Radial excitation of Ω_{cc} baryon using relativistic formalism

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INTERNATIONAL CONFERENCE ON THE STRUCTURE OF BARYON-2022

Status of Ω_{cc}

Confirmed by SELEX collaboration → $J^P\left(\frac{3}{2}^+\right) = \mathbf{3809 \pm 36}\ \boldsymbol{MeV}$

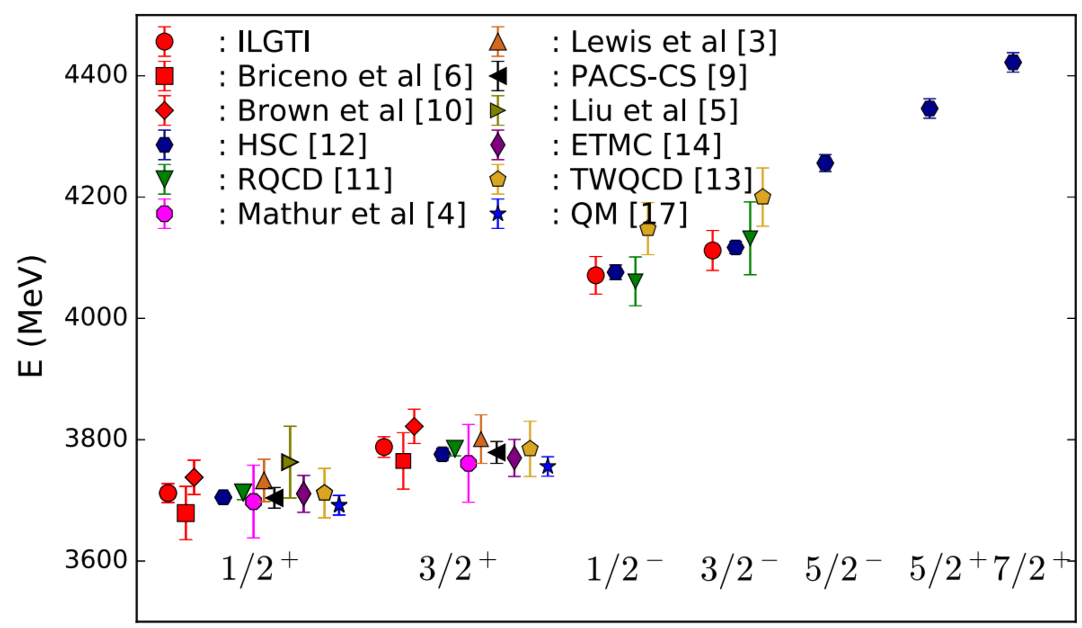
Ke-Wei Wei, Bing Chen and Xin-Heng Guo, Phys. Rev. D 92, 076008 (2015)

T. Yoshida, E. Hiyama, A. Hosaka, M. Oka, K. Sadato, Phys. Rev. D 92, 114029 (2015).

Lattice QCD Prediction → $J^P\left(\frac{1}{2}^+\right) = \mathbf{3712(11)(12)}\boldsymbol{MeV}$

$J^P\left(\frac{3}{2}^+\right) = \mathbf{3788(13)(12)}\boldsymbol{MeV}$

Nilmani Mathur and M. Padmanath, Phys. Rev. D 99, 031501 (2019).



Guo-Liang Yu, et al.
arXiv:2211.00510 [hep-ph]

2022

The theoretical references vary in the range 3700–3880 MeV.

Outline

- **Introduction**
- **Theoretical Methodology**
- **S wave mass spectra of Ω_{cc}**
- **Result and discussion**
- **References**

Introduction

- **The doubly heavy Ω_{cc} baryon represents a distinctive three quark system because they contain a strange light quark in the combination of two charm quarks.**

- **There are new decay modes and excited states seen in doubly charmed baryons by CLEO, LHCb and many other experiments and they have attempted to identify the doubly heavy baryons, but only a few states have been discovered so far.**

- **Here, The mass spectra of radially excited states of doubly heavy baryons are calculated under a mean field confinement of Martin-like potential with a parametric centre of weight mass correction in an independent quark model with Dirac relativistic formalism.**

Theoretical Methodology

- **For the present study we have considered the confinement through a Martin-like potential. The form of the model potential is,**

$$V(r) = \frac{1}{2}(1+\gamma_0)(\lambda\, r^{\nu} + V_0\,) \qquad (1)$$

where λ is the potential strength and ν is the exponent of the power potential. For the Martin-like potential, the index $\nu = 0.1$. The Dirac equation [7]

