

# Recent Results from BELLE

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## Outline



- Introduction
- ICPV :  $\sin 2\Phi_1$
- Event Reconstruction
- Flavor Tagging
- $B \rightarrow K^* \gamma$
- Conclusions

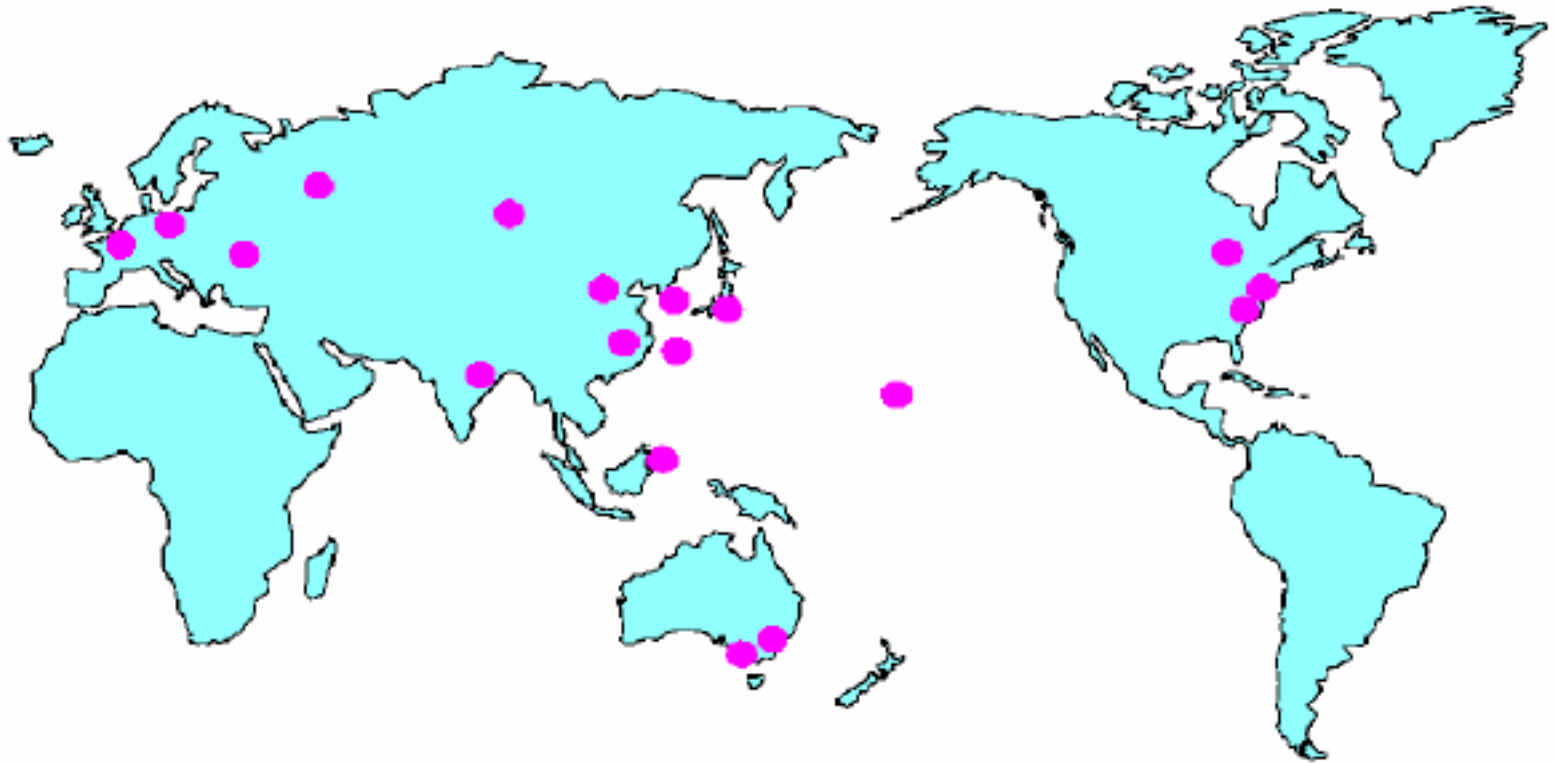


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# The BELLE Collaboration consists of 53 Institutes



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# CKM Matrix & CP Violation

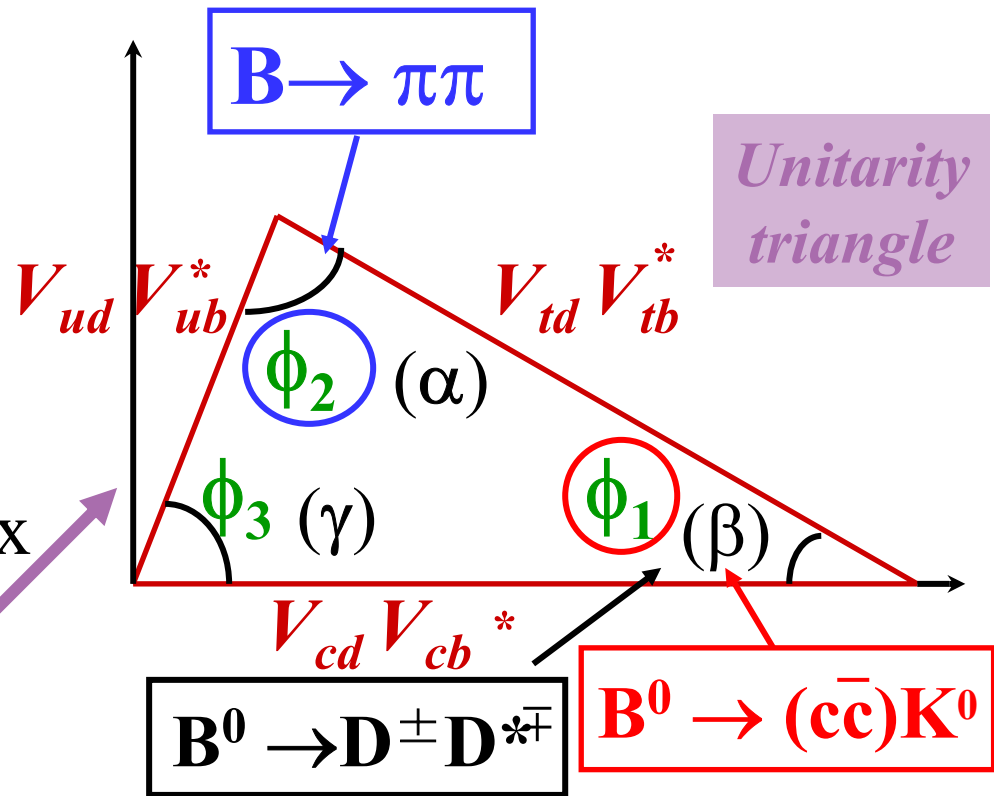
CP violation in SM due to complex phases in the quark mixing matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

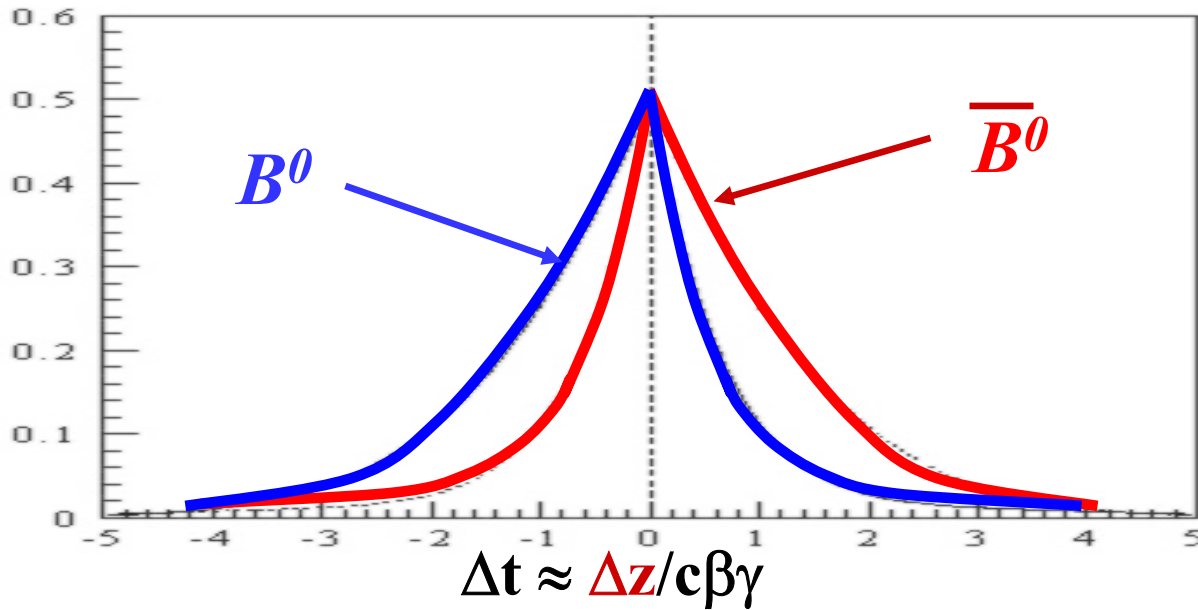
The unitarity of CKM matrix

$$\mathbf{V}\mathbf{V}^\dagger = \mathbf{1}$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



