



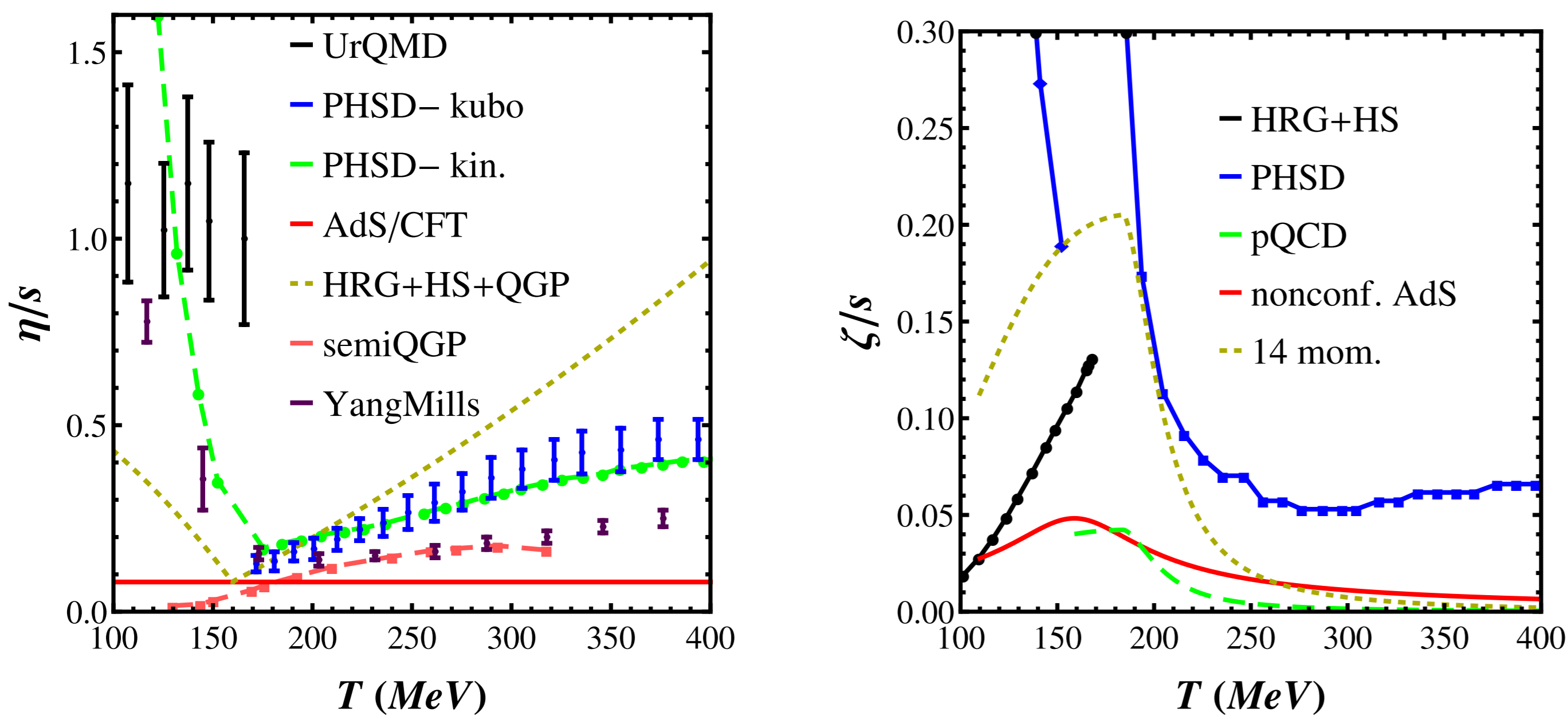
Extracting the shear viscosity of the QGP in the presence of bulk viscosity

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Theoretical Calculations of η/s and ζ/s

Wide variation in theoretical calculations...



