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Experimental constraints on the temperature dependence of η/s

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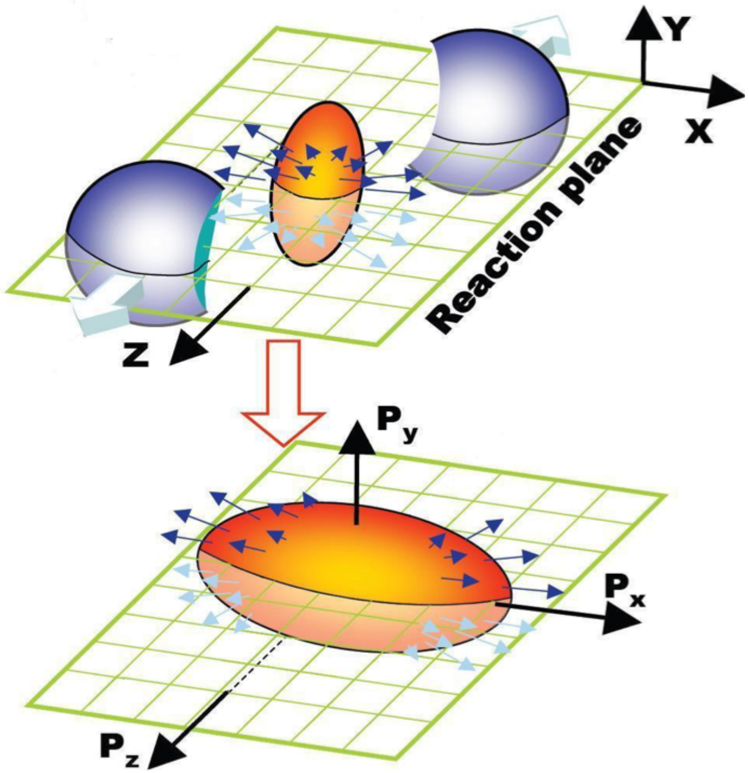
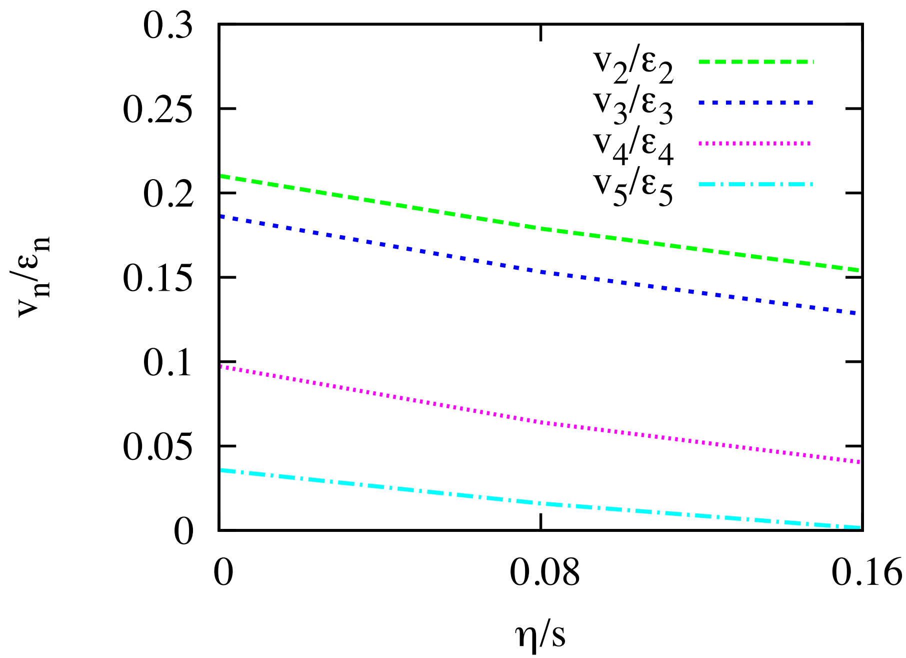
Azimuthal flow and shear viscosity



PRC 82 (2010) 034913



- Momentum anisotropy means higher in-plane fluid velocities compared to out of plane
  - ✓ Shear viscosity is resistance to fluid elements moving at difference velocities.

