Decay Properties of P-wave Bottom Baryons in Light-cone Sum Rules

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Collaborators: Hui-Min Yang, Hua-Xing Chen, Atsushi Hosaka, Qiang Mao

Based on: E-L Cui, etc., PRD 99, 094021 (2019)
H-M Yang, etc, arXiv:1909.13575

CLHC2019@DLUT, 2019.10.23-2019.10.27

CONTENTS

- Internal structure of heavy baryons
- QCD sum rules and light-cone sum rules
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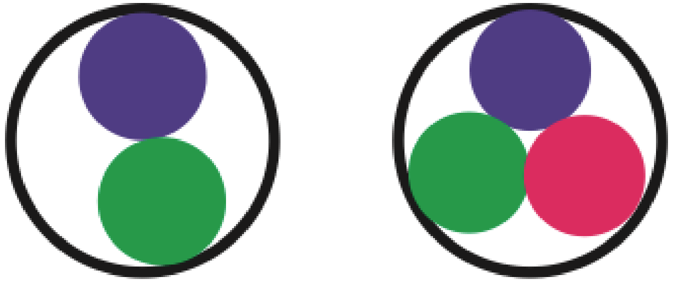
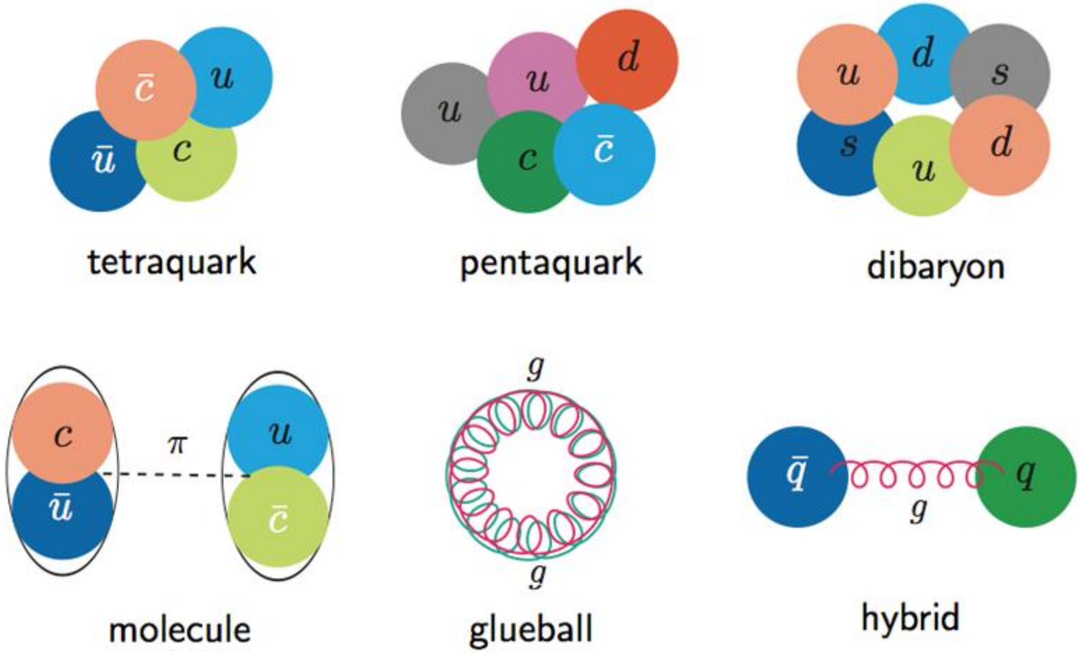
Hadron categorizations



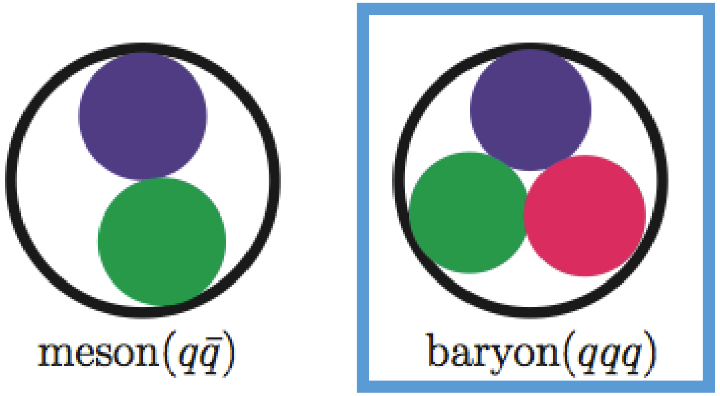
meson($q\bar{q}$) baryon(qqq)

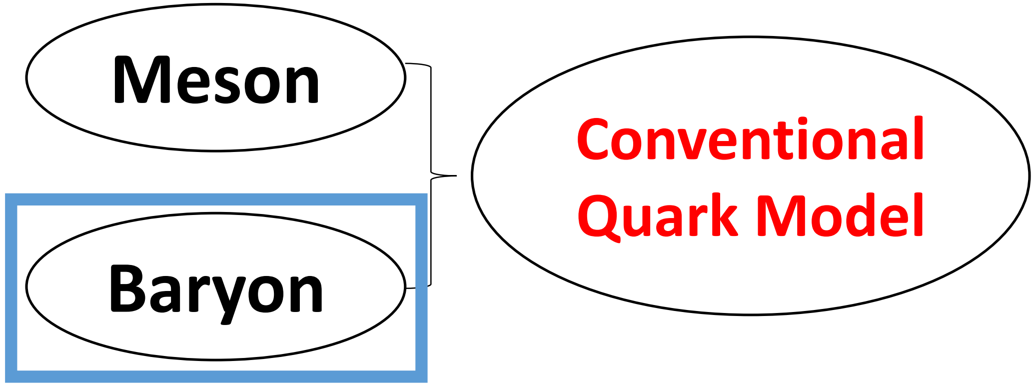
Meson
Baryon
Conventional Quark Model

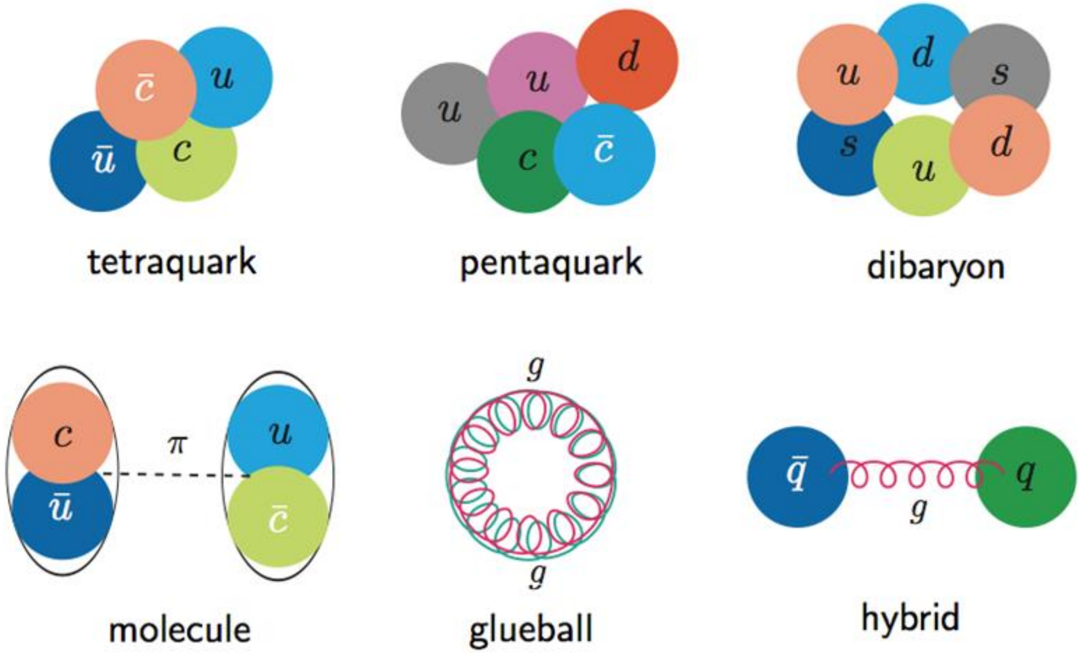


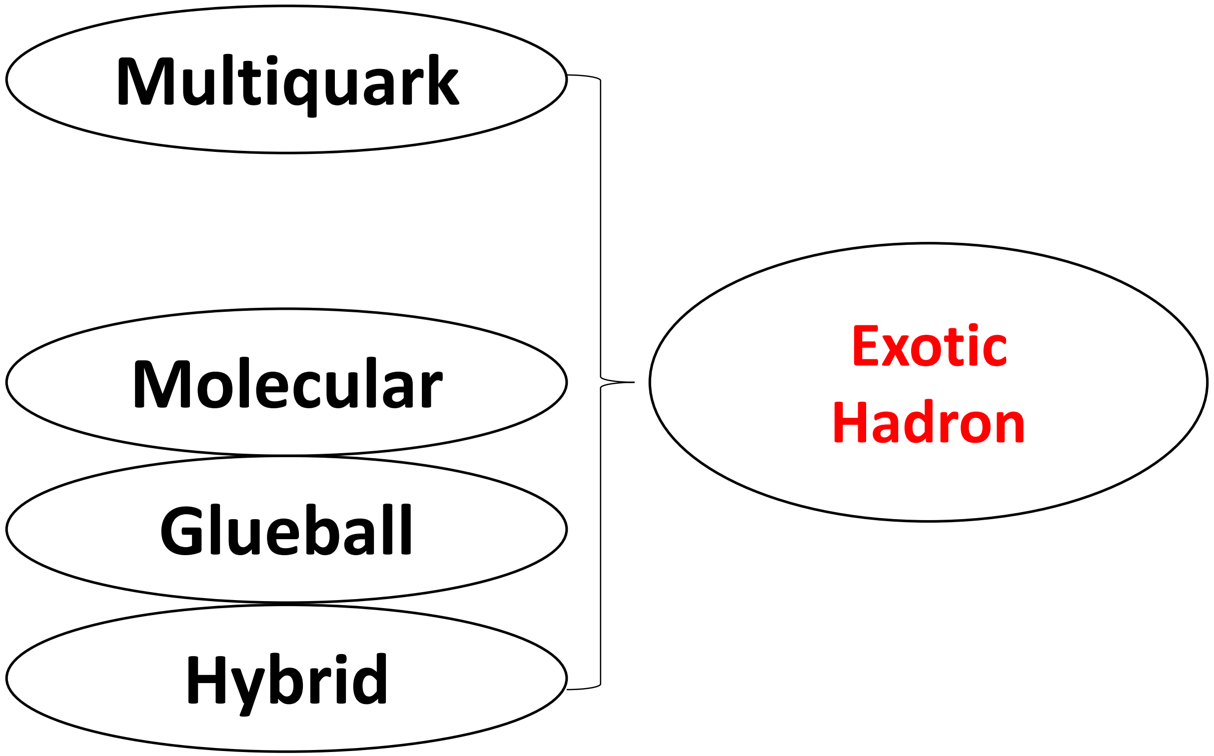
Multiquark
Molecular
Glueball
Hybrid
Exotic Hadron

Hadron categorizations









SU(3) and SU(4) multiplets

- Since the quarks are fermions, the state function must be antisymmetric under interchange of any two equal-mass quarks (up and down quarks in the limit of isospin symmetry). Thus it can be written as

$$|\,qqq\,\rangle_A = |\,\text{color}\,\rangle_A \times |\,\text{space, spin, flavor}\,\rangle_S$$

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- The "ordinary" baryons are made up of u, d, and s quarks. The three flavors imply an approximate flavor SU(3). Baryons belong to

$$\mathbf{3} \otimes \mathbf{3} \otimes \mathbf{3} = \mathbf{10}_S \oplus \mathbf{8}_M \oplus \mathbf{8}_M \oplus \mathbf{1}_A$$

