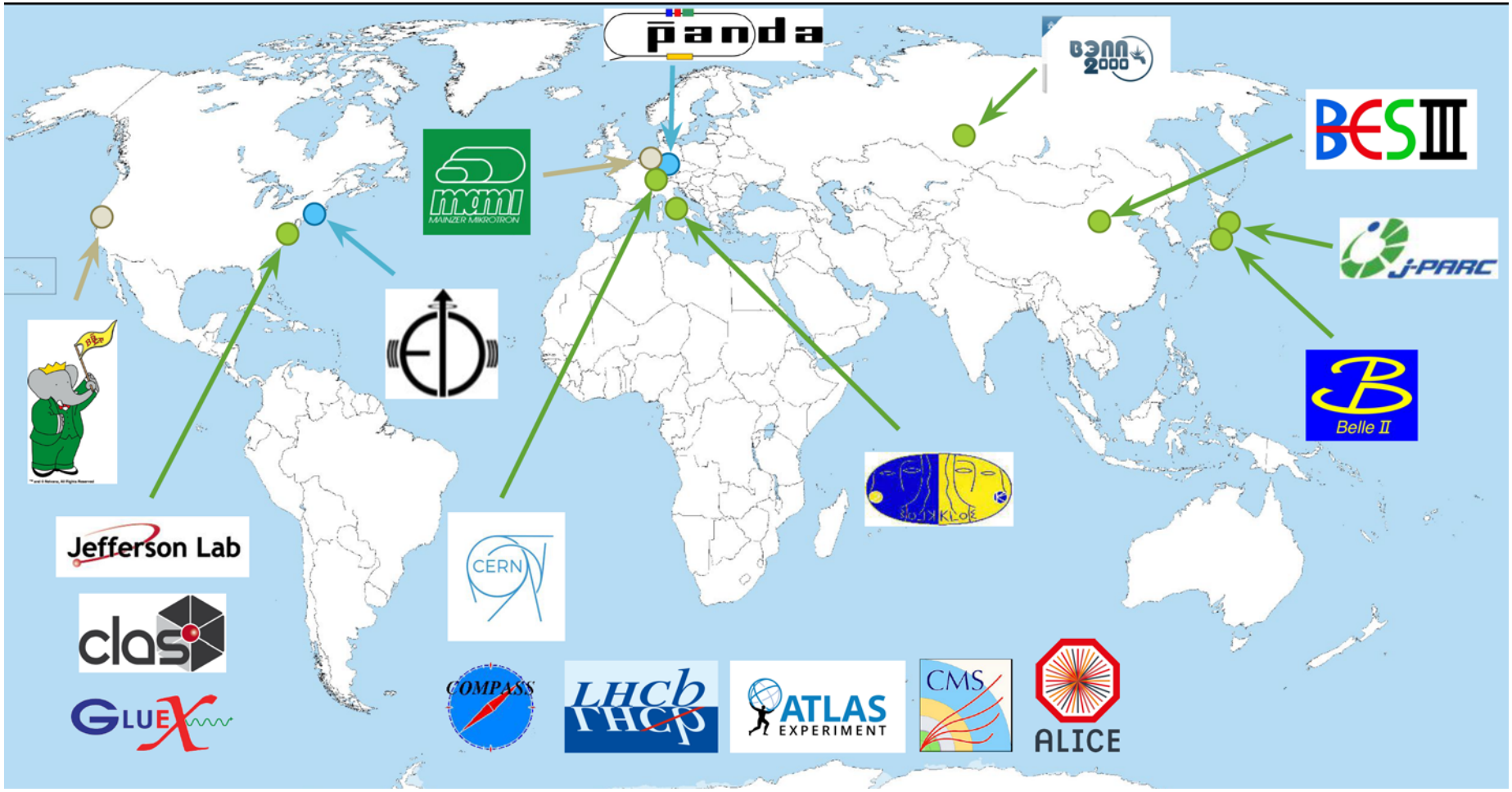
Heavy Baryon Spectroscopy

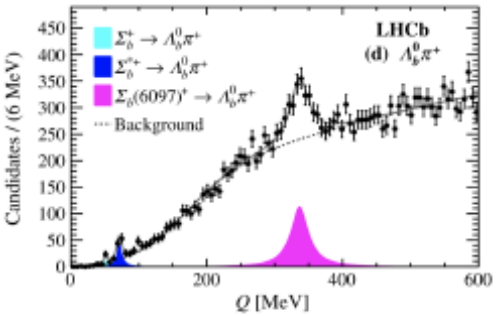
- Introduction
- Heavy baryons
- Nonrelativistic CQM
- Mass spectra
- Radiative and strong decay widths
- Summary and conclusions

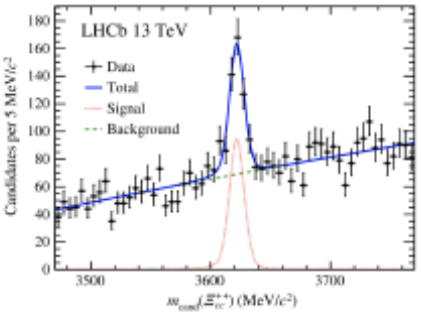
HADRON 2023

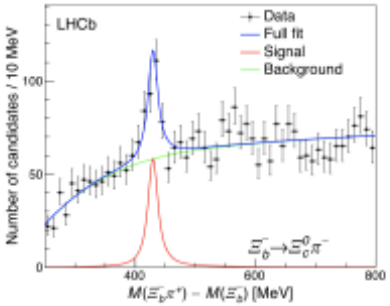

panda
BESIII
j-PARC
Belle II
Jefferson Lab
clas
GLUEX
CERN
COMPASS
LHCb
ATLAS
EXPERIMENT
CMS
ALICE

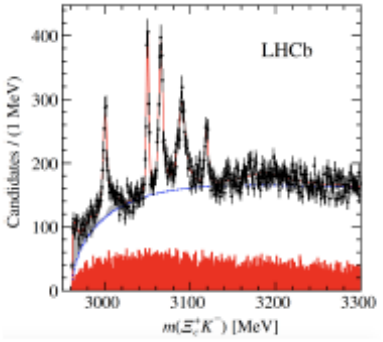
LHCb, Belle, BaBar, BESIII

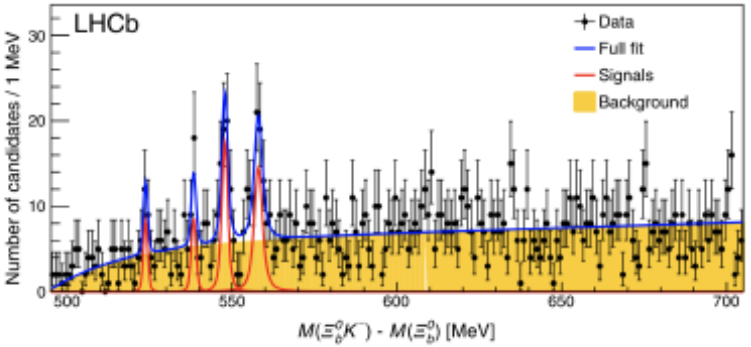
Observation of resonances with quark content c and b. [1] [2] [3]











