Measurements of the Branching Fractions and CP asymmetries in B→Kπ decays with B*A*B*AR*

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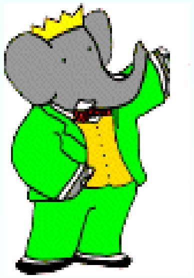

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On behalf of B*A*B*AR* Collaboration

Physics Motivations

- The $B \rightarrow K\pi$ decays are an important source of information to:
  - improve our knowledge of the fundamental parameters (weak phases and CPV effects)
  - test the Standard Model
  - constrain the parameter space of New Physics models
  - precise measurements provide useful information to improve the theoretical model calculations, such as QCD factorization and perturbative QCD, etc.

Quark mixing matrix in the Standard Model

- In the Standard Model, the Cabibbo-Kobayashi-Maskawa (CKM) Matrix describes the electroweak coupling strength of quarks to the W boson;
- 3x3 unitary matrix with 4 independent parameters;
- The irreducible phase parameter (η) is the source of possible CP violation.

the CKM Matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

the Wolfenstein Parameterization of CKM Matrix

$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

The Decay Amplitudes

A. Buras & J. Silvestrini
arXiv: hep-ph/9812392

Dominant penguin ~ λ^2 | $V_{us}V_{ub}^{*} \sim \lambda^4$

$$A(B^+ \to K^0\pi^+) = -V_{ts}V_{tb}^{*} X P_1() + V_{us}V_{ub}^{*} X \{A_1() - P_1^{GIM}()\}$$

$$\sqrt{2} \bullet A(B^+ \to K^+\pi^0) = V_{ts}V_{tb}^{*} X P_1() - V_{us}V_{ub}^{*} X \{E_1() + E_2() - P_1^{GIM}() + A_1()\}$$

$$A(B^0 \to K^+\pi^-) = V_{ts}V_{tb}^{*} X P_1() - V_{us}V_{ub}^{*} X \{E_1() - P_1^{GIM}()\}$$

$$\sqrt{2} \bullet A(B^0 \to K^0\pi^0) = -V_{ts}V_{tb}^{*} X P_1() - V_{us}V_{ub}^{*} X \{E_2() + P_1^{GIM}()\}$$

Ratios of BFs of central interest:

$$R \equiv \frac{BF(B^0 \to K^{\pm}\pi^{\mp})}{BF(B^{\pm} \to K^0\pi^{\pm})}\frac{\tau_{B^+}}{\tau_{B_d^0}}$$

$$R_c \equiv 2\frac{BF(B^{\pm} \to K^{\pm}\pi^0)}{BF(B^{\pm} \to K^0\pi^{\pm})}$$

$$R_n \equiv \frac{1}{2}\frac{BF(B^0 \to K^{\pm}\pi^{\mp})}{BF(B^0 \to K^0\pi^0)}$$

Within the SM, $R_c - R_n \approx 0$

Buras, Fleischer, etc.
arXiv: hep-ph/0411373

Three Types of CPV in B Decays

1. CP violation in decay, also called “the direct CP violation”, happens when the amplitude for a decay and its CP conjugate process have different magnitudes:

   $$\left|\bar{A}_{\bar{f}} / A_f\right| = \left|\sum_i A_i e^{i(\delta_i - \phi_i)} \Big/ \sum_i A_i e^{i(\delta_i + \phi_i)}\right| \neq 1 \Rightarrow \text{CP violation.}$$

   * It can only happen when at least 2 amplitudes have different weak and strong phases.

