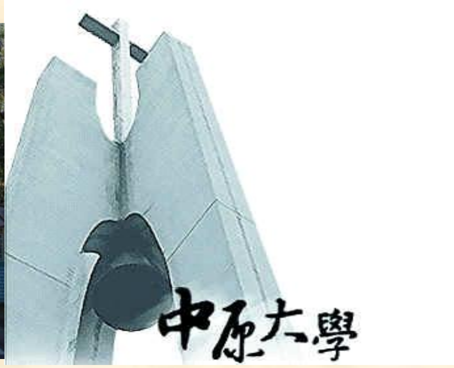
Charmless Two-Body B Decays Involving a Tensor Meson

Kwei-Chou Yang
Chung-Yuan Christian University, Taiwan

The 36th International Conference on High Energy Physics (ICHEP2012)

in collaboration with Hai-Yang Cheng



Outline

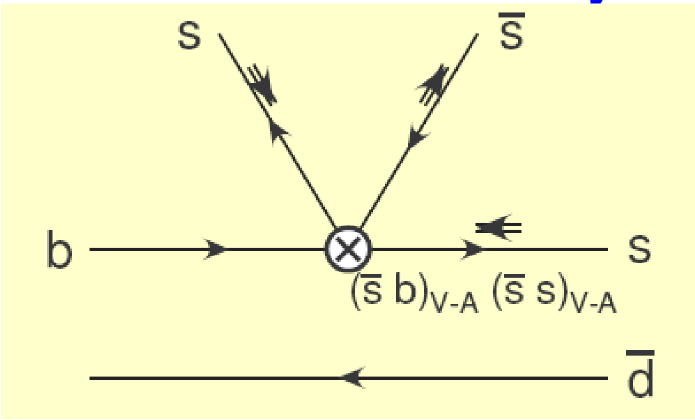
- Polarization puzzles in $B \to V\,V$
  ---- SM or New-Physics

- B decays involving a tensor meson
  ----further test: SM or New-Physics

- Conclusion

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

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

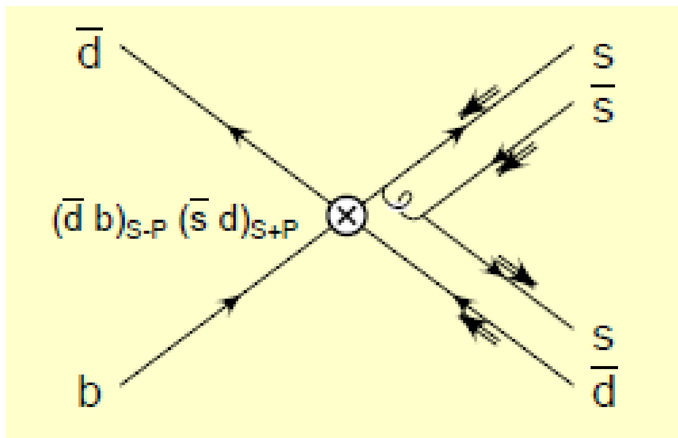
Why is f_T sizable ~ 0.5 in $B\to K^* \varphi$ decays ?

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

Explanation within the SM: Annihilation

In SM, the Annihilation effect is 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
$$\int_0^1 \frac{dx}{x} = \ln \frac{m_B}{\Lambda} \left(1 + \rho_A \, e^{i\phi_A}\right)$$

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

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

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

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

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

Coefficients are helicity dependent !

