Inverse Magnetic Catalysis within (P)NJL models

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Introduction

The structure of the QCD phase diagram in the presence of an external magnetic field, at $\mu_B = 0$, has been subject of several studies. Almost all low-energy effective models, including the NJL type models, found an enhancement of the condensate due to the magnetic field (magnetic catalysis) at any temperature. Recent LQCD studies [1, 2] show a suppression of the light condensates (Inverse Magnetic Catalysis) in the transition temperature region due to the magnetic field. Thus, the condensates show a non-monotonic behavior as a function of eB, resulting in a decreasing transition temperature with increasing eB. Furthermore, it was shown that also the deconfinement transition temperature is a decreasing function of eB [3]. The QCD coupling is also affected by the presence of the magnetic field [4]: it decreases with increasing magnetic field strenght. We use a magnetic field dependent coupling within the SU(3) (P)NJL models [5], in order to mimic the α_s dependence on B, and compare the results with LQCD [1, 2].

The model

We describe quark matter subject to strong magnetic fields within the SU(3) PNJL model,

$$\mathcal{L} = \bar{\psi}_f \left[i\gamma_\mu D^\mu - \hat{m}_f \right] \psi_f + \mathcal{L}_{sym} + \mathcal{L}_{det} + \mathcal{U}\left(\Phi, \bar{\Phi}; T\right) - \frac{1}{4} F_{\mu\nu} F^{\mu\nu},$$

with $\mathcal{L}_{sym}$ and $\mathcal{L}_{det}$ given by:

$$\mathcal{L}_{sym} = G_s \sum_{a=0}^{8} \left[(\bar{\psi}_f \lambda_a \psi_f)^2 + (\bar{\psi}_f i\gamma_5 \lambda_a \psi_f)^2 \right],$$

$$\mathcal{L}_{det} = -K \left(\det_f \left[\bar{\psi}_f (1+\gamma_5) \psi_f \right] + \det_f \left[\bar{\psi}_f (1-\gamma_5) \psi_f \right] \right).$$

$D^\mu = \partial^\mu - i q_f A^\mu_{EM} - i A^\mu$, where $A^{EM}_\mu = \delta_{\mu 2} x_1 B$ is a static and constant magnetic field in the z direction, and $A^\mu = \delta^\mu_0 A^0 = -i \delta^\mu_4 A^4$ (Polyakov gauge). The chosen Polyakov potential is given by

$$\frac{\mathcal{U}\left(\Phi, \bar{\Phi}; T\right)}{T^4} = -\frac{a\left(T\right)}{2} \bar{\Phi}\Phi + b(T) \ln \left[1 - 6\bar{\Phi}\Phi + 4(\bar{\Phi}^3 + \Phi^3) - 3(\bar{\Phi}\Phi)^2 \right],$$

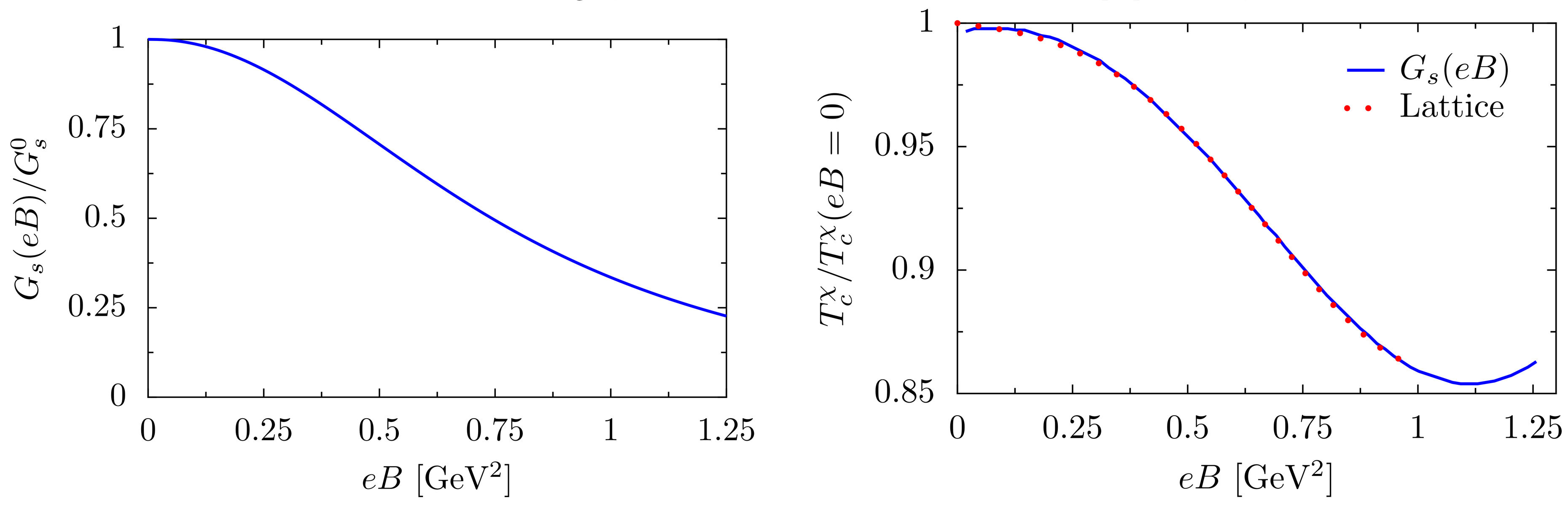
where $a\left(T\right) = a_0 + a_1 \left(\frac{T_0}{T}\right) + a_2 \left(\frac{T_0}{T}\right)^2$, $b(T) = b_3 \left(\frac{T_0}{T}\right)^3$.

