Decay widths of ground-state and excited Ξ_b baryons in a nonrelativistic quark model

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Decay processes of ground and excited bottom baryons are studied in the $^3P_0$ nonrelativistic quark model with all model parameters fixed in the sector of light quarks. Using as an input the recent mass of Ξ_b and the theoretical masses of Ξ_b^* and Ξ_b', narrow decay widths are predicted for the ground-state bottom baryons Ξ_b^* and Ξ_b'. The work predicts large decay widths, about 100 MeV for the ρ-type orbital excitation states of Ξ_b.

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I. INTRODUCTION

The first bottom baryon Λ_b, with the *udb* configuration and a mass around 5640 MeV, was reported by the UA1 Collaboration at CERN in the late 1990s [1]. Later the Λ_b was confirmed by other experiments such as the DELPHI Collaboration [2], ALEPH Collaboration [3], and CDF Collaboration [4] with neutral charge and mass between 5614 to 5668 MeV. The mass of Λ_b was further measured to be 5619.7 MeV by the CDF Collaboration at Fermilab [5]. In 2007, five new bottom baryons, $\Sigma_b^{(*)}$ and Ξ_b^- were reported by the CDF and D0 Collaborations [6–9] in proton-antiproton collisions ($\bar{p}p$) at $\sqrt{s} = 1.96$ TeV. Recently the doubly strange bottom baryon Ω_b^- was first observed in $\bar{p}p$ collisions at $\sqrt{s} = 1.96$ TeV by the D0 Collaboration at Fermilab with a mass of 6165 MeV [10].

Decay processes of the ground-state (S wave) bottom baryons, $\Sigma_b \to \Lambda_b\pi$ and $\Sigma_b^* \to \Lambda_b\pi$ were studied in the Bethe-Salpeter formalism under the covariant instantaneous approximation [11], in the combined chiral dynamics and MIT bag model [12] and in the nonrelativistic $^3P_0$ quark model [13]. The theoretical results for the decay widths of $\Sigma_b^{(*)}$ are consistent with the experimental data. However, the strong decay reactions of excited (P wave) bottom baryons have not been studied systematically.

In this work we aim to explore decay widths of both S-wave and P-wave bottom baryons by studying the decay processes: S-wave $\Sigma_b^*(\Sigma_b) \to \Lambda_b\pi$, S-wave $\Xi_b^*(\Xi_b') \to \Xi_b\pi$, P-wave $\Xi_b \to \Xi_b\pi$, and P-wave $\Xi_b \to \Xi_b'\pi$, in the $^3P_0$ quark dynamics with the effective coupling strength of the $^3P_0$ vertex determined by the decay processes of the $\Sigma(1385)$ baryons and all other model parameters taken from other works. The employment of the $\Sigma(1385)$ to fix model parameters is based on the consideration that the baryons couple weakly to the $\Lambda\pi$, $\Sigma\pi$, and $N\overline{K}$ channels via P wave and are likely to be $3q$ dominant particles. The article is arranged as follows. In Sec. II transition amplitudes of various decay processes are evaluated in the $^3P_0$ model. The decay widths for S-wave and P-wave bottom baryons are displayed in Sec. III. A discussion and conclusions are given in Sec. IV.

II. GROUND AND EXCITED Ξ_b BARYONS DECAY IN $^3P_0$ QUARK DYNAMICS

The processes $\Sigma_b^*(\Sigma_b) \to \Lambda_b\pi$, $\Xi_b^*(\Xi_b') \to \Xi_b\pi$, P-wave $\Xi_b \to \Xi_b\pi$, and P-wave $\Xi_b \to \Xi_b'\pi$ are studied in this work by using the $^3P_0$ nonrelativistic quark model. The generic diagram for the processes is shown in Fig. 1.

The transition amplitudes of the decay processes in the $^3P_0$ quark model are defined as

$$T = \langle \Psi_f | V_{67} | \Psi_i \rangle, \tag{1}$$

where Ψ_f and Ψ_i are, respectively, the final and initial states of the reactions. V_{67} is the quark-antiquark $^3P_0$ vertex (see Appendix A). The wave functions of the charm and bottom baryons in question are constructed in the framework of the flavor SU(3) (u, d, and s quarks) and spin SU(2) symmetries. For the light quark sector, however, we apply the flavor SU(2) (u and d quarks) and spin SU(2) symmetries. As shown in Tables I and II, ϕ^S and ϕ^A are the flavor wave functions with the two light flavors of the charm and bottom baryons symmetric and antisymmetric, respectively. χ^S, χ^ρ, χ^λ, and χ^A are, respectively, the symmetric, ρ type, λ type, and antisymmetric spin wave functions. The radial wave functions of ground-state baryon, ρ, and λ excitation types are $\Psi_{00}(\vec{\lambda}, \vec{\rho}\,)$, $\Psi_{11}^\rho(\vec{\lambda}, \vec{\rho}\,)$, and $\Psi_{11}^\lambda(\vec{\lambda}, \vec{\rho}\,)$, respectively, taking the Gaussian form

