Direct CP Violation in Charmless B decays

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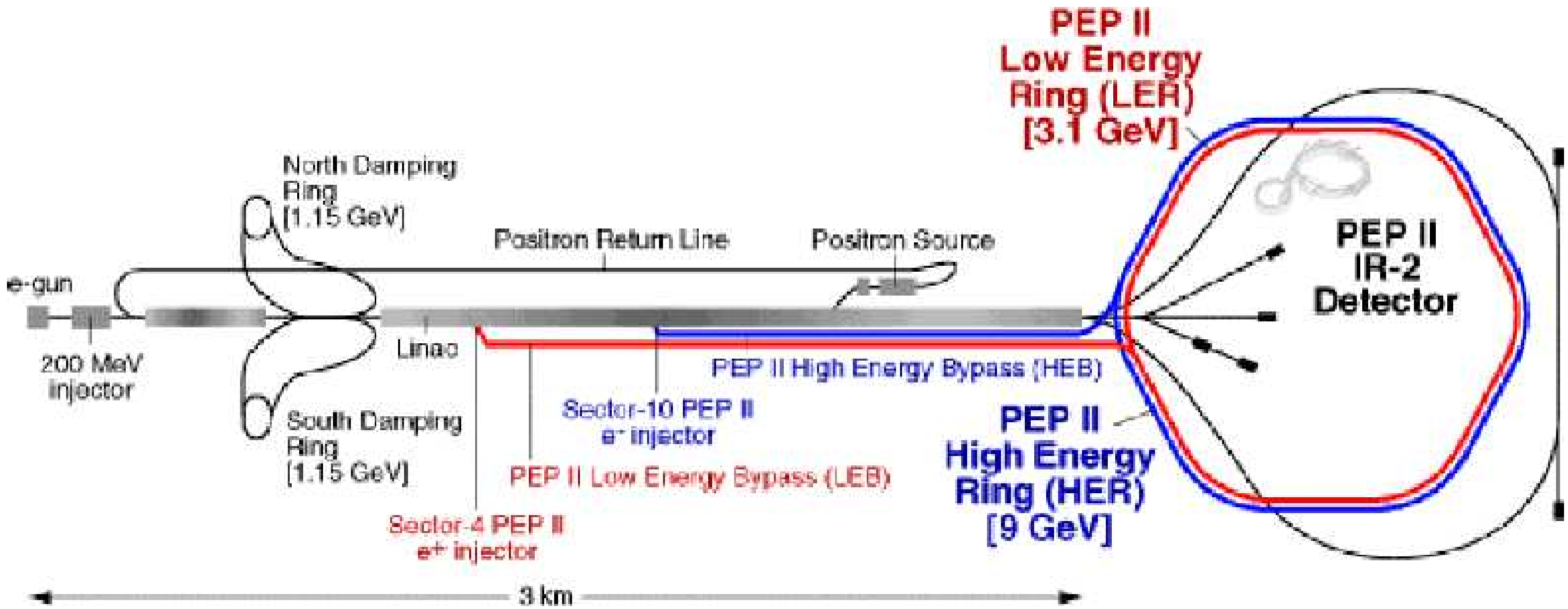
Outline

- Introduction
- The main players
- Overview of analysis
- $\mathcal{A}_{CP}$'s for $B \to hh$
- $\mathcal{A}_{CP}$'s for $B \to K\pi\pi$
- Summary & Conclusion

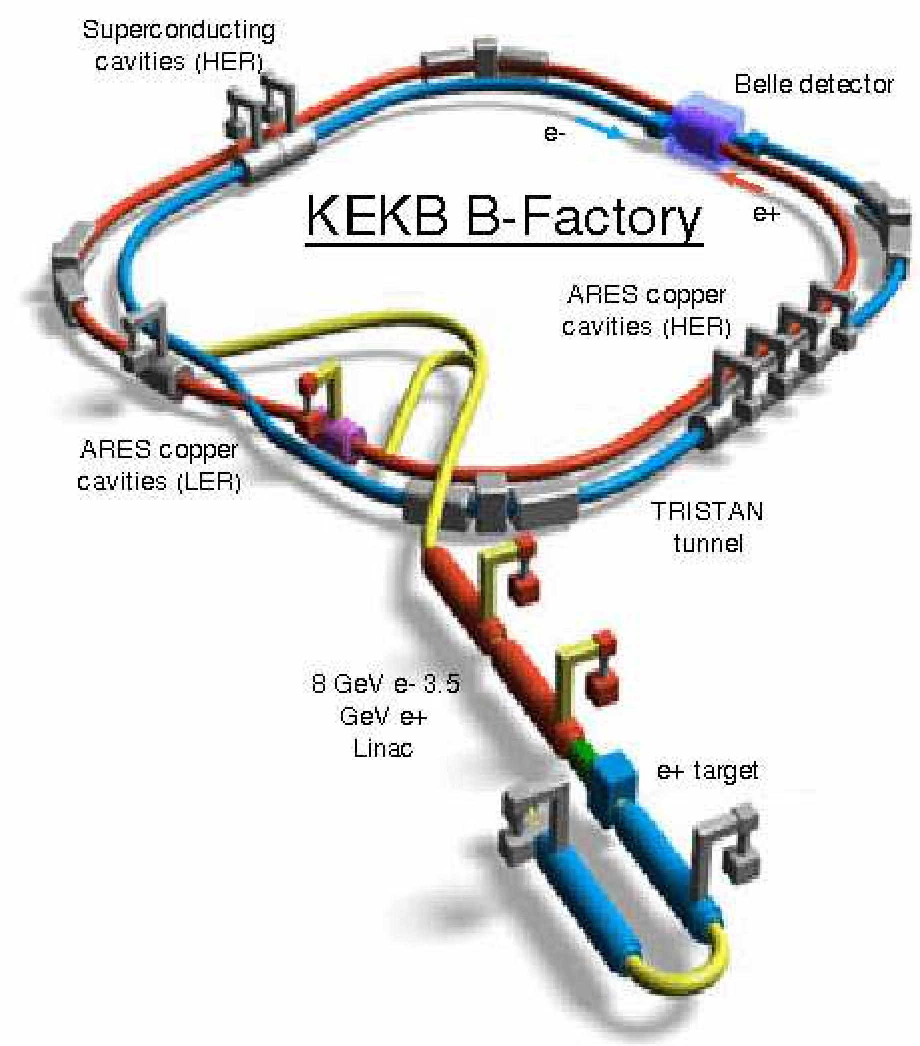
PEP-II



Stanford, USA

- 3.1 GeV e^+ on 9 GeV e^-
- cms boost $<\beta\gamma>= 0.55$
- $\mathcal{L}_{\rm p} = 10.0 \times 10^{33}/cm^2/s^2$

KEKB



Tsukuba, Japan

8 GeV e^- + 3.5 GeV e^+

$W_{CM} = m(\Upsilon(4S))$

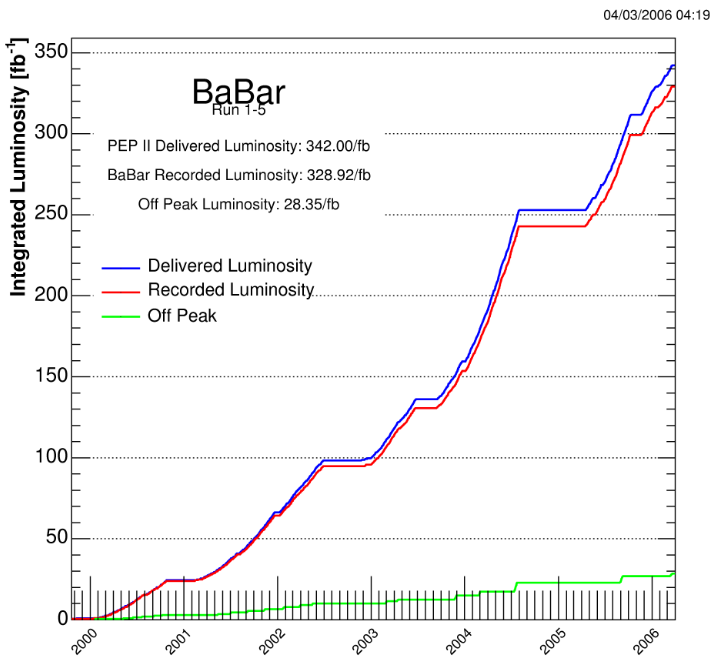
3 km circumference

$\sim$ 11 mrad crossing angle

$\mathcal{L}_{\rm p} = 1.63 \times 10^{34}/cm^2/s^2$

Luminosity

BaBar



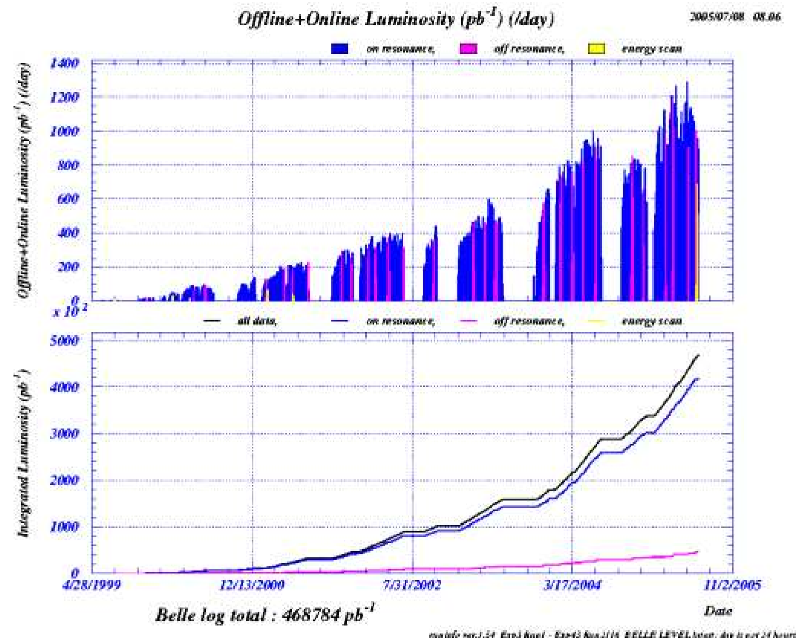
$\mathcal{L}_{\rm p} = 1.00 \times 10^{34}/cm^2/s^2$

Int. $\mathcal{L} \sim 340$/fb

($\sim 330/fb$ on Υ(4S) + $\sim 28/fb$ off peak)

Up to 232M $B\bar{B}$ used

BELLE



$\mathcal{L}_{\rm p} = 1.63 \times 10^{34}/cm^2/s^2$

Int. $\mathcal{L} \sim 560$/fb

($\sim 90\%$ on Υ(4S) + $\sim 10\%$ off peak)

