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P-wave bottom baryons of the SU(3) flavor 6_F

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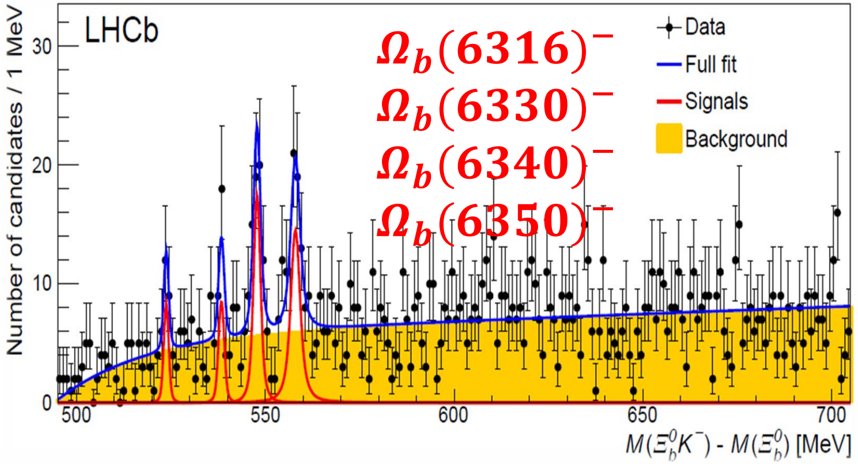
- P-wave bottom baryons of SU(3) flavor 6_F
    - *Mass spectra of bottom baryons*
    - *Decay widths of bottom baryons*
- Summary

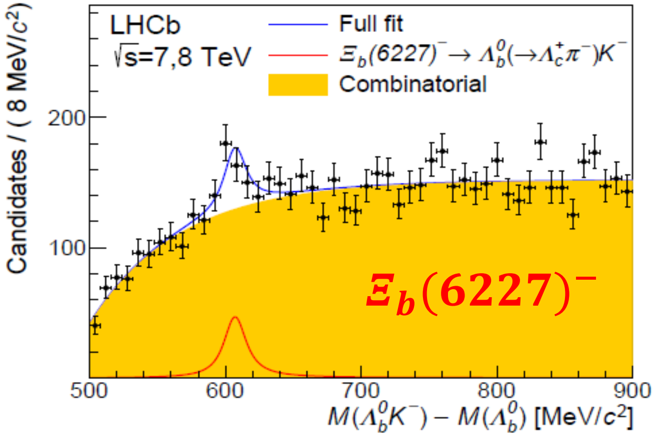
background

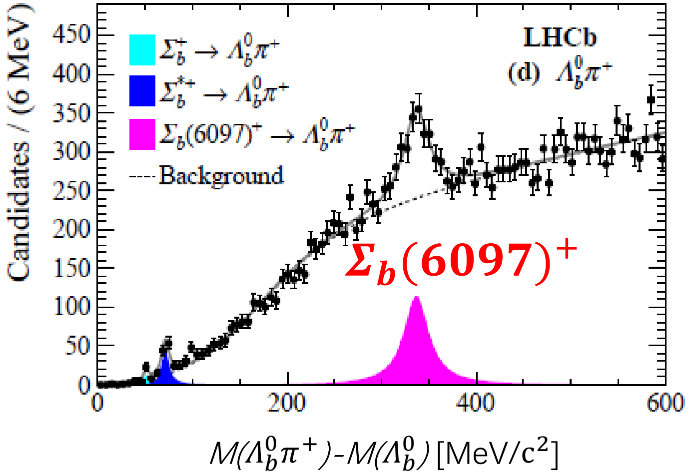
Discovery of excited bottom baryons

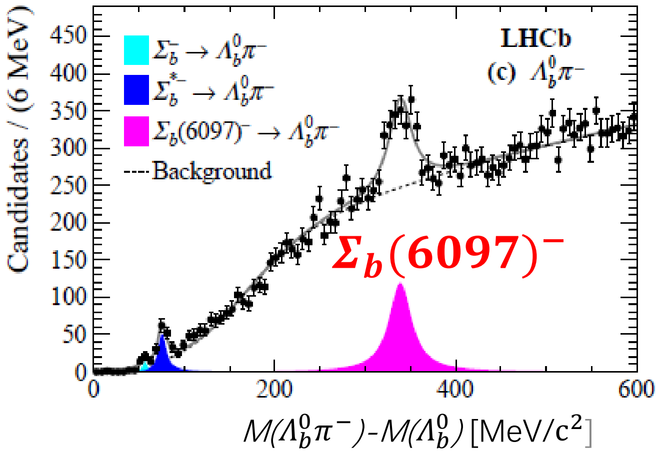
LHCb, PRL 121, 072002 (2018)
LHCb, PRL 122, 012001 (2018)
LHCb, PRL 124, 082002 (2020)
CMS, PLB 803, 135345 (2020)
Belle, PRD 94, 052011 (2016)

State	Mass(MeV)	Width(MeV)
$\Sigma_b(6097)^+$	$6095.8\pm1.7\pm0.4$	$31\pm5.5\pm0.7$
$\Sigma_b(6097)^-$	$6098.0\pm1.7\pm0.5$	$28.9\pm4.2\pm0.9$
$\Xi_b(6227)^-$	$6226.9\pm2.0\pm0.3\pm0.2$	$18.1\pm5.4\pm1.8$
$\Omega_b(6316)^-$	$6315.64\pm0.31\pm0.07\pm0.50$	<2.8
$\Omega_b(6330)^-$	$6330.03\pm0.28\pm0.07\pm0.50$	<3.1
$\Omega_b(6340)^-$	$6339.71\pm0.26\pm0.05\pm0.50$	<1.5
$\Omega_b(6350)^-$	$6349.88\pm0.35\pm0.05\pm0.50$	$1.4^{+1.0}_{-0.8}\pm0.1$









approaches

Various quark models

- ✓ K. L. Wang, Q. F. Lv, and X. H. Zhong, Phys. Rev. D99, 014011
- ✓ D. Ebert, R. N. Faustov, and V. O. Galkin, Phys. Lett. B659, 612
- ✓ T. Yoshida, E. Hiyama, A. Hosaka, and K. Sadato, Phys. Rev. D92,114029
- ✓ L. X. Gutierrez-Guerrero, A. Bashir, and M. A. Bedolla, Phys. Rev. D 100, 114032
- ✓ Y. Kawakami and M. Harada, Phys. Rev. D 99, 094016

…

Various molecular models

- ✓ W. H. Liang, C. W. Xiao, and E. Oset, Phys. Rev. D89, 054023
- ✓ Y. Huang, C. J. Xiao, L. S. Geng, and J. He, Phys. Rev. D99, 014008
- ✓ C. Garcia-Recio, J. Nieves, and O. Romanets, Phys. Rev. D 87, 034032
- ✓ R. Chen, A. Hosaka, and X. Liu, Phys. Rev. D 97, 036016
- ✓ J. Nieves, R. Pavao, and L. Tolos, Eur. Phys. J. C 80, 22

…

Quark pair creation model

- ✓ B. Chen and X. Liu, Rhys. Rev. D98, 074032
- ✓ W. Liang and Q. F. Lv, Eur. Phys. J. C80, 198
- ✓ P. Yang, J. J. Guo, and A. Zhang, Phys. Rev. D 99, 034018

…

Chiral perturbation theory

- ✓ J. X. Lu, Y. Zhou, H. X. Chen, J. J. Xie, and L. S. Geng, phys. Rev. D92, 014036
- ✓ H. Y. Cheng and C. K. Chua, Phys. Rev. D92, 074014

…

QCD sum rules

- ✓ T. M. Aliev, K. Azizi, Y. Sarac, and H. Sundu, Phys. Rev. D99,094003
- ✓ Z. G. Wang, Int. J. Mod. A35, 2050043
- ✓ H. X. Chen, Q. Mao, W. Chen, A. Hosaka, X. Liu, and S. L. Zhu, Phys. Rev. D 95, 094008

