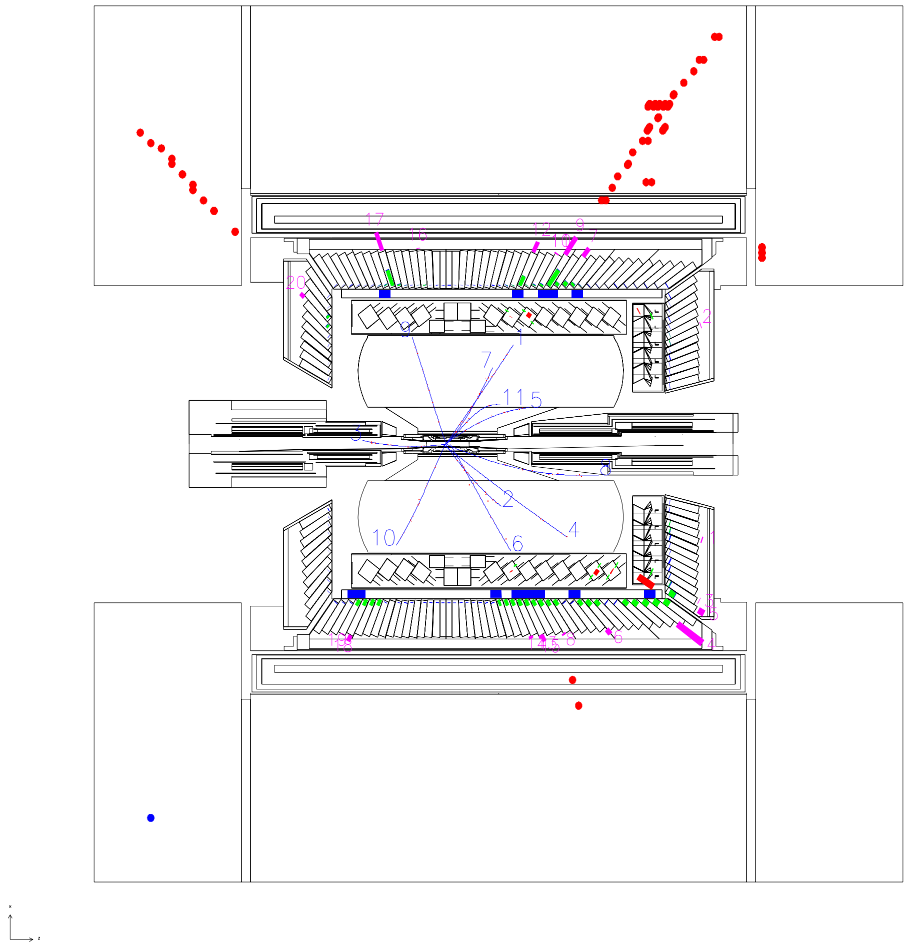
First Results From Belle



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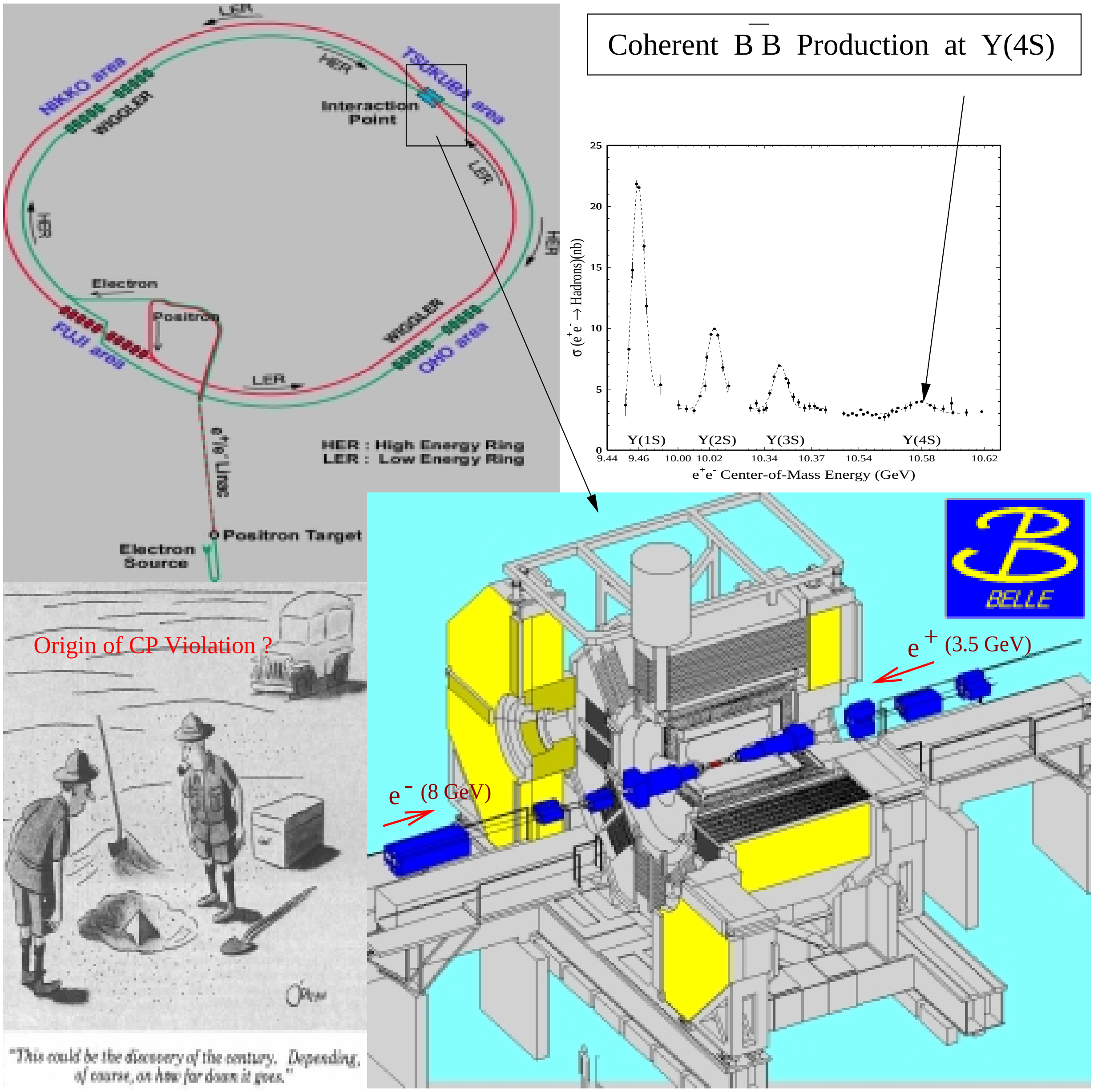
University of Cincinnati / KEK

(Belle Collaboration)

Out Line

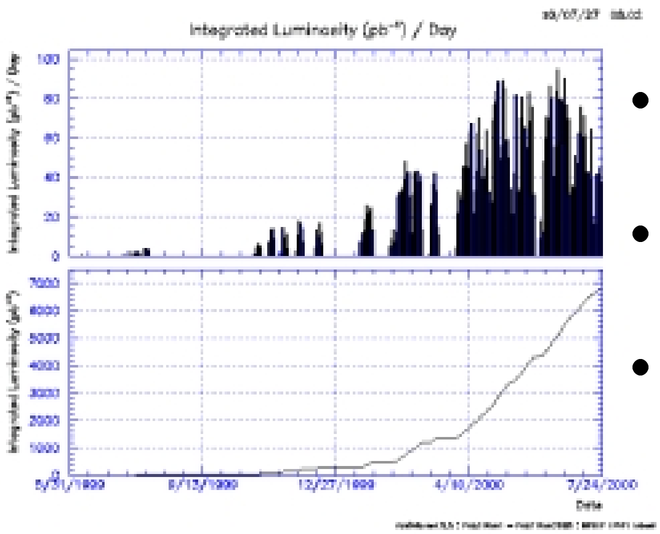
- Introduction to KEK-B and Belle Detector
- Particle Identification Capabilities with Belle
- Data Set and Global Analysis Technique
- Selected Branching Ratio Measurement :
- CP Measurement
  - Benchmark Test
    - B Lifetime Measurement
    - $B^0 - \bar{B}^0$ Mixing
  - Measurement of $\sin(2\phi_1)$
- Conclusion and Prospects

B Fair at KEK : Impressive Start



We all welcome the second coming of the CP Violation at B-factory.

