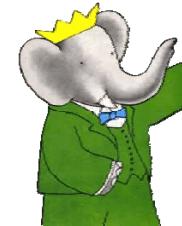


CP-violation in $b \rightarrow s$ Penguin Decays at BaBar

UNIVERSITY OF
BIRMINGHAM

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(For BaBar Collaboration)



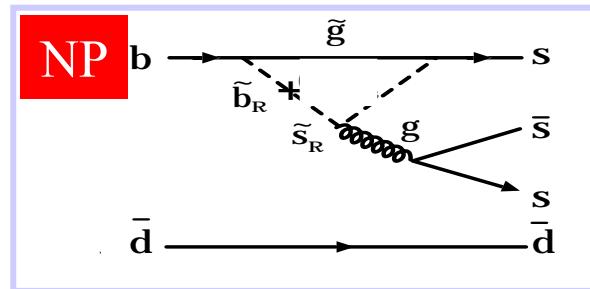
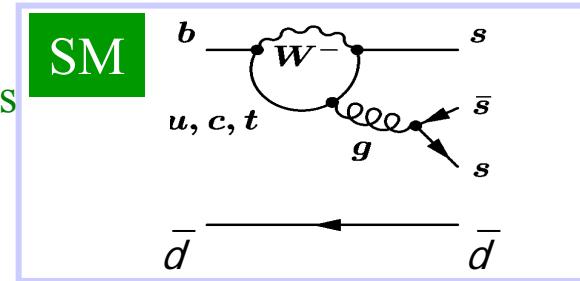
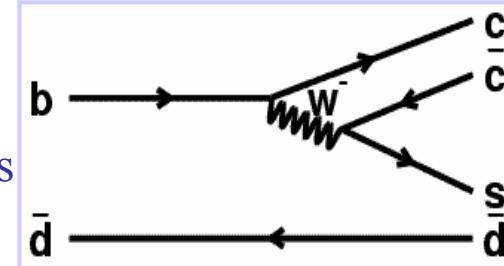
The 15th International Conference on
Supersymmetry and the Unification of Fundamental Interactions
@ Karlsruhe, Germany
July 26 - August 1, 2007

Outline

- Motivation → Why measurement of CP-violation in $b \rightarrow s$ decays
- Measurement of CP asymmetries at B-factories
- Following topics will be covered:
 - $B^0 \rightarrow \eta' K^0$
 - $B^0 \rightarrow \rho^0 K^0$
 - $B^0 \rightarrow K^+ K^- K^0$
 - $B^0 \rightarrow K_S^0 \pi^0$
 - $B^0 \rightarrow K_S^0 K_S^0 K_S^0, \pi^0 \pi^0 K_S^0$
 - $B^\pm \rightarrow \eta' K^\pm, \eta K^\pm, \omega K^\pm$
- Summary of Results
- Conclusions

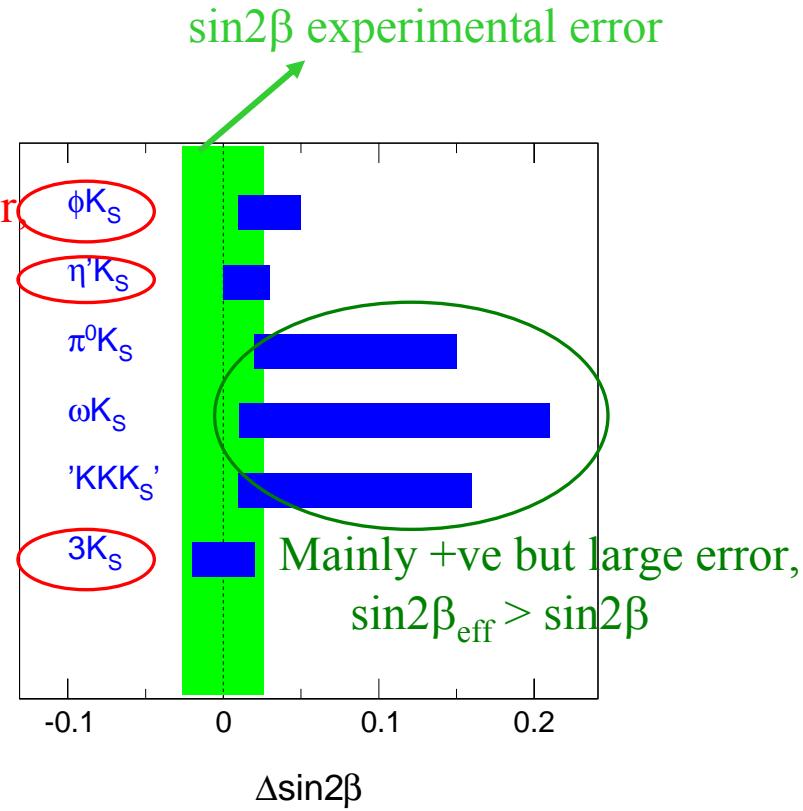
Motivation (SM or New Physics?)