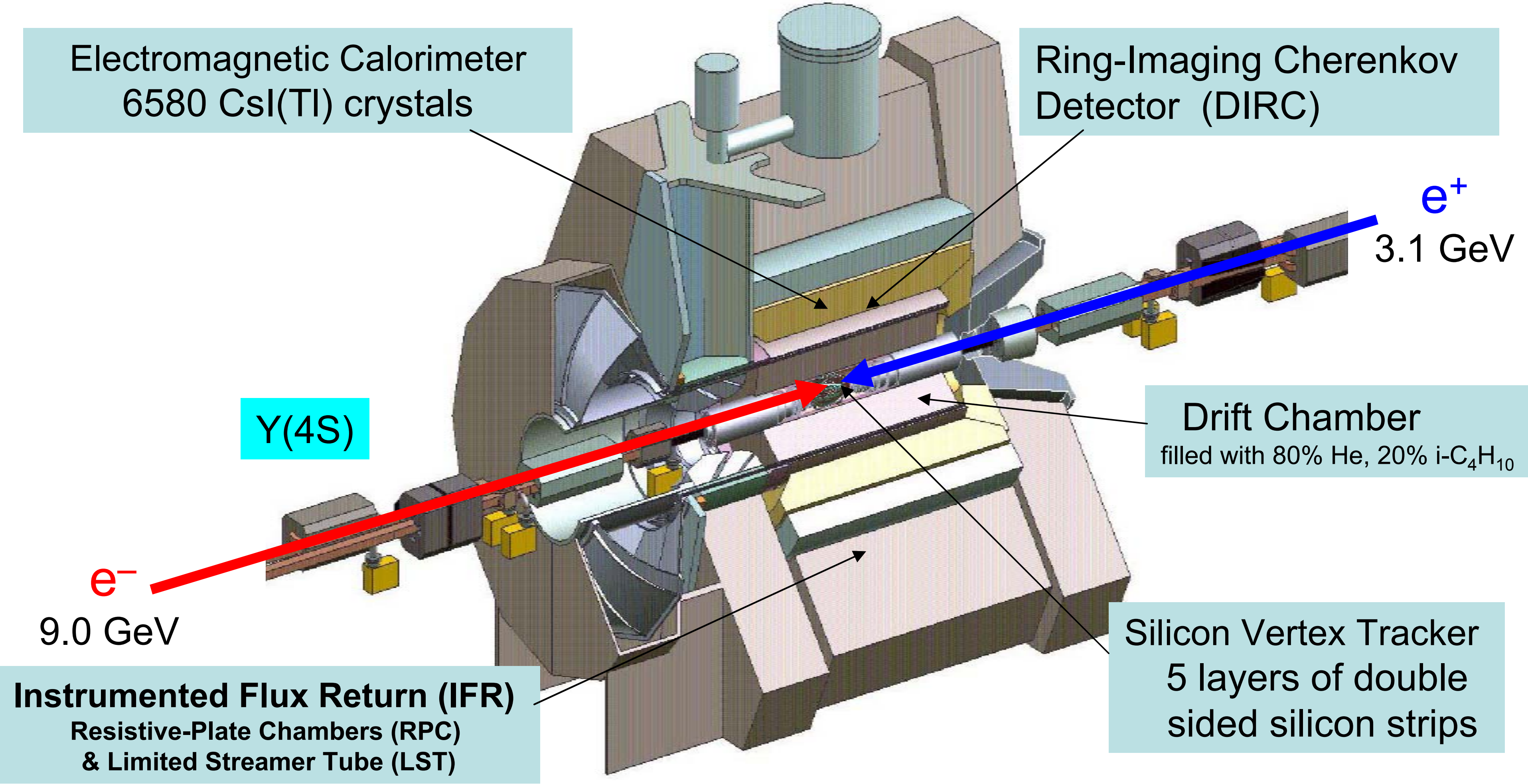
   The direct CP asymmetry: $$A_{CP} \equiv \frac{\left|A(\bar{B}\to\bar{f})\right|^2 - \left|A(B\to f)\right|^2}{\left|A(\bar{B}\to\bar{f})\right|^2 + \left|A(B\to f)\right|^2} = \frac{N(\bar{B}\to\bar{f}) - N(B\to f)}{N(\bar{B}\to\bar{f}) + N(B\to f)}$$

   Where the $B/\bar{B}$ are either the charged B^+/B^- or the (self) tagged $B^0/\bar{B}^0$.

