QGP viscosity at RHIC and LHC energies

New Results from Viscous Hydro + URQMD (VISHNU)

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References:

H. Song , S. Bass and U. Heinz, Phys. Rev. C83, 024912 (2011)
H. Song, S. Bass, U. Heinz, T. Hirano and C. Shen, Phys. Rev. Lett. 106, 192301(2011)
H. Song, S. Bass, U. Heinz, T. Hirano and C. Shen, Phys. Rev. C83, 054910(2011)
H. Song, S. Bass, U. Heinz, Phys Rev. C83 054912(2011)

viscous hydrodynamics

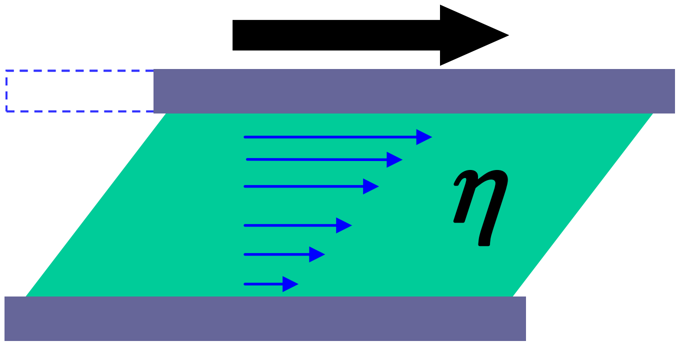
$$\partial_\mu T^{\mu\nu}(x) = 0 \qquad T^{\mu\nu} = (e + p + \Pi)u^\mu u^\nu - (p + \Pi)g^{\mu\nu} + \pi^{\mu\nu}$$

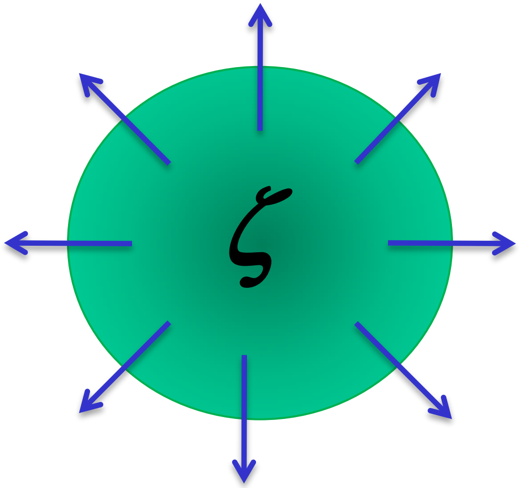
$$\tau_\pi \Delta^{\alpha\mu}\Delta^{\beta\nu}\dot{\pi}_{\alpha\beta} + \pi^{\mu\nu} = 2\eta\sigma^{\mu\nu} - \frac{1}{2}\pi^{\mu\nu}\frac{\eta T}{\tau_\pi}\partial_\lambda\left(\frac{\tau_\pi}{\eta T}u^\lambda\right)$$

$$\tau_\Pi \dot{\Pi} + \Pi = -\zeta(\partial \cdot u) - \frac{1}{2}\Pi\frac{\zeta T}{\tau_\Pi}\partial_\lambda\left(\frac{\tau_\Pi}{\zeta T}u^\lambda\right)$$

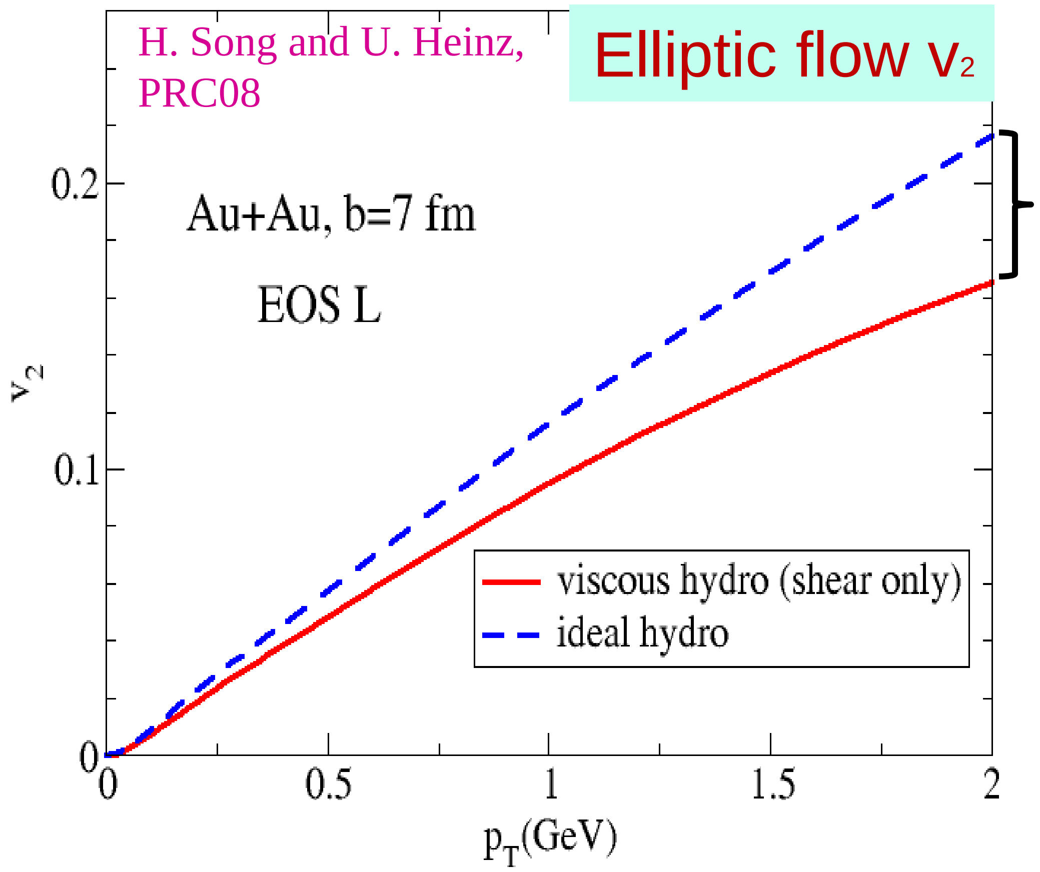
Input: “EOS”

