Measurement of CP violation parameter sin $2\phi_1$ at Belle

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for
The Belle Collaboration

SLAC Summer Institute Topical Conference
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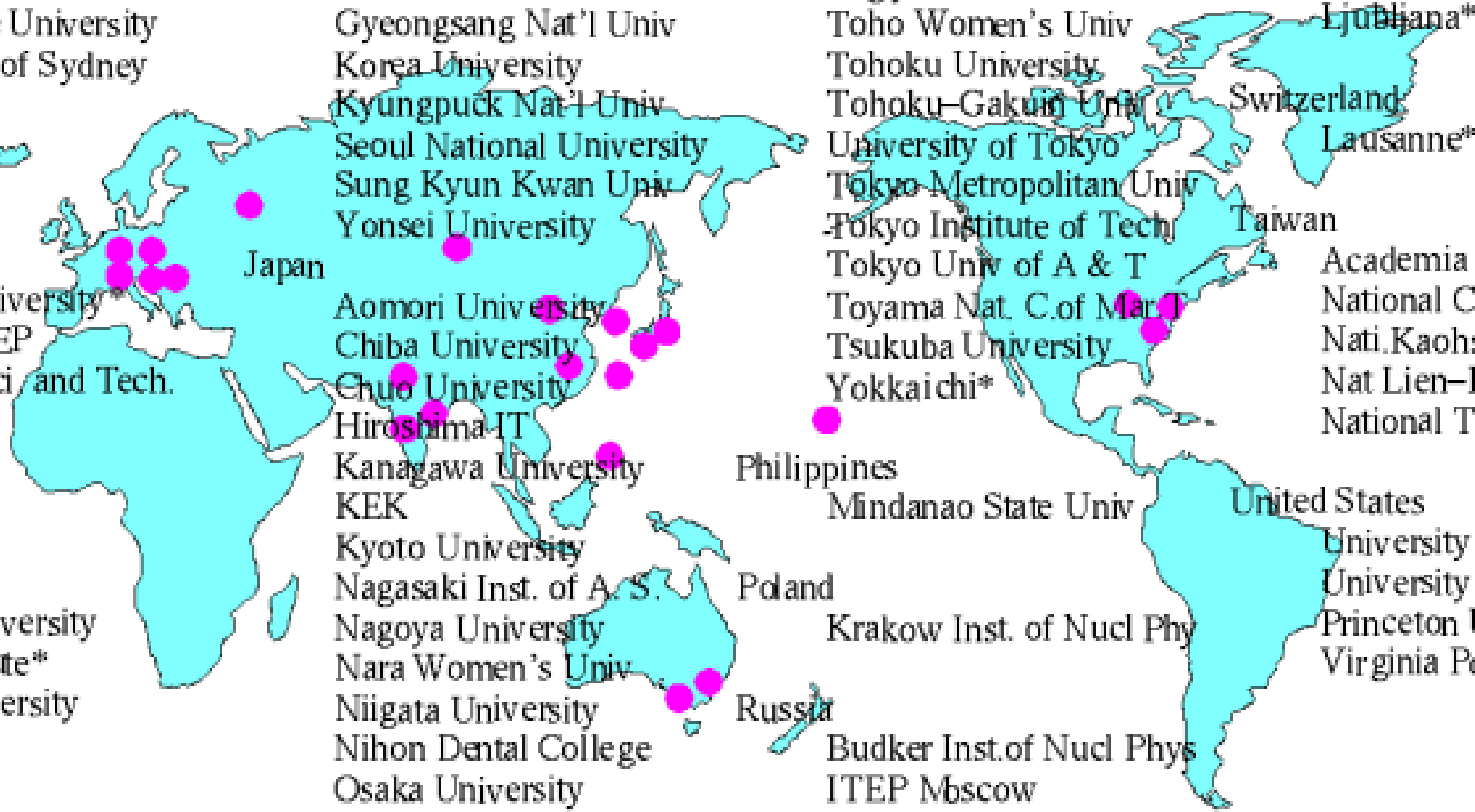
Belle Collaboration



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- Princeton University
- Virginia Polytechnic

14 countries, > 50 institutions, > 300 members

Outline

1. Introduction
2. Accelerator and Detector
3. Reconstruction of CP modes
4. Flavor Tagging
5. Vertex Reconstruction
6. CP fitting
7. Conclusion

1. Introduction

- CP violation is still one of the major mysteries in particle physics.

  might be the explanation for the unbalance of matter and anti−matter in the universe

- First observed in K system (1964; Cronin, Fitch et. al.)

  $K_L \to \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$ (CP conserving decay)

  $K_L \to \pi^+\pi^-, \pi^0\pi^0$ (CP violating decay)

  $\sim 2 \times 10^{-3}$

CP violation was not observed in other place for a long time.

- Sanda, Carter and Bigi (1980):

  Possibility of sizable CP violation in B meson decays in Kobayashi−Maskawa model

Cabibbo−Kobayashi−Maskawa (CKM) matrix

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

- CKM matrix is unitary and elements can be complex
- One phase cannot be rotated away

→ Source of CP violation in Standrad Model

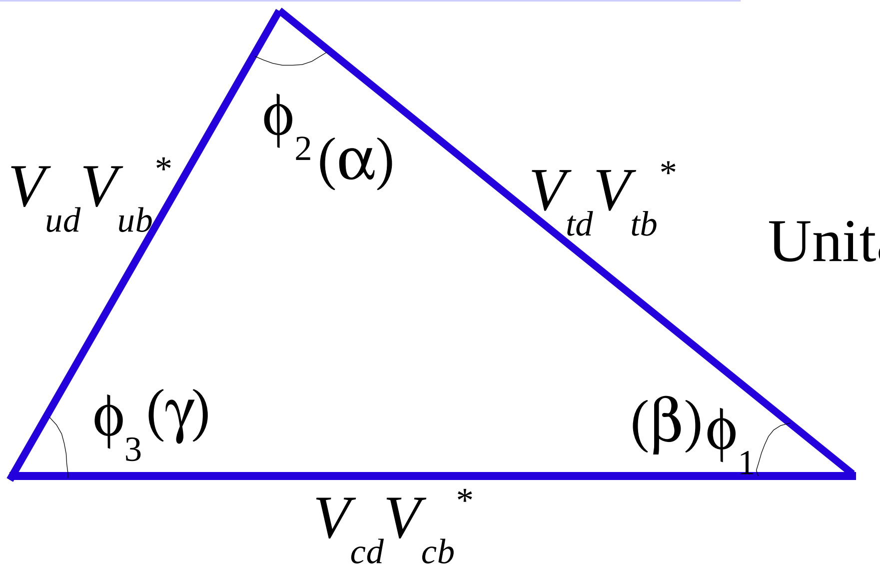
[Wolfenstein Notation]

$$\begin{pmatrix} 1-\lambda^2 & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & \lambda^2 A \\ \lambda^3 A(1-\rho-i\eta) & -\lambda^2 A & 1 \end{pmatrix}$$

Complex phase appears here.

Unitarity of CKM matrix:

$$V_{td}V_{tb}^{*}+V_{cd}V_{cb}^{*}+V_{ud}V_{ub}^{*}=1$$



Unitarity Triangle

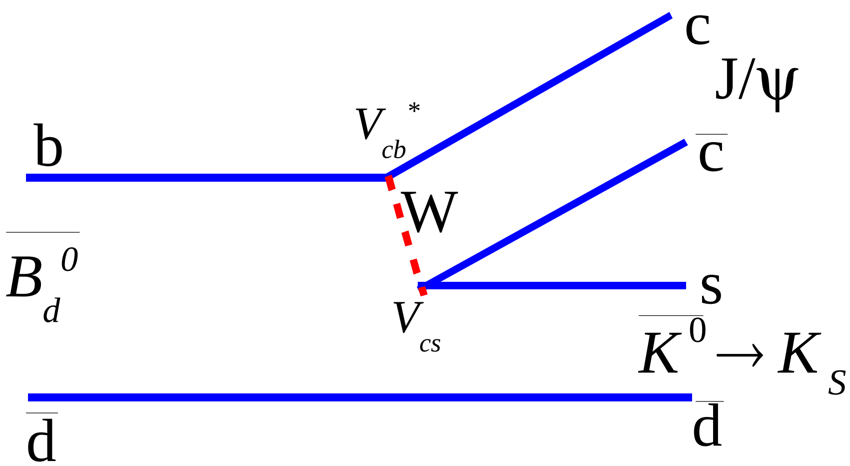
CP violation ≡ non−zero angle

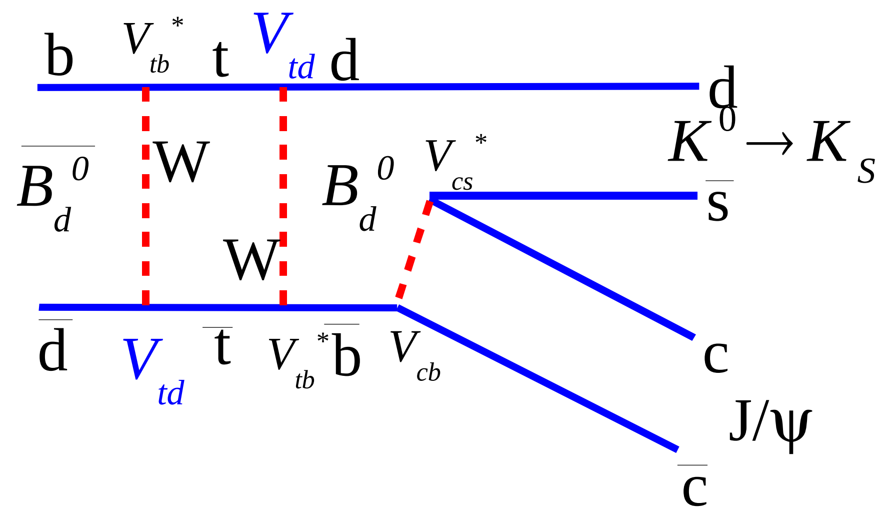
- Size of CP violation is proportional to the area of the triangle

"Indirect" CP violation in B meson decay

Sanda, Carter and Bigi

Golden Mode : $B_d^0 \rightarrow J/\psi\, K_S$





Phase difference between two diagrams:

$$\frac{V_{tb}^{*} V_{td}}{V_{tb} V_{td}^{*}} \cdot \frac{V_{cs}^{*} V_{cb}}{V_{cs} V_{cb}^{*}} \cdot \frac{V_{cd}^{*} V_{cs}}{V_{cd} V_{cs}^{*}} = e^{-2i\phi_1}$$

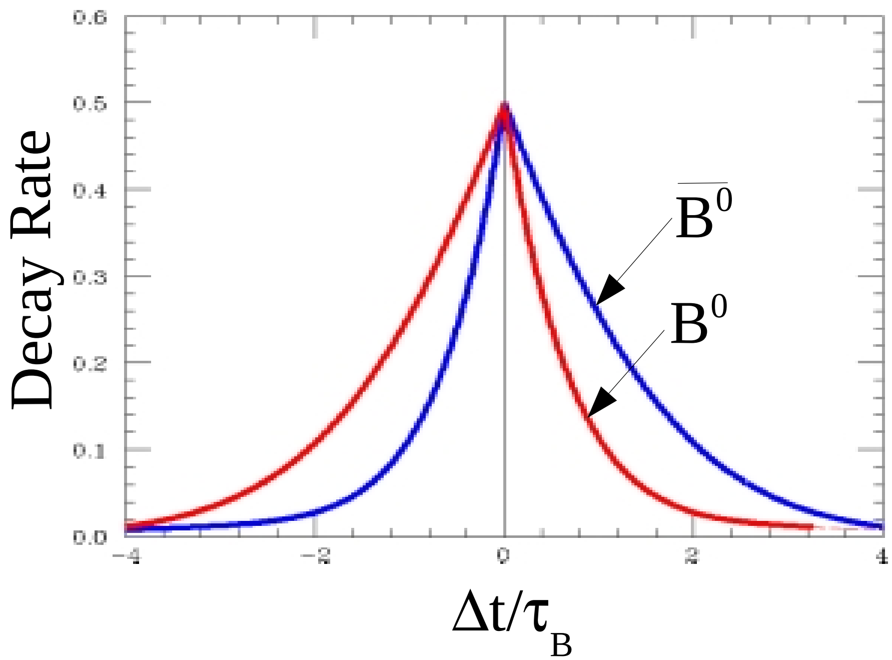
$2\phi_1$

Asymmetry :

$$A(\Delta t) = \frac{[\Gamma(B_d^0 \to J/\psi K_S) - \Gamma(\overline{B^0}_d \to J/\psi K_S)]}{[\Gamma(B_d^0 \to J/\psi K_S) + \Gamma(\overline{B^0}_d \to J/\psi K_S)]} = \sin 2\phi_1 \sin \Delta m \Delta t$$

Δm : mass difference between 2 B^0 mass eigenstates (B_1 and B_2)

$\Delta t = t\,(B_0 \text{ decay}) - t(\overline{B}_0 \text{ decay})$



Time integrated asymmetry becomes 0 at the Y(4S) !

need to know:
1. initial flavor of B
2. decay time

Requirements for the experiment

1. A large number of B meson decays

   $Br(B \to f_{CP} \to f_{obs}) \sim 10^{-4-5} \to$ needs 10^{7-8} B decays

   accelerator with very high lumionosity

   high−speed / background−tolerable detector

2. Full reconstruction of B meson decays to CP eigenstate

   full angle coverage

   high precision momentum/energy measurement

3. Tagging of B^0 or $\bar{B}^0$

   good particle ID capability

4. Measurement of Δt

   accelerator with asymmetric collision

   good vertex detection

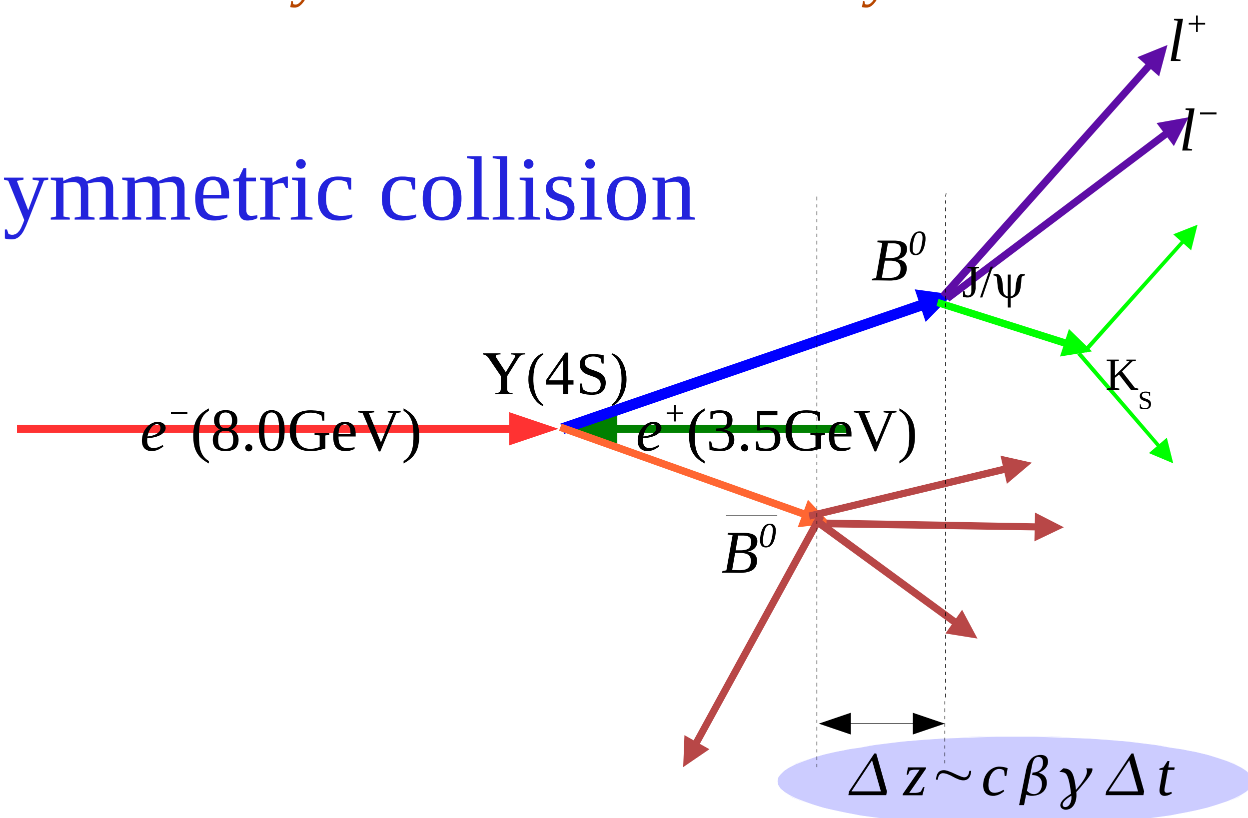
- How to measure the decay time of B^0?
  - At B factory, B^0 is produced from

$$e^+ e^- \rightarrow Y(4S) \rightarrow B^0 \overline{B}^0$$

    - Decay time of B^0 is measured by looking for the decay vertex.
    - B^0 is produced almost at rest.
    - The lifetime of B^0 is ~ 1.5ps.

