手征夸克模型下重味五夸克系统的研究

- 张奇; 何秉然; 平加伦; arXiv:2006.01042
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第七届XYZ粒子研讨会
@青岛
2021年5月15日

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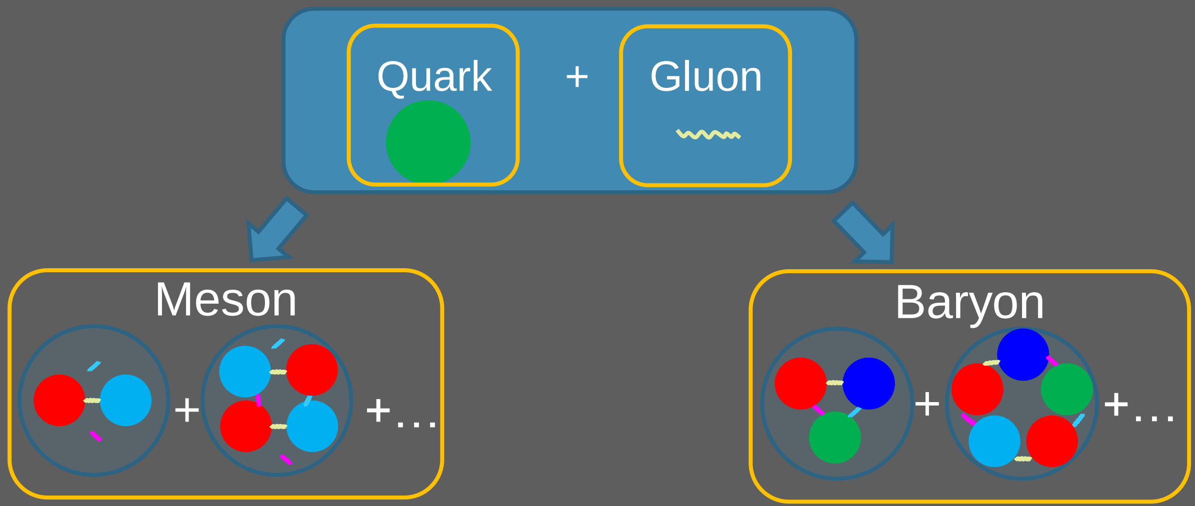
Outline

- ***Introduction***
- Chiral quark model
- $qqs\bar{Q}Q$ and $qqq\bar{q}Q$ system
- Summary

Introduction

Hadron are made by quarks and gluons



The dynamics of quarks and gluons are described by Quantum chromodynamics (QCD)

- QCD have two important features:
  - Color confinement
  - Asymptotic freedom

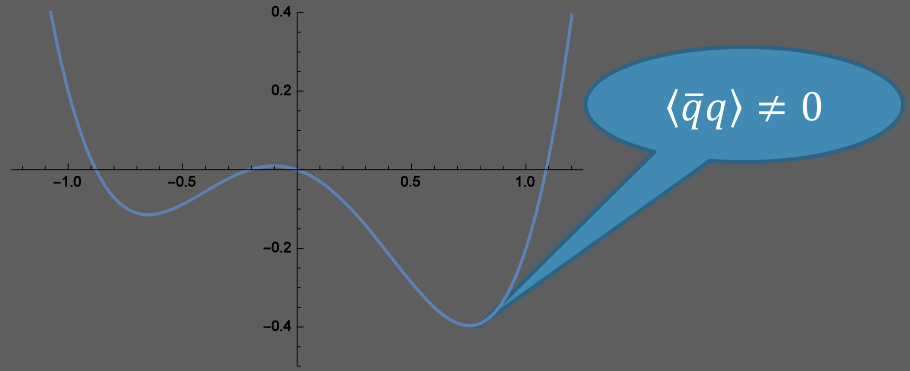
- In low energy region the perturbative calculation for QCD is impossible, alternatively:
  - Lattice QCD (non-perturbative calculation)
  - Effective models (chiral perturbation theory, quark model, etc…)

The chiral symmetry

The chiral symmetry:

Spontaneously breaking of chiral symmetry:

$$\langle \bar{q}q \rangle = \langle \overline{q_L} q_R + \overline{q_R} q_L \rangle \neq 0$$



The effective theory based on chiral symmetry:

- Nonlinear sigma model
- Chiral perturbation theory

The $P_{c(s)}$ states

Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays

#1

$P_c(4380)^+$, $P_c(4450)^+$

LHCb Collaboration • Roel Aaij (CERN) et al. (Jul 13, 2015)

Published in: *Phys.Rev.Lett.* 115 (2015) 072001 • e-Print: 1507.03414 [hep-ex]

pdf links DOI cite

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Observation of a narrow pentaquark state, $P_c(4312)^+$, and of two-peak structure of the $P_c(4450)^+$ #1

$P_c(4312)^+$, $P_c(4440)^+$, $P_c(4457)^+$

LHCb Collaboration • Roel Aaij (NIKHEF, Amsterdam) et al. (Apr 8, 2019)

Published in: *Phys.Rev.Lett.* 122 (2019) 22, 222001 • e-Print: 1904.03947 [hep-ex]

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Published in: *Phys.Rev.Lett.* 122 (2019) 22, 222001 • e-Print: 1904.03947 [hep-ex]

pdf links DOI cite datasets 280 citations

Evidence of a $J/\psi\Lambda$ structure and observation of excited Ξ^- states in the $\Xi_b^- \to J/\psi \Lambda K^-$ decay

#1

$P_{cs}(4459)^0$

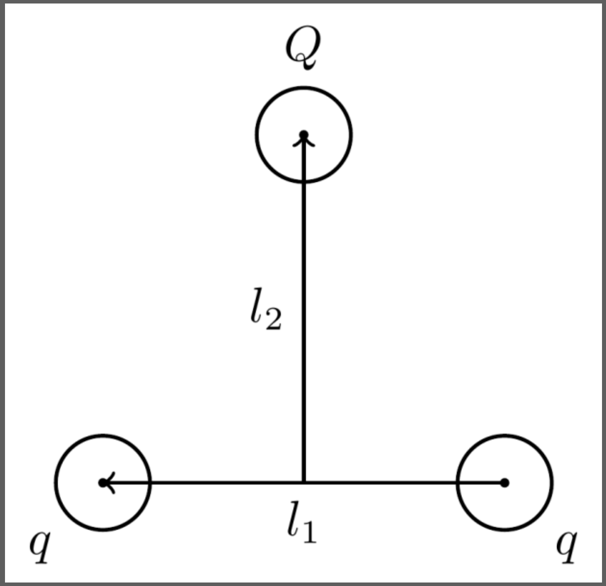
LHCb Collaboration • Roel Aaij (NIKHEF, Amsterdam) et al. (Dec 18, 2020)

e-Print: 2012.10380 [hep-ex]

pdf cite 17 citations

The states beyond 3 quark picture

$\Lambda_c(2595)$
$\Lambda_b(5912)$



State	IJ^P	(l_1, l_2)	I	II	Exp.	$\|\Delta M\|$
Λ_c	$0\frac{1}{2}^-$	$(1,0)$	2667	2665		73MeV
		$(0,1)$	2465	2456		136MeV
		coupling	2465	2456	2592	136MeV
Σ_c	$1\frac{1}{2}^-$	$(1,0)$	2671	2669		
		$(0,1)$	2629	2628		
		coupling	2628	2628		
Σ_c^*	$1\frac{1}{2}^-$	$(0,1)$	2633	2632		
Λ_b	$0\frac{1}{2}^-$	$(1,0)$	6006	6012		100MeV
		$(0,1)$	5783	5785		127MeV
		coupling	5783	5785	5912	127MeV
Σ_b	$1\frac{1}{2}^-$	$(1,0)$	6008	6015		
		$(0,1)$	5954	5963		
		coupling	5954	5963		
Σ_b^*	$1\frac{1}{2}^-$	$(0,1)$	5956	5965		

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Chiral quark model

Naïve quark model:

- Quark mass term
- Kinetic term
- Color confinement potential (CON)
- One gluon exchange (OGE)

- Gell-Mann, M., 1964, Phys. Lett. 8, 214.
- Zweig, G., 1964, CERN Reports No. 8182/TH. 401 and No. 8419/TH. 412).
- N. Isgur, G. Karl, Phys.Lett.B 72 (1977) 109.

The Nambu–Goldstone boson exchange:

- Chiral symmetry is spontaneously broken
- Pseudoscalars (π, K, η) are the Nambu–Goldstone (NG) bosons of chiral symmetry breaking
- Scalar meson σ as the chiral partner of NG bosons

- Makato Oka, Koichi Yazaki, Nuclear Physics A402 (1983) 477-490
- L.Ya Glozman, Z. Papp, W. Plessas, Physics Letters B 381 (1996) 311-316
- J . Vijande, F . Fernandez, A . Valcarce, J. Phys. G 31, 481(2005)

The Hamiltonian

$$H = \sum_{i=1}^{n} \left(m_i + \frac{\boldsymbol{p}_i^2}{2m_i} \right) - T_{cm} + \sum_{j>i=1}^{n} \left(V_{ij}^{CON} + V_{ij}^{OGE} + V_{ij}^{\pi} + V_{ij}^{K} + V_{ij}^{\eta} + V_{ij}^{\sigma} \right)$$

J . Vijande, F . Fernandez, A . Valcarce, J. Phys. G 31, 481(2005)

$$V_{ij}^{CON} = (\boldsymbol{\lambda}_i^c \cdot \boldsymbol{\lambda}_j^c) \left[-a_c \left(1 - e^{-\mu_c r_{ij}}\right) + \Delta \right],$$

$$V_{ij}^{OGE} = \frac{1}{4} \alpha_s (\boldsymbol{\lambda}_i^c \cdot \boldsymbol{\lambda}_j^c) \left[\frac{1}{r_{ij}} - \frac{1}{6 m_i m_j} \frac{e^{-\frac{r_{ij}}{r_0(\mu_{ij})}}}{r_{ij} r_0^2(\mu_{ij})} \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j \right],$$

$$V_{ij}^{\sigma} = -\frac{g_{ch}^2}{4\pi} \frac{\Lambda_\sigma^2}{\Lambda_\sigma^2 - m_\sigma^2} m_\sigma \left[Y(m_\sigma r_{ij}) - \frac{\Lambda_\sigma}{m_\sigma} Y(\Lambda_\sigma r_{ij}) \right],$$

$$V_{ij}^{\pi} = \frac{g_{ch}^2}{4\pi} \frac{m_\pi^2}{12 m_i m_j} \frac{\Lambda_\pi^2}{\Lambda_\pi^2 - m_\pi^2} m_\pi \left[Y(m_\pi r_{ij}) - \frac{\Lambda_\pi^3}{m_\pi^3} Y(\Lambda_\pi r_{ij}) \right] \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j \sum_{a=1}^{3} \lambda_i^a \lambda_j^a,$$

$$V_{ij}^{K} = \frac{g_{ch}^2}{4\pi} \frac{m_K^2}{12 m_i m_j} \frac{\Lambda_K^2}{\Lambda_K^2 - m_K^2} m_K \left[Y(m_K r_{ij}) - \frac{\Lambda_K^3}{m_K^3} Y(\Lambda_K r_{ij}) \right] \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j \sum_{a=4}^{7} \lambda_i^a \lambda_j^a,$$

$$V_{ij}^{\eta} = \frac{g_{ch}^2}{4\pi} \frac{m_\eta^2}{12 m_i m_j} \frac{\Lambda_\eta^2}{\Lambda_\eta^2 - m_\eta^2} m_\eta \left[Y(m_\eta r_{ij}) - \frac{\Lambda_\eta^3}{m_\eta^3} Y(\Lambda_\eta r_{ij}) \right] \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j \left(\lambda_i^8 \lambda_j^8 \cos\theta_p - \lambda_i^0 \lambda_j^0 \sin\theta_p \right).$$

The Gaussian expansion method

$$\psi_{lm}(\boldsymbol{r}) = \sum_{n=1}^{n_{max}} c_n \psi^G_{nlm}(\boldsymbol{r}),$$

$$\psi^G_{nlm}(\boldsymbol{r}) = N_{nl} r^l e^{-\nu_n r^2} Y_{lm}(\hat{\boldsymbol{r}}),$$

$$N_{nl} = \left(\frac{2^{l+2}(2\nu_n)^{l+\frac{3}{2}}}{\sqrt{\pi}(2l+1)!!} \right)^{\frac{1}{2}},$$

$$\nu_n = \frac{1}{r_n^2}, r_n = r_{min} a^{n-1}, a = \left(\frac{r_{max}}{r_{min}} \right)^{\frac{1}{n_{max}-1}}.$$

E. Hiyama, Y. Kino, and M. Kamimura, Prog. Part. Nucl. Phys. 51 223 (2003).

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Wave functions

- Orbital (SO(3)): (ψ_L)
- Spin (SU(2)): (χ_S^σ)
- Flavor (SU(2)): (χ_I^f)
- Color (SU(3)): (χ^c)

