Time-dept. CP Asymmetries studies with Ks Vertexing in B Factories

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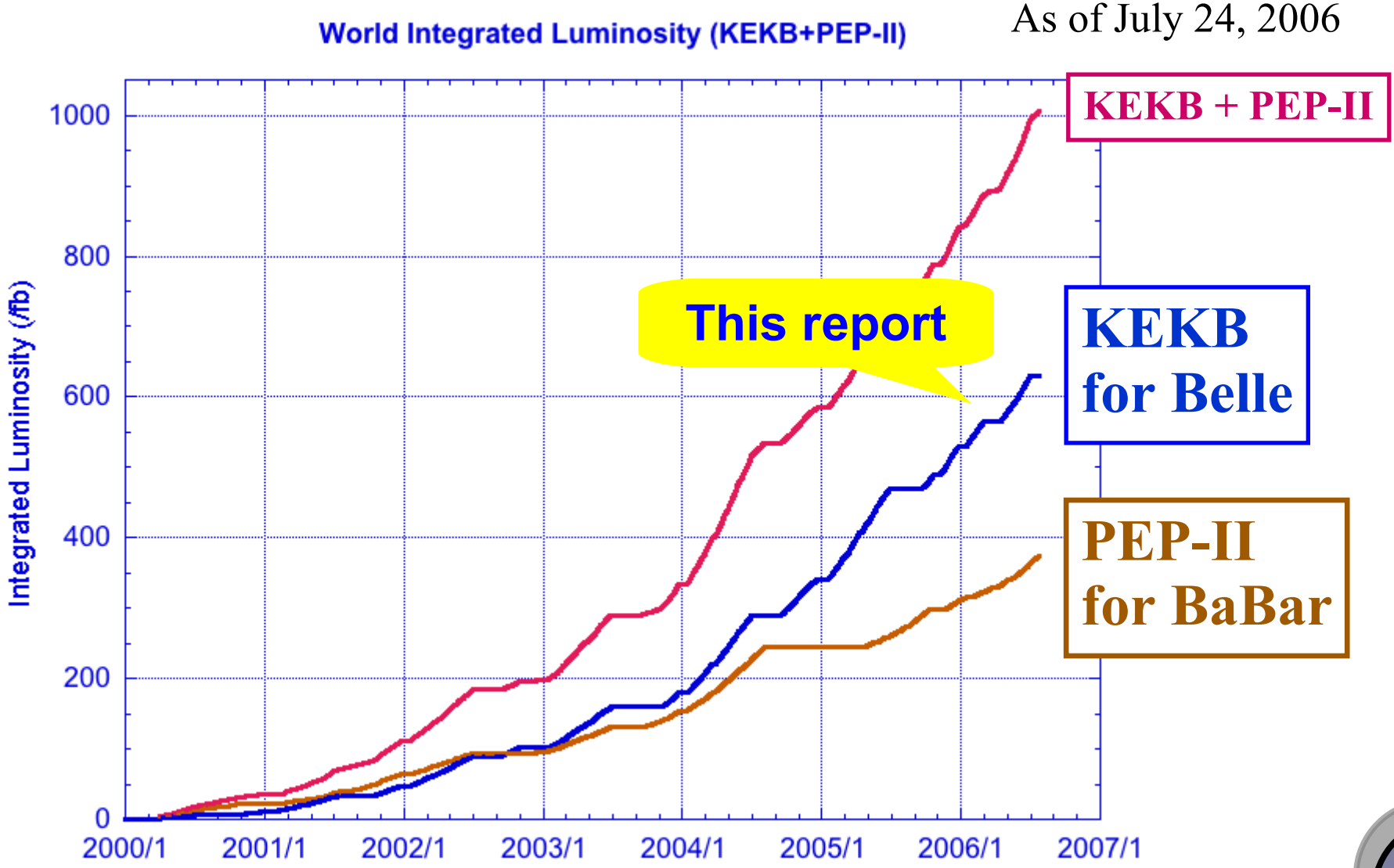
Introduction

Integrated Luminosity

As of July 24, 2006



Accelerators

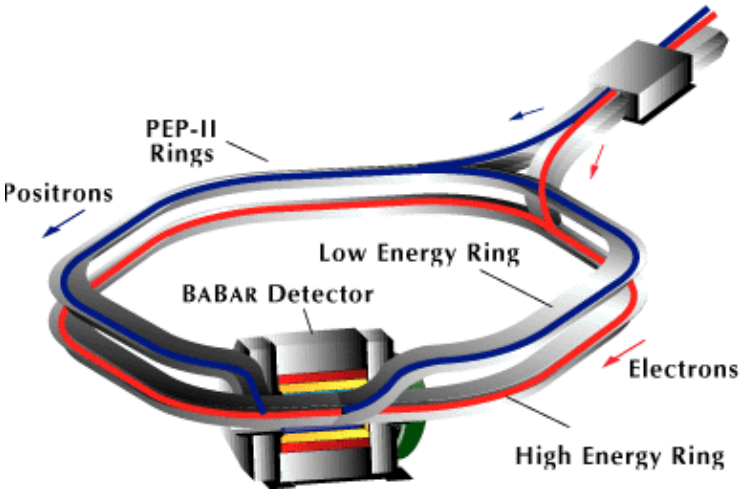
PEP II: Standford, USA

3.1 GeV e^+ on 9 GeV e^-

W_{CM} = M(Y(4s))

CMS boost $<\beta\gamma>=0.56$

$L_{peak}=1.21 \times 10^{34}\ /cm^2/s^2$



KEKB: Tsukuba, Japan

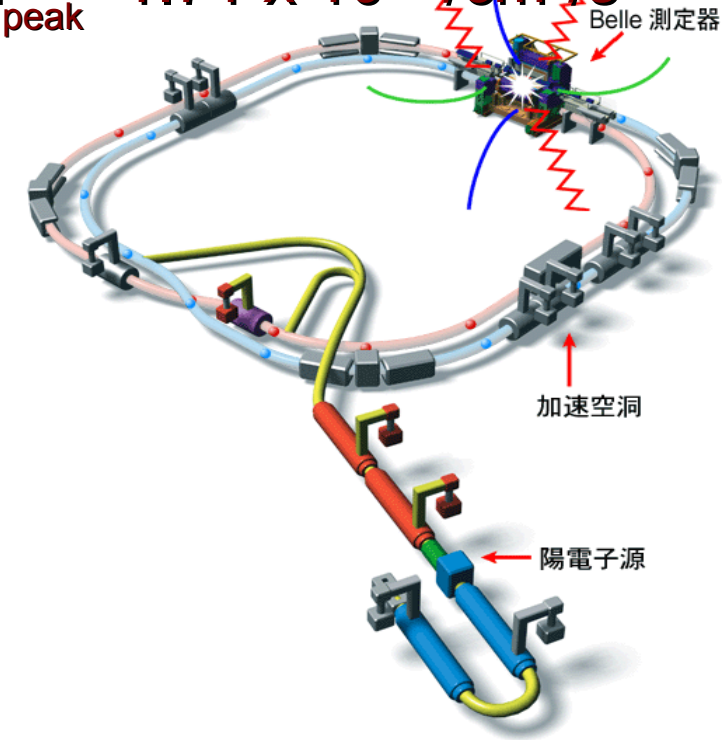
3.5 GeV e^+ on 8 GeV e^-

W_{CM} = M(Y(4s))

