Static properties of heavy baryons in a mean field approach

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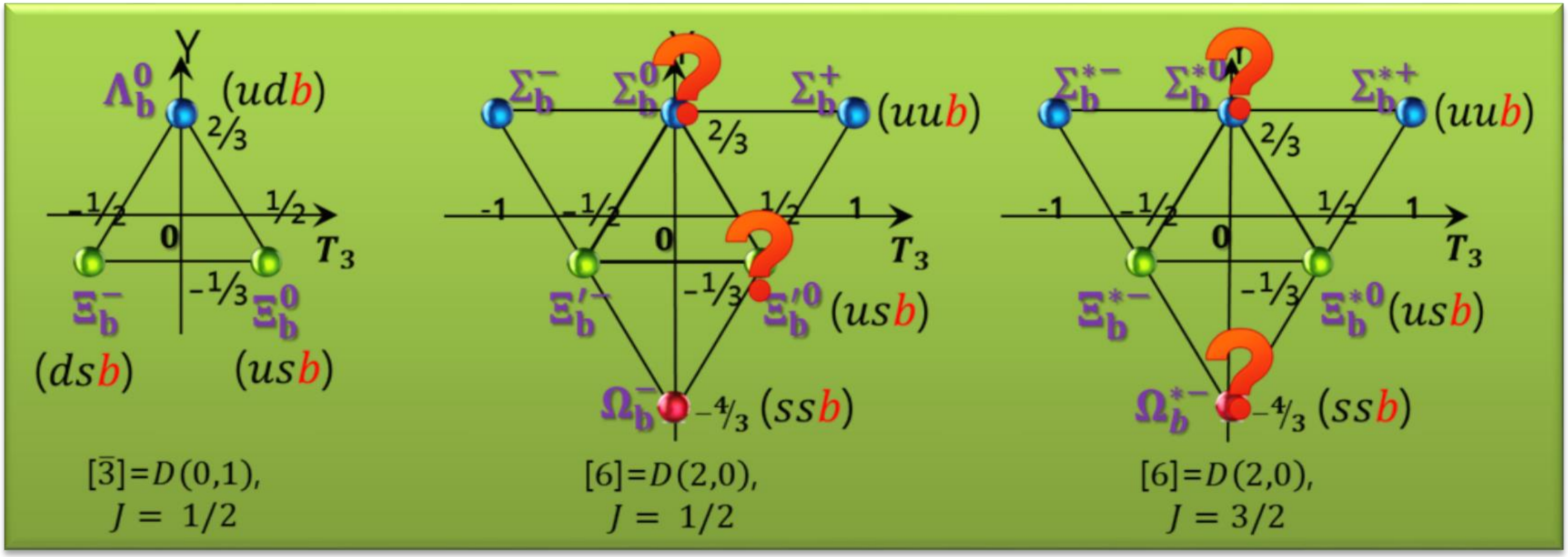
Outline

- Motivations
- Chiral Soliton Model for SU(3) baryons
  - Mean field picture
- Heavy baryon picture
  - Modification of Hamiltonian
- Numerical Results
  - **Masses** of Heavy baryons
  - **Decay widths** of Heavy baryons
- Summary and Outlook

Ref.: - Strong decays of exotic and nonexotic heavy baryons in the chiral quark-soliton model
(Phys.Rev. D96 (2017) 094021 arXiv:1709.04927 [hep-ph])

- Pion mean fields and heavy baryons
(Phys.Rev. D94 (2016) 071502 arXiv:1607.07089 [hep-ph])

Motivation



$$M_{\Xi_b} = 5948.9 \pm 0.8 \pm 1.2\,\mathrm{MeV}$$ CMS, PRL 108, 252002 (2012)

$$M_{\Xi_b'} = 5935.02 \pm 0.02 \pm 0.05\,\mathrm{MeV}$$

$$M_{\Xi_b^*} = 5955.33 \pm 0.12 \pm 0.05\,\mathrm{MeV}$$

LHCb, PRL 114 062004 (2015)

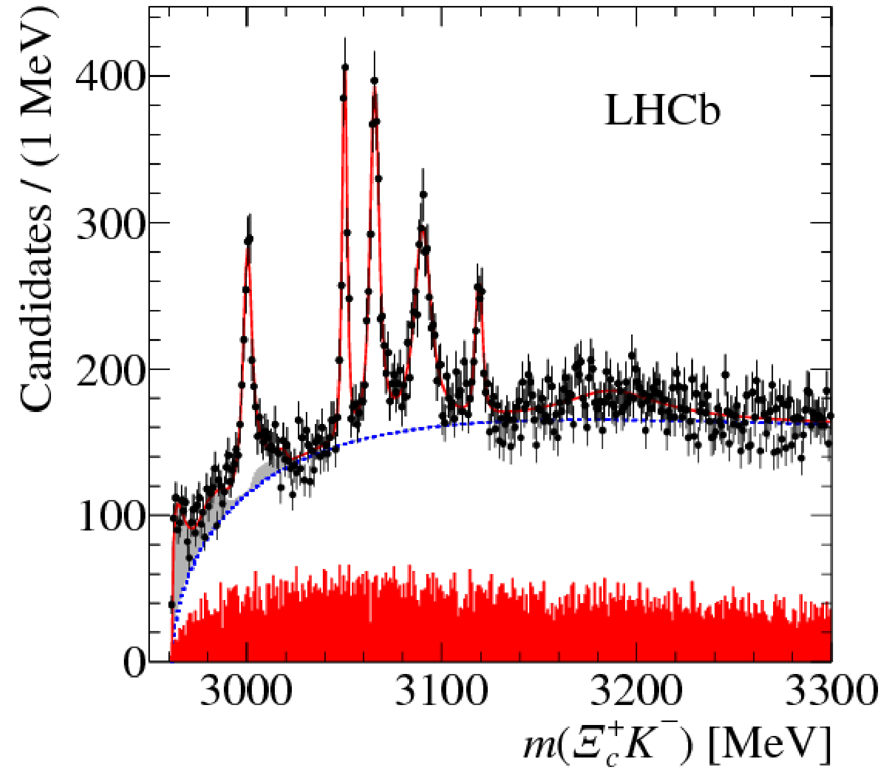
The masses of the low-lying bottom baryons are now much known with the help of LHC.

$\Sigma_c(2455)$ $I(J^P) = 1(\frac{1}{2}^+)$

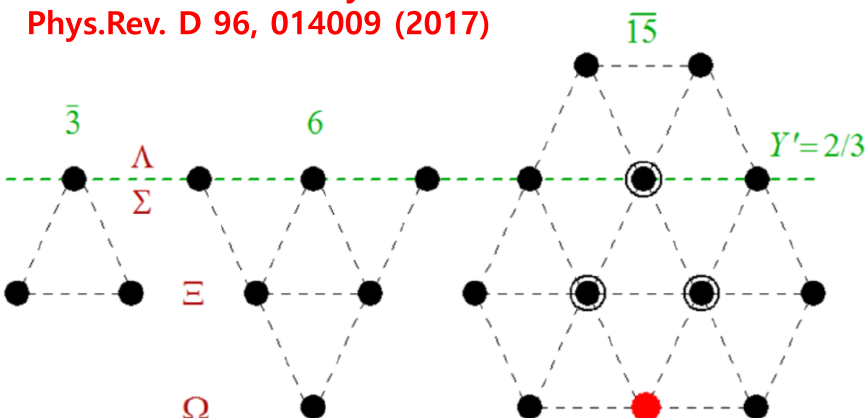
$\Sigma_c(2455)^{++}$ mass $m = 2453.97 \pm 0.14$ MeV
$\Sigma_c(2455)^{+}$ mass $m = 2452.9 \pm 0.4$ MeV
$\Sigma_c(2455)^{0}$ mass $m = 2453.75 \pm 0.14$ MeV
$m_{\Sigma_c^{++}} - m_{\Lambda_c^+} = 167.510 \pm 0.017$ MeV
$m_{\Sigma_c^{+}} - m_{\Lambda_c^+} = 166.4 \pm 0.4$ MeV
$m_{\Sigma_c^{0}} - m_{\Lambda_c^+} = 167.290 \pm 0.017$ MeV
$m_{\Sigma_c^{++}} - m_{\Sigma_c^0} = 0.220 \pm 0.013$ MeV
$m_{\Sigma_c^{+}} - m_{\Sigma_c^0} = -0.9 \pm 0.4$ MeV
$\Sigma_c(2455)^{++}$ full width $\Gamma = 1.89^{+0.09}_{-0.18}$ MeV (S = 1.1)
$\Sigma_c(2455)^{+}$ full width $\Gamma < 4.6$ MeV, CL = 90%
$\Sigma_c(2455)^{0}$ full width $\Gamma = 1.83^{+0.11}_{-0.19}$ MeV (S = 1.2)

$\Lambda_c^+\pi$ is the only strong decay allowed to a Σ_c having this mass.