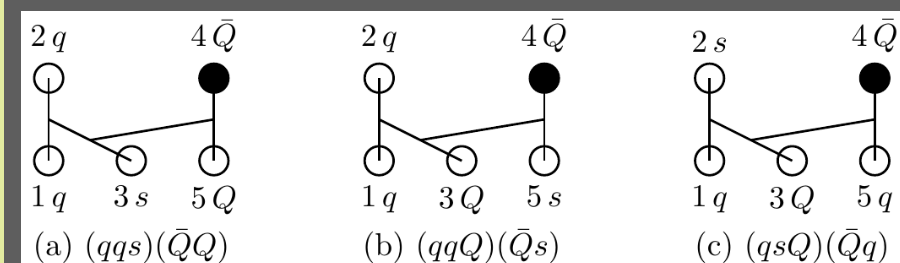
$$\Psi^{ijk}_{JM_J IM_I} = \mathcal{A}\left[\left[\psi_L \chi_S^{\sigma i}\right]_{JM_J} \chi_I^{fj} \chi_k^c\right]$$

Wave functions

- Orbital (SO(3)): (ψ_L)
- Spin (SU(2)): (χ_S^σ)
- Flavor (SU(2)): (χ_I^f)
- Color (SU(3)): (χ^c)

$$\Psi^{ijk}_{JM_JIM_I} = \mathcal{A}\left[\left[\psi_L \chi_S^{\sigma i}\right]_{JM_J} \chi_I^{fj} \chi_k^c\right]$$

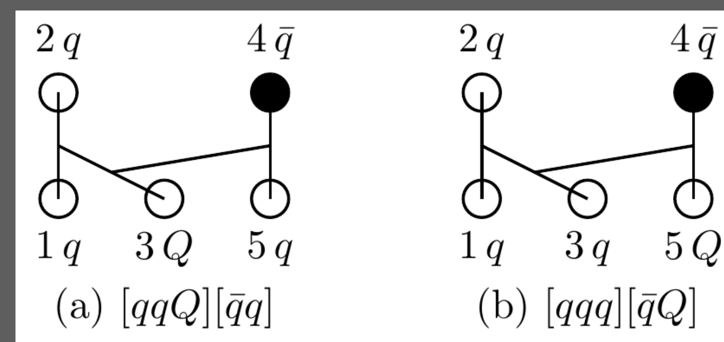
$qqs\bar{Q}Q$:



(a, b): $\mathcal{A} = 1 - (12)$

(c): $\mathcal{A} = 1 - (15)$

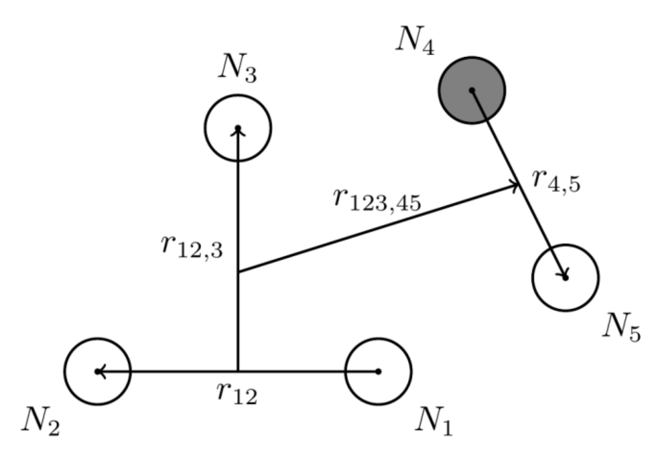
$qqq\bar{q}Q$:



(a): $\mathcal{A} = 1 - (15) - (25)$

(b): $\mathcal{A} = 1 - (13) - (23)$

Orbital wave functions



$$\psi_{LM_L} = [[[\psi_{l_1}(\boldsymbol{r}_{12})\psi_{l_2}(\boldsymbol{r}_{12,3})]_l \psi_{l_3}(\boldsymbol{r}_{45})]_{l'} \psi_{l_4}(\boldsymbol{r}_{123,45})]_{LM_L}$$

$$\begin{aligned}
\boldsymbol{r}_{12} &= \boldsymbol{r}_2 - \boldsymbol{r}_1 \, , \\
\boldsymbol{r}_{12,3} &= \boldsymbol{r}_3 - \frac{m_1\boldsymbol{r}_1 + m_2\boldsymbol{r}_2}{m_1 + m_2} \, , \\
\boldsymbol{r}_{45} &= \boldsymbol{r}_5 - \boldsymbol{r}_4 \, , \\
\boldsymbol{r}_{123,45} &= \frac{m_4\boldsymbol{r}_4 + m_5\boldsymbol{r}_5}{m_4 + m_5} - \frac{m_1\boldsymbol{r}_1 + m_2\boldsymbol{r}_2 + m_3\boldsymbol{r}_3}{m_1 + m_2 + m_3} \, .
\end{aligned}$$

Spin wave functions

$$\chi^{\sigma}_{\frac{3}{2},\frac{3}{2}}(3) = \alpha\alpha\alpha,$$
$$\chi^{\sigma}_{\frac{3}{2},-\frac{3}{2}}(3) = \beta\beta\beta,$$
$$\chi^{\sigma}_{\frac{3}{2},\frac{1}{2}}(3) = \sqrt{\frac{1}{3}}(\alpha\alpha\beta + \alpha\beta\alpha + \beta\alpha\alpha),$$
$$\chi^{\sigma}_{\frac{3}{2},-\frac{1}{2}}(3) = \sqrt{\frac{1}{3}}(\alpha\beta\beta + \beta\alpha\beta + \beta\beta\alpha),$$
$$\chi^{\sigma 1}_{\frac{1}{2},\frac{1}{2}}(3) = \sqrt{\frac{1}{6}}(2\alpha\alpha\beta - \alpha\beta\alpha - \beta\alpha\alpha),$$
$$\chi^{\sigma 2}_{\frac{1}{2},\frac{1}{2}}(3) = \sqrt{\frac{1}{2}}(\alpha\beta\alpha - \beta\alpha\alpha),$$
$$\chi^{\sigma 1}_{\frac{1}{2},-\frac{1}{2}}(3) = \sqrt{\frac{1}{6}}(\alpha\beta\beta + \beta\alpha\beta - 2\beta\beta\alpha),$$
$$\chi^{\sigma 2}_{\frac{1}{2},-\frac{1}{2}}(3) = \sqrt{\frac{1}{2}}(\alpha\beta\beta - \beta\alpha\beta),$$

$$\chi^{\sigma}_{1,1}(2) = \alpha\alpha,$$
$$\chi^{\sigma}_{1,-1}(2) = \beta\beta,$$
$$\chi^{\sigma}_{1,0}(2) = \sqrt{\frac{1}{2}}(\alpha\beta + \beta\alpha),$$
$$\chi^{\sigma}_{0,0}(2) = \sqrt{\frac{1}{2}}(\alpha\beta - \beta\alpha).$$

$$\chi^{\sigma 1}_{\frac{1}{2},\frac{1}{2}}(5) = \sqrt{\frac{1}{6}}\chi^{\sigma}_{\frac{3}{2},-\frac{1}{2}}(3)\chi^{\sigma}_{1,1}(2) - \sqrt{\frac{1}{3}}\chi^{\sigma}_{\frac{3}{2},\frac{1}{2}}(3)\chi^{\sigma}_{1,0}(2) + \sqrt{\frac{1}{2}}\chi^{\sigma}_{\frac{3}{2},\frac{3}{2}}(3)\chi^{\sigma}_{1,-1}(2),$$
$$\chi^{\sigma 2}_{\frac{1}{2},\frac{1}{2}}(5) = \sqrt{\frac{1}{3}}\chi^{\sigma 1}_{\frac{1}{2},\frac{1}{2}}(3)\chi^{\sigma}_{1,0}(2) - \sqrt{\frac{2}{3}}\chi^{\sigma 1}_{\frac{1}{2},-\frac{1}{2}}(3)\chi^{\sigma}_{1,1}(2),$$
$$\chi^{\sigma 3}_{\frac{1}{2},\frac{1}{2}}(5) = \sqrt{\frac{1}{3}}\chi^{\sigma 2}_{\frac{1}{2},\frac{1}{2}}(3)\chi^{\sigma}_{1,0}(2) - \sqrt{\frac{2}{3}}\chi^{\sigma 2}_{\frac{1}{2},-\frac{1}{2}}(3)\chi^{\sigma}_{1,1}(2),$$
$$\chi^{\sigma 4}_{\frac{1}{2},\frac{1}{2}}(5) = \chi^{\sigma 1}_{\frac{1}{2},\frac{1}{2}}(3)\chi^{\sigma}_{0,0}(2),$$
$$\chi^{\sigma 5}_{\frac{1}{2},\frac{1}{2}}(5) = \chi^{\sigma 2}_{\frac{1}{2},\frac{1}{2}}(3)\chi^{\sigma}_{0,0}(2),$$
$$\chi^{\sigma 1}_{\frac{3}{2},\frac{3}{2}}(5) = \sqrt{\frac{3}{5}}\chi^{\sigma}_{\frac{3}{2},\frac{3}{2}}(3)\chi^{\sigma}_{1,0}(2) - \sqrt{\frac{2}{5}}\chi^{\sigma}_{\frac{3}{2},\frac{1}{2}}(3)\chi^{\sigma}_{1,1}(2),$$
$$\chi^{\sigma 2}_{\frac{3}{2},\frac{3}{2}}(5) = \chi^{\sigma}_{\frac{3}{2},\frac{3}{2}}(3)\chi^{\sigma}_{0,0}(2),$$
$$\chi^{\sigma 3}_{\frac{3}{2},\frac{3}{2}}(5) = \chi^{\sigma 1}_{\frac{1}{2},\frac{1}{2}}(3)\chi^{\sigma}_{1,1}(2),$$
$$\chi^{\sigma 4}_{\frac{3}{2},\frac{3}{2}}(5) = \chi^{\sigma 2}_{\frac{1}{2},\frac{1}{2}}(3)\chi^{\sigma}_{1,1}(2),$$
$$\chi^{\sigma 1}_{\frac{5}{2},\frac{5}{2}}(5) = \chi^{\sigma}_{\frac{3}{2},\frac{3}{2}}(3)\chi^{\sigma}_{1,1}(2).$$

Flavor wave functions ($qqs\bar{Q}Q$)

$$\chi^{f}_{\frac{1}{2},\frac{1}{2}}(3) = usb, \quad \chi^{f}_{\frac{1}{2},-\frac{1}{2}}(3) = dsb,$$

$$\chi^{f1}_{1,1}(3) = uus, \quad \chi^{f2}_{1,1}(3) = uub,$$

$$\chi^{f1}_{1,0}(3) = \sqrt{\frac{1}{2}}(ud + du)s,$$

$$\chi^{f2}_{1,0}(3) = \sqrt{\frac{1}{2}}(ud + du)b,$$

$$\chi^{f1}_{1,-1}(3) = dds, \quad \chi^{f2}_{1,-1}(3) = ddb,$$

$$\chi^{f1}_{0,0}(3) = \sqrt{\frac{1}{2}}(ud - du)s,$$

$$\chi^{f2}_{0,0}(3) = \sqrt{\frac{1}{2}}(ud - du)b,$$

$$\chi^{f1}_{0,0}(2) = \bar{b}b, \quad \chi^{f2}_{0,0}(2) = \bar{b}s,$$

$$\chi^{f}_{\frac{1}{2},\frac{1}{2}}(2) = \bar{b}u, \quad \chi^{f}_{\frac{1}{2},-\frac{1}{2}}(2) = \bar{b}d.$$

$$\chi^{f1}_{0,0}(5) = \chi^{f1}_{0,0}(3)\chi^{f1}_{0,0}(2),$$

$$\chi^{f2}_{0,0}(5) = \chi^{f2}_{0,0}(3)\chi^{f2}_{0,0}(2),$$

$$\chi^{f3}_{0,0}(5) = \sqrt{\frac{1}{2}}\chi^{f}_{\frac{1}{2},\frac{1}{2}}(3)\chi^{f}_{\frac{1}{2},-\frac{1}{2}}(2) - \sqrt{\frac{1}{2}}\chi^{f}_{\frac{1}{2},-\frac{1}{2}}(3)\chi^{f}_{\frac{1}{2},\frac{1}{2}}(2),$$

$$\chi^{f1}_{1,1}(5) = \chi^{f}_{\frac{1}{2},\frac{1}{2}}(3)\chi^{f}_{\frac{1}{2},\frac{1}{2}}(2),$$

$$\chi^{f2}_{1,1}(5) = \chi^{f1}_{1,1}(3)\chi^{f1}_{0,0}(2),$$

$$\chi^{f3}_{1,1}(5) = \chi^{f2}_{1,1}(3)\chi^{f2}_{0,0}(2).$$

Flavor wave functions ($qqq\bar{q}Q$)

$$\chi^f_{0,0}(3)=\sqrt{\frac{1}{2}}(ud-du)c,$$
$$\chi^{f1}_{\frac{1}{2},\frac{1}{2}}(3)=\sqrt{\frac{1}{6}}(2uud-udu-duu),$$
$$\chi^{f2}_{\frac{1}{2},\frac{1}{2}}(3)=\sqrt{\frac{1}{2}}(udu-duu),$$
$$\chi^{f1}_{\frac{1}{2},-\frac{1}{2}}(3)=\sqrt{\frac{1}{6}}(udd+dud-2ddu),$$
$$\chi^{f2}_{\frac{1}{2},-\frac{1}{2}}(3)=\sqrt{\frac{1}{2}}(udd-dud),$$
$$\chi^f_{1,1}(3)=uuc,$$
$$\chi^f_{1,-1}(3)=ddc,$$
$$\chi^f_{1,0}(3)=\sqrt{\frac{1}{2}}(ud+du)c,$$
$$\chi^f_{\frac{3}{2},\frac{3}{2}}(3)=uuu,$$
$$\chi^f_{\frac{3}{2},\frac{1}{2}}(3)=\sqrt{\frac{1}{3}}(uud+udu+duu),$$

