Charmless B decays in Factorization Assisted Topological amplitude approach

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Based on work collaborated with Cai-Dian Lü and Qi-An Zhang
(arXiv:1608.02819)

Outline

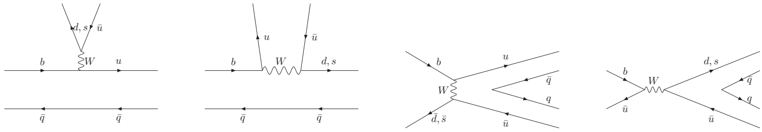
- Introduction/Motivation
- Factorization Assisted Topological Amplitude approach
- Numerical results for $B \to PP$,PV decays and Analysis
- Summary

$B \to PP$, VP and PV in QCD-methods

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}}\{V_{ub}V^*_{ud(s)}C_{1,2}(\mu)O^u_{1,2}(\mu) - V_{tb}V^*_{td(s)}\Sigma^{10}_{i=3}C_i(\mu)O_i(\mu)\}$$

- Collinear QCD Factorization approach need to include a large penguin annihilation contribution (as free parameter) to enhance the branching fractions and direct CP asymmetry of penguin-dominated charmless B decays.
- penguin annihilation contribution replaced by the power suppressed nonperturbative charming penguin effect in Soft-Collinear Effective Theory.
- Calulated in Perturbative QCD approach based on k_T factorization.
- Although some soft and sub-leading effects were considered, $\pi\pi$ and πK puzzle etc was still left in the conventional factorization approaches

Topological diagrammatic approach[Cheng, Chiang and Kuo 2015]



(a) T (b) C (c) E (d) A

1. Distinct by weak interaction and flavor flows with all strong interaction encoded, including non-perturbative ones.
2. Amplitudes with strong phases extracted from data.
3. Based on flavor $SU(3)$ symmetry. $SU(3)$ **breaking effect was lost**.
4. $B \to PP$, VP and PV fitted separately, $13 + 19 = 32$ parameters. **Less predictive** *(Phys. Rev. D **91**, no. 1, 014011 (2015).)*

- Improved by Factorization Assisted Topological amplitude (FAT)approach.
  - keep flavor $SU(3)$ symmetry breaking effect.
  - further reducing the number of free parameters by fitting all the decay channels

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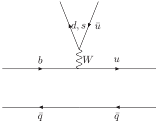
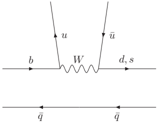
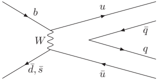


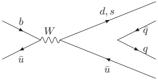
(a) T



(b) C



(c) E



(d) A

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Factorization Assisted Topological amplitude approach first applied in hadronic D decays

[H. n. Li, C. D. Lu and F. S. Yu, Phys. Rev. D **86***, 036012 (2012),Phys. Rev. D* **89***, no. 5, 054006 (2014)]*

- ⋆ Was in great success to resolve the long-standing puzzle from the large difference of $D_0 \to \pi^+\pi^-$ and $D_0 \to K^+K^-$ branching fractions.
- ⋆ Also predicted 0.1% of direct CP asymmetry difference between them.

NEW *LHCb-PAPER-2015-055*
to be submitted to PRL

$\Delta A_{CP\ prompt} = (-0.10 \pm 0.08(stat) \pm 0.03(syst))\%$

- ▸ "Analysis of Two-body Charmed B meson decays in Factorization Assisted Topological amplitude approach,"
  S. H. Zhou, Y. B. Wei, Q. Qin, Y. Li, F. S. Yu and C. D. Lu, Phys. Rev. D **92***, no. 9, 094016 (2015)*
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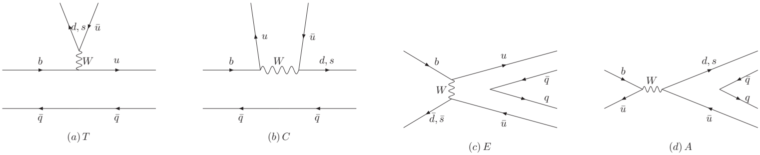
Factorization Assisted Topological amplitude approach in $B \to PP$, VP and PV decays



- Color-favored tree emission diagram (T)

⋆ It is proved factorization to all order of α_s expansion in QCDF, PQCD and SCET.

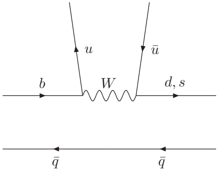
$$
\begin{aligned}
T^{P_1P_2} &= i\frac{G_F}{\sqrt{2}}V_{ub}V_{uq'}a_1(\mu)f_{p_2}(m_B^2 - m_{p_1}^2)F_0^{BP_1}(m_{p_2}^2),\\
T^{PV} &= \sqrt{2}G_F V_{ub}V_{uq'}a_1(\mu)f_V m_V F_1^{B-P}(m_V^2)(\varepsilon_V^* \cdot p_B),\\
T^{VP} &= \sqrt{2}G_F V_{ub}V_{uq'}a_1(\mu)f_P m_V A_0^{B-V}(m_P^2)(\varepsilon_V^* \cdot p_B), \qquad (1)
\end{aligned}
$$

⋆ The $SU(3)$ breaking effect is automatically kept

⋆ No free parameter

- For other diagrams dominated by non-factorization contributions.
  - ⋆ We factorize out the decay constants and form factor to keep the $SU(3)$ breaking effect.
  - ⋆ we extract the amplitude and strong phase from experimental data by χ^2 fit.