PRD,2008, Hai-Yang Cheng, KCY

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

$$P^c = [a_4^c + r_\chi a_6^c]_{SD} + \beta_3^c + \ldots$$

penguin annihilation

■ 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

$f_{||} \doteqdot f_\perp \doteqdot 0.25$

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

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

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

constructive / destructive

destructive / constructive

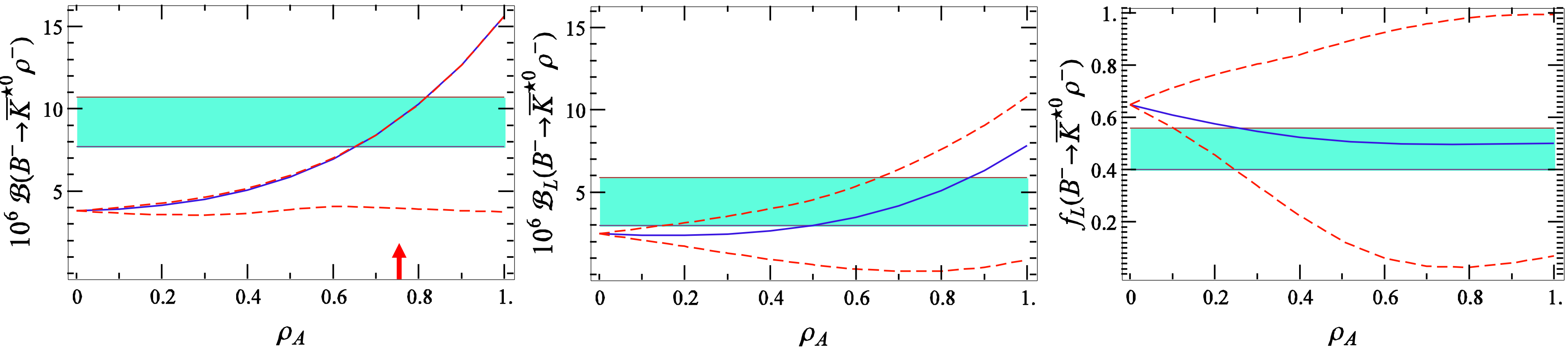
with $\beta_3=0$

⇒ $f_L(K^{*-}\rho^0)=0.96$, $f_L(K^{*0}\rho^0)=0.47$ (=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	$0.26^{+0.20}_{-0.26}$	
$B^- \to K^{*-}\rho^0$	$5.5^{+0.6+1.3}_{-0.5-2.5}$	4.6 ± 1.1	$0.67^{+0.31}_{-0.48}$	0.78 ± 0.12	$0.16^{+0.24}_{-0.15}$	
$\overline{B}^0 \to K^{*-}\rho^+$	$8.9^{+1.1+4.8}_{-1.0-5.5}$	< 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	$0.39^{+0.60}_{-0.31}$	0.40 ± 0.14	$0.30^{+0.15}_{-0.30}$	

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

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 $\rho^0\omega$

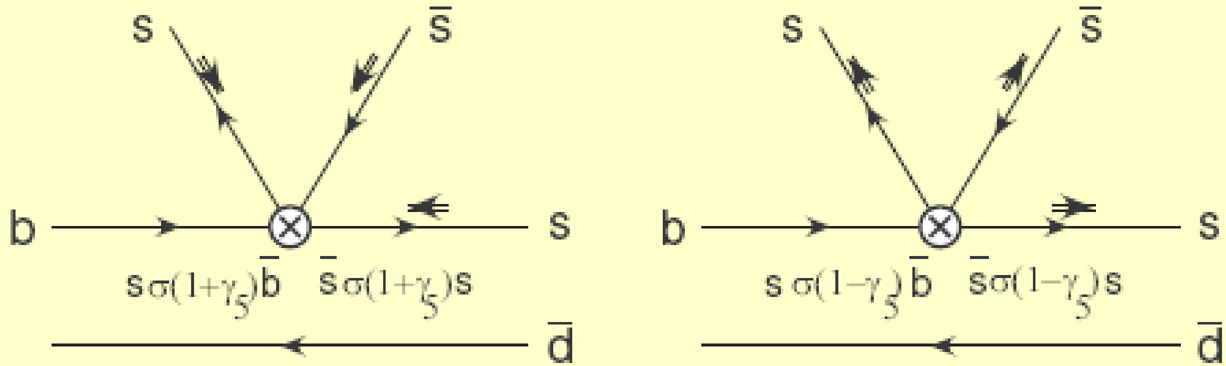
- Predicted $B\to\rho\rho$, $\omega\rho$ rates agree with the data.

