CP VIOLATION AND FINAL STATE INTERACTIONS IN $B \to K\pi\pi$ DECAYS

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Our recent articles:

1. B. El-Bennich et al., Phys. Rev. D 74 (2006) 114009, hep-ph/0608205,

   Interference between $f_0(980)$ *and* $\rho(770)$ *resonances in* $B \to \pi^+\pi^- K$ *decays*,

2. A. Furman et al., Phys. Lett. B 622 (2005)207, hep-ph/0504116,

   Long-distance effects and final state interactions in $B \to \pi\pi K$ *decays and* $B \to K\overline{K}K$ *decays*.

Motivation:

1. study of B decays into three pseudoscalar mesons,
2. search for direct CP-violation,
3. development of a model with unitarized description of final state interactions (commonly used isobar model violates unitarity and requires many free parameters) ,
4. establish a role of long-distance effects (charming penguins),
5. description of the Belle and BaBar data.

Some three body charmless reactions:

1. $B^{\pm} \to \pi^+\pi^- K^{\pm}$ $\qquad$ $B^{\pm} \to K^+K^-K^{\pm}$

2. $B^0 \to \pi^+\pi^- K^0$ $\qquad$ $B^0 \to K_S^0 K_S^0 K_S^0$

Examples of quasi two-body reactions:

$B^{\pm} \to f_0(980)K^{\pm}, \quad f_0(980) \to (\pi^+\pi^-)_S$ or $f_0(980) \to (K^+K^-)_S,$

$B^{\pm} \to \rho(770)^0 K^{\pm}, \quad \rho(770)^0 \to (\pi^+\pi^-)_P,$

$B^{\pm} \to K_0^*(1430)^0 \pi^{\pm}, \quad K_0^*(1430)^0 \to (K^+\pi^-)_S,$ S-wave,

$B^{\pm} \to K^*(892)^0 \pi^{\pm}, \quad K^*(892)^0 \to (K^+\pi^-)_P,$ P-wave.

Decay amplitudes for $B \to K\pi\pi$ reactions

Two components in weak transitions $b \to s\bar{u}u$ and $b \to s\bar{d}d$:

1. amplitudes in the QCD factorization approximation,
2. long-distance amplitudes with c-quark in loop (charming penguin terms related to intermediate $D_s^{(*)}D^{(*)}$ states).

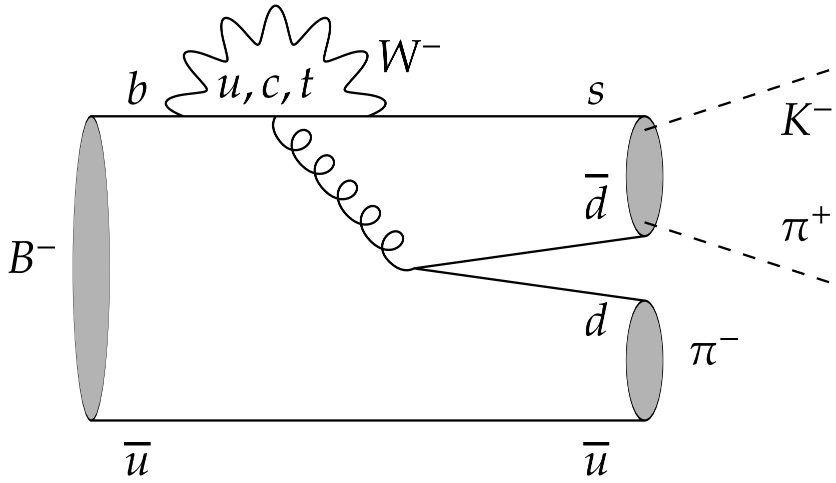
Final state strong interactions:

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

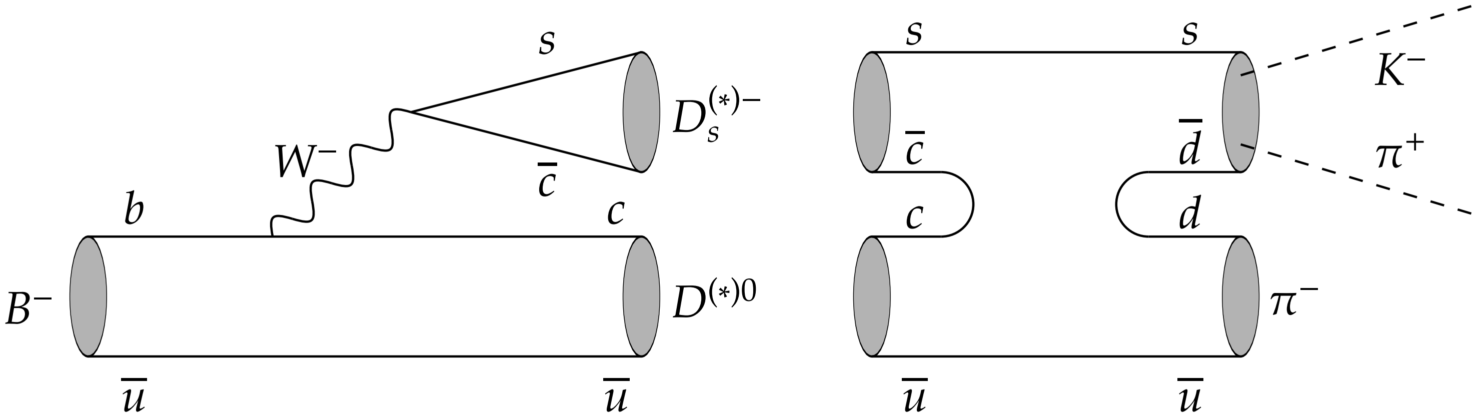
In this approach, many Breit-Wigner terms, usually used in an isobar model to fit Dalitz plots, are replaced by two amplitudes proportional to the strange scalar or to the vector form factors. The form factors are constrained by chiral perturbation theory and by experimental data on phase shifts and inelasticities known from other experiments (for example from LASS exp.).

No arbitrary phases nor intensity free parameters for different resonances are needed.

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



Long-distance amplitudes with c-quark in loop:



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

$$\langle (K^-\pi^+)_S\, \pi^- | H_{eff} | B^- \rangle = \frac{G_F}{\sqrt{2}}(M_B^2 - m_\pi^2)\frac{m_K^2 - m_\pi^2}{q^2} F_0^{B\to\pi}(q^2) f_0^{K^-\pi^+}(q^2)$$
$$\times \Big\{ \lambda_u(a_4^u - a_{10}^u/2) + \lambda_c(a_4^c - a_{10}^c/2) - 2\,\frac{q^2}{(m_b - m_d)(m_s - m_d)}$$
$$\times \Big[\lambda_u(a_6^u + S_u - a_8^u/2) + \lambda_c(a_6^c + S_c - a_8^c/2) \Big] \Big\}\,, \quad (1)$$

$$\langle (K^-\pi^+)_P\, \pi^- | H_{eff} | B^- \rangle = 2\sqrt{2} G_F\, \mathbf{p}_{\pi^-} \cdot \mathbf{p}_{\pi^+}\, F_1^{B\to\pi}(q^2) f_1^{K^-\pi^+}(q^2)$$
$$\times \left[\lambda_u \left(a_4^u + P_u - \frac{a_{10}^u}{2} \right) + \lambda_c \left(a_4^c + P_c - \frac{a_{10}^c}{2} \right) \right]. \quad (2)$$

q^2– $K^-\pi^+$ effective mass squared, $\lambda_u = V_{ub}V_{us}^*$, $\lambda_c = V_{cb}V_{cs}^*$, a_i – Wilson coefficients,
$f_0^{K^-\pi^+}(q^2)$ – scalar $K^-\pi^+$ form factor, $f_1^{K^-\pi^+}(q^2)$ – vector $K^-\pi^+$ form factor.
The complex parameters S_u, S_c, P_u and P_c represent charming penguin terms.