…

Lattice QCD

- ✓ M. Padmanath and N. Mathur, Phys. Rev. Lett. 119, 042001
- ✓ K. U. Can, H. Bahtiyar, G. Erkol, P. Gubler, M. Oka, and T. T. Takahashi, J. Phys. Soc. Jpn. Conf. Proc. 26, 022028
- ✓ M. Padmanath, R. G. Edwards, N. Mathur, and M. Peardon, arXiv:1311.4806

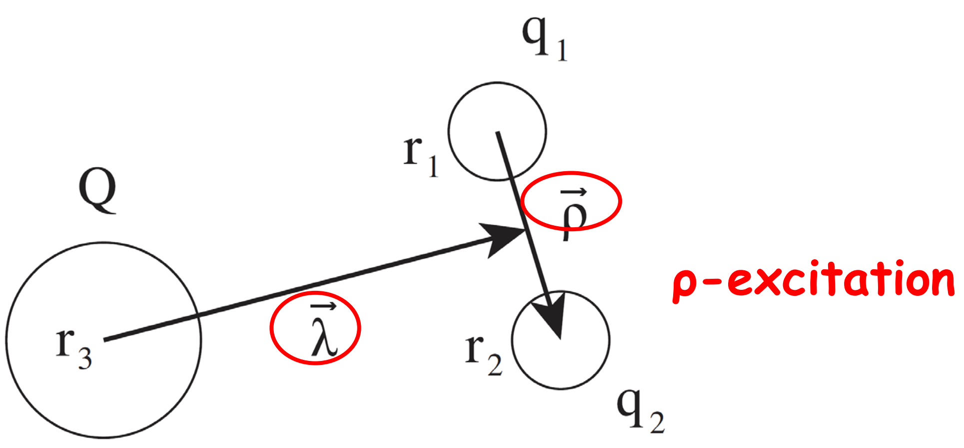
…

Internal structure of bottom baryons

- Based on **heavy quark symmetry**, the internal structure of a bottom baryon(b-q_1-q_2) is :

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

$$s_l = s_{q1} \otimes s_{q2}$$
$$j_l = s_l \otimes l_\rho \otimes l_\lambda$$



λ-excitation

Categorization of p-wave bottom baryons

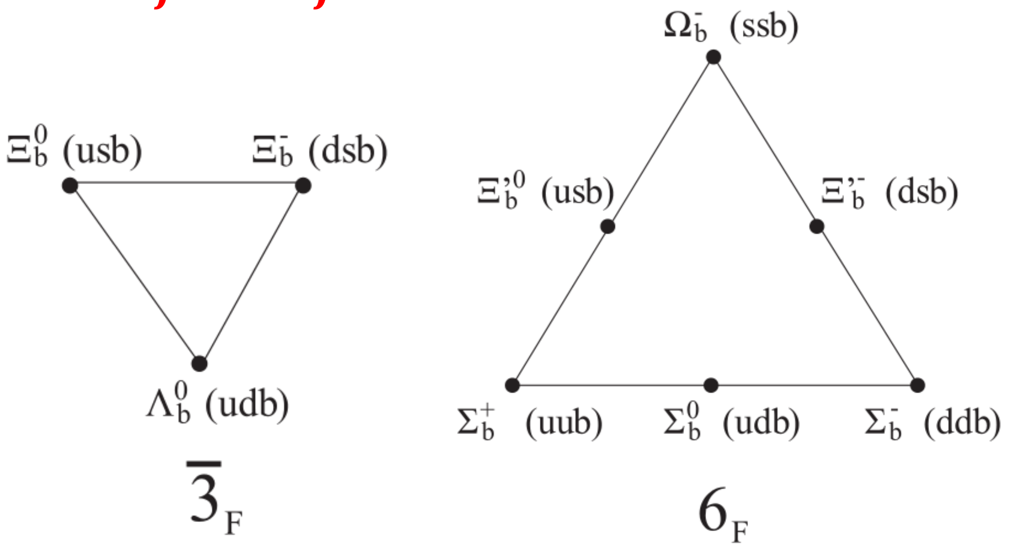
Thus the wave function for baryons can be written as :

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

The Pauli principle can be directly applied to the two light quarks:

- color $\longrightarrow \bar{3}_C$ antisymmetric
- orbital $\longrightarrow l_\rho \begin{cases} 0 \text{ symmetric} \\ 1 \text{ antisymmetric} \end{cases}$
- spin $\longrightarrow s_{qq} = \begin{cases} 1 \text{ symmetric} \\ 0 \text{ antisymmetric} \end{cases}$
- SU(3) flavor $\longrightarrow \begin{cases} 6_F \text{ symmetric} \\ \bar{3}_F \text{ antisymmetric} \end{cases}$

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



Categorization of p-wave bottom baryons

- We defined the notation of the bottom baryon's multiplet :
  [F, j_l, s_l, ρ/λ]

P-wave bottom baryons : $l_\rho + l_\lambda = 1$

- color $\longrightarrow \bar{3}_C$ antisymmetric
- orbital $\longrightarrow l_\rho \begin{cases} 0 \text{ symmetric} \\ 1 \text{ antisymmetric} \end{cases}$
- spin $\longrightarrow s_{qq} = \begin{cases} 1 \text{ symmetric} \\ 0 \text{ antisymmetric} \end{cases}$
- SU(3) flavor $\longrightarrow \begin{cases} 6_F \text{ symmetric} \\ \bar{3}_F \text{ antisymmetric} \end{cases}$

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

$(\bar{3}_C)_A \quad (l_\rho = 0)_S \quad (s_{qq} = 0)_A \quad (\bar{3}_F)_A$

A   S

$$j_l = 1, S_Q = \frac{1}{2}: \quad J_P = \left(\frac{1}{2}^-, \frac{3}{2}^-\right)$$

$[\bar{3}_F, 1, 0, \lambda]$: $\Lambda_{b1}(\frac{1}{2}^-, \frac{3}{2}^-) \Xi_{b1}(\frac{1}{2}^-, \frac{3}{2}^-)$

Categorization of p-wave bottom baryons

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- color $\longrightarrow \bar{3}_C$ antisymmetric
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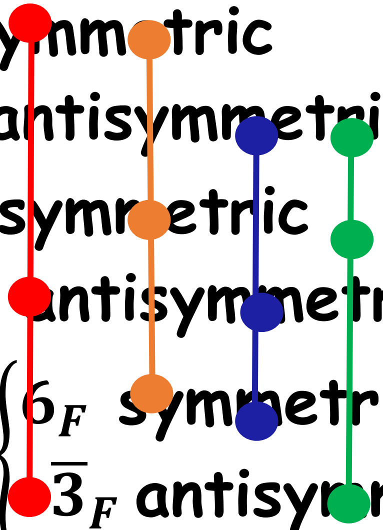

Categorization of p-wave bottom baryons

We defined the notation of the bottom baryons multiplet : $[F, j_l, s_l, \rho/\lambda]$

P-wave bottom baryons : $l_\rho + l_\lambda = 1$

- color $\longrightarrow \bar{3}_C$ antisymmetric
- orbital $\longrightarrow l_\rho$ { 0 symmetric; 1 antisymmetric }
- spin $\longrightarrow s_{qq} =$ { 1 symmetric; 0 antisymmetric }
- SU(3) flavor $\longrightarrow$ { 6_F symmetric; $\bar{3}_F$ antisymmetric }

$l_\rho=0$, $l_\lambda=1$:

- $s_{qq}=0, \bar{3}_F \rightarrow j_l = 1: \Lambda_{b1}(\frac{1}{2}^-, \frac{3}{2}^-)\Xi_{b1}(\frac{1}{2}^-, \frac{3}{2}^-)[\bar{3}_F,1,0,\lambda]$
- $s_{qq}=1, 6_F$:
  - $j_l=0: \Sigma_{b0}(\frac{1}{2}^-)\Xi'_{c0}(\frac{1}{2}^-)\Omega_{b0}(\frac{1}{2}^-)\ [6_F,0,1,\lambda]$
  - $j_l=1: \Sigma_{b1}(\frac{1}{2}^-, \frac{3}{2}^-)\Xi'_{b1}(\frac{1}{2}^-, \frac{3}{2}^-)\Omega_{b1}(\frac{1}{2}^-, \frac{3}{2}^-)[6_F,1,1,\lambda]$
  - $j_l=2: \Sigma_{b2}(\frac{3}{2}^-, \frac{5}{2}^-)\Xi'_{b2}(\frac{3}{2}^-, \frac{5}{2}^-)\Omega_{b2}(\frac{3}{2}^-, \frac{5}{2}^-)[6_F,2,1,\lambda]$

