



Measurements of B lifetimes and
 $B^0\overline{B^0}$ mixing.

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Outline

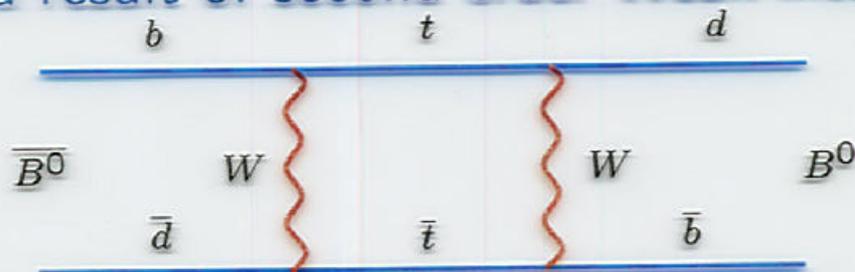
- $B^0\bar{B}^0$ Mixing using decays:
 - to Dileptons
 - Semileptonic
 - Hadronic
- \bar{B}^0 and B^- lifetimes using decays:
 - Semileptonic
 - Hadronic

Motivation

- Fundamental parameters can be extracted from $B^0\bar{B}^0$ mixing.
- Asymmetric B-Factories are great to study mixing.
- Lifetime and mixing analysis provide important information for CP studies.

Introduction to $B^0\bar{B}^0$ Mixing

Mixing is a result of second order Weak interactions:



$$B^0\bar{B}^0/\bar{B}^0B^0 : P_{SF}(\Delta t) \propto e^{-\frac{|\Delta t|}{\tau}} [1 - \cos(\Delta m \Delta t)]$$

$$B^0\bar{B}^0 : P_{OF}(\Delta t) \propto e^{-\frac{|\Delta t|}{\tau}} [1 + \cos(\Delta m \Delta t)]$$

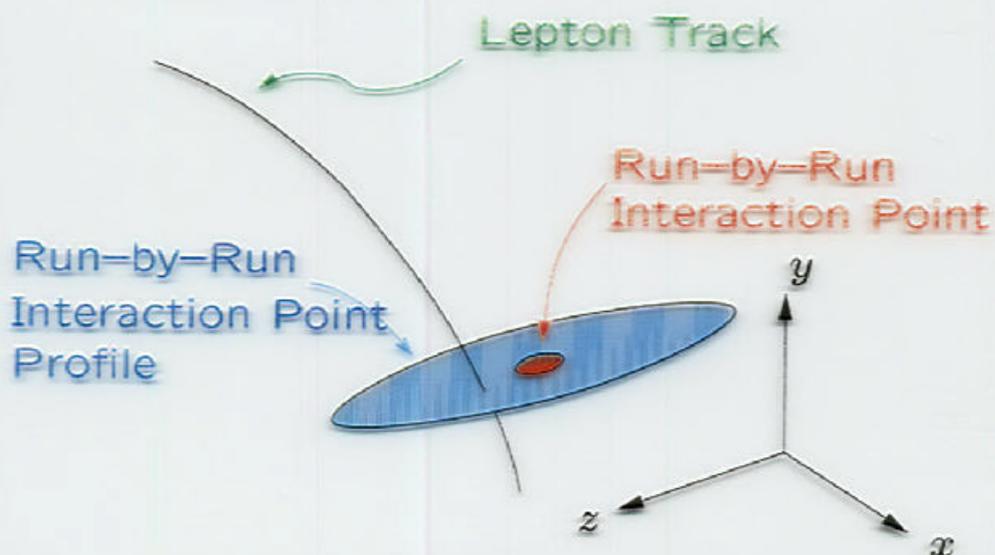
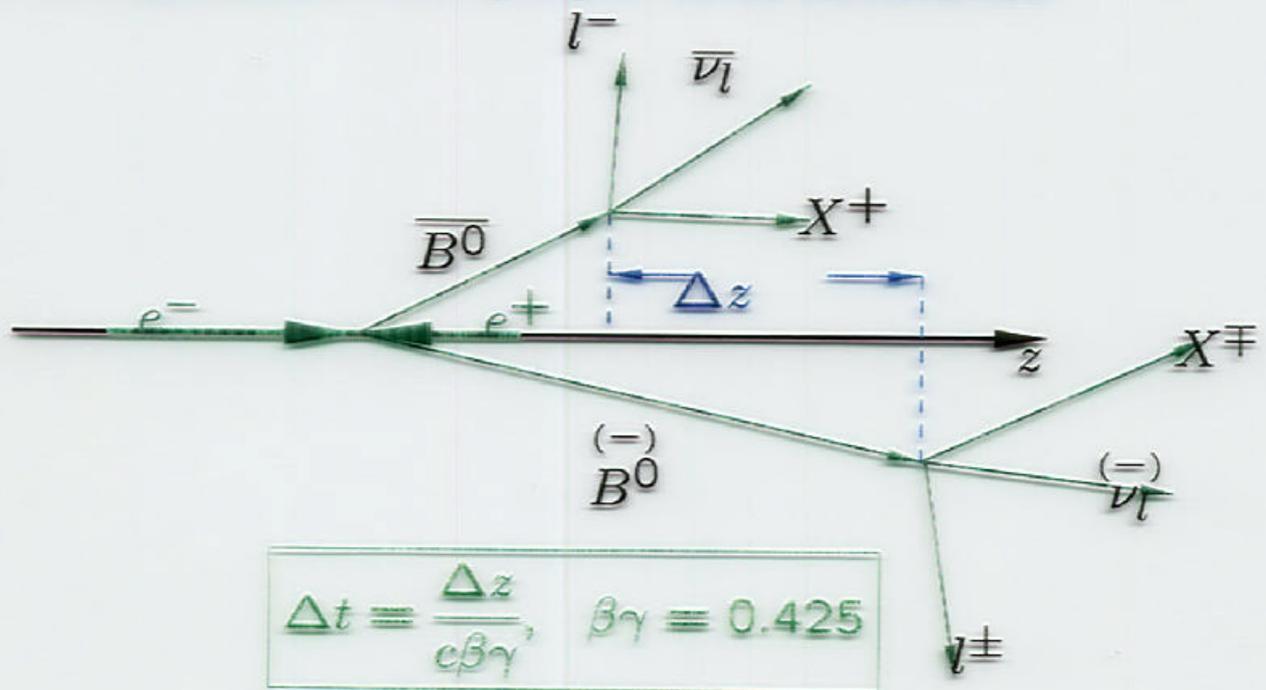
$$A_{mix} \equiv \frac{OF - SF}{OF + SF} \propto \cos(\Delta m \Delta t)$$

- Δm is the mass difference between the mass eigen states.
- Determine B meson flavor by reconstructing flavor specific modes.
- Measure the time dependence for SF and OF events.

