Measurements of Charmed Meson Lifetimes and Search for D^0-$\overline{D}^0$ Mixing with Belle

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Outline

Introduction

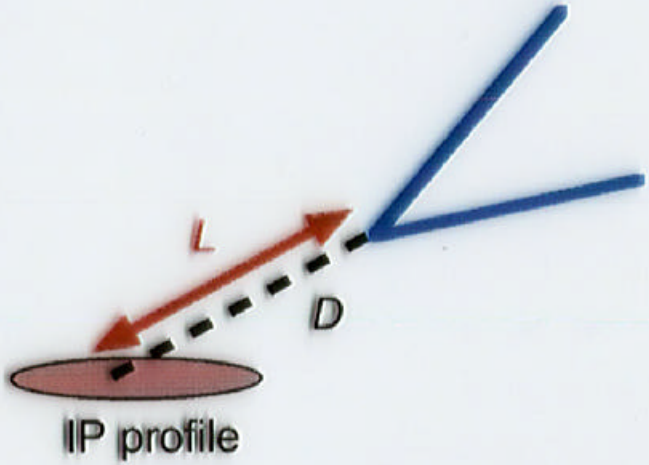
- Lifetime Physics
  - Theoretical inputs to understand non-perturbative QCD in the heavy quark decay.
    - Annihilation process, W-exchange
      - Theoretical challenge to explain $\tau(D_s^+)/\tau(D^0) \sim 1.21 \pm 0.02$
- Mixing
  - Difference of lifetime between flavor specific mode and CP mode gives mixing parameter, y_{CP}.

$$y_{cp} = \frac{\Gamma(CPeven) - \Gamma(CPodd)}{\Gamma(CPeven) + \Gamma(CPodd)} = \frac{\tau(K\pi)}{\tau(KK)} - 1$$

    - FOCUS : $y_{cp} = 3.42 \pm 1.39 \pm 0.74\%$ → inconsistent with 0 at 2.2σ
    - E791 : $y_{cp} = 0.8 \pm 2.9 \pm 1\%$ → consistent with 0
    - CLEO : $-5.8\% < y' < 1\%$ (95% CL) → consistent with 0
      $y_{cp} = -1.1 \pm 2.5 \pm 1.4\%$ → consistent with 0
- Analysis is based on 11/fb. **All results are preliminary.**

Reconstruction

- Reconstruct specific D decay modes.
  - $D^0 \rightarrow K^-\pi^+$, K^-K^+
  - $D_s^+ \rightarrow \phi(K^-K^+)\pi^+$, $\overline{K^{*0}}(K^-\pi^+)K^+$
  - $D^+ \rightarrow K^-\pi^+\pi^+$, $\phi(K^-K^+)\pi^+$
  - $p^*(D) > 2.5$GeV → from "$e^+e^- \rightarrow c\bar{c}$"
  - Obtain decay vertex point(3D).
- Reconstruct D production point.
  - Extrapolate pseudo D flight path to interaction point(IP) profile.
- Calculate proper-time.
  - $\tau = Lm(D) / cp_D$



Lifetime Fit

$$L\left(t_i,\sigma_t^i,f_{SIG}^i\right)=f_{SIG}^i\cdot\int_0^\infty dt'\,\frac{1}{\tau_{SIG}}e^{-t'/\tau_{SIG}}R_{SIG}\left(t_i-t',\sigma_t^i\right)$$ **Signal term**

$$+\left(1-f_{SIG}^i\right)\cdot\int_0^\infty dt\left[f_{\tau BG}\cdot\frac{1}{\tau_{BG}}e^{-t'/\tau_{BG}}+\left(1-f_{\tau BG}\right)\cdot\delta(t')\right]\mathbb{R}_{BG}\left(t_i-t',\sigma_t^i\right)$$ **Background term**

