B&D介子三体衰变过程中的共振态粒子的虚贡献

王文飞（山西大学）

第三届高能物理理论与实验融合发展研讨会
辽宁师范大学 2024-11-3

Outline

- 3-body B and D meson decays and the virtual contribution
- Some examples of the resonance virtual contributions
- Conclusions

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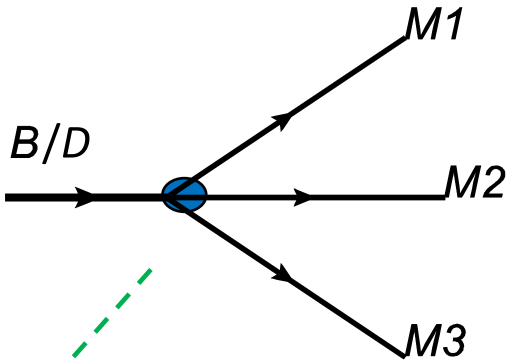
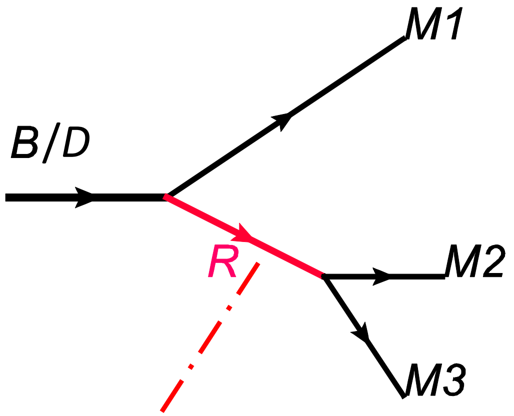
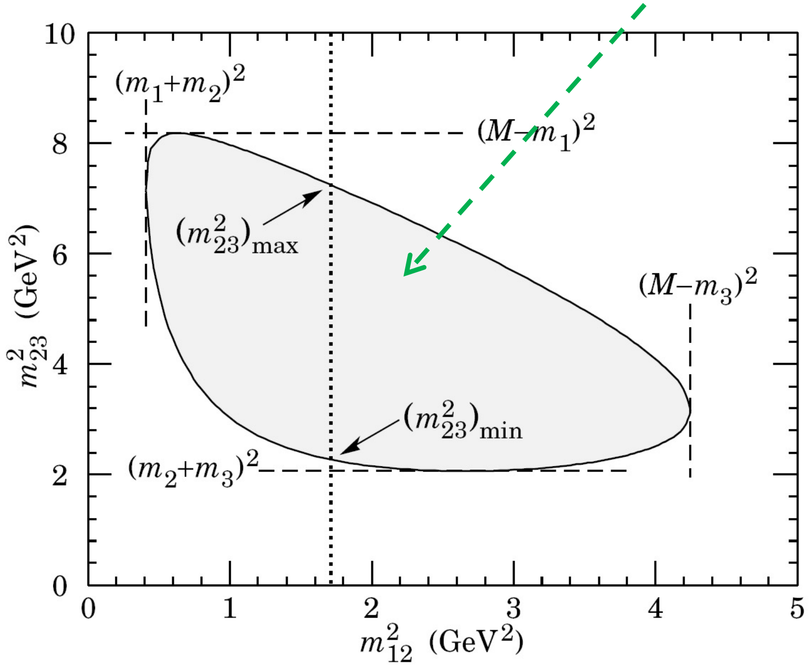
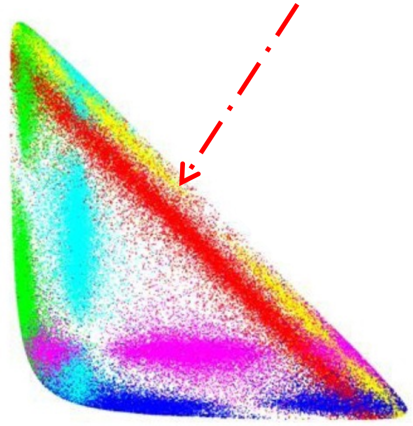
B&D → M1 M2 M3





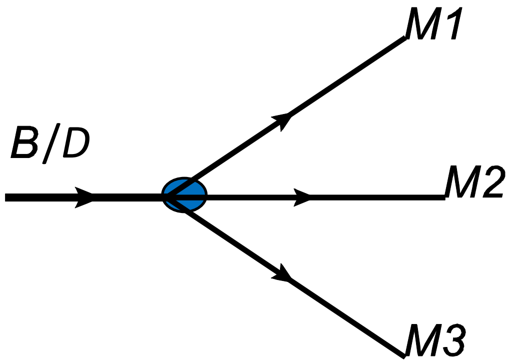


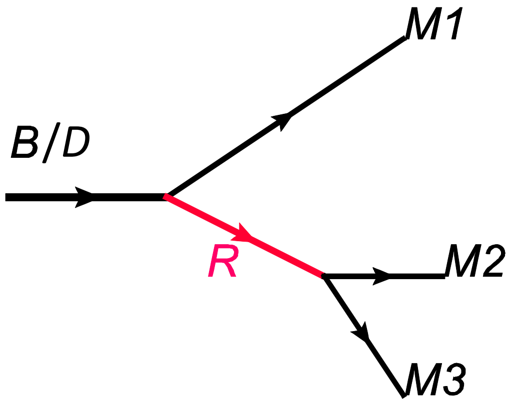


Dalitz Plot

3-body B and D meson decays and the virtual contribution

B&D → M1 M2 M3





The weak effective Hamiltonian:

1.

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

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

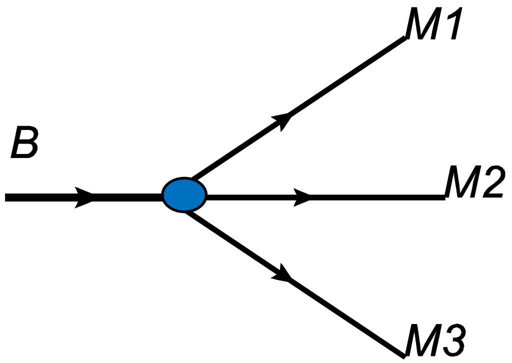
The total amplitude within isobar approach:

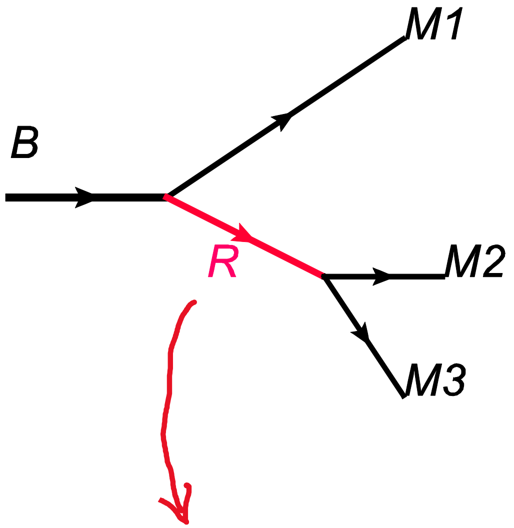
2.

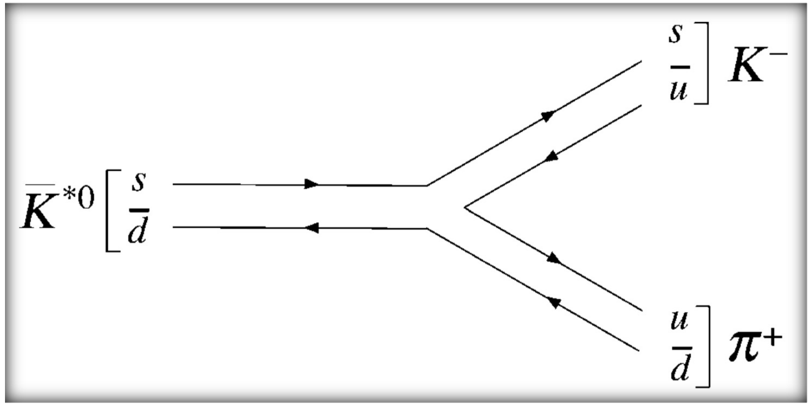
$$\mathcal{A}_{total} = \sum_i \mathcal{A}_{NR}^{i} + \sum_j \mathcal{A}_{R}^{j}$$

