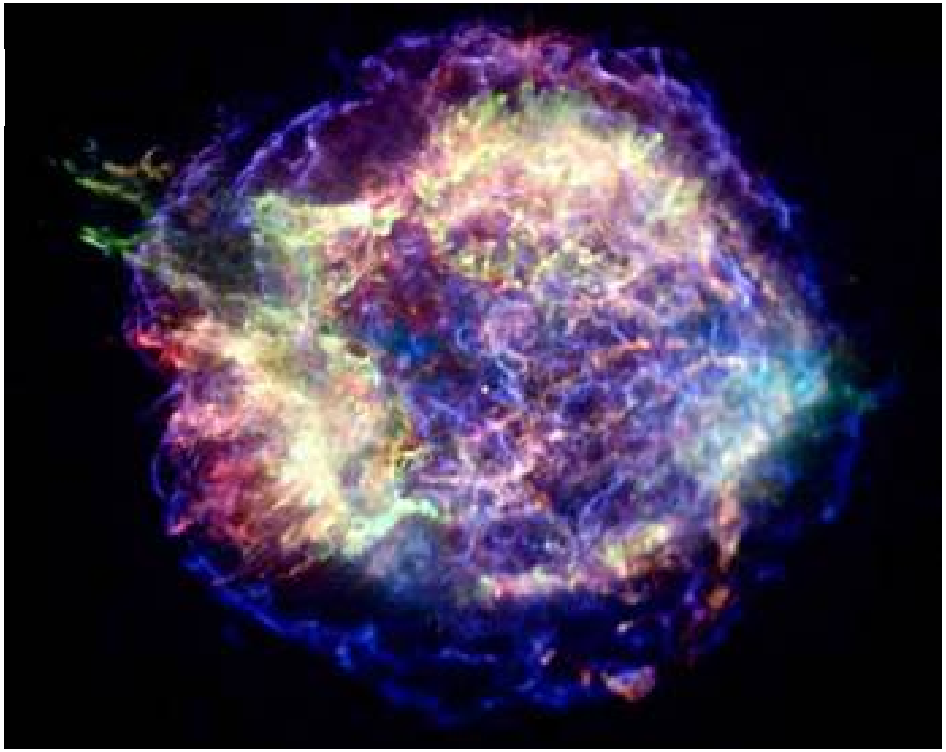
Landau Model and Viscosity



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Success of Hydrodynamical Modeling at RHIC

- Formation of Hot Dense Matter which flows as if an (almost) Ideal Fluid
- Expectation of extracting the EoS of the Quark Gluon Plasma

⇨ uncertainties on EoS+Initial condition+freezeout and the hydro dynamical observables are not so restrictive to clarify uniquely these parameters.

⇨ possibility that the hydrodynamical description seems to work as if in equilibrium but not necessarily in equilibrium.

viscosity ?

Basic Ideas of Hydrodynamical Modeling

- Formation of matter in Local Thermal Equilibrium
- Initial condition given by some other models

Conservation Law

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

very general

EoS

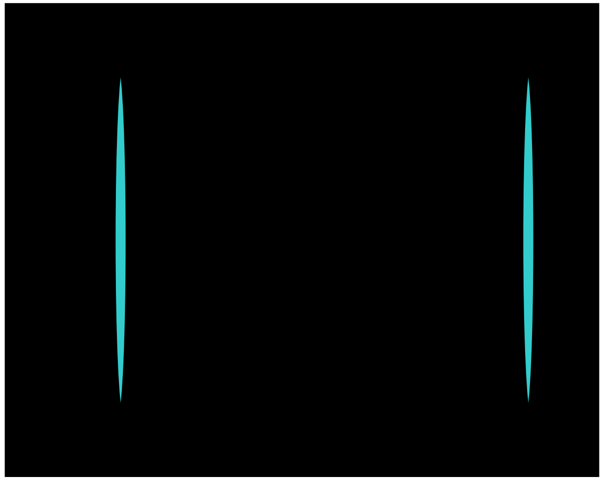
$$\varepsilon = \varepsilon(p)$$

how sensitive?

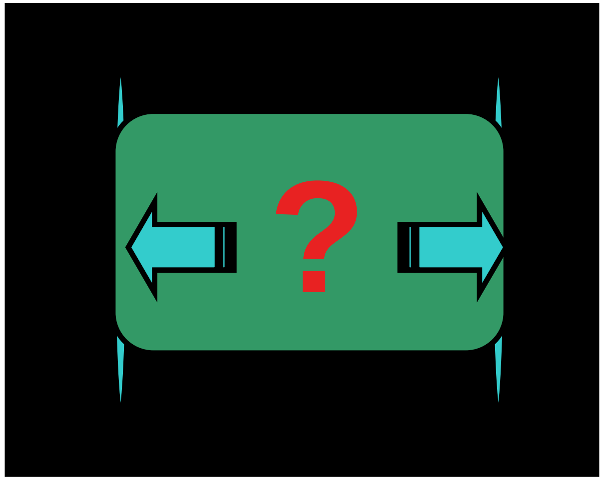
$$\zeta, \tau_R \ldots$$

viscous fluids

Normal procedures for hydro calculations



Prepare some initial distribution of energy density and flow field.

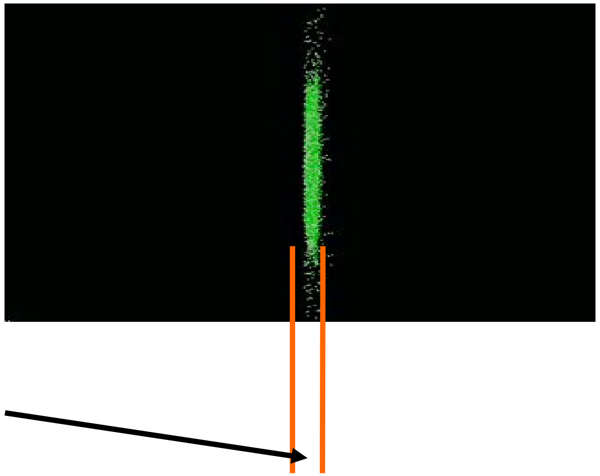


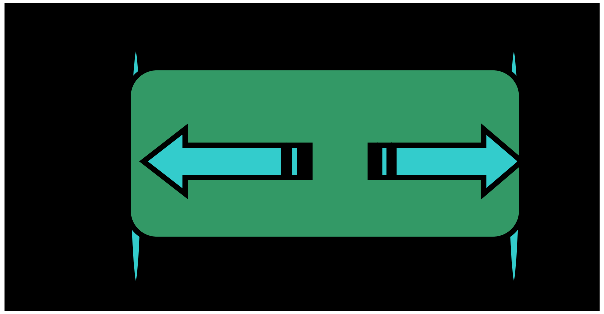
Very important to know how much depends on initial conditions.