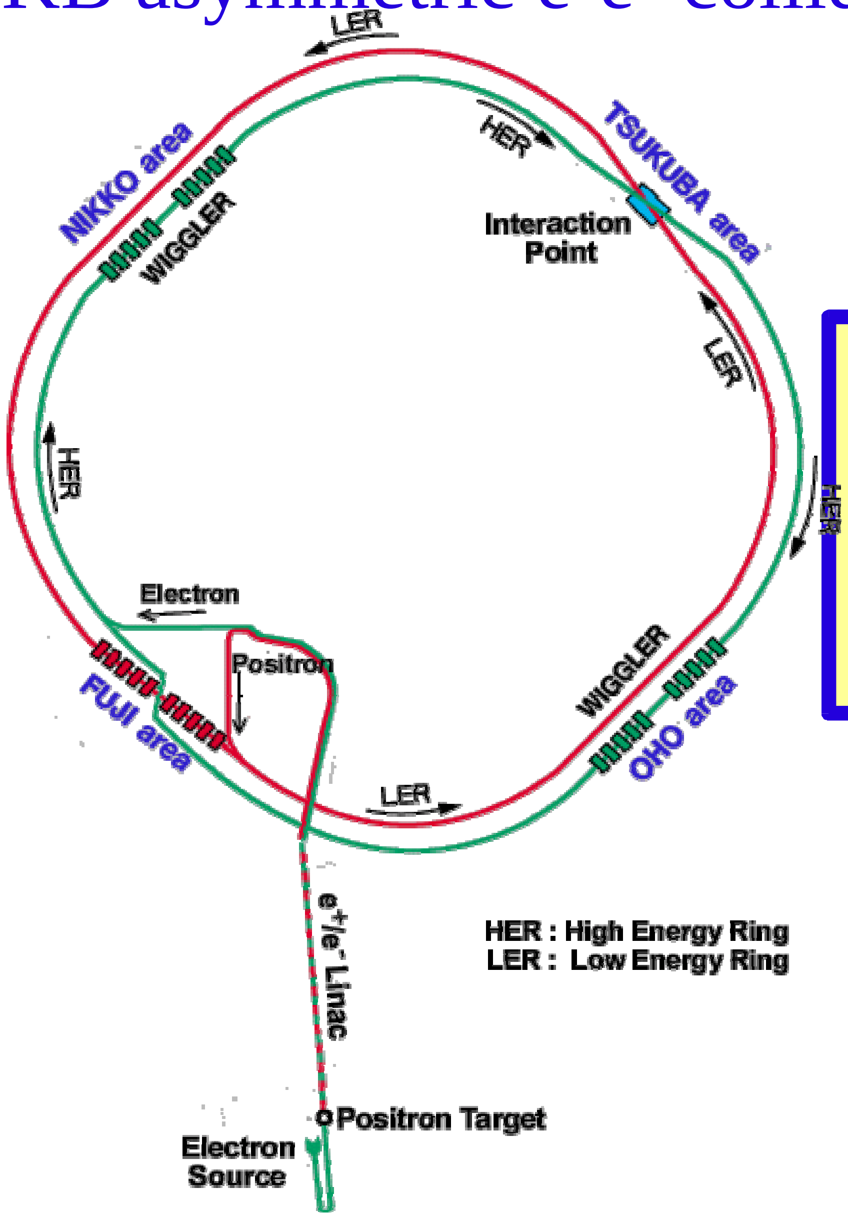
→ *very hard to measure decay vertex.*

Asymmetric collision



2. Accelerator and Detector

KEKB asymmetric e^+e^- collider



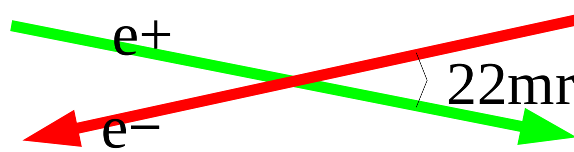
Two separate rings for
electrons (HER) : 8.0 GeV
positrons (LER) : 3.5 GeV
−> E_{CM} = Y(4S)

Luminosity: World Record!!

$$L_{peak} = 4.49 \times 10^{33}\, cm^{-2}\, sec^{-1}$$

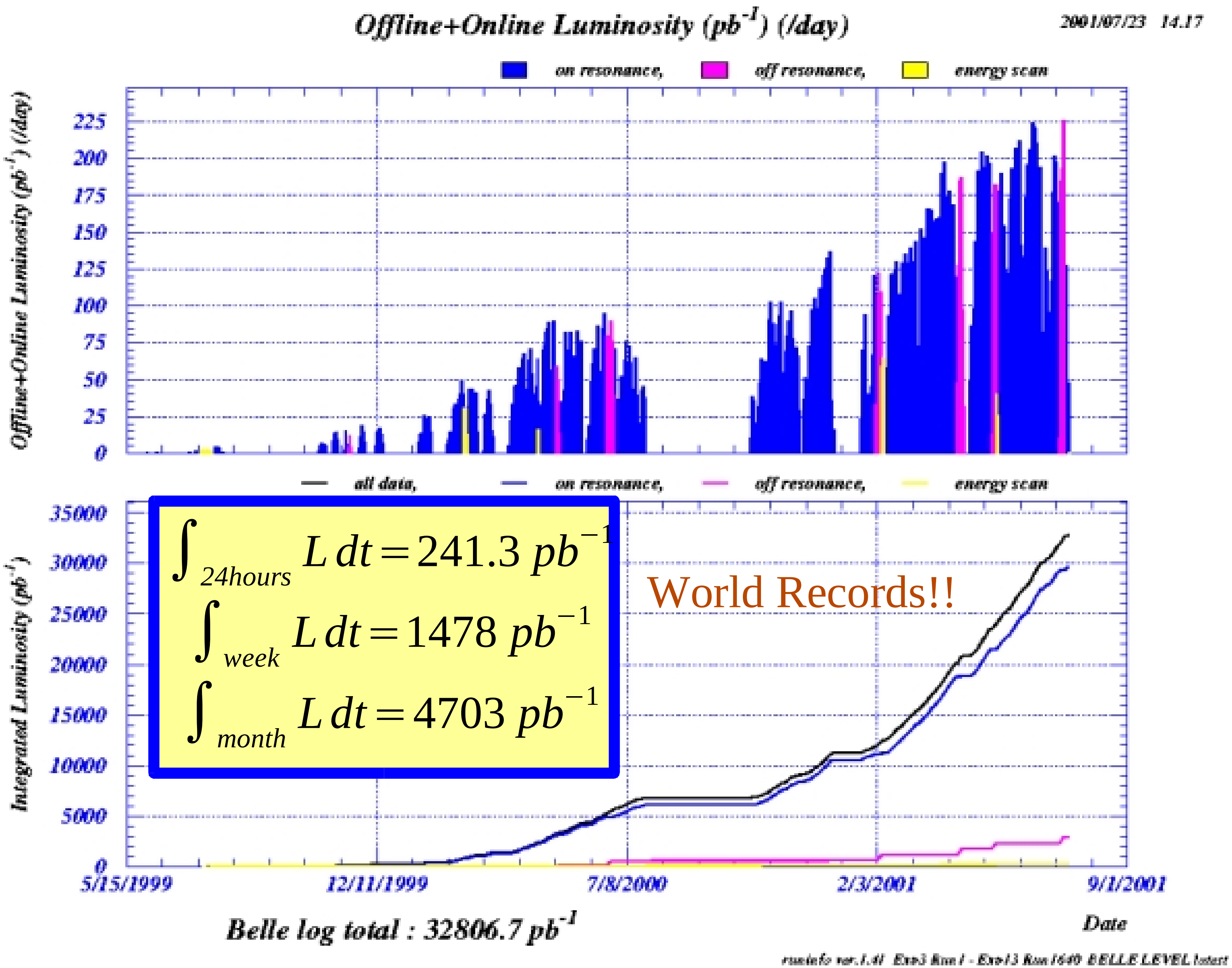
$$\left(Design = 10^{34}\, cm^{-2}\, sec^{-1} \right)$$

$$Crossing\ Angle : \pm 11\, mrad$$



- no bending magnet
- background reduction in detector

$$Beam\ Size\ : \sigma_x \sim 100\,\mu m ; \sigma_y \sim 3\,\mu m$$



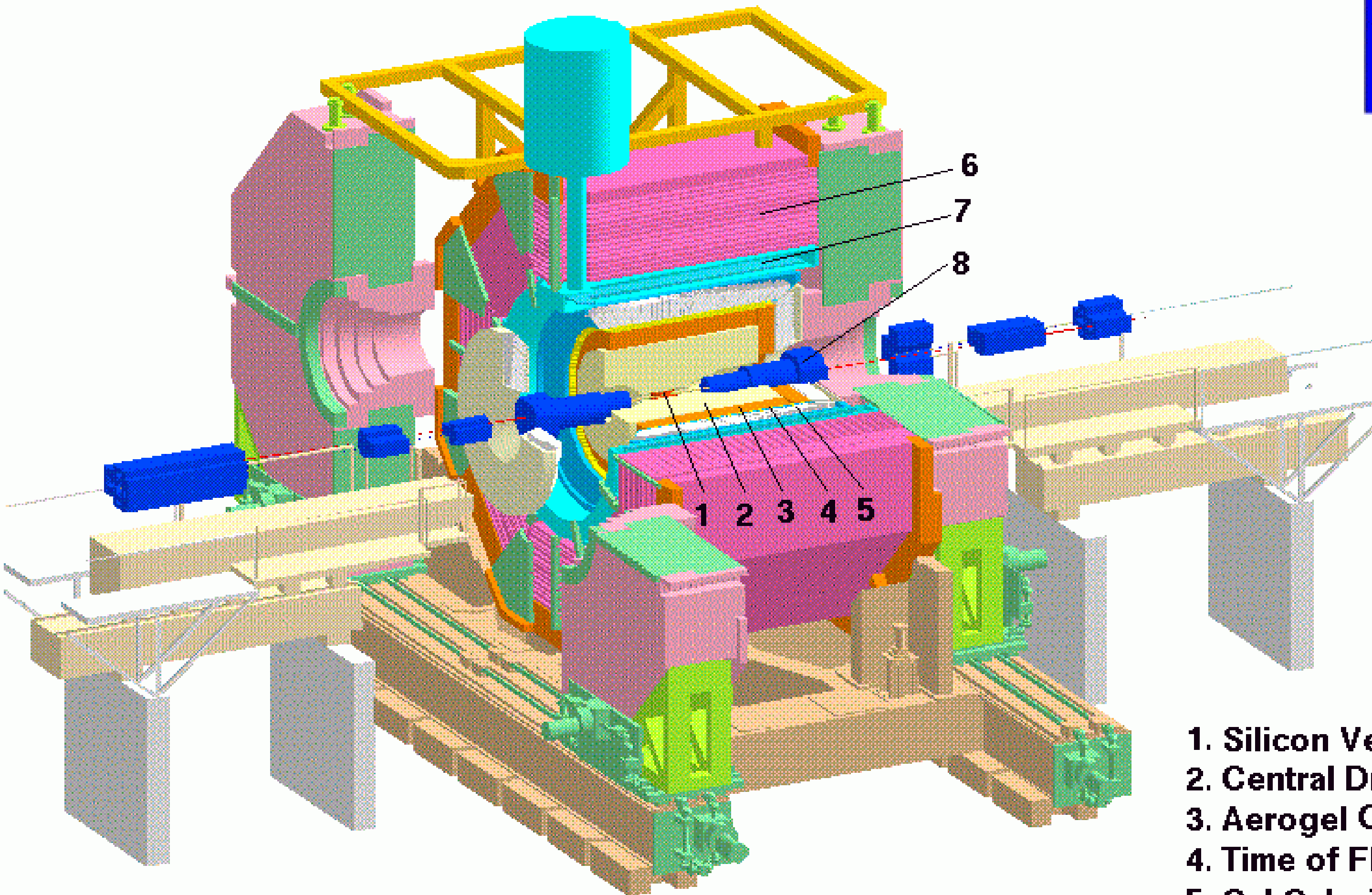
$$\int_{24hours} L\,dt = 241.3\ pb^{-1}$$

$$\int_{week} L\,dt = 1478\ pb^{-1}$$

$$\int_{month} L\,dt = 4703\ pb^{-1}$$

World Records!!

