HEAVY FLAVOURS 8

Review of Charm Lifetimes

Harry W.K. Cheung - Fermi National Accelerator Laboratory

Talk Overview

- Motivation
- Experimental Charm lifetime results
- Interaction with Theory
- Conclusions

8th International Symposium on Heavy Flavour Physics, Southampton, July 26th 1999

HEAVY FLAVOURS 8

Motivation

- "ENGINEERING"

  Needed to convert relative BR to Rates

  - to compare to theories
  - to extract parameters (e.g. CKM)

- PHYSICS

  Study of Strong Interactions

  - "Test" theoretically-challenged part of the SM
    i.e. non-perturbative QCD
  - Interaction between Data and Theory
  - Additional understanding needed to extract SM parameters

HEAVY FLAVOURS 8

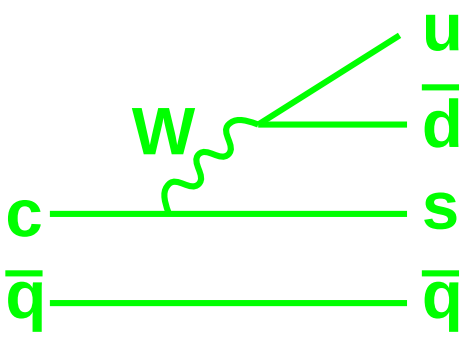
Motivation

$$\tau = \frac{\hbar}{\Gamma_{SL} + \Gamma_{NL} + \Gamma_{PL}}$$

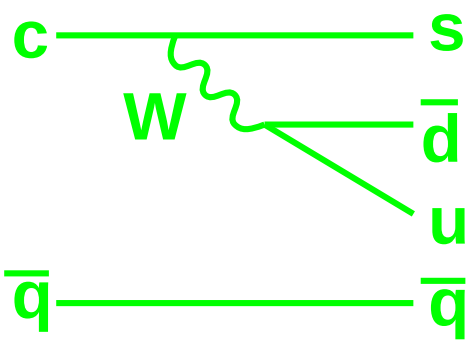
$$\Gamma_{SL}(D^+) = \frac{BR_{SL}}{\tau(D^+)} = (1.071 \pm 0.119) \times 10^{-13} GeV$$
$$\Gamma_{SL}(D^0) = \frac{BR_{SL}}{\tau(D^0)} = (1.067 \pm 0.041) \times 10^{-13} GeV$$

$$\text{PDG98}: \frac{\tau(D^+)}{\tau(D^0)} = 2.55 \pm 0.04$$

$$\Gamma_{NL}(D^0) \neq \Gamma_{NL}(D^+)$$



Spectator Decay
(Color Aligned)



Internal Spectator
(Color Suppressed)

Spectator Decays

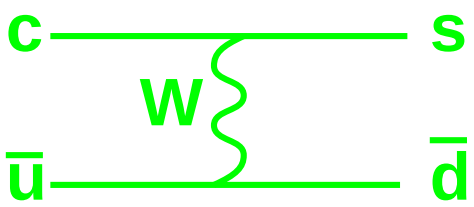
Coefficients modified by strong int.

Pauli interference:

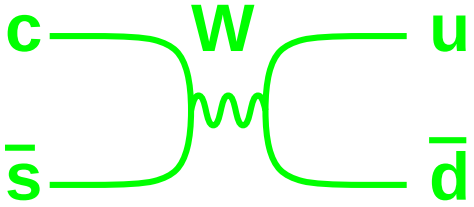
$\tau(D^+)/\tau(D^0) \sim 2.0$

W-annihilation suppressed by:

$f_D^2 m_s^2 / m_c^4 \sim 10^{-3}$?



