4th International Workshop on the CKM Unitary Triangle
Nagoya University - Nagoya - Japan

$B \rightarrow K\pi$ decays

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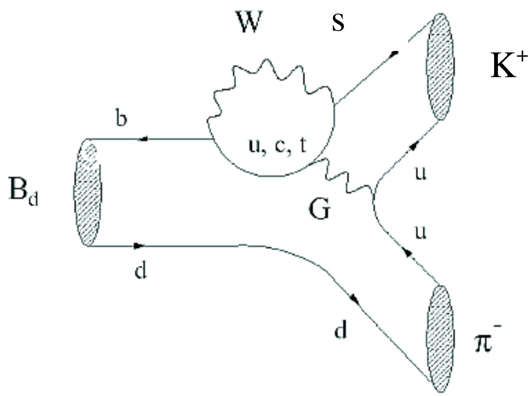
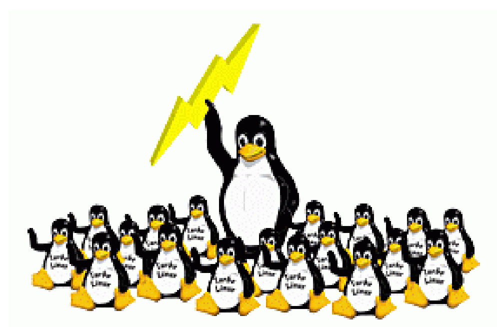
Outline

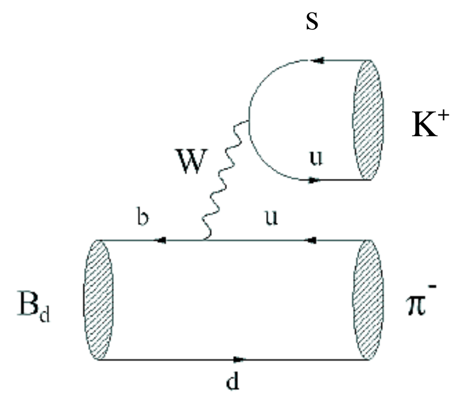
- Brief theoretical introduction
- Latest result on measurement of BR and A_{CP} of
  - $B^0 \to K^+\pi^-$
  - $B^\pm \to K^\pm\pi^0$
  - $B^\pm \to K^0\pi^\pm$
  - $B^0 \to K_s\pi^0$
- Conclusions

Why $B \to K\pi$

- At the very beginning great effort to measure BR and A_{CP} with the hope of extracting γ through SU(2) analysis
- But then big penguin diagrams were found…







- Different weak and strong phases generate direct CP violation
- So now interest shifted to the possibility of testing hadronic models and look for New Physics in penguins

Charming Penguin $\sim \lambda^2$ $\quad V_{us}\, V_{ub}^{*} \sim \lambda^4$

$$
\begin{aligned}
A(B^0 \to K^+ \pi^-) &= \boxed{V_{ts} V_{tb}^{*} \times P_1} - \boxed{V_{us} V_{ub}^{*} \times \{E_1 - P_1^{GIM}\}} \\
\sqrt{2}\cdot A(B^0 \to K^0 \pi^0) &= -\boxed{V_{ts} V_{tb}^{*} \times P_1} - \boxed{V_{us} V_{ub}^{*} \times \{E_2 + P_1^{GIM}\}} \\
\sqrt{2}\cdot A(B^+ \to K^+ \pi^0) &= \boxed{V_{ts} V_{tb}^{*} \times P_1} - \boxed{V_{us} V_{ub}^{*} \times \{E_1 + E_2 + A_1 - P_1^{GIM}\}} \\
A(B^+ \to K^0 \pi^+) &= -\boxed{V_{ts} V_{tb}^{*} \times P_1} + \boxed{V_{us} V_{ub}^{*} \times \{A_1 - P_1^{GIM}\}}
\end{aligned}
$$