Belle Detector



1. Silicon Vertex Detector
2. Central Drift Chamber
3. Aerogel Cherenkov Counter
4. Time of Flight Counter
5. CsI Calorimeter
6. KLM Detector
7. Superconducting Solenoid
8. Superconducting Final Focussing System

Detector Performance

- SVD : occupancy < 4%

  $\sigma \sim 55\mu m$ for 1GeV/c track @ 90^o
- CDC : inner layer occupancy < 10%

  $\sigma p_t/p_t = (0.19 p_t \oplus 0.3)\%$ (~0.35% @ 1GeV/c)

  $\sigma_\pi(dE/dx) \sim 7.0\%$
- ECL : pedestal spread : endcap < 1MeV; barrel < 500 keV

  $\sigma_E/E = (1.3 \oplus 0.07/E \oplus 0.8/E^{1/4})\%$ (~ 1.8% @ 1GeV)

- Hadron ID : TOF + ACC + dE/dx

  Kaon ID : efficiency> 75%, fake<5.5% for 0<p<5.0GeV

- Lepton ID: electron (E/p, dE/dx, etc), muon (KLM,ECL)

  Electron ID: Eff > 90%, 0.3% fake rate at 1GeV/c

  Muon ID : Eff > 90%, 2% fake rate > 1GeV/c

- DAQ: Trigger rate ~ 200−300Hz, Deadtime < 5%, Record Speed ~ 5MB/s

Data set used for CP analysis

- Data used for the analysis are taken on Υ(4S) resonance

  3 data sets:

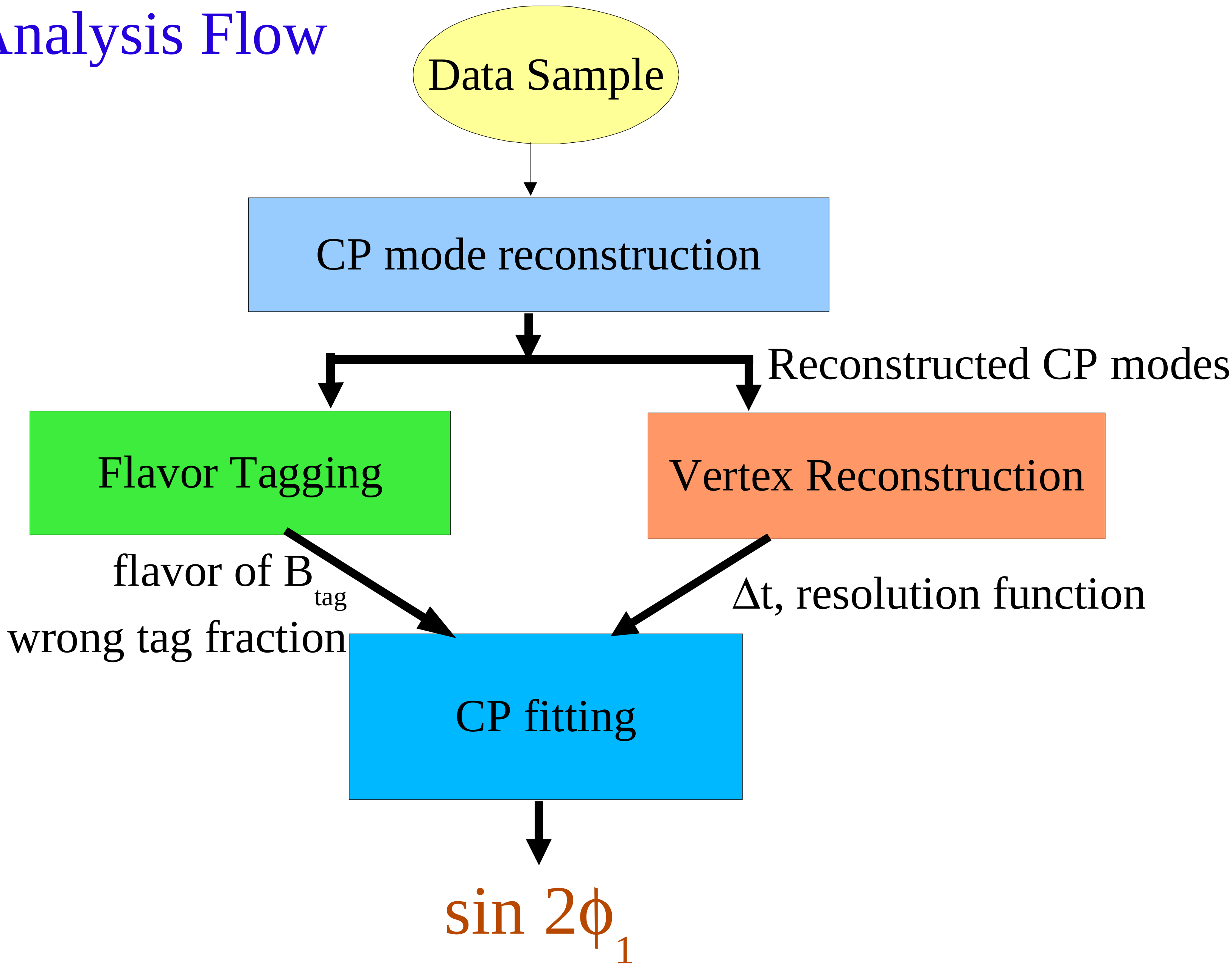
Set 1 :	10.5 fb^{-1}	(June 1999 − July 2000)
Set 2 :	10.6 fb^{-1}	(Oct 2000 − May 2001)
Set 3 :	8.0 fb^{-1}	(May 2001 − July 2001)
Total :	29.1 fb^{-1}	

  ~ 31.3M $B\bar{B}$ events

- Old data sets were reprocessed by the latest version of detector reconstruction software

Consistent reconstruction procedure for all the data set

Analysis Flow



3. Reconstruction of CP modes

We used following CP eigenstate modes for sin $2\phi_1$ measurement.

CP odd ($\xi_f = -1$)

$$B^0 \to J/\psi(\to l^+ l^-) + K_S(\to \pi^+\pi^-, \pi^0\pi^0) \quad \text{: "Golden Mode"}$$

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

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

$$\eta_c(\to K_S K^+ \pi^-, K^+ K^- \pi^0) + K_S$$

CP even ($\xi_f = +1$)

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

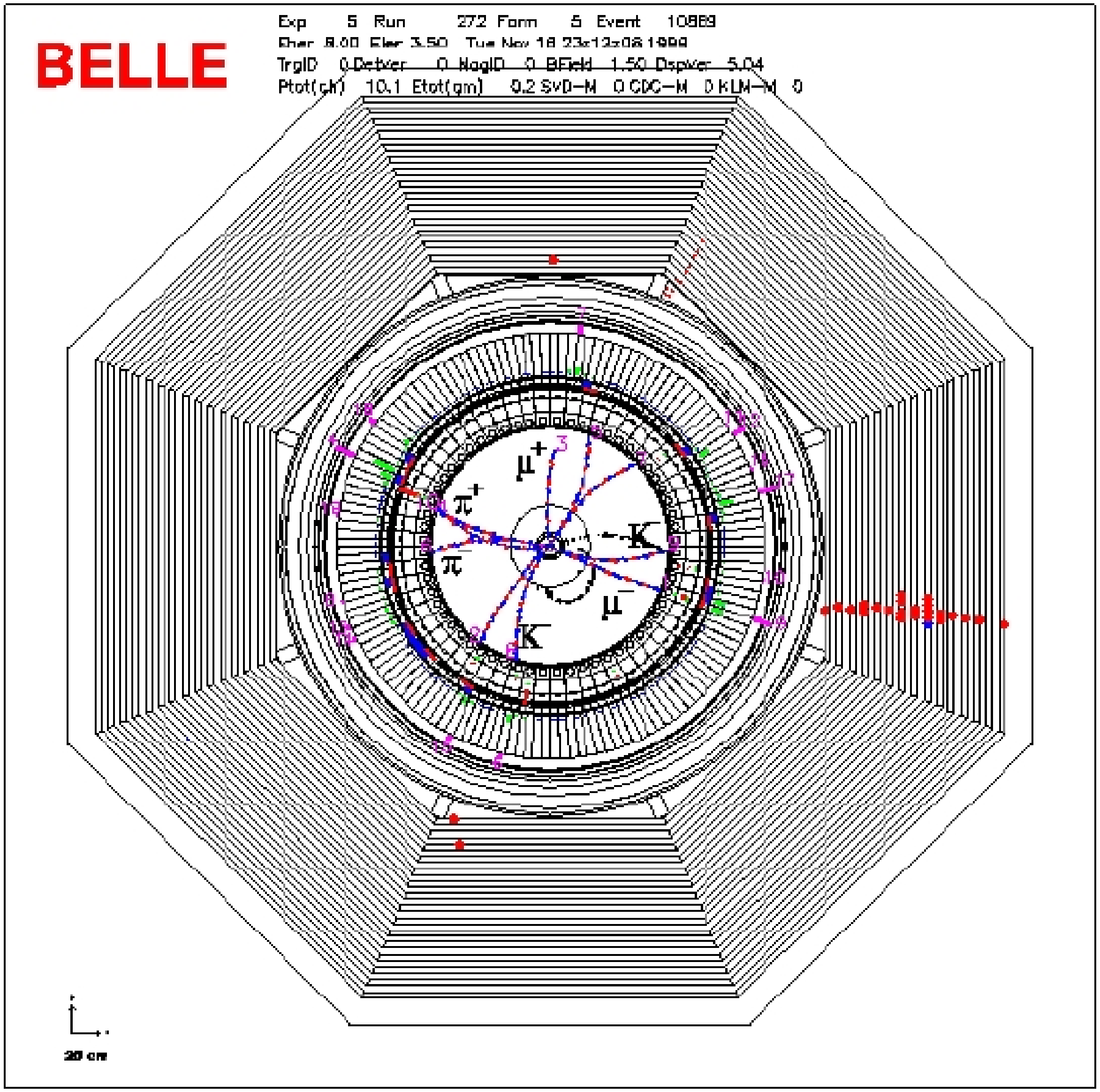
CP mixed ($\xi_f = +1$ or -1)

$$B^0 \to J/\psi + K^{*0}(\to K_S \pi^0)$$

← angular analysis is required to measure sin$2\phi_1$

How the event is seen:

$$B^0 \to J/\psi(\to \mu^+ \mu^-) + K_S(\to \pi^+ \pi^-)$$

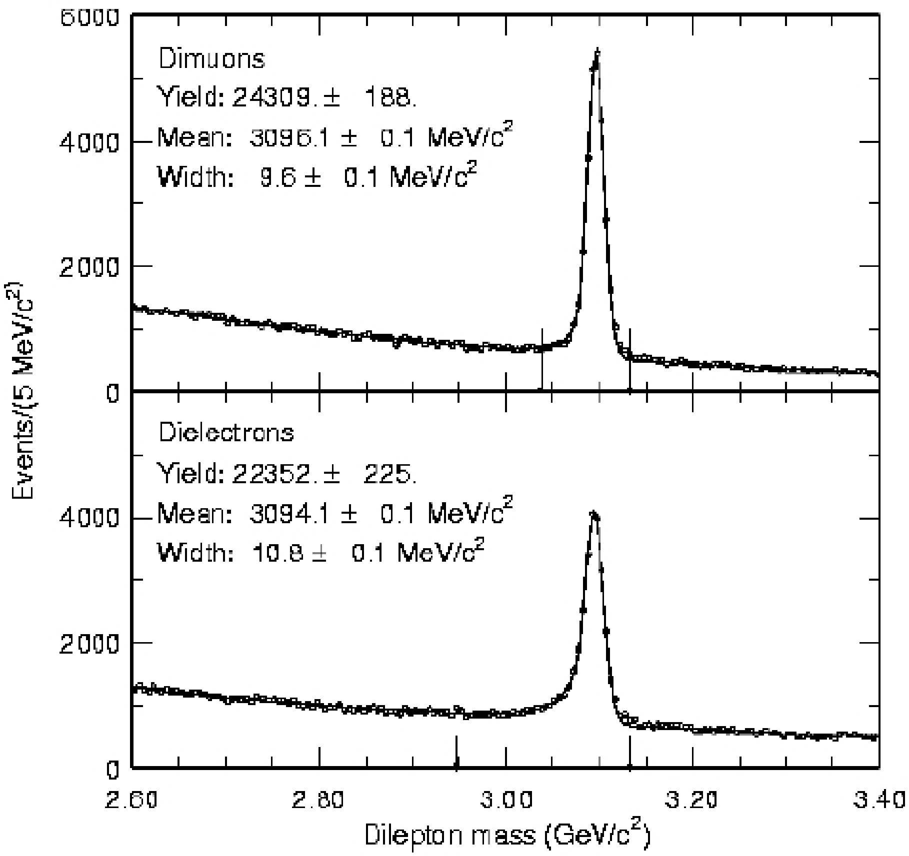


Reconstruction

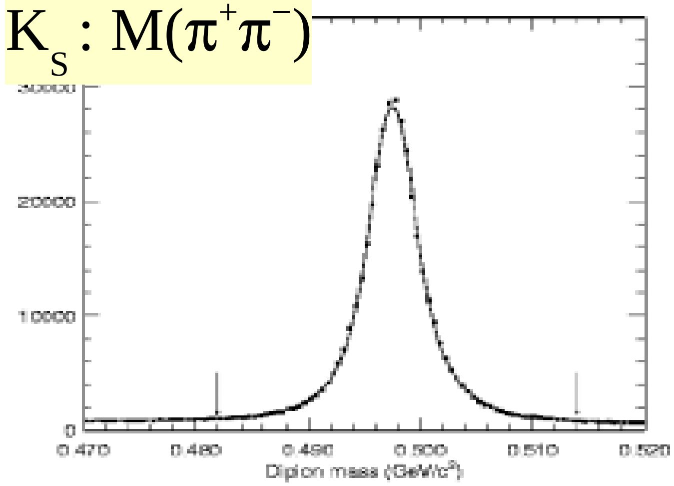
Reconstruction of $B^0 \rightarrow J/\psi(\rightarrow l^+ l^-) + K_S(\rightarrow \pi^{+/0} \pi^{-/0})$