KEK-B Performance Parameters

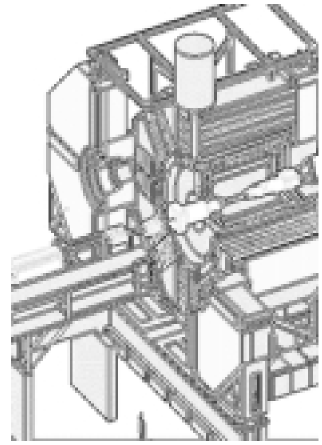


- Best Peak Luminosity :
  2.04×10^{33} cm^{-2}sec^{-1}
- Luminosity per day/week :
  94/504 pb^{-1}
- Total $\int L.dt$ Recorded :
  6.2/0.6 fb^{-1} On/Off $\Upsilon(4S)$

Numbers Achieved (Designed/Modeled)

Parameters	LER	HER	unit
1. Horizontal Emmitance	18	30	nm
2. Beam Current	465(2600)	420 (1100)	mA
3. Number of Bunches	1146(2700)		
4. Bunch Current	0.41 (0.96)	0.37 (0.41)	mA
5. Bunch Spacing	2.4 (1.2)		m
6. Horizontal Size @ IP	112 (112)	145 (145)	μm
7. Vertical Size @ IP	1.7 (1.12)	1.7 (1.45)	μm
8. Emmitance Ratio	2.3 (1.0)	1.4 (1.0)	%
9. $\beta_x^* \ / \ \beta_y^*$	70/0.7	70/0.7	cm
10. Beam lifetime	130 @ 465 mA	180 @ 420 mA	min.

The Belle Collaboration



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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 Collage of Maritime Tech.
ICRR, University of Tokyo
IHEP, Beijing
ITEP, Moscow
Joint Crystal Collaboration Group
Kanagawa University
KEK
Korea University
Krakow Institute of Nuclear Physics
Kyoto University
University of Melbourne
Mindanao State University
Nagasaki Institute of Applied Science
Nagoya University
Nara Woman's University
National Central Univesity
National Kaoshing University
National Lien-Ho College of Tech. and Commerce
National Taiwan University
Nihon Dental College
Niigata University
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Sungkyukwan University
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Toho University
Tohoku University
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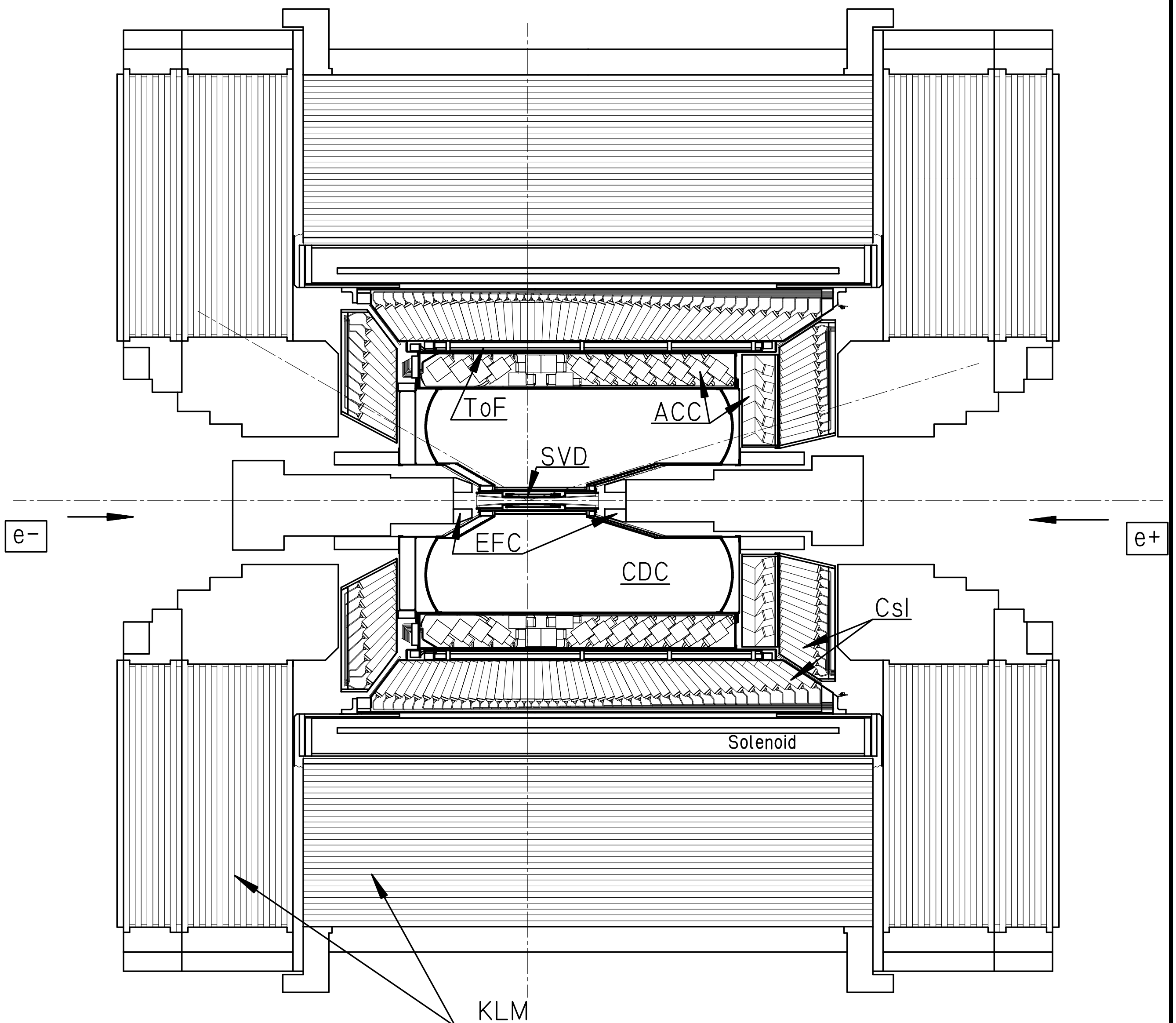
University of Tokyo
Tokyo Institute of Technology
Tokyo Metropolitan University
Tokyo Univ. of Agriculture and Technology
Toyama National College of Maritime Technology
University of Tsukuba
Utkal University
Virginia Polytechnic Institute & State University
Yonsei University

Belle Detector Components



- Vertexing and Tracking: SVD + CDC, $\sigma_{pt} = 0.34 \oplus 0.19\ p_t$ %
- Particle Identification (K/π separation): CDC + ACC + ToF
- Neutral Photons : ECL, $\sigma_E/E = 1.8$ % ($\gamma\gamma$ events between 4-8 GeV)
- K_L and Muons : KLM

Data Set

- Most of the analysis use 5.1 fb^{-1} ON-resonance data. CP Violation measurement was done with 6.2 fb^{-1} ON-resonance data.
- 0.6 fb^{-1} OFF-resonance data were used for the background studies.
- Results reported here are all PRELIMINARY.

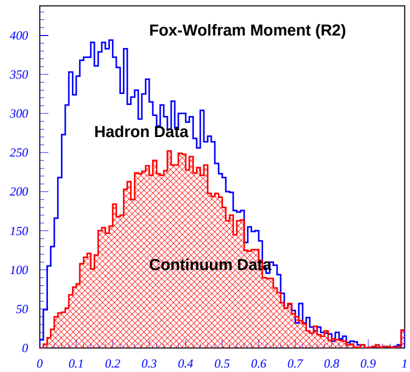
Full Reconstruction of B Mesons

The key variables of reconstructed B candidates are:

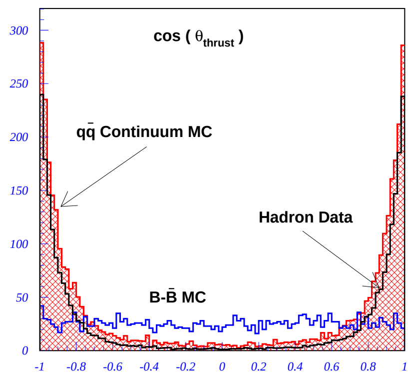
- $\Delta E = E_{beam} - \sum E_i^{cms}$
  - E_{beam} = Beam energy in $\Upsilon(4S)$ rest frame : 5.29 GeV
  - Expresses Energy Conservation
  - Peaks at zero for real events
  - Sensitive to missing particles
  - Sensitive to $K - \pi$ mis-ID.
- $M_B = \sqrt{E_{beam}^2 - |\sum P_i^{cms}|^2}$
  - Expresses the momentum conservation
  - Using well known E_{beam} improves the mass resolution.