The thermodynamical potential and the respective gap equations, in the presence of a magnetic field, can be found in [6].

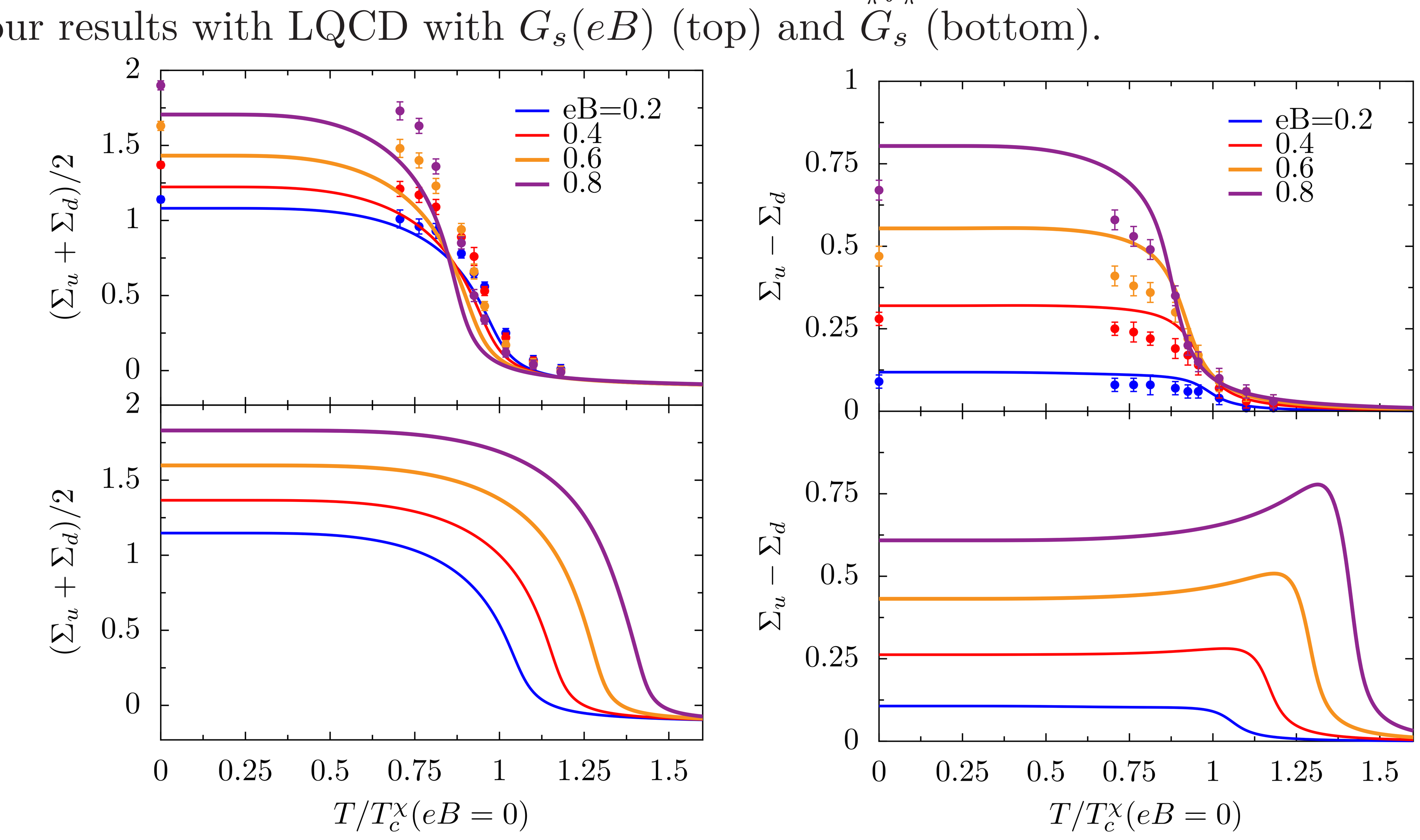
For the parameters of the model, we consider [7]: $\Lambda = 602.3$ MeV, $m_u = m_d = 5.5$ MeV, $m_s = 140.7$ MeV, $G_s \Lambda^2 = 1.385$ and $K \Lambda^5 = 12.36$.

