Fermilab Fixed Target Charm Program

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Tau-Charm Factory Workshop
SLAC
Stanford, California
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Charm Particle Yield from Fixed Target Experiments

1. Experiments with 10,000 Reconstructed, $10^6$ Produced
   (a) E691-1985 photoproduction, $>10$K events
   (b) NA-32-1986 hadroproduction – 3-4K range
   (c) E687-1988, photoproduction, 10K events
   (d) E653-1988, hadroproduction, 10K events
   (e) E769-1988 hadroproduction – 6-7K range
   (f) WA-89-1993, Hyperon Beam – 6-7K range
   (g) WA-92-1993, hadroproduction – 10K range
   (h) E771-1992 $\pi^-$ beam, limits on $D^0 \to \mu\mu$
   (i) E789-1992 p beam – two-arm spectrometer ???

2. Experiments with 100K Reconstructed and $10^7$ Produced
   (a) E687-1991, photoproduction
   (b) E791, hadrons — (200K evts?)

3. Guess at the $e^+e^-$ competition by end of 1995
   (a) CLEO II – $5 \times 10^6 B\bar{B}$ events
   (b) LEP – $3 \times 10^6 Z$'s and $6 \times 10^5 D\bar{D}$ events

4. Experiments with 1,000,000 Reconstructed, $10^8$ Produced
   (a) E831 1996-1997? photoproduction
   (b) E781 Charm Baryons??? hadron beam
   (c) CLEO III ???
   (d) B Factory ???
   (e) $\tau$-Charm Factory
Charm Baryons
from E781
(Jim Russ)

\( \Sigma^- \) beam, new spectrometer

Goals

A. Weak Decay Physics
   i) Precision lifetimes \( \Lambda_c^-, \Xi_c^{+0}, \Sigma_c^0 \) \( \pm 3\% \)
   ii) Baryon semileptonic decays

B. Spectroscopy
   i) Comprehensive description of \( J^P \) structure + hyperfine splittings

C. Production Mechanisms
   i) Leading particle effects
   ii) \( x_F \) dependence
   iii) Elucidate role of diquarks
   iv) ccq baryons
Negative Beam Fraction at Pt=0, z=10 m

Beam Fraction

Momentum (GeV/c)

- Pt-
- K-
- Pbar
- Sigma-
- Cascade-
- Omega-

\( \bar{u}d\)
\( s\bar{d}\)
\( u\bar{d}d\)
\( s\bar{s}d\)
\( sss\)
E-781 : High Momentum Hyperon Experiment

Goals: Charm Baryon Production 0.1 < x < 1.0
Primakoff Studies of Hybrid Mesons (999)
Hadronic Structure Studies (EMFF, Polarizability)

New Feature: On-Line Charm Trigger

Beam: ≤ 650 GeV Σ-, pT = 0 production
Id: Beam TRD

Downstream Spectrometer: e- TRD

RICH
γ-cal
n-cal
(μ?)

Beam Momentum Definition \( \Delta p/p \sim 1\% \)

Scattered Particle: \( \Delta \theta \sim 30 \text{μrad} @ 100 \text{GeV/c}; 130 \text{μrad} @ 1560 \text{GeV} \)

\( \Delta p \sim 0.05\% @ 500 \text{GeV/c}; .2\% \text{ at 15 GeV} \)

3 Stage Magnetic Spectrometer

Stage 1 Soft pions from D*, Ds*, Λ*
Second Charm  

Stage 2 Trigger Charm  
EMFF, Hybrid Tracking  

Stage 3 Very High Energy Λ decays  
Forward Physics

339
TRD to identify e⁻

TRD to identify beam

4 PHOTON Calorimeters

Vertex Region: 20 planes arranged in 4 views (SSD has 25µm pitch)

Target is 5 foils of 1.5mm thickness
**Legend**

- Beam —
- Primary —
- $K_0^0$ decay —

- $\Xi_c^+ \rightarrow K^0 K^- \pi^+ \pi^+$ —
- • Track seen after M2

**Procedure**

1. Find beam track
2. Find tracks after M2
3. Attach silicon vertex hits to tracks from step 2
4. Accept event if no track miss beam track by >30μm.
Efficiency: 3 H2 tracks; 1 with AMISS > 30 μm

Efficiency

Simulation for combined hardware and software trigger efficiency

Event simulation: 600 GeV π- carbon interaction (Fritiof program)

And \( \Lambda_c^+ \rightarrow p K^- \pi^+ \) event at \( x_p \) point;
rescale background PE to conserve \( \Sigma p_t = 600 \text{ GeV} \).

Track all charged particles;
demand that hardware trigger condition is satisfied.
WHAT IS THE PHYSICS YIELD FROM E-781?

