Inverse magnetic catalysis and energy loss in a holographic QCD model

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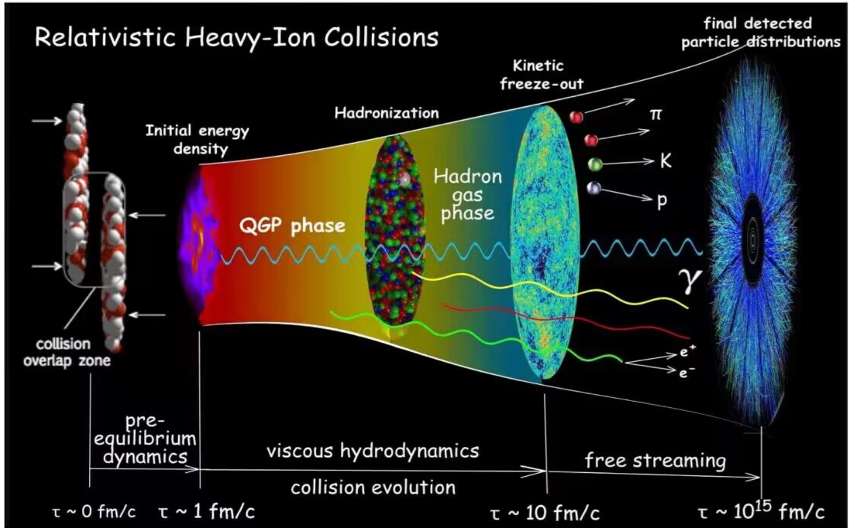
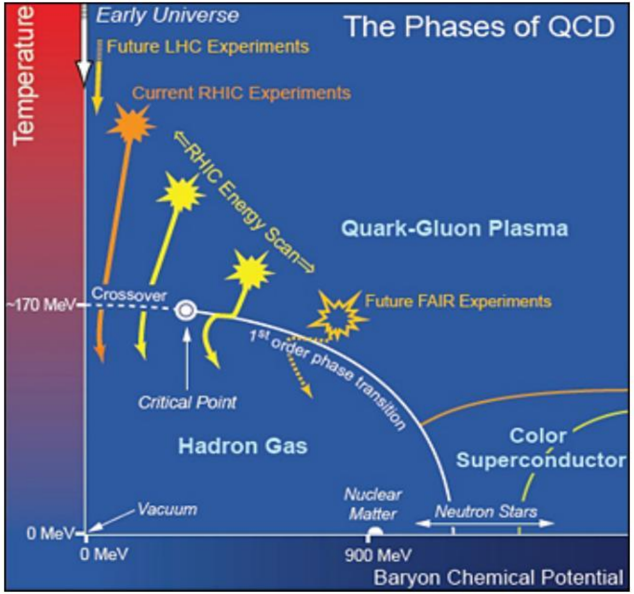
CONTENET

I. Background

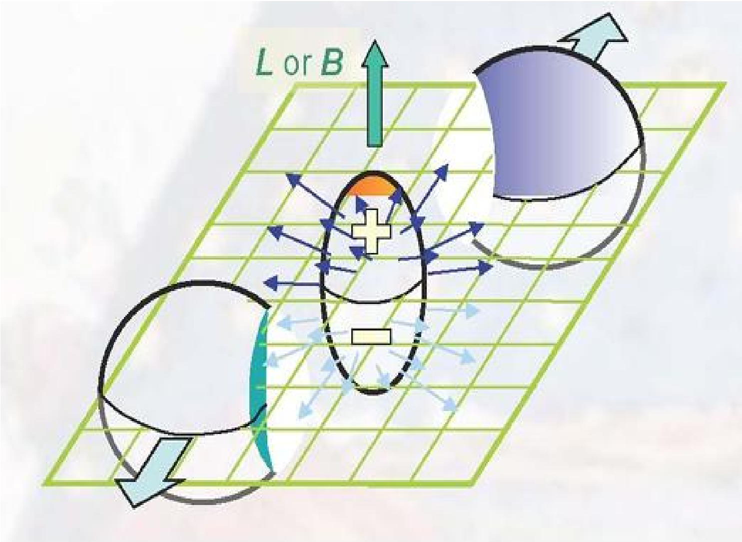




1) The generation of magnetic field

A strong magnetic field has been generated in the early stage of noncentral heavy-ion collisions*. Studying QCD phase structure under the magnetic field is still a major focus of current research.

