Charm Lifetimes and Mixing

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Review of results from the following experiments:

Fixed Target Experiments

E687

E831 FOCUS

E791

SELEX

$e^+ e^-$ Collider Experiments

CLEO

BABAR

BELLE

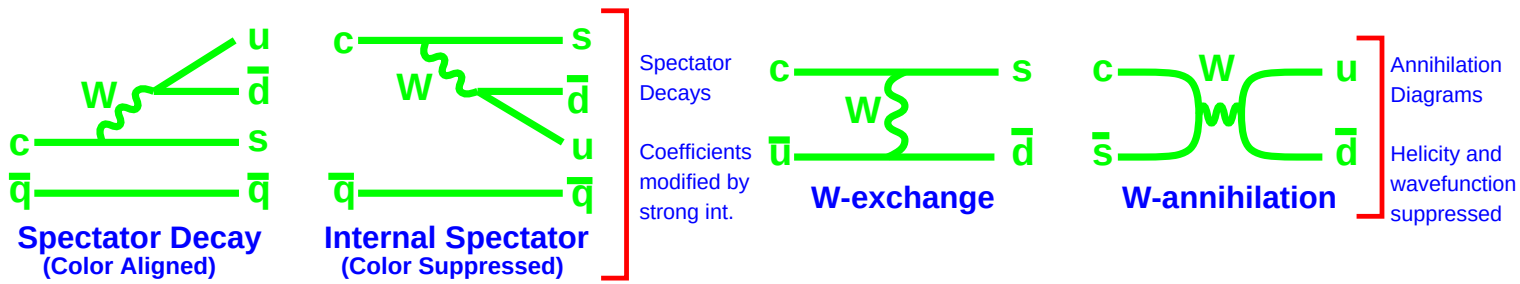
9th International Symposium on Heavy Flavor Physics

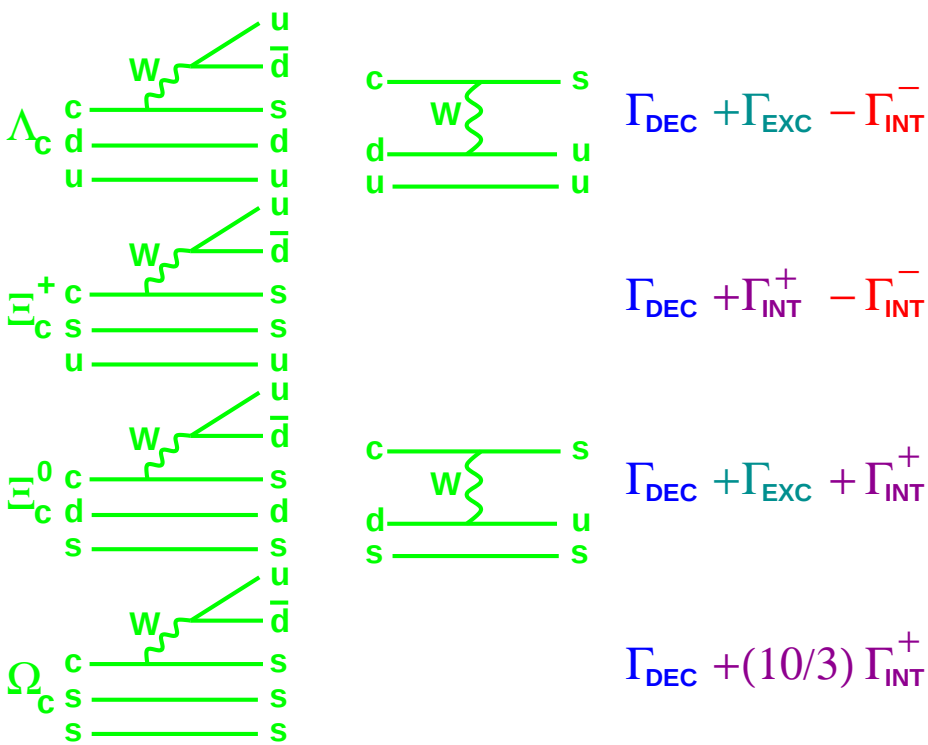
Lifetimes: Motivation

Physics: Study of strong interactions

❶ "test" theoretically challenged part of SM (i.e. non-perturbative QCD)

❷ Experimental results can give guidance





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

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

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

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

❸ Same/Similar calculations enter other areas

e.g. Extract V_{cs} and V_{cd} from charm decays

B lifetimes

Extract other SM parameters or decay constants in heavy flavour physics

Lifetimes: Motivation II

Technical:

❶ Needed to convert BR to decay rates to compare to theory and extract SM parameters

❷ Test techniques/systematics in other areas where lifetimes and lifetime resolution/vertexing is important

E.g. in D and B Δm mixing measurements (e.g. B_s)

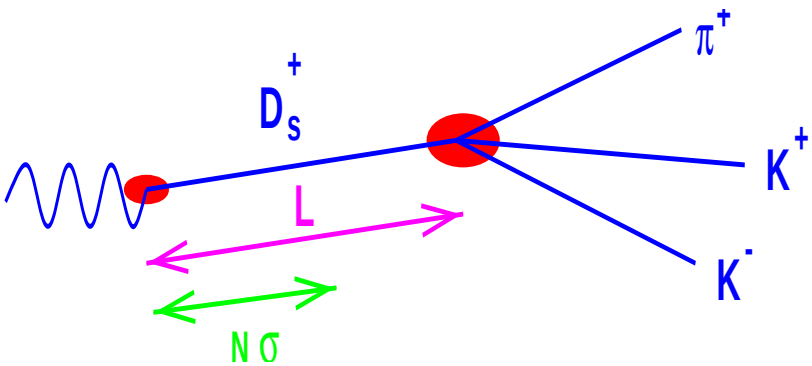
in $\Delta\Gamma$ measurements for D and B

Lifetimes: Comparison I

	Fixed Target			$e^+ e^-$ Collider		
	E791	SELEX	FOCUS (& E687)	CLEO	BABAR	BELLE
Beam	Hadronic		Photon	Off-resonance e^+e^-		
Charm	$\sim 10^5$	$\sim 10^4$	$\sim 10^6$		$>10^6$	
σ_t	~40 fs	~20 fs	~40 fs	~140 fs	~160 fs	
	Uses vertex detachment cut Uses 3-D decay length			Needs average IP position Uses ~2-D decay length		

Lifetimes: Comparison II

Fixed Target Experiments



❶ Uses $L > N\sigma_L$ (and outside target)
Cuts out short lifetimes

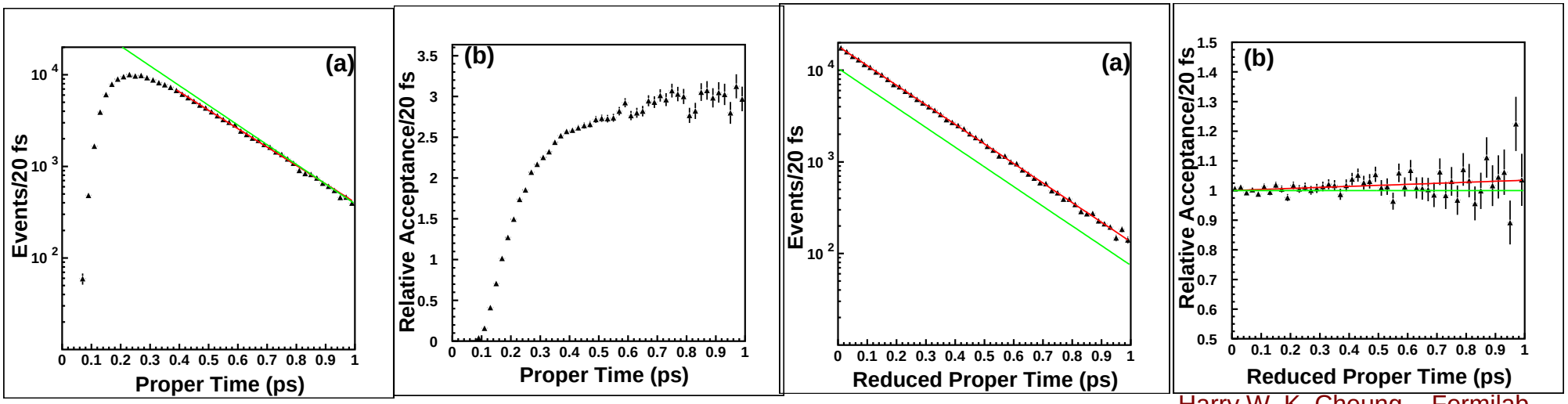
❷ Use *Reduced Proper Time*

$$t' = L/\beta\gamma c - N\sigma_L/\beta\gamma c$$

to reduce acceptance corrections

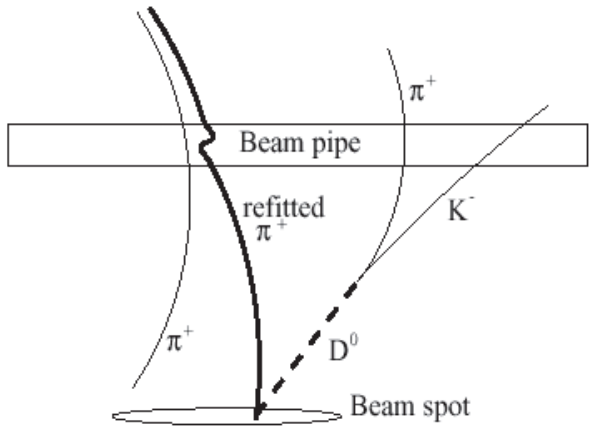
❸ Acceptance checked with data
e.g. with K_s decays

