ITEP Lattice

Charged hadrons in strong magnetic fields ArXiv:1104.3767, 1003.2180

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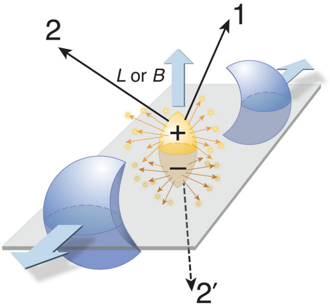
FRRC Seminar

Magnetic phenomena in heavy-ion collisions



Magnetic field strength at hadronic scale!!! [Kharzeev, McLerran '98]

Very strong magnetic fields

- Noncentral heavy-ion collisions:

$$B \sim 10^{15}\ Tl, \quad \sqrt{eB} \sim 10\ Mev \ldots 500\ MeV$$

- Early Universe after electroweak phase transition:

$$B \sim 10^{16}\ Tl, \quad \sqrt{eB} \sim 1\ GeV$$

- Magnetars:

$$B \sim 10^{10}\ Tl, \quad \sqrt{eB} \sim 1\ MeV$$

- Strong laser pulses in PHELIX:

$$B \sim 10^{7}\ T, \quad \sqrt{eB} \sim 0.01\ MeV, \quad I \sim 10^{23}\ W/cm^2$$

Magnetic phenomena in hadronic matter at low temperatures

- Low-mass mesons (π^0, $\pi^\pm$, ρ^0, $\rho^\pm$) dominate
- Pions: charged pseudo-scalar particles
- ρ-mesons: charged vector particles
- First approximation: free particles, neglect internal structure
- Gyromagnetic ratios: $g = 1$ for π, $g = 2$ for ρ

Hadron masses (free approximation)

General relativistic expression for Landau levels:

$$E^2 = p_z^2 + (2n - gs_z + 1)\, eB + m^2$$

Lowest Landau Levels:

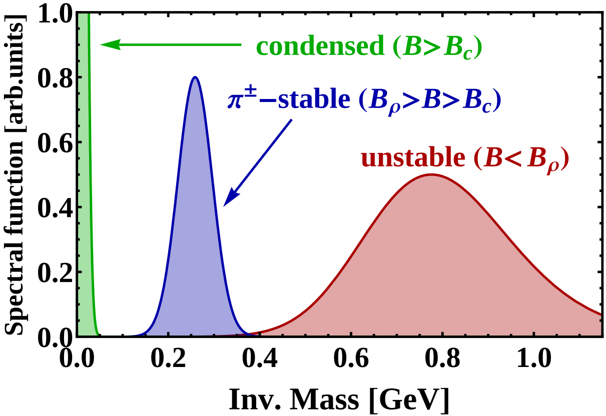
$$m^2_{\pi^\pm}(B) = m^2_{\pi^\pm}(0) + eB$$

$$m^2_{\rho^\pm}(B) = m^2_{\rho^\pm}(0) - eB$$

Hadron spectrum in magnetic field

- $\rho^{\pm}$ become lighter as eB grows
- At some critical $eB_c \approx m_\rho^2$ - tachyonic instability???
- $\pi^{\pm}$ become heavier $\Rightarrow$
- Suppression of decays $\rho^{\pm} \to \pi^{\pm} X$,
  $X = \pi^0, \quad \eta, \quad \gamma, \quad \pi\pi\pi$
- $\rho^{\pm}$ become lighter and narrower

ρ spectral functions



Superconductivity in the magnetic field

- Transport peak at $w = 0$ in $\rho^{\pm}$ spectral functions: superconductivity [Chernodub 2010]
- Strong magnetic field: charged particles move along the magnetic field
- $\Rightarrow$ Superconductivity along the magnetic field

Superconductivity: cond.matt. vs. QCD

- Electrons = quarks
- 1D motion near Fermi surface = 1D motion in magnetic field
- Phonon exchange (attractive) = gluon exchange (confinement)
- Cooper pairs = charged ρ mesons
- Condensate of Cooper pairs = Condensates of $\rho^{\pm}$

Insulator vs. conductor in Euclidean space

Insulator:

$$\langle j(0) j(x) \rangle \sim e^{-|x|/m}$$

Conductor:

$$\langle j(0) j(x) \rangle \sim C + A\, e^{-|x|/m}$$

- $\langle j_\mu j_\nu \rangle$ correlator is saturated by ρ-mesons
- C is the ρ "condensate"!!!