CONSIDER THE "CLASSIC" DECAY $\Lambda_c^+ \rightarrow p K^- \pi^+$

PRESENT WORLD DATA SETS DOMINATED BY

CLEO  ~ 6000 $\Lambda_c^+ \rightarrow p K^- \pi^+$  NO VTK INFO.

$S/B \approx 1/5$

E687  ~ 1500 $\Lambda_c^+ \rightarrow p K^- \pi^+$  LIFETIME MEAS.

$S/B \approx 1/3$

USING MEASURED HADRONIC CROSS SECTIONS AND SIMULATION-BASED RECONSTRUCTION EFFICIENCIES, E781 EXPECTS

100,000 $\Lambda_c^+ \rightarrow p K^- \pi^+$  LIFETIME MEASUREMENTS

$S/B \sim 1/1.5$

REMEMBER, ALL OTHER MODES WILL BE SEEN WITH COMPARABLE GAIN IN STATISTICS.

- GOOD SEMILEPTONIC DATA
- RARE DECAY CHANNELS $\Lambda_c^+ \rightarrow p + T$ FOR
- POLARIZATION STUDIES

FOR C-3 BARYONS, PRESENT SAMPLES ARE "A FEW HUNDRED FROM WA89 MEASUREMENTS IN A HYPERON 88AM, E781

E781 EXPECTS

$> 50,000 \Xi_c^- \rightarrow \Lambda K^- \pi^+$

$> 50,000 \Xi_c^- \rightarrow \Lambda K^- \pi^+$

$> 5,000 \Omega_c^- \rightarrow \Xi^- K^- \pi^+$

ALONG WITH SEMI-LEPTONIC DATA AND MANY OTHER MODES
Fermilab E687 Collaboration

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A High Statistics Study of States Containing Heavy Quarks Using the Wideband Photon Beam and the E687 Multiparticle Spectrometer

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Physics of a High Statistics Charm Experiment

1. $D^0 - \bar{D}^0$ Mixing and Doubly-Suppressed Cabibbo Decays
   (a) Classic Mechanism using the well-known box diagram predicts mixing at the $10^{-6}$ level, but long distance effects may be important and estimates are as large as $5 \times 10^{-4}$.
   (b) Conclusively identify several DCSD channels, $D^+$ is clearest with signature not confused with mixing. Sample channels are $D^+ \rightarrow K^+K^+K^-$, $D^+ \rightarrow K^+\pi^+\pi^-$, $D^+ \rightarrow K^+\rho^0$, and $D^+ \rightarrow K^+\omega$.

2. Absolute Branching Fractions
   (a) CLEO value 2% Statistical and 4.4% Systematic
   (b) Measurement of $\text{BR}(K^-\pi^+)$ to 2% or better
   (c) Measurement of $\text{BR}(K^-\pi^+\pi^0)$ to 3% or better

3. Semileptonic Decays
   (a) Measurement of $|V_{cs}|$ to 1%
   (b) Measurement of $|V_{cd}|$ to 2%
   (c) Measurement of $|V_{cd}|/|V_{cs}|$ to 1.5%
   (d) Measurement of vector and axial vector form factors might be used to predict the Beauty form factors
Fixed Target $D^o$ Absolute Branching Ratios

1. Basic idea

(a) Fully reconstruct a recoil charm particle ($D^{(r)}$)
(b) Find $\pi$ from $D^{*+} \rightarrow \pi^+ D^o$ Decays
   - Correlate $\pi$ charge and $P_t$ with $D^{(r)}$
   - The $D^{(r)}$ serves to "tag" the $\pi$
(c) Reconstruct specific $\pi D^o$ final state against $D^{(r)}$

$$BR(K\pi) = \frac{1}{c} \frac{(K\pi)\tilde{\pi}^+}{(\pi)\tilde{\pi}^+}$$

- Statistics limited – both $D$ and $D^{(r)}$ reconstructed!
- Combine several channels to improve statistics.

