Temperature Dependence of QGP shear Viscosity within Lattice Simulations

N. Yu. Astrakhantsev[1,2], V. V. Braguta[1,2], A. Yu. Kotov[1]

[1]Institute for Theoretical and Experimental Physics, Moscow, 117218 Russia
[2]Moscow Institute of Physics and Technology, Dolgoprudny, 141700 Russia

Introduction

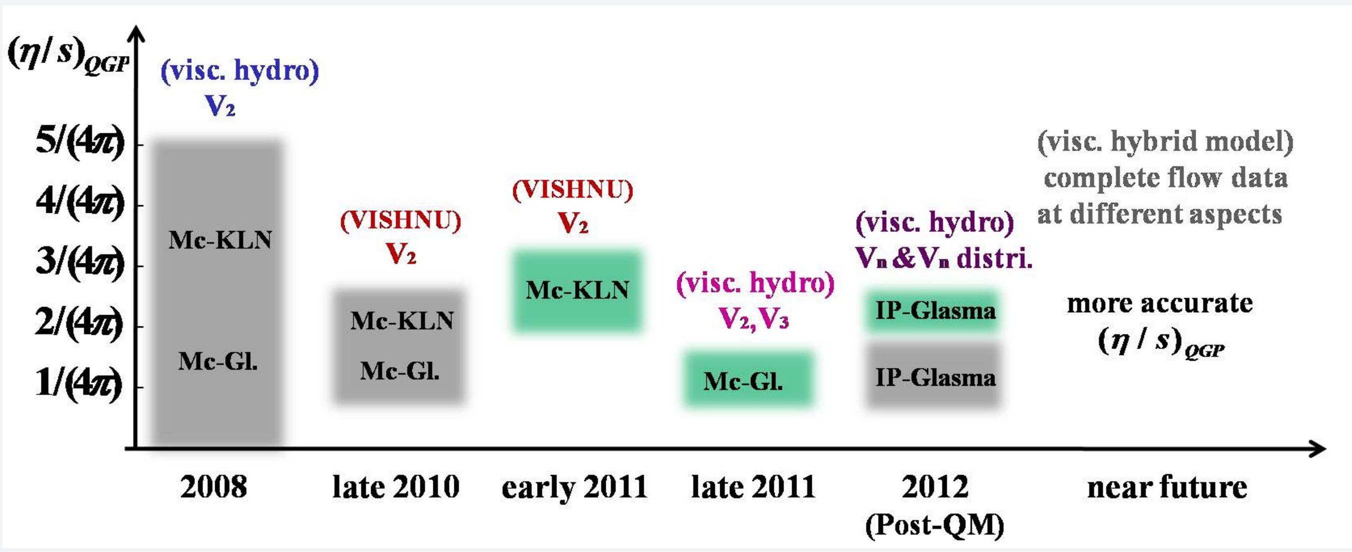
Experimental results at RHIC and LHC can be described within hydrodynamical approximation. Hydrodynamics is an effective theory which correctly represents dynamics of infrared degrees of freedom. Its parameters, such as η, ζ, σ etc., must be determined either from the experiment or from the calculation based on the first principles.

QGP shear viscosity at RHIC and LHC[1]:

$$\frac{\eta}{s} = (1-2.5)\frac{1}{4\pi}$$

Very small and close to $N=4$ SYM: $\eta/s = 1/4\pi$.

Weak coupling $\eta/s \sim 1/(g^4 \log 1/g) \sim 1 \implies$ Perturbation theory does not work $\implies$nonperturbative calculation (lattice simulations)



▇: RHIC (200 A GeV Au+Au collisions)
▇: LHC (2.76 A TeV Pb+Pb collisions)

