Time-dept. CP Asymmetries in $B \to f_0 K_S$, $\rho^0 K_S$, ωK_S, $K_S\pi^0$ at Belle

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Joint Meeting of Pacific Region Particle Physics Communities (JPS/DPF 2006)
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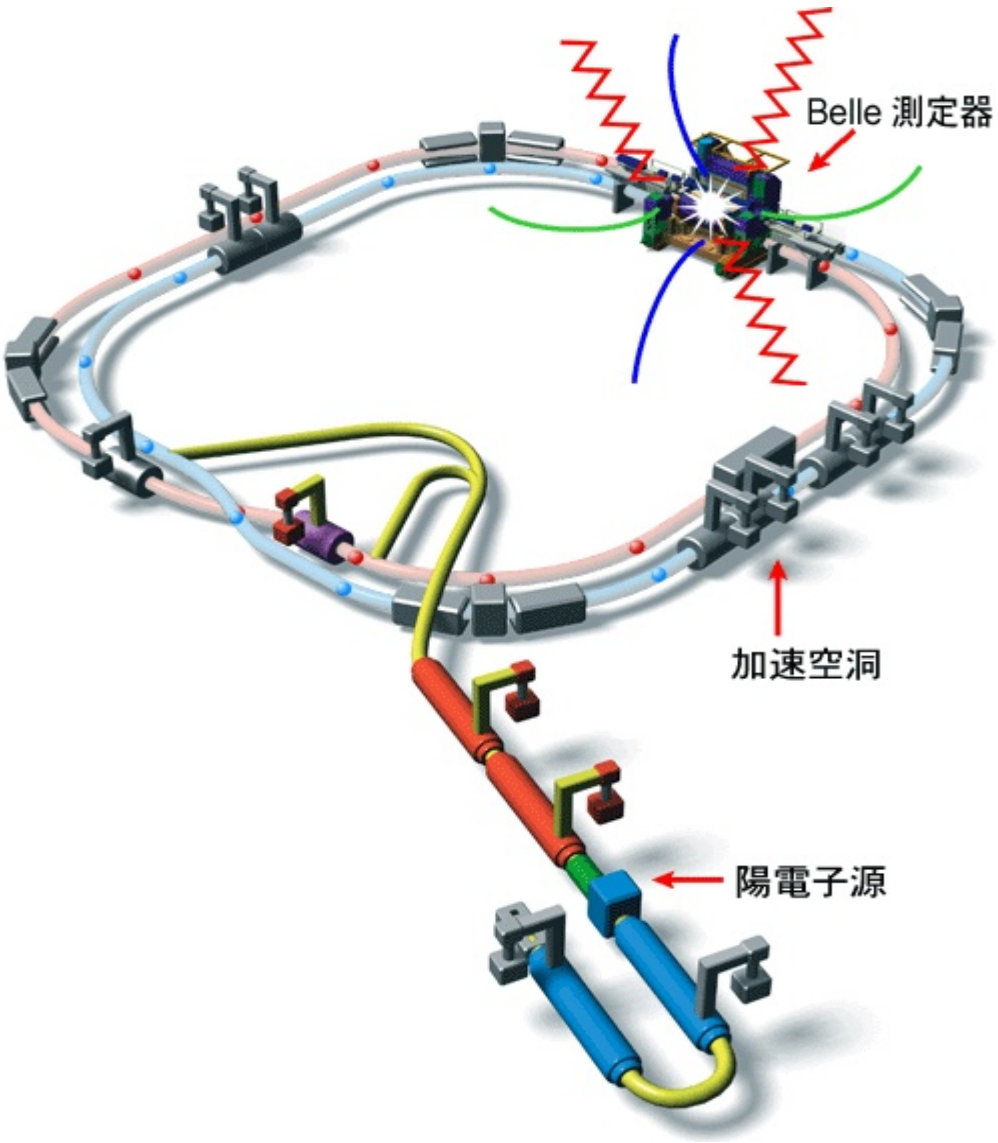
Introduction