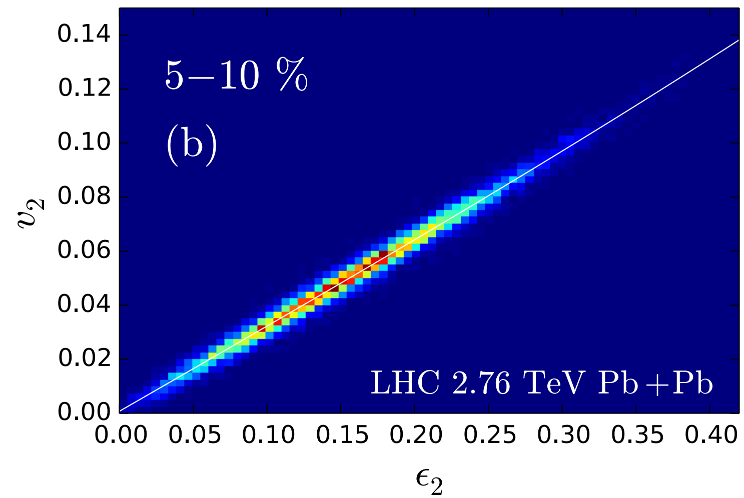
Medium response and initial state

Medium response e.g. system lifetime, η/s

Initial conditions

$$v_n = \kappa_n \varepsilon_n \big|_{n=2,3}$$

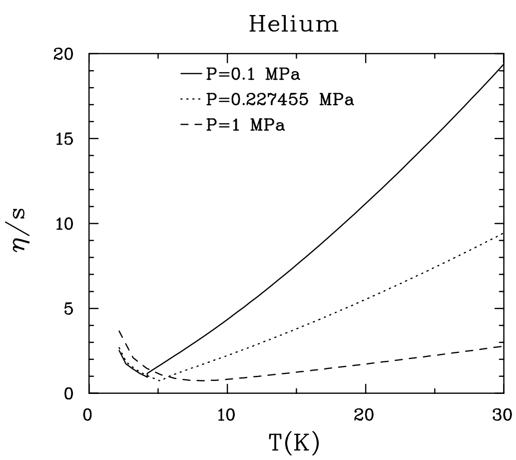
PRC 93 (2016) 024907

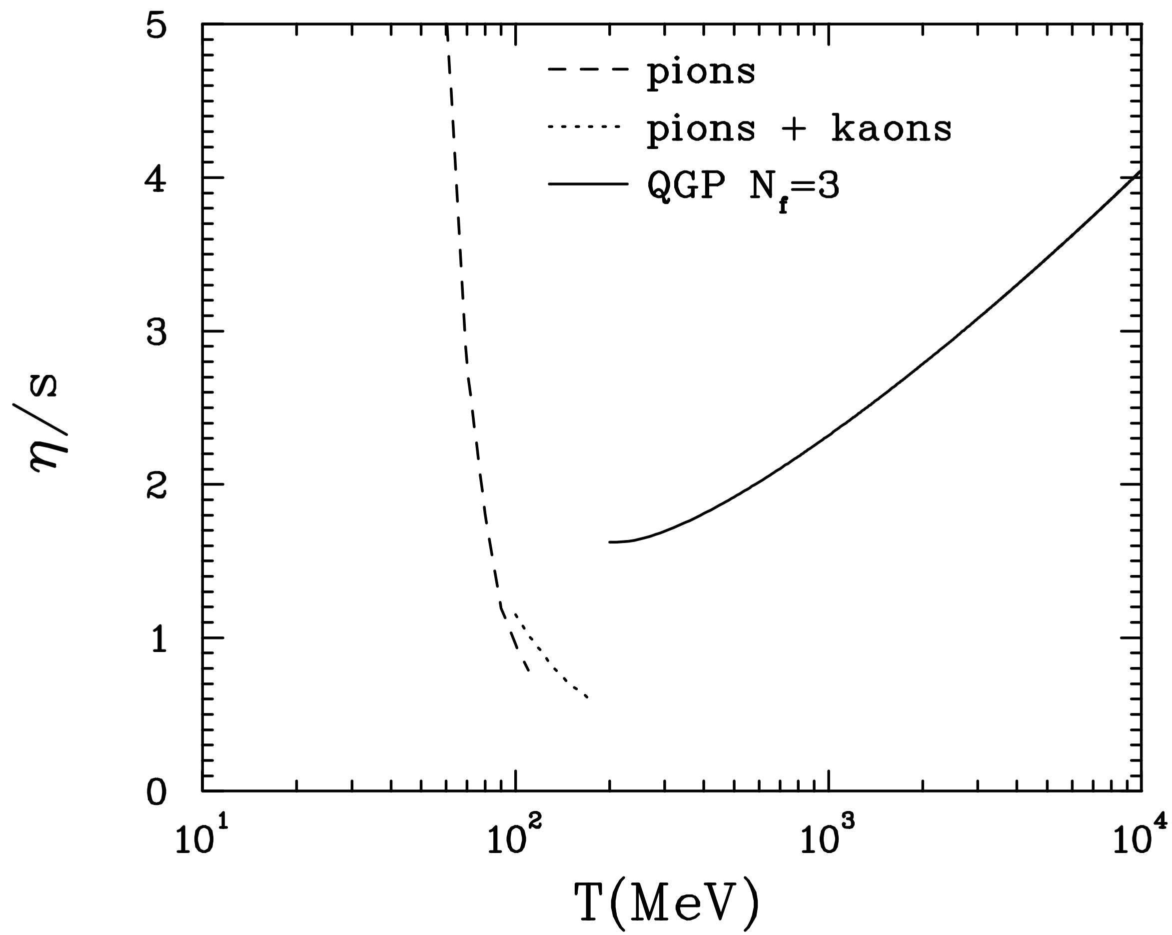


- Hydrodynamic calculations show simple factorization for lower orders
  - ✓ Not the case for n ≥ 4 e.g. v_4 has contribution from v_2

Temperature dependence of η/s

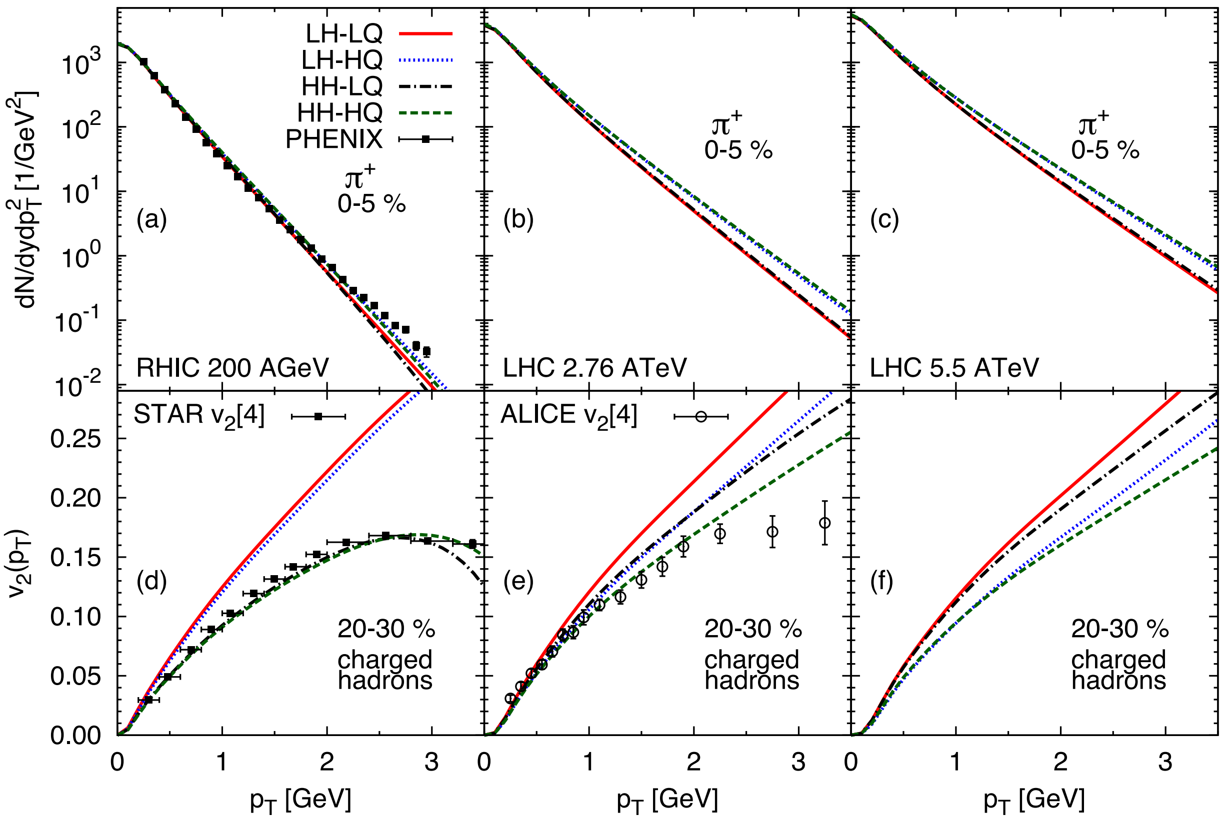
PRL 97 (2006) 152303



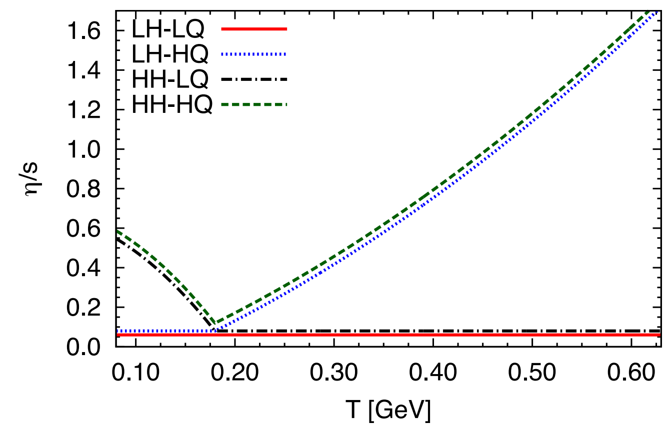


- Many fluids show temperature dependence of η/s with minimum around T_C
  - ✓ Minimum in QGP expected to correspond to ads/CFT conjecture of $1/4\pi$

