The Belle Collaboration

52 institutions

Aomori University
Budker Institute of Nuclear Physics
Chiba University
Chuo University
University of Cincinnati
Frankfurt University
Gyeongsang National University
University of Hawaii
Hiroshima Institute of Technology
Hiroshima College of Maritime Tech.
ICRR, University of Tokyo
IHEP, Beijing
ITEP, Moscow
Joint Crystal Collaboration Group
Kanagawa University
KEK
Korea University
Krakow Institute of Nuclear Physics
Kyoto University
University of Melbourne
Mindanao State University
Nagasaki Institute of Applied Science
Nagoya University
Nara Woman's University
National Central University
National Kaohsiung Normal University
National Lien-Ho Institute of Technology
National Taiwan University
Nihon Dental College
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Osaka University
Osaka City University
Panjab University
Princeton University
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Sugiyama Woman's College
Sungkyunkwan University
University of Sydney
Toho University
Tohoku University
Tohoku-gakuin University
University of Tokyo
Tokyo Institute of Technology
Tokyo Metropolitan University
Tokyo University of Agriculure and Technology
Toyama National College of Maritime Technology
University of Tsukuba
Utkal Univesity
Virginia Polytechnic Institute and State University
Yonsei University

A List of Belle contributed papers to ICHEP2000

http://bsunsrv1.kek.jp/conferences/ichep2000.html

1. Determination of B0d- B0dbar mixing rate from the time evolution of dilepton events at the Y(4S) (Paper #284)

2. Measurement of Charmed Meson Lifetimes (Paper#274)

3. Studies of Radiative B Meson Decays with Belle (Paper #281)

4. Observation of B-J/psi K1(1270) (Paper #278)

5. Charmless Hadronic B Meson Decays to Charged Particle Final States with Belle (Paper #289)

6. A Study of Charmless Hadronic B decays to h pi0 Final States (Paper #292)

7. Evidence for the charmless decay B+ - phi K+ at Belle (Paper #287)

8. Measurement of Inclusive Production of Neutral Pions from Y(4s) decays (Paper #275)

9. Observation of Cabibbo suppressed B - D(*)K decays at Belle (Paper #282)

10. A Search for the Decay B0 - Ds+ pi- (paper #291)

11. Measurements of exclusive decays B0bar - D+l-nubar and B0bar - D*+l-nubar at Belle (Paper #286)

12. Measurement of Polarization of J/psi in B0 - J/psi K*0 and B+ - J/psi K*+ Decays (Paper #285)

13. CP/T Test with Tau Leptons at Belle (Paper #277)

14. Search for the lepton flavor violating decay tau - l K0 (Paper #276)

15. Measurement of K+K- production in two-photon collisions with Belle (Paper #288)

16. Measurement of Ks0Ks0 production in two-photon collisions with Belle (Paper #290)

17. Search for CP violation in tau semi-leptonic decay tau+/- - pi+/- pi0 nu (Paper #283)

A Measurement of *CP* Violation in B_d Meson Decays at Belle

Hiroaki Aihara
University of Tokyo

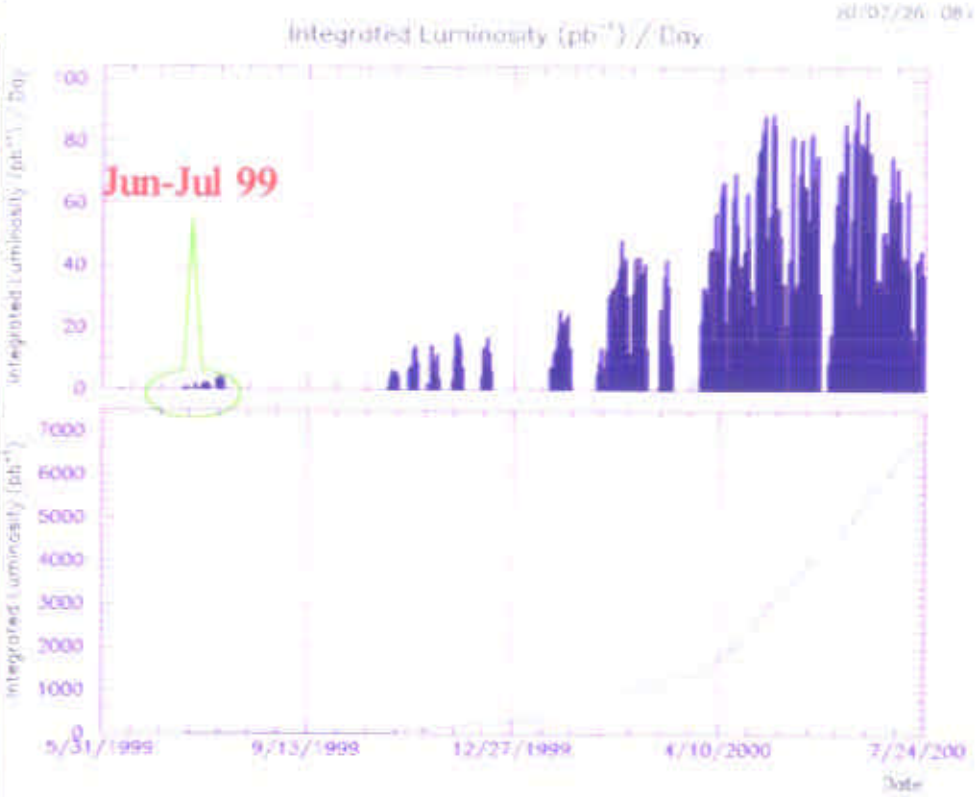
- Overview
- Event selection of $B_d \to Charmonium + K_S / K_L$
- Flavor tagging
- Proper decay time difference reconstruction
- Extraction of *CP* parameter
- Conclusion

XXXth International Conference on High Energy Physics, July27-August2, 2000, Osaka, Japan

KEKB performance

Parameters of KEKB (7/23/2000) Achieved/Design(model)

	LER	HER	
Horizontal Emittance	18	30	nm
Beam current	465 (2600)	420 (1100)	mA
Number of bunches	1146 (2700)		
Bunch current	0.41 (0.96)	0.37 (0.41)	mA
Bunch spacing	2.4 (1.2)		m
Bunch trains	8 (159 bunches each)		
Horizontal size at IP $x^*/\sqrt{2}$	112 (112)	145 (145)	m
Vertical size at IP y^*	1.7 (1.12)	1.7 (1.45)	m
Emittance ratio x/y	2.3 (1)	1.4 (1)	%
x^*/y^*	70 / 0.7	70 / 0.7	cm
beam-beam parameters x/y	0.036 / 0.037 (0.05 / 0.05)	0.029 / 0.023 (0.05 / 0.05)	
Beam lifetime	130 @ 465 mA	180 @ 420 mA	min.
Luminosity (Belle CSI)	20.4 10^{32}		$cm^{-2}s^{-1}$
Luminosity record per day / per week	90 / 504		pb^{-1}



$$\text{Total} \int Ldt = 6.8 \begin{pmatrix} 6.2 \text{ on } \Upsilon(4S) \\ +0.6 \text{ off} \end{pmatrix} \text{fb}^{-1}$$

Vertexing

- Silicon Vertex Detector (SVD)

Charged track

- Central Drift Chamber (CDC)

$$\sigma_{p_t}/p_t = (0.36 \oplus 0.28 p_t)\% \quad \text{(GeV)}$$

Electron and photon

- CsI Electromagnetic Calorimeter (ECL)

$$\sigma_E/E = (1.3 \oplus 0.07/E \oplus 0.8/E^{1/4})\%$$

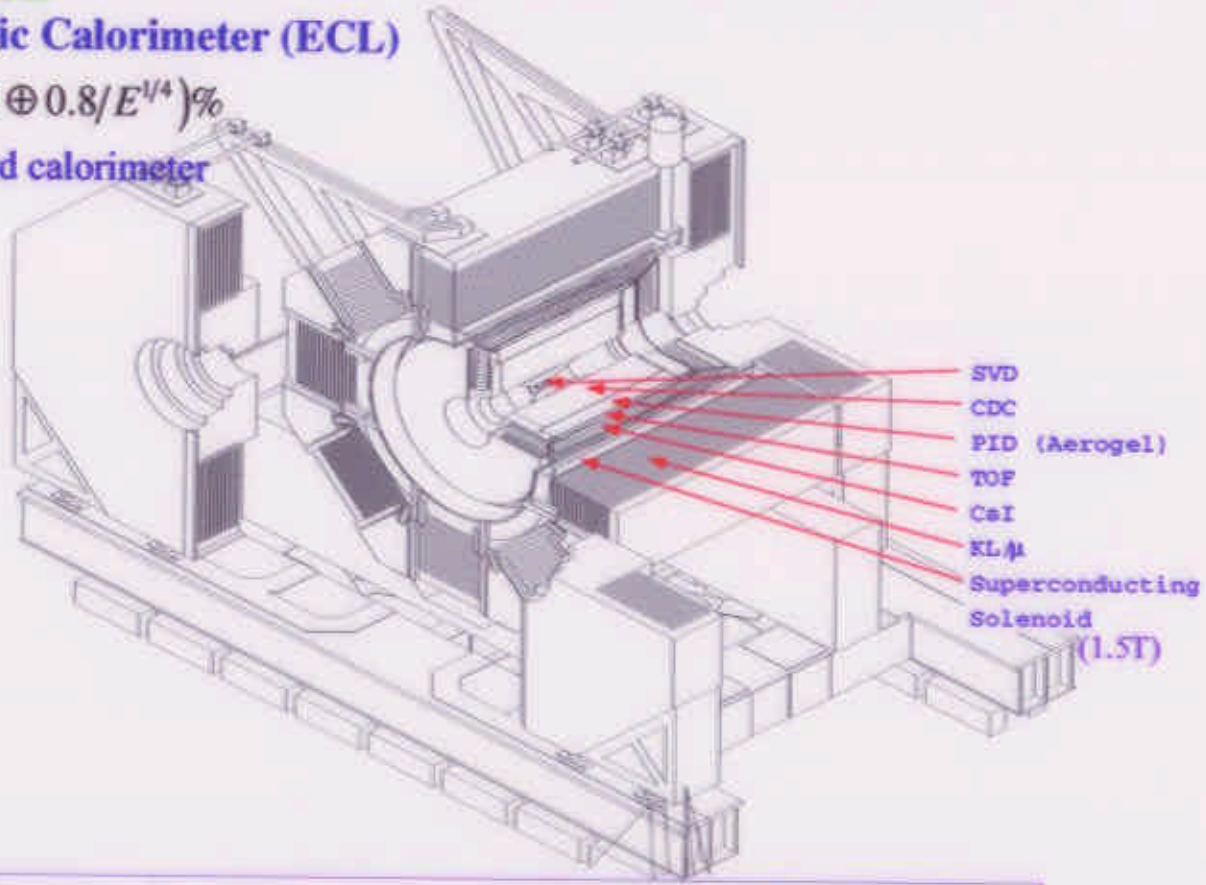
- BGO Extreme Forward calorimeter

K/π separation

- CDC : dE/dx
- Aerogel Cherenkov Counter (ACC)
- Time of Flight Counter (TOF)

K_L and muon detector (KLM)

Resistive plate Counter



Overview

★ CP violation due to the interference between direct decay and decay via mixing is expected in the SM: $B^0 \to J/\psi K_s$

