RHIC Experiments observe QGP viscosity and hadronic dissipation

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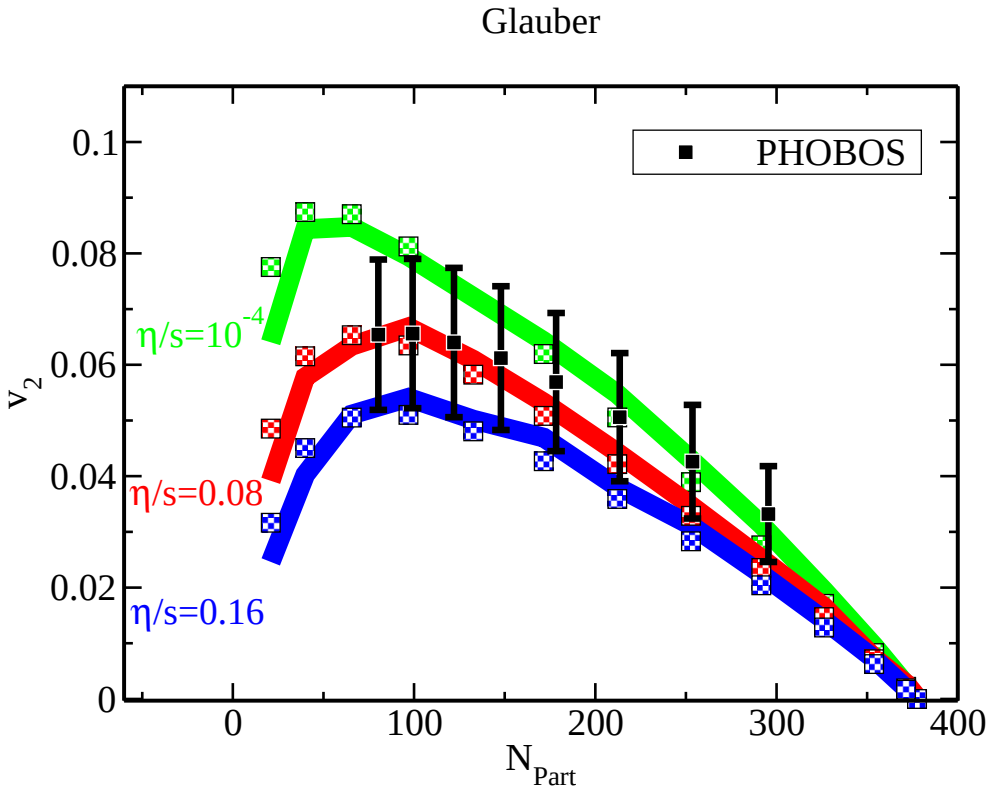
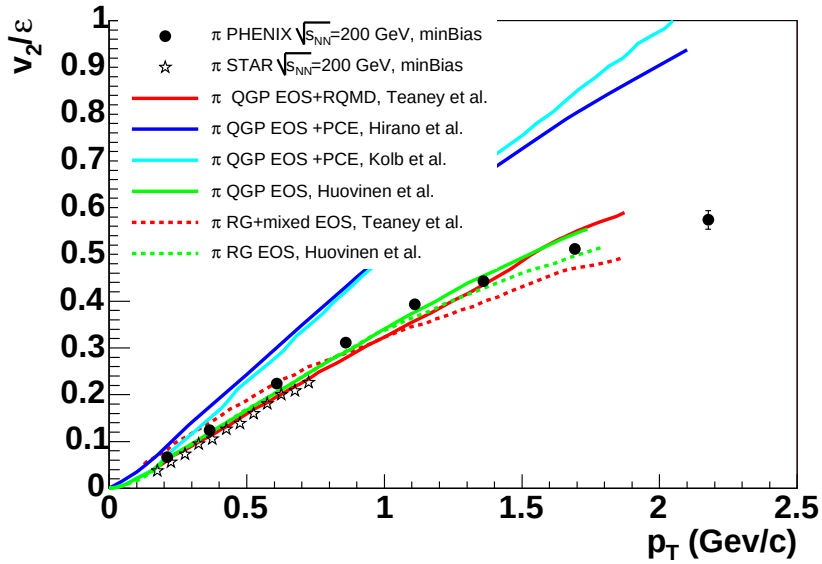
QGP viscosity estimates

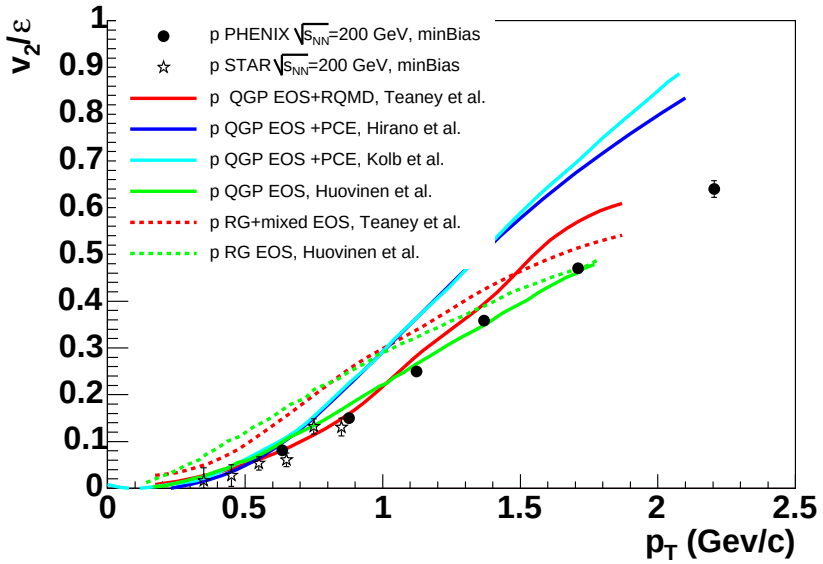
- shear viscosity reduces v_2
- initial eccentricity?
- hadronic effects?



