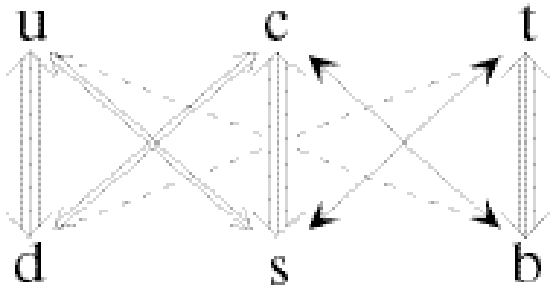
A measurement of CP asymmetry in $B^0 \to J/\psi\ \pi^0$ decay with Belle

- Introduction
- Experiment apparatus -KEKB and Belle-
- Time dependent CP analysis
- Result
- Summary

S.U.Kataoka (Nara Women's University)
K.F.Chen, T.Higuchi, K.Miyabayashi, Belle collaboration

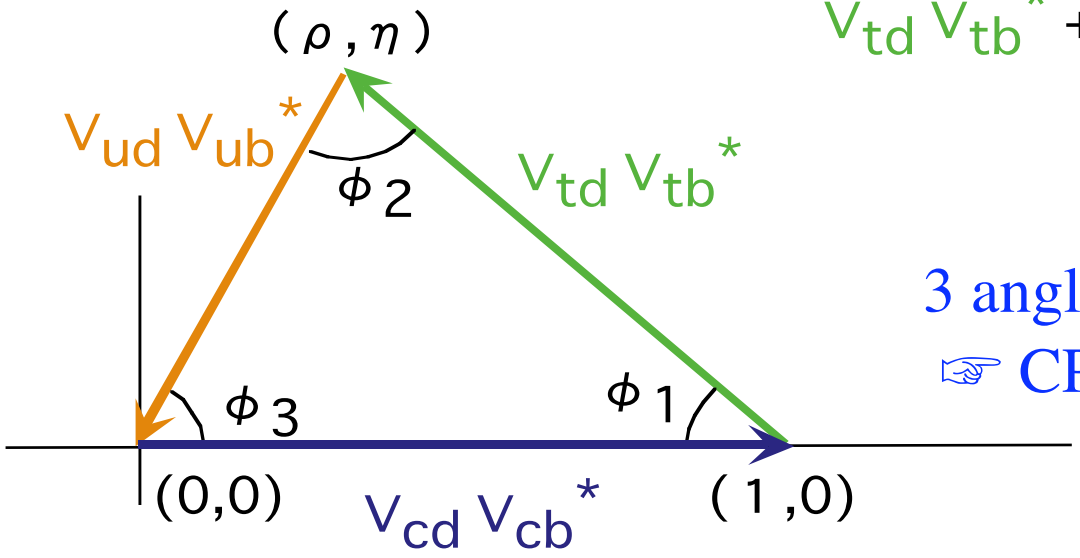
Introduction

Kobayashi-Maskawa model
(1973)



$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

CKM matrix → Unitarity Triangle



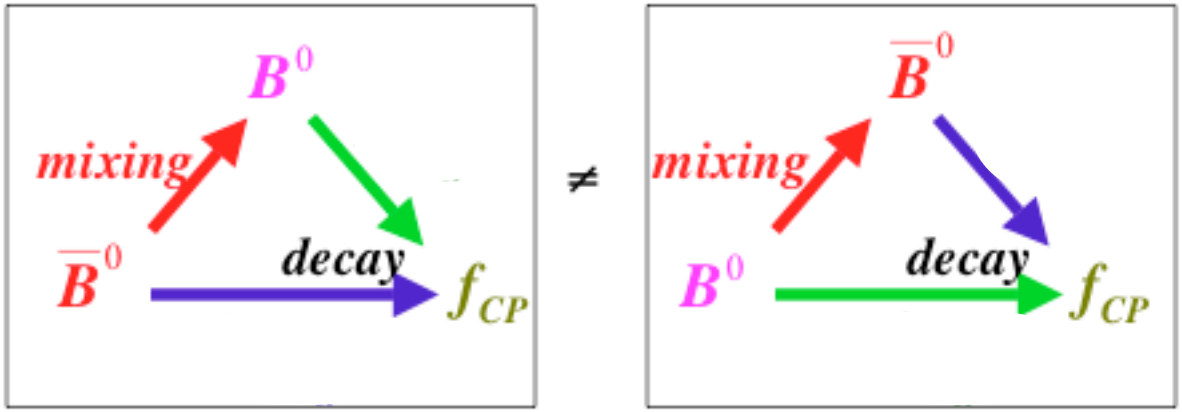
$$V_{td}V_{tb}^* + V_{cd}V_{cb}^* + V_{ud}V_{ub}^* = 0$$

3 angles: ϕ_1, ϕ_2, ϕ_3

☞ CP violation in B mesons

Introduction - CP violation in B system

CP violation from interference between B decays with and without Mixing



fcp: CP eigenstate

Time dependent CP asymmetry

$$A_{cp}(t) \equiv \frac{\Gamma(\overline{B^0} \to f_{cp};t) - \Gamma(B^0 \to f_{cp};t)}{\Gamma(\overline{B^0} \to f_{cp};t) + \Gamma(B^0 \to f_{cp};t)}$$

$$= S_f \sin(\Delta m t) + A_f \cos(\Delta m t)$$

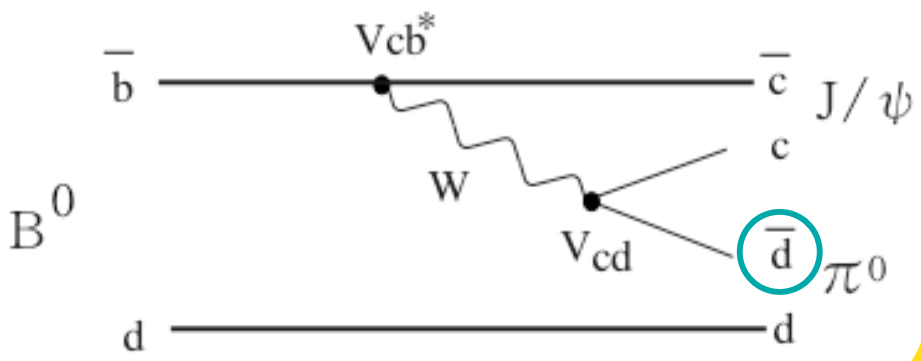
CP asymmetry parameter

$B^0 \to J/\psi\ \pi^0$

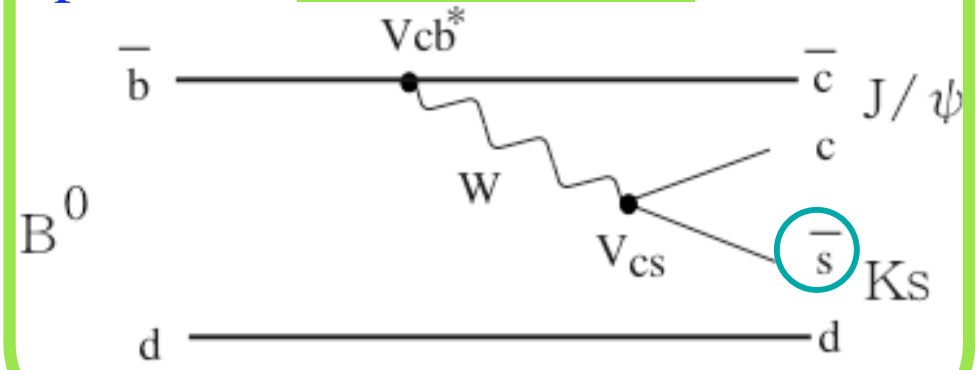
$B^0 \to J/\psi\ Ks$

Tree diagram

No complex phase



Tree diagram



	$B^0 \to J/\psi\ \pi^0$	$B^0 \to J/\psi\ Ks$
	(b → ccd)	(b → ccs)
S_f	$-\ \sin 2\phi_1$	$\sin 2\phi_1$
A_f	0 (if no penguin)	0

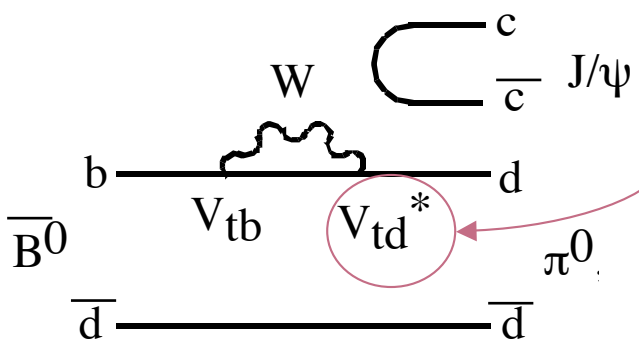
$$A_{CP}(t) = S_f \sin(\Delta m t) + A_f \cos(\Delta m t)$$