3km circumference

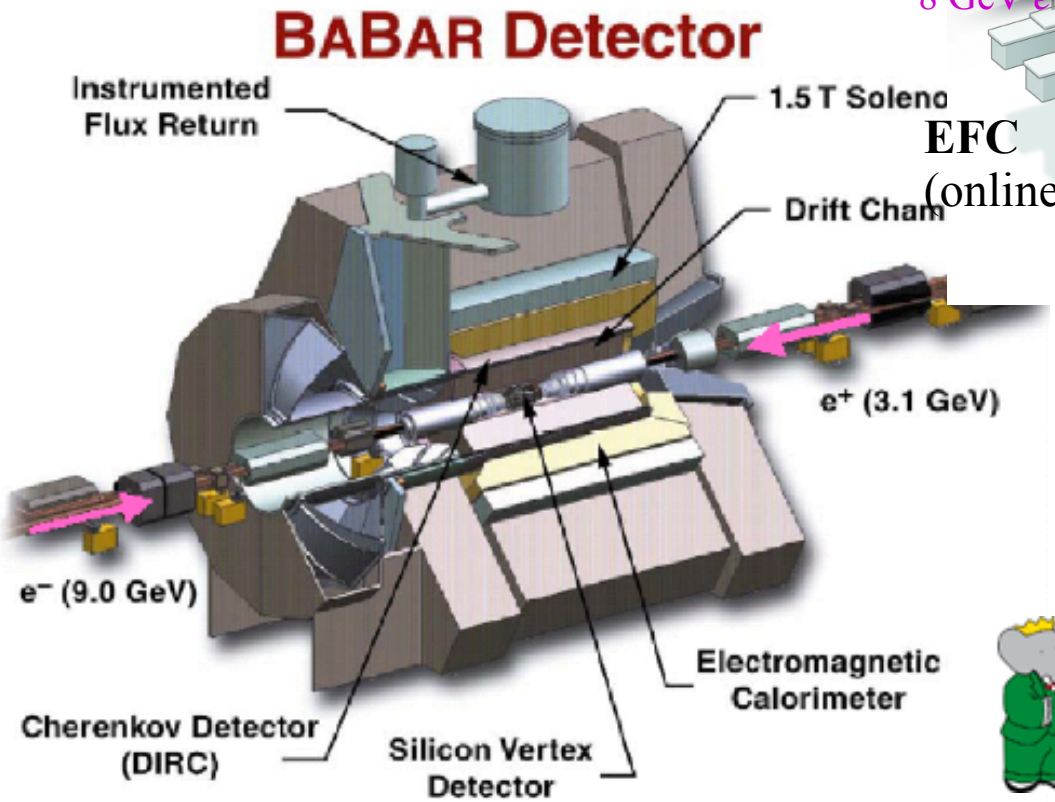
~11mrad crossing angle

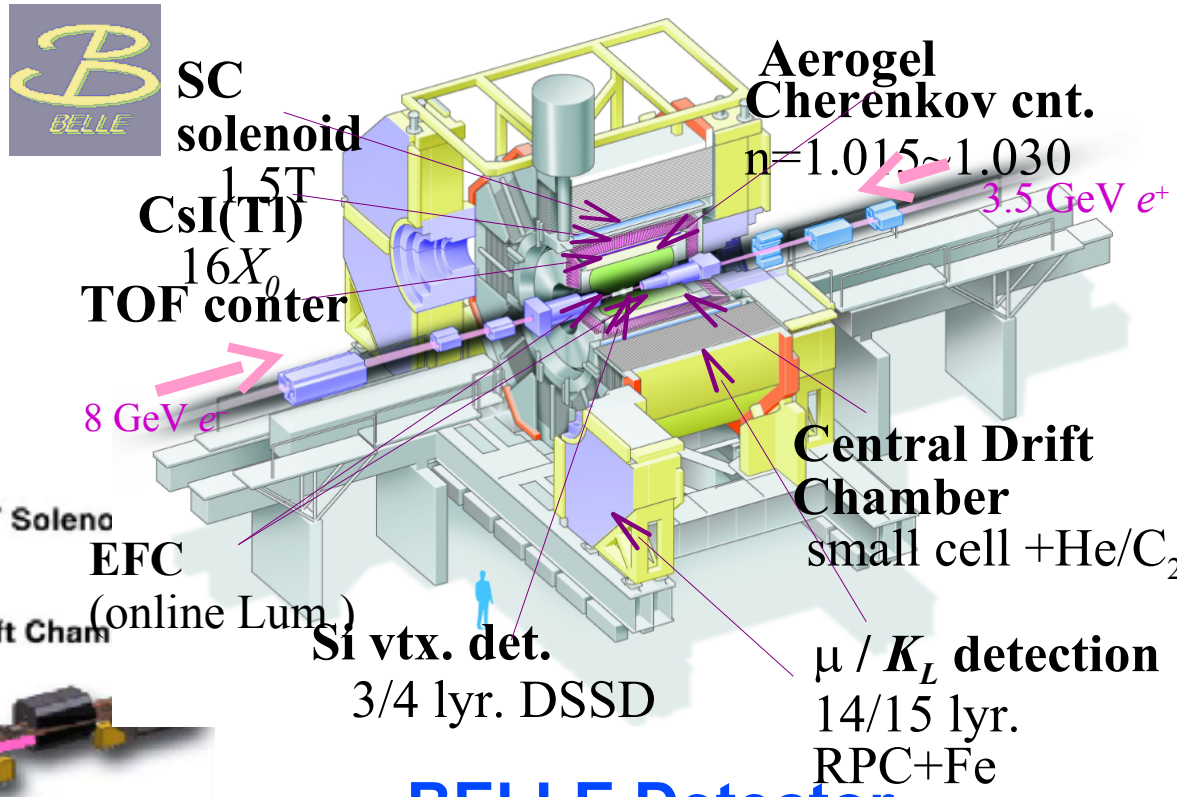
$L_{peak}=1.71 \times 10^{34}\ /cm^2/s^2$



Detector

Up to 348 M BB used





BELLE Detector

535 M BB used

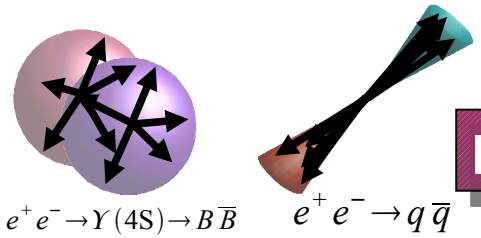
Analysis Overview

- **B extracted with Mbc, ΔE**

$$M_{bc} = \sqrt{E^{*2}_{beam} - p^{*2}_{B}}, \Delta E = E^{*2}_{B} - E^{*2}_{beam}$$

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

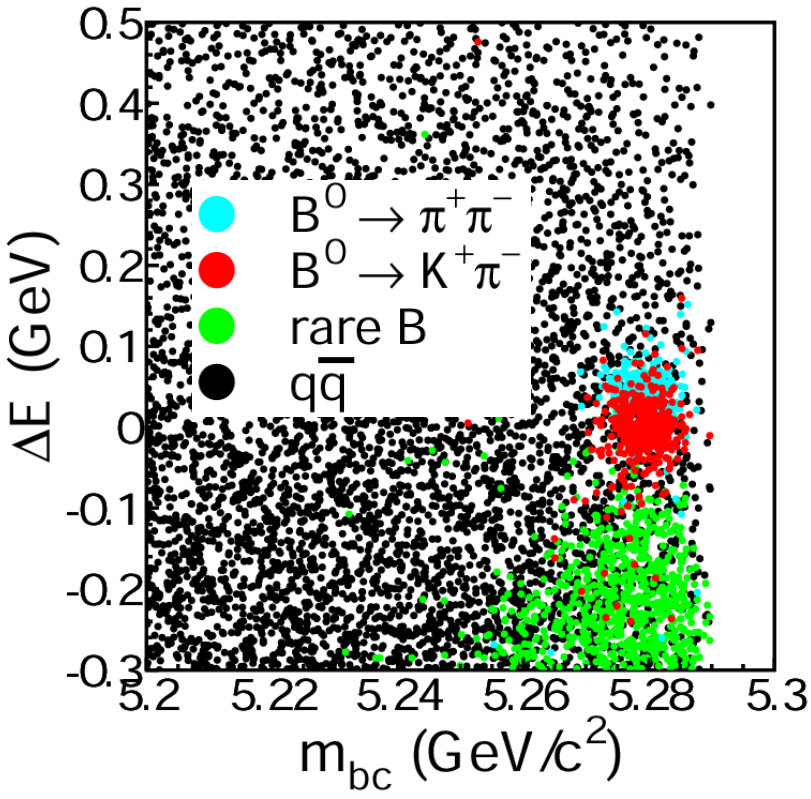
    ➔ event topology



Event Shape

(Spherical) (Jet-like)

  - Feed-across ➔ PID
  - rare B (ρπ,K*π,,,)➔ populate low ΔE



- **Signal extraction**
  - Multi-dim. (ΔE,mbc, $R_{s/b}$, ...)

    unbinned maximum likelihood fit

$$L = \frac{\exp(\Sigma_j N_j)}{N!} \prod_j N_j P_j$$

$$P_j = \frac{1}{2}(1 - q_j A_{CP})\, p_j(M_{bcj}, \Delta E_j, R_{S/B})$$

Time-dept. CP Asym.

