Flow, spectra and HBT radii in Heavy-Ion Collisions

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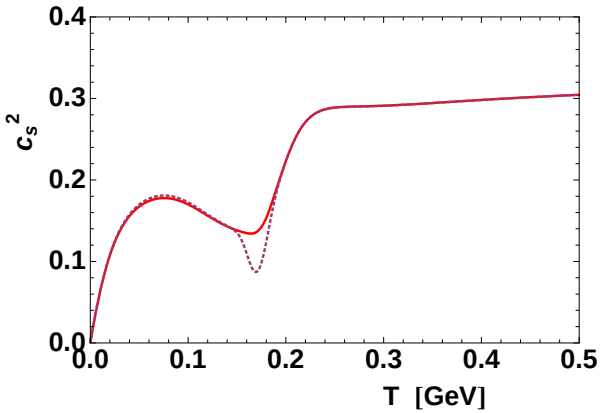
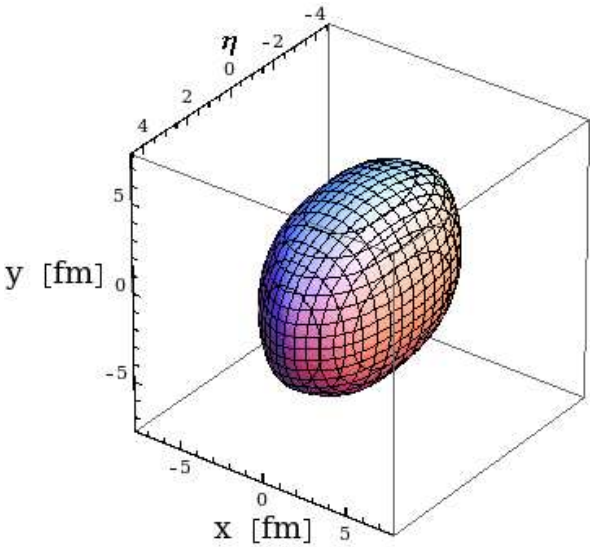
P.B. , Iwona Wyskiel, Phys. Rev. C 79, 044916 (2009)

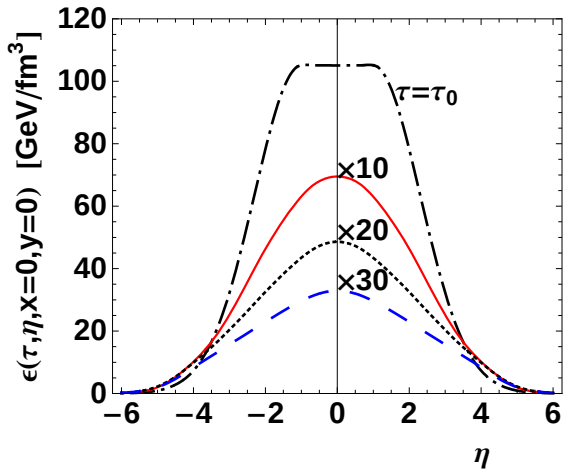
3+1D hydrodynamic model

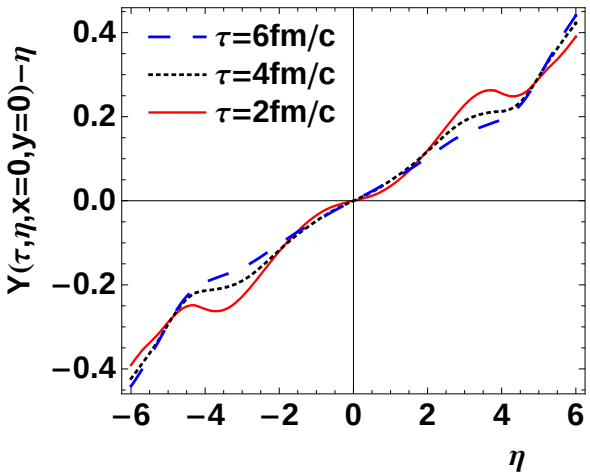
- expansion of dense matter
- ideal hydro: $\epsilon(x_\mu)$, $p(x_\mu)$, $\vec{v}(x_\mu)$.
- hard EOS
- flow + thermal emission + decays
- THERMINATOR Monte-Carlo code