$$\chi^f_{0,0}(2)=\sqrt{\frac{1}{2}}(\bar{d}d+\bar{u}u),$$
$$\chi^f_{\frac{1}{2},\frac{1}{2}}(2)=\bar{d}c,$$
$$\chi^f_{\frac{1}{2},-\frac{1}{2}}(2)=-\bar{u}c,$$
$$\chi^f_{1,1}(2)=\bar{d}u,$$
$$\chi^f_{1,-1}(2)=-\bar{u}d,$$
$$\chi^f_{1,0}(2)=\sqrt{\frac{1}{2}}(\bar{d}d-\bar{u}u).$$

$$\chi^{f1}_{0,0}(5)=\chi^f_{0,0}(3)\chi^f_{0,0}(2),$$
$$\chi^{f2}_{0,0}(5)=\sqrt{\frac{1}{2}}\chi^{f1}_{\frac{1}{2},\frac{1}{2}}(3)\chi^f_{\frac{1}{2},-\frac{1}{2}}(2)-\sqrt{\frac{1}{2}}\chi^{f1}_{\frac{1}{2},-\frac{1}{2}}(3)\chi^f_{\frac{1}{2},\frac{1}{2}}(2),$$
$$\chi^{f3}_{0,0}(5)=\sqrt{\frac{1}{2}}\chi^{f2}_{\frac{1}{2},\frac{1}{2}}(3)\chi^f_{\frac{1}{2},-\frac{1}{2}}(2)-\sqrt{\frac{1}{2}}\chi^{f2}_{\frac{1}{2},-\frac{1}{2}}(3)\chi^f_{\frac{1}{2},\frac{1}{2}}(2),$$
$$\chi^{f4}_{0,0}(5)=\sqrt{\frac{1}{3}}\chi^f_{1,1}(3)\chi^f_{1,-1}(2)-\sqrt{\frac{1}{3}}\chi^f_{1,0}(3)\chi^f_{1,0}(2)+\sqrt{\frac{1}{3}}\chi^f_{1,-1}(3)\chi^f_{1,1}(2),$$
$$\chi^{f1}_{1,1}(5)=\chi^f_{0,0}(3)\chi^f_{1,1}(2),$$
$$\chi^{f2}_{1,1}(5)=\chi^f_{1,1}(3)\chi^f_{0,0}(2),$$
$$\chi^{f3}_{1,1}(5)=\sqrt{\frac{1}{2}}\chi^f_{1,1}(3)\chi^f_{1,0}(2)-\sqrt{\frac{1}{2}}\chi^f_{1,0}(3)\chi^f_{1,1}(2),$$
$$\chi^{f4}_{1,1}(5)=\chi^{f1}_{\frac{1}{2},\frac{1}{2}}(3)\chi^f_{\frac{1}{2},\frac{1}{2}}(2),$$
$$\chi^{f5}_{1,1}(5)=\chi^{f2}_{\frac{1}{2},\frac{1}{2}}(3)\chi^f_{\frac{1}{2},\frac{1}{2}}(2),$$
$$\chi^{f6}_{1,1}(5)=\sqrt{\frac{3}{4}}\chi^f_{\frac{3}{2},\frac{3}{2}}(3)\chi^f_{\frac{1}{2},-\frac{1}{2}}(2)-\sqrt{\frac{1}{4}}\chi^f_{\frac{3}{2},\frac{1}{2}}(3)\chi^f_{\frac{1}{2},\frac{1}{2}}(2),$$
$$\chi^{f1}_{2,2}(5)=\chi^f_{1,1}(3)\chi^f_{1,1}(2),$$
$$\chi^{f2}_{2,2}(5)=\chi^f_{\frac{3}{2},\frac{3}{2}}(3)\chi^f_{\frac{1}{2},\frac{1}{2}}(2).$$

Color wave functions: $S \oplus H$ $(1 \oplus 8)$

$$\chi_1^c = \sqrt{\frac{1}{6}}(rgb - grb + brg - rbg + gbr - bgr)\sqrt{\frac{1}{3}}(\bar{r}r + \bar{g}g + \bar{b}b),$$

$$\begin{aligned}\chi_2^c = \sqrt{\frac{1}{8}}\Big[&\sqrt{\frac{1}{6}}(2rrg - rgr - grr)\bar{r}b + \sqrt{\frac{1}{6}}(rgg + grg - 2ggr)\bar{g}b - \sqrt{\frac{1}{6}}(2rrb - rbr - brr)\bar{r}g \\ &-\sqrt{\frac{1}{6}}(rbb + brb - 2bbr)\bar{b}g + \sqrt{\frac{1}{6}}(2ggb - gbg - bgg)\bar{g}r + \sqrt{\frac{1}{6}}(gbb + bgb - 2bbg)\bar{b}r \\ &+\sqrt{\frac{1}{24}}(rbg - gbr + brg - bgr)(2\bar{b}b - \bar{r}r - \bar{g}g) \\ &+\sqrt{\frac{1}{24}}(2rgb - rbg + 2grb - gbr - brg - bgr)(\bar{r}r - \bar{g}g)\Big],\end{aligned}$$

$$\begin{aligned}\chi_3^c = \sqrt{\frac{1}{8}}\Big[&\sqrt{\frac{1}{2}}(rgr - grr)\bar{r}b + \sqrt{\frac{1}{2}}(rgg - grg)\bar{g}b - \sqrt{\frac{1}{2}}(rbr - brr)\bar{r}g - \sqrt{\frac{1}{2}}(rbb - brb)\bar{b}g \\ &+\sqrt{\frac{1}{2}}(gbg - bgg)\bar{g}r + \sqrt{\frac{1}{2}}(gbb - bgb)\bar{b}r + \sqrt{\frac{1}{8}}(rbg + gbr - brg - bgr)(\bar{r}r - \bar{g}g) \\ &+\sqrt{\frac{1}{72}}(2rgb + rbg - 2grb - gbr - brg + bgr)(2\bar{b}b - \bar{g}g - \bar{r}r)\Big].\end{aligned}$$

Physical channels for $qqs\bar{b}b$

IJ^P	$[i;j;k]$	Channel
$0\frac{1}{2}^-$	$[5;1;1,2,3]$	$\Lambda\eta_b$
	$[3;1;1,2,3]$	$\Lambda\Upsilon$
	$[5;2;1,2,3]$	$\Lambda_b B_s$
	$[3;2;1,2,3]$	$\Lambda_b B_s^*$
	$[5;3;1,2,3]$	$\Xi_b B$
	$[3;3;1,2,3]$	$\Xi_b B^*$
	$[4;3;1,2,3]$	$\Xi_b' B$
	$[2;3;1,2,3]$	$\Xi_b' B^*$
	$[1;3;1,2,3]$	$\Xi_b^* B^*$
$0\frac{3}{2}^-$	$[4;1;1,2,3]$	$\Lambda\Upsilon$
	$[4;2;1,2,3]$	$\Lambda_b B_s^*$
	$[4;3;1,2,3]$	$\Xi_b B^*$
	$[2;3;1,2,3]$	$\Xi_b^* B$
	$[3;3;1,2,3]$	$\Xi_b' B^*$
	$[1;3;1,2,3]$	$\Xi_b^* B^*$
$0\frac{5}{2}^-$	$[1;3;1,2,3]$	$\Xi_b^* B^*$

IJ^P	$[i;j;k]$	Channel
$1\frac{1}{2}^-$	$[4;2;1,2,3]$	$\Sigma\eta_b$
	$[2;2;1,2,3]$	$\Sigma\Upsilon$
	$[1;2;1,2,3]$	$\Sigma^*\Upsilon$
	$[5;1;1,2,3]$	$\Xi_b B$
	$[4;3;1,2,3]$	$\Sigma_b B_s$
	$[3;1;1,2,3]$	$\Xi_b B^*$
	$[2;3;1,2,3]$	$\Sigma_b B_s^*$
	$[1;3;1,2,3]$	$\Sigma_b^* B_s^*$
	$[4;1;1,2,3]$	$\Xi_b' B$
	$[2;1;1,2,3]$	$\Xi_b' B^*$
	$[1;1;1,2,3]$	$\Xi_b^* B^*$

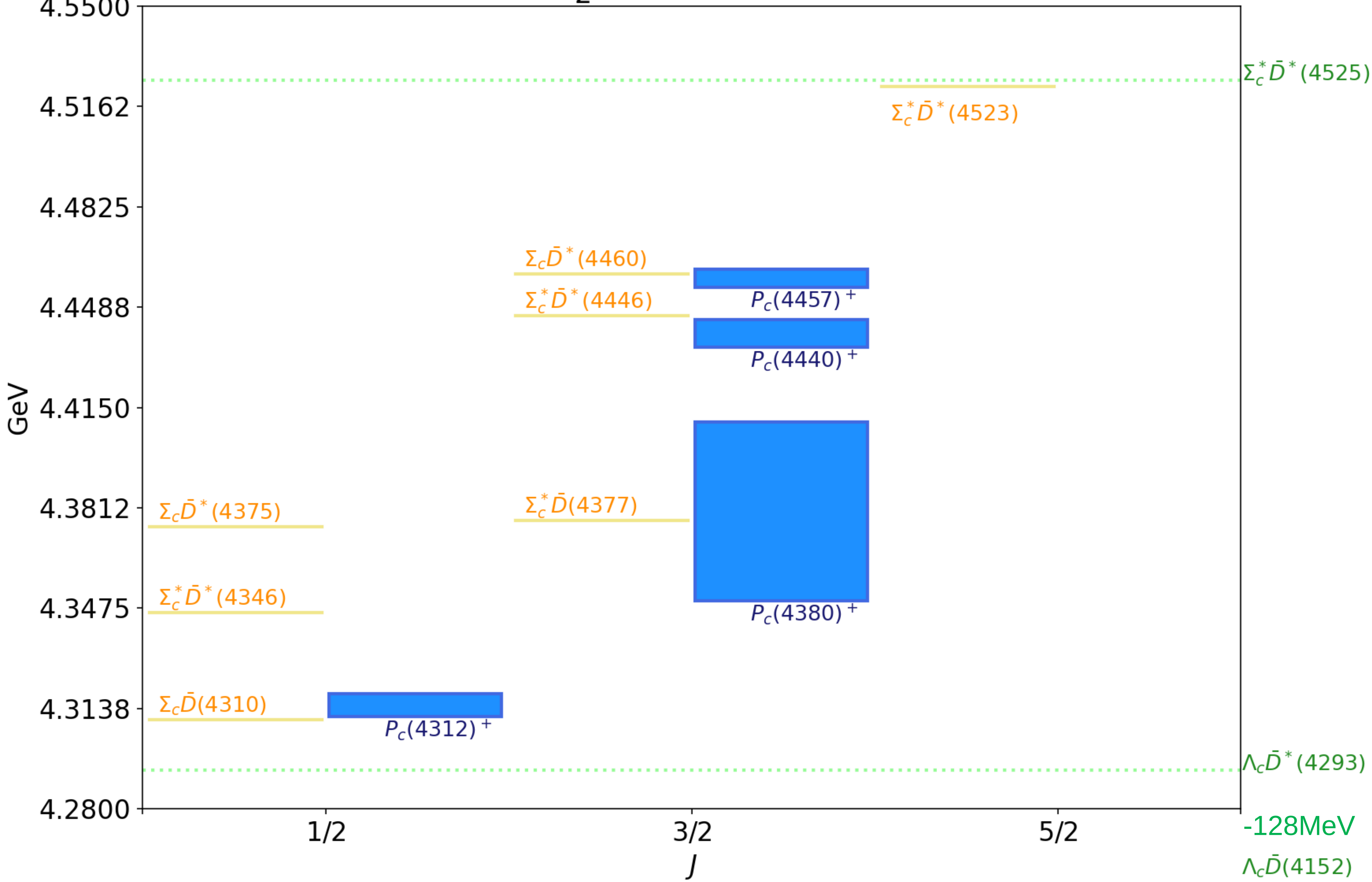
IJ^P	$[i;j;k]$	Channel
$1\frac{3}{2}^-$	$[3;2;1,2,3]$	$\Sigma\Upsilon$
	$[2;2;1,2,3]$	$\Sigma^*\eta_b$
	$[1;2;1,2,3]$	$\Sigma^*\Upsilon$
	$[4;1;1,2,3]$	$\Xi_b B^*$
	$[2;3;1,2,3]$	$\Sigma_b^* B_s$
	$[3;3;1,2,3]$	$\Sigma_b B_s^*$
	$[1;3;1,2,3]$	$\Sigma_b^* B_s^*$
	$[2;1;1,2,3]$	$\Xi_b^* B$
	$[3;1;1,2,3]$	$\Xi_b' B^*$
	$[1;1;1,2,3]$	$\Xi_b^* B^*$
$1\frac{5}{2}^-$	$[1;2;1,2,3]$	$\Sigma^*\Upsilon$
	$[1;3;1,2,3]$	$\Sigma_b^* B_s^*$
	$[1;1;1,2,3]$	$\Xi_b^* B^*$

