PROCEEDINGS OF SCIENCE

Strong and electromagnetic decays of Ξ_c baryon in quark-diquark model

PoS(QNP2012)094

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The spectroscopy and decay properties of the Ξ_c baryon has been studied by employing quark-diquark model with two body color coulomb plus power potential. The model parameters are fixed using the hyperfine mass splitting for each choice of the potential exponent ν, choice of running strong coupling constant α_s and with different quark mass parameters m_Q. These extracted spectroscopic parameters are used to compute decay width of the strong and electromagnetic decays of Ξ_c baryon. Our results are in good agreement with the available experimental as well as other theoretical results.

Sixth International Conference on Quarks and Nuclear Physics
April 16-20, 2012
Ecole Polytechnique, Palaiseau, Paris

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1. Introduction

Spectroscopy and decay properties of the heavy flavour baryons have become a subject of recent interest due to the experimental facilities at Belle, BABAR, D∅, CLEO, CDF, LHC etc. The spectroscopies as well as their decay properties are important from the point of view of understanding the heavy flavor dynamics.

2. Theoretical Methodology

In the quark-diquark model, the Hamiltonian of the baryon is expressed in terms of a diquark Hamiltonian (H_d) plus quark-diquark Hamiltonian ($H_{Q,d}$) as [1] $H = H_Q + H_{Q,d}$. Here, the internal motion of the light diquark($d = q_1q_2$) is described by $H_d = \frac{p^2}{2m_d} + V_d(r_d)$ The Hamiltonian of the relative motion of the diquark(d)- quark(Q) system is described by $H_{Q,d} = \frac{q^2}{2m_{Q,d}} + V_{Q,d}(r_{Qd})$ where, p is the relative momentum of the quarks within the diquark and q is the relative momentum of the quark-diquark system. The Schrodinger equation corresponds to the Hamiltonian is numerically solved using the Runge-Kutta method. For Ξ_c system, the potential parameters of the model are fixed to yield the spin average mass as well as the hyperfine spiltting of the ground state of $\Xi_c^*(2618) - \Xi_c(2440)$ baryon. The degeneracy of the states are removed by introducing the spin dependent interaction potential among the diquark(d) as well as among the light quark(l)-diquark($l-d$) system given by [2]

$$\begin{aligned} V_{SD}^{(d)}(r_{jk}) = & \frac{1}{2}\left(\frac{L_d \cdot S_d}{2m_c^2}\right)\left(-\frac{dV(r_{jk})}{r_{jk}dr_{jk}} + \frac{8}{3}\alpha_s\frac{1}{r_{jk}^3}\right) \\ & + \frac{2}{3}\alpha_s\frac{1}{m_c^2}\frac{L_d \cdot S_d}{r_{jk}^3} \\ & + \frac{4}{3}\alpha_s\frac{1}{3m_c^2}S_{c1} \cdot S_{c2}[4\pi\delta(r_{jk})] \end{aligned} \tag{2.1}$$

for the diquark states, and

$$\begin{aligned} V_{SD}^{(l)}(r) = & \frac{1}{2}\left(\frac{L \cdot S_d}{2m_c^2} + \frac{2L.S_l}{2m_l^2}\right)\left(-\frac{dV(r)}{rdr} + \frac{8}{3}\alpha_s\frac{1}{r^3}\right) \\ & + \frac{1}{3}\alpha_s\frac{1}{m_c m_l}\frac{L \cdot S_d + 2L \cdot S_l}{r^3} \\ & + \frac{4}{3}\alpha_s\frac{1}{3m_c^2}(S_d + L_d) \cdot S_l[4\pi\delta(r)] \end{aligned} \tag{2.2}$$

for the $(l-d)$ system. Where, r is the relative co-ordinate of $l-d$ (i, jk), L is the relative angular momentum of the $l-d$ system and S_l and S_d are the light quark and diquark spins, respectively. The first term in both expressions takes into account the relativistic corrections to the potential $V(r)$. The second and third terms are the relativistic corrections coming from the one-gluon exchange between the quarks. The mass spiltting has been studied for different choices of the quark mass parameters, m_c for each case of the potential exponent (ν) with the different choice of the running strong coupling constant α_s. The trendlines shown in Fig 1 are the predicted masss spilts against the potential exponent with different choices α_s and m_c. The solid horizontal line drawn in these plots