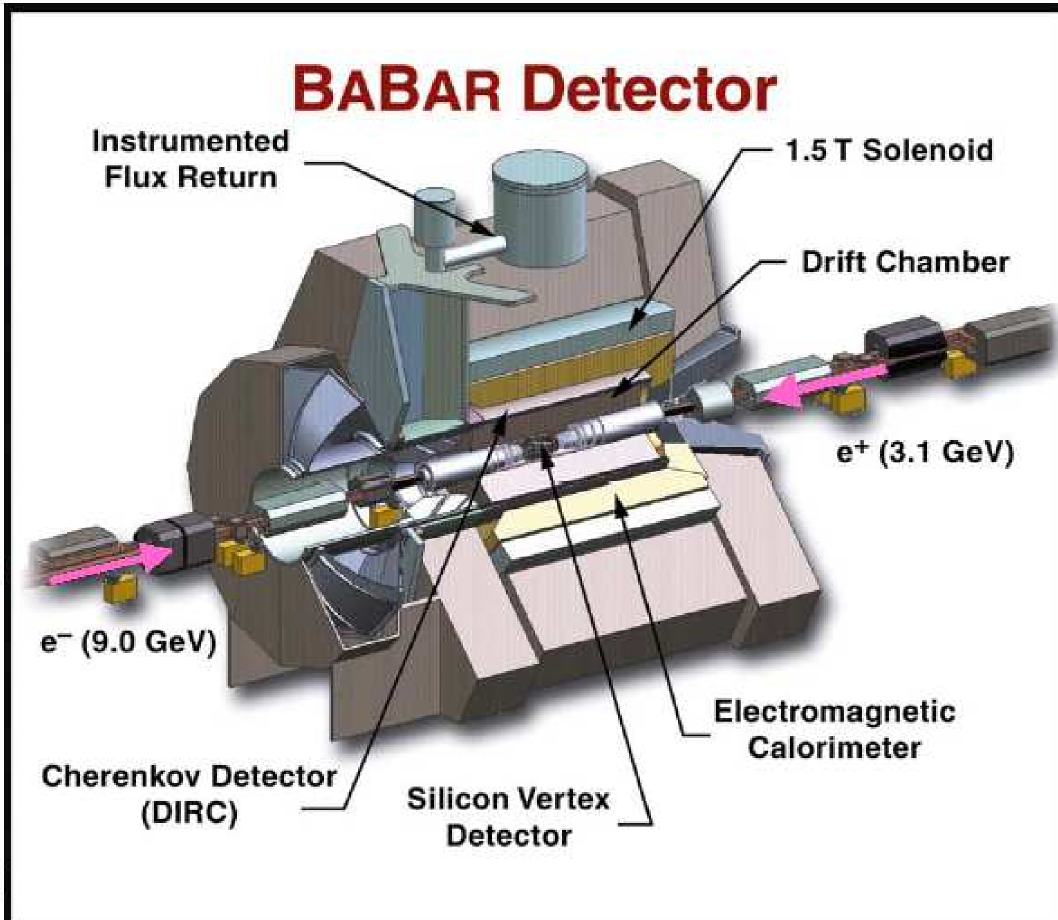
Up to 386M $B\bar{B}$ used

Apparatus

BaBar

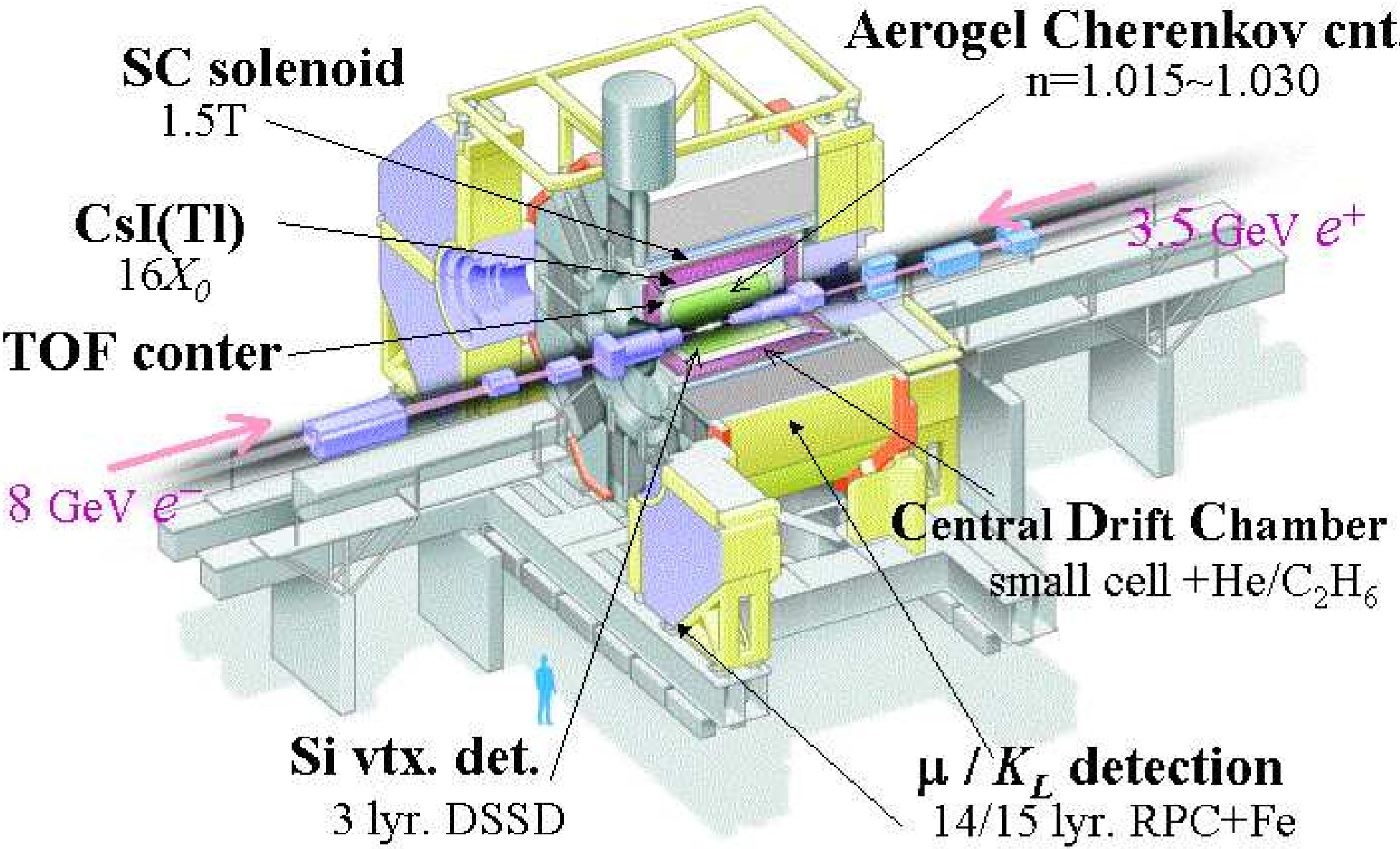
The detector

- SVT: 5 double side layers, 97% efficiency, 15 μm z hit resolution
- DCH : 40 axial and stereo layers
- Tracking: $\sigma(p_T)/p_T = 0.13\ \% \times p_T + 0.45\ \%$, $\sigma(z_0) = 65\mu$ @ 1 GeV/c
- DIRC: 144 quartz bars
- EMC: 6580 CsI(Tl) crystals $\sigma_E/E = 2.3\ \% \cdot E^{-1/4} \oplus 1.9\ \%$
- IFR: 19 RPC layers, muon and K_L id



Apparatus

Belle Detector



Introduction

- Particle detection & identification
- Background suppression
- Definition of direct CP violation

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

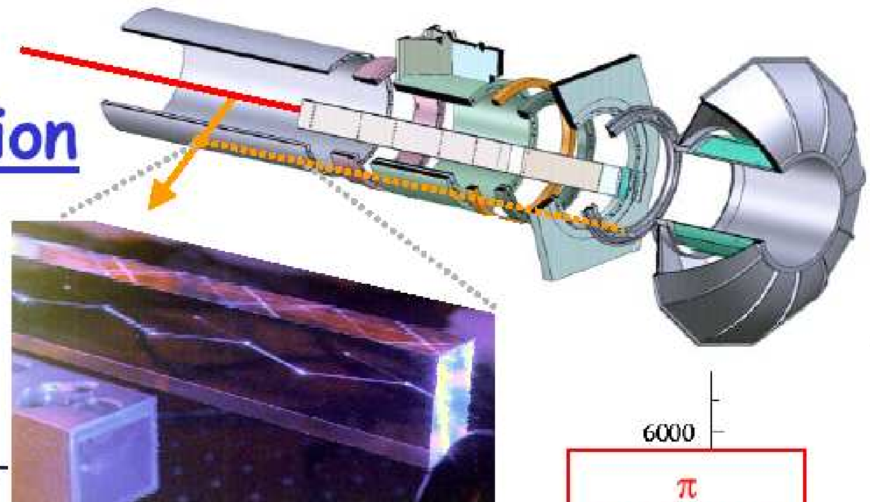
- $\mathcal{A}_{CP}$ extracted with Maximum-Likelihood fit on M_{bc}-ΔE or more variables

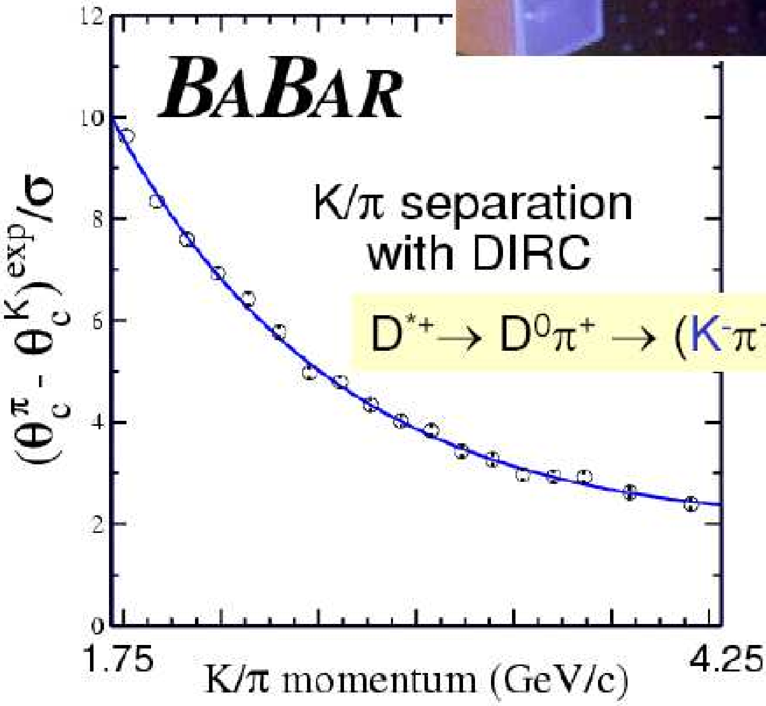
$$\mathcal{L} = \frac{e^{-\sum_b(\sum_j N_j)}}{N!} \times \prod_i [\sum_b (\sum_j N_j \cdot \mathcal{P}_j)]$$

