Viscous Hydrodynamics

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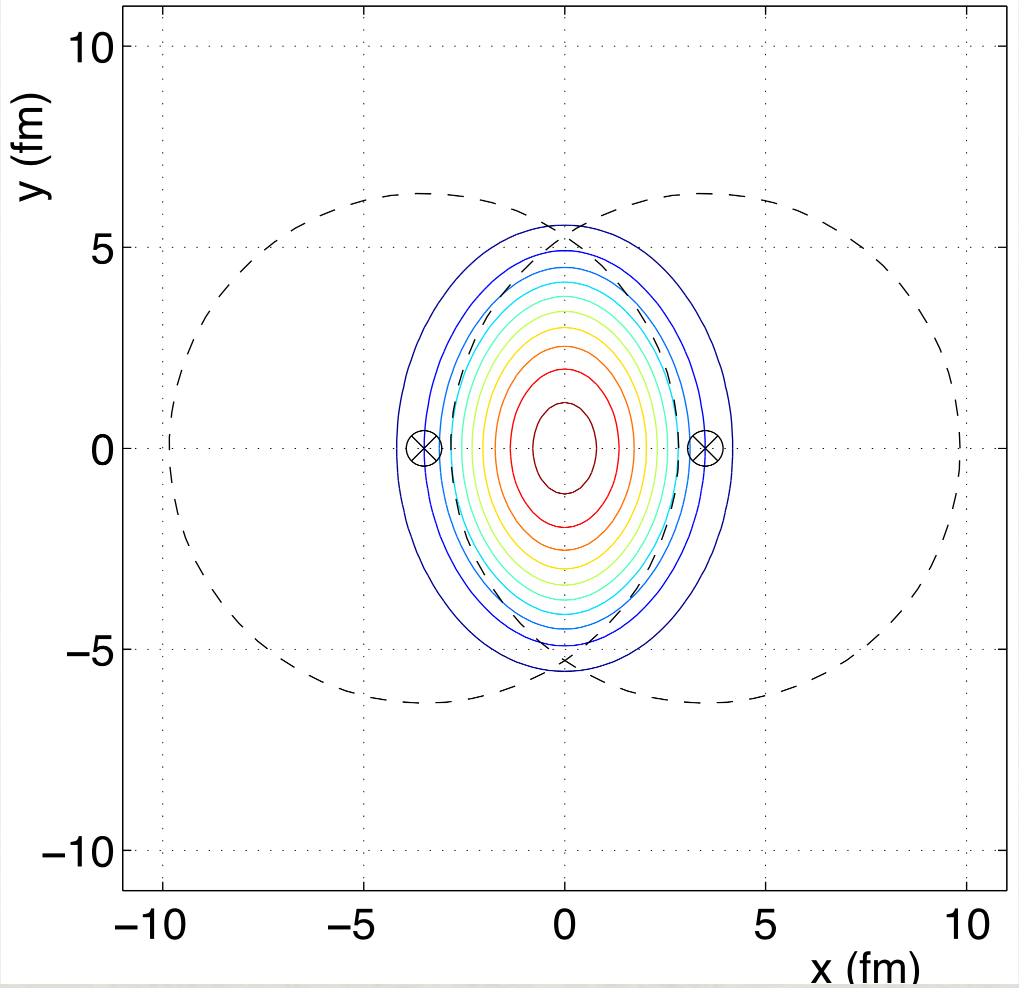
NeD-TuRiC 2012

Outline

* About Shear Viscosity with Boost Invariance.
* Signs from Longitudinal Dynamics.

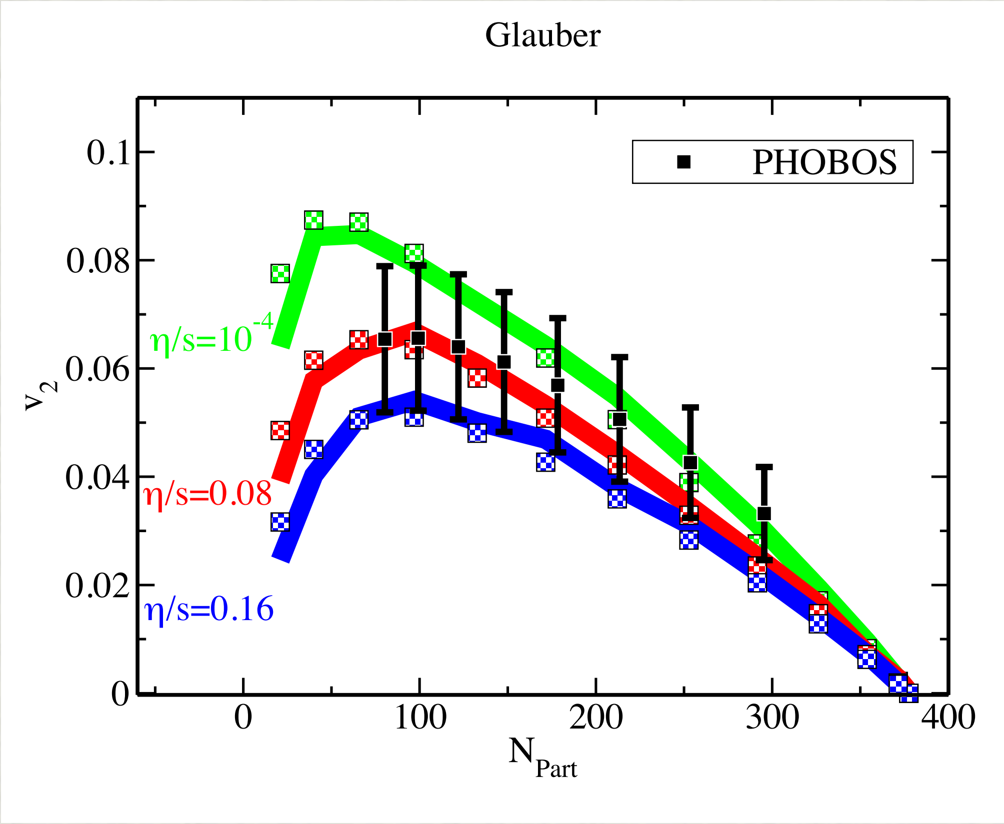
Elliptic Flow

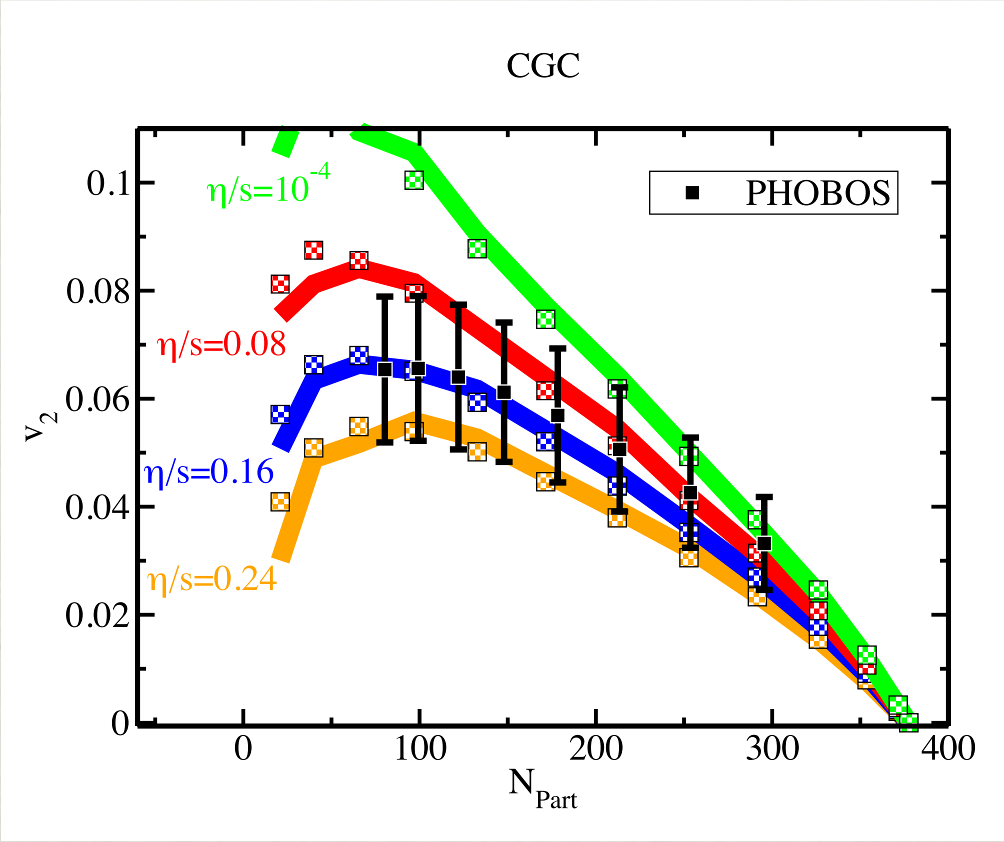


Kolb and Heinz. arxiv:nucl-th/0305084v2

- Anisotropic Distribution of nucleon scattering sites.
  - Anisotropic Gradients.
- Leads to Anisotropic Flow.

