Strong decay widths and mass spectra of charmed baryons

A. Ramirez-Morales*, H. Garcia Tecocoatzi*, A. Giachino†‡, Elena Santopinto† and J. Li*

*Center for High Energy Physics, Kyungpook National University, Daegu, South Korea

†INFN, Sezione di Genova, Genova, Italy

‡Institute of Nuclear Physics Polish Academy of Sciences, Cracow, Poland

Abstract

The total decay widths of charmed baryons, including all the possible open-flavor decay channels, are calculated by means of the 3P0 model. Our calculations consider in the final states: the charmed baryon-(vector/pseudoscalar) meson pairs and the (octet/decuplet) baryon-(pseudoscalar/vector) charmed meson pairs, within a constituent quark model. Furthermore, we calculate the masses of the charmed baryon ground states and their excitations up to the D-wave states. We also calculate the charmed baryon masses in a constituent quark model, both in the three-quark and in quark-diquark schemes, utilizing a Hamiltonian model based on a harmonic oscillator potential plus a mass splitting term that encodes the spin, spin-orbit, isospin, and flavor interactions. The parameters of the Hamiltonian model are fitted to experimental data of charmed baryon masses and decay widths. As the experimental uncertainties of the data affect the fitted model parameters, we have thoroughly propagated these uncertainties into our predicted charmed baryon masses and decay widths via a Monte Carlo bootstrap approach, which is often absent in other theoretical studies on this subject. Our quantum number assignments and predictions of mass and strong partial decay widths are in reasonable agreement with the available data. Thus, our results show the ability to guide future measurements in LHCb, Belle and Belle II experiments.

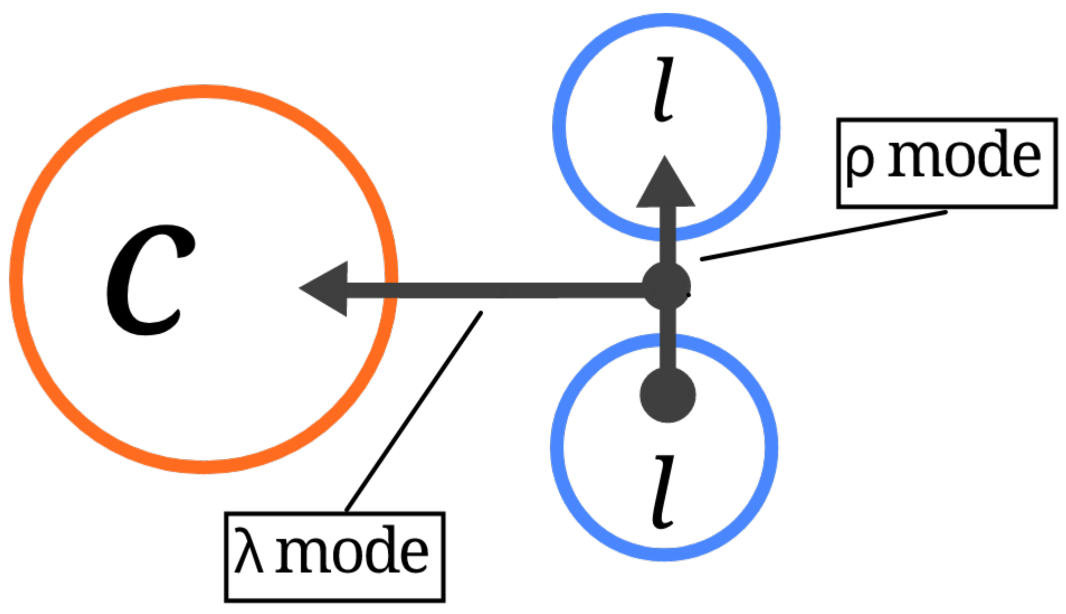
Motivations and goals

- ✔ Belle(II) and LHCb have recently observed heavy quark baryon excited states
- ✔ Quantum number of excited baryons: widths and mass patterns will give insight into their binding mechanism
- ✔ Give a model for exploring high charm baryon masses and decay widths
- ✔ Error propagation with Monte Carlo sampling
- ✔ Globally the charmed baryons: Ωc, Σc, Λc and Ξc.