Continuum Background Suppression

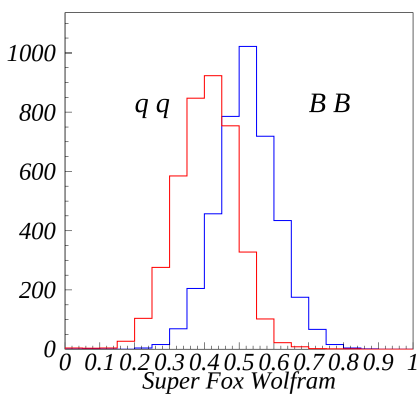
Exploit the advantage of having jetty hadronization of OFF-resonance quark jet and spherical decay of slow ON-resonance B's.



Fox-Wolfram Moment (R2) : H_2/H_0, where $H_l = \sum_{i,j} \frac{|p_i||p_j|}{E_{cms}^2} P_l(cos\theta_{i,j})$



Cos(θ_T) : Angular distribution between the thrust axis of signal B and thrust axis of the rest of the events with signal tracks removed.



Super Fox-Wolfram :

$H_l = h_l^{ss} + h_l^{so} + h_l^{oo}$

i : particles $\Rightarrow$ s : signal + o : other

$SFW = \sum_{i=1}^{4} \alpha_l h_l^{so} + \beta_l h_l^{oo}$

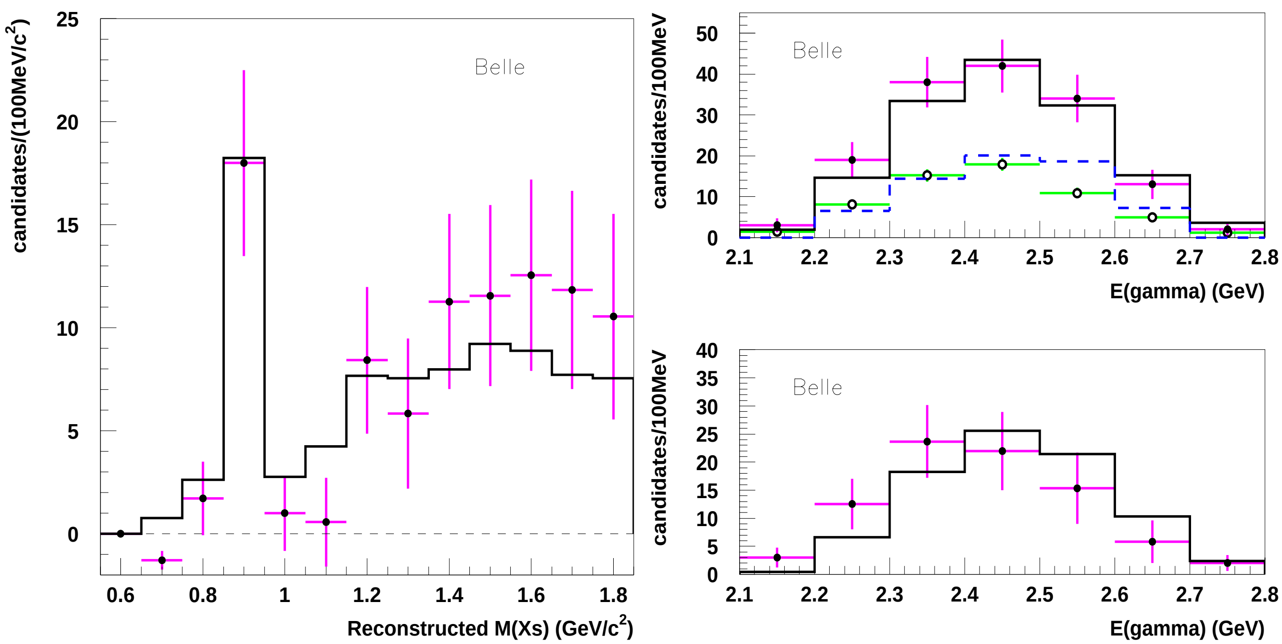
α, β = Fisher Coefficient.

$\approx 2.3\sigma$ separation ; 22 % increase in expected $\frac{S}{\sqrt{S+N}}$.

Selected Branching Ratio Measurement

Radiative B Decays : Inclusive $b \to s\gamma$

- Combine a K^+ or K_s candidate, up to 4 π's allowing only one of them to be π^0 and an energetic photon candidate $\to$ require them to be consistent with B mass. (Total 16 possible combinations)
- M_{X_s} Distribution highlights the $K^*(892)$ mass peak and supports Ali-Greub Model with Fermi Momentum of b quark $p_F = 300$ MeV.
- Efficiency is determined for 16 different modes separately.
- The signal yield is extracted from the γ energy spectrum.



- 152 signal candidate events
  (92 ±13.9 : signal yield, 60 ± 6.5 : background)
  PRELIMINARY
  $BR(b \to s\gamma) = (3.34 \pm 0.50(stat.)^{+0.34}_{-0.37}(syst.)^{+0.26}_{-0.28}(theo.)) \times 10^{-4}$

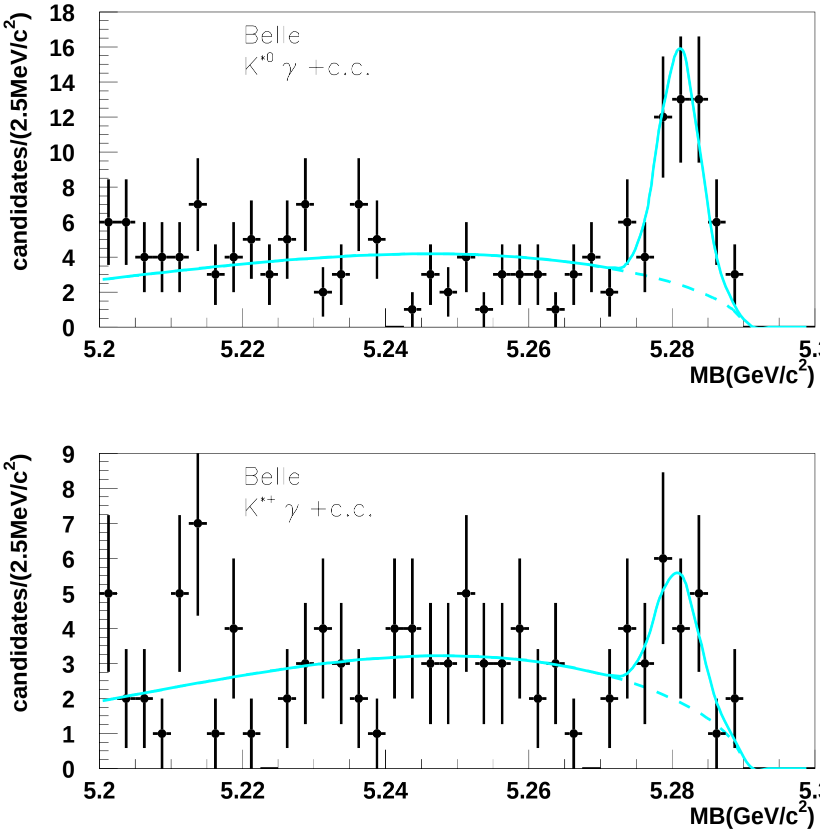
Exclusive Decay $B \to K^*\gamma$

- Reconstructed B channels :

  $B^0 \to K^+\pi^-\gamma, K_S\pi^0\gamma$ + C.C.

  $B^+ \to K_S\pi^+\gamma, K^+\pi^0\gamma$ + C.C

- Cuts are mostly same as inclusive analysis. SFW cut is replaced by a likelihood ratio of three variable.
  (1) SFW variable, (2) B meson flight direction ($\cos\theta_B$) and (3) K^* decay helicity angle.