Viscosity Scaling

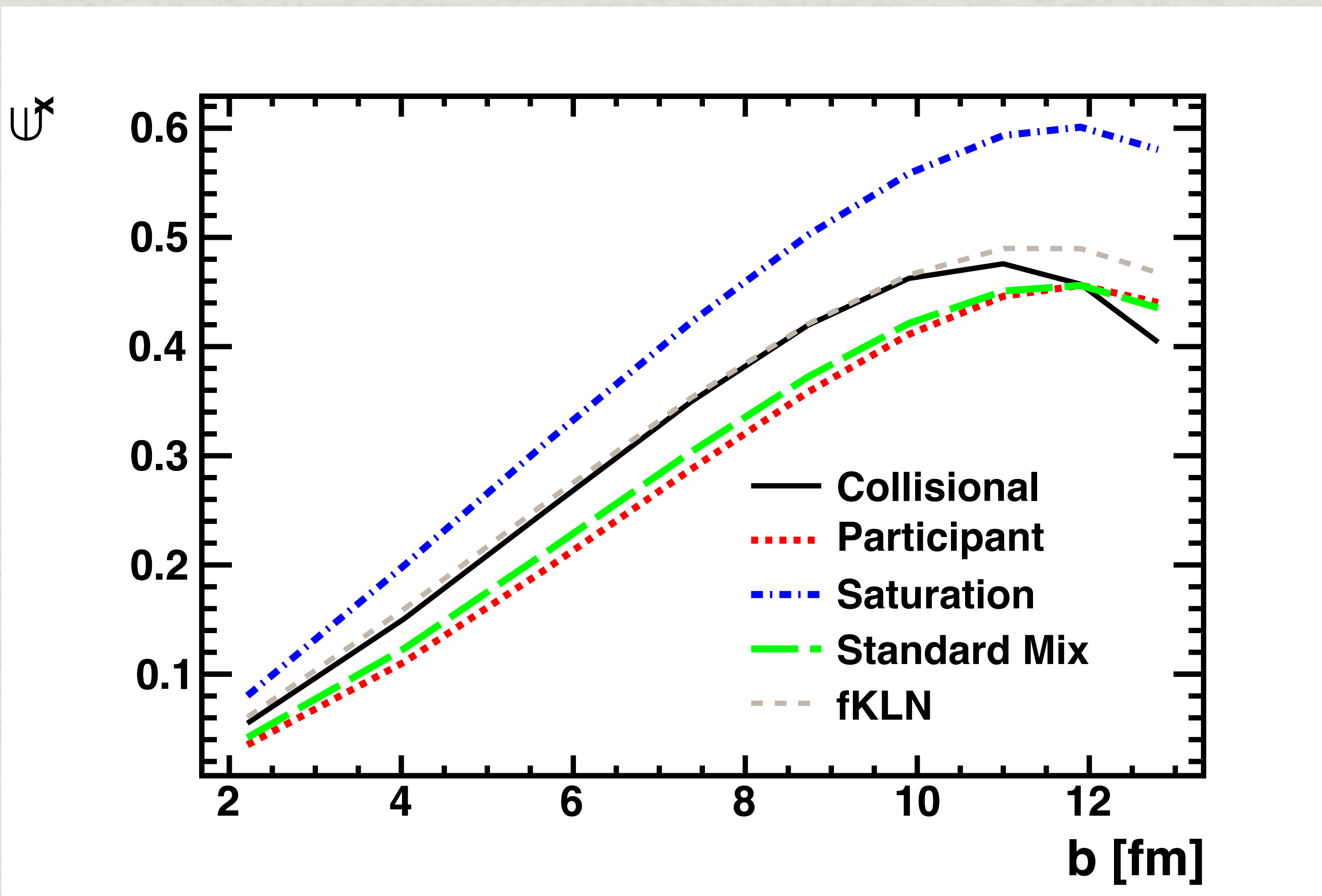




Luzum and Romatschke
arxiv:0804.4015v4

- Elliptic Flow scales very nicely with shear viscosity.
- System increasingly resist anisotropic expansion.

Source Shape



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- For smooth distributions.
- Significant uncertainty in shape.
- Leads to uncertainty in shear viscosity.

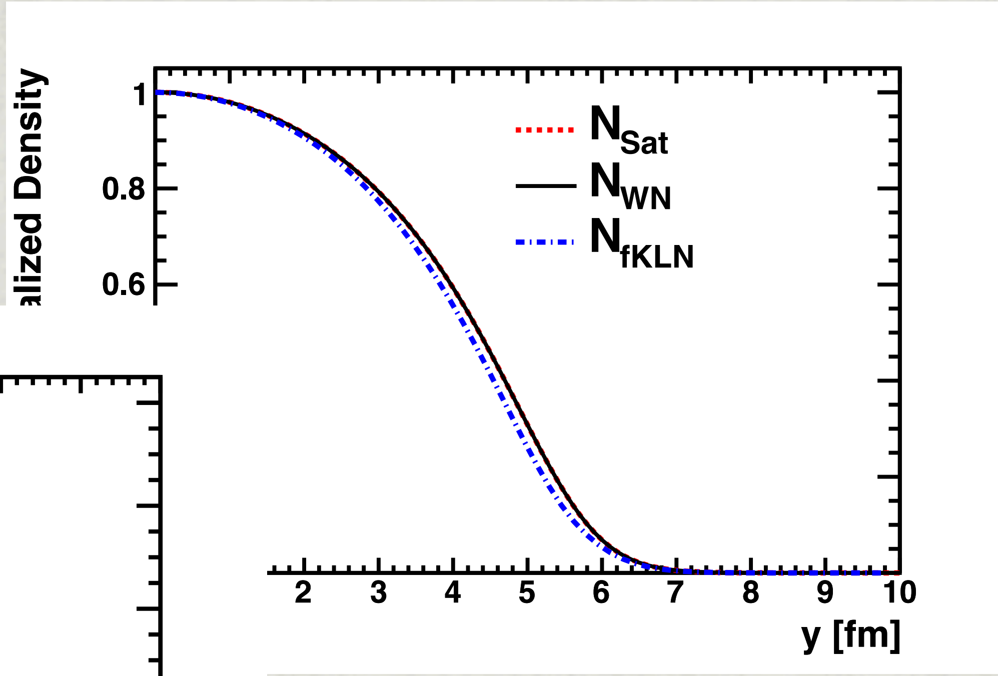
Ad Hoc Saturation

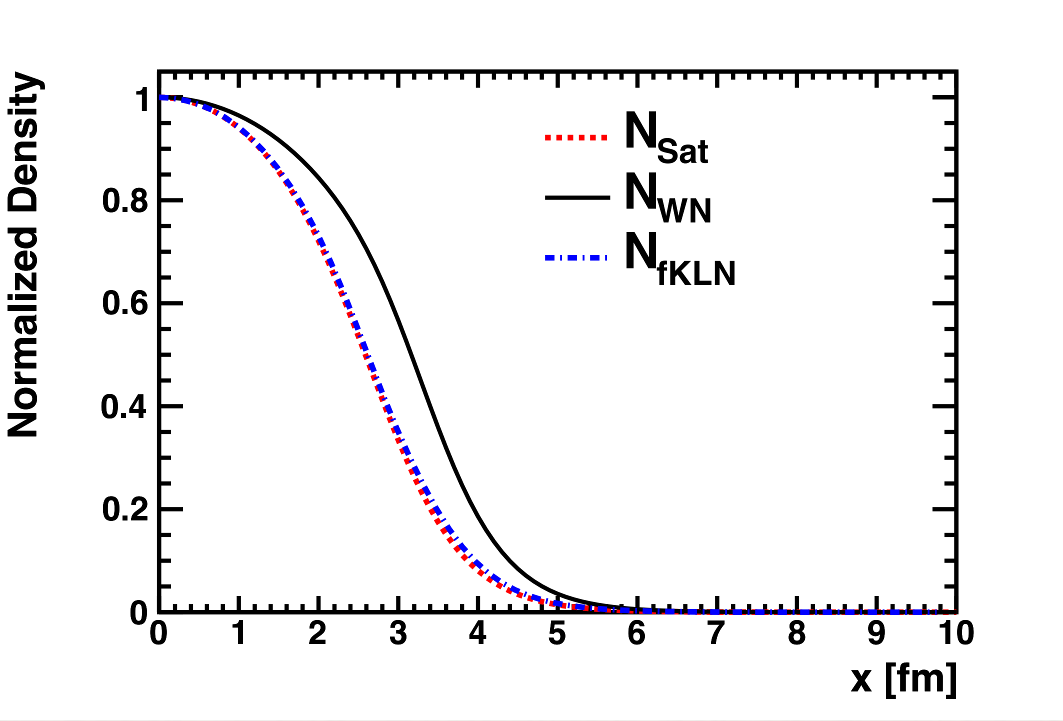
$$\bar{T} = (T_A + T_B)/2$$

$$T_R = 2T_A T_B/(T_A + T_B)$$

$$n_S = T_R \left(1 - \exp^{-\sigma \bar{T}}\right)$$

- Slight modification to wounded nucleon.
- Roughly same scaling.
- Much more eccentricity.