lepton ID: electron : E/p, shower shape in ECL, dE/dx
muon : hit in KLM/ECL

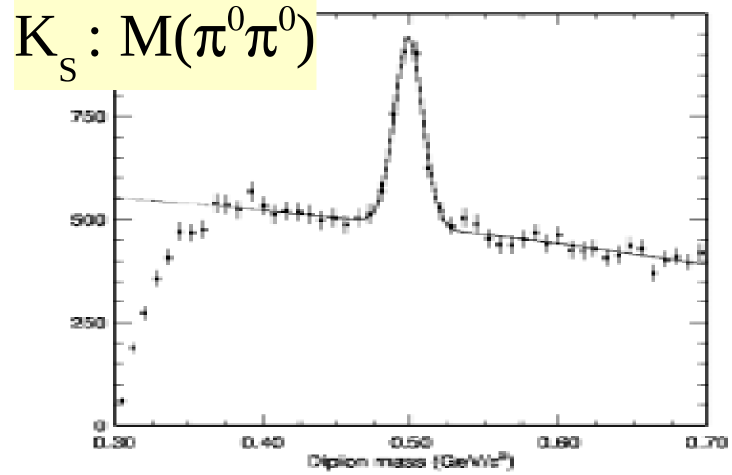
J/ψ : $M(l^+l^-)$

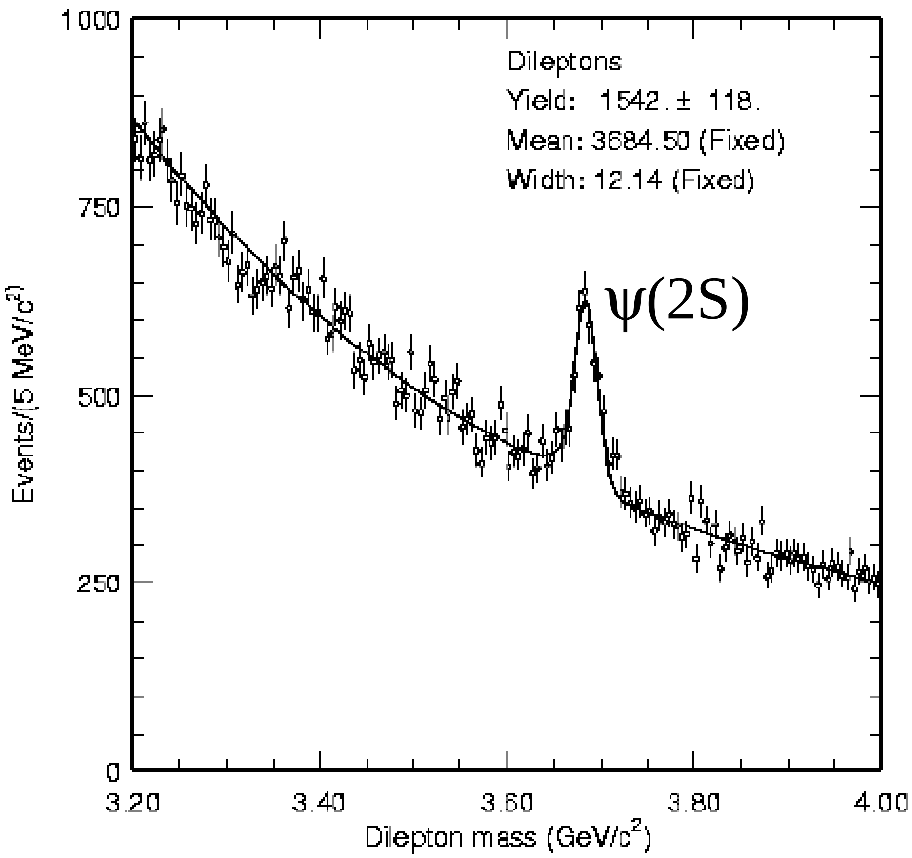


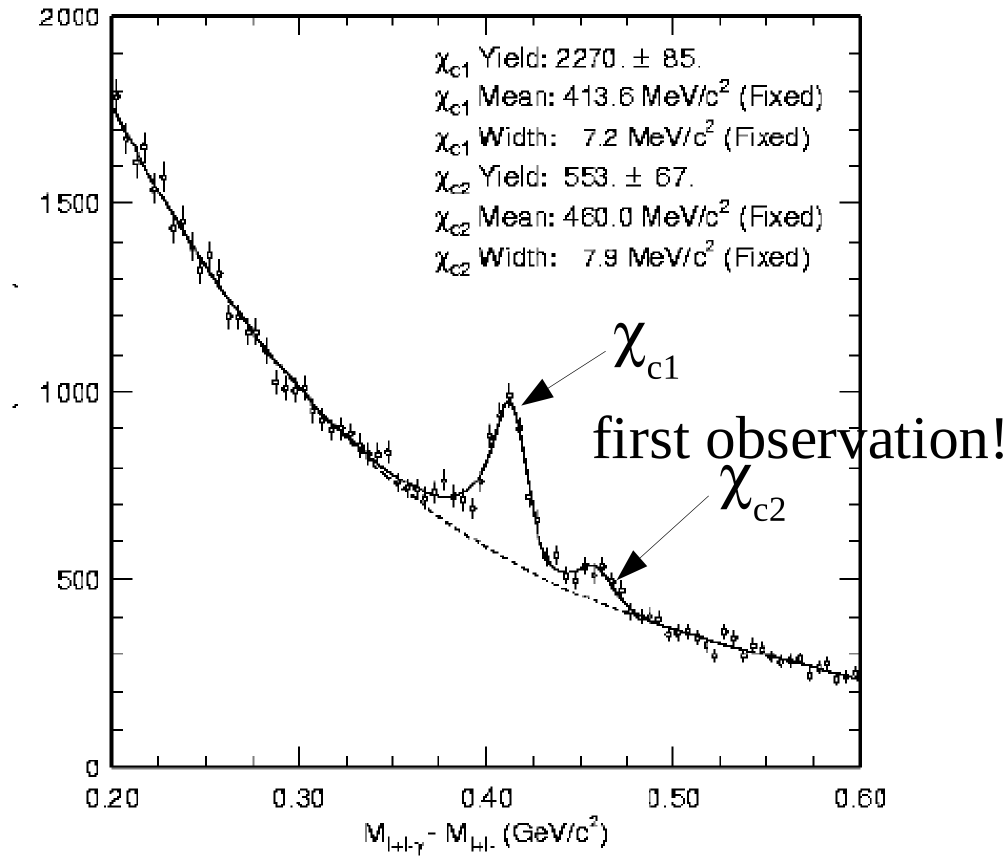
K_S : $M(\pi^+\pi^-)$



K_S : $M(\pi^0\pi^0)$




Dileptons
Yield: 1542. ± 118.
Mean: 3684.50 (Fixed)
Width: 12.14 (Fixed)
ψ(2S)
Events/(5 MeV/c²)
Dilepton mass (GeV/c²)
0
250
500
750
1000
3.20
3.40
3.60
3.80
4.00


χc1 Yield: 2270. ± 85.
χc1 Mean: 413.6 MeV/c² (Fixed)
χc1 Width: 7.2 MeV/c² (Fixed)
χc2 Yield: 553. ± 67.
χc2 Mean: 460.0 MeV/c² (Fixed)
χc2 Width: 7.9 MeV/c² (Fixed)
χc1
first observation!
χc2
0
500
1000
1500
2000
0.20
0.30
0.40
0.50
0.60

Reconstruction of B^0

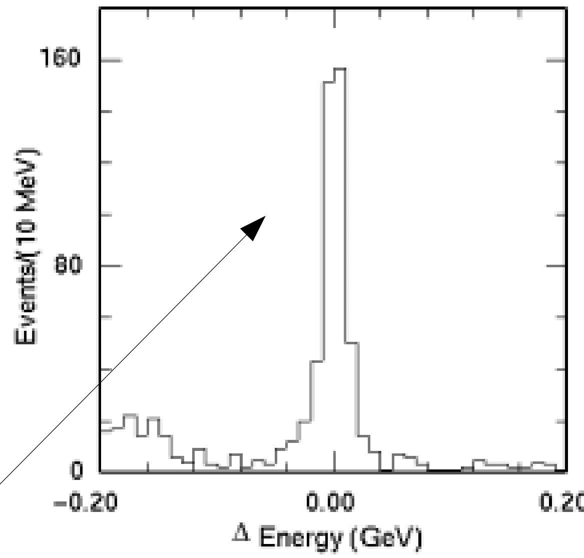
performed by calculating energy and momentum of $J/\psi + K_S$

Energy difference:

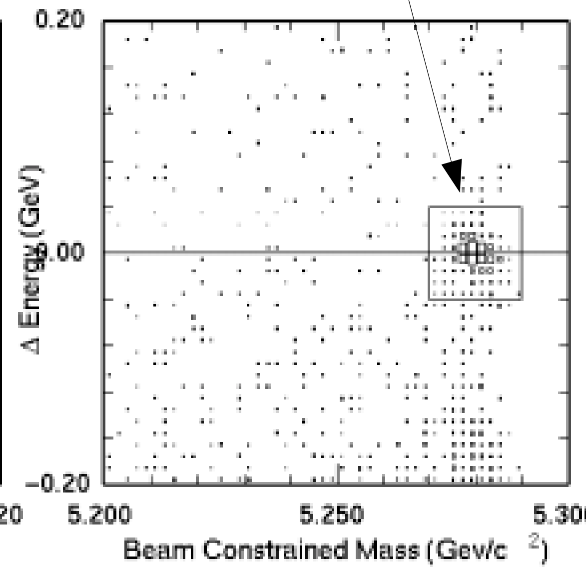
$$\Delta E = (E_{J/\psi} + E_{K_s}) - E_{CM}/2.0$$

energy of B0 candidate

expected energy of B0



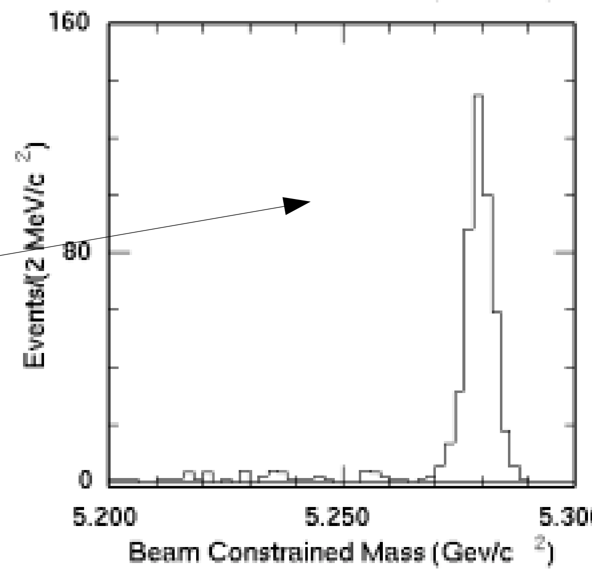
signal box



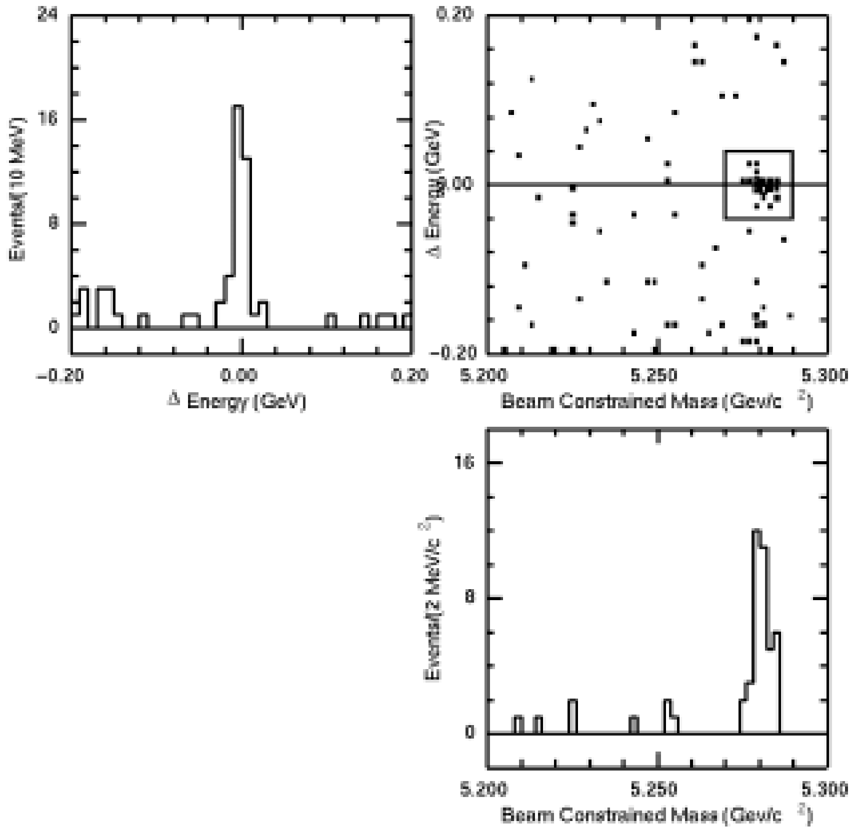
Beam Constrained Mass:

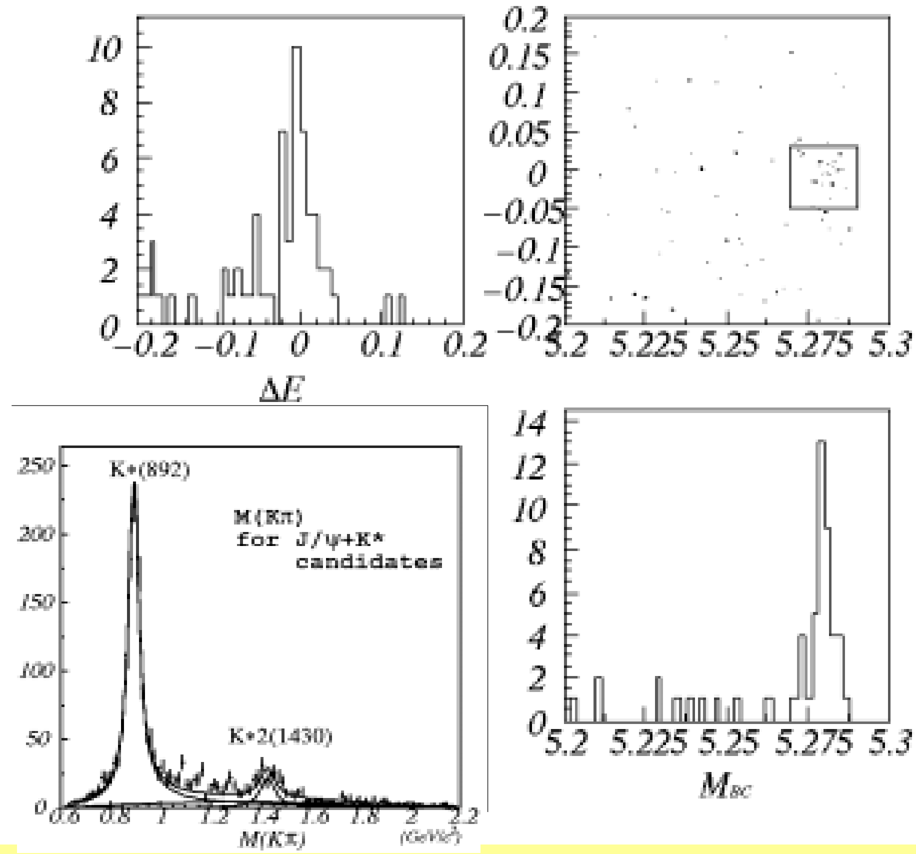
$$M_{bc} = \sqrt{(E_{CM}/2.0)^2 - (p_{J/\psi} + p_{K_s})^2}$$

momentum of B0 candidate



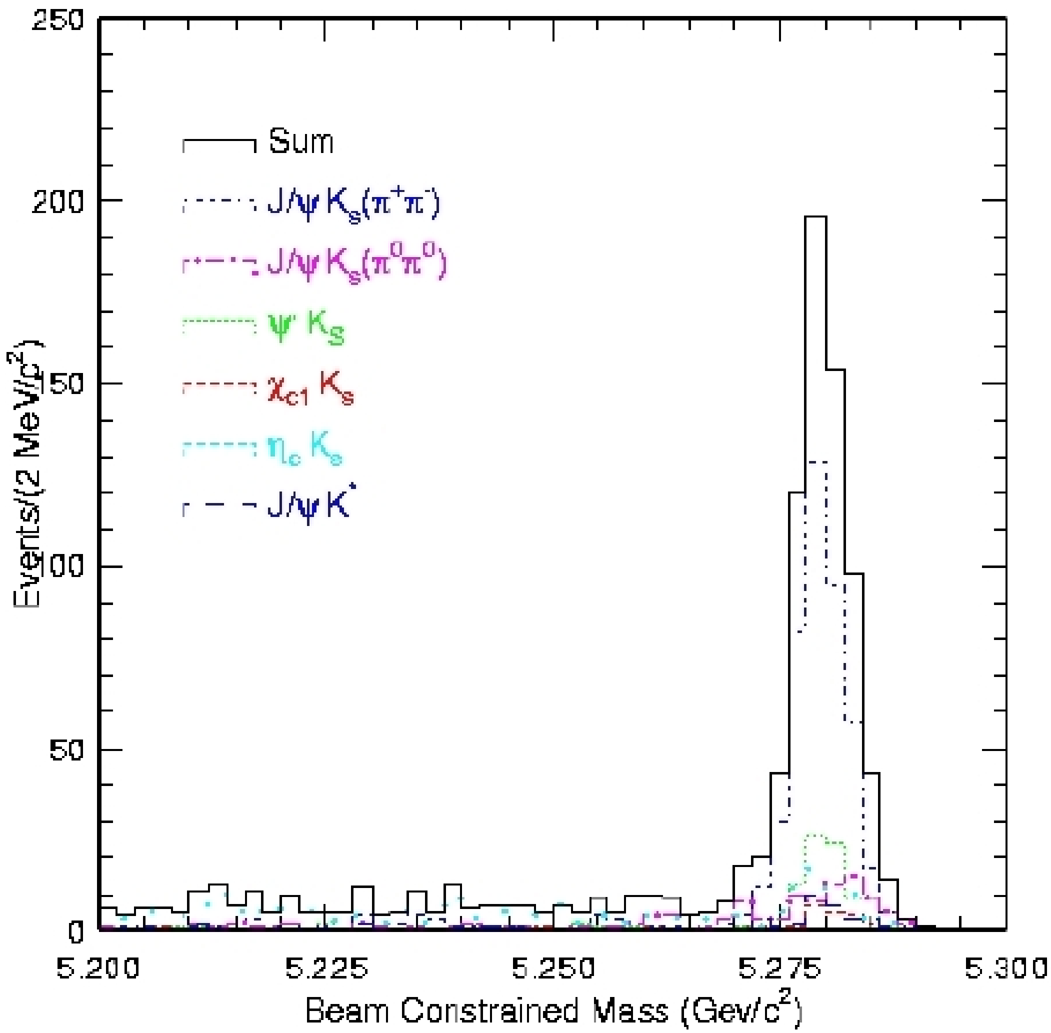
$B^0 \to \psi'(\to J/\psi \pi^+ \pi^-) + K_S(\to \pi^+ \pi^-)$ $B^0 \to J/\psi(\to l^+ l^-) + K^{*0}(\to K_S + \pi^0)$





- Background contamination is estimated from the fit to the background dominated region in ΔE and M_{bc} distributions <− combinatorial background
- Additional backgrounds in $J/\psi+K^{*0}$:
  1. non−resonant production ($J/\psi+K+\pi$) <− estimated from $M(K\pi)$ dist.
  2. feed across from other $J/\psi+K^*$ decay (such as $B^+ \to J/\psi + K^{*+}(\to K_S + \pi^+)$)
     <− estimated by Monte Carlo

Beam constrained mass distribution summed over (c$\bar{c}$)Ks and J/ψK*



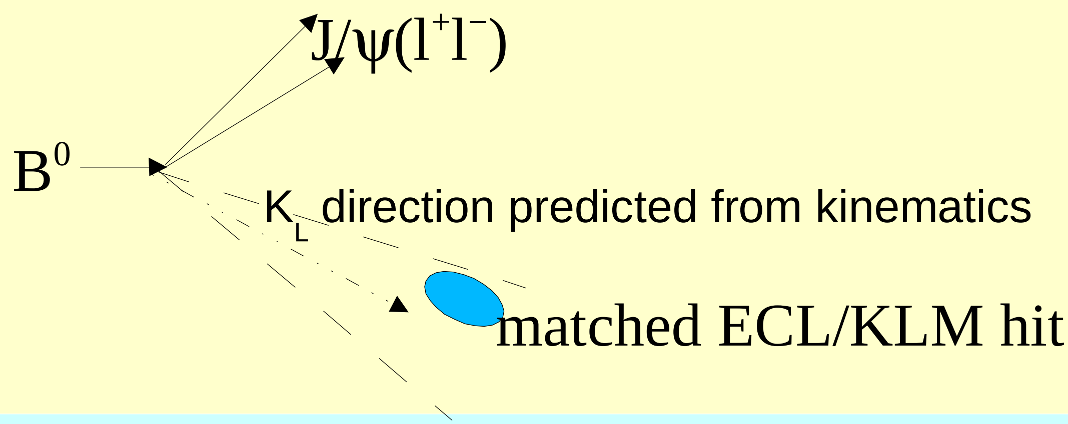
Reconstruction of $B^0 \rightarrow J/\psi(\rightarrow l^+ l^-) + K_L$

K_L detection : Detected by "hadron shower" in ECL and KLM

Reconstruction:

1) If J/ψ is found, assume the event is originated from J/ψ+K_L and calculate direction of K_L.

