Towards a unitary Dalitz plot analysis of three-body hadronic B decays

In collaboration with :

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Recent publication:

CP violation and kaon-pion interactions in $B \to K\pi\pi$ decays ,
Phys.Rev. D 79 (2009) 094005, arXiv:0902.3645[hep-ph]

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Motivation

1. search for CP violation,
2. studies of weak and strong interaction amplitudes,
3. tests of standard model and search for ``new physics'' effects,
4. determination of short and long-distance mechanisms in B-decays,
5. studies of Dalitz diagrams,
6. analysis of final state coupled channels.

Why unitarity is important?

Unitary model allows for:

1. a proper construction of B-decay amplitudes,
2. partial wave analyses of final states,
3. explanation of structures seen on Dalitz plots,
4. adequate determination of branching fractions and asymmetries for different quasi-two body decay reactions,
5. extraction of standard model parameters or estimation of amplitudes of a ’’new physics’’,
6. application of B-decay results in hadron spectroscopy.

Theoretical constraints

1. Derivation of unitary three-body strong interaction amplitudes is difficult. It is easier to satisfy unitarity in quasi two-body subchannels of the decay process.
2. Cases discussed in this talk: $B \to (K\pi)\pi$ decays with unitary $K\pi$ strong interaction amplitudes in the limited $K\pi$ effective mass less than about 1.8 GeV.
3. Other theoretical tools: analyticity, chiral symmetry at low energies, QCD factorization approach.
4. Remark: amplitudes commonly used in the isobar model are not unitary neither in three-body decay channels nor in two-body subchannels.

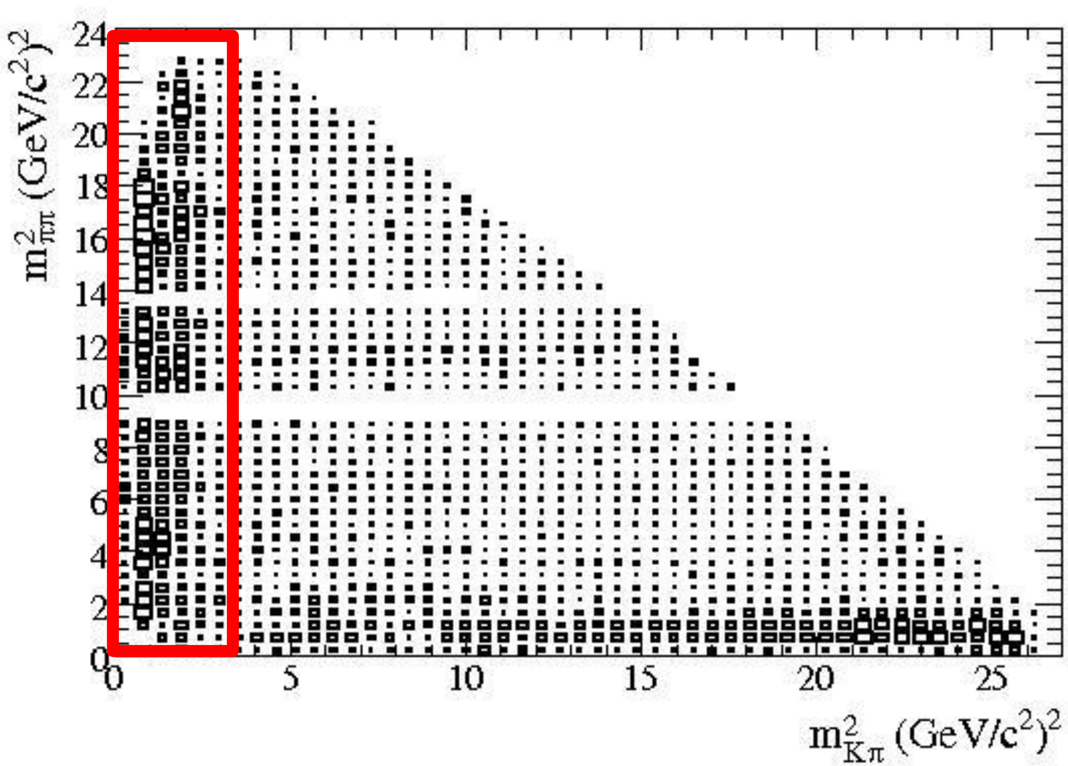
Problems within the isobar model:
determination of branching fractions in presence of wide scalar resonances

Example: $B \to K_0^*(1430)\pi$ decay.

