Study of $B_{u,d} \to K_0^*(1430)\eta^{(\prime)}$ decays within QCD factorization

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I. INTRODUCTION

Recently *BABAR* has measured charmless B decays with final states containing η or η' [1]. Comparing the first measurements of $B \to K_0^*(1430)\eta'$ and $B \to K_2^*(1430)\eta'$ by *BABAR* with previous results of $B \to K_0^*(1430)\eta$ and $B \to K_2^*(1430)\eta$ (see Table I) clearly indicates that $\mathcal{B}(B \to K_0^*(1430)\eta') < \mathcal{B}(B \to K_0^*(1430)\eta)$ and $\mathcal{B}(B \to K_2^*(1430)\eta') > \mathcal{B}(B \to K_2^*(1430)\eta)$. It is well known that $\mathcal{B}(B \to K\eta') \gg \mathcal{B}(B \to K\eta)$ and $\mathcal{B}(B \to K^*\eta') \ll \mathcal{B}(B \to K^*\eta)$. The last two patterns can be understood as the interference between the dominant penguin amplitudes.

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(a)

For the η and η' particles,it is more convenient to consider the flavor states $q\bar{q} \equiv (u\bar{u} + d\bar{d})/\sqrt{2}, s\bar{s}, and\ c\bar{c}$ labeled by the $\eta_q, \eta_s, and\ \eta_c^0$, respectively. Neglecting the small mixing with η_c^0, we write

$$\begin{pmatrix} |\eta\rangle \\ |\eta'\rangle \end{pmatrix} = \begin{pmatrix} cos\phi & -sin\phi \\ sin\phi & cos\phi \end{pmatrix} \begin{pmatrix} |\eta_q\rangle \\ |\eta_s\rangle \end{pmatrix}, \quad (1)$$

where $\phi = (39.3 \pm 1.0)^\circ$

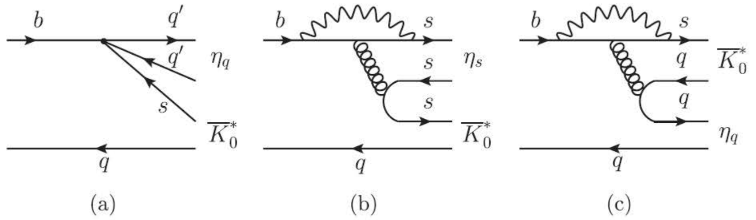

FIG. 1. Three different penguin contributions to $\bar{B} \to \bar{K}_0^*(1430)\eta^{(\prime)}$, where (a) is induced by the penguin operators $O_{3,5,7,9}$, (b) from the penguin operator O_6, and (c) from the penguin operator O_8.

(b)

$$\begin{aligned}
\sqrt{2}\mathcal{A}(\bar{B}^0 \to \bar{K}_0^{*0}\eta^{(\prime)}) &= A_{\bar{K}_0^{*0}\eta_q^{(\prime)}}[\delta_u^p\alpha_2 + 2\alpha_3^p + \frac{1}{2}\alpha_{3,\mathrm{EW}}^p] \\
&+ \sqrt{2}A_{\bar{K}_0^{*0}\eta_s^{(\prime)}}[\alpha_3^p + \alpha_4^p - \frac{1}{2}\alpha_{3,\mathrm{EW}}^p - \frac{1}{2}\alpha_{4,\mathrm{EW}}^p + \beta_3^p - \frac{1}{2}\beta_{3,\mathrm{EW}}^p] \\
&+ A_{\eta_q^{(\prime)}\bar{K}_0^{*0}}[\alpha_4^p - \frac{1}{2}\alpha_{4,\mathrm{EW}}^p + \beta_3^p - \frac{1}{2}\beta_{3,\mathrm{EW}}^p] \\
&+ \sqrt{2}A_{\bar{K}_0^{*0}\eta_c^{(\prime)}}[\delta_c^p\alpha_2 + \alpha_3^p], \qquad (2)
\end{aligned}$$