Luzum, Romatschke (2008)

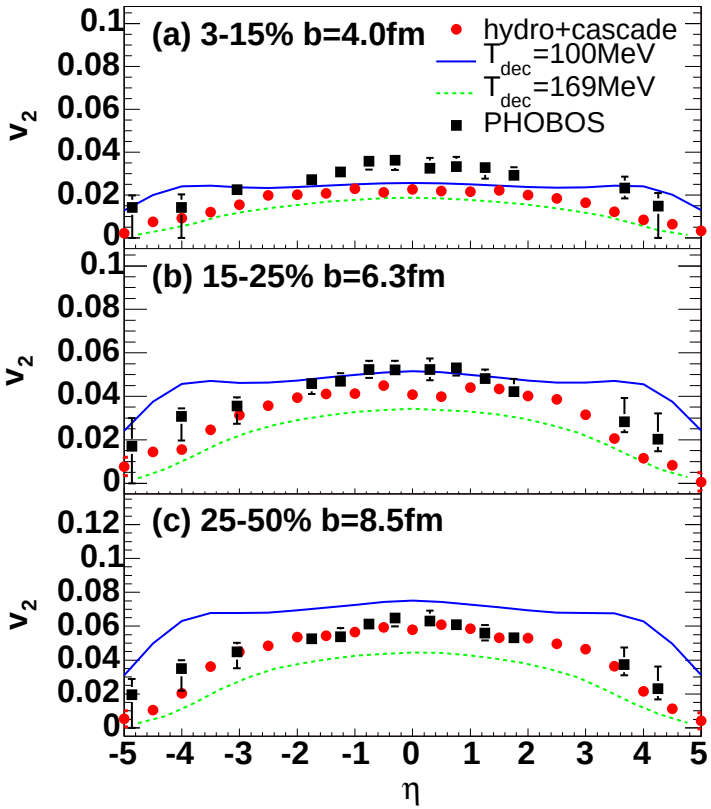
Identified particles v_2





PHENIX white paper

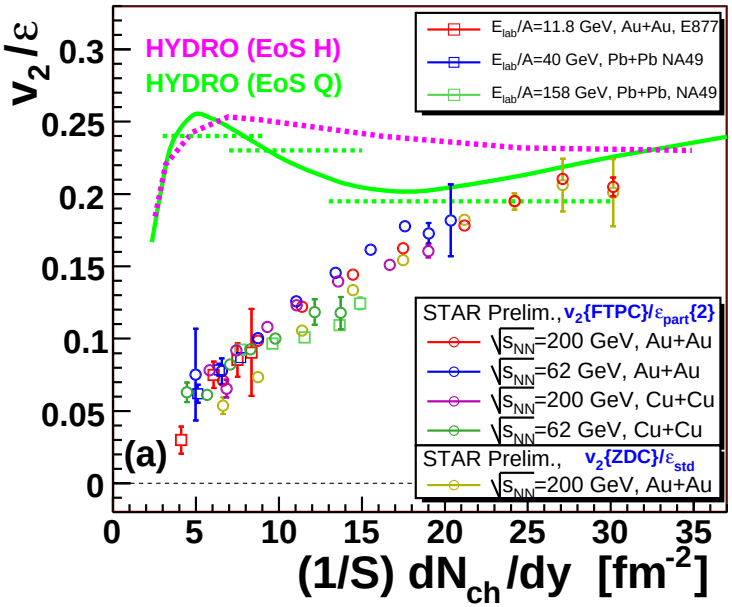
Charged particles elliptic flow

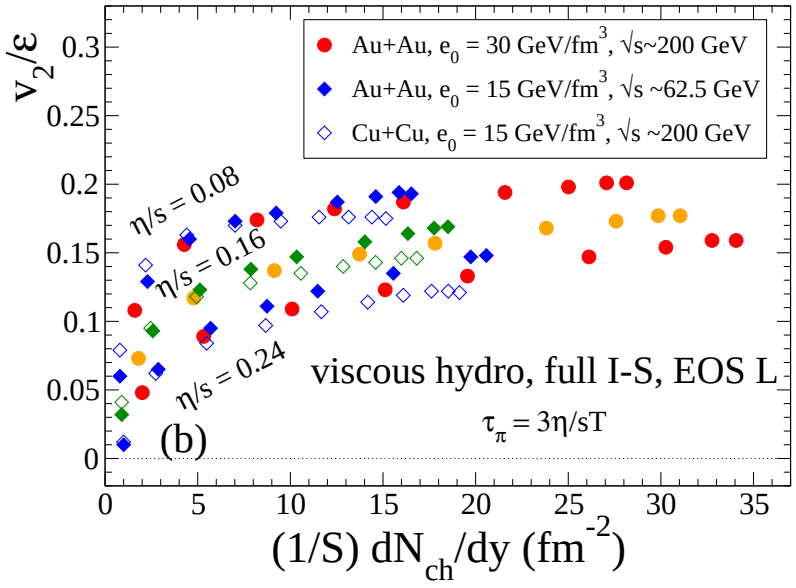


Hirano, Heinz, Karzeev, Lacey, Nara (2006)

charged particles v_2 sensitive to final stage effects !!

Multiplicity scaling





Song, Heinz (2008)

energy-momentum tensor

$$T^{\mu\nu} = \begin{pmatrix} \epsilon & 0 & 0 & 0 \\ 0 & p+\Pi & 0 & 0 \\ 0 & 0 & p+\Pi & 0 \\ 0 & 0 & 0 & p+\Pi \end{pmatrix} + \pi^{\mu\nu}$$

