Based on Phys.Rev. D101, 111901(R) (2020)

Contributions of K^+K^- from resonances ρ and ω for the $B^\pm \longrightarrow \pi^\pm K^+ K^-$ decays

Wang Wen-Fei

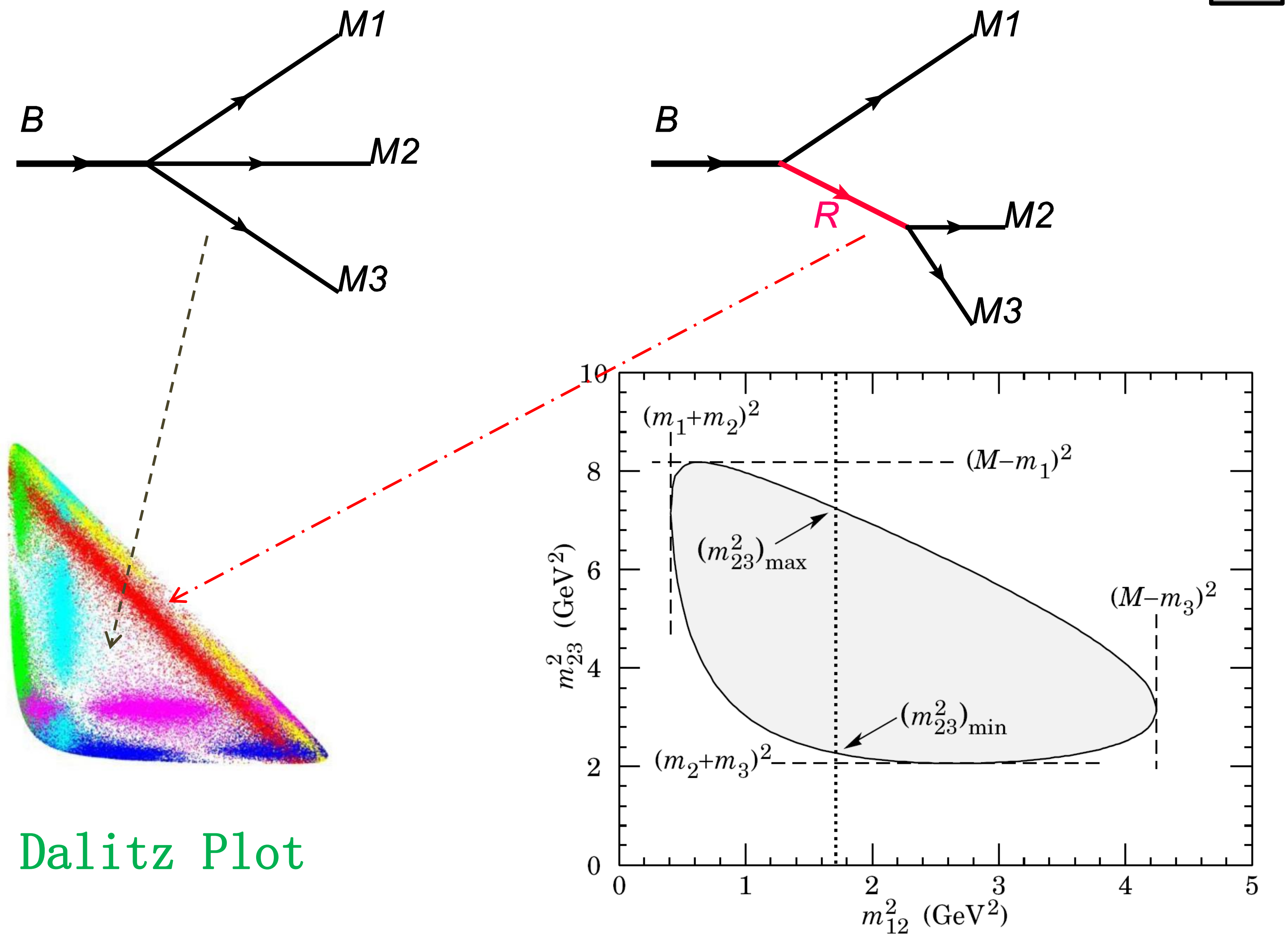
PQCD Group Meeting

2020-08-14

Outline

- **Introduction for 3-body B decays**
- **Motivation for the ρ/ω**$\longrightarrow K^+ K^-$
- **Results and discussions**
- **Summary**

Introduction for 3-body B decays



The weak effective Hamiltonian:

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}}\Big\{V_{ub}V_{uq}^*[C_1(\mu)Q_1^u(\mu) + C_2(\mu)Q_2^u(\mu)] - V_{tb}V_{tq}^*\Big[\sum_{i=3}^{10} C_i(\mu)Q_i(\mu)\Big]\Big\} + \text{H.c.}, \qquad (2)$$

where $q = d, s$. The functions Q_i $(i = 1, \ldots, 10)$ are the local four-quark operators:

1.

2.

Then what about the other strong interactions?

……

Introduction for 3-body B decays

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Physics Letters B 561 (2003) 258–265

PHYSICS LETTERS B

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Three-body nonleptonic *B* decays in perturbative QCD

Chuan-Hung Chen, Hsiang-Nan Li

Abstract

We develop perturbative QCD formalism for three-body nonleptonic *B* meson decays. Leading contributions are identified by defining power counting rules for various topologies of amplitudes. The analysis is simplified into the one for two-body decays by introducing two-meson distribution amplitudes. This formalism predicts both nonresonant and resonant contributions, and can be generalized to baryonic decays.

Introduction for 3-body B decays

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Physics Letters B 561 (2003) 258–265

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Three-body nonleptonic B decays in perturbative QCD

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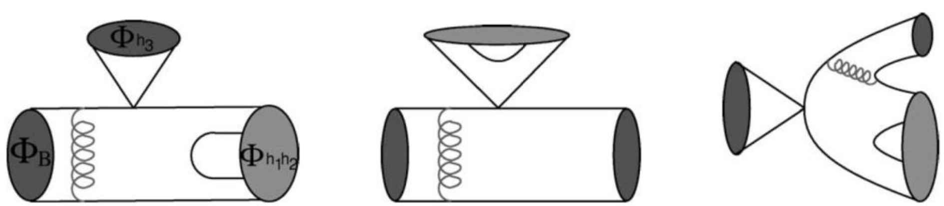

$$B \to h_1 h_2 h_3$$

$$\Rightarrow \quad \mathcal{M} = \Phi_B \otimes H \otimes \Phi_{h_1 h_2} \otimes \Phi_{h_3}$$

