New physics search in B decays involving a tensor (K-resonance) meson

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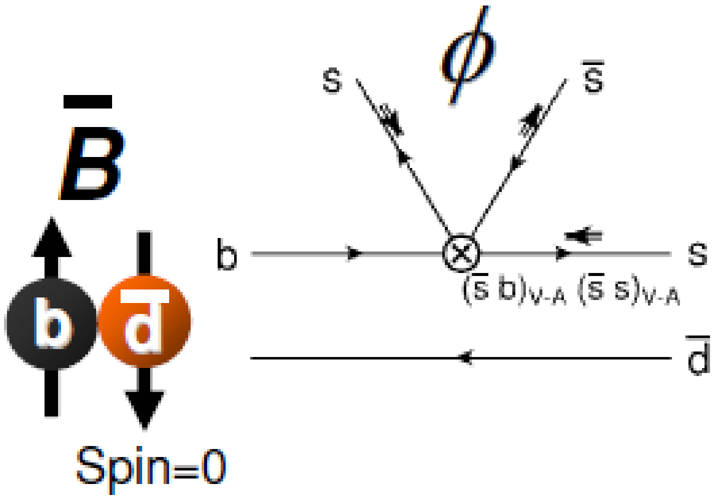
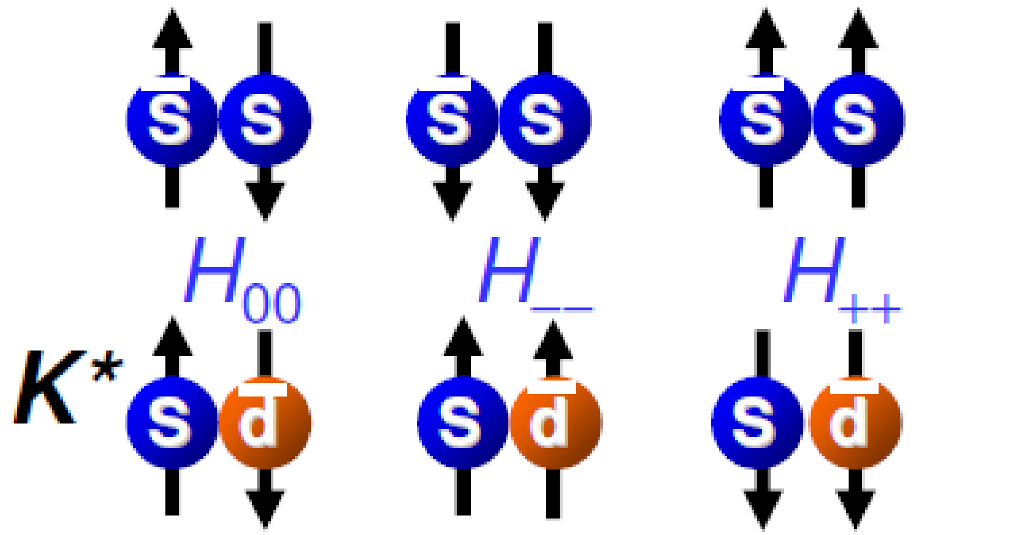
Outline

- Polarization in $B \to VV$
- Can we solve the observed $B \to \phi K^*$ anomaly in SM?
- *Annihilation in* $B \to \phi K^*, \rho K^*$ [*BBNS parametrization(QCDF)*]
- New Physics in $B \to \phi K^*$?
- **Further test**
- Conclusion

B decays into two vector mesons

Polarization reveals spin structure in the decay





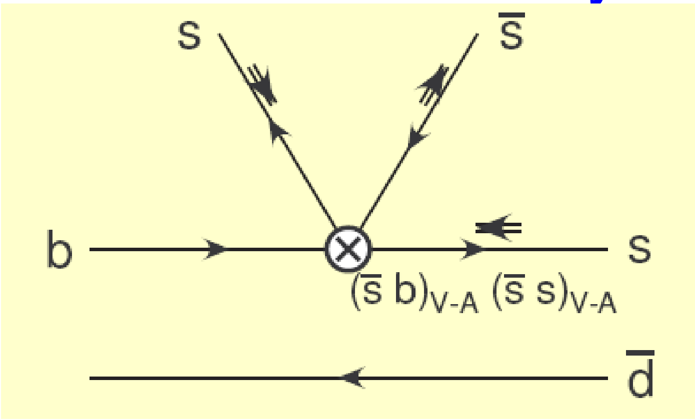
Helicity amplitudes: H_{00}, H_{++}, H_{--}

11 observables($\bar{B}$ and B): 6| H_i |, 5 arg($\bar{H}_i$ / H_j)

H_0 requires no spin flip,
H_- requires one spin flip
H_+ requires two spin flips.

Introduction

■ Polarization puzzle in charmless $\bar{B} \to VV$ decays



$$H_{00} : H_{--} : H_{++} = 1 : \frac{\Lambda}{m_b} : \left(\frac{\Lambda}{m_b}\right)^2$$

In transversity basis $A_{\perp} = (H^{--} + H^{++})/\sqrt{2}, \quad A_{\parallel} = (H^{--} - H^{++})/\sqrt{2}$

$$f_T \equiv f_{\parallel} + f_{\perp} = 1 - f_L = O(m_V^2 / m_B^2), \quad f_{\parallel} / f_{\perp} = 1 + O(m_V / m_B)$$

Why is f_T sizable ~ 0.5 in $B \to K^* \varphi$ decays ?

■ Search of new physics in $B \to VV$ decays

Transversity Basis

Transverse amplitudes in transversity basis

$$\overline{A}_{\parallel} = (\overline{H}_{++} + \overline{H}_{--})/\sqrt{2}$$

$$\overline{A}_{\perp} = -(\overline{H}_{++} - \overline{H}_{--})/\sqrt{2}$$

The $B \to V_1 V_2$ decay amplitude can be written as

$$M = A_0 \varepsilon_1^{*L} \cdot \varepsilon_2^{*L} - \frac{1}{\sqrt{2}} A_{\parallel} \vec{\varepsilon}_1^{*T} \cdot \vec{\varepsilon}_2^{*T} - \frac{i}{\sqrt{2}} A_{\perp} \vec{\varepsilon}_1^{*T} \times \vec{\varepsilon}_2^{*T} \cdot \hat{p}$$

- Polarization vectors in

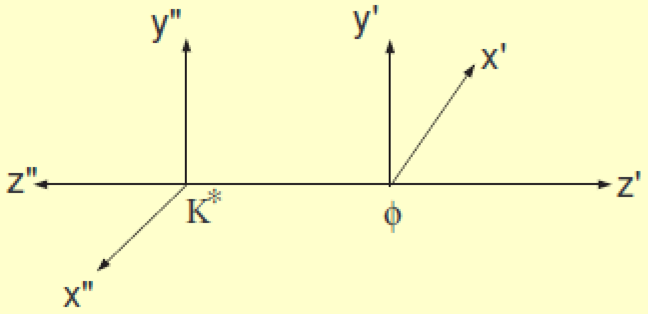
$$\varepsilon^{\mu}_{V_1}(0) = \frac{1}{m_{V_1}}(|\vec{p}|, 0, 0, -E)\,, \qquad \varepsilon^{\mu}_{V_2}(0) = \frac{1}{m_{V_2}}(|\vec{p}|, 0, 0, E)$$

(i) Helicity basis

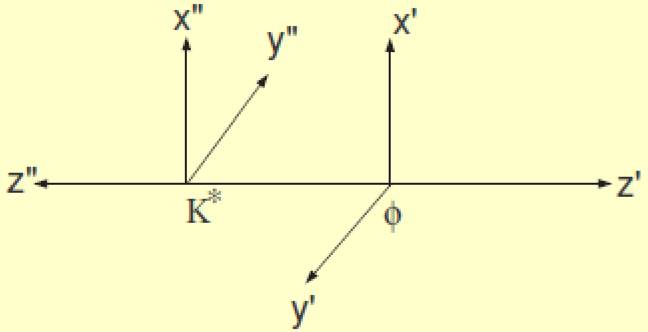
$$\varepsilon^{\mu}_{V_1}(\pm 1) = \frac{1}{\sqrt{2}}(0, \mp 1, +i, 0)\,, \qquad \varepsilon^{\mu}_{V_2}(\pm 1) = \frac{1}{\sqrt{2}}(0, \mp 1, -i, 0)$$

(ii) Transverse basis: If choosing $\varepsilon^{T}_{V_2} = (0, 1, 0, 0)$, then $\varepsilon^{T}_{V_1}$ can be decomposed in $(0, 1, 0, 0)$ and $(0, 0, -1, 0)$ directions.