- SM: CKM matrix \rightarrow irreducible phase \rightarrow CP-violation
- $b \rightarrow c\bar{c}s$ decays (e.g. $B^0 \rightarrow J/\psi K_S$): dominated by Tree diagrams
 - $\sin 2\beta = 0.678 \pm 0.026 \Rightarrow$ precision measurement O(4%)
- $b \rightarrow sq\bar{q}$ ($q=d,s$) decays (e.g. charmless $B^0 \rightarrow \phi K_S$): dominated by Penguin (loop) diagrams
 - Penguin Amplitude \sim same weak phase as the $b \rightarrow c\bar{c}s$
 - Complementary measurement of $\sin 2\beta$ ($\sin 2\beta_{\text{eff}}$)
 - SM predictions; $\sin 2\beta_{\text{eff}} \approx \sin 2\beta$
- Heavy non-SM particles could enter in the loop
 - $\sin 2\beta_{\text{eff}} \neq \sin 2\beta$ (additional phase)
 - Indication of New Physics (NP)
- Phenomenological Interest; compare experimental results to test/improve the theoretical calculations

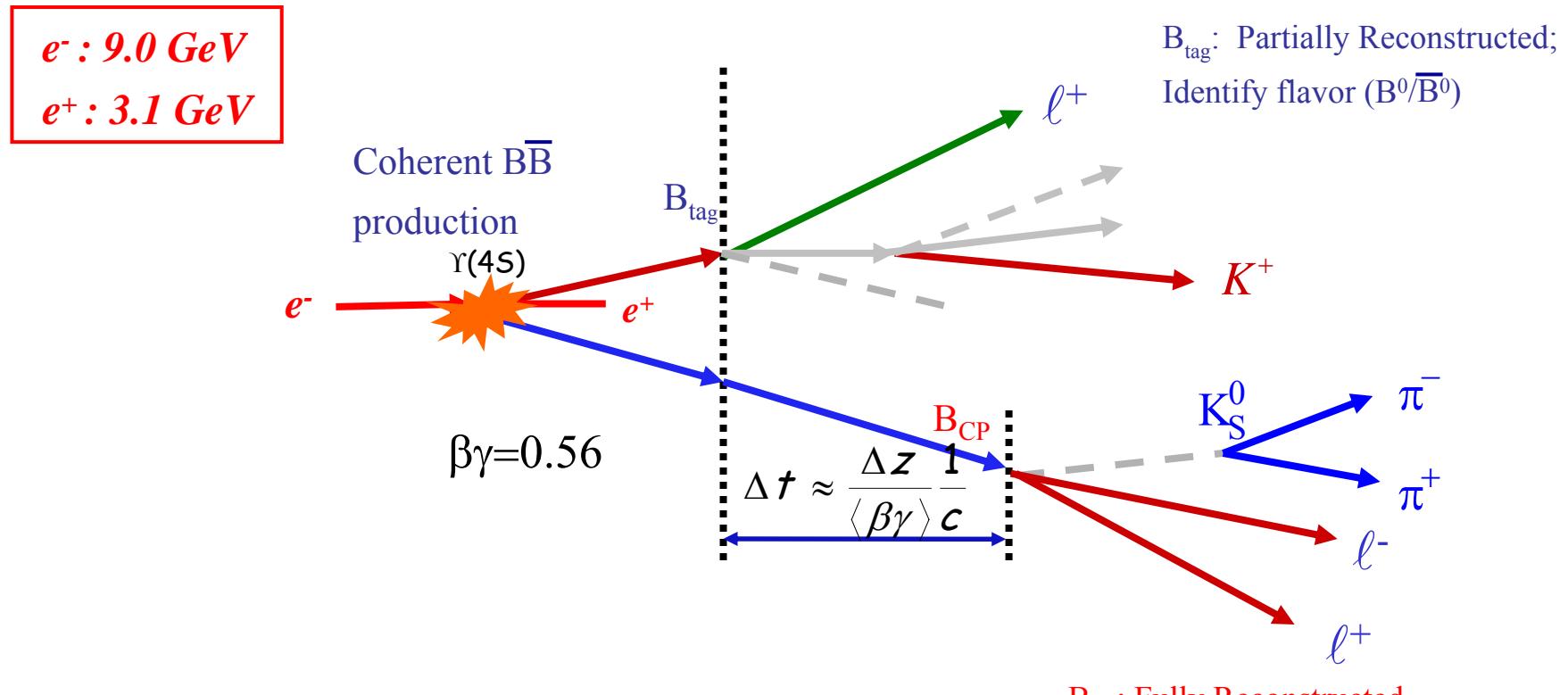


Theoretical Estimates of SM offsets:

- Short Distance Effect: $\sin 2\beta_{\text{eff}} \sim \sin 2\beta$
 - QCDF:
 - Beneke, PLB 620, 143,
 - Cheng, Chua, Yang, PRD 73, 014017
 - pQCD:
 - Minisham, Sanda, PRD 72, 114005
 - SCET:
 - Williamson and Zupan, PRD 74, 014003
- Long Distance Effect:
 - Cheng, Chua, Soni, PRD 72, 014006



CP-Asymmetry: Experimental Method



- m_{ES} and ΔE : to characterize B_{CP}
- Continuum ($e^+ e^- \rightarrow q\bar{q}$; $q=u,d,s,c$) rejection using event shape variables

Decay Rate (Δt):