Introduction for 3-body B decays

Physics Letters B 763 (2016) 29–39

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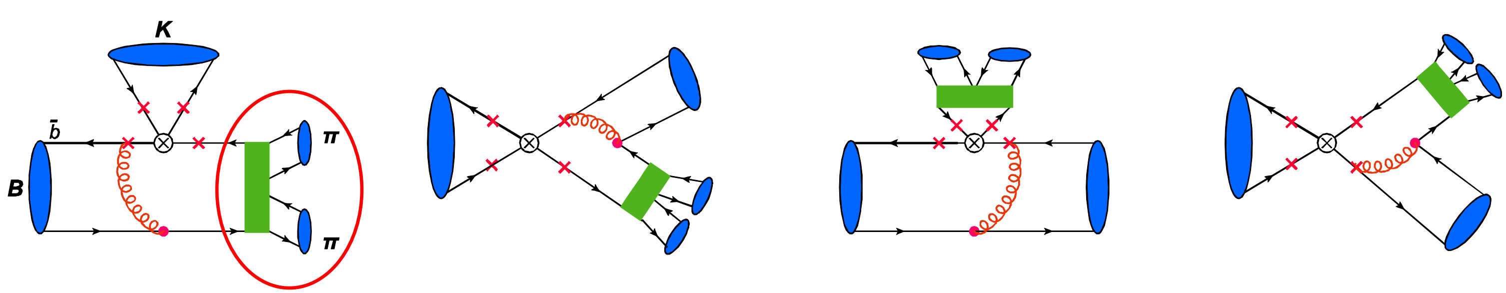
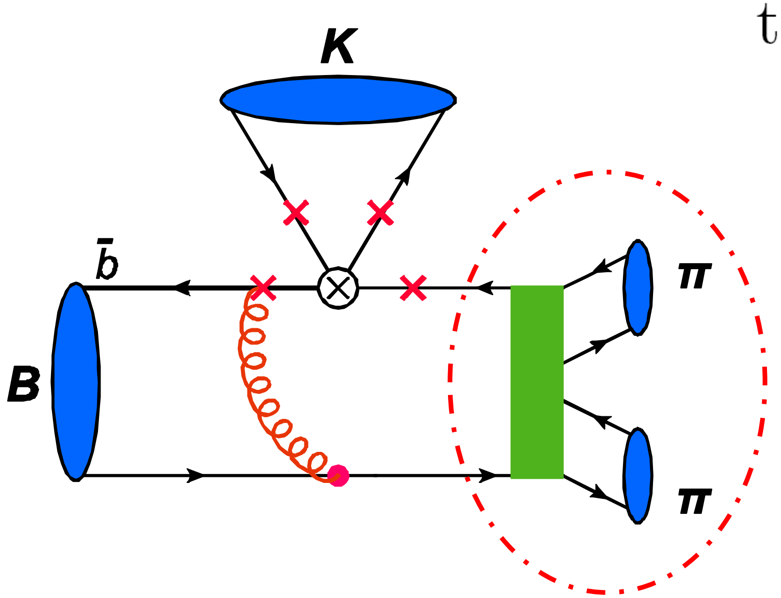
Quasi-two-body decays $B \to K\rho \to K\pi\pi$ in perturbative QCD approach

Wen-Fei Wang [a,b], Hsiang-nan Li [a,*]



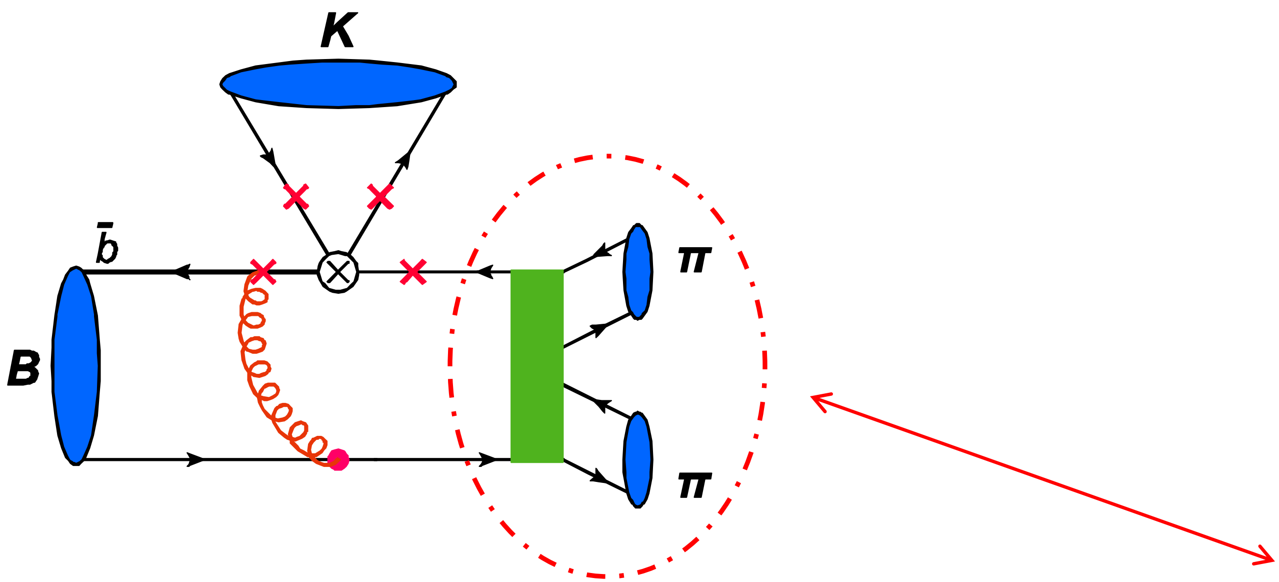
From the definition of the vector current time-like form factor F_π we have



$$F_\pi^\rho(w^2) \approx \frac{g_{\rho\pi\pi} w f_\rho}{\sqrt{2} D_\rho(w^2)}$$

$$\mathcal{M} = \Phi_B \otimes H \otimes \Phi_K \otimes \left[\Phi_\rho \frac{F_\pi^\rho(s)}{f_\rho}(2\zeta - 1)\right]$$

Introduction for 3-body B decays



$$\mathcal{M} = \Phi_B \otimes H \otimes \Phi_K \otimes \left[\Phi_\rho \frac{F_\pi^\rho(s)}{f_\rho}(2\zeta - 1)\right]$$

