B and *D* Meson Lifetime Measurements with Belle

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Outline

- Physics background.
- *D* lifetime measurements.
  - » Reconstruction.
  - » Lifetime fit.
- *B* lifetime measurements.
  - » Reconstruction.
  - » Lifetime fit.
- Summary

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Physics Background

Lifetime Physics.

- Theoretical inputs to understand non-perturbative QCD in the heavy quark decay.
  - » Annihilation process, W-exchange
    - Theoretical challenge to explain $\tau(D_s)/\tau(D^0)\approx 1.21\pm 0.02$

Mixing

- Difference of lifetime between flavor specific mode and CP mode gives mixing parameter, y_{CP}.

$$y_{CP}=\frac{\Delta\Gamma}{\Gamma}=\frac{\Gamma(\mathrm{CPeven})-\Gamma(\mathrm{CPodd})}{\Gamma(\mathrm{CPeven})+\Gamma(\mathrm{CPodd})}$$

$$=\frac{\tau(D^0\to K^-\pi^+)}{\tau(D^0\to K^-K^+)}-1\approx y\cos\phi+\frac{A_{mix}}{2}x\sin\phi$$

$$=1-\frac{\tau(\overline{B}^0\to D^{*+}\ell\upsilon,D\pi)}{\tau(\overline{B}^0\to\psi K_S)}\approx y\cos 2\phi_1$$

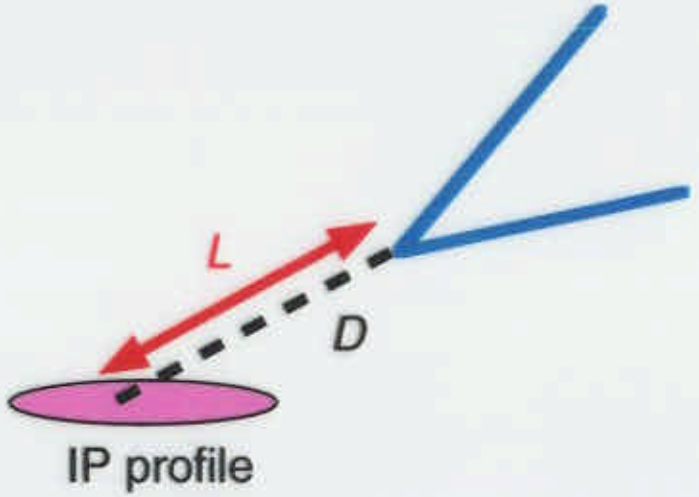
- Analysis is based on 2.75 fb-1 (*D* lifetime analysis), 5.1fb-1 (*B* lifetime analysis).

All results are preliminary.

D Proper-time Reconstruction

Reconstruction.

- Reconstruct specific *D* decay modes.
  - » $D^0 \to K^-\pi^+$, K^-K^+, $D^+ \to K^-\pi^+\pi^+$, $\phi\pi^+$, $D_s^+ \to \phi\pi^+$, $K^{*0}K^+$.
  - » Obtain decay vertex point.
- Reconstruct *D* production point.
  - » Pseudo *D* track and IP profile.
- Calculate proper time.
  - » $\tau = L^* m(D)/c^* p_D$



D Lifetime Fit

Event by event P.D.F. (probability density function).

$$P(t) = f_{SIG}\int_0^\infty dt' \frac{1}{\tau_{SIG}} e^{-t'/\tau_{SIG}} R_{SIG}(t-t') \qquad \text{Signal term}$$

$$+ (1-f_{SIG})\int_0^\infty dt' [f_{\tau BG}\frac{1}{\tau_{BG}} e^{-t'/\tau_{BG}} + (1-f_{\tau BG})\delta(t')] R_{BG}(t-t'), \qquad \text{Background term}$$

$$R(x) = (1-f_{tail})\cdot G(x; S\sigma_t) + f_{tail}\cdot G(x; S_{tail}\sigma_t),$$

$$G(x;\sigma) \equiv \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}},$$

» τ_D: *D* lifetime.

» f_{sig}(*D* mass): signal probability calculated event by event.

» τ_{BG}: Lifetime of BG component.

» $f_{\tau BG}$: Fraction of BG with lifetime.

- Resolution function = $(1\text{-}f_{tail})^{*}G(S^{*}\sigma_\tau) + f_{tail}{}^{*}G(S_{tail}{}^{*}\sigma_\tau)$

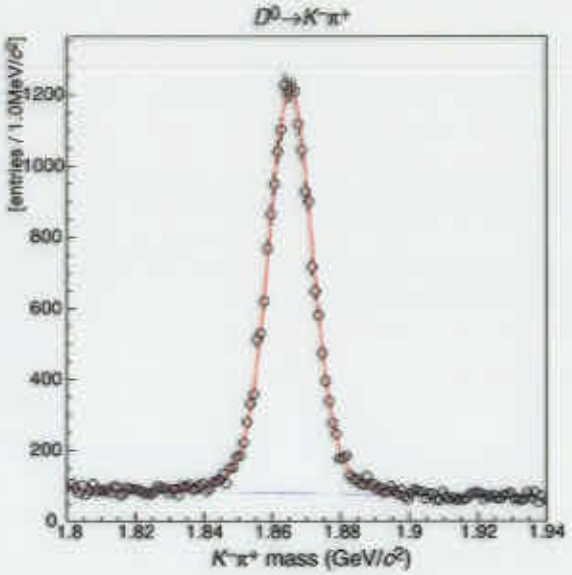
» σ_τ: Error of proper-time calculated from track error event by event.

» S, S_{tail}: Global scaling factors.

» f_{tail}: Fraction of the tail part.

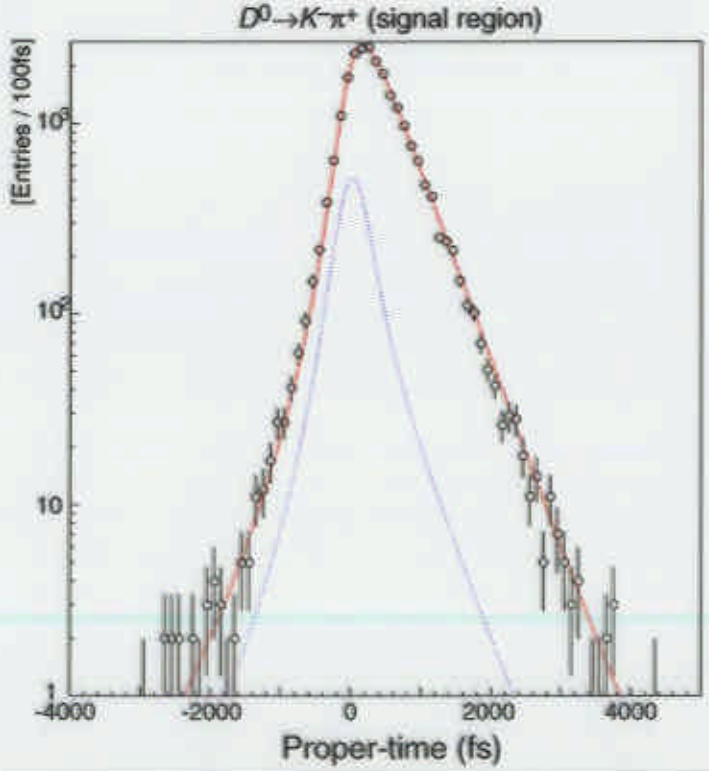
- Free parameters: τ_D, τ_{BG}, $f_{\tau BG}$, S, S_{tail}, f_{tail}, $(S, S_{tail}, f_{tail})_{BG}$