$$\begin{aligned}
\Psi_{00}(\vec{\lambda}, \vec{\rho}) &= N_{B1}\, e^{-a^2(p_\rho^2+p_\lambda^2)/2}, \\
\Psi_{11}^\rho(\vec{\lambda}, \vec{\rho}) &= N_{B2}\, e^{-a^2(p_\rho^2+p_\lambda^2)/2}(a p_\rho) Y_{1m}(\hat{\rho}), \\
\Psi_{11}^\lambda(\vec{\lambda}, \vec{\rho}) &= N_{B2}\, e^{-a^2(p_\rho^2+p_\lambda^2)/2}(a p_\lambda) Y_{1m}(\hat{\lambda}),
\end{aligned} \tag{2}$$

where $N_{B1} = 3^{3/4}a^3/\pi^{3/2}$ and $N_{B2} = 2^{3/2}3^{1/4}a^3/\pi$. The momenta $\vec{p}_\rho$ and $\vec{p}_\lambda$ are defined as

$$\vec{p}_\rho = \frac{1}{\sqrt{2}}(\vec{p}_1 - \vec{p}_2), \quad \vec{p}_\lambda = \frac{d}{\sqrt{6}}(\vec{p}_1 + \vec{p}_2 - 2m_r\vec{p}_3), \tag{3}$$

where $d = 3/(1 + 2m_r)$ and $m_r = m_u/m_q$ with q being c and b quarks for the charm and bottom baryons and being

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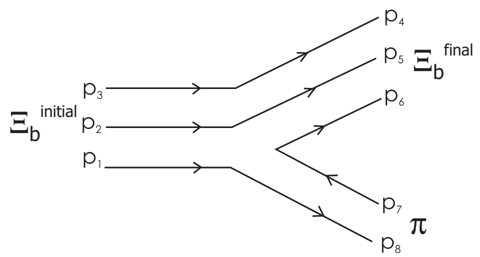

FIG. 1. Diagram for ground and excited Ξ_b baryons decay in the $^3P_0$ quark model.

s quark for $\Sigma(1385)$ baryons. Note that the λ orbital excitations involve the excitation of the "odd" quark (b quark) while the ρ orbital excitations involve the excitation of the light-diquark as depicted in Fig. 2.

In this work we have also a π meson involved. We use the Gaussian form for the radial wave function of the meson

$$\Psi(\vec{p}_1, \vec{p}_2) = N_m\, e^{-b^2(\vec{p}_1-\vec{p}_2)^2/8}, \tag{4}$$

where the normalization factor $N_m = b^{3/2}/\pi^{3/4}$.

The hadron wave functions employed in this work are just the first-order approximation of more realistic wave functions. In principle, one should use wave functions based on more realistic interaction models rather than the simple harmonic oscillator interaction. However, considering that the $^3P_0$ quark model may give a 30% overall agreement with experimental data for baryon masses and decay widths, the harmonic oscillator wave-function approximation is considered reasonable for low-lying baryons. A work by Isgur *et al.* [14], based on one-gluon-exchange interactions, concludes that the wave function of nucleon is dominated by a single harmonic oscillator wave function to about 80% in terms of the harmonic oscillator model. It is revealed [15,16] that the wave functions of low-lying baryons that are likely to be $3q$ particles are usually dominated by a single harmonic oscillator wave function. Recently, Ref. [13] applied single harmonic oscillator wave functions for baryons to calculate the decay widths of charmed baryons and ground-state bottom baryons and derived theoretical results consistent with the experimental data.

To verify the applicability of our model, we studied various decay processes in the sector of light and charmed baryons, for example, the reactions $\Sigma_c(2520) \to \Lambda_c\pi$, $\Xi_c(2645) \to \Xi_c\pi$ and $\Xi(1530) \to \Xi\pi$ and found that the theoretical results are well consistent with the experimental data, as shown in Table V. One may conclude in line with the theoretical results in Table V that it is reasonable to apply single harmonic oscillator wave functions for low-lying baryons.

To perform more accurate calculations rather than using the simple $^3P_0$ quark model, one must employ more realistic wave functions, for example, the ones based on given interaction models taking into account the constraints of heavy quark symmetry [17,18]. The wave functions developed in coordinate space [17,18] lead to satisfactory predictions for the relevant hyperon masses. However, it is really difficult for the simple $^3P_0$ model to apply to such complicated wave functions.

