A Status Report on Asymmetric B-Factories

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In order to study CPV at e^+e^- colliders: ($J/\psi K_s$)

1. High luminosity. $\sim 10^8$ $B\bar{B}$ pairs ($\sim$100 fb^{-1})
2. Good charged particle tracking
   $\rightarrow$ Cylindrical Drift Chamber
3. Flavor-tagging
   - Lepton identification
     e: EM calorimeter
     μ: muon chambers
   - π/K separation
     $\rightarrow$ Cerenkov device
4. Vertexing (measure $t_{\mathrm{sig}} - t_{\mathrm{tag}}$)
   $\rightarrow$ Silicon trackers

B-factries

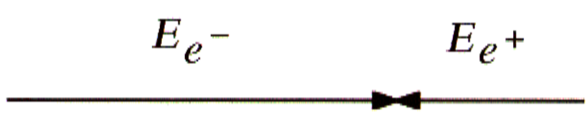
< e^+e^- B-factory accelerators>

$e^+e^- \to \Upsilon 4S \to B^0\bar{B}^0$ or B^+B^-

Symmetric energies (CESR)

$$E_{e^-} = E_{e^+} = \frac{M_{\Upsilon 4S}}{2} = 5.29 GeV$$

Asymmetric energies (PEP-II, KEK-B)



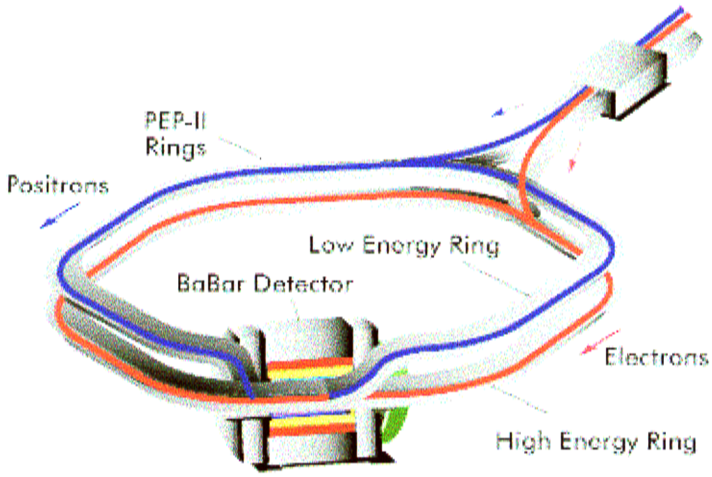
$\Upsilon 4S$ (and B's) is moving in the lab frame.
$\to$ B decay time measurements

$$E_{\text{CM}} = 2\sqrt{E_{e^+}E_{e^-}} = M_{\Upsilon 4S}$$

$$\begin{cases} E_{\Upsilon 4S} = E_{e^-} + E_{e^+} \\ P_{\Upsilon 4S} = E_{e^-} - E_{e^+} \end{cases}$$

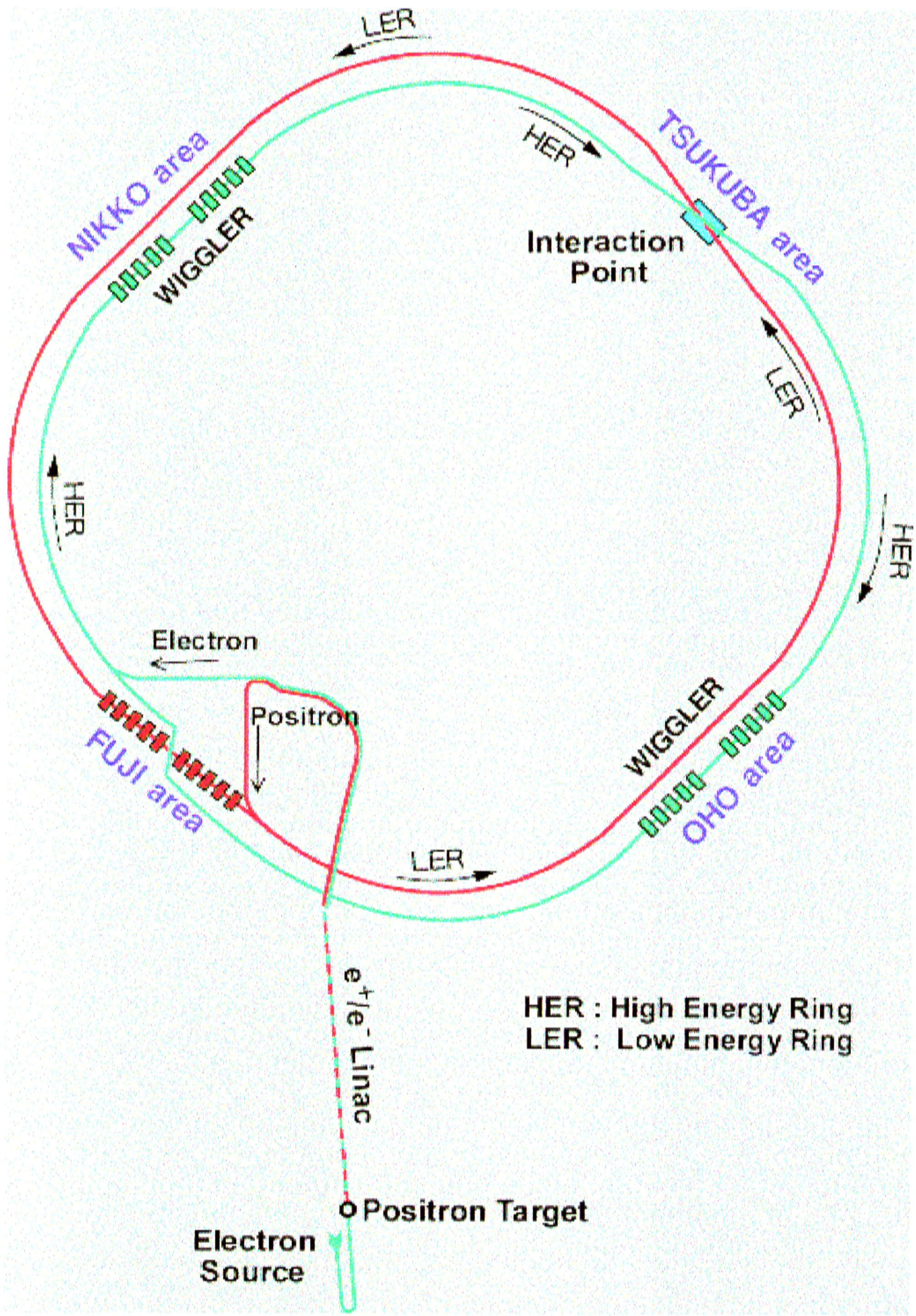
$$\to \quad \beta_{\Upsilon 4S} = \frac{P_{\Upsilon 4S}}{E_{\Upsilon 4S}} = \frac{E_{e^-} - E_{e^+}}{E_{e^-} + E_{e^+}}$$

PEP-II (SLAC)


PEP-II
Rings
Positrons
Low Energy Ring
BaBar Detector
Electrons
High Energy Ring


SPEAR
SLC

KEK-B (KEK, Japan)



Beam separation

Want collision to occur only at one location

$\rightarrow$ Need for beam separation
(avoid parasitic crossings)

CESR: Pretzel orbit

Interweaving e^+e^- orbits within a single ring

Crossing angle $= \pm 2.3$ mrad

PEP-II: Separation by bending magnet

$$E_{e^+} \neq E_{e^-}$$

$\rightarrow e^+, e^-$ beams bend differently

Head-on collision

KEK-B: Finite-angle crossing

Crossing angle $= \pm 11$ mrad

Large crossing angle

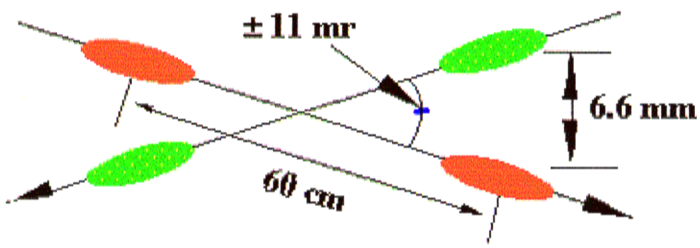
$\rightarrow$ { Beam instability (synchro-betatron resonance)
Luminosity reduction (geometrical) }

OK Now.

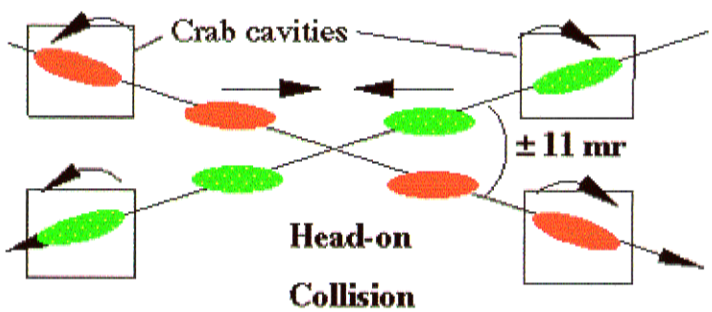
Crab crossing (KEK-B)

In case finite-angle crossing causes problems

- ☐ Without crab cavities

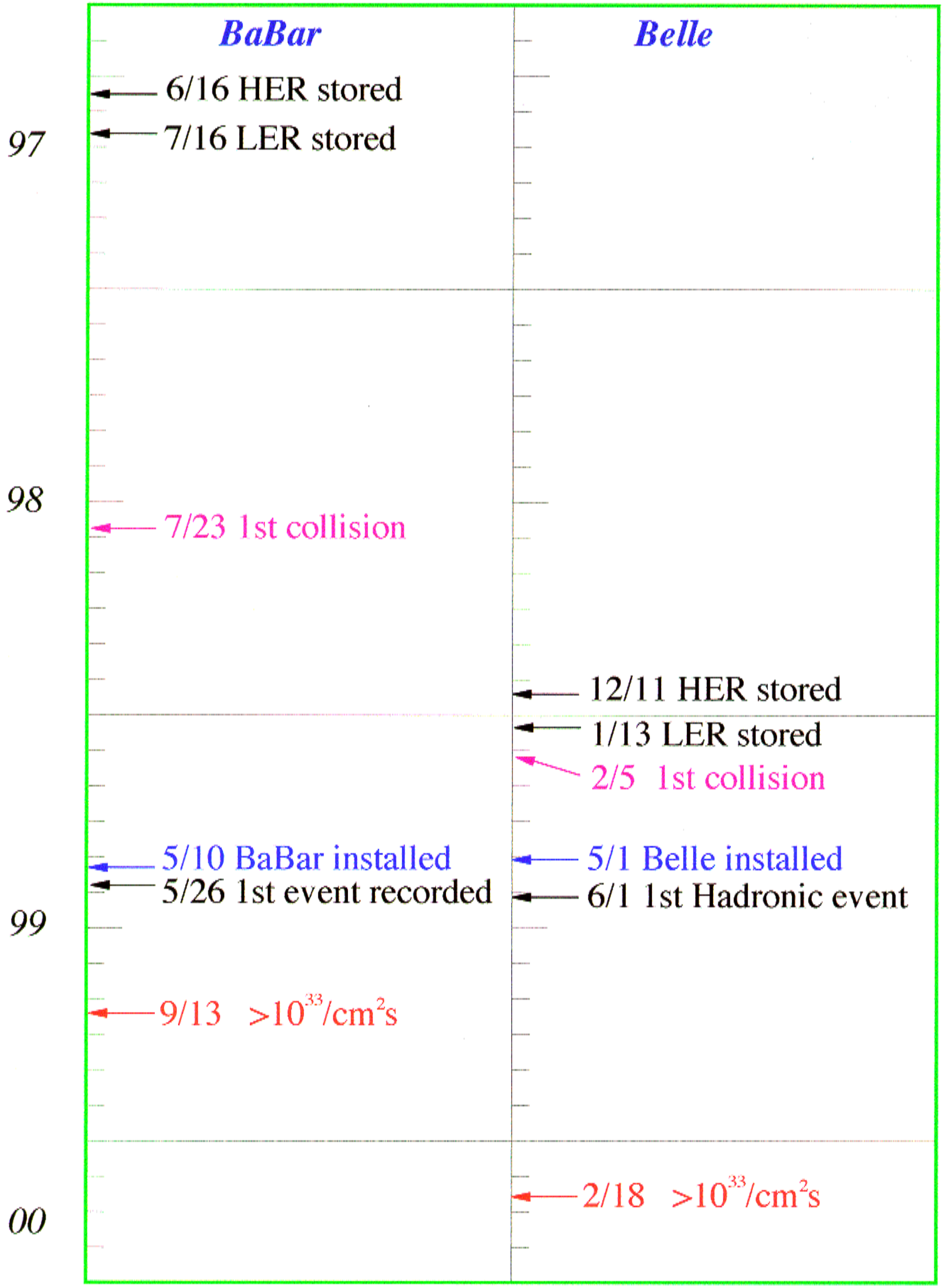


- ☐ With crab cavities

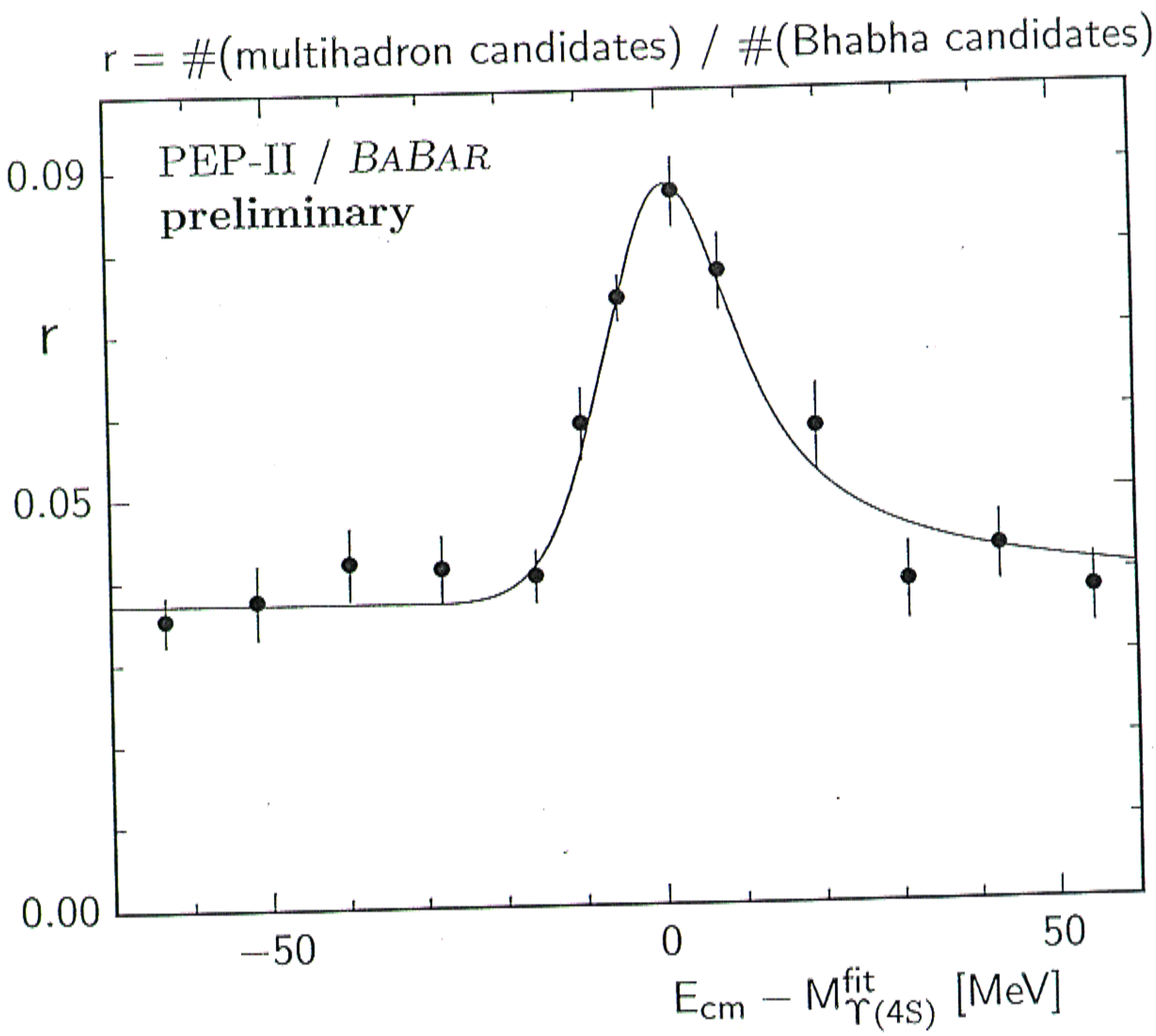


→ complete overlap of beams
(No geometrical luminosity loss.
Suppresses beam-beam instability)

machine	*CESR*	*PEP-II*	*KEK-B*
detector	*CLEO*	*BaBar*	*Belle*
circumference (km)	0.768	2.199	3.016
# of rings	1	2	2
E_{e^+}(GeV)	5.3	3.1	3.5
E_{e^-}(GeV)	5.3	9.0	8.0
$\beta_{\Upsilon 4S}$	~ 0	0.49	0.39
$\delta E/E$	6×10^{-4}	7×10^{-4}	7×10^{-4}
Δt_{bunch}	$14ns$	$4.2ns$	$2ns$
bunch size(w)	500μ	181μ	77μ
" (h)	10μ	5.4μ	1.9μ
" (l)	$1.8cm$	$1.0cm$	$0.4cm$
crossing angle(mrad)	± 2.3	0	± 11
Luminosity($cm^{-2}s^{-1}$)	1.5×10^{33}	3×10^{33}	10×10^{33}
$\#B\bar{B}/s$	1.5	3	10
achievements so far			
Lum(peak)	8×10^{32}	15×10^{32}	10.5×10^{32}
$\int Ldt$ (fb^{-1})	9.2	1.7	0.72