KEKB



Tsukuba, Japan

3.5 GeV e^+ on 8 GeV e^-

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

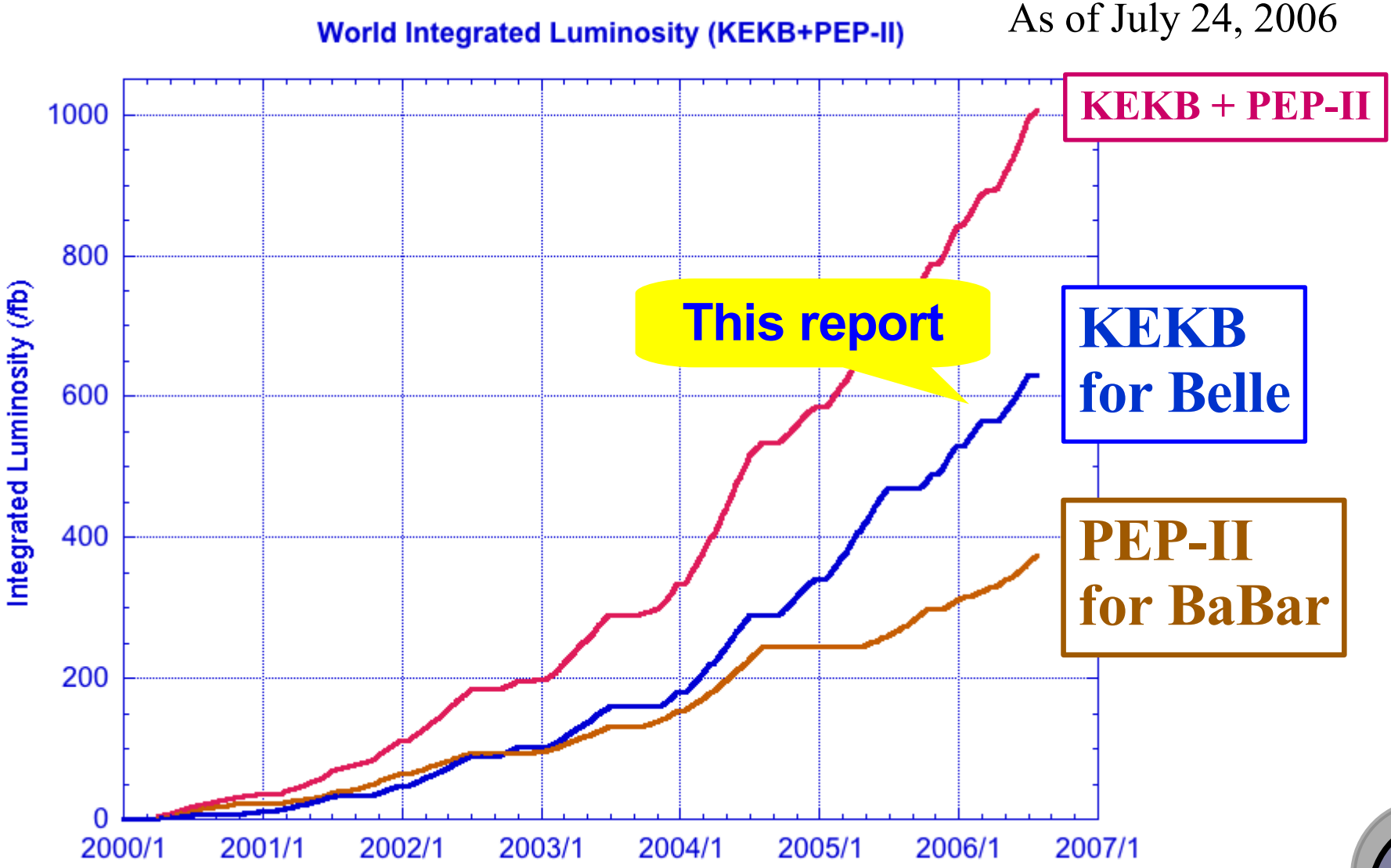
3km circumference

~11mrad crossing angle

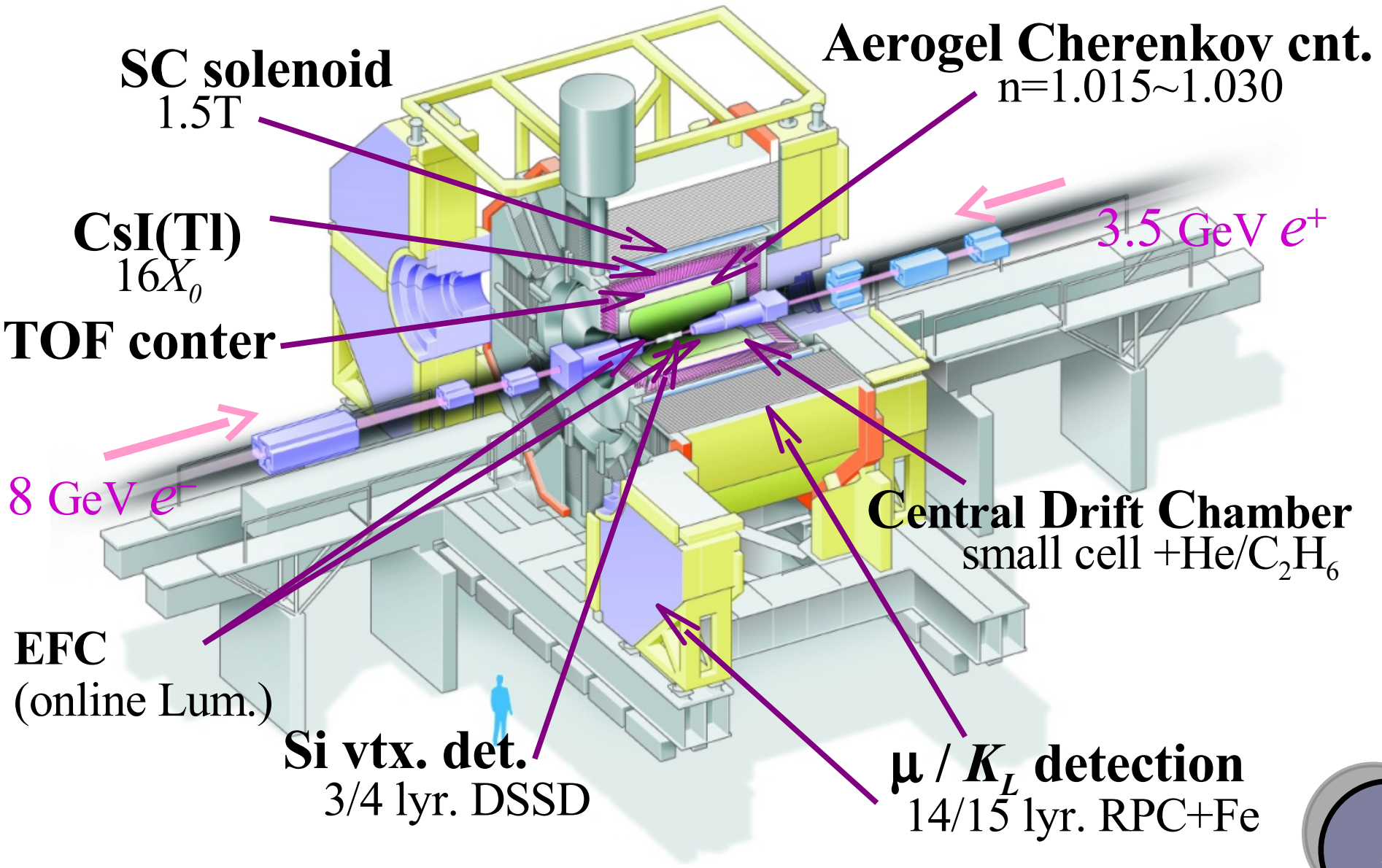
L_{peak}=1.65 x 10^{34} /cm^2/s^2

Integrated Luminosity

As of July 24, 2006



Belle Detector



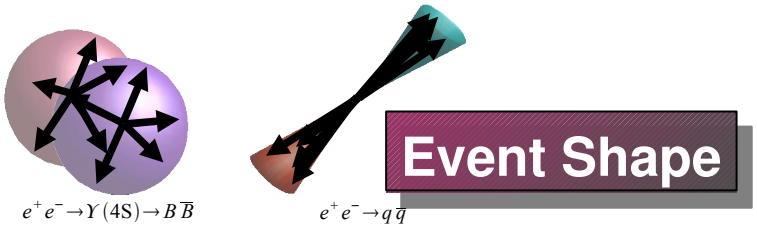
Analysis Overview

- B extracted with Mbc, dE

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

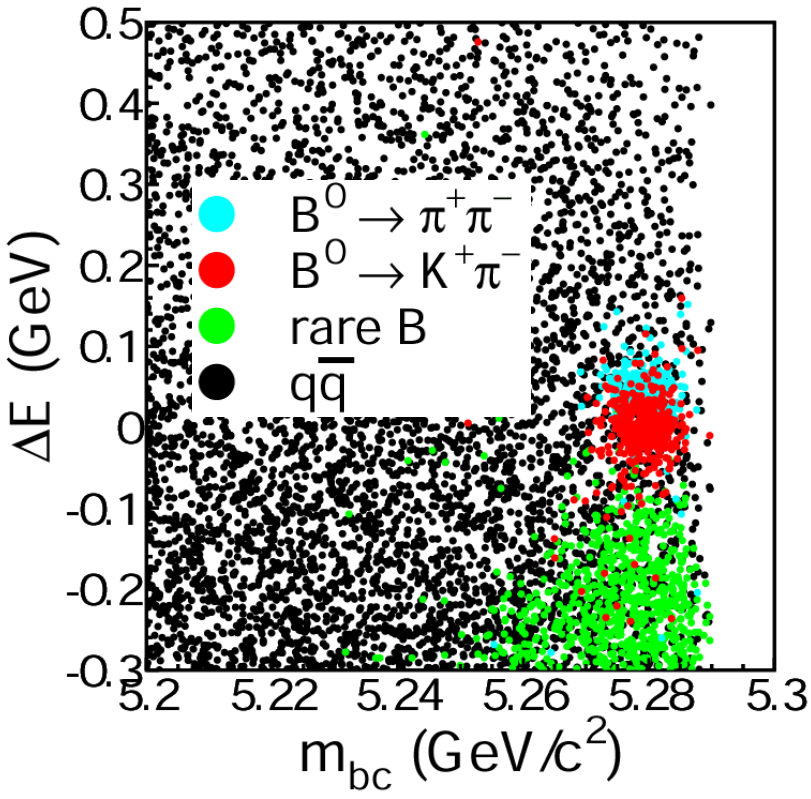
- Major background
  - $e^+e^- \to \gamma^* \to q\bar{q}\ (q=u,d,s,c)$

    ➔ event topology



(Spherical) (Jet-like)