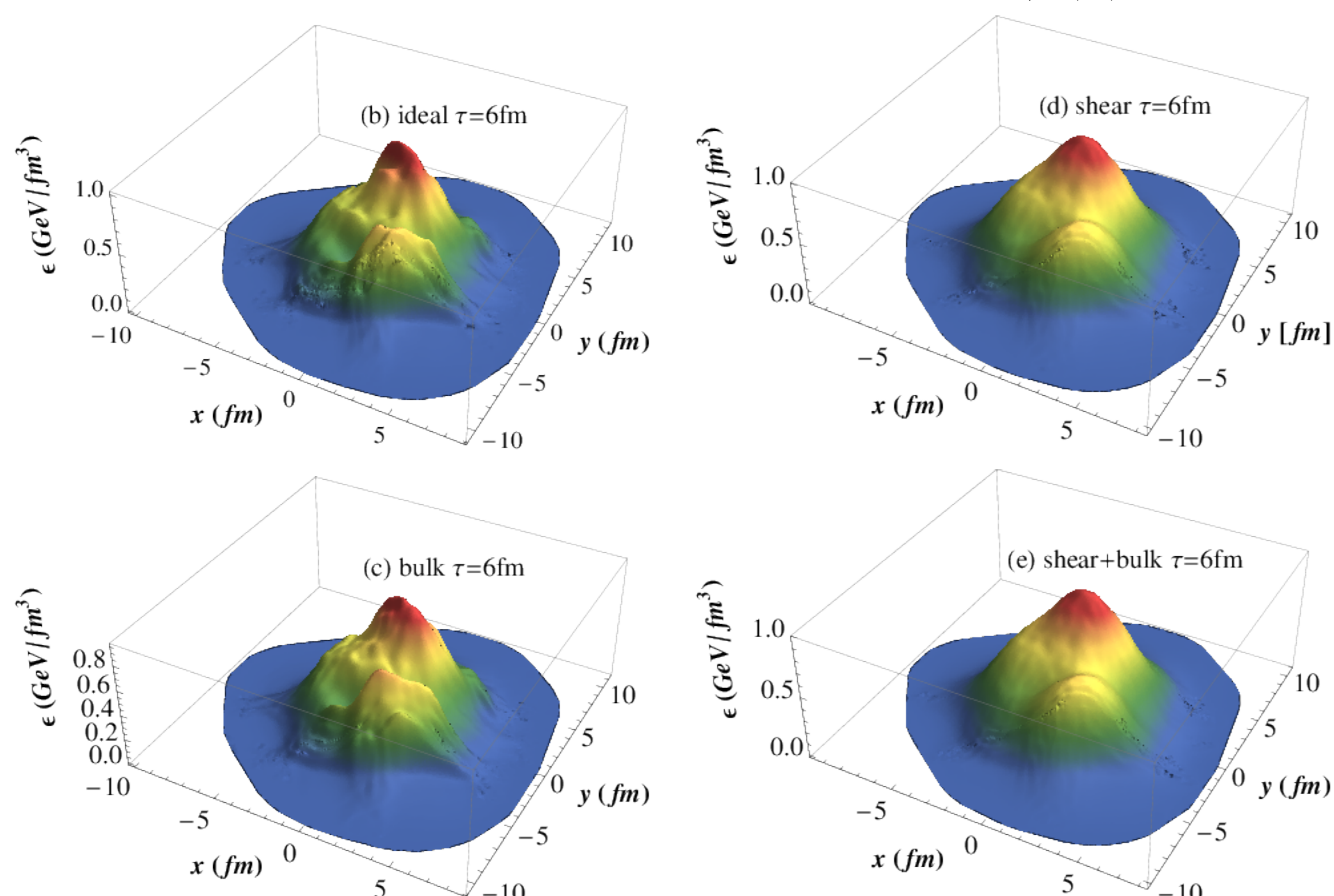
- HS [1]+QGP (Niemi et al PRL106(2011)212302)
- PHSD (PRC87(2013)064903)
- AdS/CFT (PRL94(2005)111601)
- UrQMD (Demir, Bass PRL(2009)102)
- semi-QGP- $\kappa = 32$ (Hidaka, Pisarski PRD81(2010)076002)
- Also, Csernai et al PRL 97, 152303 (2006)
- HRG+HS (Kadam and Mishra arXiv:1408.6329)
- Peak also seen in [1] and Kharzeev JHEP 0809 (2008) 093
- PHSD (PRC87(2013)064903)
- non-conformal holographic model [2]
- pQCD (Arnold et al, PRD74(2006)085021)
- 14 mom. [3]