CP Asymmetry

Δt: proper time
Δm: mass difference

$$A(\Delta t)=\frac{\Gamma(\bar{B}^0(\Delta t)\to f_{CP})-\Gamma(B^0(\Delta t)\to f_{CP})}{\Gamma(\bar{B}^0(\Delta t)\to f_{CP})+\Gamma(B^0(\Delta t)\to f_{CP})}$$

$$=\frac{2\,\Im\lambda}{1+|\lambda|^2}\sin(\Delta m\cdot\Delta t)+\frac{|\lambda|^2-1}{1+|\lambda|^2}\cos(\Delta m\cdot\Delta t)$$

$$\lambda=\frac{q}{p}\frac{A(\bar{B}^0\to f)}{A(B^0\to f)}$$

$$\approx\eta_{CP}\,e^{-i2\phi_1}$$

$\mathcal{S}$: $-\eta_{CP}\sin 2\phi_1$

Mixing-induced CPV

$\mathcal{A}\,(=-C)\sim 0$

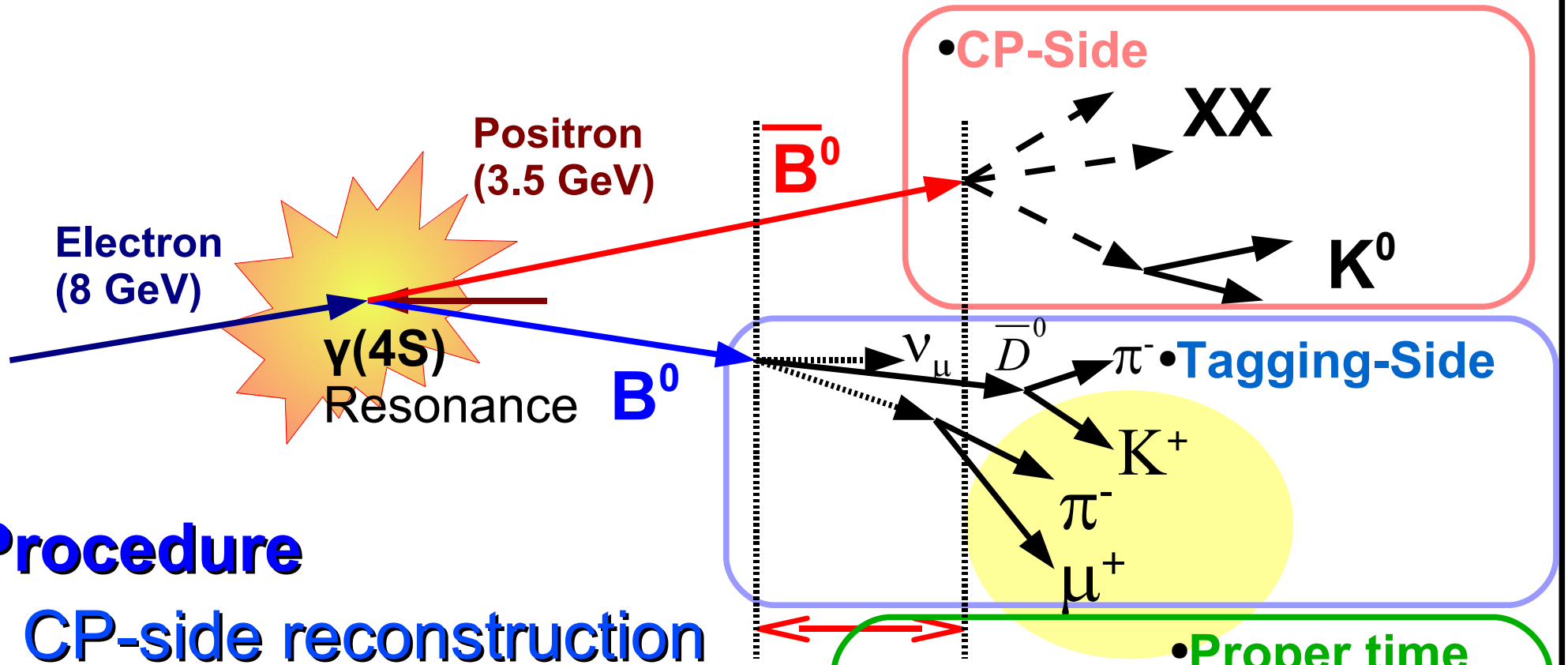
Belle BaBar

Direct CPV

Possible deviation from SM:

$$\Delta S\equiv S_{eff.}-S_{SM}$$

Analysis Procedure



Procedure

- CP-side reconstruction
- Flavor tagging & vertexing
- $\Delta z = \Delta t \, \beta\gamma c$

  Proper time measurement

$$\Delta z = \Delta t \, \beta\gamma c \sim 200 \, \mu m$$

$$\beta\gamma c = 0.43 / 0.56$$

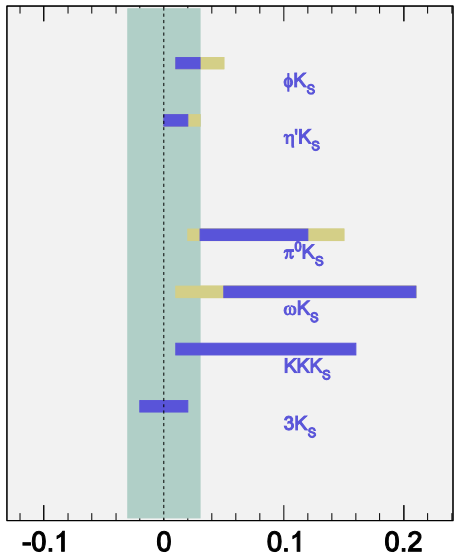
BELLE/Babar

Theoretical Estimation

- $K_SK_SK_S$,$K^0\pi^0\pi^0$:CP-even, $K^0\pi^0$:CP-odd b→s penguin
- $\eta'K^0$, ϕK^0, $K_SK_SK_S$: "Golden modes"
  smallest expected diff. from sin2ϕ_1 in SM
- Expected differences are mostly positive:

Final State	SD+LD
ϕK_S	$0.04^{+0.01+0.01}_{-0.02-0.02}$
ωK_S	$0.02^{+0.03+0.03}_{-0.04-0.02}$
$\rho^0 K_S$	$-0.04^{+0.07+0.10}_{-0.10-0.12}$
$\eta' K_S$	$0.00^{+0.01+0.00}_{-0.02-0.00}$
ηK_S	$0.07^{+0.03+0.00}_{-0.03-0.01}$
$\pi^0 K_S$	$0.04^{+0.01+0.02}_{-0.02-0.02}$

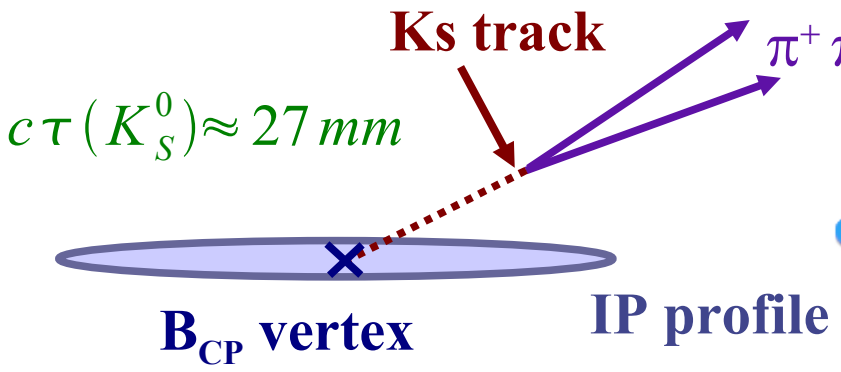
Final State	$\Delta\mathcal{S}_f$
$(K^+K^-K_S)_{\phi K_S}$ excluded	$0.03^{+0.08+0.02+0.00}_{-0.01-0.01-0.02}$
$K_SK_SK_S$	$0.02^{+0.00+0.00+0.01}_{-0.00-0.00-0.02}$



QCD factorization calculation of ΔS

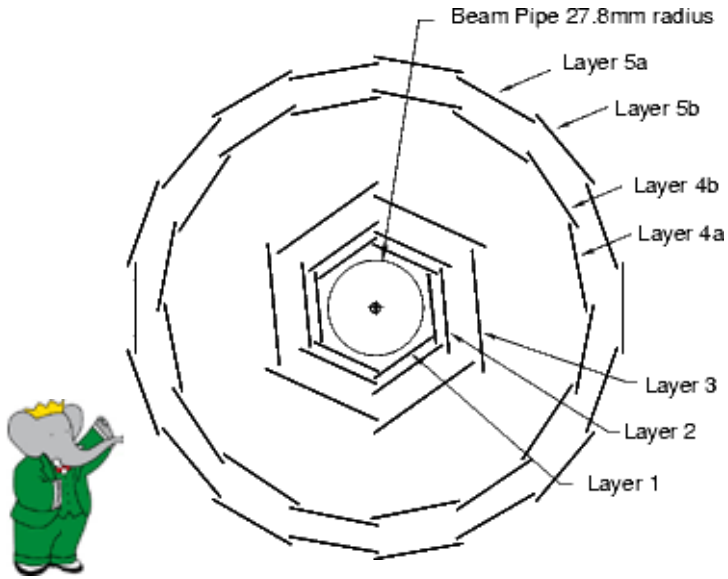
[Chua, talk at FPCP06, hep-ph/0605301]

