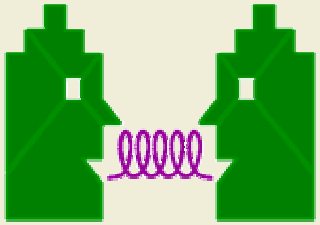


CP violation in *B* mesons

- New results from Belle -

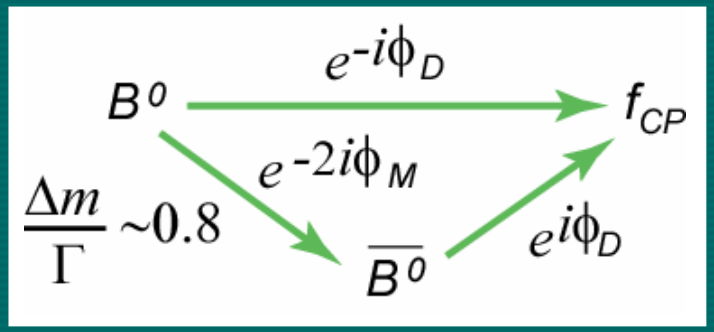
ICHEP2002, Amsterdam
July 29, 2002

Masa Yamauchi
KEK

Outline

- Introduction
- Experimental apparatus and data sample
- New results on $\sin 2\phi_1$
- New results on CPV in:
  - $B^0 \to \pi^+ \pi^-$ (41.8 fb^{-1})
  - $B^0 \to \eta' K_S$, ϕK_S and $K^+ K^- K_S$
  - $B^0 \to J/\psi \pi^0$
- New result on $b \to s\, l^+ l^-$ decay
- Summary

CP violation in $B^0\overline{B}^0$ system



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

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

$$A_f = \frac{|\lambda_f|^2 - 1}{|\lambda_f|^2 + 1}$$

$$S_f = \frac{2Im(\lambda_f)}{|\lambda_f|^2 + 1}$$

$$\lambda_f \equiv e^{-2i\phi_M} \frac{A(\overline{B} \to \overline{f})}{A(B \to f)}$$

Standard model predictions

	$b \to c\bar{c}s$	$b \to c\bar{c}d$	$b \to s\bar{s}s$	$b \to u\bar{u}d$
example	$J/\psi Ks$	$J/\psi \pi^0$	ϕKs	$\pi^+\pi^-$
A_f	0	0	small	$\neq 0$
S_f	$\sin 2\phi_1$	$\sin 2\phi_1$	$\sin 2\phi_1$	"$\sin 2\phi_2$"

Note: $A_f \neq 0$ ⇨ $\Gamma(B \to f) \neq \Gamma(\overline{B} \to \overline{f})$ ⇨ direct CP violation.

The ϕ_i's and CKM matrix

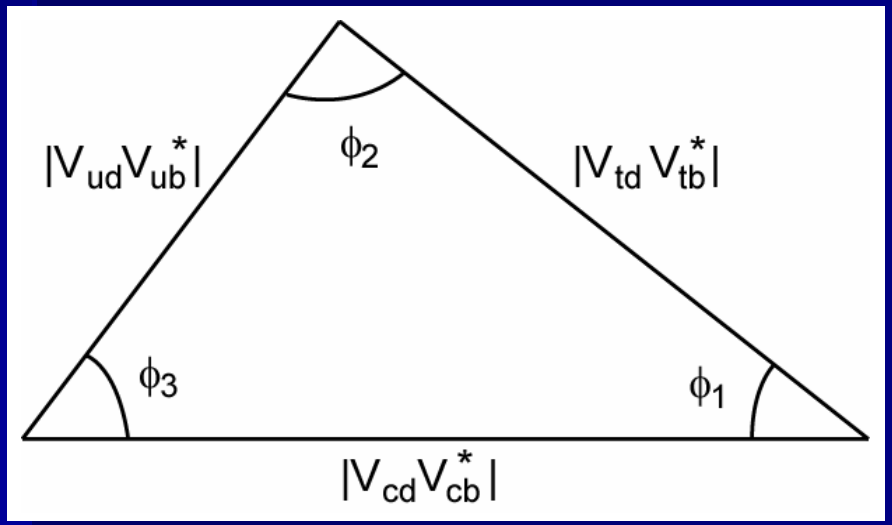
CKM quark mixing matrix

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Unitarity

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

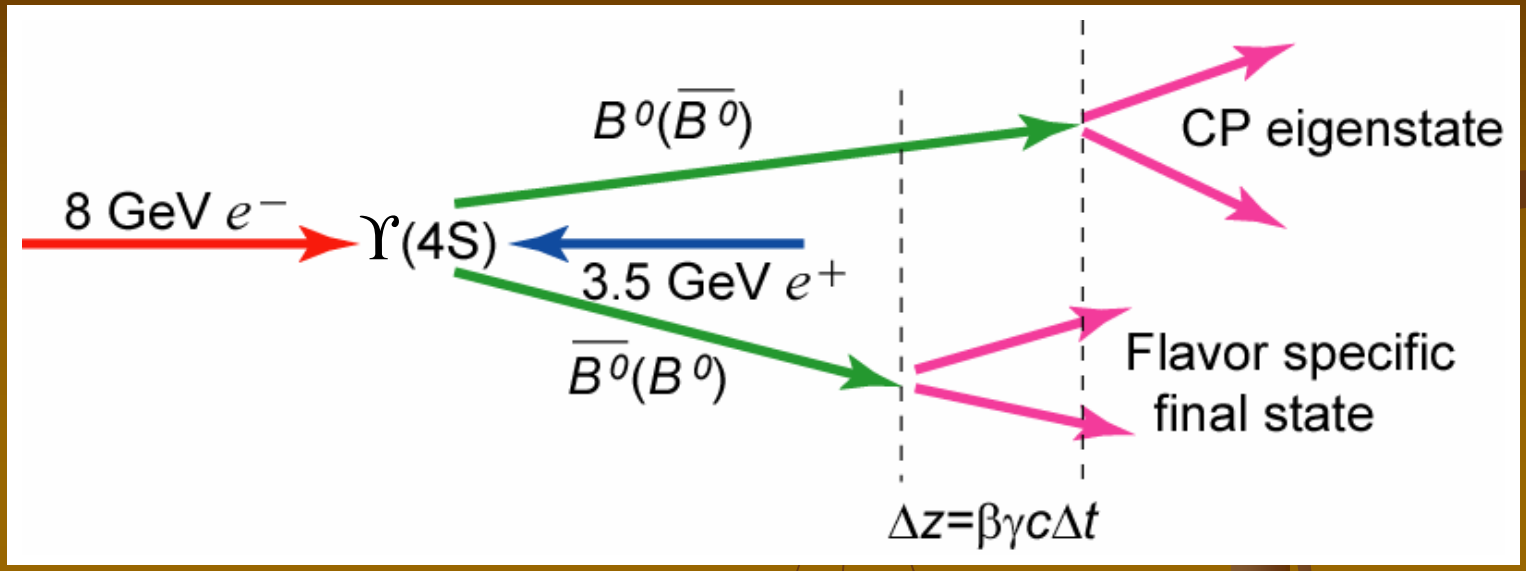
Unitarity triangle



$$\phi_1 \equiv \pi - \arg\left(\frac{-V_{tb}^{*}V_{td}}{-V_{cb}^{*}V_{cd}}\right)$$

$$\phi_2 \equiv \arg\left(\frac{V_{tb}^{*}V_{td}}{-V_{ub}^{*}V_{ud}}\right)$$

Principle of the measurement



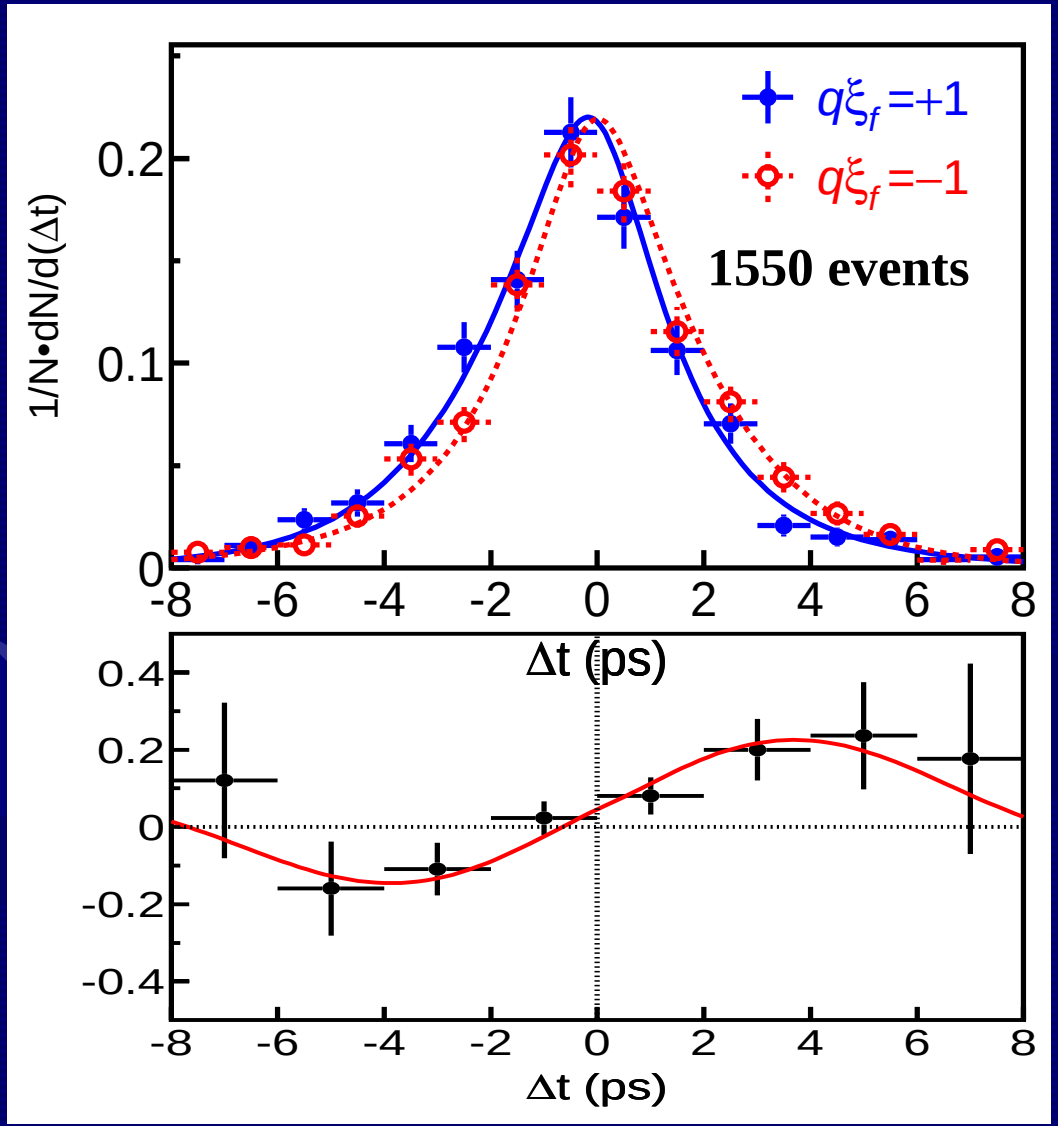
$\Gamma(B\to f_{CP};t)$ can be measured.

Large data sample

Reconstruct *B* decays into CP eigenstates → Tag flavor of the other *B* → Measure distance between the two vertices → Fit Δt distr. with expected shape → A_f and S_f

Previous result of $\sin 2\phi_1$

(Belle, Feb. 2002, hep-ex/0205020)

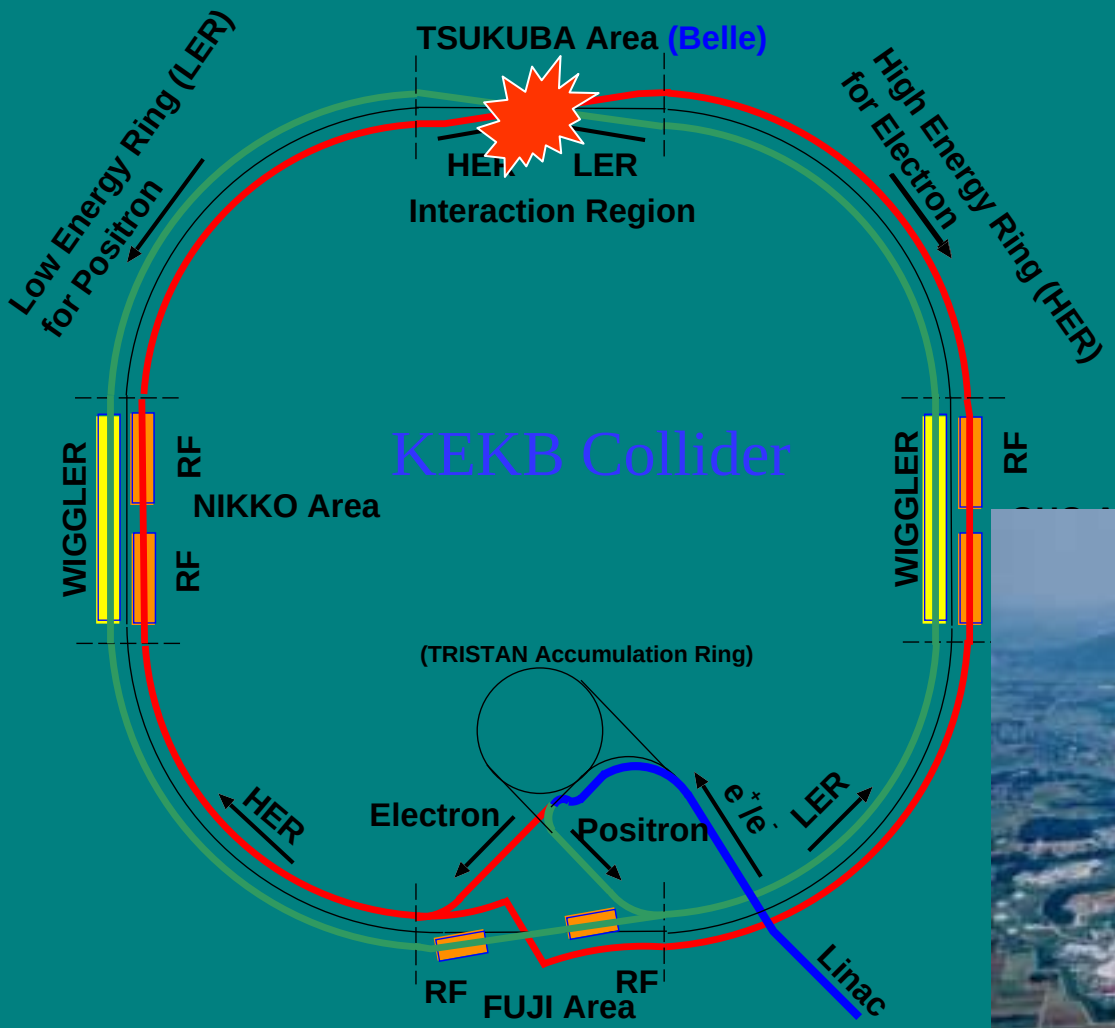


- 41.8 fb^{-1}
- 6 $b \to c\bar{c}s$ decay modes ($B \to J/\psi K_S$, $J/\psi K_L$ etc.)
- $S_{ccs} = \sin 2\phi_1$

  $= \underline{0.82 \pm 0.12 \pm 0.05}$
- $|\lambda_{ccs}| = 1.01\ ^{+0.08}_{-0.07}$ (stat.)

  i.e., A_{ccs} is consistent with 0.