3-body B and D meson decays and the virtual contribution

$$B^{+} \to K^{+}K^{-}\pi^{+}$$

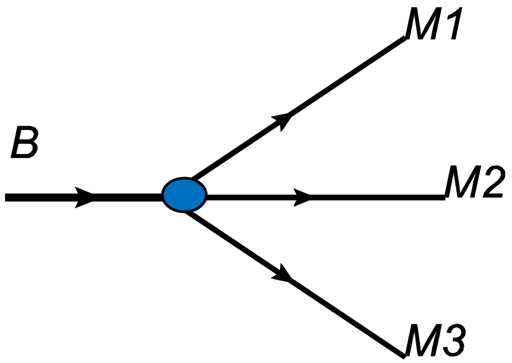


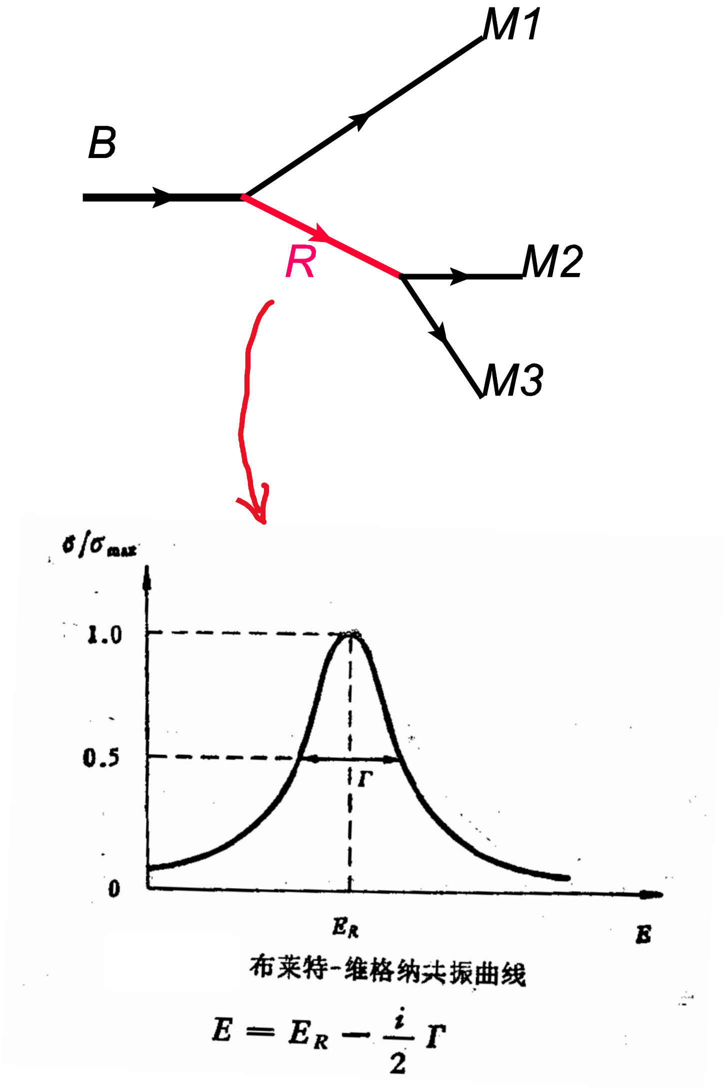




3-body B and D meson decays and the virtual contribution

$$B^+ \to K^+ K^- \pi^+$$





$$\mathrm{BW}_R = \frac{m_R^2}{m_R^2 - s - i m_R \Gamma_R(s)},$$

3-body B and D meson decays and the virtual contribution

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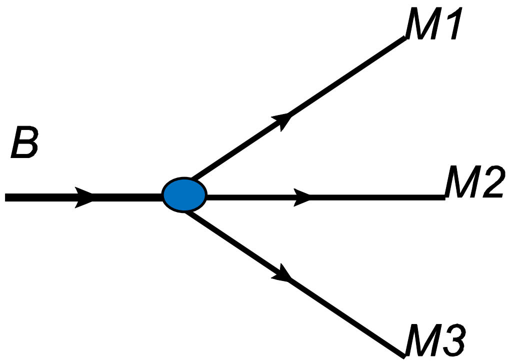
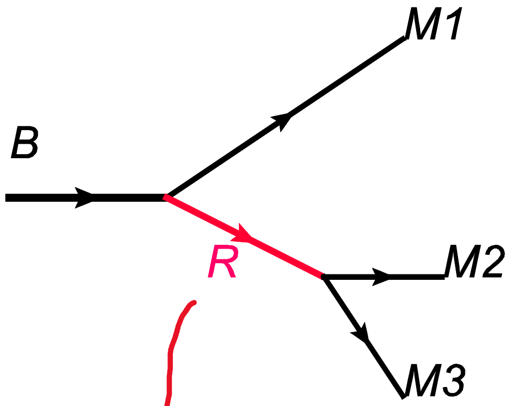
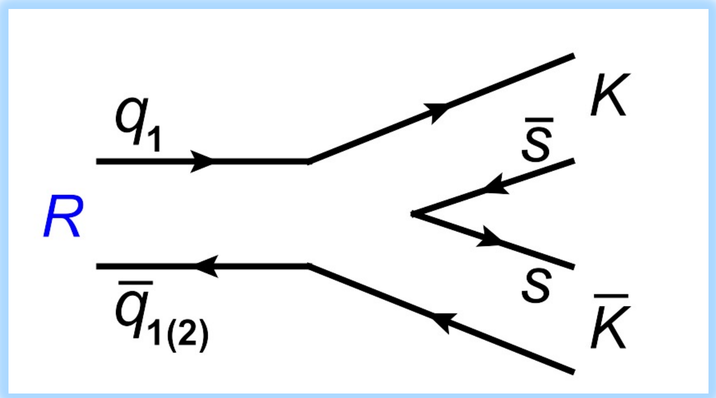
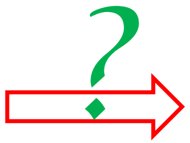
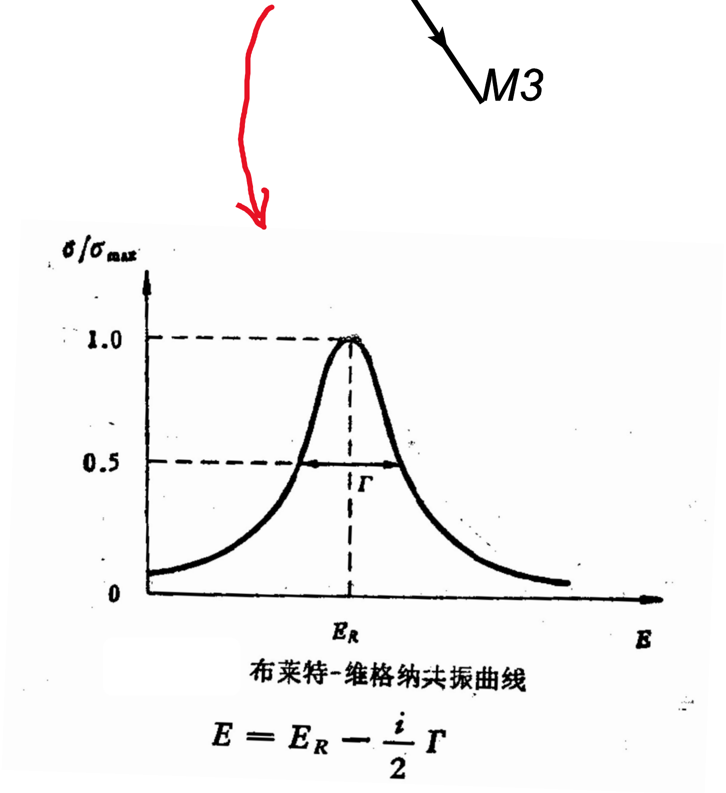




$$\rho(770)^0 \overset{?}{\to} K^+ K^-$$







3-body B meson decays and the virtual contribution

PHYSICAL REVIEW D VOLUME 15, NUMBER 11 1 JUNE 1977

High-statistics study of the reactions $\pi^- p \to K^- K^+ n$ and $\pi^+ n \to K^- K^+ p$ at 6 GeV/c*

A. J. Pawlicki, D. S. Ayres, D. Cohen, R. Diebold, S. L. Kramer, and A. B. Wicklund
Argonne National Laboratory, Argonne, Illinois 60439

(Received 23 December 1976; revised manuscript received 15 March 1977)