Initial applications to hydrodynamics

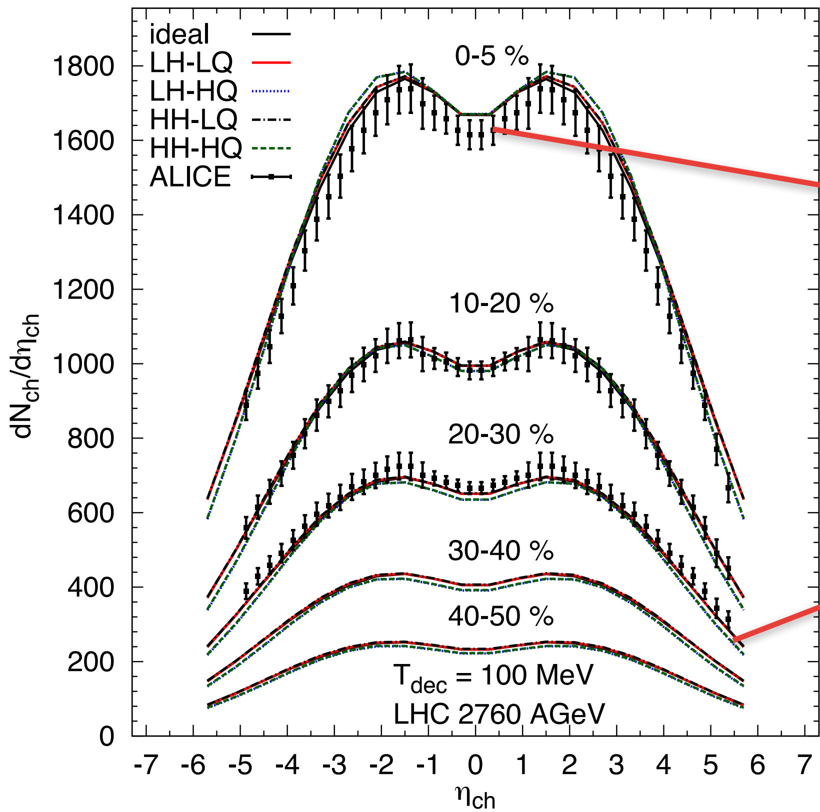


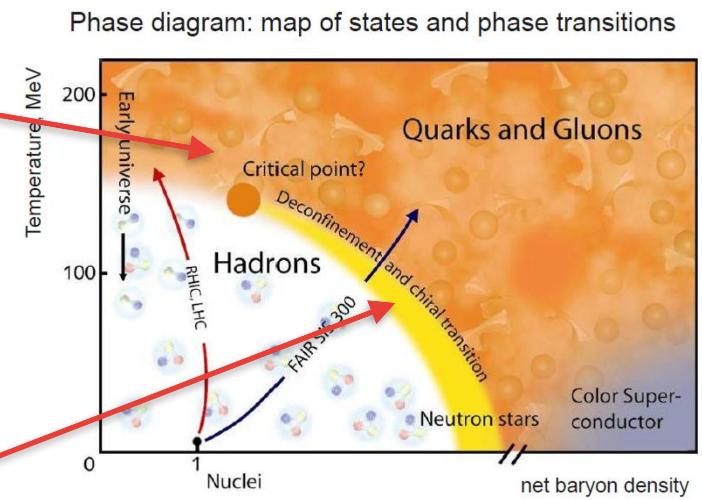
PRL 106 (2011) 212302



- Fixing value of η/s at 1/4π leads to underestimation of v_2
  - ✓ Data compatible with minimum of 1/4π only if η/s(T) allowed to vary
  - ✓ Little sensitivity to QGP η/s(T)

Beam energy scan at the LHC?