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





Viscous hydro: Shear viscosity η & elliptic flow V_2



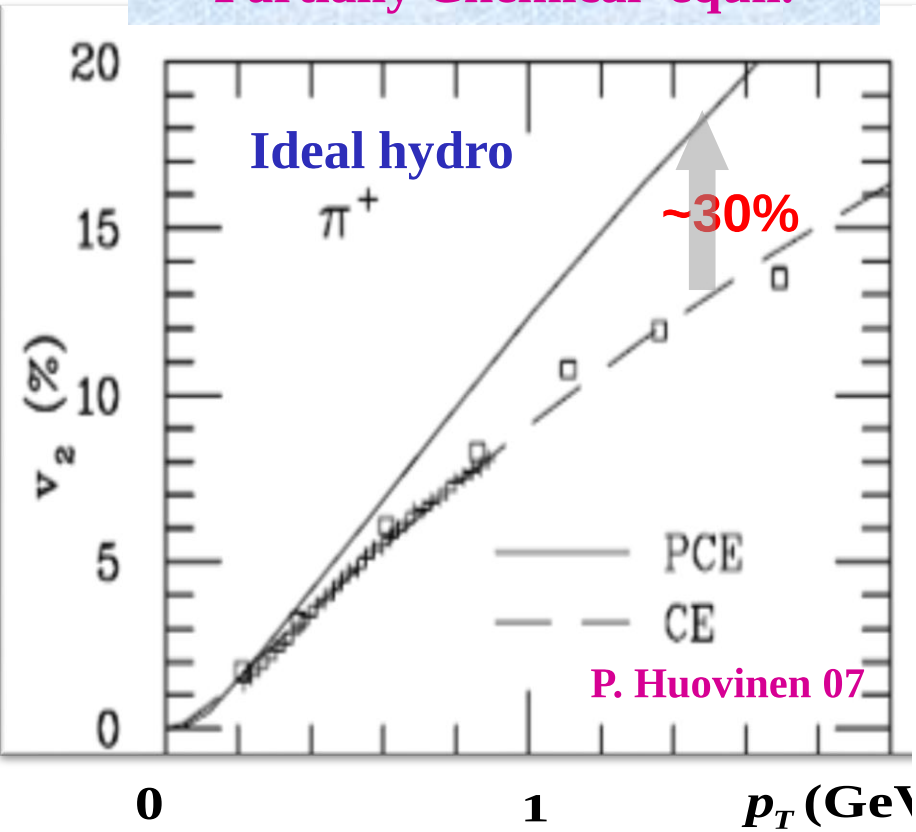
20-25% v_2 suppression $\frac{\eta}{s} = \frac{1}{4\pi}$

-V_2 can be used to extract the QGP shear viscosity

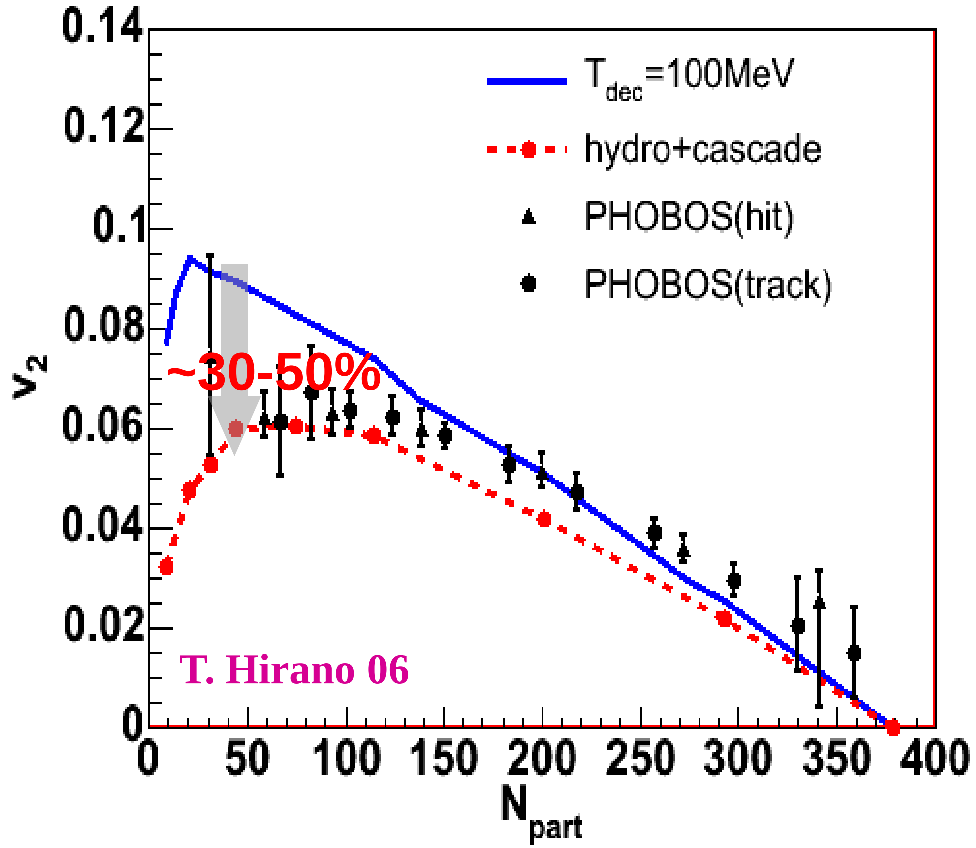
-For an accurate extraction of QGP viscosity, one needs to control the theoretical uncertainties as well as precise exp data.