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Physics Letters B

Volume 25, Issue 4, 4 September 1967, Pages 294-297

Further study of the $I = 1 K\bar{K}$ structure near threshold

A. Astier, J. Cohen-Ganouna, M. Della Negra, B. Maréchal, L. Montanet, M. Tomas †, M. Baubillier, J. Duboc

3) The $I = 1$ $K\bar{K}$ channel is dominated, at threshold, by a virtual bound state resonance

Page-4

3-body B meson decays and the virtual contribution

PHYSICAL REVIEW D **94,** 072001 (2016)

Amplitude analysis of $B^- \to D^+\pi^-\pi^-$ decays

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

(Received 4 August 2016; published 5 October 2016)

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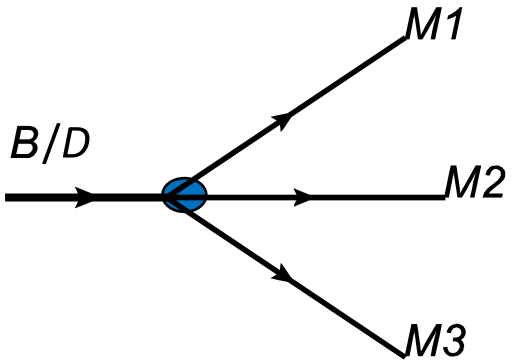
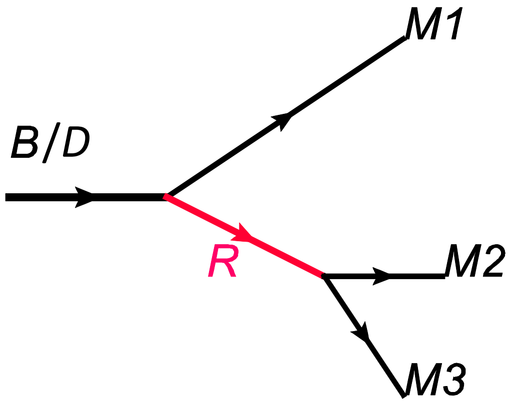
Contribution	Fit fraction (%)
$D_2^*(2460)^0$	35.7 ± 0.6
$D_1^*(2680)^0$	8.3 ± 0.6
$D_3^*(2760)^0$	1.0 ± 0.1
$D_2^*(3000)^0$	0.23 ± 0.07
$D_v^*(2007)^0$	10.8 ± 0.7
B_v^{*0}	2.7 ± 1.0
Total S wave	57.0 ± 0.8
Total fit fraction	115.7

B&D → M1 M2 M3





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- **Some examples of the resonance virtual contributions**
- Conclusions

Some examples of the resonance virtual contributions

$\rho(770)^0 \overset{?}{\to} K^+K^-$

Example - 1

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)

The first amplitude analysis of the $B^\pm \to \pi^\pm K^+ K^-$ decay is reported based on a data sample corresponding to an integrated luminosity of 3.0 fb^{-1} of pp collisions recorded in 2011 and 2012 with the LHCb detector. The data are found to be best described by a coherent sum of five resonant structures plus a nonresonant component and a contribution from $\pi\pi \leftrightarrow KK$ S-wave rescattering. The dominant contributions in the $\pi^\pm K^\mp$ and $K^+ K^-$ systems are the nonresonant and the $B^\pm \to \rho(1450)^0\pi^\pm$ amplitudes, respectively, with fit fractions around 30%. For the rescattering contribution, a sizable fit fraction is observed. This component has the largest CP asymmetry reported to date for a single amplitude of $(-66 \pm 4 \pm 2)\%$, where the first uncertainty is statistical and the second systematic. No significant CP violation is observed in the other contributions.

DOI: 10.1103/PhysRevLett.123.231802

Some examples of the resonance virtual contributions

$\rho(770)^0 \overset{?}{\rightarrow} K^+K^-$

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$(30.7 \pm 1.2 \pm 0.9)\%$

kaon pair. This fit fraction implies a branching fraction $(1.60 \pm 0.14) \times 10^{-6}$ for the quasi-two-body decay $B^+ \to \pi^+ \rho(1450)^0 \to \pi^+ K^+ K^-$ [15]; this is in view of the

Some examples of the resonance virtual contributions

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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?

Wen-Fei Wang*

Institute of Theoretical Physics, Shanxi University, Taiyuan, Shanxi 030006, China

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

We analyze the quasi-two-body decays $B^+ \to \pi^+\rho(770, 1450)^0 \to \pi^+K^+K^-$ in the perturbative QCD approach. The results in this work do not support that large branching fractions contributed by the resonances $\rho(770, 1450)^0$ in the $B^{\pm} \to \pi^{\pm}K^+K^-$ decays. The virtual contribution for K^+K^- from the tail of the resonance $\rho(770)^0$ which has been ignored in the experimental studies is about 1.5 times of the $\rho(1450)^0 \to K^+K^-$ contribution, with the predicted branching fractions $\mathcal{B}_v = (1.31 \pm 0.27) \times 10^{-7}$ and $\mathcal{B} = (8.96 \pm 2.61) \times 10^{-8}$, respectively, for these two subprocesses in the $B^{\pm} \to \pi^{\pm}K^+K^-$ decays. The absence of $\rho(770)^0 \to K^+K^-$ for the decay amplitude of a three-body hadronic B decay involving charged kaon pair could probably result in a larger proportion for the contribution from the resonance $\rho(1450)^0$ in experimental analysis.

DOI: 10.1103/PhysRevD.101.111901

Some examples of the resonance virtual contributions

$\rho(770)^0 \to K^+K^-$

Example - 1

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

Amplitude Analysis of B

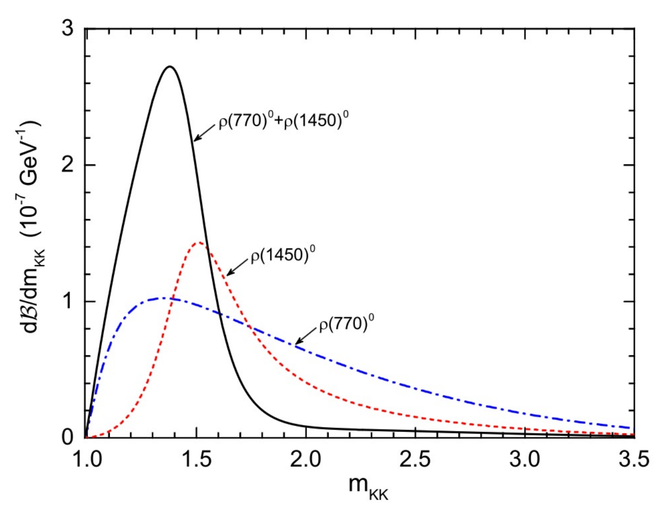

FIG. 2. The differential branching fractions for the quasi-two-body decays $B^\pm \to \pi^\pm\rho(770)^0 \to \pi^\pm K^+K^-$, $B^\pm \to \pi^\pm\rho(1450)^0 \to \pi^\pm K^+K^-$, and $B^\pm \to \pi^\pm(\rho(770)^0 + \rho(1450)^0) \to \pi^\pm K^+K^-$.

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

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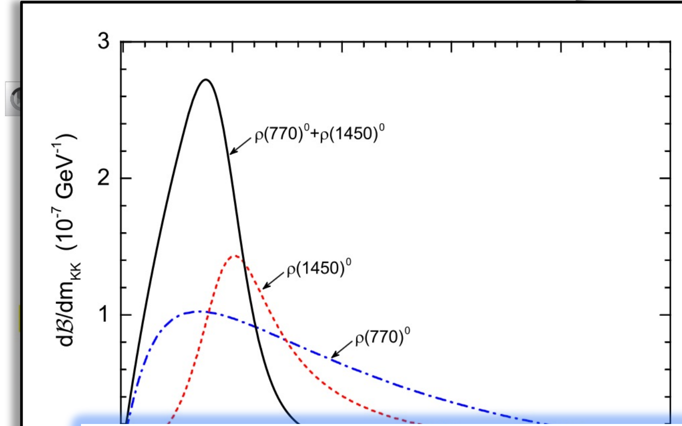

FIG
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$B^{\pm}$
$\rho(14$

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

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PHYSICAL REVIEW D **103,** 056021 (2021)

Contributions for the kaon pair from $\rho(770)$, $\omega(782)$ and their excited states in the $B \to K\bar{K}h$ decays

Wen-Fei Wang[1,2,*]

Some examples of the resonance virtual contributions

PHYSICAL REVIEW D **92,** 012013 (2015)