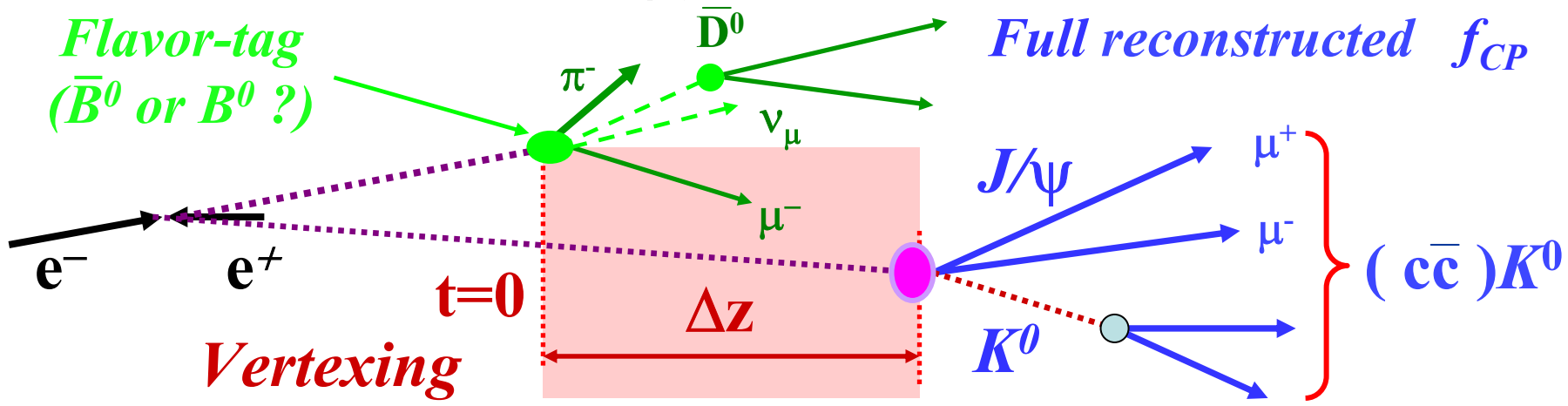
# Principle of the Measurement



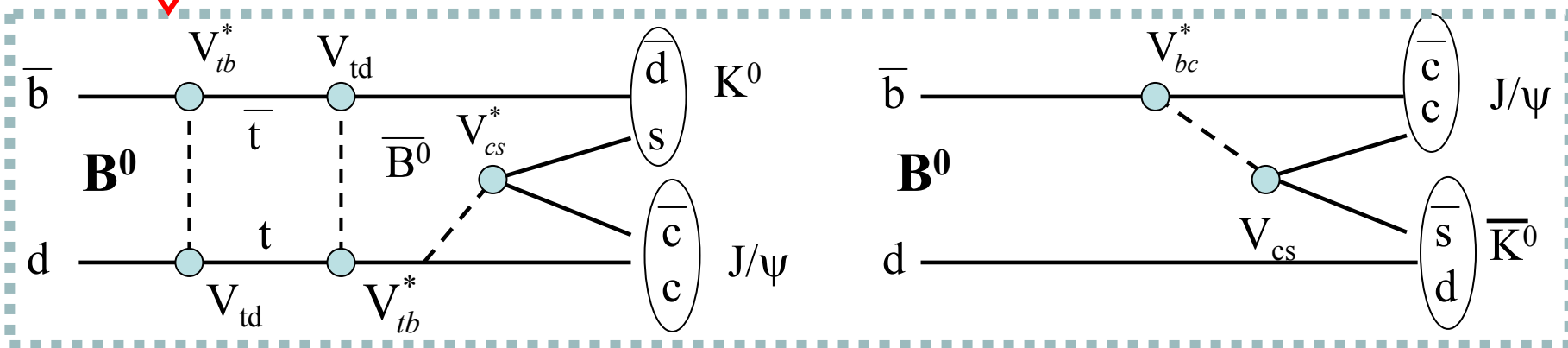
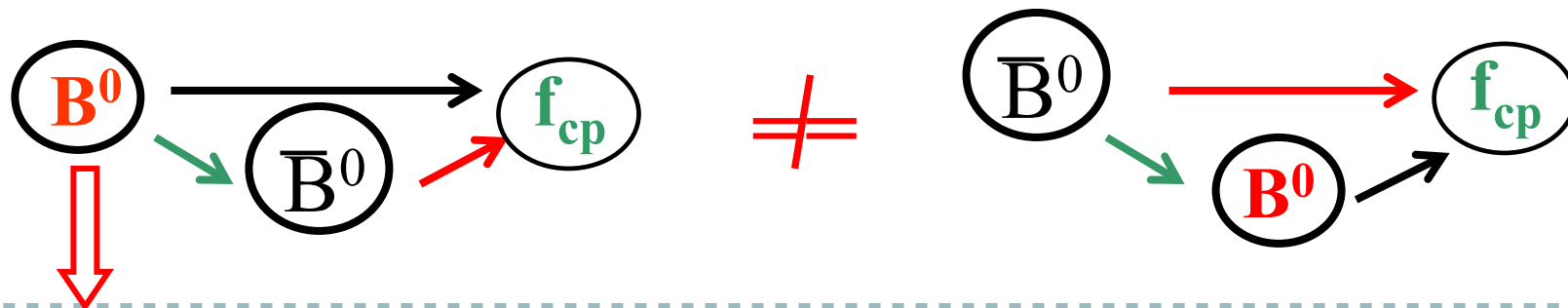
**CP Asymmetry**

$B^0 \leftrightarrow \bar{B}^0$

Asymmetric Collision  
Good Vertex Detection



# Mixing-induced CPV in B System

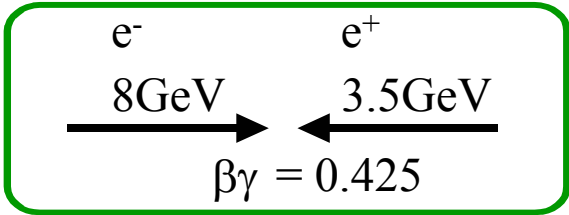


**Asymmetry**

$$A_{CP} \equiv \frac{\Gamma(\bar{B}^0 \rightarrow f_{CP}) - \Gamma(B^0 \rightarrow f_{CP})}{\Gamma(\bar{B}^0 \rightarrow f_{CP}) + \Gamma(B^0 \rightarrow f_{CP})} = -\xi_f \sin 2\phi_1 \sin(\Delta m_d \Delta t)$$



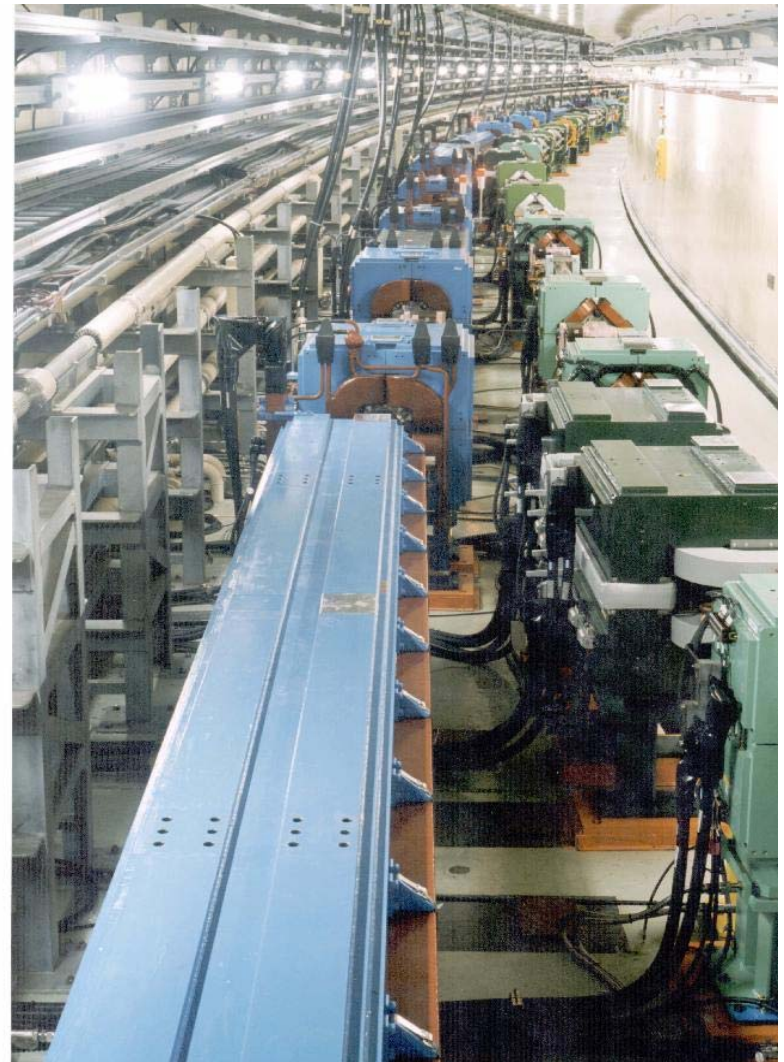
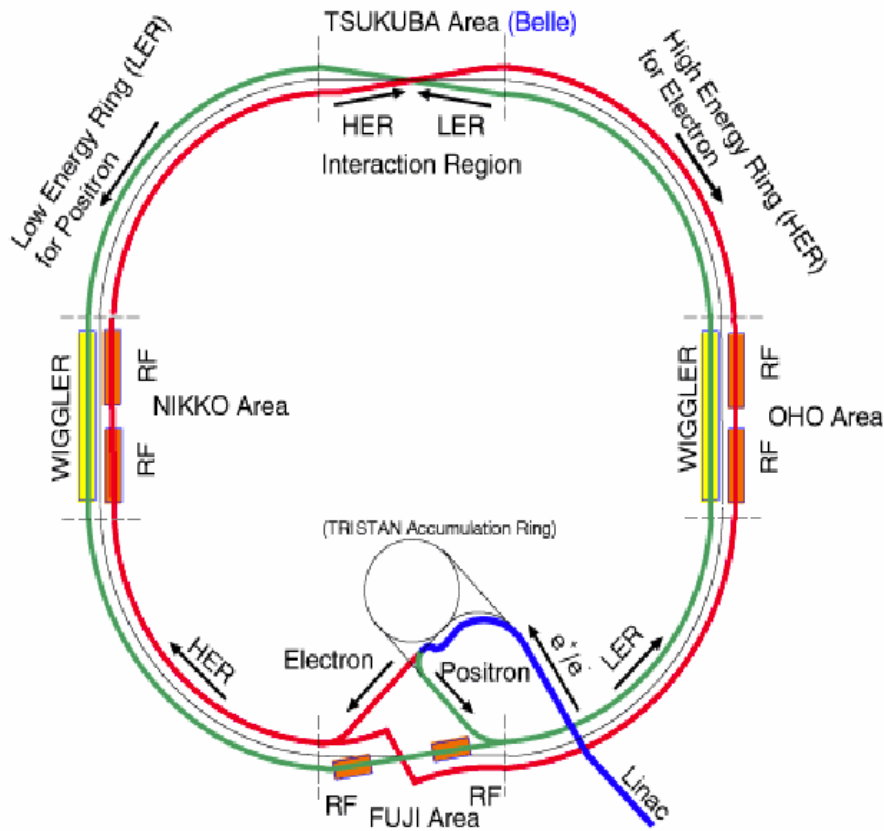
# KEKB *Asymmetric* $e^+e^-$ -Collider