2. CP violation in mixing, which occurs when two neural mass eigenstates cannot be chosen to be CP eigenstates;

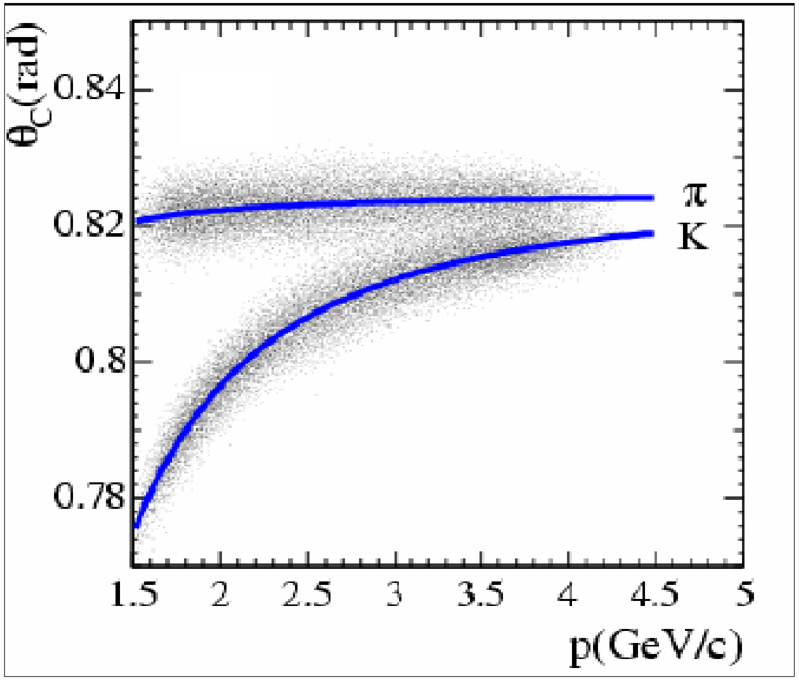
3. CP violation in the interference between decays with mixing, which usually occurs in combination with the other two types but not always the case.

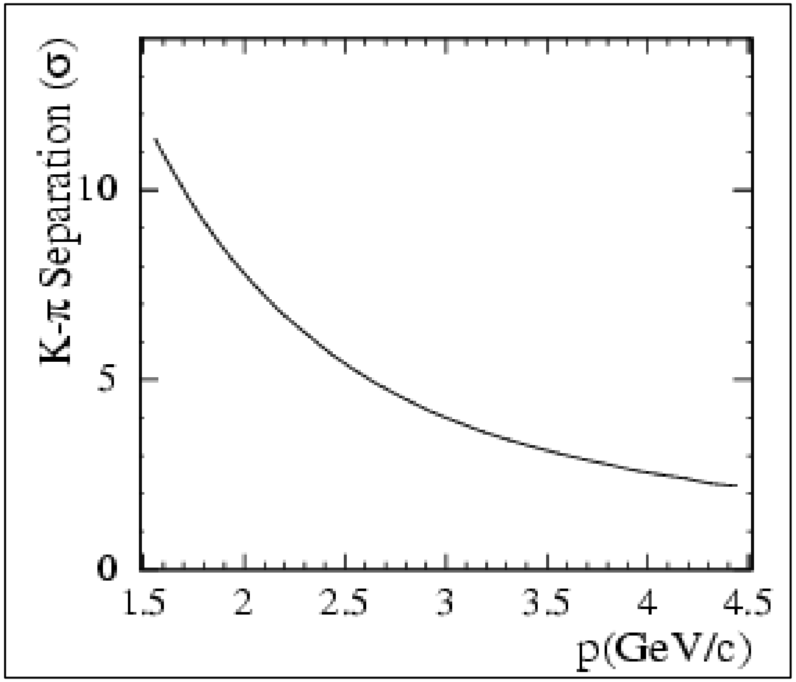
The BaBar Detector



Particle ID: Charged π/K Separation

- BaBar's Detector of Internally Reflected Cherenkov light (DIRC) provides excellent performance in the pion/kaon separation
- the separation is from 2σ up to more than 10σ depending on the momentum



