Polarization Study in $B_{u,d,s,c}$ Decays to Vector Final States

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arXiv:1501.00784

Outline

- Polarization problem in $B(B_s) \to VV$ decays
- Numerical analysis in PQCD approach based on k_T factorization/comparison with other solutions
- Summary

Polarization of B→VV decays

Table 1 Longitudinal Polarization Fractions

Process	Belle	Babar	QCDF
$B^0 \to \phi K^{*0}$,	$0.45 \pm 0.05 \pm 0.02$	$0.52 \pm 0.05 \pm 0.02$	0.91
$B^+ \to \phi K^{*+}$,	$0.52 \pm 0.8 \pm 0.03$	$0.46 \pm 0.12 \pm 0.03$	0.91
$B^+ \to \rho^0 K^{*+}$,		$0.96^{+0.04}_{-0.15} \pm 0.04$	0.94
$B^+ \to \rho^+ K^{*0}$,	$0.43 \pm 0.11^{+0.05}_{-0.07}$	$0.79 \pm 0.08 \pm 0.04 \pm 0.02$	0.95
$B^+ \to \rho^+ \rho^0$,	$0.95 \pm 0.11 \pm 0.02$	$0.97 \pm 0.04^{+0.03}_{-0.07}$	0.94
$B^+ \to \rho^+ \omega$,		$0.88 \pm 0.04^{+0.12}_{-0.15}$	
$B^0 \to \rho^+ \rho^-$,		$0.99 \pm 0.03^{+0.04}_{-0.03}$	0.95

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Definitions of observables

- flavor-tagged definitions

$$f^{B}_{L,\parallel,\perp} = \frac{\left|\mathcal{A}_{0,\parallel,\perp}\right|^2}{|\mathcal{A}_0|^2 + \left|\mathcal{A}_\parallel\right|^2 + |\mathcal{A}_\perp|^2}, \qquad \phi^{B}_{\parallel,\perp} = \arg\frac{\mathcal{A}_{\parallel,\perp}}{\mathcal{A}_0},$$

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- flavor-averaged quantities and asymmetries

$$f_h = \frac{1}{2}\left(f_h^{\bar{B}} + f_h^{B}\right), \qquad A^h_{\mathrm{CP}} = \frac{f_h^{\bar{B}} - f_h^{B}}{f_h^{\bar{B}} + f_h^{B}}$$

$$\begin{aligned} \phi_h &\equiv \phi_h^{\bar{B}} - \Delta\phi_h \quad (\mathrm{mod}\ 2\pi) \\ &\equiv \phi_h^{B} + \Delta\phi_h \quad (\mathrm{mod}\ 2\pi), \qquad -\frac{\pi}{2} \le \Delta\phi_h < \frac{\pi}{2} \end{aligned}$$

$h = L, \parallel, \perp$

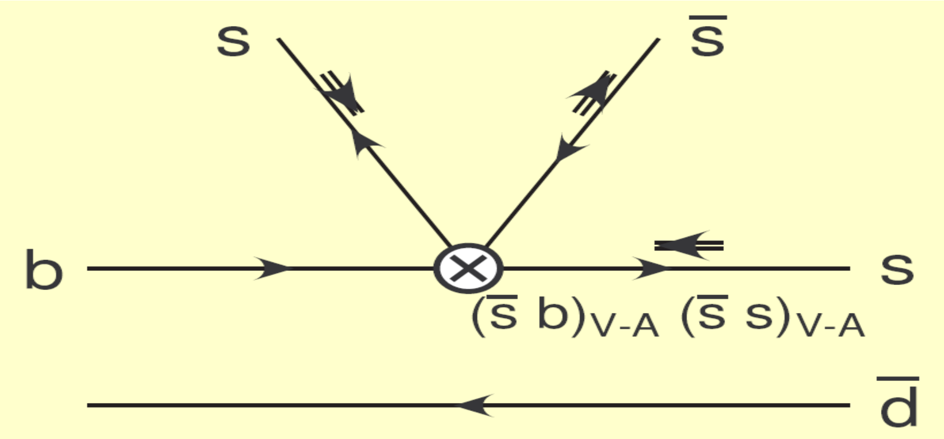
- In absence of CP violation, $A^h_{\mathrm{CP}} = 0$ and $\delta\phi_h = 0$.

Counting Rules for B→VV Polarization

- The measured longitudinal fractions R_L for $B \to \rho\rho$ are close to 1.
- $R_L \sim 0.5$ in ϕK^* dramatically differs from the counting rules.
- Are the ϕK^* polarizations understandable?

Starting point: left-handed current in weak interaction

Helicity flip suppression of the transverse polarization amplitude



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

$00, --, ++$ stand for longitudinal, negative, positive helicity

$\overline{H}_{--}/\overline{H}_{00} = \mathcal{O}(m_\phi/m_b)$: the helicity flip for $\bar{s}$ in the ϕ meson is required

$$R_L = \Gamma_L/\Gamma_{total} = \mathcal{O}(1), R_N \sim R_T = \mathcal{O}(m_V^2/m_B^2)$$

Theoretical attempts to solve these puzzles

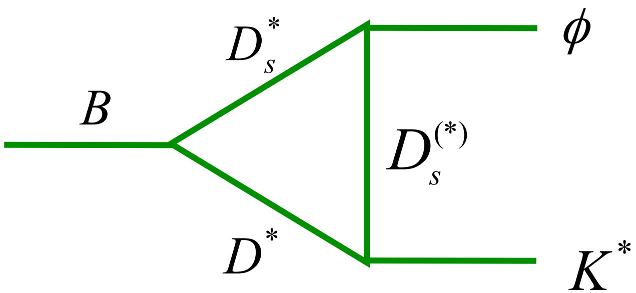
- New physics (Grossman;Yang;Giri; Das et al.)
- Annihilation effect in QCDF (Kagan)
- Charming penguin in SCET (Bauer et al)
- FSI effect (Colangelo; Ladisa; Cheng, et al)
- Exotic b→ sg (Hou,Nagashima)
- Most can not fully explain all the measurements, especially relative phases except Annihilation/ charming penguin：**Beneke, Yang, Rohrer(2006), Cheng, Chua(2009)**

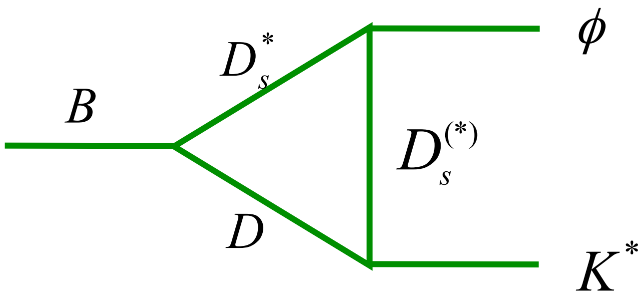
Polarization anomaly in $B \to \phi K^*$ [Cheng, Chua, Soni]

Confirmed for $B \to \rho\rho$ with $f_L \approx 0.97$

but for $B \to \phi K^*$ $\Rightarrow$ $f_L \approx 0.50$, $f_{||} \sim 0.25$, $f_\perp \sim 0.25$

- Get large transverse polarization from $B \to D_s^* D^*$ and then convey it to ϕK^* via FSI