$D^0 \to K^- \pi^+$ Lifetime Fit

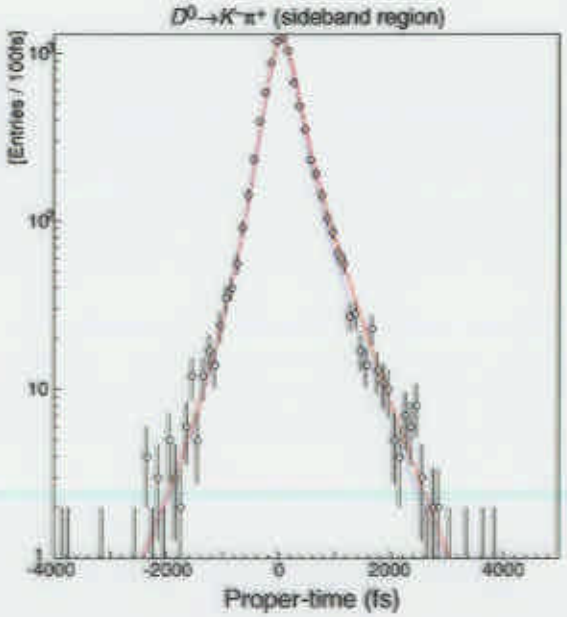


$\tau_D = (414.8 \pm 3.8 \pm 3.4)$ fs

Signal region (<3σ)

