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Flavour Physics at B-factories and Hadron Colliders

Part 7.5: direct CP

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Contents

CP violation in decay

CP in decay: $|\bar{A}/A| \neq 1$

$$a_f = \frac{\Gamma(B^+ \to f, t) - \Gamma(B^- \to \bar{f}, t)}{\Gamma(B^+ \to f, t) + \Gamma(B^- \to \bar{f}, t)} = \frac{1 - |\bar{A}/A|^2}{1 + |\bar{A}/A|^2}$$

Also possible for neutral B.

$$|A_f|^2 - |\bar{A}_{\bar{f}}|^2 = \sum_{i,j} A_i A_j \sin(\varphi_i - \varphi_j)\sin(\delta_i - \delta_j)$$

CPV in decay: need at least two interfering amplitudes with different weak and strong phases.

$$a_{f_{CP}} = S\sin(\Delta m \Delta t) + A\cos(\Delta m \Delta t)$$

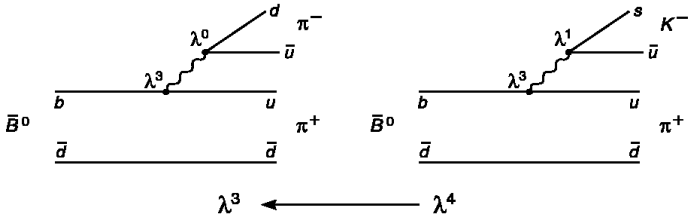
→ $\neq 0$ direct CPV; $|A(B \to f)| \neq |A(\bar{B} \to \bar{f})|$

only when multiple processes contribute to the B→f decay (tree+penguin)

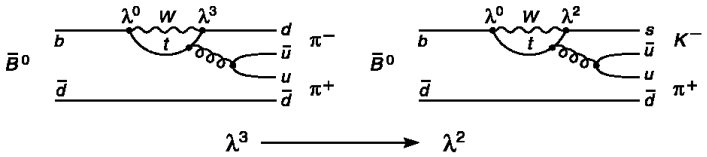
Direct CPV also in time integrated decay rates:

$$\mathcal{A}_{CP} = \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)}$$

Diagrams for B→ ππ, Kπ decays



ππ Kπ



Possibility of tree-penguin interference.

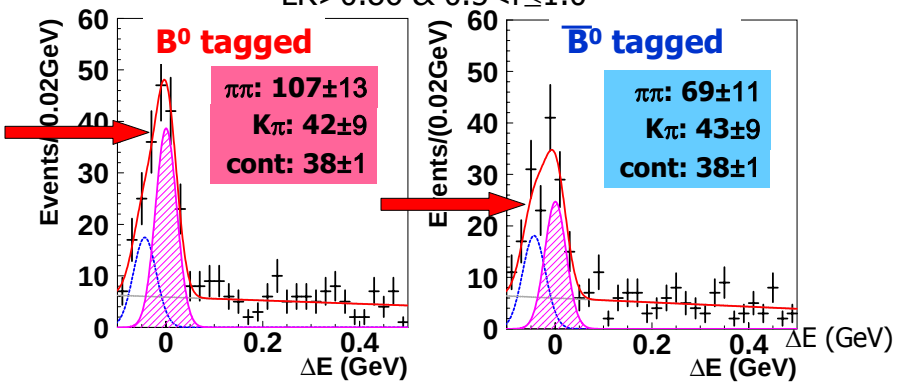
N.B. in B→ππ the two diagrams are the same order in λ

Direct CPV in $\pi^+\pi^-$: with time-integrated analysis

$A_{\pi\pi} = +0.52 \pm 0.14$

Counting experiment consistent with unbinned time-dependent fits.