Study of D^{**} production and light hadronic states in the $\bar{B}^0 \to D^{*+}\omega\pi^-$ decay

D. Matvienko,[4,50] A. Kuzmin,[4,50] S. Eidelman,[4,50] A. Abdesselam,[61] I. Adachi,[15,11] H. Aihara,[66] S. Al Said,[61,30] K. Arinstein,[4,50] D. M. Asner,[52] V. Aulchenko,[4,50] T. Aushev,[41,24] R. Ayad,[61] V. Babu,[62] I. Badhrees,[61,29] S. Bahinipati,[17] A. M. Bakich,[60] V. Bansal,[52] V. Bhardwaj,[58] B. Bhuyan,[18] J. Biswal,[25] A. Bobrov,[4,50] A. Bondar,[4,50] G. Bonvicini,[70] A. Bozek,[48] M. Bračko,[37,25] T. E. Browder,[14] D. Červenkov,[5] A. Chen,[45] B. G. Cheon,[13] K. Chilikin,[24] R. Chistov,[24] K. Cho,[31] V. Chobanova,[38] S. -K. Choi,[12] Y. Choi,[59] D. Cinabro,[70] J. Dalseno,[38,63] J. Dingfelder,[3] Z. Doležal,[5] Z. Drásal,[5] A. Drutskoy,[24,40] D. Dutta,[62] D. Epifanov,[66] H. Farhat,[70] J. E. Fast,[52] T. Ferber,[8] B. G. Fulsom,[52] V. Gaur,[62] N. Gabyshev,[4,50]

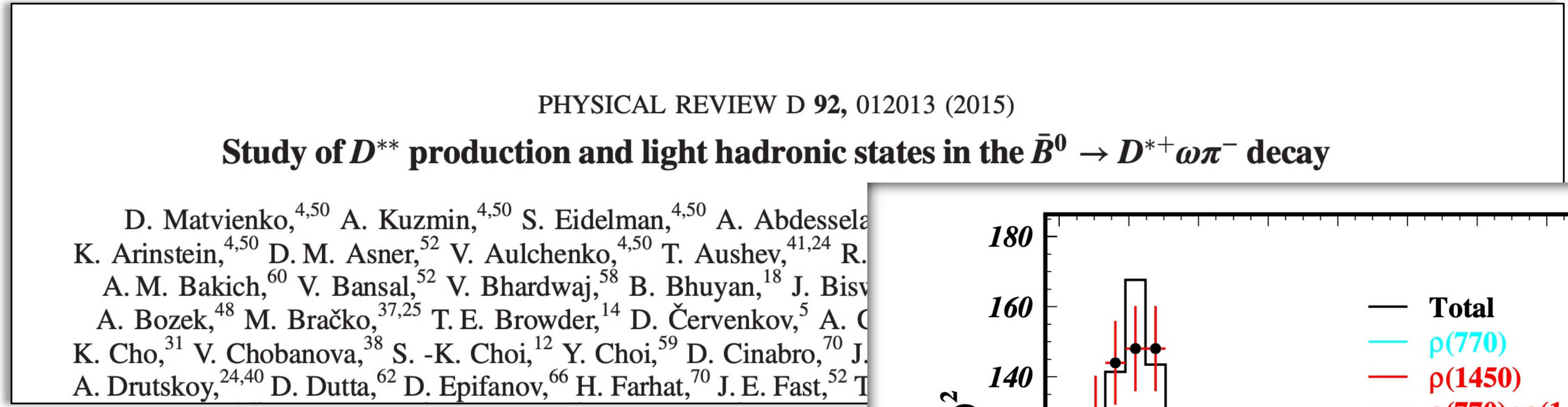
Example - 2

- $B^+ \to \overline{D}^{(*)0}\omega\pi^+$ and $B^0 \to D^{(*)-}\omega\pi^+$ have been measured but without any theoretical predictions [PRD64-092001, PRD74-012001, PRD92-012013]

- The $\omega\pi^+$ is related to the resonances $\rho(1450)$ and $\rho(770)$

Some examples of the resonance virtual contributions

Example - 2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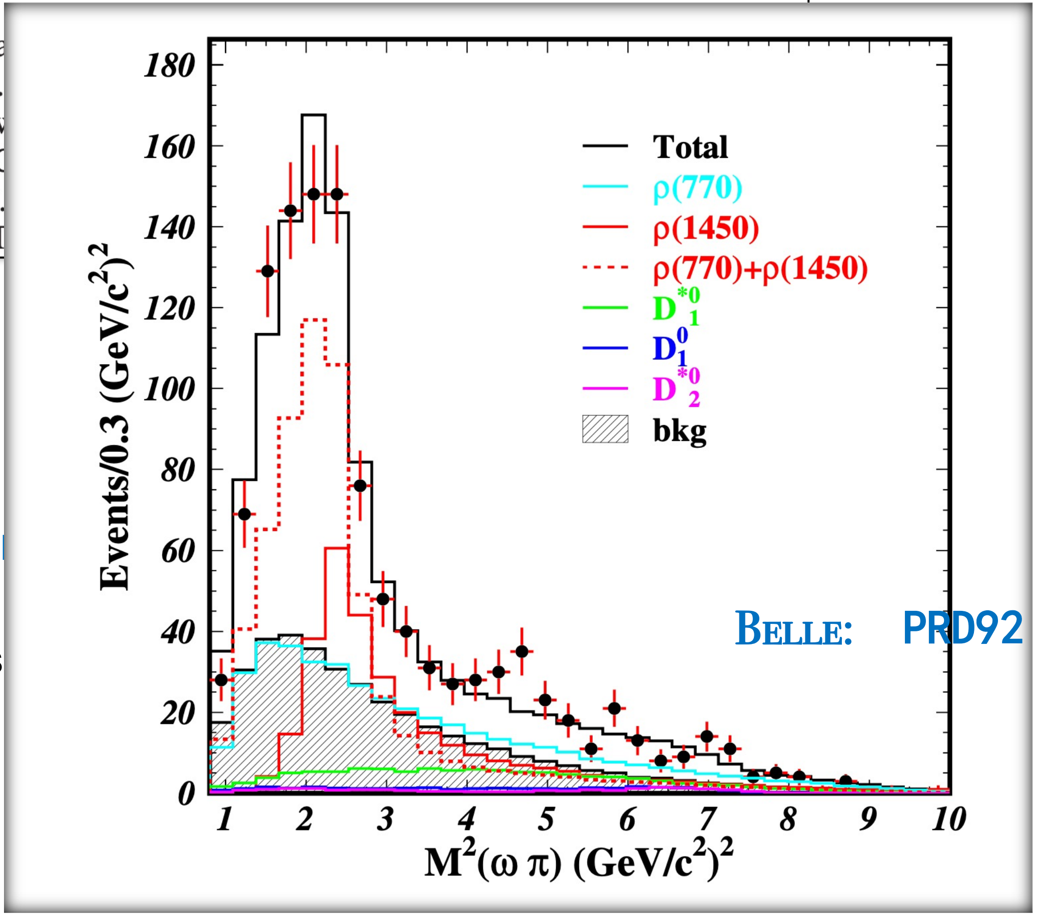

Belle: PRD92 012013

- ❖ $B^+ \to \overline{D}^{(*)0}\omega\pi^+$ and $B^0 \to D^{(*)-}\omega\pi^+$ have theoretical predictions [
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$\rho \to \omega\pi$

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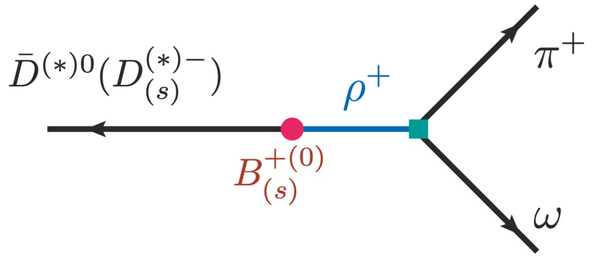
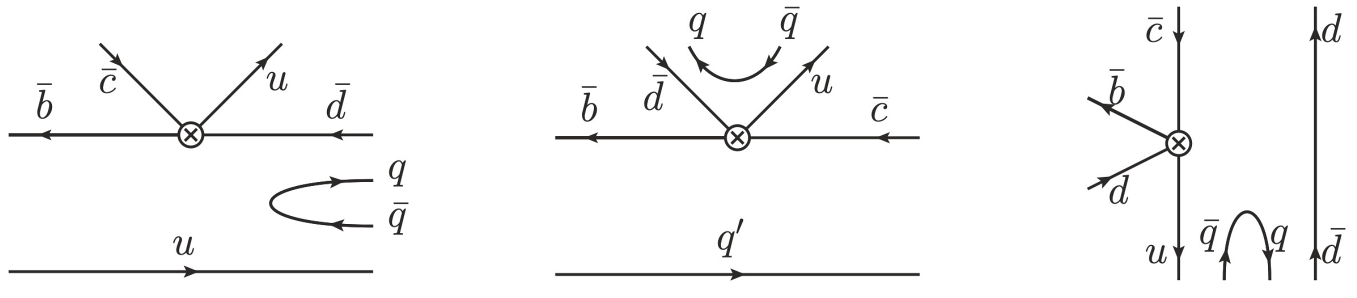




