GLUON SPECTRAL FUNCTIONS AND TRANSPORT COEFFICIENTS IN PURE GAUGE THEORY

Leonard Fister
IPhT, CEA Saclay

Haas, LF, Pawlowski, PRD 2014.

LF, Pawlowski, 1112.5440; PRD 2013.

Initial Stages 2014
Napa, Dec 3-7, 2014

MOTIVATION

- elliptic flow v_2 at RHIC and CERN:
  Quark-gluon plasma (QGP) well described by hydrodynamics

- QGP is almost perfect fluid (close to KSS 'bound')

  Kovtun, Son, Starinets, PRL 2005.

  → small ratio shear viscosity / entropy density ($\eta/s \gtrsim 1/4\pi$)

- close to transition to hadronic phase: strongly correlated plasma
  → non-perturbative methods needed

OUTLOOK

- Kubo relations
- Gluon correlation and spectral functions
- shear viscosity/entropy density

KUBO RELATION FOR SHEAR VISCOSITY

Kubo relation connects the shear viscosity η to the
spectral function $\rho_{\pi\pi}$ of spatial, traceless part of the energy-momentum tensor π_{ij}

$$\eta = \lim_{\omega \to 0} \frac{1}{20} \frac{\rho_{\pi\pi}(\omega, \vec{0})}{\omega}$$

$$\rho_{\pi\pi}(\omega, \vec{p}) = \text{F.T. } \{\langle [\pi_{ij}(x), \pi_{ij}(0)] \rangle\}$$

$$\langle \pi_{ij}[\hat{A}] \pi_{ij}[\hat{A}] \rangle = \pi_{ij} \left[G_{A\phi_k} \frac{\delta}{\delta \phi_k} + A \right] \pi_{ij} \left[G_{A\phi_k} \frac{\delta}{\delta \phi_k} + A \right] \qquad \textbf{(exact)}$$