\implies can determine Δm

$B^0\bar{B}^0$ Mixing using dileptons ($ee, e\mu, \mu\mu$)

- Charge of lepton \implies Flavor of B meson
- Z separation \implies proper time difference





$B^0\bar{B}^0$ Mixing using dileptons cont.

Event selection cuts include:

- $(1.1 \leq P_l^* \leq 2.3) \text{ GeV}/c$
- $30^\circ \leq \theta_{l(lab)} \leq 135^\circ$
- SVD hits: $r \phi \geq 1, z \geq 2$

With 5.9 fb^{-1}

8,573 Same Sign, 40,981 Opposite Sign Events.

Event Classification

Signal - Both tracks are primary leptons from different B mesons

Background - At least one lepton from non- B or fake lepton (hadron)

Fitting

Use a binned maximum likelihood fit.

simultaneous fit to Same Sign and Opposite Sign dilepton distributions

Signal - Use theoretical PDP smeared with $J/\psi \rightarrow l^+l^-$ response function

Background - Use Δm sensitive Monte Carlo distributions

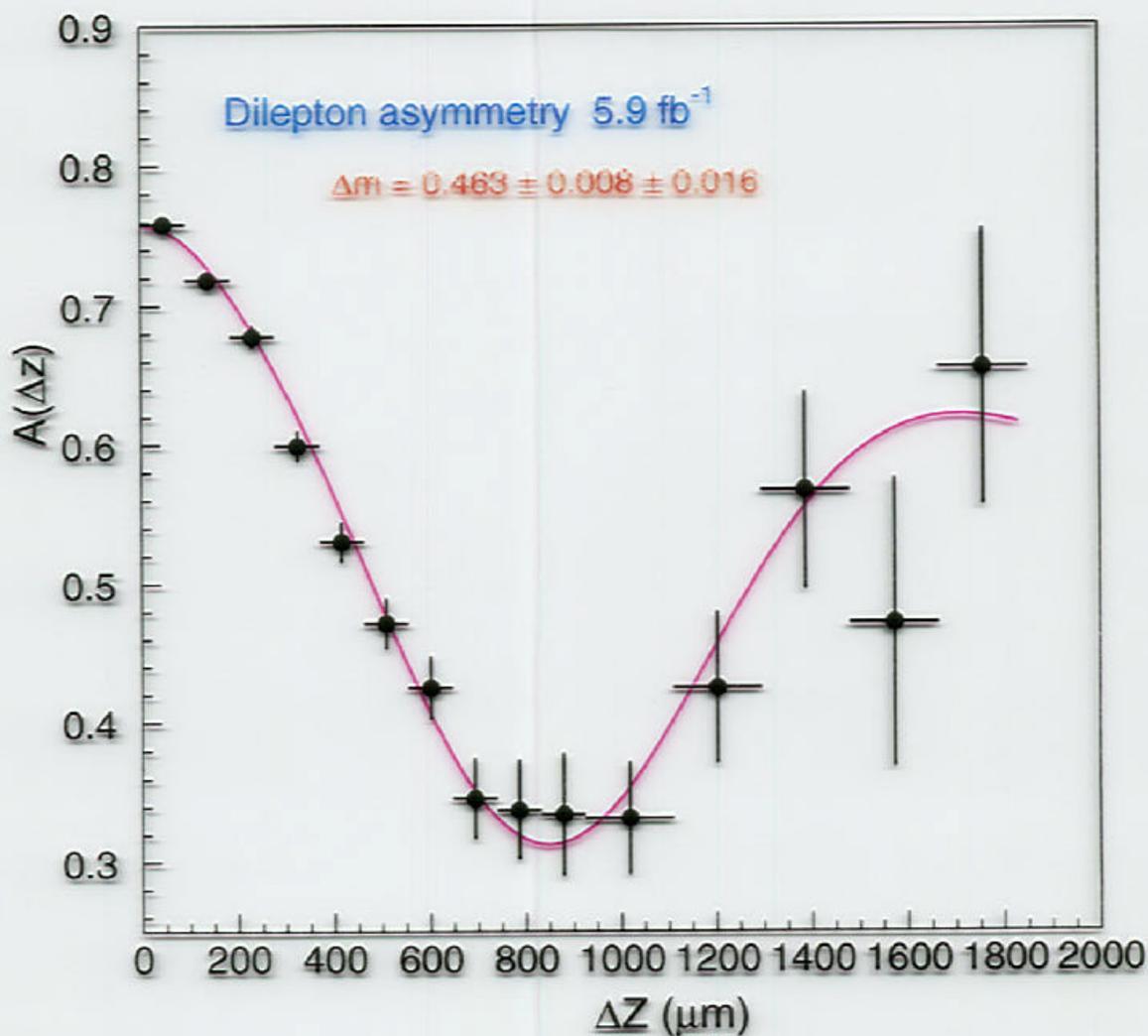
$B^0\bar{B}^0$ Mixing using dileptons cont.

Fit Results

$$\Delta m \equiv 0.463 \pm 0.008 \pm 0.016 \text{ ps}^{-1}$$

Accepted for publication by Pys. Rev. Lett.

