$(T - \mu_I)$ phase diagram in PNJL Model

Anirban Lahiri*
Center for Astroparticle Physics and Space Sciences,
Bose Institute.
Kolkata 700 091. INDIA.

Introduction

Motivation behind constructing PNJL model was to unify chiral sector of NJL model [1] and confinement sector of effective Polyakov loop model. Lattice QCD (LQCD) data shows at $\mu_q = \mu_I = 0$ chiral and deconfinement crossover coincide exactly and PNJL model gives almost this coincidence [2, 3]. Unlike non-zero μ_q case, for $\mu_I \neq 0$ there is no sign problem in LQCD. PNJL model in finite $\mu_I \neq 0$ was previously studied in ref. [5–7]. In the present work we have studed $(T - \mu_I)$ phase diagram by tuning 3-momentum cutoff parameter Λ.

Formalism

The Lagrangian of two-flavor PNJL model in finite baryon chemical potential and isospin chemical potential case, is given by

$$\mathcal{L}_{PNJL} = \bar{\psi}\left(i\gamma_\mu D^\mu + \gamma_0\hat{\mu} - \hat{m}_0\right)\psi + \frac{G}{2}\left[\left(\bar{\psi}\psi\right)^2 + \left(\bar{\psi}i\gamma_5\vec{\tau}\psi\right)^2\right] - \mathcal{U}\left(\Phi[A], \bar{\Phi}[A], T\right) \qquad (1)$$

where $\psi = (\psi_u, \psi_d)^T$ is the quark field,

$$D^\mu = \partial^\mu - iA^\mu \quad \text{and} \quad A^\mu = \delta_{\mu 0}A^0 \qquad (2)$$

The two-flavor current quark mass matrix is $\hat{m}_0 = diag(m_u, m_d)$ and we took $m_u = m_d \equiv m_0$. The quark chemical potential matrix $\hat{\mu}$ takes the form $\hat{\mu} = diag(\mu_u, \mu_d)$. From NJL model four-point interaction is introduced with an effective coupling strength G. An effective potential $\mathcal{U}(\Phi, \bar{\Phi}, T)$ expressed in terms of the traced Polyakov loop $\Phi = (\mathrm{Tr}_c L)/N_c$ and its (charge) conjugate $\bar{\Phi} = (\mathrm{Tr}_c L^\dagger)/N_c$ is present in the PNJL Lagrangian. For simplicity, A_4 is treated as a constant in PNJL, and the Polyakov loop is reduced as $L = \left[\mathcal{P}\exp\left(i\int_0^\beta A_4 d\tau\right)\right] = \exp\left[\frac{iA_4}{T}\right]$ To describe the spontaneous chiral symmetry breaking and I_3 symmetry breaking, we define the chiral condensate as $\langle\bar{\psi}\psi\rangle = \sigma$ and the pion condensates $\langle\bar{\psi}i\gamma_5\tau_i\psi\rangle = \pi_i$, i=1,2,3. where τ_i is the Pauli matrix in flavor space.

The thermodynamical potential in the mean field level is expressed as in eqn. (3). Minimizing the thermodynamical potential (3) w.r.t. the fields σ, π, Φ and $\bar{\Phi}$ we obtained equilibrium field configurations. Note that when there exist multiple roots of these coupled equations, the solution corresponding to the minimal thermodynamical potential is favored.

Figures and Tables

We studied Phase diagram in (T, μ_I) plane for two cases.

- Case A : $M = m_0 - G\sigma, \forall p$, because for finite temperature theory temerature plays the role of most natural cutoff.

- Case B : It is to some extent unphysical to admit the existence of a condensate upto arbitrarily high momentum. So we took,

$$M = \begin{cases} m_0 - G\sigma, & \text{for}\, p \leq \Lambda \\ m_0, & \text{for}\, p > \Lambda. \end{cases}$$

Although case B seems to be more physical but, lattice data [8] confirmed a first order transition in high μ_I region. We are presently investigating that by going beyond mean field if we can remove this preliminary