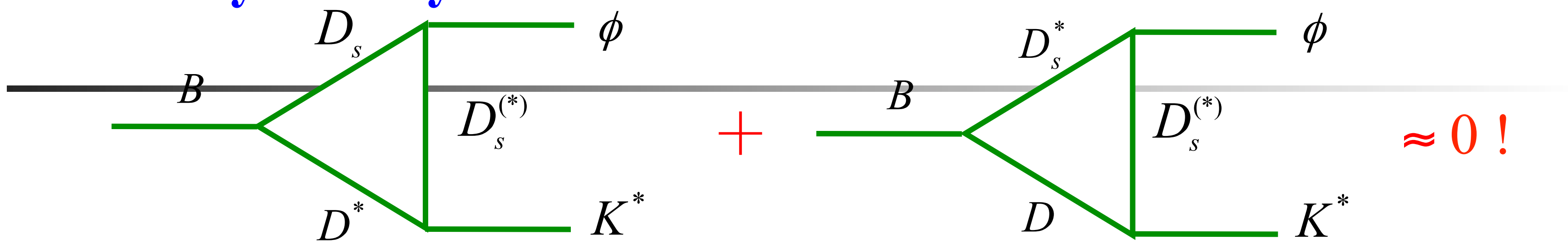


$f_L(D_s^* D^*) \sim 0.51$

$f_{||} \sim 0.41$, $f_\perp \sim 0.08$

contributes to $f_\perp$ only

Large cancellation occurs in $B \to \{D_s^* D, D_s D^*\} \to \phi K^*$ processes. This can be understood as CP & SU(3) symmetry



⇒ very small perpendicular polarization, $f_\perp \sim 2\%$, in sharp contrast to $f_\perp \sim 15\%$ obtained by Colangelo, De FArzio, Pham

While $f_T \approx 0.50$ is achieved, why is $f_\perp$ not so small ?

Cancellation in $B \to \{VP, PV\} \to \phi K^*$ can be circumvented in $B \to \{SA, AS\} \to \phi K^*$. For $S, A = D^{**}, D_s^{**}$ ⇒ $f_\perp \sim 0.22$

It is very easy to explain why $f_L \approx 0.50$ by FSI, but it takes some efforts to understand why $f_\perp \sim f_{||}$

There are still problems for some of the explanations

The perpendicular polarization is given by:

$$R_\perp(B^+ \to \phi K^{*+}) = 0.19 \pm 0.08 \pm 0.02 (Belle)$$

$$R_\perp(B^0 \to \phi K^{*0}) = 0.22 \pm 0.05 \pm 0.02 (Babar)$$

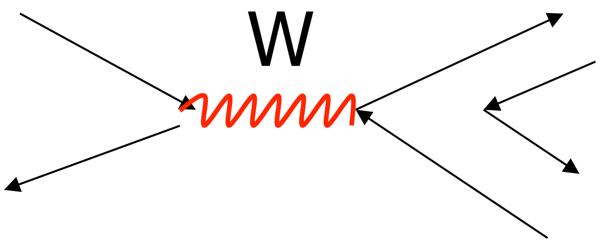
$$R_\perp(B^0 \to \phi K^{*0}) = 0.31^{+0.06}_{-0.05} \pm 0.02 (Belle)$$

Naive BaBar + Belle avg: $(f_\perp / f_{||})^{\text{exp}} = 0.9 \pm 0.3$

Final state interaction can not explain $R_N = R_T$ and some others are difficult to explain the relative phase

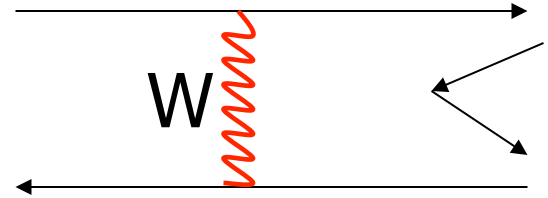
A Large Annihilation Can Help

Annihilation-Type diagrams

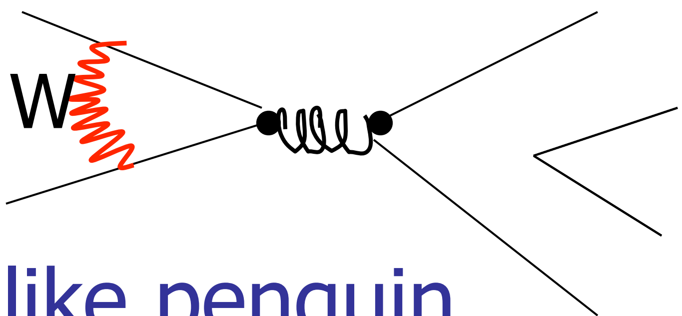


W annihilation

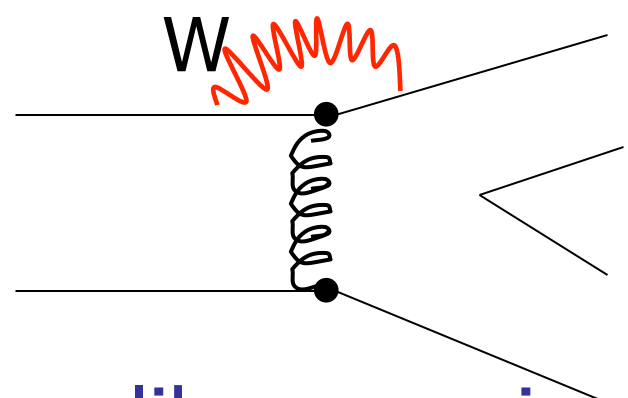
A. Kagan



W exchange

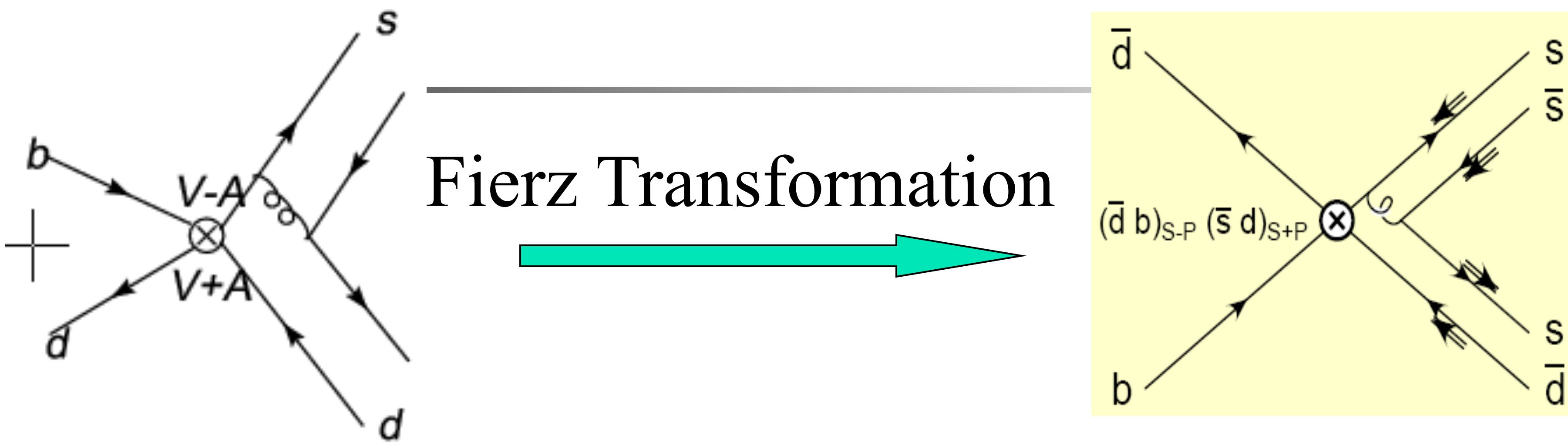


Time-like penguin



Space-like penguin

The annihilation diagram



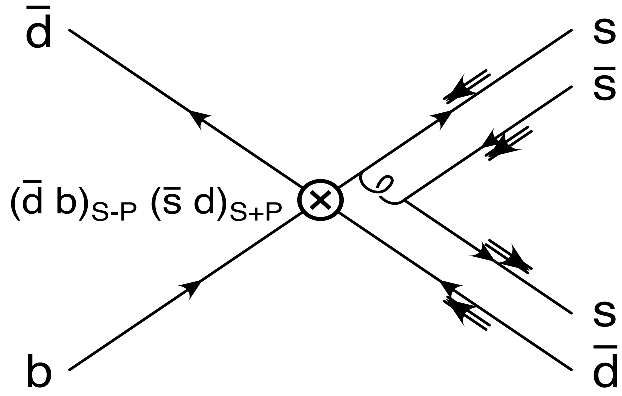
The (S+P)(S-P) current can break the counting rule,

