Decay properties of $P$-wave bottom baryons within light-cone sum rules

Hui-Min Yang, Hua-Xing Chen, Er-Liang Cui, Atsushi Hosaka, Qiang Mao

Abstract We use the method of light-cone sum rules to study decay properties of $P$-wave bottom baryons belonging to the $SU(3)$ flavor $6_F$ representation. In Cui et al. (Phys Rev D 99:094021, 2019) we have studied their mass spectrum and pionic decays, and found that the $\Sigma_b(6097)$ and $\Xi_b(6227)$ can be well interpreted as $P$-wave bottom baryons of $J^P = 3/2^-$. In this paper we further study their decays into ground-state bottom baryons and vector mesons. We propose to search for a new state $\Xi_b(5/2^-)$, that is the $J^P = 5/2^-$ partner state of the $\Xi_b(6227)$, in the $\Xi_b(5/2^-) \rightarrow \Xi_b^* \rho \rightarrow \Xi_b^0 \pi \pi$ decay process. Its mass is $12 \pm 5$ MeV larger than that of the $\Xi_b(6227)$.

1 Introduction

In the past years important progress has been made in the field of heavy baryons, and many heavy baryons were observed in various experiments [2–9]. These heavy baryons are interesting in a theoretical point of view [10–12]: the light degrees of freedom (light quarks and gluons) circle around the nearly static heavy quark, so that the whole system behaves as the QCD analogue of the hydrogen bounded by electromagnetic interaction. To understand them, various phenomenological models have been applied, such as the relativized potential quark model [13,14], the relativistic quark model [15], the constituent quark model [16], the chiral quark model [17], the heavy hadron chiral perturbation theory [18], the hyperfine interaction [19,20], the Feynman–Hellmann theorem [21], the combined expansion in $1/m_Q$ and $1/N_c$ [22], the pion induced reactions [23], the variational approach [24], the relativistic flux tube model [25], the Faddeev approach [26], the Regge trajectory [27], the extended local hidden gauge approach [28], the unitarized dynamical model [29], the unitarized chiral perturbation theory [30], and QCD sum rules [31–47], etc. We refer to reviews [48–52] for their recent progress.

In Refs. [58,59] we have systematically applied the method of QCD sum rules [53,54] to study $P$-wave heavy baryons within the heavy quark effective theory (HQET) [55–57], where we systematically constructed all the $P$-wave heavy baryon interpolating fields, and applied them to study the mass spectrum of $P$-wave heavy baryons. Later in Ref. [60] we further studied their decay properties using light-cone sum rules, including:

- $S$-wave decays of flavor $3_F$ $P$-wave heavy baryons into ground-state heavy baryons and pseudoscalar mesons;
- $S$-wave decays of flavor $6_F$ $P$-wave heavy baryons into ground-state heavy baryons and pseudoscalar mesons;
- $S$-wave decays of flavor $3_F$ $P$-wave heavy baryons into ground-state heavy baryons and vector mesons.

Very quickly, one notices that in order to make a complete study of $P$-wave heavy baryons, we still need to study:

- $S$-wave decays of flavor $6_F$ $P$-wave heavy baryons into ground-state heavy baryons and vector mesons.

Besides them, we also need to systematically study $D$-wave and radiative decay properties of $P$-wave heavy baryons.

In the present study we will study $S$-wave decays of flavor $6_F$ $P$-wave heavy baryons into ground-state heavy baryons and vector mesons. We will further use the obtained results to investigate the $\Sigma_b(6097)$ and $\Xi_b(6227)$ recently observed by...
LHCb [7,8]. Our previous sum rule study in Ref. [1] suggests that they can be well interpreted as $P$-wave bottom baryons of $J^P = 3/2^-$. This conclusion is supported by Refs. [61–67], and we refer to Refs. [68–78] for more relevant discussions. The result of Ref. [1] also suggests that they belong to the bottom baryon doublet $[6_F, 2, 1, λ]$, whose definition will be given below. This doublet contains six bottom baryons, $\Sigma_b(3^−/2^−)$, $\Xi_b(3^−/2^−)$, and $\Omega_b(3^−/2^−)$. We predicted the mass and decay width of the $Ω_b(3/2^-)$ state to be

$$M_{Ω_b(3/2^-)} = 6.46 \pm 0.12 \text{ GeV},$$

$$Γ_{Ω_b(3/2^-)} = 58_{-33}^{+65} \text{ MeV},$$

and masses of the three $J^P = 5/2^-$ states to be

$$M_{Ξ_b(5/2^-)} = 6.11 \pm 0.12 \text{ GeV},$$

$$M_{Σ_b(5/2^-)} - M_{Ξ_b(3/2^-)} = 13 ± 5 \text{ MeV},$$

$$M_{Ξ_b(3/2^-)} - M_{Σ_b(3/2^-)} = 6.29 ± 0.11 \text{ GeV},$$

$$M_{Σ_b(5/2^-)} - M_{Ξ_b(3/2^-)} = 12 ± 5 \text{ MeV},$$

$$M_{Ω_b(5/2^-)} = 6.47 ± 0.12 \text{ GeV},$$

$$M_{Ω_b(5/2^-)} - M_{Σ_b(3/2^-)} = 11 ± 5 \text{ MeV}.$$

The three $J^P = 5/2^-$ states are probably quite narrow, because their $S$-wave decays into ground-state bottom baryons and pseudoscalar mesons can not happen, and widths of the following $D$-wave decays are extracted to be zero in Ref. [1]:

$$(w') \Gamma_{Σ_b(5/2^-) → Σ_b^0 π^-} = 0,$$

$$(x') \Gamma_{Σ_b(5/2^-) → Λ_b^0 π^-} = 0,$$

$$(y') \Gamma_{Σ_b(5/2^-) → Σ_b^0 K^-} = 0,$$

$$(z') \Gamma_{Ω_b(5/2^-) → Σ_b^0 K^-} = 0.$$

To further study their decay properties, in this paper we will investigate their $S$-wave decays into ground-state bottom baryons together with vector mesons $\rho$ and $K^*$.

This paper is organized as follows. In Sect. 2 we study $S$-wave decays of flavor $6_F$ $P$-wave bottom baryons into ground-state bottom baryons and vector mesons, separately in several subsections for the four bottom baryon multiplets, $[6_F, 1, 0, ρ], [6_F, 0, 1, λ], [6_F, 1, 1, λ]$, and $[6_F, 2, 1, λ]$. A short summary is given in Sect. 3. Some relevant parameters and formulae are given in Appendix A and Appendix B.

### 2 Decay properties of $P$-wave bottom baryons

At the beginning let us briefly introduce our notations. A $P$-wave bottom baryon ($bqq$) consists of one bottom quark ($b$) and two light quarks ($qq$). Its orbital excitation can be either between the two light quarks ($l_ρ = 1$) or between the bottom quark and the two-light-quark system ($l_κ = 1$), so there are $ρ$-type bottom baryons ($l_ρ = 1$ and $l_κ = 0$) and $κ$-type ones ($l_ρ = 0$ and $l_κ = 1$). Altogether its internal symmetries are as follows:

- The color structure of the two light quarks is antisymmetric ($3_C$).
- The $SU(3)$ flavor structure of the two light quarks is either antisymmetric ($3_F$) or symmetric ($6_F$).
- The spin structure of the two light quarks is either antisymmetric ($s_l ≡ s_{qq} = 0$) or symmetric ($s_l = 1$).
- The orbital structure of the two light quarks is either antisymmetric ($l_κ = 1$) or symmetric ($l_κ = 0$).
- Due to the Pauli principle, the total symmetry of the two light quarks is antisymmetric.

According to the above symmetries, one can categorize the $P$-wave bottom baryons into eight baryon multiplets, as shown in Fig. 1. We denote these multiplets as $[F$ (flavor), $jj, l_κ, ρ/λ]$, with $jj$ the total angular momentum of the light components ($j = j_l ⊗ j_ρ ⊗ s_l$). Every multiplet contains one or two bottom baryons, whose total angular momenta are $j = jj_l ⊗ s_l = |j_l ± 1/2|$, with $s_l$ the spin of the bottom quark. Especially, the heavy quark effective theory tells that the bottom baryons inside the same doublet with $j = j_l - 1/2$ and $j = j_l + 1/2$ have similar masses.

In this section we investigate $S$-wave decays of flavor $6_F$ $P$-wave bottom baryons into ground-state bottom baryons and vector mesons. To do this we use the method of light-cone sum rules within HQET, and investigate the following decay channels (the coefficients at right hand sides are isospin factors):

\[(a1) \Gamma\left[ Σ_b[1/2^-] → Λ_b + ρ → Λ_b + π^+ + π^- \right] = \Gamma\left[ Σ_b^-[1/2^-] → Σ_b^0 + π^0 + π^- \right], \quad (1)\]

\[(a2) \Gamma\left[ Σ_b[1/2^-] → Σ_b + ρ → Σ_b + π^+ + π^- \right] = 2 \times \Gamma\left[ Σ_b^-[1/2^-] → Σ_b^0 + π^0 + π^- \right], \quad (2)\]

\[(a3) \Gamma\left[ Σ_b[1/2^-] → Σ_b^± + ρ → Σ_b^± + π^+ + π^- \right] = 2 \times \Gamma\left[ Σ_b^-[1/2^-] → Σ_b^0 + π^0 + π^- \right], \quad (3)\]

\[(b1) \Gamma\left[ Ξ_b[1/2^-] → Ξ_b + ρ → Ξ_b + π^+ + π^- \right] = \frac{3}{2} \times \Gamma\left[ Ξ_b^-[1/2^-] → Ξ_b^0 + π^0 + π^- \right], \quad (4)\]