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

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

Scenario with New Physics

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 Alex Kagan; C.S. Kim, Y.D. Yang;

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

Two-body B decays involving a tensor meson

Light-cone distribution amplitudes for a tensor meson

chiral-even

$$\langle T(P,\lambda)|\bar{q}_1(y)\gamma_\mu q_2(x)|0\rangle = -if_T m_T^2 \int_0^1 du\, e^{i(uPy+\bar{u}Px)} \left\{ P_\mu \frac{\epsilon^{(\lambda)*}_{\alpha\beta} z^\alpha z^\beta}{(Pz)^2} \Phi_\parallel^T(u) + \left(\frac{\epsilon^{(\lambda)*}_{\mu\alpha} z^\alpha}{Pz} - P_\mu \frac{\epsilon^{(\lambda)*}_{\beta\alpha} z^\beta z^\alpha}{(Pz)^2} \right) g_v(u) - \frac{1}{2} z_\mu \frac{\epsilon^{(\lambda)*}_{\alpha\beta} z^\alpha z^\beta}{(Pz)^3} m_T^2 \bar{g}_3(u) + \mathcal{O}(z^2) \right\},$$

$$\langle T(P,\lambda)|\bar{q}_1(y)\gamma_\mu\gamma_5 q_2(x)|0\rangle = -if_T m_T^2 \int_0^1 du\, e^{i(uPy+\bar{u}Px)} \varepsilon_{\mu\nu\alpha\beta} z^\nu P^\alpha \epsilon^{*\beta\delta}_{(\lambda)} z_\delta \frac{1}{2Pz} g_a(u)$$

chiral-odd

$$\langle T(P,\lambda)|\bar{q}_1(y)\sigma_{\mu\nu} q_2(x)|0\rangle = -f_T^\perp m_T \int_0^1 du\, e^{i(uPy+\bar{u}Px)} \left\{ \left[\epsilon^{(\lambda)*}_{\mu\alpha} z^\alpha P_\nu - \epsilon^{(\lambda)*}_{\nu\alpha} z^\alpha P_\mu \right] \frac{1}{Pz} \Phi_\perp^T(u) + (P_\mu z_\nu - P_\nu z_\mu) \frac{m_T^2 \epsilon^{(\lambda)*}_{\alpha\beta} z^\alpha z^\beta}{(Pz)^3} \bar{h}_t(u) + \frac{1}{2} \left[\epsilon^{(\lambda)*}_{\mu\alpha} z^\alpha z_\nu - \epsilon^{(\lambda)*}_{\nu\alpha} z^\alpha z_\mu \right] \frac{m_T^2}{(Pz)^2} \bar{h}_3(u) + \mathcal{O}(z^2) \right\},$$

$$\langle T(P,\lambda)|\bar{q}_1(y) q_2(x)|0\rangle = -f_T^\perp m_T^3 \int_0^1 du\, e^{i(uPy+\bar{u}Px)} \frac{\epsilon^{(\lambda)*}_{\alpha\beta} z^\alpha z^\beta}{2Pz} h_s(u),$$

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)

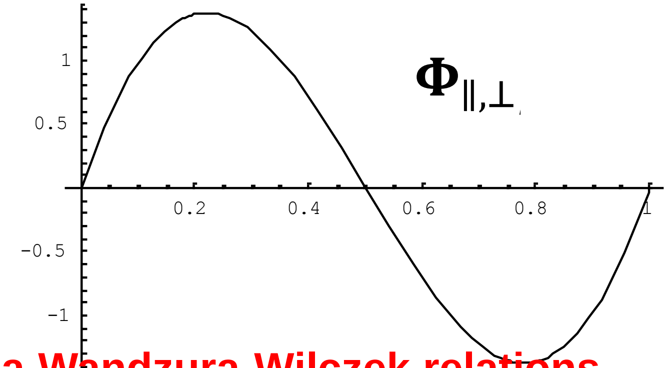
${}^3P_2$ tensor meson

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

$$\int_0^1 du\Phi_\parallel(u) = \int_0^1 dug_\perp^{(a)}(u) = \int_0^1 dug_\perp^{(v)}(u) = \int_0^1 dug_3(u) = 0$$