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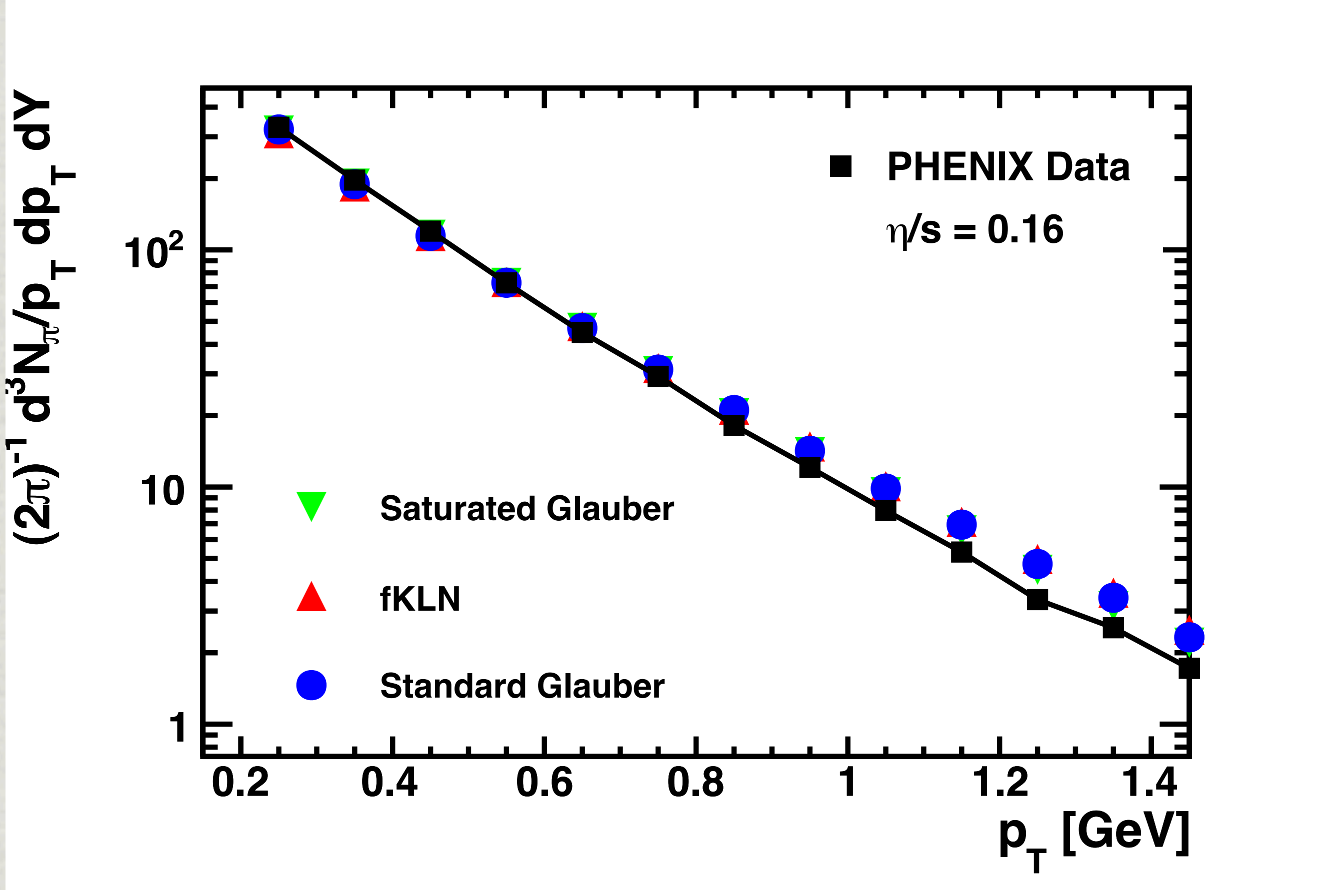
Model Description

* Longitudinally Invariant Viscous Hydrodynamics.
* No bulk viscosity or chemical potential.
* Coupled to Resonance Gas (T=155 MeV).
* Central Multiplicity fit to data.
* Initial Flow Parameter: $$\frac{T^{0x}}{T^{00}} \approx \frac{-\partial_x T^{xx}}{2T^{00}}\tau$$

Most Central Spectra



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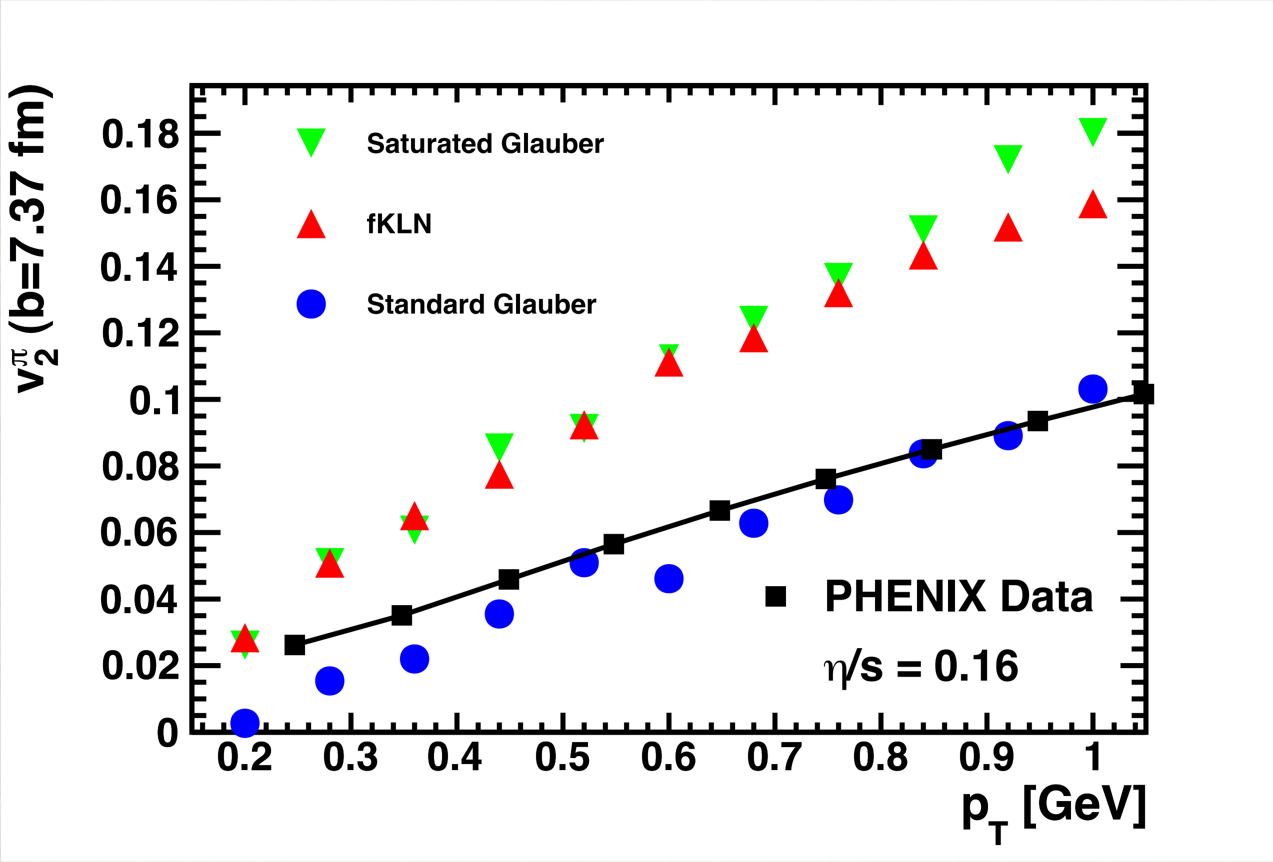
- Multiplicity tuned.
- Too much radial flow.
  - Start Time?
  - Initial Flow?
- Spectra seem insensitive to IC.

Mid-peripheral Elliptic Flow



- Move to 20-30% centrality (b=7.37 fm)
- Strong dependence on initial conditions.