Expect $\pm 2.5\% \rightarrow 4\%$ fractional errors

\[ \ln \ E83 \]
Good D\bar{D} vertex

Primary Vertex Multiplicity

Normalized D\bar{D}bar Mass

Pt Balance $\Delta_t^2 = (\bar{D}_t + (m_+/m_\pi)\bar{p}_t)^2$

Rapidity difference

$\gamma g \rightarrow D^* - D \rightarrow (\bar{\pi} - D)\ D$
$D^+ \rightarrow \bar{K}^*0 \mu \nu$ Form Factors

1. As $M_\ell \rightarrow 0$:

$$H_\perp = \alpha A_1(t) \mp \beta V(t)$$

$$H_0 = \delta A_1(t) - \epsilon A_2(t)$$

$\alpha(t, M_{K\pi}, K), \beta(t, M_{K\pi}, K), \delta(t, M_{K\pi}, K), \epsilon(t, M_{K\pi}, K)$

$\alpha, \beta, \delta,$ and $\epsilon$ are functions of $t, M_{K\pi},$ and $K$

2. Following E691:

$$R_V = \frac{V(0)}{A_1(0)} , \quad R_2 = \frac{A_2(0)}{A_1(0)}$$

$$F(t) = \frac{F(0)}{1 - t/M_P^2}$$

- $M_V = 2.1 \quad M_{A_1} = 2.5 \quad M_{A_2} = 2.5$

3. Polarization:

$$\frac{dN}{d\Omega} \propto 1 + \left(\frac{2\Gamma_\ell}{\Gamma_t} - 1\right) \cos^2 \theta_v$$

$$\frac{\Gamma_\ell}{\Gamma_t} = \frac{\int dt \, G(t) |H_0(t)|^2}{\int dt \, G(t) \left(|H_+(t)|^2 + |H_-(t)|^2\right)}$$

- $G(t)$ depends on $M_\ell$
E687

$D^+ \rightarrow K^{*0} \mu^+ \nu$

$\sqrt{s} = 2000$ GeV

- $\sigma > 20$
- $0.75 \pm 44$ events

Yield vs $1/\sigma$ cut

Yield vs Sec. C.L. cut

$1/\mu_{max} < .5$

$1/\mu_{max} > .5$

$K^{*0} \mu \nu$ Data (bin number)

Events per bin
Experiment Comparisons

\[ \Gamma_l/T_l \]

- E687
- E691
- E653
- MrkIII
- WA82

\[ R_\tau \]

- E687
- E691
- E653

\[ R_2 \]

- E687
- E691
- E653
Comparing Experiment to Theory

A Fixed-target Average

<table>
<thead>
<tr>
<th>Exp</th>
<th>$R_2$</th>
<th>$R_v$</th>
<th>$\Gamma_l/\Gamma_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E687/E691/E653</td>
<td>.74 ± .14</td>
<td>1.86 ± .20</td>
<td>1.21 ± .10</td>
</tr>
</tbody>
</table>

- The confidence level that the three experiments agree on $R_2$ and $R_v$ is 60%.

- Compute confidence level (CL) of agreement between this and theory

<table>
<thead>
<tr>
<th>Authors</th>
<th>CL(%)</th>
<th>$R_2$</th>
<th>$R_v$</th>
<th>$\Gamma_l/\Gamma_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSW$^1$</td>
<td>1</td>
<td>1.31</td>
<td>1.44</td>
<td>.91</td>
</tr>
<tr>
<td>KS$^1$</td>
<td>1</td>
<td>1.0</td>
<td>1.0</td>
<td>1.16</td>
</tr>
<tr>
<td>AW/GS$^1$</td>
<td>99</td>
<td>.75</td>
<td>1.88</td>
<td>1.20</td>
</tr>
<tr>
<td>BBD$^2$</td>
<td>7</td>
<td>1.2 ± .2</td>
<td>2.2 ± .2</td>
<td>.86 ± .11</td>
</tr>
<tr>
<td>ELC$^3$</td>
<td>47</td>
<td>.01 ± .7</td>
<td>1.63 ± .27</td>
<td>1.84 ± .63</td>
</tr>
<tr>
<td>BES$^3$</td>
<td>95</td>
<td>.70 ± .16 ± .20</td>
<td>1.99 ± .22 ± .31</td>
<td>1.21 ± .12 ± .15</td>
</tr>
</tbody>
</table>

$^1$ Quark models, $^2$QCD sum rules, $^3$Lattice
$D_s^+ \to \phi \mu \nu$ Form Factors

All Exp:
1. Reconstruct the decay as for the $D^+$ case
2. no WS

<table>
<thead>
<tr>
<th>Exp</th>
<th>mode</th>
<th>sample</th>
<th>fit to</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>E653</td>
<td>$\mu$</td>
<td>19</td>
<td>$\theta_v, \theta_\mu, t$</td>
<td>MC wht</td>
</tr>
<tr>
<td>E687</td>
<td>$\mu$</td>
<td>$90 \pm 12$</td>
<td>$\theta_v, \theta_\mu, t, \chi$</td>
<td>MC wht bins</td>
</tr>
</tbody>
</table>