The two sources of B→Kπ puzzle

1) BR's seem to violate isospin

	HFAG pre ICHEP
$R=\left[\frac{BR(B_d^0\to K^+\pi^-)+BR(\bar{B}_d^0\to K^-\pi^+)}{BR(B^+\to K^0\pi^+)+BR(B^-\to \bar{K}^0\pi^-)}\right]\frac{\tau_{B^+}}{\tau_{B_d^0}}$	0.84 ± 0.06
$R_c=2\left[\frac{BR(B^+\to K^+\pi^0)+BR(B^-\to K^-\pi^0)}{BR(B^+\to K^0\pi^+)+BR(B_d^-\to \bar{K}^0\pi^-)}\right]$	1.01 ± 0.09
$R_n=\frac{1}{2}\left[\frac{BR(B_d^0\to K^+\pi^-)+BR(\bar{B}_d^0\to K^-\pi^+)}{BR(B_d^0\to K^0\pi^0)+BR(\bar{B}_d^0\to \bar{K}^0\pi^0)}\right]$	0.83 ± 0.08

SM expectation

$R_C=1.15\pm0.05$

$R_N=1.12\pm0.05$

proposed solution:

NP in Electroweak Penguins as a source of isospin breaking

(Buras et al. Eur. Phys J. C45 (2006))

theoretically expected

$R_c-R_n\approx 0$

2) Expected correlation among $A_{CP}(K^+\pi^-)\approx A_{CP}(K^+\pi^0)$ (SAME SIGN)

not observed by experiment

HFAG pre ICHEP

$A_{CP}^{+-}=-0.108\pm0.017$

$A_{CP}^{+0}=0.04\pm0.04$

QCD factorization [hep-ph/0308039]
SCET [hep-ph/0510241,hep-ph/0601214]
pQCD at LO [hep-ph/0508041]
all predict SAME SIGN

Analyses overview

- Small branching fractions ~ 10^{-5}
- Large background from $e^+e^- \rightarrow q\bar{q}$
- Kinematic variables used for background suppression
  - $m_{ES} = \sqrt{(s/2 + p_i \cdot p_B)^2 / E_i^2 - p_B^2}$ (BaBar) or $m_{BC} = \sqrt{E_{beam}^{CM} - p_B^{CM}}$ (Belle)
  - $\Delta E = E_B^{CM} - \sqrt{s}/2$ (pion mass assumed for charged tracks)
- Topological variables for further discrimination of signal from background
- Particle ID for charged pion/kaon separation
- Unbinned Maximum Likelihood fit used to extract yields and CP asymmetries
- Completely different environment in CDF measurements: invariant ππ mass, track momenta and PID from dE/dx

$B^0 \rightarrow K^+\pi^-$

- Given the reached experimental precision, need to take EM effects into account

$$\Gamma^{meas}_{P_1P_2}(E^{max}) = \Gamma(H \rightarrow P_1P_2 + n\gamma)\,|_{\sum E_\gamma < E^{max}} = \Gamma^0_{P_1P_2}(\mu)\, G^0_{P_1P_2}(E^{max}_\gamma;\mu)$$

this is what necessarly is measured — this is what is needed in phenomenology

- In current experiment spectrum of soft photons in $B \rightarrow hh$ unobserved
- Use MC to interpret data from rare decays : need to include final state radiation in the simulation

Different approach :

- Belle : M_{BC} and ΔE PDFs from MC with FSR simulation taking into account also interference between charged particle
- BaBar : choose to rely on theoretical QED calculation instead of MC; quote both BR with a cut on photons energy and non-radiative BR
- CDF : measure only $A_{CP}(K^+\pi^-)$, use theoretical QED calculation to generate $B\rightarrow hh$ templates

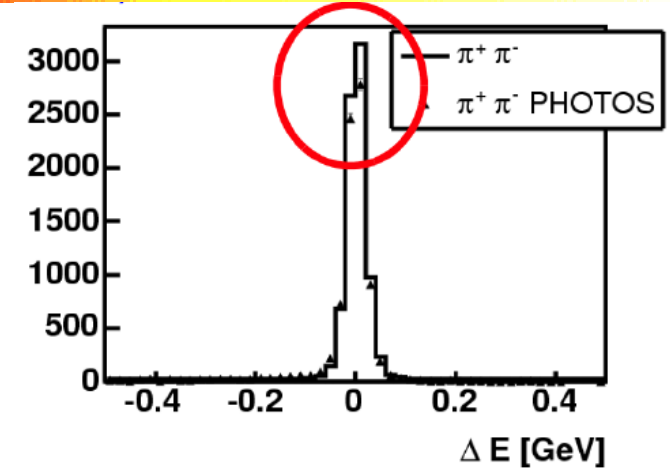
E.B. and G.Isidori
Phys. Lett. B 633: 309-313 (2006)

$B^0 \to K^+\pi^-$ results (Belle)

