E831/FOCUS RECENT RESULTS

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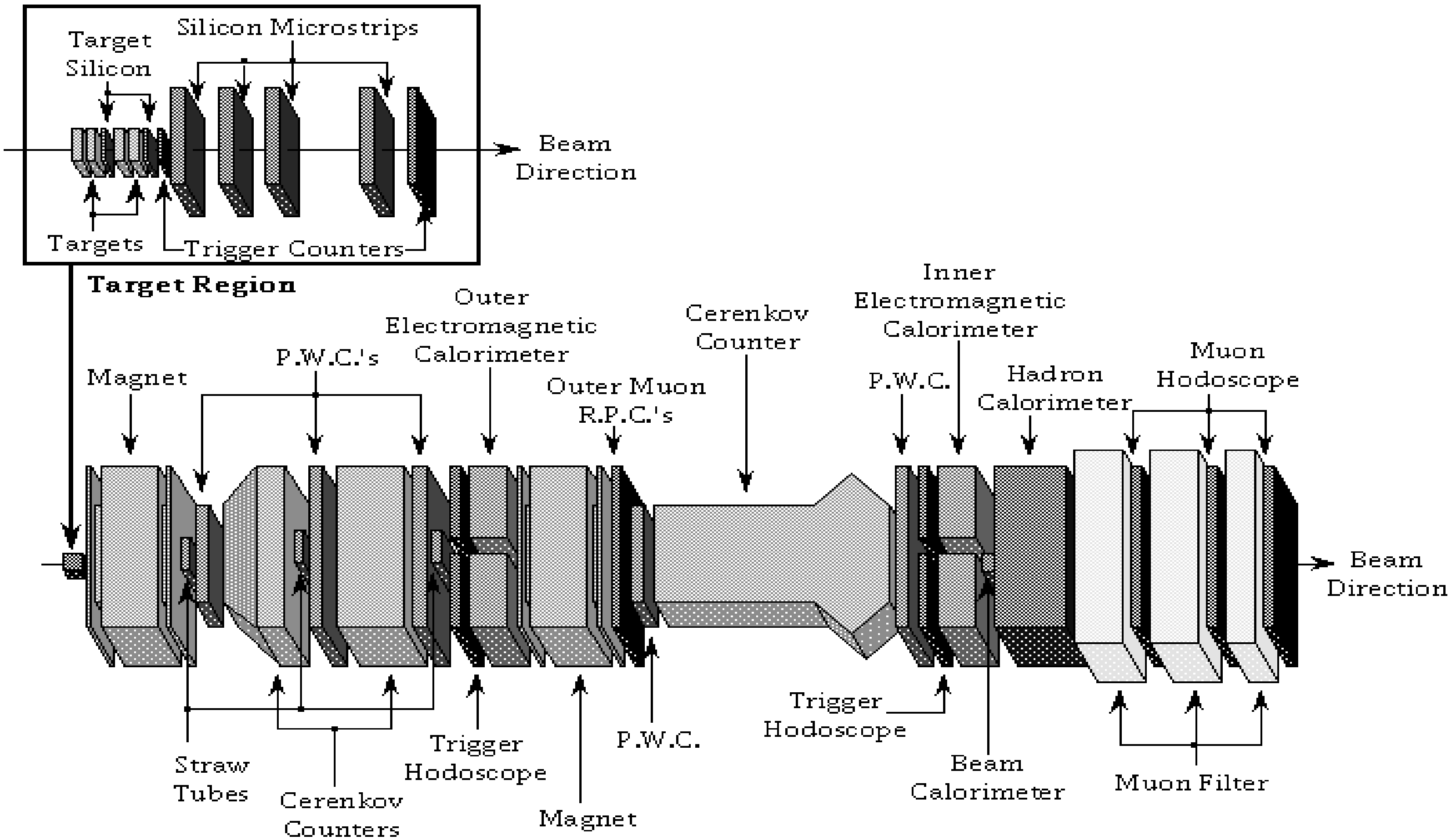
http://www-focus.fnal.gov/

Focus Spectrometer

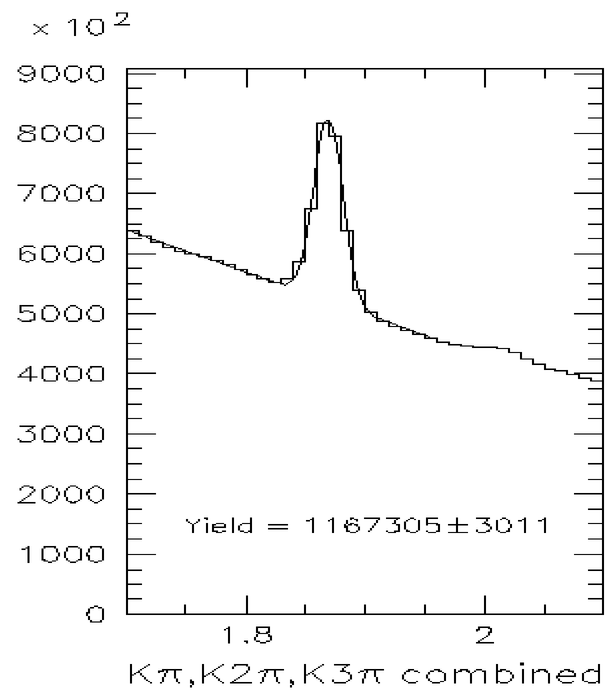


Main FOCUS Upgrades

- Si Planes Inside Segmented Target
- Fast Hadron Calorimeter
- Lead-glass Inner EM Calorimeter
- Improved and Expanded Muon Detection
- Improved Cerenkov Identification

FOCUS E831

Over 1 million reconstructed !!



A LARGE VARIETY OF CHARM PHYSICS TOPICS

SPECTROSCOPY

LIFETIMES

DOUBLY CABBIBO SUPPRESSED DECAYS

RARE AND FORBIDDEN DECAYS

MIXING

CP VIOLATION

RESONANCE STRUCTURE (DALITZ)

SEMILEPTONIC DECAYS

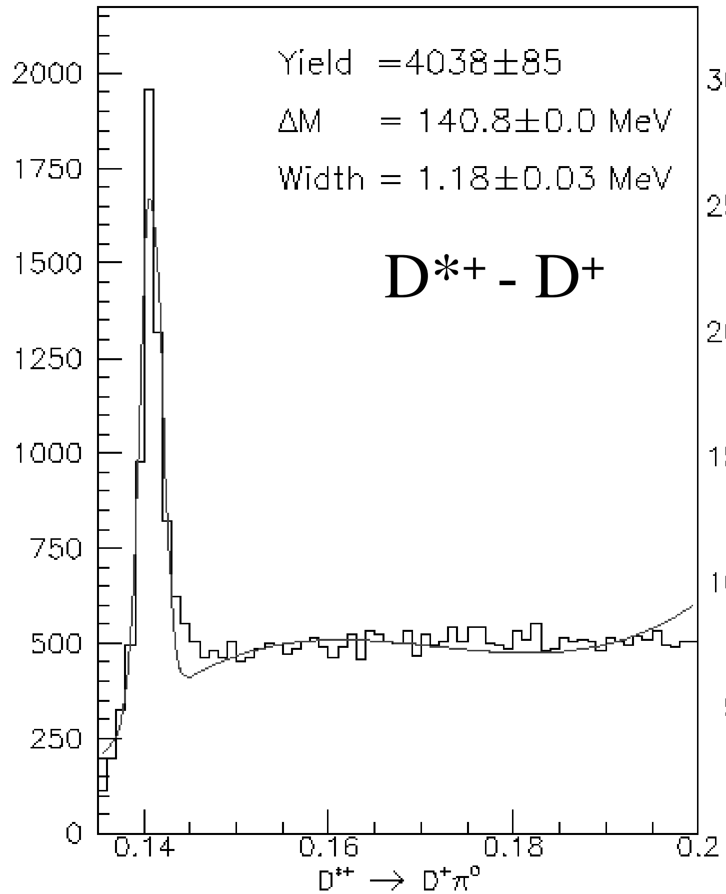
PRODUCTION DYNAMICS

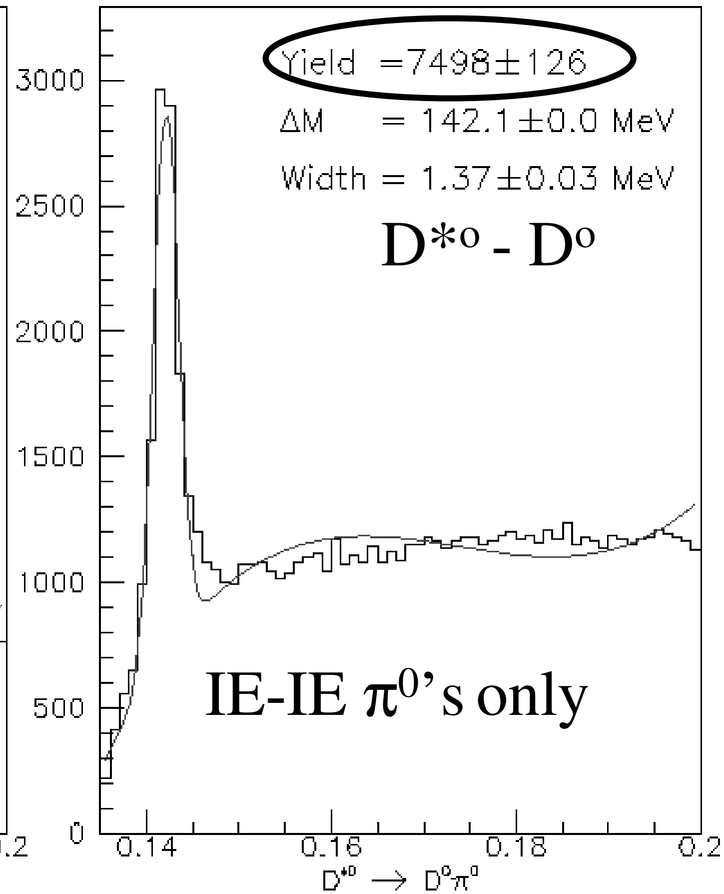
OUTLINE

- **SPECTROSCOPY**
  - **MESONS**
    - **D^{*0} - D^0 MASS DIFFERENCE**
    - **D** SIGNALS**
  - **BARYONS**
    - **• $_C^0$, • $_C^{++}$, • $_C^+$ MASS DIFFERENCES**
    - **• $_C$, • $_C^*$ SPECTROSCOPY**
    - **• $_C^+$ DECAYS**
- **D_S^+ and • $_C^+$ LIFETIMES**
- **DOUBLY CABBIBO SUPRESSED DECAYS**
- **CP VIOLATION**
- **D^0 , D^{0BAR} MIXING**
- **RARE AND FORBIDDEN DECAYS**

PRELIMINARY D*→Dπ° Mass Splittings

~50% FOCUS

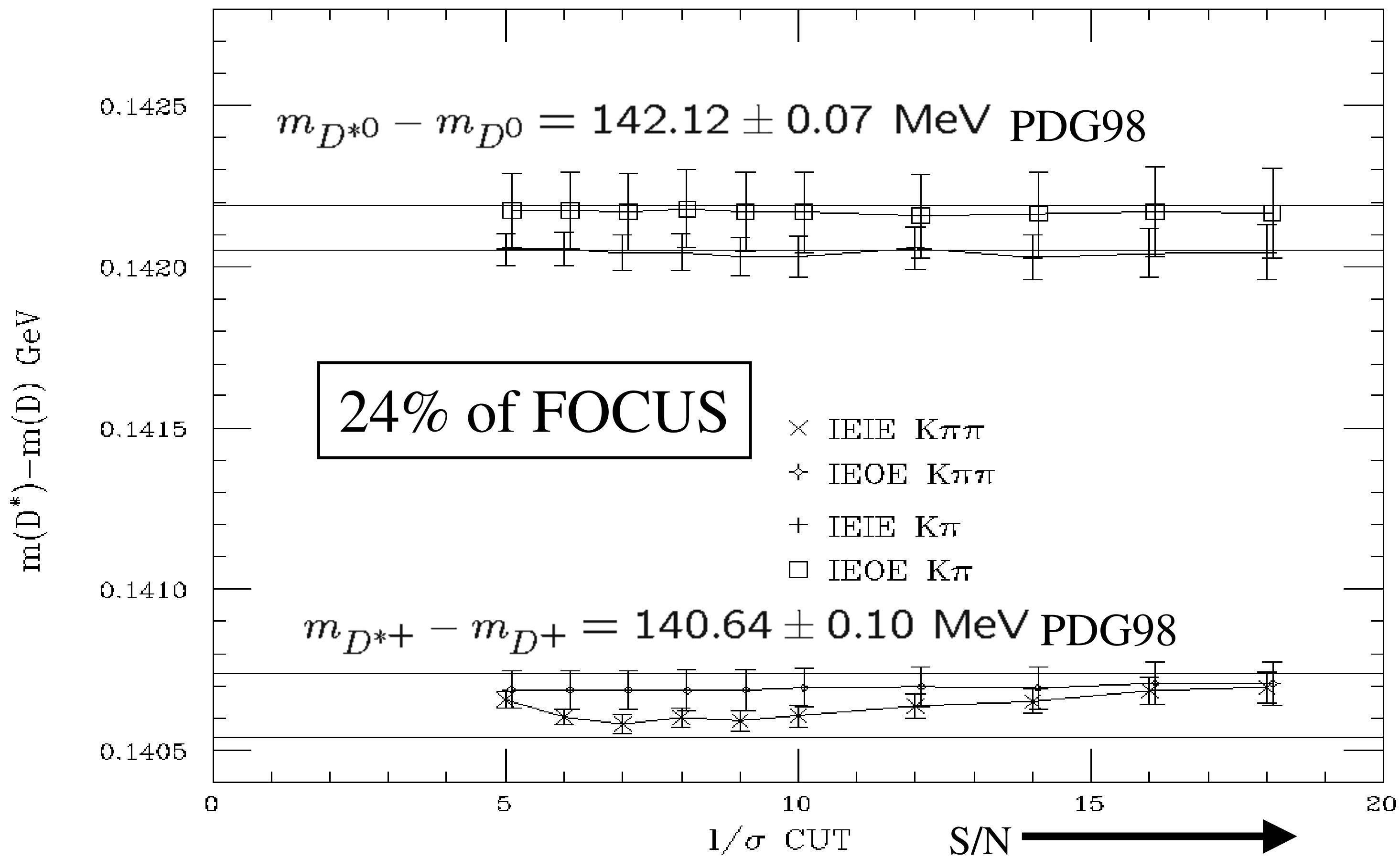




We are seeing **very strong D*o →Do π° signals** in **FOCUS** with our new & improved E&M calorimeters**. Project a final sample of 25000 D*o →Do π° decays .**