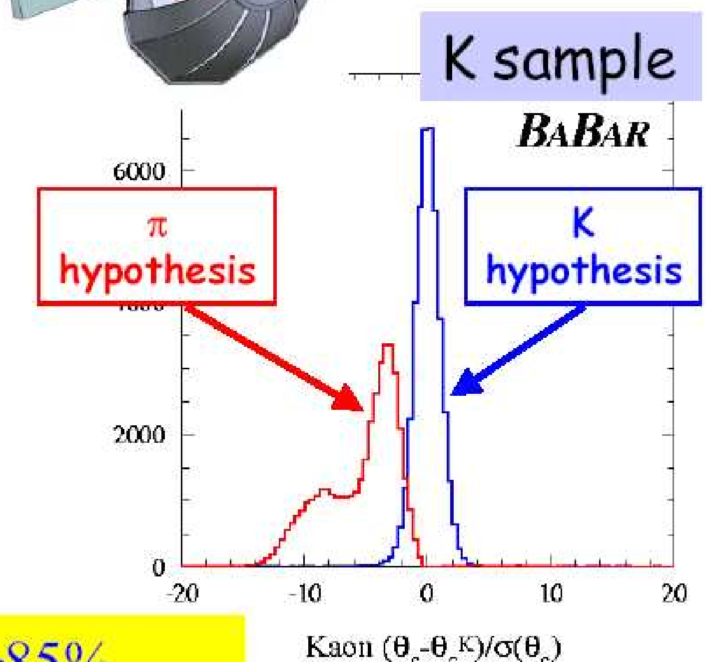
Particle Identification

BaBar

π-K separation







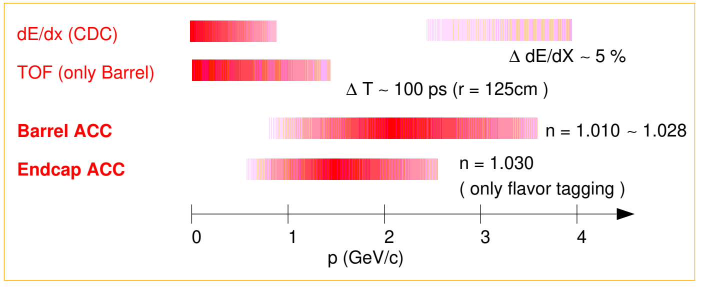
For $\varepsilon=85\%$

$P(K\to\pi)=1.7\%$

$P(\pi\to K)=2.7\%$

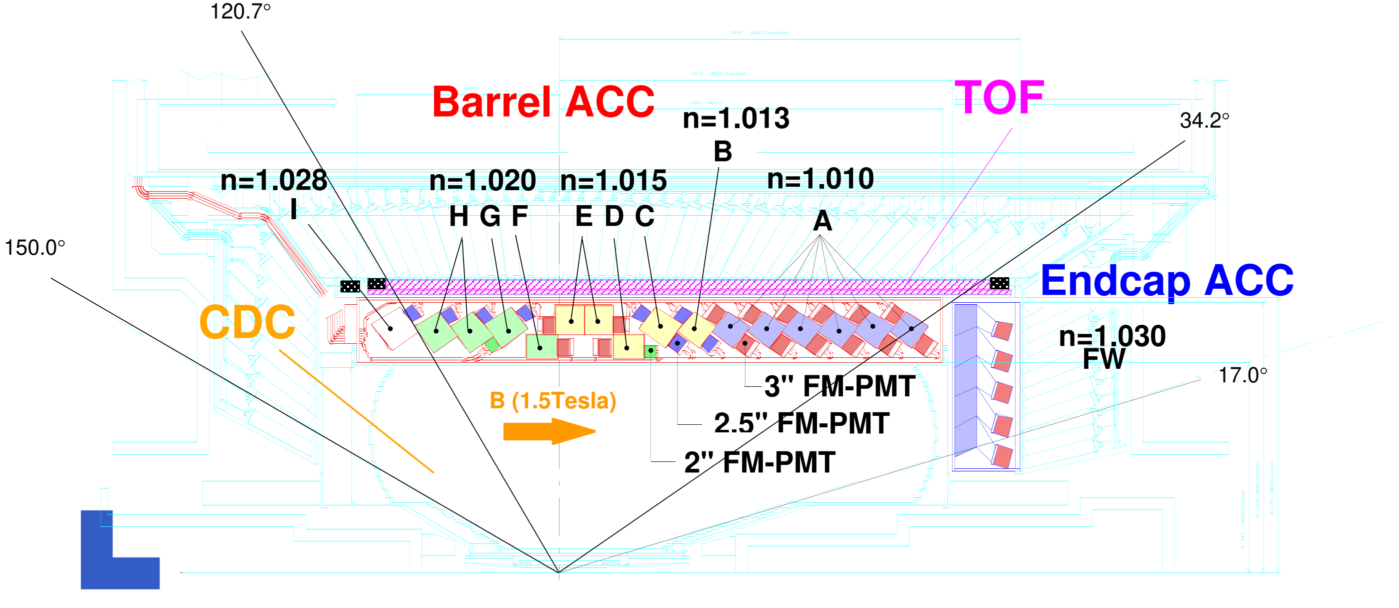
Particle Identification

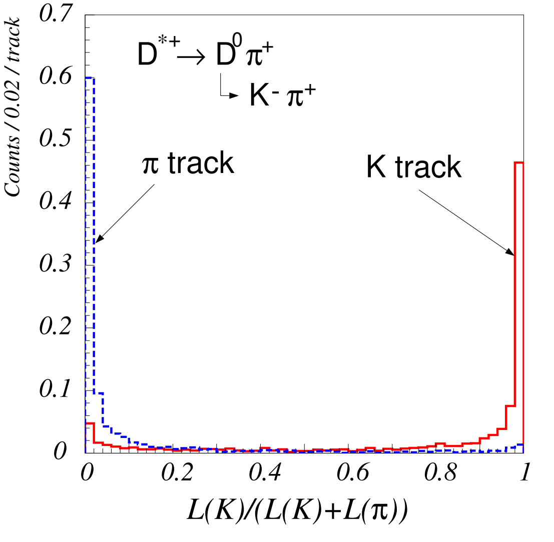
- Belle uses Aerogel+ToF+dE/dx information for particle ID
  - Wide momentum coverage
  - Info combined into likelihood
- Check high mom. performance with D^* samples



$$PID(K) = \frac{\mathcal{L}(K)}{\mathcal{L}(K)+\mathcal{L}(\pi)}$$

$$\epsilon : 80 \sim 90\%, f :\sim 5\%$$





Analysis Overview

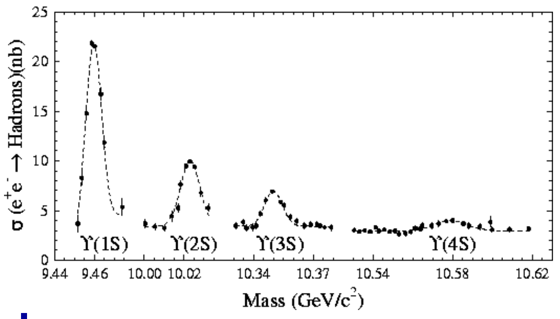
The M_{bc} and ΔE are important for B analysis in the $\Upsilon(4S)$ system.

- Beam constrained mass: $M_{bc} \equiv \sqrt{E_{beam}^{*2} - p_B^{*2}}$
  - BaBar uses a similar Energy Subsituded Mass
  - B mesons produced almost at rest
  - Precise beam energy known from accelerator
  - Much better resolution than invariant mass
- Energy difference: $\Delta E \equiv E_B^* - E_{beam}^*$
  - Energy of B candidates almost equal to half beam energy
  - Asymmetric shape and shift due to energy loss

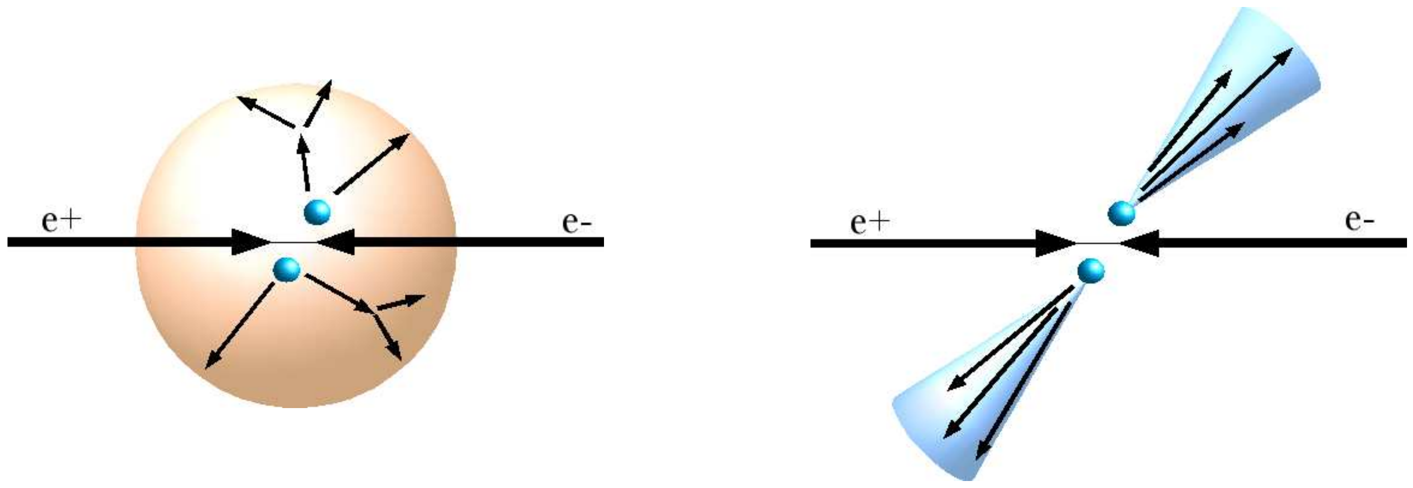
Introduction (Cont.)

Continuum suppression in this study

- Major background:
  $e^+ + e^- \to \gamma^* \to q\bar{q},\ (q = u, d, s, c)$



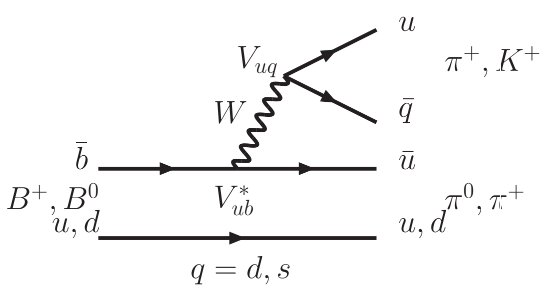
- Suppressed according to event topology



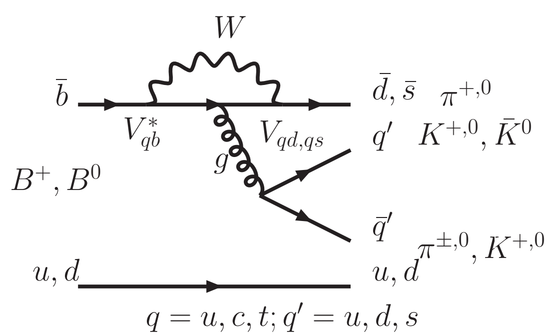
  - Modified Fox-Wolfram moments
  - Fisher's discriminent
  - Angular distribution: B flight direction

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

- Interference between 'Tree' & 'Penguin' processes.
  $\mathcal{B}(K^+\pi^-) = |T+P|^2$, $\mathcal{B}(K^-\pi^+) = |T'+P'|$



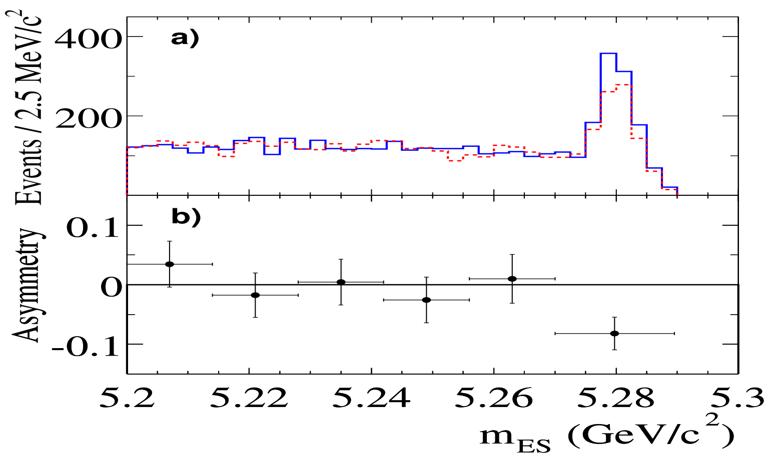
- ϕ_3 through $b \to u$ transition
  $$\mathcal{A}_{CP}(K^+\pi^-) = \frac{2|T||P|\sin\Delta\delta\sin\phi_3}{|T|^2+|P|^2+2|T||P|\cos\Delta\delta\cos\phi_3}$$
  $\Delta\delta$: strong phase diff.; ϕ_3: CKM angle (γ).

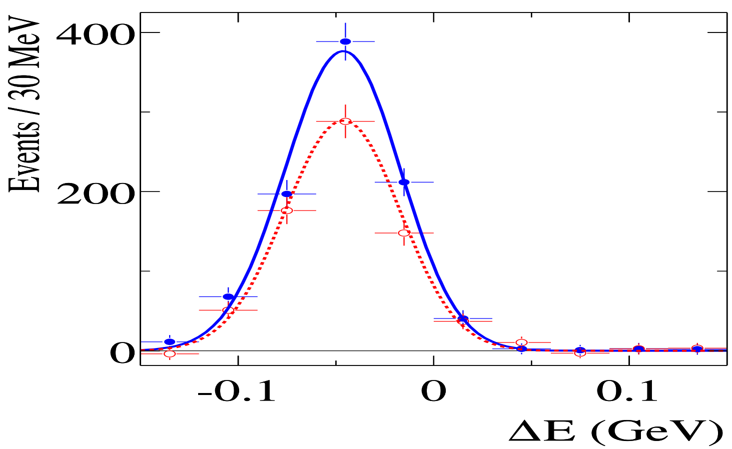


- Different theoretical predictions
  QCDF: $\mathcal{A}_{CP}(B \to K^+\pi^-) \sim 5 \pm 9\%$
  pQCD: $\mathcal{A}_{CP}(B \to K^+\pi^-) \sim -17 \pm 5\%$
  Y.-Y. Keum and A. I. Sanda, Phys. Rev. D **67**, 054009 (2003); M. Beneke *et al.*, Nucl. Phys. B **606**, 245-321 (2001); SCET.

