Некоторые результаты моделирования свойств кварк-глюонной плазмы в рамках решеточной КХД

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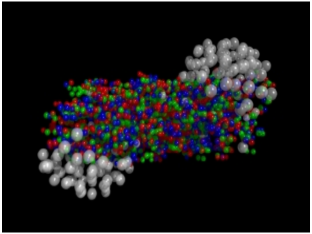
18 Февраля, 2014

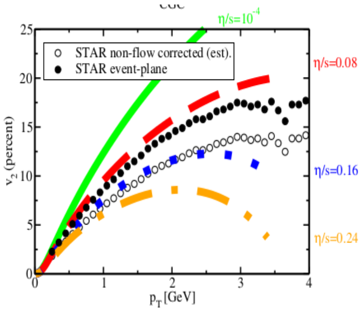
Outline:

- Shear viscosity of SU(2) QCD
- Axial magnetic effect in lattice QCD



Hydrodinamical description of the distribution of final particles

- One heavy ion collision produces a huge number of final particles
- Large number of paticles $\Rightarrow$ hydrodynamical description can be used
- In hydrodinamics transport coefficients control flow of energy, momentum, electrical charge and other quantities

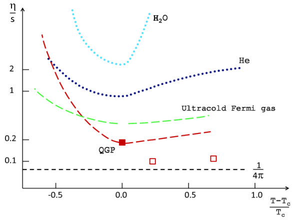


Elliptic flow at STAR (Nucl. Phys. A 757, 102 (2005))

$\frac{dN}{d\phi} \sim (1 + 2v_1 cos(\phi) + 2v_2 cos^2(\phi))$, ϕ-scattering angle

QGP close to ideal liquid ($\frac{\eta}{s} = (1-3)\frac{1}{4\pi}$)

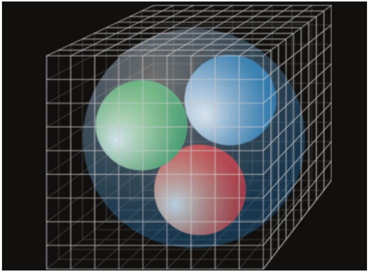
M. Luzum and P. Romatschke, Phys. Rev. C 78, 034915 (2008)



Comparison of different liquids

QGP the most superfluid liquid

The aim: first principle calculation of transport coefficients



Lattice simulation of QCD

- Allows to study strongly interacting systems
- Based on the first principles of quantum field theory
- Acknowledged approach to study QCD
- Very powerful due to the development of computer systems

Lattice calculation of transport coefficients

- Lattice measurement of the correlator $C(t) = \langle T_{12}(t) T_{12}(0) \rangle$
- Calculation of spectral density $\rho(\omega)$ from the correlator

$$C(t) = T^5 \int_0^\infty d\omega \rho(\omega) \frac{ch\left(\frac{\omega}{2T} - \omega t\right)}{sh\left(\frac{\omega}{2T}\right)}$$

- Calculation of viscosity $\eta = \pi \lim_{\omega \to 0} \frac{\rho(\omega)}{\omega}$

Previous lattice calculation (SU(3) gluodynamics)

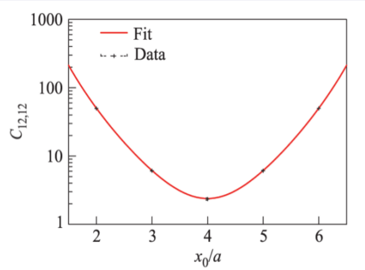
- Karsch, F. et al. Phys.Rev. D35 (1987)
- A. Nakamura, S. Sakai Phys. Rev. Lett. 94, 072305 (2005)
- H. B. Meyer, Phys.Rev.Lett. 100 (2008) 162001