Setup

- Event-by-event calculations done in v-USPhydro [4] (2+1 relativistic, viscous hydrodynamical code that uses Smoothed Particle Hydrodynamics)
- Glauber [5] and NEXUS [6] initial conditions
- δf from [8] in the form $\delta f \propto E_0 + B_0(u \cdot p) + D_0(u \cdot p)^2$
- Latticed based EOS, hadronic decays included

Effects in the hydrodynamics

Given a Glauber initial condition, after $\Delta\tau = 5$ fm [4] (very small $\zeta/s(T)$ used)



Compare percentage change of mean and variance in the presence of $\eta/s(T)+\zeta/s(T)$ vs. $\zeta/s(T)$ only (or $\eta/s(T)$ only)

Effects of $\eta/s(T)$ on Π

- The mean has almost no variation
- $\eta/s(T) \uparrow$ the variation in Π (at late times)
- Variation \downarrow significantly at early times

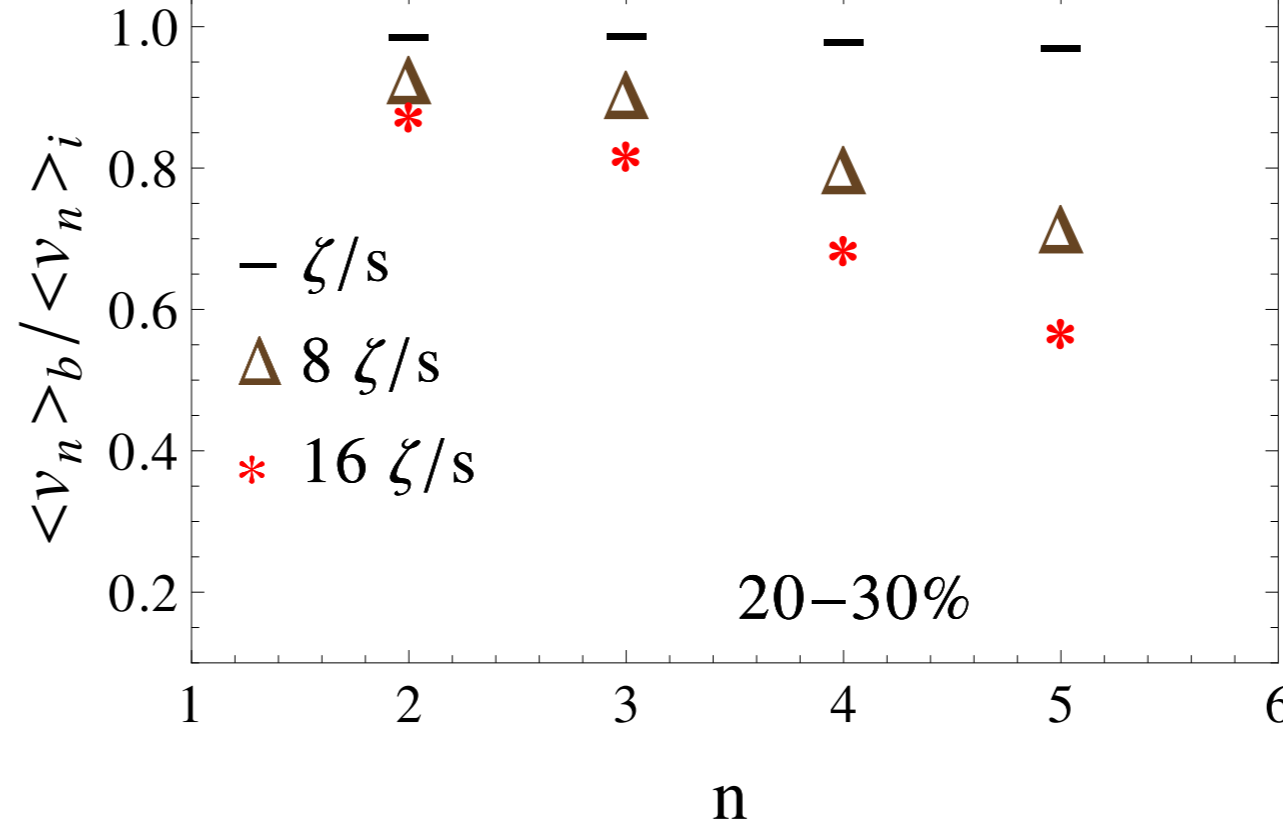
Effects of $\zeta/s(T)$ on π^{00} and π^{12}