$$\begin{aligned}
\sqrt{2}\mathcal{A}(B^- \to K_0^{*-}\eta^{(\prime)}) &= A_{K_0^{*-}\eta_q^{(\prime)}}[\delta_u^p\alpha_2 + 2\alpha_3^p + \frac{1}{2}\alpha_{3,\mathrm{EW}}^p] \\
&+ \sqrt{2}A_{K_0^{*-}\eta_s^{(\prime)}}[\alpha_3^p + \alpha_4^p - \frac{1}{2}\alpha_{3,\mathrm{EW}}^p - \frac{1}{2}\alpha_{4,\mathrm{EW}}^p + \delta_u^p\beta_2 + \beta_3^p + \beta_{3,\mathrm{EW}}^p] \\
&+ A_{\eta_q^{(\prime)}K_0^{*-}}[\delta_u^p\alpha_1 + \alpha_4^p + \alpha_{4,\mathrm{EW}}^p + \delta_u^p\beta_2 + \beta_3^p + \beta_{3,\mathrm{EW}}^p] \\
&+ \sqrt{2}A_{K_0^{*-}\eta_c^{(\prime)}}[\delta_c^p\alpha_2 + \alpha_3^p], \qquad (3)
\end{aligned}$$

$$\begin{aligned}
\sqrt{2}\mathcal{A}(\bar{B}_s \to K_0^{*0}\eta^{(\prime)}) &= A_{K_0^{*0}\eta_q^{(\prime)}}[\delta_u^p\alpha_2 + 2\alpha_3^p + \alpha_4^p + \frac{1}{2}\alpha_{3,\mathrm{EW}}^p - \frac{1}{2}\alpha_{4,\mathrm{EW}}^p + \beta_3^p - \frac{1}{2}\beta_{3,\mathrm{EW}}^p] \\
&+ \sqrt{2}A_{K_0^{*0}\eta_s^{(\prime)}}[\alpha_3^p - \frac{1}{2}\alpha_{3,\mathrm{EW}}^p] \\
&+ \sqrt{2}A_{\eta_s^{(\prime)}K_0^{*0}}[\alpha_4^p - \frac{1}{2}\alpha_{4,\mathrm{EW}}^p + \beta_3^p - \frac{1}{2}\beta_{3,\mathrm{EW}}^p] \\
&+ \sqrt{2}A_{\bar{K}_0^{*0}\eta_c^{(\prime)}}[\delta_c^p\alpha_2 + \alpha_3^p], \qquad (4)
\end{aligned}$$

Where

$$A_{M1M2} = \frac{G_F}{\sqrt{2}}\begin{cases} -(m_B^2 - m_{M_1}^2)U_0^{B\to M_1}(m_{M_2}^2)f_{M_2} & \text{if } M_1M_2 = SP\,, \\ (m_B^2 - m_{M_1}^2)F_0^{B\to M_1}(m_{M_2}^2)f_{M_2} & \text{if } M_1M_2 = PS\,. \end{cases} \qquad (5)$$

$$B_{M1M2} = \frac{G_F}{\sqrt{2}}f_{B_q}f_{M_1}f_{M_2} \qquad \text{if } M_1M_2 = PS, SP, \qquad (6)$$

chiral factors r_χ is defined as

$$r_\chi^P(\mu) = \frac{2m_P^2}{m_b(\mu)(m_1(\mu) + m_2(\mu))}, \qquad r_\chi^{\eta_s} = \frac{h_P^s}{f_P^s m_b(\mu)m_s(\mu)}, \qquad (7)$$

$$r_\chi^S(\mu) = \frac{2m_S}{m_b(\mu)}\frac{\bar{f}_S(\mu)}{f_S} = \frac{2m_S^2}{m_b(\mu)(m_1(\mu) - m_2(\mu))}\,. \qquad (8)$$

where f_P^s and h_P^s

$$\begin{pmatrix} f_\eta^q & f_\eta^s \\ f_{\eta'}^q & f_{\eta'}^s \end{pmatrix} = \begin{pmatrix} cos\phi & -sin\phi \\ sin\phi & cos\phi \end{pmatrix}\begin{pmatrix} f_q & 0 \\ 0 & f_s \end{pmatrix}, \qquad (9)$$