- shear viscosity

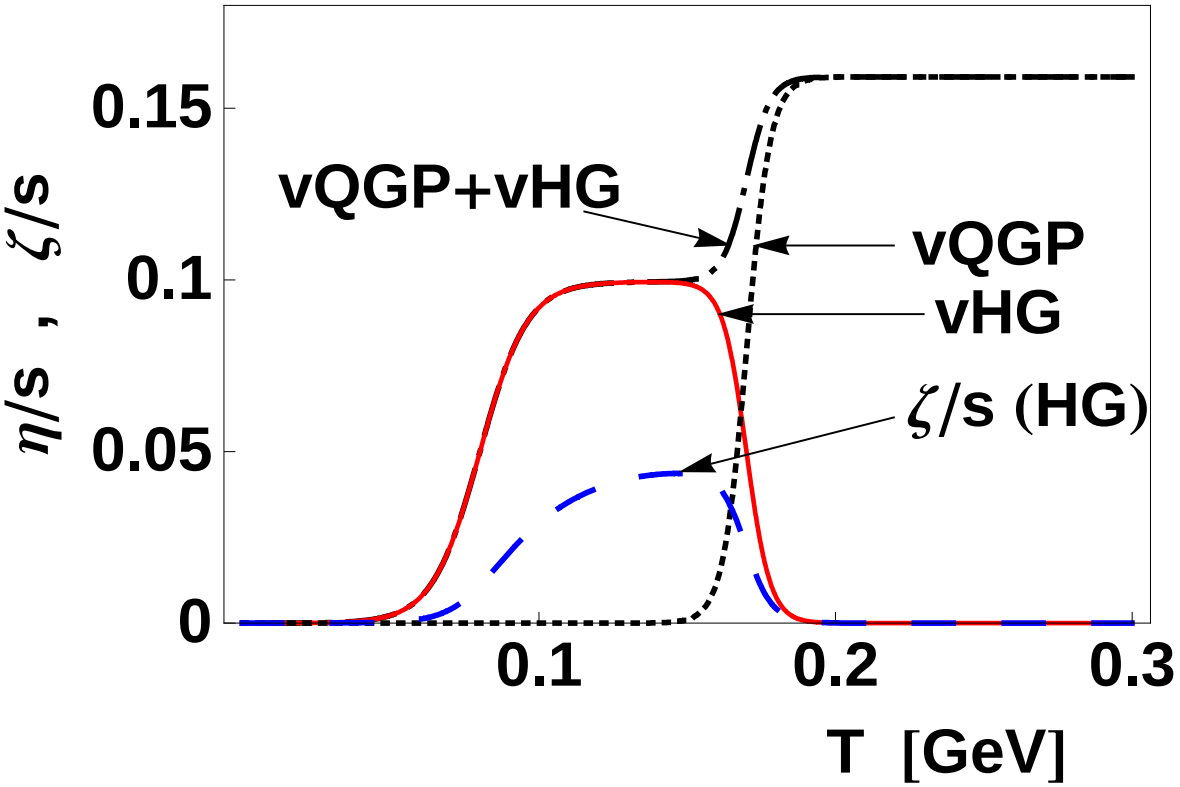
$$\Delta^{\mu\alpha}\Delta^{\nu\beta}u^{\gamma}\partial_{\gamma}\pi_{\alpha\beta} = \frac{2\eta\sigma^{\mu\nu} - \pi^{\mu\nu}}{\tau_{\pi}} - \frac{1}{2}\pi^{\mu\nu}\frac{\eta T}{\tau_{\pi}}\partial_{\alpha}\left(\frac{\tau_{\pi}u^{\alpha}}{\eta T}\right)$$

- bulk viscosity

$$u^{\gamma}\partial_{\gamma}\Pi = \frac{-\zeta\partial_{\gamma}u^{\gamma} - \Pi}{\tau_{\Pi}} - \frac{1}{2}\Pi\frac{\eta T}{\tau_{\Pi}}\partial_{\alpha}\left(\frac{\tau_{\Pi}u^{\alpha}}{\eta T}\right)$$

- nonequilibrium initial $T^{\mu\nu}$

Viscosity in HG vs. viscosity in QGP



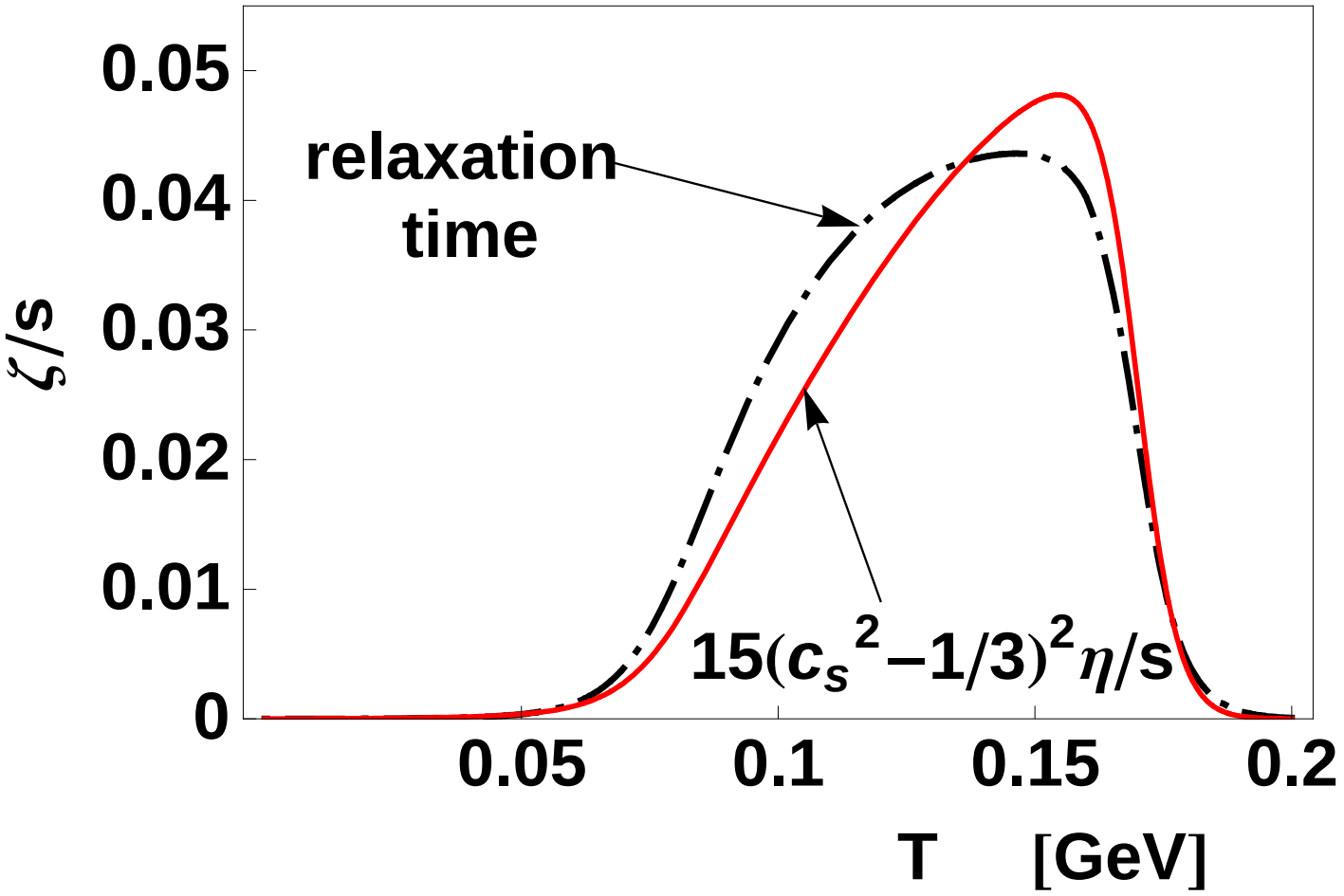
$$\frac{\eta_{QGP}}{s} = \frac{1}{2\pi} = 0.16 \qquad \frac{\eta_{HG}}{s} = 0.1$$

