Recent Results of Belle on B physics

Hirokazu Ishino (TITech)
for the Belle Collaboration
2001/10/10 @Nihon University

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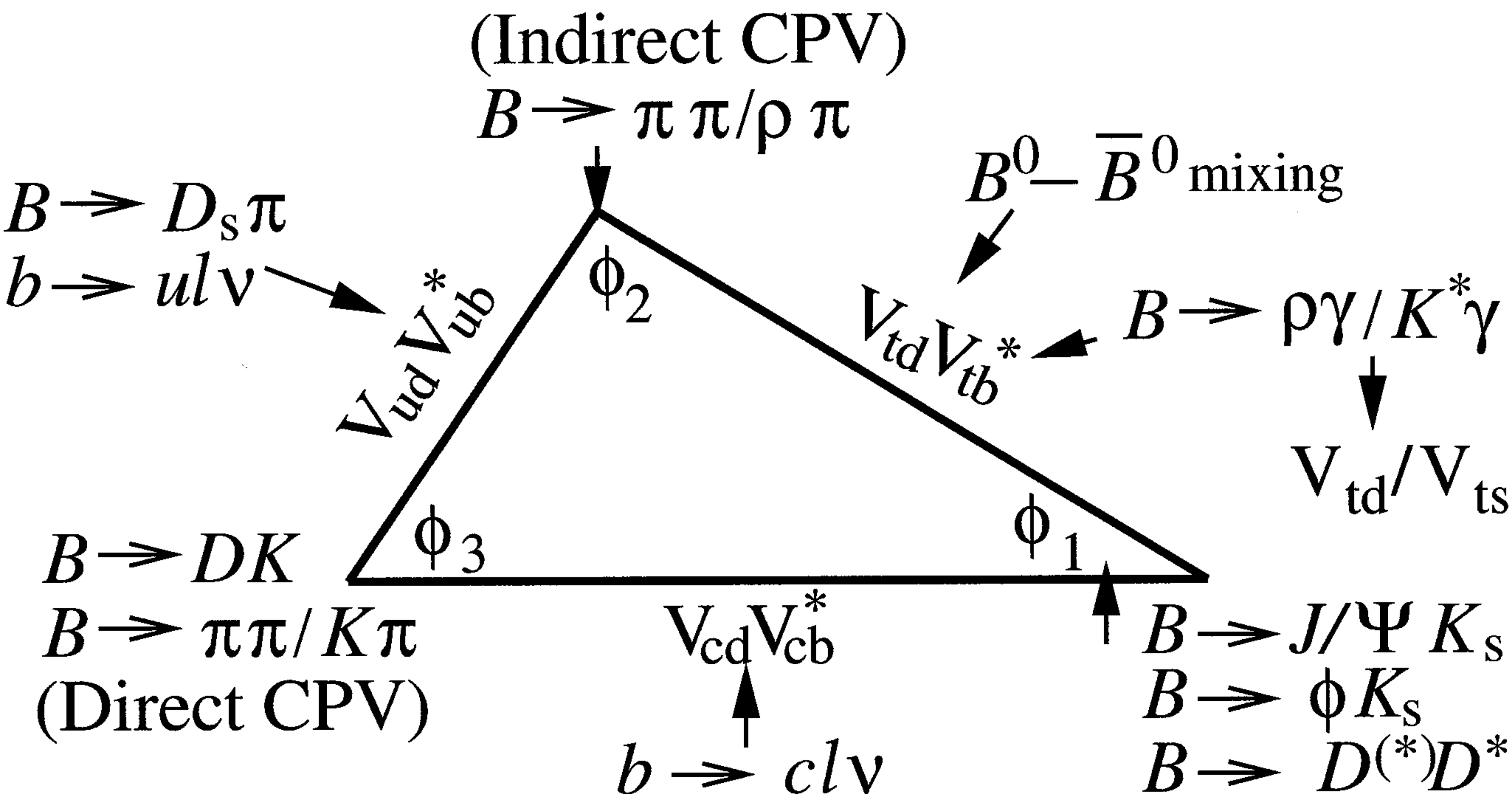
Introduction

The unitarity $V_{ud}V_{ub}^{*}+V_{cd}V_{cb}^{*}+V_{td}V_{tb}^{*}=0$ will be checked using B decays.



CP Violation with mixing

$$\lambda = \frac{q}{p}\frac{\bar{A}}{A}$$

$$\Gamma(B^0(t) \to f_{cp}) = |A|^2 e^{-\Gamma t}\left(\frac{1+|\lambda|^2}{2} + \frac{1-|\lambda|^2}{2}\cos\Delta m t - \boldsymbol{Im}\lambda \sin\Delta m t\right)$$

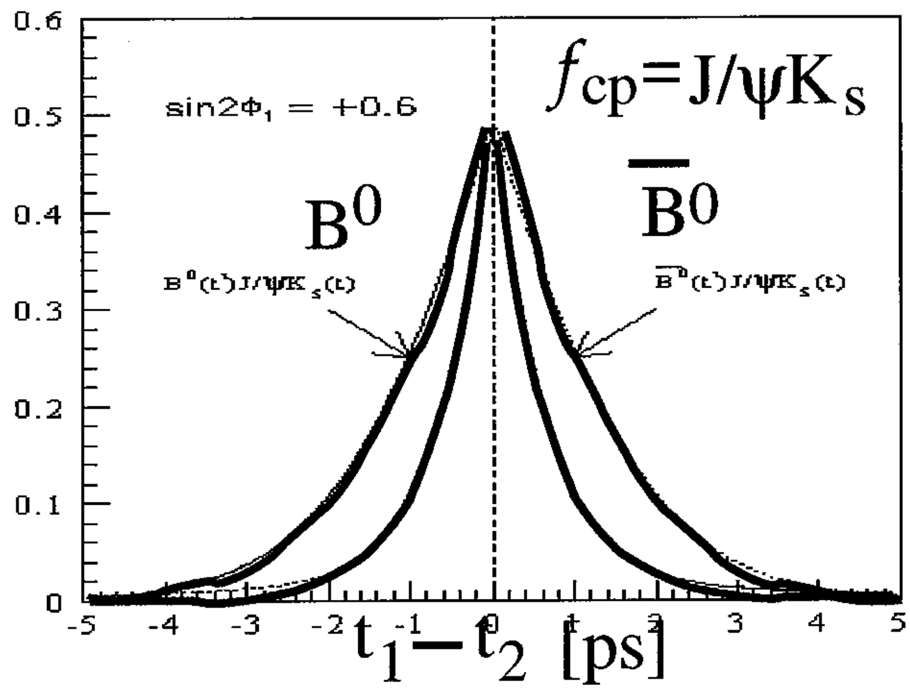
$$\Gamma(\bar{B}^0(t) \to f_{cp}) = |\bar{A}|^2 e^{-\Gamma t}\left(\frac{1+|\lambda|^2}{2} - \frac{1-|\lambda|^2}{2}\cos\Delta m t + \boldsymbol{Im}\lambda \sin\Delta m t\right)$$

In case $B \to J/\psi K^0_{S,L}$: $\boldsymbol{Im}\,\lambda = -\xi_{f_{cp}} \sin 2\phi_1 \quad |\lambda| \simeq 1$

With Y(4S)

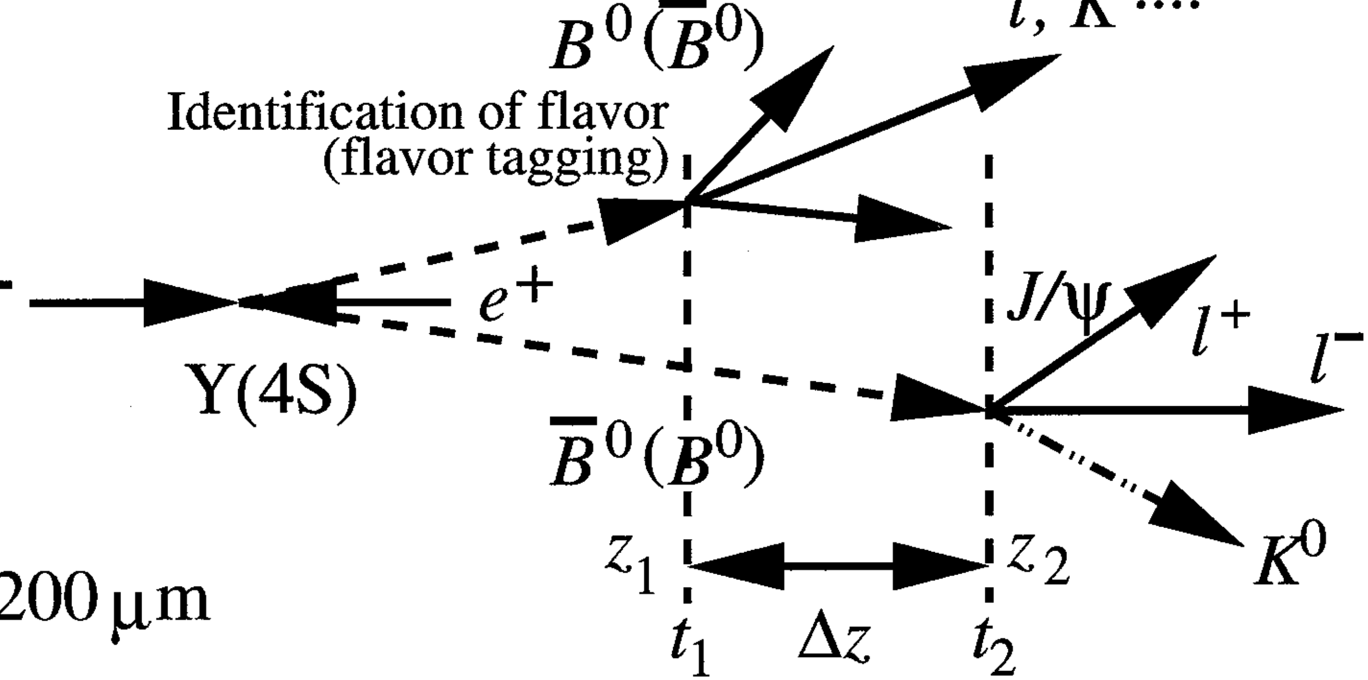
$$\Gamma(B^0(t_2), f_{cp}(t_1)) \sim e^{-\Gamma|t_1-t_2|}$$
$$\times [1+\xi_{f_{cp}} \sin 2\phi_1 \sin \Delta m(t_1 - t_2)]$$

$$\Gamma(\bar{B}^0(t_2), f_{cp}(t_1)) \sim e^{-\Gamma|t_1-t_2|}$$
$$\times [1-\xi_{f_{cp}} \sin 2\phi_1 \sin \Delta m(t_1 - t_2)]$$



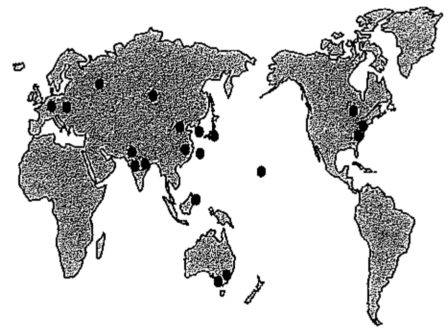
Measurement method of asymmetry of proper time difference

$E_{e^-} = 8\text{GeV}$
$E_{e^+} = 3.5\text{GeV}$
$\beta\gamma = 0.425$
$\Delta z \simeq c\beta\gamma\Delta t$
when
$\Delta t = \tau_{B^0} \longrightarrow 200\,\mu\text{m}$



$$\frac{\Gamma(\overline{B}^0 \to f_{cp}) - \Gamma(B^0 \to f_{cp})}{\Gamma(\overline{B}^0 \to f_{cp}) + \Gamma(B^0 \to f_{cp})} = -\xi_{f_{cp}} \sin 2\phi_1 \sin \Delta m \Delta t$$

Belle collaboration



13 countries
45 institutes
~300 researchers

BELLE Collaboration

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.
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
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Nagoya University
Nara Woman's University
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Osaka City University
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Sugiyama Woman's College
Sungkyunkwan University
University of Sydney
Toho University
Tohoku University
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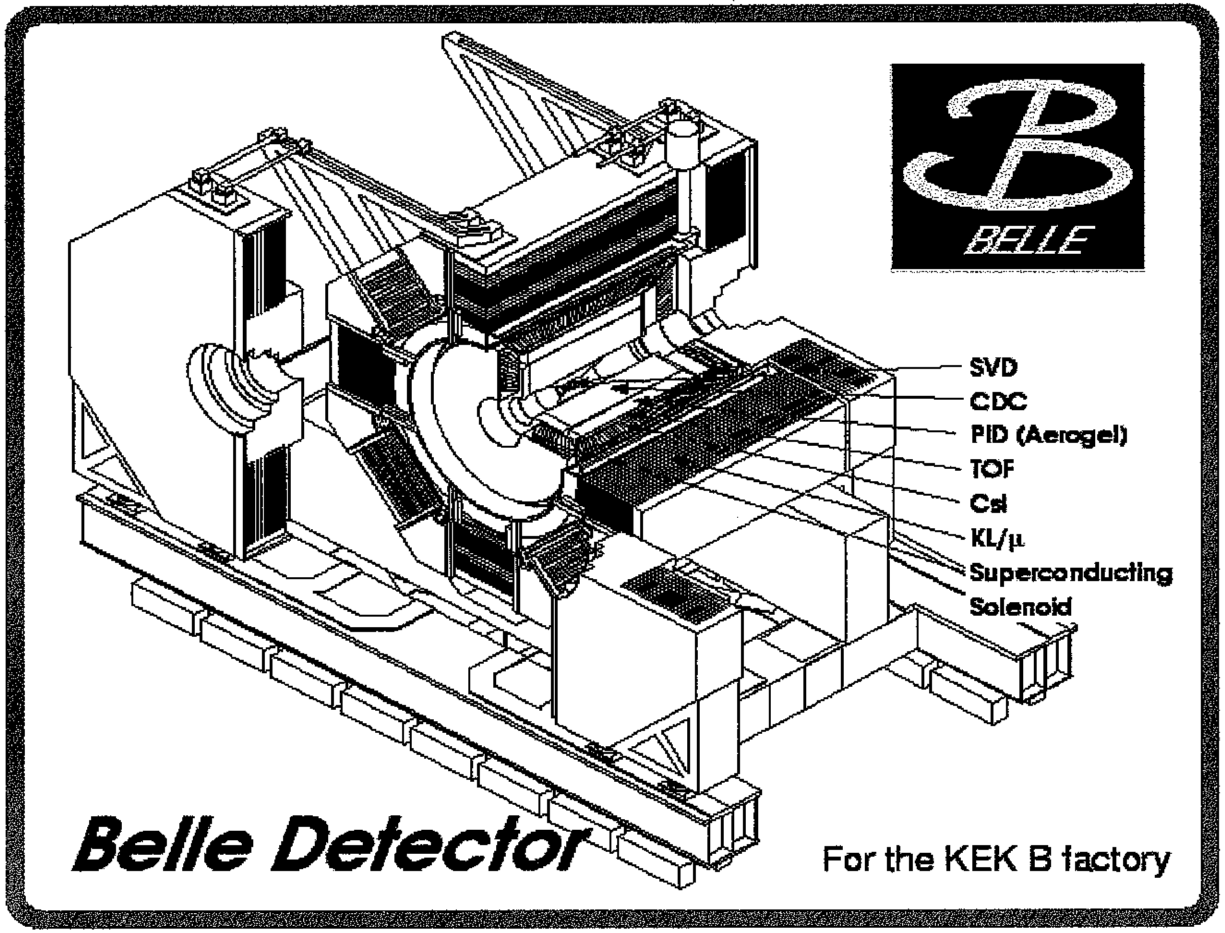
University of Tokyo
Tokyo Institute of Technology
Tokyo Metropolitan University
Tokyo University of Agriculure and Technology
Toyama National College of Maritime Technology
University of Tsukuba
Utkal Univesity
Virginia Polytechnic Institute and State University
Yonsei University

Belle Detector

Reconstruction for charged particles

- Silicon Vertex Detector (SVD)
  55μm resolution for p=1GeV/c
- Central Drift Chamber (CDC)

$(\sigma_{pt}/p_t)^2 = (0.0019 p_t)^2 + (0.0034)^2 \quad p_t\,(\mathrm{GeV/c})$



Electrons and photons

- CsI Electromagnetic Calorimeter (ECL)

Particle Identification
K/π separation

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

Electron Identification

- ECL

K_L muon identification

- K_L and muon detector (KLM)

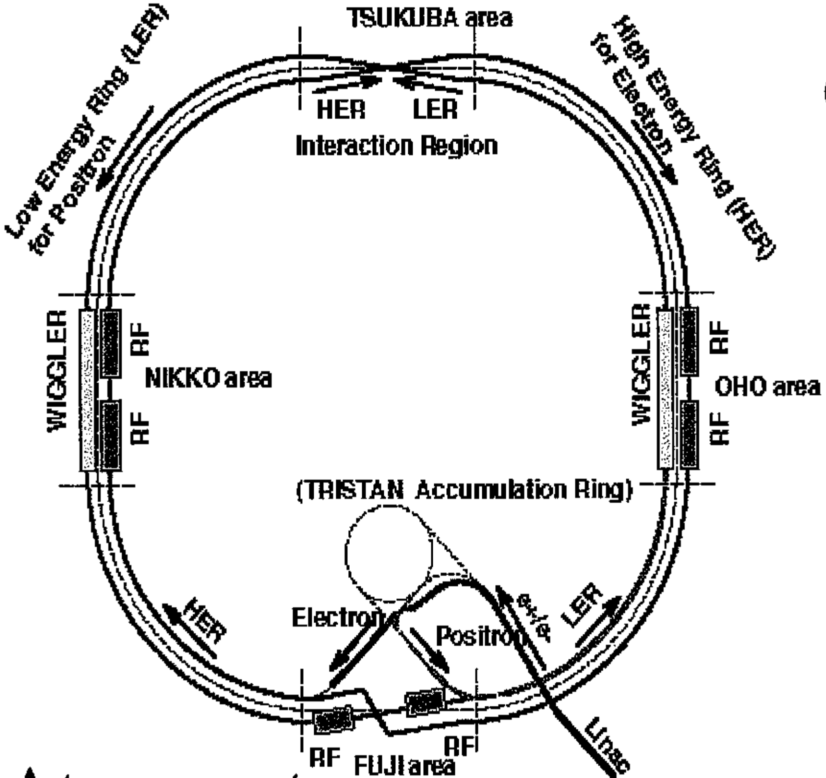
KEKB accelerator

$E_{e^+} = 3.5\text{GeV} \quad E_{e^-} = 8.0\text{GeV}$

CM energy 10.580GeV at Υ(4S)

Target luminosity $10^{34}/cm^2/s$

($2.6A$ for e^+ $1.1A$ for e^-)



At present

200/pb/day ~ $2 \cdot 10^5$ Υ(4S)/day

Total luminosity on Υ(4S)

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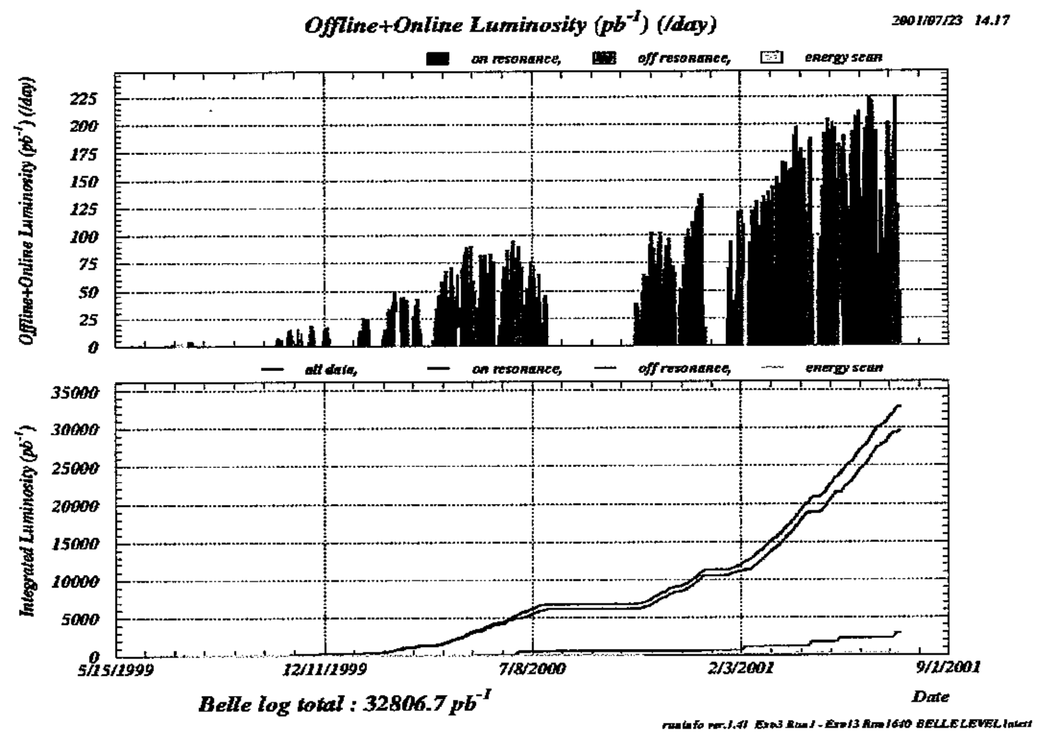
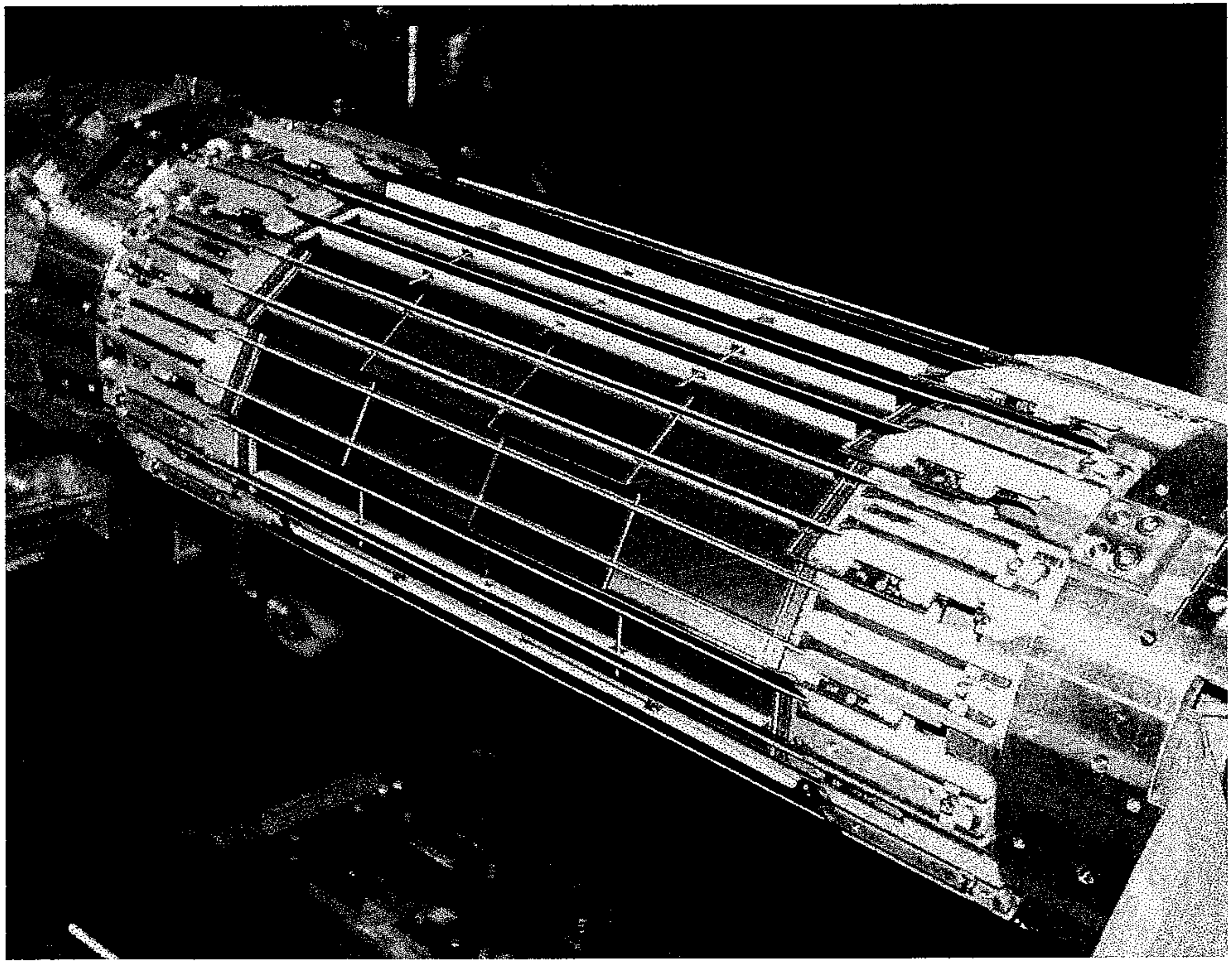