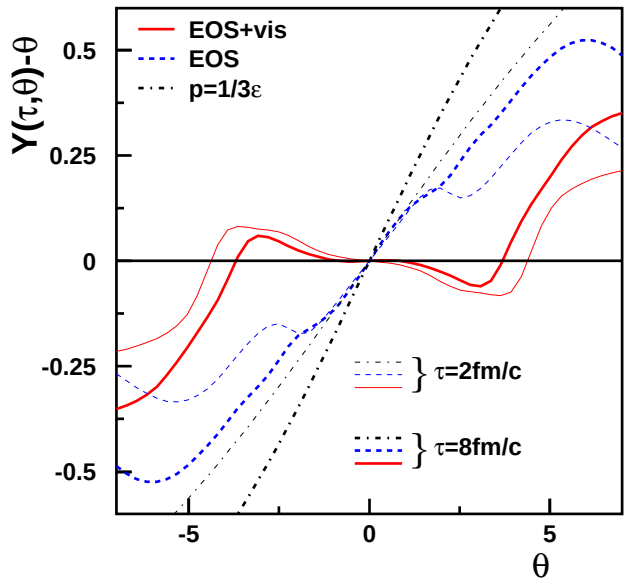
Evolution



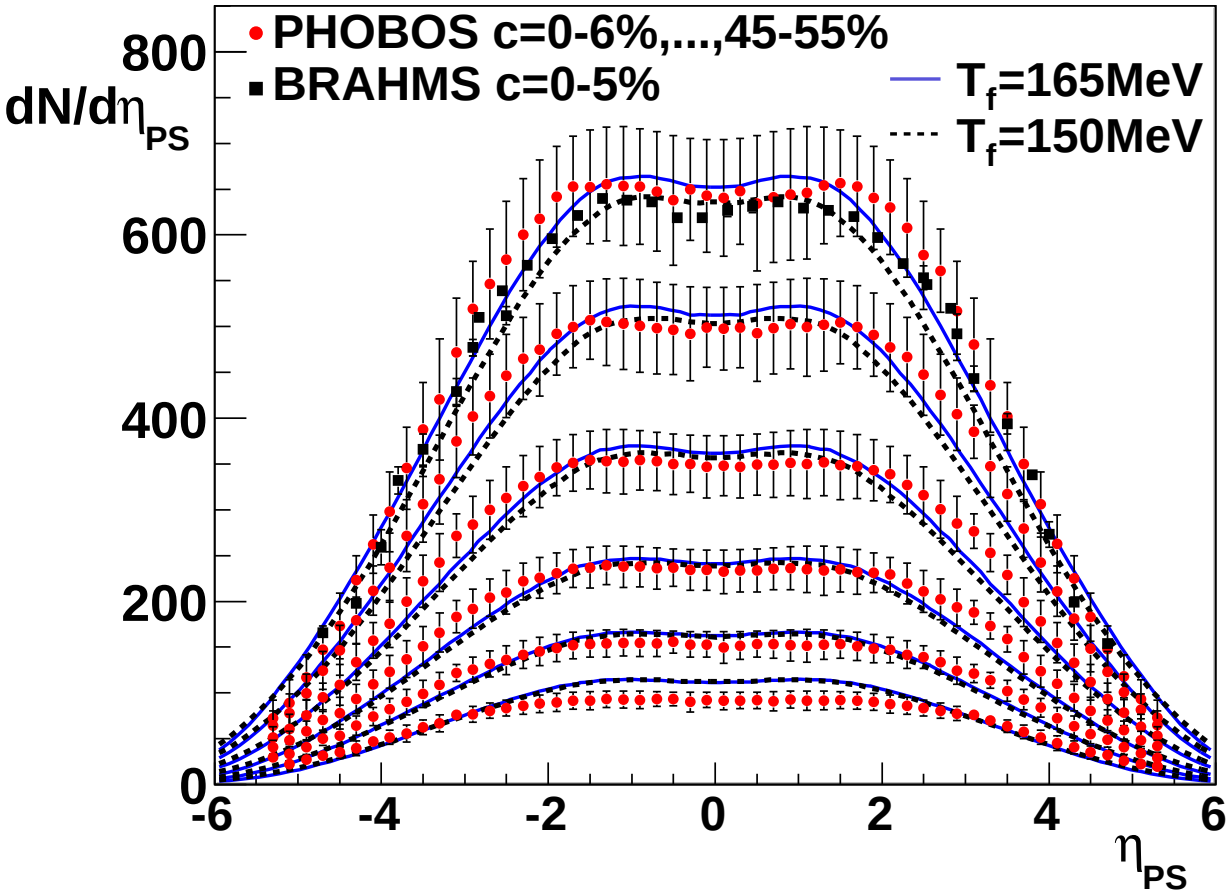


- Bjorken plateau destroyed
- Flow stronger than Bjorken
- Fast cooling

But viscosity!