$\mathcal{L} = 7.3 \times 10^{33} \text{cm}^{-2} \text{sec}^{-1}$

**World record !!**

Design =  $10^{34} \text{cm}^{-2} \text{sec}^{-1}$

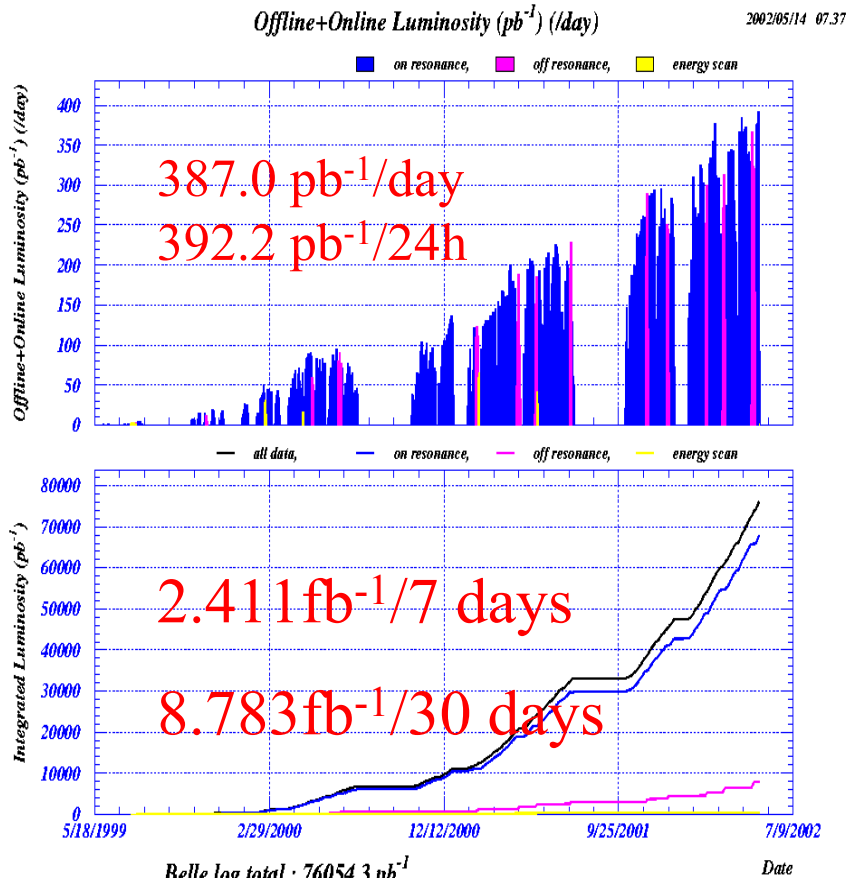


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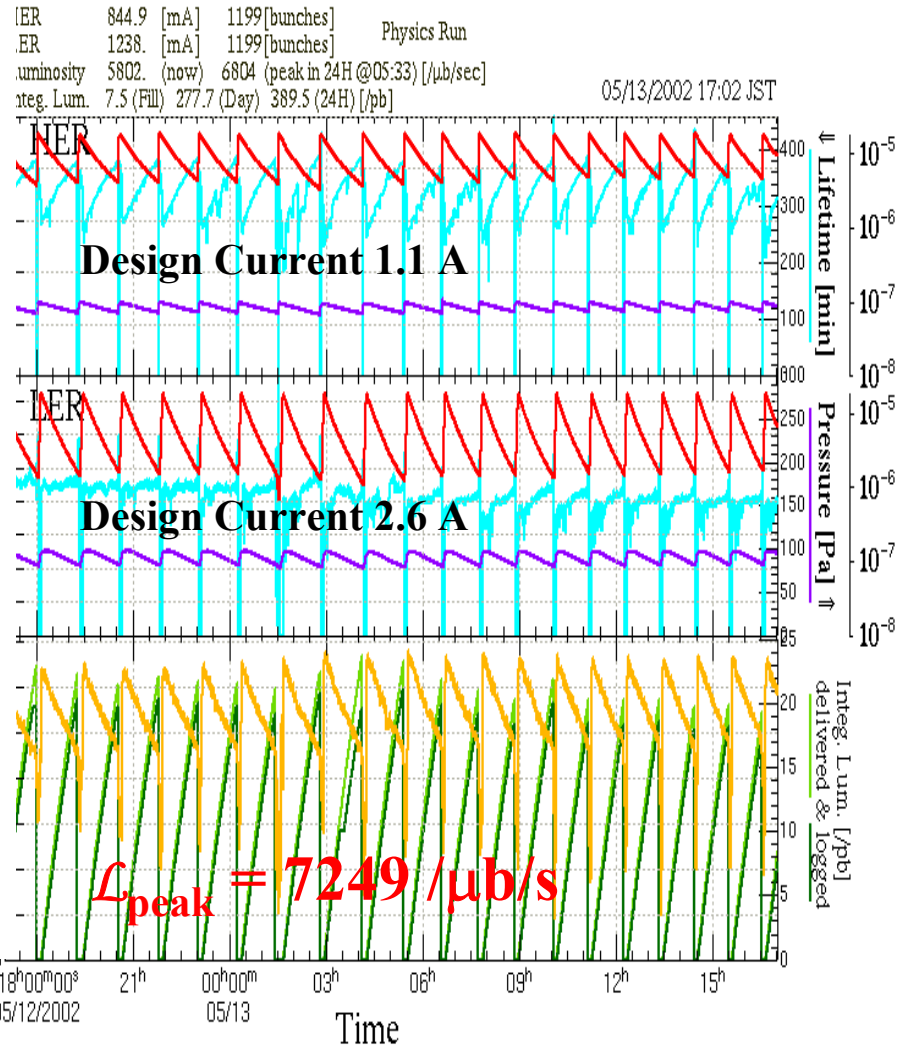
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# KEKB Performance



Beamsizes:  $\sigma_y \approx 3 \mu\text{m}$   
 $\sigma_x \approx 100 \mu\text{m}$   
 $\pm 11 \text{ mrad}$  crossing angle

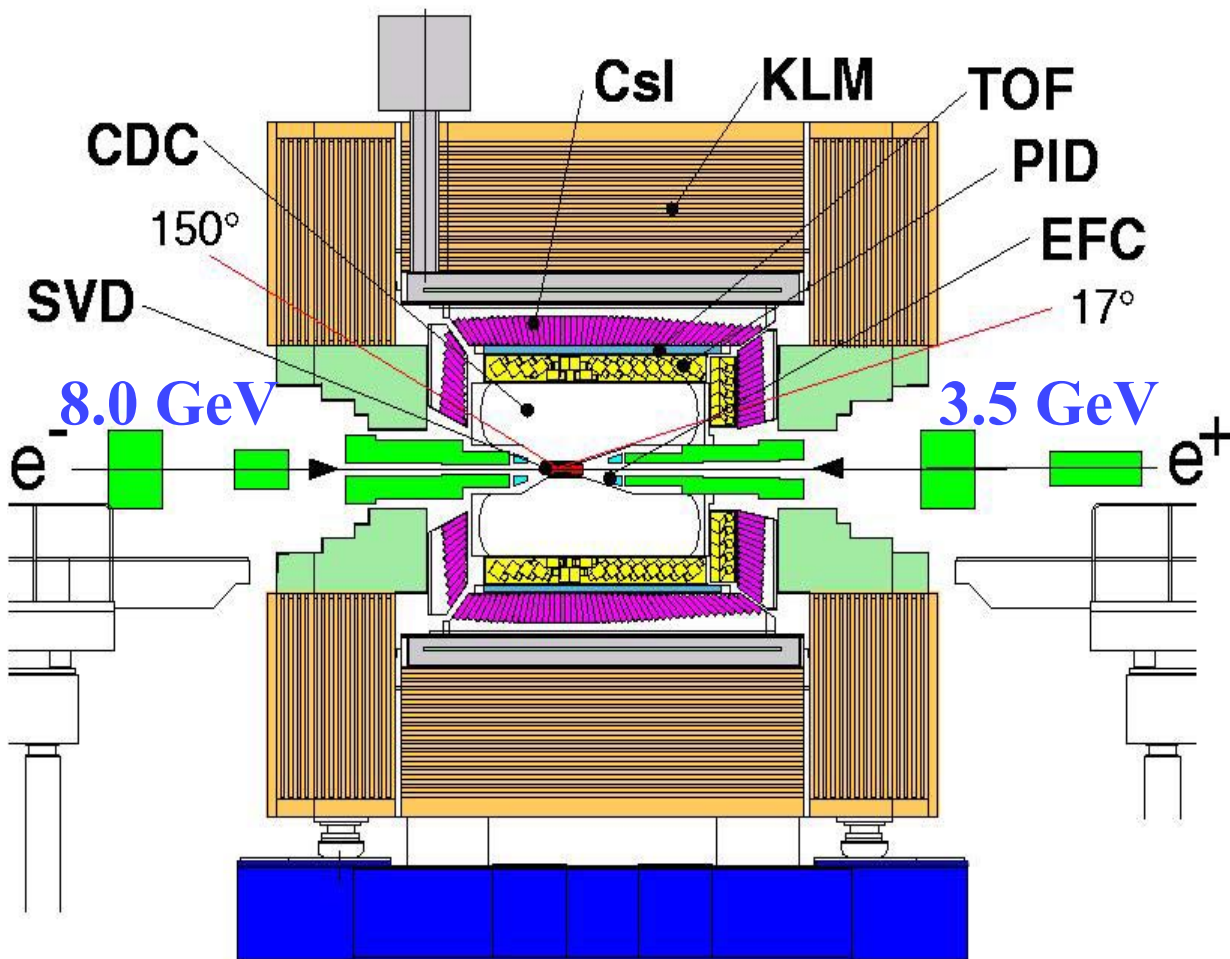


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# BELLE Detector



- SVD
- $\sigma \sim 55 \mu\text{m}$  for  $1 \text{ GeV}/c @ 90^\circ$
- CDC
- $\sigma_p/p \sim 0.35\%$  @  $1 \text{ GeV}/c$
- $\sigma_\pi(dE/dx) \sim 7\%$
- $K^\pm$  id up to  $p_{\text{lab}} = 3.5 \text{ GeV}/c$
- TOF
- $\sigma \sim 95 \text{ ps}$
- ACC(PID)
- $n = 1.01 \sim 1.03$
- $K/\pi \sim 3.5 \text{ GeV}/c$
- CsI
- $\sigma_E/E_\gamma \sim 1.8\%$  @  $1 \text{ GeV}$  ( $\gamma, \pi^0$ )
- KLM (RPC)
- $\mu^\pm : \epsilon > 90\%$  ;  $\sim 2\%$  fakes



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# Data Sample and Result

## 2001 SUMMER (presented at LP01)

Data             $\sim 30/\text{fb}$  (about 31.3 million  $B\bar{B}$ )

Result             $\sin 2\phi_1 = 0.99 \pm 0.14 \text{ (stat)} \pm 0.06 \text{ (syst)}$

*PRL87, 091802 (2001) and HEP-EX/0202027 (submitted to PRD)*

## Data sample in this report

Data             $\sim 42/\text{fb}$  (about 44.8 million  $B\bar{B}$ )

Measurement is improved with  $\sim 40\%$  more data

Results            **to be presented today** (preliminary).



