Hybrid models for relativistic Heavy Ion Reactions

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outline

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- Introduction to Hydrodynamical Model
- Introduction to PACIAE Model
- Hybrid model for HYDRO-PACIAE combining
- Hybrid model for PACIAE-HYDRO-PACIAE combining
- Results from Hybrid models
- 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 models:

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

PACIAE initial State +Hydro +PACIAE (parton/hadron cascade)

Sketch of the Hybrid models

Hydrodynamical model

No.1 Yang-Mills initial stage

Generation of partons:q, qbar, g

No.2 PACIAE initial stage

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

Stages in Hybrid models

- Pre-equilibrium stage

  → initial state (the effective string rope model)

  → initial state (PACIAE model, create particle distribution for position and energy)

- Quark Gluon Plasma

  → hydrodynamics(PIC method)

- Freeze out, and simultaneously "hadronization"

  → phase transition on hyper-surface

  → partons/hadrons (PACIAE model)

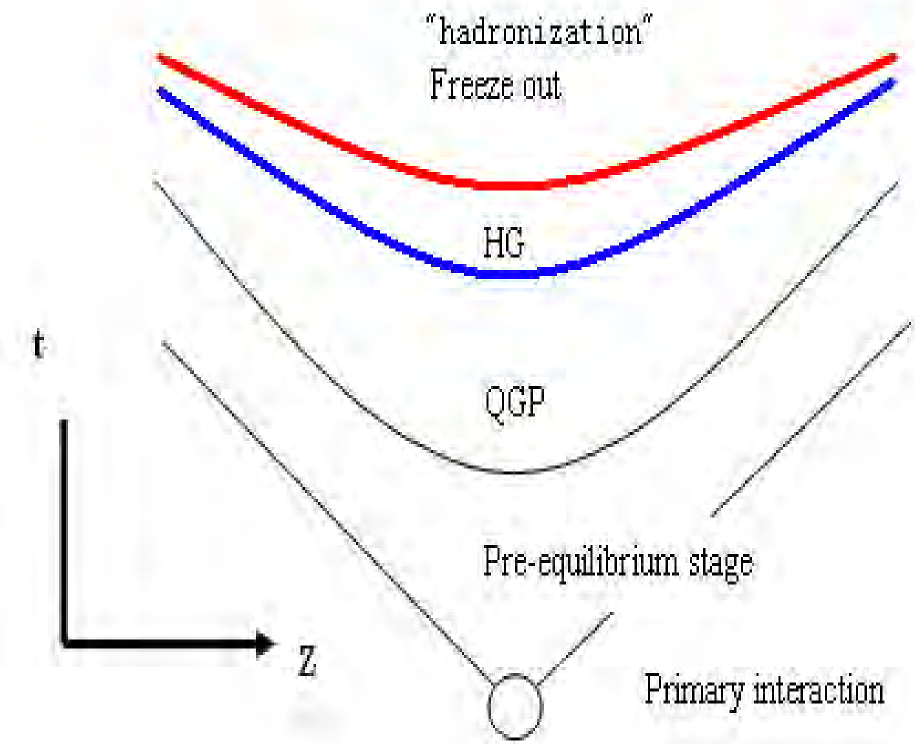
Relativistic hydrodynamics model

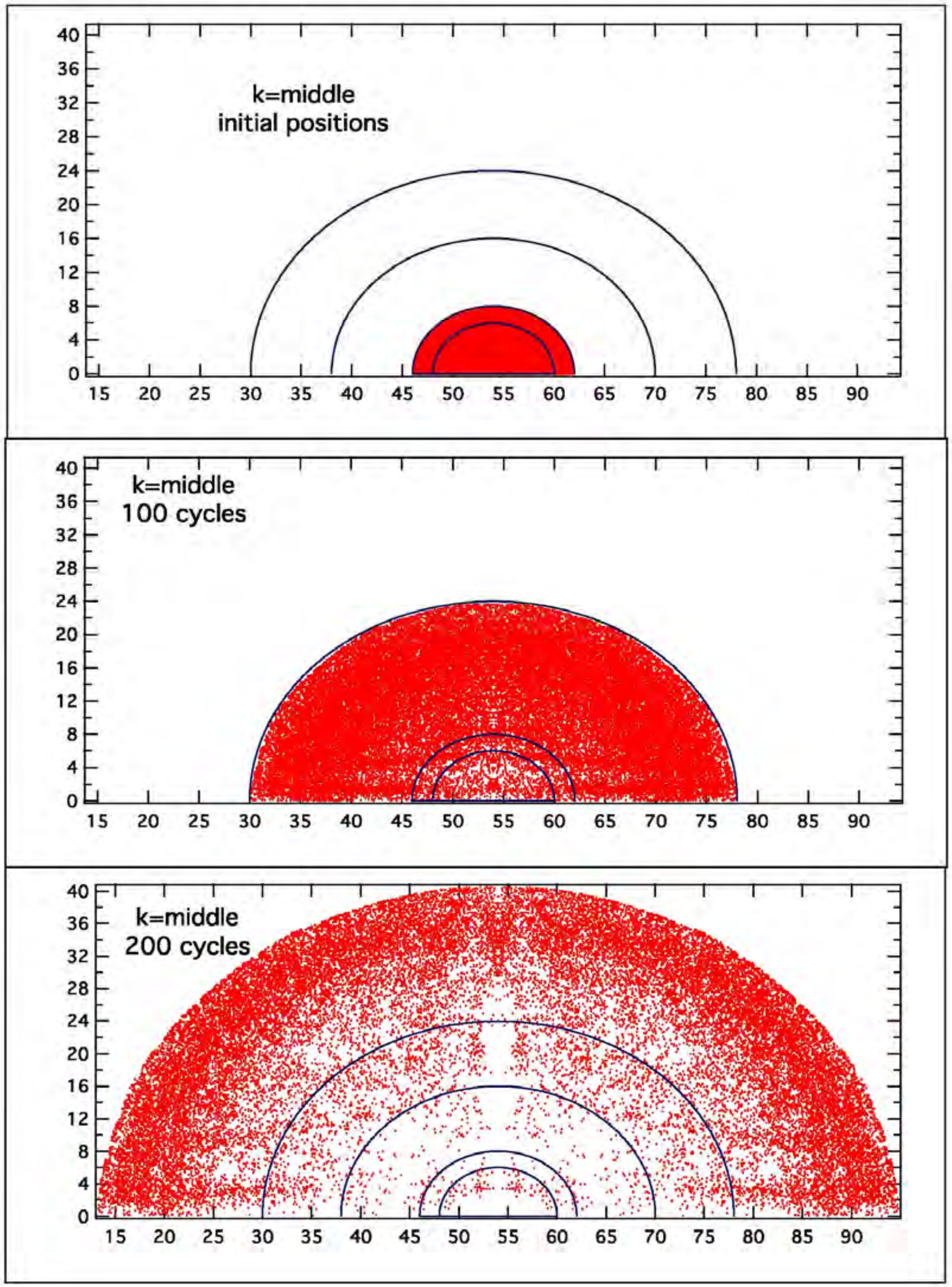
Relativistic Hydrodynamics is based on the **conservation laws** and the assumption of **local equilibrium**