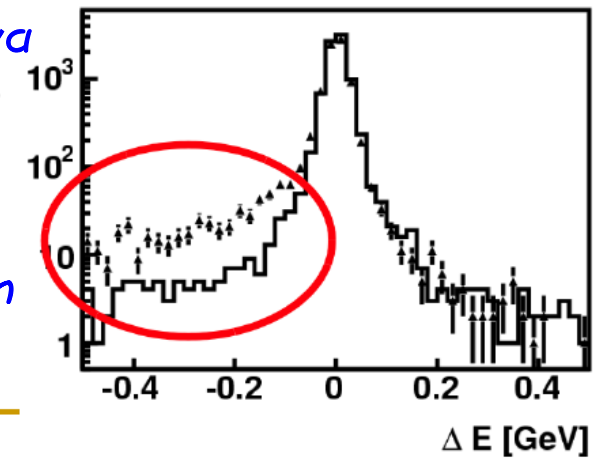
$449\ M\ \bar{B}B$
hep-ex/0609015

(A_{CP} $535\ M\ \bar{B}B$)

- Final state radiation with PHOTOS v 2.13
  - interference on
  - double photon on
  - cut-off ~ 26 MeV



- No systematic assigned to FSR relating on G.Nanava and Z. Was hep-ph/0607019 , which states that it is negligible for non SUPERB statistics



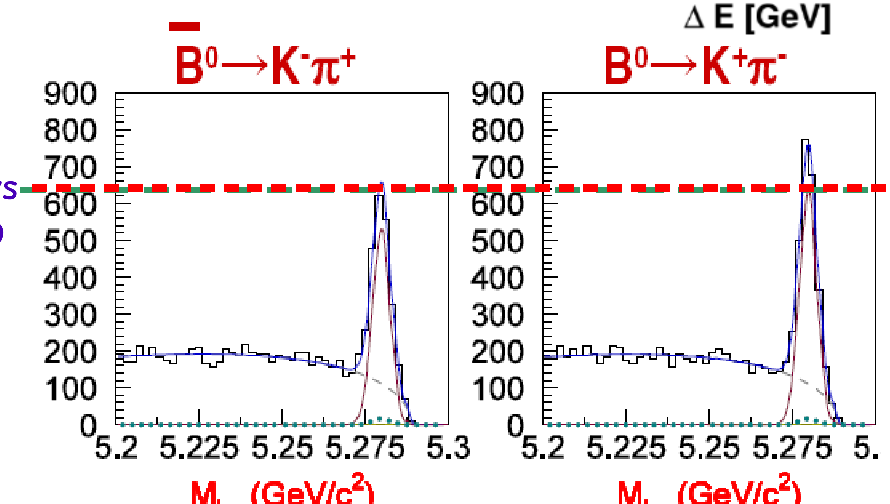
- Main systematics from charged tracks reconstruction (2%) and K-π likelihood cut (2.9%)

Impact on eff w/o PHOTOS

$\pi^+\pi^-$	$K^+\pi^-$	$h^+\pi^0$
9.4%	5.8%	3.6%

efficiency ε= 40.16%

signal
continuum
3-body B decays
bkg from mis-ID
all components



$$A_{CP}(B^0 \to K^+\pi^-) = -0.093 \pm 0.018 \pm 0.008$$

$$BR(B^0 \to K^+\pi^-) = (20.0 \pm 0.4 \pm 0.9) \times 10^{-6}$$

$B^0 \to K^+\pi^-$ results (BaBar)

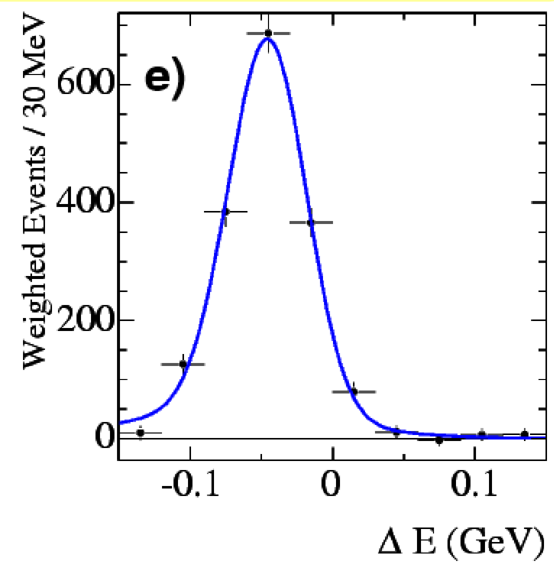
$A_{CP}(B^0 \to K^+\pi^-) = -0.108 \pm 0.024 \pm 0.008$

