# Determination of $B^0$ - $\bar{B}^0$ mixing

# from the time evolution dilepton and D*lν events

# at Belle

## contributed paper #284

XXXth International Conference on High Energy Physics
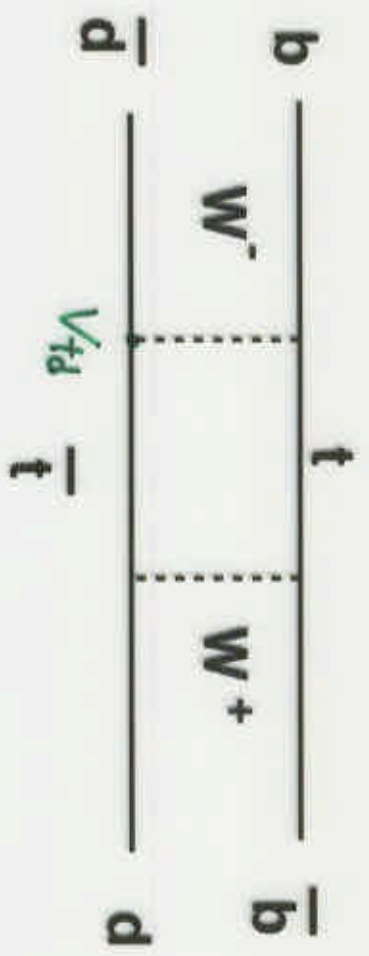
July 27 - August 2, 2000, Osaka, Japan

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Outline

1. introduction
2. Belle Detector
3. dilepton events
4. D*l ν  events
5. summary

# Introduction

Due to 2nd order weak interaction.



At proper decay time t

$$P(B^0, \overline{B^0}) = \frac{1}{2\tau} \exp(-t/\tau)(1+\cos\Delta m_d t) = P_{unmix}$$

$$P(B^0, B^0) = \frac{1}{2\tau} \exp(-t/\tau)(1-\cos\Delta m_d t) = P_{mix}$$

$$Asymmetry = \frac{P_{unmix} - P_{mix}}{P_{unmix} + P_{mix}} = \cos(\Delta m_d t)$$

$\Delta m_d$ is a fundamental parameter and is a necessary ingredient for CP measurement.

Study time evolution mixing with dilepton and D*l ν events

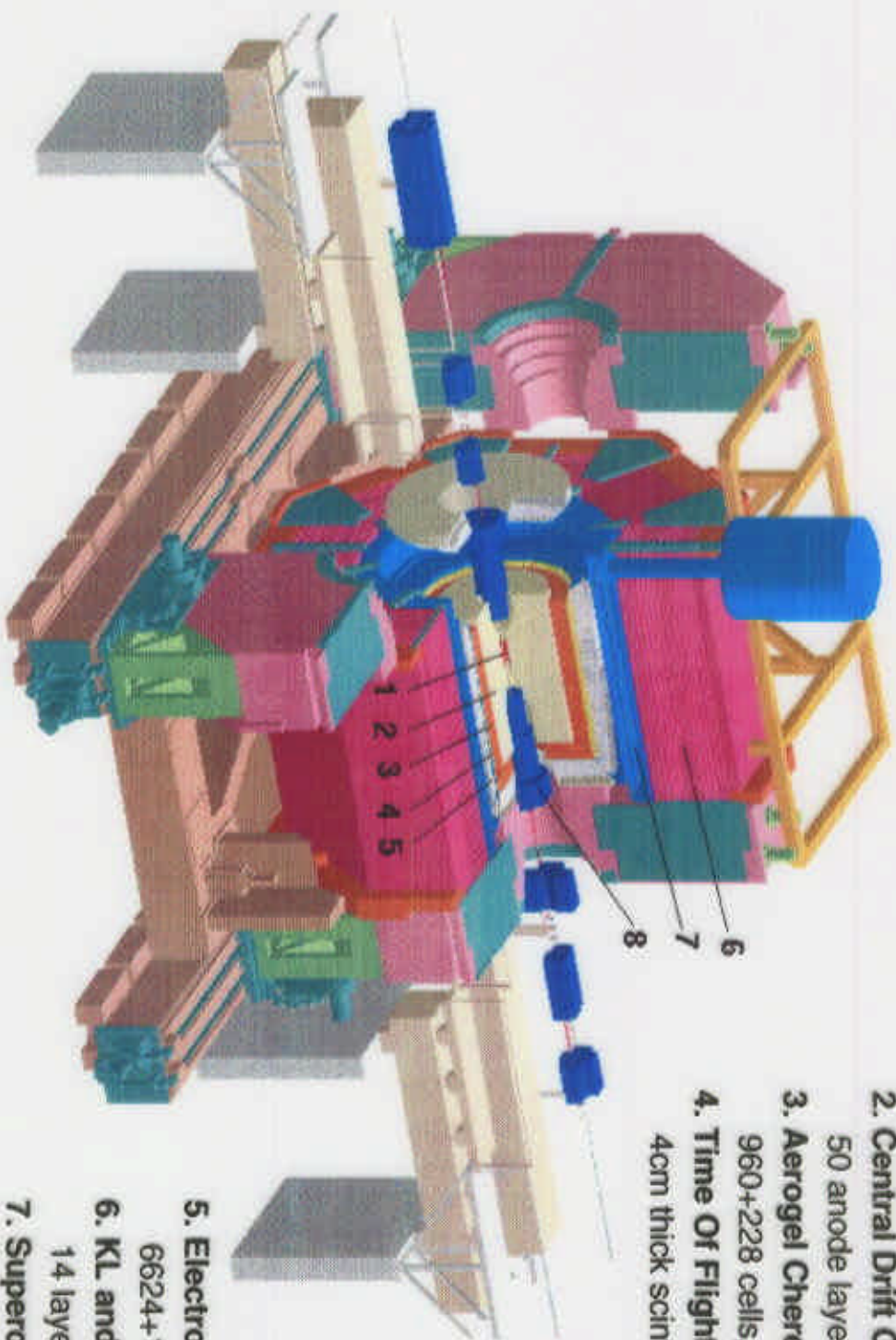8 + 3.5 GeV -> this is the first determination of $\Delta m_d$ at Υ(4S)