- $\zeta/s(T)$ suppresses the $\pi^{\mu\nu}$
- Largest effect at late times.
- Variation \downarrow across the board

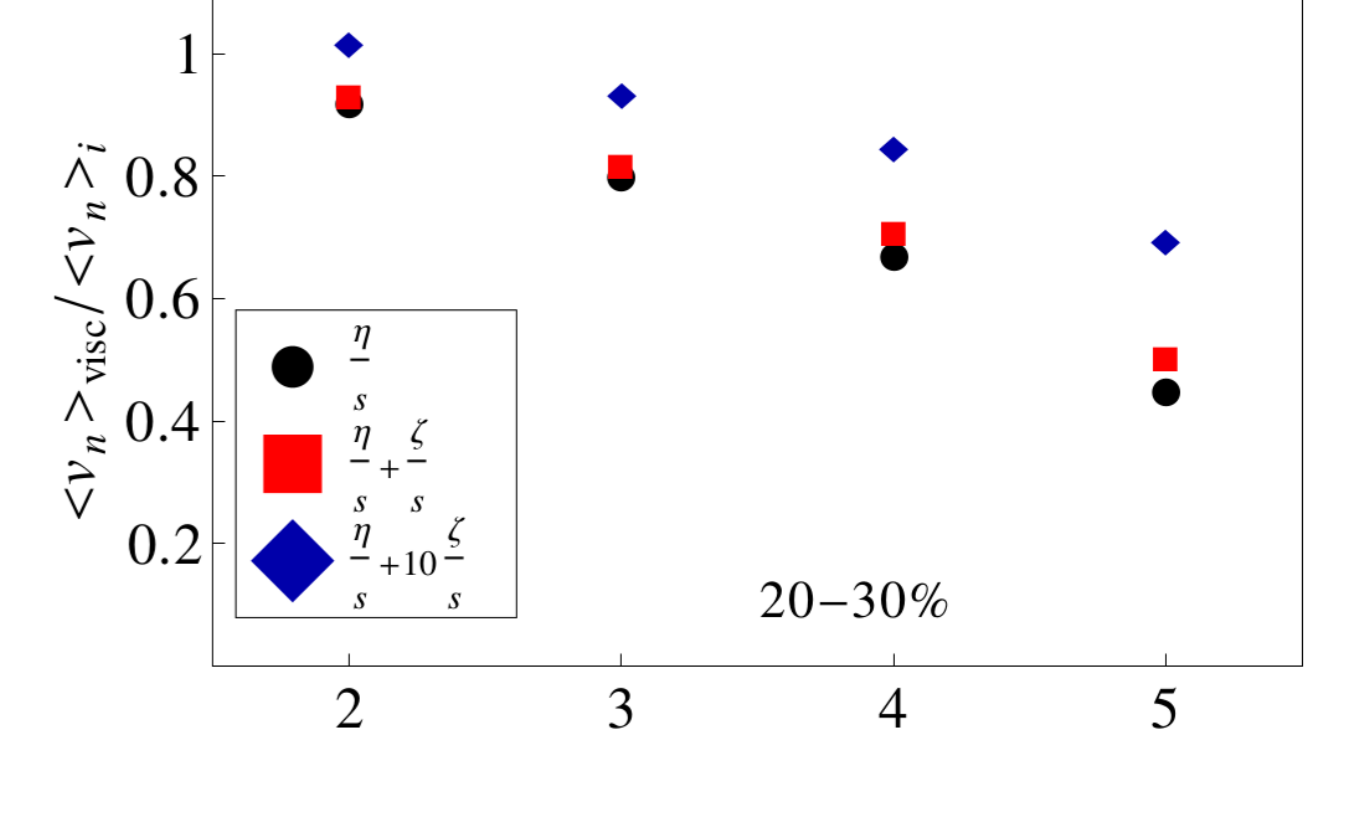
Qualitative Effects on Flow

Direct π^+ 's for $T_{FO} = 150$ MeV (Glauber initial conditions)