Table I shows the quantum numbers, total wave functions, and masses of ground-state bottom baryons Λ_b, Σ_b, and Ξ_b. For comparison, the decays of the charm baryons Σ_c and Ξ_c are also studied in the same model, and hence we also list properties of these particles. For the Ξ_b^* baryon (bsd) the diquark (sd) has spin $S = 1$ and the total spin $J = 3/2$ while the diquark of Ξ_b' baryon has $S = 1$ and $J = 1/2$. The theoretical masses of Ξ_b^* and Ξ_b' are taken from Ref. [19] while the masses of others come from the Particle Data Group (PDG) [20].

Shown in Table II are the quantum numbers, wave functions, and suggested masses by theoretical works of excited bottom baryons Ξ_b. The theoretical masses of the λ-type

TABLE I. Quantum numbers, total wave functions, and masses of the ground-state baryons in question.

Symbols	$I(J^P)$	wave functions	masses (GeV)
Ξ_b^*	$\frac{1}{2}(\frac{3}{2}^+)$	$\phi^{(S)}[\chi^{(S)} \otimes \Psi_{00}]_{J=3/2}$	5.965
Ξ_b'	$\frac{1}{2}(\frac{1}{2}^+)$	$\phi^{(S)}[\chi^{(\lambda)} \otimes \Psi_{00}]_{J=1/2}$	5.935
Ξ_b	$\frac{1}{2}(\frac{1}{2}^+)$	$\phi^{(A)}[\chi^{(\rho)} \otimes \Psi_{00}]_{J=1/2}$	5.792
$\Xi_c(2645)^{*+}$	$\frac{1}{2}(\frac{3}{2}^+)$	$\phi^{(S)}[\chi^{(S)} \otimes \Psi_{00}]_{J=3/2}$	2.646
Ξ_c^+	$\frac{1}{2}(\frac{1}{2}^+)$	$\phi^{(A)}[\chi^{(\rho)} \otimes \Psi_{00}]_{J=1/2}$	2.467
$\Sigma_b(5836)^{*-}$	$1(\frac{3}{2}^+)$	$\phi^{(S)}[\chi^{(S)} \otimes \Psi_{00}]_{J=3/2}$	5.836
$\Sigma_b(5829)^{*+}$	$1(\frac{3}{2}^+)$	$\phi^{(S)}[\chi^{(S)} \otimes \Psi_{00}]_{J=3/2}$	5.829
$\Sigma_b(5816)^-$	$1(\frac{1}{2}^+)$	$\phi^{(S)}[\chi^{(\lambda)} \otimes \Psi_{00}]_{J=1/2}$	5.815
$\Sigma_b(5807)^+$	$1(\frac{1}{2}^+)$	$\phi^{(S)}[\chi^{(\lambda)} \otimes \Psi_{00}]_{J=1/2}$	5.807
Λ_b	$0(\frac{1}{2}^+)$	$\phi^{(A)}[\chi^{(\rho)} \otimes \Psi_{00}]_{J=1/2}$	5.620
$\Sigma_c(2520)^{*0}$	$1(\frac{3}{2}^+)$	$\phi^{(S)}[\chi^{(S)} \otimes \Psi_{00}]_{J=3/2}$	2.518
$\Sigma_c(2455)^0$	$1(\frac{1}{2}^+)$	$\phi^{(S)}[\chi^{(\lambda)} \otimes \Psi_{00}]_{J=1/2}$	2.453
Λ_c^+	$0(\frac{1}{2}^+)$	$\phi^{(A)}[\chi^{(\rho)} \otimes \Psi_{00}]_{J=1/2}$	2.286

TABLE II. Quantum numbers, total wave functions, and masses of excited Ξ_b baryons.

Symbols	$I(J^P)$	wave functions	masses (GeV)
$\Xi_b^{\lambda}(\frac{3}{2}^-)$	$\frac{1}{2}(\frac{3}{2}^-)$	$\phi^{(A)}[\chi^{(\rho)} \otimes \Psi_{l_\rho=0,l_\lambda=1}]_{J=3/2}$	6.113
$\Xi_b^{\lambda}(\frac{1}{2}^-)$	$\frac{1}{2}(\frac{1}{2}^-)$	$\phi^{(A)}[\chi^{(\rho)} \otimes \Psi_{l_\rho=0,l_\lambda=1}]_{J=1/2}$	6.105
$\Xi_b^{\rho 1}(\frac{3}{2}^-)$	$\frac{1}{2}(\frac{3}{2}^-)$	$\phi^{(S)}[\chi^{(\rho)} \otimes \Psi_{l_\rho=1,l_\lambda=0}]_{J=3/2}$	6.213
$\Xi_b^{\rho 1}(\frac{1}{2}^-)$	$\frac{1}{2}(\frac{1}{2}^-)$	$\phi^{(S)}[\chi^{(\rho)} \otimes \Psi_{l_\rho=1,l_\lambda=0}]_{J=1/2}$	6.205
$\Xi_b^{\rho 2}(\frac{3}{2}^-)$	$\frac{1}{2}(\frac{3}{2}^-)$	$\phi^{(A)}[\chi^{(\lambda)} \otimes \Psi_{l_\rho=1,l_\lambda=0}]_{J=3/2}$	6.213
$\Xi_b^{\rho 2}(\frac{1}{2}^-)$	$\frac{1}{2}(\frac{1}{2}^-)$	$\phi^{(A)}[\chi^{(\lambda)} \otimes \Psi_{l_\rho=1,l_\lambda=0}]_{J=1/2}$	6.205