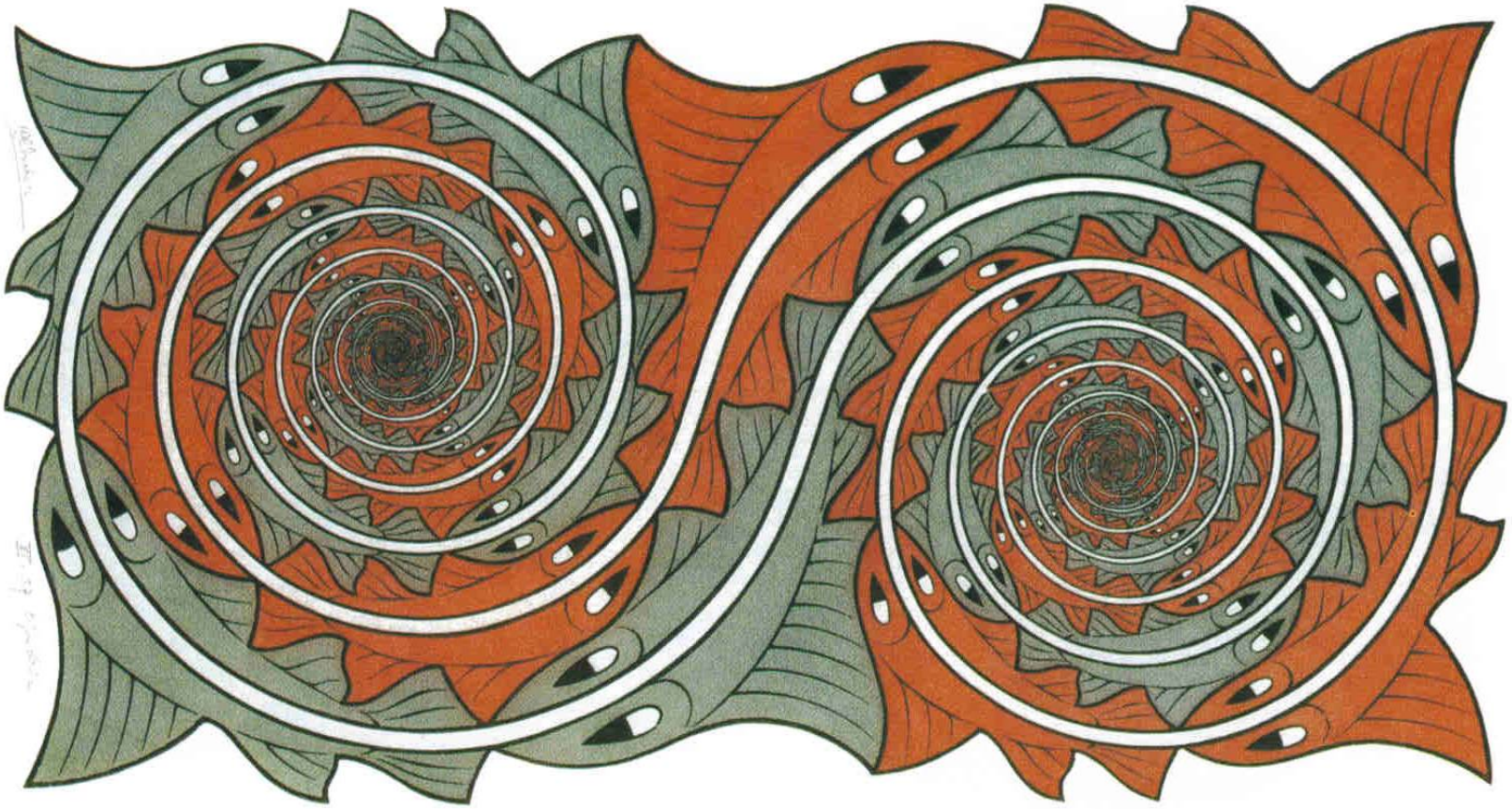
[1] R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. Lett. **122**, 012001 (2019), and **119**, 112001 (2017).

[2] R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. D **103**, 012004 (2021).

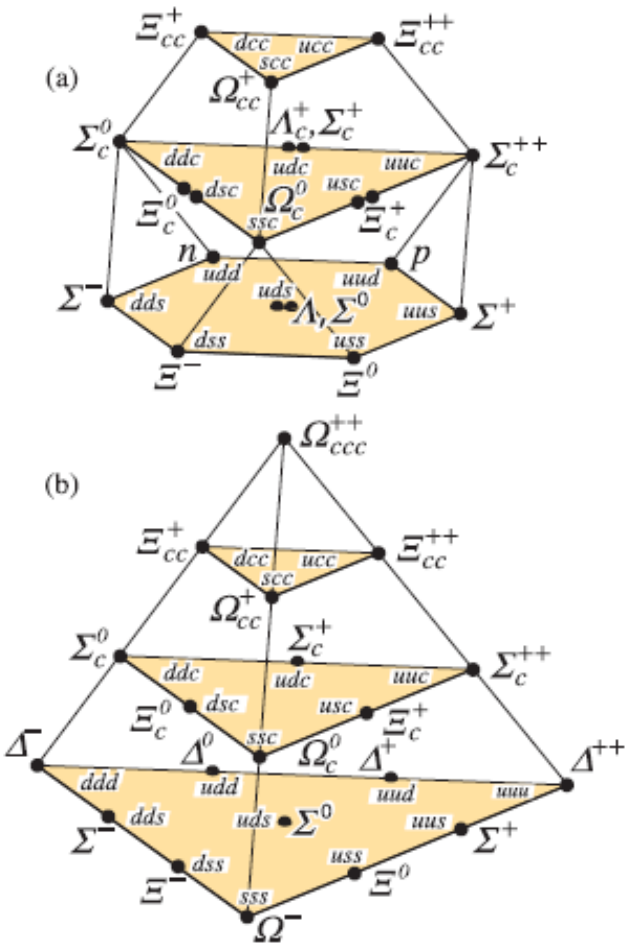
[3] R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. Lett. **118**, 182001 (2017), and **124**, 082002 (2020).

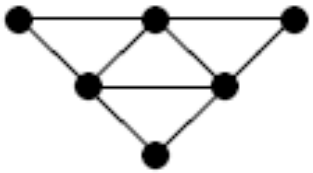
Theoretical Approaches

- Lattice QCD
- QCD sum rules
- Nonrelativistic QM
- Hypercentral QM
- Regge phenomenology
- Relativistic QM
- Chiral QM
- Harmonic oscillator QM



Flavor Multiplets



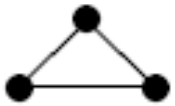


$[2] \equiv \mathbf{6}$

$\Sigma_Q(nnQ)$

$\Xi'_Q(nsQ)$

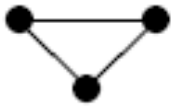
$\Omega_Q(ssQ)$



$[11] \equiv \bar{\mathbf{3}}$

$\Lambda_Q(nnQ)$

$\Xi_Q(nsQ)$



$[3] \equiv \mathbf{3}$

$\Xi_{QQ}(QQs)$

$\Omega_{QQ}(QQs)$

$[0] \equiv \mathbf{1}$

$\Omega_{QQQ}(QQQ)$

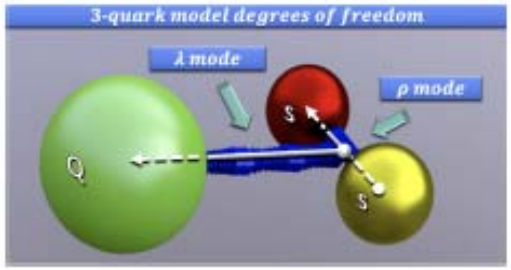
FIG. 1. Singly-heavy flavor sextet $\mathbf{6}$ and anti-triplet $\bar{\mathbf{3}}$, doubly-heavy flavor triplet $\mathbf{3}$ and triply-heavy singlet $\mathbf{1}$ configurations. Here n denotes the nonstrange light quarks $n = u$, d and Q the heavy quarks $Q = c$, b.