  - Feed-across (ππ⇔Kπ⇔KK)➔ PID
  - rare B (ρπ,K*π,,,)➔ populate low dE



- 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

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

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

$\mathcal{S}$

Mixing-induced CPV

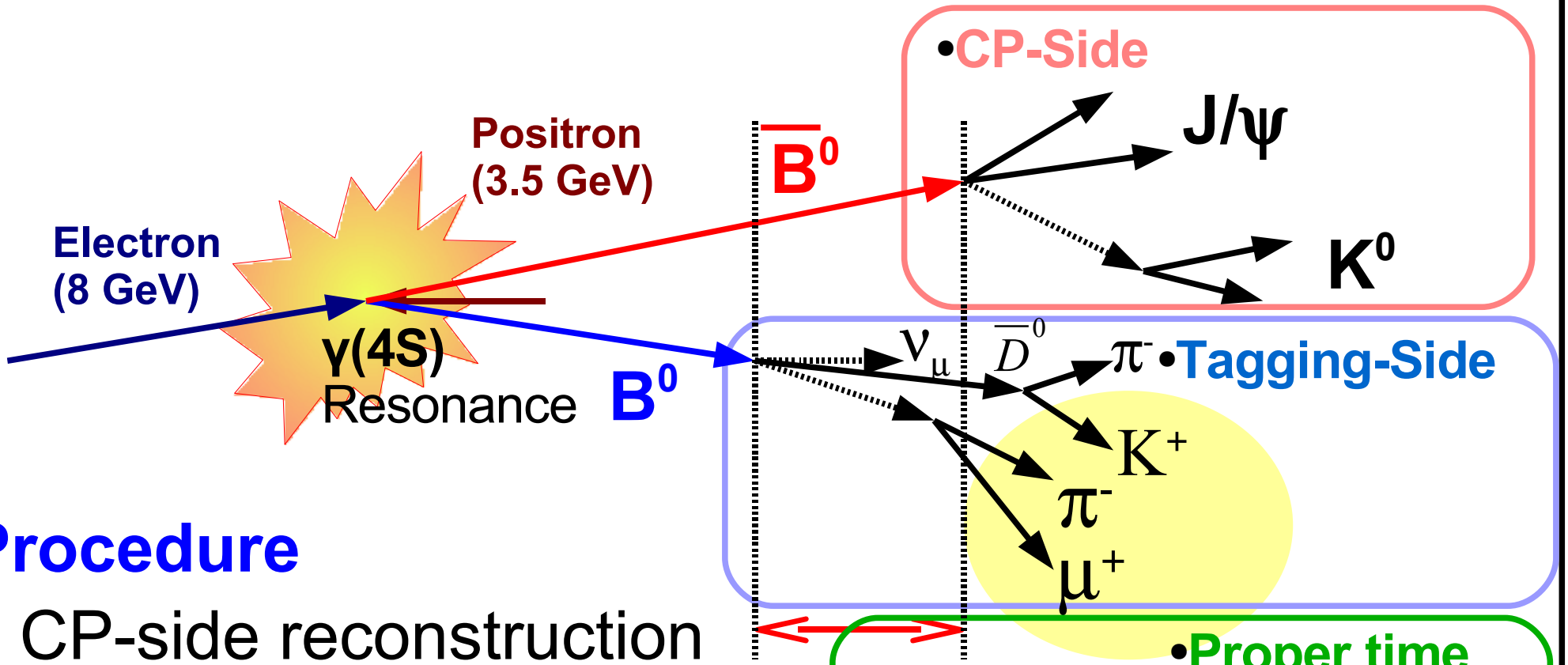
$\mathcal{A}(=-C)$

Belle BaBar

Direct CPV

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

Analysis Procedure



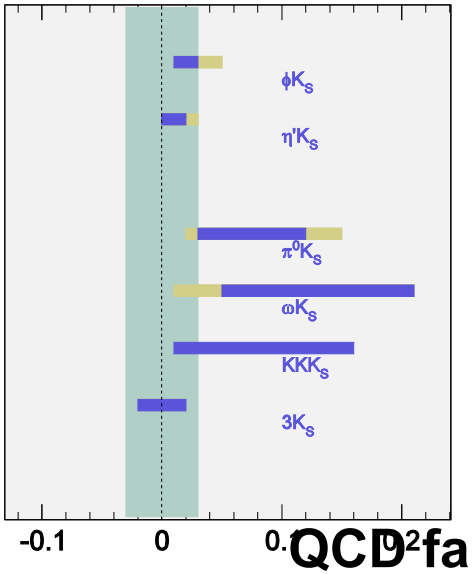
Procedure

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

Theoretical Estimation

- $\eta' K^0$, ϕK^0, $K_S K_S K_S$: "Golden modes"
  smallest expected diff. from $\sin 2\phi_1$ in SM (previous talk)
- 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	$0.07^{+0.03+0.00}_{-0.03-0.01}$
$\pi^0 K_S$	$0.04^{+0.01+0.02}_{-0.02-0.02}$



QCD factorization calculation of ΔS

Final State	ΔS_f
$(K^+K^-K_S)_{\phi K_S}$ excluded	$0.03^{+0.08+0.02+0.00}_{-0.01-0.01-0.02}$
$K_S K_S K_S$	$0.02^{+0.00+0.00+0.01}_{-0.00-0.00-0.02}$

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

New tCPV result for

$B^0 \rightarrow f_0 K_S$ & $B^0 \rightarrow \omega K_S$

Belle 2006: t*CP*V in $B^0 \to f_0 K_s$

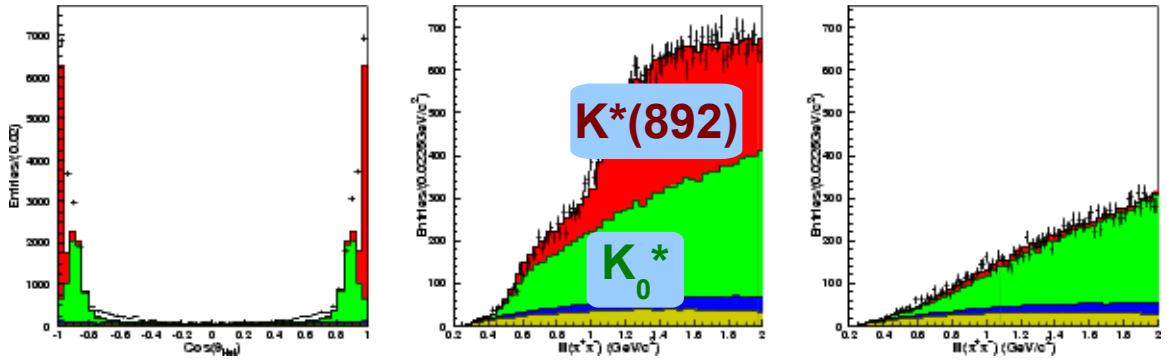
- Signal yeild extracted from a 3D fit
- Non-resonance contribution:

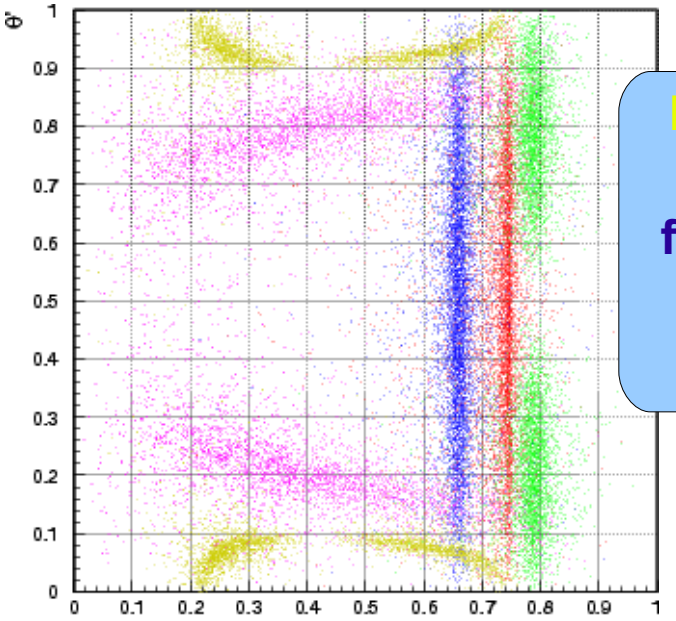
  $K^*\pi$, $K_0^*\pi$ and $\pi\pi Ks$

  eliminated with helicity

  $|\cos\theta_{hel}| < 0.9$
- Fitting components:

  $f_0 Ks$ ρKs $f_x Ks$, non-res.
- Interference considered in syst. err.