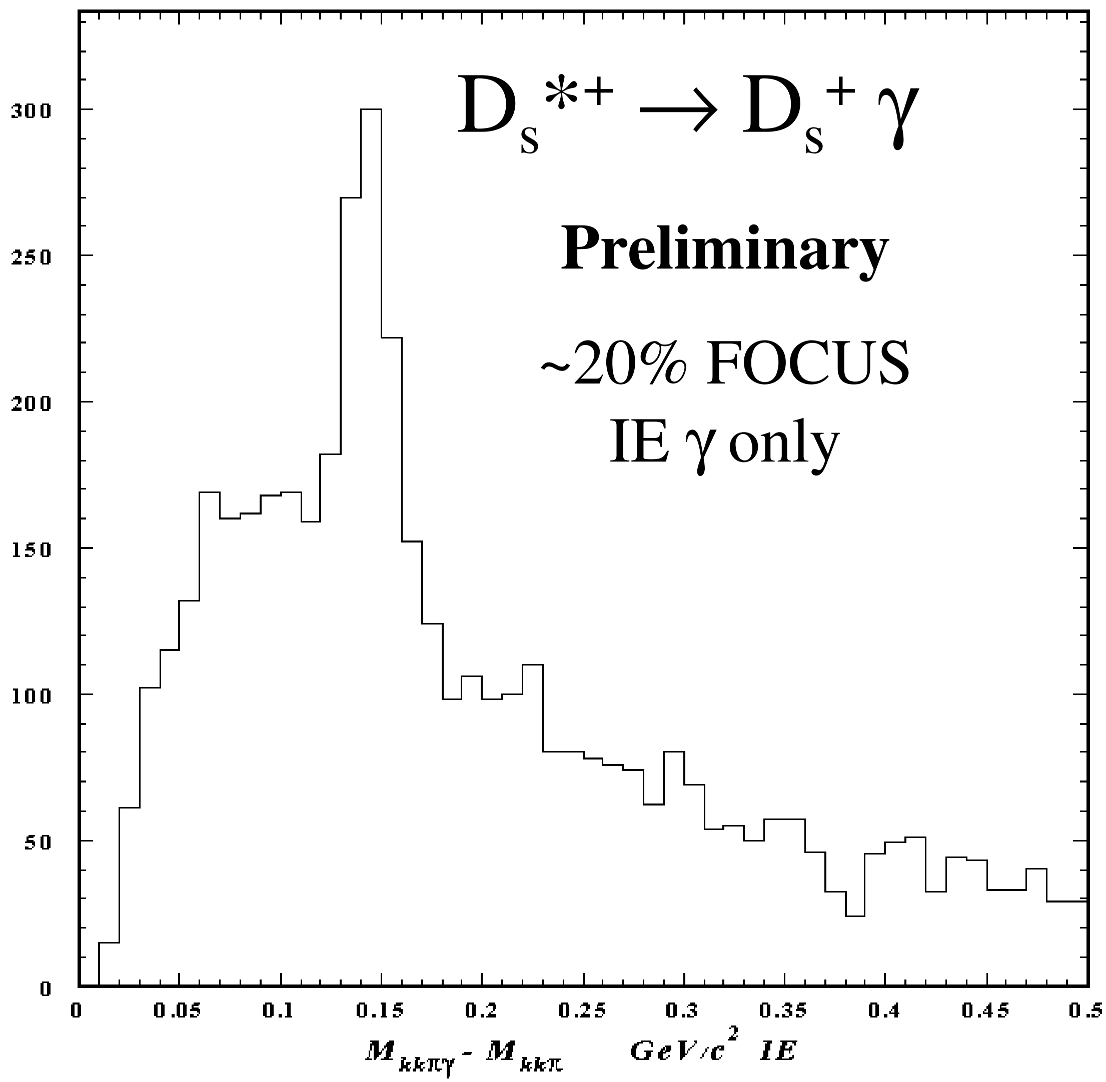
CLEO92 has provided the best past data on D^{0*} mass, widths, and branching ratios from ~1200 **D*o →Do π°** decays

PRELIMINARY Mass splittings

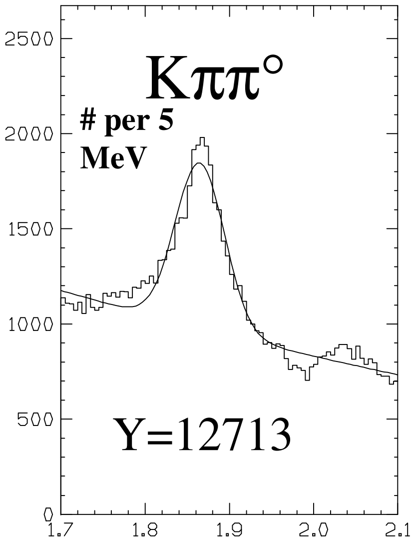


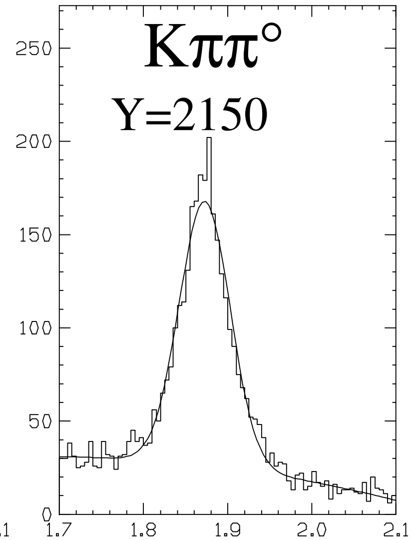
- ***Both π°samples consistent with PDG98 already w/ smaller errors!***

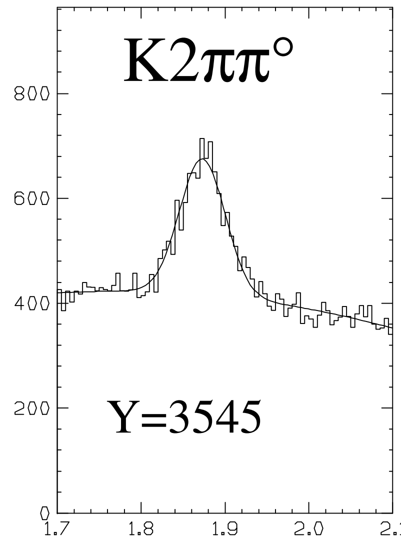
We are even getting our first glimpse at D_s^{*+}

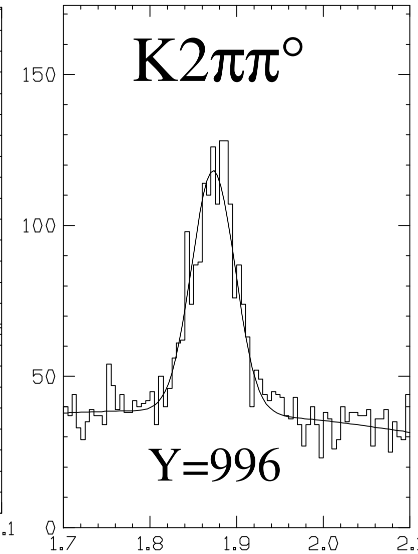


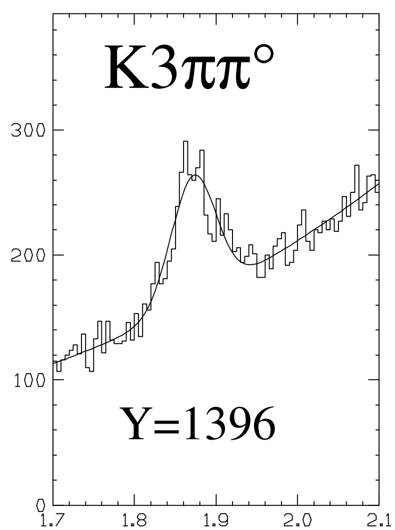
“Golden” signals with pi0’s

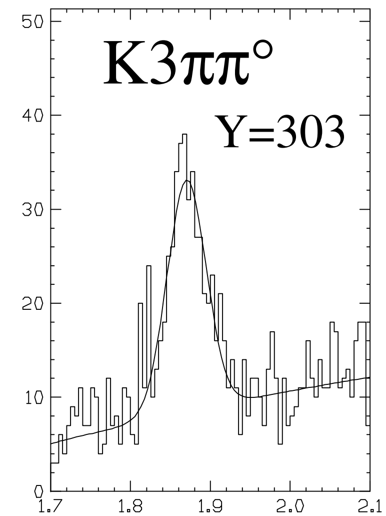










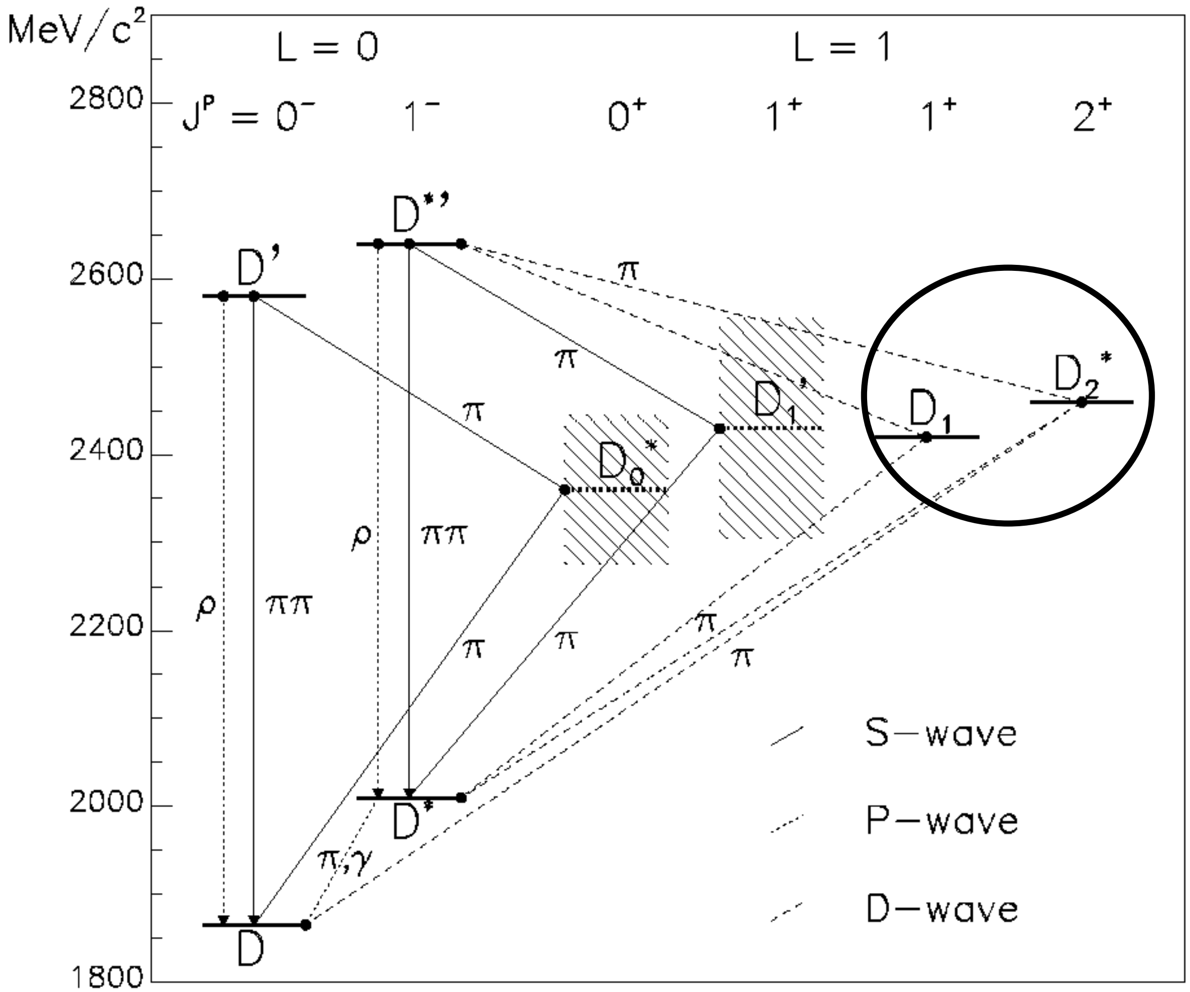


Signals based on 20% of FOCUS

No optimization of π° cuts!

- Can study a rich new set of charm decay
- Many are required to complete isospin amplitude triangles

Beyond the D*



*The low multiplicity of primary vertex gives photoproduction an advantage for D** study.*

HQET predicts a rich L=1 spectrum

- 2 broad states with s-wave π decays (CLEO has evidence for 1)
- 2 narrow states with d-wave π decays (seen in $e^+ e^-$ & γN)
- Predictions are made for masses, widths, and angular distributions and the relationship to B** splitting.