KEKB Collider



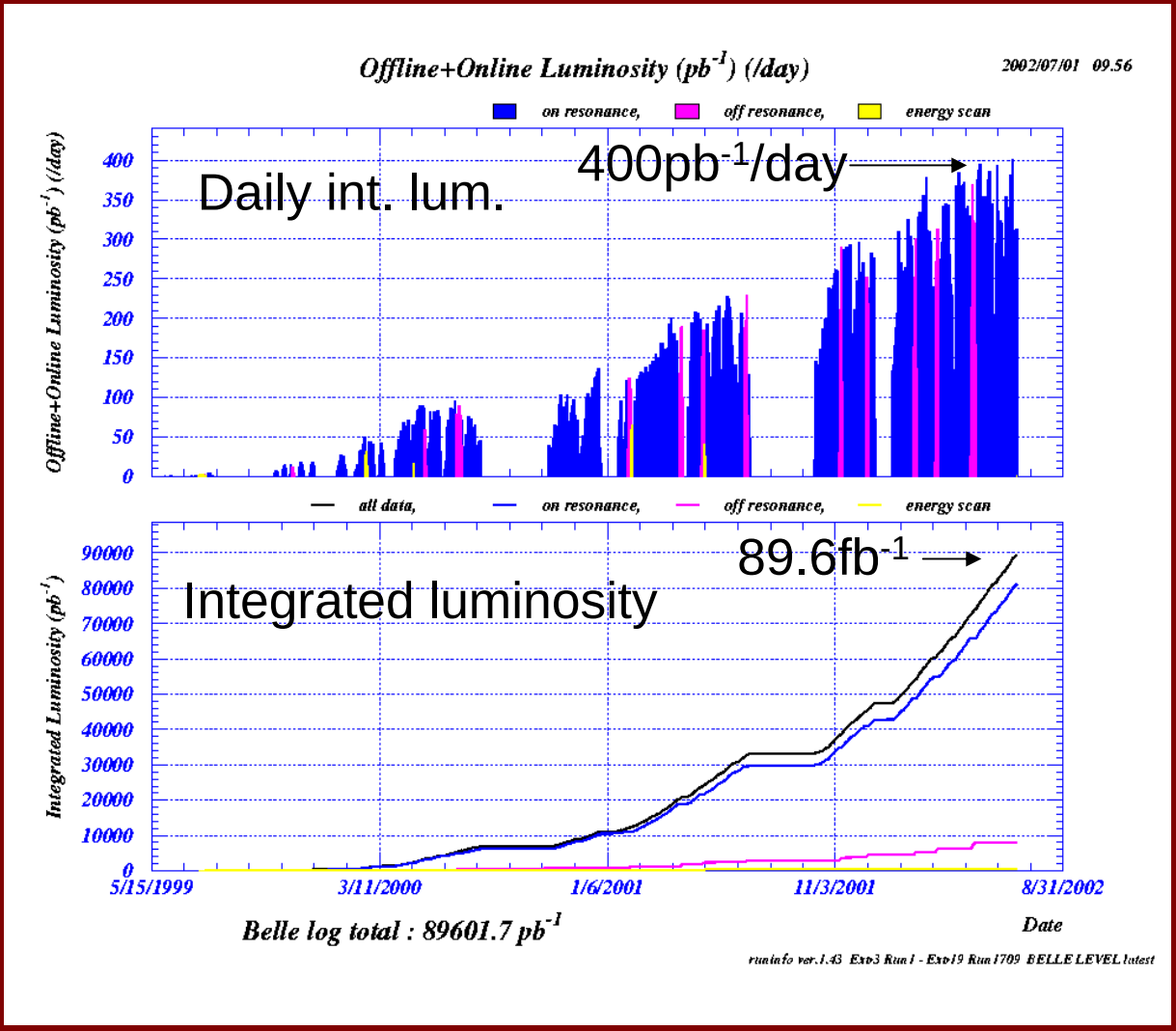
8 GeV e^- + 3.5 GeV e^+

$W_{CM}=m(\Upsilon(4s))$

3 km circumference

±11 mrad crossing angle

Luminosity

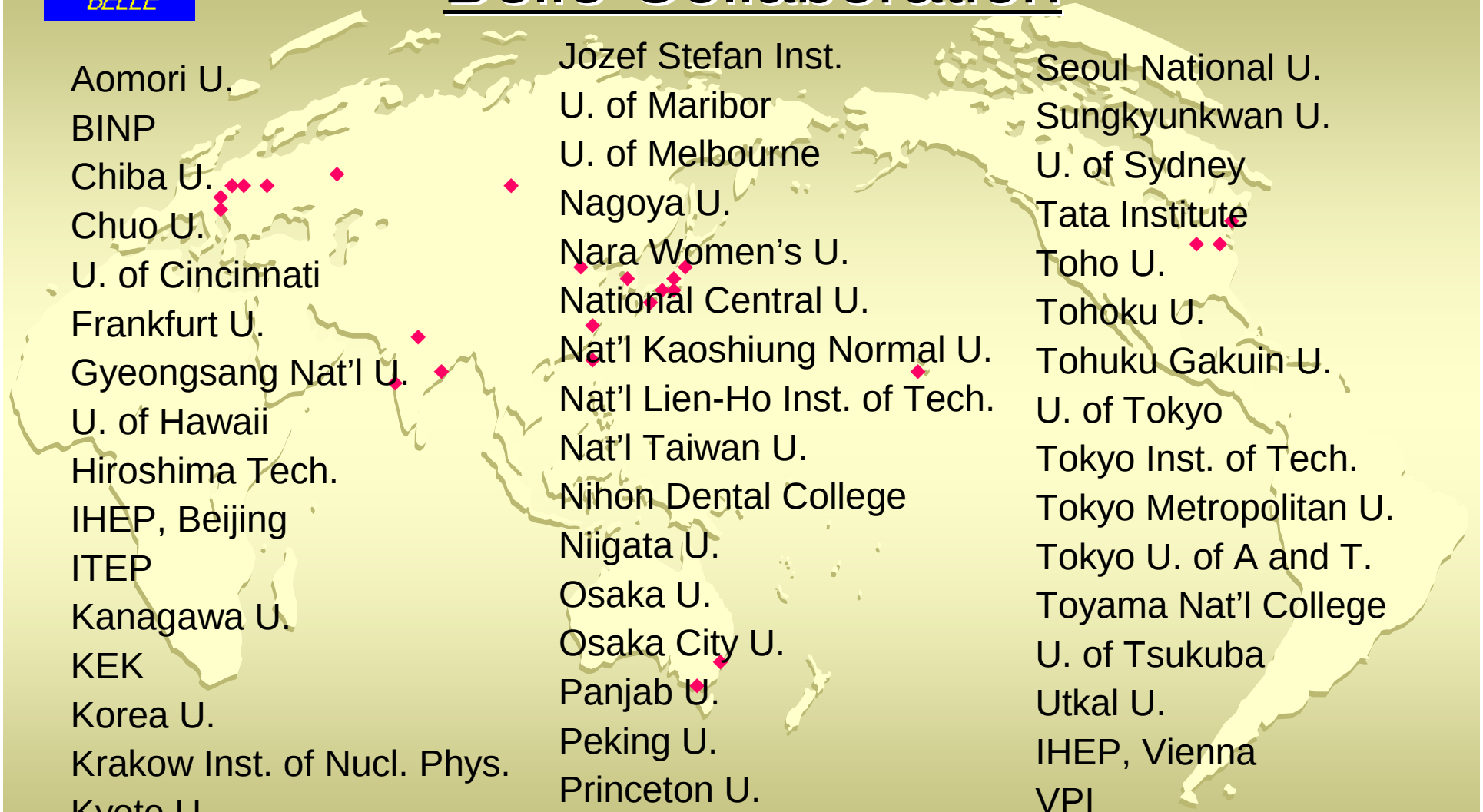


L_{peak}=7.4x10^{33} (/cm^2/s^2)

Int. lum.=89.6 fb^{-1}
(~90% on $\Upsilon(4s)$
+ ~10% off peak)

85 million $B\bar{B}$ events recorded by Belle before the summer 02.

Belle Collaboration



Aomori U.
BINP
Chiba U.
Chuo U.
U. of Cincinnati
Frankfurt U.
Gyeongsang Nat'l U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
ITEP
Kanagawa U.
KEK
Korea U.
Krakow Inst. of Nucl. Phys.
Kyoto U.
Kyungpook National U.
U. of Lausanne
Jozef Stefan Inst.
U. of Maribor
U. of Melbourne
Nagoya U.
Nara Women's U.
National Central U.
Nat'l Kaoshiung Normal U.
Nat'l Lien-Ho Inst. of Tech.
Nat'l Taiwan U.
Nihon Dental College
Niigata U.
Osaka U.
Osaka City U.
Panjab U.
Peking U.
Princeton U.
Riken
Saga U.
USTC
Seoul National U.
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Tohuku Gakuin U.
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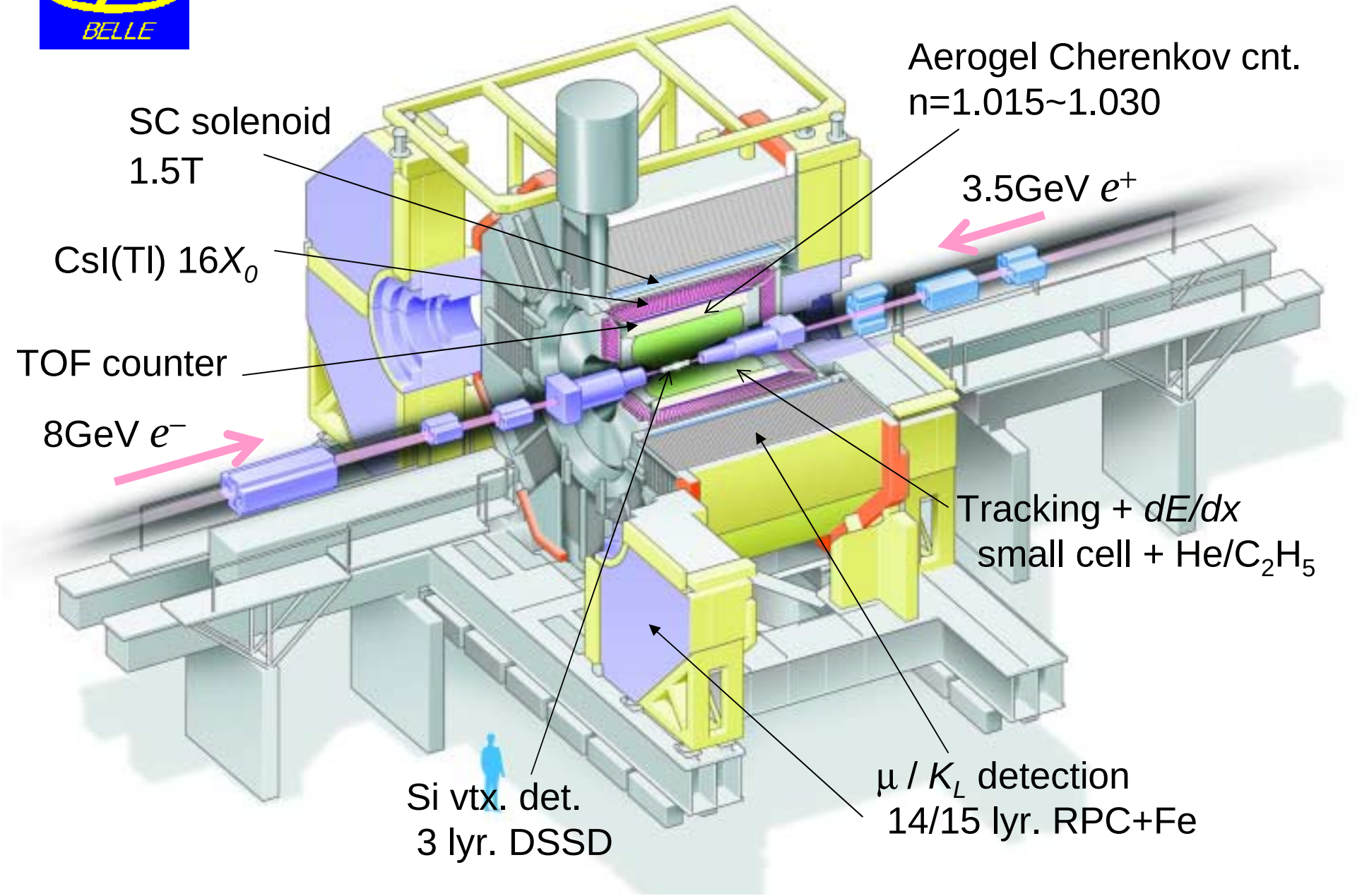
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of A and T.
Toyama Nat'l College
U. of Tsukuba
Utkal U.
IHEP, Vienna
VPI
Yokkaichi U.
Yonsei U.

Belle Detector



Detector performance

Vertex measurement

Impact parameter resolution

= 55μm for 1GeV/*c* normal trk.