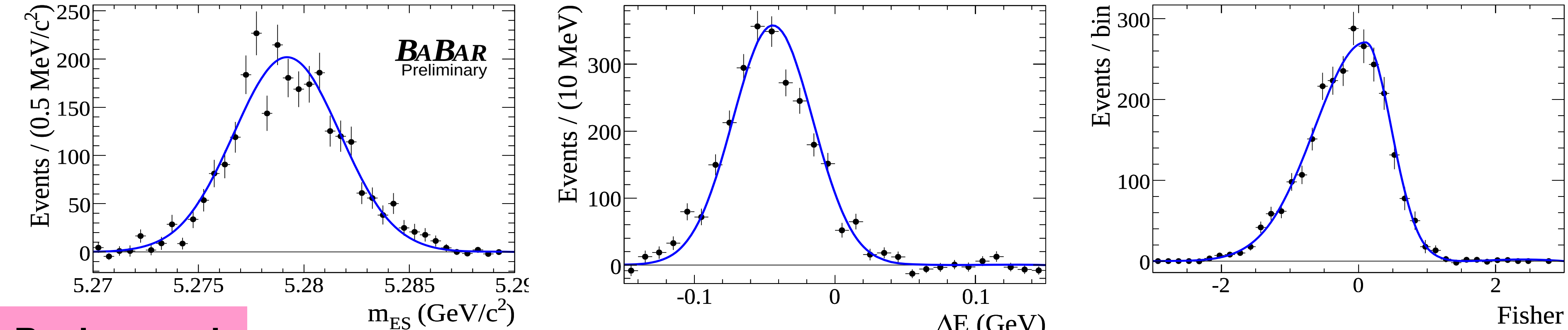


Analysis Overview

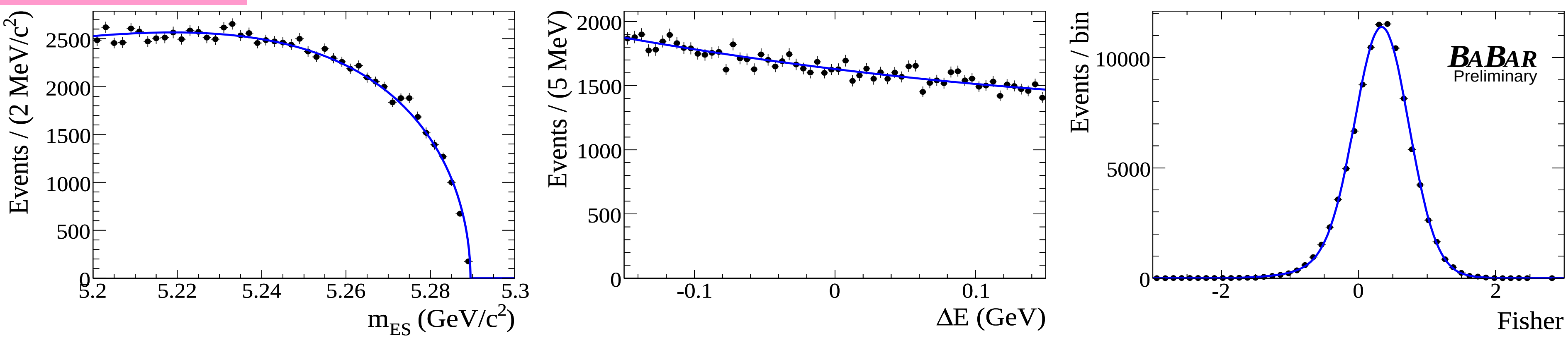
- Small BF ~ 10^{-5}
- Large background from the $e^+e^- \rightarrow q\bar{q}$, q=u,d,s,c
- Two nearly uncorrelated kinematic variables are used for the background suppression:
  - Beam-energy substituted mass: $m_{ES} = \sqrt{(s/2 + p_i.p_B)^2 / E_i^2 - p_B^2}$
  - $\Delta E = E_B^{CM} - \sqrt{s}/2$, the pion mass is assumed.
- the event shape variable Fisher discriminant (*F*) is used to enhance the separation of the signal from background.
- Particle ID: the Cherenkov angle information is used for the charged pion/kaon separation. The PDFs for θ_C are from the D* control sample: $D^{*+} \rightarrow D^0\pi^+ \rightarrow (K^-\pi^+)\pi^+$
- Unbinned Maximum Likelihood fit used to extract the yields and CP asymmetries.
- Cross check: the pure/mixed toy MC

Analysis Overview cont'd.