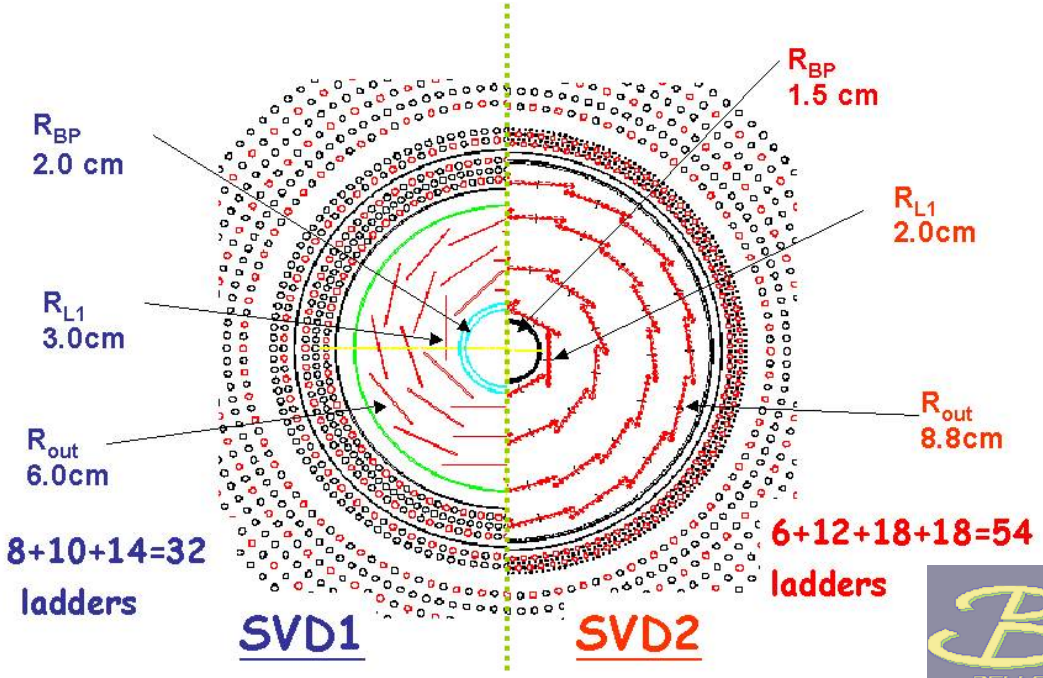
Vertex Reconstruction with K_s



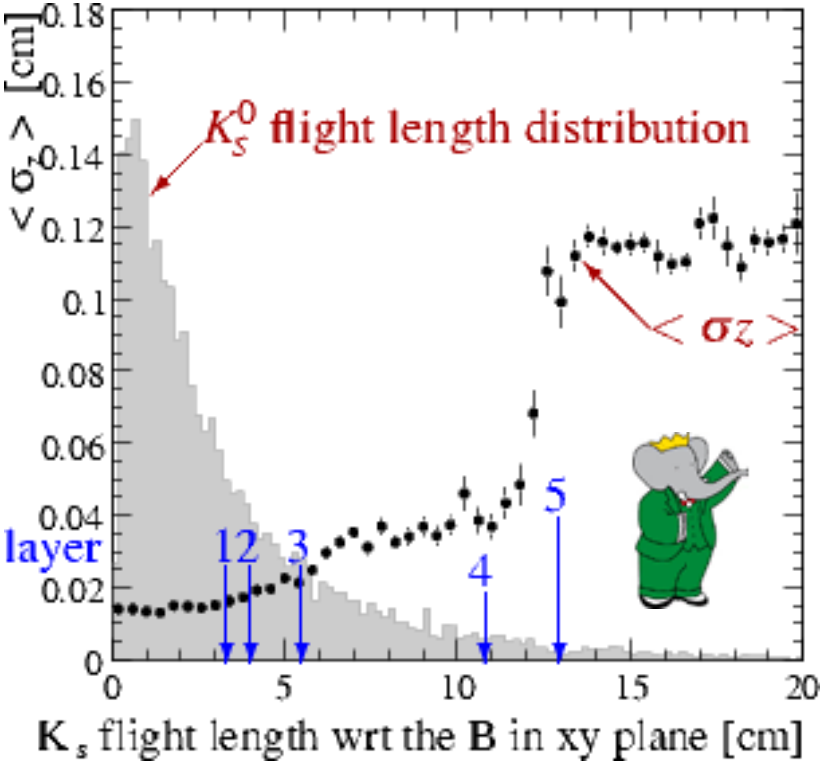
- Extrapolate K_s track to the Interaction Point (IP)
  - First from Babar
- Events w/o the vertex can still be used to measure $\mathcal{A}(-Q)$

SVD size is crucial





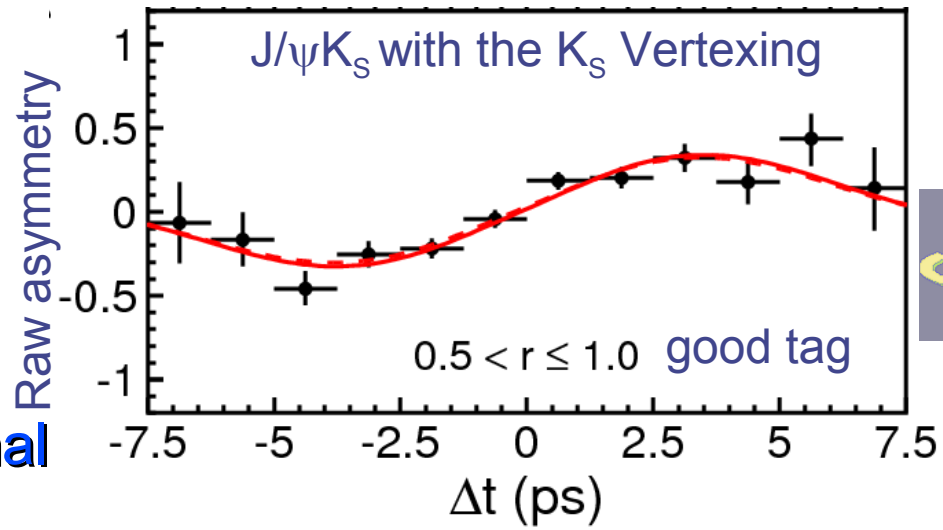
Vertex Reconstruction with K_s



The validity confirmed with the $J/\psi K_S$ control sample.

B^0 Lifetime τ:1.503+/-0.036 ps

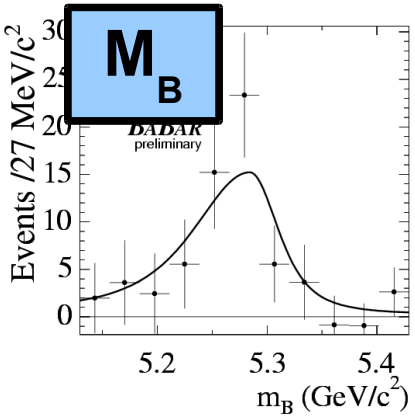
$\sin 2\phi_1$=+0.68+/-0.06

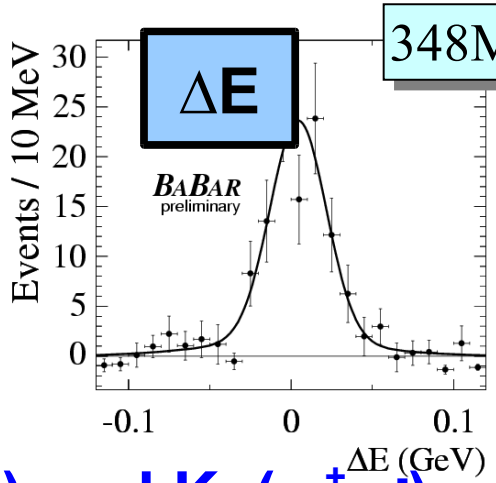


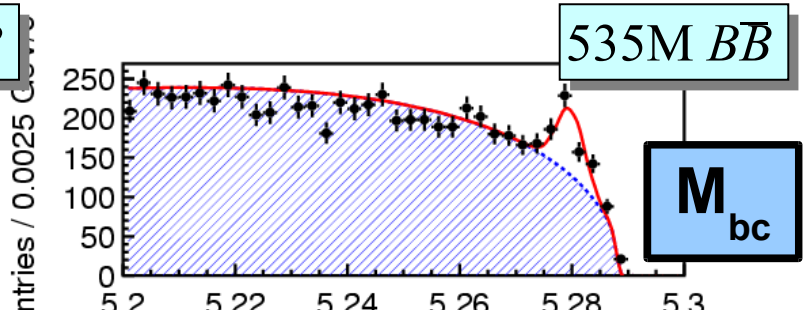
- Events are required to have enough SVD hits for vertexing
- <σz> resolution similar to normal modes

