E687

FOCUS E831

Results from Fermilab E687

and

Future High Statistics Charm Experiment FOCUS/E831

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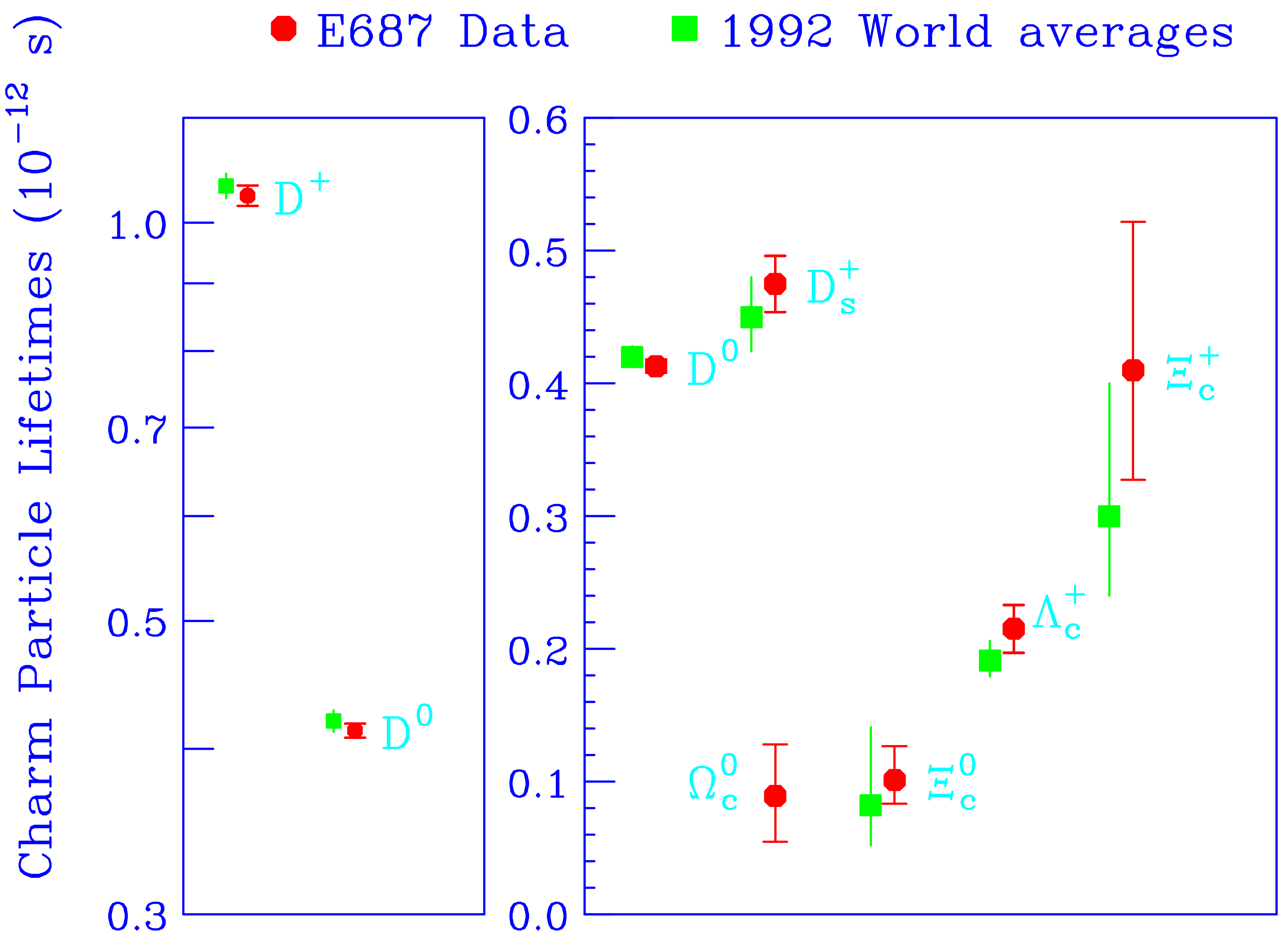
Brief History of Fermilab E687

- 1987 Data Taking Run
  - About 10^4 Charm decays reconstructed
- 1990+1991 Data Taking Run
  - About 10^5 Charm decays reconstructed
  - Run ended January 1992, Data processing of the 500 million events completed in August 1992!
  - First Physics results *published* in February 1993
  - So far 23 physics papers published in PRL or PLB from 1990/91 data
  - Still more interesting physics to come!

