

$\pi\pi$ and πK final state interactions and CP violation in $B \rightarrow \pi\pi K$ decays

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References

- B. El-Bennich *et al.*, Phys. Rev. D74 (2006) 114009, hep-ph/0608205
'Interference between $f_0(980)$ and $\rho(770)$ resonances in $B \rightarrow \pi^+ \pi^- K$ decays'
- A. Furman *et al.*, Phys. Lett. B622 (2005) 207, hep-ph/0504116
'Long-distance effects and final state interactions in $B \rightarrow \pi\pi K$ decays and $B \rightarrow KKK$ decays'

Outline

- motivation,
- experimental data,
- model for weak and strong (final state) interactions
 - interference between S - and P -waves,
- results (fits to exp. Belle and BaBar data),
- conclusions

What interesting can be studied in $B \rightarrow \pi\pi K$ decays?

- $\pi\pi$ and $K\pi$ final state interactions,
- comparison with isobar model which violates unitarity,
- direct CP-violation,
- long-distance effects (charming penguins),
- experimental data

Experimental data in our disposal:

three body decays charmless reactions:

- $B^- \rightarrow (K^- \pi^+) \pi^- \rightarrow (1,3)$
 - $B^+ \rightarrow (K^+ \pi^-) \pi^+ \rightarrow (1,3)$
 - $\bar{B}^0 \rightarrow (\bar{K}^0 \pi^-) \pi^+ \rightarrow (2,4)$
 - $B^0 \rightarrow (K^0 \pi^+) \pi^- \rightarrow (2,4)$
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- 249 data points for $K\pi$ effective mass and helicity distributions,
 - 12 values of branching ratios and direct CP-violation asymmetries for quasi-two-body decays

(1) A. Garmash *et al.* (Belle Coll.), Phys. Rev. Lett. 96, 251803 (2006) and hep-ph/0509001,

(2) A. Garmash *et al.* (Belle Coll.), Phys. Rev. D75, 012006 (2006),

(3) B. Aubert *et al.* (BaBar Coll.), Phys. Rev. D72, 072003 (2005),

(4) B. Aubert *et al.* (BaBar Coll.), Phys. Rev. D73, 031101 (2006)

Some quasi two-body reactions:

- with $\pi^+\pi^-$ or K^+K^- interactions in S - or P -wave

- $B^\pm \rightarrow f_0(980)K^\pm$ with $f_0(980) \rightarrow (\pi^+\pi^-)_S$ or $f_0(980) \rightarrow (K^+K^-)_S$ (S -wave)

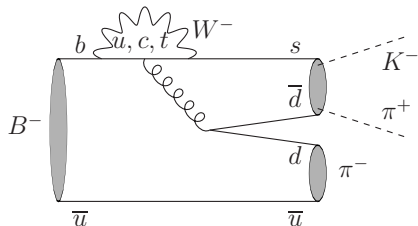
- $B^\pm \rightarrow \rho(770)^0 K^\pm$ with $\rho(770)^0 \rightarrow (\pi^+\pi^-)_P$ (P -wave)

- with $K\pi$ interactions in S - or P -wave

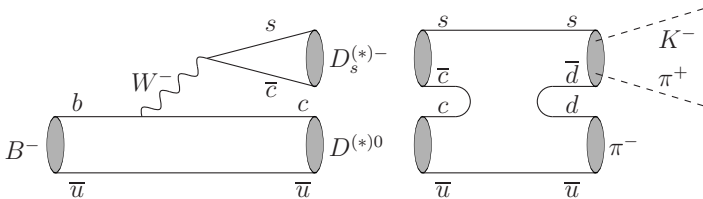
- $B^\pm \rightarrow K_0^*(1430)\pi^\pm$ with $K_0^*(1430) \rightarrow (K^+\pi^-)_S$ (S -wave)

- $B^\pm \rightarrow K^*(892)^0 \pi^\pm$ with $K^*(892)^0 \rightarrow (K^+\pi^-)_P$ (P -wave)

Penguin type diagram for the $B^- (K^- \pi^+) \pi^-$ decay:



Long-distance amplitudes with c-quark in loop:



S- and P-wave decay amplitudes for $B^- \rightarrow K^- \pi^+ \pi^-$ transition:

$K^- \pi^+$ **S-wave:**

$$\langle (K^- \pi^+)_S \pi^- | H_{\text{eff}} | B^- \rangle = \frac{G_F}{\sqrt{2}} (M_{B^-}^2 - m_{\pi^-}^2) \frac{m_{K^-}^2 - m_{\pi^+}^2}{q^2} F_0^{B^- \rightarrow \pi^-}(q^2) \times$$

$$f_0^{K^- \pi^+}(q^2) \left\{ \lambda_u (a_4^u + P_u - a_{10}^u/2) + \lambda_c (a_4^c + P_c - a_{10}^c/2) - 2 \frac{q^2}{(m_b - m_d)(m_s - m_d)} \times \right.$$

$$\left. [\lambda_u (a_6^u + S_u - a_8^u/2) + \lambda_c (a_6^c + S_c - a_8^c/2)] \right\}, \quad (1)$$

$K^- \pi^+$ **P-wave:**

$$\langle (K^- \pi^+)_P \pi^- | H_{\text{eff}} | B^- \rangle = 2\sqrt{2} G_F \mathbf{p}_{\pi^-} \cdot \mathbf{p}_{\pi^+} F_1^{B^- \rightarrow \pi^-}(q^2) f_1^{K^- \pi^+}(q^2) \times$$

$$\left[\lambda_u \left(a_4^u + P_u - \frac{a_{10}^u}{2} \right) + \lambda_c \left(a_4^c + P_c - \frac{a_{10}^c}{2} \right) \right]. \quad (2)$$

q^2 - $K^- \pi^+$ effective mass squared, $\lambda_u = V_{ub} V_{us}^*$, $\lambda_c = V_{cb} V_{cs}^*$,
 a_i - Wilson coefficients, $f_{0/1}^{K^- \pi^+}(q^2)$ - scalar/vector $K^- \pi^+$ form
 factors, S_u, S_c, P_u, P_c - charming penguin terms.

Weak transitions $b \rightarrow s\bar{u}u$, $b \rightarrow s\bar{d}d$ and final strong interactions

Weak transitions $b \rightarrow s\bar{u}u$, $b \rightarrow s\bar{d}d$ are described by TWO amplitudes:

- from QCD factorization approximation,
- long-distance one with c-quark in loop (charming penguins related to $D_s^{(*)}D^{(*)}$ states)

Final state strong interactions:

- S-wave isospin 1/2 state: two coupled channels: πK and $K\eta'$
- P-wave isospin 1/2 state: three coupled channels: πK , πK^* and ρK

!!! Breit-Wigner terms commonly used in an isobar model are replaced by scalar and vector form factors constrained by ChPT and experimental data (phase shifts and inelasticities from .e.g. LASS exp.).

Additional arbitrary phases or intensities for different resonances are NOT NEEDED.

Interference between S - and P -waves in the $B \rightarrow (K\pi)\pi$ decays

$$M = a_S + a_P \mathbf{p}_{\pi^+} \cdot \mathbf{p}_{\pi^-} = a_S + a_P p_{\pi^+} p_{\pi^-} \cos\theta$$

a_S and a_P are S - and P -wave decay amplitudes in the $\pi^+\pi^-$ c.m. system.

$$\frac{d^2\Gamma}{d\cos\Theta_H dm_{\pi^+K^-}} = K|M|^2,$$

$$K = \frac{m_{K-\pi^+} |\mathbf{p}_{\pi^+}| |\mathbf{p}_{\pi^-}|}{8(2\pi)^3 M_B^3}$$

$$\frac{d\Gamma}{d\cos\theta} = A + B\cos\theta + C\cos^2\theta,$$

$$\Gamma = 2A + \frac{2}{3}C$$

$$A = \int dm_{\pi K} K |a_S|^2,$$

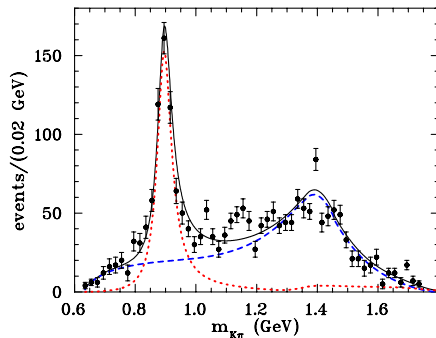
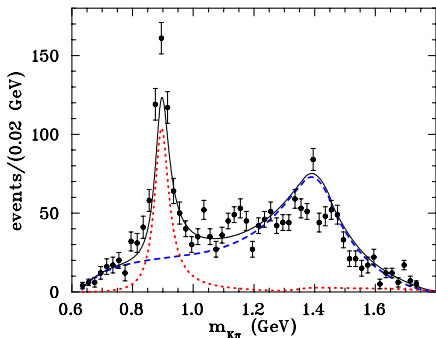
$$C = \int dm_{\pi K} K |a_P|^2,$$

$$\cos\theta_H = -\cos\theta,$$

θ_H -helicity angle

$$B = 2 \int dm_{\pi K} K \operatorname{Re}(a_S a_P^*) \longleftarrow \text{interference term}$$