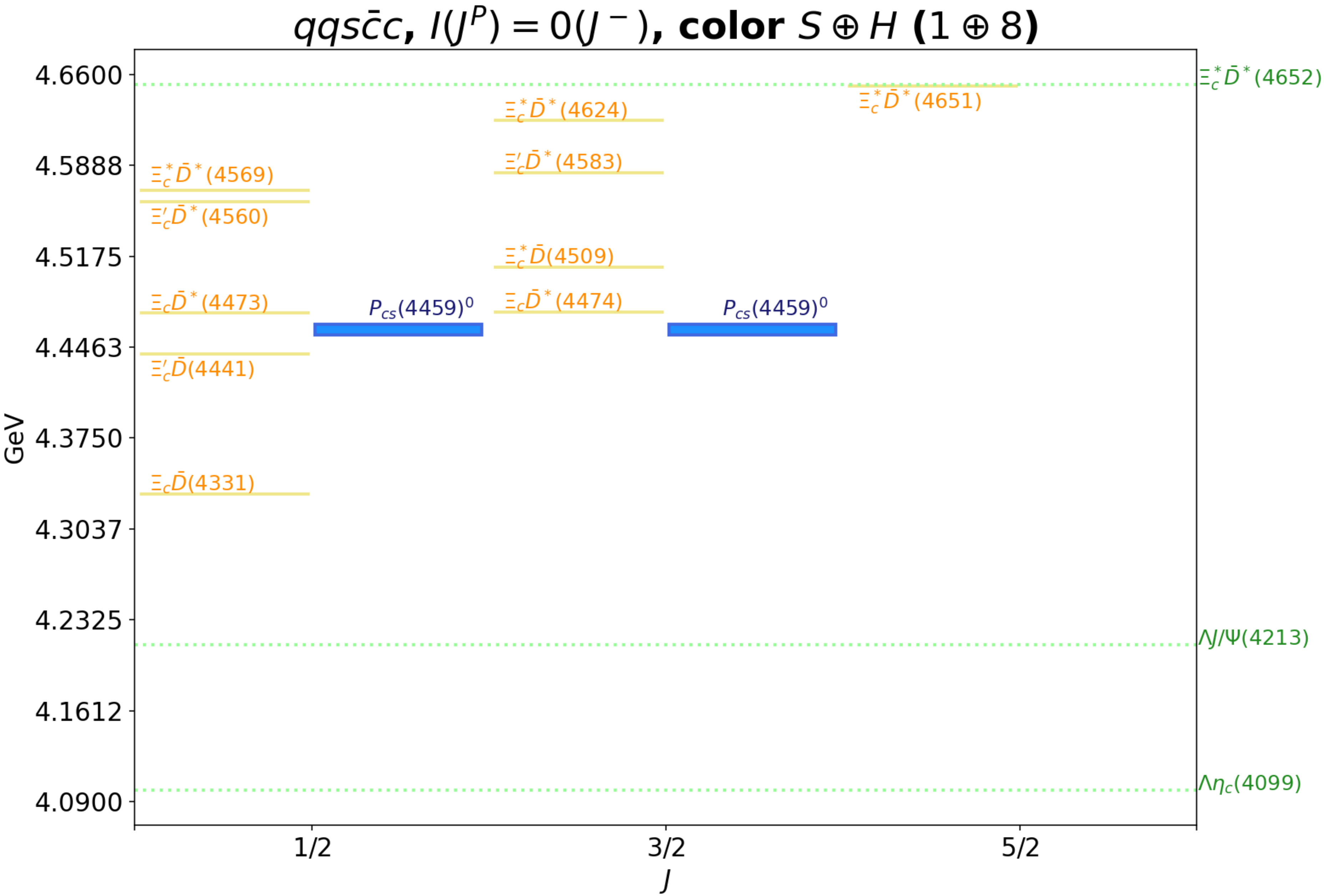
Model parameters ($qqs\bar{Q}Q$)

Quark masses	$m_u = m_d$(MeV)	313
	m_s(MeV)	555
	m_c(MeV)	1752
	m_b(MeV)	5100
Confinement	a_c(MeV)	430
	$\mu_c(fm^{-1})$	0.7
	Δ(MeV)	181.1
OGE	α_0	2.118
	$\Lambda_0(fm^{-1})$	0.113
	μ_0(MeV)	36.976
	$\hat{r}_0$(MeV·fm)	28.17
Goldstone bosons	$m_\pi(fm^{-1})$	0.7
	$m_K(fm^{-1})$	2.51
	$m_\eta(fm^{-1})$	2.77
	$m_\sigma(fm^{-1})$	3.42
	$\Lambda_\pi = \Lambda_\sigma(fm^{-1})$	4.2
	$\Lambda_K = \Lambda_\eta(fm^{-1})$	5.2
	$g_{ch}^2/(4\pi)$	0.54
	$\theta_p(^\circ)$	-15

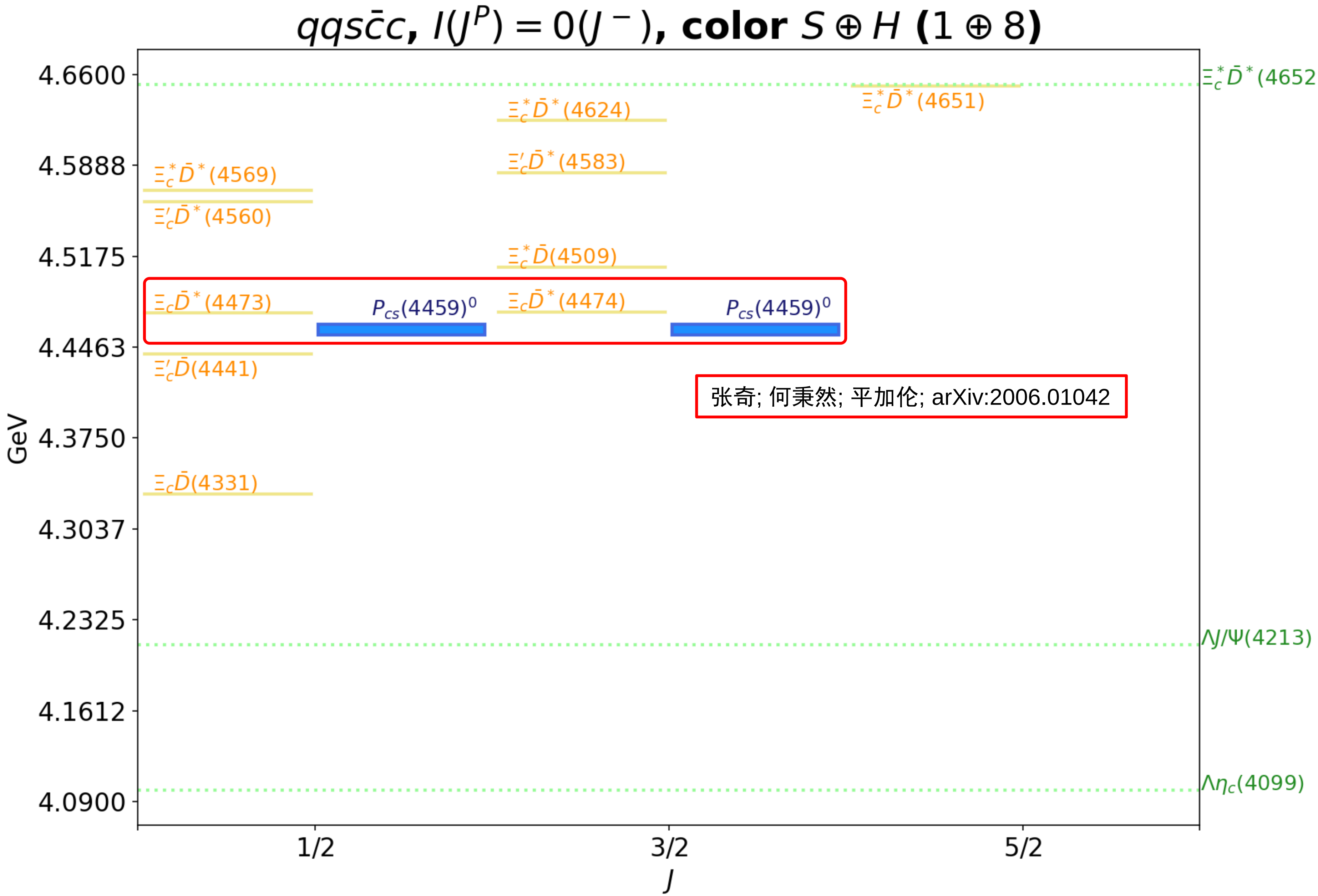
Meson	Theo.	Exp.	Baryon	Theo.	Exp.
D	1898	1865	Λ	1013	1116
D_s	1992	1968	Σ	1341	1189
D^*	2017	2007	Σ^*	1469	1383
D_s^*	2116	2112	Λ_c	2086	2286
η_c	3000	2983	Σ_c	2493	2454
J/ψ	3097	3097	Σ_c^*	2537	2518
B	5278	5279	Ξ_c	2574	2468
B^*	5319	5325	Ξ_c'	2665	2577
B_s	5356	5367	Ξ_c^*	2704	2645
B_s^*	5400	5415	Λ_b	5385	5620
B_c	6283	6275	Σ_b	5818	5811
B_c^*	6331	–	Σ_b^*	5835	5832
η_b	9468	9400	Ξ_b	5867	5792
Υ	9505	9460	Ξ_b'	5978	5935
			Ξ_b^*	5993	5950