- color-suppressed tree emission diagram(C)

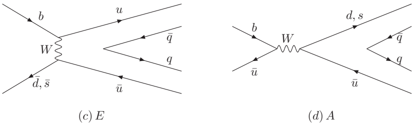


$(b)\, C$

$$C^{P_1 P_2} = i\frac{G_F}{\sqrt{2}} V_{ub} V_{uq'} \chi^C e^{i\phi^C} f_{p_2}(m_B^2 - m_{p_1}^2) F_0^{BP_1}(m_{p_2}^2),$$
$$C^{VP} = \sqrt{2} G_F V_{ub} V_{uq'} \chi^C e^{i\phi^C} f_P m_V A_0^{B-V}(m_P^2)(\varepsilon_V^* \cdot p_B),$$
$$C^{PV} = \sqrt{2} G_F V_{ub} V_{uq'} \chi^{C'} e^{i\phi^{C'}} f_V m_V F_1^{B-P}(m_V^2)(\varepsilon_V^* \cdot p_B), \qquad (2)$$

⋆ χ^C,$e^{i\phi^C}$ and $\chi^{C'}, e^{i\phi^{C'}}$ to distinguish cases in which the emissive meson is pseudo-scalar or vector respectively.

▶ The annihilation type diagrams(E and A)

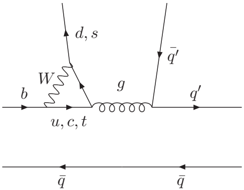


⋆ W-exchange topology (E) is non-factorization in QCD factorization approach(NLO)

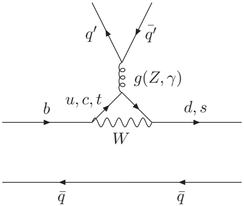
$$E^{P_1 P_2} = i\frac{G_F}{\sqrt{2}} V_{ub} V_{uq'} \chi^E \mathrm{e}^{i\phi^E} f_B m_B^2 (\frac{f_{p_1} f_{p_2}}{f_\pi^2}),$$
$$E^{PV,VP} = \sqrt{2} G_F V_{ub} V_{uq'} \chi^E \mathrm{e}^{i\phi^E} f_B m_V (\frac{f_P f_V}{f_\pi^2})(\varepsilon_V^* \cdot p_B), \quad (3)$$

⋆ As discussed in conventional topological diagram approach, W-annihilation diagram (A) contribution is negligible.

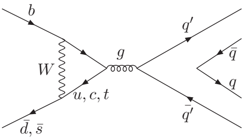
The penguin topological diagrams are grouped into QCD penguin and electro-weak penguin topologies.



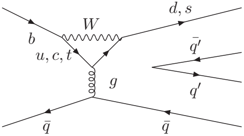
$(a)\ P$



$(b)\ P_C(P_{EW})$

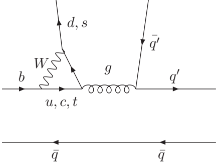


$(c)\ P_E$



$(d)\ P_A$

- color-favored penguin emission diagram (P)

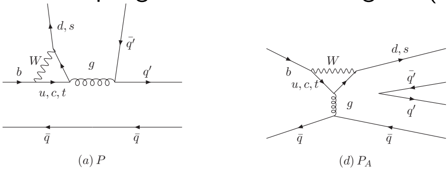


$(a)\ P$

1. The leading contribution from topology Pdiagram is similar to diagram T, which is proved factorization in various QCD-inspired approaches.
2. "chiral enhanced" penguin contributions need to be fitted.

$$
\begin{aligned}
P^{PP} &= -i\frac{G_F}{\sqrt{2}}V_{tb}V^*_{tq'}[a_4(\mu)+\chi^P e^{i\phi^P} r_\chi]f_{p_2}(m_B^2-m_{p_1}^2)F_0^{BP_1}(m_{p_2}^2),\\
P^{PV} &= -\sqrt{2}G_F V_{tb}V^*_{tq'}a_4(\mu)f_V m_V F_1^{B-P}m_V^2(\varepsilon_V^*\cdot p_B),\\
P^{VP} &= -\sqrt{2}G_F V_{tb}V^*_{tq'}[a_4(\mu)-\chi^P e^{i\phi^P} r_\chi]f_P m_V A_0^{B-V}(m_P^2)(\varepsilon_V^*\cdot p_B).
\end{aligned}
\tag{4}
$$

▶ power correction to P-penguin annihilation diagram (P_A)



⋆ P_A is similar with P and the difference is only at QCD not EW.