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# CP Eigenstate Decays

- Use **~all** low-background  $(c\bar{c})K^0$  modes

**B<sup>0</sup>** →

CP odd

J/ψ K<sub>S</sub> (→ π<sup>+</sup>π<sup>-</sup> & π<sup>0</sup>π<sup>0</sup>)

ψ(2S) (→ l<sup>+</sup>l<sup>-</sup> & J/ψ π<sup>+</sup>π<sup>-</sup>) K<sub>S</sub>

χ<sub>c1</sub> (→ J/ψ γ) K<sub>S</sub>

η<sub>c</sub> (→ K<sub>S</sub> K<sup>+</sup>π<sup>-</sup>, K<sup>+</sup>K<sup>-</sup>π<sup>0</sup>) K<sub>S</sub>

ξ<sub>f</sub> = -1

CP even

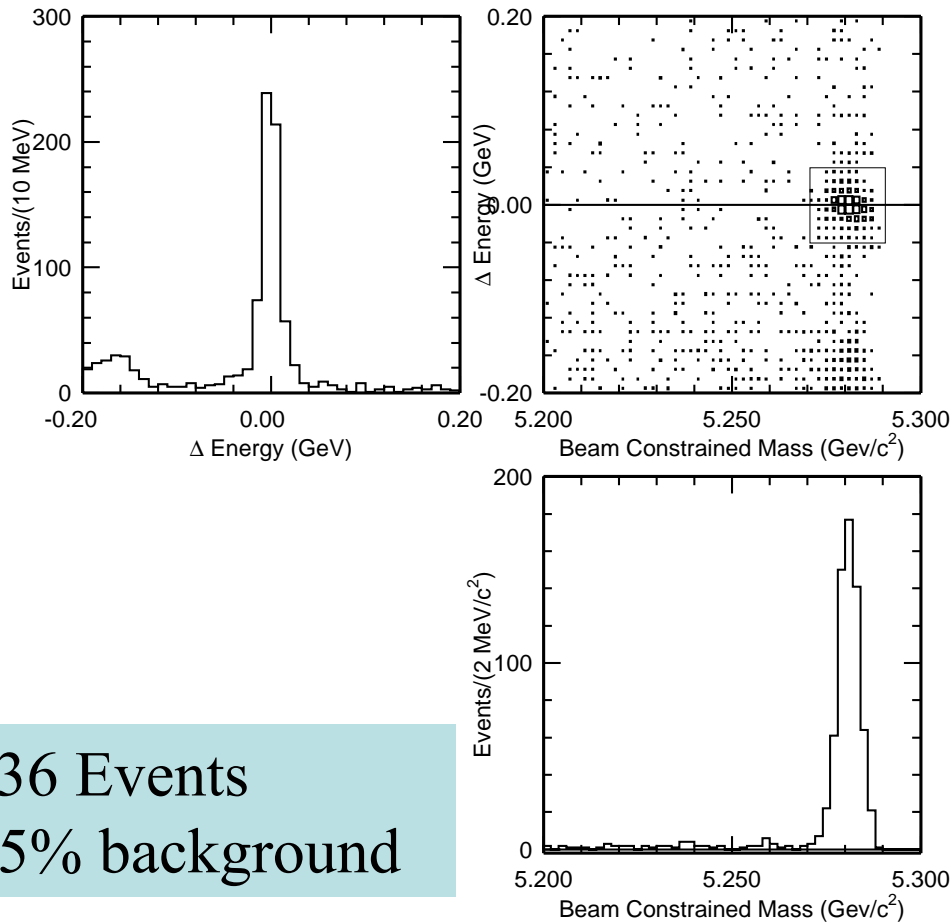
J/ψ K<sub>L</sub>

J/ψ K<sup>\*0</sup> (K<sub>S</sub>π<sup>0</sup>) (81% ξ = +1)  
( full angular analysis )

ξ<sub>f</sub> = +1



# Golden Mode: $B \rightarrow J/\psi (l^+l^-) K_S (\pi^+\pi^-)$



636 Events  
~5% background

Reconstruct B from  $J/\psi$  and  $K_S$  candidates  
In CMS

$$\Delta E = E_{J/\psi} + E_{K_S} - E_{beam}$$

Beam constrained mass

$$M_{bc} = \sqrt{E_{beam}^2 - (\sum \vec{p})^2}$$

**Signal Box**

$$|\Delta E| < 0.04 \text{ GeV}$$

$$5.27 < M_{bc} < 5.29 \text{ (GeV/c}^2\text{)}$$



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# All $c\bar{c} + K_S(K^{*0})$ modes

$B^0 \rightarrow J/\psi K_S (\pi^+ \pi^-)$  mode

Candidates **636**

Background  $\sim 31$

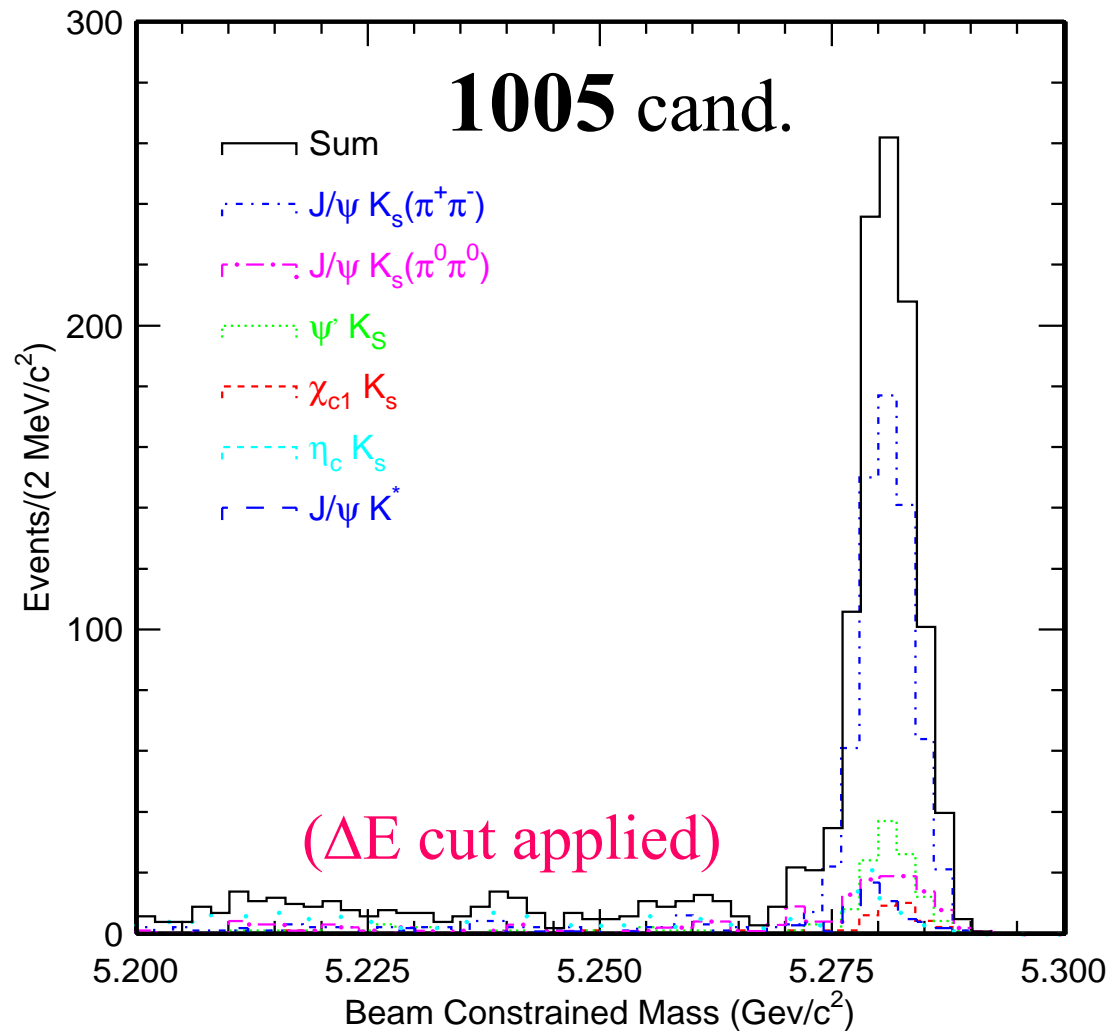
(Purity = 95%)

$B^0 \rightarrow$  other modes

Candidates **369**

Background  $\sim 59$

(Purity = 84%)



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# $B^0 \rightarrow J/\psi K_L$ Mode

$$P_B^* = \left| \vec{P}_{J/\psi}^* + \vec{P}_{K_L}^* \right|$$

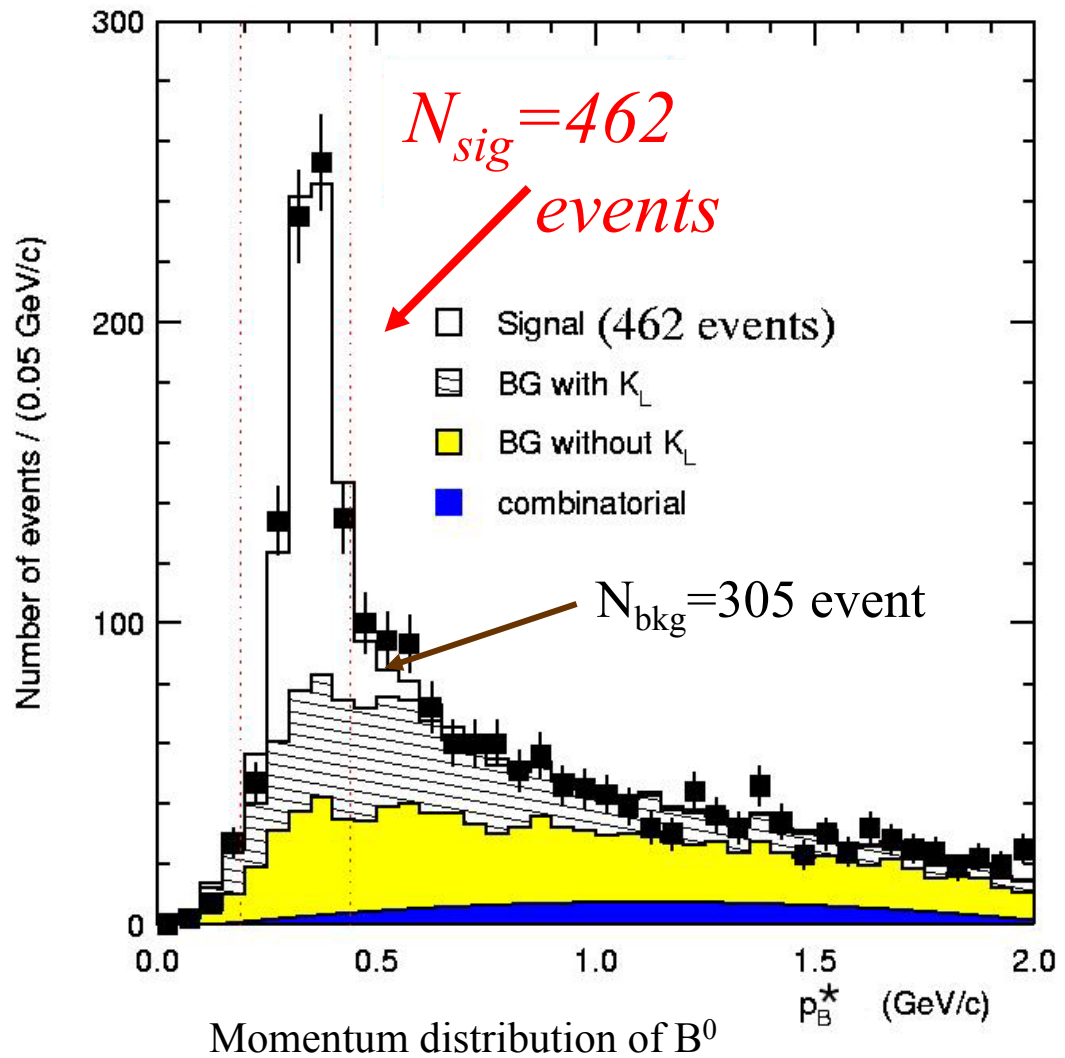
- $K_L$  direction
- 2-body decay kinematics