$\sin 2\phi_1$ measurement



Silicon Vertex Detector

CP eigenstates for ϕ_1 extraction

CP = −1

$J/\psi(\to l^+l^-)K_s(\to \pi^+\pi^-$ or $\pi^0\pi^0)$

$\psi(2S)(\to l^+l^-$ or $J/\psi\,\pi^+\pi^-)K_s$

$\chi_{c1}(\to J/\psi\,\gamma)K_s$

$\eta_c(\to K^+K^-\pi^0$ or $K_s K^\pm \pi^\mp)K_s$

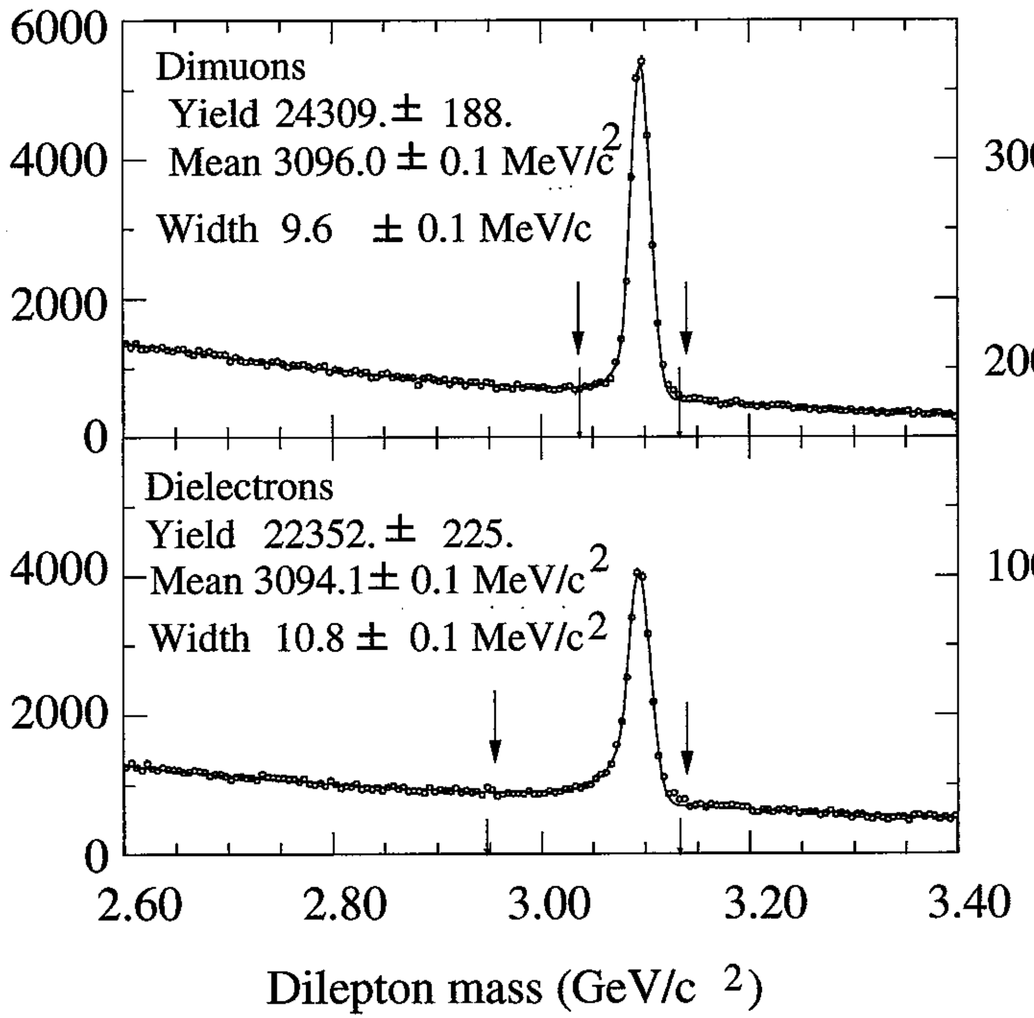
CP = +1

$J/\psi K^{*0}$ ($K_S\pi^0$) (Mostly)

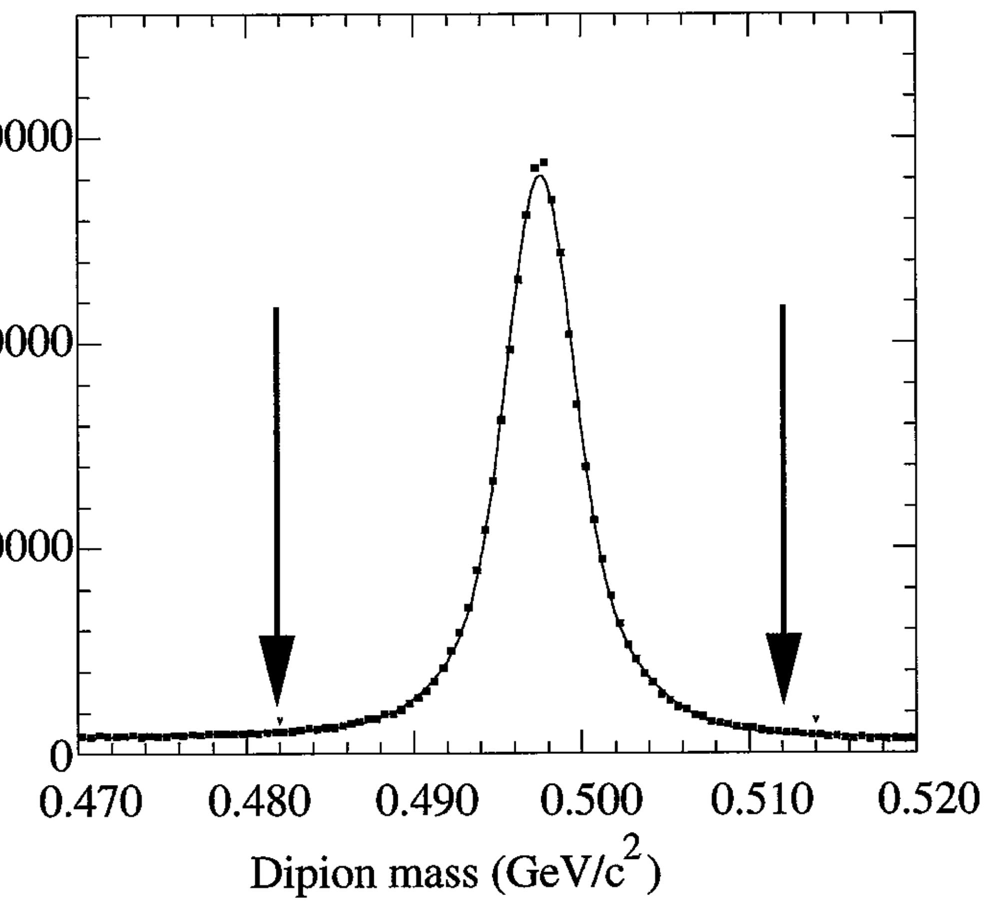
$J/\psi K_L$

Reconstruction of J/ψ and K_S invariant mass distributions

J/ψ

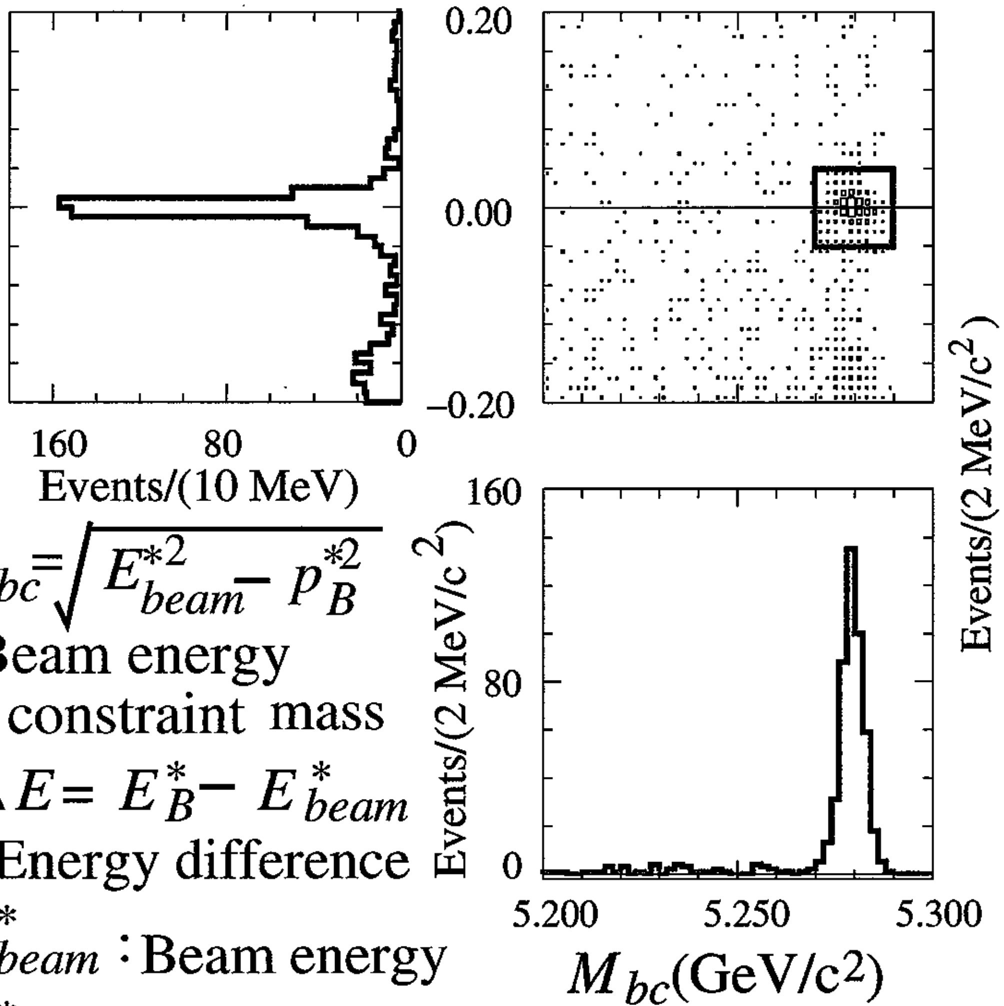


$K_S \rightarrow \pi^+\pi^-$



Reconstruction of $J/\psi K_S$ etc.

$J/\psi K_S$



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

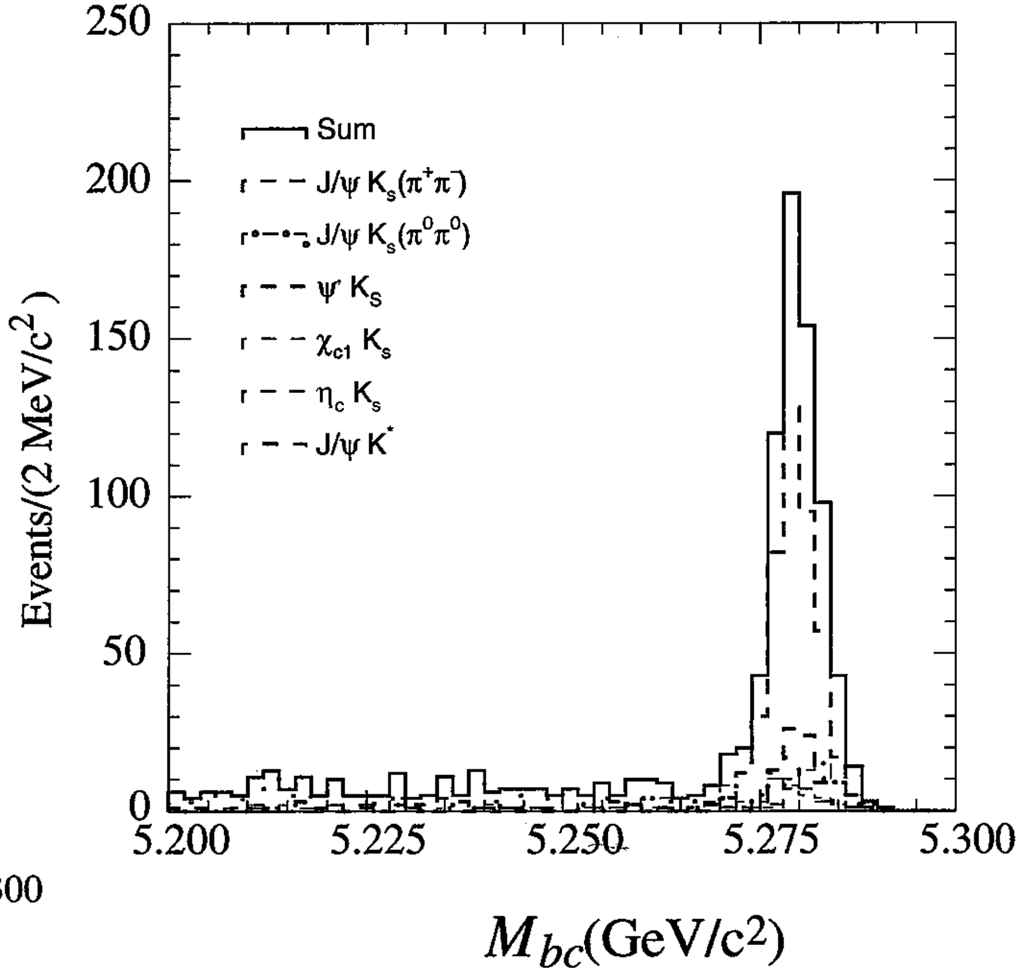
Beam energy constraint mass

$$\Delta E = E^{*}_{B} - E^{*}_{beam}$$

Energy difference

E^{*}_{beam} : Beam energy

E^{*}_{B}, p^{*}_{B} : reconstructed energy and momentum of a B meson in the CMS



Summary of CP side reconstruction

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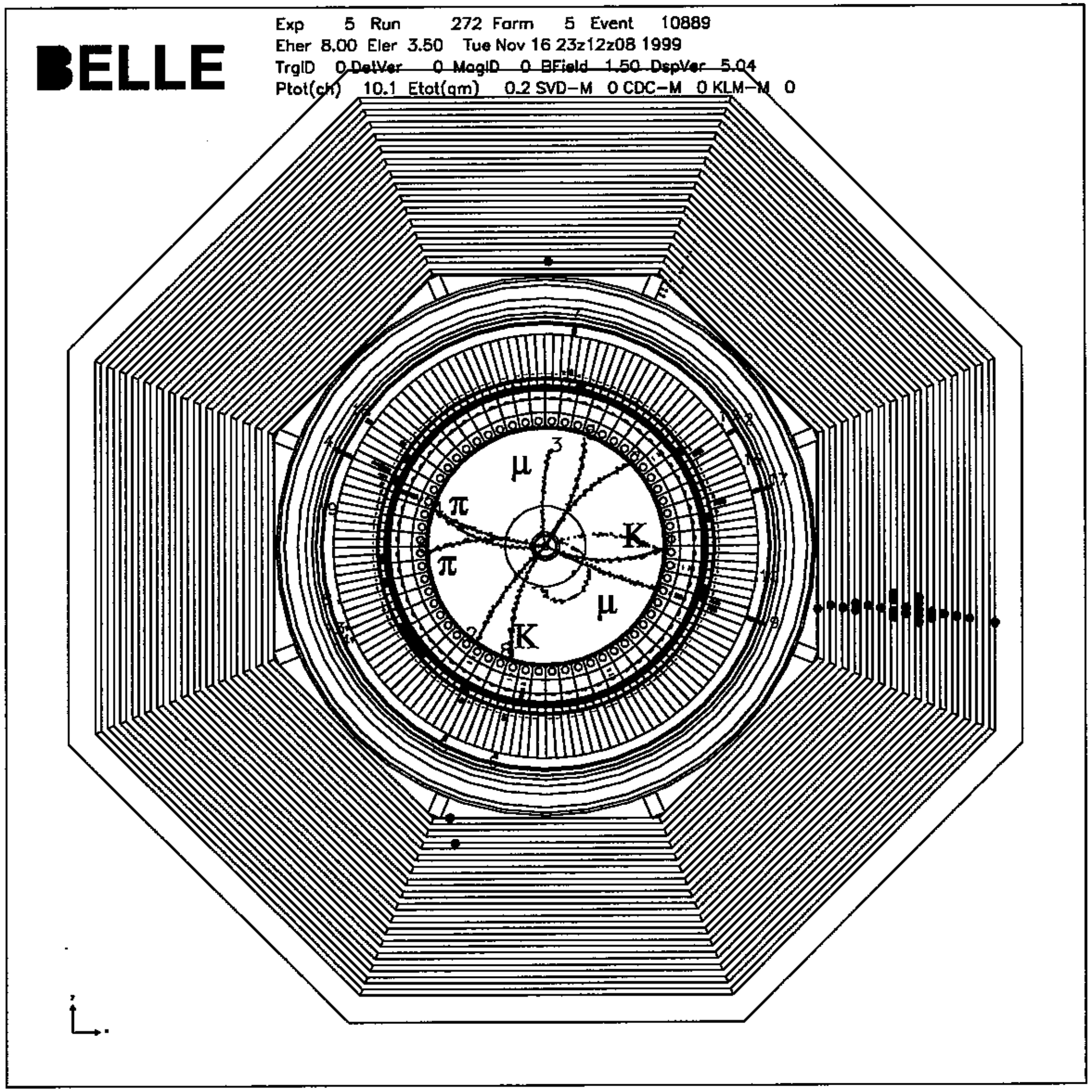
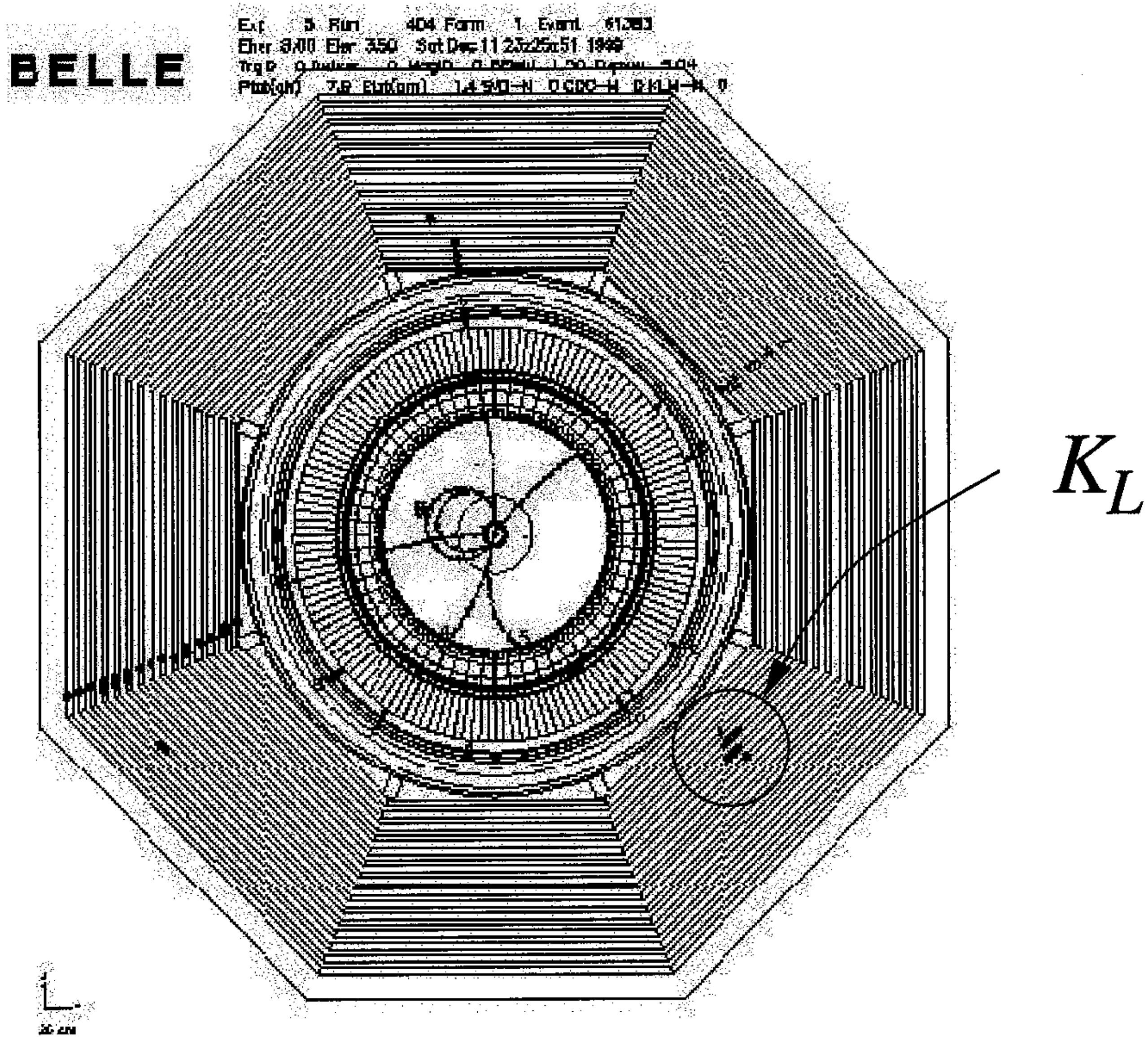
mode	N_{ev}	N_{bg}
$J/\psi\ (l^+l^-)\, K_S(\pi^+\pi^-)$	457	11.9
$J/\psi\ (l^+l^-)\, K_S(\pi^0\pi^0)$	76	9.4
$\psi(2S)\, (l^+l^-)\, K_S(\pi^+\pi^-)$	39	1.2
$\psi(2S)\, (J/\psi\, \pi^+\pi^-)\, K_S(\pi^+\pi^-)$	46	2.1
$\chi_{c1}(J/\psi\ \gamma)\, K_S(\pi^+\pi^-)$	24	2.4
$\eta_c(K^+K^-\pi^0)\ K_S(\pi^+\pi^-)$	41	13.6
$\eta_c(K_S K^\pm\pi^\mp)\ K_S(\pi^+\pi^-)$	23	11.3
$J/\psi\, (l^+l^-)\ K^{*0}(K_S\pi^0)$	41	6.7
	747	58.6
$J/\psi\, (l^+l^-)\, K_L$	346	223

$J/\psi K_S$ event display

$J/\psi \to \mu^+\mu^-$, $K_S \to \pi^+\pi^-$



$J/\psi\, K_L$
$\quad\hookrightarrow \mu^+\mu^-$



Reconstruction of $J/\psi K_L$

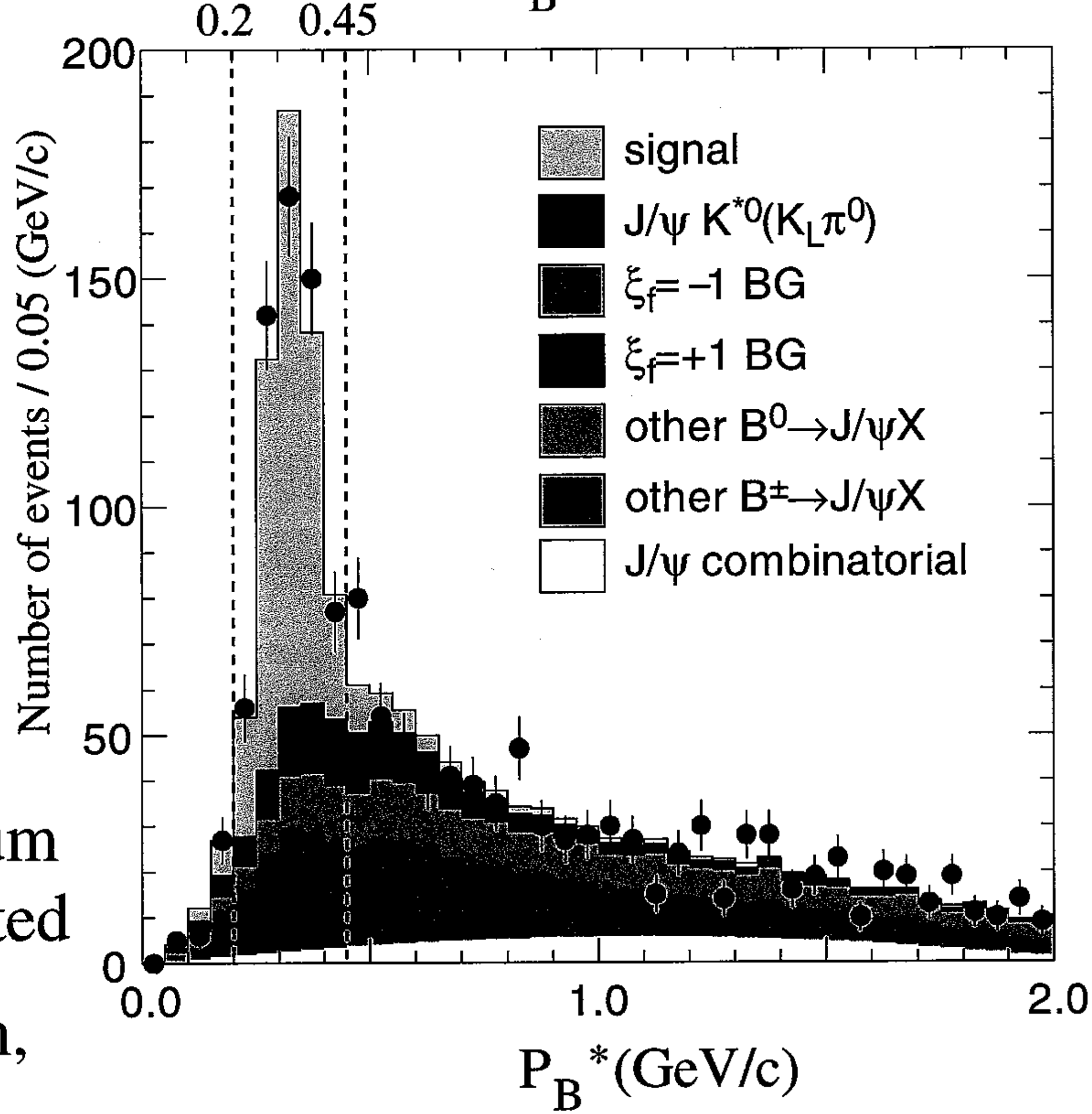
Only the direction of K_L is measurable.