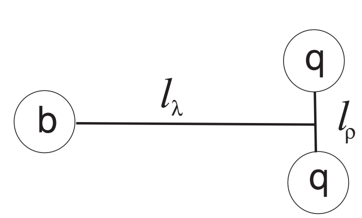

FIG. 2. Schematic view of the λ and ρ orbital excitations. q and b denote the light (u, d, s) and heavy quarks, respectively.

orbital excitations $\Xi_b^\lambda(\frac{3}{2}^-)$ and $\Xi_b^\lambda(\frac{1}{2}^-)$ are the averages of the predictions of Refs. [21–23]. The masses of the corresponding ρ-type orbital excitations are typically 100 MeV heavier than the λ-type ones as suggested in Ref. [24]. Note that the $\Xi_b^{\rho 1}$ ($\Xi_b^{\rho 2}$) is the ρ-type orbital excitation with the symmetric (antisymmetric) flavor and antisymmetric (symmetric) spin wave functions for the two light quarks.

The decay width of the studied processes takes the form in terms of the partial wave transition amplitudes [25]

$$\Gamma = \frac{2\pi E_1 E_2 k}{M_B} \frac{1}{2S_i + 1} \sum_{M,M_i} |T_{LM}|^2, \tag{5}$$

where k is the final momentum at the rest frame of the initial particle, M_B the mass of the initial baryon, and E_1 and E_2 are the energies of the two final particles.

The transition amplitudes, for the decay processes of ground-state baryons as listed in Table V, are derived in the $^3P_0$ model to take the form

$$T = C_i f(k) C(S_i m_i, 1m, S_f m_f) Y^*_{1m}(\hat{k}), \tag{6}$$

with

$$f(k) = \frac{3\sqrt{3}a^3 b^{3/2} k[(9m_r + 3)a^2 + b^2(2m_r + 1)]}{(3a^2 + b^2)^{5/2}(2m_r + 1)\pi^{3/4}} e^{-d_s k^2}, \tag{7}$$

where

$$d_s = \frac{12\left(m_r^2 + m_r + 1\right)a^4 + a^2 b^2\left(7m_r^2 + 4m_r + 4\right)}{8(3a^2 + b^2)(2m_r + 1)^2}. \tag{8}$$

The coefficients C_i in Eq. (6) are the color-spin-flavor factors for different reactions, as listed in Table III. S_i and S_f in the C-G coefficient in Eq. (6) are, respectively, the spins of the initial and final baryons. m_r in Eqs. (7) and (8) is the ratio of the light quark mass to the heavy quark one of baryons, that is, $m_r = m_{u(d,s)}/m_{(c,b)}$ for the bottom and charm baryons and $m_r = m_{u(d)}/m_s$ for baryons in the light quark sector.

TABLE III. Color-spin-flavor factors C_i in Eqs. (6) and (9) for various decay processes.

Processes	C_i
$\Xi_b^* \to \Xi_b \pi$	$\frac{1}{2\sqrt{2}}$
$\Xi_b' \to \Xi_b \pi$	$\frac{1}{4}$
$\Sigma_b(5836)^{*-} \to \Lambda_b \pi$	$\frac{1}{\sqrt{6}}$
$\Sigma_b(5829)^{*+} \to \Lambda_b \pi$	$\frac{1}{\sqrt{6}}$
$\Sigma_b(5816)^{-} \to \Lambda_b \pi$	$\frac{1}{2\sqrt{3}}$
$\Sigma_b(5807)^{+} \to \Lambda_b \pi$	$\frac{1}{2\sqrt{3}}$
$\Sigma_c(2520)^{*0} \to \Lambda_c^+ \pi^-$	$\frac{1}{\sqrt{6}}$
$\Sigma_c(2455)^{0} \to \Lambda_c^+ \pi^-$	$\frac{1}{2\sqrt{3}}$
$\Xi_c(2645)^{*+} \to \Xi_c^+ \pi^0$	$\frac{1}{2\sqrt{2}}$
$\Xi(1530) \to \Xi \pi$	$\frac{1}{2\sqrt{2}}$
$\Sigma(1385) \to \Lambda \pi$	$\frac{1}{\sqrt{6}}$
$\Xi_b^\lambda(\frac{3}{2}^-, \frac{1}{2}^-) \to \Xi_b' \pi$	$\frac{1}{4}$
$\Xi_b^{\rho 1}(\frac{3}{2}^-, \frac{1}{2}^-) \to \Xi_b' \pi$	$\frac{1}{4}$
$\Xi_b^{\rho 2}(\frac{3}{2}^-, \frac{1}{2}^-) \to \Xi_b \pi$	$\frac{1}{4}$
$\Xi_b^{\rho 2}(\frac{3}{2}^-, \frac{1}{2}^-) \to \Xi_b' \pi$	$\frac{\sqrt{3}}{6}$