BR : 227 M $B\bar{B}$ hep-ex/0608003

A_{CP} : 347 M $B\bar{B}$ hep-ex/0607106

- underestimation of radiating events in MC compared to scalar QED calculation
  → corrects ΔE shape with QED/MC ratio → fix final fit ΔE tail parameters on those extrated from reweighted
- BR with a cut on photon spectrum (105 MeV) and non-radiative BR
- Efficiency normalized to the number of events generated with E_γ < 105 MeV
- Systematics uncertainty due to FSR

Changed during the period of PRD review : will cause central value of BR and syst. error to differ a bit from hep-ex/0608003



$\mathcal{B}_{E_\gamma}(10^{-6})$	$G(E_\gamma^{\max})$	$\mathcal{B}^0(10^{-6})$
$18.6 \pm 0.6 \pm 0.6$	0.944 ± 0.005	$19.7 \pm 0.6 \pm 0.6$

hep-ex/0608003 results

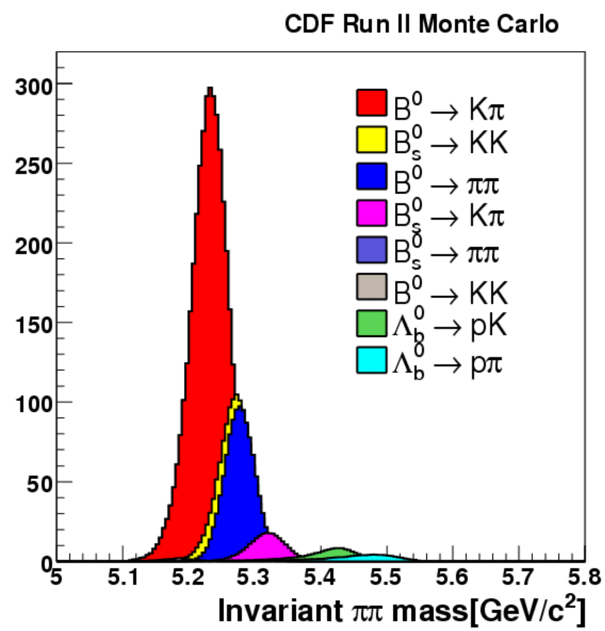
Other sys. from tracking (1.6%) and signal Fisher PDF (1.5%)

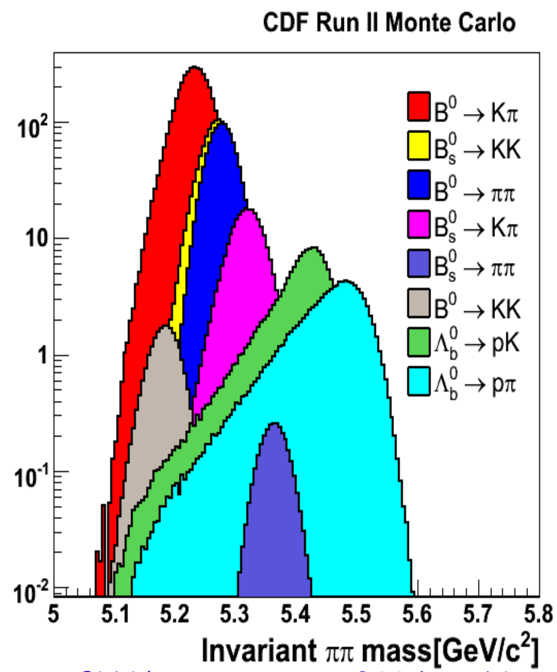
$B^0 \to K^+\pi^-$ results (CDF)