$$\begin{pmatrix} h_\eta^q & h_\eta^s \\ h_{\eta'}^q & h_{\eta'}^s \end{pmatrix} = \begin{pmatrix} cos\phi & -sin\phi \\ sin\phi & cos\phi \end{pmatrix}\begin{pmatrix} h_q & 0 \\ 0 & h_s \end{pmatrix}, \qquad (10)$$

decay amplitudes of $B \to f_0 K$, $a_0^0 \pi$, $a_0^0 K$. (ii) Attention has not been paid to the relative sign difference of the vector decay constants between a_0^- and a_0^+ and between K_0^* and $\bar{K}_0^*$ or K_0^{*-} and K_0^{*+} in our previous study. (iii) There were some errors in our previous computer code which may significantly affect some of the calculations done before. (iv) Progress has been made in the past in the study of $B \to S$ transition form factors in various approaches [14,21–26]. (v) Experimental data for some of $B \to SV$ decays such as $K_0^*(1430)\phi$, $K_0^*(1430)\rho$, and $K_0^*(1430)\omega$ are now available. (vi) It is known that in order to account for the penguin-dominated $B \to PP, VP, VV$ decay modes within the framework of QCDF, it is necessary to include power corrections due to penguin annihilation [27,28]. In the present work, we wish to examine if the same effect holds in the scalar meson sector; that is, if the penguin-annihilation induced power corrections are also needed to explain the penguin dominated $B \to SP$ and $B \to SV$ decays.

This paper is organized as follows. We specify in Sec. II various input parameters for scalar mesons, such as decay constants, form factors and light-cone distribution amplitudes. The relevant decay amplitudes are briefly discussed in Sec. III. Results and detailed discussions are presented

Numerically,

$$
\begin{aligned}
h_\eta^q &= 0.0013\ \text{GeV}^3, & h_\eta^s &= -0.0555\ \text{GeV}^3, \\
h_{\eta'}^q &= 0.0011\ \text{GeV}^3, & h_{\eta'}^s &= 0.068\ \text{GeV}^3, \\
f_\eta^q &= 109\ \text{MeV}, & f_\eta^s &= -111\ \text{MeV}, \\
f_{\eta'}^q &= 89\ \text{MeV}, & f_{\eta'}^s &= 136\ \text{MeV}, \\
f_\eta^c &= -2.3\ \text{MeV}, & f_{\eta'}^c &= -5.8\ \text{MeV}, \\
m_{\eta_q} &= 741\ \text{MeV}, & m_{\eta_s} &= 802\ \text{MeV},
\end{aligned}
\tag{A12}
$$

(c)

whether the scalar meson $K_0^*(1430)$ is an excited state of κ or a lowest-lying P-wave $q\bar{q}$ state. In scenario 1, we have (in units of GeV^3)

$$
\begin{aligned}
X^{(BK_0^*,\eta_q)} &= -0.60, & X^{(BK_0^*,\eta_s)} &= 0.61, \\
X^{(B\eta_q,K_0^*)} &= -0.15, & X^{(BK_0^*,\eta_q')} &= -0.49, \\
X^{(BK_0^*,\eta_s')} &= -0.75, & X^{(B\eta_q',K_0^*)} &= -0.12.
\end{aligned}
\tag{23}
$$

(e)

The decay pattern in scenario 2 is quite different. Because of the large magnitude of $\alpha_3(K_0^*\eta_{q,s})$ and the large cancellation between $\alpha_3(K_0^*\eta_s)$ and $\alpha_4(K_0^*\eta_s)$ in C_2, $B \to K_0^*\eta^{(\prime)}$ decays are dominated by the contributions from Figs. 1(a) and 1(c), contrary to the $B \to K^{(*)}\eta^{(\prime)}$ decays which are governed by Figs. 1(b) and 1(c). Numerically, we obtain

$$
\begin{aligned}
C_1 &= -0.098 + 0.011i, & C_3 &= 0.455 + 0.017i, \\
X^{(B\eta_q,K_0^*)} &= 0.22, & X^{(BK_0^*,\eta_q)} &= -0.74, \\
X^{(BK_0^*,\eta_q')} &= -0.60, & X^{(B\eta_q',K_0^*)} &= 0.18.
\end{aligned}
\tag{24}
$$