$\overline{B^0}$ CP eigenstate

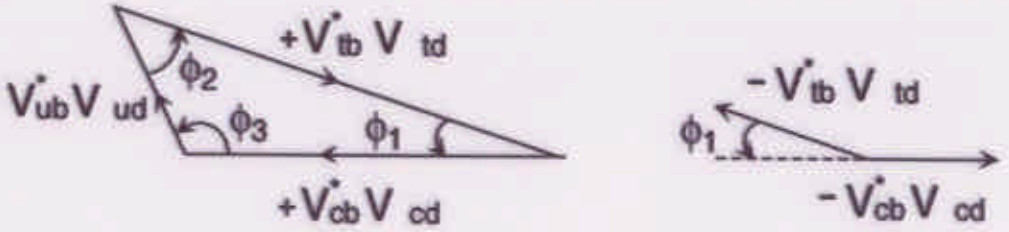
$$(1)\ \frac{dN}{dt}(\overline{B^0_{t=0}} \to f_{CP}) = \frac{e^{-\frac{t}{\tau}}}{2\tau}\left(1 - \eta_f \sin 2\phi_1 \sin \Delta m_d t\right)$$

$$(2)\ \frac{dN}{dt}(B^0_{t=0} \to f_{CP}) = \frac{e^{-\frac{t}{\tau}}}{2\tau}\left(1 + \eta_f \sin 2\phi_1 \sin \Delta m_d t\right)$$

$\eta_f = CP$ eigenvalue of $f_{CP} = \begin{cases} -1 \text{ for } J/\psi K_S \\ +1 \text{ for } J/\psi K_L \end{cases}$

$$A = \frac{(1)-(2)}{(1)+(2)} = -\eta_f \sin 2\phi_1 \sin \Delta m_d t$$

★ Unitary triangle

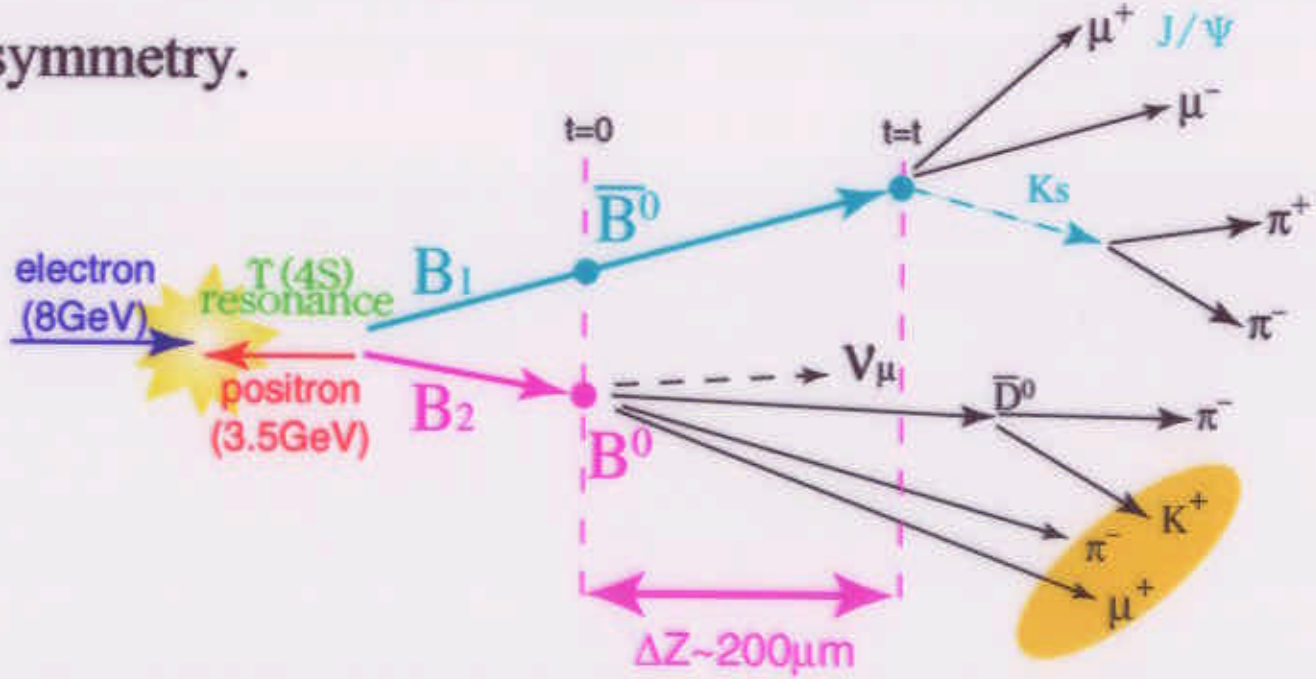


$$\phi_1 = \pi - \arg\left(\frac{-V_{tb}^* V_{td}}{-V_{cb}^* V_{cd}}\right) = \beta$$

PDG 2000 : H. Quinn and A.I.Sanda

Flow of analysis

- Select events which contain *CP* eigenstates.
- Use other *B* to identify flavor at t=0.
- Measure $\Delta z \equiv z_{CP} - z_{tag}\ ;\quad \Delta t \equiv t_{CP} - t_{tag} \approx \frac{\Delta z}{\beta\gamma c}\ ;\quad \beta\gamma = 0.425$
- Extract asymmetry.



Experimental considerations

- True *CP* asymmetry gets diluted by experimental factors:

  B: background,

  ω: wrong tag fraction = chance of making a mistake in flavor identification,

  d_{res}: dilution due to vertex resolution

$$A_{obs} = \left\{ \frac{1}{\sqrt{1+B/S}} (1-2\omega) d_{res} \right\} A_{true} = D \cdot A_{true}$$

$$0 \le D \le 1$$

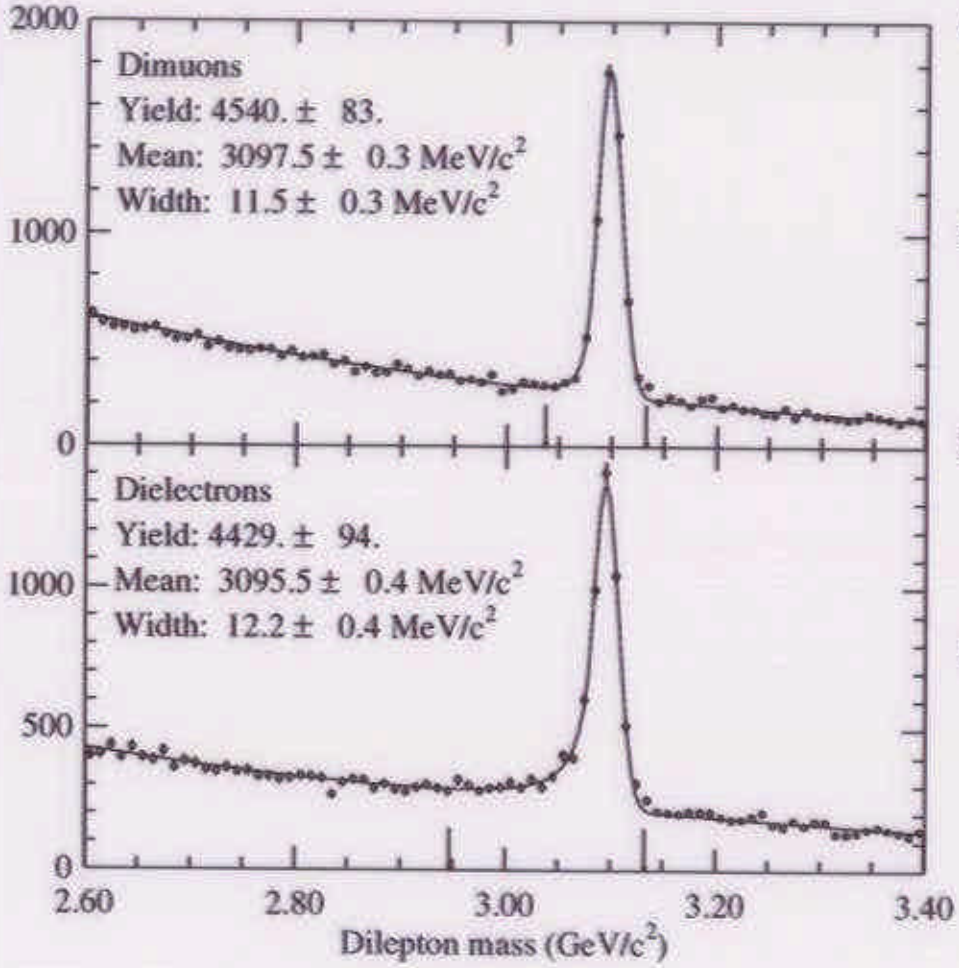
- Precision of $\sin 2\phi_1$ is inversely proportional to D:

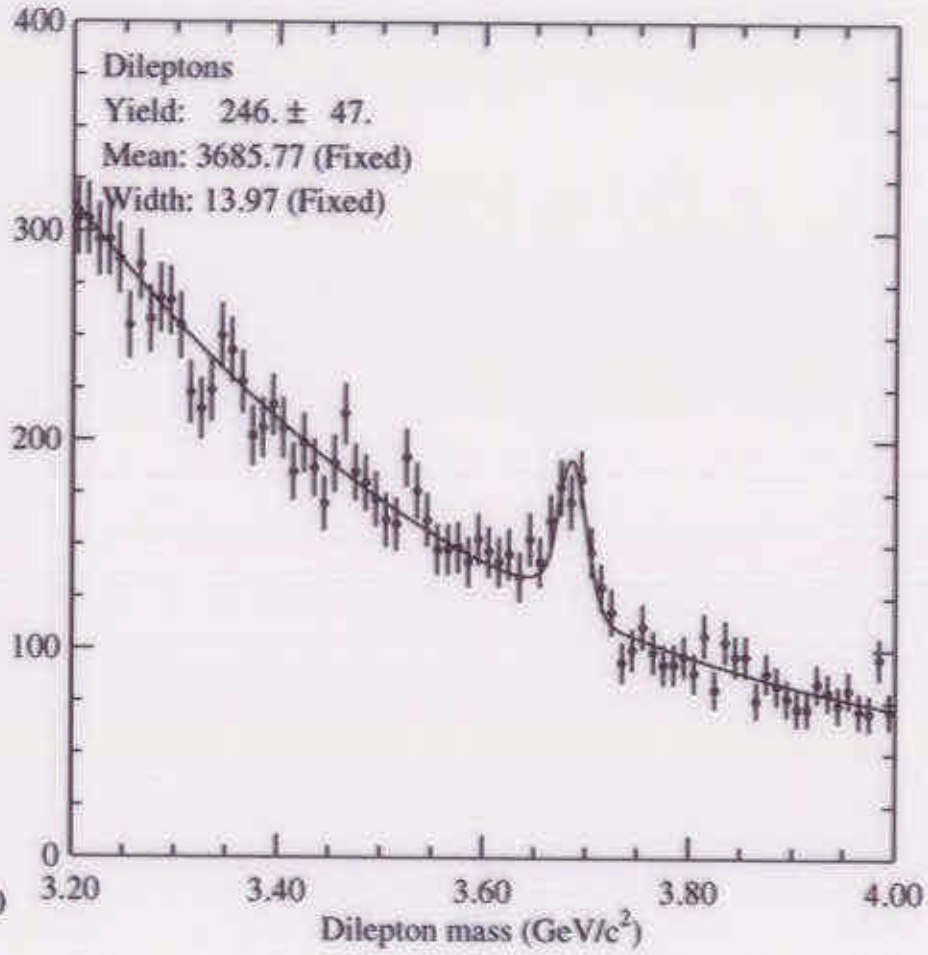
$$\delta \sin 2\phi_1 = \frac{1}{\sqrt{S}} \cdot \frac{1}{D}$$

- Good understanding of *D*ilution factor is a must to extract asymmetry.