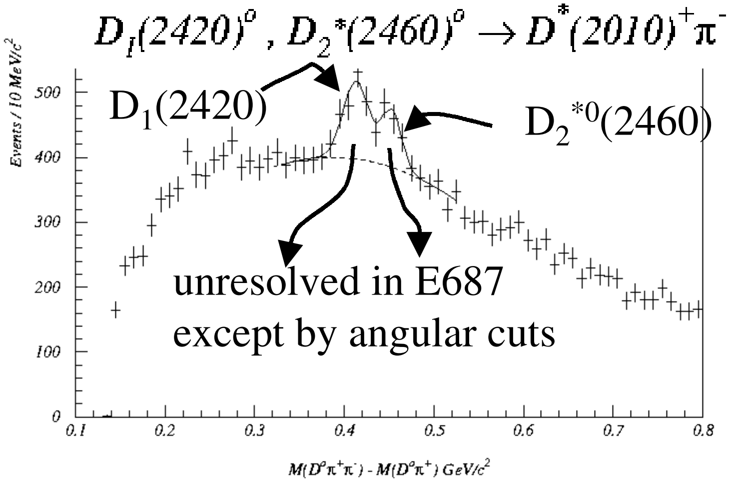
FOCUS has PRELIMINARY signals for

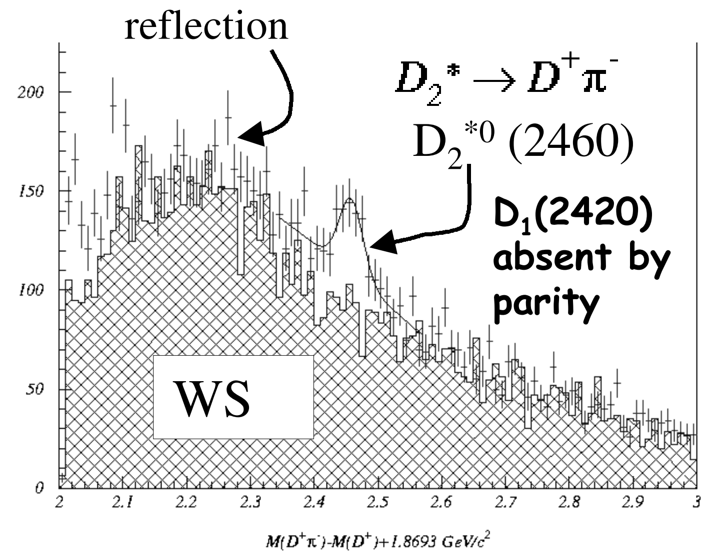
$D^0_1 \to \pi D^*$ **$D^{0*}_2 \to \pi D^*$**

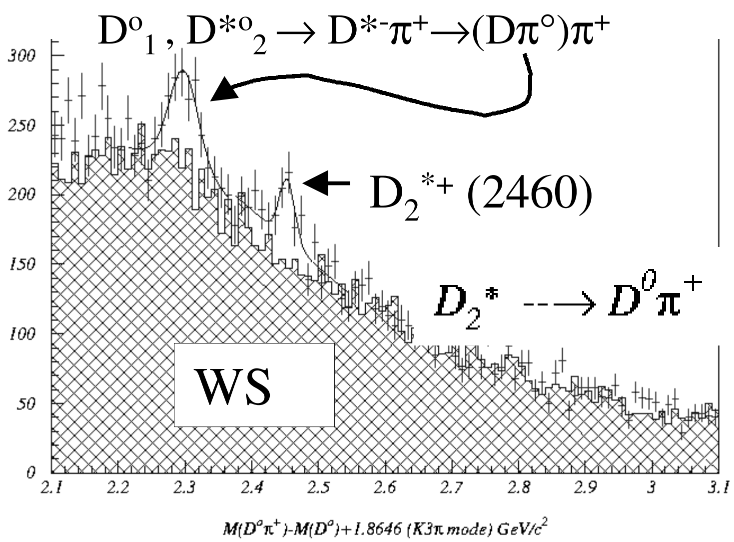
$D^{0*}_2 \to \pi D$ **$D^{+*}_2 \to \pi D$**

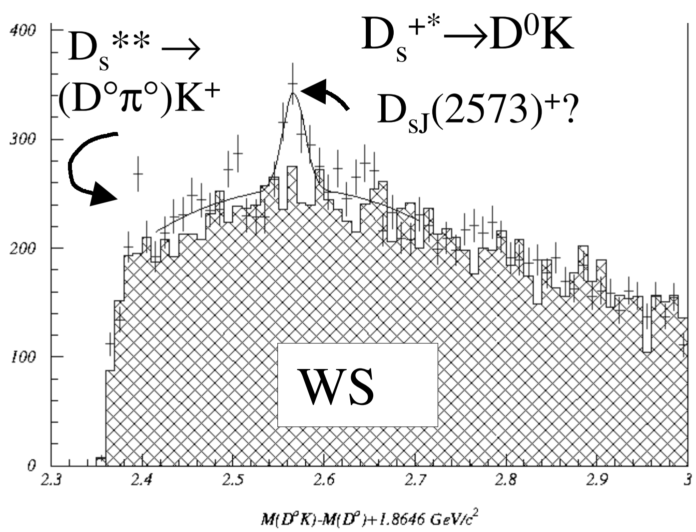
$D^*_{s?} \to K\ D$

PRELIMINARY D** signals ~27% FOCUS









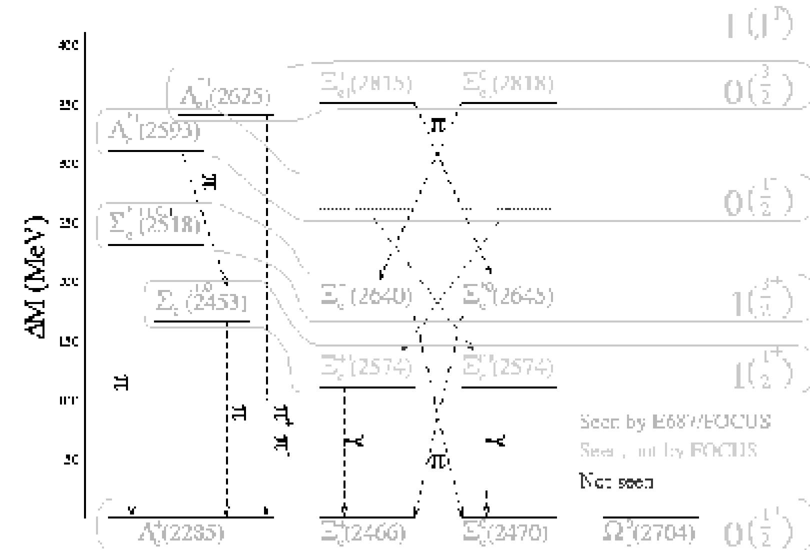
We observe

- 2 peaks in $D^{*+}\pi^-$
- 1 real peak in $D^+\pi^-$
- 1 real peak in $D^0\pi^+$
- 1? peak in D^0K^+

Also see reflections at M-m_π from $D^* \rightarrow \pi^\circ D$ with missing π°

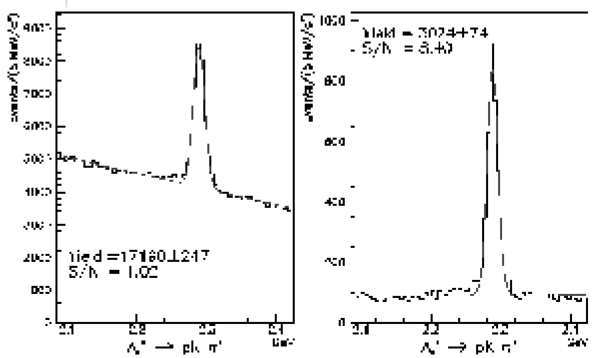
Angular distributions can often be used to disentangle states and confirm HQET predictions.

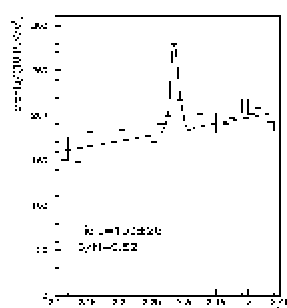
Charmed Baryon Spectroscopy



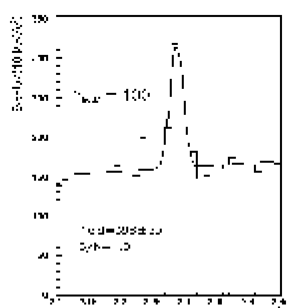
- 17 states have been observed
- Unobserved states: **Σ_c^{*+}(2518), Ξ_{c1}($\rightarrow \Xi'_c \pi$), excited Ω_c states, higher excited states..**
- There is a theoretical interest on charmed baryons **mass splitting**, but the experimental errors are still quite large. **Precise measurements can help to better understand it**.

Λ_c^+ signals





$\Lambda_c^+ \rightarrow p\,K_s\,\pi^-\pi^+$



$\Lambda_c^+ \rightarrow \Lambda^0\pi^-\pi^+\pi^+$

$pK^-\pi^+$ channel from 80% of the data sample

large and *clean* samples make possible precision studies of the excited states

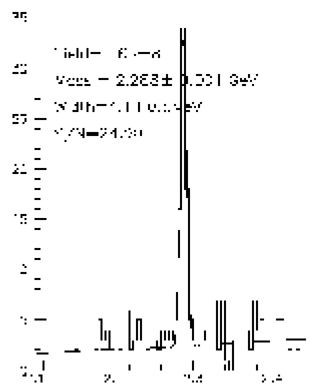
channels with Λ^0 and K_s^0

30% of the full sample

May use to increase statistics for excited states

BR measurement
(PDG98: error 25%-35%)

...and other Λ_c^+ decays channels

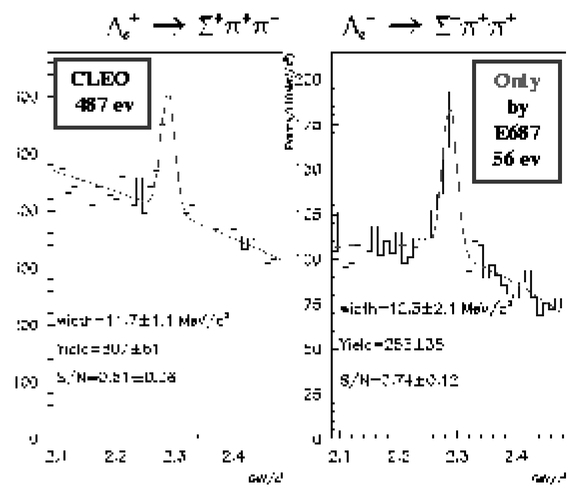


$\Lambda_c^+ \to \Xi^- K^+ \pi^+$

(75% of the full sample)

More channels are under study:

pK^+K^-, pK_s^0, $\Lambda^0\pi^+$, $p\pi^+\pi^-$

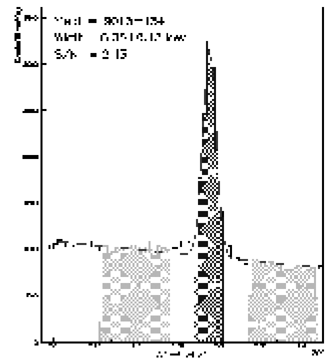


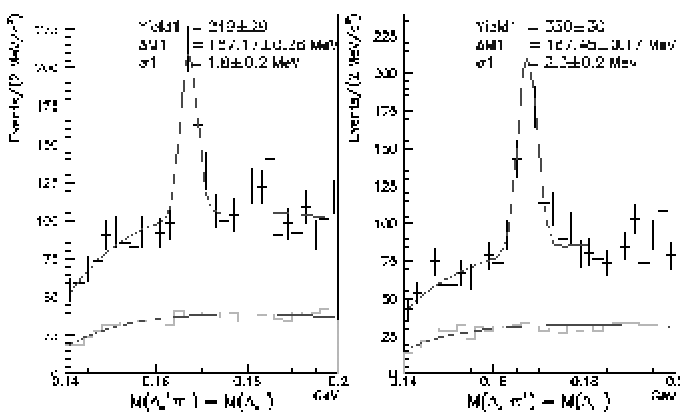
(22% of the full sample)

Interesting resonant structures to study the non-spectator diagrams

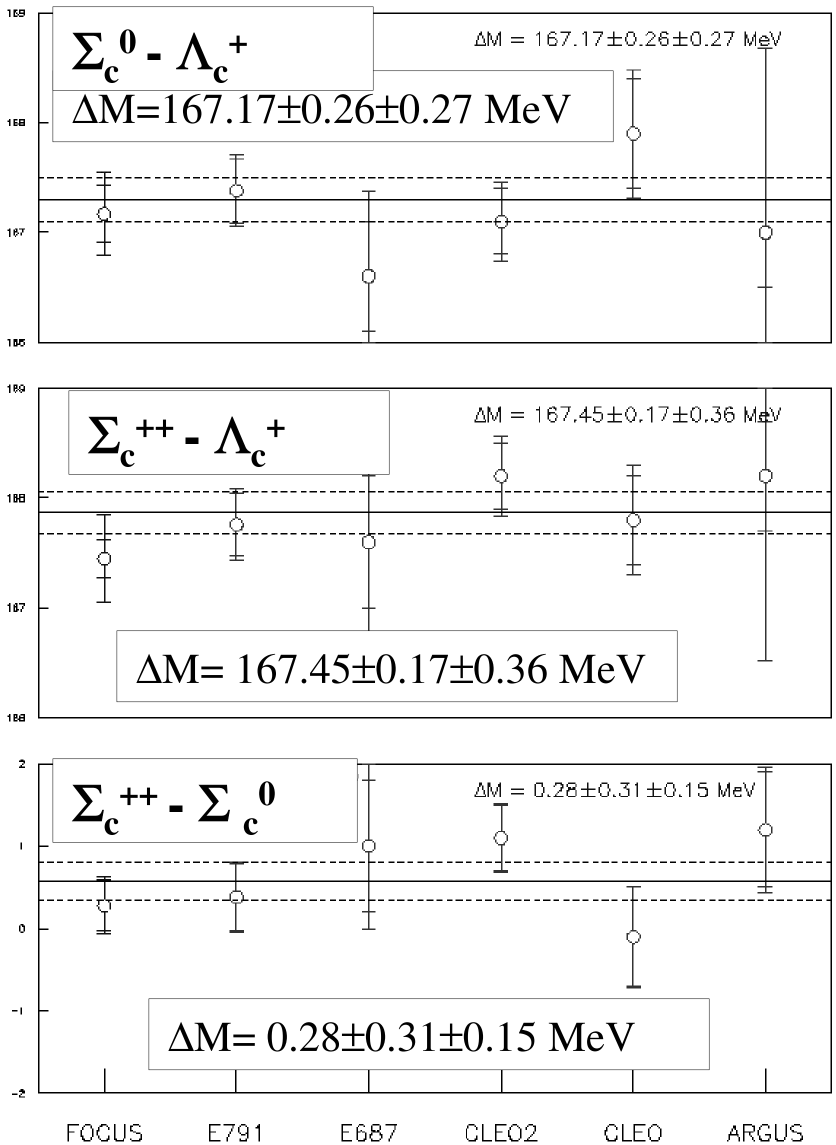
Σ_c mass splitting

- Decay chain: $\Sigma_c^{++,0} \rightarrow \Lambda_c \pi^{\pm}$
- Used only a clean $\Lambda_c \rightarrow pK\pi^+$ signal from 80% of the full sample