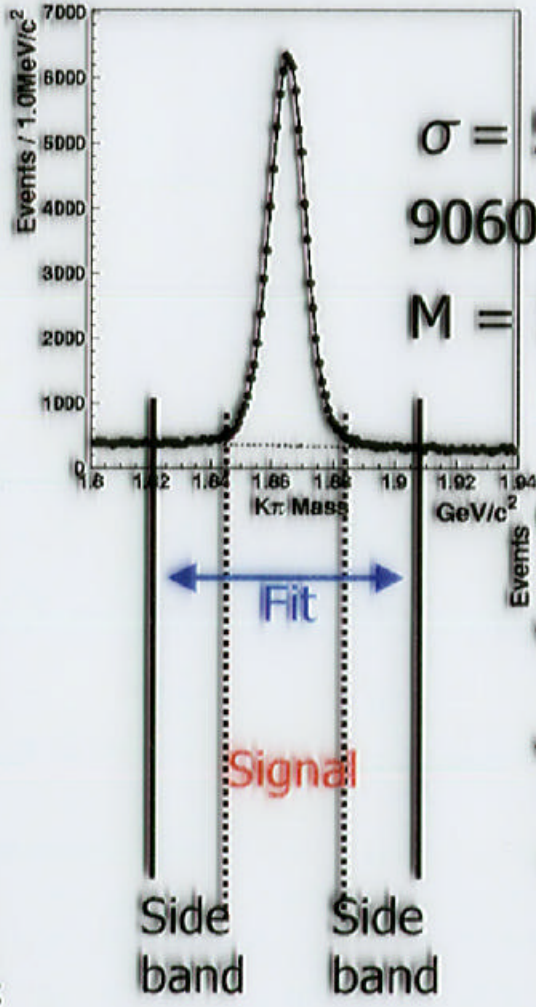
$$R\left(x,\sigma_x\right)=\left(1-f_{tail}\right)\frac{1}{\sqrt{2\pi}\sigma_x}e^{-\frac{x^2}{2S^2\sigma_x^2}}+f_{tail}\frac{1}{\sqrt{2\pi}\sigma_x}e^{-\frac{x^2}{2S_{tail}^2\sigma_x^2}}$$ **Resolution function**

Unbinned Maximum Likelihood Fit

- τ_{SIG} : D lifetime
- f_{SIG} = 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
  - σ_t : Proper-time error (event by event)
  - S : Global scaling factor.
  - S_{tail} : Global scaling factor for poorly-measured events.
    - Hard scattering, mis-association of SVD hits.
  - f_{tail} : Fraction of poorly-measured events.
- Fitting Parameters : τ_{SIG}, τ_{BG}, $f_{\tau BG}$, S, S_{tail}, f_{tail}, $(S, S_{tail}, f_{tail})_{BG}$