Hadronic effects on elliptic flow V_2

Partially Chemical equil.



hadronic dissipative effects



-These two HRG effects are not included in early viscous hydro calculations

→ **viscous hydro + hadron cascade (URQMD) hybrid approach**

URQMD includes the partially chemical equilibrium nature & hadronic dissipative effects

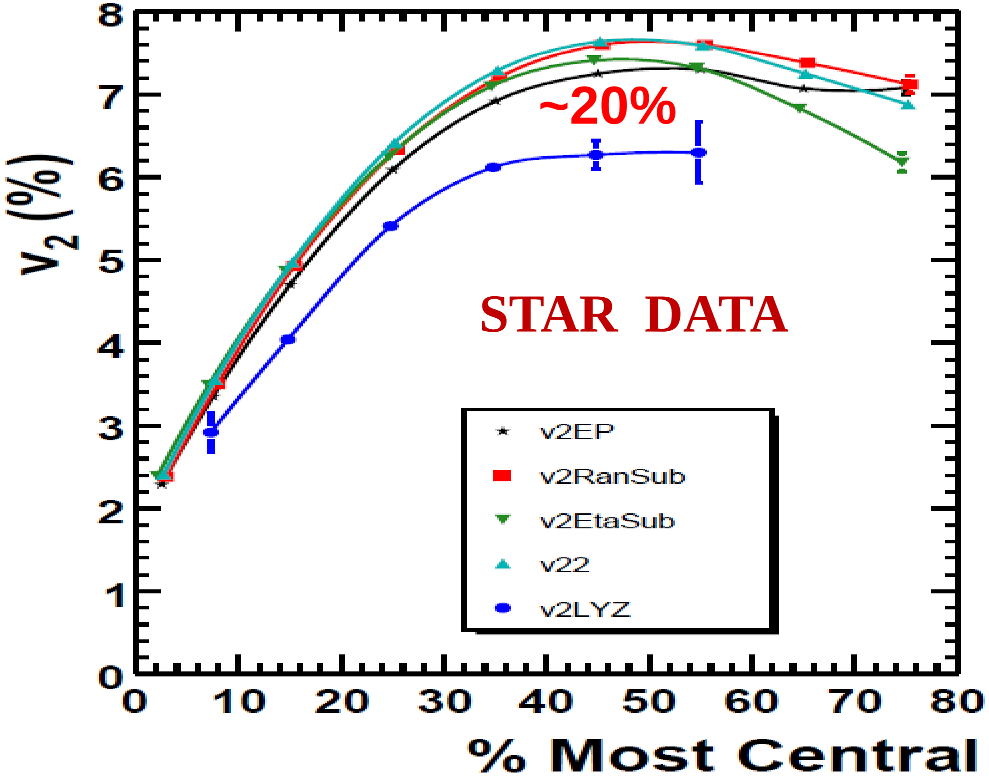
Extracting QGP viscosity from RHIC data

v_2 from different exp methods are affected by non-flow and fluctuations

~20% uncertainties in EXP v_2

→ **~100%** uncertainties for the extracted QGP viscosity

EXP.



Extracting QGP viscosity from RHIC data

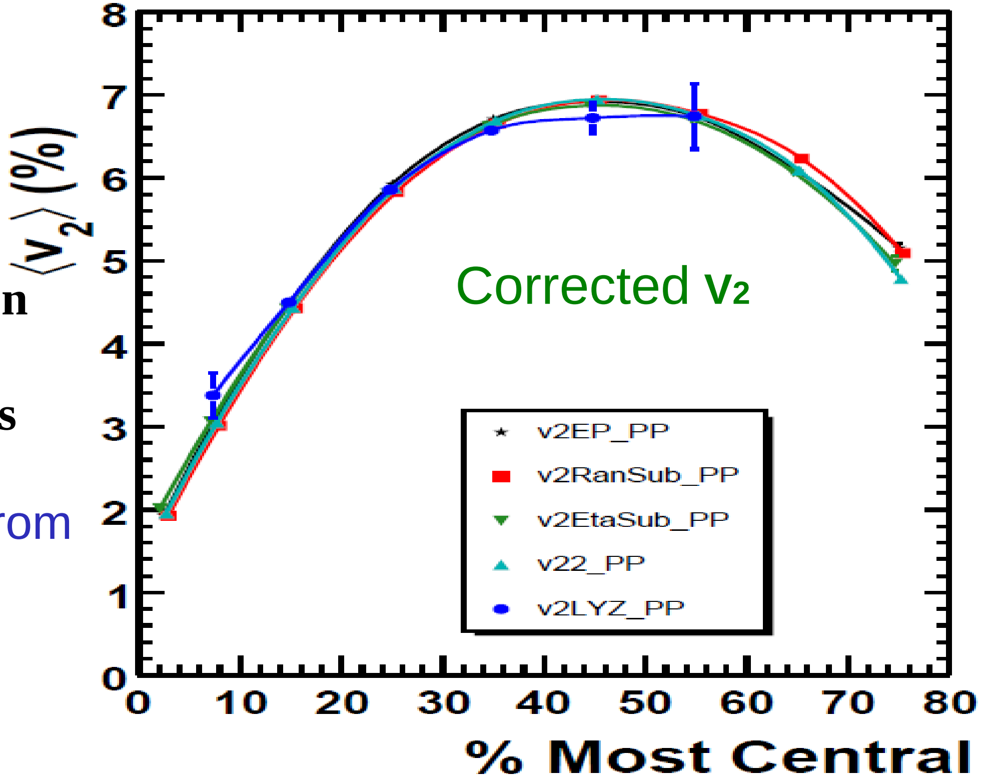
Corrected v2:

Ollitrault, Poskanzer & Voloshin, PRC09

with assumptions on fluctuations and non flow, all corrected v2 in participant / reaction plan converge to unique curves

→ greatly reduces uncertainties from EXP data for the extracted η/s

EXP.



