Direct CP violation and Charmless B decays at Belle

Paoti Chang

National Taiwan University

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Introduction

- Charmless B decays provide a rich ground to search for new physics and understand B decay mechanisms.
  - extract the angle ϕ_3/γ
  - New physics in electroweak penguins
    1. $\Delta A_{K\pi} = A_{CP}(K\pi^0) - A_{CP}(K\pi)$
    2. Ratios of branching fractions, i.e. Rc , Rn
- Update on branching fractions and direct CP asymmetries for $B \to hh$ and ηh (h= K or π) with the final dataset of 772 M $B\bar{B}$ pairs and improved tracking.

Analysis Strategy

- Distinguish charged K and π mesons using Belle PID

  Typical eff. is 84% (89%) for $K(\pi)$, fake rate is 7% (11%)

- Identify K^0 from $K_S \to \pi^+\pi^-$, π^0 via $\pi^0 \to \gamma\gamma$ and η meson from $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$

- Identify B candidates with M_{bc} (M'_{bc} for $\gamma\gamma$) and ΔE

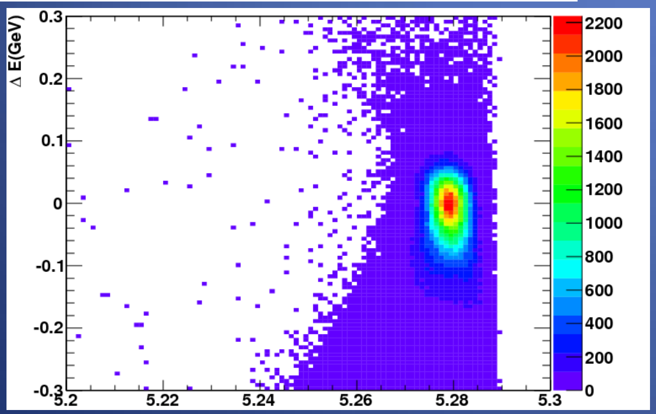
$$\Delta E = E_B - E_{beam}$$

$$M_{bc} = \sqrt{E_{beam}^2 - |\overrightarrow{P}_B|^2}$$

M'_{bc} is computed by changing the $\gamma\gamma$ momentum such that $\Delta E = 0$

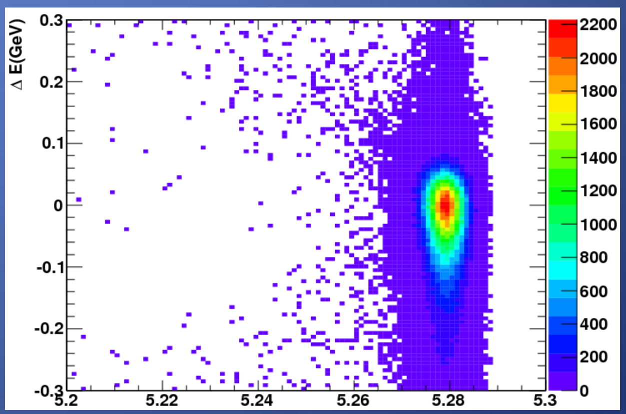
$K^+\pi^0$ MC

ΔE



M_{bc}

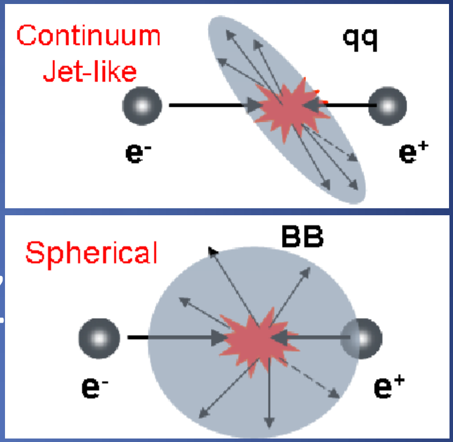
ΔE



M'_{bc}

Signal-background likelihood ratio

- Distinguish signals and continuum background using shape variables, which are combined into a variable called KSFW, as well as $\cos\theta_B$ and ΔZ

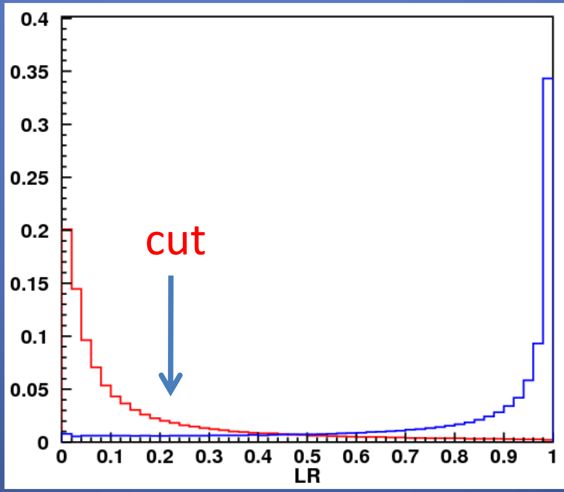


- Form Sig. Bkg. likelihood ratio

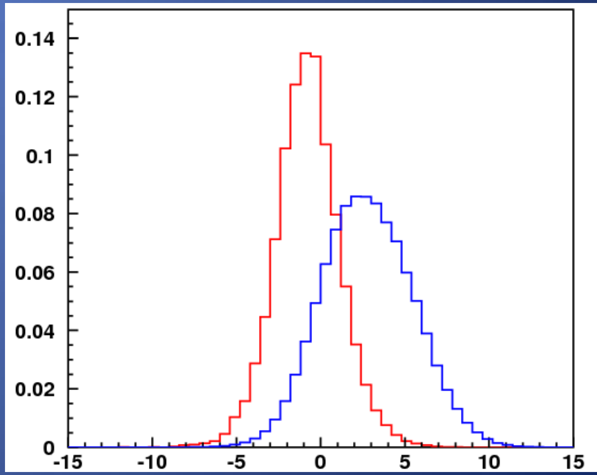
$$R = \frac{L_S}{L_S + L_B}$$

- cut at 0.2
- Define R'

$$R' = \ln\left(\frac{R - 0.2}{1.0 - R}\right)$$



R



R'