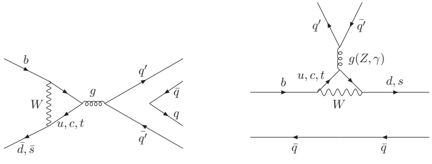
$$P^{PP} = -i\frac{G_F}{\sqrt{2}}V_{tb}V^*_{tq'}[a_4(\mu) + \chi^P e^{i\phi^P} r_\chi] f_{p_2}(m_B^2 - m_{p_1}^2)F_0^{BP_1}(m_{p_2}^2),$$
$$P^{PV} = -\sqrt{2}G_F V_{tb}V^*_{tq'} a_4(\mu) f_V m_V F_1^{B-P} m_V^2(\varepsilon_V^* \cdot p_B),$$
$$P^{VP} = -\sqrt{2}G_F V_{tb}V^*_{tq'}[a_4(\mu) - \chi^P e^{i\phi^P} r_\chi] f_P m_V A_0^{B-V}(m_P^2)(\varepsilon_V^* \cdot p_B). \quad (5)$$

⋆ The contribution of P_A can be included in χ^P, except for $B \to PV$ decays, where we need two more parameters

$$P_A^{PV} = -\sqrt{2}G_F V_{tb}V^*_{tq'} \chi^{P_A} e^{i\phi^{P_A}} f_B m_V (\frac{f_P f_V}{f_\pi^2})(\varepsilon_V^* \cdot p_B). \quad (6)$$

- P_E diagram is argued smaller than P_A diagram, which can be ignored reliably in decay modes not dominated by it, except $B_s \to \pi^+\pi^-$decay.

$$Br(B_s \to \pi^+\pi^-) = (0.76 \pm 0.19) \times 10^{-6}$$



(c) P_E (b) $P_C(P_{EW})$

- The flavor-singlet QCD penguin diagram P_C only contribute to the isospin singlet mesons η, η', ω and ϕ.

$$P_C^{PP} = -i\frac{G_F}{\sqrt{2}}V_{tb}V_{tq'}^{*}\chi^{P_C}e^{i\phi^{P_C}}f_{p_2}(m_B^2 - m_{p_1}^2)F_0^{BP_1}(m_{p_2}^2),$$
$$P_C^{VP} = -\sqrt{2}G_F V_{tb}V_{tq'}^{*}\chi^{P_C}e^{i\phi^{P_C}}f_P m_V A_0^{B-V}(m_P^2)(\varepsilon_V^{*}\cdot p_B),$$
$$P_C^{PV} = -\sqrt{2}G_F V_{tb}V_{tq'}^{*}\chi^{P'_C}e^{i\phi^{P'_C}}f_V m_V F_1^{B-P}(m_V^2)(\varepsilon_V^{*}\cdot p_B), \quad (7)$$

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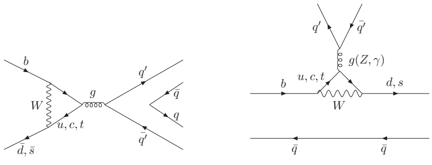

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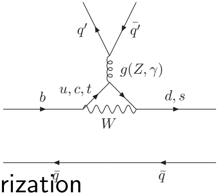
P_C^{PV} &= -\sqrt{2} G_F V_{tb}V_{tq'}^* \chi^{P'_C} e^{i\phi^{P'_C}} f_V m_V F_1^{B-P}(m_V^2)(\varepsilon_V^* \cdot p_B), \quad (7)
\end{aligned}$$

- The EW-penguin unnegligiblely contribute to the neutral isospin 1 meson emission decays.



(b) $P_C(P_{EW})$

⋆ P_{EW} is very similar to the T diagram-Factorization

$$P_{EW}^{PP} = -i\frac{G_F}{\sqrt{2}}V_{tb}V_{tq'}^{*}e_q\frac{3}{2}a_9(\mu)f_{p_2}(m_B^2-m_{p_1}^2)F_0^{BP_1}(m_{p_2}^2),$$
$$P_{EW}^{PV} = -\sqrt{2}G_FV_{tb}V_{tq'}^{*}e_q\frac{3}{2}a_9(\mu)f_Vm_VF_1^{B-P}(m_V^2)(\varepsilon_V^{*}\cdot p_B),$$
$$P_{EW}^{VP} = -\sqrt{2}G_FV_{tb}V_{tq'}^{*}e_q\frac{3}{2}a_9(\mu)f_Pm_VA_0^{B-V}(m_P^2)(\varepsilon_V^{*}\cdot p_B), \qquad (8)$$

where $a_9(\mu)$ is the effective Wilson coefficient

- All together we have 14 parameters to be fitted for all $B \to PP, PV$ and VP decays.
  - The 6 parameters for tree diagrams are:
    Color suppressed tree diagram amplitude$\chi^C, \chi^{C'}$ and their phases$\phi^C, \phi^{C'}$;
    W-exchange diagram amplitudeχ^E and its phase ϕ^E .
  - The 8 parameters for penguin diagrams are:
    Chiral enhanced penguin amplitude χ^P and its phase ϕ^P ;
    flavor singlet penguin amplitude χ^{P_C} ,$\chi^{P'_C}$ and their phases ϕ^{P_C} , $\phi^{P'_C}$ for the pseudo-scalar and vector meson emission, respectively;
    the penguin annihilation amplitude χ^{P_A} and its phase ϕ^{P_A} for the vector meson emission only.