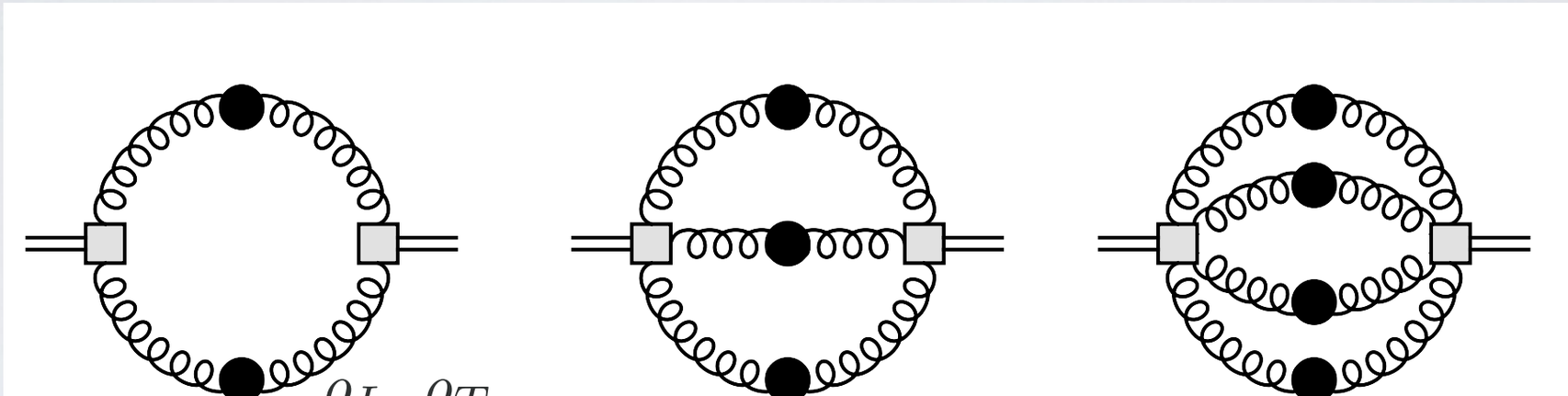
propagator

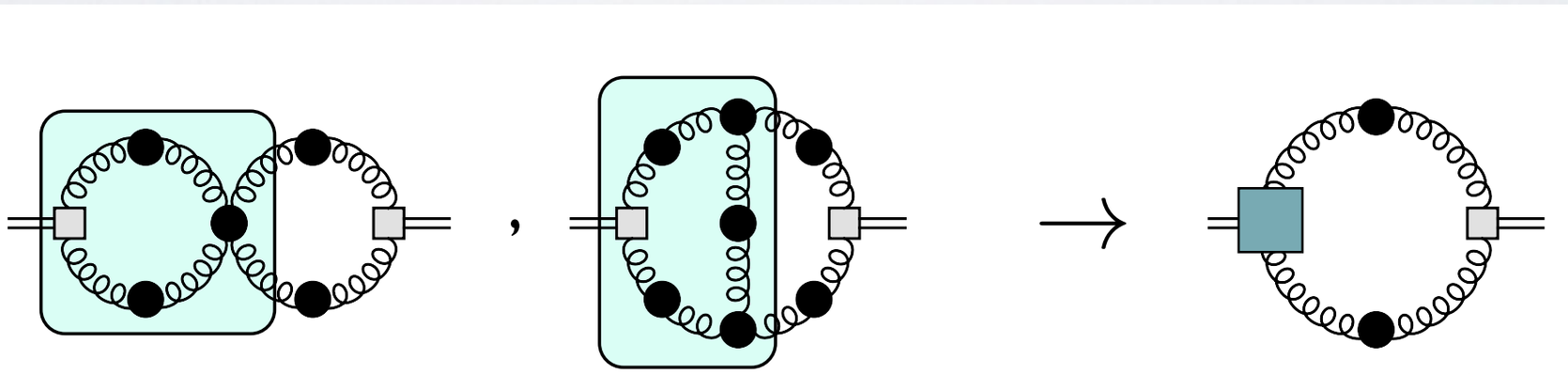
→ express $\rho_{\pi\pi}$ in terms of gluon spectral functions ρ_L , ρ_T

Aarts, Resco, JHEP 2004.
Haas, LF, Pawlowski, PRD 2014.
Christiansen, Haas, Pawlowski, Strodthoff, 1411.7986.

DIAGRAMS IN $\rho_{\pi\pi}$

contributing diagrams: up to 3-loop diagrams (in non-perturbative quantities), e.g.