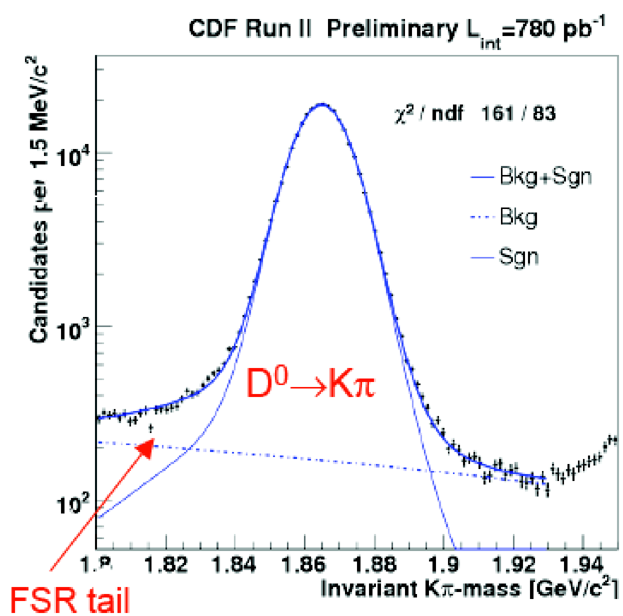
6500 $B_{(S)}$
hep-ex/0607106

$A_{CP}(B^0 \to K^+\pi^-) = -0.086 \pm 0.023 \pm 0.009$

- Unbinned ML fit on invariant ππ mass, track momenta and PID from dE/dx
- Fit to all $B_{(s)} \to h^+h'^-$
- Add QED radiation from calculation to kinematical MC from which invariant mass parametrization is extracted → good knowledge of tails needed to better discriminate different signals
- Validity of QED parametrization checked on huge $D^0 \to K^+\pi^-$ control sample







$B^{\pm} \rightarrow K^{\pm}\pi^{0}$

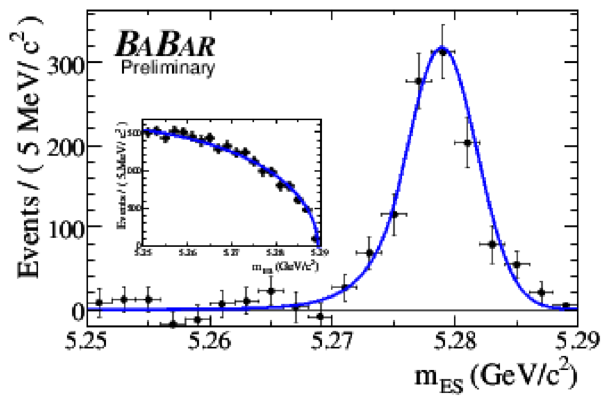
$BR(B^{\pm} \rightarrow K^{\pm}\pi^{0}) = (13.3 \pm 0.56 \pm 0.64) \times 10^{-6}$

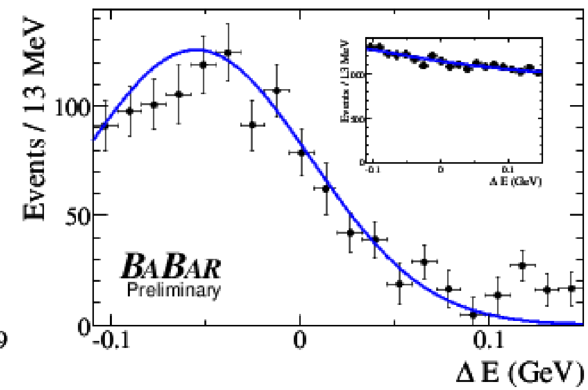
$A_{CP}(B^{\pm} \rightarrow K^{\pm}\pi^{0}) = 0.016 \pm 0.041 \pm 0.012$

347 M $\bar{B}B$
hep-ex/0607106

BABAR

Systematics mainly from PDFs and π^0s (3%) for BR and detector asymmetry for A_{CP}





Simultaneous ML fit for $\pi^{+}\pi^{0}, K^{+}\pi^{0}$ to Δe , M_{ES} , Fisher and θ_{C}