$uud\bar{c}c$, $I(J^P) = \frac{1}{2}(J^-)$, color $S \oplus H$ $(1 \oplus 8)$

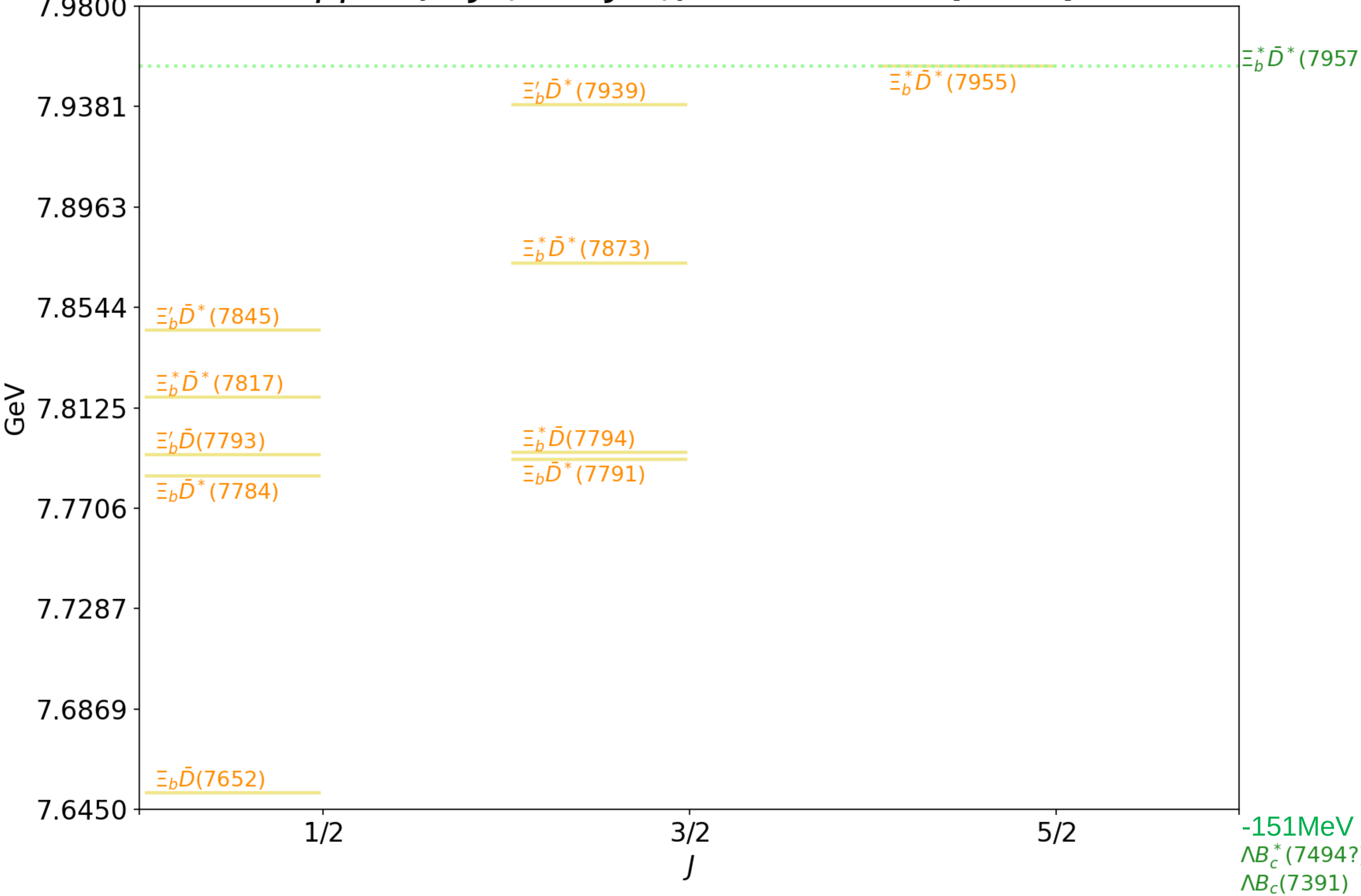


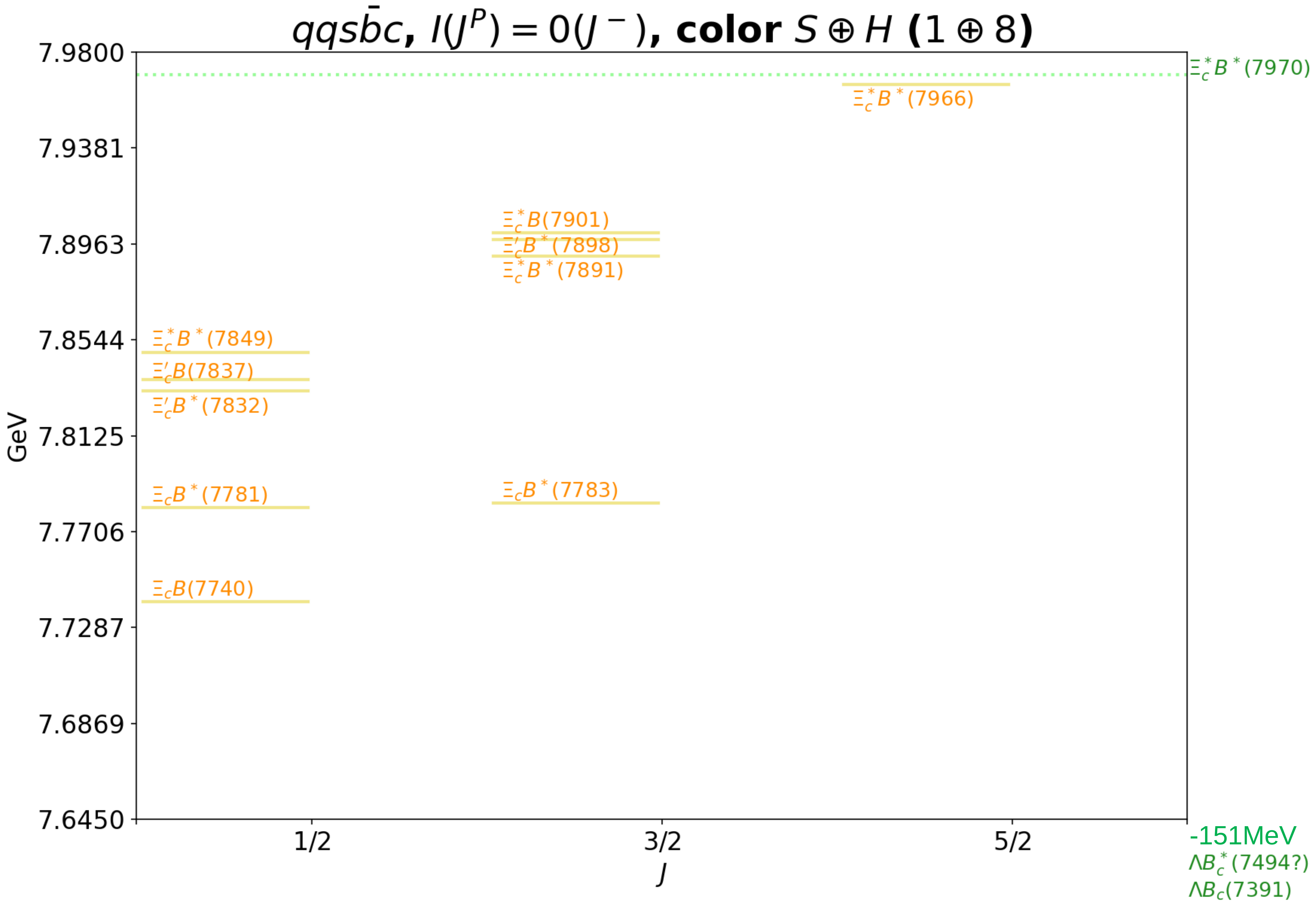


$qqs\bar{c}c$, $I(J^P) = 0(J^-)$, color $S \oplus H$ $(1 \oplus 8)$
4.6600
4.5888
4.5175
4.4463
4.3750
4.3037
4.2325
4.1612
4.0900
GeV
1/2
3/2
5/2
J
$\Xi_c^* \bar{D}^*(4652)$
$\Lambda J/\Psi(4213)$
$\Lambda \eta_c(4099)$
$\Xi_c^* \bar{D}^*(4569)$
$\Xi_c' \bar{D}^*(4560)$
$\Xi_c \bar{D}^*(4473)$
$\Xi_c' \bar{D}(4441)$
$\Xi_c \bar{D}(4331)$
$P_{cs}(4459)^0$
$\Xi_c^* \bar{D}^*(4624)$
$\Xi_c' \bar{D}^*(4583)$
$\Xi_c^* \bar{D}(4509)$
$\Xi_c \bar{D}^*(4474)$
$P_{cs}(4459)^0$
$\Xi_c^* \bar{D}^*(4651)$

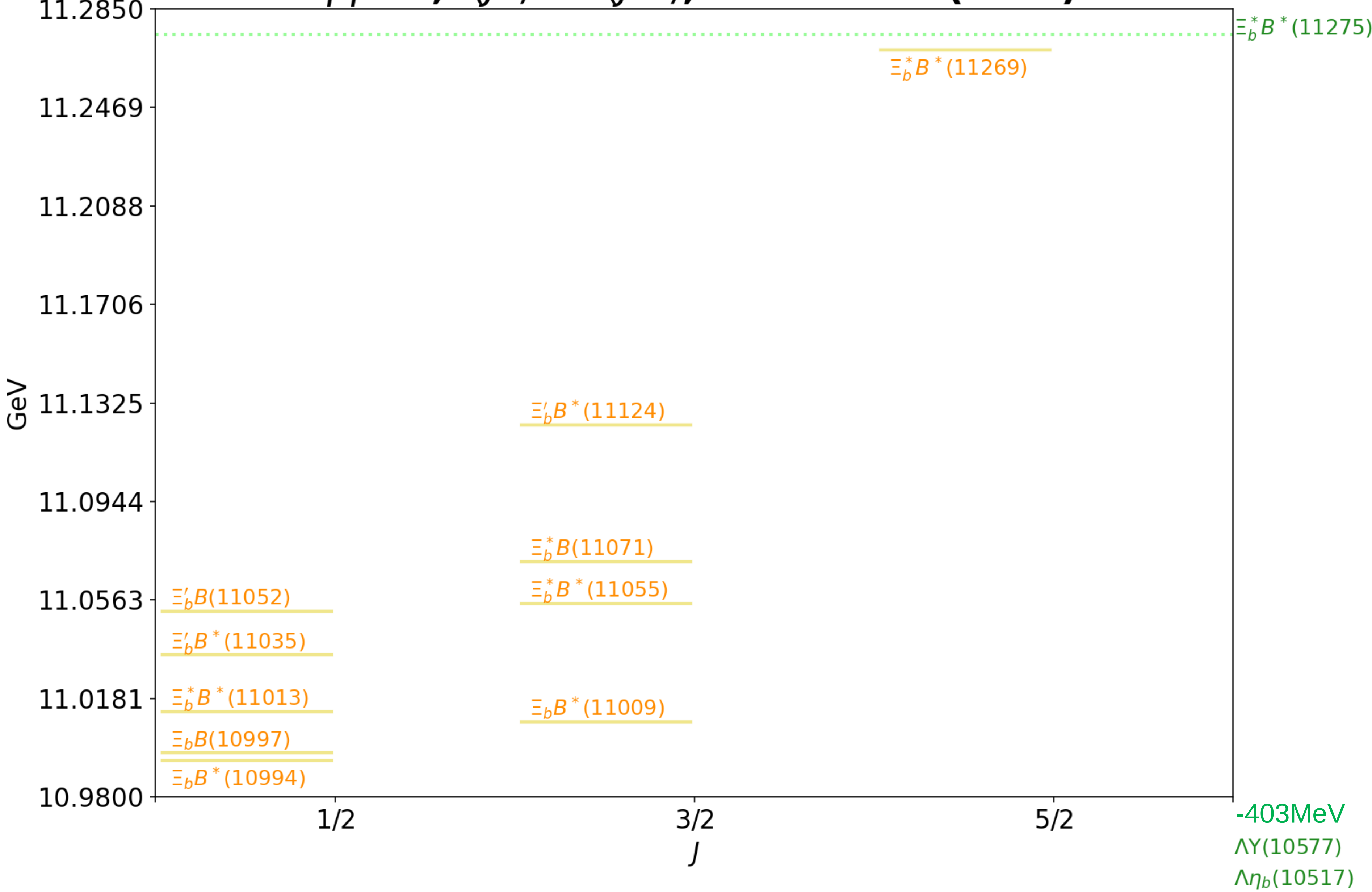

$qqs\bar{c}c$, $I(J^P) = 0(J^-)$, color $S \oplus H$ $(1 \oplus 8)$
GeV
4.6600
4.5888
4.5175
4.4463
4.3750
4.3037
4.2325
4.1612
4.0900
1/2
3/2
5/2
J
$\Xi_c^*\bar{D}^*(4569)$
$\Xi_c'\bar{D}^*(4560)$
$\Xi_c\bar{D}^*(4473)$
$\Xi_c'\bar{D}(4441)$
$\Xi_c\bar{D}(4331)$
$P_{cs}(4459)^0$
$\Xi_c^*\bar{D}^*(4624)$
$\Xi_c'\bar{D}^*(4583)$
$\Xi_c^*\bar{D}(4509)$
$\Xi_c\bar{D}^*(4474)$
$P_{cs}(4459)^0$
$\Xi_c^*\bar{D}^*(4651)$
$\Xi_c^*\bar{D}^*(4652)$
$\Lambda J/\Psi(4213)$
$\Lambda\eta_c(4099)$
张奇; 何秉然; 平加伦; arXiv:2006.01042

$qqs\bar{c}b$, $I(J^P) = 0(J^-)$, color $S \oplus H$ $(1 \oplus 8)$




$qqs\bar{b}c$, $I(J^P) = 0(J^-)$, color $S \oplus H$ $(1 \oplus 8)$
GeV
7.9800
7.9381
7.8963
7.8544
7.8125
7.7706
7.7287
7.6869
7.6450
1/2
3/2
5/2
J
$\Xi_c^* B^*(7970)$
$\Xi_c^* B^*(7966)$
$\Xi_c^* B(7901)$
$\Xi_c' B^*(7898)$
$\Xi_c^* B^*(7891)$
$\Xi_c^* B^*(7849)$
$\Xi_c' B(7837)$
$\Xi_c' B^*(7832)$
$\Xi_c B^*(7781)$
$\Xi_c B^*(7783)$
$\Xi_c B(7740)$
-151MeV
$\Lambda B_c^*(7494?)$
$\Lambda B_c(7391)$

$qqs\bar{b}b$, $I(J^P) = 0(J^-)$, color $S \oplus H$ $(1 \oplus 8)$



Root-mean-square distances ($qqs\bar{Q}Q$)

distance between two clusters

System	$(qsQ)(\bar{Q}q)$	r_{sQ}	r_{qq}	$r_{s\bar{Q}}$	$r_{Q\bar{Q}}$
$qqs\bar{c}c$	$\Xi_c^{(*,\prime)}\bar{D}^{(*)}(qsc,\bar{c}q)$	0.61	2.80	2.76	2.72
$qqs\bar{c}b$	$\Xi_b^{(*,\prime)}\bar{D}^{(*)}(qsb,\bar{c}q)$	0.54	1.14	1.03	0.90
$qqs\bar{b}c$	$\Xi_c^{(*,\prime)}B^{(*)}(qsc,\bar{b}q)$	0.62	1.08	0.90	0.78
$qqs\bar{b}b$	$\Xi_b^{(*,\prime)}B^{(*)}(qsb,\bar{b}q)$	0.59	1.10	0.61	0.33