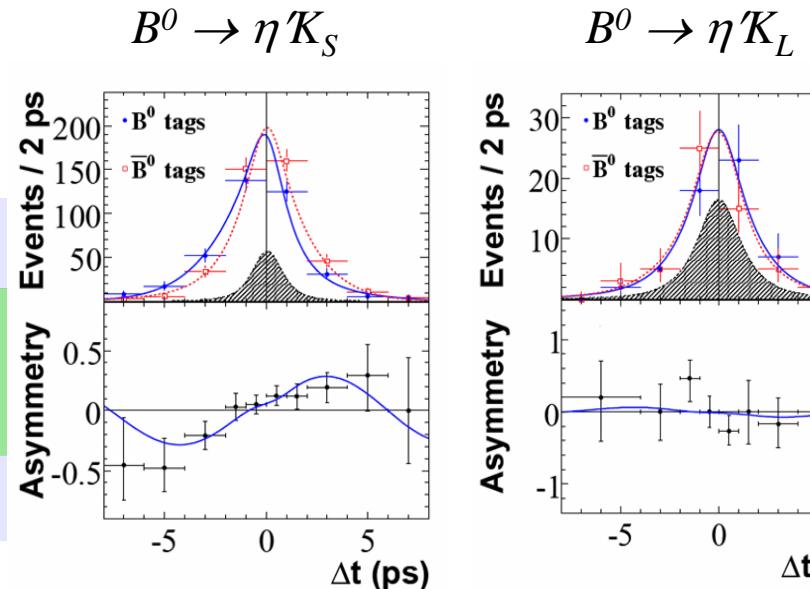
- $(d\Gamma/d\Delta t) \propto e^{-|\Delta t|/\tau} \times [1 + q_{tag} (-\eta S \sin(\Delta m \Delta t) - C \cos(\Delta m \Delta t))]$;
- CP-violation parameters:
 - $S = -2\text{Im } \lambda / (1 + |\lambda|^2)$; ($\sim \sin 2\beta$ in SM)
Interference between decay and mixing
 - $C = (1 - |\lambda|^2)/(1 + |\lambda|^2)$; (~ 0 in SM)
Direct CP
 - $\lambda = (\bar{A}/A)e^{-i2\beta}$; A = decay amplitude
- Δm : $B^0 - \bar{B}^0$ mixing frequency
- q_{tag} : +1(-1) for $B^0(\bar{B}^0)$

$B^0 \rightarrow \eta' K^0$

- Penguin mode with large BF: $\sim 65 \times 10^{-6}$
 - $\eta' \rightarrow \eta\pi^+\pi^-,\rho^0\gamma$
- Maximum likelihood fit
 - $m_{ES}, \Delta E, fisher, \Delta t$

Mode	S	C
$\eta' K_S$	0.62 ± 0.11	-0.18 ± 0.07
$\eta' K_L$	0.32 ± 0.28	0.08 ± 0.23
$\eta' K^0$	$0.58 \pm 0.10 \pm 0.03$	$-0.16 \pm 0.07 \pm 0.03$

$384 \times 10^6 B\bar{B}$ pairs

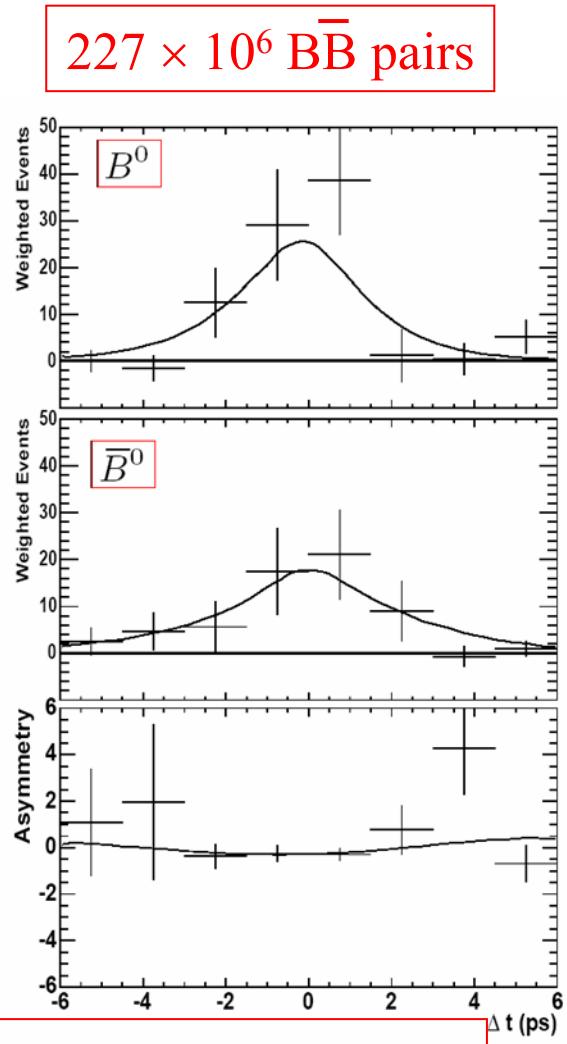


- Observed mixing induced CP violation
 - 5.5σ significance (incl. sys.)
- Consistent with WA of $\sin 2\beta$

PRL 98, 031801 (2007)

$B^0 \rightarrow \rho^0 K^0$

- Quasi-2body approach : restricting to the region $B^0 \rightarrow \pi^+ \pi^-$ K_S Dalitz Plot dominated by ρ^0
 - $\rho^0 \rightarrow \pi^+ \pi^-$ and $K_S \rightarrow \pi^+ \pi^-$
- Unbinned Maximum likelihood fit
 - m_{ES} , ΔE , NN , $\cos\theta_{\pi^+}$, $m_{\pi\pi}$, Δt
- $N_{\text{signal}} = 111 \pm 19$
 - $B(B^0 \rightarrow \rho^0 K^0) = (4.9 \pm 0.8 \pm 0.9) \times 10^{-6}$
 - 5.0σ sign. (including Systematic)
- $S = 0.20 \pm 0.52 \pm 0.24$
- $C = 0.64 \pm 0.41 \pm 0.20$



PRL 98, 051803 (2007)

B⁰ → K⁺ K⁻ K⁰

- Mixtures of CP-odd and CP-even & interference among diff. decay amplitudes
- Time-dependent Dalitz Plot analysis to extract CP-violation parameters (**Amplitude Analysis**)
- Amplitude for \bar{B}^0

$$\bar{A}(m_{K^+K^-}, \cos\theta_H) = \sum_r A_r = \sum_r c_r(1 \pm b_r) e^{i(\varphi_r \pm \delta_r)} \cdot f_r(m_{K^+K^-}, \cos\theta_H)$$

c_r, φ_r : magnitude and phase; b_r, δ_r : allow for direct asym.