❹ Systematics from acceptance
and/or background



Lifetimes: Comparison III

$e^+ e^-$ Collider Experiments

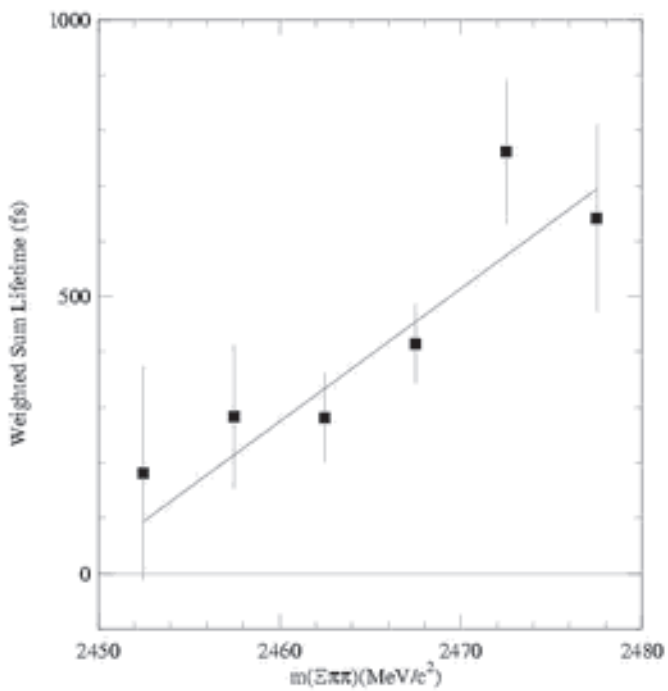


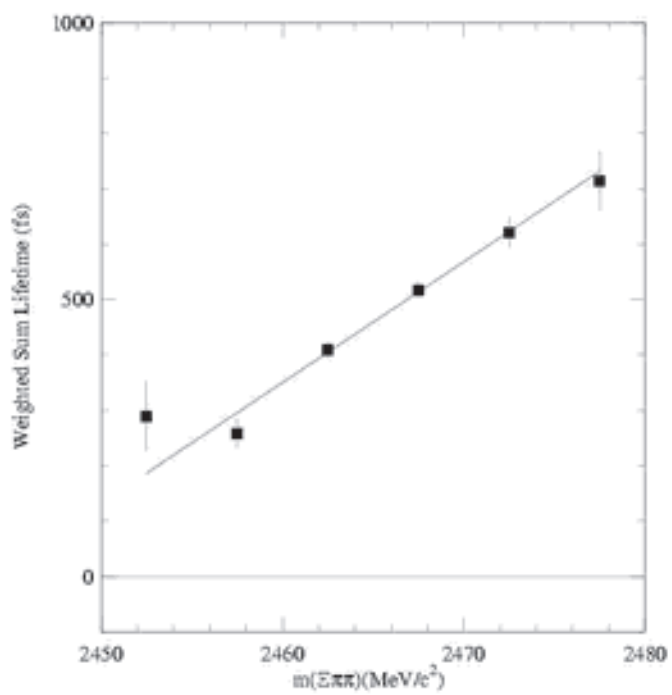
❶ **Silicon vertex detectors ⇒ charm lifetimes**
But poorer time resolution

❷ **Needs average IP position**
Needs good knowledge of m & t resolutions

❸ **More complicated fits using parameterized resolution and background functions**

❹ **Systematics from vertexing, resolutions and fit biases**





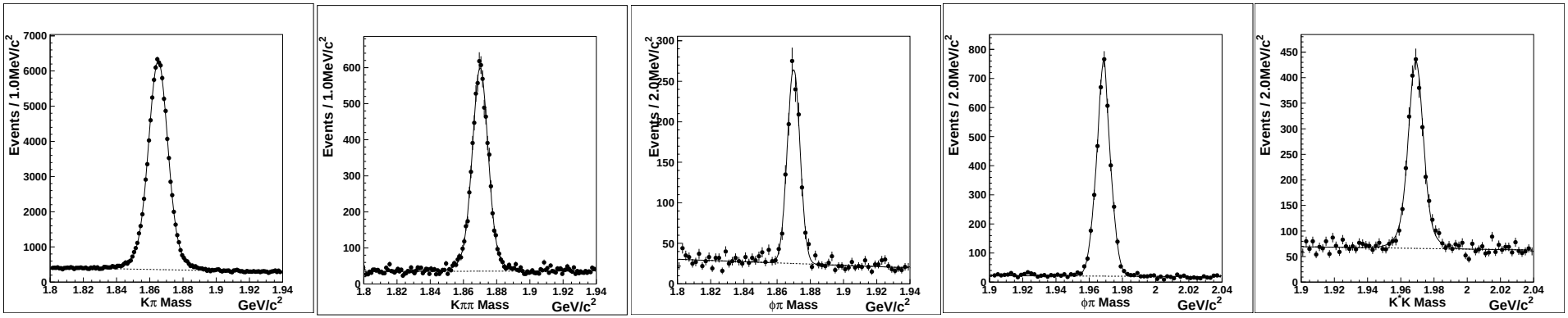
e.g. "acceptance" issues

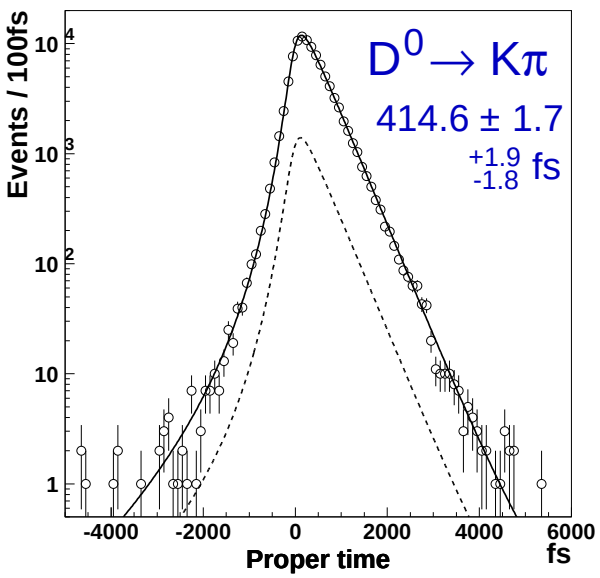
Lifetime vs recon. mass
Data and MC
for CLEO Ξ_c^+

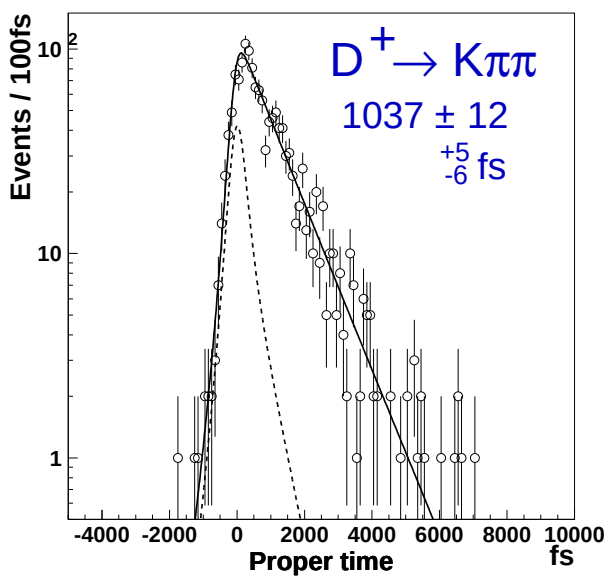
Lifetimes: Results for Mesons

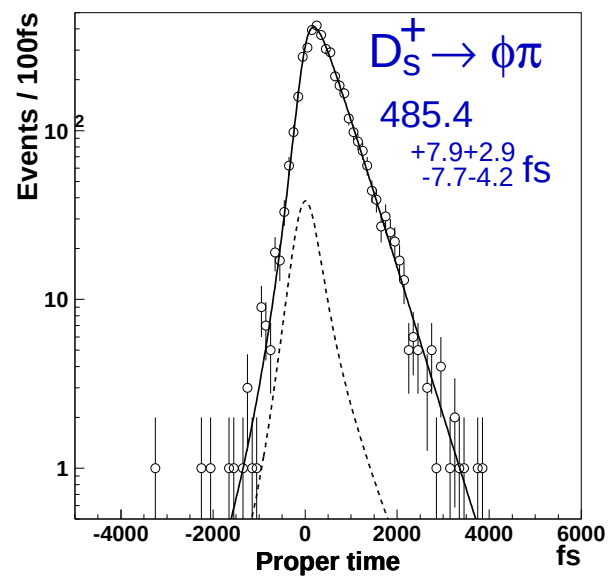
New preliminary results from BELLE (statistical and systematic errors incl.)