Shear + bulk viscosity in HG

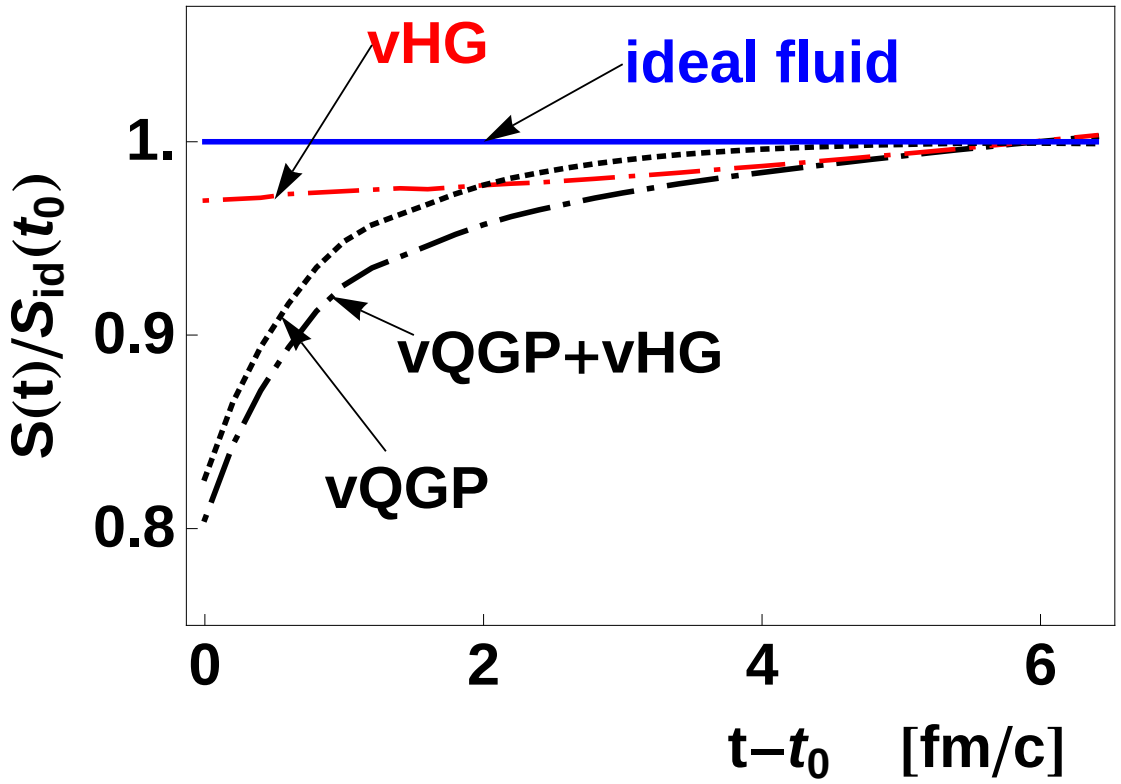
$$p^\mu \partial_\mu f_0 = -\frac{p_\mu u^\mu}{\tau_{HG}} \delta f \quad \rightarrow \quad \delta f$$

- $\Pi = \sum \int \frac{d^3p}{(2\pi)^3} \frac{\tau_{HG} m^2}{3ET} f_0(1 \pm f_0) \left(\frac{p^2}{3E} - c_s^2 E \right) \partial_\mu u^\mu = -\zeta \partial_\mu u^\mu$
- $\delta f_{bulk} = C \frac{f_0(1 \pm f_0)}{T} \left(\frac{p^2}{3E} - c_s^2 E \right) \Pi$