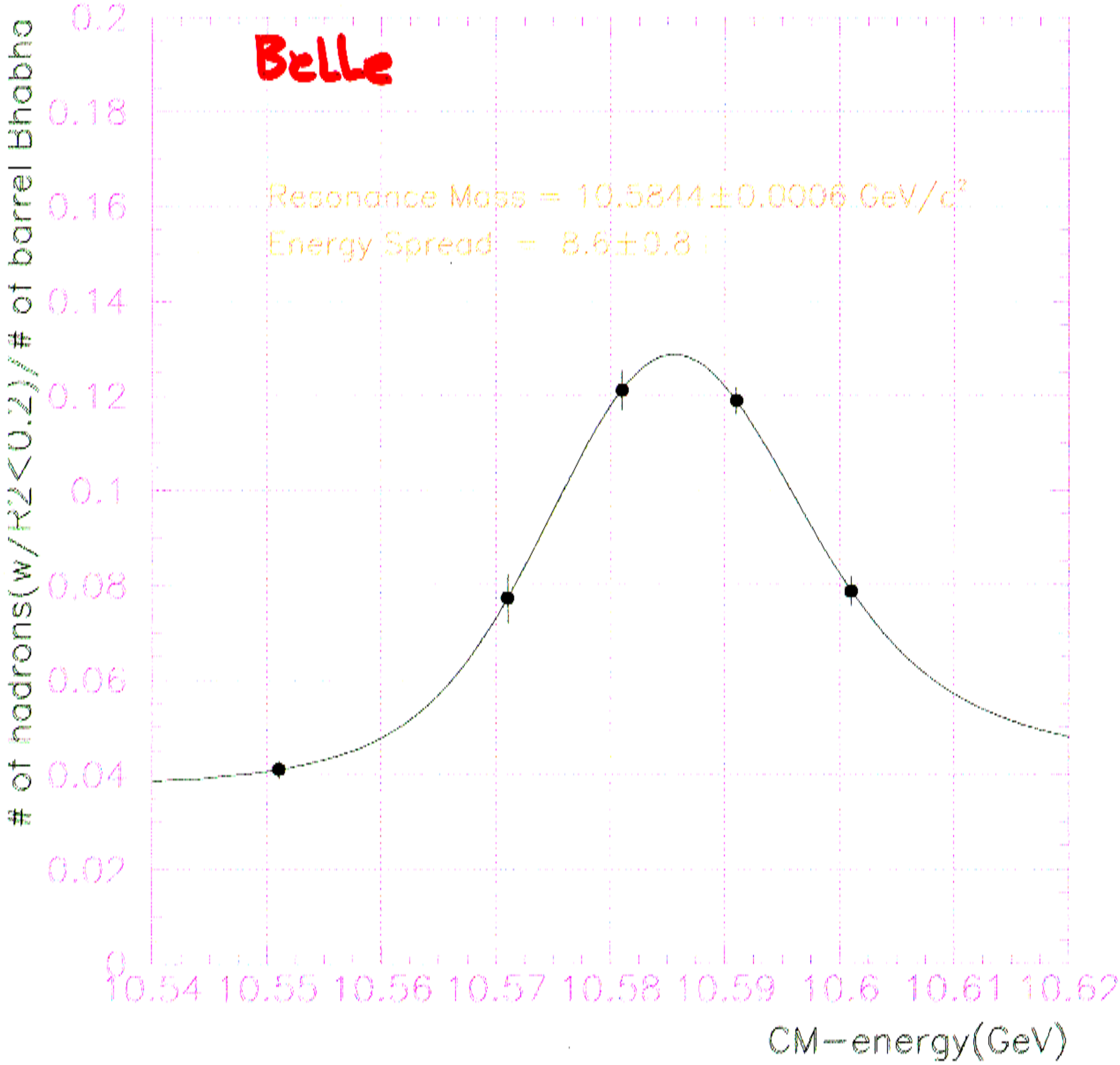

BaBar
Belle
97
6/16 HER stored
7/16 LER stored
98
7/23 1st collision
12/11 HER stored
1/13 LER stored
2/5 1st collision
5/10 BaBar installed
5/26 1st event recorded
5/1 Belle installed
6/1 1st Hadronic event
99
9/13 >10^33/cm^2s
00
2/18 >10^33/cm^2s

Energy Scan.



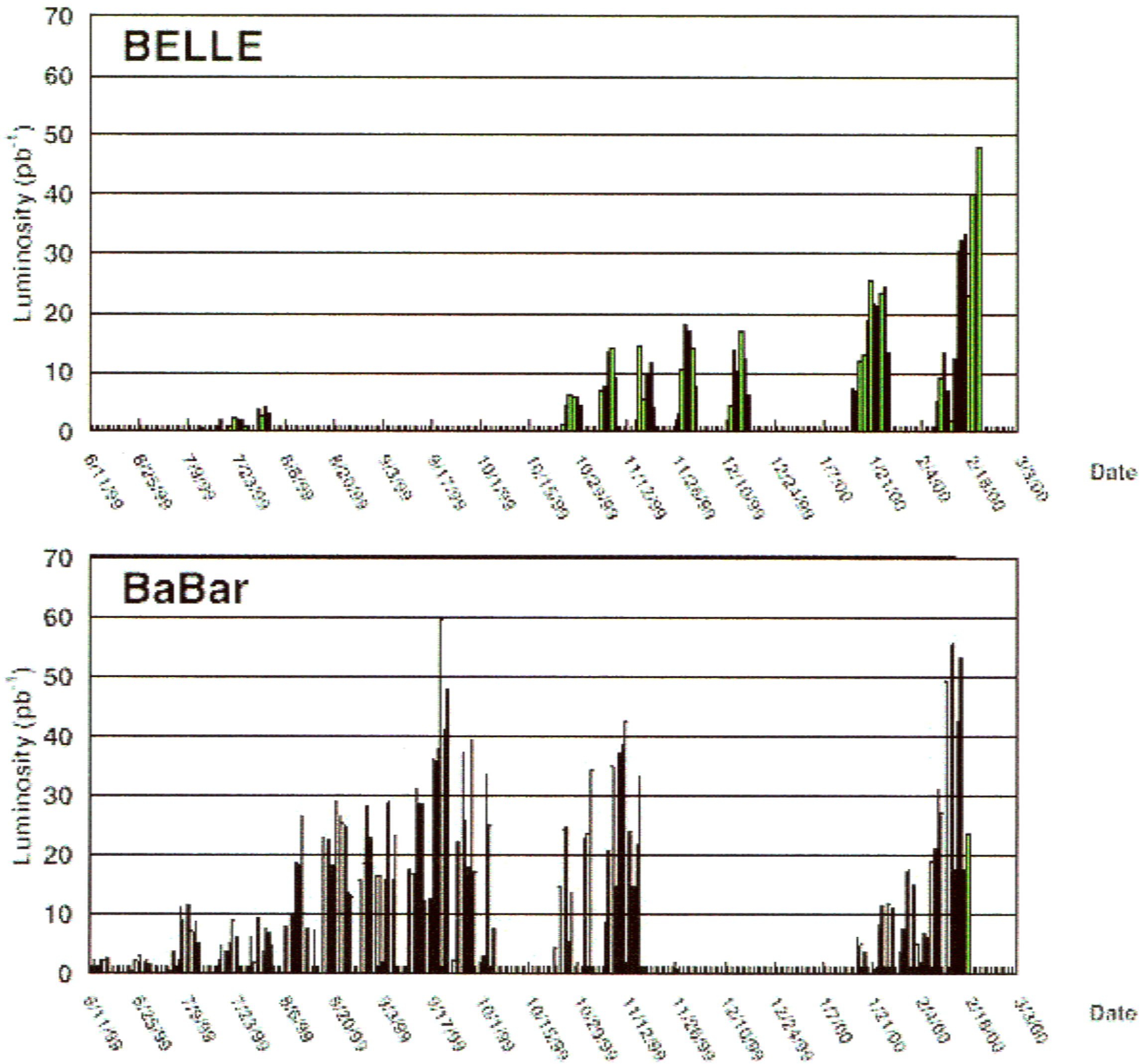
r = #(multihadron candidates) / #(Bhabha candidates)
PEP-II / BABAR
preliminary
0.09
r
0.05
0.00
−50
0
50
$E_{cm} - M^{fit}_{\Upsilon(4S)}$ [MeV]

99/07/25 23.53



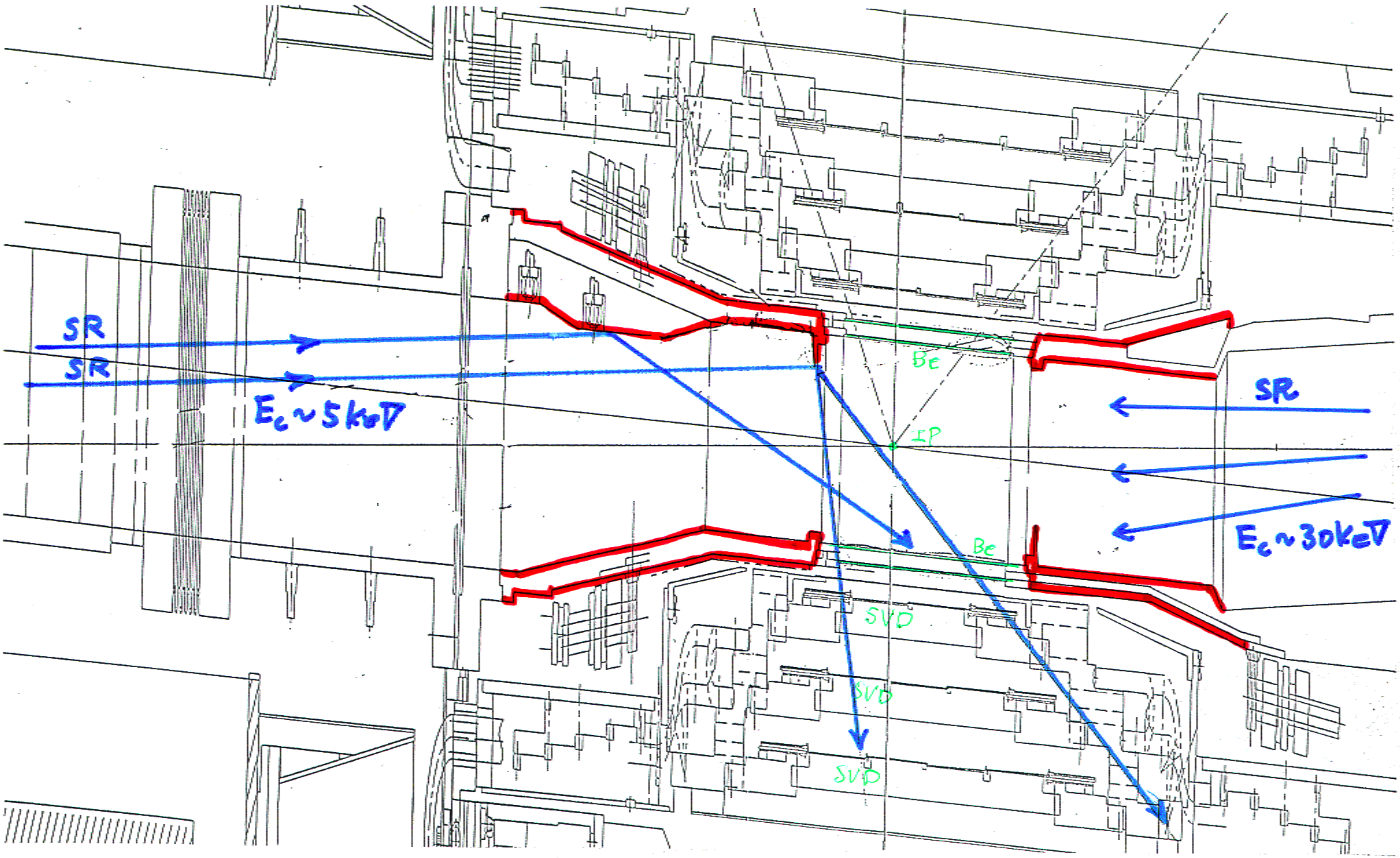
Belle
Resonance Mass = 10.5844±0.0006 GeV/c²
Energy Spread = 8.6±0.8
# of hadrons(w/R2<0.2)/# of barrel Bhabha
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
10.54
10.55
10.56
10.57
10.58
10.59
10.6
10.61
10.62
CM-energy(GeV)

Daily Recorded Luminosity



↑ 1st event

Belle SR Background (Pre 99 summer)



Problems and Issues

Belle

1. Synchrotron radiation (SR) background

   – Readout chips (VA1) of Innermost SVD started to die.

     * Traced to SR from steering magnets ($E_c < 10$ keV).
     * Put 20μm-thick Au foil around the Be pipe. (Be pipe was 'bare' before)
     * Cover VA1's with 300μm-thick Au.
     * Replaced SVD1.0 with SVD1.2 ('spare'). (Summer 1999)

   – Excess hits in CDC.

     * Probably the backscattering from downstream HER.
     * Replaced the suspect beampipe (Al $\rightarrow$ Cu).

   – No SR background is noticeable at present. (i.e. the bkg is dominated by lost particle)

2. Vacuum leaks and other glitches.

   – BPM near IP leak - fixed.

   – Movable mask leak - being redesigned. (arcs and heating)

   – Magnet coil burn out.

   These typically cost 1~2 weeks each.

3. Current issues

   – Blowup of LER vertical beamsize.

     * $\sigma_y \to \times 2$ at 350 ma.

     * Suspect: SR-induced photoelectrons (or ECE - electron cloud effect)

     * Permanent magnets around beampipe did not have a dramatic effect.

