

# Magnetic moments of spin $\frac{1}{2}^+$ and spin $\frac{3}{2}^+$ charmed baryons

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## Abstract.

The magnetic moments of spin  $\frac{1}{2}^+$  and spin  $\frac{3}{2}^+$  charmed baryons have been calculated in chiral constituent quark model ( $\chi$ CQM). The effects of configuration mixing and quark masses have also been investigated. The results are not only in good agreement with existing experimental data but also show improvement over other phenomenological models.

**Keywords:** Magnetic moments, chiral constituent quark model, charmed baryons

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## INTRODUCTION

Heavy flavor baryons play an important role to understand the dynamics of light quarks in the bound state as well as to understand QCD at the hadronic scale [1]. The phenomenological implications of the heavy quark component in the nucleon have been investigated to estimate the possible size of intrinsic charm (IC) content of the nucleon [2] as well as to calculate the static properties like masses, magnetic moment etc. [3] which give valuable information regarding the internal structure of baryons.

The magnetic moments of spin  $\frac{1}{2}^+$ , spin  $\frac{3}{2}^+$  charmed baryons have been considered in different approaches in literature. Calculations have been done in the non-relativistic quark model [4, 5], Skyrme model [6], bound state approach [7], relativistic three-quark model [8] etc.. More recently, magnetic moments have been studied by considering the effective mass of the quark bound inside the baryon [9]. Calculations for the charmed baryon magnetic moments have also been done in QCD sum rule method (QCDSR) [10], QCD Spectral sum rule method (QSSR) [11] and light cone QCD sum rule method (LCQSR) [12, 13, 14]. However, there is little consensus among the different model predictions of the magnetic moments of charmed baryons.

The *intrinsic* heavy quarks are created from the quantum fluctuations associated with the bound state hadron dynamics and the process is completely determined by nonperturbative mechanisms [15]. It has been shown that one of the important model which finds application in the nonperturbative regime is the chiral constituent quark model ( $\chi$ CQM) [16, 17, 18]. The  $\chi$ CQM with spin-spin generated configuration mixing is able to give the satisfactory explanation for the spin and flavor distribution functions [19, 20], hyperon  $\beta$  decay parameters [18], strangeness content of the nucleon [21], weak vector and axial-vector form factors [22], octet and decuplet baryon magnetic moments [23, 24, 25] etc.. The successes of  $\chi$ CQM strongly suggest that constituent quarks and the weakly interacting Goldstone bosons (GBs) provide the appropriate degrees of freedom in the nonperturbative regime of QCD. Thus, the quantum fluctuations generated by broken chiral symmetry in  $\chi$ CQM should be able to provide a viable estimate of the heavier quark flavor, in particular the  $c\bar{c}$  [15, 26].

The purpose of the present paper is to estimate the magnetic moments of spin  $\frac{1}{2}^+$ , spin  $\frac{3}{2}^+$  charmed baryons in the SU(4) framework of  $\chi$ CQM. The generalized Cheng-Li mechanism [23] has been incorporated to calculate explicitly the contribution coming from the valence spin polarization, “quark sea” polarization and its orbital angular momentum. Further, it would also be interesting to examine the effects of the configuration mixing, symmetry breaking parameters, confinement effects, quark masses etc. on the magnetic moments.

## SPIN STRUCTURE IN CHIRAL CONSTITUENT QUARK MODEL

In this section, we briefly review the essentials of the  $\chi$ CQM to calculate the spin structure of the baryons [23, 24, 25]. The basic process in the  $\chi$ CQM [16] is the internal emission of a Goldstone Boson by a constituent quark which further splits into a  $q\bar{q}$  pair as  $q_{\pm} \rightarrow GB^0 + q'_{\mp} \rightarrow (q\bar{q}') + q'_{\mp}$ , where  $q\bar{q}' + q'$  constitutes the “quark sea” [18, 19, 20, 24]. The effective Lagrangian describing interaction between quarks and GBs is  $\mathcal{L} = g_{15}\bar{\mathbf{q}}(\Phi)\mathbf{q}$ , where  $g_{15}$  is the coupling

constant,  $I$  is the  $4 \times 4$  identity matrix. The GB field  $\Phi$  is expressed as