NJL with $G_s(eB)$

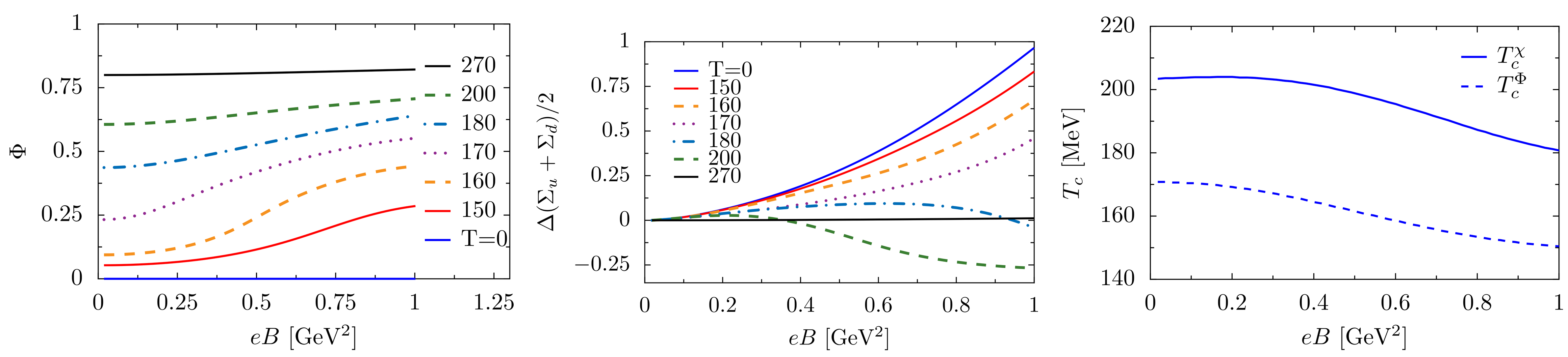
The QCD coupling α_s decreses with eB [4]. Thus, the coupling G_s in the NJL model, which can be seen as $\propto \alpha_s$, must decrease with an increasing magnetic field strenght. In the following, we fit $G_s(eB)$ (right) in order to reproduce $T_c^\chi(eB)$ obtained in LQCD [1] (left).



According to [2], we define the change of the light condensate due to the magnetic field as $\Delta\Sigma_f(B,T) = \Sigma_f(B,T) - \Sigma_f(0,T)$, with $\Sigma_f(B,T) = \frac{2m_f}{m_\pi^2 f_\pi^2} \left[\langle \bar{q}_f q_f \rangle (B,T) - \langle \bar{q}_f q_f \rangle (0,0) \right] + 1$, and compare our results with LQCD with $G_s(eB)$ (top) and G_s (bottom).



PNJL with $G_s(eB)$



- (Left) For a certain temperature the Polyakov loop value increases with the magnetic field: the deconfinement transition starts at smaller temperatures with increasing eB.
- (Center) For temperatures near the transition temperature a non-monotonic behavior of the average light condensate is obtained.
- (Right) The critical temperatures of both chiral and deconfinement phase transitions drecrease with eB.

All the qualitative results obtained by LQCD [1, 2, 3] can be reproduced using the calculated $G_s(eB)$ coupling. Therefore, a decreasing magnetic field dependent for quark coupling is essential, within effective models, to mimic the expected running of QCD coupling with eB and reproduce Inverse Magnetic Catalysis.

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