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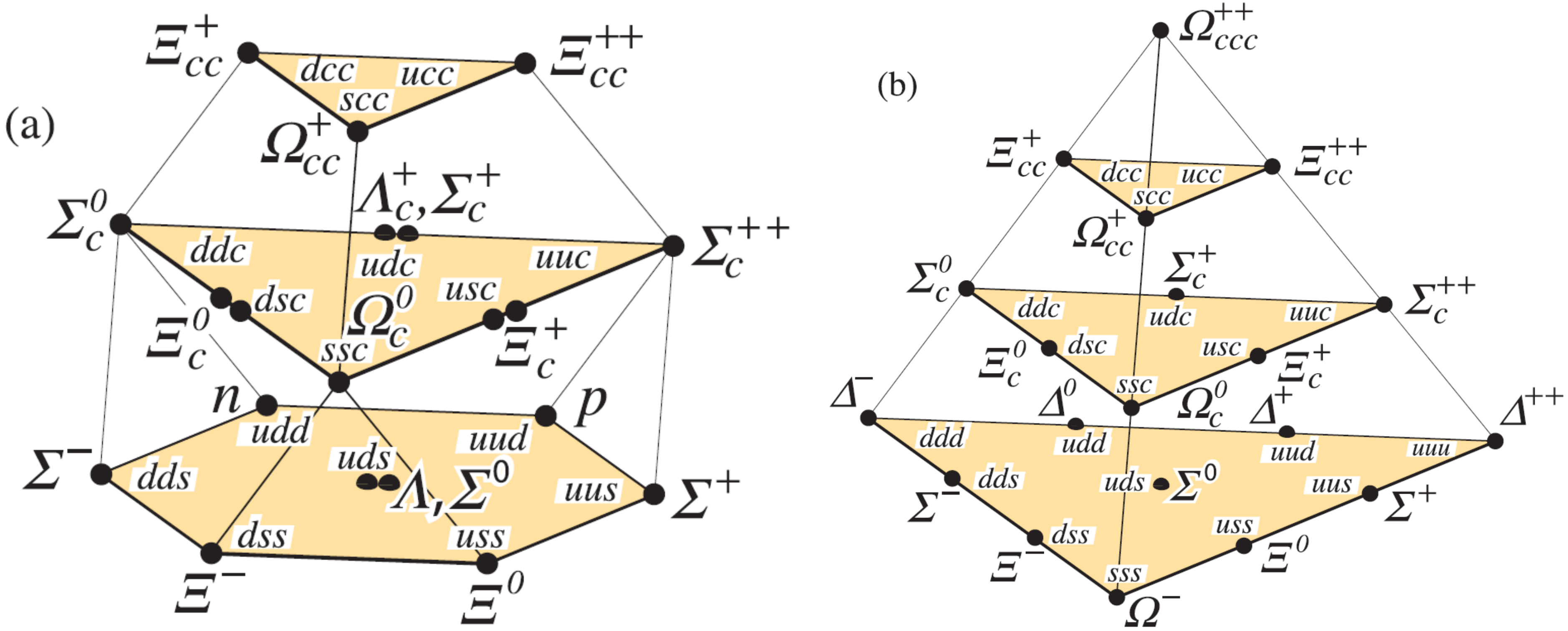
- For flavor SU(4)

$$\mathbf{4} \otimes \mathbf{4} \otimes \mathbf{4} = \mathbf{20}_S \oplus \mathbf{20}_M \oplus \mathbf{20}_M \oplus \mathbf{4}_A$$

SU(3) and SU(4) multiplets

- SU(4) multiplets of baryons made of u, d, s, and c quarks. (a) The 20-plet with an SU(3) octet. (b) The 20-plet with an SU(3) decuplet.



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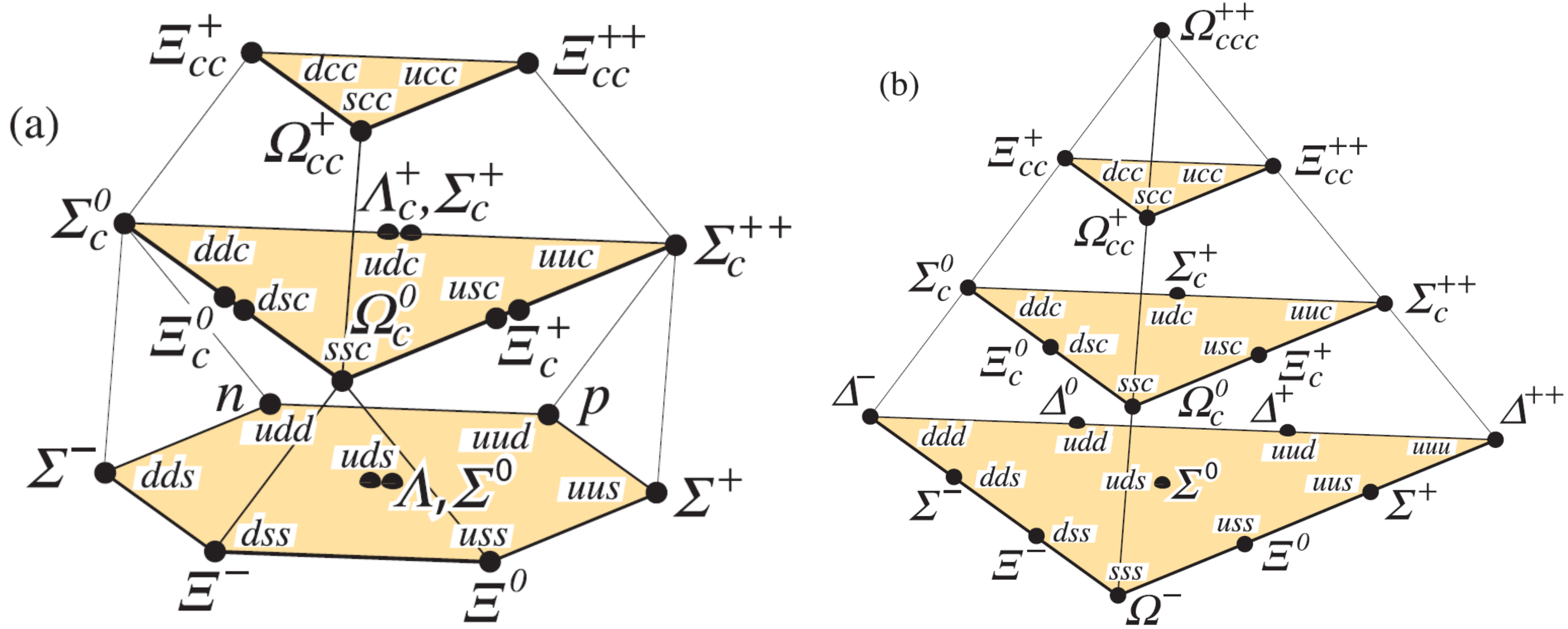

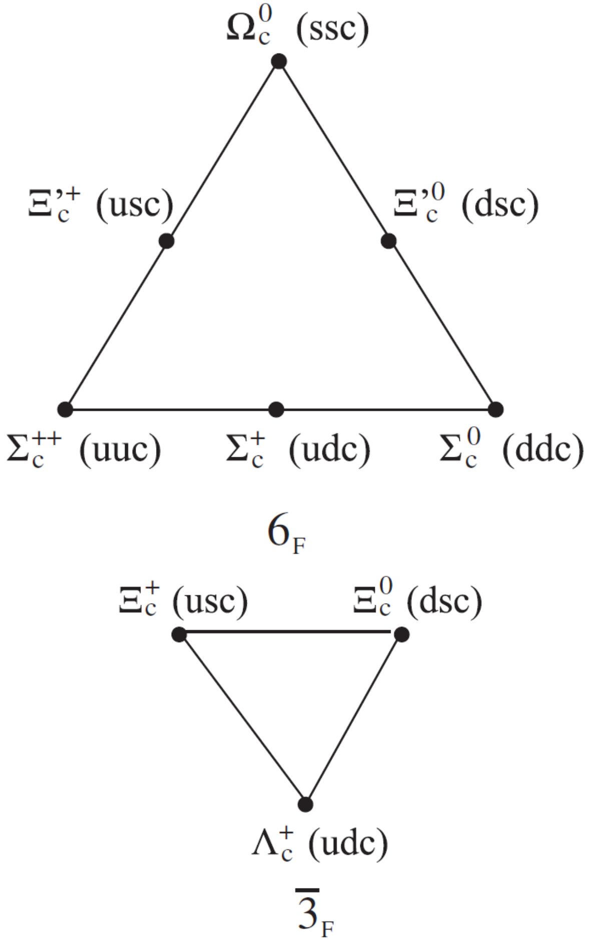

- SU(3) multiplets of charmed baryons.

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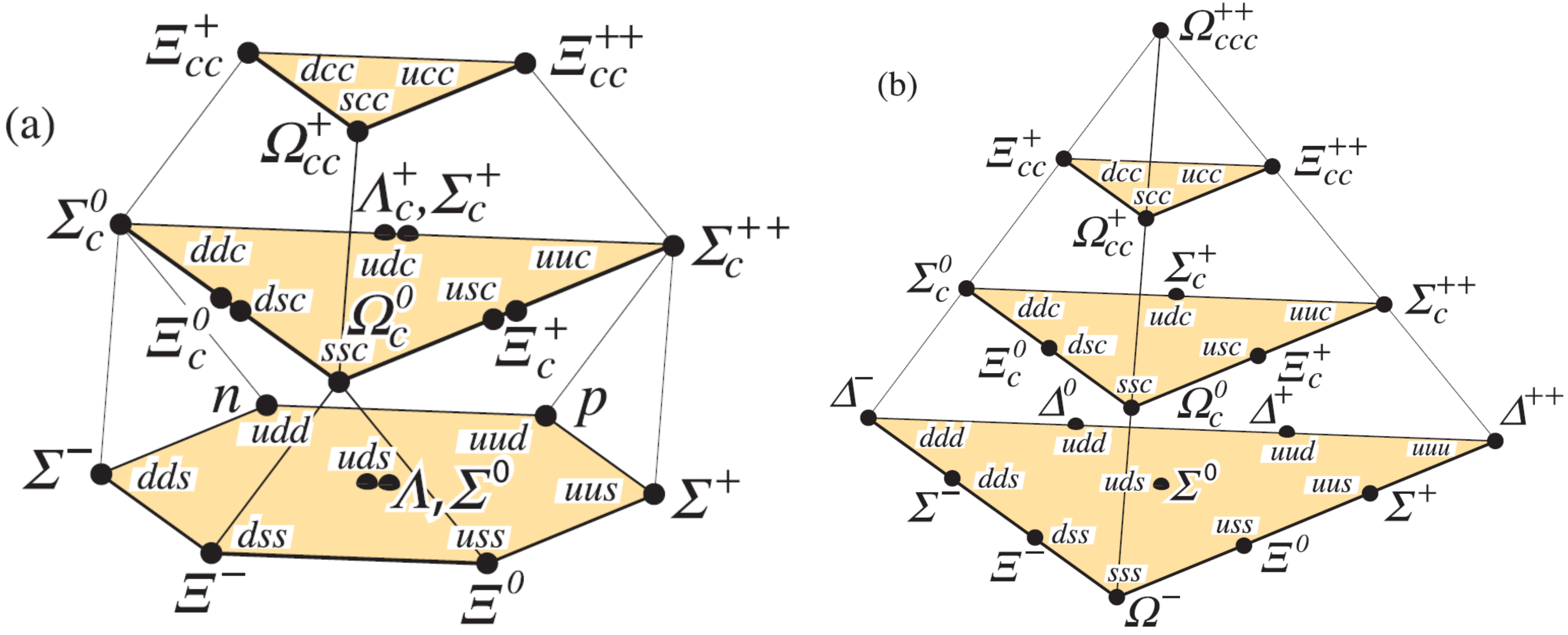
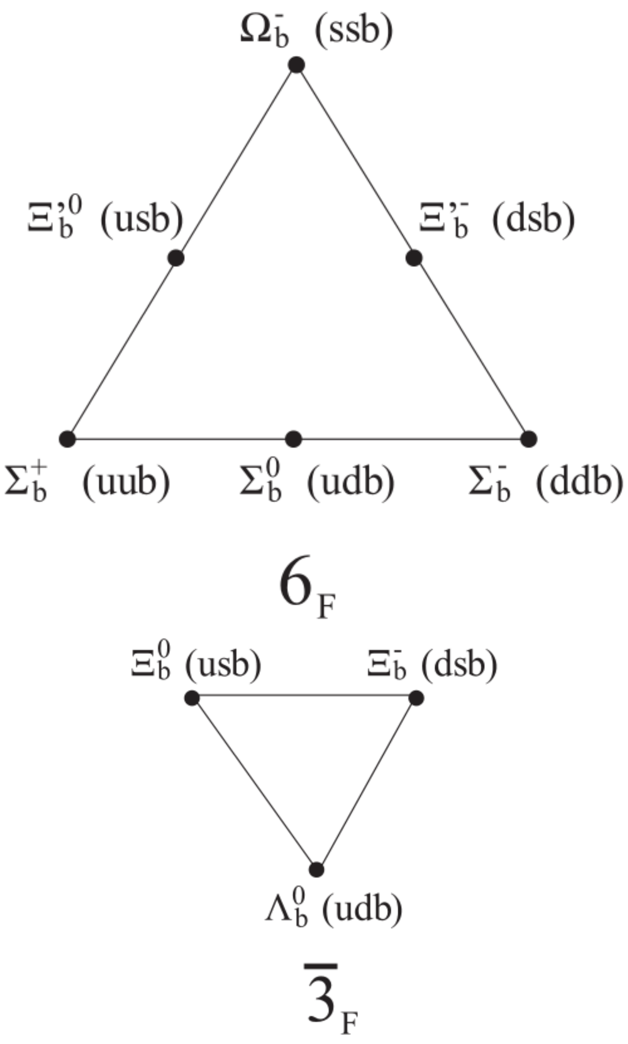