$B^0 \rightarrow J/\psi K_L$

767 total events

462 signal

(Purity = 60%)



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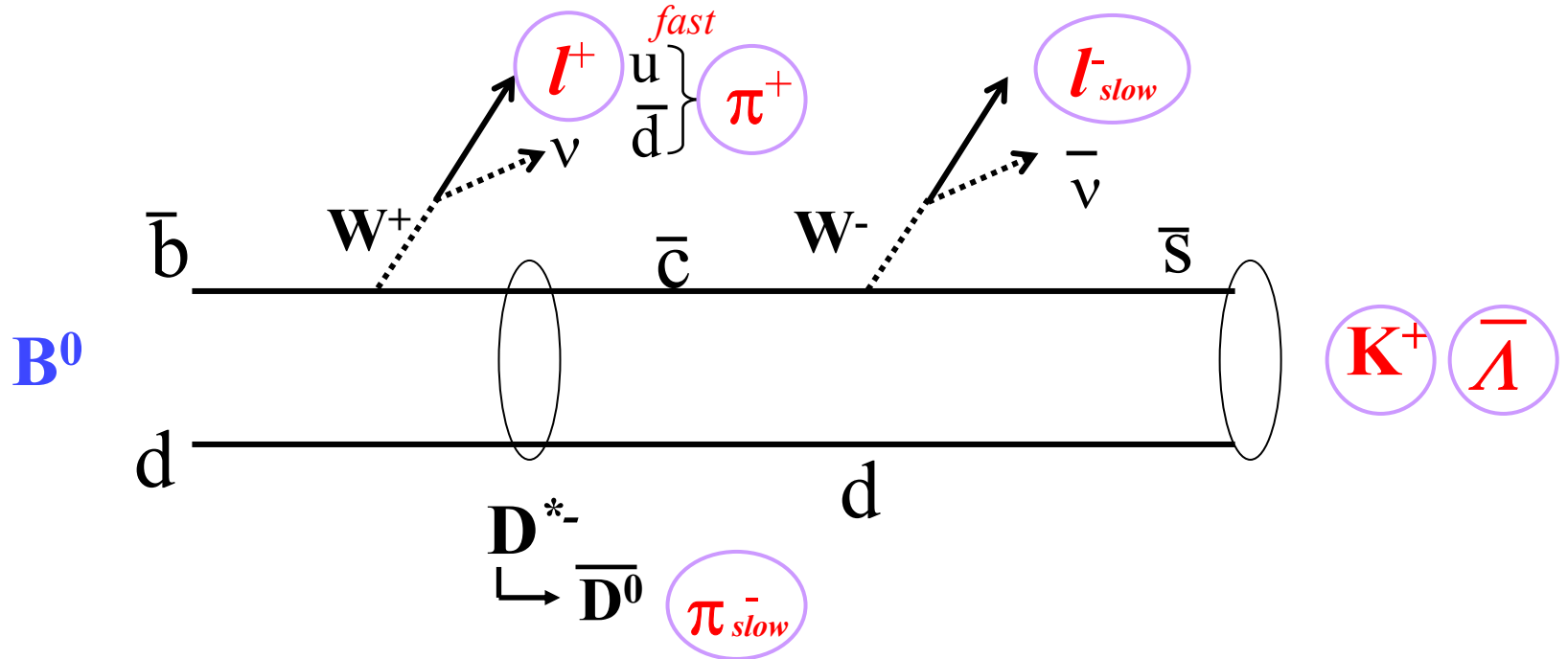


# Flavor Tagging

Particle used:  $l^\pm$ ,  $K^\pm$ ,  $\bar{\Lambda}(\Lambda)$ , fast  $\pi^\pm$  and slow  $\pi^\mp$

$B^0$ :  $l^+$ ,  $K^+$ ,  $\bar{\Lambda}$ ,  $\pi^+$ (fast),  $\pi^-$ (slow)  $l^-$  (slow)

$\bar{B}^0$ :  $l^-$ ,  $K^-$ ,  $\Lambda$ ,  $\pi^-$ (fast),  $\pi^+$  (slow)  $l^+$  (slow)



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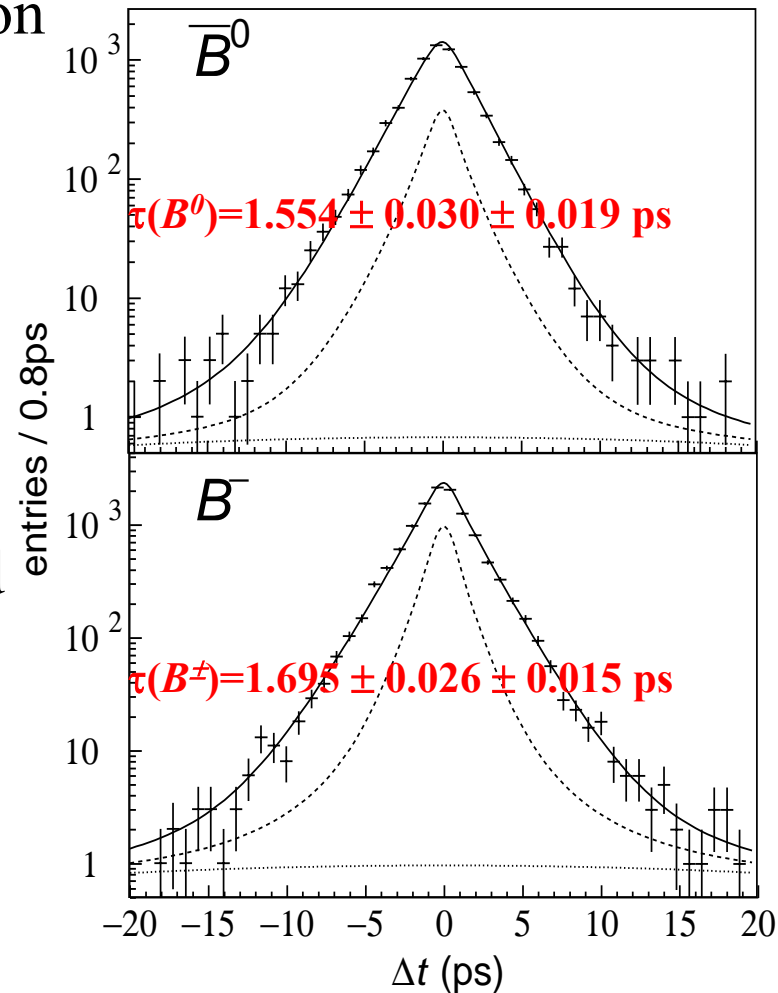


# Vertex Reconstruction

- CP side: reconstruct vertex from dilepton  $\mu^+\mu^-$ ,  $e^+e^-$ ,  $\delta z \approx 75 \mu\text{m}$  ( $\varepsilon = 92\%$ ).
- Tag-side: reconstruct vertex from charged tracks  $\delta z \approx 140 \mu\text{m}$  ( $\varepsilon = 91\%$ ).
- Both CP and tag side vertex fit use IP-profile constraint.
- New vertex resolution function adopted after LP01 and used for the B lifetime measurement.

$$\frac{\tau(B^\pm)}{\tau(B^0)} = 1.091 \pm 0.023 \pm 0.014$$

PRL 88,171801 (2002)



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# Summary of Event Sample

Total 1772 CP events

Mode	Number of events	Purity (%)
$J/\psi K_S(\rightarrow \pi^+ \pi^-)$	636	95.1
$J/\psi K_S(\rightarrow \pi^0 \pi^0)$	102	79.6
$\psi(2S)(\rightarrow l^+ l^-) K_S$	49	95.2
$\psi(2S)(\rightarrow J/\psi \pi^+ \pi^-) K_S$	57	92.5
$\chi_{c1}(\rightarrow J/\psi \gamma) K_S$	34	93.1
$\eta_c(\rightarrow K_S K^+ \pi^-) K_S$	39	71.6
$\eta_c(\rightarrow K^+ K^- \pi^0) K_S$	33	73.0
$J/\psi K^{*0}(\rightarrow K_S \pi^0)$	55	89.1
$J/\psi K_L$	767	60