dilepton    high statistics, large background, large systematics

D*  l  ν    { low statistics, small background, small systematics
            { wrong flavor tag fraction. demonstration of CP analysis.

# 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.

# Mixing with Dileptons (ee, eμ, μμ)

## Event selection

|dr(IP)|<0.05cm, |dz(IP)|<2cm

$1.1 < p^* < 2.3$ GeV/c

$30 < \theta_{lab} < 150$ deg.

SVD hits: r/φ >0, z >1

$-0.8 < \cos\theta_{ll} < 0.95$

## Dilepton Events

5.1 fb$^{-1}$ data

Same Sign
    7,418 Ev

Opposite Sign
    35,633 Ev



$$\Delta t = \frac{\Delta z}{c\beta\gamma}$$
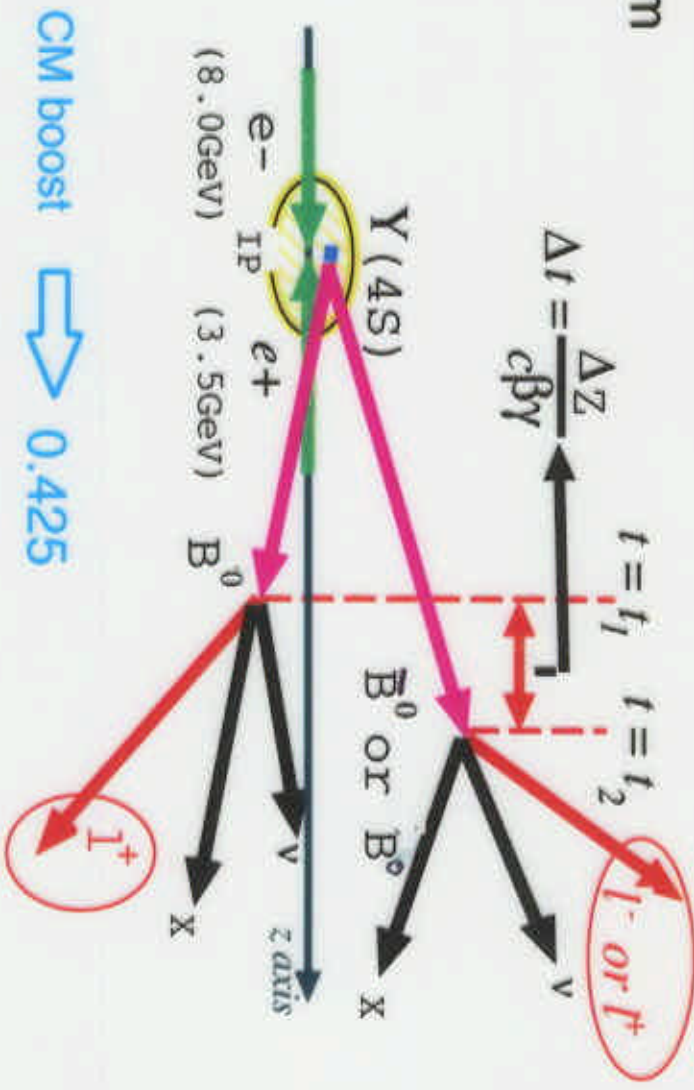
CM boost ⟹ 0.425