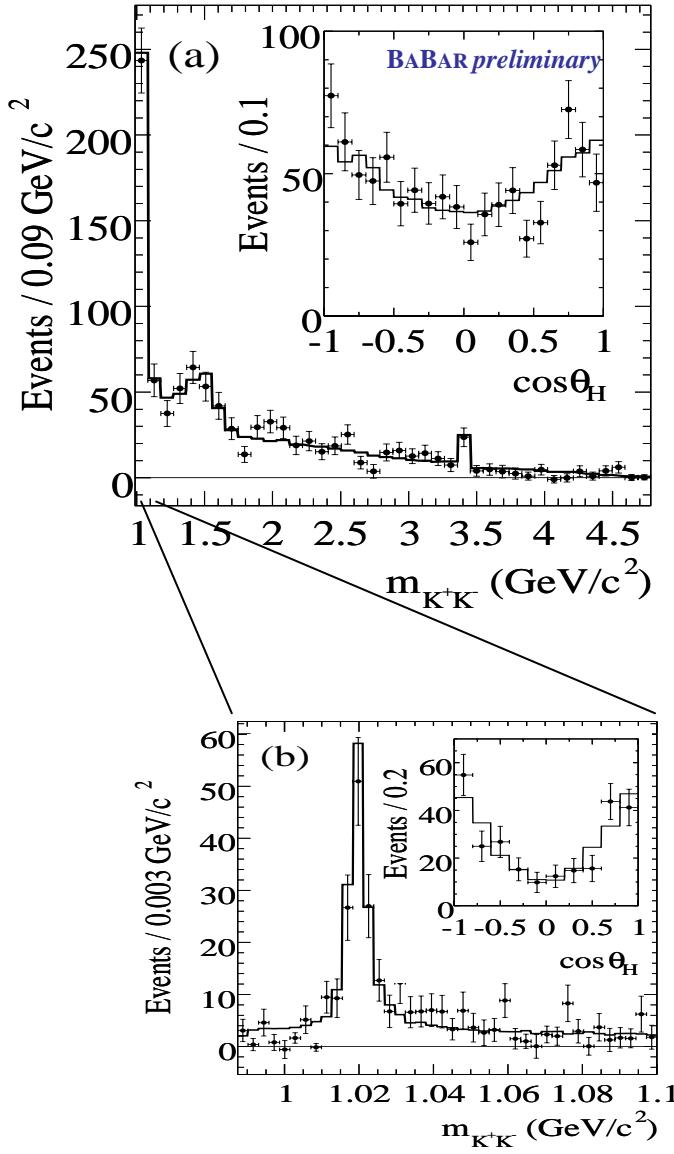
f_r : describes the dynamical properties; r = various resonance

■ Rate Asymmetry:

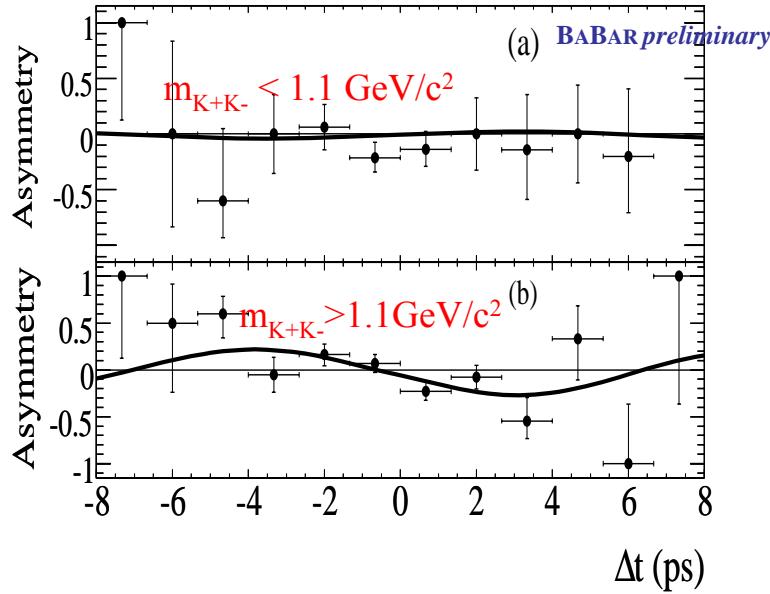
$$\mathcal{A}_{CP}(r) = \frac{|A_r|^2 - |\bar{A}_r|^2}{|A_r|^2 + |\bar{A}_r|^2} = \frac{-2b_r}{1+b_r^2}$$

■ Phase Asymmetry:

$$\beta_{eff}(r) = \delta_r + \beta$$



Mode	Fit Fr. (%)
$\phi(1020) K^0$	12.5 ± 1.3
$f_0(980) K^0$	40.2 ± 9.6
$X_0(1550) K^0$	4.1 ± 1.3
$K^+K^-K^0$ (NR)	112.0 ± 14.9
$\chi_{c0}(1P) K^0$	3.0 ± 1.2
$D^- K^+$	3.6 ± 1.5
$D_S^- K^+$	1.8 ± 0.6



$383 \times 10^6 B\bar{B}$ pairs

	A_{CP}	$\beta_{eff}(rad.)$
Whole DP	$-0.015 \pm 0.077 \pm 0.053$	$0.352 \pm 0.076 \pm 0.026$
$m_{K^+K^-} > 1.1 \text{ GeV}/c^2$	$-0.054 \pm 0.102 \pm 0.060$	$0.436 \pm 0.087 {}^{+0.055}_{-0.031}$
$\phi(1020) K^0$	$-0.08 \pm 0.18 \pm 0.04$	$0.11 \pm 0.14 \pm 0.06$
$f_0(980) K^0$	$+0.41 \pm 0.23 \pm 0.07$	$0.14 \pm 0.15 \pm 0.05$