Harmonic Oscillator CQM

$$H = \frac{{p_1}^2}{2m} + \frac{{p_2}^2}{2m} + \frac{{p_3}^2}{2m'} + \frac{1}{2}C\sum_{i<j}^{3}|\vec{r}_i - \vec{r}_j|^2$$

- Jacobi coordinates

$$\begin{cases} \vec{\rho} = \frac{1}{\sqrt{2}}(\vec{r_1} - \vec{r_2}), \\ \vec{\lambda} = \frac{1}{\sqrt{6}}(\vec{r_1} + \vec{r_2} - 2\vec{r_3}) \\ \vec{R} = \frac{m(\vec{r_1}+\vec{r_2})+m'\vec{r_3}}{2m+m'} \end{cases}$$



$$H = \frac{{P_{CM}}^2}{2M} + \frac{{p_\rho}^2}{2m_\rho} + \frac{{p_\lambda}^2}{2m_\lambda} + \frac{3}{2}C\rho^2 + \frac{3}{2}C\lambda^2$$

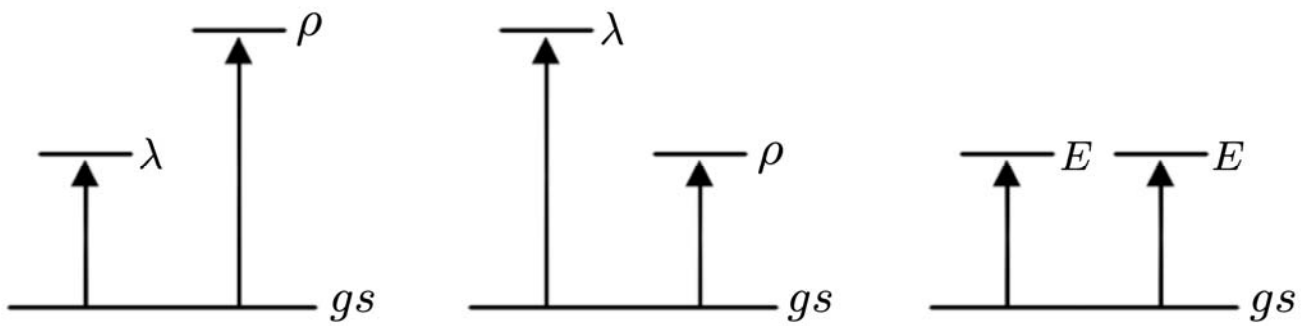
$$M = 2m + m', \qquad m_\rho \equiv m, \qquad m_\lambda \equiv \frac{3mm'}{2m+m'}$$

$$\alpha_i^2 = (3Cm_i)^{\frac{1}{2}}, \qquad \omega_i = \sqrt{\frac{3C}{m_i}}, \qquad i = \{\rho, \lambda\}.$$

$$H = H_{ho} + A\,\vec{S}^2 + B\,\vec{S}\cdot\vec{L} + E\,\vec{I}^2 + G\,C_{2SU_f(3)}$$

ρ– and λ-modes

$$E_{\mathrm{ho}} = \omega_\rho \left(n_\rho + \frac{3}{2}\right) + \omega_\lambda \left(n_\lambda + \frac{3}{2}\right)$$



qqQ
$m < m'$
$\omega_\lambda < \omega_\rho$

QQq
$m > m'$
$\omega_\lambda > \omega_\rho$

QQQ
$m = m'$
$\omega_\lambda = \omega_\rho$

Mass Spectra

$$
\begin{aligned}
M &= 2m + m' + \omega_\rho n_\rho + \omega_\lambda n_\lambda + A\, S(S+1) \\
&\quad + B\, \frac{1}{2}\,[J(J+1) - L(L+1) - S(S+1)] \\
&\quad + E\, I(I+1) + G\, \frac{1}{3}\,[p(p+3) + q(q+3) + pq] \,.
\end{aligned}
$$

$m_u = m_d$	291.53 ± 0.60	MeV
m_s	461.24 ± 0.73	MeV
m_c	1606.80 ± 1.01	MeV
m_b	4944.34 ± 1.62	MeV

	$Q = c$	$Q = b$	
C	0.02712 ± 0.00008	0.02377 ± 0.00014	GeV^3
A	22.08 ± 0.19	7.37 ± 0.25	MeV
B	21.84 ± 0.28	4.33 ± 0.55	MeV
E	30.47 ± 0.40	35.68 ± 0.61	MeV
G	56.19 ± 0.34	61.77 ± 0.28	MeV

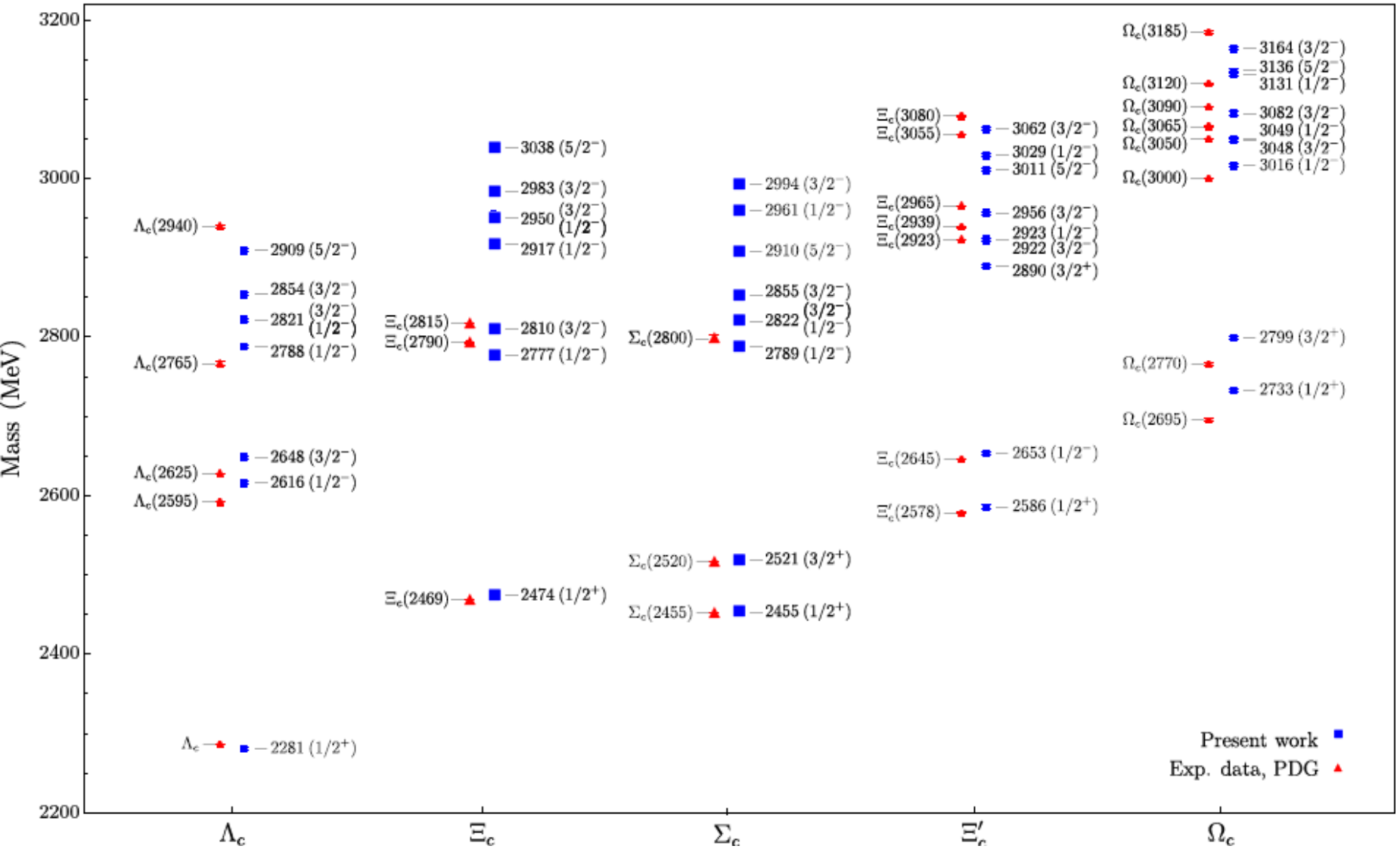
Fit to 41 heavy baryon masses:
25 single charm,
15 single bottom,
1 double charm

Maximum likelihood estimation technique

Rms deviation
19 MeV

Ortiz-Pacheco & Bijker
Submitted (2023)

Single charm baryons



Equal Spacing Mass Rules

$$M(\Omega_c(3050)^0) - M(\Xi_c(2923)^0)$$
$$\simeq M(\Omega_c(3065)^0) - M(\Xi_c(2939)^0)$$
$$\simeq M(\Omega_c(3090)^0) - M(\Xi_c(2965)^0)$$
$$\simeq 125 \text{ MeV}$$

$$M(\Xi_c(2790)) - M(\Lambda_c(2595))$$
$$\simeq M(\Xi_c(2815)) - M(\Lambda_c(2625))$$
$$\simeq 195 \text{ MeV}$$