→100μm vertex resolution in *z*

Tracking system

$(\sigma_{Pt}/p_t)^2$

$= (0.19p_t)^2+(0.34)^2$ (%^{2})

EM calorimetry

σ_E/E ~ 1.8% @ $E\gamma$= 1 GeV

$e^{\pm}$ efficiency > 90%

(~ 0.3% fake at p > 1 GeV/c)

K/π separation

dE/dx (σ = 6.9%)

TOF (σ = 95 ps)

Aerogel Cerenkov counter

⇨ Efficiency~90%,

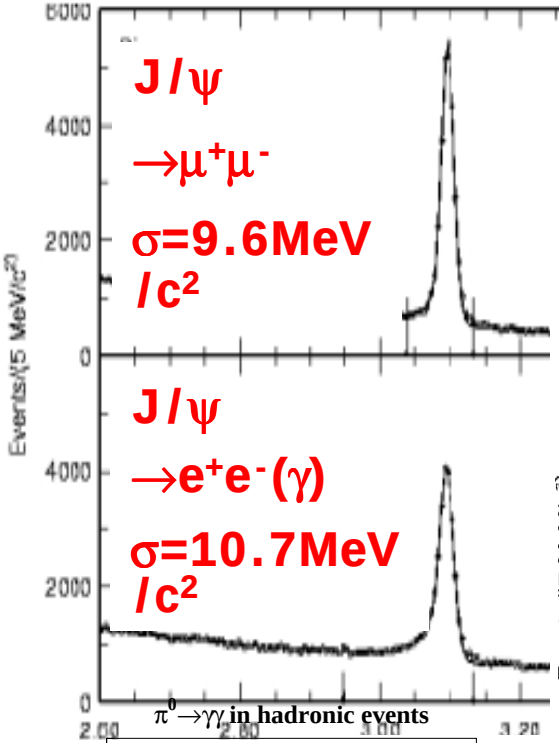
Fake rate~6% up to 3.5GeV/*c*

K_L and $\mu^{\pm}$ detection

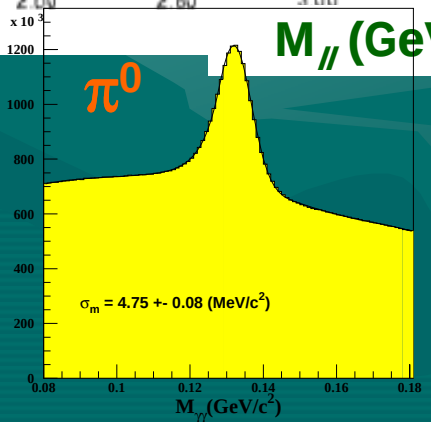
$\mu^{\pm}$ efficiency > 90%

(< 2% fake at p > 1 GeV/c)

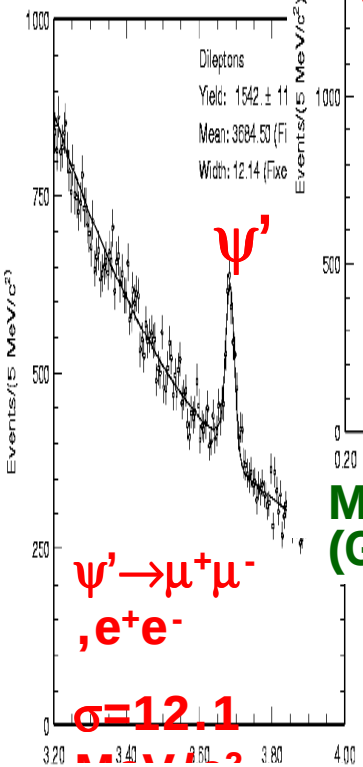
Sub decay modes



$\pi^0 \to \gamma\gamma$ in hadronic events



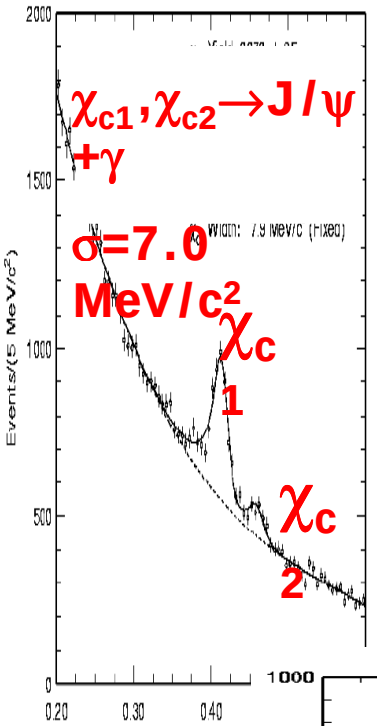
$M_{//}$ (GeV/



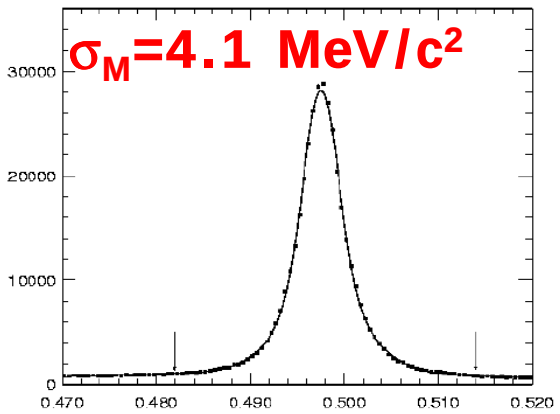
$\psi' \to \mu^+\mu^-, e^+e^-$

σ=12.1

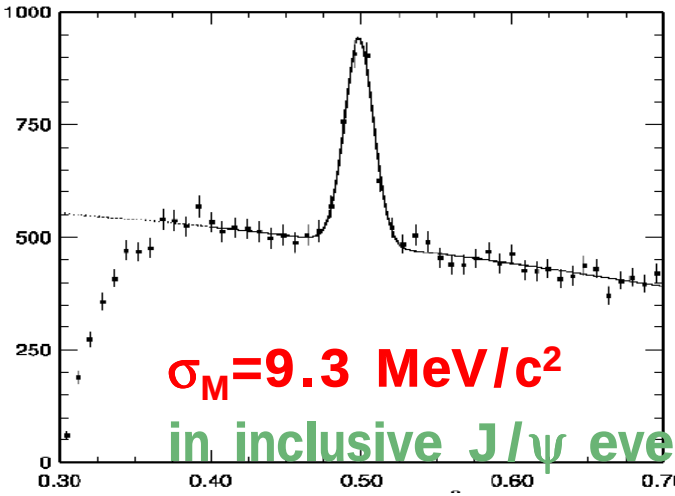
$M_{//}$ (GeV/c²)



$M_{//\gamma}$-$M_{//}$ (GeV/c²)



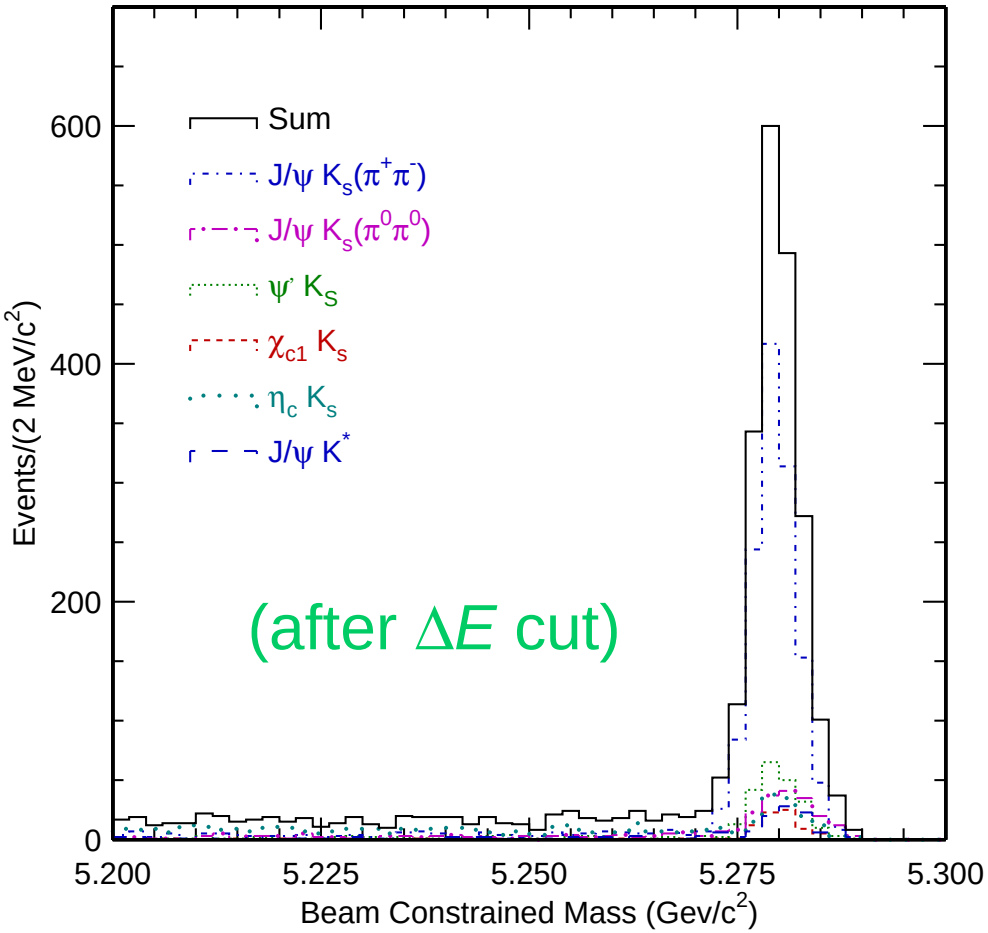
$M(K_S \to \pi^+\pi^-)$ (GeV/c²)



$M(K_S \to \pi^0\pi^0)$ (GeV/c²)

CP eigenstates ($b \to c\bar{c}s$)

$\int L\,dt = 78\ \text{fb}^{-1}$

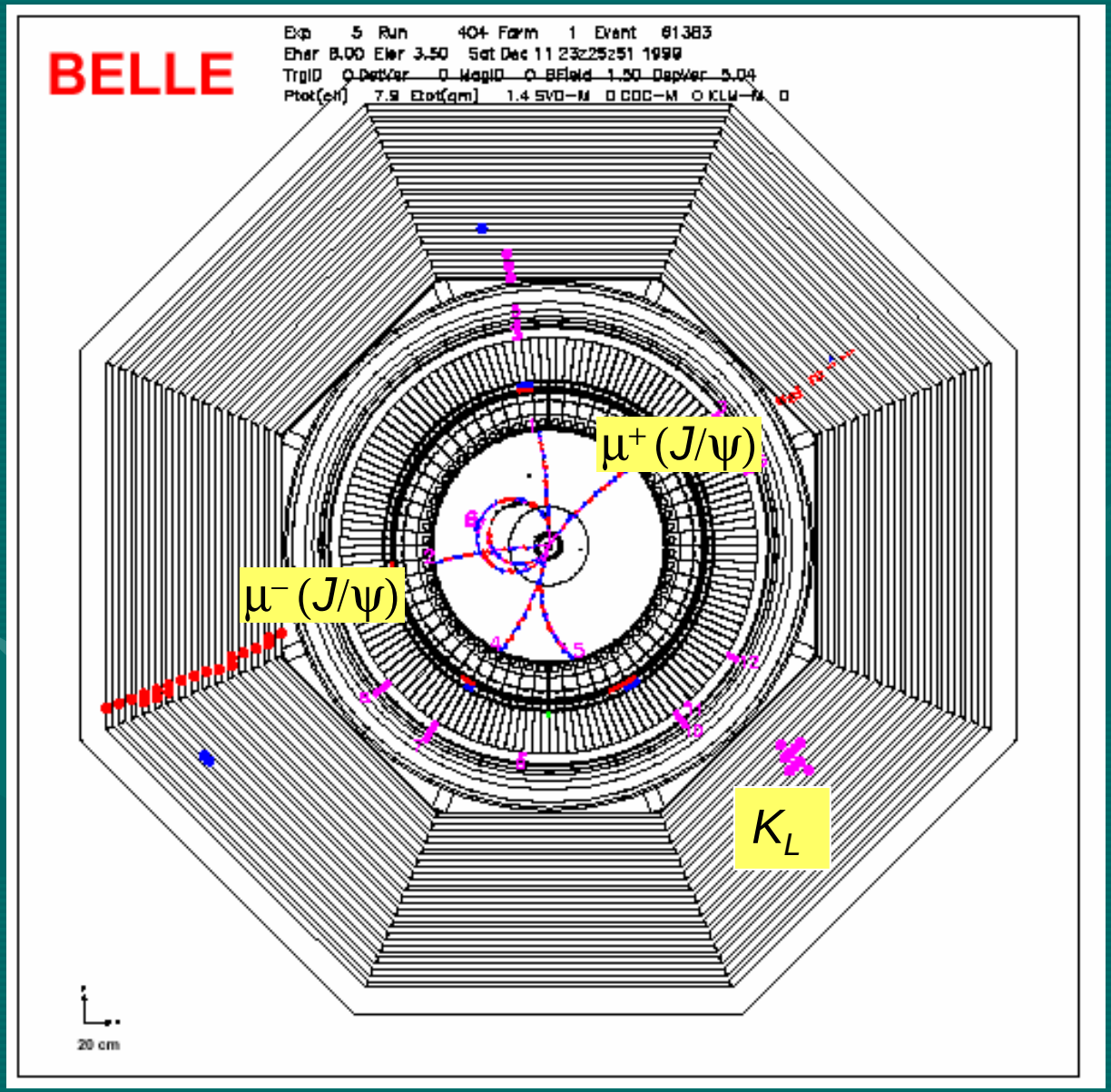


$B \to$	CP	# evts.	S/(S+N)
$J/\psi K_S$ ($K_S \to \pi^+\pi^-$)	odd	1285	0.98
$J/\psi K_S$ ($K_S \to \pi^0\pi^0$)	odd	188	0.82
$\psi(2S) K_S$ ($\psi(2S) \to l^+l^-$)	odd	91	0.96
$\psi(2S) K_S$ ($\psi(2S) \to \pi^+\pi^- J/\psi$)	odd	112	0.91
$\chi_{c1} K_S$ ($\chi_{c1} \to \gamma J/\psi$)	odd	77	0.96
$\eta_c K_S$ ($\eta_c \to K_S K^+\pi^-$)	odd	72	0.65
$\eta_c K_S$ ($\eta_c \to K^+K^-\pi^0$)	odd	49	0.73
$\eta_c K_S$ ($\eta_c \to \bar{p}p$)	odd	21	0.94
$J/\psi K^{*0}$ ($K^{*0} \to K_S \pi^0$)	81% even 19% odd	101	0.92
total		1996	0.94
$J/\psi K_L$	even	1330	0.63
total		3326	

2958 events are used in the fit.

BELLE-CONF-0201 (ABS688)

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



❶ Reconstruct $J/\psi \rightarrow l^+ l^-$.

❷ Find a K_L like cluster.

❸ Assume $B \rightarrow J/\psi K_L$ and calculate K_L energy.

