I. INTRODUCTION

Recently CDF Collaboration observed four bottom baryons $\Sigma^{+}_{c}$ and $\Sigma^{+}_{b}$, D0 Collaboration announced the observation of $\Xi_{b}^{0}$, which was confirmed by CDF collaboration later [1, 2]. Very recently, Babar Collaboration reported the observation of $\Omega^{*}_{b}$ with the mass splitting $m_{\Omega^{*}_{b}} - m_{\Omega_{b}} = 70.8 \pm 1.0 \pm 1.1 \text{MeV}$ [3]. We collect the masses of these recently observed bottom baryons in Table 1.

The heavy hadron containing a single heavy quark is particularly interesting. The light degrees of freedom (quarks and gluons) circle around the nearly static heavy quark. Such a system behaves as the QCD analogue of the familiar hydrogen bounded by electromagnetic interaction. The heavy quark expansion provides a systematic tool for heavy hadrons. When the heavy quark mass $m_{Q} \rightarrow \infty$, the angular momentum of the light degree of freedom is a good quantum number. Therefore heavy hadrons form doublets. For example, $\Omega_{c}$ and $\Omega^{*}_{b}$ will be degenerate in the heavy quark limit. Their mass splitting is caused by the chromo-magnetic interaction at the order $O(1/m_{Q})$, which can be taken into account systematically in the framework of heavy quark effective field theory (HQET).

In the past two decades, various phenomenological models have been used to study heavy baryon masses [1, 2, 3, 4, 5, 6]. Capstick and Isgur studied the heavy baryon system in a relativized quark potential model [6]. Roncaglia et al. predicted the masses of baryons containing one or two heavy quarks using the Feynman-Hellmann theorem and semiempirical mass formulas. Jenkins studied heavy baryon masses using a combined expansion of $1/m_{Q}$ and $1/N_{c}$. Mathur et al. predicted the masses of charmed and bottom baryons from lattice QCD [7]. Ebert et al. calculated the masses of heavy baryons with the light-diquark approximation [8]. Using the relativistic Faddeev approach, Gerasyuta and Ivanov calculated the masses of the S-wave charmed baryons [9]. Later, Gerasyuta and Matskevich studied the charmed ($70, 1^{-}$) baryon multiplet using the same approach [10]. Stabilized by recent experimental progress, there have been several theoretical papers on the the masses of $\Sigma_{c}, \Sigma^{*}_{b}$, and $\Xi^{*}_{c}$ using the hyperfine interaction in the quark model [11, 12, 13, 14, 15]. Recently the strong decays of heavy baryons were investigated systematically using $3P_{0}$ model in Ref. [20].

QCD sum rule (QSR) is a useful non-perturbative method in hadron physics [21], which has been applied to study heavy baryon masses previously [14, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33]. The mass sum rules of $\Lambda_{c,b}$ and $\Sigma_{c,b}$ were obtained in full QCD in Refs. [14, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33]. The mass sum rules of $\Sigma_{Q}$ and $\Lambda_{Q}$ in the leading order of the heavy quark effective theory (HQET) have been discussed in Refs. [24, 25, 26, 27, 28, 29, 30, 31]. Dai et al. calculated the $1/m_{Q}$ correction to the mass sum rules of $\Lambda_{Q}$ and $\Sigma^{(*)}_{Q}$ in HQET [27, 28]. Later the mass sum rules of $\Lambda_{Q}$ and $\Sigma^{(*)}_{Q}$ were reanalyzed in Ref. [28]. The mass sum rules of orbitally excited heavy baryons in the leading order of HQET were discussed in Refs. [29, 30, 31, 32] while the $1/m_{Q}$ correction was considered in Ref. [30, 31]. Recently Wang studied the mass sum rule of $\Omega^{+}_{b}$ [32] while Durães and Nielsen studied the mass sum rule of $\Xi_{c,b}$ using full QCD Lagrangian [33].