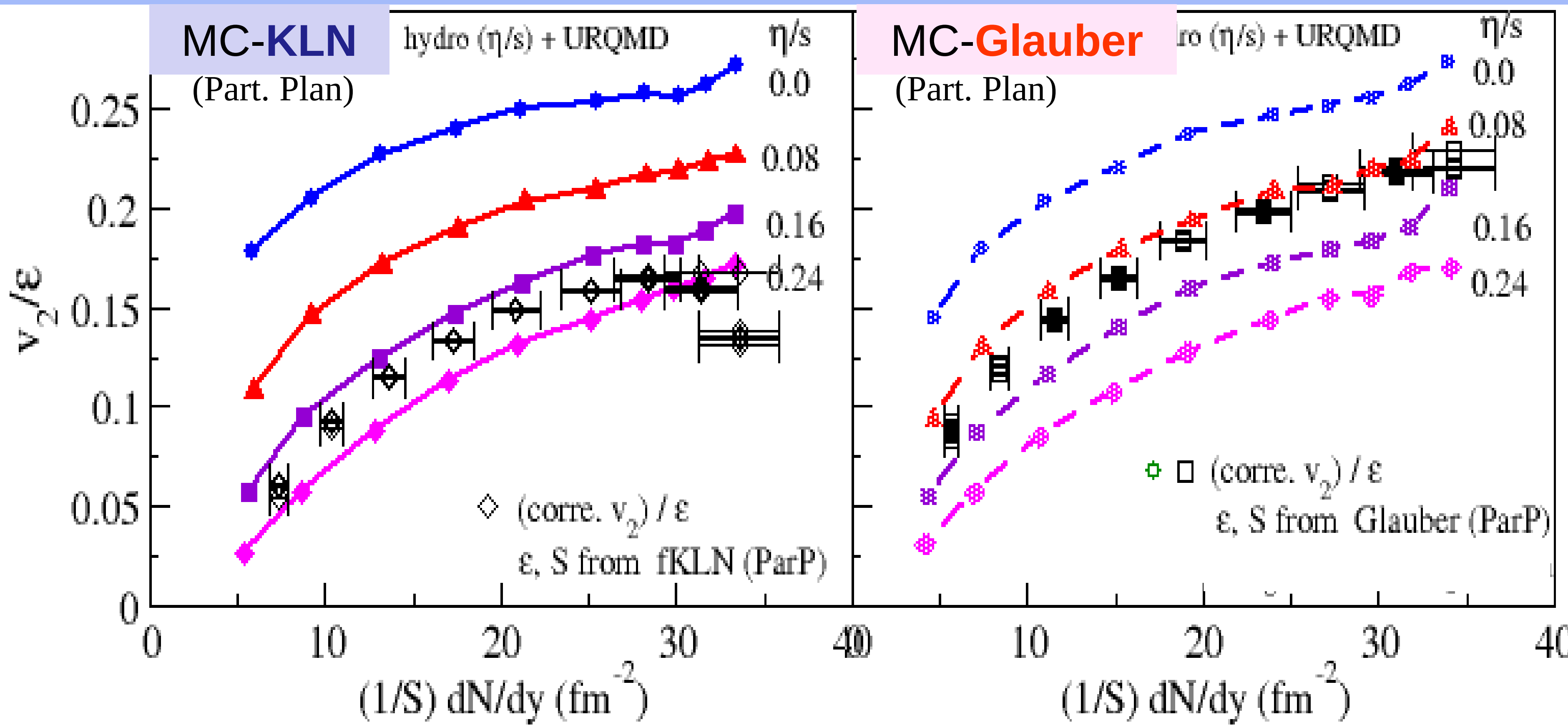
Extracting QGP viscosity from RHIC data

Theoretical Modeling

Viscous Hydro + URQMD

- -initial conditions
- -EoS: s95p-PCE ✓ Huovinen & Petreczky10
- -chemical composition of HRG ✓
- -viscosity of HRG ✓ Song, Bass & Heinz, PRC2011
- -bulk viscosity: <20% ✓ Song & Heinz, PRC 09

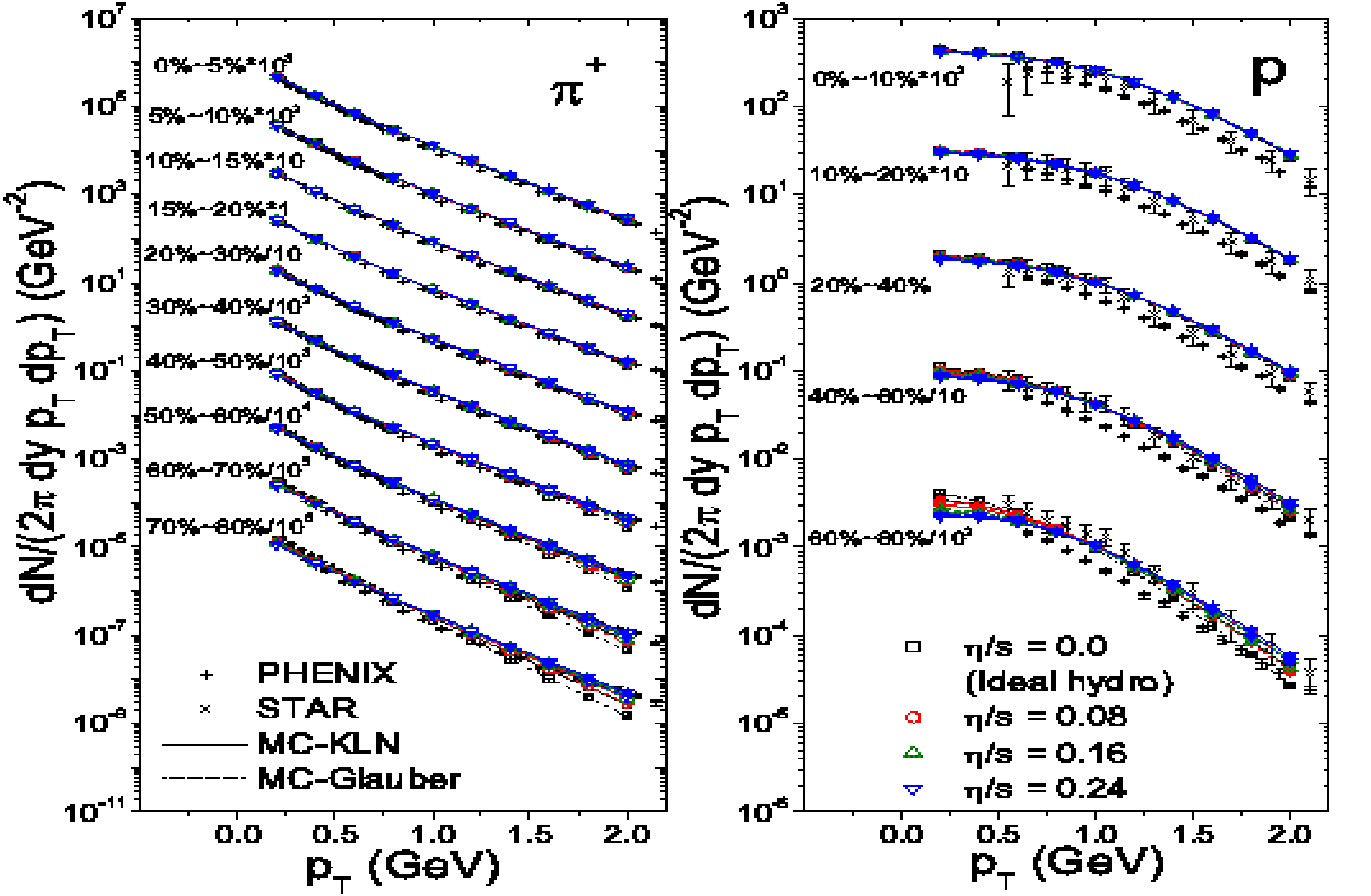
QGP viscosity from $v_2/\varepsilon - (1/S)dN/dy$