\[(b2) \Gamma\left[ Ξ_b'[1/2^-] → Λ_b + K^* → Λ_b + K + π \right] = \frac{3}{2} \times \Gamma\left[ Ξ_b'[1/2^-] → Λ_b^0 + K^0 + π^- \right], \quad (5)\]

\[(b3) \Gamma\left[ Ξ_b'[1/2^-] → Ξ_b' + ρ → Ξ_b' + π^+ + π^- \right] = \frac{3}{2} \times \Gamma\left[ Ξ_b'[1/2^-] → Ξ_b^0 + π^0 + π^- \right], \quad (6)\]
Fig. 1 Categorization of $P$-wave bottom baryons. Taken from Ref. [1]

\[\begin{align*}
(b4) & & \Gamma \left[ \Sigma_b^* \left[ \frac{1}{2}^- \right] \rightarrow \Sigma_b + K^* \rightarrow \Sigma_b + K + \pi \right] = 3 \times \Gamma \left[ \Sigma_b^* \left[ \frac{1}{2}^- \right] \rightarrow \Lambda_b^0 + K^0 + \pi^- \right]. \\
& & \text{(17)}
\end{align*}\]

\[\begin{align*}
(b5) & & \Gamma \left[ \Sigma_b^* \left[ 1^- \right] \rightarrow \Sigma_b^* + \rho \rightarrow \Sigma_b^* + \rho + \pi \right] = 3 \times \Gamma \left[ \Sigma_b^* \left[ 1^- \right] \rightarrow \Sigma_b^* + \rho + \pi \right]. \\
& & \text{(18)}
\end{align*}\]

\[\begin{align*}
(b6) & & \Gamma \left[ \Omega_b^* \left[ \frac{1}{2}^- \right] \rightarrow \Sigma_b^* + K^* \rightarrow \Sigma_b^* + K + \pi \right] = 3 \times \Gamma \left[ \Omega_b^* \left[ \frac{1}{2}^- \right] \rightarrow \Sigma_b^* + K + \pi \right]. \\
& & \text{(19)}
\end{align*}\]

\[\begin{align*}
(c1) & & \Gamma \left[ \Omega_b^* \left[ 1^- \right] \rightarrow \Sigma_b^* + K^* \rightarrow \Sigma_b^* + K + \pi \right] = \frac{1}{2} \times \Gamma \left[ \Omega_b^* \left[ 1^- \right] \rightarrow \Sigma_b^* + K + \pi \right]. \\
& & \text{(20)}
\end{align*}\]

\[\begin{align*}
(c2) & & \Gamma \left[ \Omega_b \left[ 1^- \right] \rightarrow \Sigma_b^* + K^* \rightarrow \Sigma_b^* + K + \pi \right] = \frac{1}{2} \times \Gamma \left[ \Omega_b \left[ 1^- \right] \rightarrow \Sigma_b^* + K + \pi \right]. \\
& & \text{(21)}
\end{align*}\]

\[\begin{align*}
(c3) & & \Gamma \left[ \Omega_b \left[ 1^- \right] \rightarrow \Sigma_b^* + K^* \rightarrow \Sigma_b^* + K + \pi \right] = \frac{1}{2} \times \Gamma \left[ \Omega_b \left[ 1^- \right] \rightarrow \Sigma_b^* + K + \pi \right]. \\
& & \text{(22)}
\end{align*}\]

\[\begin{align*}
(d1) & & \Gamma \left[ \Sigma_b \left[ 3/2^- \right] \rightarrow \Lambda_b + \rho \rightarrow \Lambda_b + \rho + \pi \right] = \frac{1}{2} \times \Gamma \left[ \Sigma_b \left[ 3/2^- \right] \rightarrow \Lambda_b + \rho + \pi \right]. \\
& & \text{(23)}
\end{align*}\]

\[\begin{align*}
(d2) & & \Gamma \left[ \Sigma_b \left[ 3/2^- \right] \rightarrow \Sigma_b + \rho \rightarrow \Sigma_b + \rho + \pi \right] = \frac{1}{2} \times \Gamma \left[ \Sigma_b \left[ 3/2^- \right] \rightarrow \Sigma_b + \rho + \pi \right]. \\
& & \text{(24)}
\end{align*}\]

\[\begin{align*}
(d3) & & \Gamma \left[ \Sigma_b \left[ 3/2^- \right] \rightarrow \Sigma_b^* + \rho \rightarrow \Sigma_b^* + \rho + \pi \right] = \frac{1}{2} \times \Gamma \left[ \Sigma_b \left[ 3/2^- \right] \rightarrow \Sigma_b^* + \rho + \pi \right]. \\
& & \text{(25)}
\end{align*}\]

\[\begin{align*}
(e1) & & \Gamma \left[ \Xi_b \left[ 3/2^- \right] \rightarrow \Xi_b + \rho \rightarrow \Xi_b + \rho + \pi \right] = \frac{1}{2} \times \Gamma \left[ \Xi_b \left[ 3/2^- \right] \rightarrow \Xi_b + \rho + \pi \right]. \\
& & \text{(26)}
\end{align*}\]

\[\begin{align*}
(e2) & & \Gamma \left[ \Xi_b \left[ 3/2^- \right] \rightarrow \Lambda_b + K^* \rightarrow \Lambda_b + K + \pi \right] = \frac{1}{2} \times \Gamma \left[ \Xi_b \left[ 3/2^- \right] \rightarrow \Lambda_b + K + \pi \right]. \\
& & \text{(27)}
\end{align*}\]
\[(11) \, \Gamma \left[ \Omega_b^{[5/2^-]} \rightarrow \Sigma_b^* + K^* \rightarrow \Sigma_b^* + K + \pi \right]
= 3 \times \Gamma \left[ \Omega_b^{[5/2^-]} \rightarrow \Sigma_b^{*0} + K^0 + \pi^- \right]. \tag{28} \]

We can calculate their decay widths through the following Lagrangians
\[
\mathcal{L}_{\Sigma_b}^{(1/2^-)} \rightarrow Y_b^{(1/2^+)} V = g \bar{X}_b (1/2^+) Y_b (1/2^+) V \mu, \\
\mathcal{L}_{\Sigma_b}^{(3/2^-)} \rightarrow Y_b^{(3/2^+)} V = g \bar{X}_b ^{3/2} Y_b (1/2^+) V \mu, \\
\mathcal{L}_{\Sigma_b}^{(5/2^-)} \rightarrow Y_b^{(1/2^+)} V = g \bar{X}_b ^{5/2} Y_b (3/2^+) V \mu, \\
\mathcal{L}_{\Sigma_b}^{(5/2^-)} \rightarrow Y_b^{(3/2^+)} V = g \bar{X}_b ^{5/2} Y_b (3/2^+) V \mu,
\]
where $X_b^{(\mu)}$, $Y_b^{(\mu)}$, and $V^{\mu}$ denotes the P-wave bottom baryon, ground-state bottom baryon, and vector meson, respectively.

As an example, we study the S-wave decay of the $\Sigma_b^{(1/2^-)}$ belonging to $[6_F, 1, 0, \rho]$ into $\Lambda_b^{0}(1/2^+)$ and $\rho^-(1^-)$ in the next subsection, and investigate the four bottom baryon multiplets, $[6_F, 1, 0, \rho]$, $[6_F, 0, 1, \lambda]$, $[6_F, 1, 1, \lambda]$, and $[6_F, 2, 1, \lambda]$ separately in the following subsections.

2.1 $\Sigma_b^{(1/2^-)}$ of $[6_F, 1, 0, \rho]$ decaying into $\Lambda_b^{0}(1/2^+)$ and $\rho^-(1^-)$

In this subsection we study the S-wave decay of the $\Sigma_b^{(1/2^-)}$ belonging to $[6_F, 1, 0, \rho]$ into $\Lambda_b^{0}(1/2^+)$ and $\rho^-(1^-)$. To do this we consider the following three-point correlation function:
\[
\Pi (\omega, \omega') = \int d^4 x \, e^{-i k \cdot x} \langle 0 | J_{1/2, - \Sigma_b^{(1/2^-)}, 1.0, \rho} (0) | J_{\Lambda_b^{0}} (x) | \rho^-(q) \rangle
= \frac{1 + \hat{g}}{2} G_{\Sigma_b^{(1/2^-)} \rightarrow \Lambda_b^{0, \rho-}} (\omega, \omega'), \tag{29} \]
where $J_{1/2, - \Sigma_b^{(1/2^-)}, 1.0, \rho}$ and $J_{\Lambda_b^{0}}$ are the interpolating fields coupling to $\Sigma_b^{(1/2^-)}$ and $\Lambda_b^{0}$.
\[
J_{1/2, - \Sigma_b^{(1/2^-)}, 1.0, \rho}
= i \epsilon_{abc} \left[ T \rho^b d^a + d^a T \rho^b \Sigma [\rho^a d^b] \right] Y_b^a \gamma_5 h_v^c, \tag{30} \]
\[
J_{\Lambda_b^{0}} = \epsilon_{abc} [u^a T C \Sigma d^b] h_v^c. \tag{31} \]

We refer to Refs. [58,96], where we systematically constructed all the $S$- and $P$-wave heavy baryon interpolating fields. In the above expressions $h_v^c(x)$ is the heavy quark field; $k' = k + q$, with $k'$, $k$, and $q$ the momenta of the $\Sigma_b^{(1/2^-)}$, $\Lambda_b^{0}$, and $\rho^-$, respectively; $\omega = v \cdot k$ and $\omega' = v \cdot k'$. Note that the definitions of $\omega$ and $\omega'$ in the present study are the same as those used in Refs. [1,60], but different from those used in Refs. [58,59].