(a) (b) (c)

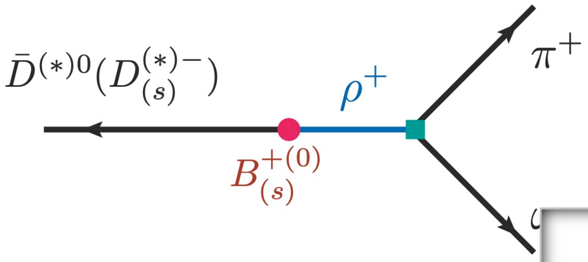
With PQCD approach

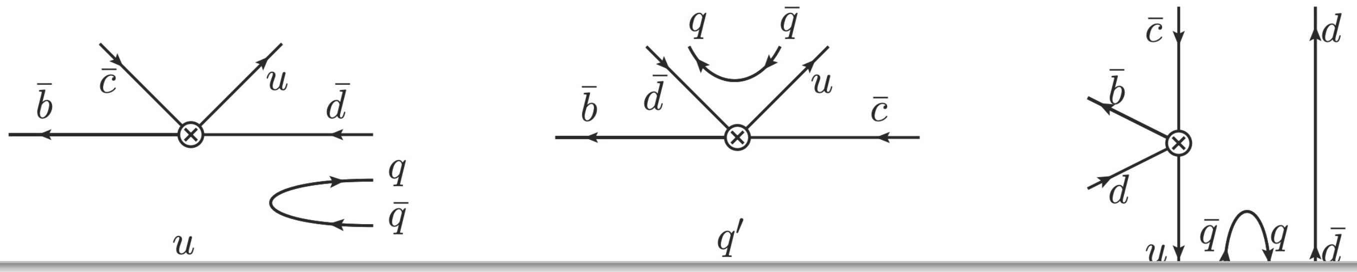
$$\mathcal{A} = \langle (\omega\pi)_{P\text{-wave}} D^{(*)} | \mathcal{H}_{\text{eff}} | B \rangle$$
$$= \phi_B \otimes \mathcal{H} \otimes \phi_{\omega\pi}^{P\text{-wave}} \otimes \phi_{D^{(*)}}$$

Some examples of the resonance virtual contributions

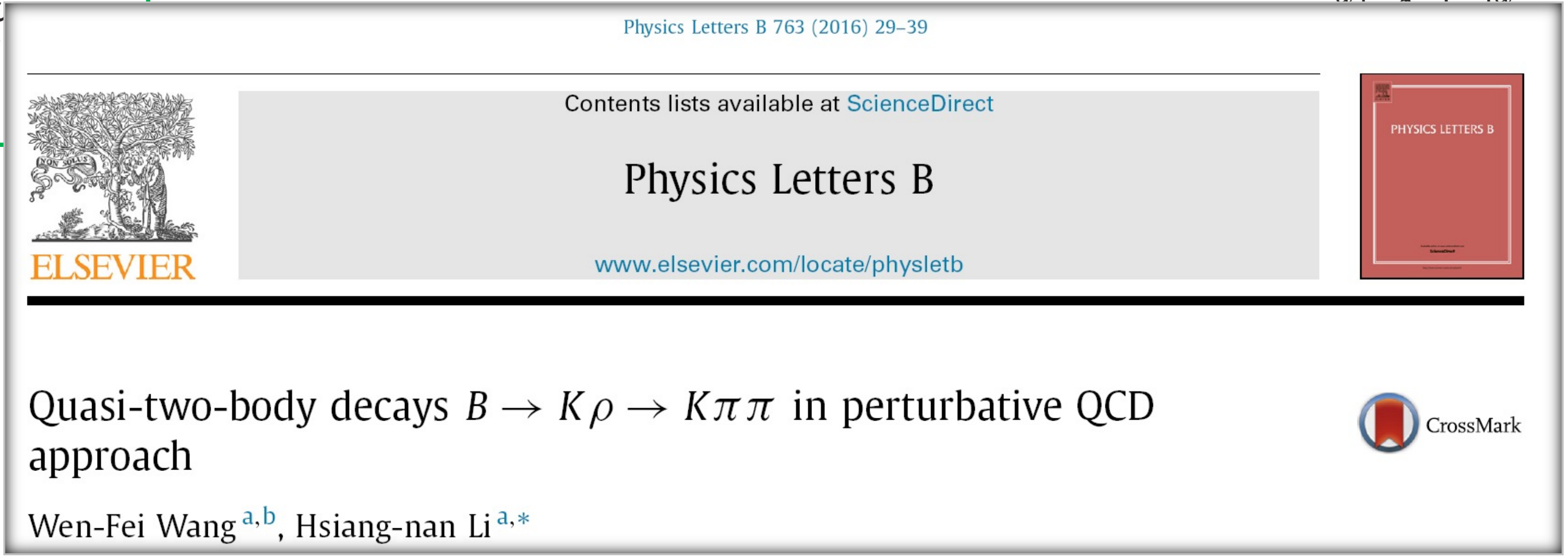
$\rho \to \omega\pi$

Example - 2





With PQCD approach


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,*]

Some examples of the resonance virtual contributions

Example - 2

JHEP

PUBLISHED FOR SISSA BY SPRINGER

RECEIVED: *November 3, 2023*
REVISED: *December 13, 2023*
ACCEPTED: *December 21, 2023*
PUBLISHED: *January 10, 2024*

The $\rho(770, 1450) \to \omega\pi$ contributions for three-body decays $B \to \bar{D}^{(*)}\omega\pi$

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ABSTRACT: The decays $B \to \bar{D}^{(*)}\omega\pi$ are very important for the investigation of ρ excitations and the test of factorization hypothesis for B meson decays. The $B^+ \to \bar{D}^{(*)0}\omega\pi^+$ and $B^0 \to D^{(*)-}\omega\pi^+$ have been measured by different collaborations but without any predictions for their observables on theoretical side. In this work, we study the contributions of $\rho(770, 1450) \to \omega\pi$ for the cascade decays $B^+ \to \bar{D}^{(*)0}\rho^+ \to \bar{D}^{(*)0}\omega\pi^+$, $B^0 \to D^{(*)-}\rho^+ \to D^{(*)-}\omega\pi^+$ and $B_s^0 \to D_s^{(*)-}\rho^+ \to D^{(*)-}\omega\pi^+$. We introduce $\rho(770, 1450) \to \omega\pi$ subprocesses into the distribution amplitudes for $\omega\pi$ system via the vector form factor $F_{\omega\pi}(s)$ and then predict the branching