$\Sigma_c(2455)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_c^+\pi$	≈ 100 %	94



H.-Ch. Kim, M. V. Polyakov, and M. Praszalowicz, Phys.Rev. D 96, 014009 (2017)



Resonance	Mass (MeV)	Γ (MeV)
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$
		<1.2 MeV, 95% C.L.
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$
		<2.6 MeV, 95% C.L.
$\Omega_c(3188)^0$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$
$\Omega_c(3066)^0_{\rm fd}$		
$\Omega_c(3090)^0_{\rm fd}$		

Ω_c^0: 2695.2, ±1.7, Ω_c^{*0}: 2765.9 ± 2.0

Observation of five new narrow Ω_c^0 states decaying to $\Xi_c^+ K^-$

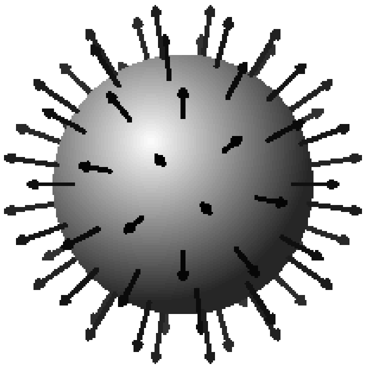
(Phys.Rev.Lett. 118 (2017) no.18, 182001)

Chiral Soliton Model for SU(3) baryons
- Mean field picture

: Effective and relativistic low energy theory

: **Large N_c limit : meson fields**
→ soliton

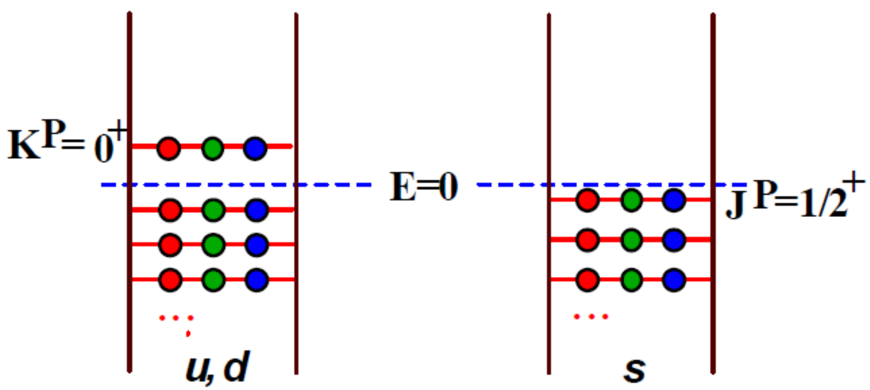
: Quantizing SU(3) rotated-meson fields
→ Collective Hamiltonian, model baryon states



hedgehog

Hedgehog Ansatz: $U_{\mathrm{SU}(2)} = \exp\left[i\gamma_5 \mathbf{n}\cdot\boldsymbol{\tau} P(r)\right]$

$$U_0 = \begin{bmatrix} e^{i\vec{n}\cdot\vec{\tau}P(r)} & 0 \\ 0 & 1 \end{bmatrix}$$



SU(2) E. Witten's imbedding into **SU(3)**: SU(2) X U(1)

The nucleon can be considered as a chiral soliton in the large Nc limit.

- Large-N_c world does not differ much from the real world with $N_c = 3$
- the N_c quarks constituting a baryon can be considered in a **mean (non-fluctuating) mesonic field**
  $\rightarrow$ all quark levels in the mean field are stable in N_c.

The model was successful in describing the structure of the nucleon.

Will this mean-field approach (large N_c limit) work also for heavy baryons as well as excited ones?

B_c, B_b ?

Diakonov, Petrov, Phys.Rev.D 69,056002, 2004, Diakonov, 1003.2157
Diakonov, Petrov, Vladimirov.PhysRevD.88.074030, 2013

Hamiltonian and baryon states

Collective Hamiltonian

$$H_{\mathrm{total}} = H_{\mathrm{cl}} + H_{\mathrm{rot}} + H_{\mathrm{sb}}$$

$$H_{\mathrm{rot}} = \frac{1}{2I_1}\sum_{i=1}^{3}\hat{J}_i^2 + \frac{1}{2I_2}\sum_{p=4}^{7}\hat{J}_p^2,$$

$$\begin{aligned} H_{\mathrm{sb}} &= (m_{\mathrm{s}} - \hat{m})\left(\alpha D_{88}^{(8)}(\mathcal{R}) + \beta\hat{Y} + \frac{1}{\sqrt{3}}\gamma\sum_{i=1}^{3} D_{8i}^{(8)}(\mathcal{R})\,\hat{J}_i\right) \\ &+ (m_{\mathrm{d}} - m_{\mathrm{u}})\left(\frac{\sqrt{3}}{2}\alpha D_{38}^{(8)}(\mathcal{R}) + \beta\hat{T}_3 + \frac{1}{2}\gamma\sum_{i=1}^{3} D_{3i}^{(8)}(\mathcal{R})\,\hat{J}_i\right) \end{aligned}$$

Model baryon state

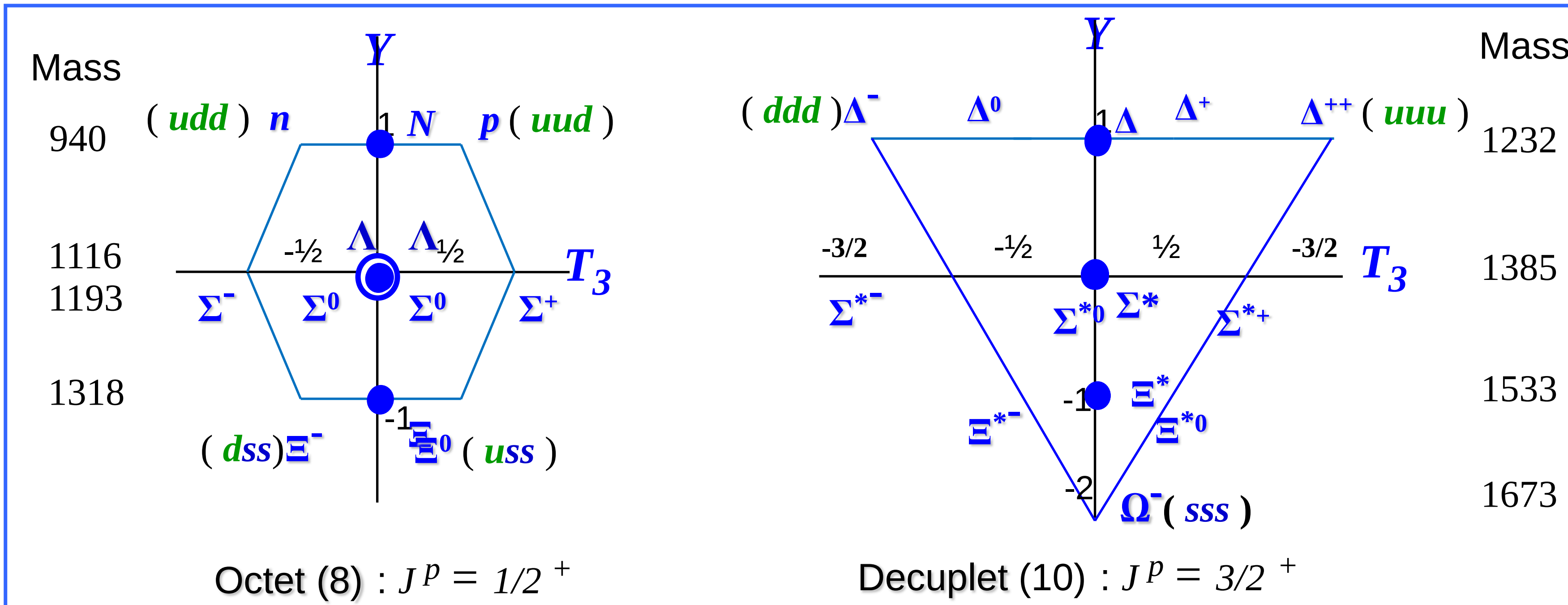
$$|B\rangle = \sqrt{\dim(\mathcal{R})}(-1)^{J_3+Y'/2} D_{(Y,T,T_3)(-Y',J,-J_3)}^{(\mathcal{R})*}$$

Constraint for the collective quantization : $Y' = -\frac{N_c B}{3}$

Collective Hamiltonian for flavor symmetry breakings

$$H_{\rm sb} = (m_{\rm s}-\hat{m})\left(\alpha D^{(8)}_{88}(\mathcal{R}) + \beta\,\hat{Y} + \frac{1}{\sqrt{3}}\gamma\sum_{i=1}^{3} D^{(8)}_{8i}(\mathcal{R})\,\hat{J}_i\right)$$

$$+ (m_{\rm d}-m_{\rm u})\left(\frac{\sqrt{3}}{2}\alpha D^{(8)}_{38}(\mathcal{R}) + \beta\,\hat{T}_3 + \frac{1}{2}\gamma\sum_{i=1}^{3} D^{(8)}_{3i}(\mathcal{R})\,\hat{J}_i\right)$$