LR>0.86 & 0.5<r≤1.0



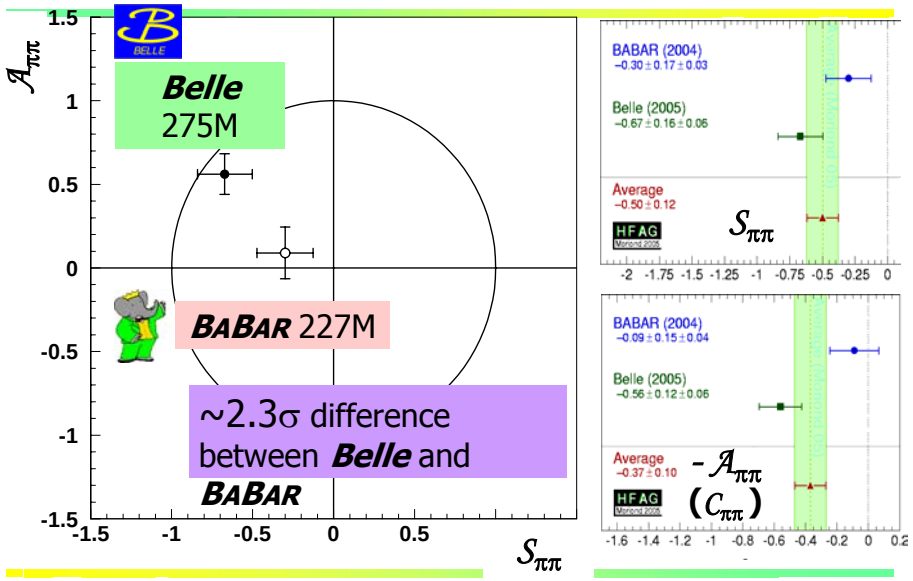
Visible indication of direct CP violation.

Direct CPV in $\pi^+\pi^-$

Belle $B\to\pi^+\pi^-$ observation from time dependent analysis $A_{+-}= 0.56 \pm 0.12 \pm 0.06$ not confirmed by BaBar.

Time integrated analysis result $A_{+-}= 0.52 \pm 0.14$ in good agreement with the time dependent analysis.

2005: Status of $B\to\pi^+\pi^-$



Direct CPV in $B^0 \to K^+\pi^-$ 2004 results from **BaBar & Belle**

PRL 93, 131801 (2004)

227M $B\bar{B}$

➢Evidence for DCPV (4.2σ)

$\mathcal{A} = -0.133 \pm 0.030 \pm 0.009$

PRL 93, 191802 (2004)

275M $B\bar{B}$

➢Evidence for DCPV (3.9σ)

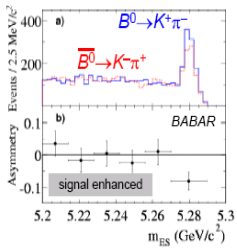
$\mathcal{A} = -0.101 \pm 0.025 \pm 0.005$