Spectral functions on the lattice

Euclidean correlators (lattice) vs. Minkowski spectral functions:
Green-Kubo relations

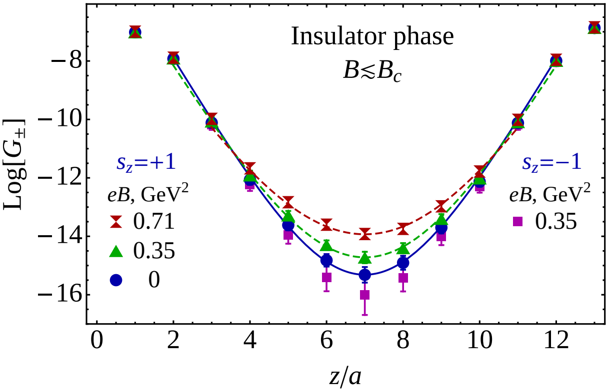
$$G_{ij}(\tau) = \int d^3\vec{x} \langle j_i\left(\vec{0},0\right) j_j(\vec{x},\tau)\rangle,$$

$$G_{ij}(\tau) = \int\limits_0^{+\infty} \frac{dw}{2\pi} K(w,\tau)\,\rho_{ij}(w),$$

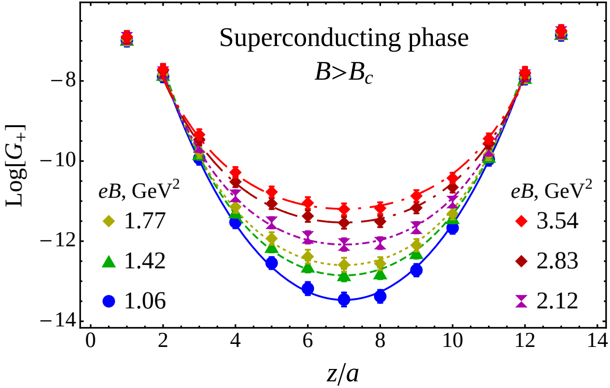
$$K(w,\tau) = \frac{w}{2T}\frac{\cosh\left(w\left(\tau-\frac{1}{2T}\right)\right)}{\sinh\left(\frac{w}{2T}\right)},$$

$$\sigma_{ij} = \lim_{\omega\to 0}\frac{\rho_{ij}(\omega)}{4T}$$

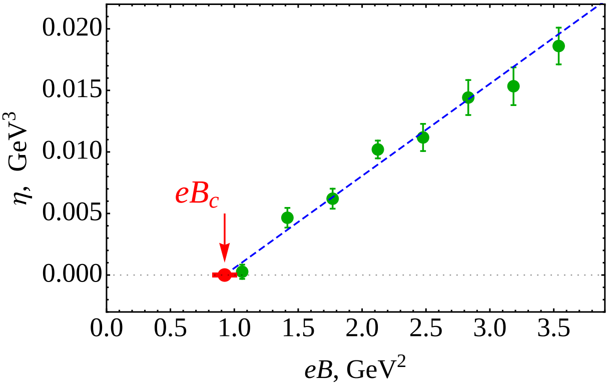
Current-Current correlator: small B



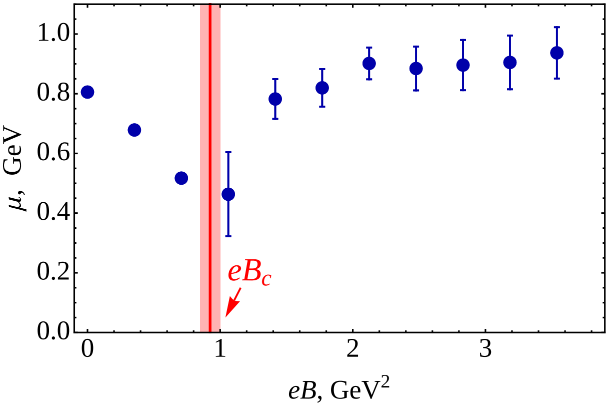
Current-Current correlator: large B



Condensate as a function of B



ρ mass as a function of B



Conclusions

- Gyromagnetic ratio $g = 2$ for $\rho^{\pm}$: ρ eventually lighter than π
- $\Rightarrow \rho^{\pm}$ become more stable
- Tachyonic instability of ρ at sufficiently large B
- Anisotropic superconductivity along the magnetic field [Chernodub 2010]???
- Critical magnetic field $eB \sim m_{\rho}^{2}$.