NEW: use merged π^0 and $\gamma \rightarrow e^{+}e^{-}$ conversion

final efficiency $\varepsilon = 26.8 \pm 1.3$ 10% increase for π^0

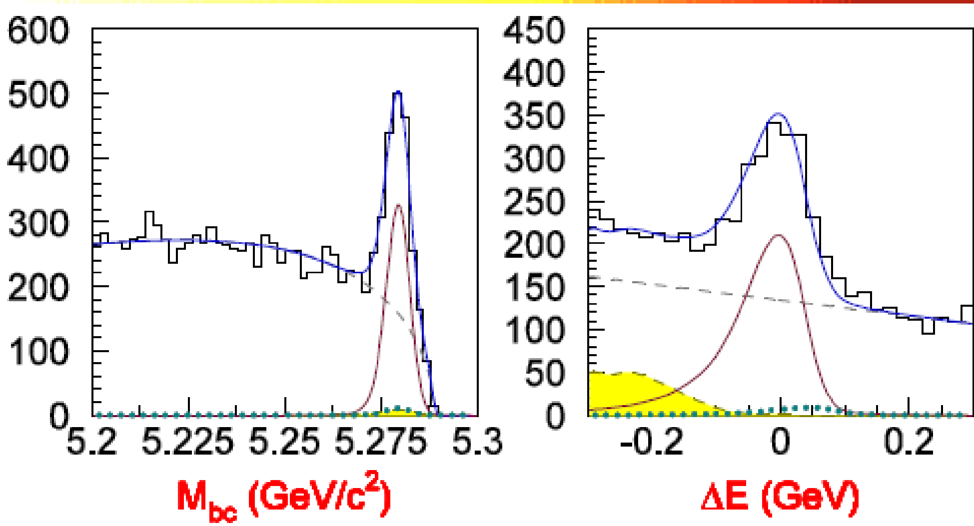
Merged π^0: the two γ too close, recovered thanks

$$M^2_{\pi^0} \approx E^2_{\pi^0}(S_{\pi^0} - S_{\gamma})$$

where S is the second EMC moment of the merged $\pi^0 \rightarrow \gamma\gamma$

$\gamma \rightarrow e^{+}e^{-}$ conversion : results from interaction with detector elements

$B^{\pm} \rightarrow K^{\pm}\pi^{0}$



535 M $\overline{B}B$
hep-ex/0609015

2D parametrization of (M_{BC} , Δe) for signal, mis-ID and 3-body B decays

signal
continuum
3-body B decays
bkg from mis-ID
all components

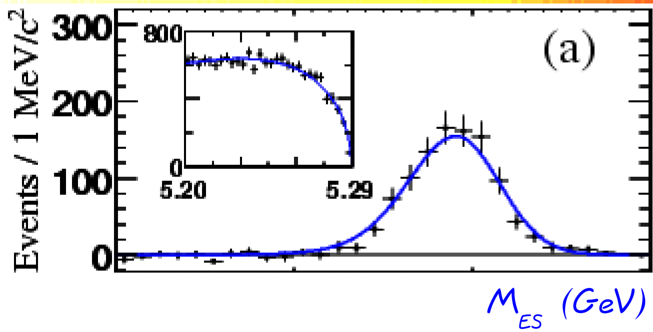
- ML fit to (Δe , M_{BC}), cut on likelihood ratio of topological variables
- systematics mainly from π^0 (4%) and likelihood ratio cut on K identification (15%)

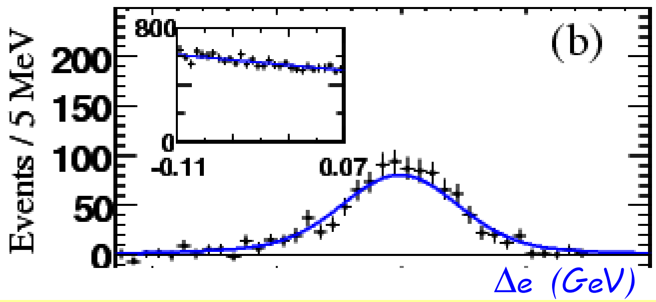
efficiency ε= 26.9 ± 1.2

$BR(B^{\pm} \rightarrow K^{\pm}\pi^{0}) = (12.4 \pm 0.5\ ^{+0.7}_{-0.6}) \times 10^{-6}$

$A_{CP}(B^{\pm} \rightarrow K^{\pm}\pi^{0}) = 0.07 \pm 0.03 \pm 0.01$

$B^{\pm} \rightarrow K^0\pi^{\pm}$





347 M $\bar{B}B$
PRL 97
171805 (2006)

Dominant systematics on BR from M_{ES} and ΔE parametrization (3%) and from detector bias for A_{CP}