Lepton charge : B flavor
Lepton z-vtx : B decay time
IP-profile constrained fit

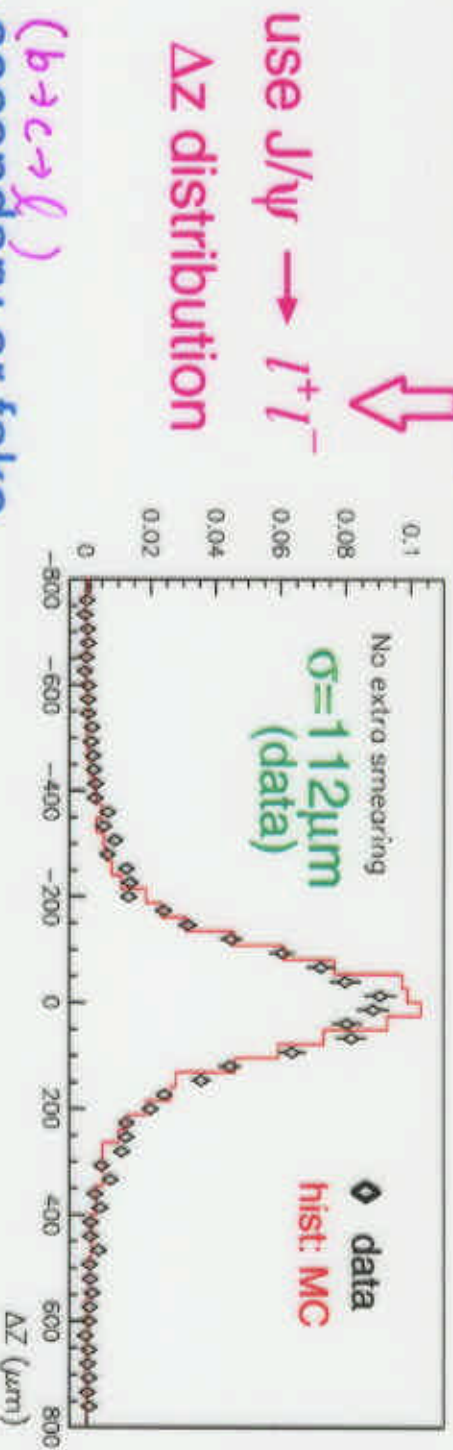# $\Delta m_d$ Determination from SS/OS Dilepton $\Delta z$ distribution

- Signal : both Primary leptons from B

  theoretical function + Response function

  use $J/\psi \longrightarrow l^+ l^-$

  $\Delta z$ distribution

  $(b \rightarrow c \rightarrow \ell\,)$



No extra smearing

$\sigma = 112\mu m$ (data)

◆ data

hist: MC

$\Delta Z\ (\mu m)$

- Background : secondary or fake

  sum of many different sources

  ⇨ use MC $\Delta z$ distributions

  + correction

  (MC - data differnece)

  resolution, fake rate, $D^0/D^+$ Br, ...

# Simultaneous Fit

to

**Same Sign**

and

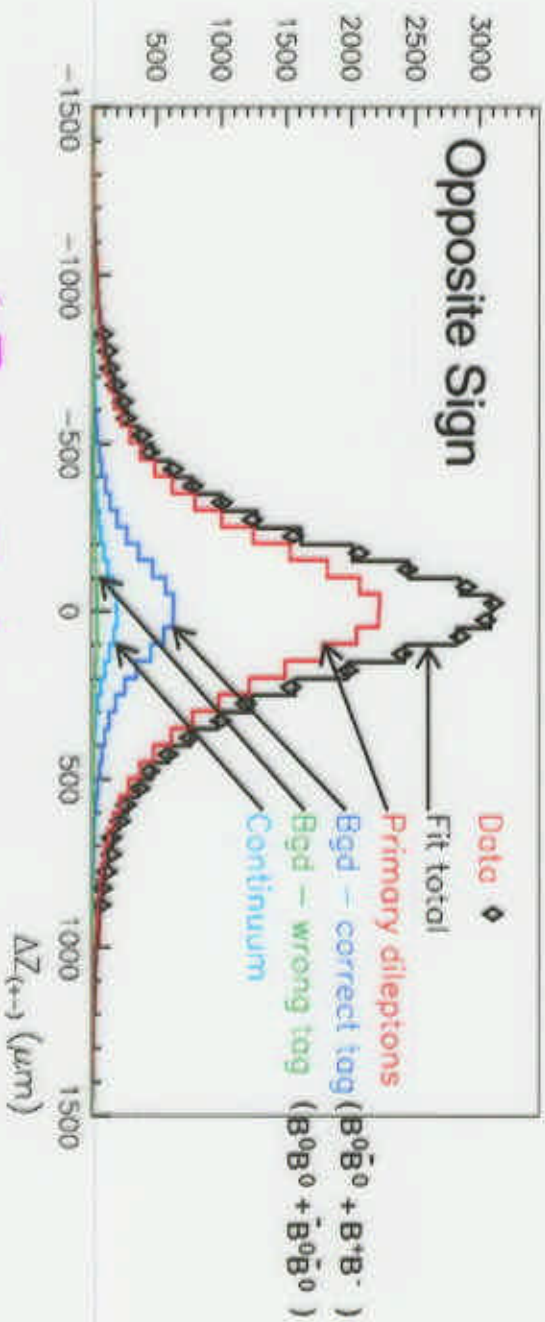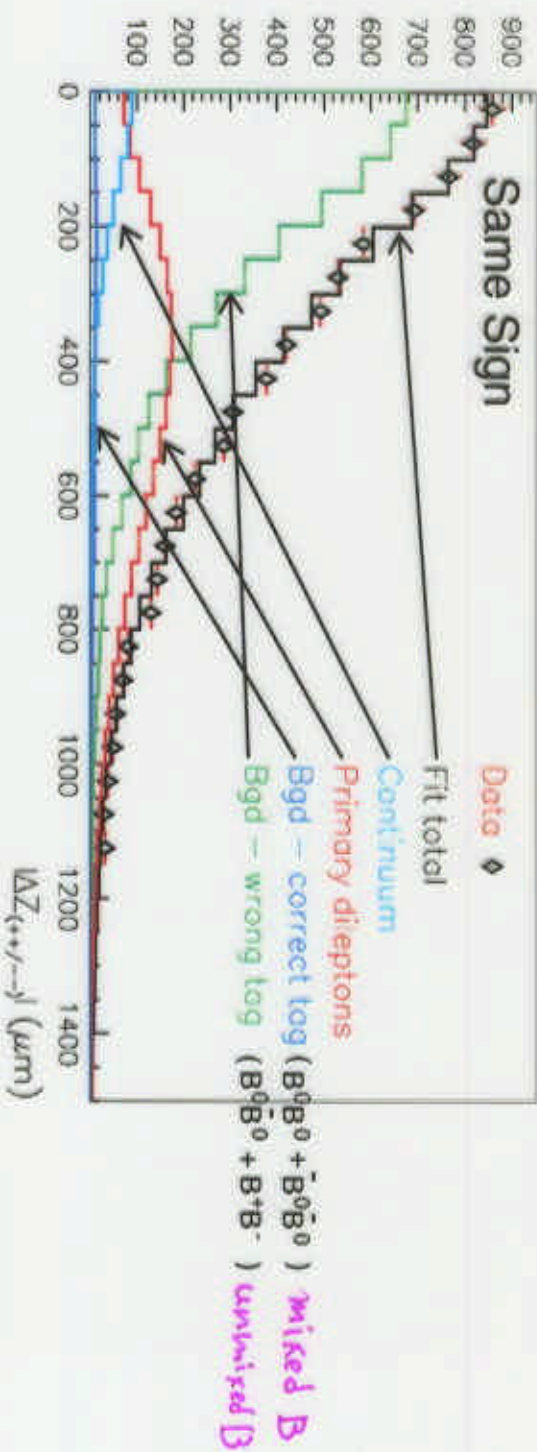**Opposite Sign**
dilepton