$D^0 \to K\pi$ $D^+ \to K\pi\pi$ $D^+ \to \phi\pi$ $D_s^+ \to \phi\pi$ $D_s^+ \to K^*K$





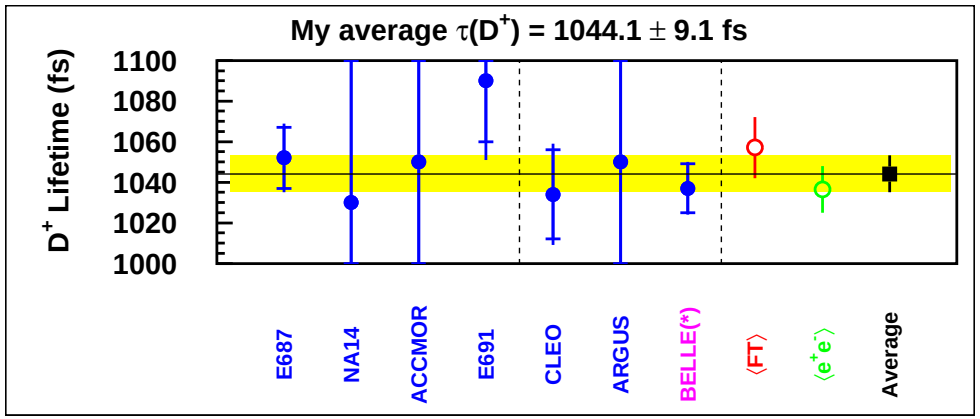




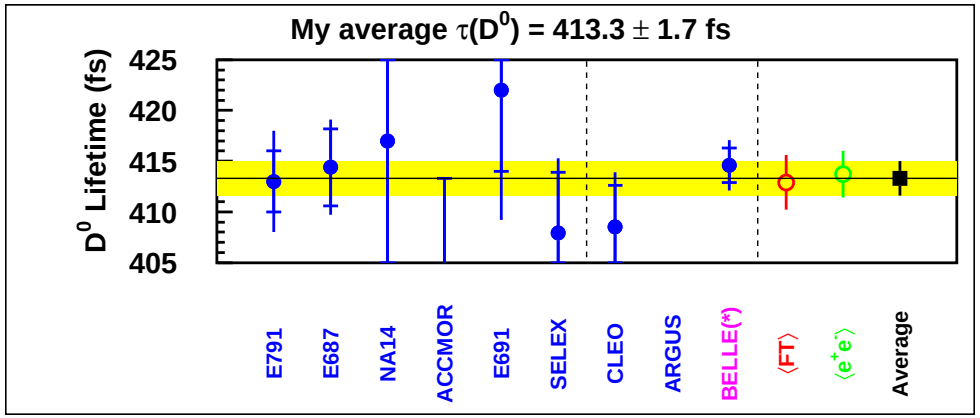
Also old preliminary result from FOCUS for $D_s^+ \to \phi\pi$

Lifetimes: Results for Mesons

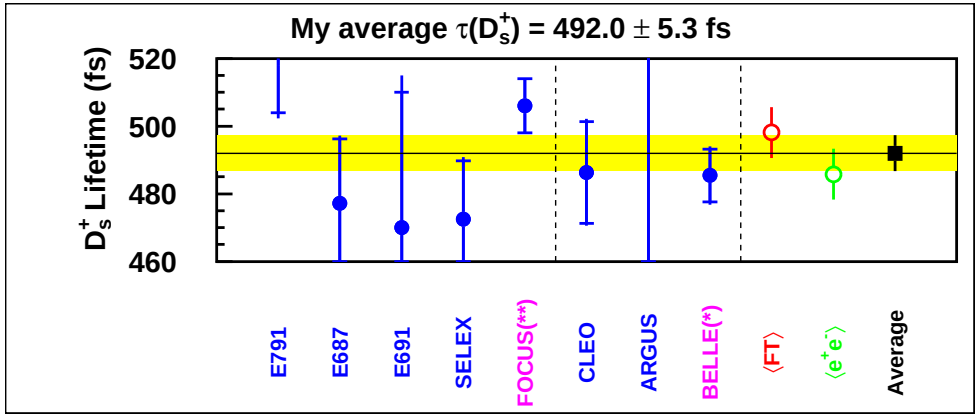
D^+



D^0



D_s^+



Preliminary Results marked with (*)

My average:

$$\tau(D_s^+)/\tau(D^0) = 1.190 \pm 0.014$$

(direct measurements (3) gives: 1.171 ± 0.018)

Expect < 1.07 without WA/WX

Bigi and Uraltsev, Z. Phys. C62 623 (1994)

Shows that WA/WX is sizable even for mesons

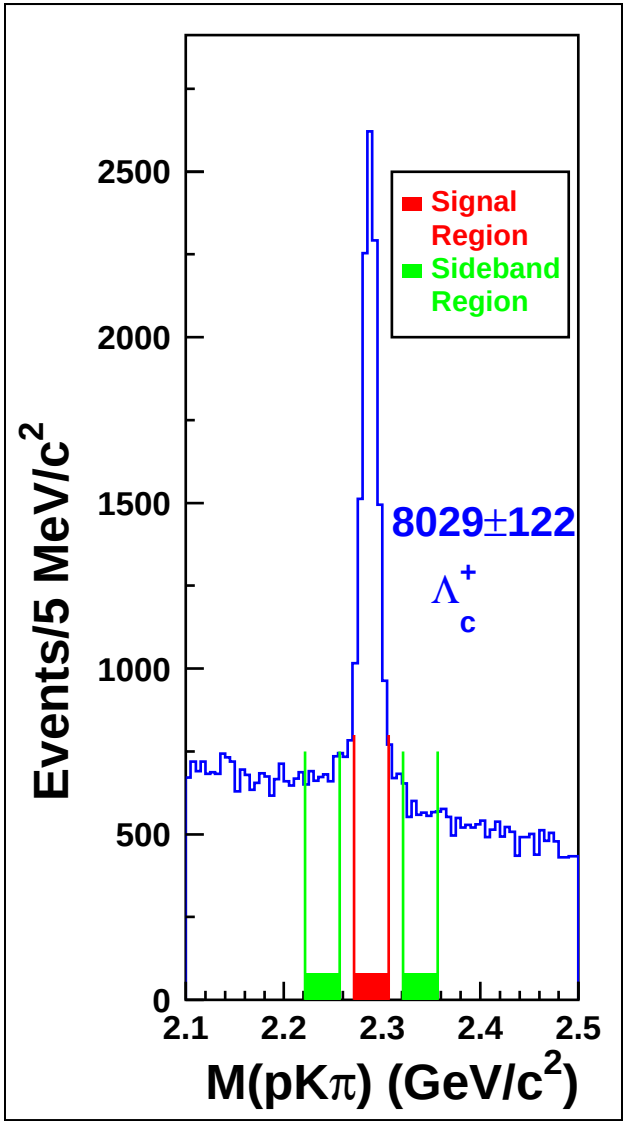
Implications for Calculations of Baryon Lifetimes?

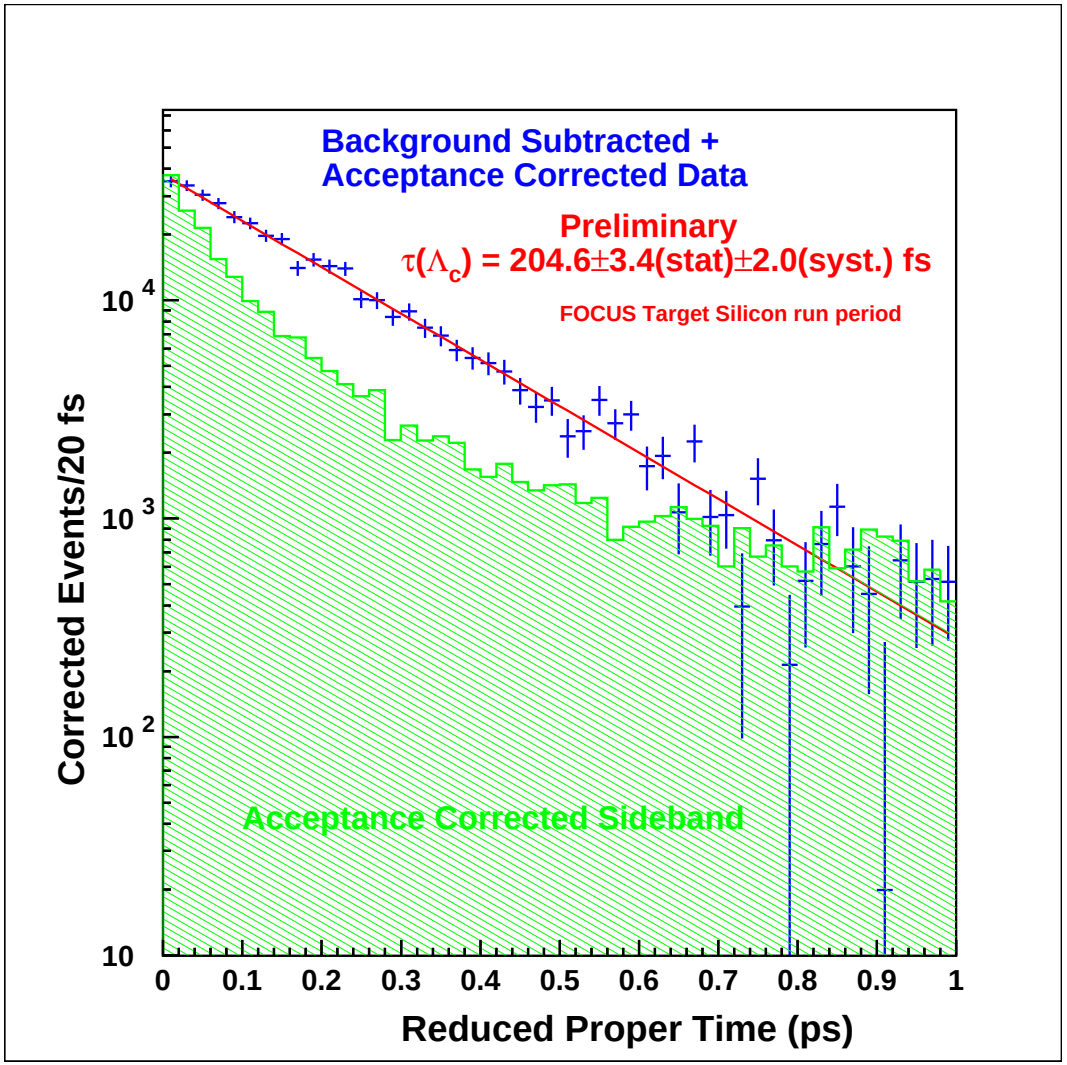
Preliminary Results with statistical errors only marked with (**)

(Stat. errors shown but used total error given by $\sqrt{2} \times$ stat. error)

Lifetimes: Results for Baryons

Λ_c^+ New preliminary result from FOCUS with stat. and syst. errors shown in HADRON 2001