Signal: M_{ES} | ΔE | Fisher



Background:

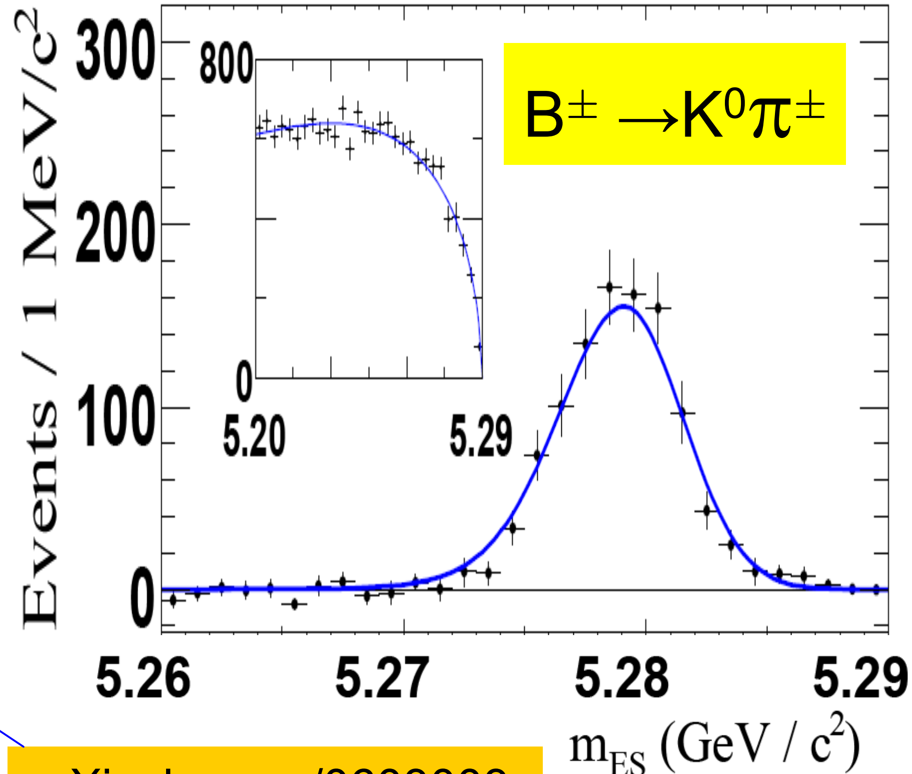


$_s$*Plots* for $B^0 \to K\pi$

M. Pivk and F. R. Le Diberder,
sPlot: a statistical tool to unfold data distributions
arXiv: physics/0402083

BF of $B^{\pm} \to K^0 \pi^{\pm}$

- Dataset contains 347 million $B\overline{B}$ pairs
- K_S reconstructed from $K_S \to \pi^+\pi^-$
- Simultaneous ML fit for $K_S\pi$ and K_SK
- M_{ES}, ΔE, Fisher, and θ_C
- Efficiency: 13.002 ± 0.030 % ($B^{\pm} \to K_S\pi^{\pm}$)



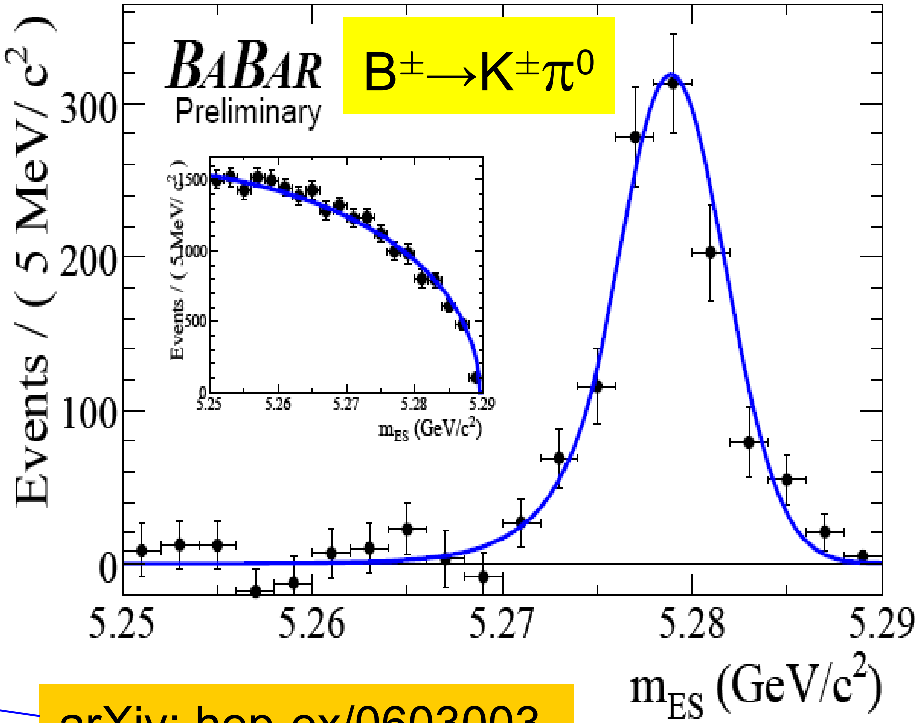
old world average BF: 24.1 ± 1.3 (10^{-6})		
Mode	N_{signal}	BF (10^{-6})
$B^+ \to K^0\pi^+$	1072±46	23.9 ± 1.1 ± 1.0

