Meson masses in external magnetic fields from Lattice QCD

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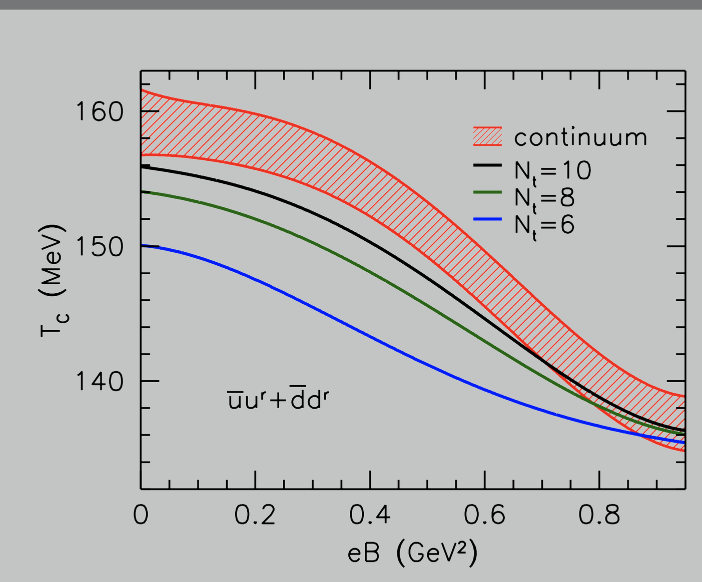
Motivation

- QCD in strong magnetic field has interesting effects like **Inverse magnetic catalysis**[1],[2] (transition critical temperature decreases as magnetic field increases), corresponding lightest Goldstone boson particle mass (m_π) is thus interesting to be investigated.



- In the framework of NJL model, QCD vacuum transforms into a **superconducting** state in sufficient strong magnetic field signaled by $\rho^\pm$ meson condensation[3],[4] i.e. $m_{\rho^\pm} = 0$. A mass relation: $m_{\rho^\pm} \geq (m_{\pi_u^0} + m_{\pi_d^0})/2$ given by QCD inequality[5] can be used to check the condensation of $\rho^\pm$.
- Results obtained from lattice simulation can be compared with the ground state energy given by the **Lowest Landau Level (LLL) approximation** $E^2 = p_z^2 + 2n|qB| + m^2$.

Recent results from Lattice

Mass v.s. eB behavior	π^0	$\pi^\pm$	ρ_0^0	ρ_+^0	ρ_0^+	ρ_+^+	ρ_-^+	K	η^0
quenched Wilson[6]/Overlap[7]	↘	↗	↘	↗	↗	↘	↗		
dynamical stout[6]	↘								

Lattice setup

- (2+1)-flavor dynamical HISQ fermion at T=0
- Lattice size: $32^3 \times 96$, $a^{-1} = 1.6852$ GeV
- $m_\pi = 230$ MeV
- Magnetic field ranges from $0 \sim 3.3$ GeV^2
- Multipule wall sources have been used to improve the signal.

Methodology

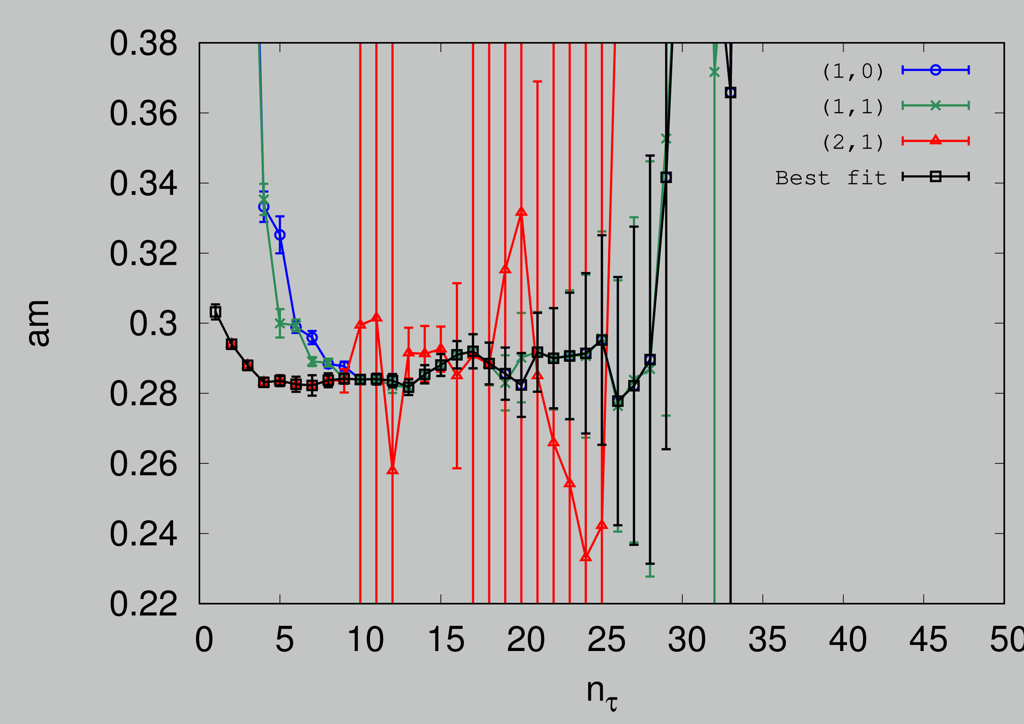
- Correlator formular for staggered fermion:

$$G(\tau) = -\sum_n \zeta(\vec{n})\, \mathrm{Tr}\left[M^{-1\dagger}(n,0)M^{-1}(n,0)\right] \quad (1)$$

- Fit ansatz:

$$G_{\mathrm{fit}}(n_\tau) = \sum_{i=1}^{N_s,no} A_{no,i} \exp\left(-m_{no,i} n_\tau\right) - (-1)^{n_\tau} \sum_{i=0}^{N_s,osc} A_{osc,i} \exp\left(-m_{osc,i} n_\tau\right) \quad (2)$$

- Selected best fit through AICc[8]:

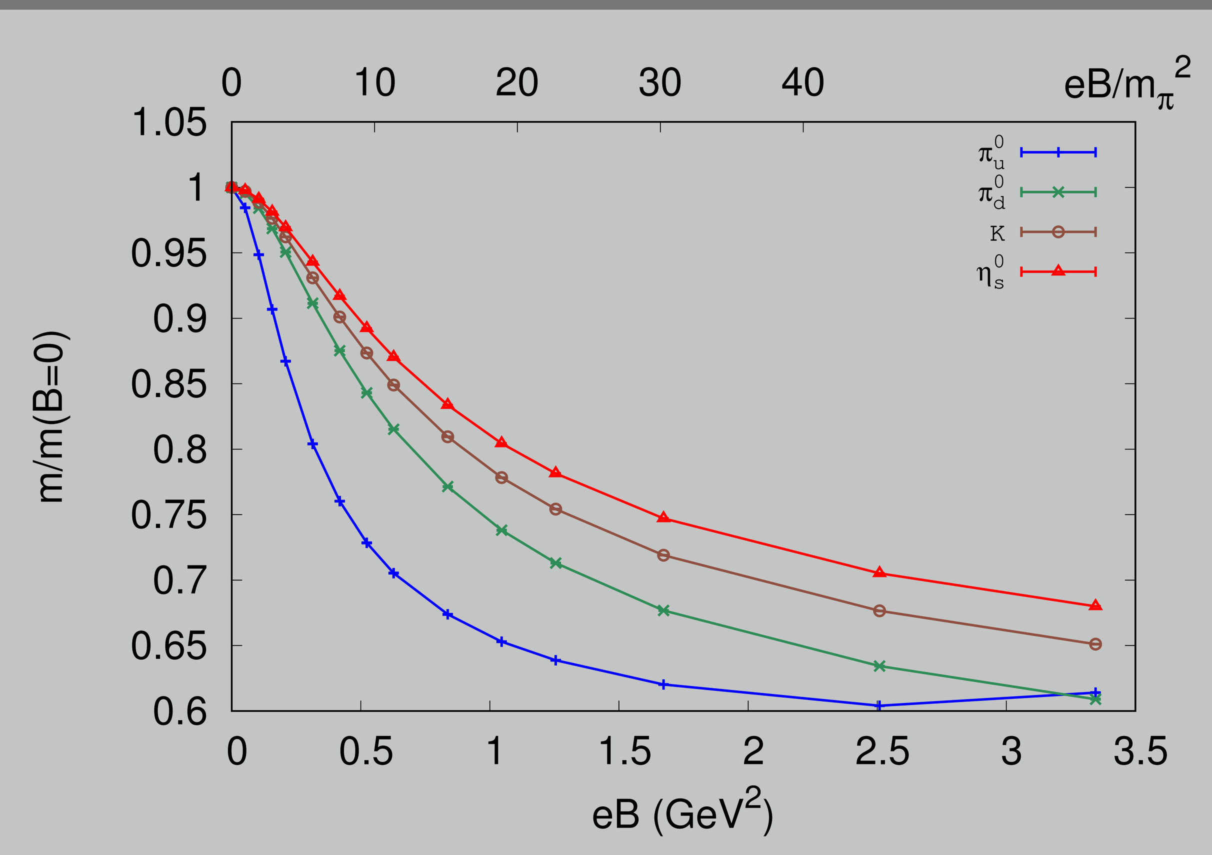


$$\mathrm{AICc} = 2k - \ln(\hat{L}) + \frac{2k^2 + 2k}{n - k - 1} \quad (3)$$

Acknowledgments

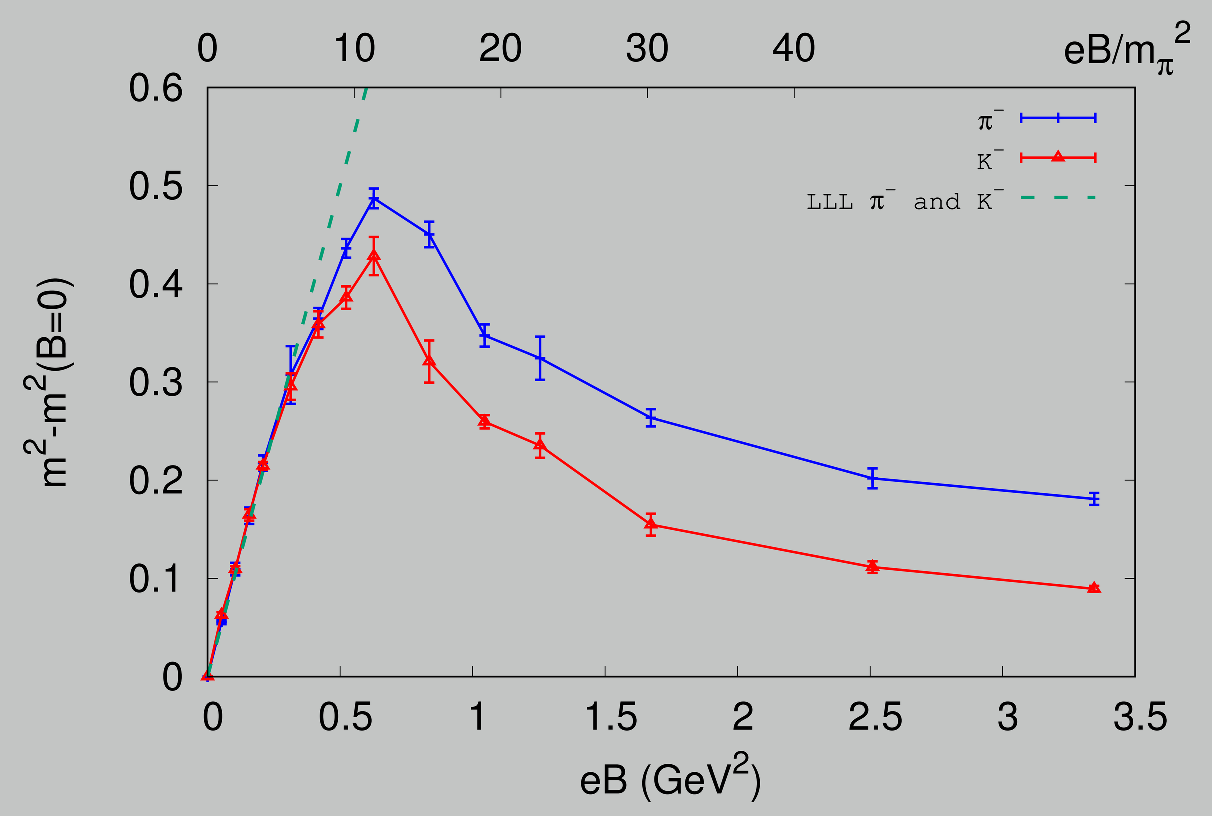
- The numerical simulations have been performed on the GPU cluster in the Nuclear Science Computing Center at CCNU (NSC³).

Neutral Pseudo-scalar particle masses π_u^0 π_d^0 K η_s^0 v.s. eB



- Neutral PS particles' masses decrease as eB grows and saturate at large eB.
- Lighter hadrons are more affected by magnetic field.
- Neutral PS particles' masses reduce about $30 \sim 40\%$, which is different from effective theory predictions.
- The decreasing of m_π explains the decreasing of transition temperature[2].

Charged Pseudo-scalar particle masses π^- K^- v.s. eB



- Charged PS particles' masses have non-monotonous behavior, which is different from quenched lattice result.
- At $0 < eB \lesssim 0.3$ GeV^2, PS particles' masses can be well described by Lowest Landau level approximation.

Conclusion

- Masses of neutral pseudo-scalar particles decrease as the magnetic field grows but saturate at large eB.
  - Neutral particles interact with magnetic field.
- Charged PS particle showed non-monotonous behavior as eB increases.
- According to the mass relation between $\rho^\pm$ meson with π_u^0 and π_d^0, there is no $\rho^\pm$ condensation in current window of eB.

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