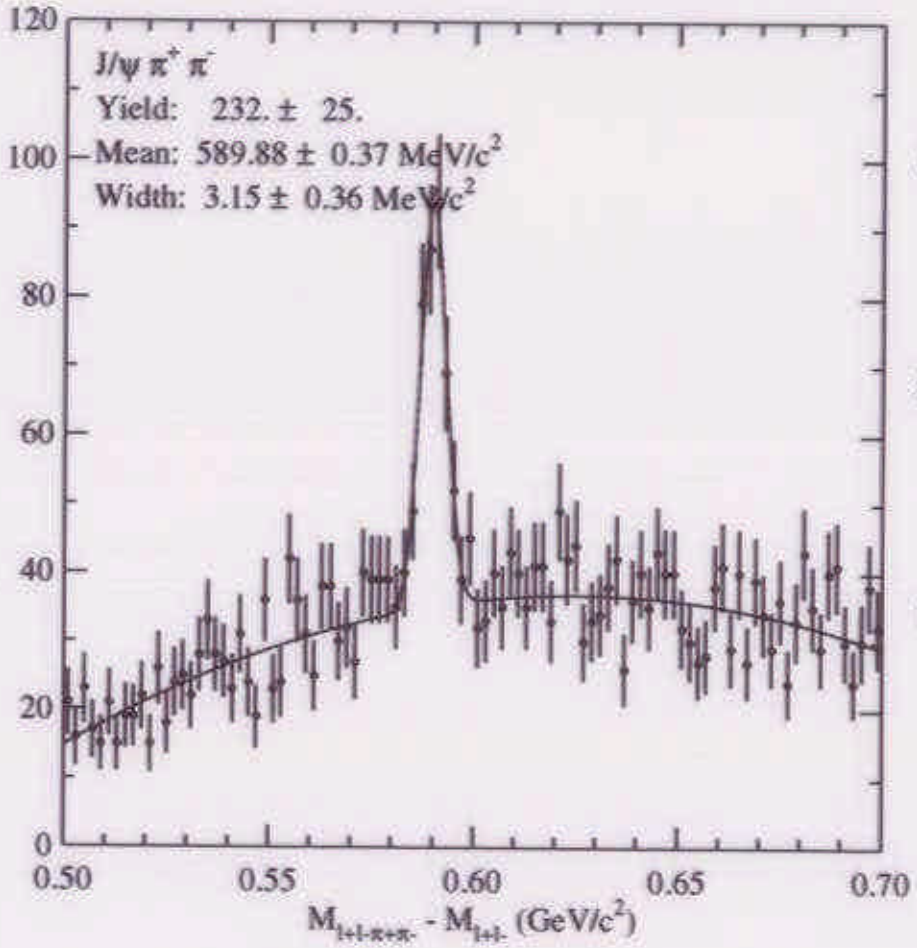
Event Selection

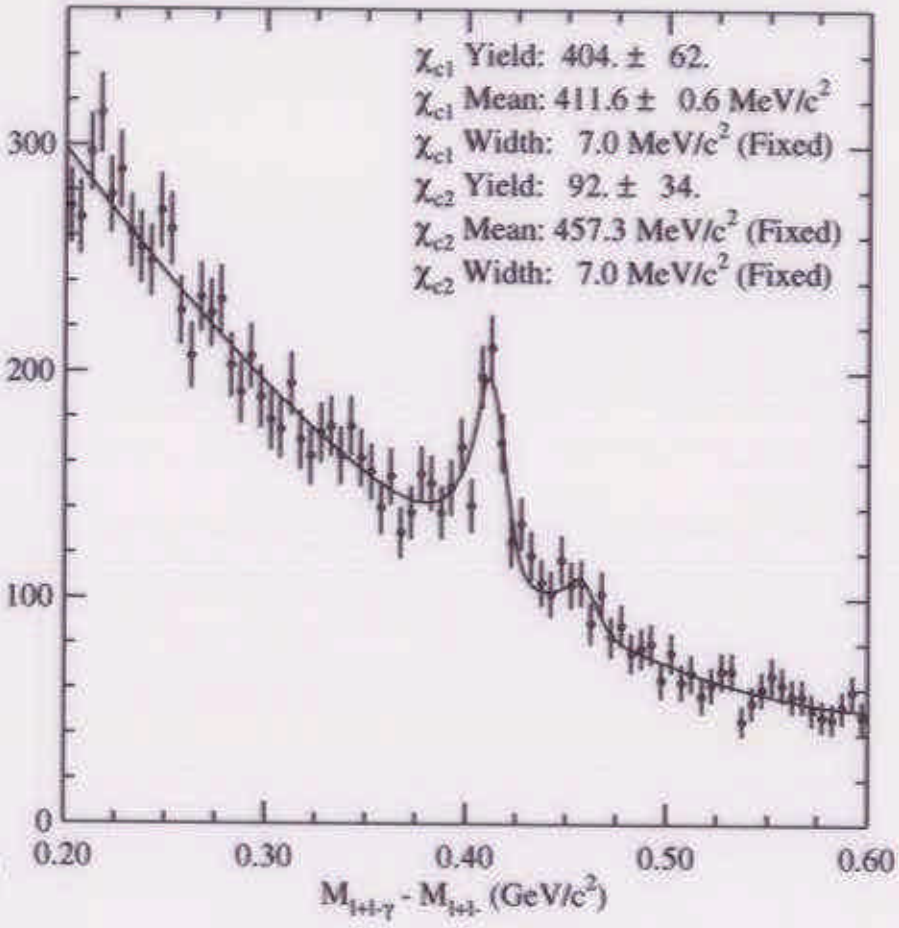
J/ψ and ψ' to dileptons





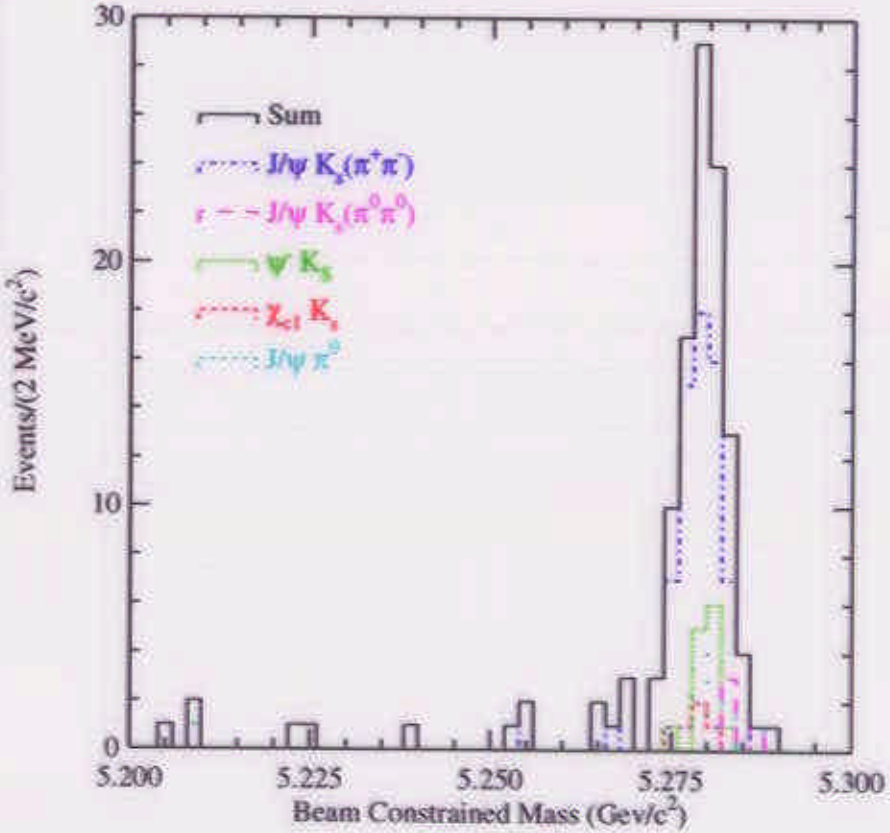
$\psi' \to J/\psi\pi^+\pi^-$ and $\chi_{c1} \to J/\psi\gamma$





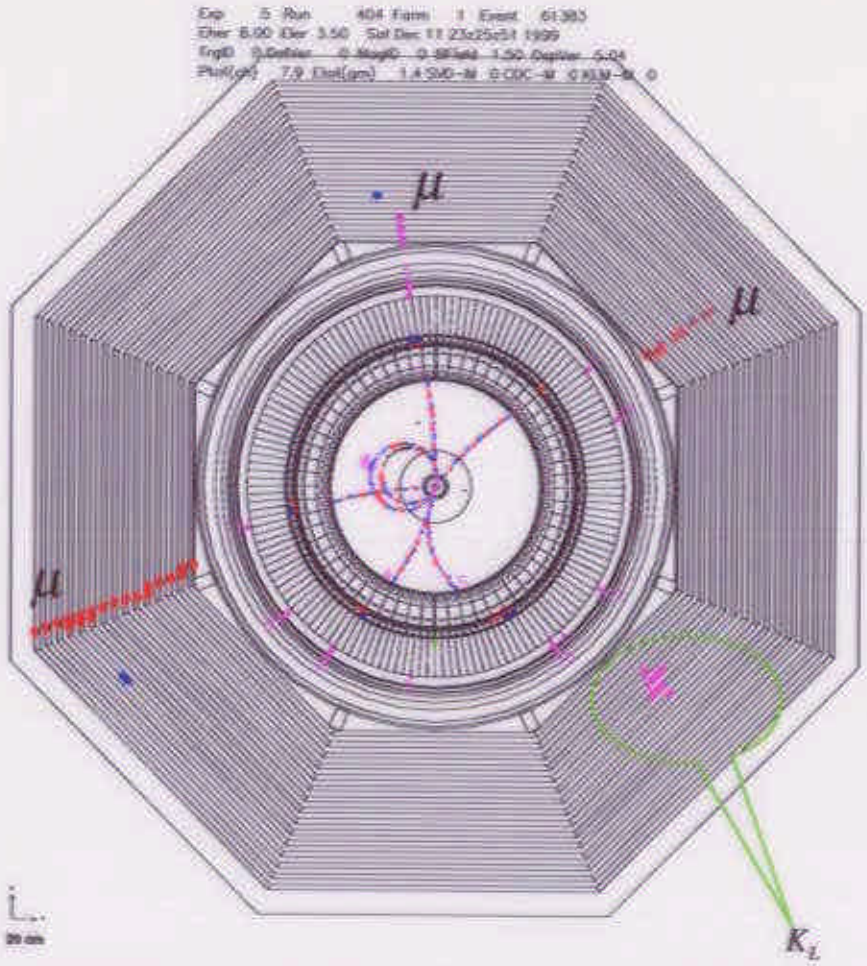
A tally of *CP* events @ $\int Ldt = 6.2\ \text{fb}^{-1}$