1. S-wave resonances are often wide:
   width of $K_0^*(1430)$ equals to 270 MeV,
   $K_0^*(800)$ may have even 550 MeV width.

2. Important source of model errors in extraction of the branching ratio for this decay is a possible wrong attribution of a part of Dalitz plot density to a background amplitude and to its interference with other amplitudes, most probably with the S-wave.

Dalitz plot for $B^{\pm} \to K^{\pm} \pi^{+} \pi^{-}$ decays



Data from BaBar Collaboration: Phys. Rev. D 78 (2008) 012004

S-wave $B^- \to K^-\pi^+\pi^-$ decay amplitude

$$A_S^- = \frac{G_F}{\sqrt{2}}(M_B^2 - m_\pi^2)\frac{m_K^2 - m_\pi^2}{q^2} F_0^{B^-\to\pi^-}(q^2)$$

$$\times \boxed{f_0^{K^-\pi^+}(q^2)}\{\lambda_u(a_4^u(S) - \frac{a_{10}^u(S)}{2} + \boxed{c_4^u}) + \lambda_c(a_4^c(S) - \frac{a_{10}^c(S)}{2} + \boxed{c_4^c})$$

$$- \frac{\boxed{2q^2}}{(m_b - m_d)(m_s - m_d)}[\lambda_u(a_6^u(S) - \frac{a_8^u(S)}{2} + \boxed{c_6^u}) + \lambda_c(a_6^c(S) - \frac{a_8^c(S)}{2} + \boxed{c_6^c})]\}$$

$\lambda_u = V_{ub}V_{us}^*$, $\lambda_c = V_{cb}V_{cs}^*$, $V_{ij} - CKM$ matrix elements

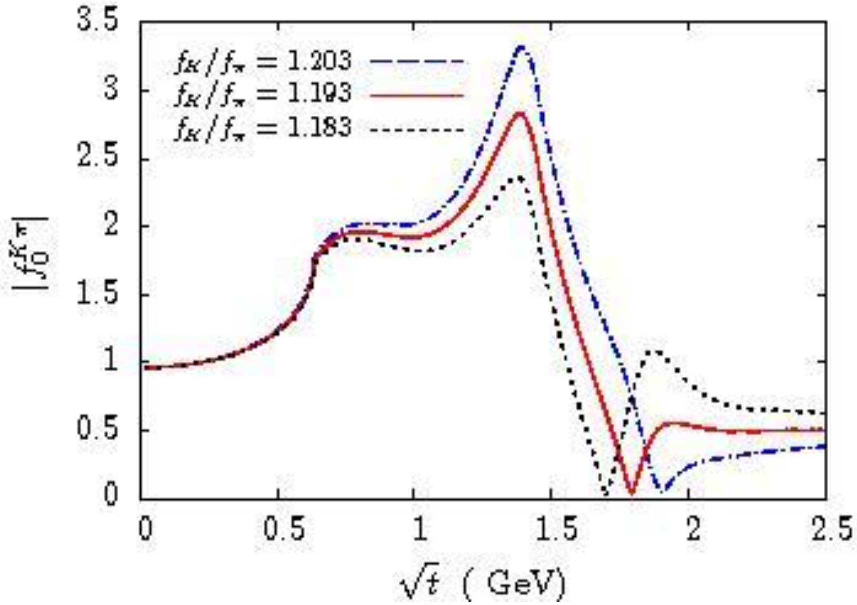
$\boxed{f_0^{K^-\pi^+}(q^2)}$ - scalar form factor, $q = m_{K\pi}$