The annihilation diagram contributes equally to the three polarization amplitudes

Example: annihilation graphs due to QCD penguin operator

$Q_6 \Rightarrow < (\bar{d}b)_{S-P} \times (\bar{s}d)_{S+P} >$ (part of P)

-

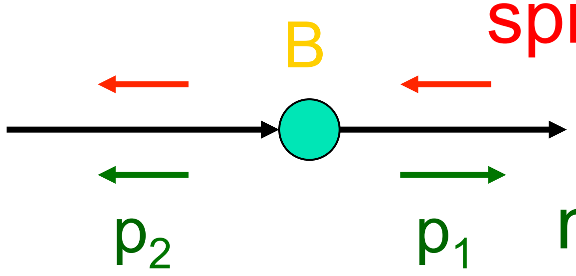


$$\propto \langle \phi K^* | (\bar{s}\, d)_{S+P} | 0 \rangle$$

$$\mathcal{A}^0,\ \mathcal{A}^- = O\left(\frac{1}{m^2}\ln^2\frac{m}{\Lambda_h}\right), \qquad \mathcal{A}^+ = O(\frac{1}{m^4})$$

- annihilation topology $\Longrightarrow$ overall $1/m$
- helicity-flips $\Longrightarrow$ rest of $1/m$ factors, or twists

For (V-A)(V-A), left-handed current



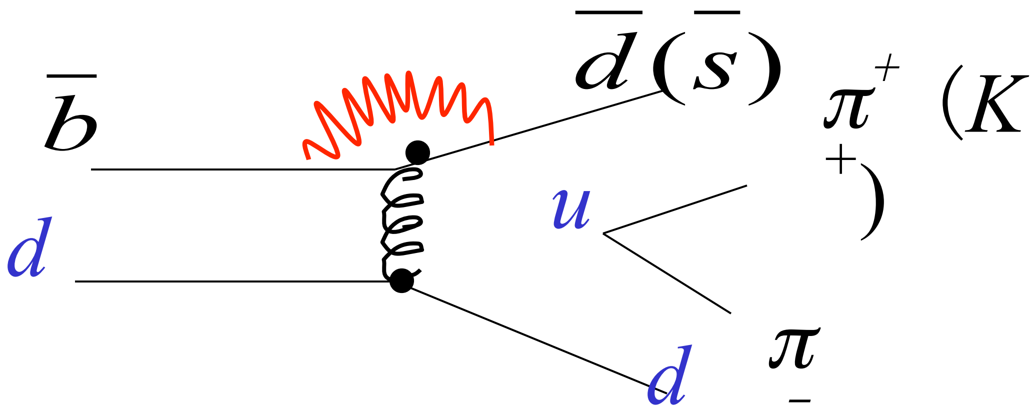
Like $B \to e\ \nu_e$

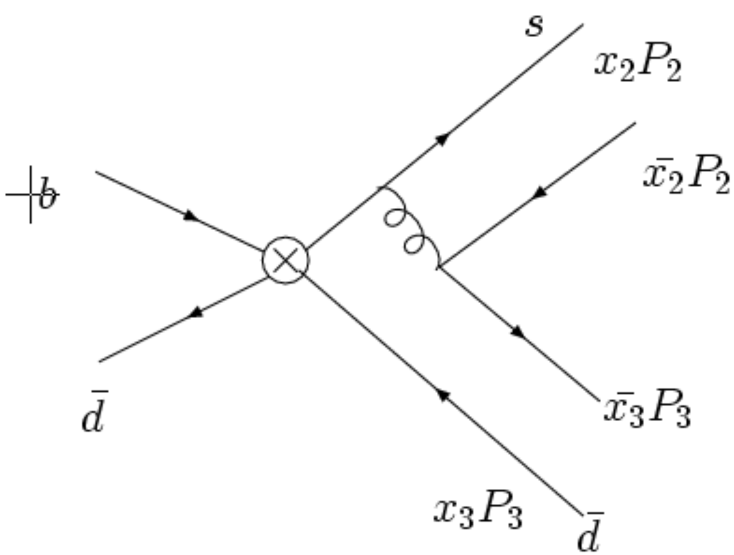
pseudo-scalar B requires spins in opposite directions, namely, helicity conservation

Annihilation suppression ~ $1/m_B$ ~ 10%

No suppression for O_6

- Space-like penguin
- Become (s-p)(s+p) operator after Fiertz transformation   Chirally enhanced
- No suppression, contribution “big” (20-30%)





$$A \propto \int_0^1 dx_2 dx_3 \frac{\phi(x_2)\phi(x_3)}{x_2 x_3^2}$$

$$\phi(x) \sim x(1-x)$$

Endpoint singularity in collinear factorization

In QCDF, the annihilation diagram can only be parameterized, data fitting

$$X_A = (1 + \varrho_A e^{i\varphi_A}) \ln \frac{m_B}{\Lambda_h}$$

- f_L can be accomodated with $O(1)$ QCD annihilation amplitude - formally $O(ln^2/m^2) \Rightarrow \rho = O(1)$

- large $\Delta S = 1$ $B \to \phi K,\ K^*\pi$ rates can be accounted for with $O(1)$ QCD annihilation amplitudes $\Rightarrow \rho = O(1)$.

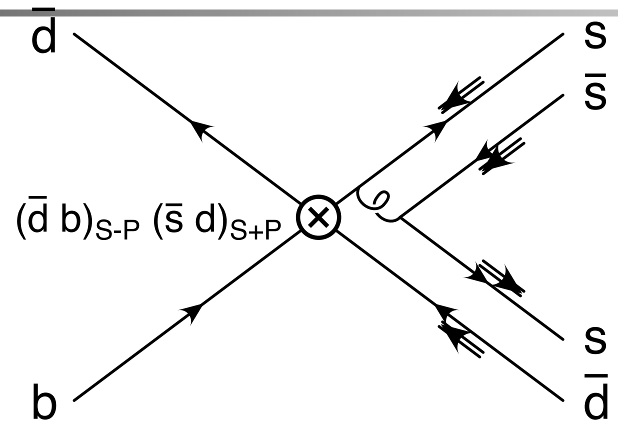
- $A_{CP}(K^+\pi^-)$ can be accounted for with $\rho = O(1)$ + large strong phase in QCD annihilation

- In principle all of the above could also be accounted for with 'charming penguins' : Leading power? Bauer et al, Subleading power? Ciuchini et al, FSI models Cheng et al, Colangelo et al

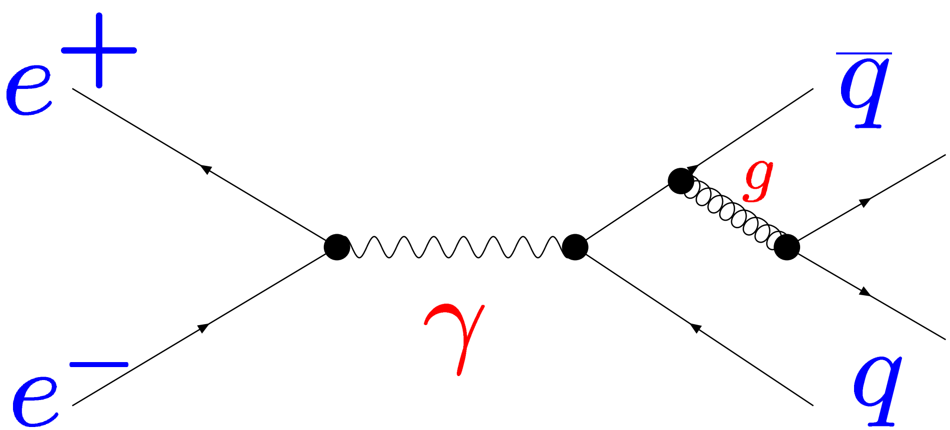
Can annihilation dynamics be probed directly: can we test for $\mathcal{O}(1)$ power corrections, or $\rho \sim 1$ in BBNS parametrization?

