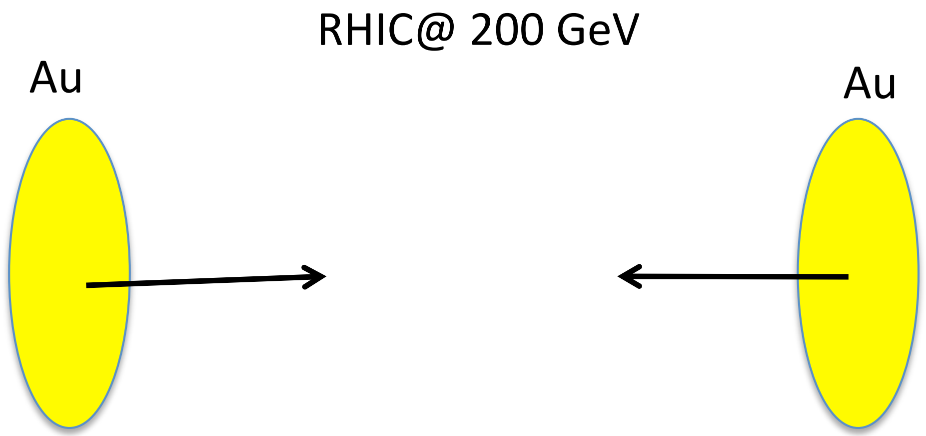
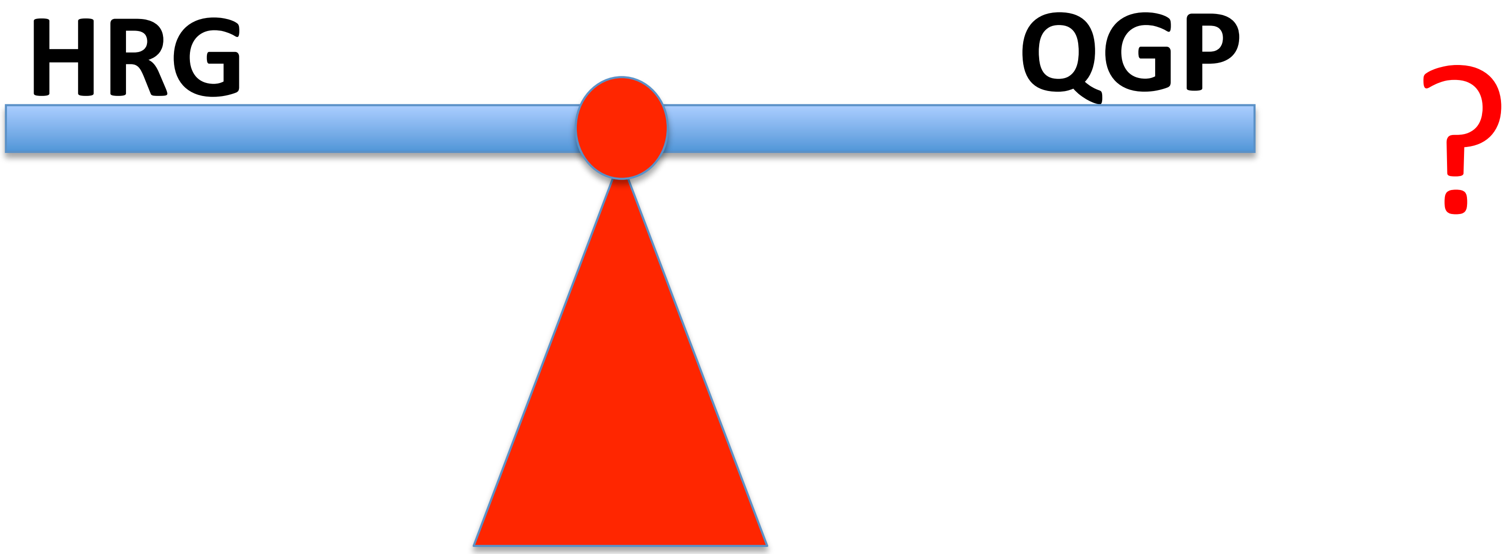
# Charged particle's $p_T$ spectra and Elliptic flow in 200 GeV Au+Au Collisions: QGP vs Hadronic resonance gas

Victor Roy
In collaboration with Dr. A.K. Chaudhuri
*Variable Energy Cyclotron Center*