$l_\rho=1$, $l_\lambda=0$:

- $s_{qq}=0, 6_F \rightarrow j_l=1: \Sigma_{b1}(\frac{1}{2}^-, \frac{3}{2}^-)\Xi'_{b1}(\frac{1}{2}^-, \frac{3}{2}^-)\ \Omega_{b1}(\frac{1}{2}^-, \frac{3}{2}^-)[6_F,1,0,\rho]$
- $s_{qq}=1, \bar{3}_F$:
  - $j_l=0: \Lambda_{b0}(\frac{1}{2}^-)\Xi_{b0}(\frac{1}{2}^-)\ [\bar{3}_F,0,1,\rho]$
  - $j_l=1: \Lambda_{b1}(\frac{1}{2}^-, \frac{3}{2}^-)\Xi_{b1}(\frac{1}{2}^-, \frac{3}{2}^-)[\bar{3}_F,1,1,\rho]$
  - $j_l=2: \Lambda_{b2}(\frac{3}{2}^-, \frac{5}{2}^-)\Xi_{b2}(\frac{3}{2}^-, \frac{5}{2}^-)[\bar{3}_F,2,1,\rho]$

Categorization of p-wave bottom baryons

Multiplet	Baryon(J^P)
$[6_F, 1, 0, \rho]$	$\Sigma_b^-(\frac{1}{2}^-), \Xi_b'^-(\frac{1}{2}^-), \Omega_b^-(\frac{1}{2}^-)$ $\Sigma_b^-(\frac{3}{2}^-), \Xi_b'^-(\frac{3}{2}^-), \Omega_b^-(\frac{3}{2}^-)$
$[6_F, 0, 1, \lambda]$	$\Sigma_b^-(\frac{1}{2}^-), \Xi_b'^-(\frac{1}{2}^-), \Omega_b^-(\frac{1}{2}^-)$
$[6_F, 1, 1, \lambda]$	$\Sigma_b^-(\frac{1}{2}^-), \Xi_b'^-(\frac{1}{2}^-), \Omega_b^-(\frac{1}{2}^-)$ $\Sigma_b^-(\frac{3}{2}^-), \Xi_b'^-(\frac{3}{2}^-), \Omega_b^-(\frac{3}{2}^-)$
$[6_F, 2, 1, \lambda]$	$\Sigma_b^-(\frac{3}{2}^-), \Xi_b'^-(\frac{3}{2}^-), \Omega_b^-(\frac{3}{2}^-)$ $\Sigma_b^-(\frac{5}{2}^-), \Xi_b'^-(\frac{5}{2}^-), \Omega_b^-(\frac{5}{2}^-)$

→ **P-wave bottom baryons of SU(3) flavor 6_F**

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QCD sum rules and light-cone sum rules

- In QCD sum rules analysis, we considered two-point correlation function:

$$\Pi(q) = i\int d^4x e^{iqx}\langle 0|T\eta(x)\bar{\eta}(0)|0\rangle \qquad (1)$$

- In light-cone sum rules analysis, we considered three-point correlation function:

$$\Pi(p,k) = \int d^4x e^{ipx}\int d^4y e^{iky}\langle 0|T\eta_2(x)\eta_3(y)\bar{\eta}_1(0)|0\rangle \qquad (2)$$

Further, the three-point correlation function can be rewrite as two-point correlation function:

$$\Pi(p) = \int d^4x e^{-ipx}\langle 0|T\eta_1(x)\bar{\eta}_2(0)|\rho\backslash K^*\rangle \qquad (3)$$

where η are the currents which can couple to hadronic states.

- In sum rules, we can calculate two-point correlation function at quark gluon level and hadron level and perform quark-hadron duality

Quark gluon level(Operator Product Expansion)	quark-hadron duality	Hadron level
Operator: quark-gluon condensates(QCD sum rules) light-cone distribution amplitudes(Light-cone sum rules)		Observables: mass, coupling constant

Mass spectra of p-wave bottom baryons

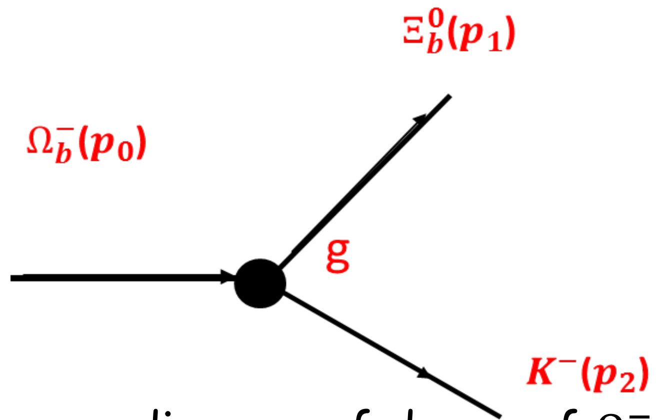
Multiplets	B	ω_c (GeV)	Working region (GeV)	$\bar{\Lambda}$ (GeV)	Baryons (j^P)	Mass (GeV)	Difference (MeV)
$[\mathbf{6}_F, 1, 0, \rho]$	Σ_b	1.83	$0.27 < T < 0.34$	1.31 ± 0.11	$\Sigma_b(1/2^-)$	6.05 ± 0.12	3 ± 1
					$\Sigma_b(3/2^-)$	6.05 ± 0.12	
	Ξ'_b	1.98	$0.26 < T < 0.36$	1.45 ± 0.11	$\Xi'_b(1/2^-)$	6.18 ± 0.12	3 ± 1
					$\Xi'_b(3/2^-)$	6.19 ± 0.11	
	Ω_b	2.13	$0.26 < T < 0.37$	1.58 ± 0.09	$\Omega_b(1/2^-)$	6.32 ± 0.11	2 ± 1
					$\Omega_b(3/2^-)$	6.32 ± 0.11	
$[\mathbf{6}_F, 0, 1, \lambda]$	Σ_b	1.70	$0.26 < T < 0.32$	1.25 ± 0.10	$\Sigma_b(1/2^-)$	6.05 ± 0.11	$\cdots$
	Ξ'_b	1.85	$0.27 < T < 0.33$	1.40 ± 0.09	$\Xi'_b(1/2^-)$	6.20 ± 0.11	$\cdots$
	Ω_b	2.00	$0.27 < T < 0.34$	1.54 ± 0.09	$\Omega_b(1/2^-)$	6.34 ± 0.11	$\cdots$
$[\mathbf{6}_F, 1, 1, \lambda]$	Σ_b	1.94	$0.29 < T < 0.36$	1.25 ± 0.11	$\Sigma_b(1/2^-)$	6.06 ± 0.13	6 ± 3
					$\Sigma_b(3/2^-)$	6.07 ± 0.13	
	Ξ'_b	1.97	$0.35 < T < 0.38$	1.38 ± 0.09	$\Xi'_b(1/2^-)$	6.21 ± 0.11	7 ± 2
					$\Xi'_b(3/2^-)$	6.22 ± 0.11	
	Ω_b	2.00	$0.38 < T < 0.39$	1.48 ± 0.07	$\Omega_b(1/2^-)$	6.34 ± 0.10	6 ± 2
					$\Omega_b(3/2^-)$	6.34 ± 0.09	
$[\mathbf{6}_F, 2, 1, \lambda]$	Σ_b	1.84	$0.27 < T < 0.34$	1.30 ± 0.13	$\Sigma_b(3/2^-)$	6.11 ± 0.16	12 ± 5
					$\Sigma_b(5/2^-)$	6.12 ± 0.15	
	Ξ'_b	1.96	$0.26 < T < 0.35$	1.41 ± 0.12	$\Xi'_b(3/2^-)$	6.23 ± 0.15	11 ± 5
					$\Xi'_b(5/2^-)$	6.24 ± 0.14	
	Ω_b	2.08	$0.26 < T < 0.37$	1.53 ± 0.10	$\Omega_b(3/2^-)$	6.35 ± 0.13	10 ± 4
					$\Omega_b(5/2^-)$	6.36 ± 0.12	