LHCb, PRL 124, 222001 (2020)

$$M(^{2S+1}\lambda(\Omega_Q)_J) - M(^{2S+1}\lambda(\Xi'_Q)_J)$$
$$= m_s - m_{u/d} + \omega_\lambda(\Omega_Q) - \omega_\lambda(\Xi'_Q) - \frac{3}{4}E$$
$$= \begin{cases} 126 \text{ MeV} & (Q = c) \\ 120 \text{ MeV} & (Q = b) \end{cases}$$

$$M(^2\lambda(\Xi_Q)_J) - M(^2\lambda(\Lambda_Q)_J)$$
$$= m_s - m_{u/d} + \omega_\lambda(\Xi_Q) - \omega_\lambda(\Lambda_Q) + \frac{3}{4}E$$
$$= \begin{cases} 161 \text{ MeV} & (Q = c) \\ 164 \text{ MeV} & (Q = b) \end{cases}$$

More ESMR

$$M(^{2S+1}\lambda(\Xi'_Q)_J) - M(^{2S+1}\lambda(\Sigma_Q)_J)$$

$$= m_s - m_{u/d} + \omega_\lambda(\Xi'_Q) - \omega_\lambda(\Sigma_Q) - \frac{5}{4}E = \begin{cases} 101 \text{ MeV} & (Q=c) \\ 93 \text{ MeV} & (Q=b) \end{cases}$$

$$M(^2\rho(\Omega_Q)_J) - M(^2\rho(\Xi'_Q)_J)$$

$$= m_s - m_{u/d} + \omega_\rho(\Omega_Q) - \omega_\rho(\Xi'_Q) - \frac{3}{4}E = \begin{cases} 102 \text{ MeV} & (Q=c) \\ 101 \text{ MeV} & (Q=b) \end{cases}$$

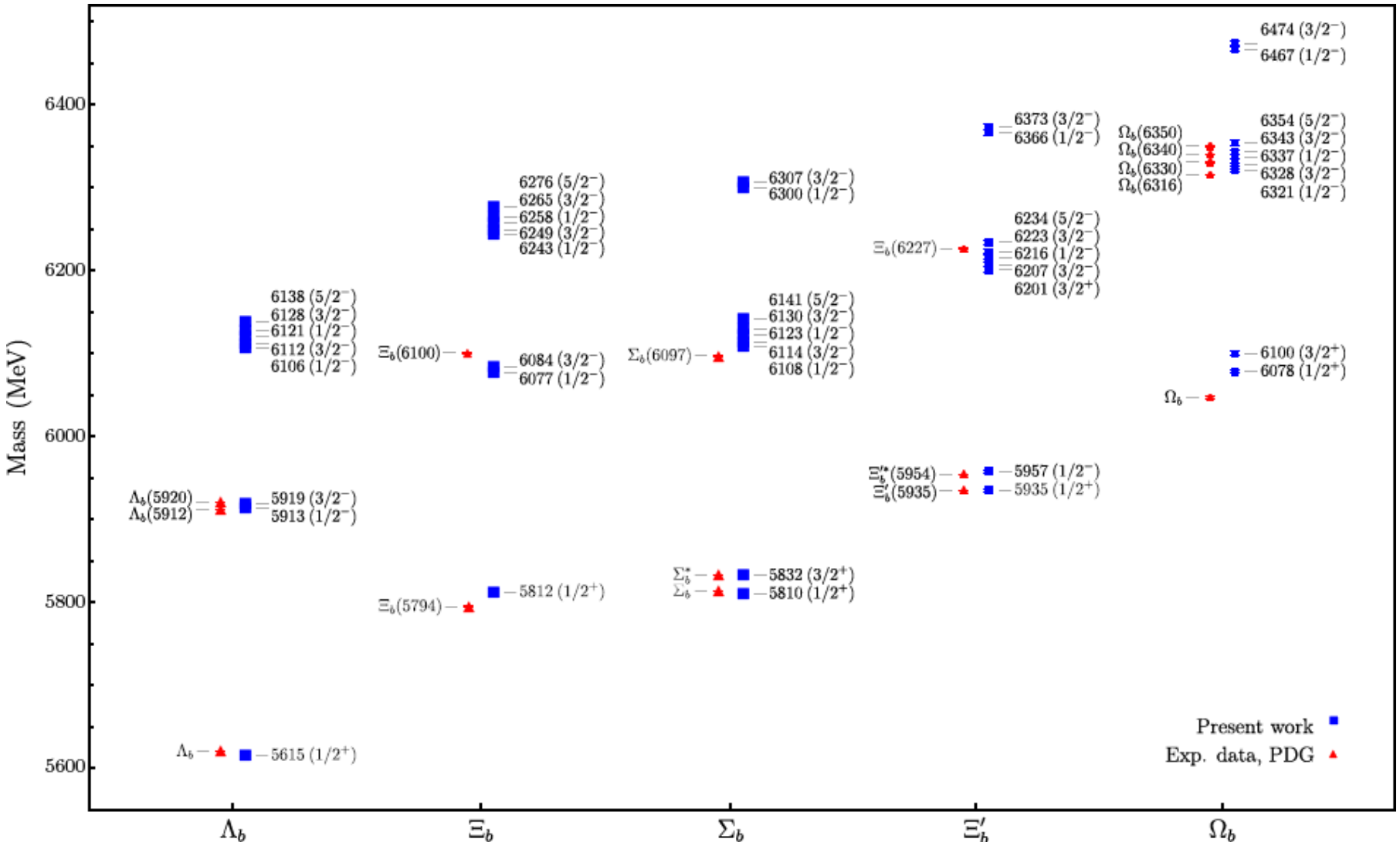
$$M(^2\rho(\Xi'_Q)_J) - M(^2\rho(\Sigma_Q)_J)$$

$$= m_s - m_{u/d} + \omega_\rho(\Xi'_Q) - \omega_\rho(\Sigma_Q) - \frac{5}{4}E = \begin{cases} 68 \text{ MeV} & (Q=c) \\ 66 \text{ MeV} & (Q=b) \end{cases}$$

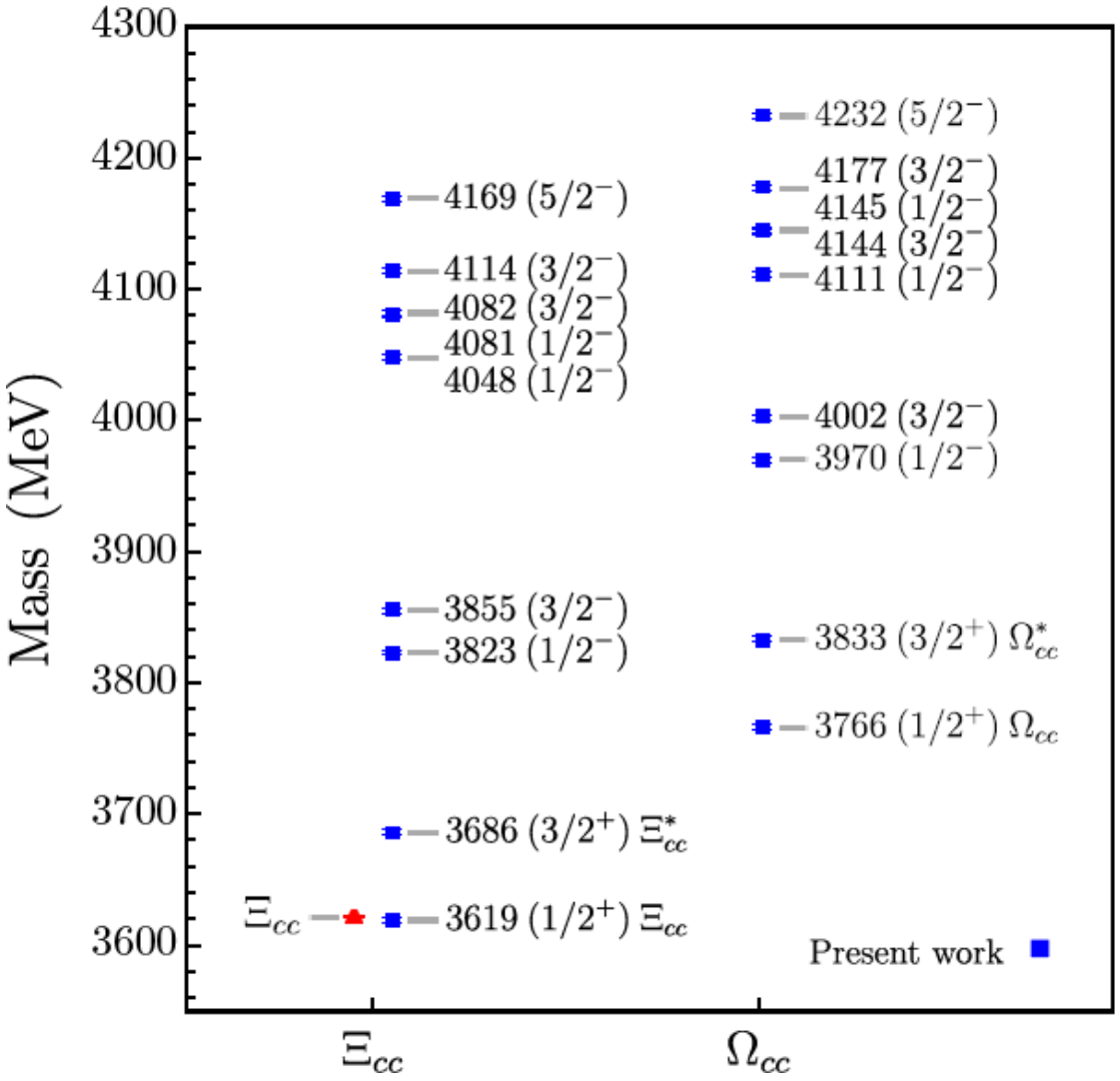
$$M(^{2S+1}\rho(\Xi_Q)_J) - M(^{2S+1}\rho(\Lambda_Q)_J)$$