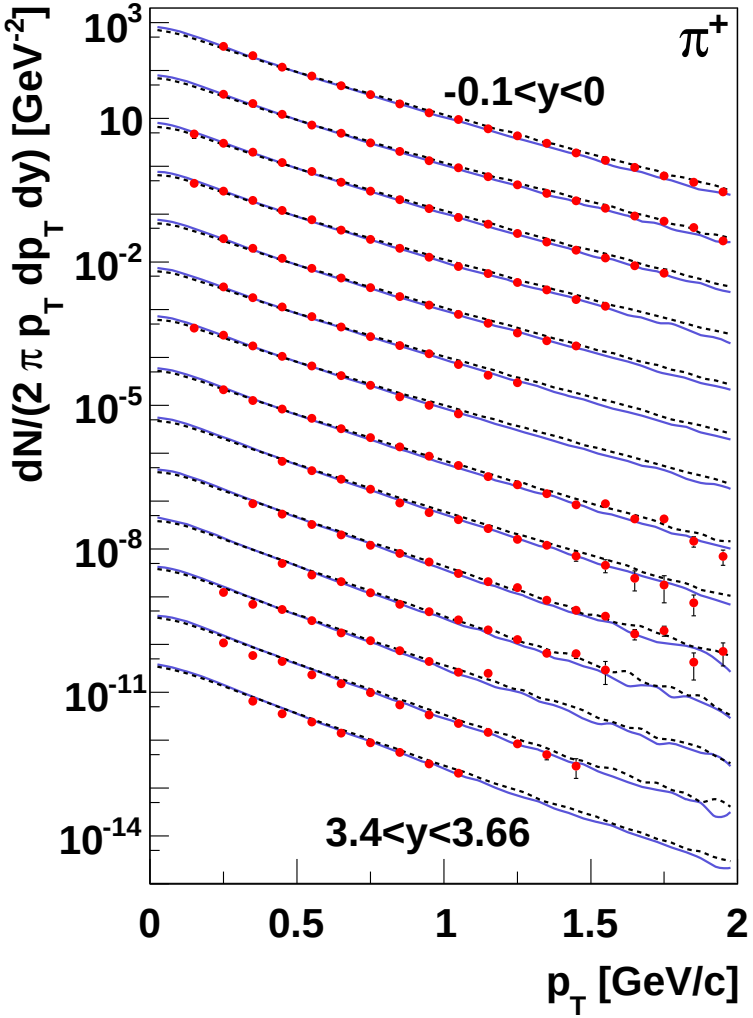
P.B. Phys.Rev. C77 ,034911 (2008)



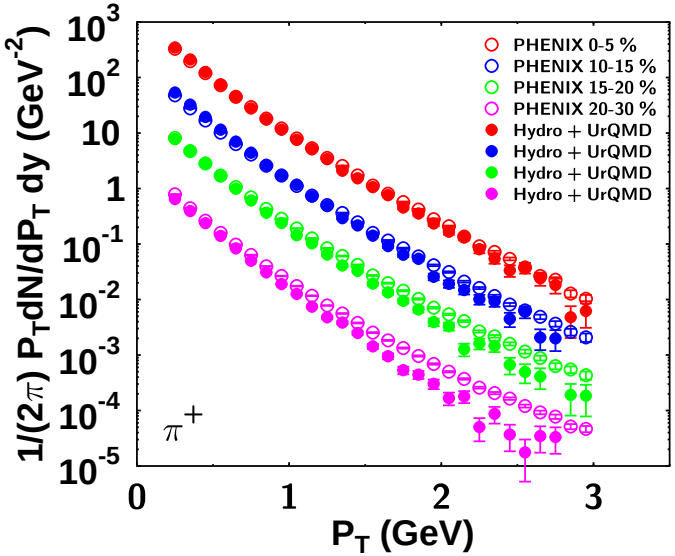
works for centralities $0 - 40\%$

Spectra $y \neq 0$

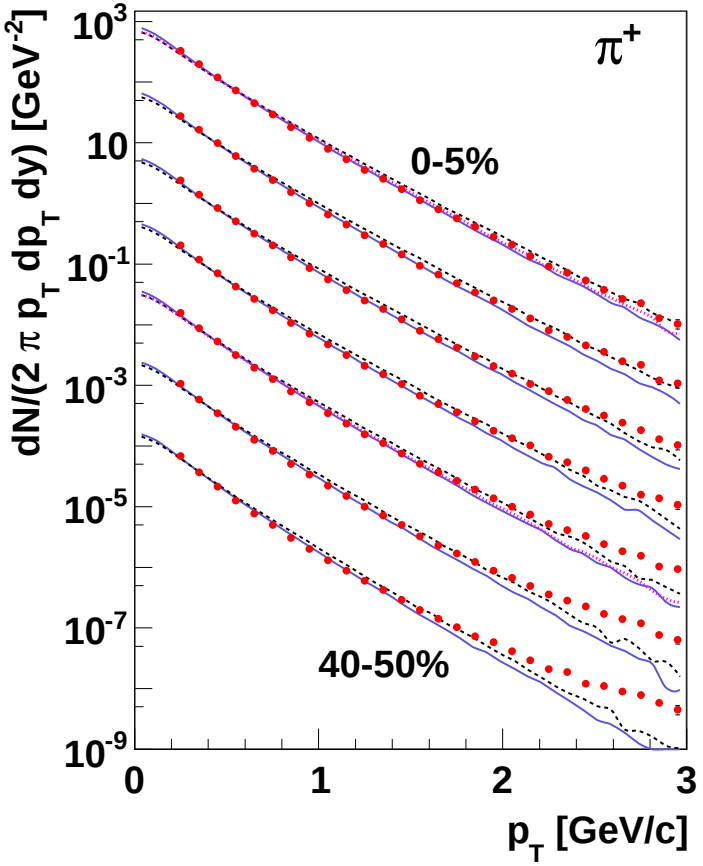
- excellent agreement
- thermal fireball
- no boost-invariance