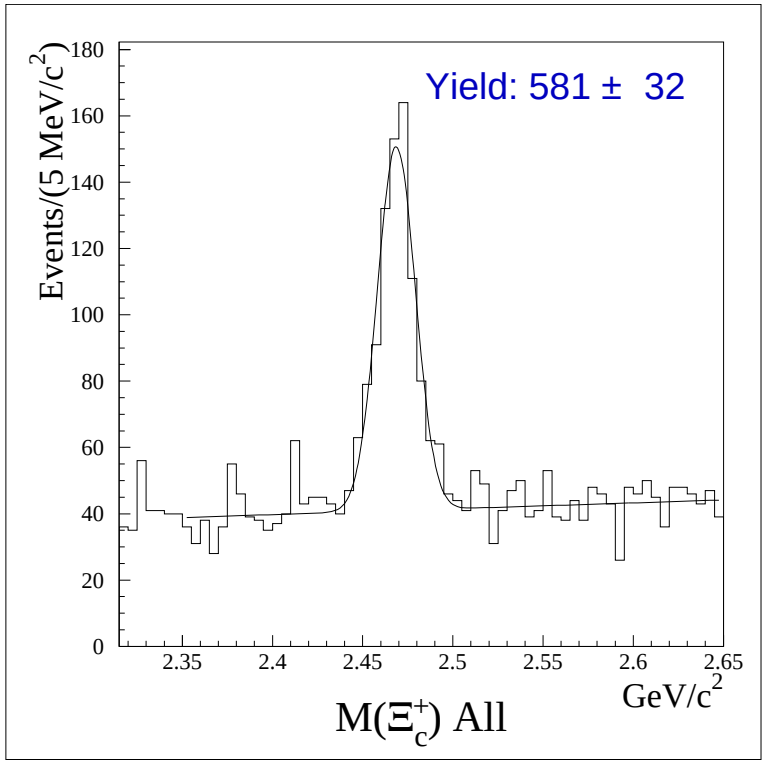


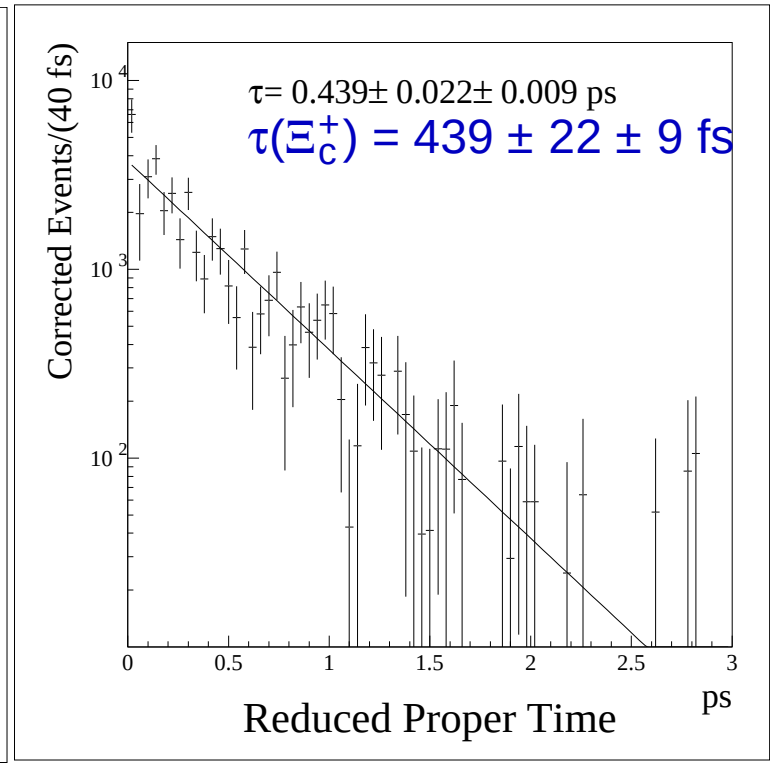
Lifetimes: Results for Baryons

Ξ_c^+ New preliminary results from FOCUS and CLEO with stat. and syst. errors

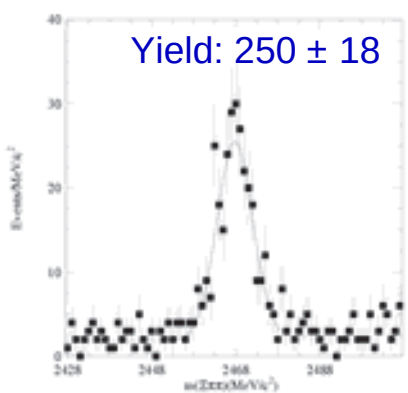
Combined

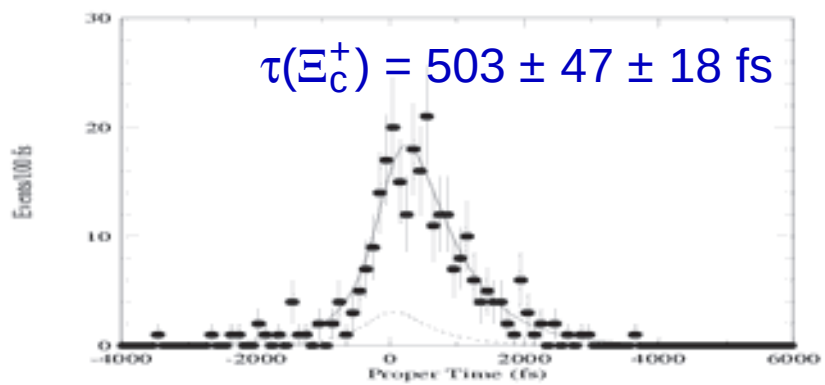
$\Xi\pi\pi$, $\Sigma^+K\pi$, $pK\pi$, $\Lambda K\pi\pi$