At the hadronic level, we write $G_{\Sigma_b^{(1/2^-)} \rightarrow \Lambda_b^{0, \rho-}}$ as:
\[
G_{\Sigma_b^{(1/2^-)} \rightarrow \Lambda_b^{0, \rho-}} (\omega, \omega')
= \frac{f_{\Sigma_b^{(1/2^-)}} f_{\Lambda_b^{0}}}{(\Lambda_{\Sigma_b^{(1/2^-)}} - \omega')(\Lambda_{\Lambda_b^{0}} - \omega)}. \tag{32} \]

At the quark and gluon level, we calculate $G_{\Sigma_b^{(1/2^-)} \rightarrow \Lambda_b^{0, \rho-}}$ using the method of operator product expansion (OPE):
\[
G_{\Sigma_b^{(1/2^-)} \rightarrow \Lambda_b^{0, \rho-}} (\omega, \omega') = \frac{f_{\Sigma_b^{(1/2^-)}} f_{\Lambda_b^{0}}}{(\Lambda_{\Sigma_b^{(1/2^-)}} - \omega')(\Lambda_{\Lambda_b^{0}} - \omega)}.
\]

After Wick rotations and making double Borel transformation with the variables $\omega$ and $\omega'$ to be $T_1$ and $T_2$, we obtain
\[
\frac{f_{\Sigma_b^{(1/2^-)}} f_{\Lambda_b^{0}}}{(\Lambda_{\Sigma_b^{(1/2^-)}} - \omega')(\Lambda_{\Lambda_b^{0}} - \omega)} = \frac{8 \times}{f_{\Sigma_b^{(1/2^-)}} f_{\Lambda_b^{0}}}
\]
\[
\frac{f_{\Sigma_b^{(1/2^-)}} f_{\Lambda_b^{0}}}{(\Lambda_{\Sigma_b^{(1/2^-)}} - \omega')(\Lambda_{\Lambda_b^{0}} - \omega)} = \frac{8 \times}{f_{\Sigma_b^{(1/2^-)}} f_{\Lambda_b^{0}}}
\]
\[
\frac{f_{\Sigma_b^{(1/2^-)}} f_{\Lambda_b^{0}}}{(\Lambda_{\Sigma_b^{(1/2^-)}} - \omega')(\Lambda_{\Lambda_b^{0}} - \omega)} = \frac{8 \times}{f_{\Sigma_b^{(1/2^-)}} f_{\Lambda_b^{0}}}
\]
\[
\frac{f_{\Sigma_b^{(1/2^-)}} f_{\Lambda_b^{0}}}{(\Lambda_{\Sigma_b^{(1/2^-)}} - \omega')(\Lambda_{\Lambda_b^{0}} - \omega)} = \frac{8 \times}{f_{\Sigma_b^{(1/2^-)}} f_{\Lambda_b^{0}}}
\]
Here $u_0 = \frac{T_1}{T_1 + T_2}$, $T = \frac{T_1 T_2}{T_1 + T_2}$, and $f_a(x) = 1 - e^{-x} \sum_{k=0}^{n} \frac{k^4}{k!}$. Explicit forms of the light-cone distribution amplitudes contained in the above expression can be found in Refs. [79–86], and we work at the renormalization scale 2 GeV for the parameters involved. More sum rule examples can be found in Appendix B.

In the present study we work at the symmetric point $T_1 = T_2 = 2T$ so that $u_0 = \frac{1}{2}$. We use the following values for the bottom quark mass and various quark and gluon condensates [2,87–95]:

\[
m_b = 4.66 \pm 0.03 \text{ GeV},
\]

\[
\langle \bar{q} q \rangle = -(0.24 \pm 0.01 \text{ GeV})^3,
\]

\[
\langle \bar{s} s \rangle = (0.8 \pm 0.1) \times \langle \bar{q} q \rangle,
\]

\[
\langle g_s \bar{q} q G_q \rangle = M_G^2 \times \langle \bar{q} q \rangle,
\]

\[
\langle g_s \bar{s} s G_s \rangle = M_G^2 \times \langle \bar{s} s \rangle,
\]

\[
M_G^2 = 0.8 \text{ GeV}^2,
\]

\[
g_s^2 G G = (0.48 \pm 0.14) \text{ GeV}^4.
\]

Now the coupling constant $g_{\Sigma_b^-(1/2^-) \to A_0^0 \rho^-}$ only depends on two free parameters, the threshold value $\omega_b$ and the Borel mass $T$. We choose $\omega_b = 1.485 \text{ GeV}$ to be the average of the threshold values of the $\Sigma_b(1/2^-)$ and $A_0^0$ mass sum rules (see Appendix A and Ref. [1]) for the parameters of the $\Sigma_b(1/2^-)$ and $A_0^0$, and extract the coupling constant $g_{\Sigma_b^-(1/2^-) \to A_0^0 \rho^-}$ to be

\[
g_{\Sigma_b^-(1/2^-) \to A_0^0 \rho^-} = 0.17 \pm 0.24 - 0.17 = 0.17 \pm 0.01 + 0.06 + 0.06 + 0.20 + 0.10 - 0.00 - 0.05 - 0.05 - 0.17 - 0.11.
\]

where the uncertainties are due to the Borel mass, the parameters of the $A_0^0$, the parameters of the $\Sigma_b^-(1/2^-)$, the light-cone distribution amplitudes of vector mesons [79–86], and various quark masses and condensates listed in Eq. (35), respectively. Besides these statistical uncertainties, there is another (theoretical) uncertainty, which comes from the scale dependence. In the present study we do not consider this, and simply work at the renormalization scale 2 GeV, since $\sqrt{M_{\Sigma_b^-(1/2^-)}^2 - M_{A_0^0}^2} = 2.4 \text{ GeV}$. However, it is useful to give a rough estimation on this. Since the largest uncertainty comes from the light-cone distribution amplitudes of vector mesons, we choose the values for the parameters contained in these amplitudes to be at the renormalization scale 1 GeV (see Tables 1 and 2 of Ref. [86]), and redo the above calculations to obtain:

\[
g_{\Sigma_b^-(1/2^-) \to A_0^0 \rho^-}(1 \text{ GeV}) = 0.42.
\]

Hence, the scale dependence leads to a significant uncertainty, and the total uncertainty of our results can be even larger.

For completeness, we show $g_{\Sigma_b^-(1/2^-) \to A_0^0 \rho^-}$ in Fig. 2a as a function of the Borel mass $T$, and find that it only slightly depends on the Borel mass, where the working region for $T$ has been evaluated in the $\Sigma_b(1/2^-)$ mass sum rules [1,58–60] to be $0.31 \text{ GeV} < T < 0.34 \text{ GeV}$ (we also summarize this in Table 5). Note that the definitions of $\omega$ and $\omega'$ in this paper are the same as those used in Refs. [1,60], but different from those used in Refs. [58,59], so the Borel windows used in this paper are also the same/similar as those used in Refs. [1,60], but just about half of those used in Refs. [58,59].

The two-body decay $\Sigma_b^-(1/2^-) \to A_0^0 \rho^-$ is kinematically forbidden, but the three-body decay process $\Sigma_b^-(1/2^-) \to A_0^0 \rho^- \to A_0^0 \pi^0 \pi^-$ is kinematically allowed, whose decay amplitude is

\[
\mathcal{M}(0 \to 3 + 4 \to 3 + 2 + 1) \\
\equiv \mathcal{M}(\Sigma_b^-(1/2^-) \to A_0^0 + \rho^- \to A_0^0 + \pi^0 + \pi^-) \\
= g_{\Sigma_b^-(1/2^-) \to A_0^0 + \rho^-} \times \frac{1}{p_{\pi^-} - m_A^2 + i m_A f_A} \times (p_{1,\nu} - p_{2,\nu}).
\]

Here $0$ denotes the initial state $\Sigma_b^-(1/2^-)$; 4 denotes the intermediate state $\rho^-$; 1, 2 and 3 denote the final states $\pi^-$, $\pi^0$ and $A_0^0$, respectively.

This amplitude can be used to further calculate its decay width

\[
\Gamma(0 \to 3 + 4 \to 3 + 2 + 1) \\
\equiv \Gamma(\Sigma_b^-(1/2^-) \to A_0^0 + \rho^- \to A_0^0 + \pi^0 + \pi^-) \\
= \frac{1}{(2\pi)^3} \times \frac{1}{32 m_0^4} \times \frac{1}{g_{\Sigma_b^-(1/2^-) \to A_0^0 + \rho^-}} \times \frac{1}{g_{\Sigma_b^-(1/2^-) \to A_0^0 + \rho^-}} \times \int dm_{12} dm_{23} \\
\times \frac{1}{2} \text{Tr}[(\dot{p}_3 + m_3) \gamma_{\mu} \gamma_{\nu} (\dot{p}_0 + m_0) \gamma_{\mu} \gamma_{\nu}]
\]

\[\Box\] Springer
so that the width of the \( \Sigma^{-}_{b}(1/2^-) \rightarrow A_{b}^{0}\rho^{-} \rightarrow A_{b}^{0}\pi^{0}\pi^{-} \) decay is evaluated to be

\[
\Gamma_{\Sigma^{-}_{b}(1/2^-) \rightarrow A_{b}^{0}\rho^{-} \rightarrow A_{b}^{0}\pi^{0}\pi^{-}} = 8.9 \pm 32.3 \text{ keV} = 8.9 \pm 1.1 + 6.7 + 7.0 + 27.9 + 13.6 \text{ keV},
\]

(40)

In the following subsections we apply the same procedures to separately study the four bottom baryon multiplets, \([6_F, 1, 0, \rho], [6_F, 0, 1, \lambda], [6_F, 1, 1, \lambda], \) and \([6_F, 2, 1, \lambda].\)

### 2.2 The bottom baryon doublet \([6_F, 1, 0, \rho]\)

The bottom baryon doublet \([6_F, 1, 0, \rho]\) consists of six members: \(\Sigma_{b}\left(1/2^-/3/2^-\right), \quad \Sigma_{b}\left(1/2^-/3/2^-\right), \) and \(\Lambda_{b}\left(1/2^-/3/2^-\right)\). We use the method of light-cone sum rules within HQET to study their decays into ground-state bottom baryons and vector mesons.

