A Status Report on Asymmetric B-Factories

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In order to study CPV at e^+e^- colliders (ΨK_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 $t_{\text{sig}} - t_{\text{tag}}$)
   $\rightarrow$ Silicon trackers

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

$e^+e^- \rightarrow \Upsilon 4S \rightarrow B^0\bar{B}^0$ 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.
$\rightarrow$ B decay time measurements

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

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

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

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

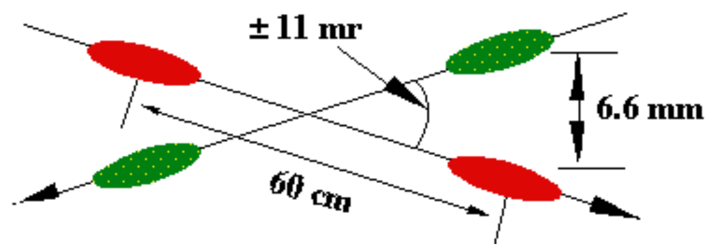
$\rightarrow$ Beam instability
Luminosity reduction (geometrical)

Looks OK for now.

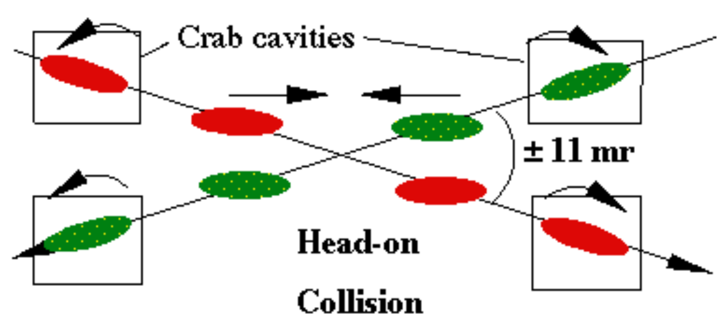
Crab crossing (KEK-B)

In case finite-angle crossing causes problems

□ Without crab cavities

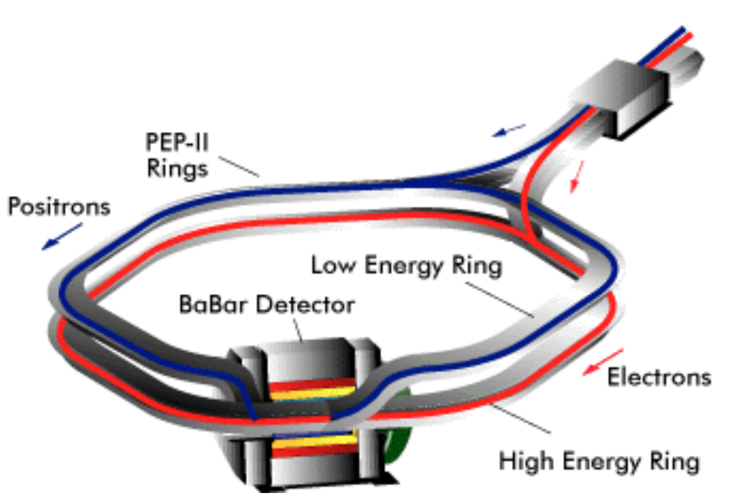


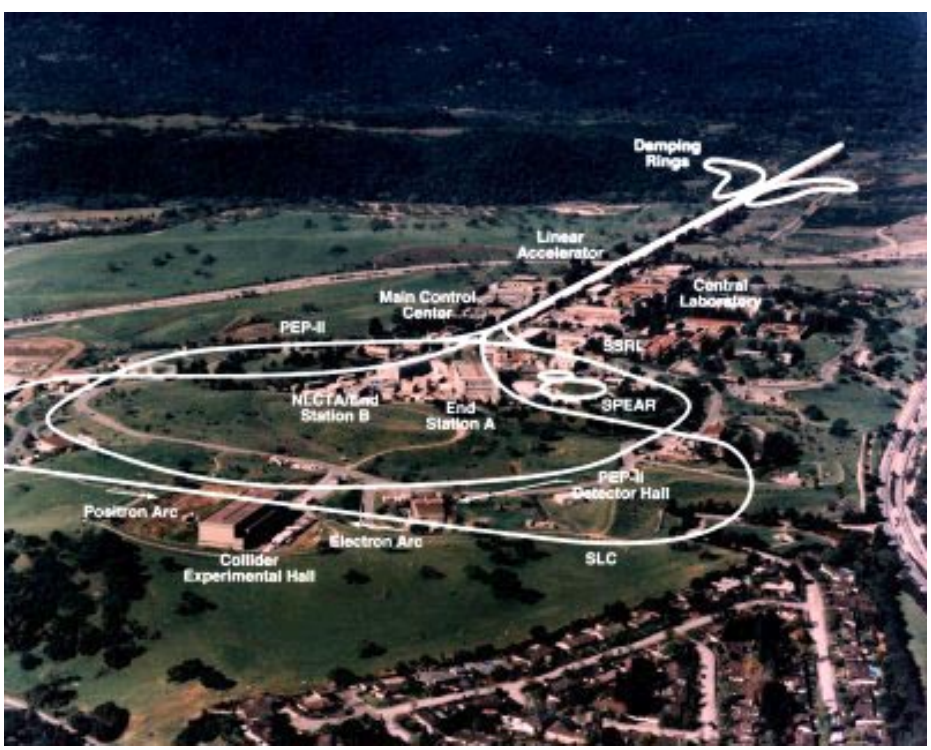
□ With crab cavities



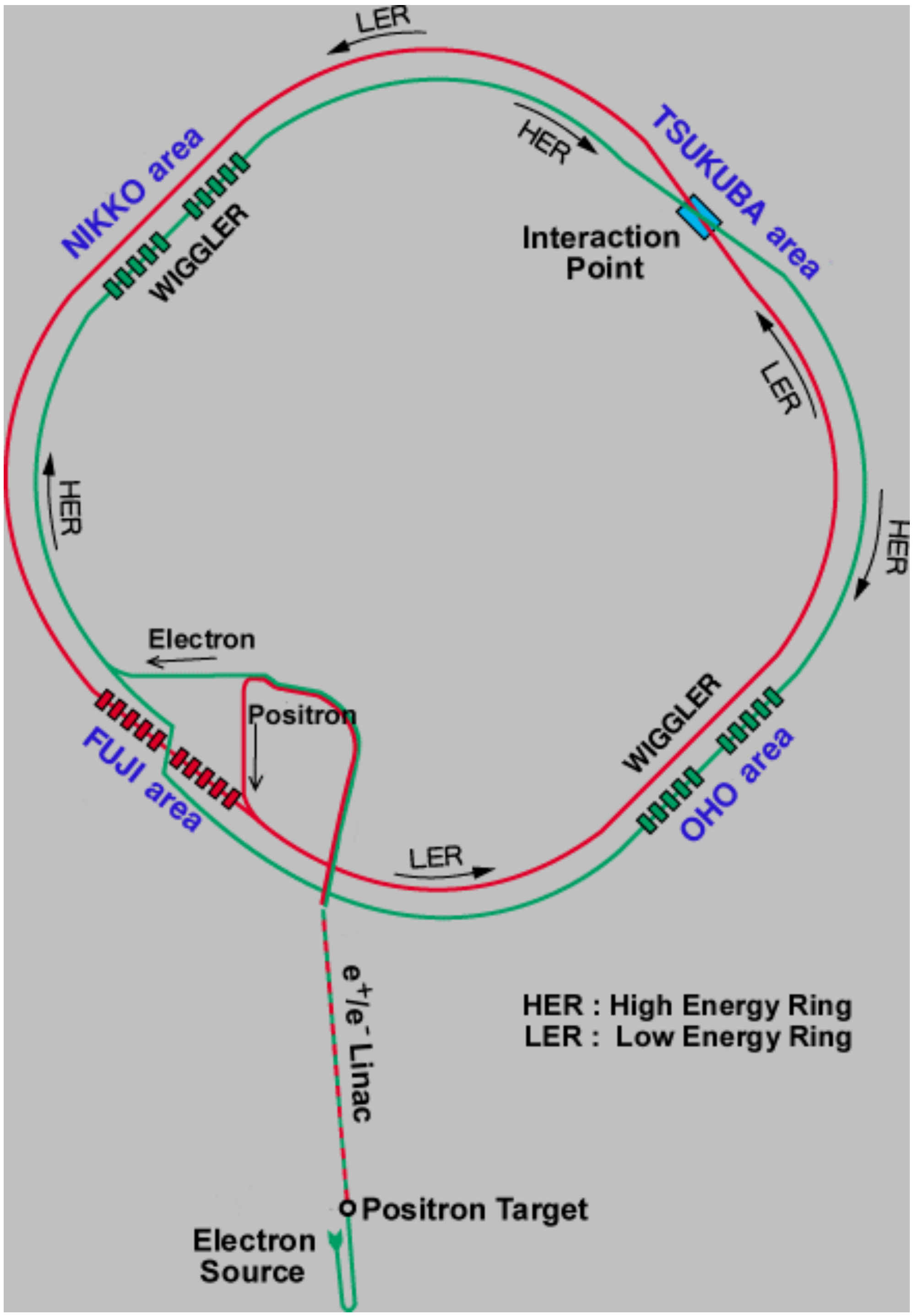
→ complete overlap of beams
(No geometrical luminosity loss.
Suppresses beam-beam instability)

PEP-II (SLAC)


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

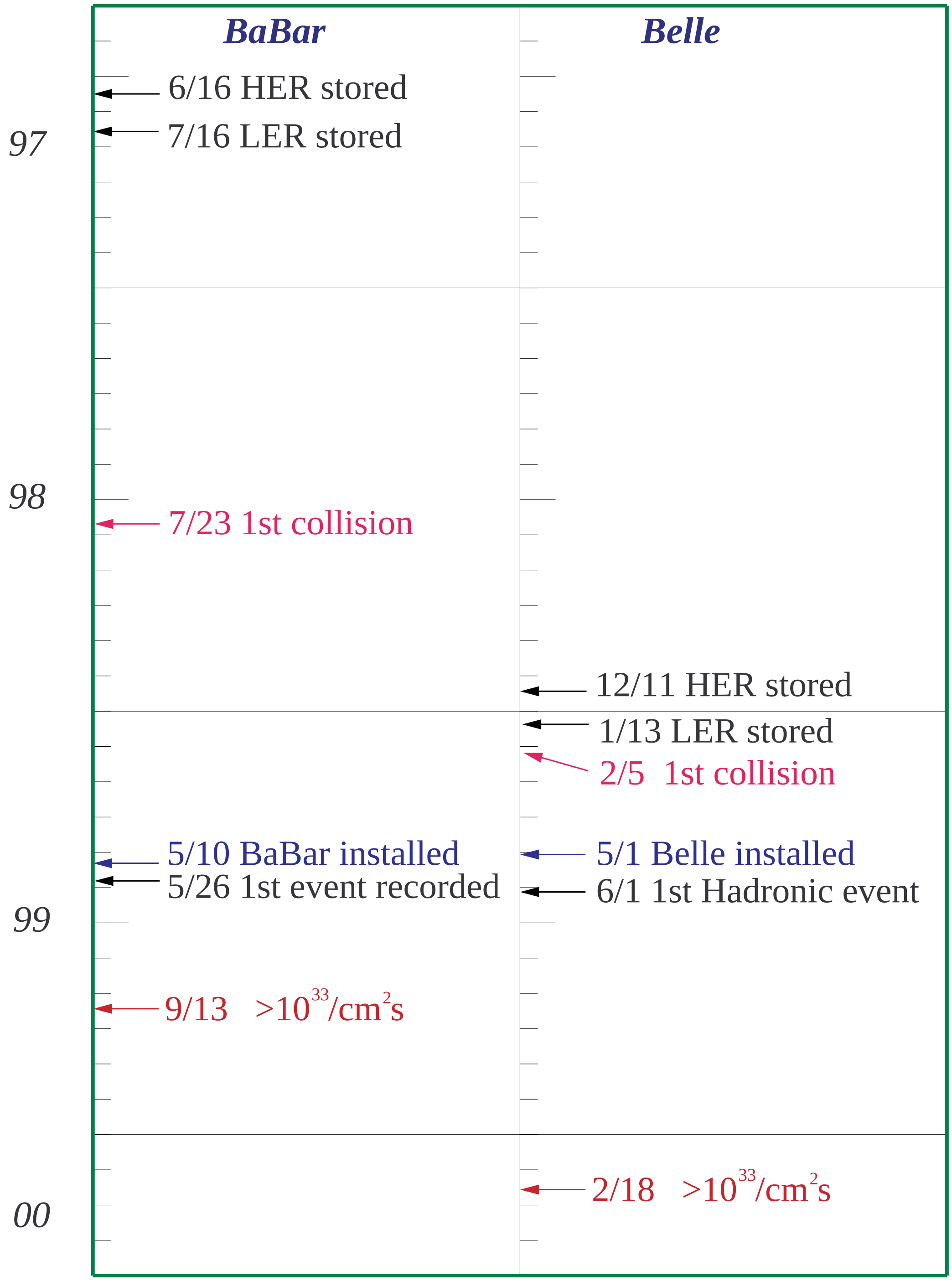

Damping
Rings
Linear
Accelerator
Central
Laboratory
Main Control
Center
PEP-II
SSRL
SPEAR
End
Station A
PEP-II
Detector Hall
Positron Arc
Electron Arc
Collider
Experimental Hall
SLC