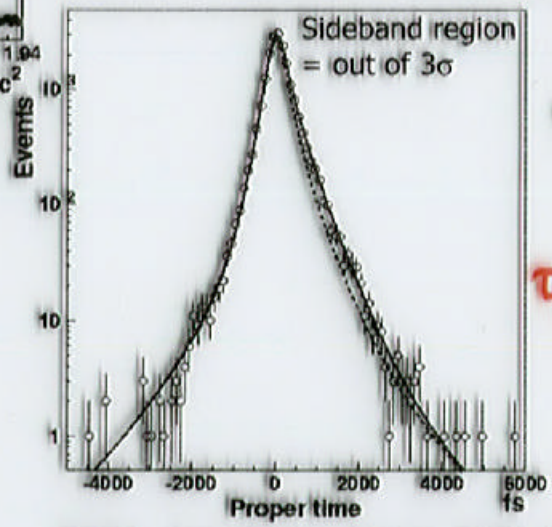
$D^0 \rightarrow K^-\pi^+$ Lifetime Fit

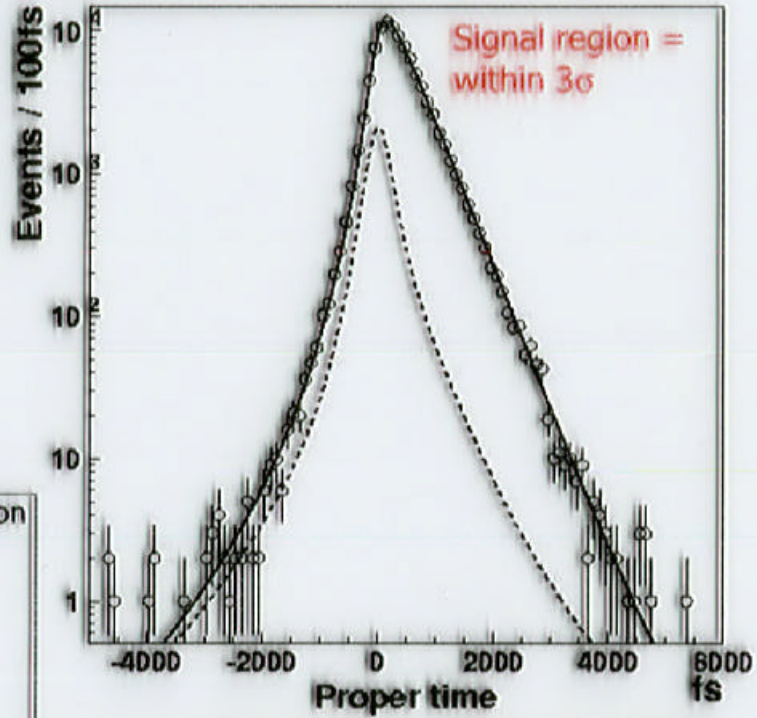


σ = 5.4MeV

90601±387 events