Signal Extraction

- Perform M_{bc}-ΔE-R' unbinned likelihood fit to extract signal yields and CP asymmetries.

$$\mathcal{L} = e^{-\sum_j N_j} \times \prod_i \left(\sum_j N_j \mathcal{P}_j^i\right) \quad \text{and}$$

$$\mathcal{P}_j^i = \frac{1}{2}[1 - q^i \cdot A_{CPj}] P_j(M_{\rm bc}^i, \Delta E^i, \mathcal{R}'^i)$$

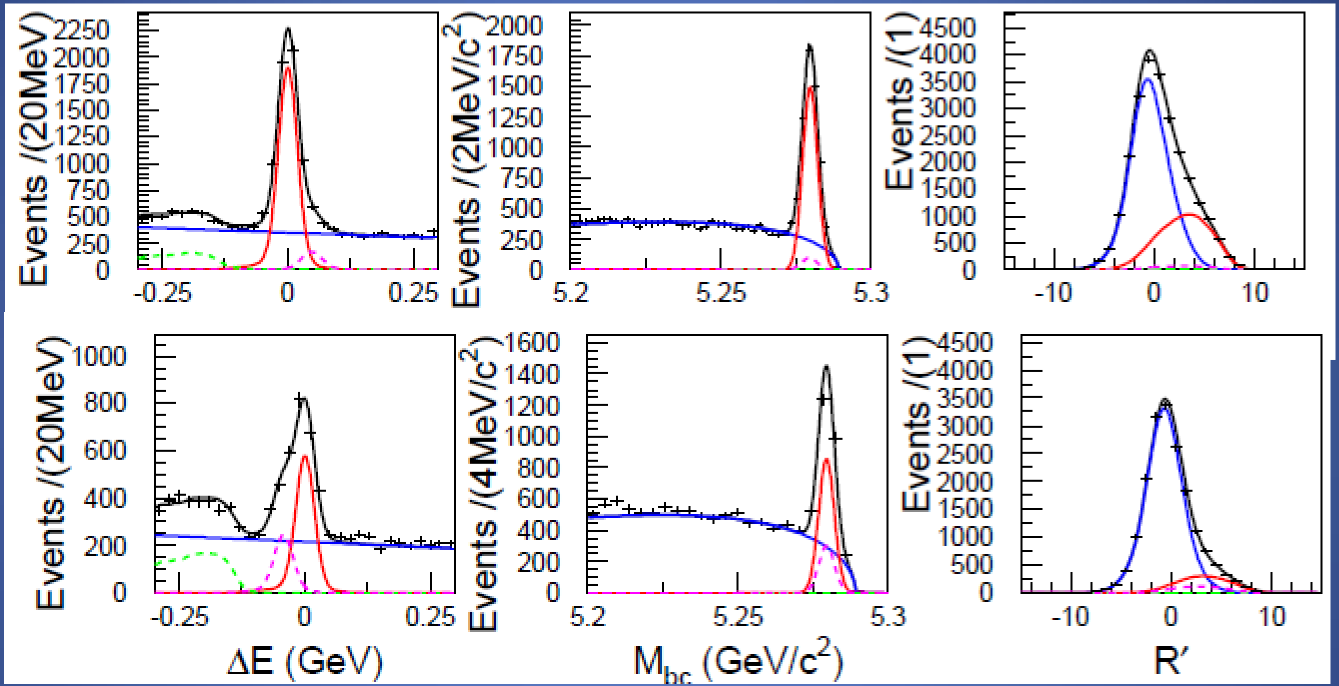
- Simultaneous fit for the $hK^{\pm}$ and $h\pi^{\pm}$ modes.
- Rare B background PDFs are from large MC samples.
- Parameters of continuum PDFs are floated.

Preliminary

$B^0 \to K^{\pm}\pi^{\mp}, \pi^+\pi^-$

$K^{\pm}\pi^{\mp}$

$\pi^+\pi^-$



- $B \to K\pi$

$N = 7527 \pm 127$

$\mathcal{B} = (20.00 \pm 0.34 \pm 0.63) \text{x} 10^{-6}$

$A_{CP} = (-0.069 \pm 0.014 \pm 0.007)$

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

$N = 2111 \pm 89$

$\mathcal{B} = (5.04 \pm 0.21 \pm 0.19) \text{x} 10^{-6}$

How the $A_{CP}(K\pi)$ central value changed since the last Belle measurement?

- A_{CP}= (-0.069±0.014 ±0.007) for 772 M $B\bar{B}$

  A_{CP}= (-0.094±0.018 ±0.008) for 535 M $B\bar{B}$

  Nature 452, 332 (2008)
- The last data set with 237 x10^6 $B\bar{B}$ pairs has a central value closer to zero.
- Most of the dataset has been reprocessed with improved tracking.