Introduction for 3-body B decays

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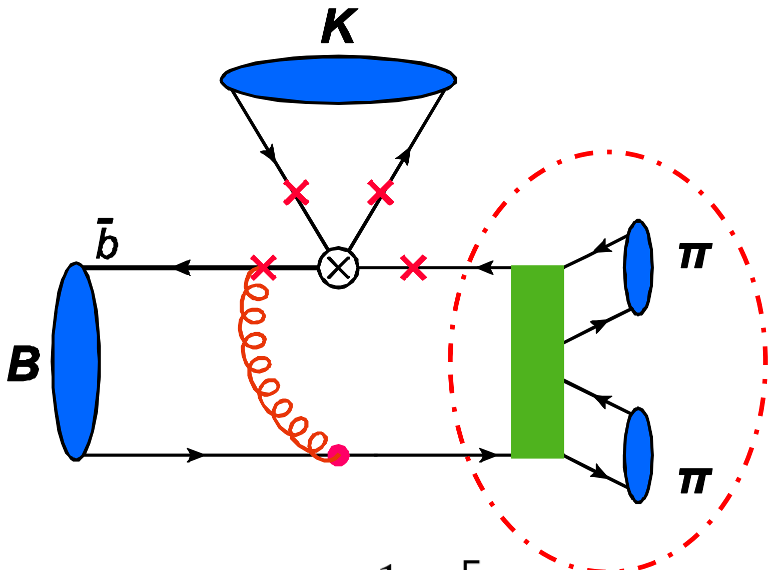


Legendre polynomial $P_1(2\zeta - 1) = 2\zeta - 1$

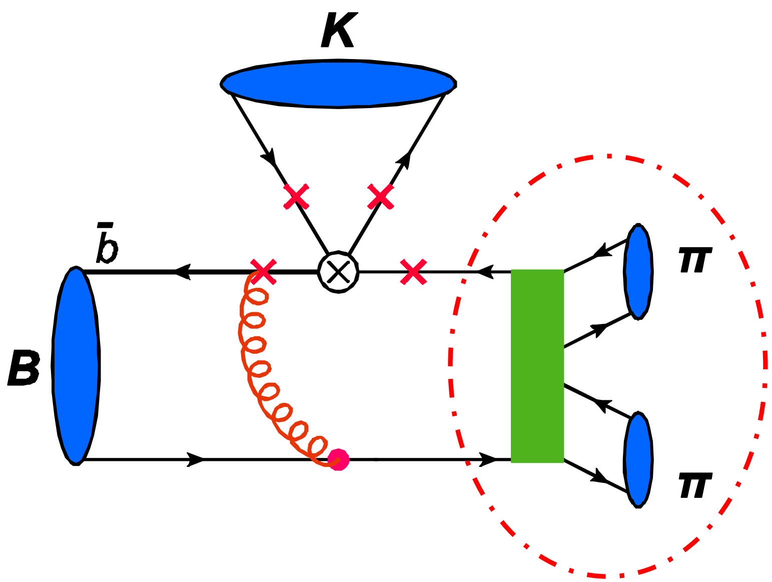
$$\phi_{\pi\pi}^{I=1} = \frac{1}{\sqrt{2N_c}}\left[\not{p}\phi_{v\nu=-}^{I=1}(z,\zeta,w^2) + w\phi_s^{I=1}(z,\zeta,w^2) + \frac{\not{p}_1\not{p}_2 - \not{p}_2\not{p}_1}{w(2\zeta-1)}\phi_{t\nu=+}^{I=1}(z,\zeta,w^2)\right],$$

$$\phi_{v\nu=-}^{I=1}(z,\zeta,w^2) \equiv \phi^0(z,\zeta,w^2) = \frac{3F_\pi(w^2)}{\sqrt{2N_c}} z(1-z)\left[1 + a_2^0 C_2^{3/2}(1-2z)\right] P_1(2\zeta - 1),$$

$$\phi_s^{I=1}(z,\zeta,w^2) \equiv \phi^s(z,\zeta,w^2) = \frac{3F_s(w^2)}{2\sqrt{2N_c}}(1-2z)\left[1 + a_2^s\left(1 - 10z + 10z^2\right)\right] P_1(2\zeta - 1),$$

$$\phi_{t\nu=+}^{I=1}(z,\zeta,w^2) \equiv \phi^t(z,\zeta,w^2) = \frac{3F_t(w^2)}{2\sqrt{2N_c}}(1-2z)^2\left[1 + a_2^t C_2^{3/2}(1-2z)\right] P_1(2\zeta - 1),$$

Introduction for 3-body B decays

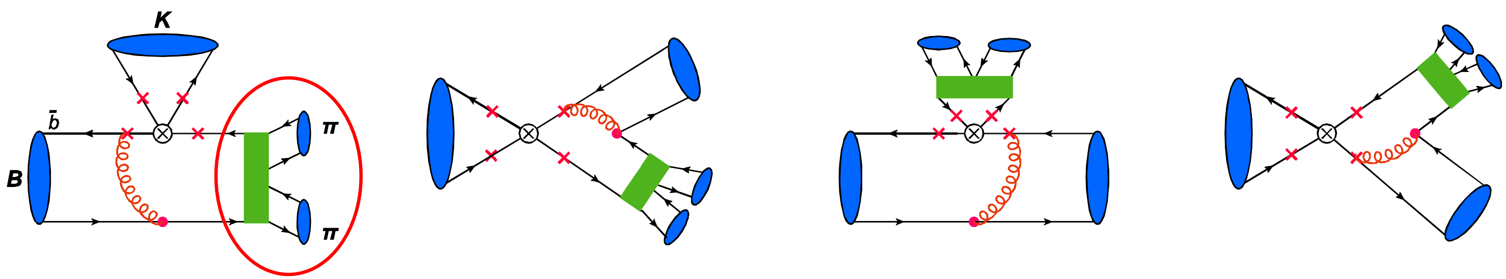


$$F_\pi(s) = \frac{\mathrm{GS}_\rho(s, m_\rho, \Gamma_\rho)\frac{1+c_\omega \mathrm{BW}_\omega(s,m_\omega,\Gamma_\omega)}{1+c_\omega} + \sum c_i \mathrm{GS}_i(s, m_i, \Gamma_i)}{1+\sum c_i}$$

$$\frac{m_\rho{}^2 + d m_\rho \Gamma_\rho}{(m_\rho{}^2 - s) + \Gamma_\rho (m_\rho{}^2/k_\rho{}^3)\{k^2[h(s) - h(m_\rho{}^2)] + k_\rho{}^2 h'(m_\rho{}^2)(m_\rho{}^2 - s)\} - i m_\rho \Gamma_\rho (k/k_\rho)^3 (m_\rho/\sqrt{s})},$$