2) Find KLM/ECL hit cluster consistent with the direction (within 45^o cone)
   − no association with charged tracks



Background rejection

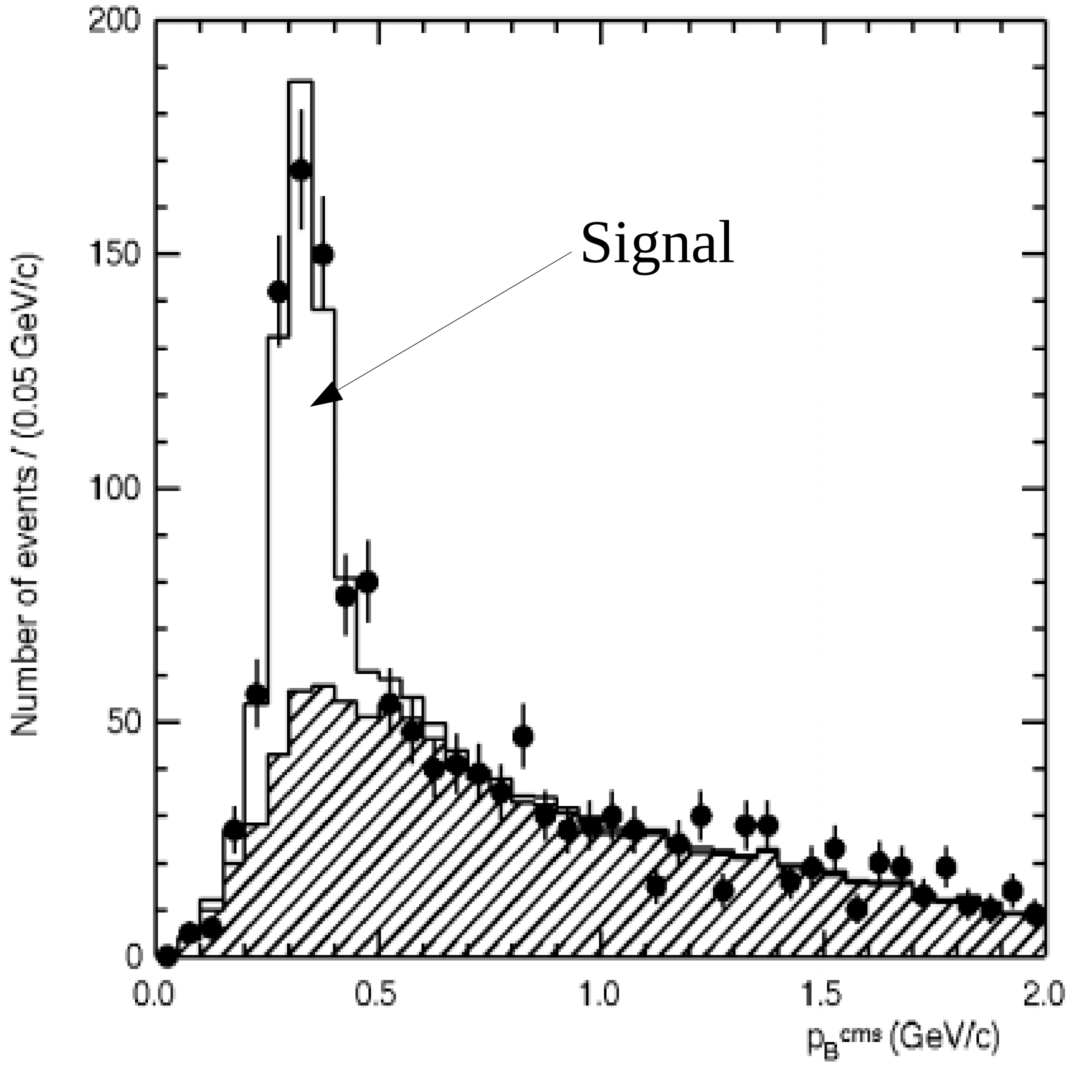
1) Remove reconstructed B−>J/ψK, J/ψK* ....

2) Cut on a likelihood based on J/ψ momentum, angle of K_L to nearest charged track, charged multiplicity, etc.

B^0 momentum distribution in CMS

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

K_L momentum is calculated from the direction and 2−body kinematics

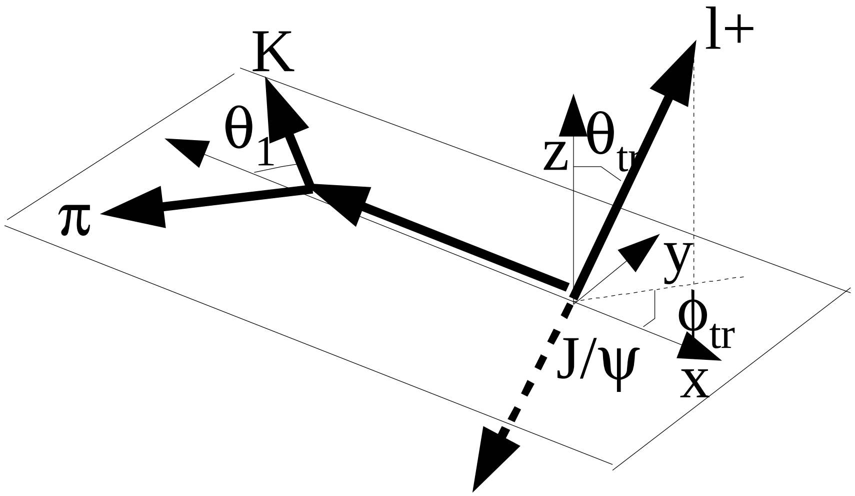


Summary of reconstructed CP eigenstate modes

	mode	N_{ev}	N_{bg}
CP= −1	$J/\psi(l^+l^-)K_S(\pi^+\pi^-)$	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
	$\psi(2S)(l^+l^-)K_S(\pi^0\pi^0)$	46	2.1
	$\chi_{c1}(J/\psi\gamma)K_S(\pi^+\pi^-)$	24	2.4
	$\eta_c(K^+K^-\pi^0)K_S(\pi^+\pi^-)$	23	11.3
	$\eta_c(K_SK^+K^-)K_S(\pi^+\pi^-)$	41	13.6
	subtotal	**706**	**51.9**
CP = +1	$J/\psi(l^+l^-)K_L$	569	223
CP = mixed	$J/\psi(l^+l^-)K^{*0}(K_S(\pi^+\pi^-)\pi^0)$	41	6.7

Total : 1316 events

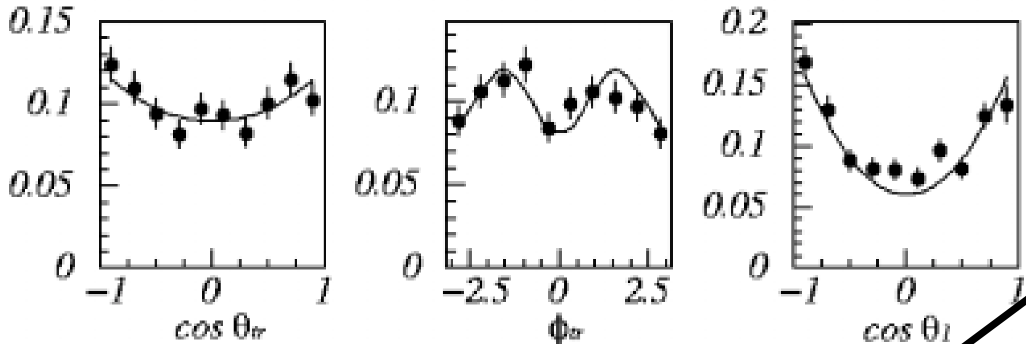
CP content in $B \to J/\psi + K^{*0}$



Angular distribution in transversity basis
-> can be expressed by 3 complex amplitudes (A_0,$A_{//}$ and A_T)

$|A_T|^2$: CP odd fraction

Unbinned maximum likelihood fit to
$J/\psi(K^+\pi^-)^{*0}$, $J/\psi(Ks\pi^+)^{*+}$ and $J/\psi(K^+\pi^0)^{*+}$



Visualization Only

$|A_0|^2 = 0.60 \pm 0.03 \pm 0.04$

$|A_T|^2 = 0.19 \pm 0.04 \pm 0.04$

$arg(A_{//}) = 2.86 \pm 0.25 \pm 0.05$

$arg(A_T) = 0.01 \pm 0.19 \pm 0.08$

$|A_0|^2 + |A_{//}|^2 + |A_T|^2 = 1$

$arg(A_{//}) = 0.0$ (definition)

CP odd = 19 ± 4%

4. Flavor Tagging

- We need to know which of B^0 or $\overline{B}^0$ decays into CP eigenstate.
  - ← No way to know from the CP eigenstate
  - → can be known from the other B^0 decay

- How the flavor can be known?

1) Inclusive Leptons

$b \to c\, l^- \nu$

$\quad\;\; \hookrightarrow s\, l^+ \nu$

- prompt lepton (high *p*)
- lepton from cascade decay (med. *p*)

2) Inclusive Hadrons

$B^0 \to D^{(*)-} \pi^+$

$\quad\quad \hookrightarrow K^+ X$

$\quad\quad \hookrightarrow D^0 \pi^-$

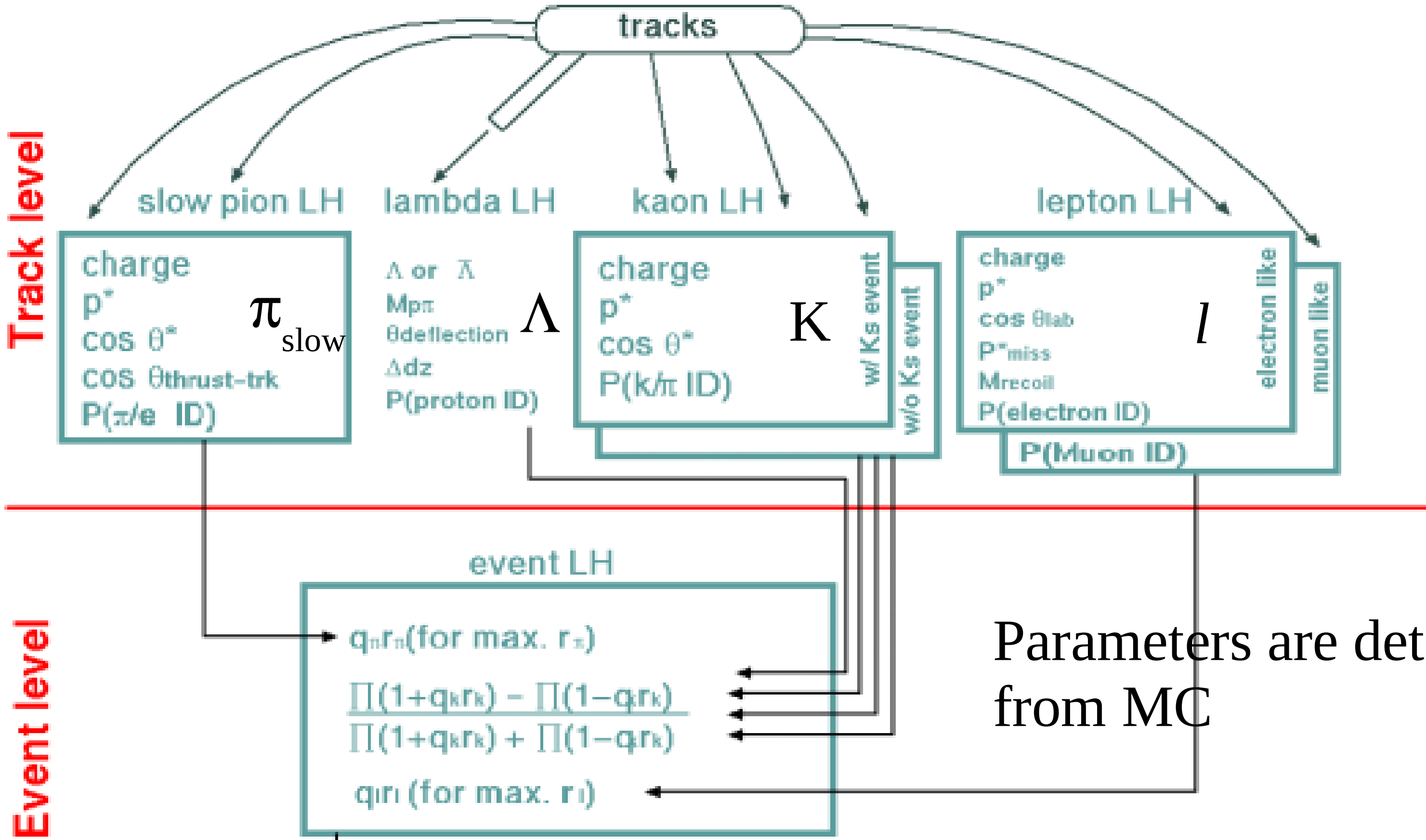
and others

- high momentum pion
- intermediate p kaon
- slow pion

charge of these particles –> flavor

"flavor tagging"

Multi−dimensional likelihood method



$$q\cdot r \equiv \frac{N(B^0_{tag})-N(\overline{B^0_{tag}})}{N(B^0_{tag})+N(\overline{B^0_{tag}})}$$

Parameters are determined from MC

gives q and r for each event

$q=+1$: Tag = B^0
$q=-1$: Tag = $\overline{B}^0$

r: flavor tagging dilution factor
−> used to sort event into 6 categories
(r=0; cannot determine flavor)

Wrong tag fraction ω

- Probability of incorrect flavor assignment -> necessary in CP fit
- given event by event
- determined from data (we don't use "r" to avoid systematics in MC)