Some Highlights of E687 Results

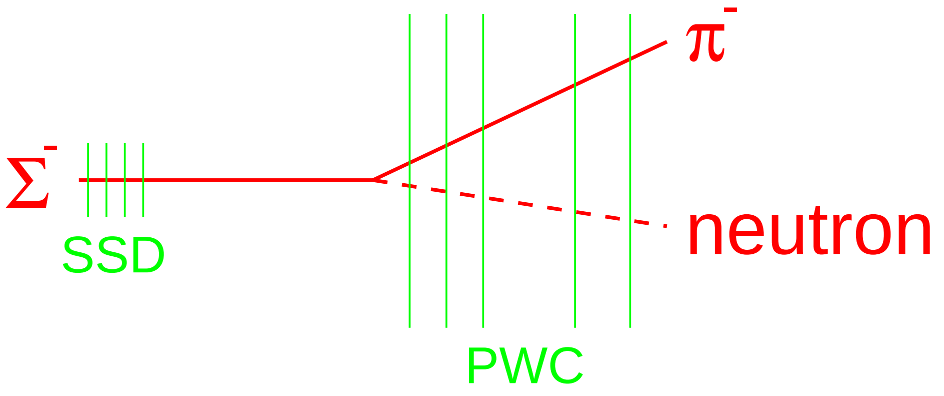
- Lifetimes
  - World's best measurements of all the charm particle lifetimes

- Charm Baryon Decays
  - Reconstructed baryon decays using the Σ^- ($\Sigma^- \to n\pi^-$), *e.g.* $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$
  - First conclusive evidence for the Ω_c^0, in $\Omega_c^0 \to \Sigma^+ K^- K^- \pi^+$
  - First confirmation of two Λ_c^{*+} states



E687 Data
1992 World averages
Charm Particle Lifetimes (10^{-12} s)
0.3
0.5
0.7
1.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
D^+
D^0
D^0
D_s^+
Ω_c^0
Ξ_c^0
Λ_c^+
Ξ_c^+

Reconstructing ‘‘Kinks’’



Using kinematics of the decay, E687 can reconstruct ‘‘kinks’’, decays of a charged particle to a neutral and a charged particle, e.g. $\Sigma^- \rightarrow n\,\pi^-$. For this decay, the Σ is reconstructed in the silicon strip detector and the π is reconstructed in the proportional wire chambers. By assuming the mass of the Σ the direction of the neutron can be computed. Appropriate energy deposition is then searched for in the calorimeters for this direction. Using this technique E687 has made the first measurement of $\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+$, (below left and [a], [b] shows mass plot for $\Lambda_c^+ \rightarrow \Sigma^+ \pi^+ \pi^-$).

$$\frac{\Gamma(\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+)}{\Gamma(\Lambda_c^+ \rightarrow \Sigma^+ \pi^+ \pi^-)} = 0.53 \pm 0.15\ (\mathrm{stat.}) \pm 0.07\ (\mathrm{syst.})$$

FIGURES

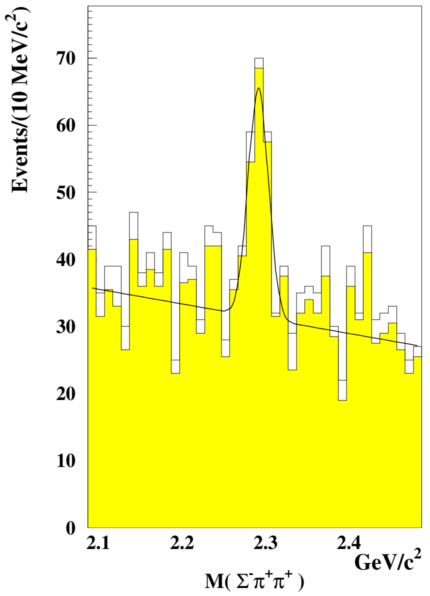


FIG. 1. Mass distribution for $\Lambda_c^+ \rightarrow \Sigma^-\pi^+\pi^+$ at $l/\sigma_l > 3.5$ with double counting (non-shaded histogram) and without double counting (shaded histogram).