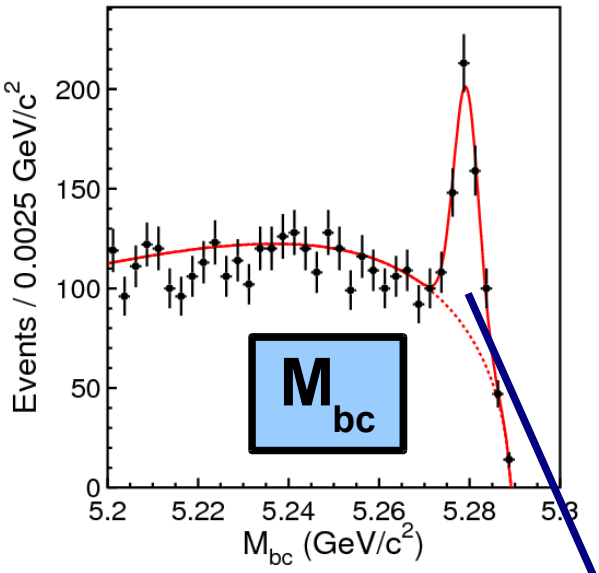


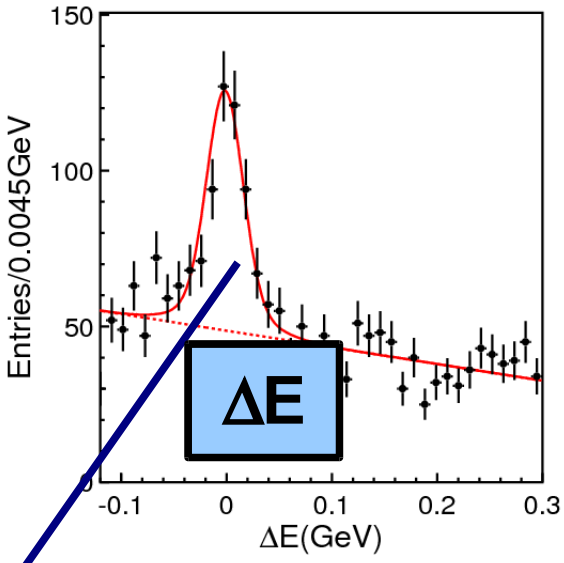


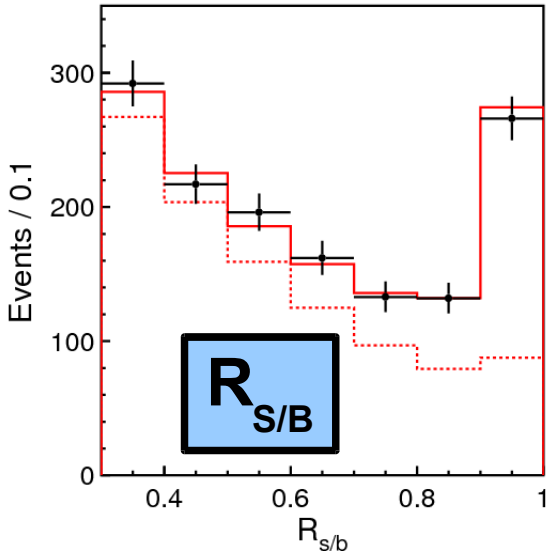
Squared Dalitz plot

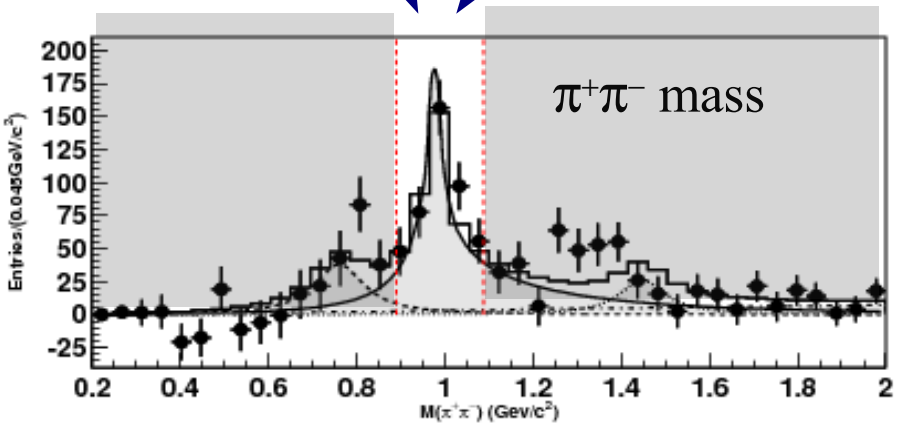
Belle 2006: t*CP*V in $B^0 \to f_0 K_S$

535M $B\bar{B}$









$377 \pm 25\, f_0 K_S$ signal

hep-ex/0609006

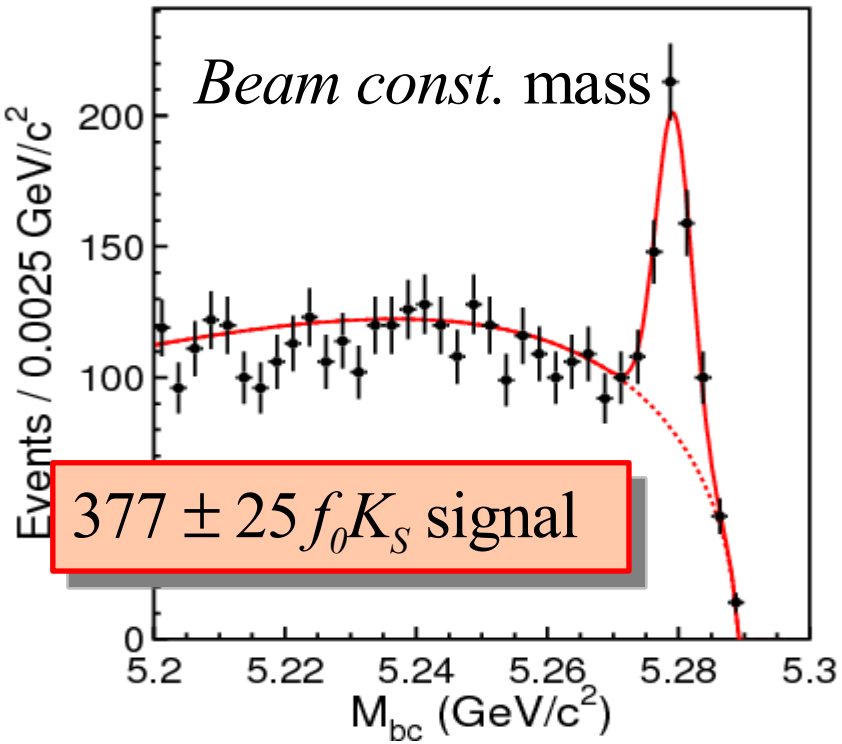
Belle 2006: t*CP*V in $B^0 \to f_0 K_S$

535M $B\bar{B}$

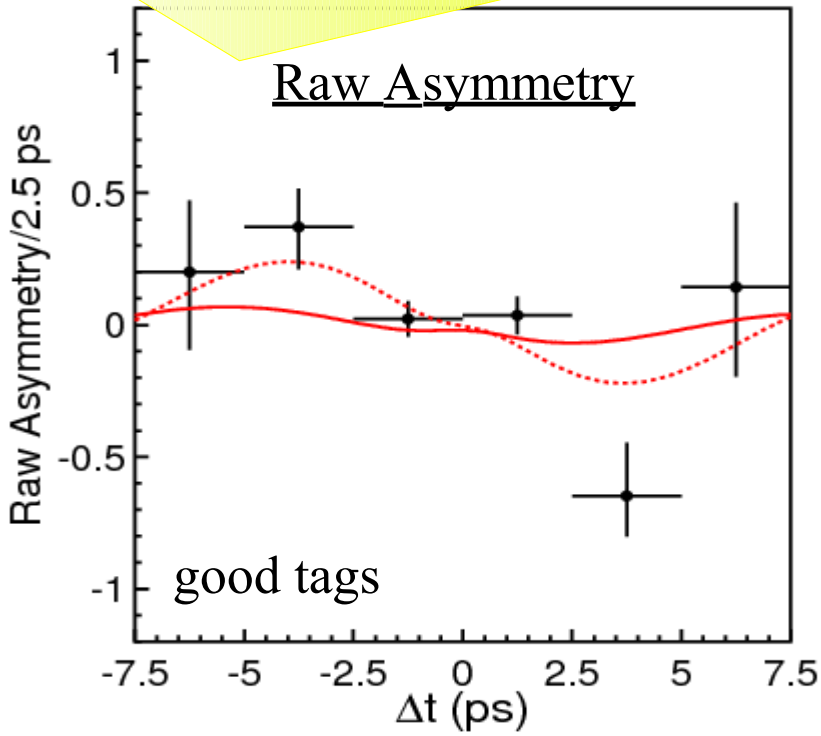
Preliminary

$$\text{“}\sin 2\phi_1\text{”} = +0.18 \pm 0.23(\text{stat}) \pm 0.11(\text{syst})$$