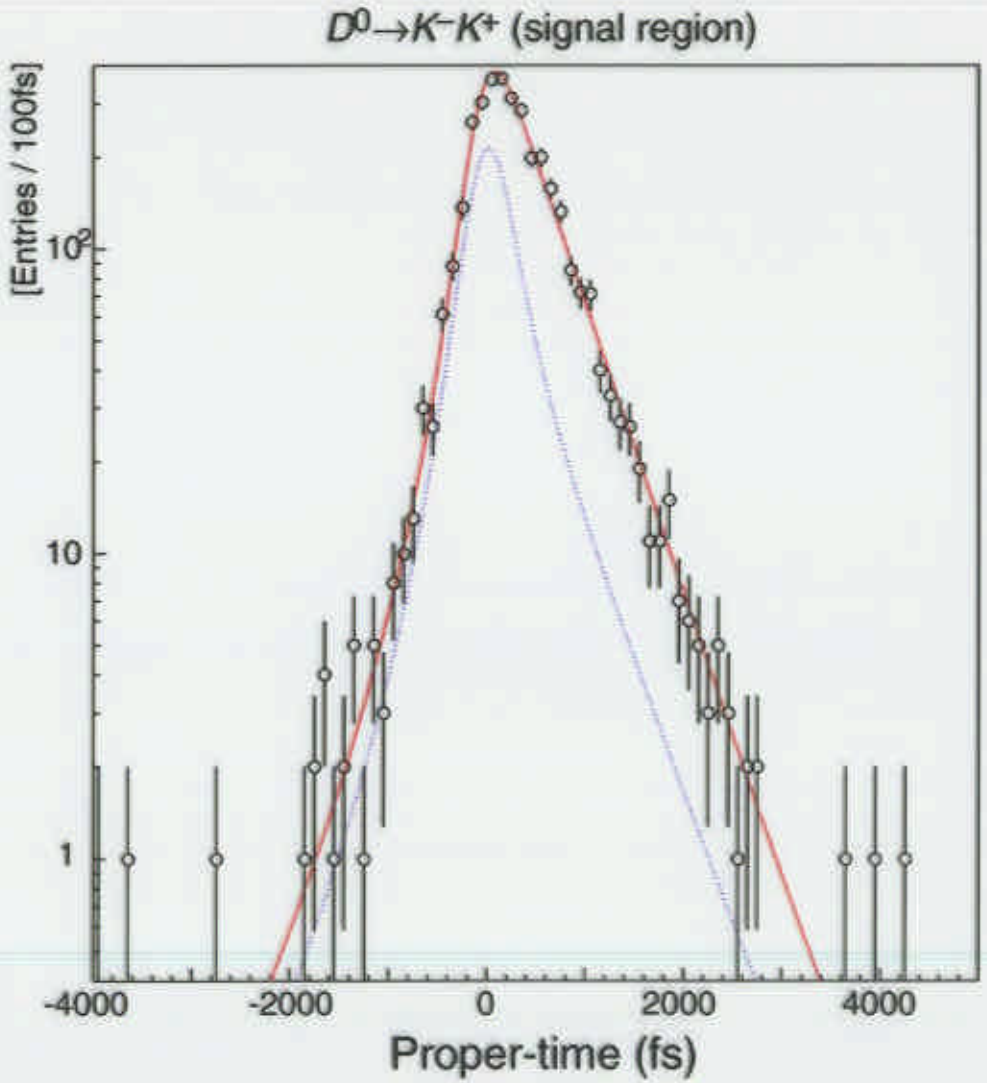


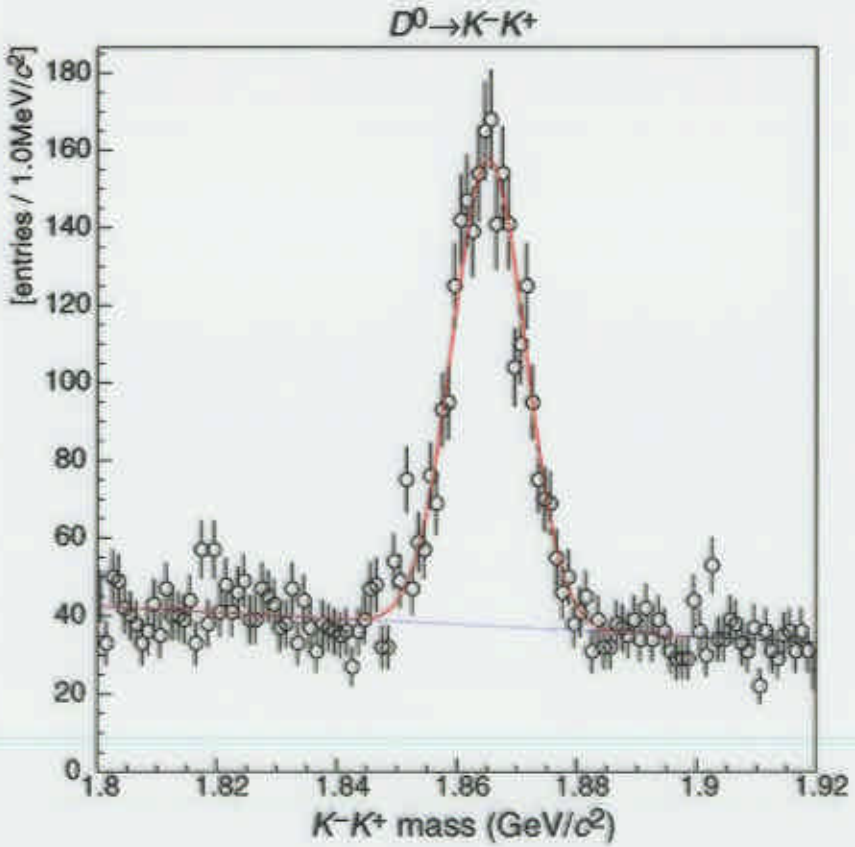
BG region (>3σ)