CP eigenvalue

$B^0 \to J/\psi\ \pi^0$; $+1$

$B^0 \to J/\psi\ Ks$; -1

$B^0 \to J/\psi\ \pi^0$



Penguin diagram

complex phase

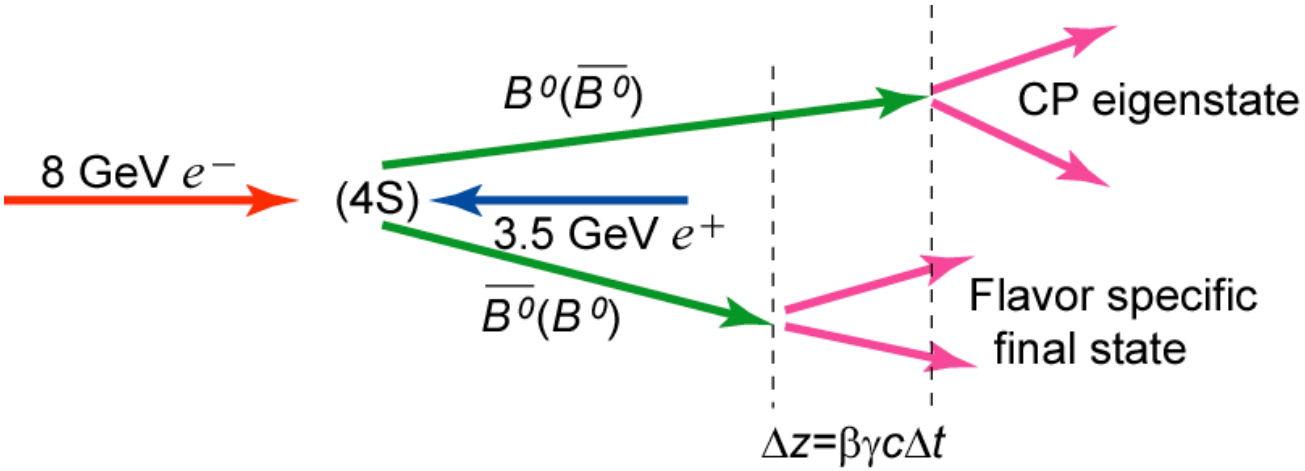
Direct CP violation will be observed

What's needed to measure CP asymmetry parameter ?

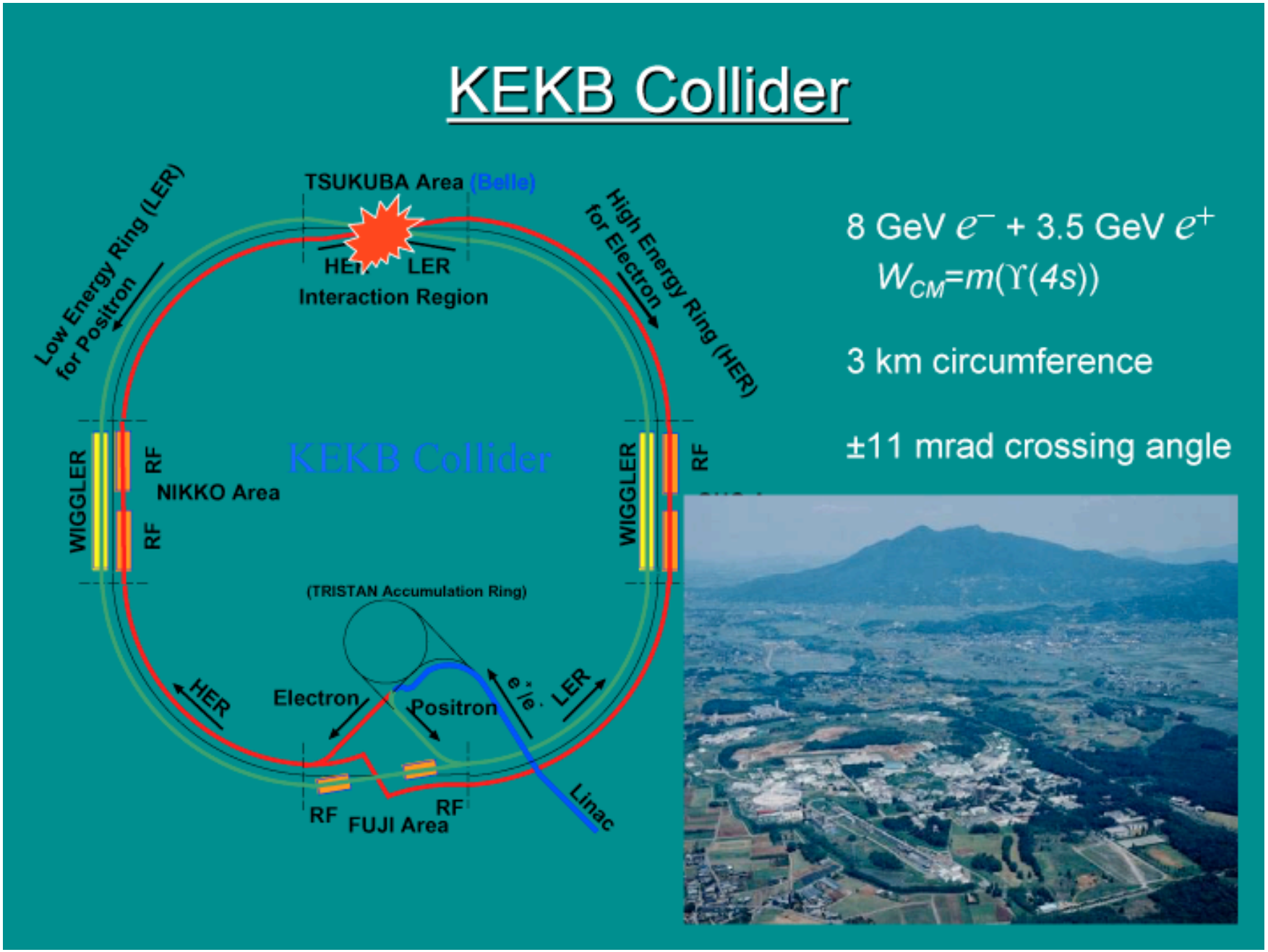
- **Lot of B mesons**
  - very high Luminosity
- **Find CP eigenstate decays**
  - high resolution 4π detector
- **Tag B's flavor**
  - good particle identification
- **Measure decay-time difference**
  - good vertexing
  - asymmetric energies