W-exchange



W-annihilation

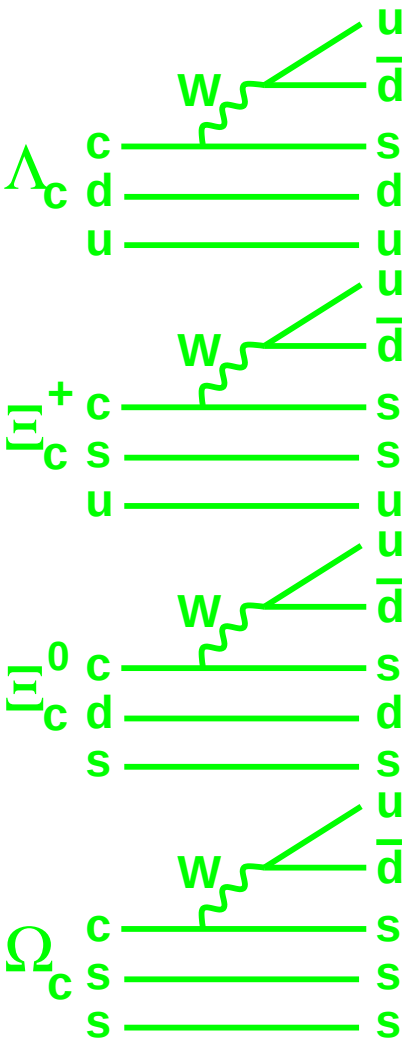
Annihilation Diagrams

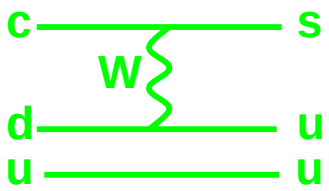
Helicity and wavefunction suppressed

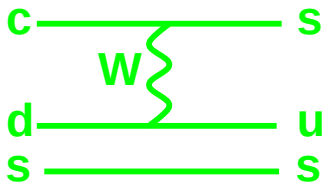
difficult to calculate reliably

HEAVY FLAVOURS 8

Motivation - Other Decays







$\Gamma_{DEC} + \Gamma_{EXC} - \Gamma_{INT}^{-}$

$\Gamma_{DEC} + \Gamma_{INT}^{+} - \Gamma_{INT}^{-}$

$\Gamma_{DEC} + \Gamma_{EXC} + \Gamma_{INT}^{+}$

$\Gamma_{DEC} + (10/3)\,\Gamma_{INT}^{+}$

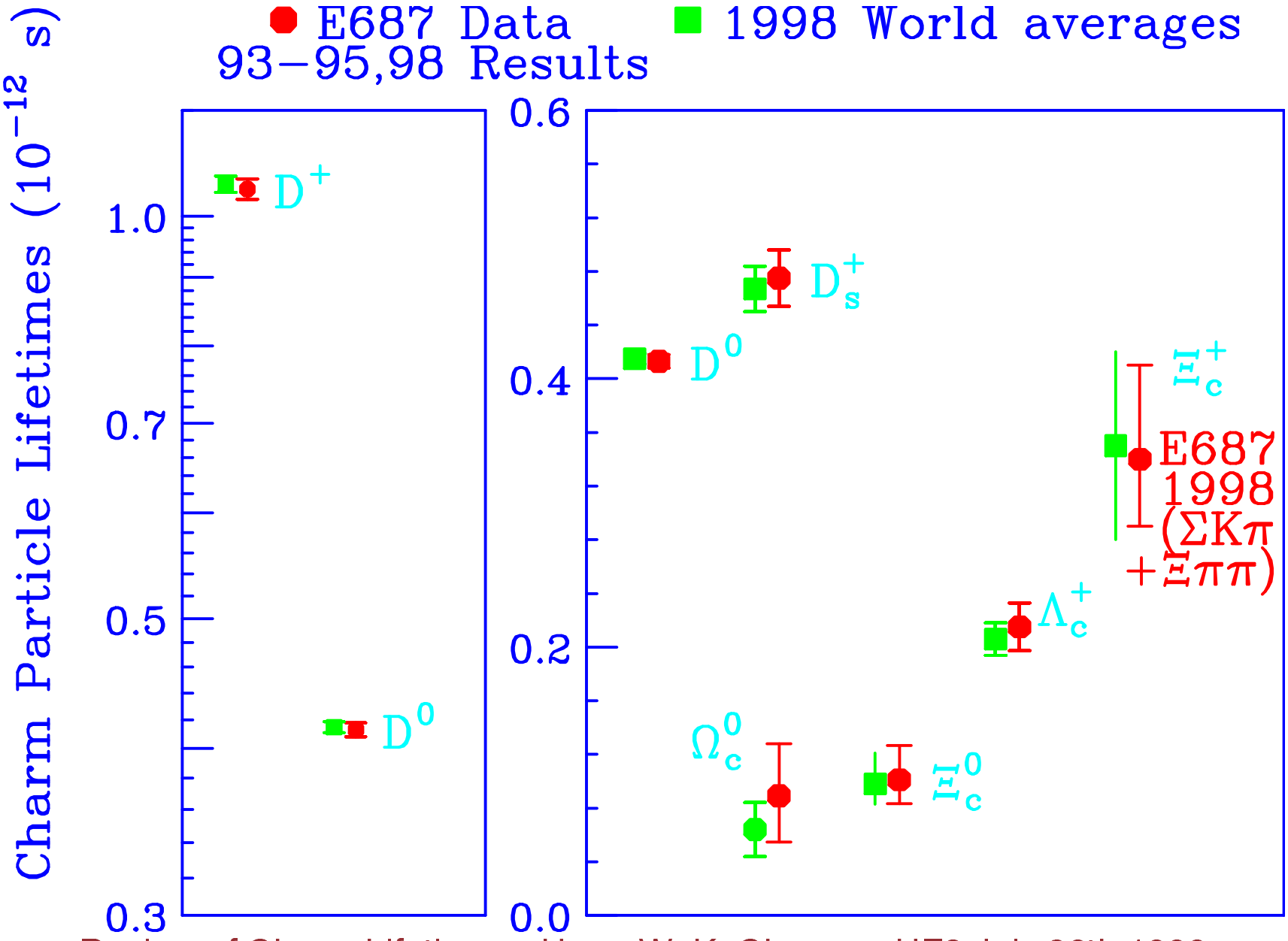
Look at other decays

- o D_s^+ decays
- o Charm baryons
- o Bottom particles

Expect: $\tau(\Omega_C) \approx \tau(\Xi_C^{\,0}) < \tau(\Lambda_C) < \tau(\Xi_C^{\,+})$

HEAVY FLAVOURS 8

PDG'98 World Averages



HEAVY FLAVOURS 8

Measurement Methods

Simple direct method for all charm τ measurements

- Use exclusive decays only in all measurements
- Fixed target experiments (e.g. E687, E791, FOCUS,SELEX)
  - Use 3-D decay length and 3-momentum to extract τ
  - Use reduced proper time = $t - t_{min}$
  - Correct for acceptance (etc.) bias using MC/data in fit
- e^+e^- Collider (CLEO II.5 with SVX)
  - Use 2-D decay length in the $r\phi$ plane
  - Use absolute proper times
  - Correct bias due to other charm in τ before fit

HEAVY FLAVOURS 8

$\tau(D^{0,\pm})$ Measurement update

New measurements since PDG'98:

Fermilab E791 used

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

$413 \pm 3 \pm 4$ fs

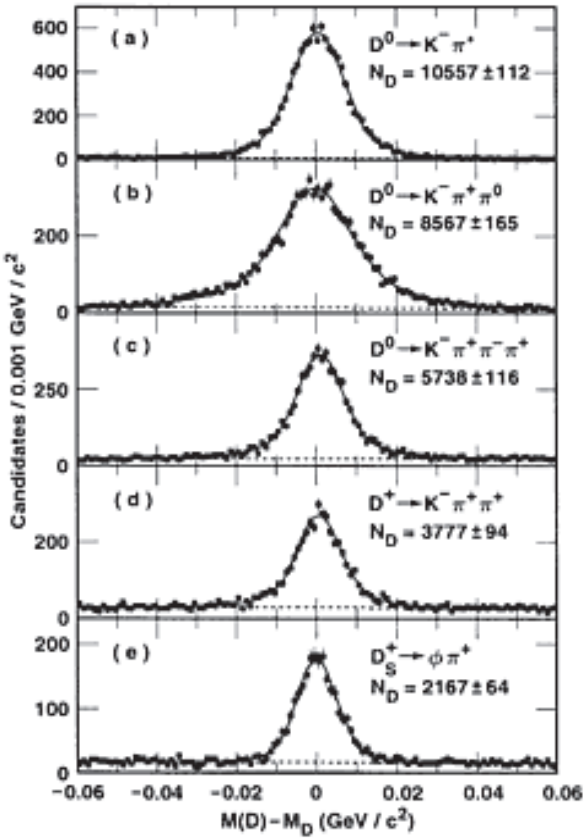
CLEO II.5 (SVX)

