Strong magnetic fields in nonlocal chiral quark models

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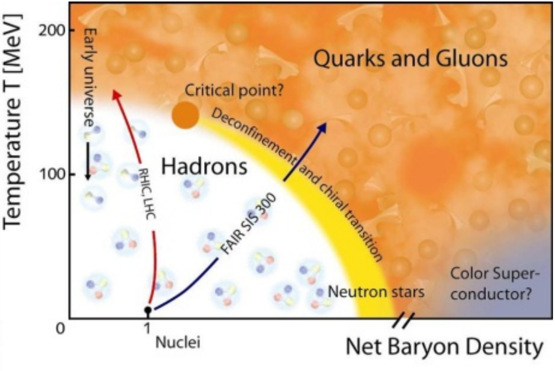
Motivation



- Cosmology (exploration of the early Universe)
- Heavy ion collisions at very high energies
- Compact objects like magnetars

$\Rightarrow$ Intense external magnetic fields of 10^{18} G ($\simeq 1,96$ GeV^2)

Nonlocal NJL-like model in the presence of magnetic fields

$$S_E = \int d^4x \left\{ \bar{\psi}(x) \left(-i\partial\!\!\!/ + m_c\right) \psi(x) - \frac{G}{2} j_a(x) j_a(x) \right\}$$

$$j_a(x) = \int d^4z\, \mathcal{G}(z)\, \bar{\psi}\left(x + \frac{z}{2}\right) \Gamma_a\, \psi\left(x - \frac{z}{2}\right) \qquad \text{with } \Gamma_a = (\mathbb{1}, i\gamma_5\vec{\tau})$$

- Add an external magnetic field:

$$\begin{aligned} \partial_\mu &\rightarrow D_\mu = \partial_\mu - i\,\hat{Q}\,B\,x_1\,\delta_{\mu 2} \\ \psi\,(x - z/2) &\rightarrow \mathcal{W}\,(x, x - z/2)\,\psi(x - z/2) \\ \psi^\dagger\,(x + z/2) &\rightarrow \psi^\dagger\,(x + z/2)\,\mathcal{W}\,(x + z/2, x) \end{aligned}$$

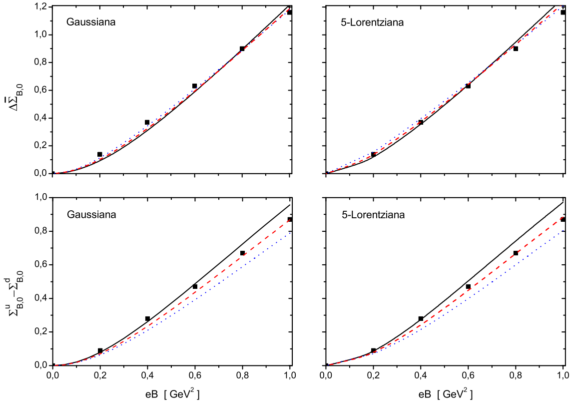
- Bozonization: $S_{\rm bos} = -\log\det \mathcal{D}_{x,x'} + \frac{1}{2G}\int d^4x \left[\sigma(x)\sigma(x) + \vec{\pi}(x)\cdot\vec{\pi}(x)\right]$
- Mean Field Aproximation
- Ritus transform: $\mathcal{D}^{\rm MFA,f}_{\bar{p},\bar{p}'} = \int d^4x\, d^4x'\, \bar{\mathbb{E}}_{\bar{p}}(x)\, \mathcal{D}^{\rm MFA,f}_{x,x'}\, \mathbb{E}_{\bar{p}'}(x') \qquad$ with $\bar{p} = (k, p_2, p_3, p_4)$

$$\Rightarrow \frac{S^{\rm MFA}_{\rm bos}}{V^{(4)}} = \frac{\bar{\sigma}^2}{2G} - N_c \sum_{f=u,d} \frac{|q_f B|}{2\pi} \int \frac{d^2 p_\parallel}{(2\pi)^2} \left[\log\left(p_\parallel^2 + M^{\lambda,f\;2}_{0,p_\parallel}\right) + \sum_{k=1}^{\infty} \log \Delta^f_{k,p_\parallel} \right]$$

  - Dinamic effective mass: $M^{\lambda,f}_{k,p_\parallel} = \left(1 - \delta_{k_\lambda,-1}\right) m_c + \bar{\sigma}\, g^{\lambda,f}_{k,p_\parallel}$
  - Quiral condensates: $\langle \bar{q}_f\, q_f \rangle = \dfrac{\partial S^{\rm MFA}_{\rm bos}}{\partial m_{q_f}}$

Magnetic catalysis

The magnetic catalysis is associated with spontaneous breaking of chiral symmetry, which is enhanced by the presence of an external magnetic field. This implys that the chiral quark condensate behaves as an increasing function of B.