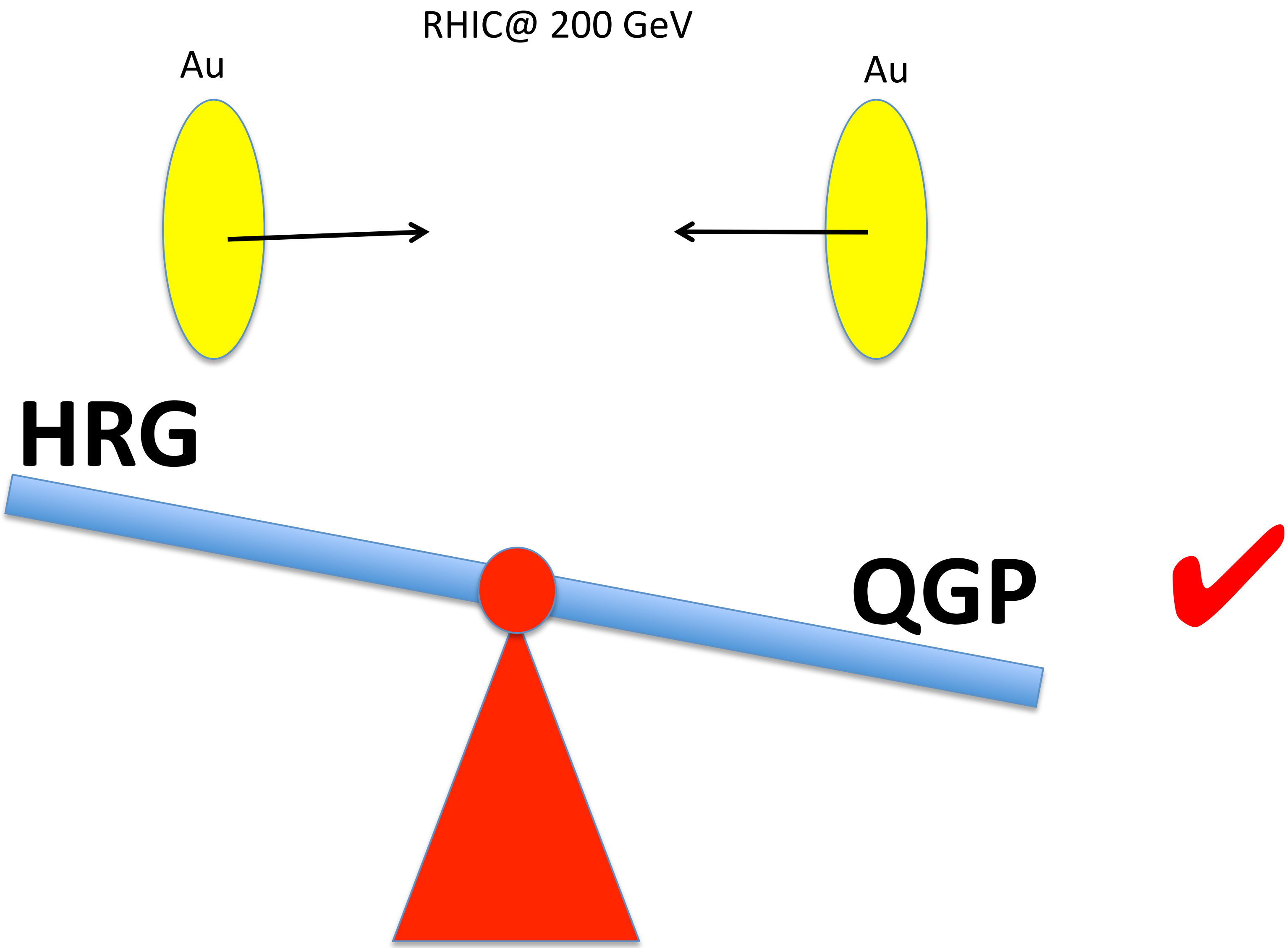
**ICPAQGP,Goa,India,6-10 Dec,2010**

# Motivation



# Motivation



# QGP better option

- **The experimental observation which are providing a strong evidence for the creation of partonic matter at high collision energy at RHIC**

1. The large azimuthal anisotropy of particle emission in non-central collisions . (Elliptic flow)
2. The scaling of this anisotropy with the constituent quark . (constituent quark scaling)
3. Suppression of high energetic particles traversing the medium. (Jet quenching)

…………..

BRAHMS Collaboration, I. Arsene *et al.*, Nucl. Phys. A **757**, 1 (2005).
PHOBOS Collaboration, B. B. Back *et al.*, Nucl. Phys. A **757**, 28 (2005).
PHENIX Collaboration, K. Adcox *et al.*, Nucl. Phys. A **757** 184 (2005).
STAR Collaboration, J. Adams *et al.*, Nucl. Phys. A **757** 102 (2005).

The CBM Physics Book

# Problems with HRG

An old quest

K.S.Lee, Heinz et. all PhysRevC.37.1452----1988

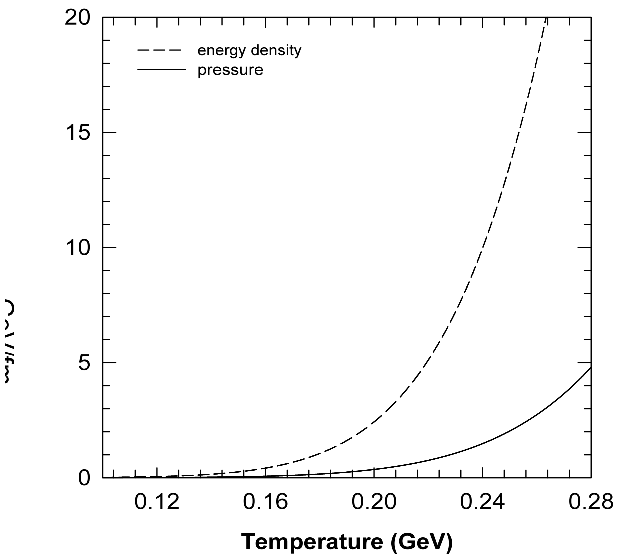
**HRG initial state, ideal hydro ,initial temperature ~270 MeV**