$D^0 \to K^- K^+$ Lifetime Fit

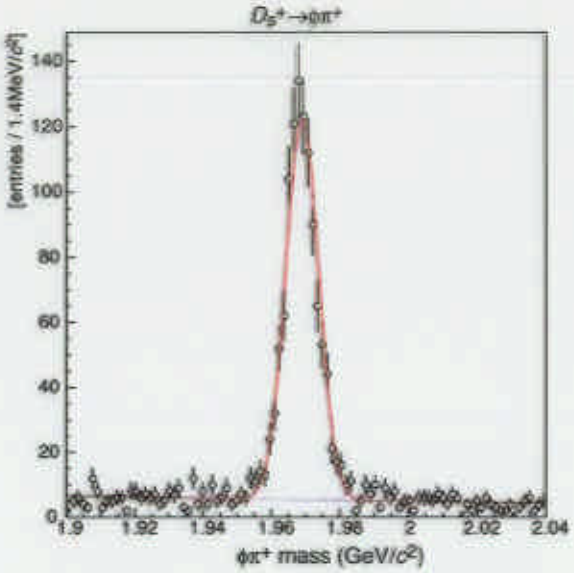
$\tau_D = (411 \pm 14^{+10}_{-6})$ fs

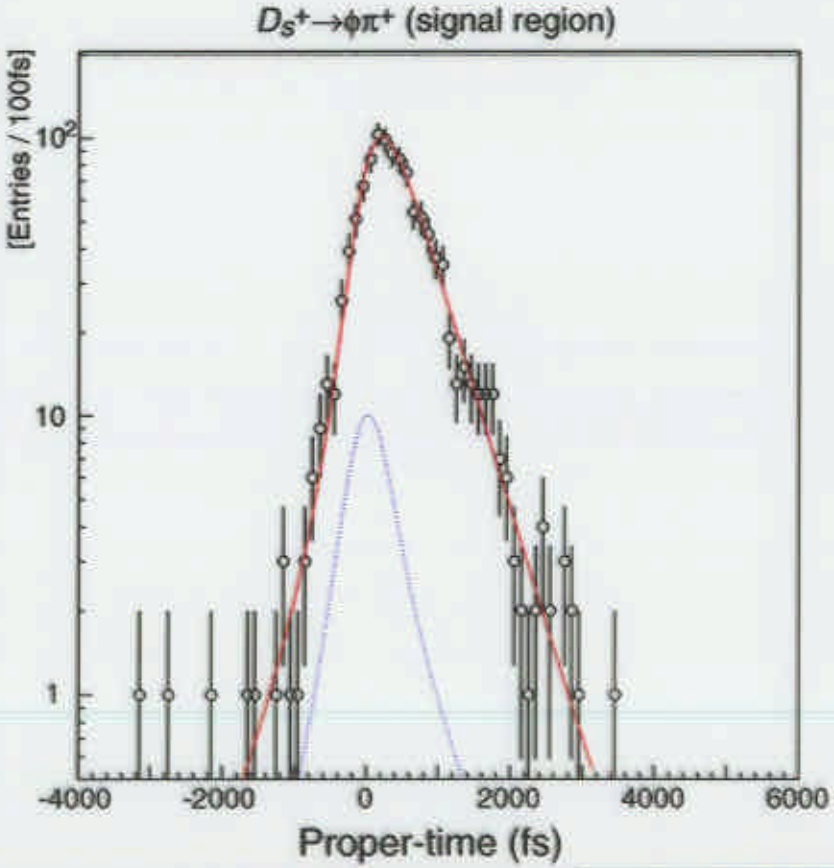




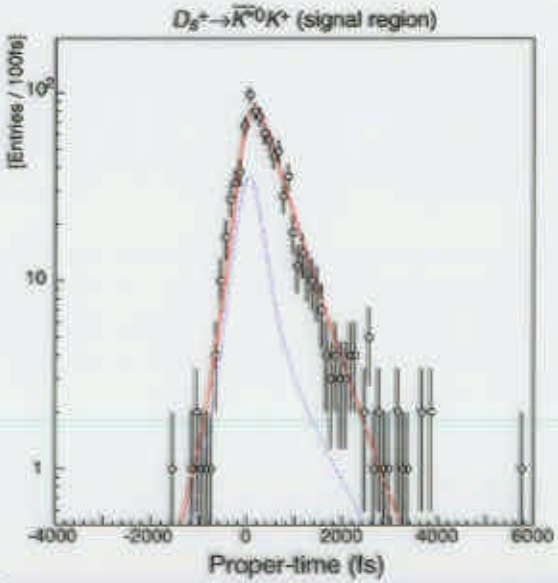
D_s^+ Lifetime Fit

$\tau_D = 470 \pm 19^{+8}_{-7}$ fs

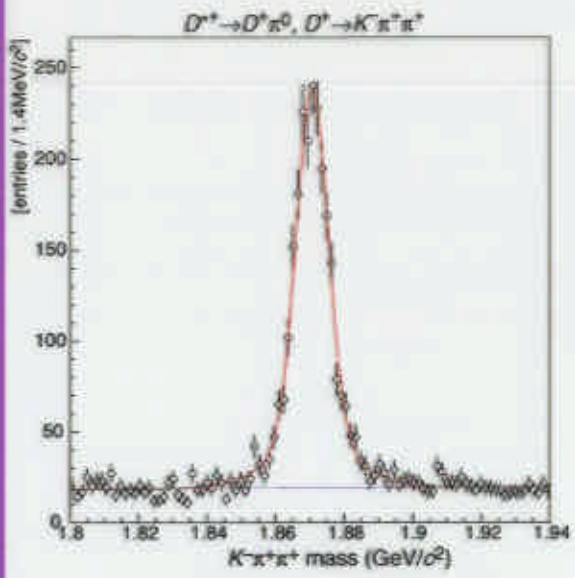




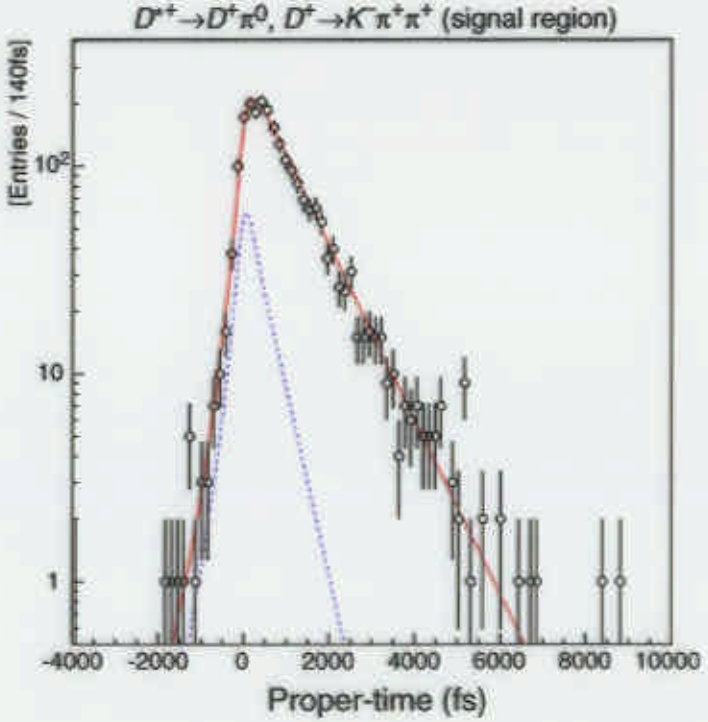
$\tau_D = 505^{+34+6}_{-33-12}$ f



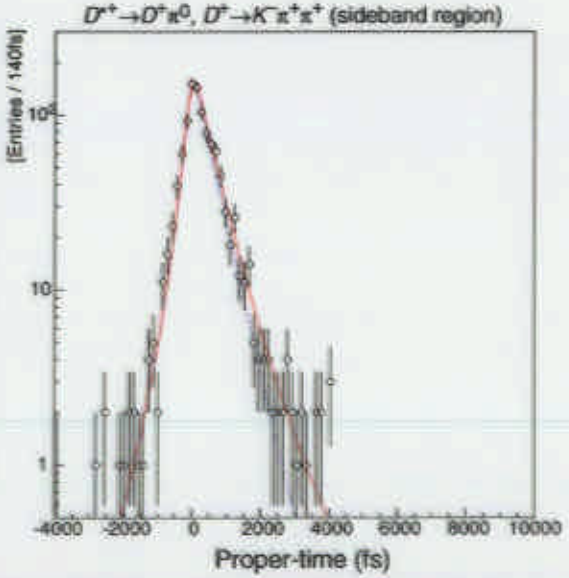
D^+ Lifetime Fit

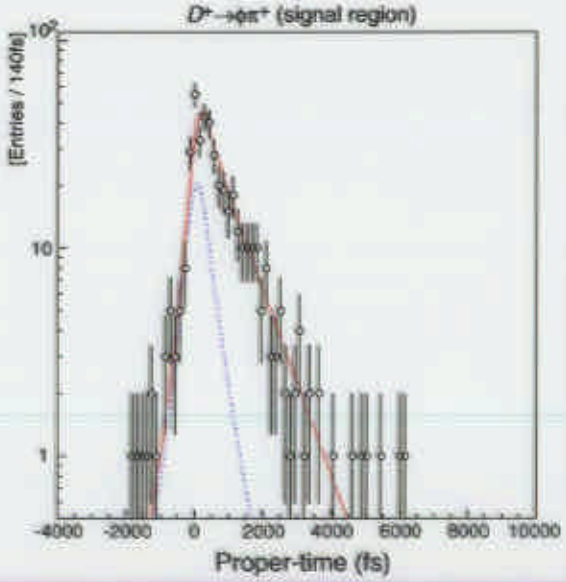


$\tau_D = 1049^{+25+16}_{-24-19}$



$\tau_D = 974^{+68+26}_{-62-18}$ fs





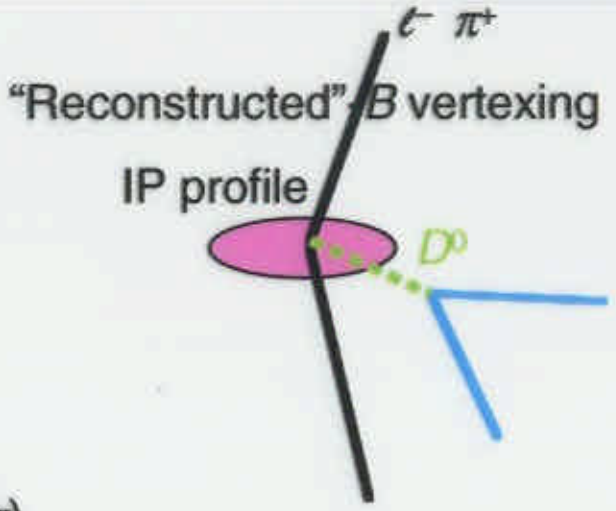
Systematic Error

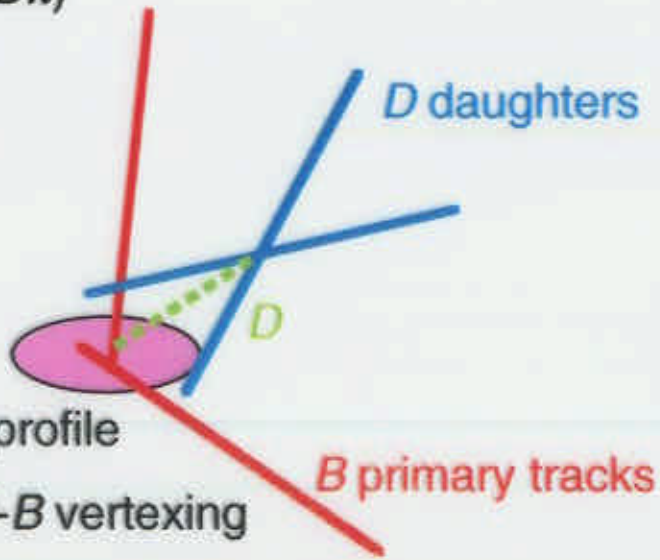
Source	$D^0 \to K^-\pi^+$	$D^0 \to K^-K^+$	$D_s^+ \to \phi\pi^+$	$D^+ \to K^-\pi^+\pi^+$
IP	$^{+0.2}_{-0.3}$	$^{+1.3}_{-0.4}$	$^{+1.0}_{-1.6}$	$^{+10}_{-13}$
Efficiency	± 1.8	± 1.8	± 2.1	± 8
Vertexing cuts	± 1.0	± 2.2	$^{+3.3}_{-0.5}$	$^{+7}_{-3}$
Decay vertex	± 1.9	± 1.8	± 2.0	± 2
Resolution function	$^{+1.5}_{-1.7}$	$^{+3.4}_{-3.6}$	± 1.9	$^{+3}_{-2}$
Background fraction	$^{+1.0}_{-0.4}$	$^{+8.3}_{-3.1}$	$^{+1.5}_{-2.8}$	$^{+6}_{-10}$
D-mass sideband region	$^{+0.0}_{-0.6}$	$^{+0.0}_{-1.1}$	$^{+0.0}_{-0.6}$	$^{+1}_{-2}$
Total	± 3.4	$^{+9.7}_{-5.9}$	$^{+5.1}_{-7.0}$	$^{+16}_{-19}$

B Proper-time Reconstruction

Reconstruction.