	$N_{B\bar{B}}$ (10^6)	N_{sig}	A_{CP}
Old tracking	535	4097	-0.094 ± 0.018
New tracking	535	5066	
New tracking	237	2459	-0.041 ± 0.023
New tracking	772	7527	-0.069 ± 0.014

Consistent $A_{CP}(K\pi)$ results

Belle: $-0.069 \pm 0.014 \pm 0.007$ This meeting

BaBar: $-0.107 \pm 0.016 ^{+0.006}_{-0.004}$ arXiv:0807.4226

CDF: $-0.086 \pm 0.023 \pm 0.009$ PRL 106, 181802 (2011)

LHCb: $-0.074 \pm 0.033 \pm 0.008$ arXiv: 1106.1197

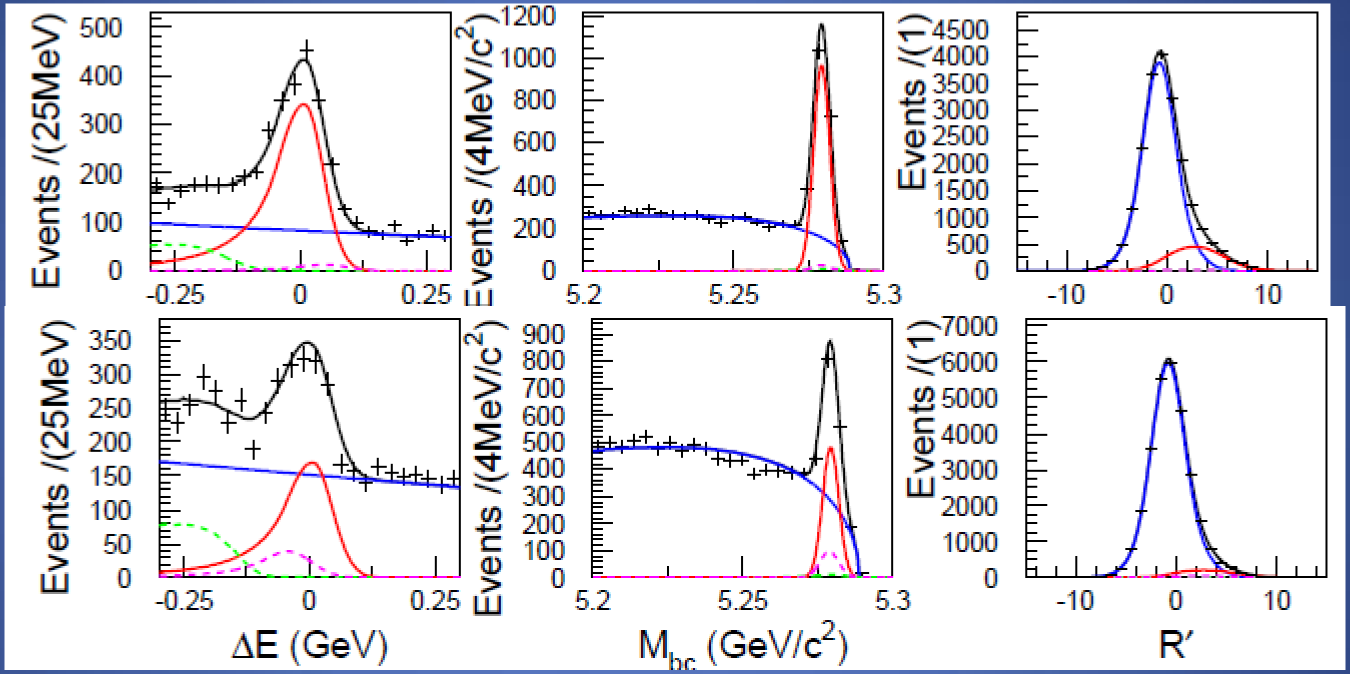
My average: $A_{CP}(K\pi) = -0.085 \pm 0.010$

Preliminary

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

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

$\pi^{\pm}\pi^{0}$



- $K^{\pm}\pi^{0}$:

  $N = 3731 \pm 92$

  $\mathcal{B} = (12.62 \pm 0.31 \pm 0.56) \times 10^{-6}$

  $A_{CP} = +0.043 \pm 0.024 \pm 0.002$

- $\pi^{\pm}\pi^{0}$:

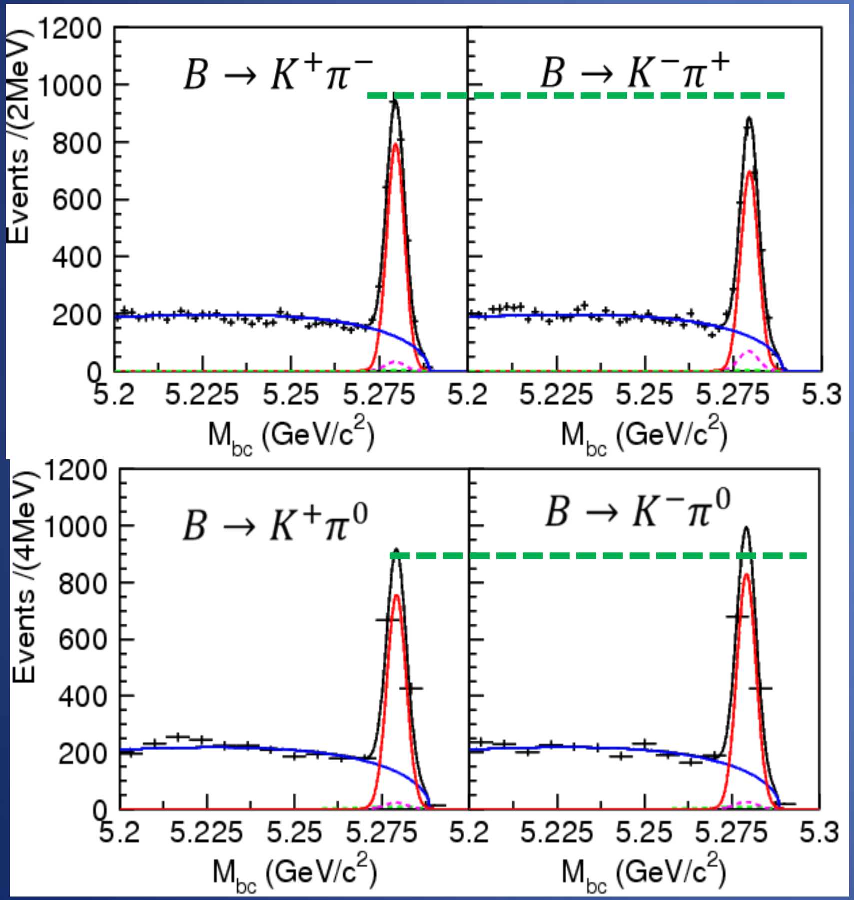
  $N = 1846 \pm 82$

  $\mathcal{B} = (5.86 \pm 0.26 \pm 0.38) \times 10^{-6}$

  $A_{CP} = +0.025 \pm 0.043 \pm 0.007$

Preliminary

$\Delta A_{K\pi} = A_{CP}(K\pi^0) - A_{CP}(K\pi)$



Belle Nature paper:

$\Delta A_{K\pi} = +0.164 \pm 0.037$ @4.4σ

Belle preliminary:

$\Delta A_{K\pi} = +0.112 \pm 0.028$ @4σ

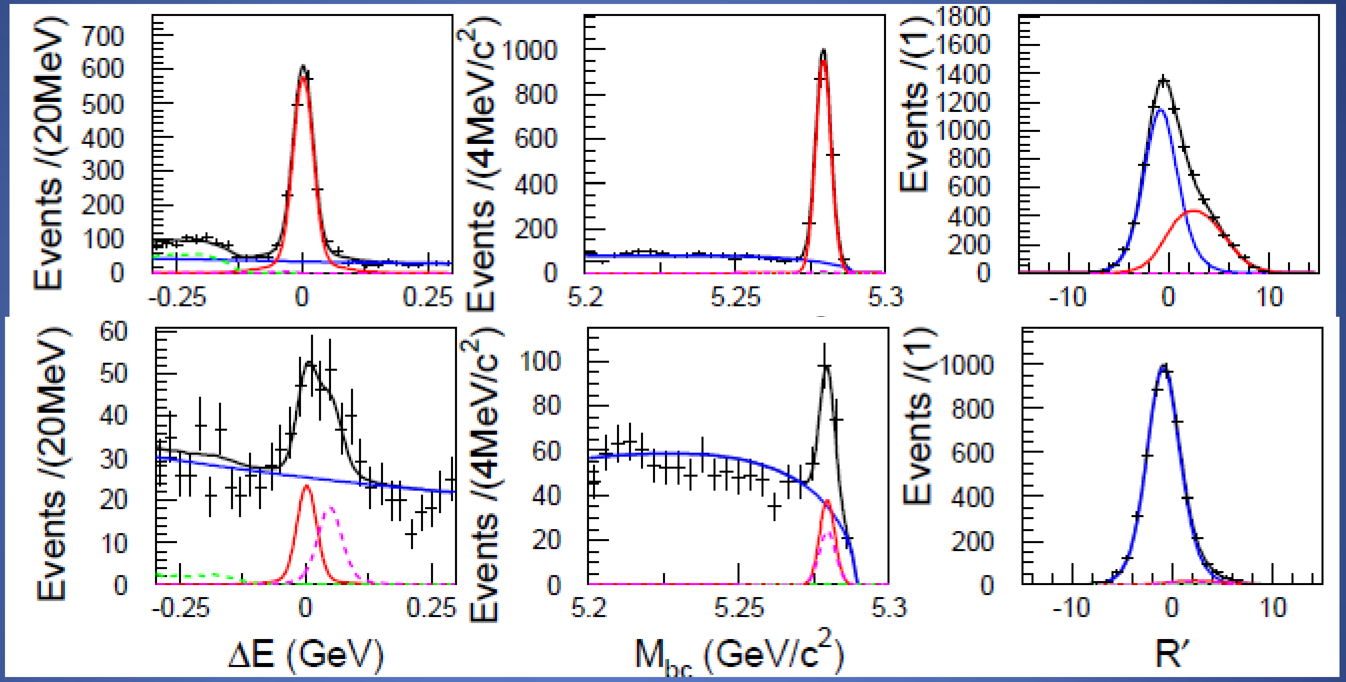
My world average:

$\Delta A_{K\pi} = +0.121 \pm 0.022$ @5.5σ

$A_{cp}(K^{\pm}\pi^0) = +0.043 \pm 0.024 \pm 0.002$

$A_{cp}(K^{\pm}\pi^{\mp}) = -0.069 \pm 0.014 \pm 0.007$

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



- $K^0\pi^{\pm}$:

  $N = 3229 \pm 71$

  $\mathcal{B} = (23.97^{+0.53}_{-0.52} \pm 0.69) \times 10^{-6}$

  $A_{CP} = -0.014 \pm 0.021 \pm 0.006$

- $K^0K^{\pm}$:

  $N = 134 \pm 23$

  $\mathcal{B} = (1.11^{+0.19}_{-0.18} \pm 0.05) \times 10^{-6}$

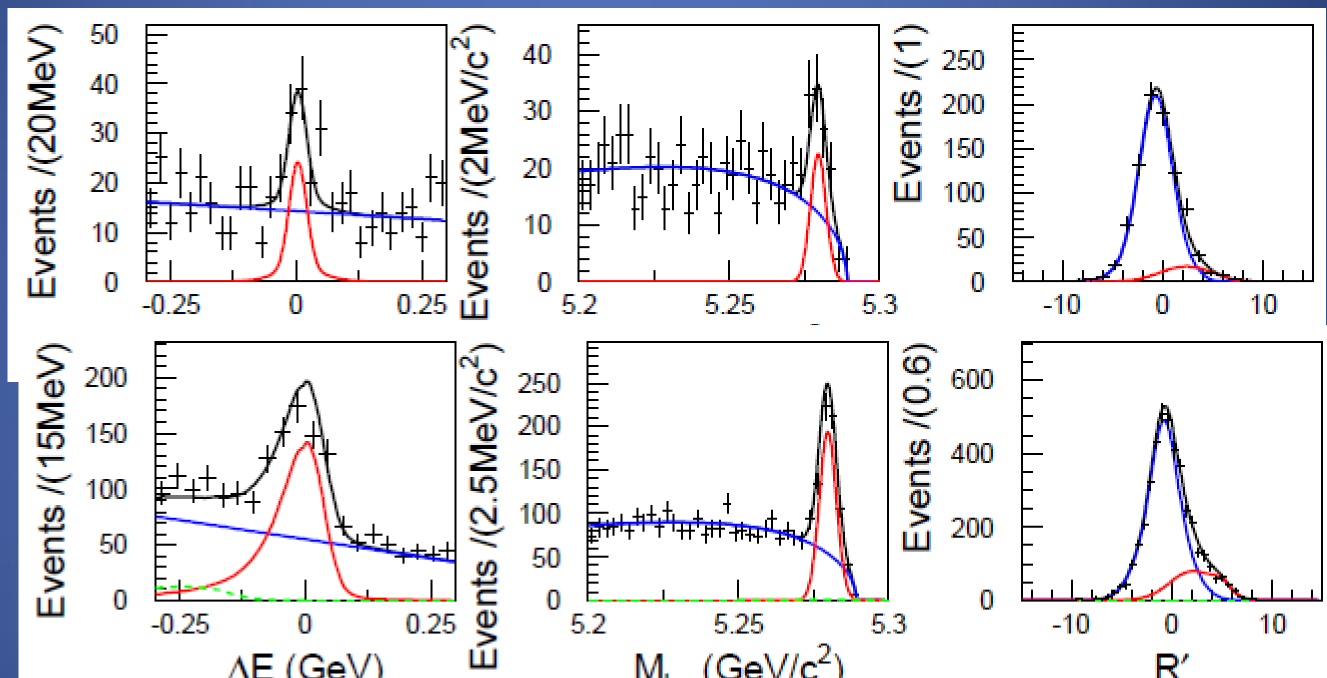
  $A_{CP} = +0.017 \pm 0.168 \pm 0.002$

Preliminary

$B^0 \to K^0\overline{K}^0, K^0\pi^0$

$K^0\overline{K}^0$

$K^0\pi^0$



- $K^0 K^0$:
  $N = 103^{+15}_{-14}$
  $\mathcal{B} = (1.26^{+0.19}_{-0.18} \pm 0.06)\text{x}10^{-6}$
- $K^0\pi^0$:
  $N = 960 \pm 46$
  $\mathcal{B} = (9.66 \pm 0.46 \pm 0.49)\text{x}10^{-6}$

Acp values will be given in the time-dependent CP fit.

Preliminary

Ratios of Branching Fractions

Modes	Belle 2007	Belle 2011	
$2\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)$	$1.08 \pm 0.06 \pm 0.08$	$1.05 \pm 0.03 \pm 0.05$	Rc
$\Gamma(K^+\pi^-)/2\Gamma(K^0\pi^0)$	$1.08 \pm 0.08 \pm 0.08$	$1.04 \pm 0.05 \pm 0.06$	Rn
$\Gamma(K^+\pi^-)/\Gamma(K^0\pi^+)$	$0.94 \pm 0.04 \pm 0.05$	$0.90 \pm 0.03 \pm 0.03$	
$\Gamma(\pi^+\pi^-)/\Gamma(K^+\pi^-)$	$0.26 \pm 0.01 \pm 0.01$	$0.25 \pm 0.01 \pm 0.01$	
$\Gamma(\pi^+\pi^-)/2\Gamma(\pi^+\pi^0)$	$0.42 \pm 0.03 \pm 0.02$	$0.46 \pm 0.03 \pm 0.03$	
$\Gamma(\pi^+\pi^0)/\Gamma(K^0\pi^0)$	$0.66 \pm 0.07 \pm 0.04$	$0.56 \pm 0.04 \pm 0.03$	
$2\Gamma(\pi^+\pi^0)/\Gamma(K^0\pi^+)$	$0.57 \pm 0.04 \pm 0.04$	$0.49 \pm 0.02 \pm 0.03$	

Consistent with SM predictions with different approaches.