arXiv: hep-ex/0603003

arXiv: hep-ex/0608036

BF of $B^{\pm}\to K^{\pm}\pi^0$

- Dataset contains 347 million $B\bar{B}$ pairs
- merged π^0 reconstructed from $\pi^0\to\gamma\,\gamma$ or $\pi^0\to\gamma(e^+e^-)$
- Simultaneous ML fit for $\pi\pi^0$ and $K\pi^0$
- M_{ES}, ΔE, Fisher, and θ_C
- Efficiency: 26.8 ±1.3 % ($B^{\pm}\to K^{\pm}\pi^0$)



old world average BF: 12.1 ± 0.8 (10^{-6})		
Mode	N_{signal}	BF (10^{-6})
$B^+\to K^+\pi^0$	1239±52	13.3 ± 0.6 ± 0.6

arXiv: hep-ex/0603003

arXiv: hep-ex/0607106

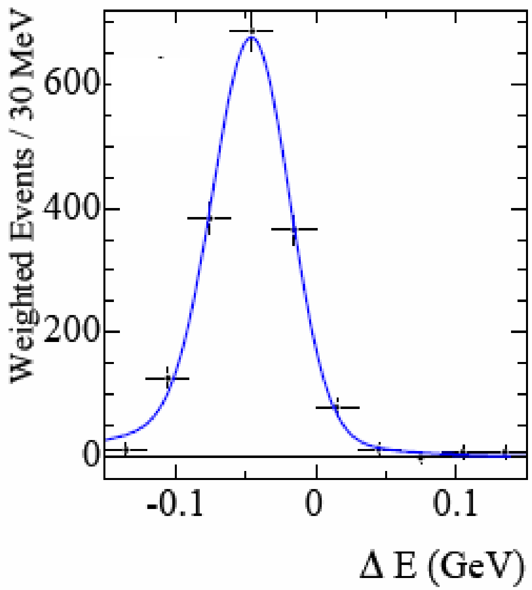
BF of $B^0 \to K^+\pi^-$

- Improved statistics (227 million $B\bar{B}$ pairs) motivates to take into account radiative corrections
- the non-radiative BF (BF^0): $\Gamma_{K\pi}(E_\gamma^{max}) = \Gamma(B^0 \to K^+\pi^- n\gamma)|_{\sum E_\gamma < E_\gamma^{max}} = \Gamma^0_{K\pi}(\mu) \bullet G_{K\pi}(E_\gamma^{max};\mu)$
- E_γ^{max} is the maximum value allowed for the sum of the undetected photon energies and μ is the renormalization scale at which $\Gamma_{K\pi}{}^0$ and $G_{K\pi}(E_\gamma^{max})$ are calculated
- The correction factor $G_{K\pi}()$ is from the paper by Baracchini and Isidori

arXiv: hep-ex/0603003

Baracchini, Isidori
Phys. Lett. B633 309-313, 2006

old world average BF: 18.9 ± 0.7 (10^{-6})			
Mode	$BF_{E_\gamma(MeV)}$ (10^{-6})	$G_{(E_\gamma{}^{max})}$	BF^0 (10^{-6})
$B^0 \to K^+\pi^-$	$18.6 \pm 0.6 \pm 0.6 \vert_{105}$	0.944 ± 0.005	$19.7 \pm 0.6 \pm 0.6$