$$N^{\mu}{}_{,\mu} = 0$$
$$T^{\mu\nu}{}_{,\mu} = 0$$

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

equation of state (EOS)





PIC method

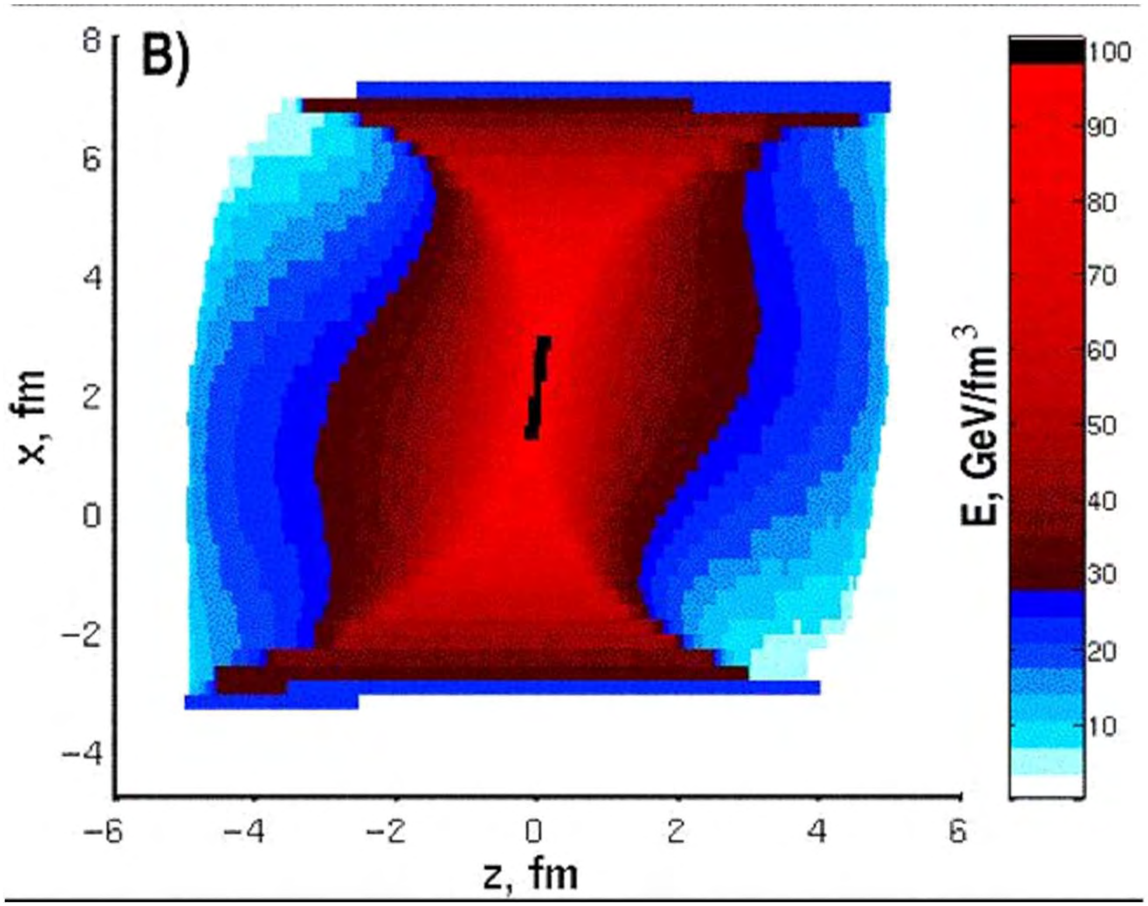
Particle in Cell method

“Marker particles” -- Lagrangian fluid cells—the baryon number.