After flavor tagging and vertex fitting

1550 CP events

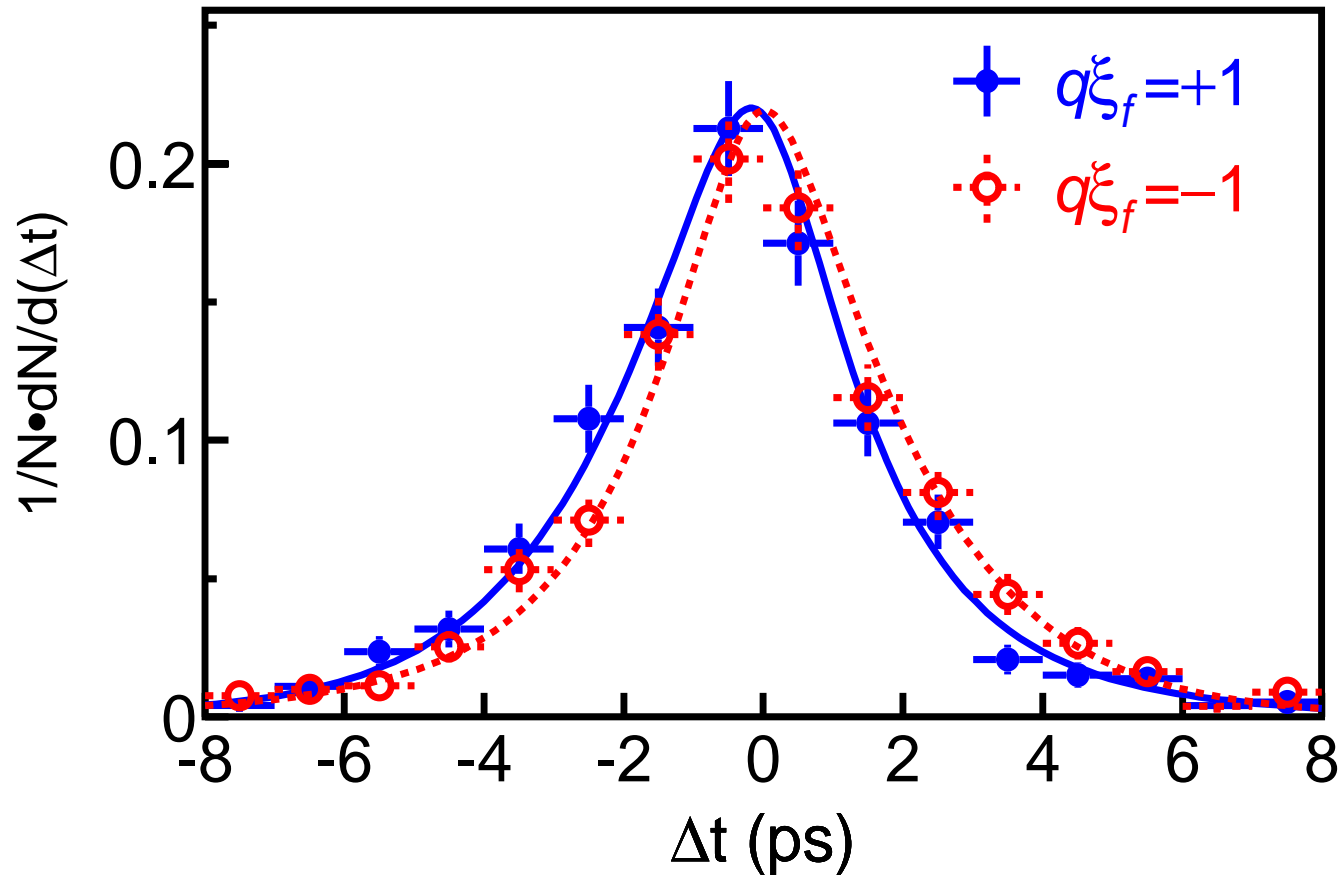
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# Fit Result of $\sin 2\phi_1$ with $42 \text{ fb}^{-1}$

$$\sin 2\phi_1 = 0.82 \pm 0.12(\text{stat}) \pm 0.05(\text{syst})$$

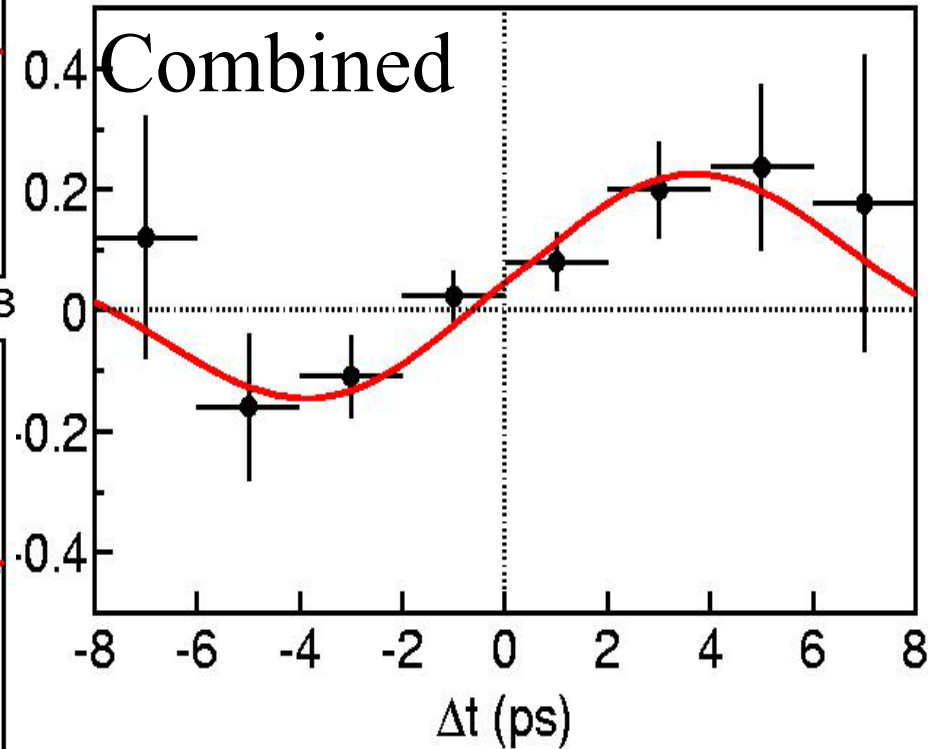
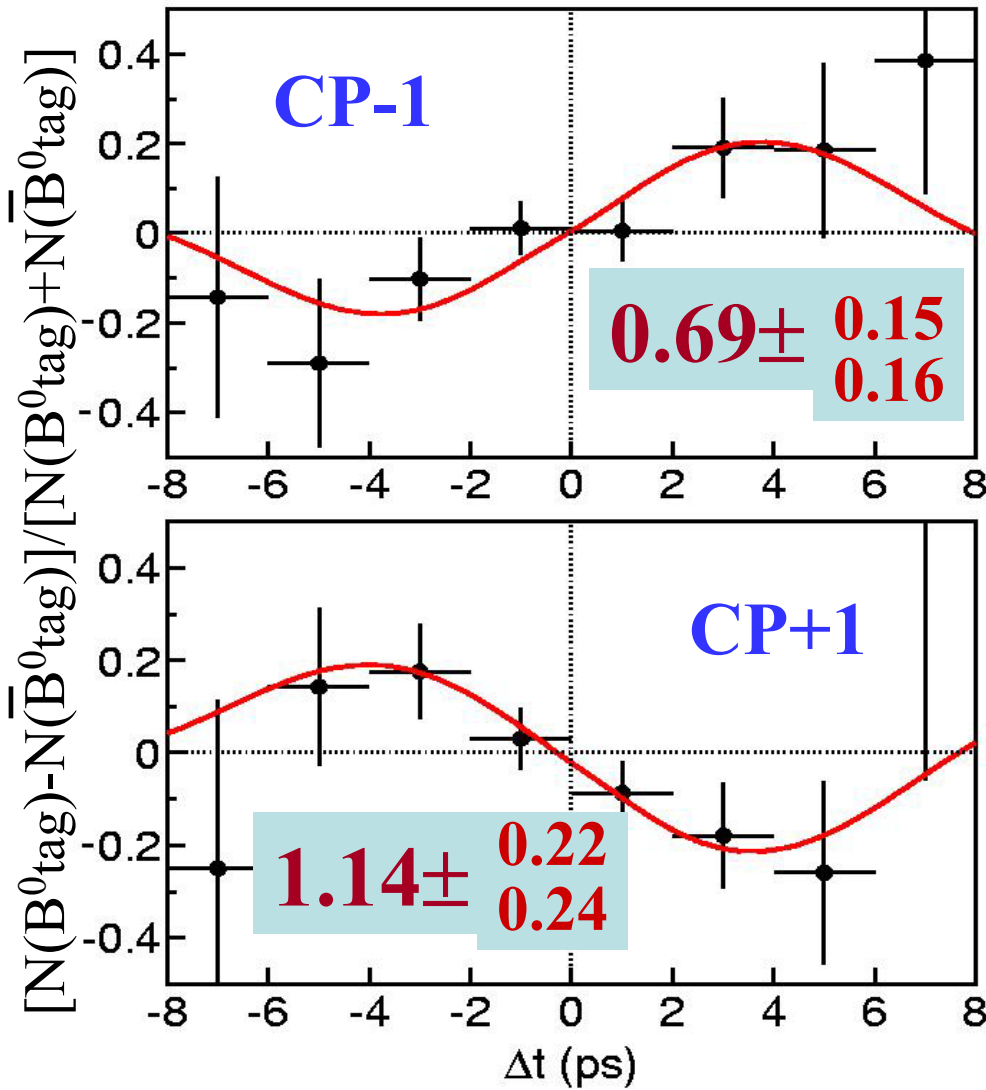


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# Raw Asymmetries



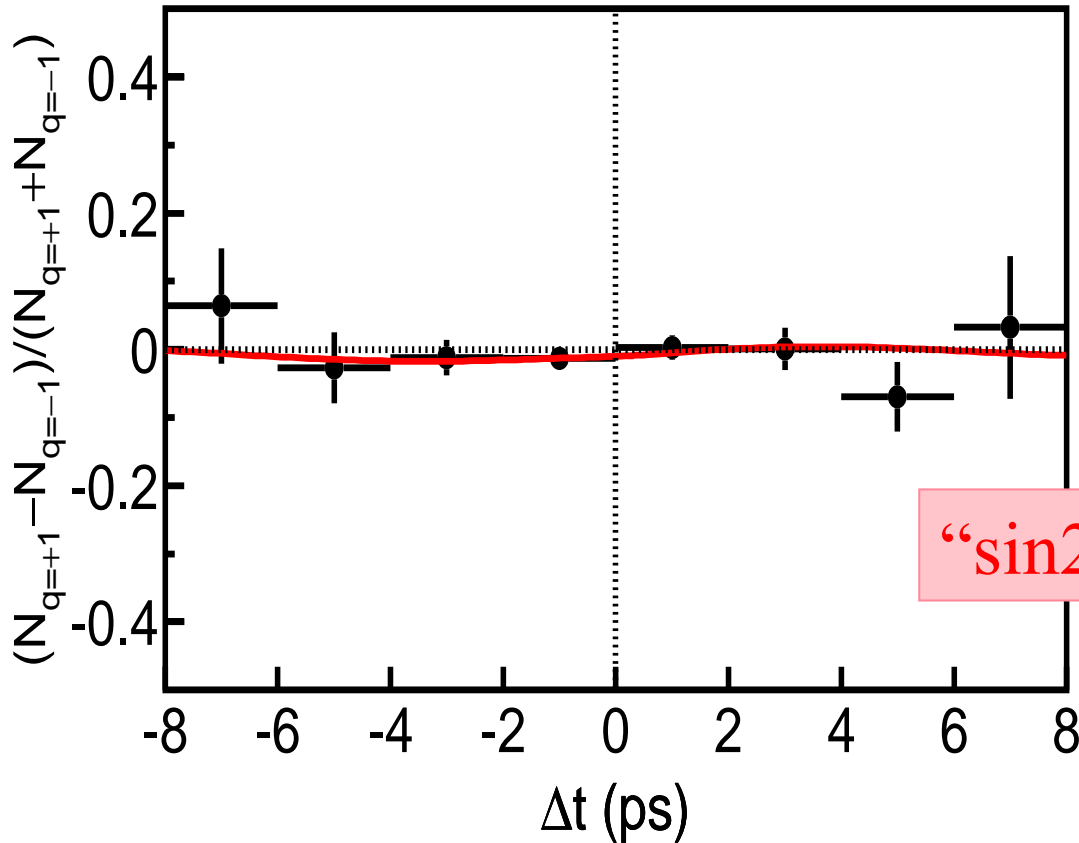
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# Control Sample: $B^0 \rightarrow$ non $f_{CP}$