Δz distribution

Signal + Bkg

⇧

$\Delta m_d$

$= 0.456 \pm 0.008 \ ps^{-1}$

( + Ntot, sig/bkg )



Same Sign

Data ◇
Fit total
Continuum
Primary dileptons
Bgd – correct tag ($B^0\bar{B}^0 + \bar{B}^0 B^0$ ) *mixed B*
Bgd – wrong tag ($B^0\bar{B}^0 + B^+B^-$ ) *unmixed B*

$|\Delta z_{(++/--)}|$ $(\mu m)$

Opposite Sign

Data ◇
Fit total
Primary dileptons
Bgd – correct tag ($B^0\bar{B}^0 + B^+B^-$ )
Bgd – wrong tag ($B^0\bar{B}^0 + B^0\bar{B}^0$ )
Continuum

$\Delta z_{(+-)}$ $(\mu m)$

$\Delta z_{(+-)} = z(\ell^+) - z(\ell^-)$

# Dilepton Asymmetry

$$A(\Delta z) = \frac{N_{OS} - N_{SS}}{N_{OS} + N_{SS}}$$

**Belle Preliminary**

Dilepton asymmetry  5.1 fb$^{-1}$

$\Delta m = 0.456 \pm 0.008 \pm 0.030$  ps$^{-1}$

PDG98: $0.464 \pm 0.018$  ps$^{-1}$

A($\Delta z$)