We determine the K_L direction by finding a cluster in ECL and KLM.

From the K_L direction, J/ψ 4–momentum and 2–body decay assumption, p_B^*, magnitude of B momentum in $\Upsilon(4s)$ restframe, is calculated

By fitting the p_B^* distribution, $J/\psi K_L$ yield is obtained.

p_B^* ~340MeV/c



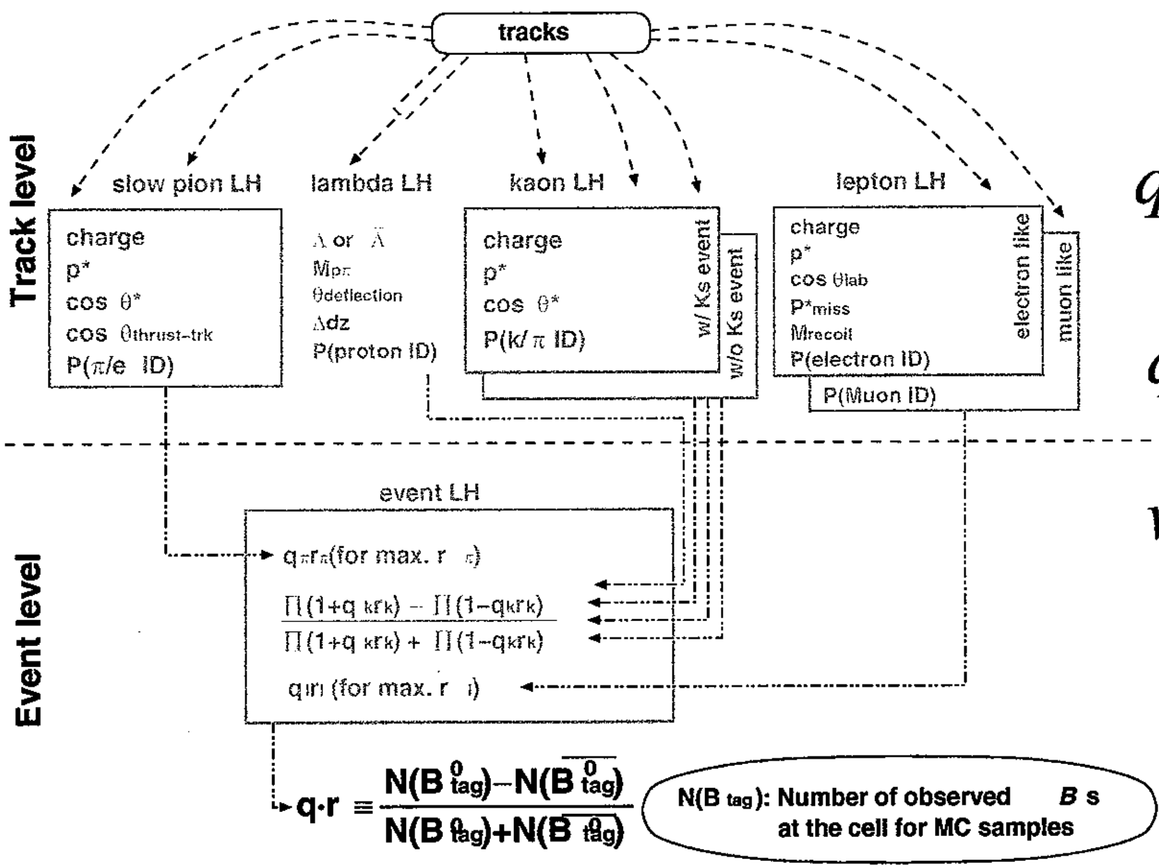
Flavor tagging

$b \to X l \nu$ (a high momentum lepton)

$b \to c \to s$ (Kaon tag)

$b \to D^*(\to D^0 \pi_s)$ (slow pion)

Multi dimensional Likelihood



$$q \cdot r = \frac{N(B^0) - N(\bar{B}^0)}{N(B^0) + N(\bar{B}^0)}$$

q : flavor tagged (1 or −1)

r : dilution factor (=1−2w)

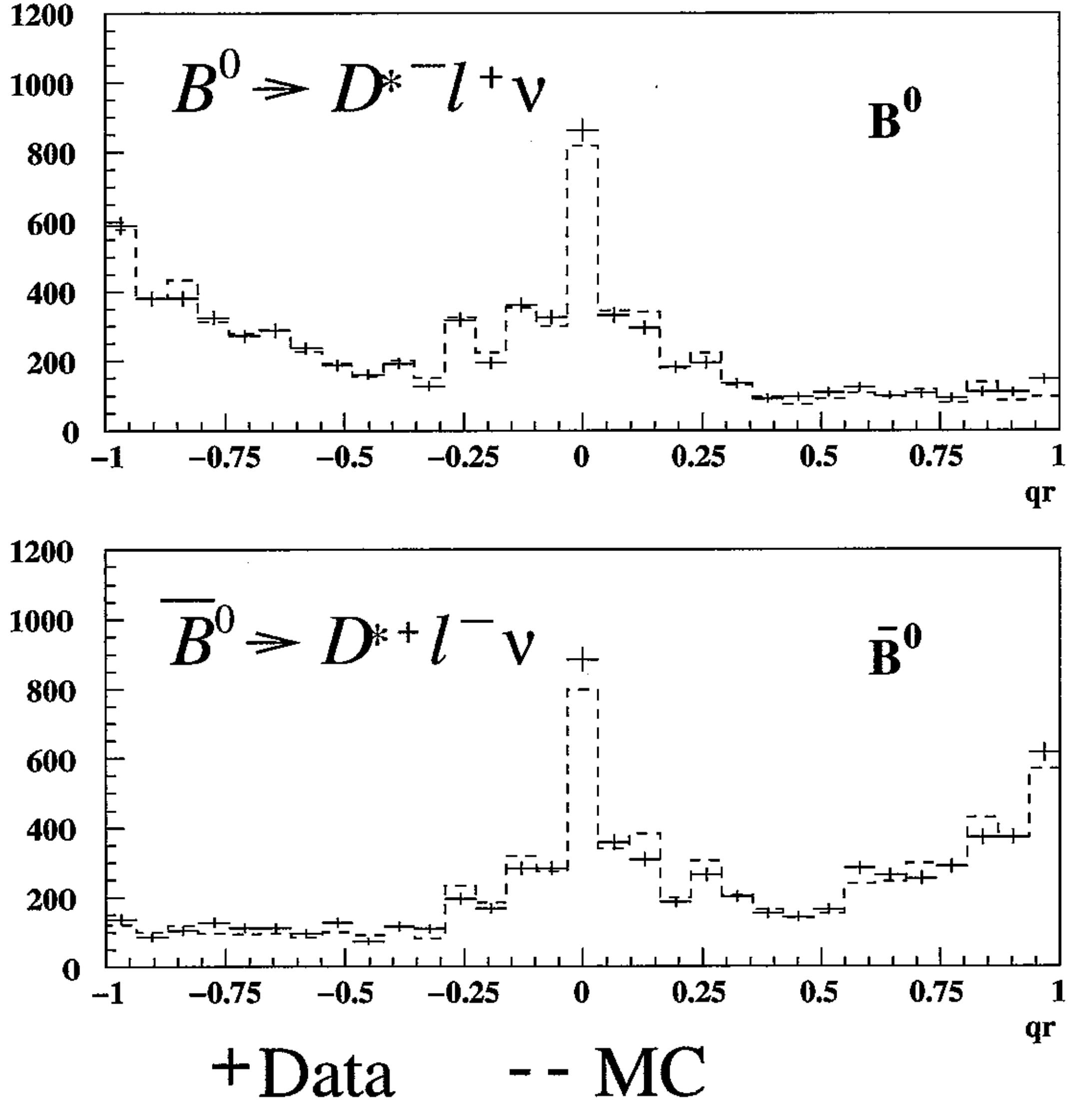
w : wrong tagging fraction

$$\sin 2\phi_1 \to (1-2w)\sin 2\phi_1$$

dilution of asymmetry

Peformance of the Flavor tagging

$B \to D^* l \nu$ events



evaluate the flavor tagging by reconstructing flavor specific decays on one side, and tagging the b–flavor for the other side

Flavor specific decays

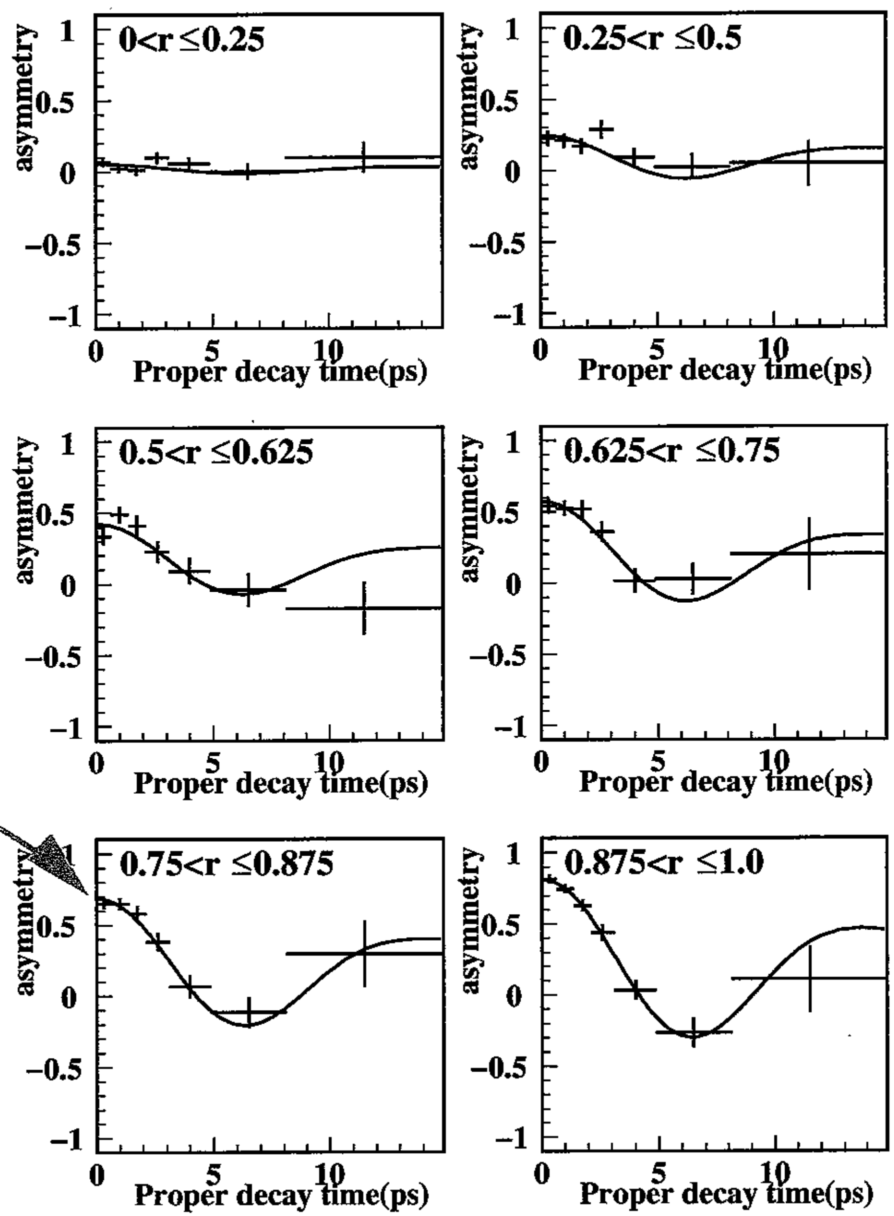
$B \to D^* l \nu$

$\to D^{(*)} \pi$

$\to D^* \rho$

Wrong tag fraction

$B^0 \to D^* l \nu$



Time evolution of B mesons with Same flavor (SF) and Opposite flavor (OF)

$$P_{OF}(\Delta t) \sim 1 + (1-2w)\cos(\Delta m_d \Delta t)$$

$$P_{SF}(\Delta t) \sim 1 - (1-2w)\cos(\Delta m_d \Delta t)$$

$$\frac{N_{OF} - N_{SF}}{N_{OF} + N_{SF}} = (1-2w)\cos(\Delta m_d \Delta t)$$

Combine semileptonic and hadronic decays ($D\pi$ $D\rho$)

Tagging efficiency $\varepsilon = 99.7\%$

Effecitve tagging efficiency $\varepsilon(1-2w)^2 = 27.0 \pm 1.2\%$

CP fitting 1

Unbinned maximum likelihood method

$$L = \prod_i L_i \qquad i \text{ for each event}$$

$$L_i = \int \{ f_{sig} P_{sig}(\Delta t', q, w, \xi_f) + (1 - f_{sig}) P_{bg}(\Delta t') \} R(\Delta t_i - \Delta t')\, d\Delta t'$$

$$P_{sig}(\Delta t, q, w, \xi_f) = \frac{exp(-|\Delta t| / \tau_{B^0})}{2\tau_{B0}} \{ 1 - \xi_f q (1 - 2w) sin2\phi_1 sin(\Delta m \Delta t) \}$$

$$P_{bg}(\Delta t) = f_t\, exp(-|\Delta t| / \tau_{bg}) / 2\tau_{bg} + (1 - f_t)\, \delta(\Delta t)$$

f_{sig} the probability that the event is signal
f_t fraction of the background component with effecitive lifetime τ_{bg}
$\delta(\Delta t)$ the Dirac delta function

For $J/\psi K_L$ events, $P_{bg}(\Delta t)$ need special treatment.

Because some BG states have CP eigenstates.
e.x. $J/\psi\ K^*(K_L \pi^0)$ is taken to be a 81/19 mixture of $\xi_f = -1$ and $+1$, respectively.

CP fitting 2

Resolution function $R(\Delta t)$

calculated event by event
from track error matrices

sum of two Gaussian component

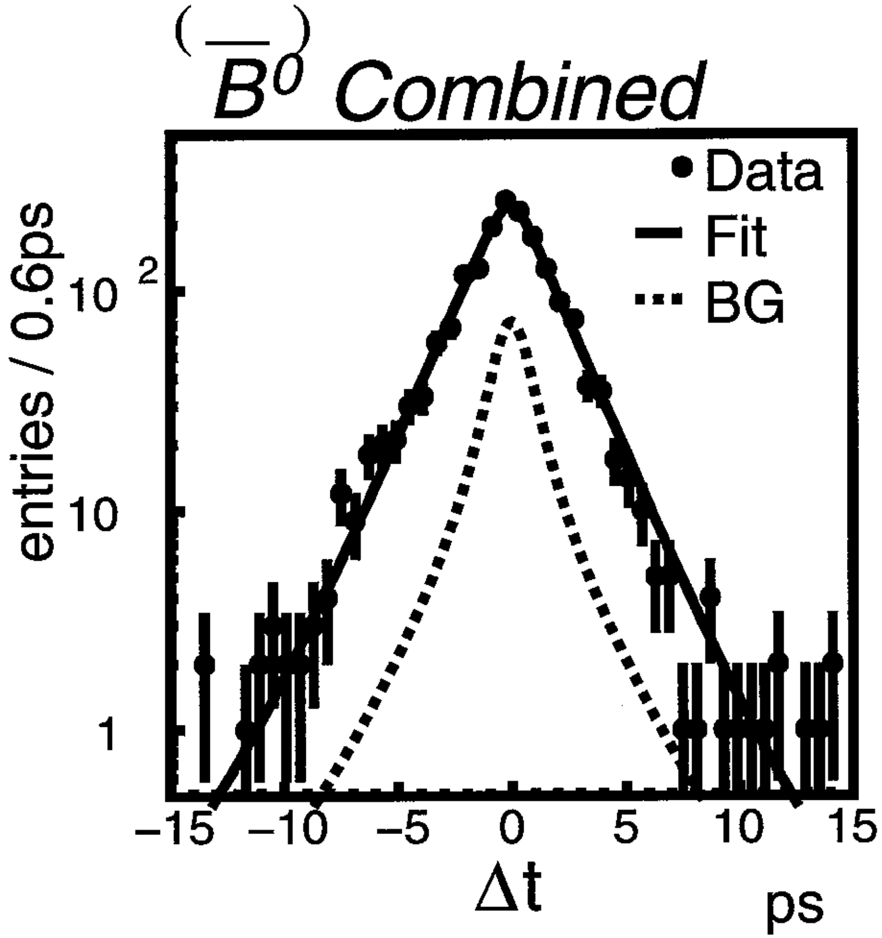
main : ○ SVD vertex resolution
○ charmed meson lifetime
○ motion of B mesons
in the CM system

tail : poorly reconstructed track

μ_{main} = −0.24 ps
μ_{tail} = 0.18 ps
σ_{main} = 1.49 ps
σ_{tail} = 3.85 ps

relative fraction of the main Gaussian: 0.97

The reliability is confirmed by the B meson life time measurment.