Strategy

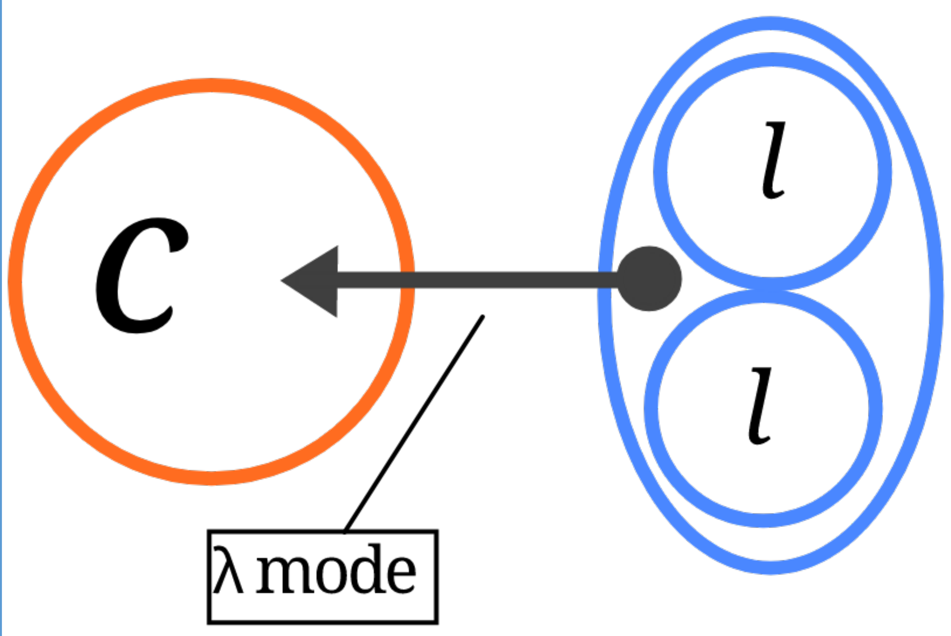
Model 1

Charmed baryon modeled as three-quark (one charm *c* two lights *l*) system bonded with two harmonic oscillators, h.o., ρ and λ



Model 2

Charmed baryon modeled as diquark (one charm and one composed object of two lights quarks) system bonded with one h. o. λ



The charmed baryon masses are the Eigenvalues of the Hamiltonian, which is a sum of the h.o. plus spin S, orbital angular L , isospin I and flavor. S,L,I and flavor are treated as perturbations, and their weights P's are fitted to data:

$$H = H_{\rm h.o.} + P_s\, \mathbf{S}^2 + P_{sl}\, \mathbf{S}\cdot\mathbf{L} + P_I\, \boldsymbol{I}^2 + P_f\, \mathbf{C_2}(\mathrm{SU(3)_f})$$

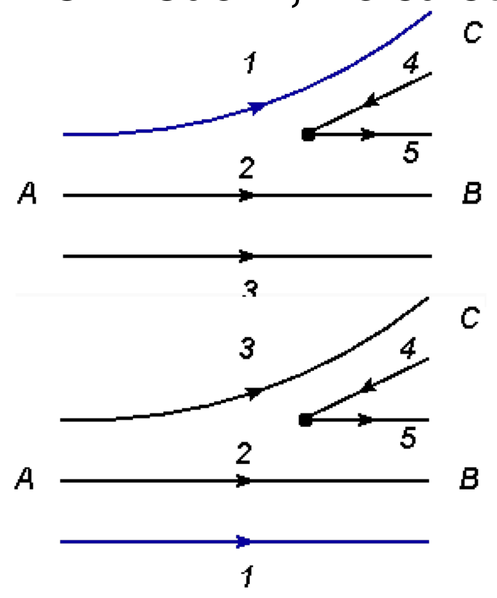
Model 1, three-quark system:

$$H_{\rm h.o.} = \sum_{i=1}^{3} m_i + \frac{\mathbf{p}_\rho^2}{2m_\rho} + \frac{\mathbf{p}_\lambda^2}{2m_\lambda} + \frac{1}{2} m_\rho \omega_\rho^2 \boldsymbol{\rho}^2 + \frac{1}{2} m_\lambda \omega_\lambda^2 \boldsymbol{\lambda}^2$$

Model 2, diquark system:

$$H_{\rm h.o.} = m_D + m_c + \frac{\mathbf{p}_r^2}{2\mu} + \frac{1}{2}\mu\omega_r^2 \boldsymbol{r}^2$$