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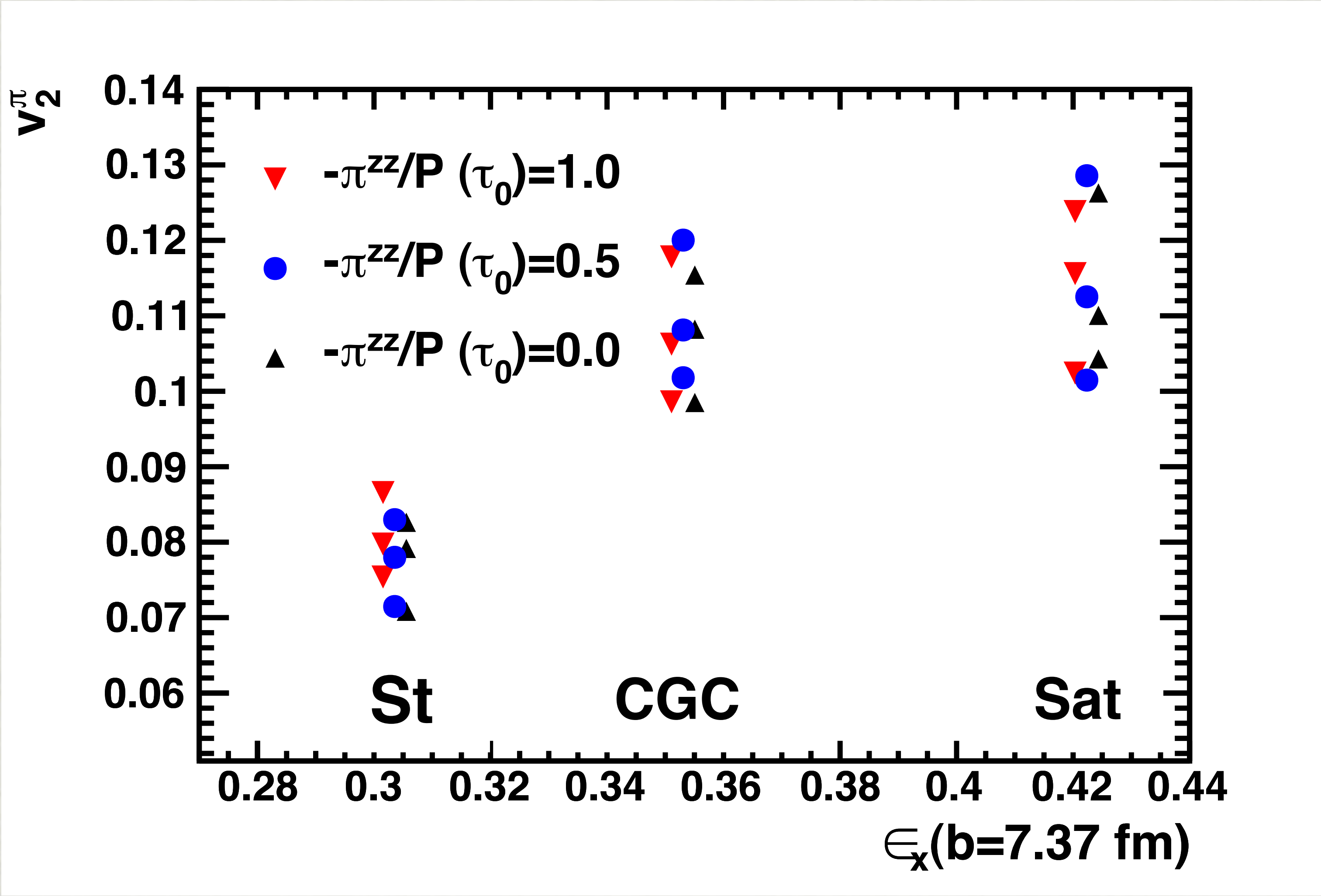
Shear Initialization

- Elliptic flow insensitive.
- Same for transverse shear.



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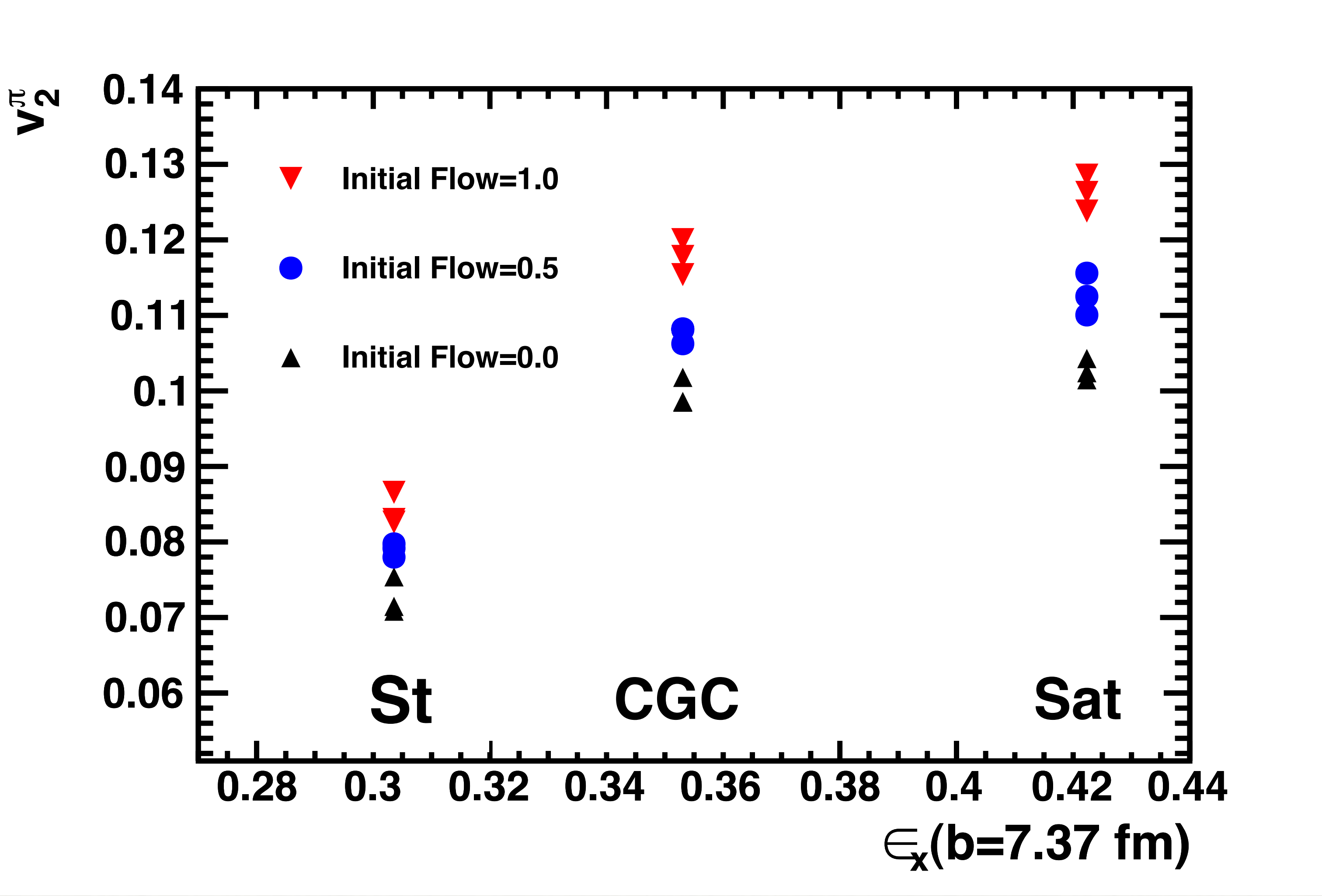
Flow Initialization



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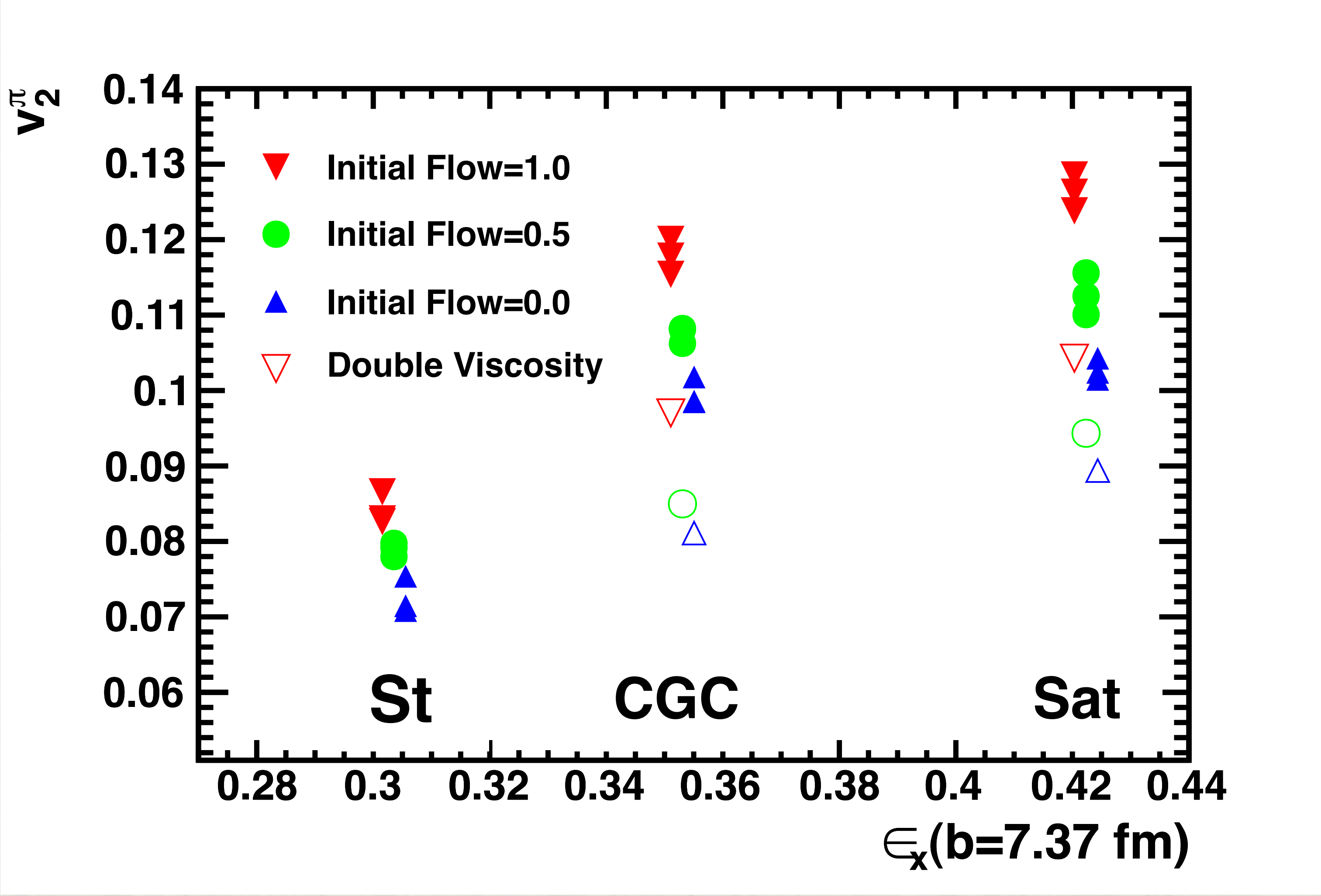
- But initial flow matters a lot.
- Radial flow also affected.
- More uncertainty.