$\eta/s = 0.16 - 0.24$ for MC-**KLN** initial conditions

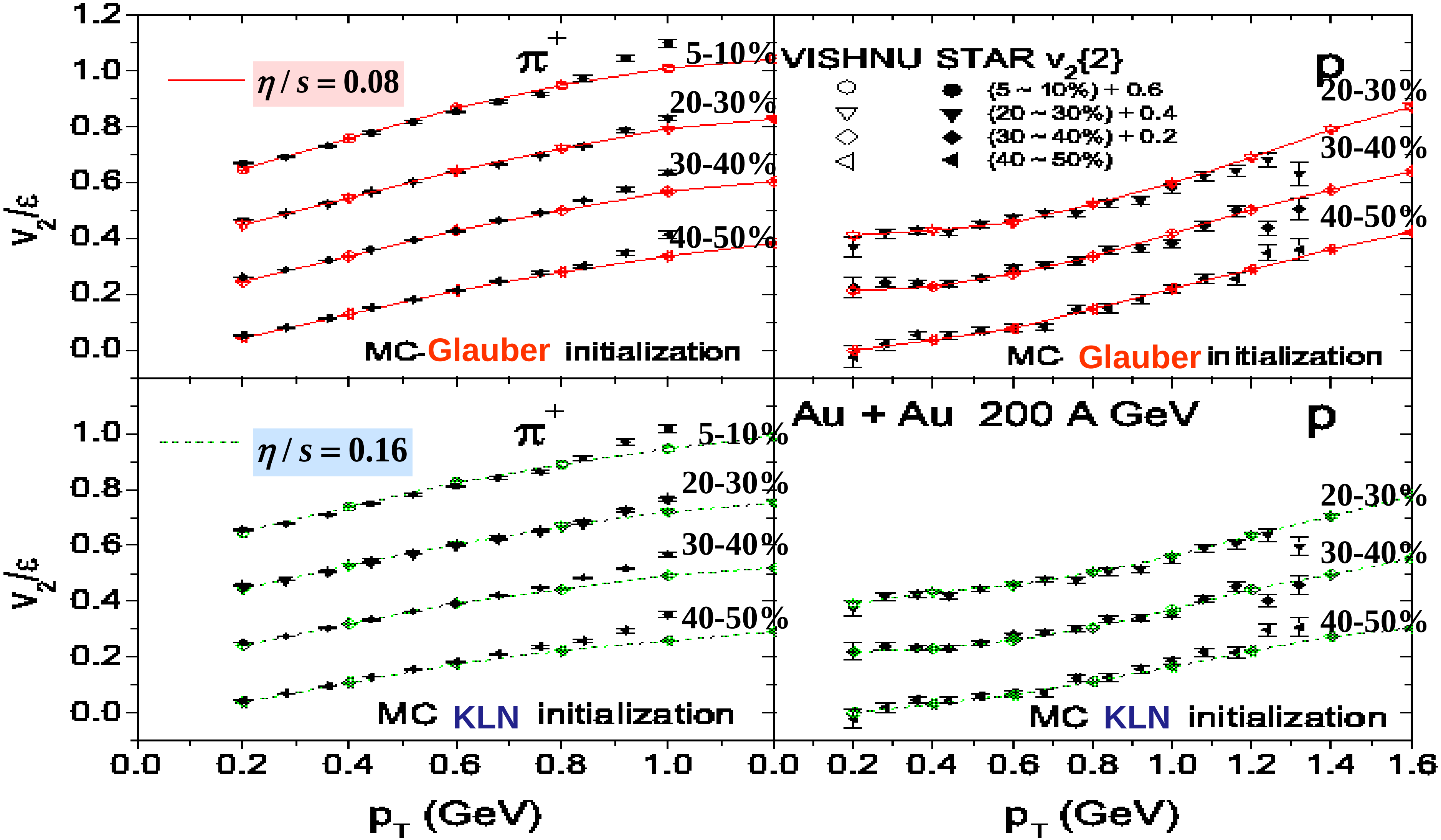
$\eta/s = 0.08 - 0.16$ for MC-**Glauber** initial conditions

H. Song, S. Bass, U. Heinz, T. Hirano, and C. Shen, PRL2011



-a nice fit for both pion and proton spectra, insensitive to QGP viscosity

H.Song, S. Bass , U. Heinz, T. Hirano, and C. Shen, PRC2011



-fluctuating effects is reduced by comparing **theory** v_2 / ε **& EXP.** $v_2\{2\}/\sqrt{\varepsilon^2}$

-hit the lower-bound of η / s extracted from $v_2 / \varepsilon - (1/S) dN/dy$ (non flow effects)