	Mode	CP eigenvalue	Number of candidates	Estimated backgrounds
1	$J/\psi(l^+l^-)K_s(\pi^+\pi^-)$	-1	70	3.4
2	$J/\psi(l^+l^-)K_s(\pi^0\pi^0)$	-1	4	0.3
3	$\psi'(l^+l^-)K_s(\pi^+\pi^-)$	-1	5	0.2
4	$\psi'(\to J/\psi\pi^+\pi^-)K_s(\pi^+\pi^-)$	-1	8	0.6
5	$\chi_{c1}(\gamma J/\psi)K_s(\pi^+\pi^-)$	-1	5	0.75
6	$J/\psi\pi^0$	+1	10	1
total			102	6.25

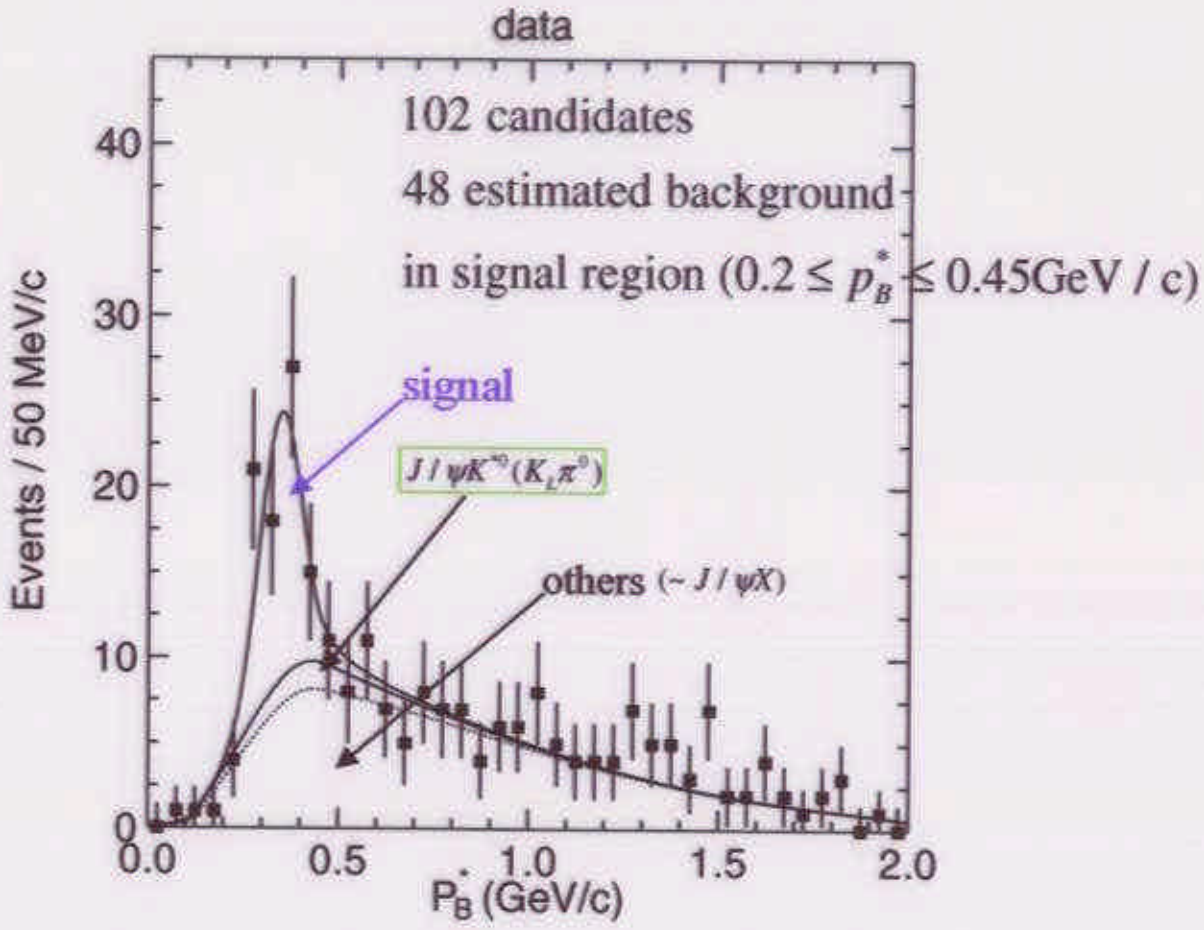


$B \to J/\psi K_L$ detection

- Two body decay ⇒ This reaction is uniquely identified through measurement of the J/ψ momentum and the K_L direction.
- Require $1.42 \le p^*_{J/\psi} \le 2.0$ GeV / c
- Calculate the B momentum in the center of mass system($\mathbf{P}^*_B$) to see if it peaks at ~ 0.340 GeV / c



p_B^* distribution with the fit



Expected shapes were obtained using Monte Carlo simulation.
Noise fraction was floated.

Flavor tagging

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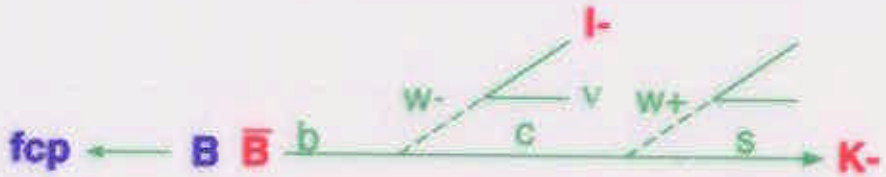
Kaon ID at Belle



Kaon ID is provided by :

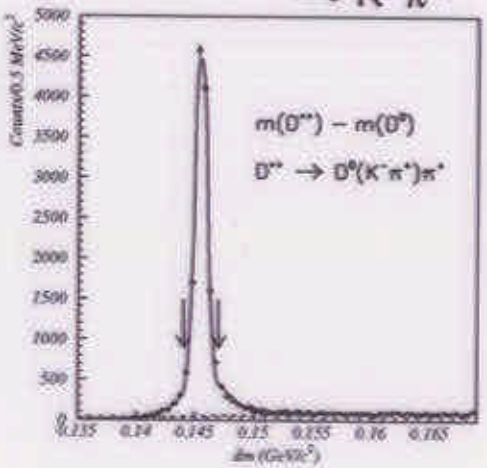
$\sigma(dE/dx) = 6.9\%$,

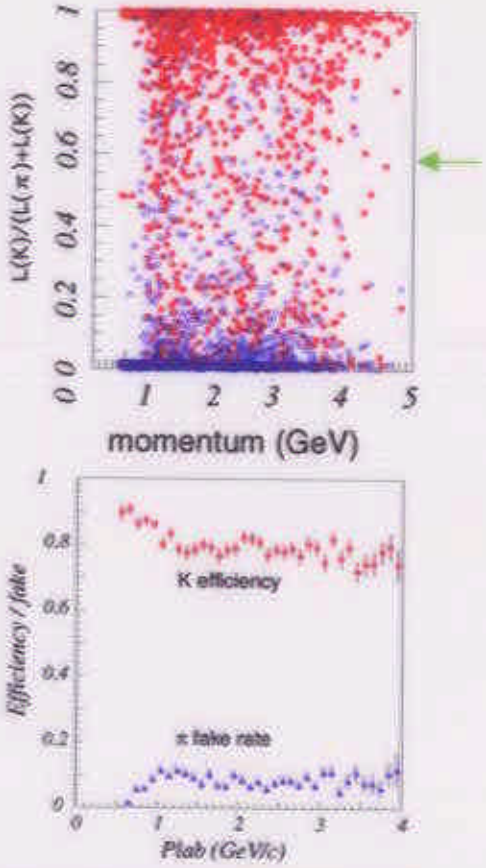
TOF resolution = 95ps (rms), and aerogel Cherenkov counters.

Tests using kinematically reconstructed

$D^{*+} \to \pi^+ D^0$

$\hookrightarrow K^- \pi^+$

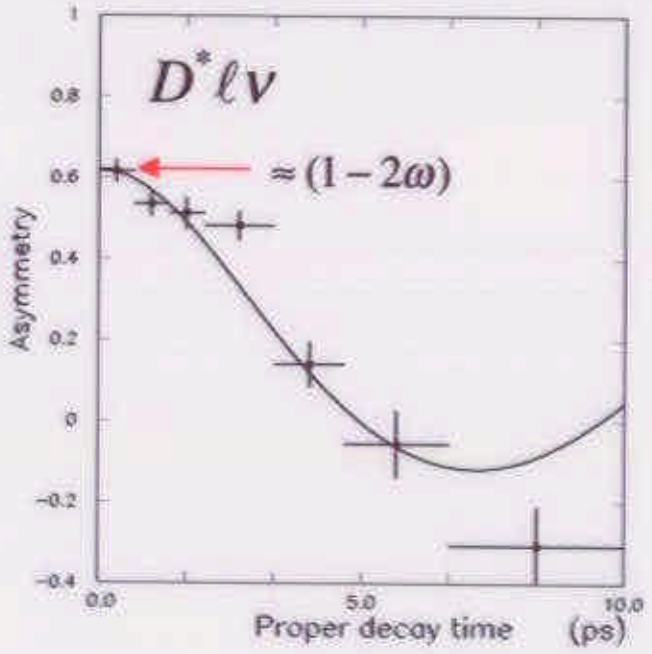


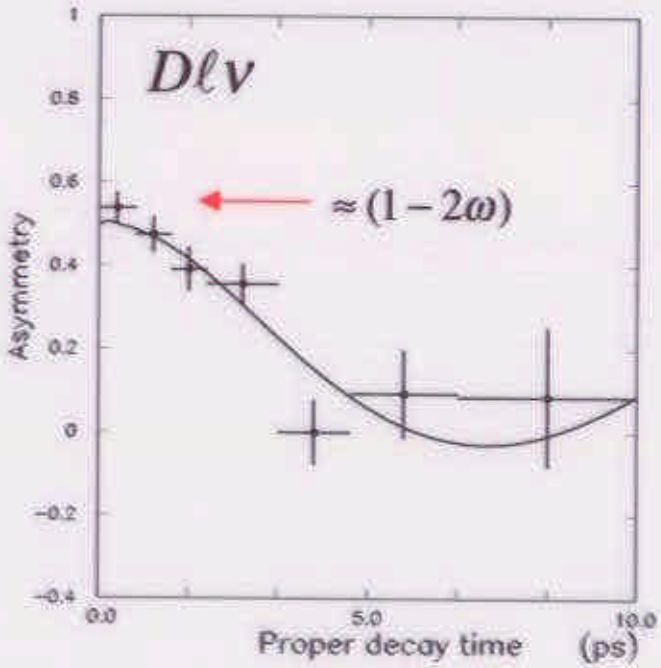


Estimation of wrong tag fraction ω

▲ Measure $B^0 - \overline{B^0}$ mixing using self-tagging B decay mode $B^0 \to D^*(D)\ell^+\nu$ +tagging of the other B

$$Asym = \frac{\text{Unmix - Mix}}{\text{Unmix + Mix}} = (1-2\omega)\cos\Delta m_d \Delta t \Rightarrow \omega$$





$\Delta m_d = 0.488 \pm 0.026\ \text{ps}^{-1}$ (Belle Preliminary)