Interference between S- and P-waves in $B \to (K\pi)\pi$ 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.

$$|M|^2 = |a_S|^2 + 2\,Re(a_S a_P^*) p_{\pi^+} p_{\pi^-} cos\theta + |a_P|^2 p_{\pi^+}^2 p_{\pi^-}^2 cos^2\theta$$

$$\frac{d^2\Gamma}{dcos\theta\, dm_{\pi K}} = K\,|M|^2 \qquad K = \frac{m_{\pi K} p_{\pi^+} p_{\pi^-}}{8 M_B^3 (2\pi)^3}$$

$$\frac{d\Gamma}{dcos\theta} = A + B\,cos\theta + C\,cos^2\theta \qquad \Gamma = 2A + \tfrac{2}{3}C$$

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

$B = 2\int dm_{\pi K}\, K\, Re(a_S a_P^*)$ $\quad$ B - interference term in angular distributions

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

$cos\theta_H = -\,cos\theta,\quad \theta_H$ – helicity angle.

Experimental data

Reactions: a) $B^- \to (K^-\pi^+)\pi^-$, b) $B^+ \to (K^+\pi^-)\pi^+$,

$$\text{c) } \overline{B}^0 \to (\overline{K}^0\pi^-)\pi^+, \quad \text{d) } B^0 \to (K^0\pi^+)\pi^-.$$

Main references to data from Belle and BaBar Collaborations:

[1] A. Garmash et al. (Belle Coll.), PR D 75 (2007) 012006 (c, d)

[2] A. Garmash et al. (Belle Coll.), PRL 96 (2006) 251803 and hep-ph/0509001 (a, b)

[3] B. Aubert et al. (BaBar Coll.), PR D 72 (2005) 072003 (a, b)

[4] B. Aubert et al. (BaBar Coll.), PR D 73 (2006) 031101(R) (c, d)

Physical observables fitted in our model:

1. branching ratios and direct CP-violation asymmetries for quasi-two-body decays (12 values),

2. $K\pi$ effective mass and helicity angle distributions (altogether 249 data points).

PRELIMINARY RESULTS

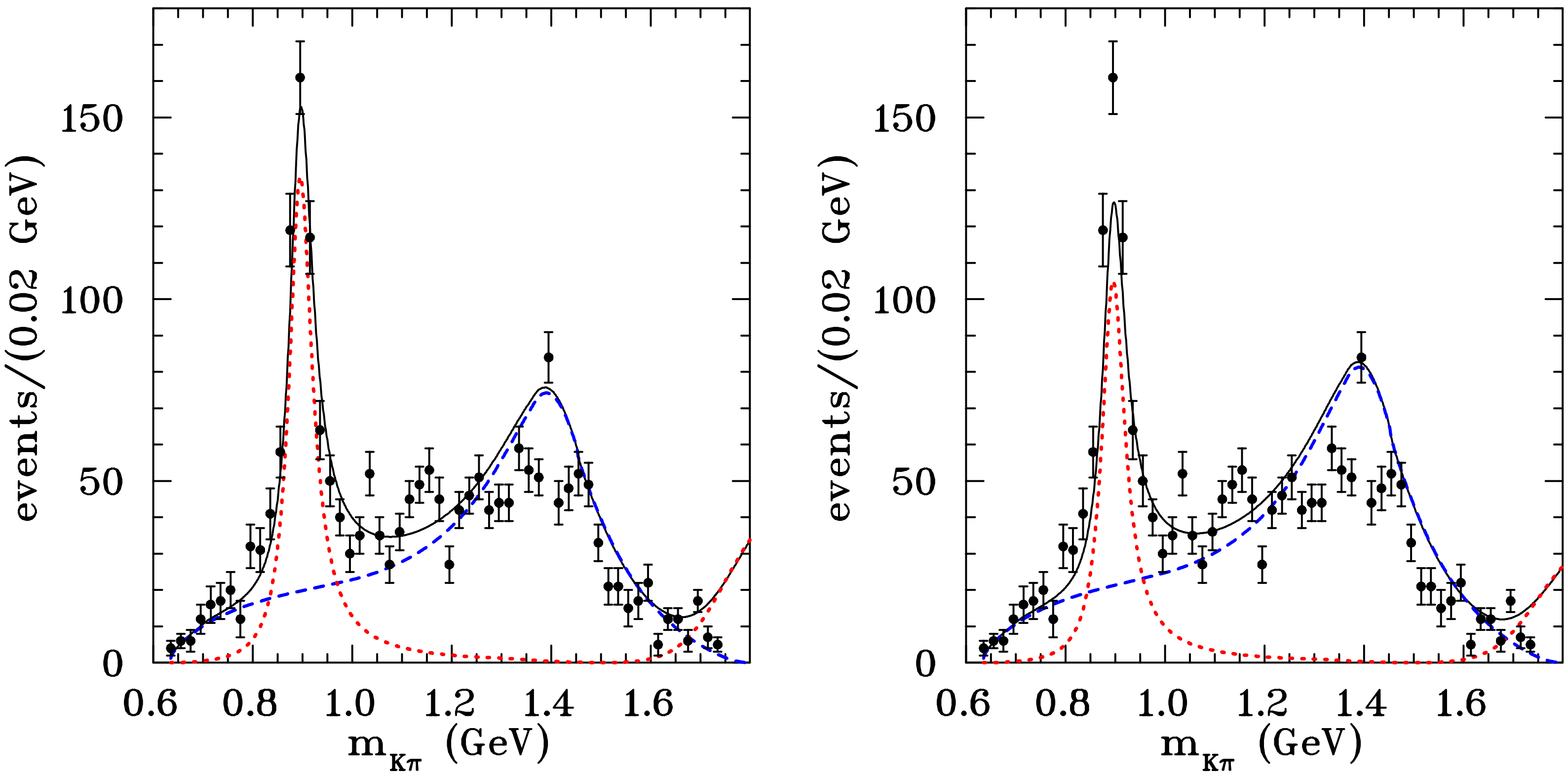
Branching fractions calculated using QCD factorization model without charming penguin terms