Preliminary Σ_c - Λ_c mass differences

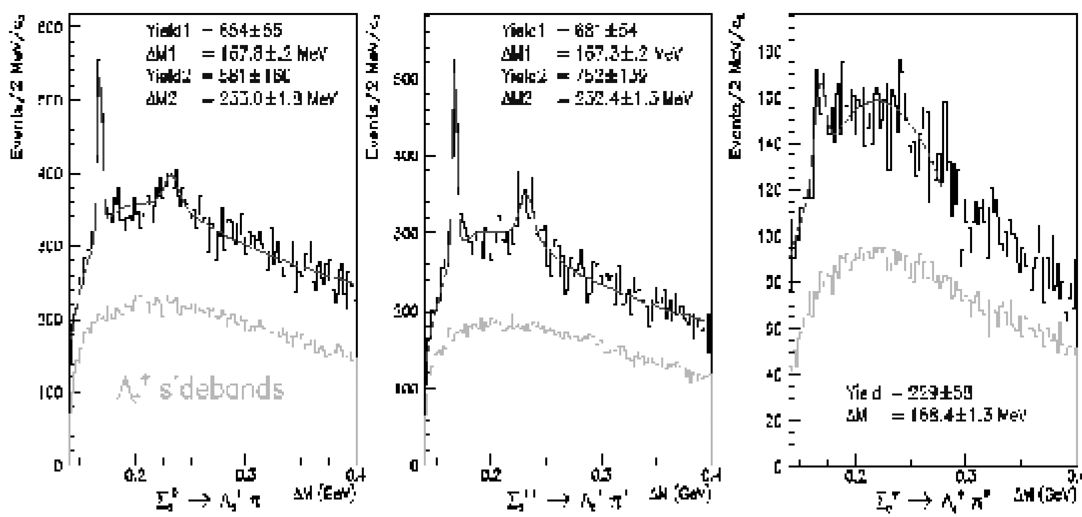


Theoretically one expects

$M(\Sigma_c^0) > M(\Sigma_c^{++})$

But world's data including our measurement has $M(\Sigma_c^0) < M(\Sigma_c^{++})$ by about 1.5σ

Σ_c excited states



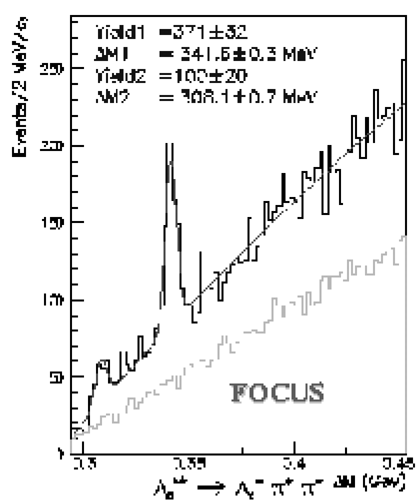
Used looser cuts than the Σ_c ΔM analysis

ΔM and width measurements only from CLEO

Σ_c^{*0}: 232.6± 1.0± 0.8 MeV

Σ_c^{*++}: 234.5± 1.1± 0.8 MeV

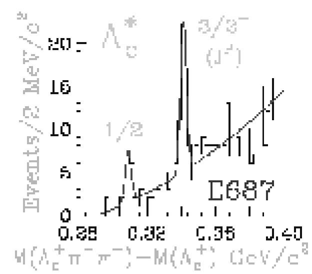
Λ_c excited states



$\Delta M\ (\Lambda_c^{*}-\Lambda_c)$

$\Lambda_c^{*+}(2625)$, $\Lambda_c^{*+}(2593)$

- Exp. results from ARGUS, CLEO, E687

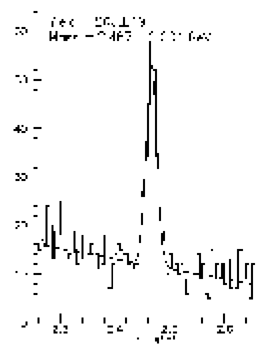


- Σ_c resonant components

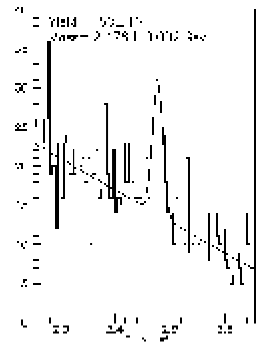
for $\Lambda_c^{*+}(3/2^-)$ state via D wave
for $\Lambda_c^{*+}(1/2^-)$ state via S wave

Ξ_c^+ and Ξ_c^0

$\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$



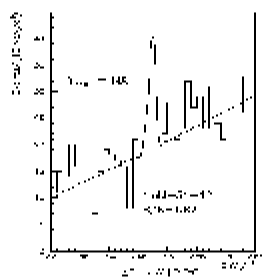
$\Xi_c^0 \rightarrow \Xi^- \pi^+$



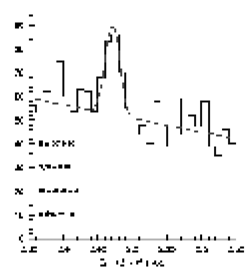
PDG Mass errors:
Ξ_c^+: 1.4 MeV
Ξ_c^0: 1.8 MeV

← 75% of the full sample

$\Xi_c^+ \rightarrow \Lambda^0 K^- \pi^+ \pi^+$



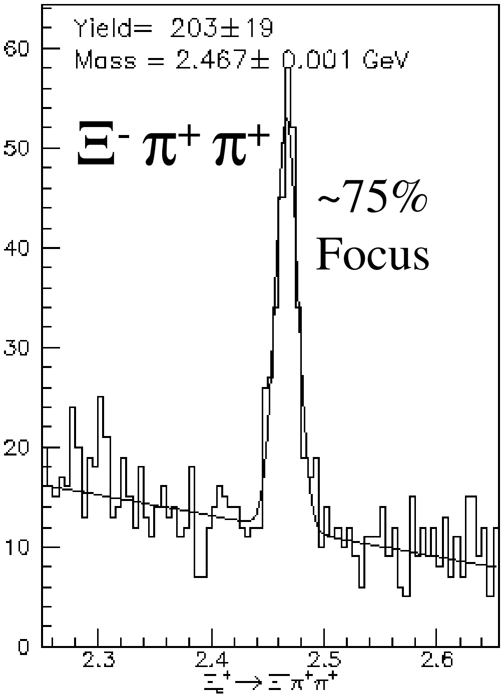
$\Xi_c^+ \rightarrow \Sigma^- K^- \pi^+$

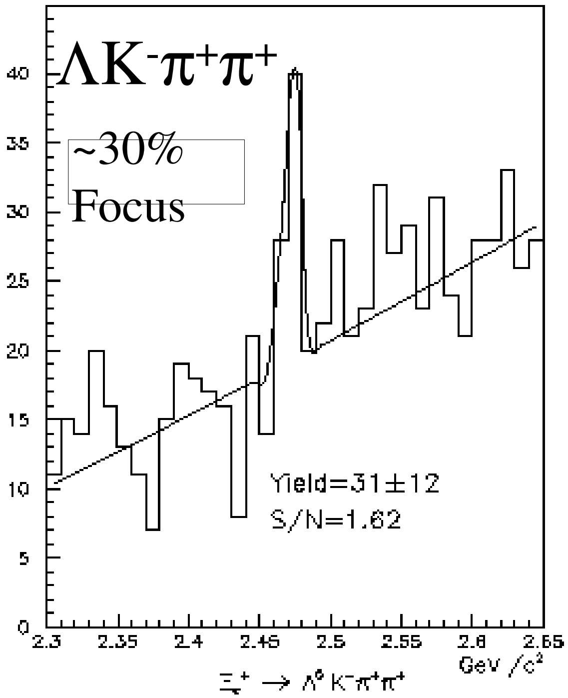


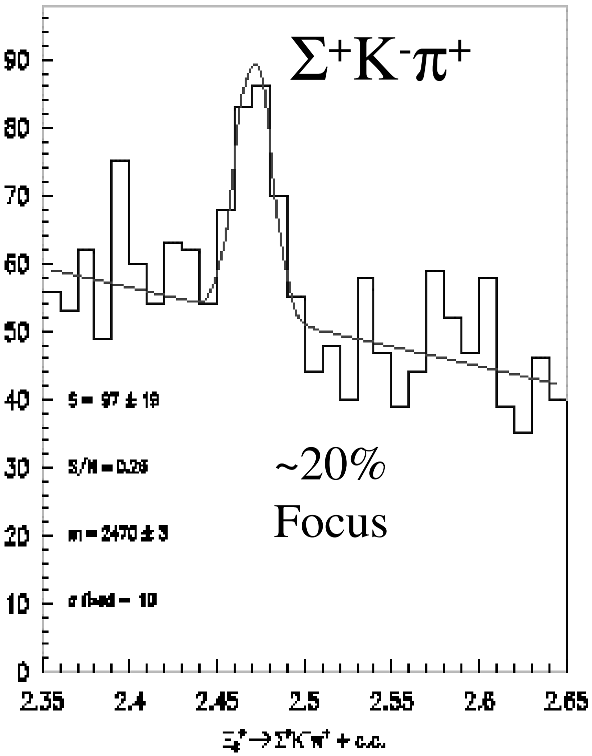
→ 30% of the full sample

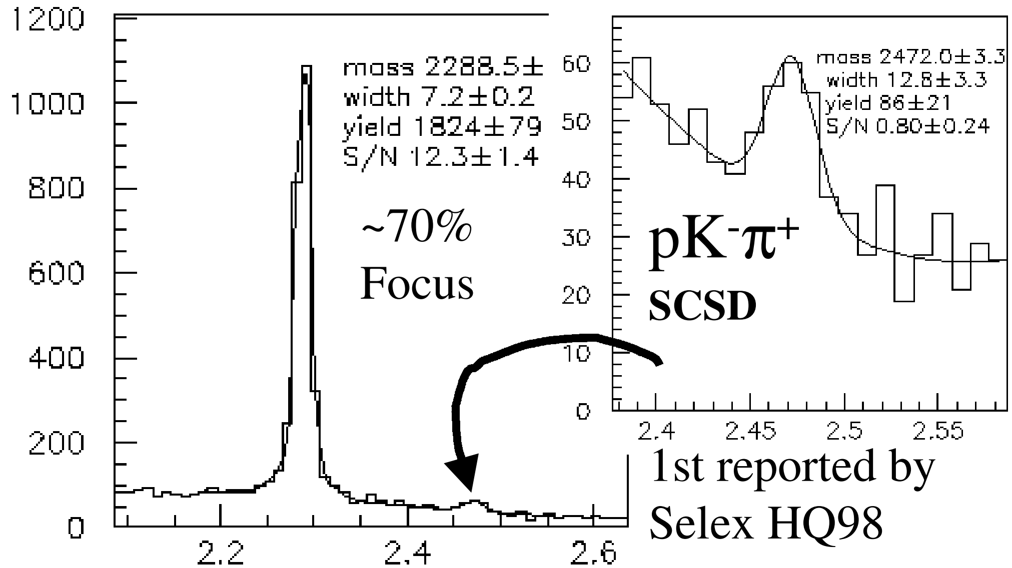
← 20% of the the full sample

A Gallery of Ξ^+_c decays







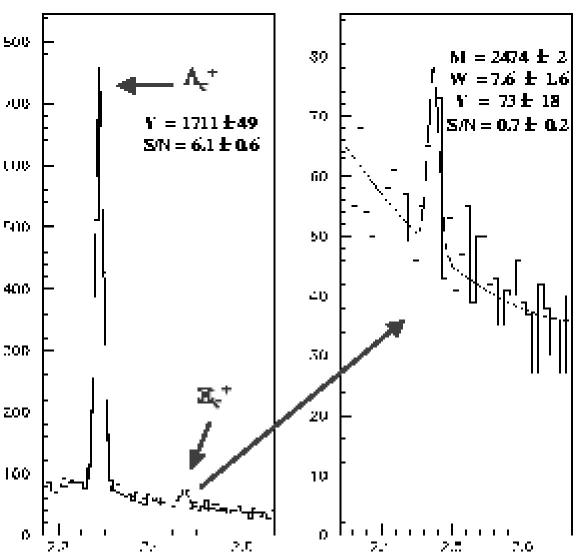


1st reported by Selex HQ98

Using the 3 favored decay modes, we project **a sample of 860 Ξ^+_c decays**

~30 times the E687 lifetime sample which provides the best Ξ_c **lifetimes**

Cabibbo suppressed $\Xi_c^+ \rightarrow p K^- \pi^+$



50 % of the full sample

First reported by Selex at HQ98

Tight selection on *p* and *K*

Future BR measurement

Conclusions

- FOCUS has reconstructed over 1 million Charm particles.

- Very preliminary results have been shown on partial data sets. Systematics are under study.

- Preliminary results point out that FOCUS can do very precise and new measurements in the hadron spectroscopy sector.

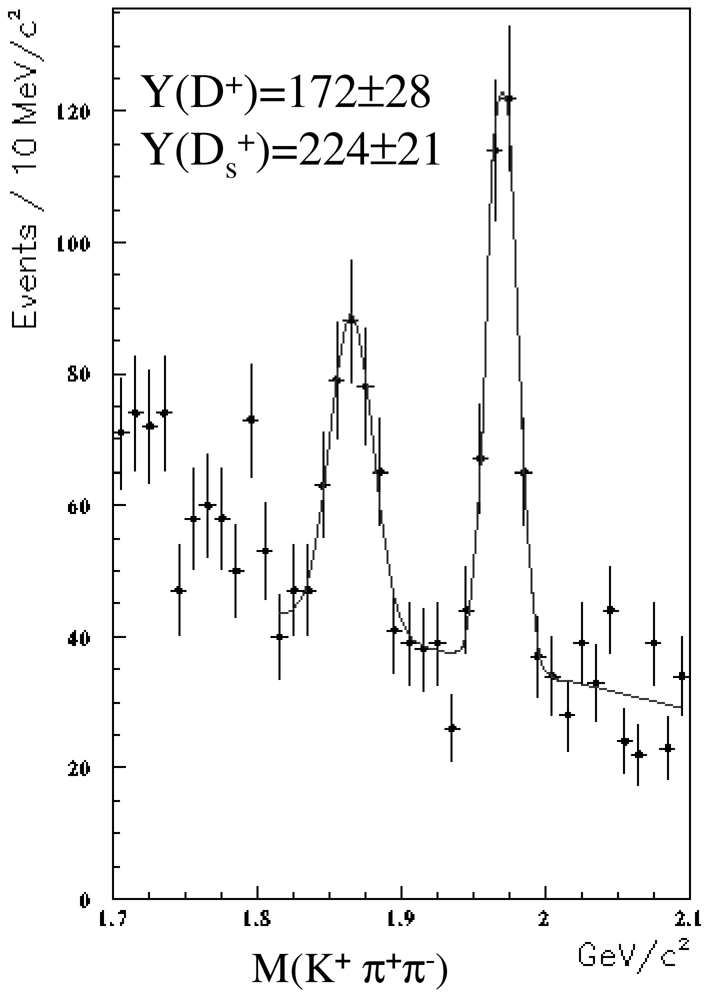
- The masses and widths of the baryon states are important to determine. FOCUS is in a good position to measure them.