Bulk viscosity

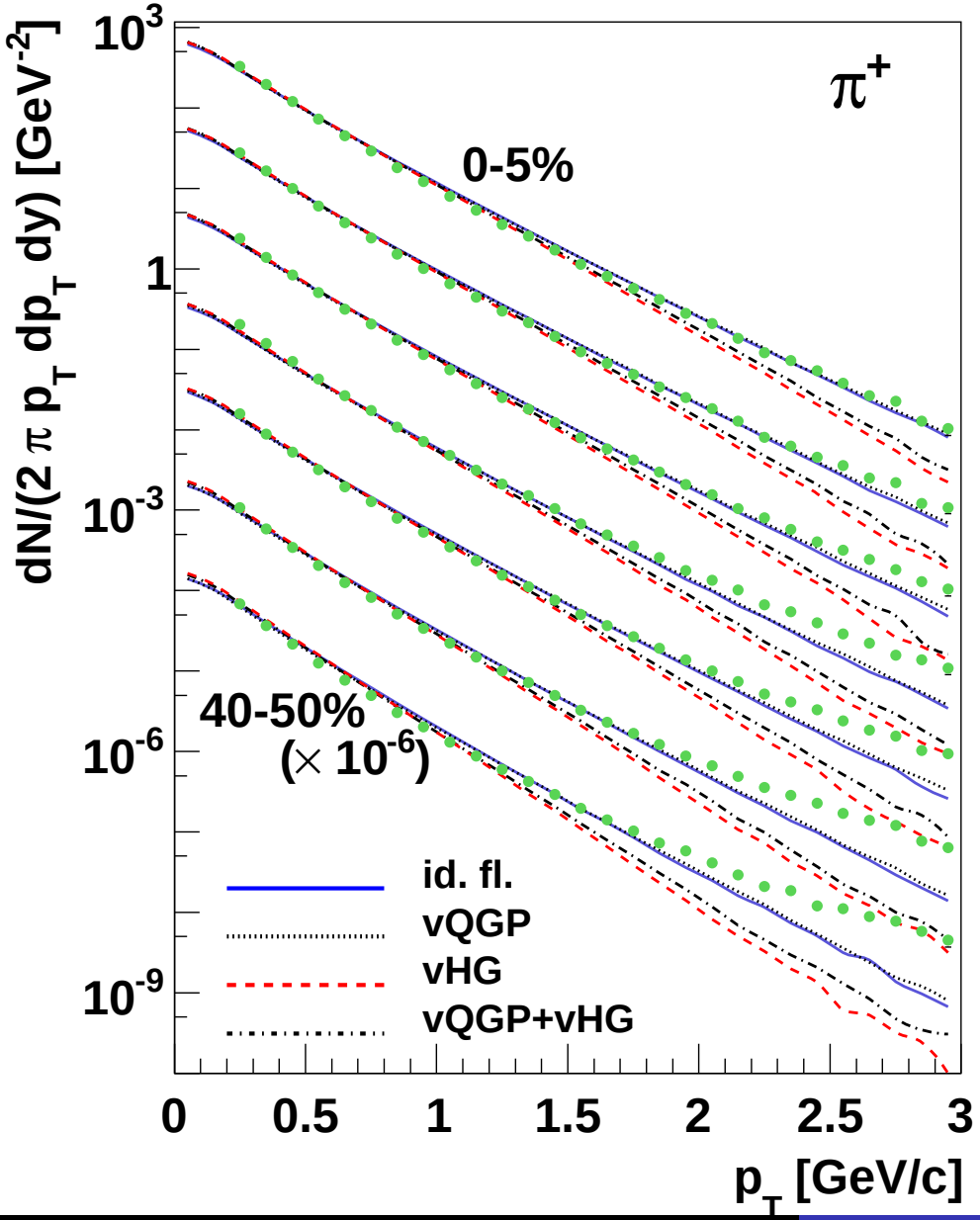


Entropy production and initial conditions



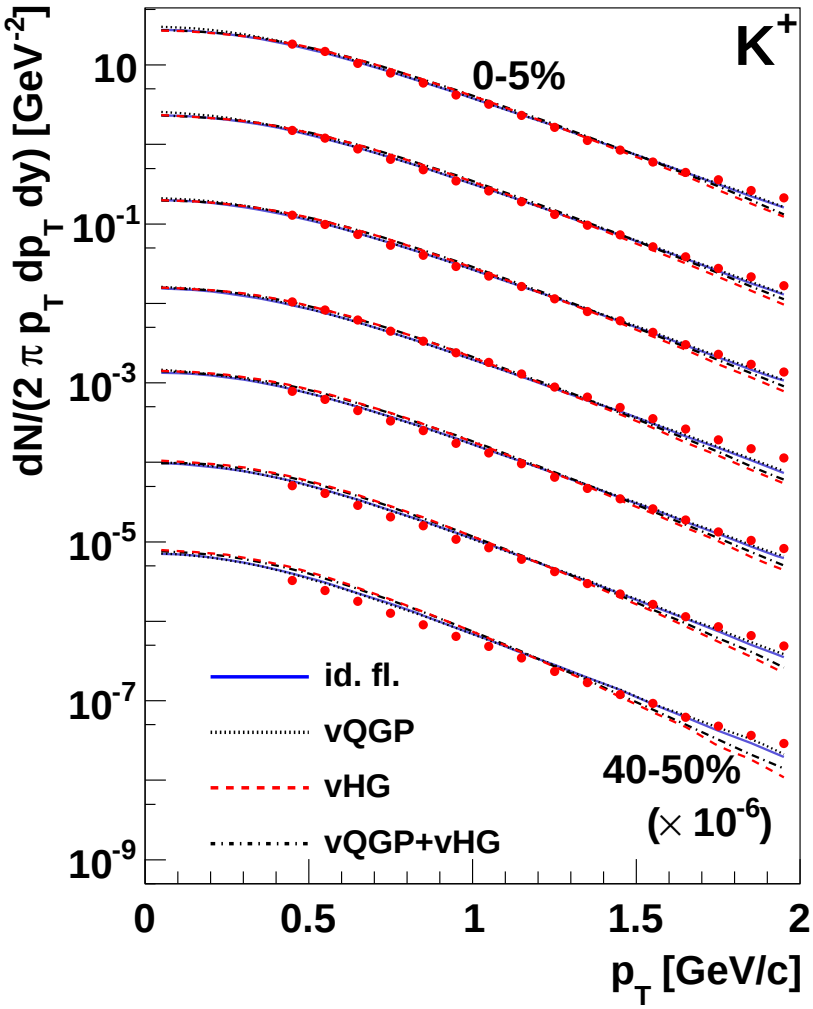
- 20% in QGP
- 2-3% in HG