JHEP01(2024)047

Example - 2

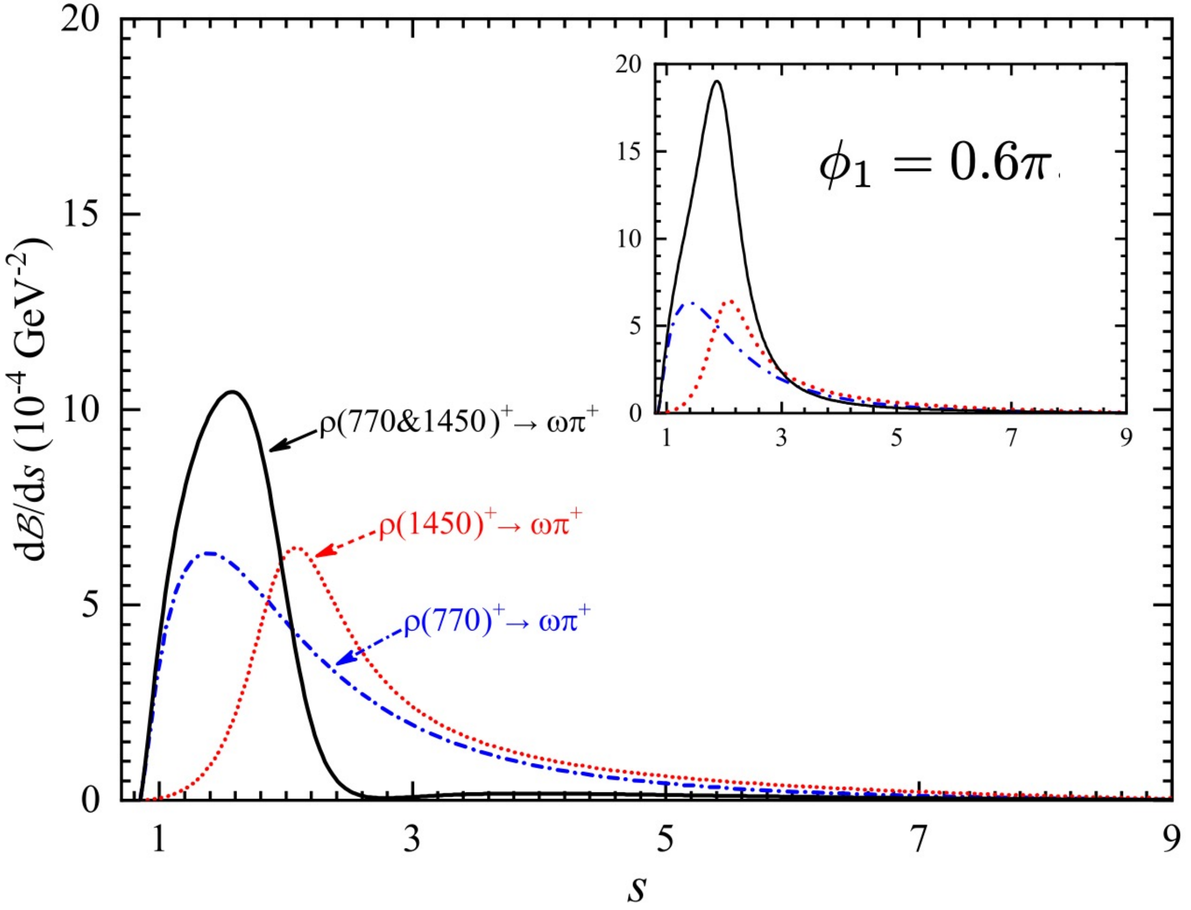
Decay modes	$\mathcal{B}$ (in 10^{-3})	Γ_L/Γ
$B^+ \to \bar{D}^{*0}[\rho(770)^+ \to]\omega\pi^+$	$1.21^{+0.17+0.09+0.05+0.07}_{-0.17-0.09-0.03-0.07}$	$0.74^{+0.02}_{-0.02}$
$B^+ \to \bar{D}^{*0}[\rho(1450)^+ \to]\omega\pi^+$	$0.87^{+0.12+0.07+0.03+0.37}_{-0.12-0.07-0.02-0.37}$	$0.67^{+0.02}_{-0.02}$
$B^0 \to D^{*-}[\rho(770)^+ \to]\omega\pi^+$	$1.20^{+0.18+0.09+0.02+0.07}_{-0.18-0.08-0.01-0.07}$	$0.68^{+0.02}_{-0.02}$
$B^0 \to D^{*-}[\rho(1450)^+ \to]\omega\pi^+$	$0.89^{+0.13+0.06+0.02+0.38}_{-0.13-0.06-0.02-0.38}$	$0.63^{+0.01}_{-0.01}$
$B_s^0 \to D_s^{*-}[\rho(770)^+ \to]\pi\pi^+$	$1.03^{+0.11+0.08+0.00+0.05}_{-0.11-0.08-0.00-0.05}$	$0.65^{+0.01}_{-0.01}$
$B_s^0 \to D_s^{*-}[\rho(1450)^+ \to]\pi\pi^+$	$0.77^{+0.08+0.06+0.00+0.32}_{-0.08-0.06-0.00-0.32}$	$0.59^{+0.01}_{-0.01}$