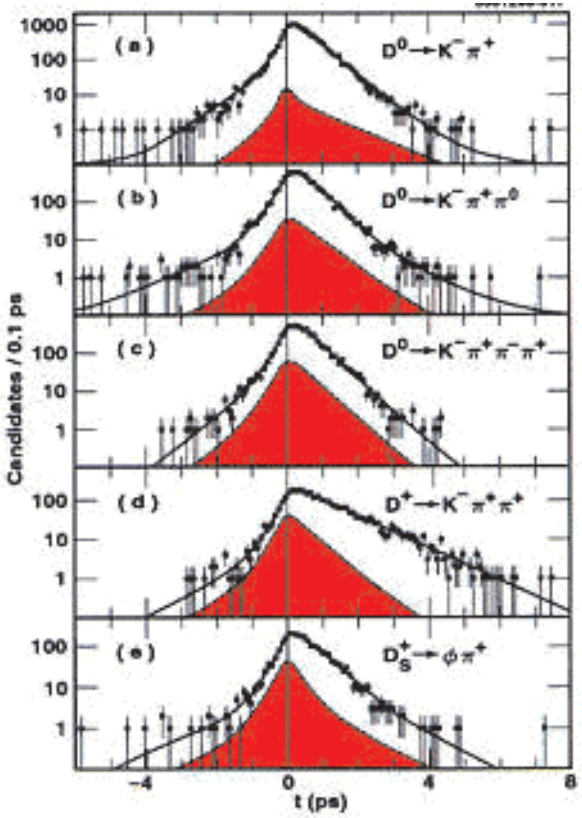
$D^{*+} \rightarrow D^0\pi^+, D^0 \rightarrow K\pi, K3\pi$ $K\pi\pi^0$

$408.5 \pm 4.1\ ^{+3.5}_{-3.4}$ fs

$D^{*+} \rightarrow D^+\pi^0, D^+ \rightarrow K2\pi,$

$1033.6 \pm 22.1\ ^{+9.9}_{-12.7}$ fs



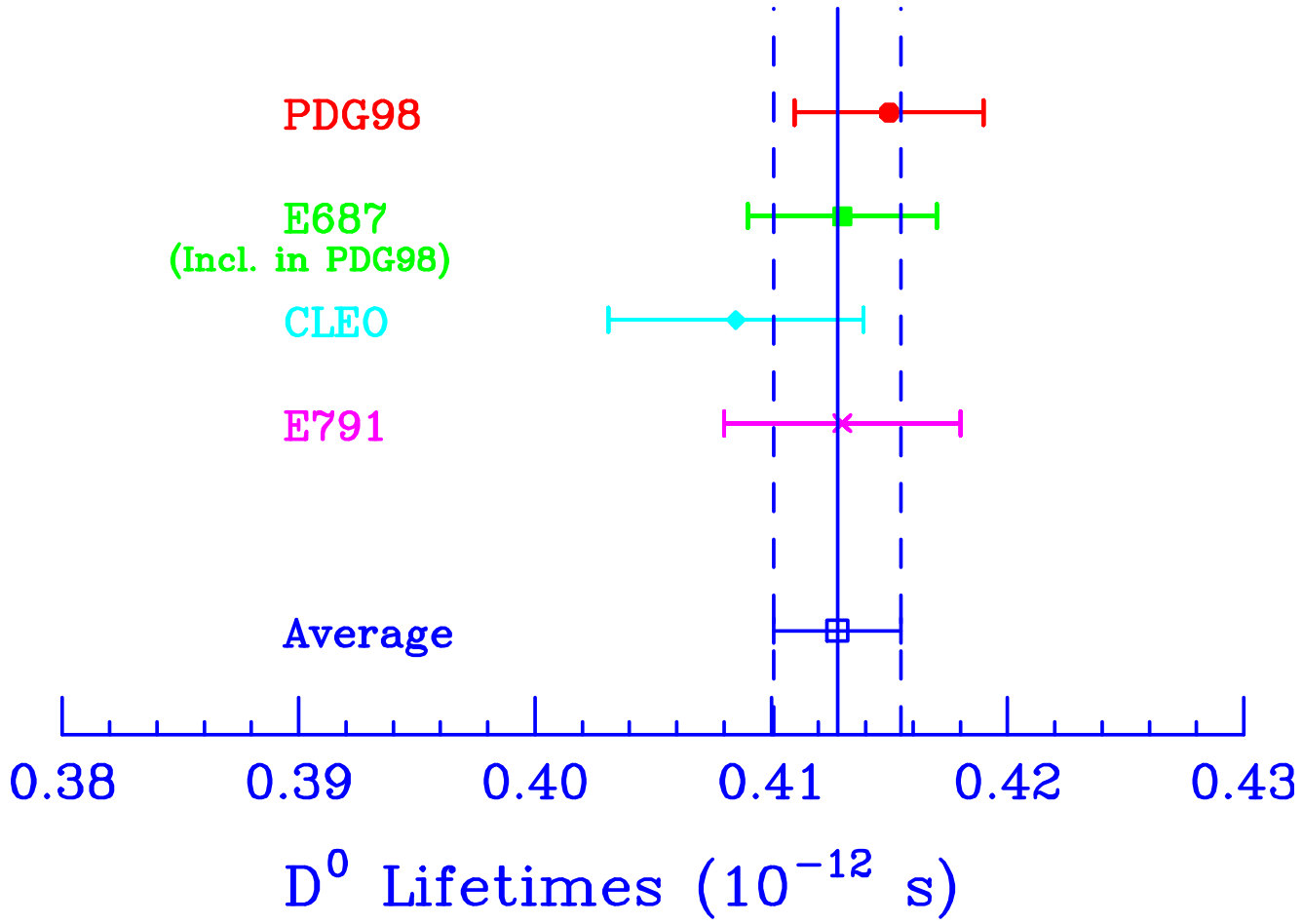


CLEO Mass Plots, Lifetime Plots

HEAVY FLAVOURS 8

$\tau(D^0)$ Measurement update

Average $\tau(D^0)$ = 0.4128 ± 0.0027 psec



HEAVY FLAVOURS 8

$\tau(D_s^+)$ Measurement update

New Published measurements since PDG'98:

Fermilab E791 using $D_s^+ \to \phi\pi$

518 ± 14 ± 7 fs

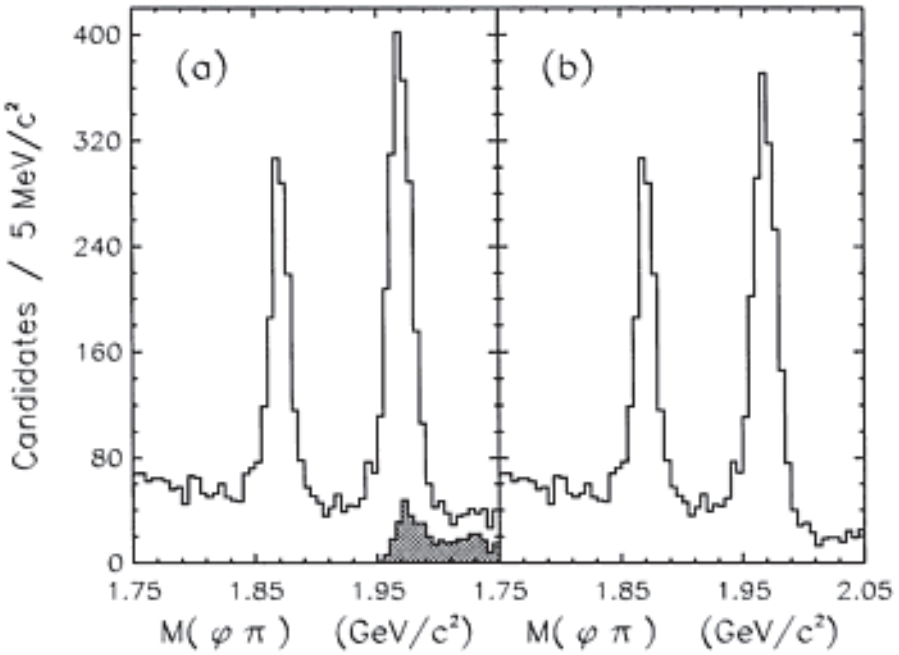
CLEO II.5 (SVX) $D_s^+ \to \phi\pi$

$486.3 \pm 15.0^{+4.9}_{-5.1}$ fs

Preliminary Results:

Fermilab FOCUS (E831)

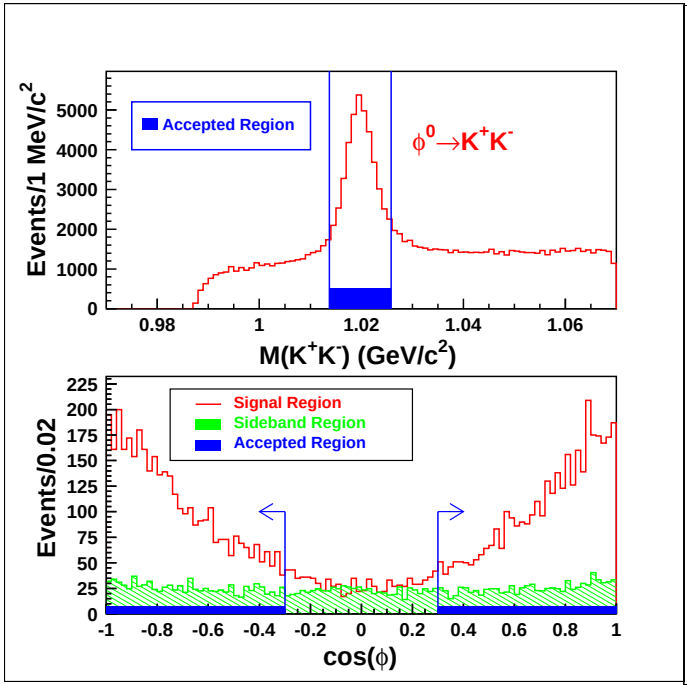
$D_s^+ \to \phi\pi$ 506 ± 8 (stat.) fs

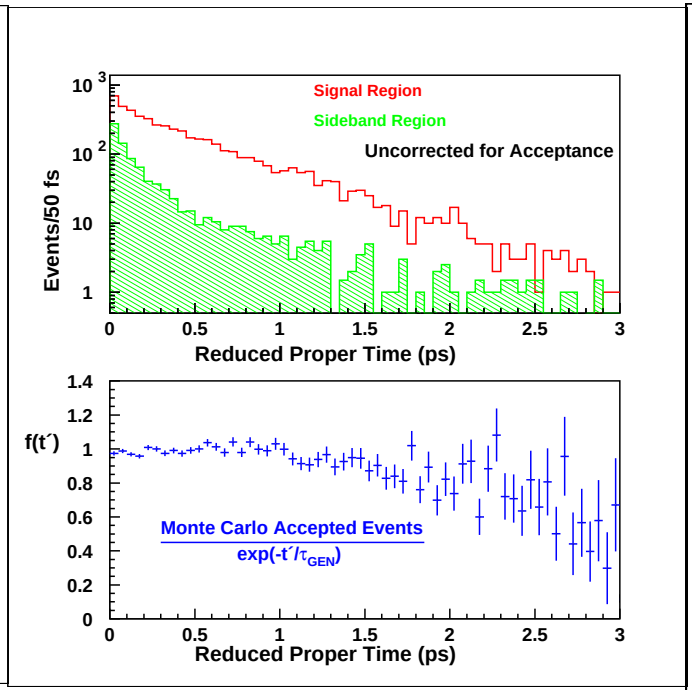


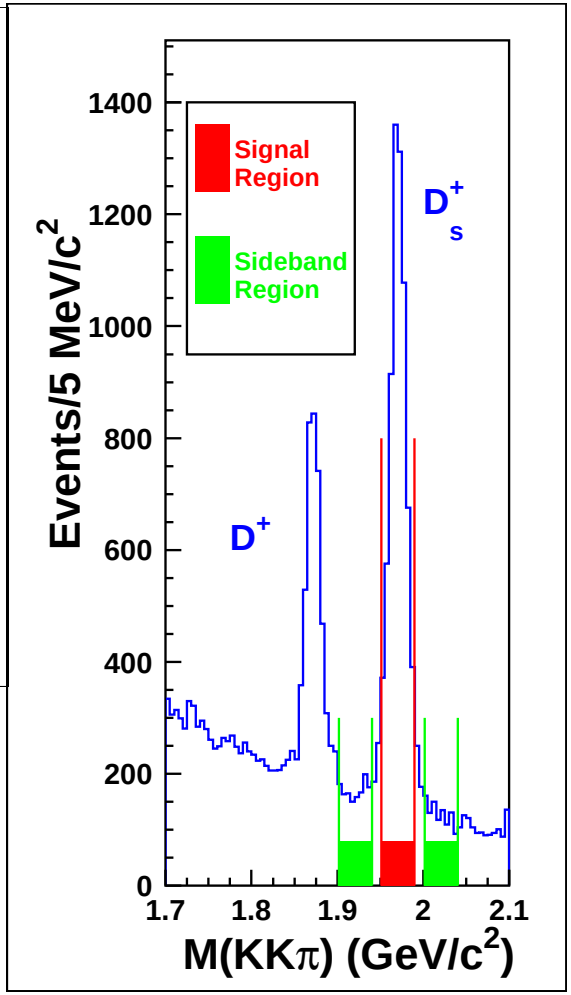
E791 Mass plots

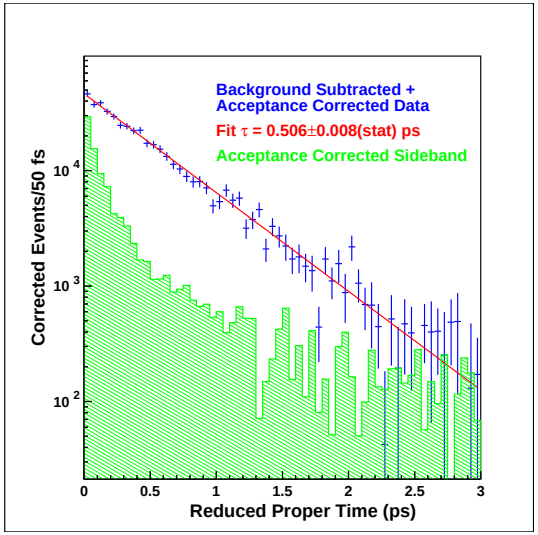
HEAVY FLAVOURS 8

$\tau(D_s^+)$ Measurement update









FOCUS E831

Preliminary result from 50% Data

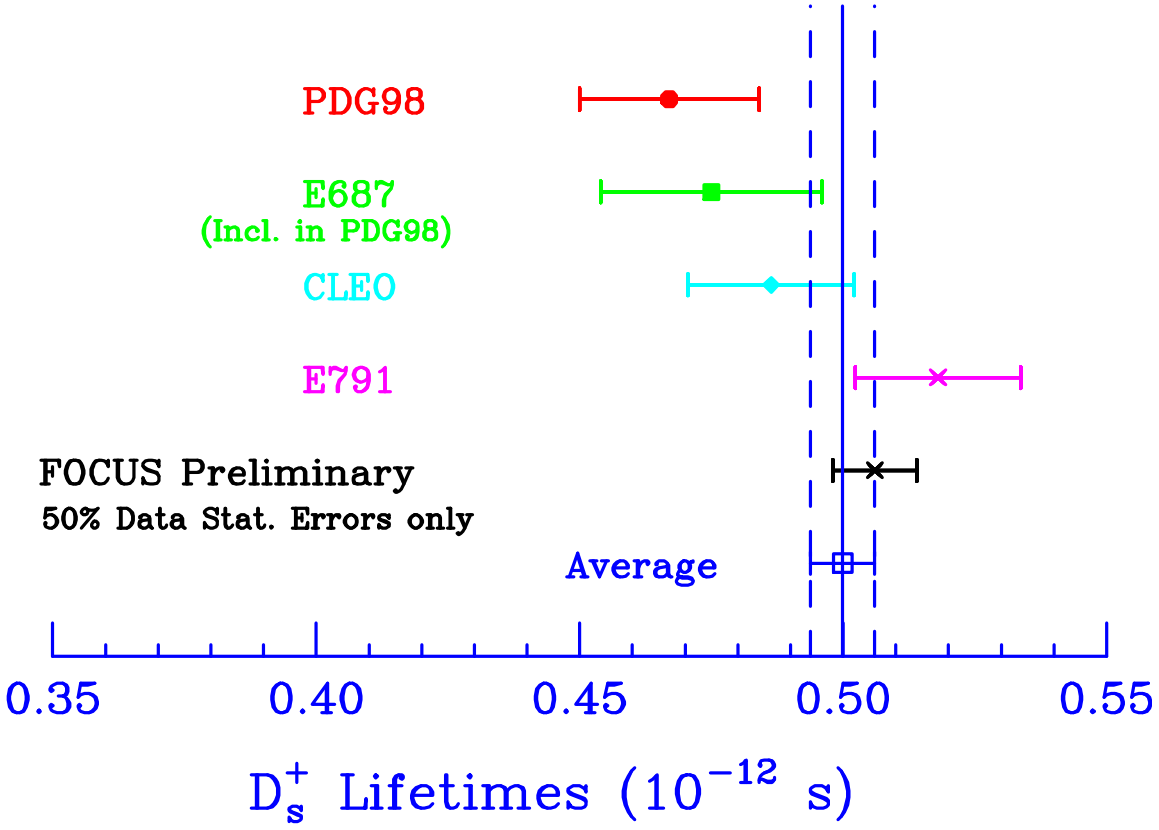