CLEO

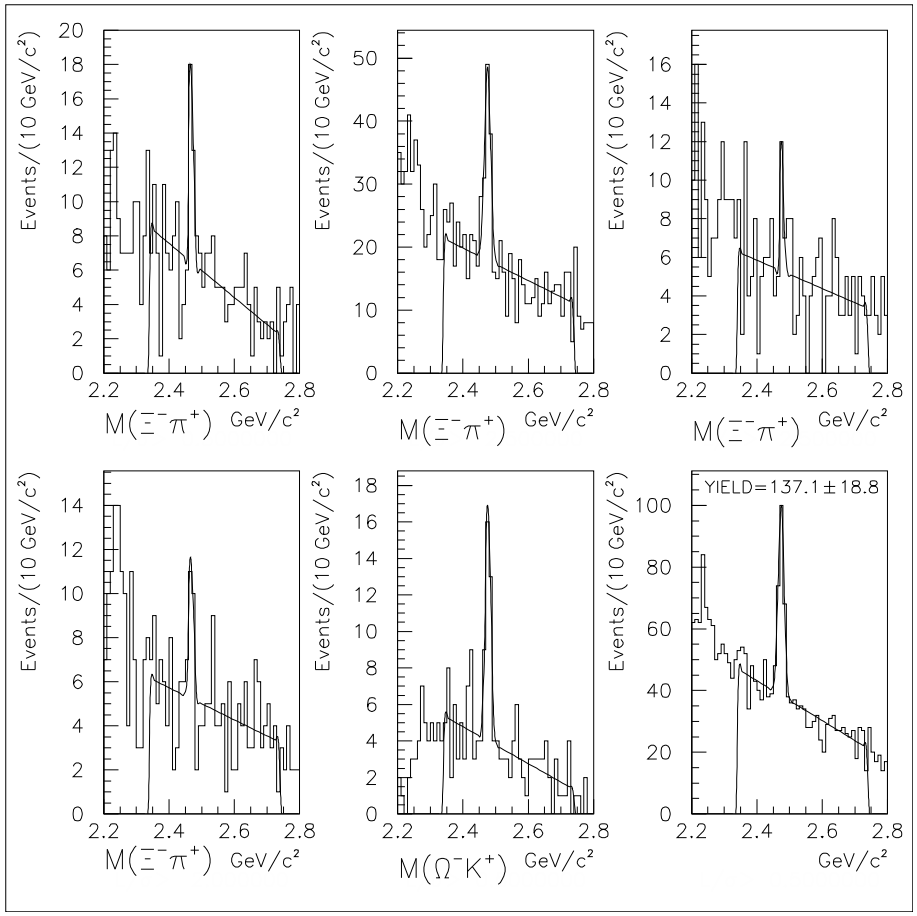




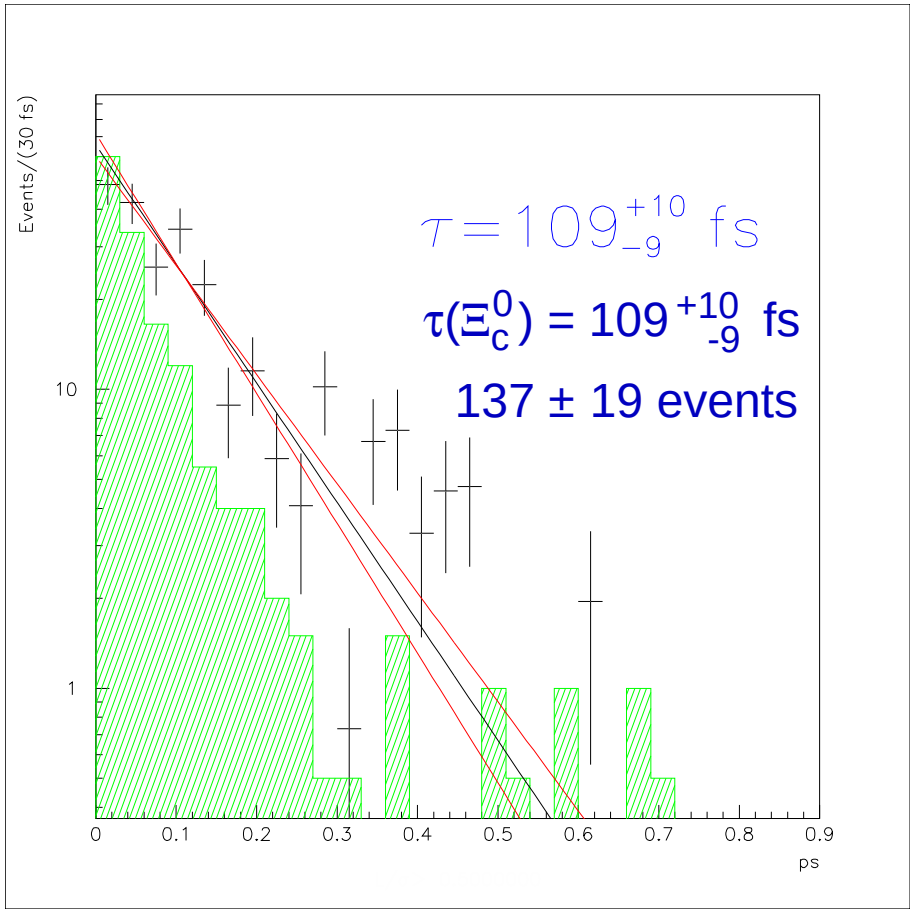
Lifetimes: Results for Baryons

Ξ_c^0 New preliminary result from FOCUS statistical errors only

Ξ^* tagged $\Xi\pi$ | $\Xi\pi$ | $\Xi\pi$ partial recon 1

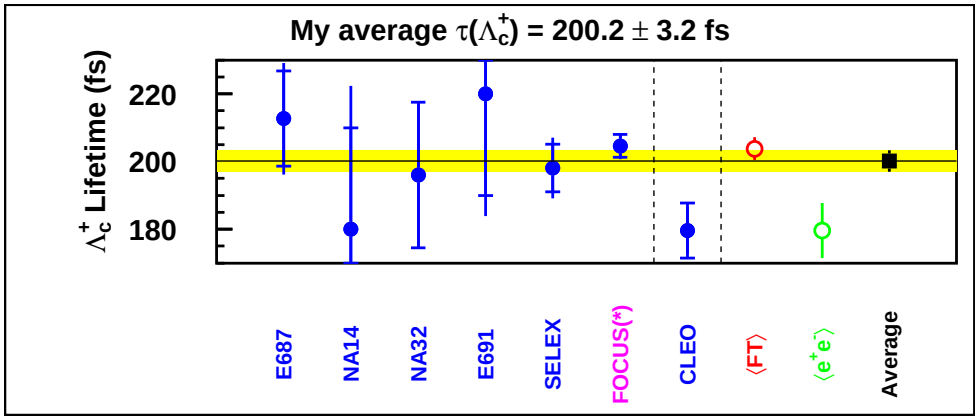


$\Xi\pi$ partial recon 2 | ΩK | Total

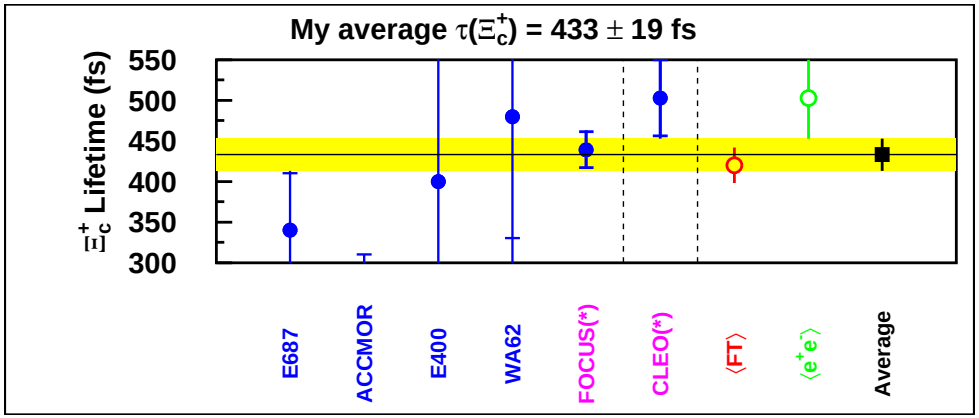


Lifetimes: Results for Baryons

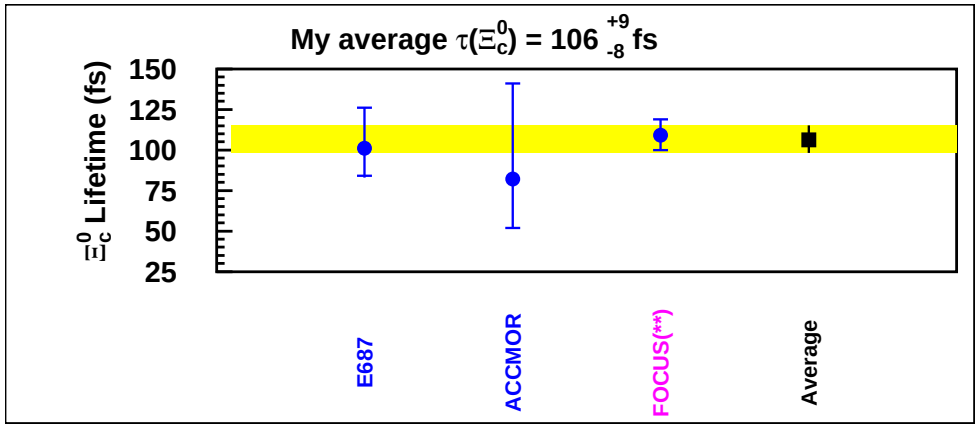
Λ_c^+



Ξ_c^+



Ξ_c^0



Preliminary Results marked with (*)

⇐ Difference between CLEO and Fixed-Target result is worrying?

(with new preliminary result from FOCUS which includes systematic errors)

No new result for Ω_c

but signals from CLEO and BELLE

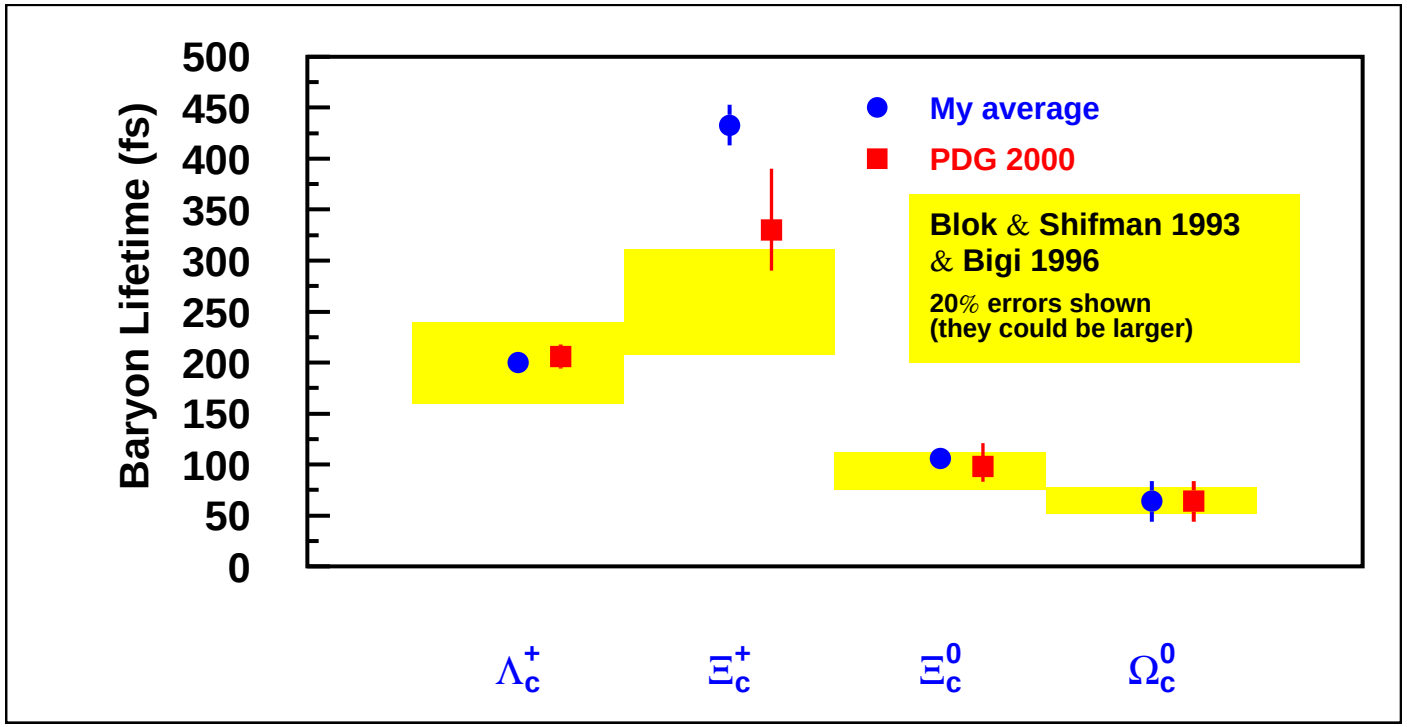
Expect Ξ_c result from SELEX

Preliminary Results with statistical errors only marked with (**)

(Stat. errors shown but used total error given by $\sqrt{2} \times$ stat. error)

Lifetimes: Results for Baryons

Summary of all charm baryon results



Blok and Shifman 1993 - hep-ph/9311331
Bigi 1996 - hep-ph/9612293

Biggest change: $\tau(\Xi_c^+)/\tau(\Lambda_c^+) = 2.16 \pm 0.11$ compared to PDG 2000 = $1.60^{+0.31}_{-0.22}$

Still need better lifetime measurements for Ξ_c^0 and Ω_c^0

Need to feedback this into theory - time for more progress?