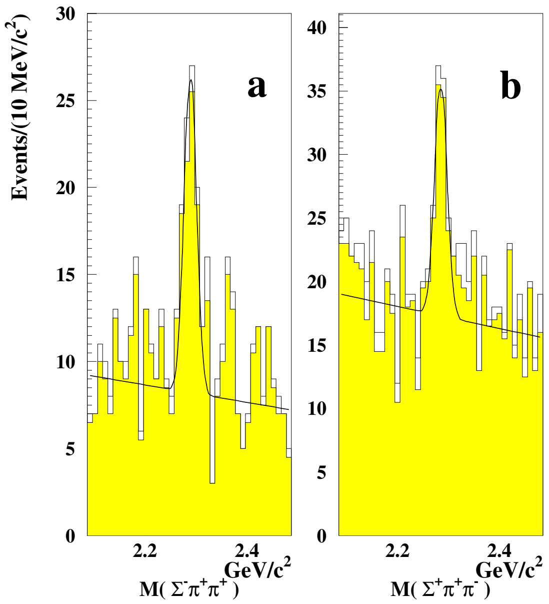
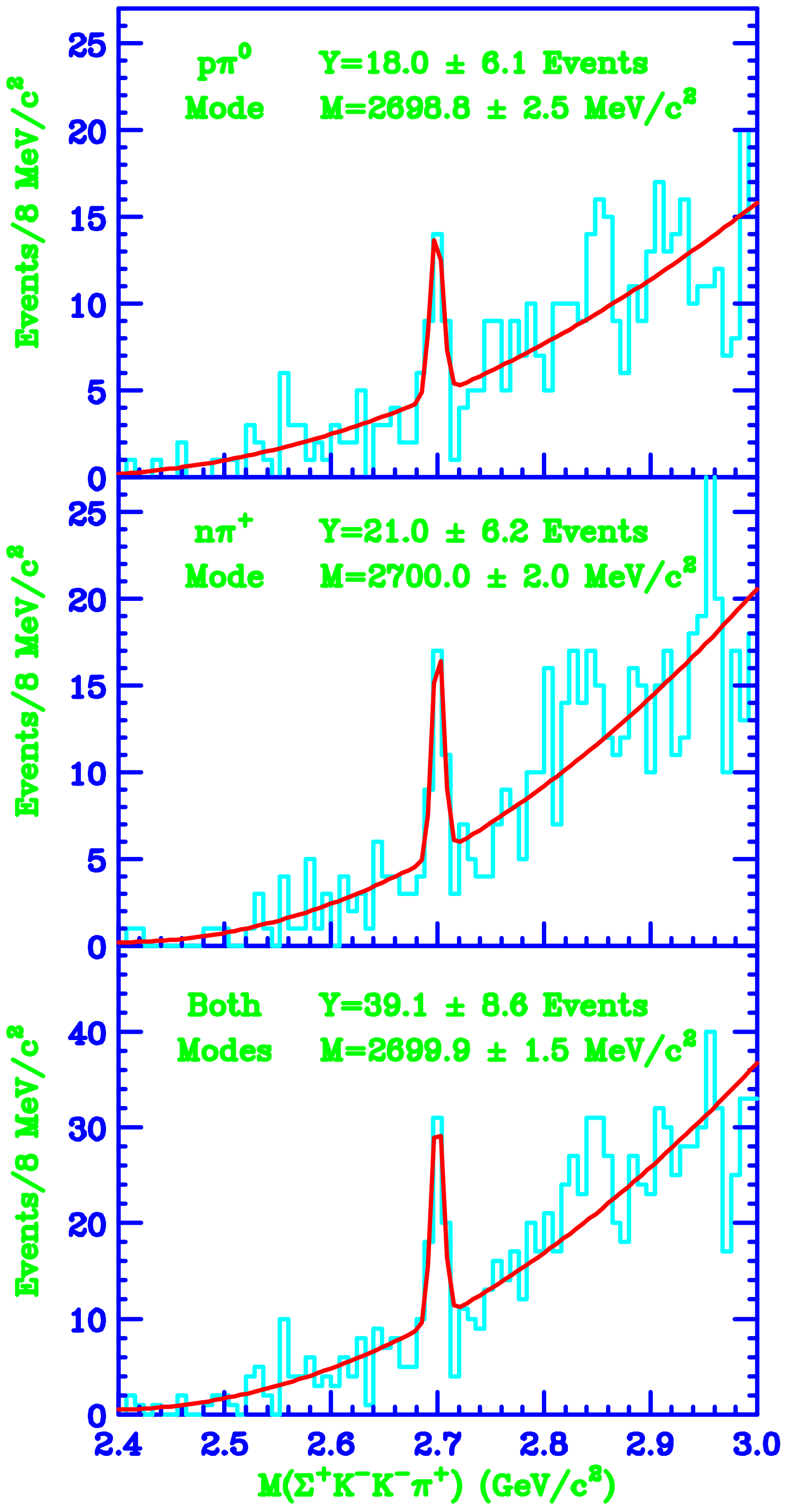
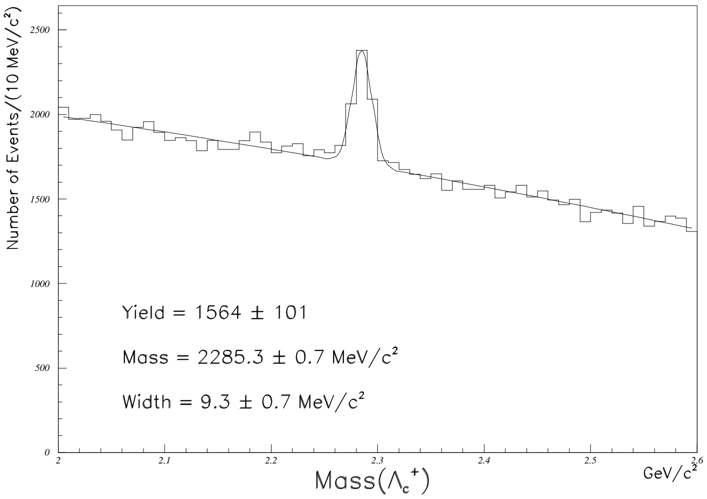