(f)

$$
\begin{aligned}
&F_0^{B\pi}(0) = 0.25\,, && F_0^{BK}(0) = 0.35\,, && F_0^{B\eta_q}(0) = 0.296\,, \\
&F_0^{B_sK}(0) = 0.24\,, && F_0^{B_s\eta_s}(0) = 0.28\,, && \\
&A_0^{B\rho}(0) = 0.303\,, && A_0^{BK^*}(0) = 0.374\,, && A_0^{B\omega}(0) = 0.281\,, \\
&A_0^{B_sK^*}(0) = 0.30\,, && A_0^{B_s\phi}(0) = 0.32\,. &&
\end{aligned}
\tag{3.1}
$$

Here for $\eta^{(\prime)}$ we have used the flavor states $q\bar{q} \equiv (u\bar{u} + d\bar{d})/\sqrt{2}$, $s\bar{s}$ and $c\bar{c}$ labeled by the η_q, η_s and η_c, respectively, and the form factors for $B \to \eta^{(\prime)}$ are given by

$$
\begin{aligned}
F^{B\eta} &= F^{B\eta_q}\cos\theta\,, & F^{B\eta'} &= F^{B\eta_q}\sin\theta\,, \\
F^{B_s\eta} &= -F^{B_s\eta_s}\sin\theta\,, & F^{B_s\eta'} &= F^{B_s\eta_s}\cos\theta\,,
\end{aligned}
\tag{3.2}
$$

(g)

$$
h_q = f_q(m_\eta^2 cos^2\phi + m_{\eta'}^2 sin^2\phi) - \sqrt{2} f_s (m_{\eta'}^2 - m_\eta^2) sin\phi\ cos\phi, \tag{11}
$$

$$
h_s = f_s(m_{\eta'}^2 cos^2\phi + m_\eta^2 sin^2\phi) - \frac{f_q}{\sqrt{2}} (m_{\eta'}^2 - m_\eta^2) sin\phi\ cos\phi, \tag{12}
$$

$$
f_q = (1.07 \pm 0.02) f_\pi, \quad f_s = (1.34 \pm 0.06) f_\pi. \tag{13}
$$

we obtain (in units of MeV)

$$f_{K_0^*(1430)} = 18 \pm 5 \quad S1, \qquad f_{K_0^*(1430)} = 43 \pm 10 \quad S2, \tag{14}$$

$$f_\pi = 131 \pm 7, \qquad f_\eta^q = 108, \qquad f_\eta^s = -111 \qquad f_{\eta'}^q = 89 \tag{15}$$

$$f_{\eta'}^s = 136, \qquad f_\eta^c = -2.3, \qquad f_{\eta'}^c = -5.8, \tag{16}$$

$$F_0^{B\eta_q} = F_0^{B\pi} = 0.27, \qquad F_0^{B\eta} = 0.217, \qquad F_0^{B\eta'} = 0.177, \tag{17}$$

Table 1: Branching fractions (in units of 10^{-6}) of $B_{u,d} \to K_0^*(1430)\eta^{(\prime)}$ decays with $(\rho_i, \phi_i) = (\rho_f, \phi_f) = (0, 0°)$.