H.-n. Li et. al, Phys. Rev.D 72, 114005 (2005) ; T. Yoshikawa, Phys. Rev. D 68, 054023 (2003); M. Gronau and J. L. Rosner, Phys. Lett. B 572, 43 (2003)

SU(3) symmetry: $R_C = 1.15 \pm 0.05$, $R_n = 1.12 \pm 0.05$

Buras et. al, EPJC 45, 701 (2006)

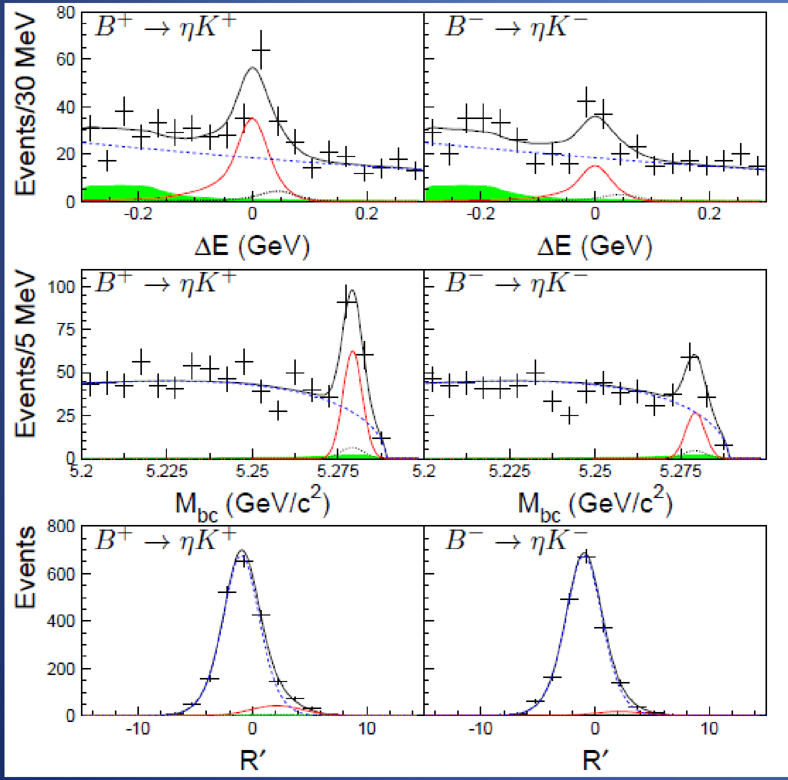
Preliminary

Evidence of Direct CPV in $B^\pm \to \eta K^\pm$

$\mathcal{B} = (2.12\,^{+0.23}_{-0.22} \pm 0.11) \times 10^{-6}$

$A_{CP} = -0.38 \pm 0.10 \pm 0.01$ @3.8σ

Consistent results btw $\gamma\gamma$ and $\pi\pi\pi^0$ modes



- Observe large negative A_{CP}. Consistent btw BaBar and Belle
- BaBar 2009 (467 M):
  $\mathcal{B} = (2.94^{+0.39}_{-0.34} \pm 0.21) \times 10^{-6}$
  $A_{CP} = -0.36 \pm 0.11 \pm 0.03$ @3.3σ
- Belle 2007 (535 M):
  $\mathcal{B} = (1.9 \pm 0.3\,^{+0.2}_{-0.1}) \times 10^{-6}$
  $A_{CP} = -0.39 \pm 0.16 \pm 0.03$ @2.4σ