(hep-ex/0011090)



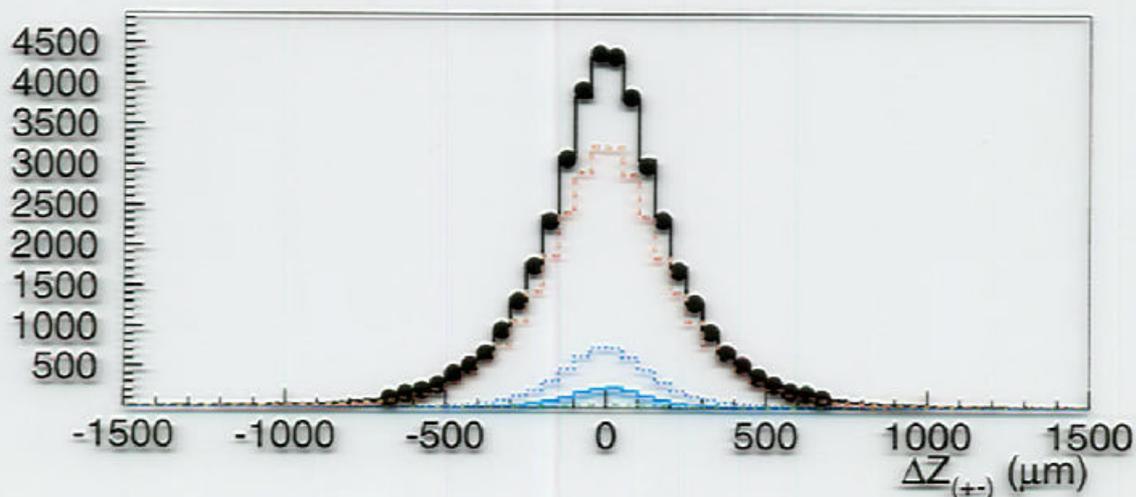
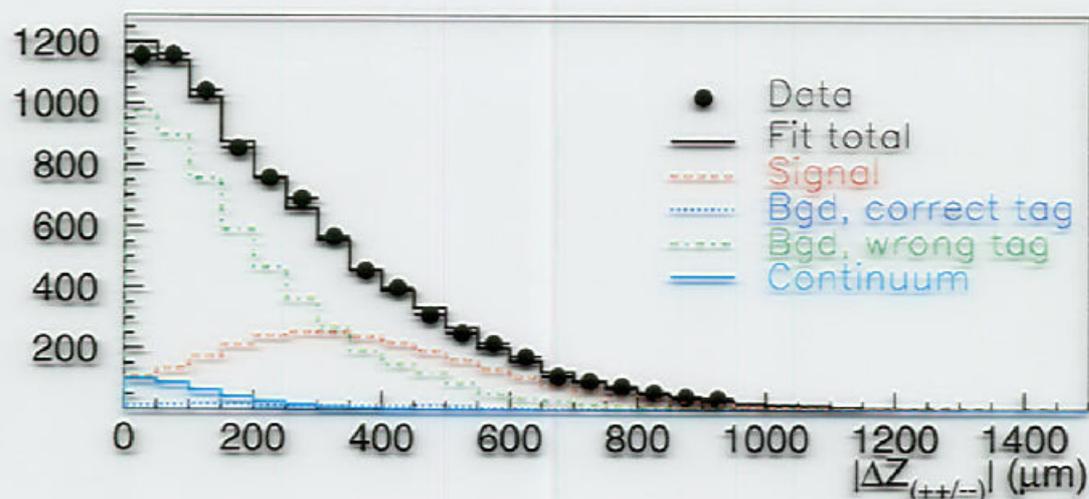
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$B^0\overline{B}^0$ Mixing using dileptons cont.

Systematic Errors

Source (uncertainty)	Δm_d
f_+/f_0 (± 0.08)	± 0.009
B_d^0 lifetime (± 0.032 ps)	± 0.004
$\tau_{B^\pm}/\tau_{B_d^0}$ (± 0.03)	± 0.009
response function	± 0.005
background fake rate ($\pm 35\%$)	± 0.004
$\mathcal{B}(B \rightarrow DX)$ (D^0 : $\pm 4.6\%$, D^\pm : $\pm 14.3\%$)	± 0.002
continuum (SS: $\pm 16\%$, OS: $\pm 7\%$)	± 0.002
detector resolution, BG ($\pm 18 \mu\text{m}$)	± 0.001
Monte Carlo statistics	± 0.004
total	± 0.016



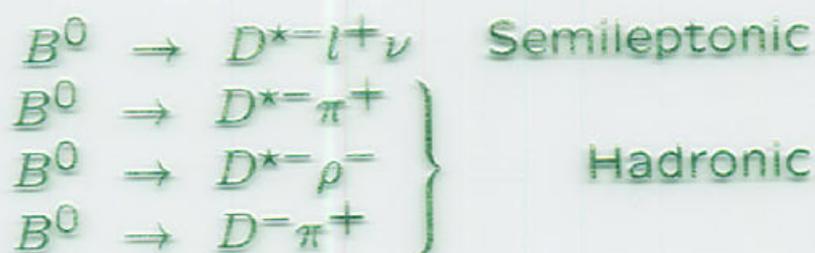
Mixing using reconstructed self tagging

modes

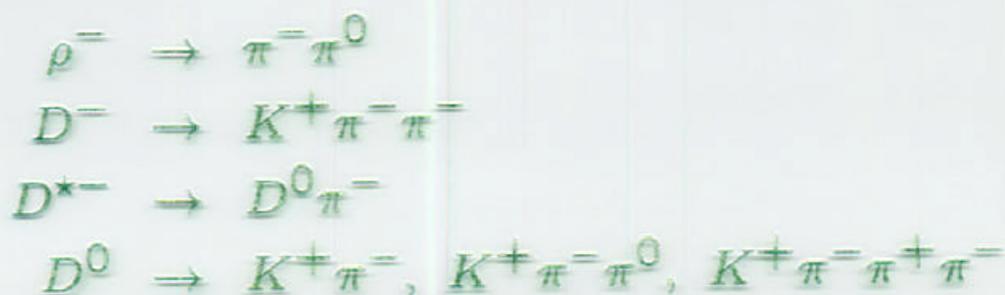
- Reconstruct $B^0 \rightarrow D^{*-}l^+\nu$ and Hadronic modes.
- Use Belle standard flavor tagging
 - Two stage Multidimensional Likelihood method
 - Output divided into six categories
- Now there is a dilution term in the PDF's

Decay modes

B^0



Secondaries

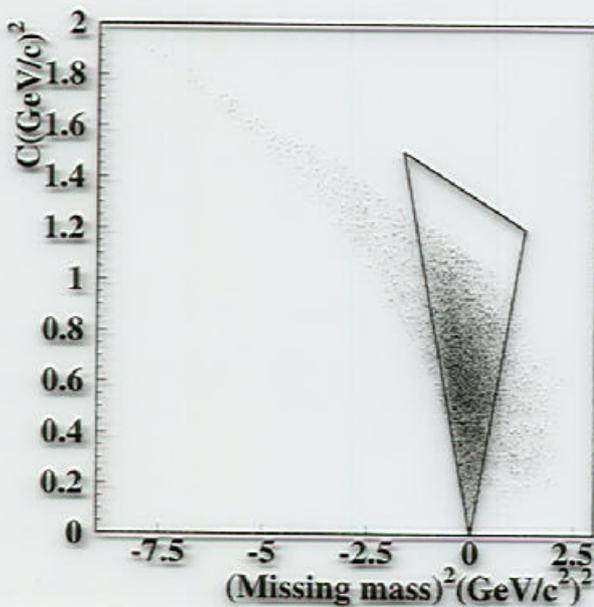


$B^0\bar{B}^0$ Mixing using $D^*l\nu$ ($10.5fb^{-1}$)