   – Crab cavity.

     * 1st full prototype in 2000.

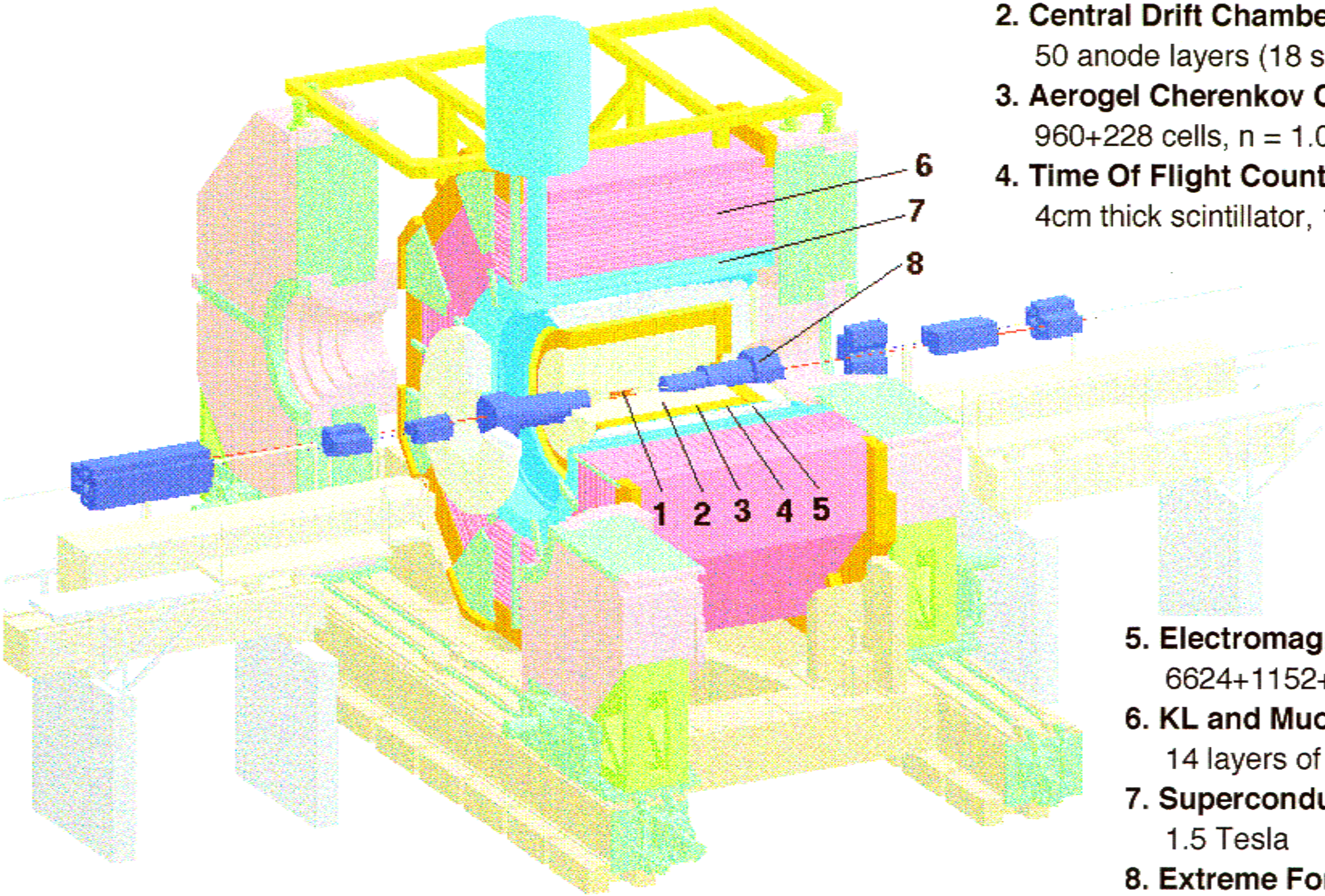
     * Installation in 2003.

Problems and Issues

BaBar

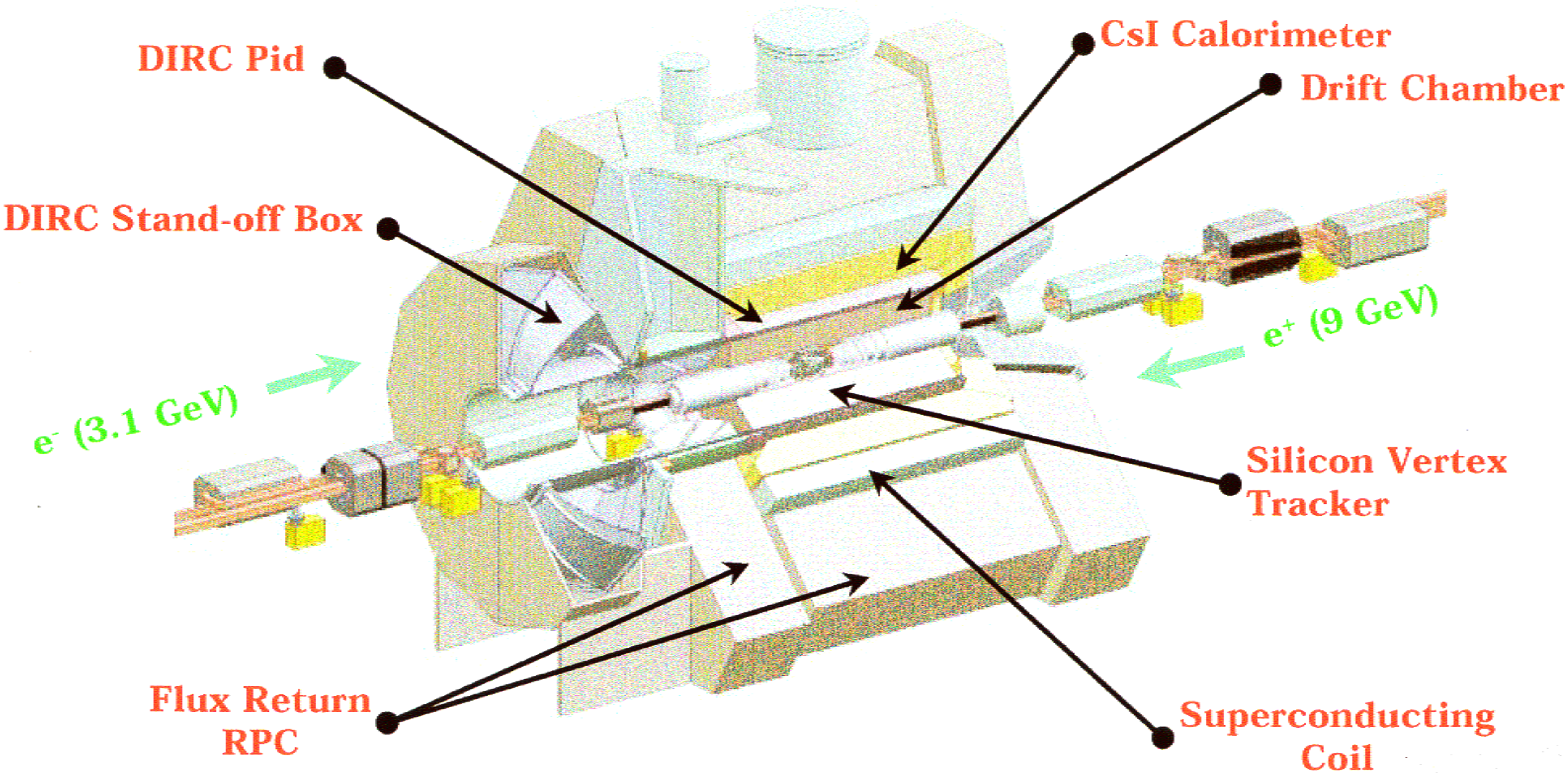
1. Vacuum leak at SR mask.
   - At Cu-SS joint.
   - Replaced.
2. Beam background
   - Dominated by lost-particle.
   - Extrapolation: SVT limit at 30 fb^{-1}.
   - Will improve with time (bake-out)

Belle Detector



1. **Silicon Vertex Detector (SVD)**
   3 layers of double sided silicon sensors
2. **Central Drift Chamber (CDC)**
   50 anode layers (18 stereo), 3 cathode layers
3. **Aerogel Cherenkov Counter (ACC)**
   960+228 cells, n = 1.01 - 1.03
4. **Time Of Flight Counter (TOF)**
   4cm thick scintillator, 128 ϕ-segmentation
5. **Electromagnetic Calorimeter (ECL)**
   6624+1152+960 CsI(Tl) crystals
6. **KL and Muon Detector (KLM)**
   14 layers of glass RPC in iron yoke
7. **Superconducting Solenoid**
   1.5 Tesla
8. **Extreme Forward Calorimeter (EFC)**
   320 BGO crystals attached on the final focus quad.

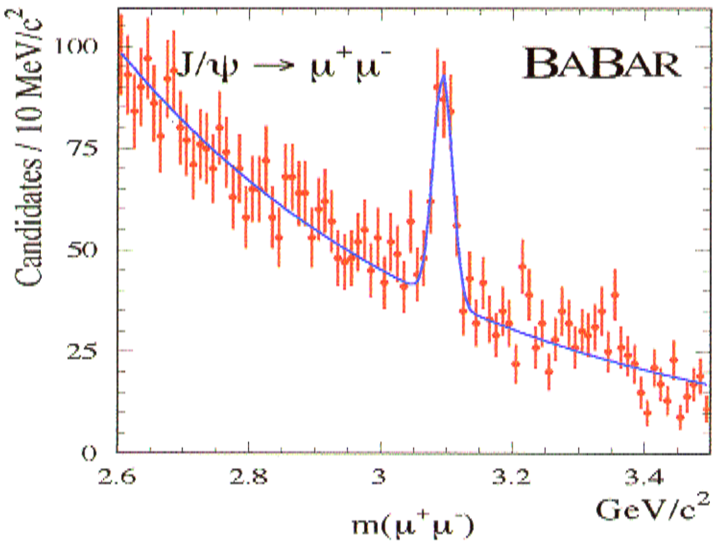
BaBar

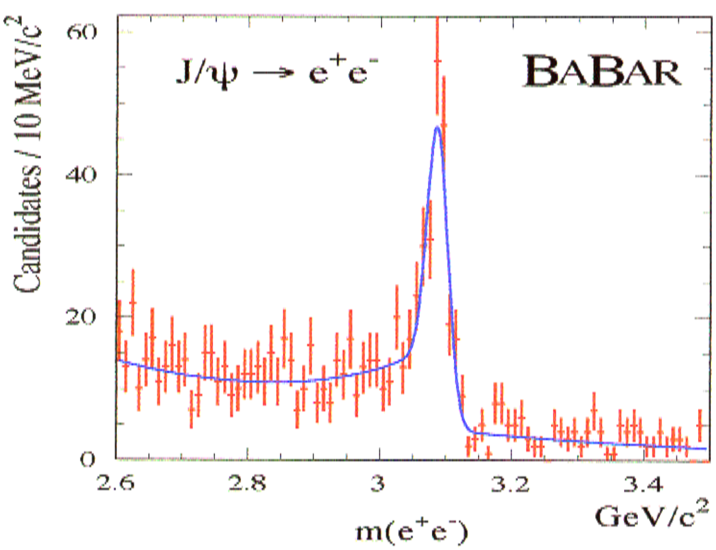


DIRC Pid
CsI Calorimeter
Drift Chamber
DIRC Stand-off Box
e⁺ (9 GeV)
e⁻ (3.1 GeV)
Silicon Vertex Tracker
Flux Return RPC
Superconducting Coil

Physics Performaqnces

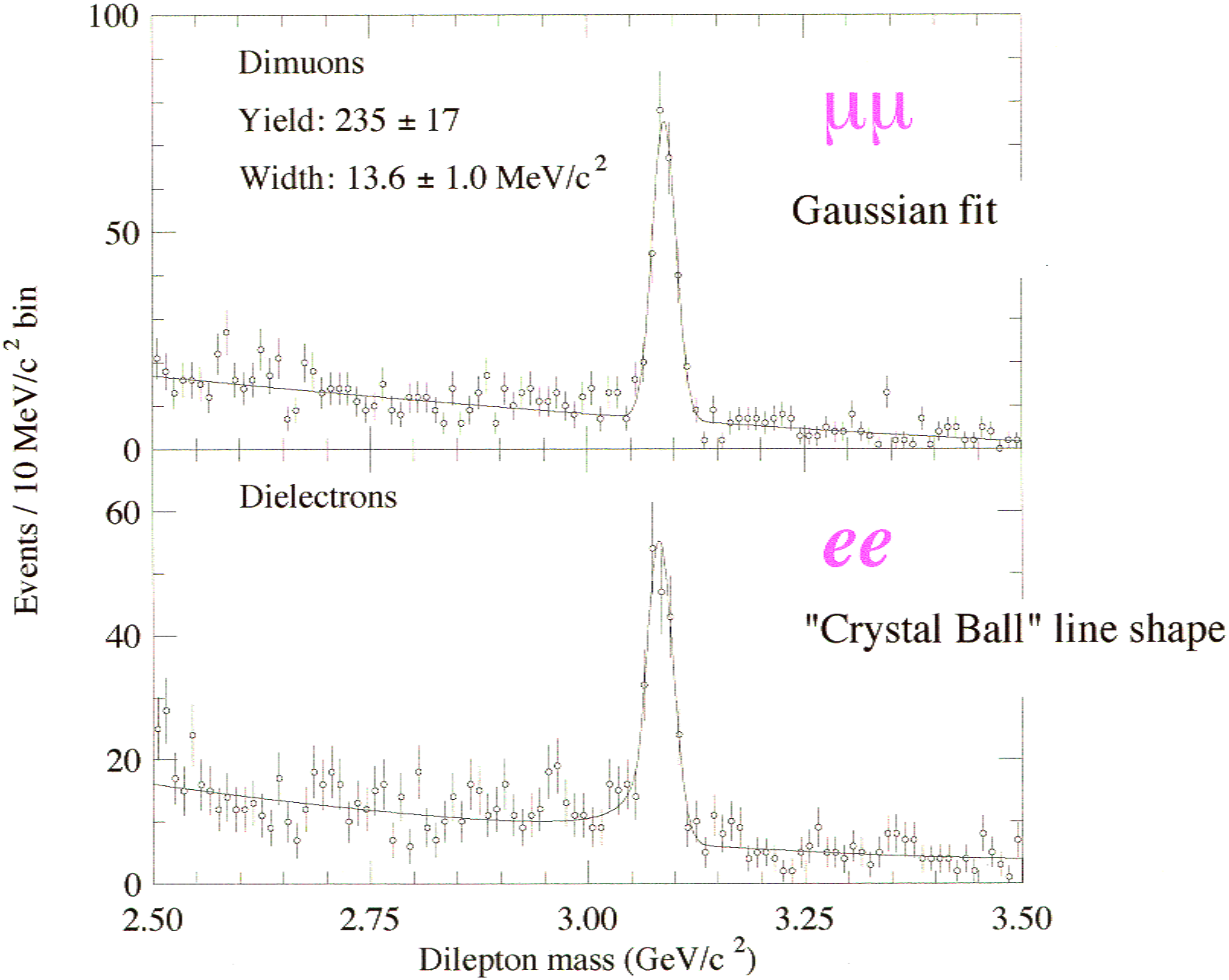
$B \rightarrow J/\psi X$



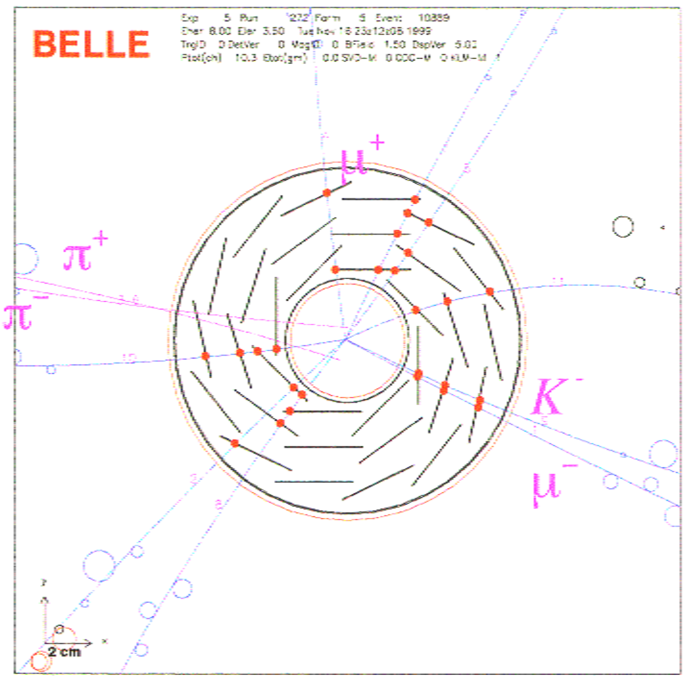


Schwenk (Nakao)