No δf correction $\downarrow v_n$'s for large ζ/s



$\delta f \uparrow v_n$'s

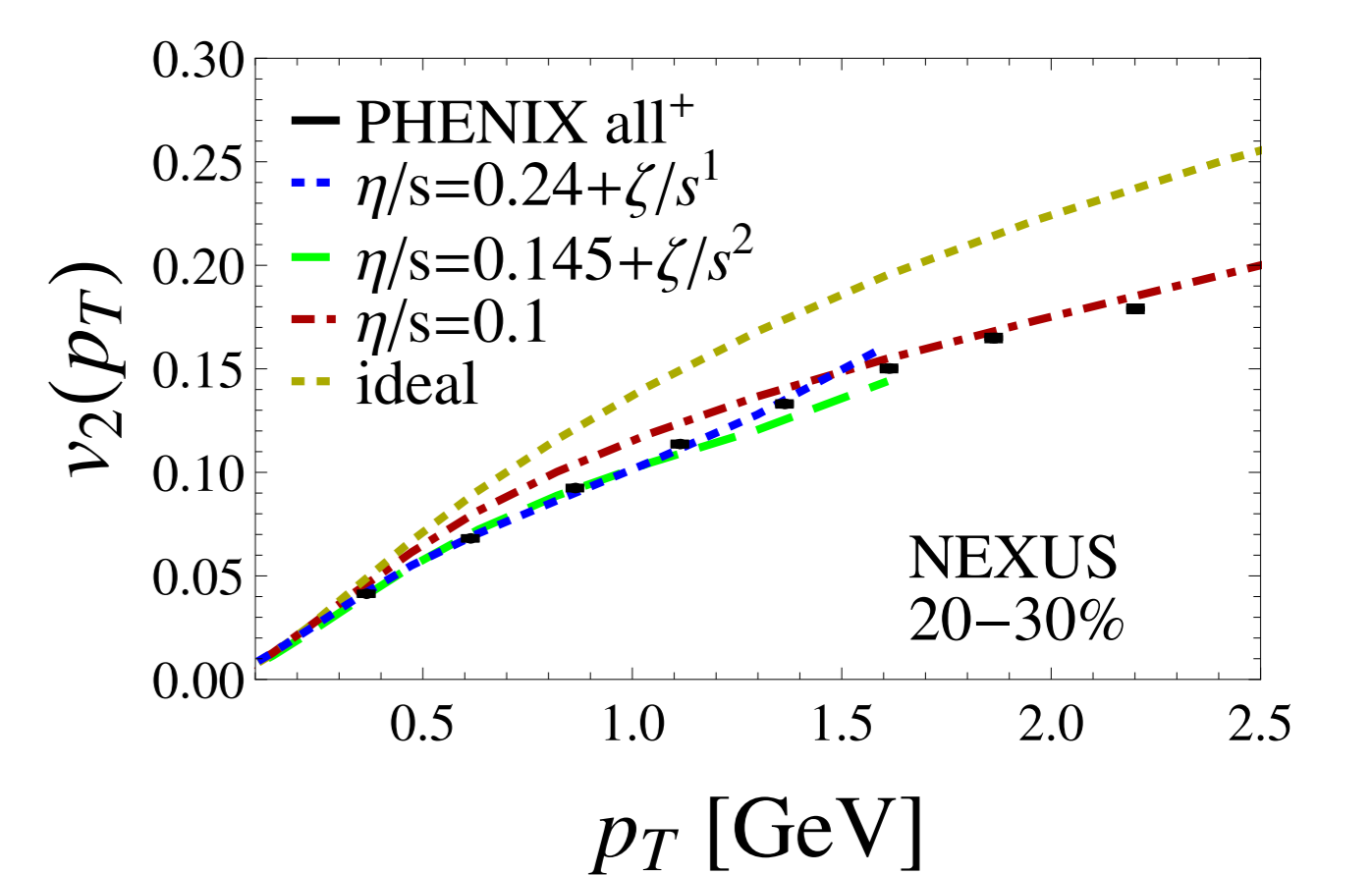
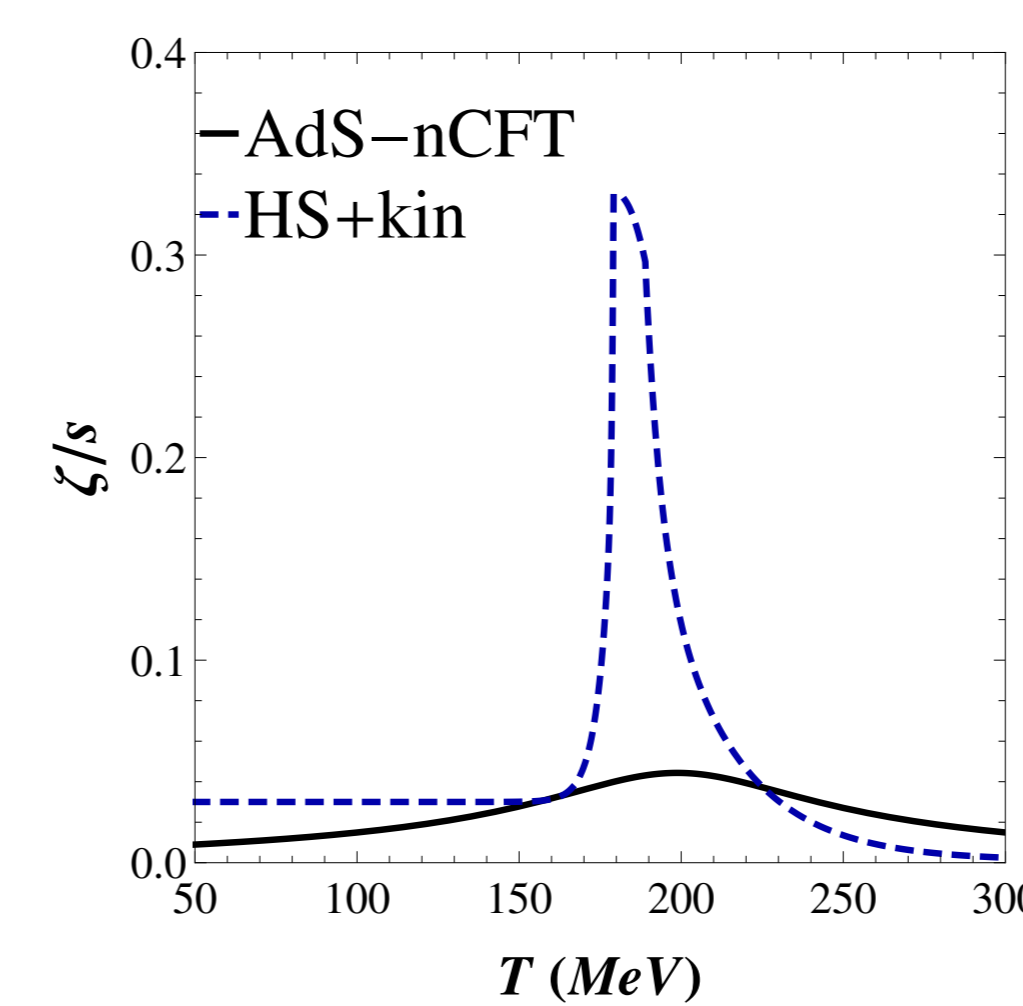