Viscosity and stress-energy tensor correlator on the lattice

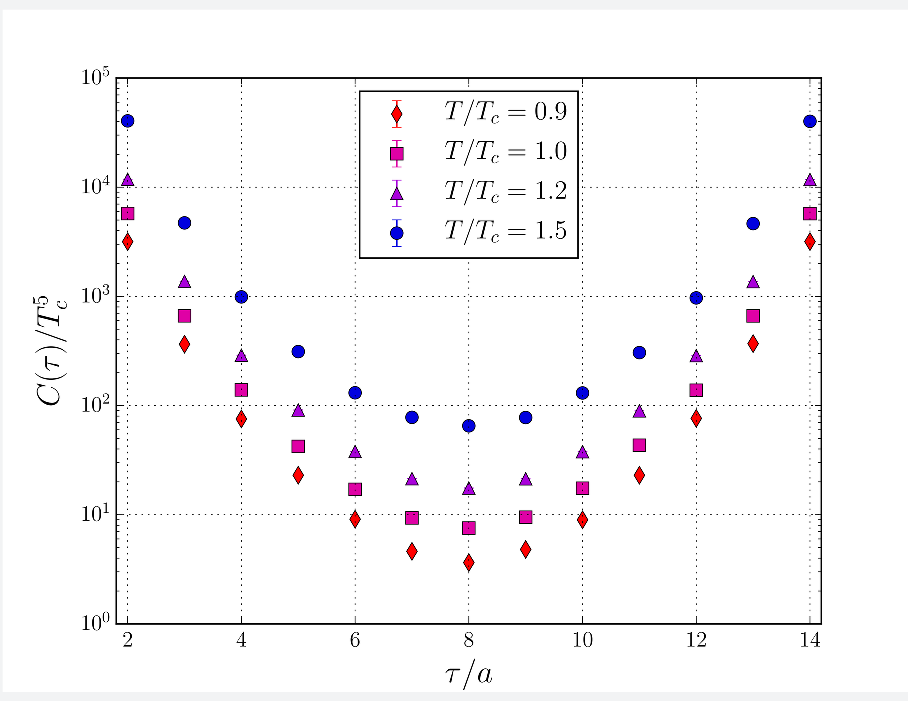
We measure on the lattice the correlator $C(x_0)$ for temperatures $T/T_c = 0.9, 0.925, 0.95, 1.0, 1.1, 1.2, 1.35, 1.5$:

$$C(x_0) = T^{-5} \int d^3\mathbf{x} \langle T_{12}(0) T_{12}(x_0, \mathbf{x})\rangle$$

Correlator is related to viscosity (Kubo formula):

$$C(x_0) = T^{-5} \int_0^\infty \rho(\omega) \frac{\cosh \omega(\frac{1}{2T} - x_0)}{\sinh \frac{\omega}{2T}} d\omega$$

$$\eta = \pi \lim_{\omega \to 0} \frac{\rho(\omega)}{\omega}$$



The correlation functions $C(x_0)$ for temperatures $T/T_c = 0.9, 1.0, 1.2, 1.5$.

Methods for inverting the Kubo formula

I. Fitting procedure

Ansatz used for fitting:

$$\rho(\omega) = BT^3\,\omega\big(1 + C\omega^2\big)\theta(\omega_0 - \omega) + A\rho_{lat}(\omega)\theta(\omega - \omega_0)$$

- $\rho_{lat}(\omega)$: asymptotic freedom + lattice corrections
- $BT^3\omega$: first-order hydrodynamics
- $C\omega^3$: corrections to first-order hydrodynamics (our results: $C \to 0$)

II. Backus-Gilbert method

No assumptions about form of the spectral function!

Instead of the spectral function $\rho(\omega)$ we calculate its estimator ($f(\omega) \sim \omega$ for sensitivity to η):

$$\bar{\rho}(\bar{\omega}) = f(\bar{\omega}) \sum C(x_i) q_i(\bar{\omega})$$

Estimator and $\rho(\omega)$ are related via resolution function $\delta(\bar{\omega}, \omega)$ ($K(x_i, \omega) = \frac{\cosh \omega(\frac{1}{2T} - x_i)}{\sinh \frac{\omega}{2T}}$)

$$\bar{\rho}(\bar{\omega}) = f(\bar{\omega}) \int_0^\infty d\omega \delta(\bar{\omega}, \omega) \frac{\rho(\omega)}{f(\omega)},$$
$$\delta(\bar{\omega}, \omega) = \sum_i q_i(\bar{\omega}) K(x_i, \omega).$$