⋆ After keeping flavor $SU(3)$ breaking effect and factorization approaches, the number of theoretical parameters to be fitted from experimental data is reduced.

Global Fit for all $B \to PP, VP$ and PV decays

- 37 branching Ratios and 11 CP violation observations data are used for the fit.
- the best-fitted parameters as:

$$
\begin{aligned}
\chi^C &= 0.48 \pm 0.06, & \phi^C &= -1.58 \pm 0.08, \\
\chi^{C'} &= 0.42 \pm 0.16, & \phi^{C'} &= 1.59 \pm 0.17, \\
\chi^E &= 0.057 \pm 0.005, & \phi^E &= 2.71 \pm 0.13, \\
\chi^P &= 0.10 \pm 0.02, & \phi^P &= -0.61 \pm 0.02. \\
\chi^{P_C} &= 0.048 \pm 0.003, & \phi^{P_C} &= 1.56 \pm 0.08, \\
\chi^{P'_C} &= 0.039 \pm 0.003, & \phi^{P'_C} &= 0.68 \pm 0.08, \\
\chi^{P_A} &= 0.0059 \pm 0.0008, & \phi^{P_A} &= 1.51 \pm 0.09,
\end{aligned}
\tag{9}
$$

with $\chi^2/\text{d.o.f} = 45.2/34 = 1.3$.

⋆ Large strong phase

⋆ This χ^2 per degree of freedom is smaller than the conventional flavor diagram approach.

Hierarchy of Topology

- $B \to \pi\pi$ and $B \to \pi\rho$

$$T^{\pi\pi} : C^{\pi\pi} : E^{\pi\pi} : P^{\pi\pi} = 1 : 0.47 : 0.29 : 0.32$$
$$T^{\rho\pi} : C'^{\pi\rho} : P^{\rho\pi} : P_{EW}^{\pi\rho} = 1 : 0.54 : 0.25 : 0.04$$
$$T^{\pi\rho} : C^{\rho\pi} : P^{\rho\pi} : P_{EW}^{\rho\pi} = 1 : 0.36 : 0.19 : 0.03.$$

$$T > C(C') > E \sim P > P_{EW}.$$

⋆ In agreement with those QCD inspired approaches

- $B \to \pi K$ and $B \to \pi K^*$

$$T^{\pi K} : C^{\pi K} : P^{\pi K} : P_{EW}^{\pi K} = 1 : 0.4 : 6.0 : 0.6$$
$$T^{\pi K^*} : C^{K^*\pi} : P^{\pi K^*} : P_A^{\pi K^*} : P_{EW}^{K^*\pi} = 1 : 0.37 : 2.87 : 1.44 : 0.52.$$

$$P > P_A > T > P_{EW} > C.$$

⋆ P_{EW} is even more larger than C

Predict branching fractions for $B \to PP, VP$ and PV and CP violation.

Mode	Amplitudes	Exp	This work	Flavor diagram
$\pi^-\pi^0$	T, C, P_{EW}	$\star 5.5 \pm 0.4$	$5.08 \pm 0.39 \pm 1.02 \pm 0.02$	5.40 ± 0.79
$\pi^-\eta$	T, C, P, P_C, P_{EW}	$\star 4.02 \pm 0.27$	$4.13 \pm 0.25 \pm 0.64 \pm 0.01$	3.88 ± 0.39
$\pi^-\eta'$	T, C, P, P_C, P_{EW}	$\star 2.7 \pm 0.9$	$3.37 \pm 0.21 \pm 0.49 \pm 0.01$	5.59 ± 0.54
$\pi^+\pi^-$	$T, E, (P_E), P$	$\star 5.12 \pm 0.19$	$5.15 \pm 0.36 \pm 1.31 \pm 0.14$	5.17 ± 1.03
$\pi^0\pi^0$	$C, E, P, (P_E), P_{EW}$	$\star 1.91 \pm 0.22$	$1.94 \pm 0.30 \pm 0.28 \pm 0.05$	1.88 ± 0.42
$\pi^0\eta$	$C, E, P_C, (P_E), P_{EW}$	< 1.5	$0.86 \pm 0.08 \pm 0.08 \pm 0.04$	0.56 ± 0.03
$\pi^0\eta'$	$C, E, P_C, (P_E), P_{EW}$	1.2 ± 0.6	$0.87 \pm 0.08 \pm 0.10 \pm 0.03$	1.21 ± 0.16
$\eta\eta$	$C, E, P_C, (P_E), P_{EW}$	< 1.0	$0.44 \pm 0.09 \pm 0.08 \pm 0.005$	0.77 ± 0.12
$\eta\eta'$	$C, E, P_C, (P_E), P_{EW}$	< 1.2	$0.77 \pm 0.13 \pm 0.14 \pm 0.008$	1.99 ± 0.26
$\eta'\eta'$	$C, E, P_C, (P_E), P_{EW}$	< 1.7	$0.38 \pm 0.05 \pm 0.07 \pm 0.003$	1.60 ± 0.20
K^-K^0	P	$\star 1.31 \pm 0.17$	$1.32 \pm 0.04 \pm 0.26 \pm 0.01$	1.03 ± 0.02
$K^0\bar{K^0}$	P	$\star 1.21 \pm 0.16$	$1.23 \pm 0.03 \pm 0.25 \pm 0.01$	0.89 ± 0.11
π^-K^0	P	$\star 23.7 \pm 0.8$	$23.2 \pm 0.6 \pm 4.6 \pm 0.2$	23.53 ± 0.42
π^0K^-	T, C, P, P_{EW}	$\star 12.9 \pm 0.5$	$12.8 \pm 0.32 \pm 2.35 \pm 0.10$	12.71 ± 1.05
ηK^-	T, C, P, P_C, P_{EW}	$\star 2.4 \pm 0.4$	$2.0 \pm 0.13 \pm 1.19 \pm 0.03$	1.93 ± 0.31
$\eta' K^-$	T, C, P, P_C, P_{EW}	$\star 70.6 \pm 2.5$	$70.1 \pm 4.7 \pm 11.3 \pm 0.22$	70.92 ± 8.54
π^+K^-	T, P	$\star 19.6 \pm 0.5$	$19.8 \pm 0.54 \pm 4.0 \pm 0.2$	20.2 ± 0.39
$\pi^0\bar{K^0}$	C, P, P_{EW}	$\star 9.9 \pm 0.5$	$8.96 \pm 0.26 \pm 1.96 \pm 0.09$	9.73 ± 0.82
$\eta\bar{K^0}$	C, P, P_C, P_{EW}	$\star 1.23 \pm 0.27$	$1.35 \pm 0.10 \pm 1.02 \pm 0.03$	1.49 ± 0.27
$\eta'\bar{K^0}$	C, P, P_C, P_{EW}	$\star 66 \pm 4$	$66.4 \pm 4.5 \pm 10.6 \pm 0.21$	66.51 ± 7.97

