b_{max} from the top (0.0) down (0.7).

Transition from QGP to parton phase

Considering the **transition** in Local rest frame, the main effects includes:

- appearance of quark mass (constituent quarks in PACIAE)
- disappearance of Bag constant
- extra degeneracy factor (N_F=2 →3 and γ_s)

$$[n\gamma]=0$$
$$[(e+P)\gamma^2-P]=0$$
$$[(e+P)\gamma^2\vec{v}]=0$$

Note:

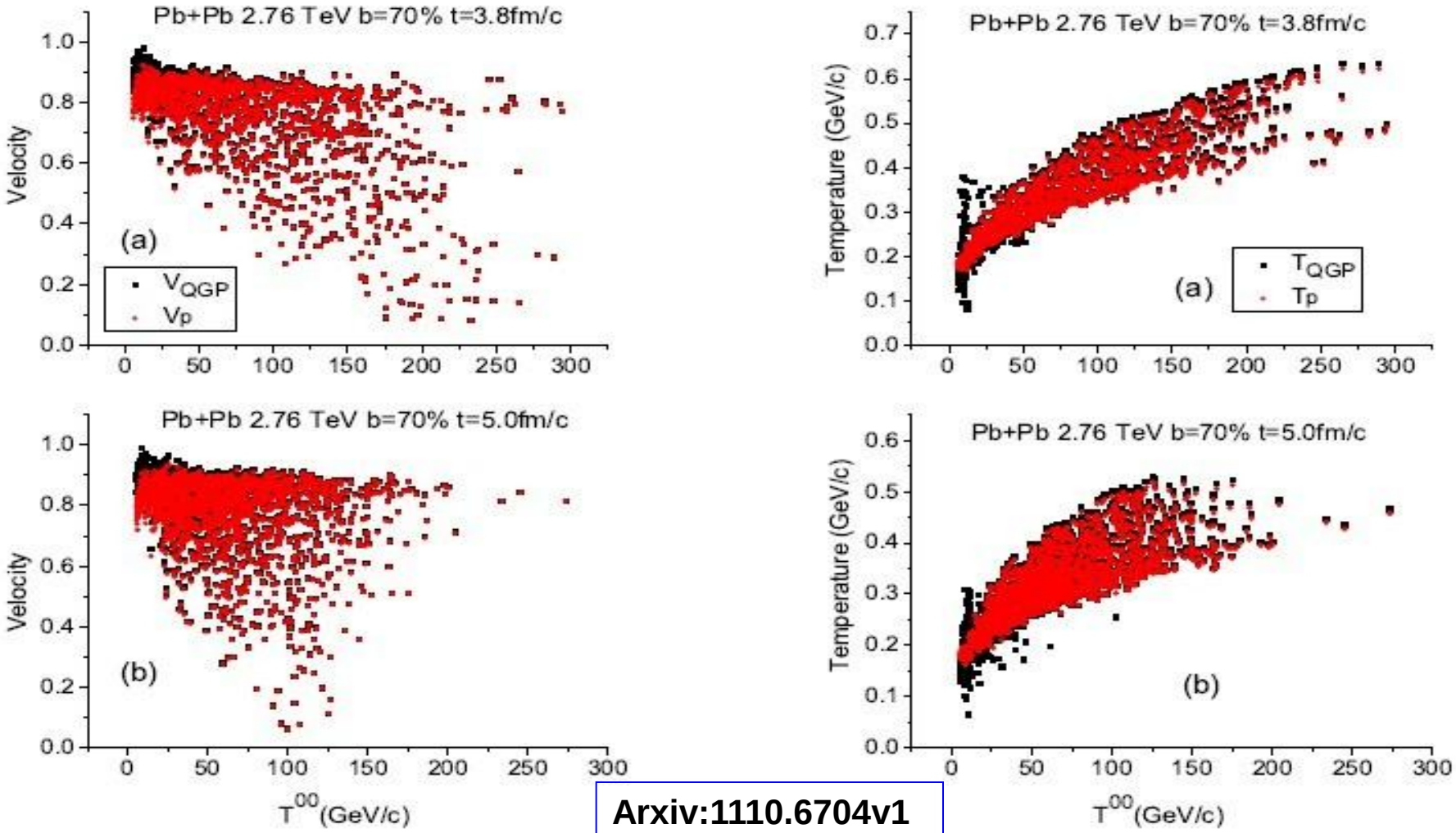
Transition is evaluated to conserve the energy momentum and baryon charge. EoS is different.