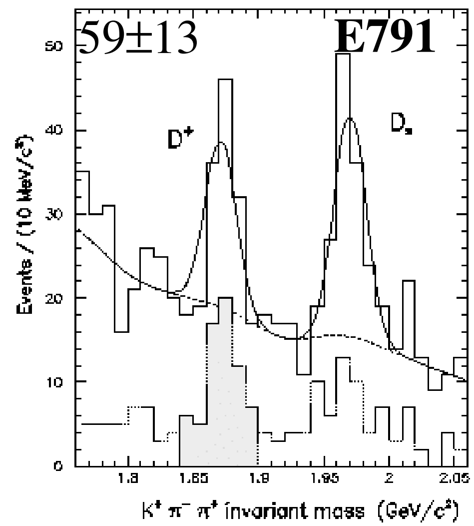
Studies of Cabibbo Suppressed decays

- •FOCUS's powerful Cerenkov ID and very large data sample gives it unique opportunities to study Cabibbo Suppressed Decays
  - •Will present evidence for **five** DCS Decays **(2.5±0.5 decays are new!)**
- •Historically the pattern of Cabibbo suppression has been full of surprises and has yielded unique insight into hadronic decay mechanisms to challenge models
  - •The rate for DCSD is often very different than $\mathbf{tan^4\theta_C}$
  - •D° DCSD interferes with hadronic decay mixing. This is good news / bad news since small amplitudes are best measured through interference

DCSD : $D^+ \rightarrow K^+ \pi^+\pi^-$

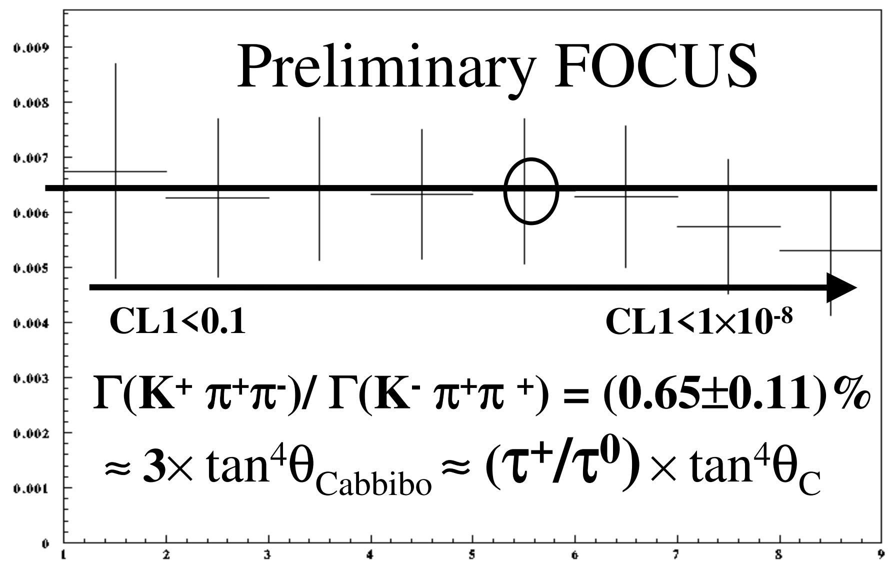
~40% of FOCUS Data



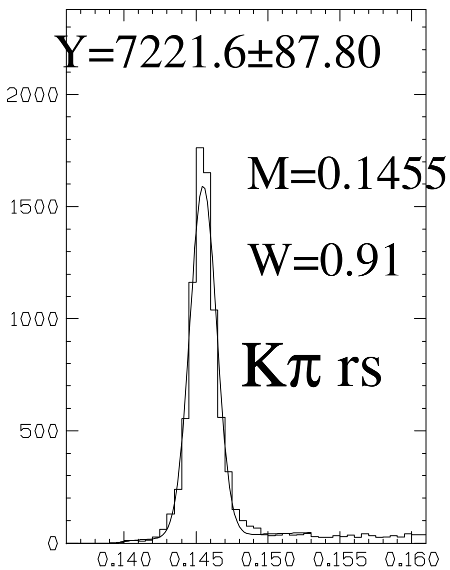


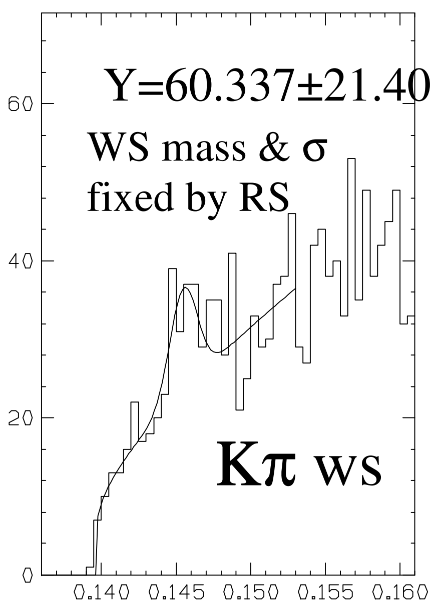
$K^+ \pi^+\pi^-)/K^- \pi^+\pi^+ =$
$(0.68 \pm 0.15)\%$ PDG98

Our results already much better than PDG98 (≈ 3 × E791)

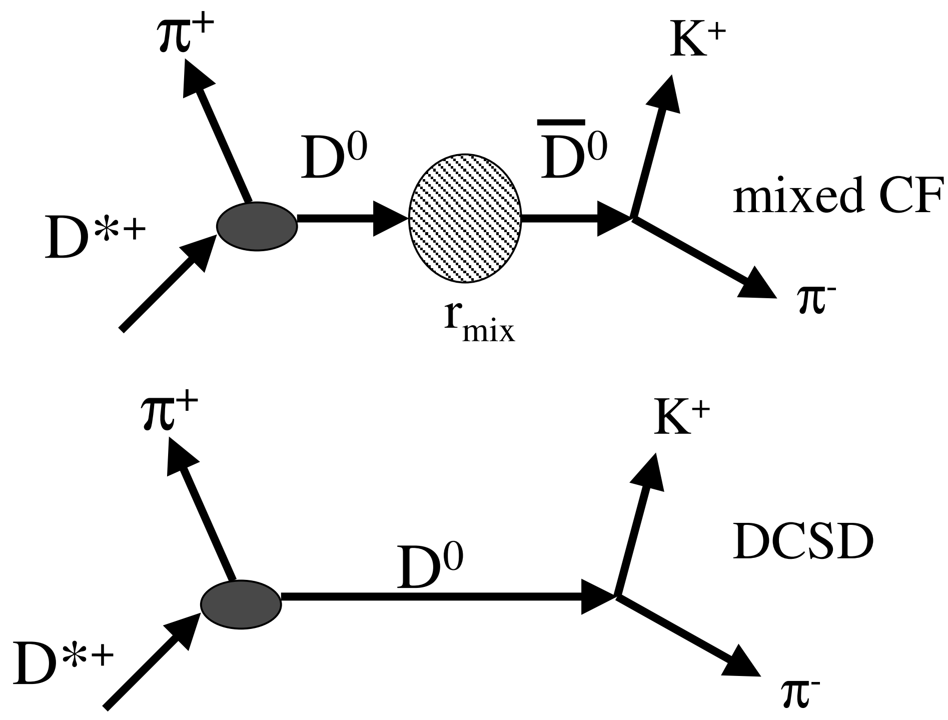


PRELIMINARY (~40%) D° DCSD



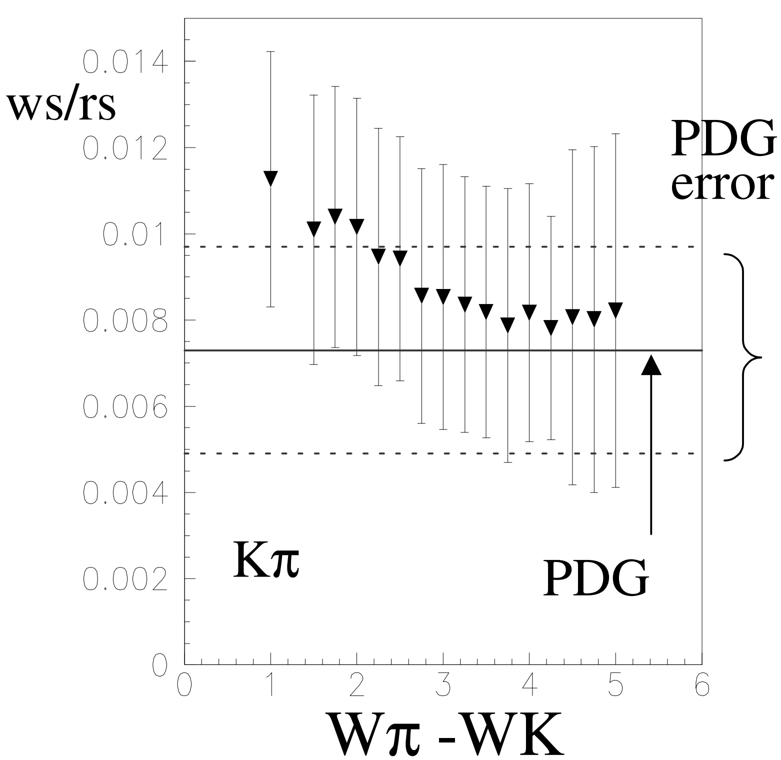


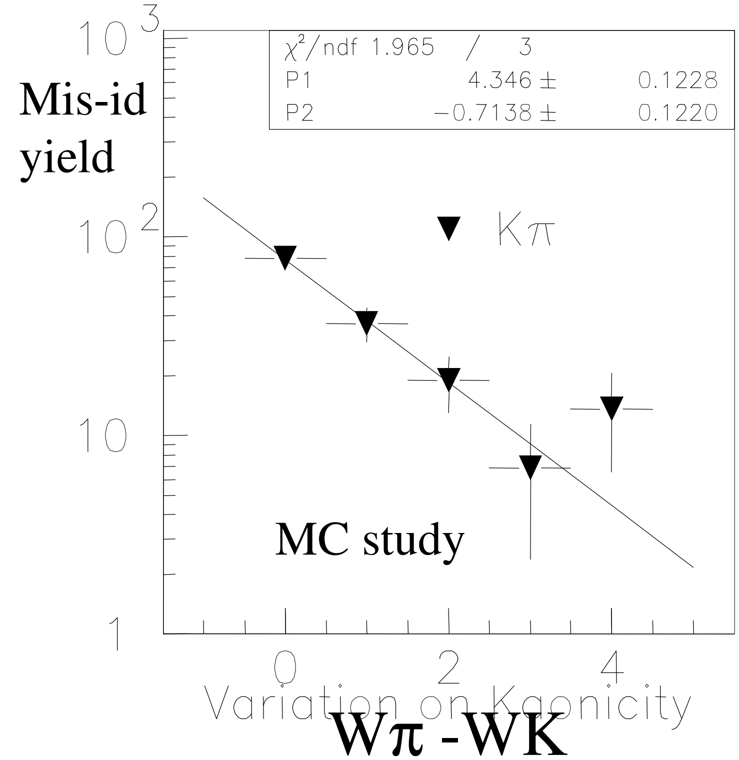
Here we look for WS D° decays where the kaon has the same sign as the D+* decay pion. This is also a classic way to search for mixing and could interfere with mixing. BR(DCSD) ≈WS/RS



Relative WS/RS ratio versus CITADL Cuts

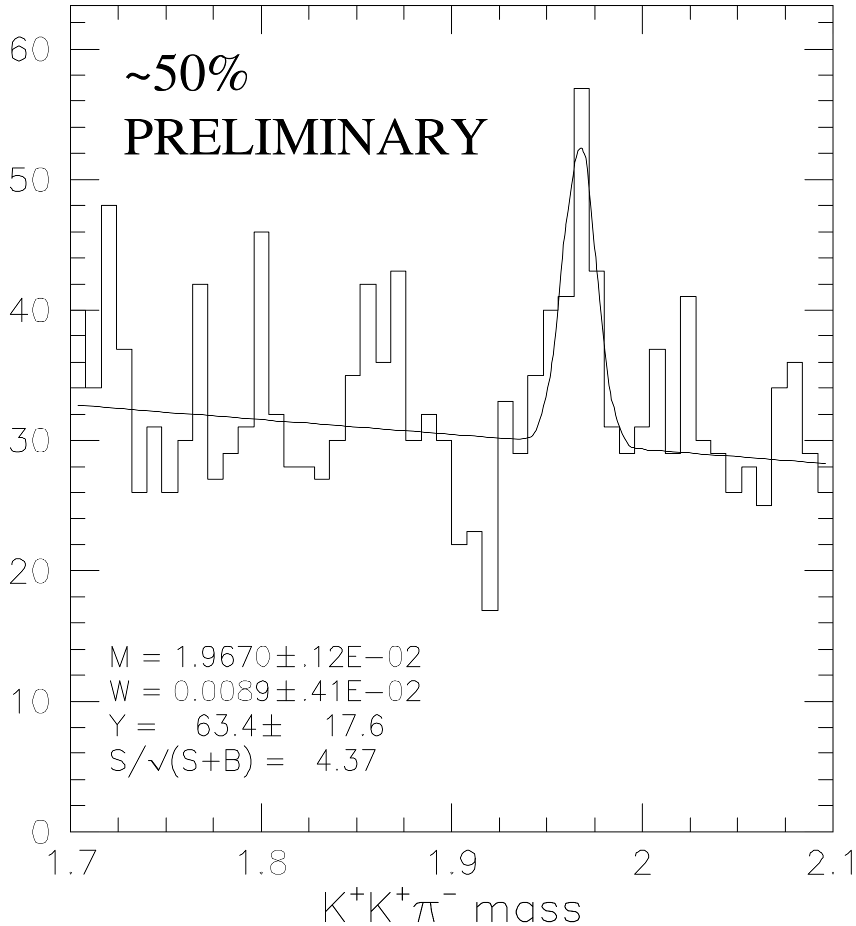
Cut variations on Γ_{19}/Γ_{155} with $K\pi$ candidates.





Slight variation in BR as pid cuts are tightened. Would expect exponential decrease if double mis-id. The signal level is consistent with existing world's average but higher than CLEO's recent measurement at APS

PRELIMINARY $D^+_s \to K^+K^+\pi^-$



This is the first observation of D^+_s DCSD

The rate relative to $K^-K^+\pi^+$ is $\approx 1.5\%$ $(\sim 6 \times \tan^4\theta_{Cabbibo})$

PRELIMINARY $D^+ \to K^+K^-K^+$ ~40% FOCUS

- $D_s^+ \to K^+K^-K^+$ is a SCSD
- $D^+ \to K^+K^-K^+$ is a $\Delta C = -\Delta S$ DCSD which cannot occur via a spectator diagram.