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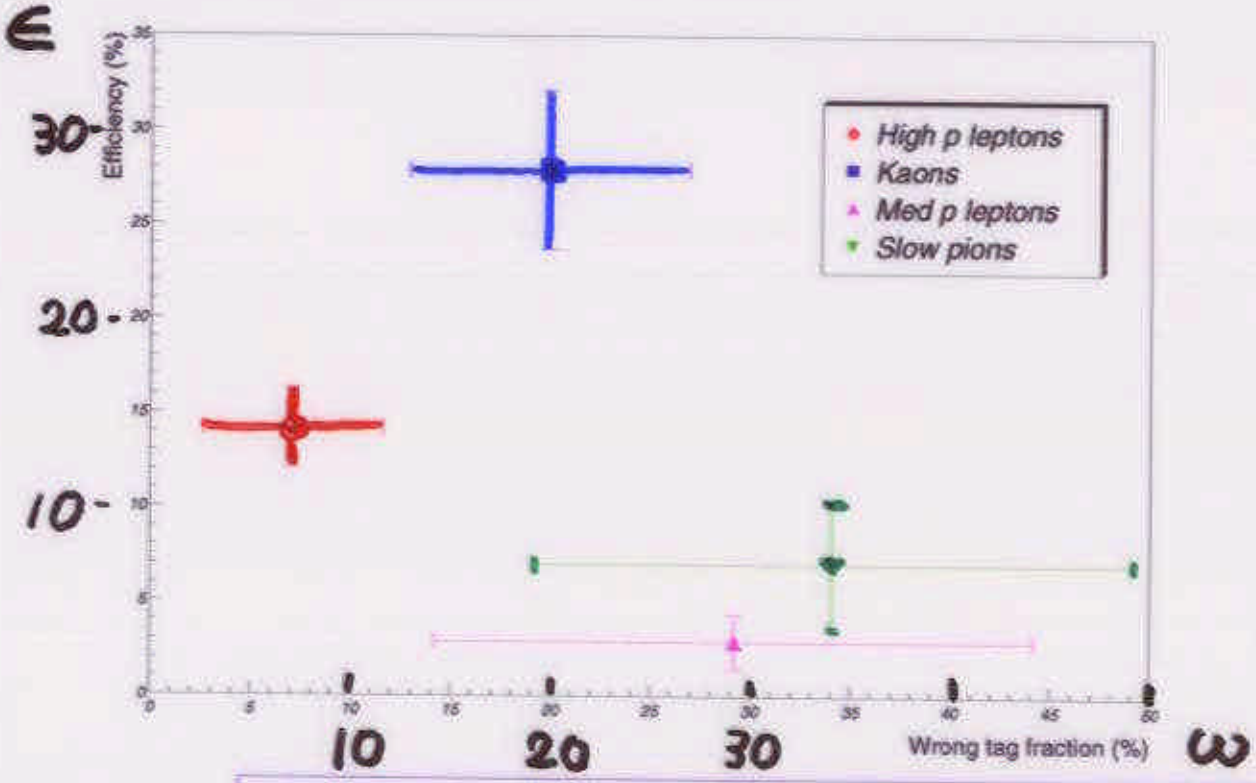
Tagging methods

1. High momentum $p^* \geq 1.1\,\mathrm{GeV}/c$ lepton charge: $+ \Rightarrow \bar{b} \Rightarrow B^0$
2. Kaon charge. $\sum Q_K \; + \Rightarrow \bar{b} \Rightarrow B^0$
3. Medium momentum lepton charge. $p_l^* \geq 0.6\,\mathrm{GeV}/c \cap p_l^* + p_\nu^* \geq 2.0\,\mathrm{GeV}/c$
4. Slow pions from D*: $\pi^+ \Rightarrow \overline{B^0}$



$$\sum \varepsilon = 52\%$$

$$\sum \varepsilon(1-2\omega)^2 = 22\%$$

Proper time difference reconstruction

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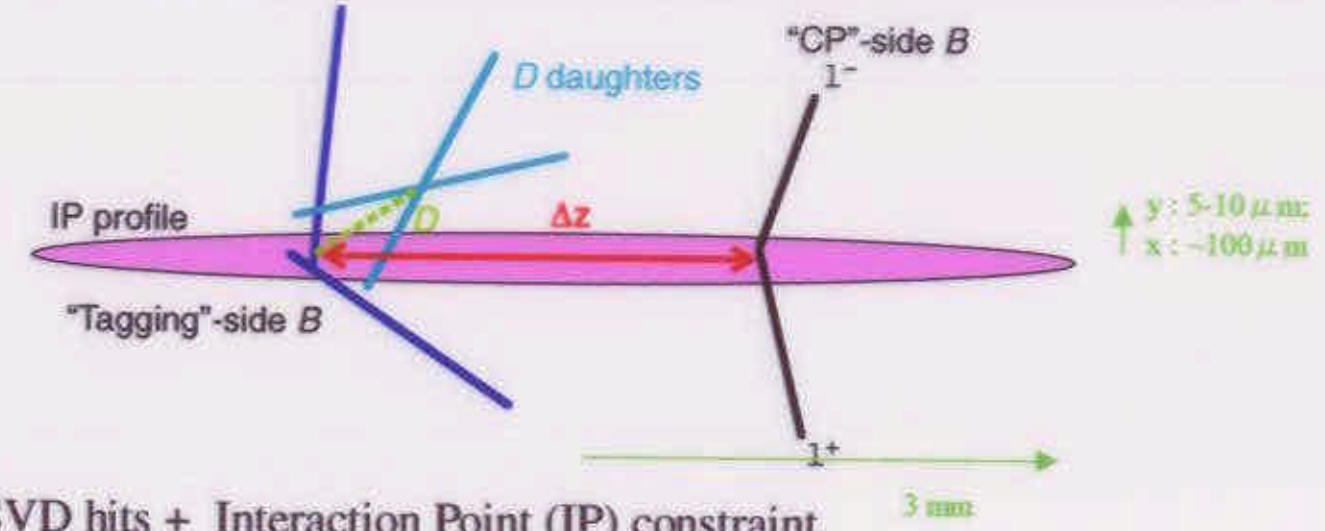
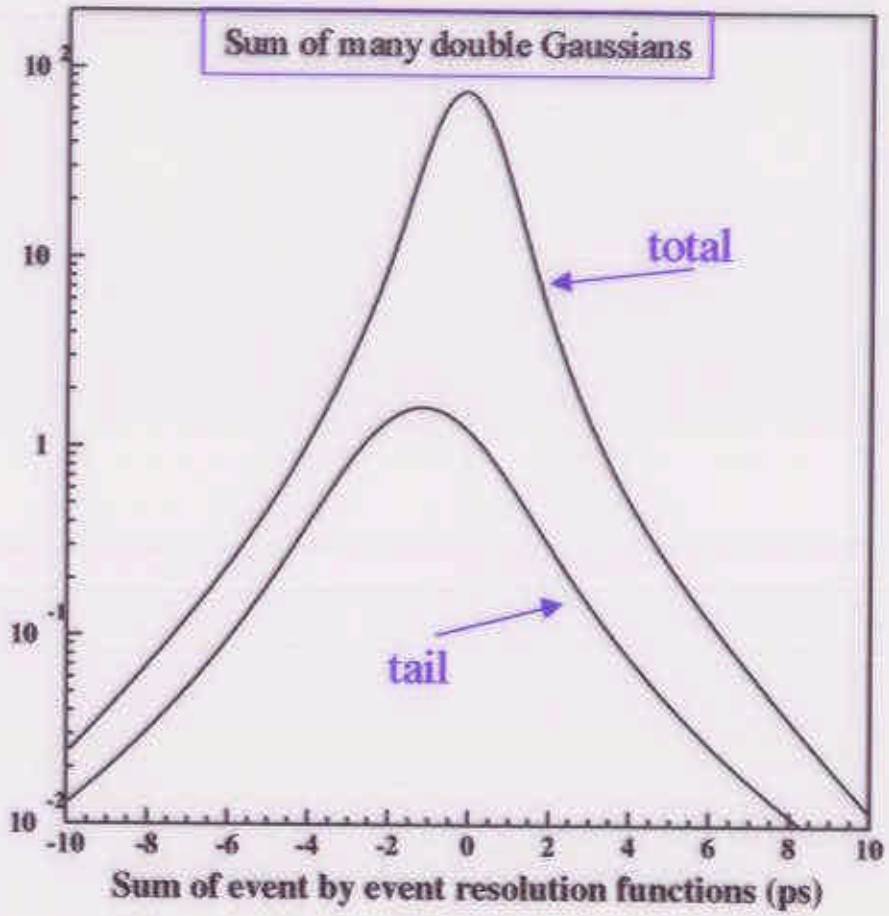
Proper-time difference reconstruction



- Tracks with SVD hits + Interaction Point (IP) constraint
- Z of CP side = Z of J/ψ: $\sigma_{z_{CP}} \sim 40\mu$m (MC)
- Z of tagging side = vertex of remaining tracks except long-lived particles such as Ks
  $\sigma_{z_{tag}} \sim 85\mu$m (MC)
- **Impact parameter resolutions:** $\sigma_{xy} = 21 \oplus 69/\left(p\beta\sin^{3/2}\theta\right)\mu$m
  $\sigma_z = 41 \oplus 48/\left(p\beta\sin^{5/2}\theta\right)\mu$m **(measured)**
- Δt inferred from Δz: $\Delta t = \frac{\Delta z}{\beta\gamma c} = \frac{\Delta z}{0.425c}$ $\sigma_{\Delta z} \sim 100\mu$m (MC)

Δt resolution

- Resolution function is a double Gaussian (main + tail) whose μs and σs are also functions of even-by-event vertex error propagated from track error matrices.
- This complexity is to take into account intrinsic detector resolutions (main part), poorly-measured tracks, and bias due to charm contribution and the $\Delta z/\beta\gamma c = \Delta t$ approximation.
- The functional forms and parameters were determined by MC simulations and by multi-parameter fit to the data, in particular, $D^0 \to K\pi$ lifetime measurement in z direction and $B \to D^* \ell \nu$ lifetime measurement.



$f_{main} = 0.96;\ \langle \sigma_{main} \rangle \sim 1.11$ ps

$f_{tail} = 0.04;\ \langle \sigma_{tail} \rangle \sim 2.24$ ps

$\langle \sigma_{total} \rangle \sim 1.18$ ps

$\langle \mu \rangle \sim -0.19$ ps

B lifetime measurements

Validate resolution estimation

$\overline{B}^0$ lifetime measurements.

Mode	# of signal	Lifetime (ps)
$\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}$	1740	$1.50 \pm 0.06^{+0.06}_{-0.04}$
$\overline{B}^0 \to D^{*+}\pi^-$	112	$1.55^{+0.18+0.10}_{-0.17-0.07}$
$\overline{B}^0 \to D^{+}\pi^-$	187	$1.41^{+0.13}_{-0.12} \pm 0.07$
$\overline{B}^0 \to J/\psi \overline{K}^{*0}$	92	$1.56^{+0.22+0.09}_{-0.19-0.15}$
Combined	–	$1.50 \pm 0.05 \pm 0.07$
$\overline{B}^0 \to J/\psi K_S$	55	$1.54^{+0.28+0.11}_{-0.24-0.19}$

B^- lifetime measurements.