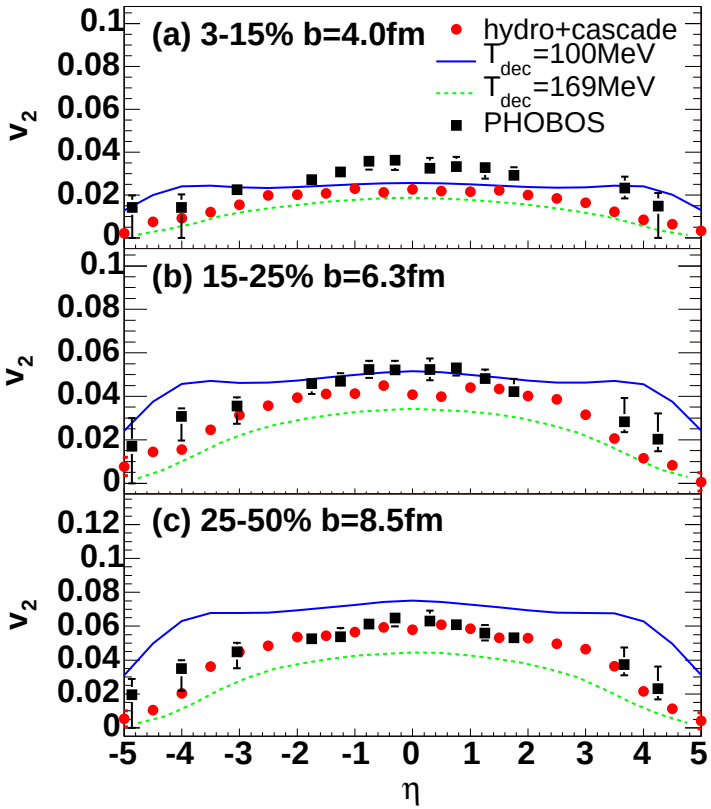
Spectra $b \neq 0$

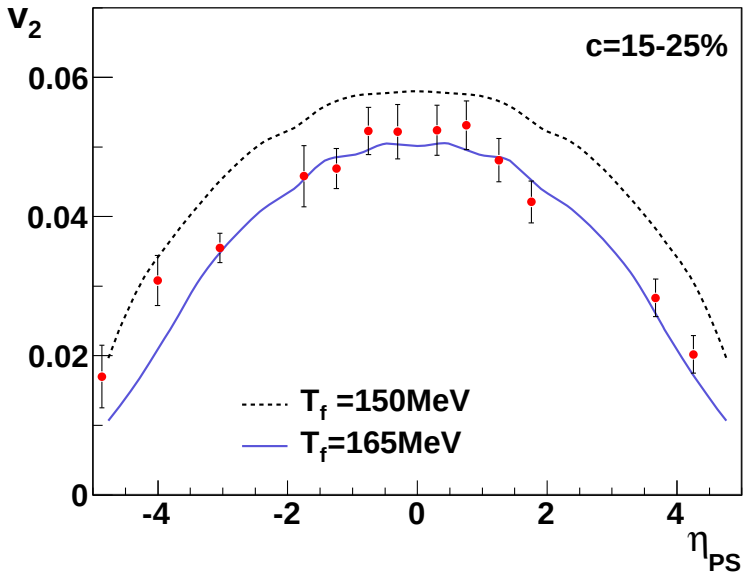


Bass, Nonaka (2007)