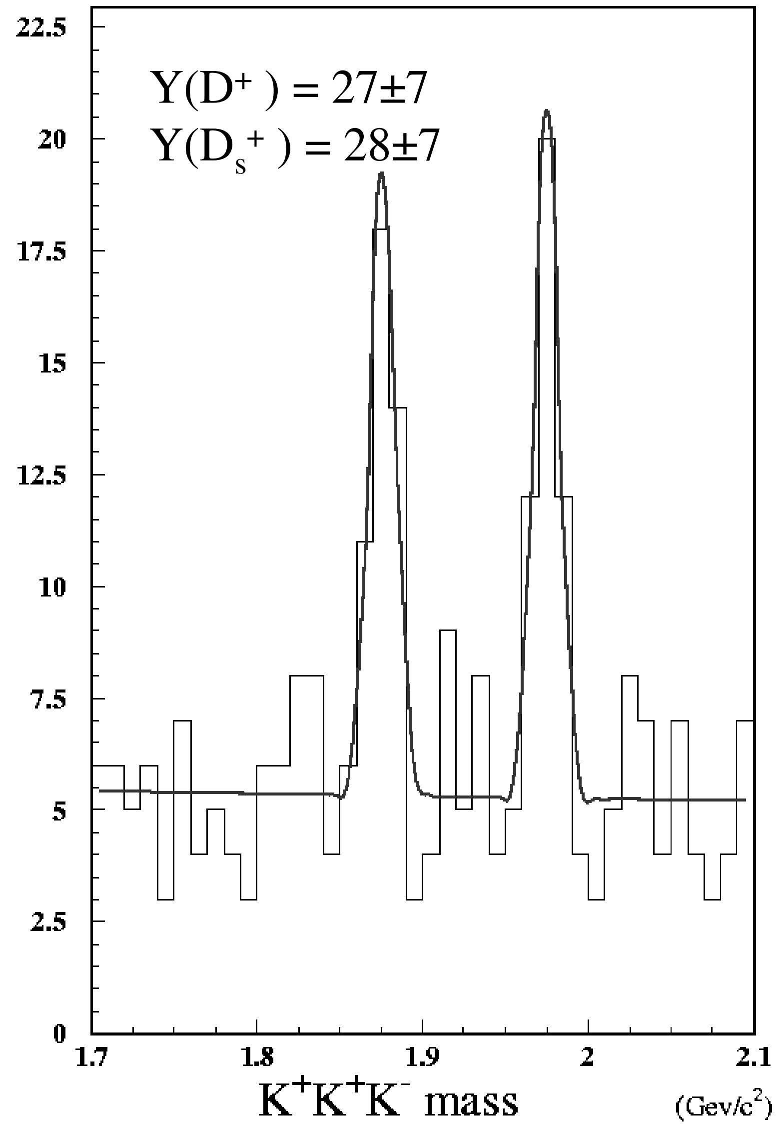
$\Gamma(D^+ \to K^+K^-K^+) / \Gamma(D^+) = (1.45 \pm 0.39) \times 10^{-4}$

Just below PDG 98 limit from E687 of
$Br < 1.4 \times 10^{-4}$ CL=90%

Our rarest DCSD BR yet :
$\Gamma(D^+ \to K^+K^-K^+) / \Gamma(K^- \pi^+\pi^+) \approx \tan^4\theta_C/2$

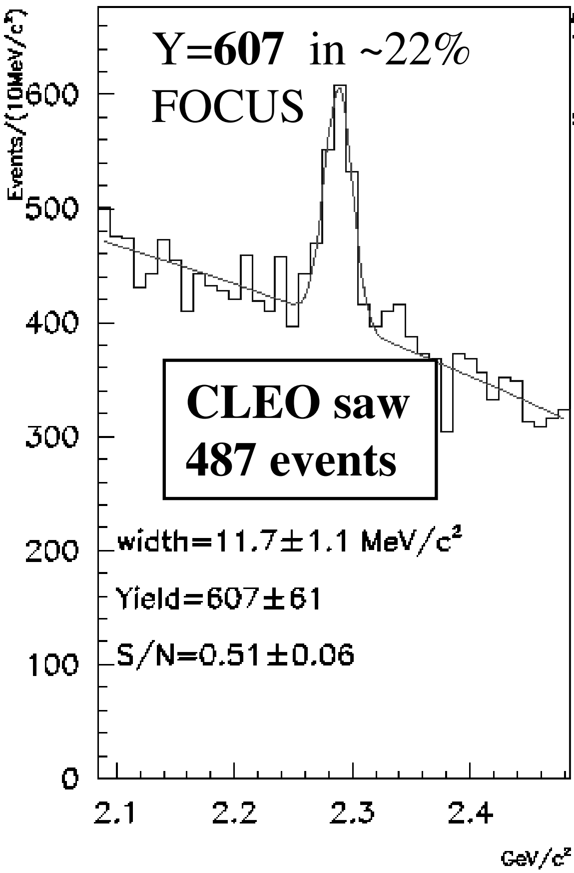
No evidence for $D^+ \to \phi K$

A KKK Dalitz analysis may shed light on the KKK decay mechanism.

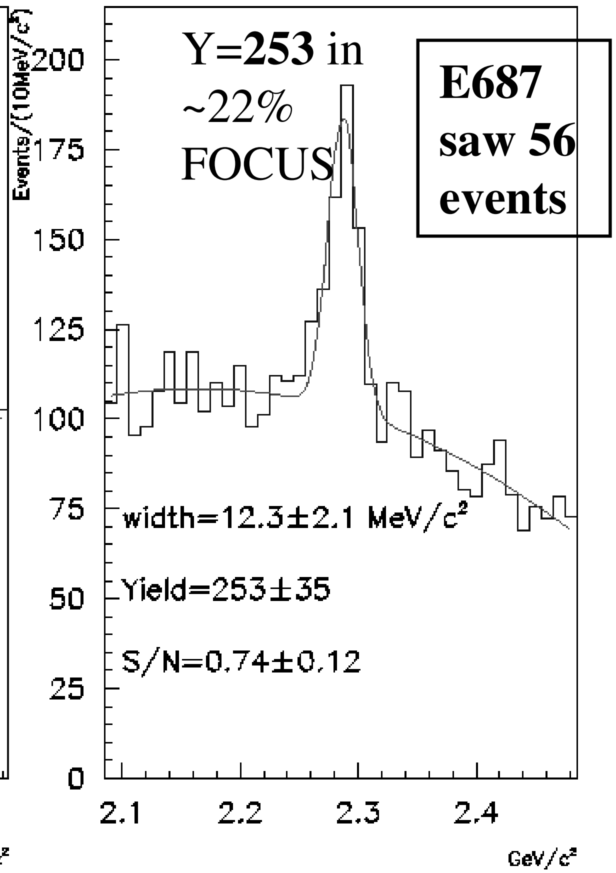


Kinky decays of the Λ_c^+

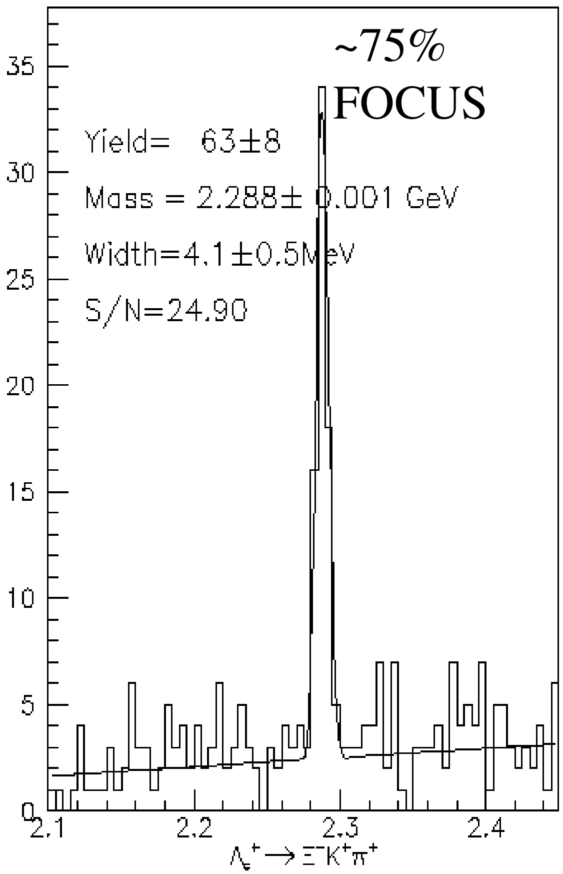
$\Lambda_c^+ \rightarrow \Sigma^+\pi^+\pi^-$



$\Lambda_c^+ \rightarrow \Sigma^-\pi^+\pi^+$



$\Lambda_c^+ \rightarrow \Xi^- K^+\pi^+$



- We have unique abilities to reconstruct the $\Sigma^- \rightarrow n\,\pi^-$
- Will study $\Sigma(1385)\,\pi^\pm$ since only contributions are internal W and WX

Motivation

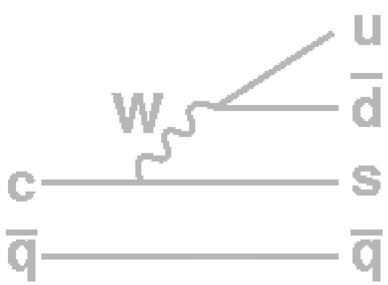
$$\tau = \frac{\hbar}{\Gamma_{SL} + \Gamma_{NL} + \Gamma_{PL}}$$

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

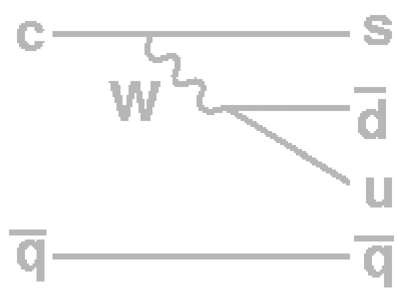
$$\Gamma_{SL}(D^0) = \frac{BR_{SL}}{\tau(D^0)} = (1.067 \pm 0.041) \times 10^{-13} GeV$$

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

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



Spectator Decay
(Color Aligned)



Internal Spectator
(Color Suppressed)

Spectator Decays

Coefficients modified by strong int.

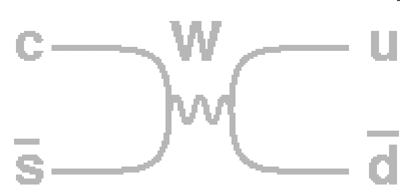
Pauli interference:

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

W-annihilation suppressed by:

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

W-exchange



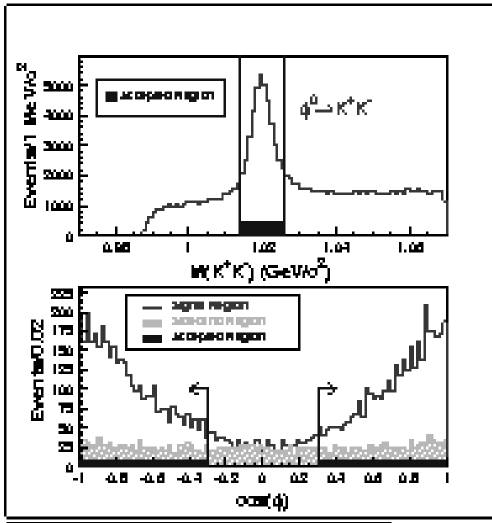
W-annihilation

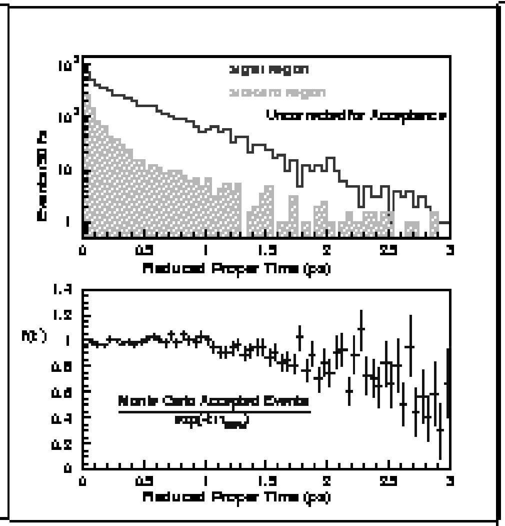
Annihilation Diagrams

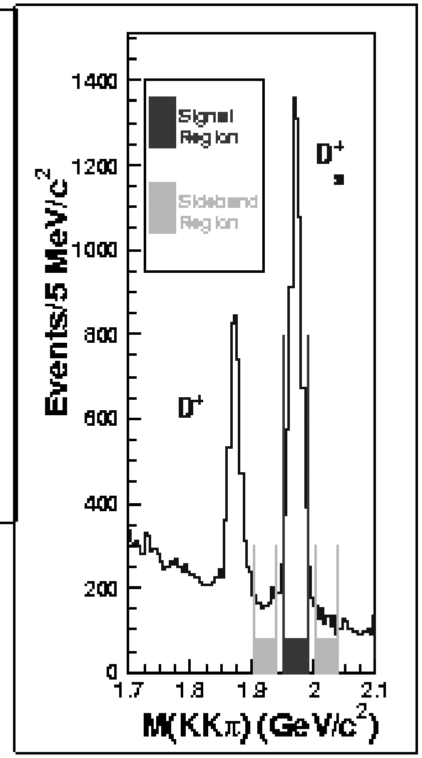
Helicity and wavefunction suppressed

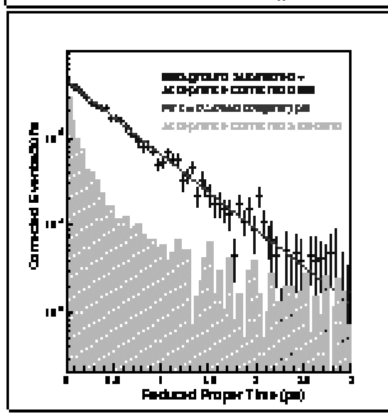
difficult to calculate reliably

$\tau(D_s^+)$ Measurement update









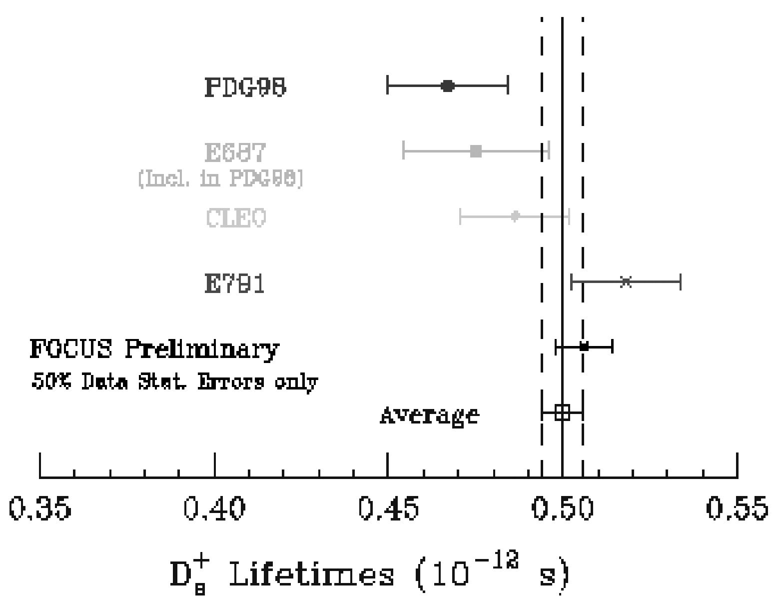
FOCUS E831

Preliminary result
from 50% Data

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

$\tau(D_s^+)$ Measurement update

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



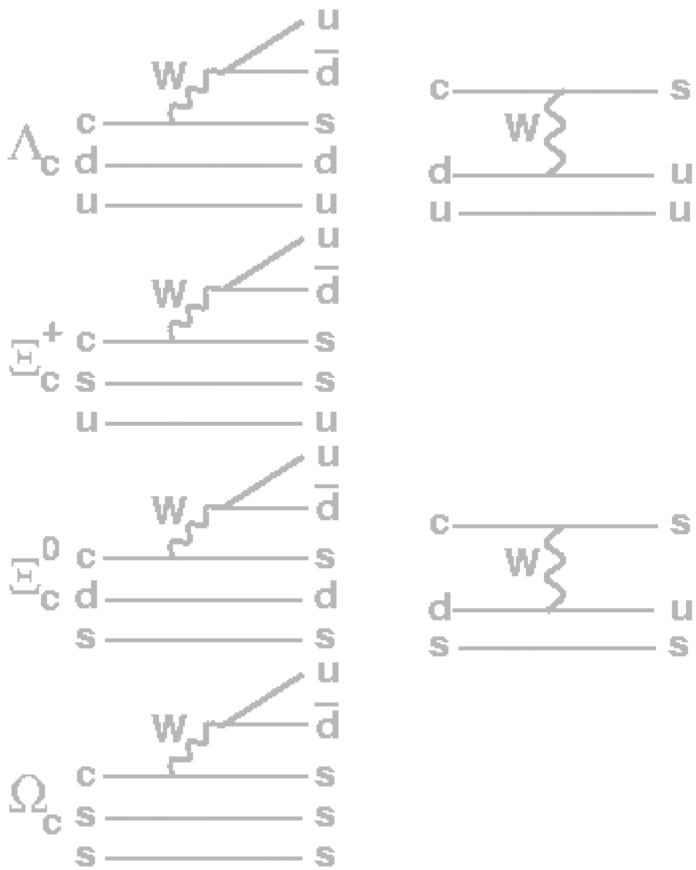
Update on $\tau(D^0)/\tau(D_s^+)$

PDG'98= 1.125 ± 0.042

New'99= 1.211 ± 0.017

12.4σ from unity

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

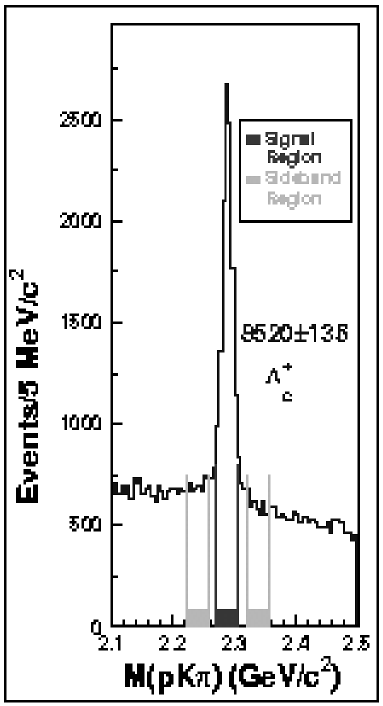
- o D_s^+ decays
- o Charm baryons
- o Bottom particles

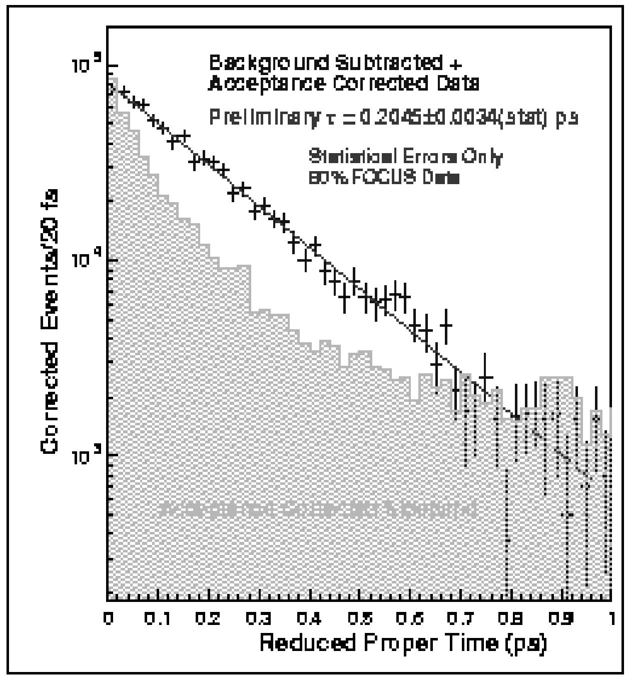
Expect: $\tau(\Omega_C) \approx \tau(\Xi_C{}^0) < \tau(\Lambda_C) < \tau(\Xi_C{}^+)$

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

New measurements since PDG'98:

Preliminary measurement from FOCUS (Fermilab E831):





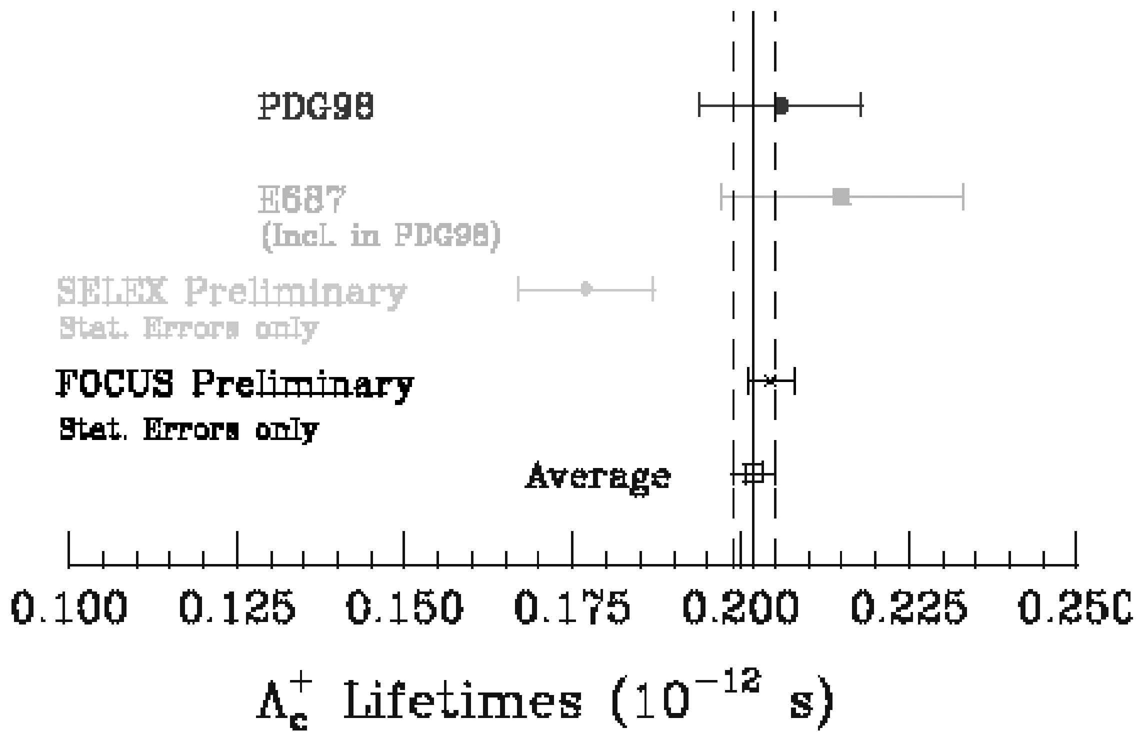
204.5 ± 3.4 fs

Stat. errors only

80% FOCUS Data

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

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



Rare and Forbidden Decays

3 categories :

1) FCNC : $D^+ \to h^+\mu^+\mu^-$; $D^0 \to l^+l^-$, ...
   Flavor Changing Neutral Current

2) LFNV : $D^+ \to h^+l_1^+l_2^-$, ...
   Lepton Family Number Violating

3) LNV : $D^+ \to h^-l_1^+l_{1,2}^+$, ...
   Lepton Number Violating

- ***Rare decays*** usually means a process which proceeds via an internal quark loop in the Standard Model (forbidden at the tree level)
- *Forbidden decays* NOT allowed in the Standard Model

Rare and Forbidden Decays, cont...

- Branching ratio method:

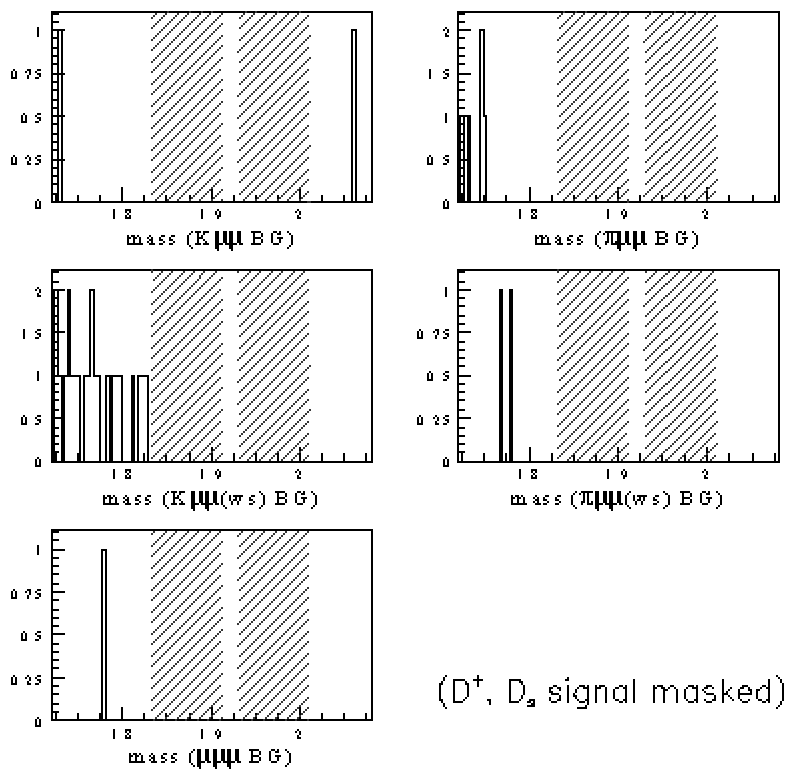
$$R = \frac{B(D \to h\ell\ell)}{B(D \to K\pi\pi)} = \frac{N_{obs}(h\ell\ell)\epsilon(K\pi\pi)}{\epsilon(h\ell\ell)N_{obs}(K\pi\pi)}$$

- Normalizing mode: $D^+ \to K^-\pi^+\pi^+$
- Multiply R by $BF(D^+ \to K^-\pi^+\pi^+) = (9.0 \pm 0.6)\%$ (PDG)
- Use same cuts for both normalizing and Rare mode (to extent possible)
- Many systematics cancel out in relative efficiency
- We will show a very very preliminary study on

$$D^+ \to K^+\mu^+\mu^-(+ws),$$
$$D^+ \to \pi^+\mu^+\mu^-(+ws),$$
$$D^+ \to \mu^-\mu^+\mu^+$$

Preliminary result out of 45 % of the data

Background (best cuts)



(D^+, D_s signal masked)

Rare and Forbidden Decays, cont...

These very very preliminary results are summarized in the following table:

Decay mode	E831: expected sensitivity 45% of the data	PDG 98 90% C.L. limit
$D^+ \to K^+\mu^+\mu^-$	8.1×10^{-6}	9.7×10^{-5}
$D^+ \to K^-\mu^+\mu^+$	12.1×10^{-6}	1.2×10^{-4}
$D^+ \to \pi^+\mu^+\mu^-$	7.8×10^{-6}	1.8×10^{-5}
$D^+ \to \pi^-\mu^+\mu^+$	7.1×10^{-6}	8.7×10^{-5}
$D^+ \to \mu^-\mu^+\mu^+$	4.4×10^{-6}	

Rare and Forbidden Decays, cont...

Decay mode	E687 90% C.L. Limit (10^{-5})	PDG 98 90% C.L. Limit (10^{-5})
$\pi^+e^+e^-$	11	6.6
$K^+e^+e^-$	20	20
$\pi^+\mu^+\mu^-$	8.9	1.8
$K^+\mu^+\mu^-$	9.7	9.7
$\pi^+\mu^+e^-$	13	13
$\pi^+\mu^-e^+$	11	11
$K^+\mu^+e^-$	12	12
$K^+\mu^-e^+$	13	13
$\pi^-e^+e^+$	11	11
$K^-e^+e^+$	12	12
$\pi^-\mu^+\mu^+$	8.7	8.7
$K^-\mu^+\mu^+$	12	12
$\pi^-\mu^+e^+$	11	11
$K^-\mu^+e^+$	13	13

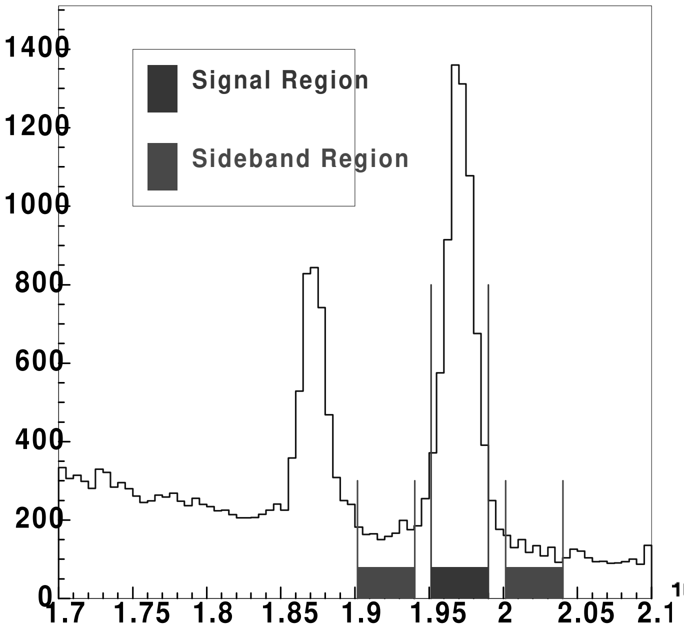
Rare and Forbidden Decays, cont...