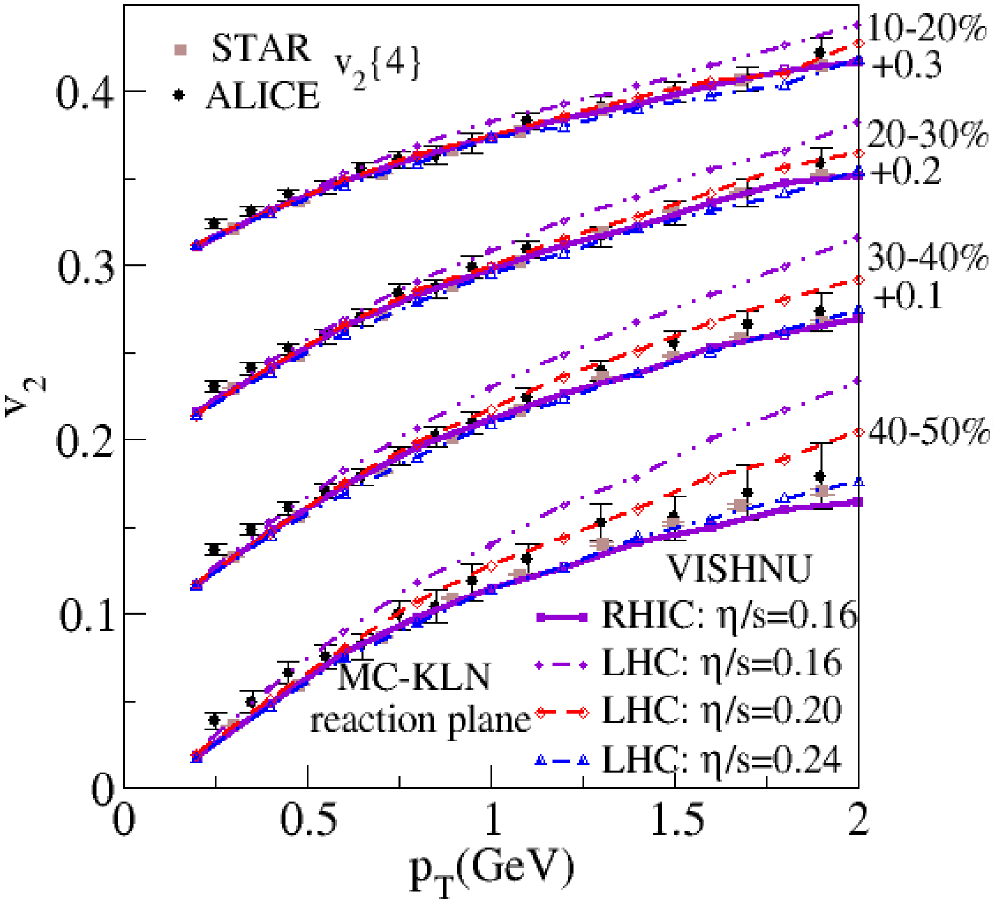
$\eta / s = 0.08 - 0.16$ for **Glauber** initial condi. $\eta / s = 0.16 - 0.24$ for **KLN** initial condi.