- Statistically dominated

<table>
<thead>
<tr>
<th></th>
<th>$R_v$</th>
<th>$R_2$</th>
<th>$\Gamma_\ell/\Gamma_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E653</td>
<td>$2.3^{+1.1}_{-0.9} \pm 0.4$</td>
<td>$2.1^{+0.6}_{-0.5} \pm 0.2$</td>
<td>$.54 \pm .21 \pm .10$</td>
</tr>
<tr>
<td>E687</td>
<td>$1.8 \pm 0.9 \pm 0.2$</td>
<td>$1.1 \pm 0.8 \pm 0.1$</td>
<td>$1.0 \pm .5 \pm .1$</td>
</tr>
<tr>
<td>E653 ($D^+$)</td>
<td>$2.00^{+0.34}_{-0.32} \pm .16$</td>
<td>$.82^{+0.22}_{-0.23} \pm .11$</td>
<td>$1.18 \pm .18 \pm .08$</td>
</tr>
<tr>
<td>E687 ($D^+$)</td>
<td>$1.74 \pm 0.27 \pm 0.28$</td>
<td>$0.78 \pm 0.18 \pm 0.10$</td>
<td>$1.20 \pm .13 \pm .13$</td>
</tr>
</tbody>
</table>

- E687 consistent with $D_s^+ \approx D^+$
- E653 $R_2$ may disagree
# E831 Extrapolations

<table>
<thead>
<tr>
<th></th>
<th>Now ((K^*))</th>
<th>(K^*\mu\nu)</th>
<th>(\phi\mu\nu)</th>
<th>(\rho\mu\nu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma(R_v))</td>
<td>(\pm .20)</td>
<td>.05</td>
<td>.15</td>
<td>.32</td>
</tr>
<tr>
<td>(\sigma(R_2))</td>
<td>(\pm .14)</td>
<td>.04</td>
<td>.11</td>
<td>.23</td>
</tr>
<tr>
<td>(\sigma(\Gamma_\ell/\Gamma_t))</td>
<td>(\pm .10)</td>
<td>.02</td>
<td>.06</td>
<td>.13</td>
</tr>
<tr>
<td>(\sigma(M_v))</td>
<td>((\pm .10))</td>
<td>.16</td>
<td>.50</td>
<td>1.0</td>
</tr>
<tr>
<td>(\sigma(M_\alpha))</td>
<td></td>
<td>.38</td>
<td>1.2</td>
<td>2.5</td>
</tr>
</tbody>
</table>

- Theoretical uncertainty \(\approx 5\%\)
- Background Systematics \(\approx 10\%\)
  - But > statistics leads to > understanding.
- Full expression for the rate

\[ \frac{d\Gamma}{dE_k} = \frac{G_F^2}{4\pi^3} |V_{cs}|^2 |f_+(q^2)|^2 \left( \frac{W_0 - E_K}{F_0} \right)^2 \]

\[ + \frac{1}{3} m_D P_K^2 + \frac{1}{3} m_l^2 \frac{P_K^2}{F_0} \]

\[ + \frac{m_l^2}{8m_D} (m_D^2 + m_K^2 + 2m_D E_K) \]

\[ + \frac{1}{4} m_l^2 m_D^2 - m_K^2 \frac{Re \left( f_-(q^2) \right)}{m_D} \frac{f_-(q^2)}{f_+(q^2)} \frac{f_-(q^2)}{f_+(q^2)} \]

\[ + \frac{1}{4} m_l^2 F_0 \left| \frac{f_-(q^2)}{f_+(q^2)} \right|^2 \]

\[ W_0 = \frac{m_D^2 + m_K^2 - m_l^2}{2m_D} \]

\[ F_0 = W_0 - E_K + \frac{m_l^2}{m_D} \]

- Must measure both muon and electron modes to get \( f_- \) behavior
• Other experiments $M_{pole}$
  compared to E687

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Mode</th>
<th>$m_{pole}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E691</td>
<td>$K^- e^+ \nu_e$</td>
<td>$2.1^{+0.4}_{-0.2} \pm 0.2$</td>
</tr>
<tr>
<td>CLEO(91)</td>
<td>$K^- e^+ \nu_e$</td>
<td>$2.1^{+0.4+0.3}_{-0.2-0.2}$</td>
</tr>
<tr>
<td>MKIII</td>
<td>$K^- e^+ \nu_e$</td>
<td>$1.8^{+0.5+0.3}_{-0.2-0.2}$</td>
</tr>
<tr>
<td>CLEO(93)</td>
<td>$K^- l^+ \nu_l$</td>
<td>$2.0 \pm 0.12 \pm 0.18$</td>
</tr>
<tr>
<td>E687</td>
<td>$K^- \mu^+ \nu_\mu$</td>
<td>$1.98^{+0.13+0.04}_{-0.10-0.10}$</td>
</tr>
</tbody>
</table>