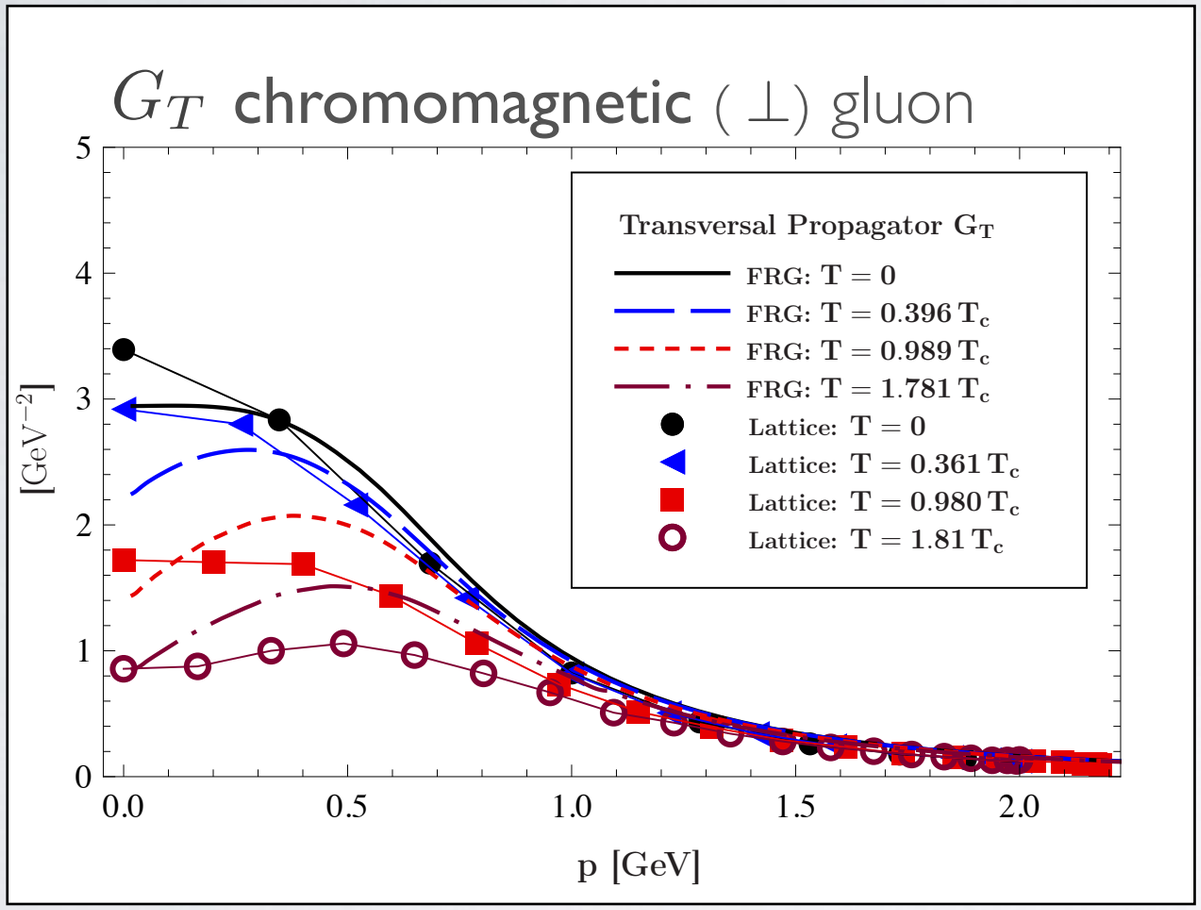


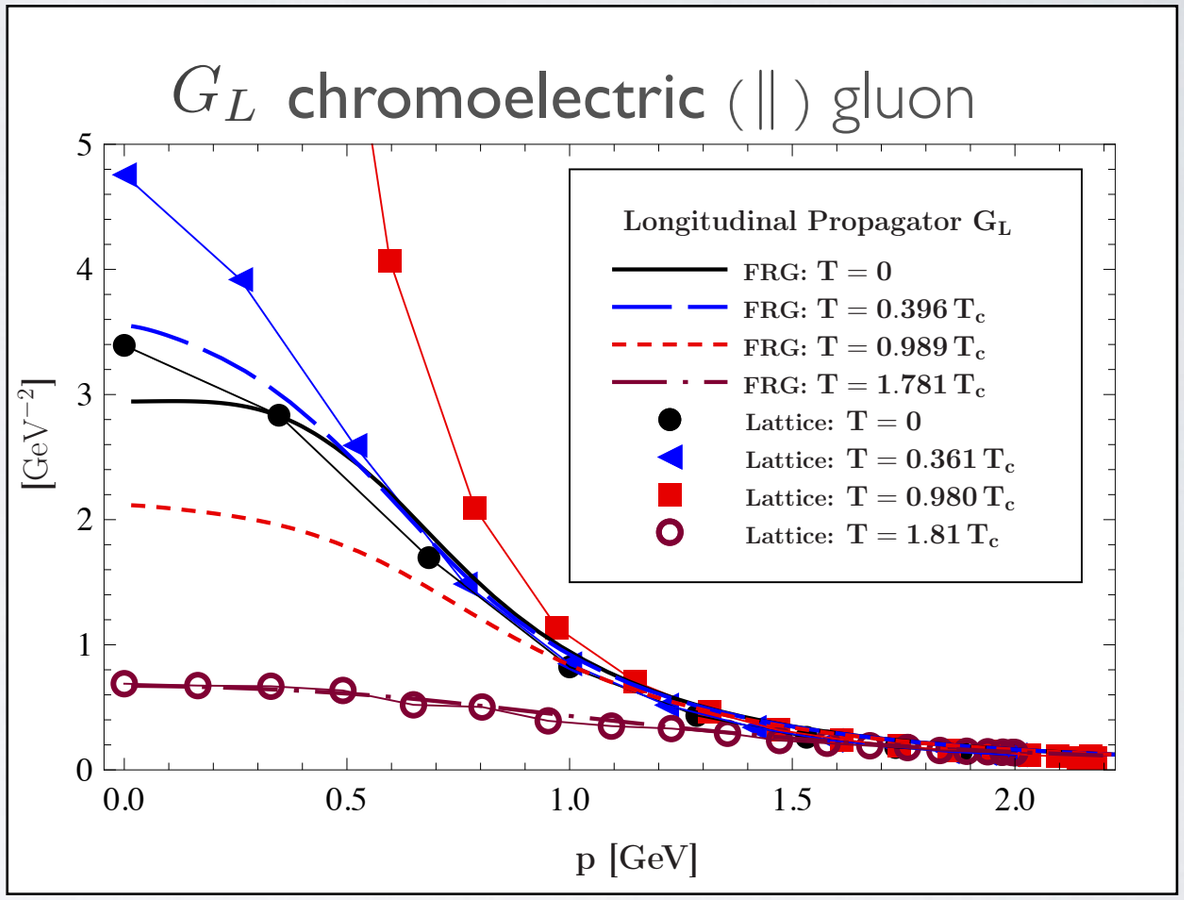
here: (for $T \approx T_c$) one-loop optimized renormalization scheme

`LF, Pawlowski, PRD 2013.`

YANG–MILLS PROPAGATORS (EUCLIDEAN)

transverse and longitudinal projections wrt the heatbath





functional renormalisation group: LF, Pawlowski, 1112.5440; PRD 2013.