$$\mathcal{A} \quad = -0.15 \pm 0.15(\text{stat}) \pm 0.07(\text{syst})$$



$377 \pm 25\ f_0 K_S$ signal



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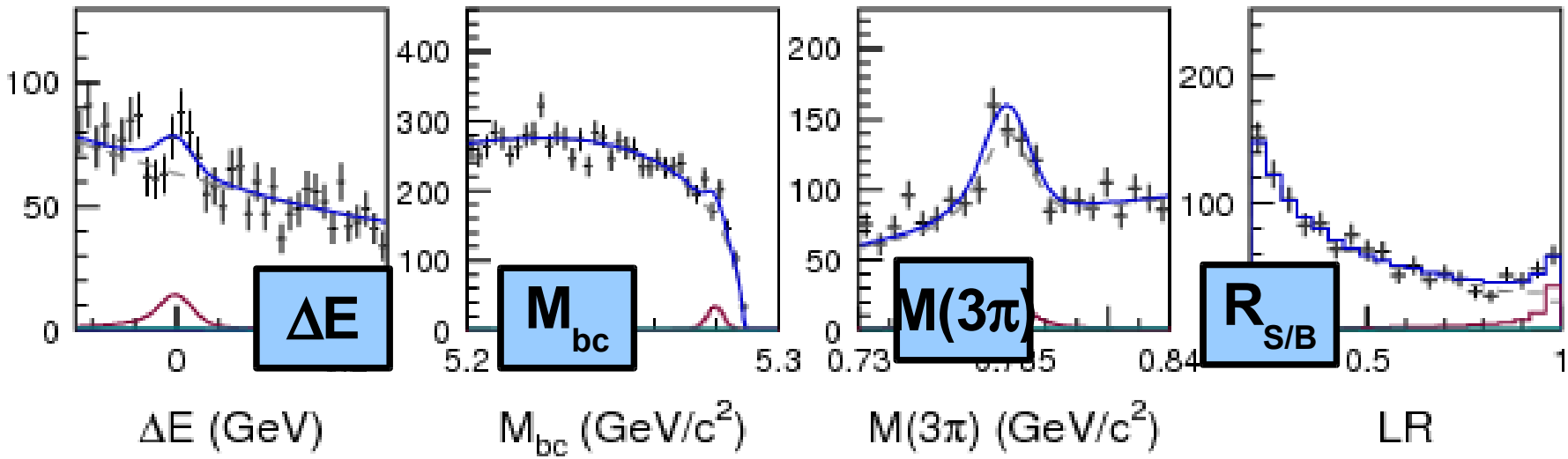
Belle 2006: t*CP*V in $B^0 \to \omega K_S$

535M $B\bar{B}$

- Signal yield extracted from a 4D fit

  Mbc, DE, M(3π), $R_{s/b}$



118 ± 18 ωK_S signal

hep-ex/0609006

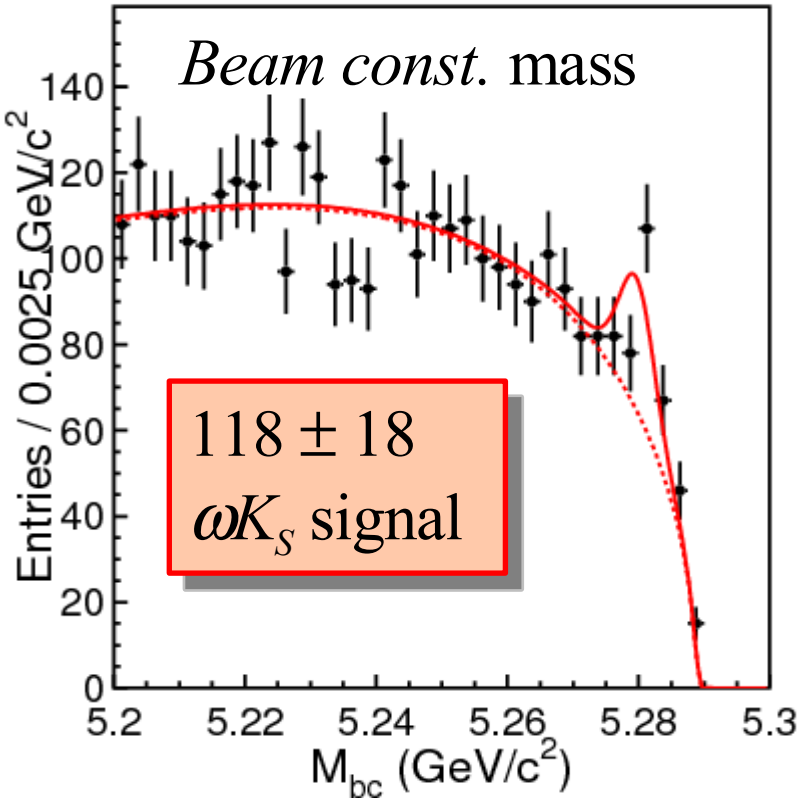
Belle 2006: t*CP*V in $B^0 \to \omega K_S$

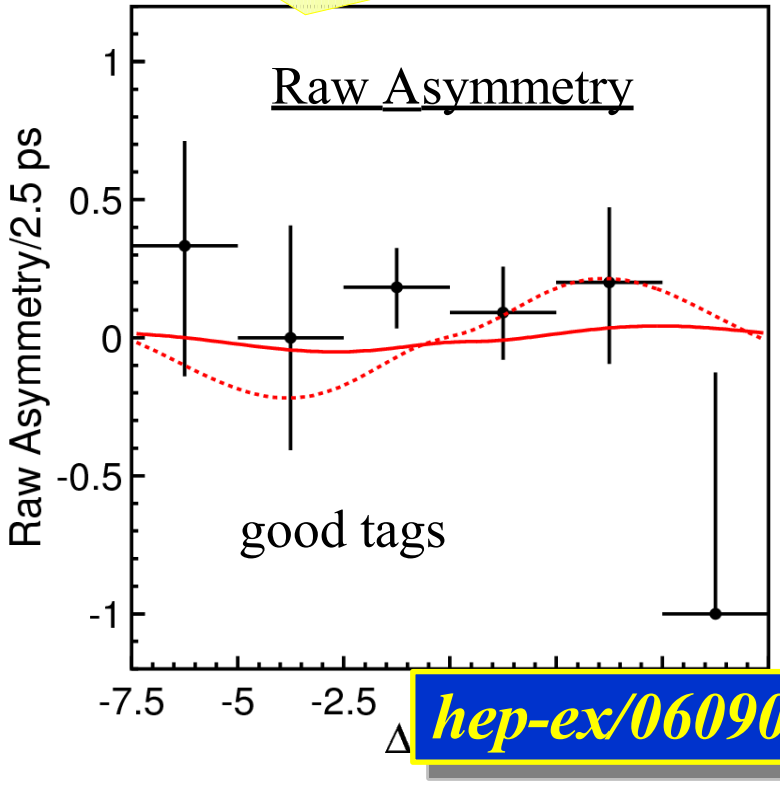
535M $B\bar{B}$

Preliminary

$$\text{“}\sin 2\phi_1\text{”} = +0.11 \pm 0.46(\text{stat}) \pm 0.07(\text{syst})$$

$$\mathcal{A} = -0.09 \pm 0.29(\text{stat}) \pm 0.06(\text{syst})$$





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New tCPV result for $B^0 \rightarrow K_S \pi^0$

tCPV in $K_S\pi^0$

- b→s penguin dominant mode: $\mathcal{S} \approx \sin 2\phi_1$
  (Possible deviation within SM ~O(0.1))
- A Member of Kπ Family

  $\mathcal{A}$ is important to check the sum rule

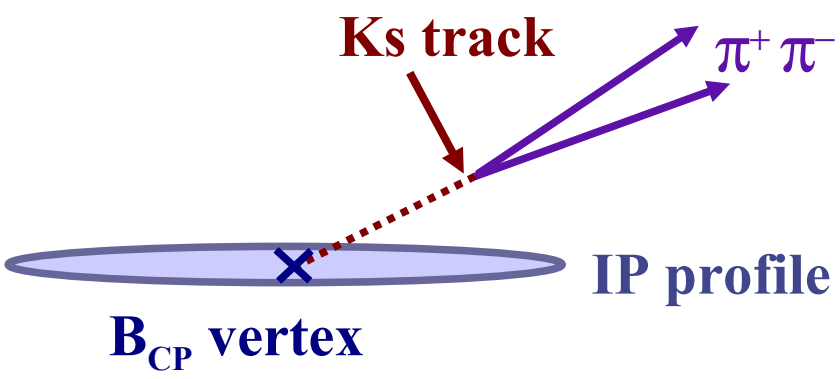
$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{B(K^0\pi^+)}{B(K^+\pi^-)}\frac{\tau_0}{\tau_+}$$