Annihilation and $e^+e^- \to M_1M_2$

Compare



$\propto \langle M_1 M_2 | \bar{s}\, d | 0 \rangle$



$\propto \langle M_1 M_2 | \bar{q}\, \gamma_\mu q | 0 \rangle$

Vector-current annihilation form factors

$$\langle VP|\bar{q}\gamma_\mu q|0\rangle = \frac{2iV^q}{m_P+m_V}\epsilon_{\mu\nu\rho\sigma}\epsilon^\nu p_V^\sigma p_P^\rho$$

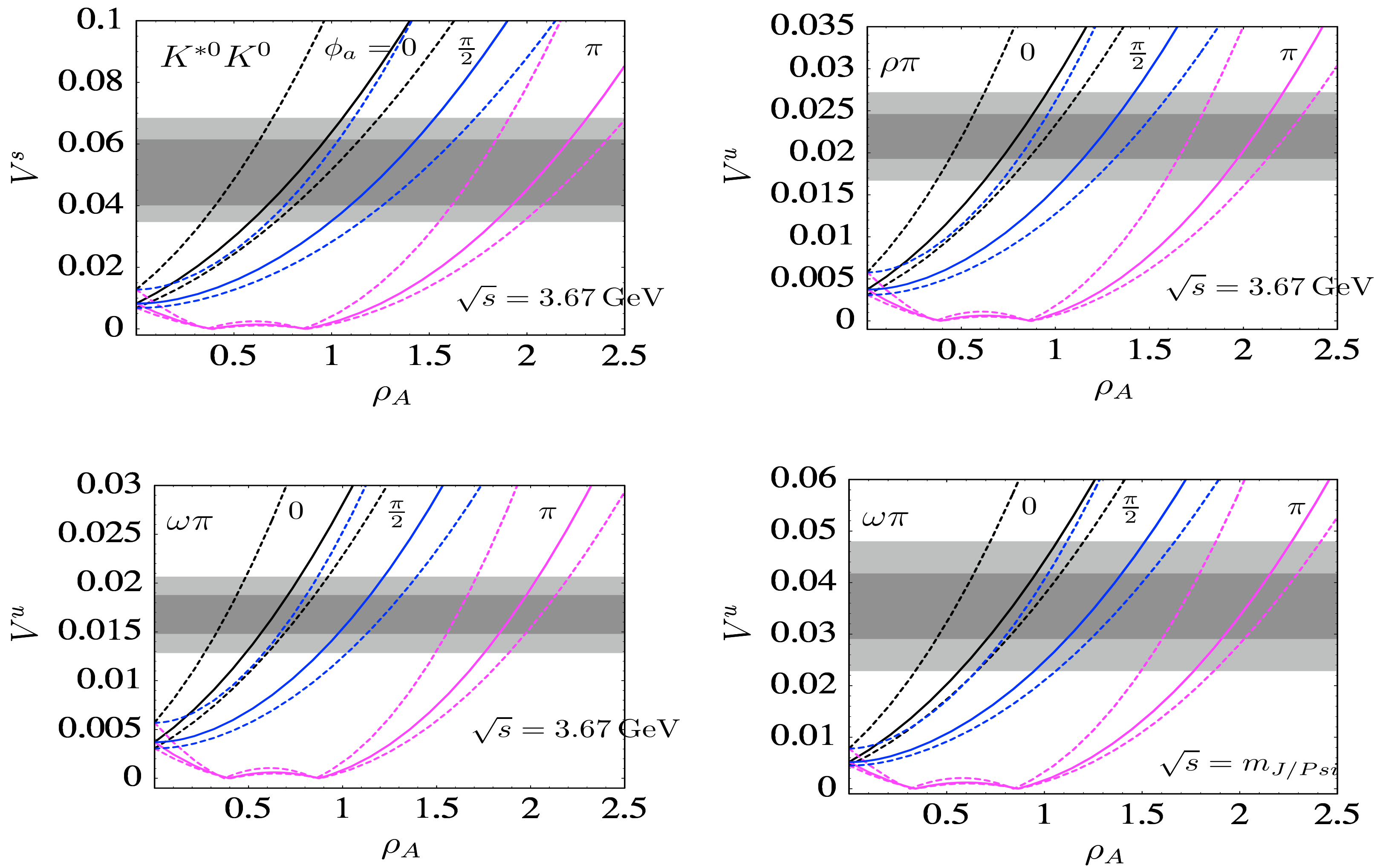
$$\langle P_1P_2|\bar{q}\gamma^m uq|0\rangle = F^q(p_1-p_2)^\mu$$

$\langle V_1V_2|\bar{q}\gamma^\mu q|0\rangle$ contains three form factors

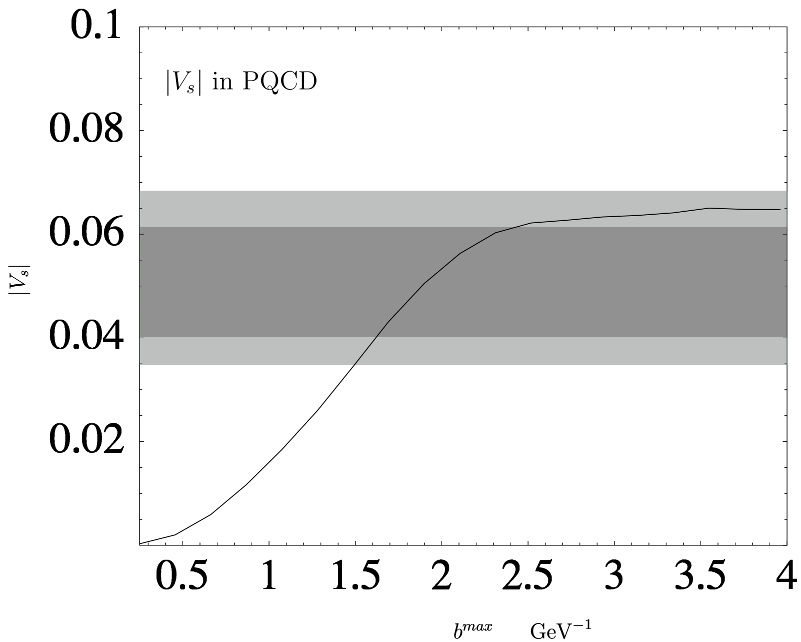
- $V^q \sim 1/s^2 ln^2(\sqrt{s}/\Lambda)$
- F^q: finite $1/s$ contribution Brodsky, Lepage + $1/s^2 ln^2(\sqrt{s}/\Lambda)$ correction
- Use continuum CLEO-c ($20.46\ \mathrm{pb}^{-1}$)+ BES VP data at $\sqrt{s}\approx 3.7$ GeV, near $\psi(2s)$, to extract $|V^q|$. Compare with BBNS parametrization, PQCD
- extrapolate to larger $\sqrt{s}\approx m_B$, compare with reach of luminosity at m_B from initial state radiation (ISR)

$e^+e^- \longrightarrow VP$ in BBNS parametrization

considered three values of $\alpha_s = 1,\ .5,\ \alpha_s(\sqrt{\sqrt{s}\Lambda_h})$; three values of strong phase $\phi_A = 0, \pm\pi/2, \pi$. Measurements $\Rightarrow \rho_A \sim 1$ or $(m/\sqrt{s})$"Log $\sqrt{s}/\Lambda$" ~ 1