*1. D. E. SkokovKharzeev, L. D. McLerran and H. J. Warringa, Nucl. Phys. A 803, 227-253 (2008);
2. V., A. Y. Illarionov and V. Toneev, Int. J. Mod. Phys. A 24, 5925-5932 (2009);
3. V. Voronyuk, V. D. Toneev, W. Cassing, E. L. Bratkovskaya,V. P. Konchakovski, and S. A. Voloshin, PRC 83,054911 (2011);
4. W. T. Deng and X. G. Huang, Phys. Rev. C 85, 044907 (2012).



2) The probes for detecting QGP

Jet quenching*: When an energetic parton with a large transverse momentum passes through the QGP, it radiates gluons, thereby losing energy

*1.X. N. Wang and M. Gyulassy, PRL. 68, 1480 (1992);
2.R. Baier, Y. L. Dokshitzer, A. H. Mueller, S. Peigne and D. Schiff, NPB 483, 291(1997)；
3.M. Gyulassy, P. Levai and I. Vitev, NPB 594, 371 (2001);
4.G. Y. Qin and X. N. Wang, Int. J. Mod. Phys. E 24, no.11, 1530014 (2015);

Heavy quark: During the interaction with the QGP medium, it will maintain flavor conservation.

The behaviors of jet quenching parameter and the energy loss of heavy quark near the phase transition temperature.

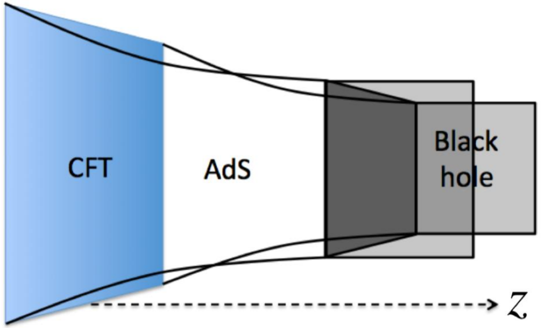
II. Holography

AdS/CFT*: The duality between the string theory in AdS_5 spacetime and the N=4 super Yang-Mills theory.

*1.Juan Martin Maldacena. Int.J.Theor.Phys. 38 (1999) 1113-1133, Adv.Theor.Math.Phys. 2 (1998) 231-252.

2.Edward Witten. Adv.Theor.Math.Phys. 2 (1998) 253-291.

3. S.S. Gubser, Igor R. Klebanov, Alexander M. Polyakov. Phys.Lett.B 428 (1998) 105-114.



AdS/QCD (Holographic QCD)

Holographic QCD model：Top-down and bottom-up

AdS	↔	QCD
• dilaton	↔	• break the conformal symmetry
• U(1) gauge field	↔	• chemical potential
• field strength tensor	↔	• magnetic field
• bulk metric	↔	• energy-momentum tensor
• Phase transition between black holes	↔	• (specious) confinement-deconfinement phase transition
• . . .		• . . .

Background geometry

The action of gravity background*:

$$S=-\frac{1}{16\pi G_5}\int d^5x\sqrt{-g}[R-\frac{f_1(\phi)}{4}F_{(1)MN}F^{MN}-\frac{f_2(\phi)}{4}F_{(2)MN}F^{MN}-\frac{1}{2}\partial_M\phi\partial^M\phi-V(\phi)],$$

The metric:

$$ds^2=\frac{L^2e^{S(z)}}{z^2}[-g(z)dt^2+dx_1^2+e^{B^2z^2}(dx_2^2+dx_3^2)+\frac{dz^2}{g(z)}],$$

The gauge field $A_t(z)$:

$$A_t(z)=\mu[1-\frac{\int_0^z d\xi\frac{\xi e^{-B^2\xi^2}}{f_1(\xi)\sqrt{S(\xi)}}}{\int_0^{z_h} d\xi\frac{\xi e^{-B^2\xi^2}}{f_1(\xi)\sqrt{S(\xi)}}}]=\widetilde{\mu}\int_z^{z_h}d\xi\frac{\xi e^{-B^2\xi^2}}{f_1(\xi)\sqrt{S(\xi)}},$$

The dilaton field:

$$\phi(z)=\int dz\sqrt{-\frac{2}{z}\left(3zA''(z)-3zA'(z)^2+6A'(z)+2B^4z^3+2B^2z\right)}+K_5.$$

*Anisotropic string tensions and inversely magnetic catalyzed deconfinement from a dynamical AdS/QCD model.PLB 801 (2020) 135184.