KEKB + Belle

Asymmetric B factory

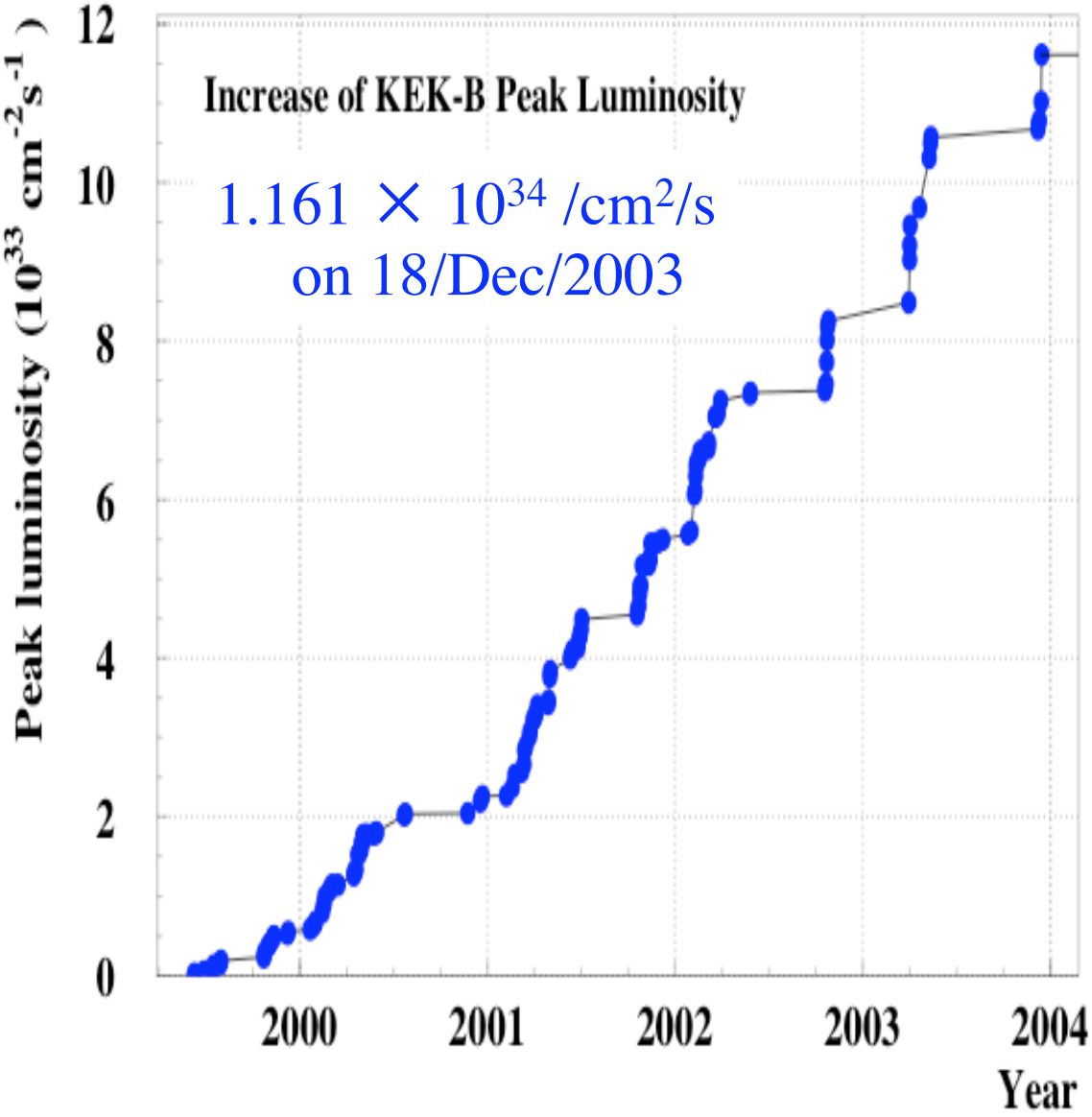


Experiment apparatus

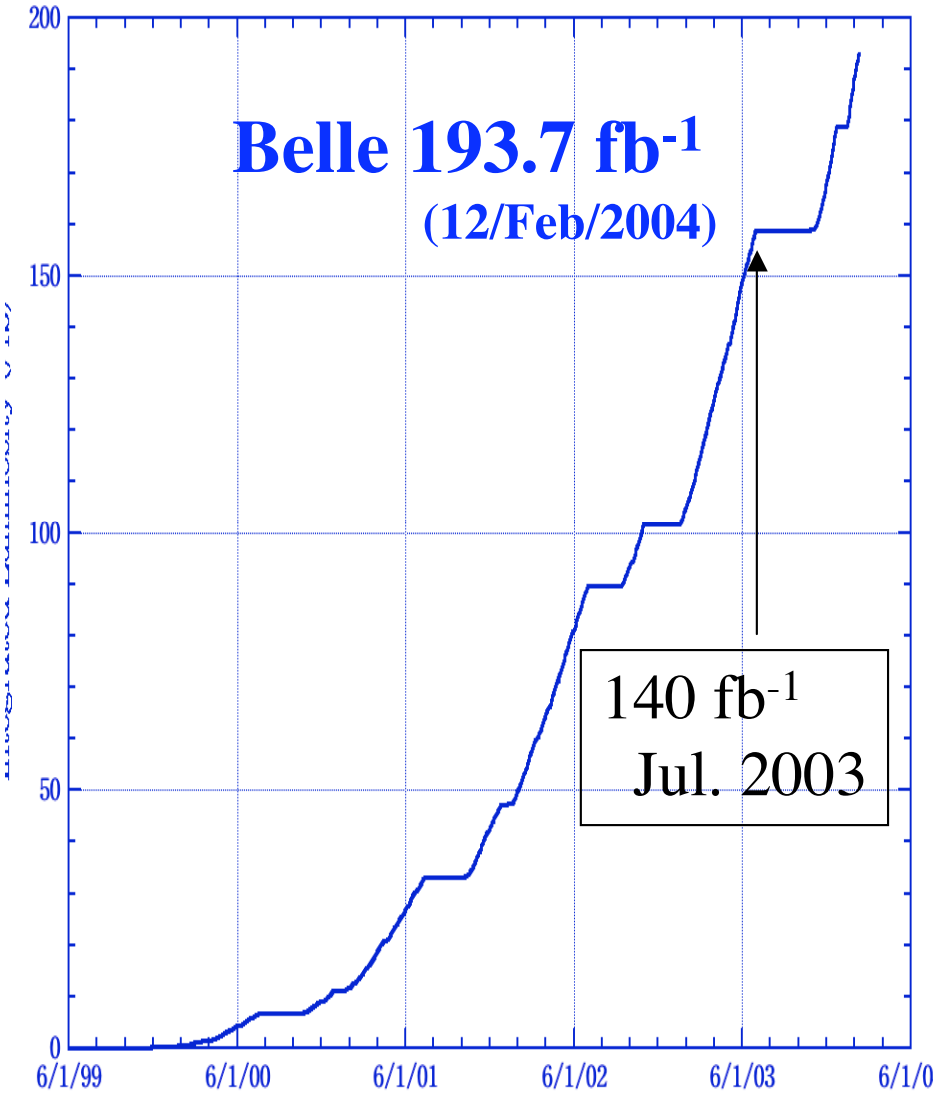


Performance of KEKB

Peak Luminosity

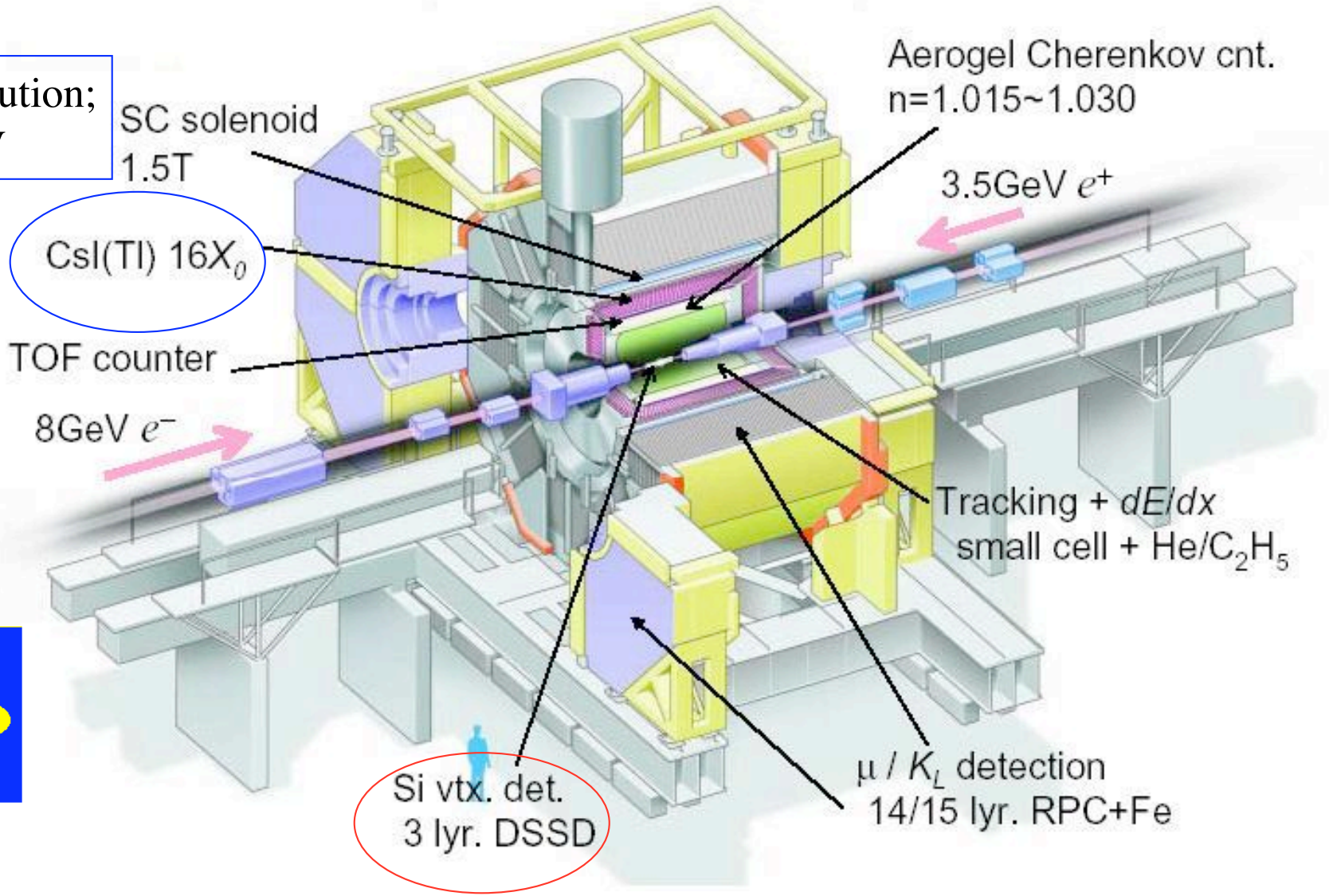


Integrated Luminosity



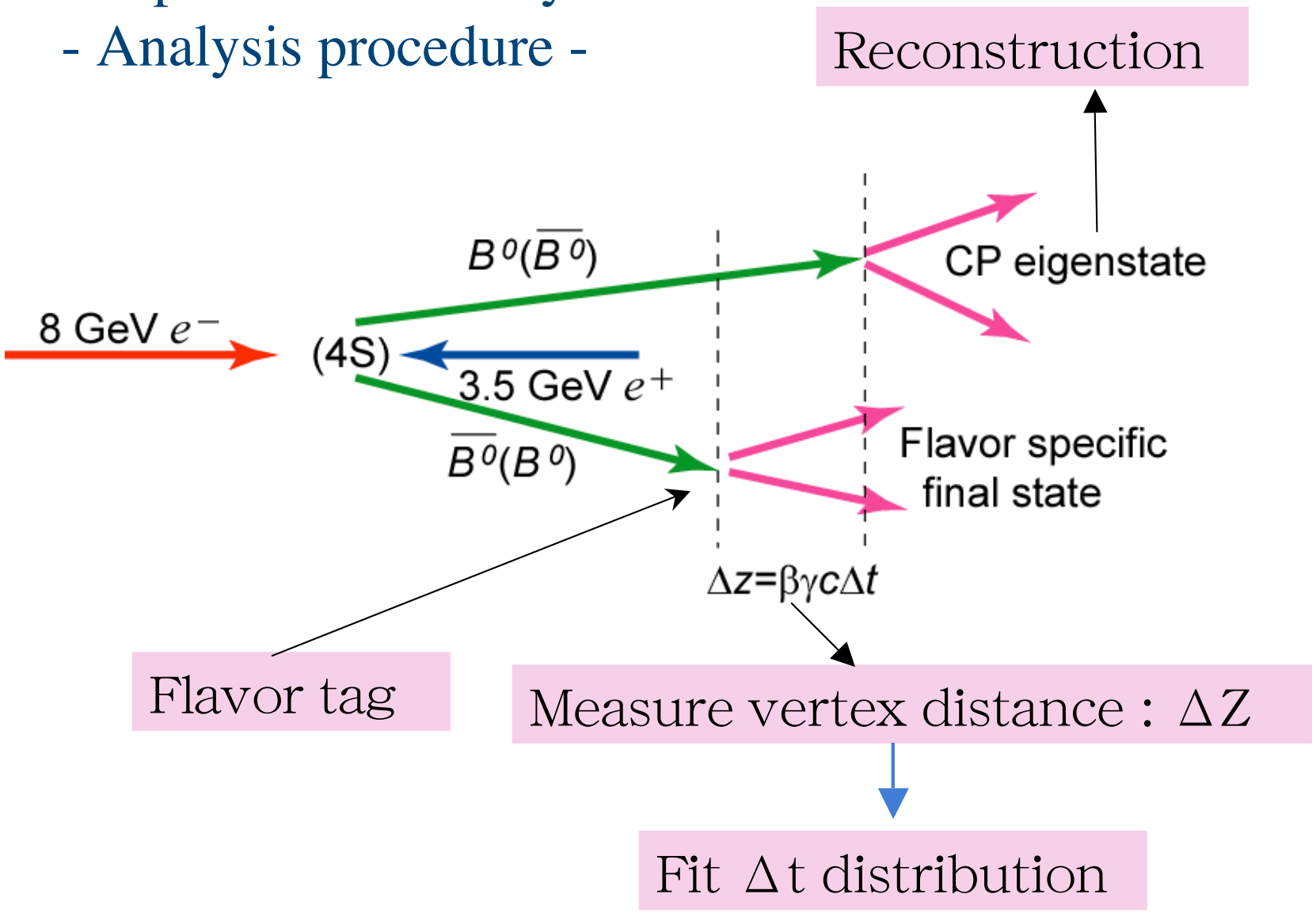
Belle detector

π^0 mass resulution;
$\sigma_{\pi 0} \sim 5$ MeV



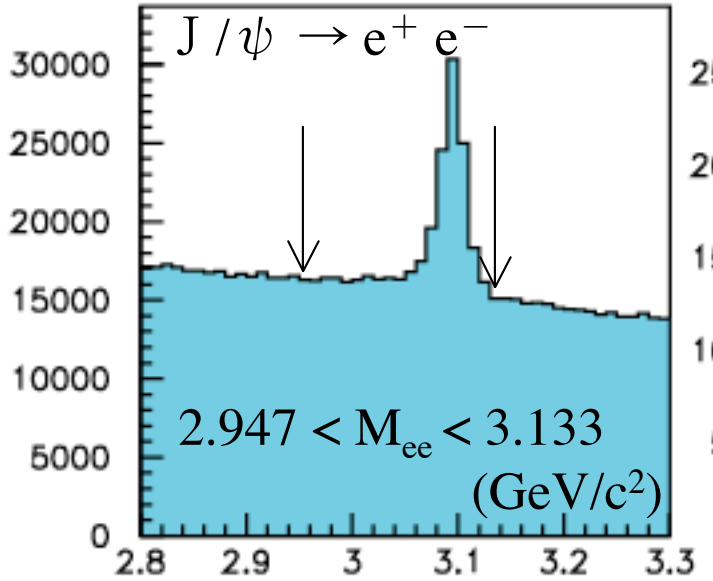
Vertex resolutions: ($\sigma(z_{cp}) = 75\mu m$; $\sigma(z_{tag}) = 140\mu m$)

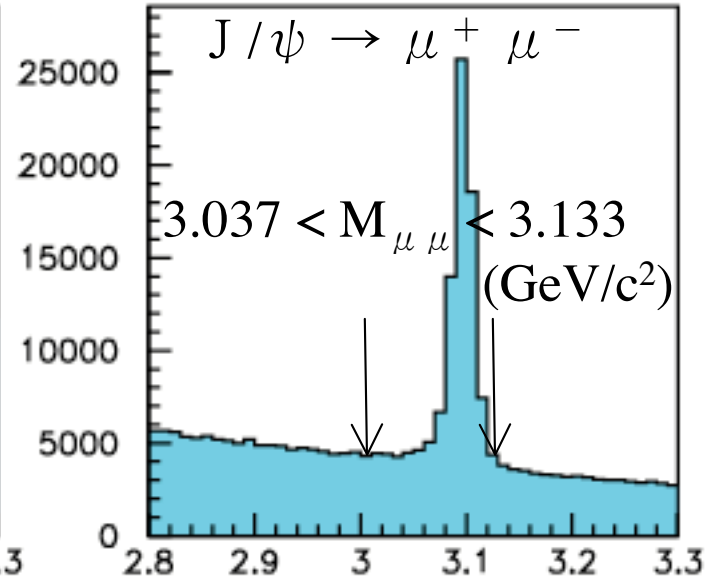