fit varibles: Δe , M_{ES} , Fisher and θ_C

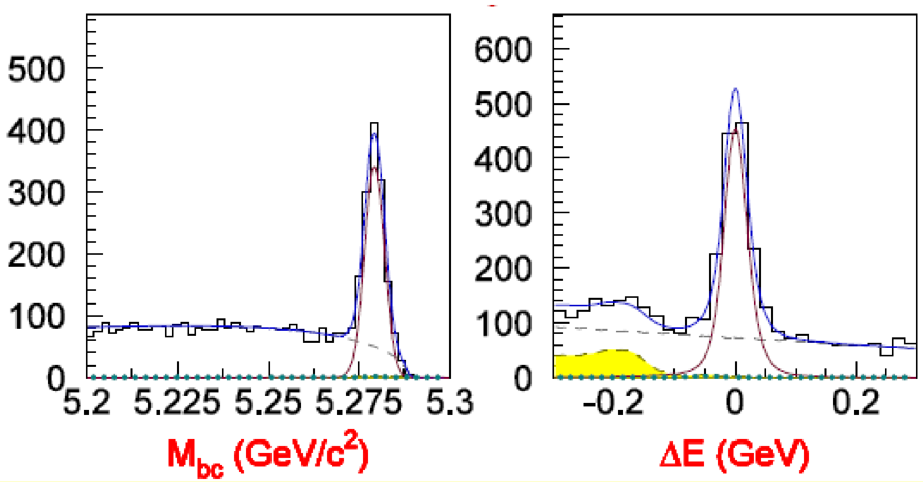
efficiency $\varepsilon = 12.9 \pm 0.4$

$BR(B^{\pm} \rightarrow K^0\pi^{\pm}) = (23.9 \pm 1.1 \ \pm 1.0) \times 10^{-6}$

$A_{CP}(B^{\pm} \rightarrow K^0\pi^{\pm}) = -0.029 \pm 0.039 \pm 0.010$

Simultaneous ML fit for $K^+ \bar{K}^0$ and $K^+\pi^0$

K^0 reconstructed as $K_S \rightarrow \pi^+\pi^-$



Dominant systematics from K_S reconstruction

fit varibles: (Δe , M_{ES})

efficiency $\varepsilon = 12.21$

signal
continuum
3-body B decays
bkg from mis-ID
all components

449 M $\bar{B}B$
hep-ex/0608049

$BR(B^{\pm} \rightarrow K^0\pi^{\pm}) = (22.9 \ ^{+0.8}_{-0.7} \pm 1.3) \times 10^{-6}$