In order to extract the chromo-magnetic splitting between the bottom baryon doublets reliably, we derive the mass sum rules up to the order of $1/m_{Q}$ in the heavy

TABLE I: The mass of bottom baryons recently observed by CDF and D0 collaborations.

| Baryon | Mass (MeV) | Experiment |
|--------|-----------|------------|
| $\Sigma^{+}_{c}$ | 5808.29 (stat.) $\pm 1.7$ (syst.) | CDF [1, 2] |
| $\Sigma^{+}_{b}$ | 5816.10 (stat.) $\pm 1.7$ (syst.) | D0 [3] |
| $\Sigma^{+}_{c,b}$ | 5829.16 (stat.) $\pm 1.7$ (syst.) | |
| $\Sigma^{0}_{b}$ | 5837.12 (stat.) $\pm 1.7$ (syst.) | |
| $\Omega^{0}_{b}$ | 5774 (stat.) $\pm 15$ (syst.) | D0 [3] |
| $\Xi^{+}_{b}$ | 5793 $\pm 2.5$ (stat.) $\pm 1.7$ (syst.) | CDF [4, 5] |

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quark effective field theory in this work. We perform a systematic study of the masses of Ξ, Ξ', Ξ'' and Ω through the inclusion of the strange quark mass correction. The resulting chromo-magnetic mass splitting agrees well with the available experimental data. As a cross-check, we reproduce the mass sum rules of Λ and Ω agreement well with the available experimental data. As a result, the heavy quark mass expansion does not work well for the charm hadrons.

This paper is organized as follows. We present the formulation of the leading order QCD sum rules in HQET for bottom baryons in Section II. The following section is about the \(1/m_Q\) correction. The numerical analysis and a short discussion are presented in Section IV.

II. QCD SUM RULES FOR HEAVY BARYONS

We first introduce our notations for the heavy baryons. Inside a heavy baryon there are one heavy quark and two light quarks (\(u, d\) or \(s\)). It belongs to either the symmetric \(6_F\) or antisymmetric \(3_F\) flavor representation (see Fig. 1). For the S-wave heavy baryons, the total flavor-spin wave function of the two light quarks must be symmetric since their color wave function is antisymmetric. Hence the spin of the two light quarks is either \(S = 1\) for \(6_F\) or \(S = 0\) for \(3_F\). The angular momentum and parity of the S-wave heavy baryons are \(J^P = \frac{1}{2}^+\) or \(\frac{3}{2}^+\) for \(6_F\) and \(J^P = \frac{1}{2}^+\) for \(3_F\). The names of S-wave heavy baryons are listed in Fig. I where we use \(*\) to denote \(\frac{1}{2}^+\) baryons and the \(t\) to denote the \(J^P = \frac{1}{2}^+\) baryons in the \(6_F\) representation. In this work, we use \(B\) to denote the heavy baryons with \(\frac{1}{2}^+\) in \(3_F\) and \(B^\prime\) and \(B^\ast\) to denote those states with \(\frac{3}{2}^+\) and \(\frac{5}{2}^+\) in \(6_F\).

![FIG. 1: The SU(3) flavor multiplets of heavy baryons. Here \(\alpha, \alpha + 1, \alpha + 2\) denote the charges of heavy baryons.](image-url)

We will study heavy baryon masses in HQET using QCD sum rule approach. HQET plays an important role in the investigation of the heavy hadron properties.

In the limit of \(m_Q \to \infty\), the heavy quark field \(Q(x)\) in full QCD can be decomposed into its small and large components

\[
Q(x) = e^{-im.Q.v.x}[H_u(x) + h_v(x)],
\]

where \(v^\mu\) is the velocity of the heavy baryon. Accordingly the heavy quark field \(h_v(x)\) reads

\[
h_v(x) = e^{im.Q.v.x}\frac{(1 + \gamma^\mu)}{2}Q(x),
\]

\[
H_v(x) = e^{im.Q.v.x}\frac{(1 - \gamma^\mu)}{2}Q(x).
\]