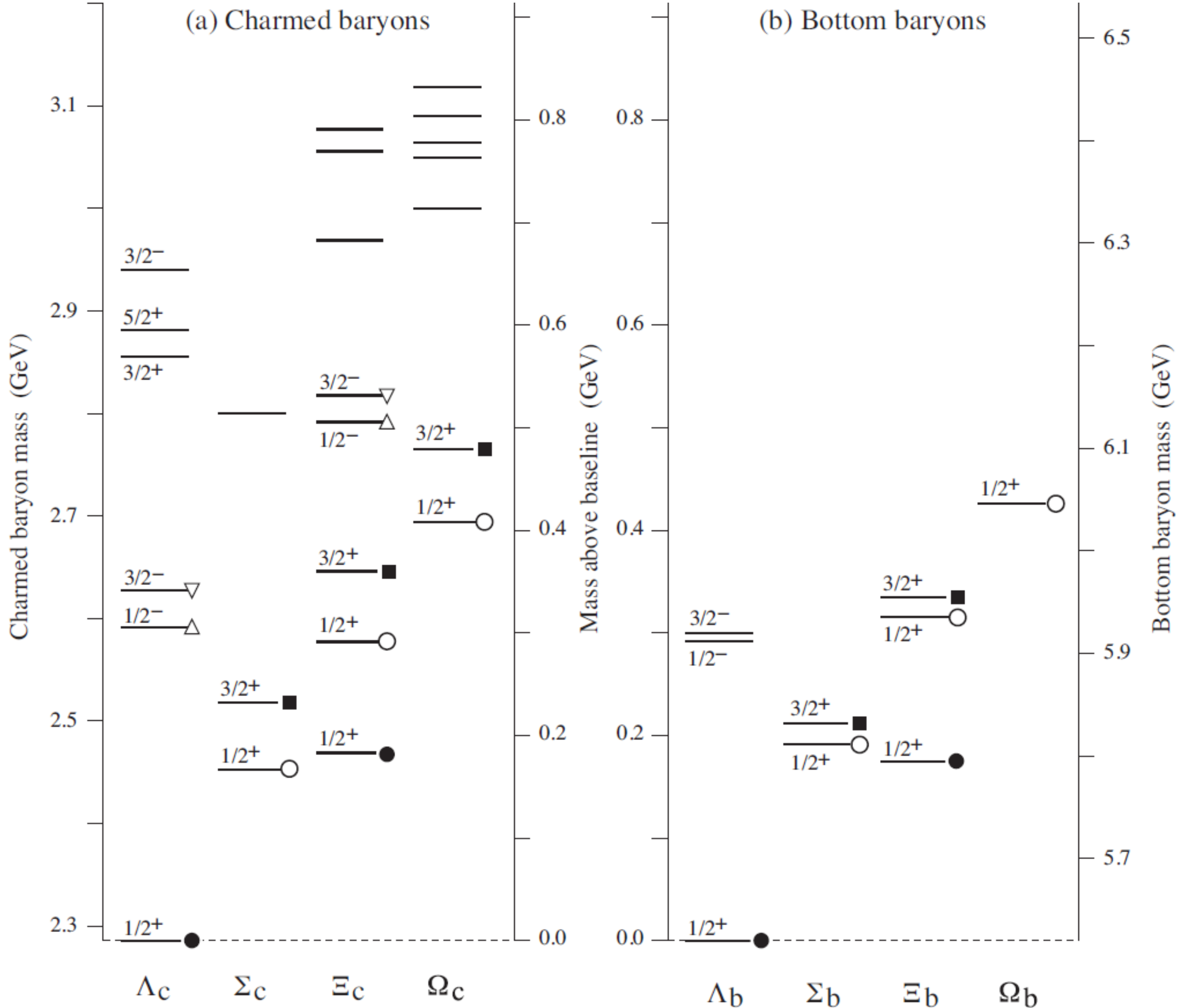
- SU(3) multiplets of bottom baryons.



PDG. 2018

Charmed and bottom baryons

- (a)The 24 known charmed baryons, and (b) the 9 known bottom baryons



PDG. 2018

Categorization of P-wave bottom baryons

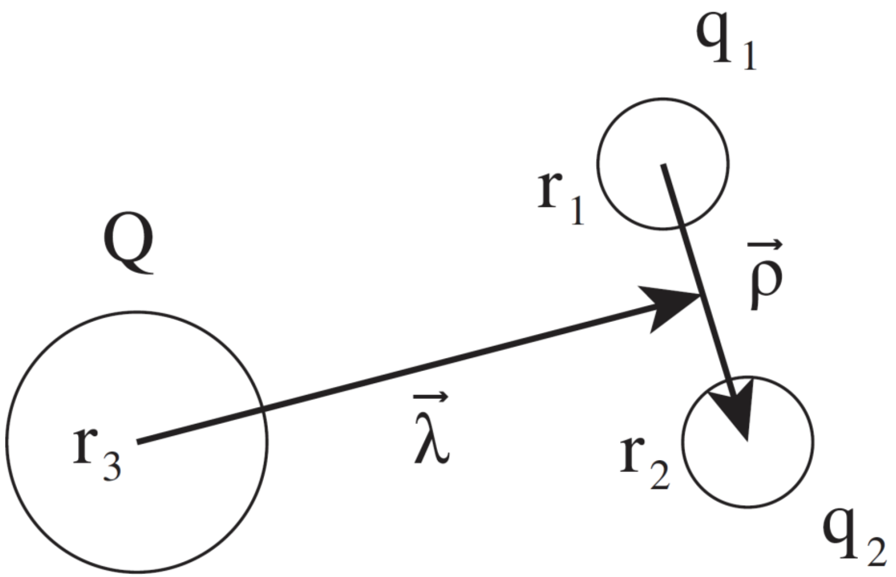
- The internal structure of heavy baryons is complicated and interesting:

λ-excitation and ρ-excitation

heavy baryon (Q-q_1-q_2):

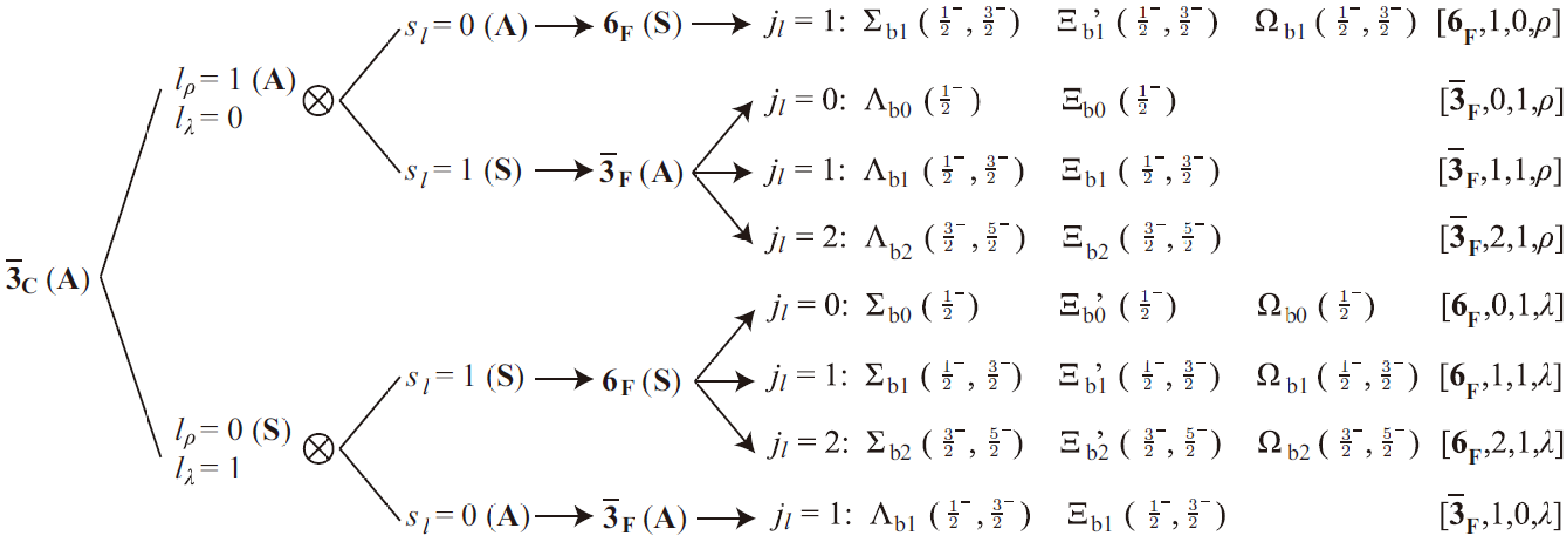
$$J = s_Q + s_{q1} + s_{q2} + l_\rho + l_\lambda$$

$$= s_Q + \left(s_{q1} + s_{q2} + l_\rho + l_\lambda\right)_{j_l}$$



Categorization of P-wave bottom baryons

- $|\, qqq \,\rangle_A = |\, \text{color} \,\rangle_A \times |\, \text{space, spin, flavor} \,\rangle_S$



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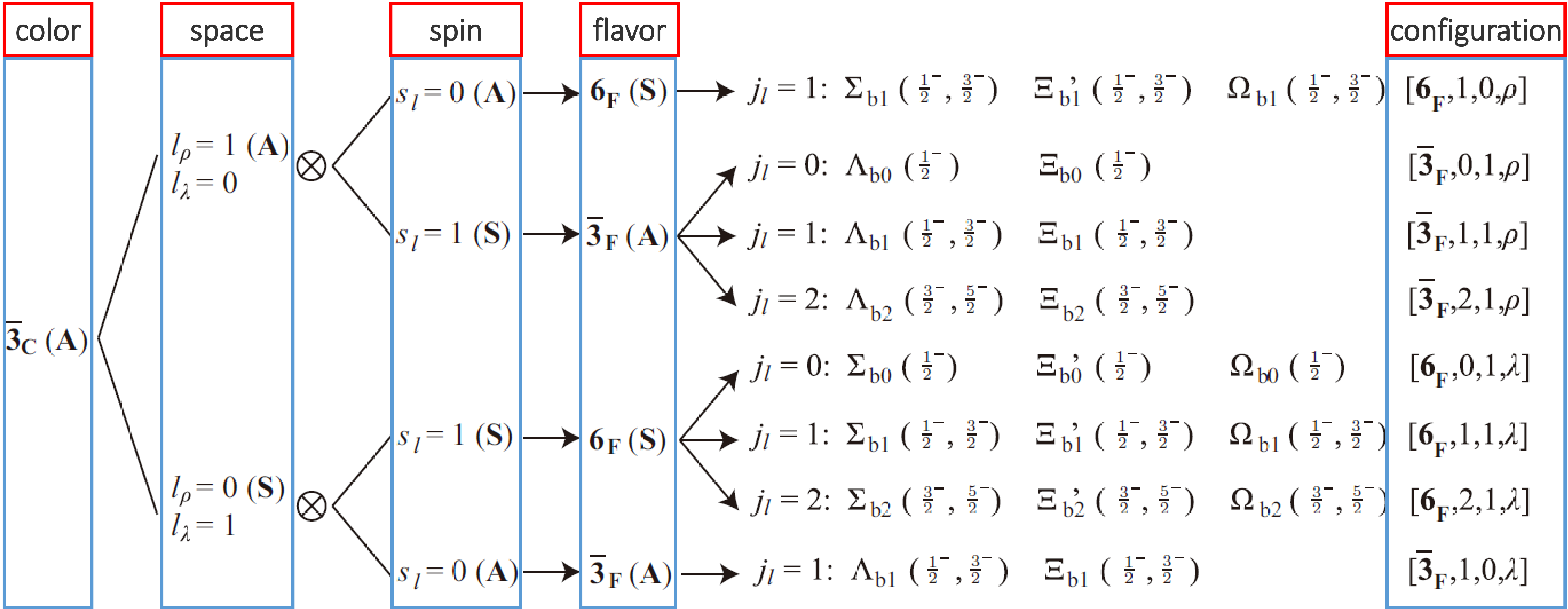