SU(3) flavor symmetry breaking + Isospin symmetry breaking

Mass [MeV]		T_3	Y	Exp. input	Numerical results
M_N	p	$1/2$	1	938.27203 ± 0.00008	938.76 ± 3.65
	n	$-1/2$		939.56536 ± 0.00008	940.27 ± 3.64
M_Λ	Λ	0	0	1115.683 ± 0.006	1109.61 ± 0.70
M_Σ	Σ^+	1	0	1189.37 ± 0.07	1188.75 ± 0.70
	Σ^0	0		1192.642 ± 0.024	1190.20 ± 0.77
	Σ^-	-1		1197.449 ± 0.030	1195.48 ± 0.71
M_Ξ	Ξ^0	$1/2$	-1	1314.83 ± 0.20	1319.30 ± 3.43
	Ξ^-	$-1/2$		1321.31 ± 0.13	1324.52 ± 3.44

$$
\begin{aligned}
(m_d - m_u)\,\alpha &= -4.390 \pm 0.004, & (m_s - \hat{m})\,\alpha &= -255.029 \pm 5.821,\\
(m_d - m_u)\,\beta &= -2.411 \pm 0.001, & (m_s - \hat{m})\,\beta &= -140.040 \pm 3.195,\\
(m_d - m_u)\,\gamma &= -1.740 \pm 0.006, & (m_s - \hat{m})\,\gamma &= -101.081 \pm 2.332,
\end{aligned}
$$

$$M_\Delta = \overline{M}_{\mathbf{10}} + c^{(1)} + \frac{1}{4}\left(c^{(8)} + \frac{8}{63}c^{(27)}\right)T_3 + \frac{5}{63}c^{(27)}\,T_3^2 + \frac{1}{8}\left(c^{(8)} - \frac{2}{3}c^{(27)}\right)$$

$$-(m_d - m_u)\left(\delta_1 - \frac{3}{4}\delta_2\right)T_3 - (m_s - \hat{m})\left(\delta_1 - \frac{3}{4}\delta_2\right),$$

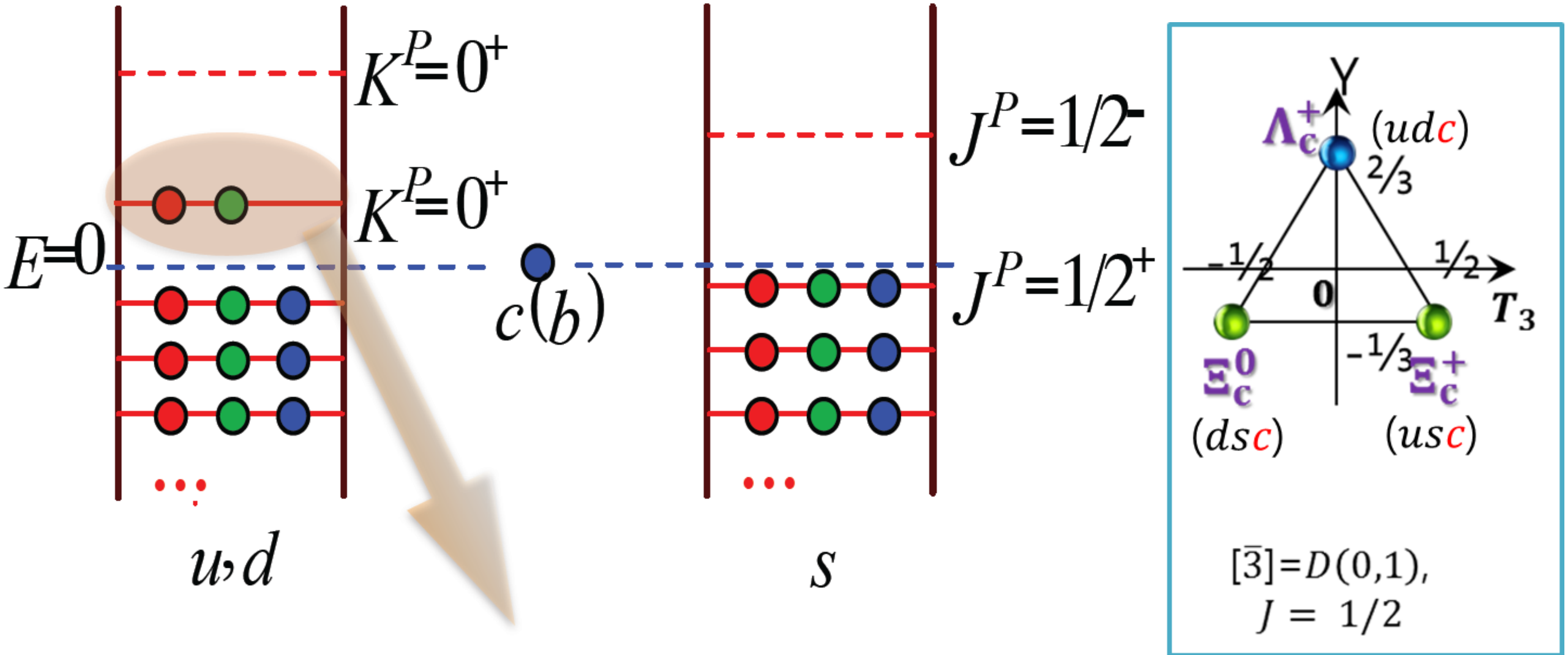
where $\delta_1 = -\frac{1}{5}\alpha - \beta + \frac{1}{5}\gamma, \quad \delta_2 = -\frac{1}{10}\alpha - \frac{3}{20}\gamma.$

Mass [MeV]		T_3	Y	Experiment[41)]	Predictions
M_Δ	Δ^{++}	$3/2$	1	$1231 - 1233$	1248.54 ± 3.39
	Δ^{+}	$1/2$			1249.36 ± 3.37
	Δ^{0}	$-1/2$			1251.53 ± 3.38
	Δ^{-}	$-3/2$			1255.08 ± 3.37
M_{Σ^*}	Σ^{*+}	1	0	1382.8 ± 0.4	1388.48 ± 0.34
	Σ^{*0}	0		1383.7 ± 1.0	1390.66 ± 0.37
	Σ^{*-}	-1		1387.2 ± 0.5	1394.20 ± 0.34
$M_{\Xi^{*0}}$	Ξ^{*0}	$1/2$	-1	1531.80 ± 0.32	1529.78 ± 3.38
	Ξ^{*-}	$-1/2$		1535.0 ± 0.6	1533.33 ± 3.37
$M^\star_{\Omega^-}$	Ω^-	0	-2	1672.45 ± 0.29	Input

G.S. Yang & HChK, Prog. Theor. Phys. 128,397(2012) ; Prog. Theor. Exp. Phys. 2013, 013D01

Heavy baryons

- Valence quarks are bound by the pion mean field.
- Light quarks govern a heavy-light quark system.
- Heavy quarks can be considered as merely static color sources.



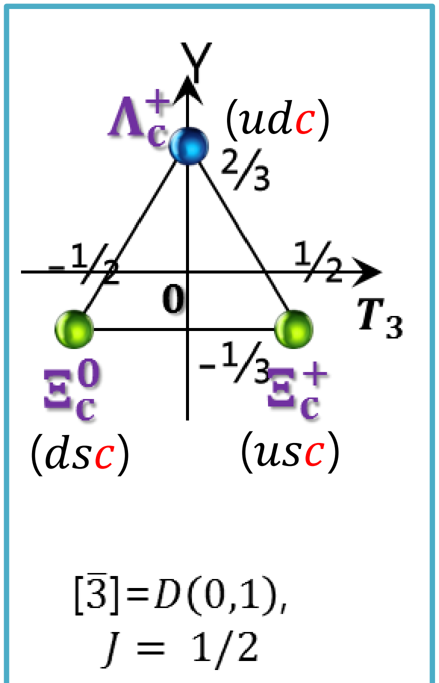
Meson mean field by ***N*c-1** valence quarks