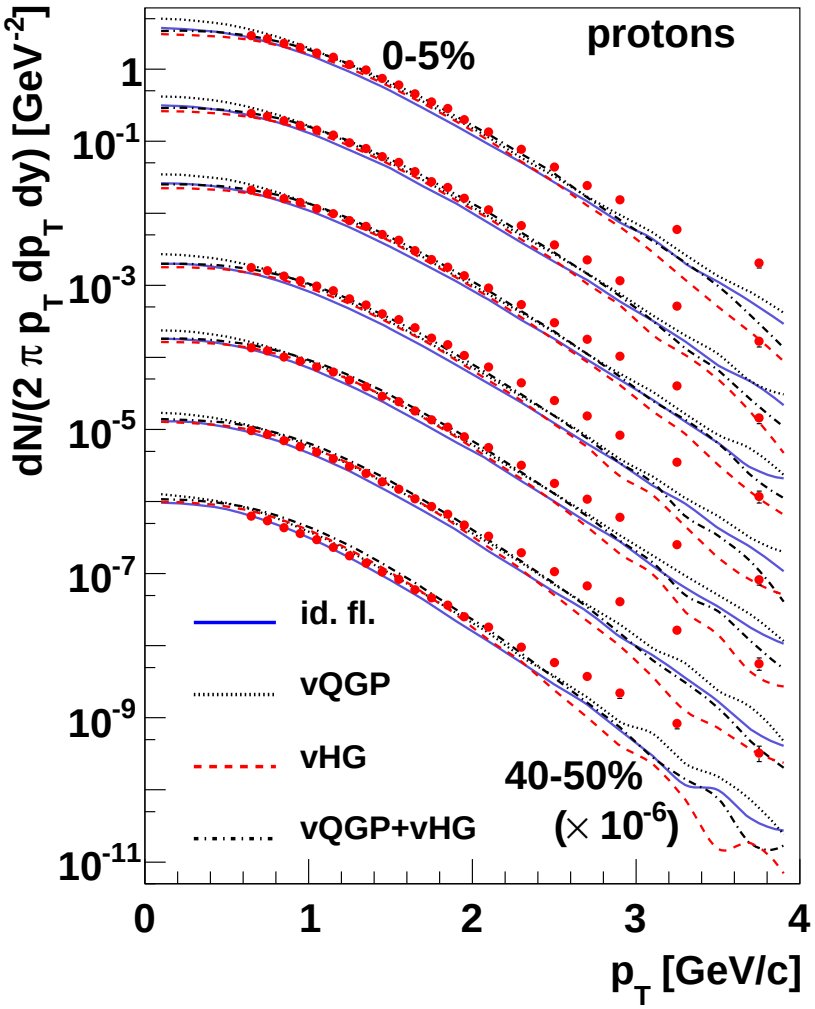
Spectra



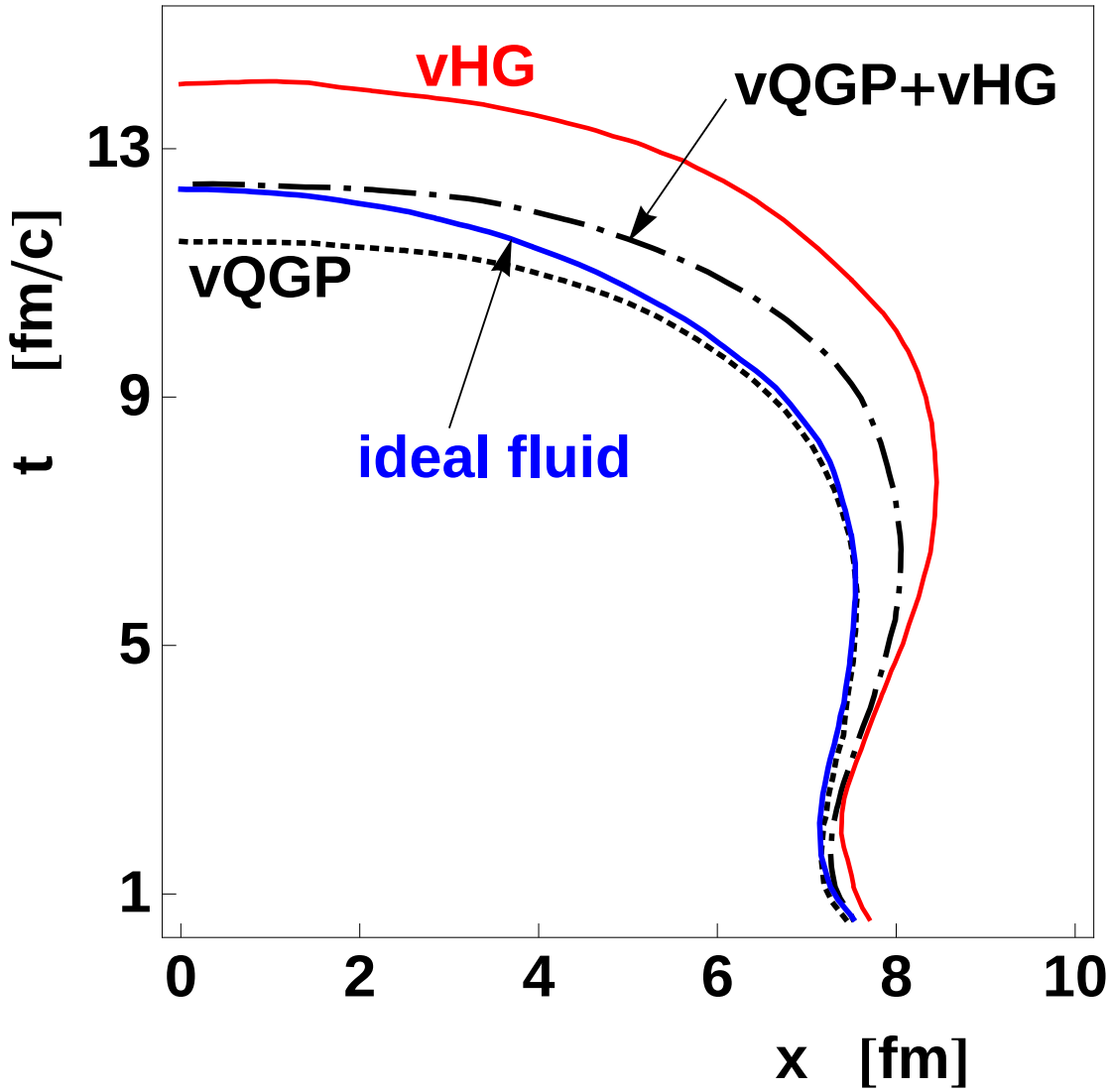
- different freeze-out temperatures
- different initial energy density
- bulk viscosity important !!