$$\Phi = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \beta \frac{\eta}{\sqrt{6}} + \zeta \frac{\eta'}{4\sqrt{3}} - \gamma \frac{\eta_c}{4} & \pi^+ & \alpha K^+ & \gamma \bar{D}^0 \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \beta \frac{\eta}{\sqrt{6}} + \zeta \frac{\eta'}{4\sqrt{3}} - \gamma \frac{\eta_c}{4} & \alpha K^0 & \gamma D^- \\ \alpha K^- & \alpha \bar{K}^0 & -\beta \frac{2\eta}{\sqrt{6}} + \zeta \frac{\eta'}{4\sqrt{3}} - \gamma \frac{\eta_c}{4} & \gamma D_s^- \\ \gamma D^0 & \gamma D^+ & \gamma D_s^+ & -\zeta \frac{3\eta'}{4\sqrt{3}} + \gamma \frac{3\eta_c}{4} \end{pmatrix}. \quad (1)$$

SU(4) symmetry breaking is introduced by considering  $M_c > M_s > M_{u,d}$  as well as by considering the masses of GBs to be nondegenerate ( $M_{\eta_c} > M_{\eta'} > M_{K,\eta} > M_\pi$ ). The parameter  $a(=|g_{15}|^2)$  denotes the transition probability of chiral fluctuation of the splitting  $u(d) \rightarrow d(u) + \pi^{+(-)}$ , whereas  $a\alpha^2$ ,  $a\beta^2$ ,  $a\zeta^2$  and  $a\gamma^2$  denote the probabilities of transitions of  $u(d) \rightarrow s + K^{-(o)}$ ,  $u(d,s) \rightarrow u(d,s) + \eta$ ,  $u(d,s) \rightarrow u(d,s) + \eta'$  and  $u(d) \rightarrow c + \bar{D}^0(D^-)$  respectively.

The spin structure of the baryon is defined as  $\hat{B} \equiv \langle B | \mathcal{N} | B \rangle$ , where  $|B\rangle$  is the baryon wave function and  $\mathcal{N}$  is the number operator defined as  $\mathcal{N} = n_{u_+}u_+ + n_{u_-}u_- + n_{d_+}d_+ + n_{d_-}d_- + n_{s_+}s_+ + n_{s_-}s_- + n_{c_+}c_+ + n_{c_-}c_-$ ,  $n_{q_\pm}$  being the number of  $q_\pm$  quarks [18, 19, 24]. The ‘‘quark sea’’ contribution to the total quark spin polarization ( $\Delta q = q_+ - q_-$ ) can be calculated by substituting for each valence quark  $q_\pm \rightarrow \sum P_q q_\pm + |\psi(q_\pm)|^2$ , where  $\sum P_q$  is the probability of emission of GBs from a  $q$  quark and  $|\psi(q_\pm)|^2$  is the probability of transforming a  $q_\pm$  quark [27]. Using the spin and flavor wave functions for a given baryon, one can easily find the spin structure and the spin polarizations.

The total wave function for the three quark system made from any of the  $u, d, s$  or  $c$  quarks is given as  $|\text{SU}(8) \otimes \text{O}(3)\rangle = \phi \chi \psi$ , where  $\phi$  is a flavor wave function,  $\chi$  is a spin wave function and  $\psi$  is a spatial wave function. The  $SU(8)$  multiplets are decomposed into  $SU(4) \otimes SU(2)$  multiplets and the details of the definition of the wave functions, can be found in [28]. The spin structure of a spin  $\frac{1}{2}^+$  and spin  $\frac{3}{2}^+$  baryons are respectively given as

$$\hat{B} \equiv \langle B | \mathcal{N} | B \rangle = \cos^2 \phi \langle 120, {}^2 20_M | \mathcal{N} | 120, {}^2 20_M \rangle_B + \sin^2 \phi \langle 168, {}^2 20_M | \mathcal{N} | 168, {}^2 20_M \rangle_B, \quad (2)$$

$$\hat{B}^* \equiv \langle B^* | \mathcal{N} | B^* \rangle = \langle 120, {}^4 20_S | \mathcal{N} | 120, {}^4 20_S \rangle_{B^*}. \quad (3)$$