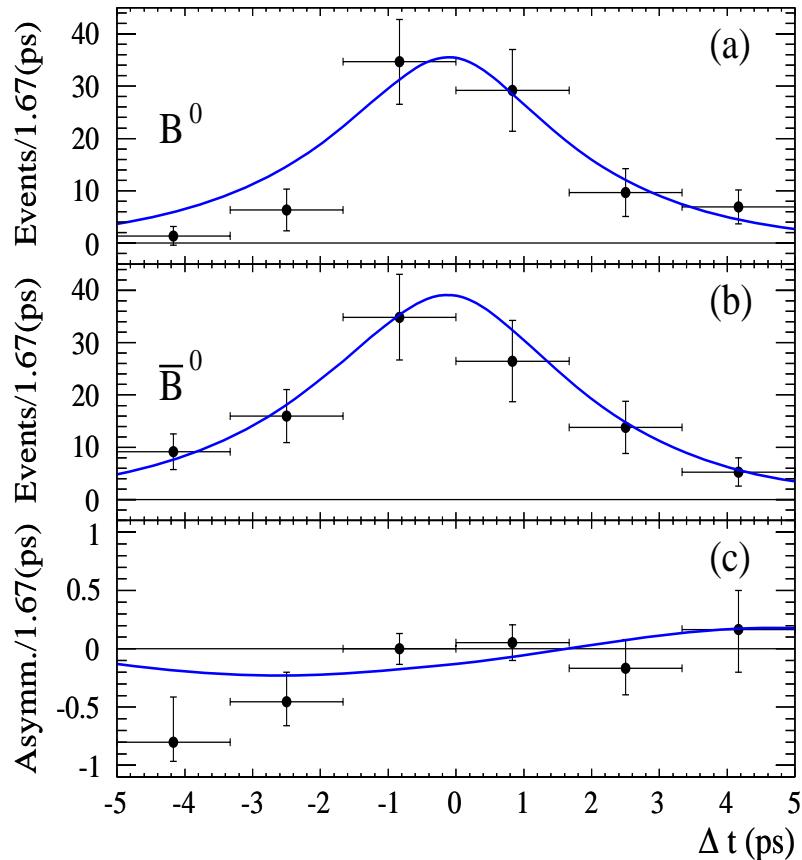
- β_{eff}, A_{CP} are consistent with SM ($\beta \sim 0.370$ rad, $A_{CP} \sim 0$); Sig. 4.8σ
- For $m_{K^+K^-} < 1.1 \text{ GeV}/c^2$: β_{eff} lower by 2σ
- For $m_{K^+K^-} > 1.1 \text{ GeV}/c^2$: β_{eff}, A_{CP} consistent; Sig.: 5.1σ

Submitted to PRL
0706.3885 [hep-ex]

$B^0 \rightarrow K_S^0 \pi^0$ (Update)

- $K_S \rightarrow \pi^+ \pi^-$ and $\pi^0 \rightarrow \gamma\gamma$
- Decay point by constraining the B-production vector to the IP.
- $B(B^0 \rightarrow K^0 \pi^0) = (10.34 \pm 0.66 \pm 0.58) \times 10^{-6}$
- $S = 0.40 \pm 0.23 \pm 0.03$
- $C = 0.24 \pm 0.15 \pm 0.03$

$383 \times 10^6 B\bar{B}$ pairs



Submitted to PRD-RC
hep-ex/0702010

$B^0 \rightarrow K_S^0 K_S^0 K_S^0 / \pi^0 \pi^0 K_S^0$

➤ $B^0 \rightarrow K_S^0 K_S^0 K_S^0$

- Pure CP-even eigenstate
- Theoretical Uncertainty ($\sin 2\beta_{\text{eff.}}$) < 4%
- All $K_S \rightarrow \pi^+ \pi^-$ or one $K_S \rightarrow \pi^0 \pi^0$
- Same vertex technique as that of $K_S \pi^0$
- $S = -0.71 \pm 0.24 \pm 0.04$
- $C = +0.02 \pm 0.21 \pm 0.05$
 - Stat. Sign. 2.9σ