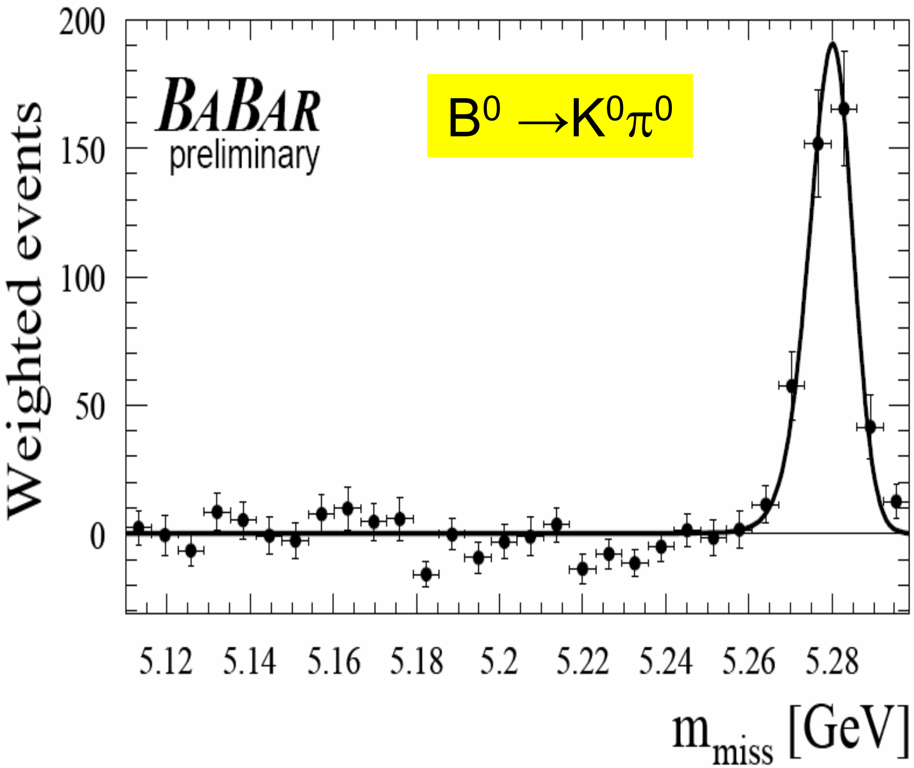
arXiv: hep-ex/0608003

BF of $B^0 \to K^0\pi^0$

- Dataset contains 347 million $B\bar{B}$ pairs
- K_S reconstructed from $K_S \to \pi^+\pi^-$
- π^0 reconstructed from $\pi^0 \to \gamma\,\gamma$
- the NN tagger used to determine the flavor of B_{tag}
- M_B, m_{miss}, L_2/L_0, $\cos\theta^*_B$, Δt
- Efficiency: 34.3 ±1.3 % ($B^0 \to K^0\pi^0$)

arXiv: hep-ex/0603003

old world average BF: 11.5 ± 1.0 (10^{-6})		
Mode	N_{signal}	BF (10^{-6})
$B^0 \to K^0\pi^0$	425 ± 28	$10.5 \pm 0.7 \pm 0.5$