Reaction	Theory/Experiment	Ref.
$B^{\pm} \to K^{*}(892)^{0}\pi^{\pm}$	0.43	[1]
$B^{\pm} \to K_{0}^{*}(1430)^{0}\pi^{\pm}$	0.28	[1]
$B^{0} \to K^{*}(892)^{+}\pi^{-}$	0.39	[2]
$B^{0} \to K_{0}^{*}(1430)^{+}\pi^{-}$	0.28	[2]

Theoretical values without charming penguins are too small !

Similar conclusions have been recently reached by Cheng, Chua and Soni (2007).

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

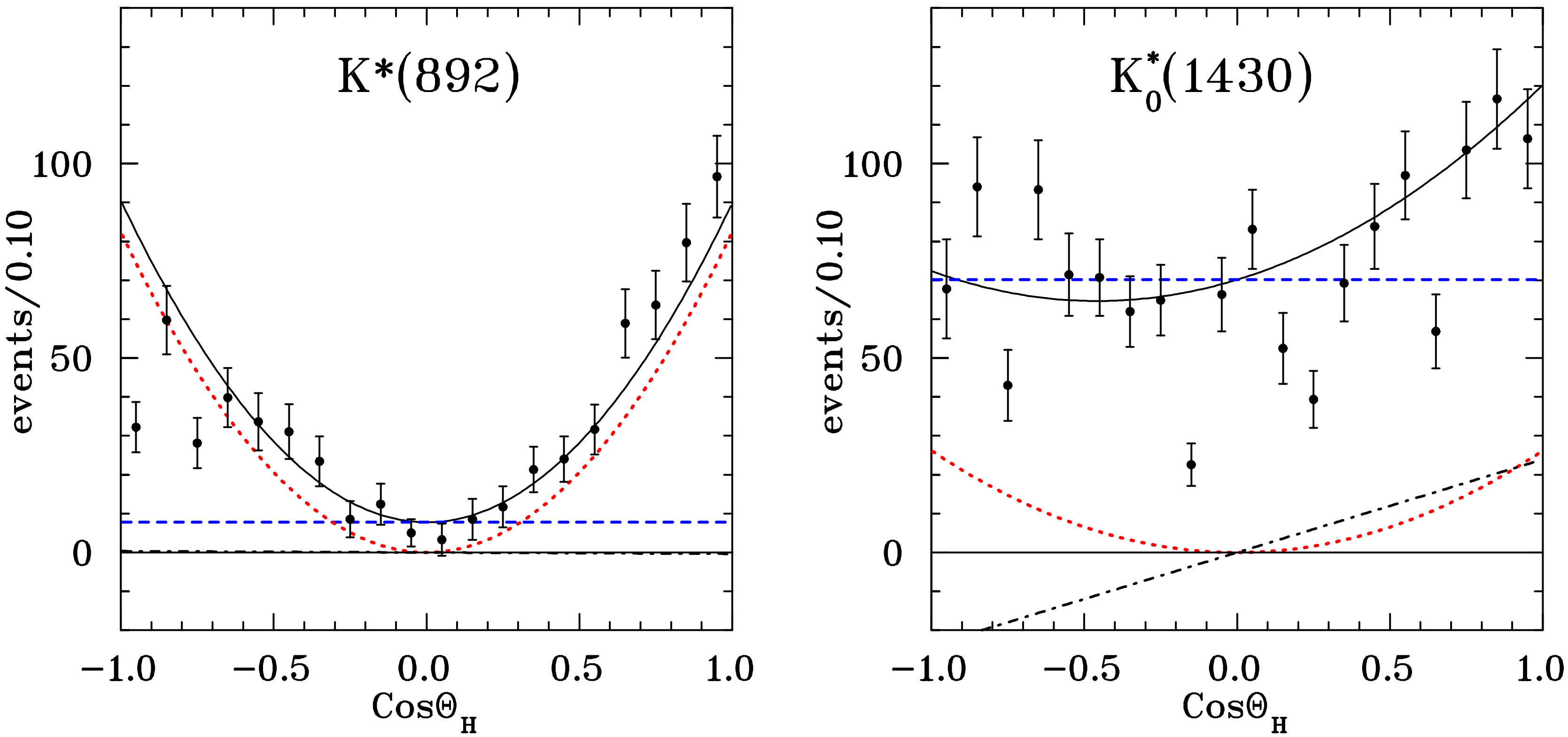


Left figure – fit without exp. $\mathrm{Br}(B \rightarrow K_0^*(1430)\pi)$

Experimental data: Belle Collaboration [2]

P-wave: red dotted line, S-wave: blue dashed line, total: solid line.

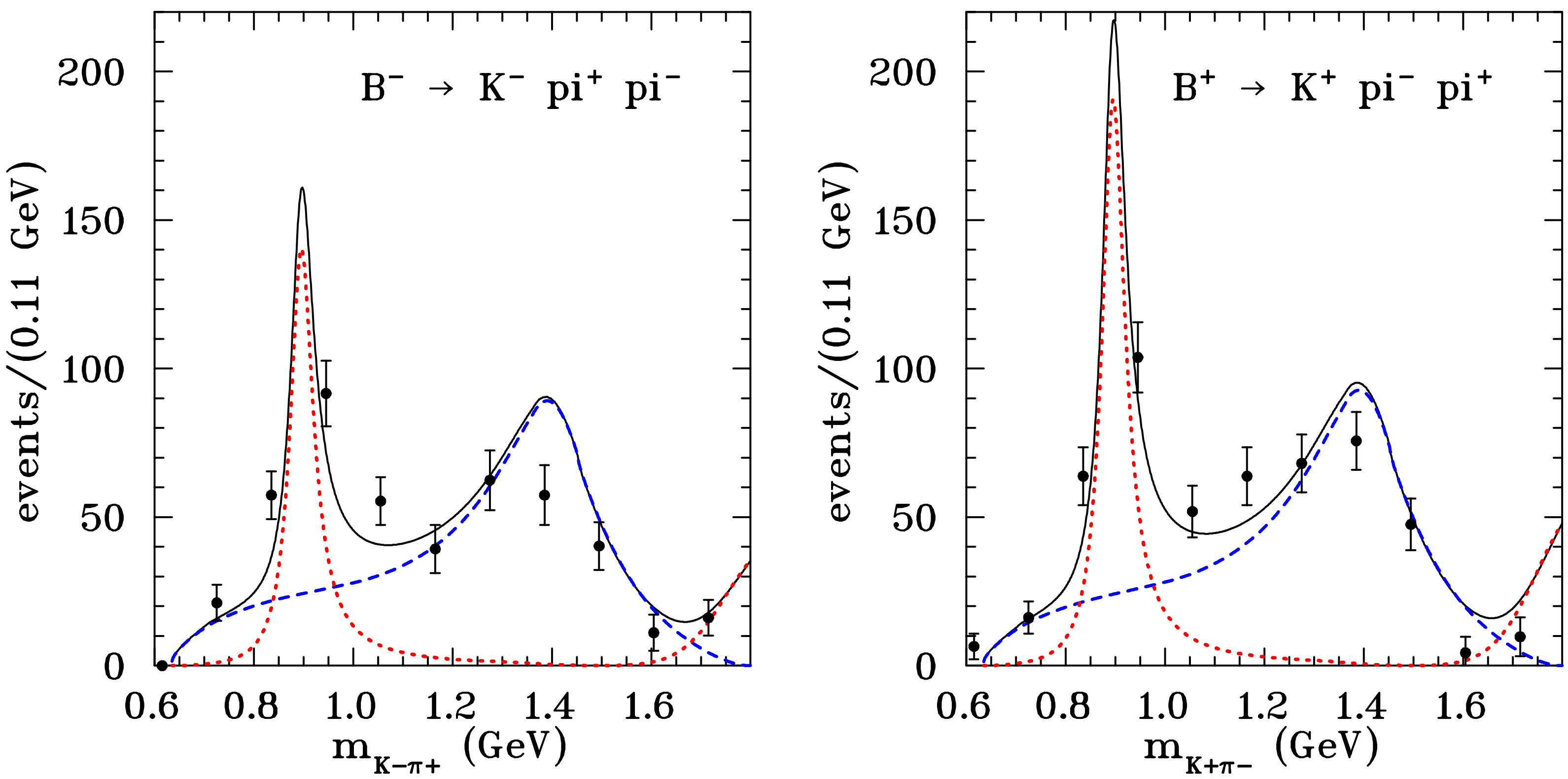
Helicity angle distributions for $B^{\pm} \to K^{\pm}\pi^{\mp}\pi^{\pm}$ decays



