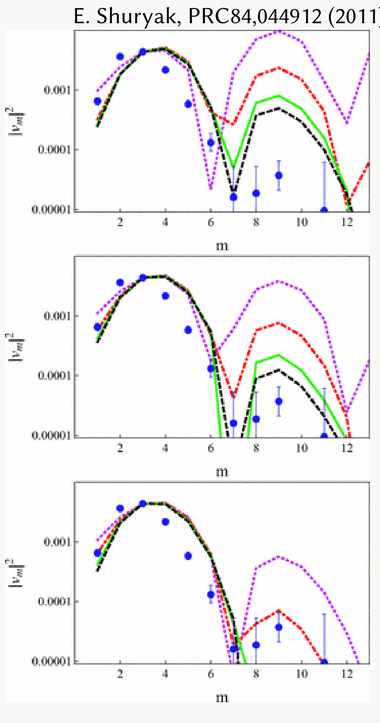
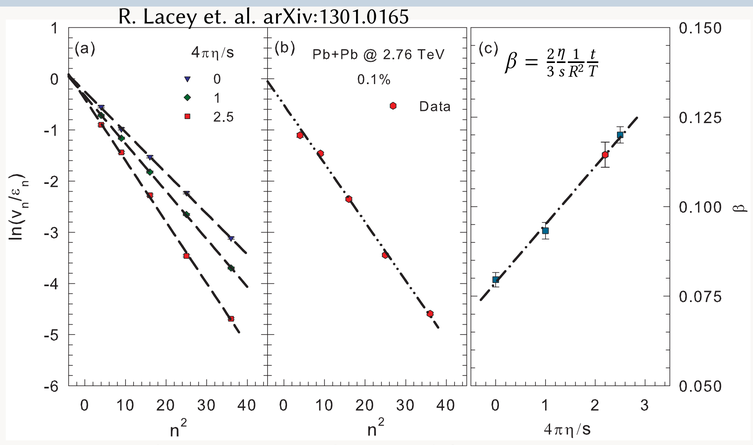
Flow harmonic power spectrum in heavy-ion collisions

Is anisotropic flow really acoustic?

E. Shuryak, PRC84,044912 (2011)



R. Lacey et. al. arXiv:1301.0165

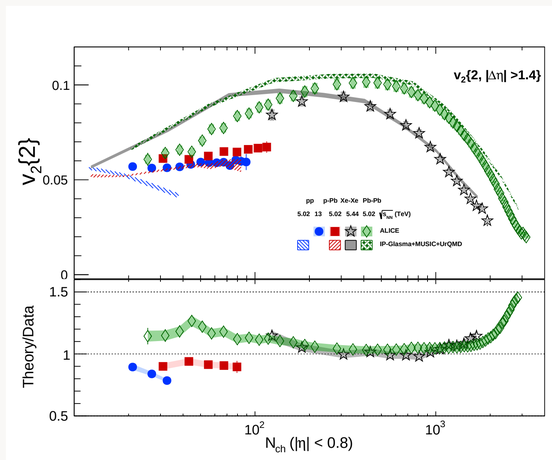


- According to E. Shuryak's paper supported by R. Lacey et. al, the following relation between v_n and n:

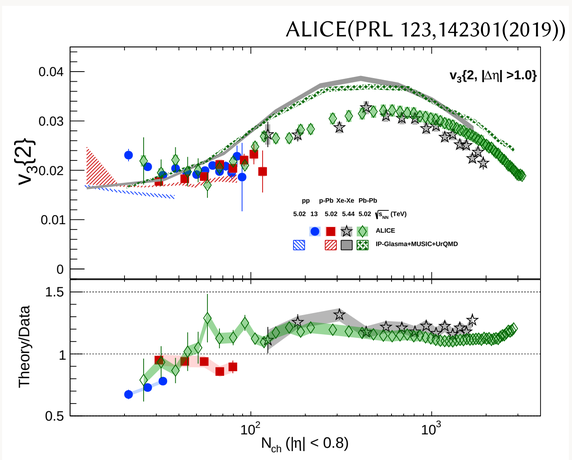
$$\log \frac{v_n}{\epsilon_n} \propto -n^2 \left(\frac{\eta}{s}\right)\left(\frac{1}{TR}\right).$$