The potential of the dilaton field:

$$V(z) = \frac{g(z)}{L^2}\left(-\frac{9B^2z^3S'(z)}{2S(z)^2} + \frac{10B^2z^2}{S(z)} - \frac{3z^2S'(z)^2}{S(z)^3} + \frac{12zS'(z)}{S(z)^2} + \frac{z^2\phi'(z)^2}{2S(z)} - \frac{12}{S(z)}\right)$$
$$- \frac{z^4 f_1(z)A_t'(z)^2}{2L^4S(z)^2} + \frac{g'(z)}{L^2}\left(-\frac{B^2z^3}{S(z)} - \frac{3z^2S'(z)}{2S(z)^2} + \frac{3z}{S(z)}\right).$$

The Hawking temperature and entropy:

$$T = -\frac{z_h^3 e^{-3A(z_h)-B^2z_h^2}}{4\pi}[K_3 + \frac{\widetilde{\mu}^2}{2cL^2}e^{cz_h^2}],$$
$$S = \frac{e^{B^2z_h^2+3A(z_h)}}{4z_h^3}$$

Fit model parameters to data

Check whether the metric solutions are self-consistent or not

Study QCD phase transition

Study the equation of state and energy loss

III. Results

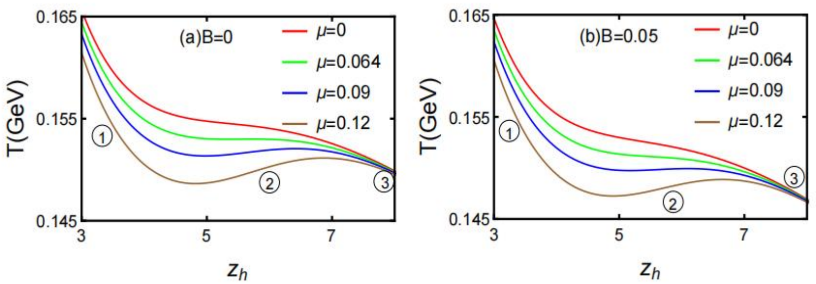


Fig.1

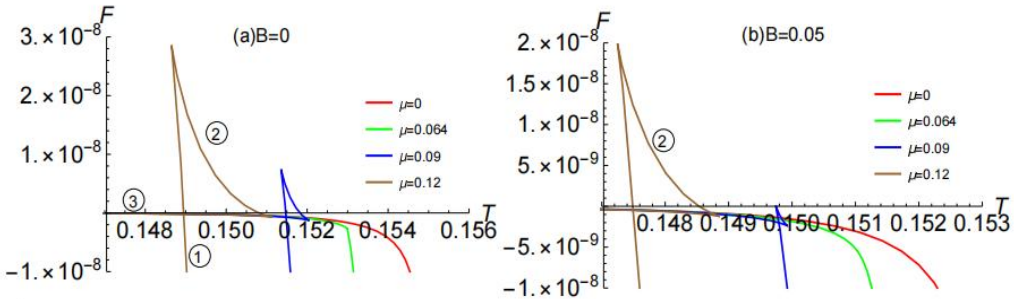


Fig.2

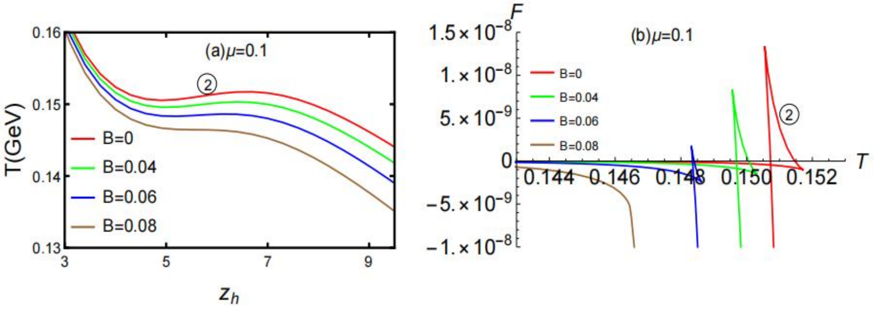


Fig.3

1) The chemical potential promotes crossover to first-order phase transition;
2) The magnetic field promotes the first-order phase transition to a crossover.

QCD phase diagram

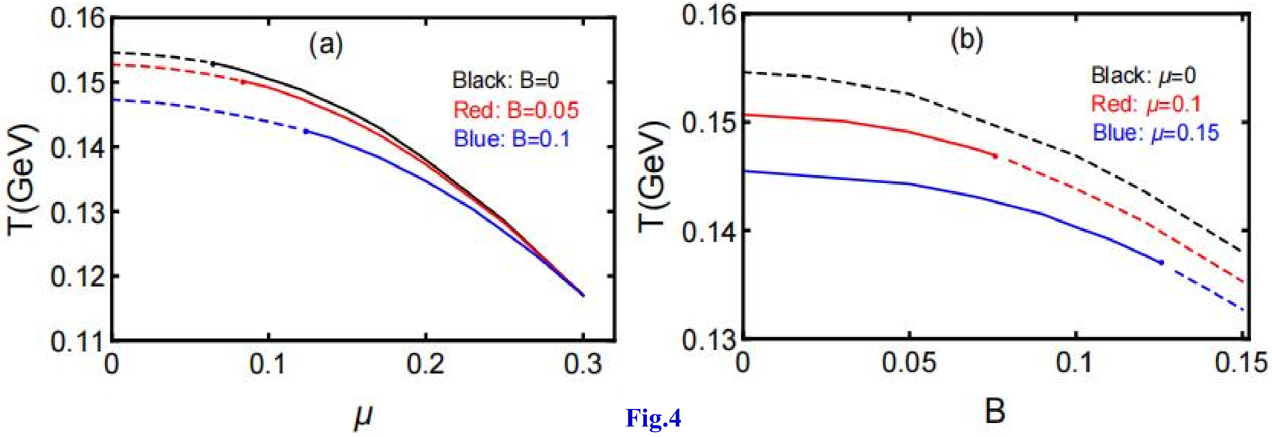


Fig.4

1) CEP would shift toward lower temperature and larger chemical potential when increasing B;
2) CEP would shift toward lower temperature and larger magnetic field when increasing μ.