M = 1865.0MeV

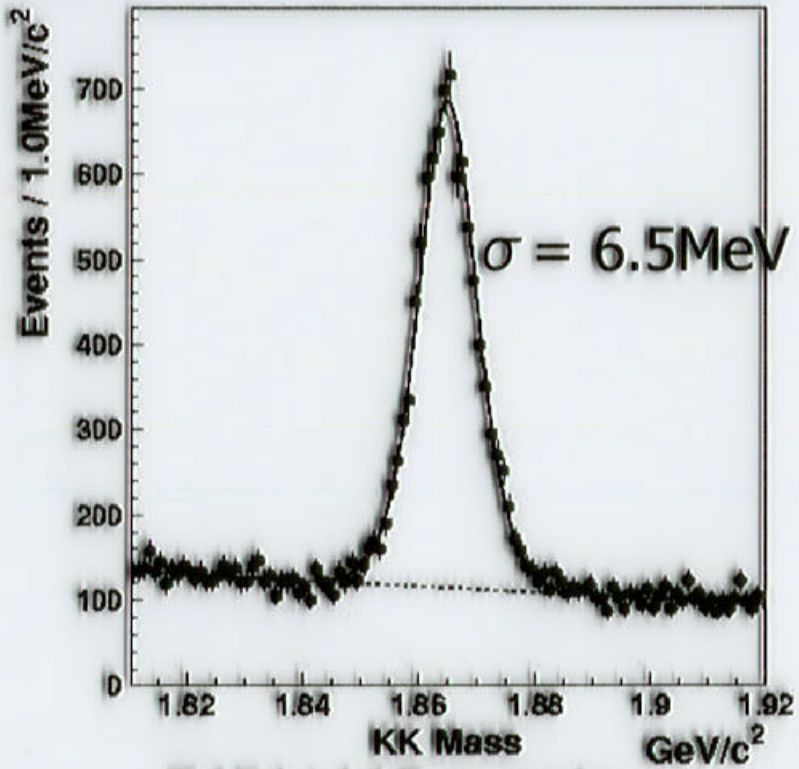


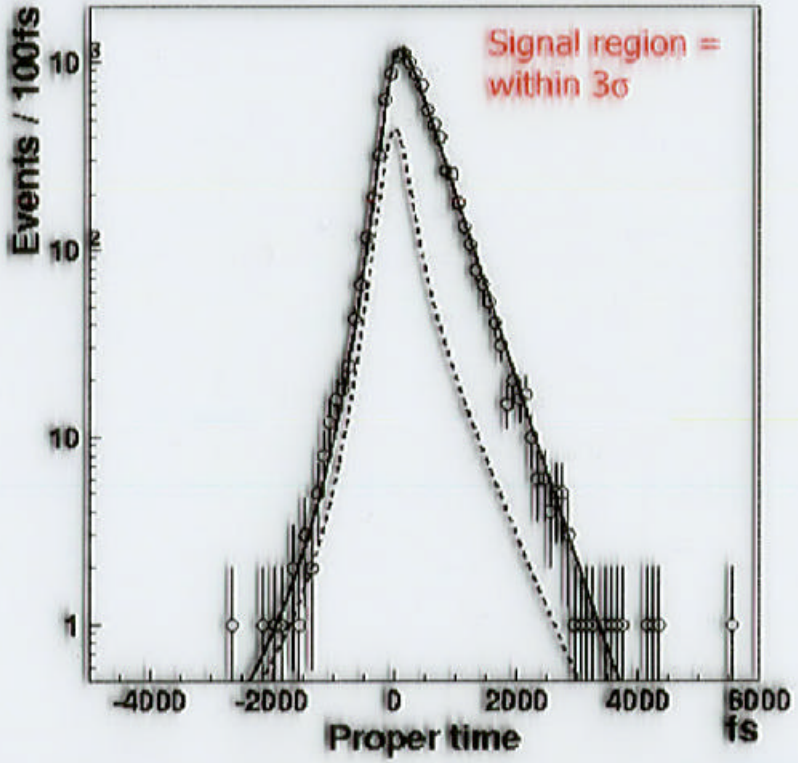


τ_{SIG} = 414.5±1.7(stat)fs

(τ = 412.6 ± 2.8 fs : PDG2k)