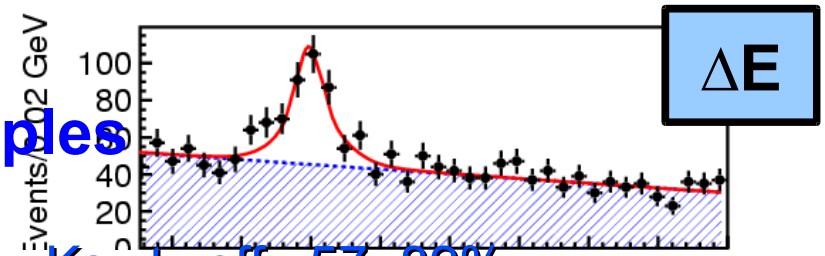
Singal Extraction

$B^0 \to K_S K_S K_S$ Signal





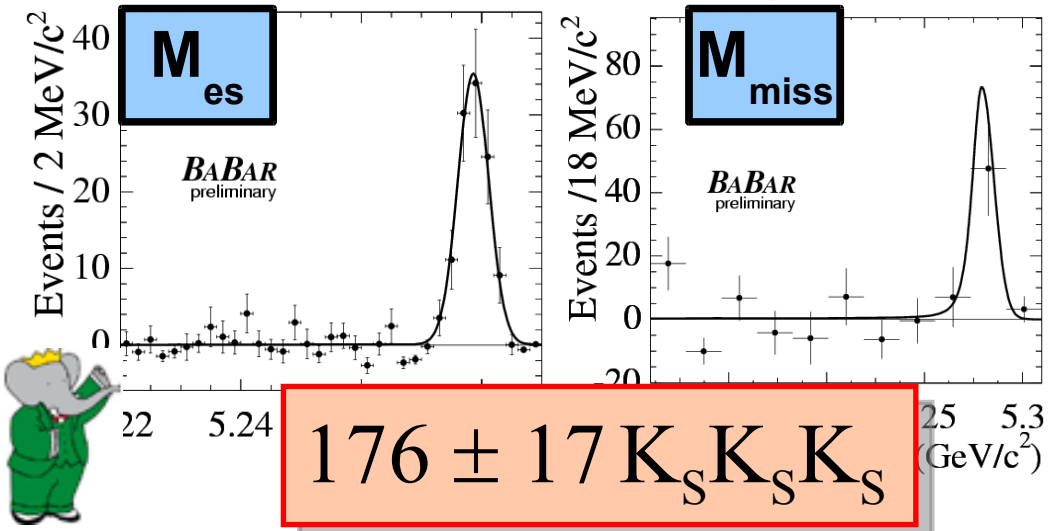


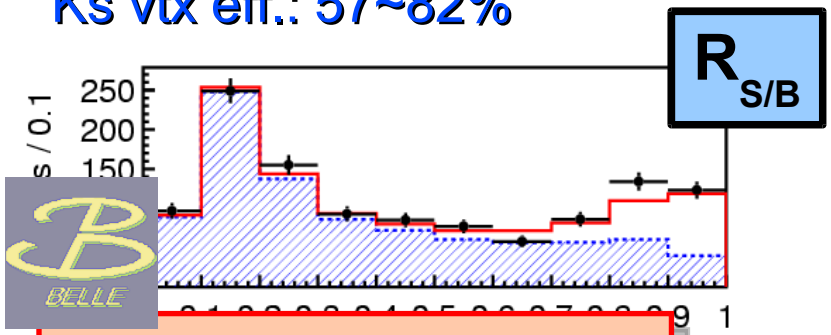


Combining $Ks(\pi^0\pi^0)$ and $Ks(\pi^+\pi^-)$ samples

Ks vtx eff.: ~100%

Ks vtx eff.: 57~82%





$176 \pm 17\ K_S K_S K_S$

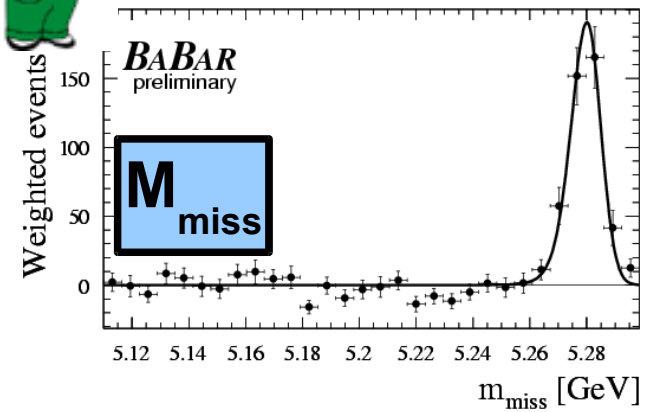
$185 \pm 17\ K_S K_S K_S$

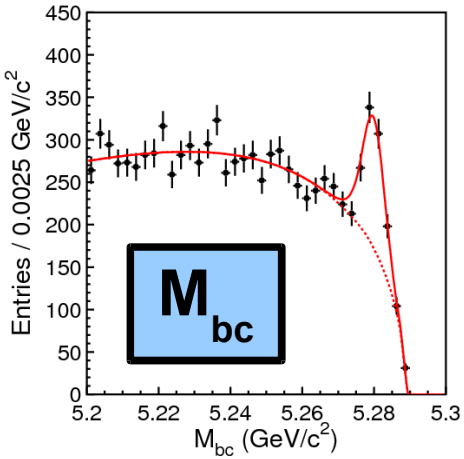
hep-ex/0607108

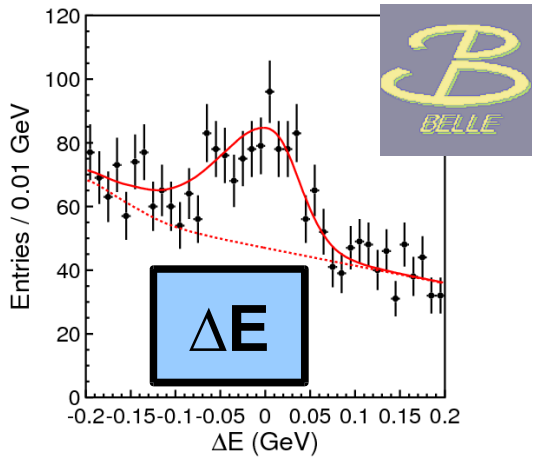
Hep-ex/0608039
Accepted by PRL

$B^0 \to K_S \pi^0$ Signal

348M $B\bar{B}$





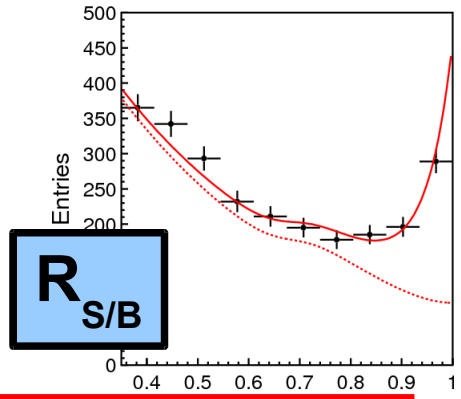


- M_B, M_{miss}, R_2, $\cos\theta_B^*$, tagging
- M_{miss}: constrained mass of tagged B
- Ks vtx eff.: ~60%