Experiment:

- $\Omega_b(6316)$
- $\Omega_b(6340)$
- $\Omega_b(6330)$
- $\Sigma_b(6097)$
- $\Xi'_b(6227)$
- $\Omega_b(6350)$

Light-cone sum rules studies on the decay widths

- **For example, we studied the D-wave decay of the $\Omega_b^-(3/2^-)$ belonging to $[6_F, 2, 1, \lambda]$ into Ξ_b^0 and K^-.**



Feynman diagram of decay of $\Omega_b^-(3/2^-)$

- The two-point correlation function can be wrote as

$$\Pi^\alpha(\omega, \omega') = \int d^4x e^{-ik\cdot x}\langle 0|J^\alpha_{3/2,-,\Omega_b^-,2,1,\lambda}(0)\bar{J}_{\Xi_b^0}(x)|K^-(q)\rangle = \frac{1+\not{v}}{2} G^\alpha_{\Omega_b^-[\frac{3}{2}^-]\to\Xi_b^0 K^-}(\omega,\omega'), \quad (4)$$

- At the hadron level, we wrote correlation function as

$$G^\alpha_{\Omega_b^-[\frac{3}{2}^-]\to\Xi_b^0 K^-}(\omega,\omega') = g_{\Omega_b^-[\frac{3}{2}^-]\to\Xi_b^0 K^-} \times \frac{f_{\Omega_b^-[\frac{3}{2}^-]} f_{\Xi_b^0}}{(\bar{\Lambda}_{\Omega_b^-[\frac{3}{2}^-]} - \omega')(\bar{\Lambda}_{\Xi_b^0} - \omega)} \gamma \cdot q \gamma_5 q^\alpha + \cdots \quad (5)$$

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Light-cone sum rules studies on the decay widths

- At the quark-gluon level, we calculated Π^{α} by the method of operator product expansion(OPE)

$$
\begin{aligned}
&G^{\alpha}_{\Omega_b^-[\frac{3}{2}^-]\to\Xi_b^0 K^-}(\omega,\omega') \\
&= \int_0^\infty dt \int_0^1 du e^{i(1-u)\omega' t} e^{iu\omega t} \times 8 \times \Big(\frac{f_K m_s u}{4\pi^2 t^2}\phi_{2;K}(u) + \frac{f_K m_s^2 u}{12(m_u+m_s)\pi^2 t^2}\phi^{\sigma}_{3;K}(u) \\
&+ \frac{f_K m_s^2 m_K^2 u}{48(m_u+m_s)\pi^2}\phi^{\sigma}_{3;K}(u) + \frac{f_K m_s u}{64\pi^2}\phi_{4;K}(u) + \frac{f_K u}{12}\langle \bar{s}s\rangle \phi_{2;K}(u) + \frac{f_K m_s m_K^2 u t^2}{288(m_u+m_s)}\langle ss\rangle \phi^{\sigma}_{3;K}(u) \\
&+ \frac{f_K u t^2}{192}\langle ss\rangle \phi_{4;K}(u) + \frac{f_K u t^2}{192}\langle g_s \bar{s}\sigma G s\rangle \phi_{2;K}(u) + \frac{f_K u t^4}{3072}\langle g_s \bar{s}\sigma G s\rangle \phi_{4;K}(u) \Big) \times \gamma\cdot q \gamma_5 q^{\alpha} \\
&- \int_0^\infty dt \int_0^1 du \int \mathcal{D}\underline{\alpha} e^{i\omega' t(\alpha_2+u\alpha_3)} e^{i\omega t(1-\alpha_2-u\alpha_3)} \times \Big(\frac{f_{3K} u}{2\pi^2 t^2}\Phi_{3;K}(\underline{\alpha}) - \frac{f_{3K}}{2\pi^2 t^2}\Phi_{3;K}(\underline{\alpha}) \\
&+ \frac{i f_{3K} u^2 \alpha_3}{2\pi^2 t v\cdot q}\Phi_{3;K}(\underline{\alpha}) + \frac{i f_{3K} u \alpha_2}{2\pi^2 t v\cdot q}\Phi_{3;K}(\underline{\alpha}) - \frac{i f_{3K} u}{2\pi^2 t v\cdot q}\Phi_{3;K}(\underline{\alpha}) \Big) \times \gamma\cdot q\gamma_5 q^{\alpha} + \cdots . \qquad (6)
\end{aligned}
$$

Light-cone sum rules studies on the decay widths

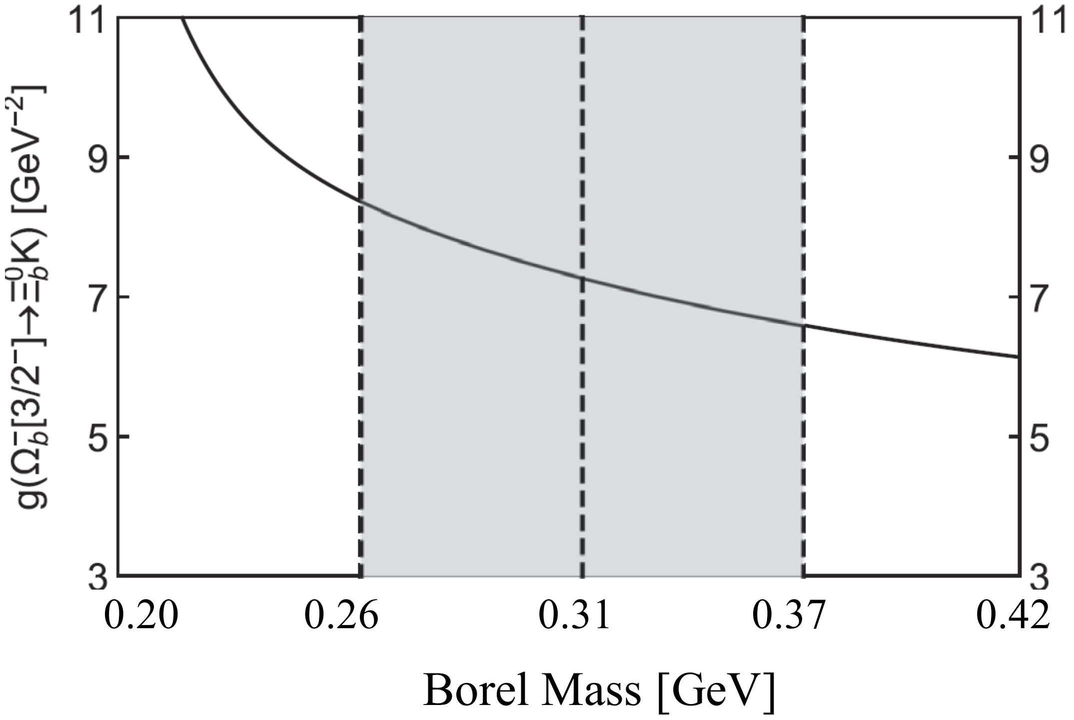
- We performed double Borel transformation for these two functions