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



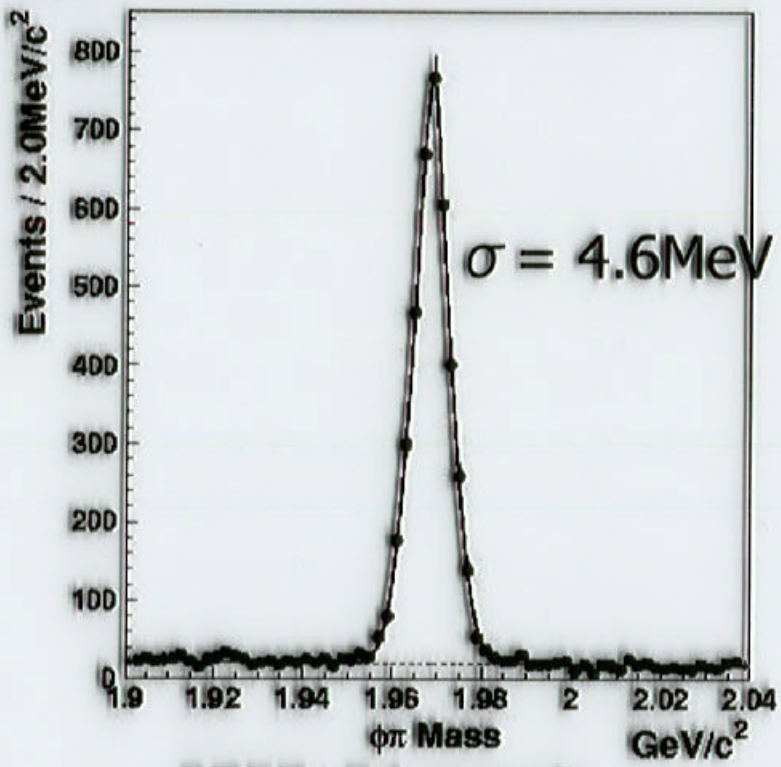


7451±118 events

M = 1865.0MeV

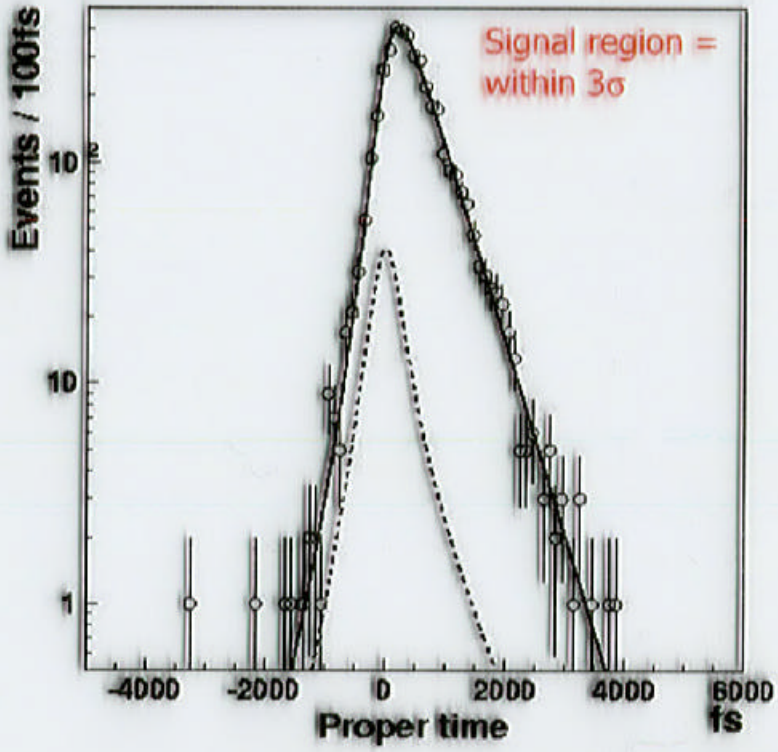
τ_{SIG} = 409.8±6.3(stat)fs

$D_s^+ \to \phi(K^-K^+)\pi^+$ Lifetime Fit



3757±54 events

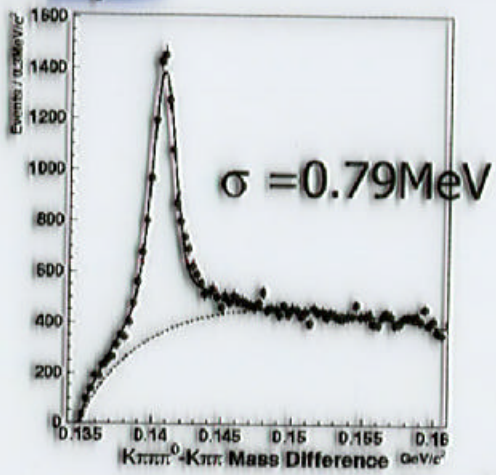
M = 1968.6MeV

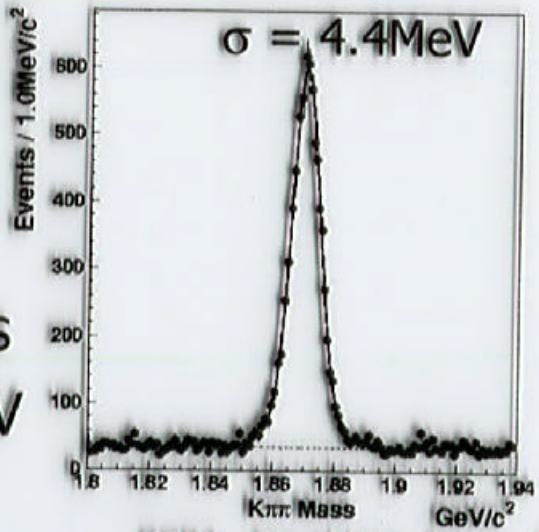


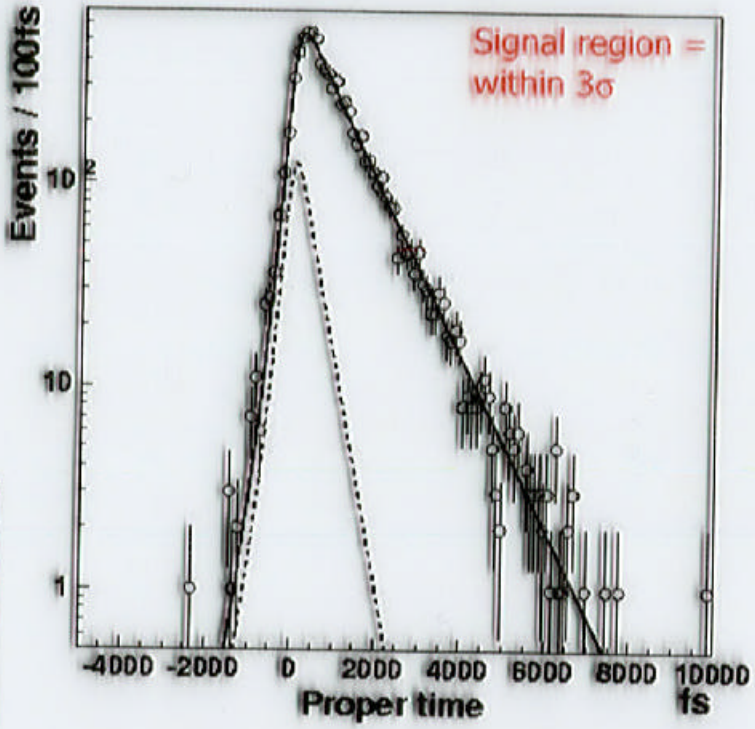
τ_{SIG} = 482.4±9.2(stat)fs

(τ = 496 ± 10 fs : PDG2k)

$D^+ \to K^-\pi^+\pi^+ (D^{*+} \to D^+\pi^0)$ Lifetime Fit







6953±99 events