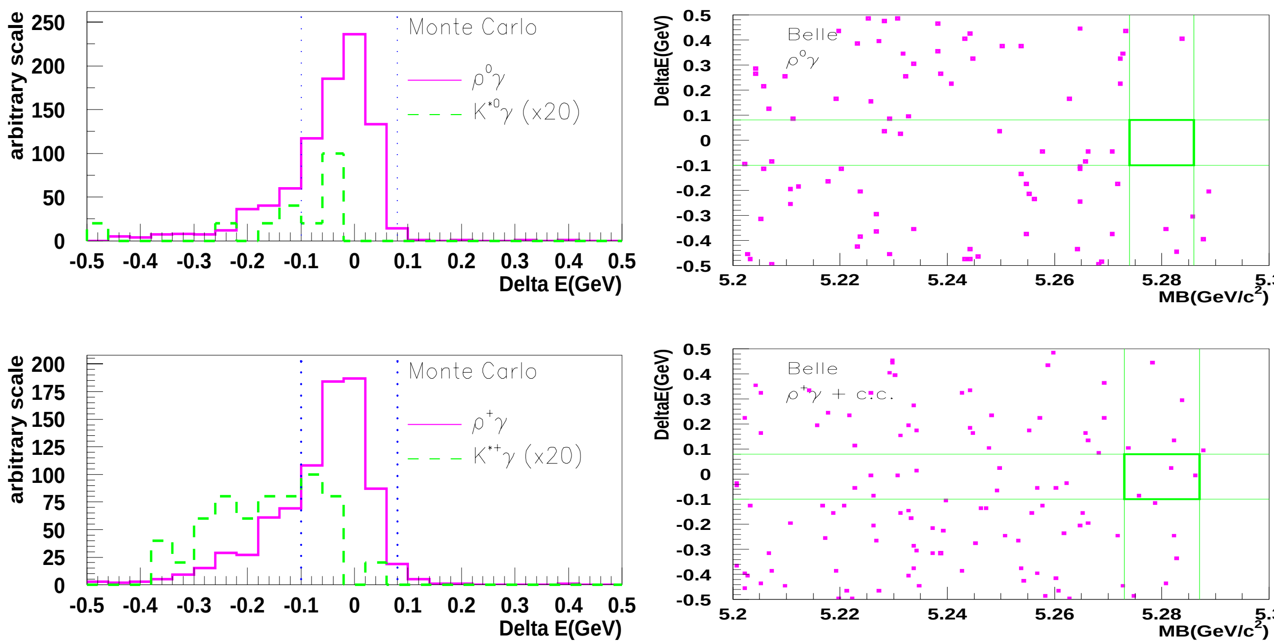
- PRELIMINARY

  $BR(B^0 \to K^{*0}\gamma) = (4.94 \pm 0.93(stat.)^{+0.55}_{-0.52}(syst.)) \times 10^{-5}$

  $BR(B^+ \to K^{*+}\gamma) = (2.87 \pm 1.20(stat.)^{+0.55}_{-0.40}(syst.)) \times 10^{-5}$

Search for $B \to \rho\gamma$

- Reconstructed B channels :
  $B^0 \to \pi^+\pi^-\gamma, B^+\pi^+\pi^0\gamma$ + C.C.
- Cuts are same as $K^*\gamma$ analysis. K^* feed down is removed with tight PID cut, K^* veto and tight Likelihood Ratio cut.



- PRELIMINARY

  $BR(B^0 \to \rho^0\gamma) < (0.56 \times 10^{-5}$ @ 90 % C.L

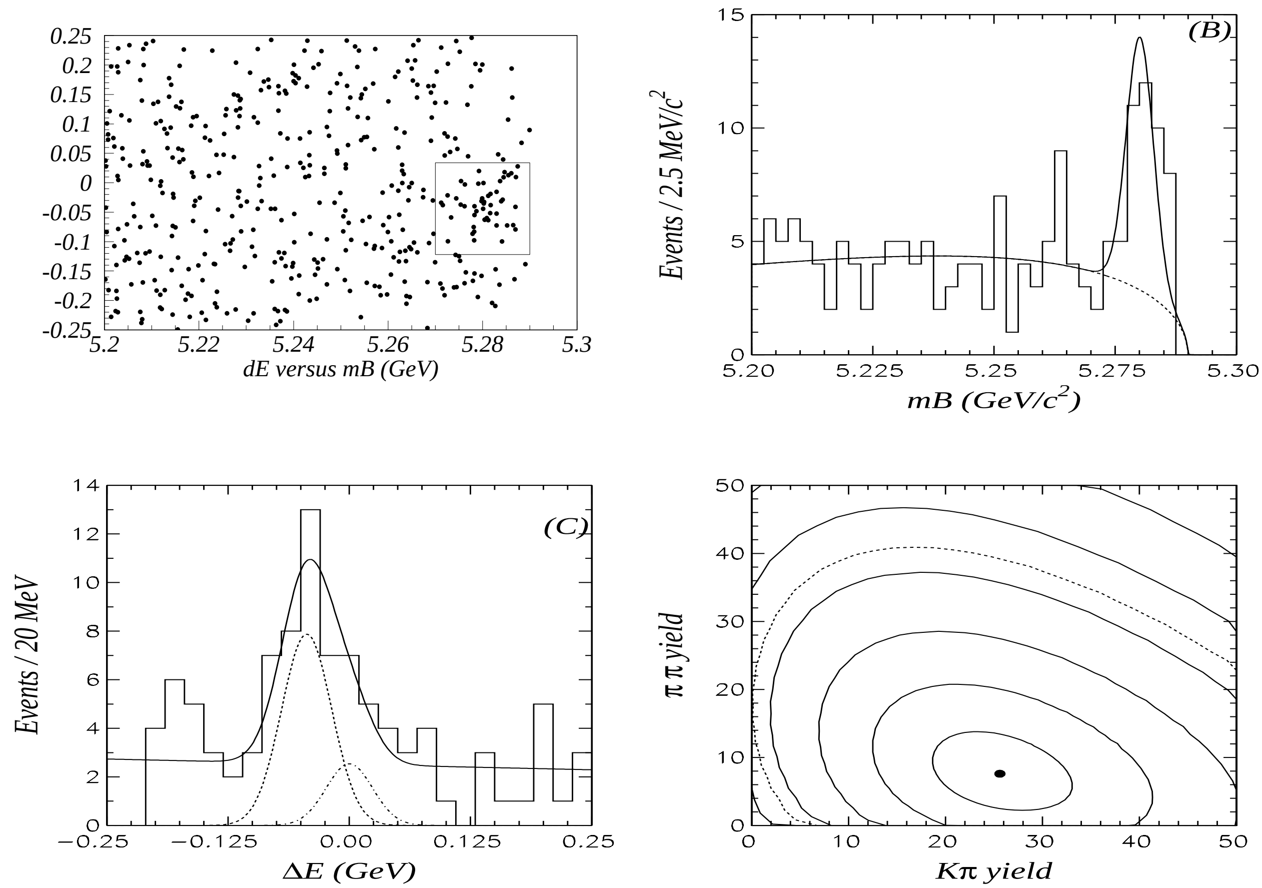
  $BR(B^+ \to \rho^+\gamma) < 2.27 \times 10^{-5}$ @ 90 % C.L.

  $\frac{BR(B\to\rho\gamma)}{BR(B\to K^*\gamma)} < 0.28$ @ 90 % C.L.

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

- Reconstructed B channels : $h^+h^-, h^\pm K_s, h^\pm \pi^0, K_s\pi^0$.
- Signal Yield extracted by fitting ΔE distribution. Three variable fit : (1) Signal Yield, (2) Continuum Yield and (3) mis-ID background yield.

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



$25.6^{+7.5}_{-6.8}$ $K^\pm\pi^\pm$ signal yield after fitting; stat. significance 4.4.

PRELIMINARY $BR(B^0 \to K^+\pi^-) = 1.74^{+0.51}_{-0.46} \times 10^{-5}$

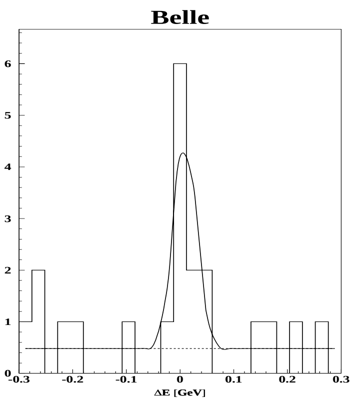
Other Charmless Hadronic Decays

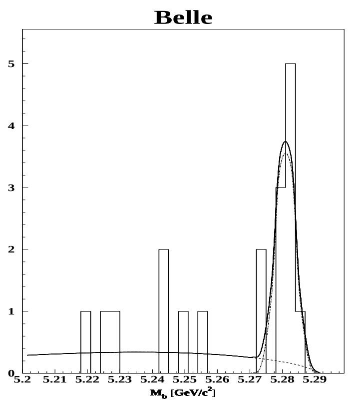
Belle PRELIMINARY

Mode	Signal Yield	significance	BR ($\times 10^{-5}$)
1. $B^+ \to \pi^+\pi^-$	$9.3^{+5.7}_{-5.1}$	$1.9\ \sigma$	< 1.65 @ 90 % CL
2. $B^+ \to K^0\pi^+$	$5.7^{+3.4}_{-2.7}$	$2.4\ \sigma$	< 3.4 @ 90 % CL
3. $B^+ \to K^+K^-$	0		< 0.8 @ 90 % CL
4. $B^+ \to K^+\pi^0$	$32.3^{+9.4+2.4}_{-8.4-2.2}$	$5.0\ \sigma$	$1.88^{+0.55}_{-0.49} \pm 0.23$
5. $B^+ \to \pi^+\pi^0$	$5.4^{+5.7+1.0}_{-4.4-1.1}$	$1.3\ \sigma$	$0.33^{+0.35}_{-0.27} \pm 0.07$
6. $B^0 \to K^0\pi^0$	$10.8^{+4.8+0.7}_{-4.0-0.5}$	$3.9\ \sigma$	$2.10^{+0.93+0.25}_{-0.78-0.23}$