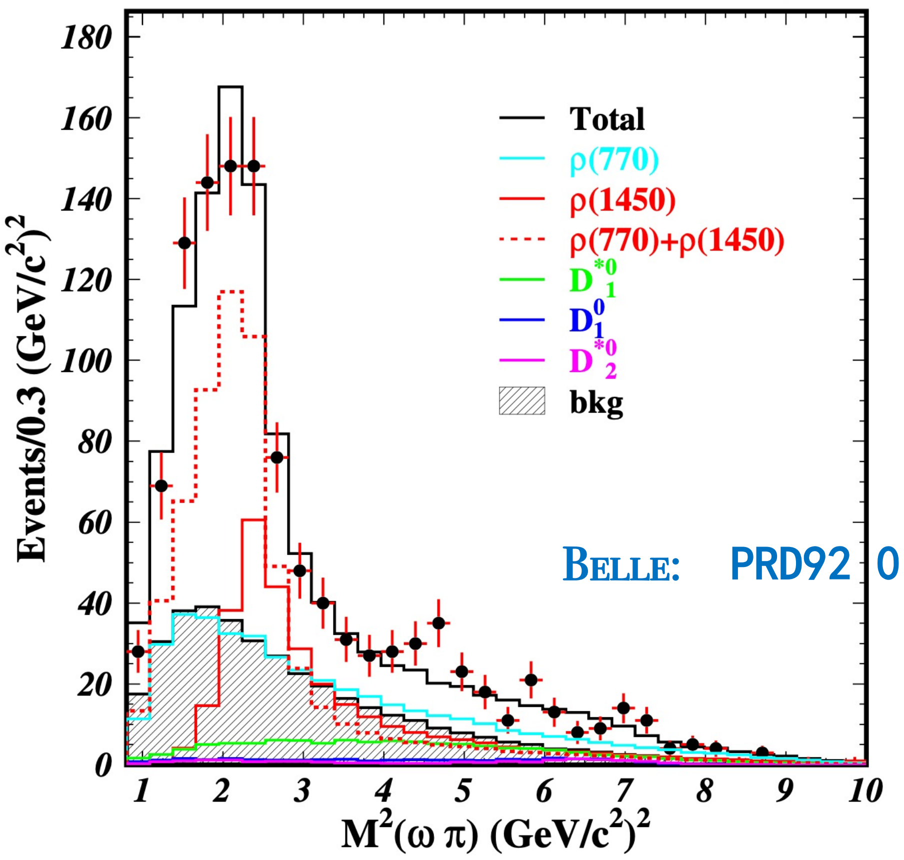
BELLE: PRD92–012013

$$\mathcal{B} = (1.48 \pm 0.27^{+0.15+0.21}_{-0.09-0.56}) \times 10^{-3}$$

$$\mathcal{B} = (1.07^{+0.15+0.06+0.40}_{-0.31-0.13-0.02}) \times 10^{-3}$$

Example - 2





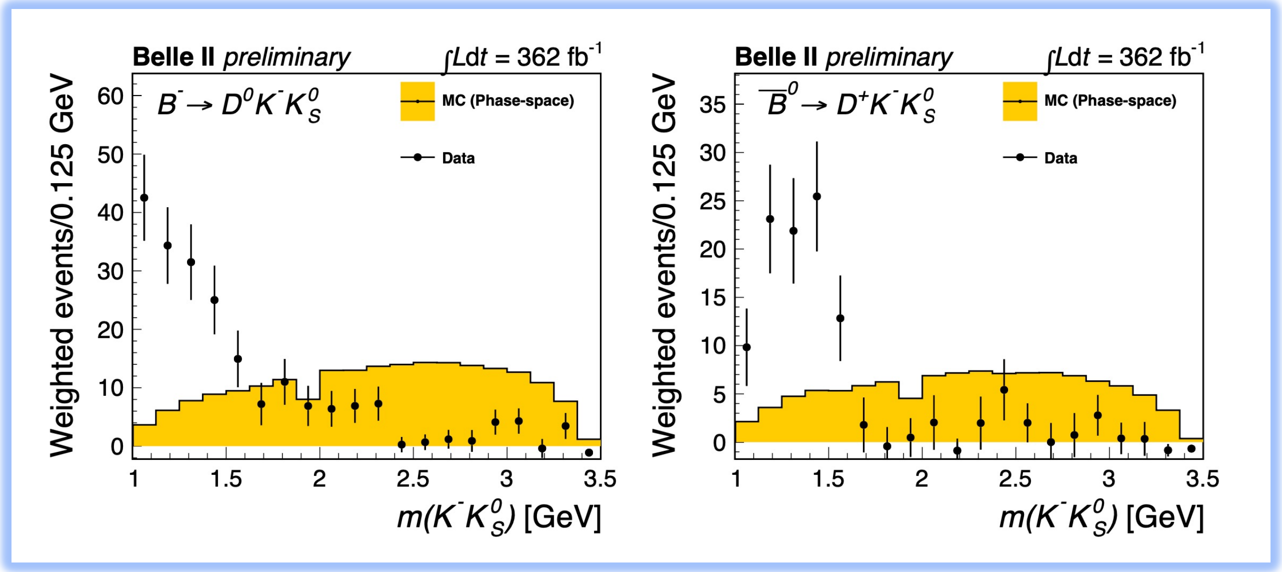
BELLE: PRD92 012013

$$B^0 \to D^{*-}\rho^+ \to D^{*-}\omega\pi^+$$

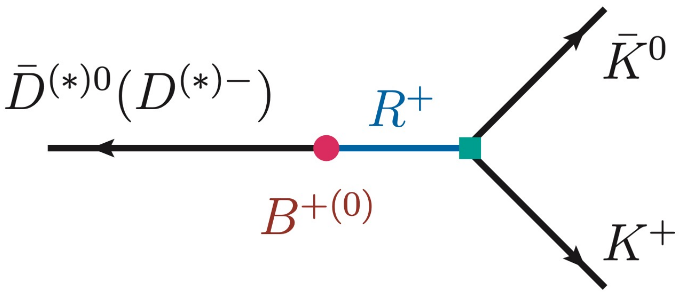
Belle-II arXiv:2305.01321

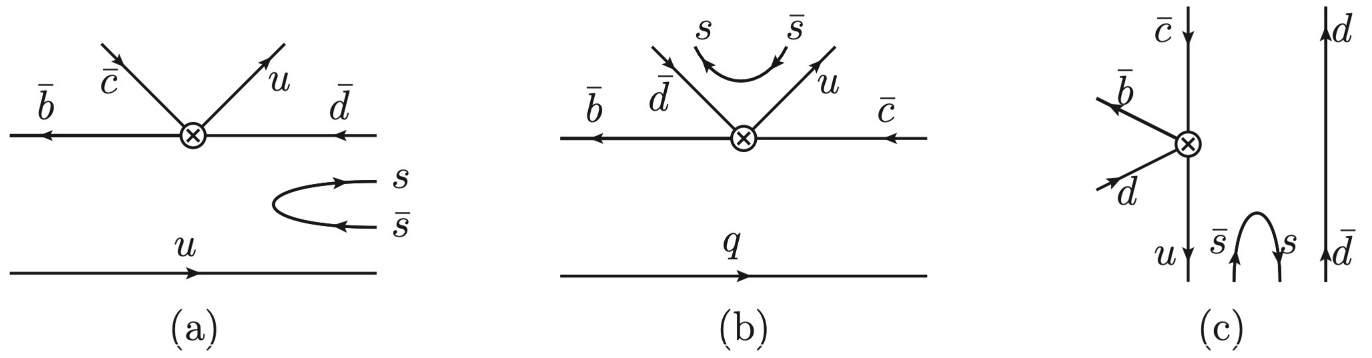
Example - 3

$$\mathcal{B}(B^- \to D^0 K^- K_S^0) = (1.89 \pm 0.16 \pm 0.10) \times 10^{-4},$$
$$\mathcal{B}(\overline{B}^0 \to D^+ K^- K_S^0) = (0.85 \pm 0.11 \pm 0.05) \times 10^{-4},$$
$$\mathcal{B}(B^- \to D^{*0} K^- K_S^0) = (1.57 \pm 0.27 \pm 0.12) \times 10^{-4},$$
$$\mathcal{B}(\overline{B}^0 \to D^{*+} K^- K_S^0) = (0.96 \pm 0.18 \pm 0.06) \times 10^{-4},$$



Example - 3





Isospin $I = 1$ $K^+\overline{K}^0$

$$\left\{ \begin{array}{l} \rho(770)^+ \ \& \ \rho(1450)^+ \ \& \ \rho(1700)^+ \\ a_0(980)^+ \ \& \ a_0(1450)^+ \\ a_2(1320)^+ \ \& \ a_2(1700)^+ \end{array} \right.$$

PHYSICAL REVIEW D **109**, 116009 (2024)

Low-mass enhancement of kaon pairs in $B^+ \to \bar{D}^{(*)0} K^+ \bar{K}^0$ and $B^0 \to D^{(*)-} K^+ \bar{K}^0$ decays

Wen-Fei Wang,[1,2,*] Li-Fei Yang,[1] Ai-Jun Ma,[3] and Àngels Ramos[2,†]

Example - 3

TABLE III: PQCD predictions for the branching fractions of the concerned quasi-two-body decays with the subprocess $\rho^+ \to K^+\bar{K}^0$, here $\rho^+ = \rho(770)^+ + \rho(1450)^+$.

Mode	Unit	$\mathcal{B}$
$B^+ \to \bar{D}^0[\rho^+ \to]K^+\bar{K}^0$	10^{-4}	$1.68^{+0.20+0.17+0.12}_{-0.20-0.15-0.12}$
$B^0 \to D^-[\rho^+ \to]K^+\bar{K}^0$	10^{-4}	$0.98^{+0.06+0.13+0.06}_{-0.06-0.12-0.06}$
$B^+ \to \bar{D}^{*0}[\rho^+ \to]K^+\bar{K}^0$	10^{-4}	$1.33^{+0.21+0.11+0.05}_{-0.21-0.11-0.07}$
$B^0 \to D^{*-}[\rho^+ \to]K^+\bar{K}^0$	10^{-4}	$1.16^{+0.19+0.08+0.02}_{-0.19-0.09-0.02}$

Belle-II arXiv:2305.01321

$$\mathcal{B}(B^- \to D^0 K^- K^0_S) = (1.89 \pm 0.16 \pm 0.10) \times 10^{-4},$$
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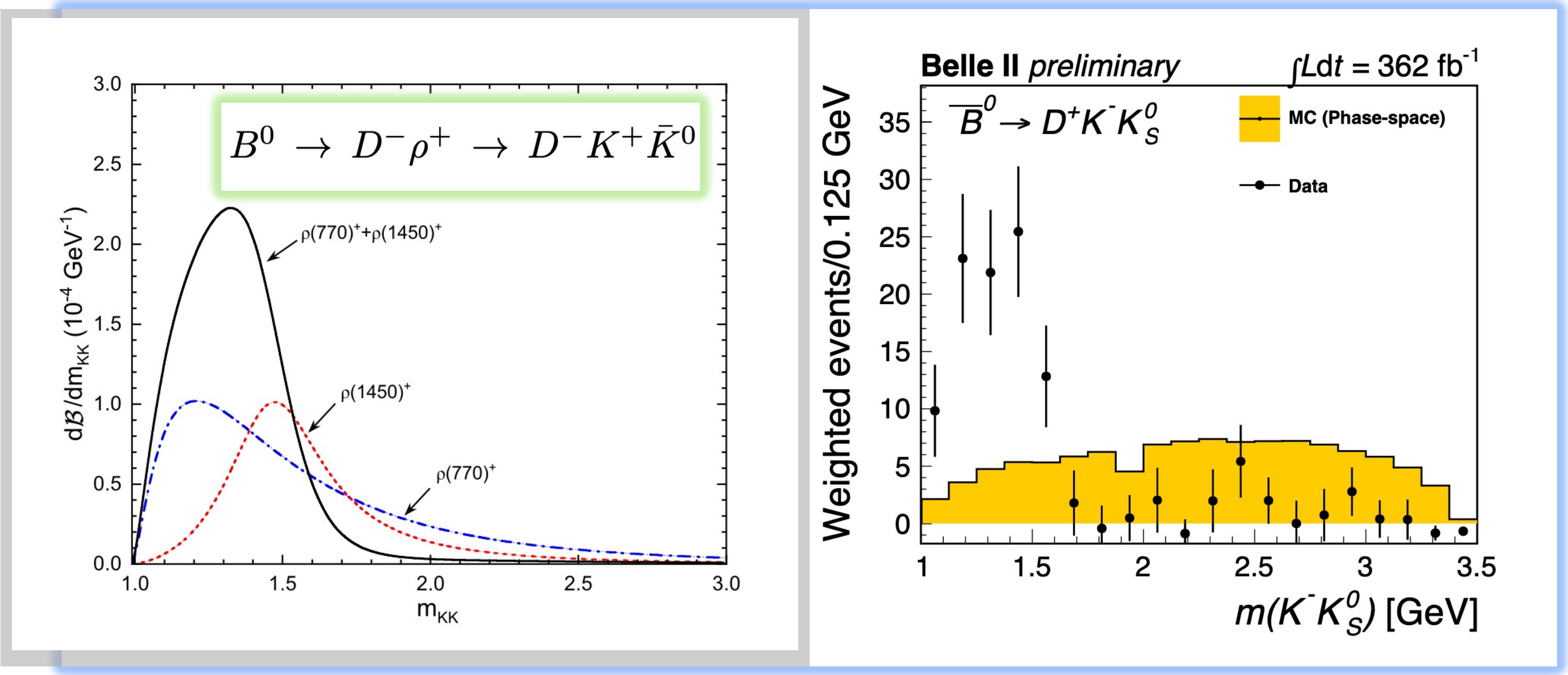
Example - 3