Suggested by the late D. Diakonov

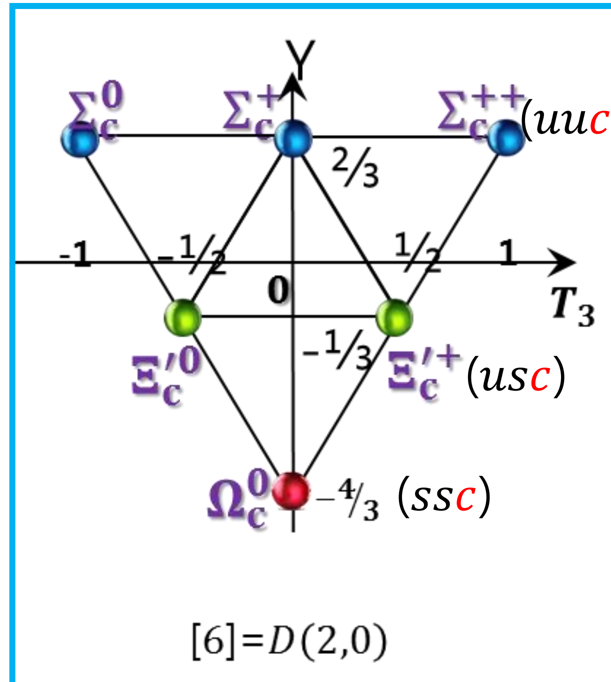
Heavy baryons

Weight diagram for charm baryons without heavy quark c

$$3 \otimes 3 = \bar{3} \oplus 6$$

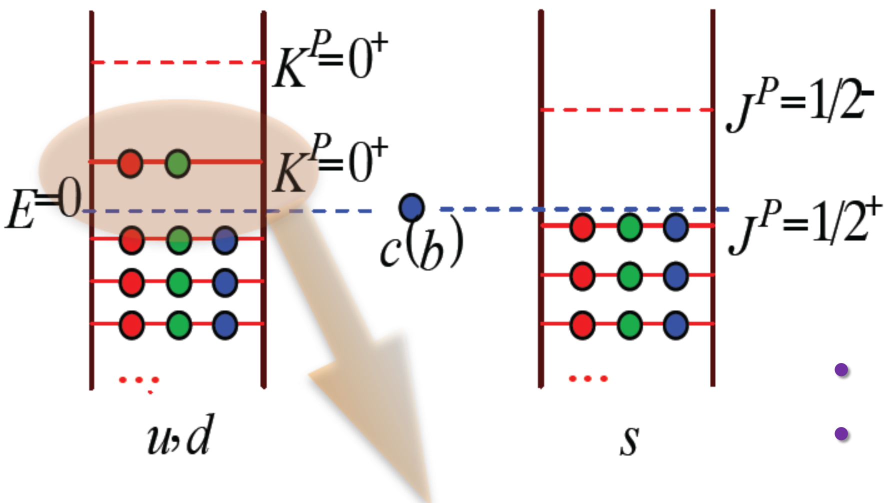


Anti-triplet



Sextet

Modification of the Hamiltonian I



- N_c-1 valence quarks in mean field
- Heavy quarks : static color sources

Moments of Inertia and Sigma pi-N term: sum over valence quark states:

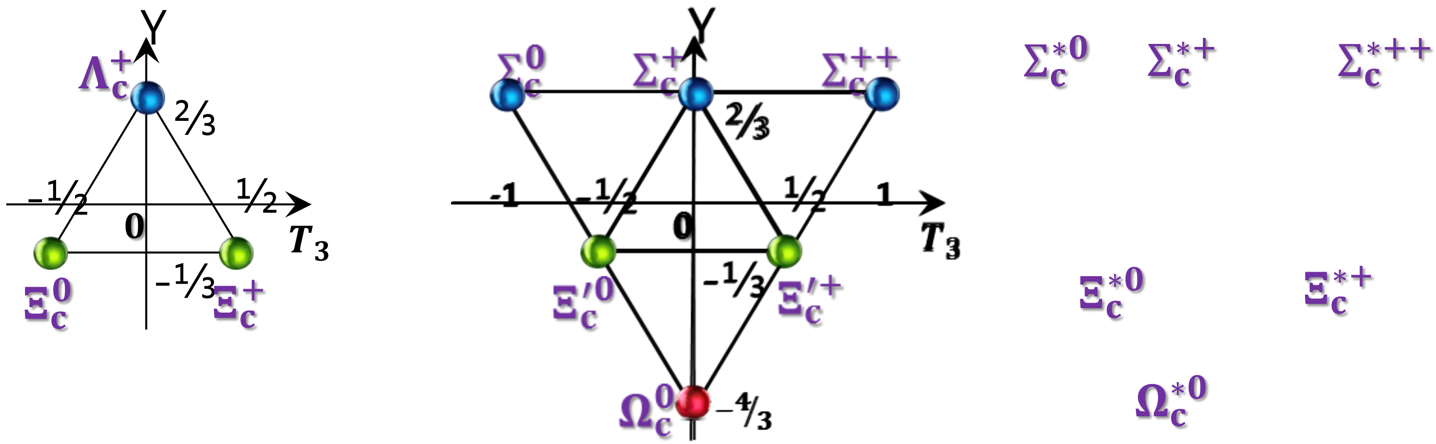
$$I_{1,2},\quad K_{1,2},\quad \Sigma_{\pi N} \longrightarrow \left(\frac{N_c-1}{N_c}\right) I_{1,2},\quad \left(\frac{N_c-1}{N_c}\right) K_{1,2},\quad \left(\frac{N_c-1}{N_c}\right) \Sigma_{\pi N},$$

$$\alpha = -\left(\frac{2}{3}\frac{\Sigma_{\pi N}}{m_u + m_d} - \frac{K_2}{I_2}\right),\quad \beta = -\frac{K_2}{I_2},\quad \gamma = 2\left(\frac{K_1}{I_1} - \frac{K_2}{I_2}\right)$$

Collective Hamiltonian for flavor symmetry breakings

$$H_{sb}^{m_s} = (m_s - \hat{m})\left[\left(\frac{N_c - 1}{N_c}\right)\alpha D_{88}^{(8)} + \beta\,\hat{Y} + \frac{1}{\sqrt{3}}\gamma \sum_{i=1}^{3} D_{8i}^{(8)}\,\hat{J}_i\right]$$

Modification of the Hamiltonian II



$[\bar{3}]=D(0,1)$, $J = 1/2$

$[6]=D(2,0)$,

$[6]=D(2,0)$, $J = 3/2$

Spin-spin interactions between masses of a **soliton** and a **heavy quark c** analogous to hyperfine splitting in electromagnetic interaction

$$\Delta M_{Q\cdot\mathrm{sol}}(J_Q,\ J_S) = \left\langle \mathcal{R},\ J_{\mathrm{sol}},\ J_Q \left| \frac{2}{3}\frac{\kappa}{m_Q\,M_{\mathrm{sol}}}\vec{J}_{\mathrm{sol}}\cdot\vec{J}_Q \right| \mathcal{R},\ J_{\mathrm{sol}},\ J_Q \right\rangle$$

$$= \begin{cases} 0 & \text{for } [\mathbf{\bar{3}}] \text{ with } J = 1/2, \\ -\frac{2}{3}\frac{\kappa}{m_Q\,M_{\mathrm{sol}}} = -\frac{2}{3}\kappa_Q & \text{for } [\mathbf{6}] \text{ with } J = 1/2, \\ \frac{1}{3}\frac{\kappa}{m_Q\,M_{\mathrm{sol}}} = \frac{1}{3}\kappa_Q & \text{for } [\mathbf{6}] \text{ with } J = 3/2. \end{cases}$$

$$M^Q_{\mathbf{6}_{3/2}} - M^Q_{\mathbf{6}_{1/2}} = \kappa_Q,$$

Expression for Heavy baryon mass

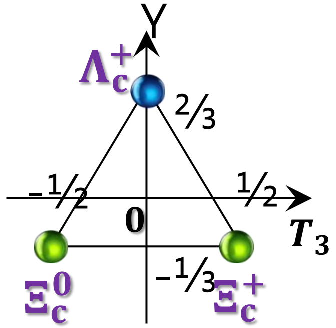
$\mathcal{R}_J$	B_Q	T	Y	m_{B_Q}
$\overline{\mathbf{3}}_{1/2}$	Λ_Q	0	$\frac{2}{3}$	$\xi_Q \frac{2}{3}\left(\frac{1}{4}\alpha+\beta\right)+M^Q_{\overline{\mathbf{3}}}$
	Ξ_Q	$\frac{1}{2}$	$-\frac{1}{3}$	$-\xi_Q \frac{1}{3}\left(\frac{1}{4}\alpha+\beta\right)+M^Q_{\overline{\mathbf{3}}}$
$\mathbf{6}_{1/2}$	Σ_Q	1	$\frac{2}{3}$	$\xi_Q \frac{2}{3}\left(\frac{1}{10}\alpha+\beta-\frac{3}{10}\gamma\right)-\frac{2}{3}\kappa_Q+M^Q_{\mathbf{6}}$
	Ξ'_Q	$\frac{1}{2}$	$-\frac{1}{3}$	$-\xi_Q \frac{1}{3}\left(\frac{1}{10}\alpha+\beta-\frac{3}{10}\gamma\right)-\frac{2}{3}\kappa_Q+M^Q_{\mathbf{6}}$
	Ω_Q	0	$-\frac{4}{3}$	$-\xi_Q \frac{4}{3}\left(\frac{1}{10}\alpha+\beta-\frac{3}{10}\gamma\right)-\frac{2}{3}\kappa_Q+M^Q_{\mathbf{6}}$
$\mathbf{6}_{3/2}$	Σ^*_Q	1	$\frac{2}{3}$	$\xi_Q \frac{2}{3}\left(\frac{1}{10}\alpha+\beta-\frac{3}{10}\gamma\right)+\frac{1}{3}\kappa_Q+M^Q_{\mathbf{6}}$
	Ξ^*_Q	$\frac{1}{2}$	$-\frac{1}{3}$	$-\xi_Q \frac{1}{3}\left(\frac{1}{10}\alpha+\beta-\frac{3}{10}\gamma\right)+\frac{1}{3}\kappa_Q+M^Q_{\mathbf{6}}$
	Ω^*_Q	0	$-\frac{4}{3}$	$-\xi_Q \frac{4}{3}\left(\frac{1}{10}\alpha+\beta-\frac{3}{10}\gamma\right)+\frac{1}{3}\kappa_Q+M^Q_{\mathbf{6}}$

$$\alpha=-\left(\frac{2}{3}\frac{\Sigma_{\pi N}}{m_u+m_d}-\frac{K_2}{I_2}\right), \quad \beta=-\frac{K_2}{I_2}, \quad \gamma=2\left(\frac{K_1}{I_1}-\frac{K_2}{I_2}\right)$$