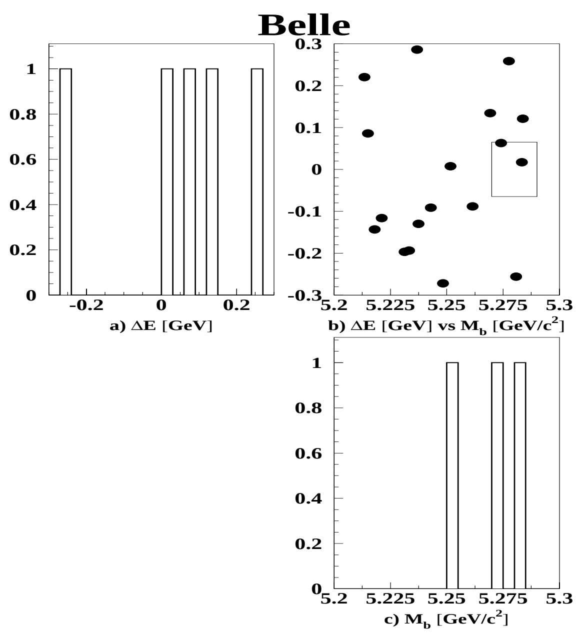
$B \to \phi K$

- Loose PID and vertex requirement for ϕ reconstruction from K^+K^-. Select only high momentum ϕ's: $p_\phi > 2$ GeV/c.
- Continuum is suppressed with a $\cos\theta_T$ cut, B flight direction and a ϕ helicity angle cut.





$B^\pm \to \phi K^\pm$: Signal yield from binned likelihood fit : $9.2^{+3.6}_{-2.9}$ with a statistical significance of $5.4\ \sigma$

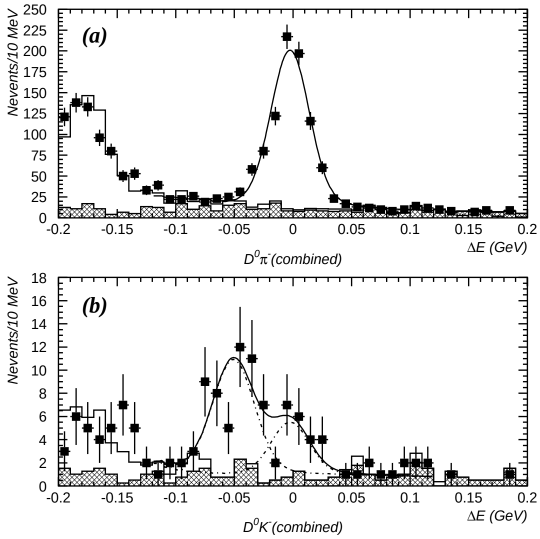


$B^0 \to \phi K^0$: 2 events observed in the 3σ signal box ; consistent with background fluctuation.

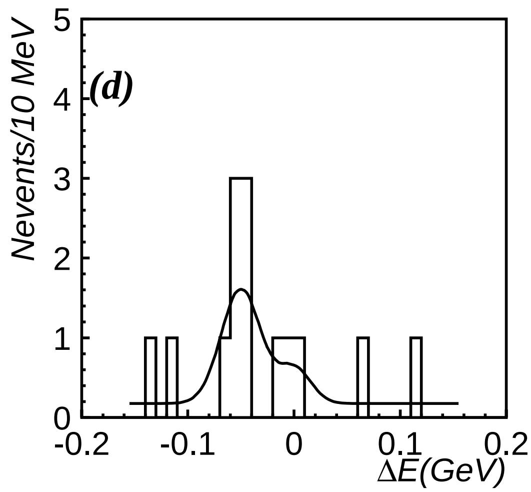
Belle PRELIMINARY

$BR(B^+ \to \phi(1020)K^\pm) : (1.72^{+0.67}_{-0.54} \pm 0.18) \times 10^{-5}$

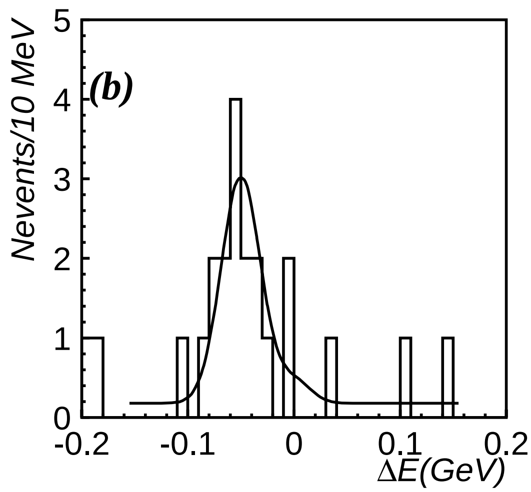
Cabibbo Suppressed $B \to D(*)K$



- $B^- \to D^0 K^-$:
- $N(D^0K^-) = 48.7 \pm 8.4$ with $N(D^0\pi^-) = 19.9 \pm 6.2$ in the feed down peak.
- R $= \frac{BR(B^- \to D^0 K^-)}{BR(B^- \to D^0 \pi^-)} = 0.081 \pm 0.014(stat.) \pm 0.011(syst.)$



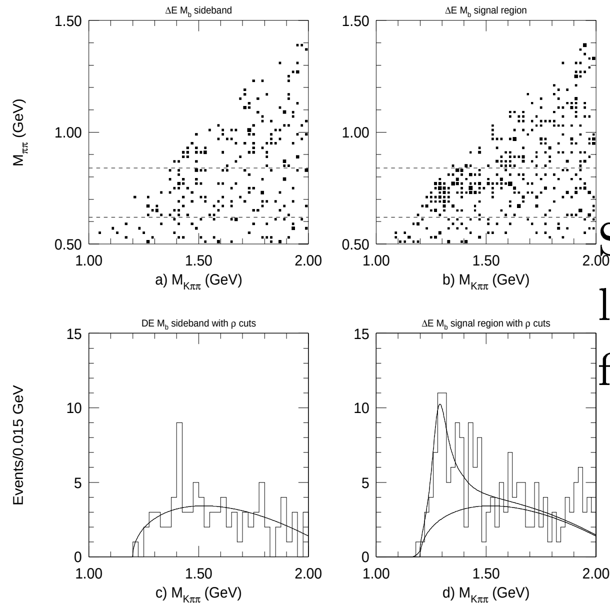
- $\bar{B^0} \to D^{*+}K^-$:
- $N(D^{*+}K^-) = 6.7^{+3.2}_{-2.5}$ with $N(D^{*+}\pi^-) = 4.2^{+2.8}_{-2.2}$ in the feed down peak.
- R $= \frac{BR(\bar{B^0} \to D^{*+}K^-)}{BR(\bar{B^-} \to D^{*+}\pi^-)} = 0.062^{+0.030}_{-0.024} \pm 0.013$



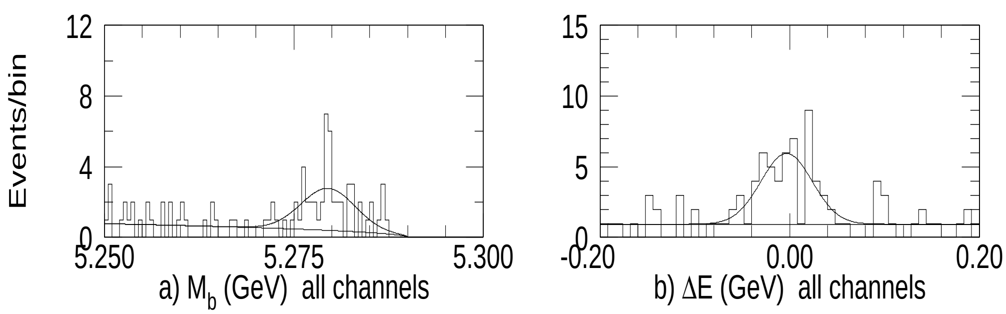
- $B^- \to D^{*0}K^-$:
- $N(D^{*0}K^-) = 13.3^{+4.3}_{-3.6}$ with $N(D^{*0}\pi^-) = 1.8^{+2.1}_{-1.4}$ in the feed down peak.
- R $= \frac{BR(B^- \to D^{*0}K^-)}{BR(B^- \to D^{*0}\pi^-)} = 0.134^{+0.045}_{-0.038} \pm 0.015.$

Observation of $B \to J/\psi K_1(1270)$

- Reconstruct $K_1 : K^+\pi^+\pi^-, K^+\pi^-\pi^0, K^0\pi^+\pi^-$
- Select events with cuts on ΔE and beam constrained mass.