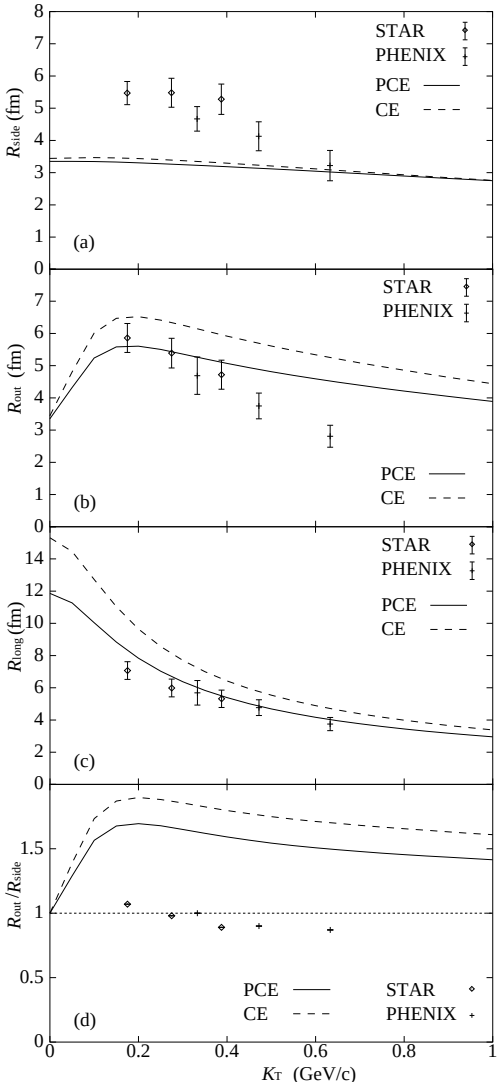
Elliptic flow



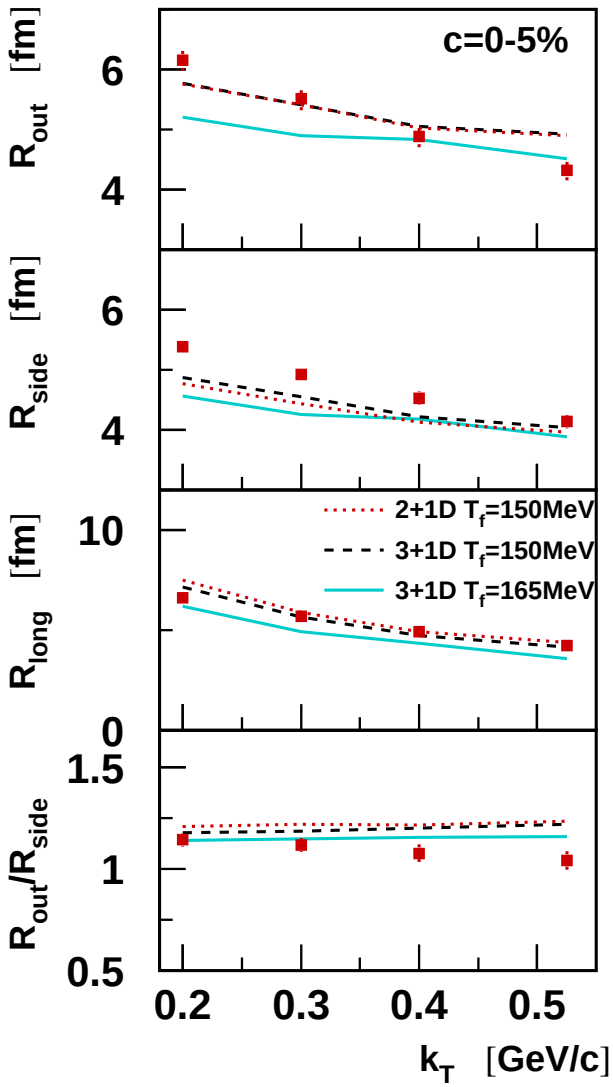


Hirano, Heinz, Karzeev. Lacey, Nara (2006)