Mode	Amplitudes	Exp	This work	Flavor diagram
$\pi^-\rho^0$	T, C', P, P_A, P_{EW}	$\star 8.3 \pm 1.2$	$8.6 \pm 1.81 \pm 1.38 \pm 0.03$	7.59 ± 1.41
$\pi^-\omega$	$T, C', P, P_C', P_A, P_{EW}$	$\star 6.9 \pm 0.5$	$6.78 \pm 1.46 \pm 1.09 \pm 0.02$	7.03 ± 1.42
$\pi^-\phi$	P_C', P_{EW}	< 0.15	$0.28 \pm 0.004 \pm 0.055 \pm 0.003$	0.04 ± 0.02
$\pi^0\rho^-$	T, C, P, P_A, P_{EW}	$\star 10.9 \pm 1.4$	$12.9 \pm 0.73 \pm 2.30 \pm 0.12$	12.15 ± 2.52
$\eta\rho^-$	$T, C, P, P_C, P_A, P_{EW}$	7.0 ± 2.9	$8.16 \pm 0.48 \pm 1.43 \pm 0.07$	5.26 ± 1.19
$\eta'\rho^-$	$T, C, P, P_C, P_A, P_{EW}$	$\star 9.7 \pm 2.2$	$6.0 \pm 0.34 \pm 0.97 \pm 0.05$	5.66 ± 1.25
$\pi^+\rho^-$	$T, E, P, (P_E), P_A$	$\star 14.6 \pm 1.6$	$12.4 \pm 0.64 \pm 3.20 \pm 0.38$	15.20 ± 1.52
$\pi^-\rho^+$	$T, E, P, (P_E)$	$\star 8.4 \pm 1.1$	$6.04 \pm 0.47 \pm 1.70 \pm 0.25$	8.22 ± 1.06
$\pi^0\rho^0$	$C, C', E, P, P_A, (P_E), P_{EW}$	$\star 2 \pm 0.5$	$1.32 \pm 0.47 \pm 0.09 \pm 0.14$	2.24 ± 0.93
$\pi^0\omega$	$C, C', E, P, P_A, (P_E), P_{EW}$	< 0.5	$2.31 \pm 0.88 \pm 0.24 \pm 0.07$	1.02 ± 0.66
$\pi^0\phi$	P_C', P_{EW}	< 0.15	$0.13 \pm 0.002 \pm 0.025 \pm 0.001$	0.02 ± 0.01
$\eta\rho^0$	$C, C', E, P, P_C, P_C', P_A, (P_E), P_{EW}$	< 1.5	$4.41 \pm 1.15 \pm 0.39 \pm 0.17$	0.54 ± 0.32
$\eta\omega$	$C, C', E, P, P_C, P_C', P_A, (P_E), P_{EW}$	$0.94^{+0.40}_{-0.31}$	$0.89 \pm 0.30 \pm 0.08 \pm 0.09$	1.12 ± 0.44
$\eta\phi$	P_C', P_{EW}	< 0.5	$0.077 \pm 0.001 \pm 0.015 \pm 0.0008$	0.01 ± 0.01
$\eta'\rho^0$	$C, C', E, P, P_C, P_C', (P_E), P_{EW}$	< 1.3	$3.19 \pm 0.77 \pm 0.29 \pm 0.12$	0.63 ± 0.33
$\eta'\omega$	$C, C', E, P, P_C, P_C', (P_E), P_{EW}$	$1.0^{+0.5}_{-0.4}$	$0.95 \pm 0.21 \pm 0.05 \pm 0.06$	1.24 ± 0.47
$\eta'\phi$	P_C', P_{EW}	< 0.5	$0.05 \pm 0.0008 \pm 0.01 \pm 0.0005$	0.01 ± 0.01
K^-K^{*0}	P, P_A	< 1.1	$0.59 \pm 0.06 \pm 0.10 \pm 0.01$	0.46 ± 0.03