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

$C_i^{3/2}$: 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 $\varepsilon_{\mu\nu}p^{\nu}=0$ $\quad \langle T(p,\lambda)|V_\mu, A_\mu|0\rangle = 0$
- 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	$0.901^{+0.059}_{-0.069}$

$K_2^*\omega = 0.05\sim0.1$
$K_2^*\phi = 2\sim9$

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

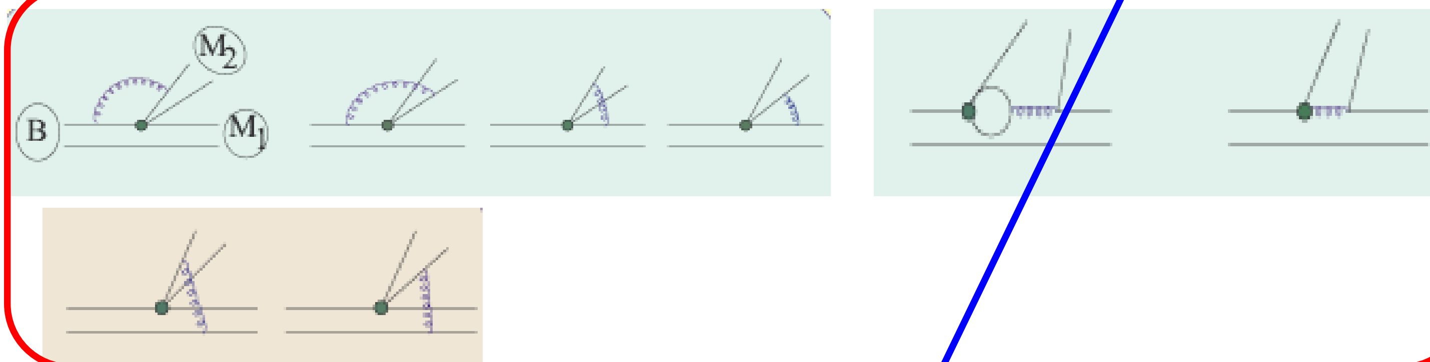
QCD factorization (without annihilation) $K_2^*\omega\sim0.2$, $K_2^*\phi = 3$ too small

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

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

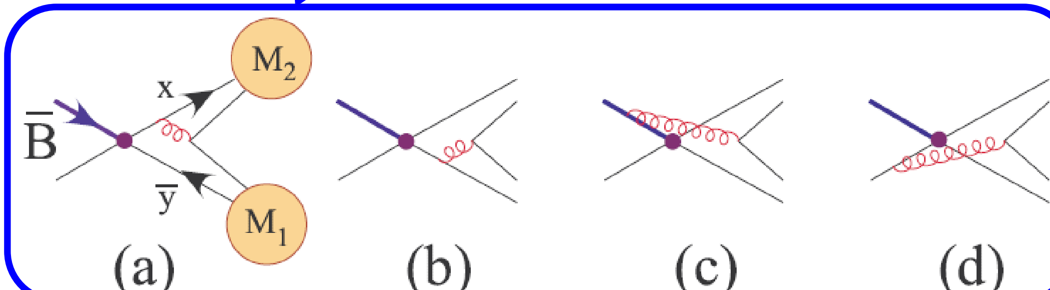
$$\sqrt{2}\mathcal{A}^h_{B^-\to K_2^{*-}\omega} \approx \sqrt{2}\mathcal{A}^h_{\overline{B}^0\to\overline{K}_2^{*0}\omega} \approx \left\{\left[\alpha_4^{p,h}+\beta_3^{p,h}\right]X_h^{(\overline{B}\omega,\overline{K}_2^*)} + \left[2\alpha_3^{p,h}\right]X_h^{(\overline{B}\overline{K}_2^*,\omega)}\right\}$$

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



Ann is dominant for

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



To account for data, penguin annihilation is necessary

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

$\neq$

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

Process-dependent ?

18

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!