$425 \pm 28\ K_S\pi^0$ signal

hep-ex/0607096

535M $B\bar{B}$

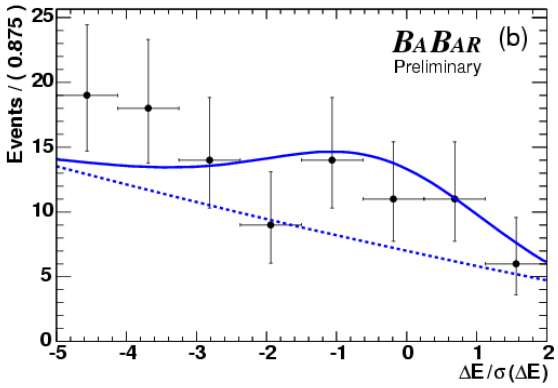


Ks vtx eff.: ~33%

$515 \pm 32\ K_S\pi^0$ signal

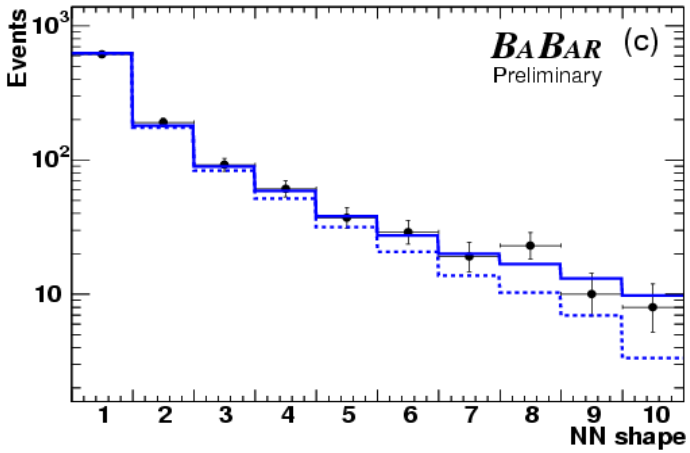
hep-ex/0609006

$B^0 \to K_S\pi^0\pi^0$ Signal

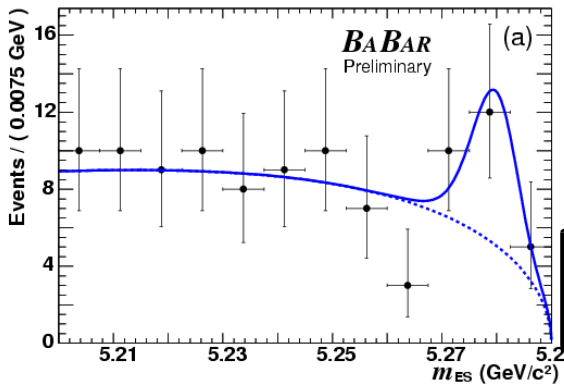


227M $B\bar{B}$

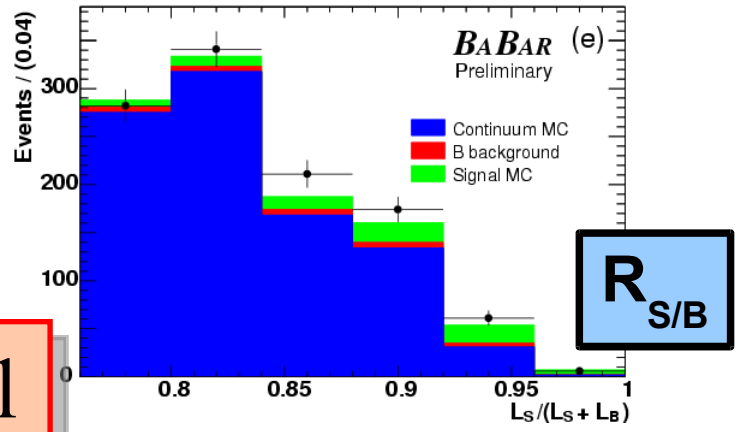
ΔE/σ(ΔE)



NN



M_{es}



$R_{S/B}$

$117 \pm 27\ K_S\pi^0\pi^0$ signal

hep-ex/0508017

Ks vtx eff.: ~70%

tCPV results

$B^0 \to K_S K_S K_S$ tCPV Result

348M $B\bar{B}$

Preliminary

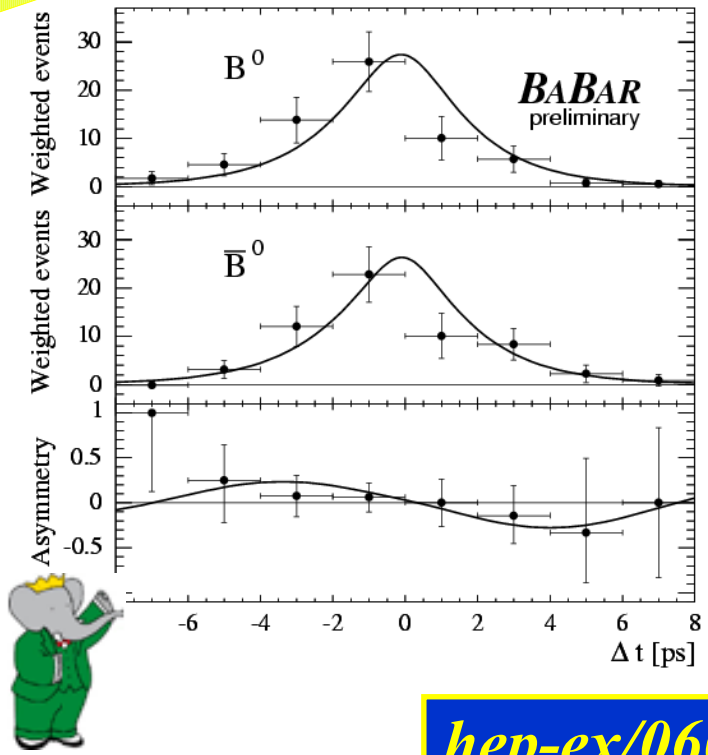
535M $B\bar{B}$

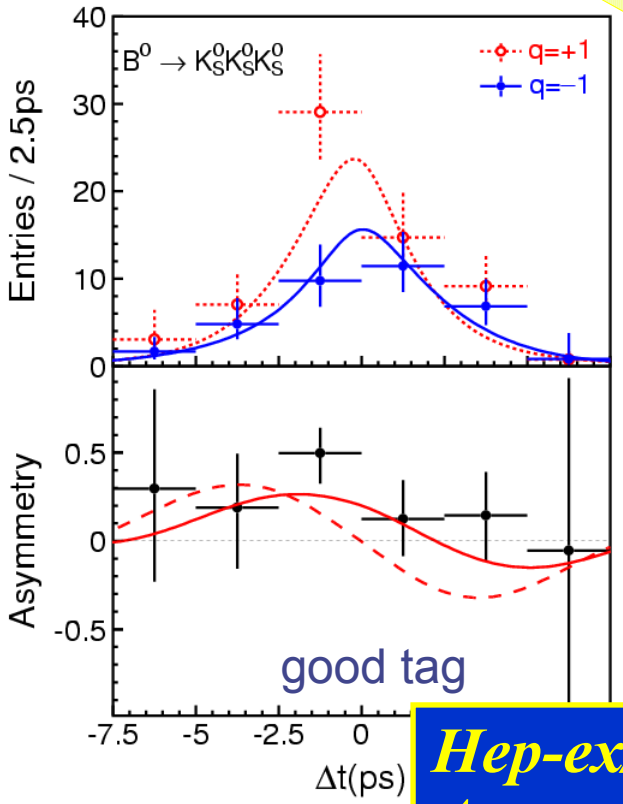
"$\sin 2\phi_1$" = $+0.66 \pm 0.26(\text{stat}) \pm 0.08(\text{syst})$

C = $-0.14 \pm 0.22(\text{stat}) \pm 0.05(\text{syst})$

"$\sin 2\phi_1$" = $+0.30 \pm 0.32(\text{stat}) \pm 0.08(\text{syst})$

$\mathcal{A}$ = $+0.31 \pm 0.20(\text{stat}) \pm 0.07(\text{syst})$





hep-ex/0607108

Hep-ex/0608039
Accepted by PRL

tCPV in $K_S\pi^0$

- $b \to s$ penguin dominant mode: $S \approx \sin 2\phi_1$
  (Possible deviation within SM ~O(0.1))
- A Member of $K\pi$ Family
  $\mathcal{A}_{CP}$ is important to check the sum rule

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{B(K^0\pi^+)}{B(K^+\pi^-)}\frac{\tau_0}{\tau_+}$$

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

[Gronau, Phys. Lett. B627, 82 (2005)]

- No primary tracks from B vertex
  - Vertex reconstruction with K_S trajectory and IP

$B^0 \to K_s \pi^0$ tCPV Result

348M $B\bar{B}$

Preliminary

"$\sin 2\phi_1$" = +0.33 ± 0.26(stat) ± 0.04(syst)

C = +0.20 ± 0.16(stat) ± 0.03(syst)