Study $M_{\pi\pi}$ Vs. $M_{K\pi\pi}$: Select $0.62 < M_{\pi\pi} < 0.84$ for final reconstruction.



- Feed down background from $K_1(1400)$, $K_1^*(1410)$, $K^*(870)\pi$ are small.

  Belle PRELIMINARY :

  $BR(B^0 \to J/\psi K_1^0(1270) = (1.5^{0.5}_{-0.4} \pm 0.4) \times 10^{-3}$,
  $BR(B^+ \to J/\psi K_1^+(1270) = (1.7^{0.5}_{-0.4} \pm 0.4) \times 10^{-3}$

CP Measurement : Extraction of $\sin(2\phi_1)$

Overview

- For a B decaying to CP eigenstate, the time dependent asymmetry a(t) :

  $a(t) = \frac{N(B^0(t)\to f) - N(\bar{B^0}(t)\to f)}{N(B^0(t)\to f) + N(\bar{B^0}(t)\to f)} = \frac{(1-|\lambda_f|^2)\cos(\Delta m_d t) - 2Im\lambda_f \sin(\Delta m_d t)}{(1+|\lambda_f|^2)}$

  where $\lambda_f = \frac{q}{p}\frac{A(\bar{B^0}\to f)}{A(B^0\to f)}$.

  This can be different from "0", indicating CP violation : $\Rightarrow$

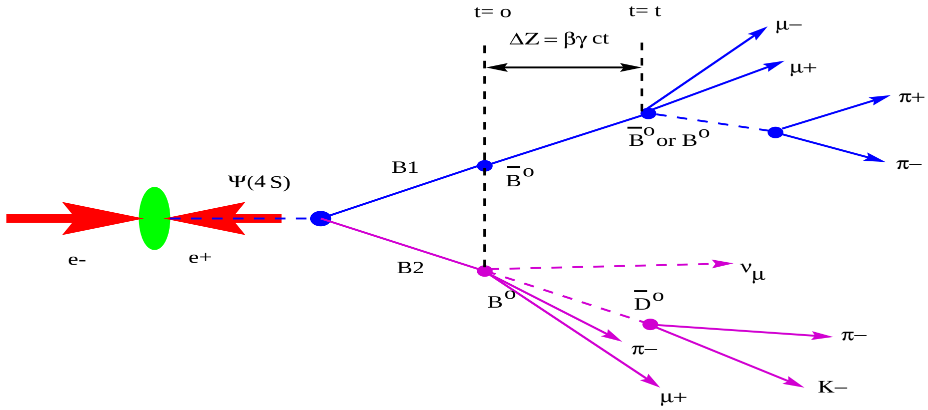
  - $|\lambda_f| \neq 1$:
    - $|q/p| \neq 1$: CP Violation in mixing (indirect)
    - $\frac{A(\bar{B^0}\to f)}{A(B^0\to f)} \neq 1$: CP violation in the decay (direct)
  - $Im\lambda_f \neq 0$: This can be related to angles of the CKM triangle : $Im\lambda_f = \sin(2\phi_1)$ which arises from the interference between the decay with and without mixing.

- Prime motivation for the Belle experiment is to measure $\sin(2\phi_1)$ to see if nature has treasured the violation of CP symmetry in B decays at all.
  - Use theoretically clean mode decaying to CP eigenstate.
  - Measure event by event asymmetry :

    a(t) $= -\eta_{CP}\sin(2\phi_1)\sin(\Delta m_d t)$,

    $$\eta_{cp} = \begin{cases} -1 & if \quad CP = odd \\ +1 & if \quad CP = even \end{cases}$$

CP Engineering

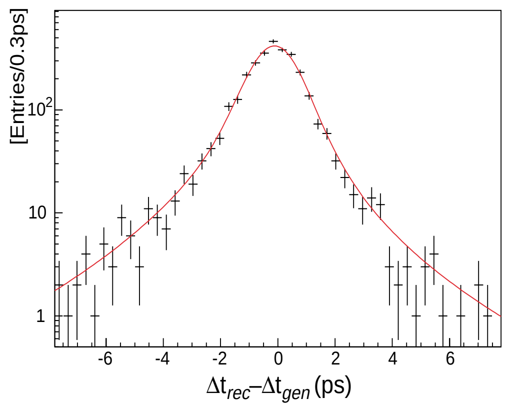


- Perform the benchmark measurements: B Lifetime and $B - \bar{B}$ Mixing
- Reconstruct the B decays to CP eigenstates and tag the flavor of the other B decay at time $t = 0$. Determine whether they are charged or neutral.
  - Determine the wrong tag fraction (w) that is responsible for the dilution (D_i) of the CP asymmetry measurement. $a(t)_{measured} = D_i.a(t)_{true}$
  - $D_i = 1 - 2w_i$; $\delta \sin(2\phi_1) = \frac{1}{\sqrt{s}} \frac{1}{D_i}$
- Measure Δz between vertices of B_{CP} and B_{tag} to determine the signed time difference (t) between the decays. $t = \Delta z / \beta\gamma c$.
- Determine the time resolution function which is dominated by the z resolution of the tagging vertex.
- Use unbinned maximum likelihood fit to the proper time distribution convoluted with the event-by-event resolution to extract $\sin(2\phi_1)$.

B Life Time Measurement

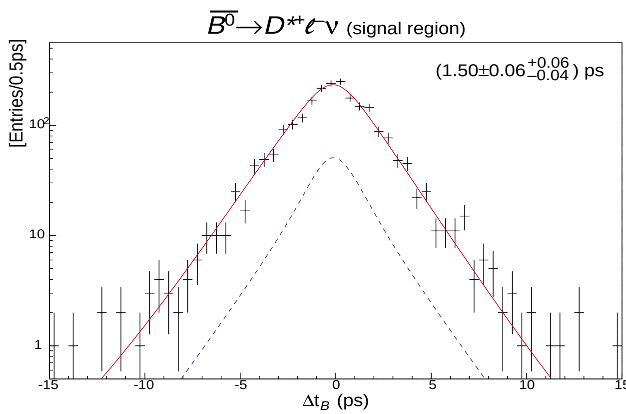
- Used B decay modes: ($D^* l\nu$, $D^*\pi$, $D\pi$, $J/\psi K^-$ and $J/\psi K_s$).
- Reconstruct B decay point and tagging side B vertex to calculate the proper time , $\Delta\tau = \Delta z / c\beta\gamma$ at $\beta\gamma = 0.425$.
- Get event by event P.D.F which looks like :

$$P(\Delta t) = f_{SIG} \int_{-\infty}^{\infty} d(\Delta t') \frac{e^{-|\Delta t'|/\tau_{SIG}}}{2\tau_{SIG}} R_{SIG}(\Delta t - \Delta t')$$
$$+ (1 - f_{SIG}) \int_{-\infty}^{\infty} d(\Delta t') [f_{\lambda_{BG}} \frac{\lambda_{BG}}{2} e^{-|\Delta t'|\lambda_{BG}} + (1 - f_{\lambda_{BG}}) \delta(\Delta t')] R_{BG}(\Delta t - \Delta t')$$



- $R(\Delta t)$ resolution function (double Gaussian) is an input to the P.D.F. : obtained from the MC.
- Shape is from various detector characteristics

- Minimization of P.D.F gives τ_B which is a free parameter in the fit.
- Solid line is the superimposed P.D.F after obtaining all the parameters from the fit.