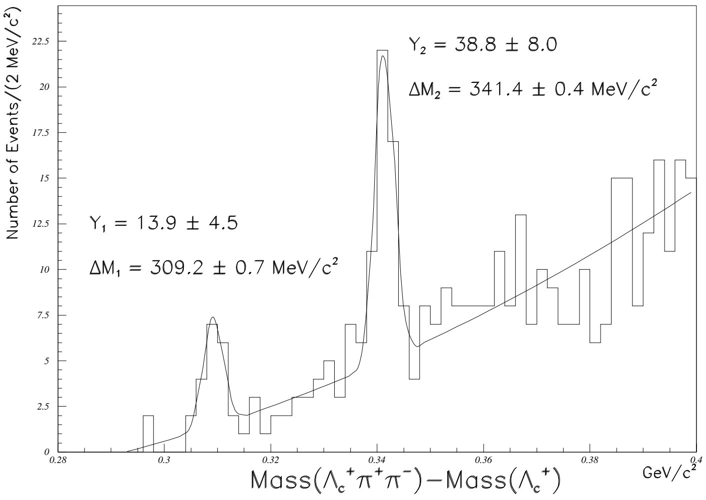
FIG. 2. Mass distributions at $l/\sigma_l > 5$ with double counting (non-shaded histograms) and without double counting (shaded histograms) for $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$ candidates (fig.a) and for $\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$ candidates (fig.b).