535M $B\bar{B}$

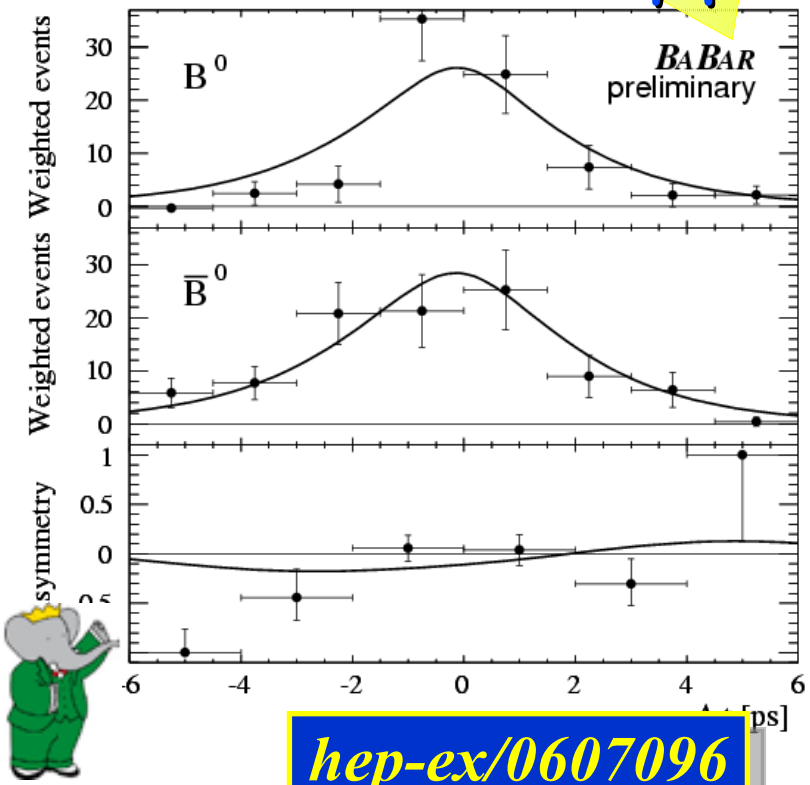
Preliminary

"$\sin 2\phi_1$" = +0.33 ± 0.35(stat) ± 0.08(syst)

A = –0.05 ± 0.14(stat) ± 0.05(syst)

the sum rule expectation

A= –0.15±0.06



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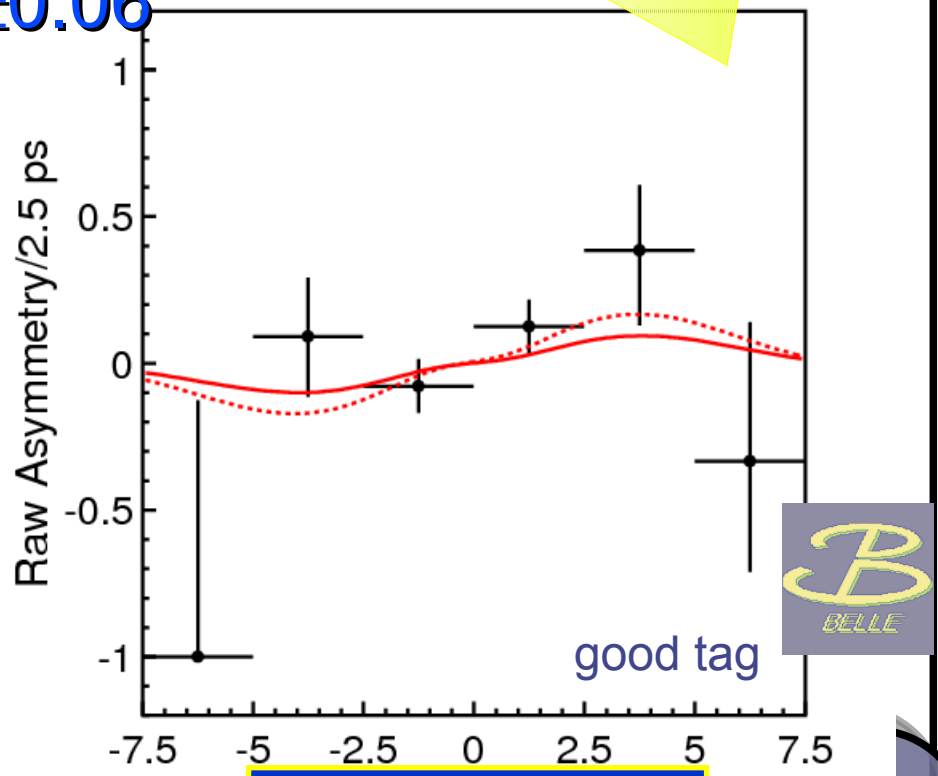


hep-ex/0609006

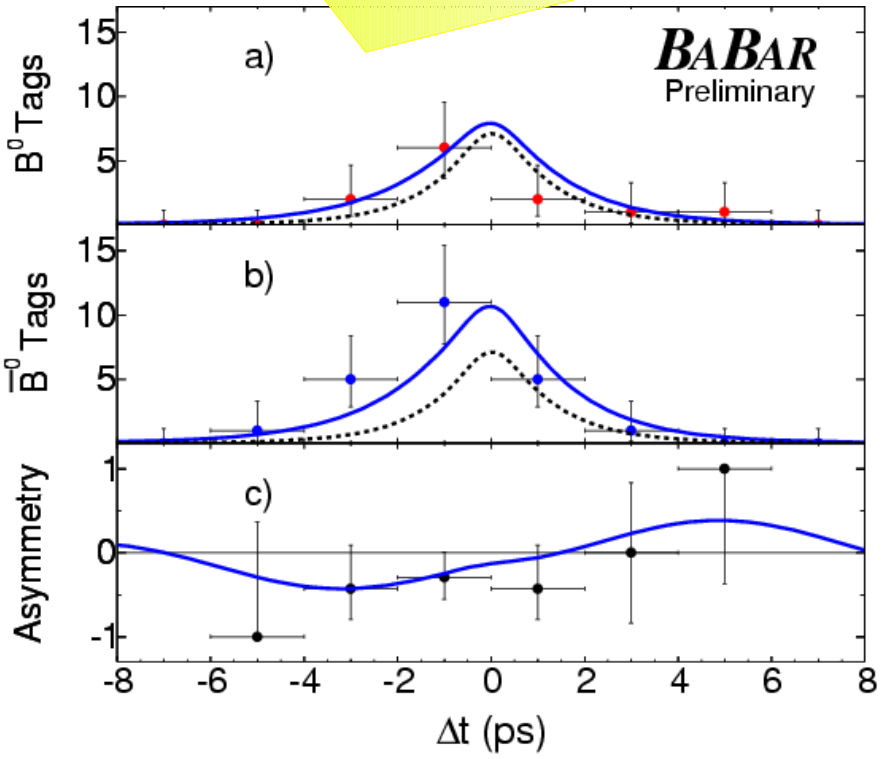
$B^0 \to K_S \pi^0 \pi^0$ tCPV Result

Preliminary

$$\text{“}\sin 2\phi_1\text{”} = -0.84 \pm 0.71(\text{stat}) \pm 0.08(\text{syst})$$

$$C = +0.27 \pm 0.52(\text{stat}) \pm 0.13(\text{syst})$$

272M $B\bar{B}$



- Consistent with SM
- Large stat. Error
  - Need more data

hep-ex/0508017

Summary

Summary & Conclusion

- Results from both B-factories
  - Babar with 348 M BB / 272 M BB
  - Belle with 535 M BB

	S	*A*
KsKsKs	+0.51±0.21	+0.23±0.15
Ksπ°	+0.33±0.21	-0.12±0.11
Ksπ°π°	-0.84±0.72	-0.23±0.14

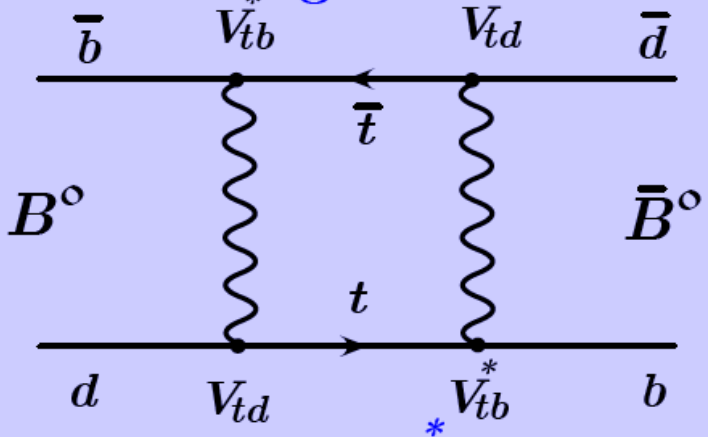
HFAG World Avg.