$\bar{m}_{pole} = 1.99^{+0.11}_{-0.09}$

*Preliminary
- Also fit to tagged sample as systematic
  - no variation from data with no tag

- Other experiments
  relative to $D^0 \rightarrow K^-\pi^+$
  compared to E687

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Mode</th>
<th>BR (rel. to $K\pi$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E691</td>
<td>$K^-e^+\nu_e$</td>
<td>0.90 ± 0.07 ± 0.11</td>
</tr>
<tr>
<td>CLEO(91)</td>
<td>$K^-e^+\nu_e$</td>
<td>0.91 ± 0.06 ± 0.06</td>
</tr>
<tr>
<td>CLEO(91)</td>
<td>$K^-\mu^+\nu_\mu$</td>
<td>0.79 ± 0.08 ± 0.09</td>
</tr>
<tr>
<td>E687(93)</td>
<td>$K^-\mu^+\nu_\mu$</td>
<td>0.82 ± 0.13 ± 0.13</td>
</tr>
<tr>
<td>CLEO(93)</td>
<td>$K^-l^+\nu_l$</td>
<td>0.978 ± 0.027 ± 0.044</td>
</tr>
<tr>
<td>E687(94)</td>
<td>$K^-\mu^+\nu_\mu$</td>
<td>0.860 ± 0.028 (\pm 0.042 ) (\pm 0.039 )</td>
</tr>
</tbody>
</table>
\[
\Gamma(f(q^2) = X f_+(q^2)) / \Gamma(f_-(q^2) = f_-(q^2))
\]
Other experiments $f_+ (0)$
compared to E687

| Exp.   | Mode     | $|f_+ (0)|$       |
|--------|----------|------------------|
| E691   | $K^- e^+ \nu_e$ | $0.79 \pm 0.05 \pm 0.06$ |
| CLEO(91) | $K^- e^+ \nu_e$ | $0.81 \pm 0.03 \pm 0.06$ |
| MKIII  | $K^- e^+ \nu_e$ | $V_{cs} \ (0.72 \pm 0.05 \pm 0.04)$ |
| CLEO(93) | $K^- l^+ \nu_l$ | $0.77 \pm 0.01 \pm 0.04$ |
| E687   | $K^- \mu^+ \nu_\mu$ | $0.730^{+0.020+0.029}_{-0.021-0.033}$ |

* Use $|V_{cs}| = 0.9743$

* preliminary
$D^o \to K^-\ell^+\nu$ form factor

- Find $\Gamma(K\mu\nu)$ using abs. BR, $\tau$
- assume $V_{cs}$
- assume simple pole
- integrate to find: $|f_+(0)|$

| Exp. | Mode       | $m_{pole}$          | $|f_+(0)|$     |
|------|------------|---------------------|----------------|
| E691 | $K^-e^+\nu_e$ | $2.1^{+0.4}_{-0.2} \pm 0.2$ | $0.79 \pm 0.05 \pm 0.06$ |
| CLEO(91) | $K^-e^+\nu_e$ | $2.1^{+0.4+0.3}_{-0.2-0.2}$ | $0.81 \pm 0.03 \pm 0.06$ |
| CLEO(93) | $K^-\ell^+\nu$ | $2.00 \pm 0.12 \pm 0.18$ | $0.77 \pm 0.01 \pm 0.04$ |
| MKIH  | $K^-e^+\nu_e$ | $1.8^{+0.5+0.3}_{-0.2-0.2}$ | $|V_{cs}| (0.72 \pm 0.05 \pm 0.04)$ |
| E687  | $K^-\mu^+\nu_{\mu}$ | $1.98^{+0.26+0.04}_{-0.16-?}$ | $0.70 \pm 0.04 \pm 0.01$ |

E687 #’s are PRELIMINARY

$q^2$ Dependence:

- All consistent with $D_g^* = 2.1$GeV pole

- CLEO II: $f_+(q^2) = f_+(0)e^{\alpha q^2}$

  $\alpha = .29 \pm .04 \pm .06$

- $f_+(0)$: Agrees with predictions ($\approx .7$)

$\frac{(D^o \to K^-\mu^+\nu_{\mu})}{(D^o \to K^-\pi^+)} = 0.86 \pm 0.028 + 0.042$ $-0.039$
Today’s signal → Tomorrows’ background

\[ M(K^{-\pi^{+}\pi^{+}}) \]

\[ D^{+} \rightarrow K^{*}\mu^{+}\nu \text{ mimics } D^{+} \rightarrow \rho\mu^{+}\nu \text{ (Loose } \tilde{C}) \]

\[ M(\pi^{+}\pi^{-}) \]
4. Leptonic Decays – $f_D$ pseudoscalar decay constant
   (a) Involves observing $D^+ \rightarrow \mu \nu \mu$, $D^{**} \rightarrow D^+ \pi^0$
   (b) Also search for $D_s^+ \rightarrow \tau^+ \nu\tau$