Runs very stable up to very high energies and follow the fluid dynamical expansion

Phys.Rev.C 17 (1978)2080
Phys.Lett.B 261 4(1991) 352-356

Initial state – reaching equilibrium from Hydro

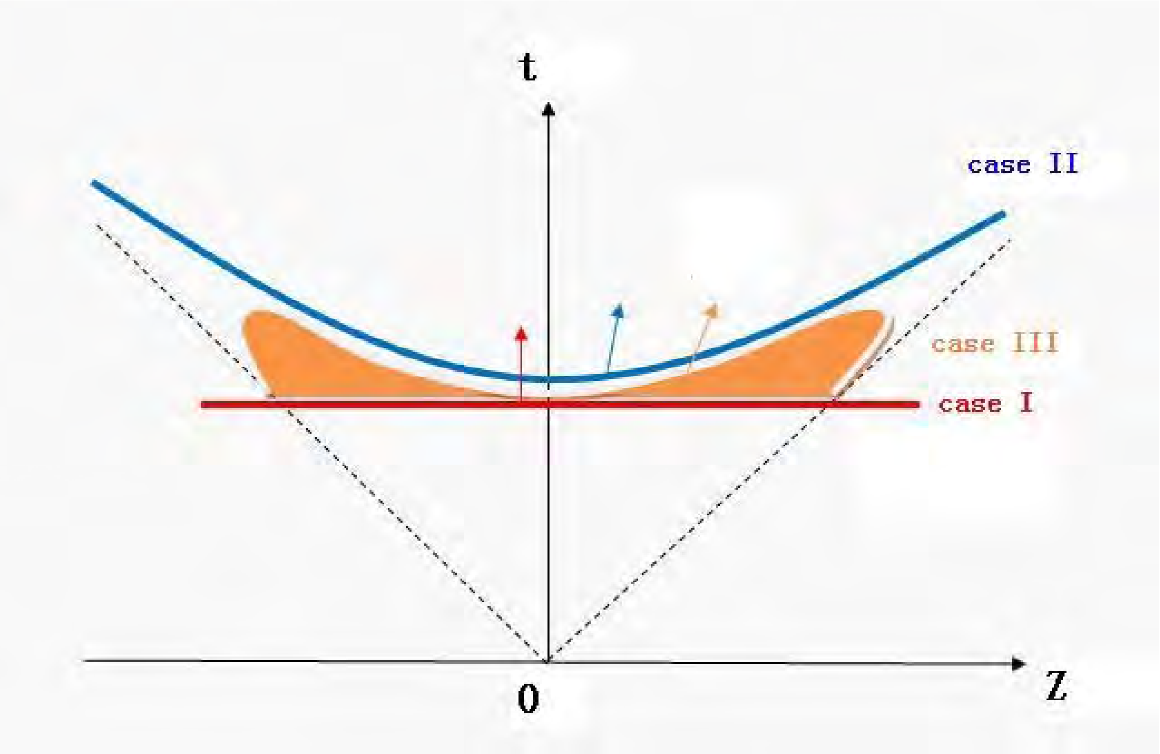


Initial state by V. Magas, L.P. Csernai and D. Strottman
Phys. Rev. C64 (01) 014901

Transition hyper-surface in hydrodynami

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

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



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

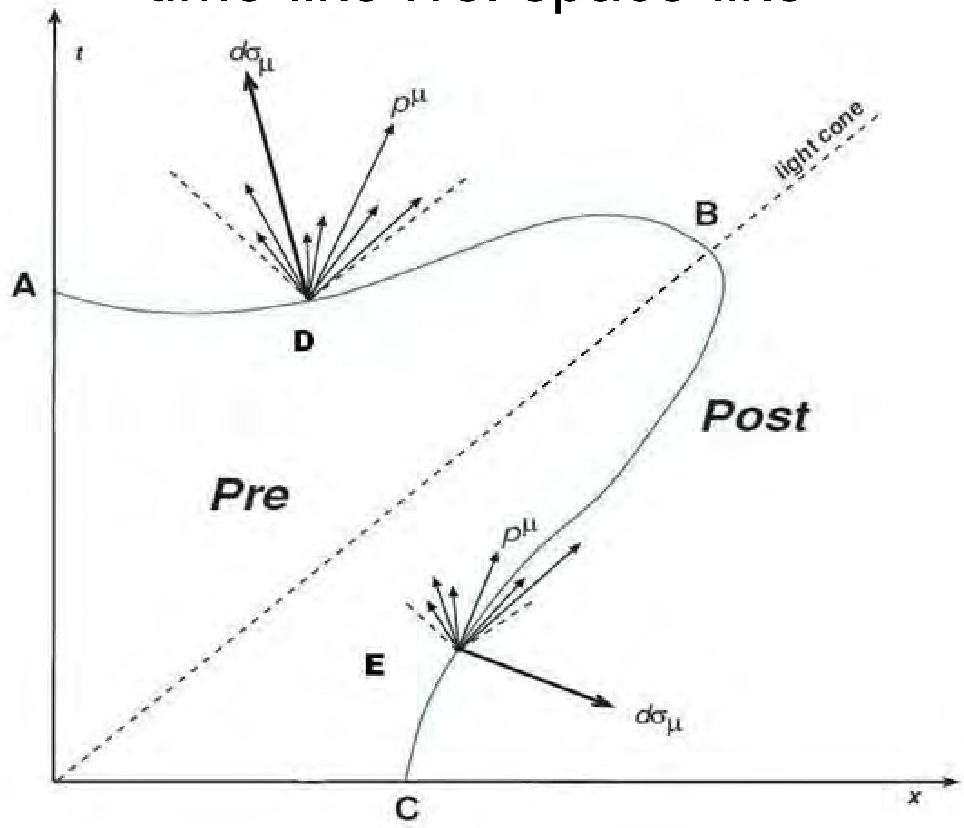
Case 2: Transition on the hyperboloid, τ=Constant. $d\sigma^\mu = \gamma_\sigma(1,0,0,v_\sigma)$