$\boxed{c_4^u, c_4^c, c_6^u, c_6^c}$ – complex parameters

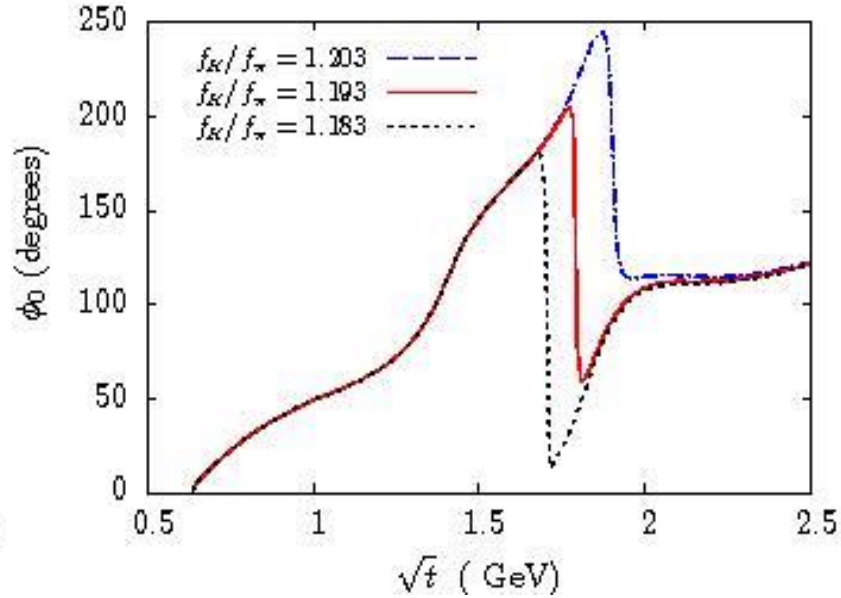
Scalar and vector form factors

- $K_0^*(1430)$ resonance is essential in the scalar form factor; K^* (892) dominates the vector form factor.
- Form factors are connected to scattering amplitudes in the S- and P-waves via unitarity and analyticity relations.
- **S**-wave - two coupled channel amplitudes: $K\pi$ and $K\eta'$, **P**-wave - three coupled channels: $K\pi$, $K^*\pi$ and $K\rho$.
- Scattering amplitudes are constrained by experimental data, especially by the LASS results from SLAC.
- Muskhelishvili- Omnès equations are used to calculate form factors (dispersion relations + unitarity).

Scalar kaon-pion form factor



modulus



phase

Dependence on the ratio of the kaon to pion decay constants f_K/f_π

Measurable physical quantities:

1. Differential effective mass branching fractions,
2. Helicity angle distributions,
3. Integrated branching fractions,
4. Direct CP asymmetries,
5. Phase difference between the decay amplitudes (for example : $B^0 \to K^{*+}(892)\pi^-$ and $\bar{B}^0 \to K^{*-}(892)\pi^+$).