5. $D_s^+$ Decays
   (a) 20,000 $D_s^+ \rightarrow K^+ K^- \pi^+$
   (b) Study excited states

6. $\Lambda_c^+$ Decays
   (a) 20,000 $pK^- \pi^+$
   (b) Absolute Branching Ratio (20% or better)
   (c) Search for new modes (containing neutrons) using the $\Lambda^{++}$ tags

7. $D^{**}$ States
   (a) Look at carefully with very clean Double D samples

8. Charmed Baryon Spectroscopy and Lifetimes
   (a) Demonstrated ability to form states with $\Lambda^0$, $\Sigma^\pm$, $\Xi^-$, and $\Omega^-$
   (b) New ability to use $\Xi^0$ as a daughter decay particle
   (c) Search for Doubly-charmed baryons

9. Hadronic Decays of the $D^0$ and $D^+$
   (a) Improved Dalitz Plot Analysis
   (b) Ability to use $K_L^0$ with new hadron calorimeter
10. Study charm production dynamics and make a detailed comparison with models
   (a) Double charm events will be particularly useful (10K events)

11. Rare Decays
   (a) Set limits for $D^0$ decays to $\mu^+\mu^-$ and $e^+e^-$
   (b) Set limits for $D^0 \rightarrow \rho\gamma$ and $D^0 \rightarrow K^*\gamma$

12. Forbidden Decays
   (a) $\mu^+e^-$

13. CP Violation Sensitivity
   (a) Difference in rates between $D^0$ and $\bar{D}^0$ decays using the $D^*$ as a tag
   (b) Polarization tests using $D^+ \rightarrow \bar{K}^0\bar{K}^{*+}$
Table 1: 90% CL Upper Limits (x 10^5) on FCNC, LFNV, and LNV Charm Decay Modes.

<table>
<thead>
<tr>
<th>Type</th>
<th>Mode</th>
<th>E653</th>
<th>E687</th>
<th>E771</th>
<th>E789</th>
<th>E791</th>
<th>PDG (expt.)</th>
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<tr>
<td></td>
<td>$D^0 \rightarrow \nu^0\rho^0 e^-$</td>
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<td>$D^0 \rightarrow \overline{K}^0 e^+$</td>
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<td>$D^0 \rightarrow \overline{K}^0 \mu^+\mu^-$</td>
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<td>$D^+ \rightarrow \pi^+ e^-$</td>
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<td></td>
<td>$\Lambda^+_c \rightarrow \mu^+\mu^-$</td>
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<td>$D^+ \rightarrow K^-\mu^+\mu^+$</td>
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<td>400 MK2</td>
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<td>$D^+ \rightarrow \rho^-\mu^+\mu^+$</td>
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<td>$\Lambda^+_c \rightarrow \Sigma^-\mu^+\mu^+$</td>
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<td>$\Lambda^+_c \rightarrow \Sigma^-\mu^+\mu^+$</td>
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Using sidebands in the dimuon invariant mass spectrum to estimate the background in the $D^0$ mass region, they find $-4.1\pm4.8$ candidate events, and set a limit of $BR(D^0 \rightarrow \mu^+\mu^-) < 3.1 \times 10^{-5}$ (90% CL). They believe it is possible that their limit will drop below $1.0 \times 10^{-5}$ when they include all of their data.

1.2.3 E771 ($D^0 \rightarrow \mu^+\mu^-$ Search)

Fermilab E771 also has a preliminary limit on $BR(D^0 \rightarrow \mu^+\mu^-)$, from data collected during the 1990-91 fixed-target run with the 800-GeV primary proton beam (interacting in
CP Asymmetry: \( \frac{(\Gamma_D - \Gamma_B)}{(\Gamma_D + \Gamma_B)} \)

<table>
<thead>
<tr>
<th>Process</th>
<th>E687 Measurement</th>
<th>E831 Extrapolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D^0 \to K^+K^- )</td>
<td>0.024 ± 0.084</td>
<td>( A_{CP} = 0.03 )</td>
</tr>
<tr>
<td>( D^+ \to K^-K^+\pi^+ )</td>
<td>-0.031 ± 0.068</td>
<td>( A_{CP} = 0.02 )</td>
</tr>
<tr>
<td>( D^+ \to K^*0K^+ )</td>
<td>-0.12 ± 0.13</td>
<td>( A_{CP} = 0.04 )</td>
</tr>
<tr>
<td>( D^+ \to \phi\pi^+ )</td>
<td>0.866 ± 0.086</td>
<td>( A_{CP} = 0.04 )</td>
</tr>
</tbody>
</table>