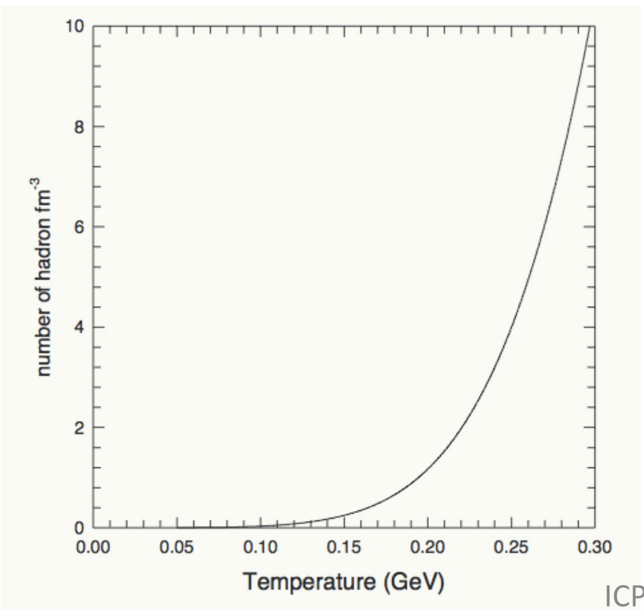
P. F. Kolb, P. Huovinen, U. W. Heinz and H. Heiselberg, Phys. Lett. B **500**, 232 (2001)

Hadron density too large~ 4 $fm^{-3}$ !!!

**Our Intention: Using Viscous Hydro For Pure HRG**

# HRG EOS




Non interacting hadron resonances

Hadron resonances mass taken up to 2.5 GeV

$$P(T) = g\sum_i \int_0^\infty d^3p \frac{p^2}{3\sqrt{p^2+m^2}} f(E,T)$$

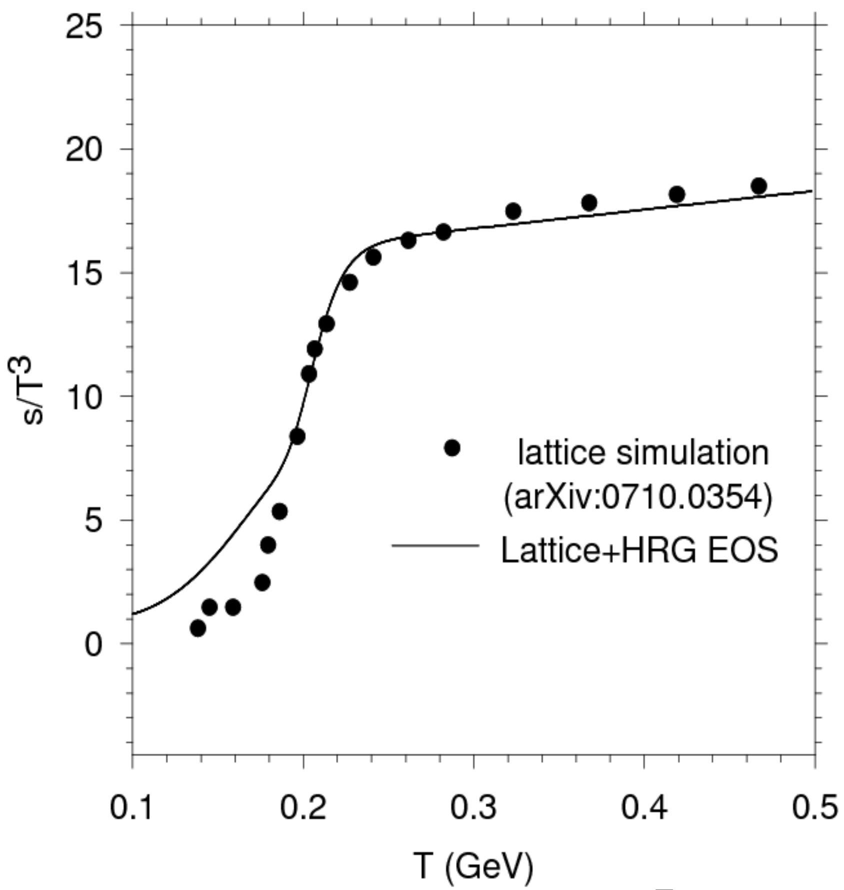
$$E(T) = g\sum_i \int_0^\infty d^3p \sqrt{p^2+m^2}\, f(E,T)$$

$$n(T) = g\sum_i \int_0^\infty d^3p\, f(E,T)$$

$$S(T) = \frac{E(T) + P(T) - \mu N(T)}{T}$$

# QGP EOS

- We construct equation of state by combining entropy density of hadron resonance gas to the entropy density obtained from recent lattice data*.