The Lagrangian in HQET reads

\[
\mathcal{L}_{HQET} = \bar{h}_v i\gamma \cdot D h_v + \frac{1}{2m_Q^2}\bar{h}_v(iD_\perp)^2 h_v
\]

\[
- C_{mag} g_{4m_Q} \bar{h}_v \sigma_{\mu\nu} G^{\mu\nu} h_v.
\]

The second and third term in the above Lagrangian corresponds to the kinetic and chromo-magnetic corrections at the order of \(1/m_Q\). Here \(D_\perp^2 = D^\mu - \bar{v}v^\mu \cdot D \) and \(D^\mu = \partial^\mu + igA^\mu\). \(C_{mag}(\mu)\) is renormalized coefficient \(C_{mag}(\mu) = (\alpha_s(m_Q)/\alpha_s(\mu))^{3/2}\frac{[1 + \frac{\ln m_w}{\ln \mu}]}{[1 + \frac{\ln m_w}{\ln \mu}]},\) where \(\mu = 11 - 2n_f/3\) and \(n_f\) is the number of quark flavors.

In order to derive the mass sum rules of \(B, B^\prime\) and \(B^\ast\), we use the following interpolating currents for the heavy baryons with \(J^P = \frac{1}{2}^+\) in \(6_F\),

\[
\begin{align*}
J_B^\prime(x) &= \epsilon_{abc} [\bar{q}_1 T^\prime(x) C \gamma_\mu q_2^b(x) \gamma_5 h_v^c(x),
\end{align*}
\]

\[
\begin{align*}
\bar{J}_B^\prime(x) &= -\epsilon_{abc} \bar{h}_v^c(x) \gamma_5 \gamma_\mu \gamma_5 \bar{q}_2^b(x) \gamma_C \bar{Q}_1^T(x).
\end{align*}
\]

For the heavy baryons with \(J^P = \frac{3}{2}^+\) in \(6_F\),

\[
\begin{align*}
J_B^\mu(x) &= \epsilon_{abc} [\bar{q}_1 T^\mu(x) C \gamma_\mu q_2^b(x)]
\end{align*}
\]

\[
\times \left(-g^\mu_\nu + \frac{1}{3} \gamma^\mu \gamma^\nu \right) h_v^c(x),
\]

\[
\begin{align*}
\bar{J}_B^\mu(x) &= \epsilon_{abc} \bar{h}_v^c(x) \left(-g^\mu_\nu + \frac{1}{3} \gamma^\mu \gamma^\nu \right)
\end{align*}
\]

\[
\times [\bar{q}_2^b(x) \gamma_C \bar{Q}_1^T(x)].
\]

For the heavy baryons with \(J^P = \frac{5}{2}^+\) in \(3_F\),

\[
\begin{align*}
J_B(x) &= \epsilon_{abc} [\bar{q}_1 T(x) C \gamma_5 q_2^b(x)] h_v^c(x),
\end{align*}
\]

\[
\begin{align*}
\bar{J}_B(x) &= -\epsilon_{abc} \bar{h}_v^c(x) [\bar{q}_2^b(x) \gamma_C \bar{Q}_1^T(x)].
\end{align*}
\]

Here \(a, b, c\) are color indices, \(q_i(x)\) denotes up, down and strange quark fields. \(T\) is the transpose matrix and \(C\) is the charge conjugate matrix. \(g^\mu_\nu = g^{\mu\nu} - v^{\mu} v^{\nu}\), \(\gamma^\mu = \gamma^{\mu} - \gamma \cdot v \gamma^{\mu}\).

The overlapping amplitudes of the interpolating currents with \(B, B^\prime\) and \(B^\ast\) are defined as

\[
\langle 0 | J_B^\prime | B \rangle = f_B u_B^\prime, \quad (11)
\]

\[
\langle 0 | J_B^\prime | B^\prime \rangle = f_B^\prime u_B^\prime, \quad (12)
\]

\[
\langle 0 | J_B^\prime | B^\ast \rangle = \frac{1}{\sqrt{3}} f_B v_B^\ast, \quad (13)
\]
where \( u_B^\mu \) is the Rarita-Schwinger spinor in HQET. \( f_B = f_B^\cdot \) due to heavy quark symmetry.