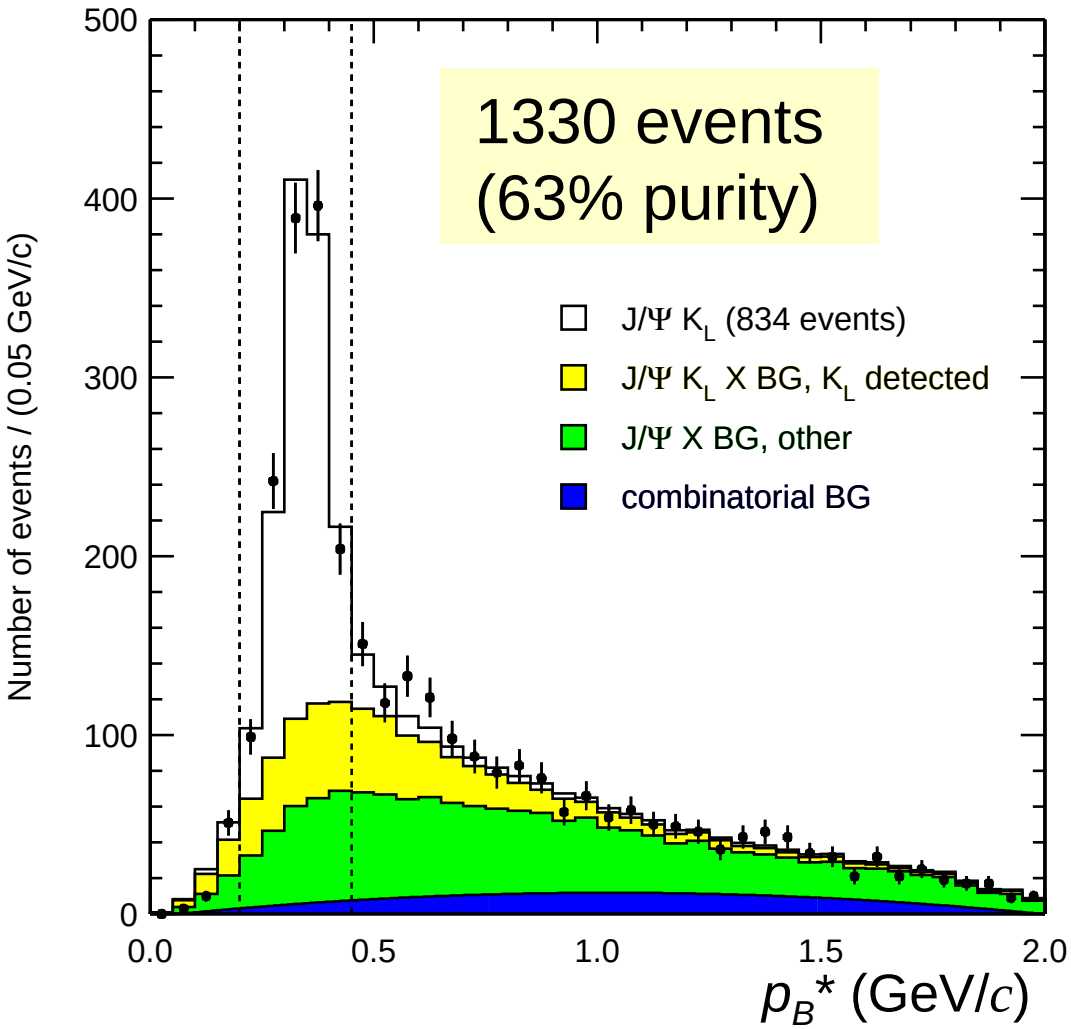
❹ See distribution of :

$$p_B^* \equiv | \vec{p}(J/\psi) + \vec{p}(K_L) |$$

BELLE-CONF-0201 (ABS688)

$B^0 \to J/\psi K_L$ reconstruction

$\int L\, dt = 78\ \text{fb}^{-1}$



- p_B^* ~ 0.35 GeV/c for true $J/\psi K_L$ events.
- Background shape is estimated by MC, and its size is determined by fit.

BELLE-CONF-0201 (ABS688)

Flavor tagging - principle

Identify B^0/ $\overline{B^0}$ by the charges of the inclusive decay products.

- 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.

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

$\hookrightarrow \overline{D^0}\, \pi^-$

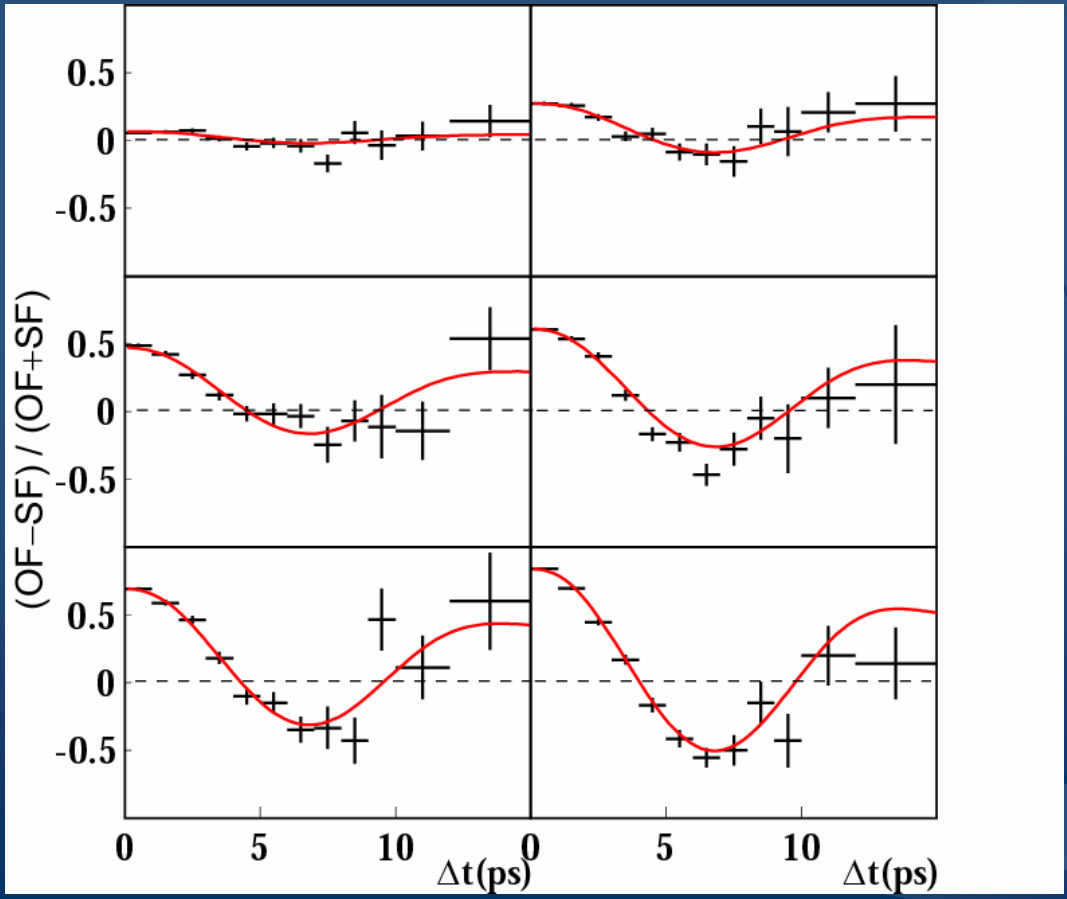
BELLE-CONF-0201 (ABS688)

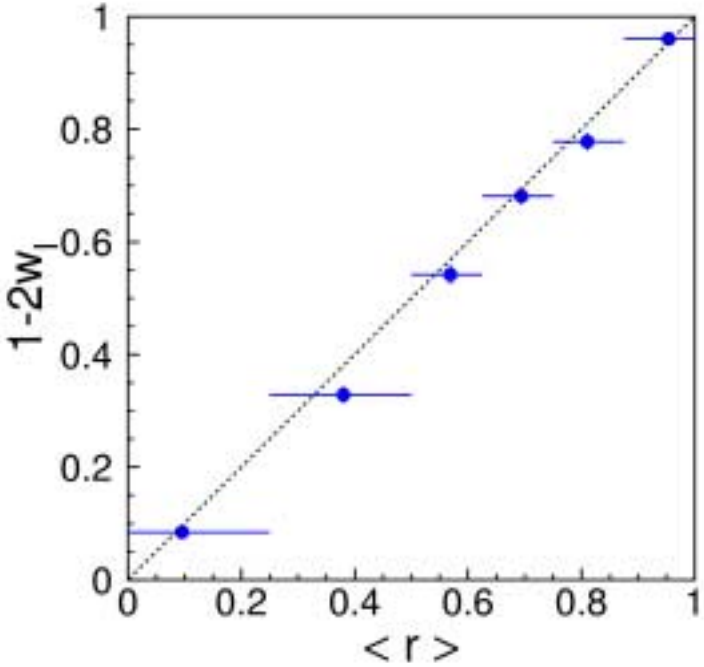
Flavor tagging – dilution factor

Classify the events into six classes and measure
$D = (1-2w)$ for each. (w : wrong tag prob.)

$B^0\overline{B}^0 \rightarrow D^*l\nu$: reconstruct

↳ tag



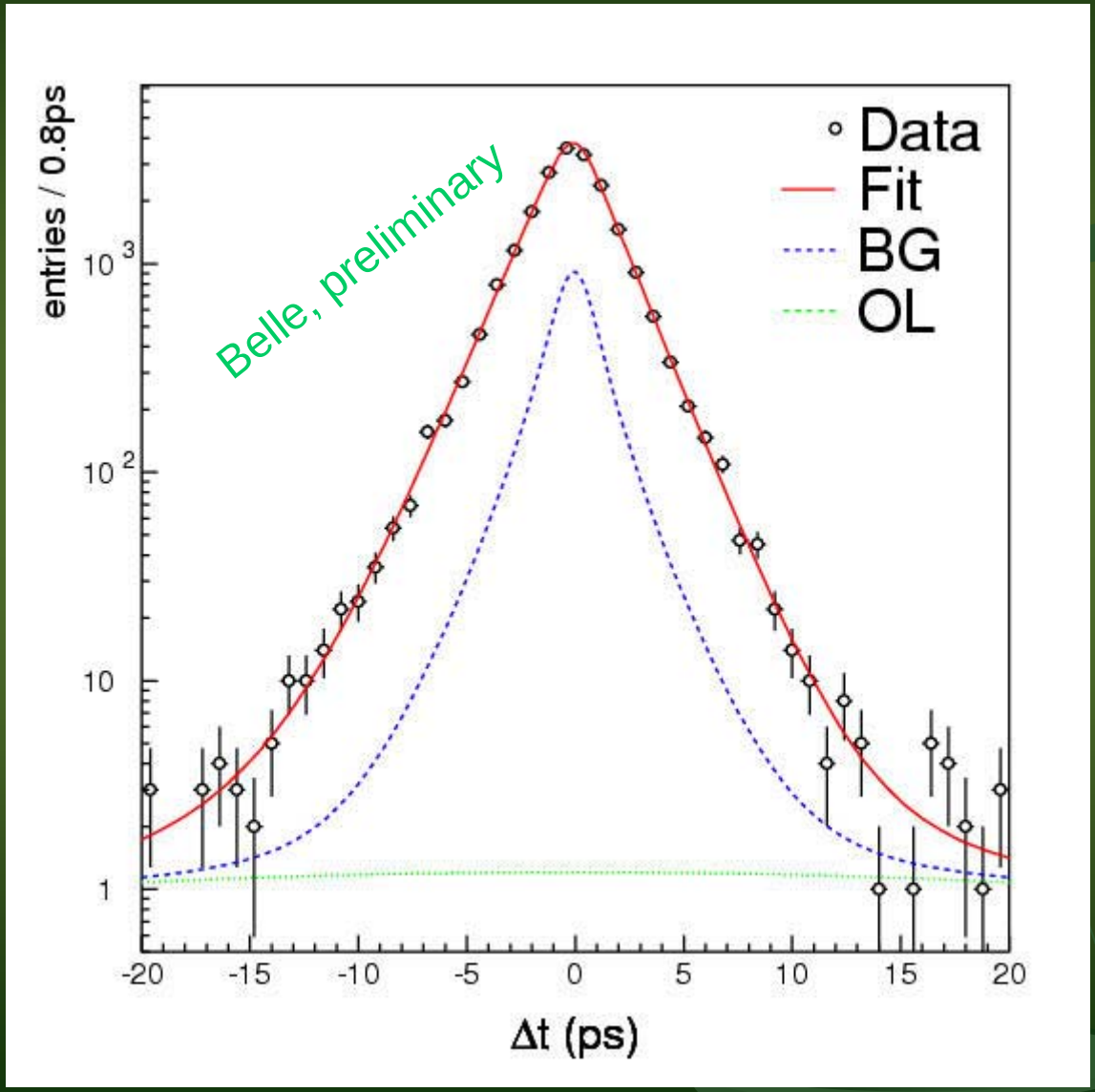


Efficiency > 99.5%

$\varepsilon_{effective} = 28.8 \pm 0.5\%$

BELLE-CONF-0201 (ABS688)

Vertexing – lifetime measurement



$\int L\,dt = 78\ \text{fb}^{-1}$

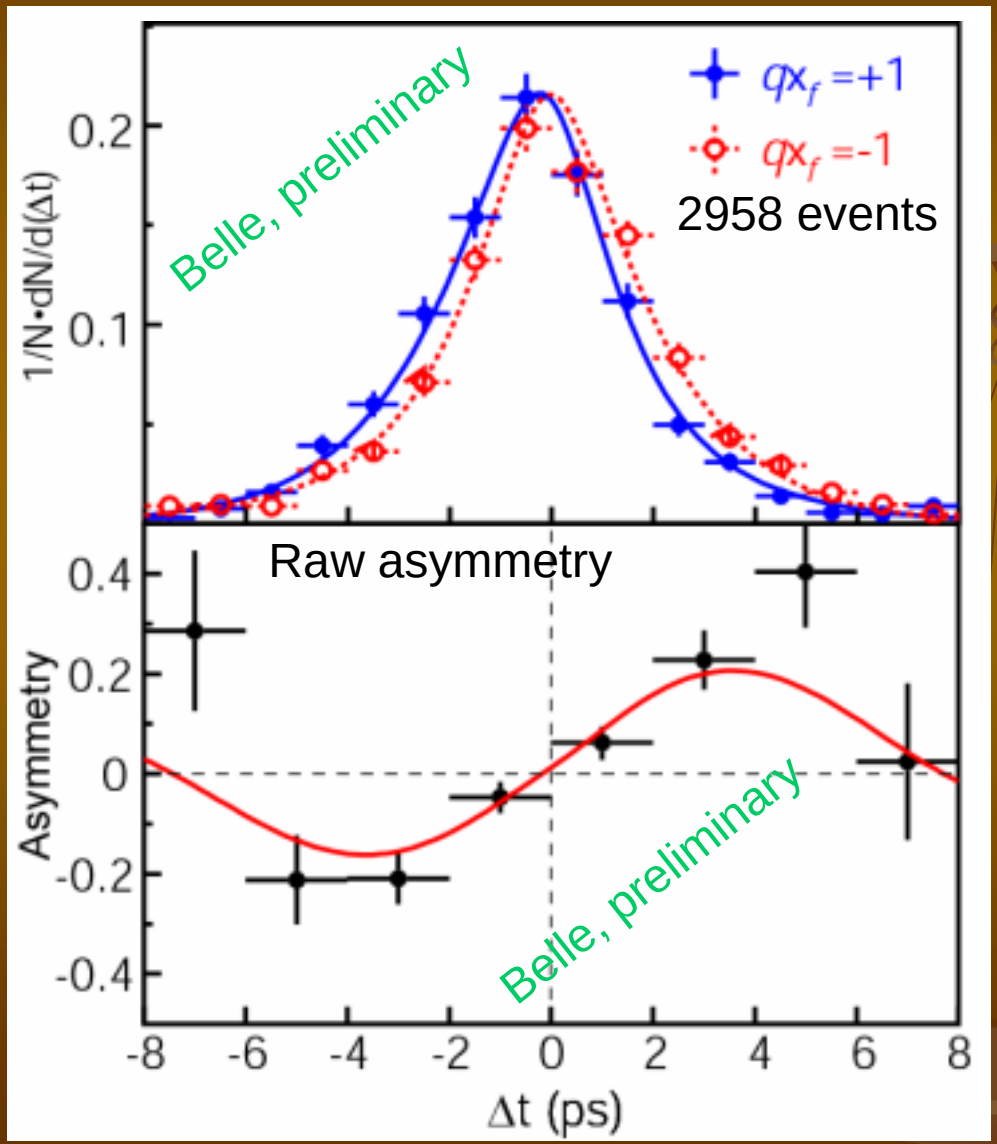
$B^0 \to D^+\pi^-$, $D^{*+}\pi^-$, $D^{*+}\rho^-$, $J/\psi K_S$ and $J/\psi K^{*0}$