The connecting work generates the final hadronic observables.

Transition on step time and options of hypersurface should still be adjusted.

Results From Hybrid Model

The velocity and temperature difference in QGP and Partonic phase at different Hydro-PACIAE transition times.



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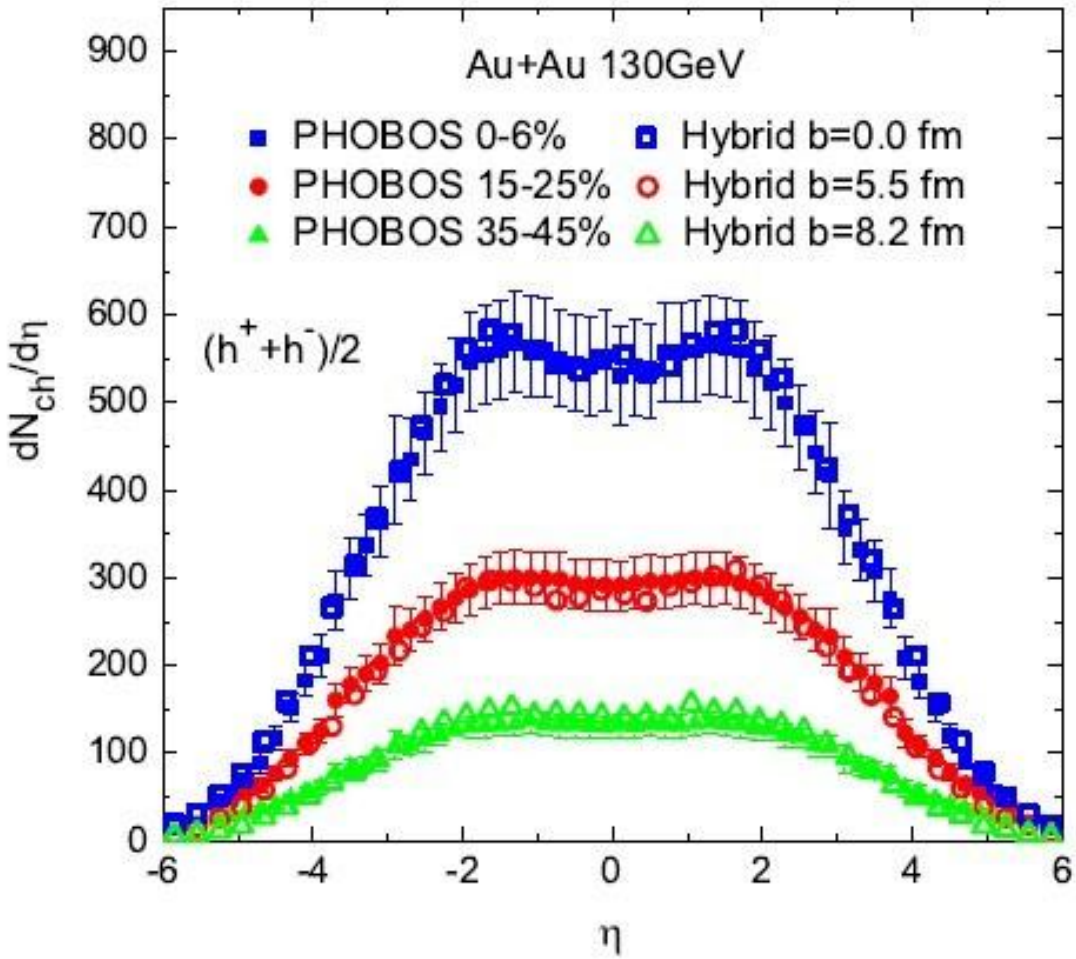
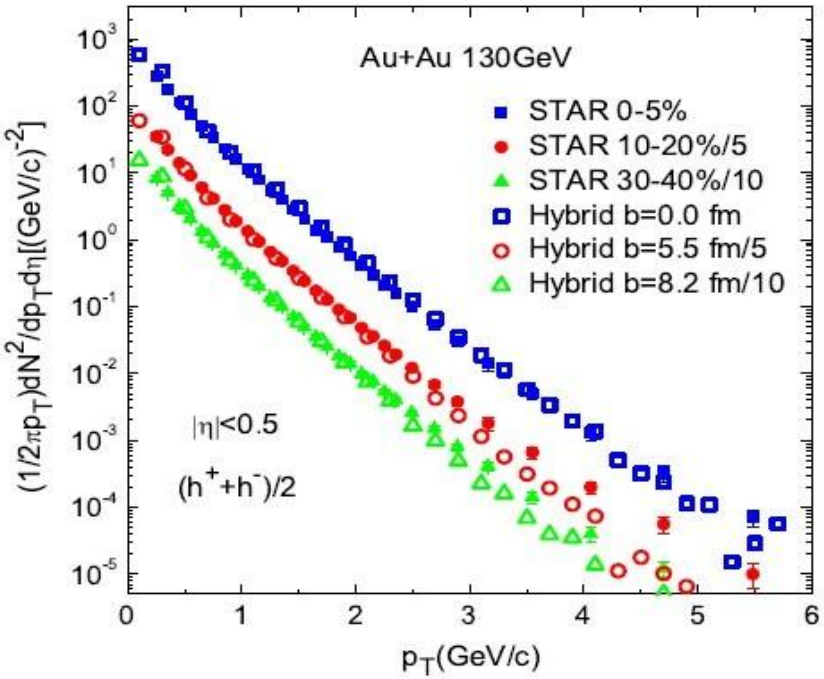
Results From Hybrid Model