$B^0 \rightarrow D^{(*)-}\pi^+, D^{*-}\rho^+, J/\psi K^*(K^+\pi^-)$



Same analysis  
as for CP-eigenstate  
modes

“ $\sin 2\phi_1$ ” =  $0.05 \pm 0.04$  (stat)



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# Systematic Errors

Vertexing	$\pm 0.030$	LP01 0.04
Flavor tagging	$\pm 0.024$ $0.026$	+0.022 -0.025
Resolution function	$\pm 0.022$ $0.019$	+0.022 -0.032
Background fraction( $K_L$ )	$\pm 0.014$ $0.015$	0.02
Background (non $K_L$ )	$\pm 0.007$ $0.006$	0.01
$\Delta m_d$ and $\tau_{B^0}$ errors	$\pm 0.007$ $0.006$	0.01
<b>Total</b>	<b><math>\pm 0.05</math></b>	0.06


Preliminary

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# Summary ICPV

- Belle/KEKB: excellent operation with world's highest peak luminosity
- New result with  $42 \text{ fb}^{-1}$  (44.8M  $\text{B}\bar{\text{B}}$ )  
 $\sin 2\phi_1 = 0.82 \pm 0.12 \pm 0.05$  
- The result: close to Standard Model prediction
- Summer 2002:  $\int \mathcal{L} dt = 90 \text{ fb}^{-1}$  *expected*

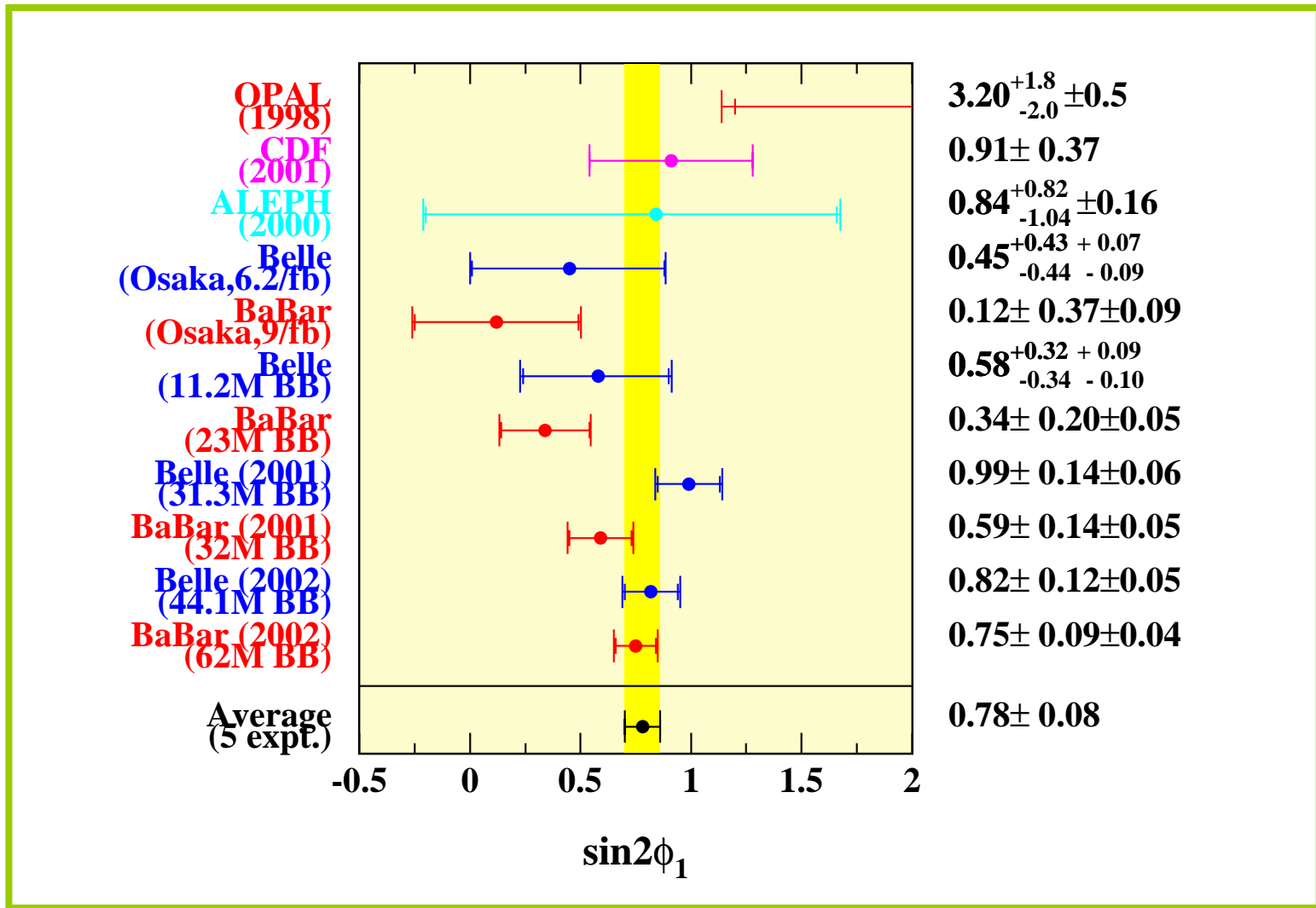


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# Compare with other experiments



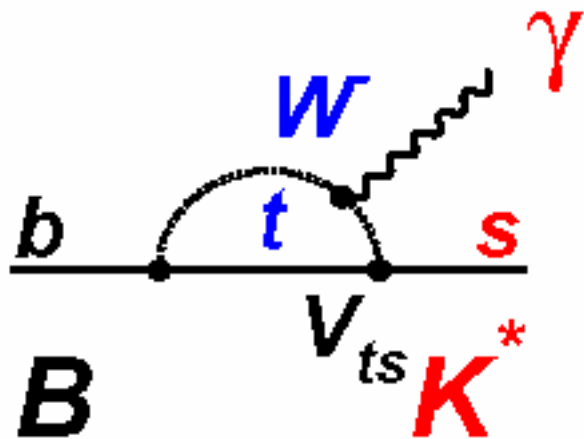
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# Flavor Changing Neutral Current

## EW-penguin diagram



$$b \rightarrow s\gamma \quad \text{Br} \sim 3 \times 10^{-4}$$

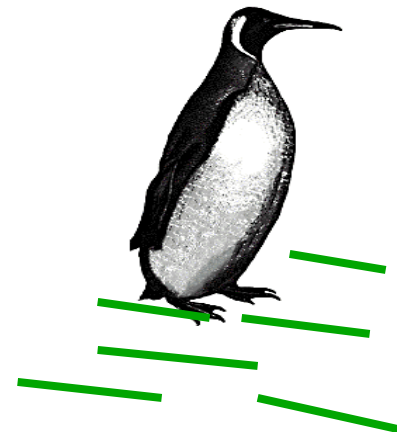
Reconstructed modes

$$B^0 \rightarrow K^+ \pi^- \gamma, K_S \pi^0 \gamma$$

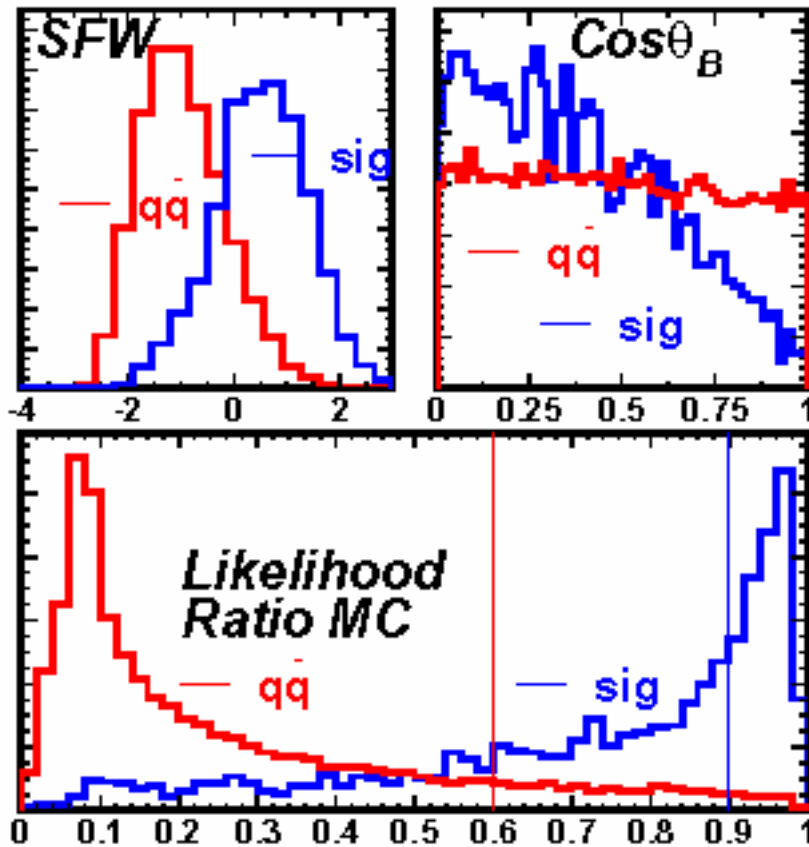
$$B^+ \rightarrow K_S \pi^+ \gamma, K^+ \pi^0 \gamma$$

$$|M_{K\pi} - M_{K^*(892)}| < 75 \text{MeV}/c^2$$

$$B \rightarrow K^*(892)\gamma \quad [B \rightarrow \rho\gamma \text{ upper limits only}]$$



# Suppression of Continuum Events



## Super Fox-Wolfram:

Fisher discriminant output of  
Modified Fox-Wolfram Moments

$$SFW = \sum_{l=2,4} \alpha_l R_l + \sum_{l=1,2,3,4} \beta_l r_l,$$

$$R_l = \frac{\sum_{i,\gamma} p_i p_\gamma P_l(\cos \theta_{i\gamma})}{\sum_{i,\gamma} p_i p_\gamma},$$

$$r_l = \frac{\sum_{i,j} p_i p_j P_l(\cos \theta_{ij})}{\sum_{i,j} p_i p_j}$$

Cosine of B flight direction

$$LR(SFW, \cos \theta_B) = \frac{L^{sig}}{L^{sig} + L^{bkg}}$$



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# $B^0 \rightarrow K^* \gamma$