Two Extreme Cases:

Landau vs. **Bjorken**

(full stopping) (boost invariant -almost)



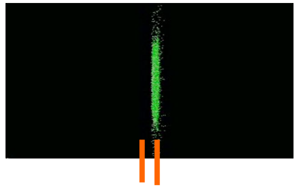


$$\Delta z \sim 1/\gamma,$$

$$\varepsilon \sim E_{tot} / \left(\pi R^3 / \gamma \right) \sim \gamma^2,$$

1D Hydrodynamics and Landau Model

Initial Energy density



$$\varepsilon_0 \propto \sqrt{s}^{\,2}$$

$$\Delta z \sim 1/\gamma,$$

"entropy density (no. of accessible states)" $S/V \propto \varepsilon_0^{\,3/4}$

So that $S \propto \left(\sqrt{s}\right)^{1/2}$

If the number of particles is proportional to the no. of states,

$$N \propto \sqrt{s}^{\,1/2}$$

Landau Model behavior of Data

- Many data on global aspects show Landau behavior (NA49, PHOBOS, BRAHMS), R. Debbe’s talk in Quark Matter and also see for example, M. Murray, J. Phys. G30, s6667 (QM2004), G. Roland, P. Steinberg, nucl-ex/0702019, and references therein.

“Landau Model Behavior”

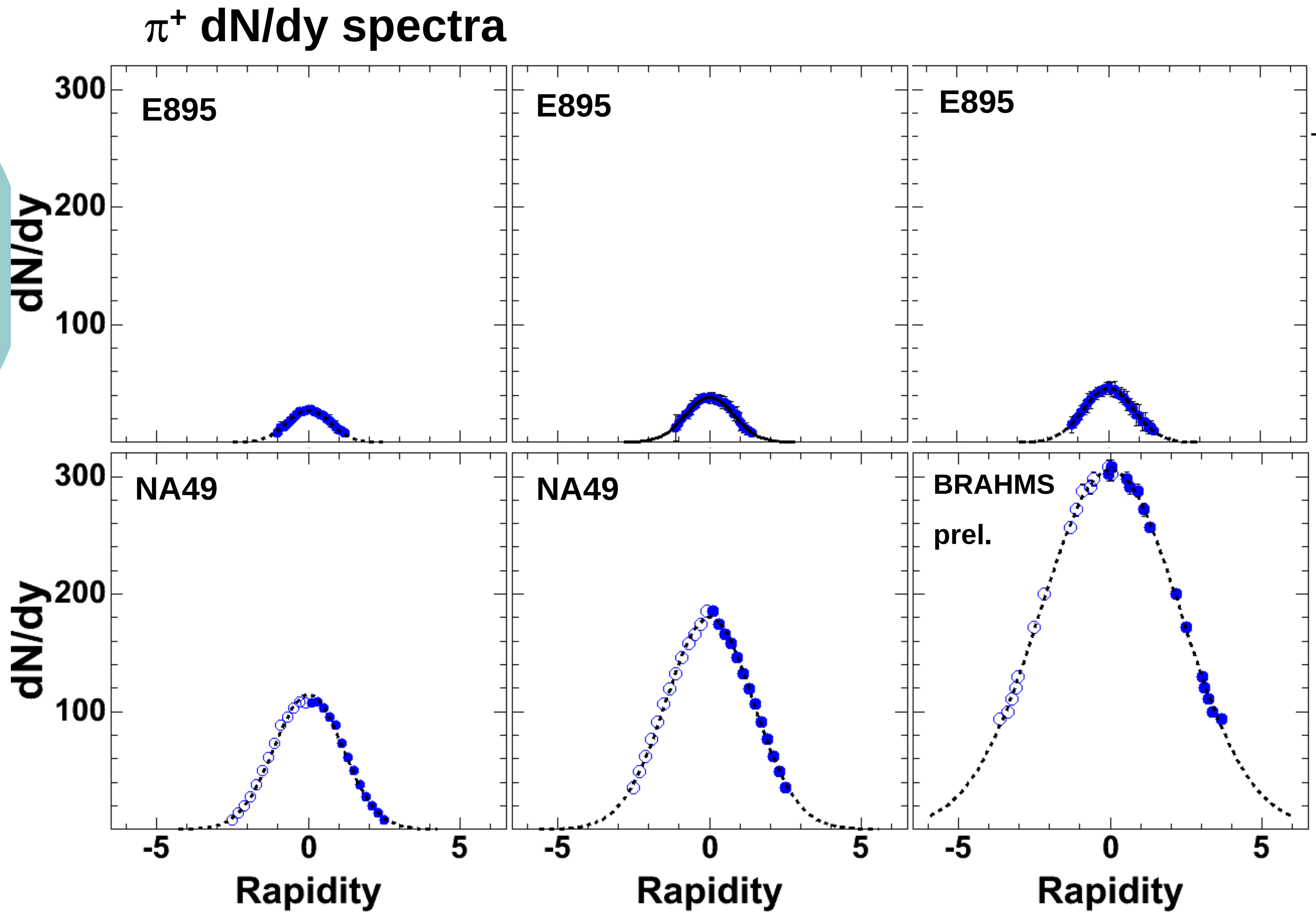
$$N_{ch} \sim K\sqrt{s}^{1/2}$$

$$\frac{dN}{dy} = N_0 \frac{e^{-y^2/2\sigma_y{}^2}}{\sqrt{2\pi\sigma_y{}^2}}$$

$$\sigma_y{}^2 = \frac{8}{3}\frac{c_s{}^2}{1-c_s{}^4}\ln\left(\frac{\sqrt{s}}{2m_p}\right)$$

Gaussian profile of rapidity distribution derived by Landau for p-p (with approximations)

Slide from G. Roland



Single Gaussian fits from 2 to 200 GeV

Longitudinal Dynamics

L. M. Satarov, I. N. Mishustin, A. V. Merdeev and H. Stoecker

PHYS. REV. C **75**, 024903 (2007)

Studies on the longitudinal fluid dynamics for ultrarelativistic heavy-ion collisions, changing the initial condition and EoS (1D)

Simple Landau initial condition doesn't work.