HBT radii



Hirano, Tsuda



Agreement within 10%

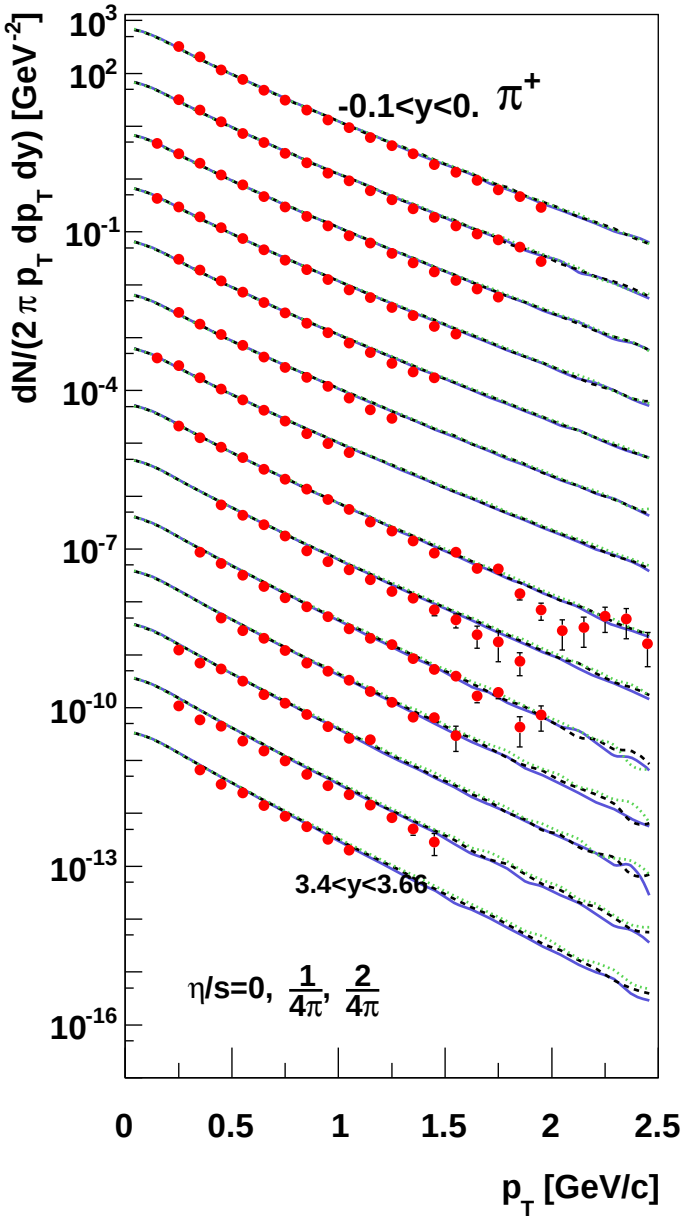
Estimate of viscous effects

important for some observables: Teaney, Heinz, Romatschke, ...

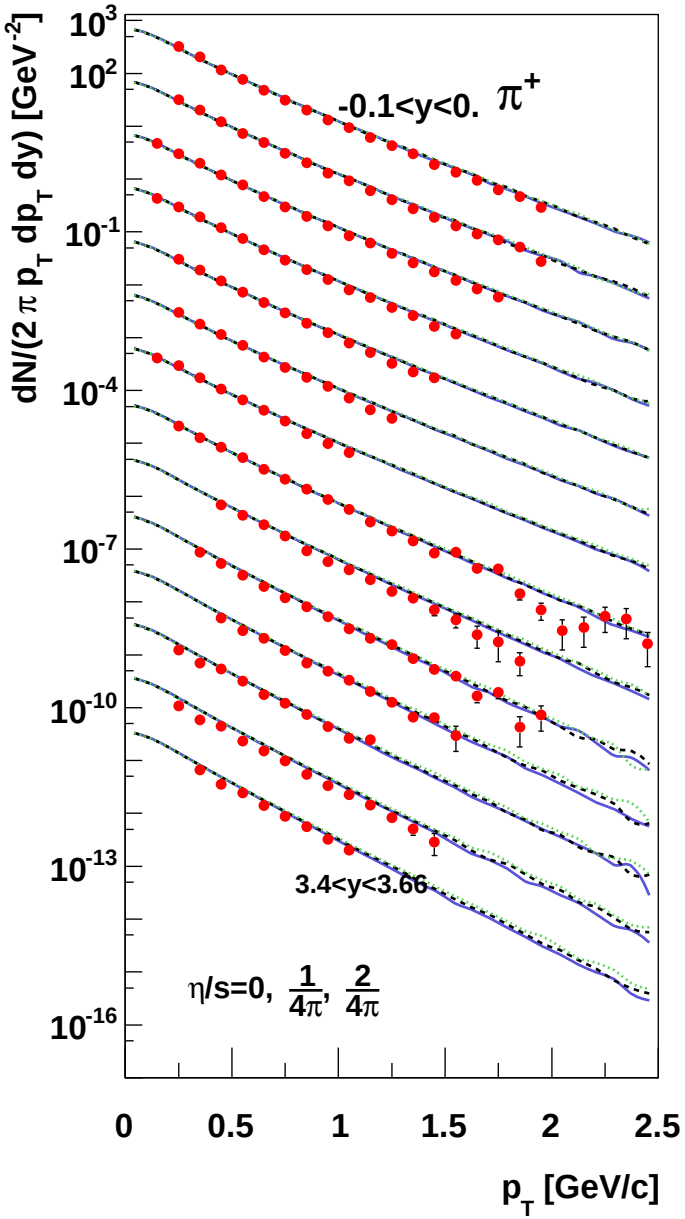
- dissipative effects at freezeout
- relaxation time $\tau = 0.8\text{fm/c} \leftrightarrow \eta/s = \frac{1}{4\pi}$
- $f = f_0 + \delta f$