- Reconstruct specific *B* decay modes.
  - » $\overline{B^0}\to D^{*+}\ell^-\nu$, $(D^{*+}\to D^0\pi^+, D^0\to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-)$
  - » $B^-\to D^{*0}\ell^-\nu$, $(D^{*0}\to D^0\pi^0, D^0\to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-)$
  - » $\overline{B^0}\to D^{*+}\pi^-$, $B^0\to D^+\pi^-$, $B^-\to D^0\pi^-$, $(D^+\to K^-\pi^+\pi^+)$
  - » $\overline{B^0}\to\psi K_S$, $\overline{B^0}\to\psi K^{*0}$, $B^-\to\psi K^-$
  - » Obtain decay vertex point.
- Reconstruct *B* decay point.
  - » Lepton track, Pseudo *D* track and IP profile ($D^{*+}\ell^-\nu$, $D\pi$)
  - » Two lepton tracks (ψK)
  - » IP constraint fit.
    - IP profile is smeared by *B* flight length in xy plane.
- Reconstruct "tagging"-side *B* vertex.
  - » No flavor tag.
  - » IP constraint fit.
- Calculate proper time.
  - » $\Delta\tau=\Delta z/c\beta\gamma$





B Lifetime Fit

Event by event P.D.F. (probability density function).

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

Signal term — Background term

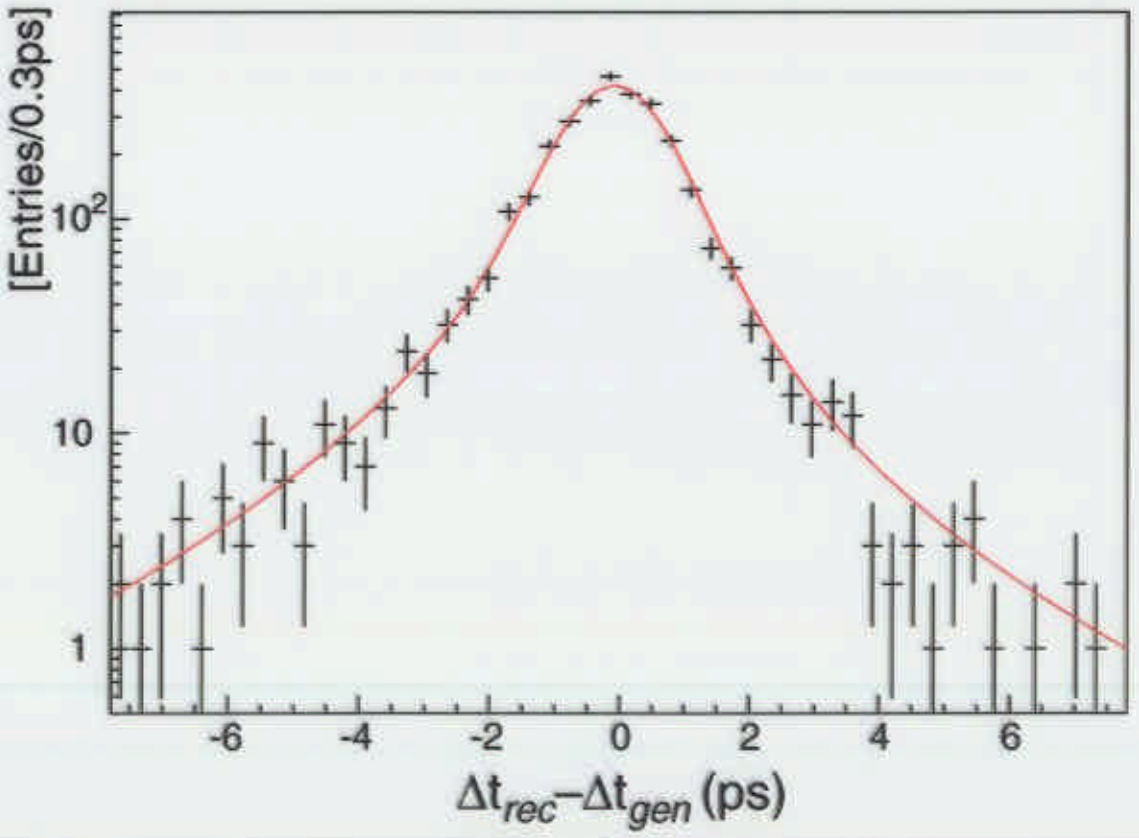
- » τ_B: B lifetime.
- » f_{sig}: signal probability calculated event by event. (ΔM, or ΔE-Mb sideband)
- » τ_{BG}: Lifetime of BG component.
- » $f_{\tau BG}$: Fraction of BG with lifetime.