The transition amplitudes for the decay processes of excited baryons, as listed in Table VI, take the form

$$T = C_i \cdot \left(T_0(k) \frac{1}{\sqrt{4\pi}} + T_2(k) Y^*_{2m}(\hat{k}) \right), \tag{9}$$

where C_i are the color-spin-flavor factors for different reactions, as listed in Table III. $T_0(k)$ and $T_2(k)$ are as follows:

$$T_0(k) = \left(\sqrt{4\pi} A + \frac{B}{\sqrt{4\pi}} \right) e^{-d_s k^2}, \tag{10}$$

$$\begin{aligned} T_2(k) = {} & B e^{-d_s k^2} \sqrt{\frac{9}{20\pi}} (-1)^{M-m_i} C(10, 10, 20) \\ & \cdot C(1m_i - M, 1m - m_i + M, 2m) \\ & \cdot C(S_i m_i, 1m - m_i + M, S_f m + M) \\ & \cdot C(S_i m_i, 1M - m_i, JM), \end{aligned} \tag{11}$$

with

$$A = \frac{9\sqrt{3}a^4 b^{3/2}}{2(3a^2 + b^2)^{5/2}\pi^{5/4}}, \tag{12}$$

$$\begin{aligned} B = {} & -3\sqrt{3}a^4 b^{3/2} k^2 [6a^2 + b^2(m_r + 2)] \\ & \cdot \frac{[(9m_r + 3)a^2 + b^2(2m_r + 1)]}{2(3a^2 + b^2)^{7/2}(2m_r + 1)^2 \pi^{1/4}}, \end{aligned} \tag{13}$$

where S_i and S_f are the spin angular momenta of the initial and final baryons and J is the total angular momentum of the initial baryons, resulting from the coupling of the spin angular momentum S_i and the orbital angular momentum $l = 1$.

III. RESULTS FOR GROUND AND EXCITED STATE BOTTOM BARYONS

We first evaluate the decay widths of the reactions of ground-state baryons $\Sigma_b^* \to \Lambda_b \pi$, $\Sigma_b \to \Lambda_b \pi$, $\Xi_b^* \to \Xi_b \pi$, and $\Xi_b' \to \Xi_b \pi$ in the $^3P_0$ quark model with all model parameters determined by other processes.

The meson size parameter b is determined to be 3.24 GeV^{-1} by the reaction $\rho \to e^+e^-$ as in the work of Refs. [26,27]. This meson size parameter leads to an rms radius $\langle r^2 \rangle^{1/2} = 0.39$ fm for the s-wave mesons. In the study of the reactions of $\bar{N}N$ annihilation [28–32], the meson size parameter b is globally adjusted to the rms radius 4.1 GeV^{-1} ($\langle r^2 \rangle^{1/2} = 0.50$ fm). However, a small pion radius ($\langle r^2 \rangle^{1/2} < 0.4$ fm) is needed to reproduce the energy dependence of the $\pi^+\pi^-$ and $\pi^+\pi^-\pi^0$ cross sections of $\bar{N}N$ annihilations [32,33]. The optimum meson size parameter derived by fitting to the partial widths of higher quarkonia [34] is $b = 2.5$ GeV^{-1}. With such a meson size parameter, however, the decay width of the ρ meson is largely underestimated in Ref. [34]. To reproduce the decay width of the ρ meson in the framework of Ref. [34] one does

TABLE IV. Summary of input parameters.

$m_{u(d)}$	300 MeV
m_s	500 MeV
m_c	1270 MeV
m_b	4200 MeV
b	3.24 GeV^{-1}
$\lambda(a = 2.0\ \mathrm{GeV}^{-1})$	2.66
$\lambda(a = 2.5\ \mathrm{GeV}^{-1})$	2.01

need a meson size parameter around the value applied in this work for light mesons. Various values have been employed in different works for the baryon size parameter, ranging from $a = 1.7$ GeV^{-1} to 3.1 GeV^{-1} [13,15,28–32,35–37]. In this work we use $a =$ 2.0 and 2.5 GeV^{-1}, just mild values.