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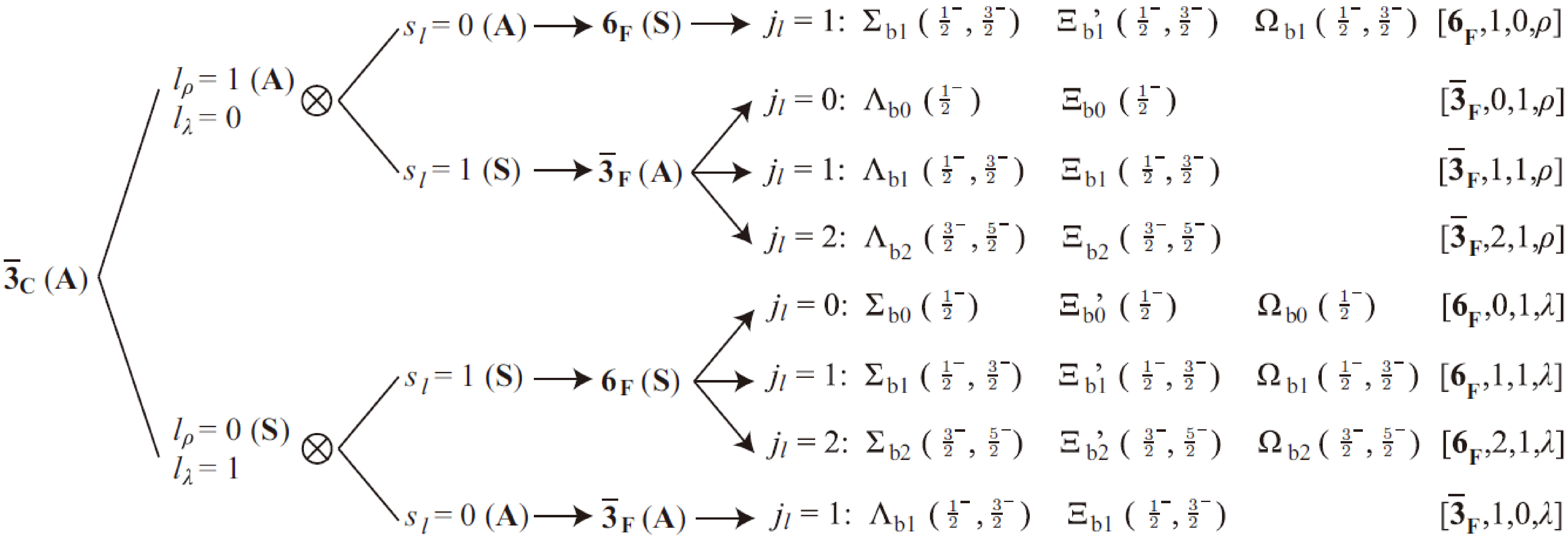
$$[F(\text{flavor}), j_l, s_l, \rho/\lambda]$$



LHCb results

- Recently, the LHCb Collaboration reported their discoveries of two new excited bottom baryons: $\Xi_b(6227)^-$ in both $\Lambda_b^0 K^-$ and $\Xi_b^0\pi^-$ invariant spectrum, $\Sigma_b(6097)^\pm$ in $\Lambda_b^0\pi^\pm$ invariant spectrum

$$\begin{aligned}
\Xi_b(6227)^- : M &= 6226.9 \pm 2.0 \pm 0.3 \pm 0.2 \text{ MeV}\,, \\
\Gamma &= 18.1 \pm 5.4 \pm 1.8 \text{ MeV}\,, \\
\Sigma_b(6097)^+ : M &= 6095.8 \pm 1.7 \pm 0.4 \text{ MeV}\,, \\
\Gamma &= 31 \pm 5.5 \pm 0.7 \text{ MeV}\,, \\
\Sigma_b(6097)^- : M &= 6098.0 \pm 1.7 \pm 0.5 \text{ MeV}\,, \\
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- The following branching ratio was measured to be

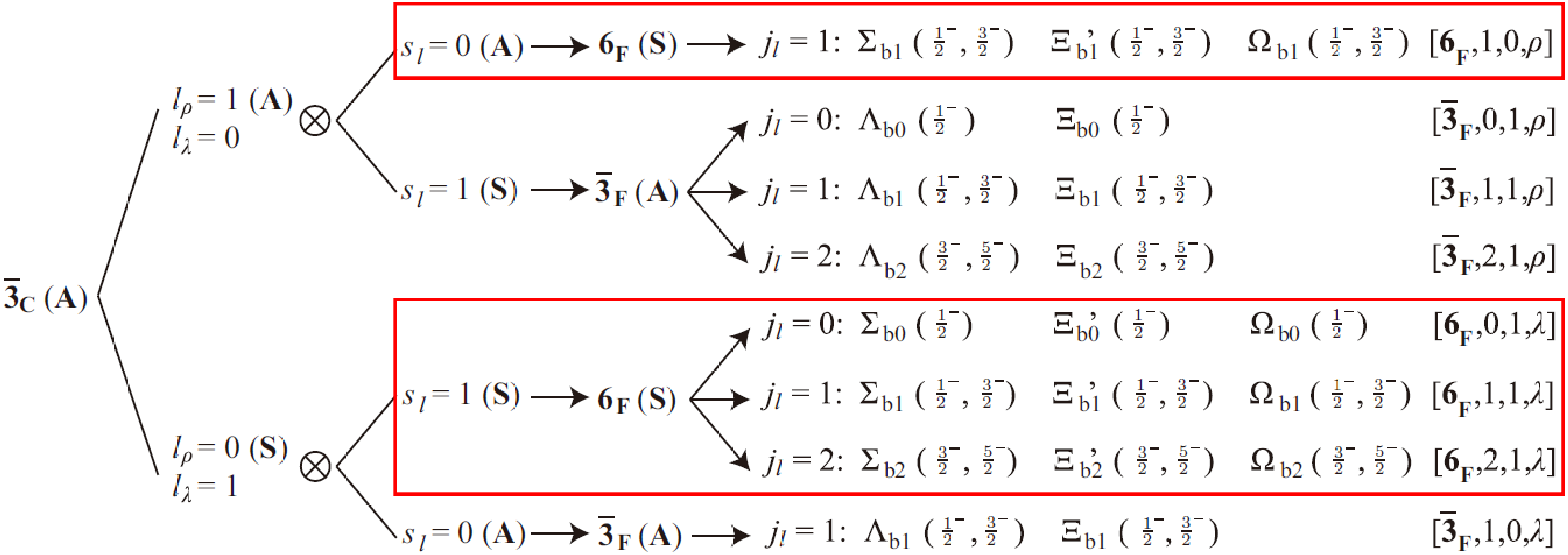
$$
\frac{\mathcal{B}(\Xi_b(6227)^- \to \Lambda_b^0 K^-)}{\mathcal{B}(\Xi_b(6227)^- \to \Xi_b^0 \pi^-)} \simeq 1\,.
$$

PRL 121, 072002 (2018)

PRL 122, 012001 (2019)

Structure of P-wave bottom baryons

- At first we should update our previous QCD sum rule analyses about the mass spectrum of P-wave bottom baryons.



PRD 92, 114007 (2015)

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QCD sum rules

- We can construct **various interpolating currents** to reflect **the internal structure of heavy baryons** by using the method of

QCD sum rules within

heavy quark effective theory (HQET)

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SVZ sum rules for spectrum

light-cone sum rules for decay properties

SVZ sum rules

- In sum rule analyses, we consider two-point correlation functions:

$$\Pi\left(q^2\right) \stackrel{\text{def}}{=} i \int d^4x e^{iqx} \langle 0|T\eta(x)\eta^+(0)\,|0\rangle$$
$$\approx \sum_n \langle 0|\eta|n\rangle\langle n|\eta^+|0\rangle$$

where η is the current which can couple to hadronic states.

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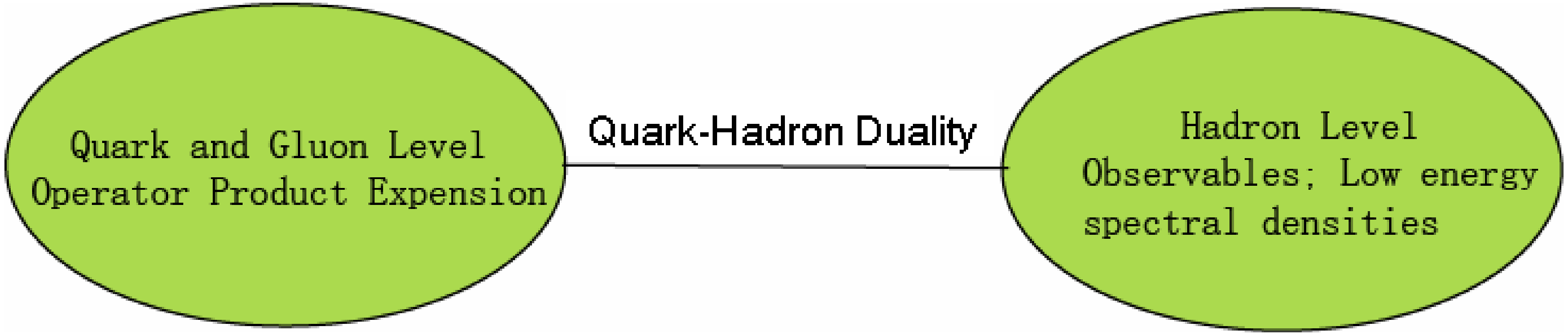
- In QCD sum rule, we can calculate these matrix elements from QCD (OPE) and relate them to observables by using dispersion relation.



SVZ sum rules

SVZ sum rule (Shifman 1979)

Quark and Gluon Level

(Convergence of OPE)

$\Pi_{\mathrm{OPE}}(q^2)$ —dispersion relation, $s = -q^2$→ $\rho_{OPE}(s) = a_n s^n + a_{n-1} s^{n-1}$

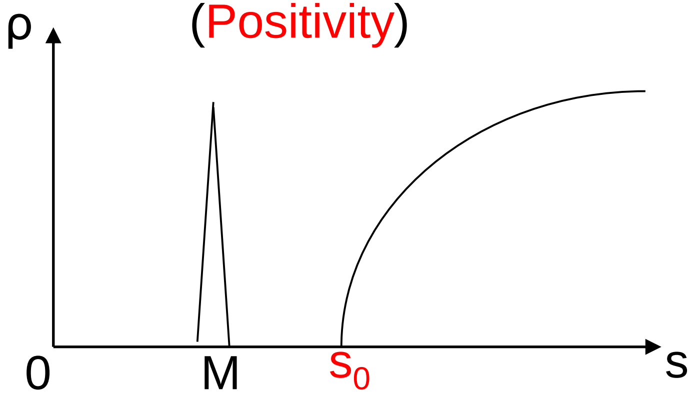
Quark-Hadron Duality

Hadron Level

$$\Pi_{phys}(q^2) = f_P^2 \frac{q + \not{M}}{q^2 - M^2} \longleftrightarrow \rho_{phys}(s) = \lambda_x^2 \delta(s - M_x^2) + \cdots$$

(for baryon case)

(Positivity)



(Sufficient amount of Pole contribution)

Light-cone sum rules

- The method of light-cone sum rules is a fruitful hybrid of the SVZ technique and the theory of hard exclusive processes, whose basic idea is to expand the three-point correlation function in terms of distribution amplitudes near the light-cone:

$$F_{\mu\nu}(p,q) = i\int d^4x e^{-iq\cdot x}\langle\pi^0(p)|T\{j_\mu^{em}(x)j_\nu^{em}(0)\}|0\rangle$$

$$F_{\mu\nu}(p,q) = -i\epsilon_{\mu\nu\alpha\rho}\int d^4x \frac{x^\alpha}{\pi^2x^4}e^{-iq\cdot x}\langle\pi^0(p)|\overline{u}(x)\gamma^\rho\gamma_5 u(0)|0\rangle\,.$$

$$\langle\pi^0(p)|\overline{u}(x)\gamma_\mu\gamma_5 u(0)|0\rangle_{x^2=0} = -ip_\mu\frac{f_\pi}{\sqrt{2}}\int_0^1 du e^{iup\cdot x}\varphi_\pi(u,\mu)$$

where $\varphi_\pi(u,\mu)$ is the pion light-cone distribution amplitude of twist 2.