- ◆ $R_{SIG} = (1-f_{tail})^* G(\mu, S^*\sigma_{\Delta\tau}) + f_{tail}^* G(\mu_{tail}, S_{tail}^*\sigma_{\Delta\tau})$
  - » μ: Mean value shift of $\Delta\tau$ (due to charm contribution).
  - » $\sigma_{\Delta\tau}$: Error of proper-time calculated from error matrix event by event.
  - » S: Global scaling factor (obtained from D^0 data sample).
  - » S_{tail}: Scaling factor for the tail part of the resolution function.
    - Hard scattering, mis-association of SVD hits.
  - » f_{tail}: Fraction of the tail part.
- ◆ Free parameters: τ_B, τ_{BG}, $f_{\tau BG}$, S_{tail}, f_{tail}

Resolution Function

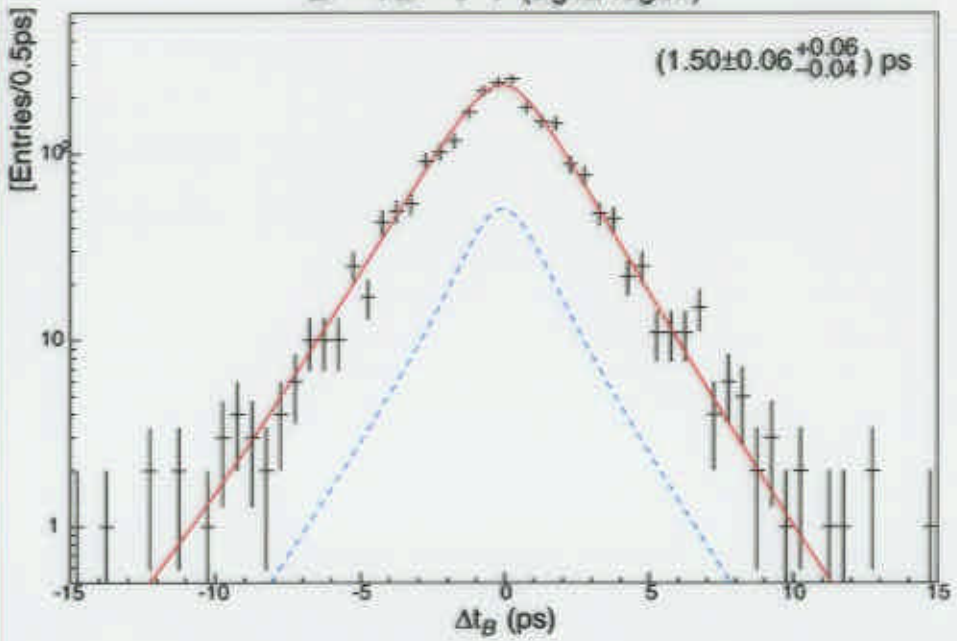
Resolution function

- Sum of many Gaussian.
- Utilize the vertex error calculated from track error.
  - » It can incorporate event by event resolution difference.
- Use larger scaling factor for the vertex with $\chi^2/n>3$.

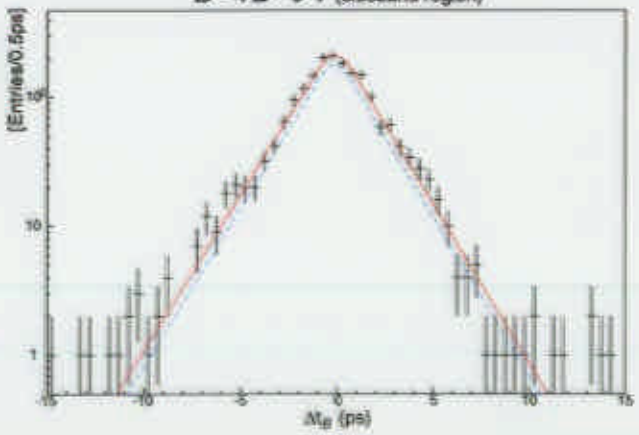


$B \to D^* \ell \nu$ Lifetime Fit

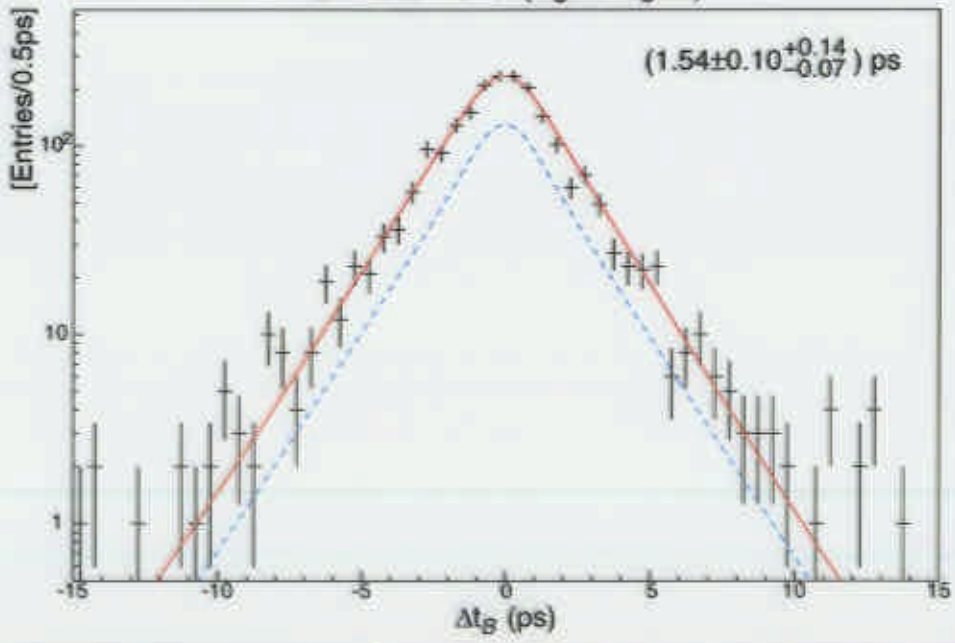
$\overline{B^0} \to D^{*+} \ell^- \nu$ (signal region)



$\overline{B^0} \to D^{*+} \ell^- \nu$ (sideband region)

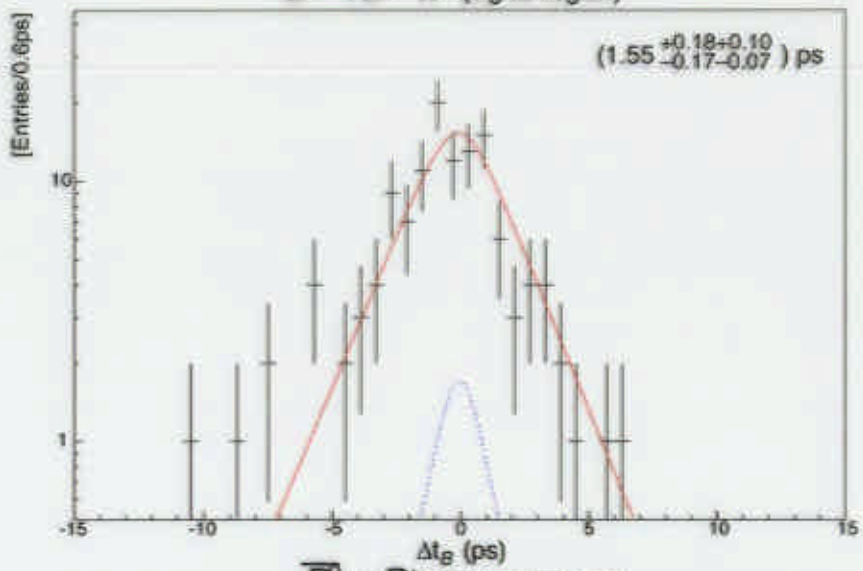


$B^- \to D^{*0} \ell^- \nu$ (signal region)

