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Charmonium and Charm Decays from the Fermilab Fixed Target Program

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CHARMONIUM AND CHARM DECAYS FROM THE FERMILAB FIXED TARGET PROGRAM

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Recent results on charm decay physics from the Fermilab Fixed Target program will be presented. There have been many physics results within the past year from experiments E687 and E791 and these will be highlighted. Many of these results are related to rare phenomena and searches. These will become even more interesting with the FOCUS experiment dataset of 1 million fully reconstructed charm decays. Preliminary signals from FOCUS as well as from SELEX will be presented together with prospects for the future. Preliminary results from E835 on the η_c' search will also be presented.

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1 Overview of the Fermilab Fixed Target Charm Experiments

During the last two Fermilab Fixed Target runs (1990-91 and 1996-97) there have been six experiments dedicated to studying charm, these are listed in Table 1. Experiment E760 is finished and has been superseded by experiment E835 using an upgraded jet target and spectrometer [1]. The FOCUS (E831) experiment uses a much upgraded version of the E687 spectrometer and beamline and will have about 15 times the data sample of E687 for charm hadronic decays and about 25 times more semileptonic decays [2]. A new experiment, SELEX (E781), was run with a mostly Σ^- beam to produce charm-strange baryons in the forward region [3].

Table 1: Fermilab Fixed Target Charm experiments in the 1990-1991 and 1996-1997 Fixed Target runs

1990-1991 Fixed Target Run

Experiment	Beam	Data	Charm Reconstructed
E687	$50 - 350$ GeV γ	0.5×10^9 triggers	1×10^5
E791	500 GeV π^-	20×10^9 triggers	2×10^5
E760	$\bar{p}$ accumulator	36 pb^{-1}	J/ψ, ψ', $\chi_{1,2}$, η_c, h_c

1996-1997 Fixed Target Run

Experiment	Beam	Data	Projection of Charm Reconstructed
FOCUS (E831)	$50 - 300$ GeV γ	6.5×10^9 triggers	1×10^6
SELEX (E781)	600 GeV Σ^-,(π^-, p)	1×10^9 triggers	Λ_c^+, Ξ_c^+, Ξ_c^0, Ω_c^0
E835	$\bar{p}$ accumulator	143 pb^{-1}	J/ψ, ψ', $\chi_{0,1,2}$, η_c, h_c, η_c' search

2 Results from Experiments E687 and E791

As well as charm production results from E687 and E791 [4], there have been many new charm decay results from both E687 [5–7] and E791 [8–11] in the past year.

Semileptonic decays are important as these are the easiest charm decays to calculate theoretically. Different theoretical calculations of the form factors can be tested when one compares these with those experimentally extracted from decay rates and angular or energy distributions in various exclusive semileptonic decay modes. Until recently these comparisons were limited to Cabibbo favoured decays only, but now we also have measurements for Cabibbo suppressed semileptonic decay rates [12] which can help distinguish between the different theoretical calculations. An understanding of the form factors is important if one is to extract CKM matrix elements from measured decay rates. E791 has a new measurement of the branching ratio $\Gamma(D^+ \to \rho^0 \ell^+ \nu)/\Gamma(D^+ \to \overline{K^{*0}} \ell^+ \nu) = 0.047 \pm 0.013$ [8], using both muon and electron decay modes. This agrees with the earlier E687 result which used the muon decay mode only and thus had about 2.5 times fewer signal events [13]. The averaged branching fraction is 0.055 ± 0.011. E791 used their data for $D^+ \to \overline{K^{*0}} \mu^+ \nu$ to measure new form factor ratios [11] and these are plotted in Figure 1 compared to previous