## MAGNETIC MOMENT IN $\chi$ CQM

The magnetic moment of a given baryon receives contributions from the valence quarks, ‘‘quark sea’’ and orbital angular momentum of the ‘‘quark sea’’ [18, 21, 23, 25] and is expressed as

$$\mu(B)_{\text{total}} = \mu(B)_{\text{val}} + \mu(B)_{\text{sea}} + \mu(B)_{\text{orbit}}, \quad (4)$$

where  $\mu(B)_{\text{val}}$  and  $\mu(B)_{\text{sea}}$  represent the contributions of the valence quarks and the ‘‘quark sea’’ to the magnetic moments due to spin polarizations. The term  $\mu(B)_{\text{orbit}}$  corresponds to the orbital angular momentum contribution of the ‘‘quark sea’’. In terms of quarks magnetic moments and spin polarizations, the valence, sea and orbital contributions can be written as

$$\mu(B)_{\text{val}} = \sum_{q=u,d,s,c} \Delta q_{\text{val}} \mu_q, \quad \mu(B)_{\text{sea}} = \sum_{q=u,d,s,c} \Delta q_{\text{sea}} \mu_q, \quad \mu(B)_{\text{orbit}} = \sum_{q=u,d,s,c} \Delta q_{\text{val}} \mu(q_+ \rightarrow q'_-), \quad (5)$$

where  $\mu_q = \frac{e_q}{2M_q}$  ( $q = u, d, s, c$ ) is the quark magnetic moment,  $\mu(q_+ \rightarrow q'_-)$  is the orbital moment for any chiral fluctuation,  $e_q$  and  $M_q$  are the electric charge and the mass respectively for the quark  $q$ .

The valence and quark sea spin polarizations ( $\Delta q_{\text{val}}$  and  $\Delta q_{\text{sea}}$ ) can be calculated for the baryons using the spin structure discussed in the previous section. The orbital angular momentum contribution of each chiral fluctuation is given as [18, 25]

$$\mu(q_+ \rightarrow q'_-) = \frac{e_{q'}}{2M_q} \langle l_q \rangle + \frac{e_q - e_{q'}}{2M_{\text{GB}}} \langle l_{\text{GB}} \rangle, \quad (6)$$

where  $\langle l_q \rangle = \frac{M_{\text{GB}}}{M_q + M_{\text{GB}}}$  and  $\langle l_{\text{GB}} \rangle = \frac{M_q}{M_q + M_{\text{GB}}}$ . The quantities ( $l_q, l_{\text{GB}}$ ) and ( $M_q, M_{\text{GB}}$ ) are the orbital angular momenta and masses of quark and GBs, respectively. The orbital moment of each process is then multiplied by the probability for such a process to take place to yield the magnetic moment due to all the transitions starting with a given valence quark

$$[\mu(u_\pm \rightarrow)] = \pm a \left[ \left( \frac{1}{2} + \frac{\beta^2}{6} + \frac{\zeta^2}{48} + \frac{\gamma^2}{16} \right) \mu(u_+ \rightarrow u_-) + \mu(u_+ \rightarrow d_-) + \alpha^2 \mu(u_+ \rightarrow s_-) + \gamma^2 \mu(u_+ \rightarrow c_-) \right], \quad (7)$$

$$[\mu(d_{\pm} \rightarrow)] = \pm a \left[ \mu(d_+ \rightarrow u_-) + \left( \frac{1}{2} + \frac{\beta^2}{6} + \frac{\zeta^2}{48} + \frac{\gamma^2}{16} \right) \mu(d_+ \rightarrow d_-) + \alpha^2 \mu(d_+ \rightarrow s_-) + \gamma^2 \mu(d_+ \rightarrow c_-) \right], \quad (8)$$

$$[\mu(s_{\pm} \rightarrow)] = \pm a \left[ \alpha^2 \mu(s_+ \rightarrow u_-) + \alpha^2 \mu(s_+ \rightarrow d_-) + \left( \frac{2}{3} \beta^2 + \frac{\zeta^2}{48} + \frac{\gamma^2}{16} \right) \mu(s_+ \rightarrow s_-) + \gamma^2 \mu(s_+ \rightarrow c_-) \right], \quad (9)$$

and

$$[\mu(c_{\pm} \rightarrow)] = \pm a \left[ \gamma^2 \mu(c_+ \rightarrow u_-) + \gamma^2 \mu(c_+ \rightarrow d_-) + \gamma^2 \mu(c_+ \rightarrow s_-) + \left( \frac{3}{16} \zeta^2 + \frac{9}{16} \gamma^2 \right) \mu(c_+ \rightarrow c_-) \right]. \quad (10)$$

The above equations can easily be generalized by including the coupling breaking and mass breaking terms and can be expressed in terms of the  $\chi$ CQM parameters ( $a, \alpha, \beta, \zeta, \gamma$ ), quark masses ( $M_u, M_d, M_s, M_c$ ) and GB masses ( $M_\pi, M_k, M_\eta, M_{\eta'}, M_D, M_{D_s}, M_{\eta_c}$ ).