Some numerical results of fits to P-wave and predictions for S-wave

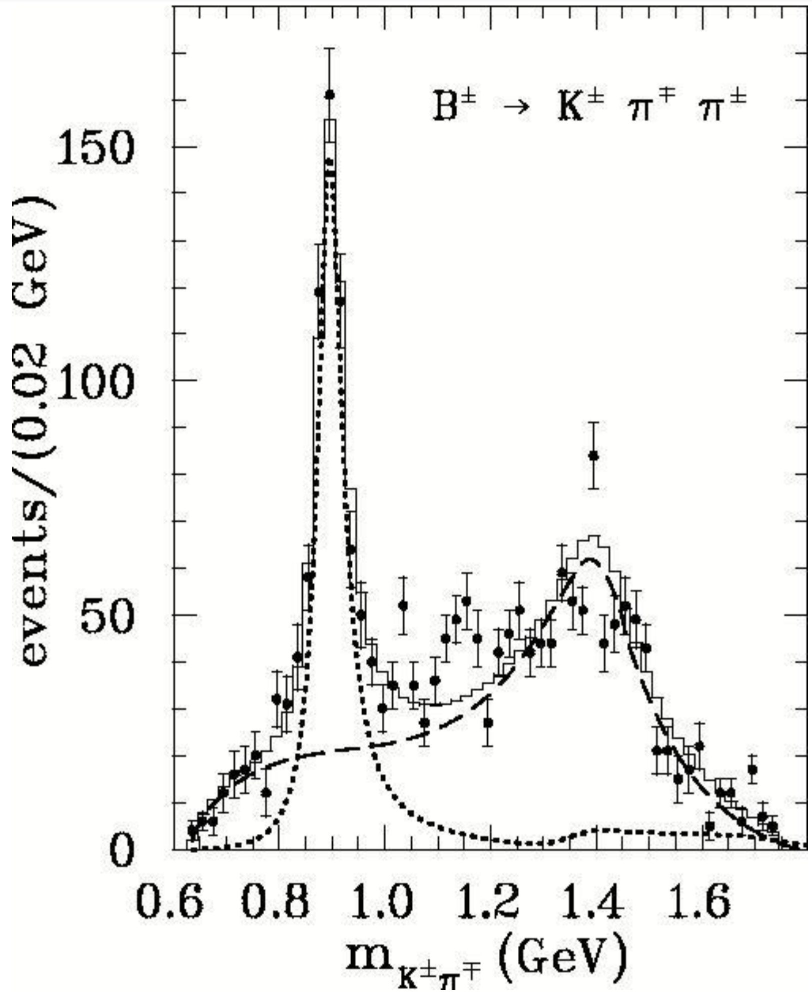
Branching ratios in units 10^{-6}

decay	Belle	BaBar	our model
$B^+ \to (K^+ \pi^-)_P \pi^+$	5.35±0.59	5.98±0.75	5.73±0.14
$B^0 \to (K^0 \pi^+)_P \pi^-$	4.65±0.77	6.47±0.75	5.42±0.16
$B^+ \to (K^+ \pi^-)_S \pi^+$	27.0±2.5	22.5±4.6	16.5±0.8
$B^0 \to (K^0 \pi^+)_S \pi^-$	26.0±3.4	17.3±4.6	15.8±0.7

prediction

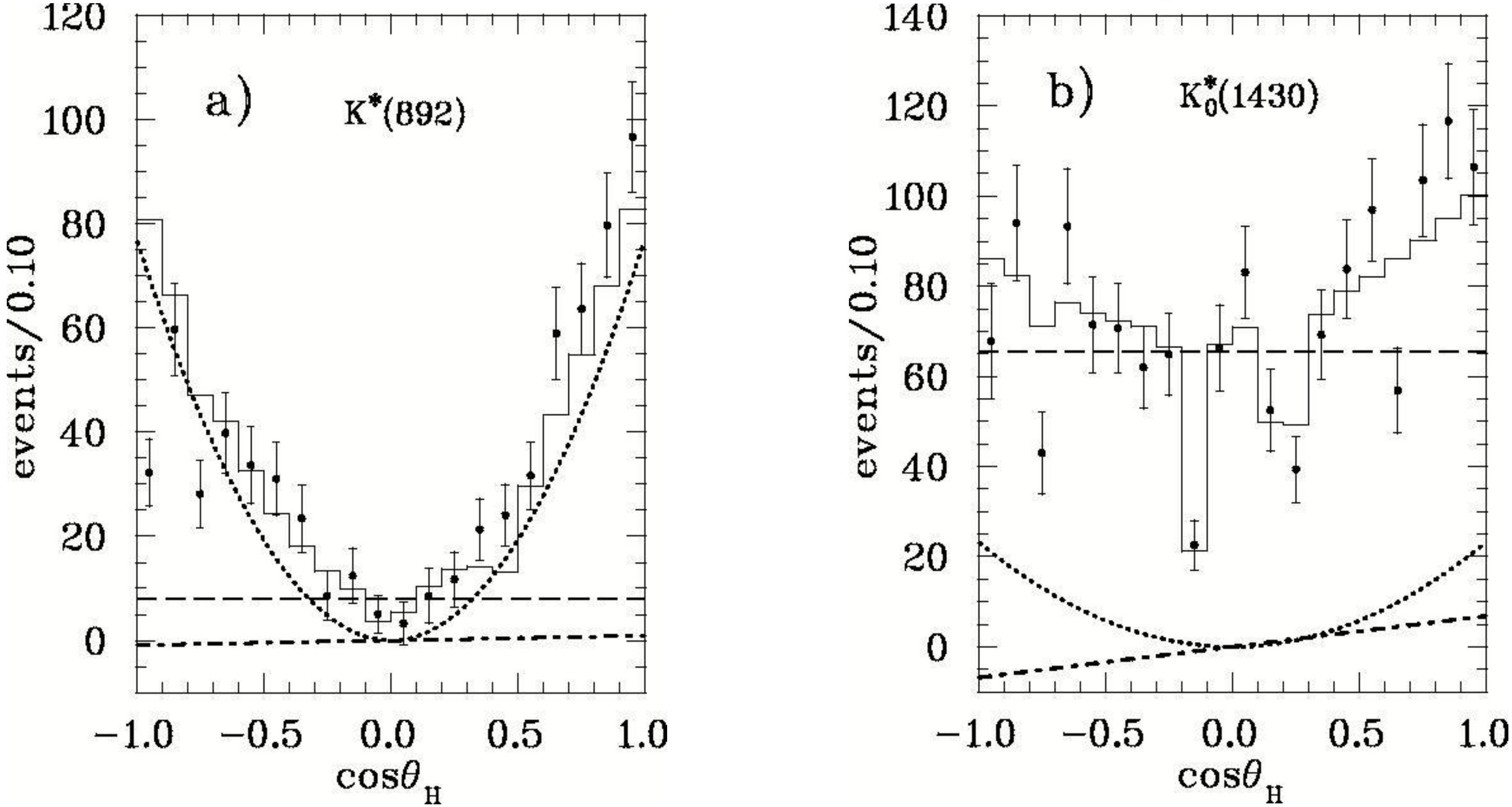
S-wave: $0.64 < m_{K\pi} < 1.76$ GeV, P-wave: $0.82 < m_{K\pi} < 0.97$ GeV