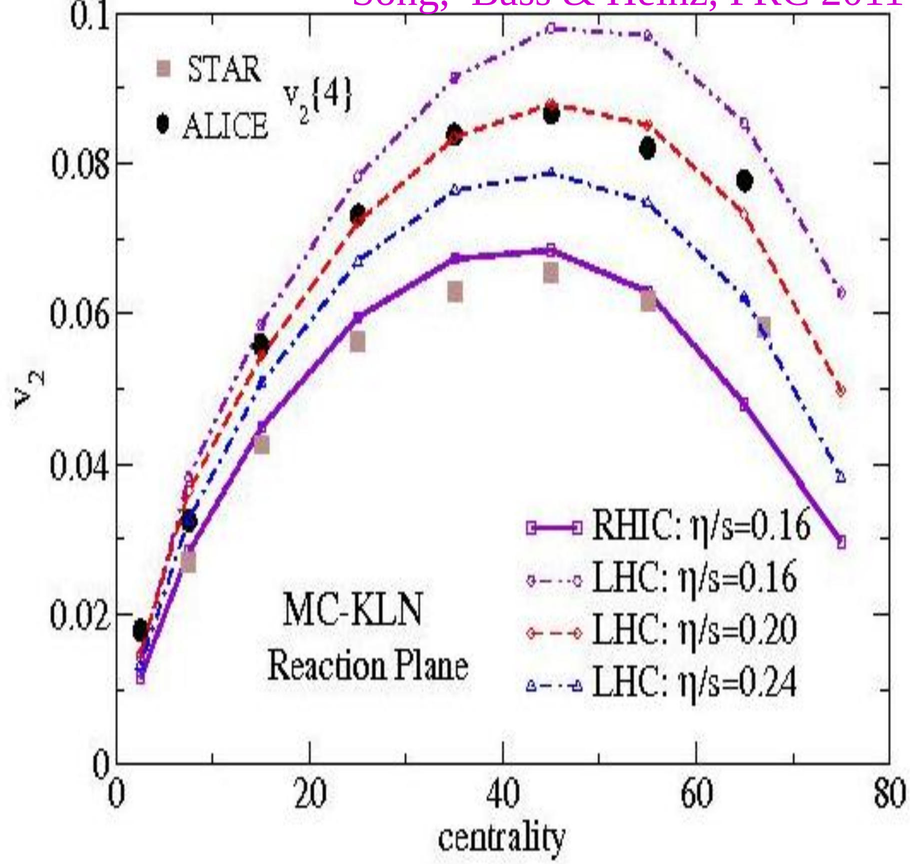
QGP viscosity at RHIC & LHC energies

-- H. Song, S. Bass, U. Heinz, PRC2011

$V_2(P_T)$ at RHIC and LHC

Song, Bass & Heinz, PRC 2011





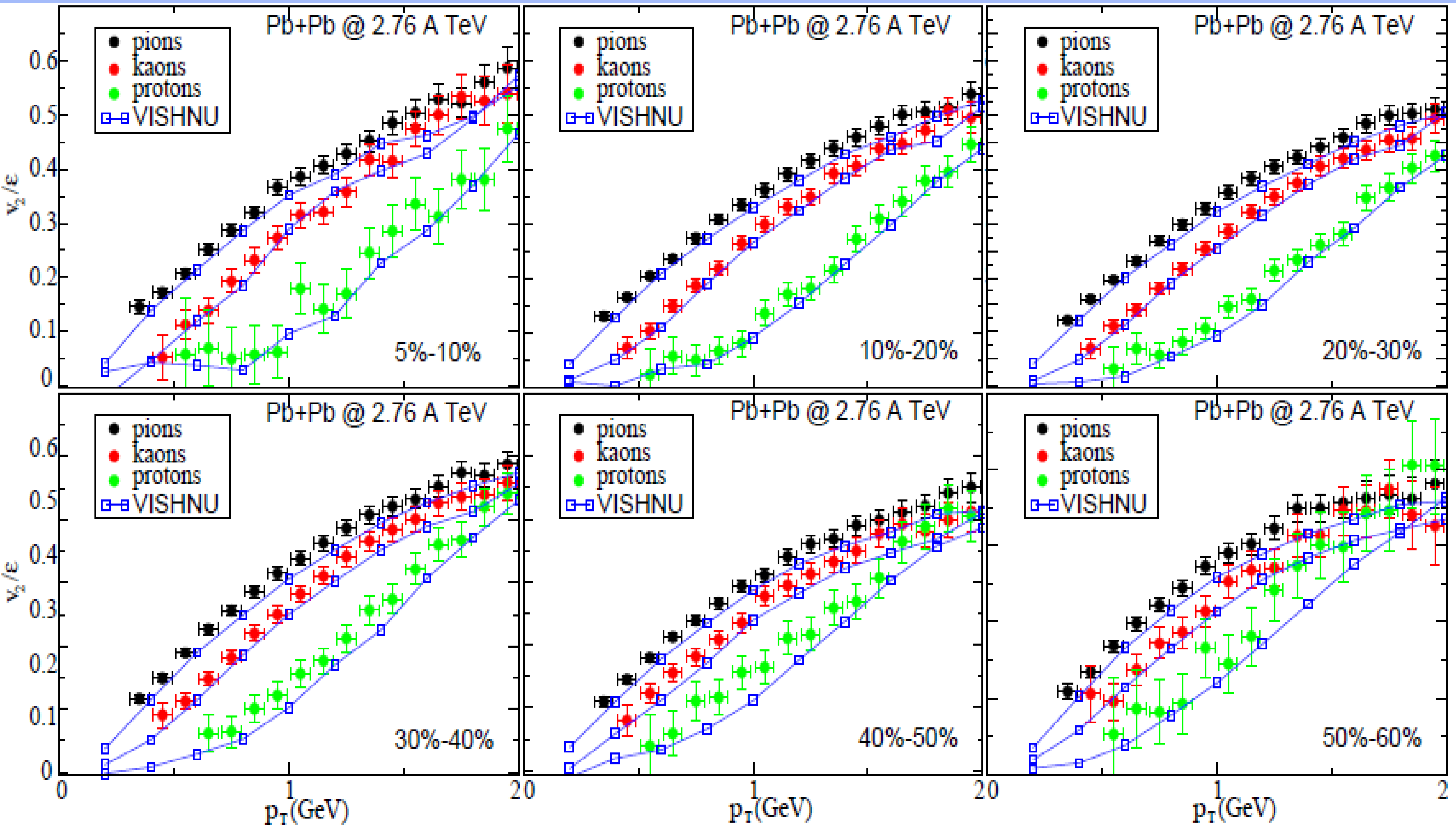
Assuming const. η / s

RHIC: $\eta / s \approx 0.16$

LHC: $\eta / s \approx 0.20 - 0.24$

This is not aim for extracting QGP viscosity at LHC energy with reliable uncertainty estimates

$V_2(P_T)$ for pion kaon & protons at LHC



Assuming const. η / s **LHC:** $\eta / s \approx 0.20$

This is not aim for extracting QGP viscosity at LHC energy with reliable uncertainty estimates

A short summary

- v_2 is sensitive to η/s

Extraction η/s from elliptic flow data using viscous hydro + UrQMD indicates:

$$1\times(1/4\pi)\leq\eta/s\leq 3\times(1/4\pi)$$

Similar averaged QGP viscosity at RHIC and LHC energies

-Relatively larger uncertainties are from initial geometry

MC-Glauber: $\eta/s=(1-2)\times(1/4\pi)$ **MC-KLN:** $\eta/s=(2-3)\times(1/4\pi)$

-Relatively smaller uncertainties are from

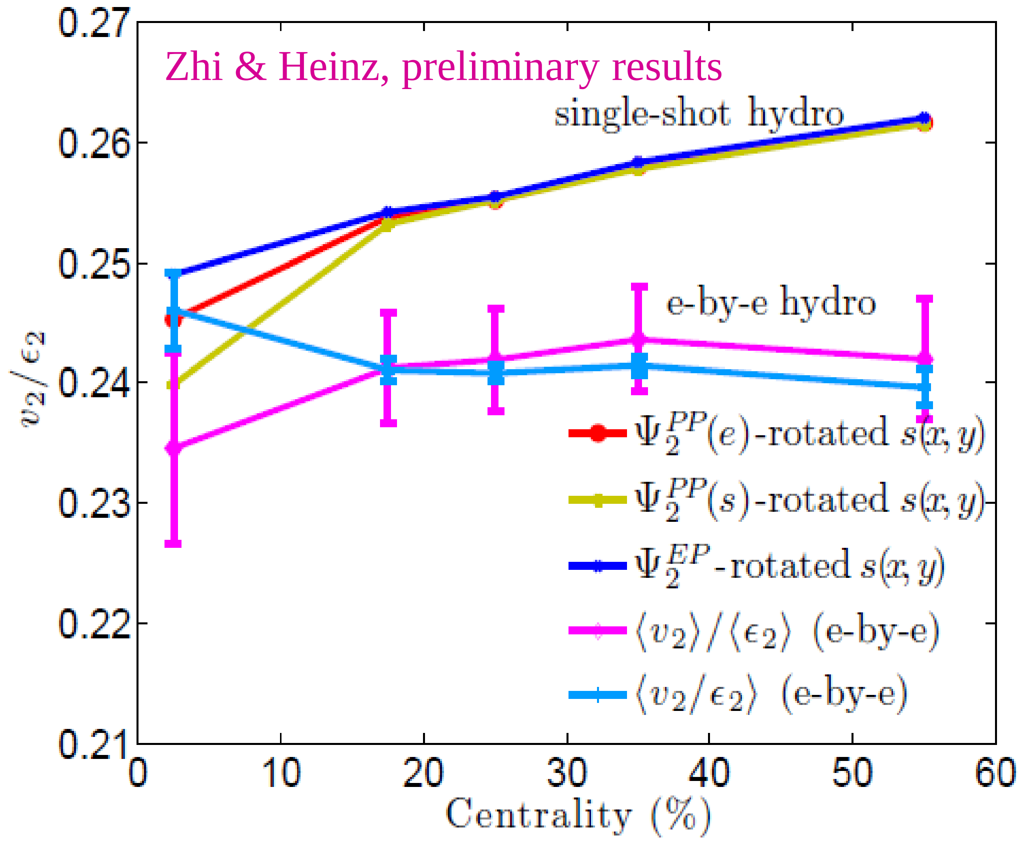
initial flow, bulk viscosity, single short hydro vs. e-by-e simulations …

