Ground state masses of Ξ_{cc} and Ξ_{bc} baryons

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Introduction

The study of baryons containing heavy quarks (c, b) is of major interest due to the large number of data recently reported by many worldwide experimental facilities. Experimentally, the existence of the first doubly heavy baryon Ξ_{cc}^{++} was confirmed in 2017 by the LHCb Collaboration [1] having a mass of 3621.6±0.4 MeV reported in the Particle data group (PDG) [2]. In addition to doubly charmed baryons, a different kind of doubly heavy baryon, the beauty-charmed baryon containing one bottom quark (b) and one charm quark (c) should also exist. The search for beauty-charmed baryons has been the main focus of experimentalists nowadays. In 2020, the LHCb Collaboration seeks for the doubly heavy Ξ_{bc}^0 baryon using its decay to the D^0pK^- the final state is performed using proton-proton collision data between 2016 and 2018. No significant signal is found in the invariant mass range of 6.7 to 7.2 GeV/c^2 [3].

The purpose of this study is to obtained the ground state masses of Ξ_{cc} and Ξ_{bc} baryons. Various theoretical approaches have been used to study the doubly heavy baryons by the researchers in recent years [4–8]. In the present work, we have used the Regge phenomenology and extracted the relations, between the intercept, slope ratios, and baryon masses with the assumption of linear Regge trajectories. With the aid of these relations we obtain the ground state masses of Ξ_{cc} and Ξ_{bc} baryons..

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Theoretical Framework

In our previous work, the Regge theory was effectively applied to obtain the mass spectra of light as well as heavy baryons [9–11]. The general form of linear Regge trajectories can be expressed as [9, 12],

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

where $a(0)$ and $\alpha^{'}$ are, respectively, the slope and intercept of the Regge trajectory. These Regge parameters for different flavors of a baryon multiplet can be related by the following relations ([9, 10] and Refs. therein),

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

$$\frac{1}{\alpha^{'}{}_{iiq}} + \frac{1}{\alpha^{'}{}_{jjq}} = \frac{2}{\alpha^{'}{}_{ijq}}, \quad (3)$$

where i, j, q represents the quark flavors. Combining Eqs. (1), (2), and (3) we obtain a pair of solutions as,

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

The details of this study can be found in Ref. [9, 10, 13]. Now to obtain the ground state ($\frac{1}{2}^+$ and $\frac{3}{2}^+$) masses we use Eq. (11) in Ref. [13] obtained from relation (4) by inserting the values of i, j, q, and k according to the quark composition of Ξ_{cc}^{++} (ucc) and Ξ_{bc}^0 (dcb) baryons. We obtain the mass expressions to calculate the ground state masses of Ξ_{cc}^{++} and Ξ_{bc}^0 baryons which are expressed as,

$$[(M_{\Xi^0} + M_{\Xi_{cc}^{++}})^2 - 4M^2_{\Xi_c^+}] \quad (5)$$
$$= \sqrt{(4M^2_{\Xi_c^+} - M^2_{\Xi^0} - M^2_{\Xi_{cc}^{++}})^2 - 4M^2_{\Xi^0}M^2_{\Xi_{cc}^{++}}}$$

and

$$[(M_{\Xi_{cc}^{+}} + M_{\Xi_{bb}^{-}})^2 - 4M^2_{\Xi_{bc}^{0}}] \quad (6)$$
$$= \sqrt{(4M^2_{\Xi_{bc}^{0}} - M^2_{\Xi_{cc}^{+}} - M^2_{\Xi_{bb}^{-}})^2 - 4M^2_{\Xi_{cc}^{+}} M^2_{\Xi_{bb}^{-}}}$$

Similarly, we can obtain the mass expressions for Ξ_{cc}^{+} and Ξ_{bc}^{+} baryons also. Now, after inserting the masses of Ξ^0 and Ξ_c^+ from PDG [2] and Ξ_{bb}^- from Ref. [9] into relations (5) and (6) we get the masses for Ξ_{cc}^{++} and Ξ_{bc}^{0} baryons for $J^P = \frac{1}{2}^+$, where J is the total spin and P denotes the parity. Similarly, we can obtain the masses for $\frac{3}{2}^+$ state also. The predicted masses are expressed as $M \pm \delta M$, where M is the observed mass and δM is the experimental error in the mass.

Results and Discussion

TABLE I: Predicted ground state masses of Ξ_{cc} and Ξ_{bc} baryons (in MeV).

Baryon		$J^P=\frac{1}{2}^+$	$J^P=\frac{3}{2}^+$
Ξ_{cc}^{++}	Our	3620.6±0.5	3758.4±0.7
Ξ_{cc}^{+}	Our	3619.7±0.6	3757.3±0.8
	PDG [2]	3621.6±0.4	
	[14]	3620	3727
Ξ_{bc}^{+}	Our	6922.8±0.2	7044.2±0.3
Ξ_{bc}^{0}	Our	6924.8±0.3	7045.2±0.4
	[14]	6933	6980
	[8]	6945	6989

Table I shows our calculated ground state masses for Ξ_{cc} and Ξ_{bc} baryons along with the experimental data where available and the theoretical predictions. Since, Ξ_{cc}^{++} is the only doubly heavy baryon observed experimentally having a mass 3621.6±0.4 MeV reported in PDG [2]. Our estimated mass for $\frac{1}{2}^+$ state as 3620.6±0.5 MeV is very close to the experimentally detected mass with a mass difference of only 1 MeV. Also, our predicted masses for $\frac{3}{2}^+$ state are in good agreement with the results of Ref. [14] with a mass difference of few MeV.

In a recent search for the Ξ_{bc}^{0} baryon, the LHCb Collaboration detected no significant signal in the invariant mass range from 6.7-7.2 GeV/c^2. In this work, our estimated ground state mass of 6924.8±0.3 MeV for Ξ_{bc}^{0} baryon lies within this range, which can be useful for future experimental searches. Also, we compared our evaluated results with the other theoretical predictions and they are in good agreement with the calculated masses of Ref. [8, 14] with a mass difference of a few MeV. Hence our mass value predictions could be useful in future experimental studies at LHCb, CMS, Belle II, SELEX etc.

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