Jacob-Wick convention



Jackson convention



In the Jackson convention:

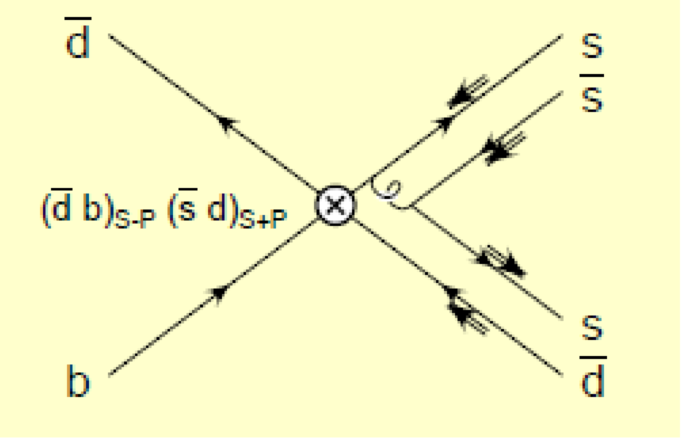
$$\overline{A}_0^{SM} \propto f_\phi m_B^2 \zeta_\parallel,$$
$$\overline{A}_\parallel^{SM} \propto -\sqrt{2} f_\phi m_\phi m_B \zeta_\perp,$$
$$\overline{A}_\perp^{SM} \propto -\sqrt{2} f_\phi m_\phi m_B \zeta_\perp,$$

Scenario with the SM

Annihilation

In SM, two effects are important:

■Annihilation $H_{00}:H_{--}:H_{++} = \frac{1}{m_b^2} ln^2 \frac{m_b}{\Lambda} : \frac{1}{m_b^2} ln^2 \frac{m_b}{\Lambda} : \frac{1}{m_b^4}$ (Kagan, 04)



Annihilation topology: ⇨ overall $1/m_b$

Helicity-flips: ⇨ $1/m_b$

Parametrization $\int_0^1 \frac{dx}{x} = \ln \frac{m_B}{\Lambda} (1 + \rho_A e^{i\phi_A})$

$B \to K^*\phi$ (without annihilation)

$$\mathcal{A}^h_{\bar B\to\bar K^*\phi} \approx V_c(\alpha_3^h + \alpha_4^{c,h} + \beta_3^h - \frac{1}{2}\alpha^h_{3,\rm EW})X^h_{\bar K^*\phi}.$$

$\alpha_3=a_3+a_5$, $\alpha_4=a_4-r_\chi^\phi a_6$, $\alpha_{3,EW}=a_9+a_7$, β_3= penguin ann

$$X^h_{\bar K^*\phi} = \langle\phi|J_\mu|0\rangle\langle\overline{K}^*|J^\mu|B\rangle, \qquad |X^0_{\bar K^*\phi}|:|X^-_{\bar K^*\phi}|:|X^+_{\bar K^*\phi}| = 1:0.35:0.007$$

	h=0	h= -		h=0	h= -
$\alpha_3(K^*\phi)$	$0.005 - 0.001i$	$-0.004 - 0.001i$	$\alpha_{3,\rm EW}(K^*\phi)$	$-0.009 - 0.000i$	$0.002 - 0.000i$
$\alpha_4^u(K^*\phi)$	$-0.022 - 0.014i$	$-0.047 - 0.016i$	$\alpha_4^c(K^*\phi)$	$-0.027 - 0.014i$	$-0.049 - 0.006i$

Coefficients are helicity dependent !

PRD,2008, Hai-Yang Cheng, KCY

$$\left.\frac{\mathcal{A}^-}{\mathcal{A}^0}\right|_{\bar B\to\bar K^*\phi} \approx \left(\frac{\alpha_3^- + \alpha_4^{c,-} - \frac{1}{2}\alpha^-_{3,\rm EW}}{\alpha_3^0 + \alpha_4^{c,0} - \frac{1}{2}\alpha^0_{3,\rm EW}}\right)\left(\frac{X^-_{\bar K^*\phi}}{X^0_{\bar K^*\phi}}\right)$$ with $\beta_3=0$

constructive (destructive) interference in A^- (A^0) $\Rightarrow$ $f_L \sim 0.58$

NLO corrections alone will bring down f_L significantly !

Br ~4.3*10-6 (without annihilation), too small compared with data

Although f_L is reduced to 60% level, polarization puzzle is not resolved as the predicted rate, BR~ 4.3*10^{-6}, is too small compared to the data,~ 10*10^{-6} for $B \to K^* \phi$

$$P^c = [a_4^c + r_\chi a_6^c]_{SD} + \underbrace{\beta_3^c}_{\text{penguin annihilation}} + \dots$$

- Br & f_L are fit by adjusting $\Rightarrow \rho_A \simeq 0.65, \ \phi_A \simeq -53°$

Decay	$\mathcal{B}$		f_L		$f_\perp$	
	Theory	Expt	Theory	Expt	Theory	Expt
$B^- \to K^{*-}\phi$ ^{c}	$10.0^{+1.4+12.3}_{-1.3-\ 6.1}$	10.0 ± 1.1	$0.49^{+0.51}_{-0.42}$	0.50 ± 0.05	$0.25^{+0.21}_{-0.25}$	0.20 ± 0.05
$\overline{B}^0 \to \bar{K}^{*0}\phi$	$9.5^{+1.3+11.9}_{-1.2-\ 5.9}$	9.5 ± 0.8	$0.50^{+0.50}_{-0.42}$	0.484 ± 0.034	$0.25^{+0.21}_{-0.25}$	0.256 ± 0.032

$f_\parallel \fallingdotseq f_\perp \fallingdotseq 0.25$

Parameter	$h=0$	$h=-$	Parameter	$h=0$	$h=-$
$\alpha_1(\rho K^*)$	$0.96 + 0.02i$	$1.11 + 0.03i$	$\alpha_{3,\rm EW}(K^*\rho)$	$-0.009 - 0.000i$	$0.005 - 0.000i$
$\alpha_2(K^*\rho)$	$0.28 - 0.08i$	$-0.17 - 0.17i$	$\alpha_{4,\rm EW}(K^*\rho)$	$-0.002 + 0.001i$	$0.001 + 0.001i$
$\alpha_4^u(\rho K^*)$	$-0.022 - 0.014i$	$-0.048 - 0.016i$	$\beta_3(\rho K^*)$	$0.015 - 0.020i$	$-0.012 + 0.016i$
$\alpha_4^c(\rho K^*)$	$-0.026 - 0.014i$	$-0.050 - 0.006i$			

$$\left.\frac{\mathcal{A}^-}{\mathcal{A}^0}\right|_{\bar B^0\to\bar K^{*0}\rho^0} \approx \left(\frac{\alpha_4^{c,-}-\frac{3}{2}\alpha_{3,\rm EW}^-}{\alpha_4^{c,0}-\frac{3}{2}\alpha_{3,\rm EW}^0}\right)\left(\frac{X^-_{\bar K^*\rho}}{X^0_{\bar K^*\rho}}\right)$$

$$\left.\frac{\mathcal{A}^-}{\mathcal{A}^0}\right|_{B^-\to K^{*-}\rho^0} \approx \left(\frac{\alpha_4^{c,-}+\frac{3}{2}\alpha_{3,\rm EW}^-}{\alpha_4^{c,0}+\frac{3}{2}\alpha_{3,\rm EW}^0}\right)\left(\frac{X^-_{\bar K^*\rho}}{X^0_{\bar K^*\rho}}\right)$$