Mode	# of signal	Lifetime (ps)
$B^- \to D^{*0}\ell^-\overline{\nu}$	730	$1.54 \pm 0.10^{+0.14}_{-0.07}$
$B^- \to D^0\pi^-$	440	$1.73 \pm 0.10 \pm 0.09$
$B^- \to J/\psi K^-$	293	$1.87^{+0.13+0.07}_{-0.12-0.14}$
Combined	–	$1.70 \pm 0.06^{+0.11}_{-0.10}$

CP fit

An unbinned maximum likelihood analysis

- Signal distribution:

$$Sig^{tag=\pm}(\Delta t) = \left\{ \frac{1}{2\tau_{B^0}} \exp\left(-\frac{|\Delta t|}{\tau_{B^0}} \right) \left\{ 1 \pm (1-2\omega_{tag})\eta_f \sin 2\phi_1 \sin(\Delta m_d \Delta t) \right\} \right\}$$

$$tag = \begin{cases} +: B^0(\bar{b}d) \\ -: \overline{B^0}(b\bar{d}) \end{cases}$$

  - τ_{B^0} and Δm_d were fixed to PDG2000 numbers: $\tau_{B^0} = 1.548 \pm 0.032$ ps

    $\Delta m_d = 0.472 \pm 0.017$ ps^{-1}
  - Background distribution: lifetime from sidebands : $\tau_{bkg} = 0.73 \pm 0.12$ ps

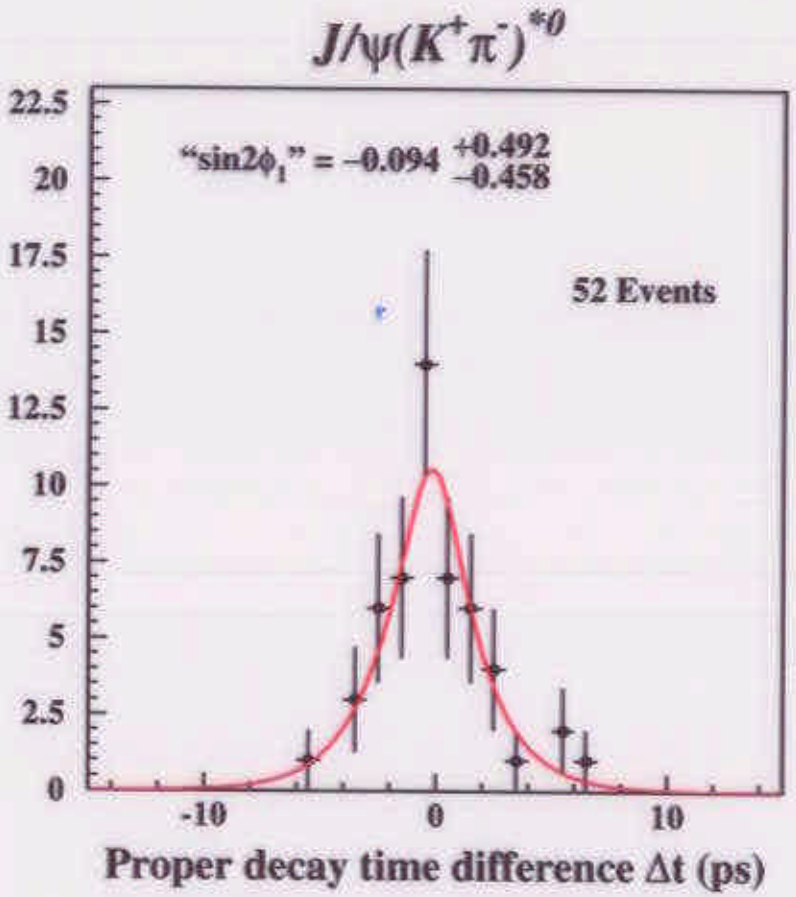
- Convolute with event-by-event resolution:

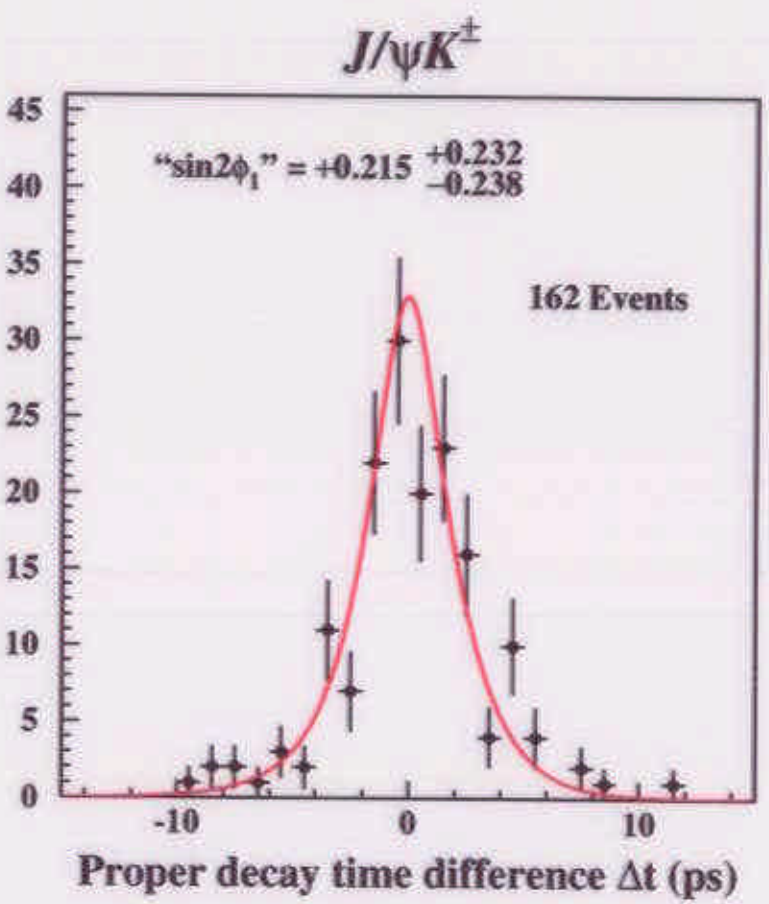
$$\rho_i(\Delta t_i) = p_{sig} \int Sig^{tag=\pm}(\Delta t') R(\Delta t - \Delta t') d\Delta t' + (1 - p_{sig}) \int Bkg(\Delta t) R(\Delta t - \Delta t') d\Delta t'$$

Likelihood function : $L(\sin 2\phi_1) = \prod_{i=1,n} \rho_i(\Delta t_i)$

Minimize $-\ln L(\sin 2\phi_1)$ by scanning $\sin 2\phi_1$.

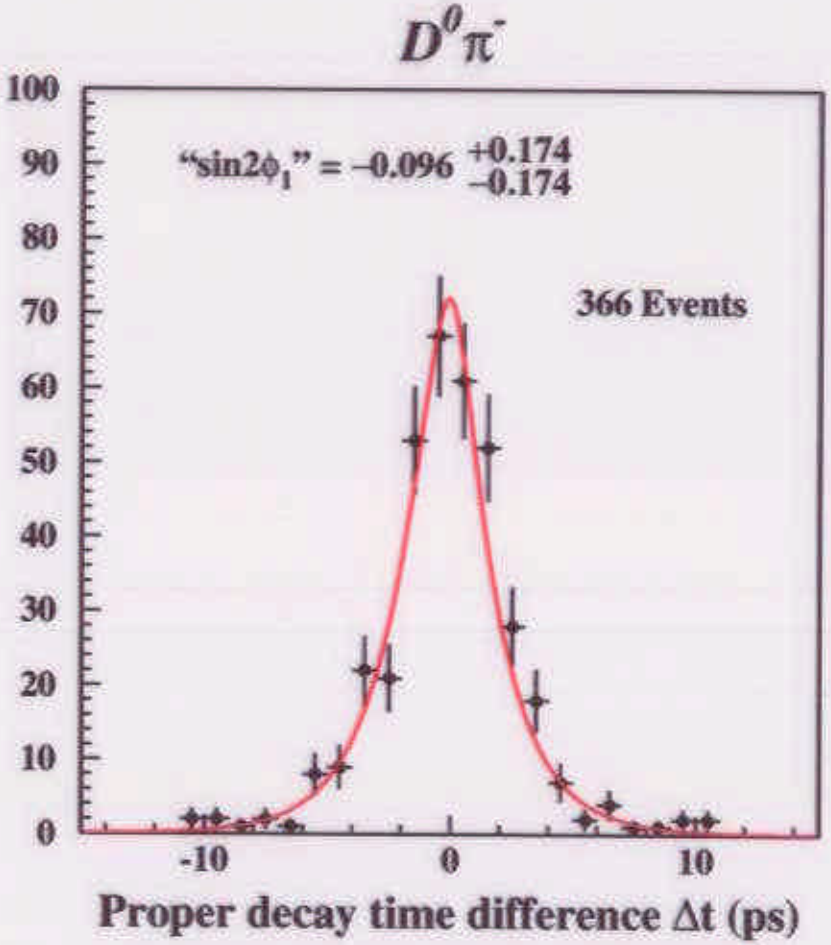
Fit to control samples

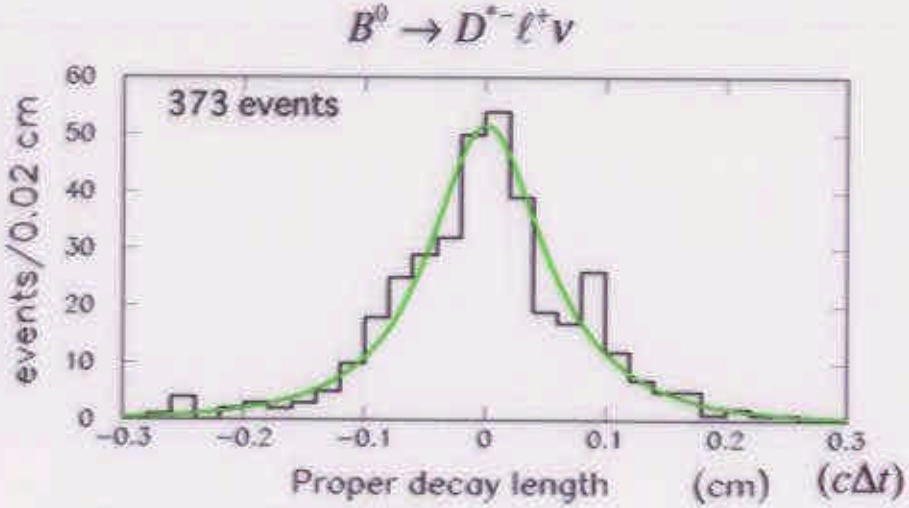


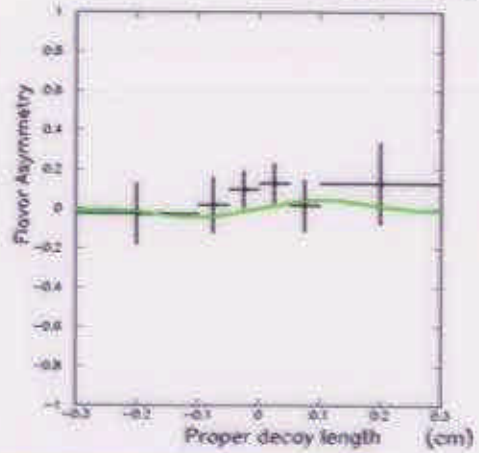


Asymmetry consistent with zero.

