

# Impact of external magnetic field on magnetic moment of $\Xi$

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# Importance of studying magnetic moments

## Why Study Magnetic Moments?

- Provide critical insights into the internal structure of hadrons.
- Provide valuable understanding of strong interaction at low energies (non perturbative regime of QCD).
- Test predictions from theoretical frameworks, such as effective field theories, under different conditions.

## Connection to Momentum Transfer Studies:

- Momentum transfer experiments, such as deep inelastic scattering, probe the spatial and momentum distributions of quarks inside hadrons.
- Magnetic moment measurements complement momentum transfer studies by providing information about the spin and charge distributions of quarks.

# Why study the effect of magnetic fields on baryons?

- **Fundamental Physics:**

- Might help analyze QGP evolution.
- Exploring QCD in extreme conditions.

- **Astrophysical Relevance:**

- Strong magnetic fields in neutron stars and magnetars (up to  $10^{15}$  G).
- Impact on the nuclear equation of state (EoS).
- Explains polarization effects in cosmic radiation.

## Applications:

- Understanding heavy-ion collisions in particle accelerators.

# Chiral SU(3) quark mean field model

## Theoretical Overview

- The Chiral SU(3) quark mean field model is a theoretical framework that considers quarks as fundamental degrees of freedom interacting via scalar and vector meson fields.
- The model takes into account chiral symmetry and spontaneous symmetry breaking.

# Symmetry restoration in dense nuclear matter

## Theoretical Background:

### • Chiral Asymmetry:

- Fundamental symmetry of Quantum Chromodynamics (QCD), spontaneously broken in vacuum due to quark condensates.
- Responsible for the mass of hadrons.

### • Restoration Mechanism:

- At high baryon densities, the quark condensate decreases due to interactions.
- Leads to a partial or complete restoration of chiral symmetry.

# Impact of dense nuclear matter

## Effect of Dense Nuclear Matter:

- Scalar and vector meson fields are modified due to high density.
- A variation in quark masses is observed.
- Consequently, the magnetic moment of decuplet baryons is also altered.

## Relevance:

Understanding these changes helps to explain baryonic behavior in neutron stars and other astrophysical phenomena.

# Thermodynamic potential

**Why we use:** To obtain density, temperature and magnetic field strength dependent scalar and vector fields.

The thermodynamic potential ( $\Omega$ ) for isospin asymmetric matter in the chiral SU(3) quark mean field model is given by:

$$\Omega = -T \sum_i \frac{|q_i|B}{2\pi} \sum_{s=\pm 1} \sum_{\nu=0}^{\infty} (2 - \delta_{\nu 0}) \int_{-\infty}^{\infty} \frac{dk_z}{2\pi} \\ \times \left\{ \ln [1 + e^{-\beta(\tilde{E}_{\nu,s}^i - \mu_i^*)}] + \ln [1 + e^{-\beta(\tilde{E}_{\nu,s}^i + \mu_i^*)}] \right\}.$$

## Effect on magnetic field on thermodynamic potential

The external magnetic field impacts are realised through the scalar and vector densities.

- $$\rho_i^V = \frac{1}{2\pi^2} \sum_{s=\pm 1} \int_0^\infty p_\perp^i dp_\perp^i \int_0^\infty dp_\parallel^i (f_{p,s}^i - \bar{f}_{p,s}^i),$$

- $$\rho_i^S = \frac{1}{2\pi^2} \sum_{s=\pm 1} \int_0^\infty p_\perp^i dp_\perp^i \left( 1 - \frac{s\mu_N \kappa_i B}{\sqrt{m_i^{*2} + (p_\perp^i)^2}} \right) \\ \times \int_0^\infty dp_\parallel^i \frac{m_i^*}{\tilde{E}_s^i} (f_{p,s}^i + \bar{f}_{p,s}^i).$$

# Lagrangian of the chiral SU(3) model

## Key Components of the Lagrangian:

- Quark coupling to scalar and vector mesons.
- Chiral symmetry breaking terms.
- Interactions among mesons.

## Lagrangian expression for the magnetized medium:

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{q0} + \mathcal{L}_{qm} + \mathcal{L}_{\Sigma\Sigma} + \mathcal{L}_{VV} + \mathcal{L}_{\chi SB} + \mathcal{L}_{\Delta m} + \mathcal{L}_c + \mathcal{L}_{\text{mag}}.$$

where,

$$\mathcal{L}_{\text{mag}} = -\bar{\psi}_i q_i \gamma_\mu A^\mu \psi_i - \frac{1}{4} \kappa_i \mu_N \bar{\psi}_i \sigma^{\mu\nu} F_{\mu\nu} \psi_i - \frac{1}{4} F^{\mu\nu} F_{\mu\nu}.$$