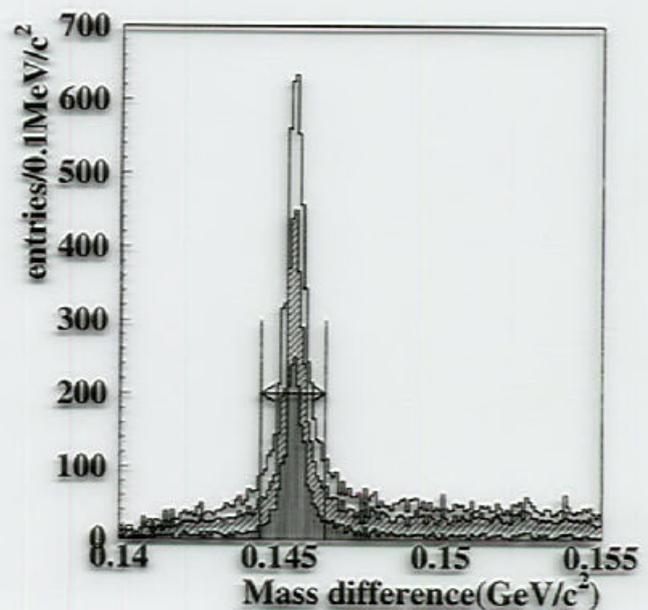
Event Selection

- Require tracks with associated SVD hits.
- $1.4 < P_l^* < 2.4$ GeV/c, $P_{D^{*-}}^* < 2.6$ GeV/c
- Missing mass² $\equiv (E_B - E_{D^*l})^2 - |\vec{p}_B|^2 - |\vec{p}_{D^*l}|^2$
- $C \equiv 2|\vec{p}_B||\vec{p}_{D^*l}|$
- Mass Difference $\equiv m_{D^*} - m_{D^0}$

C vs. Missing Mass

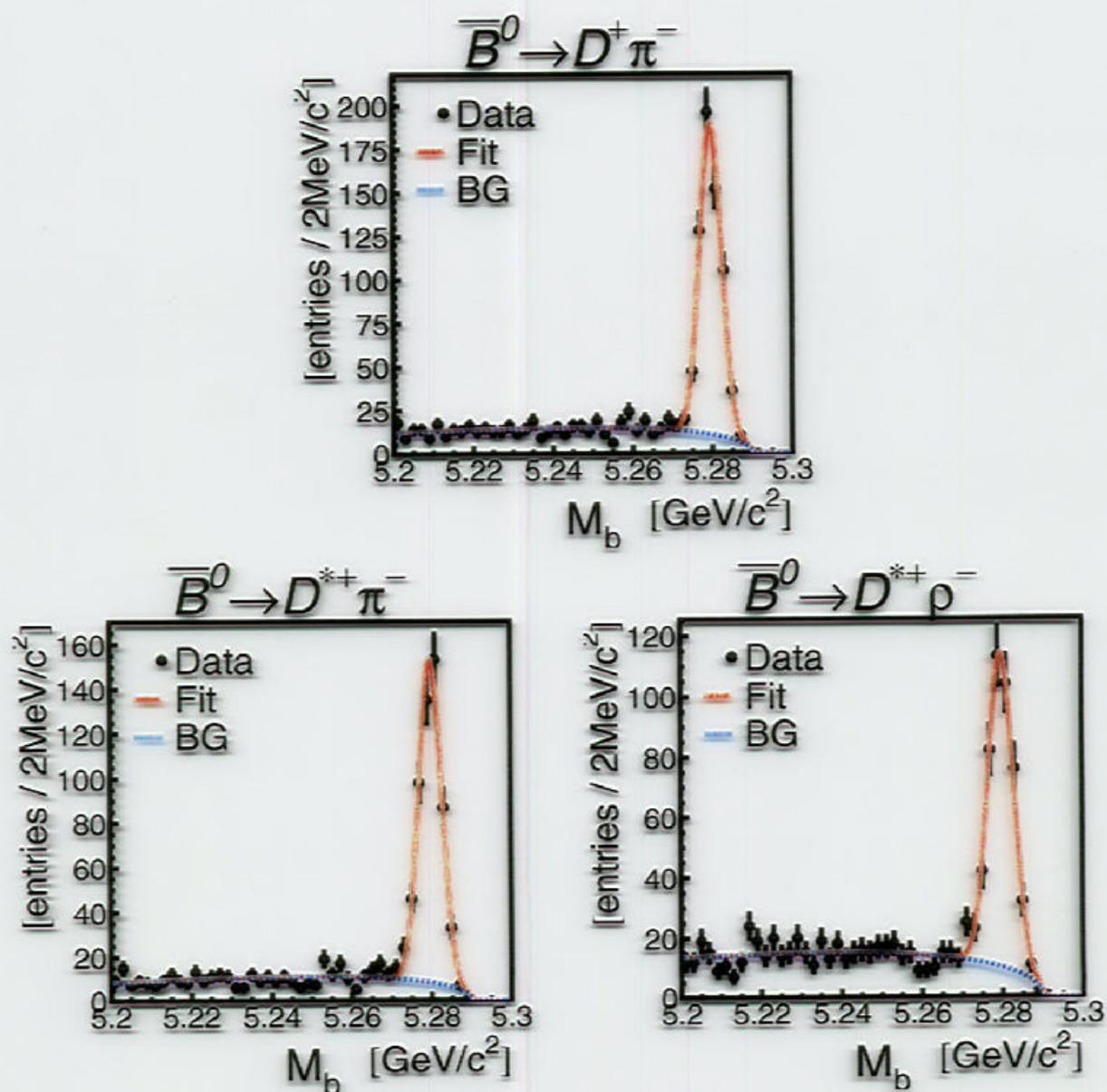


Mass Difference



Mixing using Hadronic modes ($10.5 fb^{-1}$)