Details of the calculation

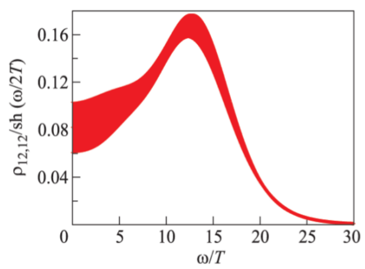
- SU(2) gluodynamics (speed of the calculations is enhanced)
- Two level algorithm for generation of gauge field configurations
- Lattice $32^3 \times 8$
- Temperature $T/T_c = 1.2$

V.V. Braguta, A.Yu. Kotov, JETP lett. 98 (2013) 147

Correlation function

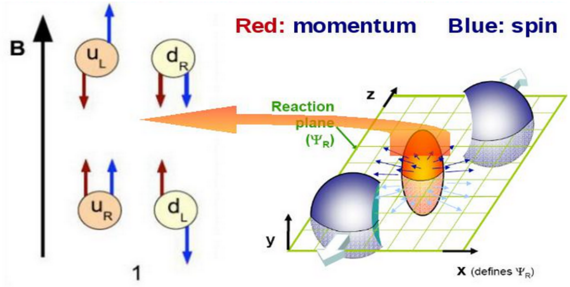


Spectral density



The results of the calculation

- $\frac{\eta}{s} = 0.111 \pm 0.032(stat.)$ (SU(2), JETP lett. 98 (2013) 147)
- $\frac{\eta}{s} = \frac{1}{4\pi} \simeq 0.08$ N=4 SYM $\lambda = \infty$ (Phys. Rev. Lett. 87 (2001) 081601)
- $\frac{\eta}{s} \sim 2$ Perturbative result (JHEP 11 (2000) 001)
- $\frac{\eta}{s} = 0.102 \pm 0.056$ (SU(3), Phys.Rev.Lett. 100 (2008) 162001)



Chiral magnetic effect

- Topological charge($n_R \neq n_L$) + magnetic field $\Rightarrow$ chiral magnetic effect
  (D. Kharzeev, L. McLerran, H. Warringa, NPA 803 ('08) 227)
- Related to axial anomaly
- $J_V = \sigma_{AV} H$ can be studied experimentaly
  (observed at RHIC and LHC, STAR Collaboration Phys.Rev.Lett. 103 (2009) 251601, ...)

Anomalous transport

- Chiral magnetic effect: $J_V = \sigma_{VV} H, \quad \sigma_{VV} = \frac{\mu_A}{2\pi^2}$
- Axial chiral magnetic effect: $J_A = \sigma_{AV} H, \quad \sigma_{AV} = \frac{\mu}{2\pi^2}$
- Chiral vortical effect: $J_V = \sigma_V \omega, \quad \sigma_V = \frac{\mu_A \mu}{2\pi^2}$
- Axial chiral vortical effect: $J_A = \sigma_A \omega, \quad \sigma_A = \frac{\mu^2 + \mu_A^2}{4\pi^2} + \frac{T^2}{12}$

Why anomalous transport phenomena are so interesting?

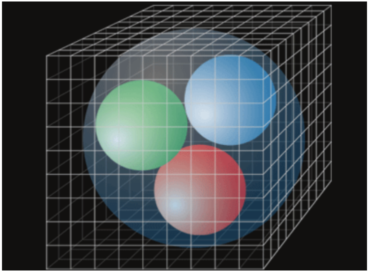
- Can be seen in current heavy ion collision experiments
- Related to the first principles of quantum field theory (anomalies)
- Non-dissipative phenomena

Axial chiral vortical effect:

Axial chiral vortical effect: $J_A = \sigma_A \omega, \quad \sigma_A = \frac{T^2}{12}\ (\mu = \mu_A = 0)$

Axial magnetic effect:

- $L = \bar{\psi}(\hat{\partial} - ig\hat{A}^a t^a - ie\gamma_5 \hat{A}_5)\psi$
- $J^i_\epsilon = \langle T^{0i} \rangle = \sigma H_5, \quad \sigma = \sigma_A = \frac{T^2}{12}$