D-Mixing Review I

Phenomenology:

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

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

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

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

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

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

$$y=\frac{\Delta\Gamma}{2\Gamma}=\frac{\Gamma_{CPeven}-\Gamma_{CPodd}}{\Gamma_{CPeven}+\Gamma_{CPodd}} \qquad R_{DCS}=\left|\frac{<K^+\pi^-|T|D^0>}{<K^+\pi^-|T|\overline{D^0}>}\right|^2$$

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

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

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

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

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

δ= strong phase difference between CF and DCS

D-Mixing Review I

Types of measurements:

❶ Measure lifetime difference between CP-even and CP-odd states
and with the flavour specific states (or CP-mixed states)

Requires good vertex resolution

This gives y (or really y_{CP})

❷ Measure Wrong Sign semileptonic decays

No need for lifetime-dependent studies, needs excellent lepton ID

This gives $(x^2 + y^2)$

❸ Measure Wrong Sign hadronic decays

E.g. $D^0 \to K^+\pi^-$, $D^0 \to K^+\pi^-\pi^+\pi^-$, $D^0 \to K^+\pi^-\pi^0$, $D^0 \to K^{*+}\pi^-$

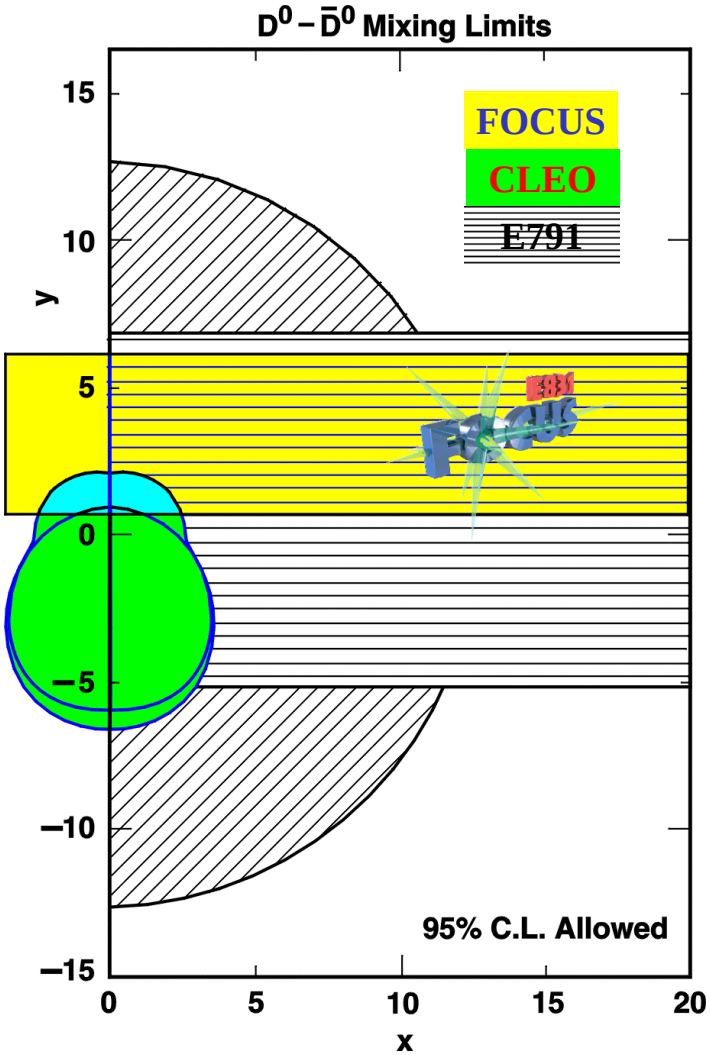
Needs lifetime dependent study and good S/N

Gives information on x and y but extra unknown is δ (s)

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

D-Mixing Review II

Experimental situation at the beginning of 2001:



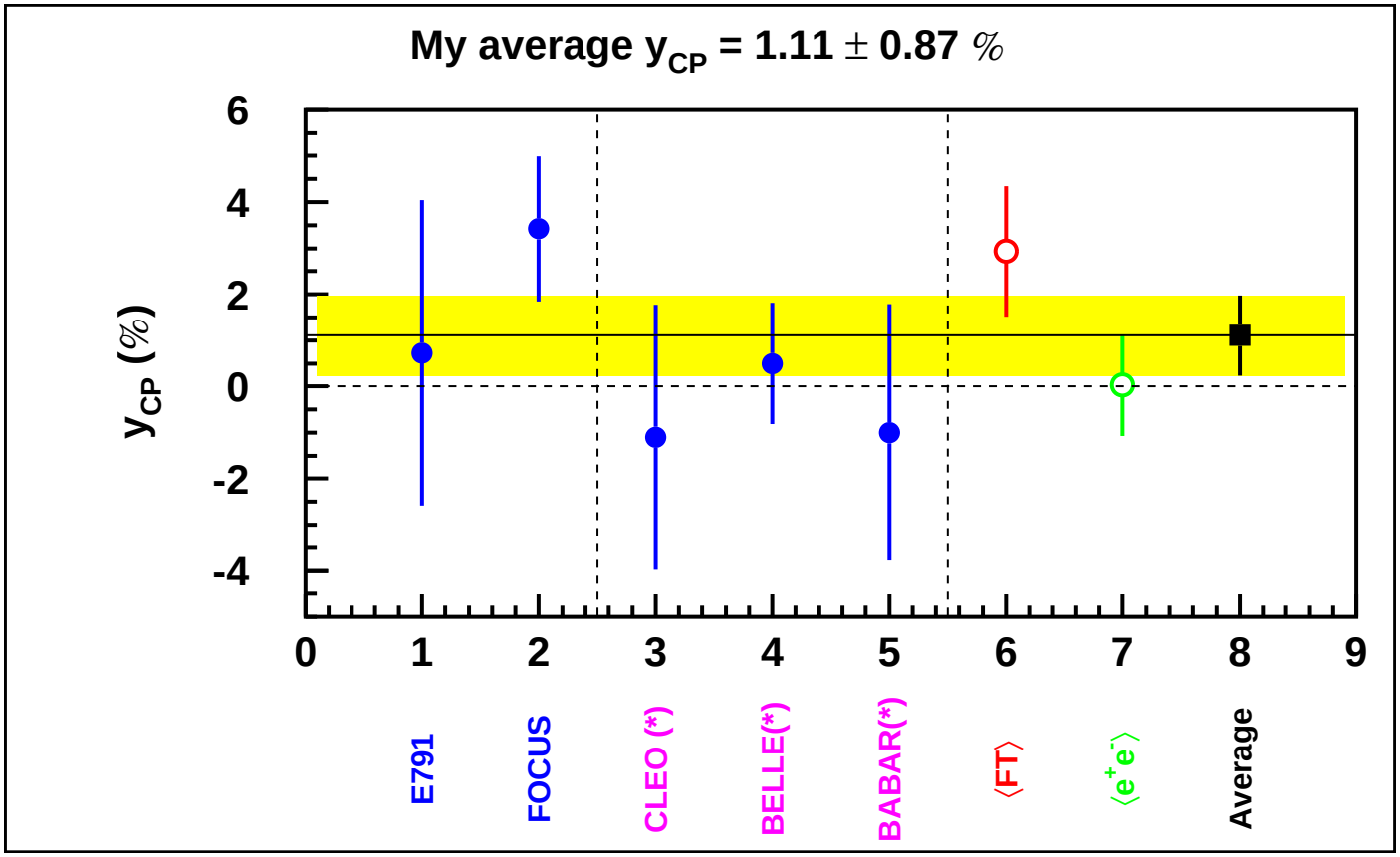
❶ Comparison with CLEO results valid for small δ

❷ Results provoked a large amount of theoretical and experimental interests

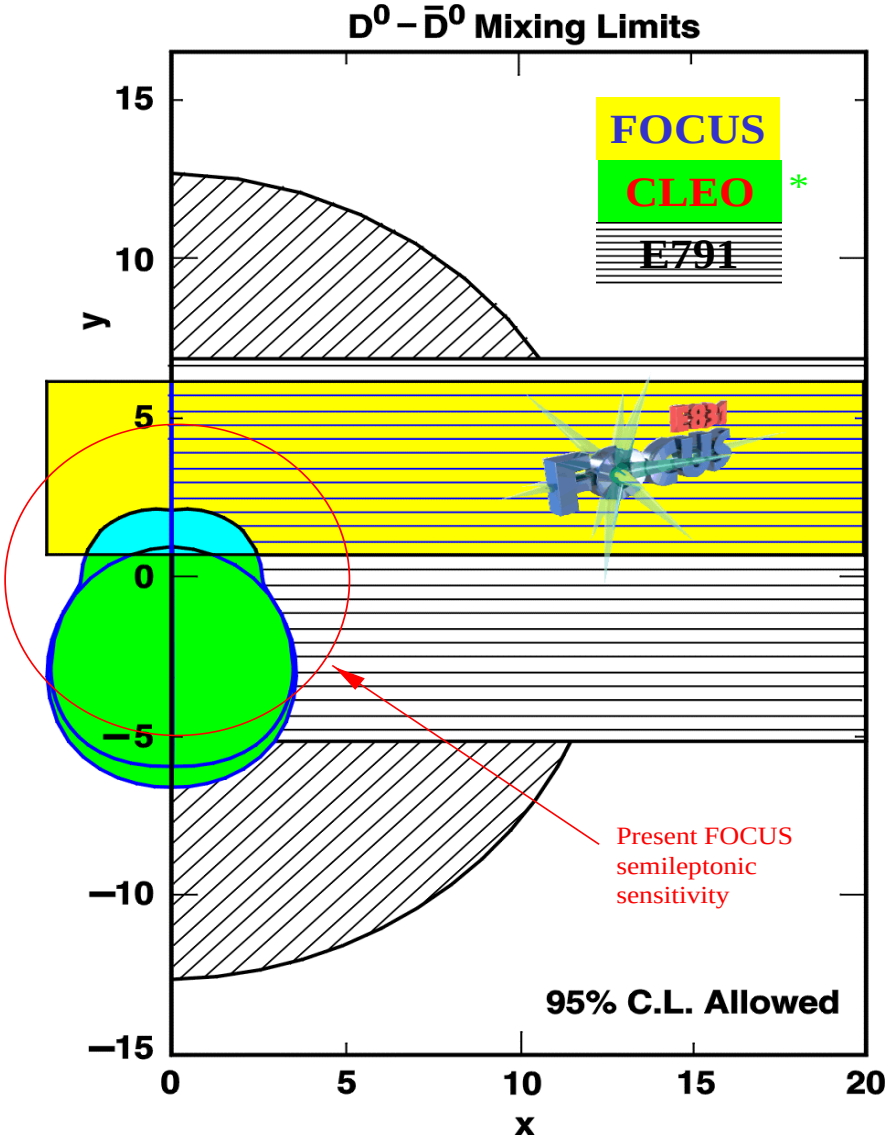
❸ Experimentally favoured value of δ is larger than expected