KEK-B (KEK, Japan)



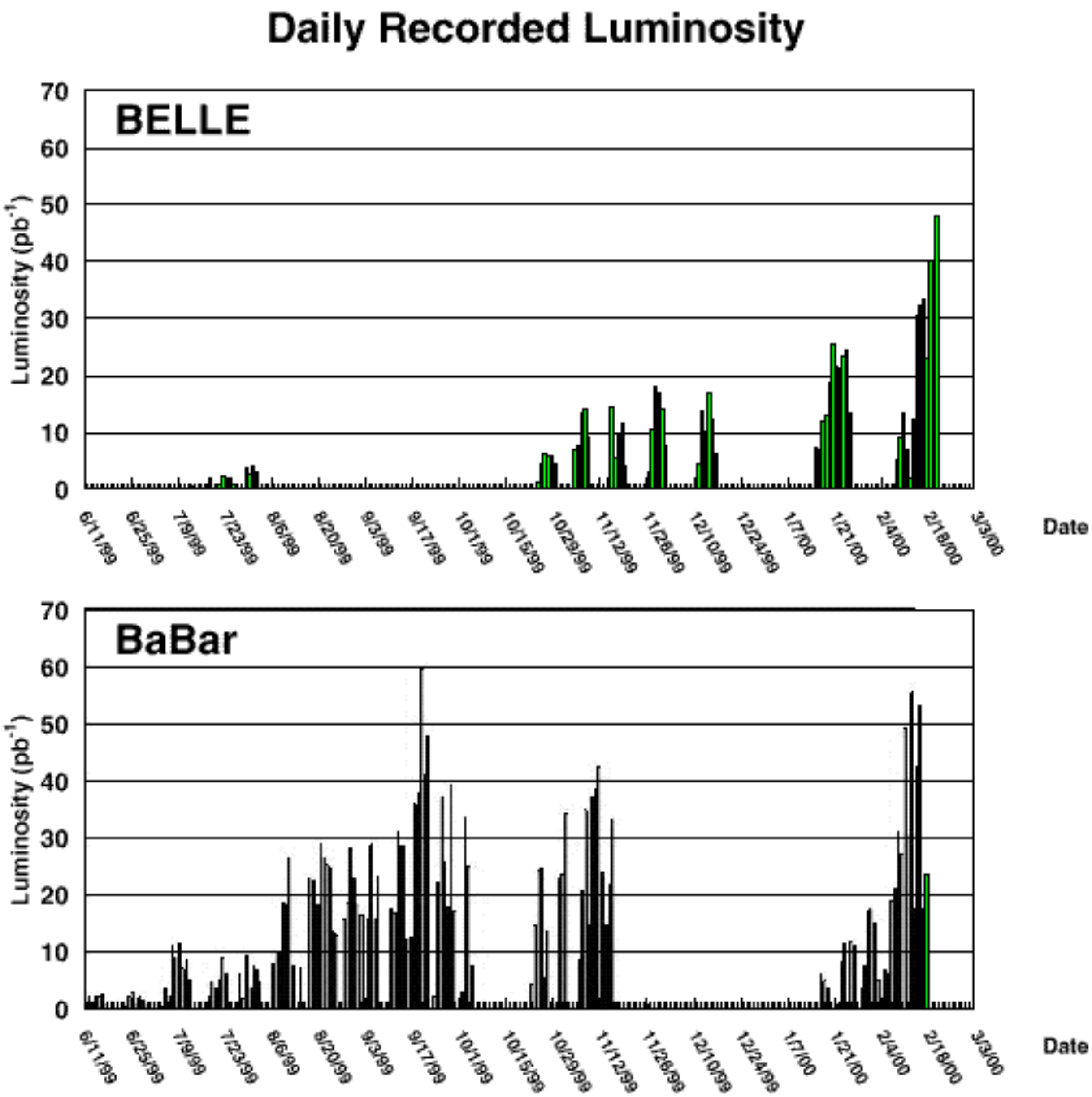
machine	$CESR$	$PEP\text{-}II$	$KEK\text{-}B$
detector	$CLEO$	$BaBar$	$Belle$
circumference (km)	0.768	2.199	3.016
# of rings	1	2	2
E_{e^+}(GeV)	5.3	3.1	3.5
E_{e^-}(GeV)	5.3	9.0	8.0
$\beta_{\Upsilon 4S}$	~ 0	0.49	0.39
$\delta E/E$	6×10^{-4}	7×10^{-4}	7×10^{-4}
Δt_{bunch}	$14ns$	$4.2ns$	$2ns$
bunch size(w)	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

Benchmarks



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

Luminosity


Daily Recorded Luminosity
BELLE
Luminosity (pb^{-1})
70
60
50
40
30
20
10
0
6/11/99
6/25/99
7/9/99
7/23/99
8/6/99
8/20/99
9/3/99
9/17/99
10/1/99
10/15/99
10/29/99
11/12/99
11/26/99
12/10/99
12/24/99
1/7/00
1/21/00
2/4/00
2/18/00
3/3/00
Date
BaBar
Luminosity (pb^{-1})
70
60
50
40
30
20
10
0
6/11/99
6/25/99
7/9/99
7/23/99
8/6/99
8/20/99
9/3/99
9/17/99
10/1/99
10/15/99
10/29/99
11/12/99
11/26/99
12/10/99
12/24/99
1/7/00
1/21/00
2/4/00
2/18/00
3/3/00
Date

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$\sim$2 weeks each.

3. Current issues

   – Blowup of LER vertical beamsize.

     * $\sigma_y \rightarrow \times 2$ 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.

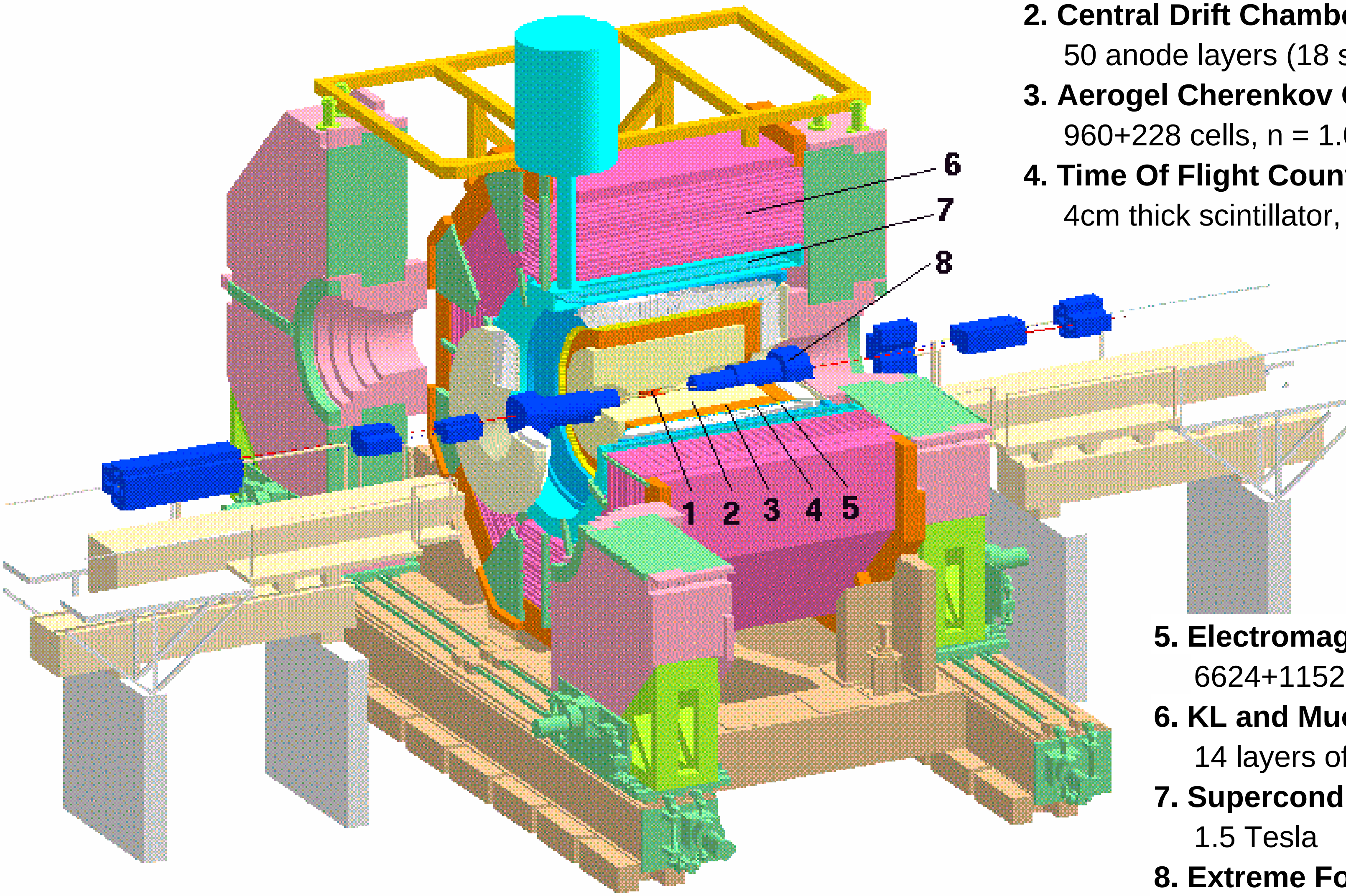
     * Installation in 2003.

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)
   - Not compromising data taking for now.

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

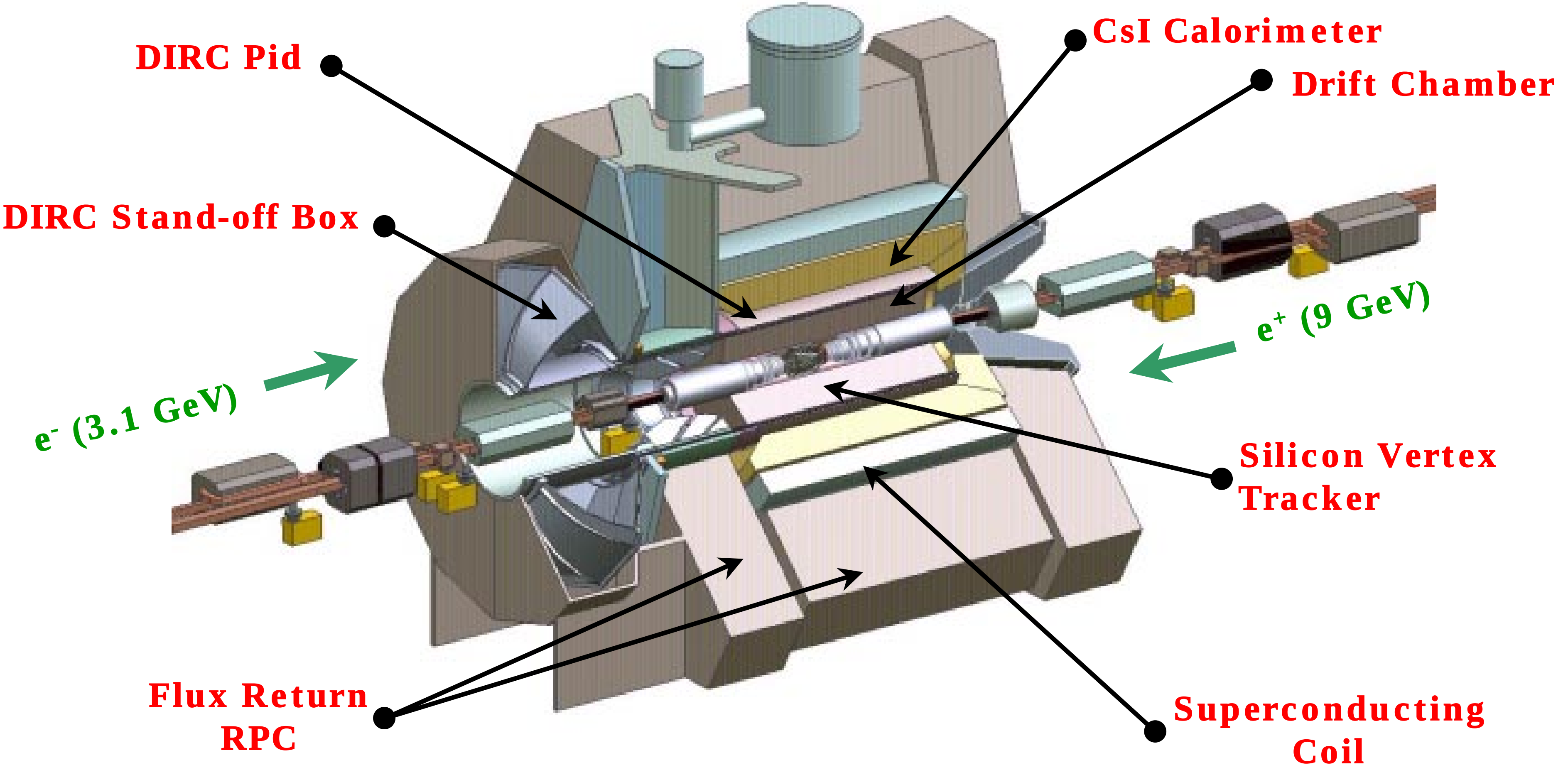
4. Time Of Flight Counter (TOF)
4cm thick scintillator, 128 ϕ-segmentation