$\tau_{B^0} = 1.54 \pm 0.03 \pm 0.07$ ps

$\tau_{B^+} = 1.67 \pm 0.04 \pm^{0.11}_{0.10}$ ps

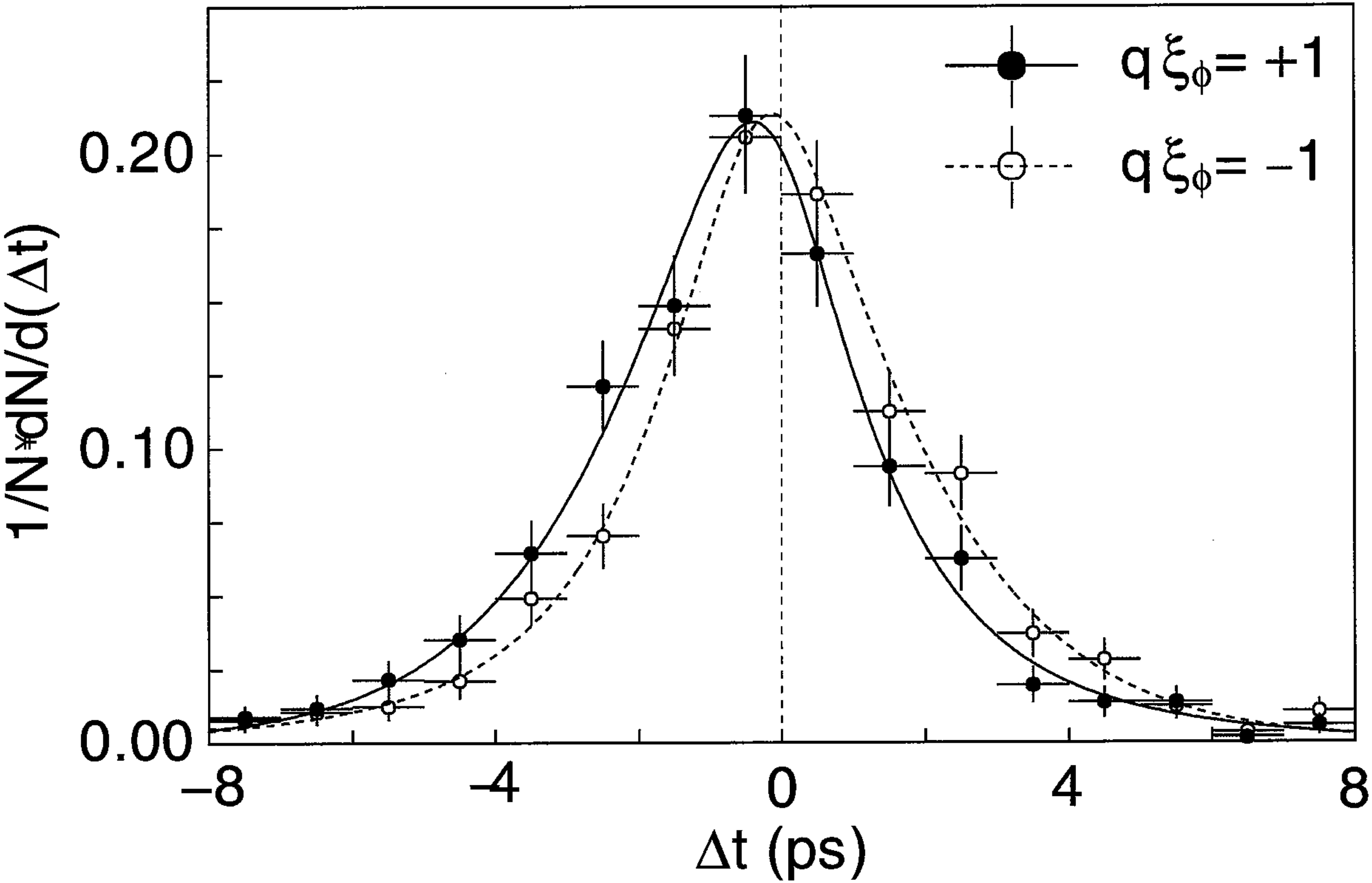
PDG value

τ_{B0} = 1.548± 0.032 ps

τ_{B+} = 1.653± 0.028 ps

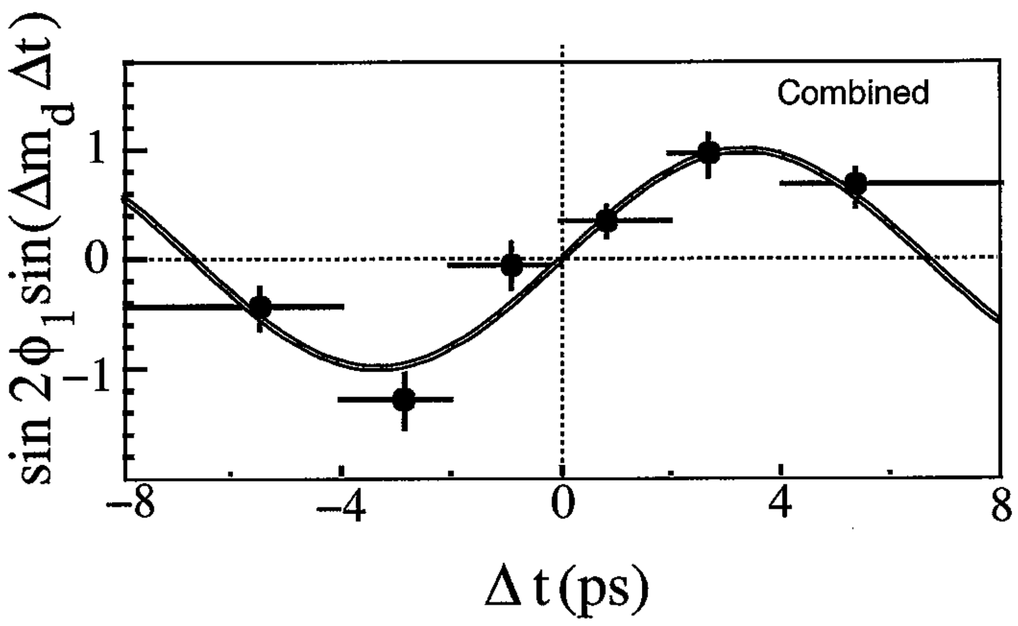
CP fit result 1

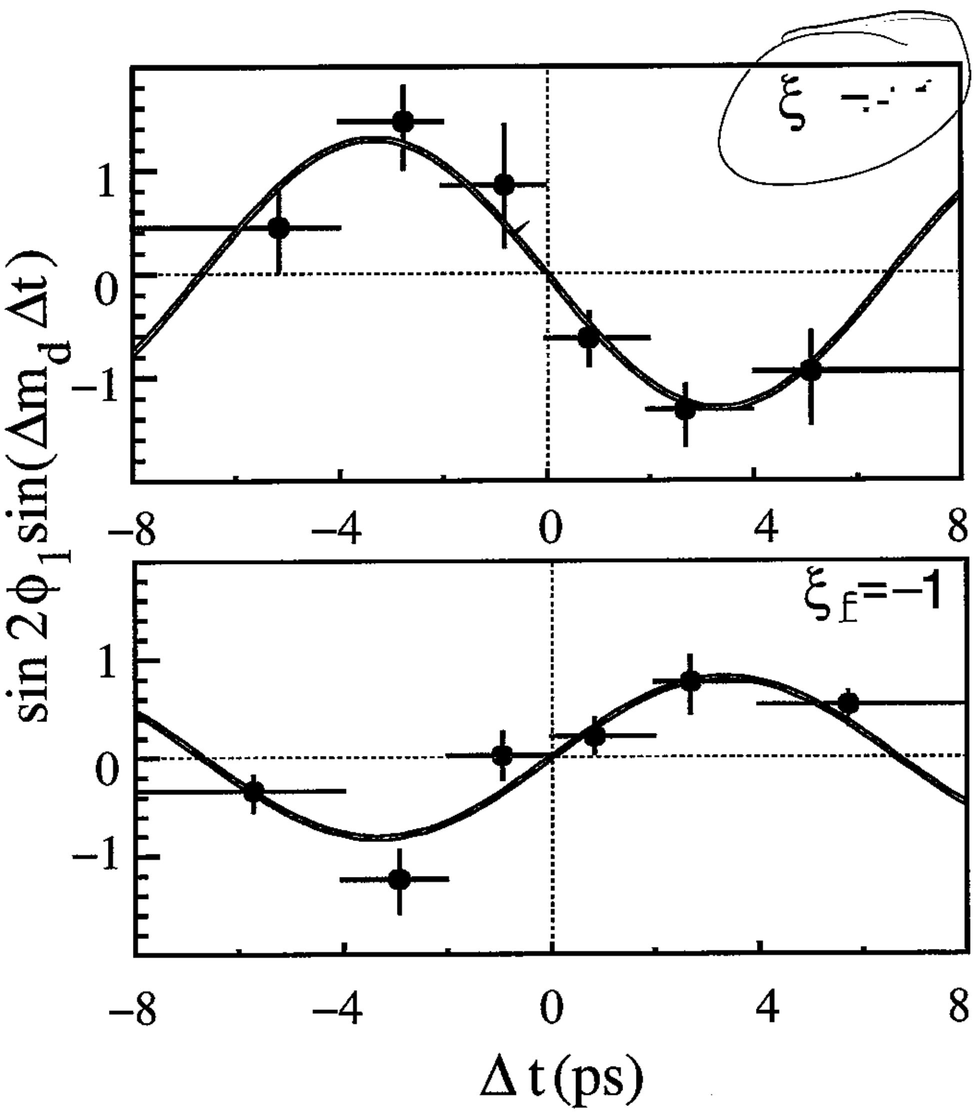
$\sin 2\phi_1 = 0.99 \pm 0.14(\text{stat.}) \pm 0.06(\text{syst.})$



CP fit results 2

apply the CP fit to events in Δt separately





CP fit results 3

	# of events	$\sin 2\phi_1$
All events	1137	0.99 ± 0.14
CP = − 1	578	0.84 ± 0.17
CP = + 1	559	1.31 ± 0.23
$J/\psi K_S(\pi^+\pi^-)$	387	0.81 ± 0.20
$(c\bar{c})K_S$ except $J/\psi K_S(\pi^+\pi^-)$	191	1.00 ± 0.40
$J/\psi K_L$	523	1.31 ± 0.23
$J/\psi K^{*0}(K_S\pi^0)$	36	0.85 ± 1.45
$q = +1$	560	$1.11 \pm^{0.15}_{0.17}$
$q = -1$	577	$0.84 \pm^{0.21}_{0.22}$

systematic uncertainties on $\sin 2\phi_1$	
vertex resolution	± 0.040
wrong tag fraction	$\pm^{0.024}_{0.034}$
resolution function	$\pm^{0.023}_{0.020}$
physics parameters ($\tau_B, \Delta m$)	$\pm^{0.007}_{0.004}$
BG fraction except K_L	$\pm^{0.003}_{0.004}$
BG fraction for K_L	± 0.020
BG shape	± 0.001
Total	± 0.060

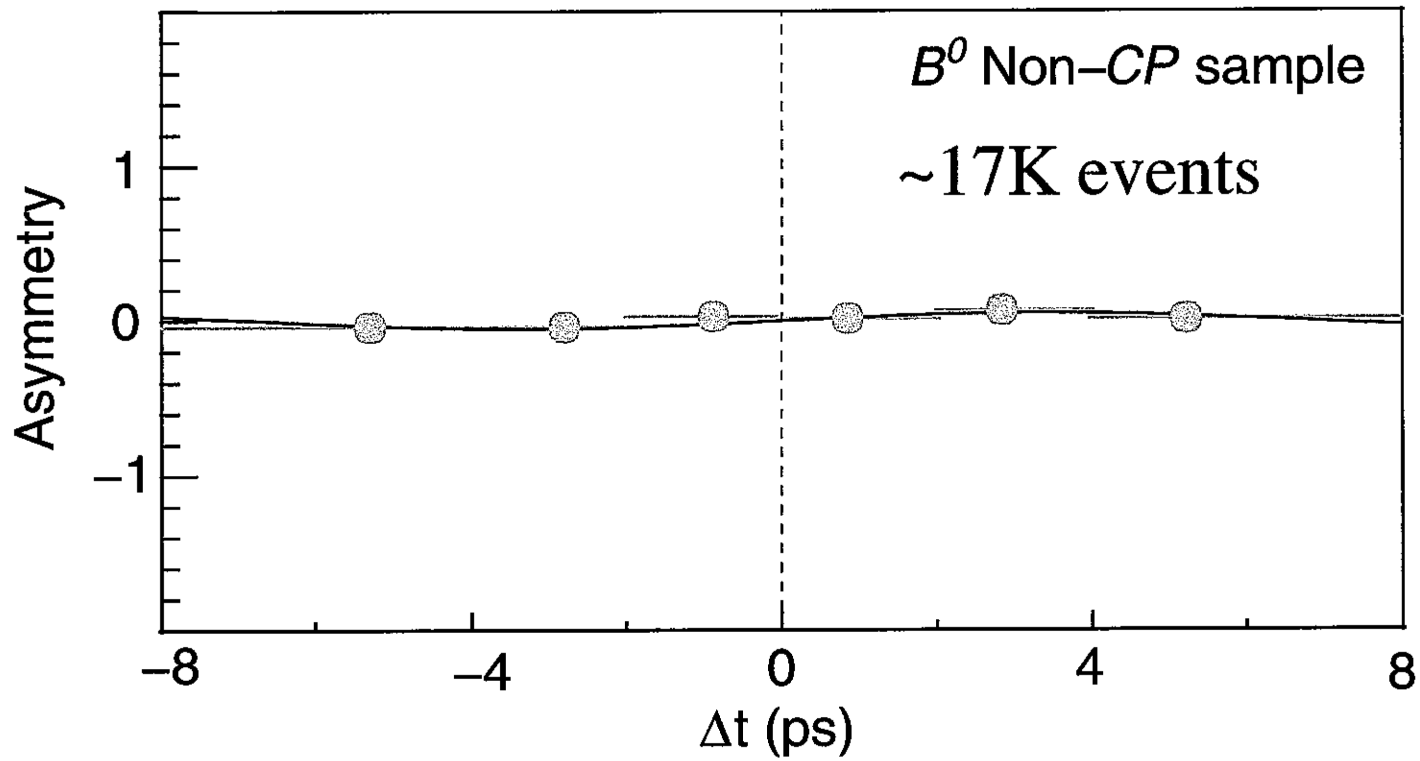
CP fit results 4

Null asymmetry sample

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

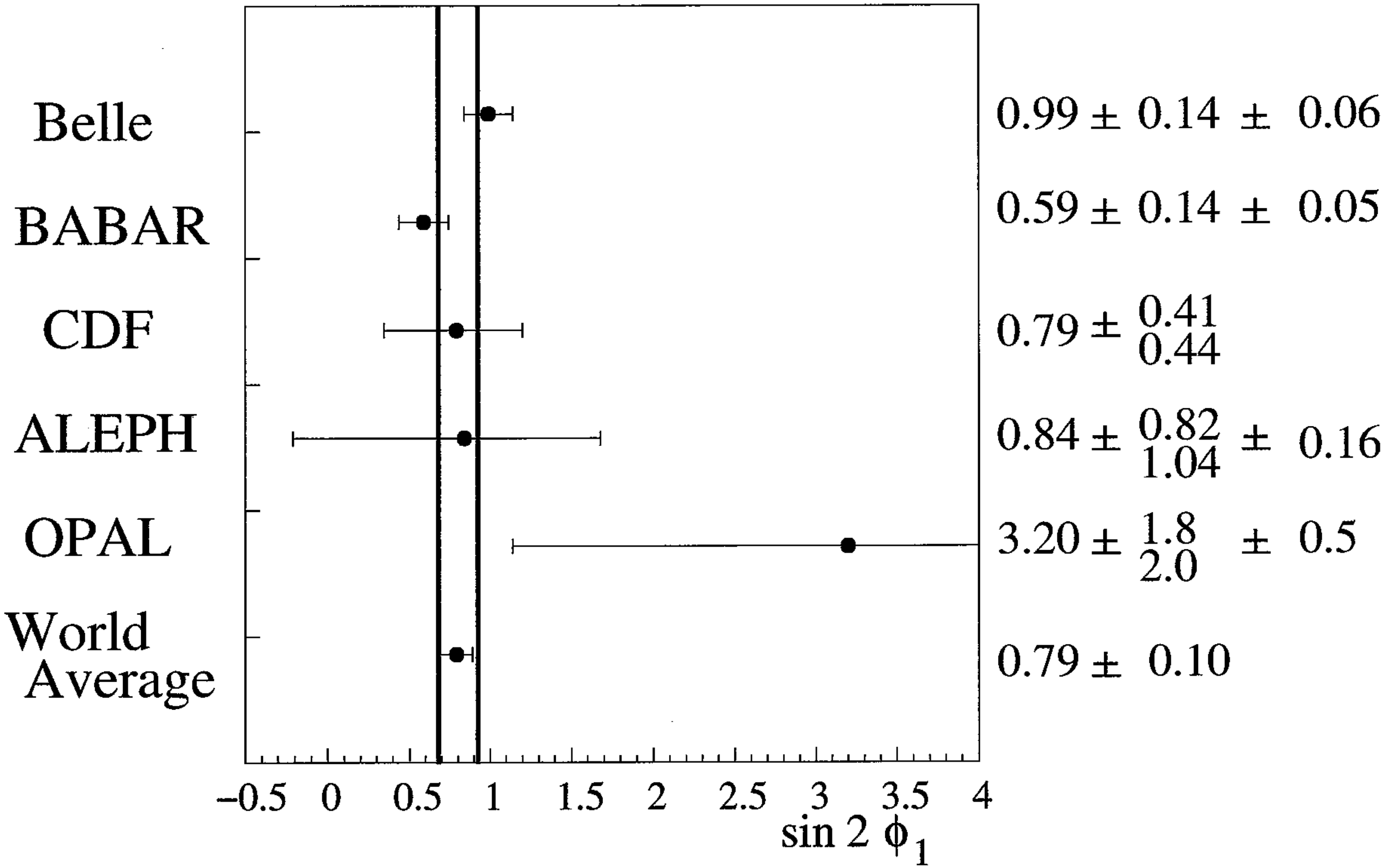
$$\sin 2\phi_1 = 0.05 \pm 0.04$$

No fitting bias

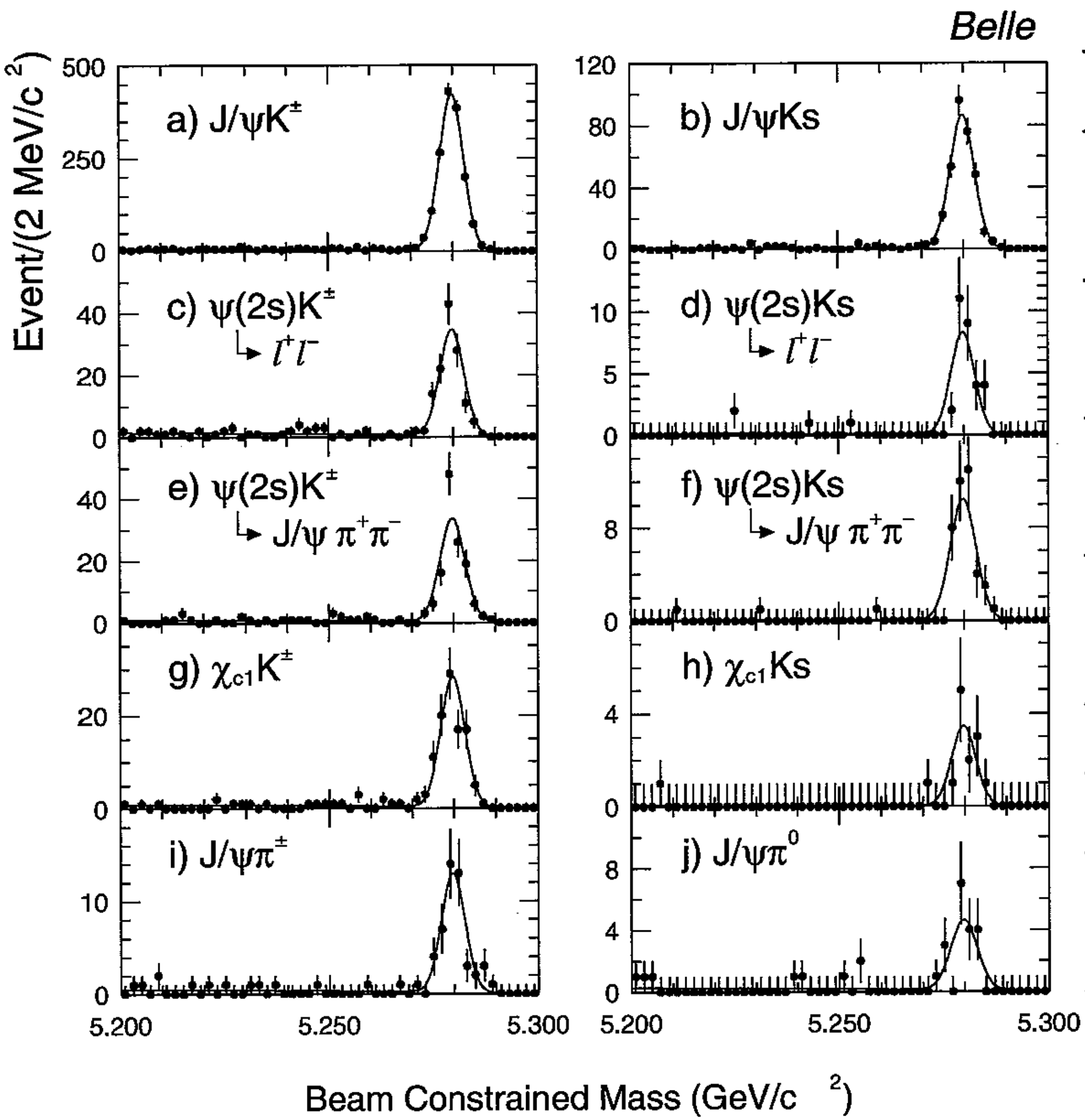


Summary for $\sin 2\phi_1$ measurement

Comparison of $\sin 2\phi_1$ measurements



Two body decays including Charmonium



Decay mode	BF (10^{-4})
$B^- \to J/\psi\ K^-$	$10.1 \pm 0.3 \pm 0.8$
$B^0 \to J/\psi\ K^0$	$7.7 \pm 0.4 \pm 0.7$
$B^- \to \psi(2S) K^-$ $\psi(2S) \to l^+ l^-$	$6.7 \pm 0.6 \pm 0.7$
$B^- \to \psi(2S) K^-$ $\psi(2S) \to J/\psi \pi\pi$	$5.7 \pm 0.5 \pm 0.8$
$B^0 \to \psi(2S) K^0$ $\psi(2S) \to l^+ l^-$	$6.0 \pm 1.1 \pm 0.7$
$B^0 \to \psi(2S) K^0$ $\psi(2S) \to J/\psi \pi\pi$	$7.2 \pm 1.1 \pm 1.1$
$B^- \to \chi_{c1}\ K^-$	$6.1 \pm 0.6 \pm 0.6$
$B^0 \to \chi_{c1}\ K^0$	$3.1 \pm 0.9 \pm 0.4$
$B^- \to J/\psi\ \pi^-$	0.52 ± 0.07 ± 0.07
$B^0 \to J/\psi\ \pi^0$	0.24 ± 0.06 ± 0.02

$B \to \phi K$

$B^0 \to \phi K_S^0$ was observed.

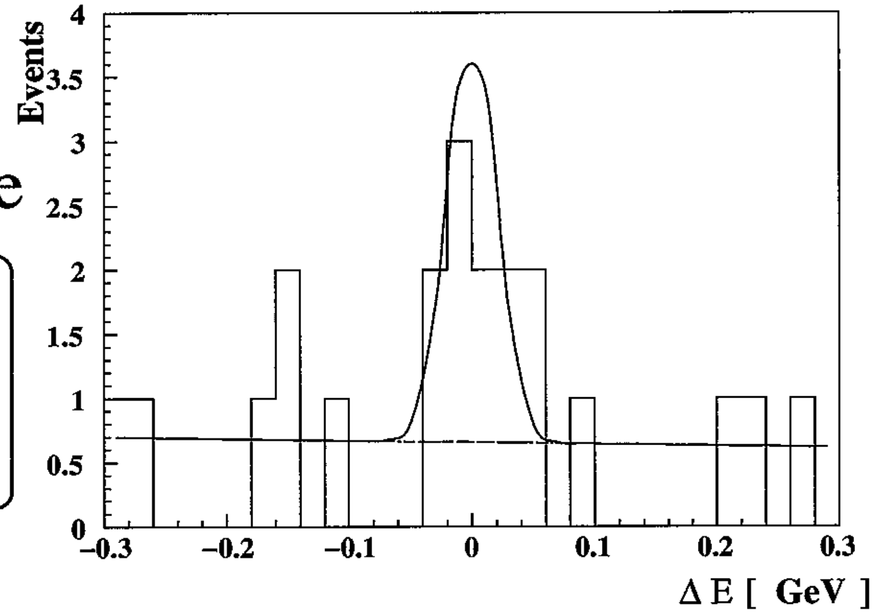
$8.0^{+3.5}_{-2.8}$ events 4.2σ significance

$$\mathcal{B}(B^0 \to \phi K_S^0) = (0.89^{+0.34}_{-0.27} \pm 0.10) \times 10^{-5}$$

$\sin 2\phi_1$ next summer

Sensitive to new physics in Penguin loop.

$B^0 \to \phi K_S^0$



$$\mathcal{B}(B^+ \to \phi K^+) = (1.12^{+0.22}_{-0.20} \pm 0.14) \times 10^{-5}$$

$$\mathcal{B}(B^0 \to \phi K^{(*)0}) = (1.30^{+0.64}_{-0.52} \pm 0.21) \times 10^{-5}$$

$B \rightarrow D^{(*)}D^{(*)}$ decays

Cabibbo suppressed decay

$A(t) \sim sin(2f_1 + d)$

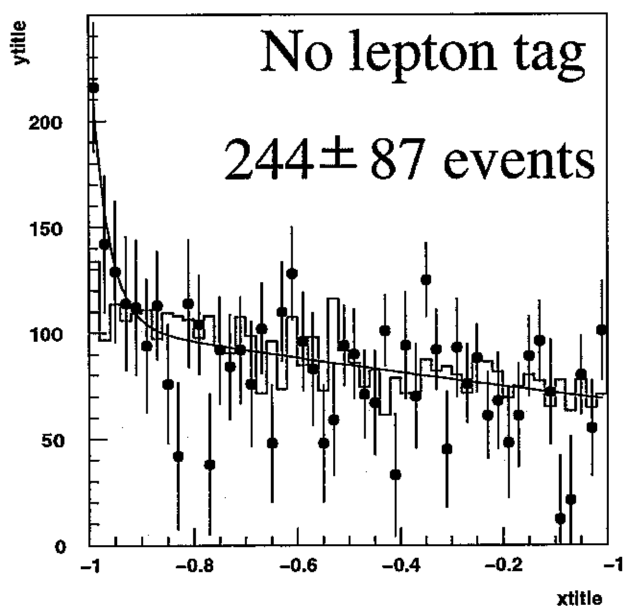
Partial reconstruction

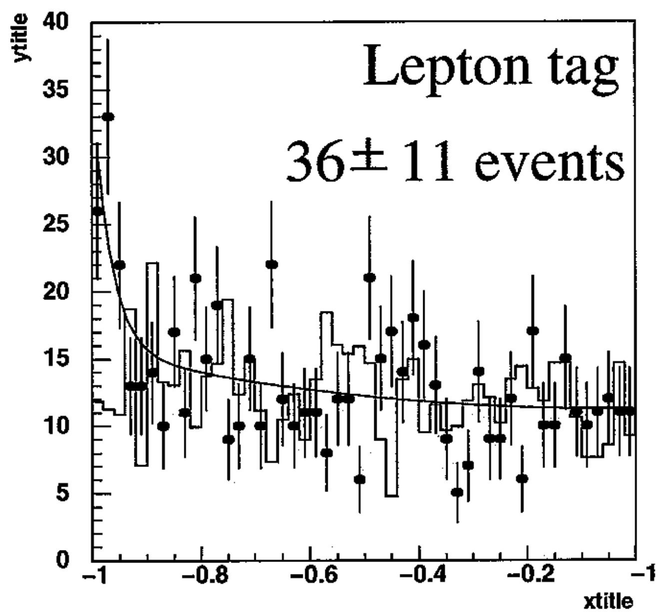
$$D^{*-} \rightarrow D^0 \underline{\pi^-}$$

Signatures

Angle α between D^+ and π^- peaks at 180 degrees.