- Effective sin2φ_1 is lower as other b→s modes
- t*CPV* in b → s: interesting (and tantalizing) hint of deviation from SM expectations:
  - One magnitude more data may resolve the issue
  - Higher luminosity machines are needed

Backup Slides

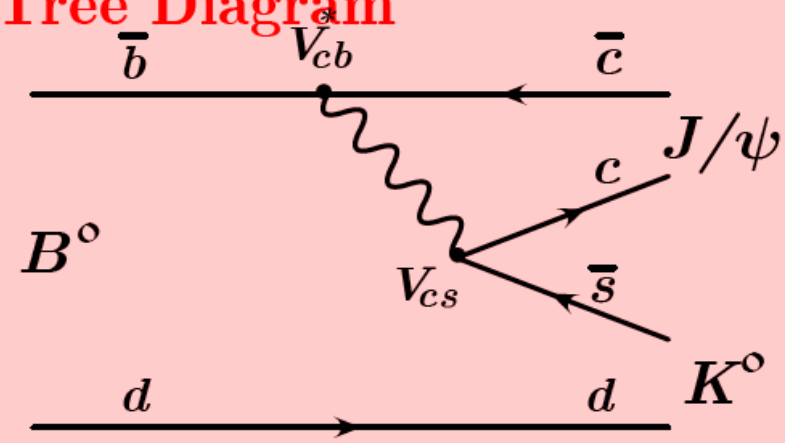
Time-dept. CP Asym.

$B^\circ\bar{B}^\circ$ Mixing



$$\frac{q}{p} \propto \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}$$

Tree Diagram



$$A \propto V_{cb}^* V_{cs}$$

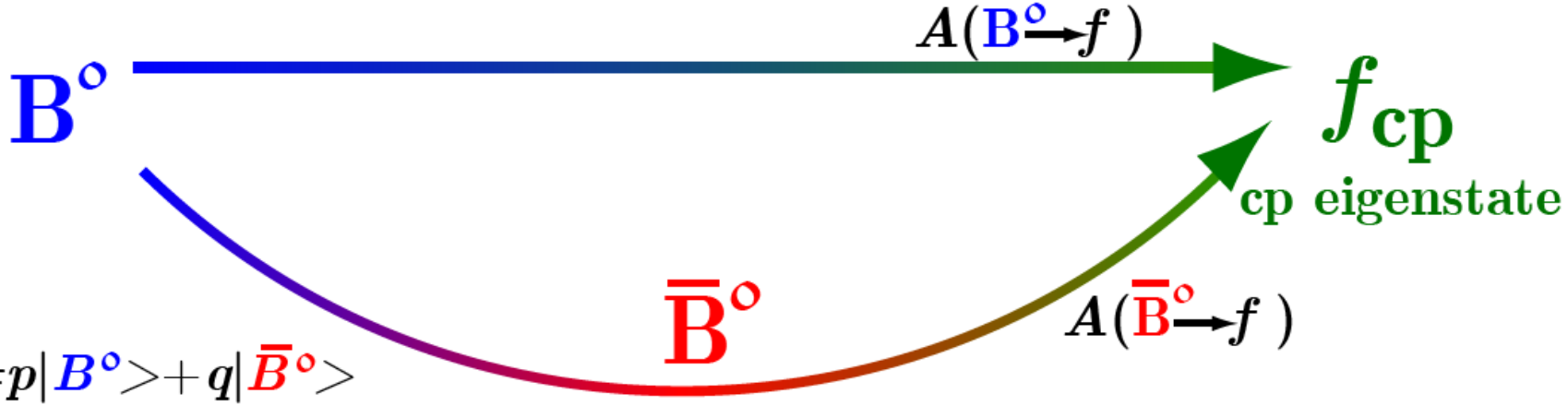
$$\lambda = \frac{q}{p}\frac{\bar{A}}{A} = \eta_{cp} e^{-i2\phi_1} \longrightarrow \begin{array}{l} \mathcal{S} = -\eta_{cp} \sin 2\phi_1 \\ \mathcal{A}(-\mathcal{C}) = 0 \end{array}$$

$$\mathcal{A}(\Delta t) = -\eta_{cp} \sin 2\phi_1 \sin(\Delta m \cdot \Delta t)$$

η_{cp} : CP eigenvalue $= \mp 1$

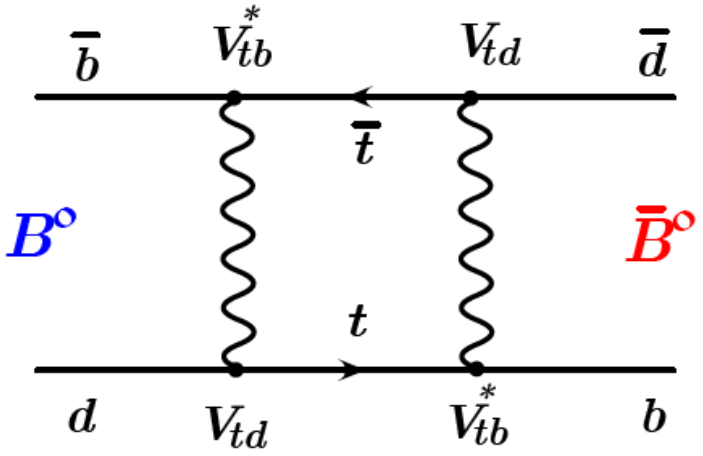
CP Asym. from mixing

Interference between $B^0 \to f_{cp}$ & $B^0 \to \bar{B}^0 \to f_{cp}$



$|B_H\rangle = p|B^0\rangle + q|\bar{B}^0\rangle$

$|B_L\rangle = p|B^0\rangle - q|\bar{B}^0\rangle$



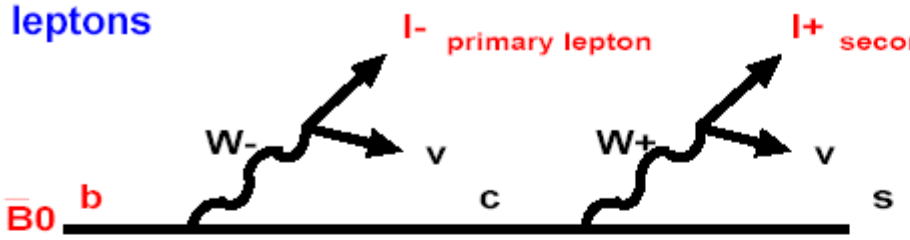
$$\frac{q}{p} \propto \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} = e^{-i2\phi_1}$$

Flavor Tag

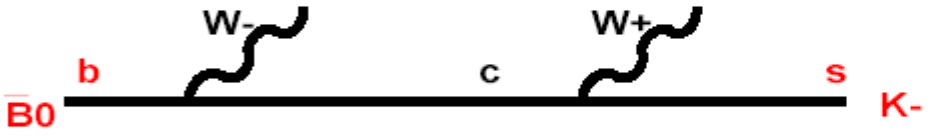
- Use the information of charged particles

NIM A 533, 516 (2004)

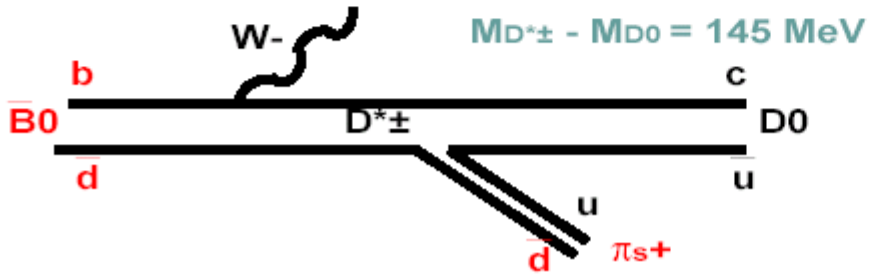
leptons



Kaons



slow pions



Quality of tagging

ε: tagging efficiency

w: wrong tag fraction

$0 \leftarrow w \rightarrow 0.5$

perfect — no flavor info.

$\mathcal{P}(B^0)_{obs} \rightarrow (1-w)\mathcal{P}(B^0) + w\mathcal{P}(\overline{B^0})$

$\mathcal{A}_{obs} \rightarrow (1-2w)\mathcal{A}$

1-2w: dilution factor

	ε	w
lepton	low	low
Kaon	high	high
slow pion	low	high

Systematic Errors

	$\eta'K^0$		$K_S\pi^0$	
	dS	dA	dS	dA
Vertexing	0.013	0.021	0.011	0.020
Flavor tagging	0.004	0.007	0.008	0.005
Resolution	0.035	0.024	0.066	0.010
Physics	0.001	0.007	0.007	0.001
Possible Fit bias	0.007	0.005	0.009	0.004
BG fraction	0.020	0.022	0.009	0.001
BG dt shape	0.004	0.002	0.046	0.019
Tag-side interference	0.001	0.024	0.001	0.043
Total	0.043	0.047	0.082	0.053