$$\frac{\text{constructive}}{\text{destructive}}$$

$$\frac{\text{destructive}}{\text{constructive}}$$

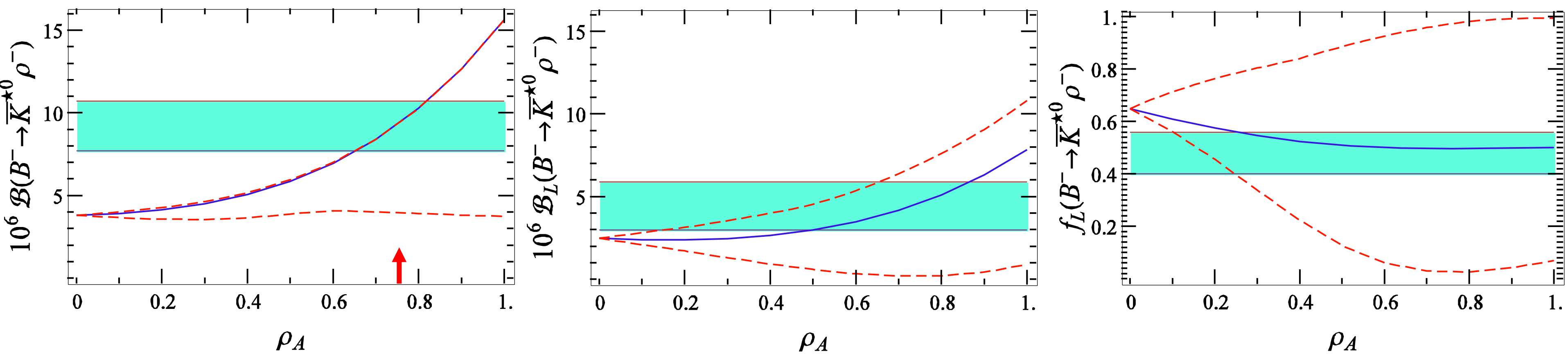
with β_3=0

⇒ $f_L(K^{*-}\rho^0)$=0.96, $f_L(K^{*0}\rho^0)$=0.47 (=0.91 if a_i^h are helicity indep)

Decay	Expt		(i)	
	$\mathcal{B}$	f_L	$\mathcal{B}$	f_L
$B^- \to \bar K^{*0}\rho^-$	9.2 ± 1.5	0.48 ± 0.08	3.8	0.78
$B^- \to K^{*-}\rho^0$	< 6.1	$0.96^{+0.06}_{-0.16}$	3.6	0.96
$\overline{B}^0 \to K^{*-}\rho^+$	< 12	–	3.6	0.84
$\overline{B}^0 \to \bar K^{*0}\rho^0$	5.6 ± 1.6	0.57 ± 0.12	1.1	0.47

Without Annihilation

But, the predicted rates for $K^{*-}\rho^0$ & $K^{*0}\rho^0$ are too small !



Choose $K^{*0}\rho^-$ as an input, a fit to BR and f_L yields $\rho_A \simeq 0.78$, $\phi_A \simeq -43°$, slightly different from the ones $\rho_A \simeq 0.65$, $\phi_A \simeq -53°$ inferred from $B\to K^*\phi$

Process dependent

Decay	$\mathcal{B}$ Theory	$\mathcal{B}$ Expt	f_L Theory	f_L Expt	$f_\perp$ Theory	$f_\perp$ Expt
$B^- \to \bar{K}^{*0}\rho^-$ [a]	$9.2^{+1.2+3.6}_{-1.1-5.4}$	9.2 ± 1.5	$0.48^{+0.52}_{-0.40}$	0.48 ± 0.08	$0.26^{+0.20}_{-0.26}$	
$B^- \to K^{*-}\rho^0$	$5.5^{+0.6+1.3}_{-0.5-2.5}$	< 6.1	$0.67^{+0.31}_{-0.48}$	$0.96^{+0.06}_{-0.16}$ [b]	$0.16^{+0.24}_{-0.15}$	
$\overline{B}^0 \to K^{*-}\rho^+$	$8.9^{+1.1+4.8}_{-1.0-5.5}$	< 12	$0.53^{+0.45}_{-0.32}$		$0.24^{+0.16}_{-0.22}$	
$\overline{B}^0 \to \bar{K}^{*0}\rho^0$	$4.6^{+0.6+3.5}_{-0.5-3.5}$	3.4 ± 1.0	$0.39^{+0.60}_{-0.31}$	0.57 ± 0.12	$0.30^{+0.15}_{-0.30}$	

$K^{*-}\rho^0$ was contaminated by $K^{*-}f_0(980)$ in previous 2003 measurement of $f_L(K^{*-}\rho^0)$.
BaBar measurement (2006) of $f_L=0.9 \pm 0.2$ has only 2.5 significance

$$f_L(K^{*-}\rho^0) > f_L(K^{*-}\rho^+) > f_L(\bar{K}^{*0}\rho^-) > f_L(\bar{K}^{*0}\rho^0)$$

Tree-dominated VV modes

Decay	$\mathcal{B}$		f_L		$f_\perp$	
	Theory	Expt	Theory	Expt	Theory	Expt
$B^- \to \rho^- \rho^0$	$20.0^{+4.0+2.0}_{-1.9-0.9}$	$24.0^{+1.9}_{-2.0}$	$0.96^{+0.02}_{-0.02}$	0.950 ± 0.016	0.02 ± 0.01	
$\overline{B}^0 \to \rho^+ \rho^-$	$25.5^{+1.5+2.4}_{-2.6-1.5}$	$24.2^{+3.1}_{-3.2}$	$0.92^{+0.01}_{-0.02}$	$0.978^{+0.025}_{-0.022}$	$0.04^{+0.01}_{-0.00}$	
$\overline{B}^0 \to \rho^0 \rho^0$	$0.9^{+1.5+1.1}_{-0.4-0.2}$	$0.73^{+0.27}_{-0.28}$	$0.92^{+0.06}_{-0.36}$	$0.75^{+0.12}_{-0.15}$	$0.04^{+0.14}_{-0.03}$	
$B^- \to \rho^- \omega$	$19.2^{+3.3+1.7}_{-1.6-1.0}$	15.9 ± 2.1	$0.96^{+0.02}_{-0.02}$	0.90 ± 0.06	0.02 ± 0.01	
$\overline{B}^0 \to \rho^0 \omega$	$0.1^{+0.1+0.4}_{-0.1-0.0}$	< 1.5	$0.55^{+0.47}_{-0.29}$		$0.22^{+0.16}_{-0.23}$	

- Longitudinal amplitude dominates tree-dominated decays

  except for $\rho^0\omega$

- Predicted $B \to \rho\rho$, $\omega\rho$ rates agree with the data.

H.Y. Cheng & KCY, PRD, 2008 vs. data (2010)

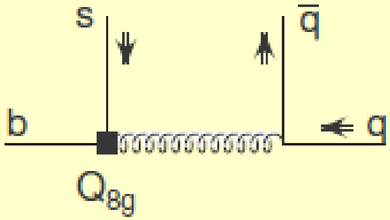
Central values correspond to $\rho_A = \phi_A = 0$

Scenario with New Physics

New Physics: Color Diploe Operator?

Possible NP effects to chromomagnetic dipole operator:

$$O_{8g} = \frac{g_s}{8\pi^2} m_b \bar{s} \sigma^{\mu\nu} (1+\gamma_5) T^a b G^a_{\mu\nu},$$



$$G^0_{8g} = -2 \int_0^1 du \frac{\Phi_\parallel^V(u)}{1-u},$$

$$G^\pm_{8g} = \int_0^1 \frac{du}{\bar{u}} \left[\int_0^u \left(\Phi_\parallel^V(v) - g_\perp^{(v)}(v) \right) dv - \bar{u} g_\perp^{(v)}(u) \mp \frac{\bar{u}}{4} \frac{g_\perp^{(a)}(u)}{du} + \frac{g_\perp^{(a)}(u)}{4} \right] = 0$$

by P.Das, KCY, PRD71,094002(2005); confirmed by A.Kagan.

✠ NP gives no contribution via chromomagnetic dipole operator

Helicity conservation requires that the outgoing s and $\bar{s}$ arising from $s - \bar{s} - n\ gluons$ vertex have *opposite helicities*. The transversely polarized amplitudes should be suppressed as $\overline{H}_{00} : \overline{H}_{--} : \overline{H}_{++} \sim \mathcal{O}(1) : \mathcal{O}(1/m_b) : \mathcal{O}(1/m_b^2)$; otherwise the results will violate the angular momentum conservation.

Rechecked recently by Y.D.Yang et.al., hep-ph/0411211 v2, but $G^-_{8g} \neq 0$? (Still no help)

New Physics: Right-handed currents?