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

is solved in the two component form [3,4],

$$\psi_q(\vec{r}) = \psi_{nlj}\,(\vec{r}) = \begin{pmatrix}\psi_A\\ \psi_B\end{pmatrix} \qquad (3)$$

- **To get the positive and negative energy solutions corresponds to the confined quark and antiquark respectively as;**

$$\psi_A{}^{(+)}(\vec{r}) = N_{nlj}\begin{pmatrix}\frac{i\,g(r)}{r}\\ \frac{(\sigma.\vec{r})f(r)}{r}\end{pmatrix}\mathcal{Y}_{ljm}(\hat{r}) \text{ and } \psi_A{}^{(-)}(\vec{r}) = N_{nlj}\begin{pmatrix}\frac{i(\sigma.\vec{r})f(r)}{r}\\ \frac{g(r)}{r}\end{pmatrix}(-1)^{j+m_j-l}\,\mathcal{Y}_{ljm}(\hat{r}) \qquad (4)$$

and N_{nlj} is the normalization constant.

Theoretical Methodology

- The reduced radial part *g(r)* of the upper component and *f(r)* of the lower component of the Dirac spinor ψ_{nlj}(r) satisfy the equations given by,

$$\frac{d^2 g(r)}{dr^2} + \left[\left(E_D + m_q\right)\left(E_D - m_q - V(r)\right) - \frac{\kappa(\kappa+1)}{r^2}\right] g(r) = 0 \quad (5)$$

$$\frac{d^2 f(r)}{dr^2} + \left[\left(E_D + m_q\right)\left(E_D - m_q - V(r)\right) - \frac{\kappa(\kappa-1)}{r^2}\right] f(r) = 0 \quad (6)$$

- On transforming into a convenient dimensionless form,

$$\frac{d^2 g(\rho)}{d\rho^2} + \left[\epsilon - \rho^{0.1} - \frac{\kappa(\kappa+1)}{\rho^2}\right] g(\rho) = 0 \quad (7)$$

$$\frac{d^2 f(\rho)}{d\rho^2} + \left[\epsilon - \rho^{0.1} - \frac{\kappa(\kappa-1)}{\rho^2}\right] f(\rho) = 0 \quad (8)$$

- The corresponding energy eigen value is obtained from the equation [3,4];

$$\epsilon = \left(E_D - m_q - V_0\right)\left(E_D + m_q\right)^{\frac{1}{21}} \left(\frac{2}{\lambda}\right)^{\frac{20}{21}} \quad (9)$$

Theoretical Methodology

- **The solutions *g(ρ)* and *f(ρ)* are normalized to get;**

$$\int_0^{\infty} \left(f_q^2(\rho) + g_q^2(\rho)\right) d\rho = 1$$

- **The mass of the specific $^{2s+1}L_J$ states of the QQq system is expressed as,**

$$M_{^{2s+1}L_J} = E_Q^D + E_Q^D + E_q^D + \left\langle V_{q\bar{q}}^{j_1 j_2} \right\rangle - E_{CM}$$

- **The spin-spin part is defined here as,**

$$\left\langle V_{QQq}^{j\,j}(r) \right\rangle = \sum_{i=1,\, i<k}^{i,k=3} \frac{\sigma \langle j_i j_k J M | \hat{j}_i \hat{j}_k \, | j_j j_k J M \rangle}{(E_{q_i} + m_{q_i})(E_{q_k} + m_{q_k})}$$

S wave mass spectra of Ω_{cc}

TABLE I: S wave mass spectra of Ω_{CC} (in GeV)

$n^{2S+1}S_J$	M_{SA}^{QQq}	$\langle V_{QQq}^{jj}(r)\rangle$	Our	[9]	[10]	[11]	[12]
$1^2S_{\frac{1}{2}}$	3.841	-0.059	3.782	3.778	3.650	3.815	3.697
$1^4S_{\frac{3}{2}}$	3.841	0.035	3.876	3.872	3.810	3.876	3.769
$2^2S_{\frac{1}{2}}$	4.181	-0.049	4.131	4.075	4.028	4.18	4.112
$2^4S_{\frac{3}{2}}$	4.181	0.029	4.210	4.174	4.085	4.188	4.16
$3^2S_{\frac{1}{2}}$	4.378	-0.045	4.333	4.321	4.317	-	-
$3^4S_{\frac{3}{2}}$	4.378	0.027	4.406	-	4.345	-	-
$4^2S_{\frac{1}{2}}$	4.519	-0.043	4.477	-	4.57	-	-
$4^4S_{\frac{3}{2}}$	4.519	0.026	4.545	-	4.586	-	-
$5^2S_{\frac{1}{2}}$	4.631	-0.041	4.590	-	4.811	-	-
$5^4S_{\frac{3}{2}}$	4.631	0.024	4.655	-	4.801	-	-