The effective strength parameter λ of the $^3P_0$ quark vertex is fixed by the reaction $\Sigma(1385) \to \Lambda\pi$ to be 2.66 and 2.01 for the baryon size parameter $a = 2.0$ and 2.5 GeV^{-1}, respectively. The constituent masses of u, d, and s quarks, as shown in Table IV, are applied to the evaluation of the process $\Sigma(1385) \to \Lambda\pi$. For simplicity, however, we let the s quark take the same constituent mass as the u and d quarks for the bottom and charm baryons. The masses of c and b quarks are taken from the PDG.

By applying the $^3P_0$ quark model with model parameters as shown in Tables I and IV, the decay widths of ground state $\Xi_{b(c)}$, $\Sigma_{b(c)}$ and other light baryons are evaluated and shown in Table V. It is found that the decay widths of $\Xi_c(2645)^{*+}$, $\Xi(1530)^0$, $\Xi(1530)^-$, $\Sigma_c(2520)^{*0}$, and $\Sigma_c(2455)^0$ are consistent with the PDG. The predictions for the decay widths of the reactions $\Sigma_b(5836)^{*-} \to \Lambda_b\pi$, $\Sigma_b(5829)^{*+} \to \Lambda_b\pi$, $\Sigma_b(5816)^- \to \Lambda_b\pi$, and $\Sigma_b(5807)^+ \to \Lambda_b\pi$ are also in line with the experimental estimations. The work predicts very narrow decay widths 1.8 and 0.05 MeV for Ξ_b^* and Ξ_b', respectively.

For the excited bottom baryons, partial decay widths are calculated by considering both λ and ρ type orbital excitations. Shown in Table VI are the predicted partial decay widths for the various allowed processes. It is found that baryons of spin 3/2 have much smaller decay widths than those of spin 1/2. The partial decay widths of $J^P = \frac{1}{2}^-$ ρ-type excitations are very large, about 100 MeV.

TABLE V. Model predictions for decay widths (MeV) of ground state $\Xi_{b(c)}$, $\Sigma_{b(c)}$, and other light baryons compared with experimental data. The $^3P_0$ results are displayed for $a = 2.0$ and 2.5 GeV^{-1}, respectively.

Reactions	$^3P_0$ results	PDG [20]
$\Xi_b^* \to \Xi_b\pi$	1.85, 1.83	–
$\Xi_b' \to \Xi_b\pi$	0.052, 0.052	–
$\Sigma_b(5836)^{*-} \to \Lambda_b\pi$	12.34, 11.81	~15 Ref. [7]
$\Sigma_b(5829)^{*+} \to \Lambda_b\pi$	10.06, 9.68	~15 Ref. [7]
$\Sigma_b(5816)^- \to \Lambda_b\pi$	6.49, 6.31	~8 Ref. [7]
$\Sigma_b(5807)^+ \to \Lambda_b\pi$	4.94, 4.82	~8 Ref. [7]
$\Sigma_c(2520)^{*0} \to \Lambda_c^+\pi^-$	17.60, 17.27	16.1 ± 2.1
$\Sigma_c(2455)^0 \to \Lambda_c^+\pi^-$	1.81, 1.84	2.2 ± 0.4
$\Xi_c(2645)^{*+} \to \Xi_c^+\pi^0$	2.86, 2.88	< 3.1
$\Xi(1530)^0 \to \Xi\pi$	8.50, 8.68	9.1 ± 0.5
$\Xi(1530)^- \to \Xi\pi$	9.21, 9.39	$9.9^{+1.7}_{-1.9}$

TABLE VI. Model predictions for decay widths (MeV) of excited Ξ_b baryons with $a = 2.0$ and 2.5 GeV^{-1}, respectively.

Reactions	$^3P_0$ results
$\Xi_b^{\lambda}(\frac{3}{2}^-) \to \Xi_b'\pi$	0.02, 0.03
$\Xi_b^{\lambda}(\frac{1}{2}^-) \to \Xi_b'\pi$	11.55, 10.15
$\Xi_b^{\rho 1}(\frac{3}{2}^-) \to \Xi_b'\pi$	0.65, 0.90
$\Xi_b^{\rho 1}(\frac{1}{2}^-) \to \Xi_b'\pi$	97.29, 77.33
$\Xi_b^{\rho 2}(\frac{3}{2}^-) \to \Xi_b\pi$	8.09, 9.48
$\Xi_b^{\rho 2}(\frac{1}{2}^-) \to \Xi_b\pi$	132.87, 80.91
$\Xi_b^{\rho 2}(\frac{3}{2}^-) \to \Xi_b'\pi$	0.86, 1.20
$\Xi_b^{\rho 2}(\frac{1}{2}^-) \to \Xi_b'\pi$	129.73, 103.11

IV. DISCUSSION AND CONCLUSION

The decay widths of the ground and excited state bottom baryons are calculated in this work by applying the $^3P_0$ quark model with all model parameters either taken from other works or determined in the light quark sector.