$e^+e^- \to K^{*0}K^0$ in PQCD



$|V_s|$ vs. $\mathrm{b}^{\max}$, $\sqrt{\mathrm{s}} = 3.67$ GeV

CDL,Wang[2], PRD 75, 094020 (2007)

PQCD annihilation in right ballpark,

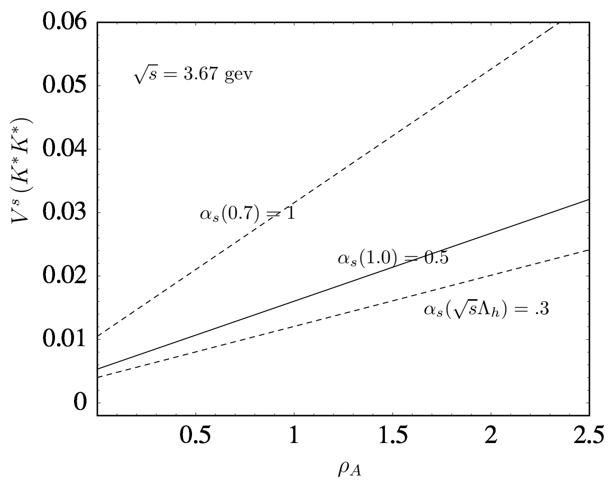
$e^+e^- \to VV$

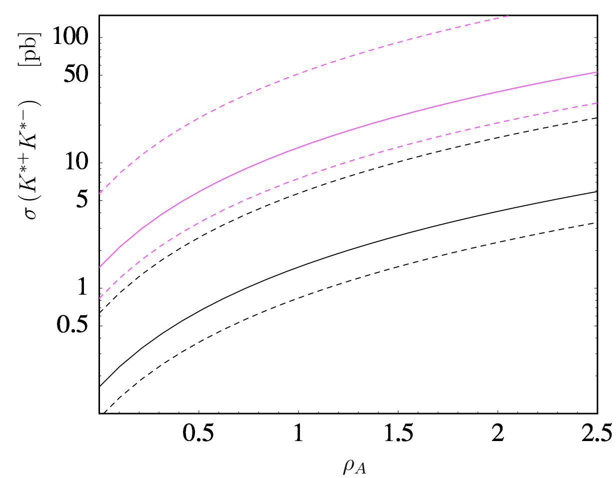
$$\langle K^*K^*|\bar{q}\,\gamma_\mu q|0\rangle = V_1^q(\epsilon_\mu^*\,\eta^*\cdot p_1 - \eta_\mu^*\,\epsilon^*\cdot p_2) + V_2^q(\epsilon^*\cdot\eta^*)q_\mu + V_3^q\,\frac{\epsilon^*\cdot p_2\,\eta^*\cdot p_1}{Q^2}\,q_\mu$$

Polarizations:

$$V_1^q \Rightarrow LT, \quad Amp \sim 1/Q^3\,\mathrm{Log}^2\,Q/\Lambda_h \qquad Q \equiv \sqrt{s}$$

$$V_3^q \Rightarrow TT, \quad Amp \sim 1/Q^4\,\mathrm{Log}^2\,Q/\Lambda_h, \qquad V_2^q \Rightarrow LL, \quad Amp \sim m_q/Q^4\,\mathrm{Log}^2\,Q/\Lambda_h$$





$\sqrt{s} = 3.67$ GeV, $\phi = 0$, left : $V_1^s(K^{*+}K^{*-})$ vs. ρ; right: $\sigma_{LT}(K^{*+}K^{*-})$ [pb] vs. ρ for $V_1^u = V_1^d = 0$ (lower), $SU(3)$ limit $V_1^s = V_1^{d,u}$ (upper).

Strategies in penguin-dominated decays

- QCDF loses predictive power in penguin annihilations with transverse polarization;
- Use information from experiments as much as we can;
  - Strategy 1: fit only the penguin annihilation from $B \to \phi K^*$ measurements;
  - Strategy 2: fit the whole penguin amplitude from $B \to \phi K^*$;
  - Trust the predictions for other topological amplitudes using QCDF;
  - Constrained X_A:

$$\varrho_A = 0.5 \pm 0.2_{\text{exp.}} \qquad \varphi_A = (-43 \pm 19_{\text{exp.}})^\circ,$$

  - $\hat{\alpha}_4^{c-} = \alpha_4^{c-} + \beta_3$ from data:

$$\begin{aligned} \bar{A}_- &= A_{K^*\phi}\lambda_c^{(s)} P_-^{K^*\phi}, \\ P_-^{K^*\phi} &= (-0.084 \pm 0.008(\text{exp})^{+0.008}_{-0.009}(\text{th})) \\ &\quad + i\,(0.021 \pm 0.015(\text{exp})^{+0.003}_{-0.002}(\text{th})), \end{aligned}$$

with α_3^{c-} from QCDF

$$\hat{\alpha}_4^{c-} = (-0.08 \pm 0.02) + i\,(0.03 \pm 0.02).$$

In Perturbative QCD approach, we do not neglect the quark transverse momentum

$$\frac{1}{x_2 x_3^2 m_B^2} \to \frac{1}{[x_2 x_3 m_B^2 - (k_{2T} + k_{3T})^2](x_3 m_B^2 - k_{3T}^2)}$$

Then there is no endpoint singularity

large double logarithm are produced after radiative corrections,

they should be resummed to generate the Sudakov form factor to improve the perturbation theory.

PQCD approach

- $A \sim \int d^4k_1\, d^4k_2\, d^4k_3\, Tr\, [\, C(t)\ \Phi_B(k_1)\ \Phi_\pi(k_2)\ \Phi_\pi(k_3)\ H(k_1,k_2,k_3,t)\,]\ exp\{-S(t)\}$
- $\Phi_\pi(k_3)$ are the light-cone wave functions for mesons: non-perturbative, but universal
- $C(t)$ is Wilson coefficient of 4-quark operator
- $exp\{-S(t)\}$ is Sudakov factor， to relate the short- and long-distance interaction
- $H(k_1,k_2,k_3,t)$ is perturbative calculation of six quark interaction