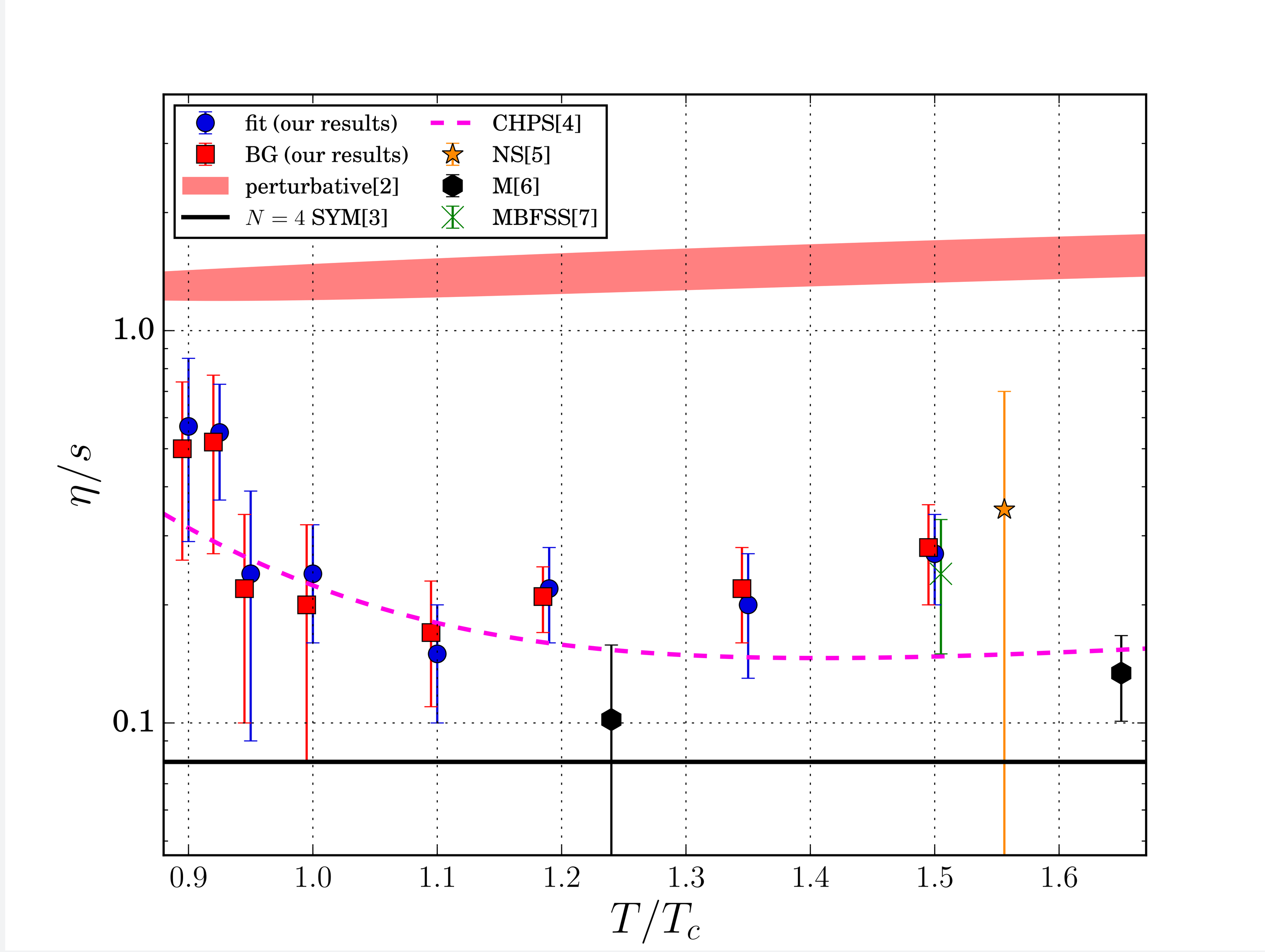
Choice of $q_i(\omega)$:

- $\delta(\bar{\omega}, \omega)$ should be close to $\delta(\bar{\omega} - \omega)$
- Numerical stability

See arXiv:1701.02266 for detailed description.

Results for gluodynamics

Dependence of the ratio $\frac{\eta}{s}$ on the temperature T:



Our results are in agreement previous lattice studies.