$|\Delta Z|(\mu m)$
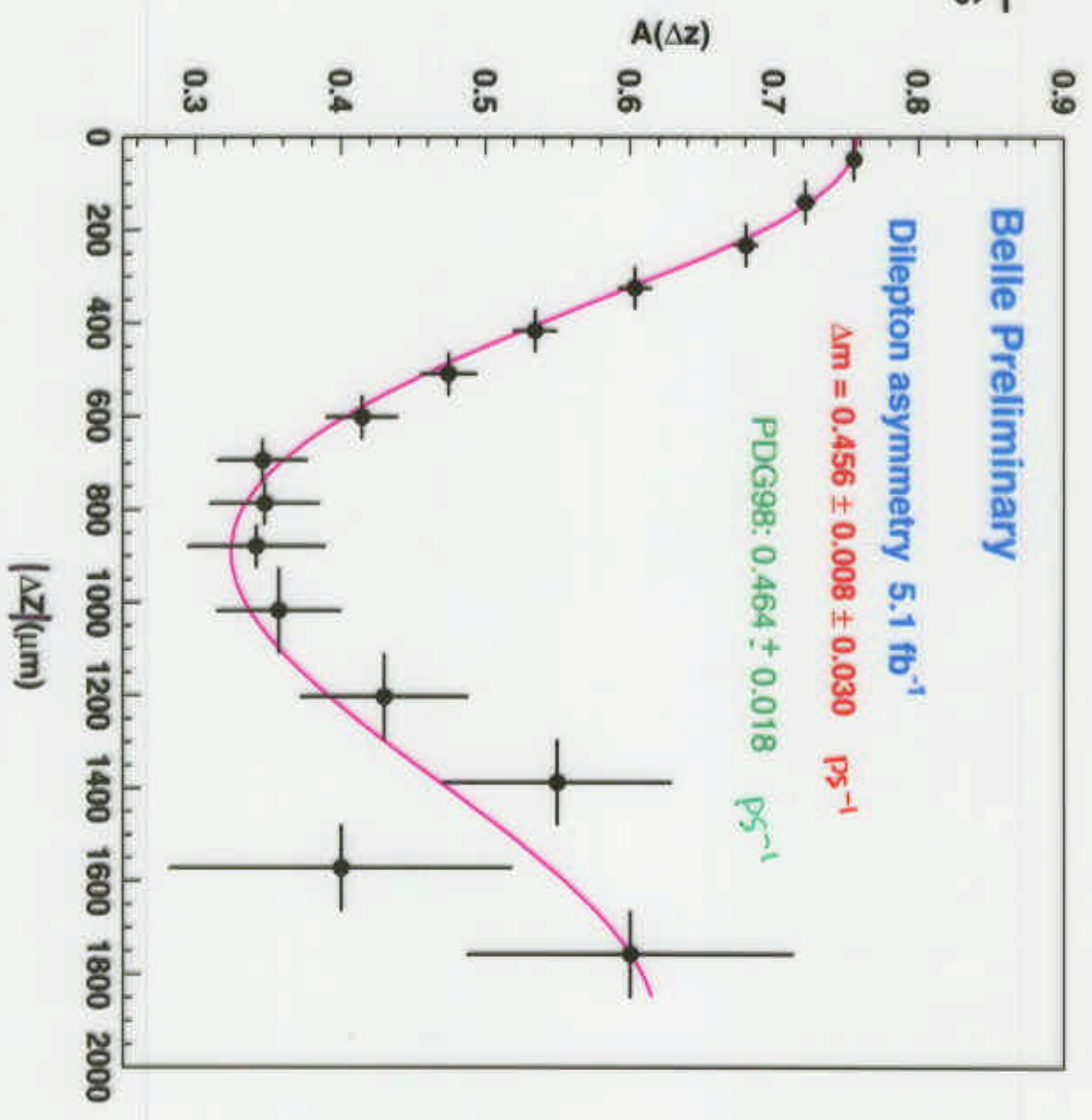
# Summary of Systematic Errors

| Source (uncertainty) | Sys. error |
|---|---|
| $f_\pm/f_0$ (1.07 ± 0.09) | ±0.012 |
| $B^0$ life time (1.56 ± 0.04) | ±0.007 |
| $\tau_{B\pm}/\tau_{B^0}$ (1.04 ± 0.04) | ±0.022 ← largest |
| Response function | ±0.011 |
| Background fake rate (±35%) | ±0.007 |
| $B \to D^0 X$ branching fraction (±4.6%) | < ±0.001 |
| $B \to D^\pm X$ branching fraction (±14.3%) | ±0.002 |
| Continuum components (± 10%) | ±0.001 |
| Background detector resolution (±18μm) | ±0.007 |
| **Total** | ±0.030 |

# D*l ν Analysis

## 1) decay mode

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

$B^0 \to D^- l^+ \nu$
   $\to K^+ \pi^- \pi^-$

**Belle preliminary**  **5.1 fb⁻¹**

## 2) flavor tagging

### i) High p* (> 1.1 GeV) Lepton

### ii) Kaons and sum up Kaon's charge

$\left( \begin{array}{l} B^0 \\ \bar{B}^0 \end{array} \right.$   if $Q(l)$ or $\Sigma\, Q(K) > 0$
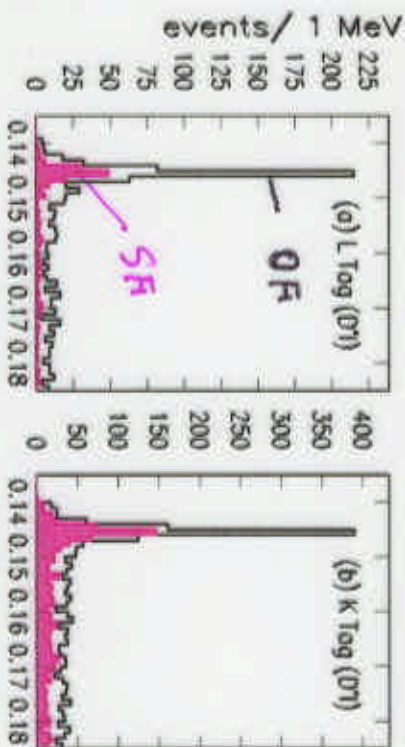
   if $Q(l)$ or $\Sigma\, Q(K) < 0$