1D Hydrodynamics and Landau Model

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

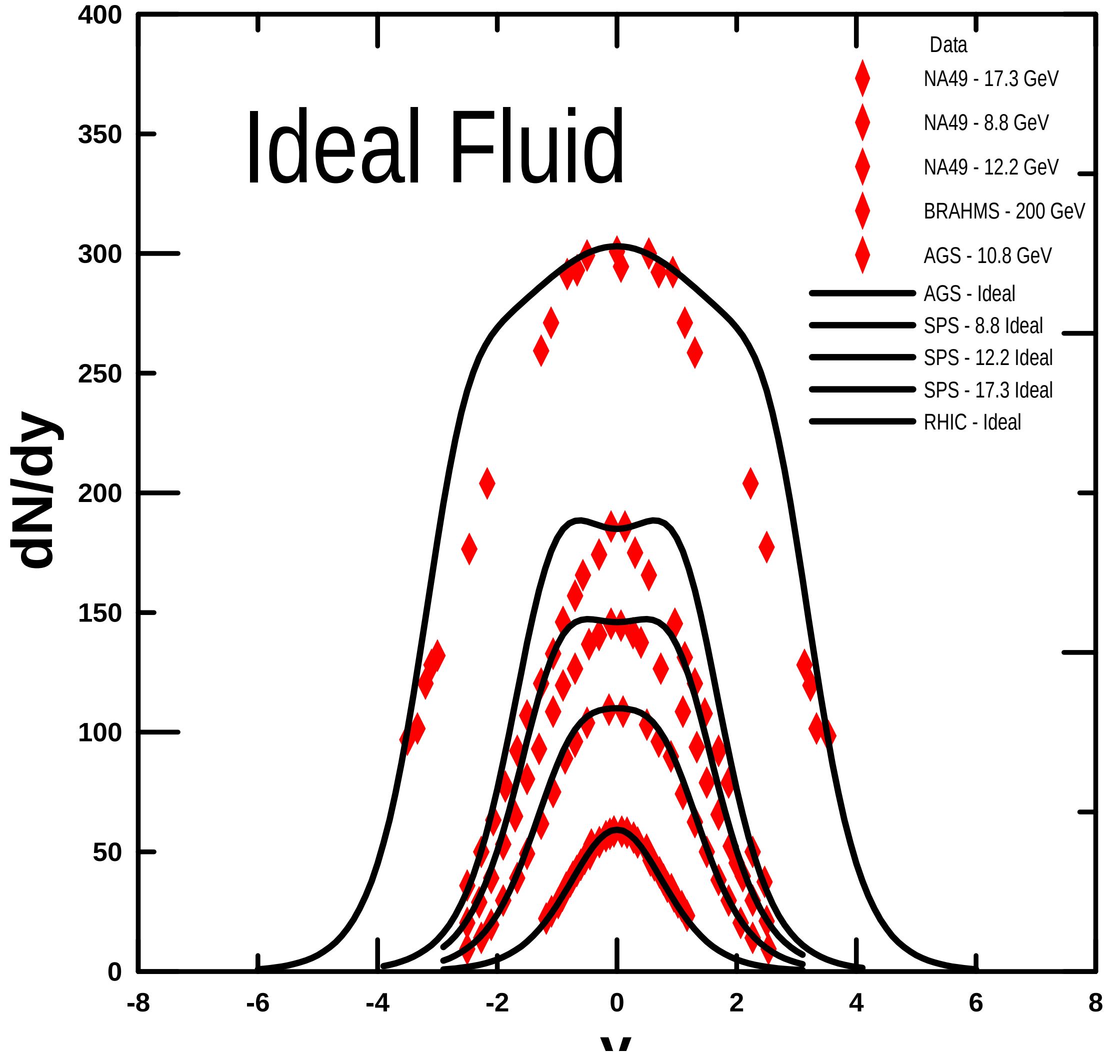
Define the velocity field by:

$$T^{\mu\nu} u_\nu = \varepsilon u^\mu$$

Then in a local rest frame $u^\mu \to (1, 0)$

$$T^{\mu\nu} \to \begin{pmatrix} \varepsilon & 0 \\ 0 & \pi \end{pmatrix} \qquad \varepsilon = 3\pi \quad \left(T_\mu^\mu = 0\right)$$

Landau Initial Condition (full stopping)
1D + thermal freezeout at T=170 MeV



Ideal Massless EoS

Viscous fluid dynamics

$$\partial_\mu T^{\mu\nu} = 0$$ Conservation of energy and momentum

$$T^{\mu\nu} u_\nu = \varepsilon u^\mu$$ Definition of velocity field

$$T^{\mu\nu} \to \begin{pmatrix} \varepsilon & 0 \\ 0 & \pi \end{pmatrix}$$ in a local rest frame

If not ideal fluid, then $\varepsilon - 3\pi \equiv -3\Pi \neq 0$

We need $$\frac{d\Pi}{d\tau} = ?$$

Minimum Ansatz within a linear response theory with causality:

$$\Pi(\tau) = -\int_{-\infty}^{\tau} d\tau' G(\tau,\tau') \zeta \partial_\mu u^\mu ,$$

with $$G(t,t') = \frac{1}{\tau_R} e^{-\frac{t-t'}{\tau_R}}$$

then

$$\frac{d\Pi}{d\tau} = -\frac{1}{\tau_R}\Pi - \frac{\zeta}{\tau_R}\partial_\mu u^\mu \qquad \zeta = \zeta_{Bulk} + \frac{3}{2}\eta_{shear}$$

(2nd order causal viscous theory)