Decay modes	S2(Cheng)	S2(This)	S1(Cheng)	S1(This)	Exp
$B^- \to K_0^*(1430)^-\eta$	$17.9^{+3.9+8.3+9.1}_{-3.4-5.3-12.3}$	$14.12^{+0.25+0.75}_{-0.19-0.71}$	$5.4^{+1.9+1.2+3.7}_{-1.6-1.0-4.4}$	$3.14^{+0.61+2.55}_{-0.44+2.39}$	18.2 ± 3.7
$B^- \to K_0^*(1430)^-\eta'$	$9.3^{+4.7+4.0+51.6}_{-3.6-4.4-8.0}$	$2.03^{+0.01+0.04}_{-0.01-0.03}$	$6.2^{+1.0+1.0+35.8}_{-0.8-1.0-6.1}$	$0.08^{+0.04+0.12}_{-0.03-0.11}$	5.2 ± 2.1
$\bar{B}_d^0 \to \bar{K}_0^*(1430)^0\eta$	$16.1^{+3.6+7.6+9.1}_{-3.1-4.9-11.7}$	$13.11^{+0.01+0.03}_{-0.01-0.03}$	$5.8^{+2.1+1.4+4.9}_{-1.7-1.1-5.2}$	$2.92^{+0.03+0.11}_{-0.03-0.10}$	11.0 ± 2.2
$\bar{B}_d^0 \to \bar{K}_0^*(1430)^0\eta'$	$8.7^{+4.4+3.7+48.7}_{-3.3-4.1-7.5}$	$1.88^{+0.01+0.06}_{-0.01-0.05}$	$5.9^{+0.9+0.9+33.6}_{-0.8-0.9-5.8}$	$0.08^{+0.01+0.03}_{-0.01-0.03}$	6.3 ± 1.6

Table 2: Branching fractions (in units of 10^{-6}) of $B_{u,d} \to K_0^*(1430)\eta^{(\prime)}$ decays with $(\rho_i, \phi_i) = (\rho_f, \phi_f) = (1, -55°)$.

Decay modes	S2	S1	Exp
$B^- \to K_0^*(1430)^-\eta$	$14.26^{+1.90+5.97}_{-1.60-5.09}$	$3.18^{+0.61+2.55}_{-0.44+2.39}$	18.2 ± 3.7
$B^- \to K_0^*(1430)^-\eta'$	$9.43^{+1.00+6.82}_{-0.80-4.90}$	$1.48^{+0.04+0.12}_{-0.03-0.11}$	5.2 ± 2.1
$\bar{B}_d^0 \to \bar{K}_0^*(1430)^0\eta$	$13.28^{+2.10+5.56}_{-1.70-5.56}$	$2.96^{+0.03+0.11}_{-0.03-0.10}$	11.0 ± 2.2
$\bar{B}_d^0 \to \bar{K}_0^*(1430)^0\eta'$	$8.63^{+0.90+6.25}_{-0.80-4.49}$	$1.35^{+0.01+0.03}_{-0.01-0.03}$	6.3 ± 1.6

$$r_\chi^{\eta_s} = r_\chi^{\eta_s'} = 1.49 \qquad r_\chi^{\eta_q} = r_\chi^{\eta_q'} = 0.93 \qquad r_\chi^{K_0^*} = 12.6, \tag{18}$$

$$\frac{X(B\eta_q K_0^*)}{X(B\eta_q' K_0^*)} = cot\phi \approx 1.23, \tag{19}$$

$$\frac{A(B \to K_0^*\eta_q)}{A(B \to K_0^*\eta_q')} \approx cot\phi \tag{20}$$

$$\frac{A(\bar{B}_d^0 \to \bar{K}_0^{*0}\eta_q)}{A(\bar{B}_d^0 \to \bar{K}_0^{*0}\eta_q')} \approx 1.85, \qquad \frac{A(B^- \to K_0^{*-}\eta_q)}{A(B^- \to K_0^{*-}\eta_q')} \approx 1.92. \qquad Cheng \tag{21}$$

$$\frac{A(\bar{B}_d^0 \to \bar{K}_0^{*0}\eta_q)}{A(\bar{B}_d^0 \to \bar{K}_0^{*0}\eta_q')} \approx 1.54, \qquad \frac{A(B^- \to K_0^{*-}\eta_q)}{A(B^- \to K_0^{*-}\eta_q')} \approx 1.51. \qquad This\ work \tag{22}$$