# Magnetic Moment and Decay properties of $\Xi_{cc}^{++}$ baryon in relativistic Dirac formalism with independent quark model

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## Introduction

The observation of the first doubly heavy baryon $\Xi_{cc}^{++}$ at LHCb [1, 2] opens up the uncharted territory of double heavy flavour hadrons which are difficult to detect. We continue the method outlined in references [3–5] and extend our study for computing the magnetic moment, radiative decay width, and lifetime of $\Xi_{cc}^{++}$.

## 1. Methodology

In our study, we examine the individual confinement of quarks within a baryon employing Martin potential characterized by the form $\frac{1}{2}(1+\gamma_0)(\lambda r^{0.1}+V_0)$ within the framework of relativistic Dirac formalism [3–5]. The spin-average mass of a baryon can be expressed as follows:

$$M_{SA}^{Qqq} = 2E_Q^D + E_q^D - E_{CM}, \qquad (1)$$

where, $E_Q^D$ and $E_q^D$ represent the Dirac energy of $Q$ and $q$ quarks respectively, which can be obtained by solving the Dirac equation for this system

$$[\gamma^0 E_q - \vec{\gamma}\vec{P} - m_q - V(r)]\psi_q(\vec{r}) = 0 \qquad (2)$$

and $E_{CM}$ is the parametric center of mass correction.

## 2. Magnetic moments and radiative decay

Magnetic moment can be obtained in terms of the confined quark masses $m_q^{eff}$ as given in Ref.[6], $m_q^{eff}$ defined as

$$m_q^{eff} = E_q^D\left(1+\frac{<H> - E_{CM}}{\sum_q E_q^D}\right). \qquad (3)$$

which follows the property of $M_J = \sum_{q=1}^{3} m_q^{eff}$. Our prediction and comparison with other different approaches are given in **TABLE I**.

**TABLE I :** Magnetic moments in terms of nuclear magneton

| State | Our | [7] | [8] | [9] |
|---|---|---|---|---|
| $\Xi_{cc}^{++}\frac{1}{2}^{+}$ | 0.0930 | 0.031 | 0.114 | 0.17 |
| $\Xi_{cc}^{++}\frac{3}{2}^{+}$ | 2.060 | 2.218 | 2.001 | 2.54 |

J. Dey et.al [10] showed the way to calculate the radiative decay widths for the doubly heavy baryon using the heavy quark effective theory (HQET) in terms of the radiative transition magnetic moment.

$$\Gamma = \frac{k^3}{4\pi}\frac{2}{2J+1}\frac{e^2}{m_p^2}\mu^2_{B_{\frac{3}{2}}\to B_{\frac{1}{2}}} \qquad (4)$$

where the radiative transition magnetic moment can be calculated as $\mu_{B_{\frac{3}{2}}\to B_{\frac{1}{2}}} = <B_{\frac{3}{2}}|\hat{\mu}_{B'z}|B_{\frac{1}{2}}>$. we can find the transition magnetic moments for the spin $\frac{3}{2}$ to $\frac{1}{2}$ for $\Xi_{cc}^{++}$ by using the following equation

$$\frac{4}{3\sqrt{2}}(\mu_c - \mu_u) \qquad (5)$$

We predict the decay width for $\Xi_{cc}^{++}{}_{(\frac{3}{2}^{+})} \to \Xi_{cc}^{++}{}_{(\frac{1}{2}^{+})}\gamma$ to be 1.504 $keV$ which is in accordance with other theoretical model [11, 12].

## 3. Lifetime

We have estimated the lifetime of the $\Xi_{cc}^{++}$ by considering the two c quarks going to decay

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independently[13] as given by Eq.(6)

$$\Gamma(\Xi_{cc}^{++}) = \frac{10G_F^2|V_{cs}||V_{cd}|M^5(\Xi_{cc})F(\chi_{cc})}{192\pi^3}, \quad (6)$$

where the kinematic suppression factor can be expressed as

$$F(\chi_{cc}) = F_1 + F_2 + F_3. \quad (7)$$

given

$$F_i = 1 - 8x_i + 8x_i^3 - x_i^4 + 12x_i^2 ln(\frac{1}{x_i}). \quad (8)$$

The $x_1$, $x_2$ & $x_3$ are squared ratios $M_{\Xi_c^+}/M_{\Xi_{cc}}$, $M_{\Sigma_c^+}/M_{\Xi_{cc}}$, and $M_{\Lambda_c^+}/M_{\Xi_{cc}}$ respectively. Using this equation, we calculated the total decay width width as shown below

$$\Gamma(\Xi_{cc}^{++}) = 3.1543 \times 10^{-12}(in\ GeV). \quad (9)$$

The resultant lifetime 0.205 $ps$ is very close to the experimentally observed value [14]. We anticipate it will overlap with the experimental value after including the omitted two effects (1) a form factor for the weak transitions of $\Xi_{cc}^{++}$, and (2) the excitation of $csu$ and $cdu$ states.

## 4. Discussion and Conclusion

Our computed magnetic moment, radiative decay width, and total decay width are in good agreement with other theoretical predictions.

Notably, we computed the basic estimation of the lifetime, which closely aligns with the observed experimental value. Our calculated value is 0.205 ps, while the experimental value is 0.256 ps [14]. We anticipate that more experimental details of $\Xi_{cc}^{++}$ will be available.


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