## RESULTS AND DISCUSSION

Using the following set of  $\chi$ CQM parameters  $a = 0.12$ ,  $\alpha \simeq \beta = 0.45$ ,  $\zeta = -0.21$  and  $\gamma = 0.11$  as well as the on mass shell values of quarks and GBs [29, 30], we have calculated the magnetic moments of spin  $\frac{1}{2}^+$  and spin  $\frac{3}{2}^+$  baryons in Tables 1 and 2 respectively. In the tables we have also presented the available experimental data, the results of NRQM [4] and the results of other model calculations. From Table 1, we find that our results compare fairly well with the experimental data available for the octet baryons. It is interesting to observe that our results in the case of  $p$ ,  $\Sigma^+$ ,  $\Xi^0$  and  $\Lambda^0$  give a perfect fit when compared with the experimental values [3] whereas for all other octet baryons our predictions are within 10% of the observed values. Since there is no experimental information available in case of charmed baryon magnetic moments, we compare our results with the predictions of QCD sum rule method (QCDSR)[10], Light Cone QCD sum rule method (LCQSR) [12], QCD Spectral sum rule method (QSSR) [11]. Our results are found to be consistent with these approaches as well as with the other models existing in literature. The explicit results for the valence, sea and orbital contributions to the baryons magnetic moments have been presented. A cursory look at the results in the table reveals that the sea and orbital contributions to the magnetic moments are significant. The orbital part contributes with the same sign as valence quark distribution, while the sea part contributes with the opposite sign. However, the sea and orbital contributions cancel each other to a large extent. The sum of residual sea quark contribution and valence quark contribution give the magnetic moment of baryons. Numerically speaking, the sea quark contribution and orbital contributions are quite large in magnitude except for  $\Omega_c^0$ ,  $\Lambda_c^+$ ,  $\Xi_c^+$ ,  $\Xi_c^0$  and  $\Omega_{cc}^+$ . It is also interesting to examine the role of configuration mixing in spin  $\frac{1}{2}^+$  baryon magnetic moments. A detailed analysis of the configuration mixing parameter  $\phi$  reveals that the results with mixing are in better agreement with the experimental data where the data is available.

In Table 2, we have compared our results for the spin  $\frac{3}{2}^+$  baryons with other model calculations as well as with the available experimental data. Presently, only three experimental results are available for the decuplet baryons magnetic moments. Our predicted value for  $\mu_{\Delta^{++}}$  is well within the experimental range [3]. Similarly, in the case of  $\mu_{\Delta^+}$  and  $\Omega^-$ , our predicted values agree with the experimental value [31, 32]. In case of charmed baryons, there is no experimental information available, therefore, we have compared our results with the predictions of the QCD sum rule [10] and Light Cone QCD sum rule [14]. In this case also, we have presented the results for the valence, sea and the orbital contributions separately and we find that our predictions are in agreement with their results. There is a small discrepancy in the case of  $\Sigma^{*0}$  magnetic moment, which is due to the significant sea contribution. The ‘‘quark sea’’ and orbital contributions are quite large in magnitude for all the charmed baryons except in the case of  $\Omega_c^{*-}$ ,  $\Omega_c^{*0}$ ,  $\Omega_{cc}^{*+}$  and  $\Omega_{cc}^{*++}$ . The measurements of the magnetic moments of charmed baryons represent an experimental challenge and several groups BTeV, SELEX Collaboration are contemplating the possibility of performing it in the near future which would test the success of present scheme.

## SUMMARY AND CONCLUSION

We have calculated the magnetic moments of spin  $\frac{1}{2}^+$  and  $\frac{3}{2}^+$  baryons in the framework of SU(4)  $\chi$ CQM. Without taking any of the magnetic moment as input, a considerable good fit is achieved in the case of the octet and decuplet baryons where the experimental data is available. In the case of charmed baryons, our results are consistent with the

other approaches existing in the literature. The success of  $\chi$ CQM with the Cheng-Li mechanism and configuration mixing in achieving a fit to the magnetic moments suggest that constituent quarks and weakly interacting Goldstone Bosons provide the appropriate degree of freedom in the nonperturbative regime of QCD.