Fit to control samples (2)





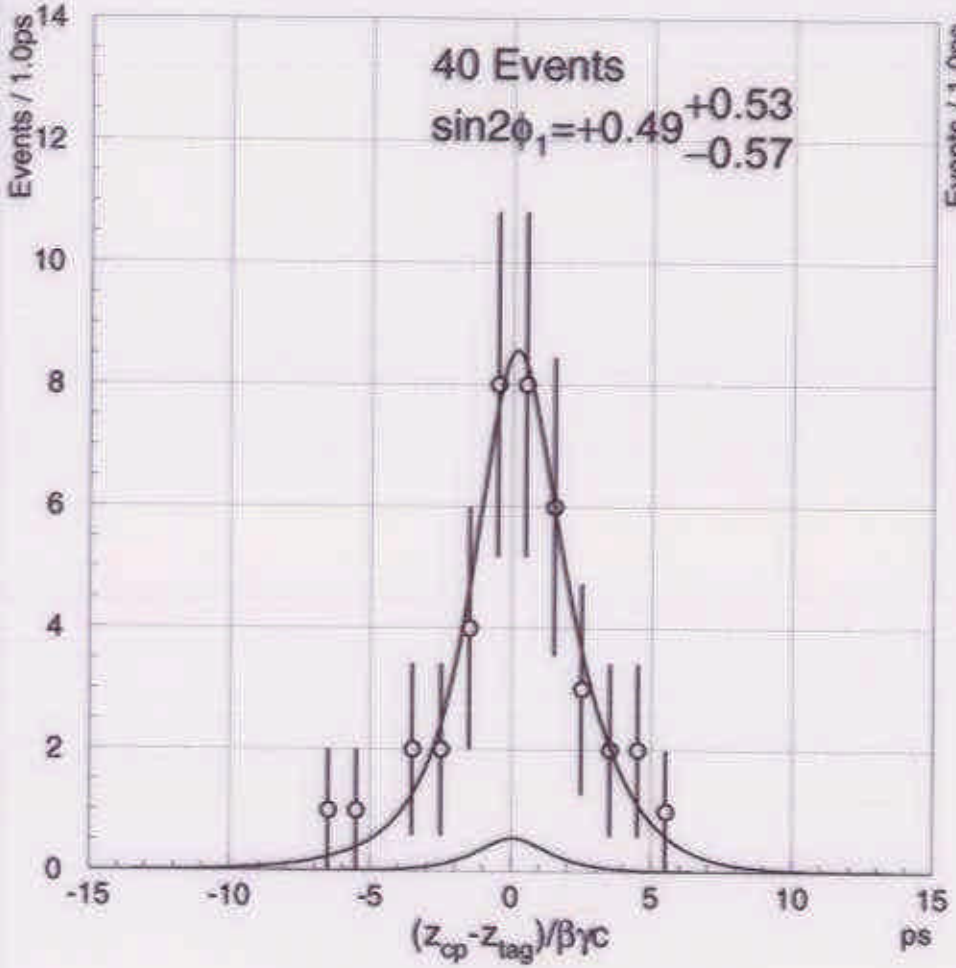


"sin2ϕ_1"= +0.09 $^{+0.18}_{-0.18}$

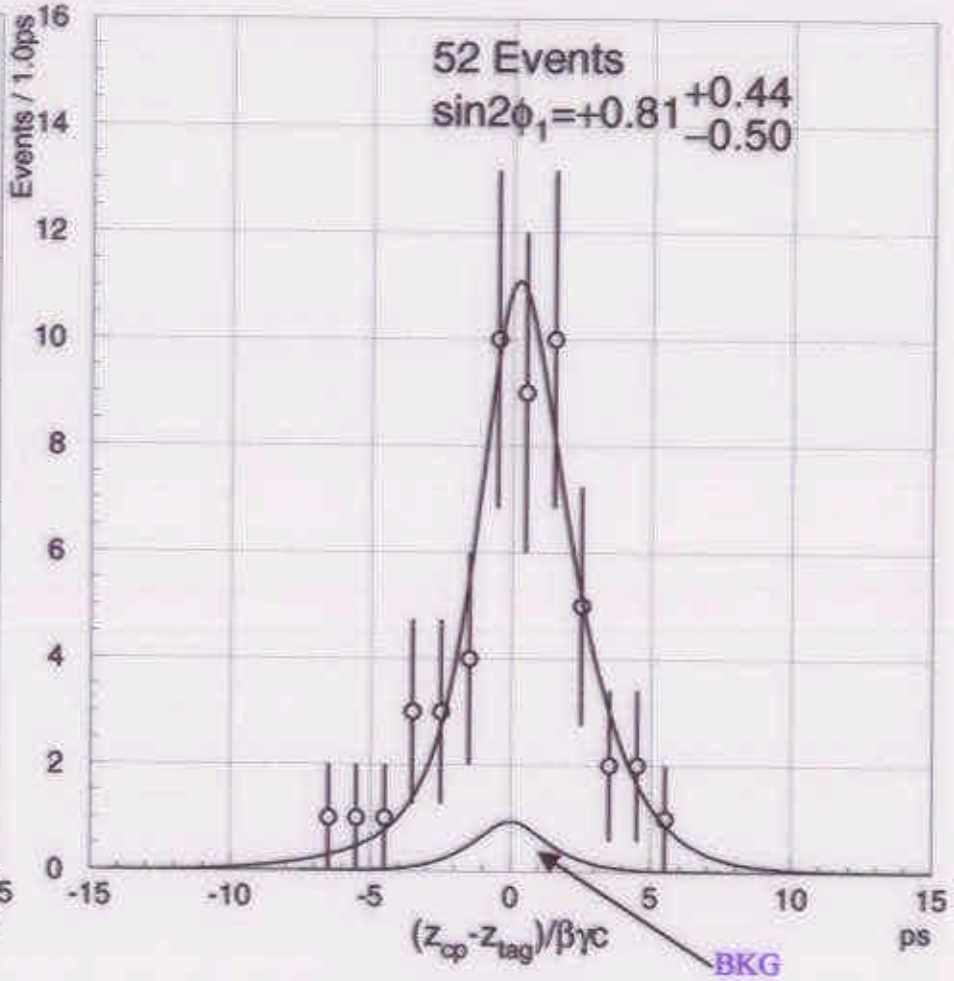
Asymmetry consistent with zero.