DATA SET  $31.7 \times 10^6 B\bar{B}$

$$\text{Br}(B^0 \rightarrow K^{*0} \gamma) = (40.8_{-3.3}^{+3.5} \pm 2.6) \times 10^{-6}$$

*[BELLE preliminary]*

$$\text{Br}(B^+ \rightarrow K^{*+} \gamma) = (49.2_{-5.4-3.7}^{+5.9+3.8} \pm 2.6) \times 10^{-6}$$

*[BELLE preliminary]*

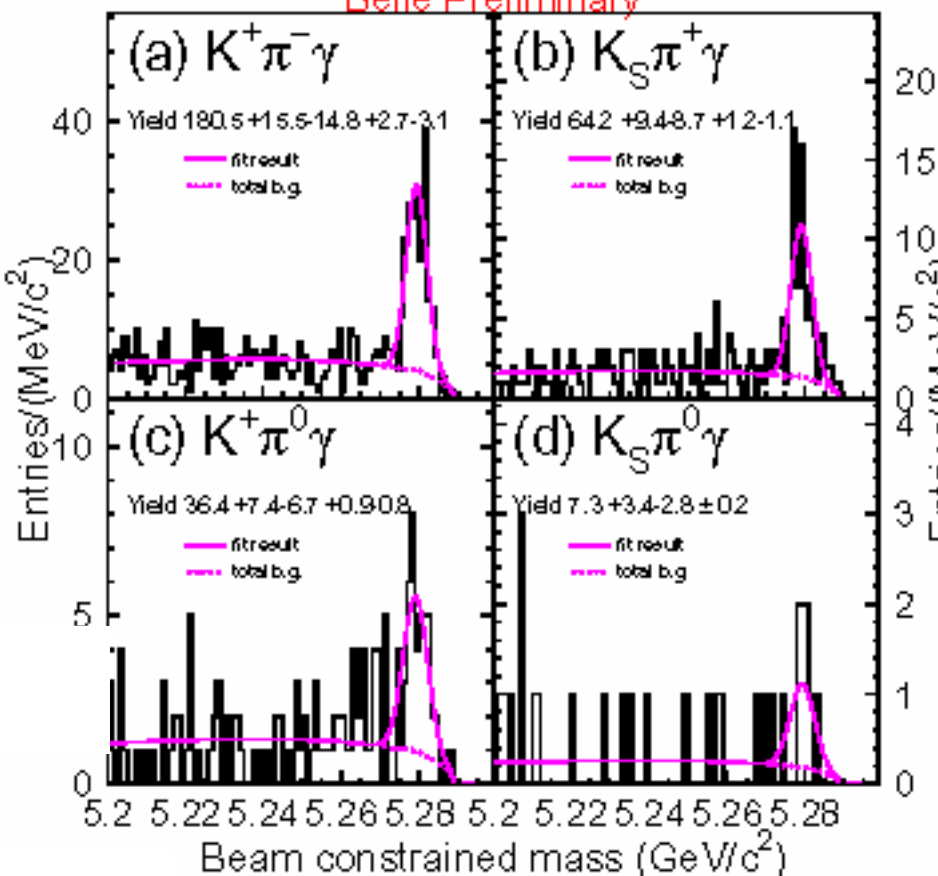
Recent theory predictions Bosch and Buchalla, NP. B621 (2002)

$$\text{Br}(B^0 \rightarrow K^{*0} \gamma) = (71 \pm 23) \times 10^{-6}$$

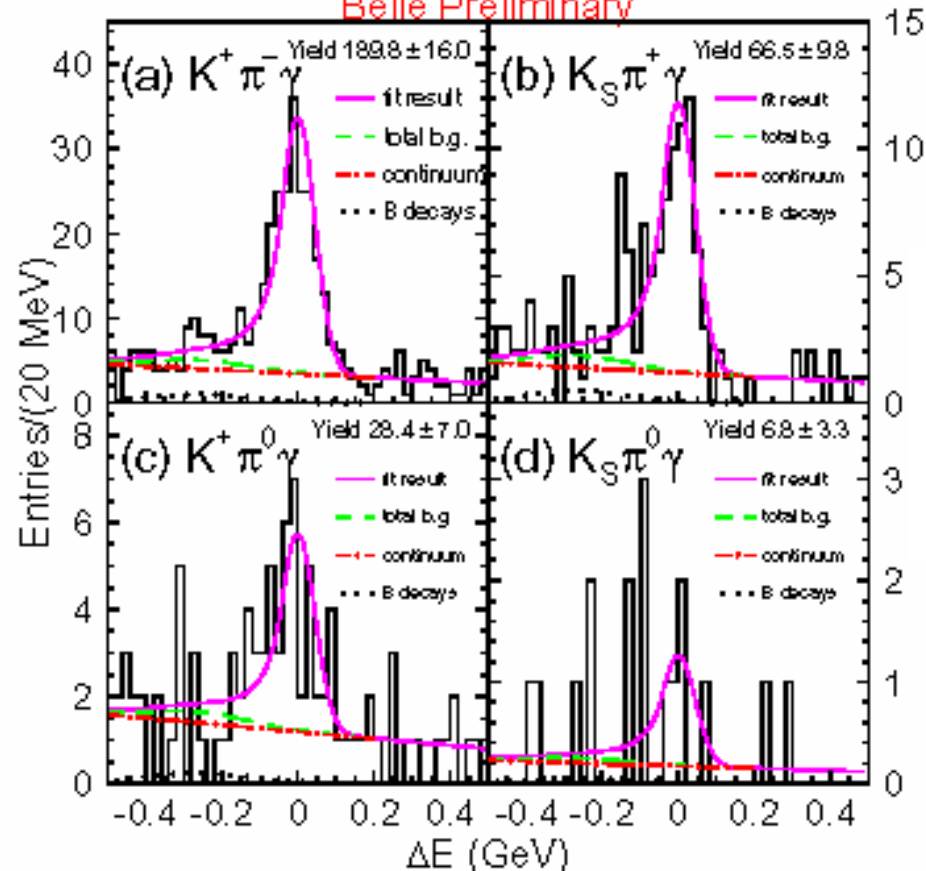


# $B^0 \rightarrow K^* \gamma$

Belle Preliminary



Belle Preliminary



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# Conclusions

- KEK-B Collider and BELLE-Detector show excellent performance, reliable operation and worlds highest luminosity
- CP-Violation in B-Mesons is well established
- Many results on B decays, i.e.  $b \rightarrow s \gamma$
- Look forward to obtain new exciting results
- Until this summer  $90 \text{ fb}^{-1}$
- Normal summer shutdown (2 months)



# Backup slides



**SUSY02-DESY**

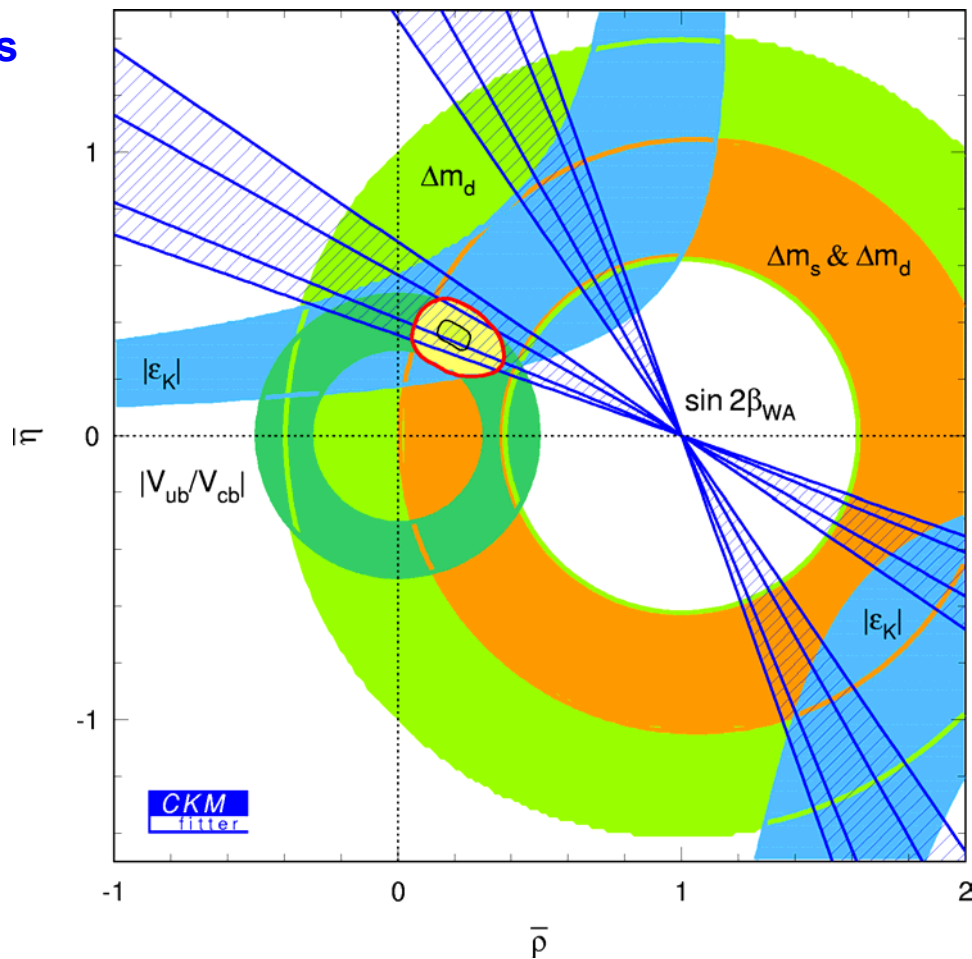
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# Present CKM-Constraint

Standard Constraints

(not including  $\sin 2\beta$ )



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# Refit with direct & indirect CPV

- All CP-sensitive modes are refit with  $|\lambda|$  as a free parameter.

$$A_{\text{CP}}(\Delta t) = \mathbf{A}_f \cos(\Delta m \Delta t) + \mathbf{S}_f \sin(\Delta m \Delta t)$$

(direct CPV)                      (indirect CPV)

$$\mathbf{S}_f = \frac{-2 \text{Im}\lambda}{1 + |\lambda|^2} \rightarrow -\xi_f |\lambda| \text{“sin}2\phi_1\text{”} \qquad \mathbf{A}_f = \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1}$$

$$\text{All modes: } \begin{cases} |\lambda| = 1.06 \pm 0.09 \text{ (stat.)} \\ \text{“sin}2\phi_1\text{”} = 0.82 \pm 0.12 \text{ (stat.)} \end{cases}$$

- The fitting result are consistent with  $|\lambda| = 1$  (C=0).