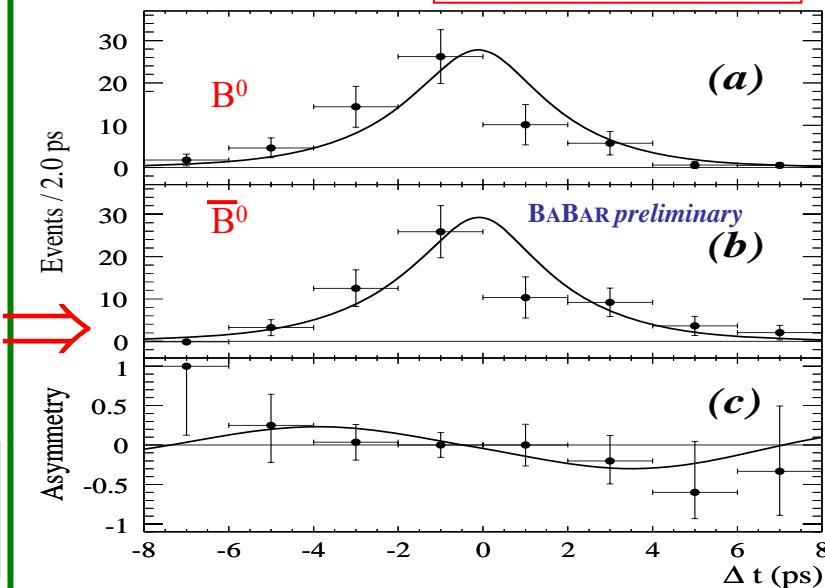
Submitted to PRD-RC
hep-ex/0702046

➤ $B^0 \rightarrow \pi^0 \pi^0 K_S^0$

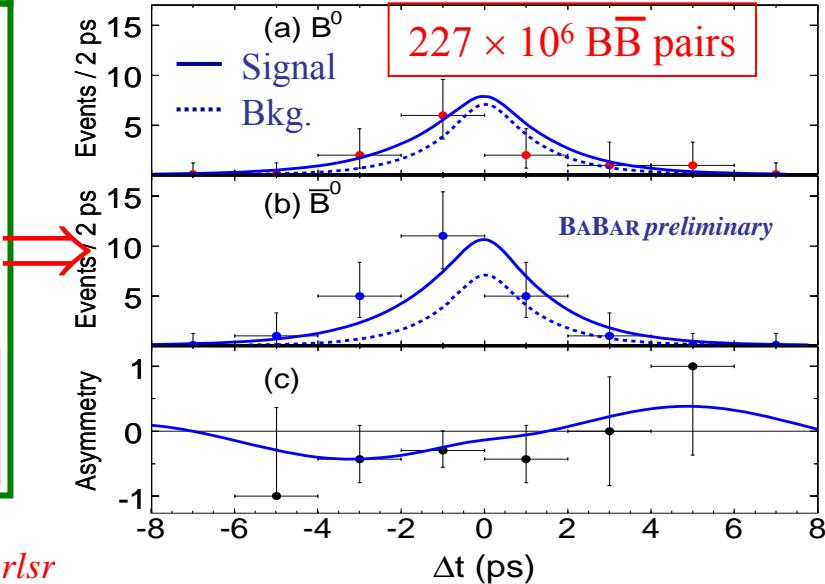
- CP = +1
- Same vertex technique
- $S = 0.72 \pm 0.71 \pm 0.08$
- $C = 0.23 \pm 0.52 \pm 0.13$
 - Stat. Sign. 2.2σ

Submitted to PRD-RC
hep-ex/0702010

$384 \times 10^6 B\bar{B}$ pairs



$227 \times 10^6 B\bar{B}$ pairs



$B^\pm \rightarrow \{\eta, \eta', \omega\} K^\pm$ Update

- Decay Chain Reconstruction

- $\eta \rightarrow \pi^+ \pi^- \pi^0, \gamma \gamma$
- $\eta' \rightarrow \eta \pi^+ \pi^-, \rho^0 \gamma$
- $\omega \rightarrow \pi^+ \pi^- \pi^0$

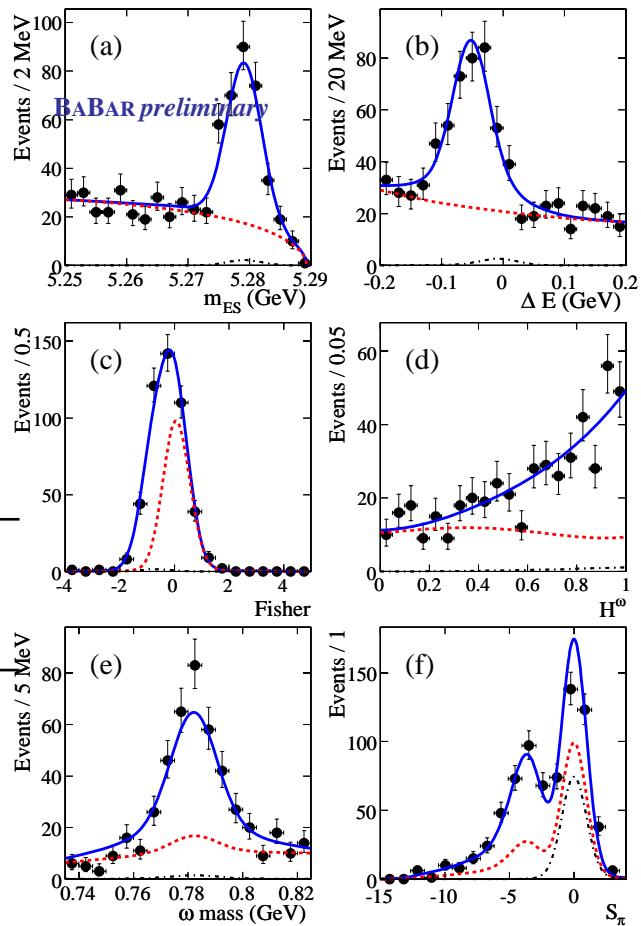
— Total fit
- - - Signal
.... Bkg.

- Max. Likelihood Fit

- $m_{ES}, \Delta E, F, H_r, m_r, S_{\pi/K},$
- $r: (\eta, \eta', \omega); H_r: \text{decay angle}; m_r: \text{mass}$
- $A_{ch} = (\Gamma^- - \Gamma^+)/(\Gamma^- + \Gamma^+)$

Mode	Previous BaBar Results (A_{ch})	New BaBar Results (A_{ch})
$B^+ \rightarrow \eta K^+$	$-0.20 \pm 0.15 \pm 0.01$	$-0.22 \pm 0.11 \pm 0.01$
$B^+ \rightarrow \eta' K^+$	$+0.03 \pm 0.03 \pm 0.02$	$+0.010 \pm 0.022 \pm 0.006$
$B^+ \rightarrow \omega K^+$	$+0.05 \pm 0.09 \pm 0.01$	$-0.01 \pm 0.07 \pm 0.01$

$383 \times 10^6 B\bar{B}$ pairs



Submitted to PRD-RC
 0706.3893 [hep-ex]