✠ Could NP of Right-handed currents explain the ϕK^* data?

Contributions from right-handed current

$$\propto \langle \overline{K}^* | \bar{s}\gamma_\mu(1+\gamma_5)b|\overline{B}\rangle\langle\phi|s\gamma^\mu(1\mp\gamma_5)s|0\rangle = \langle \overline{K}^* | \bar{s}\gamma_\mu(1+\gamma_5)b|\overline{B}\rangle\langle\phi|s\gamma^\mu s|0\rangle$$

compared with the SM result

$$\propto \langle \overline{K}^* | \bar{s}\gamma_\mu(1-\gamma_5)b|\overline{B}\rangle\langle\phi|s\gamma^\mu s|0\rangle$$

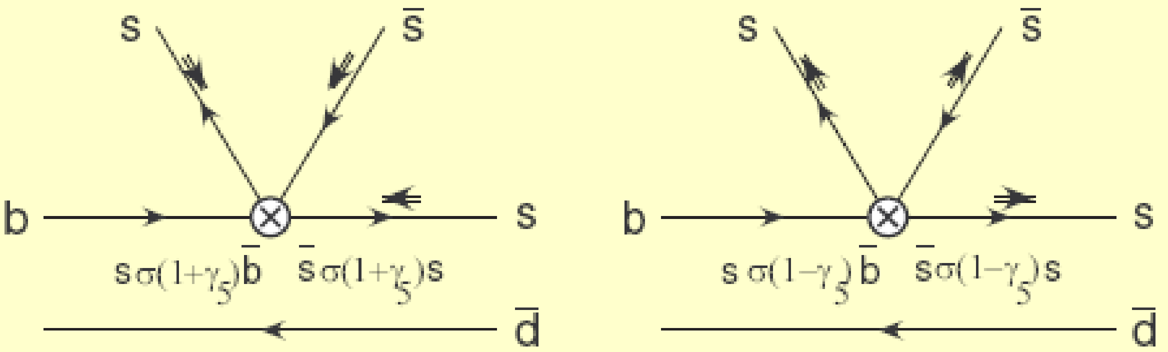
- If the right-handed currents contribute constructively to $\overline{A}_\perp$, they become destructively to $\overline{A}_{0,\parallel}$, vice versa.

- Choosing $|\overline{A}_\perp/\overline{A}_0|^2 \approx 1/2$ to account for the data, however the resulting $|\overline{A}_\parallel|^2 \ll |\overline{A}_\perp|^2$ will be in contrast to the recent observations

✠ Answer is "NO".

✠ We do not consider NP of left-handed currents, $\bar{s}\gamma_\mu(1-\gamma_5)b\ \bar{s}\gamma^\mu(1\mp\gamma_5)s$, which give corrections to SM Wilson coefficients since they have no help for understanding large polarized amplitudes

Possible New Physics



✠ $\bar{s}\sigma^{\mu\nu}(1+\gamma_5)b\,\bar{s}\sigma_{\mu\nu}(1+\gamma_5)s$, $\bar{s}(1+\gamma_5)b\,\bar{s}(1+\gamma_5)s$

$\overline{H}_{00} : \overline{H}_{--} : \overline{H}_{++} \sim \mathcal{O}(1/m_b) : \mathcal{O}(1) : \mathcal{O}(1/m_b^2)$

✠ $\bar{s}\sigma^{\mu\nu}(1-\gamma_5)b\,\bar{s}\sigma_{\mu\nu}(1-\gamma_5)s$, $\bar{s}(1-\gamma_5)b\,\bar{s}(1-\gamma_5)s$

$\overline{H}_{00} : \overline{H}_{--} : \overline{H}_{++} \sim \mathcal{O}(1/m_b) : \mathcal{O}(1/m_b^2) : \mathcal{O}(1)$

TENSOR operators can be related to the SCALAR operators by Fierz transformation.

Phys. Rev. D71, 094002 (2005), KCY& Das

See also works by C.S. Kim, Y.D. Yang; Alex Kagan

Table 2: Possible NP operators and their candidacy in satisfying the anomaly resolution criteria. We have adopted the convention $\Gamma_1 \otimes \Gamma_2 \equiv \bar{s}\Gamma_1 b\, \bar{s}\Gamma_2 s$.

Model	Operators	$\overline{H}_{00}$	$\overline{H}_{--}$	$\overline{H}_{++}$	Choice
SM	$\gamma^\mu(1-\gamma_5)\otimes\gamma_\mu(1\mp\gamma_5)$	$\mathcal{O}(1)$	$\mathcal{O}(1/m_b)$	$\mathcal{O}(1/m_b^2)$	
NP	$\gamma^\mu(1+\gamma_5)\otimes\gamma_\mu(1+\gamma_5)$	$\mathcal{O}(1)$	$\mathcal{O}(1/m_b^2)$	$\mathcal{O}(1/m_b)$	N
NP	$\gamma^\mu(1+\gamma_5)\otimes\gamma_\mu(1-\gamma_5)$	$\mathcal{O}(1)$	$\mathcal{O}(1/m_b^2)$	$\mathcal{O}(1/m_b)$	N
NP	$(1+\gamma_5)\otimes(1+\gamma_5)$	$\mathcal{O}(1/m_b)$	$\mathcal{O}(1)$	$\mathcal{O}(1/m_b^2)$	Y
NP	$(1-\gamma_5)\otimes(1-\gamma_5)$	$\mathcal{O}(1/m_b)$	$\mathcal{O}(1/m_b^2)$	$\mathcal{O}(1)$	Y
NP	$(1+\gamma_5)\otimes(1-\gamma_5)$	$\mathcal{O}(1)$	$\mathcal{O}(1/m_b^2)$	$\mathcal{O}(1/m_b)$	N
NP	$(1-\gamma_5)\otimes(1+\gamma_5)$	$\mathcal{O}(1)$	$\mathcal{O}(1/m_b)$	$\mathcal{O}(1/m_b^2)$	N
NP	$\sigma^{\mu\nu}(1+\gamma_5)\otimes\sigma_{\mu\nu}(1+\gamma_5)$	$\mathcal{O}(1/m_b)$	$\mathcal{O}(1)$	$\mathcal{O}(1/m_b^2)$	Y
NP	$\sigma^{\mu\nu}(1-\gamma_5)\otimes\sigma_{\mu\nu}(1-\gamma_5)$	$\mathcal{O}(1/m_b)$	$\mathcal{O}(1/m_b^2)$	$\mathcal{O}(1)$	Y
NP	$\sigma^{\mu\nu}(1+\gamma_5)\otimes\sigma_{\mu\nu}(1-\gamma_5)$	$\mathcal{O}(1)$	$\mathcal{O}(1/m_b^2)$	$\mathcal{O}(1/m_b)$	N
NP	$\sigma^{\mu\nu}(1-\gamma_5)\otimes\sigma_{\mu\nu}(1+\gamma_5)$	$\mathcal{O}(1)$	$\mathcal{O}(1/m_b)$	$\mathcal{O}(1/m_b^2)$	N

(pseudo-)scalar-type operators

$$O_{15} = \overline{s}(1+\gamma^5)b\,\overline{s}(1+\gamma^5)s\,, \qquad O_{16} = \overline{s}_\alpha(1+\gamma^5)b_\beta\,\overline{s}_\beta(1+\gamma^5)s_\alpha\,,$$
$$O_{17} = \overline{s}(1-\gamma^5)b\,\overline{s}(1-\gamma^5)s\,, \qquad O_{18} = \overline{s}_\alpha(1-\gamma^5)b_\beta s\,\overline{s}_\beta(1-\gamma^5)s_\alpha\,,$$

tensor-type operators

$$O_{23} = \overline{s}\sigma^{\mu\nu}(1+\gamma^5)b\,\overline{s}\sigma_{\mu\nu}(1+\gamma^5)s\,, \qquad O_{24} = \overline{s}_\alpha\sigma^{\mu\nu}(1+\gamma^5)b_\beta\,\overline{s}_\beta\sigma_{\mu\nu}(1+\gamma^5)s_\alpha$$
$$O_{25} = \overline{s}\sigma^{\mu\nu}(1-\gamma^5)b\,\overline{s}\sigma_{\mu\nu}(1-\gamma^5)s\,, \qquad O_{26} = \overline{s}_\alpha\sigma^{\mu\nu}(1-\gamma^5)b_\beta\,\overline{s}_\beta\sigma_{\mu\nu}(1-\gamma^5)s_\alpha$$

By Fierz transformation

$$O_{15} = \frac{1}{12}O_{23} - \frac{1}{6}O_{24}, \qquad O_{16} = \frac{1}{12}O_{24} - \frac{1}{6}O_{23}$$
$$O_{17} = \frac{1}{12}O_{25} - \frac{1}{6}O_{26}, \qquad O_{18} = \frac{1}{12}O_{26} - \frac{1}{6}O_{25}$$

Can only (pseudo-)scalar-type operators explain the data?