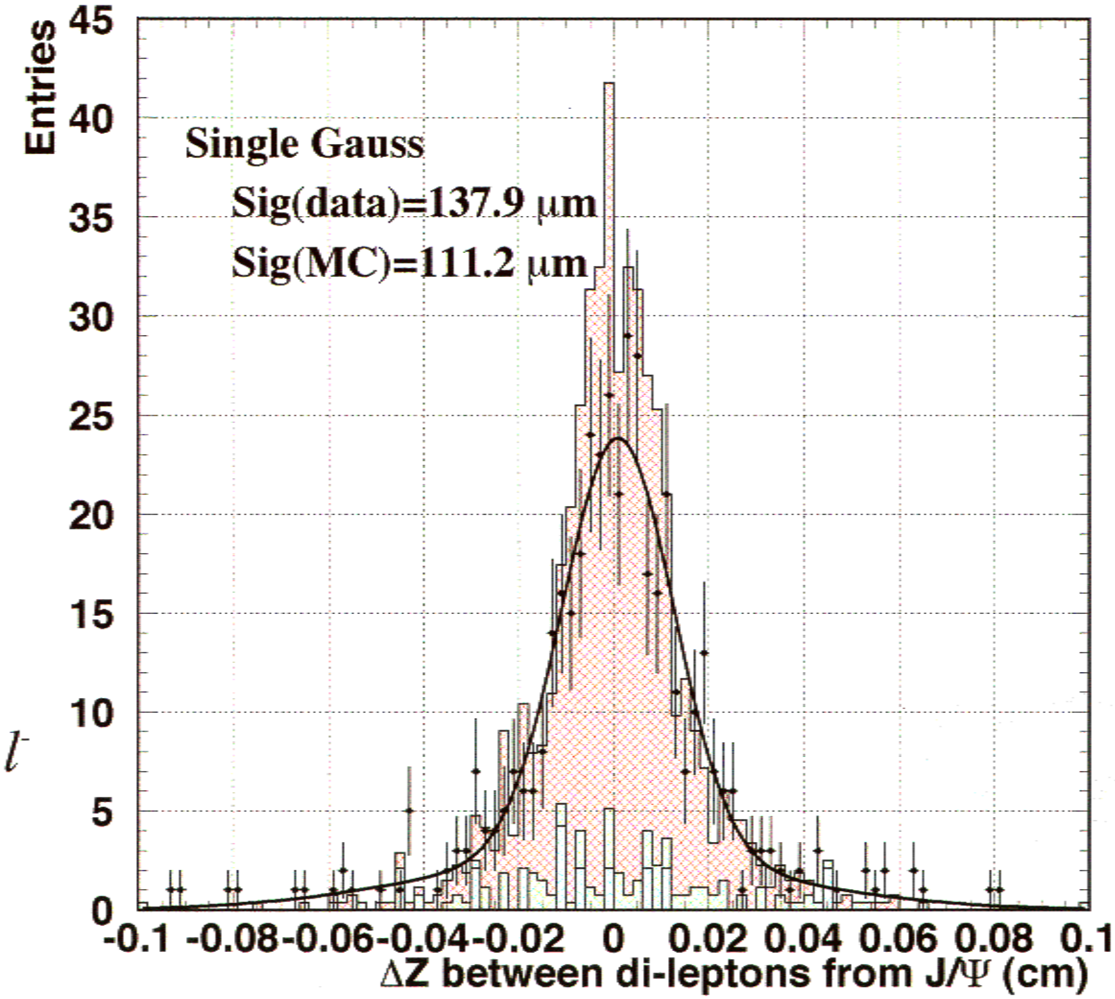
Belle: J/ψ in μμ / ee channels (~ 0.45 fb⁻¹)



Vertexing Belle



Matching eff. = 97% (Bhabha) / 96.7% for hadron



Δz resolution from $J/\psi \rightarrow l^+ l^-$

138 μm

<Full reconstruction on $\Upsilon 4S$ >

$$B \to f_1 \cdots f_n$$

Energy and absolute momentum of B in the $\Upsilon 4S$ frame are known:

$$E_B = E_{\text{beam}} = 5.290 \text{ GeV}$$
$$|\vec{P}_B| = \sqrt{E_{\text{beam}}^2 - M_B^2} = 0.34 \text{ GeV/c}$$

→**Move to the $\Upsilon 4S$ rest frame** and require that candidates satisfy

$$E_{\text{tot}} = E_{\text{beam}}\,, \quad |\vec{P}_{\text{tot}}| = |\vec{P}_B|$$

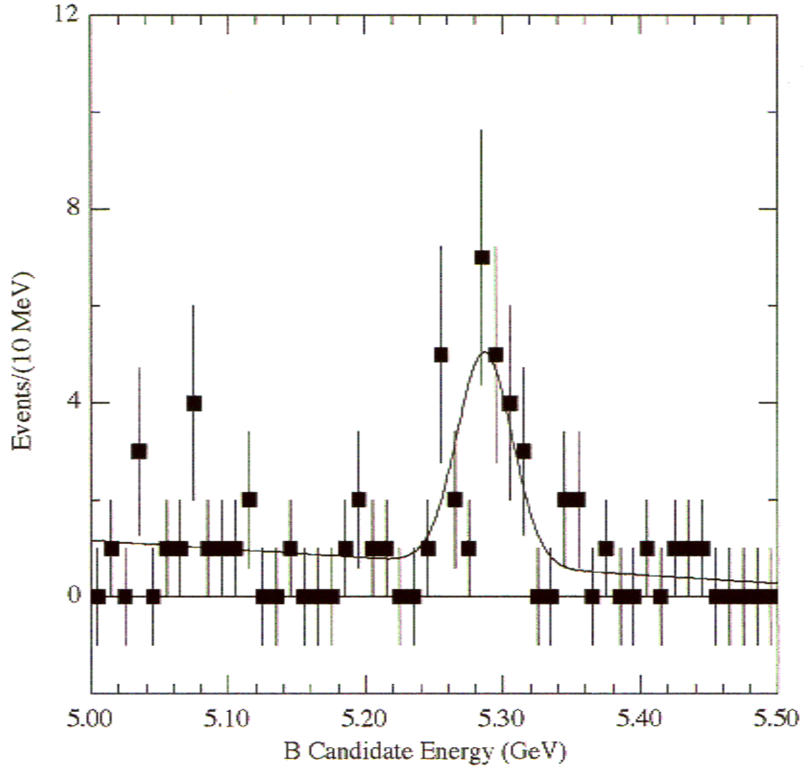
where

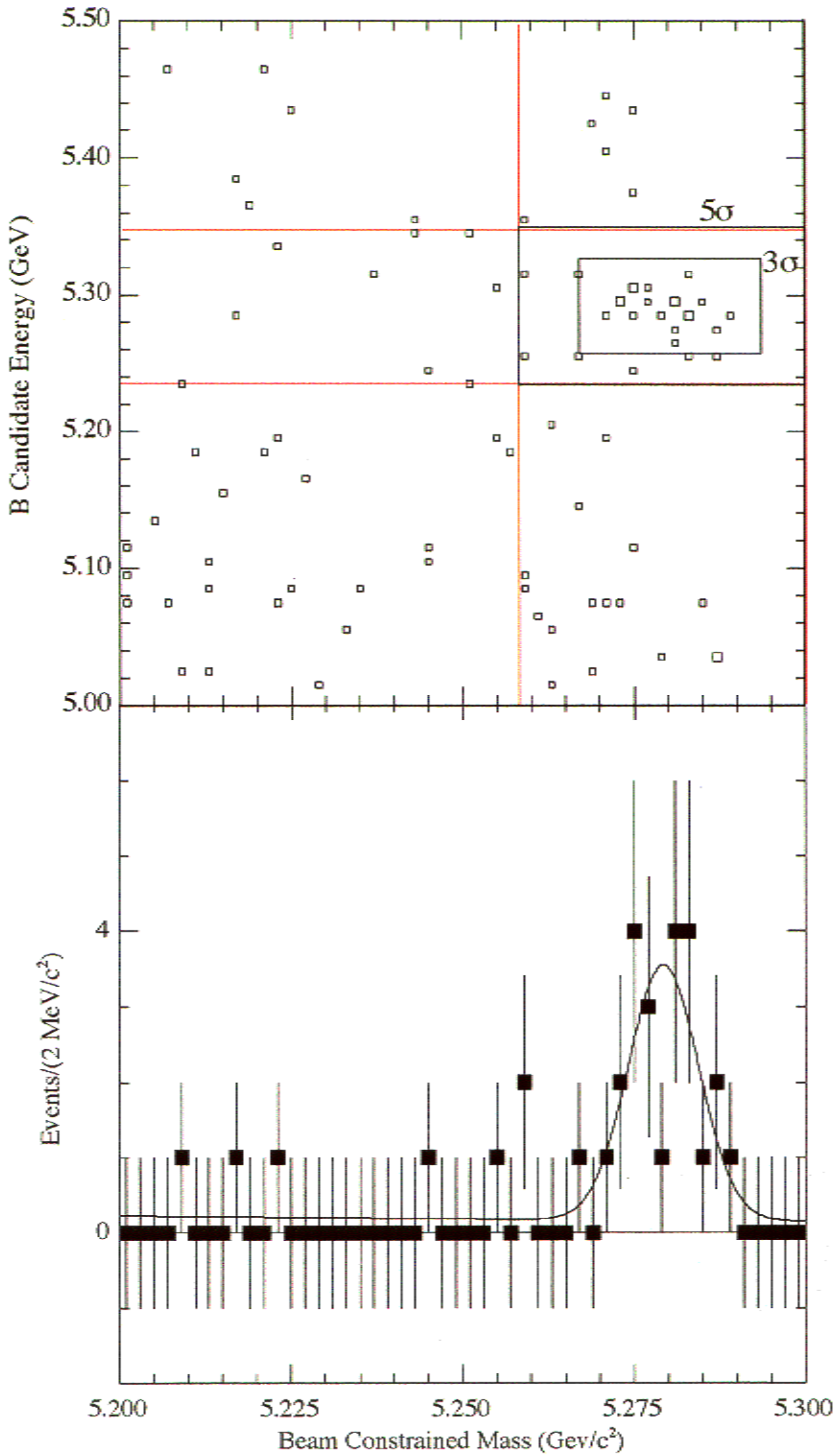
$$E_{\text{tot}} \equiv \sum_{i=1}^{n} E_i\,, \quad \vec{P}_{\text{tot}} \equiv \sum_{i=1}^{n} \vec{P}_i$$

Instead of E_{tot} and $|\vec{P}_{\text{tot}}|$, we historically use

$\Delta E \equiv E_{\text{tot}} - E_B$ (energy difference)

$M_{\text{bc}} \equiv \sqrt{E_{\text{beam}}^2 - \vec{P}_{\text{tot}}^2}$ (beam-constrained mass)



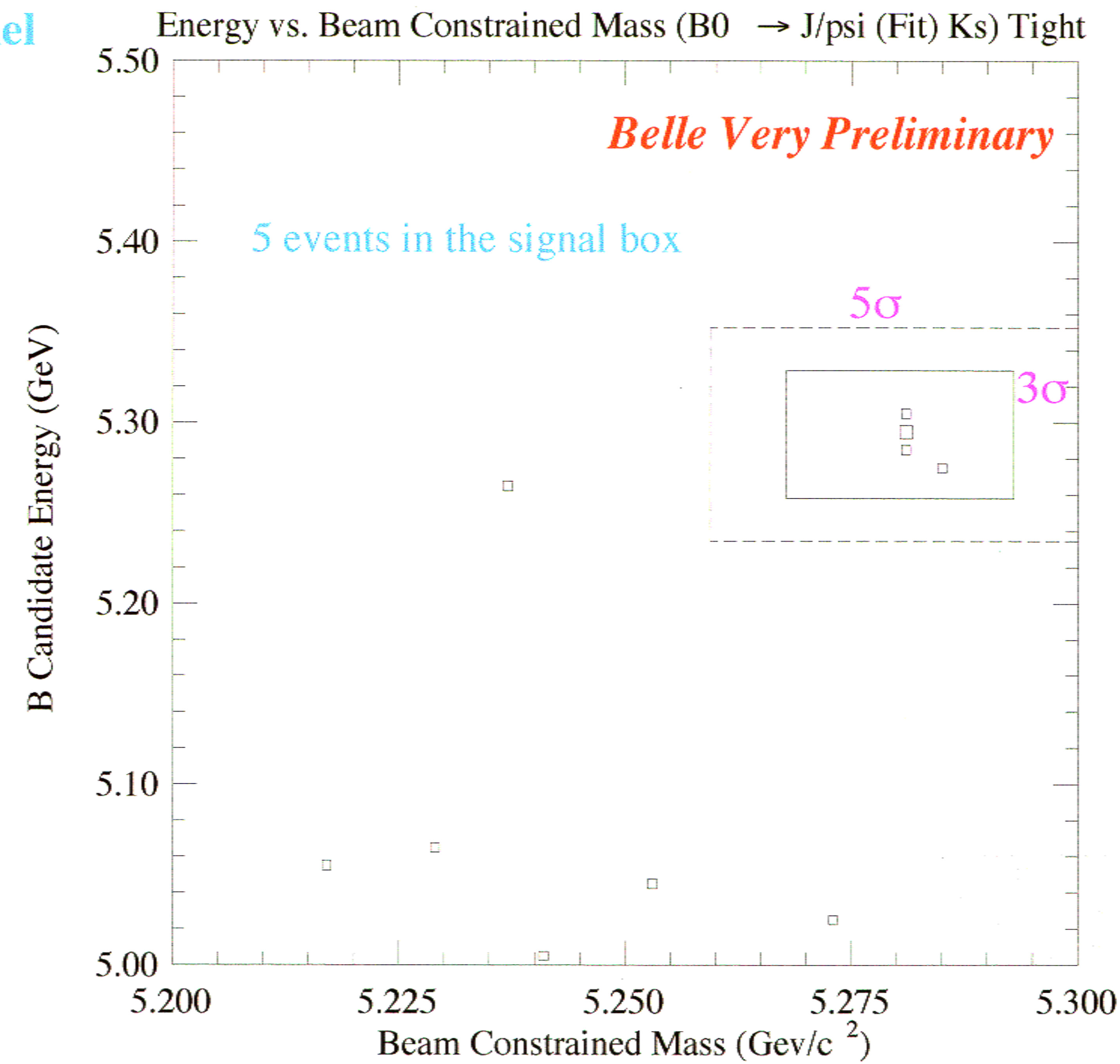


$B \rightarrow J/\psi\ K^+$ channel

22 ± 6 events (~ 0.45 fb^{-1})

Belle Very Preliminary

$B \to J/\psi\, K_S$ channel



Number of candidates in 440 pb data:

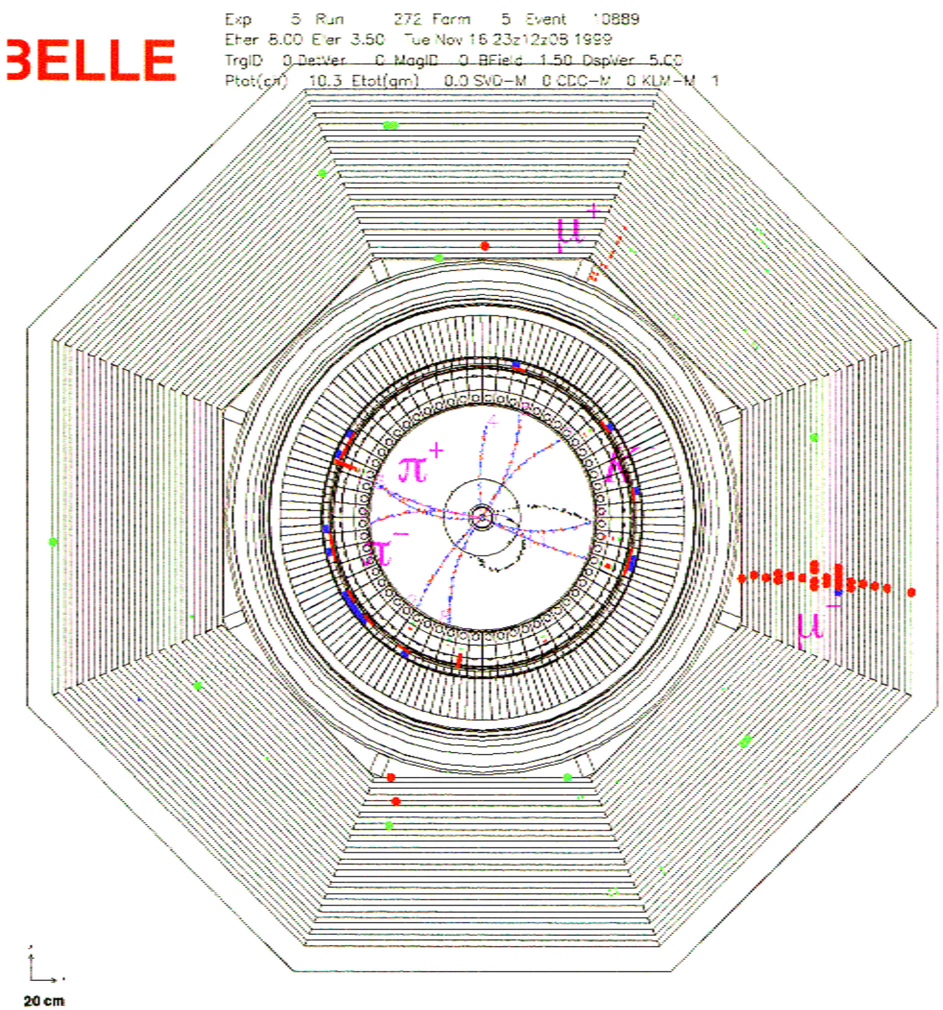
$B^0 \to J/\psi K_S$	5
$B^0 \to J/\psi K_L$	6 ←
$B^0 \to \psi' K_S$	2
$B^0 \to J/\psi K^{*0}$	10
$B^+ \to J/\psi K^+$	22

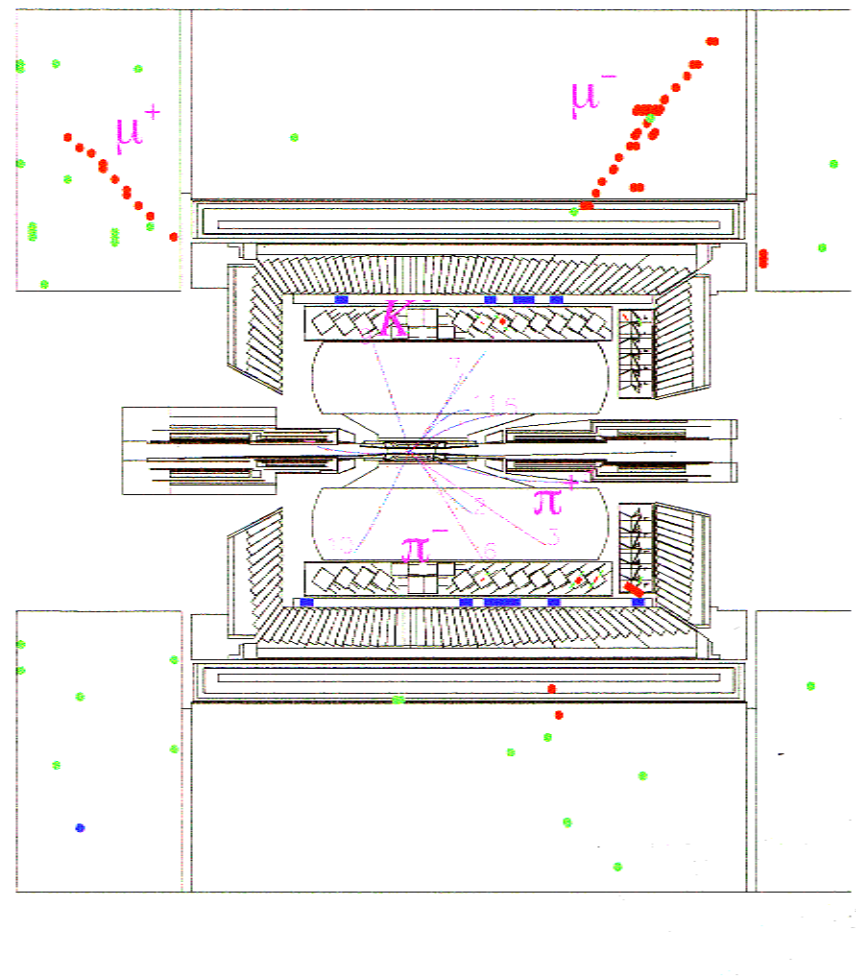
(Nakao)

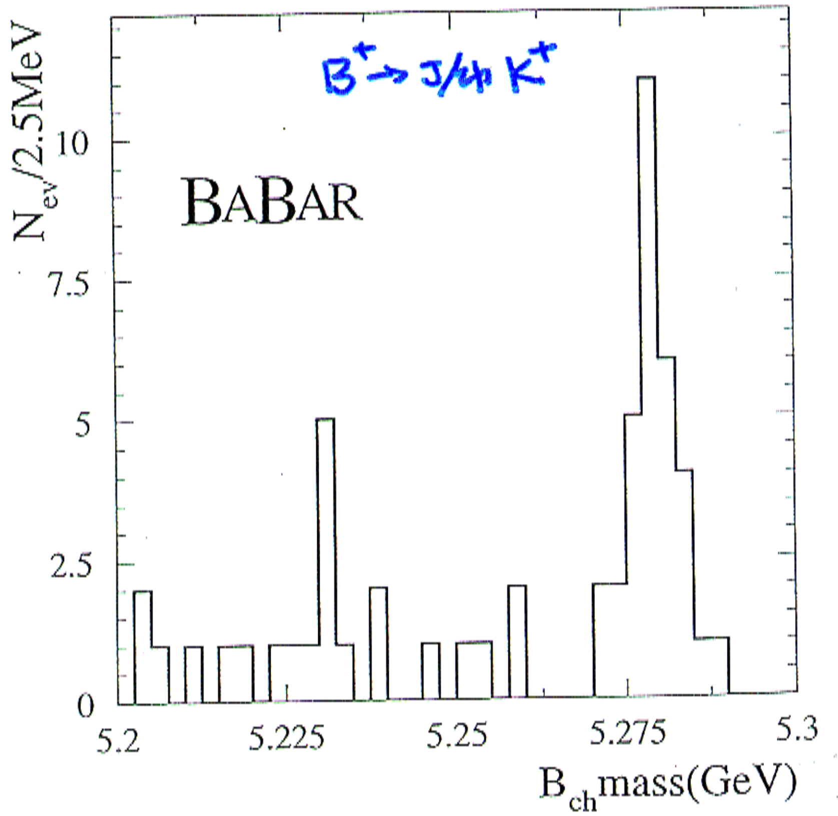
A $B^0 \rightarrow J/\psi K_S$ candidate.

$\hookrightarrow \pi^+\pi^-$

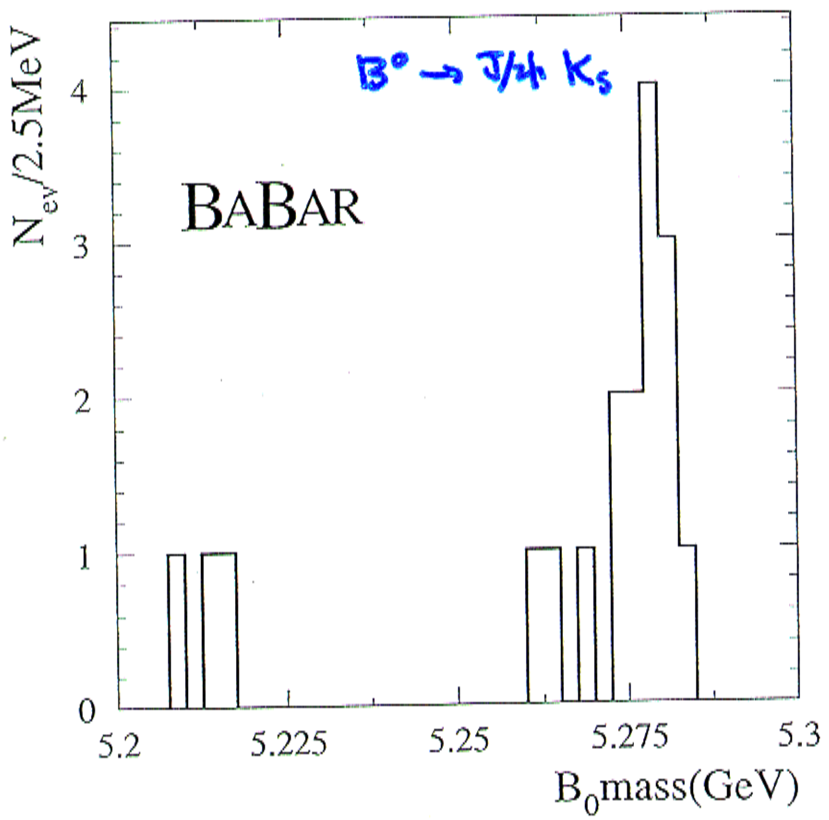
$\hookrightarrow \mu^+\mu^-$





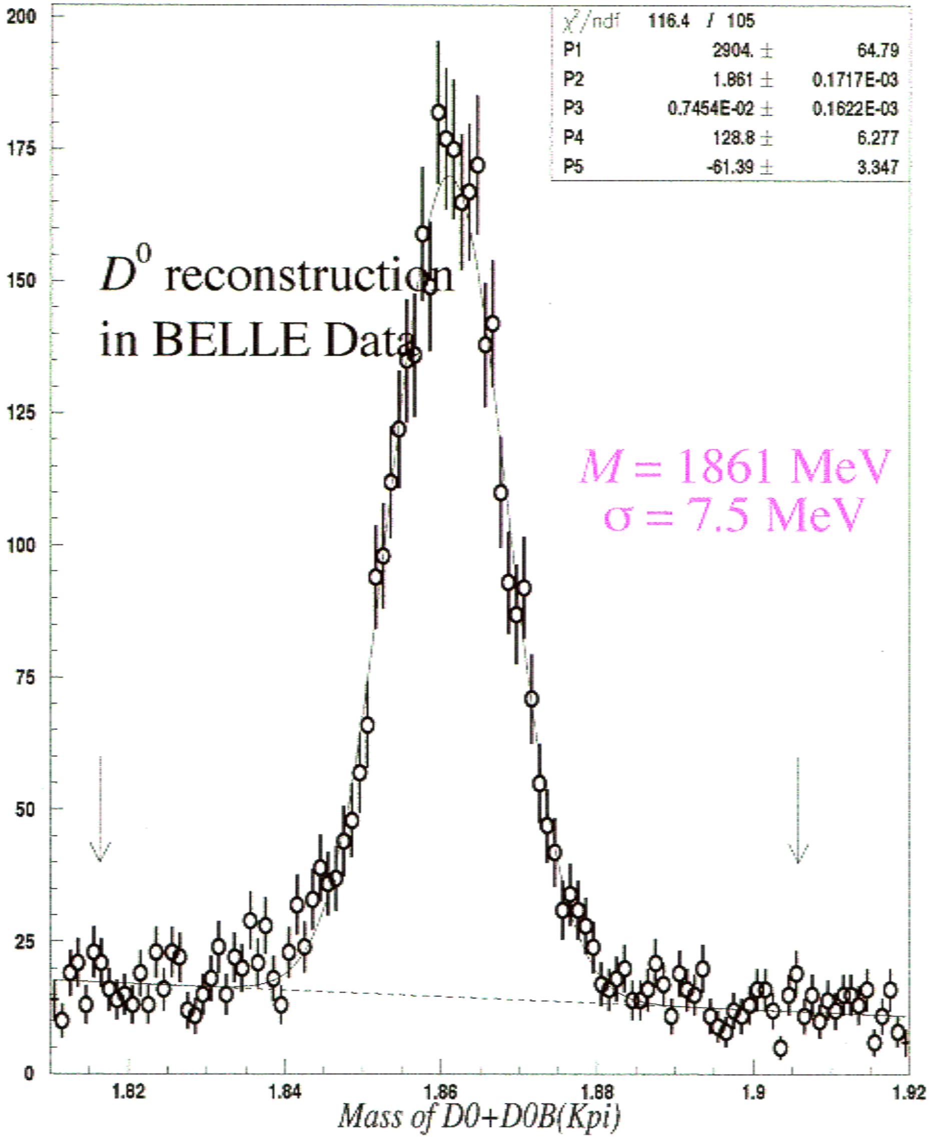


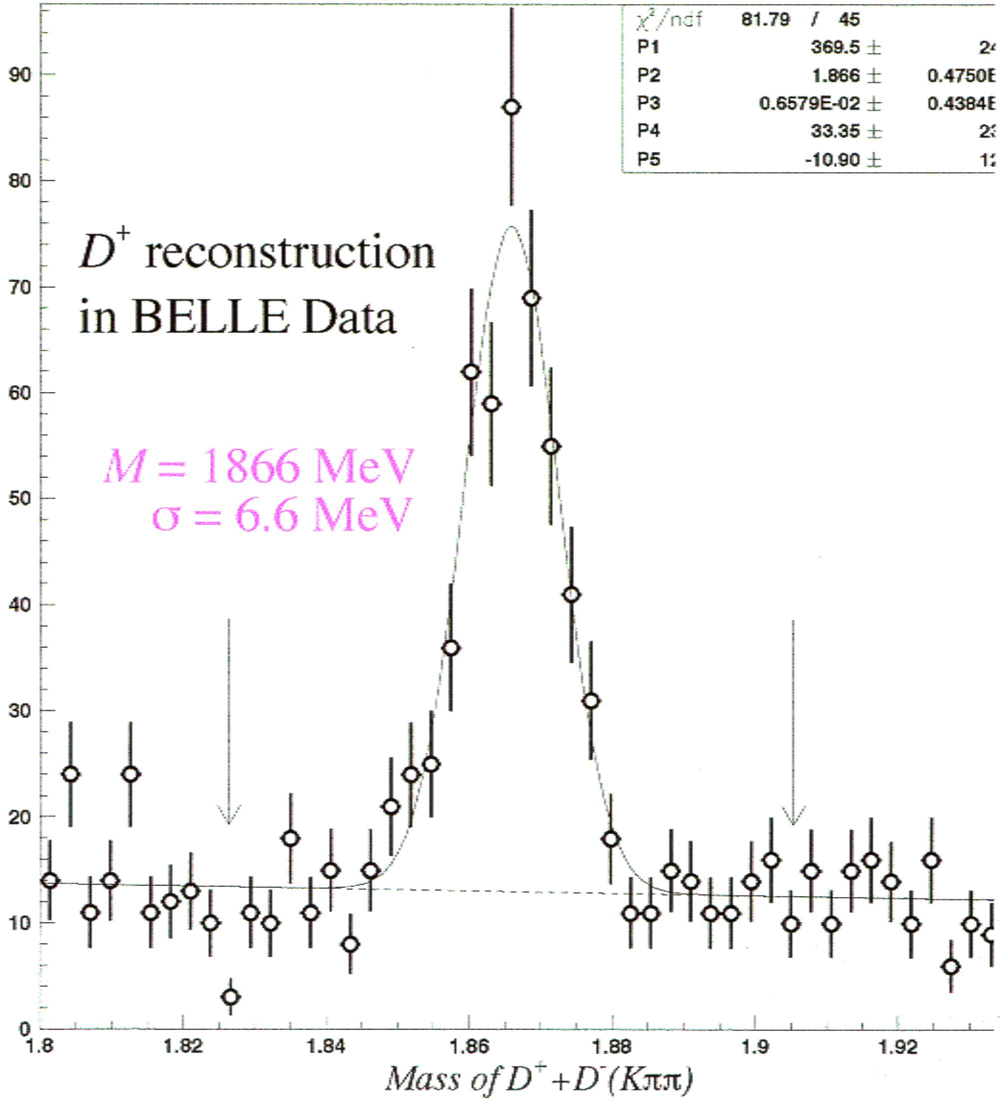
B+ → J/ψ K+
BABAR
Nev/2.5MeV
0
2.5
5
7.5
10
5.2
5.225
5.25
5.275
5.3
Bch mass(GeV)