**Parameterization of entropy density for LATTICE**

$$\frac{s}{T^3} = \alpha + [\beta + \gamma T][1 + tanh\frac{T - T_c}{\Delta T}],$$

$$\alpha = 0.64, \beta = 6.93, \gamma = 0.55$$

$$T_c = 196\,\text{MeV}, \Delta T = 0.1 T_c$$

**pressure and energy density are**

$$p(T) = \int_0^T s(T')dT'$$

$$\varepsilon(T) = Ts - p.$$

We complement Lattice by HRG ($m_{res}$<2.5 GeV)

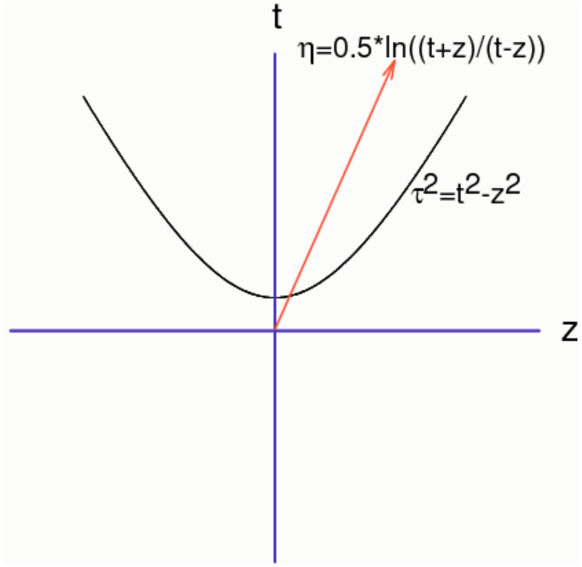
**Combined entropy** $$s = 0.5[1 + \tanh(x)]s_{HRG} + 0.5[1 - \tanh(x)]s_{LATTICE}$$

$$x = \frac{T - T_c}{\Delta T}$$

**A.K.Chaudhuri, Phys. Lett. B 681,418(2009)**

*M. Cheng *et al.*, Phys. Rev. D **77**, 014511

# Hydrodynamics Equation




**Energy momentum conservation equation:**

Solved using "AZHYDRO-KOLKATA"

$$\partial_\mu T^{\mu\nu} = 0$$

$$T^{\mu\nu} = (\varepsilon + p)u^\mu u^\nu - p g^{\mu\nu} + \pi^{\mu\nu}$$

Relaxation equation for shear stress tensor:

$$D\pi^{\mu\nu} = -\frac{1}{\tau_\pi}\left(\pi^{\mu\nu} - 2\eta\nabla^{\langle \mu}u^{\nu\rangle}\right) - \left[u^\mu \pi^{\nu\lambda} + u^\nu \pi^{\mu\lambda}\right]Du_\lambda$$

$$D = u^\mu \partial_\mu$$

Convective derivative

Shear viscous coefficient

$$\nabla^{\langle \mu}u^{\nu\rangle} = \frac{1}{2}\left(\nabla^\mu u^\nu + \nabla^\nu u^\mu\right) - \frac{1}{3}(\partial . u)\left(g^{\mu\nu} - u^\mu u^\nu\right)\left[u^\mu \pi^{\nu\lambda} + u^\nu \pi^{\mu\lambda}\right]Du_\lambda$$