Answer: NO

In the minimal supersymmetric standard model (MSSM), such scalar/pseudoscalar operators can be induced by the penguin diagrams of neutral-Higgs bosons.

A combined analysis of the decays $B \to K\eta^{(\prime)},\ \phi K^*$ decays shows that the NP effects only due to (pseudo-)scalar-type operators is much smaller.

⟺ consistent with the data for $B_s \to \mu^+\mu^-$

PRD**77,** 035013 (2008), H. Hatanaka, KCY

Looking for clean evidence for annihilations and new physics

Why do we study $h_1(1380)K^*$?

Reasons:

- $B \to h_1(1380)K^*$ is a factorization forbidden process.

  - for h_1, $I^G(J^{PC}) = ?^-(1^{+-})$, the charge conjugate (or say G-parity) of which does not match with the axial current; the quark content is $\bar{s}s$ suggested in the QCD sum rule calculation.

  - In SM, the leading term in the amplitude is $\mathcal{O}(\alpha_s)$: QCD corrections to the vertex, spectator scattering, penguin, spectator, annihilation.

    - local axial vector current $\Rightarrow$ non-local axial vector current
    - the DA defined by the non-local axial vector current is antisymmetric under the exchange of s and $\bar{s}$.

NPB,2007; JHEP,2005, KCY

- the tensor current can couple to h_1 with non-vanishing coupling constant. Sensitive to NEW PHYSICS

PRD, 2005, KCY

Comparison for new-physics amplitude

$\bar{B} \to h_1(1380)\bar{K}^*$

$$\overline{A}_0^{NP} \simeq 4\frac{G_F}{\sqrt{2}} f_{h_1}^T m_B m_{h_1} \left[\tilde{a}_{23} + \tilde{a}_{25}\right] \zeta_\parallel,$$

$$\overline{A}_\parallel^{NP} \simeq -4\frac{G_F}{\sqrt{2}} \sqrt{2} f_{h_1}^T m_B^2 (\tilde{a}_{23} + \tilde{a}_{25}) \zeta_\perp,$$

$$\overline{A}_\perp^{NP} \simeq -4\frac{G_F}{\sqrt{2}} \sqrt{2} f_{h_1}^T m_B^2 (\tilde{a}_{23} - \tilde{a}_{25}) \zeta_\perp,$$

$\bar{B} \to \phi\bar{K}^*$

$$\overline{A}_0^{NP} \simeq -4i\frac{G_F}{\sqrt{2}} f_\phi^T m_B m_\phi \left[\tilde{a}_{23} - \tilde{a}_{25}\right] \zeta_\parallel,$$

$$\overline{A}_\parallel^{NP} \simeq 4i\frac{G_F}{\sqrt{2}} \sqrt{2} f_\phi^T m_B^2 (\tilde{a}_{23} - \tilde{a}_{25}) \zeta_\perp,$$

$$\overline{A}_\perp^{NP} \simeq 4i\frac{G_F}{\sqrt{2}} \sqrt{2} f_\phi^T m_B^2 (\tilde{a}_{23} + \tilde{a}_{25}) \zeta_\perp,$$

In units of 10^{-6}

SM with annihilations

Mode	$\mathcal{B}$	f_L
$B^- \to h_1(1380)K^{*-}$	$8.1^{+4.0+21.3}_{-2.8-6.6}$	$0.87^{+0.13}_{-0.75}$
	$3.7^{+2.0+7.8}_{-1.3-2.2}$	$0.88^{+0.12}_{-0.53}$
$\bar{B}^0 \to h_1(1380)\bar{K}^{*0}$	$8.3^{+4.4+21.8}_{-2.9-6.9}$	$0.88^{+0.12}_{-0.80}$
	$3.9^{+1.9+8.3}_{-1.3-2.6}$	$0.88^{+0.12}_{-0.64}$

NP scenario

New physics	Process	$\mathrm{BR_{tot}}$	$\mathrm{BR}_{\parallel}$	$\mathrm{BR}_{\perp}$
Scenario 1:	$B^- \to h_1(1380)K^{*-}$	15.3 ± 4.0	3.4 ± 1.5	2.0 ± 1.0
$\tilde{a}_{25}$	$\overline{B}^0 \to h_1(1380)K^{*0}$	14.5 ± 4.0	3.2 ± 1.5	2.0 ± 1.0
Scenario 2:	$B^- \to h_1(1380)K^{*-}$	9.1 ± 2.0	2.1 ± 0.5	2.0 ± 0.5
$\tilde{a}_{23}$	$\overline{B}^0 \to h_1(1380)K^{*0}$	8.5 ± 2.0	2.0 ± 0.5	1.8 ± 0.5

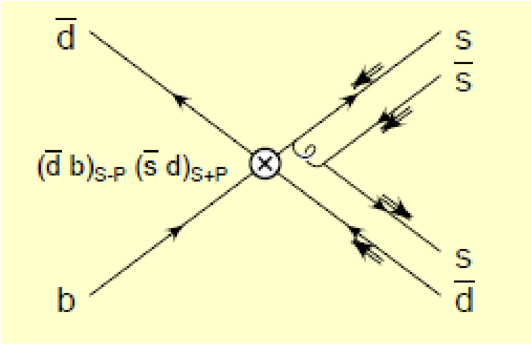
New physics can be distinguishable

f_L~0.4-0.5

Annihilation contributions (and f_L) are highly related to

(i) $\Phi_{\perp}^{1^3P_1}$ for $B \to f_1 K^*, a_1 K^*$

(ii) $\Phi_{\parallel}^{1^1P_1}$ for $B \to h_1 K^*, b_1 K^*$



$$A_3^{f,0}(V\,^3P_1) \approx 18\pi\alpha_s(2X_A^0-1)\left[a_1^{\perp,\,^3P_1} r_\chi^{\,^3P_1}(X_A^0-3) - r_\chi^V(X_A^0-2)\right]$$

$$A_3^{f,-}(V\,^3P_1) \approx -18\pi\alpha_s(2X_A^- -3) \times\left[\frac{m_{^3P_1}}{m_V} r_\chi^V(X_A^- -1) - 3a_1^{\perp,\,^3P_1}\frac{m_V}{m_{^3P_1}} r_\chi^{\,^3P_1}(X_A^- -2)\right]$$

$$A_3^{f,0}(V\,^1P_1) \approx 18\pi\alpha_s(X_A^0-2)\left[r_\chi^{\,^1P_1}(2X_A^0-1) - a_1^{\parallel,\,^1P_1} r_\chi^V(6X_A^0-11)\right]$$

$$A_3^{f,-}(V\,^1P_1) \approx -18\pi\alpha_s(X_A^- -1) \times\left[-\frac{m_V}{m_{^1P_1}} r_\chi^{\,^1P_1}(2X_A^- -3) + a_1^{\parallel,\,^1P_1}\frac{m_{^1P_1}}{m_V} r_\chi^V\left(2X_A^- - \frac{17}{3}\right)\right]$$