- Belle PRELIMINARY Combined Results:

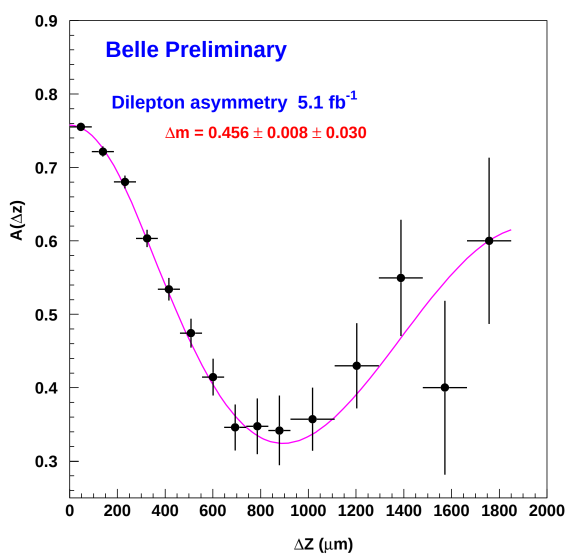
$\tau_{\bar{B}^0}$: $1.50 \pm 0.05 \pm 0.07$ ps, τ_{B^-} : $1.70 \pm 0.06^{+0.11}_{-0.10}$ ps

$\tau_{B^-}/\tau_{\bar{B}^0} = 1.14 \pm 0.06^{0.06}_{-0.05}$

$y_{CP} = 0.03^{+0.15+0.05}_{-0.18-0.08}$ (-0.36 $< y_{CP} <$ 0.35 @ 95 % C.L.)

$B^0 - \bar{B}^0$ Mixing

- Time evolution asymmetry of same-flavor ($B_d^0 B_d^0$, $\bar{B}_d^0 \bar{B}_d^0$) and opposite-flavor ($B_d^0 \bar{B}_d^0$) decays given a $B_d^0 \bar{B}_d^0$ initial state is given by : $A(t) = \frac{N_{same} - N_{opp}}{N_{same} - N_{opp}} = \cos(\Delta m_d t)$
- Search for fully reconstructed $\Upsilon(4S)$ decays into $B^0 B^0$ or $\bar{B}^0 \bar{B}^0$ pair is accomplished by :
  - B decays involving high momentum di-Leptons (high statistic, large background, large systematics) .
  - B decays involving D^*, say $B \to D^* l\nu$ (low statistics, small background, small systematics). This gives the measure of wrong flavor tagging fraction.
- Δm_d from the SS/OS Dilepton Δz distribution :



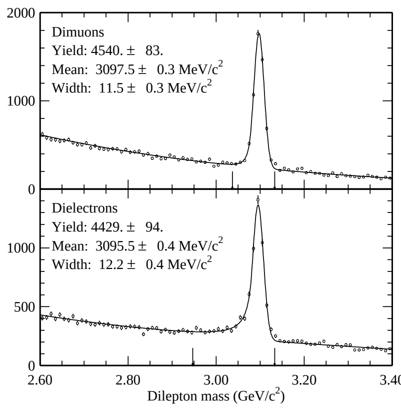
- Measure the decay distance of the OS and SS Dilepton and plot asymmetry as a function of Δz.
- The smooth curve is the result from the fit.
- $\Delta m_d = 0.456 \pm 0.008 \pm 0.030\ ps^{-1}$

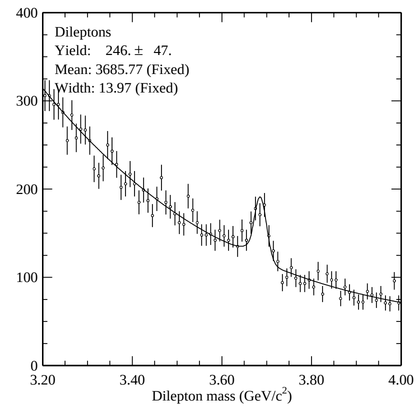
B_{CP} Event Reconstruction

- We reconstruct only B's that decay into CP eigenstate.
  CP Odd Modes
  - $B^0 \to J/\psi K_s$
    - $J/\psi \to \mu^+\mu^-, e^+e^-$
    - $K_s \to \pi^+\pi^-, \pi^0\pi^0$
  - $B^0 \to \psi(2s) K_s$
    - $\psi(2s) \to \mu^+\mu^-, e^+e^-, J/\psi\pi^+\pi^-$
  - $B^0 \to \chi_{c1} K_s$
    - $\chi_{c1} \to J/\psi\gamma$

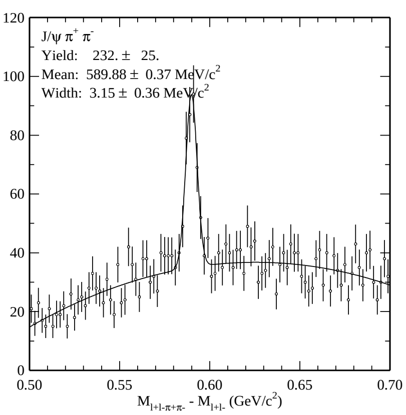
  CP Even Modes
  - $B^0 \to J/\psi K_L$
  - $B^0 \to J/\psi \pi^0$

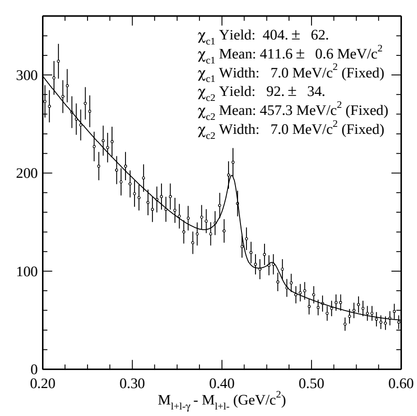
- Inclusive J/ψ and $\psi(2s)$ Reconstruction :



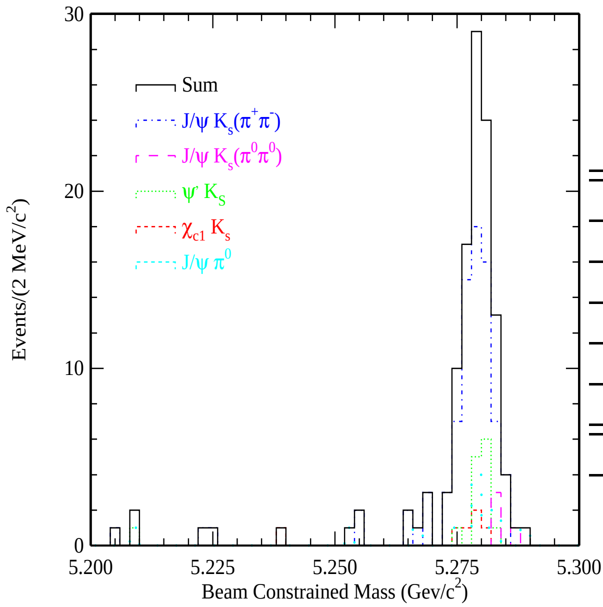


- Inclusive $\psi(2s) \to J/\psi\pi^+\pi^-$ and $\chi_{c1} \to J/\psi\gamma$ Reconstruction :





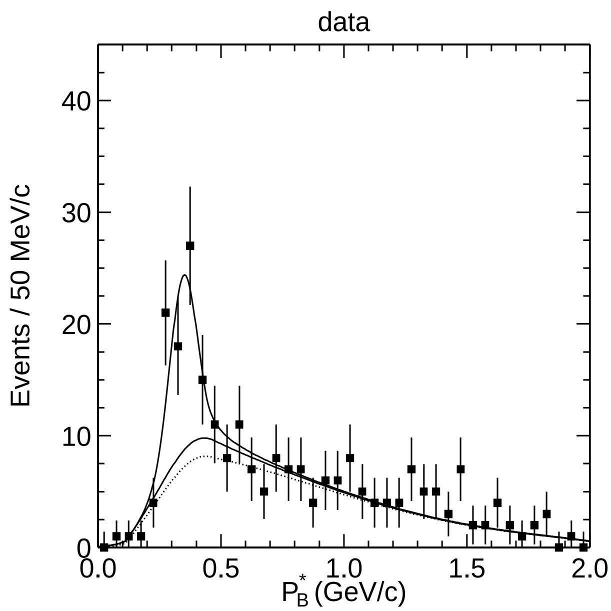
Total B_{CP} Sample Before Tagging



Modes	CP	S / N
$J/\psi(l^+l^-)K_s(\pi^+\pi^-)$	-1	70 / 3.4
$J/\psi(l^+l^-)K_s(\pi^0\pi^0)$	-1	4 / 0.3
$\psi'(l^+l^-)K_s(\pi^+\pi^-)$	-1	5 / 0.2
$\psi'(J/\psi\pi^+\pi^-)K_s(\pi^+\pi^-)$	-1	8 / 0.6
$\chi_{c1}(J/\psi\gamma)K_s(\pi^+\pi^-)$	-1	5 / 0.75
$J/\psi(l^+l^-)\pi^0$	+1	10 / 1
Total		102 / 6.25