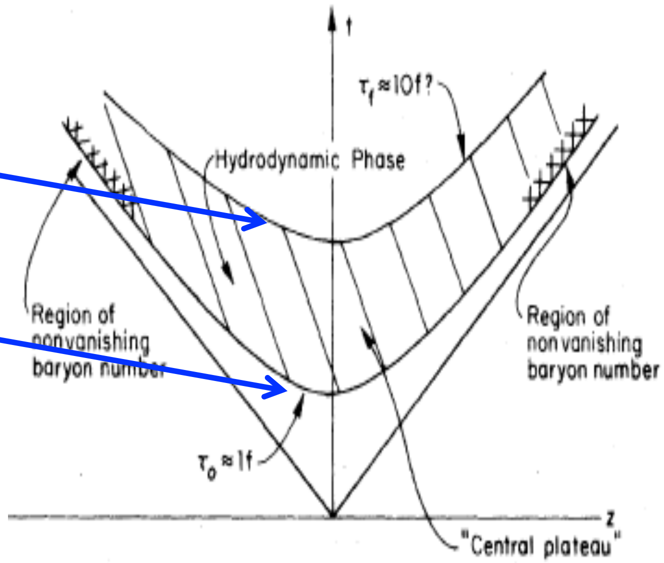
Symmetric traceless tensor

# Initial Condition, HRG

- **Freeze-out temperature**

$$T_f = 110 \text{ MeV}$$

- **Initial time** $\tau_i = 1.0\, fm$




- **Initial transverse fluid velocity**

$$V_T(x, y) = 0.0$$

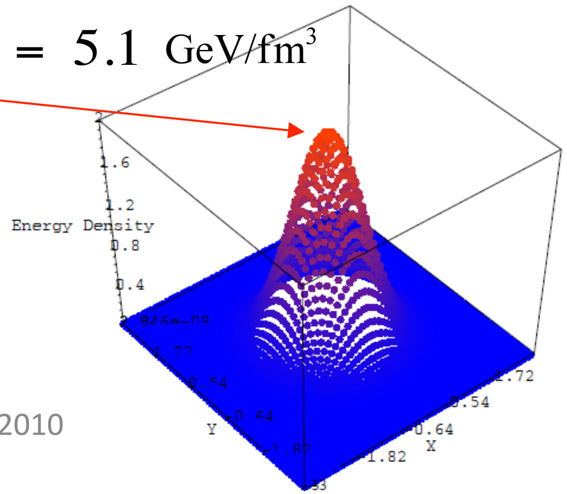
- **Initial transverse energy density profile**

$$\varepsilon(b,x,y) = \varepsilon_0 \left\{ 0.99 N_{part}(b,x,y) + 0.01\, N_{coll}(b,x,y) \right\}$$

- **Relaxation time for shear viscous stress**

$$\tau_\pi = \frac{6\eta}{4p}$$

Central peak energy density $\varepsilon_0 = 5.1 \text{ GeV/fm}^3$




- **Shear viscosity to entropy ratio, input parameter**

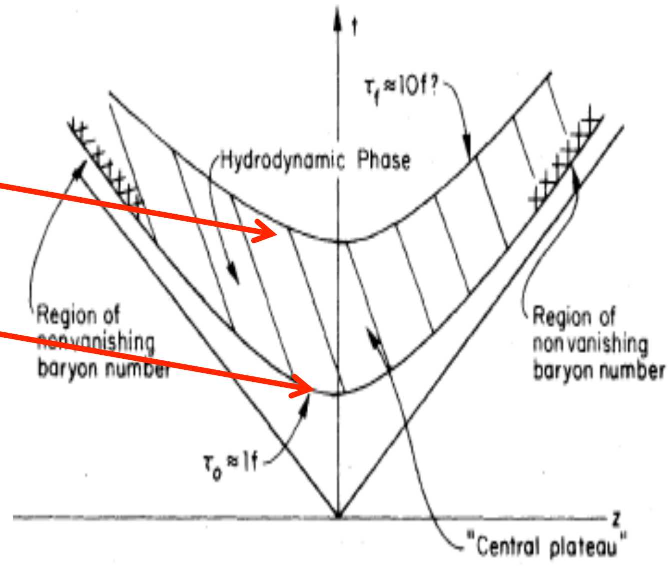
$$\frac{\eta}{s} = 0.0, 0.08, 0.16, 0.24, 0.30$$

# Initial Condition, QGP

- **Freeze-out temperature**

$T_f = 150\,\text{MeV}$

- **Initial time** $\tau_i = 0.6\, fm$




- **Initial transverse fluid velocity**

$V_T(x,y) = 0.0$

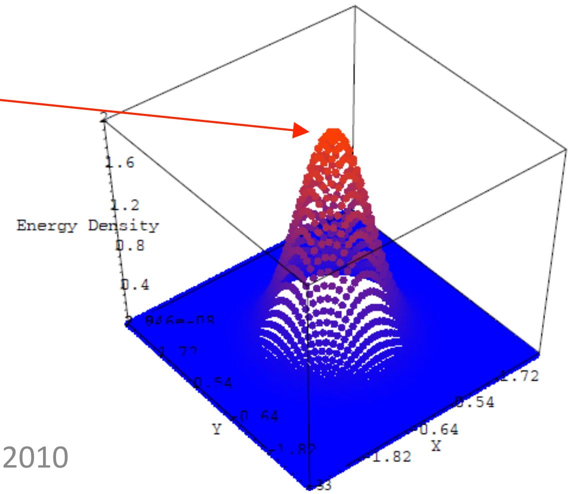
- **Initial transverse energy density profile**

$$\varepsilon(b,x,y) = \varepsilon_0 \left\{ 0.75 N_{part}(b,x,y) + 0.25\, N_{coll}(b,x,y) \right\}$$