Experimental data: Belle Collaboration [2]

P-wave: red dotted line, S-wave: blue dashed line, interference: dotted-dashed line, total: solid line.

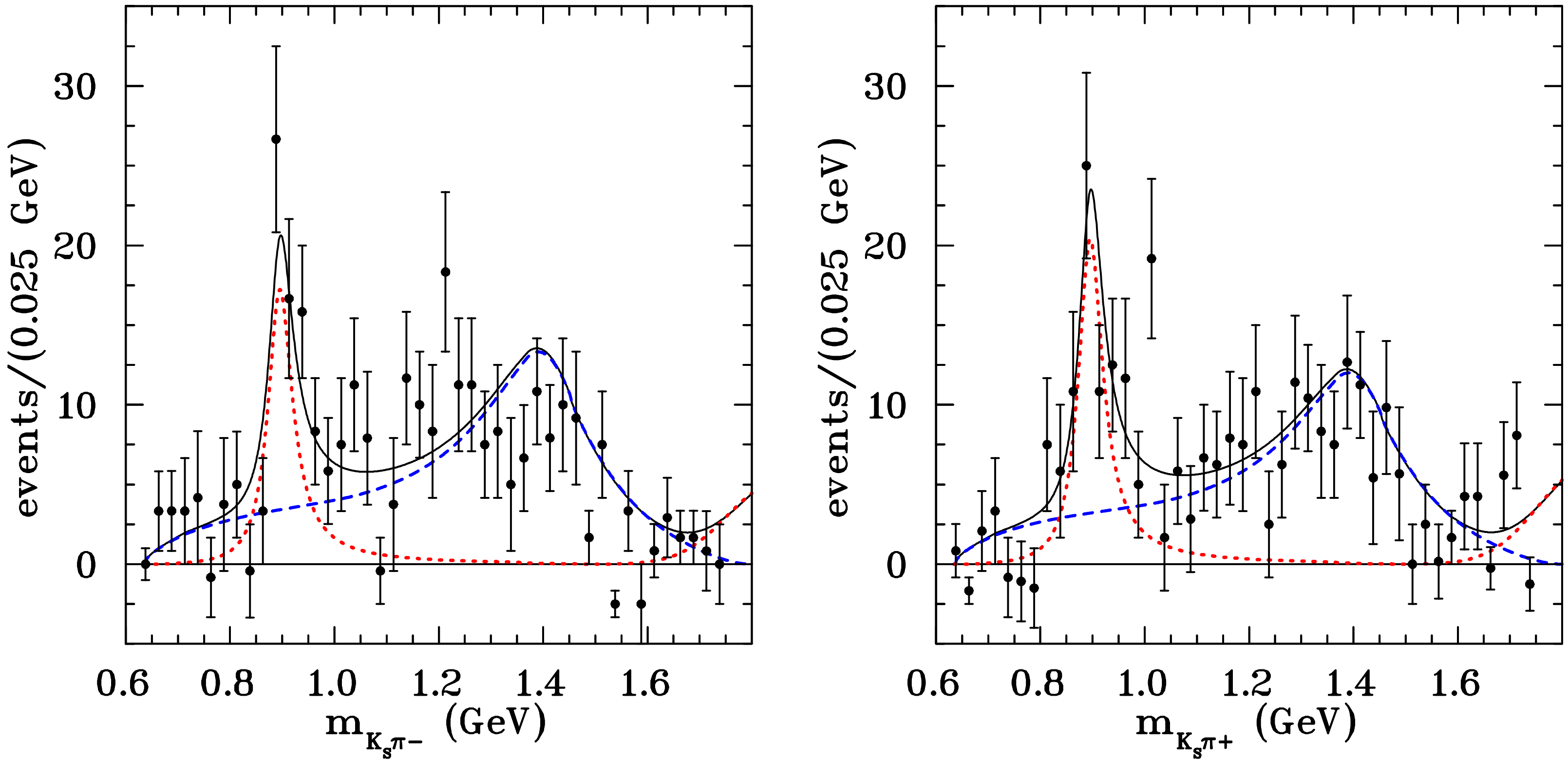
$K^\pm\pi^\mp$ effective mass distributions for $B^\pm \to K^\pm\pi^\mp\pi^\pm$ decays