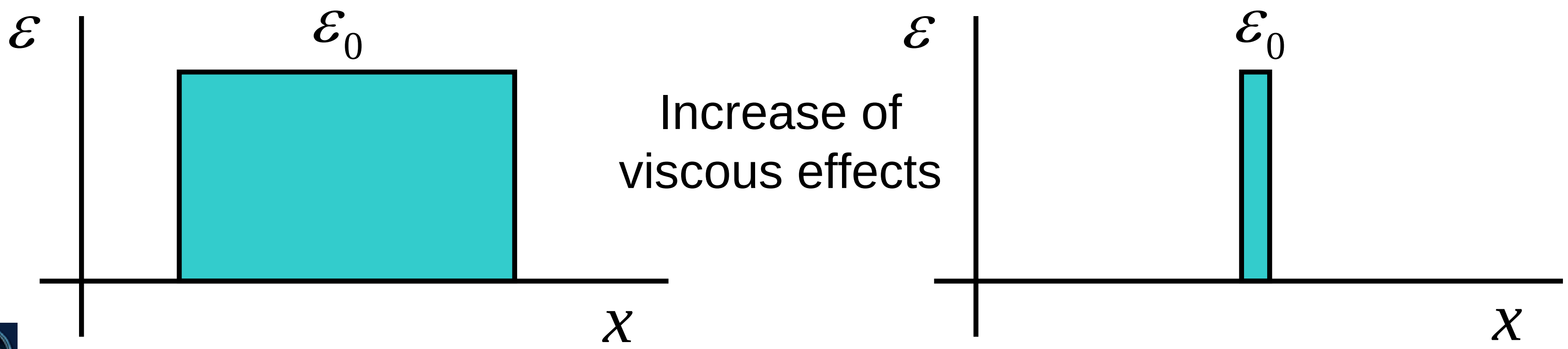
Viscosity

$$\frac{\zeta}{s} = a$$ → Does not reflect the effect of viscosity

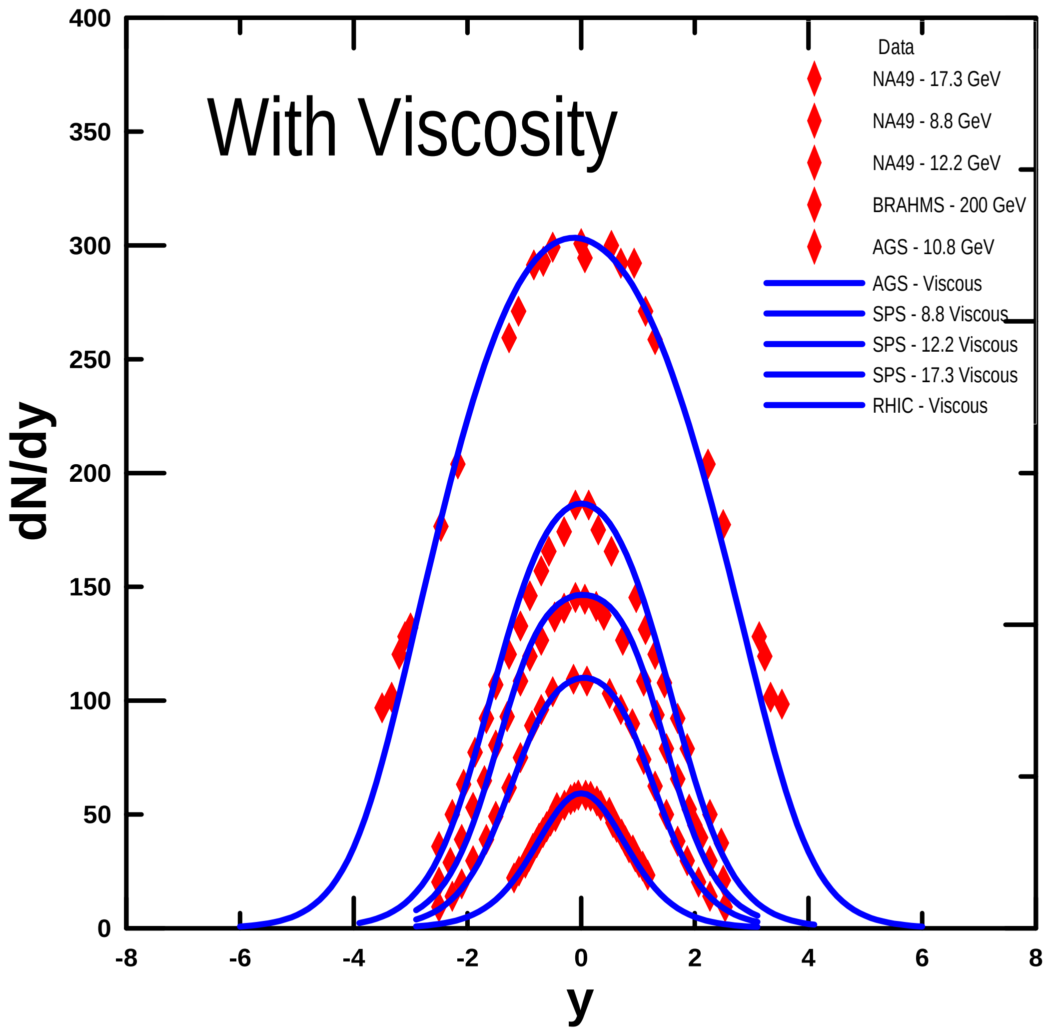
$$\Pi \Leftrightarrow (\varepsilon + p)$$