The model predictions for decay widths of the ground-state bottom baryons $\Sigma_b(5836)^{*-}$, $\Sigma_b(5829)^{*+}$, $\Sigma_b(5816)^-$, and $\Sigma_b(5807)^+$ are in line with the experimental estimations. The work predicts very narrow decay widths for the bottom baryons Ξ_b^* and Ξ_b', based on the theoretical masses taken from Ref. [19]. However, the theoretical results are very sensitive to the Ξ_b^* and Ξ_b' masses since those masses, especially for Ξ_b' are just a few MeV above the mass threshold of the reactions.

The work predicts large partial decay widths, about 100 MeV for the ρ-type orbital excitations of Ξ_b.

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APPENDIX: $^3P_0$ QUARK-ANTIQUARK VERTEX

The $^3P_0$ nonrelativistic quark model was first proposed by Micu in Ref. [38]. Later the model was further developed by Yaouanc [39–41]. This model is successful and widely used in calculating the hadron processes [15,16,26,42–48]. The $^3P_0$ quark-antiquark vertex has the form

$$\begin{aligned} V_{ij} &= \lambda\vec{\sigma}_{ij} \cdot (\vec{p}_i - \vec{p}_j)\hat{C}_{ij}\hat{F}_{ij}\delta(\vec{p}_i + \vec{p}_j) \\ &= \lambda \sum_{\mu} \sqrt{\frac{4\pi}{3}}(-1)^{\mu}\sigma_{ij}^{\mu} y_{1\mu}(\vec{p}_i - \vec{p}_j)\hat{C}_{ij}\hat{F}_{ij}\delta(\vec{p}_i + \vec{p}_j), \end{aligned} \tag{A1}$$

with

$$\vec{\sigma}_{ij} = \frac{\vec{\sigma}_i + \vec{\sigma}_j}{2}, \tag{A2}$$

$$y_{1\mu}(\vec{p}) \equiv |\vec{p}| Y_{1\mu}(\hat{p}), \tag{A3}$$

where $\hat{p} \equiv \vec{p}/|\vec{p}|$, σ_i are Pauli matrices and $Y_{1m}(\hat{p})$ are the spherical harmonics. $\vec{p}_i$ and $\vec{p}_j$ are the momenta of the quark and antiquark, which are pumped out from a vacuum, and $\hat{C}_{ij}$ and $\hat{F}_{ij}$ are, respectively, the color and flavor operators projecting a quark-antiquark pair to a vacuum in the color and flavor spaces. The operators' properties can be displayed as

$$\langle 0, 0|\hat{F}_{ij}|T, T_z\rangle = \sqrt{2}\delta_{T,0}\delta_{T_z,0}, \tag{A4}$$

$$\langle 0, 0|\sigma^{\mu}_{ij}|[\bar{\chi}_i \otimes \chi_j]_{J,M}\rangle = (-1)^M \sqrt{2}\delta_{J,1}\delta_{M,-\mu}, \tag{A5}$$

$$\langle 0, 0|\hat{C}_{ij}|q^i_{\alpha}\bar{q}^j_{\beta}\rangle = \delta_{\alpha\beta}. \tag{A6}$$

The derivation and interpretation of the quark-antiquark $^3P_0$ dynamics may be found in the literature [39–41].