-other possible observables may help to reduce these uncertainties ,

photons, HBT radii, triangular flow …

Thank You

e-b-e hydro vs. single shot hydro

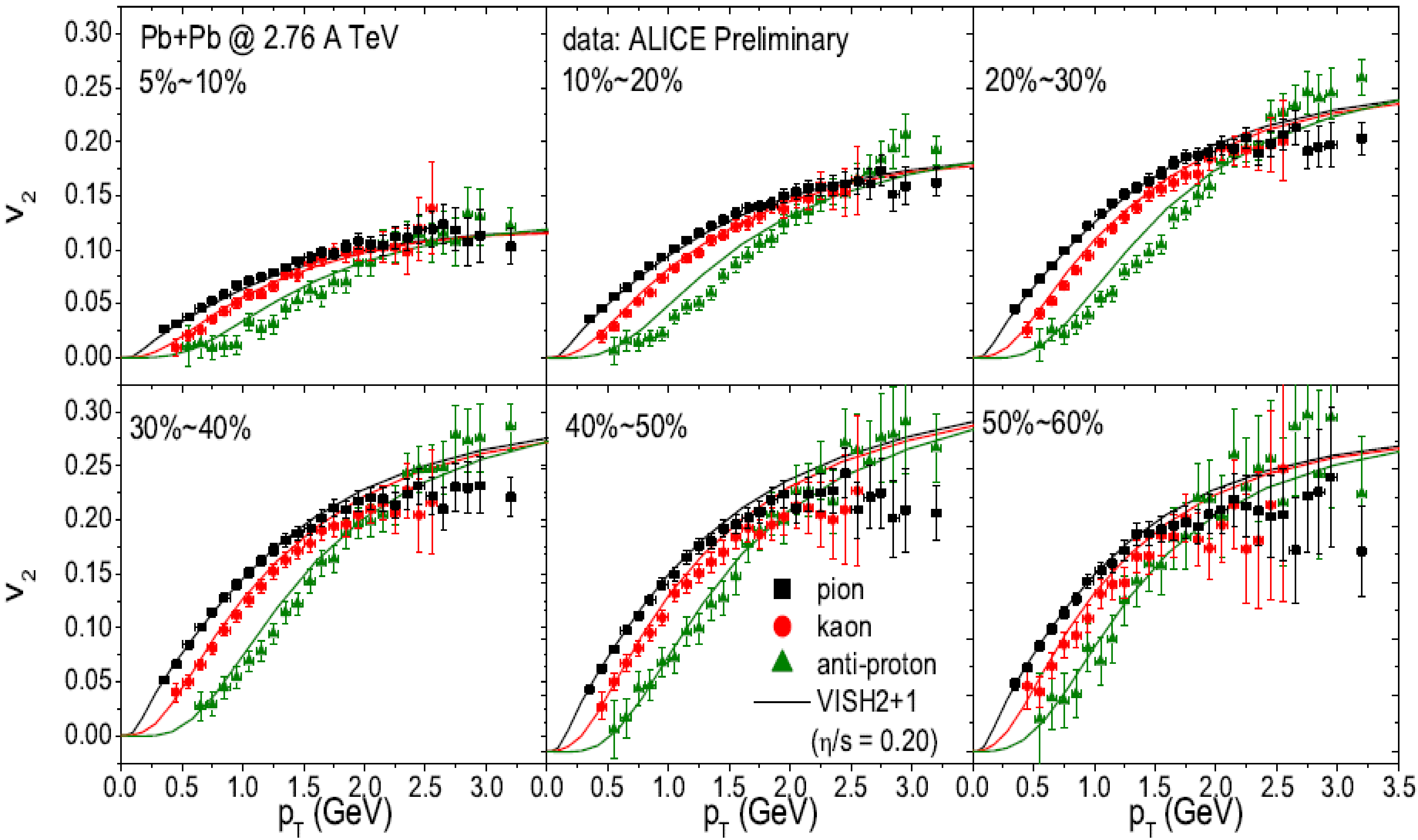


Event-by-event hydro produces 5% less v2/ecc than single-shot hydro with smooth averaged initial profile

initial flow, bulk viscosity and e-b-e hydro: { each of them shifts v_2 by a few; cancelation among them

$\eta/s = 0.16-0.24$ for MC-**KLN** initial conditions

$\eta/s = 0.08-0.16$ for MC-**Glauber** initial conditions



Pb+Pb @ 2.76 A TeV
5%~10%
data: ALICE Preliminary
10%~20%
20%~30%
30%~40%
40%~50%
50%~60%
pion
kaon
anti-proton
VISH2+1
(η/s = 0.20)
v_2
p_T (GeV)