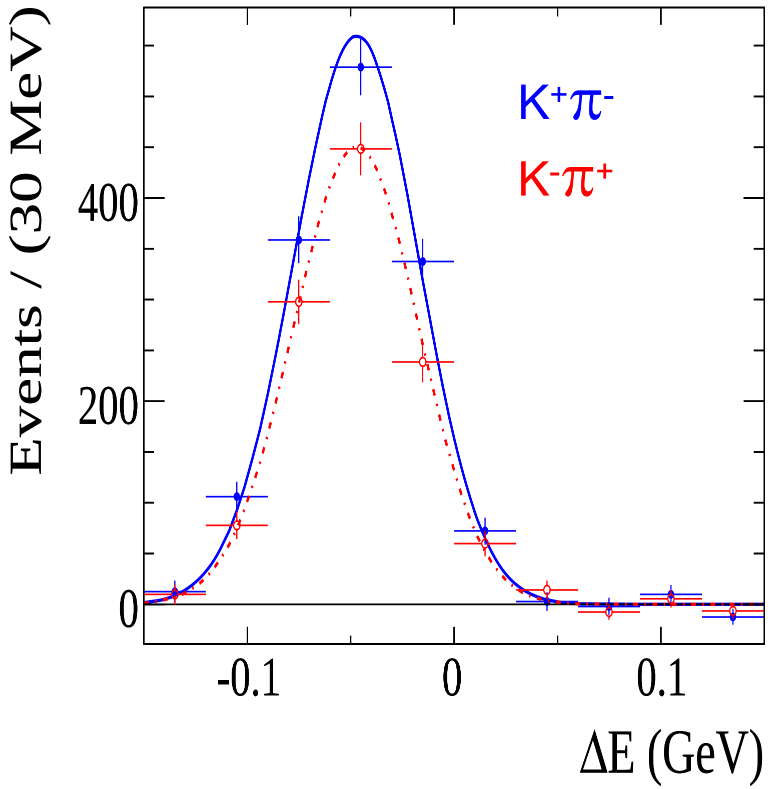


arXiv: hep-ex/0607096

Direct CP Asymmetries in $B \to K\pi$

Mode	A_{CP}
$B^{\pm} \to K^0\pi^{\pm}$	-0.029 ±0.039±0.010
$B^{\pm} \to K^{\pm}\pi^0$	0.016 ±0.041±0.010
$B^0 \to K^{\pm}\pi^{\mp}$	-0.108 ±0.024±0.007
$B^0 \to K^0\pi^0$	-0.20 ±0.16 ±0.03

the Direct CPV in $B \to K\pi$ @ 4.3σ



For the time-dependent CP Violations:

in $B \to \pi\pi$, M. Allen's talk

in $B \to KK$, J. Biesiada's talk

arXiv: hep-ex/0608036, 0607106, 0607096

The K-π Puzzle

- Revisit of two ratios of interest: R_c and R_n
  - Using our new BFs, we have: R_c=1.11$\pm$0.07, R_n=0.94$\pm$0.07
  - The pattern that $R_c > R_n$ would imply the enhancement of the EW penguin and/or the color suppressed tree contributions.

Buras, Fleischer, etc.
arXiv: hep-ph/0402112

- About A_{CP}
  - $A_{CP}(B^+ \rightarrow K^+\pi^0)$ is expected to be almost the same as $A_{CP}(B^0 \rightarrow K^+\pi^-)$. In particular, they would have the same sign.
  - Our new result shows $A_{CP}(B^+ \rightarrow K^+\pi^0)=0.016\pm0.041$ differs from $A_{CP}(B^0 \rightarrow K^+\pi^-)=-0.108\pm0.024$ by 2.6σ
  - Hints of New Physics? Gronau and Rosner say this violation may be accounted for by a large color suppressed tree amplitude.

Gronau and Rosner
arXiv: hep-ph/0608040

Summary

- The $B \to K\pi$ decays play an important role in testing models and searching for the New Physics;
- BFs in $B \to K\pi$ decays updated, including the final state radiation;
- The direct CP asymmetries also updated:
  - Evidence of the direct CP violation in $B^0 \to K^+\pi^-$ decays.
  - Direct CP asymmetries in $B^\pm \to K^0\pi^\pm$, $B^\pm \to K^\pm\pi^0$ and $B^0 \to K^0\pi^0$ decays are consistent with 0.
- The K-π puzzle in BFs can be explained by the enhanced EW penguin contributions, and the puzzle in A_{CP} may be explained by large color suppressed tree amplitude.

Mode	BF (10^{-6})	A_{CP}
$B^\pm \to K^0\pi^\pm$	23.9 ±1.1 ±1.0	-0.029 ±0.039±0.010
$B^\pm \to K^\pm\pi^0$	13.3 ±0.5 ±0.6	0.016 ±0.041±0.010
$B^0 \to K^\pm\pi^\mp$	19.7 ±0.6 ±0.6*	-0.108 ±0.024±0.007
$B^0 \to K^0\pi^0$	10.5 ±0.7 ±0.5	-0.20 ±0.16 ±0.03

*BF^0