PQCD approach

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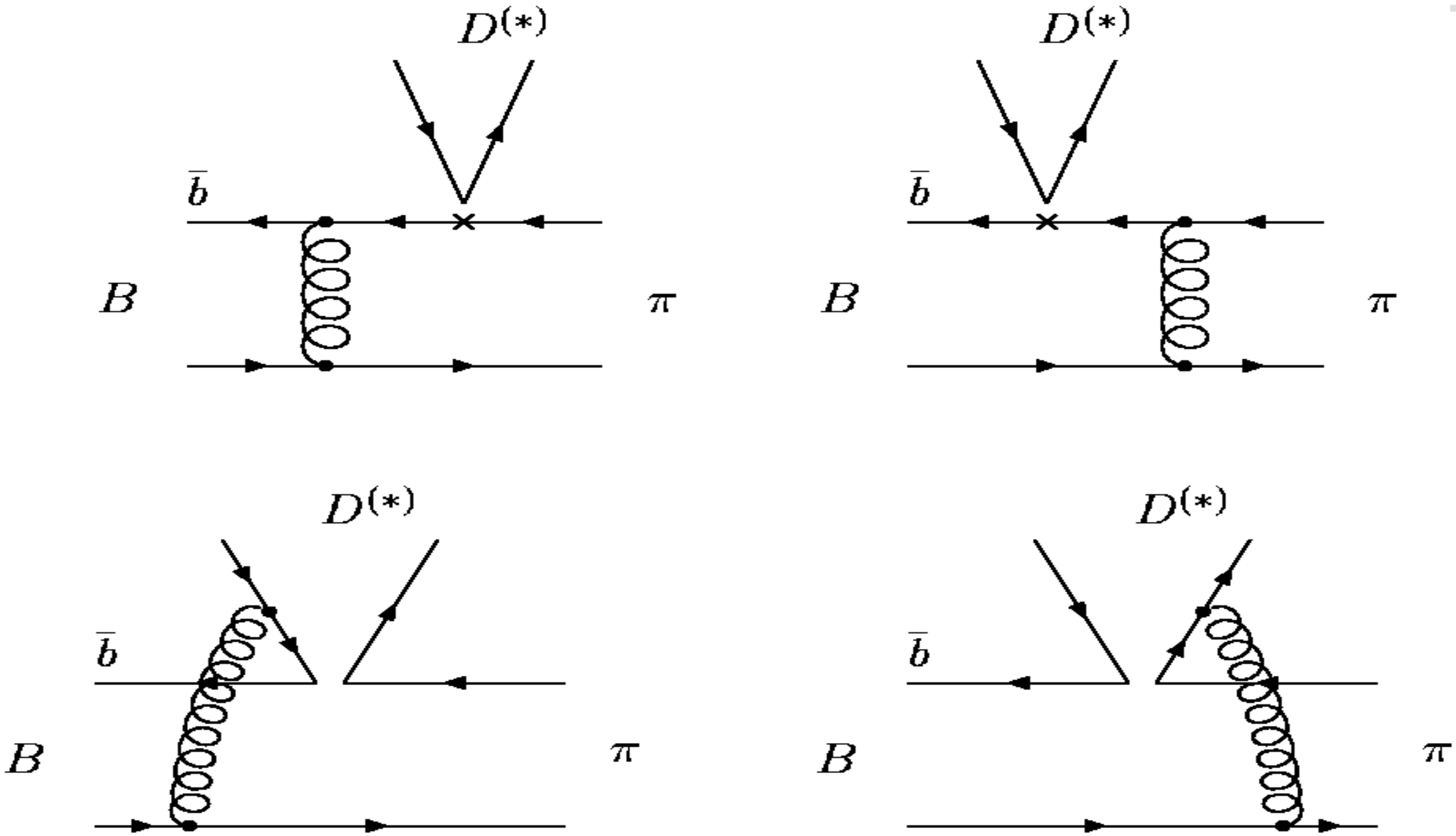
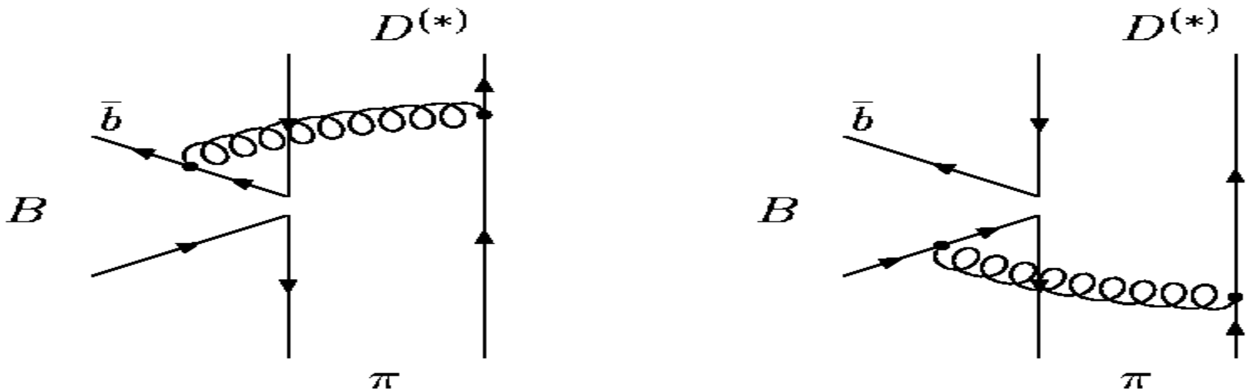
Perturbative Calculation of H(t) in PQCD Approach



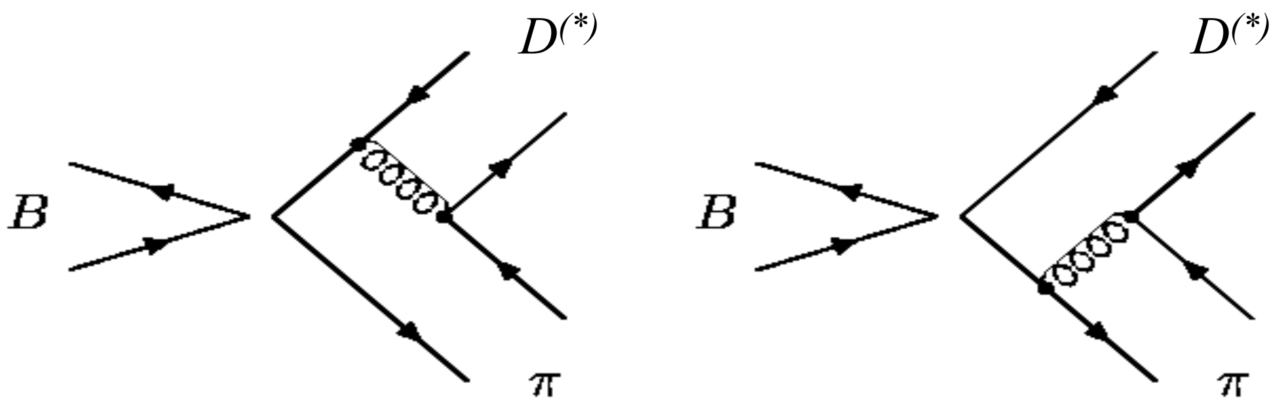
Form factor—factorizable

Non-factorizable

Perturbative Calculation of H(t) in PQCD Approach



Non-factorizable annihilation diagram



Factorizable annihilation diagram

- All diagrams using the same wave functions
- All channels use same wave functions
- Number of parameters reduced

$$A = \phi_B(x_1, b_1) \otimes \phi_{M_1}(x_2, b_2) \otimes \phi_{M_2}(x_3, b_3) \otimes H(x_i, b_i, t) \otimes C(t) \otimes e^{-S(t)}$$

New calculation with updated vector meson wave functions

Longitudinal wave functions are different from transverse wave functions

Twist-3

$$\Phi_V^L = \frac{1}{\sqrt{6}}\left[M_V \not\epsilon_L \phi_V(x) + \not\epsilon_L \not P \phi_V^t(x) + M_V \phi_V^s(x)\right]$$

$$\Phi_V^\perp = \frac{1}{\sqrt{6}}\left[M_V \not\epsilon_T \phi_V^v(x) + \not\epsilon_T \not P \phi_V^T(x) + M_V i\epsilon_{\mu\nu\rho\sigma}\gamma_5\gamma^\mu \epsilon_T^\nu n^\rho v^\sigma \phi_V^a(x)\right]$$

Twist-2

New calculation with updated vector meson wave functions

Longitudinal wave functions are different from transverse wave functions

Twist-3

$$\Phi_V^L = \frac{1}{\sqrt{6}}\left[M_V \not\epsilon_L \phi_V(x) + \not\epsilon_L \not P \phi_V^t(x) + M_V \phi_V^s(x)\right]$$