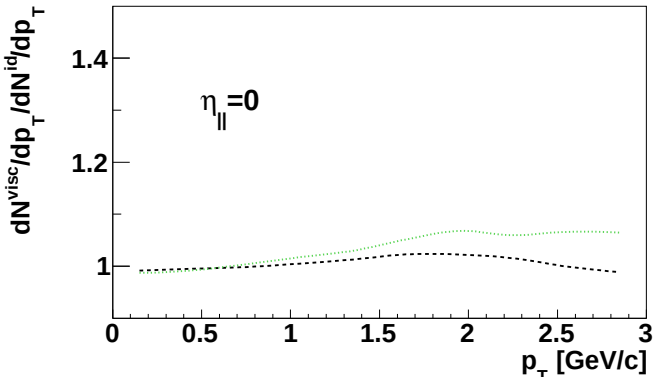
$$\begin{aligned} \delta f &\propto \eta \left(\nabla_\mu u_\nu + \nabla_\nu u_\mu - \frac{2}{3} \Delta_{\mu\nu} \nabla_\alpha u^\alpha \right) p^\mu p^\nu \\ &\propto \eta \, \sigma_{\mu\nu} p^\mu p^\nu \end{aligned}$$

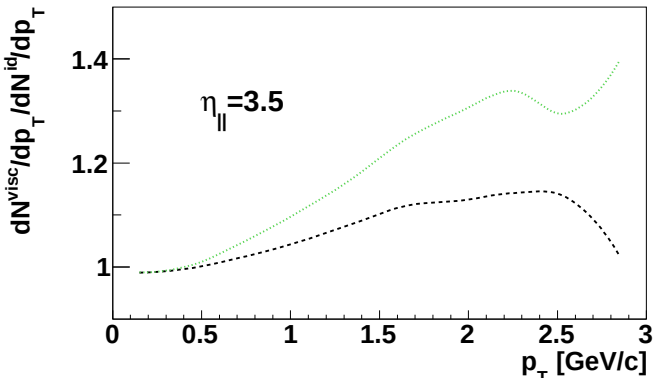
Small effect on spectra



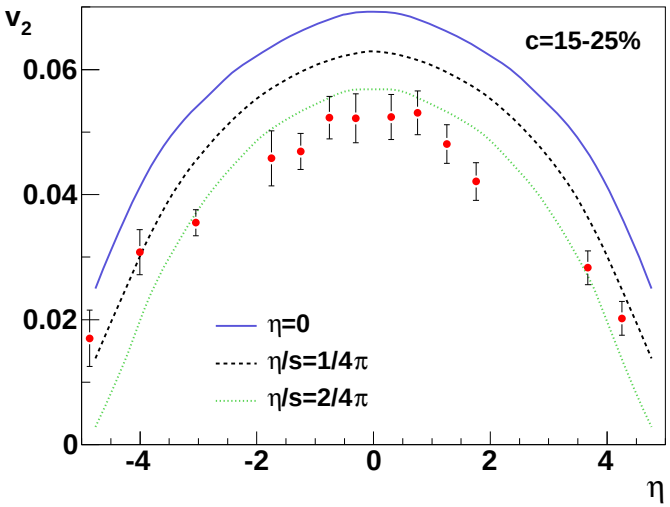
Small effect on spectra

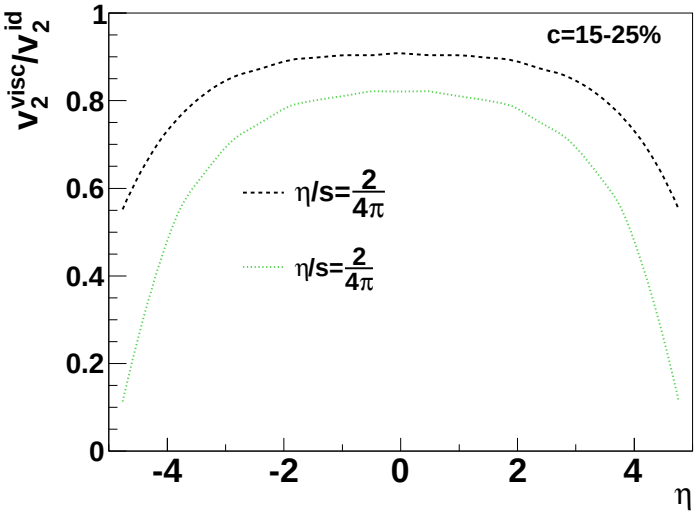






Large effect on elliptic flow

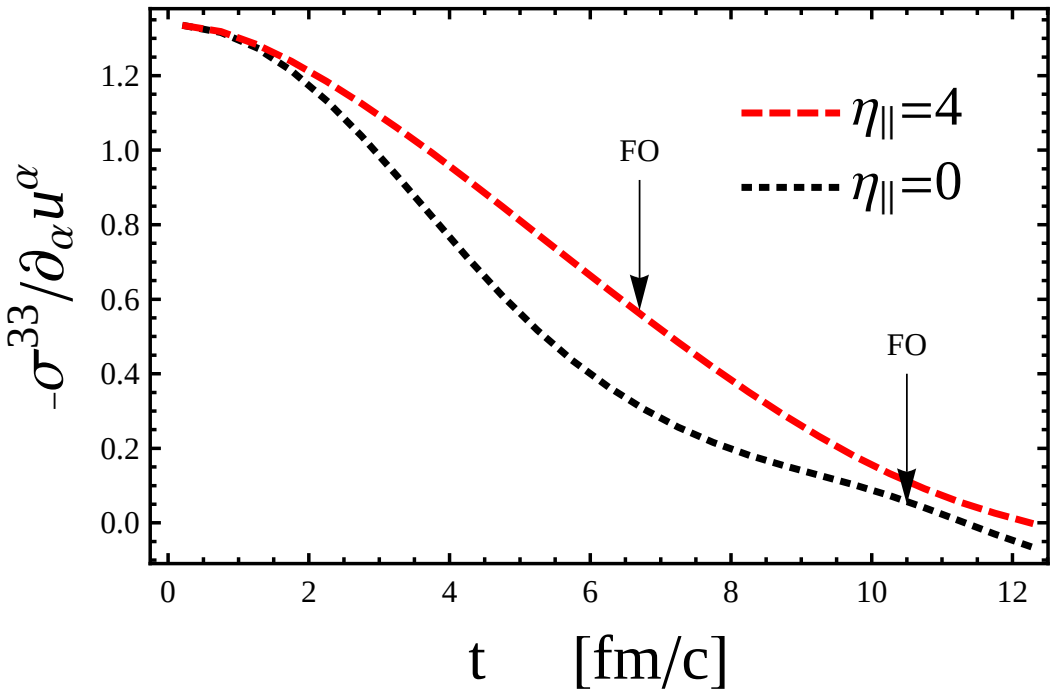