B^0 lifetime
1.551±0.018(stat) ps

PGD02:
1.542±0.016 ps

Time resolution (rms)
1.43 ps

New result of $\sin 2\phi_1$



- 78 fb^{-1} (85M $B\bar{B}$)
- 6 $b \to c\bar{c}s$ decay modes ($B \to J/\psi K_S$, $J/\psi K_L$ etc.)
- $S_{ccs} = \sin 2\phi_1$

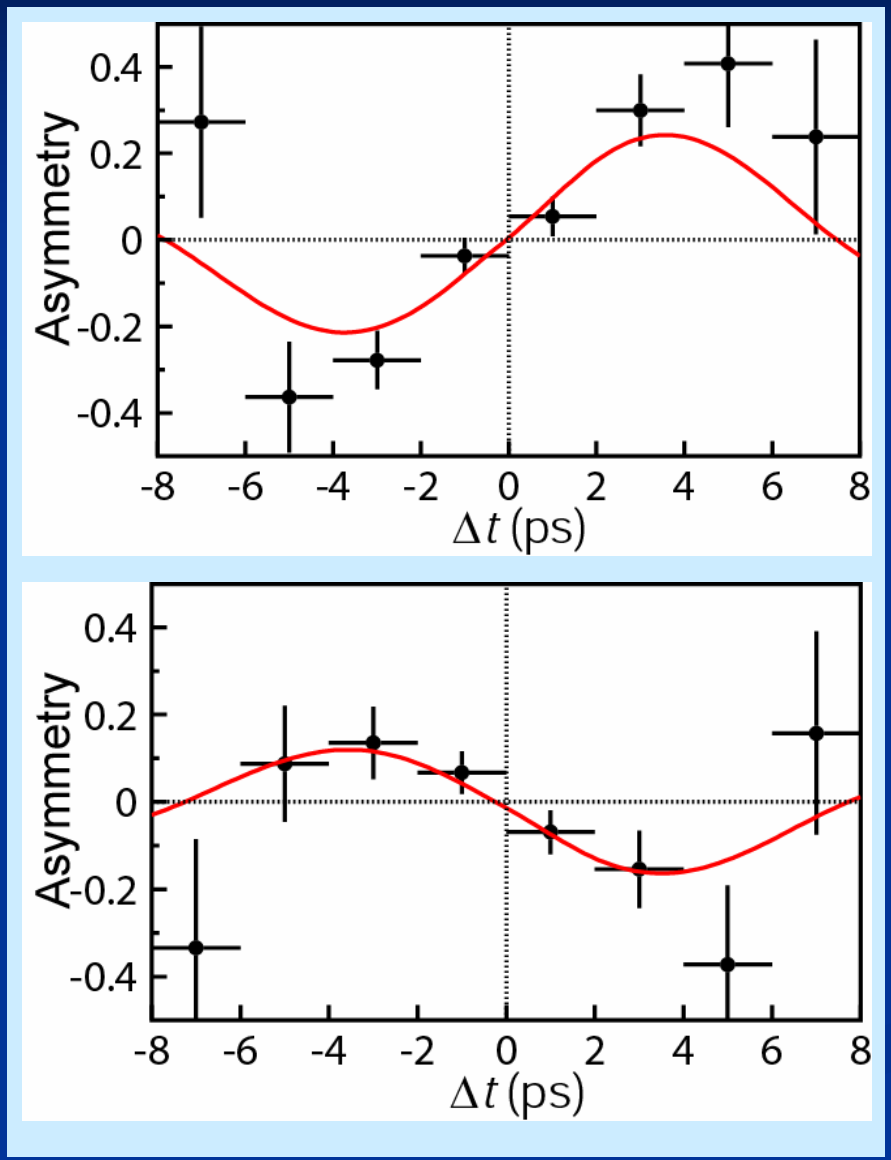
  $= 0.719 \pm 0.074 \pm 0.035$
- $|\lambda_{ccs}|$ $= 0.950 \pm 0.049 \pm 0.026$

i.e., A_{ccs} is consistent with 0.

BELLE-CONF-0201 (ABS688)

Comparison between CP-odd and -even

Raw asymmetry



$\int L\,dt = 78\ \text{fb}^{-1}$

CP = –1 sample

$\sin 2\phi_1$
$= 0.716 \pm 0.083$

CP = +1 sample
($B^0 \to J/\psi K_L$)

$\sin 2\phi_1$
$= 0.78 \pm 0.17$

BELLE-CONF-0201 (ABS688)

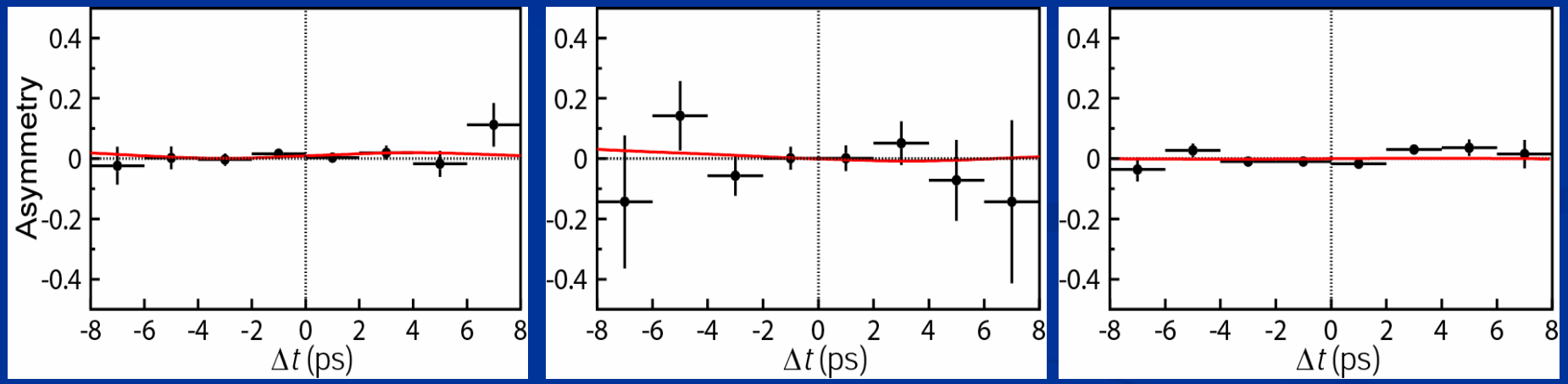
Control sample test

$\int L\,dt = 78\ \text{fb}^{-1}$

Apply the same analysis to non-CP eigenstate sample to see if "$\sin 2\phi_1$"=0.

$\hookrightarrow K^+\pi^-$

$B^0 \to D^{*\pm}\pi^{\mp}$ | $B^0 \to J/\psi K^*$ | $B^0 \to D^* l\nu$



"$\sin 2\phi_1$"= 0.035 ± 0.032

"$\sin 2\phi_1$"= -0.021 ± 0.093

"$\sin 2\phi_1$"= 0.004 ± 0.017

BELLE-CONF-0201 (ABS688)

Changes from the previous results

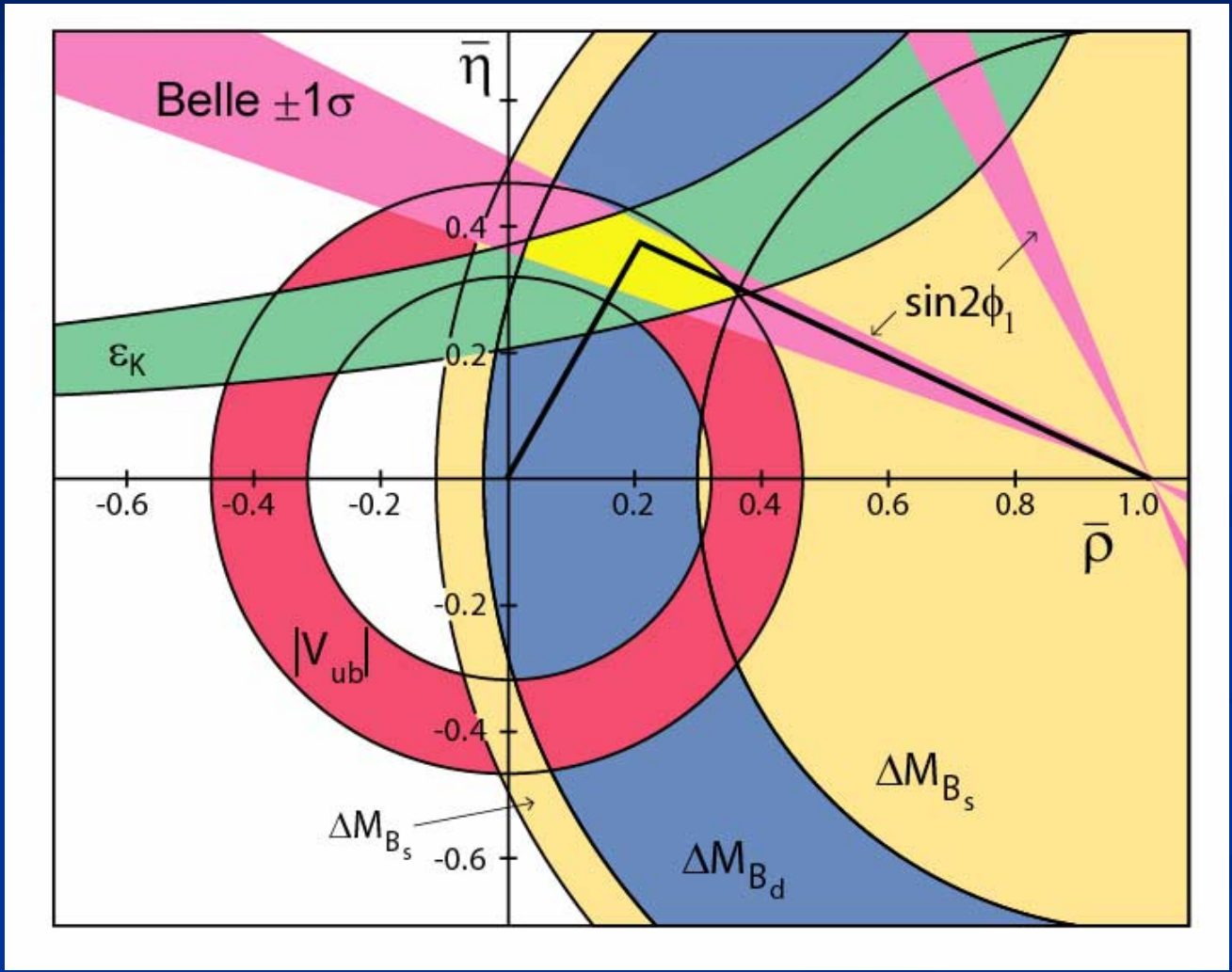
- More data !! (41.8 fb^{-1} → 78 fb^{-1})

  All data have been reprocessed with consistent analysis code.
- Better understanding of the detector.
  - ☛ Better tracking quality.
  - ☛ Better SVD alignment.

$\sin 2\phi_1$ with the first 41.8 fb^{-1} data sample: 0.78 ± 0.10

$\longleftrightarrow$ 0.82 ± 0.12 (Feb. 02)

ρ-η plane



$\sin 2\phi_1$

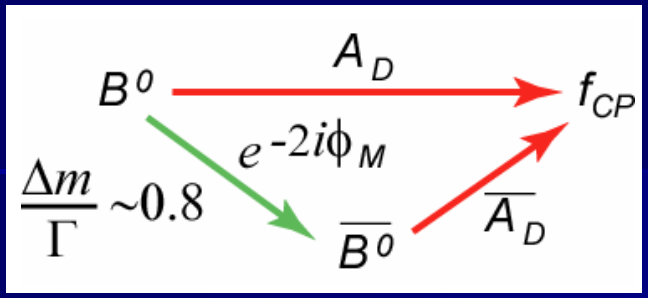
$=0.719 \pm 0.074 \pm 0.035$

Belle July, 2002

PDG2002 (http://pdg.lbl.gov/2002/kmmixrpp)

+ New Belle result

CPV in $b \to u\bar{u}d$

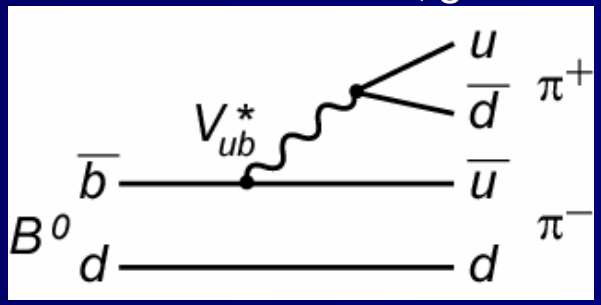


→ Time dependent CPV

$S_{\pi\pi}$ and $A_{\pi\pi}$

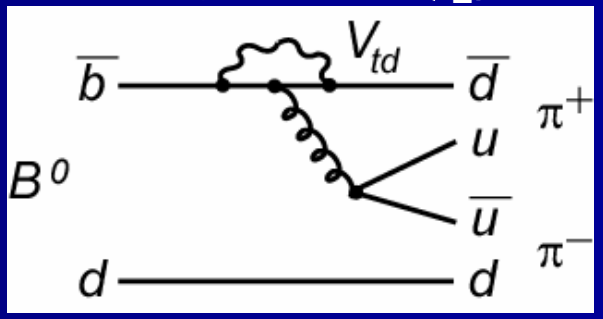
A_D =

Tree (∋ ϕ_3)



+

Penguin (∋ ϕ_1)