Further test

Sizable BR

$f_L = 0.65$

Decay	$\mathcal{B}$ QCDF	$\mathcal{B}$ KLO [20]	$\mathcal{B}$ MQ [21]	$\mathcal{B}$ Expt.	f_L QCDF	f_L Expt.	A_{CP}
$B^- \to \bar{K}_2^*(1430)^0 \rho^-$	$18.6^{+50.1}_{-17.2}$				$0.63^{+0.10}_{-0.09}$		$-1.0^{+0.8}_{-1.0}$
$B^- \to K_2^*(1430)^- \rho^0$	$10.4^{+18.8}_{-9.2}$	0.253	0.74		$0.66^{+0.06}_{-0.07}$		$2.1^{+11.1}_{-9.9}$
$\overline{B}^0 \to K_2^*(1430)^- \rho^+$	$19.8^{+52.0}_{-18.2}$				$0.64^{+0.07}_{-0.03}$		$-1.5^{+2.6}_{-2.0}$
$\overline{B}^0 \to \bar{K}_2^*(1430)^0 \rho^0$	$9.5^{+33.4}_{-9.5}$	0.235	0.68		$0.64^{+0.15}_{-0.37}$		$-4.0^{+14.1}_{-10.8}$
$B^- \to K_2^*(1430)^- \omega$	$7.5^{+19.7}_{-7.0}$	0.112	0.06	21.5 ± 4.3	$0.64^{+0.08}_{-0.07}$	0.56 ± 0.11	$2.0^{+12.2}_{-10.5}$
$\bar{B}^0 \to \bar{K}_2^*(1430)^0 \omega$	$8.1^{+21.7}_{-7.6}$	0.104	0.053	10.1 ± 2.3	$0.66^{+0.11}_{-0.15}$	0.45 ± 0.12	$4.4^{+10.9}_{-10.0}$
$B^- \to K_2^*(1430)^- \phi$	$7.4^{+25.8}_{-5.2}$	2.180	9.24	8.4 ± 2.1	$0.85^{+0.16}_{-0.77}$	0.80 ± 0.10	$0.1^{+1.2}_{-0.5}$
$\bar{B}^0 \to \bar{K}_2^*(1430)^0 \phi$	$7.7^{+26.9}_{-5.5}$	2.024	8.51	7.5 ± 1.0	$0.86^{+0.16}_{-0.77}$	$0.901^{+0.059}_{-0.069}$	$0.09^{+0.82}_{-0.21}$
$B^- \to a_2(1320)^0 K^{*-}$	$2.9^{+11.7}_{-2.5}$	1.852	2.80		$0.73^{+0.22}_{-0.33}$		$-15.0^{+56.0}_{-15.0}$
$B^- \to a_2(1320)^- \overline{K}^{*0}$	$6.1^{+23.8}_{-5.4}$	4.495	8.62		$0.79^{+0.20}_{-0.64}$		$-0.1^{+1.3}_{-0.3}$
$\overline{B}^0 \to a_2(1320)^+ K^{*-}$	$6.1^{+24.3}_{-5.3}$	3.477	7.25		$0.77^{+0.19}_{-0.46}$		$-13.3^{+38.2}_{-7.0}$
$\overline{B}^0 \to a_2(1320)^0 \overline{K}^{*0}$	$3.4^{+12.4}_{-2.8}$	2.109	4.03		$0.82^{+0.14}_{-0.67}$		$1.2^{+7.0}_{-13.3}$
$B^- \to f_2(1270) K^{*-}$	$8.3^{+17.3}_{-6.7}$	2.032			$0.93^{+0.07}_{-0.63}$		$-8.1^{+13.7}_{-7.1}$
$\overline{B}^0 \to f_2(1270) \overline{K}^{*0}$	$9.1^{+18.8}_{-7.3}$	2.314			$0.94^{+0.06}_{-0.69}$		$-0.08^{+4.3}_{-3.1}$
$B^- \to f_2'(1525) K^{*-}$	$12.6^{+24.0}_{-11.1}$	0.025			$0.65^{+0.28}_{-0.38}$		$0.6^{+2.5}_{-2.9}$
$\overline{B}^0 \to f_2'(1525) \overline{K}^{*0}$	$13.5^{+25.4}_{-11.9}$	0.029			$0.66^{+0.27}_{-0.38}$		$0.2^{+0.3}_{-0.4}$