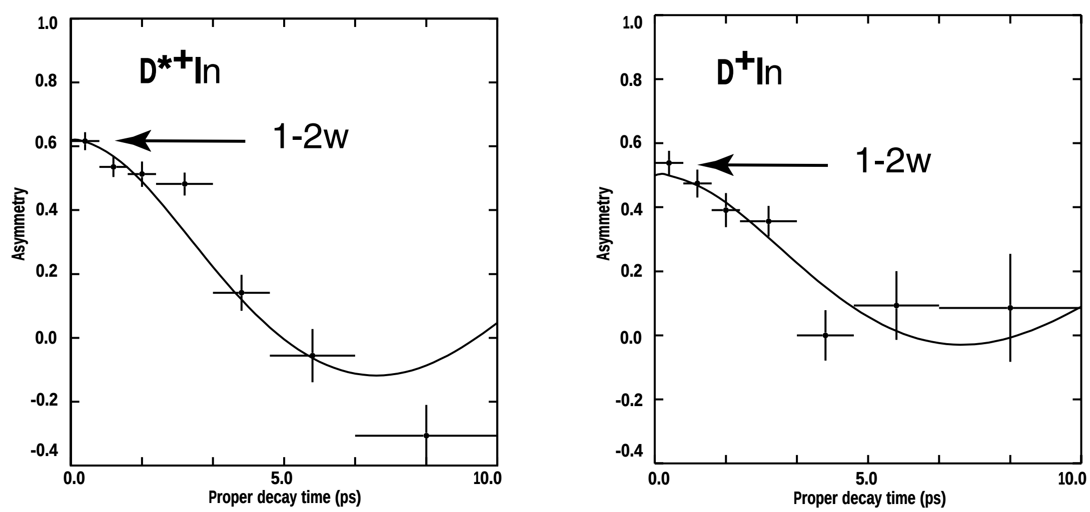
$B \to J/\psi K_L$ Detection :

- Two body decay $\Rightarrow$ Use J/ψ momentum to predict K_L momentum.
- Search for K_L shower.
- Use shower position to calculate p_B^*
- 102 Candidates, 48 Estimated Background



Flavor Tagging & Wrong Tag Fraction

- Reconstruct $B \to D^{(*)} l\nu$ decay and apply the flavor tagging algorithm to the remaining tracks of the event.
  - This decay is 'self-tagging' : charge of lepton tags the flavor of B.
  - Tagging Algorithm :
    * Use tight PID requirement for leptons and Kaon.
    * Use the sign of the high momentum lepton : $p^* > 1.1 GeV$ (+ve lepton tags B^0)
    * Use sum of K charges.(+ve sum tags B^0)
    * Sign of slow pions from D^{*+} decays
    * Medium momentum leptons : charge is anti-correlated with flavor of B.
- Perform a Maximum Likelihood fit to the mixing asymmetry and extract w and Δm_d from the fit.
  $A_{mix}(\Delta t) = \frac{N(\Delta t)^{OF} - N(\Delta t)^{SF}}{N(\Delta t)^{OF} + N(\Delta t)^{SF}} = (1 - 2w)\cos(\Delta m_d t)$

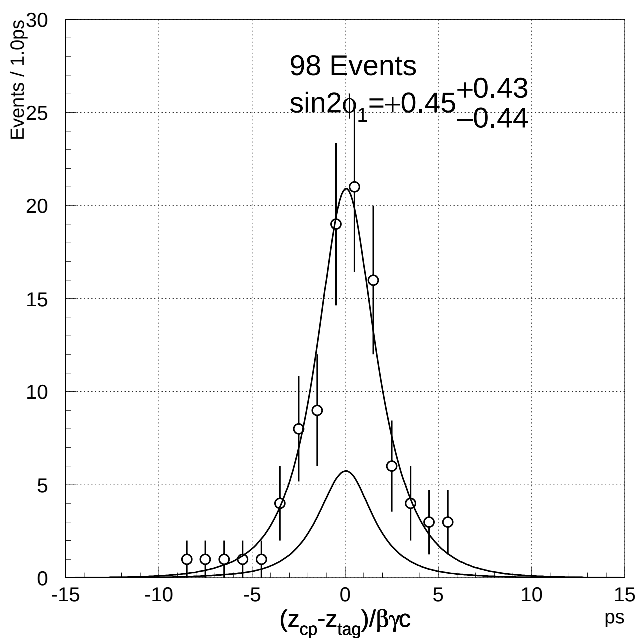


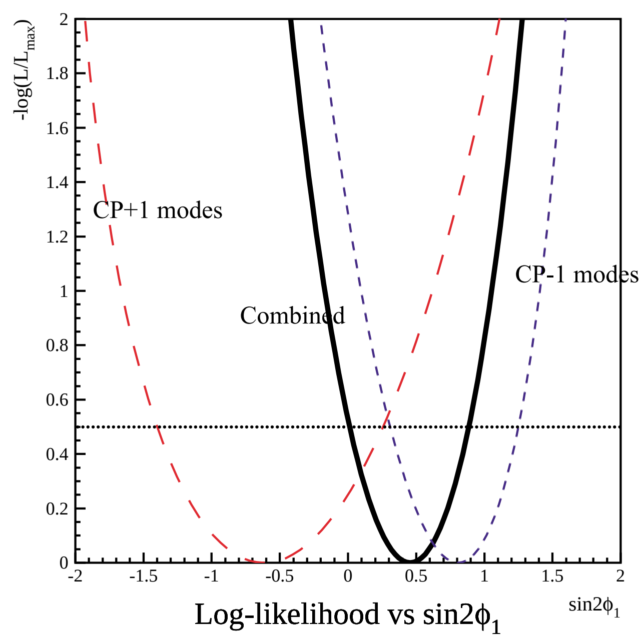
- Belle PRELIMINARY : From the measured asymmetry we obtain : $\Delta m_d = 0.488 \pm 0.026 \;\; ps^{-1}$, $w_{lepton} = 0.071 \pm 0.019$, $w_{Kaon} = 0.199 \pm 0.021$

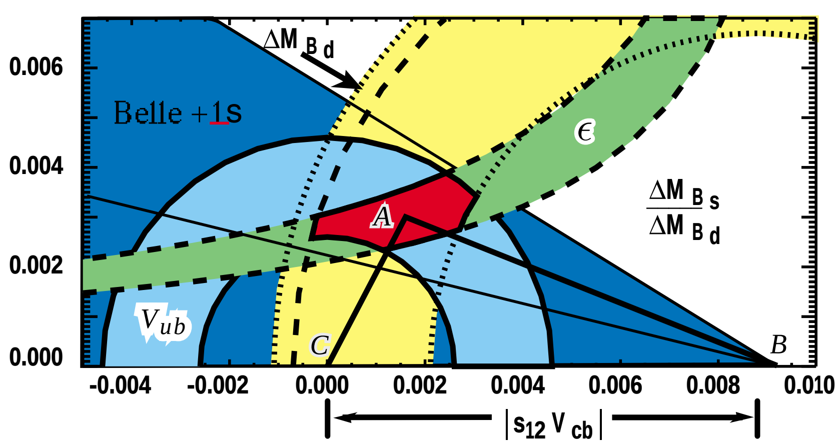
CP Fit : Extraction of $\sin(2\phi_1)$

- Out of 102+102 events, 98 events are tagged. Proper time distribution of those tagged CP eigenstate decays are analyzed using Maximum Likelihood fit to extract the CP asymmetry.
- Results of the likelihood fit to the full sample is :

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







Conclusion

- Belle had a very successful and exciting first year run and is marching along a well defined road to measuring $\sin(2\phi_1)$ with a a very good precision. First preliminary results were reported.
- We need a lot more data to constrain the CKM triangle with less error. A very good start though.
- Observed first evidence of Cabibbo suppressed $B \to D^* K-$ process, first measurement of $Br(B \to J/\psi K_1(1270))$ and $Br(B^+ \to \phi K^+)$.
- Rare decays responsible for direct CP violation have been observed and things will be more interesting as we continue accumulating data with higher rate.
- The physics scope at Belle is not limited to B physics only. We have reported five different tau and two-photon physics related results at the ICHEP2000 conference. Check out for more..... http://www.bsunsrv1.kek.jp/conferences/ichep2000.html

Future Prospects

- We resume data taking from mid-October.
- We hope to achieve $\sim 4 \times 10^{33} cm^{-1} s^{-1}$ this fall and take 4-5 fb^{-1} data per month though next summer, July 2001.
- We have replaced the current SVD with a more radiation hard ($\sim$ 1 Mrad) SVD.
- Upgrades of the detector component are under study.
- New Millennium will bring new excitement. Stay tuned.