There are altogether twenty-four non-vanishing decay channels, whose coupling constants are extracted to be

\[
\begin{align*}
(a1) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho} = 0.17, \\
(a2) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho} = 0.35, \\
(a3) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho} = 0.20, \\
(b1) \; & g_{\Sigma_{b}\left(3/2^-\right) \rightarrow \Sigma_{b}\left(3/2^+\right)\rho} = 0.03, \\
(b2) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)K^*} = 0.31, \\
(b3) \; & g_{\Sigma_{b}\left(3/2^-\right) \rightarrow \Sigma_{b}\left(3/2^+\right)K^*} = 0.24, \\
(b4) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)K^*} = 0.38, \\
(b5) \; & g_{\Sigma_{b}\left(3/2^-\right) \rightarrow \Sigma_{b}\left(3/2^+\right)K^*} = 0.14, \\
(b6) \; & g_{\Sigma_{b}\left(3/2^-\right) \rightarrow \Sigma_{b}\left(3/2^+\right)K^*} = 0.22, \\
(c1) \; & g_{\Omega_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho} = 0.24, \\
(c2) \; & g_{\Omega_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho} = 0.49, \\
(c3) \; & g_{\Omega_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho} = 0.28, \\
(d1) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Omega_{b}\left(1/2^+\right)\rho} = 0.29, \\
(d2) \; & g_{\Sigma_{b}\left(3/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho} = 0.19, \\
(d3) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)\rho} = 0.24, \\
(e1) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)\rho} = 0.06, \\
(e2) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho} = 0.42, \\
(e3) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)\rho} = 0.14.
\end{align*}
\]

(41)

Then we compute the three-body decay widths, which are kinematically allowed:

\[
\begin{align*}
(a1) \; & \Gamma_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho \rightarrow \Lambda_{b}\left(1/2^+\right)\pi\pi} = 8.9 \text{ keV}, \\
(a2) \; & \Gamma_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho \rightarrow \Lambda_{b}\left(1/2^+\right)\pi\pi} = 2.2 \times 10^{-3} \text{ keV}, \\
(b1) \; & \Gamma_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)K^*} = 0.2 \text{ keV}, \\
(b2) \; & \Gamma_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho \rightarrow \Lambda_{b}\left(1/2^+\right)\pi\pi} = 5.1 \times 10^{-3} \text{ keV}, \\
(c1) \; & \Gamma_{\Omega_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho} = 4.1 \text{ keV}, \\
(d2) \; & \Gamma_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Lambda_{b}\left(1/2^+\right)\rho \rightarrow \Lambda_{b}\left(1/2^+\right)\pi\pi} = 2.1 \times 10^{-4} \text{ keV}, \\
(e1) \; & \Gamma_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Omega_{b}\left(1/2^+\right)\rho} = 0.2 \text{ keV}, \\
(e2) \; & \Gamma_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Omega_{b}\left(1/2^+\right)\rho} = 5.8 \times 10^{-4} \text{ keV}.
\end{align*}
\]

(42)

We summarize these results in Table 1. For completeness, we also show the coupling constants as functions of the Borel mass \(T\) in Fig. 2.

### 2.3 The bottom baryon singlet \([6_F, 0, 1, \lambda]\)

The bottom baryon singlet \([6_F, 1, 0, \rho]\) consists of three members: \(\Sigma_{b}\left(1/2^-\right), \quad \Sigma_{b}\left(1/2^-\right), \) and \(\Omega_{b}\left(1/2^-\right)\). We use the method of light-cone sum rules within HQET to study their decays into ground-state bottom baryons and vector mesons.

There are altogether eight non-vanishing decay channels, whose coupling constants are extracted to be

\[
\begin{align*}
(a2) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)\rho} = 2.25, \\
(a3) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)\rho} = 7.74, \\
(b3) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)\rho} = 1.58, \\
(b4) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)\rho} = 1.77, \\
(b5) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)\rho} = 5.70, \\
(b6) \; & g_{\Sigma_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)\rho} = 5.77, \\
(c2) \; & g_{\Omega_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)\rho} = 2.37, \\
(c3) \; & g_{\Omega_{b}\left(1/2^-\right) \rightarrow \Sigma_{b}\left(1/2^+\right)\rho} = 8.18.
\end{align*}
\]

(43)

Then we compute the three-body decay widths, which are kinematically allowed:

\[
\begin{align*}
(a2) \; & \Gamma_{\Sigma_{b}\left(1/2^-\right) \rightarrow \lambda_{b}\left(1/2^+\right)\rho \rightarrow \Sigma_{b}\left(1/2^+\right)\pi\pi} = 5.9 \times 10^{-2} \text{ keV},
\end{align*}
\]
Fig. 2 The coupling constants a $g_{\Sigma_{b}^{+}(3/2^-)\to\Lambda_{b}^{0}\rho^-}$, b $g_{\Sigma_{b}^{+}(1/2^-)\to\Sigma_{b}^{0}\rho^-}$, c $g_{\Sigma_{b}^{+}(1/2^-)\to\Sigma_{b}^{0}p^-}$, d $g_{\Sigma_{b}^{+}(1/2^-)\to\Sigma_{b}^{0}p^-}$, e $g_{\Sigma_{b}^{+}(1/2^-)\to\Lambda_{b}^{0}\rho^-}$, f $g_{\Sigma_{b}^{+}(1/2^-)\to\Lambda_{b}^{0}\rho^-}$, g $g_{\Sigma_{b}^{+}(1/2^-)\to\Sigma_{b}^{0}p^-}$, and h $g_{\Sigma_{b}^{+}(1/2^-)\to\Sigma_{b}^{0}p^-}$ as functions of the Borel mass $T$. Here the baryons $\Sigma_{b}^{+}(3/2^-)$ and $\Sigma_{b}^{+}(1/2^-)$ belong to the bottom baryon doublet $[6_F, 1, 0, \rho]$, and the working regions for $T$ have been evaluated in mass sum rules [1,58–60] and summarized in Table 5.
Table 1  S-wave decays of $P$-wave bottom baryons belonging to the doublet $[6_F, 1, 0, \rho]$ into ground-state bottom baryons and vector mesons

| Decay channels | Coupling constant $g$ | Partial width $\Gamma$ | Total width $\Gamma$ |
|---------------|-----------------------|------------------------|----------------------|
| (a1) $\Sigma_b(\frac{1}{2}^-) \rightarrow \Lambda_b(\frac{1}{2}^+)\rho \rightarrow \Lambda_b(\frac{1}{2}^-)\pi\pi$ | 0.17 | 8.9 keV | 8.9 MeV |
| (a2) $\Sigma_b(\frac{1}{2}^-) \rightarrow \Sigma_b(\frac{1}{2}^+)\rho \rightarrow \Sigma_b(\frac{1}{2}^-)\pi\pi$ | 0.35 | $2.2 \times 10^{-3}$ keV | |
| (b1) $\Xi_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{1}{2}^+)\rho \rightarrow \Xi_b(\frac{1}{2}^-)\pi\pi$ | 0.03 | 0.2 keV | 0.2 keV |
| (b3) $\Xi_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{1}{2}^+)\rho \rightarrow \Xi_b(\frac{1}{2}^-)\pi\pi$ | 0.24 | $5.1 \times 10^{-3}$ keV | |
| (d1) $\Sigma_b(\frac{3}{2}^-) \rightarrow \Lambda_b(\frac{3}{2}^+)\rho \rightarrow \Lambda_b(\frac{3}{2}^-)\pi\pi$ | 0.29 | 4.1 keV | 4.1 keV |
| (d2) $\Sigma_b(\frac{3}{2}^-) \rightarrow \Sigma_b(\frac{3}{2}^+)\rho \rightarrow \Sigma_b(\frac{3}{2}^-)\pi\pi$ | 0.19 | $2.1 \times 10^{-4}$ keV | |
| (c1) $\Xi_b(\frac{3}{2}^-) \rightarrow \Xi_b(\frac{3}{2}^+)\rho \rightarrow \Xi_b(\frac{3}{2}^-)\pi\pi$ | 0.06 | 0.2 keV | 0.2 keV |
| (c3) $\Xi_b(\frac{3}{2}^-) \rightarrow \Xi_b(\frac{3}{2}^+)\rho \rightarrow \Xi_b(\frac{3}{2}^-)\pi\pi$ | 0.14 | $5.8 \times 10^{-4}$ keV | |

We summarize these results in Table 2. For completeness, we also show the coupling constants as functions of the Borel mass $T$ in Fig. 3.

2.4 The bottom baryon doublet $[6_F, 1, 1, \lambda]$

The bottom baryon doublet $[6_F, 1, 1, \lambda]$ consists of six members: $\Sigma_b(\frac{1}{2}^-/\frac{3}{2}^-)$, $\Xi_b(\frac{1}{2}^-/\frac{3}{2}^-)$, and $\Omega_b(\frac{1}{2}^-/\frac{3}{2}^-)$. We use the method of light-cone sum rules within HQET to study their decays into ground-state bottom baryons and vector mesons.