Light-cone sum rules

- The pion light-cone distribution amplitudes:

$$\langle 0|\bar{u}(z)\gamma_\mu\gamma_5 d(-z)|\pi^-(P)\rangle = i f_\pi p_\mu \int_0^1 du\, e^{i\xi pz}\, \phi_\pi(u) + \frac{i}{2} f_\pi m^2 \frac{1}{pz} z_\mu \int_0^1 du\, e^{i\xi pz} g_\pi(u)\,, \tag{C.32}$$

$$\langle 0|\bar{u}(x) i\gamma_5 d(-x)|\pi^-(P)\rangle = \frac{f_\pi m_\pi^2}{m_u + m_d} \int_0^1 du\, e^{i\xi Px}\, \phi_p(u)\,, \tag{C.33}$$

$$\langle 0|\bar{u}(x)\sigma_{\alpha\beta}\gamma_5 d(-x)|\pi^-(P)\rangle = -\frac{i}{3}\frac{f_\pi m_\pi^2}{m_u + m_d}\left\{1 - \left(\frac{m_u + m_d}{m_\pi}\right)^2\right\} \times (P_\alpha x_\beta - P_\beta x_\alpha) \int_0^1 du\, e^{i\xi Px}\, \phi_\sigma(u)\,, \tag{C.34}$$

$$\langle 0|\bar{u}(z)\sigma_{\mu\nu}\gamma_5 g G_{\alpha\beta}(vz) d(-z)|\pi^-(P)\rangle = i\frac{f_\pi m_\pi^2}{m_u + m_d}\left(p_\alpha p_\mu g^\perp_{\nu\beta} - p_\alpha p_\nu g^\perp_{\mu\beta} - p_\beta p_\mu g^\perp_{\nu\alpha} + p_\beta p_\nu g^\perp_{\alpha\mu}\right)\mathcal{T}(v, pz) + \ldots\,, \tag{C.35}$$

$$\langle 0|\bar{u}(z)\gamma_\mu\gamma_5 g G_{\alpha\beta}(vz) d(-z)|\pi^-(P)\rangle = p_\mu(p_\alpha z_\beta - p_\beta z_\alpha)\frac{1}{pz} f_\pi m_\pi^2 \mathcal{A}_\parallel(v, pz) + (p_\beta g^\perp_{\alpha\mu} - p_\alpha g^\perp_{\beta\mu}) f_\pi m_\pi^2 \mathcal{A}_\perp(v, pz)\,, \tag{C.36}$$

$$\langle 0|\bar{u}(z)\gamma_\mu i g\widetilde{G}_{\alpha\beta}(vz) d(-z)|\pi^-(P)\rangle = p_\mu(p_\alpha z_\beta - p_\beta z_\alpha)\frac{1}{pz} f_\pi m_\pi^2 \mathcal{V}_\parallel(v, pz) + (p_\beta g^\perp_{\alpha\mu} - p_\alpha g^\perp_{\beta\mu}) f_\pi m_\pi^2 \mathcal{V}_\perp(v, pz)\,. \tag{C.37}$$

Ball P., et al. PRD. 1998; Ball P., et al. NPB. 1998; Ball P., et al. NPB. 1999;
Ball P., et al. PRD. 2005; Ball P., et al. JHEP. 2007; Ball P., et al. JHEP. 2007.

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Mass spectrum of P-wave bottom baryons

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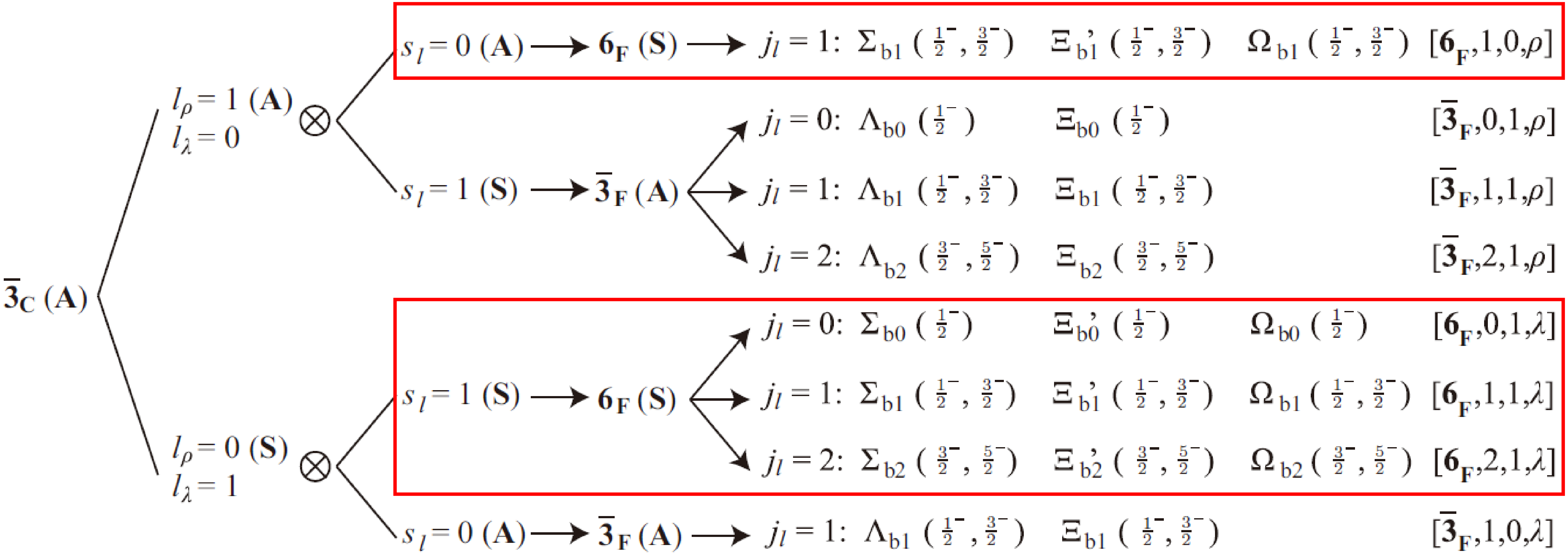

PRD 92, 114007 (2015)

Mass spectrum of P-wave bottom baryons

- The interpolating field of configuration $[6_F, 1, 0, \rho]$

$$J_{1/2,-,\mathbf{6}_F,1,0,\rho} = i\epsilon_{abc}([\mathcal{D}_t^\mu q^{aT}]C\gamma_5 q^b - q^{aT}C\gamma_5[\mathcal{D}_t^\mu q^b])\gamma_t^\mu\gamma_5 h_v^c,$$

- At the hadronic level, the two-point correlation function can be written as

$$\begin{aligned}\Pi^{\alpha_1\cdots\alpha_{j-1/2},\beta_1\cdots\beta_{j-1/2}}_{j,P,F,j_l,s_l,\rho/\lambda}(\omega) &= i\int d^4x e^{ikx}\langle 0|T[J^{\alpha_1\cdots\alpha_{j-1/2}}_{j,P,F,j_l,s_l,\rho/\lambda}(x)\bar{J}^{\beta_1\cdots\beta_{j-1/2}}_{j,P,F,j_l,s_l,\rho/\lambda}(0)]|0\rangle \\ &= \mathbb{S}[g_t^{\alpha_1\beta_1}\cdots g_t^{\alpha_{j-1/2}\beta_{j-1/2}}]\times\frac{1+\not{v}}{2}\times\Pi_{j,P,F,j_l,s_l,\rho/\lambda}(\omega)\,, \\ &= \mathbb{S}[g_t^{\alpha_1\beta_1}\cdots g_t^{\alpha_{j-1/2}\beta_{j-1/2}}]\times\frac{1+\not{v}}{2}\times\left(\frac{f^2_{F,j_l,s_l,\rho/\lambda}}{\overline{\Lambda}_{F,j_l,s_l,\rho/\lambda}-\omega}+\text{higher states}\right).\end{aligned}$$

- At the quark-gluon level, the two-point correlation function can be calculated by the method of Operator Product Expansion (OPE).

PRD 92, 114007 (2015)

Mass spectrum of P-wave bottom baryons

Multiplets	B	ω_c (GeV)	Working region (GeV)	$\overline{\Lambda}$ (GeV)	Baryons (j^P)	Mass (GeV)	Difference (MeV)	f (GeV^4)
$[\mathbf{6}_F, 0, 1, \lambda]$	Σ_b	1.75	$0.30 < T < 0.33$	1.29 ± 0.08	$\Sigma_b(1/2^-)$	6.09 ± 0.10	–	0.085 ± 0.017 $(\Sigma_b^-(1/2^-))$
	Ξ'_b	1.90	$0.30 < T < 0.34$	1.44 ± 0.08	$\Xi'_b(1/2^-)$	6.25 ± 0.10	–	0.077 ± 0.016 $(\Xi_b^{\prime -}(1/2^-))$
	Ω_b	2.05	$0.29 < T < 0.35$	1.59 ± 0.08	$\Omega_b(1/2^-)$	6.40 ± 0.11	–	0.143 ± 0.030 $(\Omega_b^-(1/2^-))$
$[\mathbf{6}_F, 1, 0, \rho]$	Σ_b	1.87	$0.31 < T < 0.34$	1.35 ± 0.09	$\Sigma_b(1/2^-)$	6.10 ± 0.11	3 ± 1	0.087 ± 0.018 $(\Sigma_b^-(1/2^-))$
					$\Sigma_b(3/2^-)$	6.10 ± 0.10		0.050 ± 0.011 $(\Sigma_b^-(3/2^-))$
	Ξ'_b	2.02	$0.29 < T < 0.36$	1.49 ± 0.09	$\Xi'_b(1/2^-)$	6.24 ± 0.11	3 ± 1	0.080 ± 0.016 $(\Xi_b^{\prime -}(1/2^-))$
					$\Xi'_b(3/2^-)$	6.24 ± 0.11		0.046 ± 0.009 $(\Xi_b^{\prime -}(3/2^-))$
	Ω_b	2.17	$0.33 < T < 0.38$	1.67 ± 0.09	$\Omega_b(1/2^-)$	6.42 ± 0.11	3 ± 1	0.155 ± 0.030 $(\Omega_b^-(1/2^-))$
					$\Omega_b(3/2^-)$	6.42 ± 0.11		0.090 ± 0.017 $(\Omega_b^-(3/2^-))$
$[\mathbf{6}_F, 2, 1, \lambda]$	Σ_b	1.84	$0.30 < T < 0.34$	1.29 ± 0.09	$\Sigma_b(3/2^-)$	6.10 ± 0.12	13 ± 5	0.102 ± 0.022 $(\Sigma_b^-(3/2^-))$
					$\Sigma_b(5/2^-)$	6.11 ± 0.12		0.045 ± 0.010 $(\Sigma_b^-(5/2^-))$
	Ξ'_b	1.99	$0.30 < T < 0.36$	1.45 ± 0.09	$\Xi'_b(3/2^-)$	6.27 ± 0.12	12 ± 5	0.099 ± 0.021 $(\Xi_b^{\prime -}(3/2^-))$
					$\Xi'_b(5/2^-)$	6.29 ± 0.11		0.044 ± 0.009 $(\Xi_b^{\prime -}(5/2^-))$
	Ω_b	2.14	$0.32 < T < 0.38$	1.62 ± 0.09	$\Omega_b(3/2^-)$	6.46 ± 0.12	11 ± 5	0.194 ± 0.038 $(\Omega_b^-(3/2^-))$
					$\Omega_b(5/2^-)$	6.47 ± 0.12		0.087 ± 0.017 $(\Omega_b^-(3/2^-))$