K^0K^{*-}	P		$0.44 \pm 0.03 \pm 0.09 \pm 0.004$	0.31 ± 0.03
$K^0\bar{K}^{*0}$	P		$0.41 \pm 0.02 \pm 0.08 \pm 0.004$	0.29 ± 0.03
$\bar{K}^0K^{*0}$	P, P_A		$0.55 \pm 0.05 \pm 0.09 \pm 0.01$	0.43 ± 0.02
π^-K^{*0}	P, P_A	$\star 10.1 \pm 0.9$	$10.0 \pm 0.95 \pm 1.78 \pm 0.15$	10.47 ± 0.60
π^0K^{*-}	T, C, P, P_A, P_{EW}	$\star 8.2 \pm 1.9$	$6.23 \pm 0.51 \pm 0.98 \pm 0.07$	9.79 ± 2.95
ηK^{*-}	$T, C, P, P_C, P_A, P_{EW}$	$\star 19.3 \pm 1.6$	$17.3 \pm 0.8 \pm 2.4 \pm 0.3$	16.57 ± 2.58
$\eta' K^{*-}$	$T, C, P, P_C, P_A, P_{EW}$	$4.8^{+1.8}_{-1.6}$	$3.31 \pm 0.44 \pm 0.38 \pm 0.13$	3.43 ± 1.43
$K^-\rho^0$	T, C', P, P_{EW}	$\star 3.7 \pm 0.5$	$3.97 \pm 0.25 \pm 0.80 \pm 0.04$	3.97 ± 0.90
$K^-\omega$	T, C', P, P_C', P_{EW}	$\star 6.5 \pm 0.4$	$6.52 \pm 0.73 \pm 1.13 \pm 0.06$	6.43 ± 1.49
$K^-\phi$	P, P_C', P_A, P_{EW}	$\star 8.8 \pm 0.7$	$8.38 \pm 1.21 \pm 0.69 \pm 0.50$	8.34 ± 1.31
$\bar{K}^0\rho^-$	P	$\star 8 \pm 1.5$	$7.74 \pm 0.47 \pm 1.55 \pm 0.07$	7.09 ± 0.77
π^+K^{*-}	T, P, P_A	$\star 8.4 \pm 0.8$	$8.40 \pm 0.77 \pm 1.46 \pm 0.14$	8.35 ± 0.50
$\pi^0\bar{K}^{*0}$	C, P, P_A, P_{EW}	$\star 3.3 \pm 0.6$	$3.35 \pm 0.36 \pm 0.65 \pm 0.08$	3.89 ± 1.98
$\eta\bar{K}^{*0}$	C, P, P_C, P_A, P_{EW}	$\star 15.9 \pm 1$	$16.6 \pm 0.7 \pm 2.3 \pm 0.3$	16.34 ± 2.48
$\eta'\bar{K}^{*0}$	$C, P, P_C, P_C', P_A, P_{EW}$	$\star 2.8 \pm 0.6$	$3.0 \pm 0.5 \pm 0.3 \pm 0.1$	3.14 ± 1.24
$K^-\rho^+$	T, P	$\star 7 \pm 0.9$	$8.27 \pm 0.44 \pm 1.65 \pm 0.07$	8.28 ± 0.80
$\bar{K}^0\rho^0$	C', P, P_{EW}	$\star 4.7 \pm 0.4$	$4.59 \pm 0.34 \pm 0.79 \pm 0.04$	4.97 ± 1.14
$\bar{K}^0\omega$	C', P, P_C', P_{EW}	$\star 4.8 \pm 0.6$	$4.80 \pm 0.61 \pm 0.95 \pm 0.05$	4.82 ± 1.26
$\bar{K}^0\phi$	P, P_C', P_A, P_{EW}	$\star 7.3 \pm 0.7$	$7.77 \pm 1.12 \pm 0.64 \pm 0.46$	7.72 ± 1.21