Effective $K\pi$ mass distribution



Data from BaBar Collaboration: Phys. Rev. D 78 (2008) 012004

Helicity angle distributions in $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$ decays



⋯⋯ P-wave, – – – – – S-wave, – · – · – · interference

Data from Belle Colaboration: arXiv: hep-ex/0509001

Proposal for future experimental parametrizations of the S-wave amplitude in $B \to (K\pi)\pi$ decays

$$A_S(m_{K\pi}) = f_0^{K\pi}(m_{K\pi})\left(\frac{c_0}{m_{K\pi}^2} + c_1\right)$$

C_0 and C_1 are constant complex parameters to be fitted from data.

Scalar form factor is well constrained by unitarity and by data obtained from other experiments than B-decay studies.

Numerical values of the complex scalar form factor can be provided on request.

Summary

1. Analysis of the $B \to K\pi^+\pi^-$ decays has been performed with inclusion of the kaon-pion strong interactions.
2. Final state $K\pi$ interactions have been described using the scalar form factor for the S-wave and the vector $K\pi$ form factor for the P-wave.
3. Good agreement with data is obtained if four phenomenological parameters are incorporated into the decay amplitudes obtained from the QCD factorization approach.
4. The model describes well $K\pi$ effective mass distributions below 1.8 GeV, angular kaon or pion distributions and CP asymmetries.
5. A number of free parameters is smaller than that in the isobar model and in addition a **two-body unitarity is satisfied**.