- Differential flow, $v_n(p_T)$ harmonics show a much strong dependence on the type of δf corrections (specifically at high p_T)
- Choice in δf plays a much smaller role for integrated v_n 's
- Peripheral collisions and higher order flow harmonics more strongly affected by bulk viscosity

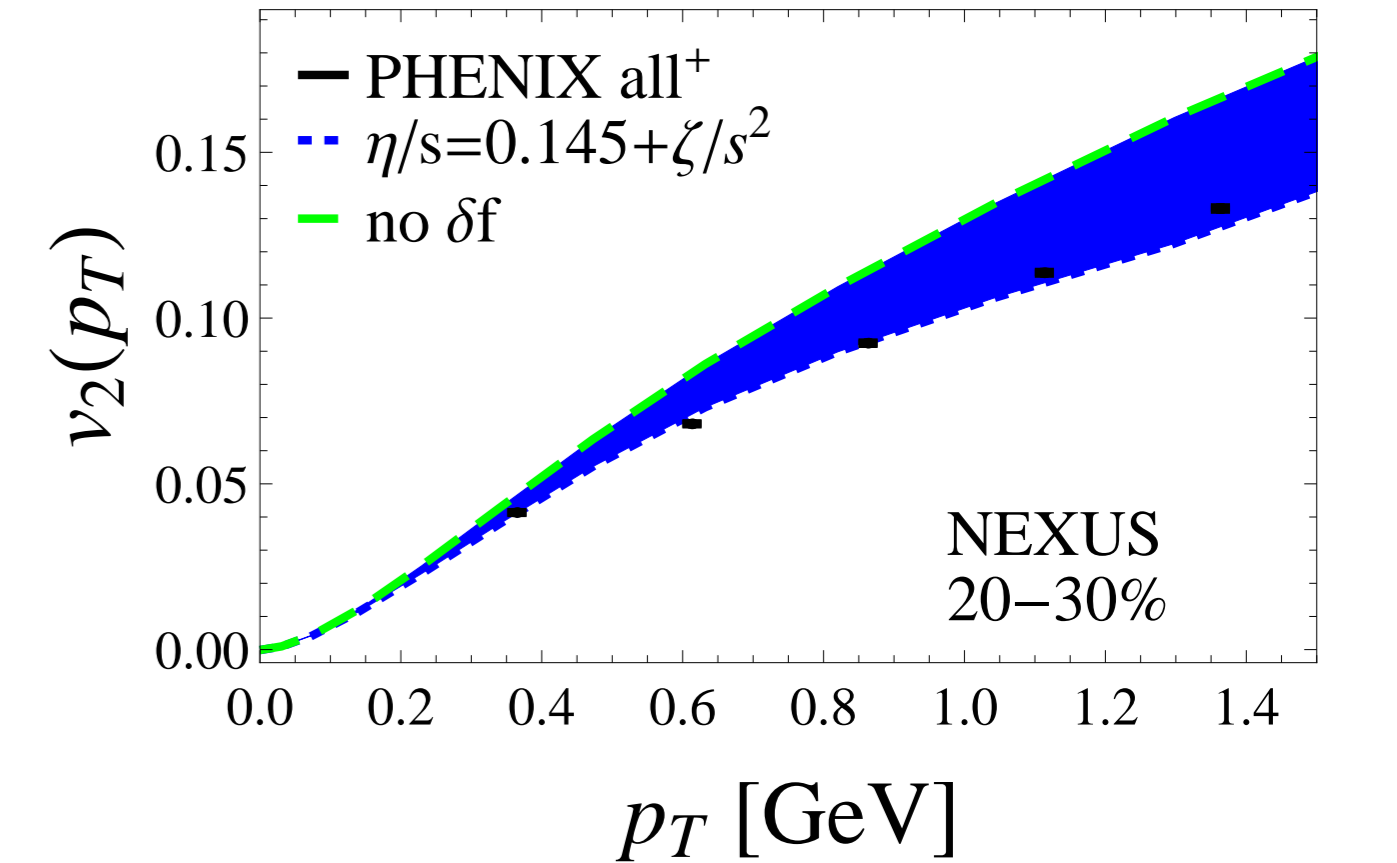
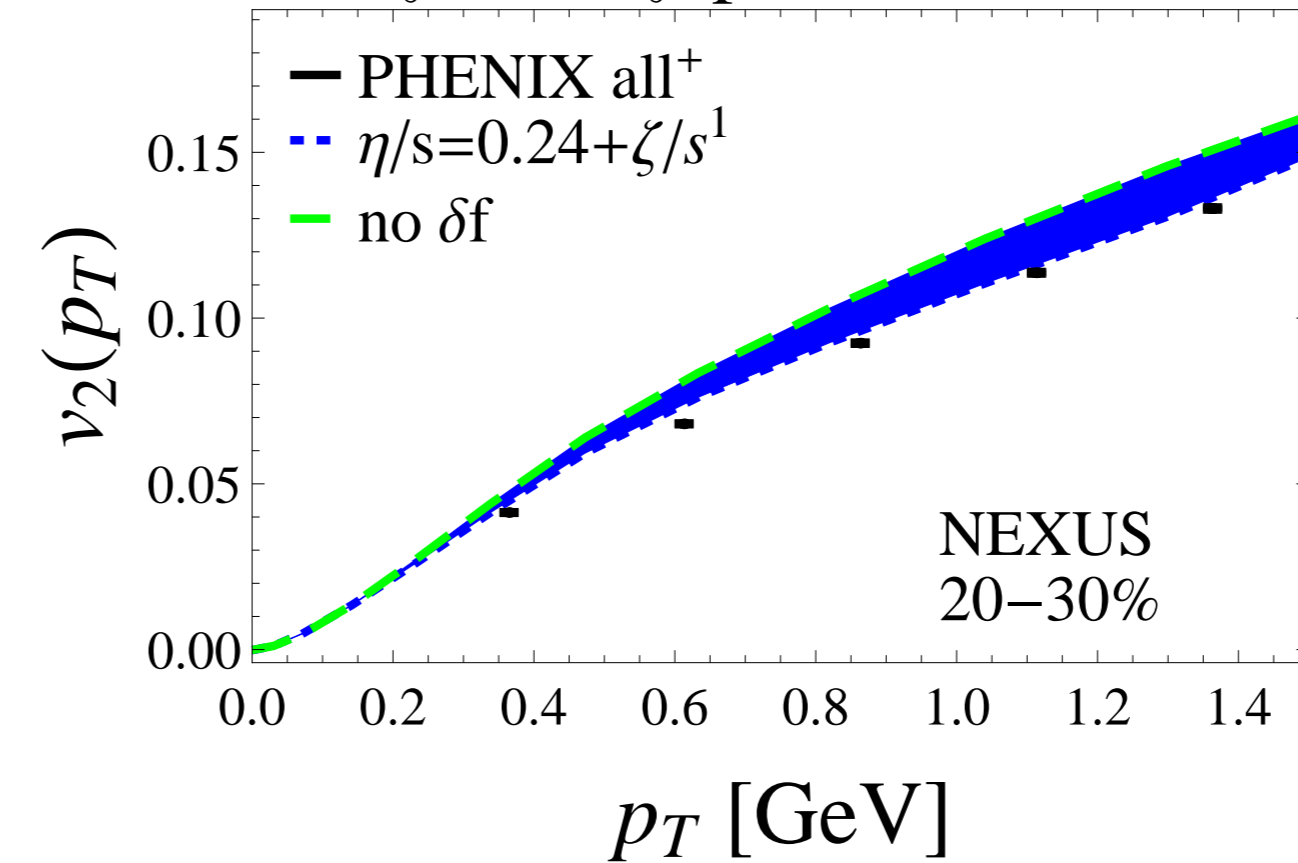
Extracting η/s from ζ/s