Double Viscosity?

- Change only normalization and shear viscosity.
- Result changes by factor of two.



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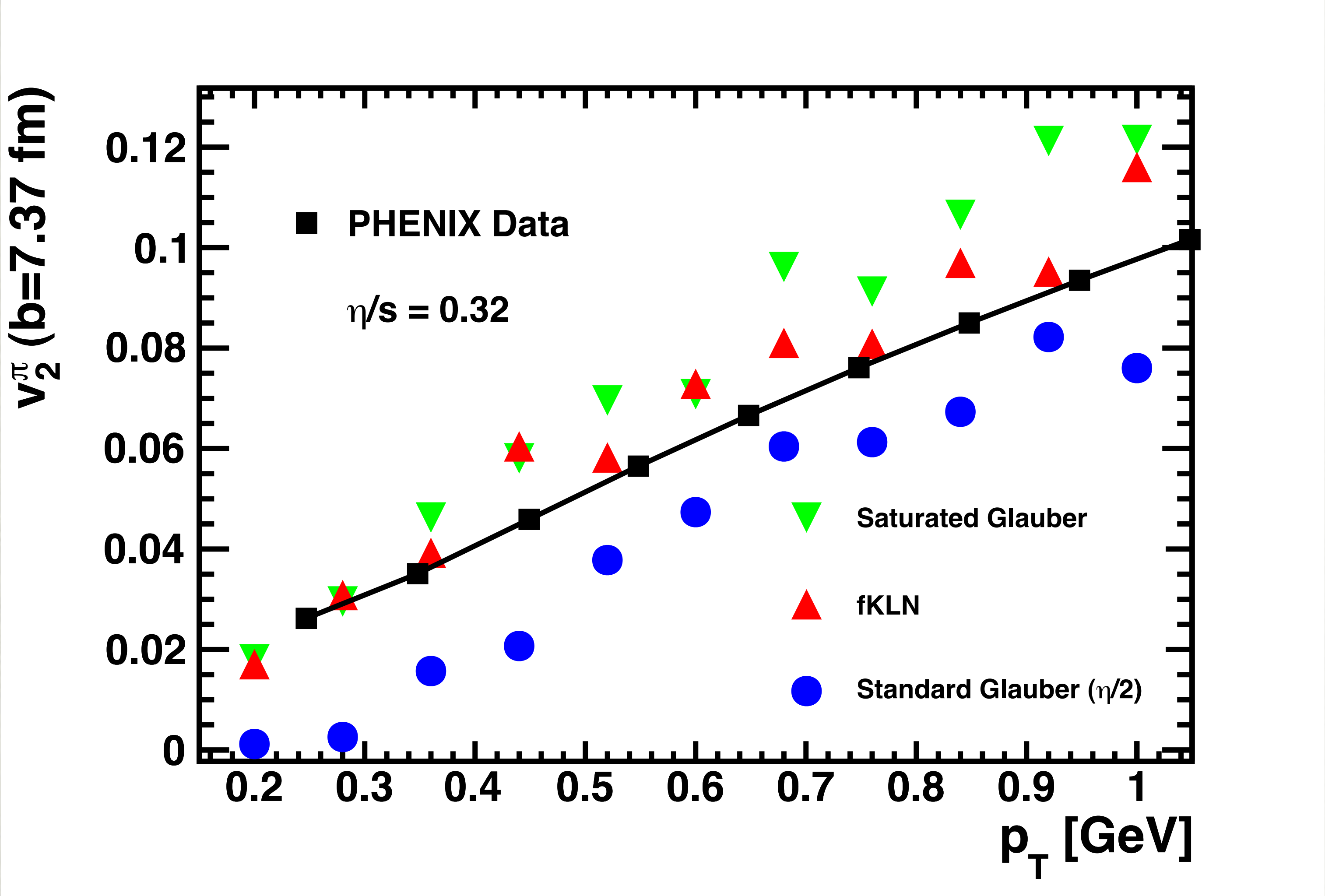
Doubled Viscosity



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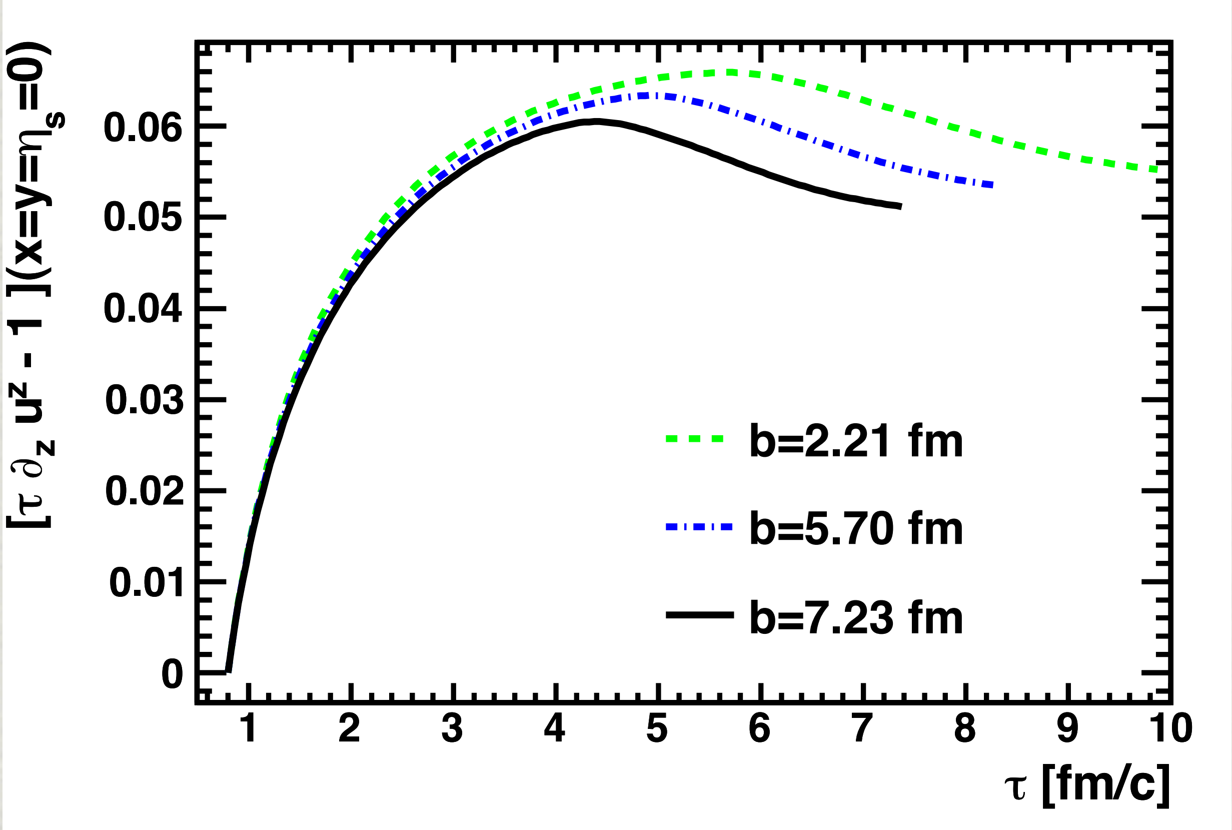
- Without initial flow.
- Somewhat overpredicts elliptic flow.
- Even larger shear?

(3+1) Viscous Hydro

- Fully functional for smooth conditions.
- Surface finding in testing.
- Longitudinal initial conditions are Gaussian.

Near Zero Rapidity



- Longitudinal velocity gradient at origin.
- Bjorken Subtracted.
- Shows perhaps 5% effect of longitudinal extent.