[1] C. Albajar *et al.* (UA1 Collaboration), Phys. Lett. B **273**, 540 (1991).
[2] P. Abreu *et al.* (DELPHI Collaboration), Phys. Lett. B **374**, 351 (1996).
[3] D. Buskulic *et al.* (ALEPH Collaboration), Phys. Lett. B **380**, 442 (1996).
[4] F. Abe *et al.* (CDF Collaboration), Phys. Rev. D **55**, 1142 (1997).
[5] D. E. Acosta *et al.* (CDF Collaboration), Phys. Rev. Lett. **96**, 202001 (2006).
[6] T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **99**, 202001 (2007).
[7] I. V. Gorelov, J. Phys. Conf. Ser. **69**, 012009 (2007).
[8] T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **99**, 052002 (2007).
[9] V. M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **99**, 052001 (2007).
[10] V. M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **101**, 232002 (2008).
[11] X. H. Guo, K. W. Wei, and X. H. Wu, Phys. Rev. D **77**, 036003 (2008).
[12] C. W. Hwang, Eur. Phys. J. C **50**, 793 (2007).
[13] C. Chen, X. L. Chen, X. Liu, W. Z. Deng, and S. L. Zhu, Phys. Rev. D **75**, 094017 (2007).
[14] N. Isgur, G. Karl, and R. Koniuk, Phys. Rev. Lett. **41**, 1269 (1978); **45**, 1738 (1980).
[15] S. Capstick and W. Roberts, Phys. Rev. D **47**, 1994 (1993).
[16] S. Capstick and W. Roberts, Phys. Rev. D **49**, 4570 (1994).
[17] C. Albertus, J. E. Amaro, E. Hernandez, and J. Nieves, Nucl. Phys. A **740**, 333 (2004).
[18] C. Albertus, E. Hernandez, and J. Nieves, Phys. Rev. D **71**, 014012 (2005).
[19] M. Karliner, Nucl. Phys. B, Proc. Suppl. **187**, 21 (2009).
[20] C. Amsler *et al.* (Particle Data Group), Phys. Lett. B **667**, 1 (2008).
[21] D. Ebert, R. N. Faustov, and V. O. Galkin, Phys. Lett. B **659**, 612 (2008).
[22] M. Karliner, B. Keren-Zur, H. J. Lipkin, and J. L. Rosner, arXiv:0708.4027.
[23] W. Roberts and M. Pervin, Int. J. Mod. Phys. A **23**, 2817 (2008).
[24] I. M. Narodetskii, M. A. Trusov, and A. I. Veselov, Phys. At. Nucl. **72**, 536 (2009).
[25] C. J. Joachain, *Quantum Collision Theory* (North-Holland, Amsterdam, 1975).
[26] Y. Yan, C. Kobdaj, P. Suebka, Y. M. Zheng, A. Faessler, T. Gutsche, and V. E. Lyubovitskij, Phys. Rev. C **71**, 025204 (2005).
[27] K. Kittimanapun, K. Khosonthongkee, C. Kobdaj, P. Suebka, and Y. Yan, Phys. Rev. C **79**, 025201 (2009).
[28] M. Maruyama, S. Furui, and A. Faessler, Nucl. Phys. A **472**, 643 (1987).
[29] M. Maruyama, S. Furui, A. Faessler, and R. Vinh Mau, Nucl. Phys. A **473**, 649 (1987).
[30] T. Gutsche, M. Maruyama, and A. Faessler, Nucl. Phys. A **503**, 737 (1989).
[31] A. Muhm, T. Gutsche, R. Thierauf, Y. Yan, and A. Faessler, Nucl. Phys. A **598**, 285 (1996).
[32] C. B. Dover, T. Gutsche, M. Maruyama, and A. Faessler, Prog. Part. Nucl. Phys. **29**, 87 (1992).
[33] S. Mundigl, M. J. Vicente Vacas, and W. Weise, Nucl. Phys. A **523**, 499 (1991).
[34] T. Barnes, F. E. Close, P. R. Page, and E. S. Swanson, Phys. Rev. D **55**, 4157 (1997).
[35] N. Isgur and G. Karl, Phys. Rev. D **18**, 4187 (1978).
[36] N. Isgur and G. Karl, Phys. Rev. D **20**, 1191 (1979).
[37] S. Capstick and N. Isgur, Phys. Rev. D **34**, 2809 (1986).
[38] L. Micu, Nucl. Phys. B **10**, 521 (1969).
[39] A. Le Yaouanc, L. Oliver, O. Pene, and J. C. Raynal, Phys. Rev. D **8**, 2223 (1973).
[40] A. Le Yaouanc, L. Oliver, O. Pene, and J. C. Raynal, Phys. Rev. D **9**, 1415 (1974).
[41] A. Le Yaouanc, L. Oliver, O. Pene, and J. C. Raynal, Phys. Rev. D **11**, 1272 (1975).
[42] H. G. Blundell and S. Godfrey, Phys. Rev. D **53**, 3700 (1996).
[43] E. S. Ackleh, T. Barnes, and E. S. Swanson, Phys. Rev. D **54**, 6811 (1996).
[44] Y. Yan, C. Kobdaj, W. Uchai, A. Faessler, T. Gutsche, and Y. M. Zheng, Mod. Phys. Lett. A **18**, 370 (2003).
[45] P. Suebka, C. Kobdaj, and Y. Yan, Int. J. Mod. Phys. E **14**, 987 (2005).
[46] H. Q. Zhou, R. G. Ping, and B. S. Zou, Phys. Lett. B **611**, 123 (2005).
[47] J. Lu, W. Z. Deng, X. L. Chen, and S. L. Zhu, Phys. Rev. D **73**, 054012 (2006).
[48] B. Zhang, X. Liu, W. Z. Deng, and S. L. Zhu, Eur. Phys. J. C **50**, 617 (2007).