**Classify events:**

$(B^0, B^0)(\bar{B}^0, \bar{B}^0) \to$ Same Flavor(SF)

$(B^0, \bar{B}^0)$   $\to$ Opposite Flavor (OF)
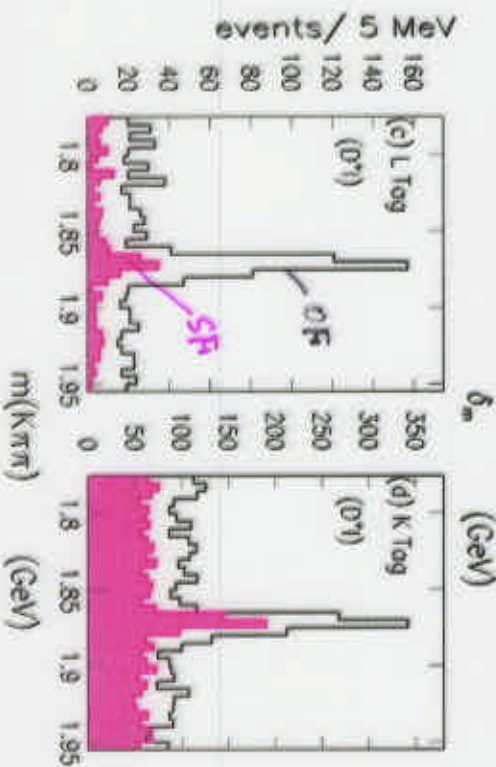
# $\Delta m_d$ Measurement

**Simultaneous Fit to OF and SF proper decay length distributions**

**Param. :$\Delta m_d$, $w_L$, and $w_K$.**

**(w is wrong tag fraction due to mis-flavor tag.)** $= \dfrac{1}{\beta\gamma}\left(Z_{D^*\ell} - Z_{tag}\right)$

$$B^0 \rightarrow D^*\ell\nu$$

$$\begin{cases} P_{OF} \propto 1 + (1 - 2w)\cos(\Delta m_d\, t) \\ P_{SF} \propto 1 - (1 - 2w)\cos(\Delta m_d\, t) \end{cases}$$
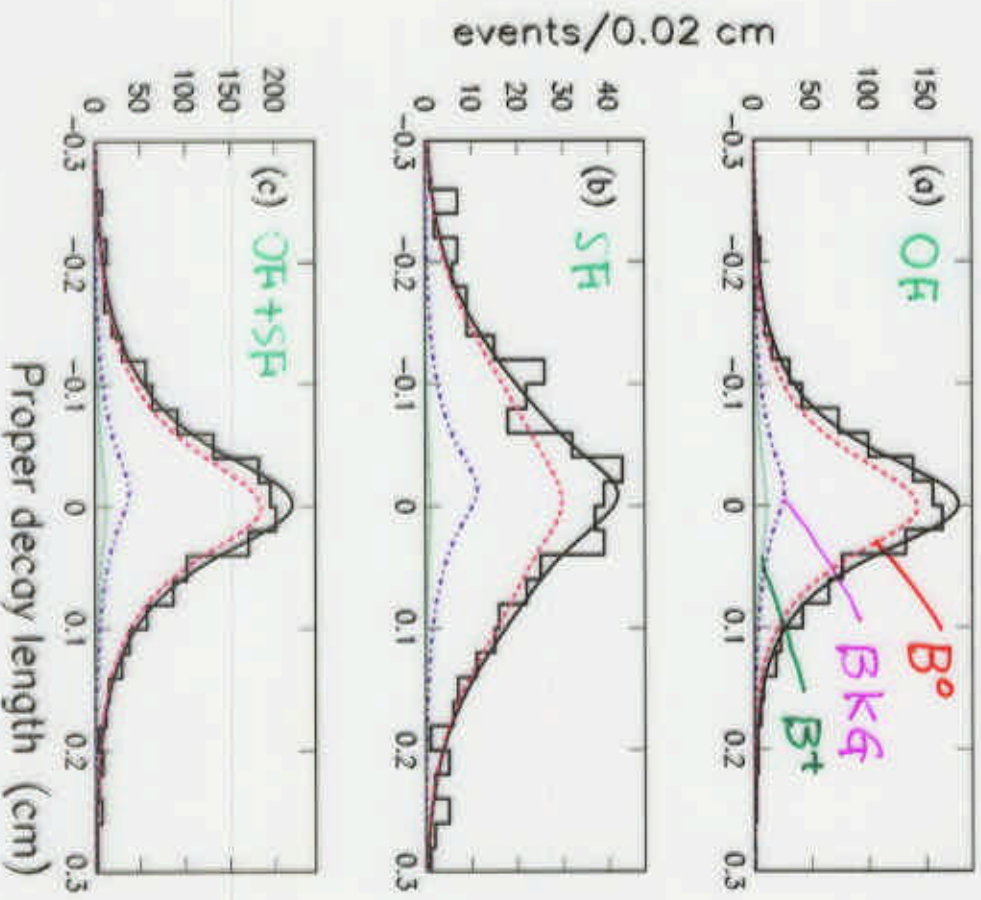
**Belle preliminary**