*Electronic address: `anirbanlahiri.boseinst@gmail.com`

$$\Omega = \frac{G}{2}(\sigma^2+\pi^2) \; + \; \mathcal{U}'(\Phi,\bar{\Phi},T) - 2N_c\int\frac{d^3p}{(2\pi)^3}\left[E_p^- + E_p^+\right]\theta(\Lambda^2-\vec{p}^2)$$
$$-2T\int\frac{d^3p}{(2\pi)^3} \quad \ln\left[1+3\left(\Phi+\bar{\Phi}\mathrm{e}^{-\left(E_p^- -\mu\right)/T}\right)\mathrm{e}^{-\left(E_p^- -\mu\right)/T}+\mathrm{e}^{-3\left(E_p^- -\mu\right)/T}\right]$$
$$+ \quad \ln\left[1+3\left(\bar{\Phi}+\Phi\mathrm{e}^{-\left(E_p^- +\mu\right)/T}\right)\mathrm{e}^{-\left(E_p^- +\mu\right)/T}+\mathrm{e}^{-3\left(E_p^- +\mu\right)/T}\right]$$
$$+ \quad \ln\left[1+3\left(\Phi+\bar{\Phi}\mathrm{e}^{-\left(E_p^+ -\mu\right)/T}\right)\mathrm{e}^{-\left(E_p^+ -\mu\right)/T}+\mathrm{e}^{-3\left(E_p^+ -\mu\right)/T}\right]$$
$$+ \quad \ln\left[1+3\left(\bar{\Phi}+\Phi\mathrm{e}^{-\left(E_p^+ +\mu\right)/T}\right)\mathrm{e}^{-\left(E_p^+ +\mu\right)/T}+\mathrm{e}^{-3\left(E_p^+ +\mu\right)/T}\right] \qquad (3)$$

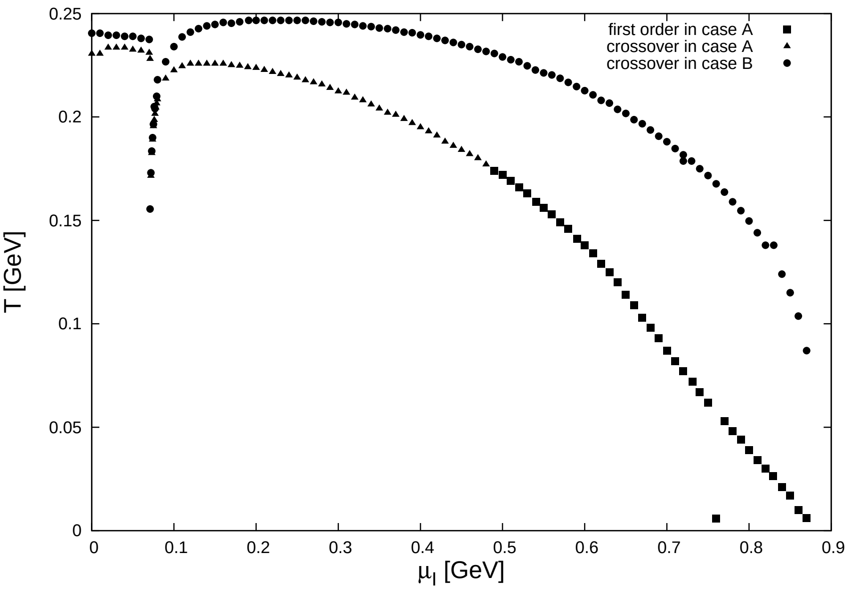

FIG. 1: Comparison of phase diagrams in (T, μ_I) plane for the two cases mentioned in text.

mismatch. It should be mentioned that although (T, μ_I) phase diagram differs in these two cases, (T, μ_B) phase diagram does not depend on the mode of use of Λ.

Acknowledgments

I would like to thank CSIR for giving financial support.

References

[1] Y. Nambu and G. Jona-Lasinio, Phys. Rev. **122**, 345 (1961); Phys. Rev. **124**, 246 (1961).
[2] C. Ratti, M. A. Thaler and W. Weise, Phys. Rev. D **73**, 014019 (2006).
[3] S. K. Ghosh *et.al.* Phys. Rev. D **73**, 114007 (2006)
[4] S. K. Ghosh *et.al.* Phys. Rev. D **77**, 094024 (2008)
[5] S. Mukherjee, M. G. Mustafa and R. Ray, Phys. Rev. D **75**, 094015 (2007)
[6] H. Abuki *et.al.* Phys. Rev. D **78**, 014002 (2008)
[7] Z.Zhang and Y.X.Liu, Phys. Rev. **C 75**, 064910 (2007).
[8] J. B. Kogut and D. K. Sinclair, Phys. Rev. D **66**, 034505 (2002)