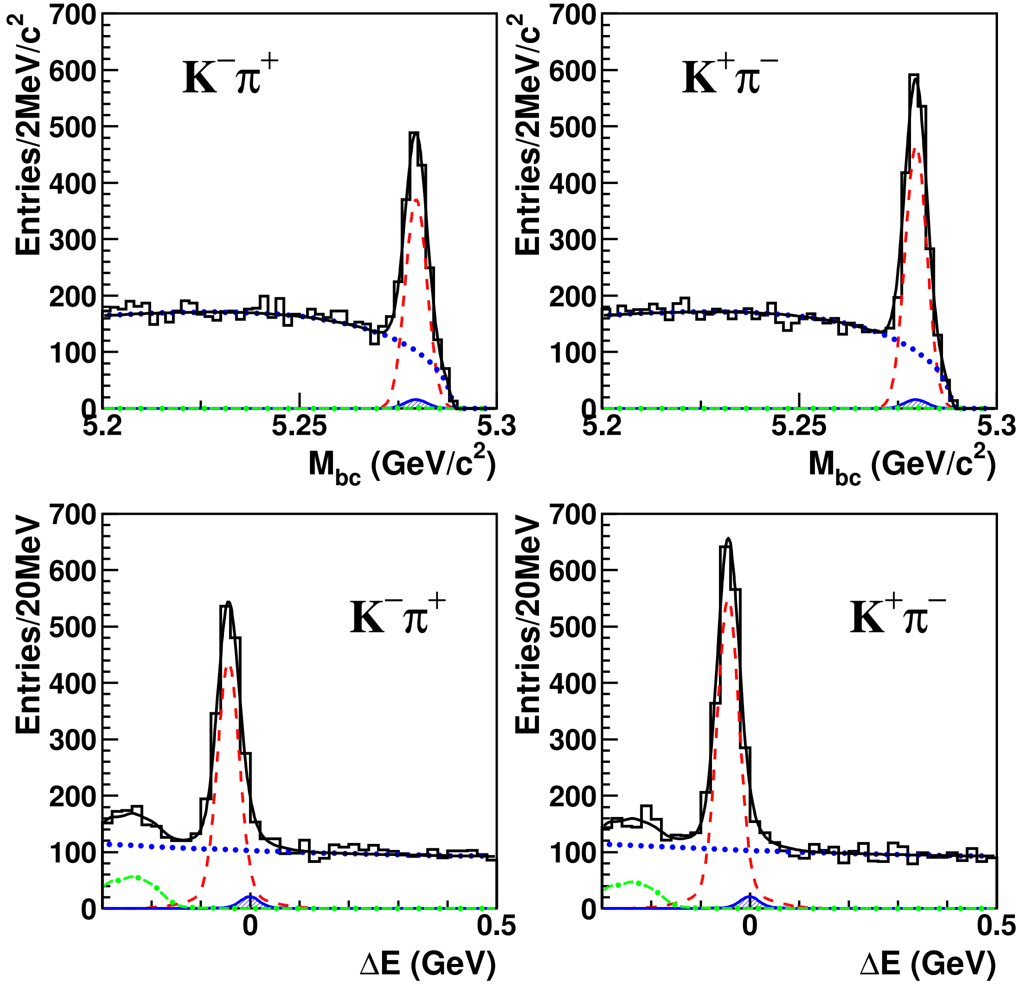
$\mathcal{A}_{CP}(B \to K\pi)$

BaBar 232M $B\overline{B}$



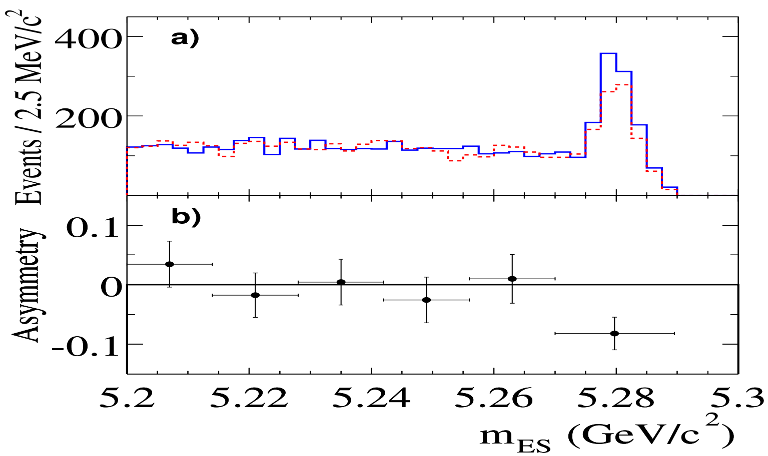


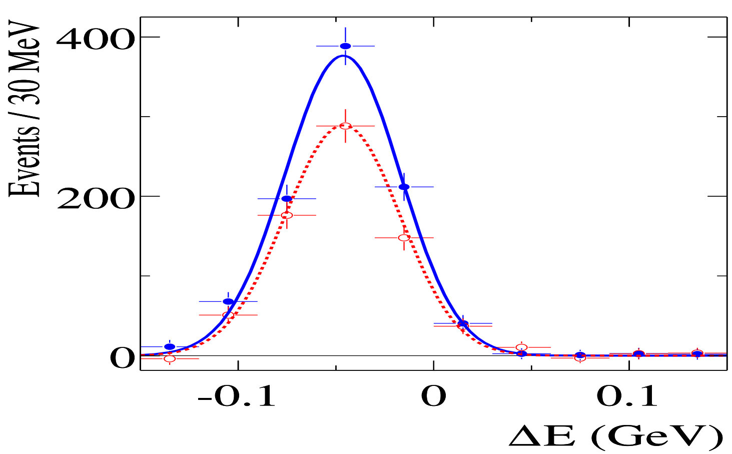
Belle 386M $B\overline{B}$



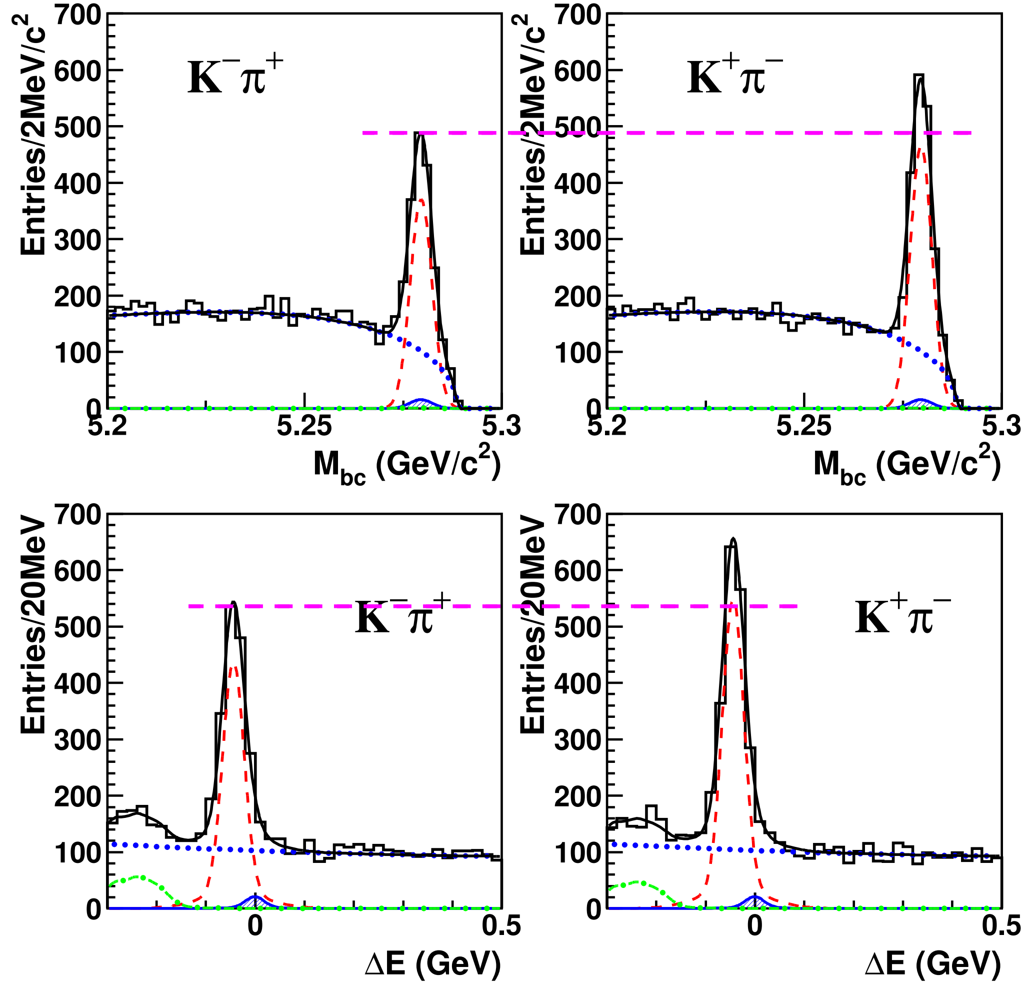
$\mathcal{A}_{CP}(B \to K\pi)$

BaBar 232M $B\overline{B}$





Belle 386M $B\overline{B}$



$\mathcal{A}_{CP}(B \to K\pi)$

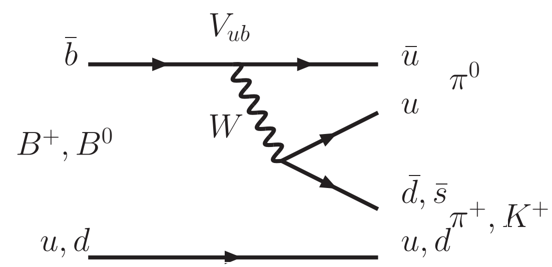
	Sig. Yield	Sig. $\mathcal{A}_{CP}$	Bkg. $\mathcal{A}_{CP}$	Sig.
BaBar (274M)	1606 ± 51	$-0.133 \pm 0.030 \pm 0.009$	-0.001 ± 0.008	4.2
Belle (386M)	3026 ± 63	$-0.113 \pm 0.022 \pm 0.008$	-0.001 ± 0.04	$\sim$5.0
CDF (355/pb)	2327 ± 77	$-0.058 \pm 0.039 \pm 0.007$	$S/N \simeq 6.5$ (peak)	—
World (HFAG)	—	-0.108 ± 0.017	—	—

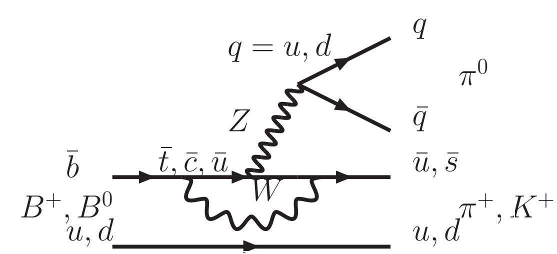
- Observation of direct CP violation in $B \to K^{\pm}\pi^{\mp}$
- Both restults consistent with each other.
- Theoretical interp. improved with NLO calculation
  - pQCD: $-10 \pm 8\%$
  - QCDF+SCET: $\sim -3.9\%$

(H.-N. Li, S. Mishima, hep-ph/0602214)

$B \to h^+\pi^0$

- $B \to K^+\pi^0$
  - $\mathcal{B}(K^+\pi^0) = |P + P_{\rm EW} + T + C|^2$ 'Electroweak penguin' and 'color-suppressed tree'
  - Theoretical predictions gives similiar asymmetry to $\mathcal{A}_{CP}(B \to K^+\pi^-)$
  - Difference seen in experimental results $\Rightarrow$ the $K\pi$ puzzle?
  - Recent theoretical works:
    - SCET
    - NLO on pQCD & QCDF
    - 4G?