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**TABLE 1.** Magnetic moment of spin  $\frac{1}{2}^+$  charmed baryons with configuration mixing (in units of  $\mu_N$ ).

| Baryon          | Data [3]             | NRQM  | QCDSR [10]<br>QSSR[11] | LCQSR [12]      | Valence | Sea     | Orbital | Total |
|-----------------|----------------------|-------|------------------------|-----------------|---------|---------|---------|-------|
| $p$             | $2.79 \pm 0.00$      | 3     | $2.82 \pm 0.26$        | $2.7 \pm 0.5$   | 2.90    | -0.58   | 0.47    | 2.80  |
| $n$             | $-1.91 \pm 0.00$     | -2    | $-1.97 \pm 0.15$       | $-1.8 \pm 0.35$ | -1.85   | 0.18    | -0.44   | -2.11 |
| $\Sigma^+$      | $2.458 \pm 0.010$    | 2.88  | $2.31 \pm 0.25$        | $2.2 \pm 0.4$   | 2.51    | -0.51   | 0.40    | 2.39  |
| $\Sigma^0$      | -                    | 0.88  | $0.69 \pm 0.07$        | $0.5 \pm 0.10$  | 0.74    | -0.22   | 0.02    | 0.54  |
| $\Sigma^-$      | $-1.160 \pm 0.025$   | -1.12 | $-1.16 \pm 0.10$       | $-0.8 \pm 0.2$  | -1.02   | 0.06    | -0.36   | -1.32 |
| $\Xi^0$         | $-1.250 \pm 0.014$   | -1.53 | $-1.15 \pm 0.05$       | $-1.3 \pm 0.3$  | -1.29   | 0.14    | -0.09   | -1.24 |
| $\Xi^-$         | $-0.6507 \pm 0.0025$ | -0.53 | $-0.64 \pm 0.06$       | $-0.7 \pm 0.2$  | -0.59   | 0.03    | 0.06    | -0.50 |
| CSGR            | $0.49 \pm 0.05$      | 0.0   |                        |                 |         |         |         | 0.46  |
| $\Lambda^0$     | $-0.613 \pm 0.004$   | -0.65 | $-0.56 \pm 0.15$       | $-0.7 \pm 0.2$  | -0.59   | -0.06   | -0.01   | -0.66 |
| $\Sigma_c^{++}$ | ...                  | 2.54  | $2.1 \pm 0.3$          | ...             | 2.32    | -0.52   | 0.40    | 2.20  |
| $\Sigma_c^+$    | ...                  | 0.54  | $0.6 \pm 0.1$          | ...             | 0.51    | -0.23   | 0.02    | 0.30  |
| $\Sigma_c^0$    | ...                  | -1.46 | $-1.6 \pm 0.2$         | ...             | -1.30   | 0.06    | -0.36   | -1.60 |
| $\Xi_c^+$       | ...                  | 0.77  | ...                    | ...             | 0.77    | -0.21   | 0.19    | 0.76  |
| $\Xi_c^0$       | ...                  | -1.23 | ...                    | ...             | -1.16   | 0.03    | -0.19   | -1.32 |
| $\Omega_c^0$    | ...                  | -0.99 | ...                    | ...             | -0.93   | 0.04    | -0.01   | -0.90 |
| $\Lambda_c^+$   | ...                  | 0.39  | $0.15 \pm 0.05$        | $0.40 \pm 0.05$ | 0.409   | -0.019  | 0.002   | 0.392 |
| $\Xi_c^+$       | ...                  | 0.39  | ...                    | $0.50 \pm 0.05$ | 0.41    | -0.02   | 0.01    | 0.40  |
| $\Xi_c^0$       | ...                  | 0.39  | ...                    | $0.35 \pm 0.05$ | 0.29    | -0.0003 | -0.01   | 0.28  |
| $\Xi_{cc}^{++}$ | ...                  | -0.15 | ...                    | ...             | 0.025   | 0.111   | -0.080  | 0.006 |
| $\Xi_{cc}^+$    | ...                  | 0.85  | ...                    | ...             | 0.79    | -0.02   | 0.07    | 0.84  |
| $\Omega_{cc}^+$ | ...                  | 0.73  | ...                    | ...             | 0.706   | -0.012  | -0.004  | 0.697 |