$\Delta m_d = 0.488 \pm 0.026(\text{stat})\ \text{ps}^{-1}$

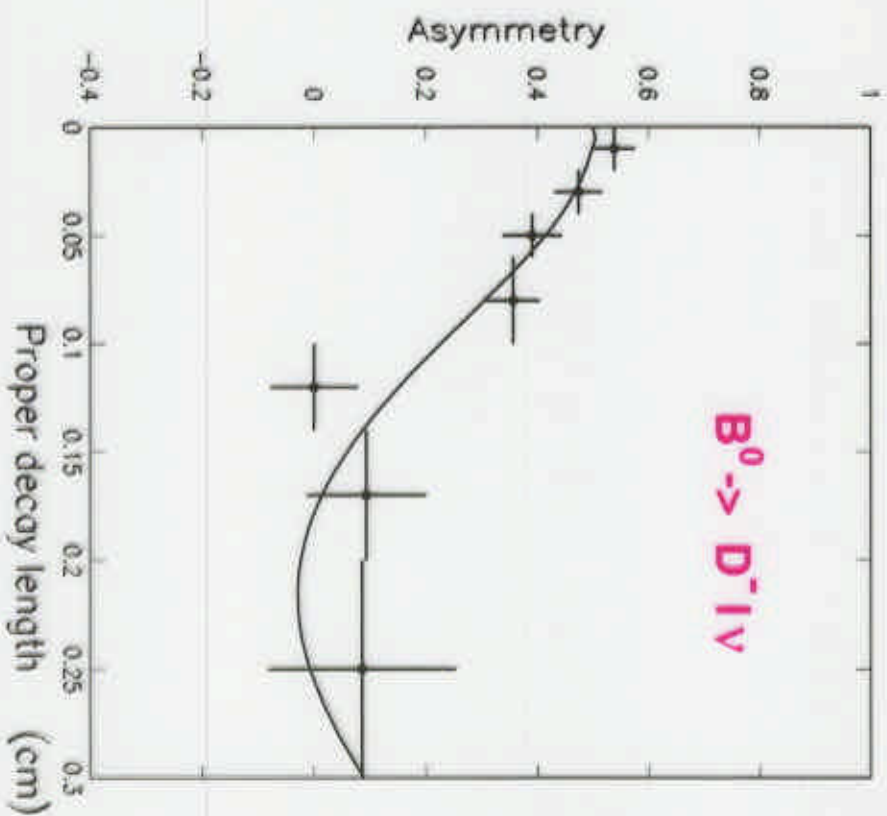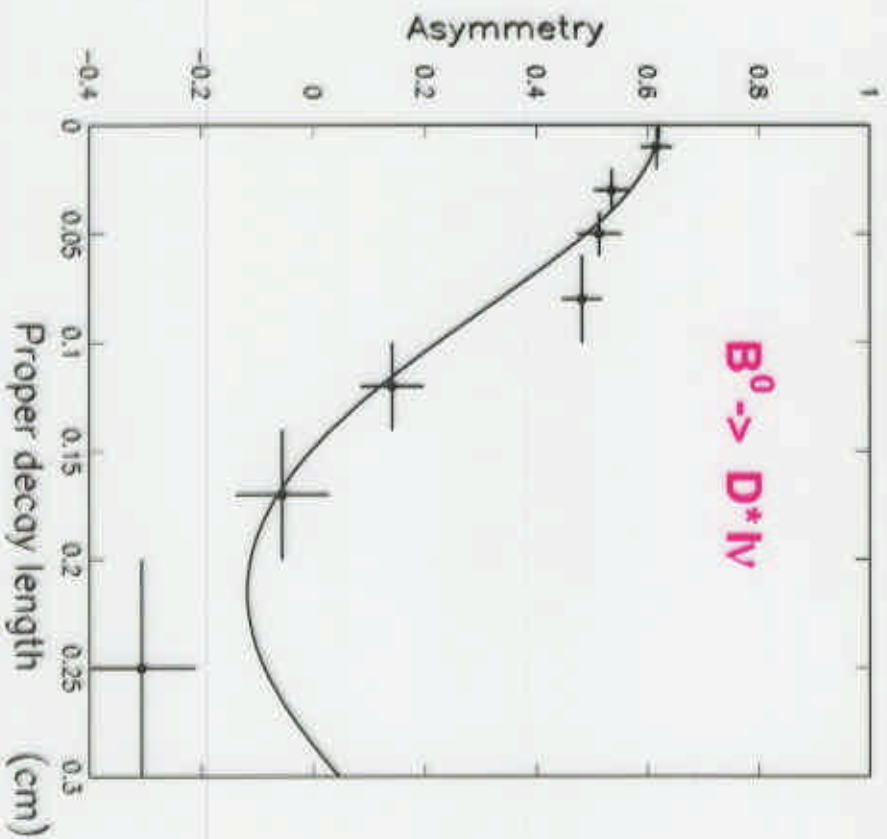$w_L = 0.07 \pm 0.02(\text{stat})$