$B \to {}^3P_1 \; V$

SM with annihilations

$B \to {}^1P_1 \; V$

Mode	Br	f_L	CMV
$\overline{B}^0 \to a_1^+ \rho^-$	$23.9^{+10.5+3.2}_{-9.2-0.4}$	$(0.82^{+0.05}_{-0.13})$	4.3
$\overline{B}^0 \to a_1^- \rho^+$	$36.0^{+3.5+3.5}_{-4.0-0.7}$	$(0.84^{+0.02}_{-0.06})$	4.7
$\overline{B}^0 \to a_1^0 \rho^0$	$1.2^{+2.0+5.1}_{-0.7-0.3}$	$(0.82^{+0.06}_{-0.68})$	0.01
$B^- \to a_1^0 \rho^-$	$17.8^{+10.1+3.1}_{-6.4-0.2}$	$(0.91^{+0.03}_{-0.10})$	2.4
$B^- \to a_1^- \rho^0$	$23.2^{+3.6+4.8}_{-2.9-0.1}$	$(0.89^{+0.11}_{-0.18})$	3.0
$\overline{B}^0 \to a_1^0 \omega$	$0.2^{+0.1+0.4}_{-0.1-0.0}$	$(0.75^{+0.11}_{-0.65})$	0.003
$B^- \to a_1^- \omega$	$22.5^{+3.4+3.0}_{-2.7-0.7}$	$(0.88^{+0.10}_{-0.14})$	2.2
$\overline{B}^0 \to a_1^0 \phi$	$0.002^{+0.002+0.009}_{-0.001-0.000}$	$(0.94^{+0.00}_{-0.69})$	0.0005
$B^- \to a_1^- \phi$	$0.01^{+0.01+0.04}_{-0.00-0.00}$	$(0.94^{+0.01}_{-0.69})$	0.001
$\overline{B}^0 \to a_1^+ K^{*-}$	$10.6^{+5.7+31.7}_{-4.0-8.1}$	$(0.37^{+0.39}_{-0.29})$	0.92
$\overline{B}^0 \to a_1^0 \overline{K}^{*0}$	$4.2^{+2.8+15.5}_{-1.9-4.2}$	$(0.23^{+0.45}_{-0.19})$	0.64
$B^- \to a_1^- \overline{K}^{*0}$	$11.2^{+6.1+31.9}_{-4.4-9.0}$	$(0.37^{+0.48}_{-0.37})$	0.51
$B^- \to a_1^0 K^{*-}$	$7.8^{+3.2+16.3}_{-2.5-4.3}$	$(0.52^{+0.41}_{-0.42})$	0.86

Mode	Br	f_L	CMV
$\overline{B}^0 \to b_1^+ \rho^-$	$32.1^{+16.5+12.0}_{-14.7-4.6}$	$(0.96^{+0.01}_{-0.02})$	1.6
$\overline{B}^0 \to b_1^- \rho^+$	$0.6^{+0.6+1.9}_{-0.3-0.2}$	$(0.98^{+0.00}_{-0.33})$	0.55
$\overline{B}^0 \to b_1^0 \rho^0$	$3.2^{+5.2+1.7}_{-2.0-0.4}$	$(0.99^{+0.00}_{-0.18})$	0.002
$B^- \to b_1^0 \rho^-$	$29.1^{+16.2+5.4}_{-10.6-5.9}$	$(0.96^{+0.01}_{-0.06})$	0.86
$B^- \to b_1^- \rho^0$	$0.9^{+1.7+2.6}_{-0.6-0.5}$	$(0.90^{+0.05}_{-0.38})$	0.36
$\overline{B}^0 \to b_1^0 \omega$	$0.1^{+0.2+1.6}_{-0.0-0.0}$	$(0.04^{+0.96}_{-0.00})$	0.004
$B^- \to b_1^- \omega$	$0.8^{+1.4+3.1}_{-0.5-0.3}$	$(0.91^{+0.07}_{-0.33})$	0.38
$\overline{B}^0 \to b_1^0 \phi$	$0.01^{+0.01+0.01}_{-0.00-0.00}$	$(0.98^{+0.01}_{-0.33})$	0.0002
$B^- \to b_1^- \phi$	$0.02^{+0.02+0.03}_{-0.01-0.00}$	$(0.98^{+0.01}_{-0.33})$	0.0004
$\overline{B}^0 \to b_1^+ K^{*-}$	$12.5^{+4.7+20.1}_{-3.7-9.0}$	$(0.82^{+0.18}_{-0.41})$	0.32
$\overline{B}^0 \to b_1^0 \overline{K}^{*0}$	$6.4^{+2.4+8.8}_{-1.7-4.8}$	$(0.79^{+0.21}_{-0.73})$	0.15
$B^- \to b_1^- \overline{K}^{*0}$	$12.8^{+5.0+20.1}_{-3.8-9.6}$	$(0.79^{+0.21}_{-0.74})$	0.18
$B^- \to b_1^0 K^{*-}$	$7.0^{+2.6+12.0}_{-2.0-4.8}$	$(0.82^{+0.16}_{-0.26})$	0.12

- $Br(\bar{B}^0 \to b_1^+ \rho^-) >> Br(\bar{B}^0 \to b_1^- \rho^+)$; BaBar: $Br(B^0 \to a_1^{\pm} \rho^{\mp}) < 61 \times 10^{-6}$ (2006);
- $Br(B^0 \to b_1^{\pm} \pi^{\mp}) = (10.9 \pm 1.5) \times 10^{-6}$; $Br(B^0 \to b_1^{\pm} \rho^{\mp}) < 1.4 \times 10^{-6}$?

it is expected that $b_1^+ \rho^- \sim b_1^+ \pi^-$ $(f_\rho / f_\pi)^2$ **$\sim 32 \times 10^{-6}$**

- $a_1 K^*$ modes are dominated by transverse amplitudes (we use $\rho_A = 0.65$ & $\phi_A = -53^o$)

SM results

$$f_L(b_1K^*) > f_L(\rho K^*) > f_L(a_1K^*)$$

if $\rho_A = 0.65$ and $\phi_A = -53°$ for VA modes

$$f_L(b_1K^*) > f_L(a_1K^*) > f_L(\rho K^*)$$

if neglecting the penguin annihilation for VA

Two-body decays involving a tensor meson

Light-cone distribution amplitudes for a tensor meson

chiral-even

$$\langle T(P,\lambda)|\bar q_1(y)\gamma_\mu q_2(x)|0\rangle = -if_T m_T^2 \int_0^1 du\, e^{i(uPy+\bar uPx)} \left\{ P_\mu \frac{\epsilon^{(\lambda)*}_{\alpha\beta} z^\alpha z^\beta}{(Pz)^2} \Phi_\parallel^T(u) + \left(\frac{\epsilon^{(\lambda)*}_{\mu\alpha} z^\alpha}{Pz} - P_\mu \frac{\epsilon^{(\lambda)*}_{\beta\alpha} z^\beta z^\alpha}{(Pz)^2} \right) g_v(u) - \frac{1}{2} z_\mu \frac{\epsilon^{(\lambda)*}_{\alpha\beta} z^\alpha z^\beta}{(Pz)^3} m_T^2\, \bar g_3(u) + \mathcal{O}(z^2) \right\},$$

$$\langle T(P,\lambda)|\bar q_1(y)\gamma_\mu\gamma_5 q_2(x)|0\rangle = -if_T m_T^2 \int_0^1 du\, e^{i(uPy+\bar uPx)} \varepsilon_{\mu\nu\alpha\beta} z^\nu P^\alpha \epsilon^{*\beta\delta}_{(\lambda)} z_\delta \frac{1}{2Pz} g_a(u)$$

chiral-odd

$$\langle T(P,\lambda)|\bar q_1(y)\sigma_{\mu\nu} q_2(x)|0\rangle = -f_T^\perp m_T \int_0^1 du\, e^{i(uPy+\bar uPx)} \left\{ \left[\epsilon^{(\lambda)*}_{\mu\alpha} z^\alpha P_\nu - \epsilon^{(\lambda)*}_{\nu\alpha} z^\alpha P_\mu\right] \frac{1}{Pz} \Phi_\perp^T(u) + (P_\mu z_\nu - P_\nu z_\mu) \frac{m_T^2 \epsilon^{(\lambda)*}_{\alpha\beta} z^\alpha z^\beta}{(Pz)^3} \bar h_t(u) + \frac{1}{2}\left[\epsilon^{(\lambda)*}_{\mu\alpha} z^\alpha z_\nu - \epsilon^{(\lambda)*}_{\nu\alpha} z^\alpha z_\mu\right] \frac{m_T^2}{(Pz)^2} \bar h_3(u) + \mathcal{O}(z^2) \right\},$$

$$\langle T(P,\lambda)|\bar q_1(y) q_2(x)|0\rangle = -f_T^\perp m_T^3 \int_0^1 du\, e^{i(uPy+\bar uPx)} \frac{\epsilon^{(\lambda)*}_{\alpha\beta} z^\alpha z^\beta}{2Pz} h_s(u)$$

twist-2: $\Phi_\parallel, \Phi_\perp$
twist-3: g_v, g_a, h_t, h_s
twist-4: g_3, h_3