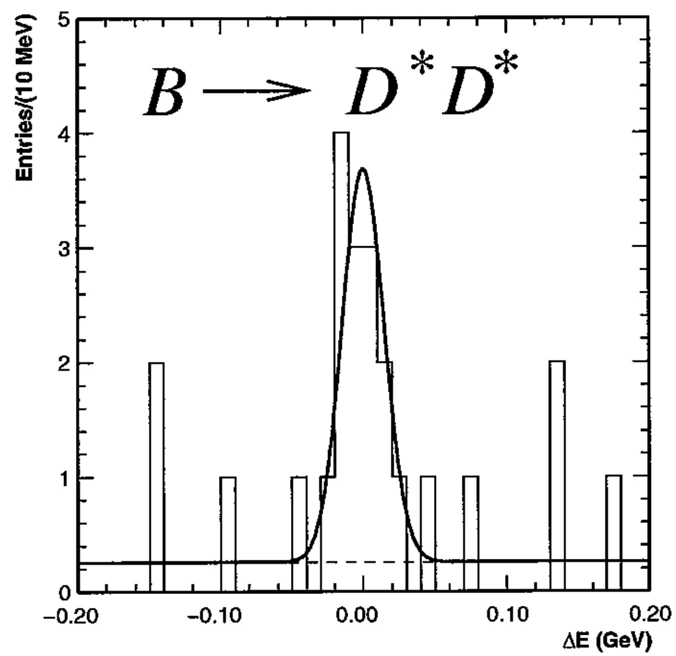
$$\mathcal{B}(B^0 \rightarrow D^+ D^{*-}) = (1.84 \pm 0.46^{+0.68}_{-0.60}) \times 10^{-3}$$





$B \rightarrow D^{(*)} D^{(*)}$

with Full Reconstruction

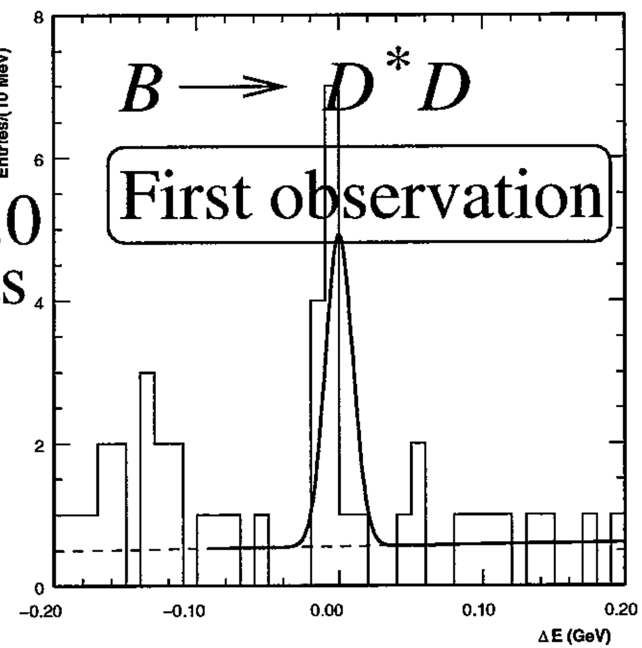


$\mathcal{B}(B^0 \rightarrow D^{*+} D^{*-})$

$= (1.21 \pm 0.41 \pm 0.26) \times 10^{-3}$

$\mathcal{B}(B^0 \rightarrow D^{\pm} D^{*\mp})$

$= (1.04 \pm 0.38 \pm 0.22) \times 10^{-3}$



$B^0 \rightarrow D^0 D^{*-} K^+$

11.0 ±4.0 events

may reduce "charm counting problem"

G.Buchalla et.al Pys. Lett. B364, 188 (1995)

$\mathcal{B}(B^0 \rightarrow D^0 D^{*-} K^+)$

$= (3.2 \pm 0.8 \pm 0.7) \times 10^{-3}$

$B \to J/\psi K_1(1270)$ Decay

$K_1^0(1270) \to K^0 \rho^0$ decay dominant

$\longrightarrow$ useful for CP violation study

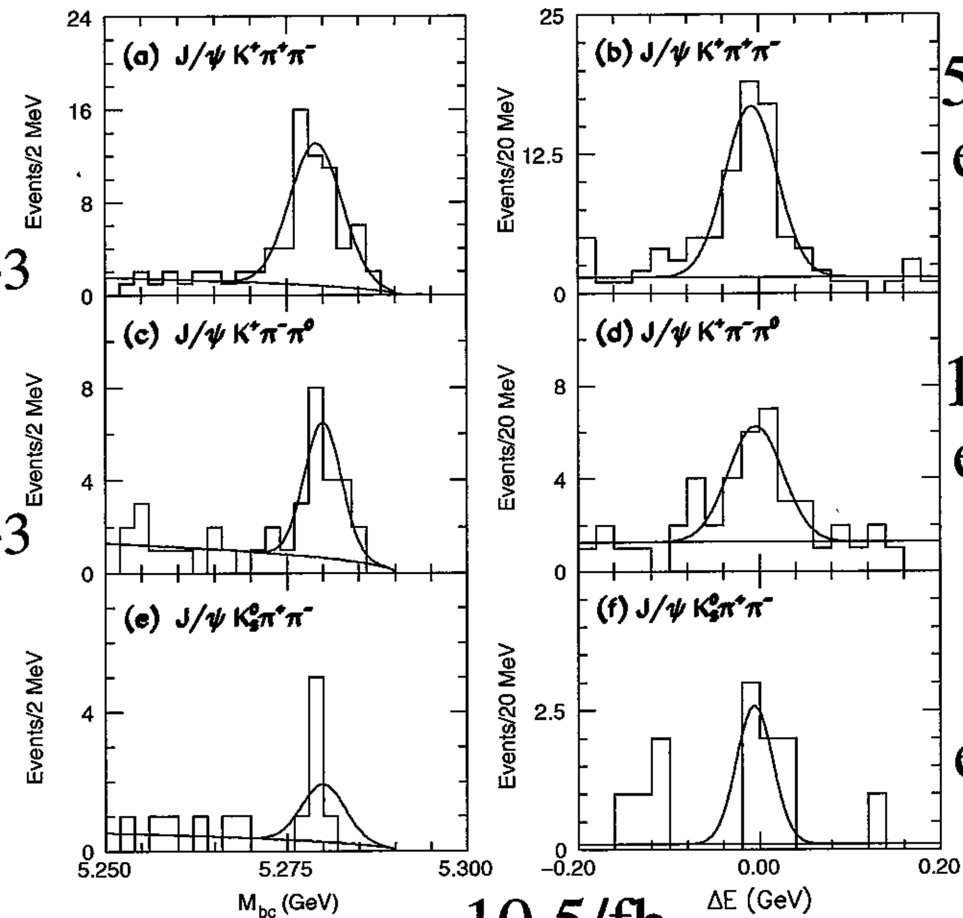
$\mathcal{B}(B^+ \to J/\psi K_1^+(1270))$

$= (1.80 \pm 0.34 \pm 0.39) \times 10^{-3}$

$\mathcal{B}(B^0 \to J/\psi K_1^0(1270))$

$= (1.30 \pm 0.34 \pm 0.31) \times 10^{-3}$

First observation



53 ± 9 events

19 ± 5 events

6 ± 3 events

10.5/fb

B meson rare decays 1

The observations of B rare dacays provide us an opportunity to study CKM matrix elements $|V_{cb}|$ $|V_{ub}|$ $|V_{td}|$ and $|V_{ts}|$ and their phases.

Decays with loop diagrams have sensitivity to new physics.

Cabibbo suppressed decays

$B \to D^{(*)} K^{(*)}$

Charmless hadronic decays

$B \to \pi\pi, K\pi, KK$

$B \to \eta' h \, (h = K, \pi)$

$B \to \rho h, \omega h$

$B \to \phi K^{(*)}$

$B \to K\pi\pi, KK\pi, KKK$

EW penguin decays

$B \to K^{(*)} ll$

$B \to K^{(*)} \gamma$

$B \to X_s \gamma, X_s ll$

$B \to \rho\gamma$

Rare dacays for V_{ub}

$B \to \pi l \nu, \rho l \nu$

$B \to D_s \pi$

Decay rate asymmetry with $K\pi$, $K^{(*)}\gamma$

B meson rare decays 2

B meson reconstruction

B mesons are reconstructed using two variables; M_{bc} and ΔE.

$$M_{bc} = \sqrt{(E^*_{beam})^2 - (|\sum_i \vec{p}_i|)^2}$$

$E^*_{beam} \sim 5.29$ GeV

$|\sum_i \vec{p}_i| \sim$ small

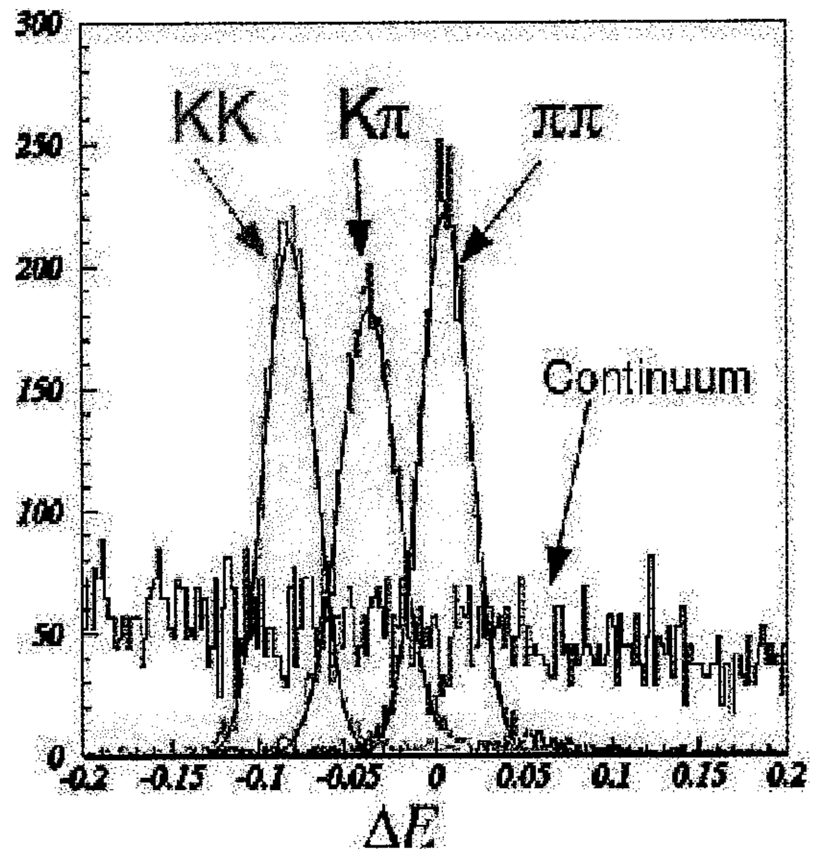
$\sigma \sim 3$ MeV

$$\Delta E = \sum_i E_i^{measured} - E^*_{beam}$$

$E_i^{measured}$: calculated with pion mass assumption

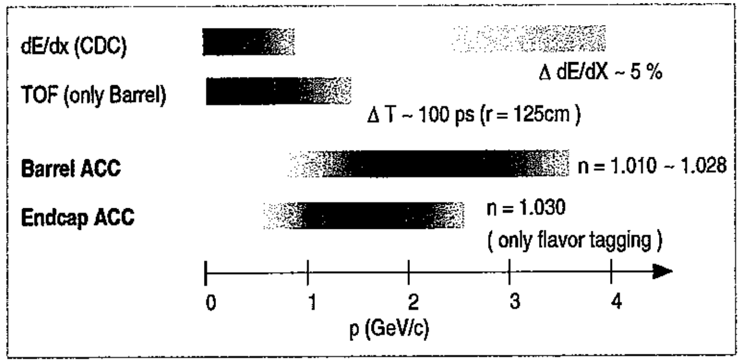
~ 44 MeV shift for K

$\sigma \sim 16 \sim 40$ MeV depending on # of tracks # of π^0 # of γ



B meson rare decays 3

Particle Identification



A clear separation of charged K and π is essential to find rare decay signals.

$B \to DK / D\pi$

$B \to K\pi / \pi\pi / KK$

Belle use dE/dx + TOF + ACC

dE/dx : from CDC

TOF : Time of Flight

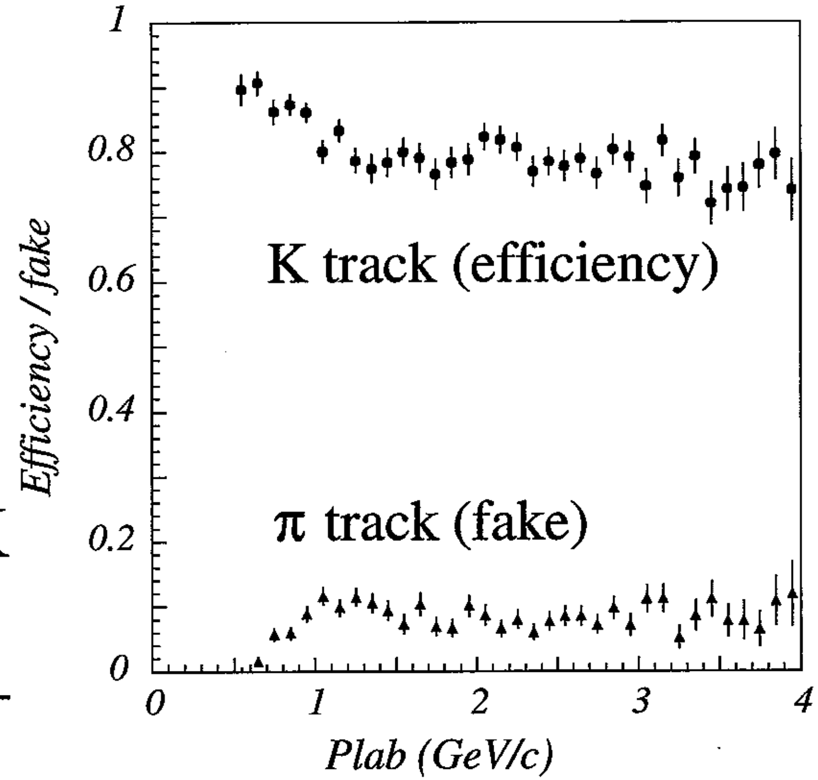
ACC : Aerogel Cherenkov Counter

covering wide momentum range combined into likelihood

$$\mathrm{PID(K)} = \frac{L(K)}{L(K) + L(\pi)}$$ ~1 for K, ~0 for π

Calibration $D^{*+} \to D^0 \pi^+$, $D^0 \to K^- \pi^+$

PID(K) > 0.6



B meson rare decays 4

continuum background suppression 1

Event shape
- B signal → spherial
- qq events → jet–like

Using shape variable "Super Fox Wolfram"

$$R_l^{SO} = \sum_{i,s} |p_i||p_s| P_l(\cos\theta_{is}) / \sum_{i,s} |p_i||p_s|$$

signal – other

$$R_l^{OO} = \sum_{i,j} |p_i||p_j| P_l(\cos\theta_{ij}) / \sum_{i,j} |p_i||p_j|$$

other–other

s : B cand. track, i,j : non–B

$$F_{SFW} = \sum_{l=1,4} (\alpha_l R_l^{SO} + \beta_l R_l^{OO})$$

Fisher discriminants

$\cos\theta_B$: polar angle of flight B mesons

- B signal → $1 - \cos^2\theta_B$
- qq events → flat

$\cos\theta_{hh}$: thrust angle

- B signal → flat
- qq events → $1 + \cos^2\theta_{hh}$

B meson rare decays 5

continuum background suppression 2

Likelihood ratio (LR)

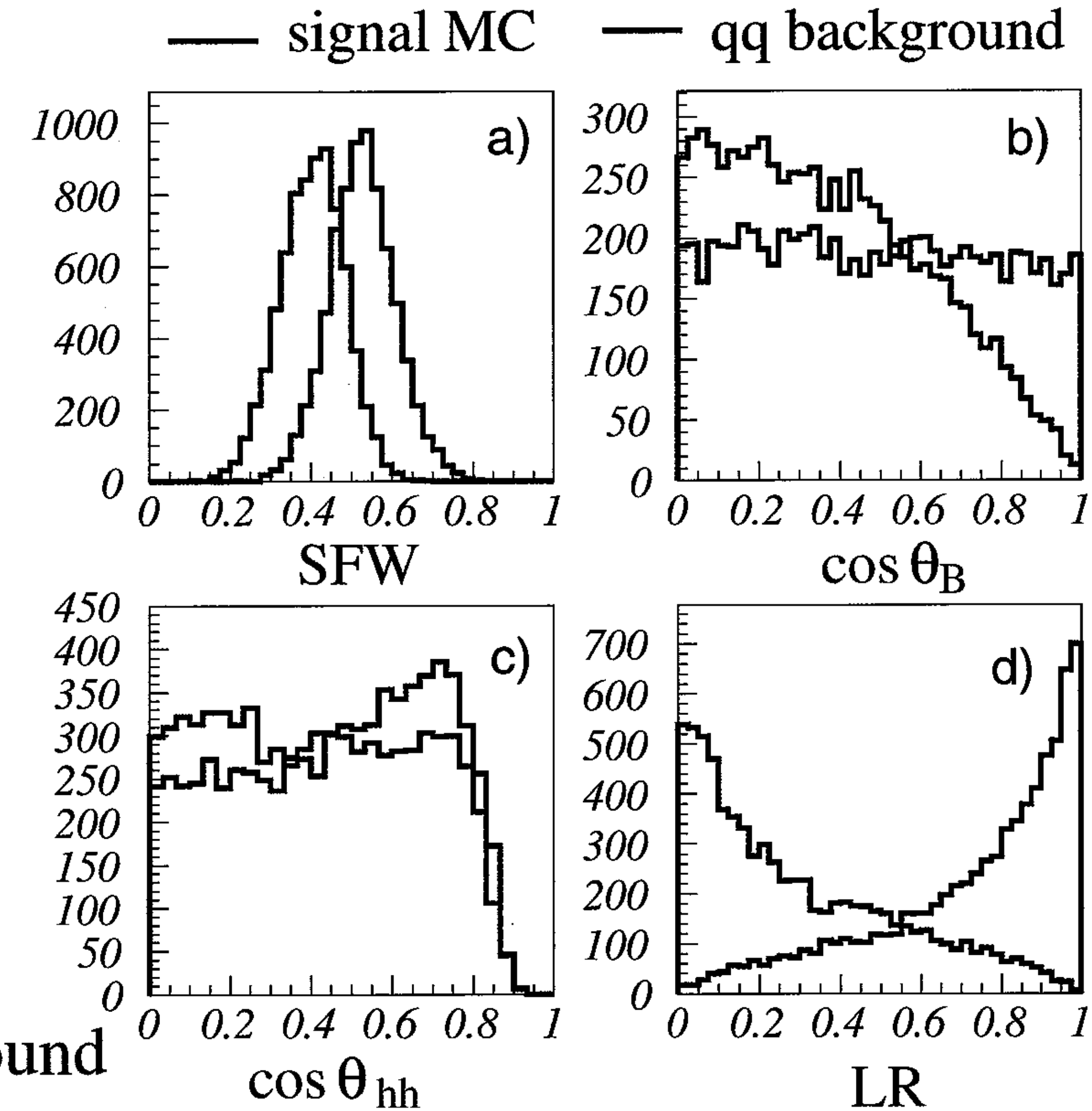
$$L(B\overline{B}) = L^{SFW}_{B\overline{B}} \times L^{\cos\theta_B}_{B\overline{B}} \times L^{\cos\theta_{hh}}_{B\overline{B}}$$

$$LR = \frac{L(B\overline{B})}{L(B\overline{B}) + L(q\overline{q})}$$

Systematic check with

$B \to D\pi$ data for signals

Side–band data for background



B meson rare decays 6
systematics

MC efficiency has been cross checked with independent decays.
Total systematic error for Br. varies 10 ~ 20 % depending on decay modes.

Tracking ~2%/track

$N(\eta \to \pi^+ \pi^- \pi^0) / N(\eta \to \gamma\gamma)$

Detection of K_S and π^0 ~5%/track

Inclusive D decays

Inclusive K^* decays

PID ~2%/track

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

$D^0 \to K^- \pi^+$

Continuum suppression cuts ~5%

Consistency check with $B \to D\pi$ signals

# of BB pairs ~1%

f_{+-} / f_{00} ratio of branching fraction of charged to neutral Bs from Υ(4S) decays 6%

Rare decay MC to check feeddown background

Cabibbo Suppressed Decays

Extraction of ϕ_3 using interference between $b \to c$ and $b \to u$ transitions.

$B \to DK$ (Cabibbo suppressed decays)

For example, $B^+ \to \overline{D}^0 K^+$ and $B^+ \to D^0 K^+$

$B \to D\pi$ (Doubly Cabibbo suppressed decays)

For example, $B^+ \to D^+ \pi^0$ ($B^+ \to D^0 \pi^+$ is an allowed decay)

The first step is to establish the Cabibbo suppressed decays.

