Effect of relativistic quark confinement on the in-medium magnetic moments of the $S_{11}^{+(0)}(1535)$ resonance

Abhinaba Upadhyay,* Suneel Dutt,† Harleen Dahiya,‡ and Arvind Kumar§
Department of Physics, Dr.B.R.Ambedkar National Institute of Technology, Jalandhar - 144008, Punjab, India

Introduction

In light of the chiral constituent quark model (χCQM) we have calculated the magnetic moments of $J_p = \frac{1}{2}^-$ low-lying N^* resonances with explicit contributions coming from the valence quark polarizations, sea quark polarizations, and their orbital angular moment. As a potential improvement to the earlier study [1], we have accounted for the quark confinement and relativistic corrections by using the mass adjusted effective magnetic moments of constituent quarks which is observed to have a potential impact on overall value of magnetic moment of baryons. The mass adjusted magnetic moments of quarks have been calculated within the framework of chiral quark mean field model (CQMF).

Methodology

In CQMF, we investigate the properties of nuclear matter at finite density where the effective quark mass m_q^* is defined as

$$m_q^* = -g_\sigma^q \sigma - g_\zeta^q \zeta + m_{q0}, \tag{1}$$

where σ, ζ are scalar fields and m_{q0} is fitted to obtain reasonable vacuum constituent quark masses [2]. Further, the in-medium baryon mass is expressed in terms of its effective energy E_i^* and spurious center of mass momentum p_{icm} as [2],

$$M_i^* = \sqrt{E_i^{*2} - < p_{icm}^{*2} >}. \tag{2}$$

In χCQM, the explicit individual contributions to the baryonic magnetic moment is given by the sum of valence, sea and orbital contributions as

$$\mu_B^* = \mu_{val}^* + \mu_{sea}^* + \mu_{orb}^*. \tag{3}$$

Individually, these contribution are calculated using expressions

$$\begin{aligned} \mu_{val}^* &= \sum_{q=u,d,s} \Delta q_{\rm val} \mu_q^*, \\ \mu_{sea}^* &= \sum_{q=u,d,s} \Delta q_{\rm sea} \mu_q^*, \\ \mu_{orb}^* &= \sum_{q=u,d,s} \Delta q_{\rm val} \mu^* \left(q_+ \to q'_-\right), \end{aligned} \tag{4}$$

where $\Delta q_{\rm val}$ and $\Delta q_{\rm sea}$ represent the spin polarization due to valence and sea quarks. The magnetic moments of constituent quarks depend upon their corresponding effective masses expressed as,

$$\mu_q^* = \frac{e_q}{2m_q^*}, \tag{5}$$

where ($q = u, d, s$), e_q is electric charge of the quark. In nuclear magnetic moment units (μ_N), μ_u^*, μ_d^* and μ_s^* becomes $2\mu_N$, $-\mu_N$ and $\frac{m_u^*}{m_s^*}\mu_N$, respectively. However, this formula lacks consistency for calculation of magnetic moments of relativistically confined quarks. In the present study, after the inclusion of this effect the mass adjusted effective magnetic moments of its constituent quarks are expressed as [3]

$$\mu_d^* = -\left(1 - \frac{\Delta M}{M_i^*}\right), \quad \mu_s^* = -\frac{m_u^*}{m_s^*}\left(1 - \frac{\Delta M}{M_i^*}\right), \quad \mu_u^* = -2\mu_d^*. \tag{6}$$

*Electronic address: abhinaba1708@gmail.com
†Electronic address: dutts@nitj.ac.in
‡Electronic address: dahiyah@nitj.ac.in
§Electronic address: kumara@nitj.ac.in

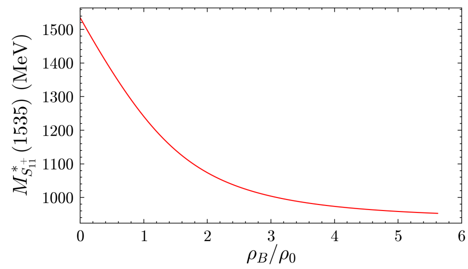

FIG. 1: Effective mass of $S^+_{11}(1535)$ in nuclear medium as a function of medium density ρ_B (in nuclear saturation density ρ_0 units).