PRD82:054019,2010, H.Y. Cheng, Y. Koike, KCY

Asymptotic form of chiral-even DAs is first studied by Braun & Kivel ('01)

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$^3P_2$ tensor meson

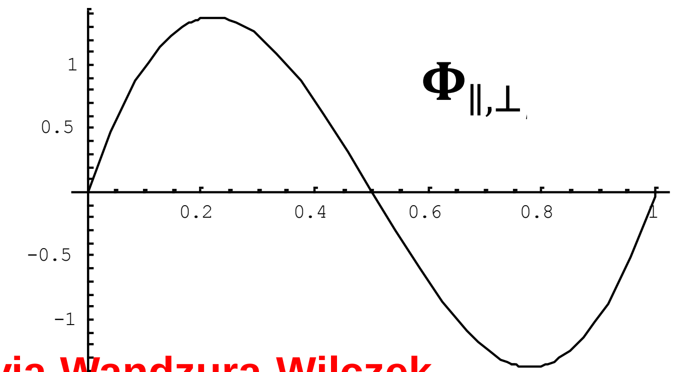
Due to G-parity, $\Phi_\perp$, $h_\parallel^{(t)}$, $h_\parallel^{(p)}$, $\Phi_\parallel$, $g_\perp^{(v)}$, $g_\perp^{(a)}$ are antisymmetric with the replacement $u \to 1-u$ in SU(3) limit

$$\int_0^1 du \Phi_\parallel(u) = \int_0^1 du g_\perp^{(a)}(u) = \int_0^1 du g_\perp^{(v)}(u) = \int_0^1 du g_3(u) = 0$$

$$\Phi^T_{\parallel,\perp}(u,\mu) = 6u(1-u) \sum_{\ell=0}^{\infty} a_\ell^{(\parallel,\perp),T}(\mu) C_\ell^{3/2}(2u-1),$$

$C_i^{3/2}$: Gegenbauer polynomial

$$\Phi_{\parallel,\perp}(u) \simeq 6u(1-u)(2u-1)\, a_1^{\parallel,\perp}$$



twist-2: $\Phi_\parallel$, $\Phi_\perp$

twist-3: $g_\perp^{(v)}$, $g_\perp^{(a)}$, $h_\perp^{(t)}$, $h_\parallel^{(p)}$ related to twist-2 ones via Wandzura-Wilczek relations (neglecting 3-parton distributions)

$$g_v^{WW}(u) = \int_0^u dv \frac{\Phi_\parallel^T(v)}{\bar{v}} + \int_u^1 dv \frac{\Phi_\parallel^T(v)}{v},$$

$$g_a^{WW}(u) = 2\bar{u} \int_0^u dv \frac{\Phi_\parallel^T(v)}{\bar{v}} + 2u \int_u^1 dv \frac{\Phi_\parallel^T(v)}{v},$$

$$h_t^{WW}(u) = \frac{3}{2}(2u-1) \left(\int_0^u dv \frac{\Phi_\perp^T(v)}{\bar{v}} - \int_u^1 dv \frac{\Phi_\perp^T(v)}{v} \right)$$

$$h_s^{WW}(u) = 3 \left(\bar{u} \int_0^u dv \frac{\Phi_\perp^T(v)}{\bar{v}} + u \int_u^1 dv \frac{\Phi_\perp^T(v)}{v} \right).$$

Decay constants

- **Tensor meson cannot be produced from local V-A current owing to $\varepsilon_{\mu\nu}p^{\nu}=0$** $\langle T(p,\lambda)|V_\mu, A_\mu|0\rangle = 0$
- **Can be created from local current involving covariant derivatives**

$$\langle T(P,\lambda)|J_{\mu\nu}(0)|0\rangle = f_T m_T^2 \epsilon_{\mu\nu}^{*(\lambda)},$$
$$\langle T(P,\lambda)|J^{\perp}_{\mu\nu\alpha}(0)|0\rangle = -i f_T^{\perp} m_T (\epsilon_{\mu\alpha}^{(\lambda)*}P_\nu - \epsilon_{\nu\alpha}^{(\lambda)*}P_\mu),$$

with

$$J_{\mu\nu}(0) = \frac{1}{2}\left(\bar{q}_1(0)\gamma_\mu i \overleftrightarrow{D}_\nu q_2(0) + \bar{q}_1(0)\gamma_\nu i \overleftrightarrow{D}_\mu q_2(0)\right)$$
$$J^{\perp}_{\mu\nu\alpha}(0) = \bar{q}_1(0)\sigma_{\mu\nu} i \overleftrightarrow{D}_\alpha q_2(0),$$

Normalized with $a_1^{\parallel} = a_1^{\perp} = \frac{5}{3}$

Previous estimates: Aliev & Shifman ('82); Aliev, Azizi, Bashiry ('10)

Based on QCD sum rules we obtain (Cheng, Koike, KCY, arXiv:1007.3526)

Light tensor mesons [40]

T	f_T (MeV)	$f_T^{\perp}$ (MeV)
$f_2(1270)$	102 ± 6	117 ± 25
$f_2'(1525)$	126 ± 4	65 ± 12
$a_2(1320)$	107 ± 6	105 ± 21
$K_2^*(1430)$	118 ± 5	77 ± 14

VT modes

Data from BaBar branching fractions (in units of 10^{-6})

Mode	$\mathcal{B}$	f_L	Mode	$\mathcal{B}$	f_L
$\mathcal{B}(B^+ \to K_2^*(1430)^+\omega)$	21.5 ± 4.3	0.56 ± 0.11	$\mathcal{B}(B^0 \to K_2^*(1430)^0\omega)$	10.1 ± 2.3	0.45 ± 0.12
$\mathcal{B}(B^+ \to K_2^*(1430)^+\phi)$	8.4 ± 2.1	0.80 ± 0.10	$\mathcal{B}(B^0 \to K_2^*(1430)^0\phi)$	7.5 ± 1.0	$0.901^{+0.059}_{-0.069}$

$K_2^*\omega = 0.05{\sim}0.1$
$K_2^*\phi = 2{\sim}9$

⇔ Naïve factorization,
Kim,Lee & Oh, PRD (2003);
Munoz,Quintero, J.Phys.G (2009)

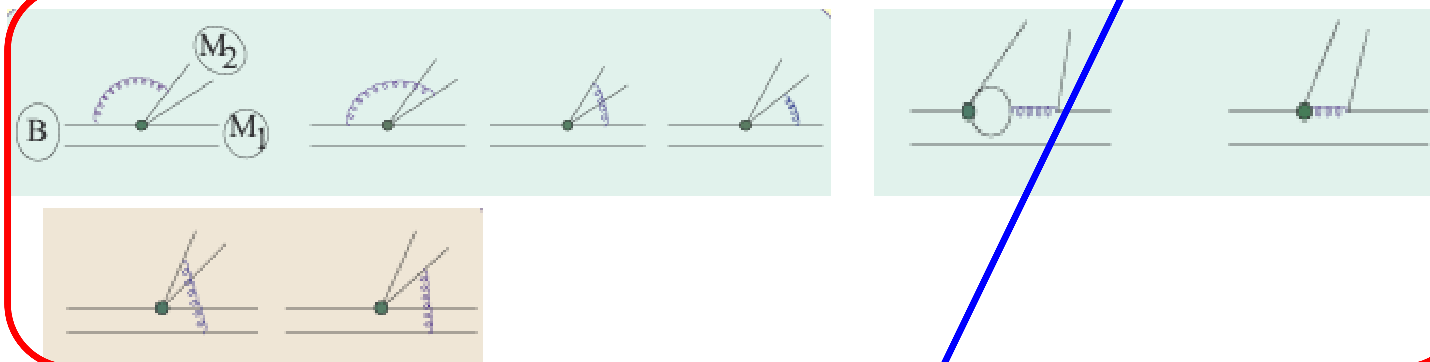
QCD factorization (without annihilation) $K_2^*\omega{\sim}0.2$, $K_2^*\phi = 3$, too small