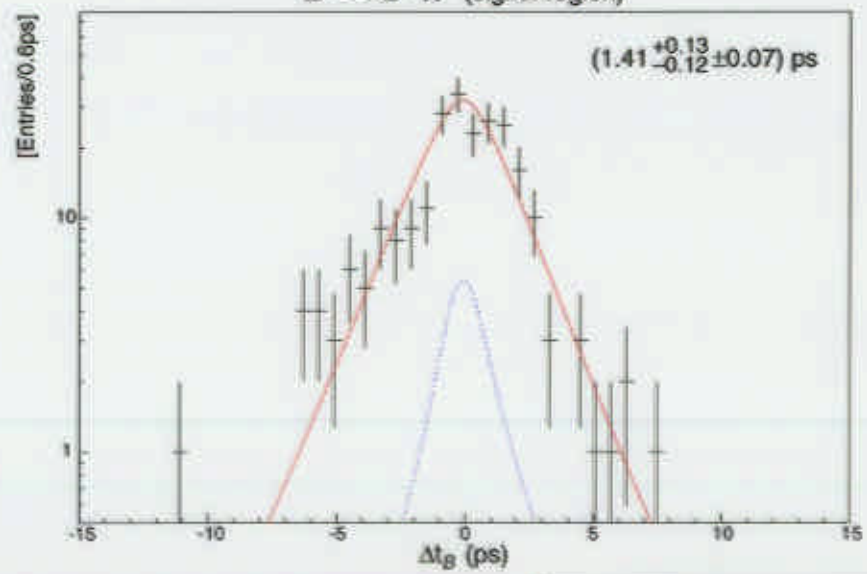


$B \to D\pi$ Lifetime Fit

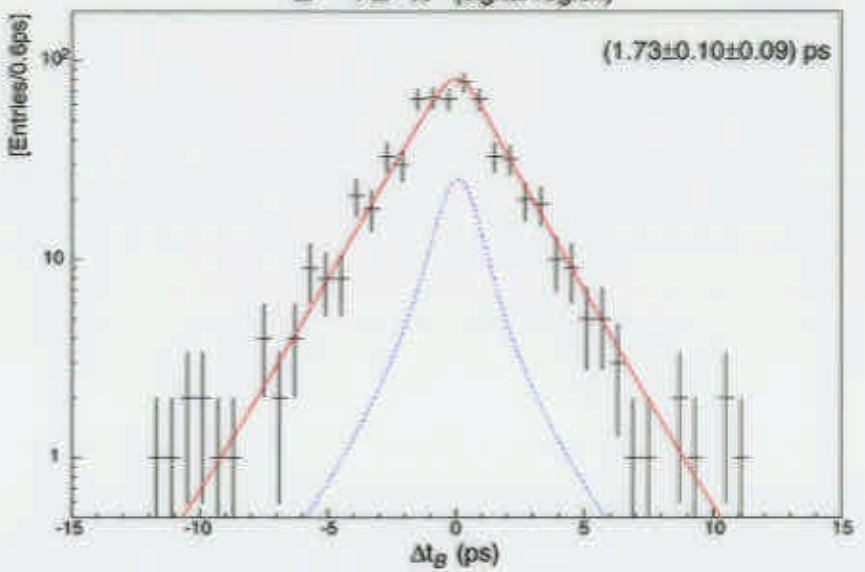
$\overline{B^0} \to D^{*+}\pi^-$ (signal region)



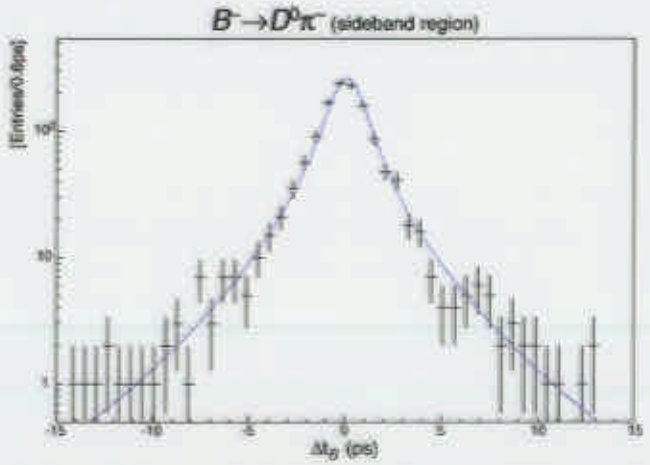
$\overline{B^0} \to D^{+}\pi^-$ (signal region)



$B^- \to D^0\pi^-$ (signal region)

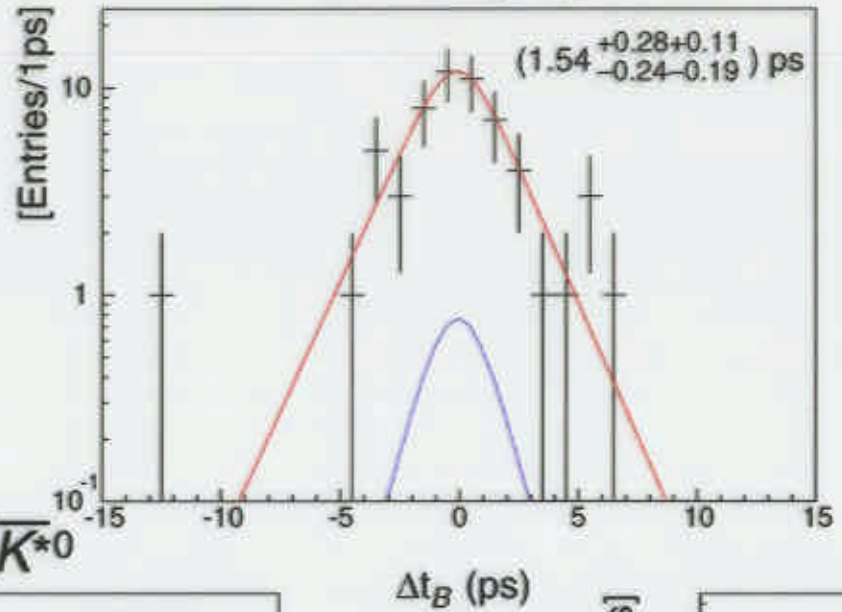


$B^- \to D^0\pi^-$ (sideband region)