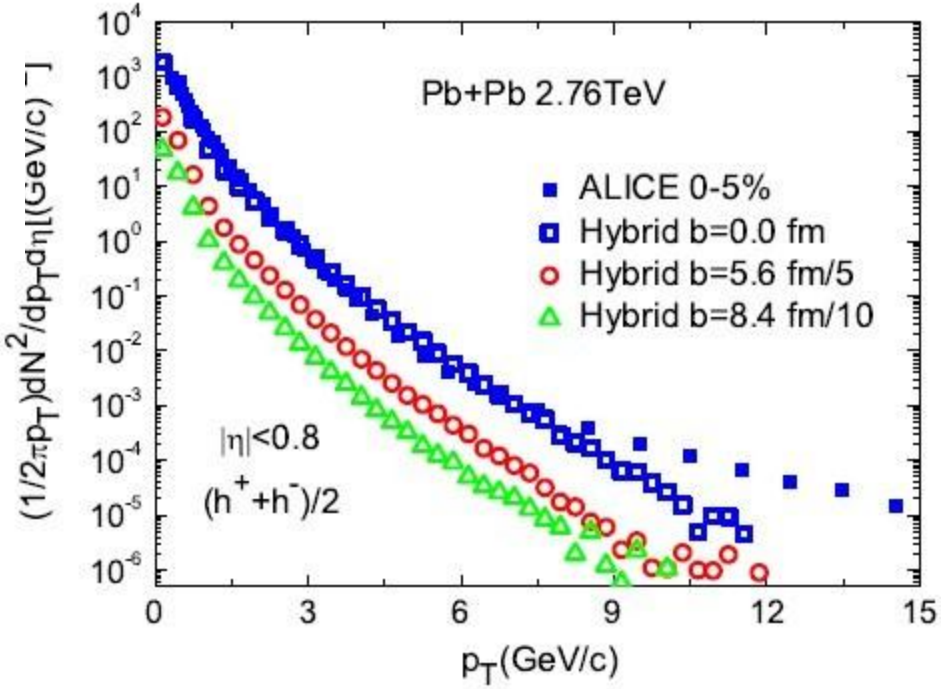
Pseudo-rapidity distribution of the charged final hadrons in hybrid model, compared to PHOBOS data.