The binding energy \( \Lambda_i \) is defined as the mass difference between the heavy baryon and heavy quark when \( m_Q \to \infty \). In order to extract \( \Lambda_i \), we consider the following correlation function

\[
i \int d^4 x \ e^{iq\cdot x} \langle 0 | T \{ J_{B^{(i)}}(x) \bar{J}_{B^{(i)}}(0) \} | 0 \rangle = \frac{1 + f \Pi_{B^{(i)}}(\omega)}{2},
\]

with \( \omega = v \cdot q \).

The dispersion relation for \( \Pi(\omega) \) is

\[
\Pi(\omega) = \int \frac{\rho(\omega')}{\omega' - \omega - i\epsilon} \ d\omega',
\]

where \( \rho(\omega) \) denotes the spectral density in the limit of \( m_Q \to \infty \). At the phenomenological level,

\[
\Pi(\omega) = \frac{f_i^2}{\Lambda_i - \omega} + \text{continuum}.
\]

Making the Borel transformation with variable \( \omega \), we obtain

\[
f_i^2 e^{-\Lambda_i/T} = \int_0^{\omega_0} \rho(\omega)e^{-\omega/T}d\omega,
\]

where we have invoked the quark-hadron duality assumption and approximated the continuum above \( \omega_0 \) with the perturbative contribution at the quark-gluon level. The mass sum rules of \( B, B' \) and \( B^* \) are

\[
f_B^2 e^{-\Lambda_B/T} = \int_0^{\omega_B} \left[ \frac{3\omega_5}{20\pi^4} - \frac{2m_q^2 - 3m_{q_2}^2 - 3m_{q_1}^2}{4\pi^2} \right] \omega^3 d\omega - \frac{m_q^2 \langle \bar{q}q \rangle}{128\pi^4} + \frac{m_{q_2} \langle \bar{q}_2q \rangle + m_{q_1} \langle \bar{q}_1q \rangle}{4\pi^2} e^{-\omega/T} d\omega - \frac{m_q^2 \langle \bar{q}_2 \sigma G q \rangle + m_{q_2} \langle \bar{q}_1 \sigma G q \rangle}{32\pi^2} + \frac{m_{q_1} \langle \bar{q}_1 \sigma G q \rangle + m_{q_2} \langle \bar{q}_2 \sigma G q \rangle + 4m_q \langle \bar{q}_1q \rangle}{128\pi^4} e^{-\omega/T} d\omega - \frac{m_{q_2} \langle \bar{q}_2 \sigma G q \rangle}{4\pi^2} + \frac{m_{q_1} \langle \bar{q}_1 \sigma G q \rangle + m_{q_2} \langle \bar{q}_2 \sigma G q \rangle + 4m_q \langle \bar{q}_1q \rangle}{128\pi^4} e^{-\omega/T} d\omega \]

The mass sum rule of \( B^* \) is same as that of \( B' \) at the leading order of HQET. In the above equations, \( \langle \bar{q}_i q \rangle \) is the quark condensates, \( \langle g^2 G G \rangle \) is the gluon condensate and \( \langle gg \sigma G q \rangle \) is the quark-gluon mixed condensate. The above sum rules have been derived in the massless light quark limit in Refs. \[21, 23, 26, 27\]. Up and down quark mass correction is tiny for heavy baryons \( \Lambda_b, \Sigma_b \) and \( \Xi_b \). In this work we have included the finite quark mass correction which is important for heavy baryons \( \Xi_b, \Sigma_b^* \) and \( \Omega_b \).

The binding energy \( \Lambda_i \) can be extracted using the following formula

\[
\tilde{\Lambda}_i = \frac{T^2d\Gamma_i}{\mathbb{R}_i dT},
\]

where \( \mathbb{R}_i \) denotes the right-hand part in the above sum rules.