Particle composition

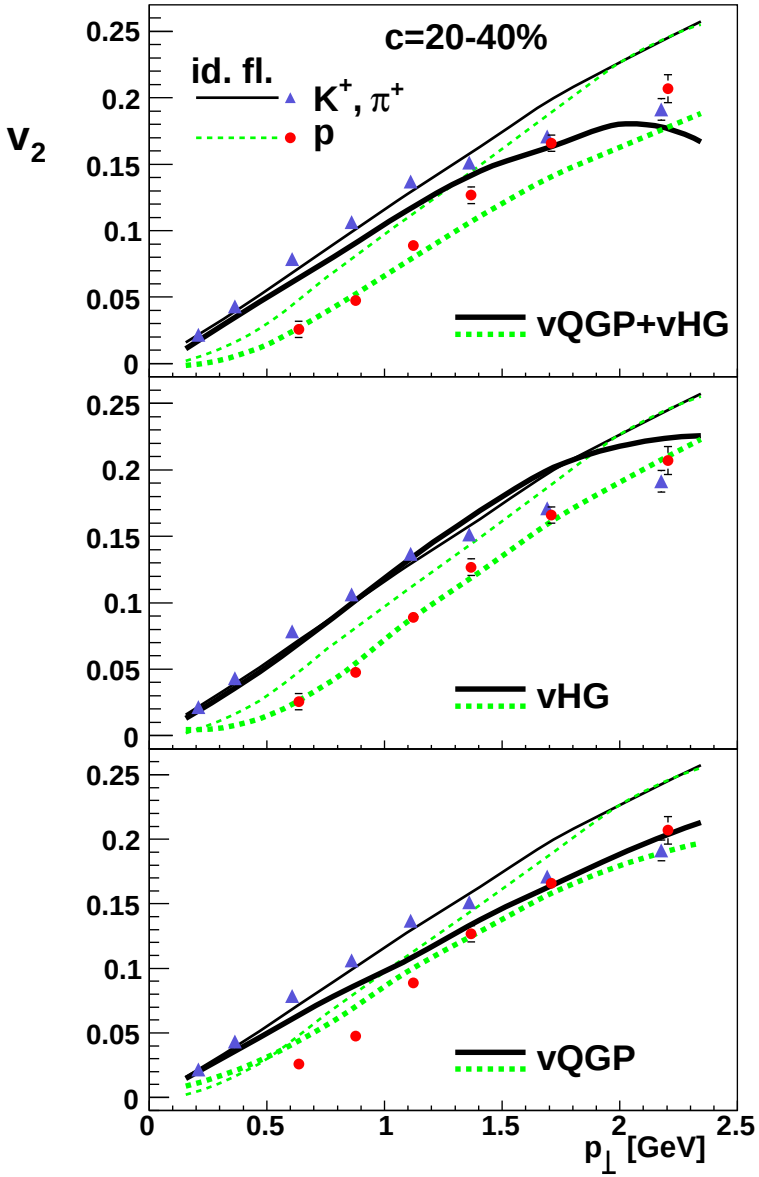




Freeze-out

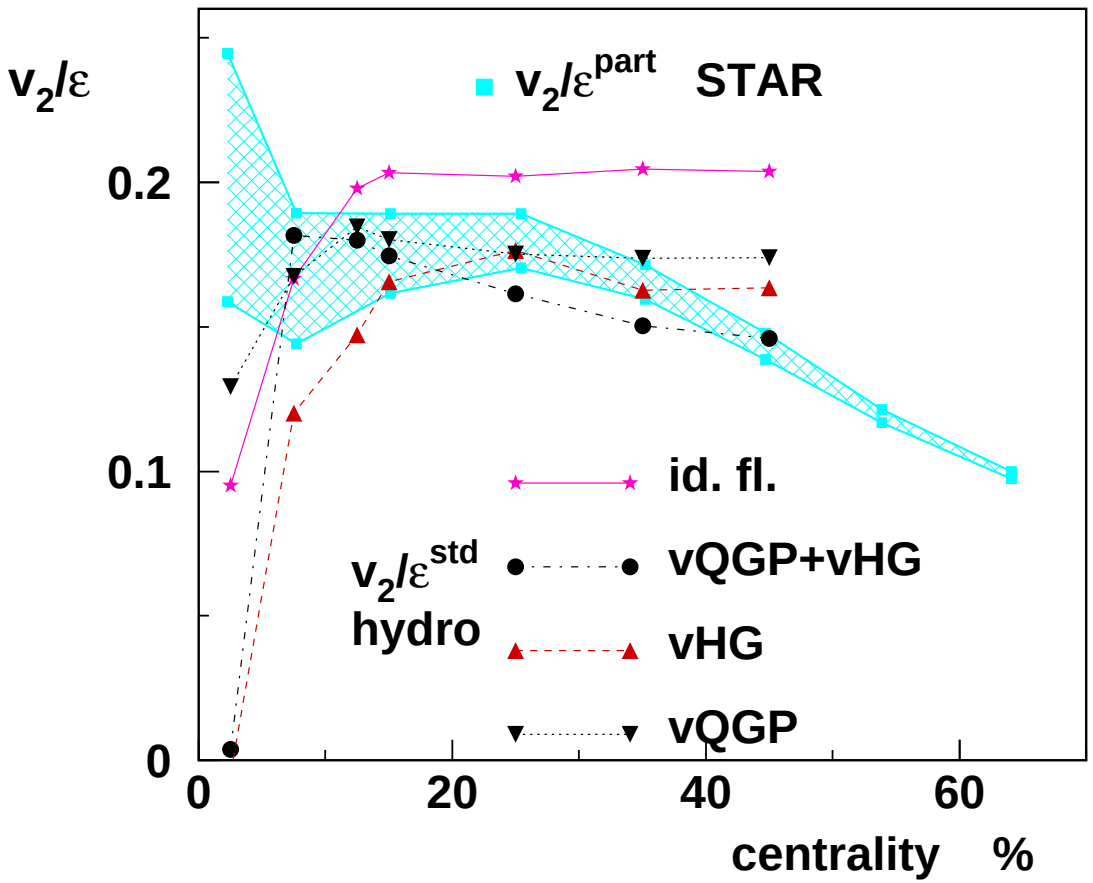


Elliptic flow - HG, QGP or both?



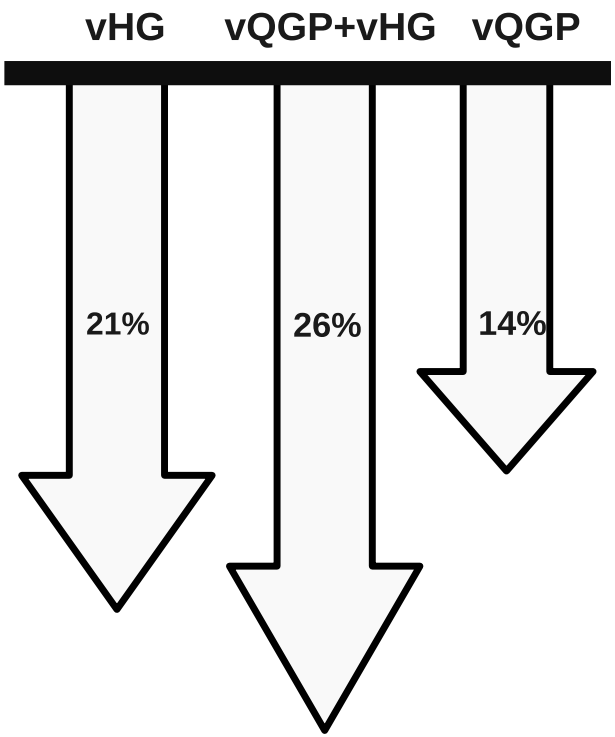
- viscosity in HG important
  vHG or vHG+vQGP
- bulk viscosity important