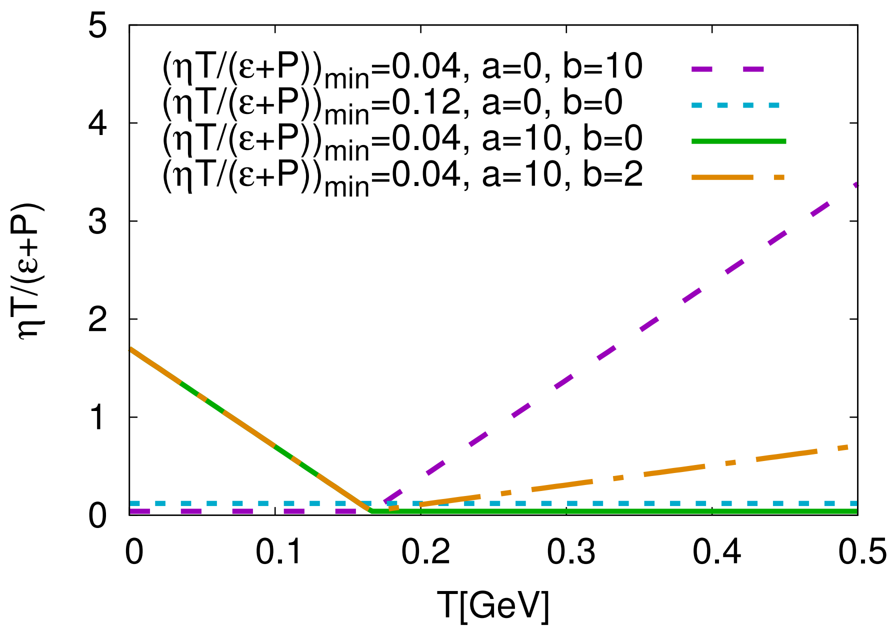




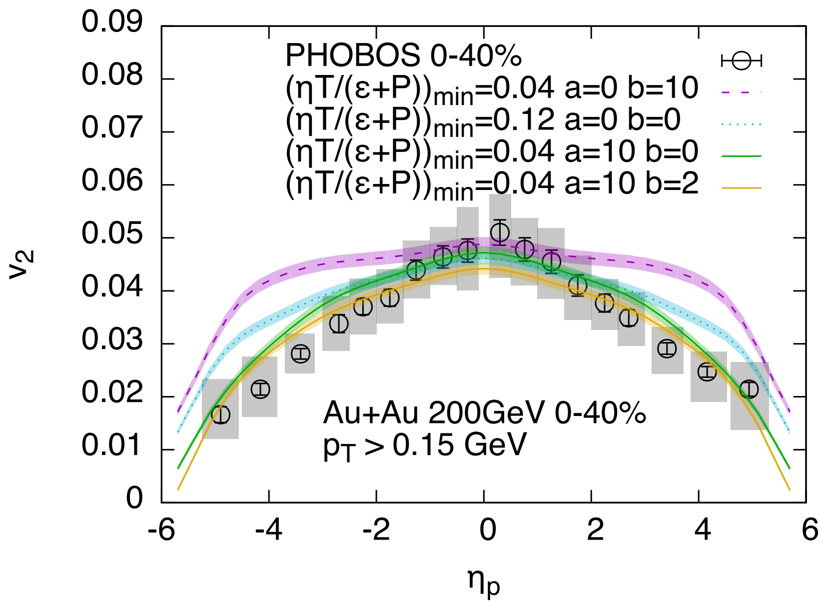
PRC 90 (2014) 044904
arXiv:1407.8152

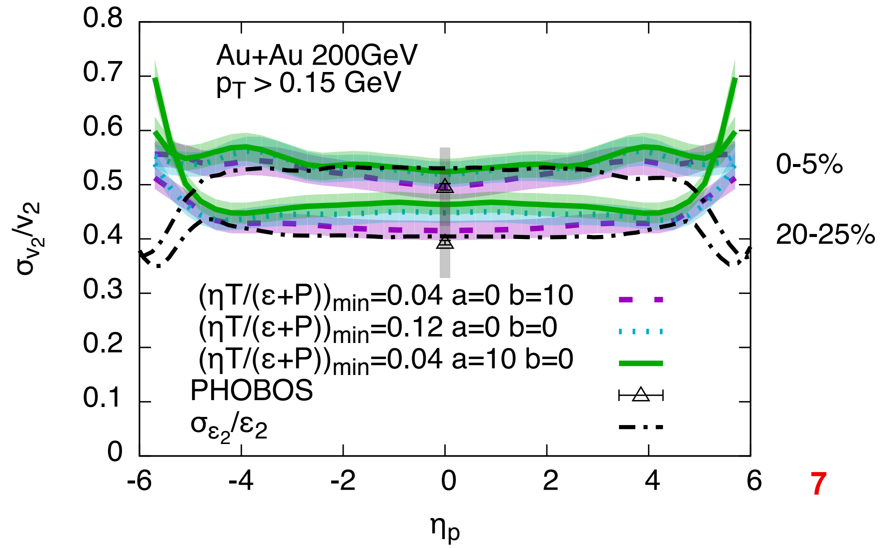
- Experimental observation: <p_T> and pbar/p decreases with increasing |η|
  - ✓ Average temperature decreases with increasing |η|
  - ✓ Extra handle on η/s(T)…

Moving forward to constrain the shear viscosity of QCD matter



PRL 116 (2016) 212301

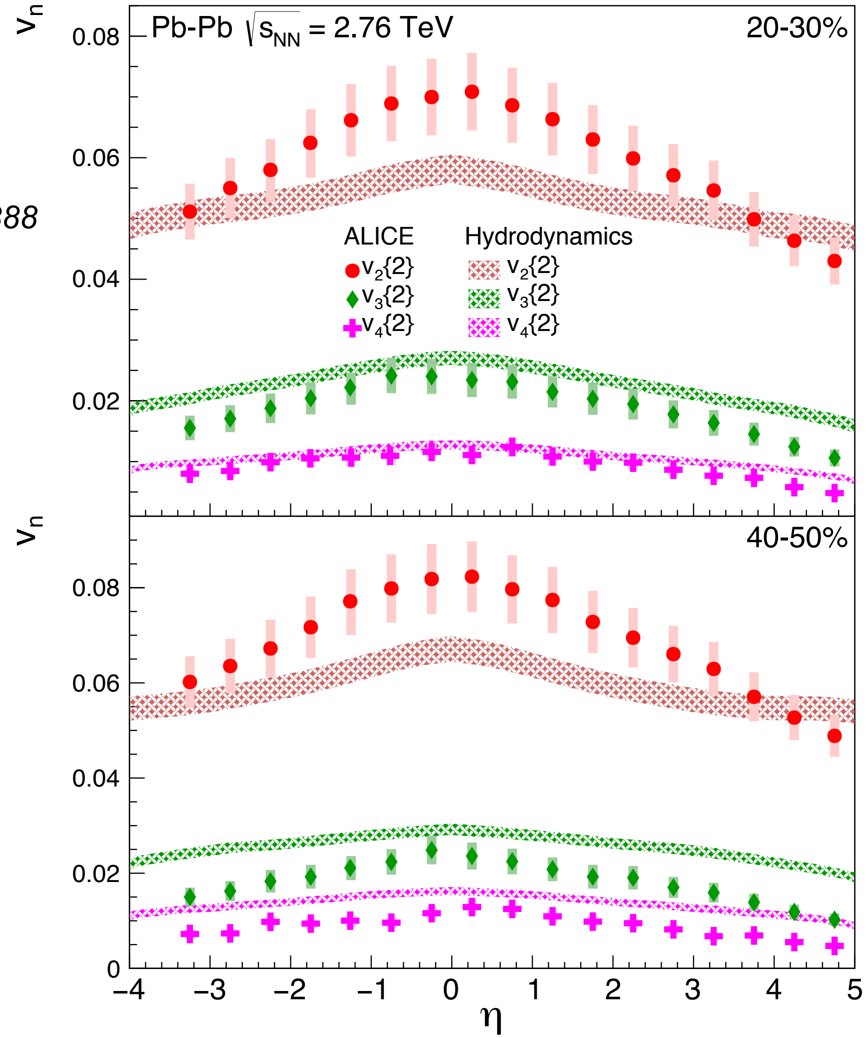


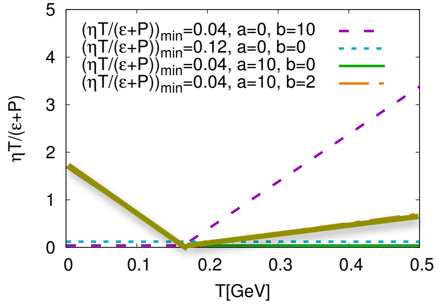


- Data favor **strong hadronic η/s, mild QGP η/s**
  - ✓ Initial conditions also appear to be modeled well.