B° → J/ψ Ks
BABAR
Nev/2.5MeV
0
1
2
3
4
5.2
5.225
5.25
5.275
5.3
B0 mass(GeV)

D reconstruction (with help of PID devices): Belle

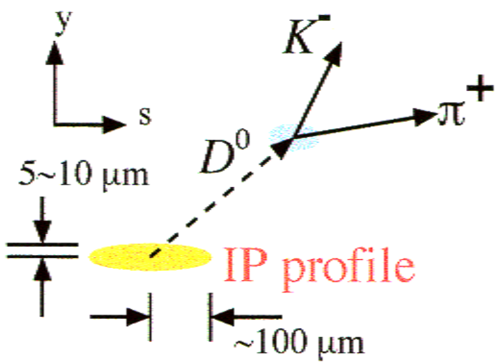




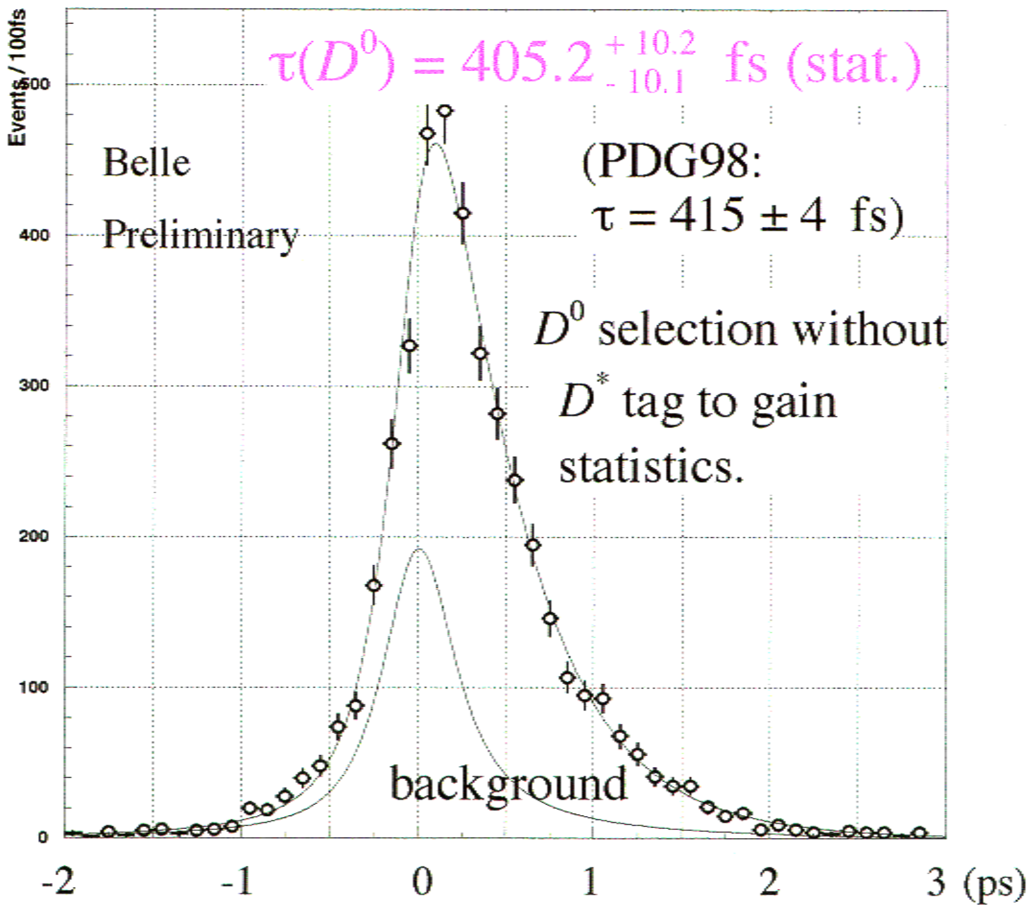
(Nakae)

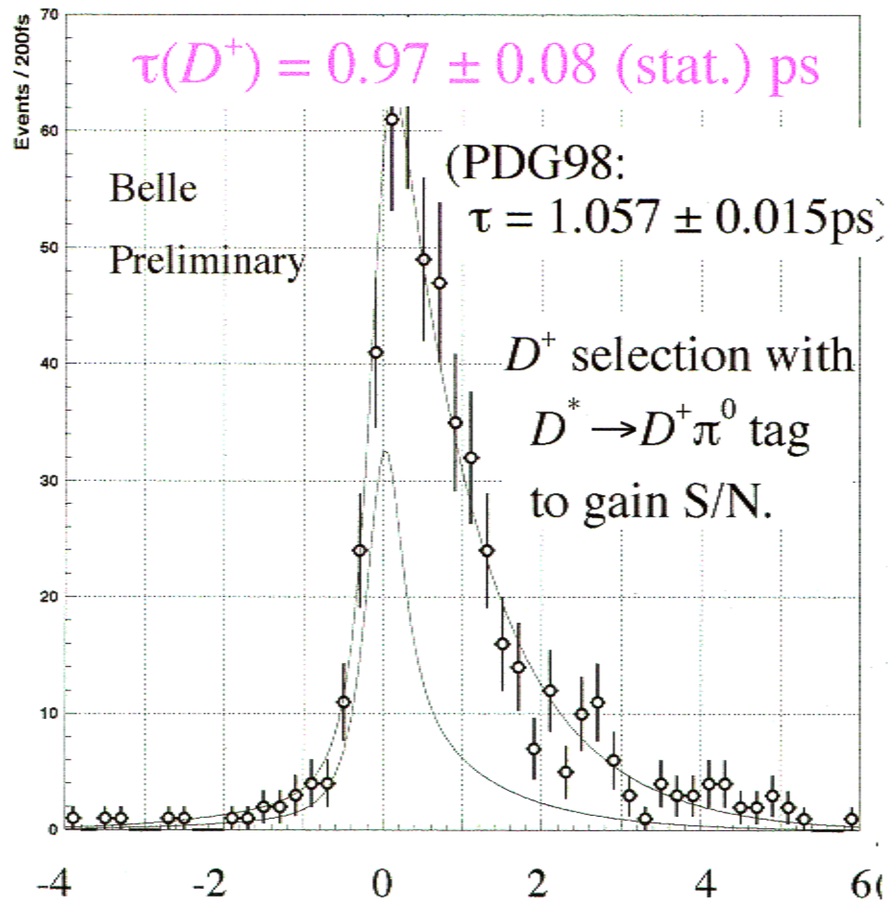
D^0 / D^+ lifetime measurement - vertex reconstruction in x-y: Belle

The lifetime is calculated from flight distance of D^0 from IP in the x-y plane. (using run-by-run IP profile)



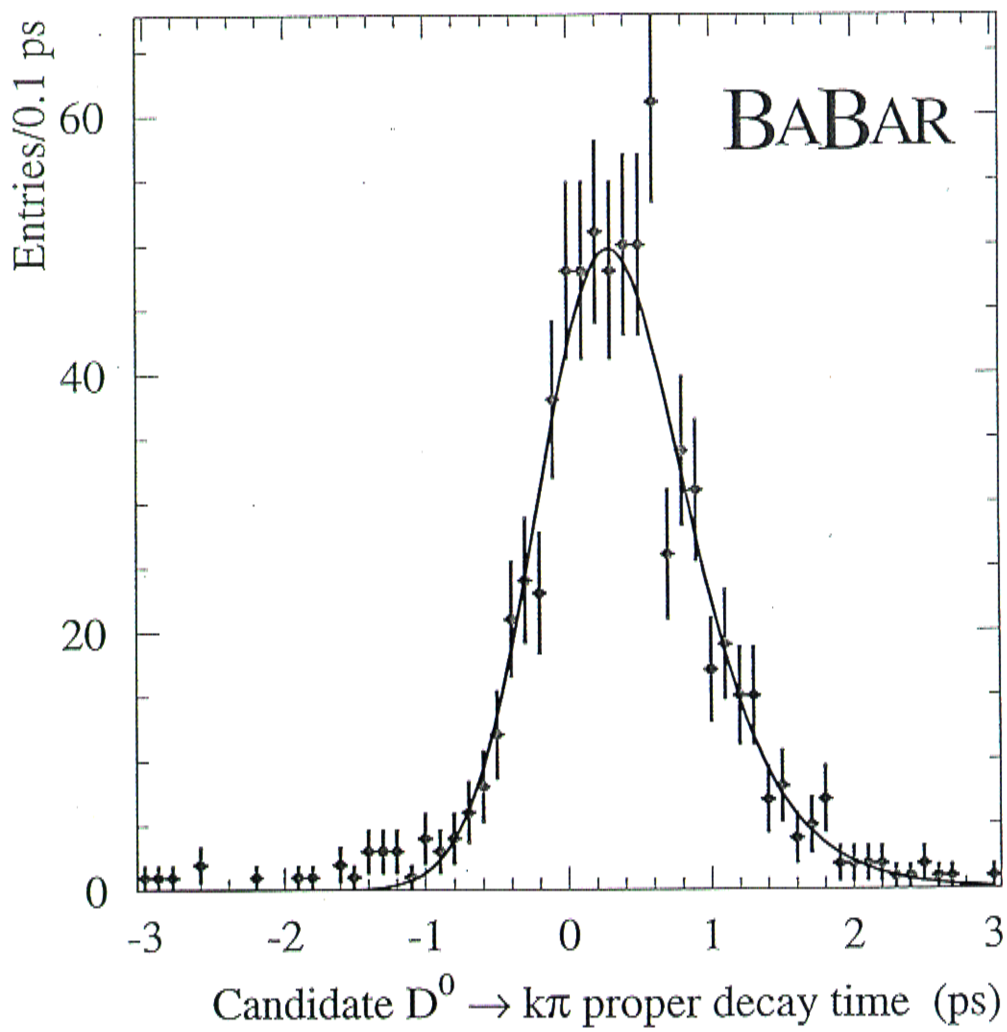
D from charm production (not *b* to avoid *b* lifetime effect. ($2.5 < p^{cm}(D) < 5.3$ GeV)





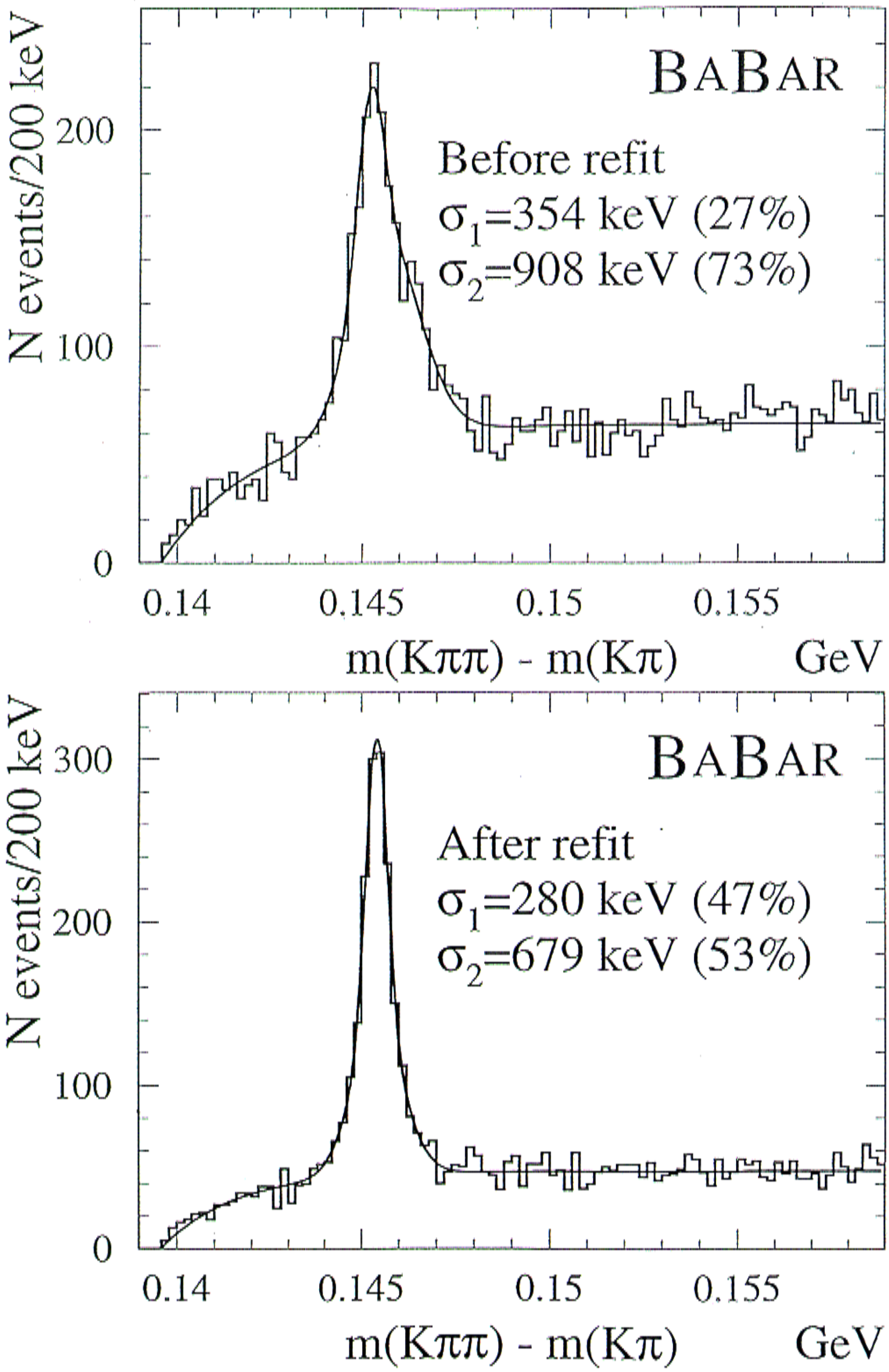
BaBar : D^0 lifetime

$D^{*+} \to D^0 \pi^+$: D^* - tagged
$\hookrightarrow K^- \pi^+$



$D^{*+} \to D^0 \pi_s^+$
$\quad \hookrightarrow K^- \pi^+$

Effect of IP constraint for π_s^+



Iijima (Nakao)