M = 1870.1MeV

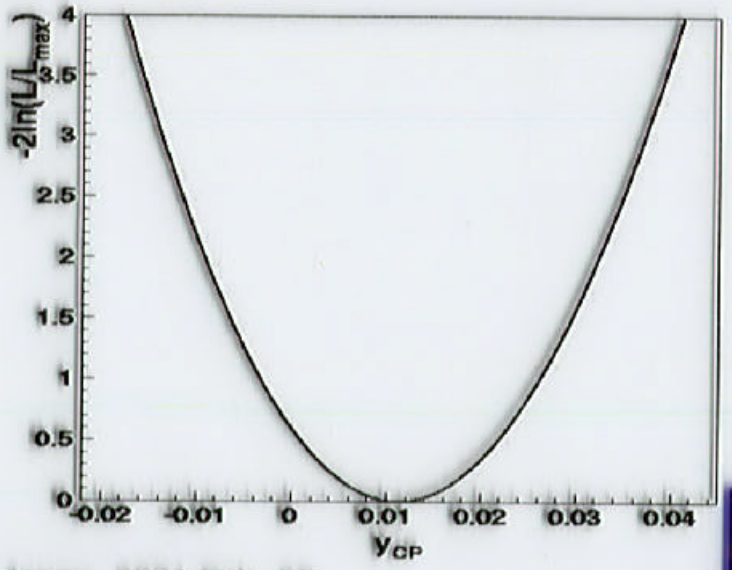
τ_{SIG} = 1021±13(stat)fs

(τ = 1051±13 fs : PDG2k)

Combined Lifetime/y_{cp} Fit

- A likelihood is combined to obtain y_{cp} and lifetimes of D^+ and D_s^+ since these measurements are obtained from two decay chains.
  - D^+,D_s^+: use a common lifetime value.
  - y_{cp} : $\tau(D^0 \to KK) = y_{cp}$ and $\tau(D^0 \to K\pi)$ "$\tau_{D^0 \to KK} = \tau_{D^0 \to K\pi}/(1+y_{cp})$"

	Combined fit
D^+	1029 ± 12 fs
D_s^+	$488.4^{+7.8}_{-7.7}$ fs
y_{cp}	$1.16^{+1.67}_{-1.65}$ %