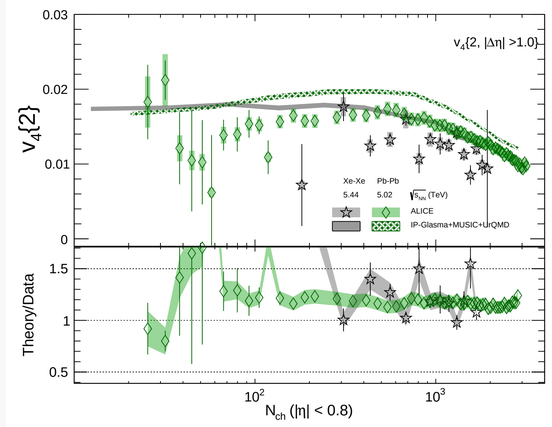
- three widths of the initial perturbation, 0.4, 0.7, and 1 fm, from top to bottom.
- η/s = 0, 0.08, 0.134, 0.16 lines from the top.

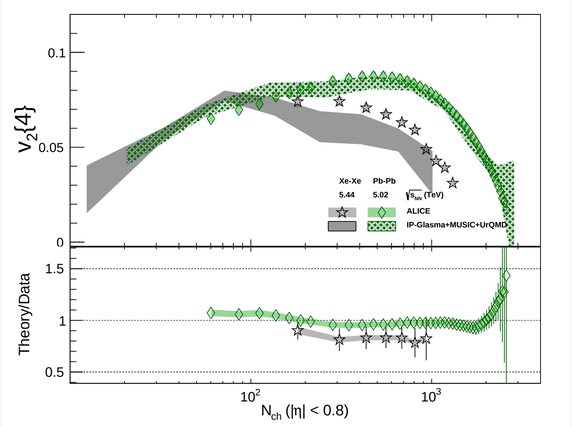
Small and large systems



ALICE(PRL 123,142301(2019))



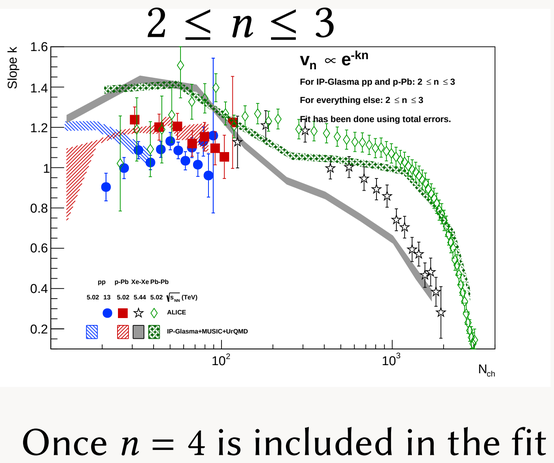




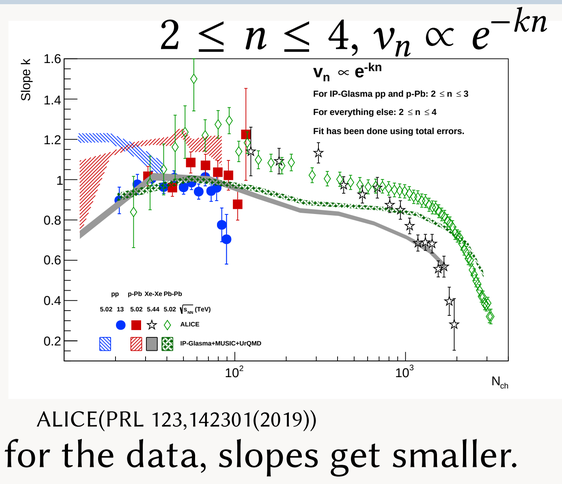
- Hydro agrees better for p-Pb than Pb-Pb, problem with pp data?
- Some cautions were left out for the most central collisions.
- What is the level of agreements we want to achieve from the theory?
- Current data are not sensitive to differentiate initial conditions and hydrodynamic response in small systems?
- Can we measure v_n for $n > 4$ in small systems?