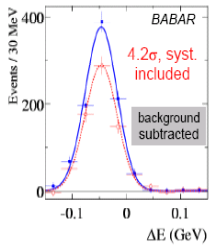
$n_{K\pi} = 1606 \pm 51$

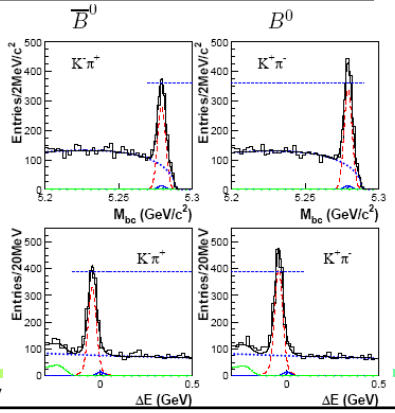
$A_{K\pi} = -0.133 \pm 0.030 \pm 0.009$

$n(B^0 \to K^+\pi^-) = 910$

$n(\bar{B}^0 \to K^-\pi^+) = 696$





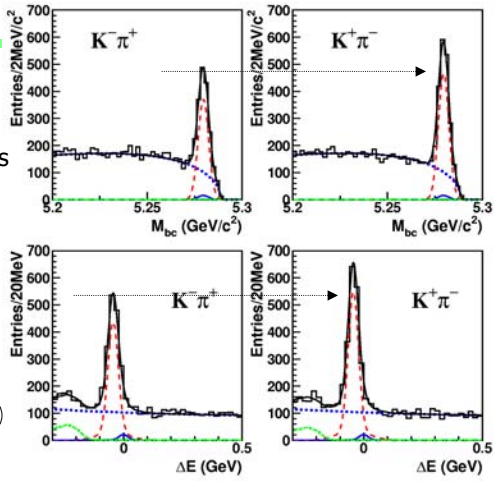


sity

2005: "Observation" of Direct CPV in $B \to K^-\pi^+$

Belle update with
386 x 10^6 B Bbar pairs

(hep-ex/0507045)



Significance
5.0 σ

One more nail in the Superweak coffin.

$$\mathcal{A}_{CP}(K^+\pi^-) \equiv \frac{N(\bar{B} \to K^-\pi^+) - N(B \to K^+\pi^-)}{N(\bar{B} \to K^-\pi^+) + N(B \to K^+\pi^-)} = 0.113 \pm 0.022 \pm 0.008.$$

Interpretation: Direct CP violation+SU(3)

The results support the expectation from SU(3) symmetry that

$$A_{CP}(K^+\pi^-) \sim -\frac{1}{3} A_{CP}(\pi^+\pi^-)$$

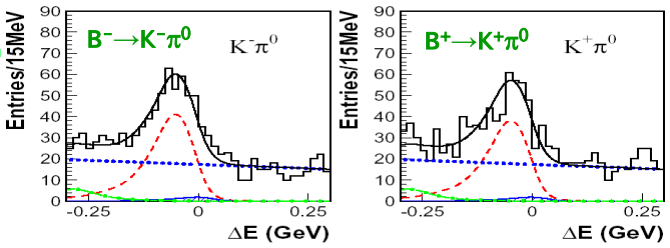
N.G. Deshpande and X.-G. He, PRL 75, 1703 (1995)

M. Gronau and J.L. Rosner, PLB 595, 339 (2004)

$A_{CP}(K^+\pi^-) = -0.115 \pm 0.018$ HFAG summer 2005

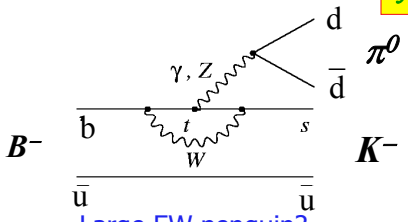
$-\frac{1}{3} A_{CP}(\pi^+\pi^-) = -0.19 \pm 0.04$ Belle measurement

Direct CPV in $K^+\pi^0$



$\mathcal{A}_{CP}$= 0.04 ± 0.05 ± 0.02 **Belle**

$\mathcal{A}_{CP}$= 0.06 ± 0.06 ± 0.01 **BaBar**



Large EW penguin?

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

$\mathcal{A}_{CP}$= -0.101±0.025±0.005

2.4σ diff.

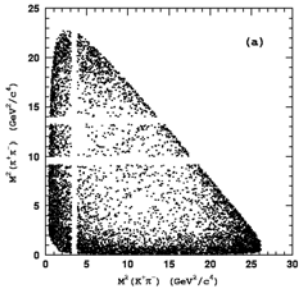
A new approach to direct CPV using the Dalitz plot in $B^{\pm} \to K^{\pm} \pi^{+} \pi^{-}$

Sample used for $B^{\pm} \to K^{\pm} \pi^{+}\pi^{-}$ study:

contains 2248±79 B^{-} , 2038±76 B^{+}

Fix the resonant substructure, then allow both the phase and amplitude to be different for B^{+} and B^{-} decays.