G. Gounaris, J.J. Sakurai
PRL21-244(1968)

Introduction for 3-body B decays



$$\phi_{\pi\pi}^{I=1} = \frac{1}{\sqrt{2N_c}}\left[\not{p}\phi_{v\nu=-}^{I=1}(z,\zeta,w^2) + w\phi_s^{I=1}(z,\zeta,w^2) + \frac{\not{p}_1\not{p}_2 - \not{p}_2\not{p}_1}{w(2\zeta-1)}\phi_{t\nu=+}^{I=1}(z,\zeta,w^2)\right],$$

$$\phi_{v\nu=-}^{I=1}(z,\zeta,w^2) \equiv \phi^0(z,\zeta,w^2) = \frac{3F_\pi(w^2)}{\sqrt{2N_c}} z(1-z)\left[1 + a_2^0 C_2^{3/2}(1-2z)\right] P_1(2\zeta-1),$$

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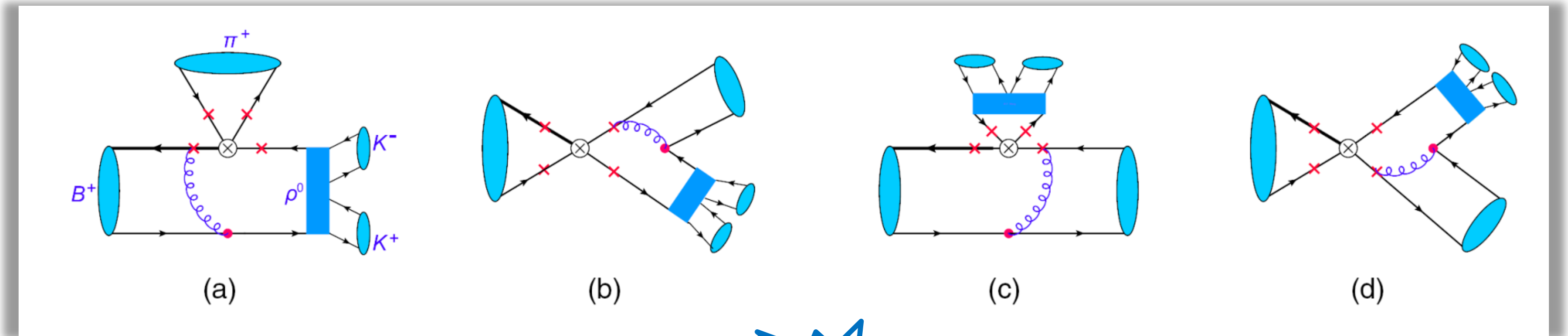
$$\phi_{t\nu=+}^{I=1}(z,\zeta,w^2) \equiv \phi^t(z,\zeta,w^2) = \frac{3F_t(w^2)}{2\sqrt{2N_c}}(1-2z)^2\left[1 + a_2^t C_2^{3/2}(1-2z)\right] P_1(2\zeta-1),$$

$\Rightarrow$ $a_\rho^0 = 0.25, a_\rho^t = -0.60\,, a_\rho^s = 0.75$

Introduction for 3-body B decays



2.

$$\frac{d\mathcal{B}}{d\eta} = \tau_B \frac{|\vec{q_\pi}|^3 |\vec{q_K}|^3}{12\pi^3 m_B^5} \overline{|\mathcal{A}|^2},$$

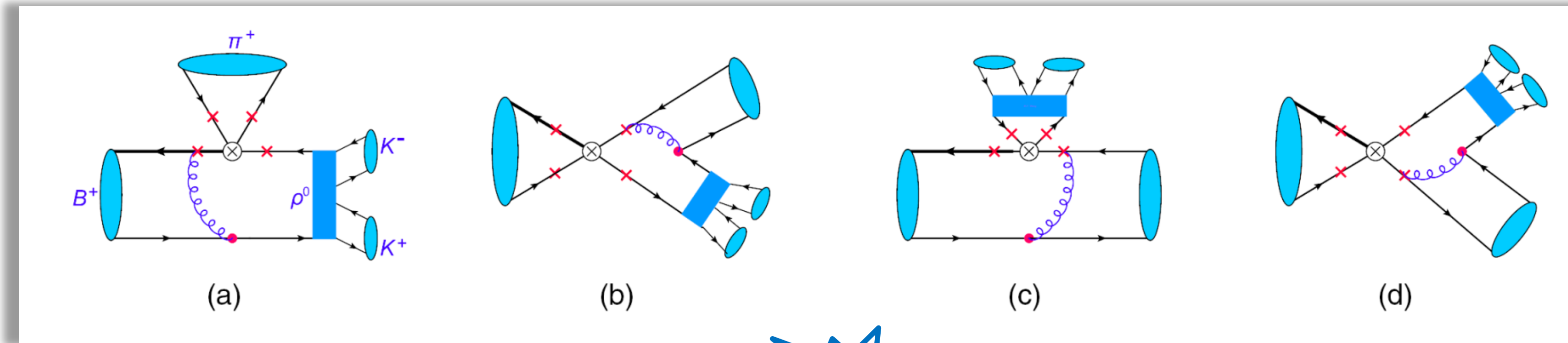
1.

In the rest frame of KK pair !

$$|\vec{q_K}| = \frac{1}{2}\sqrt{s - 4m_K^2},$$

$$|\vec{q_\pi}| = \frac{1}{2\sqrt{s}}\sqrt{(m_B^2 - m_\pi^2)^2 - 2(m_B^2 + m_\pi^2)s + s^2},$$

Introduction for 3-body B decays



2.

$$\frac{d\mathcal{B}}{d\eta} = \tau_B \frac{|\vec{q}_\pi|^3 |\vec{q}_K|^3}{12\pi^3 m_B^5} \overline{|\mathcal{A}|^2},$$