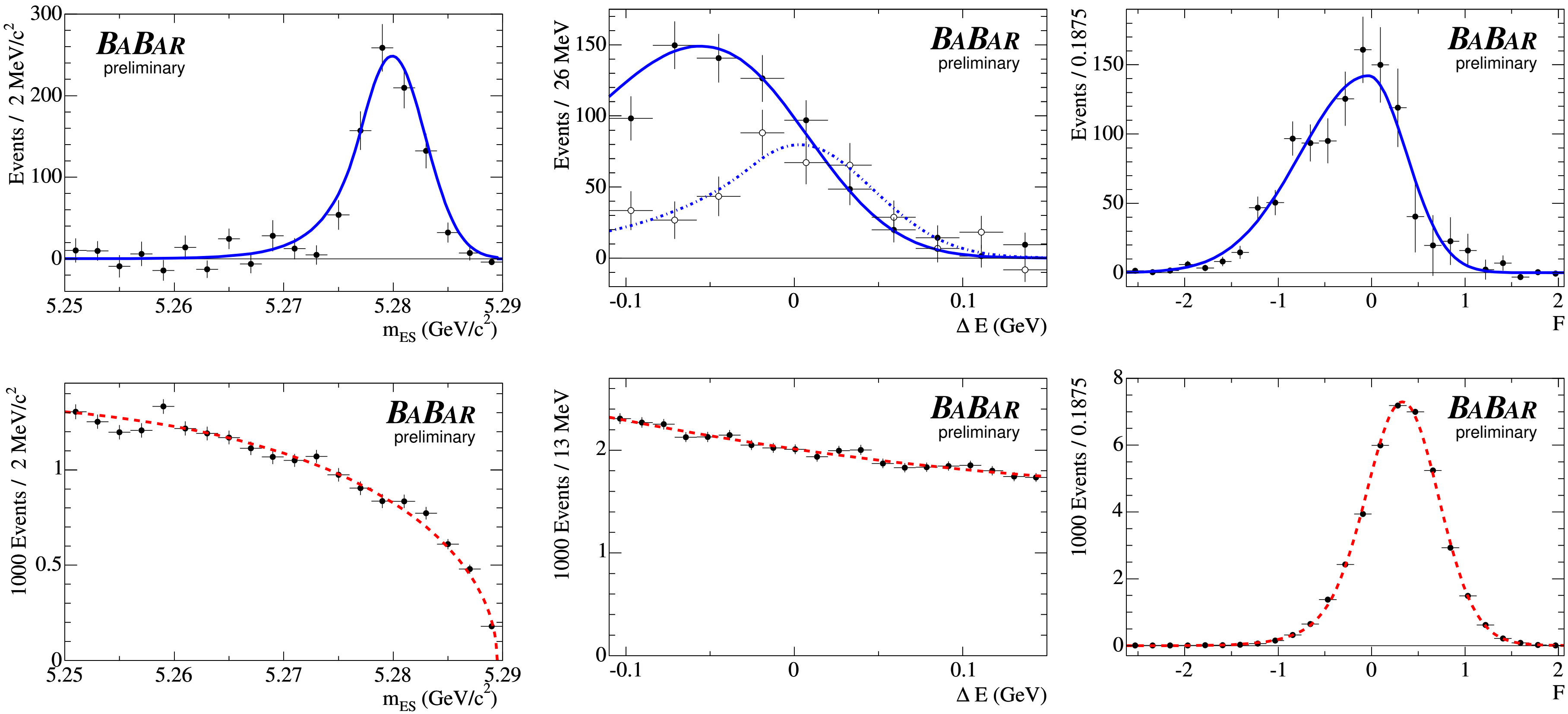




- $B \to \pi^+\pi^0$: null asym. expected

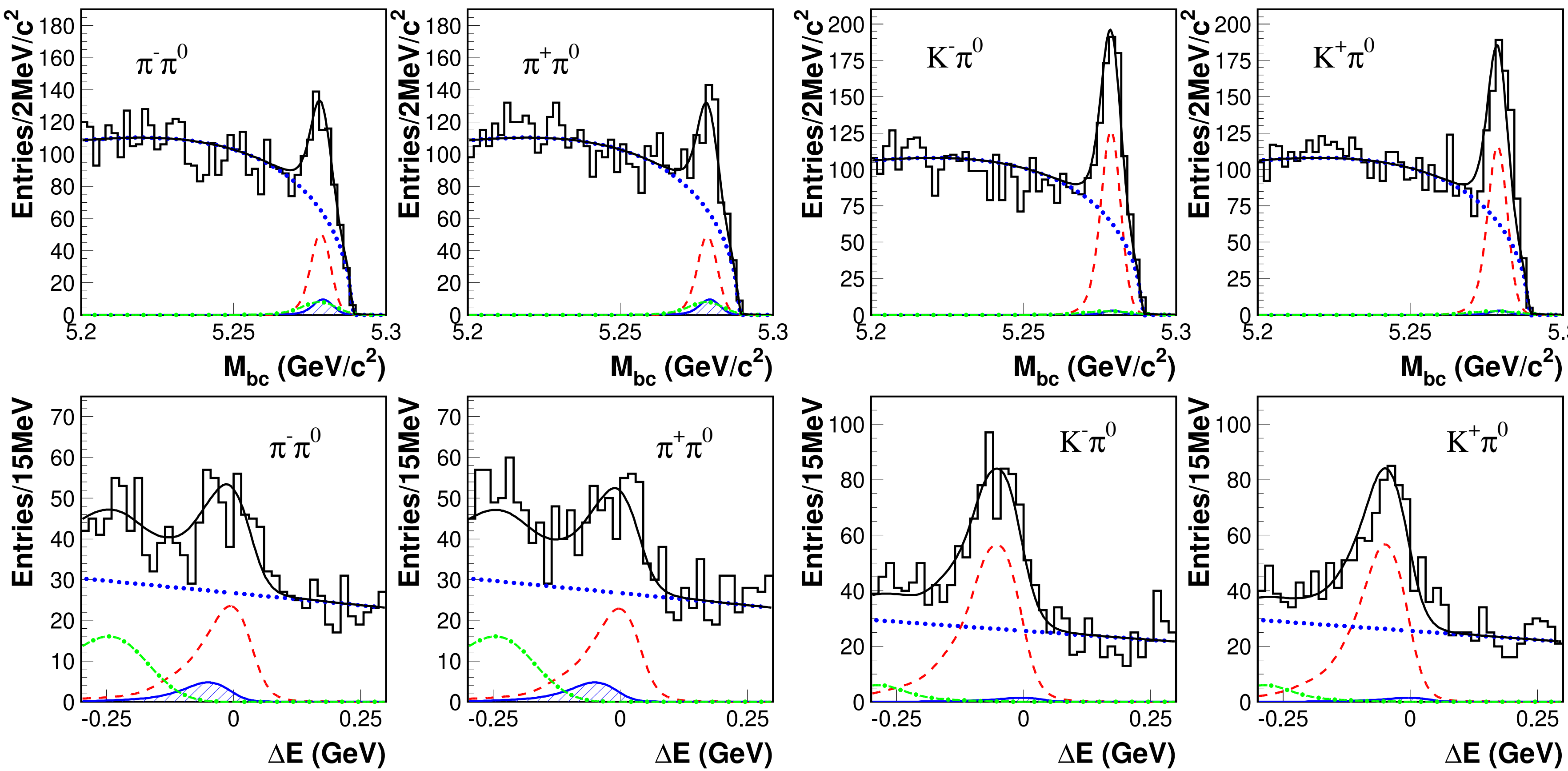
$\mathcal{A}_{CP}(B \to h\pi^0)$ BaBar (227M)

M_{ES} ΔE $\mathcal{F}$



$\mathcal{A}_{CP}(B \to h\pi^0)$ Belle (386M)

$\pi^\pm\pi^0$ $K^\pm\pi^0$



$\mathcal{A}_{CP}(B \to h\pi^0)$

	mode	Sig. Yield	Bkg. Yield	sig. $\mathcal{A}_{CP}$	bkg. $\mathcal{A}_{CP}$
BaBar	$K^\pm\pi^0$	682 ± 39	12483	$+0.06 \pm 0.06 \pm 0.01$	—
(227M)	$\pi^\pm\pi^0$	315 ± 29	29571	$-0.01 \pm 0.10 \pm 0.02$	—
Belle	$K^\pm\pi^0$	1084 ± 45	15698 ± 132	$+0.04 \pm 0.04 \pm 0.02$	-0.02 ± 0.01
(386M)	$\pi^\pm\pi^0$	454 ± 36	16457 ± 136	$+0.02 \pm 0.08 \pm 0.01$	-0.01 ± 0.01
World	$K^\pm\pi^0$	—	—	$+0.04 \pm 0.04$	—
(HFAG)	$\pi^\pm\pi^0$	—	—	$+0.01 \pm 0.06$	—

- A 3.1σ difference seen between $\mathcal{A}_{CP}(B \to K^+\pi^-)$ and $\mathcal{A}_{CP}(B \to K^\pm\pi^0)$; also seen by BaBar.
  $\Rightarrow$ world average combined $\Delta\mathcal{A}_{CP} > 3.8\sigma$
- Several improved theoretical efforts may explain this difference.

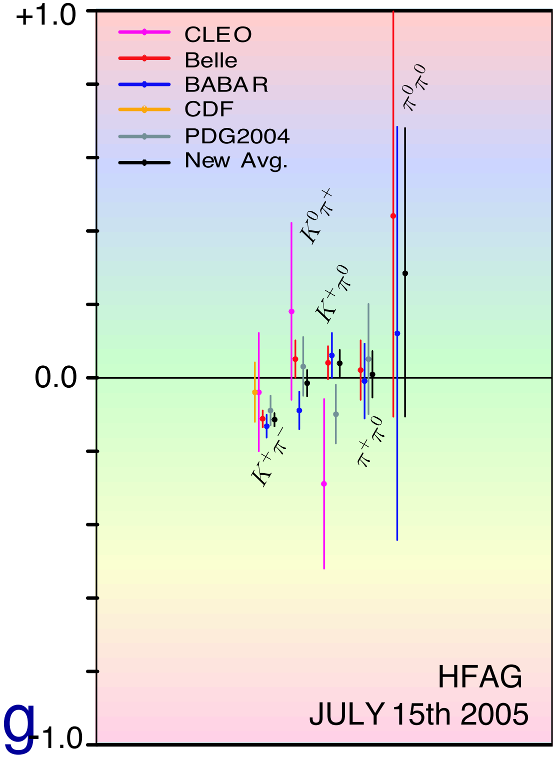
Summary on $B \to K\pi$

$\mathcal{A}_{CP}(\%)$	BaBar	Belle	World Avg.(HFAG)
$K^+\pi^-$	$-13.3 \pm 3.0 \pm 0.9$	$-11.3 \pm 2.2 \pm 0.8$	-10.8 ± 0.17
$K^+\pi^0$	$+6 \pm 6 \pm 1$	$+4 \pm 4 \pm 2$	$+4 \pm 4$
$\pi^+\pi^0$	$-1 \pm 10 \pm 2$	$-2 \pm 8 \pm 1$	$+1 \pm 6$

- Updated $\mathcal{A}_{CP}$ values for $B \to K^+\pi^-$, $B \to K^+\pi^0$ & $B \to \pi^+\pi^0$
  - Observation of $\mathcal{A}_{CP}(B \to K^+\pi^-)$ $\Rightarrow \sim 5.0\sigma$ significance
- $\mathcal{A}_{CP}(B \to K^+\pi^-) \not\approx \mathcal{A}_{CP}(B \to K^+\pi^0)$
  - Large contribution from CT or EWP?

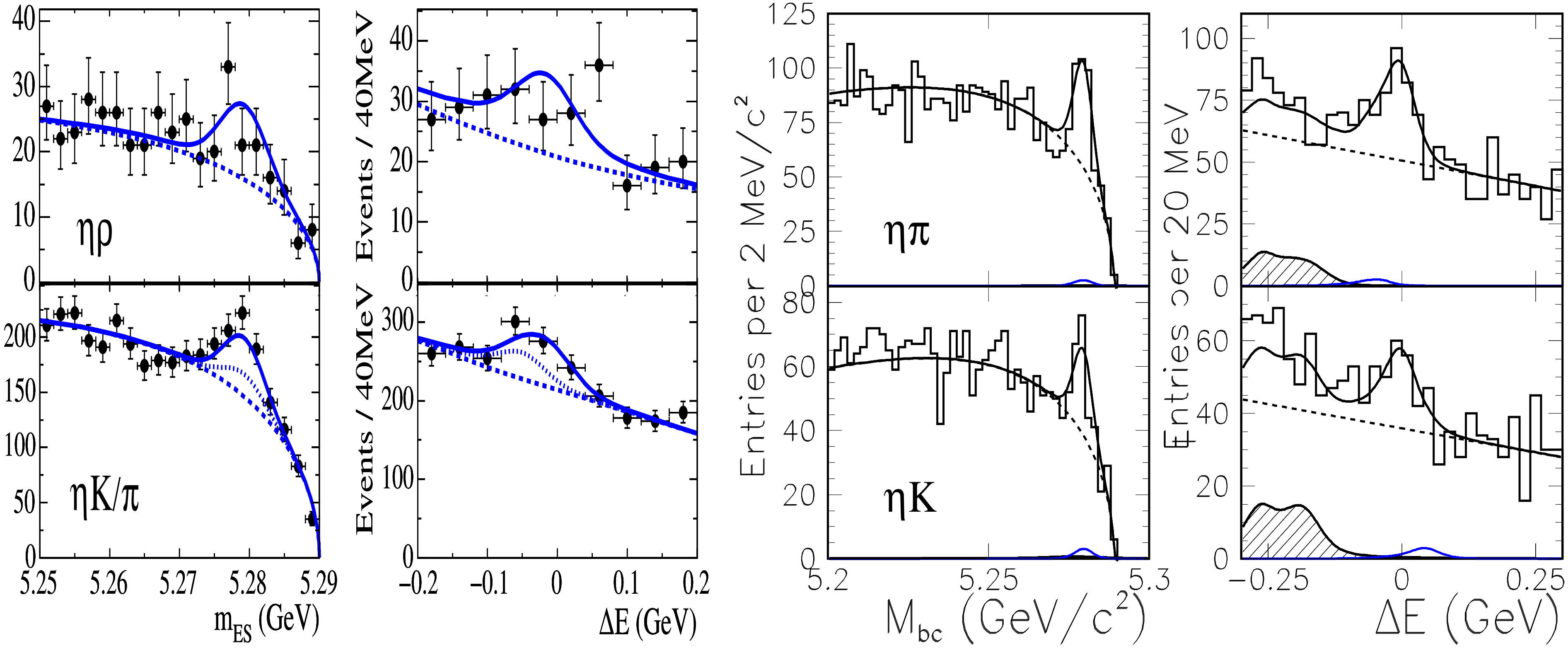
    ex. Gronau and Rosner
  - Needs more theoretical understanding