- SVD hits: $r/\phi \geq 2$, $z \geq 2$ for tracks in vertex fit
- Particle identification for charged π and K candidates (except slow π)



Reconstructing the vertices

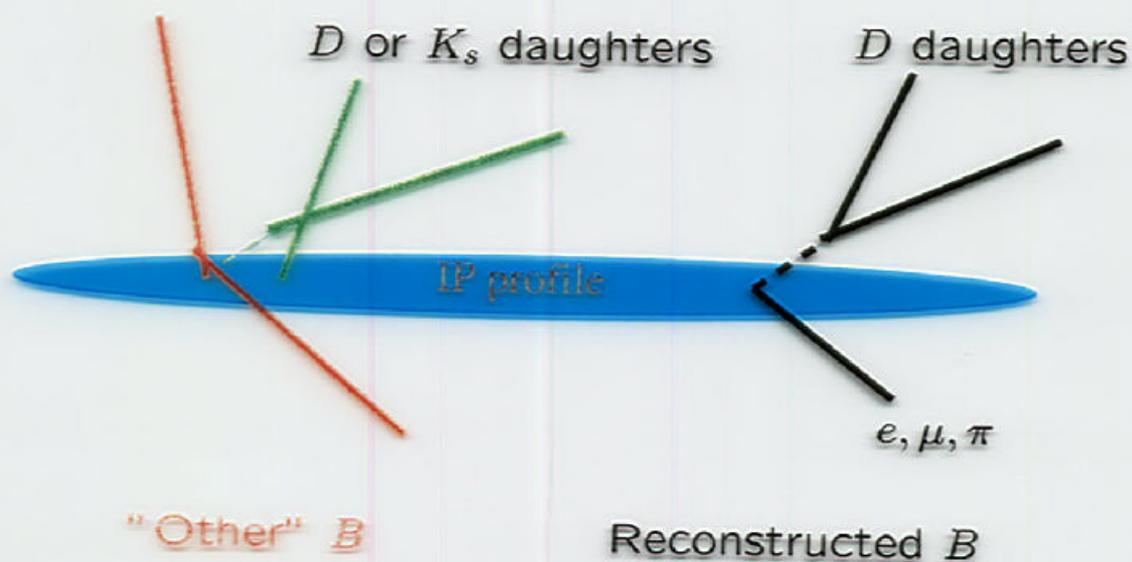
Reconstructed B

- SVD and track quality conditions
- Vertex reconstructed D with high momentum primary track (e, μ, π)

Tagging Side or "Other" B

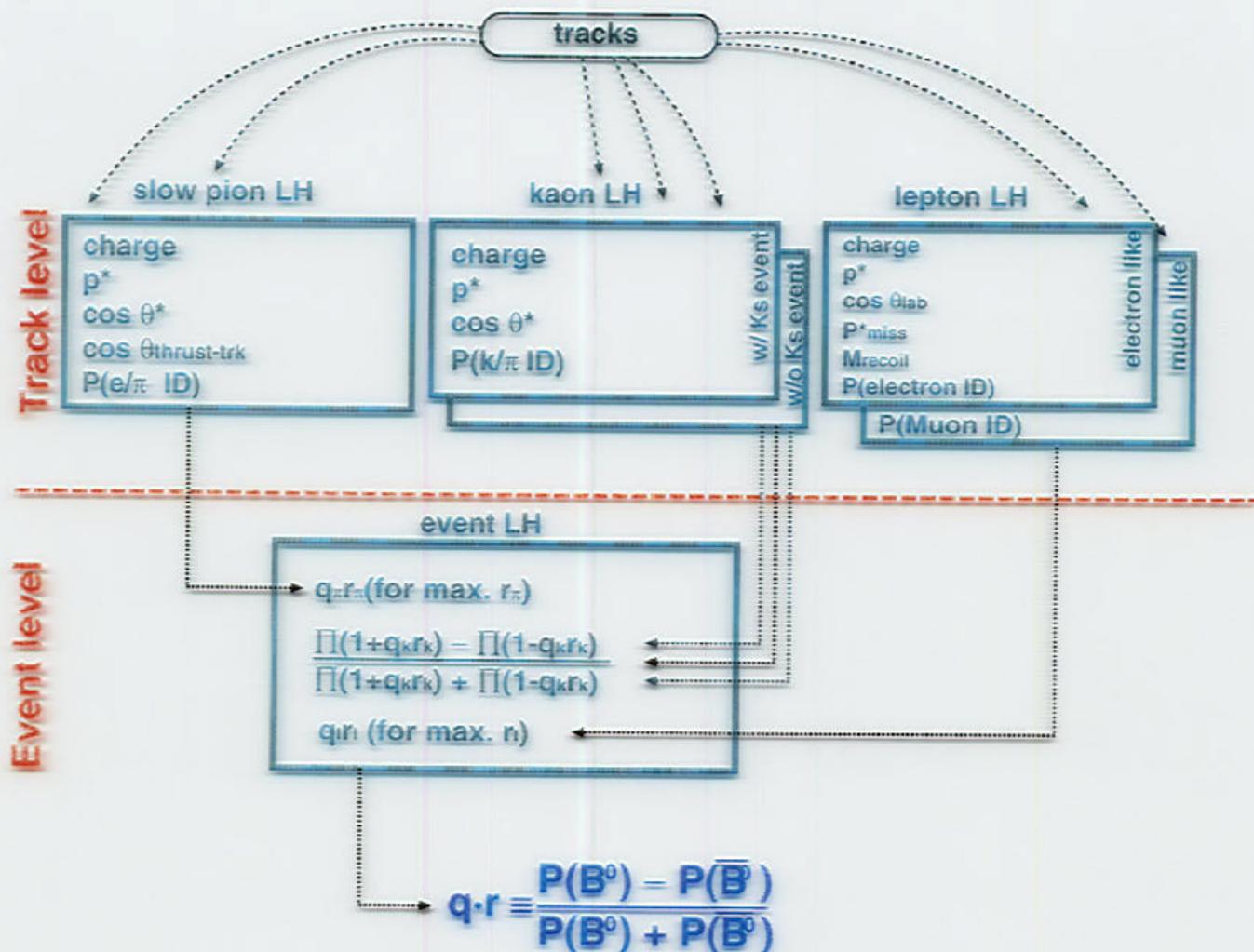
Standard Belle tag side vertexing:

- Reject charged π 's from K_s candidates.
- SVD and track quality conditions
- Conditions on χ^2 of vertex



Multidimensional likelihood Flavor Tagging

Introduce the flavor multiplied dilution factor $q \cdot r$:



$$\epsilon_{\text{tag}} \equiv 99.4\%, \quad \epsilon_{\text{eff}} \equiv 27.0\%$$

A note on PDF's

The actual PDF's for OF and SF distributions used in the mixing fits are the sum of two distinct components.