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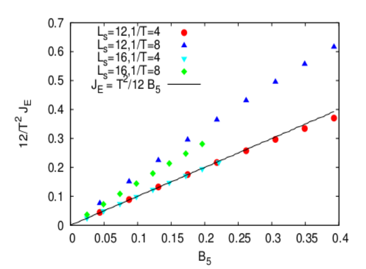
Aim: lattice study of axial magnetic effect

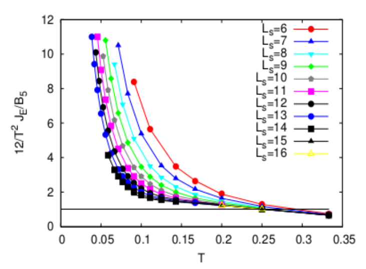
From axial magnetic to usual magnetic field

- $J_E = \langle T^{0i} \rangle = \frac{i}{2} \langle \bar{\psi} (\gamma^0 D_5^i + \gamma^i D_5^0) \psi \rangle, D_5^\mu = \partial^\mu - igA^\mu - ie\gamma_5 A_5^\mu$
- $C_\mu(x, y, A_5) = \langle \bar{\psi}(x) U_{xy} \gamma_\mu \psi(y) \rangle = -Tr\big(U\ S_5(A_5)\gamma_\mu\big)$
- $Tr\big[S_5(A_5)\gamma_\mu\big] = Tr\big[(P_R + P_L) S_5(A_5)\gamma_\mu\big] =$
  $Tr\big[P_R S(A_5)\gamma_\mu\big] + Tr\big[P_L S(-A_5)\gamma_\mu\big]$

The motion in axial magnetic field can be related to the motion in usual magnetic field

Free fermions (P. V. Buividovich, arXiv:1309.4966)



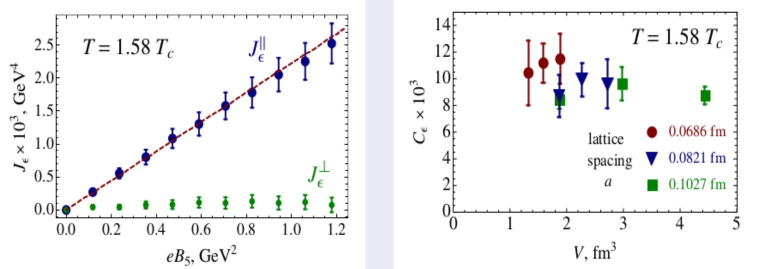


Theoretical result for free fermions can be reproduced in lattice QCD

Simulation details

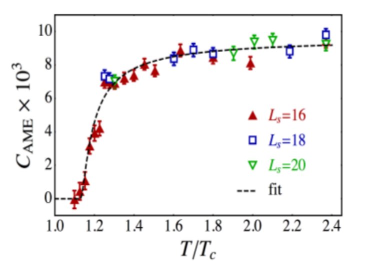
- Tadpole improved action
- SU(2) quenched QCD
- Statistics $900 + 900 + 900$
- Lattice parameters: $L_s = 14 - 20,\ \ L_t = 4 - 6,\ \ \beta = 3.0 - 3.5$

Quarks in quenched SU(2) QCD (V. Braguta et. al., Phys.Rev. D88 (2013) 071501)



- First lattice observation of non-dissipative phenomenon
- $J_\epsilon \sim H_5$
- $\sigma_{lat}(T = 1.58 T_c) = 2.2 \times 10^{-3} GeV^2$
- $\sigma_{lat}(T = 1.58 T_c)$ is by an order of magnitude smaller than $\sigma_{th}(T = 1.58 T_c)$

Quarks in quenched SU(2) QCD (arXiv:1401.8095)



- $C_{AME} = \frac{J_E}{eH_5 T^2}$
- Good fit: $C_{AME}(T) = C^{\infty}_{AME} \exp\left(-\frac{h}{T-T_c}\right)$
- $C_{AME}(T > T_c) > 0$
- $C_{AME}(T < T_c) = 0$

Clean signature of axial magnetic effect in experiments

THANK YOU