Combined Dalitz plot, signal region



For each resonant amplitude replace $ae^{i\delta}$ with $ae^{i\delta}(1 \pm b\, e^{i\varphi})$

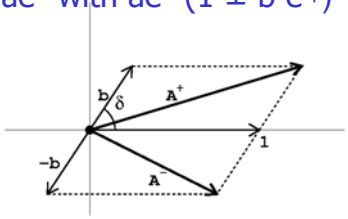
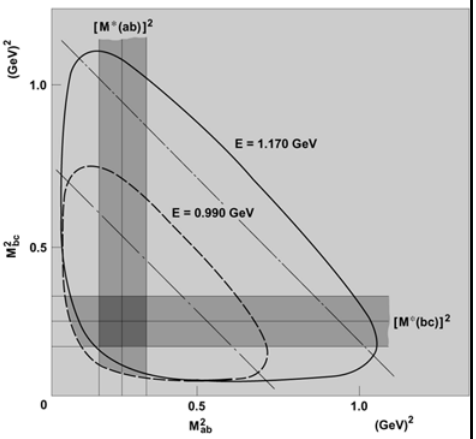


FIG. 9: Illustartion of the amplitude parametrization with Eq. 7.

(hep-ex/0509001)

What is a Dalitz plot?

Example: three body decay X->abc. M_{ij} denotes the invariant mass of the two-particle system (ij) in a three body decay. Kinematic boundaries: drawn fo equal masses $m_a = m_b = m_c = 0.14$ Ge and for two values of total energy E of the three-pion system. Resonance bands: drawn for states (ab) and (bc) corresponding to a (fictitious) resonanc with M=0.5 GeV and Γ=0.2 GeV; dot-dash lines show the locations a (ca) resonance band would have for this mass of 0.5 GeV, for the two values of the total energy E.



The pattern becomes much more complicated, if the resonances interfere.

Richard H. Dalitz, "Dalitz plot", in AccessScience@McGraw-Hill, http://www.accessscience.com.

Evidence for CP Violation in the Decay $B^{\pm}\to\rho^0 K^{\pm}$

TABLE I: Results of the best fit to $K^{\pm}\pi^{\pm}\pi^{\mp}$ events in the B signal region. The first quoted error is statistical and the second is the model dependent uncertainty. The quoted A_{CP} significance is statistical only.

Channel	Fraction (%)	δ (°)	b	φ (°)	A_{CP} significance (σ)
$K^*(892)\pi^{\pm}$	$13.0\pm0.8^{+0.5}_{-0.7}$	0 (fixed)	$0.078\pm0.033^{+0.012}_{-0.003}$	$-18\pm44^{+5}_{-13}$	2.6
$K_0^*(1430)\pi^{\pm}$	$65.5\pm1.5^{+2.2}_{-3.9}$	$55\pm4^{+1}_{-5}$	$0.069\pm0.031^{+0.010}_{-0.008}$	$-123\pm16^{+4}_{-5}$	2.7
$\rho(770)^0K^{\pm}$	$7.85\pm0.93^{+0.64}_{-0.59}$	$-21\pm14^{+14}_{-19}$	$0.28\pm0.11^{+0.07}_{-0.09}$	$-125\pm32^{+10}_{-85}$	3.9
$\omega(782)K^{\pm}$	$0.15\pm0.12^{+0.03}_{-0.02}$	$100\pm31^{+38}_{-21}$	0 (fixed)	–	–
$f_0(980)K^{\pm}$	$17.7\pm1.6^{+1.1}_{-3.3}$	$67\pm11^{+10}_{-11}$	$0.30\pm0.19^{+0.05}_{-0.10}$	$-82\pm8^{+2}_{-2}$	1.6
$f_2(1270)K^{\pm}$	$1.52\pm0.35^{+0.22}_{-0.37}$	$140\pm11^{+18}_{-7}$	$0.37\pm0.17^{+0.11}_{-0.04}$	$-24\pm20^{+14}_{-20}$	2.7
$f_X(1300)K^{\pm}$	$4.14\pm0.81^{+0.31}_{-0.30}$	$-141\pm10^{+8}_{-9}$	$0.12\pm0.17^{+0.04}_{-0.07}$	$-77\pm56^{+88}_{-43}$	1.0
Non-Res.	$34.0\pm2.2^{+2.1}_{-1.8}$	$\delta_1^{nr}=-11\pm5^{+3}_{-3}$ $\delta_2^{nr}=185\pm20^{+62}_{-19}$	0 (fixed)	–	–
$\chi_{c0}K^{\pm}$	$1.12\pm0.12^{+0.24}_{-0.08}$	$-118\pm24^{+37}_{-38}$	$0.15\pm0.35^{+0.08}_{-0.07}$	$-77\pm94^{+154}_{-11}$	0.7