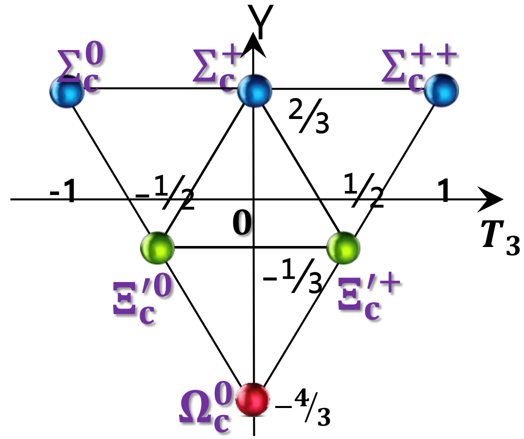
from light baryons !

No free parameters

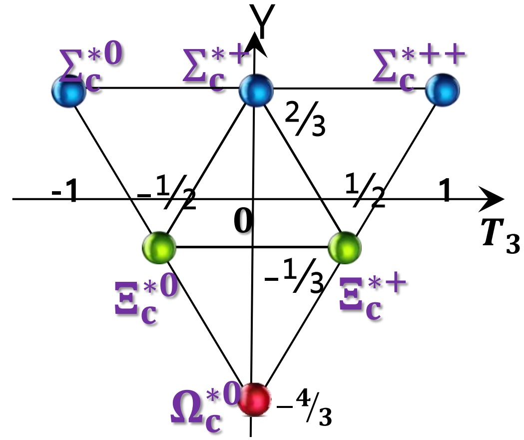
Numerical Results for Charmed baryons



$[\bar{3}]=D(0,1)$,
$J = 1/2$



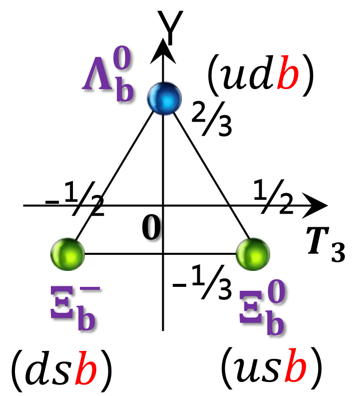
$[6]=D(2,0)$,
$J = 1/2$



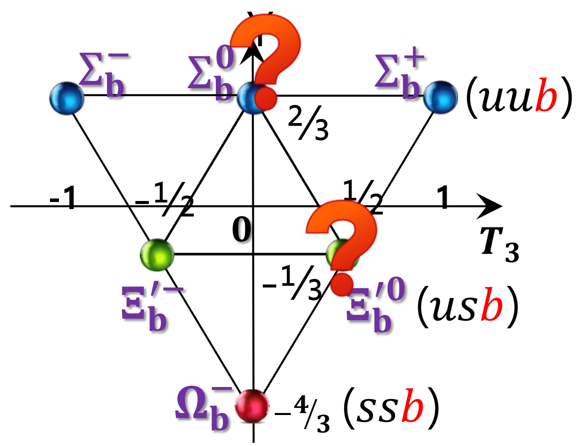
$[6]=D(2,0)$,
$J = 3/2$

$\mathcal{R}_J^Q$	B_c	Mass	Experiment [17]
$\bar{\mathbf{3}}_{1/2}^c$	Λ_c	2272.5 ± 2.3	2286.5 ± 0.1
	Ξ_c	2476.3 ± 1.2	2469.4 ± 0.3
$\mathbf{6}_{1/2}^c$	Σ_c	2445.3 ± 2.5	2453.5 ± 0.1
	Ξ_c'	2580.5 ± 1.6	2576.8 ± 2.1
	Ω_c	2715.7 ± 4.5	2695.2 ± 1.7
$\mathbf{6}_{3/2}^c$	Σ_c^*	2513.4 ± 2.3	2518.1 ± 0.8
	Ξ_c^*	2648.6 ± 1.3	2645.9 ± 0.4
	Ω_c^*	2783.8 ± 4.5	2765.9 ± 2.0

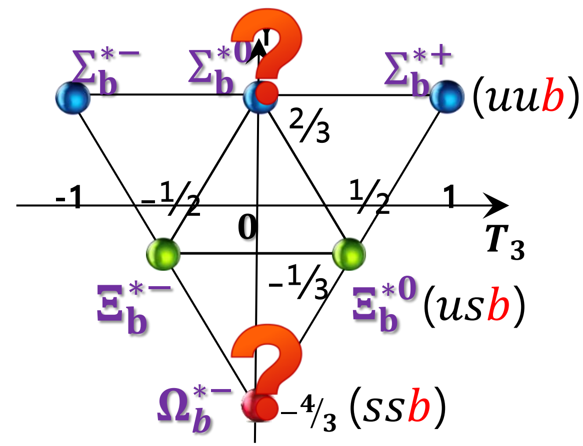
Numerical Results for Bottom baryons



$[\bar{3}]=D(0,1)$,
$J = 1/2$



$[6]=D(2,0)$,
$J = 1/2$

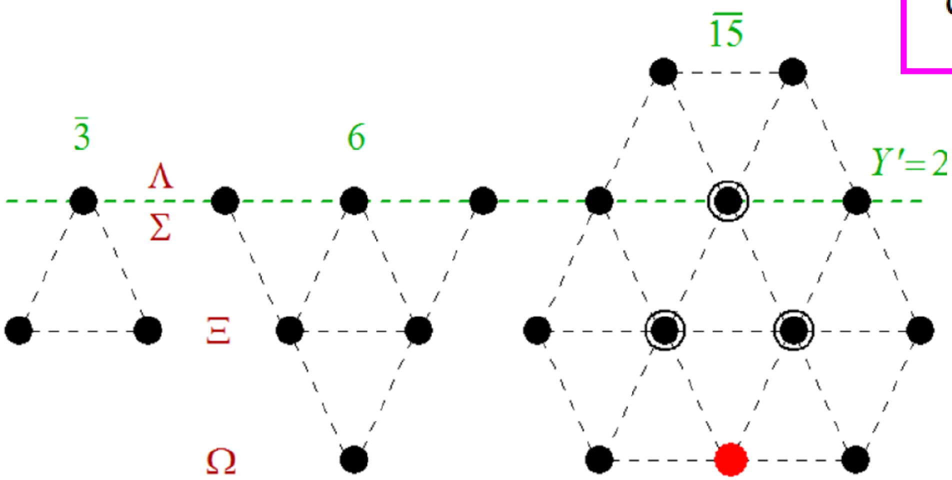


$[6]=D(2,0)$,
$J = 3/2$

$\mathcal{R}_J^Q$	B_b	Mass	Experiment [17]
$\bar{\mathbf{3}}_{1/2}^b$	Λ_b	5599.3 ± 2.4	5619.5 ± 0.2
	Ξ_b	5803.1 ± 1.2	5793.1 ± 0.7
$\mathbf{6}_{1/2}^b$	Σ_b	5804.3 ± 2.4	5813.4 ± 1.3
	Ξ_b'	5939.5 ± 1.5	5935.0 ± 0.05
	Ω_b	6074.7 ± 4.5	6048.0 ± 1.9
$\mathbf{6}_{3/2}^b$	Σ_b^*	5824.6 ± 2.3	5833.6 ± 1.3
	Ξ_b^*	5959.8 ± 1.2	5955.3 ± 0.1
	Ω_b^*	6095.0 ± 4.4	–

Decay widths of heavy baryons

$$\hat{\mathcal{O}}^{(0)}_{\varphi} = \tilde{a}_1 D^{(8)}_{\varphi 3} + a_2 d_{3bc} D^{(8)}_{\varphi b} \hat{J}_c + \frac{a_3}{\sqrt{3}} D^{(8)}_{\varphi 8} \hat{J}_3 .$$



$$a_1 = A_0 - \frac{B_1}{I_1}, \qquad a_2 = 2\frac{A_2}{I_2}, \qquad a_3 = 2\frac{A_1}{I_1}.$$

In NR limit

$$A_0 \to -N_c, \qquad \frac{B_1}{I_1} \to 2, \qquad \frac{A_2}{I_2} \to 2, \qquad \frac{A_1}{I_1} \to 1$$

$$a_1 \to -(N_c + 2), \qquad a_2 \to 4, \qquad a_3 \to 2.$$

In the NR limit ($a_1 \to -(N_c+2)$, $a_2 \to 4$, $a_3 \to 2$), the coupling constant of $\overline{10} \to 8$ becomes zero:

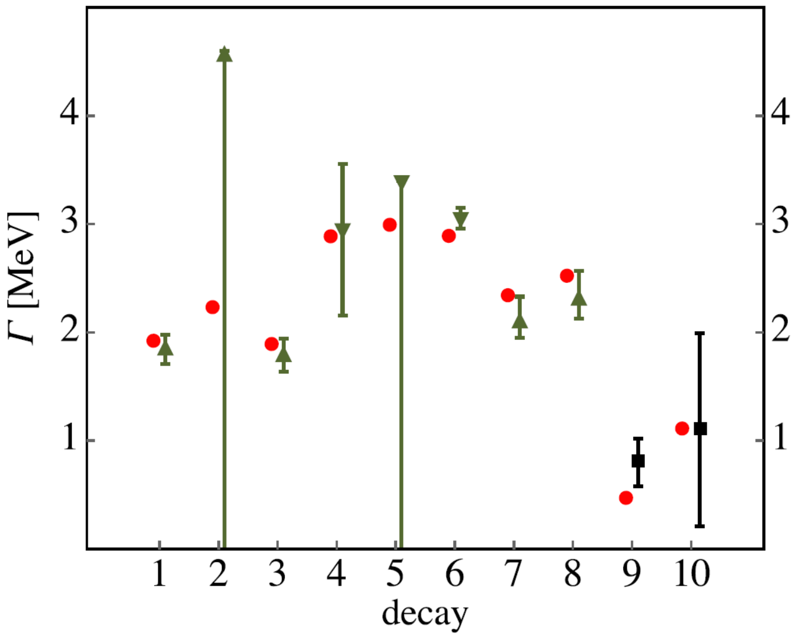
$$G_{\overline{10}} = -a_1 - a_2 - \frac{1}{2}a_3 \to (N_c + 2) - 4 - 1 = 0. \qquad (12)$$

The coupling constant of $\overline{\mathbf{15}}_1 \to \mathbf{6}_1$ in the NR limit and N_c-modification , G_6 is the same as $G_{\overline{10}}$:

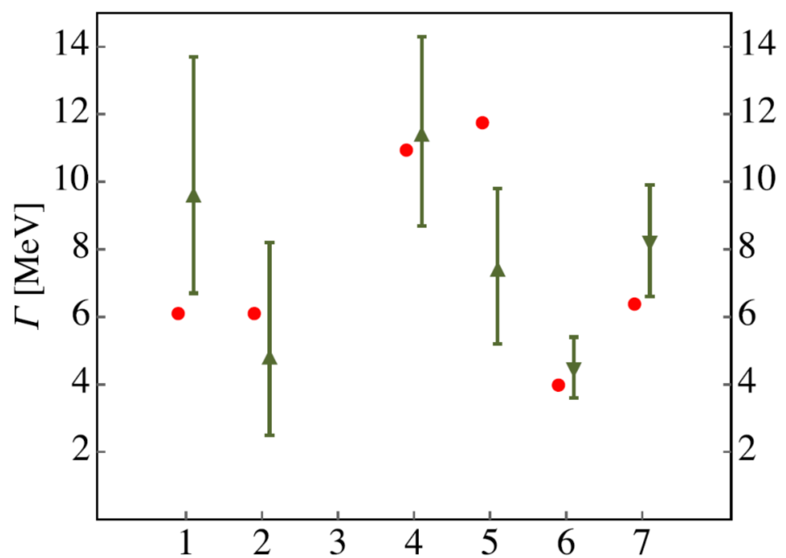
$$G_6 = -a_1 - \frac{1}{2}a_2 - a_3 \to [(N_c - 1) + 2] - 2 - 2 = 0. \qquad (13)$$

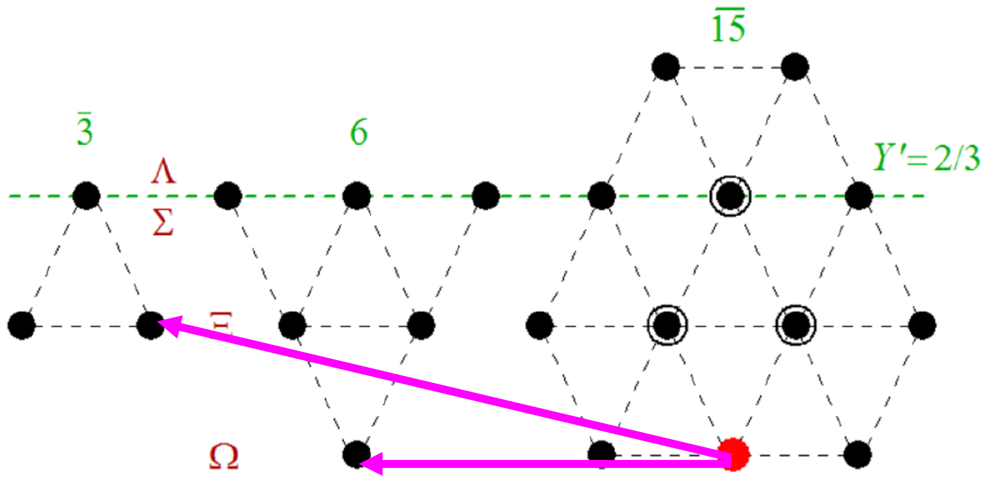
This might be the reason why symmetric contributions are very small comparing to those from $\mathcal{O}(m_s^1)$ for $\overline{\mathbf{15}}_1 \to \mathbf{6}_1$.

#	Decay	This work	Exp.
1	$\Sigma_c^{++}(\mathbf{6}_1, 1/2) \to \Lambda_c^{+}(\bar{\mathbf{3}}_0, 1/2) + \pi^+$	1.93	$1.89^{+0.09}_{-0.18}$
2	$\Sigma_c^{+}(\mathbf{6}_1, 1/2) \to \Lambda_c^{+}(\bar{\mathbf{3}}_0, 1/2) + \pi^0$	2.24	<4.6
3	$\Sigma_c^{0}(\mathbf{6}_1, 1/2) \to \Lambda_c^{+}(\bar{\mathbf{3}}_0, 1/2) + \pi^-$	1.90	$1.83^{+0.11}_{-0.19}$
4	$\Sigma_c^{++}(\mathbf{6}_1, 3/2) \to \Lambda_c^{+}(\bar{\mathbf{3}}_0, 1/2) + \pi^+$	▼ 14.47/5	$14.78^{+0.30}_{-0.19}$
5	$\Sigma_c^{+}(\mathbf{6}_1, 3/2) \to \Lambda_c^{+}(\bar{\mathbf{3}}_0, 1/2) + \pi^0$	▼ 15.02/5	<17
6	$\Sigma_c^{0}(\mathbf{6}_1, 3/2) \to \Lambda_c^{+}(\bar{\mathbf{3}}_0, 1/2) + \pi^-$	▼ 14.49/5	$15.3^{+0.4}_{-0.5}$
7	$\Xi_c^{+}(\mathbf{6}_1, 3/2) \to \Xi_c(\bar{\mathbf{3}}_0, 1/2) + \pi$	2.35	2.14 ± 0.19
8	$\Xi_c^{0}(\mathbf{6}_1, 3/2) \to \Xi_c(\bar{\mathbf{3}}_0, 1/2) + \pi$	2.53	2.35 ± 0.22



#	Decay	This work	Exp.
1	$\Sigma_b^{+}(\mathbf{6}_1, 1/2) \to \Lambda_b^{0}(\bar{\mathbf{3}}_0, 1/2) + \pi^+$	6.12	$9.7^{+4.0}_{-3.0}$
2	$\Sigma_b^{-}(\mathbf{6}_1, 1/2) \to \Lambda_b^{0}(\bar{\mathbf{3}}_0, 1/2) + \pi^-$	6.12	$4.9^{+3.3}_{-2.4}$
3	$\Xi_b'(\mathbf{6}_1, 1/2) \to \Xi_c(\bar{\mathbf{3}}_0, 1/2) + \pi$	0.07	<0.08
4	$\Sigma_b^{+}(\mathbf{6}_1, 3/2) \to \Lambda_b^{0}(\bar{\mathbf{3}}_0, 1/2) + \pi^+$	10.96	11.5 ± 2.8
5	$\Sigma_b^{-}(\mathbf{6}_1, 3/2) \to \Lambda_c^{0}(\bar{\mathbf{3}}_0, 1/2) + \pi^-$	11.77	7.5 ± 2.3
6	$\Xi_b^{0}(\mathbf{6}_1, 3/2) \to \Xi_b(\bar{\mathbf{3}}_0, 1/2) + \pi$	▼ 0.80× 5	0.90 ± 0.18
7	$\Xi_b^{-}(\mathbf{6}_1, 3/2) \to \Xi_b(\bar{\mathbf{3}}_0, 1/2) + \pi$	▼ 1.28× 5	1.65 ± 0.33