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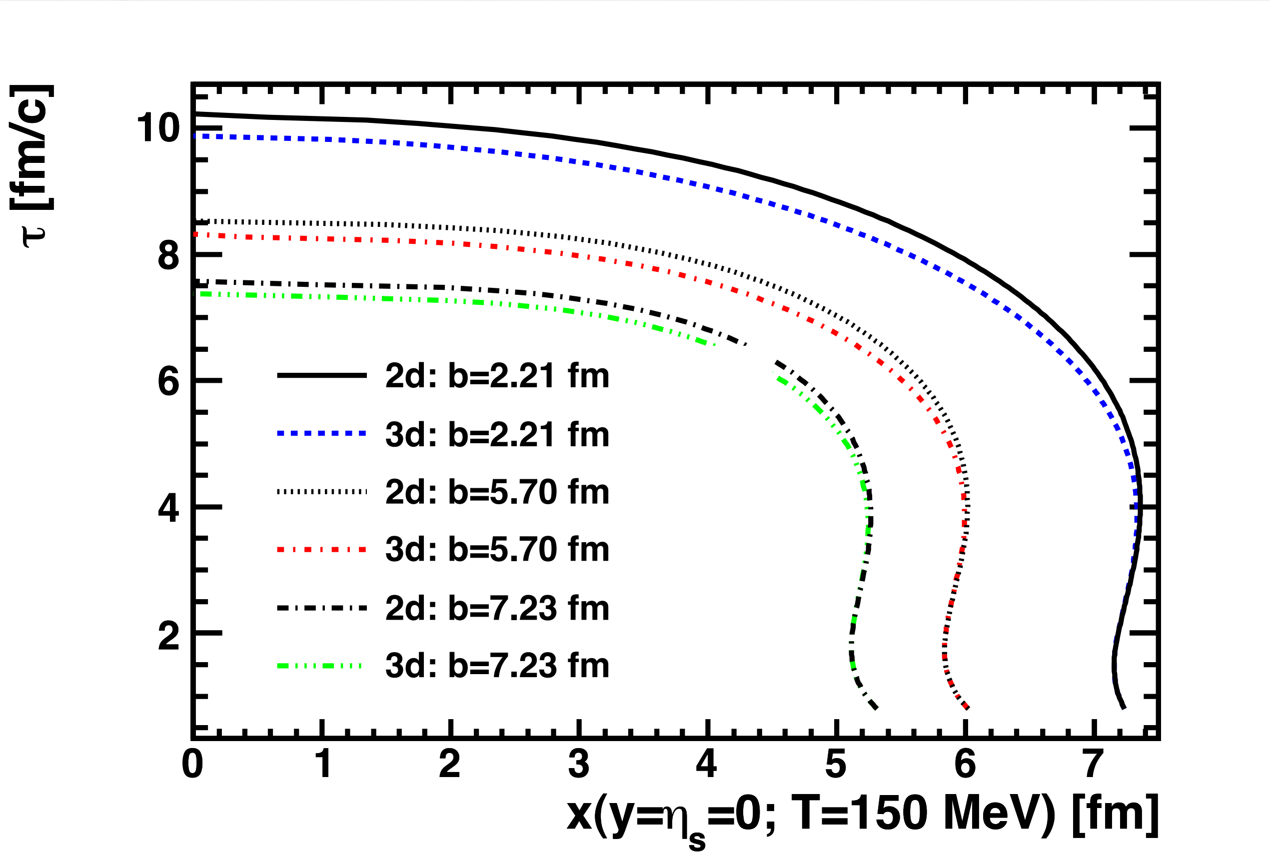
Cooling

- Longitudinal gradient speed cooling.
- Structure of surface changes very little.



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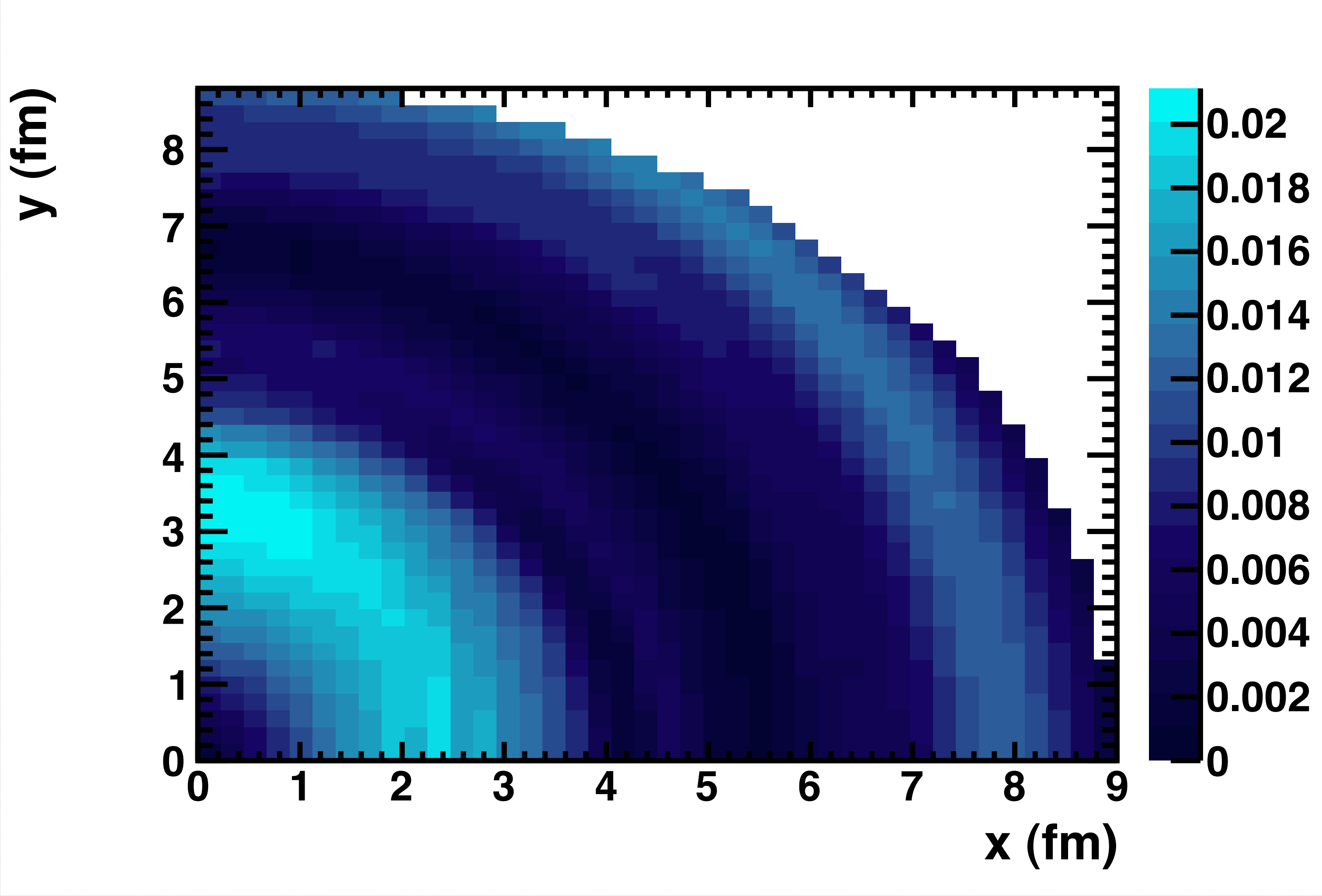
Transverse Velocity