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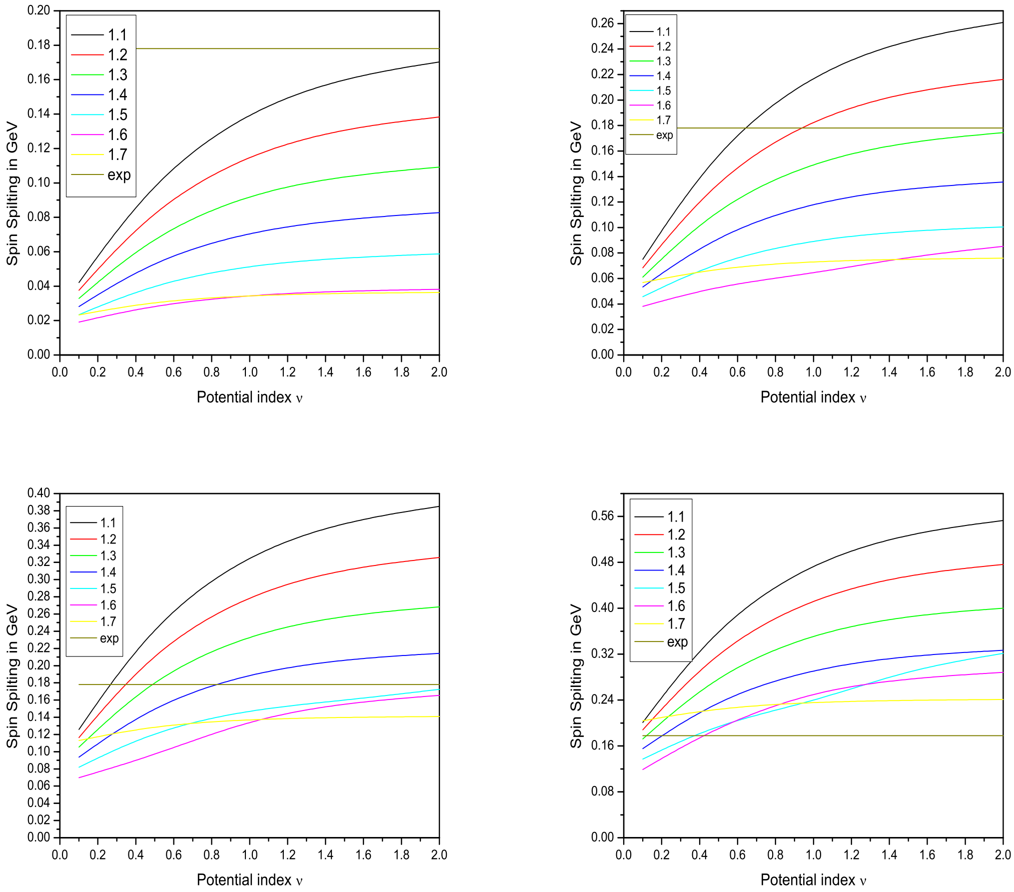

Figure 1: ($\Delta M = M_{\Xi_c^*} - M_{\Xi_c}$) Mass difference against potential index ν for different b-quark mass parameter (1.1 GeV$\leq m_c \leq$ 1.7 GeV)with different range of running strong coupling constant. $\alpha_s = 0.25$ [a], $\alpha_s = 0.30$ [b], $\alpha_s = 0.35$ [c], $\alpha_s = 0.40$[d].

correspond to the experimental mass spilt of 178 MeV. It is found that the choices of heavy quark mass parameter, m_c and α_s plays a decisive role in the mass splitting of the ground state baryons. The plots in 1 show the saturation property beyond the potential exponent $\nu > 1.5$. However, the solid line correspond to the experimental mass spilt cut the trend lines for the different choices of m_c at different exponent (ν) in the cases of $\alpha_s = 0.20$, $\alpha_s = 0.25$ and $\alpha_s = 0.30$. It is explicitly seen from 1[a] that choice of $\alpha_s \geq 0.25$ do not yield the experimental mass spilt for any choice of m_c between range of 1.1 to 1.8 GeV in the entire range (0-2) of the potential exponent. The model parameters thus extracted here for the choices of $\alpha_s = 0.30$ (Set A), $\alpha_s = 0.35$ (Set B)and $\alpha_s = 0.40$ (Set C) are listed in Table 1. These extracted spectroscopic parameters are used to compute decay width of the strong and electromagnetic decays.

Table 1: Model parameters Ξ_c with different choice of Potential exponent ν in quark-diquark model.