CP Asymmetry in Charmless B Decays



$\mathcal{A}_{CP}(B \to \eta K/\pi/\rho)$

BaBar 232M   Belle 386M



$\mathcal{A}_{CP}(B \to \eta K/\pi/\rho)$

Mode	BaBar	Belle	World Avg. (HFAG)
$B \to \eta K^+$	$-0.20 \pm 0.15 \pm 0.01$	$-0.55 \pm 0.19 \pm 0.04$	-0.33 ± 0.12
$B \to \eta \pi^+$	$-0.13 \pm 0.12 \pm 0.01$	$-0.10 \pm 0.11 \pm 0.02$	-0.11 ± 0.08
$B \to \eta \rho^+$	$+0.02 \pm 0.18 \pm 0.02$	$-0.17 \pm 0.33 \pm 0.02$ (old)	-0.03 ± 0.16

- Dataset used in this analysis
  - Babar: 232M $B\bar{B}$
  - Belle: 386M $B\bar{B}$ (new), 152M (old)
- Both $\eta \to \gamma\gamma, \pi^+\pi^-\pi^0$ used
- About 2.9σ non-zero $\mathcal{A}_{CP}$ seen in ηK by Belle, but only $\sim 1\sigma$ by BaBar
- Needs more statistics to clearify

$A_{CP}(B \to \eta' K/\pi)$

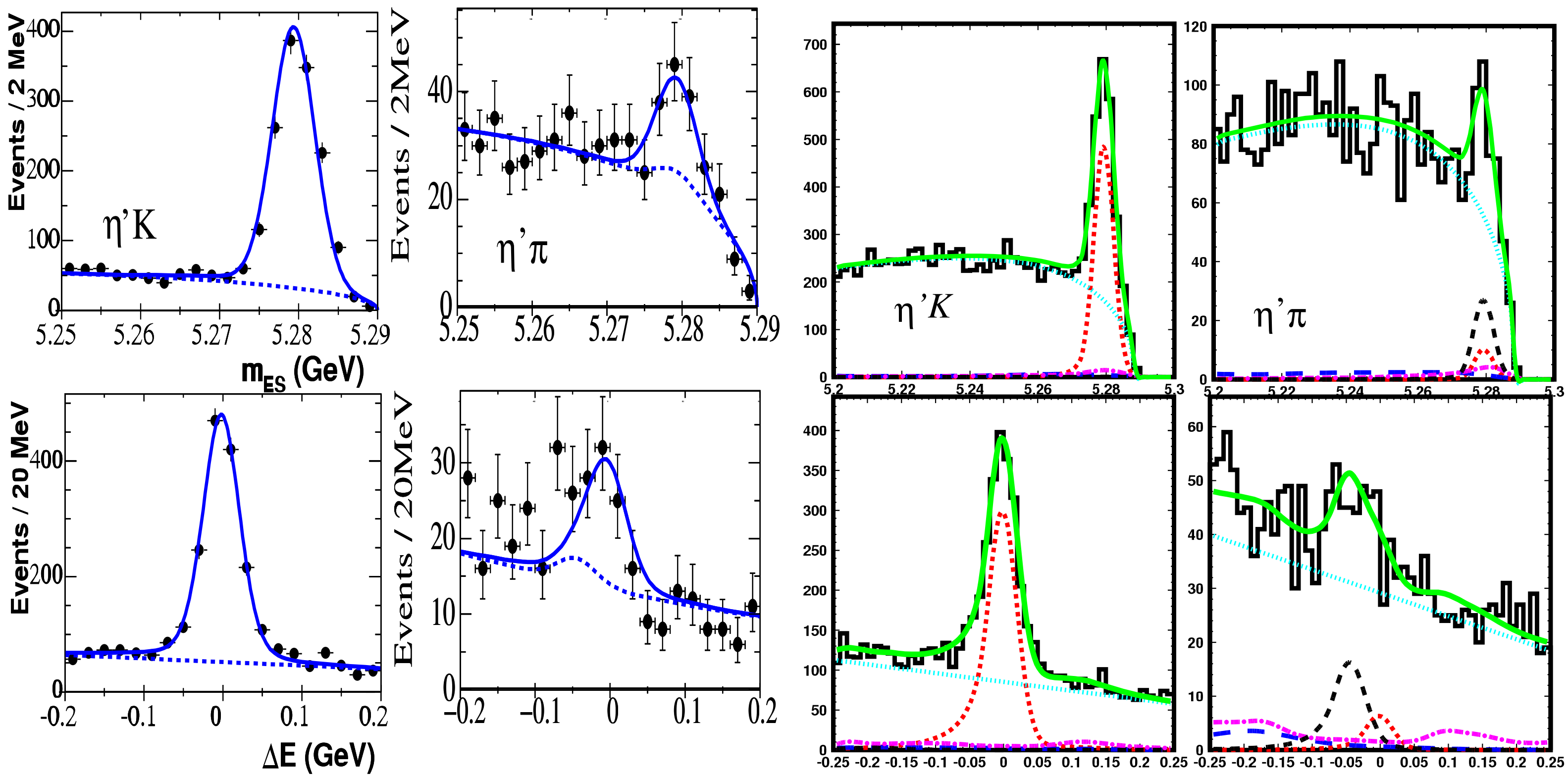
- Unexpectedly large BF first observed by CLEO ('97/98) and confirmed by Belle with 10/fb
- Present status:

BF(10^{-6})	CLEO(2000)	BaBar(2005)	Belle(2005)
$B \to \eta' K^+$	$80^{+10}_{-9} \pm 7$	$68.9 \pm 2.0 \pm 3.2$	$68.6 \pm 2.1 \pm 3.6$
$B \to \eta' K^0$	$89^{+18}_{-16} \pm 9$	$67.4 \pm 3.3 \pm 3.2$	$56.6 \pm 3.6 \pm 3.3$
$B \to \eta' \pi^+$	$1.0^{+5.8}_{-1.0}$	$4.0 \pm 0.8 \pm 0.4$	$1.73 \pm 0.69 \pm 0.10$

- Both BaBar and Belle updated in 2005
  - Babar: 232M $B\bar{B}$
  - Belle: 386M $B\bar{B}$, about 35 times more
- $B \to \eta' K^+$: penguin dominated, no DCPV expcted
- $B \to \eta' \pi^+$: both $T\&P$ contribute, possibly large DCPV

$\mathcal{A}_{CP}(B \to \eta' K/\pi)$

BaBar 232M Belle 386M



$\mathcal{A}_{CP}$	BaBar	Belle	World Avg. (HFAG)
$B \to \eta' K^+$	$+0.033 \pm 0.028 \pm 0.005$	$+0.029 \pm 0.028 \pm 0.021$	$+0.031 \pm 0.021$
$B \to \eta' \pi^+$	$+0.14 \pm 0.16 \pm 0.01$	$+0.15 \pm 0.38 \pm 0.06$	$+0.14 \pm 0.15$

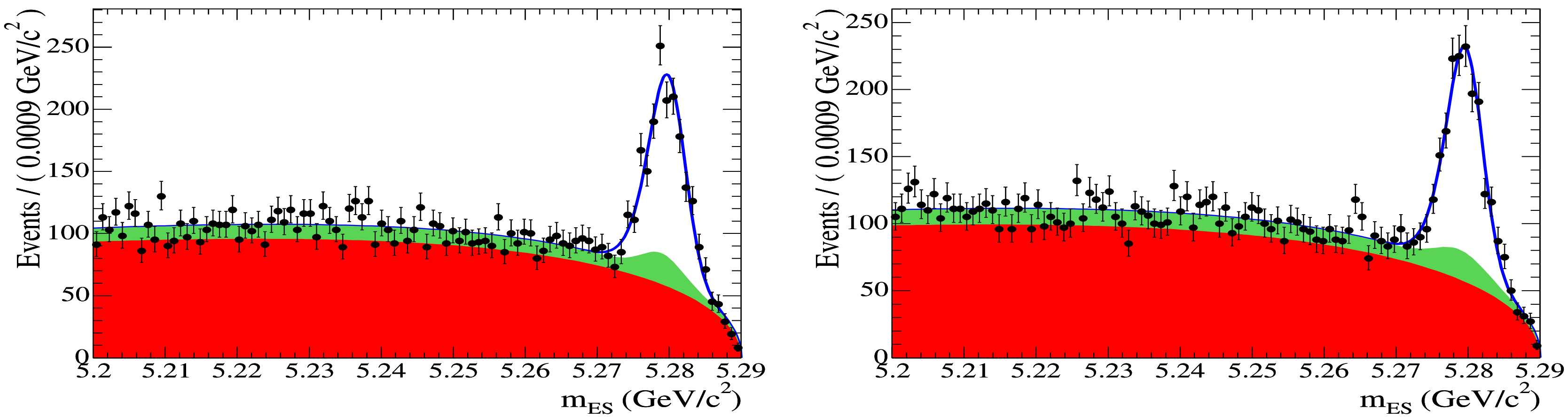
$\mathcal{A}_{CP}(B \to K^+\pi^+\pi^-)$

- Direct CP Violation in three-body decays
  - decay rates difference between B and $\bar{B}$
  - relative phases between two quasi-two-body amplitudes

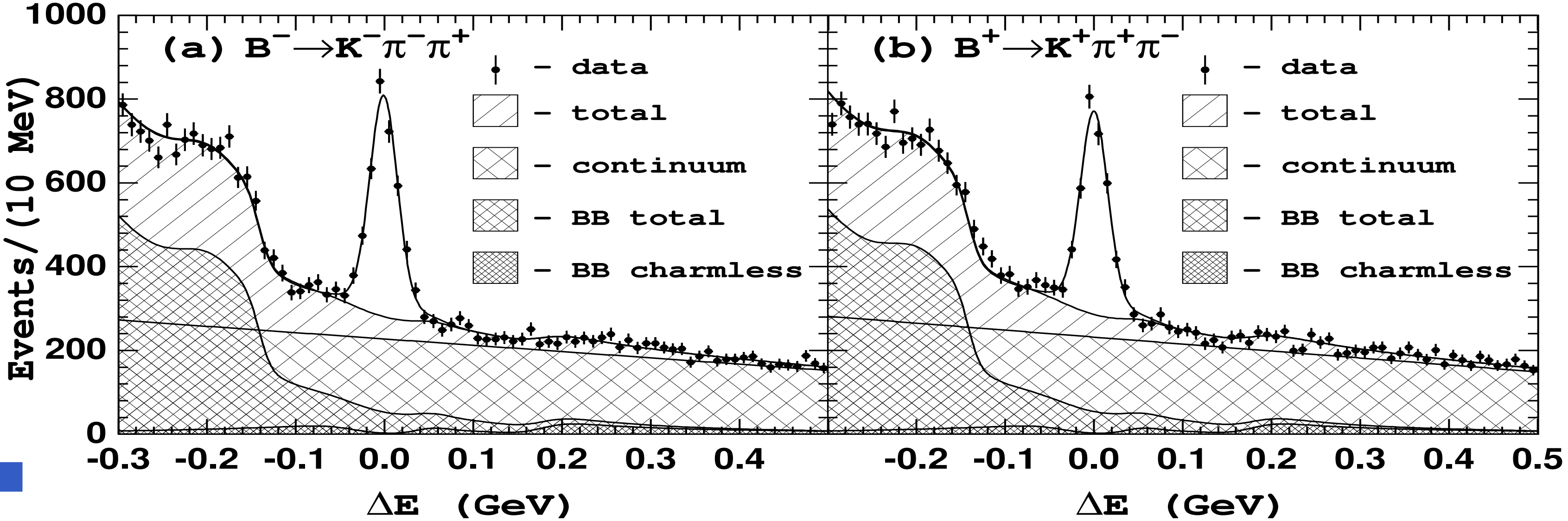
  $\Rightarrow$ Dalitz analysis needed
- Theoretical predictions: large DCPV in charmless three-body expected
  - M. Beneke $\&$ M. Neubert, Nucl. Pys. B 657, 333(2003)
  - C.-W. Chiang et al. Phys. Rev. D69, 0304001 (2004)
- Dataset: Babar: 226M $B\bar{B}$, Belle: 386M $B\bar{B}$