$p\pi^0$ Mode
Y=18.0 ± 6.1 Events
M=2698.8 ± 2.5 MeV/c^2
$n\pi^+$ Mode
Y=21.0 ± 6.2 Events
M=2700.0 ± 2.0 MeV/c^2
Both Modes
Y=39.1 ± 8.6 Events
M=2699.9 ± 1.5 MeV/c^2
Events/8 MeV/c^2
$M(\Sigma^+K^-K^-\pi^+)$ (GeV/c^2)



Number of Events/(10 MeV/c²)
2500
2000
1500
1000
500
0
2
2.1
2.2
2.3
2.4
2.5
2.6
GeV/c²
Mass(Λc+)
Yield = 1564 ± 101
Mass = 2285.3 ± 0.7 MeV/c²
Width = 9.3 ± 0.7 MeV/c²



Number of Events/(2 MeV/c²)
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
0.28
0.3
0.32
0.34
0.36
0.38
0.4
GeV/c²
Mass(Λc⁺π⁺π⁻)−Mass(Λc⁺)
Y₁ = 13.9 ± 4.5
ΔM₁ = 309.2 ± 0.7 MeV/c²
Y₂ = 38.8 ± 8.0
ΔM₂ = 341.4 ± 0.4 MeV/c²

Some Highlights of E687 Results

- Many Competitive Semileptonic Results
  - $D^+ \to K^{*0}\mu^+\nu_\mu$ form factors and branching ratios
  - $D_s^+ \to \phi\mu^+\nu_\mu$ form factors and branching ratios
  - $D^0 \to K^-\mu^+\nu_\mu$ form factor, branching ratio, pole mass and $f_-(0)/f_+(0)$
  - Coming soon: $D^0 \to K^-e^+\nu_e$, $D^0 \to \pi^-e^+\nu_e$, $D^0 \to \pi^-\mu^+\nu_\mu$ branching ratios, ratio of form factors and $|V_{cd}|/|V_{cs}|$

TABLES

TABLE I. Final Results and Comparison to Other Experiments

Reference	$\frac{BR(D^0 \to K^- l^+ \nu_l)}{BR(D^0 \to K^- \pi^+)}$	Pole Mass M_{pole}	$\frac{BR(D \to K^* l \nu_l)}{BR(D \to K l \nu_l)}$
This Paper	$0.852 \pm 0.034 \pm 0.028$	$1.87^{+0.11+0.07}_{-0.08-0.06}$ (GeV/c^2)	$0.62 \pm 0.11 \pm 0.02$
[8](CLEO '93)	$0.978 \pm 0.027 \pm 0.044$	$2.00 \pm 0.12 \pm 0.18$	0.62 ± 0.08
[15](CLEO '91)	$0.79 \pm 0.08 \pm 0.09 (\mu\ only)$	$2.0^{+0.4+0.3}_{-0.2-0.2}$	$0.51 \pm 0.18 \pm 0.06$
[5, 10](E691)	$0.91 \pm 0.07 \pm 0.11$	$2.1^{+0.4}_{-0.2} \pm 0.2$	0.55 ± 0.14

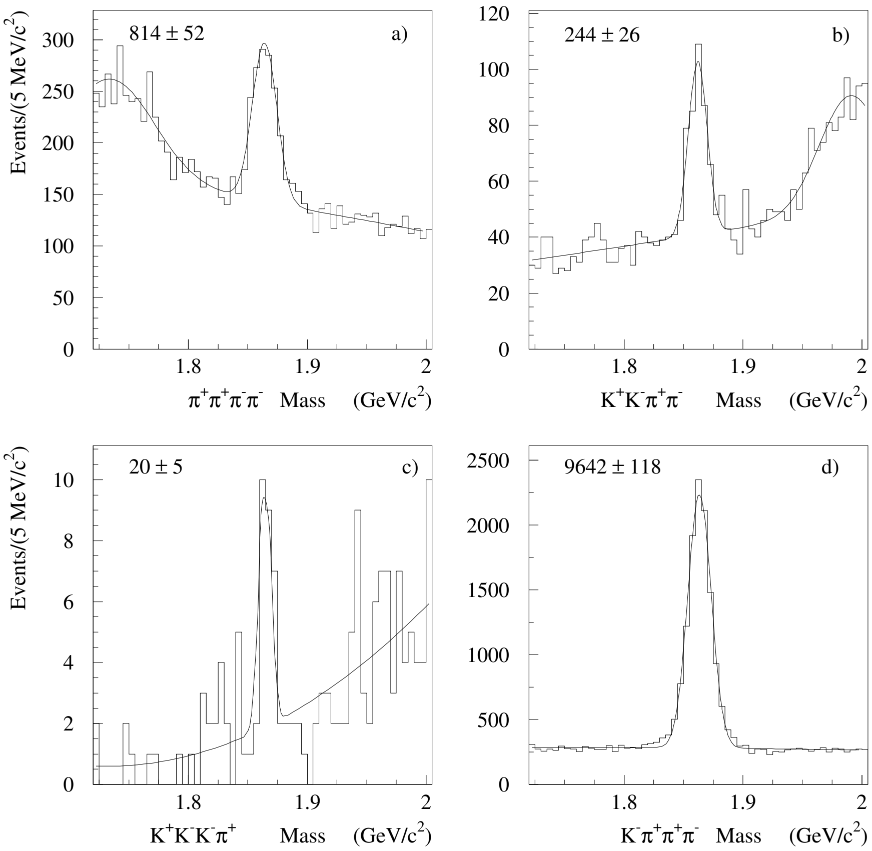
Reference	$\Gamma(D^0 \to K^- l^+ \nu_\mu) 10^{10}/sec$	$f_+(0)$
This Paper	$8.07 \pm 0.52 \pm 0.27$	$0.71 \pm 0.03 \pm 0.02$
[8] (CLEO '93)	$9.1 \pm 0.3 \pm 0.6$	$0.77 \pm 0.01 \pm 0.04$
[15] (CLEO '91)		$0.81 \pm 0.03 \pm 0.06$
[5] (E691)	$9.1 \pm 1.1 \pm 1.4$	$0.79 \pm 0.05 \pm 0.06$