$w_K = 0.20 \pm 0.02(\text{stat})$

**systematic uncertainty is under study.**



events/0.02 cm

(a) OF

(b) SF

(c) OF+SF

Proper decay length (cm)

Δm$_d$ Measurement

$$\text{Asymmetry} = \frac{N_{OF} - N_{SF}}{N_{OF} + N_{SF}}$$

Belle preliminary



B$^0$ -> D*lv

B$^0$ -> D$^-$ l v

## Summary

# First observation of time evolution mixing at $\Upsilon(4S)$

**Measure oscillation frequency $\Delta m_d$ in 5.1 fb$^{-1}$ :**

**i) dilepton :**

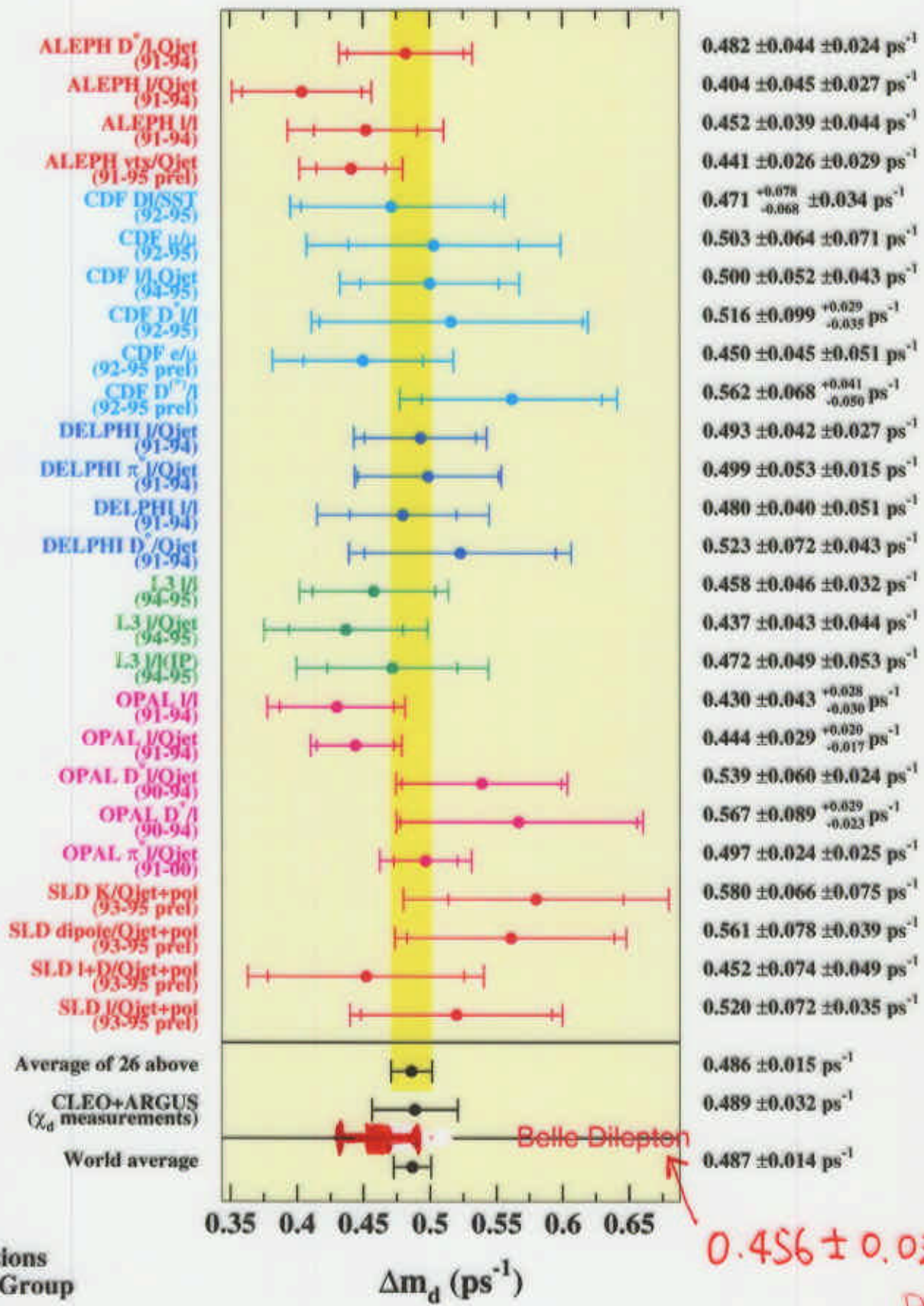$\Delta m_d = 0.456 \pm 0.008(stat) \pm 0.030 \ (syst) \ ps^{-1}$(preliminary)

systematic uncertainty is assigned conservatively.

we will be able to reduce it with further study.

**ii) B->D*l $\nu$ :**

$\Delta m_d = 0.488 \pm 0.026(stat) \ ps^{-1} \ $ (preliminary)

systematic uncertainty is under study.