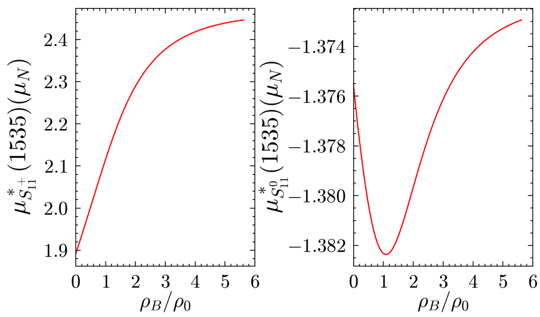

FIG. 2: Effective magnetic moments of $S^+_{11}(1535)$ and $S^0_{11}(1535)$ as a function of medium density ρ_B in units of ρ_0.

In the above relations, $\Delta M = M_i^{vac} - M_i^*$ where M_i^{vac} is the vacuum mass of the given baryon and M_i^* denotes the in-medium mass of this baryon. The factor $(1-\Delta M/M_i^*)$ leads to a suppression in μ_q^*, which in turn reduces the computed baryon magnetic moment.

Results and Discussions

It is evident from fig. 1, that the mass of $S^+_{11}(1535)$, similar to $S^0_{11}(1535)$, smoothly decreases as the medium gets denser. On the

Baryon (μ_N)	ρ_B	Contributions			
		μ^*_{val}	μ^*_{sea}	μ^*_{orbit}	μ^*_B
$S^+_{11}(1535)$ (relati. corr.)	0	1.859	-0.138	0.349	1.889
	ρ_0	2.299	-0.392	0.207	2.114
	$3\rho_0$	2.843	-0.483	0.016	2.376
$S^+_{11}(1535)$ [1]	0	2.271	-0.389	0.426	2.308
	ρ_0	3.585	-0.612	0.323	3.296
	$3\rho_0$	8.612	-1.465	0.050	7.196

TABLE I: Magnetic moments of $S^+_{11}(1535)$, in μ_N units, in symmetric nuclear matter at finite densities $(\rho_B/\rho_0 = 0, 1, 3)$ are tabulated above.

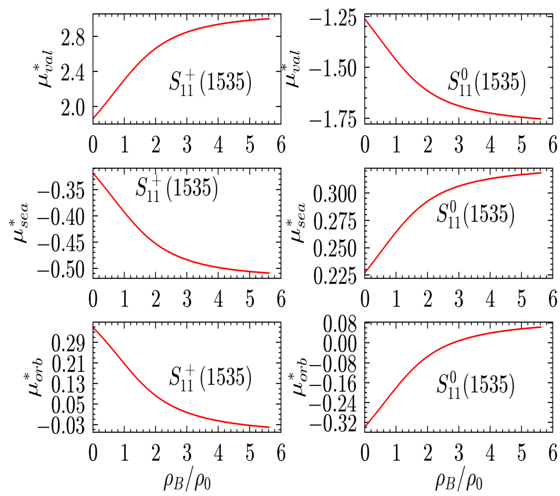

FIG. 3: Explicit contributions to baryonic magnetic moments coming from valence quarks, sea quarks and orbital moment of sea quarks, shown as a function of ρ_B in ρ_0 units.

left of fig. 2, we see that the magnetic moment of $S^+_{11}(1535)$ increases as the nuclear medium grows denser and approaches a saturation point at extreme higher densities. This trend in the $\mu_{S^+_{11}(1535)}$ curve is justified by the dominance of valence quark contributions (μ^*_{val}) in the total magnetic moment, as evident from the left column of fig. 3. By deriving similar justifications from fig. 3, the observed density effects on $\mu_{S^0_{11}(1535)}$ (right side of fig. 2) can be understood. The calculated $\mu_{S^+_{11}(1535)}$, in free space, from the present study being $1.889\mu_N$ is found to be 18.15% lower than that obtained in [1], which is $2.308\mu_N$, owing to the factor $(1 - \Delta M/M_i^*)$. Table I suggests that with rise in density at $\rho_B = \rho_0, 3\rho_0$ the $\mu_{S^+_{11}(1535)}$ value is 35.8% and 66.9% lower, respectively, from the earlier results as the factor $\Delta M/M_i^*$ increases with denser mediums.

References

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