Nitesh Soni

SUSY'07, Karlsruhe

$B^+ \rightarrow \omega K^+$

14

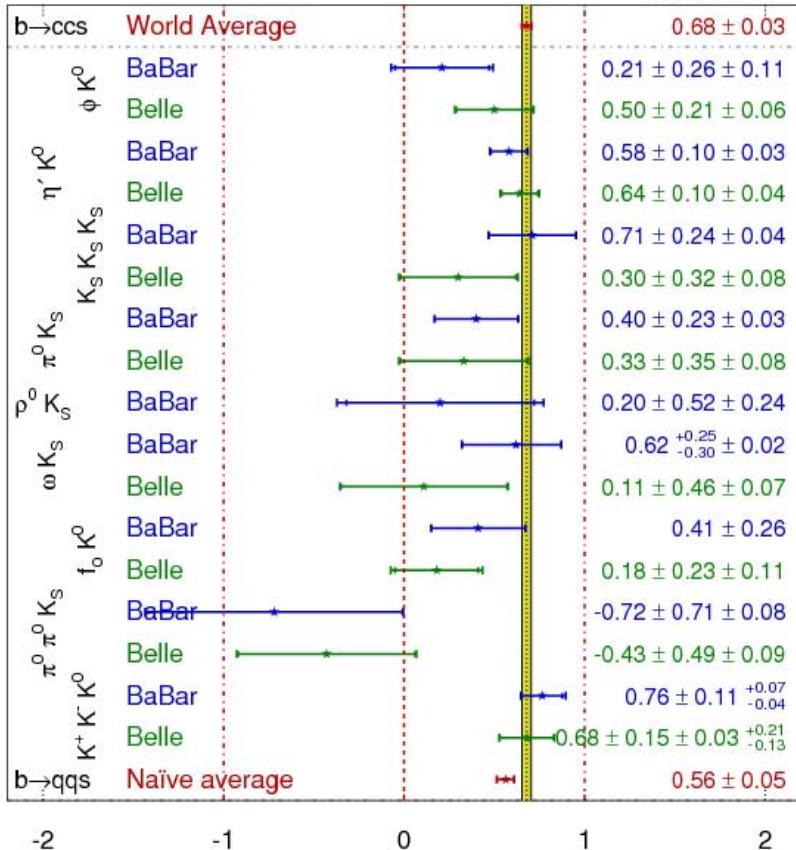
Summary of Results

Individual Results are consistent

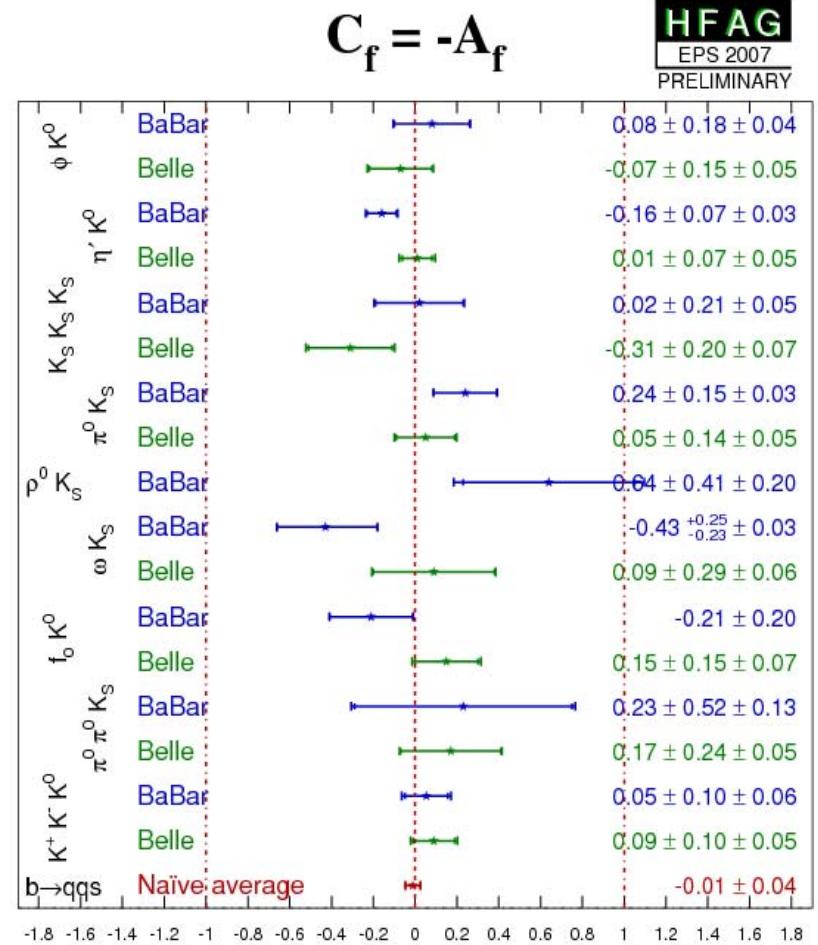
But naïve average of $\sin^2\beta_{\text{eff}}$ is lower than $\sin^2\beta$