Expectation:

$$R_c = \frac{\mathcal{B}(B \to D^{(*)} K^-)}{\mathcal{B}(B \to D^{(*)} \pi^-)} \sim tan\theta_c (f_K / f_\pi)^2 \sim 0.074$$

$$R'_c = \frac{\mathcal{B}(B^- \to D^0 K^{*-})}{\mathcal{B}(B^- \to D^0 \pi^-)} \sim 0.19$$

$B \to D^{(*)} h^-$ reconstruction

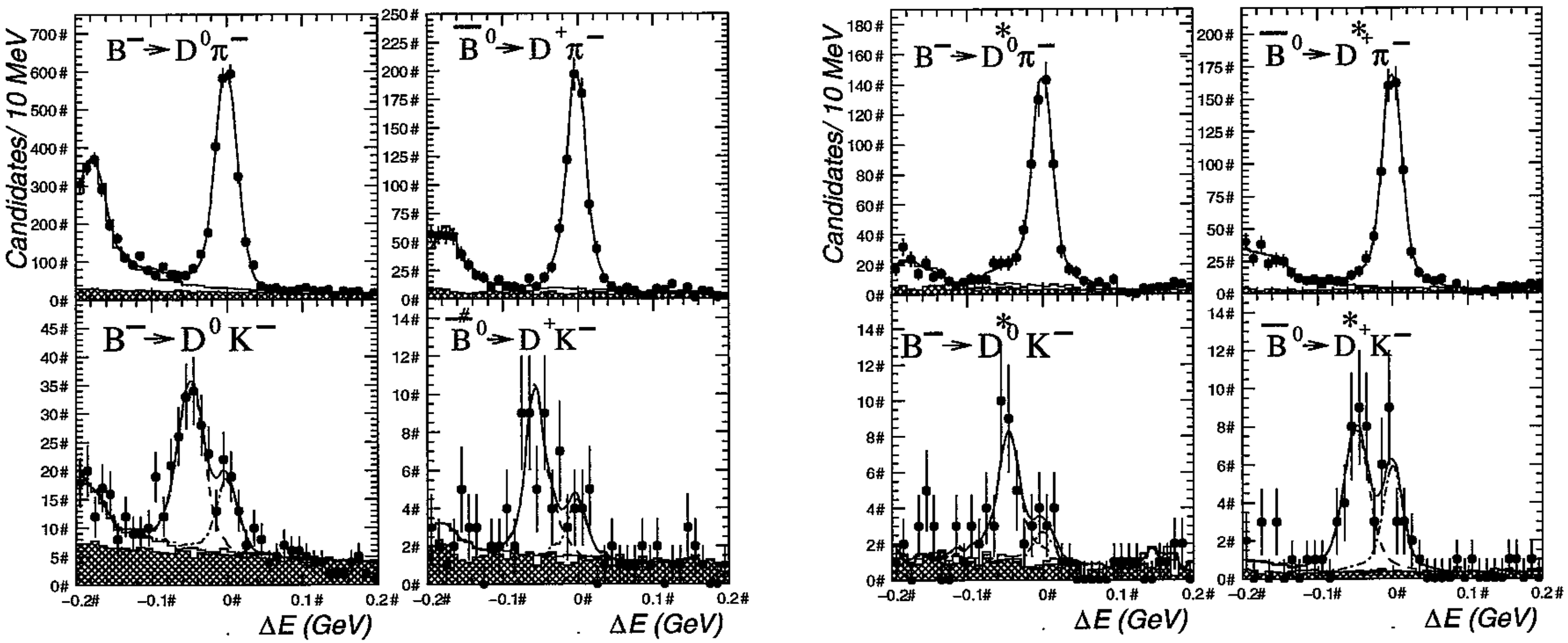
$D^{*+} \to D^0 \pi^+, D^+ \pi^0$, $D^{*0} \to D^0 \pi^0$
$D^+ \to K^- \pi^+ \pi^+$, $K_S \pi^+$, $K_S \pi^+ \pi^+ \pi^-$, $K^- K^+ \pi^-$
$D^0 \to K^- \pi^+$, $K^- \pi^+ \pi^0$, $K^- \pi^+ \pi^+ \pi^-$

ΔE for π ~ 0 MeV ΔE for K ~ 49 MeV

PID(K)

< 0.8

>0.8



K efficiency = 76.5% π fake = 2.0%

$B \rightarrow D^{(*)} h^-$ reconstruction

	PID(K)<0.8	PID(K)>0.8		Br(DK)/Br(Dπ)
	N(Dπ)	N(DK)	N(Dπ)	
$D^0 h^-$	2402.8 ± 97.8	135.7 ± 15.6	49.0 ± 11.3	0.0770 ± 0.0094 ± 0.0058
$D^+ h^-$	681.9 ± 32.1	32.9 ± 7.3	10.1 ± 4.9	0.066 ± 0.015 ± 0.007
$D^{*0} h^-$	584.8 ± 32.4	32.3 ± 7.7	6.5 ± 4.9	0.076 ± 0.019 ± 0.009
$D^{*+} h^-$	640.9 ± 30.8	35.4 ± 7.1	20.6 ± 5.7	0.072 ± 0.015 ± 0.006

first error : statistical
second error : systematic

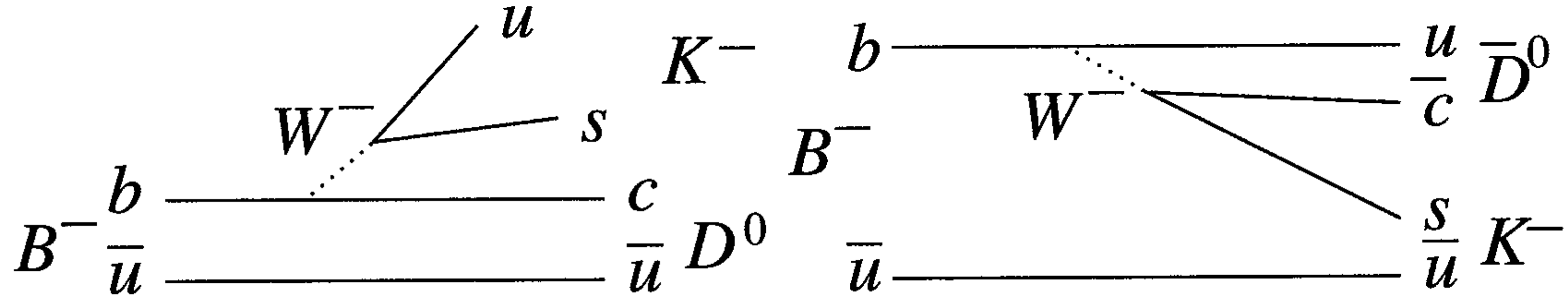
Results agree with the expected ratio

$R_c \sim 0.074$

CLEO with 3.3M BBbar $\mathcal{B}(D^0 K^-) / \mathcal{B}(D^0 \pi^-) = 0.055 \pm 0.015 \pm 0.005$

ϕ_3 from $B^- \to D_{CP} K^-$ decays

$B^- \to D_{CP} K^-$ $D_{CP} \to K^+K^-, \pi^+\pi^-$



$$A_1 \equiv \frac{\mathcal{B}(B^- \to D_1 K^-) - \mathcal{B}(B^+ \to D_1 K^+)}{\mathcal{B}(B^- \to D_1 K^-) + \mathcal{B}(B^+ \to D_1 K^+)} = \frac{2r \sin\delta' \sin\phi_3}{1 + r^2 + 2r\cos\delta' \cos\phi_3}$$

$$R_1 \equiv R^{CP}_{K/\pi} / R^{non-CP}_{K/\pi} = 1 + r^2 + 2r\cos\delta' \cos\phi_3$$

$$R_{K/\pi} \equiv \frac{\mathcal{B}(B^- \to D^0 K^-) + \mathcal{B}(B^+ \to \overline{D}^0 K^+)}{\mathcal{B}(B^- \to D^0 \pi^-) + \mathcal{B}(B^+ \to \overline{D}^0 \pi^+)}$$

$$\delta' = \begin{cases} \delta & (CP = +1) \\ \delta + \pi & (CP = -1) \end{cases}$$

$$r \equiv \frac{A(B^- \to \overline{D}^0 K^-)}{A(B^- \to D^0 K^-)}$$

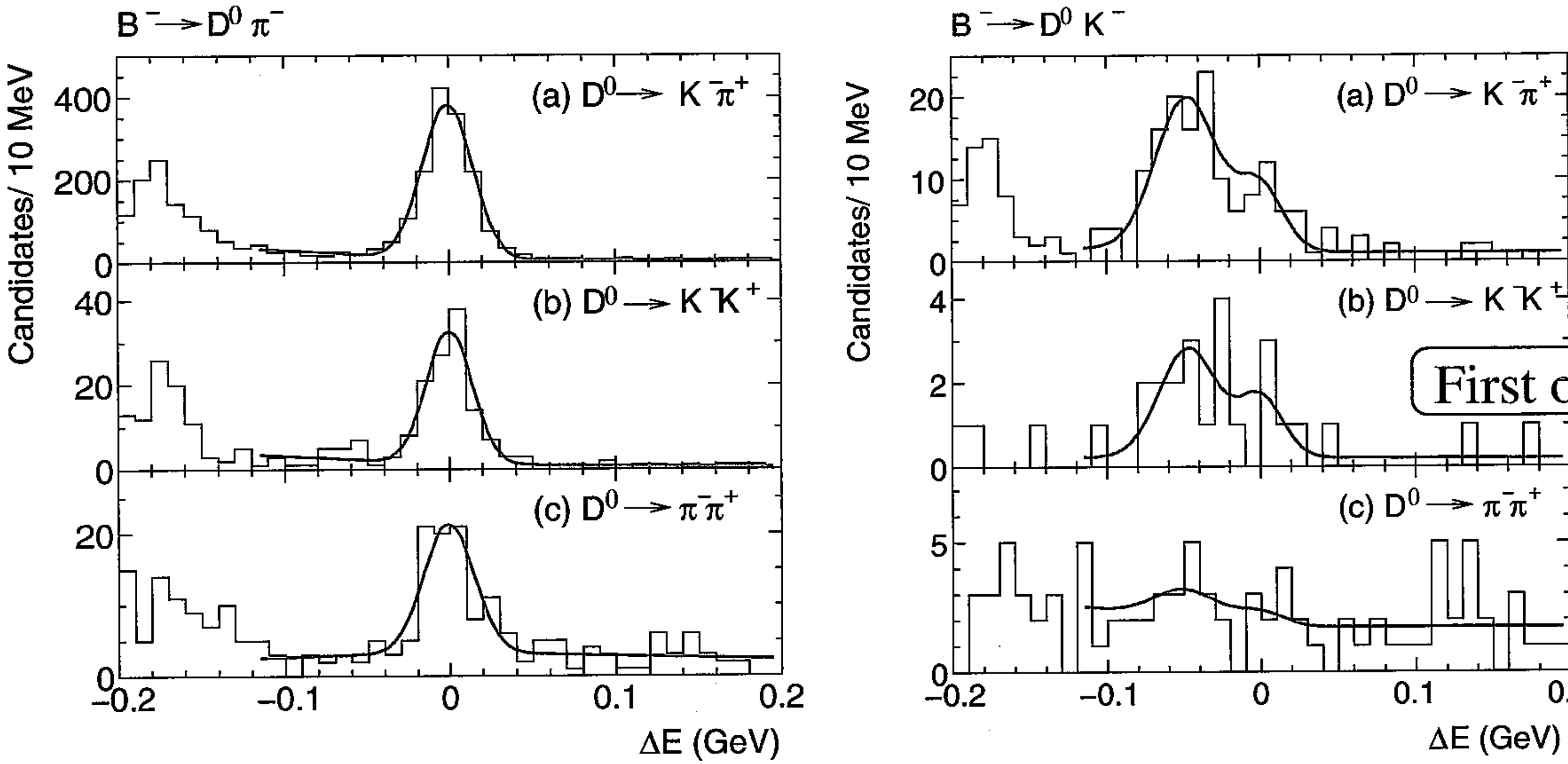
$$R^{non-CP}_{K/\pi} = 0.077 \pm 0.009 \pm 0.006$$

(Belle : PRL)

$B^- \rightarrow D^0 K^-, D^0\pi^-$ measurements

$A_1 = 0.04 \pm {}^{0.40}_{0.35} \pm 0.15$ $\quad -0.78 < A_1 < 0.94$ @90% C.L.

$R_1 = 1.39 \pm 0.53 \pm 0.26$



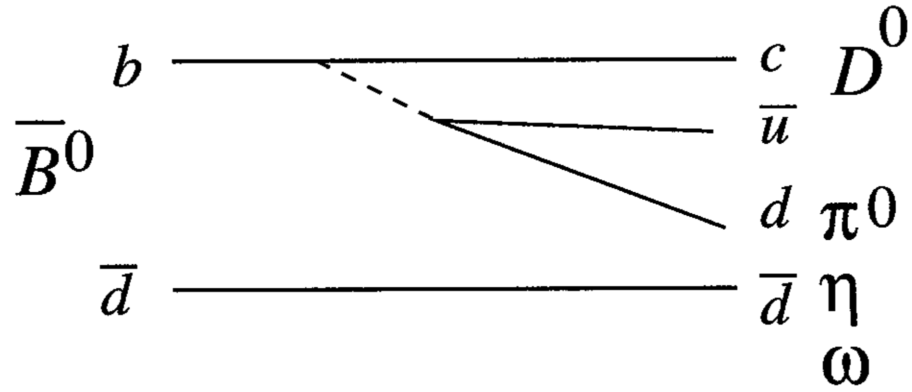
12.3 ± 3.9

First observation

Color–Suppressed B Decays

$\overline{B}^0 \rightarrow D^{(*)} X^0 (\pi^0, \eta, \omega)$

Test of factorization
Final state interaction



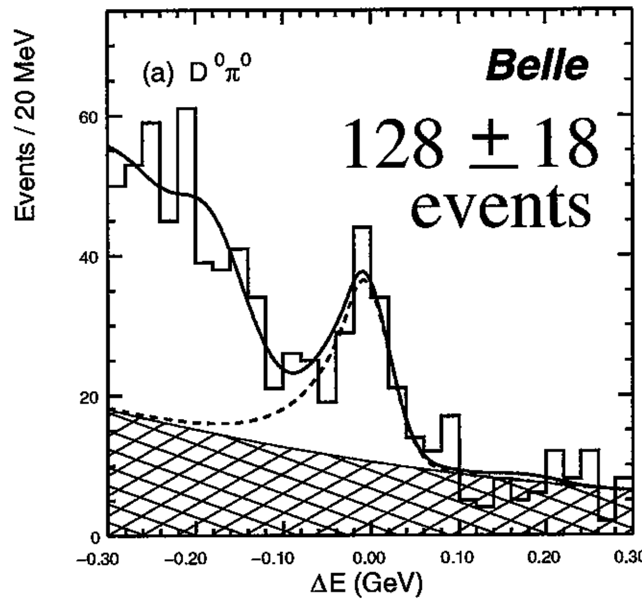
$\mathcal{B}(\overline{B}^0 \rightarrow D^0\pi^0)$
$= (2.9 \pm {}^{0.4}_{0.3} \pm 0.6) \times 10^{-4}$ 7.9σ

$\mathcal{B}(\overline{B}^0 \rightarrow D^0\omega)$
$= (1.7 \pm {}^{0.5}_{0.4} \pm {}^{0.3}_{0.4}) \times 10^{-4}$ 4.7σ

$\mathcal{B}(\overline{B}^0 \rightarrow D^{*0}\omega)$
$= (3.4 \pm {}^{1.3}_{1.1} \pm 0.8) \times 10^{-4}$ 4.3σ

$D^{*0}\pi^0$ 3.2σ
$D^{*0}\eta$ 3.8σ
$D^{*0}\eta$ 3.6σ

First observation
$D^0\pi^0$



Charmless Two body decays

Extraction of ϕ_2

$B \to \pi\,\pi$

$B \to \rho\,\pi$

Search for direct CP violation
(Tree and Penguin interference)

$\sim \sin\phi_3 \sin(\delta_p - \delta_t)$

$$A_{cp} = \frac{\mathcal{B}(K^-\pi^+) - \mathcal{B}(K^+\pi^-)}{\mathcal{B}(K^-\pi^+) + \mathcal{B}(K^+\pi^-)}$$

$$A_{cp} = \frac{\mathcal{B}(K^-\pi^0) - \mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^-\pi^0) + \mathcal{B}(K^+\pi^0)}$$

Constraint on ϕ_3 using ratios of
$\mathcal{B}(K\pi)$ and $\mathcal{B}(\pi\pi)$

Fleischer et al. (hep–ph/0003323)

Neubert et al. (hep–ph/0008072)

$$\frac{\mathcal{B}(\pi^+\pi^-)}{\mathcal{B}(K^\pm\pi^\mp)} \qquad \frac{\mathcal{B}(K^\pm\pi^\mp)}{2\,\mathcal{B}(K^0\pi^0)}$$

$$\frac{2\,\mathcal{B}(K^\pm\pi^0)}{\mathcal{B}(K^0\pi^\pm)} \qquad \frac{\tau_{B^+}\mathcal{B}(K^\pm\pi^\mp)}{\tau_{B^0}\mathcal{B}(K^0\pi^\pm)}$$

Probe new physics

$B \to \pi^+\pi^- \quad K^+\pi^- \quad K_S^0\pi^+$ 10.4/fb

$\pi^+\pi^-$ $N = 17.7 \pm ^{7.1}_{6.4}$

$K\pi$ background 9.6 ± 6

$\mathcal{B}(B \to \pi^+\pi^-) = (0.56 \pm ^{0.23}_{0.20}) \times 10^{-5}$

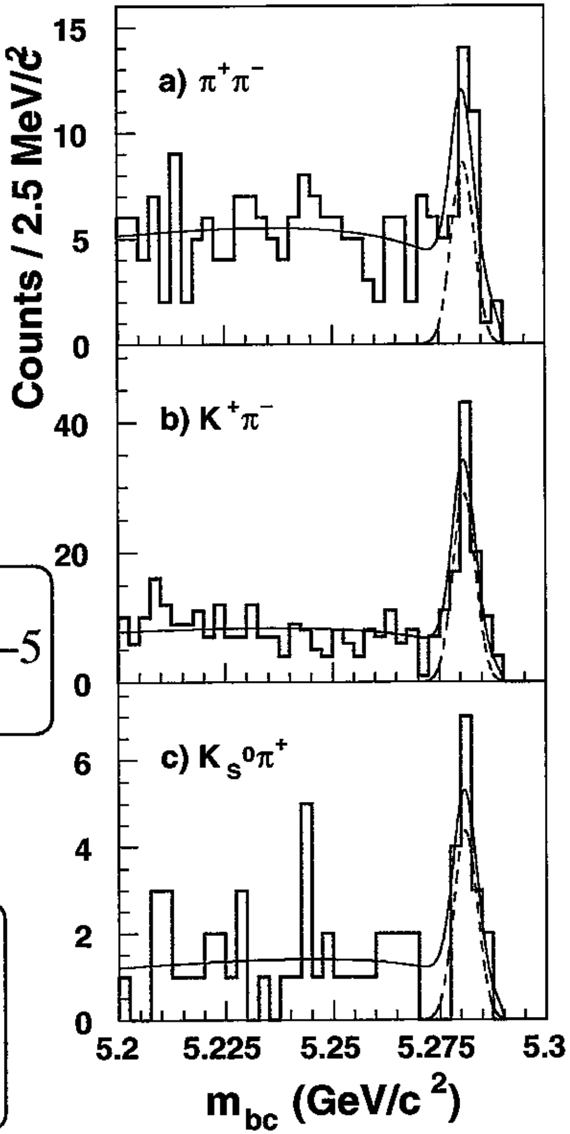
$K^+\pi^-$ $N = 60.3 \pm ^{10.6}_{9.9}$

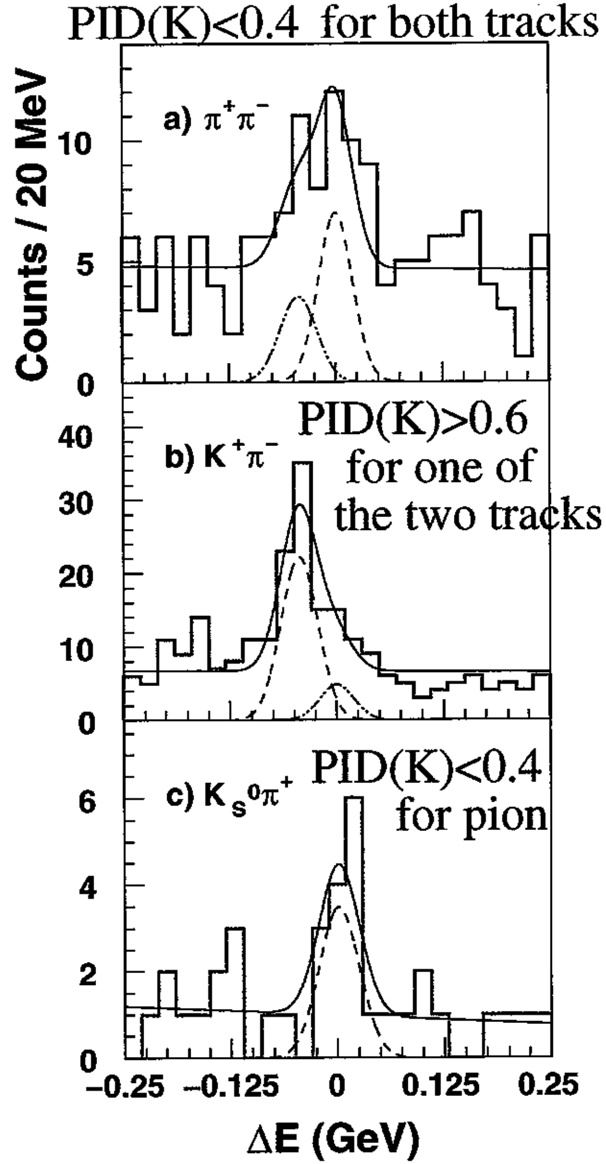
$\pi\pi$ background 12 ± 7

$\mathcal{B}(B \to K^+\pi^-) = (1.93 \pm ^{0.37}_{0.33}) \times 10^{-5}$

$K_S^0\pi^+$ $N = 10.3 \pm ^{4.3}_{3.6}$

$\mathcal{B}(B \to K^0\pi^+) = (1.37 \pm ^{0.60}_{0.51}) \times 10^{-5}$





$B \to K^+\pi^0 \quad \pi^+\pi^0 \quad K^0\pi^0$

10.4/fb

$\pi^+\pi^0$ $\quad N = 8.4 \pm ^{4.8}_{4.0}$ events

$\mathcal{B}(B \to \pi^+\pi^0) = (0.78 \pm ^{0.39}_{0.34}) \times 10^{-5}$

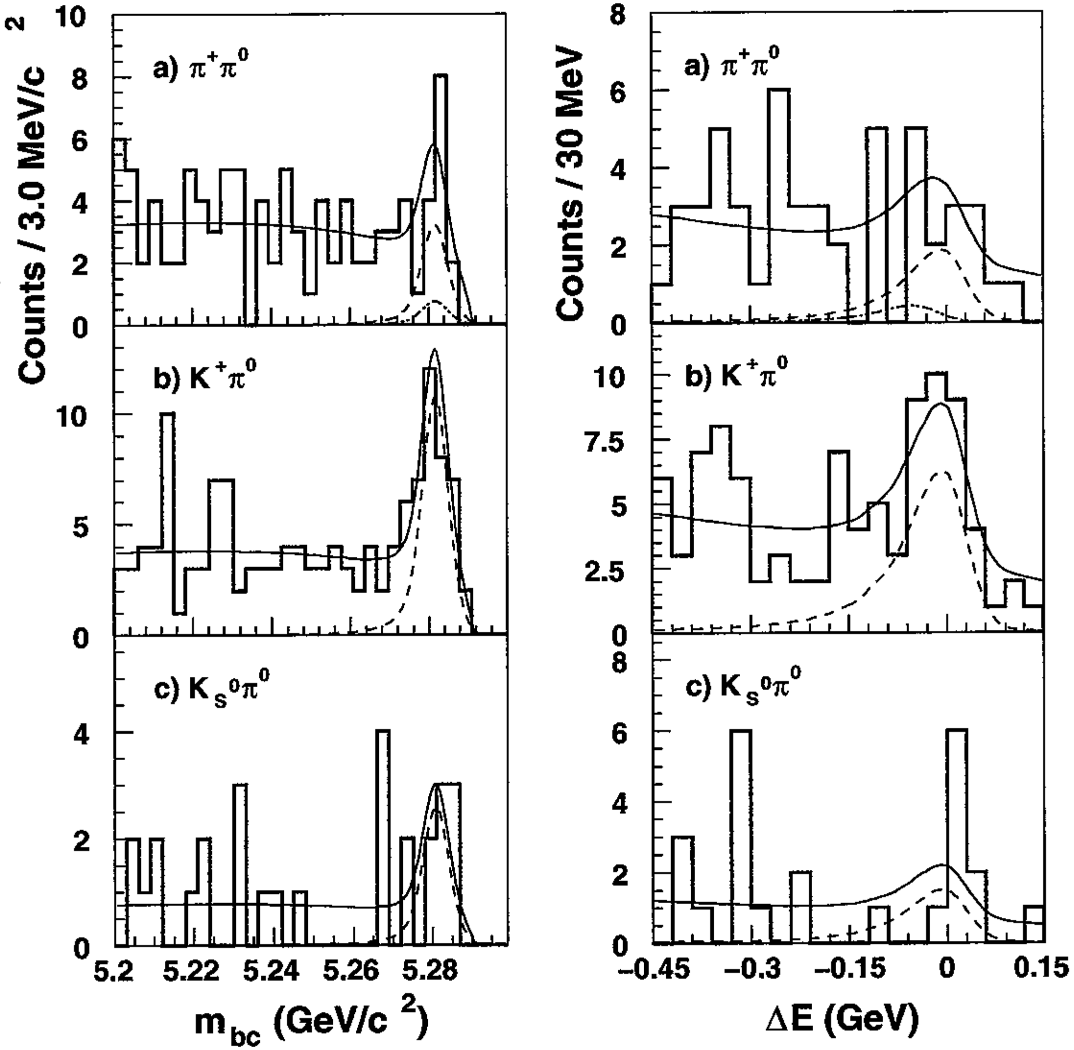
2.9 σ signif. $< 1.34 \times 10^{-5}$ @90C.L.