$$\Pi \sim (\varepsilon + p)$$ high viscosity

$$\Pi \ll (\varepsilon + p)$$ low viscosity

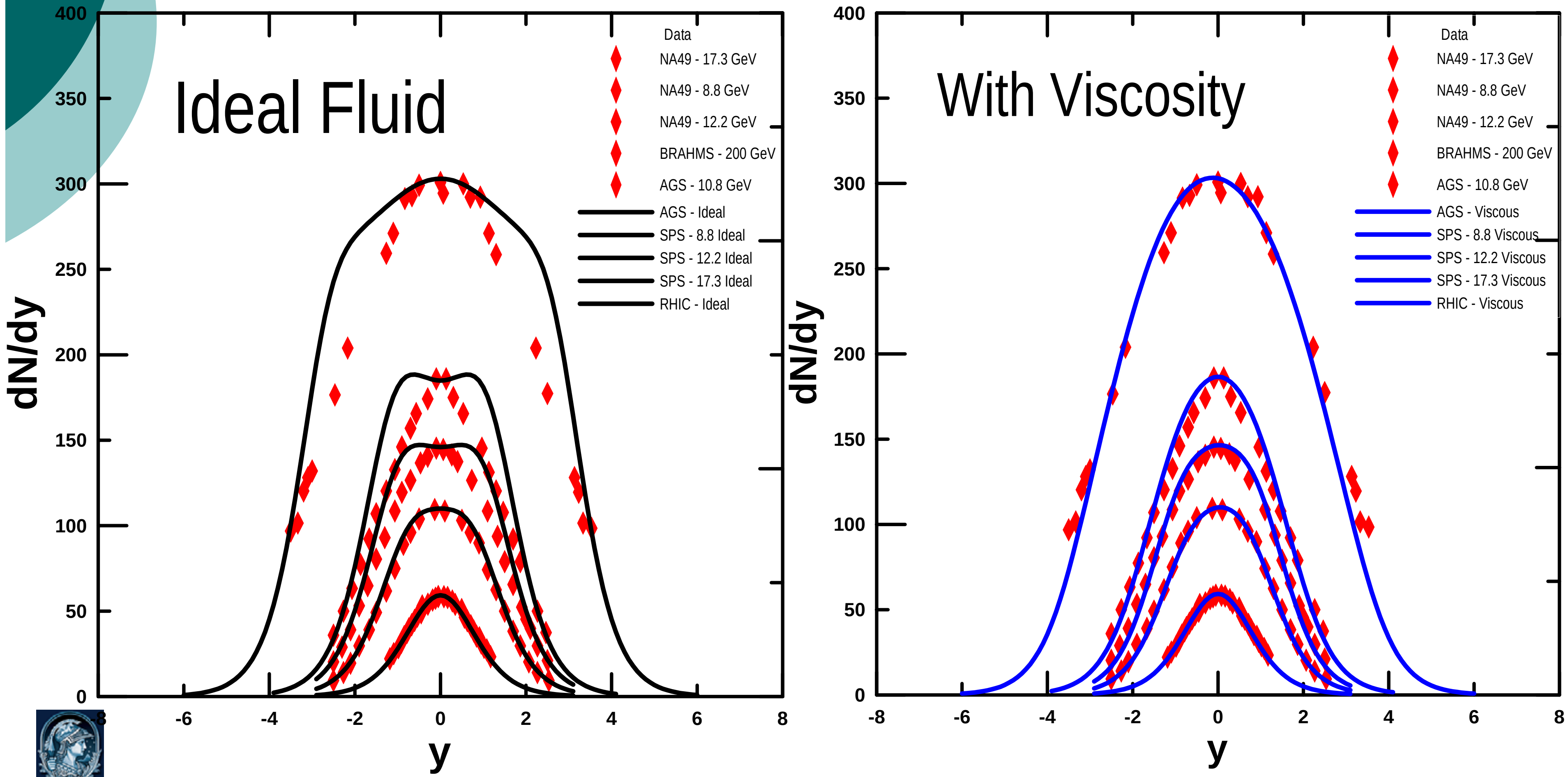


Landau Initial Condition (full stopping) 1D + thermal freezeout at T=170 MeV

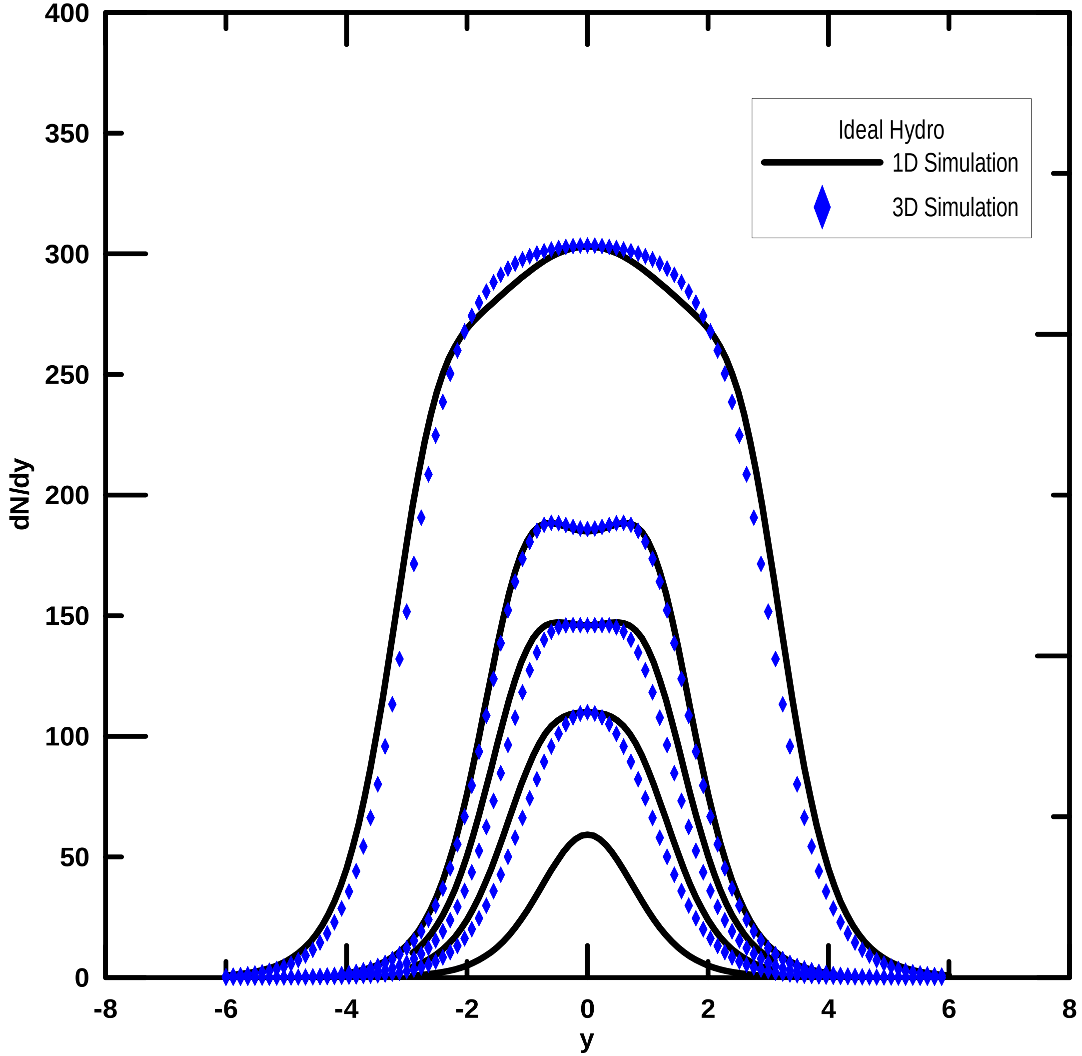


$$\zeta \approx 0.2s$$

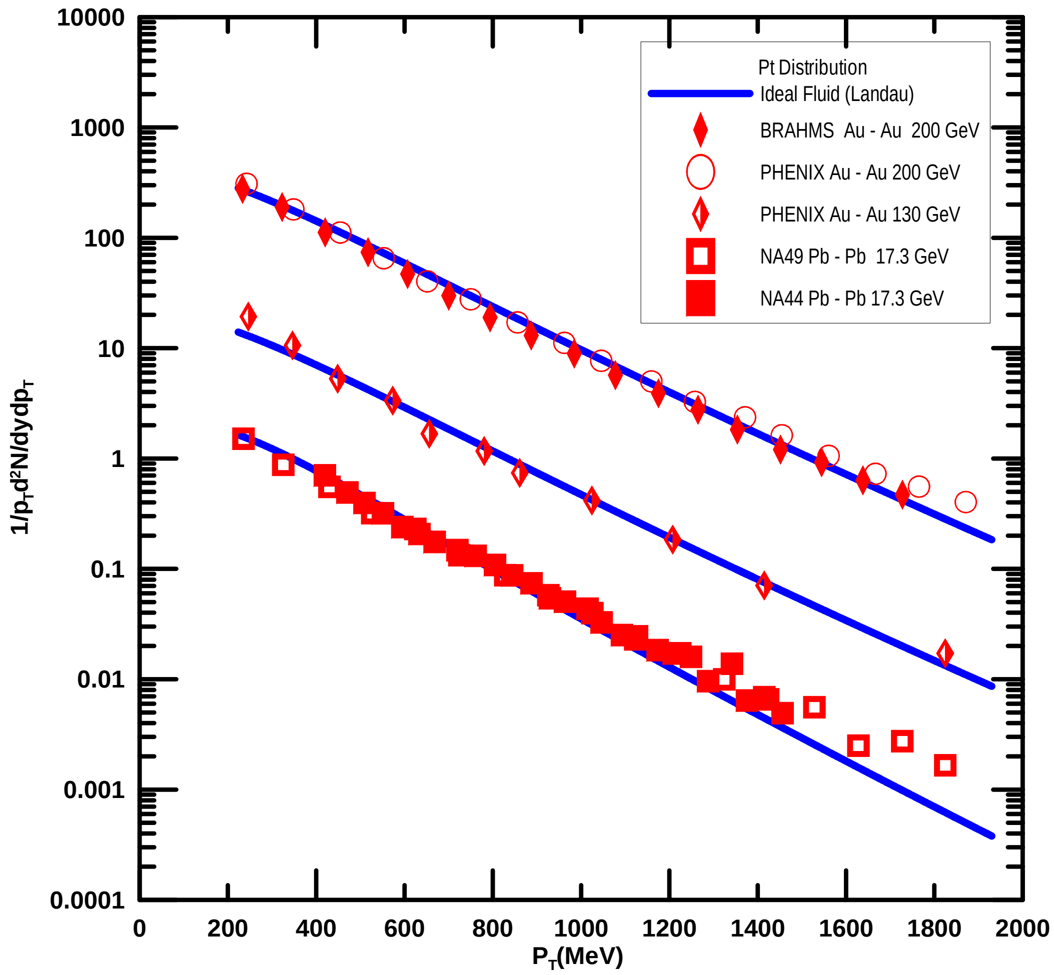
Landau Initial Condition (full stopping)
1D + thermal freezeout at T=170 MeV



Rapidity Distribution 3D vs. 1D (Ideal)