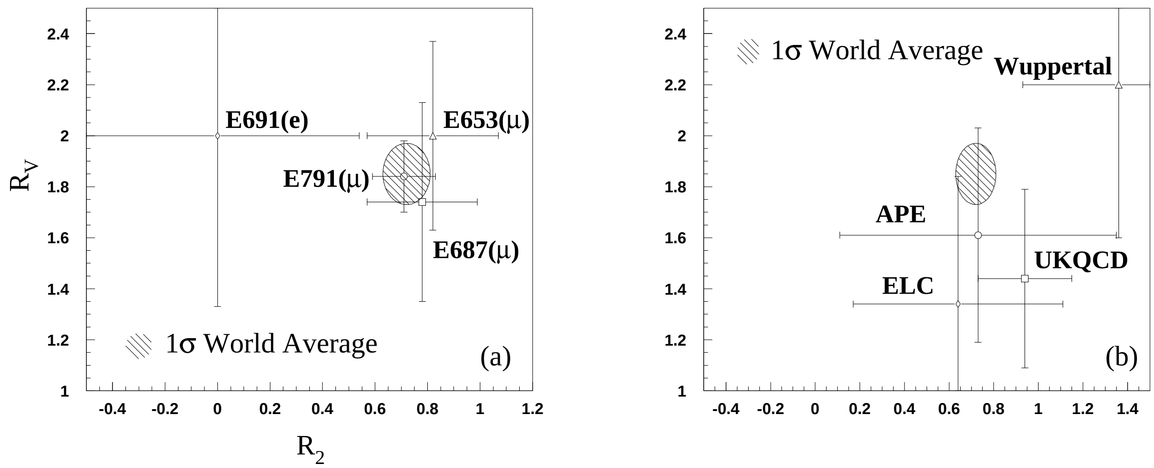

Figure 1: (a) Measurements and (b) calculations of the ratios of the three form factors describing the hadronic matrix element in the decay $D^+ \to \overline{K^{*0}}\ell^+\nu$. Definitions of the two ratios and experiment and theory references are given in reference 11.

measurements. Current analyses are still very statistically limited, but data from the FOCUS high statistics charm experiment may be able to be used to study the q^2 dependence of the form factors as well as study the form factors from Cabibbo suppressed decays instead of just measuring decay rates.

E687 has included the $\Xi_c^+ \to \Sigma^+ K^- \pi^+$ mode to measure a new lifetime of the Ξ_c^+ to be $0.34^{+0.07}_{-0.05} \pm 0.02$ ps [6] which supersedes their old measurement. This gives a world average of $0.31^{+0.06}_{-0.04}$ ps which is still only 2.5σ longer than the Λ_c^+ lifetime. E687 has also confirmed the $\Xi_c^{*+} \to \Xi_c^0 \pi^+$ [7] first seen by CLEO [14], measuring a mass above the Ξ_c^0 mass of $177.1 \pm 0.5 \pm 1.1$ MeV/c^2. This is agrees well with the value $174.3 \pm 0.5 \pm 1.0$ MeV/c^2 measured by CLEO.

Both E687 and E791 have new results on amplitude analyses of hadronic decays and their search for rare phenomena. E791 has new limits for CP violation in both D^0 and D^+ decays, but these are still far from the interesting range of ± 0.1–1.0% . E791 has a new limit for $D^0 - \overline{D^0}$ mixing from hadronic $K\pi$ and $K3\pi$ decay modes, allowing for both the possibility of interference from DCSD and direct CP violation in the decay [10]. Their limit of $r_{mix} < 0.85\%$ is not better than the limit of $r_{mix} < 0.50\%$ obtained by the same experiment using semileptonic decays since the latter does not have the complication of DCSD interference.

3 Preliminary Results from Experiment E835

Experiment E835 used the stochastically cooled antiproton beam in the Fermilab Antiproton Accumulator with a hydrogen gas jet target. Theoretically the $\bar{p}p$ collisions can directly produce charmonium states of any allowed J^{PC} quantum numbers unlike e^+e^- collisions. Although the $\bar{p}p \to c\bar{c}$ cross section is only about 1 μb compared to a cross section of about 70 mb for $\bar{p}p \to hadrons$, this background is significantly reduced in E835 by looking for decays into electromagnetic final states. The mass resolution and

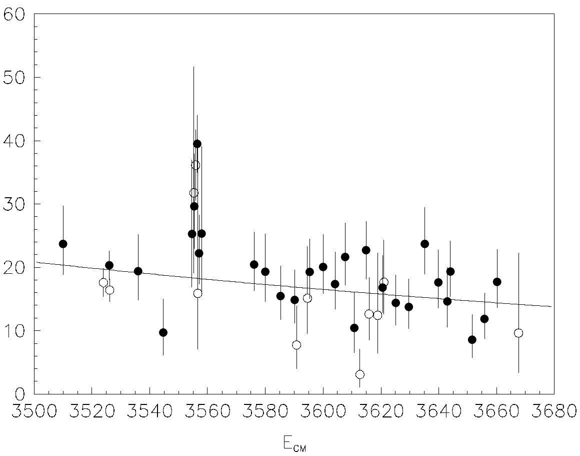

Figure 2: Cross section for $\bar{p}p \to \gamma\gamma$ with $|cos\theta^*| < 0.4$ at the η_c' region (filled circles). The open circles show E760 measurements and the peak at 3556 MeV corresponds to $\chi_2 \to \gamma\gamma$.

width are determined by knowledge of the $\bar{p}$ momentum. Since the momentum spread is very small ($\Delta p/p \approx 2 \times 10^{-4}$) and the accumulator parameters are known well, they can calibrate their energy scale with the ψ' mass (known to ± 0.1 MeV/c^2) and get a small (center of) mass energy resolution of about 0.5 MeV/c^2.