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Twist-2

The twist-2 distribution amplitudes

$$\phi_V(x) = \frac{3f_V}{\sqrt{6}} x(1-x) \left[1 + a_{1V}^{\parallel} C_1^{3/2}(t) + a_{2V}^{\parallel} C_2^{3/2}(t)\right]$$

$$\phi_V^T(x) = \frac{3f_V^T}{\sqrt{6}} x(1-x) \left[1 + a_{1V}^{\perp} C_1^{3/2}(t) + a_{2V}^{\perp} C_2^{3/2}(t)\right]$$

$$a_{1\rho}^{\parallel(\perp)} = a_{1\omega}^{\parallel(\perp)} = a_{1\phi}^{\parallel(\perp)} = 0, \quad a_{1K^*}^{\parallel(\perp)} = 0.03 \pm 0.02\,(0.04 \pm 0.03)$$

$$a_{2\rho}^{\parallel(\perp)} = a_{2\omega}^{\parallel(\perp)} = 0.15 \pm 0.07\,(0.14 \pm 0.06)\; a_{2\phi}^{\parallel(\perp)} = 0\;(0.20 \pm 0.07)$$

$$a_{2K^*}^{\parallel(\perp)} = 0.11 \pm 0.09\;(0.10 \pm 0.08)$$

The twist-2 distribution amplitudes are not far away from the asymptotic form

The twist-2 distribution amplitudes

$$\phi_V(x) = \frac{3f_V}{\sqrt{6}} x(1-x)\left[1 + a_{1V}^{\parallel} C_1^{3/2}(t) + a_{2V}^{\parallel} C_2^{3/2}(t)\right]$$

$$\phi_V^T(x) = \frac{3f_V^T}{\sqrt{6}} x(1-x)\left[1 + a_{1V}^{\perp} C_1^{3/2}(t) + a_{2V}^{\perp} C_2^{3/2}(t)\right]$$

Comparing with previous input

$$a_{1K^*}^{||} = 0.03 \pm 0.02, \qquad a_{2\rho}^{||} = a_{2\omega}^{||} = 0.15 \pm 0.07,$$

$$a_{2K^*}^{||} = 0.11 \pm 0.09, \qquad a_{2\phi}^{||} = 0.18 \pm 0.08,$$

$$a_{1K^*}^{\perp} = 0.04 \pm 0.03, \qquad a_{2\rho}^{\perp} = a_{2\omega}^{\perp} = 0.14 \pm 0.06,$$

$$a_{2K^*}^{\perp} = 0.10 \pm 0.08, \qquad a_{2\phi}^{\perp} = 0.14 \pm 0.07.$$

New calculation with updated vector meson wave functions

There are not enough information to constrain the twist-3 distribution amplitudes. We just use the asymptotic form for simplicity.

$$\phi_V^t = \frac{3 f_V^T}{2\sqrt{6}} t^2$$

$$\phi_V^s = \frac{3 f_V^T}{2\sqrt{6}} (-t)$$

$$\phi_V^v = \frac{3 f_V}{8\sqrt{6}} (1 + t^2)$$

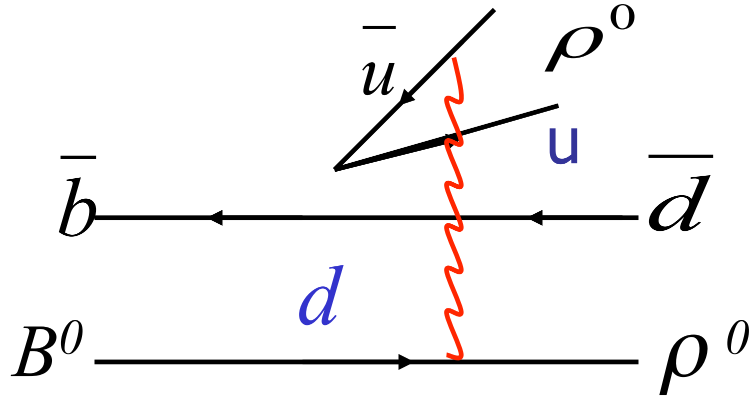
$$\phi_V^a = \frac{3 f_V}{4\sqrt{6}} (-t)$$

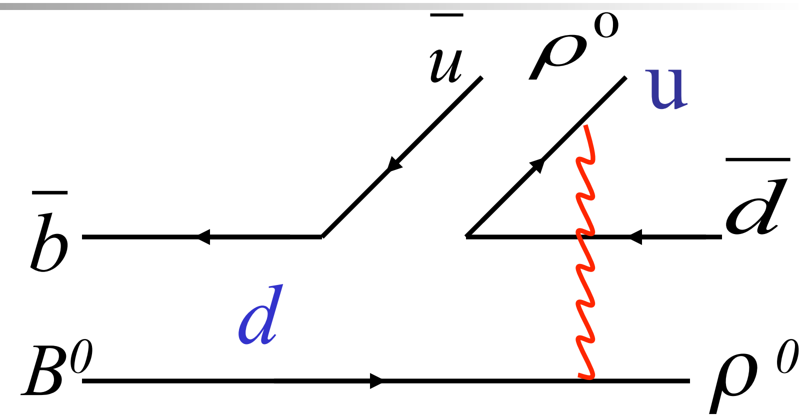
B→ρρ(ω) decays

	Branching ratio(10^{-6})			f_L		
	QCDF	PQCD	Expt	QCDF	PQCD	Expt
$B^+ \to \rho^+\rho^0$	20.0	13.4	24.0±1.9	0.96	0.98	0.95±0.016
$B^0 \to \rho^+\rho^-$	25.5	26.1	24.2±3.1	0.92	0.94	0.977±0.026
$B^0 \to \rho^0\rho^0$	0.9	0.27	0.73±0.28	0.92	0.18	0.75±0.14
1212.4015			$1.02 \pm 0.30 \pm 0.15$			$0.21^{+0.18}_{-0.22} \pm 0.13$
$B^+ \to \rho^+\omega$	16.9	12.1	15.9±2.1	0.96	0.97	0.90±0.06

H. Y. Cheng and C. K. Chua, Phys. Rev. D 80, 114008 (2009)

Two operators contribute to $B^0 \to \rho^0 \rho^0$ decay





$O_1 = (\bar{u}u)\cdot(\bar{b}d)$

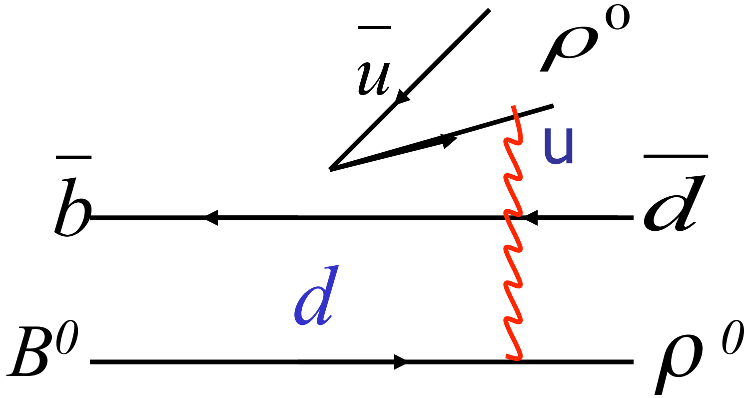
$O_2 = (\bar{u}d)\cdot(\bar{b}u)$

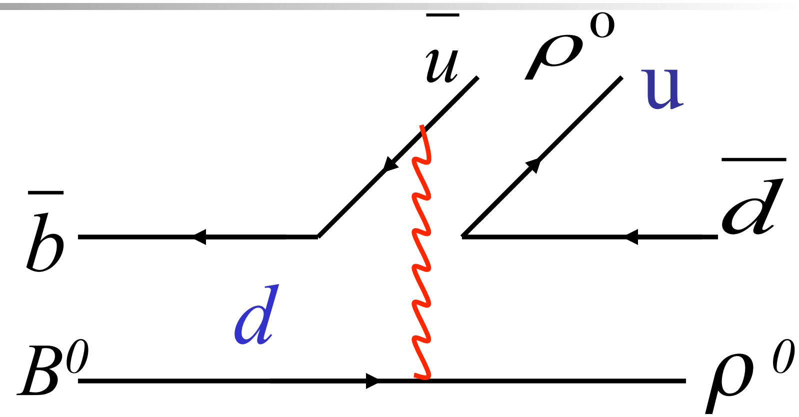
color enhanced

color suppressed

$C_1 \sim -0.2 \quad \sim \quad C_2(1/3 \quad) \equiv C_2/N_c \sim 1/3$

Two operators contribute to $B^0 \to \rho^0\rho^0$ decay:





$O_1 = (\bar{u}u)\cdot(\bar{b}d)$

$O_2 = (\bar{u}d)\cdot(\bar{b}u)$

color enhanced

color suppressed

$C_1 \sim -0.2 \quad \sim \quad C_2(1/3 + s_8) \equiv C_2/N_c^{eff} \sim 1/3 + \ldots$

Branching ratio(10^{-6}) f_L

	QCDF	PQCD	Expt	QCDF	PQCD	Expt
$B^0 \to \rho^0\omega$	0.08	0.39	<1.5	0.52	0.67	
$B^0 \to \omega\omega$	0.7	0.5	<4.0	0.94	0.66	
$B^0 \to \rho^0\Phi$		0.013	<0.33		0.95	
$B^+ \to \rho^+\Phi$		0.028	<3.0		0.95	
$B^0 \to \omega\Phi$		0.01			0.94	
$B^0 \to \Phi\Phi$		0.01			0.97	

7

$B \to K^* \rho(\omega)$ decays

	Branching ratio(10^{-6})			f_L		
	QCDF	PQCD	Expt	QCDF	PQCD	Expt
$B^+ \to K^{*0}\rho^+$	9.2	9.9	9.2±1.5	0.48	0.70	0.48±0.08
$B^+ \to K^{*+}\rho^0$	5.5	6.0	4.6±1.1	0.67	0.75	0.78±0.12
$B^+ \to K^{*+}\omega$	3.0	4.0	<7.4	0.67	0.64	0.41±0.19
$B^0 \to K^{*0}\rho^0$	4.6	3.2	3.4±1.5	0.39	0.65	0.57±0.10
$B^0 \to K^{*+}\rho^-$	8.9	8.4	<12.0 (10.3)	0.53	0.68	0.38±0.13 ±0.03 (BaBar)
$B^0 \to K^{*0}\omega$	2.5	4.7	2.0±0.5	0.58	0.65	0.69±0.13

$B \to K^* K^*$ decays

	Branching ratio(10^{-6})			f_L		
	QCDF	PQCD	Expt	QCDF	PQCD	Expt
$B^+ \to K^{*+} \bar{K}^{*0}$	0.6	0.55	1.2±0.5	0.45	0.74	0.75±0.25
$B^0 \to K^{*+} K^{*-}$	0.1	0.21	<2.0	~1.0	~1.0	
$B^0 \to K^{*0} \bar{K}^{*0}$	0.6	0.33	0.8±0.5	0.52	0.58	0.80±0.13

Bs → VV decays

Bs→ρρ(ω) decays

	Branching ratio(10^{-6})			f_L		
	QCDF	PQCD	Expt	QCDF	PQCD	Expt
$B_s \to \rho^+\rho^-$	0.68	1.5		1.0	1.0	
$B_s \to \rho^0\rho^0$	0.34	0.75		1.0	1.0	
$B_s \to \rho^0\omega$	0.004	0.009		1.0	1.0	
$B_s \to \omega\omega$	0.19	0.36		1.0	1.0	

$B_s \to K^{*}\rho(\omega)$ decays

	Branching ratio(10^{-6})			f_L		
	QCDF	PQCD	Expt	QCDF	PQCD	Expt
$B_s \to K^{*-}\rho^{+}$	21.6	24.0		0.92	0.95	
$B_s \to \underline{K}^{*0}\rho^{0}$	1.3	0.39		0.90	0.57	
$B_s \to \underline{K}^{*0}\omega$	1.1	0.34		0.90	0.49	

	Branching ratio(10^{-6})			f_L		
	QCDF	PQCD	Expt	QCDF	PQCD	Expt
$Bs \to K^{*+}K^{*-}$	7.6	5.5		0.52	0.41	
$Bs \to K^{*0}\underline{K}^{*0}$	6.6	5.4	8.1±4.6±5.6	0.56	0.38	0.31±0.13
$Bs \to \rho^0\Phi$	0.18	0.23		0.88	0.86	
$Bs \to \omega\Phi$	0.18	0.17		0.95	0.69	
$Bs \to \Phi\Phi$	16.7	16.7	19±5	0.36	0.35	0.361±0.022
$Bs \to \underline{K}^{*0}\Phi$	0.37	0.39	1.1±0.29	0.43	0.50	0.51±0.17

More obsevables

Modes	$Br(10^{-6})$	$f_L(\%)$	$f_\perp$ (%)	$\phi_\parallel$(rad)
$B^0 \to K^{*0}\phi$	$9.8^{+4.9}_{-3.8}$	$56.5^{+5.8}_{-5.9}$	$21.3^{+2.8}_{-2.9}$	$2.15^{+0.22}_{-0.19}$
Exp	9.8 ± 0.6	48 ± 3	24 ± 5	2.40 ± 0.13
$B^+ \to K^{*+}\phi$	$10.3^{+4.9}_{-3.8}$	$57.0^{+6.3}_{-5.9}$	$21.0^{+3.0}_{-3.0}$	$2.18^{+0.23}_{-0.19}$
Exp	10.0 ± 2.0	50 ± 5	20 ± 5	2.34 ± 0.18
$B_s \to \phi\phi$	$16.7^{+8.9}_{-7.1}$	$34.7^{+8.9}_{-7.1}$	$31.6^{+3.5}_{-4.4}$	$2.01^{+0.23}_{-0.23}$
Exp	19 ± 5	34.8 ± 4.6	$36.5 \pm 4.4 \pm 2.7$	$2.71^{+0.31}_{-0.36} \pm 0.22$
$B_s \to \bar{K}^{*0}\phi$	$0.39^{+0.20}_{-0.17}$	$50.0^{+8.1}_{-7.2}$	$24.2^{+3.6}_{-3.9}$	$1.95^{-0.21}_{-0.22}$
Exp^a	1.10 ± 0.29	$51 \pm 15 \pm 7$	$28 \pm 11 \pm 2$	$1.75 \pm 0.58 \pm 0.30$
$B_s \to K^{*0}\bar{K}^{*0}$	$5.4^{+3.0}_{-2.4}$	$38.3^{+12.1}_{-10.5}$	$30.0^{+5.3}_{-6.1}$	$2.12^{+0.21}_{-0.25}$
Exp	$28.1 \pm 4.6 \pm 5.6$	$31 \pm 12 \pm 4$	$38 \pm 11 \pm 4$	

More obsevables

	$A_{CP}^{dir}(\%)$	$A_{CP}^{0}(\%)$	$A_{CP}^{\perp}(\%)$	$\Delta\phi_{\parallel}(rad)$	$\Delta\phi_{\perp}(rad)$
$B^0 \to K^{*0}\phi$	0.0	0.0	0.0	0.0	0.0
Exp		4 ± 6	-11 ± 12	0.11 ± 0.22	0.08 ± 0.22
$B^+ \to K^{*+}\phi$	$-1.0^{+0.18}_{-0.26}$	$-0.60^{+0.12}_{-0.14}$	$0.75^{+0.23}_{-0.11}$	$-0.05^{+0.12}_{-0.33}$	-0.01
Exp	-1 ± 8	$17 \pm 11 \pm 2$	$22 \pm 24 \pm 8$	$0.07 \pm 0.2 \pm 0.05$	$0.19 \pm 0.20 \pm 0.07$
$B_s \to \phi\phi$	0.0	0.0	0.0	0.0	0.0
$B_s \to \bar{K}^{*0}\phi$	0.0	0.0	0.0	0.0	0.0
$B_s \to K^{*0}\bar{K}^{*0}$	0.0	0.0	0.0	0.0	0.0

Summary

- The polarization in B→VV decays can be explained by PQCD

Important role of Annihilation type diagram

New physics seems still not show up

Thank you!