$\mathcal{A}_{CP}(B \to K^+\pi^+\pi^-)$

BaBar 226M

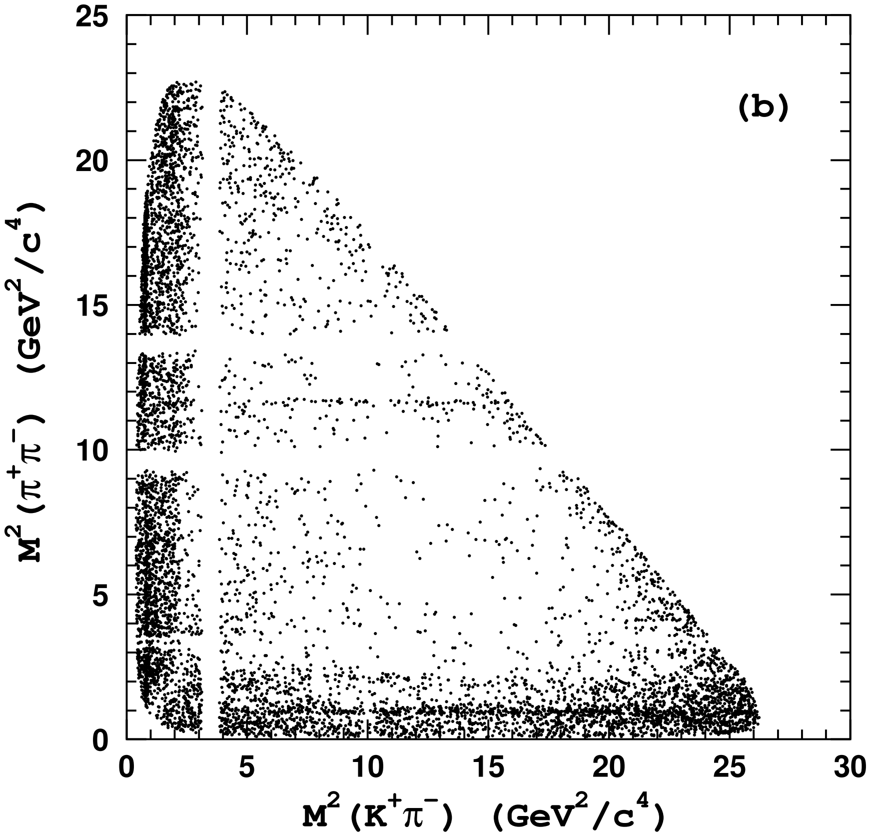


Belle 386M

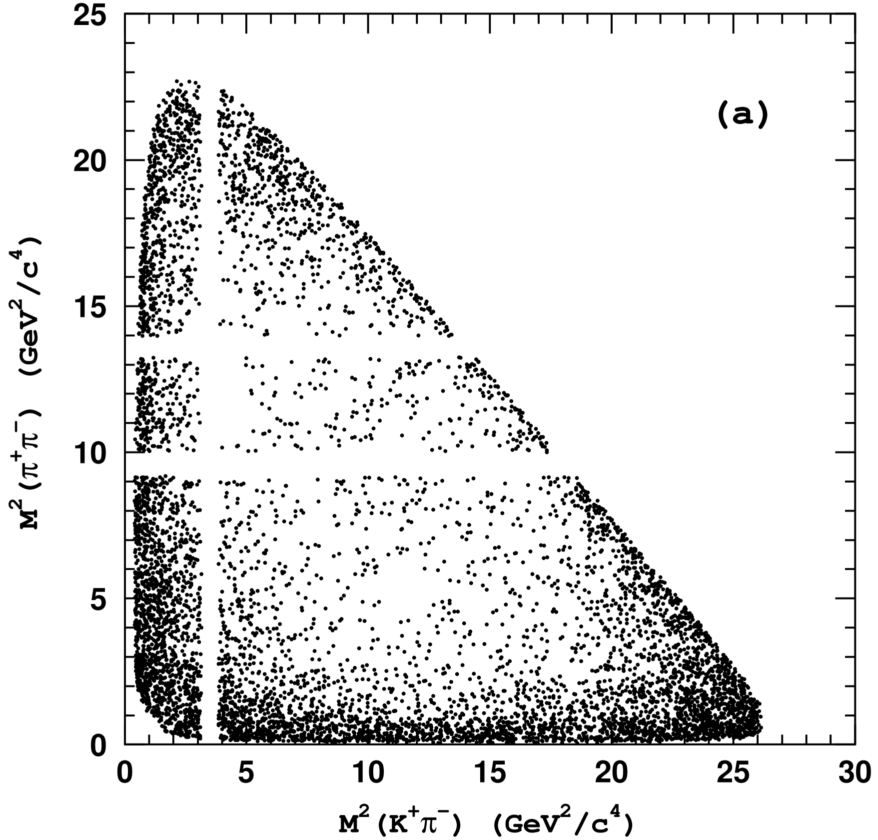


$\mathcal{A}_{CP}(B \to K^+\pi^+\pi^-)$

Dalitz Plot

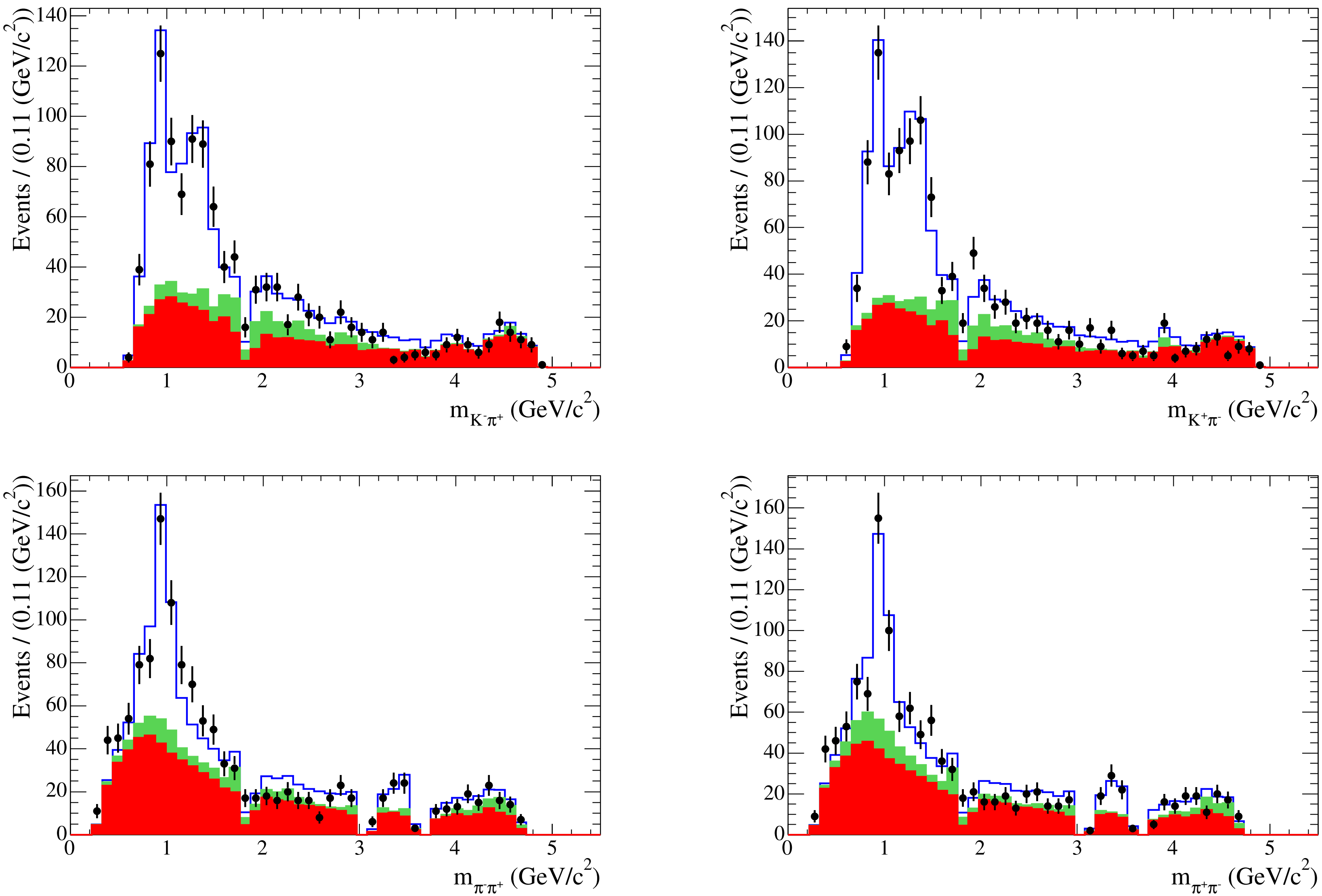


$(\Delta E - M_{\rm bc})$ signal region

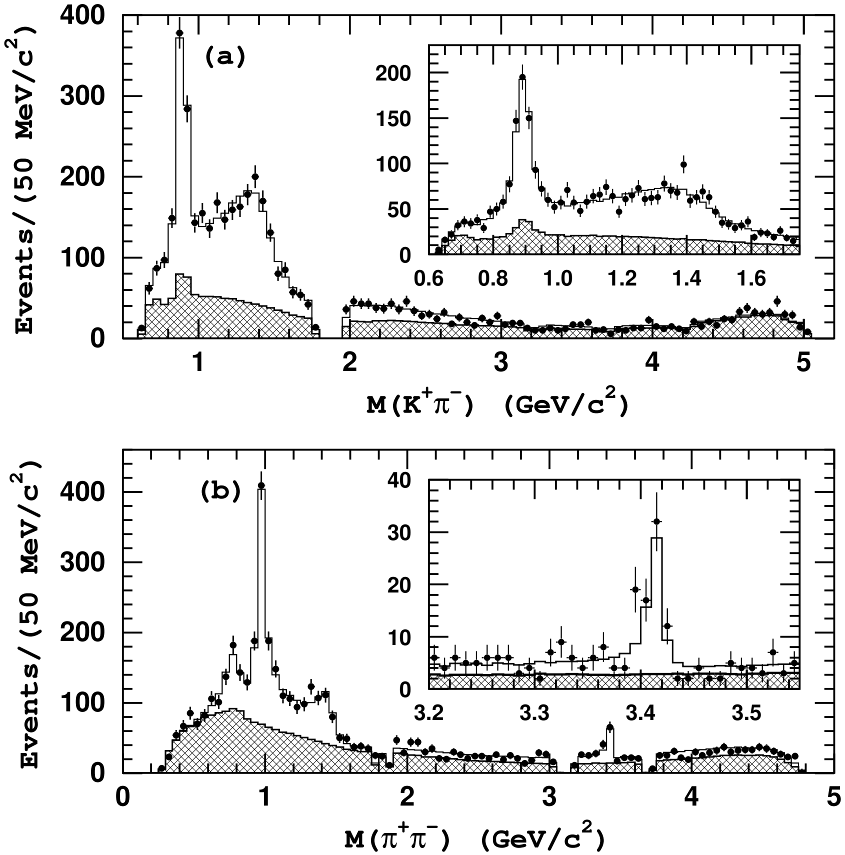


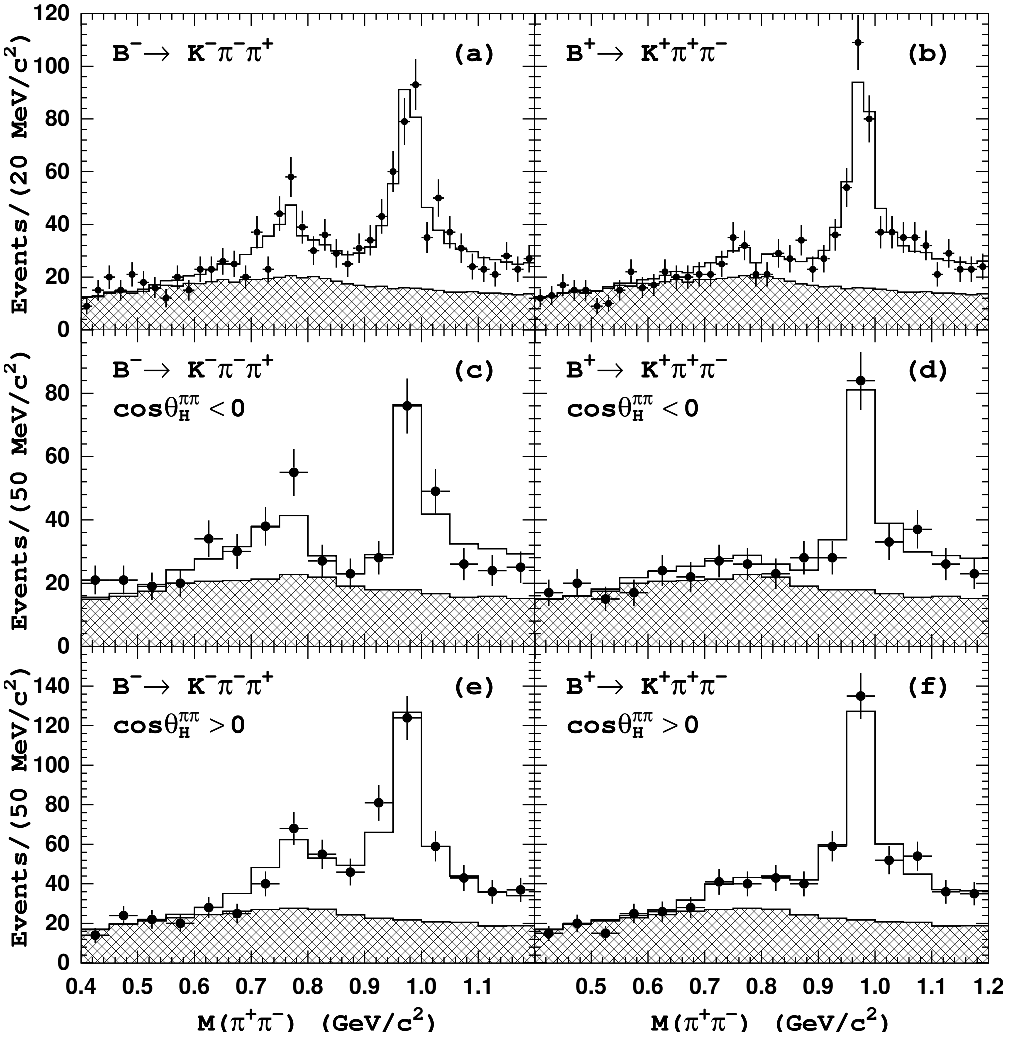
$(\Delta E - M_{\rm bc})$ sideband region

Inv. Mass Spectrum: BaBar (226M)



Inv. Mass Spectrum: Belle (386M)





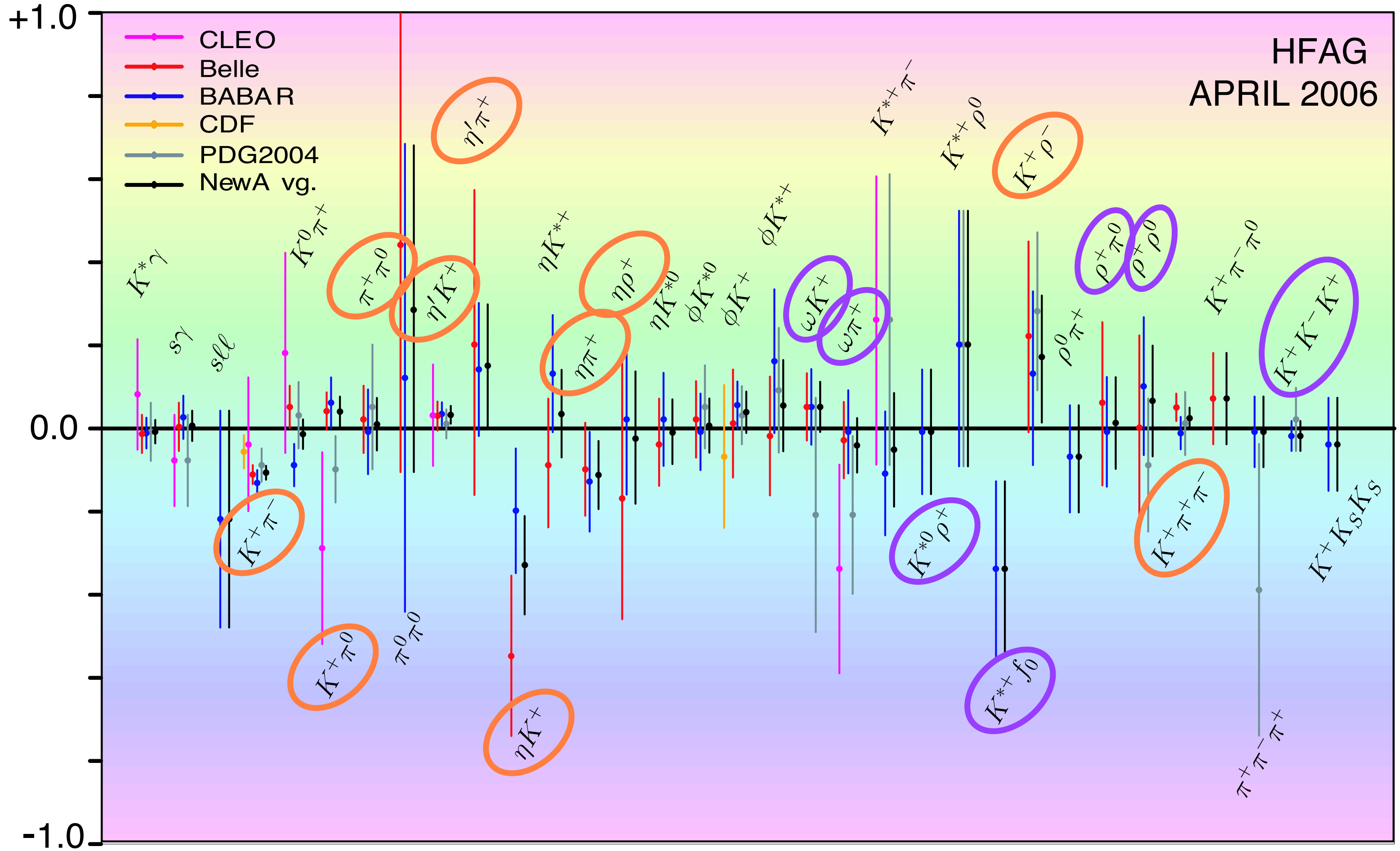
$\mathcal{A}_{CP}(B \to K^+\pi^+\pi^-)$

$\mathcal{A}_{CP}\%$	BaBar(226M)	Belle(386M)	World Avg. (HFAG)
$K^\pm\pi^\pm\pi^\mp$ tot.	$-1.3 \pm 3.7 \pm 1.1$	$+4.9 \pm 2.6 \pm 2.0$	$+2.2 \pm 2.9$
$K^*(892)\pi^\pm$	$+6.8 \pm 7.8 \pm 5.7^{+4}_{-3.5}$	$-14.9 \pm 6.4 \pm 2.0 \pm 0.8$	-9.3 ± 6.0
$K^*(1430)\pi^\pm$	$-6.4 \pm 3.2 \pm 2.0^{+1.1}_{-1.7}$	$+7.6 \pm 3.8 \pm 2.0 \pm 2.0$	$+1.9 \pm 3.7$
$\rho(770)K^\pm$	$+32 \pm 13 \pm 6^{+8}_{-5}$	$+30 \pm 11 \pm 2^{+11}_{-4}$	$+31^{+12}_{-11}$
$f_0(980)K^\pm$	$+8.8 \pm 9.5 \pm 2.6^{+9.3}_{-5.0}$	$-7.7 \pm 6.5 \pm 2.0^{+4.1}_{-1.6}$	$-2.0^{+6.8}_{-6.5}$
$f_2(1270)K^\pm$	—	$-59 \pm 22 \pm 2.0 \pm 3$	-59 ± 22
$\chi_{c0}K^\pm$	—	$-6.5 \pm 20 \pm 2^{+29}_{-14}$	—

- Large DCPV seen in $B \to \rho(770)K^\pm$
  - the first evidence by Belle
  - 3.9σ stat. significance ($3.7 \sim 4.0$ for diff. models)
- T-PS mode $B \to f_2(1270)K^\pm$ observed by Belle with stat. significance $> 6\sigma$ but only U.L. from BaBar

Summary & Conclusion

CP Asymmetry in Charmless B Decays