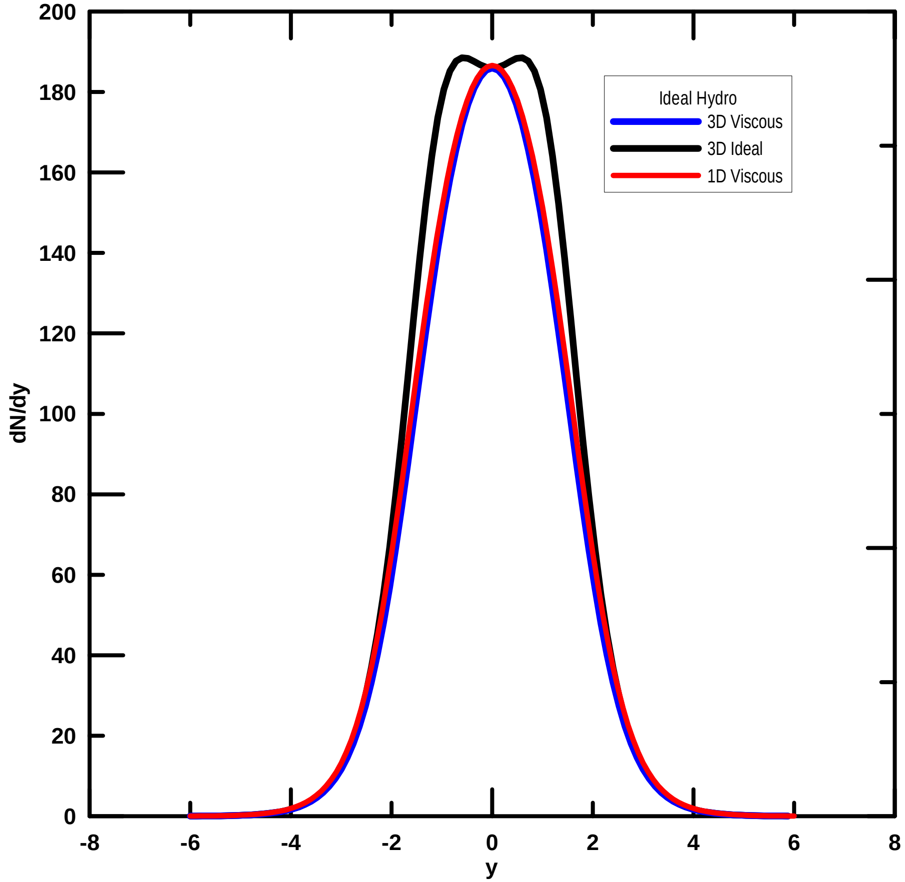


π–Transverse Momentum Distribution
Ideal 3D Landau



Rapidity with viscosity (3D)

SPS 17.3GeV



Rapidity with viscosity (3D)