lattice gauge theory: Maas, Pawlowski, von Smekal, Spielmann, PRD 2011.

… FROM PROPAGATORS IN EQUILIBRIUM

- static quark confinement

  SU(3) $T_c \approx 275$ MeV

  FRG / DSE / 2PI $T_c^{\text{func.}}/\sqrt{\sigma} \approx 0.65$ LF, Pawlowski, PRD 2013.

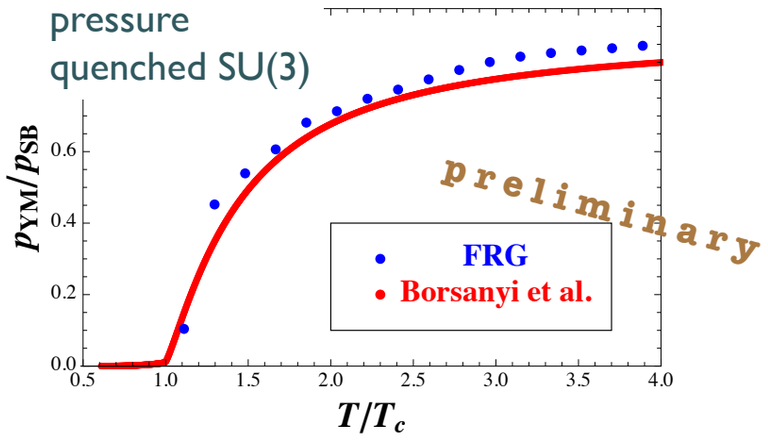
  lattice gauge theory $T_c^{\text{latt.}}/\sqrt{\sigma} \approx 0.645$ Lucini, Teper, Wenger, JHEP 2004.