CP asymmetry

- The direct CP asymmetry parameter is also proportional to the strong phase difference
- The mixing induced CP asymmetries are dominated by the B_0 - $\bar{B}_0$ mixing phase with little dependence on strong phases, searching possible new physics.

Mode	$\mathcal{A}_{\rm exp}$	$\mathcal{A}_{this\ work}$	$\mathcal{S}_{\rm exp}$	$\mathcal{S}_{this\ work}$
$\pi^+\pi^-$	$\star 0.31 \pm 0.05$	0.31 ± 0.04	$\star - 0.67 \pm 0.06$	-0.60 ± 0.03
$\pi^0\pi^0$	0.43 ± 0.24	0.57 ± 0.06		0.58 ± 0.06
$\pi^0\eta$		-0.16 ± 0.16		-0.98 ± 0.04
$\pi^0\eta^{'}$		0.39 ± 0.14		-0.90 ± 0.07
$\eta\eta$		-0.85 ± 0.06		0.33 ± 0.12
$\eta\eta^{'}$		-0.97 ± 0.04		-0.20 ± 0.15
$\eta^{'}\eta^{'}$		-0.87 ± 0.07		-0.46 ± 0.14
$\pi^0 K_s$	0.00 ± 0.13	-0.14 ± 0.03	$\star 0.58 \pm 0.17$	0.73 ± 0.01
ηK_s		-0.30 ± 0.10		0.68 ± 0.04
$\eta^{'} K_s$	0.06 ± 0.04	0.030 ± 0.004	$\star 0.63 \pm 0.06$	0.69 ± 0.00
$K^0\bar{K}^0$		-0.057 ± 0.002	0.8 ± 0.5	0.099 ± 0.002
$\pi^-\pi^0$	0.03 ± 0.04	-0.026 ± 0.003		
$\pi^-\eta$	-0.14 ± 0.07	-0.081 ± 0.074		
$\pi^-\eta^{'}$	0.06 ± 0.16	0.374 ± 0.087		
$\pi^-\bar{K}^0$	-0.017 ± 0.016	0		
$\pi^0 K^-$	0.037 ± 0.021	0.047 ± 0.025		
ηK^-	$\star - 0.37 \pm 0.08$	-0.426 ± 0.043		
$\eta^{'} K^-$	0.013 ± 0.017	-0.027 ± 0.008		
$K^- K^0$	-0.21 ± 0.14	0		
$\pi^+ K^-$	$\star - 0.082 \pm 0.006$	-0.080 ± 0.011		

Estimate the $SU(3)$ breaking effect in FAT

- $SU(3)$ breaking effects in amplitudes for $B \to PP$ to be around 10%

$$|\frac{T(B^- \to \pi^0 K^-)}{V_{ub}V_{us}^*}| : |\frac{T(B^- \to \pi^0 \pi^-)}{V_{ub}V_{ud}^*}| = 1 : 0.83,$$

$$|\frac{C(B^- \to \pi^0 K^-)}{V_{ub}V_{us}^*}| : |\frac{C(B^- \to \pi^0 \pi^-)}{V_{ub}V_{ud}^*}| = 1 : 0.91,$$

$$|\frac{P(\bar{B}^0 \to \pi^+ K^-)}{V_{tb}V_{ts}^*}| : |\frac{P(\bar{B}^0 \to \pi^+ \pi^-)}{V_{tb}V_{td}^*}| = 1 : 0.89,$$

$$|\frac{P_C(B^- \to \eta K^-)}{V_{tb}V_{ts}^*}| : |\frac{P_C(B^- \to \eta \pi^-)}{V_{tb}V_{td}^*}| = 1 : 0.91.$$

- $SU(3)$ breaking effects in amplitudes for $B \to PV$ are larger than 20%.

$$
\begin{aligned}
|\frac{T(B^- \to \pi^0 K^{*-})}{V_{ub}V_{us}^*}| : |\frac{T(B^- \to \pi^0 \rho^-)}{V_{ub}V_{ud}^*}| &= 1 : 0.83, \\
|\frac{C(B^- \to K^{*-}\pi^0)}{V_{ub}V_{us}^*}| : |\frac{C(B^- \to \rho^-\pi^0)}{V_{ub}V_{ud}^*}| &= 1 : 0.80, \\
|\frac{P(\bar{B}^0 \to \pi^+ K^{*-})}{V_{tb}V_{ts}^*}| : |\frac{P(\bar{B}^0 \to \pi^+ \rho^-)}{V_{tb}V_{td}^*}| &= 1 : 0.74, \\
|\frac{P_C(B^- \to K^{*-}\eta)}{V_{tb}V_{ts}^*}| : |\frac{P_C(B^- \to \rho^-\eta)}{V_{tb}V_{td}^*}| &= 1 : 0.80, \\
|\frac{P_A(\bar{B}^0 \to \pi^+ K^{*-})}{V_{tb}V_{ts}^*}| : |\frac{P_A(\bar{B}^0 \to \pi^+ \rho^-)}{V_{tb}V_{td}^*}| &= 1 : 0.84.
\end{aligned}
$$

Summary

- studied $B \to PP, PV$ in factorization assisted topological amplitude approach.
- T was in factorization without free parameters. P_{EW} was also included.
- For most other topological diagrams, the corresponding decay constants, form factors were factorized out from them before χ^2 fit assisted by factorization hypothesis to indicate the flavor $SU(3)$ breaking effect.
- Only 14 universal non-perturbative parameters to be fitted from all $B \to PP, PV$ decay channels. the χ^2 per degree of freedom is smaller than the conventional flavor diagram approach.
- predict branching fractions and CP asymmetry parameters of nearly 100 $B_{u,d}$ and B_s decay modes. The long-standing puzzles of $\pi\pi$branching ratios has been resolved consistently.

