Recent Charm Physics Results From Fixed Target Experiments

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Results from 3 Fermilab experiments:

E791 Data in 1990/1991 - 500 GeV/c π^- beam

FOCUS Data in 1996/1997 - 50-300 GeV/c photon beam

SELEX Data in 1996/1997 - 600 GeV/c π^- and Σ^- beam

Concentrate on D^0 - $\overline{D^0}$ Mixing and CP Violation related topics

Results on D^0- $\bar{D}^0$ Mixing

Results receiving the most attention

Phenomenology:

$$|D_H>=p|D^0>+q|\overline{D^0}> \qquad |D_L>=p|D^0>-q|\overline{D^0}>$$

$$|D_H(t)>=e^{-im_Ht}e^{-\Gamma_Ht/2}|D_H> \qquad |D_L(t)>=e^{-im_Lt}e^{-\Gamma_Lt/2}|D_L>$$

$$|D^0(t)>=\frac{1}{2}\left(e^{-im_Ht}e^{-\Gamma_Ht/2}+e^{-im_Lt}e^{-\Gamma_Lt/2}\right)|D^0> +\frac{1}{2}\frac{q}{p}\left(e^{-im_Ht}e^{-\Gamma_Ht/2}-e^{-im_Lt}e^{-\Gamma_Lt/2}\right)|\overline{D^0}>$$

$$\Gamma(D^0\to K^+\pi^-)=\left|<K^+\pi^-|T|D^0(t)>\right|^2$$

Assume CP conservation and use approximations for charm: $\left|\frac{q}{p}\right|=1 \quad |x|,|y|,R_{DCS}<<1$

$$x=\frac{\Delta m}{\Gamma},\quad \Delta m=m_H-m_L,\quad \Gamma=\frac{1}{2}(\Gamma_H+\Gamma_L)$$

$$y=\frac{\Delta\Gamma}{2\Gamma}=\frac{\Gamma_{CPeven}-\Gamma_{CPodd}}{\Gamma_{CPeven}+\Gamma_{CPodd}}$$

$$R_{DCS}=\left|\frac{<K^+\pi^-|T|D^0>}{<K^+\pi^-|T|\overline{D^0}>}\right|^2$$

$$R_{WS}(t)=\left[R_{DCS}+(y\cos\delta-x\sin\delta)t\sqrt{R_{DCS}}+\frac{(x^2+y^2)}{4}t^2\right]e^{-t}$$

δ = strong phase difference between CF and DCS

$$R_{WS}(t)=\left[R_{DCS}+y't\sqrt{R_{DCS}}+\frac{(x'^2+y'^2)}{4}t^2\right]e^{-t}$$

$$y'\equiv y\cos\delta-x\sin\delta$$

$$x'\equiv x\cos\delta+y\sin\delta$$

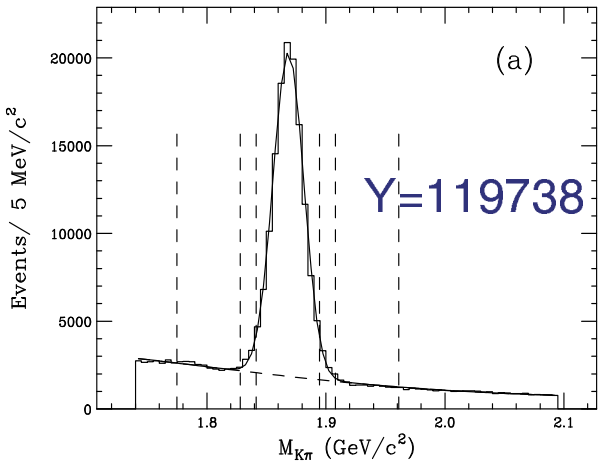
$$\Gamma(D^0\to K^-\pi^+)\sim e^{-t}\left(1+\frac{(y^2-x^2)}{4}t^2\right)$$

Results on D^0 - $\bar{D}^0$ Mixing

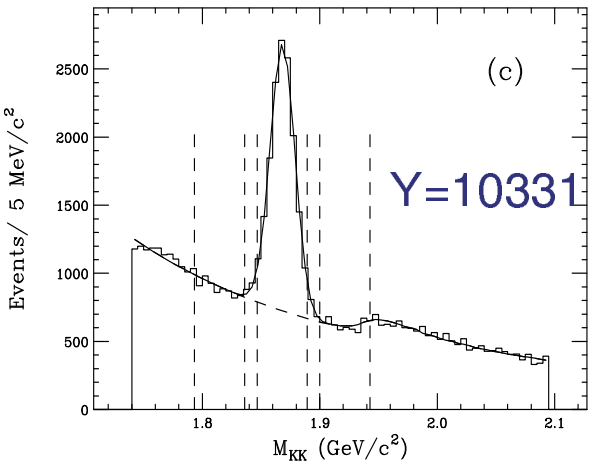
Looking at the decay rate difference

FOCUS has measured a lifetime difference:

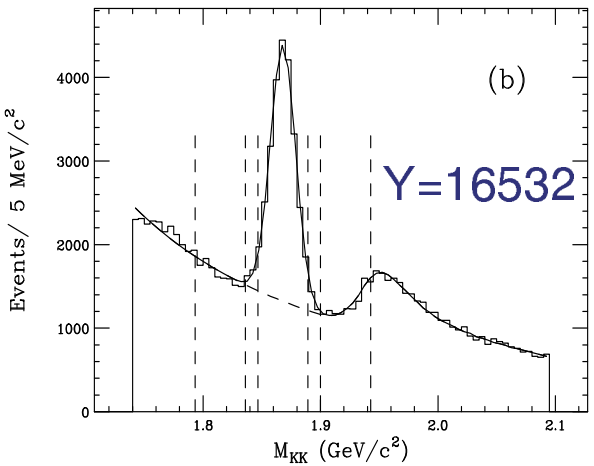
$$y_{CP} = \frac{\Gamma(CPeven)-\Gamma(CPodd)}{\Gamma(CPeven)+\Gamma(CPodd)} = \frac{\tau(D^0 \to K^- \pi^+)}{\tau(D^0 \to K^- K^+)} - 1$$