η/s is taken as a constant to fit the data with two different bulk choices (NEXUS initial conditions):

- $(\zeta/s)_1$ Hagedorn States (hadron gas phase) [1] +kinetic theory (QGP) [3] (as in [7])
- $(\zeta/s)_2$ non-conformal AdS [2]



Effects from δf . No δf plots exclude both bulk and shear corrections



Conclusions and Outlook

- For no δf correction $\uparrow \zeta/s \downarrow v_n$'s. However, the bulk δf correction $\uparrow v_n$ (in contrast the shear δf correction $\downarrow v_n$).
- $\eta/s + \zeta/s$ provides a slight better fit to v_2 over just η/s for NEXUS initial conditions
- Size of η/s plays the largest role for no δf correction, also $\uparrow \eta/s$ appears to \downarrow total effect of δf for both shear and bulk

References

- [1] JNH et al PRL103(2009)172302
- [2] Finazzo et al - JHEP 1502 (2015) 051
- [3] Denicol et al, PRC90(2014)024912
- [4] JNH et al, PRC90(2014)3,034907; PRC88(2013)044916
- [5] Miller et al, Ann. Rev. Nucl. Part. Sci. 57, 205 (2007); Alver et al, arXiv:0805.4411; Loizides et al, arXiv:1408.2549; Albacete et al, J.Phys.Conf.Ser. 316 (2011) 012011; Drescher et al, Phys.Rev. C74 (2006) 044905
- [6] Drescher et al, Phys.Rept.(2001)350 93
- [7] Ryu et al, arXiv:1502.01675
- [8] Monnai and Hirano, Nucl.Phys. A847 (2010) 283-314