Root-mean-square distances ($qqs\bar{Q}Q$)

distance between two clusters

System	$(qsQ)(\bar{Q}q)$	r_{sQ}	r_{qq}	$r_{s\bar{Q}}$	$r_{Q\bar{Q}}$
$qqs\bar{c}c$	$\Xi_c^{(*,\prime)}\bar{D}^{(*)}(qsc,\bar{c}q)$	0.61	2.80	2.76	2.72
$qqs\bar{c}b$	$\Xi_b^{(*,\prime)}\bar{D}^{(*)}(qsb,\bar{c}q)$	0.54	1.14	1.03	0.90
$qqs\bar{b}c$	$\Xi_c^{(*,\prime)}B^{(*)}(qsc,\bar{b}q)$	0.62	1.08	0.90	0.78
$qqs\bar{b}b$	$\Xi_b^{(*,\prime)}B^{(*)}(qsb,\bar{b}q)$	0.59	1.10	0.61	0.33

molecular states

compact states

compact $\bar{b}b$-pair surrounded by three other quarks

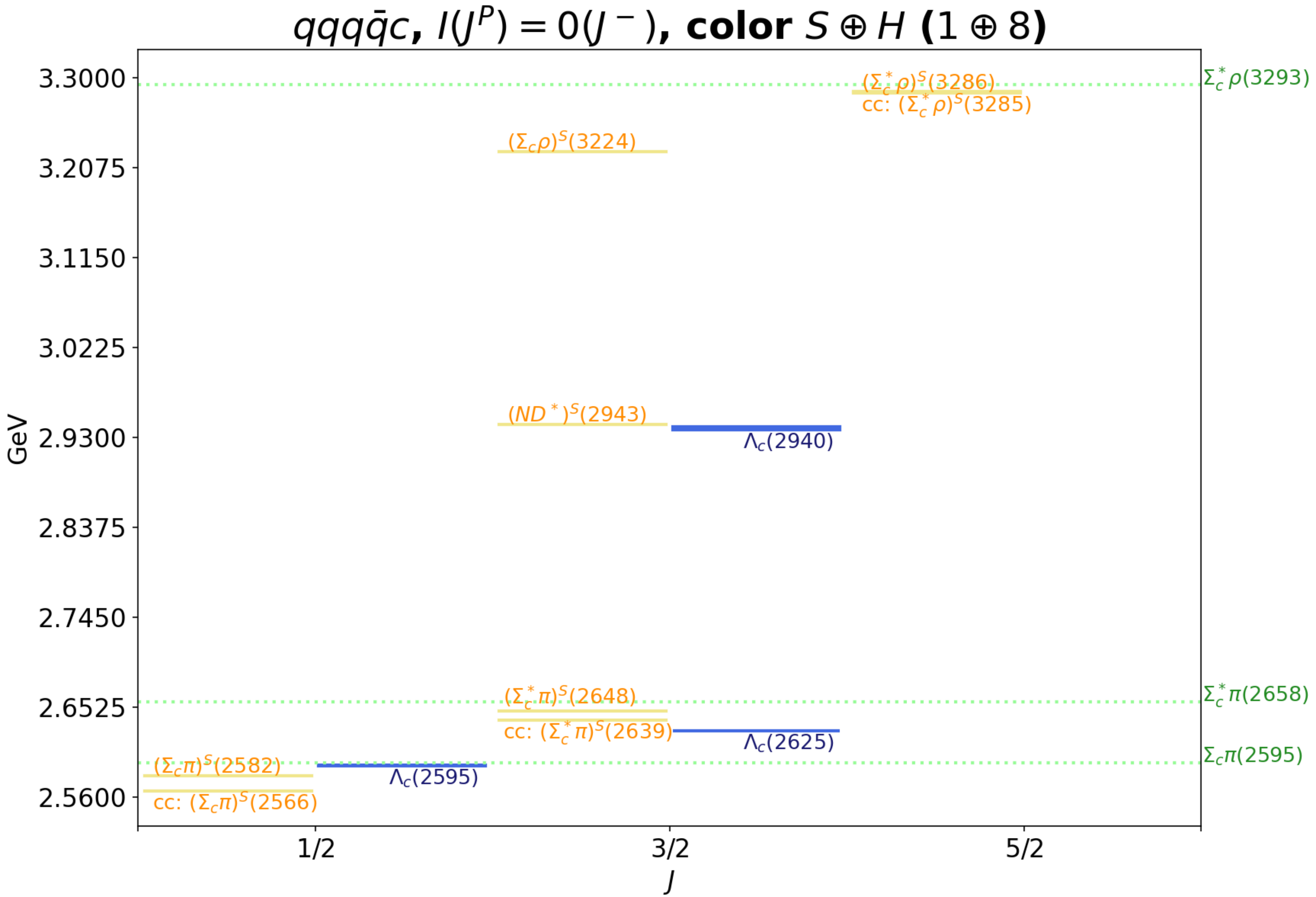
Physical channels for $qqq\bar{q}Q$

IJ^P	$[i;j;k]$	Channel
$0\frac{1}{2}^-$	$[4;4;1]$	$(\Sigma_c\pi)^S$
	$[4,5;4;2,3]$	$(\Sigma_c\pi)^H$
	$[5;1;1]$	$(\Lambda_c\eta)^S$
	$[4,5;1;2,3]$	$(\Lambda_c\eta)^H$
	$[3;1;1]$	$(\Lambda_c\omega)^S$
	$[2,3;1;2,3]$	$(\Lambda_c\omega)^H$
	$[2;4;1]$	$(\Sigma_c\rho)^S$
	$[2,3;4;2,3]$	$(\Sigma_c\rho)^H$
	$[1;4;1]$	$(\Sigma_c^*\rho)^S$
	$[1;4;3]$	$(\Sigma_c^*\rho)^H$
	$[4,5;2,3;1]$	$(ND)^S$
	$[4,5;2,3;2,3]$	$(ND)^H$
	$[2,3;2,3;1]$	$(ND^*)^S$
	$[2,3;2,3;2,3]$	$(ND^*)^H$
$0\frac{3}{2}^-$	$[2;4;1]$	$(\Sigma_c^*\pi)^S$
	$[2;4;3]$	$(\Sigma_c^*\pi)^H$
	$[4;1;1]$	$(\Lambda_c\omega)^S$
	$[3,4;1;2,3]$	$(\Lambda_c\omega)^H$
	$[3;4;1]$	$(\Sigma_c\rho)^S$
	$[3,4;4;2,3]$	$(\Sigma_c\rho)^H$
	$[1;4;1]$	$(\Sigma_c^*\rho)^S$
	$[1;4;3]$	$(\Sigma_c^*\rho)^H$
	$[3,4;2,3;1]$	$(ND^*)^S$
	$[3,4;2,3;2,3]$	$(ND^*)^H$
$0\frac{5}{2}^-$	$[1;4;1]$	$(\Sigma_c^*\rho)^S$
	$[1;4;3]$	$(\Sigma_c^*\rho)^H$
$1\frac{1}{2}^-$	$[5;1;1]$	$(\Lambda_c\pi)^S$
	$[4,5;1;2,3]$	$(\Lambda_c\pi)^H$
	$[4;3;1]$	$(\Sigma_c\pi)^S$
	$[4,5;3;2,3]$	$(\Sigma_c\pi)^H$
	$[4;2;1]$	$(\Sigma_c\eta)^S$
	$[4,5;2;2,3]$	$(\Sigma_c\eta)^H$
	$[3;1;1]$	$(\Lambda_c\rho)^S$
	$[2,3;1;2,3]$	$(\Lambda_c\rho)^H$
	$[2;3;1]$	$(\Sigma_c\rho)^S$
	$[2,3;3;2,3]$	$(\Sigma_c\rho)^H$
	$[2;2;1]$	$(\Sigma_c\omega)^S$
	$[2,3;2;2,3]$	$(\Sigma_c\omega)^H$
	$[1;3;1]$	$(\Sigma_c^*\rho)^S$
	$[1;3;3]$	$(\Sigma_c^*\rho)^H$
	$[1;2;1]$	$(\Sigma_c^*\omega)^S$
	$[1;2;3]$	$(\Sigma_c^*\omega)^H$
	$[4,5;4,5;1]$	$(ND)^S$
	$[4,5;4,5;2,3]$	$(ND)^H$
	$[2,3;4,5;1]$	$(ND^*)^S$
	$[2,3;4,5;2,3]$	$(ND^*)^H$
	$[1;6;1]$	$(\Delta D^*)^S$
	$[1;6;3]$	$(\Delta D^*)^H$
$1\frac{3}{2}^-$	$[2;3;1]$	$(\Sigma_c^*\pi)^S$
	$[2;3;3]$	$(\Sigma_c^*\pi)^H$
	$[4;1;1]$	$(\Lambda_c\rho)^S$
	$[3,4;1;2,3]$	$(\Lambda_c\rho)^H$
	$[2;2;1]$	$(\Sigma_c^*\eta)^S$
	$[2;2;3]$	$(\Sigma_c^*\eta)^H$
	$[3;3;1]$	$(\Sigma_c\rho)^S$
	$[3,4;3;2,3]$	$(\Sigma_c\rho)^H$
	$[3;2;1]$	$(\Sigma_c\omega)^S$
	$[3,4;2;2,3]$	$(\Sigma_c\omega)^H$
	$[1;3;1]$	$(\Sigma_c^*\rho)^S$
	$[1;3;3]$	$(\Sigma_c^*\rho)^H$
	$[1;2;1]$	$(\Sigma_c^*\omega)^S$
	$[1;2;3]$	$(\Sigma_c^*\omega)^H$
	$[3,4;4,5;1]$	$(ND^*)^S$
	$[3,4;4,5;2,3]$	$(ND^*)^H$
	$[2;6;1]$	$(\Delta D)^S$
	$[2;6;3]$	$(\Delta D)^H$
	$[1;6;1]$	$(\Delta D^*)^S$
	$[1;6;3]$	$(\Delta D^*)^H$
$1\frac{5}{2}^-$	$[1;3;1]$	$(\Sigma_c^*\rho)^S$
	$[1;3;3]$	$(\Sigma_c^*\rho)^H$
	$[1;2;1]$	$(\Sigma_c^*\omega)^S$
	$[1;2;3]$	$(\Sigma_c^*\omega)^H$
	$[1;6;1]$	$(\Delta D^*)^S$
	$[1;6;3]$	$(\Delta D^*)^H$
$2\frac{1}{2}^-$	$[4;1;1]$	$(\Sigma_c\pi)^S$
	$[4,5;1;2,3]$	$(\Sigma_c\pi)^H$
	$[2;1;1]$	$(\Sigma_c\rho)^S$
	$[2,3;1;2,3]$	$(\Sigma_c\rho)^H$
	$[1;1;1]$	$(\Sigma_c^*\rho)^S$
	$[1;1;3]$	$(\Sigma_c^*\rho)^H$
	$[1;2;1]$	$(\Delta D^*)^S$
	$[1;2;3]$	$(\Delta D^*)^H$
$2\frac{3}{2}^-$	$[2;1;1]$	$(\Sigma_c^*\pi)^S$
	$[2;1;3]$	$(\Sigma_c^*\pi)^H$
	$[3;1;1]$	$(\Sigma_c\rho)^S$
	$[3,4;1;2,3]$	$(\Sigma_c\rho)^H$
	$[1;1;1]$	$(\Sigma_c^*\rho)^S$
	$[1;1;3]$	$(\Sigma_c^*\rho)^H$
	$[2;2;1]$	$(\Delta D)^S$
	$[2;2;3]$	$(\Delta D)^H$
	$[1;2;1]$	$(\Delta D^*)^S$
	$[1;2;3]$	$(\Delta D^*)^H$
$2\frac{5}{2}^-$	$[1;1;1]$	$(\Sigma_c^*\rho)^S$
	$[1;1;3]$	$(\Sigma_c^*\rho)^H$
	$[1;2;1]$	$(\Delta D^*)^S$
	$[1;2;3]$	$(\Delta D^*)^H$

Model parameters ($qqq\bar{q}Q$)

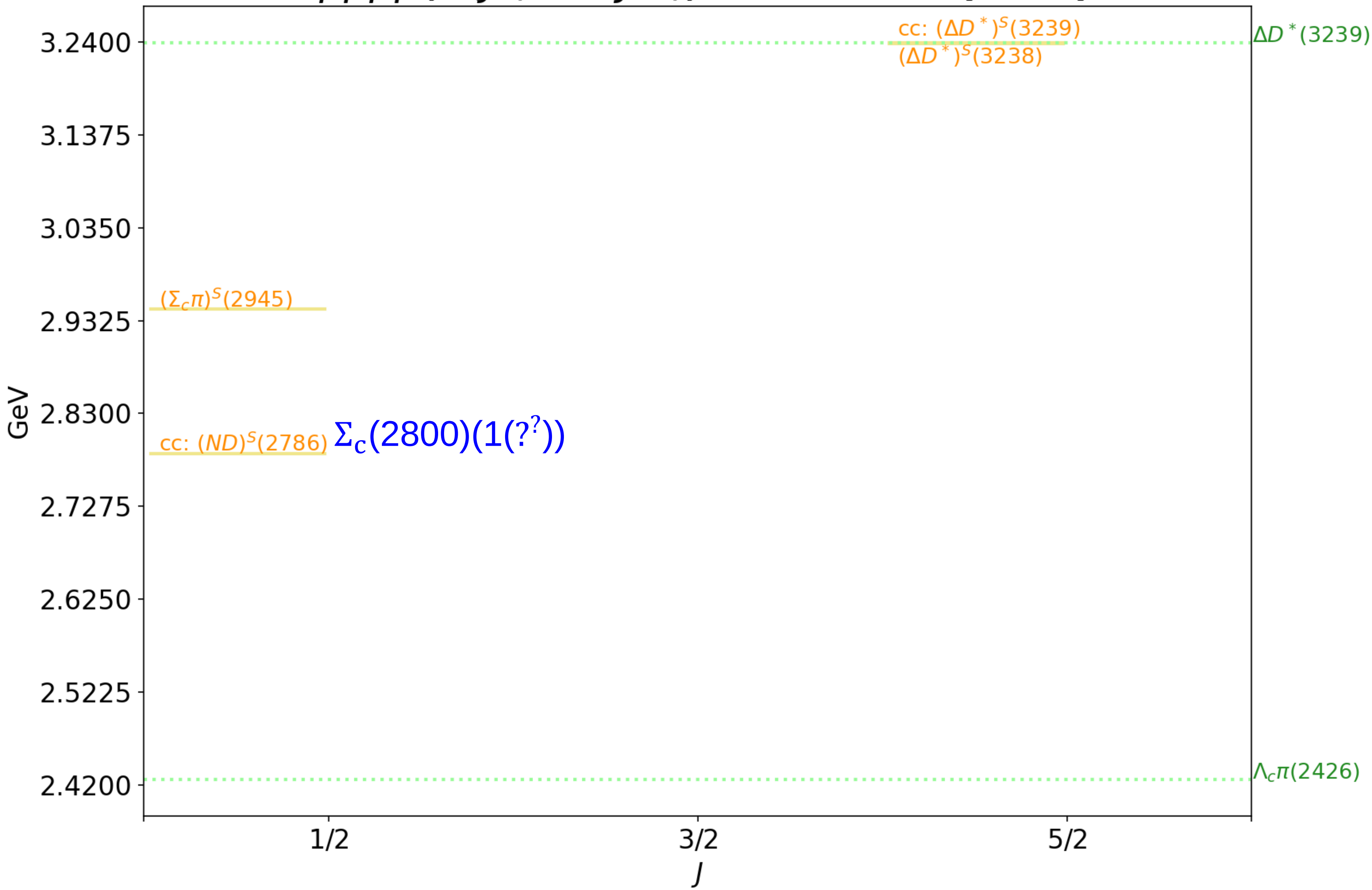
		I	II
Quark masses	$m_q = m_{\bar{q}}(MeV)$	450	430
	$m_c(MeV)$	1750	1734
	$m_b(MeV)$	5100	5092
Confinement	$a_c(MeV)$	80	74
	$\mu_c(fm^{-1})$	0.7	0.7
	$\Delta(MeV)$	46	36
OGE	α_s^{qq}	0.67	0.68
	α_s^{qc}	0.61	0.63
	α_s^{qb}	0.59	0.61
	$\hat{r}_0(MeV \cdot fm)$	28.17	28.17
Goldstone bosons	$m_\pi(fm^{-1})$	0.7	0.7
	$m_K(fm^{-1})$	2.51	2.51
	$m_\eta(fm^{-1})$	2.77	2.77
	$m_\sigma(fm^{-1})$	3.42	3.42
	$\Lambda_\pi = \Lambda_\sigma(fm^{-1})$	4.2	4.2
	$\Lambda_K = \Lambda_\eta(fm^{-1})$	5.2	5.2
	$g_{ch}^2/(4\pi)$	0.54	0.54
	$\theta_p(^\circ)$	-15	-15