$$\sqrt{\delta u_x^2 + \delta u_y^2},\ \eta = \{0.0, 0.8\}$$

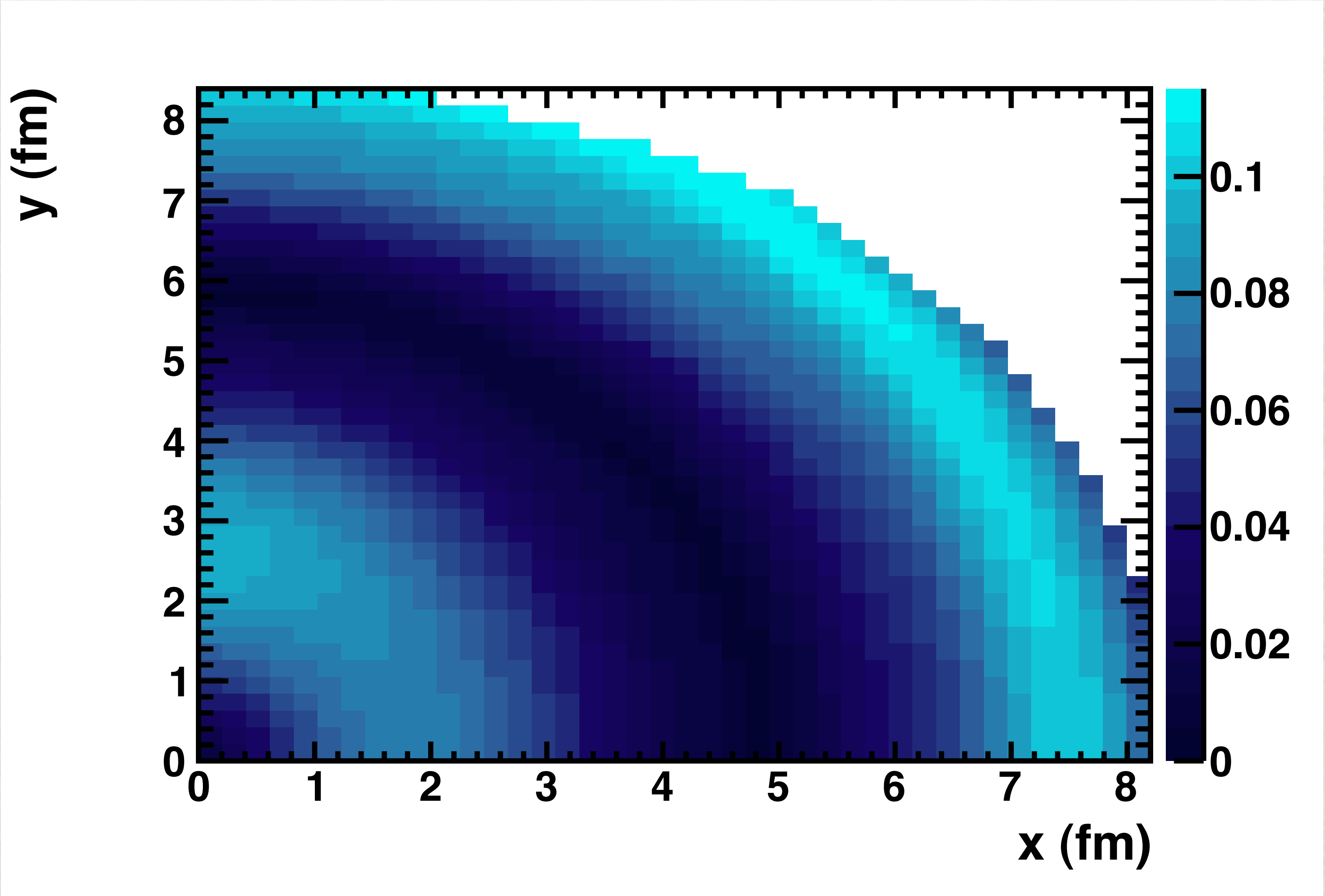
- Transverse velocity difference.
- Modest Effect.
- Likely somewhat smaller flow.
- Consistent with experimental data?



Transverse Velocity

$$\sqrt{\delta u_x^2 + \delta u_y^2},\ \eta = \{0.0, 2.4\}$$

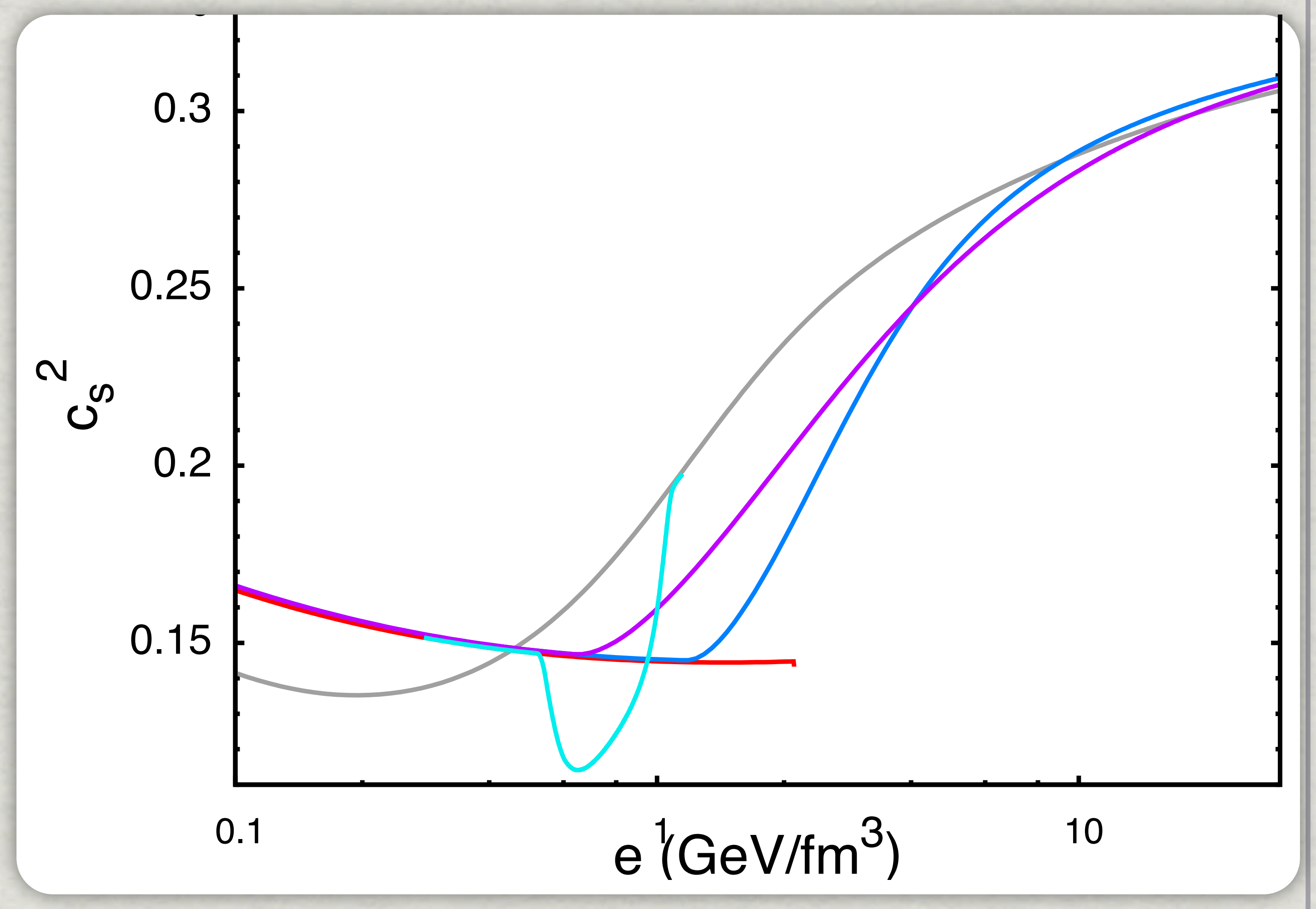
- At larger rapidity.
- Significant differences.
- Much less flow.



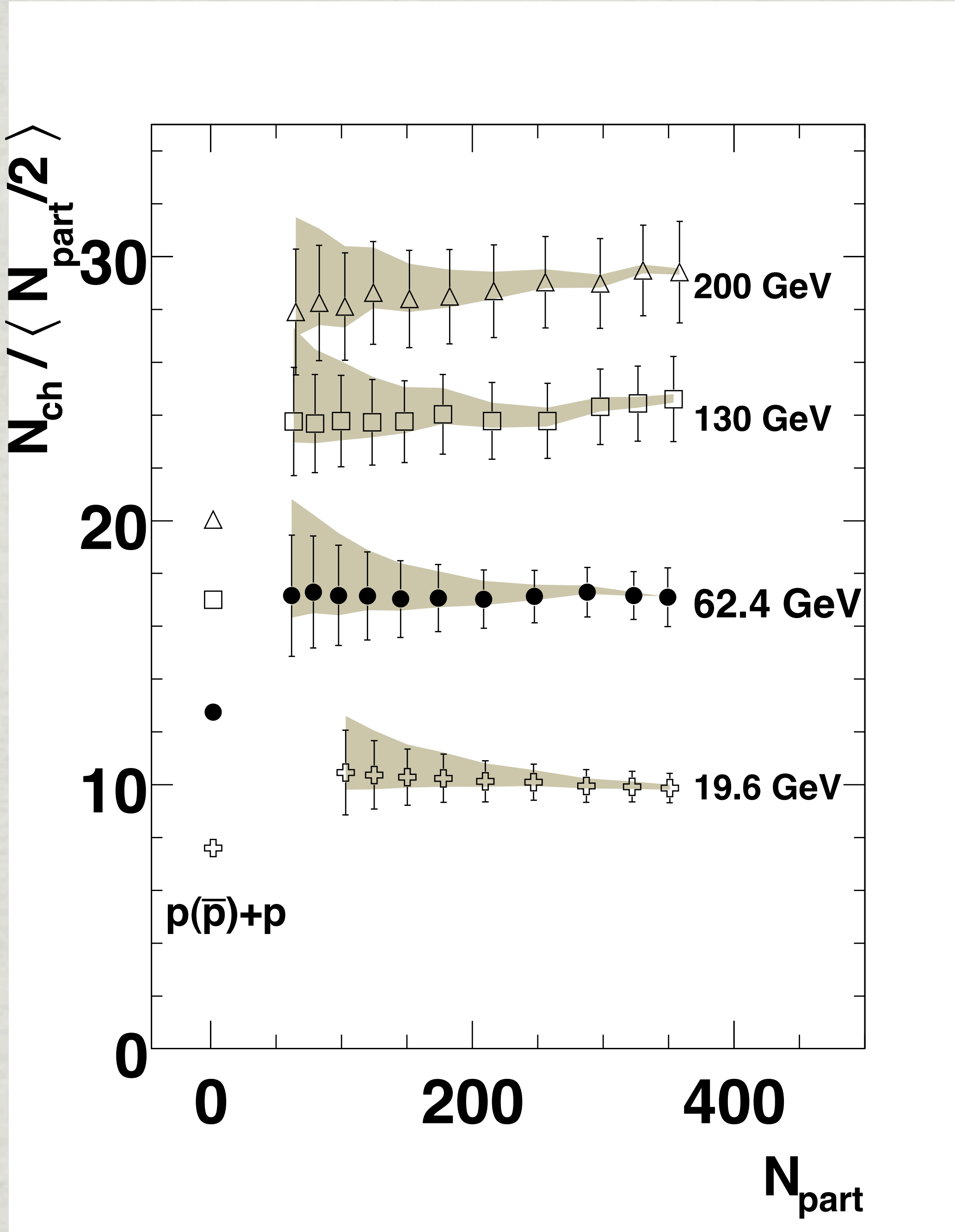
Concluding Remarks

- Estimate of shear viscosity depends on initial shape and velocity.
  - No initial velocity gives minimum result.
- Longitudinal effects likely small at midrapidity.
- Longitudinal shape of elliptic flow likely an interesting constraint.