There are altogether twenty-four non-vanishing decay channels, whose coupling constants are extracted to be

(a1) $g_{\Sigma_b(\frac{1}{2}^-) \rightarrow \Lambda_b(\frac{1}{2}^+)\rho} = 0.83$,
(a2) $g_{\Sigma_b(\frac{1}{2}^-) \rightarrow \Sigma_b(\frac{1}{2}^+)\rho} = 2.21$,
(a3) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{1}{2}^+)\rho} = 1.28$,
(b1) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{1}{2}^+)\rho} = 0.59$,
(b2) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Lambda_b(\frac{1}{2}^-)\rho} = 1.60$,
(b3) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{3}{2}^+)\rho} = 1.45$,
(b4) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Omega_b(\frac{1}{2}^-)\rho} = 0.13$,
(b5) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{3}{2}^+)\rho} = 0.84$,
(b6) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Omega_b(\frac{1}{2}^-)\rho} = 0.08$,
(c1) $g_{\Omega_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{1}{2}^+)\rho} = 2.25$,
(c2) $g_{\Omega_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{3}{2}^+)\rho} = 0.17$,
(c3) $g_{\Omega_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{3}{2}^+)\rho} = 0.10$,
(d1) $g_{\Sigma_b(\frac{1}{2}^-) \rightarrow \Lambda_b(\frac{1}{2}^-)\rho} = 1.62$,
(d2) $g_{\Sigma_b(\frac{1}{2}^-) \rightarrow \Sigma_b(\frac{1}{2}^+)\rho} = 0.90$,
(d3) $g_{\Sigma_b(\frac{1}{2}^-) \rightarrow \Sigma_b(\frac{3}{2}^+)\rho} = 1.48$,
(e1) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{1}{2}^+)\rho} = 0.57$,
(e2) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Lambda_b(\frac{1}{2}^-)\rho} = 1.31$,
(e3) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{3}{2}^+)\rho} = 0.84$,
(e4) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Omega_b(\frac{1}{2}^-)\rho} = 0.08$,
(e5) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{3}{2}^+)\rho} = 0.97$,
(e6) $g_{\Xi_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{3}{2}^+)\rho} = 0.09$,
(f1) $g_{\Omega_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{1}{2}^+)\rho} = 1.61$,
(f2) $g_{\Omega_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{3}{2}^+)\rho} = 0.10$,
(f3) $g_{\Omega_b(\frac{1}{2}^-) \rightarrow \Omega_b(\frac{1}{2}^+)\rho} = 0.12$.

Then we compute the three-body decay widths, which are kinematically allowed:

(a1) $\Gamma_{\Sigma_b(\frac{1}{2}^-) \rightarrow \Lambda_b(\frac{1}{2}^+)\rho \rightarrow \Lambda_b(\frac{1}{2}^-)\pi\pi} = 207.4$ keV,
(a2) $\Gamma_{\Sigma_b(\frac{1}{2}^-) \rightarrow \Sigma_b(\frac{1}{2}^+)\rho \rightarrow \Sigma_b(\frac{1}{2}^-)\pi\pi} = 5.7 \times 10^{-2}$ keV,
(b1) $\Gamma_{\Xi_b(\frac{1}{2}^-) \rightarrow \Sigma_b(\frac{1}{2}^+)\rho \rightarrow \Sigma_b(\frac{1}{2}^-)\pi\pi} = 61.0$ keV,
(b3) $\Gamma_{\Xi_b(\frac{1}{2}^-) \rightarrow \Xi_b(\frac{3}{2}^+)\rho \rightarrow \Xi_b(\frac{3}{2}^-)\pi\pi} = 0.2$ keV,
(d1) $\Gamma_{\Sigma_b(\frac{1}{2}^-) \rightarrow \Lambda_b(\frac{1}{2}^+)\rho \rightarrow \Lambda_b(\frac{1}{2}^-)\pi\pi} = 261.1$ keV,
(d2) $\Gamma_{\Sigma_b(\frac{1}{2}^-) \rightarrow \Sigma_b(\frac{1}{2}^+)\rho \rightarrow \Sigma_b(\frac{1}{2}^-)\pi\pi} = 3.2 \times 10^{-3}$ keV.

© Springer
(a) The coupling constants \( g_{\Sigma_1^-(1^-)\rightarrow \Sigma_0^0(0^-)} \) and \( g_{\Sigma_0^0(0^-)\rightarrow \Sigma_0^0(0^-)} \) as functions of the Borel mass \( T \). Here the baryons \( \Sigma_0(1/2^-) \) and \( \Sigma_1^-(1^-) \) belong to the bottom baryon singlet \([6_F, 0, 1, \lambda]\), and the working regions for \( T \) have been evaluated in mass sum rules [1,58–60] and summarized in Table 5.

(b) The coupling constants \( g_{\Xi_1^0(1^-)\rightarrow \Xi_0^0(0^-)} \) and \( g_{\Xi_0^0(0^-)\rightarrow \Xi_0^0(0^-)} \) as functions of the Borel mass \( T \). Here the baryons \( \Xi_0(1/2^-) \) and \( \Xi_1^0(1^-) \) belong to the bottom baryon singlet \([6_F, 0, 1, \lambda]\), and the working regions for \( T \) have been evaluated in mass sum rules [1,58–60] and summarized in Table 5.

Table 3 S-wave decays of P-wave bottom baryons belonging to the doublet \([6_F, 1, 1, \lambda]\) into ground-state bottom baryons and vector mesons

| Decay channels | Coupling constant \( g \) | Partial width | Total width |
|----------------|--------------------------|---------------|-------------|
| (a1) \( \Sigma_1(1^-) \rightarrow \Lambda_b(1^-) \rho \rightarrow \Lambda_b(1^-) \pi \pi \) | 0.83 | 207.5 keV | 207.4 keV |
| (a2) \( \Sigma_1(1^-) \rightarrow \Sigma_0(1^-) \rho \rightarrow \Sigma_0(1^-) \pi \pi \) | 2.21 | 5.7 \times 10^{-2} keV | |
| (b1) \( \Xi_1(1^-) \rightarrow \Xi_0(1^-) \rho \rightarrow \Xi_0(1^-) \pi \pi \) | 0.59 | 61.0 keV | 61.2 keV |
| (b2) \( \Xi_1(1^-) \rightarrow \Xi_0(1^-) \rho \rightarrow \Xi_0(1^-) \pi \pi \) | 1.45 | 0.2 keV | |
| (d1) \( \Omega_1(1^-) \rightarrow \Lambda_0(1^-) \rho \rightarrow \Lambda_0(1^-) \pi \pi \) | 1.62 | 261.1 keV | 261.1 keV |
| (d2) \( \Omega_1(1^-) \rightarrow \Lambda_0(1^-) \rho \rightarrow \Lambda_0(1^-) \pi \pi \) | 0.90 | 3.2 \times 10^{-3} keV | |
| (e1) \( \Xi_1(1^-) \rightarrow \Xi_0(1^-) \rho \rightarrow \Xi_0(1^-) \pi \pi \) | 0.57 | 18.8 keV | 18.8 keV |
| (e2) \( \Xi_1(1^-) \rightarrow \Xi_0(1^-) \rho \rightarrow \Xi_0(1^-) \pi \pi \) | 0.84 | 2.1 \times 10^{-2} keV | |

We summarize these results in Table 3. For completeness, we also show the coupling constants as functions of the Borel mass \( T \) in Fig. 4.

2.5 The bottom baryon doublet \([6_F, 2, 1, \lambda]\)

The bottom baryon doublet \([6_F, 2, 1, \lambda]\) consists of six members: \( \Sigma_1(1/2^-) \), \( \Sigma_1(1/2^-) \), \( \Sigma_1(1/2^-) \), and \( \Omega_1(1/2^-) \). We use the method of light-cone sum rules within HQET to study their decays into ground-state bottom baryons and vector mesons.

There are altogether twelve non-vanishing decay channels, whose coupling constants are extracted to be

\[
\begin{align*}
\text{(d2)} \ g_{\Sigma_1(1^-) \rightarrow \Sigma_1(1^-) \rho} &= 5.90^{+3.56}_{-3.08}, \\
\text{(d3)} \ g_{\Sigma_1(1^-) \rightarrow \Sigma_1(1^-) \rho} &= 0.69^{+0.41}_{-0.35}, \\
\text{(e3)} \ g_{\Xi_1(1^-) \rightarrow \Xi_1(1^-) \rho} &= 4.23^{+2.42}_{-2.13}, \\
\text{(e4)} \ g_{\Xi_1(1^-) \rightarrow \Xi_1(1^-) \rho} &= 3.17^{+2.37}_{-2.20}, \\
\text{(e5)} \ g_{\Xi_1(1^-) \rightarrow \Xi_1(1^-) \rho} &= 0.50^{+0.50}_{-0.48}, \\
\text{(e6)} \ g_{\Xi_1(1^-) \rightarrow \Xi_1(1^-) \rho} &= 0.40^{+0.40}_{-0.38}, \\
\text{(f2)} \ g_{\Omega_1(1^-) \rightarrow \Omega_1(1^-) \rho} &= 4.56^{+3.19}_{-2.97}, \\
\text{(f3)} \ g_{\Omega_1(1^-) \rightarrow \Omega_1(1^-) \rho} &= 0.60^{+0.38}_{-0.35}, \\
\text{(g1)} \ g_{\Sigma_1(1^-) \rightarrow \Sigma_1(1^-) \rho} &= 3.78^{+2.01}_{-1.65}, \\
\text{(h1)} \ g_{\Xi_1(1^-) \rightarrow \Xi_1(1^-) \rho} &= 4.09^{+2.08}_{-1.72}, \\
\text{(h2)} \ g_{\Xi_1(1^-) \rightarrow \Xi_1(1^-) \rho} &= 2.14^{+1.33}_{-1.18}, \\
\text{(i1)} \ g_{\Omega_1(1^-) \rightarrow \Omega_1(1^-) \rho} &= 6.36^{+3.75}_{-2.62}. 
\end{align*}
\]

(47)

Then we compute the three-body decay widths, which are kinematically allowed.