→

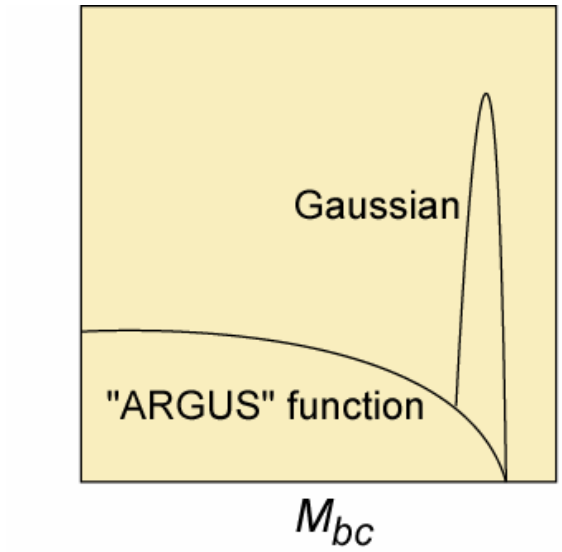
$S_{\pi\pi} \neq \sin 2\phi_2$

$A_{\pi\pi} \neq 0$

i.e. $|\lambda_{\pi\pi}| \neq 1$

i.e. $\Gamma(B^0 \to \pi^+\pi^-) \neq \Gamma(\overline{B^0} \to \pi^+\pi^-)$

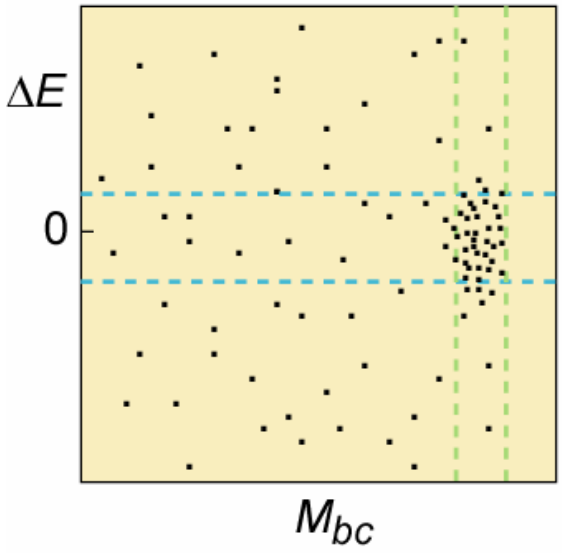
B reconstruction method

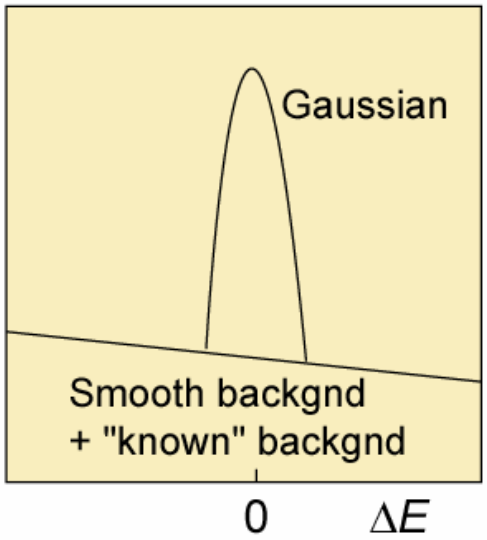


$\Delta E = E(B \text{ cand.}) - E_{beam}$

$M_{bc} = \sqrt{E_{beam}^2 - P(B \text{ cand.})^2}$

(all in CM frame)

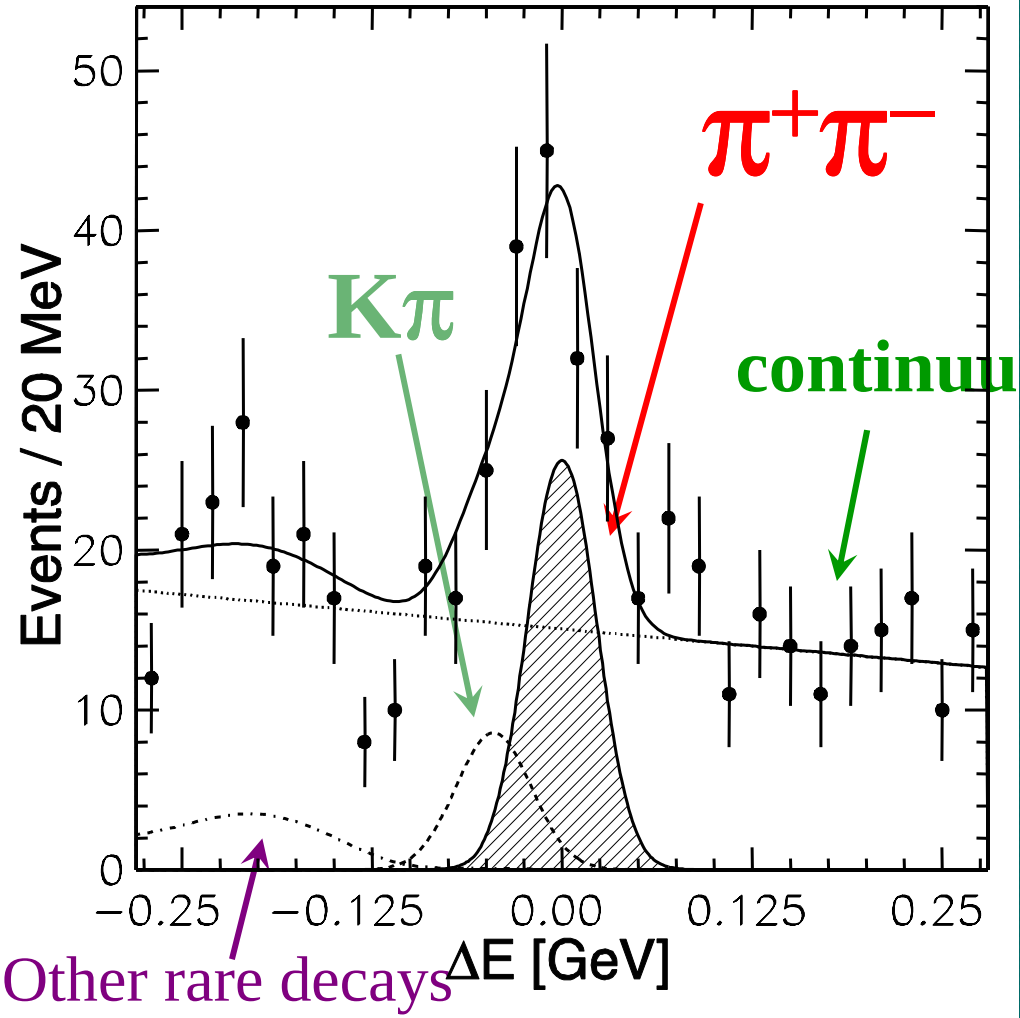




$B^0 \to \pi^+\pi^-$ reconstruction

$\int L\,dt = 41.8\ \mathrm{fb}^{-1}$

ΔE distr. after M_{bc} cut



Signal region:

$5.271 < M_{bc} < 5.287\ \mathrm{GeV}/c^2$

$|\Delta E| < 0.067\ \mathrm{GeV}$

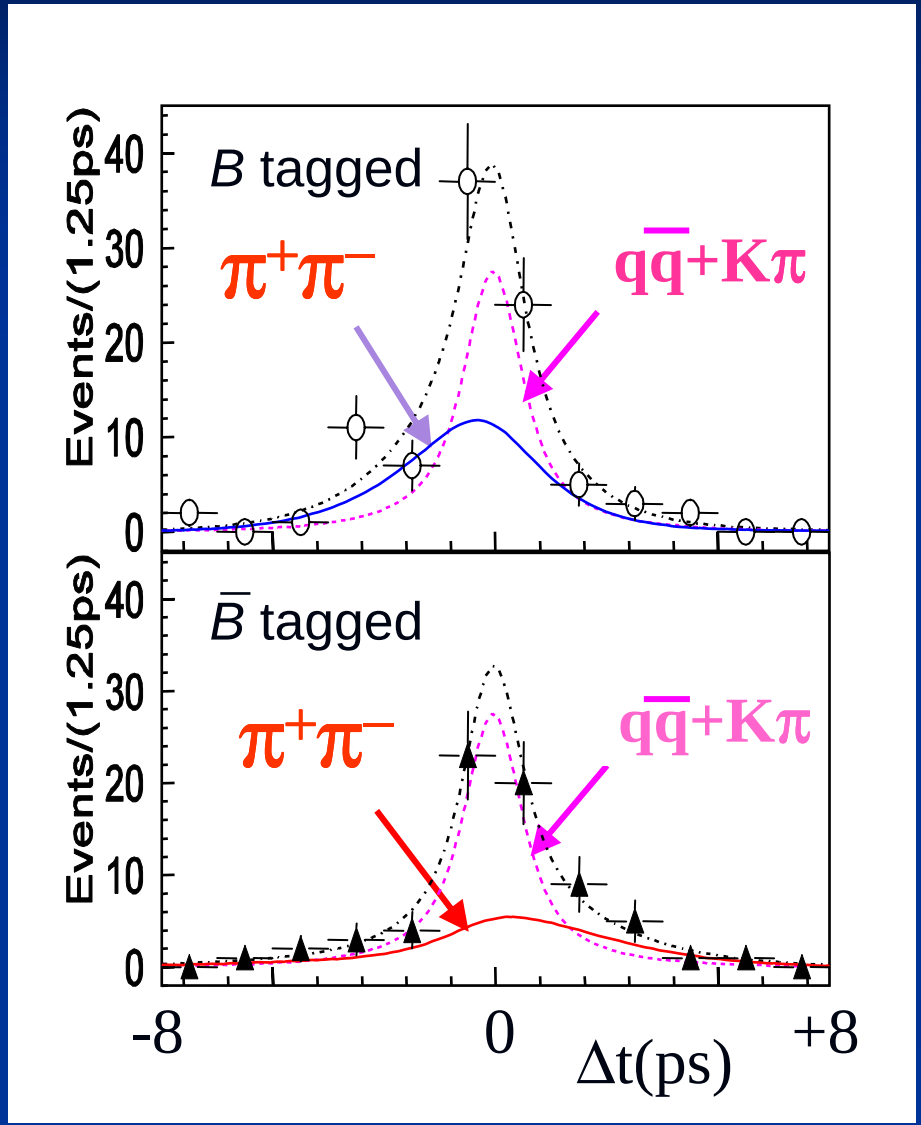
$N(\pi^+\pi^-) = 73.5 \pm 13.8$ events

$N(K^+\pi^-) = 28.4 \pm 12.5$ events

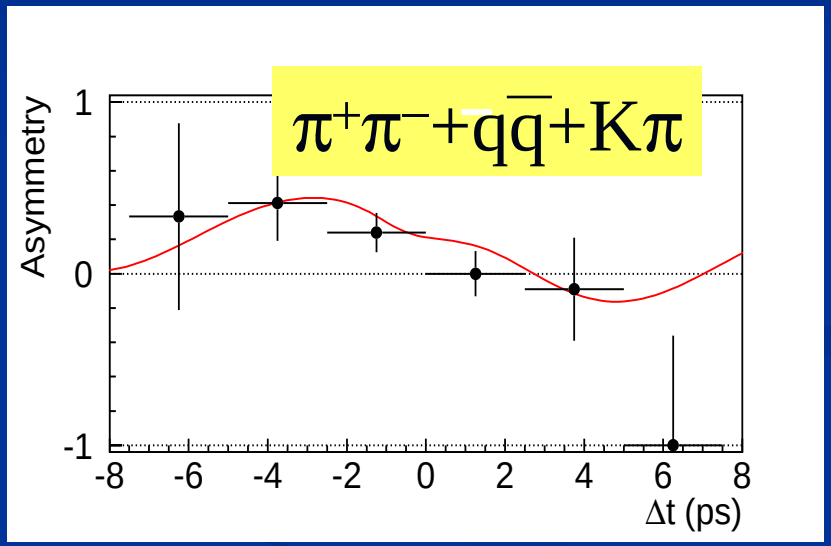
Talk given by K.Suzuki at CP-4 and BELLE-CONF-0219 (ABS707) for detail of the event selection.