TABLE II. Comparison of $f_-(0)/f_+(0)$ to Theoretical Estimates

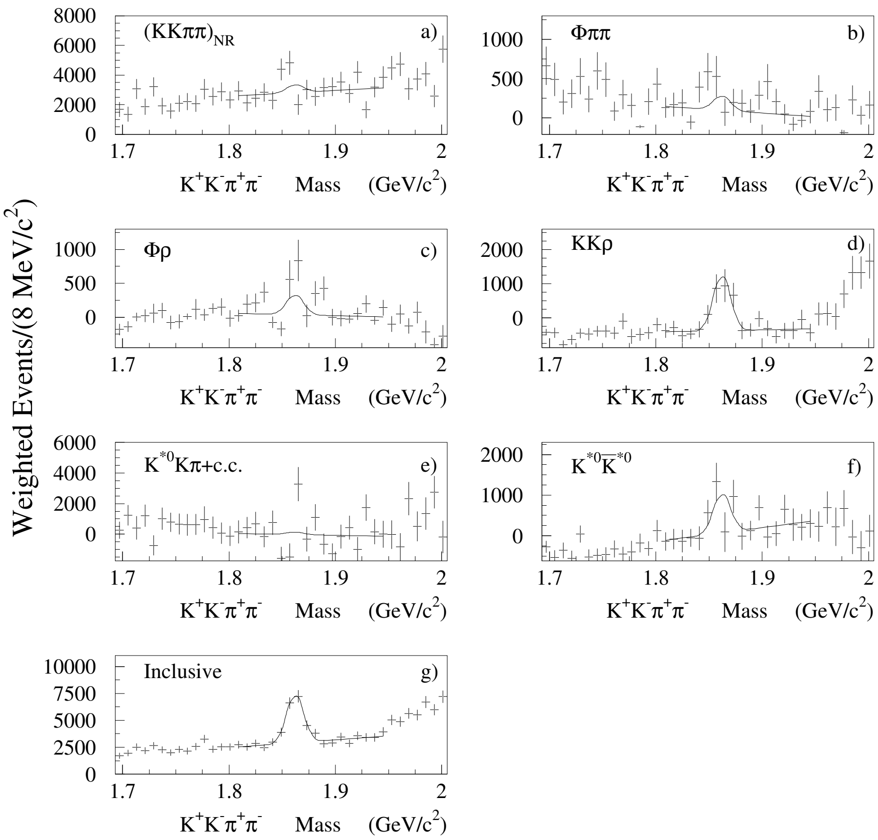
Reference	f_-/f_+
This Paper	$-1.3^{+3.6}_{-3.4} \pm 0.6$
[18] (BES)	-1.2 ± 0.5
[19] (BSW)	-0.46
[20–22] (GISW,AW)	-0.60
[23, 24] (KS)	-0.46
[25] (GBD)	$-0.36 \to -1.07$