$B^0 \to D^-\rho^+ \to D^-K^+\bar{K}^0$
$\rho(770)^+ + \rho(1450)^+$
$\rho(1450)^+$
$\rho(770)^+$
$d\mathcal{B}/dm_{KK}$ (10^{-4} GeV^{-1})
m_{KK}
Belle II preliminary
$\int Ldt = 362$ fb^{-1}
$\bar{B}^0 \to D^+K^-K^0_S$
MC (Phase-space)
Data
Weighted events/0.125 GeV
$m(K^-K^0_S)$ [GeV]

Some examples of the resonance virtual contributions

PHYSICAL REVIEW D **104,** 116019 (2021)

Subprocesses $\rho(770,1450) \to K\bar{K}$ for the three-body hadronic D meson decays

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(Received 15 October 2021; accepted 2 December 2021; published 21 December 2021)

We construct the theoretical framework for quasi-two-body D meson decays with the help of pion and kaon electromagnetic form factors and with which we study the contributions of the subprocesses $\rho(770,1450) \to K\bar{K}$ for the three-body D decays within the flavor $SU(3)$ symmetry. Because of the limitations imposed by phase space and strong coupling, the contributions for the kaon pair from the virtual bound state $\rho(770)$ are channel dependent and generally small for the concerned three-body D decays, but some quasi-two-body processes could still be observed in the Dalitz plot analyses for related decays, such as $D^0 \to K^-\rho(770)^+ \to K^-K^+K^0_S$ and $D^+ \to K^0_S\rho(770)^+ \to K^0_S K^+ K^0_S$, they are predicted to have the branching fractions $\mathcal{B} = (0.82 \pm 0.04) \times 10^{-4}$ and $\mathcal{B} = 0.47^{+0.05}_{-0.03} \times 10^{-4}$, which are $(1.86 \pm 0.16)\%$ and $(1.84^{+0.21}_{-0.16})\%$, respectively, of the total branching fractions for the corresponding three-body D decays. We find in this work that the normal subprocesses like $\rho(1450)^+ \to \pi^+\pi^0$ or $\rho(1450)^+ \to K^+\bar{K}^0$, which are bound by the masses of decaying initial states, will provide virtual contributions in some special decays.

DOI: 10.1103/PhysRevD.104.116019

Example - 4

Some examples of the resonance virtual contributions

Example - 5

PHYSICAL REVIEW D **107,** 052010 (2023)

Observation of the decay $D_s^+ \to \omega\pi^+\eta$

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M. ABLIKIM *et al.* PHYS. REV. D **107,** 052010 (2023)

(Received 9 February 2023; accepted 13 March 2023; published 27 March 2023)

Using 7.33 fb^{-1} of e^+e^- collision data collected by the BESIII detector at c.m. energies between 4.128 GeV and 4.226 GeV, we observe for the first time the decay $D_s^\pm \to \omega\pi^\pm\eta$ with a statistical significance of 7.6σ. The measured branching fraction of this decay is $(0.54 \pm 0.12 \pm 0.04)\%$, where the first uncertainty is statistical and the second is systematic.

DOI: 10.1103/PhysRevD.107.052010

Some examples of the resonance virtual contributions

Example - 5

M. ABLIKIM *et al.* PHYS. REV. D **107,** 052010 (2023)

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DOI: 10.1103/PhysRevD.107.052010

PDG-2024

74 Meson Summary Table

$2\pi^+\pi^-\pi^0$		—		935
$\eta\pi^+$	[ddd]	(1.67 ±0.09) %	S=1.1	902
$\omega\pi^+$	[ddd]	(1.92 ±0.30) × 10^{-3}		822
$\omega\pi^+$, $\omega \to \pi^+\pi^-$		(3.9 ±0.5) × 10^{-5}		–
$3\pi^+2\pi^-$		(7.8 ±0.8) × 10^{-3}		899
$2\pi^+\pi^-2\pi^0$		—		902
$\eta\rho^+$	[ddd]	(8.9 ±0.8) %		724

Outline

- 3-body B and D meson decays and the virtual contribution
- Some examples of the resonance virtual contributions
- Conclusions

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1. $\mathcal{A}_{total} = \sum_i \mathcal{A}_{NR}^i + \sum_j \mathcal{A}_R^j$

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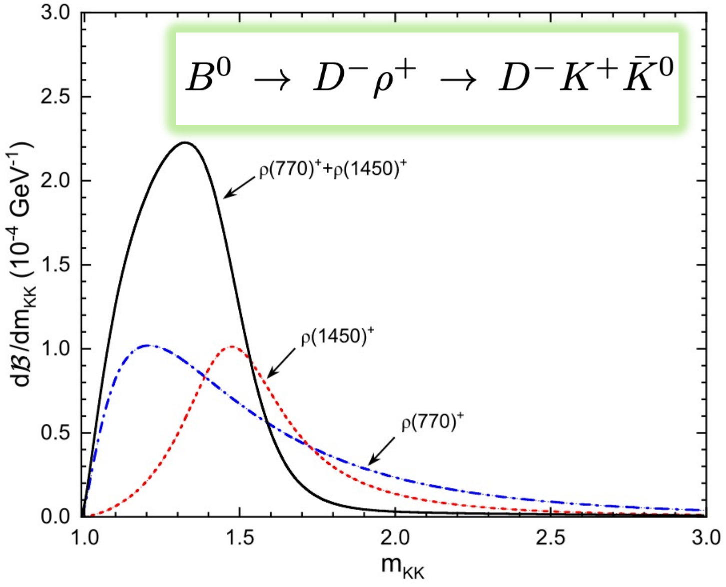
3. $$D_{\rho_i}(s) = m_{\rho_i}^2 - s - i\sqrt{s}\,\Gamma_{\rho_i}(s)$$

4. **A bump does not always mean a new state**



Conclusions

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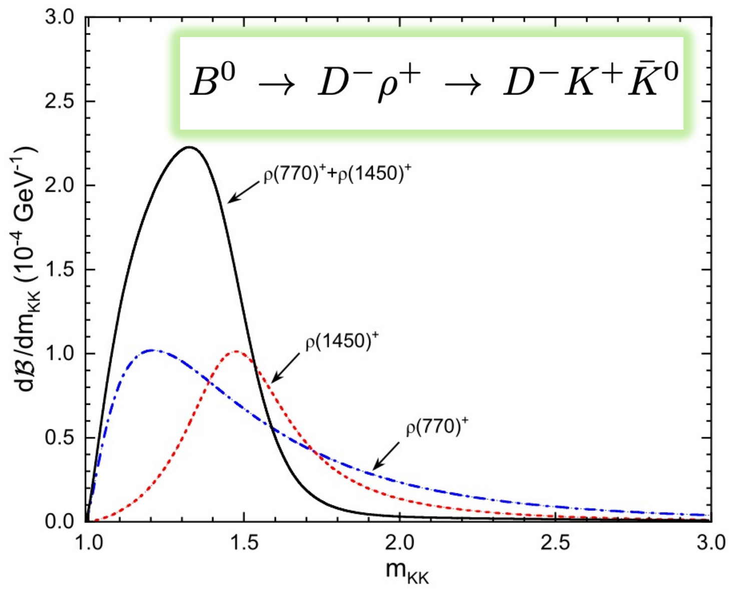

Thank You !