Time dependent CP analysis
- Analysis procedure -



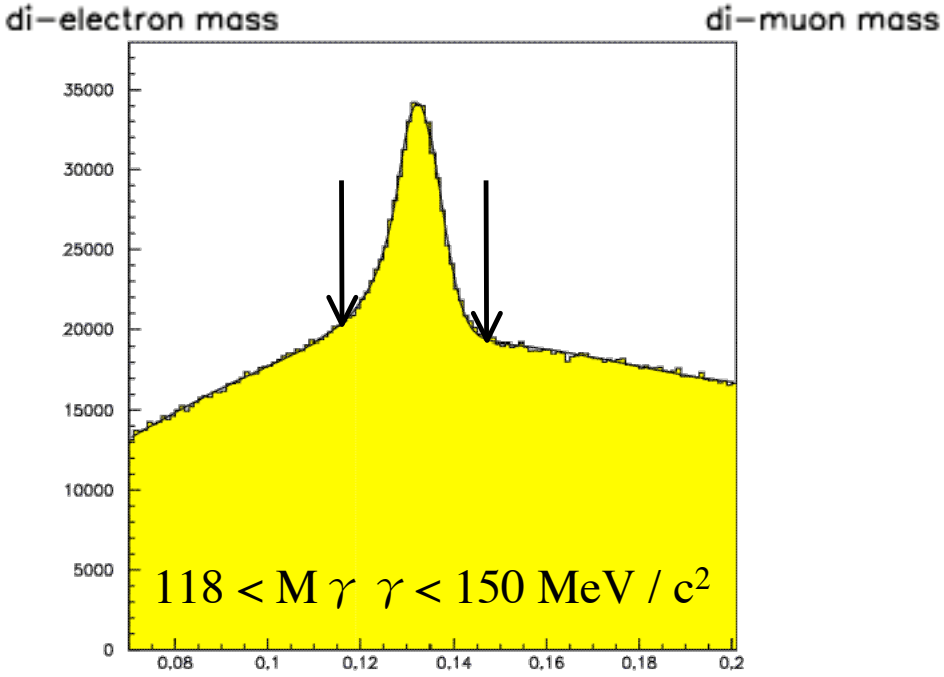
Reconstruction of $B^0 \to J/\psi\ \pi^0$

$J/\psi \to l^+ l^-$





$\pi^0 \to \gamma\ \gamma$



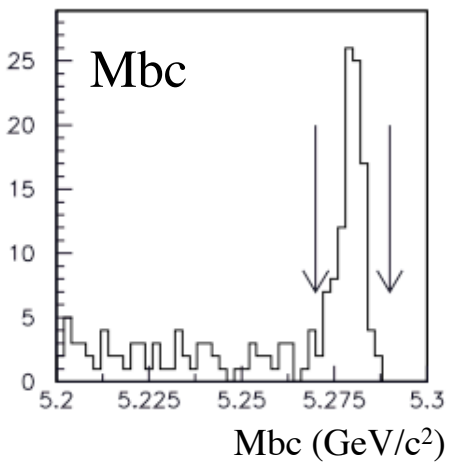
Reconstruction of $B^0 \to J/\psi\, \pi^0$

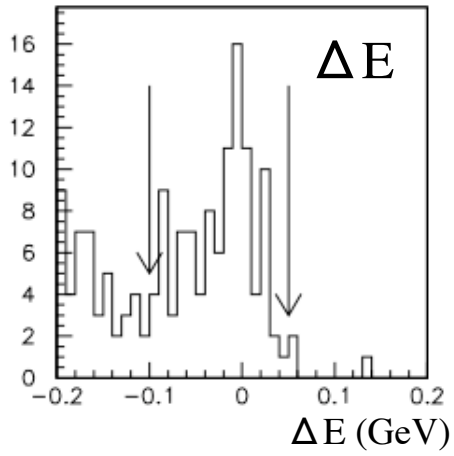
$$\Delta E \equiv E^*_{J/\psi} + E^*_{\pi 0} - E^*_{beam} \quad (GeV)$$

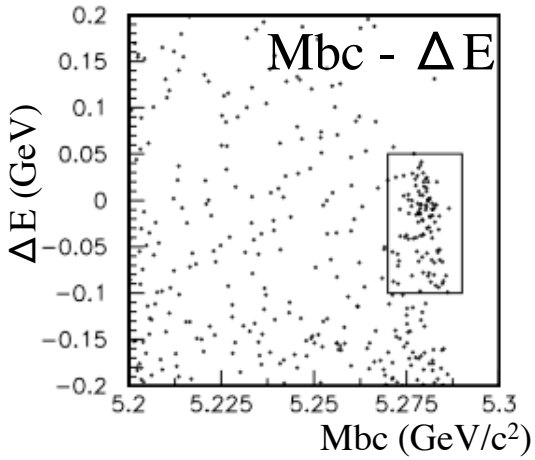
$$M_{bc} \equiv \{ (E^*_{beam})^2 - | P^*_{J/\psi} + P^*_{\pi 0} |^2 \}^{1/2} \quad (GeV/c^2)$$