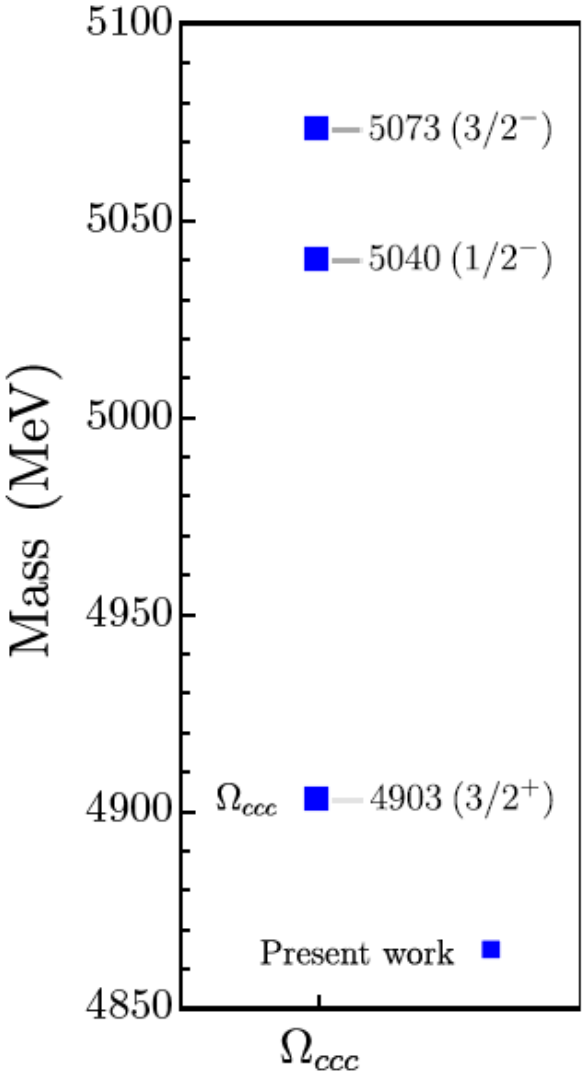
$$= m_s - m_{u/d} + \omega_\rho(\Xi_Q) - \omega_\rho(\Lambda_Q) + \frac{3}{4}E = \begin{cases} 129 \text{ MeV} & (Q=c) \\ 137 \text{ MeV} & (Q=b) \end{cases}$$

Single bottom baryons



Double and triple charm baryons





Equal Spacing Mass Rules

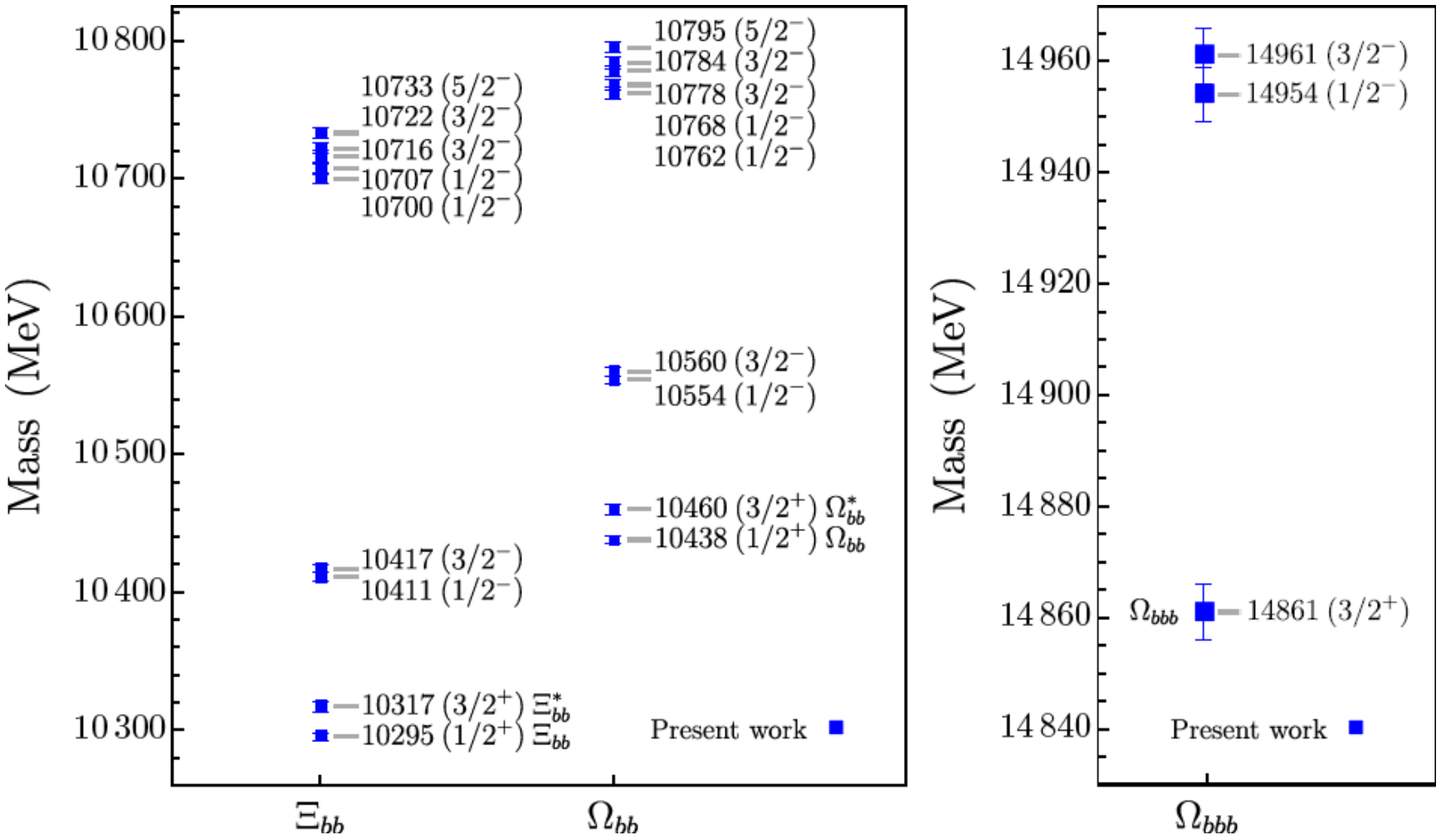
$$M(^{2S+1}\lambda(\Omega_{QQ})_J) - M(^{2S+1}\lambda(\Xi_{QQ})_J)$$

$$= m_s - m_{u/d} + \omega_\lambda(\Omega_{QQ}) - \omega_\lambda(\Xi_{QQ}) - \frac{3}{4}E = \begin{cases} 63 \text{ MeV} & (Q = c) \\ 62 \text{ MeV} & (Q = b) \end{cases}$$

$$M(^{2}\rho(\Omega_{QQ})_J) - M(^{2}\rho(\Xi_{QQ})_J)$$

$$= m_s - m_{u/d} - \frac{3}{4}E = \begin{cases} 147 \text{ MeV} & (Q = c) \\ 143 \text{ MeV} & (Q = b) \end{cases}$$