$K^+\pi^0$ $\quad N = 34.1 \pm ^{7.7}_{7.0}$ events

$\mathcal{B}(B \to K^+\pi^0) = (1.63 \pm ^{0.38}_{0.38}) \times 10^{-5}$

$K^0\pi^0$ $\quad N = 8.2 \pm ^{3.7}_{3.1}$ events

$\mathcal{B}(B \to K^0\pi^0) = (1.60 \pm ^{0.76}_{0.65}) \times 10^{-5}$



$B \to \pi\pi / K\pi / KK$ Summary

Results with 11.1M BB

Mode	N(signal)	signif.	eff.(%)	Br (10^{-5})	U.L.(10^{-5})
$\pi^+\pi^-$	$17.7 \pm ^{7.1}_{6.4} \pm ^{0.3}_{1.1}$	3.1	28	$0.56 \pm ^{0.23}_{0.20} \pm 0.04$	
$\pi^+\pi^0$	$10.4 \pm ^{5.1}_{4.3} \pm ^{1.2}_{1.6}$	2.7	12	$0.78 \pm ^{0.38}_{0.32} \pm ^{0.08}_{0.12}$	1.34
$K^+\pi^-$	$60.3 \pm ^{10.6}_{9.9} \pm ^{2.7}_{1.1}$	7.8	28	$1.93 \pm ^{0.34}_{0.32} \pm ^{0.15}_{0.06}$	
$K^+\pi^0$	$34.9 \pm ^{7.6}_{7.0} \pm ^{0.6}_{2.0}$	7.2	19	$1.63 \pm ^{0.35}_{0.33} \pm ^{0.16}_{0.18}$	
$K^0\pi^+$	$10.3 \pm ^{4.3}_{3.6} \pm ^{0.4}_{0.1}$	3.5	14	$1.37 \pm ^{0.57}_{0.48} \pm ^{0.19}_{0.18}$	
$K^0\pi^0$	$8.4 \pm ^{3.8}_{3.1} \pm ^{0.4}_{0.6}$	3.9	9	$1.60 \pm ^{0.72}_{0.59} \pm ^{0.25}_{0.27}$	
K^+K^-	$0.2 \pm ^{3.8}_{0.2}$		24		0.27
K^+K^0	$0.0 \pm ^{0.9}_{0.0}$		12		0.50

Ratios of $\mathcal{B}(\pi\pi)$ and $\mathcal{B}(K\pi)$

The ratios give constraint on ϕ_3

$$\frac{\mathcal{B}(B\to\pi^+\pi^-)}{\mathcal{B}(B\to K^+\pi^-)} = 0.29 \pm^{0.13}_{0.12} \pm^{0.01}_{0.02}$$

$$\frac{\mathcal{B}(B\to K^+\pi^-)}{2\,\mathcal{B}(B\to K^0\pi^0)} = 0.60 \pm^{0.25}_{0.29} \pm^{0.11}_{0.16}$$

$$\frac{2\,\mathcal{B}(B\to K^+\pi^0)}{\mathcal{B}(B\to K^0\pi^+)} = 2.38 \pm^{0.98}_{1.10} \pm^{0.39}_{0.26}$$

$$\frac{\mathcal{B}(B\to K^+\pi^-)}{\mathcal{B}(B\to K^0\pi^+)} = 1.41 \pm^{0.55}_{0.63} \pm^{0.22}_{0.20}$$

$B \to K\pi$ A_{cp} Results

Require PID on both tracks to minimize double mis–identification.
for $K^{\pm}\pi^{\mp}$ (double mis–ID probability = 0.46%)

$N(B \to K^-\pi^+) = 27.7^{+6.8}_{-6.1}$

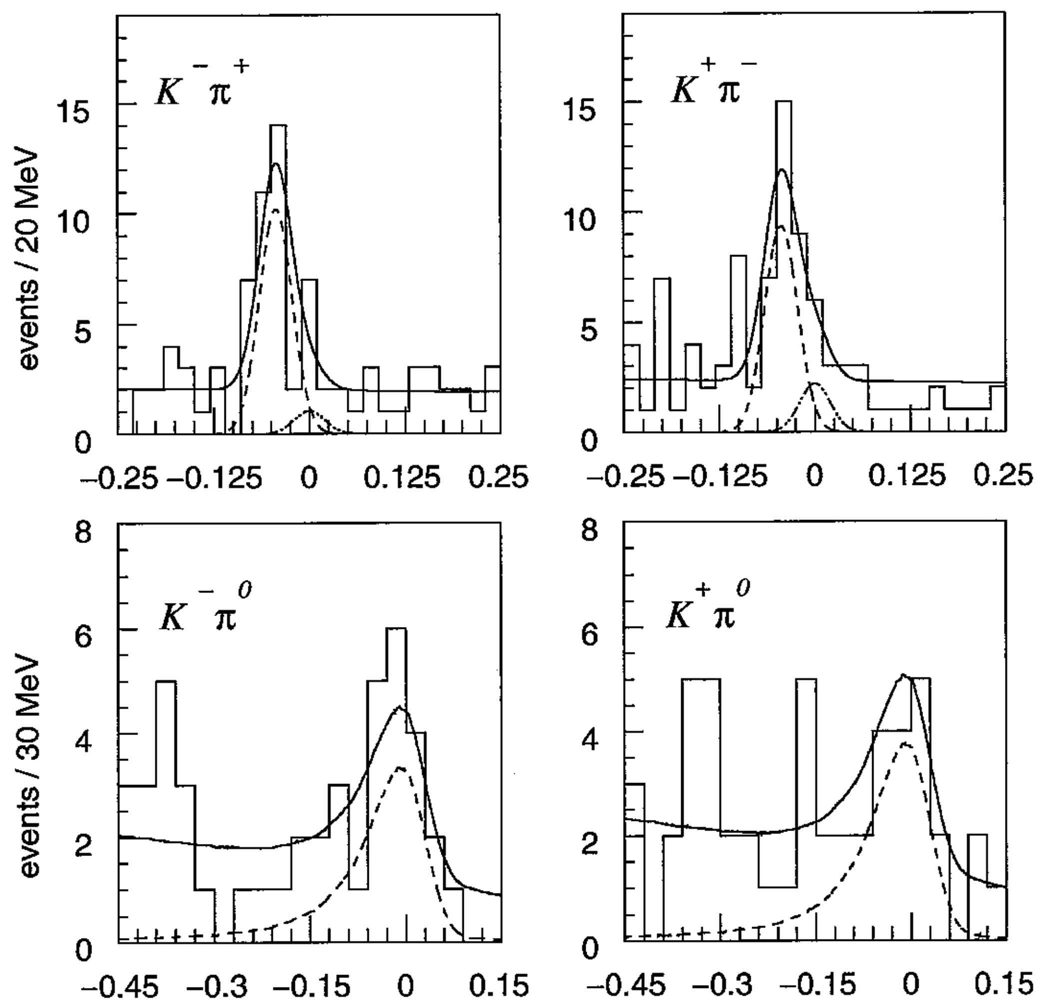
$N(B \to K^+\pi^-) = 25.4^{+7.0}_{-6.3}$

$N(B \to K^-\pi^0) = 16.5^{+5.3}_{-4.7}$

$N(B \to K^+\pi^0) = 18.6^{+5.7}_{-5.0}$

$A_{cp}(B \to K^{\pm}(\pi^{\mp} + \pi^0))$
$= +0.003^{+0.142}_{-0.126}{}^{+0.017}_{-0.014}$

$-0.22 < A_{cp} < +0.25$
@90%C.L.

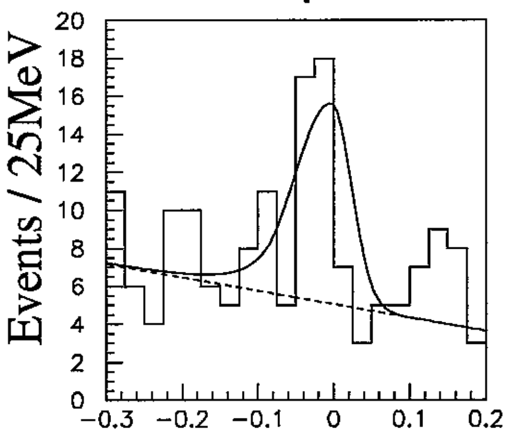


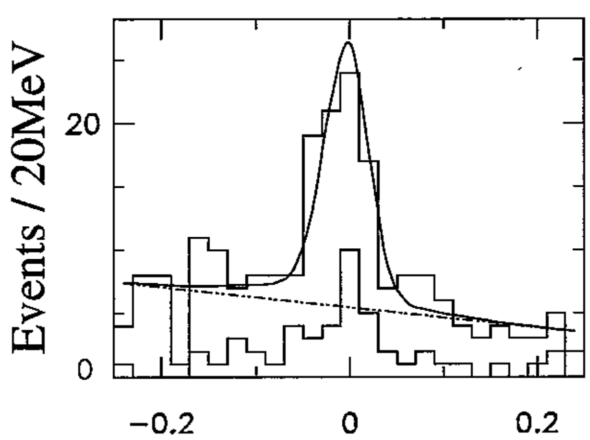
$B \to \eta' K \quad \eta K^*$

Large branching fraction was reported by CLEO.

$$\mathcal{B}(B^+ \to \eta' K) = (80 \pm 12) \times 10^{-6}$$

Theoretically difficult to explain. $(21 \sim 53) \times 10^{-6}$





$$\mathcal{B}(B \to \eta K^{*0}) = (21.2 \pm {}^{5.4}_{4.7} \pm 2.0) \times 10^{-6}$$

$$\mathcal{B}(B \to \eta' K^+) = (79 \pm {}^{12}_{11} \pm 9) \times 10^{-6}$$

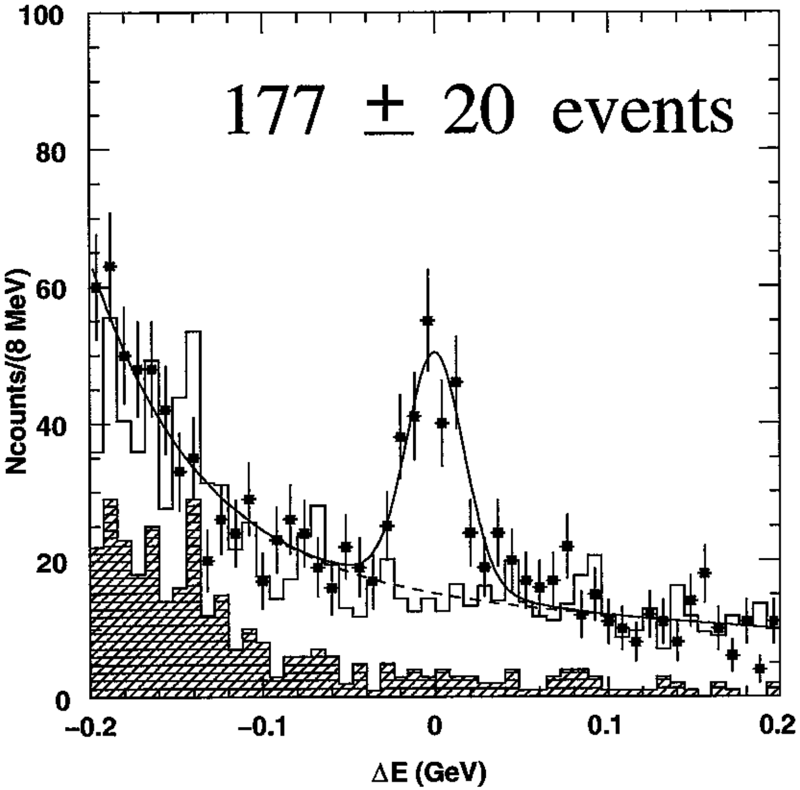
theory $(2.0\text{–}8.0) \times 10^{-6}$

Confirm large branching ratios

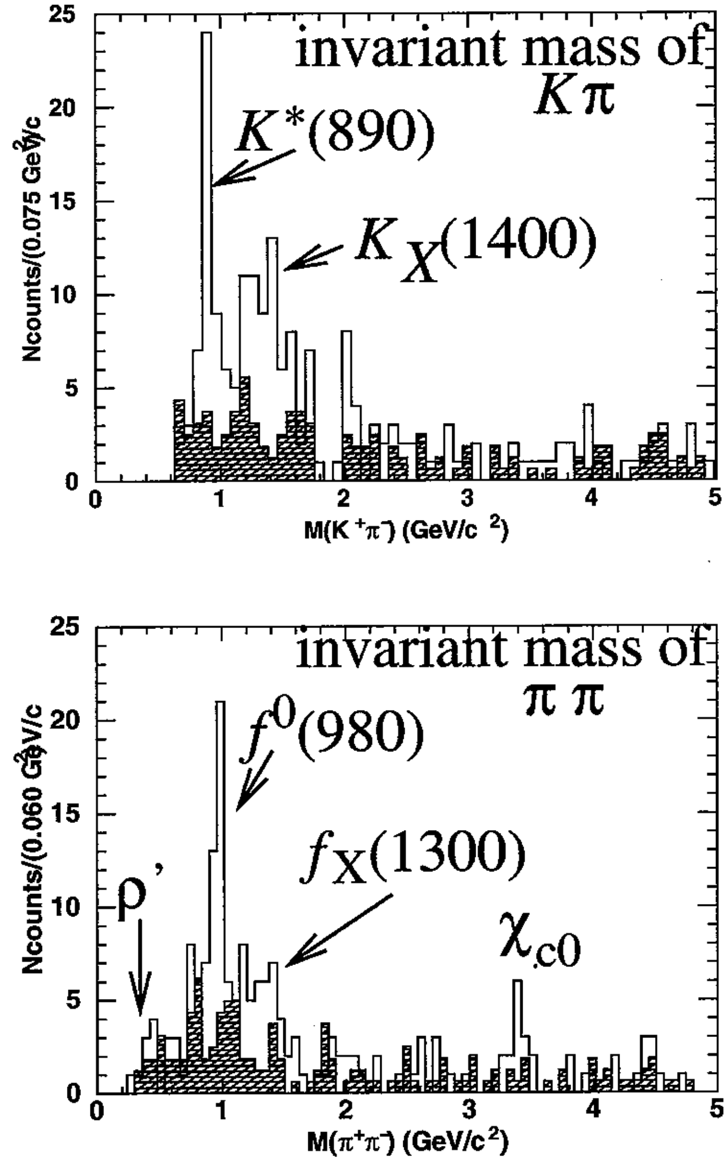
$B^+ \to K^+\pi^+\pi^-$ three body decays

$$\mathcal{B}(B^+ \to K^+\pi^+\pi^-) = (58.5 \pm 7.1 \pm 8.8)\times 10^{-6}$$

After removing D^0, J/ψ and ψ (2S)



Intermediate resonance states



$B \longrightarrow K^+ K^+ K^-,\ K^+ \pi^- \pi^0$

after removing $B^+ \to D_{CP} K^+$

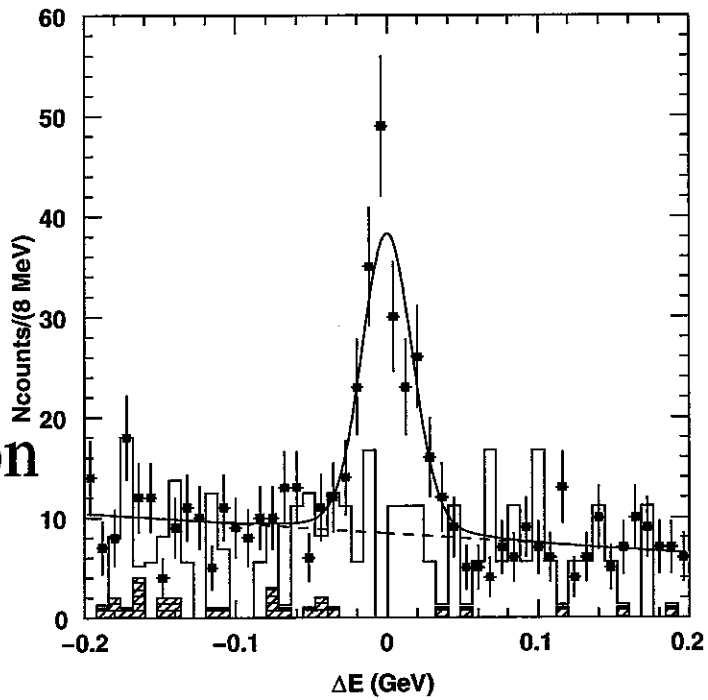
$D_{CP} \to K^+ K^-$

$\mathcal{B}(B^+ \to K^+ K^+ K^-)$

$= (37.0 \pm 3.9 \pm 4.4) \times 10^{-6}$

162 $\pm$ 16 events

First observation



$\mathcal{B}(B^0 \to K^+ \pi^- \pi^0) = (35.6 \pm {}^{8.1}_{7.7} \pm 5.2) \times 10^{-6}$

105 $\pm$ 24 events with 4.8σ significance

Radiative B meson decay

Radiative B meson decays are sensitive to non–Standard Model contributions.

$B \to X_s \gamma$ branching fraction is calculated using SM with an accuracy of 10%.

Experimental measurments of the fraction will limit or identify non–SM theories.

$b \to d\gamma$ process will provide us a precise measurment of $|V_{td} / V_{ts}|$ and direct CP violation.

$b \to s l l$ will provide more stringent test of SM, since this mode is theoretically clean.

theoretical prediction $B \to K^{(*)} l l \sim (1\text{–}2.5) \times 10^{-6}$

Semi–inclusive reconstruction

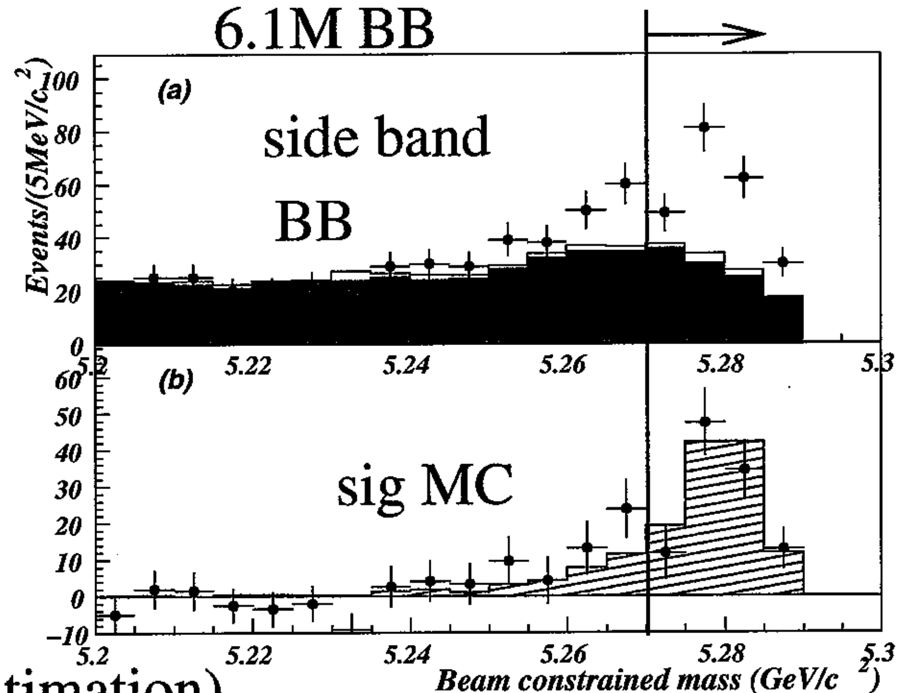
Exclusive B : easy to measure, difficult to predict
Inclusive B : difficult to measure, easy to predict

$\mathcal{B}(B \to X_s\gamma) = (3.29 \pm 0.33) \times 10^{-4}$ (prediction)

Semi inclusive reconstruction:

A Kaon($K^{\pm}$ or $K_S^0(\pi^+\pi^-)$) + 1~4 pions (at most 1 π^0) to form X_s

- Reconstruct hardest $\gamma + X_s$
- Choose only one B–candidate per event using best fit or $\theta_{\gamma X_s}$
- Reduce continuum events using SFW



N (obs) = 222 (M_{bc} >5.27GeV)
N(sideband) = 106.4 ± 7.5
N(BB) = 9.1 ± 1.8

$N(X_s\gamma)$ = 106.5 ± 16.8 ± 5.0
(stat.) (syst. from bg estimation)

M_{X_s} Efficiency and Branching Fraction

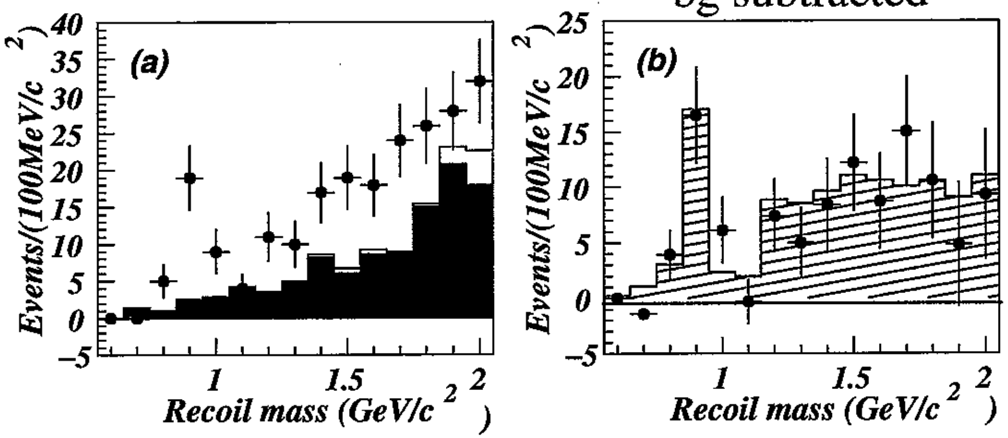
Clear $K^*(892)$ peak + Continuum X_s

Model the recoil mass as $K^*(892)$
+ Kagan–Neuber
[Eur. Phys. J. C7, 5 (1999)]
with $m_b = 4.75 \pm 0.10$ GeV/c^2

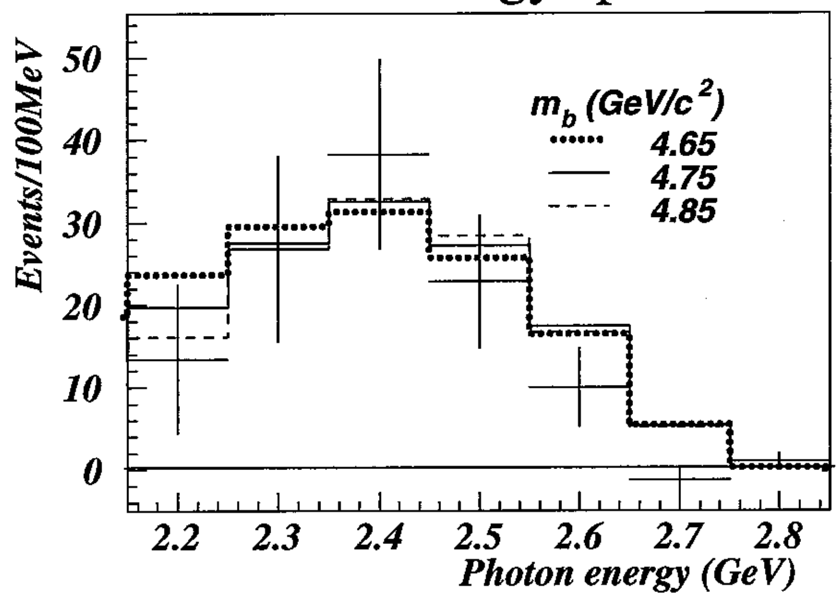
$\varepsilon = 2.58 \pm 0.29$ (syst.) $\pm\,^{0.42}_{0.39}$ (model)