ω_l : obtained for 6 "r" bins using

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

l	r	*fraction*	w_l
1	$0.000 - 0.250$	0.405	$0.465^{+0.010}_{-0.009}$
2	$0.250 - 0.500$	0.149	$0.352^{+0.015}_{-0.014}$
3	$0.500 - 0.625$	0.081	$0.243^{+0.021}_{-0.030}$
4	$0.625 - 0.750$	0.099	$0.176^{+0.022}_{-0.017}$
5	$0.750 - 0.875$	0.123	$0.110^{+0.022}_{-0.014}$
6	$0.875 - 1.000$	0.140	$0.041^{+0.011}_{-0.010}$

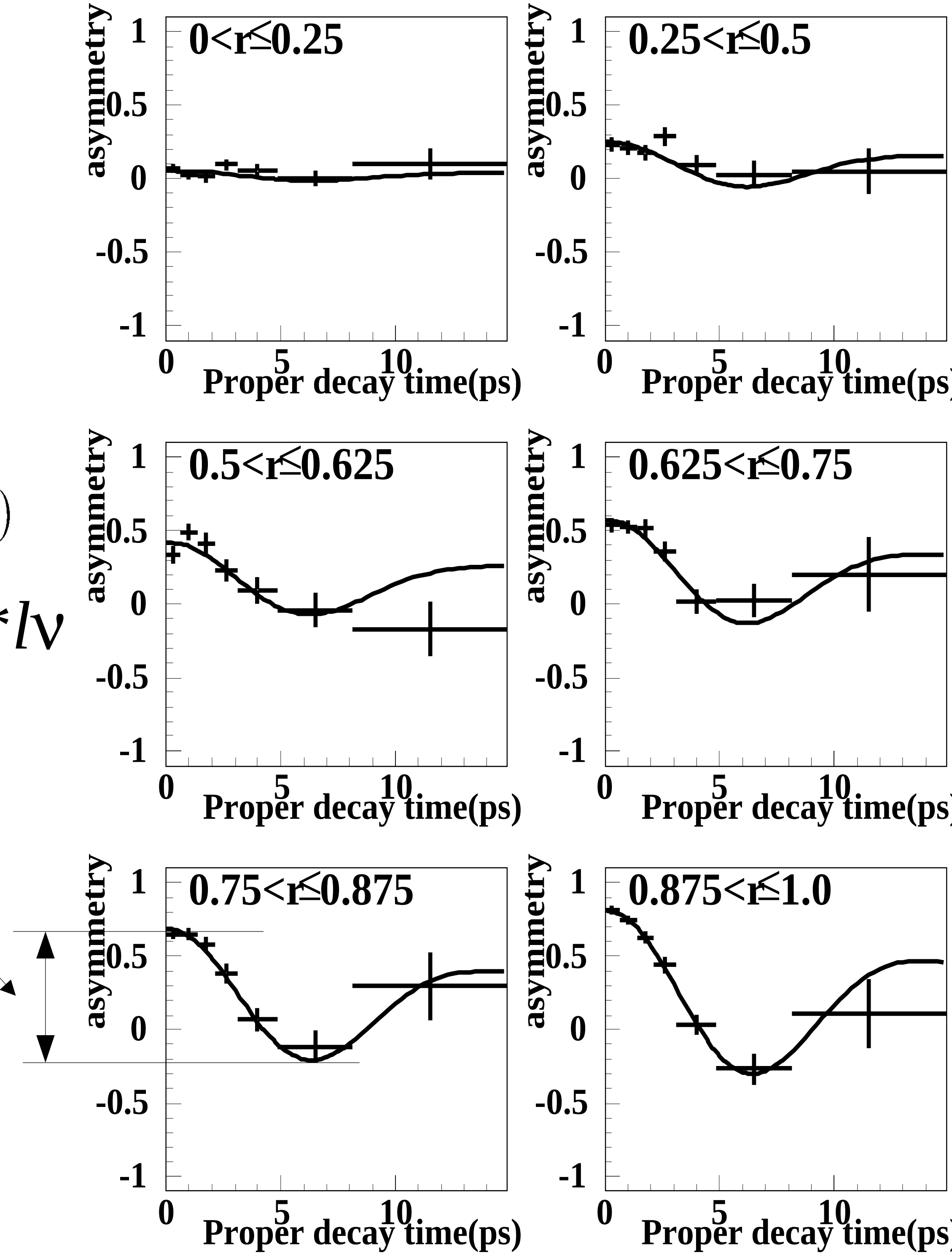
"ω = 0.5" is equivalent to just tossing a coin.

ω_l is determined by observing the asymmetry

$$Asym_{obs} \equiv \frac{N_{OF} - N_{SF}}{N_{OF} + N_{SF}}$$

$$= (1 - 2\omega_l)\cos(\Delta m_d \Delta t)$$

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



- Clear mixing observed

Procedure of flavor tagging

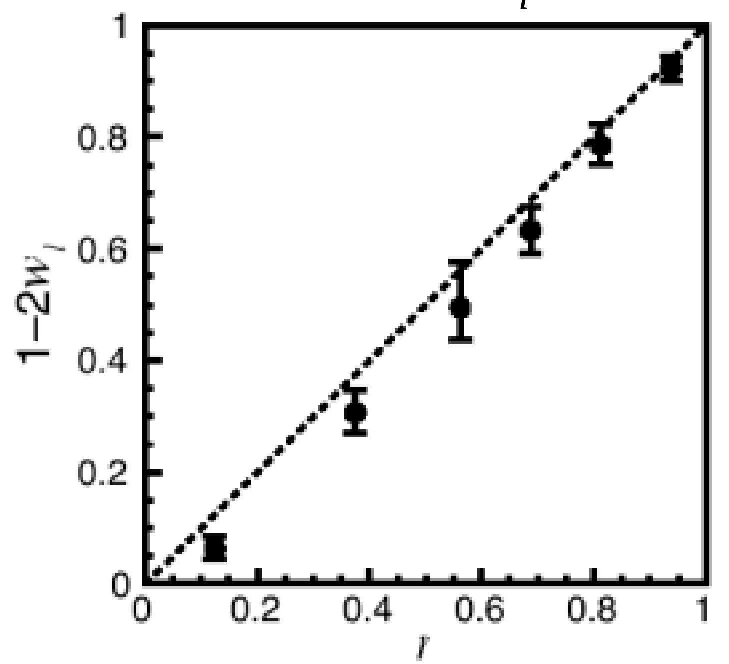
1) obtain "q" and "r" from MDLH
(based on the parameteres determined from MC)
2) "r" is used to classify the wrong tagging fraction
into 6 categories
3) Data−determined wrong tagging fraction ω_l is used for CP fit.

− Efficiency of flavor tagging
ε = > 99.5%
(uses all events)

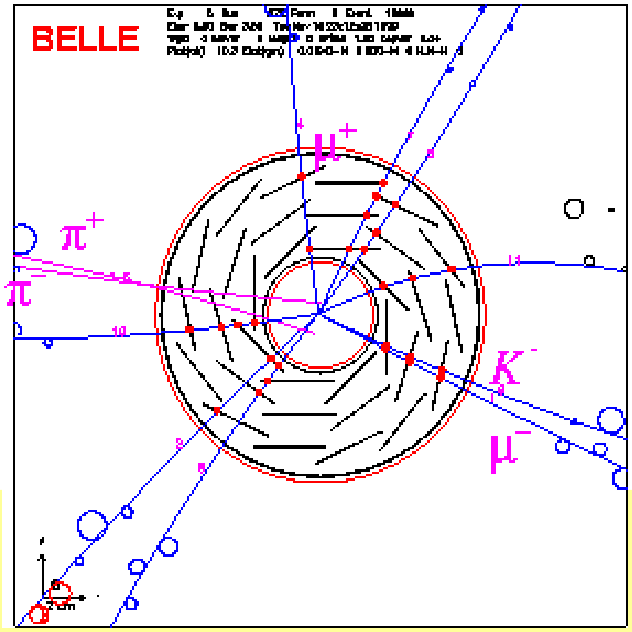
− Effective tagging efficiency

$$\epsilon_{eff} \equiv \epsilon r^2$$
$$= 27.0 \pm 1.2\,\%$$

r vs. ω_l



5. Vertex Reconstruction



- need to determine both of B^0 and $\overline{B}^0$ decay verteces.
- Measured z position difference is used to determine Δt

CP−side:
- vertex is determined from $J/\psi \to l^+ l^-$ vertex (kinematical constrained fit. reject badly fitted events.)
- efficiency = 92%, $\sigma(z_{cp})$ = 75 μm

Tag−side:
- use tracks other than those used for CP−side reconstruction (Ks tracks are not used, reject badly fitted tracks)
- efficiency = 91%, $\sigma(z_{tag})$ = 140 μm

- Require |Zcp − Ztag| < 2mm (~ 10 τ_B)

$\longrightarrow$ 1137 events (q=+1: 560 events, q=−1: 577 events)
(Efficiency = 85%)

Resolution Function

- Measured vertex position is smeared by detector effect, charmed meson lifetime, etc.

  −> has finite resolution

- Resolution function is expressed as a sum of two Gaussians

$$R = (1 - f_{tail})\, G(\Delta t; \mu_{main}, \sigma_{main}) + f_{tail}\, G(\Delta t; \mu_{tail}, \sigma_{tail})$$

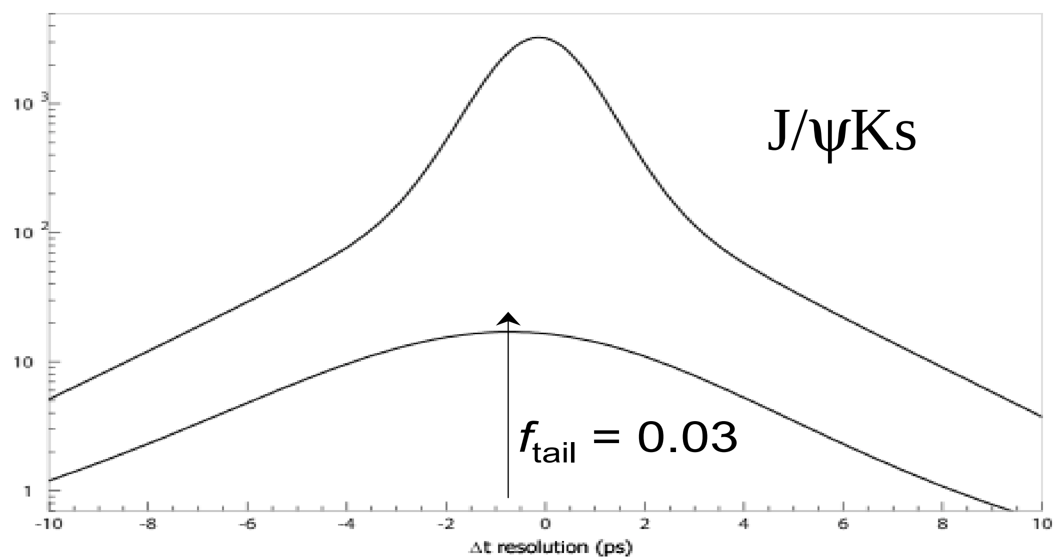
SVD vertex resol.
charmed meson lifetime

poorly reconstructed tracks

σ/μ : calculated event by event from vertex fit errors

- Resolution function for BG: the same form, parameters <− sideband

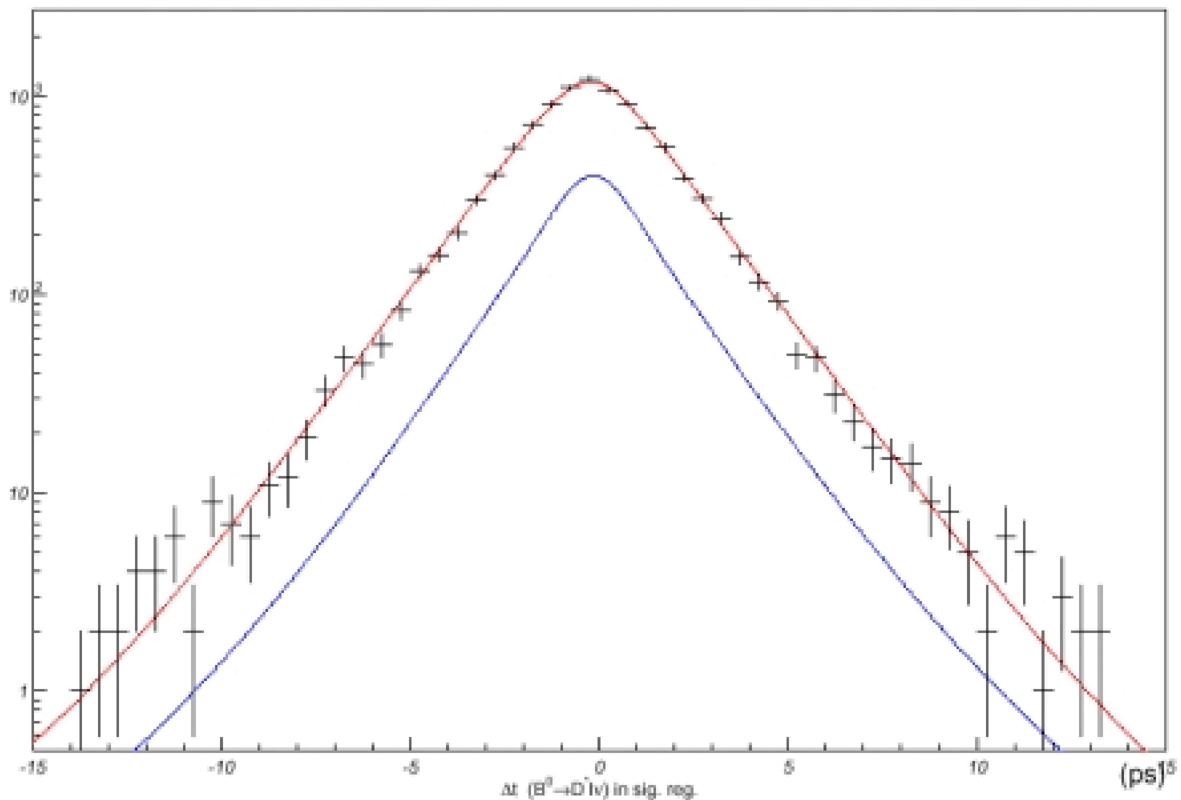
$\mu_{main} = -0.24$ps
$\sigma_{main} = 1.49$ps
$\mu_{tail} = 0.18$ ps
$\sigma_{tail} = 3.85$ ps