1. Signal term: typically has:

- Lifetime term = exponential
- mixing term = cosine
- wrong tag dilution term = $(1 - 2\omega)$
- resolution term = two Gaussians

2. Background term: consisting of:

- lifetime term = exponential
- zero lifetime term = delta function
- resolution term = two Gaussians

$$P_{SIG}^{(OF/SF)} \propto \int_{-\infty}^{\infty} dt' e^{-\frac{t'}{\tau}} (1 \pm (1 - 2\omega) \cos(\Delta m t')) R(\Delta t - t')$$

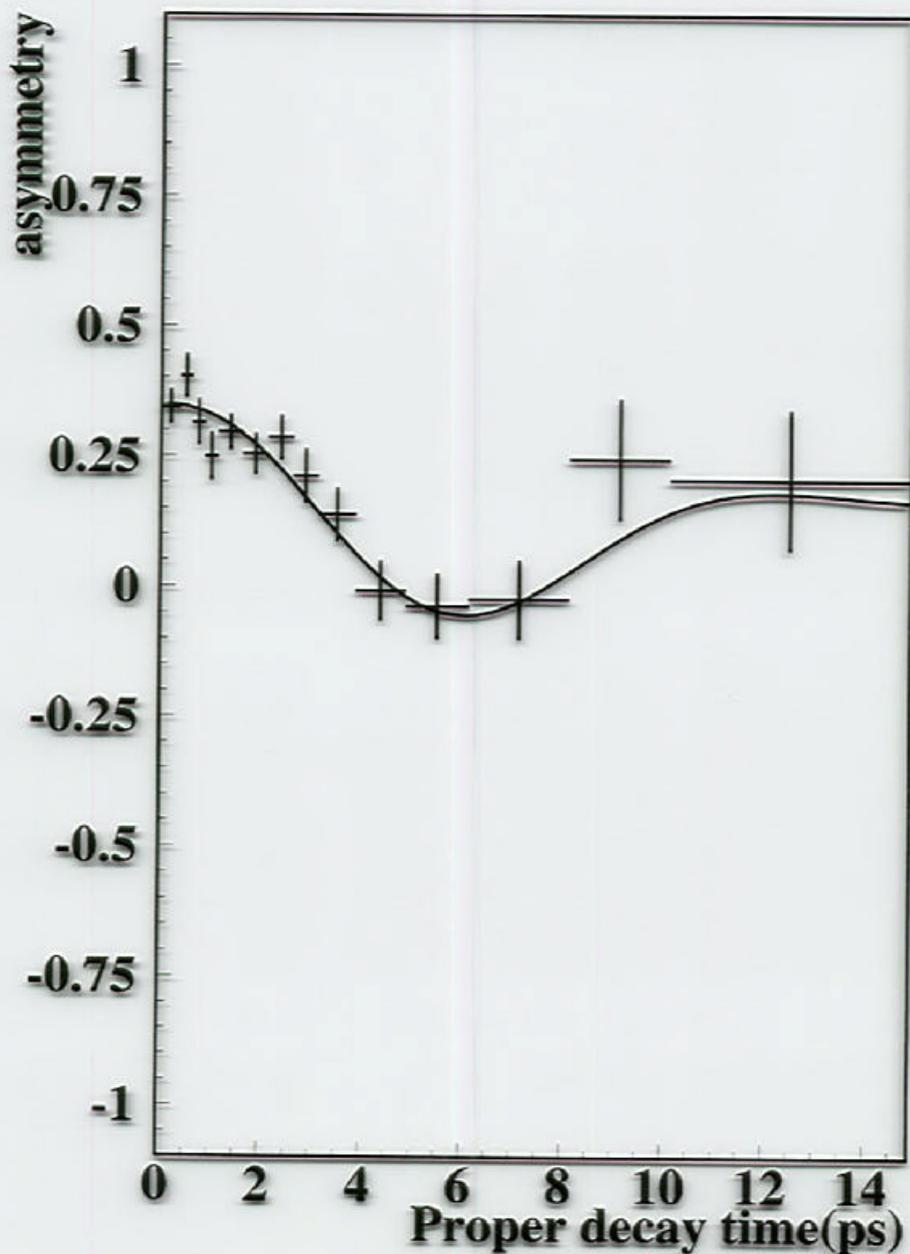
$$P_{BG} \propto \int_{-\infty}^{\infty} dt' [e^{-\frac{t'}{\tau_{BG}}} + \delta(t')] R_{BG}(\Delta t - t')$$

A lifetime fit still has the same form but is simplified since the cosine term is zero, and there is no distinction b/w OF and SF.

Results: Mixing using $D^*l\nu$ ($10.5fb^{-1}$)