M(Kπ)



M(KK)

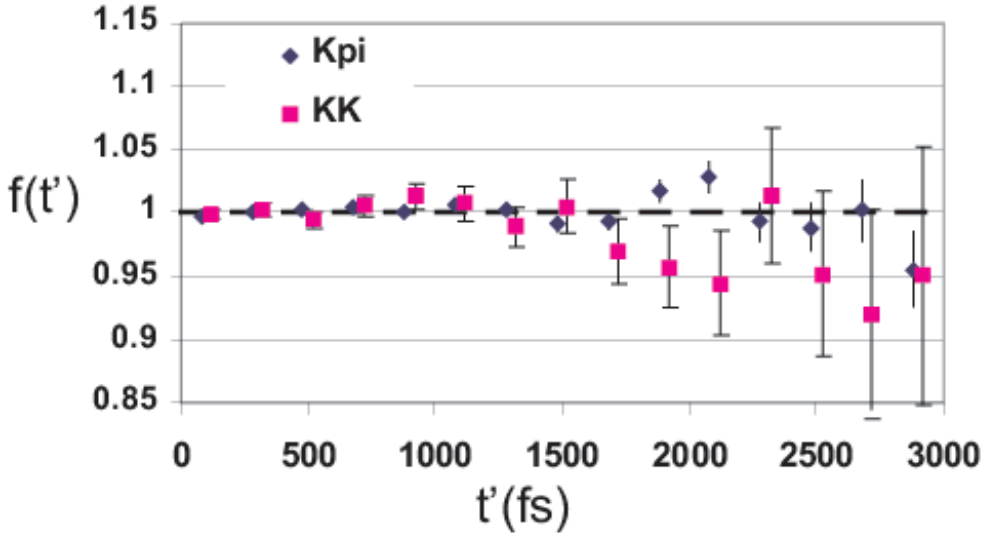


M(KK)
looser Kπ separation

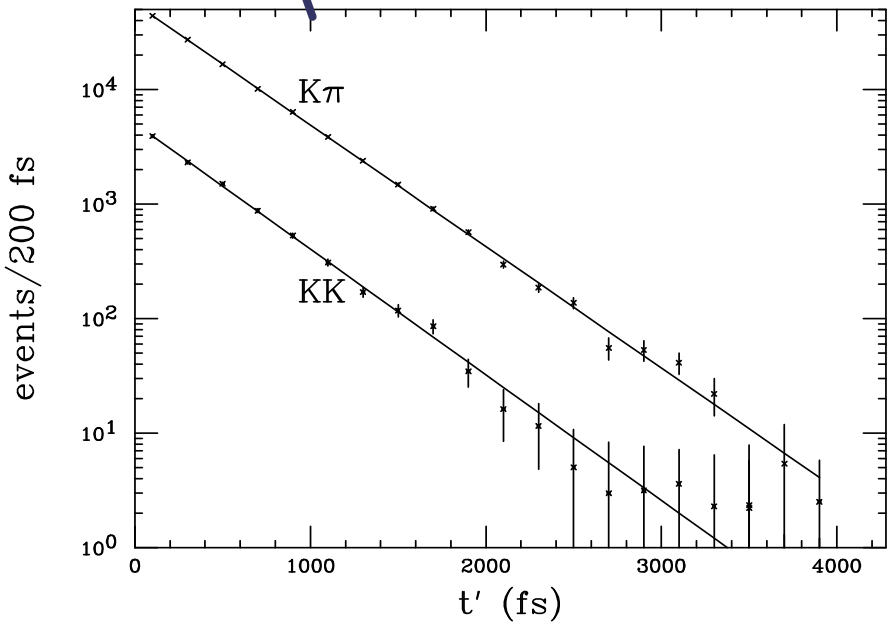
Results on D^0- $\bar{D}^0$ Mixing

Looking at the decay rate difference

Corrections from a pure exponential decay:



Lifetime fits



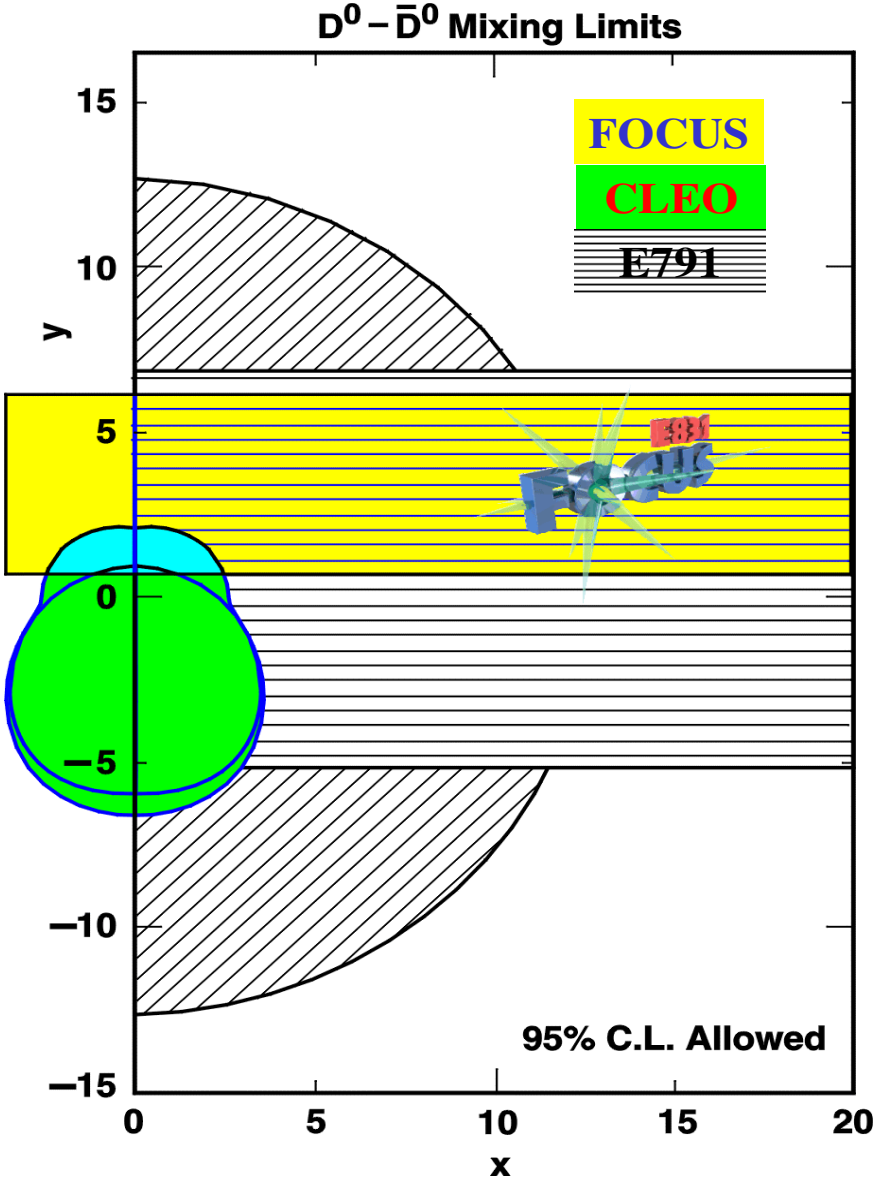
$$y_{CP} = (3.42 \pm 1.39 \pm 0.74)$$

$$\tau(D^0 \to K^-\pi^+) = 409.2 \pm 1.3 \text{ fs}$$

(statistical error only)

Results on D^0 - $\bar{D}^0$ Mixing

Comparison of Results



- Comparison to CLEO and E791 results
  Valid for small δ (strong phase difference)
- These results have provoked a large amount of theoretical interest centred on the following:
  - IF true values of y and y' are within 1σ of measured values
  - Expectation for δ (SU(3) breaking)
  - SM expectation for y
- Results still consistent with no mixing (or much smaller values of x and y)

Results on D^0- $\bar{D}^0$ Mixing

Theoretical analysis of the comparison of FOCUS and CLEO Results

Bergmann, Grossman, Ligeti, Nir and Petrov - Phys. Lett. B486 (2000) 418

- Model independent analysis of FOCUS and CLEO results (IF within 1σ of these)
  - $y \sim$ few % even with CP violation and $x \neq 0$
  - Need δ large than about 45 degrees (this is zero in SU(3) limit)

Gronau and Rosner - hep-ph/0010237

- Study of SU(3) breaking within D decays
  - Can get up to 20 degrees but 45 degrees not accommodated in their scheme

Bigi and Uraltsev - Nucl. Phys. B592 (2001) 92

- Reanalysis of SM short-range and long-range contributions to mixing
- Reanalysis based on x, y ~ SU(3) breaking $\times 2\sin^2\vartheta_C \times \Gamma_D \sim$ few $\times$ 0.01
  - higher level quark level contributions can give x,y ~ 10^{-3} Only estimated! (without LD contributions)
  - Dispersive LD calculations have phases like δ in the calculation, set to 0
  - SU(3) breaking for exculsive versus inclusive rates
  - x ~ y and matrix elements too small; or local quark-hadron duality violation

Still need better understanding of SM expectation for x and y AND more data

Results on D^0 - $\bar{D}^0$ Mixing

New result from FOCUS on WS decay $D^0 \rightarrow K^+\pi^-$

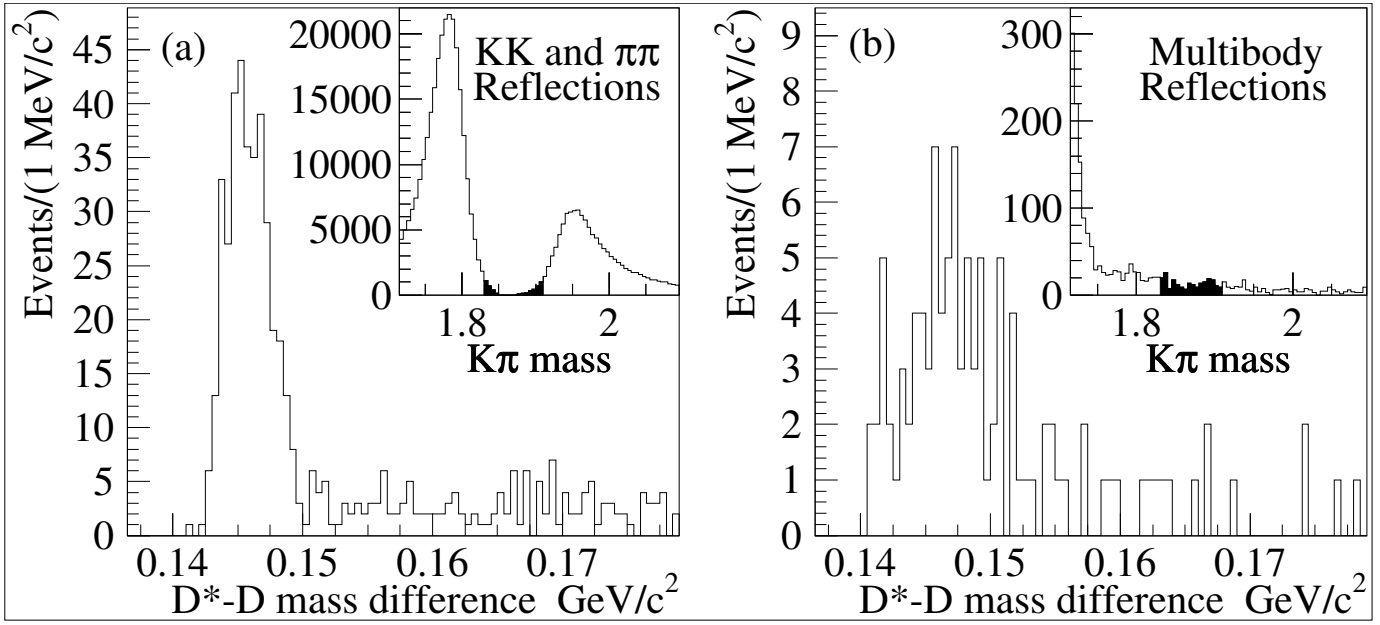
Signal/Background lower than in CLEO:

- Double mis-ID Cabibbo favoured decay: $D^0 \rightarrow K^-\pi^+$

  Tight particle ID cut for $M(K^-\pi^+)$ within 4σ of D^0 mass

- Single Mis-ID and multi-body (KK, $\pi\pi$, $K\pi\pi^0$, $K l \upsilon$,...)

  New method to handle these to increase observed signal

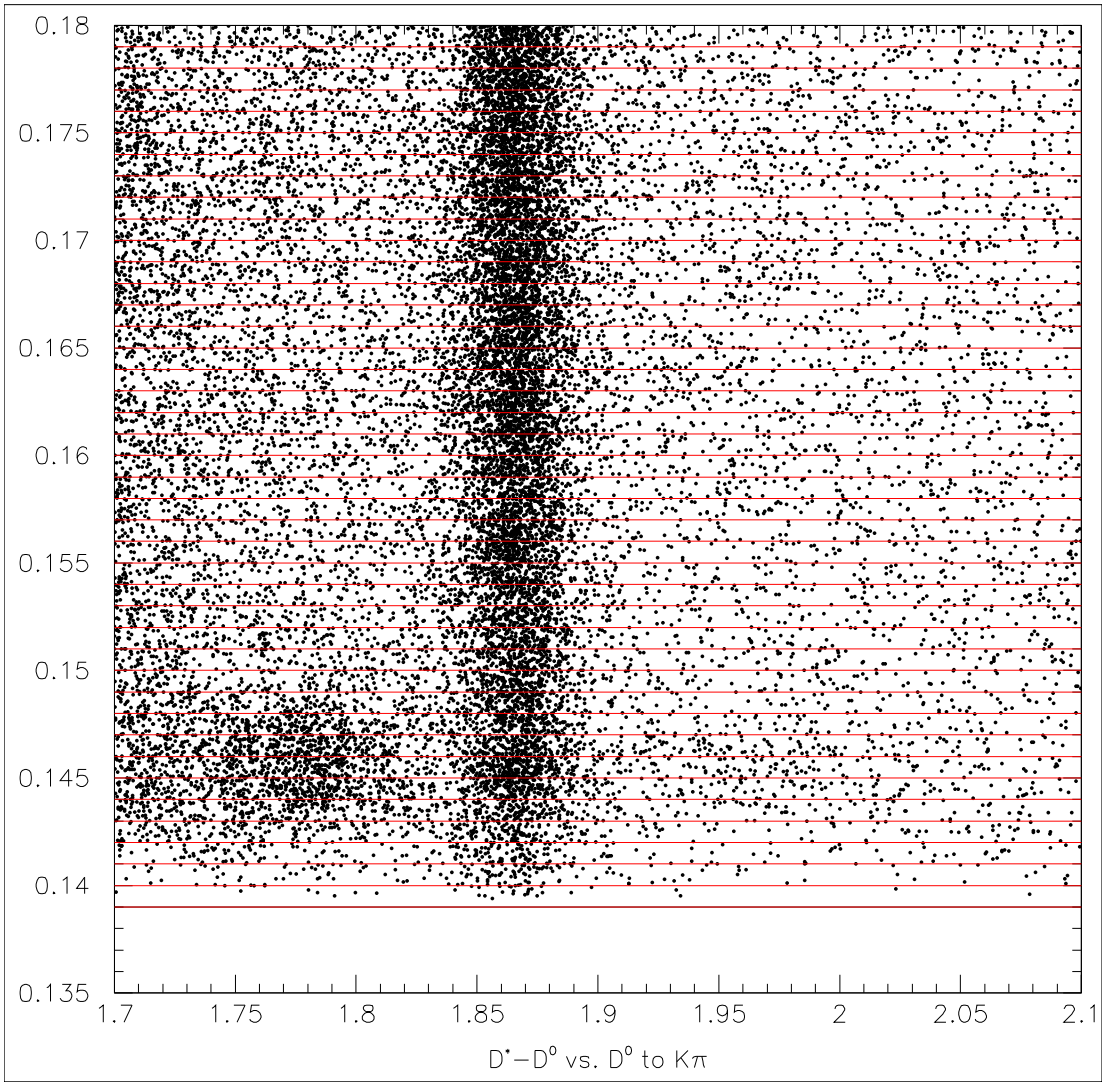


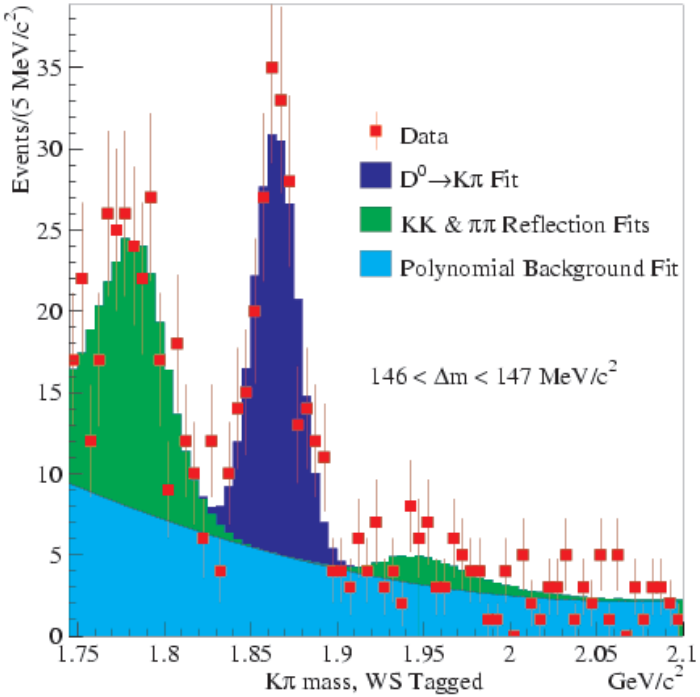
Monte Carlo study

Results on D^0- $\bar{D}^0$ Mixing