Good agreement!

Results From Hybrid Model



P_T distribution of the charged hardons at final detection, in different centrality collisions. Compared with STAR and in Alice data.



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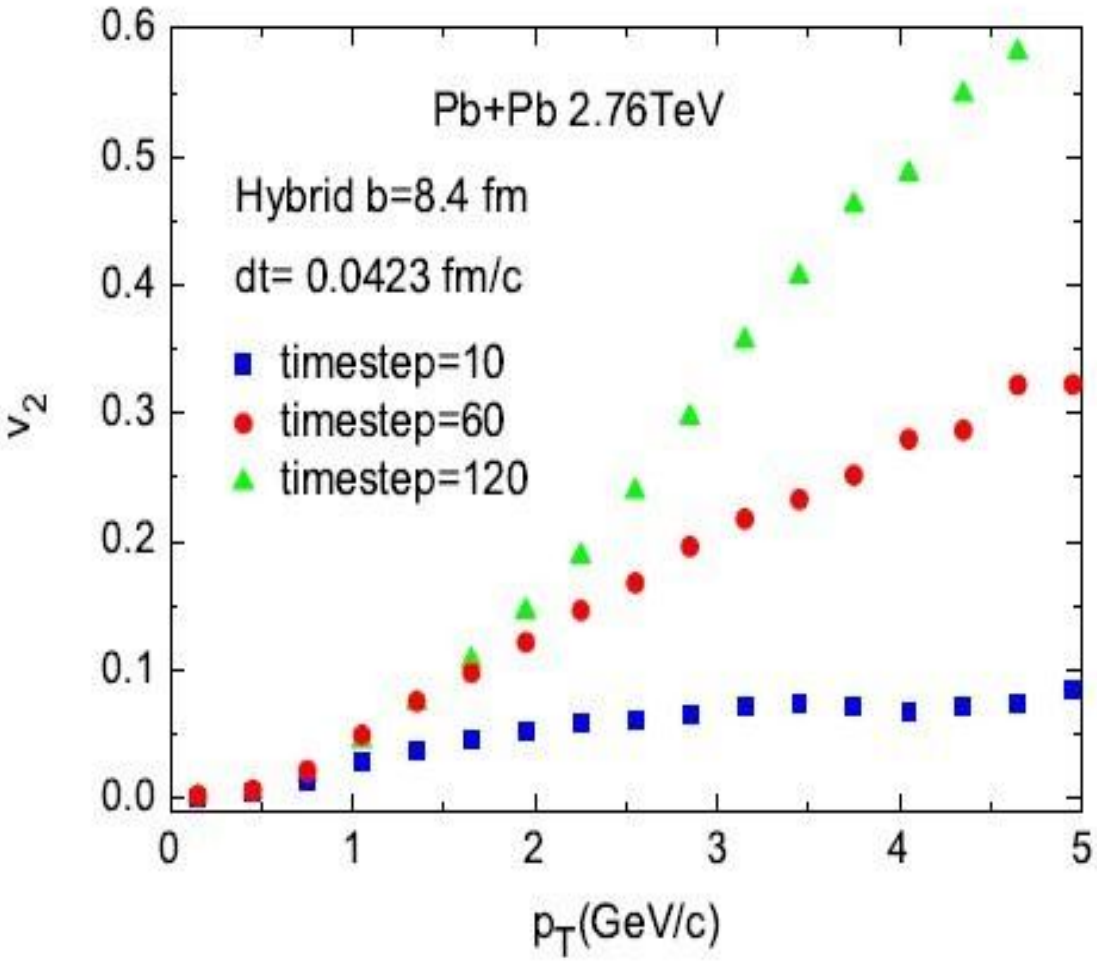
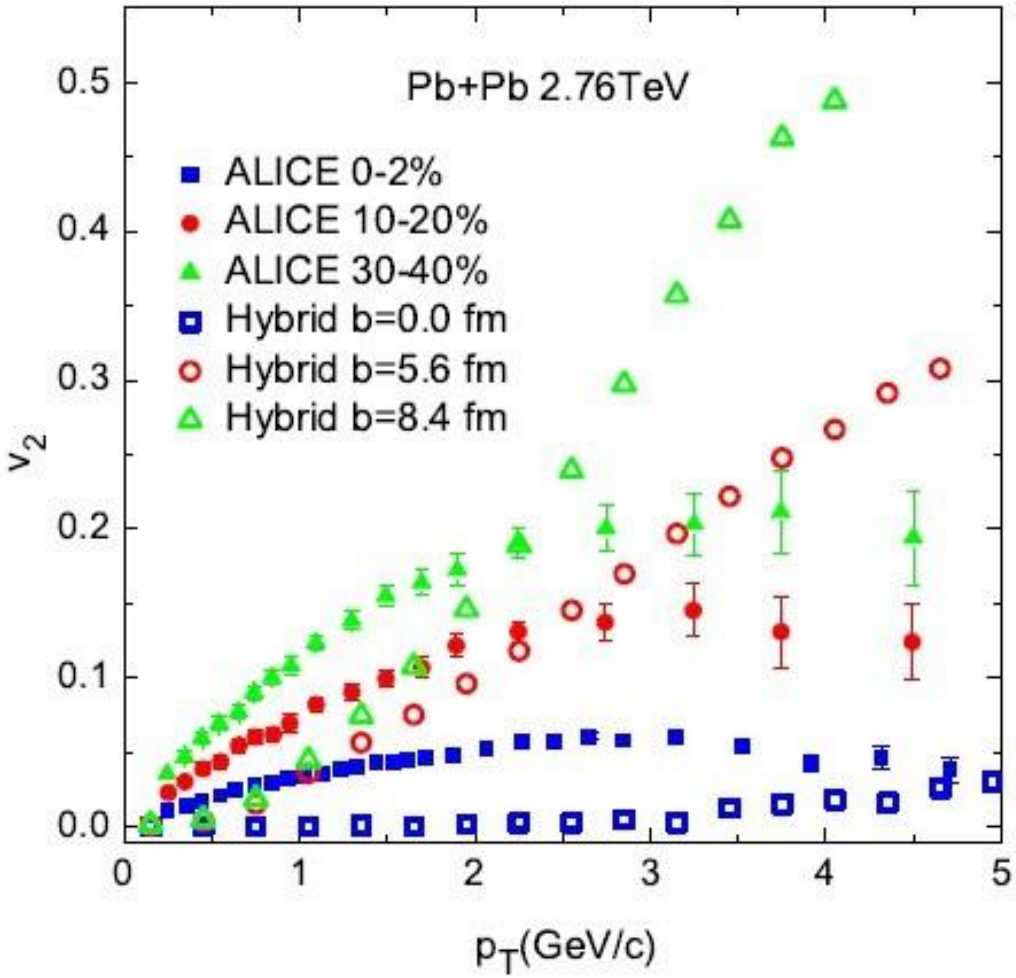
Results From Hybrid Model



The elliptic flow v_2 in hybrid model at different Hydro-PACIAE transition times in Pb+Pb 2.76 TeV.

Results From Hybrid Model



P_T distribution of the charged final hadrons in different centrality collisions in Pb+Pb 2.76 TeV. Compared to ALICE data.

Possible Effects:

Transition hyper-surface

Transition time

Parton scattering

…….

Summary

Achievements are the following:

- ✓ **Applying the hybrid model (Hydro-PACIAE) simulation to explore the pseudo-rapidity distribution, transverse momentum distribution and fit to the experiment data successfully.**
- ✓ **Investigation on the collective flow properties by the Hybrid model and got preliminary results.**
- ✓ **The Hybrid model is significant and more realistic method for giving good observation with inside properties in the energetic reactions.**

Further work in progress!


Thanks for your attention!