$*$: $\Upsilon(4S)$ rest frame

E_{beam}: Beam energy







152 × 10^6 $B\bar{B}$ Events (140/fb)
collected by KEKB/Belle

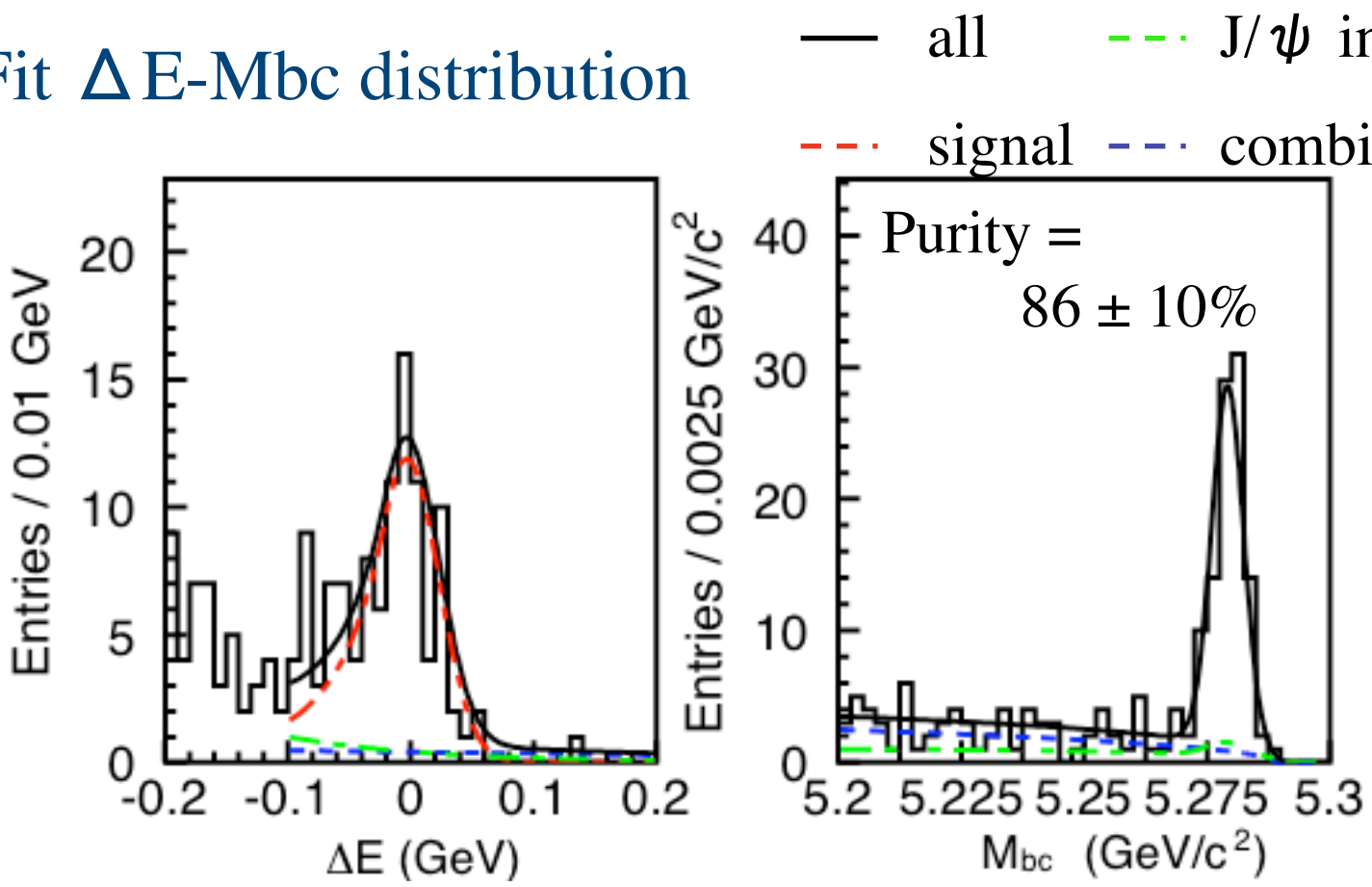
103 events
in the signal box

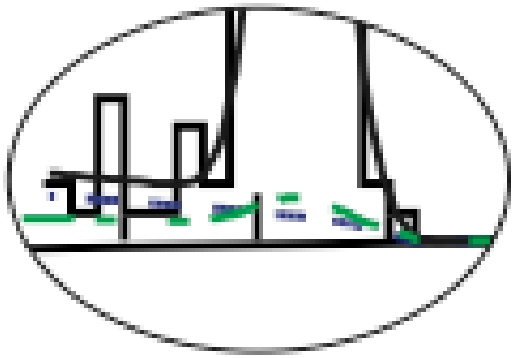
Signal box;

$-0.1 < \Delta E < 0.05$ (GeV)

$5.27 < Mbc < 5.29$ (GeV/c^2)

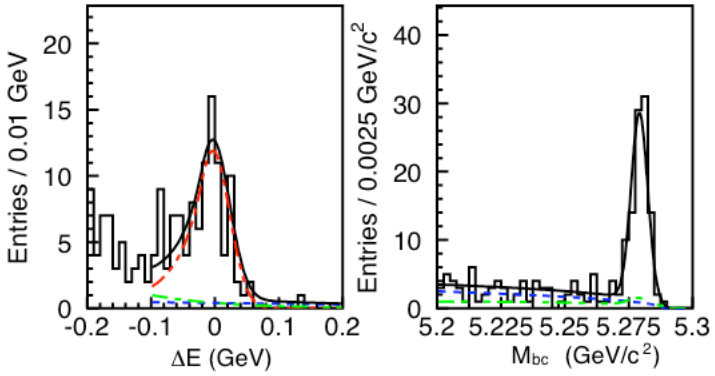
2D Fit ΔE-Mbc distribution





The deference of BG shape between J/ψ inclusive BG and combinatorial BG is considered.

Fit ΔE-Mbc distribution



N(signal) = 88.9 + 10.4 (events)
N(combinatorial) = 6.2 + 3.0
N(psi inclusive) = 7.9 (fixed)

	Mbc	ΔE
Signal	Gaussian	Crystal Ball
Combinatorial BG	ARGUS	polynomial
B->J/ψ X BG	Gaussian + ARGUS	exponential

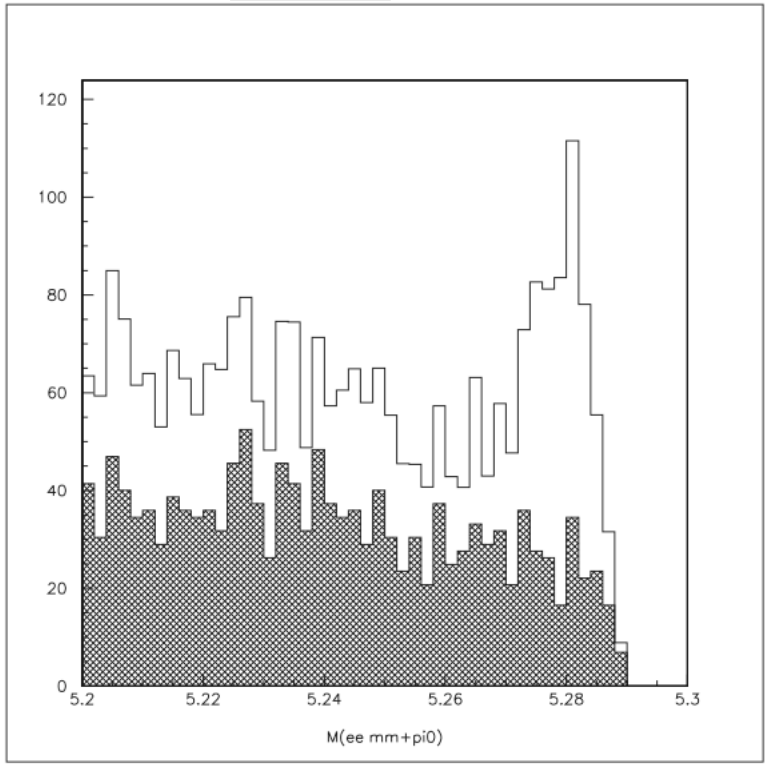
Shape : determined from MC

J/ψ inclusive background

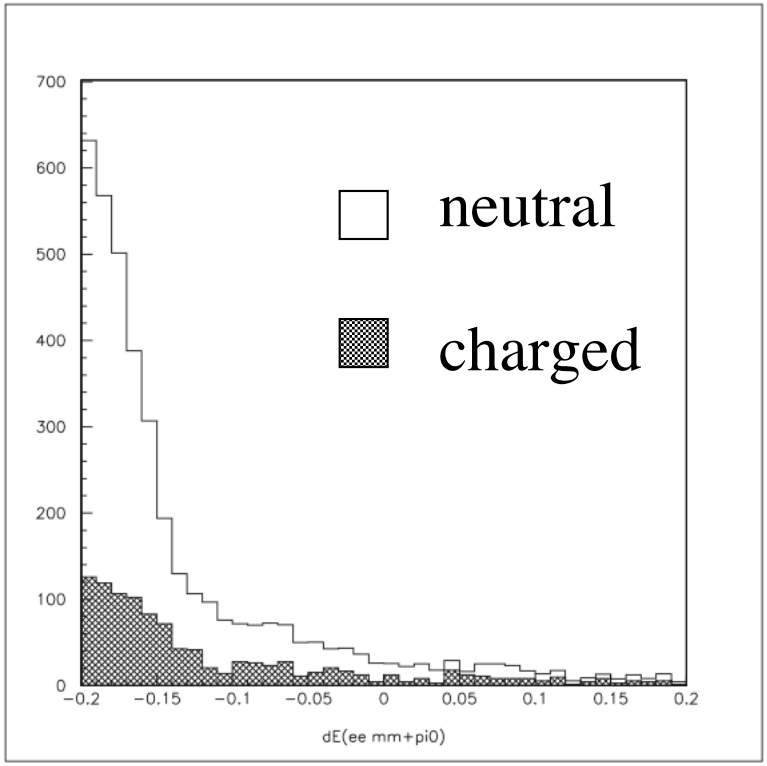
Neutral J/ψ inclusive ($B^0 \rightarrow J/\psi X$) MC : 11.6 /ab