EOS Merging

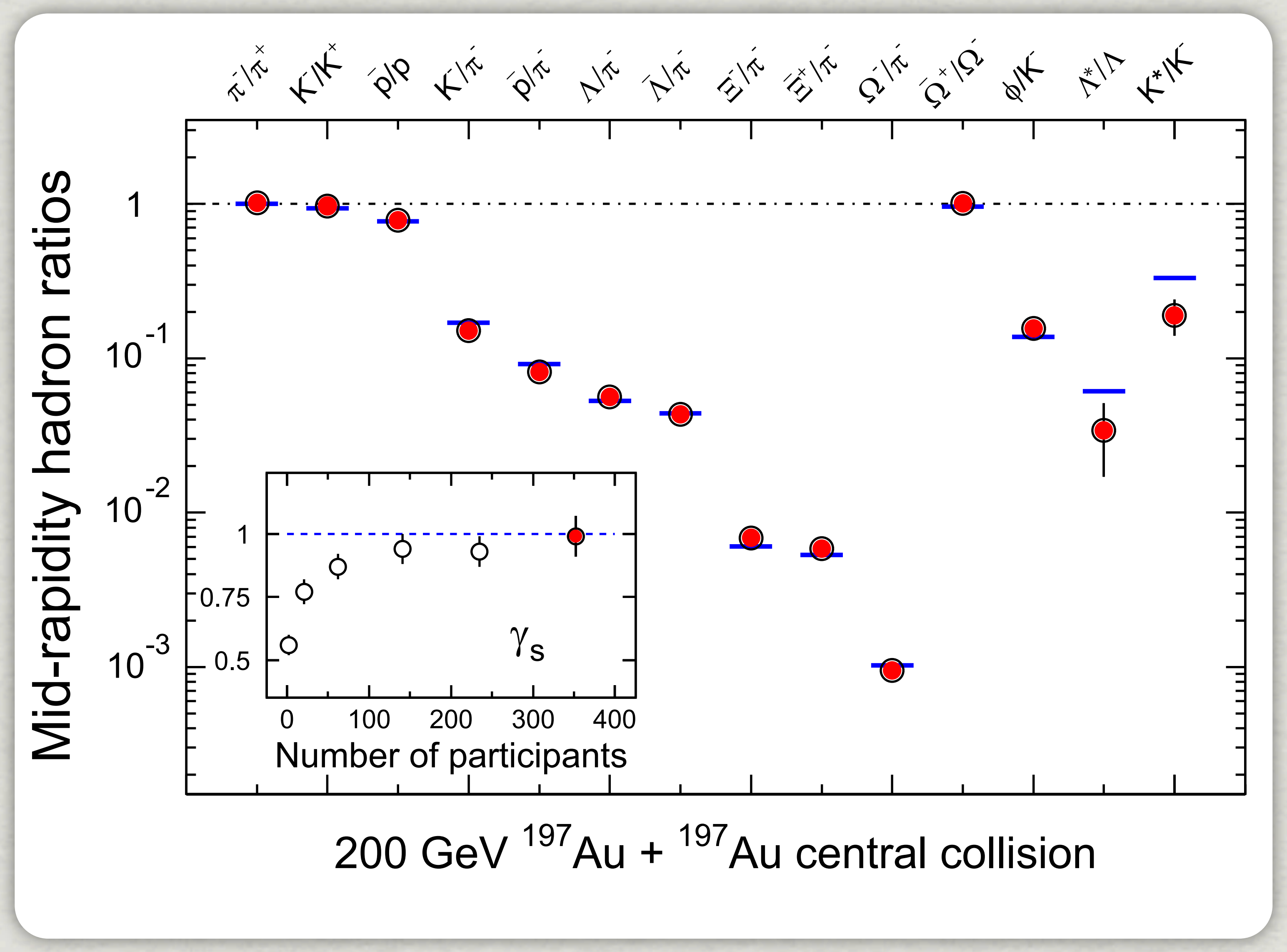


Multiplicity Scaling



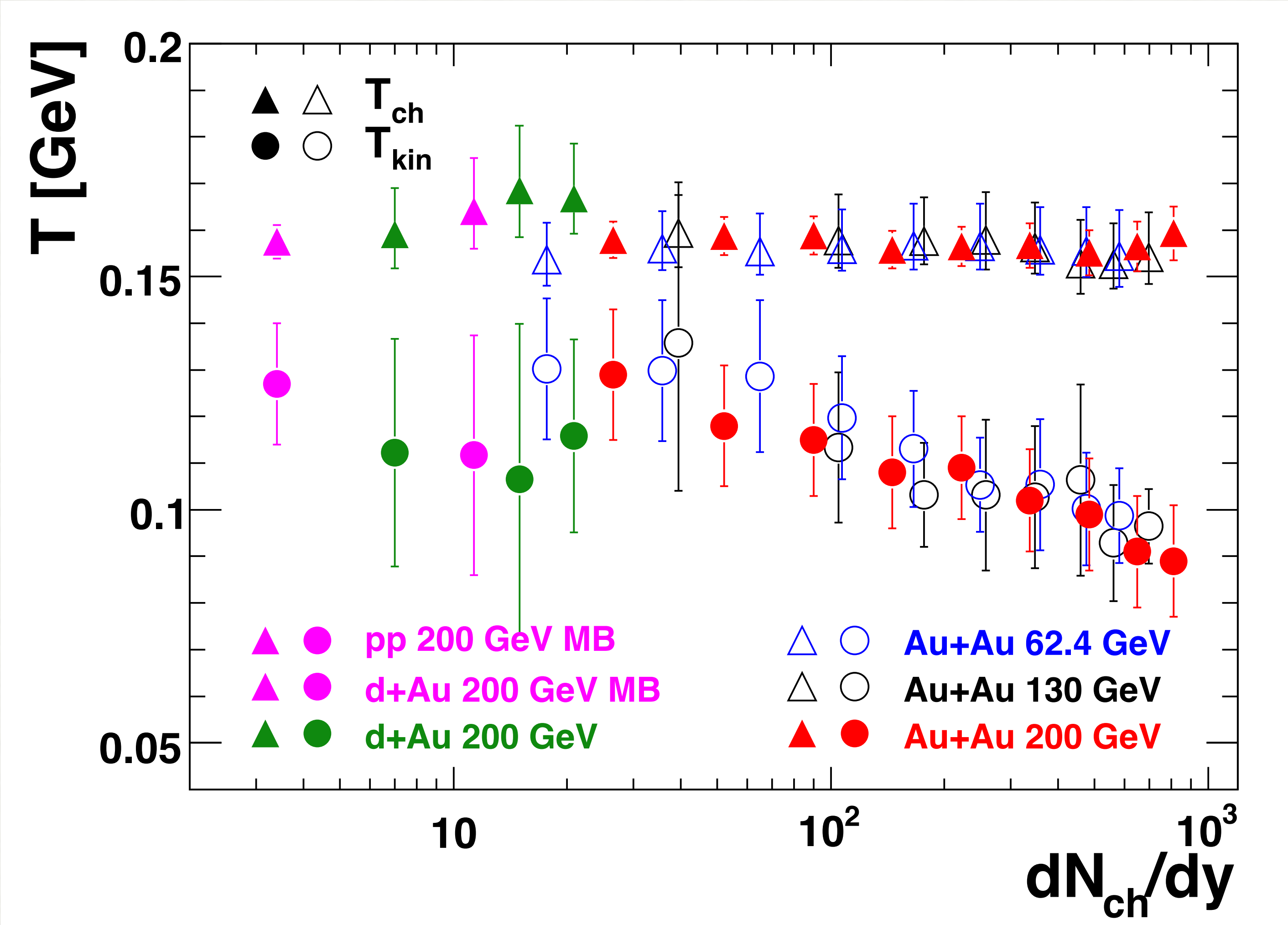
STAR Collaboration. arxiv:nucl-ex/0808.2041v2

Chemical Temperature



Braun-Munzinger et al., PLB 518 (2001) 41.

Two Temperatures



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