Equations of state

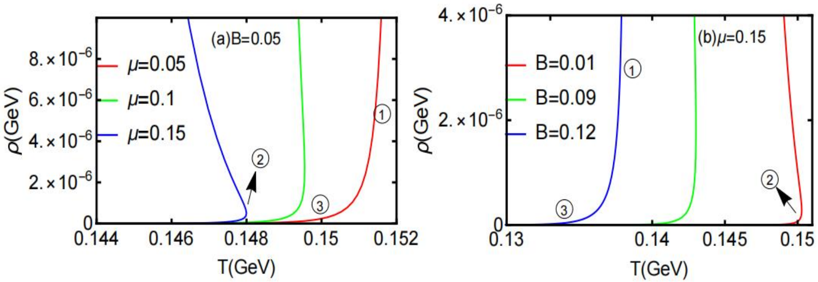


Fig.5

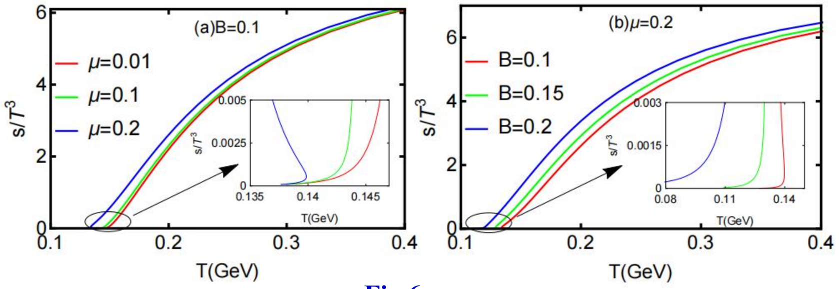


Fig.6

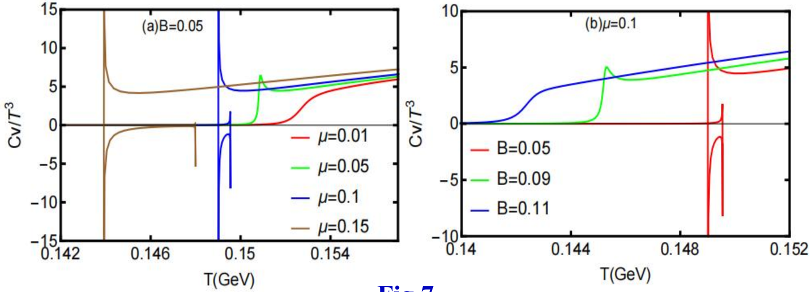


Fig.7

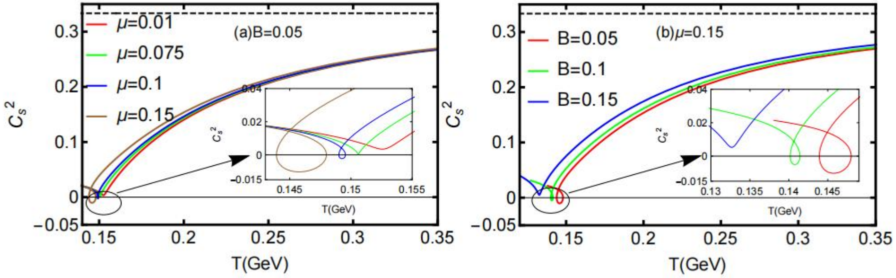


Fig.8

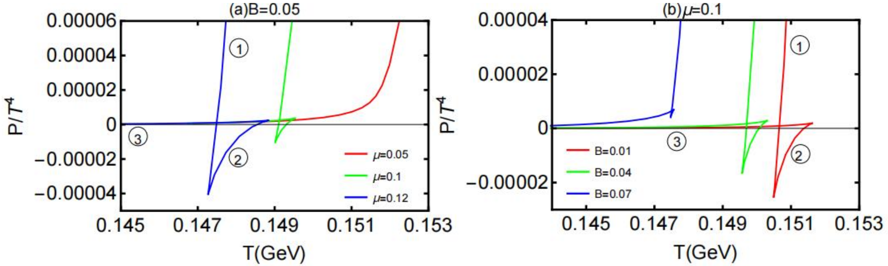
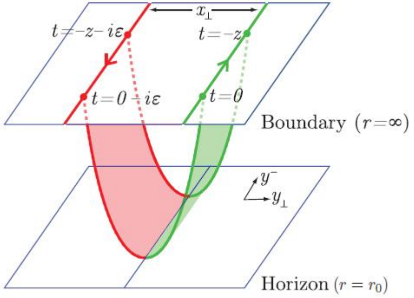


Fig.9

Energy loss near phase transition temperature

Jet quenching parameter

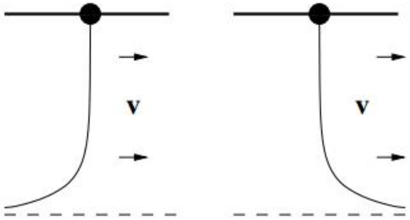
$$\langle W^A[C]\rangle \approx exp(-\frac{1}{4\sqrt{2}}\hat{q}L_-L^2)$$



H. Liu, K. Rajagopal, and U. A. Wiedemann,
Phys. Rev. Lett. 97, 182301 (2006).

Drag force

$$\tilde{F}_{\rm drag} = \frac{d\tilde{p}_x}{d\tilde{t}} = \frac{d\tilde{E}}{d\tilde{x}}$$