Assumes no improvement in signal to noise from E687
Plan to Increase our Charm Yield a Factor of 10

- Increase DAQ and Efficiency by a factor of two

1. Previous livetime was 60%
2. Improve Trigger – Change Hadron Calorimeter to Scintillator
3. Detector Upgrades
   (a) Faster and thinner Microstrip
   (b) Segmented Target

- Increase Beam Flux a factor of five

- Assume that we have a year run - same amount of beam as there was in 1990 and 1991 Running periods
Bremstrahlung Photon Beam

800 GeV Protons → Photon Beams

Step 1: Get a Neutral beam

Step 2: Convert photons to electron beam

Step 3: Capture electrons in regular charged beam transport

Step 4: Convert electrons back into photons by bremsstrahlung

Figure 3: Steps required to produce a bremsstrahlung photon beam
- 350 GeV electron beam with ±13% momentum spread.
- 30% radiator.

Mean Energy 221 GeV
Method for Obtaining Higher Flux

- Also Use Positron Beam $\times 1.5$
- Change the Secondary Energy
- Reduce Material in Beamline
- Use More Intense Primary Proton Beam $6 \times 10^{12}$
  1. Only need $4.5 \times 10^{12}$ scaling from last run
- Coherent Bremstrahlung Beam
  1. Consulted Experts From Europe (Uggerhoj)
  2. Calculations underway (Bologna and Artru)

<table>
<thead>
<tr>
<th>Planned Changes</th>
<th>350 GeV</th>
<th>250 GeV</th>
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<tbody>
<tr>
<td>Add Positrons</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Proton Energy to 900 GeV</td>
<td>1.88</td>
<td>1.68</td>
</tr>
<tr>
<td>Secondary Energy (includes $\sigma_c$)</td>
<td>1.0</td>
<td>(2.65) 2.0</td>
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<tr>
<td>Reduce Material in Beamline</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>More Intensity</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2.5</strong></td>
<td><strong>5.0</strong></td>
</tr>
</tbody>
</table>

Actual Measurements
E831 Changes from E687

1. SSD
   (a) Faster
   (b) Thinner

2. MWPC
   (a) Lower gain - get more efficiency
   (b) Deaden Central Region
   (c) Add straw tubes in central region to keep good efficiency

3. New fast Hadron Calorimeter
   (a) Tower Geometry
   (b) Scintillating tiles

4. Segmented Target
   (a) Allows for 50% of D^0's to decay outside of target

5. Upgraded and expanded muon system
   (a) Expect at least a factor of 20 increase in decays containing muons
   (b) Inner muon signals should have 4x better pion misidentification
   (c) Outer muon detector to be made faster and will further increase our muon yields
6. Improved Electromagnetic Calorimetry
   (a) Change from Scintillating fiber to Lead Glass
   (b) Outer Electromagnetic calorimeter to have better pattern recognition

7. New Data Acquisition System

8. Improved trigger
   (a) Transverse Energy Trigger
   (b) Zero degree blind counter

9. Improved Monte Carlo
   (a) Allows for many more particles
   (b) Ready to go from E687 Experience
Modifications to the E687 Apparatus

• **Segmented Target**
  1. Segmented Target allows for better Signal to Noise
  2. Denser Target allows for 50% of $D^0$ outside target
  3. Diamond Target Could Be Instrumented (Colorado)

• **Microstrip Detector** (Milan Group)
  1. Replace Preamps to shorten gate to 50ns
     (a) Already submitted production of new monolithic preamps
     (b) New preamps have 20% reduced noise from old
  2. New frames, fanouts, and supports being readied
     (a) Dissipate additional heat from new preamps
     (b) G-10 to Alumina frames improves rigidity and reduces bowing
  3. Wafer thickness will be reduced
     (a) Tests will be made on 250 micron and 140 micron thick pieces obtained from Micron Semiconductor.
     (b) Decision on the thickness to be made in June 1994
Kπ Background study: in and outside E687 target

OUT OF TARGET

\[ M = 1.8624 \pm 0.0006 \]
\[ W = 11.843 \pm 0.5908 \]
\[ Y = 644.90 \pm 33.60 \]
\[ S/N = 4.96796 \]