$$
\begin{aligned}
& g_{\Omega_b^-[\frac{3}{2}^-]\to\Xi_b^0 K^-} f_{\Omega_b^-[\frac{3}{2}^-]} f_{\Xi_b^0} e^{-\frac{\bar{\Lambda}_{\Omega_b^-[\frac{3}{2}^-]}}{T_1}} e^{-\frac{\bar{\Lambda}_{\Xi_b^0}}{T_2}} \\
&= 8 \times \Bigg(-\frac{i f_k m_s u_0}{4\pi^2} T^3 f_2\left(\frac{\omega_c}{T}\right) \phi_{2;K}(u_0) - \frac{i f_K m_K^2 u_0}{12(m_u+m_s)\pi^2} T^3 f_2\left(\frac{\omega_c}{T}\right) \phi_{3;K}^{\sigma}(u_0) + \frac{i f_K m_s u_0}{64\pi^2} T f_0\left(\frac{\omega_c}{T}\right) \phi_{4;K}(u_0) \\
&\quad + \frac{i f_K u_0}{12} \langle \bar{s}s \rangle T f_0\left(\frac{\omega_c}{T}\right) \phi_{2;K}(u_0) - \frac{i f_K m_s u_0}{288(m_u+m_s)} \langle \bar{s}s \rangle \frac{1}{T} \phi_{3;K}^{\sigma}(u_0) - \frac{i f_K u_0}{192} \langle \bar{s}s \rangle \frac{1}{T} \phi_{4;K}(u_0) \\
&\quad - \frac{i f_K u_0}{192} \langle g_s \bar{s}\sigma G s \rangle \frac{1}{T} \phi_{2;K}(u_0) + \frac{i f_K u_0}{3072} \langle g_s \bar{s}\sigma G s \rangle \frac{1}{T^3} \phi_{4;K}(u_0) \Bigg) \\
&\quad - \left(-\frac{i f_{3K}}{2\pi^2} T^3 f_2\left(\frac{\omega_c}{T}\right) \right) \int_0^{\frac{1}{2}} d\alpha_2 \int_{\frac{1}{2}-\alpha_2}^{1-\alpha_2} d\alpha_3 \left(\frac{u_0}{\alpha_3} \Phi_{3;K}(\underline{\alpha}) - \frac{1}{\alpha_3} \Phi_{3;K}(\underline{\alpha}) \right) \\
&\quad + \frac{i f_{3K}}{2\pi^2} T^3 f_2\left(\frac{\omega_c}{T}\right) \int_0^{\frac{1}{2}} d\alpha_2 \int_{\frac{1}{2}-\alpha_2}^{1-\alpha_2} d\alpha_3 \frac{1}{\alpha_3} \frac{\partial}{\partial \alpha_3} \Big(\alpha_3 u_0 \Phi_{3;K}(\underline{\alpha}) + \alpha_2 \Phi_{3;K}(\underline{\alpha}) - \Phi_{3;K}(\underline{\alpha}) \Big) \Bigg).
\end{aligned}
\tag{7}
$$

$$
g^D_{\Omega_b^-[\frac{3}{2}^-]\to\Xi_b^0\pi^-} = 7.27^{+3.92}_{-2.83}\ \mathrm{GeV}^{-2}
$$

Light-cone sum rules studies on the decay widths

- The coupling constant $g^{D}_{\Omega_b^-[\frac{3}{2}^-]\to\Xi_b^0\pi^-}$ as function of the Borel mass T



- Lagrangian:

$$\mathcal{L}_{X_b(3/2^-)\to Y_b(1/2^+)P} = g\bar{X}_{b\mu}(3/2^-)\gamma_\nu\gamma_5 Y_b(1/2^+)\partial^\mu\partial^\nu P$$

- Partial decay width

$$\begin{aligned}\Gamma(\Omega_b^-(3/2^-) \to \Xi_b^0 + K^-) &= \frac{|\vec{p}_2|}{32\pi^2 m_0^2} \times g^2_{\Omega_b^-[\frac{3}{2}^-]\to\Xi_b^0K^-} \times p_{2,\mu}p_{2,\nu}p_{2,\rho}p_{2,\sigma} \\ &\times \mathrm{Tr}\Big[\gamma^\nu\gamma_5(\not{p}_1 + m_1)\gamma^\sigma\gamma_5 \\ &\times \left(g^{\rho\mu} - \frac{\gamma^\rho\gamma^\mu}{3} - \frac{p_0^\rho\gamma^\mu - p_0^\mu\gamma^\rho}{3m_0} - \frac{2p_0^\rho p_0^\mu}{3m_0^2}\right)(\not{p}_0 + m_0)\Big]\end{aligned} \quad (8)$$

$$\Gamma_{\Omega_b^-[\frac{3}{2}^-]\to\Xi_b^0K^-} = 4.6^{+3.3}_{-1.9}\ \mathrm{MeV}$$

Probable decay channels

- We studied the S-wave and D-wave decays of P-wave Ω_b^- baryons into ground-state bottom baryons with a pseudoscalar meson Kaon.

- S-wave(->ground-state +pseudoscalar)

$$\Gamma[\Omega_b(1/2^-) \to \Xi_b(1/2^+) + K] = 2 \times \Gamma[\Omega_b^-(1/2^-) \to \Xi_b^0(1/2^+) + K^-]$$

$$\Gamma[\Omega_b(1/2^-) \to \Xi_b'(1/2^+) + K] = 2 \times \Gamma[\Omega_b^-(1/2^-) \to \Xi_b'^0(1/2^+) + K^-]$$

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

- D-wave(-> ground-state +pseudoscalar)

$$\Gamma[\Omega_b[1/2^-] \to \Xi_b^* + K] = 2 \times \Gamma[\Omega_b^-[1/2^-] \to \Xi_b^{*0} + K^-]$$

$$\Gamma[\Omega_b[3/2^-] \to \Xi_b + K] = 2 \times \Gamma[\Omega_b^-[3/2^-] \to \Xi_b^0 + k^-]$$

$$\Gamma[\Omega_b[3/2^-] \to \Xi_b' + K] = 2 \times \Gamma[\Omega_b^-[3/2^-] \to \Xi_b'^0 + K^-]$$

$$\Gamma[\Omega_b[3/2^-] \to \Xi_b^* + K] = 2 \times \Gamma[\Omega_b^-[3/2^-] \to \Xi_b^{*0} + K^-]$$

$$\Gamma[\Omega_b[5/2^-] \to \Xi_b + K] = 2 \times \Gamma[\Omega_b^-[5/2^-] \to \Xi_b^0 + k^-]$$

$$\Gamma[\Omega_b[5/2^-] \to \Xi_b' + K] = 2 \times \Gamma[\Omega_b^-[5/2^-] \to \Xi_b'^0 + K^-]$$

$$\Gamma[\Omega_b[5/2^-] \to \Xi_b^* + K] = 2 \times \Gamma[\Omega_b^-[5/2^-] \to \Xi_b^{*0} + K^-]$$

Probable decay channels

- We also investigated their S-wave decaying into ground-states with a vector meson K*. Then, K* decays into double pseudouscalar mesons pion and kaon.

  - S-wave(->ground-state+ vector -> ground-state + double pseudoscalar)

$$\Gamma\left[\Omega_b[1/2^-] \to \Xi_b + K^* \to \Xi_b + K + \pi\right] = 3 \times \Gamma\left[\Omega_b^-[1/2^-] \to \Xi_b^0 + K^0 + \pi^-\right]$$

$$\Gamma\left[\Omega_b[1/2^-] \to \Xi_b' + K^* \to \Xi_b' + K + \pi\right] = 3 \times \Gamma\left[\Omega_b^-[1/2^-] \to \Xi_b'^0 + K^0 + \pi^-\right]$$

$$\Gamma\left[\Omega_b[1/2^-] \to \Xi_b^* + K^* \to \Xi_b^* + K + \pi\right] = 3 \times \Gamma\left[\Omega_b^-[1/2^-] \to \Xi_b^{*0} + K^0 + \pi^-\right]$$