D-Mixing: $\Delta\Gamma$

New preliminary measurements from CLEO, BELLE, BABAR



D-mixing: Semileptonic Decays



* CLEO result displayed assuming strong phase = 0

No new results in this area though BELLE and BABAR can contribute greatly to semileptonic sensitivity

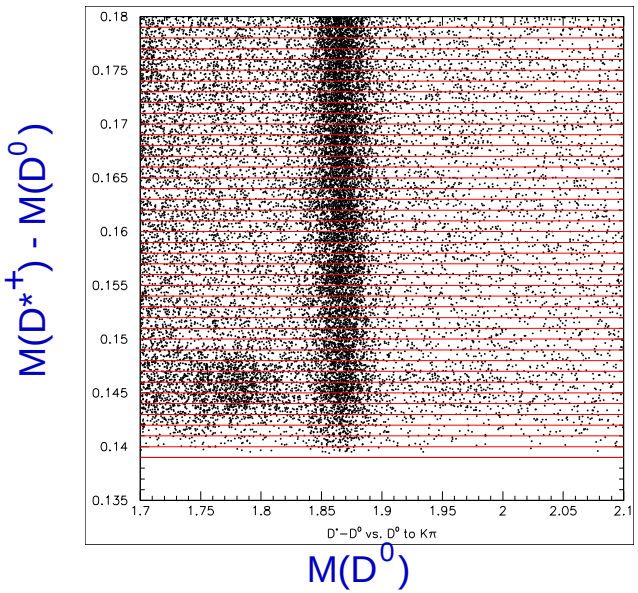
(uncertain about lepton ID, i.e. backgrounds)

D-Mixing: Hadronic Decays

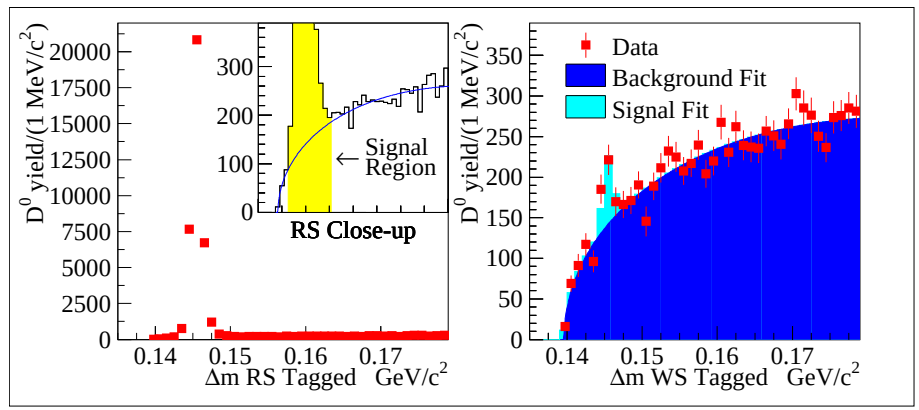
Study of Wrong-Sign D^0 decays E.g. $D^0 \to K^+\pi$ (E791,ALEPH,CLEO,FOCUS,BABAR)

Complications due to DCSD $D^0 \to K^+\pi\pi\pi$ (E691,E791,CLEO) $D^0 \to K^+\pi\pi^0$ (CLEO)

More challenging for fixed-target experiments due to backgrounds (and small t)

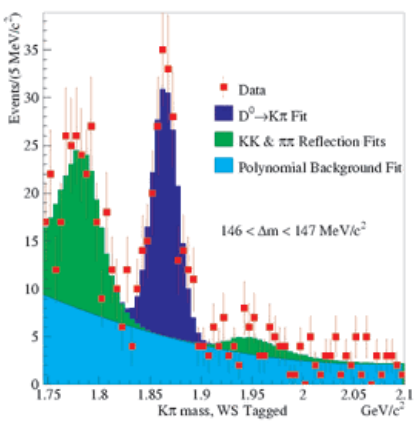


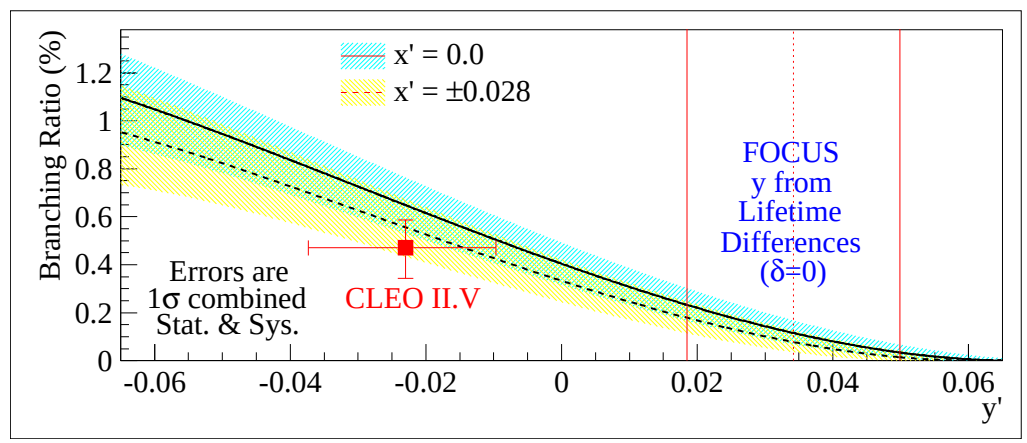
FOCUS has developed a new method:



Interpretation in the possible presence of mixing?

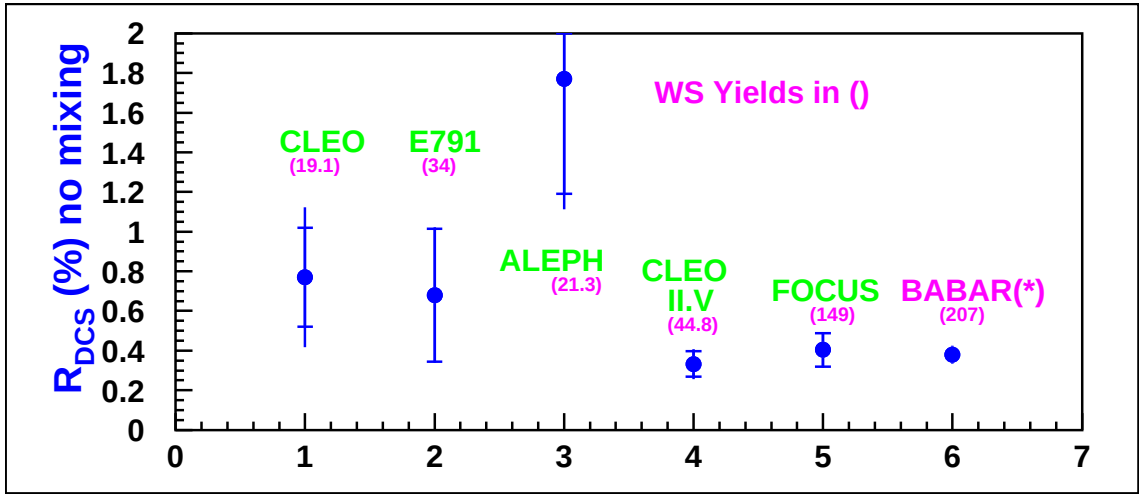
$$R_{WS}^{meas} = R_{DCS} + y' < t > \sqrt{R_{DCS}} + \frac{(x'^2 + y'^2)}{4} < t^2 >$$