Within SM, to account for data,
penguin annihilation is necessary

PRD83:034001,2011, Hai-Yang Cheng, KCY

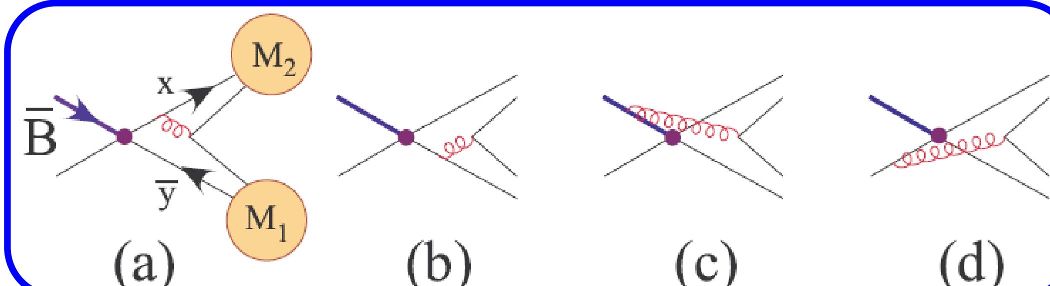
$$\sqrt{2}\mathcal{A}^h_{B^-\to K_2^{*-}\omega} \approx \sqrt{2}\mathcal{A}^h_{\overline{B}^0\to\overline{K}_2^{*0}\omega} \approx \left\{\left[\alpha_4^{p,h}+\beta_3^{p,h}\right]X_h^{(\overline{B}\omega,\overline{K}_2^*)} + \left[2\alpha_3^{p,h}\right]X_h^{(\overline{BK}_2^*,\omega)}\right\}$$

$$\mathcal{A}^h_{B^-\to K_2^{*-}\phi} \approx \mathcal{A}^h_{\overline{B}^0\to\overline{K}_2^{*0}\phi} \approx \left[\alpha_3^{p,h}+\alpha_4^{p,h}+\beta_3^{p,h}+\beta_{3,\mathrm{EW}}^{p,h}\right]X_h^{(\overline{BK}_2^*,\phi)}.$$



Ann is dominated by

$$(M_1, M_2) = \begin{cases}(K_2^*\phi)\\(\omega \mathrm{K}_2^*)\end{cases}$$



To account for data, penguin annihilation is necessary

$\rho_A^{TV} \simeq 0.65,\ \phi_A^{TV} \simeq -33°,\ (K_2^*\phi)$ where $M_1 = T, M_2 = V$

$\neq$

$\rho_A^{VT} \simeq 1.20,\ \rho_A^{VT} \simeq -60°,\ (\omega K_2^*)$ where $M_1 = V, M_2 = T$

Process-dependent ?

Polarization puzzle in $B \to K_2^*\phi$

$f_L(K_2^{*+}\omega) = 0.56\pm0.11$, $f_L(K_2^{*0}\omega) = 0.45\pm0.12$,

$f_L(K_2^{*+}\phi) = 0.80\pm0.10$, $f_L(K_2^{*0}\phi) = 0.901^{+0.059}_{-0.069}$

BaBar

Why is $f_T/f_L \ll 1$ for $B\to K_2^*\phi$ and $f_T/f_L \sim 1$ for $B\to K_2^*\omega$?

Why is that f_T behaves differently in $K_2^*\phi$ and $K^*\phi$?

In QCDF, f_L is very sensitive to the phase ϕ_A^{TV} for $B\to K_2^*\phi$, but not so sensitive to ϕ_A^{VT} for $B\to K_2^*\omega$

$f_L(K_2^*\phi) = 0.88, 0.72, 0.48$ for $\phi_A^{TV} = -30^o, -45^o, -60^o$,
$f_L(K_2^*\omega) = 0.68, 0.66, 0.64$ for $\phi_A^{VT} = -30^o, -45^o, -60^o$

Rates & polarization fractions can be accommodated in QCDF

$$\rho_A^{TV} = 0.65, \qquad \phi_A^{TV} = -33^\circ, \qquad \rho_A^{VT} = 1.20, \qquad \phi_A^{VT} = -60^\circ$$

but no dynamical explanation is offered

Fine-tuning!

New Physics due to tensor currents

$B \to K_2^* \phi$

$$\overline{A}_0^{NP} = 4 i f_\phi^T m_B^2 \left[\tilde{a}_{23} - \tilde{a}_{25}\right] \left[h_2 T_2(m_\phi^2) - h_3 T_3(m_\phi^2)\right] \frac{p_3}{m_{K_2^*}} \sqrt{\frac{2}{3}},$$

$$\overline{A}_\parallel^{NP} = -4 i \sqrt{2} f_\phi^T m_B^2 (\tilde{a}_{23} - \tilde{a}_{25}) f_2 T_2(m_\phi^2) \frac{p_3}{m_{K_2^*}} \sqrt{\frac{1}{2}},$$

$$\overline{A}_\perp^{NP} = -4 i \sqrt{2} f_\phi^T m_B^2 (\tilde{a}_{23} + \tilde{a}_{25}) f_1 T_1(m_\phi^2) \frac{p_3}{m_{K_2^*}} \sqrt{\frac{1}{2}},$$

Relatively smaller

Larger f_L compared with ϕK^*

$B \to K^* \phi$

$$\overline{A}_0^{NP} = +4 i f_\phi^T m_B^2 \left[\tilde{a}_{23} - \tilde{a}_{25}\right] \left[h_2 T_2(m_\phi^2) - h_3 T_3(m_\phi^2)\right]$$

$$\overline{A}_\parallel^{NP} = -4 i \sqrt{2} f_\phi^T m_B^2 (\tilde{a}_{23} - \tilde{a}_{25}) f_2 T_2(m_\phi^2),$$

$$\overline{A}_\perp^{NP} = -4 i \sqrt{2} f_\phi^T m_B^2 (\tilde{a}_{23} + \tilde{a}_{25}) f_1 T_1(m_\phi^2),$$

NEW-PHYSICS CORRECTIONS TO $B \to \phi K_J^*$

$$\overline{A}_0^{NP} = 4i f_\phi^T m_B^2 \left[\tilde{a}_{23} - \tilde{a}_{25}\right] \left[h_2 T_2(m_\phi^2) - h_3 T_3(m_\phi^2)\right] \left(\frac{p_3}{m_{K_2^*}}\right)^{J-1} \alpha_J^{(J)},$$

$$\overline{A}_\parallel^{NP} = -4i\sqrt{2} f_\phi^T m_B^2 (\tilde{a}_{23} - \tilde{a}_{25}) f_2 T_2(m_\phi^2) \left(\frac{p_3}{m_{K_2^*}}\right)^{J-1} \beta_J^{(J)},$$

$$\overline{A}_\perp^{NP} = -4i\sqrt{2} f_\phi^T m_B^2 (\tilde{a}_{23} + \tilde{a}_{25}) f_1 T_1(m_\phi^2) \left(\frac{p_3}{m_{K_2^*}}\right)^{J-1} \beta_J^{(J)},$$

Larger J → f_L ~ unchanged

TABLE II: The Clebsch-Gordan coefficients, $\alpha_L^{(J)}$ and $\beta_T^{(J)}$, with $J = 1, 2, \cdots, 5$.

J	1	2	3	4	5
$\alpha_L^{(J)}$	1	$\sqrt{\frac{2}{3}}$	$\sqrt{\frac{2}{5}}$	$2\sqrt{\frac{2}{35}}$	$\frac{2}{3}\sqrt{\frac{2}{7}}$
$\beta_T^{(J)}$	1	$\sqrt{\frac{1}{2}}$	$\frac{2}{\sqrt{15}}$	$\frac{1}{\sqrt{7}}$	$2\sqrt{\frac{2}{105}}$

Conclusions

Possible solutions for polarization in $B \to VV decays$:

- In SM, we need large constructive annihilation corrections to the transverse amplitudes via the $O_6 = -2\bar{d}(1-\gamma_5)b\ \bar{s}(1+\gamma_5)d$
  - the annihilation corrections are only significant for penguin dominant processes $\phi K^*, \rho K^*, \ldots$

New physics solutions:

1. It is unlikely to explain data using color dipole operator and right-handed currents.

2. the only candidates are the tensor operators (Pure $(S \pm P)(S \pm P)$ operators are unlikely)

Further information ($b \to s\ \bar{s}\ s$) can be extracted from

$B \to h_1(1380)K^*$ $B \to \phi K_2^*, \omega K_2^*$ $B \to \phi K_J^*$