IN TARGET

\[ M = 1.8637 \pm 0.0004 \]
\[ W = 12.372 \pm 0.4424 \]
\[ Y = 2802.9 \pm 99.04 \]
\[ S/N = 1.48581 \]
Fig 10: Cutting downstream of the target
$l/\sigma > 10$ and $p/\sigma < 3$, $z_{sec} < .8$

\[ Y(D^+) = 364.7423 \pm 40.08343 \]
\[ S/N = 0.3584375 \]
\[ Y(D_s^+) = 185.5739 \pm 37.68046 \]
\[ S/N = 0.1973259 \]

\[ Y(D^+) = 171.3121 \pm 19.97209 \]
\[ S/N = 3.11596 \]
\[ Y(D_s^+) = 50.81475 \pm 11.17807 \]
\[ S/N = 1.583829 \]
Figure 2: Present target
Be: 0.143, 0.329
Figure 3: Alternative Target Configurations

Be: 0.269, 0.473

BE: 0.3737027, 0.5103226

Diamond: 0.403, 0.606

Diamond: 0.493, 0.630
Vertex Resolution vs Momentum

- Target
- No TRI
- 30% SSD
- TRI+SSD

Graphs showing the relationship between momentum and vertex resolution.
Inner Muon Upgrade Progress

Overview

1. Augment p-tubes with scintillator arrays
   - Goal 1 RF bucket timing

2. Two XY stations (MH1 & MH2)
   (a) Fine pitch upstream array (MH1)
   - Reduced MCS for tracking
   (b) Coarse grain downstream array (MH2)
   - Better hadron shielding

3. Spans 2 m x 3 m (X x Y)
   - Two 150 cm spans (X) & Two 100 cm spans (Y)
   - 1 PMT per slab

4. Pitches
   (a) 5 cm width MH1
       - 210 counters
   (b) 10 - 16 cm width MH2
       - 64 - 102 counters
E-831 Downstream Components

HxV

MH1 gap - 8"

HC

moved ds. 25"

new Fe

24"

51" steel

27" steel

base plate

all units are INCHES

Lead Glass, fibers, pmt, base, BGM, NO HUT inches
Muon Momentum

\[ D^{*-}D^0 \text{ Mass difference} \]

**K\mu\nu yield**
- Whole spectrometer
- Outer spectrometer
- Inner spectrometer

Ratio (Outer/Total) = 1/3

Implies 50% improvement
Muon Misidentification from $\Phi \rightarrow K^+K^-$ kaons

- Noise
- Punch thru from hadronic showers
- Kaon mflight decay
- Accidentals (beamline muon)
- Nearby real muon
- Bigger problem than for pions
- Use protons from $\Lambda^0$ to test MC without decays
• We need two more feet of iron!
• Will extra shield degrade track matching?

<table>
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<tr>
<th></th>
<th>( P \times \sigma )</th>
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<tbody>
<tr>
<td>E687 system</td>
<td>20 mr-GeV</td>
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<tr>
<td>IE + HC</td>
<td>8.4 mr-GeV</td>
</tr>
<tr>
<td>IE + HC + 60 cm Fe</td>
<td>10.8 mr-GeV</td>
</tr>
</tbody>
</table>

- About 30% worse matching
- Still twice as good as E687! in each view!

2. Miscellaneous studies
   (a) Optical simulations
   (b) \( \delta \)-ray abatement
   (c) Overlap
   (d) Cable choice
Conclusions

1. E831 will get to $10^6$ or better reconstructed charm
   a) Anticipate cleaner signals in E831 than in E687
   b) States containing electrons + muons should see about $\sim 20$ improvement
   c) Should do much better on states containing $\pi^0$'s.
   d) May be able to track several of the $D^+ + D_s^+$ parent particles

2. E781 will produce a large sample of Charm Baryons
   a) 100K $\Lambda^+_c \rightarrow pK^-\pi^+$
   b) 50K $\Xi^+_c \rightarrow \Xi^-\pi^+\pi^+$

3. Very important to have different types of systematics & limiting experiments as statistical errors decrease - FT, $e^+e^-$, B-factory, e-Charm

4. Next step in my opinion is a very high statistics expl. at BNC or FNAL using large production $\sigma$. 
## Comparison list of tau/charm measurements

<table>
<thead>
<tr>
<th>Topic</th>
<th>Parameter to be measured</th>
<th>Best measurement to date</th>
<th>Factory</th>
<th>B factory</th>
<th>Fix target</th>
<th>LEP</th>
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<td>Rare charm</td>
<td>gamma + K*</td>
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<td>Mu mass</td>
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<td>Other BR</td>
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<td>Pred decays</td>
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\[ \text{See attached sheets} \]

\[ \text{D^+} \rightarrow \text{rho} \, \text{D}^+ \]

\[ \nu \text{3} \times 10^{-4} \]

\[ \text{No Z's in Fixed Target} \]

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