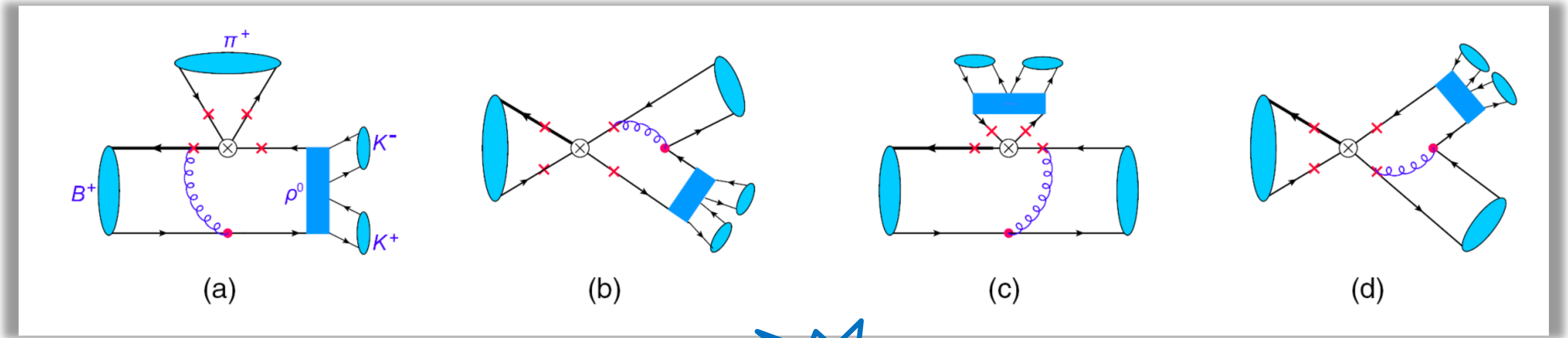
$$\Delta_{K\pi} = (m_K^2 - m_\pi^2)$$

$$\langle K^+(p_1)\pi^-(p_2)|\bar{d}\gamma_\mu(1-\gamma_5)s|0\rangle = \left[(p_1-p_2)_\mu - \frac{\Delta_{K\pi}}{p^2}p_\mu\right] F_+^{K\pi}(s) + \frac{\Delta_{K\pi}}{p^2}p_\mu F_0^{K\pi}(s) \ ,$$

$$\langle \pi(q_2)|\bar{b}(0)\gamma_\mu(1-\gamma_5)q(0)|B(q_1)\rangle = \left[(q_1+q_2)_\mu - \frac{m_B^2-m_\pi^2}{q^2}q_\mu\right] F_+^{B\pi}(q^2) + \frac{m_B^2-m_\pi^2}{q^2}q_\mu F_0^{B\pi}(q^2)$$

$$q = q_1 - q_2$$

Introduction for 3-body B decays



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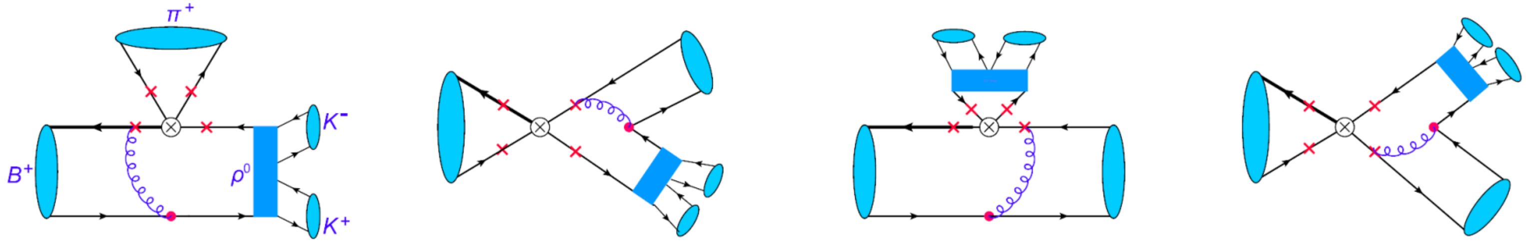
$$q = q_1 - q_2$$

S-wave: PLB730(2014)336
JHEP03(2020)162

Introduction for 3-body B decays



(a) (b) (c) (d)

2.

$$\frac{d\mathcal{B}}{d\eta} = \tau_B \frac{|\vec{q_\pi}|^3 |\vec{q_K}|^3}{12\pi^3 m_B^5} \overline{|\mathcal{A}|^2},$$

$$\Delta_{K\pi} = (m_K^2 - m_\pi^2)$$

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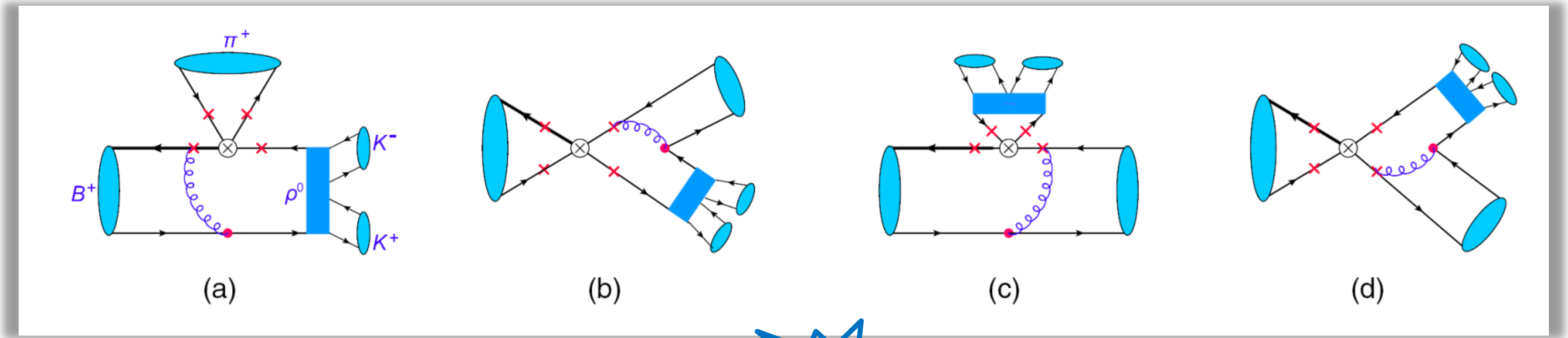
Introduction for 3-body B decays



2.

$$\frac{d\mathcal{B}}{d\eta} = \tau_B \frac{|\vec{q}_\pi|^3 |\vec{q}_K|^3}{12\pi^3 m_B^5} \overline{|\mathcal{A}|^2},$$

$$m_{K^-\pi^-}^2 - m_{\pi^+\pi^-}^2 - (M_B^2 - m_\pi^2)\frac{m_K^2 - m_\pi^2}{q^2} = 4\mathbf{p}_{\pi^+}\cdot\mathbf{p}_{\pi^-} = 4|\mathbf{p}_{\pi^+}||\mathbf{p}_{\pi^-}|\cos\theta,$$

$$\langle K^+(p_1)\pi^-(p_2)|\bar{d}\gamma_\mu(1-\gamma_5)s|0\rangle = \left[(p_1-p_2)_\mu - \frac{\Delta_{K\pi}}{p^2}p_\mu\right]F_+^{K\pi}(s) + \frac{\Delta_{K\pi}}{p^2}p_\mu F_0^{K\pi}(s)\ ,$$