CP fit to *CP*=-1 states

Belle Preliminary



$J/\psi K_s(\pi^+\pi^-)$ only

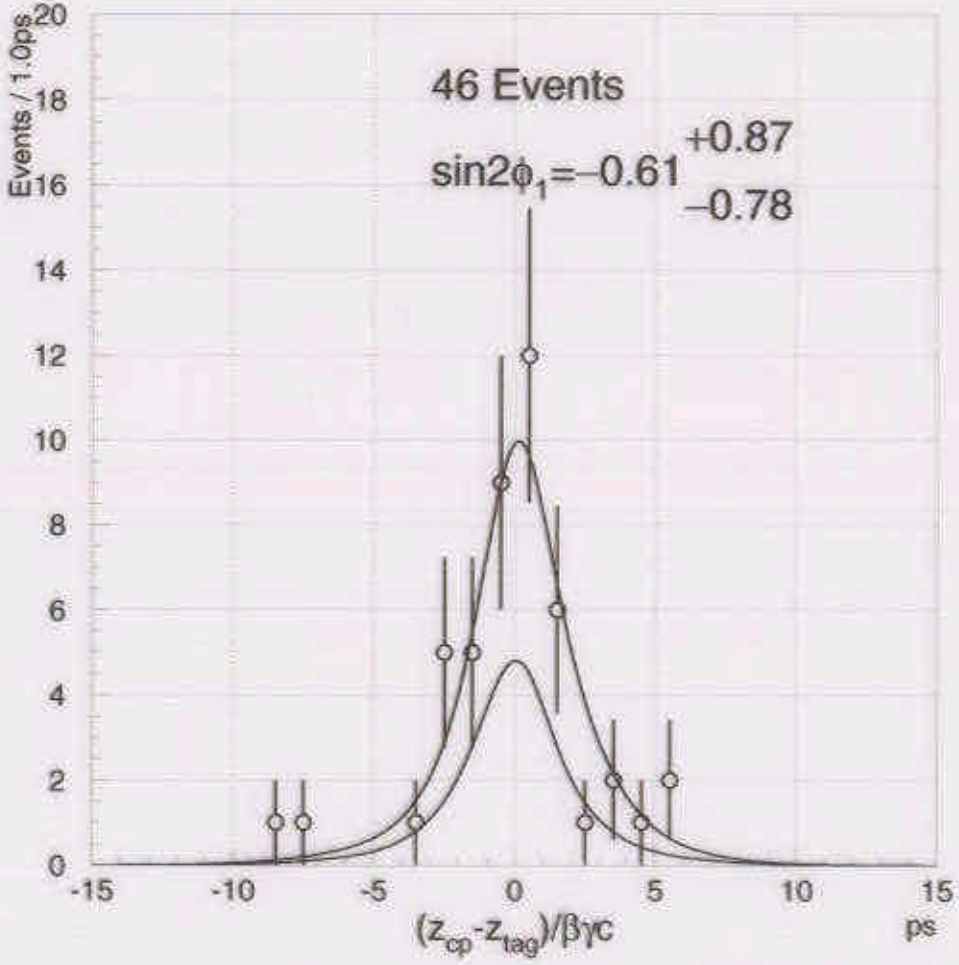


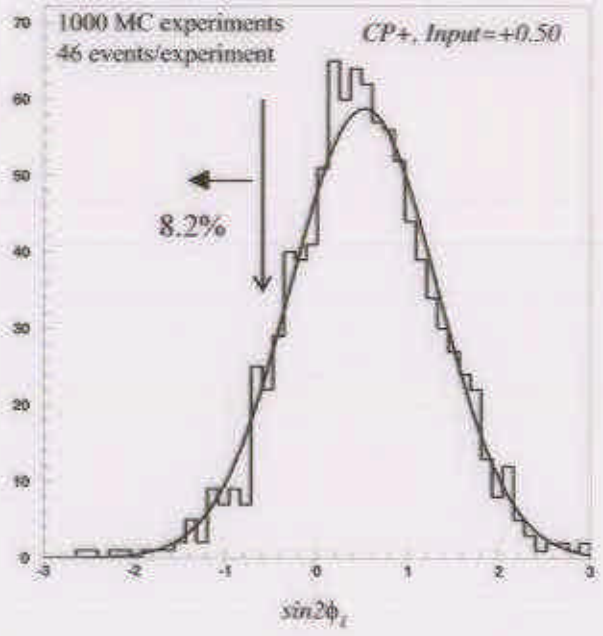
All CP=-1 modes

CP fit to *CP*=+1 states

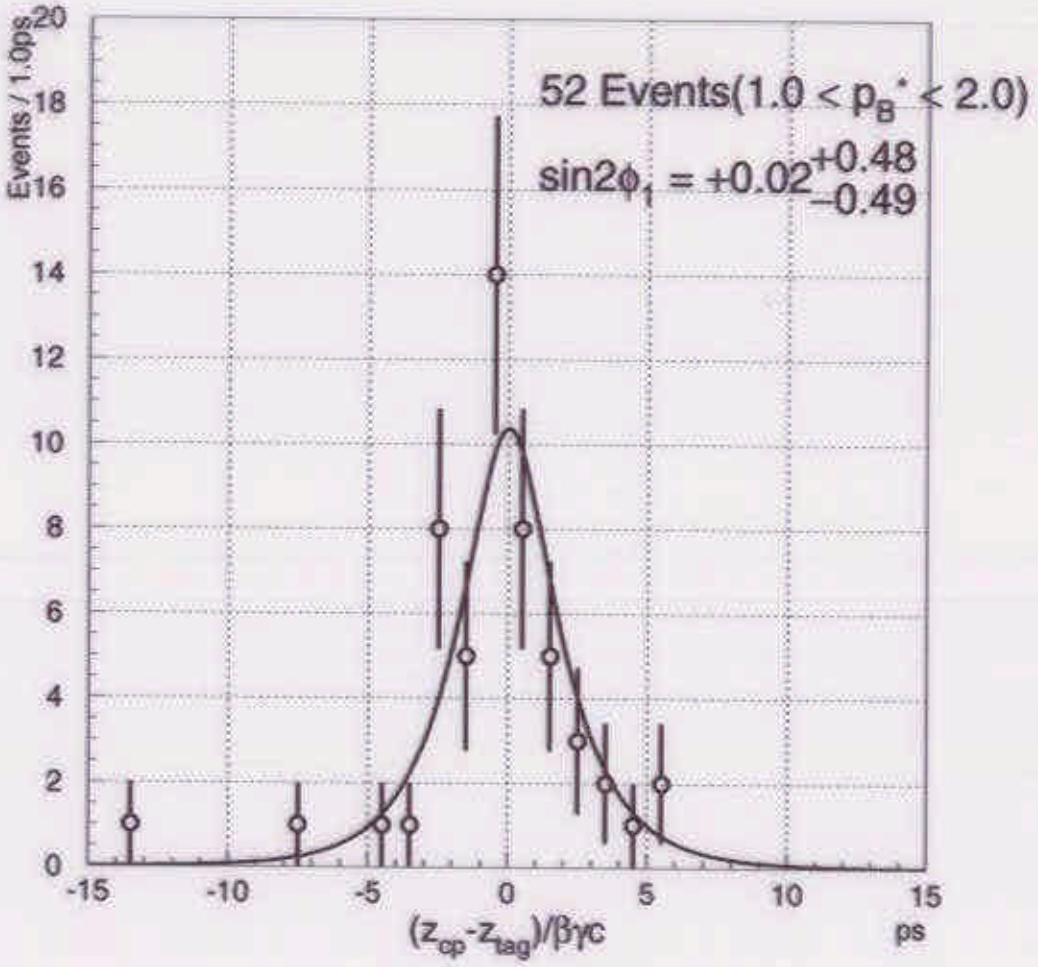
Belle Preliminary

$(J/\psi K_L + J/\psi \pi^0)$

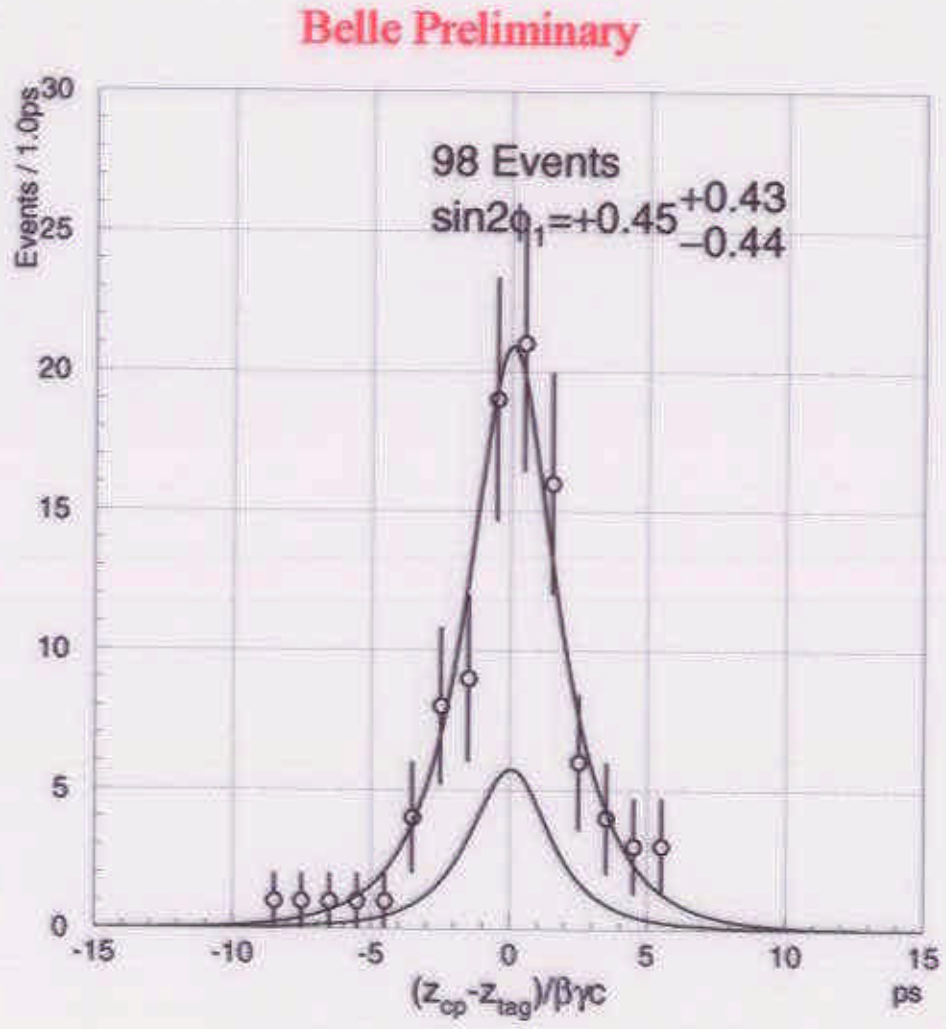


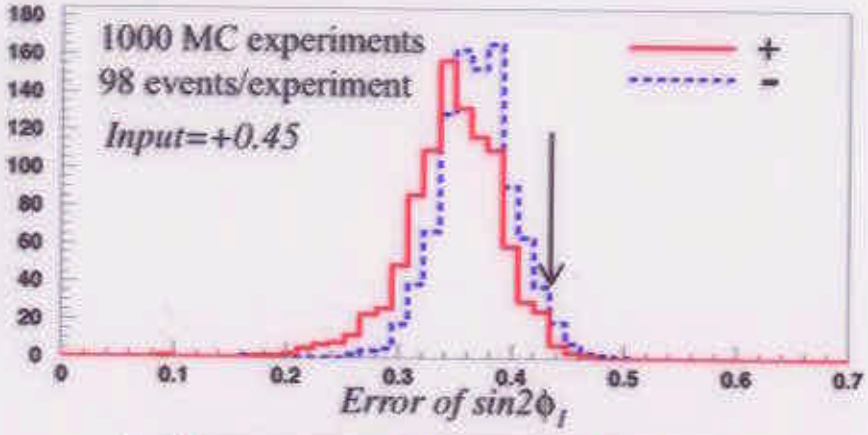


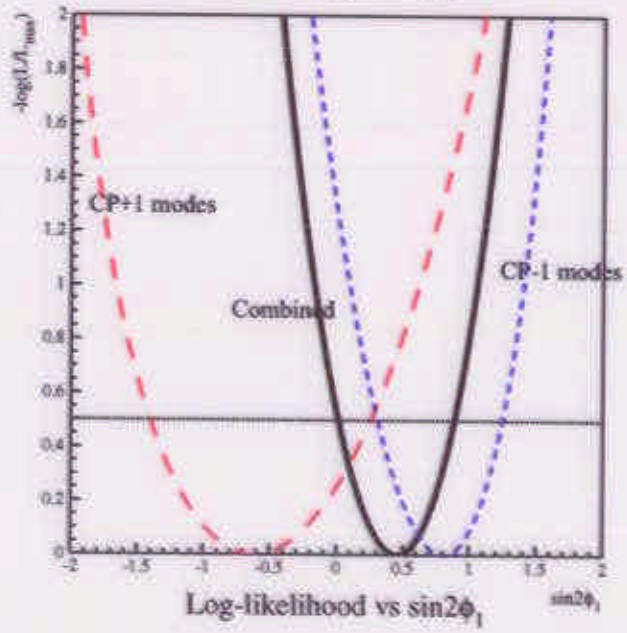
CP fit to K_L sideband



Combined *CP* fit



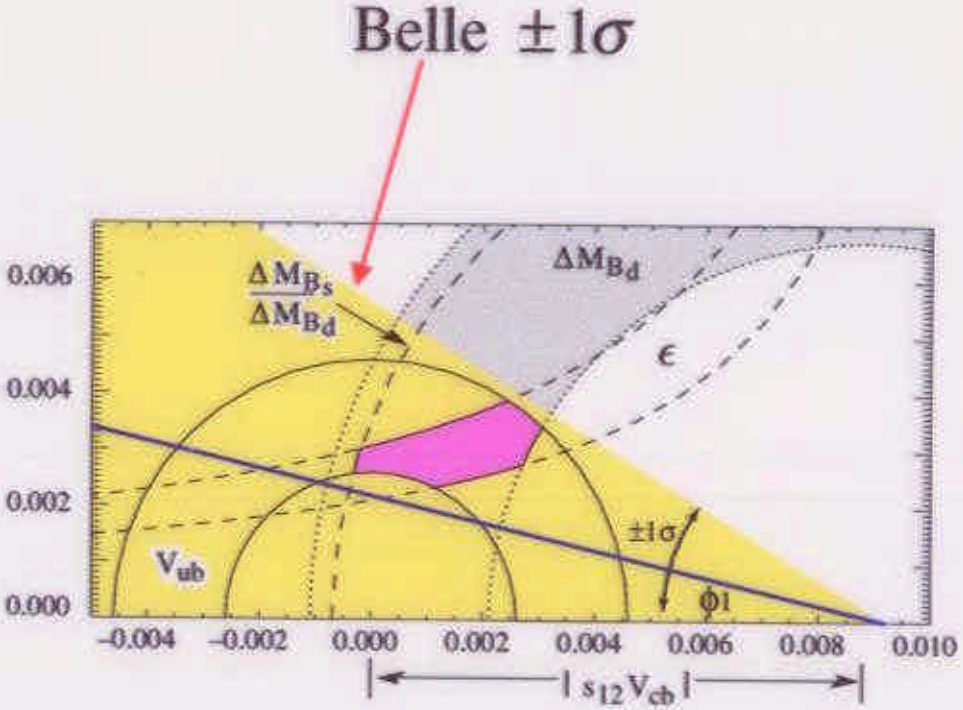




Result of *CP* fit

Systematic errors

Source	$\sigma+$	$\sigma-$
Wrong tag fraction	0.0495	-0.0660
Resolution for signal	0.0264	-0.0246
Resolution for background	0.0292	-0.0421
Background fraction/shape	0.0291	-0.0323
$\tau_B, \Delta m_d$	0.0054	-0.0056
IP profile	0.0041	-0.0000
Total	+0.0699	-0.0884



Belle preliminary

$$\sin 2\phi_1 = 0.45^{+0.43}_{-0.44}(\text{stat})^{+0.07}_{-0.09}(\text{syst})$$

à la PDG2000

Conclusion/Prospect

- We had a very successful 99-00 running period which produced 17 contributed papers.
- We have presented a measurement of $\sin 2\phi_1$ based on $\int Ldt = 6.2\ \text{fb}^{-1}$ on $\Upsilon(4S)$ collected at KEKB.
  We find $\sin 2\phi_1 = 0.45^{+0.44}_{-0.45}\ (\text{stat} + \text{syst})$ **Belle Preliminary**
- Other modes including are in stock.

$J/\psi K^*(K_S\pi^0)$	16 events
tagged D^*D	17 events
$J/\psi\, K_1(1270) \to J/\psi K^0 \pi^+\pi^-$ (Paper#278)	5 events

- More tagging methods in stock.
- After many engineering improvements KEKB will resume run with higher currents in October and run till summer 2001.