Central peak energy density

- **Relaxation time for shear viscous stress**

$$\tau_\pi = \frac{3\eta}{4p}$$



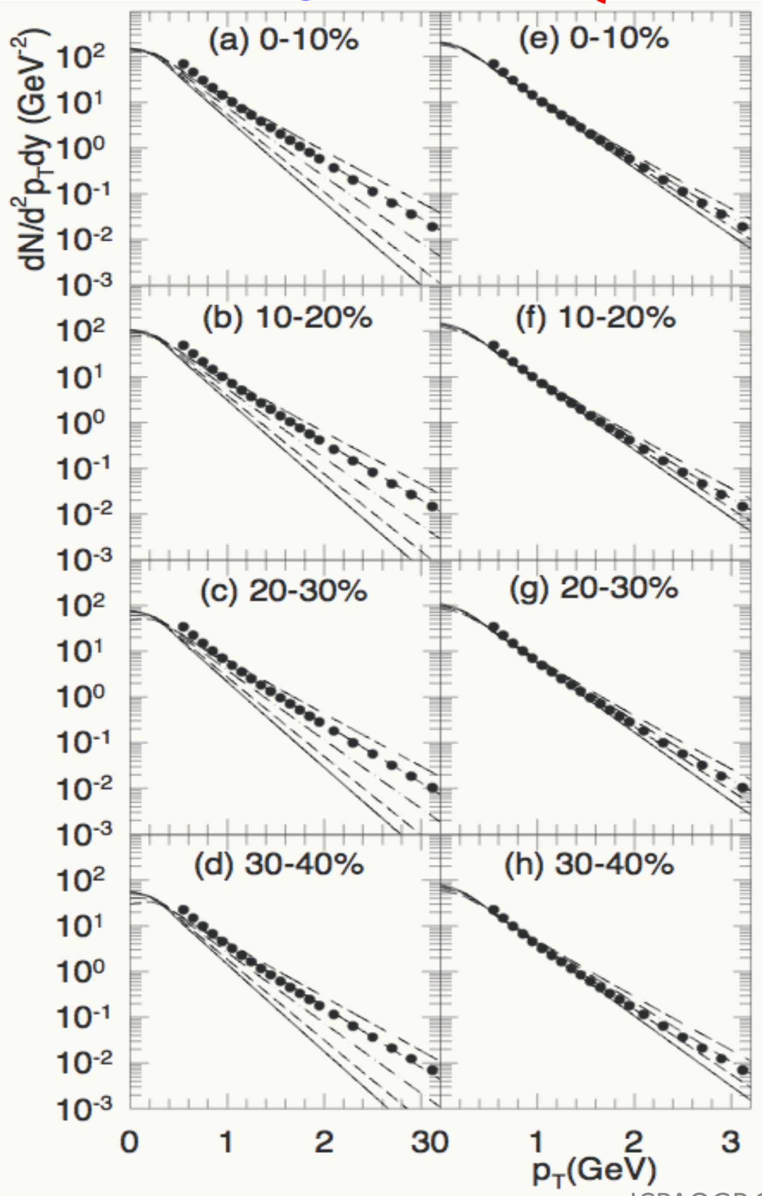

- **Shear viscosity to entropy ratio, input parameter**

$$\frac{\eta}{s} = 0.0,\ 0.08,\ 0.12,\ 0.16$$

$$\varepsilon_0 = 35.5,\ 29.1,\ 25.6,\ 20.8\ \ \text{GeV/fm}^3$$

# Charged Particles $p_T$ spectra

HRG QGP




HRG

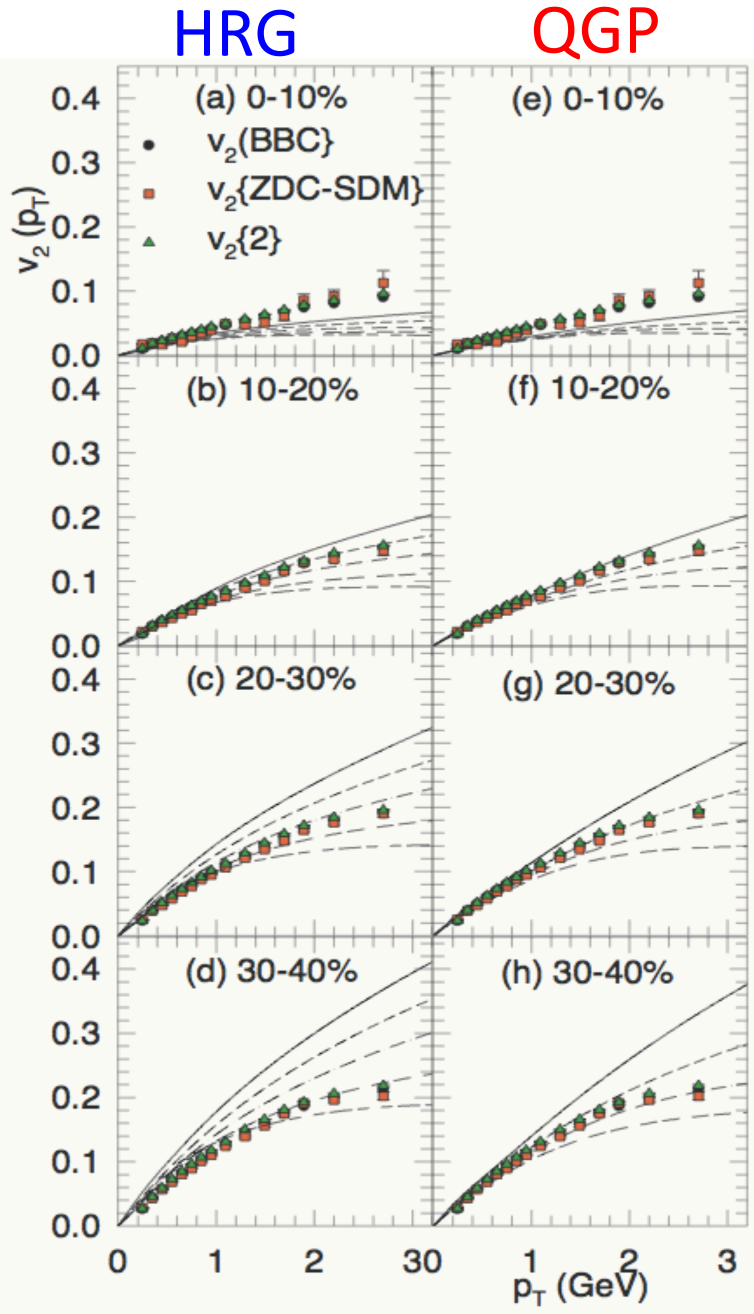
$$\frac{\eta}{s} = 0.0, 0.08, 0.16, 0.24, 0.30$$