5. Electromagnetic Calorimeter (ECL)
6624+1152+960 CsI(Tl) crystals

6. KL and Muon Detector (KLM)
14 layers of glass RPC in iron yoke

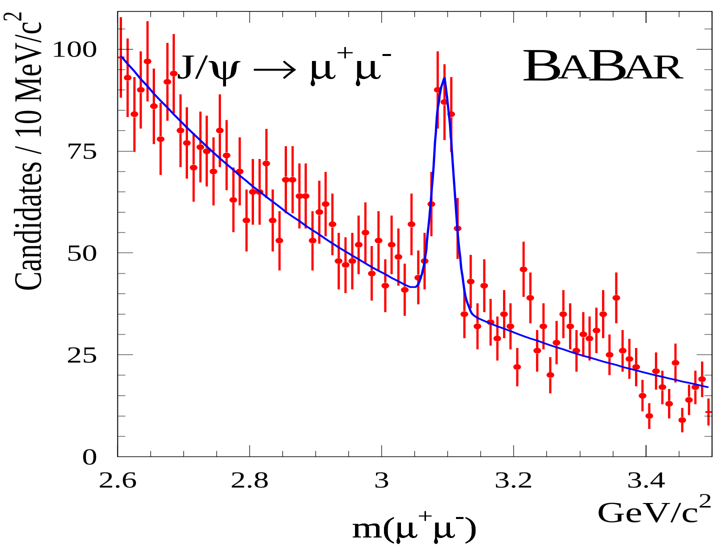
7. Superconducting Solenoid
1.5 Tesla

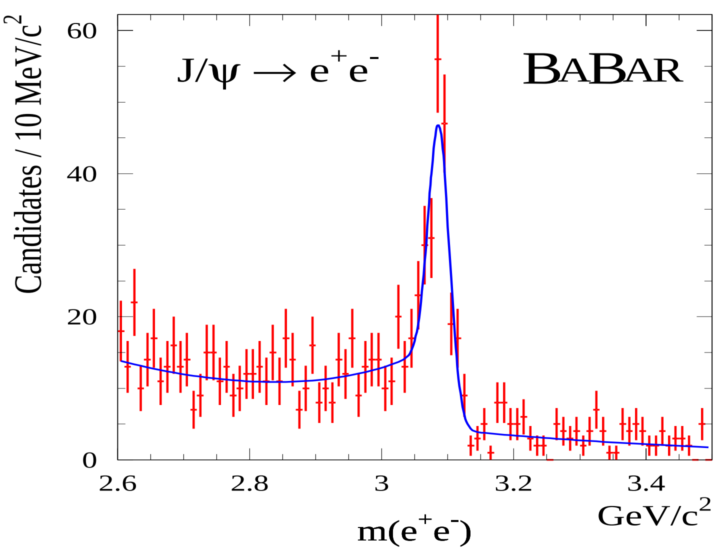
8. Extreme Forward Calorimeter (EFC)
320 BGO crystals attached on the
final focus quad.