Some Highlights of E687 Results

- Hadronic Decays of Charm Mesons
  - Detailed Dalitz plot analyses of $D^+, D_s^+ \to K^+K^-\pi^+$ and $D \to K\pi\pi$
    Coming soon: $D^+, D_s^+ \to \pi^+\pi^-\pi^+$
  - Decays with K_s^0
    $D^0 \to 2K_s^0$ and $3K_s^0$
    $D^+, D_s^+ \to K_s^0 K^+$ and $K_s^0 K^{*+}$
  - Multibody decays, *e.g.* $D^0 \to K^+K^-\pi^+\pi^-$, $K^-\pi^+\pi^+\pi^-$, $K^+K^-K^-\pi^+$ and $\pi^+\pi^-\pi^+\pi^-$
- Tests of QCD with Double D Events
- Competitive D^{**} Results
- CP Violation search in Charm decays
- Coming soon: DCSD decay $D^+ \to K^+\pi^-\pi^+$



814 ± 52
a)
Events/(5 MeV/c²)
π⁺π⁺π⁻π⁻ Mass (GeV/c²)
244 ± 26
b)
K⁺K⁻π⁺π⁻ Mass (GeV/c²)
20 ± 5
c)
Events/(5 MeV/c²)
K⁺K⁻K⁻π⁺ Mass (GeV/c²)
9642 ± 118
d)
K⁻π⁺π⁺π⁻ Mass (GeV/c²)



Weighted Events/(8 MeV/c²)
(KKππ)NR
a)
Φππ
b)
Φρ
c)
KKρ
d)
K*0Kπ+c.c.
e)
K*0K̄*0
f)
Inclusive
g)
K+K-π+π- Mass (GeV/c²)

TABLE III. Branching ratios for $\Gamma(D^0 \to \text{Decay Mode})/\Gamma(D^0 \to K^-\pi^+\pi^+\pi^-)$ and comparison to previous experiments. The branching ratios for the unseen decay modes of intermediate resonances have been included where appropriate.

Decay Mode	E687 (This work)	E691 [9]	CLEO [10]
$(K^-K^+\pi^-\pi^+)_{NR}$	< 0.011 (90%$C.L.$)	$0.001^{+0.011}_{-0.001}$	
$\phi\pi^-\pi^+$ 3-body	< 0.006 (90%$C.L.$)		
$\phi\rho^0$	0.005 ± 0.003		0.024 ± 0.006
$K^-K^+\rho^0$ 3-body	0.012 ± 0.003		
$K^{*0}K^-\pi^+$ 3-body $+c.c.$	< 0.017 (90%$C.L.$)	$0.010^{+0.016}_{-0.010}$	
$\overline{K^{*0}}K^{*0}$	0.016 ± 0.006	$0.036^{+0.020}_{-0.016}$	< 0.033 (90%$C.L.$)

FOCUS E831

Photoproduction of Charm in an Upgraded Spectrometer

- Accumulate 10^6 Fully Reconstructed Charm Decays
- *Tremendous* Experience gained from E687
- Run at 5 times the luminosity of E687
- Improve Efficiency of the DAQ+Detector by $\times 2$
  - Upgrade to handle higher beam intensity
  - 5 New detectors
  - Upgrades to all detectors except Cerenkovs
  - New Trigger System
  - New DAQ System

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Physics Goals for FOCUS

- High Precision Studies of the D Semileptonic Decays
  - Muon yields are anticipated to be 30× E687
  - Muon misidentification reduced by ×5
  - Much improved electron detectors
  - Measurement of $|V_{cd}|/|V_{cs}|$ to 1.5%
  - Measurement of vector and axial vector form factors might be used to predict the Beauty form factors
- Leptonic Decays – f_D pseudoscalar decay constant
  - Observing $D^+ \rightarrow \mu^+\nu_\mu$, $D^{*+} \rightarrow D^+\pi^0$
  - Search for $D_s^+ \rightarrow \tau^+\nu_\tau$
- Absolute Branching Fractions
  - CLEO value 2% statistical and 4.4% systematic
  - Measurement of $BR(K^-\pi^+)$ to 3%
  - Measurement of $BR(K^-\pi^+\pi^+)$ to 4%
- Hadronic Decays of the D^0 and D^+
  - Improved Dalitz plot analyses
  - Ability to use K_L^0 with new hadron calorimeter

Physics Goals for FOCUS....