PHOBOS tune applied to LHC data

Phys. Lett. B 762 (2016) 376-388

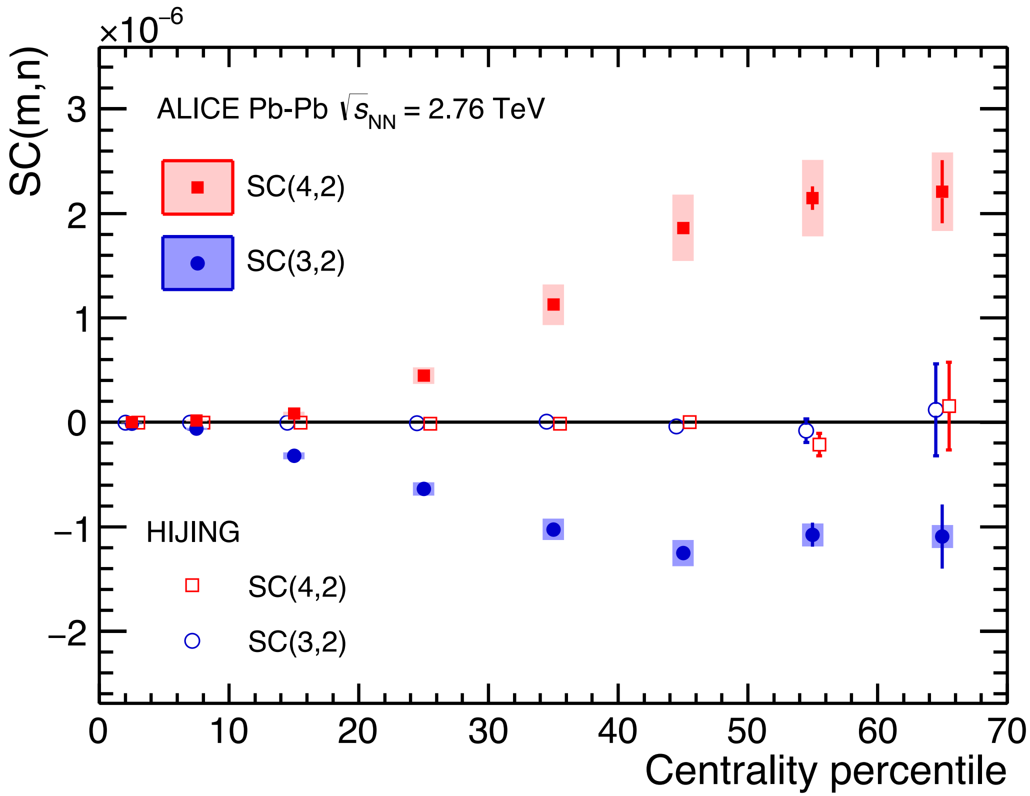




- **v_2 under predicted, v_3 and v_4 over predicted:**
  - ✓ Reduce hadronic η/s, increase QGP η/s? LHC data key constraint.

More differential tests..

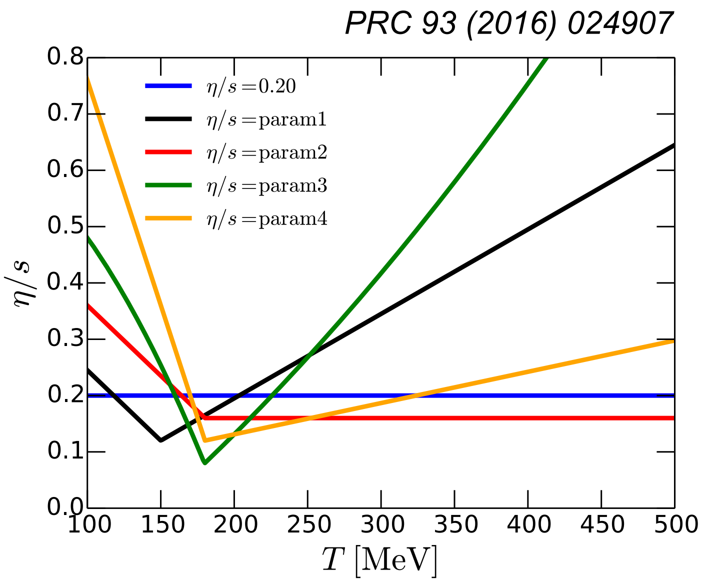
$$SC(m,n) = \langle v_m^2 v_n^2 \rangle - \langle v_m^2 \rangle \langle v_n^2 \rangle$$

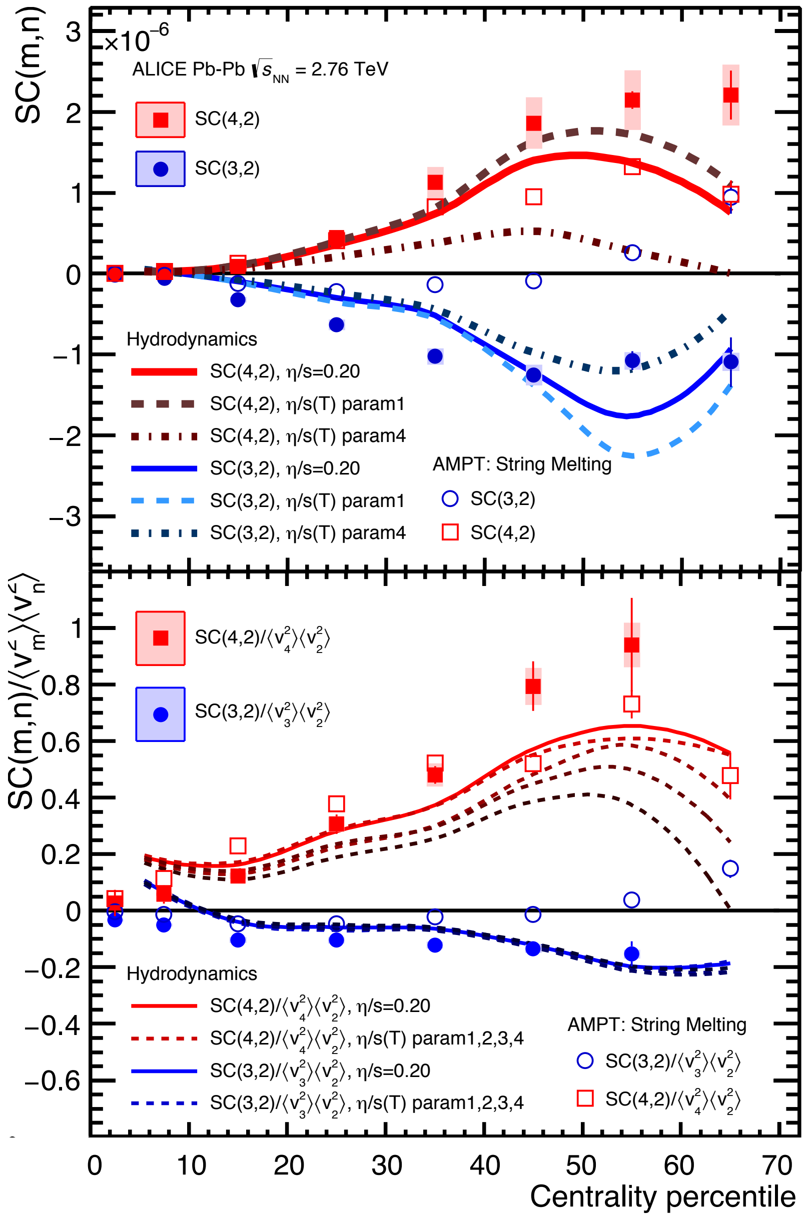


PRL 117 (2016) 182301

- SC(m,n) measures event by event covariance between v_m^2 and v_n^2
  - ✓ Non-flow highly suppressed.
  - ✓ Sensitivity to η/s(T)?