- Reduction of v_2
- Important at large η

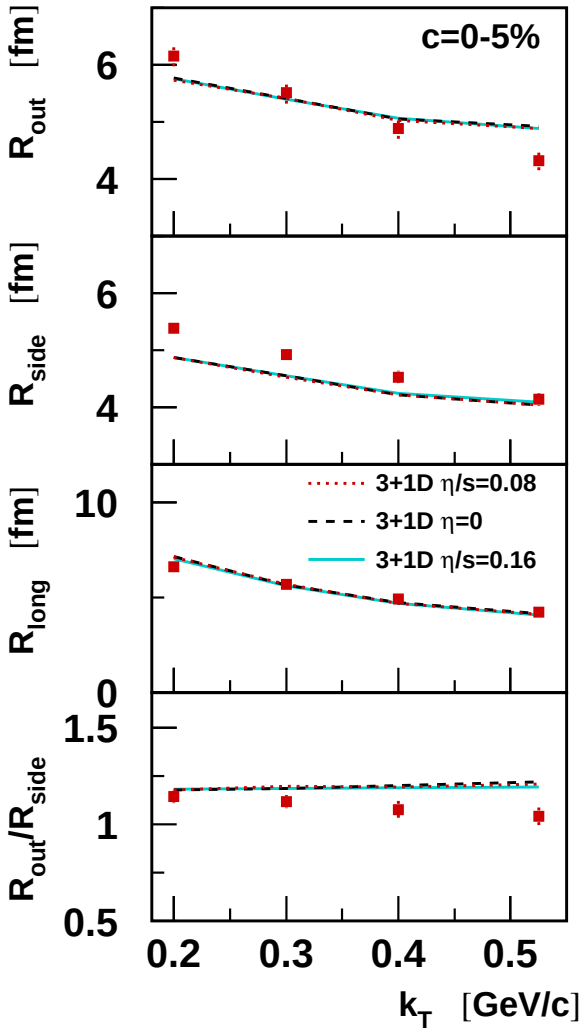
Rapidity dependence of shear viscosity effects

$$\frac{\nabla_\mu u_\nu + \nabla_\nu u_\mu - \frac{2}{3}\Delta_{\mu\nu}\nabla_\alpha u^\alpha}{\partial_\alpha u^\alpha} = \frac{shear}{bulk}$$



Shear viscosity dominates at large η

No effect of viscosity on HBT



Conclusions

- Thermal fireball
- Hydro excellent at $p_\perp < 2\text{GeV/c}$, $|\eta| < 4$
- HBT radii reproduced !!
- Shear viscosity effects important for v_2