- chiral symmetry breaking

  dynamical hadronization techniques

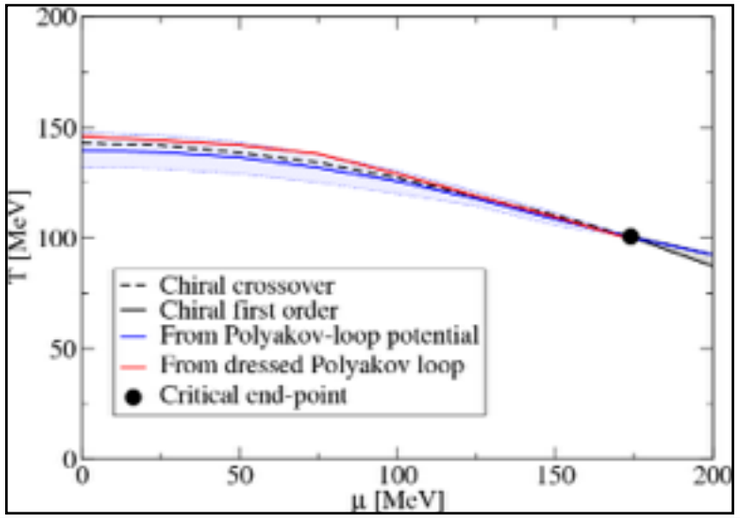
  Braun, LF, Pawlowski, Rennecke, 1412.1045.

- thermodynamics



LF, Pawlowski, in prep.
Borsanyi et al., JHEP 2012.

- phase diagram



2+1 flavor QCD

Fischer, LF, Lücker, Pawlowski, PLB 2014.

MAXIMUM ENTROPY METHOD (MEM)

$$G\left(\tau,\vec{p}\right)=\int_0^\infty \frac{d\omega}{2\pi}K_T(\tau,\omega)\rho(\omega,\vec{p})$$

$G\left(\tau,\vec{p}\right)$ … (FT. of) euclidean propagator

$K_T(\tau,\omega)$ … analytic function

$\rho(\omega,\vec{p})$ … gluon spectral function

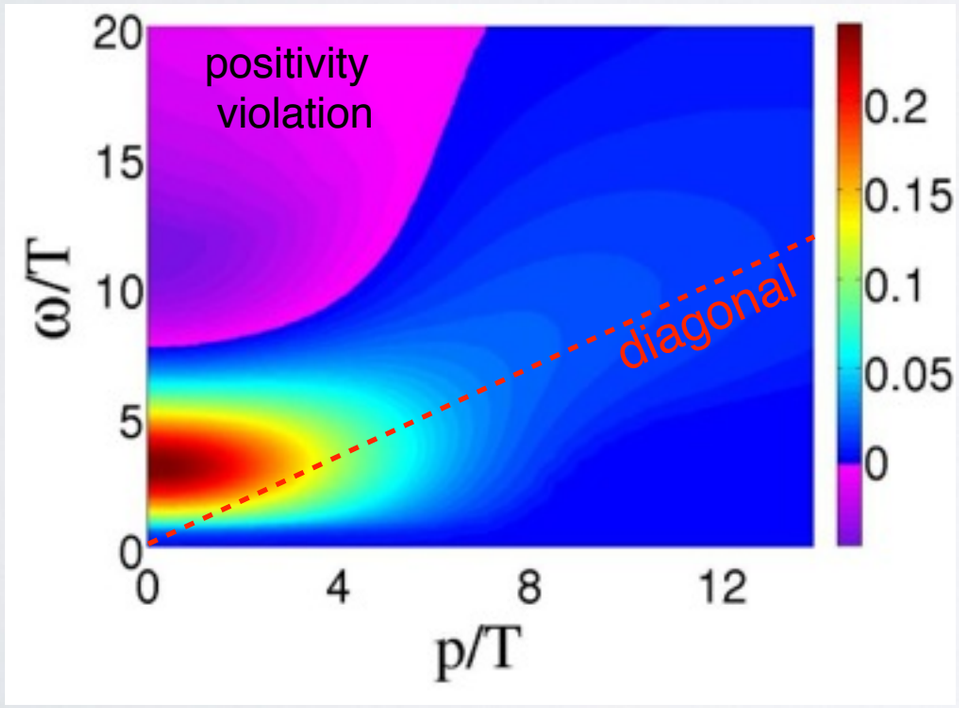
MEM:

- inversion with additional (UV) information
- minimization of $L-\alpha S$, L … likelihood term

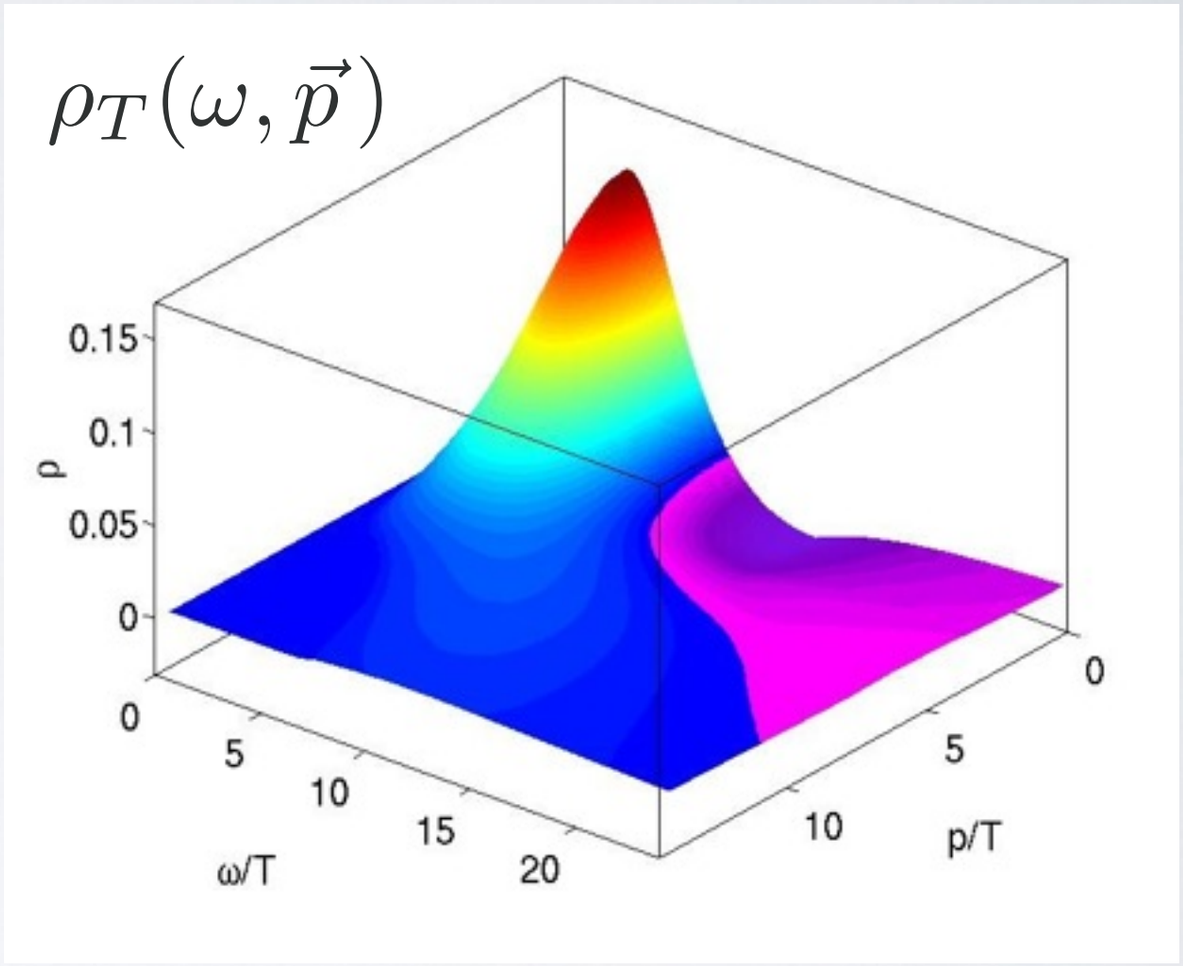
  αS … (weighted) entropy
- gluon no asymptotic state → generalization of MEM

