Exploring Ξ_{cb} Baryon Mass Spectra with hCQM

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Introduction

Recent data from leading experimental facilities such as LHCb, CMS, and SELEX has intensified interest in studying baryons with heavy quarks (charm and bottom). This influx of information presents a unique opportunity to deepen our understanding of these complex particles, offering new insights into the fundamental aspects of particle physics.There are numerous baryons with single heavy quark have been detected in experiments so far and the quantum numbers of these observed states have been successfully determined and providing valuable insights into their properties [1].In the constituent quark model, doubly heavy baryons can be formed by binding two heavy quarks (either b or c) with a light quark (u, d, or s). They can be classified into two groups according to their strangeness Ξ and Ω.The Ω baryon contains a light strange quark, while the Ξ baryon has an up or down quark. Both baryons are unique due to the presence of two heavy quarks, either charm (c) or bottom (b).Investigating these particles is essential for gaining insights into hadron spectroscopy and exploring the behavior of Quantum Chromodynamics (QCD) in the low-energy regime.

The first doubly heavy baryon observed in experiments was a Ξ_{cc}^{++} baryon characterized by a charm quantum number of C = 2 [2].The LHCb experiment at CERN searched for the Ξ_{cb} by analyzing the decay channel $D^0\text{p}K^-$ at a center-of-mass energy of 13 TeV during proton-proton collisions, but no significant evidence for its existence was found [3].In 2021, the LHCb Collaboration conducted their first investigation into the Ω_{bc} baryon and carried out a renewed search for the Ξ_{cb} baryon, focusing on a mass range from 6.7 to 7.3 $\frac{GeV}{c^2}$, using proton-proton collisions.In recent years, a significant amount of research has been dedicated to understanding the properties of doubly heavy baryons, such as their mass spectra, decay modes, and internal structure, employing various theoretical frameworks and phenomenological models. [13, 14].
This article aims to explore the mass spectra of Ξ_{cb} baryons in both their ground and excited states and to compare these findings with predictions from other theoretical models.

Theoretical Framework

The Hypercentral Constituent Quark Model(hCQM) has been utilized to investigate the constituent quark interactions inside doubly heavy baryons, providing a simplified and effective description of their internal structure and properties. We have used the relative coordinates, specifically Jacobian coordinates, enables the description of interactions within a three-quark baryonic system, providing a framework to study the dynamics of quark-quark correlations.The model dictates that the chosen potential must be hypercentral, depending exclusively on the hyper-radius, denoted as x_1 [4]. In this model the Coulomb term, a confining potential, and a spin-dependent interaction V_{SD}, which accounts for spin-orbit, spin-spinand tensor interactions.

$$V(x_1) = -\frac{\tau_1}{x_1} + \alpha x_1 \tag{1}$$

The expression $\tau_1 = \frac{2}{3}\alpha_s$, where α_s being running coupling constant.We initially applied

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a first-order correction $O(\frac{1}{m})$ to the spin-dependent sector, but this failed to correctly reproduce the spin-splitting pattern. To address this, we subsequently implemented a second-order correction $O(\frac{1}{m^2})$ [5–8] in the spin-orbit and spin-tensor terms, which successfully resolved the mass hierarchy and properly ordered the spin-splitting."

$$V^1(x_1) = -C_F C_A \frac{\alpha_s^2}{4x_1^2} \tag{2}$$

where C_F and C_A are the Casimir charges of the fundamental and the adjoint representation respectively.

$$H = \frac{P^2}{2m} + V(x_1) + V_{SD}(x_1) + \frac{1}{m}V^1(x_1) + \frac{1}{m^2}V^2(x_1) \tag{3}$$

Results and Discussion

The mass spectra of the Ξ_{cb} baryon have been computed for a range of states, including the ground state 1S and excited states up to 3S, as well as the 1P and 1D states. The results are summarized in Table 1, providing a comprehensive overview of the predicted masses for these states.

Our predicted ground state mass for the Ξ_{cb} baryon is in agreement with predictions from other theoretical models, such as those in ref[12], with a minor deviation of approximately 12 MeV compared to ref [9, 10], we assign spin-parity $J^P = \frac{1}{2}^+$.The predicted masses for the 2S and 3S states deviate slightly, by around 10-15 MeV, from the values proposed by other theoretical models.The predicted masses of the orbitally excited 1P and 1D states in our study are in good agreement with other theoretical models, exhibiting a small variation of 10-25 MeV.

TABLE I: Predicted masses for Ξ_{bc} states of ours and other approaches

State	J^P	$Mass_{theo.}$	[9]	[10]	[11]	[12]
1S	$\frac{1}{2}^+$	6904	6914	6915	7014	6904
2S	$\frac{1}{2}^+$	7219	7231	7247	7321	7478
3S	$\frac{1}{2}^+$	7496	7492	7481		7904
1P	$\frac{1}{2}^-$	7134	7146	7183		
	$\frac{3}{2}^-$	7145	7135	7179		
1D	$\frac{3}{2}^+$	7329	7303	7268		
	$\frac{5}{2}^+$	7341	7294	7263		

Conclusion

In this study we employed the Hypercentral Constituent Quark Model (hCQM) framework to investigate the ground and orbitally excited states of the Ξ_{cb} baryon, taking into account higher-order corrections in mass and spin-dependent interactions. The refined calculations yielded accurate predictions for the mass spectra, enabling a precise determination of the excited state hierarchy and spin-parity assignments, in agreement with alternative theoretical approaches.

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