$A_{CP}(B^{\pm} \rightarrow K^0\pi^{\pm}) = 0.03 \pm 0.03 \pm 0.010$

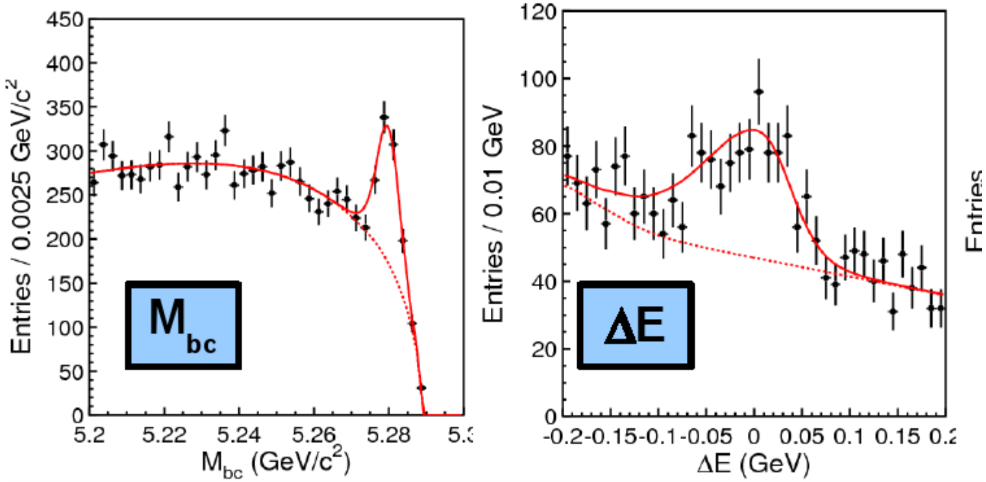
$B^0 \rightarrow K^0\pi^0$

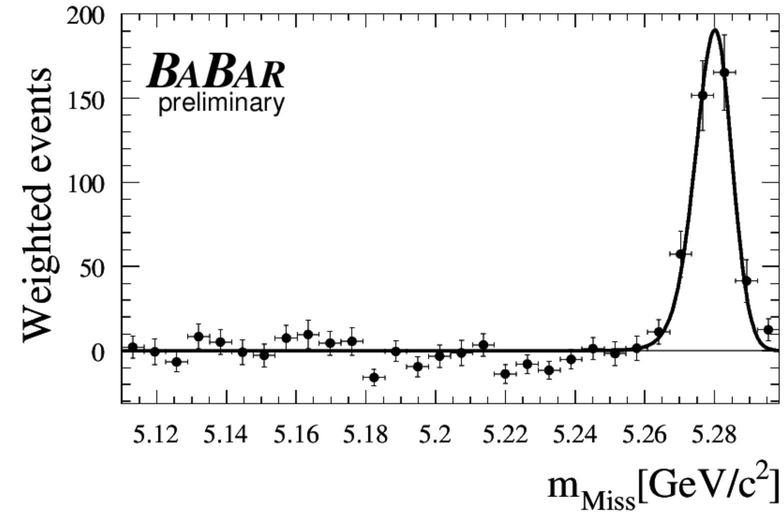
BELLE

535 M $\bar{B}B$
hep-ex/0609006

348 M $\bar{B}B$
hep-ex/0607096

BABAR





$(M_{BC}, \Delta e)$ and Δt, cut on topological variable

M_B, M_{MISS}, L_2/L_0, $\cos\theta^*_B$ and Δt

$C(K^0\pi^0) = 0.05 \pm 0.14 \pm 0.05$

$BR(B^0 \rightarrow K^0\pi^0) = (9.2 \pm 0.7 \pm 0.7) \times 10^{-6}$

$C(K^0\pi^0) = 0.20 \pm 0.16 \pm 0.03$

$BR(B^0 \rightarrow K^0\pi^0) = (10.5 \pm 0.7 \pm 0.5) \times 10^{-6}$

Systematics :

- BF : PDF knowledge (2.6%)
- S : PDF and vertex method
- C : resolution function and correlation among fit variables

all affected by K_S and π^0 reconstruction

- BF : PDF and likelihood ratio
- S : bkg dt PDF and resolution function
- C : tag interference and vertex reconstruction

$B \rightarrow K\pi$ asymmetries

.....and many other: A.Soni and D.Atwood Phys. Rev. D 58 036005(1998), H.J.Lipkin Phys.Lett. B 621 (2005) ...

★ Obey sum rule dictated by CPT theorem i.e.

Gronau Phys. Lett. B 627: 82 (2005)

$$A_{CP}(K^+\pi^-)+A_{CP}(K^0\pi^+)\frac{BR(K^0\pi^+)}{BR(K^+\pi^-)}\frac{\tau_0}{\tau_+}=A_{CP}(K^+\pi^0)\frac{2\,BR(K^+\pi^0)}{BR(K^+\pi^-)}\frac{\tau_0}{\tau_+}+A_{CP}(K^0\pi^0)\frac{2\,BR(K^0\pi^0)}{BR(K^+\pi^-)}$$

Both measures and WA compatible with sum rule prediction but still errors too large

From HFAG averages post ICHEP

$-0.08 \pm 0.03 = -0.06 \pm 0.11$

or else use it to predict

$A(K^0\pi^0) = -0.13 \pm 0.04$

WA

$A_{CP}(K^0\pi^0) = -0.12 \pm 0.11$

note that previous Belle measurement pushed WA towards positive A_{CP}

★But even with the new HFAG averages, $A_{CP}(K^{\pm}\pi^0)$ differs from $A_{CP}(K^+\pi^-)$ by 4.7 σ

→ Calculations are missing something?

Conclusions

- Given the reached experimental precision on BR, secondary effects as QED radiation can not be neglected anymore $\rightarrow$ different approach in Belle, Babar and CDF

$R_C = 1.11 \pm 0.07$ $\quad R_N = 0.99 \pm 0.07$

- Latest result on measurement of BR of $K\pi$ family brings R_C and R_N closer : with the new WA $R_C - R_N = 0.12 \pm 0.10$

Not a very big puzzle on BR

- Measurement of A_{CP}
  - direct CP violation in $B^0 \rightarrow K^+\pi^-$ established at 7σ (WA)
  - $A_{CP}(K\pi)$ obey general sum rules

$4.7\ \sigma$ still big puzzle on A_{CP}

  - BUT $A_{CP}(K^+\pi^0) - A_{CP}(K^+\pi^-) = 0.14 \pm 0.03$ and should have same sign

- Expecially BR measurements near to be systematic limitated, nevertheless all of above asks for improved precision