$$\Delta m \equiv 0.522 \pm 0.026(\text{stat})ps^{-1}$$

Belle Preliminary

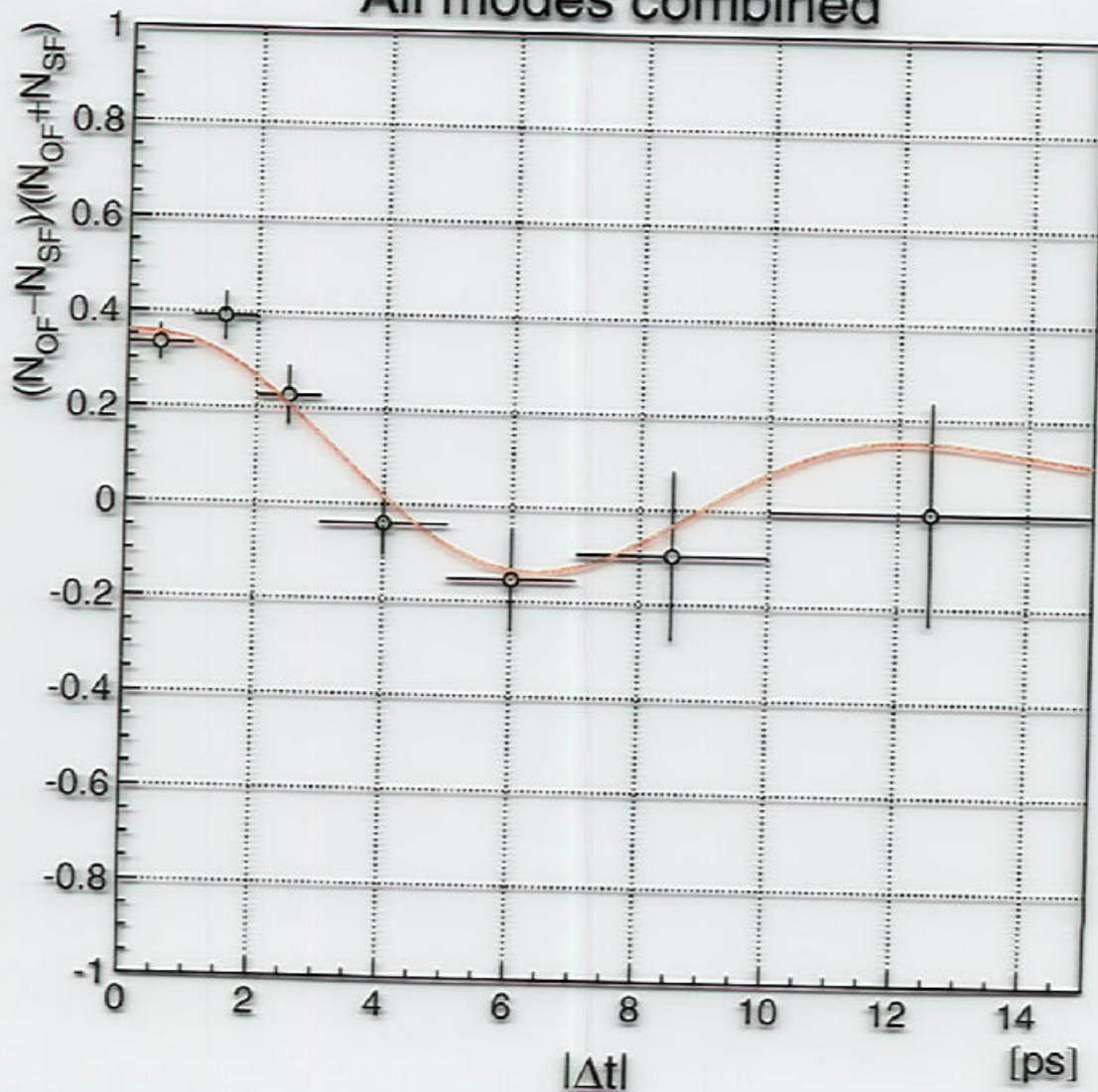


Results: Mixing using Hadronic events ($10.5 fb^{-1}$)

$$\Delta m \equiv 0.527 \pm 0.032(\text{stat}) ps^{-1}$$

Belle Preliminary

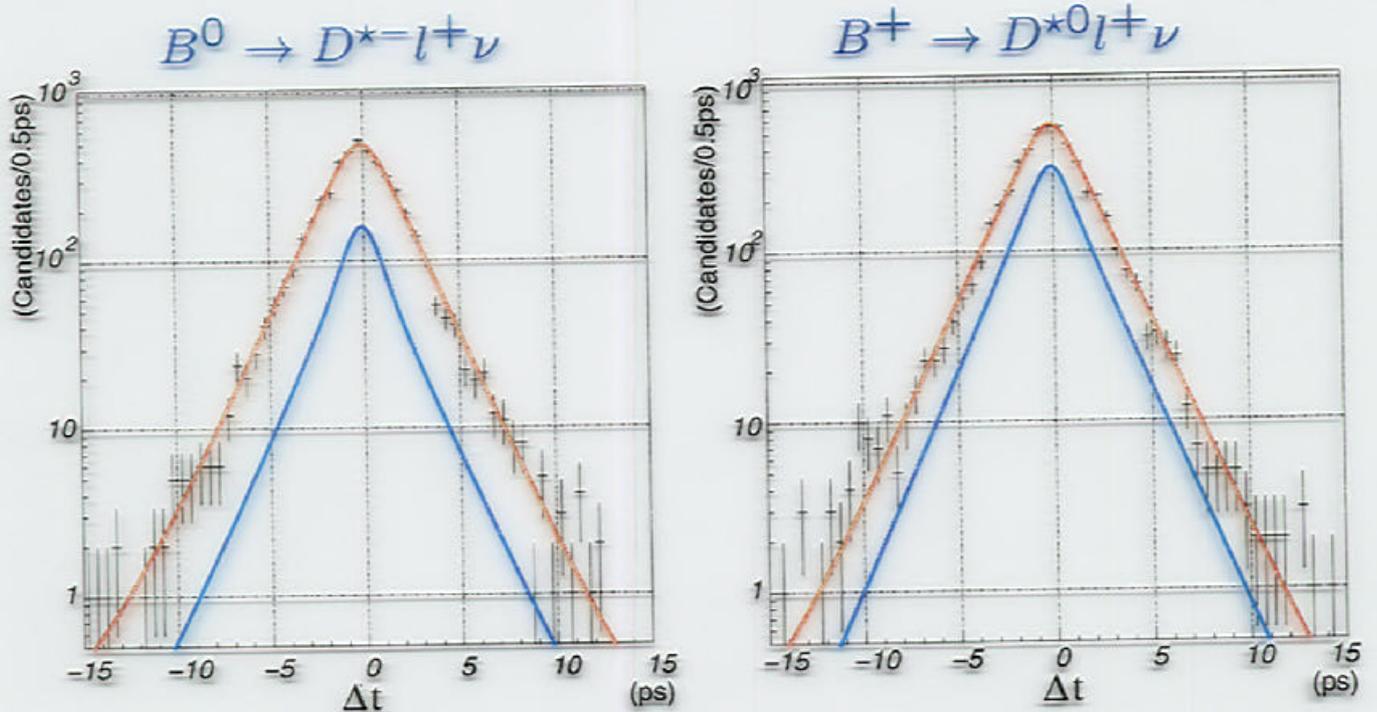
All modes combined



B meson life times

$B \rightarrow D^* l \nu$

- Reconstruction and vertexing similar to mixing analysis, but with no need to flavor tag!
- Also reconstruct charged B 's