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

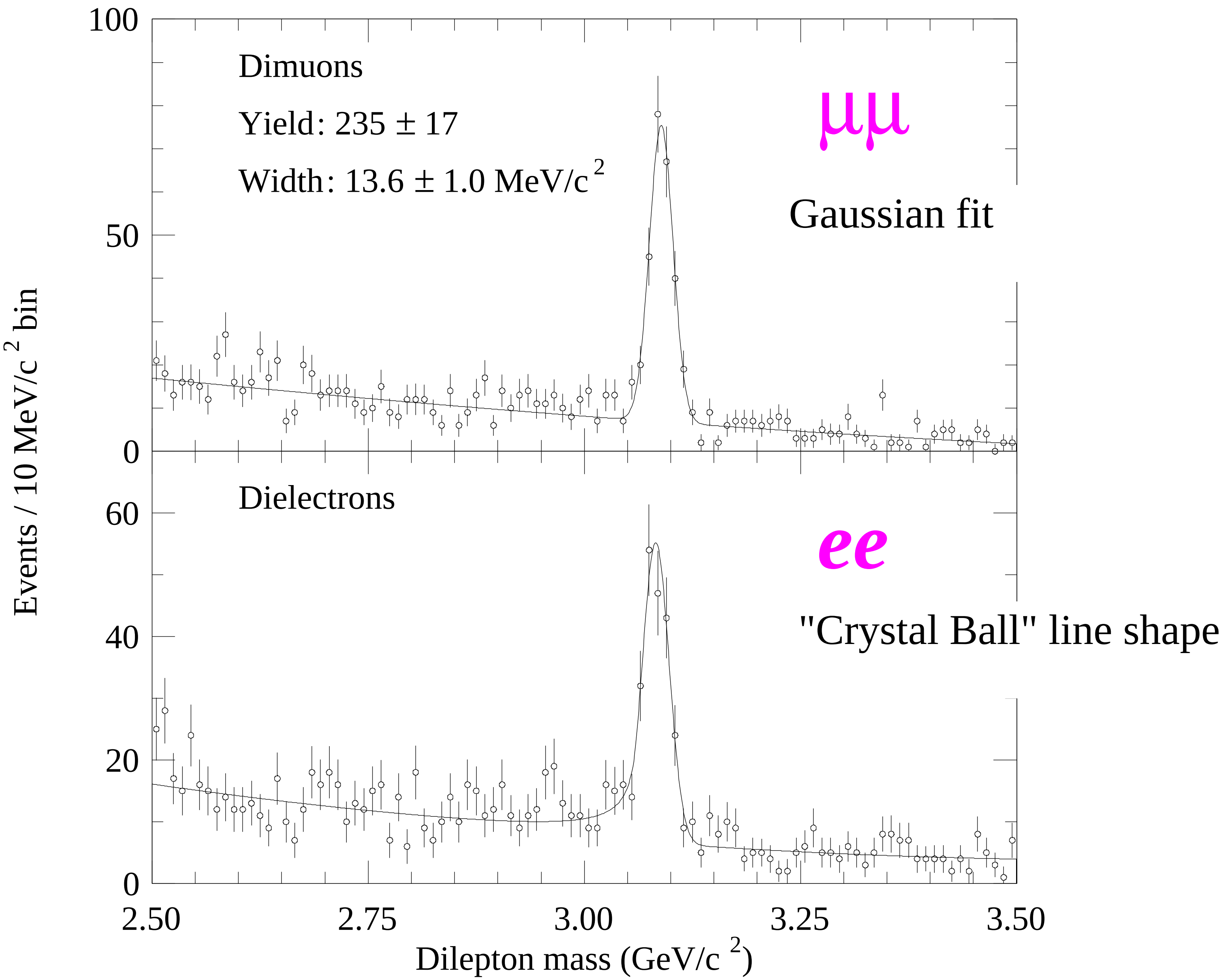
Physics Performaqnces

$$B \to J/\Psi X$$

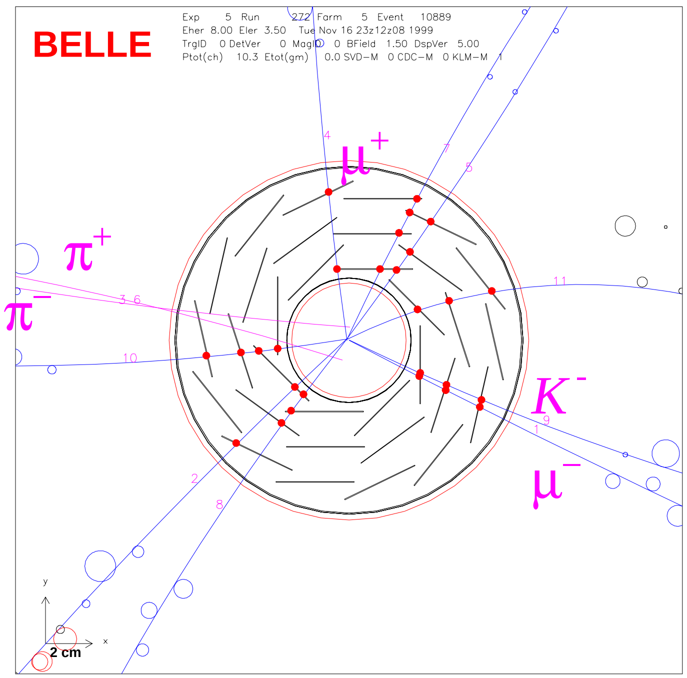




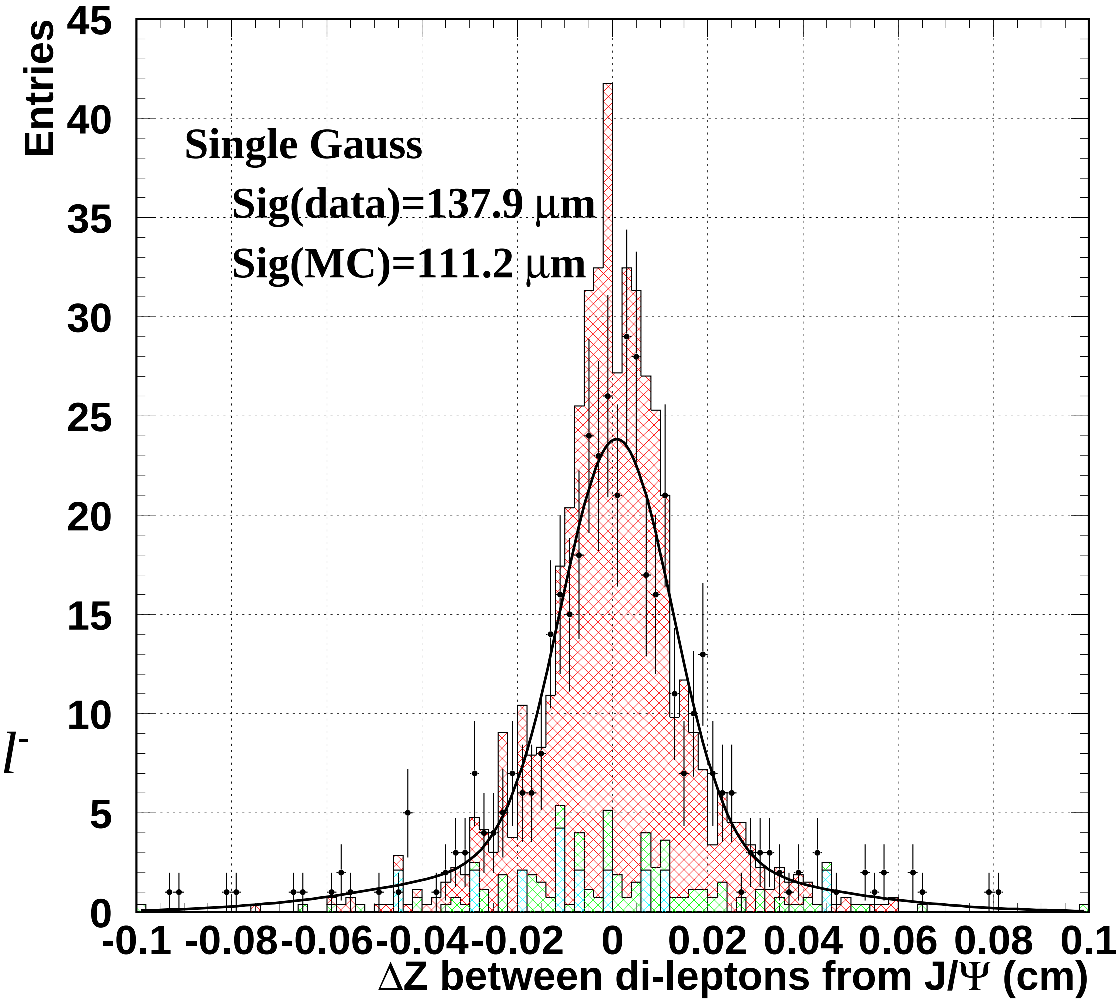
Belle: J/ψ in μμ / *ee* channels



Vertexing: Belle



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



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

138 μm

<**Full reconstruction on $\Upsilon 4S$** >

$$B \rightarrow f_1 \cdots f_n$$

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

$$E_B = E_{\rm beam} = 5.290 \text{ GeV}$$

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

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

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

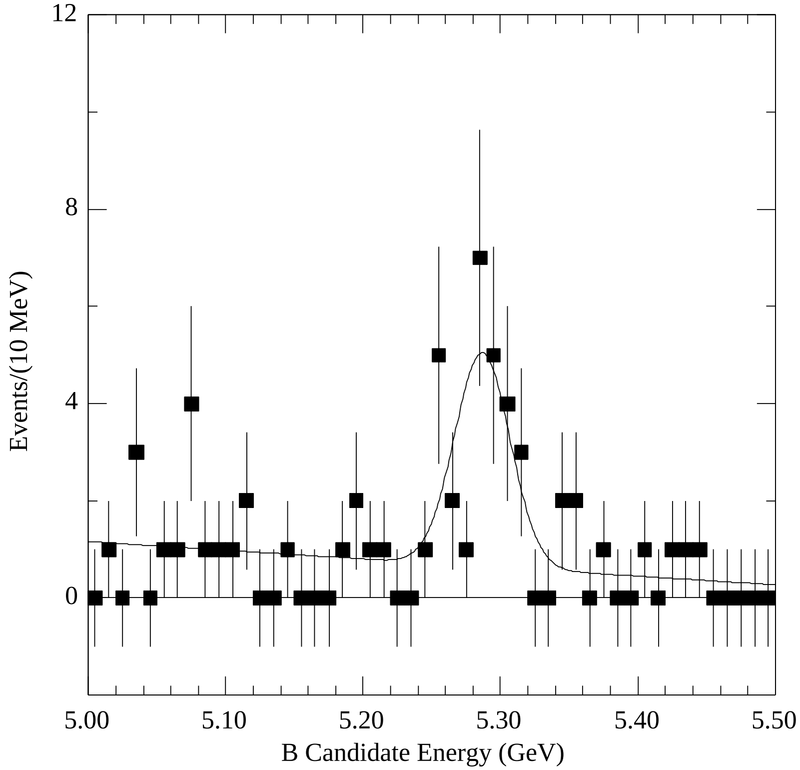
where

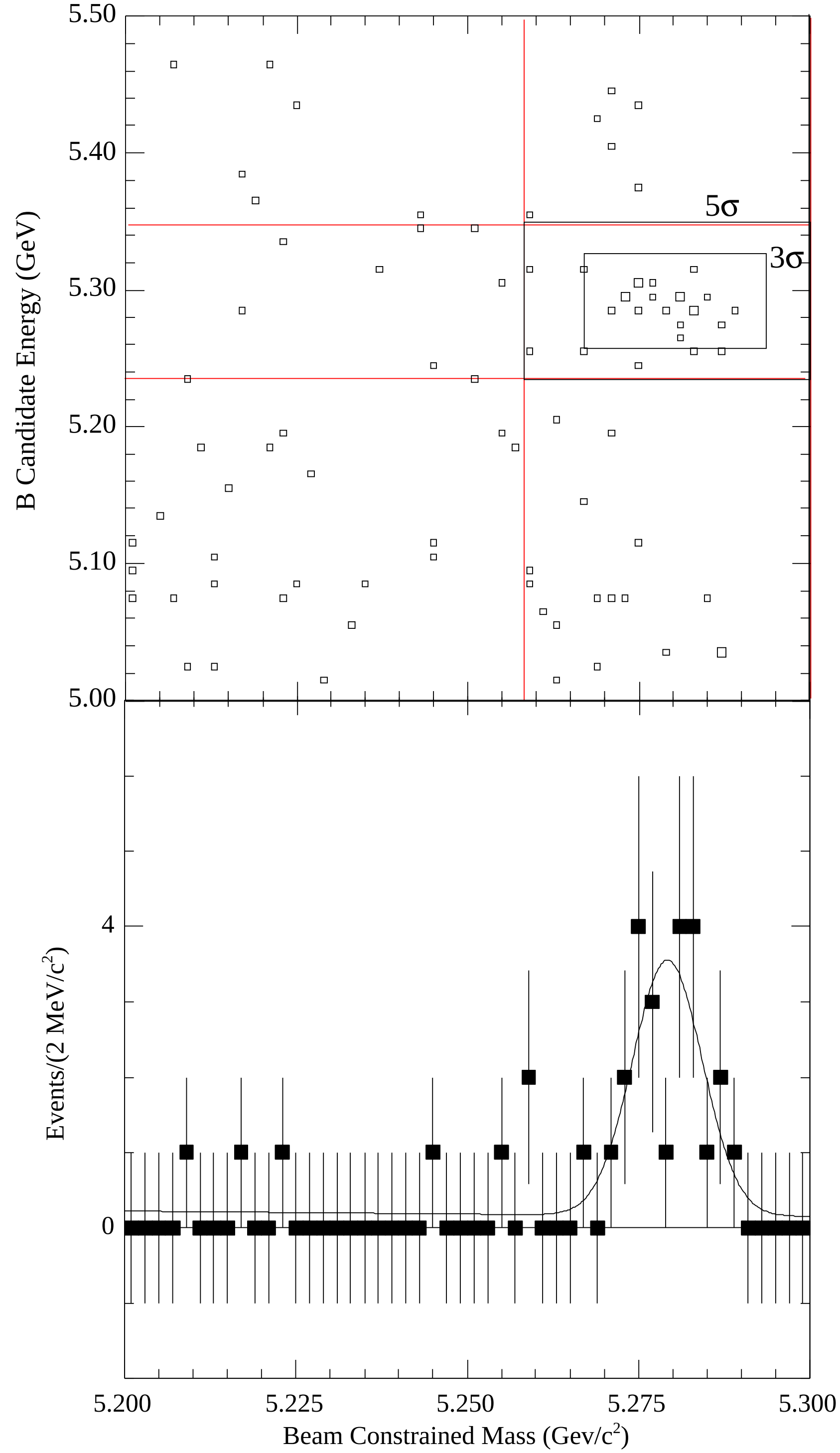
$$E_{\rm tot} \equiv \sum_{i=1}^{n} E_i\,, \quad \vec{P}_{\rm tot} \equiv \sum_{i=1}^{n} \vec{P}_i$$

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

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

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



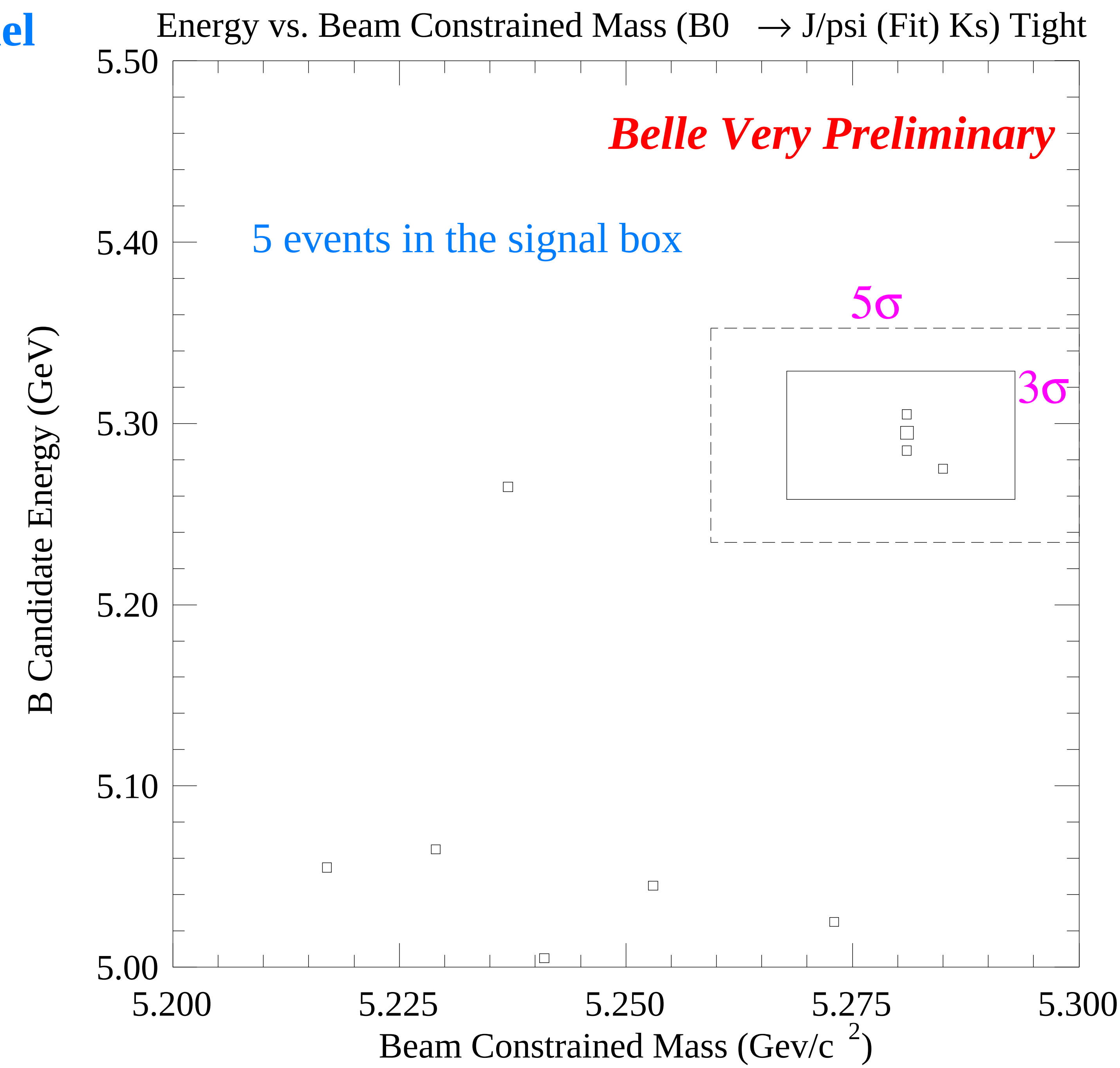


$B \to J/\psi\, K^{+}$ channel

22 ± 6 events

Belle Very Preliminary

$B \rightarrow J/\psi\ K_S$ channel



Number of candidates in 440 pb data:

$B^0 \rightarrow J/\psi K_S$ 5

$B^0 \rightarrow J/\psi K_L$ 6

$B^0 \rightarrow \psi' K_S$ 2

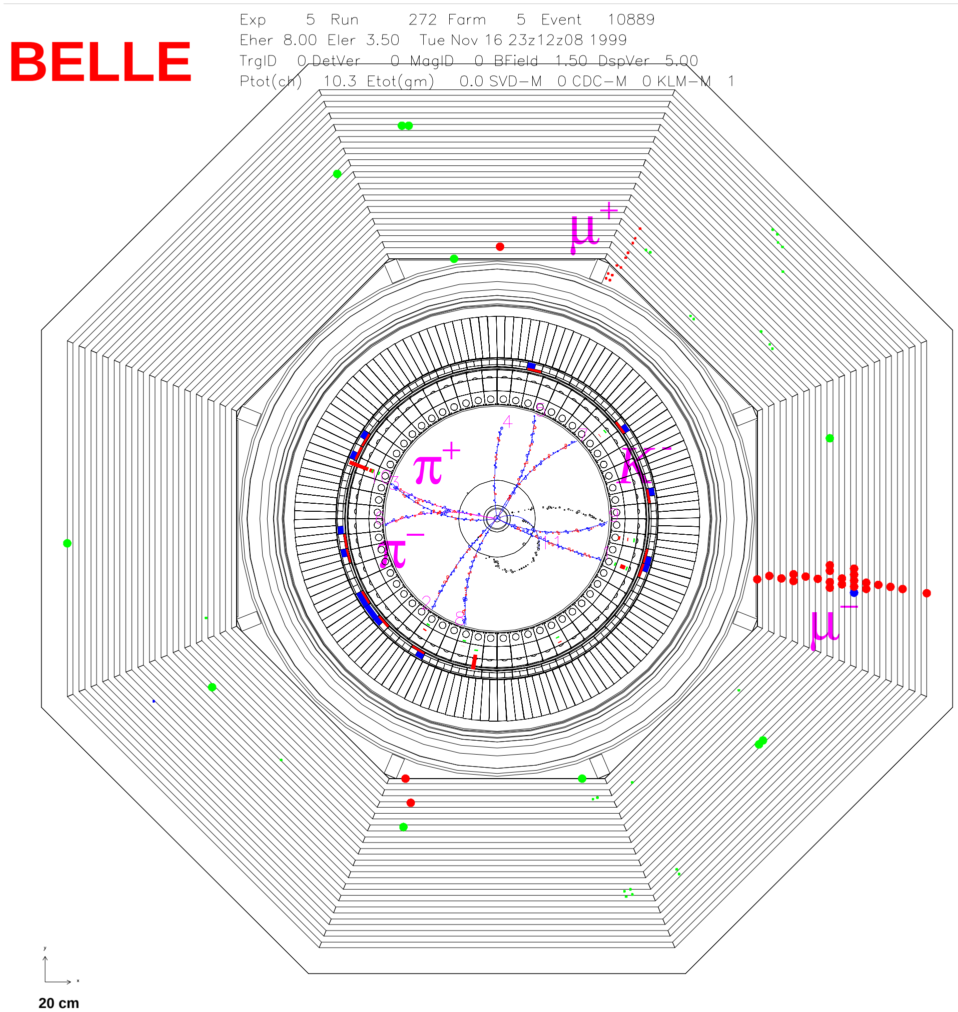
$B^0 \rightarrow J/\psi K^{*0}$ 10

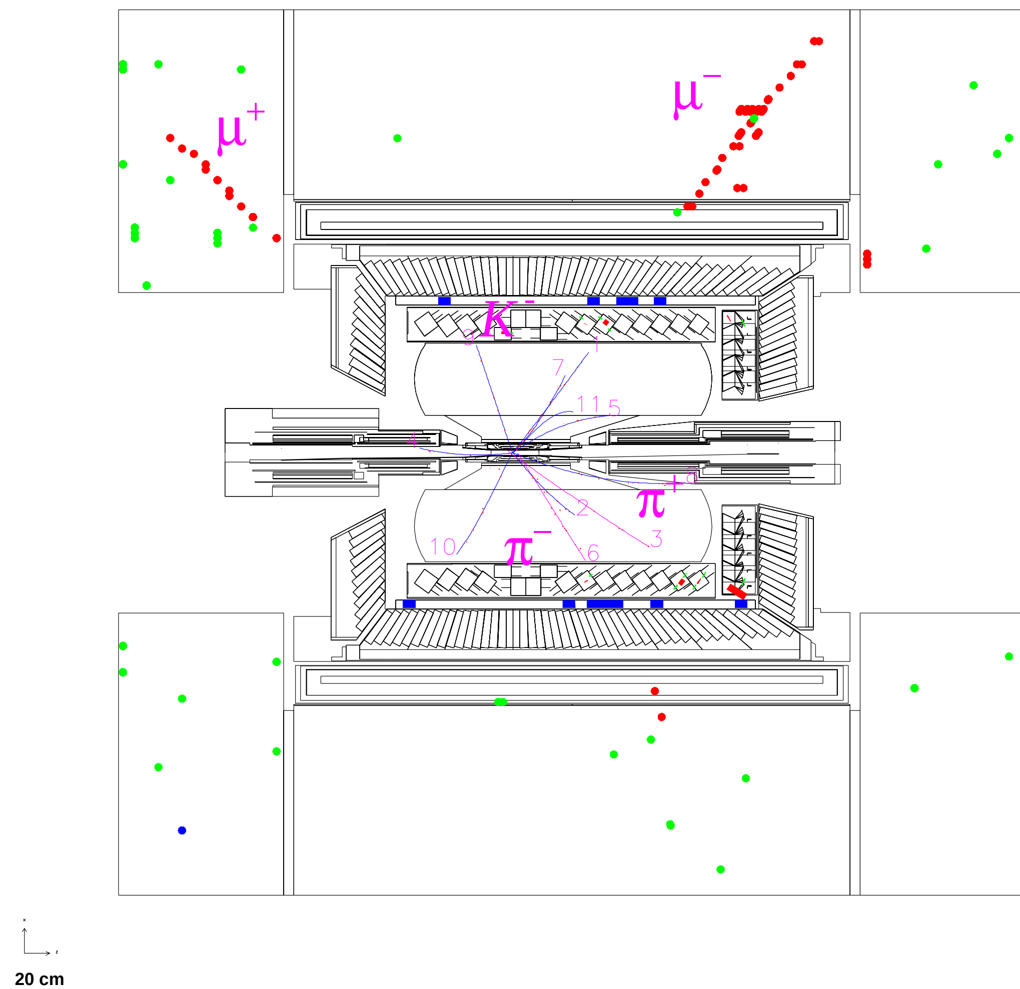
$B^+ \rightarrow J/\psi K^+$ 22

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

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

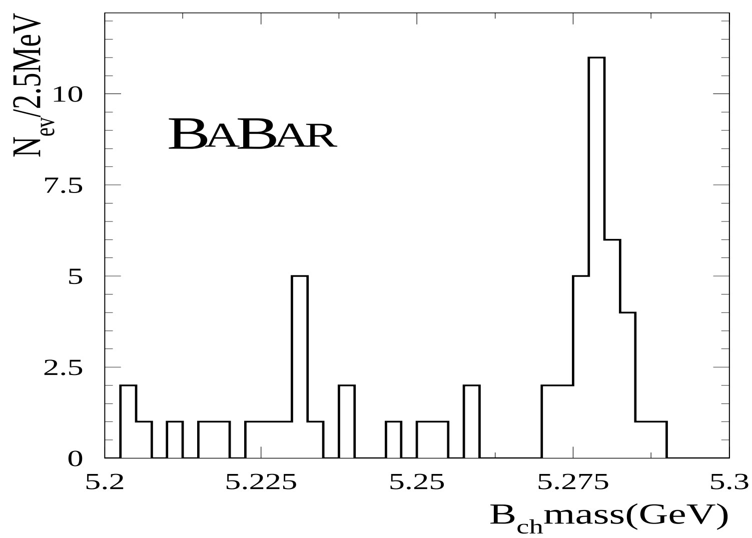
$\hookrightarrow \mu^+\mu^-$



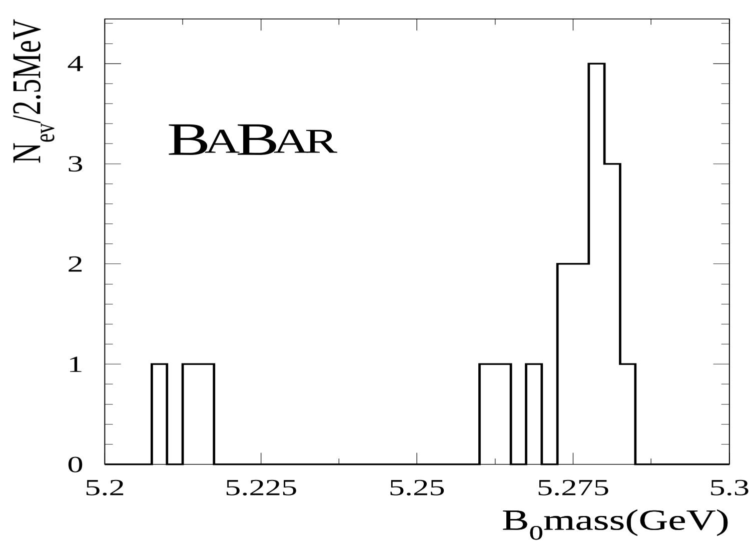


BaBar $B \to J/\Psi K^{0,+}$

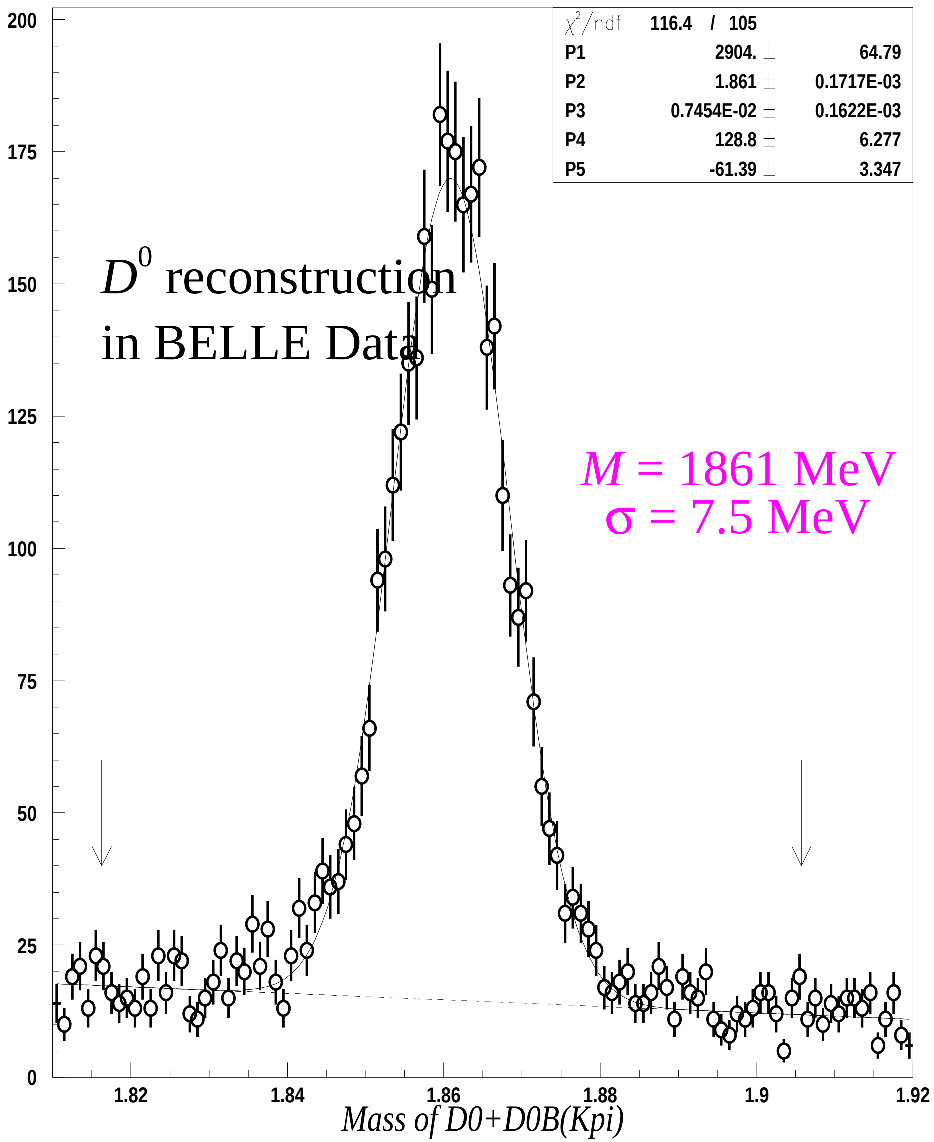
$B^+ \to J/\Psi K^+$

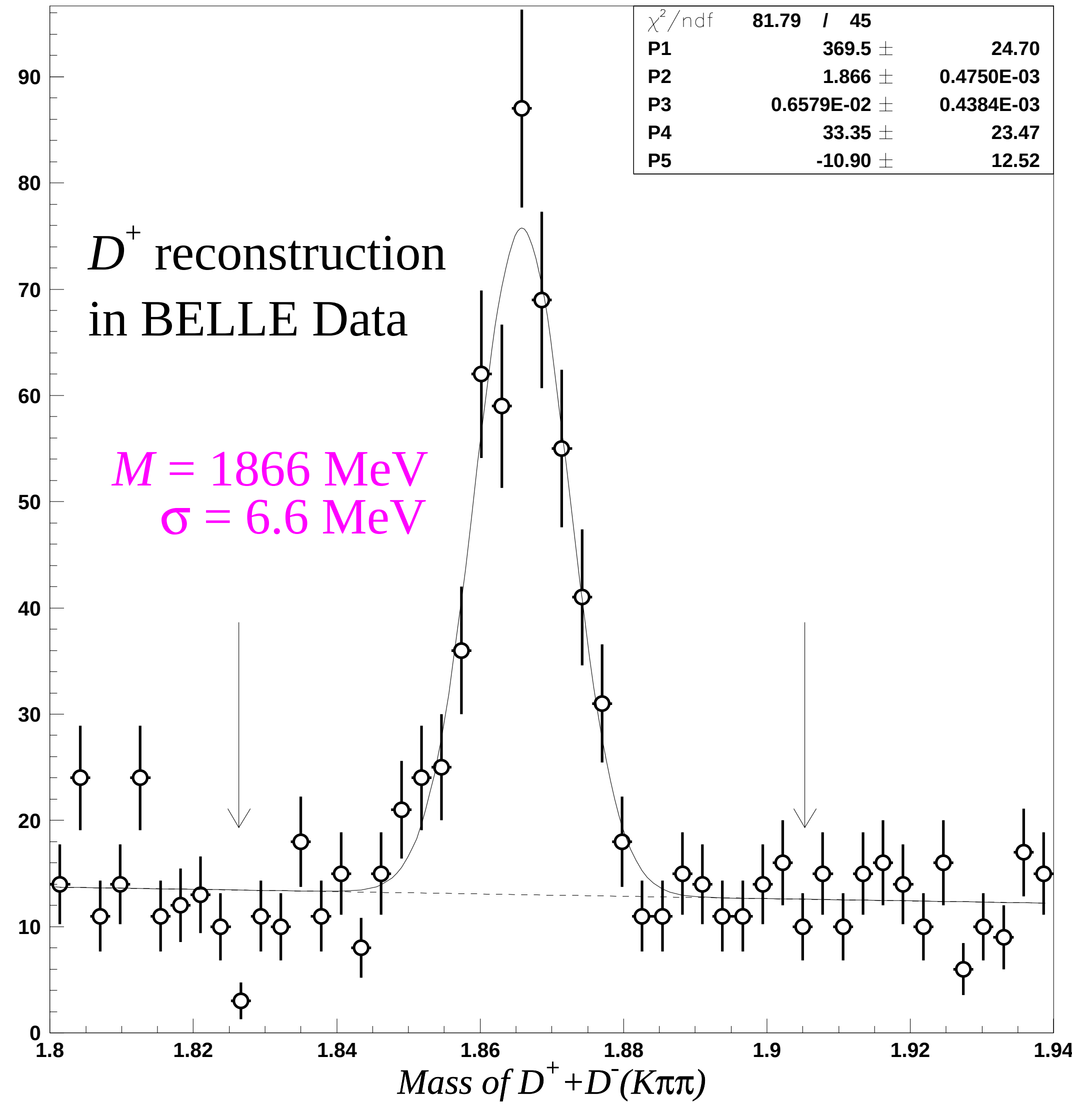


$B^0 \to J/\Psi K_S$



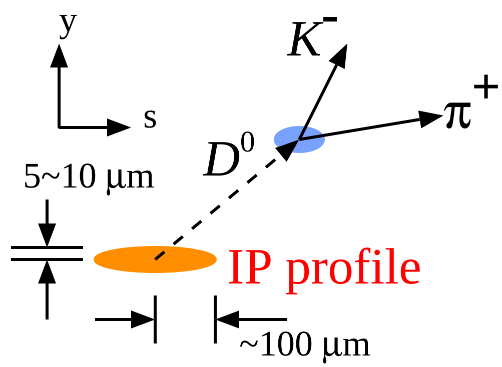
D reconstruction (with help of PID devices): Belle