For Model 1, we calculate the decay widths with the 3P0 model

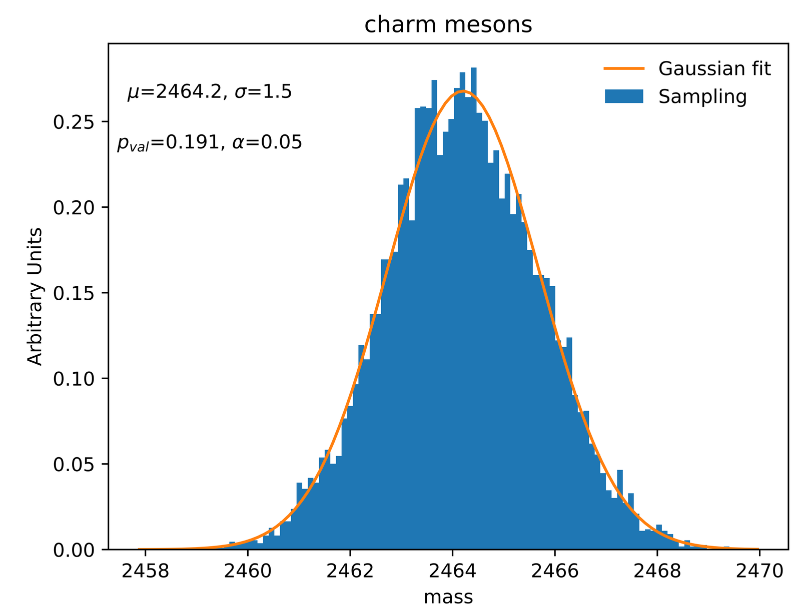


$$\Gamma_{A\to BC} = \frac{2\pi\gamma_0^2}{2J_A+1}\,\Phi_{A\to BC}(q_0) \times \sum_{M_{J_A},M_{J_B}} \left|\mathcal{M}^{M_{J_A},M_{J_B}}\right|^2$$

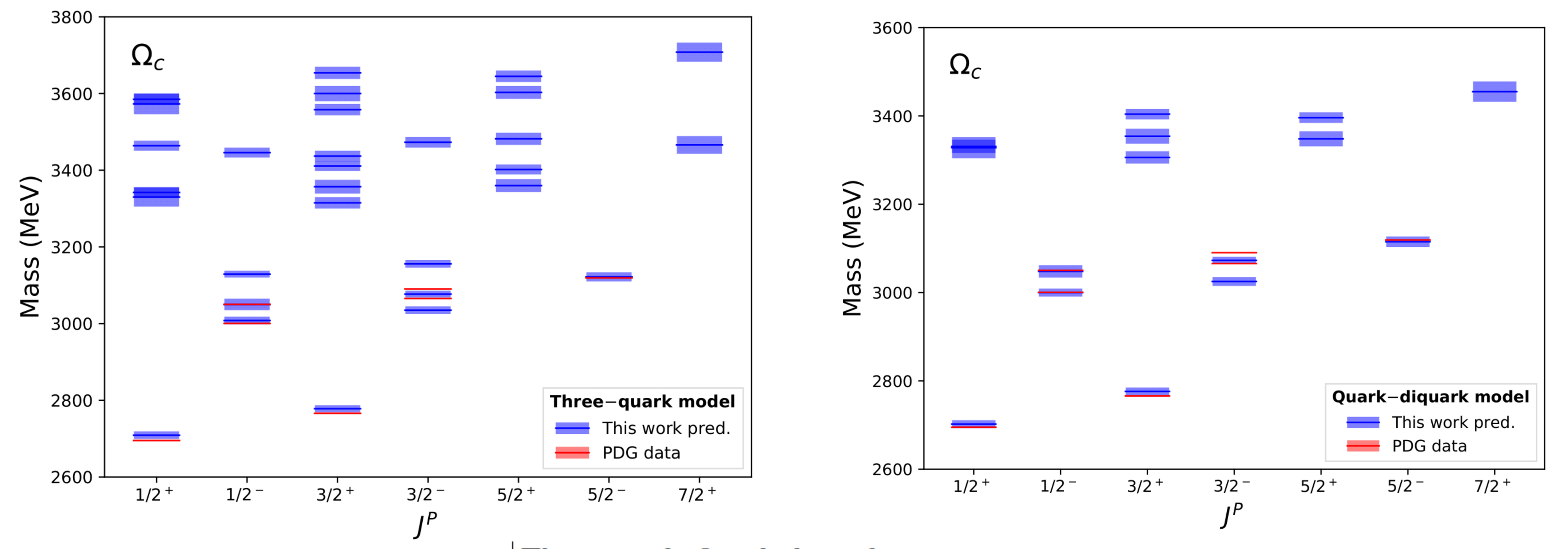
Model parameters are found with the least-squares minimization and the error propagated by sampling gaussian distributions