Charged particles



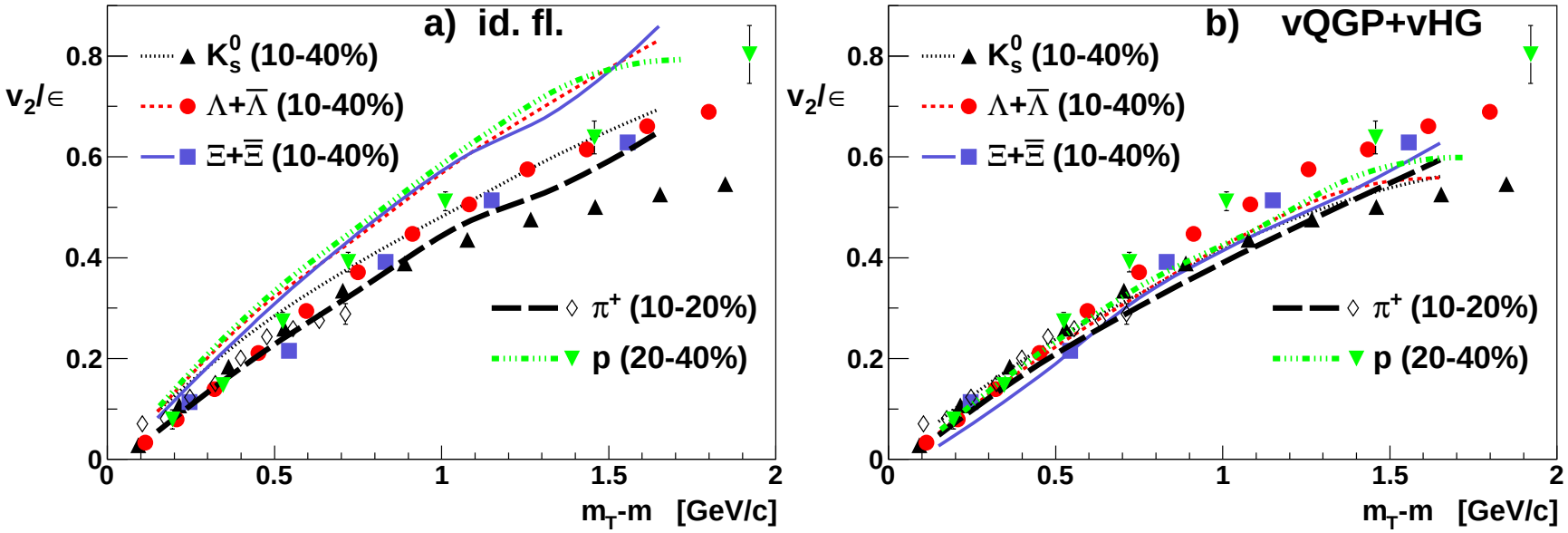
v_2 reduction

centrality=30-40%

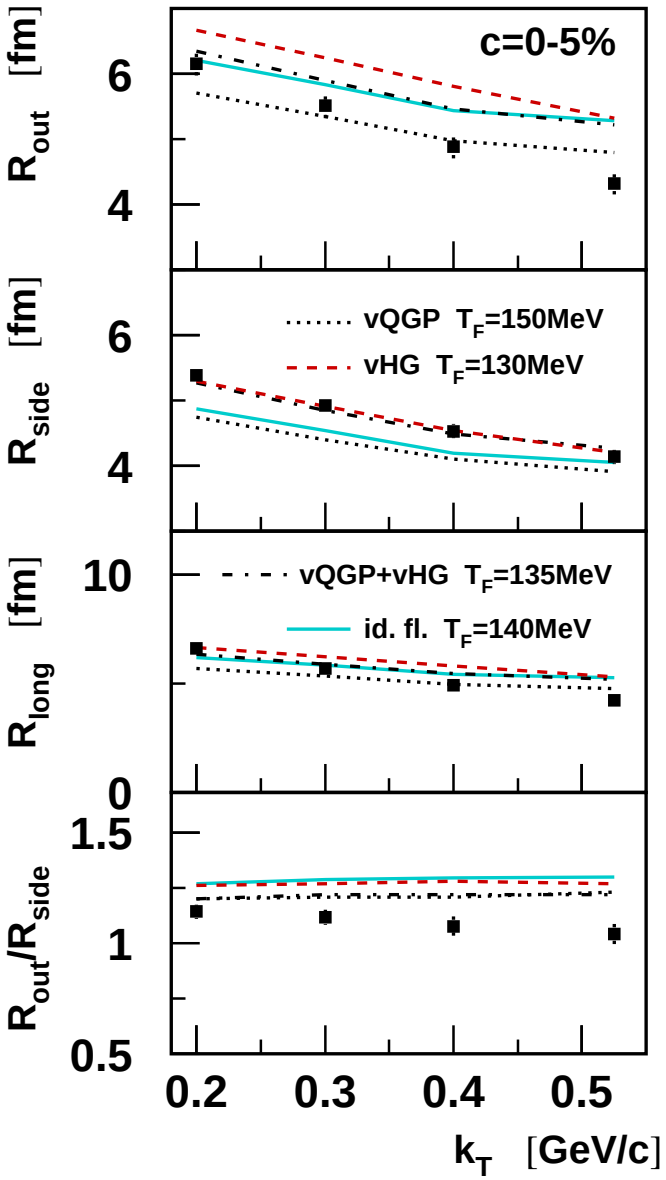


HG dissipation important !!

v_2 scaling


a) id. fl.
b) vQGP+vHG
v_2/ϵ
K^0_s (10-40%)
$\Lambda+\bar{\Lambda}$ (10-40%)
$\Xi+\bar{\Xi}$ (10-40%)
π^+ (10-20%)
p (20-40%)
m_T-m [GeV/c]
0
0.2
0.4
0.6
0.8
0.5
1
1.5
2

HBT sensitive to early stages



- sensitive to early flow
- less sensitive to hadronic effects
- T, lifetime, flow

Technical summary

	id. fl.	vQGP	vHG	vQGP+vHG	vQGP+vHG ($\zeta = 0$)
T_F	140MeV	150MeV	130MeV	135MeV	150MeV
spectra	$< 2GeV$	$< 2GeV$	$< 1.2GeV$	$< 1.2GeV+$	$< 2GeV$
v_2	$\simeq$	reduced	$\simeq$	$\simeq$	strong red.
p/π v_2	no	no	yes	yes	no
HBT	$\pm 15\%$	$\pm 10\%$	$\pm 15\%$	$\pm 10\%$	$\pm 10\%$

viscosity in HG seems favored by v_2 (vHG or vQGP+vHG)
viscosity in QGP (early transverse push ?) improves spectra, HBT

Conclusions

- HG masks v_2 measure of viscosity
- add HBT into the game
- extracting η_{QGP} difficult (τ_0, initial push, ...)

Conclusions + Prospects

- HG masks v_2 measure of viscosity
- add HBT into the game
- extracting η_{QGP} difficult (τ_0, initial push, ...)

- HBT insensitive to details of freeze-out
  lifetime $\leftrightarrow$ size
- hadronic effects must be constrained
- hadronic effects can be constrained !
- LHC - more QGP