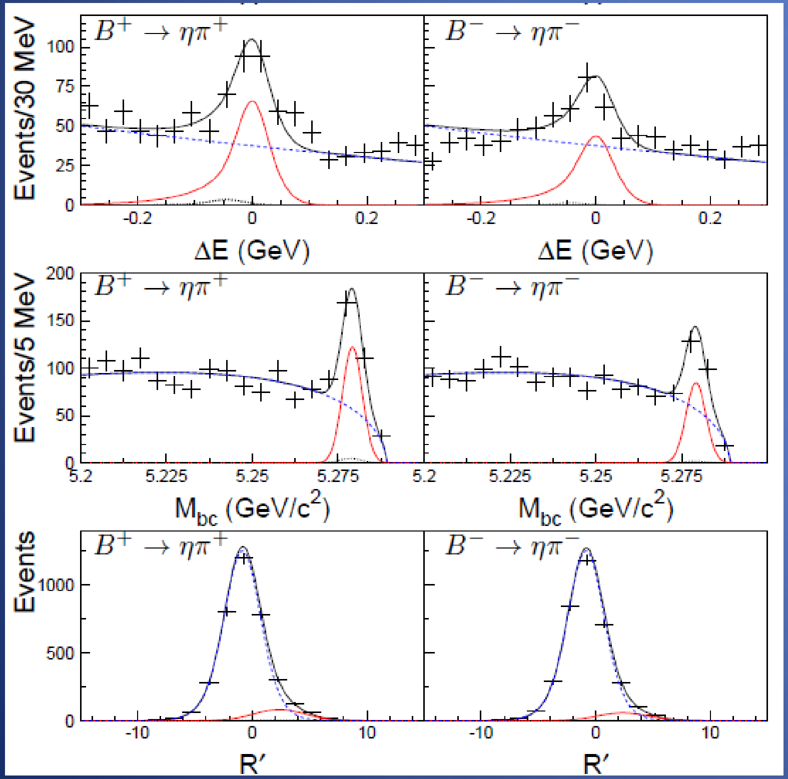
Preliminary

Evidence of Direct CPV in $B^{\pm} \to \eta\pi^{\pm}$

$\mathcal{B} = (4.07 \pm 0.26 \pm 0.21) \times 10^{-6}$

$A_{CP} = -0.19 \pm 0.06 \pm 0.01$ @3.0σ

Consistent results btw $\gamma\gamma$ and $\pi\pi\pi^0$ modes



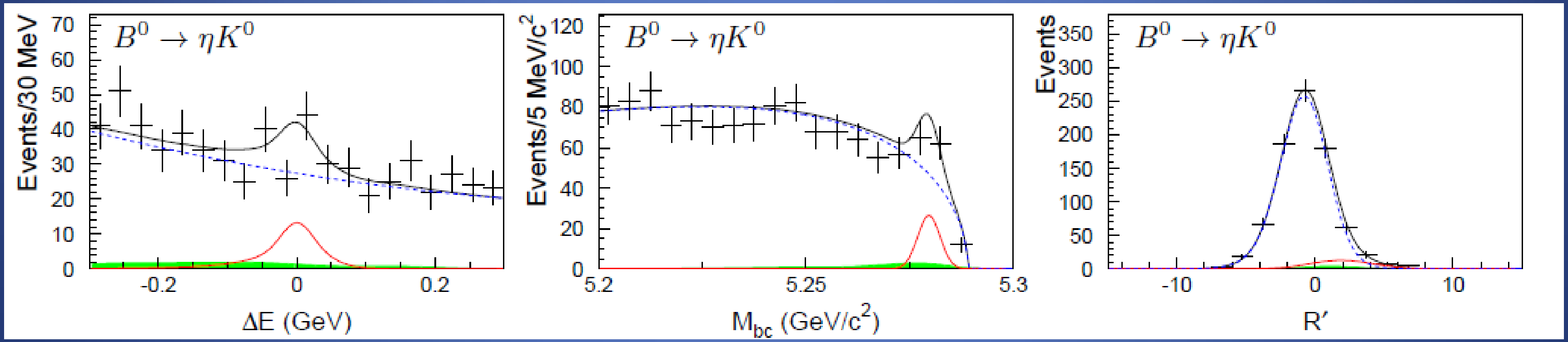
- Observe large negative A_{CP}. Tension between previous BaBar and Belle results.
- BaBar 2009 (467 M):
  $\mathcal{B} = (4.00 \pm 0.40 \pm 0.24) \times 10^{-6}$
  $A_{CP} = -0.03 \pm 0.09 \pm 0.03$ @0.3σ
- Belle 2007 (535 M):
  $\mathcal{B} = (4.2 \pm 0.4 \pm 0.2) \times 10^{-6}$
  $A_{CP} = -0.23 \pm 0.09 \pm 0.02$ @2.5σ

Preliminary

Observation of $B^0 \to \eta K^0$

$\mathcal{B} = (1.32\ ^{+0.33}_{-0.29} \pm 0.07) \times 10^{-6}$ @5.4σ

Both $\gamma\gamma$ and $\pi\pi\pi^0$ modes have 4σ excess.



BaBar: $(1.15^{+0.43}_{-0.38} \pm 0.09) \times 10^{-6}$ @3.5σ PRD 80, 112002 (2009)

Old Belle: $(1.1 \pm 0.4 \pm 0.1) \times 10^{-6}$ @2.9σ PRD 74, 0711004 (2007)

Summary 1

- Belle updated branching fractions and direct A_{CP} with the final data sample for $B \to hh$ and ηh.
- Improve precision due to statistics, new analysis method and better understanding of our detector.
- The central value of $A_{CP}(K\pi)$ has decreased slightly but is consistent with other experimental results.
- $\Delta A(K\pi)$ remains large.

Belle:

$A_{CP}(K\pi) = -0.069 \pm 0.014 \pm 0.007$

$\Delta A(K\pi) = +0.112 \pm 0.028$

My world average:

$A_{CP}(K\pi) = -0.085 \pm 0.010$

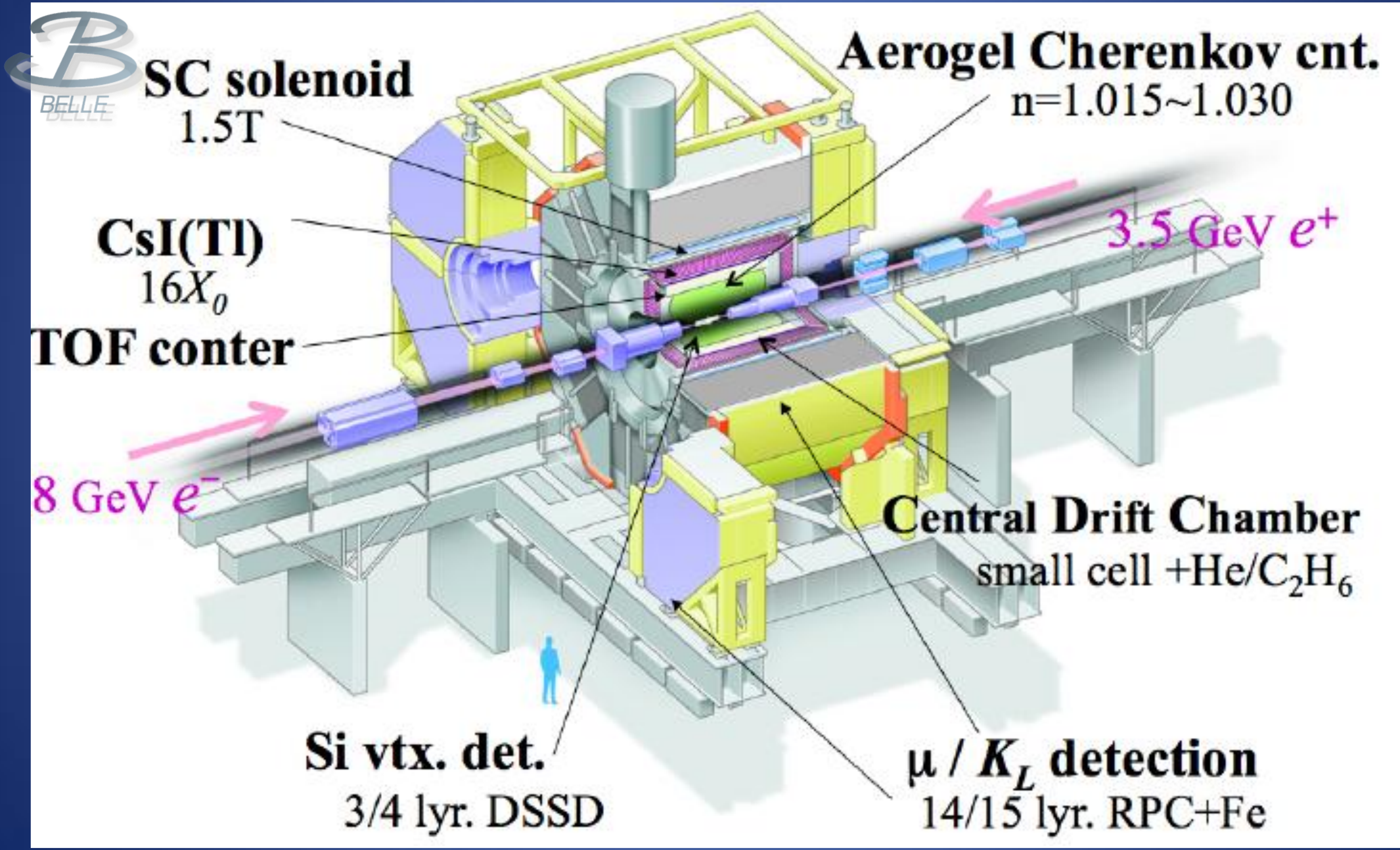
$\Delta A(K\pi) = +0.121 \pm 0.022$

Summary 2

- No CPV asymmetries were observed for $K^0h^{\pm}$ and $\pi^{\pm}\pi^0$, as expected with a single dominant diagram.
- Rc and Rn are consistent with theoretical prediction with various approaches.
- Find evidence of direct CPV for $B \rightarrow \eta K^{\pm}$ and $\eta\pi^{\pm}$, while BaBar's $A_{CP}(\eta\pi^{\pm})$ is consistent with zero.
- First observation of $B \rightarrow \eta K^0$ @5.4σ.

BACK UP

Belle Detector



Summary table of B→ ηh

Mode	ϵ_{eff} (%)	Yield	$\Sigma(\mathcal{B})$	$\mathcal{B}$ (10^{-6})	$\Sigma(A_{CP})$	A_{CP}
$B^{\pm} \to \eta K^{\pm}$			13.2	$2.12^{+0.23}_{-0.22} \pm 0.11$	3.8	$-0.38 \pm 0.11 \pm 0.01$
$\eta_{\gamma\gamma} K^{\pm}$	13.25	$201.88^{+27.08}_{-26.48}$	10.2	$2.07 \pm 0.27 \pm 0.10$	2.9	$-0.36 \pm 0.13 \pm 0.01$
$\eta_{3\pi} K^{\pm}$	4.94	$80.17^{+14.92}_{-13.85}$	8.6	$2.29^{+0.43}_{-0.40} \pm 0.15$	2.4	$-0.42 \pm 0.18 \pm 0.01$
$B^{\pm} \to \eta \pi^{\pm}$			22.4	$4.07 \pm 0.26 \pm 0.21$	3.0	$-0.19 \pm 0.06 \pm 0.01$
$\eta_{\gamma\gamma} \pi^{\pm}$	15.34	$480.61^{+35.06}_{-35.97}$	19.0	$4.24^{+0.31}_{-0.32} \pm 0.19$	1.8	$-0.14 \pm 0.08 \pm 0.01$
$\eta_{3\pi} \pi^{\pm}$	5.44	$138.55^{+18.50}_{-17.47}$	12.2	$3.63 \pm 0.49 \pm 0.25$	2.5	$-0.31^{+0.13}_{-0.12} \pm 0.01$
$B^{0} \to \eta K^{0}$			5.4	$1.27^{+0.33}_{-0.29} \pm 0.08$		
$\eta_{\gamma\gamma} K^{0}$	4.15	$38.03^{+12.62}_{-11.45}$	4.0	$1.18^{+0.39}_{-0.35} \pm 0.06$		
$\eta_{3\pi} K^{0}$	1.48	$16.23^{+6.45}_{-5.43}$	4.1	$1.48^{+0.59}_{-0.49} \pm 0.10$		

Summary Table for B $\longrightarrow$ hh

	yield	Total ϵ(%)	$\mathcal{BR}(\times 10^{-6})$	$\mathcal{A}_{cp}$
$K^{\pm}\pi^{\mp}$	7525^{+127}_{-126}	48.82	$20.00 \pm 0.34 \pm 0.63$	$-0.069 \pm 0.014 \pm 0.007$
$\pi^{\pm}\pi^{\mp}$	2111^{+89}_{-88}	54.79	$5.04 \pm 0.21^{+0.18}_{-0.19}$	
$K^{\pm}\pi^{0}$	3731^{+92}_{-91}	38.30	$12.62 \pm 0.31 \pm 0.56$	$+0.043 \pm 0.024 \pm 0.002$
$\pi^{\pm}\pi^{0}$	1846^{+82}_{-81}	40.80	$5.86 \pm 0.26 \pm 0.38$	$+0.025 \pm 0.043 \pm 0.007$
$K^{0}K^{\pm}$	134^{+23}_{-22}	15.64	$1.11^{+0.19}_{-0.18} \pm 0.05$	$+0.017 \pm 0.168 \pm 0.002$
$K^{0}\pi^{\pm}$	3229^{+71}_{-70}	17.46	$23.97^{+0.53}_{-0.52} \pm 0.69$	$-0.014 \pm 0.021 \pm 0.006$
$K^{0}\overline{K}^{0}$	103^{+15}_{-14}	10.61	$1.26^{+0.19}_{-0.18} \pm 0.06$	
$K^{0}\pi^{0}$	960^{+46}_{-45}	12.87	$9.66^{+0.46}_{-0.45} \pm 0.49$	