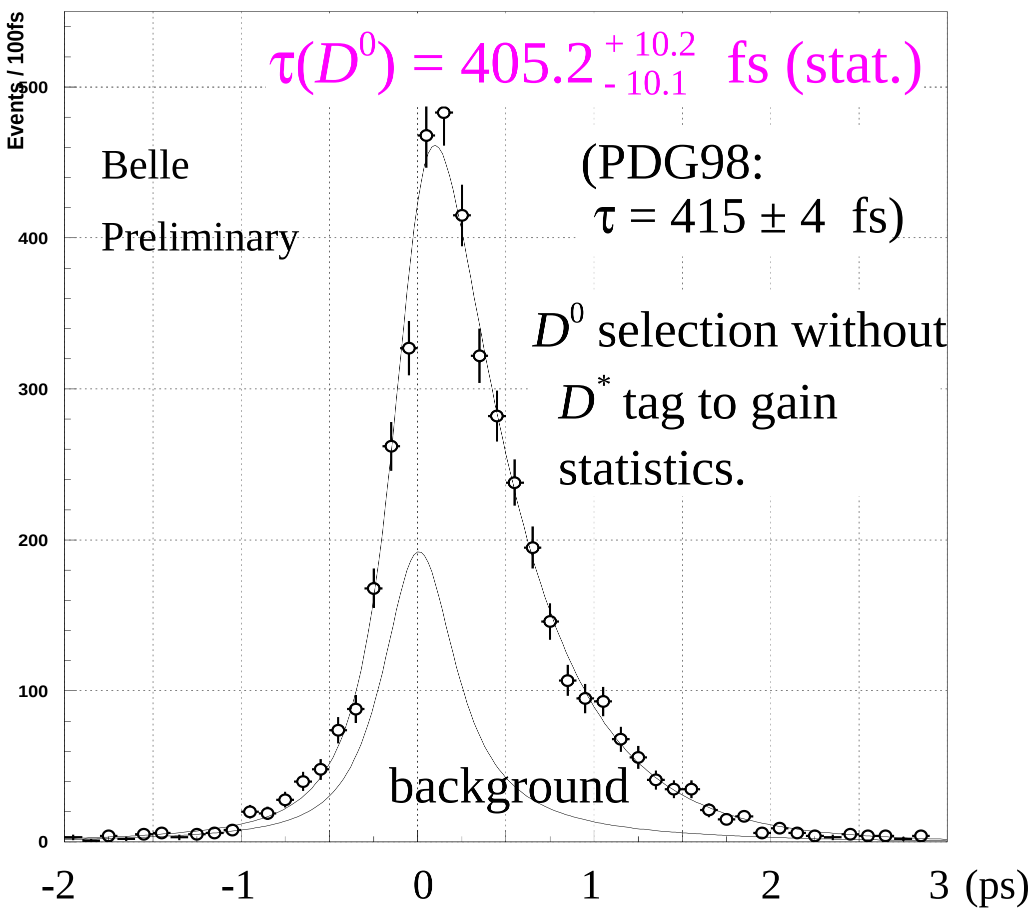


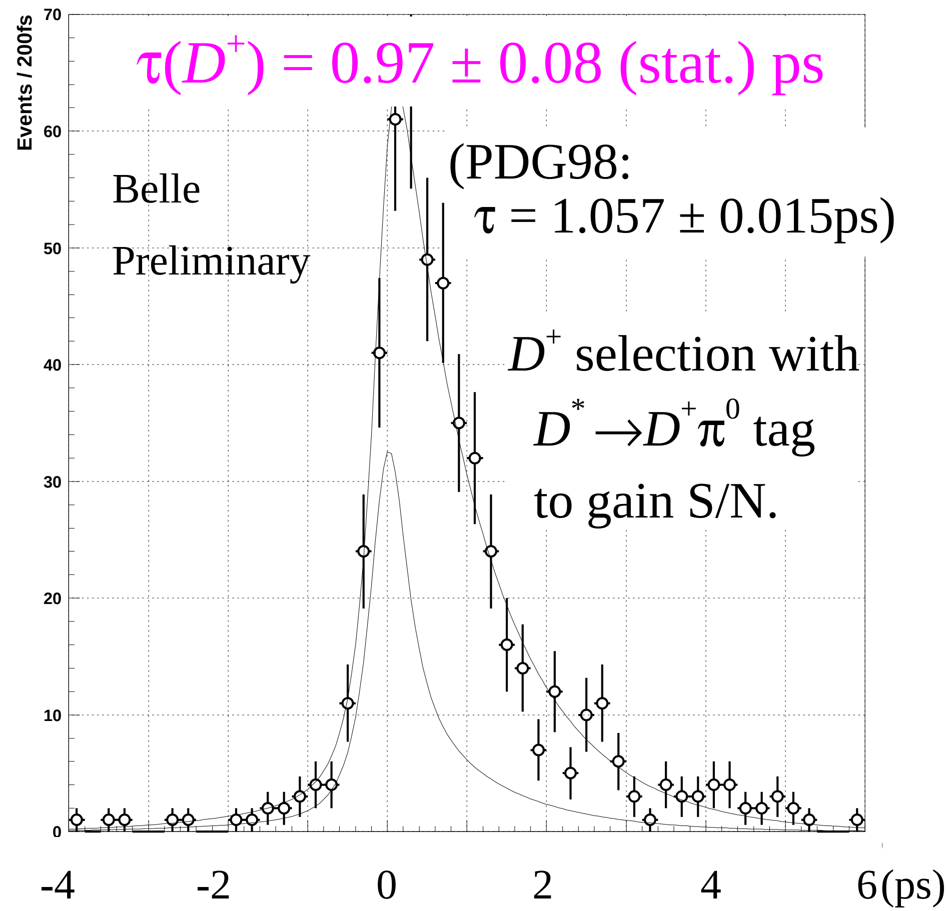
D^0 / D^+ lifetime measurement - vertex reconstruction in x-y: Belle

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

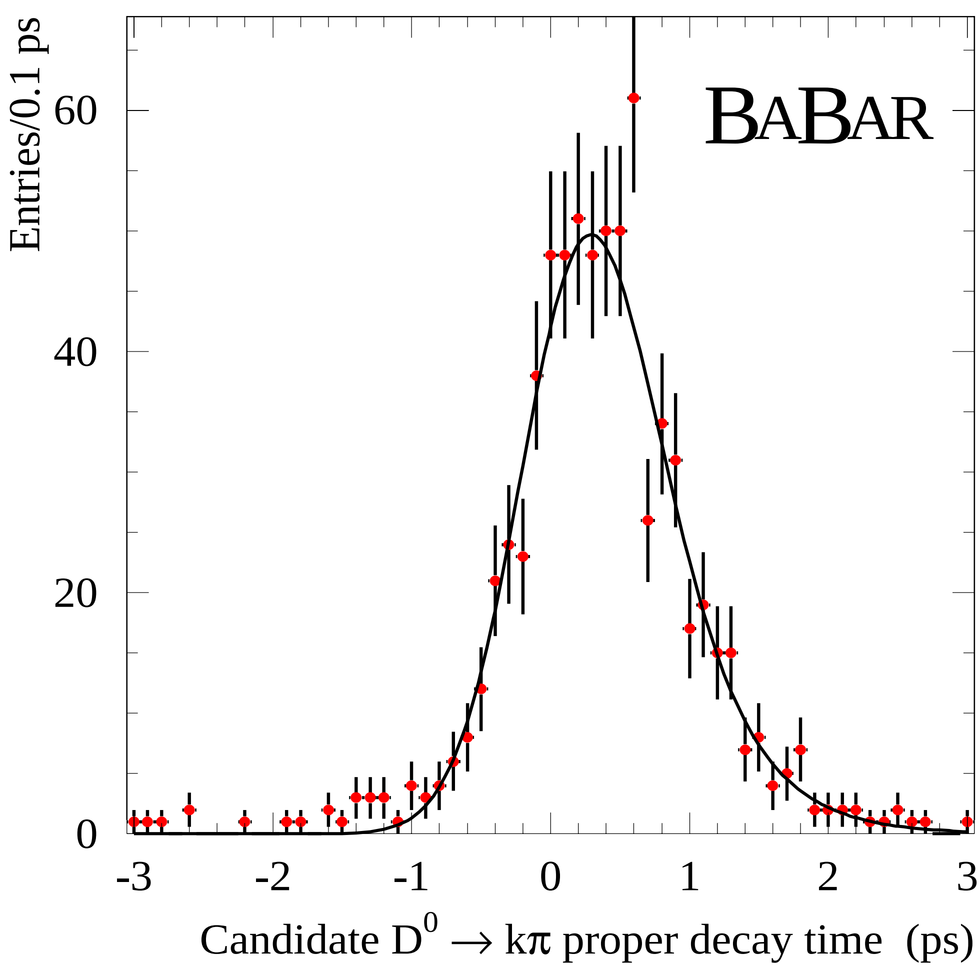


D from charm production (not *b*) to avoid *b* lifetime effect. ($2.5 < p^{cm}(D) < 5.3$ GeV)



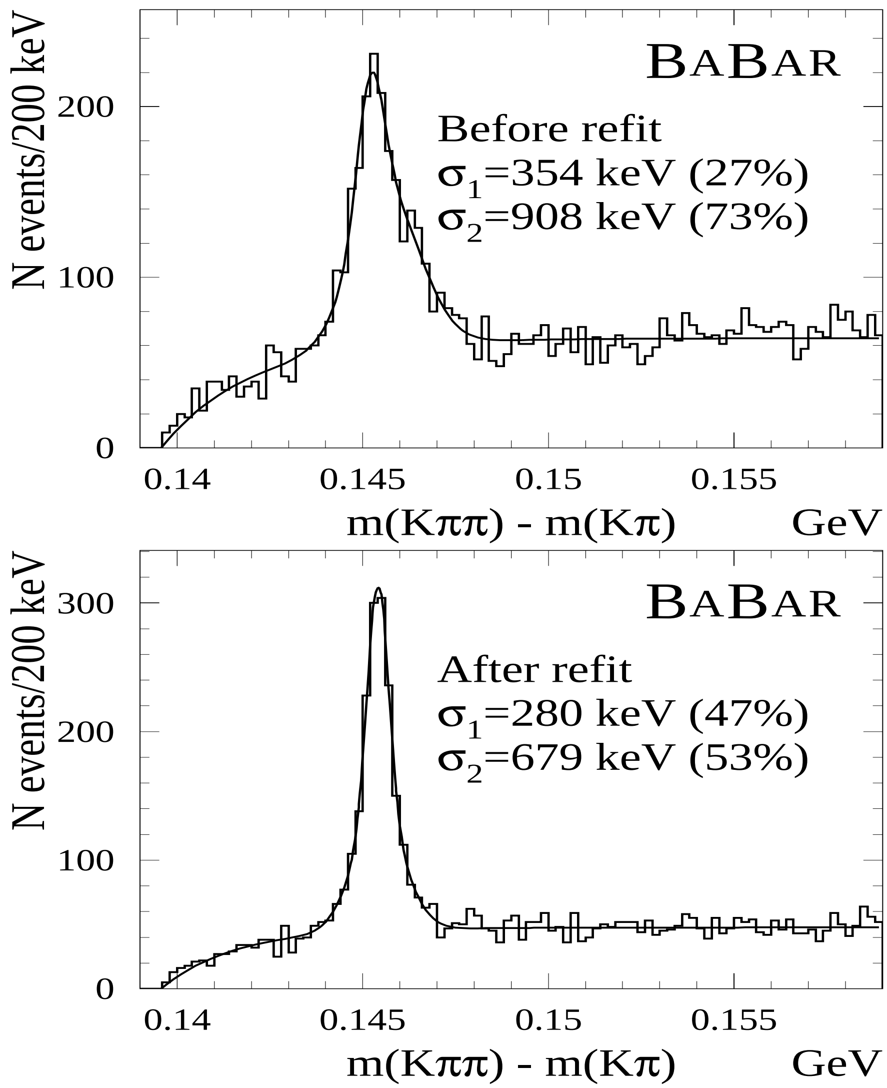


BaBar D^0 lifetime



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

Effect of IP constraint for π_s^+



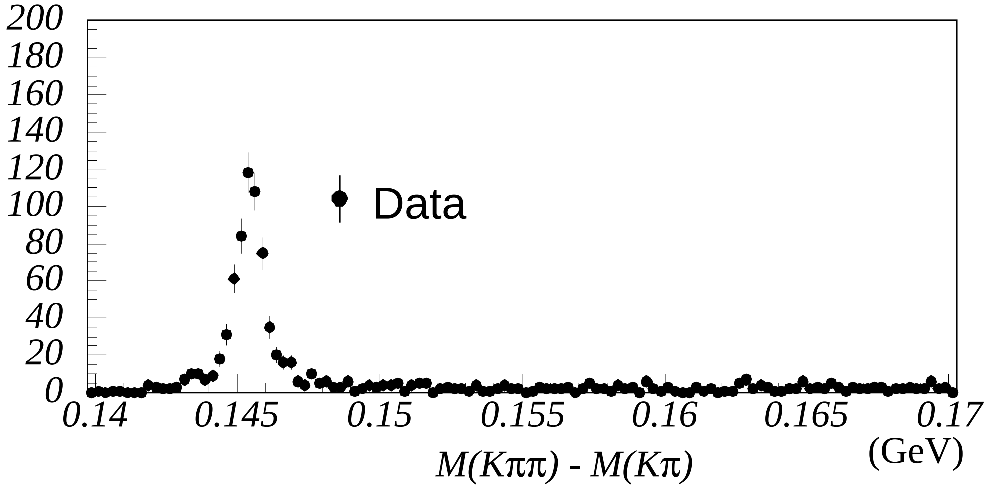
Test of Kaon ID with D^*

$D^{*+} \rightarrow D^0 \pi^+$ (tag)