$\tau(D_s^+) = 506 \pm 8$ fs

Review of Charm Lifetimes - Harry W. K. Cheung - HF8 1999

HEAVY FLAVOURS 8

$\tau(D_s^+)$ Measurement update

Average $\tau(D_s^+) = 0.4999 \pm 0.0061$ psec



Update on $\tau(D_s^+)/\tau(D^0)$

PDG'98= 1.125 ± 0.042

New'99= 1.211 ± 0.017

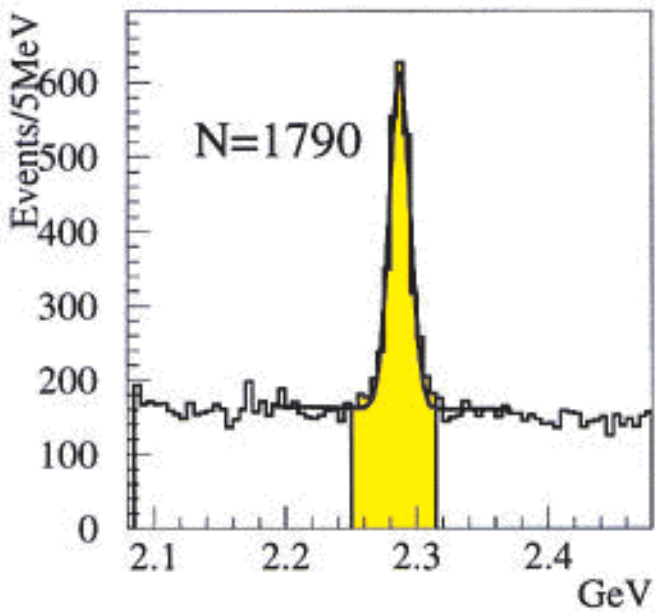
12.4σ from unity

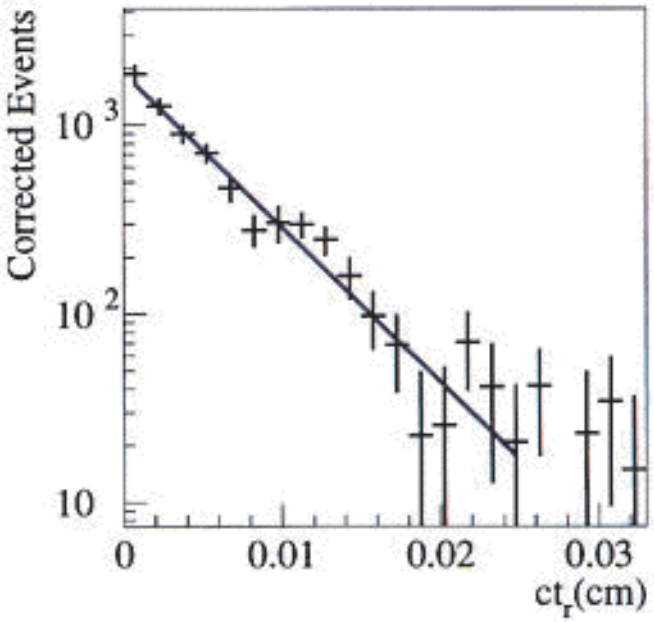
$\tau(\Lambda_c^+)$ Measurement update