GLUON SPECTRAL FUNCTIONS ρ_T, ρ_L

- broad maximum at $\omega/T \approx 2 \div 3$,
- peak broadens with T
- positivity violation at low spatial mom.
- does not show diagonal ($\omega \approx p$) quasiparticle structure at low p



transverse gluon spectral function at $T \approx 2T_c$
(longitudinal qualitatively similar)



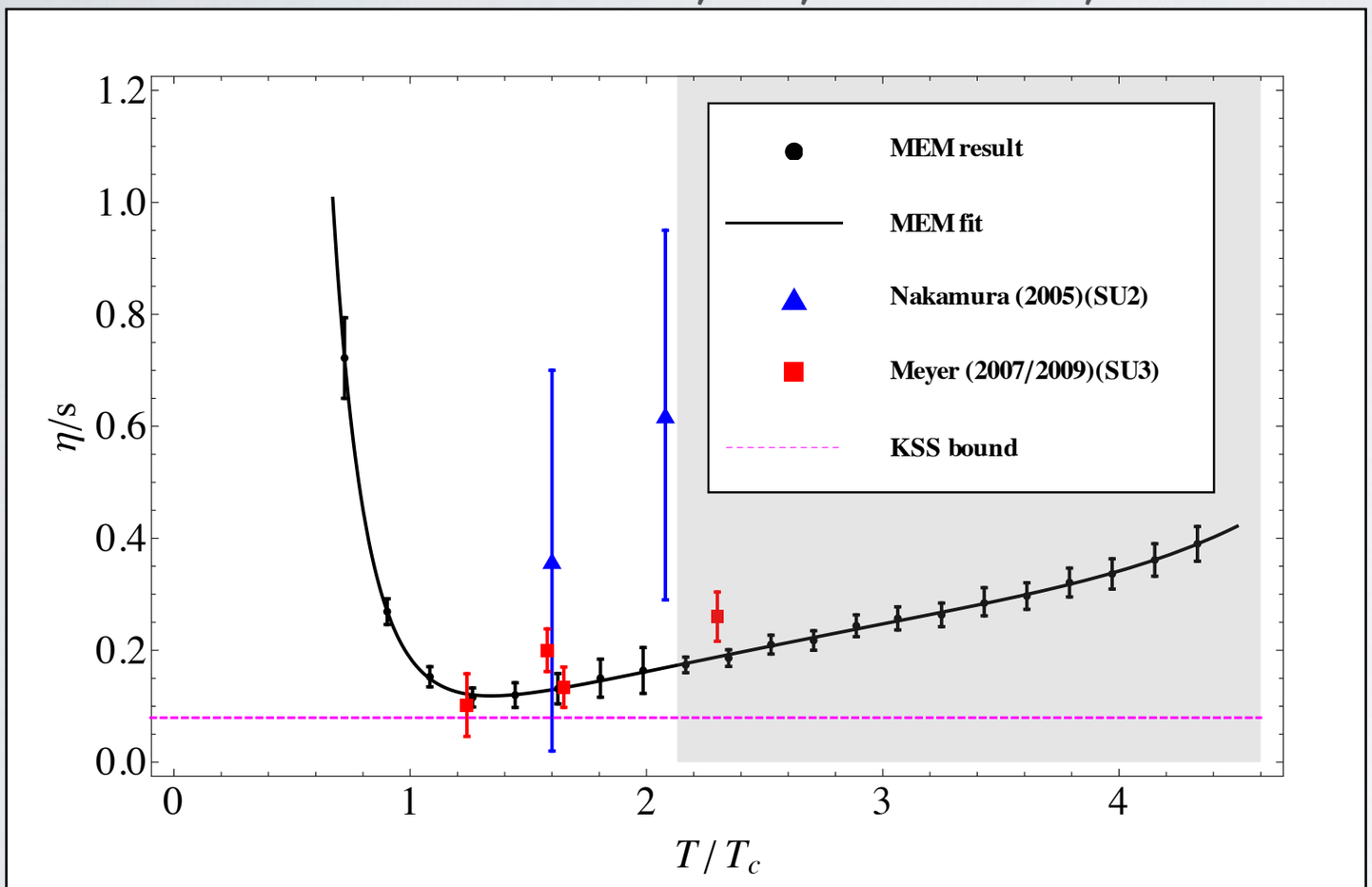
Haas, LF, Pawlowski, PRD 2014.