\[
\text{(d2)} \ \Gamma_{\Sigma_1(1^-) \rightarrow \Sigma_1(1^-) \rho \rightarrow \Sigma_1(1^-) \pi \pi} = 0.14^{+0.19}_{-0.12} \text{ keV},
\]

\( \Xi \) Springer
Fig. 4 The coupling constants \( a \) \( g_{\Sigma^\prime(1^+)} \rightarrow \Lambda^0_{ho^-} \), \( b \) \( g_{\Sigma^\prime(1^-)} \rightarrow \Sigma^0_{ho^-} \), \( c \) \( g_{\Sigma^\prime(1^-)} \rightarrow \Sigma^0_{ho^-} \), \( d \) \( g_{\Sigma^\prime(1^-)} \rightarrow \Sigma^0_{ho^-} \), \( e \) \( g_{\Sigma^\prime(1^-)} \rightarrow \Lambda^0_{ho^-} \), \( f \) \( g_{\Sigma^\prime(1^-)} \rightarrow \Sigma^0_{ho^-} \), \( g \) \( g_{\Sigma^\prime(1^-)} \rightarrow \Sigma^0_{ho^-} \), and \( h \) \( g_{\Sigma^\prime(1^-)} \rightarrow \Sigma^0_{ho^-} \) as functions of the Borel mass \( T \). Here the baryons \( \Sigma_{b\frac{1}{2}}(\frac{1}{2}^-) \) and \( \Sigma_{b\frac{3}{2}}(\frac{1}{2}^-) \) belong to the bottom baryon doublet \( [6F, 1, 1, \lambda] \), and the working regions for \( T \) have been evaluated in mass sum rules \( [1, 58–60] \) and summarized in Table 5.
Table 4  $S$-wave decays of $P$-wave bottom baryons belonging to the doublet $[6_F, 2, 1, \lambda]$ into ground-state bottom baryons and vector mesons

| Decay channels | Coupling constant $g$ | Partial width | Total width |
|----------------|----------------------|----------------|-------------|
| $(d2)$ $\Sigma_b(\frac{1}{2}^- ) \rightarrow \Sigma_b(\frac{1}{2}^+) \rho \rightarrow \Sigma_b(\frac{1}{2}^+) \pi \pi$ | $5.90 \pm 3.56 \pm 3.08$ | $0.14 \pm 0.10 \pm 0.12$ keV | $0.14 \pm 0.10 \pm 0.12$ keV |
| $(c3)$ $\Xi_b^{*}(\frac{1}{2}^- ) \rightarrow \Xi_b^{*}(\frac{1}{2}^+) \rho \rightarrow \Xi_b^{*}(\frac{1}{2}^+) \pi \pi$ | $4.23 \pm 2.42 \pm 2.13$ | $0.53 \pm 0.68 \pm 0.46$ keV | $0.53 \pm 0.68 \pm 0.46$ keV |
| $(g1)$ $\Xi_b(\frac{1}{2}^- ) \rightarrow \Xi_b(\frac{1}{2}^+) \rho \rightarrow \Xi_b(\frac{1}{2}^+) \pi \pi$ | $3.75 \pm 2.01 \pm 1.65$ | $(3 \pm 4) \times 10^{-6}$ keV | $(3 \pm 4) \times 10^{-6}$ keV |
| $(h2)$ $\Xi_b(\frac{3}{2}^- ) \rightarrow \Xi_b(\frac{3}{2}^+) \rho \rightarrow \Xi_b(\frac{3}{2}^+) \pi \pi$ | $4.09 \pm 2.08 \pm 1.72$ | $0.29 \pm 0.32 \pm 0.23$ keV | $0.29 \pm 0.32 \pm 0.23$ keV |

Fig. 5  The coupling constants $a \ g_{\Sigma_b(\frac{1}{2}^- ) \rightarrow \Sigma_b(\frac{1}{2}^+) \rho}$, $b \ g_{\Xi_b^{*}(\frac{1}{2}^- ) \rightarrow \Xi_b^{*}(\frac{1}{2}^+) \rho}$, $c \ g_{\Xi_b(\frac{1}{2}^- ) \rightarrow \Xi_b(\frac{1}{2}^+) \rho}$, and $d \ g_{\Xi_b(\frac{1}{2}^- ) \rightarrow \Xi_b(\frac{1}{2}^+) \rho}$ as functions of the Borel mass $T$. Here the baryons $\Sigma_b(\frac{1}{2}^- / \frac{3}{2}^-)$ and $\Xi_b(\frac{1}{2}^- / \frac{3}{2}^-)$ belong to the bottom baryon doublet $[6_F, 2, 1, \lambda]$, and the working regions for $T$ have been evaluated in mass sum rules $[1.58–60]$ and summarized in Table 5.

3 Summary and discussions

To summarize this paper, we have used the method of light-cone sum rules within heavy quark effective theory to study decay properties of $P$-wave bottom baryons belonging to the flavor $6_F$ representation. We have studied their $S$-wave decays into ground-state bottom baryons and vector mesons. The possible decay channels are given in Eqs. (1–28), and the extracted decay widths are listed in Tables 1, 2, 3, and 4. These results are obtained separately for the four bottom baryon multiplets of flavor $6_F$: $[6_F, 1, 0, \rho]$, $[6_F, 0, 1, \lambda]$, $[6_F, 1, 1, \lambda]$, and $[6_F, 2, 1, \lambda]$. 

 Springer
In Ref. [1] we have studied the mass spectrum and pionic decay properties of the \( \Sigma_b(6097) \) and \( \Xi_b(6227) \) \([7,8]\). Our results suggest that they can be well interpreted as \( P\)-wave bottom baryons of \( J^P = 3/2^- \), belonging to the bottom baryon doublet \([6,F, 2, 1, \lambda]\). This doublet contains altogether six bottom baryons, \( \Sigma_b(3/2^-/2^-/5^-) \), \( \Xi_b(3/2^-/5^-) \), and \( \Omega_b(1/2^-/5^-) \). In the present study we further investigate their \( S\)-wave decays into ground-state bottom baryons and vector mesons, and extract:

\[
\begin{align*}
(1) & \quad \Gamma_{\Sigma_b(3/2^-)} \to \Sigma_b(3/2^-) \pi = 0.14 \pm 0.10 \pm 0.12 \text{ keV}, \\
(2) & \quad \Gamma_{\Sigma_b(5/2^-)} \to \Sigma_b(5/2^-) \pi = 0.53 \pm 0.08 \pm 0.46 \text{ keV}, \\
(3) & \quad \Gamma_{\Xi_b(3/2^-)} \to \Xi_b(3/2^-) \pi = (3.49 \pm 1.20) \times 10^{-6} \text{ keV}, \\
(4) & \quad \Gamma_{\Xi_b(5/2^-)} \to \Xi_b(5/2^-) \pi = 0.23 \pm 0.23 \text{ keV}.
\end{align*}
\]

Hence, these three \( J^P = 5/2^- \) states are probably quite narrow, because their \( S\)-wave decays into ground-state bottom baryons and pseudoscalar mesons can not happen, and widths of the following \( D\)-wave decays are also calculated to be zero in Ref. [1]:

\[
\begin{align*}
(5) & \quad \Gamma_{\Sigma_b(5/2^-)} \to \Lambda_b^0 \pi^- = 0, \\
(6) & \quad \Gamma_{\Xi_b(5/2^-)} \to \Xi_b^* \pi^- = 0, \\
(7) & \quad \Gamma_{\Xi_b(5/2^-)} \to \Lambda_b^0 K^- = 0, \\
(8) & \quad \Gamma_{\Xi_b(5/2^-)} \to \Xi_b^* K^- = 0.
\end{align*}
\]

We suggest the LHCb and Belle/Belle-II experiments to search for these three narrow states. Especially, we propose to search for the \( \Xi_b(5/2^-) \), that is the \( J^P = 5/2^- \) partner state of the \( \Xi_b(6227) \), in the \( \Xi_b(5/2^-) \to \Sigma_b^* \rho \to \Sigma_b^* \pi \pi \) decay process. Its mass is \( 12 \pm 5 \text{ MeV} \) larger than that of the \( \Xi_b(6227) \).

To end this work, we note that in the present study we have studied \( S\)-wave decays of flavor \( 6_F \) \( P\)-wave heavy baryons into ground-state heavy baryons and vector mesons, which is actually a complement to Ref. [60], where we studied \( S\)-wave decays of flavor \( 3_F \) \( P\)-wave heavy baryons into ground-state heavy baryons together with pseudoscalar and vector mesons, and \( S\)-wave decays of flavor \( 6_F \) \( P\)-wave heavy baryons into ground-state heavy baryons together with pseudoscalar mesons. To make a complete QCD sum rule studies of \( P\)-wave heavy baryons within HQET, we still need to systematically study their \( D\)-wave and radiative decay properties, which is currently under investigation.

**Acknowledgements** This project is supported by the National Natural Science Foundation of China under Grant No. 11722540, the Fundamental Research Funds for the Central Universities, Grants-in-Aid for Scientific Research (No. JP17K05441 (C)), Grants-in-Aid for Scientific Research on Innovative Areas (No. 18H05407), and the Foundation for Young Talents in College of Anhui Province (Grant No. gxyq2018103).

**Data Availability Statement** This manuscript has no associated data or the data will not be deposited. [Authors’ comment: All data generated during this study are contained in this published article.]

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

Funded by SCOAP³.