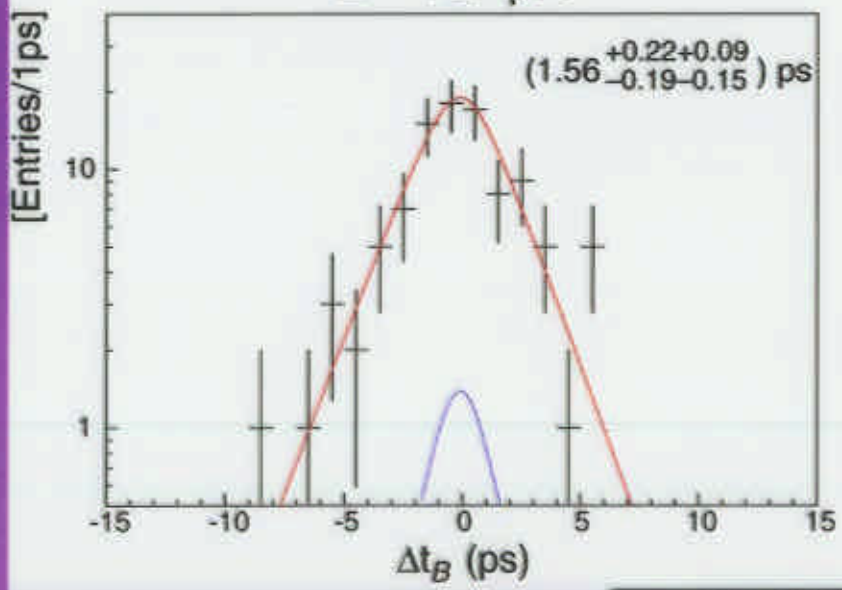


$B \to \psi K$ Lifetime Fit

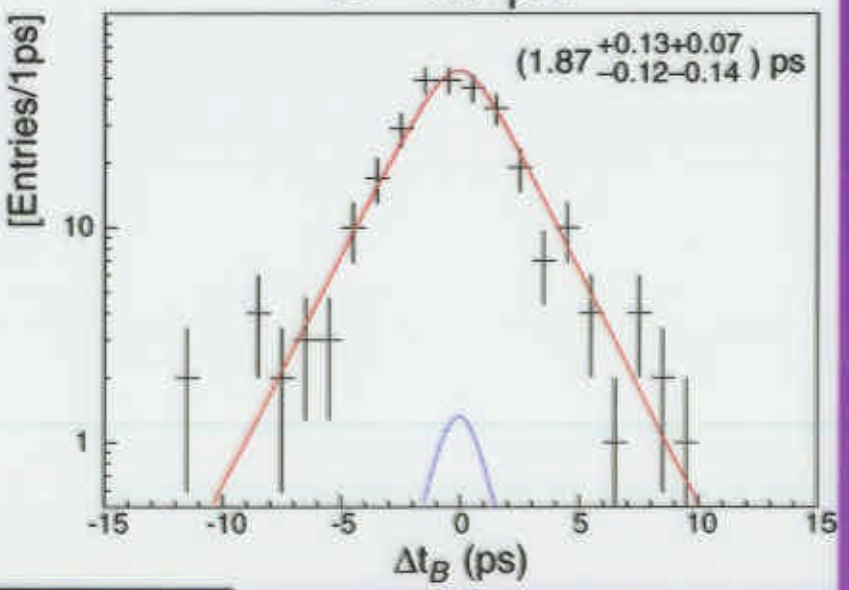
$\overline{B^0} \to J/\psi K_S$



$\overline{B^0} \to J/\psi \overline{K^{*0}}$



$B^- \to J/\psi K^-$



B Lifetime Summary

$\overline{B}^0$ lifetime measurements.

Mode	# of signal	Lifetime (ps)
$\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}$	1740	$1.50 \pm 0.06^{+0.06}_{-0.04}$
$\overline{B}^0 \to D^{*+}\pi^-$	112	$1.55^{+0.18+0.10}_{-0.17-0.07}$
$\overline{B}^0 \to D^{+}\pi^-$	187	$1.41^{+0.13}_{-0.12} \pm 0.07$
$\overline{B}^0 \to J/\psi \overline{K}^{*0}$	92	$1.56^{+0.22+0.09}_{-0.19-0.15}$
Combined	–	$1.50 \pm 0.05 \pm 0.07$
$\overline{B}^0 \to J/\psi K_S$	55	$1.54^{+0.28+0.11}_{-0.24-0.19}$

B^- lifetime measurements.

Mode	# of signal	Lifetime (ps)
$B^- \to D^{*0}\ell^-\overline{\nu}$	730	$1.54 \pm 0.10^{+0.14}_{-0.07}$
$B^- \to D^0\pi^-$	440	$1.73 \pm 0.10 \pm 0.09$
$B^- \to J/\psi K^-$	293	$1.87^{+0.13+0.07}_{-0.12-0.14}$
Combined	–	$1.70 \pm 0.06^{+0.11}_{-0.10}$

$$\tau(B^-)/\tau(\overline{B}^0) = 1.14 \pm 0.06^{+0.06}_{-0.05}$$

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

Summary

D lifetime results

- Factor of 1.5 improvement is expected with full data set by summer.

Experiment	$\tau(D^0)$ fs	$\tau(D^+)$ fs	$\tau(D_s^+)$ fs	y_{CP} %
PDG99	415 ± 4	1057 ± 15	495 ± 13	–
E791	$413 \pm 3 \pm 4$	–	$518 \pm 14 \pm 7$	$0.8 \pm 2.9 \pm 1.0$
CLEO	$408.5 \pm 4.1^{+3.5}_{-3.4}$	$1034 \pm 22^{+10}_{-13}$	$486 \pm 15 \pm 5$	–
FOCUS	409.2 ± 1.3	–	506 ± 8	$3.42 \pm 1.39 \pm 0.74$
Belle	$414.8 \pm 3.8 \pm 3.4$	$1040^{+23}_{-22} \pm 18$	479^{+17+6}_{-16-8}	$1.0^{+3.8+1.1}_{-3.5-2.1}$ $-7.0 < y_{CP} < 8.7$

B lifetime results

Experiment	$\tau(\overline{B}^0)$ (ps)	$\tau(B^-)$ (ps)	y_{CP}
B lifetime WG	1.548 ± 0.032	1.653 ± 0.028	–
CLEO	–	–	$\lvert y \rvert < 0.41$@95% C.L.
Belle	$1.50 \pm 0.05 \pm 0.07$	$1.70 \pm 0.06^{+0.11}_{-0.10}$	$y_{CP} = 0.03^{+0.15+0.05}_{-0.18-0.08}$ $-0.36 < y_{CP} < 0.35$

All results are preliminary.