Double and triple bottom baryons



Ground-State Charm Baryons

State	KR	LQCD	Present	Exp.
Λ_c	2286.5	2254(48)(31)	2281	2286.5(1)
Σ_c	2444.0	2474(41)(25)	2455	2453.5(1)
Σ_c^*	2507.7	2551(43)(25)	2521	2518.1(2)
Ξ_c	2475.3	2433(35)(30)	2474	2469.1(2)
Ξ_c'	2565.4	2574(37)(23)	2586	2578.5(4)
Ξ_c^*	2632.6	2648(38)(25)	2653	2645.6(2)
Ω_c	2692.1	2679(37)(20)	2733	2695.2(17)
Ω_c^*	2762.8	2755(37)(24)	2799	2765.9(20)
Ξ_{cc}	3627(12)	3610(23)(22)	3619	3621.6(4)
Ξ_{cc}^*	3690(12)	3692(28)(21)	3686	
Ω_{cc}		3738(20)(20)	3766	
Ω_{cc}^*		3822(20)(22)	3833	
Ω_{ccc}		4796(8)(18)	4903	

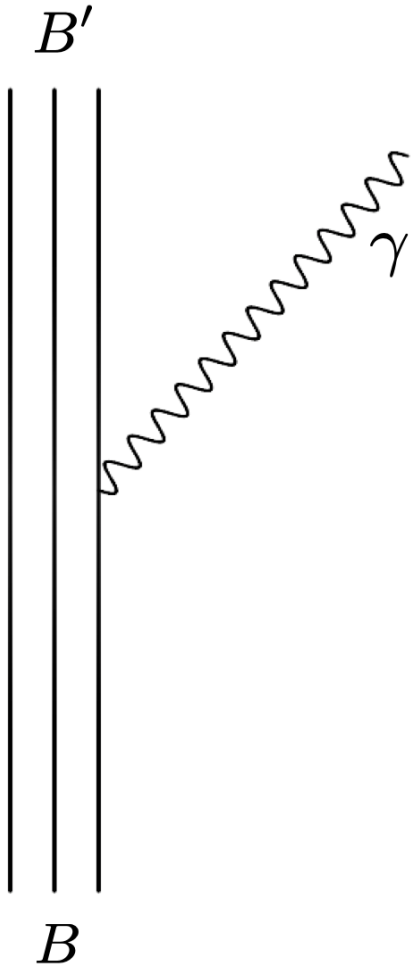
KR: Karliner & Rosner, PRD 90, 094007
LQCD: Brown et al., PRD 90, 094507

Ground-State Bottom Baryons

State	KR	LQCD	Present	Exp.
Λ_b	5619.4	5626(52)(29)	5615	5619.6(2)
Σ_b	5805.1	5856(56)(27)	5810	5813.1(2)
Σ_b^*	5826.7	5877(55)(27)	5832	5832.5(2)
Ξ_b	5801.5	5771(41)(24)	5812	5794.5(4)
Ξ_b'	5921.3	5933(47)(24)	5935	5935.0(1)
Ξ_b^*	5944.1	5960(47)(25)	5957	5953.8(3)
Ω_b	6042.8	6056(47)(20)	6078	6045.2(12)
Ω_b^*	6066.7	6085(47)(20)	6100	
Ξ_{bb}	10162(12)	10143(30)(23)	10295	
Ξ_{bb}^*	10184(12)	10178(30)(24)	10317	
Ω_{bb}		10273(27)(20)	10438	
Ω_{bb}^*		10308(27)(21)	10460	
Ω_{bbb}		14366(9)(20)	14861	

KR: Karliner & Rosner, PRD 90, 094007
LQCD: Brown et al, PRD 90, 094507

Electromagnetic Couplings



$$\mathcal{H} = e \int d^3x \sum_q e_q \bar{q}(\vec{x}) \gamma^\mu q(\vec{x}) \, A_\mu(\vec{x})$$

$$\mathcal{H}_{\rm em} = 2\sqrt{\frac{\pi}{k_0}} \sum_{j=1}^{3} \mu_j \left[k s_{j,-} e^{-i\vec{k}\cdot\vec{r}_j} - \frac{1}{2g} \left(p_{j,-} e^{-i\vec{k}\cdot\vec{r}_j} + e^{-i\vec{k}\cdot\vec{r}_j} p_{j,-} \right) \right]$$

$$\Gamma(B \to B' + \gamma) = 2\pi\rho \frac{1}{(2\pi)^3} \frac{2}{2J+1} \sum_{\nu>0} |\mathcal{A}_\nu(k)|^2$$

$$\mathcal{A}_\nu(k) = \langle \psi_{B'}, J', \nu - 1 \,|\, \mathcal{H}_{\rm em} \,|\, \psi_B, J, \nu \rangle$$

Radiative Decay Widths

	Present	χQM	MB	LCQSR	RQM	Belle
$\Xi_c(2790)^+ \to {}^2\Xi_c^+\gamma$	7.4	4.6	249.6 ± 41.9	265 ± 106		< 350
$\Xi_c(2790)^0 \to {}^2\Xi_c^0\gamma$	202.5	263.0	119.3 ± 21.7	2.7 ± 0.8		800 ± 320
$\Xi_c(2815)^+ \to {}^2\Xi_c^+\gamma$	4.8	2.8			190 ± 5	< 80
$\Xi_c(2815)^0 \to {}^2\Xi_c^0\gamma$	292.6	292.0			497 ± 14	$320 \pm 45^{+45}_{-80}$

State	${}^2\Xi_c^+$	${}^2\Xi_c^0$	State	${}^2\Xi_c^+$	${}^2\Xi_c^0$
${}^2\lambda(\Xi_c')_{1/2}$	37.9	0.8	${}^2\lambda(\Xi_c)_{1/2}$	7.4	202.5
${}^2\lambda(\Xi_c')_{3/2}$	50.2	1.1	${}^2\lambda(\Xi_c)_{3/2}$	4.8	292.6
${}^4\lambda(\Xi_c')_{1/2}$	25.2	0.5	${}^4\lambda(\Xi_c)_{1/2}$	12.3	20.1
${}^4\lambda(\Xi_c')_{3/2}$	90.6	1.9	${}^4\lambda(\Xi_c)_{3/2}$	16.2	26.5
${}^4\lambda(\Xi_c')_{5/2}$	83.4	1.8	${}^4\lambda(\Xi_c)_{5/2}$	7.8	12.8
${}^2\rho(\Xi_c')_{1/2}$	709.5	15.0	${}^2\rho(\Xi_c)_{1/2}$	28.0	45.9
${}^2\rho(\Xi_c')_{3/2}$	760.5	16.1	${}^2\rho(\Xi_c)_{3/2}$	25.7	42.1

χQM: Wang et al, PRD 96. 116016 (2017)

MB: Gamermann et al, PRD 83, 074018 (2011)

LCQSR: Aliev et al, EPJC 79, 437 (2019)

RQM: Ivanov et al, PRD 60, 094002 (1999)