Phenomenological parameters

$$c_4^u = 0.402\pm0.244 + i\,(-3.641\pm0.054)$$

$$c_4^c = 0.015\pm0.003 + i\,(0.033\pm0.004)$$

$$c_6^u = -0.051\pm0.153 + i\,(-0.161\pm0.184)$$

$$c_6^u = 0.075\pm0.009 + i\,(-0.033\pm0.007)$$

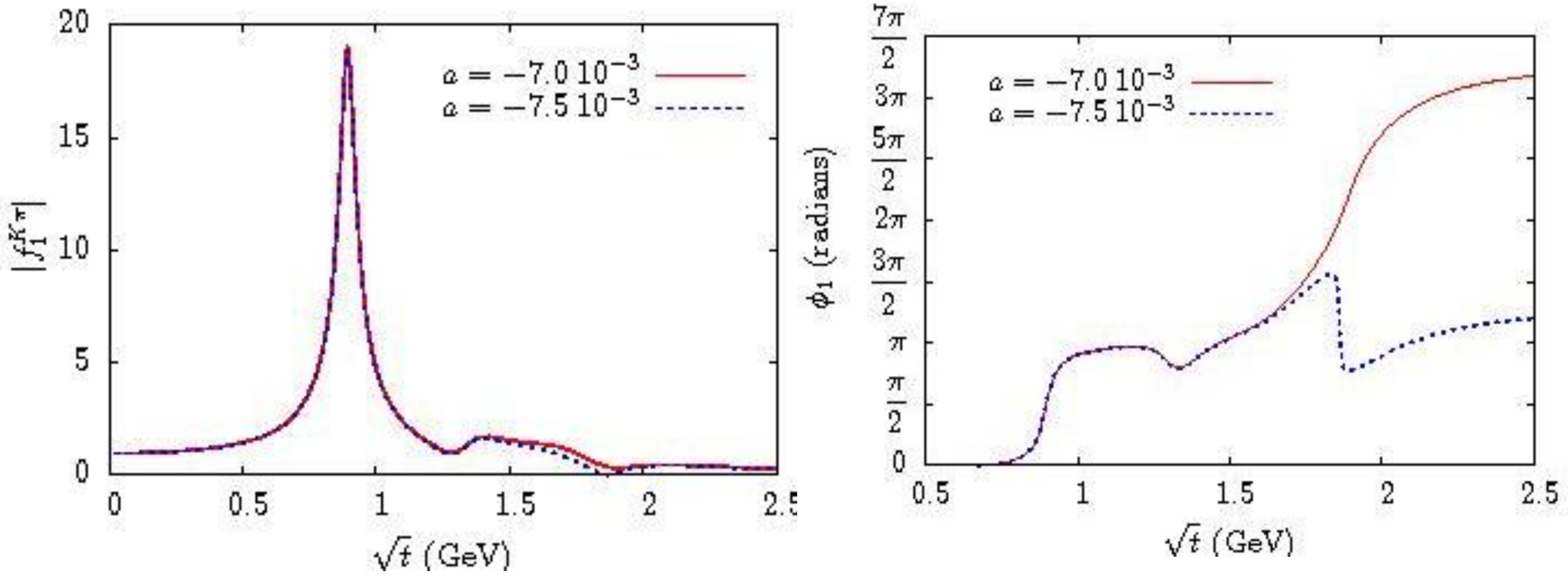
P-wave $B^- \to K^- \pi^+ \pi^-$ decay amplitude

$$A_P^- = 2\sqrt{2} G_F \, p_{\pi^-} \cdot p_{\pi^+} F_1^{B^- \to \pi^-}(q^2) \, f_1^{K^- \pi^+}(q^2)$$

$$\{\lambda_u (a_4^u(P) - \frac{a_{10}^u(P)}{2} + c_4^u) + \lambda_c (a_4^c(P) - \frac{a_{10}^c(P)}{2} + c_4^c)$$

$$+ 2 \frac{m_{K*}}{m_b} \frac{f_V^{\perp}}{f_V} [\lambda_u (a_6^u(P) - \frac{a_8^u(P)}{2} + c_6^u) + \lambda_c (a_6^c(P) - \frac{a_8^c(P)}{2} + c_6^c)]\}$$

Vector kaon-pion form factor



Direct CP asymmetries in %

decay	Belle	BaBar	our model
$B^+ \to (K^+\pi^-)_P \pi^+$	-14.9±6.8	3.2±5.4	-2.5±1.3
$B^0 \to (K^0\pi^+)_P \pi^-$	-	-14±12	-19.6±3.0
$B^+ \to (K^+\pi^-)_S \pi^+$	7.4±4.6	3.2±4.6	5.4±1.0
$B^0 \to (K^0\pi^+)_S \pi^-$	-	17±26	-0.2±1.3