QGP

$$\frac{\eta}{s} = 0.0, 0.08, 0.12, 0.16$$

S. S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. C **69**, 034910 (2004)

# Charged particles Elliptic flow




HRG

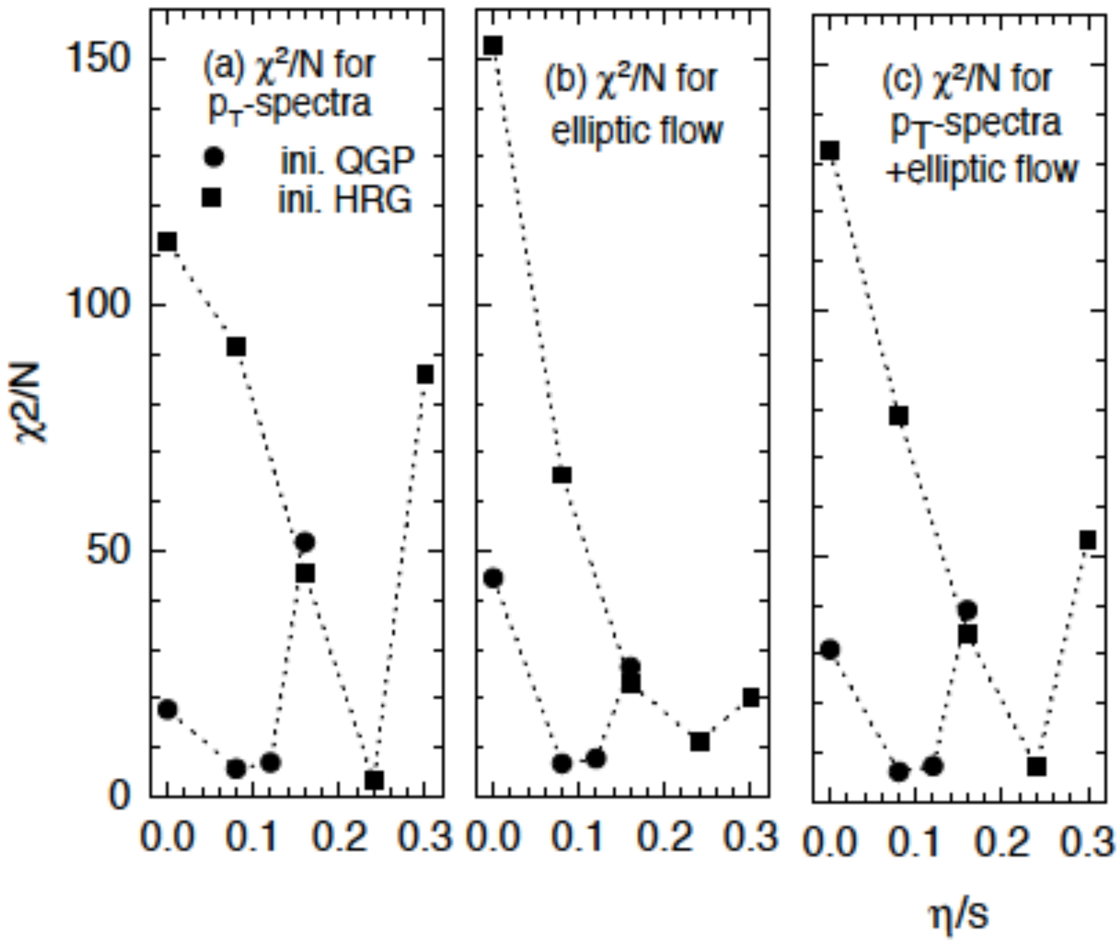
$$\frac{\eta}{s} = 0.0, 0.08, 0.16, 0.24, 0.30$$

QGP

$$\frac{\eta}{s} = 0.0, 0.08, 0.12, 0.16$$

S. S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. C 69, 034910 (2004)

# How good is the two picture




$$\chi^2/N = \frac{1}{N}\sum_i \frac{(ex(i) - th(i))^2}{error^2}$$

It is a measure, how good is the agreement between experimental measurement and theoretical prediction

# Comments

- Shear Viscosity to entropy ration taken as independent of temperature.
- Cross-over temperature taken as 196 MeV.
- Initial central temperature for HRG should not > ~ 220 MeV

# Summary & Conclusion

❖The possibility of QGP formation in initial state was studied in a viscous hydrodynamic model.