New result from FOCUS on WS decay $D^0 \rightarrow K^+\pi^-$

Fit the $K\pi$ mass in 1 MeV bins of D^*- D mass difference:

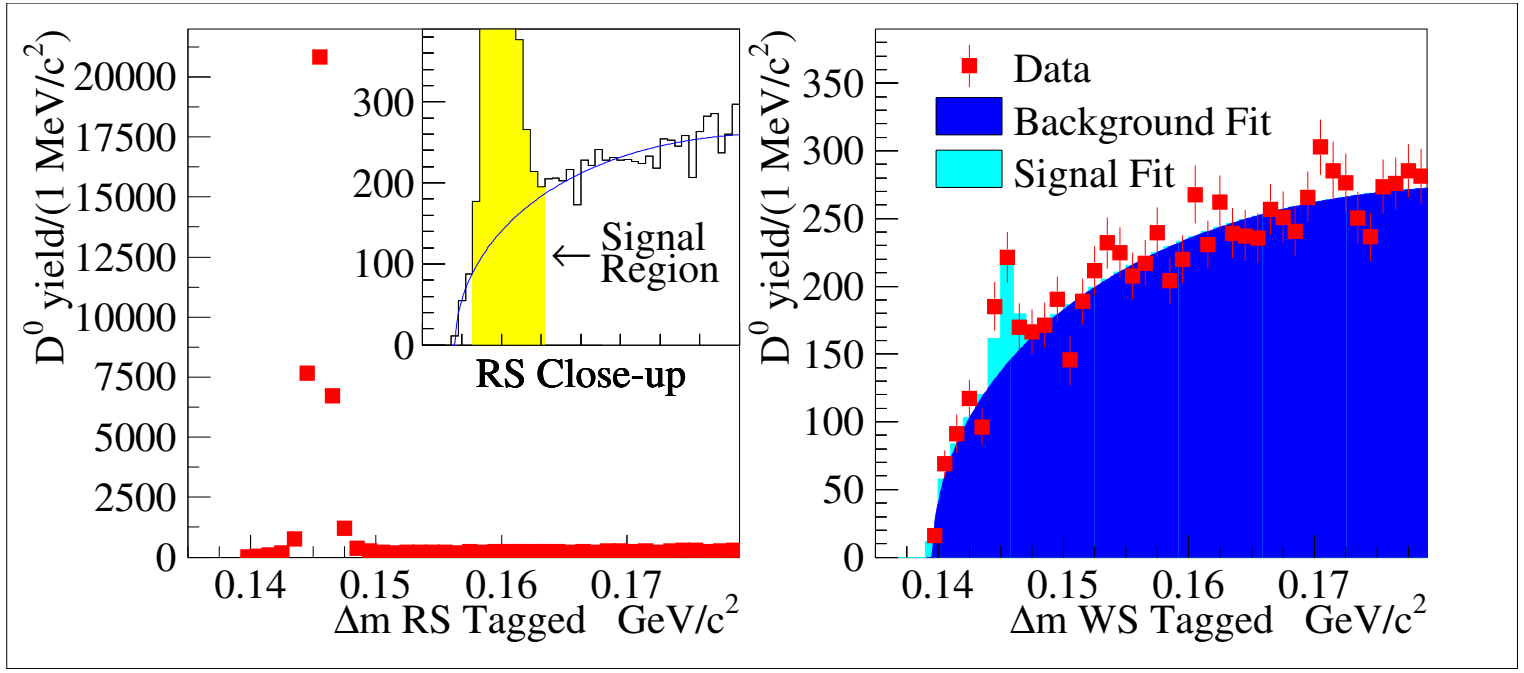




Results on D^0 - $\bar{D}^0$ Mixing

New result from FOCUS on WS decay $D^0 \rightarrow K^+\pi^-$

Fit the real D yields vs D^* - D mass difference:



$R_{WS} = (0.404 \pm 0.085 \pm 0.025)\%$

Yield(RS) = 36760 ± 195

Yield(WS) = 149 ± 31

Interpretation in the possible presence of mixing?