**Appendix A: Parameters of \( S/P\)-wave bottom baryons and \( S\)-wave mesons**

We list masses of ground-state bottom baryons used in the present study, taken from PDG [2]:

\[
\begin{align*}
\Lambda_b(1/2^+) & : m = 5619.60 \text{ MeV}, \\
\Xi_b(1/2^+) & : m = 5793.20 \text{ MeV}, \\
\Sigma_b(1/2^+) & : m = 5813.4 \text{ MeV}, \\
\Sigma_b^*(3/2^+) & : m = 5833.6 \text{ MeV}, \\
\Xi_b^*(1/2^+) & : m = 5935.02 \text{ MeV}, \\
\Xi_b^*(3/2^+) & : m = 5952.6 \text{ MeV}, \\
\Omega_b(1/2^+) & : m = 6046.1 \text{ MeV}, \\
\Omega_b^*(3/2^+) & : m = 6063 \text{ MeV}.
\end{align*}
\]

Their QCD sum rule parameters can be found in Refs. [1,60,96].

We list masses of \( P\)-wave bottom baryons used in the present study, taken from the LHCb experiments [7,8] as well as our previous QCD sum rule studies [1,58,59]:

\[
\begin{align*}
M_{\Sigma_b(1/2^-)} & = M_{\Sigma_b(3/2^-)} = 6096.9 \text{ MeV}, \\
M_{\Sigma_b^*(5/2^-)} & = M_{\Sigma_b^*(3/2^-)} = 13 \text{ MeV}, \\
M_{\Xi_b^*(5/2^-)} & = M_{\Xi_b^*(3/2^-)} = 6226.9 \text{ MeV}, \\
M_{\Xi_b^*(3/2^-)} - M_{\Sigma_b^*(3/2^-)} & = 12 \text{ MeV}, \\
M_{\Omega_b(1/2^-)} & = M_{\Omega_b(3/2^-)} = 6460 \text{ MeV}, \\
M_{\Omega_b^*(5/2^-)} - M_{\Omega_b^*(3/2^-)} & = 11 \text{ MeV}.
\end{align*}
\]

Their QCD sum rule parameters can be found in Table 5.

We list masses and decay widths of the pseudoscalar and vector mesons used in the present study, taken from PDG [2]:

\[
\begin{align*}
\pi(0^-) & : m = 138.04 \text{ MeV}, \\
K(0^-) & : m = 495.65 \text{ MeV}, \\
\rho(1^-) & : m = 775.21 \text{ MeV}, \\
\Gamma & = 148.2 \text{ MeV}, g_{\rho_{\pi\pi}} = 5.94,
\end{align*}
\]
Table 5 Parameters of P-wave bottom baryons belonging to the bottom baryon multiplets \([6_F, 1, 0, \rho], [6_F, 0, 1, \lambda], [6_F, 1, 1, \lambda]\) and \([6_F, 2, 1, \lambda]\). Detailed discussions can be found in Refs. [1,58,59].

| Multiplets  | B   | \(\Delta (\text{GeV})\) | \(\Sigma (\text{GeV})\) | Baryons (j^P) | Mass (GeV) | Difference (MeV) | \(f (\text{GeV}^4)\) |
|------------|-----|------------------------|------------------|--------------|------------|------------------|------------------|
| \([6_F, 1, 0, \rho]\) | \(\Sigma_b\) | 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 |
| \(\Xi_b'\) | 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 |
| \(\Omega_b\) | 2.17 | 0.33 < \(T < 0.38\) | 1.67 ± 0.09 | \(\Omega_b(1/2^-)\) | 6.42 ± 0.11 | 3 ± 1 | 0.046 ± 0.009 |
| \([6_F, 0, 1, \lambda]\) | \(\Sigma_b\) | 1.75 | 0.30 < \(T < 0.33\) | 1.29 ± 0.08 | \(\Sigma_b(1/2^-)\) | 6.09 ± 0.10 | – | 0.085 ± 0.017 |
| \(\Xi_b'\) | 1.90 | 0.30 < \(T < 0.34\) | 1.44 ± 0.08 | \(\Xi_b'(1/2^-)\) | 6.25 ± 0.10 | – | 0.077 ± 0.016 |
| \(\Omega_b\) | 2.05 | 0.29 < \(T < 0.35\) | 1.59 ± 0.08 | \(\Omega_b(1/2^-)\) | 6.40 ± 0.11 | – | 0.143 ± 0.030 |
| \([6_F, 1, 1, \lambda]\) | \(\Sigma_b\) | 1.95 | 0.33 < \(T < 0.36\) | 1.28 ± 0.12 | \(\Sigma_b(1/2^-)\) | 6.10 ± 0.13 | 7 ± 3 | 0.078 ± 0.018 |
| \(\Xi_b'\) | 2.10 | 0.32 < \(T < 0.39\) | 1.47 ± 0.11 | \(\Xi_b'(1/2^-)\) | 6.33 ± 0.13 | 5 ± 3 | 0.085 ± 0.017 |
| \(\Omega_b\) | 2.25 | 0.31 < \(T < 0.42\) | 1.63 ± 0.14 | \(\Omega_b(1/2^-)\) | 6.50 ± 0.16 | 4 ± 2 | 0.171 ± 0.036 |
| \([6_F, 2, 1, \lambda]\) | \(\Sigma_b\) | 1.84 | 0.30 < \(T < 0.34\) | 1.29 ± 0.09 | \(\Sigma_b(1/2^-)\) | 6.10 ± 0.12 | 13 ± 5 | 0.102 ± 0.022 |
| \(\Xi_b'\) | 1.99 | 0.30 < \(T < 0.36\) | 1.45 ± 0.09 | \(\Xi_b'(1/2^-)\) | 6.27 ± 0.12 | 12 ± 5 | 0.099 ± 0.021 |
| \(\Omega_b\) | 2.14 | 0.32 < \(T < 0.38\) | 1.62 ± 0.09 | \(\Omega_b(1/2^-)\) | 6.46 ± 0.12 | 11 ± 5 | 0.194 ± 0.038 |

\(K^*(1^-) : m = 893.57\ \text{MeV},\)

\(\Gamma = 49.1\ \text{MeV},\quad g_{K^*K}\pi = 3.20,\)

where the two coupling constants \(g_{\rho\pi\pi}\) and \(g_{K^*K}\pi\) are evaluated using the experimental decay widths of the \(\rho\) and \(K^*\) [2] through the following Lagrangians

\[
\mathcal{L}_{\rho\pi\pi} = g_{\rho\pi\pi} \times (\rho_\mu^\dagger \partial^\mu \pi - \rho_\mu^\dagger \rho - \rho^\mu \partial^\mu \pi) + \cdots,
\]

\[
\mathcal{L}_{K^*K\pi} = g_{K^*K}\pi K_{\mu}^* \times (K^7 - \rho_\mu^\dagger \pi^0 - \rho^\mu K^7 - \pi^0) + \cdots.
\]

Appendix B: Sum rule equations

In this appendix we show several examples of sum rule equations, which are used to extract S-wave decays of P-wave bottom baryons into ground-state bottom baryons and vector mesons.

The sum rule for \(\Sigma_b'\) belonging to \([6_F, 0, 1, \lambda]\) is

\[
G_{\Sigma_b'}(z_0) = \int_0^\infty dt \int_0^1 du e^{i(1-u)\omega t} e^{i\omega u t} \times 4 \times \left(\frac{if_{\rho}^\dagger m_{\rho}^\dagger}{6\pi^2 t^4} \phi_{2,\rho}^\dagger(u) - \frac{2if_{\rho}^\dagger m_{\rho}^\dagger}{3\pi^2 t^4} \phi_{3,\rho}^\dagger(u)\right)
\]
\[ -\frac{f_{f}^{\parallel} m_{f} p v \cdot q}{288} (\tilde{r} s) \psi_{\frac{1}{2}, \rho}^{\perp} (u) + \frac{f_{f}^{\parallel} m_{f} p v^{2}}{2304} (\tilde{r} s) \phi_{\frac{3}{2}, \rho}^{\perp} (u) \\
- \frac{i f_{f}^{\perp} m_{f} p v \cdot q}{1152} (g_{s} s \sigma G s) \psi_{\frac{3}{2}, \rho}^{\perp} (u) \\
- \frac{i f_{f}^{\perp} m_{f} p v^{2}}{576} (g_{s} s \sigma G s) \phi_{\frac{3}{2}, \rho}^{\perp} (u) \\
- \frac{i f_{f}^{\perp} m_{f} p v^{2}}{576} (\tilde{r} s) \phi_{\frac{3}{2}, \rho}^{\perp} (u) \\
+ \frac{i f_{f}^{\perp} m_{f} p m_{u} u^{2} (v \cdot q)^{2}}{2304} (g_{s} s \sigma G s) \phi_{\frac{3}{2}, \rho}^{\perp} (u) \\
\]