# Effective mass and energy

- Dirac equation under the influence of meson mean field:

$$[-i\vec{\alpha} \cdot \vec{\nabla} + \chi_c(r) + \beta m_q^*] \Psi_{qi} = e_q^* \Psi_{qi}$$

- Confinement Potential:

$$\chi_c(r) = \frac{1}{4} k_c r^2 (1 + \gamma^0)$$

- Effective Quark Mass:

$$m_q^* = -g_\sigma^q \sigma - g_\zeta^q \zeta - g_\delta^q I_3^q \delta + m_{q0}$$

- Effective Baryon Mass:

$$M_i^* = \sqrt{E_i^{*2} - \langle p_{i\text{cm}}^{*2} \rangle}$$

- Effective Quark Energy:

$$e_q^* = m_q^* + \frac{3\sqrt{k_c}}{\sqrt{2(e_q^* + m_q^*)}}$$

- Effective Baryon Energy:

$$E_i^* = \sum n_{qi} e_q^* + E_{i\text{spin}}$$

# Numerical result: in-medium mass of $\Xi^0$

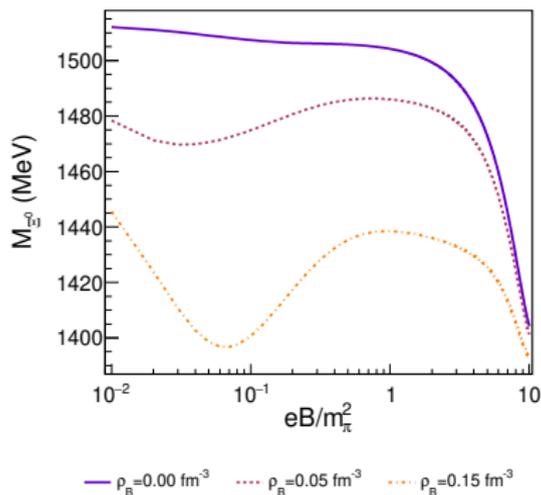


Figure: Effective mass of  $\Xi^0$  at  $T = 100$  MeV in symmetric nuclear matter.

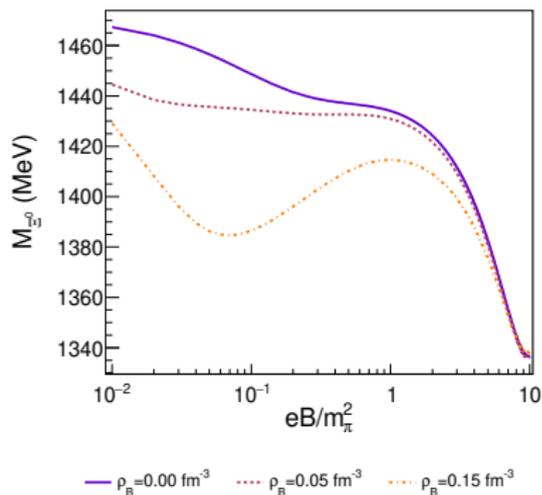


Figure: Effective mass of  $\Xi^0$  at  $T = 150$  MeV in symmetric nuclear matter.

# Chiral constituent quark model

- The magnetic moment ( $\vec{\mu}$ ) of a quark is calculated by the total contribution from valence quarks, sea quarks and orbital angular momentum of sea quarks:

$$\mu_B^* = \mu_{B,\text{val}}^* + \mu_{B,\text{sea}}^* + \mu_{B,\text{orbital}}^*$$

where \* the asterik implies that these values will be different compared to free space.

# Effective magnetic moments of constituent quarks

The effective masses can be directly substituted in this model to get the magnetic moments of the quarks as well as the baryons. Hence we find this model to be well suited for our analysis.

## Mass adjusted magnetic moments of constituent quarks:

$$\mu_d^* = -\left(1 - \frac{\Delta M}{M_B^*}\right), \quad \mu_s^* = -\frac{m_u^*}{m_s^*} \left(1 - \frac{\Delta M}{M_B^*}\right), \quad \mu_u^* = -2\mu_d^*, \quad \mu_c^* = -\frac{2m_u^*}{m_c} \mu_d^*.$$

in units of  $\mu_N$  (nuclear magneton).

## Explanation of Terms:

- $\mu_u^*$ ,  $\mu_d^*$ ,  $\mu_s^*$ : Effective magnetic moments of up, down, and strange quarks, respectively.
- $m_u^*$ ,  $m_s^*$ : Masses of up and strange quarks.
- $\Delta M = M_B^* - M_{\text{vac}}$
- $M_B^*$ : Effective mass of the baryon.