Belle Preliminary

4636 events

$$\tau_{B^0} \equiv 1.518 \pm 0.045 \text{ ps}$$

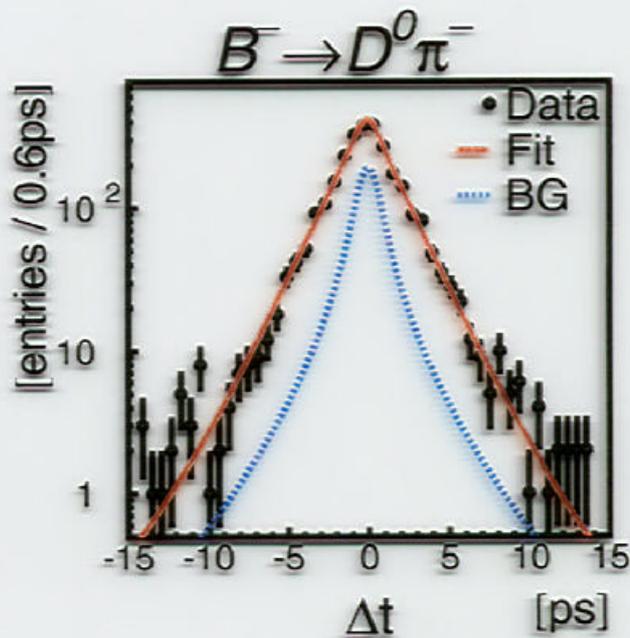
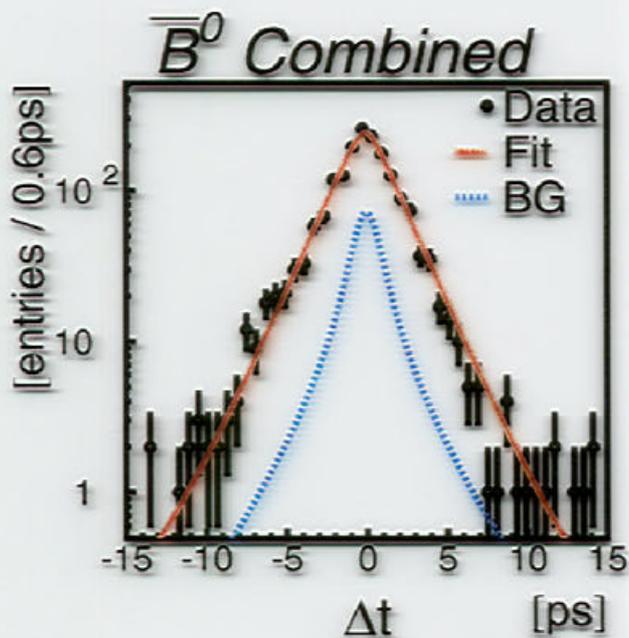
5049 events

$$\tau_{B^+} \equiv 1.628 \pm 0.060 \text{ ps}$$

B meson life times cont.

B \rightarrow Hadrons

- Again, reconstruction and vertexing similar to mixing analysis.
- Reconstruct charged B 's



Belle Preliminary

1819 events

$$\tau_{B^0} \equiv 1.585^{+0.053}_{-0.051} \text{ ps}$$

2838 events

$$\tau_{B^-} \equiv 1.679^{+0.049}_{-0.048} \text{ ps}$$



Summary Of Results

Mixing:

Method	Δm (ps^{-1})
Dilepton	$0.463 \pm 0.008 \pm 0.016$
Semileptonic	0.522 ± 0.026 (stat)
Hadronic	0.527 ± 0.032 (stat)
PDG	0.472 ± 0.17

Lifetime:

Method	τ_{B^0} (ps)	τ_{B^+} (ps)
Semileptonic	1.518 ± 0.045	1.628 ± 0.060
Hadronic	$1.585^{+0.053}_{-0.051}$	$1.679^{+0.049}_{-0.048}$
PDG	1.548 ± 0.032	1.653 ± 0.028

All lifetime errors are statistical

CPT limits from dileptons:

$$|m_{B^0} - m_{\bar{B}^0}|/m_{B^0} < 1.6 \times 10^{-14} \text{ (90\%C.L.)}$$

$$|\Gamma_{B^0} - \Gamma_{\bar{B}^0}|/\Gamma_{B^0} < 0.161 \text{ (90\%C.L.)}$$

All results other than dilepton are preliminary.

- Most precise measurement of Δm to date.
- New CPT bound.
- Precision lifetime measurements.

CPT

Remove CPT conservation constraint from $B^0\bar{B}^0$ the theoretical functions:

$$F(\Delta t) \equiv (1/4\tau_{B_d^0})e^{-|\Delta t|/\tau_{B_d^0}}[1 - \cos(\Delta m_d \Delta t)]$$

$$\bar{F}(\Delta t) \equiv (1/4\tau_{B_d^0})e^{-|\Delta t|/\tau_{B_d^0}}[1 + \cos(\Delta m_d \Delta t)]$$

they then become

$$F(\Delta t) \equiv (|\sin \theta|^2/4\tau_{B_d^0})e^{-|\Delta t|/\tau_{B_d^0}}[1 - \cos(\Delta m_d \Delta t)]$$

$$\begin{aligned} \bar{F}(\Delta t) \equiv & (1/4\tau_{B_d^0})e^{-|\Delta t|/\tau_{B_d^0}}[1 + |\cos \theta|^2 \\ & + (1 - |\cos \theta|^2) \cos(\Delta m_d \Delta t) \\ & - 2\text{Im}(\cos \theta) \sin(\Delta m_d \Delta t)] \end{aligned}$$

and χ_d becomes

$$\chi_d \equiv \frac{|\sin \theta|^2 x_d^2}{|\sin \theta|^2 x_d^2 + (2 + x_d^2 + x_d^2 |\cos \theta|^2)}$$

A non-zero value of the complex parameter $\cos \theta$ would be an indication of CPT violation.

Fit results:

$$\text{Im}(\cos \theta) \equiv 0.035 \pm 0.029(\text{stat}) \pm 0.051(\text{sys})$$

$$\text{Re}(\cos \theta) \equiv 0.00 \pm 0.15(\text{stat}) \pm 0.06(\text{sys})$$

and $\Delta m_d \equiv 0.461 \text{ ps}^{-1}$.