in agreement with

Strauss, Fischer, Kellermann, PRL 2012.

VISCOSITY / ENTROPY DENSITY η/s

Haas, LF, Pawlowski, PRD 2014.



- almost perfect fluid
- minimum at ~1.25 T_c

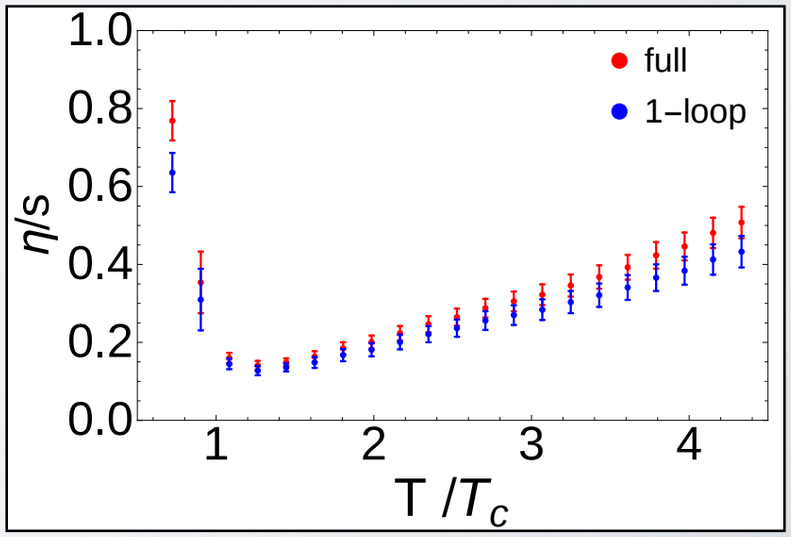
$$\min\left(\frac{\eta}{s}\right) = 0.12 \gtrsim \frac{1}{4\pi} \text{ (KSS)}$$

- qualitative rise below T_c
- agreement with lattice gauge theory

- entropy from lattice gauge theory

  Borsanyi, Endrodi, Fodor, Katz, Szabo, JHEP 2012.
- one-loop optimized scheme Fister, Pawlowski, PRD 2013; confirmed by two-loop computation

  Christiansen, Haas, Pawlowski, Strodthoff, 1411.7986.



CONCLUSIONS

- pure SU(3) gauge theory
- modified version of MEM
- gluon spectral functions
  - peak broadens with T
  - diagonal structure at large $\vec{p}$ only
  - positivity violation at low $\vec{p}$
- η/s around hadronic transition
  - almost perfect fluid
  - minimum value $0.12 \gtrsim \frac{1}{4\pi}$