Experimental data: BaBar Collaboration [3]

P-wave: red dotted line, S-wave: blue dashed line, total: solid line.

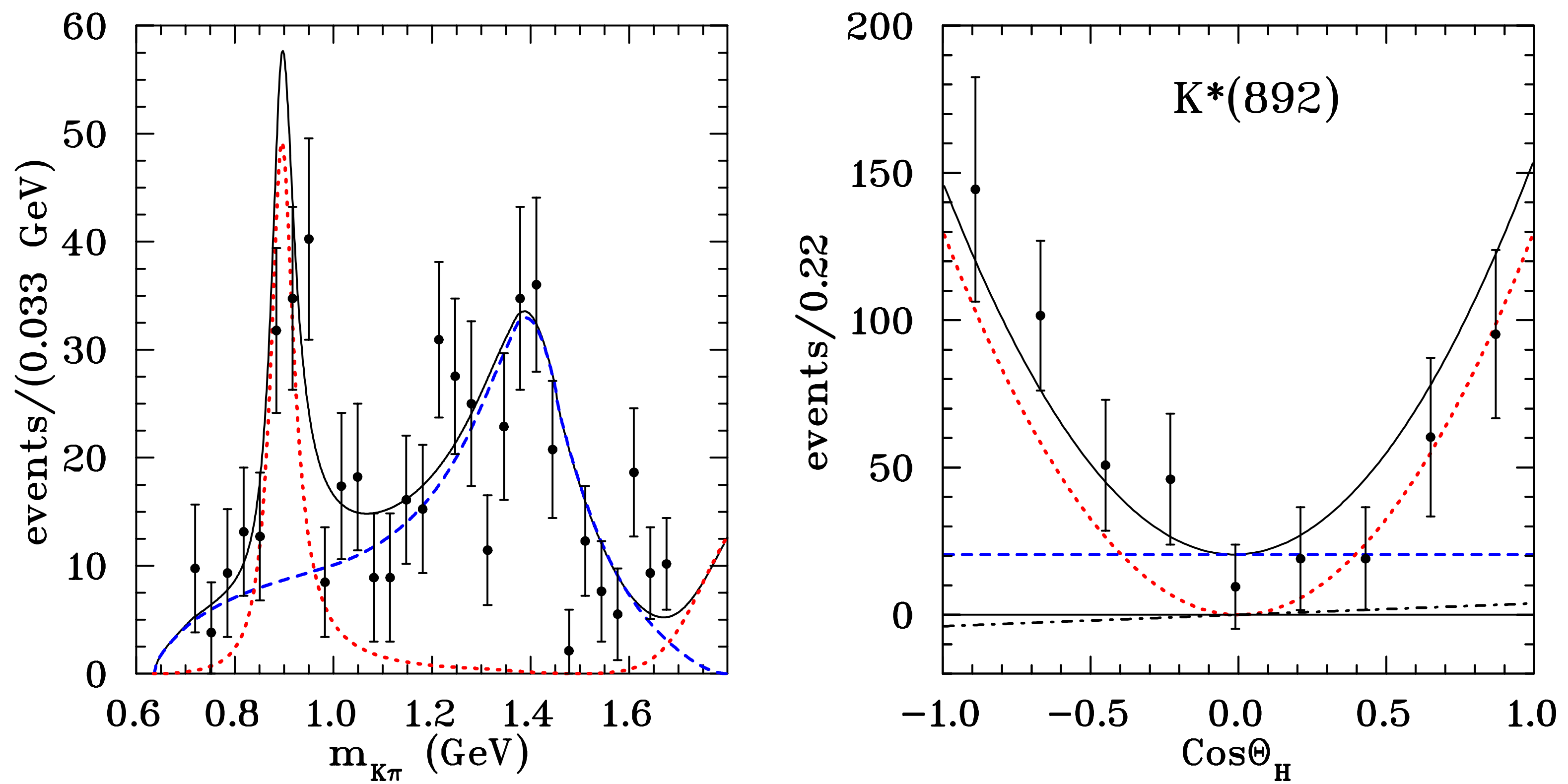
$K_S^0\pi^\mp$ effective mass distributions for B^0 or $\overline{B}^0$ decays into $K_S^0\pi^+\pi^-$