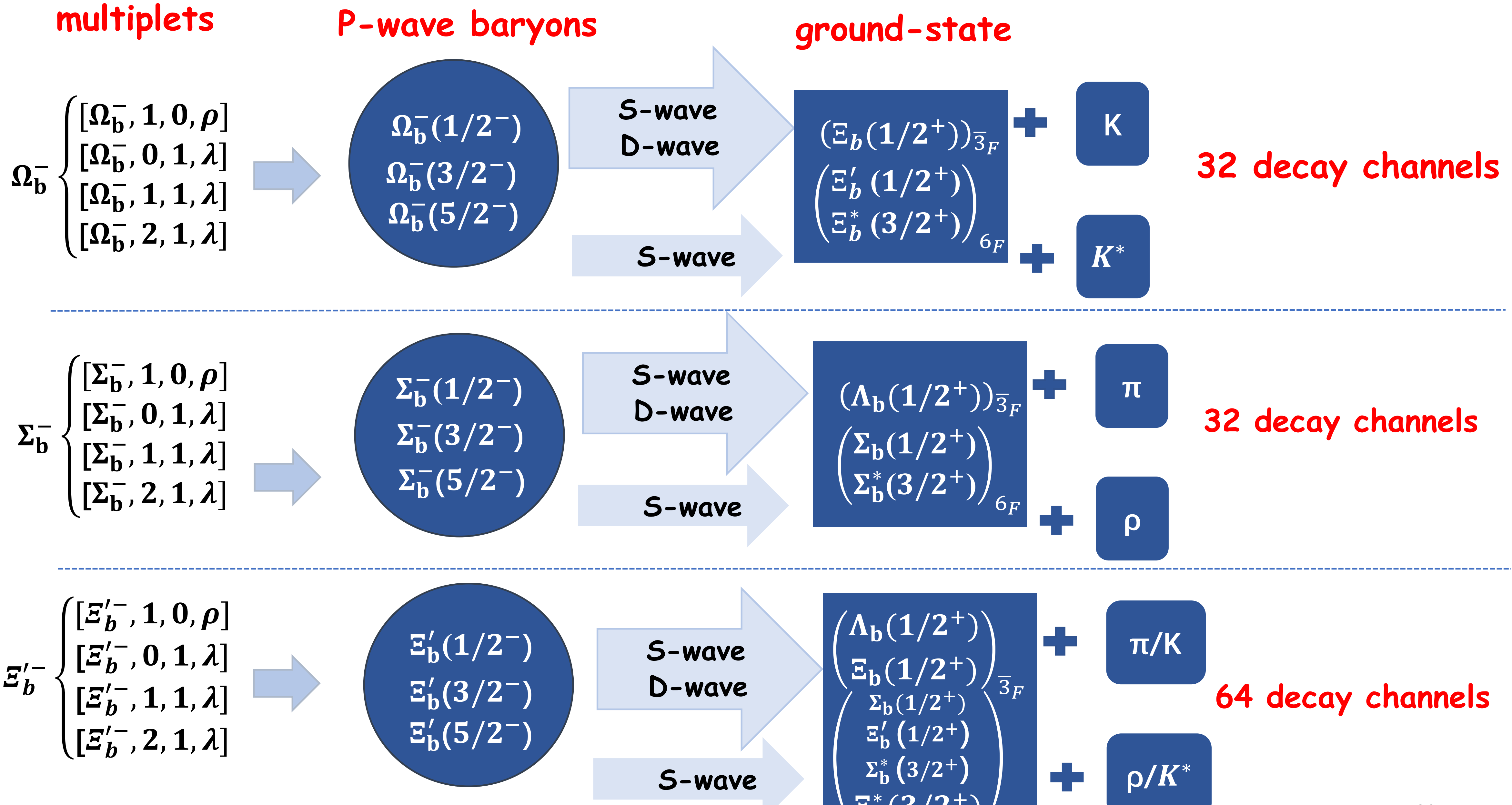
$$\Gamma\left[\Omega_b[3/2^-] \to \Xi_b + K^* \to \Xi_b + K + \pi\right] = 3 \times \Gamma\left[\Omega_b^-[3/2^-] \to \Xi_b^0 + K^0 + \pi^-\right]$$

$$\Gamma\left[\Omega_b[3/2^-] \to \Xi_b' + K^* \to \Xi_b' + K + \pi\right] = 3 \times \Gamma\left[\Omega_b^-[3/2^-] \to \Xi_b'^0 + K^0 + \pi^-\right]$$

$$\Gamma\left[\Omega_b[3/2^-] \to \Xi_b^* + K^* \to \Xi_b^* + K + \pi\right] = 3 \times \Gamma\left[\Omega_b^-[3/2^-] \to \Xi_b^{*0} + K^0 + \pi^-\right]$$

$$\Gamma\left[\Omega_b[5/2^-] \to \Xi_b^* + K^* \to \Xi_b^* + K + \pi\right] = 3 \times \Gamma\left[\Omega_b^-[5/2^-] \to \Xi_b^{*0} + K^0 + \pi^-\right]$$

Probable decay channels



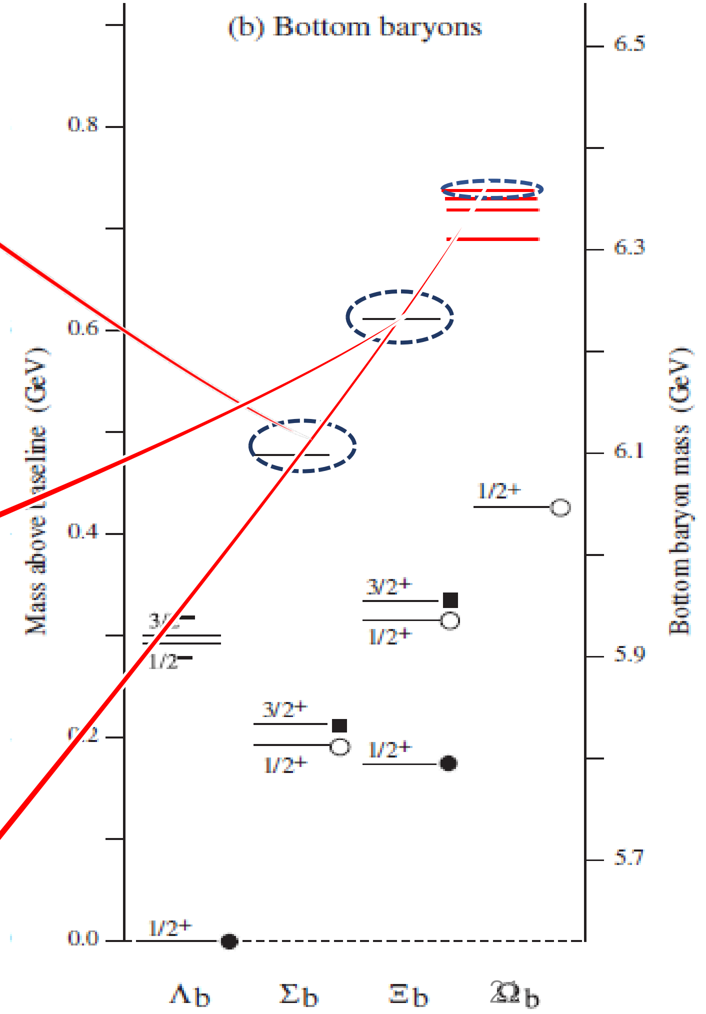
Total: 128 decay channels

Results

- P-wave bottom baryons belonging to the $[6_F, 2, 1, \lambda]$ doublet decay into ground-state baryons accompanied by a pseudoscalar or vector mesons