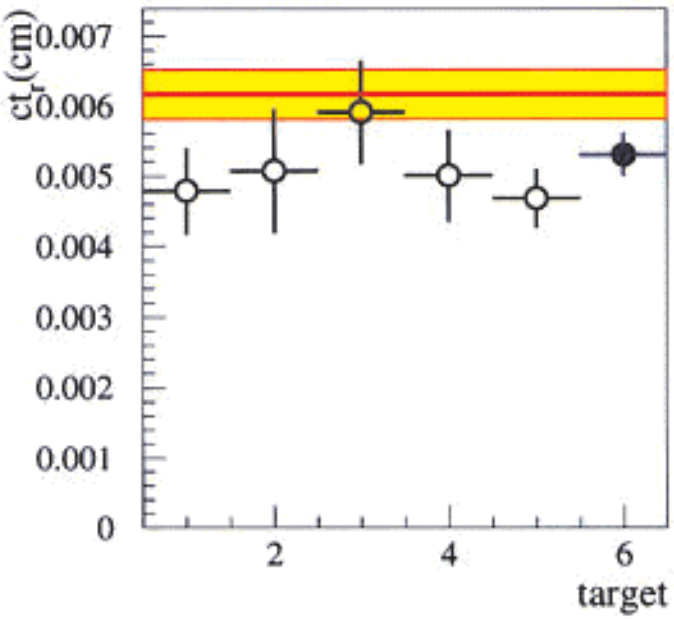
New measurements since PDG'98:

Preliminary measurement from SELEX (Fermilab E781):

177 ± 10 fs





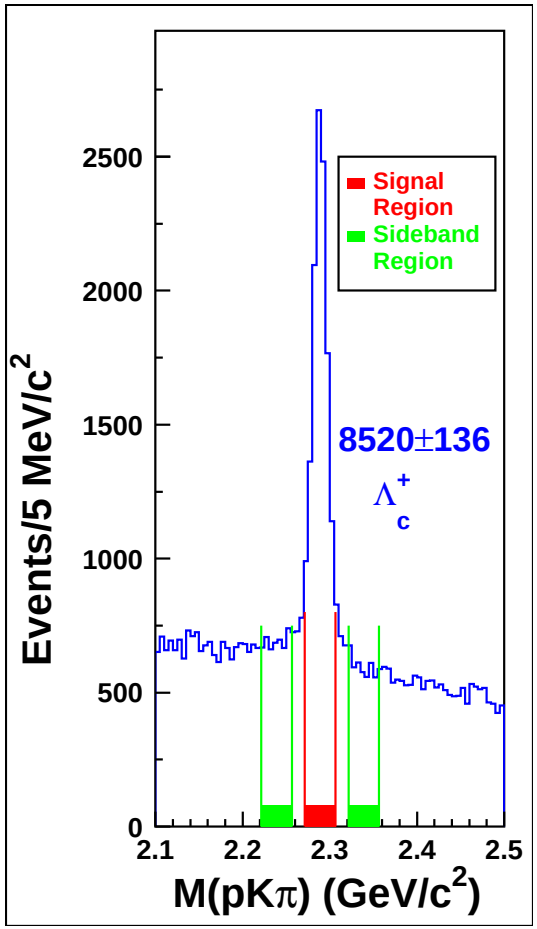


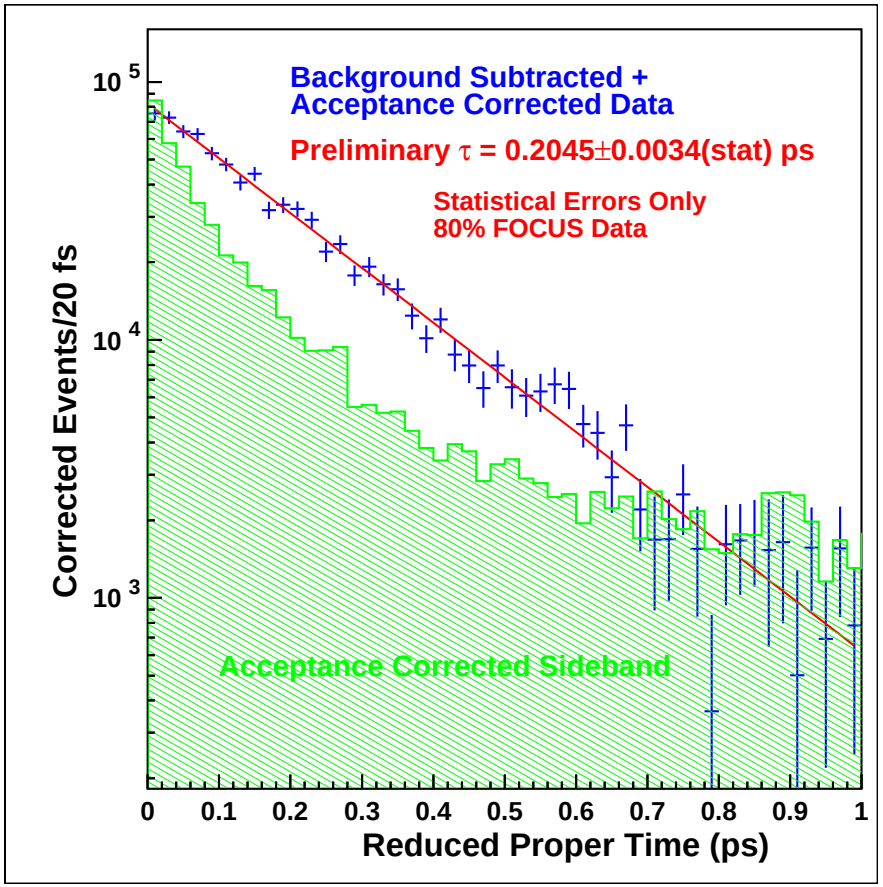
HEAVY FLAVOURS 8

$\tau(\Lambda_c^+)$ Measurement update

New measurements since PDG'98:

Preliminary measurement from FOCUS (Fermilab E831):