Results

Parameter	three-quark Value	diquark Value
m_c	$1606.15^{+57.82}_{-61.2}$ MeV	$1562.94^{+22.65}_{-24.38}$ MeV
m_s	$455.31^{+29.24}_{-26.76}$ MeV	†
$m_{u,d}$	$283.91^{+30.03}_{-30.93}$ MeV	†
m_{D_Ω}	†	$947.05^{+2.95}_{-2.95}$ MeV
m_{D_Ξ}	†	$790.85^{+17.52}_{-14.34}$ MeV
$m_{D_{\Sigma,\Lambda}}$	†	$612.98^{+19.55}_{-16.79}$ MeV
K_c	$0.029^{+0.0007}_{-0.0008}$ GeV^3	$0.0195^{+0.0007}_{-0.0007}$ GeV^3
P_s	$23.07^{+3.16}_{-3.1}$ MeV	$24.27^{+3.09}_{-3.11}$ MeV
P_{sl}	$18.02^{+5.39}_{-5.4}$ MeV	$16.92^{+5.38}_{-5.3}$ MeV
P_I	$45.15^{+8.47}_{-8.43}$ MeV	$41.22^{+8.8}_{-8.74}$ MeV
P_f	$52.42^{+5.75}_{-5.74}$ MeV	$52.34^{+6.58}_{-6.61}$ MeV



Results are shown for Ωc, but similar plots and tables are available at our arxiv: https://arxiv.org/abs/2205.07049v2