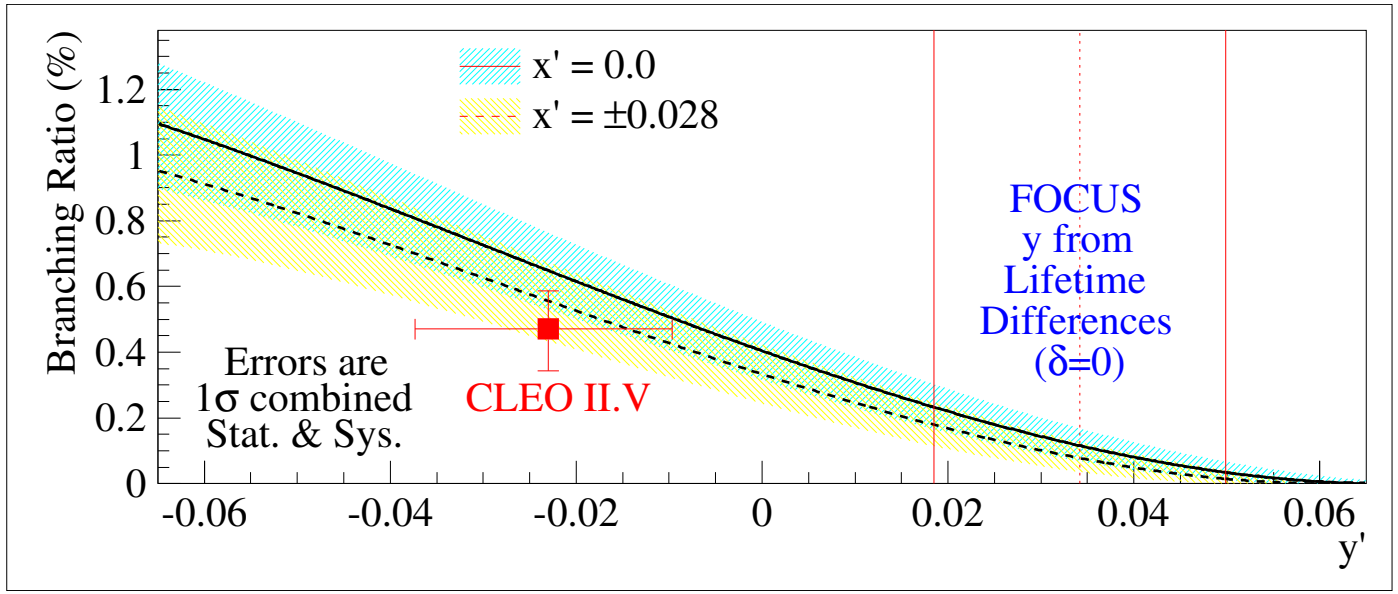
$$R_{WS}(t) = \left[R_{DCS} + y' t \sqrt{R_{DCS}} + \frac{(x'^2 + y'^2)}{4} t^2 \right] e^{-t}$$

Results on D^0 - $\bar{D}^0$ Mixing

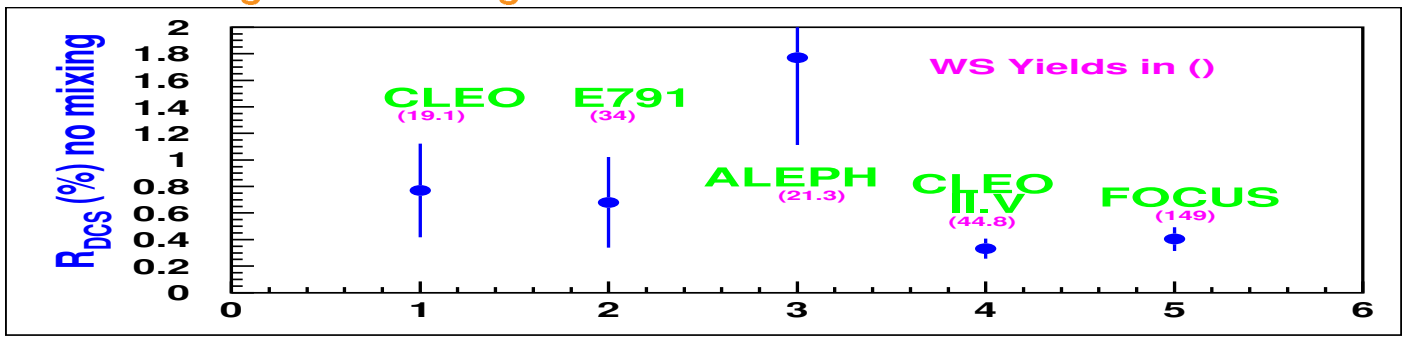
New result from FOCUS on WS decay $D^0 \rightarrow K^+\pi^-$

Interpretation in the possible presence of mixing gives a profile:

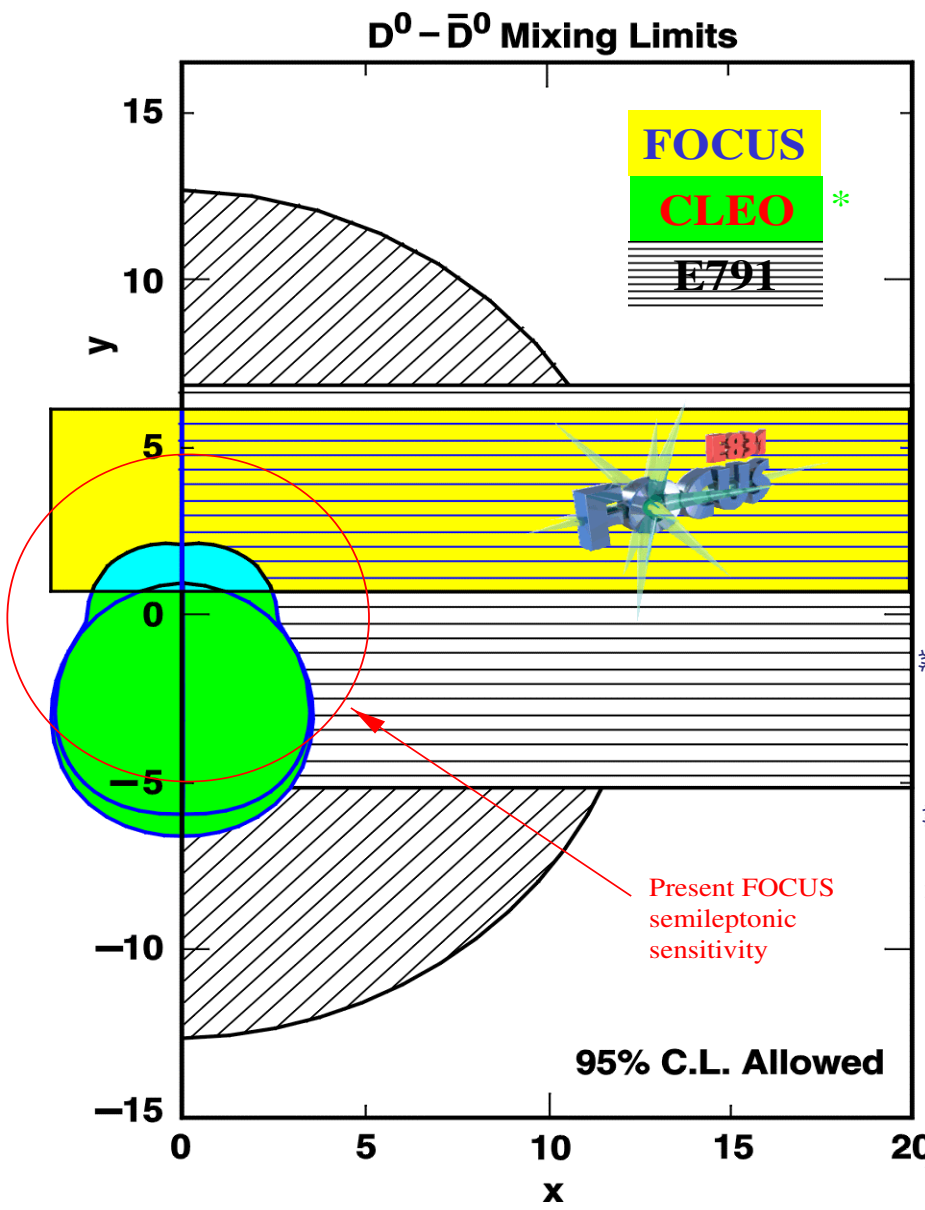
$$R_{WS}^{meas.} = R_{DCS} + y' < t > \sqrt{R_{DCS}} + \frac{(x'^2 + y'^2)}{4} < t^2 >$$

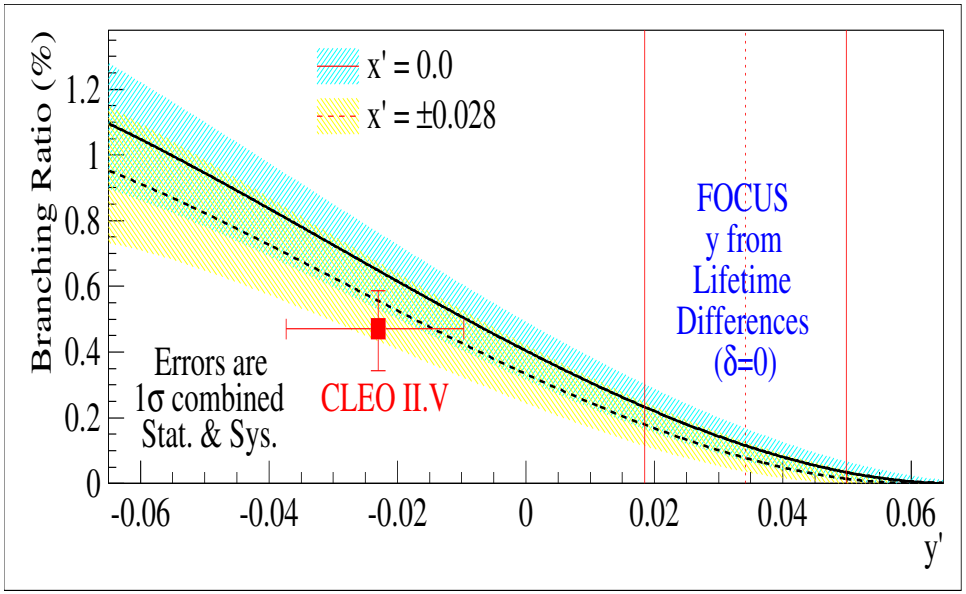


Interpretation assuming zero mixing:



Summary on D^0 - $\bar{D}^0$ Mixing





- Data is still inconclusive
  - Expected sensitivity from semileptonic decays from FOCUS is shown
- Results consistent with zero (small) mixing
- Even IF y ~ few %, x must be measured
  - Cannot infer New Physics from a single measurement, need many, e.g. δ
  - (Much like for B physics)
- Wait with interest for data from B factories!

* CLEO result displayed assuming strong phase = 0

Search for CP Violation in Charm

New results from FOCUS

Need to normalize out production asymmetries as well as use tagging

$$A_{CP} = \frac{\eta(D) - \eta(\bar{D})}{\eta(D) + \eta(\bar{D})} \qquad \eta(D) = \frac{N(D^0 \to K^- K^+)}{N(D^0 \to K^- \pi^+)} \frac{\epsilon(D^0 \to K^- \pi^+)}{\epsilon(D^0 \to K^- K^+)}$$

Summary of measured Asymmetries

Experiment	$D^+ \to K^- K^+ \pi^+$	$D^0 \to K^- K^+$	$D^0 \to \pi^+ \pi^-$
E687	-3.1 ± 6.8	2.4 ± 8.4	
CLEO II		8.0 ± 6.1	
E791	-1.4 ± 2.9	$-1.0 \pm 4.9 \pm 1.2$	$-4.9 \pm 7.8 \pm 3.0$
FOCUS	$0.6 \pm 1.1 \pm 0.5$	$-0.1 \pm 2.2 \pm 1.5$	$+4.8 \pm 3.9 \pm 2.5$

Sensitivities now at the few % level

A LONG way to go to the SM ~ 10^{-3} level

Still sensitive to new physics (at least if seen in multiple decay modes!)