III. THE 1/m_Q CORRECTION

In order to calculate the \( 1/m_Q \) correction, we insert the heavy baryon eigen-state of the Hamiltonian up to the order \( O(1/m_Q) \) into the correlation function

\[
i \int d^4 x e^{iq\cdot x} \langle 0 | T \{ J_i(x) \bar{J}_i(0) \} | 0 \rangle.
\]

Its pole contribution is

\[
\Pi(\omega) = \frac{(f + \delta f)^2}{(\Lambda + \delta \Lambda) - \omega} = \frac{f^2}{\Lambda - \omega} - \frac{f^2 \delta m}{(\Lambda - \omega)^2} + \frac{2f \delta f}{\Lambda - \omega},
\]

where both \( \delta m \) and \( \delta f \) are \( O(1/m_Q) \).

We consider the three-point correlation function

\[
\frac{1 + \delta}{2} \delta^0 \Pi(\omega, \omega') = \frac{i^2}{2} \int d^4 z d^4 y e^{i p \cdot z} e^{i p' \cdot y} \langle 0 | T \{ J_i(z) O(x) \bar{J}_i(y) \} | 0 \rangle.
\]
where operators $O = K$ and $S$ correspond to the kinetic energy and chromo-magnetic interaction in Eq. (4). The double dispersion relation for $\delta^0 \Pi(\omega, \omega')$ reads

$$
\delta^0 \Pi(\omega, \omega') = \int_0^\infty ds \int_0^\infty ds' \frac{\rho^O(s, s')}{(s - \omega)(s' - \omega')}.
$$

(24)

At the hadronic level,

$$
\delta^K \Pi(\omega, \omega') = \frac{f^2 K_i}{(\Lambda - \omega)(\Lambda - \omega')} + \cdots,
$$

(25)

$$
\delta^S \Pi(\omega, \omega') = \frac{f^2 S_i}{(\Lambda - \omega)(\Lambda - \omega')} + \cdots
$$

(26)

with

$$
K_i = \frac{1}{2m_Q} \langle B_i | \bar{h}_\nu(iD_L)^2 h_\nu | B_i \rangle,
$$

(27)

$$
S_i = -\frac{1}{4m_Q} \langle B_i | \bar{h}_\nu g\sigma \mu \nu h_\nu | B_i \rangle.
$$

(28)

After setting $\omega = \omega'$ in Eqs. (25) and (26) and comparing them with Eq. (22), we can extract $\delta m$

$$
\delta m_i = -(K_i + C_{mag} S_i).
$$

(29)

Here the renormalization coefficient $C_{mag}$ for bottom baryons is $C_{mag} \approx 0.8$ [29].

We calculate the diagrams listed in Fig. 2 to derive $\delta^0 \Pi(\omega, \omega')$. After invoking double Borel transformation to Eq. (24) we obtain the spectral density $\rho^O(s, s')$. Then we redefine the integration variable

$$
s_+ = \frac{s + s'}{2},
$$

(30)

$$
s_- = \frac{s - s'}{2}.
$$

(31)

Now the integral in Eq. (24) is changed as

$$
\int_0^\infty ds \int_0^\infty ds' \ldots = 2 \int_0^\infty ds_+ \int_-^{s_+} ds_- \ldots.
$$

(32)

In the subtraction of the continuum contribution, quark hadron duality is assumed for the integration variable $s_+$ [35].

For $B(1^+)$ in $3_F$, the $1/m_Q$ correction comes from the kinetic term only.