α_s	ν	b	m_c
0.30	0.8	0.0710	1.180
(Set A)	1.0	0.0466	1.225
	0.4	0.1212	1.275
0.35	0.6	0.0696	1.365
(Set B)	0.8	0.0438	1.405
	1.0	0.0284	1.430
0.40	0.2	0.1327	1.420
(Set C)	0.4	0.0650	1.530

3. Radiative decay of $\Gamma_{\Xi_c^{*0}\to\Xi_c^0\gamma}$ transition

The electromagnetic radiative decay width can be expressed in terms of the radiative transition magnetic moment(in μ_N) and photon energy (k) as [3]

$$\Gamma_\gamma = \frac{k^3}{4\pi}\frac{2}{2J+1}\frac{e^2}{m_p^2}\mu^2_{B\to B'\gamma} \tag{3.1}$$

here, m_p is the proton mass, $\mu_{B\to B'\gamma}$ is the radiative transition magnetic moments (in nuclear magnetons), which are expressed in terms of the magnetic moments of the constituting quarks (μ_i) of the initial and final state of the Baryon [3]. The radiative transition magnetic moment is calculated as $\mu_{B\to B'\gamma} = \left\langle B \mid \hat{\mu}_{B-B'z} \mid B' \right\rangle$. Here k is the photon energy and it is expressed as $m_B - m_{B'}$. In case of $\Sigma_c^+ \to \Lambda_c^+\gamma$, we can write transition magnetic moment as $\langle \Sigma_c^+ \mid \hat{\mu}_{\Lambda_c^+ z} \mid \Lambda_c^+ \rangle$. Here, the transition magnetic moment (μ_i) of the constituting quarks are computed using the spin flavour wave functions of the initial and final state baryons as [4] $\mu_i = \left\langle \phi_{sf} \mid \frac{e_i}{2m^{eff}_{i_{B-B'}}}\sigma_{iz} \mid \phi_{sf} \right\rangle$ Here, $m^{eff}_{i_{B-B'}}$ corresponds to the effective mass of the constituent quarks within the baryons B and B' is defined as $m^{eff}_{i_{B-B'}} = \sqrt{m^{eff}_{i_B} m^{eff}_{i_{B'}}}$. here, $m^{eff}_{i_B}$ and $m^{eff}_{i_{B'}}$ are the effective masses of the quarks constituting the baryonic states B and B' respectively.

4. Hadronic decay of $\Gamma_{\Xi_c^{*0}\to\Xi_c^0\pi}$

By studying the strong decay modes, one expects to extract information about their structures and the low energy dynamics of heavy baryons *vis a vis* interaction with pion and other pseudoscalar mesons. The decay width is computed as [5]

$$\Gamma(\Xi_Q^* \to \Xi_Q, \pi) = \frac{g_2^2}{4\pi f_\pi^2}\frac{M_{\Xi_Q}}{M_{\Xi_Q^*}}|\overrightarrow{p_\pi}|^3 \tag{4.1}$$

where, g_2 and g_1 are the axial vector coupling constants. For the present study, we employ the experimental value $g_A^N = 1.0$, $f_\pi = 135$ MeV and p_π, the momentum carried by the pion is computed as $\sqrt{(\frac{m^2_{\Sigma_Q}+m^2_\pi-m^2_{\Lambda_Q}}{2m_{\Sigma_Q}})^2 - m^2_\pi}$, in the center of mass frame.

5. Results and Conclusion

Using the deduced spectroscopic parameters, we have predicted the strong and electromagnetic decay widths of $\Gamma_{\Xi_c^{*0}\rightarrow\Xi_c^0\pi}$, $\Gamma_{\Xi_c^{*0}\rightarrow\Xi_c^0\gamma}$ based on quark-diquark model with interquark interaction as coulomb plus power law potential. The decay widths for these transitions are listed in the Table 2. Our results are in good agreement with the available experimental as well as other theoretical results.

Table 2: Electromagnetic and strong decay width of $\Gamma_{\Xi_c^{*0}\rightarrow\Xi_c^0\pi}$, $\Gamma_{\Xi_c^{*0}\rightarrow\Xi_c^0\gamma}$ transition

Decay width	Our	Others
$\Gamma_{\Xi_c^{*0}\rightarrow\Xi_c^0\pi}$	2.55 MeV	$<$ 5.5 MeV [6]
$\Gamma_{\Xi_c^{*0}\rightarrow\Xi_c^0\gamma}$	0.87 keV	0.90 keV [7]

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