Correlations between different flow harmonics



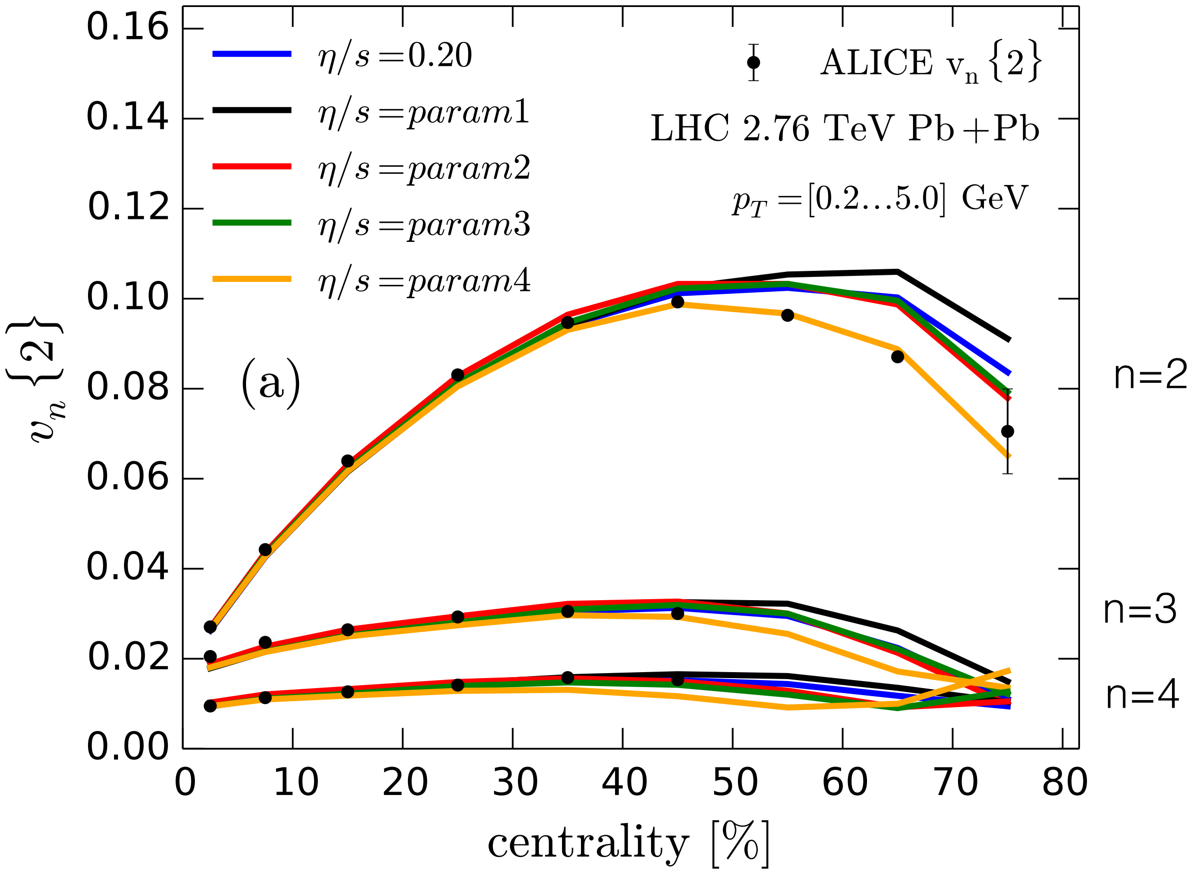


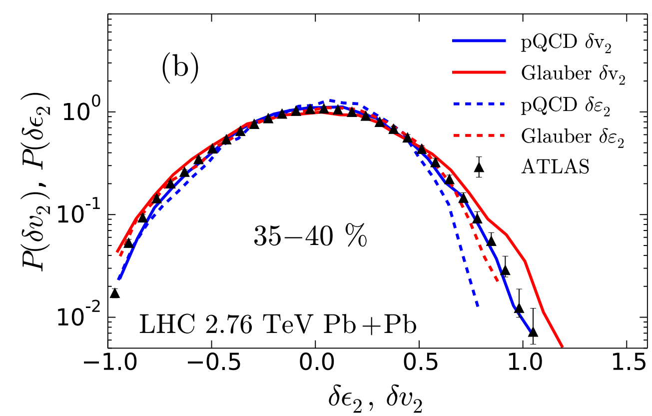
- SC(m,n) appears very promising in constraining η/s(T)

- Scaled SC(3,2) x2 bigger in data than initial conditions for 0-40%

$$SC(m,n) = \langle v_m^2 v_n^2 \rangle - \langle v_m^2 \rangle \langle v_n^2 \rangle$$

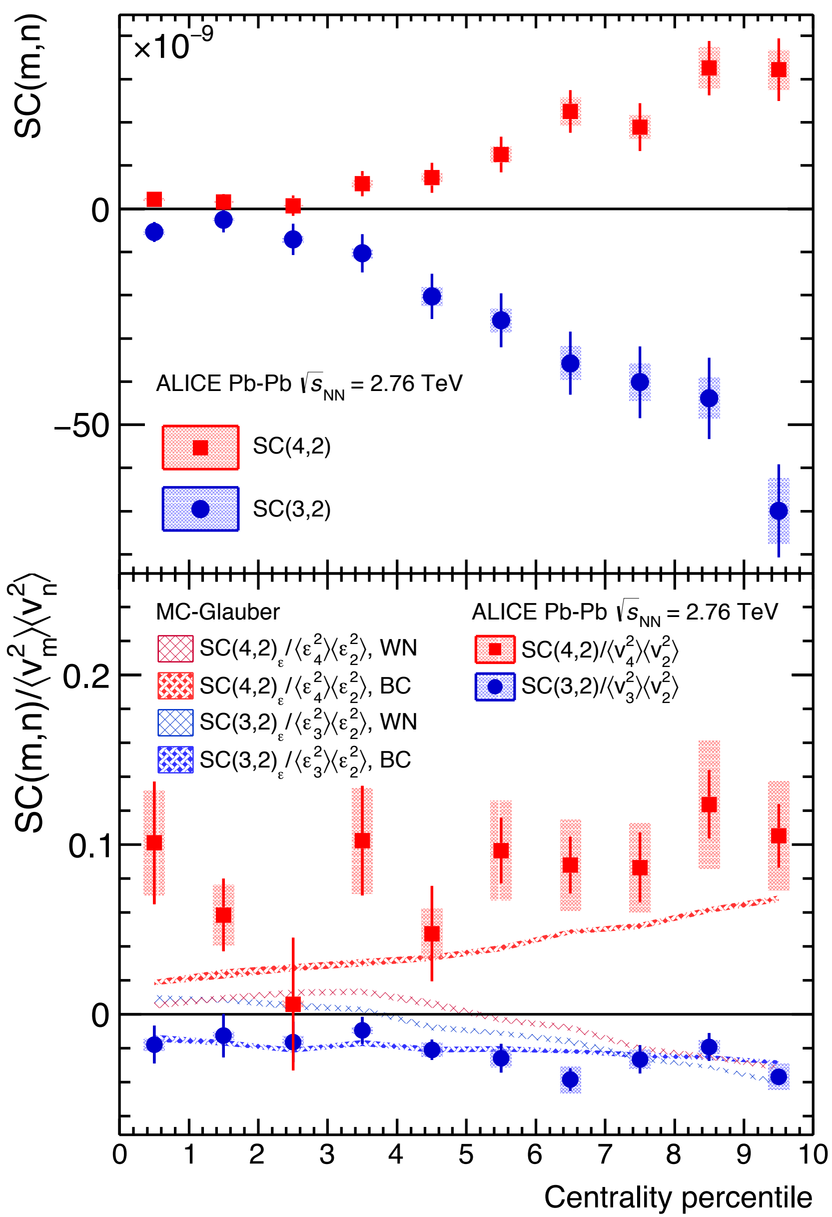
So, param4 is definitely wrong?