Small vs larger systems, $2 \leq n \leq 4$

$2 \leq n \leq 3$



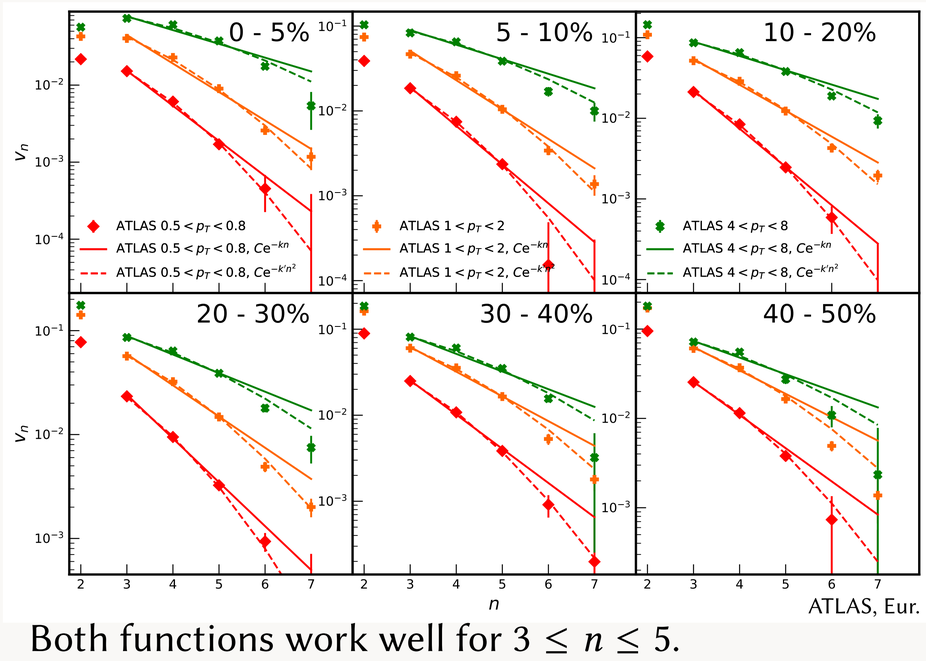
$2 \leq n \leq 4$, $v_n \propto e^{-kn}$



ALICE(PRL 123,142301(2019))

- Once $n = 4$ is included in the fit for the data, slopes get smaller.
  - The nature of v_n might be same for higher N_{ch} in pp and p-Pb compared to higher N_{ch} in Pb-Pb.
- Need to check with hydrodynamic model calculations $n > 3$.
- The higher order $v_n(n > 4)$ measurements in small systems should play an important role.