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PHYSICAL REVIEW D **79**, 094005 (2009)

Motivation for the ρ/ω⟶ $K^+ K^-$

Physics Letters B 791 (2019) 342–350

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Physics Letters B

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Virtual contributions from $D^*(2007)^0$ and $D^*(2010)^\pm$ in the $B \to D\pi h$ decays

Wen-Fei Wang [a,b,*], Jian Chai [a,b]

[a] Institute of Theoretical Physics, Shanxi University, Taiyuan, Shanxi 030006, China
[b] State Key Laboratory of Quantum Optics and Quantum Optics Devices, Shanxi University, Taiyuan, Shanxi 030006, China

Table 2
The PQCD predictions of the virtual contributions from D^* state in the $D\pi$ invariant mass region $\sqrt{s} > 2.1$ GeV for the $B \to D^*h \to D\pi h$ decays.

Mode	Unit	$\mathcal{B}_v$
$\bar{B}^0 \to D^{*+}\pi^- \to D^0\pi^+\pi^-$	(10^{-4})	$0.87^{+0.43}_{-0.27}(\omega_B)^{+0.08}_{-0.07}(f_{D^*})^{+0.08}_{-0.06}(a_{D\pi}) \pm 0.03(A)^{+0.02}_{-0.01}(\omega_{D\pi})$
$\bar{B}^0 \to D^{*+}K^- \to D^0\pi^+K^-$	(10^{-5})	$0.72^{+0.35}_{-0.22}(\omega_B)^{+0.07}_{-0.06}(f_{D^*}) \pm 0.06(a_{D\pi}) \pm 0.03(A) \pm 0.02(\omega_{D\pi})$
$B^- \to D^{*0}\pi^- \to D^+\pi^-\pi^-$	(10^{-4})	$1.91^{+0.86}_{-0.59}(\omega_B)^{+0.17}_{-0.16}(f_{D^*})^{+0.12}_{-0.10}(a_{D\pi}) \pm 0.07(A)^{+0.04}_{-0.05}(\omega_{D\pi})$
$B^- \to D^{*0}K^- \to D^+\pi^-K^-$	(10^{-5})	$1.48^{+0.65}_{-0.46}(\omega_B) \pm 0.13(f_{D^*})^{+0.09}_{-0.08}(a_{D\pi}) \pm 0.05(A)^{+0.02}_{-0.03}(\omega_{D\pi})$

Motivation for the ρ/ω⟶ $K^+ K^-$

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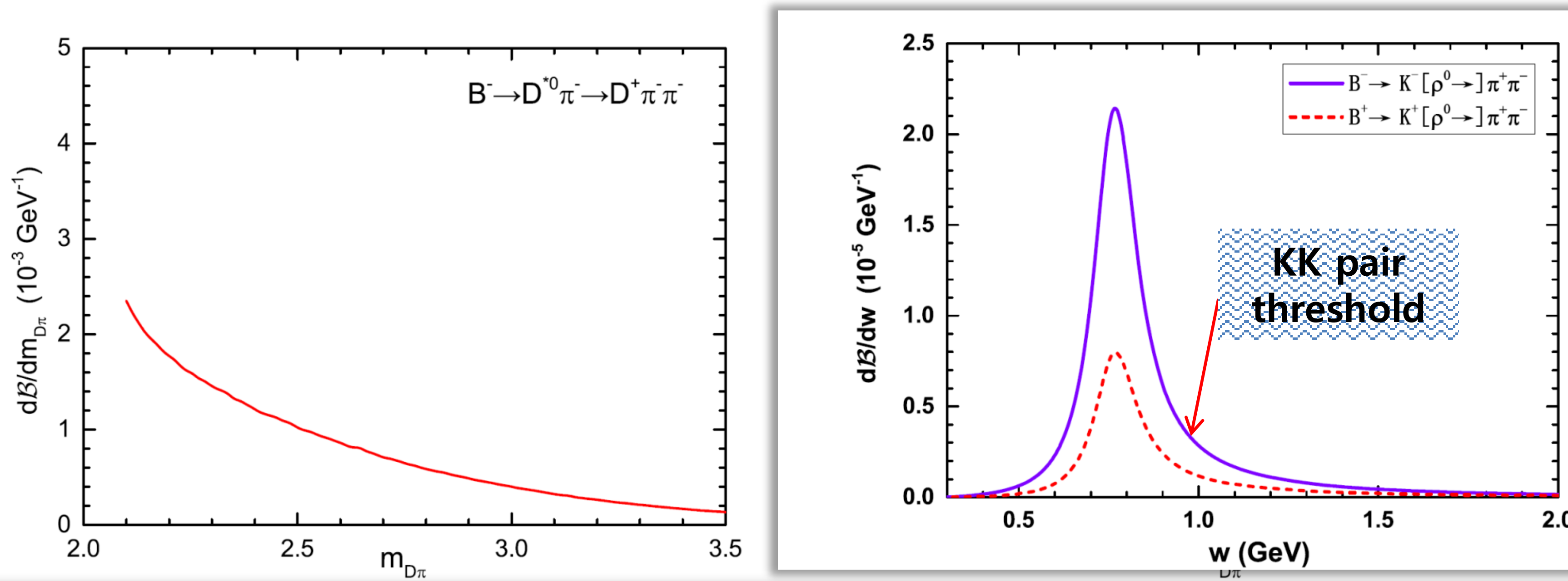

Motivation for the $\rho/\omega \longrightarrow K^{+}\ K^{-}$

$\rho(770,1450) \longrightarrow \pi^{+}\ \pi^{-}$ ✓

$\rho/\omega \longrightarrow K^{+}\ K^{-}$ **? !**

$$\pi^{-} p \rightarrow K^{-} K^{+} n$$

$$\pi^{+} n \rightarrow K^{-} K^{+} p$$

$$e^{+} e^{-} \rightarrow K^{+} K^{-}$$

✓

Motivation for the ρ/ω⟶ $K^+ K^-$

PHYSICAL REVIEW LETTERS **123,** 231802 (2019)

Amplitude Analysis of $B^{\pm} \to \pi^{\pm} K^+ K^-$ Decays

R. Aaij *et al.*[*]
(LHCb Collaboration)

(Received 12 June 2019; revised manuscript received 15 October 2019; published 6 December 2019)

TABLE I. Results of the Dalitz plot fit, where the first uncertainty is statistical and the second systematic. The fitted values of c_i ($\bar{c}_i$) are expressed in terms of magnitudes $|c_i|$ ($|\bar{c}_i|$) and phases $\arg(c_i)$ [$\arg(\bar{c}_i)$] for each B^+ (B^-) contribution. The top row corresponds to B^+ and the bottom to B^- mesons.