Case 3: Realistic and complex condition. $d\sigma^\mu \to different \quad in \;\; every \;\; cell$

[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:

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

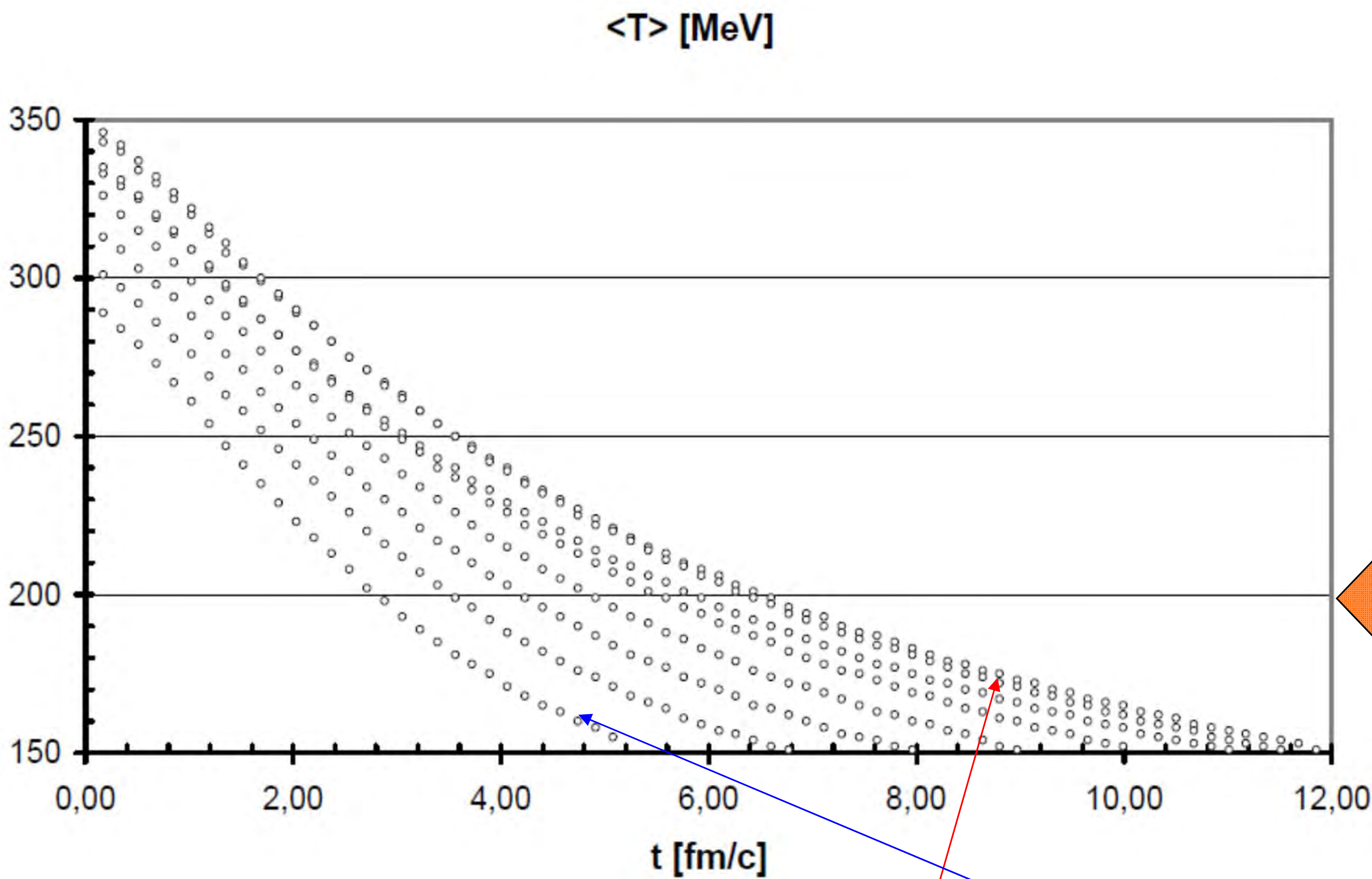
Generating the phase space distribution of non-interacting particles

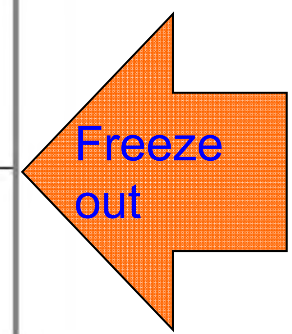
When space-like FO surface

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

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

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).

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. No1 hybrid model, we create partons from hydro.

2) Parton Evolution (Parton Scattering)

$2 \to 2$ 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.

Physical Quantities in Hydro and PACIAE model

Quantities of cells in Hydro

1), Energy density: E_{cf}

2), Baryon density: n

3), Pressure: p

4), Velocity: v_x, v_y, v_z

5), Temperature and Entropy: T and sq

Quantities of particles in PACIAE model

1), Particle number: N

2), Particle type: KF code

3), Momentum and energy of each particle: E, p_x, p_y, p_z

4), Coordinates and time of each particle: v_x, v_y, v_z

Structure of the hybrid models

No.1 hybrid model

1. Initial stage

   (effective string rope model)

   ESRM

2. Hydrodynamic evolution (Hydro code).

3. Translate hydro into parton

   (Cooper-Frye formula)

4. Hadronization (PACIAE model).

5. Hadron rescattering (PACIAE model).

No.2 hybrid model

1. Initial stage

   (PACIAE model)