S. S. Gubser, Phys. Rev. D 74 (2006) 126005
C. P. Herzog, JHEP 0609 (2006) 032

Jet quenching parameter

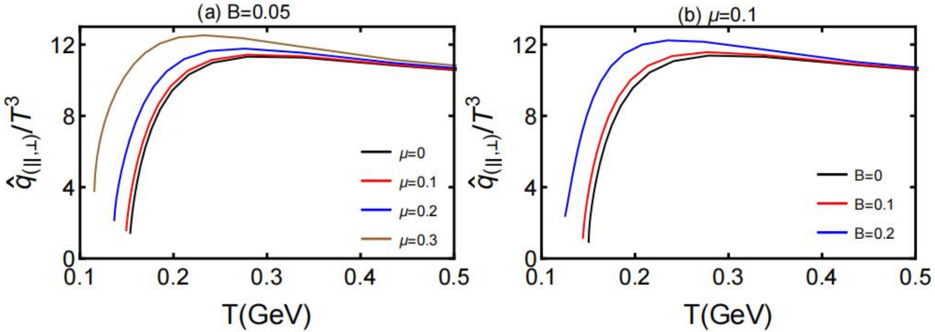


Fig.10. $\hat{q}_{(\parallel,\perp)}$

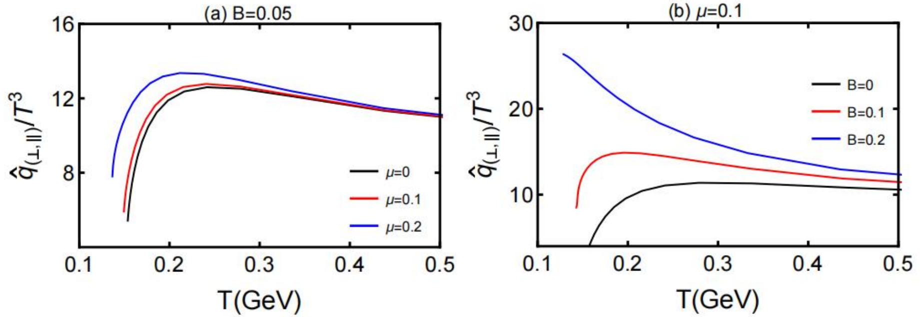


Fig.11. $\hat{q}_{(\perp,\parallel)}$

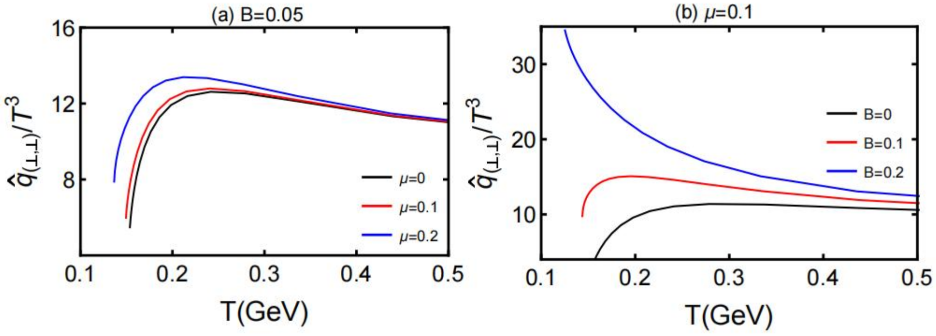


Fig.12. $\hat{q}_{(\perp,\perp)}$

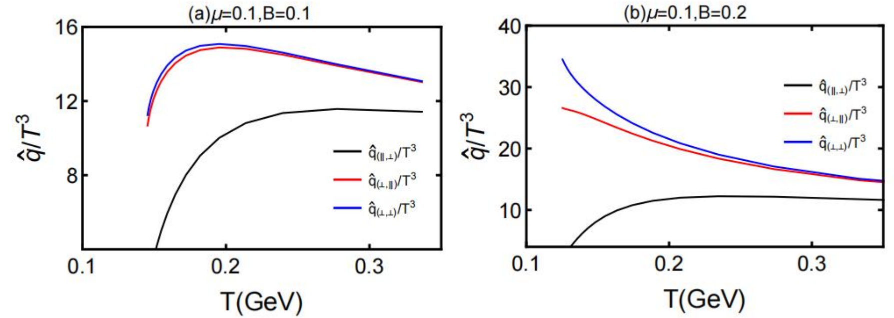


Fig.13. $\hat{q}/T^3$

$\hat{q}$ \ (μ,B)	(0, 0)	(0, 0.1)	(0.1, 0.1)	(0.1, 0.2)	(0.2, 0.2)
$\hat{q}_{(\parallel,\perp)}$	6.71	6.82	6.86	7.13	7.31
$\hat{q}_{(\perp,\parallel)}$	6.71	8.00	8.05	9.36	9.55
$\hat{q}_{(\perp,\perp)}$	6.71	8.04	8.09	9.55	9.75

Table 1.

$$\hat{q}_{(\perp,\perp)} > \hat{q}_{(\perp,\parallel)} > \hat{q}_{(\parallel,\perp)} \rightarrow \hat{q}_{\perp} > \hat{q}_{\parallel}$$