$K^\pm \pi^\pm$ effective mass distributions for $B^\pm \rightarrow K^\pm \pi^\mp \pi^\pm$ decays



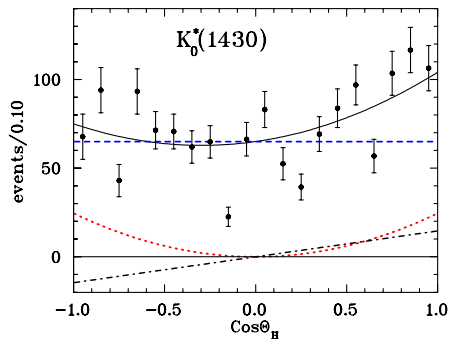
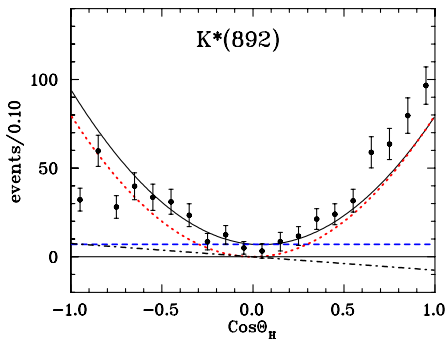
Fit WITH (left) and WITHOUT (right) exp. BR($B \rightarrow K_0^*(1430)\pi$)

Red - P-wave, blue - S-wave

Experimental data: Belle Collaboration (1)

χ^2 : 240 and 139 for 56 data points below 1.8 GeV

Helicity angle distributions for $B^\pm \rightarrow K^\pm \pi^\mp \pi^\pm$ decays

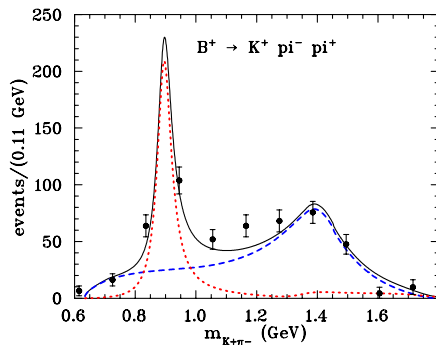
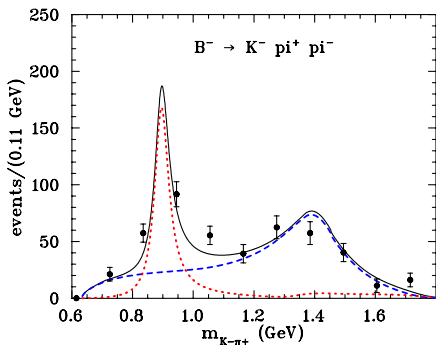


Red - *P*-wave, blue - *S*-wave,
interference - dotted-dashed line

Experimental data: Belle Collaboration (1)

χ^2 : 47 and 32 for 20 data points

$B^\pm \pi^\pm$ effective mass distributions for $B^\pm \rightarrow K^\pm \pi^\mp \pi^\pm$ decays

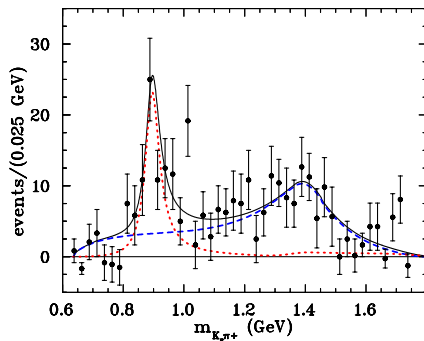
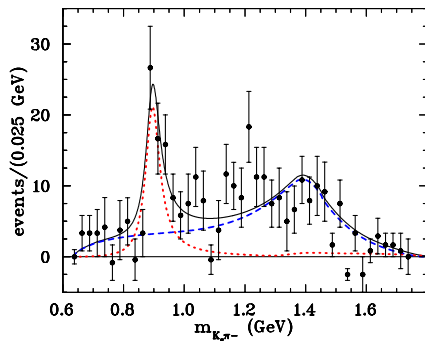


Red - *P*-wave, blue - *S*-wave

Experimental data: BaBar Collaboration (3)