Δt distribution in $B^0 \to \pi^+\pi^-$

$\int L\, dt = 41.8\ \text{fb}^{-1}$

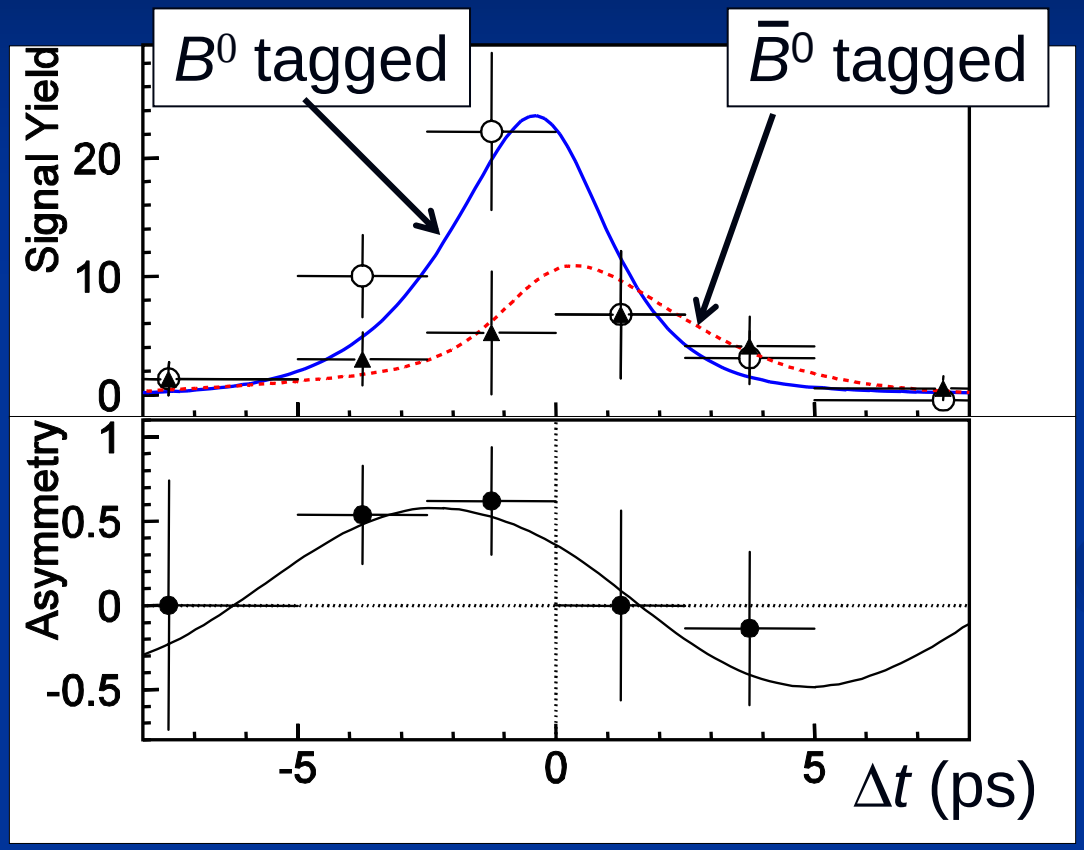


Raw asymmetry



$S_{\pi\pi}$ and $A_{\pi\pi}$

$\int L\,dt = 41.8\ \text{fb}^{-1}$



hep-ex/0204002

$$S_{\pi\pi} = -1.21\ ^{+0.38\ +0.16}_{-0.27\ -0.13}$$

$$A_{\pi\pi} = +0.94\ ^{+0.25}_{-0.31} \pm 0.09$$

$A_{\pi\pi} \neq 0$ indicates Direct CPV

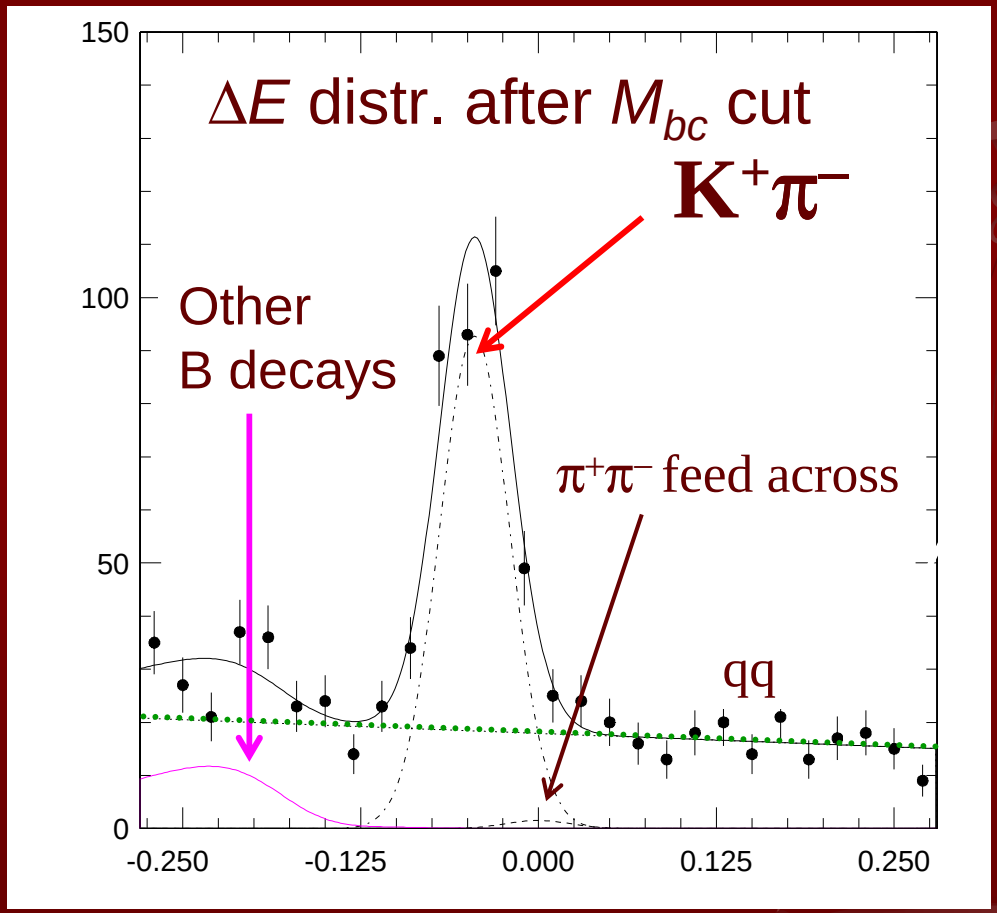
i.e., $\Gamma(B^0 \to \pi^+\pi^-) \neq \Gamma(\overline{B}^0 \to \pi^+\pi^-)$

$A_{\pi\pi} > 0$ with 99.6%CL.
$S_{\pi\pi} < 0$ with 99.6%CL.

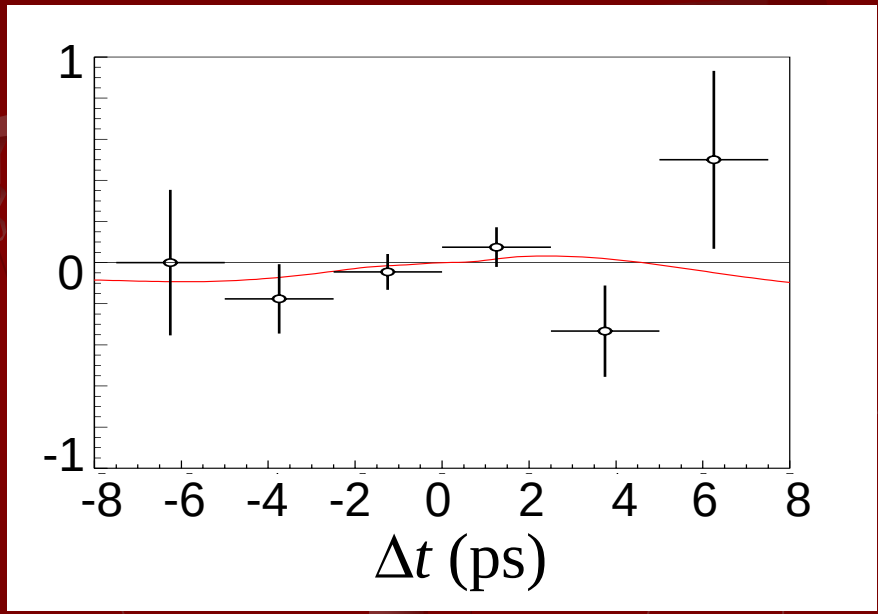
Test with $B^0 \to K^-\pi^+$

$\int L\,dt = 41.8\ \text{fb}^{-1}$

N($K^+\pi^-$) = 289.5±21.5 events



Observed asymmetry

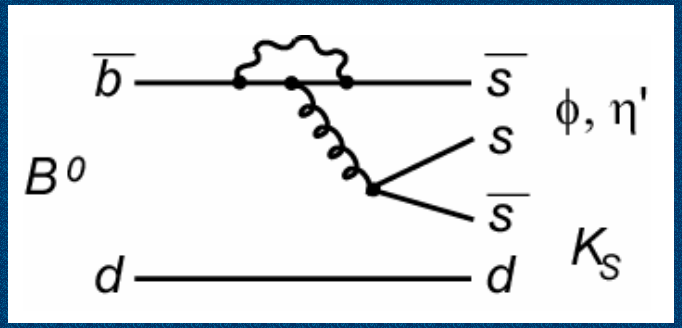


Consistent with null asymmetry

"$S_{K\pi}$"=0.15±0.24

"$A_{K\pi}$"=0.07±0.17

CPV in $b \to s\bar{s}s$



In the Standard Model,

$S_{sss} = \sin 2\phi_1$ ($b \to c\bar{c}s$)

$A_{sss} = \sim 0$

$B(B^0 \to \eta' K^0) = 5.8 \times 10^{-5}$: anomalously large

New physics contribution ??
Measure its phase.

$B^0 \to \eta' K_S$, ϕK_S and $K^+K^-K_S$

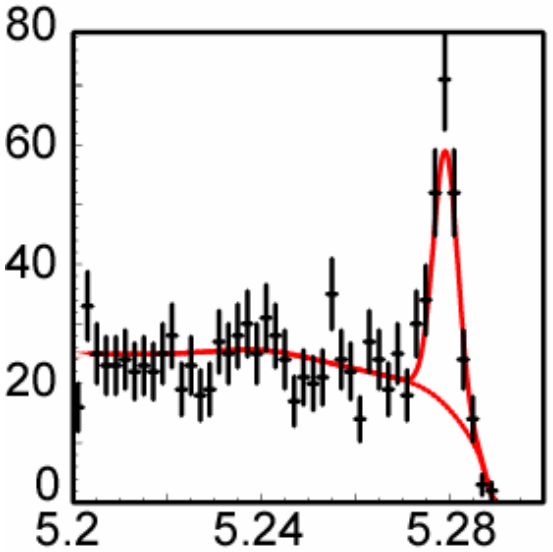
Talks given by T.Aushev at CP-3 and by K.F.Chen at HQ-4.

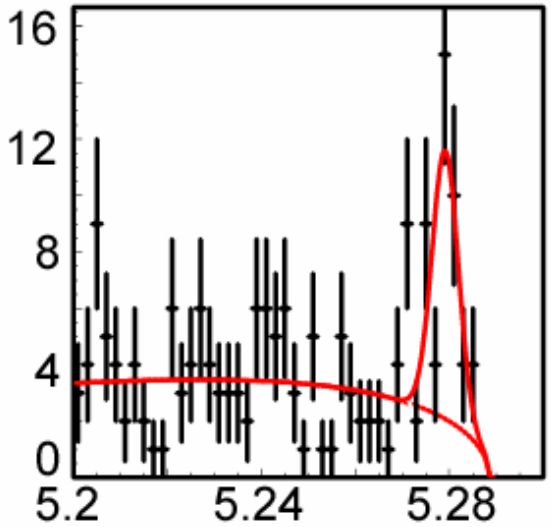
$\int L\,dt = 78\ \text{fb}^{-1}$

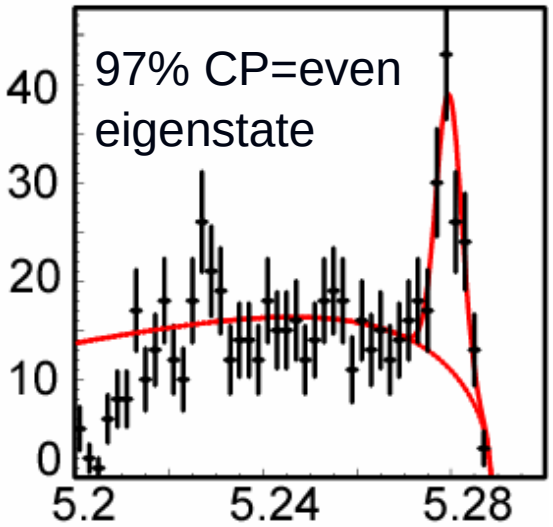
$B^0 \to \eta' K_S$, $\eta' \to \rho\gamma$ ($\rho \to \pi^+\pi^-$), $\eta' \to \pi^+\pi^-\eta$ ($\eta \to \gamma\gamma$)

$B^0 \to \phi K_S$, $\phi \to K^+K^-$, $K_S \to \pi^+\pi^-$

$B^0 \to K^+K^-K_S$ ($K^+K^- \neq \phi$), $K_S \to \pi^+\pi^-$







$N(\eta' K_S) = 147.9 \pm 14.6$

$N(\phi K_S) = 35.4 \pm 2.9$

$N(K^+K^-K_S) = 94.3 \pm 7.3$

Talk given by P.Chang at HQ-3
BELLE-CONF-0225 (ABS713)

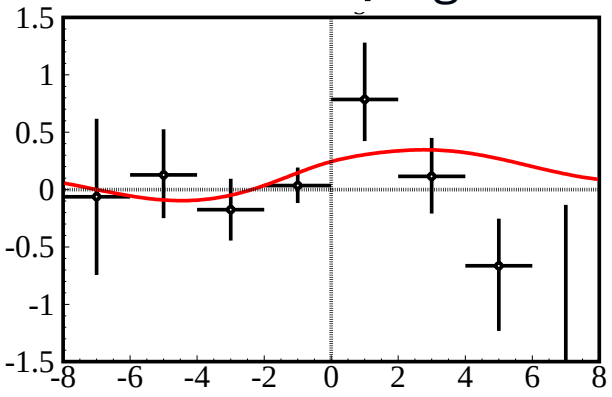
CPV in $b \to s\bar{s}s$

$\int L\,dt = 78\ \text{fb}^{-1}$

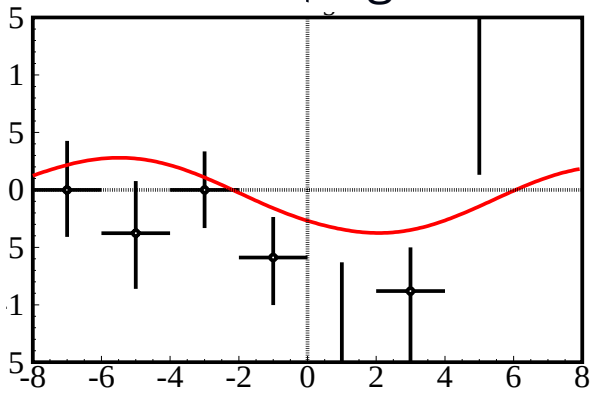
Preliminary

Raw asymmetries

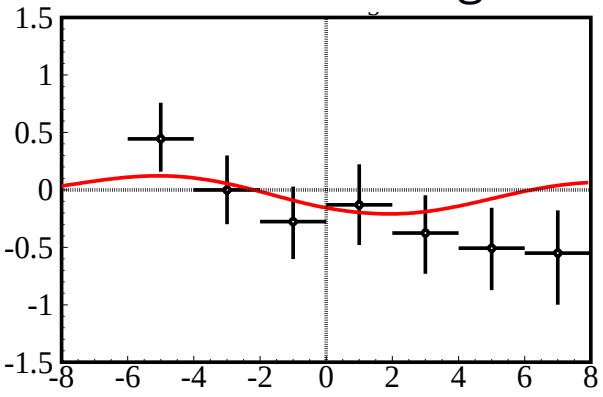
$B \to \eta' K_S$



$B \to \phi K_S$



$B \to K^+K^-K_S$



$-S_{\eta' K} = +0.76 \pm 0.36^{+0.05}_{-0.06}$

$A_{\eta' K} = +0.26 \pm 0.22 \pm 0.03$

$S_{\phi K} = -0.73 \pm 0.64 \pm 0.18$

$A_{\phi K} = -0.56 \pm 0.41 \pm 0.12$

$-S_{KKK} = +0.52 \pm 0.46 \pm 0.11\ ^{+0.27}_{-0.03}\ ^{+0.03}_{-0.22}$

$A_{KKK} = -0.42 \pm 0.36 \pm 0.09$

$(-)S \leftrightarrow \sin 2\phi_1$ in $b \to c\bar{c}s$
$(=0.719 \pm 0.074 \pm 0.035)$