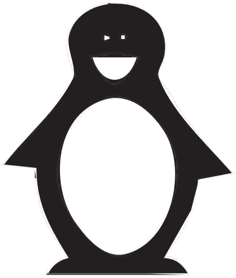
Please refer to Belle/BaBar hot topics and J. Smith's summary!

Summary & Conclusion (cont.)

- Observation of $\mathcal{A}_{CP}(B^0 \to K^+\pi^-)$
  - Belle found first evidence for DCPV in $B^0 \to \pi^+\pi^-$
  - No significant $\mathcal{A}_{CP}$ in other $B \to K\pi/\pi\pi$ seen yet.
- Evidence for $\mathcal{A}_{CP}(B^\pm \to \rho(770)K^\pm)$

  First evidence for large DCPV in a charged meson decay
- Still we need MORE statistics!
  - new datasets will be available soon

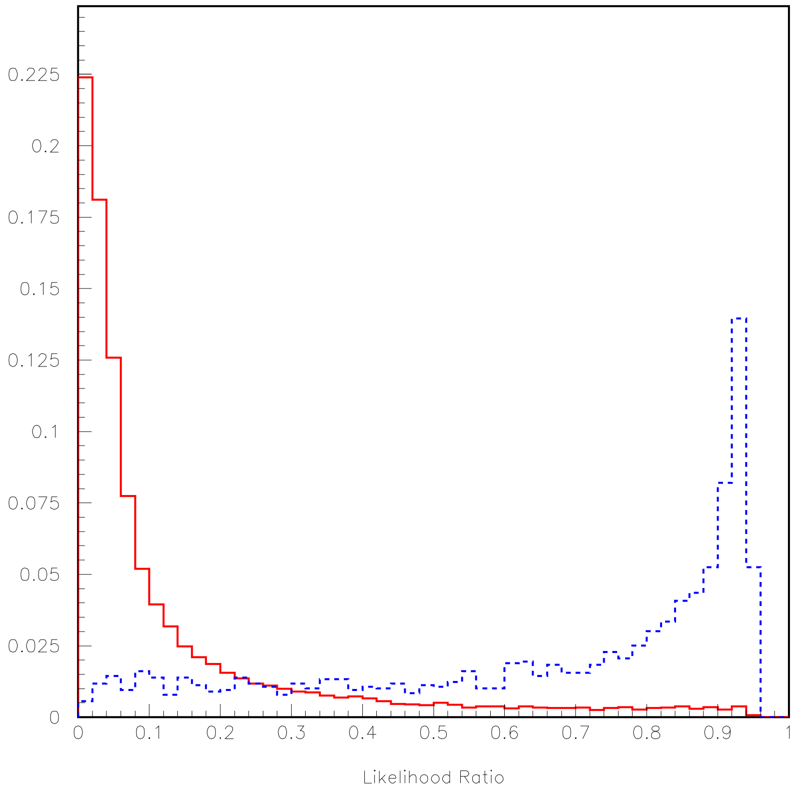
    $\Rightarrow$ Stay tuned for more new results in summer!



Backup Slides

Introduction (Cont.)

Likelihood Ratio



- Combining uncorrelated variables into a single value

$$R_{\mathcal{L}} = \frac{\mathcal{L}_s}{\mathcal{L}_s + \mathcal{L}_{q\bar{q}}}$$

- Continuum suppressed by direct cutting on LR
- Further suppression with the Belle Tagging information

Belle KID perfomance

- Used for correction on $\mathcal{A}_{CP}(B \to K\pi)$
- Studied with high mom. D^* tagged D samples
- Updated for both data set I and II

Data		$(+)$	$(-)$	$[(+)-(-)]/[(+)+(-)]$
Set I	$\epsilon(K)[\%]$	83.76 ± 0.18	84.76 ± 0.18	-0.57 ± 0.15
	$f(\pi)[\%]$	5.10 ± 0.12	5.69 ± 0.12	-5.01 ± 1.61
	$\epsilon(\pi)[\%]$	91.24 ± 0.15	90.53 ± 0.15	0.31 ± 0.12
	$f(K)[\%]$	10.72 ± 0.15	10.08 ± 0.15	3.25 ± 1.01
Set II	$\epsilon(K)[\%]$	81.92 ± 0.15	82.79 ± 0.14	-0.45 ± 0.13
	$f(\pi)[\%]$	6.29 ± 0.10	6.71 ± 0.10	-2.62 ± 1.13
	$\epsilon(\pi)[\%]$	89.88 ± 0.12	89.08 ± 0.13	0.39 ± 0.11
	$f(K)[\%]$	12.28 ± 0.12	1183 ± 0.12	1.67 ± 0.73