204.5 ± 3.4 fs

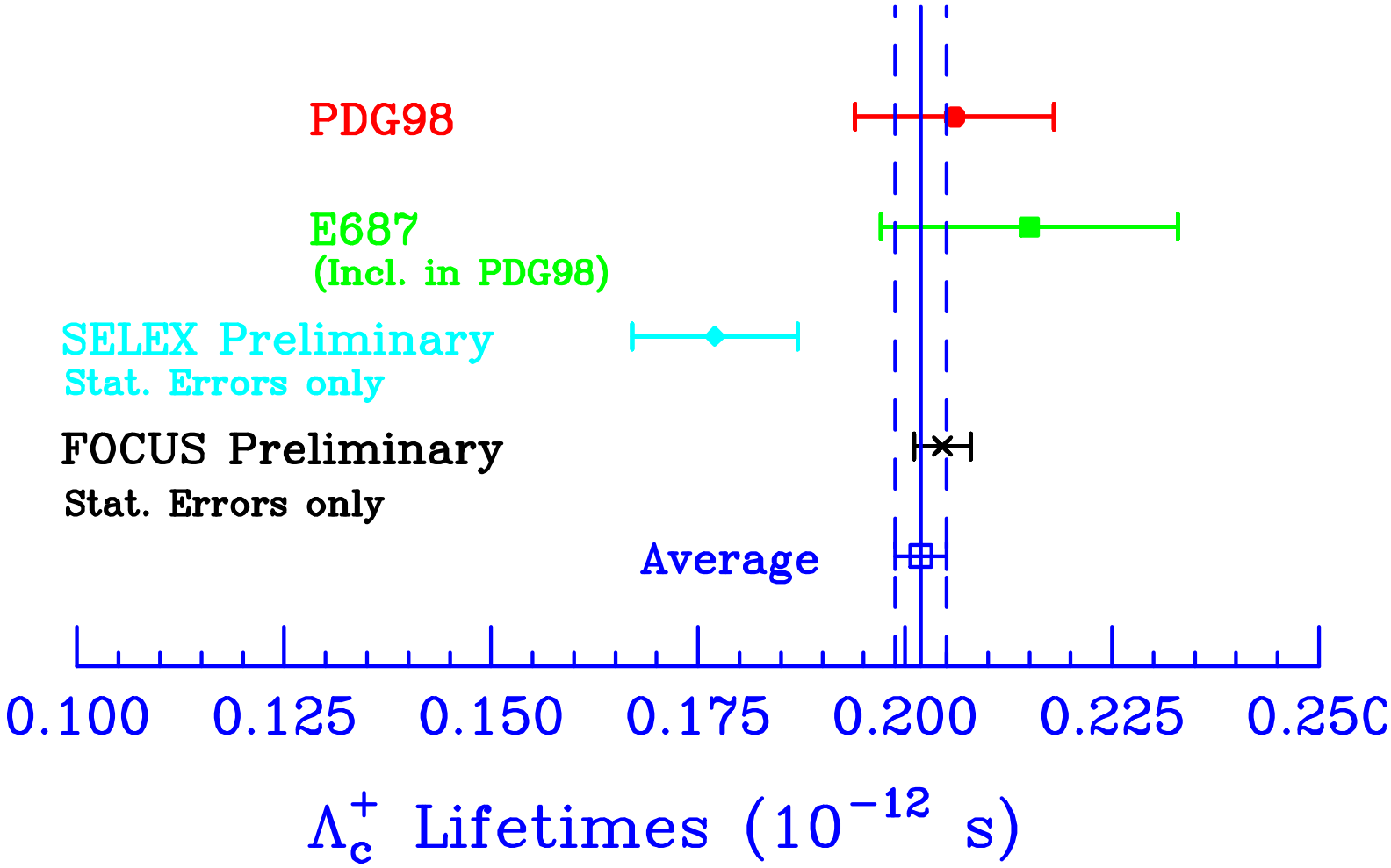
Stat. errors only

80% FOCUS Data

HEAVY FLAVOURS 8

$\tau(\Lambda_c^+)$ Measurement update

Average $\tau(\Lambda_c^+) = 0.2019 \pm 0.0031$ psec



HEAVY FLAVOURS 8

Theoretical Approach

- Treatment of *Inclusive* decays based on QCD
- Operator Production Expansion in the Heavy Quark Mass

$$\Gamma_{H_Q} = \frac{G_F^2 m_Q^5}{192\pi^3} \times (\Sigma f_i |V_{Qq_i}|^2) \times \left[A_1 + \frac{A_2}{\Delta^2} + \frac{A_3}{\Delta^3} + \frac{A_4}{\Delta^4} + \ldots \right]$$

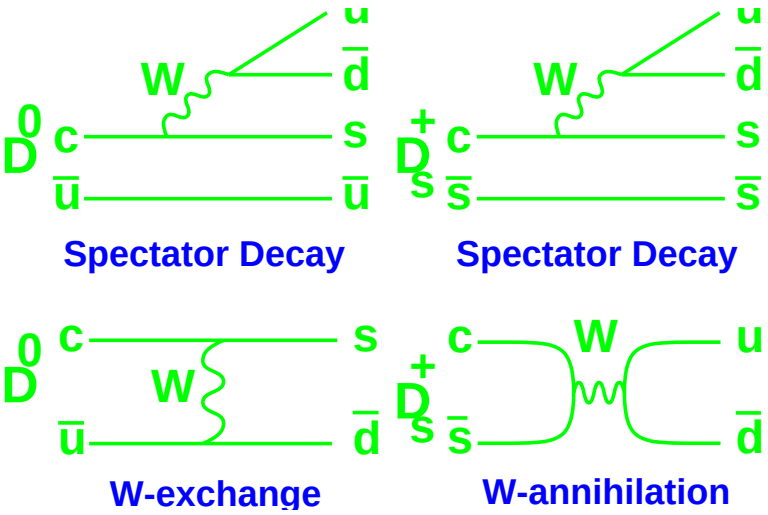
$$\Delta = m_Q$$

- A_1 Gives the Spectator Model term
- A_2 Produces differences in baryon/meson lifetimes
- A_3 Includes Non-spectator WA and PI effects

  Mesons: A_3 related to observables
  Baryons: Need Quark Models or QCD Sum Rules

- A_4 not (all) calculated, may be sizable

D^0 vs D_s^+ Lifetimes



$$\frac{\tau(D_s^+)}{\tau(D^0)} = 1.211 \pm 0.017 \qquad \text{July '99}$$

(using FOCUS measurement with statistical errors only)