Belle

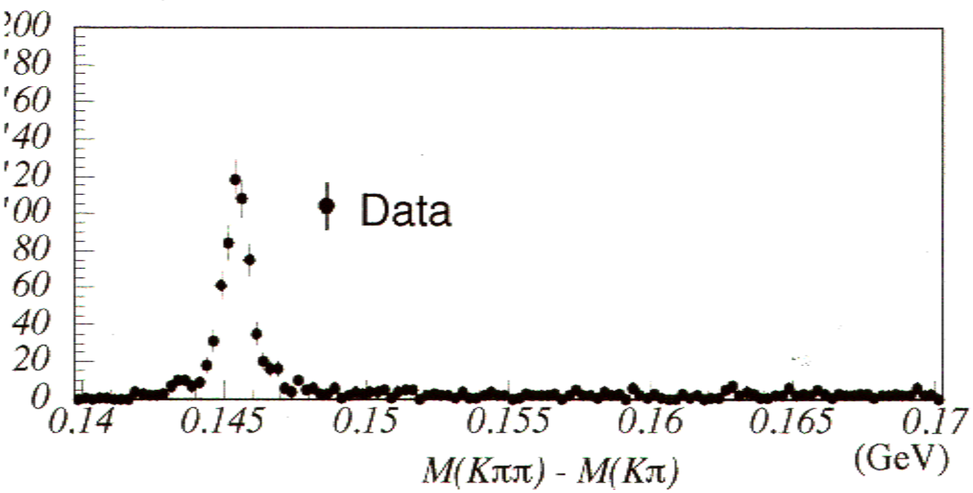
Test of Kaon ID with D^*

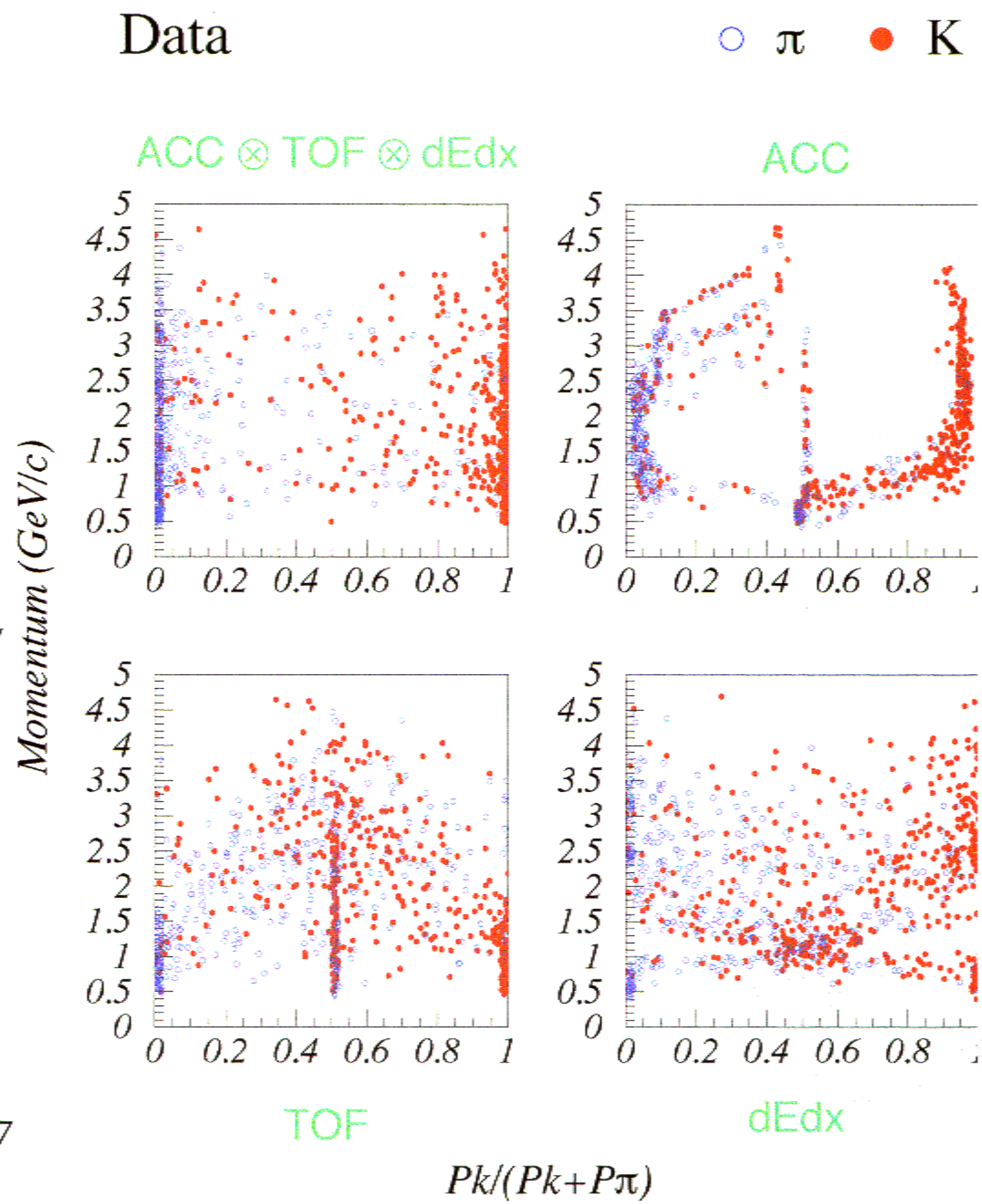
$D^{*+} \rightarrow D^0 \pi^+$ → tag

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

- $|\,M(D)-1.865\,| \leq 0.030$
- $P(D^*)/Eb(CM) > 0.5$
- $|\cos\theta k| \leq 0.8$
- reject if K-p inversed comb in the D mass window

⇒ Estimated purity ~ 95%

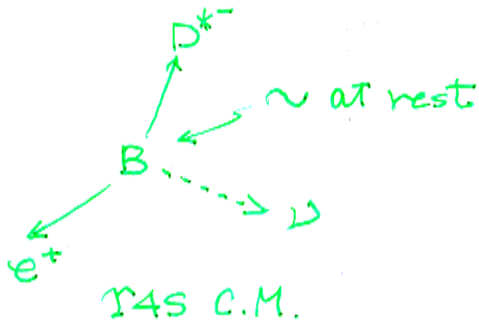


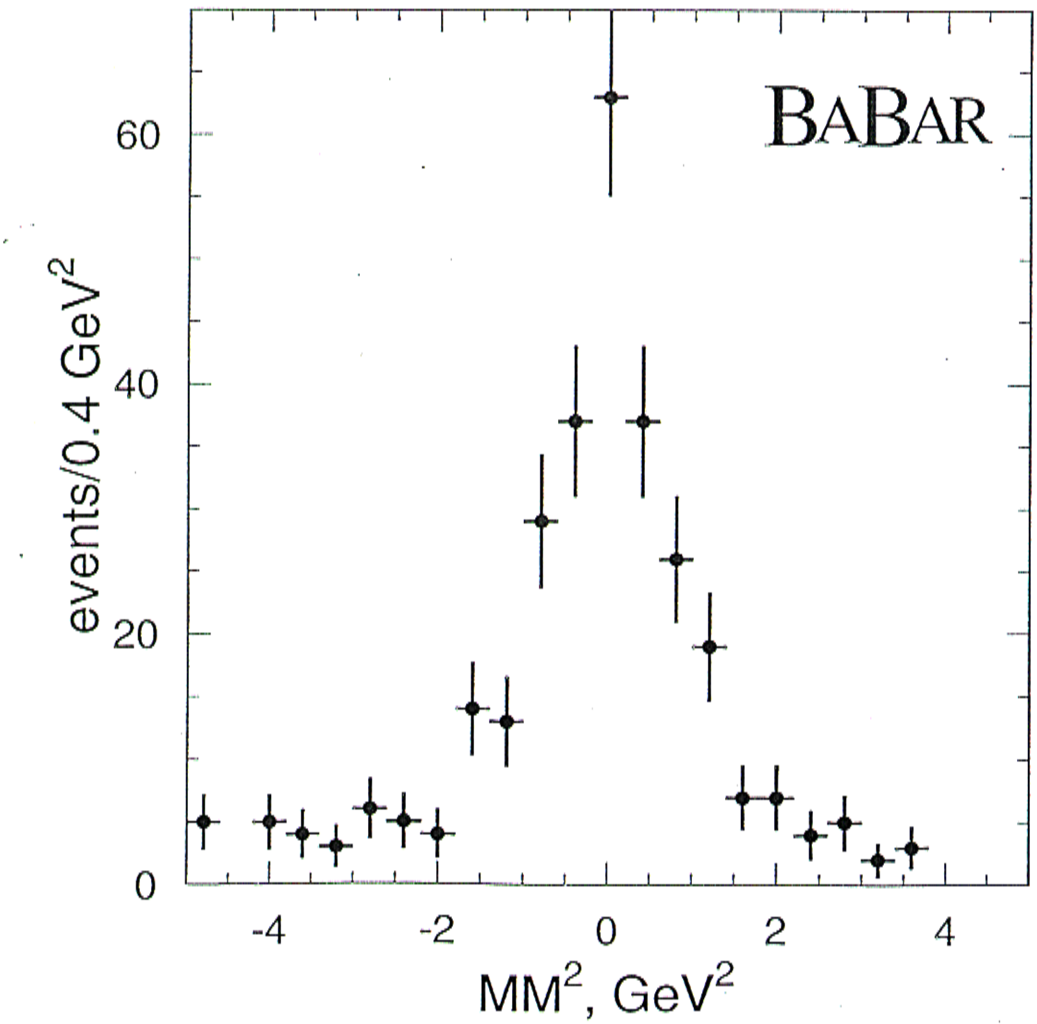


$B^0 \to D^{*-} e^+ \nu_e$

$\hookrightarrow \bar{D}^0 \pi^-$

$\hookrightarrow K^+ \pi^-$





(missing mass)^2

$\equiv$

ν-mass^2

(Nakao)

Test of flavor tagging: Belle

$B^0 \to D^{*-} l^+ \nu$

Algorithm

Lepton tag: high $p^{c.m.}$ (> 1.1 GeV) lepton to tag $b \to c l \nu$ decay, and if it fails,

Kaon tag: charge sum of the charged Kaons to tag $b \to c \to s$ decay

Performance check

Use $B^0 \to D^{(*)-} l^+ \nu$ decay sample as CP side, remaining particles as tagging side.

~200 events

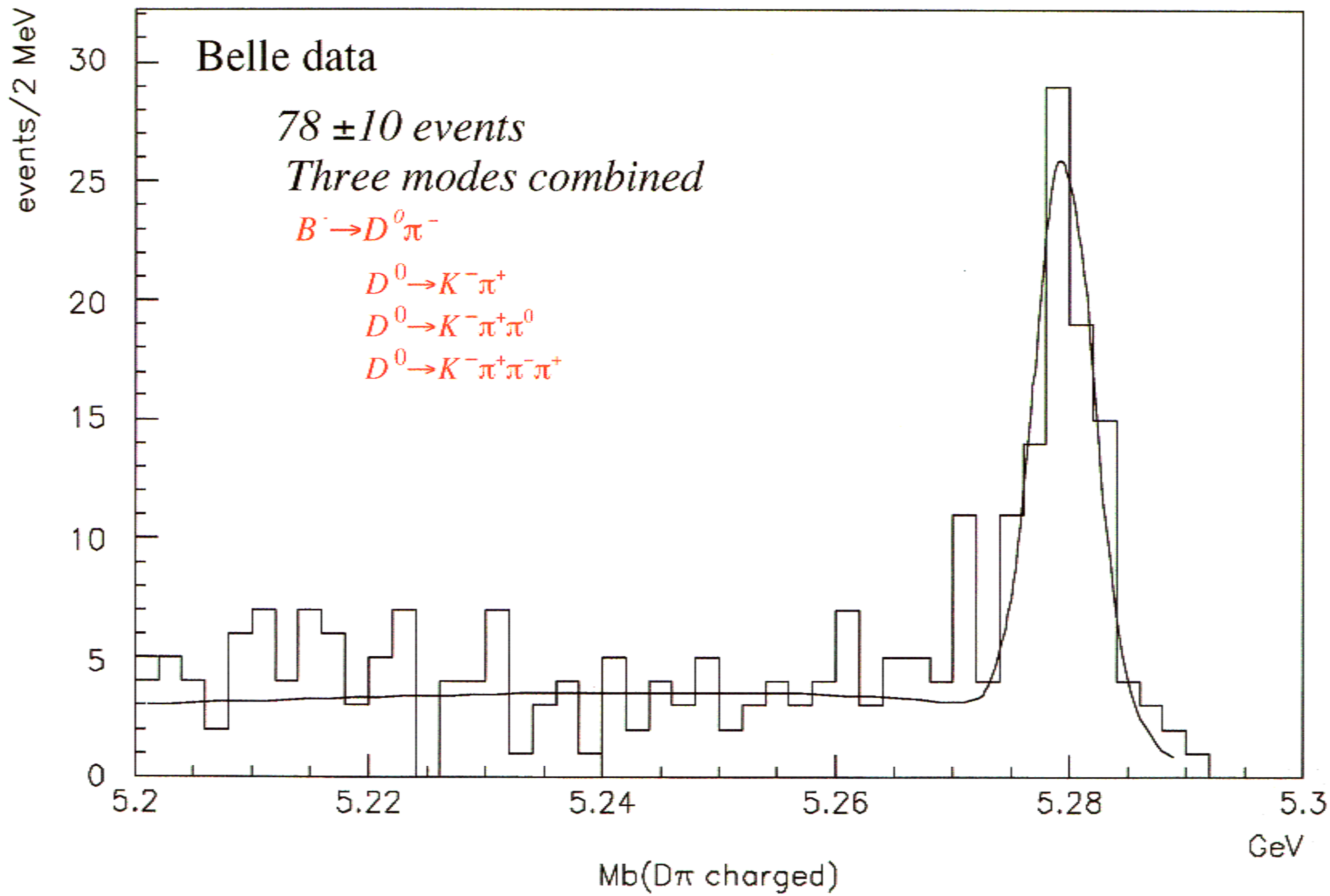
	ε(%)	wrong tag(%)	effective ε(%)
Lepton tag	8 ± 1 (11.9)	1 ± 10 (8.2)	7 ± 3 (8.3)
Kaon tag	31 ± 3 (28.2)	21 ± 7 (15.2)	10 ± 5 (13.7)
Sum	40 ± 3 (40.1)	18 ± 6 (13.1)	16 ± 6 (21.8)