The sum rule for \( S_{\frac{1}{2}}^{2} \) belonging to \( \{6,1,0,\rho\} \) is

\[ G_{S_{\frac{1}{2}}^{2}} \psi_{\frac{1}{2}, \rho}^{\perp} (\omega, \omega') = \frac{g_{s} s}{2} \int_{\omega}^{\infty} d e \int_{\omega}^{\infty} d e' \epsilon_{\omega \rho} (u) \times 4 \\
\times \left( \frac{i f_{f}^{\perp} m_{f} p v \cdot q}{2\pi^{2} t^{2}} \phi_{\frac{3}{2}, \rho}^{\perp} (u) - \frac{i f_{f}^{\parallel} m_{f} m_{K} v^{2}}{2\pi^{2} t^{2}} \phi_{\frac{3}{2}, \rho}^{\perp} (u) \\
+ \frac{i f_{f}^{\perp} m_{f} m_{K} v \cdot q}{2\pi^{2} t^{2}} \phi_{\frac{3}{2}, \rho}^{\perp} (u) + \frac{f_{f}^{\perp} m_{f} u (v \cdot q)^{2}}{4\pi^{2} t^{2}} \phi_{\frac{3}{2}, \rho}^{\perp} (u) \\
+ \frac{i f_{f}^{\perp} m_{f} m_{u} u (v \cdot q)^{2}}{32\pi^{2} t^{2}} \phi_{\frac{3}{2}, \rho}^{\perp} (u) - \frac{f_{f}^{\perp} m_{f} m_{u} u^{2} (v \cdot q)^{2}}{64\pi^{2} t^{2}} \phi_{\frac{3}{2}, \rho}^{\perp} (u) \\
- \frac{f_{f}^{\parallel} m_{K} m_{K} v \cdot q}{48} (\tilde{q} q) \psi_{\frac{3}{2}, \rho}^{\perp} (u) \\
\]

\[ \frac{f_{f}^{\parallel} m_{K} m_{K} v \cdot q}{96} (\tilde{q} q) \psi_{\frac{3}{2}, \rho}^{\perp} (u) \\
- \frac{i f_{f}^{\perp} m_{K} m_{K} v \cdot q}{768} (\tilde{q} q) \sigma G q \psi_{\frac{3}{2}, \rho}^{\perp} (u) \\
\frac{f_{f}^{\parallel} m_{K} m_{K} v \cdot q}{1536} (\tilde{q} q) \sigma G q \psi_{\frac{3}{2}, \rho}^{\perp} (u) \\
\]

\[ - \int_{0}^{\infty} d t \int_{0}^{1} d u \int d e \int d e' \epsilon_{\omega \rho} (u) \epsilon_{\omega' \rho} (u) \\
\times \frac{1}{2} \left( \frac{i f_{f}^{\perp} m_{f} p v \cdot q}{2\pi^{2} t^{2}} \Phi_{\frac{3}{2}, \rho}^{\perp} (\omega) + \frac{i f_{f}^{\perp} m_{f} m_{K} v \cdot q}{2\pi^{2} t^{2}} \Phi_{\frac{3}{2}, \rho}^{\perp} (\omega) \\
+ \frac{i f_{f}^{\perp} m_{f} m_{K} v \cdot q}{2\pi^{2} t^{2}} \tilde{\psi}_{\frac{3}{2}, \rho}^{\perp} (\omega) + \frac{f_{f}^{\perp} m_{f} m_{u} u (v \cdot q)^{2}}{8\pi^{2} t^{2}} \Phi_{\frac{3}{2}, \rho}^{\perp} (\omega) \\
+ \frac{i f_{f}^{\perp} m_{f} m_{u} u (v \cdot q)^{2}}{8\pi^{2} t^{2}} \tilde{\psi}_{\frac{3}{2}, \rho}^{\perp} (\omega) + \frac{f_{f}^{\perp} m_{K} m_{K} v \cdot q}{8\pi^{2} t^{2}} \Phi_{\frac{3}{2}, \rho}^{\perp} (\omega) \\
\right.

\[ \left. - \frac{f_{f}^{\parallel} m_{K} m_{K} v \cdot q}{16\pi^{2} t^{2}} \Phi_{\frac{3}{2}, \rho}^{\perp} (\omega) + \frac{f_{f}^{\parallel} m_{K} m_{K} v \cdot q}{16\pi^{2} t^{2}} \tilde{\psi}_{\frac{3}{2}, \rho}^{\perp} (\omega) + \frac{f_{f}^{\perp} m_{f} m_{u} u (v \cdot q)^{2}}{16\pi^{2} t^{2}} \Phi_{\frac{3}{2}, \rho}^{\perp} (\omega) \\
- \frac{f_{f}^{\perp} m_{f} m_{u} u (v \cdot q)^{2}}{16\pi^{2} t^{2}} \tilde{\psi}_{\frac{3}{2}, \rho}^{\perp} (\omega) + \frac{f_{f}^{\perp} m_{K} m_{K} v \cdot q}{16\pi^{2} t^{2}} \Phi_{\frac{3}{2}, \rho}^{\perp} (\omega) \\
\right)
\]
\[ G_{\Omega_b^-(1^2_-)} \rightarrow s_b^{0} K^+(\omega, \omega') = \frac{g_{\Omega_b^-(1^2_-)}}{\omega} f_{\Omega_b^-(1^2_-)} f_{s_b^{0} K^+} \]

\( (A_{\Omega_b^-(1^2_-)} - \omega')(A_{s_b^{0} K^+} - \omega) \]

0.

References

1. E.L. Cui, H.M. Yang, H.X. Chen, A. Hosaka, Identifying the \( 799 \) properties. Phys. Rev. Lett. 99, 092001 (2019)
2. M. Tanabashi et al. [Particle Data Group], Review of particle physics. Phys. Rev. D 98, 030001 (2018)
3. J. Yelton et al., [Belle Collaboration], Study of excited \( \Xi \) states decaying into \( s_b^{0} \) and \( \Xi_b^{+} \). Phys. Rev. D 94, 052011 (2016)
4. Y. Kato et al. [Belle Collaboration], Studies of charmed strange baryons in the \( A^0 \) final state at Belle. Phys. Rev. D 94, 052002 (2016)
5. R. Aaij et al. [LHCb Collaboration], Observation of five new narrow \( \Omega_b^0 \) states decaying to \( \Xi_b^{+} \) and \( K^- \). Phys. Rev. Lett. 118, 182001 (2017)
6. R. Aaij et al. [LHCb Collaboration], Study of the \( D^* \) amplitude in \( \Lambda_b^0 \rightarrow D^* \pi^- \) decays. JHEP 1705, 030 (2017)
7. R. Aaij et al. [LHCb Collaboration], Observation of a new \( \Xi_b^{-} \) resonance. Phys. Rev. Lett. 121, 072002 (2018)
8. R. Aaij et al. [LHCb Collaboration], Observation of two resonances in the \( \Lambda_b^0 \pi^- \) systems and precise measurement of \( \Sigma_b^{*+} \) and \( \Sigma_b^{++} \) properties. Phys. Rev. Lett. 122, 012001 (2019)
9. R. Aaij et al. [LHCb Collaboration], Observation of a new resonance in the \( \Lambda_b^0 \pi^- \pi^0 \) system. arXiv:1907.13598 [hep-ex]
10. J.G. Körner, M. Kramer, D. Pirjol, Heavy baryons. Prog. Part. Nucl. Phys. 33, 787 (1994)
11. A.V. Manohar, M.B. Wise, Heavy quark physics. Camb. Monogr. Part. Phys. Nucl. Phys. Cosmol. 10, 1 (2000)
12. E. Klempt, J.M. Richard, Baryon spectroscopy. Rev. Mod. Phys. 82, 1095 (2010)
13. S. Capstick, N. Isgur, Baryons in a relativized quark model with chromodynamics. Phys. Rev. D 34, 2809 (1986)
14. S. Capstick, N. Isgur, Baryons in a relativized quark model with chromodynamics. AIP Conf. Proc. 132, 267 (1985)
81. P. Ball, R. Zwicky, B_{d,s} \to \rho, \omega, K^*, \phi decay form-factors from light-cone sum rules revisited. Phys. Rev. D 71, 014029 (2005)

82. P. Ball, V.M. Braun, Exclusive semileptonic and rare B meson decays in QCD. Phys. Rev. D 58, 094016 (1998)

83. P. Ball, V.M. Braun, Y. Koike, K. Tanaka, Higher twist distribution amplitudes of vector mesons in QCD: Formalism and twist-three distributions. Nucl. Phys. B 529, 323 (1998)

84. P. Ball, V.M. Braun, Higher twist distribution amplitudes of vector mesons in QCD: twist-4 distributions and meson mass corrections. Nucl. Phys. B 543, 201 (1999)

85. P. Ball, G.W. Jones, Twist-3 distribution amplitudes of K* and phi mesons. JHEP 0703, 069 (2007)

86. P. Ball, V.M. Braun, A. Lenz, Twist-4 distribution amplitudes of the K* and phi mesons in QCD. JHEP 0708, 090 (2007)

87. K.C. Yang, W.Y.P. Hwang, E.M. Henley, L.S. Kisslinger, QCD sum rules and neutron proton mass difference. Phys. Rev. D 47, 3001 (1993)

88. W.Y.P. Hwang, K.C. Yang. QCD sum rules: Δ - N and Σ 0 - Δ mass splittings. Phys. Rev. D 49, 460 (1994)

89. A.A. Ovchinnikov, A.A. Pivovarov. QCD sum rule calculation of the quark gluon condensate. Sov. J. Nucl. Phys. 48, 721 (1988)

90. A.A. Ovchinnikov, A.A. Pivovarov. QCD sum rule calculation of the quark gluon condensate. Yad. Fiz. 48, 1135 (1988)

91. M. Jamin, Flavor symmetry breaking of the quark condensate and chiral corrections to the Gell–Mann–Oakes–Renner relation. Phys. Lett. B 538, 71 (2002)

92. B.L. Ioffe, K.N. Zyablyuk, Gluon condensate in charmonium sum rules with three loop corrections. Eur. Phys. J. C 27, 229 (2003)

93. S. Narison, Withdrawn: QCD as a theory of hadrons from partons to confinement. Camb. Monogr. Part. Phys. Nucl. Phys. Cosmol. 17, 1 (2002). arXiv:hep-ph/0205006

94. V. Gimenez, V. Lubicz, F. Mescia, V. Porretti, J. Reyes, Operator product expansion and quark condensate from lattice QCD in coordinate space. Eur. Phys. J. C 41, 535 (2005)

95. P. Colangelo, A. Khodjamirian, At the Frontier of Particle Physics/Handbook of QCD (World Scientific, Singapore, 2001), p. 1495

96. X. Liu, H.X. Chen, Y.R. Liu, A. Hosaka, S.L. Zhu, Bottom baryons. Phys. Rev. D 77, 014031 (2008)