$\Omega_c(ssc)$ $\mathcal{F}=\mathbf{6}_\mathrm{f}$	$^{2S+1}L_J$	Three-quark Predicted Mass (MeV)	Quark-diquark Predicted Mass (MeV)	Experimental Mass (MeV)	Predicted Γ_{tot} (MeV)	Experimental Γ (MeV)
$N=0$						
$\lvert l_\lambda=0,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^2S_{1/2}$	2709^{+10}_{-10}	2702^{+9}_{-9}	2695.0 ± 1.7 (*)	$0.0^{+0.0}_{-0.0}$	$<10^{-7}$
$\lvert l_\lambda=0,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^4S_{3/2}$	2778^{+9}_{-9}	2776^{+9}_{-9}	2765.9 ± 2.0 (*)	$0.0^{+0.0}_{-0.0}$	†
$N=1$						
$\lvert l_\lambda=1,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^2P_{1/2}$	3008^{+10}_{-10}	3000^{+9}_{-9}	3000.4 ± 0.22 (*)	$4.1^{+2.0}_{-2.0}$	$4.5\pm0.6\pm0.3$ (*)
$\lvert l_\lambda=1,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^4P_{1/2}$	3050^{+15}_{-15}	3048^{+14}_{-14}	3050.2 ± 0.13	$7.5^{+3.7}_{-3.7}$	$0.8\pm0.2\pm0.1$
$\lvert l_\lambda=1,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^2P_{3/2}$	3035^{+10}_{-10}	3025^{+10}_{-10}	3065.6 ± 0.28	$26.3^{+12.9}_{-12.9}$	$3.5\pm0.4\pm0.2$
$\lvert l_\lambda=1,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^4P_{3/2}$	3077^{+9}_{-9}	3073^{+8}_{-8}	3090.2 ± 0.5	$6.6^{+3.3}_{-3.3}$	$8.7\pm1.0\pm0.8$
$\lvert l_\lambda=1,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^4P_{5/2}$	3122^{+12}_{-12}	3115^{+12}_{-11}	3119.1 ± 1.0 (*)	$50.0^{+24.7}_{-24.3}$	60 ± 26 (*)
$\lvert l_\lambda=0,l_\rho=1,k_\lambda=0,k_\rho=0\rangle$	$^2P_{1/2}$	3129^{+9}_{-9}	††	†	$14.4^{+1.6}_{-9.5}$	†
$\lvert l_\lambda=0,l_\rho=1,k_\lambda=0,k_\rho=0\rangle$	$^2P_{3/2}$	3156^{+10}_{-10}	††	†	$71.6^{+36.1}_{-35.2}$	†
$N=2$						
$\lvert l_\lambda=2,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^2D_{3/2}$	3315^{+15}_{-14}	3306^{+14}_{-14}	†	$10.6^{+5.3}_{-5.3}$	†
$\lvert l_\lambda=2,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^2D_{5/2}$	3360^{+17}_{-16}	3348^{+17}_{-17}	†	$24.4^{+12.0}_{-11.9}$	†
$\lvert l_\lambda=2,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^4D_{1/2}$	3330^{+25}_{-25}	3328^{+24}_{-23}	†	$16.3^{+8.2}_{-8.0}$	†
$\lvert l_\lambda=2,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^4D_{3/2}$	3357^{+18}_{-19}	3354^{+17}_{-17}	†	$30.4^{+14.8}_{-14.9}$	†
$\lvert l_\lambda=2,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^4D_{5/2}$	3402^{+13}_{-13}	3396^{+12}_{-12}	†	$62.3^{+31.0}_{-31.1}$	†
$\lvert l_\lambda=2,l_\rho=0,k_\lambda=0,k_\rho=0\rangle$	$^4D_{7/2}$	3466^{+23}_{-23}	3455^{+23}_{-23}	†	$123.0^{+61.4}_{-62.1}$	†
$\lvert l_\lambda=0,l_\rho=0,k_\lambda=1,k_\rho=0\rangle$	$^2S_{1/2}$	3342^{+14}_{-14}	3331^{+15}_{-15}	†	$1.3^{+0.6}_{-0.6}$	†
$\lvert l_\lambda=0,l_\rho=0,k_\lambda=1,k_\rho=0\rangle$	$^4S_{3/2}$	3411^{+13}_{-13}	3404^{+12}_{-12}	†	$3.2^{+1.6}_{-1.6}$	†
$\lvert l_\lambda=0,l_\rho=0,k_\lambda=0,k_\rho=1\rangle$	$^2S_{1/2}$	3585^{+15}_{-15}	††	†	$18.3^{+9.2}_{-9.2}$	†
$\lvert l_\lambda=0,l_\rho=0,k_\lambda=0,k_\rho=1\rangle$	$^4S_{3/2}$	3654^{+16}_{-16}	††	†	$24.0^{+12.1}_{-12.0}$	†
$\lvert l_\lambda=1,l_\rho=1,k_\lambda=0,k_\rho=0\rangle$	$^2D_{3/2}$	3437^{+14}_{-14}	††	†	$198.0^{+97.9}_{-98.0}$	†
$\lvert l_\lambda=1,l_\rho=1,k_\lambda=0,k_\rho=0\rangle$	$^2D_{5/2}$	3482^{+16}_{-16}	††	†	$114.9^{+56.6}_{-56.3}$	†
$\lvert l_\lambda=1,l_\rho=1,k_\lambda=0,k_\rho=0\rangle$	$^2P_{1/2}$	3446^{+13}_{-13}	††	†	$2.1^{+1.1}_{-1.0}$	†
$\lvert l_\lambda=1,l_\rho=1,k_\lambda=0,k_\rho=0\rangle$	$^2P_{3/2}$	3473^{+14}_{-14}	††	†	$3.1^{+1.5}_{-1.5}$	†
$\lvert l_\lambda=1,l_\rho=1,k_\lambda=0,k_\rho=0\rangle$	$^2S_{1/2}$	3464^{+13}_{-13}	††	†	$88.2^{+43.1}_{-44.0}$	†
$\lvert l_\lambda=0,l_\rho=2,k_\lambda=0,k_\rho=0\rangle$	$^2D_{3/2}$	3558^{+15}_{-15}	††	†	$217.1^{+108.6}_{-107.4}$	†
$\lvert l_\lambda=0,l_\rho=2,k_\lambda=0,k_\rho=0\rangle$	$^2D_{5/2}$	3603^{+17}_{-17}	††	†	$174.3^{+85.1}_{-86.0}$	†
$\lvert l_\lambda=0,l_\rho=2,k_\lambda=0,k_\rho=0\rangle$	$^4D_{1/2}$	3573^{+27}_{-26}	††	†	$217.6^{+140.3}_{-138.5}$	†
$\lvert l_\lambda=0,l_\rho=2,k_\lambda=0,k_\rho=0\rangle$	$^4D_{3/2}$	3600^{+20}_{-20}	††	†	$284.8^{+144.4}_{-144.7}$	†
$\lvert l_\lambda=0,l_\rho=2,k_\lambda=0,k_\rho=0\rangle$	$^4D_{5/2}$	3645^{+15}_{-16}	††	†	$212.0^{+102.7}_{-103.8}$	†
$\lvert l_\lambda=0,l_\rho=2,k_\lambda=0,k_\rho=0\rangle$	$^4D_{7/2}$	3708^{+25}_{-25}	††	†	$383.1^{+191.8}_{-193.9}$	†

Summary and conclusions

We studied globally all charmed baryons up to D-wave a provided a description in good agreement with data for both the proposed three-quark and diquark models. We included all the possible strong decays. We considered experimental and model uncertainties and propagated to our calculations. This work was supporte by INFN, sezione di Genova, CONACyT and National Research Foundation of Korea. Further details and references are given at https://arxiv.org/abs/2205.07049v2