χ^2 : 19 and 14 for 11 data points below 1.8 GeV

$K_S^0 \pi^\mp$ effective mass distributions for B^0 or \bar{B}^0 decays into $K_S^0 \pi^+ \pi^-$

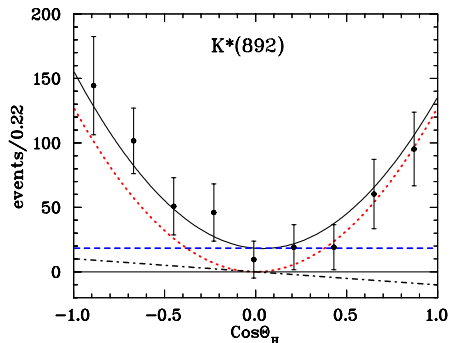
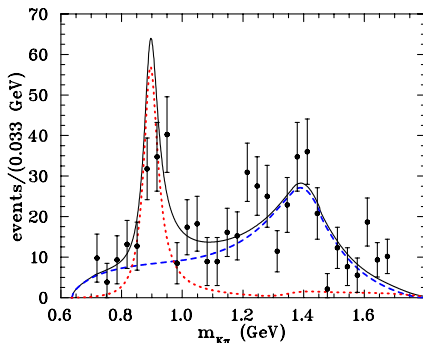


Red - *P-wave*, blue - *S-wave*

Experimental data: Belle Collaboration (2)

χ^2 : 59 and 61 for 46 data points below 1.8 GeV

$K_S^0 \pi^\pm$ effective mass and angular distributions for B^0 or \bar{B}^0 decays into $K_S^0 \pi^+ \pi^-$



Red - *P*-wave, blue - *S*-wave
interference - dotted-dashed line

Experimental data: BaBar Collaboration (4)

χ^2 : 68 for 30 data points and 2 for 9 data points

results without charming penguins

Results from QCD factorization model WITHOUT charming penguins:

Reactions	Theory/Experiment	Ref.
$B^\pm \rightarrow K^*(892)^0 \pi^\pm$	0.43	(2)
$B^\pm \rightarrow K^*(1430)^0 \pi^\pm$	0.28	(2)
$B^0 \rightarrow K^*(892)^+ \pi^-$	0.39	(1)
$B^0 \rightarrow K_0^*(1430)^+ \pi^-$	0.28	(1)

Theoretical values for branching ratios are significantly smaller than experimental ones

results for BR and A_{CP}

Branching ratios ($\times 10^6$) and asymmetries ($\times 10^2$):

Calculated in ranges: 0.82-0.97 GeV for $K^*(982)$ (P -wave) and 1.0-1.7 GeV for $K_0^*(1430)$ (S -wave).

obs.	channel	our model	Belle	BaBar
BR	$K^*(892)^0 \pi^+$	6.14 ± 0.15	5.35 ± 0.59	7.46 ± 0.81
A_{CP}	$K^*(892)^0 \pi^+$	-7.95 ± 2.42	-14.9 ± 6.8	6.8 ± 10.4
BR	$K_0^*(1430)^0 \pi^+$	12.52 ± 0.64	24.9 ± 3.2	27.5 ± 2.2
A_{CP}	$K_0^*(1430)^0 \pi^+$	-0.42 ± 1.25	7.6 ± 4.5	-6.4 ± 4.0

!!! Theoretical branching ratio for $B^+ \rightarrow K_0^*(1430)^0 \pi^+$ decay is smaller by 50% than the average of the Belle and BaBar values obtained from the isobar model !!!

Conclusions

- experimental data from Belle and BaBar on $K\pi$ effective mass (up to 1.8 GeV) and on angular distributions around $K^*(982)$ and $K_0^*(1430)$ have been well described
 - in our fit using we did not use an isobar model in description of Dalitz plot distributions,
- resonant structures in the $K\pi$ system are described by strange scalar and vector form factors, additional nonresonant structure is not needed,
- branching ratio for $B \rightarrow K_0^*(1430)\pi$ obtained in our fit is 50% smaller than those obtained by Belle and BaBar groups with use of the isobar model,
- charming penguin amplitudes are needed to describe the branching ratios, CP asymmetry and $K\pi$ effective mass + angular distributions for the $B \rightarrow K^*(982)\pi$ $B \rightarrow K_0^*(1430)\pi$ decays

Values of charming penguin parameters

parameter	modulus	phase
S_u	0.128	-1.10
S_c	0.125	-0.34
P_u	0.405	0.34
P_c	0.031	-0.09