$$
K_B = -\frac{e^{\Lambda_B/T}}{m_Q f_B} \left\{ \int_0^{\omega_B} \left[ \frac{54 \omega^7}{714 \pi^4} - \frac{9 \omega^5}{60 \pi^5} (m_{q_1}^2 + m_{q_2}^2 - m_{q_1} m_{q_2}) \right. \\
+ \frac{3 (q^2 G G) \omega_3}{128 \cdot 31 \pi^4} + \frac{3 \omega^3}{4 \cdot 31 \pi^2} \left( m_{q_1} \langle \bar{q}_1 q_1 \rangle + m_{q_2} \langle \bar{q}_2 q_2 \rangle - 2 m_{q_2} \langle \bar{q}_1 q_1 \rangle - 2 m_{q_1} \langle \bar{q}_2 q_2 \rangle \right) \\
- \frac{3 \omega}{128 \pi^2} \left( m_{q_1} \langle g_c \bar{q}_1 \sigma G q_1 \rangle + m_{q_2} \langle g_c \bar{q}_2 \sigma G q_2 \rangle \right) \\
+ \frac{3 \omega}{32 \pi^2} \left( m_{q_1} \langle g_c \bar{q}_2 \sigma G q_2 \rangle + m_{q_2} \langle g_c \bar{q}_1 \sigma G q_1 \rangle \right) \right\} e^{-\omega/T} d\omega
$$

$$
S_B = 0.
$$

(33)

(34)

Here $S_B = 0$ is consistent with the simple expectation in the constituent quark model that the chromo-magnetic interaction $\langle S_Q \cdot j_i \rangle = 0$ since $j_i = 0$ for $B(1^+)$. 
For $B'(\frac{1}{2}^+)$ in $6_F$, the $1/m_Q$ corrections are

$$K_{B'} = e^{\lambda_{B'}/T} \frac{1}{m_Q f_{B'}} \left\{ \int_0^{\omega_{B'}} \left[ \frac{18 \cdot 11 \omega^7}{7! \pi^4} - \frac{9 \omega^5}{5 \pi^2} (4m^2_{q_1} + 4m^2_{q_2}) \right. \
- 3m_{q_1} m_{q_2} - \frac{(g^2 GG) \omega^3}{128 \cdot 3! \pi^4} + \frac{3 \omega^3}{4 \cdot 3! \pi^2} (5m_{q_1} \langle \bar{q}_1 q_1 \rangle \\
+ 5m_{q_2} \langle \bar{q}_2 q_2 \rangle - 6m_{q_1} \langle \bar{q}_1 q_1 \rangle - 6m_{q_1} \langle \bar{q}_2 q_2 \rangle) \\
+ \frac{11 \omega}{32 \pi^2} \left( m_{q_1} \langle g_c q_1 \sigma G q_1 \rangle + m_{q_2} \langle g_c q_2 \sigma G q_2 \rangle \right) \right\} e^{-\omega/T} d\omega \left. \right\}$$

Through explicit calculation, we obtain

$$K_{B'} = K_{B''},$$

$$S_{B'} = -S_{B''}/2,$$

$$m_{B'} - m_{B''} = \frac{3}{2} S_{B''},$$

which are consistent with the heavy quark symmetry.

### IV. RESULTS AND DISCUSSION

In our numerical analysis, we use $\bar{\Lambda}$, $\bar{K}_i$, $\bar{S}_i$ and mass splitting $m_{B'} - m_{B''}$ on $T$ and $\omega_c$ for $\Sigma_b$, $\Xi'_b$, $\Omega_b$. The variation of a sum rule with both $T$ and $\omega_i$ contributes to the errors of the extracted value, together with the truncation of the operator product expansion and the uncertainty of vacuum condensate values. We collect the extracted $\bar{\Lambda}$, $\bar{K}_i$, $\bar{S}_i$ and mass splitting $m_{B'} - m_{B''}$ in Table III.

The masses of bottom baryons from the present work are presented in Table III. It’s well known that the heavy quark expansion does not work very well for the charmed baryons since the charm quark is not heavy enough to ensure the good convergence of $1/m_Q$ expansion. For example, the chromo-magnetic splitting between $\bar{\Omega}_c$ and $\bar{\Omega}_c$ from our work is around 133 MeV, which is much larger than the experimental value 67.4 MeV. However, we still choose to present the masses of S-wave charmed baryons also in Table III simply for the sake of comparison with experimental data.