$f_L = 0.93$

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^*

$B \to K^*\phi$

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

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

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

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:
the only candidates are the tensor operators
(Pure (S ± P)(S ± P) operators are unlikely)

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

$$B \to \phi K_2^*, \omega K_2^*$$

and some other modes involving the tensor meson (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

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

shows that the NP effects only due to (pseudo-)scalar-type operators is much smaller in $B \to K^*\phi$ modes.

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

Penguin-dominated B→ TP

Decay	QCDF	$\mathcal{B}$ Kim-Lim-Oh [20]	Munoz-Quintero [21]	Experiment
$B^- \to \bar{K}_2^*(1430)^0\pi^-$	$3.1^{+8.3}_{-3.1}$			$5.6^{+2.2}_{-1.4}$
$B^- \to K_2^*(1430)^-\pi^0$	$2.2^{+4.7}_{-1.9}$	0.090	0.15	
$\bar{B}^0 \to K_2^*(1430)^-\pi^+$	$3.3^{+8.5}_{-3.2}$			<6.3
$\bar{B}^0 \to \bar{K}_2^*(1430)^0\pi^0$	$1.2^{+4.3}_{-1.3}$	0.084	0.13	<4.0
$B^- \to a_2(1320)^0K^-$	$4.9^{+8.4}_{-4.2}$	0.311	0.39	<45
$B^- \to a_2(1320)^-\bar{K}^0$	$8.4^{+16.1}_{-7.2}$	0.011	0.015	
$\bar{B}^0 \to a_2(1320)^+K^-$	$9.7^{+17.2}_{-8.1}$	0.584	0.73	
$\bar{B}^0 \to a_2(1320)^0\bar{K}^0$	$4.2^{+8.3}_{-3.5}$	0.005	0.014	
$B^- \to f_2(1270)K^-$	$3.8^{+7.8}_{-3.0}$	0.344		$1.06^{+0.28}_{-0.29}$
$\bar{B}^0 \to f_2(1270)\bar{K}^0$	$3.4^{+8.5}_{-3.1}$	0.005		$2.7^{+1.3}_{-1.2}$
$B^- \to f_2'(1525)K^-$	$4.0^{+7.4}_{-3.6}$	0.004		<7.7
$\bar{B}^0 \to f_2'(1525)\bar{K}^0$	$3.8^{+7.3}_{-3.5}$	7×10^{-5}		
$B^- \to K_2^*(1430)^-\eta$	$6.8^{+13.5}_{-8.7}$	0.031	1.19	9.1 ± 3.0
$B^- \to K_2^*(1430)^-\eta'$	$12.1^{+20.7}_{-12.1}$	1.405	2.70	$28.0^{+5.3}_{-5.0}$
$\bar{B}^0 \to \bar{K}_2^*(1430)^0\eta$	$6.6^{+13.5}_{-8.7}$	0.029	1.09	9.6 ± 2.1
$\bar{B}^0 \to \bar{K}_2^*(1430)^0\eta'$	$12.4^{+21.3}_{-12.4}$	1.304	2.46	$13.7^{+3.2}_{-3.1}$

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

$B^- \to \underline{K_2}^{*0}\pi^-$ vanishes in naïve factorization, while its BR is measured to be ~ 5.6×10^{-6}
$\Rightarrow$ importance of nonfactorizble effects

■ **Penguin annihilation is needed in QCDF to account for rates & CP asymmetries**

$$X_A \equiv \int_0^1 \frac{dy}{y} = \ln\frac{m_B}{\Lambda_h}\left(1+\rho_A e^{i\varphi_A}\right)$$

ρ_A^{TP}=0.83, ϕ_A^{TP} = -70°
ρ_A^{PT}=0.75, ϕ_A^{PT} = -30°

similar to the parameters for $B\to PP$