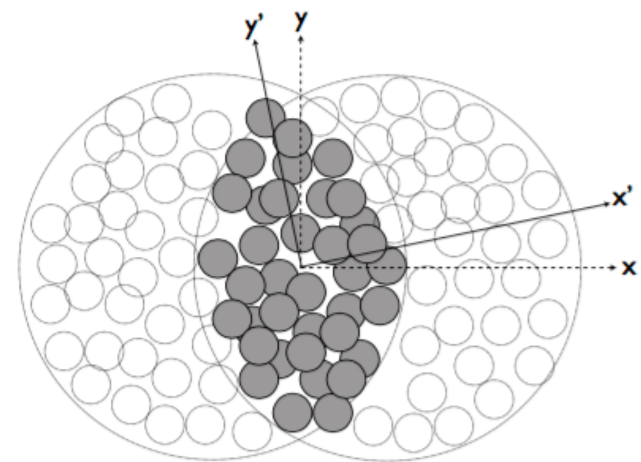


- Works well for single harmonics
  - ✓ Failure of modeling of initial conditions leads to difficulties using SC(m,n) for constraining η/s(T)?

Differing initial conditions for SC(m,n)



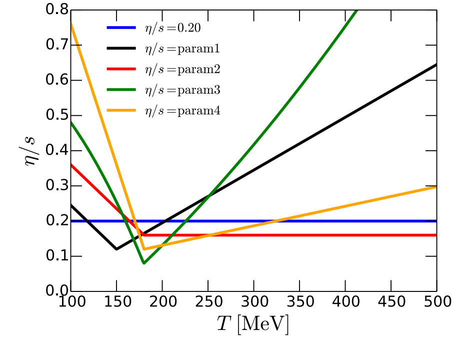
- Improvements can be made using different weights for eccentricity sources



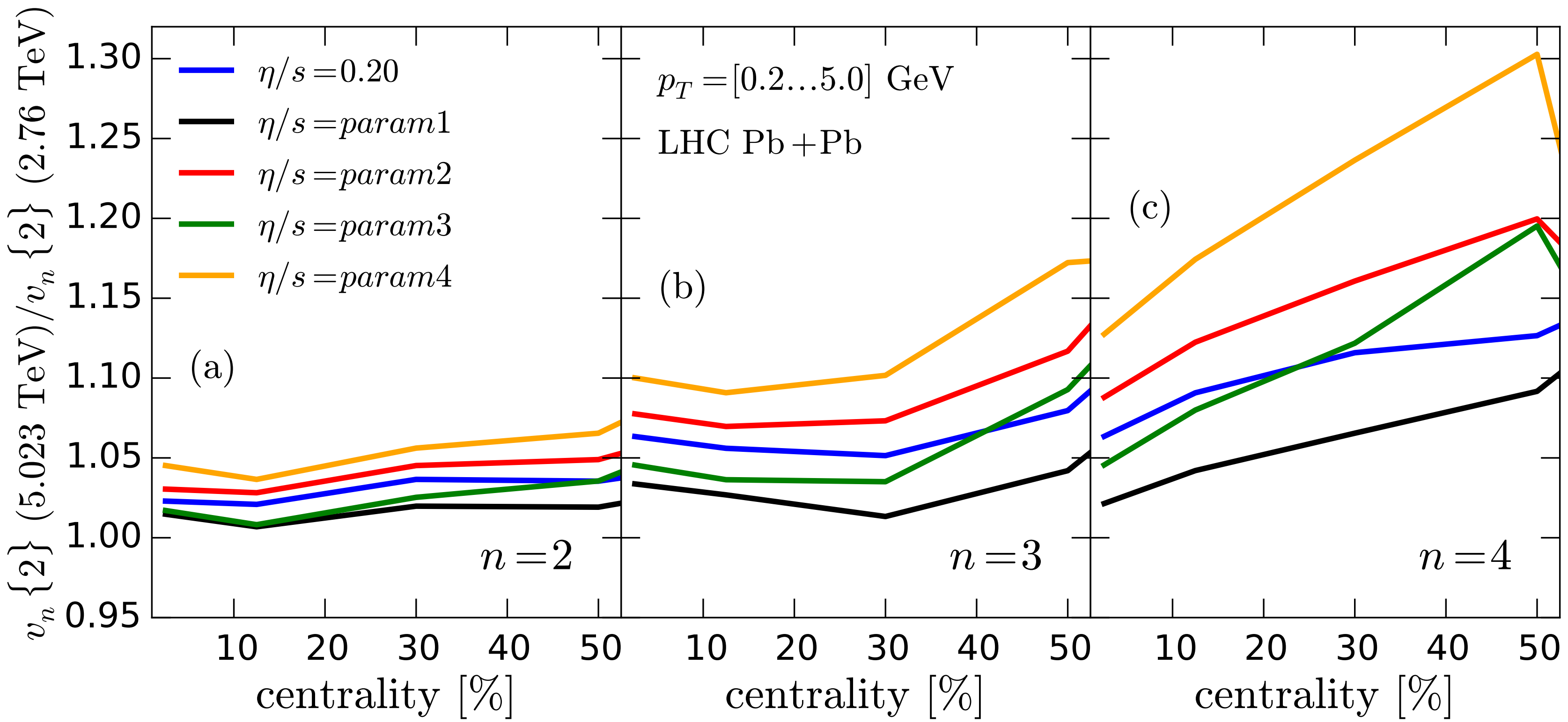
$$\epsilon_{\text{part}} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2}$$

where σ_x^2, σ_y^2 and σ_{xy} are the (co-)variances of the participant-weighted nucleon distribution in a given MCG event [2]. Their definitions and relation to the stan-

Ratios of v_n from different energies



PRC 93 (2016) 014912



- Predicted increase in LHC run 2 also depends on η/s(T)
  - ✓ Higher harmonics have better sensitivity…

Do the initial conditions cancel?