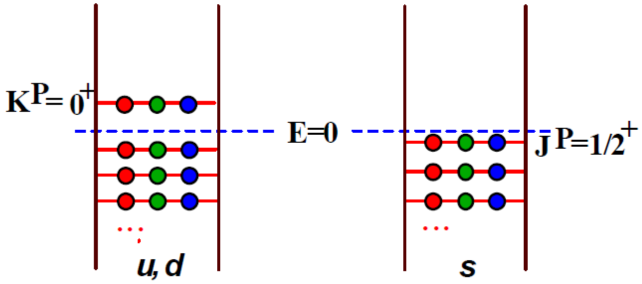




#	Decay	This work	Exp.(LHCb)
	$\Omega_c(\overline{\mathbf{15}}_1, 1/2) \to \Xi_c(\bar{\mathbf{3}}_0, 1/2) + K$	0.339	$\cdots$
	$\Omega_c(\overline{\mathbf{15}}_1, 1/2) \to \Omega_c(\mathbf{6}_1, 1/2) + \pi$	0.097	$\cdots$
	$\mathbf{6}_1, 3/2) + \pi$	0.045	$\cdots$
		0.48	$0.8 \pm 0.2 \pm 0.1$

Decay	$J = 1/2$	$J = 3/2$
$\Xi_c^{3/2}(\overline{\mathbf{15}}_1, J) \to \Xi_c(\bar{\mathbf{3}}_0, 1/2) + \pi$	1.67	2.49
$\Xi_c^{3/2}(\overline{\mathbf{15}}_1, J) \to \Xi_c(\mathbf{6}_1, 1/2) + \pi$	0.045	0.079
$\Xi_c^{3/2}(\overline{\mathbf{15}}_1, J) \to \Xi_c(\mathbf{6}_1, 3/2) + \pi$	0.022	0.046
$\Xi_c^{3/2}(\overline{\mathbf{15}}_1, J) \to \Sigma_c(\mathbf{6}_1, 1/2) + K$	$\cdots$	0.019
Total	1.74	2.64

#	Decay	This work	Exp. (LHCb)
	$\bar{\mathbf{3}}_0, 1/2) + K$	0.848	$\cdots$
	$\mathbf{6}_1, 1/2) + K$	0.009	$\cdots$
	$\Omega_c(\overline{\mathbf{15}}_1, 3/2) \to \Omega_c(\mathbf{6}_1, 1/2) + \pi$	0.169	$\cdots$
	$\Omega_c(\overline{\mathbf{15}}_1, 3/2) \to \Omega_c(\mathbf{6}_1, 3/2) + \pi$	0.096	$\cdots$
10	Total	1.12	$1.1 \pm 0.8 \pm 0.4$



$$\hat{g}_1^{(0)} = a_1\, D^{(8)}_{X3} + a_2 d_{pq3}\, D^{(8)}_{Xp}\, \hat{J}_q + \frac{a_3}{\sqrt{3}}\, D^{(8)}_{X8}\, \hat{J}_3,$$

$$\hat{g}_1^{(1)} = \frac{a_4}{\sqrt{3}}\, d_{pq3} D^{(8)}_{Xp}\, D^{(8)}_{8q} + a_5 \left(D^{(8)}_{X3}\, D^{(8)}_{88} + D^{(8)}_{X8}\, D^{(8)}_{83} \right) + a_6 \left(D^{(8)}_{X3}\, D^{(8)}_{88} - D^{(8)}_{X8}\, D^{(8)}_{83} \right),$$

$$\Psi^{(\mathcal{R}_J)}_{B_Q} = \sum C^{J\ J_3}_{J_{\rm sol} j_{\rm sol}; J_Q, j_Q}\, \chi_{j_Q}\, \psi^{(\mathcal{R})}_{B_Q(Y', J_{\rm sol}, j_{\rm sol})}$$
$$= C^{J\ J_3}_{J_{\rm sol},\, J_3-\frac{1}{2};\, \frac{1}{2},\, \frac{1}{2}}\, \chi_{\uparrow}\, \psi^{(\mathcal{R})}_{B_Q(Y', J_{\rm sol}, J_3-\frac{1}{2})} + C^{J\ J_3}_{J_{\rm sol},\, J_3+\frac{1}{2};\, \frac{1}{2},\, -\frac{1}{2}}\, \chi_{\downarrow}\, \psi^{(\mathcal{R})}_{B_Q(Y', J_{\rm sol}, J_3+\frac{1}{2})},$$

#	decay	Ref.[1]	$\Gamma^{(0)}_{\rm sol} = \Gamma^{(0)}_{\rm full}$	$\Gamma^{(0)}_{\rm sol} = \Gamma^{(\rm total)}_{\rm full}$	exp.
1	$\Sigma_c^{++}(\mathbf{6}_1, 1/2) \to \Lambda_c^+(\overline{\mathbf{3}}_0, 1/2) + \pi^+$	1.93	1.92 ± 0.03	2.06 ± 0.04	$1.89^{+0.09}$
2	$\Sigma_c^{+}(\mathbf{6}_1, 1/2) \to \Lambda_c^+(\overline{\mathbf{3}}$				
3	$\Sigma_c^{0}(\mathbf{6}_1, 1/2) \to \Lambda_c^+(\overline{\mathbf{3}}$				
4	$\Sigma_c^{++}(\mathbf{6}_1, 3/2) \to \Lambda_c^+($				
5	$\Sigma_c^{+}(\mathbf{6}_1, 3/2) \to \Lambda_c^+(\overline{\mathbf{3}}$				
6	$\Sigma_c^{0}(\mathbf{6}_1, 3/2) \to \Lambda_c^+(\overline{\mathbf{3}}$				
7	$\Xi_c^{+}(\mathbf{6}_1, 3/2) \to \Xi_c(\overline{\mathbf{3}}$				
8	$\Xi_c^{0}(\mathbf{6}_1, 3/2) \to \Xi_c(\overline{\mathbf{3}}$				

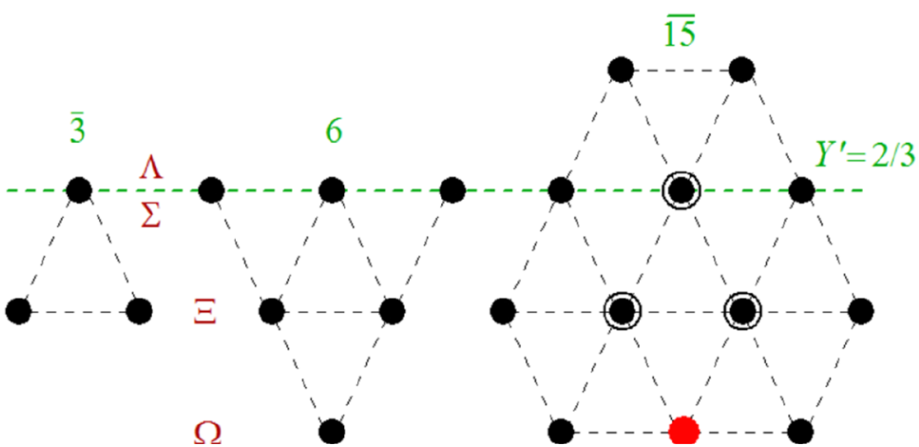
#	decay	Ref.[1]	$\Gamma^{(0)}_{\rm sol} = \Gamma^{(0)}_{\rm full}$	$\Gamma^{(0)}_{\rm sol} = \Gamma^{(\rm total)}_{\rm full}$	exp.
1	$\Sigma_b^{+}(\mathbf{6}_1, 1/2) \to \Lambda_b^0(\overline{\mathbf{3}}_0, 1/2) + \pi^+$	6.12	6.03 ± 0.39	6.47 ± 0.42	$9.7^{+4.0}_{-3.0}$
	$\Sigma_b^{0}(\mathbf{6}_1, 1/2) \to \Lambda_b^0(\overline{\mathbf{3}}_0, 1/2) + \pi^0$	–	7.14 ± 0.29	7.66 ± 0.32	–
2	$\Sigma_b^{-}(\mathbf{6}_1, 1/2) \to \Lambda_b^0(\overline{\mathbf{3}}_0, 1/2) + \pi^-$	6.12	6.89 ± 0.39	7.39 ± 0.42	$4.9^{+3.3}_{-2.4}$
3	$\Xi_b^{'}(\mathbf{6}_1, 1/2) \to \Xi_c(\overline{\mathbf{3}}_0, 1/2) + \pi$	0.07	0.07 ± 0.01	0.06 ± 0.01	< 0.08
4	$\Sigma_b^{+}(\mathbf{6}_1, 3/2) \to \Lambda_b^0(\overline{\mathbf{3}}_0, 1/2) + \pi^+$	10.96	10.83 ± 0.52	11.63 ± 0.57	11.5 ± 2.8
	$\Sigma_b^{0}(\mathbf{6}_1, 3/2) \to \Lambda_b^0(\overline{\mathbf{3}}_0, 1/2) + \pi^0$	–	12.04 ± 0.40	12.93 ± 0.44	–
5	$\Sigma_b^{-}(\mathbf{6}_1, 3/2) \to \Lambda_c^0(\overline{\mathbf{3}}_0, 1/2) + \pi^-$	11.77	11.64 ± 0.54	12.49 ± 0.59	7.5 ± 2.3
6	$\Xi_b^{0}(\mathbf{6}_1, 3/2) \to \Xi_b(\overline{\mathbf{3}}_0, 1/2) + \pi$	0.80	0.80 ± 0.06	0.72 ± 0.06	0.90 ± 0.18
7	$\Xi_b^{-}(\mathbf{6}_1, 3/2) \to \Xi_b(\overline{\mathbf{3}}_0, 1/2) + \pi$	1.28	1.28 ± 0.05	1.15 ± 0.05	1.65 ± 0.33