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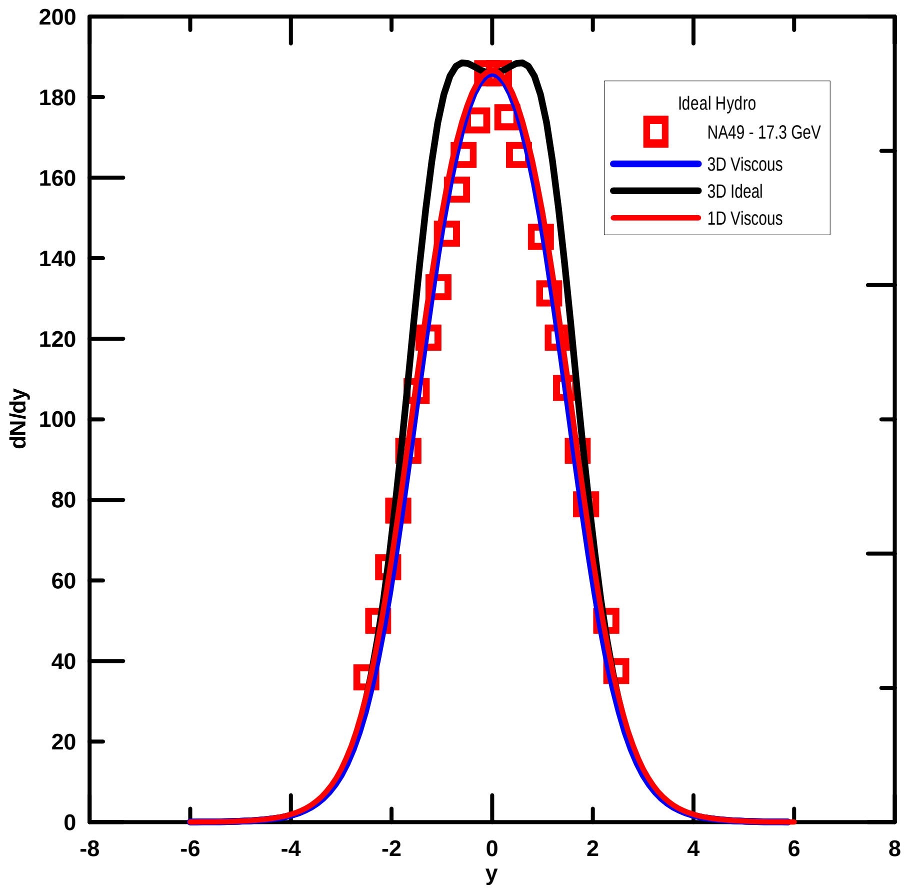
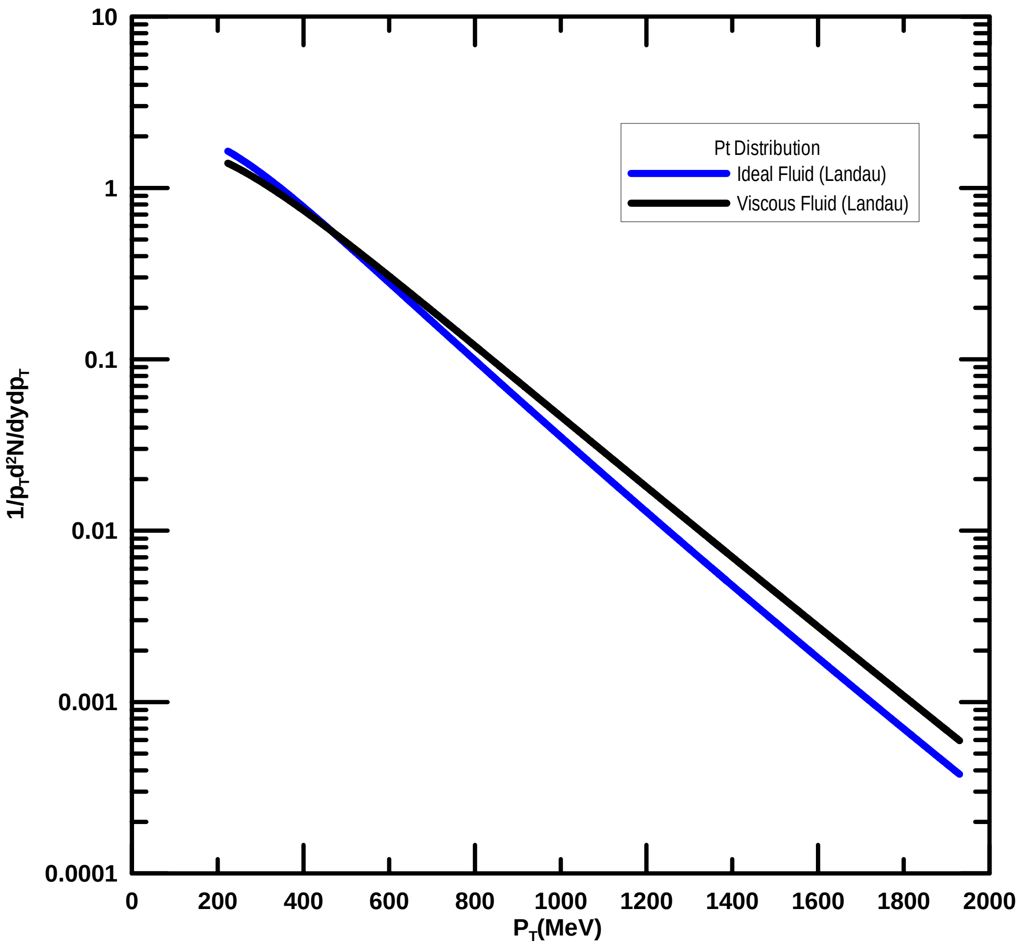
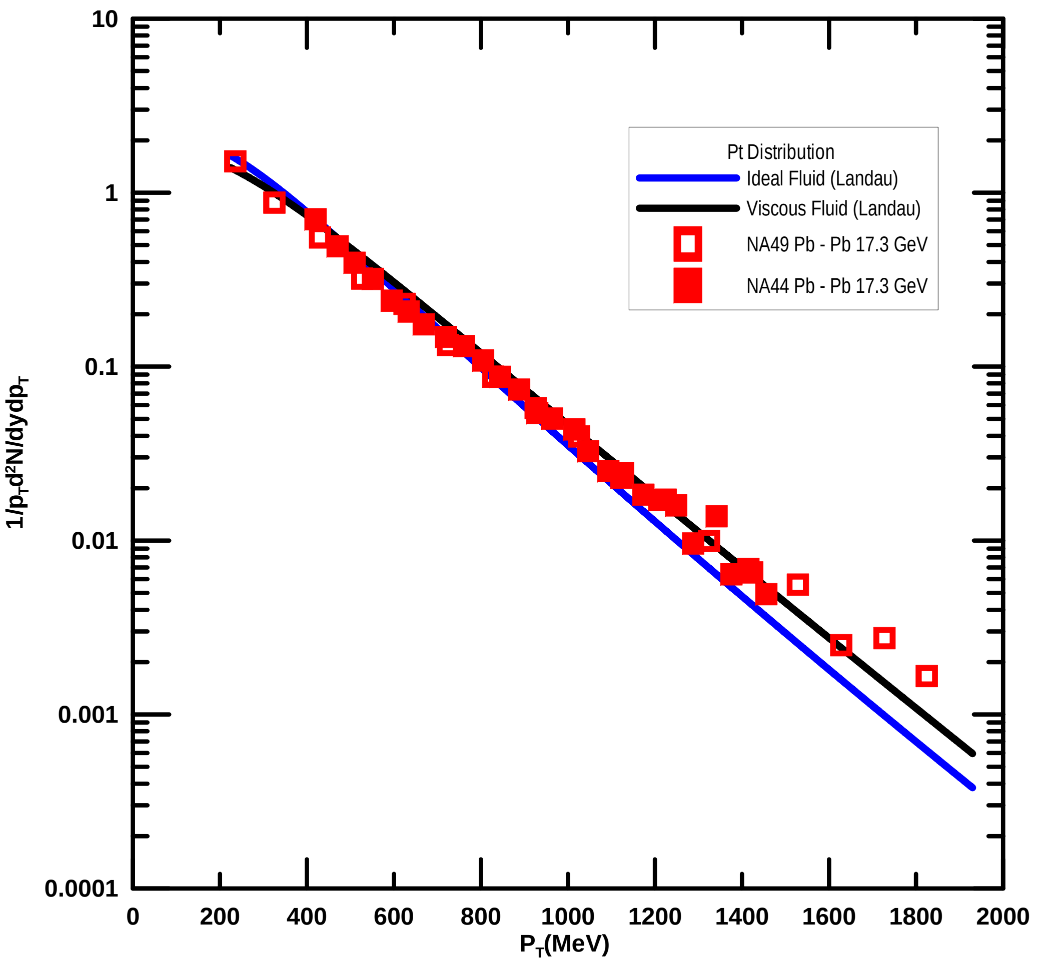