S-wave decay properties

- We investigated the following decay channel

$$(k)\quad \mathbf{\Gamma}\Big[\Sigma_b(1/2^-) \to \Lambda_b(1/2^+) + \pi\Big] = \mathbf{\Gamma}\Big[\Sigma_b^-(1/2^-) \to \Lambda_b^0(1/2^+) + \pi^-\Big],$$

$$(l)\quad \mathbf{\Gamma}\Big[\Sigma_b(1/2^-) \to \Sigma_b(1/2^+) + \pi\Big] = 2 \times \mathbf{\Gamma}\Big[\Sigma_b^-(1/2^-) \to \Sigma_b^0(1/2^+) + \pi^-\Big],$$

$$(m)\quad \mathbf{\Gamma}\Big[\Xi_b'(1/2^-) \to \Xi_b(1/2^+) + \pi\Big] = \frac{3}{2} \times \mathbf{\Gamma}\Big[\Xi_b'^-(1/2^-) \to \Xi_b^0(1/2^+) + \pi^-\Big],$$

$$(n)\quad \mathbf{\Gamma}\Big[\Xi_b'(1/2^-) \to \Lambda_b(1/2^+) + K\Big] = \mathbf{\Gamma}\Big[\Xi_b'^-(1/2^-) \to \Lambda_b^0(1/2^+) + K^-\Big],$$

$$(o)\quad \mathbf{\Gamma}\Big[\Xi_b'(1/2^-) \to \Xi_b'(1/2^+) + \pi\Big] = \frac{3}{2} \times \mathbf{\Gamma}\Big[\Xi_b'^-(1/2^-) \to \Xi_b'^0(1/2^+) + \pi^-\Big],$$

$$(p)\quad \mathbf{\Gamma}\Big[\Xi_b'(1/2^-) \to \Sigma_b(1/2^+) + K\Big] = 3 \times \mathbf{\Gamma}\Big[\Xi_b'^-(1/2^-) \to \Sigma_b^0(1/2^+) + K^-\Big],$$

$$(q)\quad \mathbf{\Gamma}\Big[\Omega_b(1/2^-) \to \Xi_b(1/2^+) + K\Big] = 2 \times \mathbf{\Gamma}\Big[\Omega_b^-(1/2^-) \to \Xi_b^0(1/2^+) + K^-\Big],$$

$$(r)\quad \mathbf{\Gamma}\Big[\Omega_b(1/2^-) \to \Xi_b'(1/2^+) + K\Big] = 2 \times \mathbf{\Gamma}\Big[\Omega_b^-(1/2^-) \to \Xi_b'^0(1/2^+) + K^-\Big],$$

$$(s)\quad \mathbf{\Gamma}\Big[\Sigma_b(3/2^-) \to \Sigma_b^*(3/2^+) + \pi\Big] = 2 \times \mathbf{\Gamma}\Big[\Sigma_b^-(3/2^-) \to \Sigma_b^{*0}(3/2^+) + \pi^-\Big],$$

$$(t)\quad \mathbf{\Gamma}\Big[\Xi_b'(3/2^-) \to \Xi_b^*(3/2^+) + \pi\Big] = \frac{3}{2} \times \mathbf{\Gamma}\Big[\Xi_b'^-(3/2^-) \to \Xi_b^{*0}(3/2^+) + \pi^-\Big],$$

$$(u)\quad \mathbf{\Gamma}\Big[\Xi_b'(3/2^-) \to \Sigma_b^*(3/2^+) + K \to \Lambda_b(1/2^+) + \pi + K\Big]$$

$$= \quad 3 \times \mathbf{\Gamma}\Big[\Xi_b'^-(3/2^-) \to \Sigma_b^{*0}(3/2^+) + K^- \to \Lambda_b^0(3/2^+) + \pi^0 + K^-\Big],$$

$$(v)\quad \mathbf{\Gamma}\Big[\Omega_b(3/2^-) \to \Xi_b^*(3/2^+) + K\Big] = 2 \times \mathbf{\Gamma}\Big[\Omega_b^-(3/2^-) \to \Xi_b^{*0}(3/2^+) + K^-\Big].$$

S-wave decay properties

- We calculate the S-wave decay of the $\Sigma_b^-(1/2^-)$ belonging to $[6_F, 1,0,\rho]$ into $\Sigma_b^0(1/2^+)\pi^-(0^-)$ to introduce the application of light-cone sum rules. At first we consider the three-point correlation function:

$$\begin{aligned}\Pi(\omega,\,\omega') &= \int d^4x\; e^{-ik\cdot x}\;\langle 0|J_{1/2,-,\Sigma_b^-,1,0,\rho}(0)\bar{J}_{\Sigma_b^0}(x)|\pi^-\rangle \\ &= \frac{1+\not{v}}{2} G_{\Sigma_b^-[\frac{1}{2}^-]\to\Sigma_b^0\pi^-}(\omega,\omega')\,,\end{aligned}$$

- At the hadronic level, we can rewrite the correlation function by using double dispersion relation:

$$G_{\Sigma_b^-[\frac{1}{2}^-]\to\Sigma_b^0\pi^-}(\omega,\omega') = g_{\Sigma_b^-[\frac{1}{2}^-]\to\Sigma_b^0\pi^-} \times \frac{f_{\Sigma_b^-[\frac{1}{2}^-]} f_{\Sigma_b^0}}{(\bar{\Lambda}_{\Sigma_b^-[\frac{1}{2}^-]} - \omega')(\bar{\Lambda}_{\Sigma_b^0} - \omega)}\,,$$

S-wave decay properties

- At the quark-gluon level, we calculate the correlation function using the method of OPE to expand in terms of light-cone distribution amplitudes

$$G_{\Sigma_b^-[\frac{1}{2}^-]\to\Sigma_b^0\pi^-}(\omega,\omega') = g_{\Sigma_b^-[\frac{1}{2}^-]\to\Sigma_b^0\pi^-} \times \frac{f_{\Sigma_b^-[\frac{1}{2}^-]} f_{\Sigma_b^0}}{(\bar{\Lambda}_{\Sigma_b^-[\frac{1}{2}^-]} - \omega')(\bar{\Lambda}_{\Sigma_b^0} - \omega)}$$

$$= \int_0^\infty dt \int_0^1 du e^{i(1-u)\omega' t} e^{iu\omega t} \times 8 \times \Big(\frac{3 f_\pi m_\pi^2}{4\pi^2 t^4 (m_u + m_d)} \phi_{3;\pi}^p(u) + \frac{i f_\pi m_\pi^2 v\cdot q}{8\pi^2 t^3 (m_u + m_d)} \phi_{3;\pi}^\sigma(u)$$
$$- \frac{i f_\pi}{16 t v\cdot q} \langle \bar{q}q\rangle \psi_{4;\pi}(u) - \frac{i f_\pi t}{256 v\cdot q} \langle g_s \bar{q}\sigma G q\rangle \psi_{4;\pi}(u) \Big) .$$

- After Wick rotations and double Borel transformation we obtain

$$g_{\Sigma_b^-[\frac{1}{2}^-]\to\Sigma_b^0\pi^-} f_{\Sigma_b^-[\frac{1}{2}^-]} f_{\Sigma_b^0} e^{-\frac{\bar{\Lambda}_{\Sigma_b^-[\frac{1}{2}^-]}}{T_1}} e^{-\frac{\bar{\Lambda}_{\Sigma_b^0}}{T_2}}$$
$$= 8 \times \Big(\frac{3 i f_\pi m_\pi^2}{4\pi^2 (m_u + m_d)} T^5 f_4(\frac{\omega_c}{T}) \phi_{3;\pi}^p(u_0) + \frac{i f_\pi m_\pi^2}{8\pi^2 (m_u + m_d)} T^5 f_4(\frac{\omega_c}{T}) \frac{d\phi_{3;\pi}^\sigma(u_0)}{du}$$
$$+ \frac{i f_\pi}{16} \langle \bar{q}q\rangle T f_0(\frac{\omega_c}{T}) \int_0^{u_0} \psi_{4;\pi}(u) du - \frac{i f_\pi}{256} \langle g_s \bar{q}\sigma G q\rangle \frac{1}{T} \int_0^{u_0} \psi_{4;\pi}(u) du \Big) ,$$

S-wave decay properties

- The S-wave decay properties of P-wave bottom baryons are summarized below

TABLE II: S-wave decay properties of the P-wave bottom baryons belonging to the baryon multiplets $[\mathbf{6}_F, 0, 1, \lambda]$, $[\mathbf{6}_F, 1, 0, \rho]$ and $[\mathbf{6}_F, 2, 1, \lambda]$.

Multiplets	S-wave decay channels	g	S-wave decay width (MeV)
$[\mathbf{6}_F, 1, 0, \rho]$	(l) $\Sigma_b(\frac{1}{2}^-) \to \Sigma_b(\frac{1}{2}^+)\pi$	$3.41^{+1.74}_{-1.33}$	850^{+1100}_{-540}
	(o) $\Xi'_b(\frac{1}{2}^-) \to \Xi'_b(\frac{1}{2}^+)\pi$	$2.31^{+1.13}_{-0.87}$	310^{+370}_{-190}
	(s) $\Sigma_b(\frac{3}{2}^-) \to \Sigma^*_b(\frac{3}{2}^+)\pi$	$2.28^{+1.16}_{-0.89}$	350^{+440}_{-220}
	(t) $\Xi'_b(\frac{3}{2}^-) \to \Xi^*_b(\frac{3}{2}^+)\pi$	$1.54^{+0.75}_{-0.58}$	130^{+150}_{-80}
	(u) $\Xi'_b(\frac{3}{2}^-) \to \Sigma^*_b(\frac{3}{2}^+)K \to \Lambda_b(\frac{1}{2}^+)\pi K$	$2.10^{+1.07}_{-0.79}$	$0.029^{+0.036}_{-0.017}$
	(v) $\Omega_b(\frac{3}{2}^-) \to \Xi^*_b(\frac{3}{2}^+)K$	$2.72^{+1.29}_{-0.96}$	–
$[\mathbf{6}_F, 0, 1, \lambda]$	(k) $\Sigma_b(\frac{1}{2}^-) \to \Lambda_b(\frac{1}{2}^+)\pi$	$4.70^{+2.39}_{-1.84}$	1400^{+1800}_{-900}
	(m) $\Xi'_b(\frac{1}{2}^-) \to \Xi_b(\frac{1}{2}^+)\pi$	$3.40^{+1.69}_{-1.30}$	1000^{+1300}_{-630}
	(n) $\Xi'_b(\frac{1}{2}^-) \to \Lambda_b(\frac{1}{2}^+)K$	$4.56^{+2.35}_{-1.74}$	1000^{+1300}_{-620}
	(q) $\Omega_b(\frac{1}{2}^-) \to \Xi_b(\frac{1}{2}^+)K$	$6.38^{+3.16}_{-2.35}$	3900^{+4900}_{-2400}
$[\mathbf{6}_F, 2, 1, \lambda]$	(s) $\Sigma_b(\frac{3}{2}^-) \to \Sigma^*_b(\frac{3}{2}^+)\pi$	$0.014^{+0.008}_{-0.007}$	$0.013^{+0.019}_{-0.010}$
	(t) $\Xi'_b(\frac{3}{2}^-) \to \Xi^*_b(\frac{3}{2}^+)\pi$	$0.009^{+0.005}_{-0.005}$	$0.004^{+0.006}_{-0.003}$
	(u) $\Xi'_b(\frac{3}{2}^-) \to \Sigma^*_b(\frac{3}{2}^+)K \to \Lambda_b(\frac{1}{2}^+)\pi K$	$0.006^{+0.010}_{-0.006}$	$2^{+14}_{-2} \times 10^{-7}$
	(v) $\Omega_b(\frac{3}{2}^-) \to \Xi^*_b(\frac{3}{2}^+)K$	$0.007^{+0.012}_{-0.007}$	$0.001^{+0.008}_{-0.001}$

S-wave decay properties

- The S-wave decay properties of P-wave bottom baryons are summarized below

TABLE II: S-wave decay properties of the P-wave bottom baryons belonging to the baryon multiplets $[\mathbf{6}_F, 0, 1, \lambda]$, $[\mathbf{6}_F, 1, 0, \rho]$ and $[\mathbf{6}_F, 2, 1, \lambda]$.