Experimental data: Belle Collaboration [1]

P-wave: red dotted line, S-wave: blue dashed line, total: solid line.

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



Experimental data: BaBar Collaboration [4]

P- wave: red dotted line, S- wave: blue dashed line, interference: dotted-dashed line, total: solid line.

Average branching ratios Br$\cdot 10^6$ and direct CP asymmetries $A_{CP} \cdot 10^2$

obs.	channel	$K\pi$ mass range [GeV]	our model	Belle	BaBar
Br	$K^*(892)^0\pi^+$	0.82 – 0.97	6.14	5.35 ± 0.59	7.46 ± 0.81
A_{CP}	$K^*(892)^0\pi^+$	0.82 – 0.97	-8.0	-14.9 ± 6.8	6.8 ± 10.4
Br	$K_0^*(1430)^0\pi^+$	1.0 – 1.76	17.1	24.9 ± 3.2	27.5 ± 2.2
A_{CP}	$K_0^*(1430)^0\pi^+$	1.0 – 1.76	5.6	7.6 ± 4.5	-6.4 ± 4.0

The theoretical branching ratio of the $B^+ \to K_0^*(1430)^0\pi^+$ decay is smaller by 35 per cent than the average of the Belle and BaBar values, both obtained from the isobar model.

CONCLUSIONS

1. Alternative approach to the isobar model for three-body B decays into $K\pi\pi$ has been proposed. Final state interactions between kaon and one pion for the $K\pi$ effective mass smaller than 1.8 GeV have been included.

2. Resonant structure of the $K\pi$ system is described in terms of the strange scalar and vector form factors which play an essential role in explanation of the Belle and BaBar data. Arbitrary nonresonant part of the decay amplitudes is not necessary in our model.

3. Charming penguin amplitudes are needed to describe the branching fractions, direct CP asymmetries of the quasi-two-body $B \to K^*(892)\pi$ and $B \to K_0^*(1430)\pi$ decays as well as the helicity angle distributions.

4. There is an indication that the experimental branching fractions for the $B \to K_0^*(1430)\pi$ decay, obtained by the Belle and BaBar Collaborations using the isobar model, are too large by about 35 per cent.

Charming penguin parameters

parameter	modulus	phase (rad)
S_u	1.18	−0.92
S_c	0.150	−0.50
P_u	0.233	0.80
P_c	0.0383	−0.09