Construct fluid cells/particles distribution as input to hydro code

2. Hydrodynamic evolution (Hydro code).

3. Translate hydro into parton

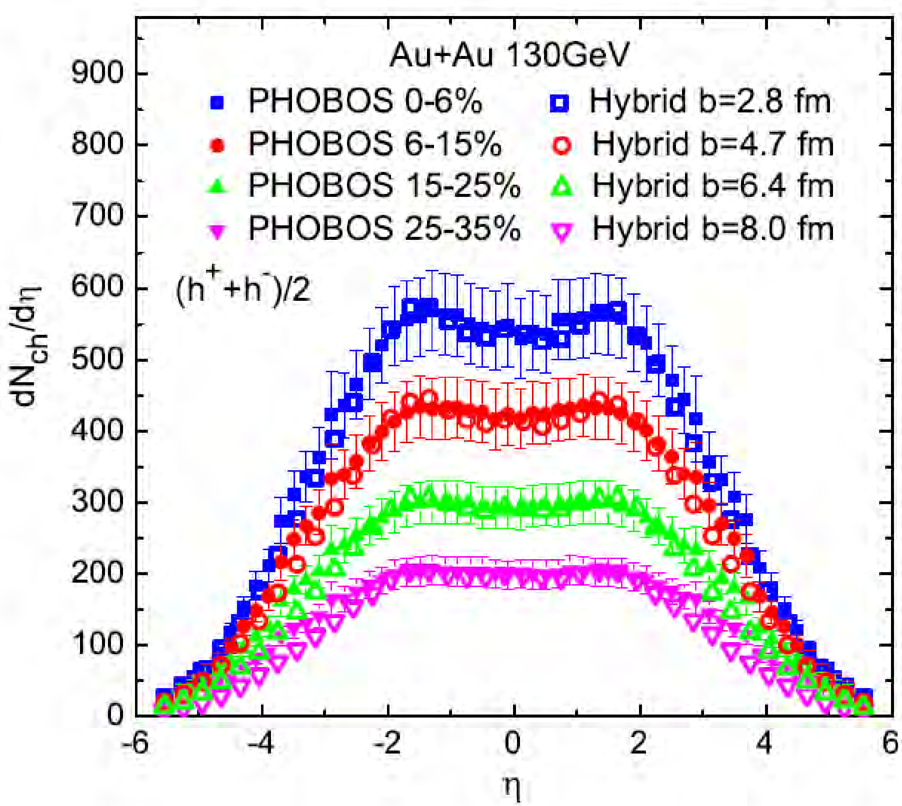
   (Cooper-Frye formula).

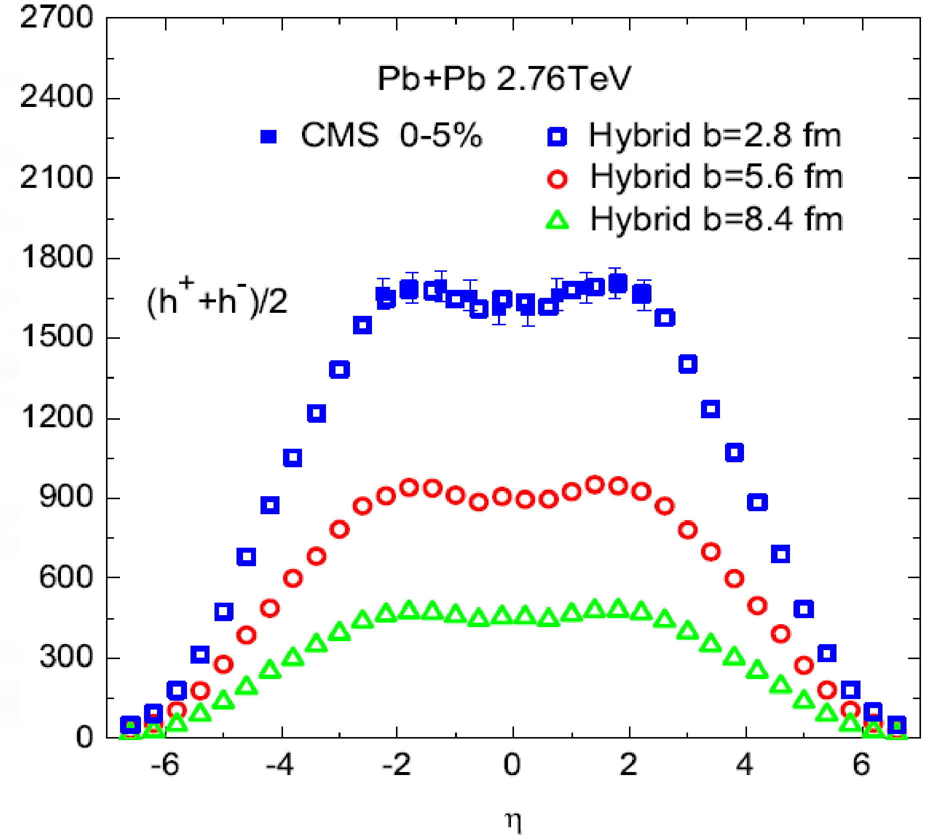
4. Hadronization (PACIAE model).