Multiplets	S-wave decay channels	g	S-wave decay width (MeV)
$[\mathbf{6}_F, 1, 0, \rho]$	(l) $\Sigma_b(\frac{1}{2}^-) \to \Sigma_b(\frac{1}{2}^+)\pi$	$3.41^{+1.74}_{-1.33}$	850^{+1100}_{-540}
	(o) $\Xi'_b(\frac{1}{2}^-) \to \Xi'_b(\frac{1}{2}^+)\pi$	$2.31^{+1.13}_{-0.87}$	310^{+370}_{-190}
	(s) $\Sigma_b(\frac{3}{2}^-) \to \Sigma^*_b(\frac{3}{2}^+)\pi$	$2.28^{+1.16}_{-0.89}$	350^{+440}_{-220}
	(t) $\Xi'_b(\frac{3}{2}^-) \to \Xi^*_b(\frac{3}{2}^+)\pi$	$1.54^{+0.75}_{-0.58}$	130^{+150}_{-80}
	(u) $\Xi'_b(\frac{3}{2}^-) \to \Sigma^*_b(\frac{3}{2}^+)K \to \Lambda_b(\frac{1}{2}^+)\pi K$	$2.10^{+1.07}_{-0.79}$	$0.029^{+0.036}_{-0.017}$
	(v) $\Omega_b(\frac{3}{2}^-) \to \Xi^*_b(\frac{3}{2}^+)K$	$2.72^{+1.29}_{-0.96}$	–
$[\mathbf{6}_F, 0, 1, \lambda]$	(k) $\Sigma_b(\frac{1}{2}^-) \to \Lambda_b(\frac{1}{2}^+)\pi$	$4.70^{+2.39}_{-1.84}$	1400^{+1800}_{-900}
	(m) $\Xi'_b(\frac{1}{2}^-) \to \Xi_b(\frac{1}{2}^+)\pi$	$3.40^{+1.69}_{-1.30}$	1000^{+1300}_{-630}
	(n) $\Xi'_b(\frac{1}{2}^-) \to \Lambda_b(\frac{1}{2}^+)K$	$4.56^{+2.35}_{-1.74}$	1000^{+1300}_{-620}
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$[\mathbf{6}_F, 2, 1, \lambda]$	(s) $\Sigma_b(\frac{3}{2}^-) \to \Sigma^*_b(\frac{3}{2}^+)\pi$	$0.014^{+0.008}_{-0.007}$	$0.013^{+0.019}_{-0.010}$
	(t) $\Xi'_b(\frac{3}{2}^-) \to \Xi^*_b(\frac{3}{2}^+)\pi$	$0.009^{+0.005}_{-0.005}$	$0.004^{+0.006}_{-0.003}$
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	(v) $\Omega_b(\frac{3}{2}^-) \to \Xi^*_b(\frac{3}{2}^+)K$	$0.007^{+0.012}_{-0.007}$	$0.001^{+0.008}_{-0.001}$

Too large to interpret the newly observed exited bottom baryons

D-wave decay properties

- We investigated the following decay channel

$$(w)\quad \mathbf{\Gamma}\Big[\Sigma_b(3/2^-)\to\Lambda_b(1/2^+)+\pi\Big]=\mathbf{\Gamma}\Big[\Sigma_b^-(3/2^-)\to\Lambda_b^0(1/2^+)+\pi^-\Big],$$

$$(x)\quad \mathbf{\Gamma}\Big[\Xi_b'(3/2^-)\to\Xi_b(1/2^+)+\pi\Big]=\frac{3}{2}\times\mathbf{\Gamma}\Big[\Xi_b'^-(3/2^-)\to\Xi_b^0(1/2^+)+\pi^-\Big],$$

$$(y)\quad \mathbf{\Gamma}\Big[\Xi_b'(3/2^-)\to\Lambda_b(1/2^+)+K\Big]=\mathbf{\Gamma}\Big[\Xi_b'^-(3/2^-)\to\Lambda_b^0(1/2^+)+K^-\Big],$$

$$(z)\quad \mathbf{\Gamma}\Big[\Omega_b(3/2^-)\to\Xi_b(1/2^+)+K\Big]=2\times\mathbf{\Gamma}\Big[\Omega_b^-(3/2^-)\to\Xi_b^0(1/2^+)+K^-\Big],$$

$$(w')\quad \mathbf{\Gamma}\Big[\Sigma_b(5/2^-)\to\Lambda_b(1/2^+)+\pi\Big]=\mathbf{\Gamma}\Big[\Sigma_b^-(5/2^-)\to\Lambda_b^0(1/2^+)+\pi^-\Big],$$

$$(x')\quad \mathbf{\Gamma}\Big[\Xi_b'(5/2^-)\to\Xi_b(1/2^+)+\pi\Big]=\frac{3}{2}\times\mathbf{\Gamma}\Big[\Xi_b'^-(5/2^-)\to\Xi_b^0(1/2^+)+\pi^-\Big],$$

$$(y')\quad \mathbf{\Gamma}\Big[\Xi_b'(5/2^-)\to\Lambda_b(1/2^+)+K\Big]=\mathbf{\Gamma}\Big[\Xi_b'^-(5/2^-)\to\Lambda_b^0(1/2^+)+K^-\Big],$$

$$(z')\quad \mathbf{\Gamma}\Big[\Omega_b(5/2^-)\to\Xi_b(1/2^+)+K\Big]=2\times\mathbf{\Gamma}\Big[\Omega_b^-(5/2^-)\to\Xi_b^0(1/2^+)+K^-\Big],$$

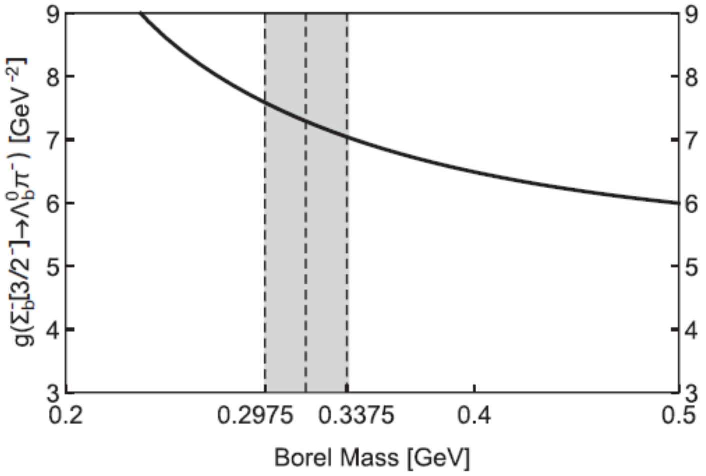
D-wave decay properties

- The D-wave decay properties of P-wave bottom baryons are summarized below

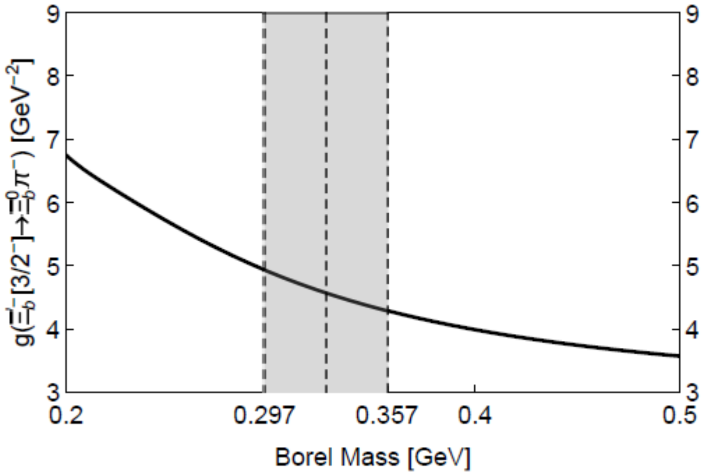
TABLE III: D-wave decay properties of the P-wave bottom baryons belonging to the baryon doublet $[\mathbf{6}_F, 2, 1, \lambda]$.

Multiplets	D-wave decay channels	g (GeV^{-2})	D-wave decay width (MeV)
$[\mathbf{6}_F, 2, 1, \lambda]$	(w) $\Sigma_b(\frac{3}{2}^-) \to \Lambda_b(\frac{1}{2}^+)\pi$	$7.29^{+3.65}_{-2.75}$	46^{+58}_{-28}
	(x) $\Xi'_b(\frac{3}{2}^-) \to \Xi_b(\frac{1}{2}^+)\pi$	$4.57^{+2.17}_{-1.67}$	16^{+19}_{-10}
	(y) $\Xi'_b(\frac{3}{2}^-) \to \Lambda_b(\frac{1}{2}^+)K$	$5.44^{+2.65}_{-1.95}$	$6.5^{+7.9}_{-3.8}$
	(z) $\Omega_b(\frac{3}{2}^-) \to \Xi_b(\frac{1}{2}^+)K$	$6.51^{+2.97}_{-2.22}$	58^{+65}_{-33}

- We also show the stability of coupling constant as a function of Borel Mass T



(a)



(b)

CONTENTS

- Internal structure of heavy baryons
- QCD sum rules and light-cone sum rules
- Decay properties of bottom baryons
- **Summary and discussions**

Summary and discussions

- The masses and decay widths of the $\Sigma_b(3/2^-)$ and $\Xi_b'(3/2^-)$ belonging to $[\mathbf{6}_F, 2, 1, \lambda]$ are extracted to be

Theo

$$
\begin{aligned}
M_{\Sigma_b(3/2^-)} &= 6.10 \pm 0.12 \text{ GeV}, \\
\Gamma_{\Sigma_b(3/2^-)} &= 46 \,^{+58}_{-28} \text{ MeV (total)}, \\
M_{\Xi_b'(3/2^-)} &= 6.27 \pm 0.12 \text{ GeV}, \\
\Gamma_{\Xi_b'(3/2^-)} &= 23 \,^{+27}_{-14} \text{ MeV (total)},
\end{aligned}
$$

Exp

$$
\begin{aligned}
\Sigma_b(6097)^+ : M &= 6095.8 \pm 1.7 \pm 0.4 \text{ MeV}, \\
\Gamma &= 31 \pm 5.5 \pm 0.7 \text{ MeV}, \\
\Sigma_b(6097)^- : M &= 6098.0 \pm 1.7 \pm 0.5 \text{ MeV}, \\
\Gamma &= 28.9 \pm 4.2 \pm 0.9 \text{ MeV}. \\
\Xi_b(6227)^- : M &= 6226.9 \pm 2.0 \pm 0.3 \pm 0.2 \text{ MeV}, \\
\Gamma &= 18.1 \pm 5.4 \pm 1.8 \text{ MeV},
\end{aligned}
$$

- Their non-vanishing decay channels are extracted to be

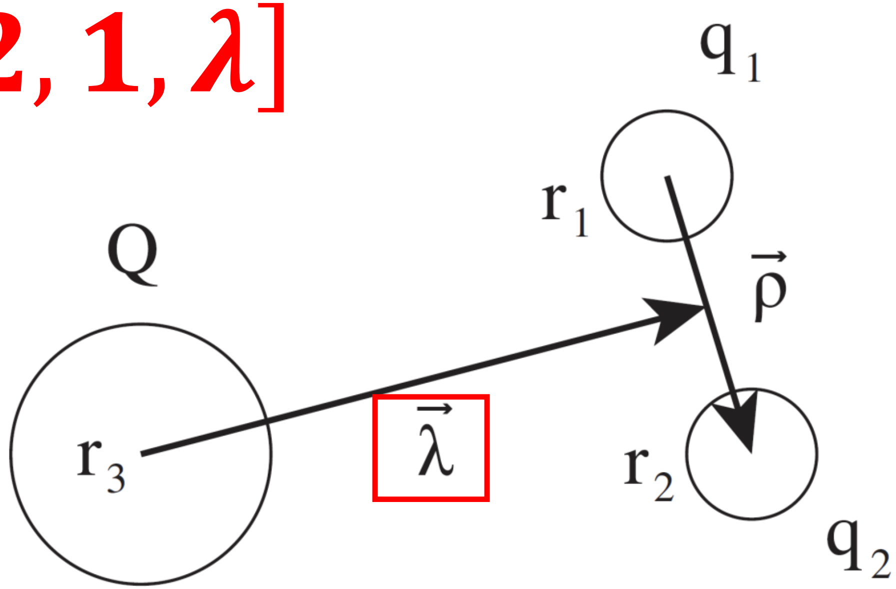
Theo

$$
\begin{aligned}
\Gamma_{\Sigma_b(3/2^-) \to \Lambda_b \pi} &= 46 \,^{+58}_{-28} \text{ MeV}, \\
\Gamma_{\Sigma_b(3/2^-) \to \Sigma_b^* \pi} &= 1.3 \,^{+1.9}_{-1.0} \times 10^{-2} \text{ MeV}, \\
\Gamma_{\Xi_b'(3/2^-) \to \Xi_b \pi} &= 16 \,^{+19}_{-10} \text{ MeV}, \\
\Gamma_{\Xi_b'(3/2^-) \to \Lambda_b K} &= 6.5 \,^{+7.9}_{-3.8} \text{ MeV}, \\
\Gamma_{\Xi_b'(3/2^-) \to \Xi_b^* \pi} &= 4 \,^{+6}_{-3} \times 10^{-3} \text{ MeV}, \\
\Gamma_{\Xi_b'(3/2^-) \to \Sigma_b^* K} &= 2 \,^{+14}_{-2} \times 10^{-7} \text{ MeV}.
\end{aligned}
$$

