Properties of neutral pions in a hot and magnetized quark matter

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Creation of strong magnetic fields in HIC

Collisions between heavy nuclei produce some of the strongest magnetic fields that can be generated under laboratory conditions


The transverse plane of a non-central heavy-ion collision (HIC). The impact parameter of the collision is denoted by b. A magnetic field is created in the direction perpendicular to the reaction plane (dashed lines)


The time evolution of the magnetic field strength at the central point in Au-Au collisions with impact parameter b=4fm, in one event and averaged over 100 events

It is shown that the magnetic field emerging in HIC has the magnitude of the order of $eB\sim0.1m_π^2$ for the SPS energy range and $eB\sim m_π^2$ for the RHIC energies. The estimated value of the magnetic field strength for the LHC energy amounts to $eB\sim 15m_π^2$

[Note: $m_π=140$ MeV, $eB\sim$ GeV$^2$ equ. with $B\sim 10^{15}$ G]

Questions and expectations

Although the created magnetic field is extremely short living, it may affect the properties of hadrons made of magnetized quarks

- In particular, we are interested in
  - $T$ dependence of neutral pion mass
  - $T$ dependence of neutral pion's refraction indices in the presence of constant magnetic field at finite $T$

Effective action of a two-flavor NJL model in a second order derivative expansion

Modified energy dispersion relation for $π^0$ including directional refraction indices

[Sh. Fahyazbakhsh, S. Sadeghian and N.S. PRD 86 (2012) 085042]

Modified Gell-Mann-Oakes-Renner (GOR) relation

Modified low energy QCD theorems

Modified energy dispersion relation of $π^0$

$$ω^2 = u_1^2 p_1^2 + u_2^2 p_2^2 + u_3^2 p_3^2 + m_π^2$$

$u_i=1,2,3$ are $n^0$ directional refraction indices and $m_π$ is the $n^0$ mass

Modified PCAC relation

$\langle 0 | T F_{\mu\nu}^{(B)}(0) | n^\mu(q) \rangle = f_π q_\nu \delta^{\mu\nu} + G \delta^{\mu\nu}(0)$

$G$ is the axial vector current, $f_π$ is a constant

The Bethe-Salpeter equation for quark-antiquark scattering in random phase approximation. It leads to the modified GOR relation

Modified Gell-Mann-Oakes-Renner (GOR) relation

$t_{\mu\nu} \mu=0,1,2,3$ are directional weak decay constants of $π^0$

$u_{\mu\nu} \mu=0,1,2,3$ are directional refraction indices of $n^0$

$G$ is the bare mass of quarks

$\sigma_0$ is the chiral condensate of the NJL model

Results: Sh. Fahyazbakhsh and N.S. PRD 88 (2013) 065030

$T$ dependence of $m_π$ for various magnetic field strengths $eB$: Below the crossover temperature, pions are Goldstone bosons and therefore (approximately) massless

$T$ dependence of directional refraction indices $u_{\mu\nu}$ for various magnetic field strengths $eB$: In general we have

Summary

Uniform magnetic field breaks the Lorentz invariance and induces certain anisotropy in the refraction indices and weak decay constants of neutral pions. They are related through modified low energy theorems of QCD.