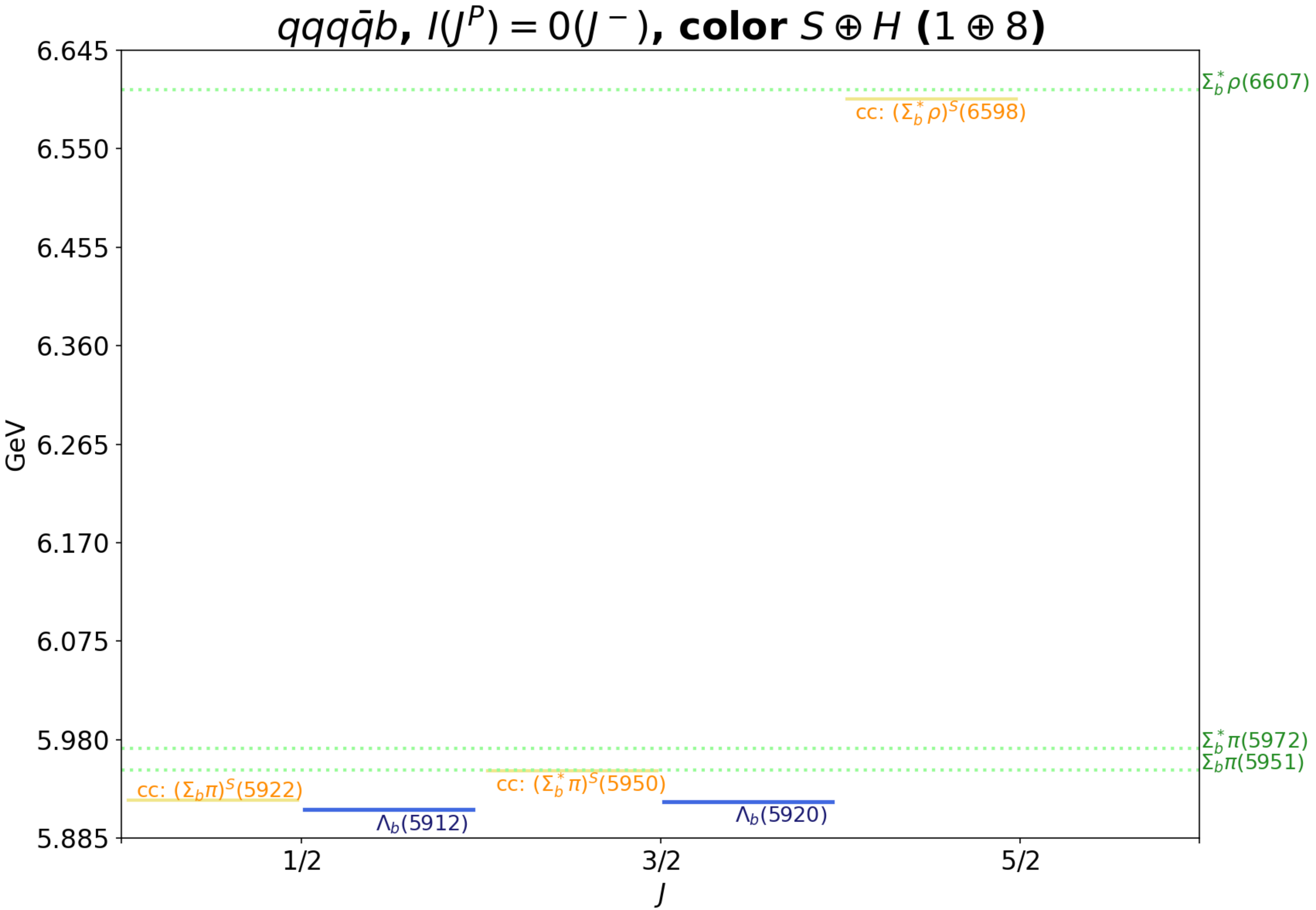
Meson	I	II	Exp.
π	156	149	140
ρ	795	799	775
η	660	672	548
ω	773	777	783
D	1867	1866	1869
D^*	2031	2034	2007
B	5303	5315	5279
B^*	5350	5362	5325
Baryon	**I**	**II**	**Exp.**
N	915	908	939
Δ	1229	1235	1232
Λ_c	2270	2263	2286
Σ_c	2469	2473	2455
Σ_c^*	2495	2499	2518
Λ_b	5586	5589	5620
Σ_b	5808	5821	5811
Σ_b^*	5818	5832	5832



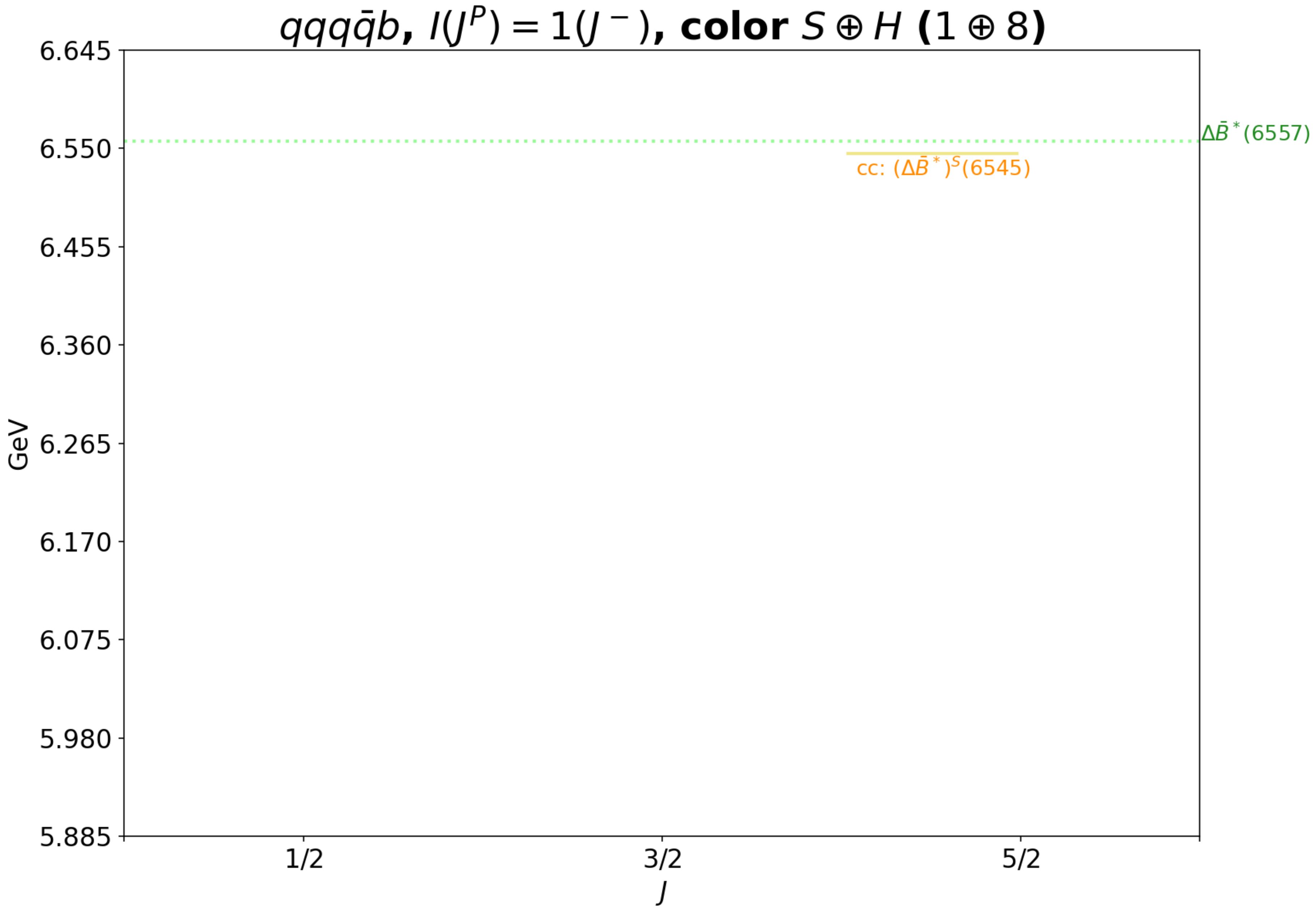
$qqq\bar{q}c$, $I(J^P) = 0(J^-)$, color $S \oplus H$ (1 ⊕ 8)
GeV
3.3000
3.2075
3.1150
3.0225
2.9300
2.8375
2.7450
2.6525
2.5600
1/2
3/2
5/2
J
$(\Sigma_c^* \rho)^S(3286)$
cc: $(\Sigma_c^* \rho)^S(3285)$
$\Sigma_c^* \rho(3293)$
$(\Sigma_c \rho)^S(3224)$
$(ND^*)^S(2943)$
$\Lambda_c(2940)$
$(\Sigma_c^* \pi)^S(2648)$
cc: $(\Sigma_c^* \pi)^S(2639)$
$\Sigma_c^* \pi(2658)$
$\Lambda_c(2625)$
$\Sigma_c \pi(2595)$
$(\Sigma_c \pi)^S(2582)$
cc: $(\Sigma_c \pi)^S(2566)$
$\Lambda_c(2595)$

$qqq\bar{q}c$, $I(J^P) = 1(J^-)$, color $S \oplus H$ $(1 \oplus 8)$





$qqq\bar{q}b$, $I(J^P) = 0(J^-)$, color $S \oplus H$ (1 ⊕ 8)
6.645
6.550
6.455
6.360
6.265
6.170
6.075
5.980
5.885
GeV
1/2
3/2
5/2
J
$\Sigma_b^*\rho(6607)$
cc: $(\Sigma_b^*\rho)^S(6598)$
$\Sigma_b^*\pi(5972)$
$\Sigma_b\pi(5951)$
cc: $(\Sigma_b\pi)^S(5922)$
cc: $(\Sigma_b^*\pi)^S(5950)$
$\Lambda_b(5912)$
$\Lambda_b(5920)$



$qqq\bar{q}b$, $I(J^P)=1(J^-)$, color $S \oplus H$ $(1 \oplus 8)$
6.645
6.550
6.455
6.360
6.265
6.170
6.075
5.980
5.885
GeV
1/2
3/2
5/2
J
$\Delta\bar{B}^*(6557)$
cc: $(\Delta\bar{B}^*)^S(6545)$

Root-mean-square distances ($qqq\bar{q}Q$)

$I(J^P)$	Main channel	r_{qq}	$r_{q\bar{q}}$	r_{qc}	$r_{c\bar{q}}$
$0(\frac{1}{2}^-)$	$\Sigma_c\pi(qqc,\bar{q}q)$	1.1	1.0	0.9	1.0
$0(\frac{3}{2}^-)$	$\Sigma_c^*\pi(qqc,\bar{q}q)$	1.4	1.3	1.1	1.3
$0(\frac{5}{2}^-)$	$\Sigma_c^*\rho(qqc,\bar{q}q)$	2.0	2.0	1.5	2.2
$1(\frac{5}{2}^-)$	$\Delta D^*(qqq,\bar{q}c)$	1.2	1.9	1.7	1.0