In our calculation, we adopt the phenomenological spectral function by the classical and simple ansatz of a
TABLE II: The central values in this table are extracted at $T = 0.5$ GeV, $\omega_i = 1.3$ GeV for $\Sigma_b^{(*)}$, $\omega_i = 1.4$ GeV for $\Xi_b^{(*)}$, $\omega_i = 1.55$ GeV for $\Omega_b^{(*)}$, $\omega_i = 1.1$ GeV for $\Lambda_b$ and $\omega_i = 1.25$ GeV for $\Xi_b$ (in MeV).

| Baryon | $\Sigma_b$ | $\Xi_b$ | $\Omega_b^0$ | $\Lambda_b$ | $\Xi_b$ |
|--------|------------|----------|-------------|-------------|-------|
| $\Lambda$ | 950$^{+15}_{-13}$ | 1042$^{+10}_{-14}$ | 1169 $^{+13}_{-7}$ | 773$^{+68}_{-59}$ | 908$^{+72}_{-67}$ |
| $\delta m$ | 59$^{+6}_{-2}$ | 60$^{+6}_{-6}$ | 67$^{+7}_{-6}$ | 65$^{+2}_{-1}$ | 72$^{+1}_{-2}$ |

mass splitting $m_{\Sigma_b} - m_{\Lambda_b}$, $m_{\Xi_b} - m_{\Omega_b}$, $m_{\Omega_b} - m_{\Lambda_b}$, $m_{\Xi_b} - m_{\Omega_b}$.

The systematic uncertainty of hadron parameters obtained with such an approximation was discussed recently in Ref. [44]. We have not considered the next-to-leading order $\alpha_s$ corrections, which may also result in large contribution and uncertainty as indicated by the study of the $\alpha_s^2$ corrections in the light-quark baryon system in Ref. [45].

In short summary, inspired by recent experimental observation of charmed and bottom baryons [1, 2, 3, 4, 5, 6, 7, 8, 9], we have investigated the masses of heavy baryons systematically using the QCD sum rule approach in HQET. The chromo-magnetic splitting of the bottom baryon doublet from the present work agrees well with the recent experimental data. Recently $\Xi_b^{(*)}$ was observed by CDF collaboration [1, 2]. Our results are also consistent with their experimental value. Our prediction of the masses of $\Sigma_b^{(*)}$, $\Xi_b^{(*)}$, $\Omega_b$ and $\Omega_b^*$ can be tested through the future discovery of these interesting states at Tevatron at Fermi Lab.

**Acknowledgments**

X.L. thanks W. Wei for useful discussion. This project was supported by the National Natural Science Foundation of China under Grants 10421503, 10625521 and 10705001, Key Grant Project of Chinese Ministry of Education (No. 305001) and the China Postdoctoral Science Foundation (No. 2006040376). H.X.C. is grateful to the Monkasho fellowship for supporting his stay at Research Center for Nuclear Physics where this work is done. A.H. is supported in part by the Grant for Scientific Research ((C) No.19540297) from the Ministry of Education, Culture, Science and Technology, Japan.

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FIG. 3: The dependences of $\bar{\Lambda}_{\Sigma_b}$, $K_{\Sigma_b}$, $S_{\Sigma_b}$, and the mass splitting $m_{\Sigma_b^*} - m_{\Sigma_b}$ on $T$. Here the dotted, solid and dashed line corresponds to the threshold value $\omega_{\Sigma_b} = 1.2, 1.3, 1.4$ GeV respectively.

FIG. 4: The dependences of $\bar{\Lambda}_{\Xi_b'}$, $K_{\Xi_b'}$, $S_{\Xi_b'}$, and the mass splitting $m_{\Xi_b^*} - m_{\Xi_b}$ on $T$. The dotted, solid and dashed line corresponds to $\omega_{\Xi_b'} = 1.3, 1.4, 1.5$ GeV respectively.
FIG. 5: The dependences of $\bar{\Lambda}_{\Omega_b}$, $\bar{K}_{\Omega_b}$, $S_{\Omega_b}$, and the mass splitting $m_{\Omega_b^*} - m_{\Omega_b}$ on $T$. The dotted, solid and dashed line corresponds to $\omega_{\Omega_b} = 1.45, 1.55, 1.65 \text{ GeV}$ respectively.