$[6_F, 2, 1, \lambda]$

Baryon (j^P)	Mass (GeV)	Difference (MeV)	Decay channels	S-wave width (MeV)	D-wave width (MeV)	Total width (MeV)	Candidate
$\Sigma_b(\frac{3}{2}^-)$	6.11 ± 0.16	12 ± 5	$\Sigma_b(\frac{3}{2}^-) \to \Lambda_b\pi$	–	$49.6\ ^{+76.4}_{-32.9}$	$51.4\ ^{+76.5}_{-32.9}$	$\Sigma_b(6097)^{\pm}$ [16]
			$\Sigma_b(\frac{3}{2}^-) \to \Sigma_b\pi$	–	$1.6\ ^{+3.2}_{-1.1}$		
			$\Sigma_b(\frac{3}{2}^-) \to \Sigma_b^*\pi$	$0.019\ ^{+0.065}_{-0.019}$	$0.23\ ^{+0.36}_{-0.16}$		
			$\Sigma_b(\frac{3}{2}^-) \to \Sigma_b\rho \to \Sigma_b\pi\pi$	$(1.4\ ^{+2.5}_{-1.1}) \times 10^{-4}$			
$\Sigma_b(\frac{5}{2}^-)$	6.12 ± 0.15		$\Sigma_b(\frac{5}{2}^-) \to \Lambda_b\pi$	–	$20.8\ ^{+23.7}_{-13.8}$	$23.3\ ^{+23.9}_{-13.9}$	–
			$\Sigma_b(\frac{5}{2}^-) \to \Sigma_b\pi$	–	$0.36\ ^{+0.71}_{-0.24}$		
			$\Sigma_b(\frac{5}{2}^-) \to \Sigma_b^*\pi$	–	$2.1\ ^{+3.2}_{-1.4}$		
$\Xi_b'(\frac{3}{2}^-)$	6.23 ± 0.15	11 ± 5	$\Xi_b'(\frac{3}{2}^-) \to \Xi_b\pi$	–	$19.0\ ^{+26.3}_{-13.3}$	$27.3\ ^{+28.5}_{-14.2}$	$\Xi_b(6227)^-$ [illegible]
			$\Xi_b'(\frac{3}{2}^-) \to \Lambda_b K$	–	$7.4\ ^{+11.0}_{-4.8}$		
			$\Xi_b'(\frac{3}{2}^-) \to \Xi_b'\pi$	–	$0.79\ ^{+1.13}_{-0.79}$		
			$\Xi_b'(\frac{3}{2}^-) \to \Xi_b^*\pi$	$0.007\ ^{+0.023}_{-0.007}$	$0.12\ ^{+0.17}_{-0.08}$		
			$\Xi_b'(\frac{3}{2}^-) \to \Xi_b'\rho \to \Xi_b'\pi\pi$	$(5.6\ ^{+9.1}_{-4.3}) \times 10^{-4}$			
$\Xi_b'(\frac{5}{2}^-)$	6.24 ± 0.14		$\Xi_b'(\frac{5}{2}^-) \to \Lambda_b K$	–	$3.4\ ^{+5.1}_{-2.2}$	$12.7\ ^{+12.4}_{-6.1}$	–
			$\Xi_b'(\frac{5}{2}^-) \to \Xi_b\pi$	–	$8.1\ ^{+11.2}_{-5.7}$		
			$\Xi_b'(\frac{5}{2}^-) \to \Xi_b'\pi$	–	$0.17\ ^{+0.24}_{-0.11}$		
			$\Xi_b'(\frac{5}{2}^-) \to \Xi_b^*\pi$	–	$1.0\ ^{+1.4}_{-0.69}$		
			$\Xi_b'(\frac{5}{2}^-) \to \Xi_b^*\rho \to \Xi_b^*\pi\pi$	$(1.4\ ^{+2.3}_{-1.0}) \times 10^{-4}$			
$\Omega_b(\frac{3}{2}^-)$	6.35 ± 0.13	10 ± 4	$\Omega_b(\frac{3}{2}^-) \to \Xi_b K$	–	$4.6\ ^{+3.3}_{-1.9}$	$4.6\ ^{+3.3}_{-1.9}$	$\Omega_b(6350)^-$ [illegible]
$\Omega_b(\frac{5}{2}^-)$	6.36 ± 0.12		$\Omega_b(\frac{5}{2}^-) \to \Xi_b K$	–	$2.5\ ^{+3.5}_{-1.6}$	$2.5\ ^{+3.5}_{-1.6}$	–



Results

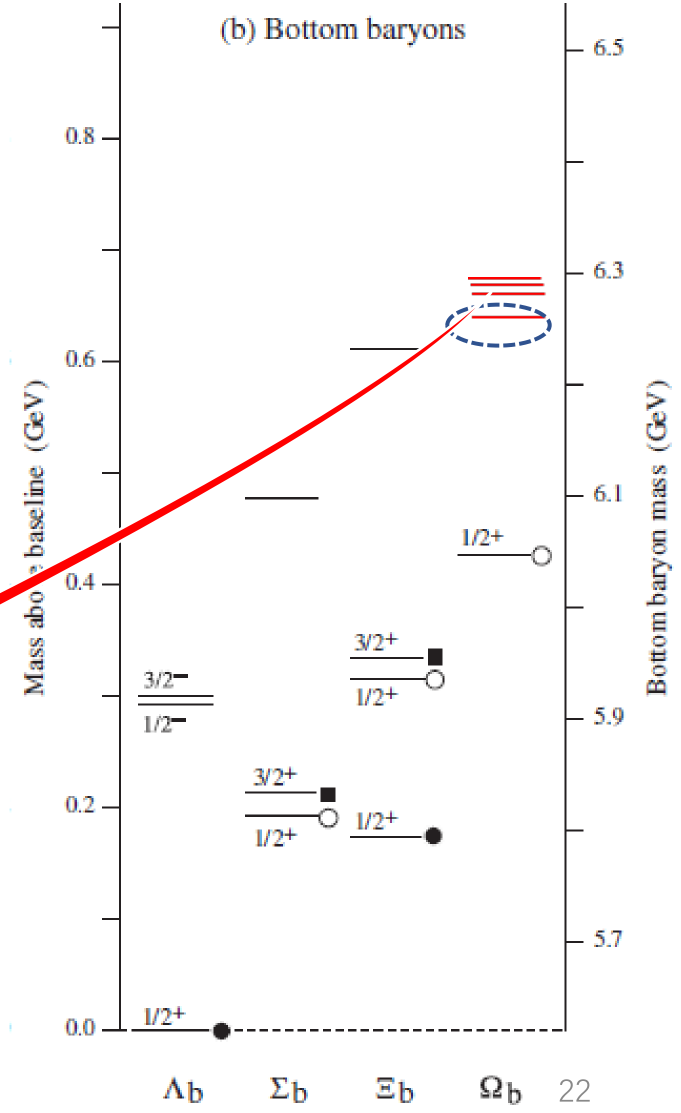
- Partial and total decay widths of P-wave bottom baryons belong to the $[6_F, 1, 0, \rho]$、$[6_F, 0, 1, \lambda]$ respectively

$[6_F, 1, 0, \rho]$

Baryon (j^P)	Mass (GeV)	Difference (MeV)	Decay channels	S-wave width (MeV)	D-wave width (MeV)	Total width (MeV)	Candidate
$\Sigma_b(\frac{1}{2}^-)$	6.05 ± 0.12	3 ± 1	$\Sigma_b(\frac{1}{2}^-) \to \Sigma_b\pi$	710	–	710	–
			$\Sigma_b(\frac{1}{2}^-) \to \Sigma_b^*\pi$	–	0.62		
			$\Sigma_b(\frac{1}{2}^-) \to \Lambda_b\rho \to \Lambda_b\pi\pi$	4.3×10^{-3}			
$\Sigma_b(\frac{3}{2}^-)$	6.05 ± 0.12		$\Sigma_b(\frac{3}{2}^-) \to \Sigma_b\pi$	–	0.84	410	–
			$\Sigma_b(\frac{3}{2}^-) \to \Sigma_b^*\pi$	410	0.098		
			$\Sigma_b(\frac{3}{2}^-) \to \Lambda_b\rho \to \Lambda_b\pi\pi$	5.1×10^{-3}			
$\Xi_b'(\frac{1}{2}^-)$	6.18 ± 0.12	3 ± 1	$\Xi_b'(\frac{1}{2}) \to \Xi_b'\pi$	250	–	250	–
			$\Xi_b'(\frac{1}{2}^-) \to \Xi_b^*\pi$	–	0.29		
			$\Xi_b'(\frac{1}{2}^-) \to \Xi_b\rho \to \Xi_b\pi\pi$	1.2×10^{-5}			
$\Xi_b'(\frac{3}{2}^-)$	6.19 ± 0.11		$\Xi_b'(\frac{3}{2}^-) \to \Xi_b'\pi$	–	0.47	160	–
			$\Xi_b'(\frac{3}{2}^-) \to \Xi_b^*\pi$	160	0.064		
			$\Xi_b'(\frac{3}{2}^-) \to \Xi_b\rho \to \Xi_b\pi\pi$	8.0×10^{-5}			
$\Omega_b(\frac{1}{2}^-)$	6.32 ± 0.11	2 ± 1	–			~ 0	$\Omega_b(6316)^-$
$\Omega_b(\frac{3}{2}^-)$	6.32 ± 0.11		–			~ 0	