# Numerical result: magnetic moment of $\Xi^0$

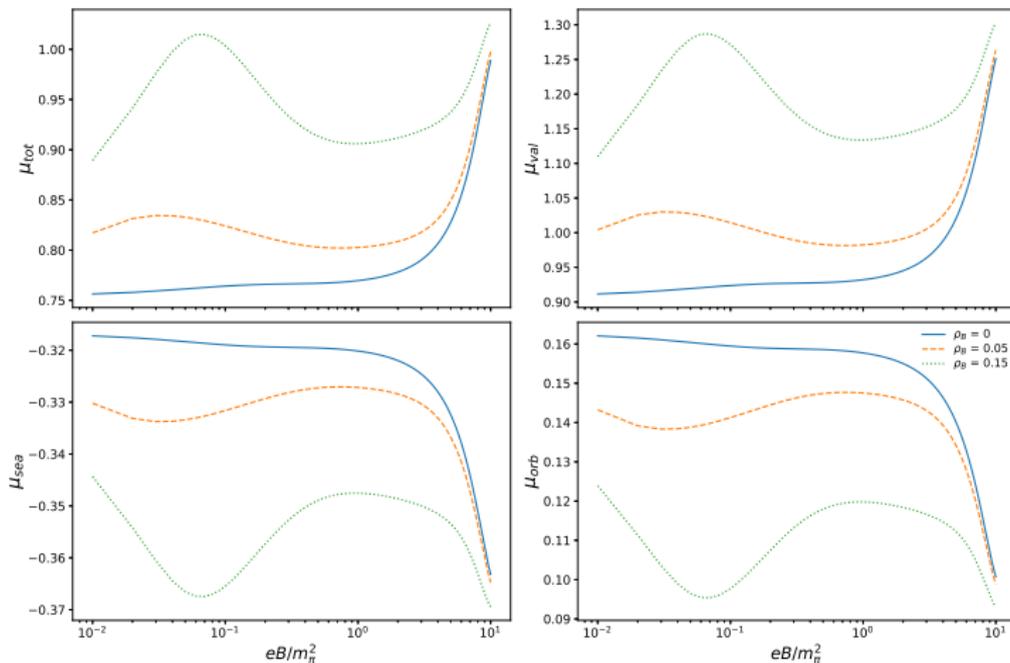


Figure: Variation of  $\mu_{\Xi^0}$  with  $eB/m_\pi^2$  at  $T = 100$  MeV.

# Numerical result: magnetic moment of $\Xi^0$

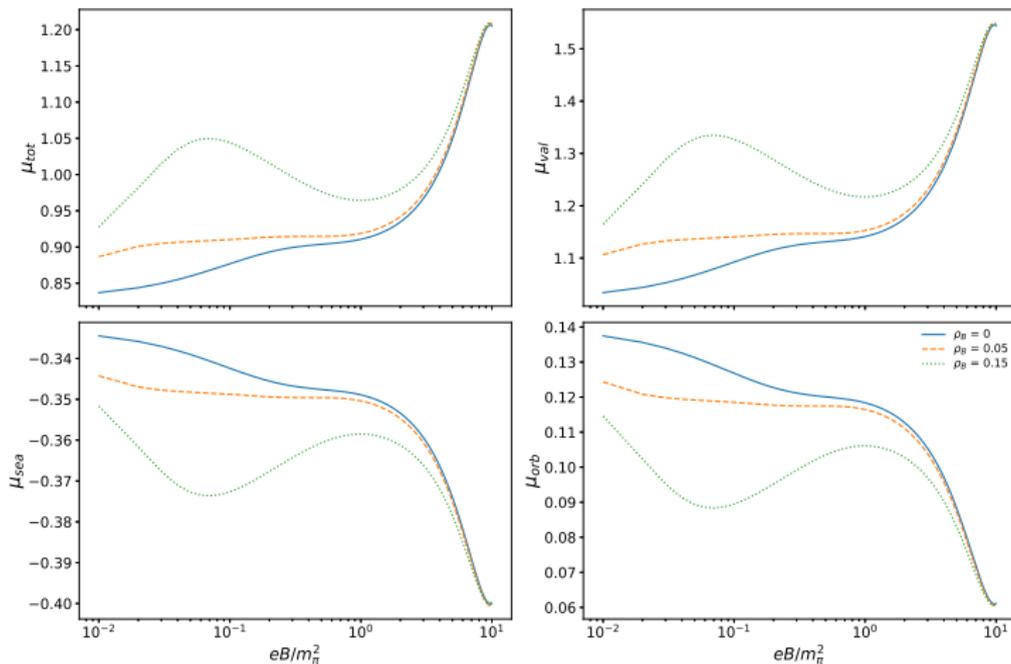


Figure: Variation of  $\mu_{\Xi^0}$  with  $eB/m_\pi^2$  at  $T = 150$  MeV.

# Thank You