Charged J/ψ inclusive ($B^{\pm} \rightarrow J/\psi X$) MC : 8.4/ab

Mbc

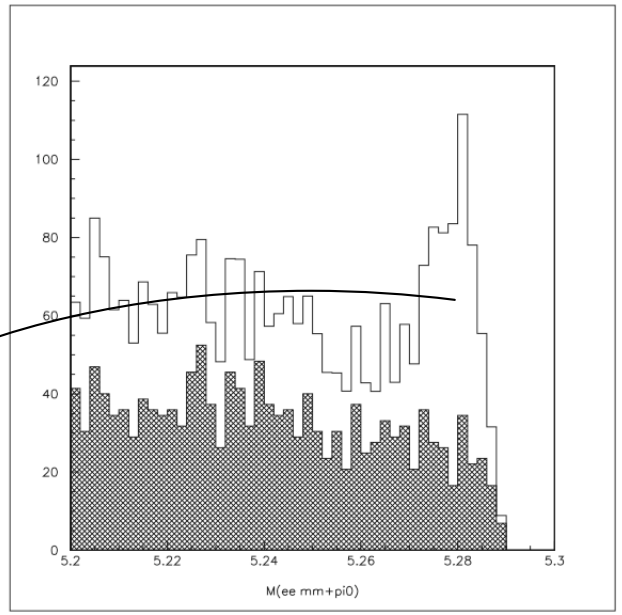


ΔE



Estimated BG(B →J/psi X)
in signal Box; 7.9 events

J/ψ inclusive background
- M_{bc} distribution -



Neutral : 422 events in the signal box for 11.6/ab

J/Psi Ks	179	(events)
J/Psi KL	142	
J/Psi $K^{*0}(892)$	48	
J/Psi $K_1{}^0(1270)$	28	
J/Psi K^0 pi0 pi0	5	
J/Psi K^0 pi+ pi-	3	
J/Psi $K^{\pm}$ pi $^{\pm}$ pi ^{0}	3	
Chic1 feeddown related	7	
Psi(2S) feeddown related	3	

→ CP asymmetry is almost cancelled.

Flavor tagging

- **Inclusive Leptons:**
  - high-p l^-
  - intermed-p l^+

$b \rightarrow c\ l^-\ \nu$

$\hookrightarrow s\ \ l^+\ \nu$

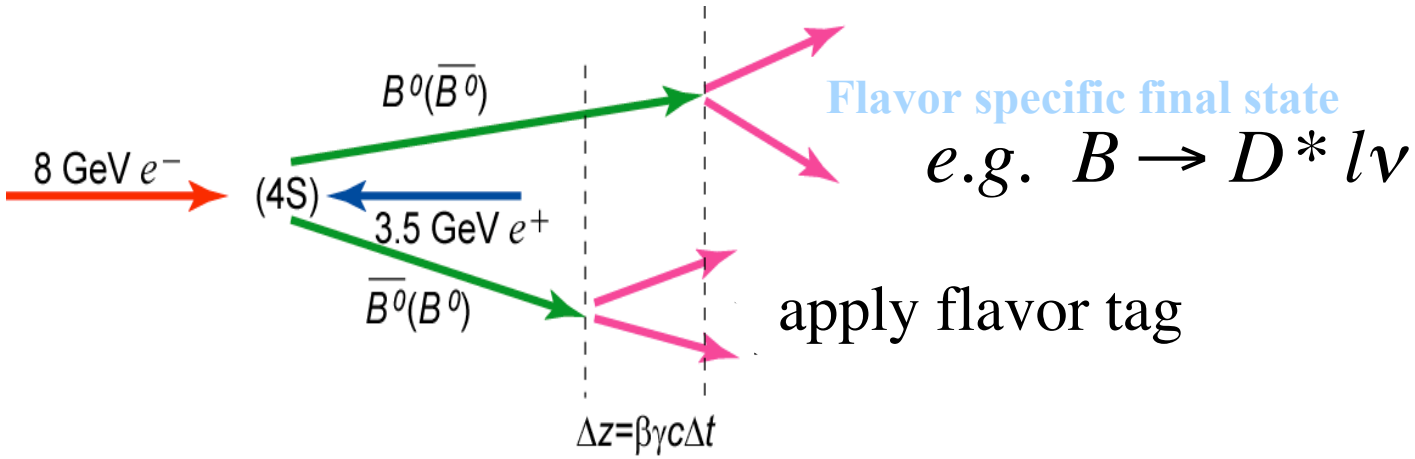
- **Inclusive Hadrons:**
  - high-p π^+
  - intermed-p K^+
  - low-p π^-

$B^0 \rightarrow D^{(*)-}\ \pi^+,\ D^{(*)-}\ \rho^+,\ etc.$

$\rightarrow K^+\ X,$ $\hookrightarrow \pi^+\pi^0$

$\rightarrow D^0\ \pi^-$

Flavor tagging - dilution factor
Wrong tag fraction



$$w = \frac{w_{B^0} + w_{\overline{B}^o}}{2}$$

$$\Delta w = w_{B^0} - w_{\overline{B}^o}$$

CP asymmetry
- Unbinned event-by-event maximum likelihood Fit -

$$L_i = \int \Big\{ f_{sig} P_{sig} R_{sig}(\Delta t - \Delta t') + f_{bkg} P_{bkg} R_{bkg}(\Delta t - \Delta t') + \left(1 - f_{sig} - f_{bkg}\right) P_{bkg}^{J/\varphi X} R_{bkg}^{J/\varphi X}(\Delta t - \Delta t') \Big\} \times d(\Delta t')$$

signal fraction

Resolution function validated by B-lifetime studies

$$P_{sig} = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B}\left[1 - q \cdot \Delta w + q \cdot (1 - 2w)\left\{S_f \sin(\Delta m_d \Delta t) + A_f \cos(\Delta m_d \Delta t)\right\}\right]$$