$[6_F, 0, 1, \lambda]$

Baryon (j^P)	Mass (GeV)	Difference (MeV)	Decay channels	S-wave width (MeV)	D-wave width (MeV)	Total width (MeV)	Candidate
$\Sigma_b(\frac{1}{2}^-)$	6.05 ± 0.11	–	$\Sigma_b(\frac{1}{2}^-) \to \Lambda_b\pi$	1300	–	1300	–
$\Xi_b'(\frac{1}{2}^-)$	6.20 ± 0.11	–	$\Xi_b'(\frac{1}{2}^-) \to \Xi_b\pi$	990	–	1900	–
			$\Xi_b'(\frac{1}{2}^-) \to \Lambda_b K$	910	–		
$\Omega_b(\frac{1}{2}^-)$	6.34 ± 0.11	–	$\Omega_b(\frac{1}{2}^-) \to \Xi_b K$	2700	–	2700	–

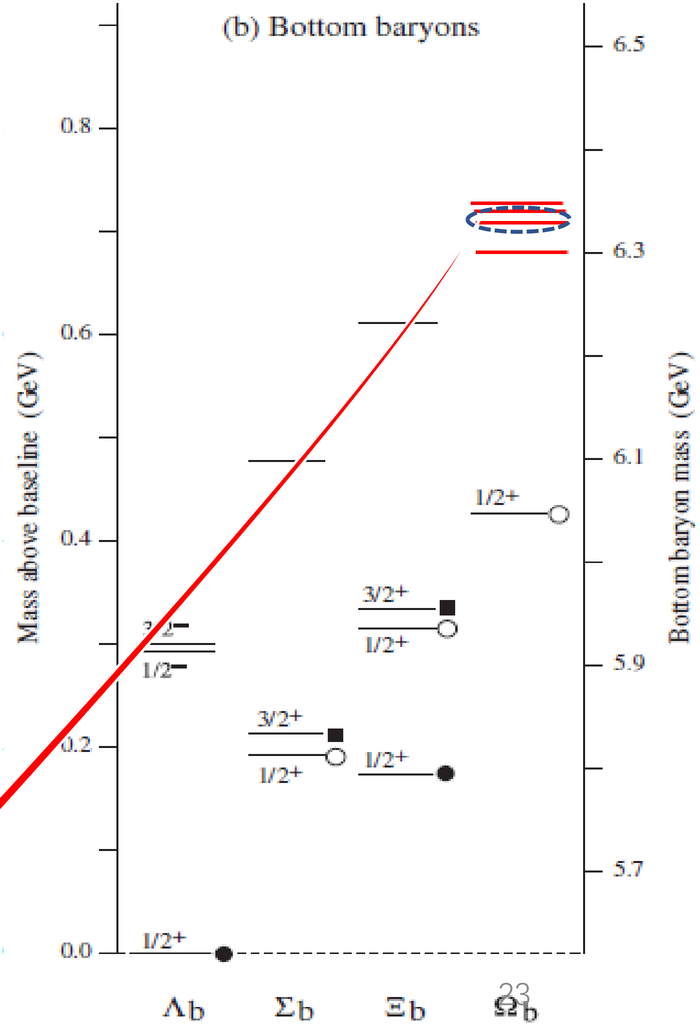


Result

- P-wave bottom baryons belonging to the $[6_F, 1, 1, \lambda]$ doublet decay into ground-state baryons accompanied by a pseudoscalar or vector mesons

$[6_F, 1, 1, \lambda]$

Baryon (j^P)	Mass (GeV)	Difference (MeV)	Decay channels	S-wave width (MeV)	D-wave width (MeV)	Total width (MeV)	Candidate
$\Sigma_b(\frac{1}{2}^-)$	6.06 ± 0.13	6 ± 3	$\Sigma_b(\frac{1}{2}^-) \to \Sigma_b \pi$	$14.1^{+21.2}_{-10.9}$	–	$14.3^{+21.2}_{-10.9}$	–
			$\Sigma_b(\frac{1}{2}^-) \to \Sigma_b^* \pi$	–	$0.076^{+0.144}_{-0.076}$		
			$\Sigma_b(\frac{1}{2}^-) \to \Lambda_b \rho \to \Lambda_b \pi\pi$	$0.087^{+0.224}_{-0.085}$			
$\Sigma_b(\frac{3}{2}^-)$	6.07 ± 0.13		$\Sigma_b(\frac{3}{2}^-) \to \Sigma_b \pi$	–	$0.55^{+0.74}_{-0.36}$	$4.8^{+5.9}_{-2.9}$	–
			$\Sigma_b(\frac{3}{2}^-) \to \Sigma_b^* \pi$	$3.9^{+5.8}_{-2.9}$	$0.070^{+0.096}_{-0.047}$		
			$\Sigma_b(\frac{3}{2}^-) \to \Lambda_b \rho \to \Lambda_b \pi\pi$	$0.23^{+0.45}_{-0.20}$			
$\Xi_b'(\frac{1}{2}^-)$	6.21 ± 0.11	7 ± 2	$\Xi_b'(\frac{1}{2}) \to \Xi_b' \pi$	$4.5^{+5.8}_{-3.3}$	–	$4.7^{+5.8}_{-3.3}$	–
			$\Xi_b'(\frac{1}{2}^-) \to \Xi_b^* \pi$	–	$0.16^{+0.18}_{-0.10}$		
			$\Xi_b'(\frac{1}{2}^-) \to \Xi_b \rho \to \Xi_b \pi\pi$	$0.043^{+0.079}_{-0.038}$			
$\Xi_b'(\frac{3}{2}^-)$	6.22 ± 0.11		$\Xi_b'(\frac{3}{2}^-) \to \Xi_b' \pi$	–	$0.34^{+0.35}_{-0.20}$	$1.8^{+1.07}_{-0.92}$	–
			$\Xi_b'(\frac{3}{2}^-) \to \Xi_b^* \pi$	$1.3^{+1.0}_{-0.9}$	$0.051^{+0.057}_{-0.030}$		
			$\Xi_b'(\frac{3}{2}^-) \to \Xi_b \rho \to \Xi_b \pi\pi$	$0.078^{+0.147}_{-0.068}$			
			$\Xi_b'(\frac{3}{2}^-) \to \Xi_b' \rho \to \Xi_b' \pi\pi$	$(5.5^{+6.4}_{-3.5}) \times 10^{-6}$			
$\Omega_b(\frac{1}{2}^-)$	6.34 ± 0.10	6 ± 2	–			~ 0	$\Omega_b(6330)^-$ [[illegible]]
$\Omega_b(\frac{3}{2}^-)$	6.34 ± 0.09		–			~ 0	$\Omega_b(6340)^-$ [17]



Summary

- We categorized the P-wave bottom baryons of the SU(3) flavor 6_F into four multiplets: $[6_F,1,0,\rho]$, $[6_F,0,1,\lambda]$, $[6_F,1,1,\lambda]$ and $[6_F,2,1,\lambda]$
- We studied the mass spectra and decay properties of P-wave bottom baryons using the method of QCD sum rules and light-cone sum rules within the framework of HQET

> - $\Sigma_b(6097)^{\pm}$ → P-wave Σ_b baryon $\in [6_F,2,1,\lambda]$, $J^P=3/2^-$
> - $\Xi_b(6227)^{-}$ → P-wave Ξ_b' baryon $\in [6_F,2,1,\lambda]$, $J^P=3/2^-$
> - $\Omega_b(6350)^{-}$ → P-wave Ω_b baryon $\in [6_F,2,1,\lambda]$, $J^P=3/2^-$
> - $\Omega_b(6330)^{-}$ → P-wave Ω_b baryon $\in [6_F,1,1,\lambda]$, $J^P=1/2^-$
> - $\Omega_b(6340)^{-}$ → P-wave Ω_b baryon $\in [6_F,1,1,\lambda]$, $J^P=3/2^-$
> - $\Omega_b(6316)^{-}$ → P-wave Ω_b baryon $\in [6_F,1,0,\rho]$, $J^P=1/2^-$ or $3/2^-$

Thank you for listening