5. Hadron rescattering (PACIAE model).

Results of the No.1 hybrid model

Charged Hadron Pseudorapidity distribution:

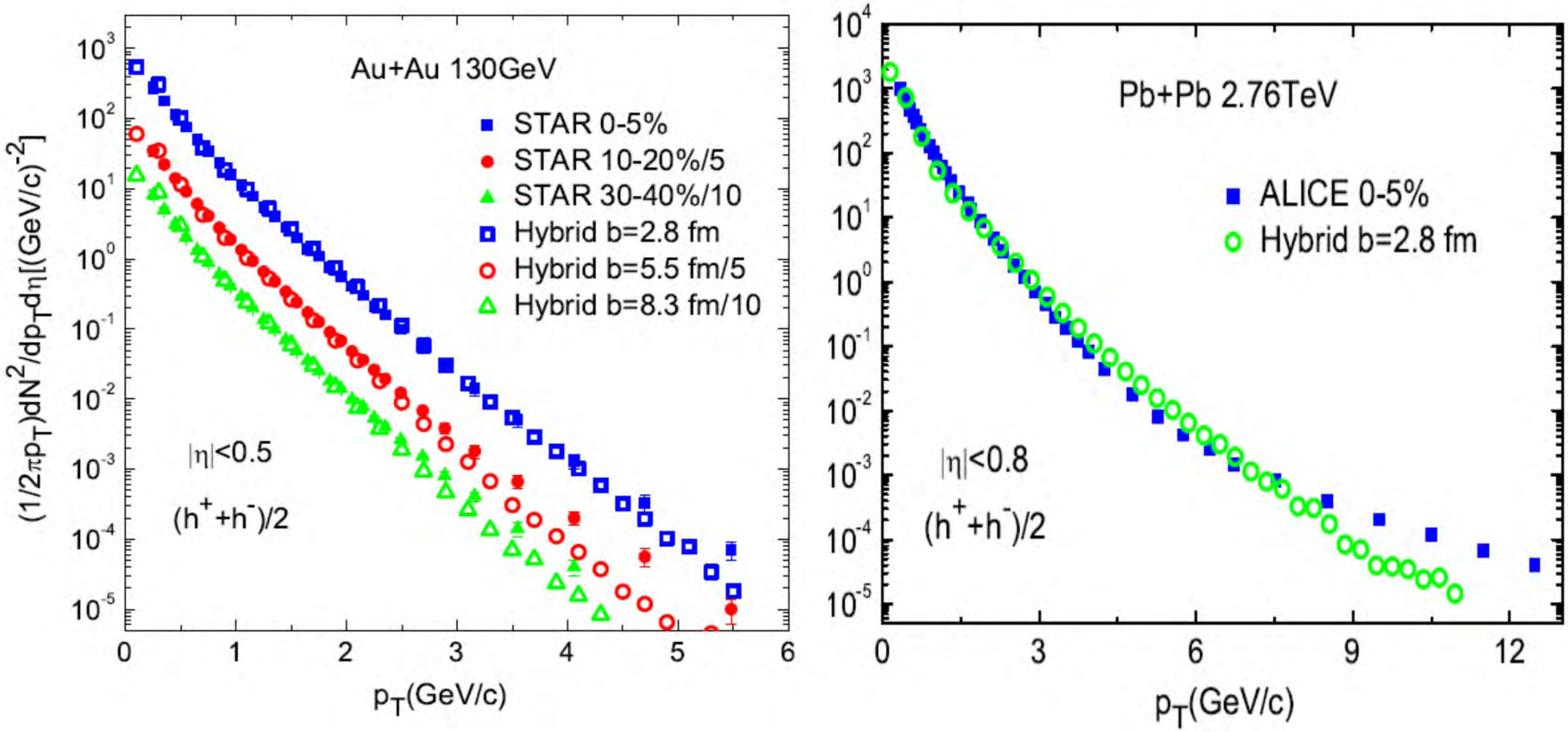




Experiment data are taken from Phys.Rev.Lett.87,102303 (2001)

Published in J.Phys. G40 (2013) 025102

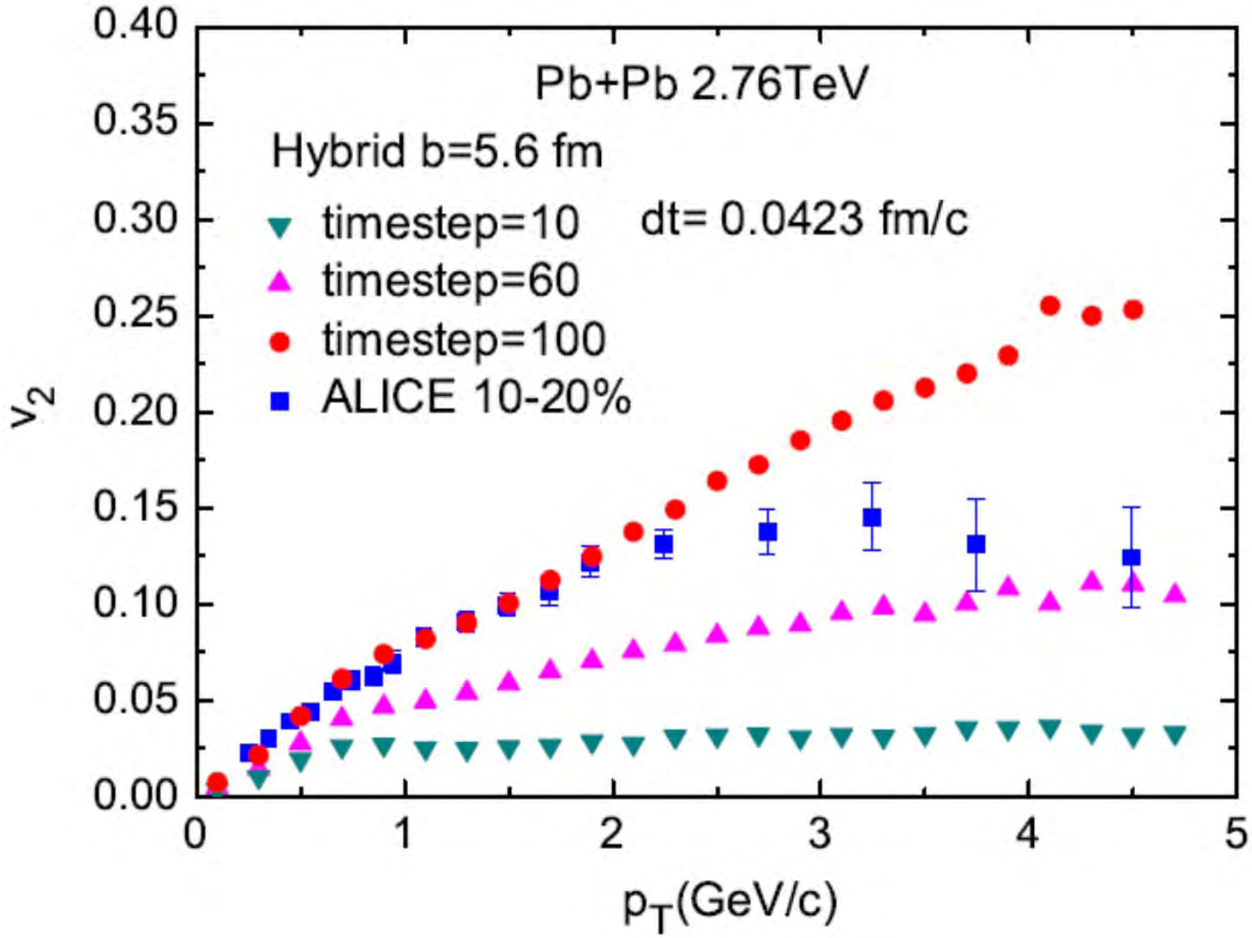
Charged Hadron p_T distribution:



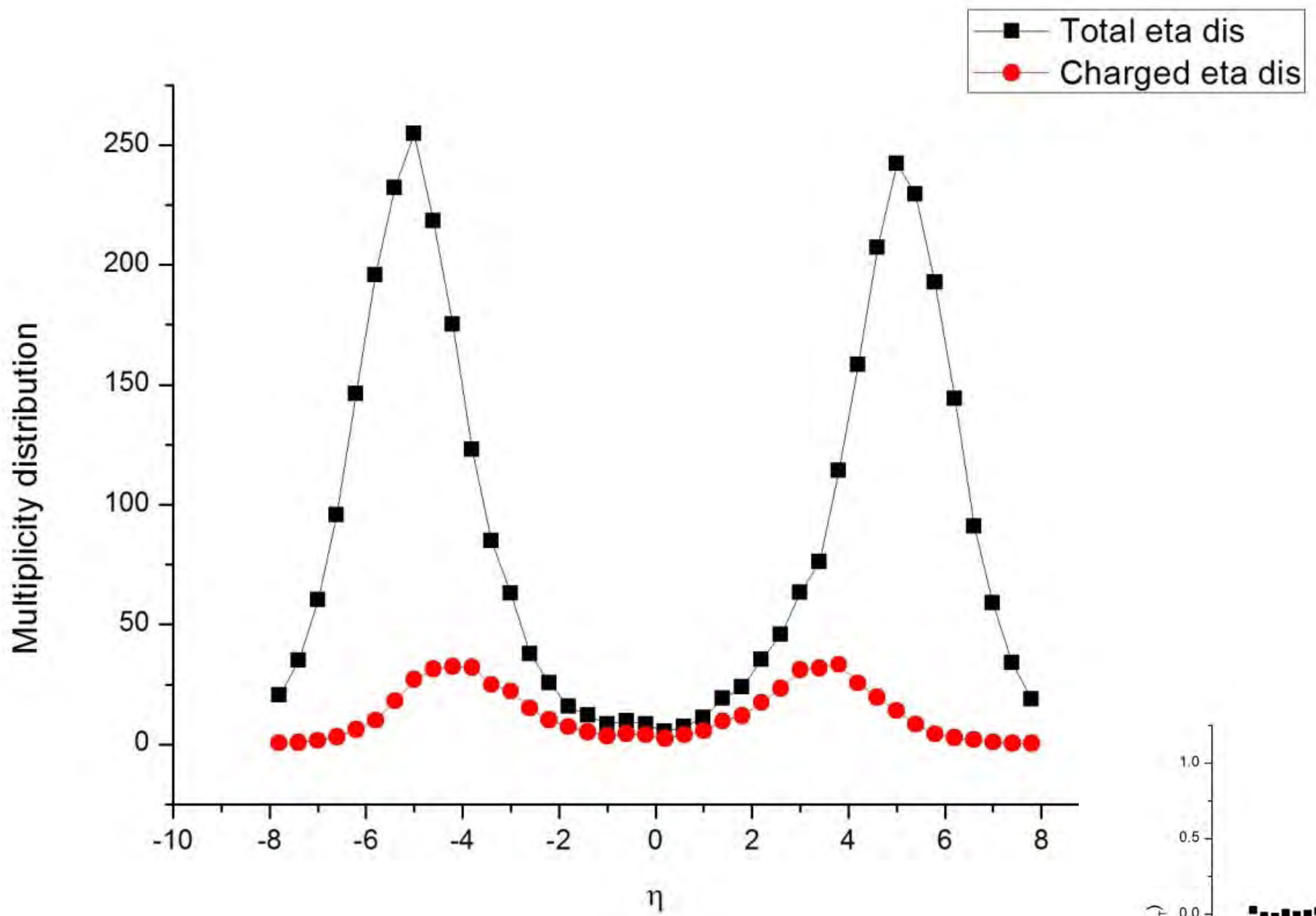
Experiment data are taken from Phys. Rev. Lett. 89 (2002) 202301