Solid (black), dashed (red), and dotted (blue) curves correspond to parameterizations leading to $\langle \bar{q}_f\, q_f \rangle_0^{\rm reg} = 220$, 230, and 240 MeV, respectively. Full square symbols indicate LQCD results.

$$\Sigma_B^f = -\frac{2\,m_c}{S^4}\left[\langle \bar{q}_f q_f \rangle_B^{\rm reg} - \langle \bar{q}_f q_f \rangle_0^{\rm reg}\right] + 1$$

$$\Delta\Sigma_B^f = \Sigma_B^f - \Sigma_0^f$$

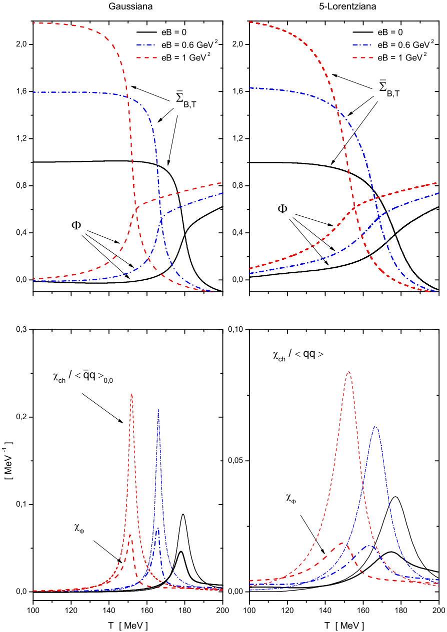
$$\Delta\bar{\Sigma}_B = \frac{\Delta\Sigma_B^u + \Delta\Sigma_B^d}{2}$$

Extension to finite temperature

- Standard Matsubara formalism.
- Coupling of fermions to the Polyakov loop.

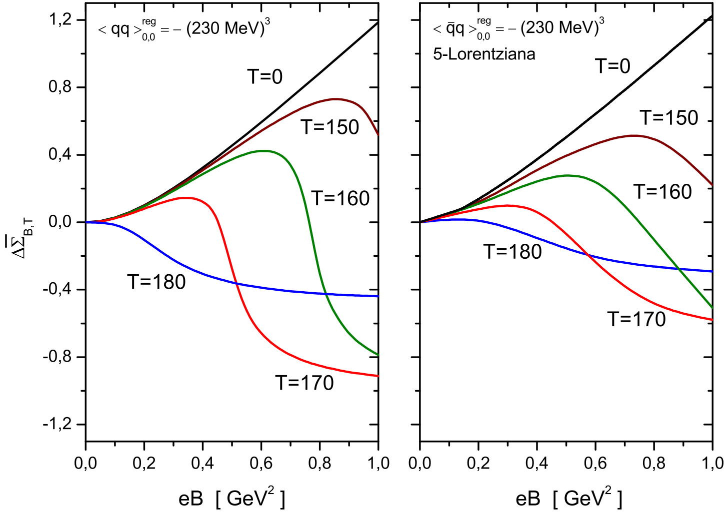
Phase transitions

- **Chiral restoration**
  Order parameter: quiral condensate
  $$\langle \bar{q}_f q_f \rangle_{B,T}^{\text{reg}} = \frac{\partial \Omega_{B,T}^{\text{MFA,reg}}}{\partial m_{q_f}}$$
- **Deconfinement**
  Order parameter: traced Polyakov loop
  $$\Phi = \frac{1}{3}\left[1 + 2\cos\left(\frac{\phi_3}{T}\right)\right]$$

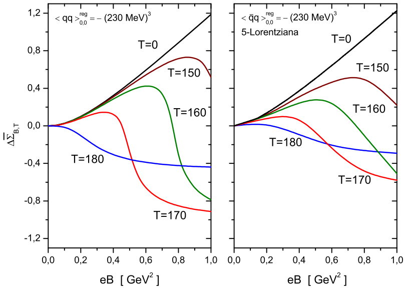


Inverse magnetic catalysis

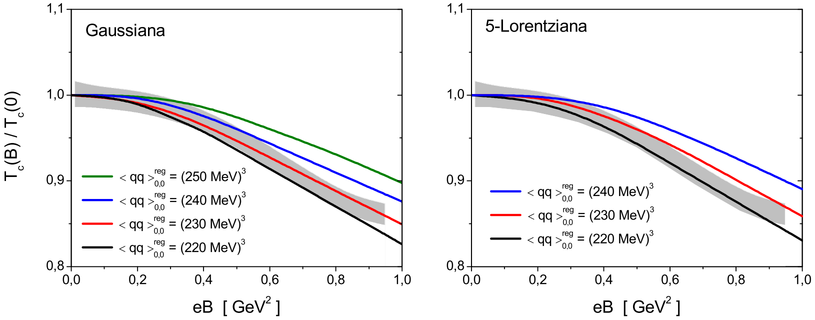
Close to the chiral restoration temperature light quark-antiquark condensates do not show a monotonic increase with B for a fixed value of the temperature.



Inverse magnetic catalysis



This leads to a decrease of the chiral restoration critical temperature when the magnetic field is increased.



Thank you!