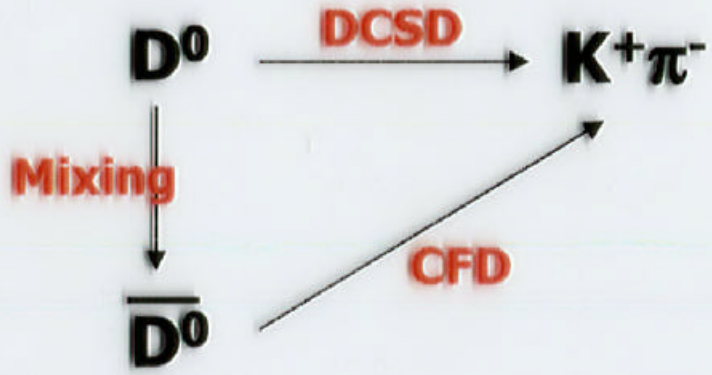
Systematic Error

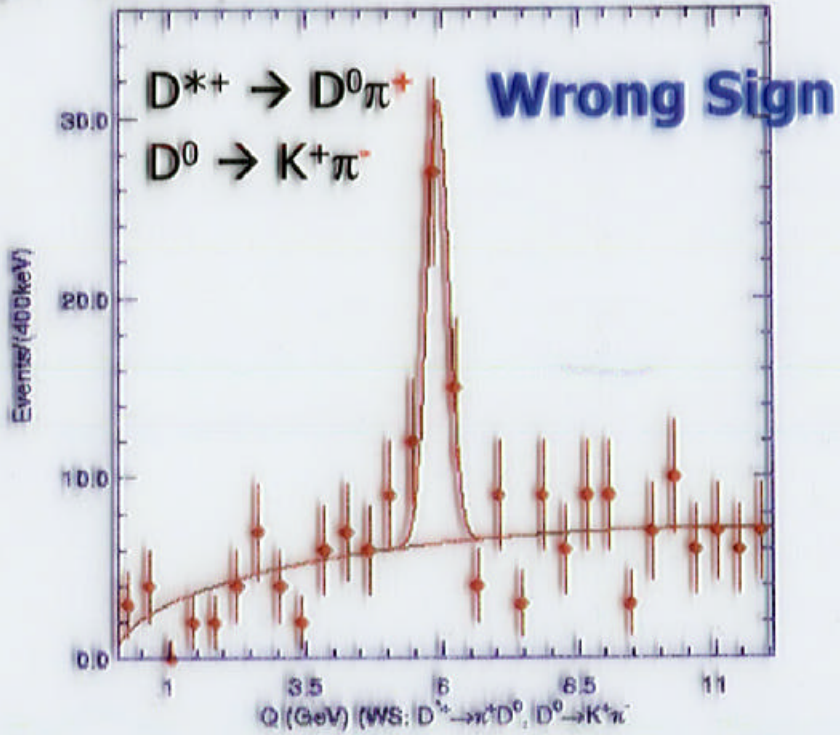
- We consider the following items as systematic uncertainties.
  - Due to reconstruction
    - Interaction point.
    - Reconstruction efficiency.
    - Decay vertex bias by $2\gamma \rightarrow 4\pi$ which has a "zero" lifetime.
    - Mass dependence of proper-time.
  - Due to fitting
    - Signal probability.
    - Mass peak shift.
    - Fitting bias.
    - Used mass region.

They are not quoted since our study does not finish yet.

DCSD and D^0-$\overline{D^0}$ Mixing Search

- We are studying "wrong sign" decays $D^0 \to K^+\pi^-$.





- When BG is understood, we will perform a fit to decay time to extract DCSD rate and mixing parameters x′, y′.

Summary

Experiment	$\tau(D^0)$ fs	$\tau(D^+)$ fs	$\tau(D_s^+)$ fs	y_{CP} %
PDG2000	412.6 ± 2.8	1051 ± 13	496^{+10}_{-9}	–
E791	$(413 \pm 3 \pm 4)^\dagger$	–	$(518 \pm 14 \pm 7)^\dagger$	$0.8 \pm 2.9 \pm 1.0$
CLEO	$(408.5 \pm 4.1^{+3.5}_{-3.4})^\dagger$	$(1034 \pm 22^{+10}_{-13})^\dagger$	$(486 \pm 15 \pm 5)^\dagger$	$-1.1 \pm 2.5 \pm 1.4$
FOCUS	$409.2 \pm 1.3^\ddagger$	–	$506 \pm 8^\ddagger$	$3.42 \pm 1.39 \pm 0.74$
Belle	$414.5 \pm 1.7(stat.)$	$1029 \pm 12(stat.)$	$488.4^{+7.8}_{-7.7}(stat.)$	$1.16^{+1.67}_{-1.65}(stat.)$

†This result is included in the PDG2000 world average.

‡No systematic error is given.

Preliminary

- Our statistical uncertainties on the lifetimes are better than those of the best published measurements.
- After our systematic study is done, we will publish these lifetimes and y_{cp}.