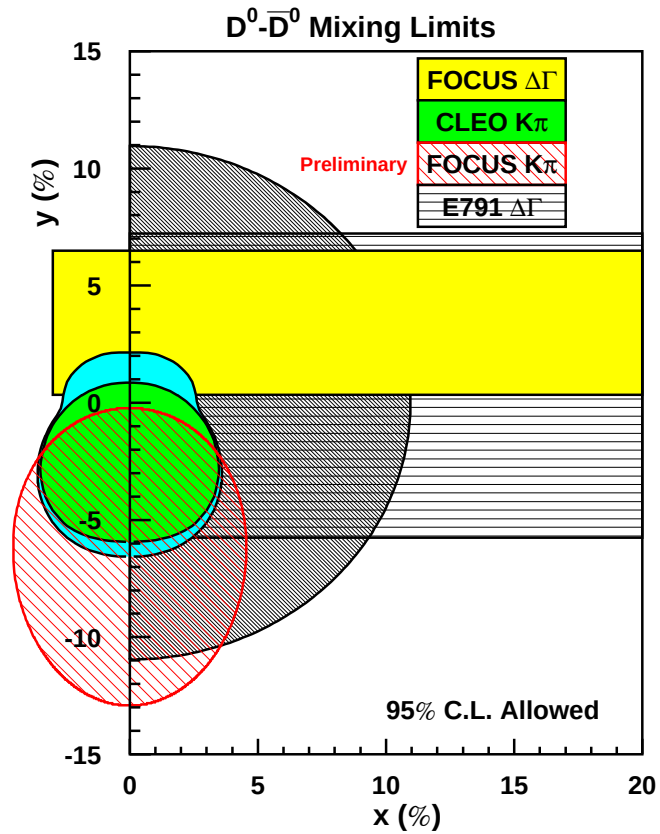


D-Mixing: Hadronic Decays II

Interpretation assuming zero mixing

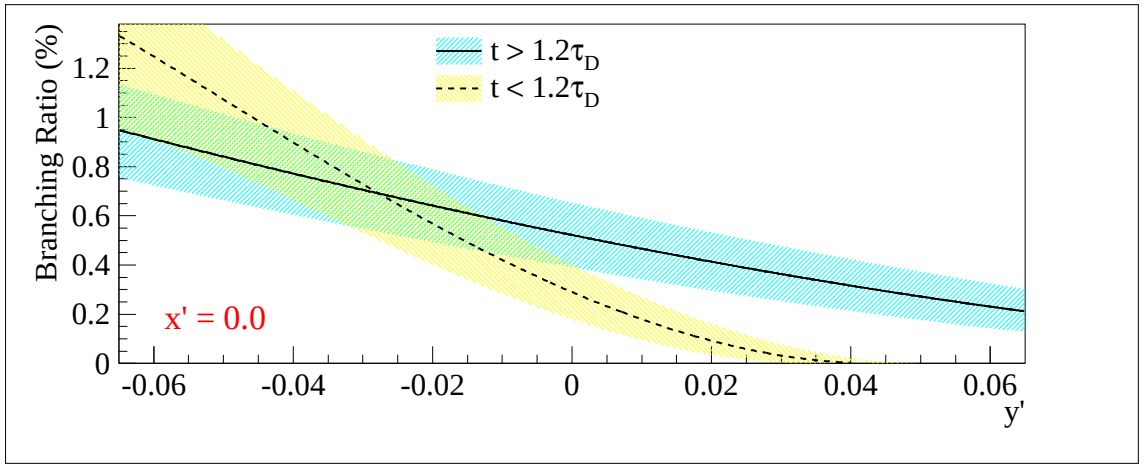


FOCUS Preliminary 95% CL

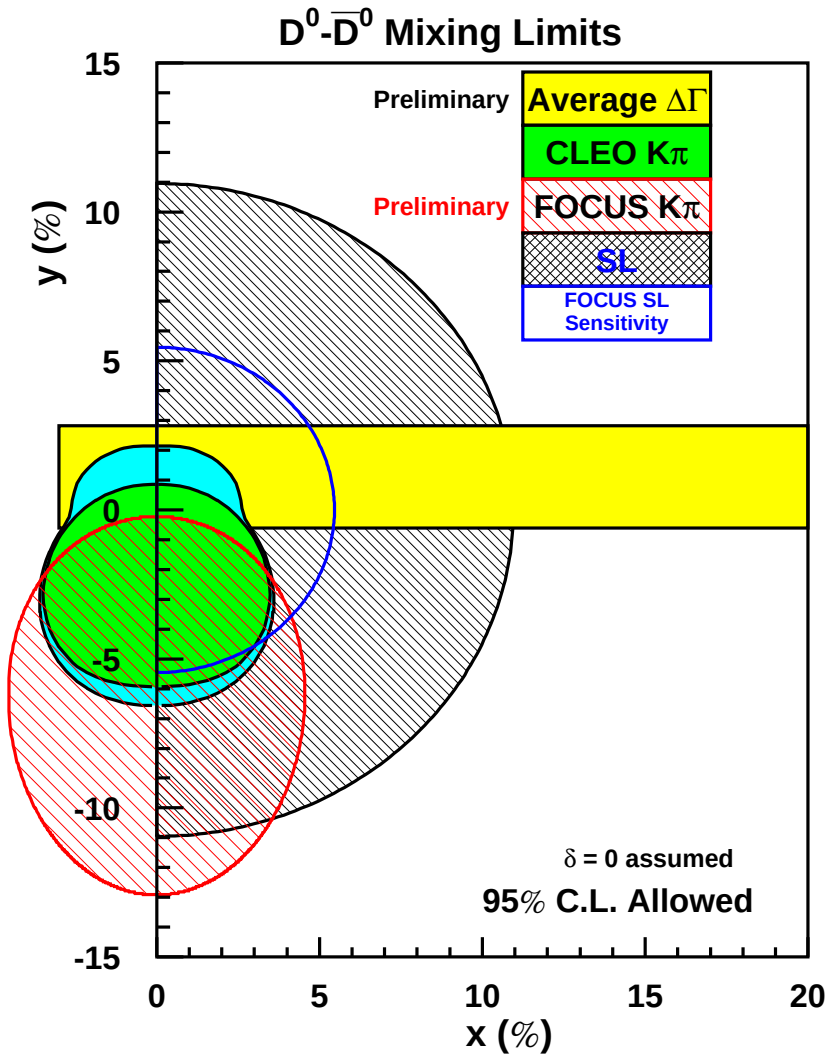


Split data into two time bins:

FOCUS Preliminary



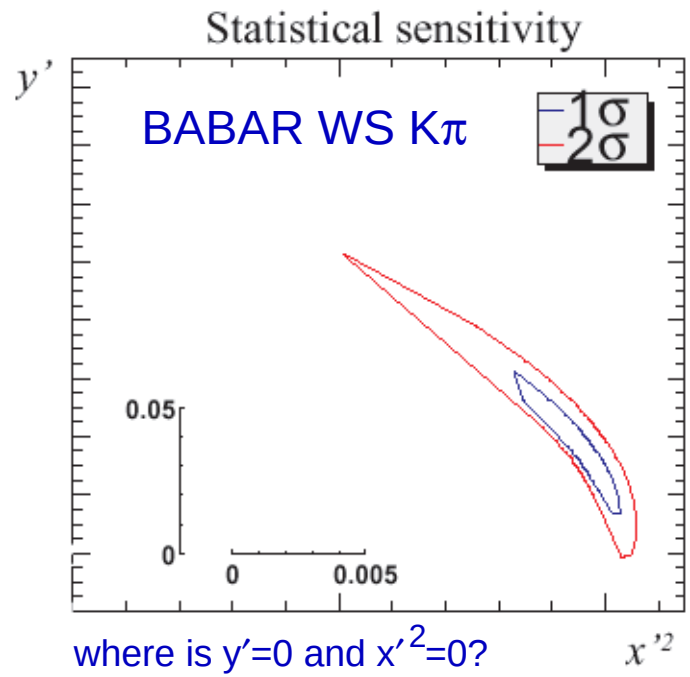
D-Mixing: Summary



Still unknown phase difference δ

Being addressed theoretically and experimentally by BELLE in $K_L\pi^0$ and $K_S\pi^0$ decays

Smaller favoured phase difference δ but still non-zero



where is y′=0 and x'^2=0?

Still want better measurements!

Conclusions

New Lifetime averages and ratios:

$$\tau(D_s^+)/\tau(D^0) = 1.190 \pm 0.014$$

$$\tau(\Xi_c^+)/\tau(\Lambda_c^+) = 2.16 \pm 0.11$$

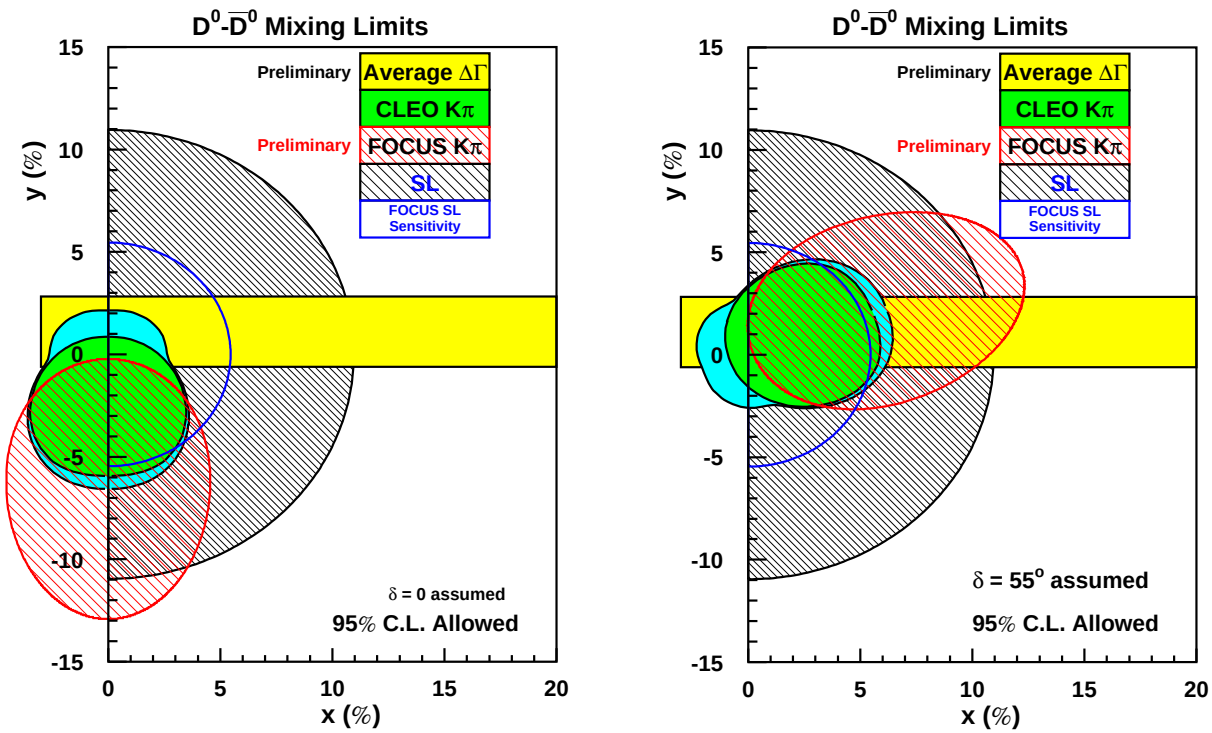
c.f. theoretical expectation of ~ 1.3

Implications of larger than expected WX?

Still need better lifetime measurements for Ξ_c^0 and Ω_c^0

New D mixing results:

Results are still exciting and we need more!

Need likelihood distributions to combine results!

We need δ !