Ground and Excited state masses of Ω_c^0 baryon

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Introduction

The study of hadron spectroscopy has been a subject of intense interest. In recent years, numerous hadronic states have been found. Masses, decay widths, branching ratios, isospin mass splittings, spin, parity, polarisation amplitudes, and other aspects of hadron spectroscopy have all been discovered thanks to improved experimental techniques. The study of bound states of heavy (charm (c) and bottom (b)) and light (up (u), down (d) and strange (s)) flavor quarks is an excellent way to learn about the low-energy dynamics of quantum chromodynamics (QCD).

In 2017, the LHCb Collaboration announced the discovery of five extremely narrow excited $\Omega_c^0(ssc)$ states decaying into Ξ^+K^-, namely $\Omega_c(3000)^0$, $\Omega_c(3050)^0$, $\Omega_c(3066)^0$, $\Omega_c(3090)^0$, and $\Omega_c(3119)^0$ [1]. Only the ground states Ω_c^0 and $\Omega_c(2770)^0$ have been confirmed experimentally with quantum numbers $J^P = \frac{1}{2}^+$ and $\frac{3}{2}^+$, respectively [2], where J represents total-spin and P denotes parity. The J^P values of the excited states of Ω_c^0 baryon have yet to be determined. Many theoretical approaches have been used to study the mass spectra of heavy-light flavored baryons, such as the non-relativistic constituent quark model [3–5], the relativistic quark model [6], and QCD sum rules [7] etc. In the present investigation, we used Regge phenomenology to find the correlations between the intercept, slope ratios, and baryon masses in the (J, M^2) plane under the assumption of linear Regge trajectories. Using these relations, we will obtain the mass expressions of the ground, as well as excited states of Ω_c^0 baryon. The mass relationships and mass value predictions could be beneficial in future experimental searches and spin-parity assignment of these states.

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Theoretical Framework

Regge theory is one of the simplest and most effective phenomenological approaches to study the hadron spectroscopy. The plots of Regge trajectories of hadrons in the (J, M^2) plane are usually called Chew-Frautschi plots [8]. The most general form of linear Regge trajectories can be expressed as [9, 10],

$$J = \alpha(M) = a(0) + \alpha' M^2, \tag{1}$$

where $a(0)$ and α' represent the intercept and slope of the trajectory, respectively. These parameters for different quark constituents of a baryon multiplet can be related by two relations [10–12]:

$$a_{iiq}(0) + a_{jjq}(0) = 2a_{ijq}(0), \tag{2}$$

$$\frac{1}{\alpha'_{iiq}} + \frac{1}{\alpha'_{jjq}} = \frac{2}{\alpha'_{ijq}}, \tag{3}$$

where i, j, q represent quark flavors, $m_i < m_j$, and q denotes an arbitrary light or heavy quark.

Combining Eqs. (2) and (3) and solving the quadratic equation, we obtain a pair of solutions as,

$$\frac{\alpha'_{jjq}}{\alpha'_{iiq}} = \frac{1}{2M_{jjq}^2} \times [(4M_{ijq}^2 - M_{iiq}^2 - M_{jjq}^2) \pm \sqrt{(4M_{ijq}^2 - M_{iiq}^2 - M_{jjq}^2)^2 - 4M_{iiq}^2 M_{jjq}^2}]. \tag{4}$$

This is an important relation between the slope ratios and baryon masses. The details of this study can be found in Ref. [9]. Eq. (4) can also be expressed in terms of baryon masses by introducing k, where k can be any quark flavor,

$$\frac{\alpha'_{jjq}}{\alpha'_{iiq}} = \frac{\alpha'_{kkq}}{\alpha'_{iiq}} \times \frac{\alpha'_{jjq}}{\alpha'_{kkq}}. \quad (5)$$

Since Ω_c^0 is composed of two strange (s) quarks and one charm (c) quark. Putting the values of i, j, q, and k accordingly and with the aid of Eqs. (4) and (5), we can derive the expression in terms of baryon masses only, which can be used to evaluate the ground-state masses of Ω_c^0 baryon. Also, from Eq. (1) we have

$$M_{J+1} = \sqrt{M_J^2 + \frac{1}{\alpha'}}. \quad (6)$$

Now using Eq. (4) we can evaluate the Regge slope α' for $\frac{1}{2}^+$ and $\frac{3}{2}^+$ trajectories. Hence with help of Regge slopes and ground-state masses we obtain the orbitally excited state masses of Ω_c^0 for both natural ($P = (-1)^{J-\frac{1}{2}}$) and unnatural ($P = (-1)^{J+\frac{1}{2}}$) parities in the (J, M^2) plane using Eq. (6).

Results and Discussion

In the framework of Regge phenomenology, ground-state as well as excited-state masses of Ω_c^0 baryon were obtained successfully in the (J, M^2) plane (see Table I).

TABLE I: Masses of excited states of the Ω_c^0 baryon (in GeV) in the (J, M^2) plane

States	Present	PDG [2]	Ref. [3]	Ref. [4]
$1^2S_{\frac{1}{2}}$	2.702	2.695	2.695	2.696
$1^2P_{\frac{3}{2}}$	3.049	3.050	3.024	2.968
$1^2D_{\frac{5}{2}}$	3.360		3.299	3.251
$1^4S_{\frac{3}{2}}$	2.772	2.765	2.765	2.766
$1^4P_{\frac{5}{2}}$	3.055		3.010	2.962
$1^4D_{\frac{7}{2}}$	3.314		3.276	3.241

We compared our calculated ground-state masses with experimentally available data and other theoretical predictions. Our results are very close to Particle Data Group [2] with a slight mass difference of 7-8 MeV, and they are also in good agreement with Refs. [3, 4]. Further, the excited state masses are also in accordance with the predictions of other theoretical studies Refs. [3, 4]. The experimentally observed state $\Omega_c(3050)^0$ with mass 3.050 GeV is close to our prediction 3.049 GeV, so we assigned $\Omega_c(3050)^0$ as a $1P$ state with $J^P = 3/2^-$ for $S = 1/2$.

We have successfully employed the Regge phenomenological approach to calculate the masses of Ω_c^0 baryon. This study will definitely help future experimental studies at LHCb, Belle II etc. to identify these baryonic states from resonances.

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