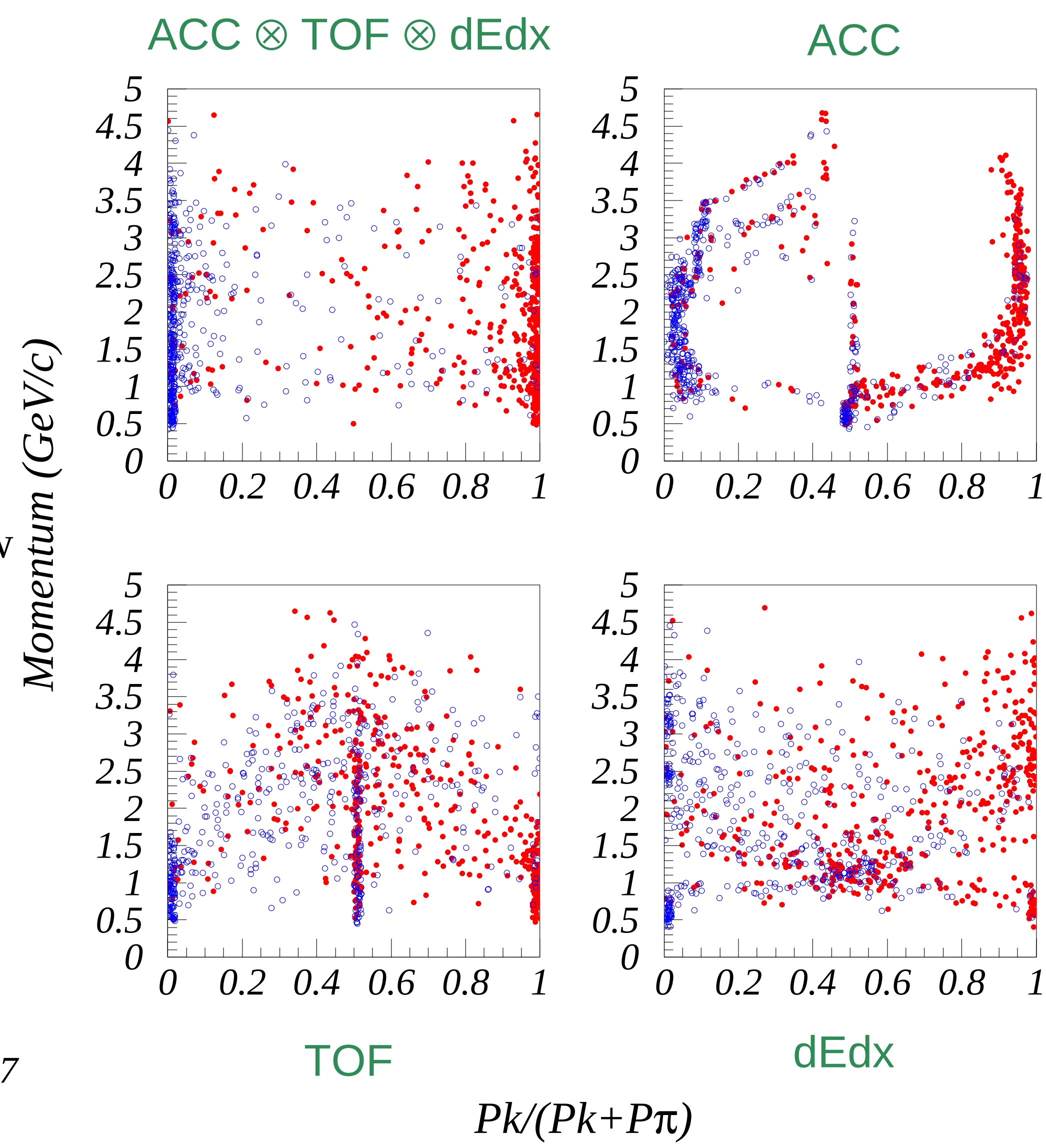
$D^0 \rightarrow K^- \pi^+$

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

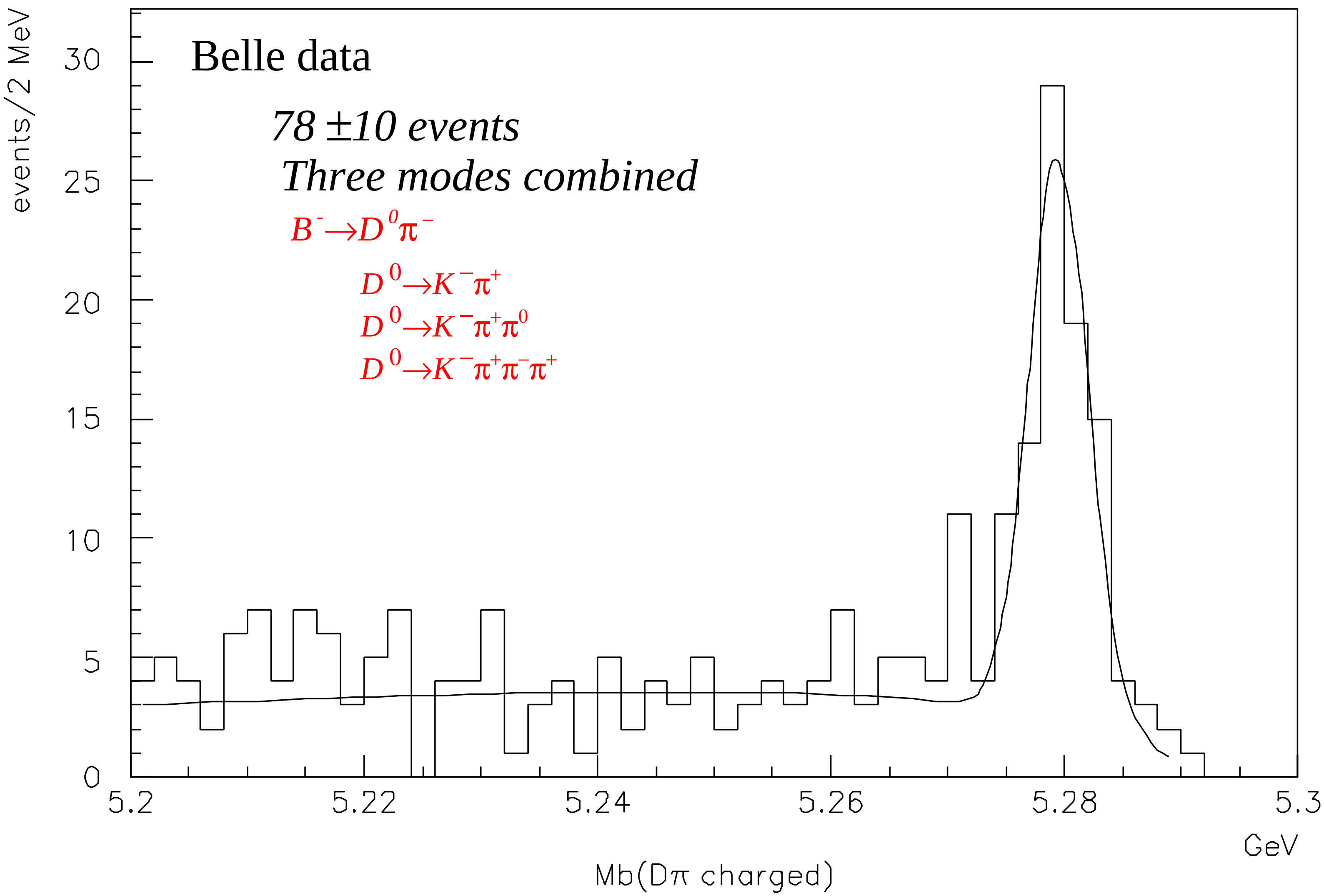
$\Rightarrow$ Estimated purity ~ 95%

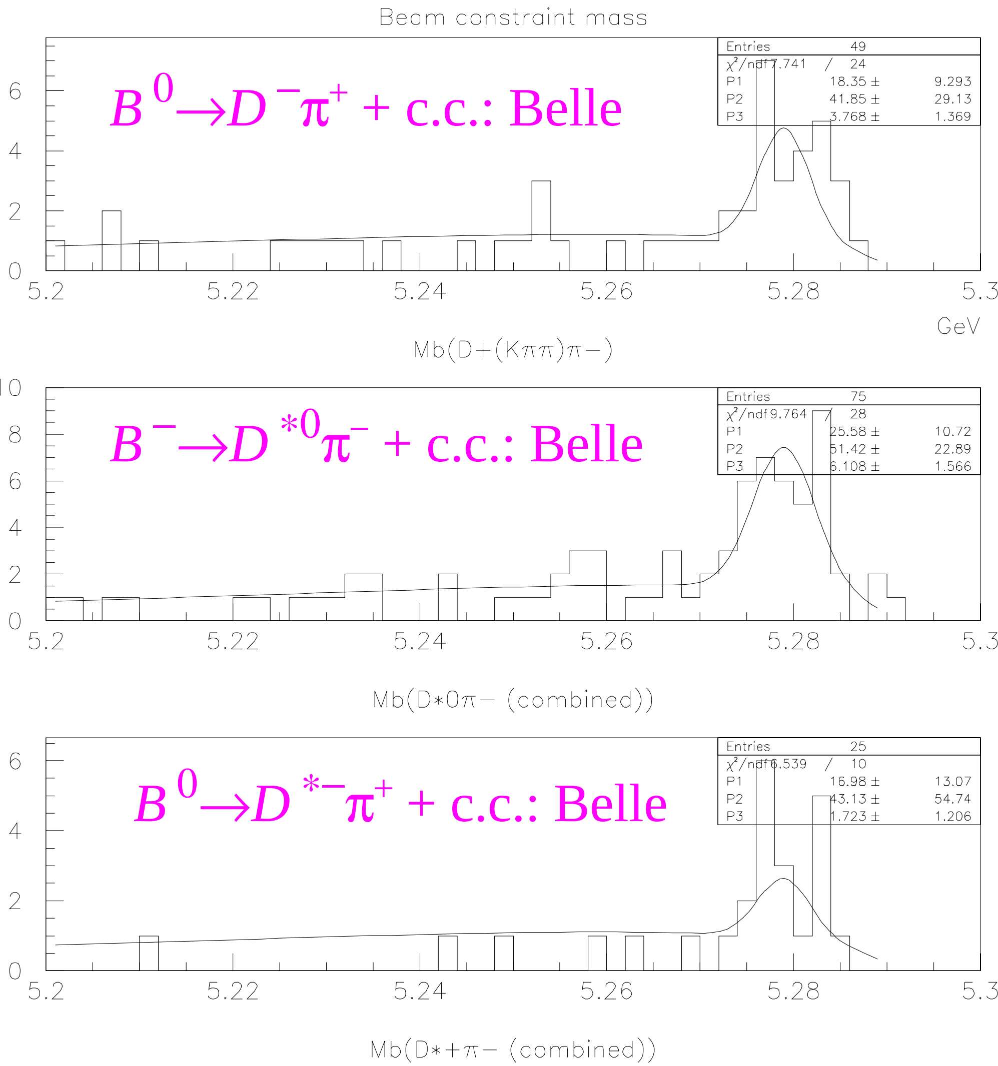


Belle Data ○ π ● K

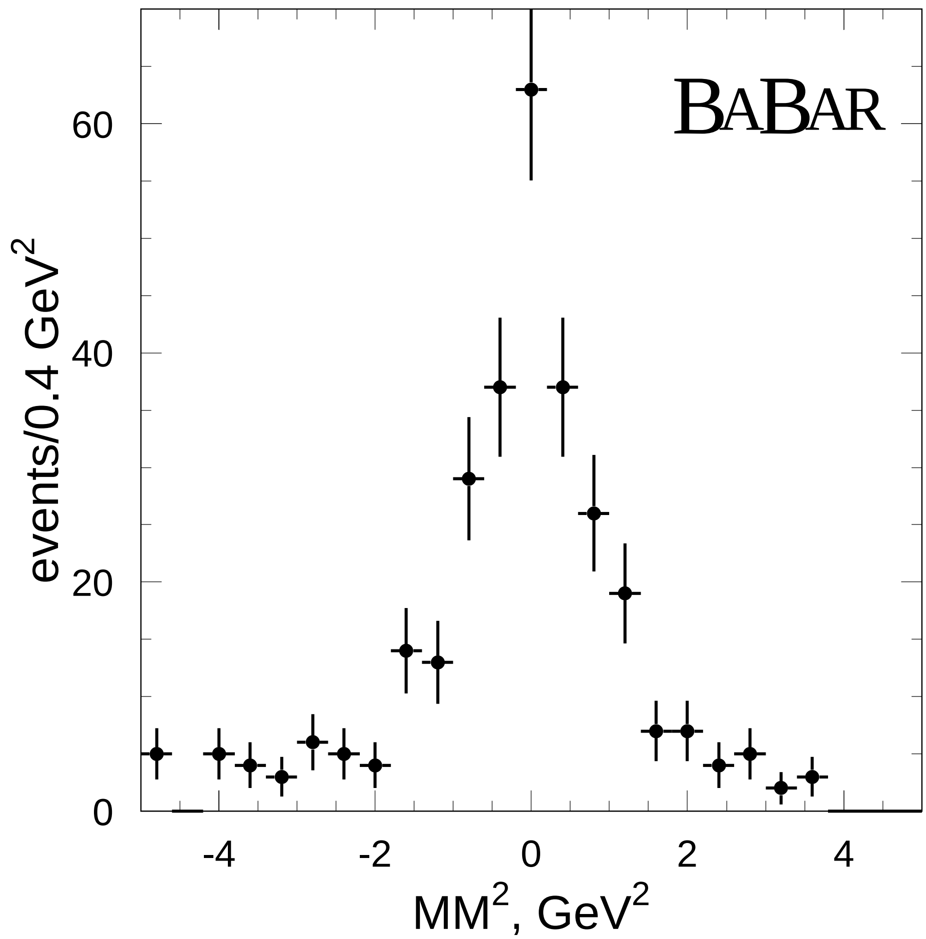


$B^- \to D^0\pi^-$ combined




Beam constraint mass
$B^0 \rightarrow D^- \pi^+$ + c.c.: Belle
Entries 49
χ^2/ndf 7.741 / 24
P1 18.35 ± 9.293
P2 41.85 ± 29.13
P3 3.768 ± 1.369
GeV
Mb(D+(Kππ)π−)
$B^- \rightarrow D^{*0} \pi^-$ + c.c.: Belle
Entries 75
χ^2/ndf 9.764 / 28
P1 25.58 ± 10.72
P2 51.42 ± 22.89
P3 6.108 ± 1.566
Mb(D∗0π− (combined))
$B^0 \rightarrow D^{*-} \pi^+$ + 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))