$\mathcal{B}(X_s\gamma) = (33.6 \pm 5.3$ (stat.) ± 4.2 (syst.) ± 5.4 (model)$) \times 10^{-5}$

bg subtracted



Photon energy spectrum



No significant model dependence
in photon energy spectrum

$B \rightarrow K^*(892)\gamma$

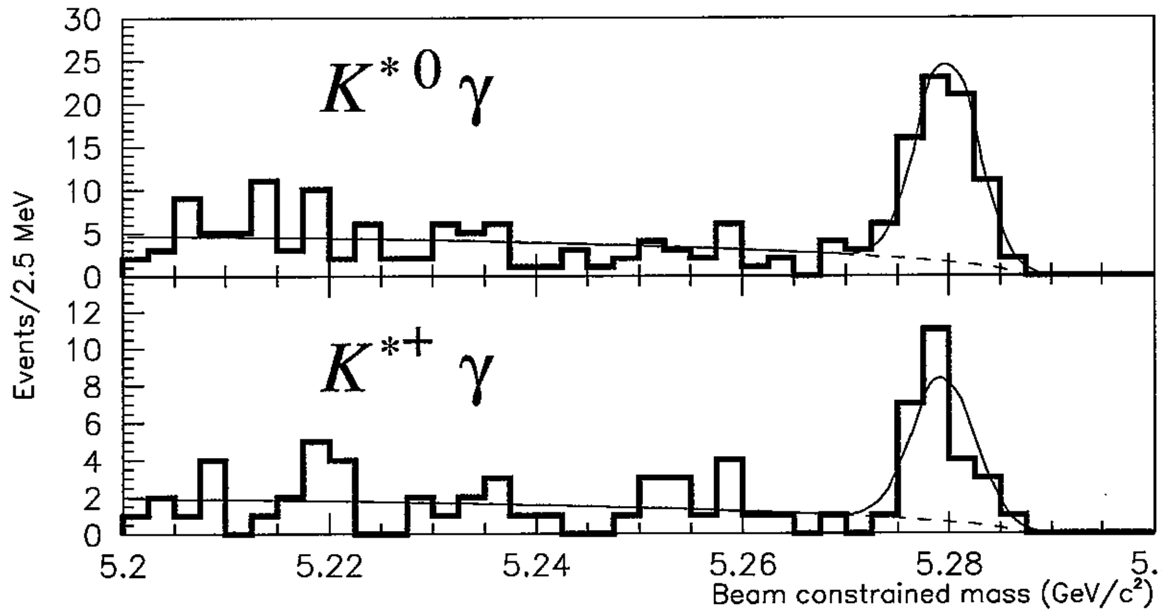
K^* is reconstructed with $K^\pm \pi^\mp$ $K^0_S \pi^0$ $K^0_S \pi^\pm$ $K^\pm \pi^0$

signal yield: $K^{*0}\gamma$ $70.1 \pm 9.0 \pm ^{1.1}_{1.2}$

$K^{*+}\gamma$ $23.8 \pm 5.2 \pm ^{0.5}_{0.6}$

$\mathcal{B}(K^{*0}\gamma) = (4.96 \pm 0.67 \pm 0.45) \times 10^{-5}$

$\mathcal{B}(K^{*+}\gamma) = (3.89 \pm 0.93 \pm 0.41) \times 10^{-5}$



M_{bc}

Search for $B \rightarrow \rho\gamma$

Yield

$\rho^0\gamma$ $3.5 \pm 2.0 \pm 0.5$ events

$\rho^+\gamma$ $0.3 \pm 0.9 \pm 0.2$ events

No significant exess

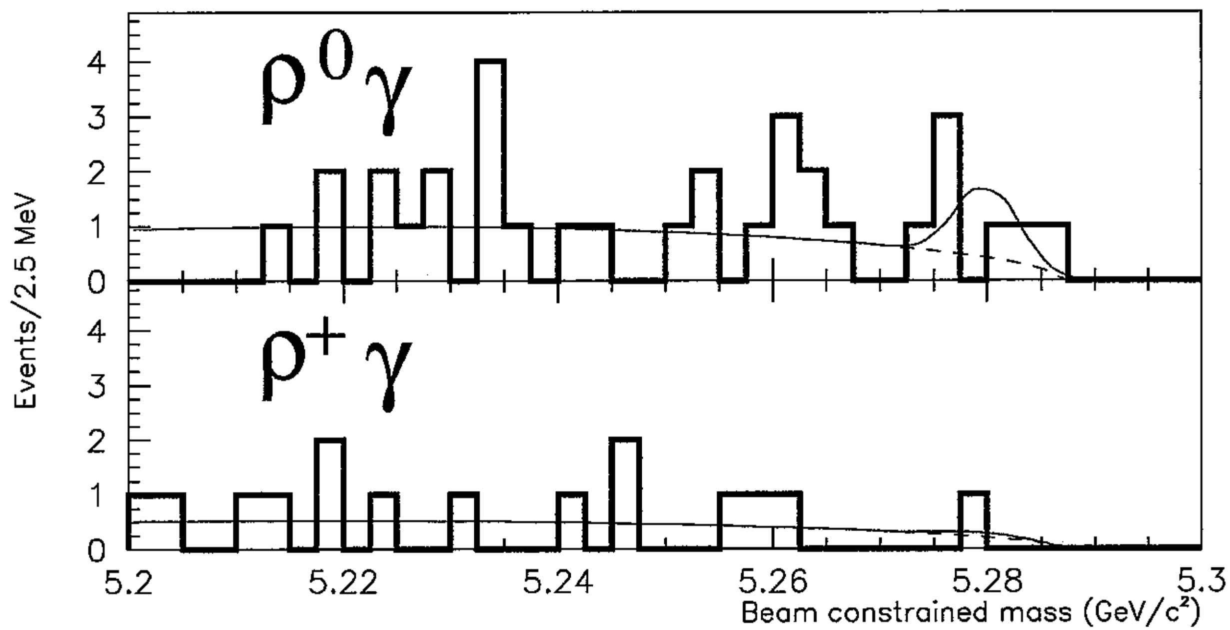
$\mathcal{B}(\rho^0\gamma) < 10.6 \times 10^{-6}$

$\mathcal{B}(\rho^+\gamma) < 9.9 \times 10^{-6}$

@90%C.L.

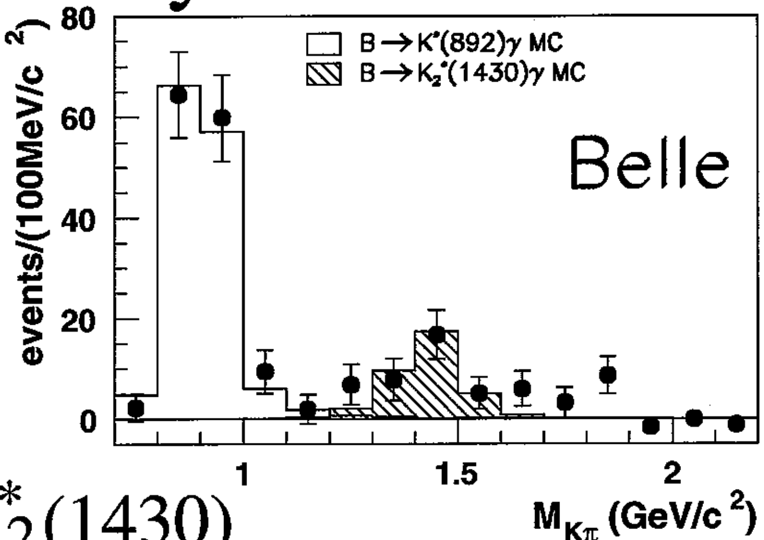
$\mathcal{B}(\rho\gamma) / \mathcal{B}(K^*(892)\gamma)$

< 0.19 @90%C.L.



$B^0 \to K_2^*(1430)^0\gamma$ Decays

$B^0 \to K_2^*(1430)^0\gamma \quad K_2^{*0} \to K^+\pi^-$

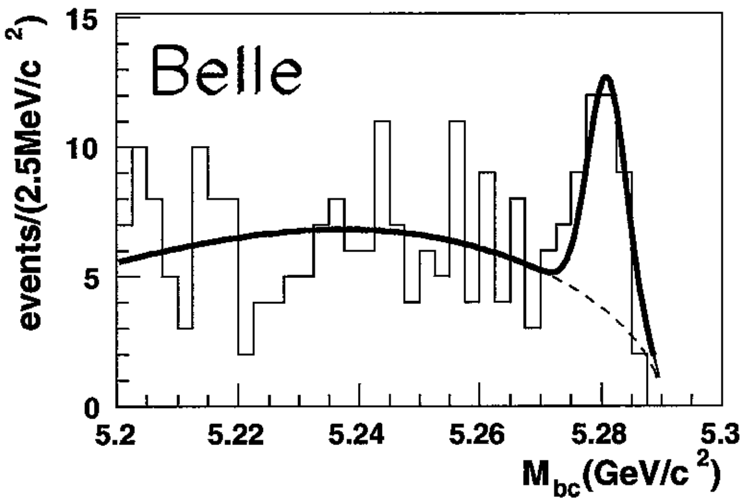


Helicity angle analysis

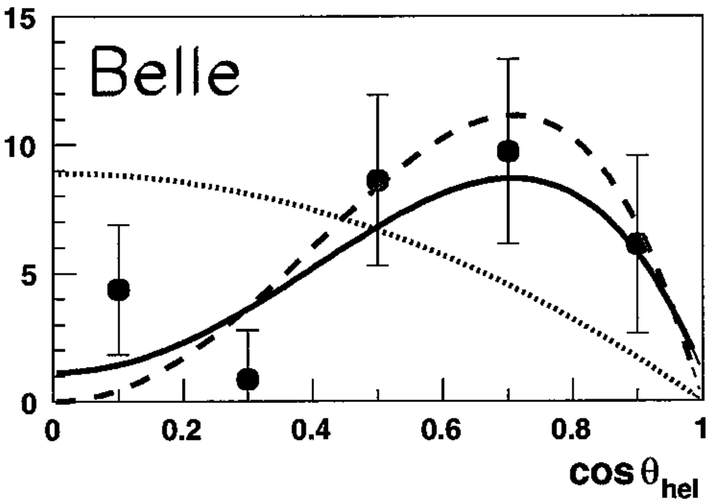
Identify spin state of the resonance

$K_2^*(1430)$

29.1 ± 6.7 events



20.1 ± 10.5 events



$K_2^*(1430)$

$K^*(1410)$

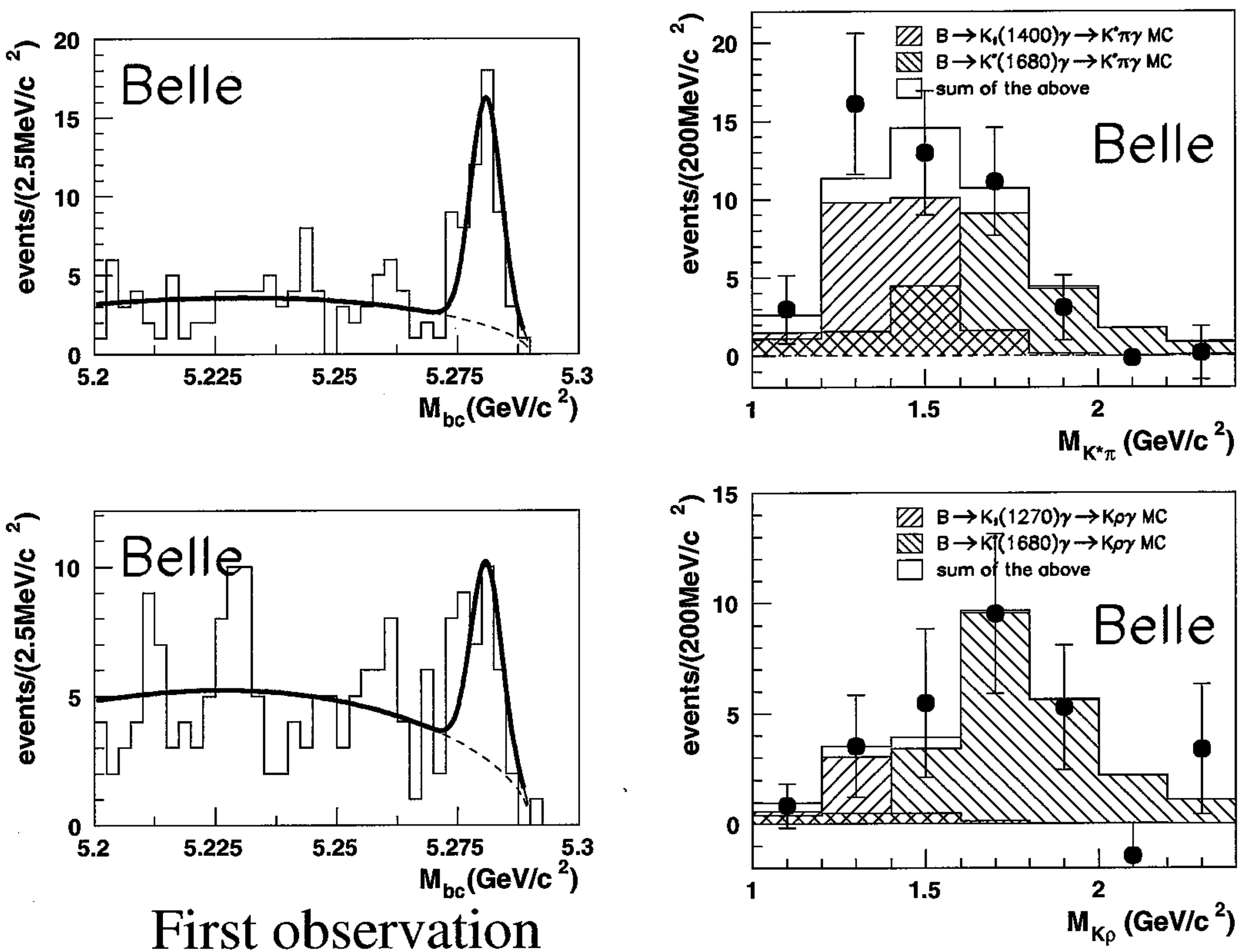
fit results

$$\mathcal{B}(B^0 \to K_2^*(1430)^0\gamma) = (1.26 \pm 0.66 \pm 0.10) \times 10^{-5}$$

$B^{\pm} \to K^{+}\pi^{-}\pi^{+}\gamma$ Decays

$B^{\pm} \to K^{*0}\pi^{+}\gamma$

$B^{\pm} \to K^{+}\rho^{0}\gamma$



First observation

$b \to s\gamma$ decays

Inclusive $B \to X_s \gamma$ decays

$$\mathcal{B}(B \to X_s \gamma) = (33.6 \pm 5.3 \pm 4.2 \pm 5.4) \times 10^{-5}$$

Exclusive $B \to K^{(*)} X \gamma$ decays

$$\mathcal{B}(B^0 \to K^*(892)^0 \gamma) = (4.96 \pm 0.67 \pm 0.45) \times 10^{-5}$$

$$\mathcal{B}(B^+ \to K^*(892)^+ \gamma) = (3.89 \pm 0.93 \pm 0.41) \times 10^{-5}$$

$$\mathcal{B}(B^0 \to K^*_2(1430)^0 \gamma) = (1.26 \pm 0.66 \pm 0.10) \times 10^{-5}$$

$$\mathcal{B}(B^+ \to K^*(892)^0 \pi^+ \gamma) = (5.6 \pm 1.1 \pm 0.9) \times 10^{-5}$$

$$(M_{K^*\pi} < 2.0 \text{ GeV}/c^2)$$

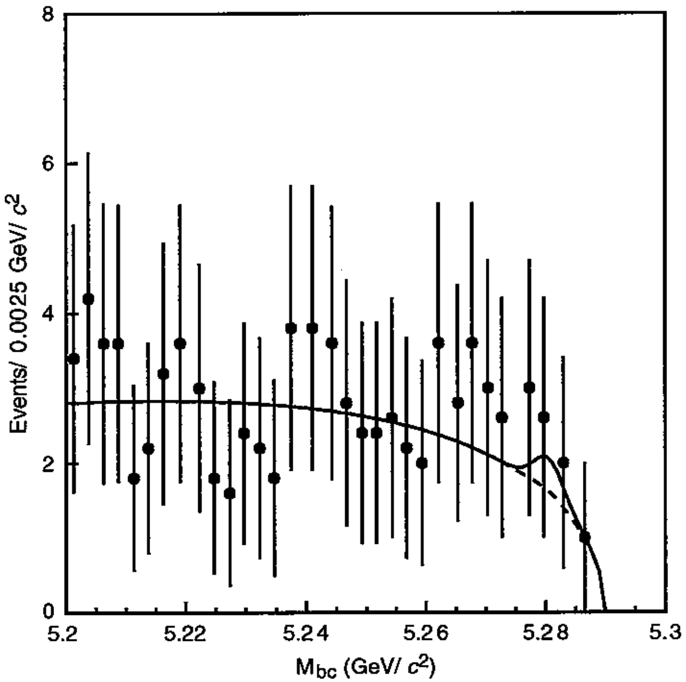
$$\mathcal{B}(B^+ \to K^+ \rho^0 \gamma) = (6.5 \pm 1.7 \pm 1.2) \times 10^{-5}$$

$$(M_{K\rho} < 2.0 \text{ GeV}/c^2)$$

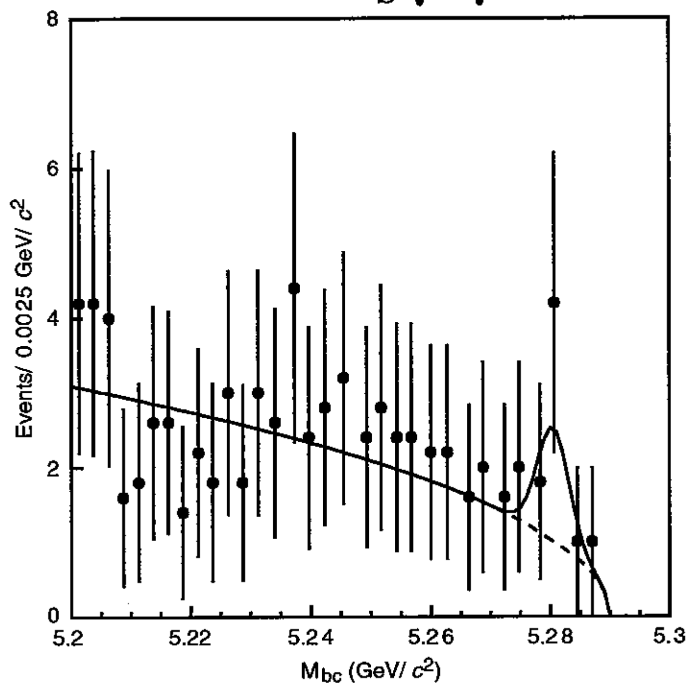
Total exclusive rate account for about 50% of inclusive rate.

$B \rightarrow X_s\, l\, l$ Semi–inclusive reconstruction

$B \longrightarrow X_s\, e^+e^-$



$B \longrightarrow X_s\, \mu^+\mu^-$



$\mathcal{B}(B \longrightarrow X_s\, e^+e^-)$ $< 10.2 \times 10^{-6}$ @90% C.L.

$\mathcal{B}(B \longrightarrow X_s\, \mu^+\mu^-)$ $< 19.9 \times 10^{-6}$ @90% C.L.

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

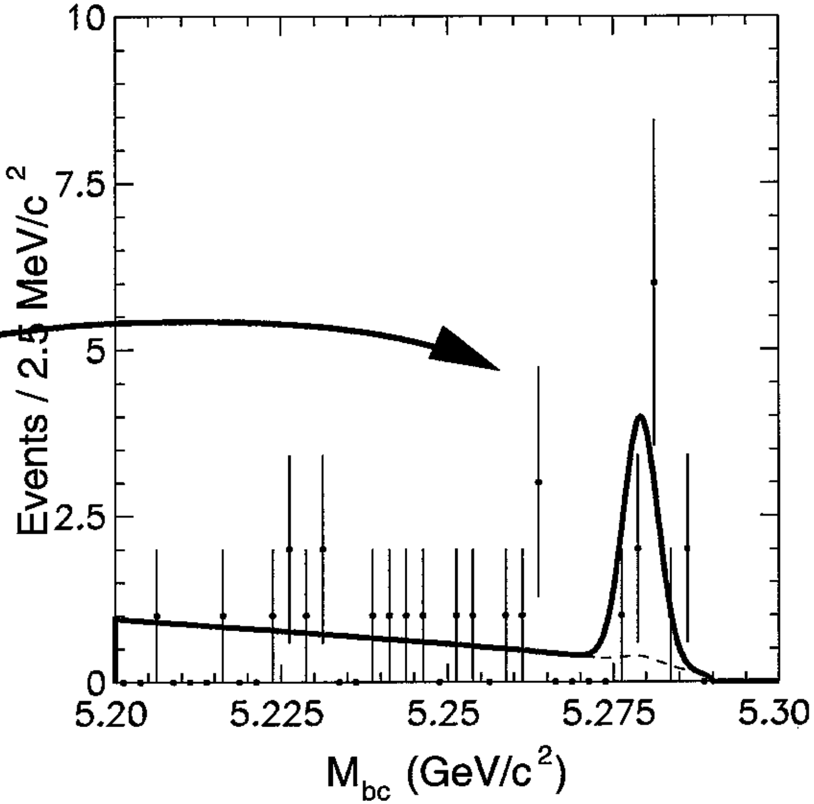
$\mathcal{B}(B \to K e^+e^-) < 1.2 \times 10^{-6}$

$\mathcal{B}(B \to K^* e^+e^-) < 5.1 \times 10^{-6}$

$\mathcal{B}(B \to K \mu^+\mu^-)$
$= (0.99 \pm^{0.39}_{0.32} \pm^{0.13}_{0.15}) \times 10^{-6}$

$\mathcal{B}(B \to K^* \mu^+\mu^-) < 3.0 \times 10^{-6}$

First observation



$9.5 \pm^{3.7}_{3.1}$ events

4.8σ significance

V_{cb} measurement

Semi–leptonic decay inclusive

$\mathcal{B}(Xe\nu) = 10.86 \pm 0.14(\text{stat.}) \pm 0.47(\text{syst.})\%$ @5.1/fb

$B \rightarrow D^{(*)+} l^{-} \nu$ @10.4/fb

$|V_{cb}|$ is determined from form factor at zero recoil limit using HQET.

$\mathcal{B}(D^{*+} l^{-} \nu) = 4.77 \pm 0.38 \pm 0.40\ \%$

$|V_{cb}|\, F(1) = (3.62 \pm 0.15(\text{stat.}) \pm 0.18(\text{syst.})) \times 10^{-2}$

$\mathcal{B}(D^{+} l^{-} \nu) = 2.09 \pm 0.11 \pm 0.31\ \%$

$|V_{cb}|\, F(1) = (3.98 \pm 0.45(\text{stat.}) \pm 0.45(\text{syst.})) \times 10^{-2}$

V_{ub} measurment

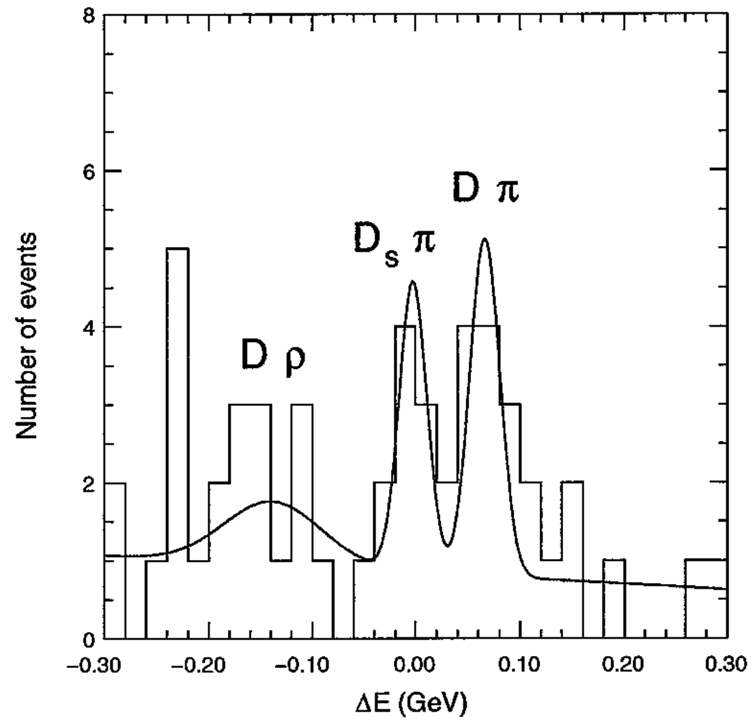
Exclusive semi leptonic decay $B \rightarrow (\pi \text{ or } \rho \text{ or } \omega)\, l\, \nu$

$\mathcal{B}(\pi l \nu) = (1.28 \pm 0.20 \pm 0.26) \times 10^{-4}$ @21.3/fb

Exclusive hadronic B decay $B \rightarrow D_s\, \pi$ or ρ @21.3/fb

$\mathcal{B}(D_s^+ \pi^-) < 1.1 \times 10^{-4}$ @90% C.L.

$\mathcal{B}(D_s^- K^+) < 0.7 \times 10^{-4}$



Summary

Using 29.1/fb data, we obtained

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

CP is violated in B decays!!!

$B \to D^{(*)}D^{*}$ was established.
with $B \to \phi K \longrightarrow \sin 2\phi_1$

$B \to D_{CP}K$ first step to ϕ_3 measurements

$B \to K\mu^+\mu^-$ decay was observed

Future Prospect

precise measurment of sin $2\phi_1$ with an accuracy of O(1)%.

measurment of ϕ_2 $\longrightarrow$ next summer

beyond 2001 summer

DAQ system was upgraded @2001 autumn

4 layer SVD will be installed @2002 summer

500/fb until 2005