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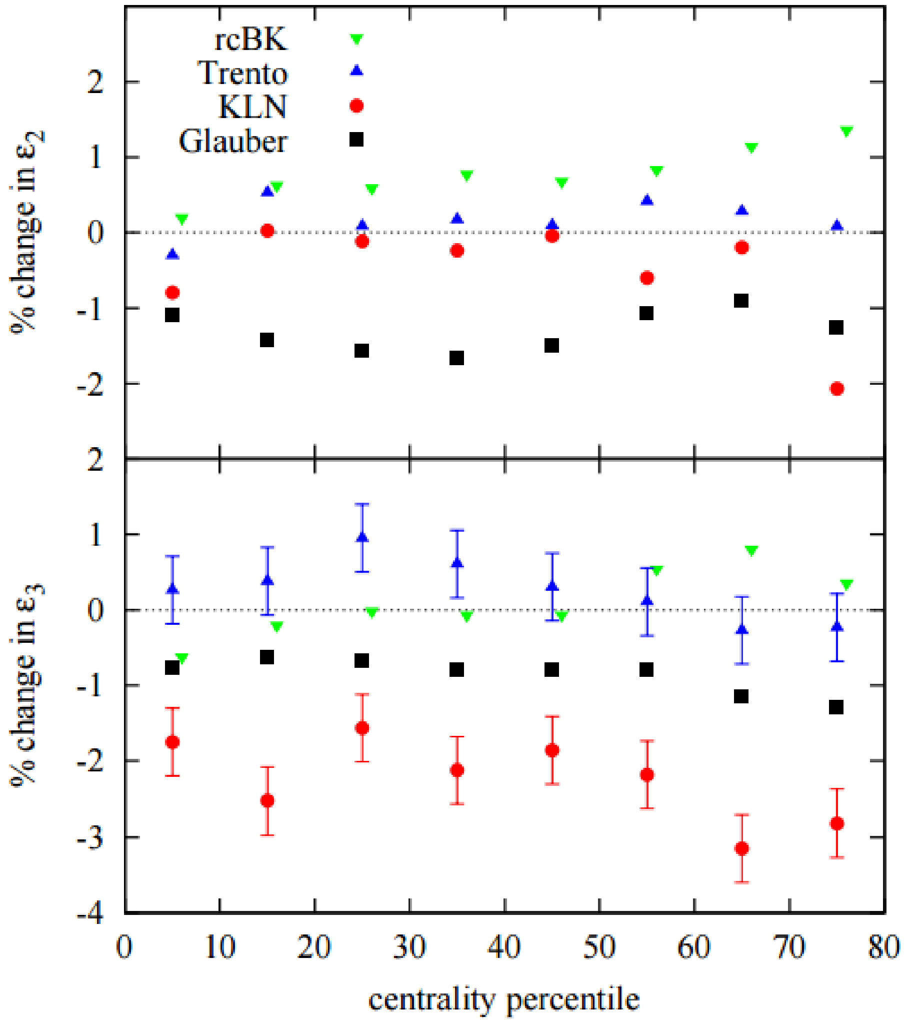
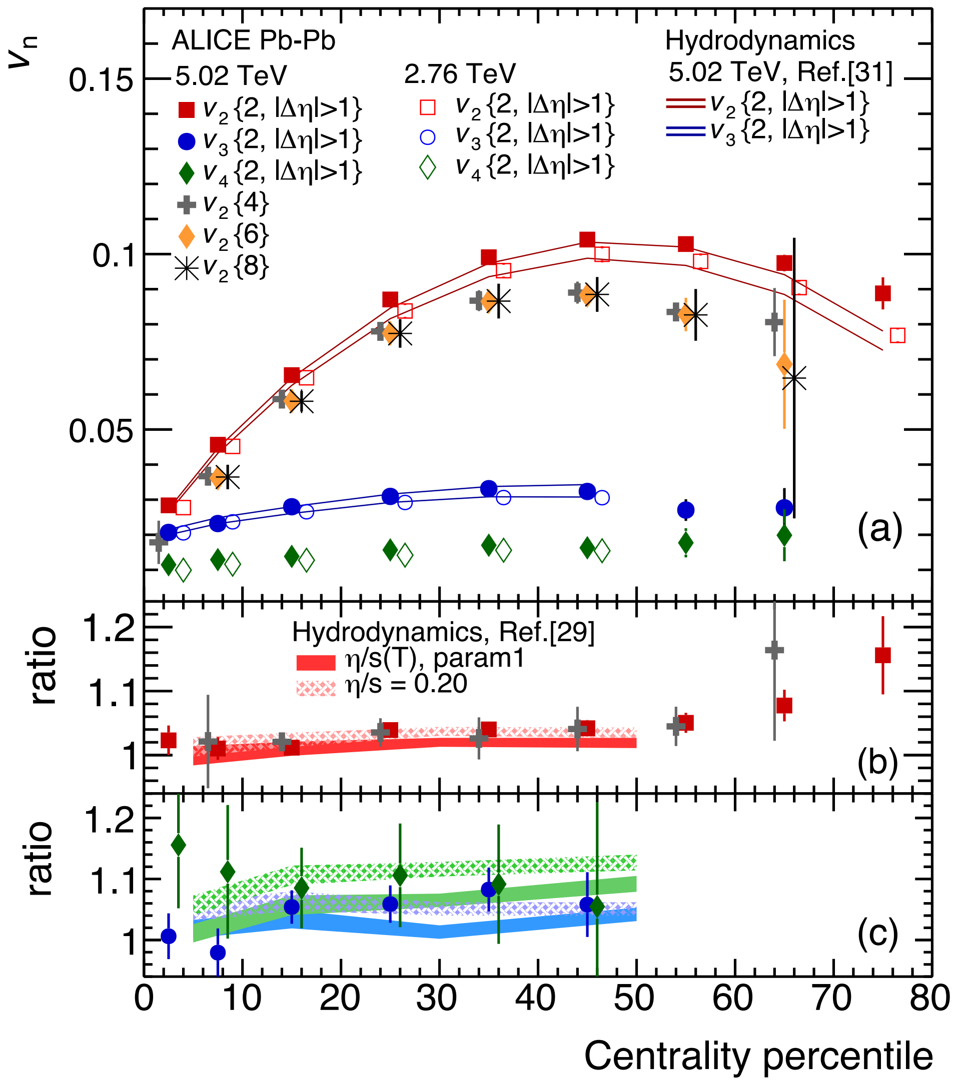
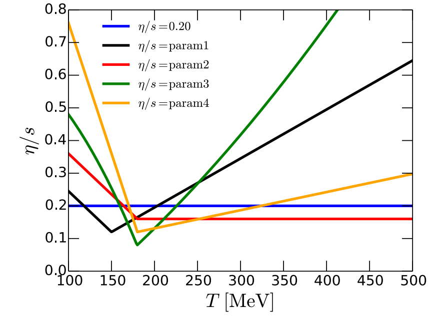


PRC 93 (2016) 034912

- Not quite, changes on order of differing hydrodynamic responses

Ratios of v_n from different energies





PRL 116 (2016) 132302

- Data follows predicted hydro increases. Need more stats to fully constrain η/s(T)

Conclusion

We still do not know $\eta/s(T)$ exactly for QGP matter!!