$I(J^P)$	Main channel	r_{qq}	$r_{q\bar{q}}$	r_{qb}	$r_{b\bar{q}}$
$0(\frac{1}{2}^-)$	$\Sigma_b\pi(qqb,\bar{q}q)$	1.2	1.1	0.9	1.1
$0(\frac{3}{2}^-)$	$\Sigma_b^*\pi(qqb,\bar{q}q)$	1.3	1.2	1.0	1.2
$0(\frac{5}{2}^-)$	$\Sigma_b^*\rho(qqb,\bar{q}q)$	1.8	1.8	1.3	1.9
$1(\frac{5}{2}^-)$	$\Delta\bar{B}^*(qqq,\bar{q}b)$	1.2	1.6	1.4	0.9

distance between two clusters

Root-mean-square distances ($qqq\bar{q}Q$)

$I(J^P)$	Main channel	r_{qq}	$r_{q\bar{q}}$	r_{qc}	$r_{c\bar{q}}$
$0(\frac{1}{2}^-)$	$\Sigma_c\pi(qqc,\bar{q}q)$	1.1	1.0	0.9	1.0
$0(\frac{3}{2}^-)$	$\Sigma_c^*\pi(qqc,\bar{q}q)$	1.4	1.3	1.1	1.3
$0(\frac{5}{2}^-)$	$\Sigma_c^*\rho(qqc,\bar{q}q)$	2.0	2.0	1.5	2.2
$1(\frac{5}{2}^-)$	$\Delta D^*(qqq,\bar{q}c)$	1.2	1.9	1.7	1.0

$I(J^P)$	Main channel	r_{qq}	$r_{q\bar{q}}$	r_{qb}	$r_{b\bar{q}}$
$0(\frac{1}{2}^-)$	$\Sigma_b\pi(qqb,\bar{q}q)$	1.2	1.1	0.9	1.1
$0(\frac{3}{2}^-)$	$\Sigma_b^*\pi(qqb,\bar{q}q)$	1.3	1.2	1.0	1.2
$0(\frac{5}{2}^-)$	$\Sigma_b^*\rho(qqb,\bar{q}q)$	1.8	1.8	1.3	1.9
$1(\frac{5}{2}^-)$	$\Delta\bar{B}^*(qqq,\bar{q}b)$	1.2	1.6	1.4	0.9

molecular states

compact states

Outline

- Introduction
- Chiral quark model
- $qqs\bar{Q}Q$ and $qqq\bar{q}Q$ system
- ***Summary***

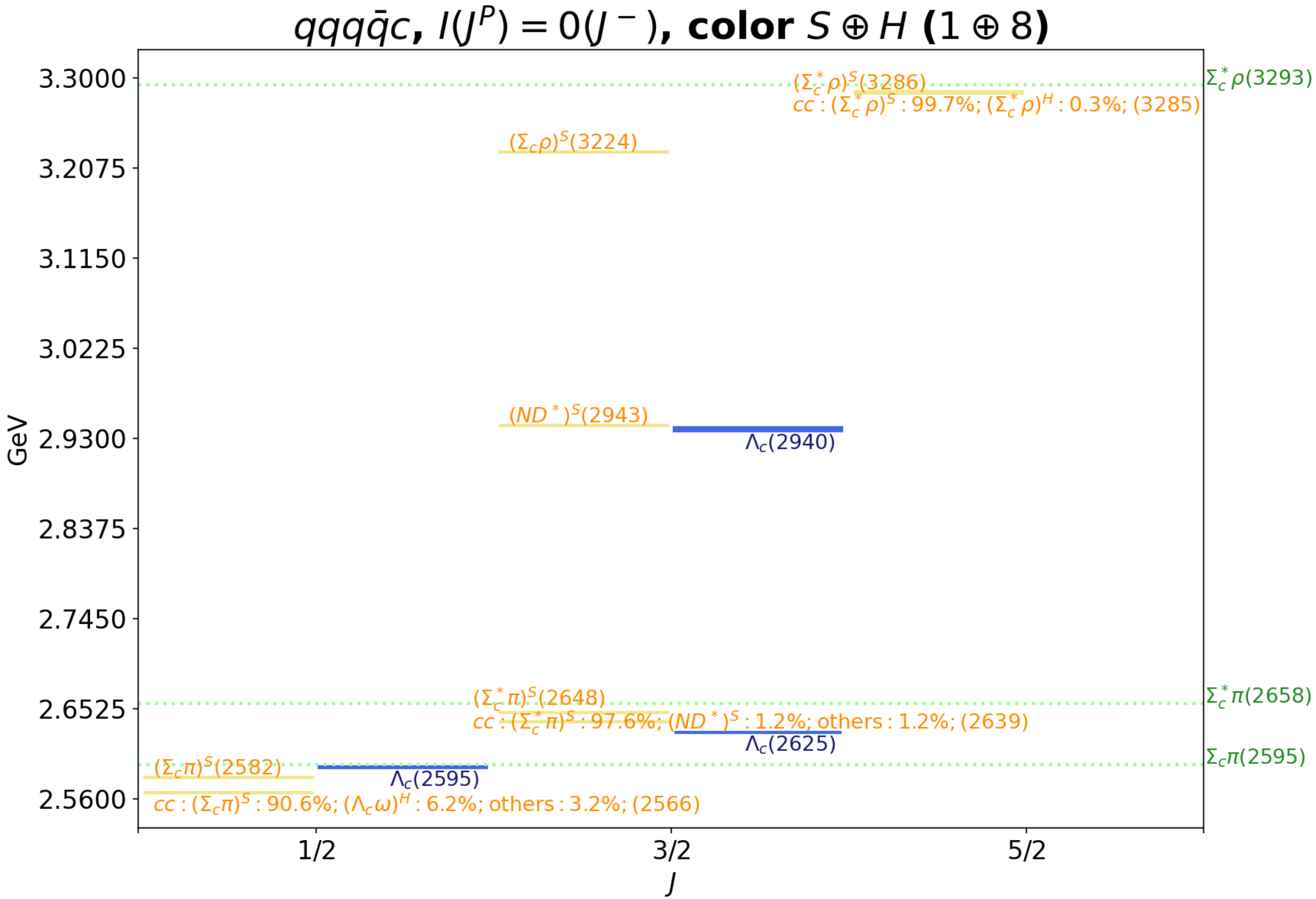
Summary:

- A series of possible pentaquarks with heavy flavors are predicted by five-body dynamical calculations.

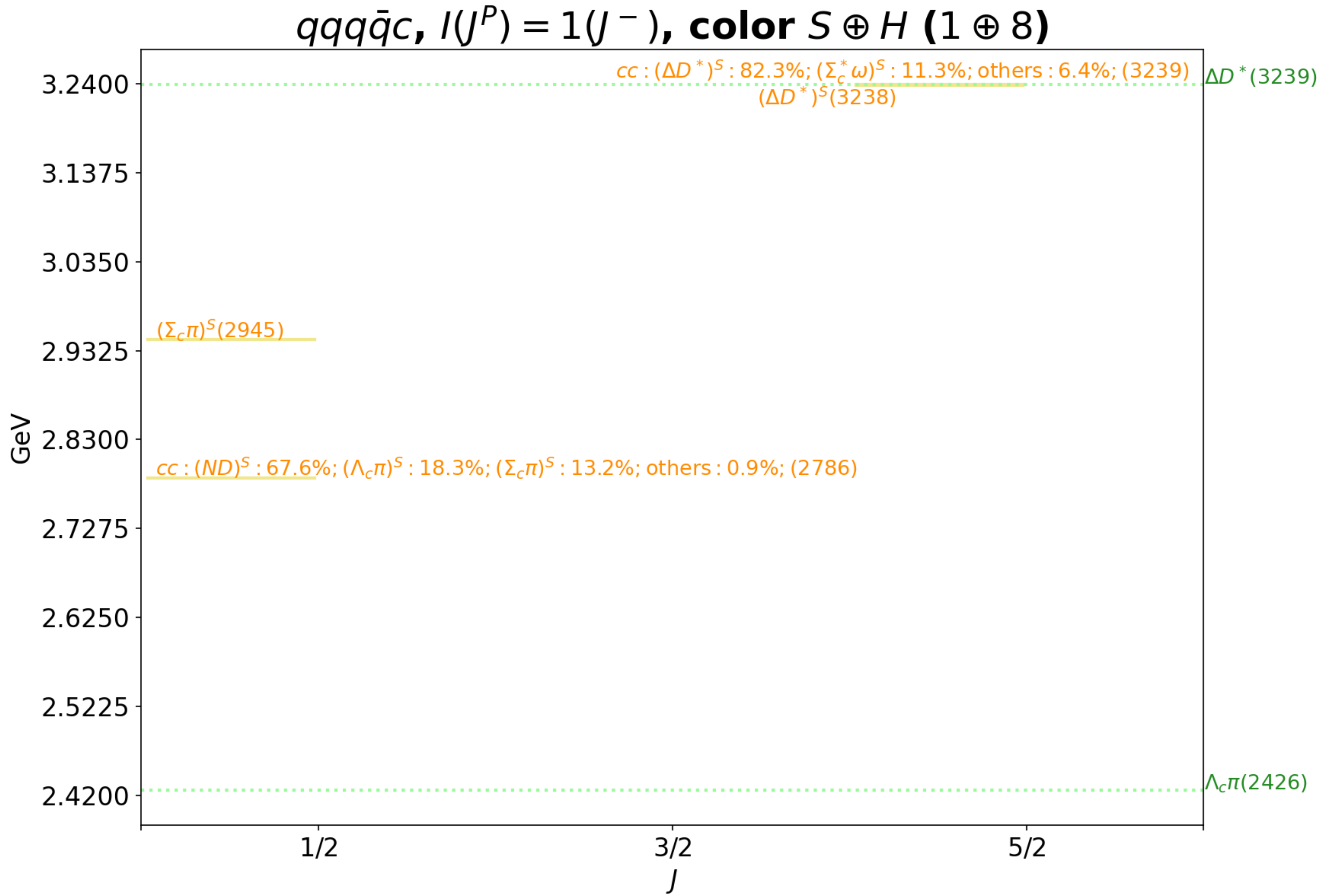
- Taking hidden color structure into consideration always provides more binding energy than color singlet structure.

- The more heavier quark presents, the easier to form the bound states.

Thank you for your attention!



$qqq\bar{q}c$, $I(J^P) = 0(J^-)$, color $S \oplus H$ $(1 \oplus 8)$
GeV
3.3000
3.2075
3.1150
3.0225
2.9300
2.8375
2.7450
2.6525
2.5600
1/2
3/2
5/2
J
$(\Sigma_c^*\rho)^S(3286)$
$cc : (\Sigma_c^*\rho)^S : 99.7\%; (\Sigma_c^*\rho)^H : 0.3\%; (3285)$
$\Sigma_c^*\rho(3293)$
$(\Sigma_c\rho)^S(3224)$
$(ND^*)^S(2943)$
$\Lambda_c(2940)$
$(\Sigma_c^*\pi)^S(2648)$
$cc : (\Sigma_c^*\pi)^S : 97.6\%; (ND^*)^S : 1.2\%; \text{others} : 1.2\%; (2639)$
$\Sigma_c^*\pi(2658)$
$\Lambda_c(2625)$
$\Sigma_c\pi(2595)$
$(\Sigma_c\pi)^S(2582)$
$\Lambda_c(2595)$
$cc : (\Sigma_c\pi)^S : 90.6\%; (\Lambda_c\omega)^H : 6.2\%; \text{others} : 3.2\%; (2566)$



$qqq\bar{q}c$, $I(J^P) = 1(J^-)$, color $S \oplus H$ $(1 \oplus 8)$
GeV
3.2400
3.1375
3.0350
2.9325
2.8300
2.7275
2.6250
2.5225
2.4200
$cc : (\Delta D^*)^S : 82.3\%; (\Sigma_c^* \omega)^S : 11.3\%; \text{others} : 6.4\%; (3239)$
$(\Delta D^*)^S(3238)$
$\Delta D^*(3239)$
$(\Sigma_c \pi)^S(2945)$
$cc : (ND)^S : 67.6\%; (\Lambda_c \pi)^S : 18.3\%; (\Sigma_c \pi)^S : 13.2\%; \text{others} : 0.9\%; (2786)$
$\Lambda_c \pi(2426)$
1/2
3/2
5/2
J

	rest mass	kinetic	V^C	V^G
$\Sigma_c \pi$	3550.0	4136.9	-233.9	-4667.7
$\Sigma_c + \pi$	3550.0	4081.8	-232.2	-4635.0
Δ_E	0.0	55.1	-1.7	-32.7
	V^π	V^K	V^η	V^σ
$\Sigma_c \pi$	-279.8	0.0	214.4	-107.9
$\Sigma_c + \pi$	-278.0	0.0	212.1	-73.6
Δ_E	-1.8	0.0	2.3	-34.3

	rest mass	kinetic	V^C	V^G
ND^*	3550.0	1021.2	-166.6	-1097.0
$N+D^*$	3550.0	986.5	-167.2	-1096.4
Δ_E	0.0	34.7	0.6	-0.6
	V^π	V^K	V^η	V^σ
ND^*	-332.2	0.0	62.8	-95.1
$N+D^*$	-319.5	0.0	63.6	-71.2
Δ_E	-12.7	0.0	-0.8	-23.9