Contribution	Fit fraction (%)	A_{CP} (%)	Magnitude (B^+/B^-)	Phase [°] (B^+/B^-)
$K^*(892)^0$	$7.5 \pm 0.6 \pm 0.5$	$+12.3 \pm 8.7 \pm 4.5$	$0.94 \pm 0.04 \pm 0.02$	0 (fixed)
			$1.06 \pm 0.04 \pm 0.02$	0 (fixed)
$K_0^*(1430)^0$	$4.5 \pm 0.7 \pm 1.2$	$+10.4 \pm 14.9 \pm 8.8$	$0.74 \pm 0.09 \pm 0.09$	$-176 \pm 10 \pm 16$
			$0.82 \pm 0.09 \pm 0.10$	$136 \pm 11 \pm 21$
Single pole	$32.3 \pm 1.5 \pm 4.1$	$-10.7 \pm 5.3 \pm 3.5$	$2.19 \pm 0.13 \pm 0.17$	$-138 \pm 7 \pm 5$
			$1.97 \pm 0.12 \pm 0.20$	$166 \pm 6 \pm 5$
$\rho(1450)^0$	$30.7 \pm 1.2 \pm 0.9$	$-10.9 \pm 4.4 \pm 2.4$	$2.14 \pm 0.11 \pm 0.07$	$-175 \pm 10 \pm 15$
			$1.92 \pm 0.10 \pm 0.07$	$140 \pm 13 \pm 20$
$f_2(1270)$	$7.5 \pm 0.8 \pm 0.7$	$+26.7 \pm 10.2 \pm 4.8$	$0.86 \pm 0.09 \pm 0.07$	$-106 \pm 11 \pm 10$
			$1.13 \pm 0.08 \pm 0.05$	$-128 \pm 11 \pm 14$
Rescattering	$16.4 \pm 0.8 \pm 1.0$	$-66.4 \pm 3.8 \pm 1.9$	$1.91 \pm 0.09 \pm 0.06$	$-56 \pm 12 \pm 18$
			$0.86 \pm 0.07 \pm 0.04$	$-81 \pm 14 \pm 15$
$\phi(1020)$	$0.3 \pm 0.1 \pm 0.1$	$+9.8 \pm 43.6 \pm 26.6$	$0.20 \pm 0.07 \pm 0.02$	$-52 \pm 23 \pm 32$
			$0.22 \pm 0.06 \pm 0.04$	$107 \pm 33 \pm 41$

Motivation for the ρ/ω⟶ $K^+ K^-$

PHYSICAL REVIEW LETTERS **123,** 231802 (2019)

Amplitude Analysis of $B^\pm \to \pi^\pm K^+ K^-$ Decays

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$\rho(1450)^0\pi^+$, $\rho^0 \to \pi^+\pi^-$	$(1.4 {+0.6 \atop -0.9}) \times 10^{-6}$			2434
$\rho(1450)^0\pi^+$, $\rho^0 \to K^+K^-$	$(1.60 \pm 0.14) \times 10^{-6}$	PDG2020		–

Contribu				/B^-)
$K^*(892)$				
$K_0^*(1430)^0$	$4.5 \pm 0.7 \pm 1.2$	$+10.4 \pm 14.9 \pm 8.8$	$0.74 \pm 0.09 \pm 0.09$	$-176 \pm 10 \pm 16$
			$0.82 \pm 0.09 \pm 0.10$	$136 \pm 11 \pm 21$
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Eur. Phys. J. C 39, 41–54 (2005)
Digital Object Identifier (DOI) 10.1140/epjc/s2004-02064-3

THE EUROPEAN PHYSICAL JOURNAL C

Modeling the pion and kaon form factors in the timelike region

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[2] Theoretische Physik 1, Fachbereich Physik, Universität Siegen, 57068 Siegen, Germany

Received: 7 October 2004 /

$$
\begin{aligned}
F_{K^+}(s) &= \frac{1}{2}\left(c_\rho^K \mathrm{BW}_\rho(s) + c_{\rho'}^K \mathrm{BW}_{\rho'}(s) + c_{\rho''}^K \mathrm{BW}_{\rho''}(s)\right) \\
&+ \frac{1}{6}\left(c_\omega^K \mathrm{BW}_\omega(s) + c_{\omega'}^K \mathrm{BW}_{\omega'}(s) + c_{\omega''}^K \mathrm{BW}_{\omega''}(s)\right) \\
&+ \frac{1}{3}\left(c_\phi \mathrm{BW}_\phi(s) + c_{\phi'} \mathrm{BW}_{\phi'}(s)\right), \qquad (64)
\end{aligned}
$$

$$
\begin{aligned}
g_{\rho^0\pi^+\pi^-} &\equiv g_{\rho\pi\pi} = \sqrt{2}A_{qq}, \\
g_{\rho^0K^+K^-} &= g_{\omega K^+K^-} = \frac{1}{\sqrt{2}}A_{qs}, \\
g_{\rho^0K^0\bar{K}^0} &= -g_{\omega K^0\bar{K}^0} = -\frac{1}{\sqrt{2}}A_{qs}, \\
g_{\phi K^+K^-} &= g_{\phi K^0\bar{K}^0} = -A_{sq}. \qquad (59)
\end{aligned}
$$

PHYSICAL REVIEW D **101,** 111901(R) (2020)

Rapid Communications

Will the subprocesses $\rho(770, 1450)^0 \to K^+K^-$ contribute large branching fractions for $B^\pm \to \pi^\pm K^+K^-$ decays?