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



Test of flavor tagging: Belle

Algorithm

Lepton tag: high $p^{\text{c.m.}}$ (> 1.1 GeV) lepton to tag $b \to cl\upsilon$ decay, and if it fails,
Kaon tag: charge sum of the charged Kaons to tag $b \to c \to s$ decay

Performance check

Use $B^0 \to D^{(*)-} l^+ \upsilon$ 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

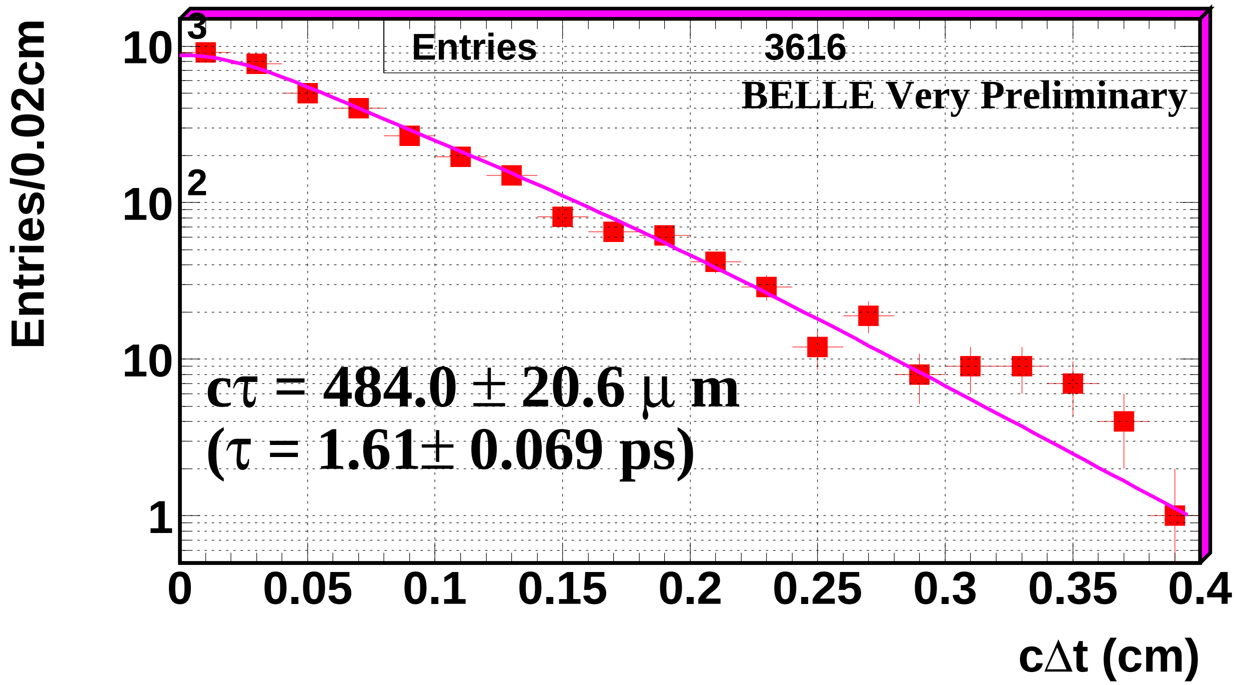
Belle: B lifetime & mixing

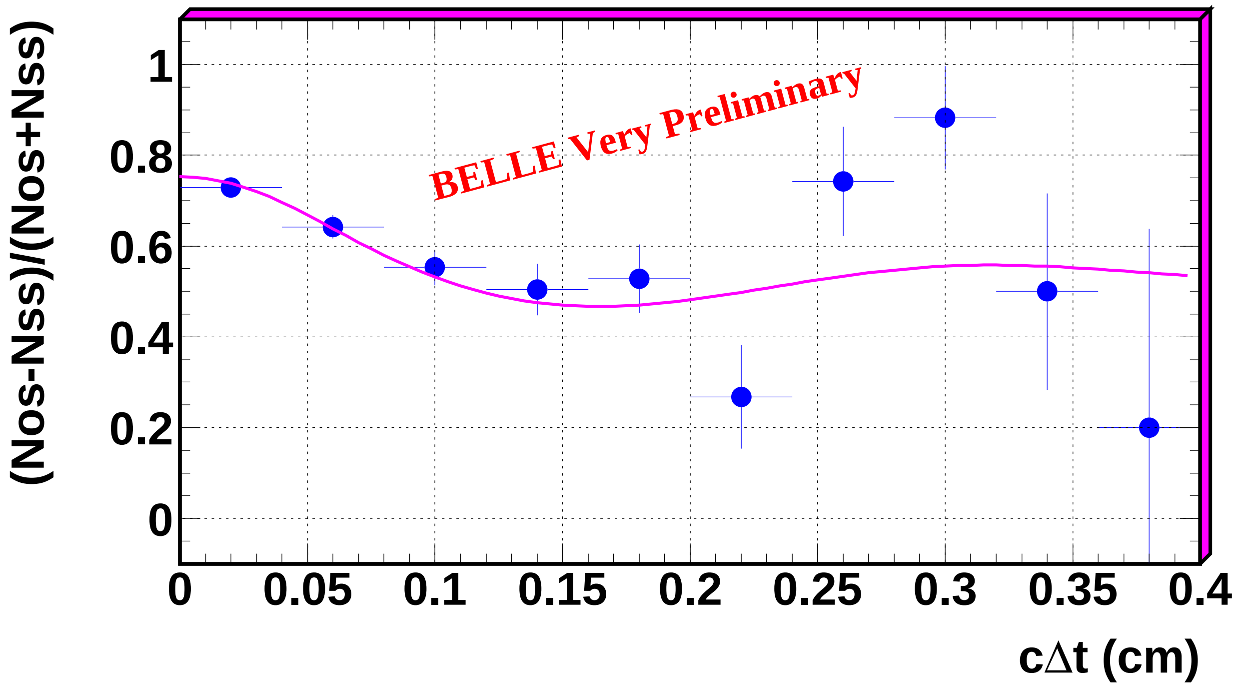
Lifetime fit:

Fixed parameters:

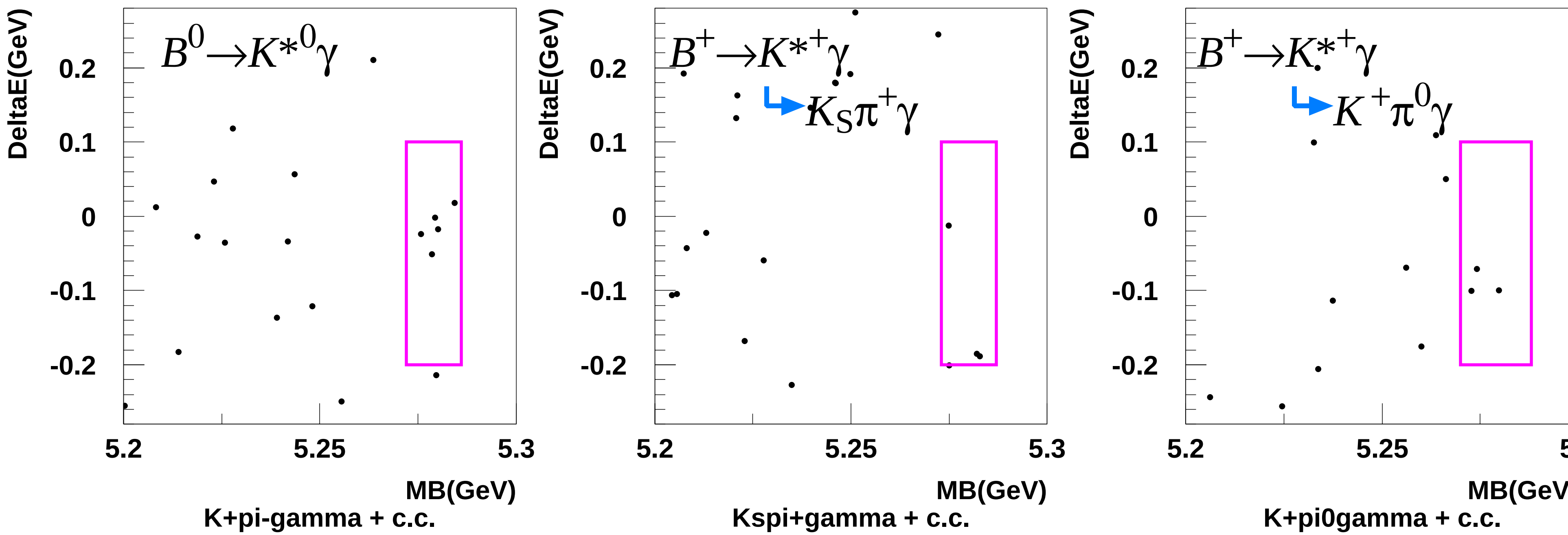
$\beta\gamma = 0.425$

$x_d = 0.723$

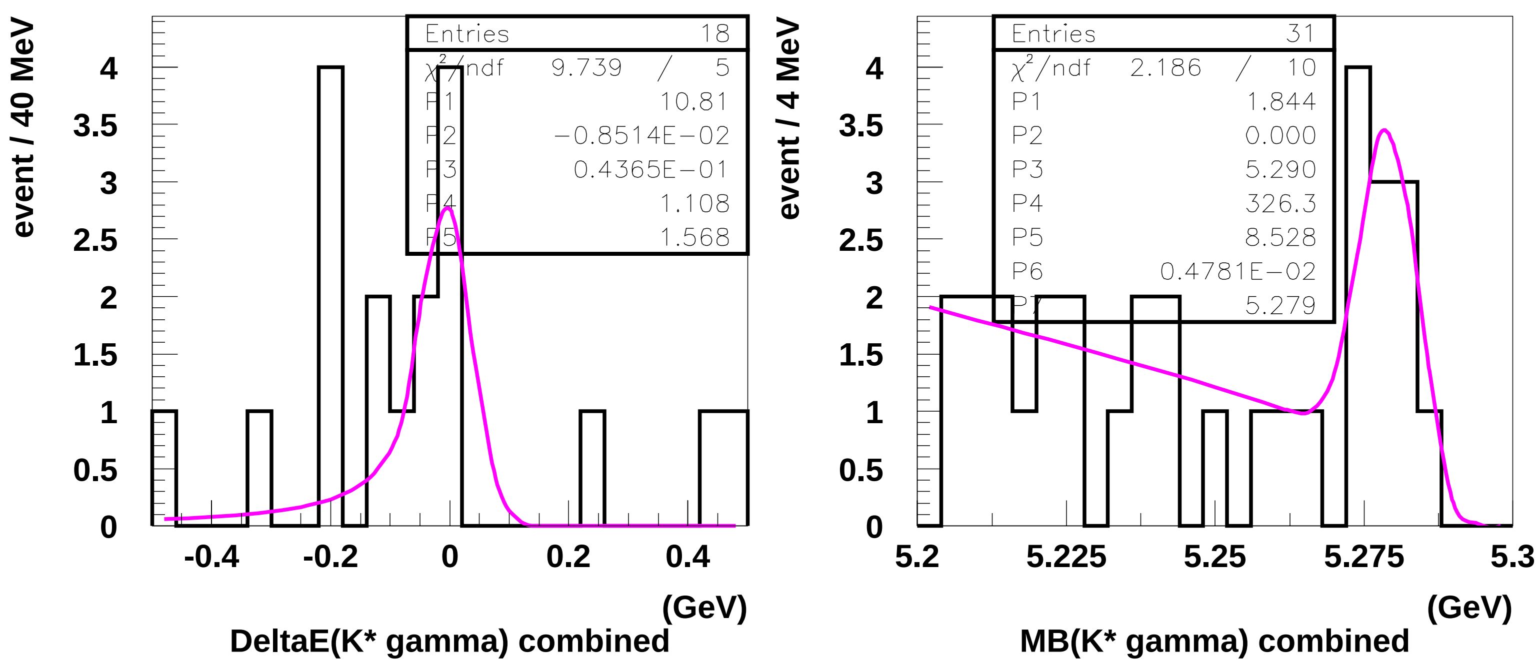




Belle: $B \to K^{*}\gamma$ signal candidates



10 candidates,
2 background
expected.



Summary

- Both PEP-II and KEK-B exceeded $L = 10^{33}/\mathrm{cm}^2\mathrm{s}$, and are operating steadily.

- Integrated luminosity of 5$\sim$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$\sim$0.3 is expected by this summer from each experiment.

Acknowledgement: Thanks to all at KEK/Belle and SLAC/BaBar who made so much progress and also to Nakao-san whose Belle physics plots I borrowed with minor editings.