$$A_{CP}(B^{\pm}\to\rho^0K^{\pm})=0.28\pm0.10^{+0.07}_{-0.09}\quad(3.9\sigma)$$

Significance varies from 3.7σ to 4.0σ depending on the model for the resonant substructure (add or remove modes, change nr model, cpv in b→u background).

Evidence for CP Violation in the Decay $B^{\pm}\to\rho^0 K^{\pm}$

B- vs B+ in the ρ and f^0 (980) $m_{\pi\pi}$ region

- helicity hemisphere

+helicity hemisphere

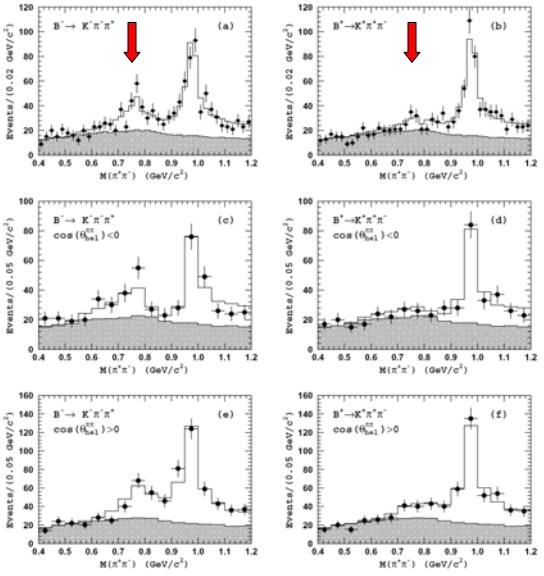


FIG. 7: $M(\pi^+\pi^-)$ mass spectra for B^- (left column) and B^+ (right column) for different helicity regions: (a,b) no helicity cuts; (c,d) $\cos\theta_H^{\pi\pi}<0$; (e,f) $\cos\theta_H^{\pi\pi}>0$; Points with error bars are data, the open histogram is the fit result and the hatched histogram is the background component.

Comparison of result to predictions and BaBar

Belle Data: $A_{CP}(B^{\pm} \to \rho^0 K^{\pm}) = 0.28 \pm 0.10^{+0.07}_{-0.09}$ (3.9σ)

First evidence for DCPV in a charged meson decay

Cheng, Gronau, Luo, Rosner, Suprun; PRD 69, 034001 (2004)

$$A_{CP}(B^{\pm} \to \rho^0 K^{\pm}) = 0.21 \pm 0.10$$

M. Beneke and M. Neubert; Nucl. Phys. B675, 333 (2003)

$$A_{CP}(B^{\pm} \to \rho^0 K^{\pm}) = -13.6^{+4.5+6.9+3.7+62.7}_{-5.7-4.4-3.1-55.4}\%$$

Four representative scenarios (-27.3, -9.3, 26.6, 31.7)%

BaBar Data: $A_{CP}(B^{\pm} \to \rho^0 K^{\pm}) = 0.32 \pm 0.13 \pm 0.06^{+0.08}_{-0.05}$ (2.4σ)