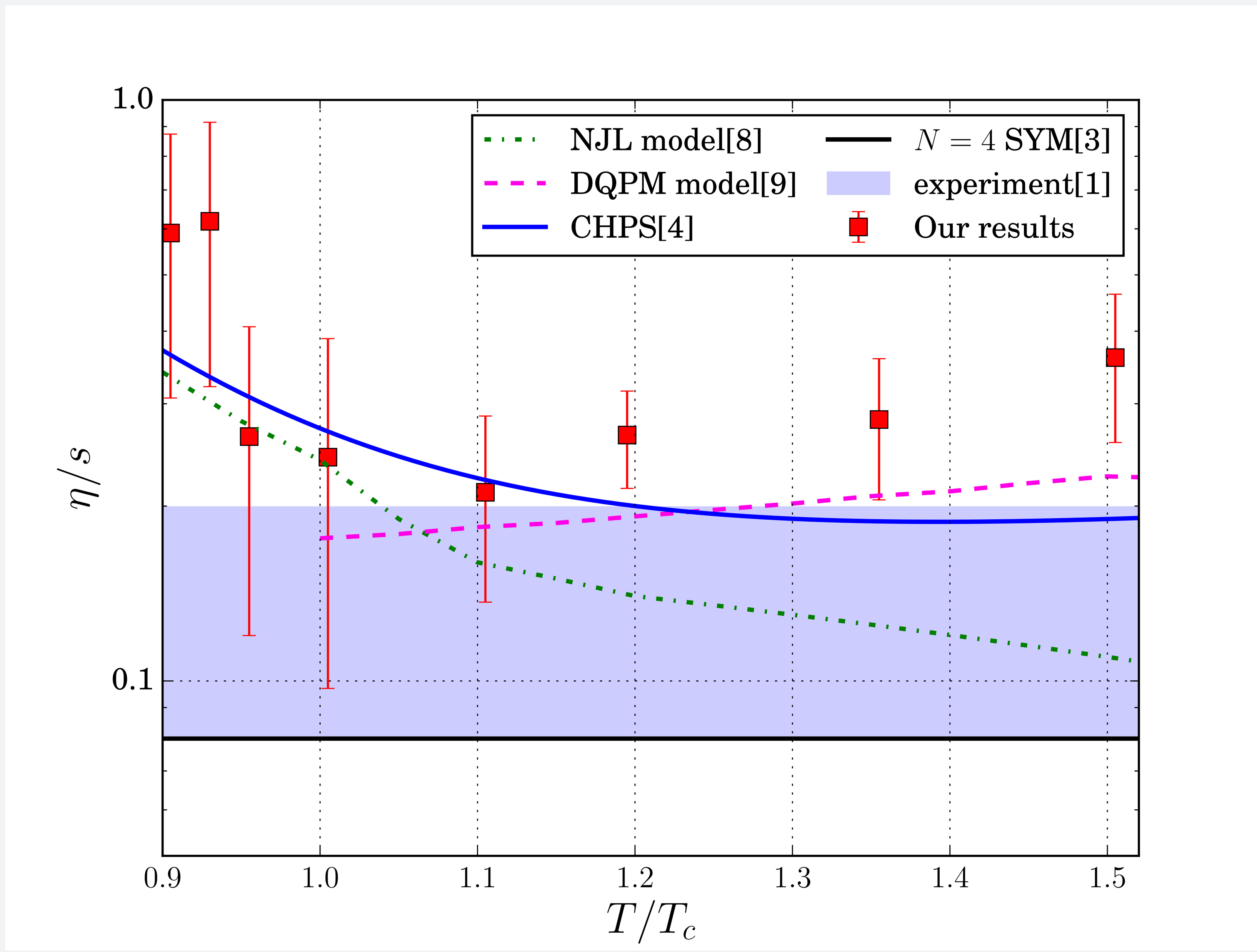
They cannot be described perturbatively $\implies$ QGP is strongly coupled!

Estimation for QCD

We estimate η/s in QCD according to:

$$\left.\frac{\eta}{s}\right|_{QCD} = \left.\frac{\eta}{s}\right|_{gluo} \times \frac{\left(\frac{\eta_{QCD}}{\eta_{gluo}}\right)}{\left(\frac{s_{QCD}}{s_{gluo}}\right)}$$

Ratios $\frac{\eta_{QCD}}{\eta_{gluo}}$ and $\frac{s_{QCD}}{s_{gluo}}$: LO PT[4].



Our results are in agreement with calculations performed within other approaches and experimental results.

References

[1] H. Song, Nucl. Phys. A 904-905, 114c (2013), arXiv:1210.5778

[2] P. B. Arnold, G. D. Moore and L. G. Yaffe, JHEP 0305, 051 (2003), hep-ph/0302165

[3] G. Policastro, D. T. Son and A. O. Starinets, Phys. Rev. Lett. 87, 081601 (2001), hep-th/0104066

[4] N. Christiansen et al., Phys. Rev. Lett. 115, no. 11, 112002 (2015), arXiv:1411.7986

[5] A. Nakamura and S. Sakai, Phys. Rev. Lett. 94, 072305 (2005), hep-lat/0406009

[6] H. B. Meyer, Phys. Rev. D 76, 101701 (2007), arXiv:0704.1801

[7] S. W. Mages et al., PoS LATTICE 2014, 232 (2015)

[8] R. Marty et al., Phys. Rev. C 88, 045204 (2013), arXiv:1305.7180

[9] H. Berrehrah et al., Int. J. Mod. Phys. E 25, no. 07, 1642003 (2016), arXiv:1605.02371

More information at arXiv:1701.02266