Summary and discussions

- The internal structures of $\Xi_b(6227)^-$ and $\Sigma_b(6097)^{\pm}$ are estimated to be

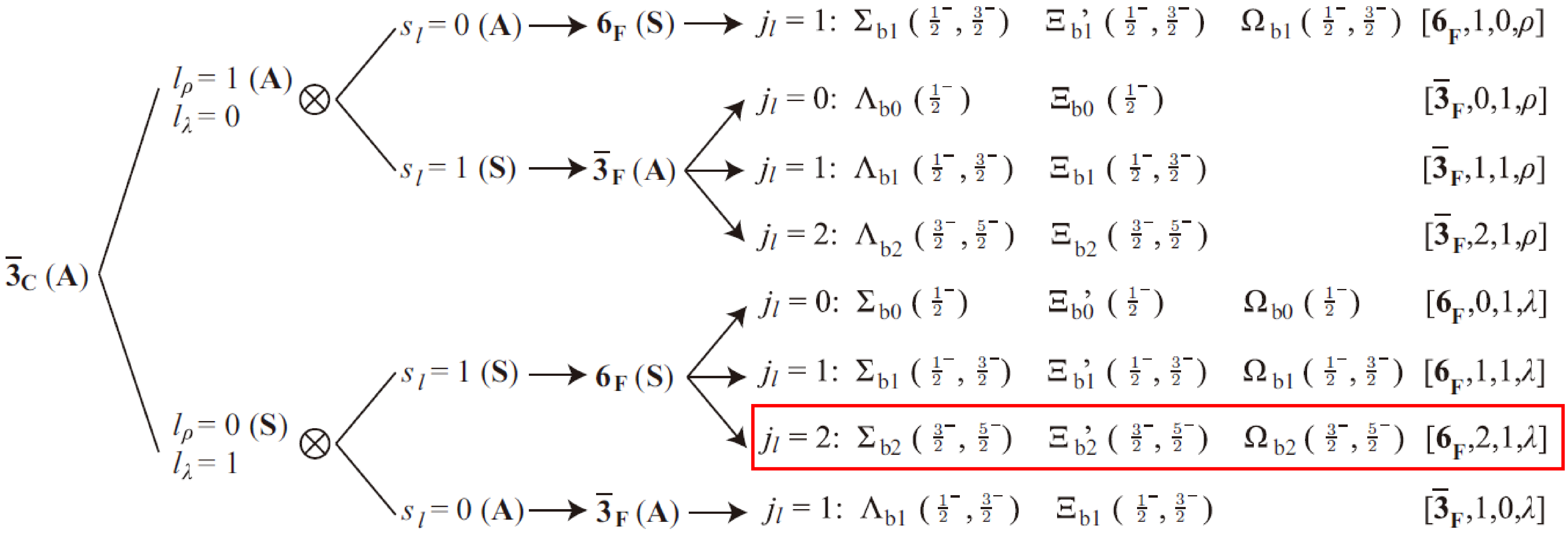
λ-excitation and $[6_F, 2, 1, \lambda]$



Summary and discussions

- The internal structures of $\Xi_b(6227)^-$ and $\Sigma_b(6097)^\pm$ are estimated to be

λ-excitation and $[6_F, 2, 1, \lambda]$



Summary and discussions

- Especially the branching ratio is extracted to be

$$\frac{\mathcal{B}(\Sigma_b(3/2^-)^- \to \Lambda_b^0 K^-)}{\mathcal{B}(\Sigma_b(3/2^-)^- \to \Xi_b^0 \pi^-)} = 0.6\,^{+1.1}_{-0.5}\,,$$

Theo

$$\frac{\mathcal{B}(\Xi_b(6227)^- \to \Lambda_b^0 K^-)}{\mathcal{B}(\Xi_b(6227)^- \to \Xi_b^0 \pi^-)} \simeq 1\,.$$

Exp

- Furthermore we predict the mass and decay width of $\Omega_b(3/2^-)$

Theo

$$M_{\Omega_b(3/2^-)} = 6.46 \pm 0.12 \text{ GeV}\,,$$
$$\Gamma_{\Omega_b(3/2^-)} = 58\,^{+65}_{-33} \text{ MeV}\,,$$

$$\Gamma_{\Omega_b(3/2^-)\to\Xi_b K} = 58\,^{+65}_{-33} \text{ MeV}\,,$$
$$\Gamma_{\Omega_b(3/2^-)\to\Xi_b^* K} = 1\,^{+8}_{-1} \times 10^{-3} \text{ MeV}\,.$$

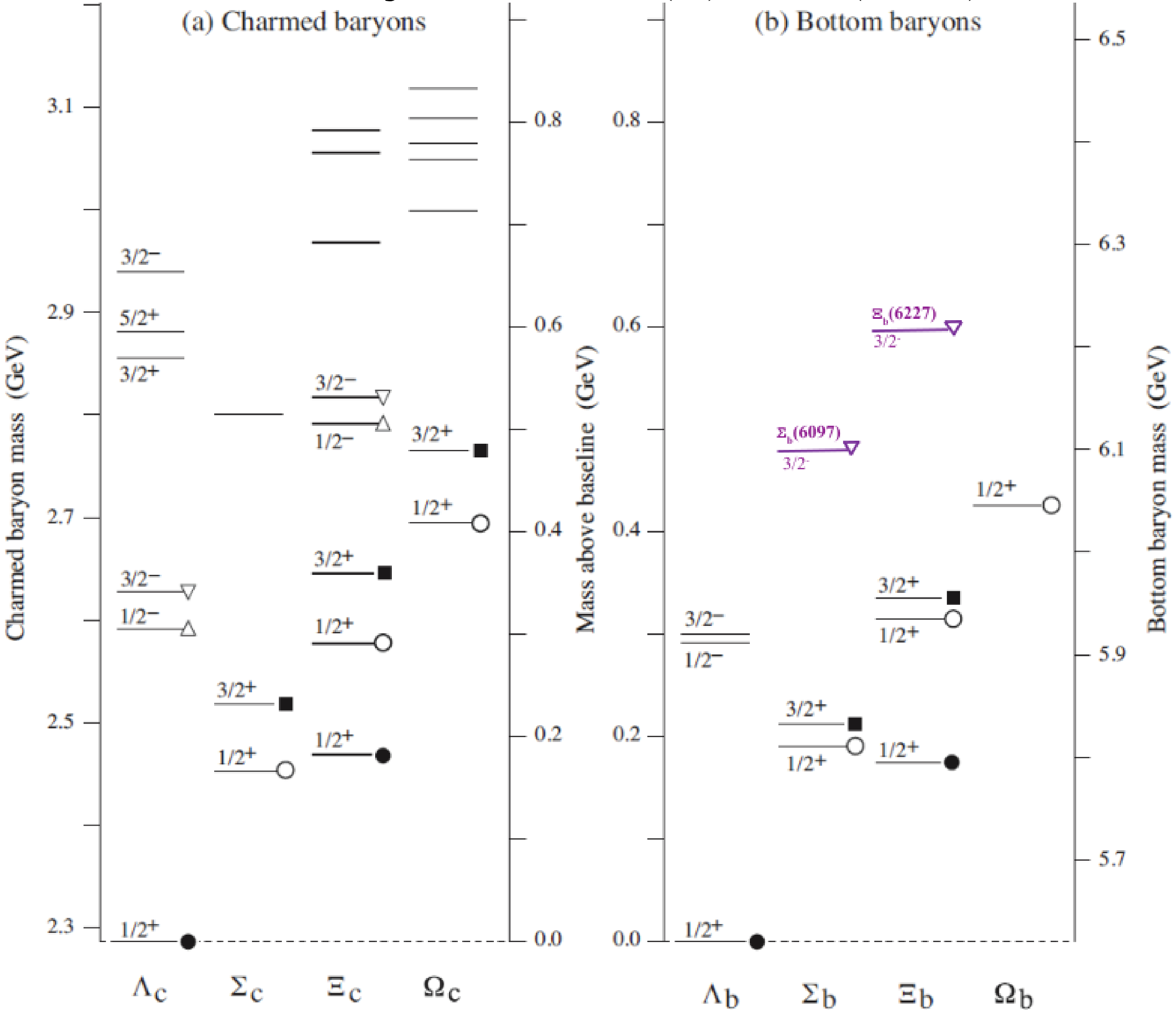
- Moreover the differences within the same doublet are extracted to be

Theo

$$M_{\Sigma_b(5/2^-)} = 6.11 \pm 0.12 \text{ GeV}\,, \quad M_{\Sigma_b(5/2^-)} - M_{\Sigma_b(3/2^-)} = 13 \pm 5 \text{ MeV}\,,$$
$$M_{\Xi_b^\prime(5/2^-)} = 6.29 \pm 0.11 \text{ GeV}\,, \quad M_{\Xi_b^\prime(5/2^-)} - M_{\Xi_b^\prime(3/2^-)} = 12 \pm 5 \text{ MeV}\,,$$
$$M_{\Omega_b(5/2^-)} = 6.47 \pm 0.12 \text{ GeV}\,, \quad M_{\Omega_b(5/2^-)} - M_{\Omega_b(3/2^-)} = 11 \pm 5 \text{ MeV}\,.$$

Summary and discussions

- (a)The 24 known charmed baryons, and (b) the (9+2) known bottom baryons



PDG. 2018

Summary and discussions

- We have also studied their S-wave decays into ground-state bottom baryons accompanied by vector mesons (ρ or K^*).
- 28 possible decay channels are calculated for each P-wave bottom baryon mutiplet of flavor 6_F: $[6_F, 1, 0, \rho]$, $[6_F, 0, 1, \lambda]$, $[6_F, 1, 1, \lambda]$ and $[6_F, 2, 1, \lambda]$.

$$(d2)\quad \Gamma_{\Sigma_b[\frac{3}{2}^-]\to\Sigma_b[\frac{1}{2}^+]\rho\to\Sigma_b[\frac{1}{2}^+]\pi\pi} = 0.2\ ^{+0.3}_{-0.2}\ \text{keV}\,,$$

$$(e3)\quad \Gamma_{\Xi'_b[\frac{3}{2}^-]\to\Xi'_b[\frac{1}{2}^+]\rho\to\Xi'_b[\frac{1}{2}^+]\pi\pi} = 0.9\ ^{+1.2}_{-0.8}\ \text{keV}\,,$$

$$(g1)\quad \Gamma_{\Sigma_b[\frac{5}{2}^-]\to\Sigma^*_b[\frac{3}{2}^+]\rho\to\Sigma^*_b[\frac{3}{2}^+]\pi\pi} = 2.7^{+3.1}_{-2.1}\times 10^{-3}\text{keV}\,,$$

$$(h2)\quad \Gamma_{\Xi'_b[\frac{5}{2}^-]\to\Xi^*_b[\frac{3}{2}^+]\rho\to\Xi^*_b[\frac{3}{2}^+]\pi\pi} = 5.1\ ^{+5.6}_{-4.0}\ \text{keV}\,.$$

- We suggest the LHCb and Belle/Belle-II experiments to search for the $\Xi_b(5/2^-)$, which is the $J^P = 5/2^-$ partner state of the $\Xi_b(6227)^-$ in the decay channel of $\Xi_b(5/2^-) \to \Xi_b^*(3/2^+)\rho \to \Xi_b^*(3/2^+)\pi\pi$.

arXiv:1909.13575

Thanks for your attention!

谢谢