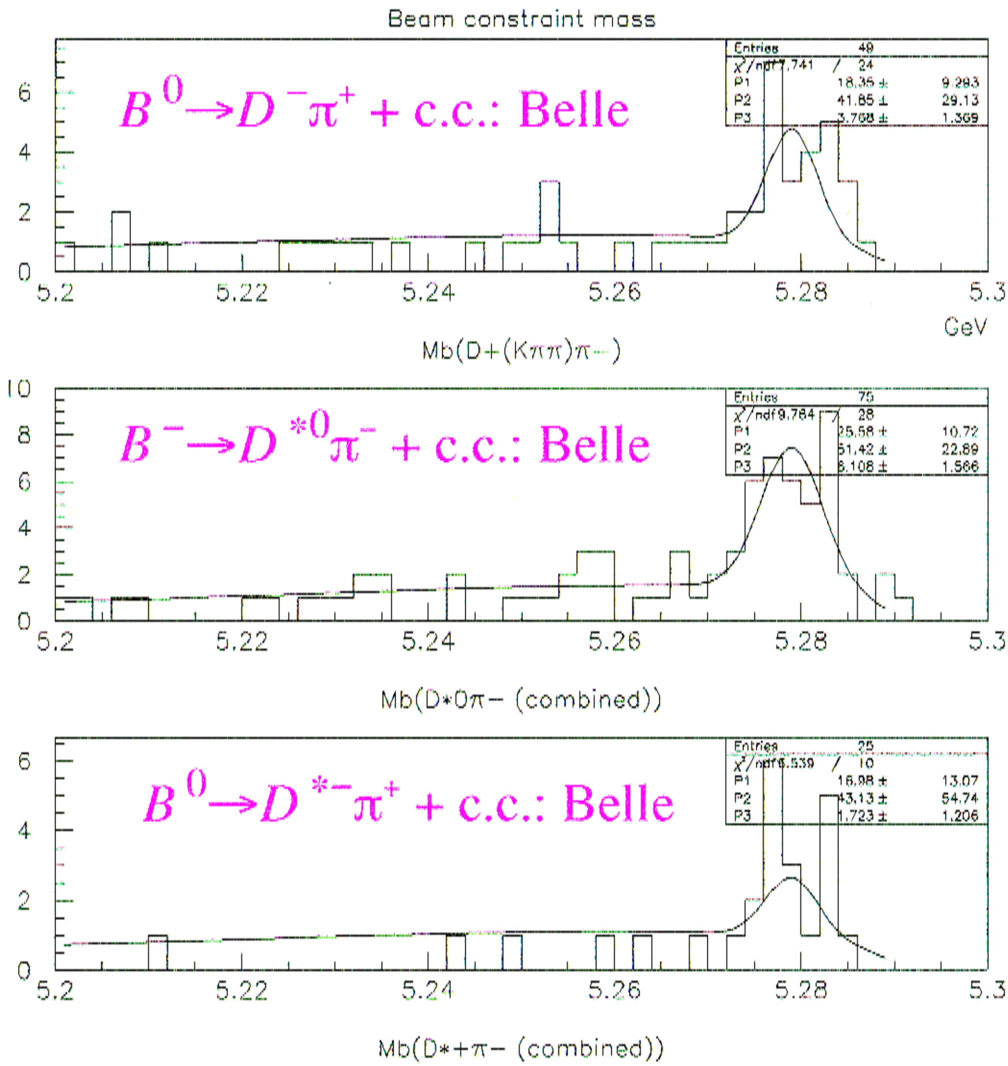
(): Monte Carlo estimation

effective $\varepsilon = \varepsilon(1-2w)^2$

(Nakao)

$B^- \to D^0\pi^-$ combined





Beam constraint mass
$B^0 \to D^- \pi^+$ + c.c.: Belle
Entries 49
χ^2/ndf 7.741 / 24
P1 18.35 ± 9.283
P2 41.85 ± 29.13
P3 3.768 ± 1.309
GeV
Mb(D+(Kππ)π−)
$B^- \to D^{*0} \pi^-$ + c.c.: Belle
Entries 75
χ^2/ndf 9.784 / 28
P1 25.58 ± 10.72
P2 51.42 ± 22.89
P3 8.108 ± 1.566
Mb(D*0π− (combined))
$B^0 \to D^{*-} \pi^+$ + c.c.: Belle
Entries 25
χ^2/ndf 6.539 / 10
P1 16.98 ± 13.07
P2 43.13 ± 54.74
P3 1.723 ± 1.206
Mb(D*+π− (combined))

(Nakao)

Belle

B lifetime fit and mixing

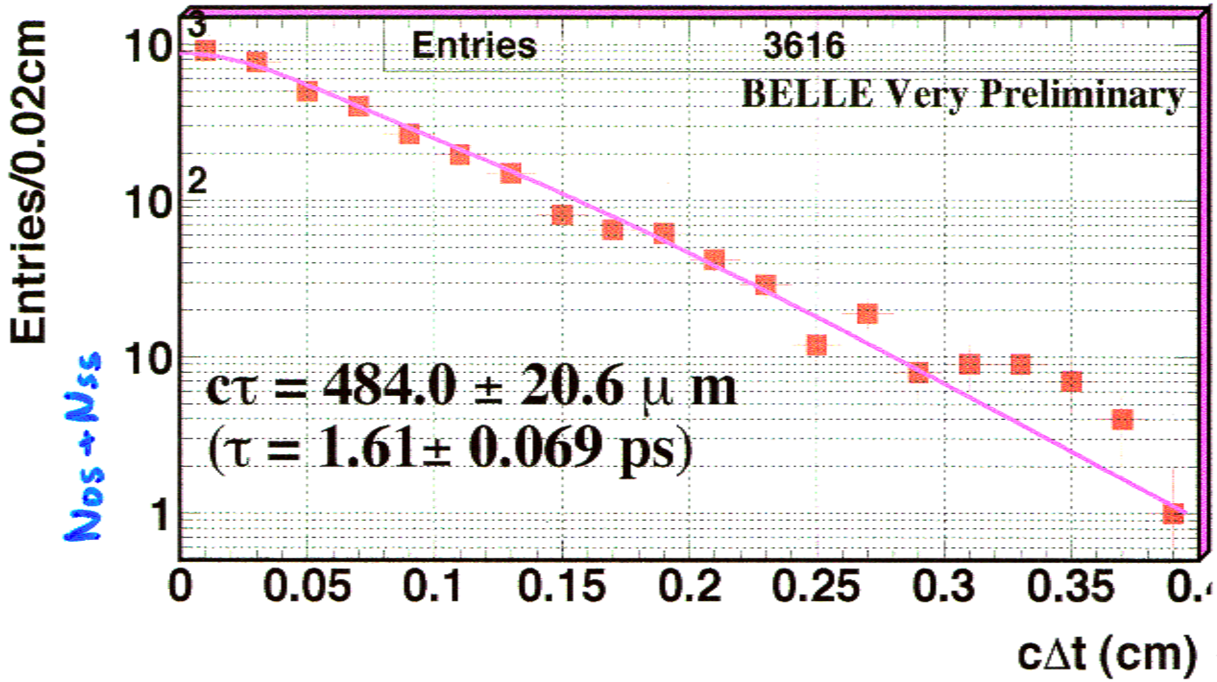
- Di-lepton sample

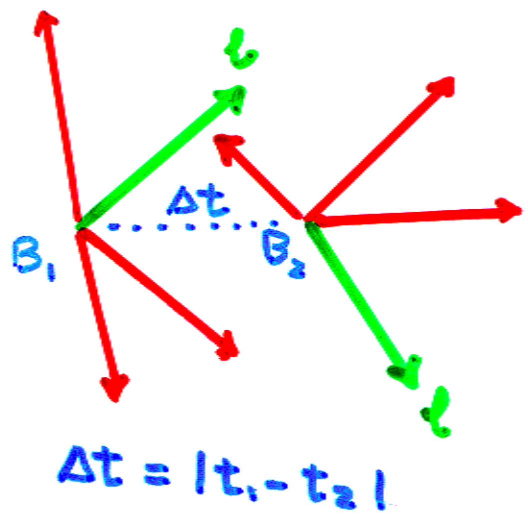
Lifetime fit:

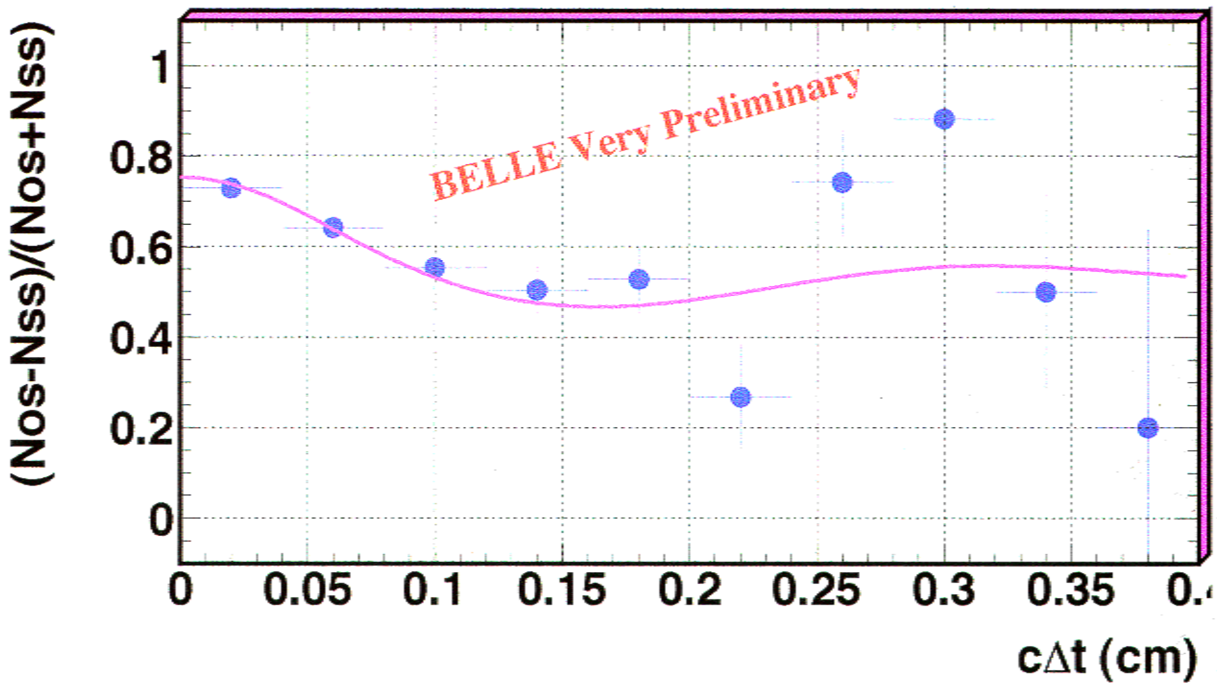
Fixed parameters:

$\beta\gamma = 0.425$

$x_d = 0.723$



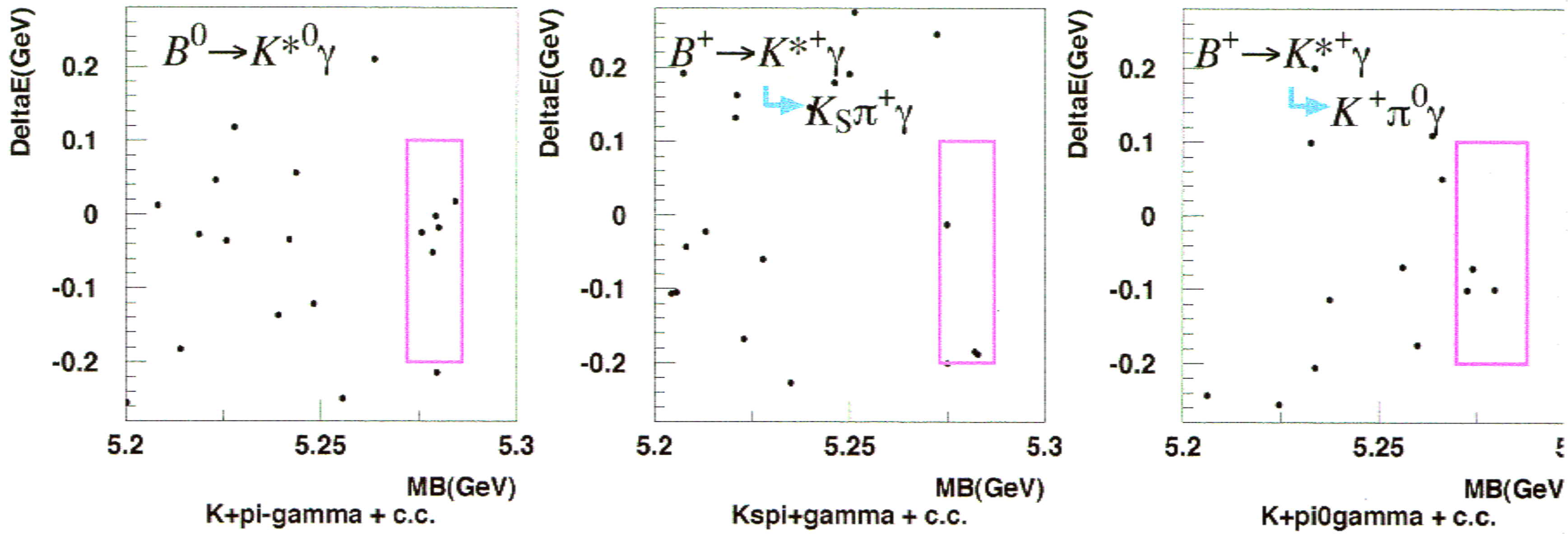




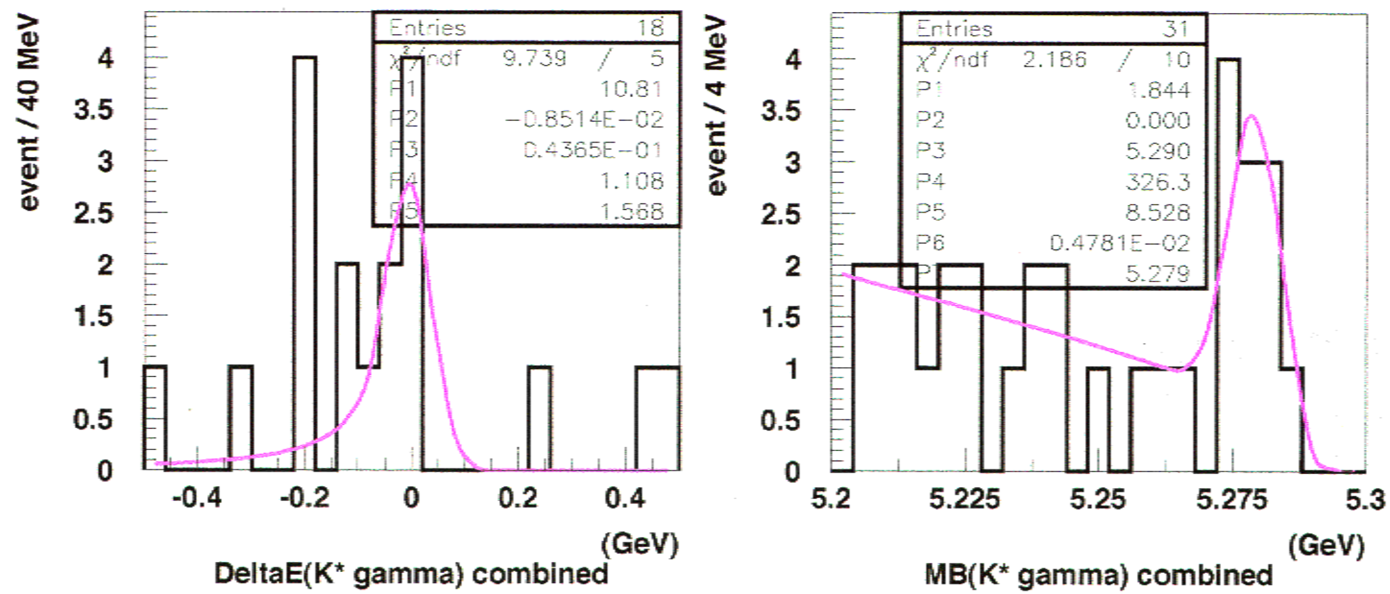
~ 3000 events

(Nakao)

Belle: $B \to K^* \gamma$ signal candidates



10 candidates,
2 background
expected.



Summary

- Both PEP-II and KEK-B exceeded $L = 10^{33}/\text{cm}^2\text{s}$, and are operating steadily.
- Integrated luminosity of 5∼10 fb^{-1} by this summer for each detector is realistic.
- Components of both detectors are functioning reasonably well.
- Beam backgrounds are more or less under control.
- If no major obtacles occur, $\sigma_{\sin 2\beta}$ of 0.2∼0.3 is expected by this summer from each experiment.