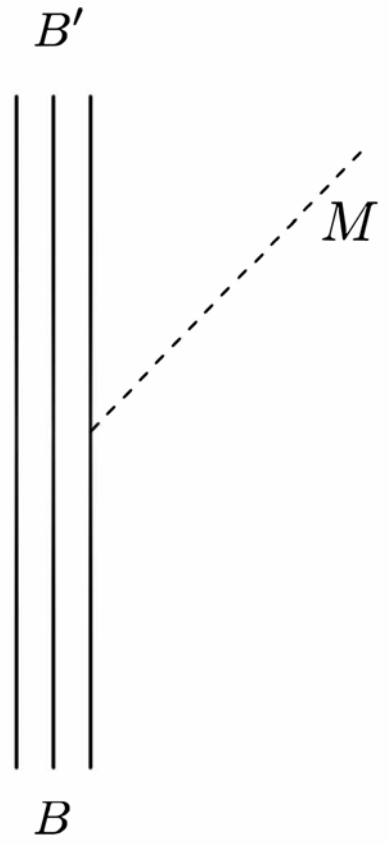
Belle: Yelton et al, PRD 102, 071103 (2020)

$B_Q \to B'_Q\gamma$	Present	LCQSR	BM	VMD	χQM	NRQM	HBχPT	RQM	hCQM		
${}^4\Sigma_c^{++} \to {}^2\Sigma_c^{++}\gamma$	2.1	2.65 ± 1.60	0.826	3.567	3.94	1.15	1.20		1.32	0.85	
${}^4\Sigma_c^{+} \to {}^2\Sigma_c^{+}\gamma$	0.0	0.40 ± 0.22	0.004	0.187	0.004	$< 10^{-4}$	0.04	0.14 ± 0.004	1×10^{-4}	9×10^{-5}	
${}^4\Sigma_c^{0} \to {}^2\Sigma_c^{0}\gamma$	1.8	0.08 ± 0.042	1.08	1.049	3.43	1.12	0.49		1.072	1.20	1.55
${}^2\Sigma_c^{+} \to {}^2\Lambda_c^{+}\gamma$	87.2	50.0 ± 17.0	46.1		80.60	60.55	65.6	60.7 ± 1.5	71.20	58.13	
${}^4\Sigma_c^{+} \to {}^2\Lambda_c^{+}\gamma$	199.4	130 ± 35	126	409.3	373	154.48	161.8	151 ± 4	171.9	143.97	213.3
${}^4\Xi_c^{\prime+} \to {}^2\Xi_c^{\prime+}\gamma$	0.1	0.274	0.011	0.485	0.004		0.07				
${}^4\Xi_c^{\prime0} \to {}^2\Xi_c^{\prime0}\gamma$	1.4	2.142	1.03	1.317	3.03		0.42				
${}^2\Xi_c^{\prime+} \to {}^2\Xi_c^{+}\gamma$	20.6	8.5 ± 2.5	10.2		42.3		5.43	12.7 ± 1.5			
${}^2\Xi_c^{\prime0} \to {}^2\Xi_c^{0}\gamma$	0.4	0.27 ± 0.06	0.0015		0.00		0.46	0.17 ± 0.002			
${}^4\Xi_c^{\prime+} \to {}^2\Xi_c^{+}\gamma$	74.2	52 ± 32	44.3	152.4	139	63.32	21.6	54 ± 3		17.48	
${}^4\Xi_c^{\prime0} \to {}^2\Xi_c^{0}\gamma$	1.6	0.66 ± 0.41	0.908	1.318	0.00	0.30	1.84	0.68 ± 0.04		0.45	0.91
${}^4\Omega_c^{0} \to {}^2\Omega_c^{0}\gamma$	1.0	0.932	1.07	1.439	0.89	2.02	0.32		0.34		1.44

$B_Q \to B'_Q\gamma$	Present	LCQSR	BM	VMD	χQM	NRQM	HBχPT
${}^4\Sigma_b^{+} \to {}^2\Sigma_b^{+}\gamma$	0.1	0.46 ± 0.28	0.054	0.137	0.25	0.08	0.05
${}^4\Sigma_b^{0} \to {}^2\Sigma_b^{0}\gamma$	0.0	0.028 ± 0.02	0.005	0.006	0.02	$< 10^{-3}$	3×10^{-3}
${}^4\Sigma_b^{-} \to {}^2\Sigma_b^{-}\gamma$	0.0	0.11 ± 0.076	0.01	0.040	0.06	0.01	0.013
${}^2\Sigma_b^{0} \to {}^2\Lambda_b^{0}\gamma$	128.1	152.0 ± 60.0	58.9		130	94.79	108.0
${}^4\Sigma_b^{0} \to {}^2\Lambda_b^{0}\gamma$	168.8	114 ± 62	81.1	221.5	335	128.62	142.1
${}^4\Xi_b^{\prime0} \to {}^2\Xi_b^{\prime0}\gamma$	0.0	0.131	0.004	0.281	5.19		1.5×10^{-3}
${}^4\Xi_b^{\prime-} \to {}^2\Xi_b^{\prime-}\gamma$	0.0	0.303	0.005	0.702	15.0		8.2×10^{-3}
${}^2\Xi_b^{\prime0} \to {}^2\Xi_b^{0}\gamma$	28.4	47.0 ± 21.0	14.7		84.6		13.0
${}^2\Xi_b^{\prime-} \to {}^2\Xi_b^{-}\gamma$	0.6	3.3 ± 1.3	0.118		0.00		1.0
${}^4\Xi_b^{\prime0} \to {}^2\Xi_b^{0}\gamma$	45.2	135 ± 85	24.7	270.8	104	18.79	17.2
${}^4\Xi_b^{\prime-} \to {}^2\Xi_b^{-}\gamma$	1.0	1.50 ± 0.095	0.278	2.246	0.00	0.09	1.4
${}^4\Omega_b^{-} \to {}^2\Omega_b^{-}\gamma$	0.0	0.092	0.006	2.873	0.1	0.03	0.031

LCQSR: Aliev
BM: Bernotas
VMD: Aliev
ChQM: K.-L. Wang
NRQM: Majethiya
HBChPT: G.-J. Wang
RQM: Ivanov
hCQM: Shah et al

Strong Couplings (EEM)



$$\mathcal{H}_S = \frac{1}{(2\pi)^{3/2}(2k_0)^{1/2}} \sum_{j=1}^{3} X_j^M \left[2g(\vec{s}_j \cdot \vec{k}) e^{-i\vec{k}\cdot\vec{r}_j} + h\vec{s}_j \cdot \left(\vec{p}_j e^{-i\vec{k}\cdot\vec{r}_j} + e^{-i\vec{k}\cdot\vec{r}_j} \vec{p}_j \right) \right]$$

$$\Gamma(B \to B' + M) = 2\pi\rho \frac{1}{(2\pi)^3} \frac{2}{2J+1} \sum_{\nu>0} |\mathcal{A}_\nu(k)|^2$$