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

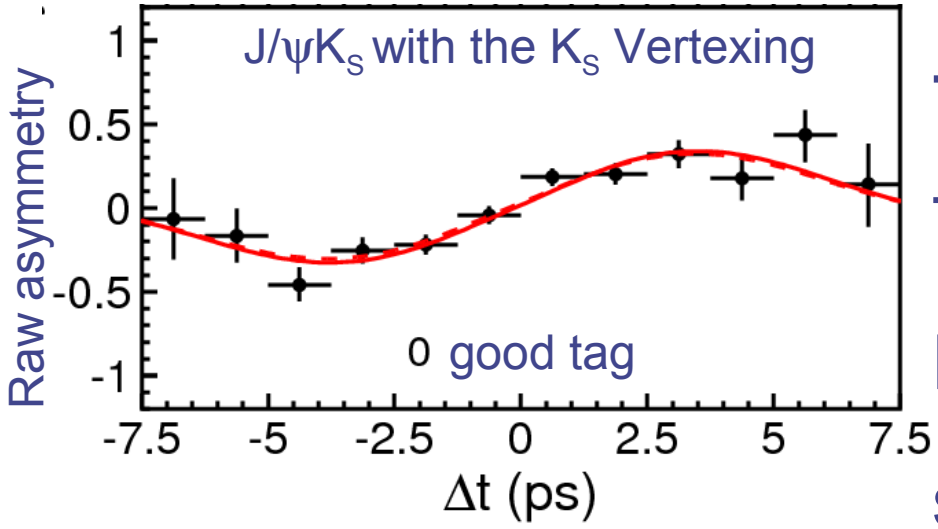
[Gronau, Phys. Lett. B627, 82 (2005)]

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

Vertex Reconstruction with K_S



- Extrapolate K_S track to the Interaction Point (IP)
  - Vertex recon. eff. ~33%
- Events w/o the vertex can still be used to measure $\mathcal{A}$



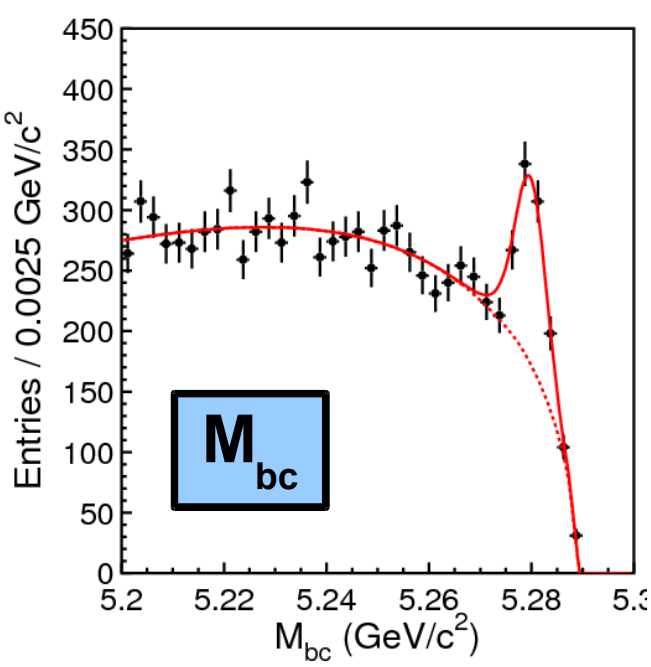
The validity confirmed with the $J/\psi K_S$ control sample.

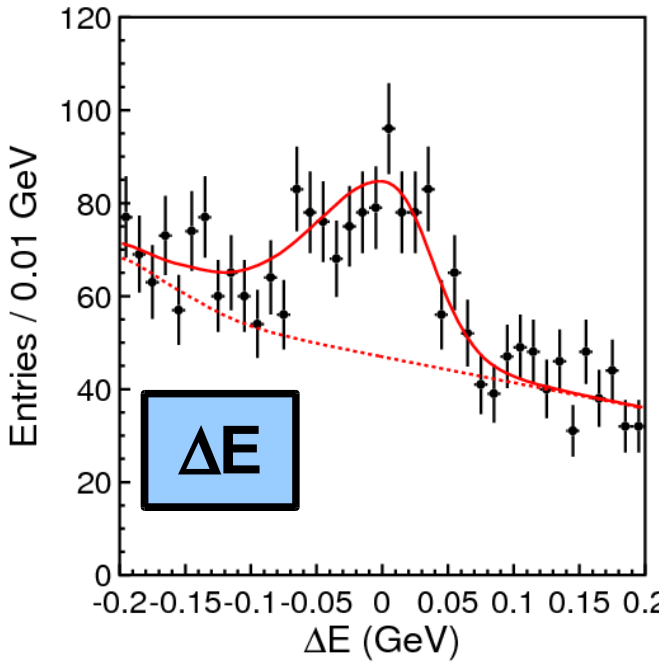
B^0 Lifetime τ:1.503+/-0.036 ps

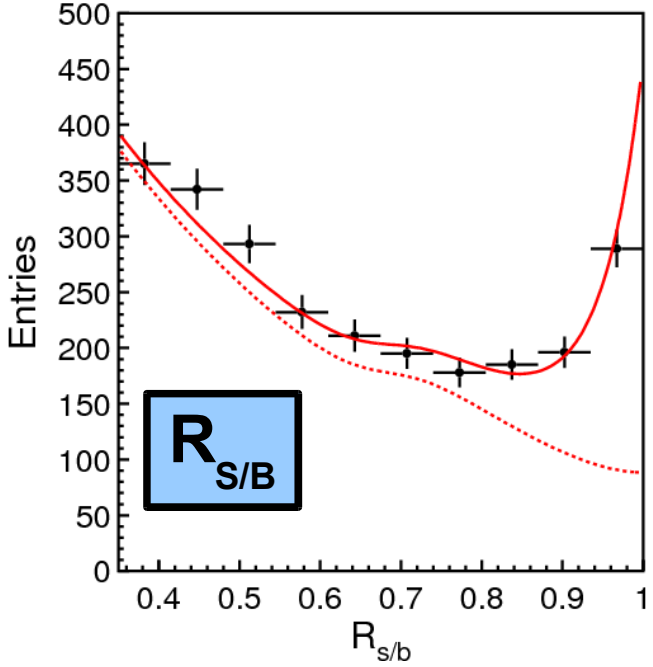
$\sin 2\phi_1$=+0.68+/-0.06

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

535M $B\bar{B}$







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

hep-ex/0609006

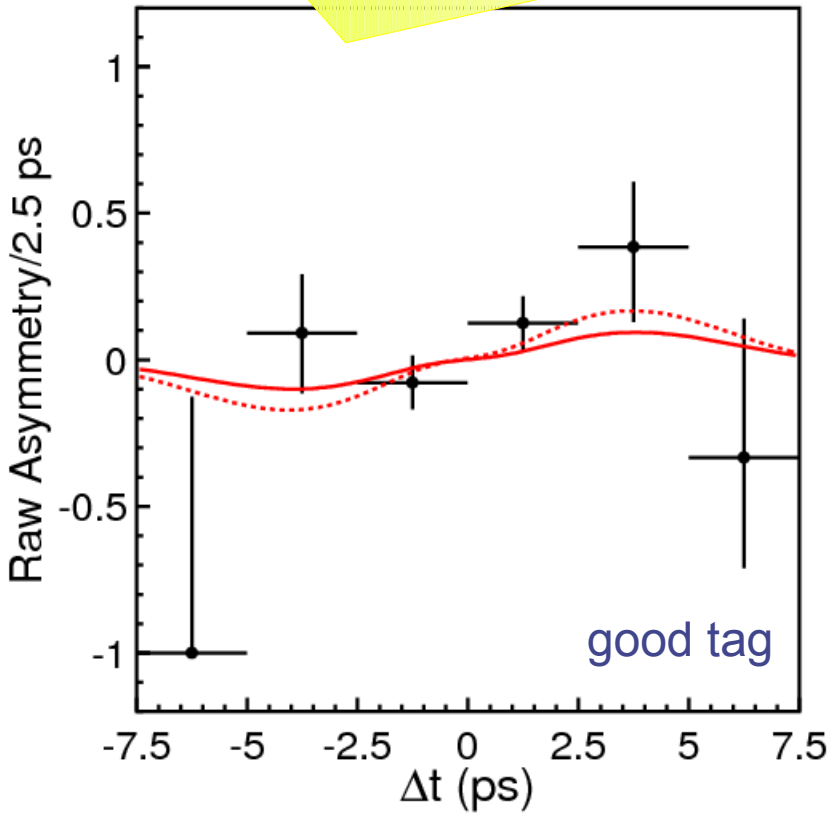
$B^0 \to K_S \pi^0$ tCPV Result

535M $B\bar{B}$

Preliminary

$$\text{“}\sin 2\phi_1\text{”} = +0.33 \pm 0.35(\text{stat}) \pm 0.08(\text{syst})$$

$$\mathcal{A} = -0.05 \pm 0.14(\text{stat}) \pm 0.05(\text{syst})$$



Consistent with:

- $\sin 2\phi_1$ from $b \to c$
- the sum rule expectation $\mathcal{A} = -0.15 \pm 0.06$

using Belle 535M $\mathcal{A}$, Br and PDG2006 τ^+/τ^0

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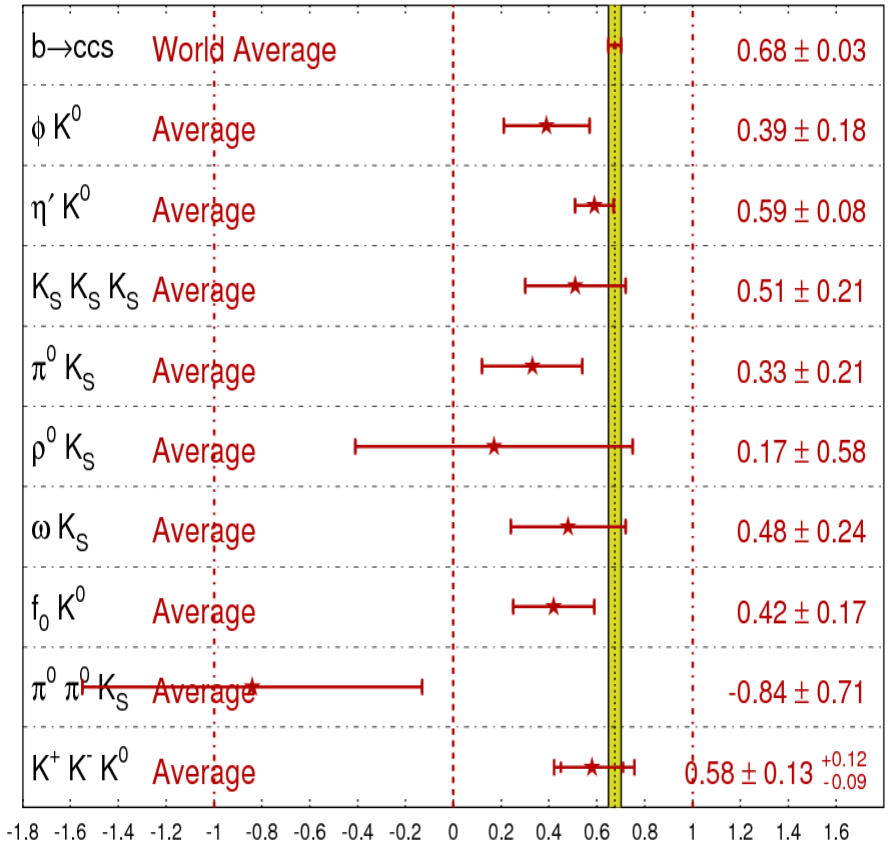
Summary

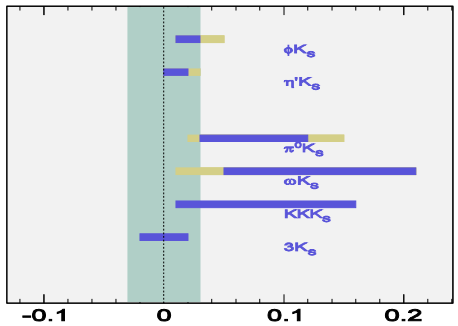
$\phi_1(\beta)$ from b → s penguins

$\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$ HFAG ICHEP 2006 PRELIMINARY



More statistics are crucial in each studied mode

- Smaller than b→ccs in all of the 9 modes
- Theorists tend to predict ***increase*** on $\sin2\beta_{eff}$ (phase in V_{ts})



QCD factorization calculation of ΔS

Naïve average of all b → s modes

$\sin2\beta^{eff} = +0.52 \pm 0.05$

2.6 σ deviation between **Penguin** and **Tree**

(b → s) (b → c)

Summary & Conclusion

- Results from Belle with 535 M $B\bar{B}$

$B^0 \to f^0 K^0$

"$\sin 2\phi_1$" $= +0.18 \pm 0.23 \pm 0.11$

$\mathcal{A} = -0.15 \pm 0.15 \pm 0.07$

$B^0 \to \omega K^0$

"$\sin 2\phi_1$" $= +0.11 \pm 0.46 \pm 0.07$

$\mathcal{A} = -0.09 \pm 0.29 \pm 0.06$

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

"$\sin 2\phi_1$" $= +0.33 \pm 0.35 \pm 0.08$

$\mathcal{A} = -0.05 \pm 0.14 \pm 0.05$

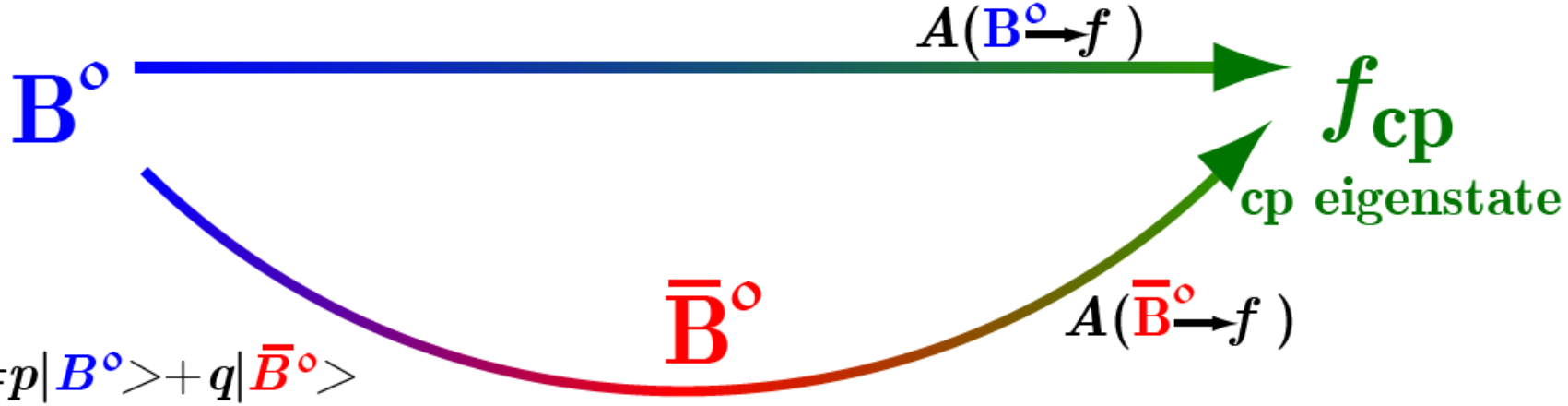
- t*CP*V in b → s: interesting (and tantalizing) hint of deviation from SM expectations:

one magnitude more data may resolve the issue

Backup Slides

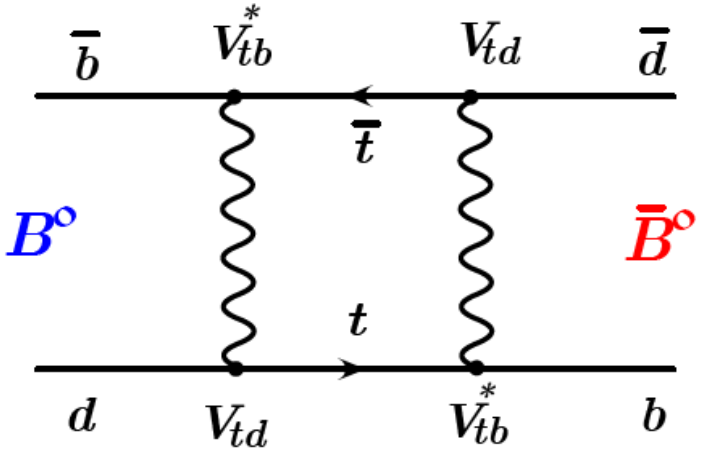
CP Asym. from mixing

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



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

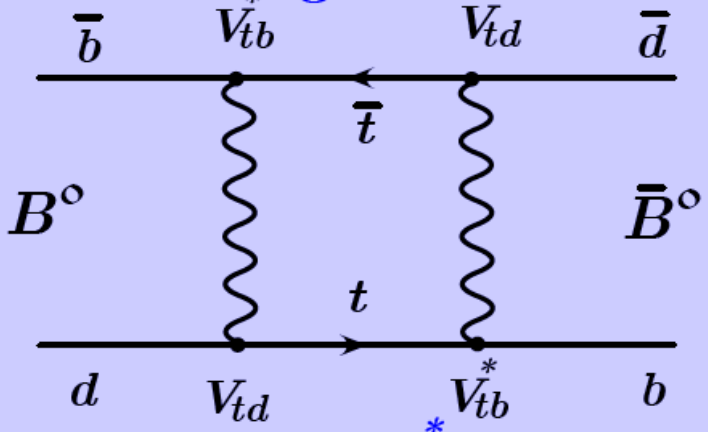
$|B_L\rangle = p|B^0\rangle - q|\bar{B}^0\rangle$



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

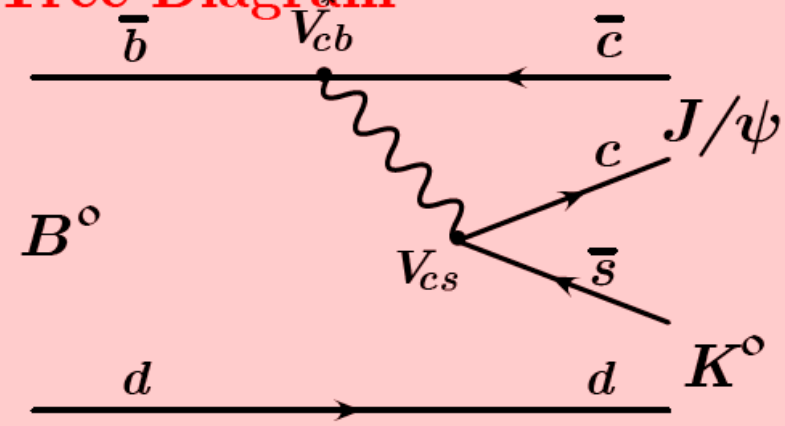
Time-dept. CP Asym.

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



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

Tree Diagram



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

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

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

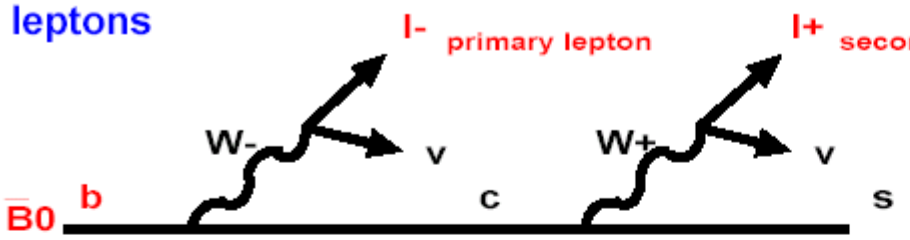
η_{cp} : CP eigenvalue $= \mp 1$

Flavor Tag

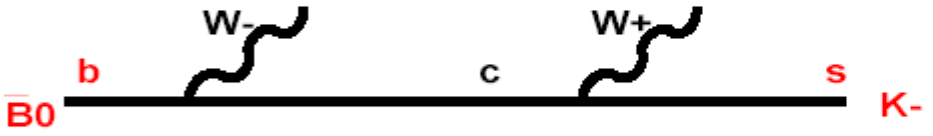
- Use the information of charged particles

NIM A 533, 516 (2004)

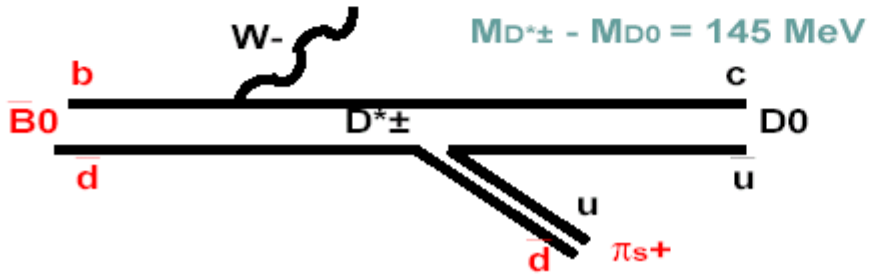
leptons



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

Systematic Errors

$f^0 K_S$

	dS	dA
Vertexing	0.0127	0.0211
Flavor tag	0.0054	0.0062
Resolution	0.0224	0.0083
Physics	0.0022	0.0021
Fit bias	0.0620	0.0212
BG frac	0.0366	0.0292
BG dt	0.0851	0.0396
TSI	0.001	0.043
Total	0.1145	0.0726

ωK_S

	dS	dA
Vertexing	0.013	0.021
Flavor tag	0.015	0.006
Resolution	0.052	0.024
Physics	0.005	0.003
Fit bias	0.011	0.014
BG frac	0.041	0.024
BG dt	0.006	0.005
TSI	0.001	0.044
Total	0.070	0.062

CP Eigenvalues

Mode	ξ_f	$N_{\rm sig}$
ωK^0_S	-1	118 ± 18
$f_0 K^0_S$	$+1$	377 ± 25
$K^0_S \pi^0$	-1	515 ± 32
$K^+ K^- K^0_S$	$+0.86 \pm 0.18 \pm 0.09$	840 ± 34

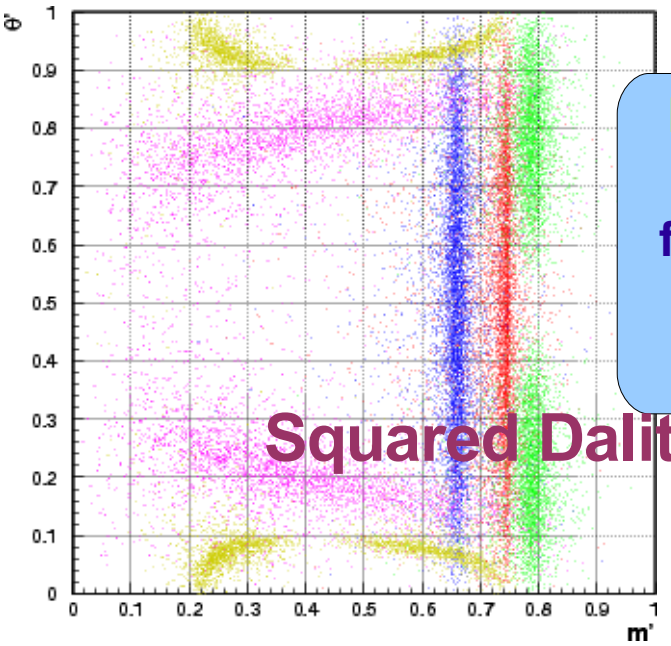
Squared Dalitz plot

$$m' = \frac{1}{\pi} acos\left(\frac{2*(m_{12}-2*M_{\pi})}{(M_B-M_K-2*M_{\pi})}-1\right)$$

$$\theta' = \frac{1}{\pi} acos(\cos\theta_{12})$$

where m_{12}: mass of $\pi^+\pi^-$

$\cos\theta_{12}$: helicity of $\pi^+\pi^-$



Component	Yield	fraction
$f_0 K_S$	$336.6^{+27.4}_{-27.2}$	0.607 ± 0.049
ρK_S	14.5 ± 3.4	0.159 ± 0.038
$f_x K_S$	$1.9^{+0.7}_{-0.6}$	0.102 ± 0.035
NR ($f_{NR} = 1 - f_{f_0} - f_\rho - f_{f_x}$)	12.2 ($K^*\pi$:1.2, $K_0^*\pi$:7.1, NR($K\pi$):1.2, NR($\pi\pi$):2.7)	

Outline

- Introduction
- Experimental Apparatus
- Analysis Approaches
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