π-Transverse Momentum Distribution
Ideal 3D Landau vs. Viscous



π-Transverse Momentum Distribution NA49 17.3GeV case



3D Landau model with viscosity (preliminary)

Experimental data (rapidity and pt) can be fitted by Landau (full stopping) Initial condition with viscosity

Can we take this seriously as the usual hydo interpretation ??

Dilemmas:

- Initial temperature and entropy too high. Can not be interpreted “thermally equilibrated energy density” as usual QGP degrees of freedom. $T_0=300$MeV at SPS and 1.5GeV at RHIC !!!

- Why the same mechanism works similarly to p+p case? This is certainly out of equilibrium.

What we have used for Ideal case?

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

Conservation of energy and momentum

$$T^{\mu\nu} u_\nu = \varepsilon u^\mu$$

Definition of velocity field

$$T^{\mu\nu} = A u^\mu u^\nu + B g^{\mu\nu}$$

Isotropy in local *u* - frame

$$T_r\left(T^\mu{}_\nu\right) = 0$$

Scale invariance

Then ⇒ $A = \frac{4}{3}\varepsilon,\ \ B = -\frac{1}{3}\varepsilon$

and $\partial_\mu\left(\varepsilon^{3/4} u^\mu\right) = 0$

Conclusion:

For a system where the longitudinal dynamics is dominant, everything works as if a hydrodynamical system, but this has nothing to do with the local thermal equilibrium.
Here, any "temperature" and "entropy",

$$"T" = K^{-1}\varepsilon^{1/4}, \qquad "s" = \frac{4}{3}K\varepsilon^{3/4}$$

with any K work. And also, the above argument valid for p+p if we substitute

$$T^{\mu\nu} \Rightarrow \langle T^{\mu\nu} \rangle$$

To be understood:

Further studies such as v2 and HBT observables should be done, changing IC and EoS (see L. M. Satarov, I. N. Mishustin, A. V. Merdeev and H. Stoecker, PHYS. REV. C **75**, 024903 (2007). Also investigate the shear effect.

Interesting question: Study the Event-by-Event fluctuations of rapidity distribution varying the system size. See the role of τ (fluctuation-dissipation)

How to deal with the dynamics of baryon number?

How will be in LHC energies?