- Study Charm Production Dynamics and Make a Detailed Comparison with Models
  - Double charm events will be particularly useful (10K events)
- D_s^+ Decays
  - 20,000 $D_s^+ \to K^+K^-\pi^+$
  - Study excited states
- Λ_c^+ Decays
  - 20,000 $\Lambda_c^+ \to \mathrm{p}K^-\pi^+$
  - Absolute Branching ratio (to 20% statistical)
  - Search for new modes (containing neutrons) using the Λ_c^{*+} tags
- D^{**} States
  - Look at carefully with very clean Double D samples
- Charm Baryon Spectroscopy and Lifetimes
  - New ability to use Ξ^0 as a daughter decay particle as well as Λ^0, $\Sigma^\pm$, Ξ^- and Ω^-
  - Search for doubly-charmed baryons

Physics Goals for FOCUS....

Search for New Physics

- $D^0 - \bar{D}^0$ Mixing and Double Cabbibo Suppressed Decays
  - Current predictions for mixing including long distance effects are $\approx 10^{-8}$, but various new phenomena like a heavy $b\,'$, or two-Higgs-Doublet models could produce visible mixing effects
  - Conclusively identify several DCSD channels, *e.g.* $D^+ \to K^+\pi^+\pi^-$, $K^+K^+K^-$
- Rare D Decays
  - Set limits for D^0 decays to $\mu^+\mu^-$ and e^+e^-
  - Set limits for $D^0 \to \rho\gamma$ and $K^*\gamma$
- Forbidden Decays
  - $D^0 \to \mu^+e^-$
- CP Violation
  - Difference in rates between D^0 and $\bar{D}^0$ decays using the D^{*+} as a tag

Changes for FOCUS from E687

Ten Times More Charm

- Upgrades to the Beamline
  - Use positron beam $\times 1.50$
  - Lower secondary energy $\times 2.65$
    effect on charm cross section $\times 0.75$
  - Reduce material in beamline $\times 1.10$
  - More intensity/run longer $\times 1.50$
  - Total increase in flux $\times 5$
- DAQ, Trigger and Spectrometer
  - DAQ upgrade and hadron calorimeter in improved trigger $\times 1.5$
  - Upgrades to spectrometer $\times 1.4$-2.0
  - Increase in livetime/efficiency $\times 2$-3
- Total increase in Charm $> \times 10$

Changes for FOCUS from E687

Many Upgrades and Five New Detectors

- Segmented Target
  - Allows for 50% of D^0's to decay outside of target
- Silicon Vertex Detector
  - Faster and Thinner
- NEW Target Silicon Detector
  - Better spatial resolution
  - Increased efficiency
  - Increased acceptance
  - Improved momentum resolution
- Multiwire Proportional Chambers
  - 2 of 5 chambers rebuilt
  - Lower gain - higher efficiency
  - Deaden central region
  - Cover central region with NEW Straw tubes to keep good efficiency

Changes for FOCUS from E687

- Upgraded and Expanded Muon System
  - Expect 30$\times$ more reconstructed decays with muons
  - NEW Inner muon system should have 5$\times$ better pion misidentification
  - NEW outer muon detector extends muon acceptance to lower momentum
- Improved Electromagnetic Calorimetry
  - NEW Inner electromagnetic calorimeter using Lead Glass will give much better energy resolution
  - Upgraded outer electromagnetic calorimeter will have better pattern recognition
- NEW Fast Hadron Calorimeter
  - Tower Geometry with scintillating tiles
  - Use in the first level trigger to reduce DT
- Improved Trigger
  - Transverse energy trigger
  - Zero degree blind trigger
- NEW Data Acquisition System

Schedule for FOCUS

- Start 17 month run in April 1996

- Concurrent data processsing during the run

- Expect exciting physics results in 1997

Future Of Charm in the US!