$$\sin(2\beta^{\text{eff}}) \equiv \sin(2\phi_1^{\text{eff}})$$

HFAG
EPS 2007
PRELIMINARY



No evidence of Direct CP violation in
Neutral and Charged modes



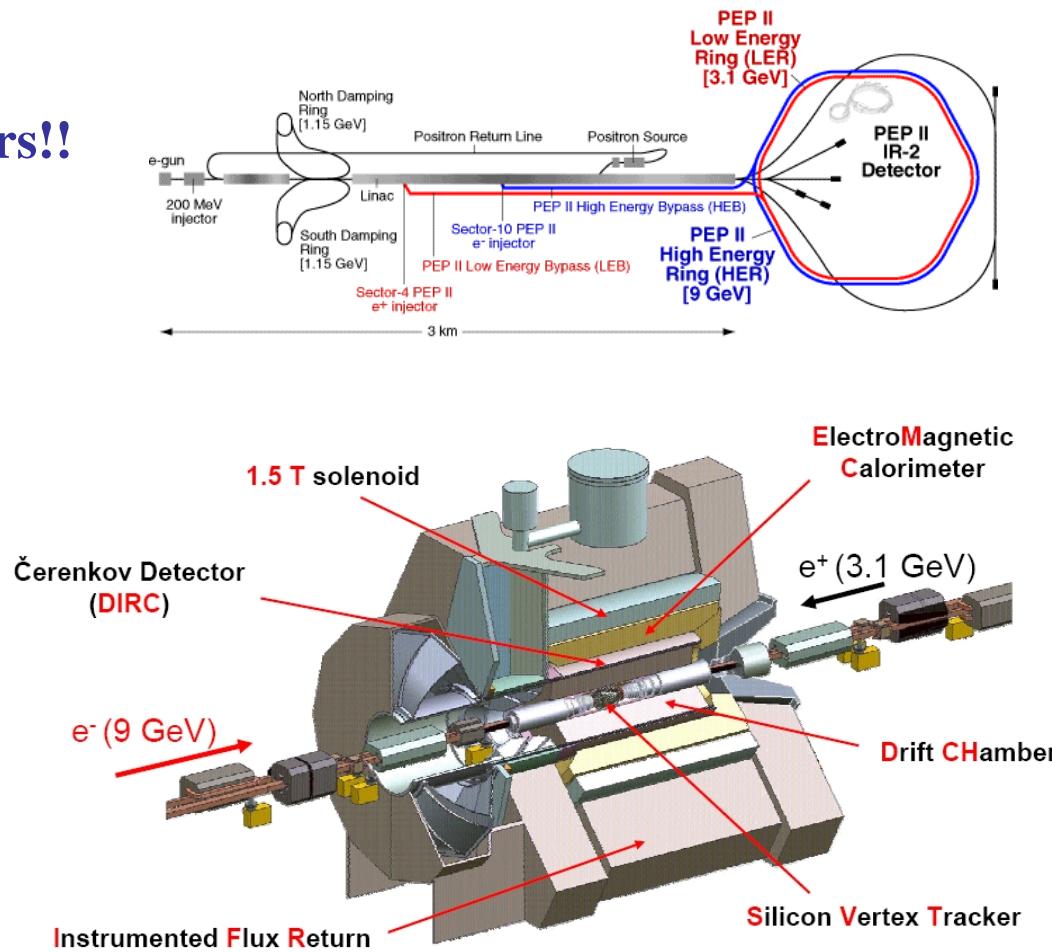
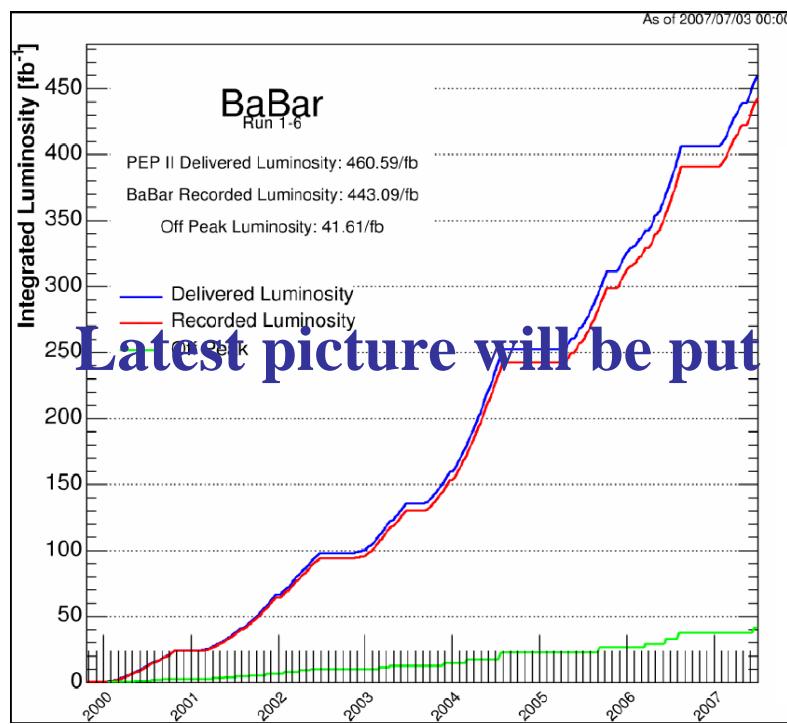
Conclusions

- First observation of CP-violation in Penguin decay ($B^0 \rightarrow \eta' K^0$)
- Time-dependent Dalitz Plot Analysis technique for better measurement
- Observe CP-violation in high mass region of ($B^0 \rightarrow K^+ K^- K^0$)
- Naïve average of S ($\sin 2\beta_{\text{eff}}$) of all penguin modes is lower than $\sin 2\beta$ of charmonium (Opposite to theoretical expect.)
- No evidence for Direct CP-violation charge asymmetries
- Not a clear picture yet; Need more data BaBar, LHCb or SuperB

Back-up Slides

The Experiment: BaBar @ PEP-II

More than 400 millions BB-pairs!!



Common Analysis Technique

- Likelihood fits with discriminating variables:

- Kinematics:

$$m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$

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

- Particle ID: π , K, e, μ , ...
- Event shape variables, to separate the continuum background from signal