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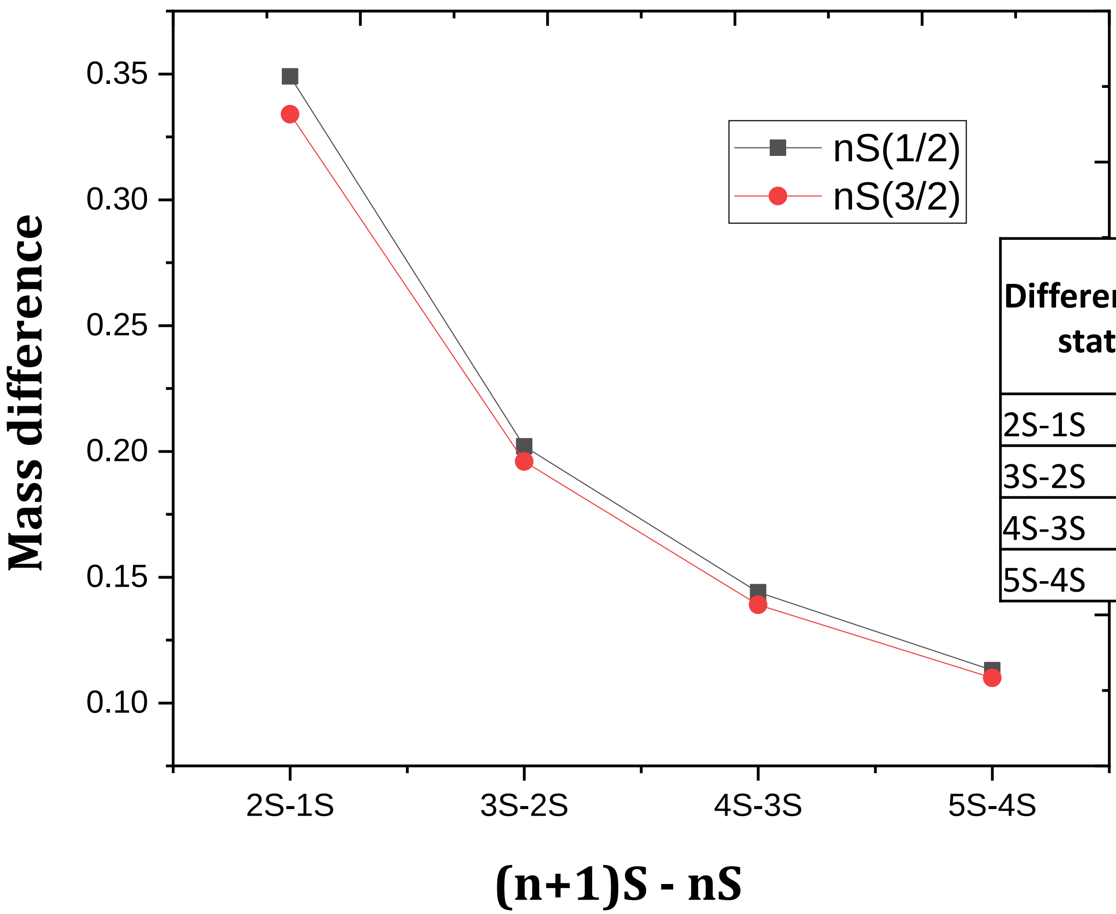
S wave mass spectra of Ω_{cc}



Difference of states	$(n+1)S_{1/2}$ - $(n)S_{1/2}$	$(n+1)S_{3/2}$ - $(n)S_{3/2}$
2S-1S	0.349	0.334
3S-2S	0.202	0.196
4S-3S	0.144	0.139
5S-4S	0.113	0.11

Result And Discussion

- **Many of these states and their structures not understood. The status of these states can be understood also with the help of quark model.**
- **The predicted S-wave masses of Ω_{CC} baryon are in very good agreement with other theoretical predictions results as given in Table 1.**
- **In our calculations, we have included hyperfine splitting and radial excited states of doubly charmed baryons are summarized in Table I.**
- **High statistics data required for the investigation of this doubly heavy baryon spectroscopy.**

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THANK YOU