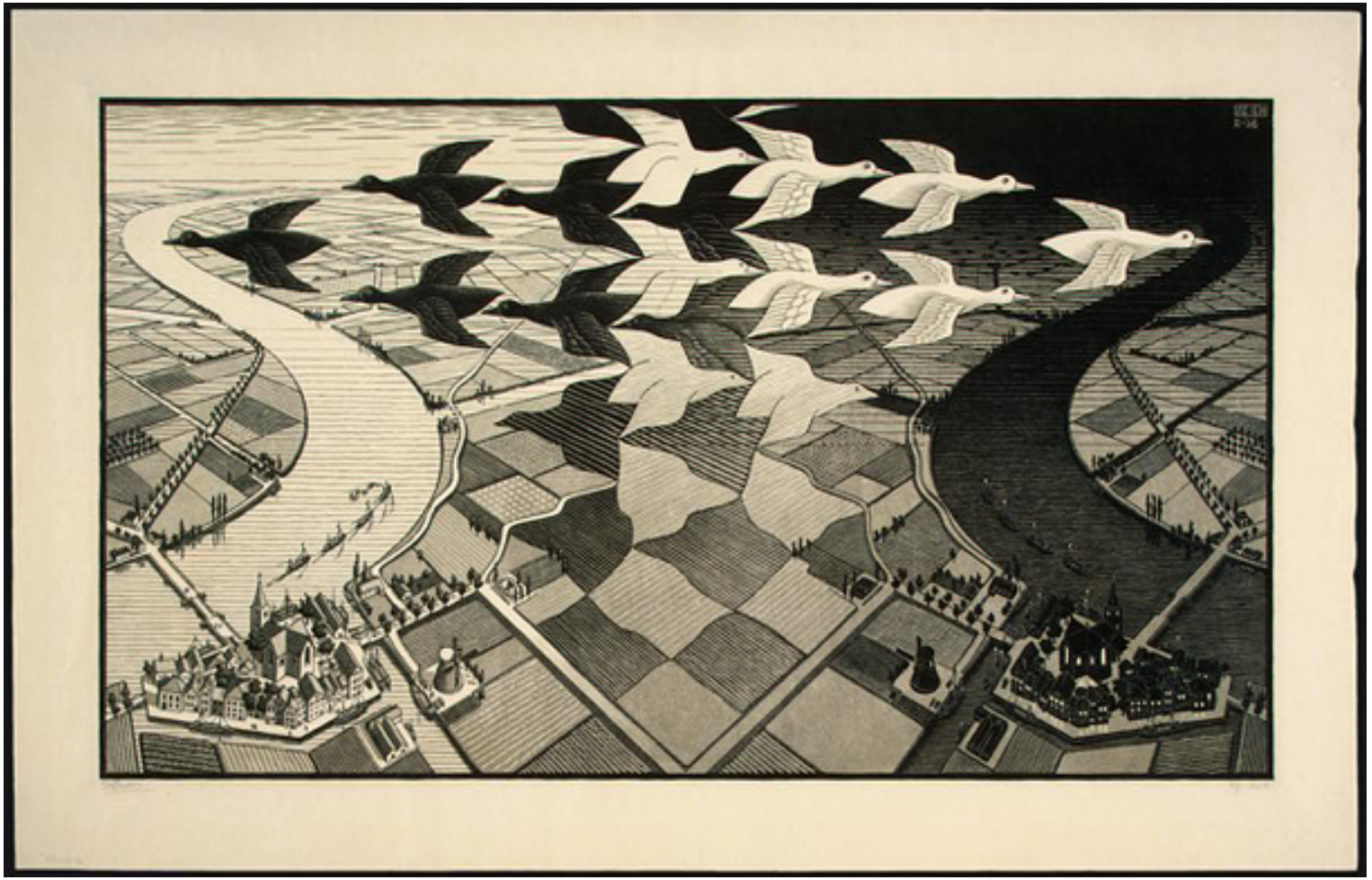
$$\mathcal{A}_\nu(k) = \langle \psi_{B'}, J', \nu \,|\, \mathcal{H}_S \,|\, \psi_B, J, \nu \rangle$$

Strong couplings

State	Present	ChQM	Exp	Γ_{tot}^{exp}(MeV)
$^2(\Sigma_c)_{1/2^+}$	0.57	...	$\Sigma_c(2455)$	1.86 ± 0.19
$^4(\Sigma_c)_{3/2^+}$	3.36	...	$\Sigma_c(2520)$	15.04 ± 0.45
$^2\lambda(\Sigma_c)_{1/2^-}$	3.55	22.65	$\Sigma_c(2800)$	69.67 ± 41
$^4\lambda(\Sigma_c)_{1/2^-}$	6.80	17.63		
$^2\lambda(\Sigma_c)_{3/2^-}$	11.82	36.5		
$^4\lambda(\Sigma_c)_{3/2^-}$	6.76	24.69		
$^4\lambda(\Sigma_c)_{5/2^-}$	17.08	33.22		
$^2\rho(\Sigma_c)_{1/2^-}$	19.40	...		
$^2\rho(\Sigma_c)_{3/2^-}$	21.34	...		
$^2(\Xi_c)_{1/2^+}$	–	...	$\Xi_c(2469)$	
$^2\lambda(\Xi_c)_{1/2^-}$	0.02	3.61	$\Xi_c(2790)$	9.5 ± 2.0
$^2\lambda(\Xi_c)_{3/2^-}$	0.22	2.11	$\Xi_c(2815)$	2.48 ± 0.5
$^2\rho(\Xi_c)_{1/2^-}$	2.87	...		
$^4\rho(\Xi_c)_{1/2^-}$	4.95	...		
$^2\rho(\Xi_c)_{3/2^-}$	9.69	...		
$^4\rho(\Xi_c)_{3/2^-}$	4.62	...		
$^4\rho(\Xi_c)_{5/2^-}$	16.64	...		
$^2(\Omega_c)_{1/2^+}$	–	...	$\Omega_c(2695)$	$< 10^{-7}$
$^4(\Omega_c)_{3/2^+}$	–	...	$\Omega_c(2770)$	
$^2\lambda(\Omega_c)_{1/2^-}$	1.92	4.38/4.28	$\Omega_c(3000)$	4.6 ± 0.6
$^4\lambda(\Omega_c)_{1/2^-}$	0.8*	–	$\Omega_c(3050)$	0.8 ± 0.2
$^2\lambda(\Omega_c)_{3/2^-}$	3.5*	4.96	$\Omega_c(3066)$	3.5 ± 0.4
$^4\lambda(\Omega_c)_{3/2^-}$	1.05	0.94	$\Omega_c(3090)$	8.7 ± 1.0
$^4\lambda(\Omega_c)_{5/2^-}$	16.83	9.53	$\Omega_c(3188)$	60 ± 26
$^2\rho(\Omega_c)_{1/2^-}$	6.28	...		
$^2\rho(\Omega_c)_{3/2^-}$	7.04	...		

Emmanuel Ortiz-Pacheco
Ph.D. thesis, UNAM (2021)

State	Present	$ChQM$	Exp	Γ_{tot}^{exp}(MeV)
$^2(\Lambda_c)_{1/2^+}$	–	...	Λ_c	
$^2\lambda(\Lambda_c)_{1/2^-}$	0.05	...	$\Lambda_c(2595)$	2.6 ± 0.6
$^2\lambda(\Lambda_c)_{3/2^-}$	0.06	...	$\Lambda_c(2625)$	< 0.97
$^2\rho(\Lambda_c)_{1/2^-}$	4.27	...		
$^4\rho(\Lambda_c)_{1/2^-}$	3.31	...		
$^2\rho(\Lambda_c)_{3/2^-}$	12.24	...		
$^4\rho(\Lambda_c)_{3/2^-}$	13.90	...	$\Lambda_c(2940)$	20 ± 6
$^4\rho(\Lambda_c)_{5/2^-}$	18.40	...		
$^2(\Xi_c')_{1/2^+}$	–	...	$\Xi_c'(2578)$	
$^4(\Xi_c')_{3/2^+}$	0.70	...	$\Xi_c(2645)$	2.25 ± 0.41
$^2\lambda(\Xi_c')_{1/2^-}$	0.96	21.67		
$^4\lambda(\Xi_c')_{1/2^-}$	2.01	37.05	$\Xi_c(2923)$	7.1 ± 2.0
$^2\lambda(\Xi_c')_{3/2^-}$	6.55	20.89	$\Xi_c(2939)$	10.2 ± 0.14
$^4\lambda(\Xi_c')_{3/2^-}$	2.12	12.33	$\Xi_c(2965)$	14.1 ± 1.6
$^4\lambda(\Xi_c')_{5/2^-}$	12.28	20.2		
$^2\rho(\Xi_c')_{1/2^-}$	6.13	...	$\Xi_c(3055)$	7.8 ± 1.9
$^2\rho(\Xi_c')_{3/2^-}$	12.14	...	$\Xi_c(3080)$	4.6 ± 3.3



Credits

- Santopinto, Giachino, Ferretti, García-Tecocoatzi, Bedolla, Bijker & Ortiz-Pacheco, EPJC 79, 1012 (2019)
- Emmanuel Ortiz-Pacheco, Ph.D. thesis, UNAM (2021)
- Bijker, García-Tecocoatzi, Giachino, Ortiz-Pacheco & Santopinto, PRD 105, 074029 (2022)
- Ortiz-Pacheco & Bijker, submitted (2023)

Summary and Conclusions

- Singly-, doubly and triply-heavy charm and bottom baryons
- Nonrelativistic HOQM
- Assignments based on energy systematics, radiative and strong decay widths
- Good overall agreement with exp data
- Equal spacing mass rules
- Missing 1P-wave states
- 2S-, 1D-wave states