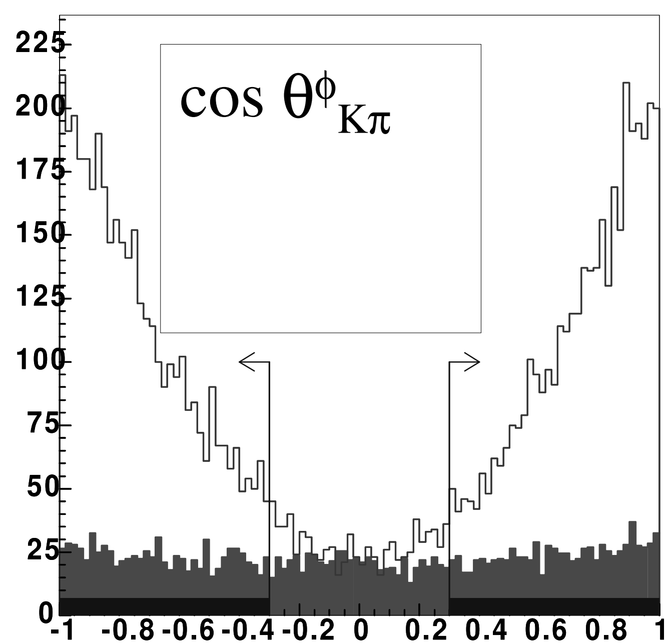
- reasonable gain of 50 , with respect to the E687 measurements, because of the improved EM calorimeters and Muon detectors

$$\Downarrow$$

reach 90% C.L. limit of the order of 1×10^{-5}

Preliminary measurement of the D_s^+ lifetime

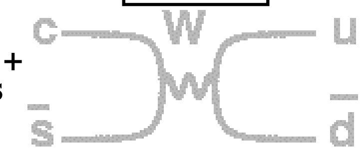




D_s^+ and D^o have unique CF non-spectator decays

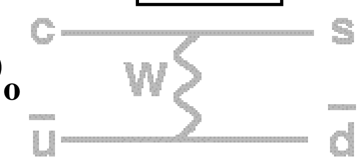
WA

D_s^+

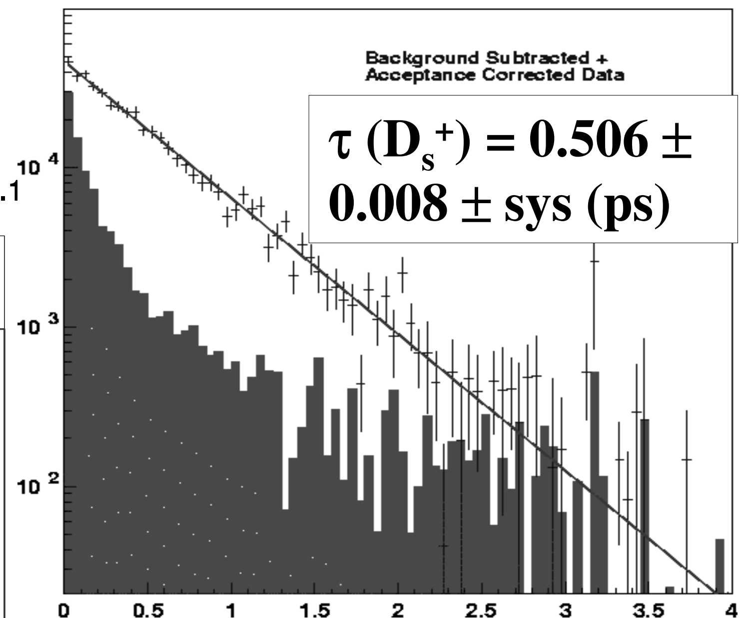


WX

D_o



Theory $\tau\,(D_s^+)\,/\tau\,(D^o) = 1.07 \rightarrow 1.20$



We use 5668 $D_s^+ \rightarrow \phi\pi$ decays in ~50% of FOCUS to suppresses long-lived backgnd from $D^+ \rightarrow K^- \pi^+ \pi^+ \searrow K^+$

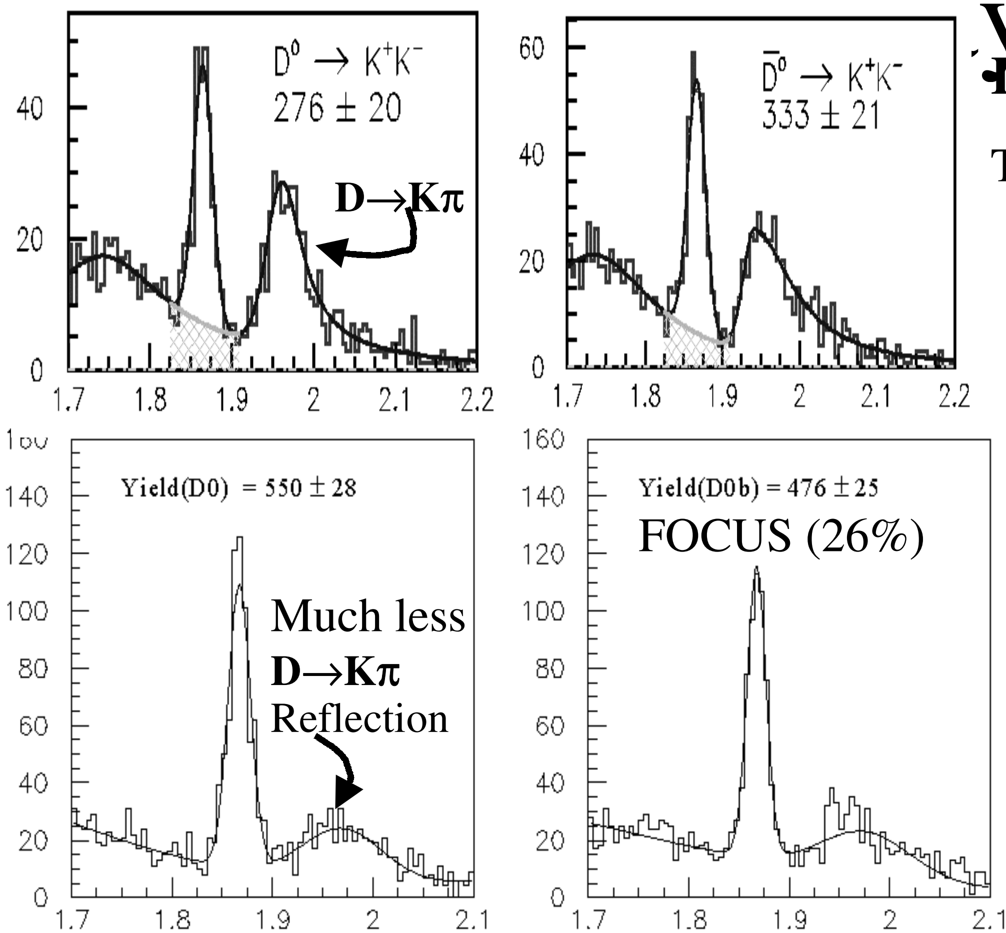
Also allows us to enhance S/N with $\cos\,\theta$ cut

Using E791 $\tau\,(D_s^+) = 0.518 \pm 0.014 \pm 0.007$ ps

We project:WA is **$\tau\,(D_s^+)\,/\tau\,(D^o) = 1.214 \pm 0.017$**

Search for CP Violating SCSD ...ys

E791



- **Look for $\Gamma(D \to K^+K^-) \neq \Gamma(\overline{D} \to K^+K^-)$**

Tag D charm through $D^{\pm *} \to D\pi^{\pm}$

We normalize to **$D^\circ \to K^-\pi^+$** to eliminate ≈4% production asymmetry.

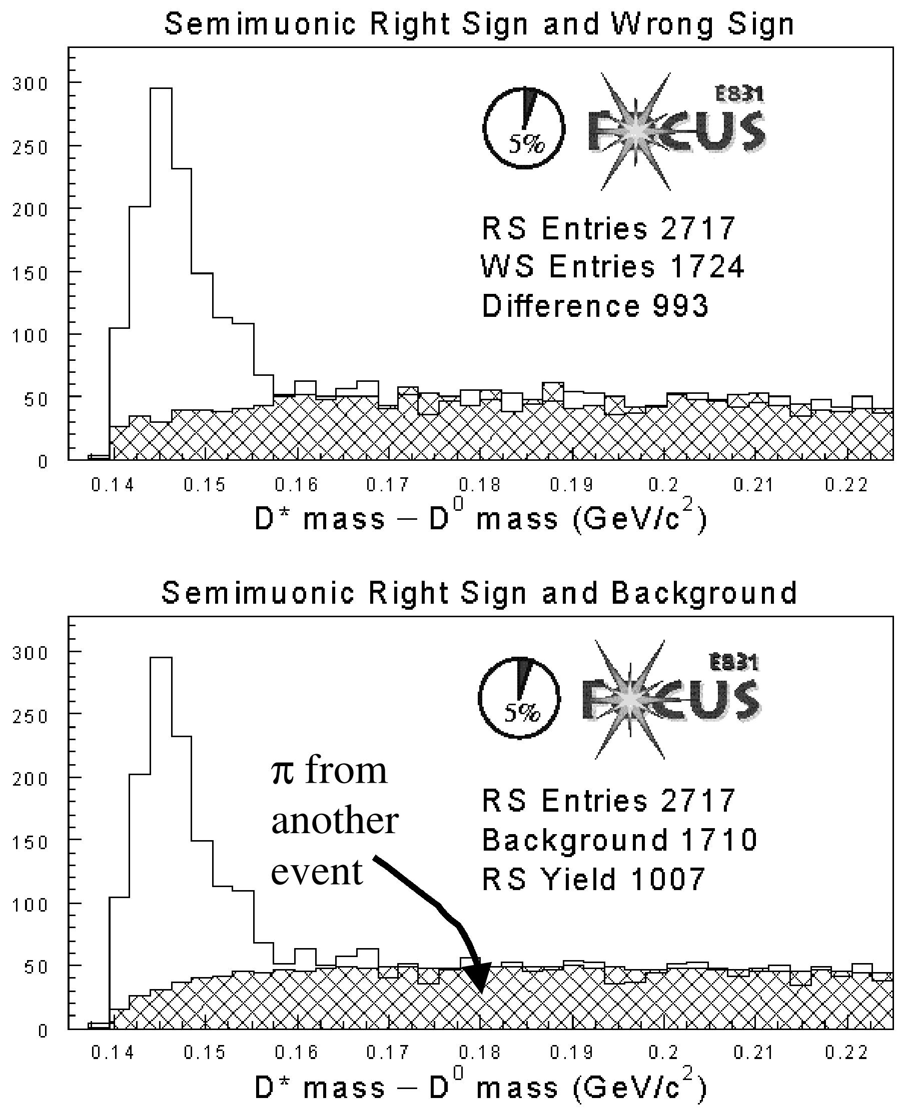
$$A_{CP} = \frac{\eta(D) - \eta(\overline{D})}{\eta(D) + \eta(\overline{D})}$$

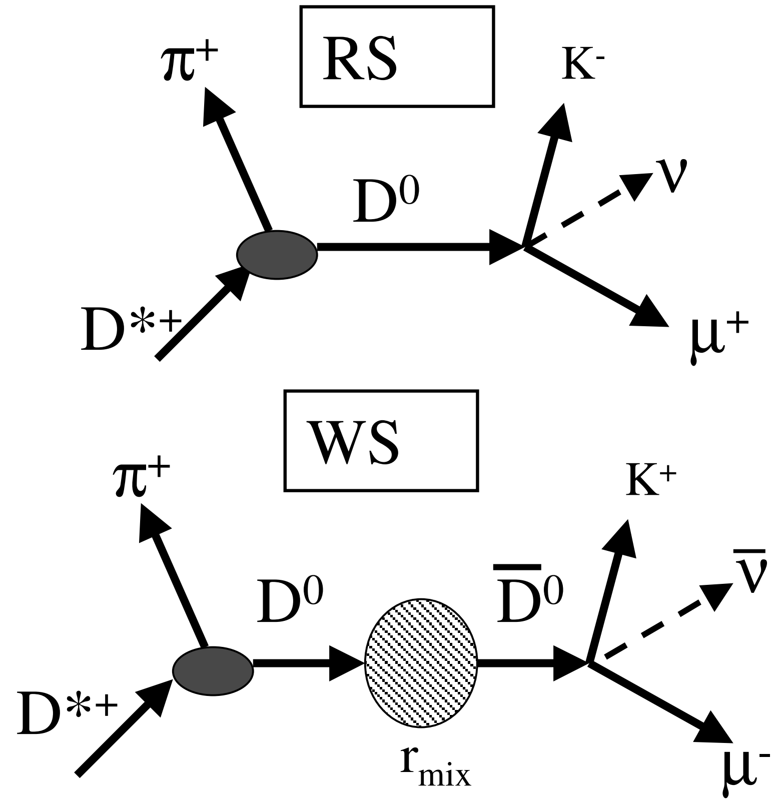
$$\eta(D) = \frac{N(D^0 \to K^-K^+)}{N(D^0 \to K^-\pi^+)}$$

Decay mode	First Look (E831)	Best measurement
$D^+ \to K^-K^+\pi^+$	-0.004 ± 0.027	-0.014 ± 0.029 (E791)
$D^0 \to K^-K^+$	0.021 ± 0.050	$-0.010 \pm 0.049 \pm 0.012$ (E791)

≈World's best data using 26% of **Focus**!

Semileptonic Mixing Searches





$$I_{RS}(t) \approx e^{-\Gamma t} \qquad I_{WS}(t) \propto \frac{r_{mix}}{2} \Gamma^2 t^2 \; e^{-\Gamma t}$$

Limit follows from fitting **time evolution** of WS and RS signal. No DCSD interference.

Mixing sensitivity

- FOCUS projected sensitivity is $r_{mix} \sim 0.15\%$
  - Including electrons we project $r_{mix} \sim 0.1\%$
- **Present E791 limit $r_{mix} < 0.50\%$ (90% CL)**

We have unique advantages in searching for direct $\Delta\Gamma$ differences between CP-even eigenstates such as $\mathbf{D^\circ \to K^+ K^-}$ and states of mixed CP such as $\mathbf{D^\circ \to K^- \pi^+}$ or CP odd states such as $\mathbf{K_s}\rho$ or $\mathbf{K_s}\varphi$

We expect a yield of from 5000-10000 $D^\circ \to K^+ K^-$ decays. This should give us a lifetime measurement for CP even states of better than

$$\sigma(\tau)/\tau < 1.5\%$$