Drag force

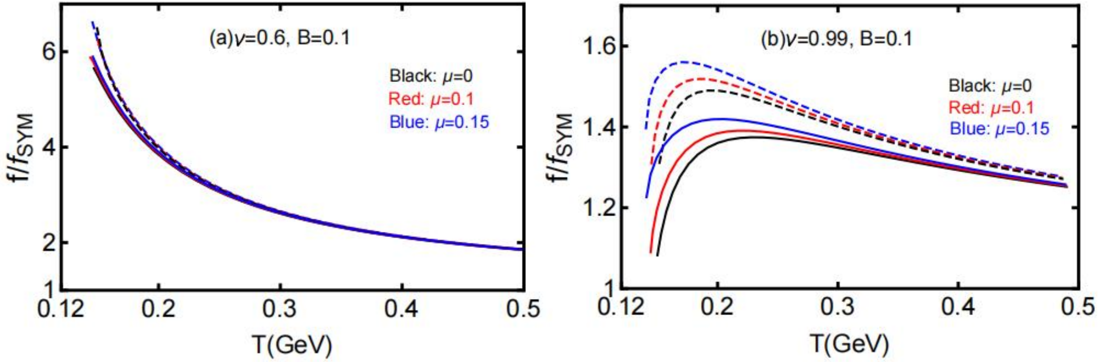


Fig.14

$f_{\perp} > f_{\parallel}$

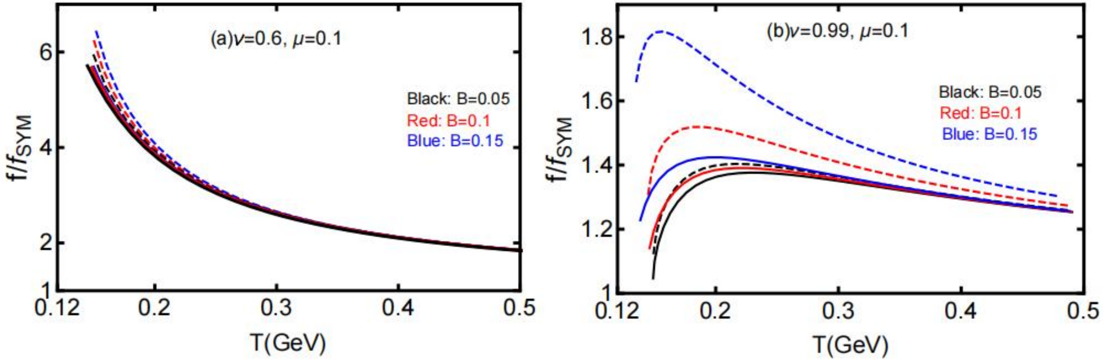


Fig.15

IV. Summary and outlook

Summary:

1) It is found that the magnetic field increases the critical μ_{CEP} of the CEP in the T-μ plane and the chemical potential increases the critical B_{CEP} of the CEP in the T-B plane.

2) EoS near the phase transition temperature are nonmonotonic and nontrivial.

3) The peak value of energy loss moves toward lower temperature with increasing magnetic field which agrees the phase transition temperature decrease with increasing B.

Outlook:

1) Quantitative fitting of model parameters to the EoS.

2) QCD phase diagram in the rotating background.