Magnetized equation of state of QGP at RHIC and LHC

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Introduction

The possibility of creating strong magnetic field in non central collision at RHIC and LHC opened many interesting and unresolved challenges in theoretical and experimental high energy physics as well as in cosmology and astrophysics. At RHIC and LHC, physicists noted that very strong magnetic fields can be produced in heavy-ion collisions [1–3]. It is estimated that at the relativistic heavy ion collider magnetic fields are created of order $eB \sim {m_\pi}^2$ and at large hadron collider, it is around $eB \sim 10{m_\pi}^2$. There are even higher estimates [4] for such strong magnetic field.

The role of magnetic field is important not only from a theoretical point of view but also for many applications to the problems of quark gluon plasma. Although several efforts have been taken with the help of experimental and theoretical high energy groups to detect the QGP, the understanding of QGP in the presence of magnetic field is still not satisfactory [5, 6]. Yet the theoretical knowledge in the evolution of interacting system has improved considerably since the early studies. Moreover, the equation of state (EoS) has become an important properties of QGP in central collisions of heavy massive nuclei.

Lattice QCD simulations [7] have also explored the effects of background magnetic fields on the EoS by computing the thermodynamic variables like as pressures, entropy, speed of sound and energy density etc. The results of Tawfik, Endrodi and Ayala et al. provided an excellent dynamics of EoS where the thermodynamic quantities increases well with the magnetic field [8–10]. There are many results which explore cases as a medium with either para or diamagnetic properties. In these studies, it is found that the system behaves as a paramagnetic due to the positive value of magnetization and positive permeability [11].

Using above information, we try to calculate the one of important thermodynamic variable as magnetization.

Theoretical model description

The study is based on our earlier model where it has been shown that how the temperature dependent quark mass affects the EoS of QGP in heavy-ion collisions. Now in this current work, we work on the theoretical model used as the effective quark mass. It is expressed in Ref. [12] :

$$m_{eff}^2 = {\mathfrak{m}_c}^2 + \sqrt{2}\mathfrak{m}_c m_q + {m_q}^2 \ , \qquad (1)$$

where $\mathfrak{m}_c$ is the current mass of the quark and m_q is the thermal mass of the quark [12].

In order to match the Lattice QCD results, the suitable parametrization factors are incorporated. So our model is thermodynamically self consistent to describe QGP EoS. The single particle energy eigen value for a constant magnetic field is given by [13],

$$E = \left[k^2 + m_{eff}^2 + eB(2n + s + 1)\right]^{1/2} \ , \quad (2)$$

where $n = 0, 1, 2, ...,$ are the principle quantum numbers for allowed Landau levels, $s = \pm 1$ refers to spin up (+) or down (−) states, and k is the component of particle momentum along the direction of the external magnetic field. We set the relation $2\nu = 2n + s + 1$. In the strong magnetic field, the quarks are rarely excited thermally to the higher Landau levels, so only the lowest Landau levels $n = 0$

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are populated. we can rewrite the single particle energy eigenvalue in the form

$$E = \left[k^2 + m_{eff}^2 + 2\nu eB\right]^{1/2} \ , \qquad (3)$$

Using above expression, we modified free energy (F) in the non-zero magnetic field and then produced EoS of QGP with the effect of magnetic field. By successfully calculating these variables, we further calculate the magnetization which gives one of the most fundamental properties of the QCD matter. It is defined as,

$$M = -\frac{1}{v}\frac{\partial F}{\partial(eB)} \ , \qquad (4)$$

Here the value of positive magnetization refers to paramagnetism and the value of negative M to diamagnetism. Finally, we plot the magetization with respect to temperature range from $110MeV < T < 300\ MeV$ at one particular value of magnetic field $eB = 0.4\ GeV^2$.

Results

The Figure [1] shows the magnetization with respect to the temperature in the presence of effective quark mass at particular value of magnetic field. We found the result is confronted to recent lattice QCD simulations [7]. The above observations could have interesting implications on the expansion dynamics of the medium produced at RHIC and LHC in the presence of a strong magnetic field, which may influence the outcomes of various signatures. Finally we conclude that our model results with the help of effective quark mass and in the presence of magnetic field shows significant output at $eB = 0.4\ GeV^2$. Thus the effective quark mass fitted well with the result of Lattice QCD simulation. The results are also important to produce EoS of QGP and significant in heavy-ion nuclear collisions.

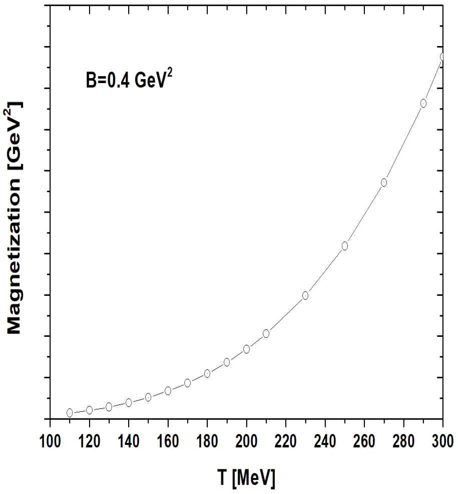

FIG. 1: The plot for magnetization with respect to temperature is shown at particular value of magnetic field $B = 0.4GeV^2$

References

- [1] I. V. Selyuzhenkov (STAR Collaboration), Romanian Rep. Phys. **58**, 049 (2006).
- [2] D. Kharzeev, Phys. Lett. B **633**, 260 (2006).
- [3] D. E. Kharzeev, L. D. McLerran, and H. J. Warringa, Nucl. Phys. A **803**, 227 (2008).
- [4] V. Skokov, A. Y. Illarionov, and V. Toneev, Int. J. Mod. Phys. A **24**, 5925 (2009).
- [5] E. Shuryak, Prog. Part. Nucl. Phys. **62**, 48 (2009).
- [6] H. Satz, Int. J. Mod. Phys A **21**, 672 (2006).
- [7] G. S. Bali, F. Bruckmann, G. Endrodi, S. D. Katz and A. Schafer, JHEP **1408**, 177 (2014).
- [8] A. N. Tawfik et al., Adv. High E. Phys. **2016**, 1381479 (2016).
- [9] G. Endrodi, JHEP **07**, 173 (2015).
- [10] A. Ayala, M. Loewe and R. Zamora, Phys. Rev. D **91**, 016002 (2015).
- [11] G. S. Bali, F. Bruckmann, G. Endrodi and A. Schafer, Phys. Rev. Lett. **112**, 042301 (2014).
- [12] Y. Kumar, EPJ Web of Conf. **182**, 02070 (2018).
- [13] L. D. Landau and E. M. Lifshitz, **Stat. Mech.** (Pergamon Press, New York, 1965).