THANK YOU

backup

- input parameters

V_{CKM} with the Wolfenstein parameters:

$$\lambda = 0.22537 \pm 0.00061, \quad A = 0.814^{+0.023}_{-0.024}$$

$$\bar{\rho} = 0.117 \pm 0.021, \quad \bar{\eta} = 0.353 \pm 0.013.$$

Table: The decay constants of light pseudo-scalar mesons and vector mesons (in unit of MeV).(5% uncertainty)

f_π	f_K	f_B	f_{B_s}	f_ρ	f_{K^*}	f_ω	f_ϕ
130	156	190	225	213	220	192	225

Table: The transition form factors of B meson decays at q^2=0 and dipole model parameters(10 % uncertainty)

	$F_0^{B\to\pi}$	$F_0^{B\to K}$	$F_0^{B_s\to K}$	$F_0^{B\to\eta_q}$	$F_0^{B_s\to\eta_s}$
$F(0)$	0.27	0.29	0.25	0.21	0.30
α_1	0.50	0.53	0.54	0.52	0.53
α_2	-0.13	-0.13	-0.15	0	0
	$F_1^{B\to\pi}$	$F_1^{B\to K}$	$F_1^{B_s\to K}$	$F_1^{B\to\eta_q}$	$F_1^{B_s\to\eta_s}$
$F(0)$	0.27	0.29	0.25	0.21	0.30
α_1	0.52	0.54	0.57	1.43	1.48
α_2	0.45	0.50	0.50	0.41	0.46
	$A_0^{B\to\rho}$	$A_0^{B\to\omega}$	$A_0^{B\to K^*}$	$A_0^{B_s\to K^*}$	$A_0^{B_s\to\phi}$
$A(0)$	0.29	0.25	0.36	0.27	0.30
α_1	1.56	1.60	1.51	1.74	1.73
α_2	0.17	0.22	0.14	0.47	0.41

For the q^2 dependence of the transition form factors, we use the dipole parametrization:

$$F_i(q^2) = \frac{F_i(0)}{1 - \alpha_1 \frac{q^2}{M_{\rm pole}^2} + \alpha_2 \frac{q^4}{M_{\rm pole}^4}},$$

$B \to P_1 P_2 (P\ represent\ \pi, K, \eta, \eta')$

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}}\{\Sigma_{q'=d,s} V_{ub} V_{uq}^* [C_1(\mu) O_1^u(\mu) + C_2(\mu) O_2^u(\mu)] - V_{tb} V_{tq'}^* \Sigma_{i=3}^{10} C_i(\mu) O_i(\mu)\}$$

$$\begin{aligned}
O_1^u &= (\bar{q'}_\alpha u_\beta)_{V-A} (\bar{u}_\beta b_\alpha)_{V-A}, O_2^u = (\bar{q'} u)_{V-A} (\bar{u} b)_{V-A} \\
O_3 &= (\bar{q'} b)_{V-A} (\bar{q} q)_{V-A}, O_4 = (\bar{q'}_\alpha b_\beta)_{V-A} (\bar{q}_\beta q_\alpha)_{V-A} \\
O_5 &= (\bar{q'} b)_{V-A} (\bar{q} q)_{V+A}, O_6 = (\bar{q'}_\alpha b_\beta)_{V-A} (\bar{q}_\beta q_\alpha)_{V+A} \\
O_7 &= \frac{3}{2} (\bar{q'} b)_{V-A} e_q (\bar{q} q)_{V+A}, O_8 = \frac{3}{2} (\bar{q'}_\alpha b_\beta)_{V-A} e_q (\bar{q}_\beta q_\alpha)_{V+A} \\
O_9 &= \frac{3}{2} (\bar{q'} b)_{V-A} e_q (\bar{q} q)_{V-A}, O_{10} = \frac{3}{2} (\bar{q'}_\alpha b_\beta)_{V-A} e_q (\bar{q}_\beta q_\alpha)_{V-A}
\end{aligned}$$

$O_7 - O_{10}$ QED penguin contribution is not ignore although α_{em} is smaller than QCD.
Penguin contribution from quark loops correction O_{1-6}, O_{8g}.

μ =2.1.

$$
\begin{aligned}
C_1(\mu) &= -0.29, C_2(\mu) = 1.14; \\
C_3(\mu) &= 0.02, C_4(\mu) = -0.05; \\
C_5(\mu) &= 0.011, C_6(\mu) = -0.067; \\
C_7(\mu) &= -1.02e-5, C_8(\mu) = 0.00073; \\
C_9(\mu) &= -0.0098, C_{10}(\mu) = 0.0025; \\
a_1(\mu) &= 1.045, a_4(\mu) = -0.044, a_6(\mu) = -0.064; \\
a_7(\mu) &= 0.00023, a_8(\mu) = 0.0007; \\
a_9(\mu) &= -0.009, a_{10}(\mu) = -0.0008;
\end{aligned}
$$