τ_B, Δm_B

PDG values

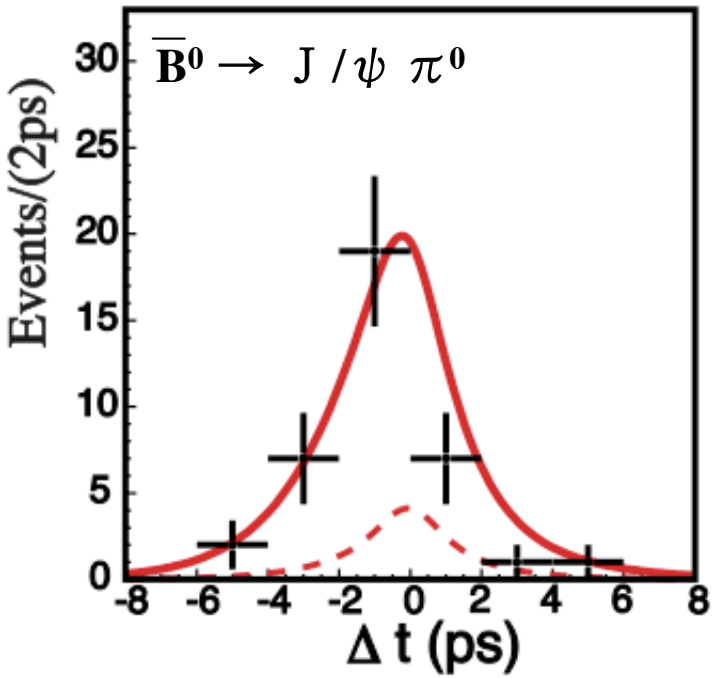
B-flavor tag

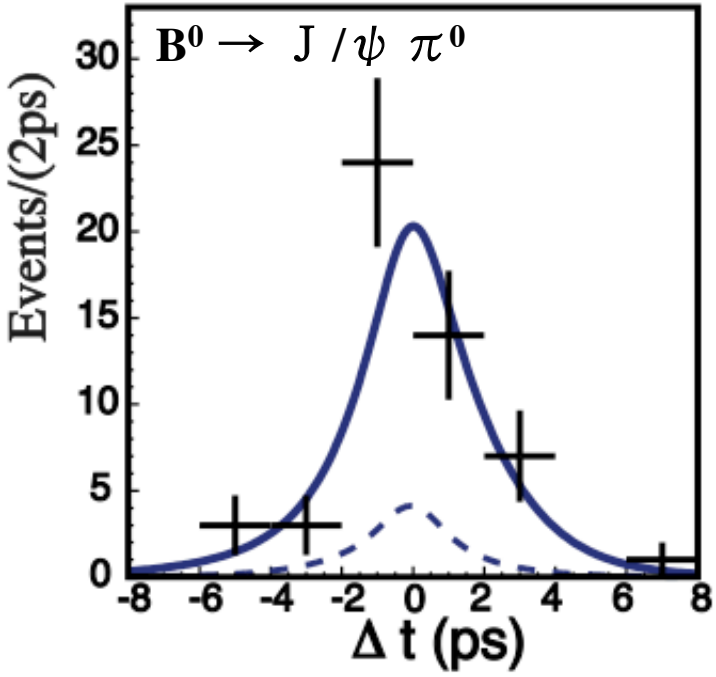
Wrong tag fraction

Free parameter

Result

- Δt distribution
  for each flavor-

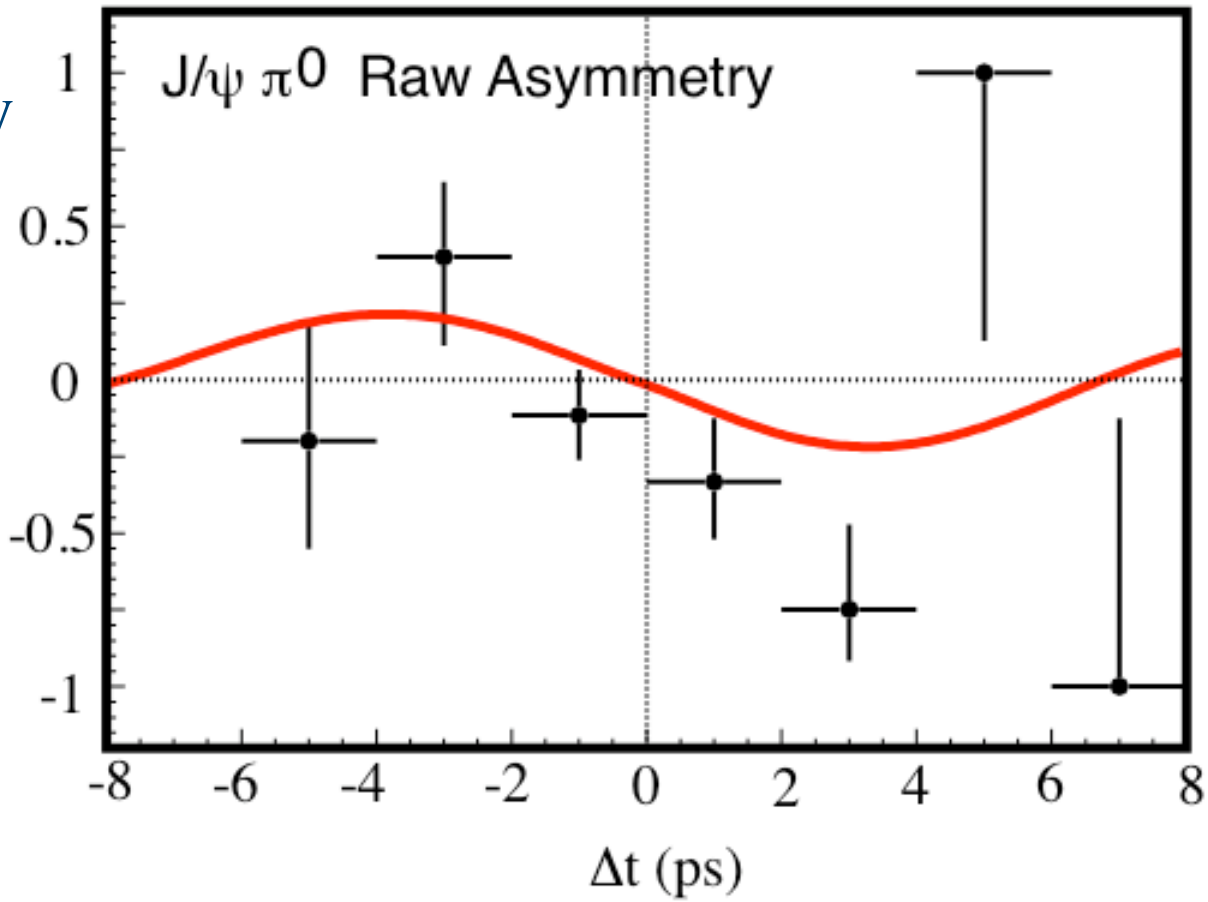




—— Fit

- - - BG

Asymmetry



Preliminary

$S_{J/\psi\pi}$ = –0.72±0.42(stat)±0.08(syst)

$A_{J/\psi\pi}$ = –0.01±0.29(stat)±0.07(syst)

(c.f) Babar (PRL.91:061802 (2003))

$S_{J/\psi\pi}$ = 0.05±0.49(stat)±0.16(syst)

$A_{J/\psi\pi} = -C_{J/\psi\pi}$

= – 0.38±0.41(stat)±0.09(syst)

(c.f) If no penguin→ S_f - $\sin 2\phi_1$

A_f 0

Belle(Belle-CONF-0353 (hep-ex/0308036))

$\sin 2\phi_1$ = 0.733±0.057(stat)±0.028(syst)

Systematic errors

	$S_{J/\psi\pi^0}$	$A_{J/\psi\pi^0}$
Wrong tag fraction	0.025	0.014
Signal fractions	0.023	0.016
Background shape	0.014	0.0065
Physics (τ_B , Δm_B)	0.0019	0.0071
Resolution function	0.010	0.0061
Fit bias	0.043	0.059
Vertexing	0.062	0.018
Total	0.084	0.066

Summary

We measure Time dependent CP asymmetry in $B^0 \to J/\psi\ \pi^0$ from 152×10^6 $B\bar{B}$ events collected by KEKB/Belle.

$$S_{J/\psi\pi} = -0.72 \pm 0.42(\text{stat.}) \pm 0.08(\text{syst.})$$

$$A_{J/\psi\pi} = -0.01 \pm 0.29(\text{stat.}) \pm 0.07(\text{syst.})$$

Preliminary

It seems that tree diagram contribution is dominant at present.
We need more statistics to get conclusive result.

Back up slide

CP violation parameter

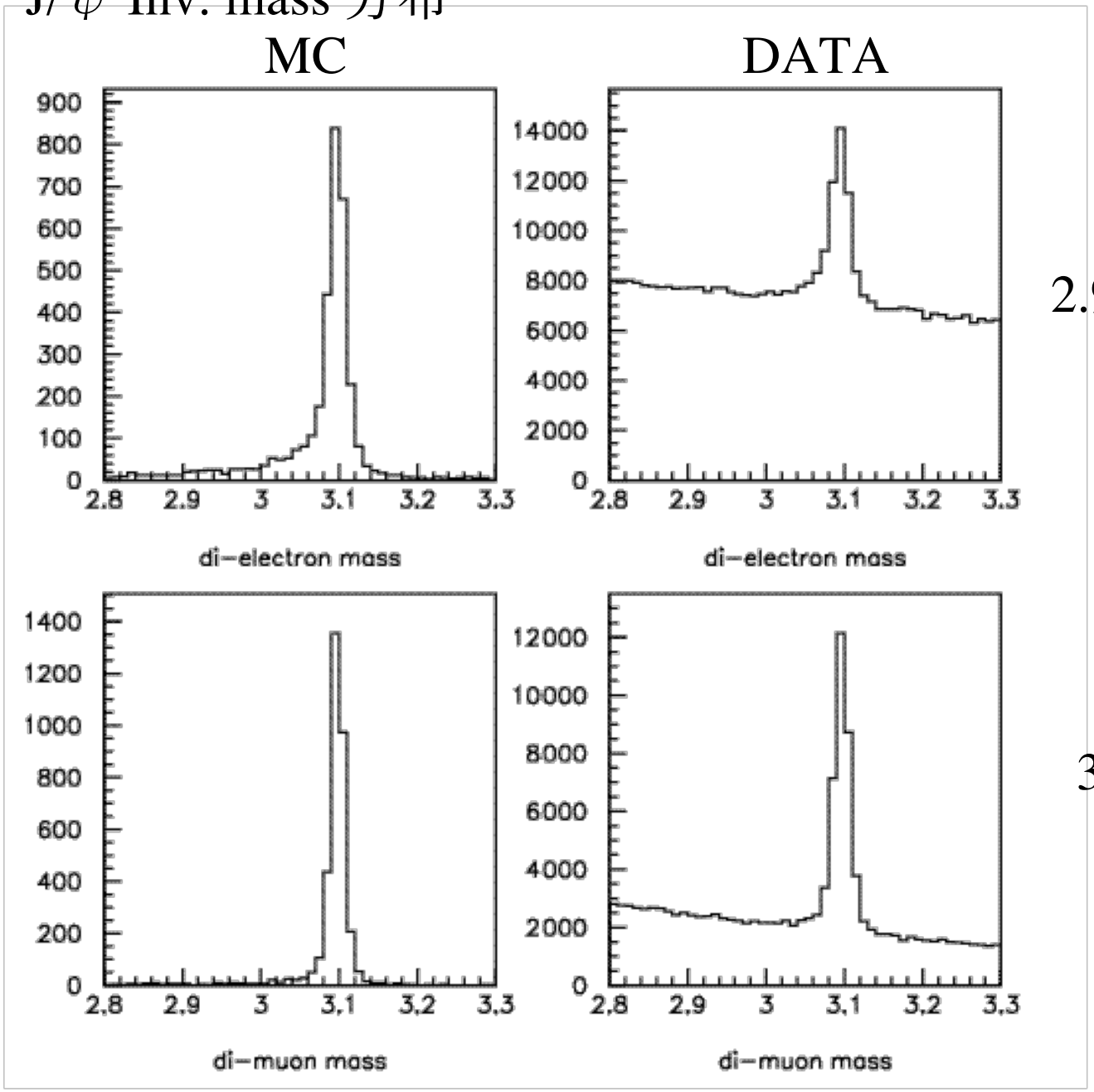
A = 0.0 fixed

S = -0.72 ± 0.42(stat.)