**TABLE 2.** The magnetic moments of the spin  $\frac{3}{2}^+$  charmed baryons (in units of  $\mu_N$ ).

| Baryon                     | Data [3]                                  | NRQM  | QCDSR [10]       | LCQSR [14]       | Valence | Sea   | Orbital | Total |
|----------------------------|---|-------|------------------|------------------|---------|-------|---------|-------|
| $\mu_{\Delta^{++}}$        | $3.7 \sim 7.5$                            | 6     | $4.13 \pm 1.30$  | $4.4 \pm 0.8$    | 4.53    | -0.97 | 0.95    | 4.51  |
| $\mu_{\Delta^+}$           | $2.7_{-1.3}^{+1.0} \pm 1.5 \pm 3$ [31]    | 3     | $2.07 \pm 0.65$  | $2.2 \pm 0.4$    | 2.27    | -0.61 | 0.34    | 2.00  |
| $\mu_{\Delta^0}$           | ...                                       | 0.0   | 0.0              | 0.0              | 0.0     | -0.25 | -0.26   | -0.51 |
| $\mu_{\Delta^-}$           | ...                                       | -3    | $-2.07 \pm 0.65$ | $-2.2 \pm 0.4$   | -2.27   | 0.12  | -0.87   | -3.02 |
| $\mu_{\Sigma^{*+}}$        | ...                                       | 3.35  | $2.13 \pm 0.82$  | $2.7 \pm 0.6$    | 2.74    | -0.67 | 0.62    | 2.69  |
| $\mu_{\Sigma^{*0}}$        | ...                                       | 0.35  | $0.32 \pm 0.15$  | $0.20 \pm 0.05$  | 0.29    | -0.29 | 0.02    | 0.02  |
| $\mu_{\Sigma^{*-}}$        | ...                                       | -2.65 | $-1.66 \pm 0.73$ | $-2.28 \pm 0.5$  | -2.16   | 0.11  | -0.59   | -2.64 |
| $\mu_{\Xi^{*0}}$           | ...                                       | 0.71  | $-0.69 \pm 0.29$ | $0.40 \pm 0.08$  | 0.51    | -0.26 | 0.29    | 0.54  |
| $\mu_{\Xi^{*-}}$           | ...                                       | -2.29 | $-1.51 \pm 0.52$ | $-2.0 \pm 0.4$   | -1.64   | 0.08  | -0.31   | -1.87 |
| $\mu_{\Omega^{*-}}$        | $-2.02 \pm 0.06$<br>$-1.94 \pm 0.31$ [32] | -1.94 | $-1.49 \pm 0.45$ | $-1.65 \pm 0.35$ | -1.76   | 0.08  | -0.03   | -1.71 |
| $\mu_{\Sigma_c^{*++}}$     | ...                                       | 4.39  | ...              | $4.81 \pm 1.22$  | 4.09    | -0.80 | 0.63    | 3.92  |
| $\mu_{\Sigma_c^{*+}}$      | ...                                       | 1.39  | ...              | $2.00 \pm 0.46$  | 1.30    | -0.36 | 0.03    | 0.97  |
| $\mu_{\Sigma_c^{*0}}$      | ...                                       | -1.61 | ...              | $-0.81 \pm 0.20$ | -1.50   | 0.09  | -0.58   | -1.99 |
| $\mu_{\Xi_c^{*+}}$         | ...                                       | 1.74  | ...              | $1.68 \pm 0.42$  | 1.67    | -0.39 | 0.31    | 1.59  |
| $\mu_{\Xi_c^{*0}}$         | ...                                       | -1.26 | ...              | $-0.68 \pm 0.18$ | -1.21   | 0.08  | -0.30   | -1.43 |
| $\mu_{\Omega_c^{*0}}$      | ...                                       | -0.91 | ...              | $-0.62 \pm 0.18$ | -0.89   | 0.05  | -0.02   | -0.86 |
| $\mu_{\Xi_{cc}^{*++}}$     | ...                                       | 2.78  | ...              | ...              | 2.78    | -0.44 | 0.32    | 2.66  |
| $\mu_{\Xi_{cc}^{*+}}$      | ...                                       | -0.22 | ...              | ...              | -0.22   | 0.04  | -0.29   | -0.47 |
| $\mu_{\Omega_{cc}^{*+}}$   | ...                                       | 0.13  | ...              | ...              | 0.13    | 0.02  | -0.01   | 0.14  |
| $\mu_{\Omega_{ccc}^{*++}}$ | ...                                       | 1.17  | ...              | ...              | 0.165   | 0.011 | -0.002  | 0.155 |