Validation of vertex reconstruction

- The lifetime of B0 meson is measured using the same procedure

$B \to D^* l \nu$



Measured

$$\tau_{B^0} = 1.55 \pm 0.02\ ps$$

$$\tau_{B^+} = 1.64 \pm 0.03\ ps$$

Consistent

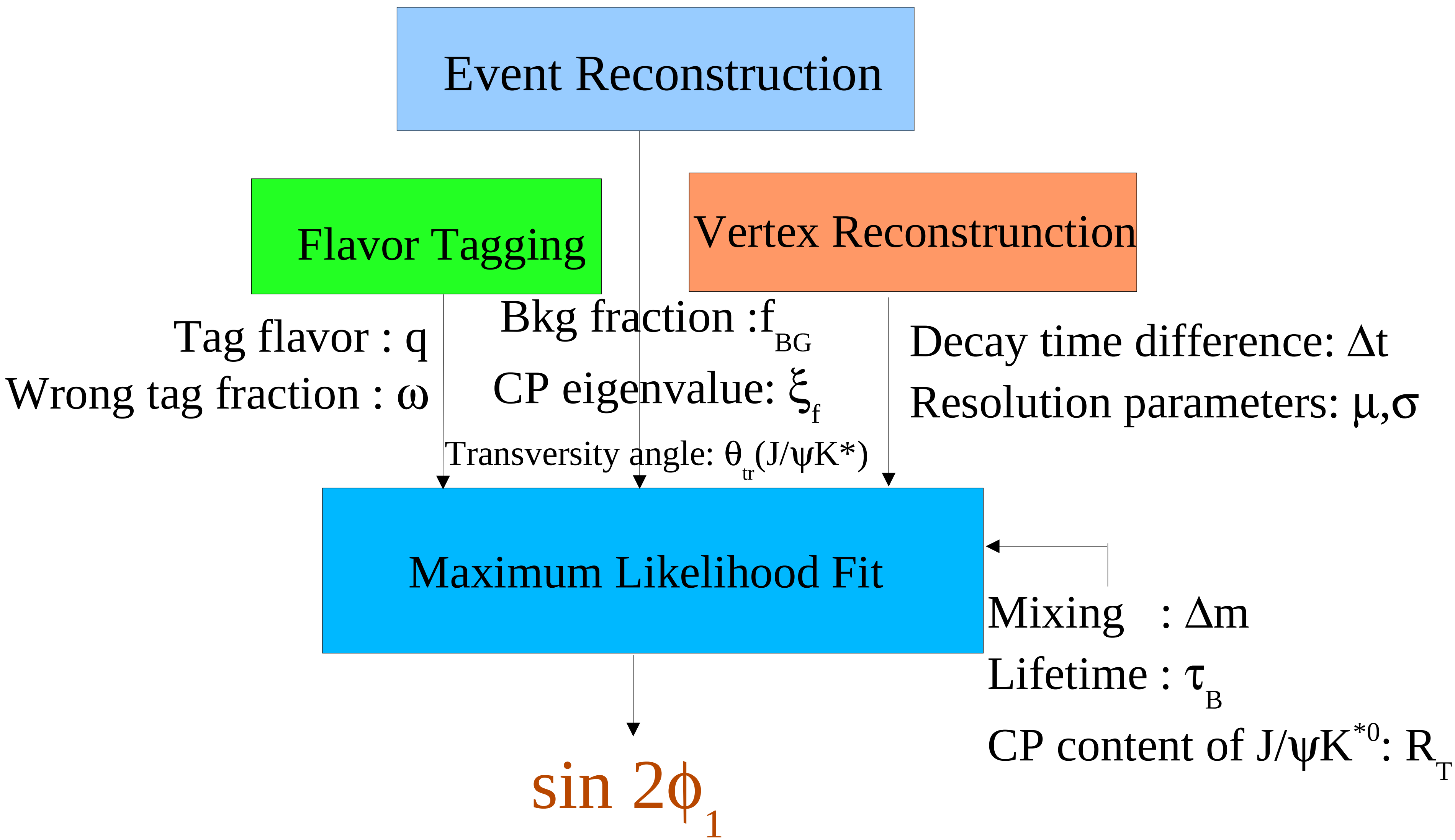
PDG

$$\tau_{B^0} = 1.55 \pm 0.03\ ps$$

$$\tau_{B^+} = 1.65 \pm 0.03\ ps$$

5. CP fitting

Procedure of CP fitting



Probability Density Function (PDF)

$$PDF = (1 - f_{BG})\, PDF_{sig} + f_{BG}\, PDF_{BG}$$

f_{BG} : given by data sideband or MC

PDF for modes with definite CP eigenstate (other than $J/\psi K^{*0}$)

$$\text{Signal:}\quad PDF_{sig} = \frac{e^{-|\Delta t|/\tau_B}}{2\tau_B}(1-\xi_f q)(1-2\omega_l)\sin 2\phi_1 \sin(\Delta m \Delta t)$$

Parameter determined from fit ($\sin 2\phi_1$)

ξ_f : +1 for CP=+1, −1 for CP = −1

q : b flavor tag

w : wrong tag fraction

(q, w: given event−by−event)

τ_B : B life time

Δm : B mixing parameter

fixed at PDG values

$$\text{BG:}\quad PDF_{BG} = f_\tau \frac{e^{-|\Delta t|/\tau_{BG}}}{2\tau_{BG}} + (1-f_\tau)\delta(\Delta t)$$

f_τ : fraction of background with effective lifetime τ_{BG}

~ < 5% for modes other than $J/\psi K_L$

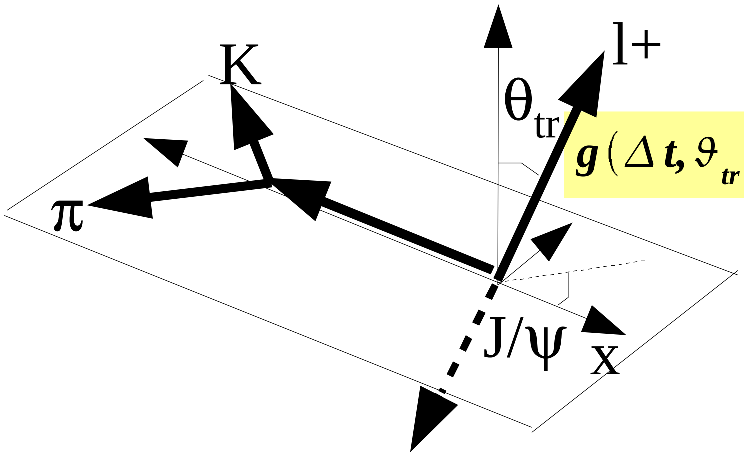
$J/\psi K_L$: non−CP decay(71%), $J/\psi K^*(K_L \pi^0)$(13%), other CP(15%)

→ − $\tau_{BG} = \tau_B$, estimated from p_B^* shape using MC

− signal PDF is used for CP decay backgrounds

PDF for $J/\psi K^{*0}$: CP mixed state -> cannot determine definite ξ_f

event-by-event CP state "likelihood" can be extracted from transversity angle -> simultaneous fit to Δt and transversity angle



$$g(\Delta t, \vartheta_{tr}) = \frac{e^{-|\Delta t|/\tau_B}}{2\tau_B}\frac{3}{8}(1-R_T)(1+\cos^2\vartheta_{tr})(1-q)(1-2\omega)\sin 2\phi_1 \sin\Delta m \Delta t$$

CP even term

$$+\frac{e^{-|\Delta t|/\tau_B}}{2\tau_B}\frac{3}{4}R_T\sin^2\vartheta_{tr}(1+q)(1-2\omega)\sin 2\phi_1\sin\Delta m\Delta t$$

CP odd term

$R_T = 0.19$; ratio of CP odd ← full angular analysis

$$PDF_{sig} = f_{sig}\,\epsilon(\vartheta_{tr})\cdot g(\Delta t, \vartheta_{tr})$$

acceptance correction function

$$PDF_{BG} = \sum f^i_{fa}\frac{e^{-|\Delta t|}/\tau_{fa}}{2\tau_{fa}} + f_{nr}\frac{e^{-|\Delta t|}/\tau_{nr}}{2\tau_{nr}} + f_{combi}\left(f_\tau\frac{e^{-|\Delta t|}/\tau_{combi}}{2\tau_{combi}} + (1-f_\tau)\delta(\Delta t)\right)$$

F

feed-across non-resonant combinatorial

τ_{fa} and τ_{nr} : set at τ_B

τ_{combi} : determined from fit to sideband

Event by Event Likelihood

$$L_i = \int ((1 - f_{BG}) PDF_{sig} + f_{BG} PDF_{BG}) \times R(\Delta t - \Delta t') d\Delta t'$$

Resolution Function

Unbinned maximum likelihood fit

Find the value of sin $2\phi_1$ which maximize $L = \prod L_i$

(i runs over all the events)

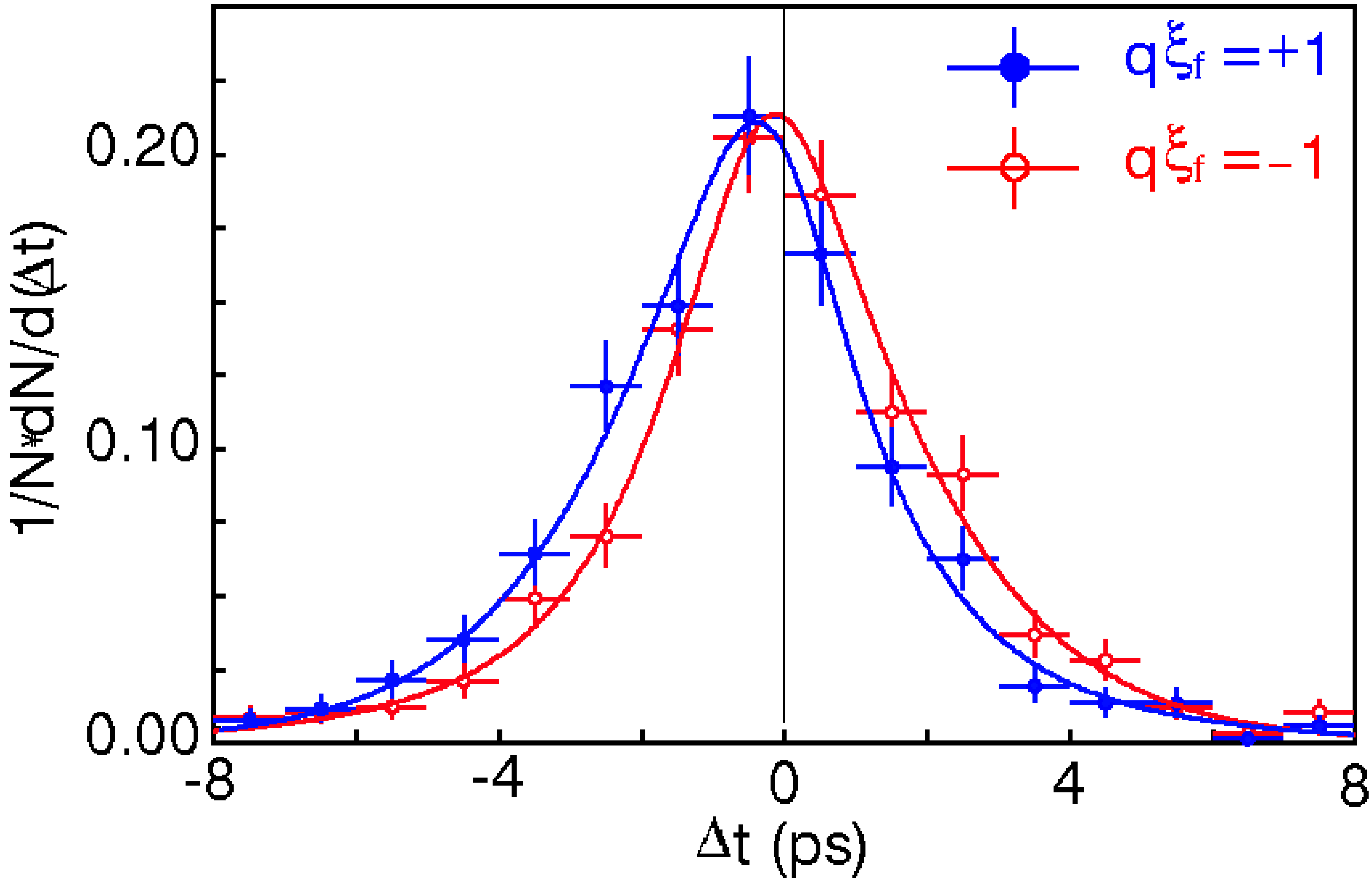
↓

sin $2\phi_1$ is determined

- L_i is calculated for each event using proper type of PDF
- All event types are combined together in a single *L*

Result:

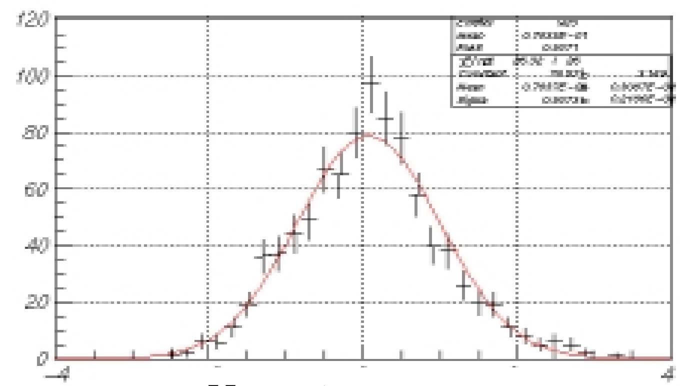
$$\sin 2\phi_1 = 0.99 \pm 0.14(stat) \pm 0.06(sys)$$



Check of CP fitting

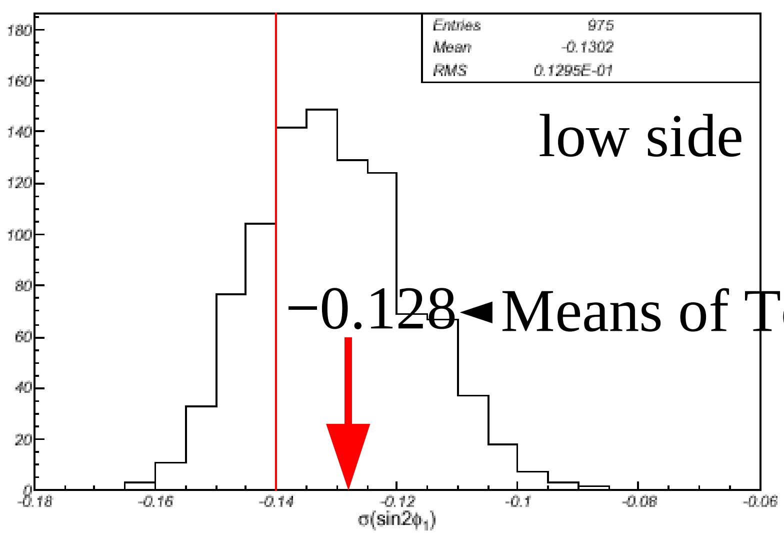
Value of sin2ϕ1 is almost at the physical limit
−> might have some systematics in the center value and error

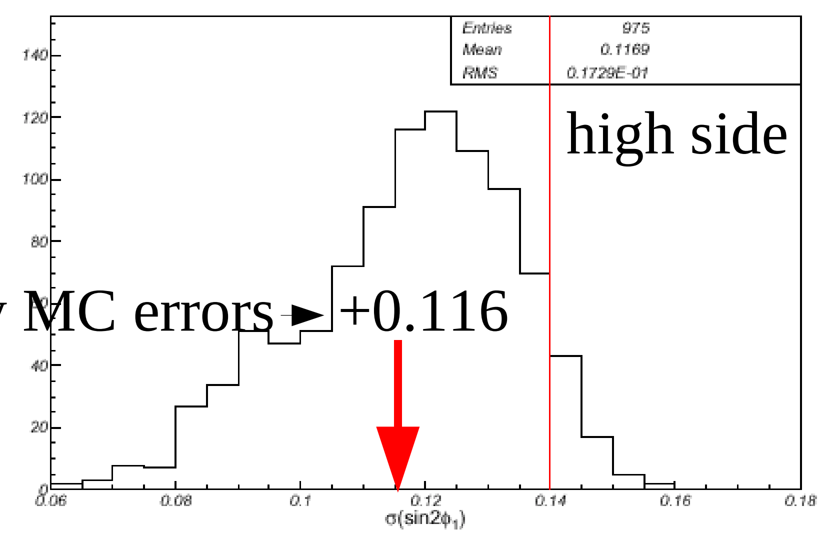
- The same fit procedure was tested for the toy MC events generated with sin $2\phi_1$ set at 0.99
- The fit was performed for 1000 different sets with the same statistics as that of the data