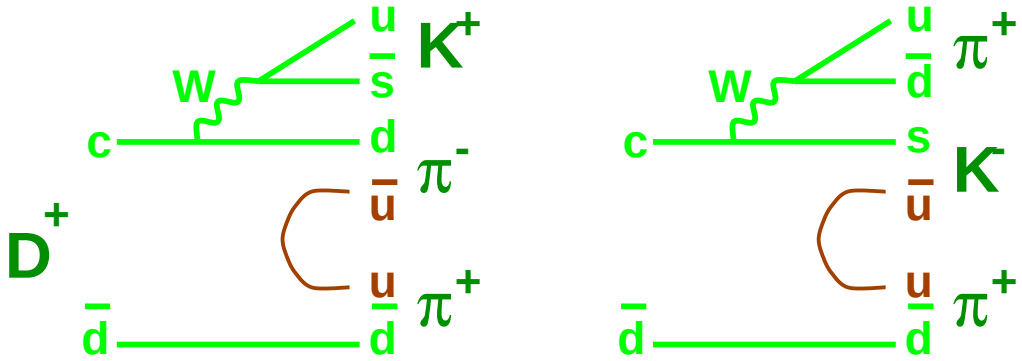
Need to obtain size of W-Annhiliation

- $D_s^+ \to \ell^+ \nu_\ell$ $\tau(D_s^+) \Downarrow 3\%$
- P.I. in Cabbibo suppressed D_s^+ decays $\tau(D_s^+) \Uparrow 4\%$
- $SU(3)_f$ breaking in *"Fermi Motion"* $\tau(D_s^+) \Uparrow 4\%$
- Differences in WX/WA,
  Bigi and Uraltsev $\Delta\tau(D_s^+ - D^0) < 7\%$ no WA
  Bigi and Uraltsev $\Delta\tau(D_s^+ - D^0) < 20\%$

Affects WA contribution to A_3 term in expansion

Consequences in other lifetime processes and other inclusive results

Looking at the Pauli interference contribution: DCSD $D^+ \to K^+\pi^-\pi^+$

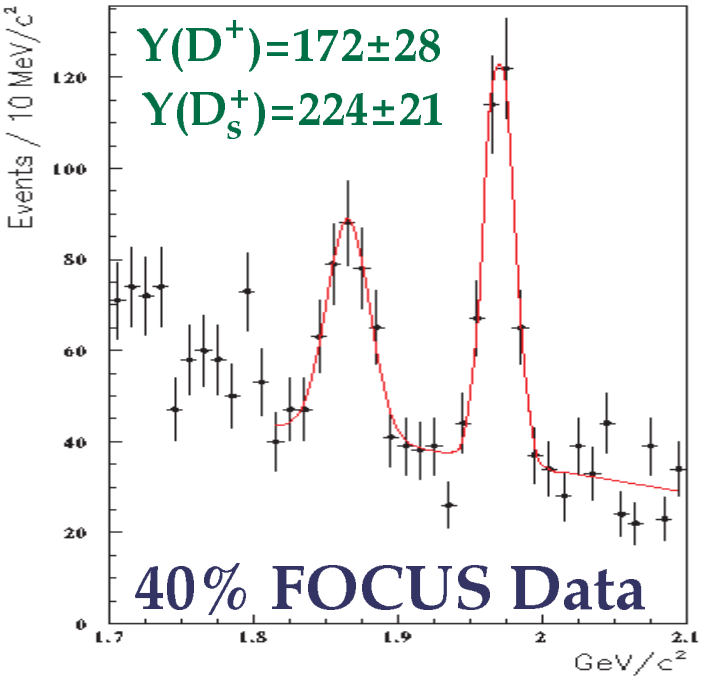


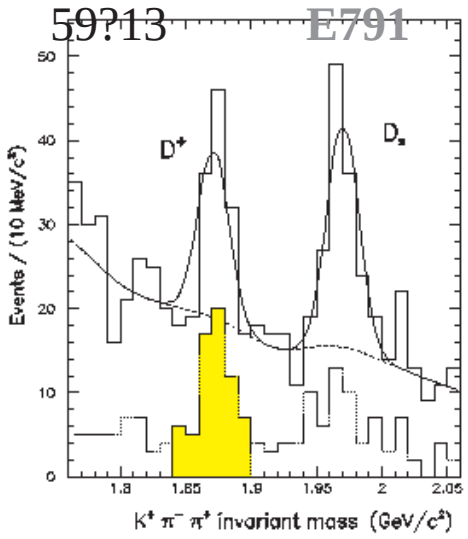
DCSD: no Pauli Interference, so without W-exchange:

$$BR(K^+\pi^-\pi^+/K^-\pi^+\pi^+) \cong \tau(D^+/D^0)\times\tan^4\theta_C$$

$$= (2.55\pm0.04)\times\tan^4\theta_C$$

$\to$ **$3.36\times\tan^4\theta_c$ with corrections for semileptonic rate**





E791 Data

PDG'98 (E687+E791) average for BR= (0.75±0.16)%

Preliminary FOCUS value:

$$\Gamma(K^+\pi^+\pi^-)/\Gamma(K^-\pi^+\pi^+) = (0.65\pm0.11)\%$$

$$\approx 3\times\tan^4\theta_C \approx (\tau^+/\tau^-)\times\tan^4\theta_C$$

Extracting the WA term in D^0 and D_s^+

World average $BR(K^+\pi\pi/K^-\pi\pi) = 0.68\pm0.09\ \% = 2.5\times\tan^4\theta_c$

$= \Gamma_{Spect}/\Gamma_{PI}\times\tan^4\theta_c$

Using $\tau(D^+)/\tau(D^0) = 2.55 = (\Gamma_{Spect}+\Gamma_{WX}+\Gamma_{SL})/(\Gamma_{PI}+\Gamma_{SL})$
and $BR_{SL}(D^0)$

$\longrightarrow \Gamma_{WX}/\Gamma_{Spect} = 0.35$ for D^0

Using $\tau(D_s^+)/\tau(D^0) = 1.2 = (\Gamma_{Spect}+\Gamma_{WX}+\Gamma_{SL})/(\alpha\Gamma_{Spect}+\beta\Gamma_{WX}+\Gamma_{SL})$
and $\alpha = 1/1.07$

$\longrightarrow \beta = 0.44$

$\Gamma_{WX}/\Gamma_{Spect} = 0.15$ for D_s^+

Can we account for these numerical values theoretically?

HEAVY FLAVOURS 8

Conclusions

- $\tau(D_s^+) > \tau(D^0)$ conclusively:

  $\tau(D_s^+)/\tau(D^0) = 1.191 \pm 0.024$ using published results

  $\tau(D_s^+)/\tau(D^0) = 1.211 \pm 0.017$ incl. preliminary FOCUS data

- Together with BR of DCSD $D^+ \to K^+\pi^+\pi^-$ one can extract:

  $\Gamma_{WX}/\Gamma_{Spect} \sim 0.35$ for D^0

  $\Gamma_{WX}/\Gamma_{Spect} \sim 0.15$ for D_s^+

  Consequences for large WA in other processes?
  e.g. lifetime of Λ_b, BR_{SL}

- More precise measurements on all charm meson and baryon lifetimes from Fermilab FOCUS and SELEX experiments very soon!

- Hope to inspire more theoretical work on understanding and calculating the uncertainties in $1/m_c$ expansion method