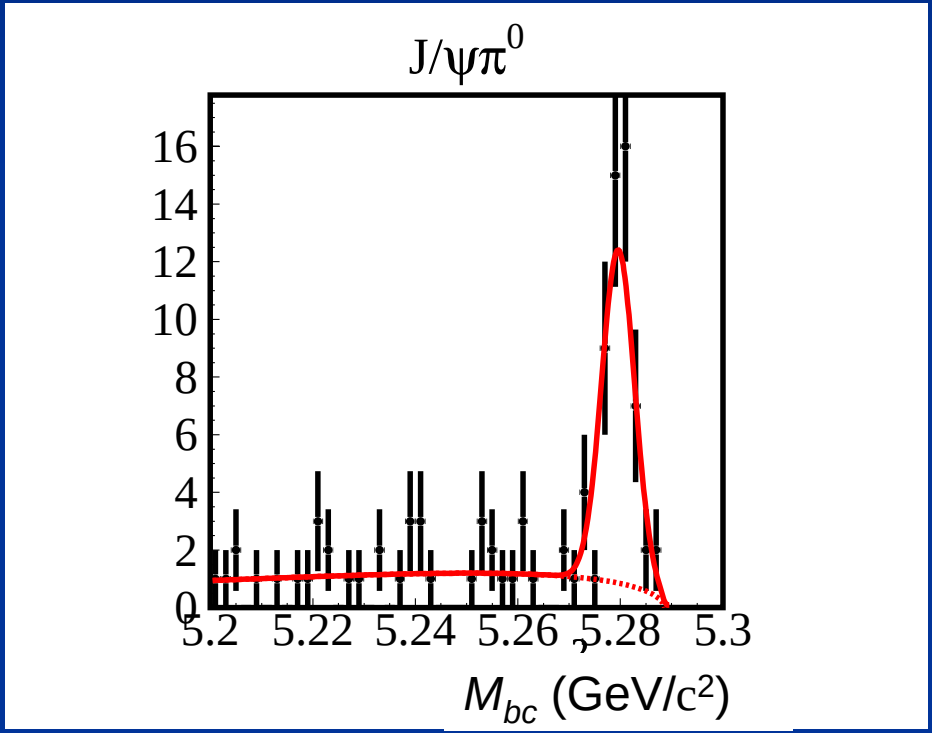
Uncertainty in CP $\pm$ fractions

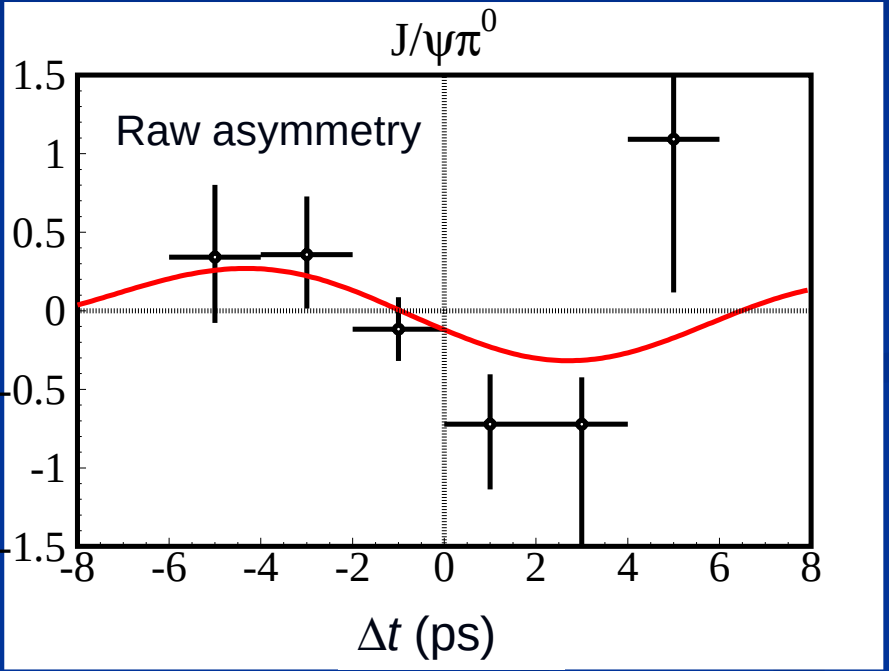
$w = (3\ ^{+16}_{-3})\%$

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

$\int L\,dt = 78\ \text{fb}^{-1}$

$J/\psi\pi^0$ is a CP-even eigenstate including $b \to c\bar{c}d$ transition.





$N(J/\psi\pi^0) = 49.1 \pm 1.3$

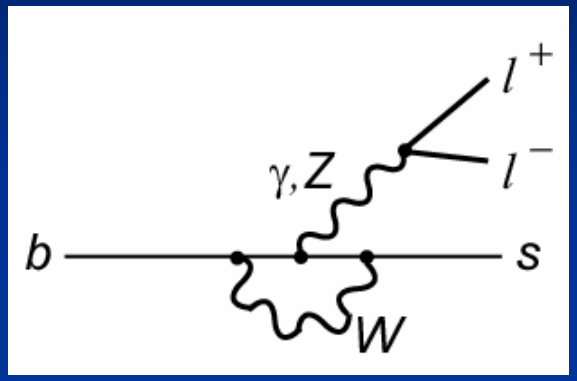
$-S_{J/\psi\pi} = +0.93 \pm 0.49 \pm 0.08$

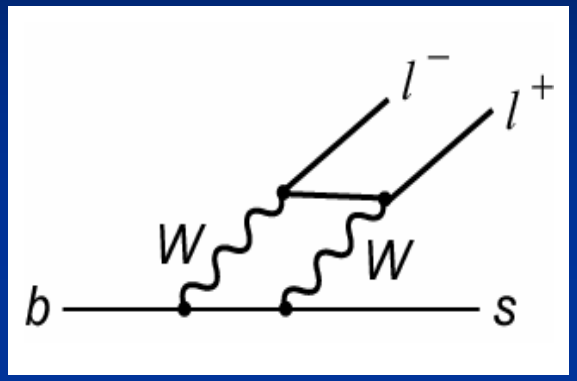
$A_{J/\psi\pi} = -0.25 \pm 0.39 \pm 0.06$

Preliminary

Talk given by S.Nishida at HQ-4
BELLE-CONF-0258

Measurement of $B \to X_s l^+ l^-$





- FCNC process $b \to sll$ was first measured in $B \to Kll$ by Belle. (PRL 88, 021801 (2002))
- Inclusive $b \to sll$ meas. will be a model independent probe for new physics.

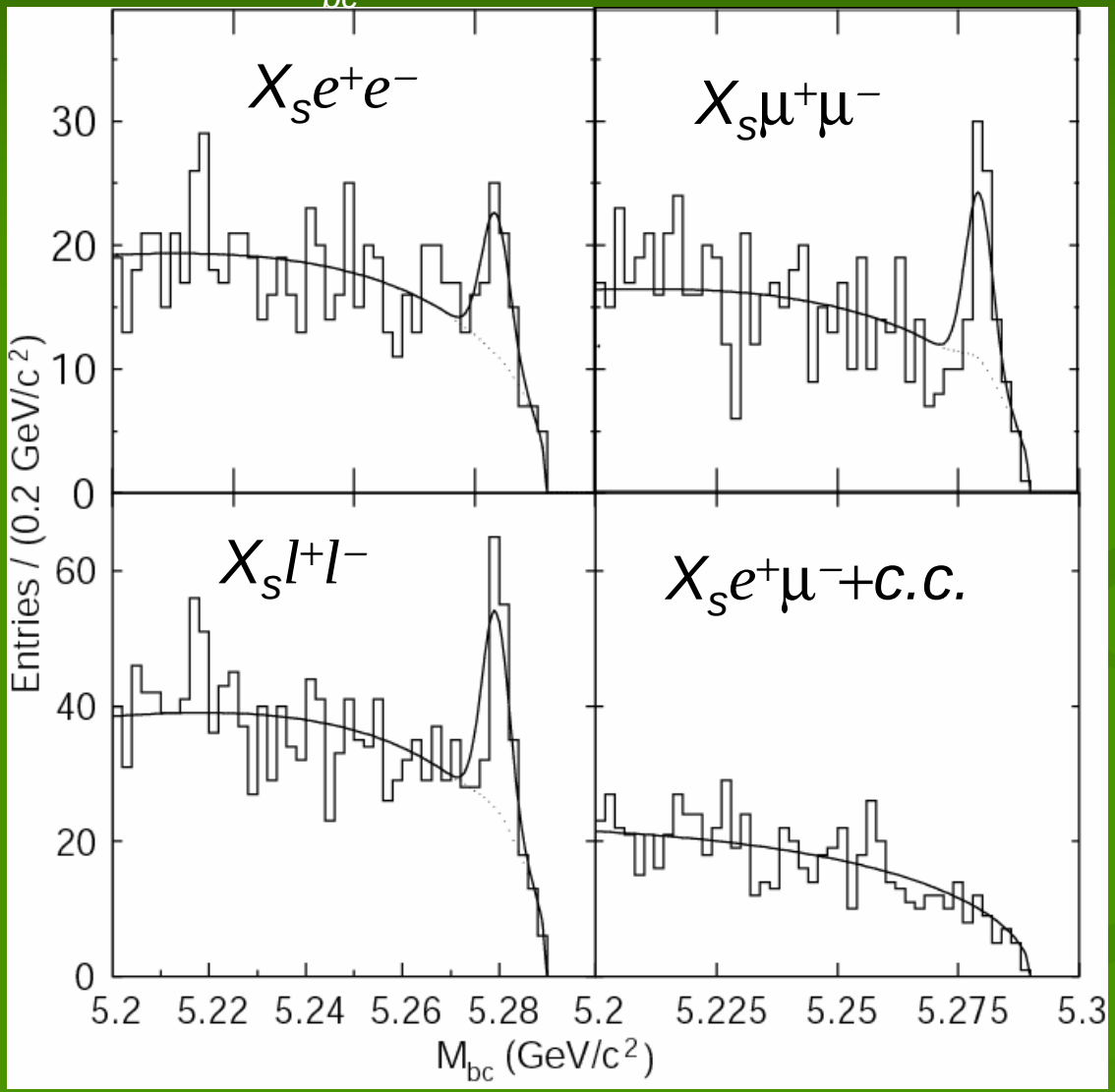
Inclusive measurement by "pseudo-reconstruction" of $B \to X_s ll$.

X_s : $K^{\pm}$ or K_S with 0~4 π's (0 or $1\pi^0$)

covers ~78% of $b \to sll$.

$B \to X_s l^+ l^-$ reconstruction

M_{bc} distr. after ΔE cut



$\int L\,dt = 60$ fb^{-1}

$B \to J/\psi(\to l^+ l^-) X_s$, $\psi'(\to l^+ l^-) X_s$ are removed by m_{ll} veto.

Contamination of $B \to X_s \pi^+ \pi^-$ (4.5 and 0.2 events in $X_s \mu\mu$ and $X_s ee$, respectively) are subtracted.

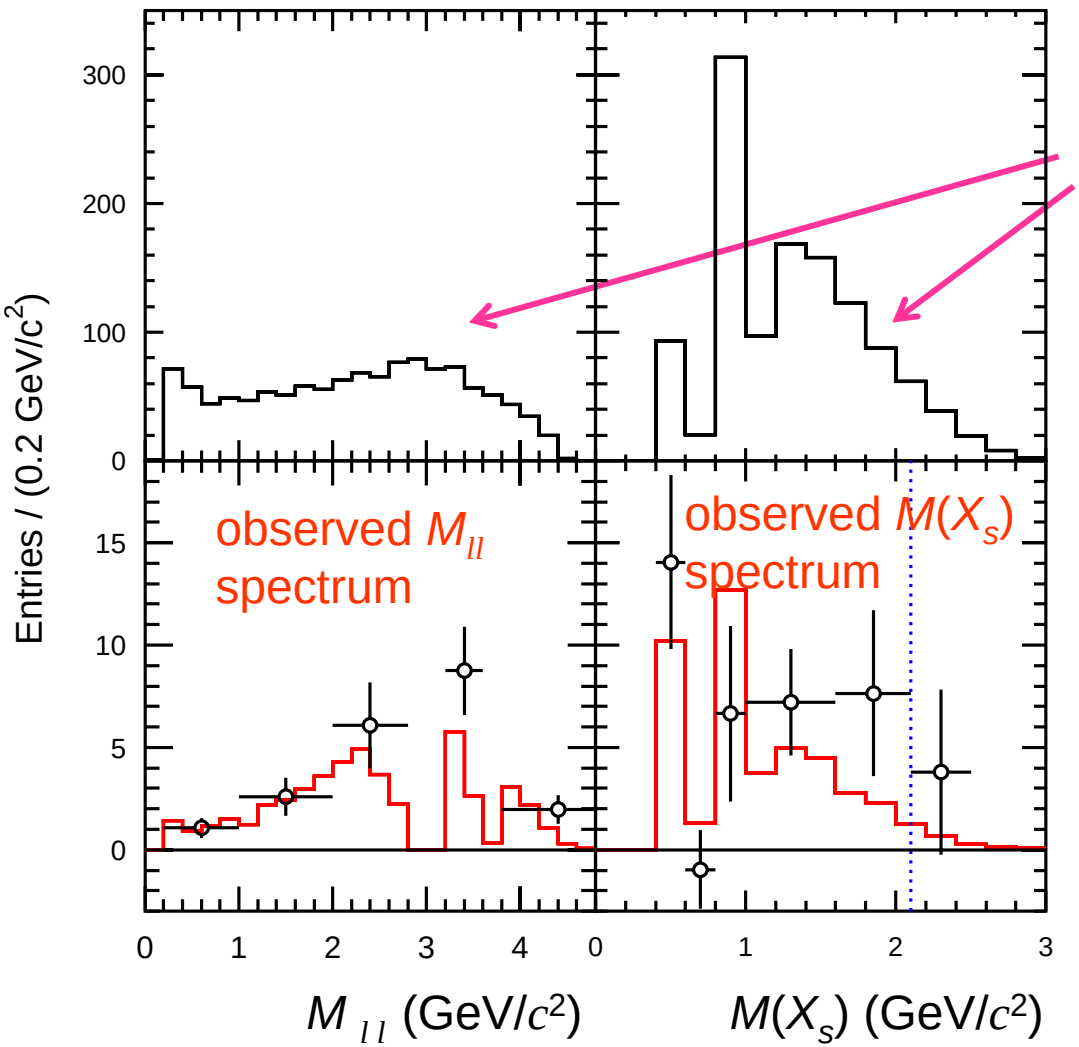
Preliminary

$B(B \to X_s l^+ l^-)$

$= (6.1 \pm 1.4^{+1.3}_{-1.1}) \times 10^{-6}$

for $M_{ll} > 0.2$ GeV/c^2

M_{ll} and $M(X_s)$ distributions



Mass spectra assumed in MC

Model by A.Ali et al.

Summary

- Belle has accumulated 89.6 fb^{-1} data (78 fb^{-1} on $\Upsilon(4S)$, 85 M $B\bar{B}$ pairs) at KEKB asymmetric B factory.
- The CPV parameters are measured by the time dependent analyses of them:

$S_{ccs}=\sin 2\phi_1=0.719\pm0.074\pm0.025,\ |\lambda_{ccs}|=0.950\pm0.046\pm0.026$

$S_{\pi\pi}=-1.21^{+0.38\ +0.16}_{-0.27\ -0.13},\ A_{\pi\pi}=0.94^{+0.25}_{-0.31}\pm0.09$ (41.8 fb^{-1}).

- Time dependent CPV in $b\to s\bar{s}s$ and $b\to c\bar{c}d$ are measured.
- Inclusive $b\to sl^+l^-$ is measured by pseudo-reconstruction:

$$\mathrm{B}(B\to X_s l^+l^-) = (6.1\pm1.4^{+1.3}_{-1.1}) \times 10^{-6}$$