Higher harmonics viscous damping, Data



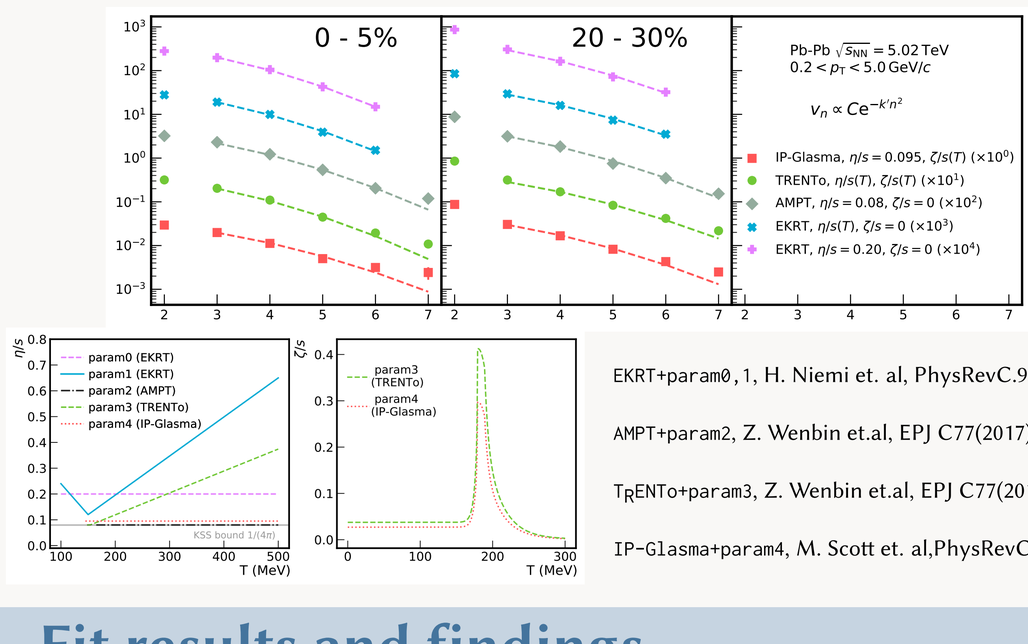
$v_n \propto e^{-kn}$

$v_n \propto e^{-k'n^2}$

ATLAS, Eur. Phys. J. C 78 (2018) 997

- Both functions work well for $3 \leq n \leq 5$.
- $e^{-k'n^2}$ works better for $n > 5$ for all the p_T bins and spectrum becomes steeper for low p_T bins.

Hydrodynamic model calculations



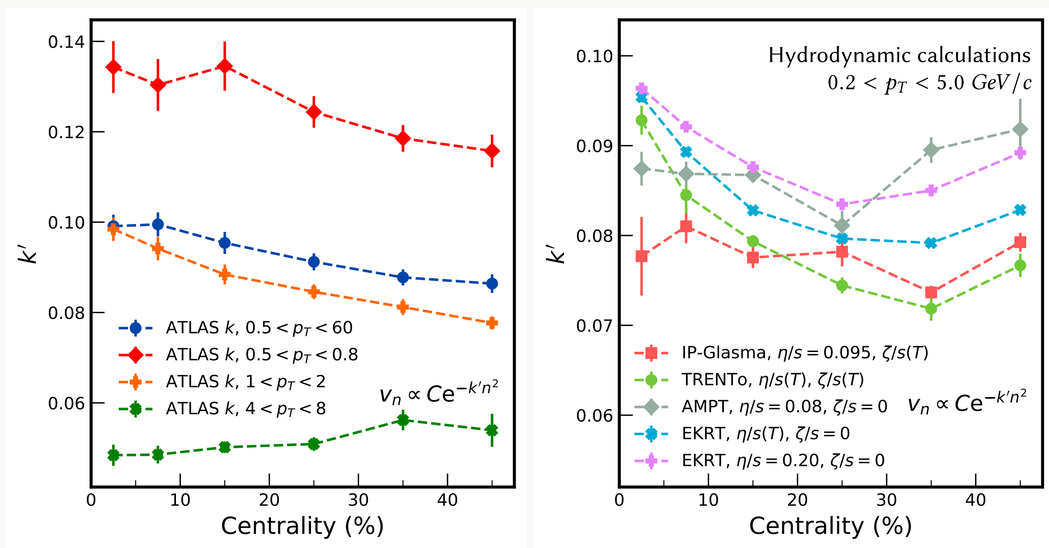
EKRT+param0,1, H. Niemi et. al, PhysRevC.93.024907

AMPT+param2, Z. Wenbin et.al, EPJ C77(2017) 645

TRENTo+param3, Z. Wenbin et.al, EPJ C77(2017) 645

IP-Glasma+param4, M. Scott et. al,PhysRevC.95.064913

Fit results and findings



- The slope(k') decreases toward peripheral collisions except for $4 < p_T < 8$ GeV/c and few hydro calculations.
- k' gets smaller for higher p_T bins and largest for intermediate p_T ranges, $0.5 < p_T < 0.8$ GeV/c, why?
- The magnitude of k' and it's centrality dependence are different in various hydrodynamic calculations with different η/s and ζ/s parametrizations.

Summary

- Flow harmonic power spectrum reflects clear viscous damping. Can reveal acoustic peak for $n > 7$?
- $v_n \propto e^{-k'n^2}$ works well up to $n = 7$.
- Interesting p_T dependence is observed for $0.5 < p_T < 0.8$ GeV/c and $4 < p_T < 8$ GeV/c.
- Clear differences of k' between the data and hydrodynamic calculations with different $\eta/s(T)$ and $\zeta/s(T)$ parameterizations.
- The higher order $v_n(n > 4)$ measurements in small systems will help us to differentiate initial conditions and hydro response in small systems.

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