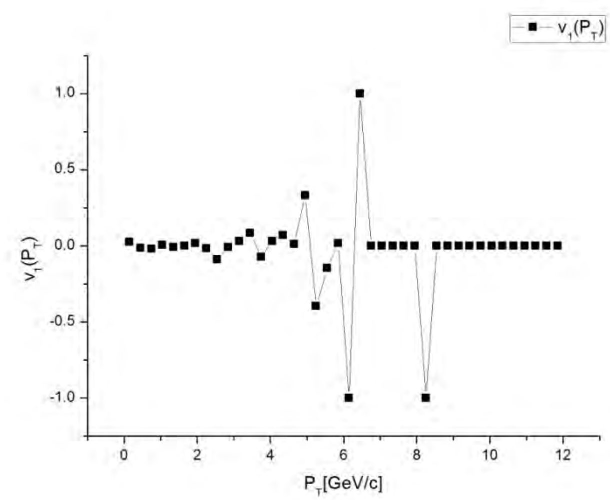
Published in J.Phys. G40 (2013) 025102

Elliptic flow v2 for different transition time



Results of the No.2 hybrid model





Can not compare to experiment data yet !

Summary

- Hybrid models provide us the way to study the partonic degrees of freedom, quark number scaling, as well as the initial state fluctuations, and so on.
- Hybrid models with two optional initial stage , was presented.
- The HYDRO+PACIAE model can reproduce the experimental data well.(Published in J.Phys. G40 (2013) 025102)
- The PACIAE+HYDRO+PACIAE model is still in work and have problems:

  connection points

  initial fluids distribution effect

  choose hydro cycle-steps

  choose more realistic transition surface

  ……

Thanks for your attention!

Backup slides!

Initial state for Hydrodynamic model

There are many initial state models, such as:

- perturbative QCD (hard scatterings) plus saturation model,
- Glauber-based parametrization method,
- color glass condensate inspired model,
- the effective string rope model,
- transport model, etc.

We use the effective string rope model (ESRM) and/or transport model in the transport and hydrodynamic hybrid model.

The effective string rope model

The idea of the effective string rope model:

1) The nucleus-nucleus collision is decomposed into streak on streak (row on row) collisions.
2) A string (rope) with constant tension is modeled by a one-dimensional coherent Yang-Mills field.
3) The streak longitudinal length Δl_f , energy density e_f nucleon density n_f , and the rapidity y_f (longitudinal momentum) determined by the string tension.
4) The pre-hydro state just consists of longitudinally expanding streaks.

Particle in Cell (PIC) method

Algorithms for solving the hydrodynamic equations:
PIC, SHASTA, and RHHLE etc.

The basic idea of the PIC method:

1) The convective fluxes are ignored, and N in each cell is held constant.

$$\partial\vec{M}\,/\,\partial t = -\nabla P$$

$$\partial E\,/\,\partial t = -\nabla\cdot(P\vec{v})$$

are solved by finite-difference method.

Particle in Cell (PIC) method

2) The baryon charge related marker particles are introduced to represent the motion of the fluid.

a) The momentum and energy are distributed evenly among the marker particles.

b) Each marker particle is given an effective velocity.

c) In a time step Δt, if the marker particle crosses to a new cell, then it transfers the corresponding amount of baryon charge, momentum, and energy from the donor cell to the acceptor cell.

Particle in Cell (PIC) method

3) Update the baryon charge, momentum, and energy values. Use the updated values to solve hydrodynamic equations.

4) Proceed the next time step of the calculations.

Reference：
Phys. Rev. C 17 (1978) 2080
Phys. Lett. B 261 (1991) 352

General steps on connecting two models

1 Cooper-Frye formula

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

where $f_i(x,p)$ **post FO distribution**

Particle four current:

$$N_i^\mu = \int \frac{d^3p}{p^0} p^\mu f_i(x,p)$$

Energy momentum tensor:

$$T_i^{\mu\nu} = \int \frac{d^3p}{p^0} p^\mu p^\nu f_i(x,p)$$

2 Parton numbers and energy in CF in post FO phase

$$N_i = V_{cell} n_i = V_{cell} N_i^\mu u_\mu \qquad E_i = V_{cell} e_i = V_{cell} u_\mu T_i^{\mu\nu} u_\nu$$

3 The ratio of generated partons types:

$$u : d : s \approx 1 : 1 : \gamma_s$$

General steps on connecting two models

4 From cells to particles

1), According to the n_i in each cell, generate the particles cell by cell.

2), If there has one cell generate zero particle, transform the energy of this cell to its neighbor.

3), If more than one particle generated, assign the cell energy to each particle (Two options: average distribution or randomly sampling).

4), The space coordinates of each particle are selected randomly in the cell; the production time is the transition time.

5), Generate the px, py for each particle, then calculate the pz using the formula

$$p_z = \sqrt{E - m^2 - p_x^2 - p_y^2}$$

$$f(p_x) \approx e^{-\lambda p} \qquad \lambda = \frac{\gamma}{T}(1 - \vec{v})$$

General steps on connecting two models

5 Conservation laws from QGP to partons

$$[N^{\mu} d\sigma_{\mu}] = 0$$

$$[T^{\mu\nu} d\sigma_{\nu}] = 0$$

Hydro code

$$e_{QGP} = e_p(\mu_i, T_i)$$

$$n_{QGP} = n_p(\mu_i, T_i)$$

From expressions

$$\tilde{n}(\mu_i, T_i) = n_q + n_{\bar{q}}$$

In every cell, with (x, y, z) and (vx, vy, vz)

> Assign the energy density and momentum of each fluid cell to every generated parton inside.

> Then the parton list can score as the parton initialization in PACIAE model.