Search for CP Violation in Charm and Dalitz Plot Analyses of Hadronic Decays

Dalitz plot (amplitude) analysis needed for multi-body decays to study

CP violation

Mixing (Rate difference) % of CPeven and CPodd states

New results from E791 for the decay modes:

$\Lambda_c^+ \rightarrow pK^-\pi^+$ - New for spin 1/2 initial state

$D_s^+ \rightarrow \pi^-\pi^+\pi^+$ - study of the f^0

$D^+ \rightarrow \pi^-\pi^+\pi^+$ - evidence for broad scalar σ

$D^+ \rightarrow K^-\pi^+\pi^+$ - evidence for broad scalar κ

$\Rightarrow$Laboratory for study of light quark physics

Will phases become an area of theoretical interest?

New results to come from FOCUS on many Dalitz plot analyses

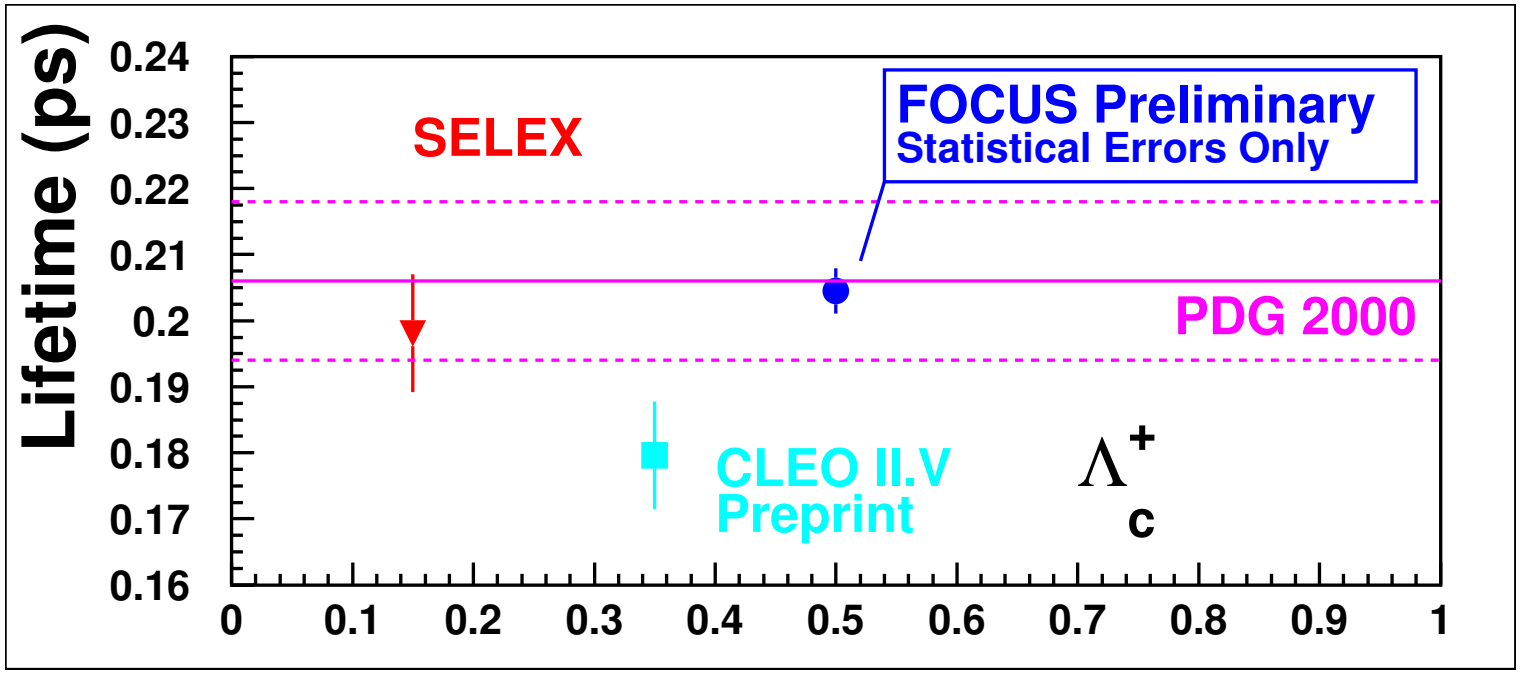
Charm Lifetime Measurements

Lifetime resolution is very important in mixing studies

New lifetimes from SELEX for D^0 (10210 events) and for the Λ_c

Compared to PDG2000, preliminary FOCUS and CLEO values:

	Number of Λ_c	Lifetime resolution
SELEX	1630	20 fs
FOCUS	8520	30 fs
CLEO II.V	4749	~140 fs



Fixed target results will provide a benchmark for B-factories

Summary

D^0 - $\overline{D}^0$ Mixing

- Data is still inconclusive
  - Current Fixed Target dataset probably will not be able to provide conclusive (5σ) measurement of non-zero x and y
- Results still consistent with zero (small) mixing
- Even IF y ~ few %, x must be measured, other quantities like δ also helpful
  - Cannot infer New Physics from a single measurement, need many and look for inconsistencies (much like for B physics)
- Wait with interest for charm data analyses from B factories!

CP Violation

- Sensitivities in the few % level
  - New Physics if see % level CP violation in multiple decay modes
- Not likely to see SM CP violation in charm decays at B factories
  - Will probably need to wait for an experiment like BTeV