PARAMETER CORRELATION COEFFICIENTS

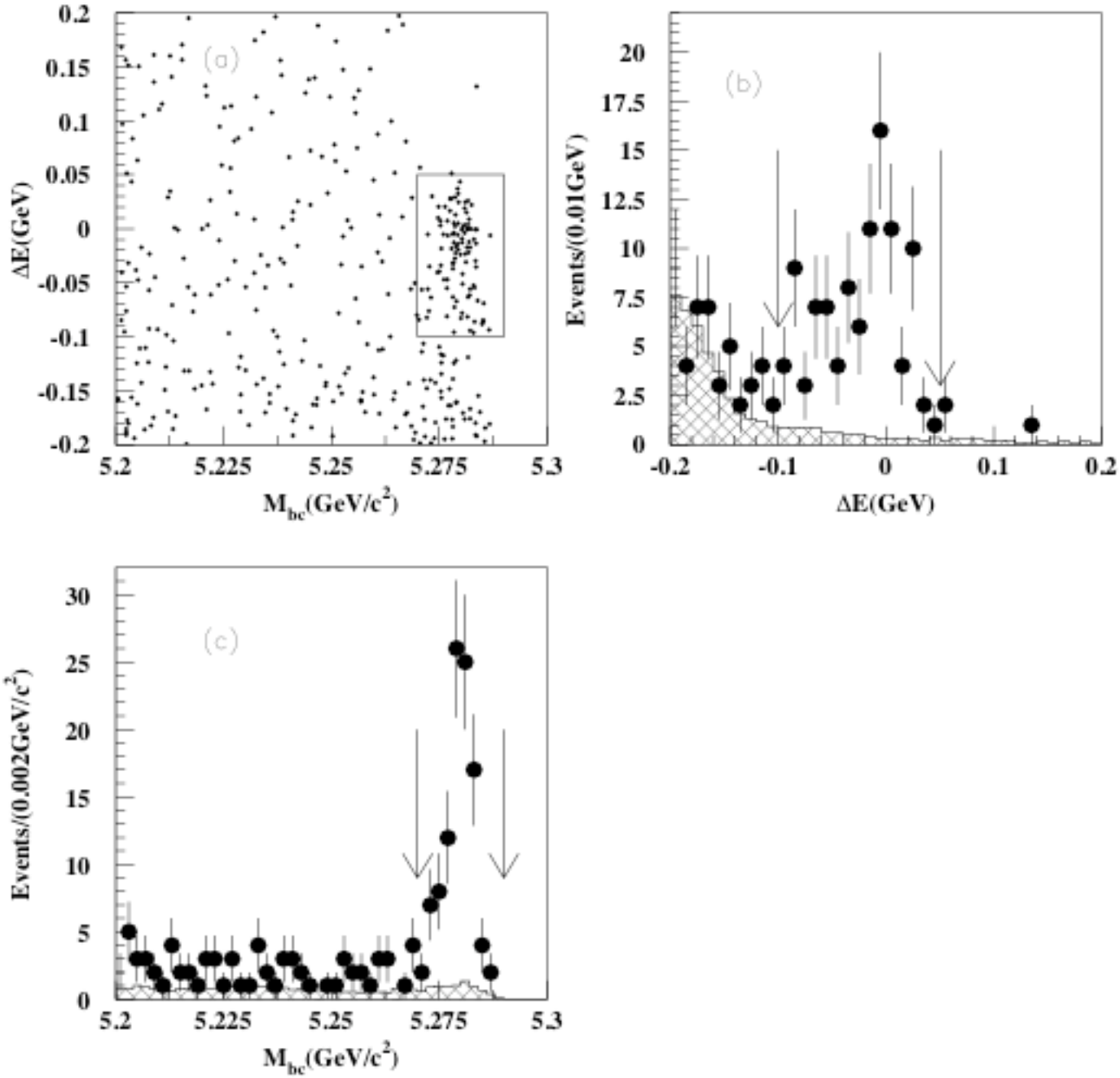
NO.	GLOBAL	A	S
A	0.11967	1.000	0.120
S	0.11967	0.120	1.000

J/ψ Inv. mass 分布

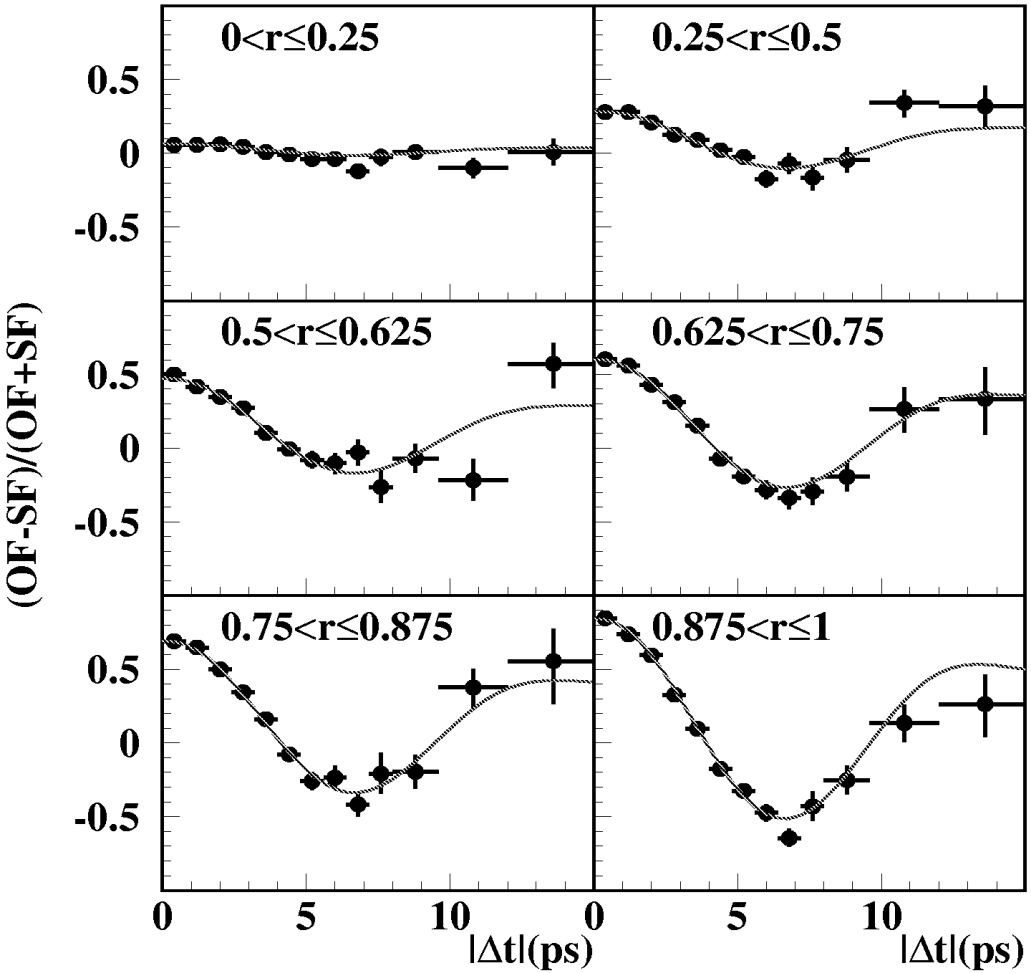


$2.947 < M_{ee} < 3.133$ (GeV/c^2)

$3.037 < M_{\mu\mu} < 3.133$ (GeV/c^2)


(a)
ΔE(GeV)
M_bc(GeV/c²)
(b)
Events/(0.01GeV)
ΔE(GeV)
(c)
Events/(0.002GeV/c²)
M_bc(GeV/c²)

Belle Tagging Performance with $B \rightarrow D^{*+} l^-$ _



$B^0 - \bar{B}^0$ mixing

(OF-SF)/(OF+SF)

~(1-2 w)cos(_m t)

12 r-bins, 6 divisions in r.
B^0 and $\bar{B}^0$ tags treated separately.

l	r interval	ϵ_l	w_l	Δw_l	$\epsilon^l_{\rm eff}$
1	0.000 – 0.250	0.398	0.464 ± 0.006	-0.011 ± 0.006	0.002 ± 0.001
2	0.250 – 0.500	0.146	0.331 ± 0.008	$+0.004 \pm 0.010$	0.017 ± 0.002
3	0.500 – 0.625	0.104	0.231 ± 0.009	-0.011 ± 0.010	0.030 ± 0.002
4	0.625 – 0.750	0.122	0.163 ± 0.008	-0.007 ± 0.009	0.055 ± 0.003
5	0.750 – 0.875	0.094	0.109 ± 0.007	$+0.016 \pm 0.009$	0.057 ± 0.002
6	0.875 – 1.000	0.136	0.020 ± 0.005	$+0.003 \pm 0.006$	0.126 ± 0.003