❖QGP fluid initialization : Best description obtained for

$$\frac{\eta}{s} = 0.08 \qquad \varepsilon_0 = 29.1 \text{ GeV/fm}^3$$

❖Hadron Gas initial state : Best description obtained for

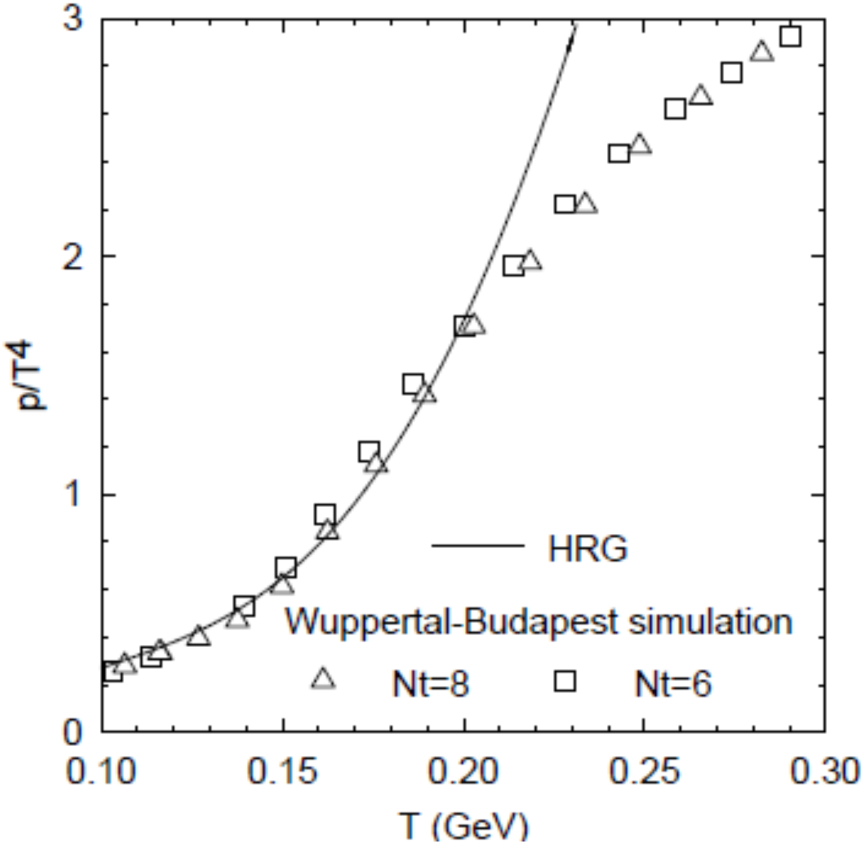
$$\frac{\eta}{s} = 0.24 \qquad \varepsilon_0 = 5.1 \text{ GeV/fm}^3$$

❖Both scenario explains the data quite well, If HRG be allowed to initialize at 220 MeV.

❖ In view of recent lattice simulation predicted $T_c$ ~170 MeV HRG only initial state should be abandoned in present viscous hydrodynamic scenario .

**Thank You**

# Backup



p/T4
T (GeV)
HRG
Wuppertal-Budapest simulation
Nt=8
Nt=6
0.10
0.15
0.20
0.25
0.30
0
1
2
3

# Chi square

| $\eta/s$ | 0-10% | | 10-20% | | 20-30% | | 30-40% | |
|---|---|---|---|---|---|---|---|---|
| | $\chi^2$ | $\chi^2/N$ | $\chi^2$ | $\chi^2/N$ | $\chi^2$ | $\chi^2/N$ | $\chi^2$ | $\chi^2/N$ |
| 0.00 | 96.1 | 6.0 | 64.7 | 4.0 | 683.3 | 43.0 | 1989.8 | 124.3 |
| 0.08 | 146.6 | 9.1 | 38.1 | 2.3 | 29.2 | 1.8 | 213.0 | 13.3 |
| 0.12 | 175.8 | 10.9 | 169.5 | 10.5 | 116.0 | 7.2 | 33.1 | 2.0 |
| 0.16 | 208.4 | 13.0 | 435.4 | 27.2 | 548.4 | 34.2 | 489.4 | 30.5 |
| HRG | | | | | | | | |
| 0.00 | 51.5 | 3.2 | 225.5 | 14.0 | 2587.9 | 161.7 | 6905.8 | 431.6 |
| 0.08 | 87.5 | 5.4 | 88.0 | 5.5 | 912.0 | 57.0 | 3093.7 | 193.3 |
| 0.16 | 130.0 | 8.1 | 33.7 | 2.1 | 185.2 | 11.5 | 1131.7 | 70.7 |
| 0.24 | 176.4 | 11.0 | 193.5 | 12.0 | 75.0 | 4.6 | 264.9 | 16.5 |
| 0.30 | 202.8 | 12.6 | 396.3 | 24.7 | 357.2 | 22.3 | 340.1 | 21.2 |