Soliton wave functions coupled by a heavy quark spinor

$$\hat{\mathcal{O}}_{\varphi}^{(0)} = \tilde{a}_1 D_{\varphi 3}^{(8)} + a_2 d_{3bc} D_{\varphi b}^{(8)} \hat{J}_c + \frac{a_3}{\sqrt{3}} D_{\varphi 8}^{(8)} \hat{J}_3.$$

$$\Psi_{B_Q}^{(\mathcal{R}_J)} = \sum C_{J_{\rm sol} j_{\rm sol}; J_Q, j_Q}^{J\ J_3} \chi_{j_Q} \psi_{B_Q(Y', J_{\rm sol}, j_{\rm sol})}^{(\mathcal{R})}$$
$$= C_{J_{\rm sol}, J_3-\frac{1}{2}; \frac{1}{2}, \frac{1}{2}}^{J\ J_3} \chi_{\uparrow} \psi_{B_Q(Y', J_{\rm sol}, J_3-\frac{1}{2})}^{(\mathcal{R})} + C_{J_{\rm sol}, J_3+\frac{1}{2}; \frac{1}{2}, -\frac{1}{2}}^{J\ J_3} \chi_{\downarrow} \psi_{B_Q(Y', J_{\rm sol}, J_3+\frac{1}{2})}^{(\mathcal{R})},$$

$$\left\langle 6_{J=1/2}, B' \left| \hat{\mathcal{O}}_{\varphi}^{(0)} \right| \overline{15}_{J=3/2}, B \right\rangle$$
$$= \int dA \left(-\sqrt{\frac{1}{3}} \chi_{\uparrow} \psi_{B_Q(-\frac{2}{3},1,0)}^{(6)*} + \sqrt{\frac{2}{3}} \chi_{\downarrow} \psi_{B_Q(-\frac{2}{3},1,1)}^{(6)*} \right) \hat{\mathcal{O}}_{\varphi}^{(0)} \left(\sqrt{\frac{2}{3}} \chi_{\uparrow} \psi_{B_Q(-\frac{2}{3},1,0)}^{(\overline{15})} + \sqrt{\frac{1}{3}} \chi_{\downarrow} \psi_{B_Q(-\frac{2}{3},1,1)}^{(\overline{15})} \right)$$
$$= \int dA \left[\left(-\sqrt{\frac{1}{3}}\sqrt{\frac{2}{3}} \right) \underbrace{\psi_{B_Q(-\frac{2}{3},1,0)}^{(6)*} \hat{\mathcal{O}}_{\varphi}^{(0)} \psi_{B_Q(-\frac{2}{3},1,0)}^{(\overline{15})}}_{\Rightarrow \text{ soliton with } J_{\rm sol}=0} + \sqrt{\frac{2}{3}}\sqrt{\frac{1}{3}} \underbrace{\psi_{B_Q(-\frac{2}{3},1,1)}^{(6)*} \hat{\mathcal{O}}_{\varphi}^{(0)} \psi_{B_Q(-\frac{2}{3},1,1)}^{(\overline{15})}}_{\Rightarrow \text{ soliton with } J_{\rm sol}=1} \right]$$
$$= \sqrt{\frac{2}{3}}\sqrt{\frac{1}{3}} \left\langle 6_{J_{\rm sol}=0}, B' \left| \hat{\mathcal{O}}_{\varphi}^{(0)} \right| \overline{15}_{J_{\rm sol}=1}, B \right\rangle.$$



$$\Psi_{B_Q}^{(\bar{3}_{1/2})} = C_{0,0;\frac{1}{2},\frac{1}{2}}^{\frac{1}{2}\ \frac{1}{2}} \chi_{\uparrow} \psi_{B_Q(-\frac{2}{3},0,0)}^{(\bar{3})} \text{ or } C_{0,0;\frac{1}{2},-\frac{1}{2}}^{\frac{1}{2}\ \frac{1}{2}} \chi_{\downarrow} \psi_{B_Q(-\frac{2}{3},0,0)}^{(\bar{3})}.$$

Soliton Full

#	$\Omega_c(\overline{\mathbf{15}}_1, 1/2,\ \mathbf{3050\ MeV})$decay	Ref.[1]	$\Gamma^{(0)}_{\rm sol}$	$\Gamma^{(\rm total)}_{\rm sol}$	$\Gamma^{(0)}_{\rm full}$	$\Gamma^{(\rm total)}_{\rm full}$	exp.(LHCb)
	$\Omega_c(\overline{\mathbf{15}}_1, 1/2) \to \Xi_c(\overline{\mathbf{3}}_0, 1/2) + K$	0.339	0.352 ± 0.040	0.659 ± 0.055	0.352 ± 0.040	0.659 ± 0.055	
	$\Omega_c(\overline{\mathbf{15}}_1, 1/2) \to \Omega_c(\mathbf{6}_1, 1/2) + \pi$	0.097	0.091 ± 0.036	1.036 ± 0.149	0.060 ± 0.024	0.691 ± 0.099	
	$\Omega_c(\overline{\mathbf{15}}_1, 1/2) \to \Omega_c(\mathbf{6}_1, 3/2) + \pi$	0.045	0.042 ± 0.017	0.482 ± 0.070	0.014 ± 0.006	0.161 ± 0.023	
9	total	**0.48**	0.485 ± 0.049	2.178 ± 0.209	0.427 ± 0.037	1.511 ± 0.119	$0.8 \pm 0.2 \pm 0.1$
	(Range)		0.44 – 0.53	2.0 – 2.4	0.39 – 0.46	1.39 – 1.63	0.5 – 1.1

#	$\Omega_c(\overline{\mathbf{15}}_1, 3/2,\ \mathbf{3119\ MeV})$decay	Ref.[1]	$\Gamma^{(0)}_{\rm sol}$	$\Gamma^{(\rm total)}_{\rm sol}$	$\Gamma^{(0)}_{\rm full}$	$\Gamma^{(\rm total)}_{\rm full}$	exp.(LHCb)
	$\Omega_c(\overline{\mathbf{15}}_1, 3/2) \to \Xi_c(\overline{\mathbf{3}}_0, 1/2) + K$	0.848	0.879 ± 0.100	1.646 ± 0.140	0.879 ± 0.100	1.646 ± 0.140	
	$\Omega_c(\overline{\mathbf{15}}_1, 3/2) \to \Xi_c(\mathbf{6}_1, 1/2) + K$	0.009	0.008 ± 0.003	0.067 ± 0.011	0.0014 ± 0.0005	0.011 ± 0.002	
	$\Omega_c(\overline{\mathbf{15}}_1, 3/2) \to \Omega_c(\mathbf{6}_1, 1/2) + \pi$	0.169	0.158 ± 0.062	1.811 ± 0.261	0.026 ± 0.010	0.302 ± 0.043	
	$\Omega_c(\overline{\mathbf{15}}_1, 3/2) \to \Omega_c(\mathbf{6}_1, 3/2) + \pi$	0.096	0.090 ± 0.035	1.027 ± 0.149	0.075 ± 0.029	0.086 ± 0.012	
10	total	**1.12**	1.136 ± 0.104	4.55 ± 0.40	0.982 ± 0.089	2.045 ± 0.135	$1.1 \pm 0.8 \pm 0.4$
	(Range)		1.03 – 1.24	4.15 – 4.95	0.89 – 1.07	1.91 – 2.18	0 – 2.3

Summary

- Assuming that the valence quarks are bound by the pion mean fields, we can regard the nucleon as a chiral soliton.
- Formulating the most general expressions of the collective Hamiltonian and determining all dynamical parameters by using the experimental data unequivocally, we are able to find the the collective baryon wavefunctions.
- Then we predicted the mass splittings of the baryon decuplet.
- **We also presented results of the masses and decay widths for the heavy baryons (light quarks govern their structure !)**

ありがとうございます

Катта Раҳмат

谢谢

धन्यवाद

Thank you

감사합니다

$$a_1 \to \tilde{a}_1 = \left[\frac{N_c - 1}{N_c}(a_1 + a_3) - a_3\right]\sigma$$

$$|g_2| = \frac{1}{4\sqrt{3}} H_{\bar{\mathbf{3}}} = \frac{1}{4\sqrt{3}} \left(-\tilde{a}_1 + \frac{1}{2} a_2\right)$$