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(Received 21 April 2020; accepted 28 May 2020; published 9 June 2020)

$$\mathcal{B}(B^\pm \to \pi^\pm \rho(1450)^0 \to \pi^\pm K^+K^-)$$
$$= (8.96 \pm 1.58(a_2^s + a_2^0 + a_2^t) \pm 0.83(\omega_B)$$
$$\pm 0.79(m_0^\pi + a_2^\pi) \pm 1.73(c^K_{\rho(1450)})) \times 10^{-8},$$

$$\mathcal{B}_v(B^\pm \to \pi^\pm \rho(770)^0 \to \pi^\pm K^+K^-)$$
$$= (1.31 \pm 0.22(a_2^s + a_2^0 + a_2^t) \pm 0.12(\omega_B)$$
$$\pm 0.11(m_0^\pi + a_2^\pi) \pm 0.02(c^K_{\rho(770)})) \times 10^{-7}.$$

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$\rho(1450)^0\pi^+$, $\rho^0 \to \pi^+\pi^-$	$(1.4 \, {}^{+\,0.6}_{-\,0.9}) \times 10^{-6}$	PDG2020	2434
$\rho(1450)^0\pi^+$, $\rho^0 \to K^+K^-$	$(1.60 \pm 0.14) \times 10^{-6}$		–

$$\mathcal{B}(B^\pm \to \pi^\pm\rho(1450)^0 \to \pi^\pm\pi^+\pi^-)$$

$$= (9.97 \pm 1.81(a_2^s + a_2^0 + a_2^t) \pm 0.98(\omega_B)$$

$$\pm 0.91(m_0^\pi + a_2^\pi)) \times 10^{-7},$$

$$g_{\rho(1450)^0 K^+ K^-} \approx \frac{1}{2} g_{\rho(1450)^0 \pi^+ \pi^-}$$

$$|g_{VPP}| = \left[\frac{6\pi m_V^2 \Gamma_V B(V \to PP)}{q_{PP}^3(m_V)} \right]^{1/2}$$

$$R_{\rho(1450)} = \frac{\mathcal{B}(\rho(1450)^0 \to K^+ K^-)}{\mathcal{B}(\rho(1450)^0 \to \pi^+ \pi^-)}$$
$$\approx \frac{g^2_{\rho(1450)^0 K^+ K^-} (m^2_{\rho(1450)} - 4m_K^2)^{3/2}}{g^2_{\rho(1450)^0 \pi^+ \pi^-} (m^2_{\rho(1450)} - 4m_\pi^2)^{3/2}}$$
$$= 0.107.$$

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$$R_{\rho(1450)} = \frac{\mathcal{B}(\rho(1450)^0 \to K^+ K^-)}{\mathcal{B}(\rho(1450)^0 \to \pi^+ \pi^-)} = 0.090 \pm 0.017,$$

$$\Gamma(B^\pm \to \rho^0 \pi^\pm \to h^+ h^- \pi^\pm) \approx \Gamma(B^+ \to \rho^0 \pi^\pm) \mathcal{B}(\rho^0 \to h^+ h^-)$$

PHYSICAL REVIEW D **95**, 072007 (2017)

Dalitz plot analyses of $J/\psi \to \pi^+\pi^-\pi^0$, $J/\psi \to K^+K^-\pi^0$, and $J/\psi \to K_s^0 K^\pm \pi^\mp$ produced via e^+e^- annihilation with initial-state radiation

J. P. Lees,[1] V. Poireau,[1] V. Tisserand,[1] E. Grauges,[2] A. Palano,[3,†] G. Eigen,[4] D. N. Brown,[5] Yu. G. Kolomensky,[5] M. Fritsch,[6]

(BABAR Collaboration)

$$R_{\rho(1450)} = \frac{\mathcal{B}(\rho(1450)^0 \to K^+K^-)}{\mathcal{B}(\rho(1450)^0 \to \pi^+\pi^-)} = 0.307 \pm 0.084(\text{stat}) \pm 0.082(\text{sys}),$$

PHYS. REV. D **101**, 111901 (2020)

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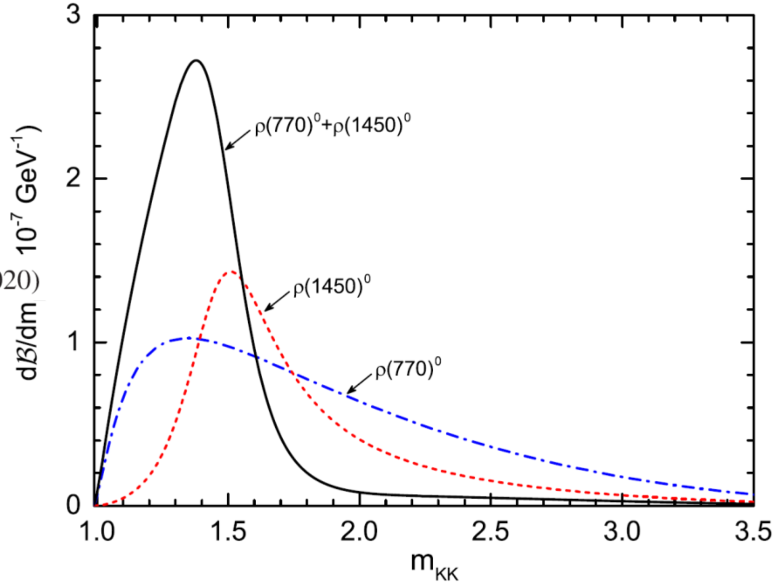
$$B^+ \to \pi^+\omega(782) \to \pi^+K^+K^-$$

$$\mathcal{B}_v \approx 2.32 \times 10^{-8}$$

$$R_{\rho(1700)} = \frac{\mathcal{B}(\rho(1700)^0 \to K^+K^-)}{\mathcal{B}(\rho(1700)^0 \to \pi^+\pi^-)} \approx \frac{g^2_{\rho(1700)^0K^+K^-}(m^2_{\rho(1700)} - 4m^2_K)^{3/2}}{g^2_{\rho(1700)^0\pi^+\pi^-}(m^2_{\rho(1700)} - 4m^2_\pi)^{3/2}} = 0.143,$$

PHYS. REV. D **101,** 111901 (2020)



arXiv:2007.02558

Branching Fractions and CP Violation in $B^- \to K^+K^-\pi^-$ and $B^- \to \pi^+\pi^-\pi^-$ Decays

Hai-Yang Cheng[1], Chun-Khiang Chua[2]

arXiv:2007.13141

Is $f_X(1500)$ observed in the $B \to \pi(K)KK$ decays $\rho^0(1450)$?

Zhi-Tian Zou[1,*] Ying Li[1,2,†] and Hsiang-nan Li[3‡]

Summary

- ✓ **Introduction for 3-body B decays**
- ✓ **Motivation for the ρ/ω⟶ $K^+ K^-$**
- ✓ **Results and discussions**

Thank You