Spin-parity assignment of $\Lambda_c(2765)^+$ baryon

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Introduction

At latest, the LHCb Collaboration have been studied the amplitude analysis in $\Lambda_b^0 \rightarrow D^0 p \pi^-$ decay and carried out the data for an integrated luminosity 3.0 fb^{-1} of pp collisions. An invariant mass distribution of final state mass spectra $D^0 p$ observed the excited Λ_c^+ resonances. Which are $\Lambda_c(2860)^+$, $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ measured with spin-parity $\frac{3}{2}^+$, $\frac{5}{2}^+$ and $\frac{3}{2}^-$ respectively [1]. The CDF II detector recorded a data corresponding to an integrated luminosity 3.0 fb^{-1} of $p\bar{p}$ collisions at the center-of-mass energy $\sqrt{s}$ = 1.96 TeV. That measured final state particles $\Lambda_c^+ \pi^+ \pi^-$ reconstructed the first orbital excited states of Λ_c^+ baryon, $\Lambda_c(2595)^+$ and $\Lambda_c(2625)^+$, with a total spin $\frac{1}{2}$ and $\frac{3}{2}$ respectively [2]. The ground state properties of the Λ_c^+ baryon is established very well. Aftermost, the BABAR detector measured its mass $m(\Lambda_c^+) = 2286.46 \pm 0.14$ from its decay into $\Lambda K_S^0 K^0$ and $\Sigma^0 K_S^0 K^0$ [3]. In 2001, CLEO detector at the Cornell Electron Storage Ring (CESR) analyzed final state mass spectra of $\Lambda_c^+ \pi^+ \pi^-$, the data was collected using 3.0 fb^{-1} of integrated luminosity. They found that states with mass differences, $\Lambda_c(2765)^+ - \Lambda_c^+ = 480.1 \pm 2.4$ MeV and $\Lambda_c(2880)^+ - \Lambda_c^+ = 595.17 \pm 0.28$ MeV. Figure 1 shows the Chew-Frautschi plot in the (J, M^2) plane where $\Lambda_c(2765)^+$ is following $\Lambda_c(2940)^+$ state on Regge line.

For $\Lambda_c(2765)^+$ baryon the Particle Data Group (PDG) need more confirmations [5]. Its quantum number investigation is still an open question. Up to now, there are many theoretical groups have made a spectroscopy assignment of excited states heavy baryons. In 1986, S. Capstick and N. Isgur introduce the relativistic quark potential model [6], D. Ebert *et al.* used relativistic quark-diquark approach [7], QCD sum rule [8], heavy quark-light quark cluster picture [9], lattice QCD study [10, 11] etc.. The spectroscopy of heavy, heavy-light and the heavy flavor baryons have been studied by our group (see Refs. [12, 13]) in the nonrelativistic framework of hypercentral constituent quark model.

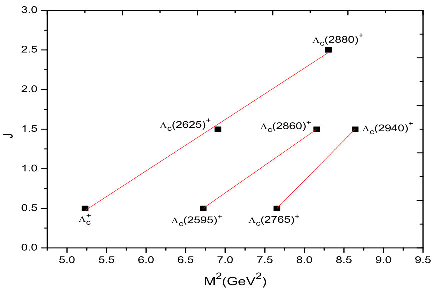

FIG. 1: Chew-Frautschi plot in the (J, M^2) plane. An experimentally observed states of Λ_c^+ baryon from PDG-2018 [5] are presented by solid square symbol with particle name .

Experimentally, the seven states of Λ_c^+ baryon are observed. Except $\Lambda_c(2765)^+$, the spin-parity of all excited states $\Lambda_c(2595)^+$, $\Lambda_c(2625)^+$, $\Lambda_c(2860)^+$, $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ baryon are known. So our aim is that to predict the spin-parity of $\Lambda_c(2765)^+$ baryon.

Regge Trajectory

Regge trajectory is an important phenomena can help to determine the possible quantum number of the particular hadronic state. Using the following definitions,

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I. Regge trajectory in (J, M^2) plane,

$$J = \alpha M^2 + \alpha_0; \tag{1}$$

II. and Regge trajectory in (n_r, M^2) plane,

$$n_r = \beta M^2 + \beta_0, \tag{2}$$

where α, β are slopes and α_0, β_0 are intercepts. $n_r = n - 1 = 0, 1, 2, ...$ is the radial quantum number and M^2 is the PDG-2018 [5] fitted square mass of the Λ_c^+ baryon. Figure 2 shows the Regge trajectories in (J, M^2) plane with natural parities $P = (-1)^{J-\frac{1}{2}}$. Therefore, the states $J^P = \frac{1}{2}^+$, $\frac{3}{2}^-$, $\frac{5}{2}^+$ and $\frac{7}{2}^-$ are available with natural parities. The Regge trajectories in (n_r, M^2) plane are presented in Figure 3.

The square masses of the Λ_c^+ baryon are fitted nicely on a Regge lines in the both plane. The $\Lambda_c(2286)^+$, $\Lambda_c(2625)^+$ and $\Lambda_c(2880)^+$ states with $J^P = \frac{1}{2}^+, \frac{3}{2}^-$ and $\frac{5}{2}^+$ are lies on the same Regge line in (J, M^2) plane. And, on the second Regge line $\Lambda_c(2940)^+$ with $J^P = \frac{3}{2}^-$ follow the $\Lambda_c(2765)^+$ of $J^P = \frac{1}{2}^+$. In (n_r, M^2) plane, the $\Lambda_c(2765)^+$ with $n_r = 1$ follows the ground state of Λ_c^+ baryon. The $\Lambda_c(2595)^+$ leading the $\Lambda_c(2940)^+$ state on a second Regge line.

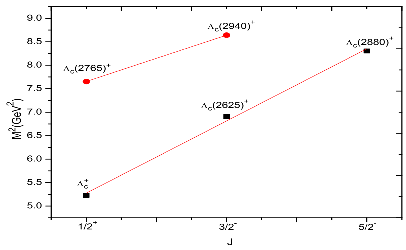

FIG. 2: The $(M^2 \to J)$ Regge trajectory of Λ_c^+ baryon with natural parity.

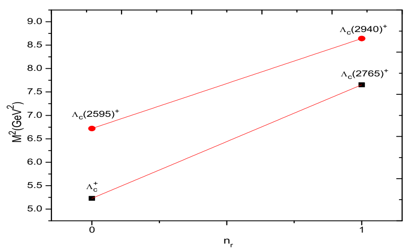

FIG. 3: The $(M^2 \to n_r)$ Regge trajectory of Λ_c^+ baryon.

Conclusion

In the present study, we confirmed spin-parity of experimentally observed $\Lambda_c(2595)^+$, $\Lambda_c(2625)^+$, $\Lambda_c(2860)^+$, $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ baryon. And, predict the $\Lambda_c(2765)^+$ baryon as a $2S$ state with total spin $\frac{1}{2}$. So we extend this scheme for other heavy flavor baryons.

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