Pull = $\Delta \sin 2\phi_1$ / σ

−0.14 ◄ Errors of our fit ► 0.14

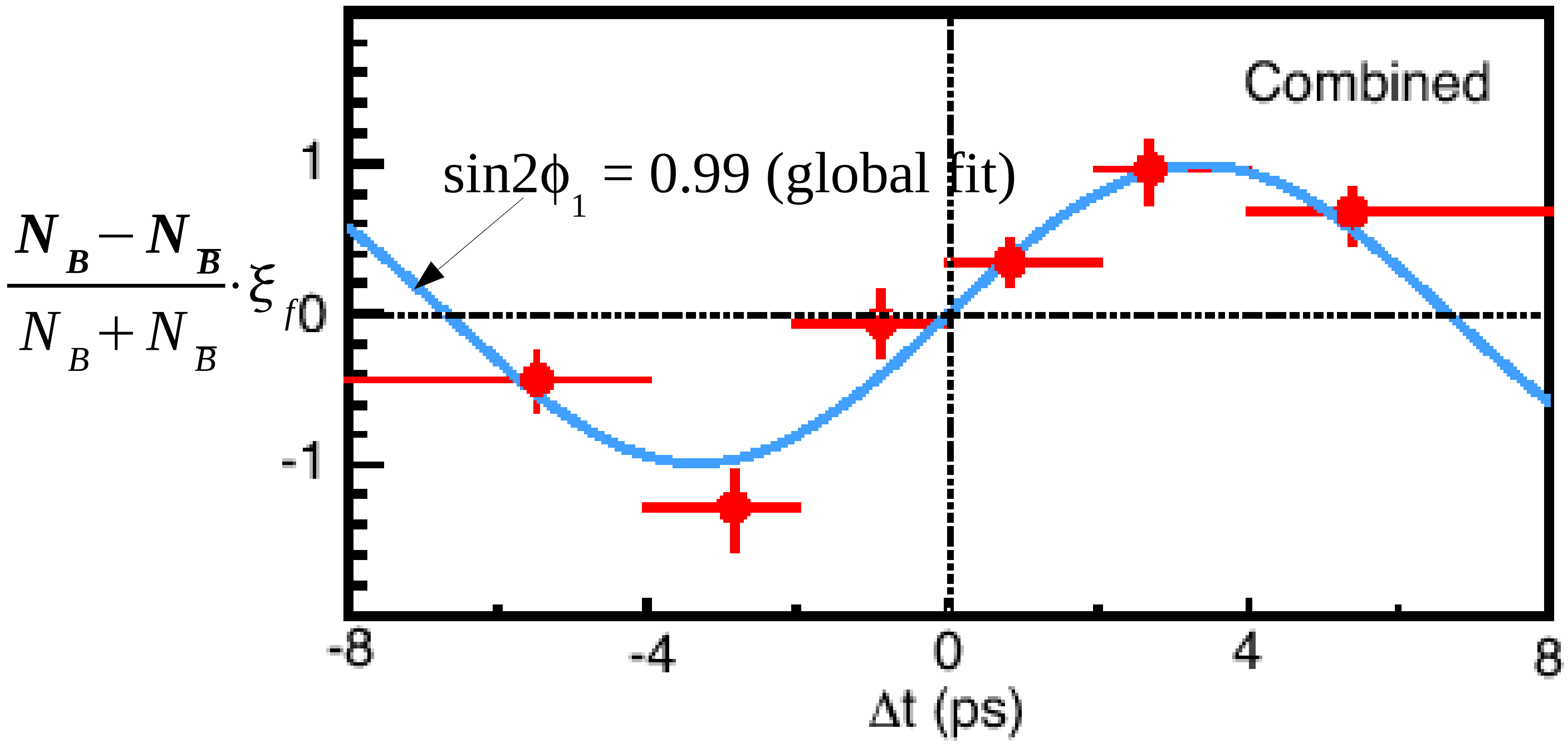




−0.128 ◄ Means of Toy MC errors ► +0.116

Distribution of fit error for 1000 sets of toy MC

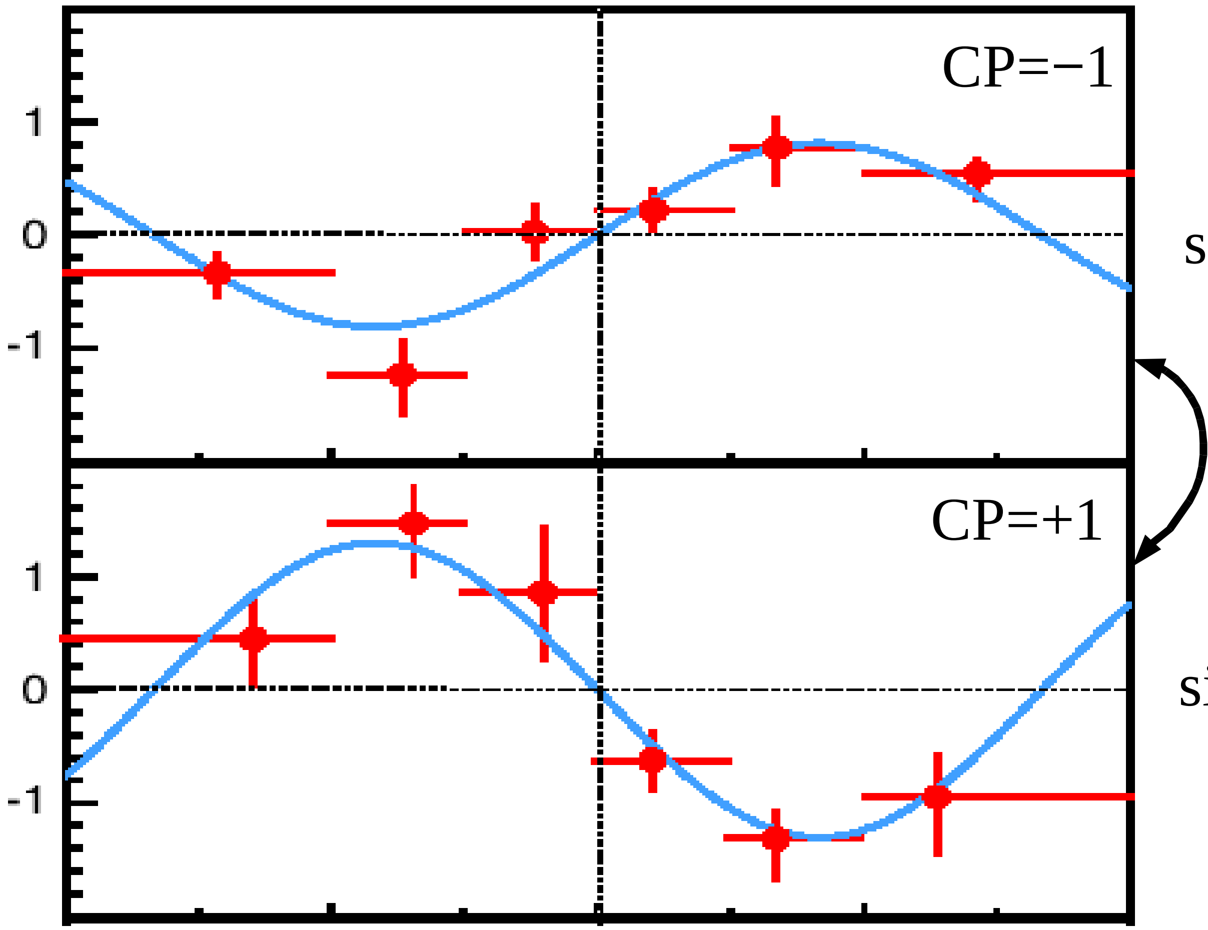
Asymmetry as a function of Δt



– events are divided into Δt bins and $\sin 2\phi_1$ is determined for each bin separately. ($\sin 2\phi_{1i}$ for bin Δt_i)

– plot $\sin 2\phi_{1i} \sin \Delta m \Delta t_i$

Comparison of CP=+1 and CP=−1 samples



$\sin 2\phi_1 = 0.84 \pm 0.17$

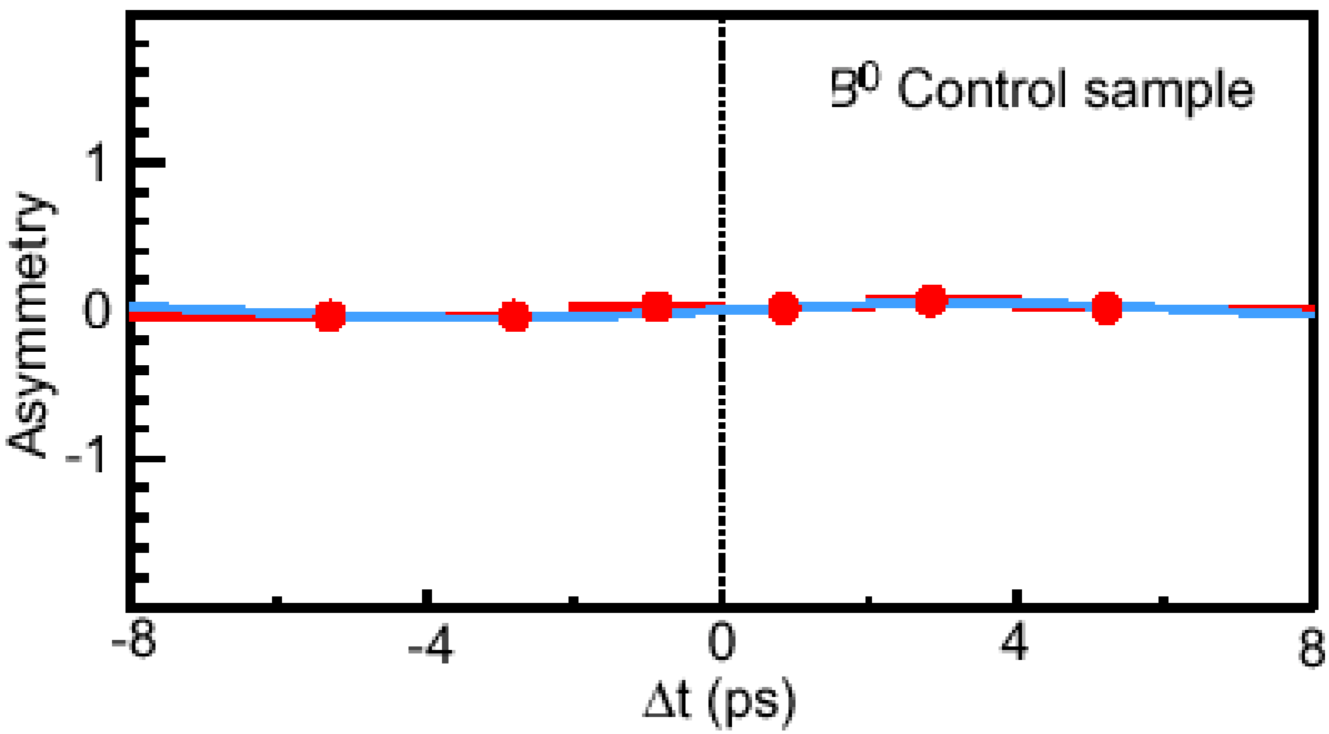
sign flipped!

$\sin 2\phi_1 = 1.31 \pm 0.23$

Asymmetry for non−CP control samples

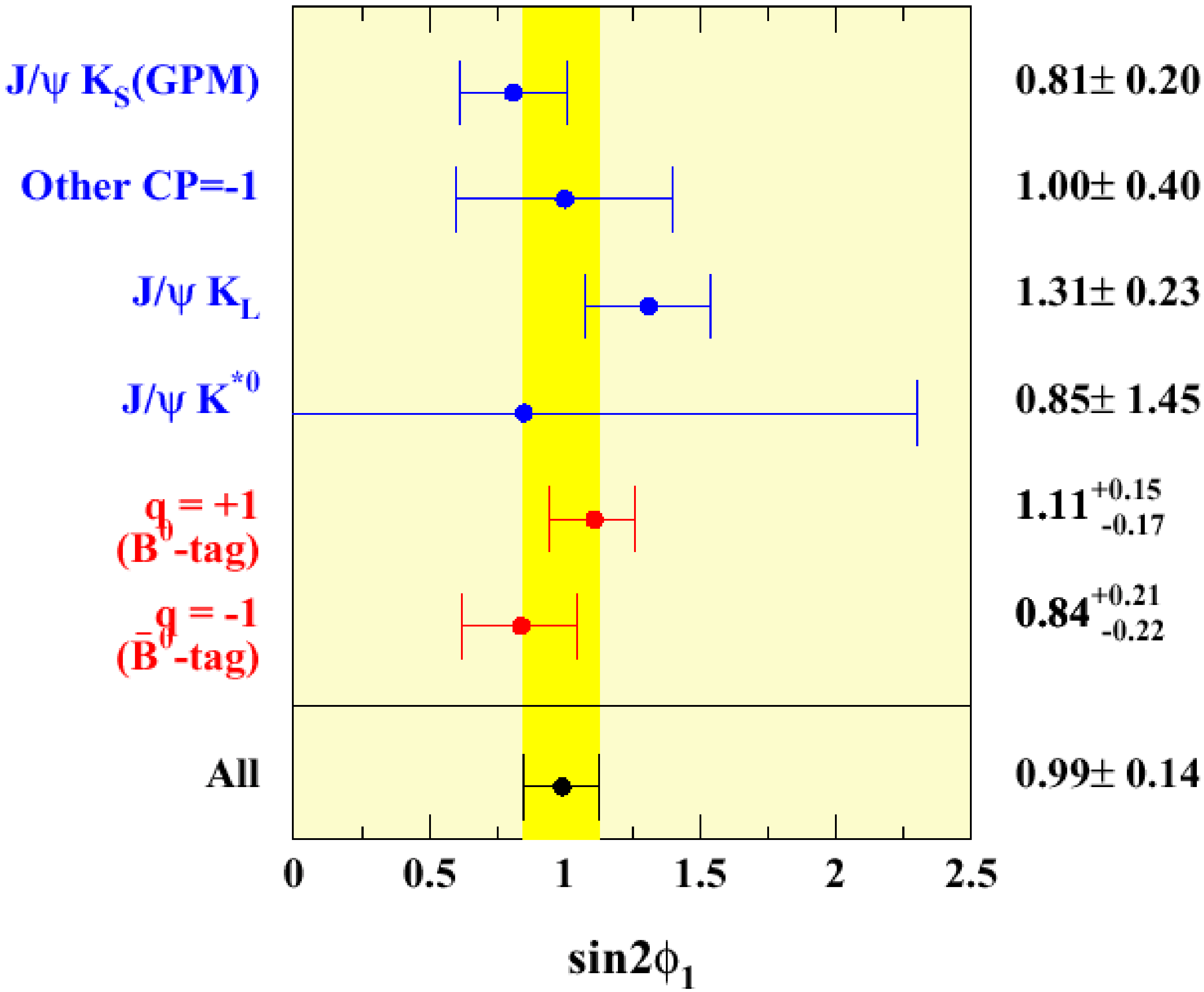
- Asymmetry was plotted for
$$B^0 \to D^{(*)-}\pi^+, D^{*-}\rho^+, D^{*-} l^+ \nu, J/\psi\, K^{*0}(K^+\pi^-)$$
in the same manner.

Total events in the control sample : ~ 17K events



"$\sin 2\phi_1$" = 0.05 ± 0.04

$\sin 2\phi_1$ measured for various data subsets:



Systematic error

Source	$\Delta(\sin 2\phi_1)$
Vertex algorithm	± 0.04
Flavor Tagging	± 0.03
Resolution Function	± 0.02
K_L background fraction	± 0.02
Background shapes	± 0.01
Δm_d and τ_B^0 errors	± 0.01
Total	± 0.06

6. Conclusion

- We measured a CP violating parameter sin $2\phi_1$ in B meson system using Belle detector and KEKB accelerator.
- The measurement was done in ~31.3M $B\bar{B}$ candidate events.
- 1137 events were used for the CP fitting and we found

$$\sin 2\phi_1 = 0.99 \pm 0.14(stat) \pm 0.06(sys)$$

CP is violated in B meson system

> 6 σ effect

Impact on CKM constraints