The E835 collaboration have already presented preliminary results in previous conferences during the past year [1] and the reader is referred to those proceedings on their preliminary results for the η_c, the χ_2 and the $\bar{p}p \to \pi^0\pi^0$ cross section.

E835 also searched for the η_c' first reported by the Crystal Ball experiment [15] as a structure in the inclusive photon spectrum from ψ' decay corresponding to a mass of 3594 ± 5 MeV/c^2. This has not yet been confirmed. E835 searched for $\eta_c' \to \gamma\gamma$ in the mass region from 3575 to 3660 MeV/c^2 in steps of < 5 MeV/c^2. Figure 2 shows the preliminary results where backgrounds from $\pi^0\pi^0$ and $\pi^0\gamma$ have been reduced by using a cut on the angular distribution of the two photons. E835 had initially expected that a $\eta_c' \to \gamma\gamma$ signal would have the same height as the $\chi_2 \to \gamma\gamma$ in Figure 2. The η_c' width was expected to be between about 8 and 12 MeV/c^2. Their preliminary results show no $\eta_c' \to \gamma\gamma$ signal though they are still working on reducing the $\gamma\gamma$ background. This lack of signal could be due to any combination of the following: the mass of the η_c' is not between 3575 and 3660 MeV/c^2; the η_c' is much narrower than 5 MeV; and the branching fractions may be much lower than expected.

4 Preliminary Results from FOCUS

The FOCUS collaboration significantly upgraded both the E687 beamline, trigger and data acquisition as well as upgrading and building new detectors with the goal of reconstructing ten times more charm than in E687 [2]. They have surpassed their goals with a projected charm hadronic decay sample of 15 times that of E687 and have projected 25 times more data in semileptonic decays due to the additional improvements in the leptonic detectors. These projections should be quite accurate since they have reconstructed about 17% of their data online.

As well as these huge improvements in statistics, their vertex resolution, which was

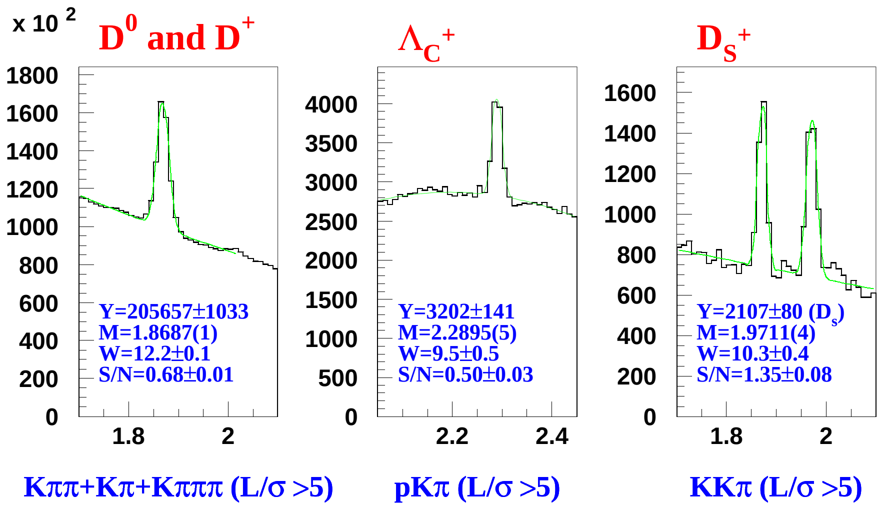

Figure 3: Charm signals for $D^0 \to K^-\pi^+$, $K^-3\pi$ and $D^+ \to K^-\pi^+\pi^+$; $\Lambda_c^+ \to pK^-\pi^+$; and $D^+, D_s^+ \to K^-K^+\pi^+$ from about 22% of the data so far processed (April 12th 1998).

already excellent in E687, was improved by the addition of four new planes of silicon strip detectors near the target. The particle identification (both hadronic and leptonic) have also been improved. FOCUS should finish reconstruction of their 6.5 billion events by the end of 1998. The charm signals from 22% of their data so far processed are shown in Figure 3. Note that some improvements in the reconstruction code were not yet incorporated into these plots produced for monitoring purposes only.

Improvements are also expected for photon and π^0 reconstruction, Figure 4 shows preliminary signals for $\Sigma_c^{++,0,+} \to \Lambda_c^+\pi^{+,-,0}$ from about 15% of the FOCUS data. FOCUS should have about 10–20 times more reconstructed charm baryon decays than E687. They should have about 10,000 events where both the D and $\bar{D}$ are reconstructed which will be really interesting for production studies. The huge factor of 25 improvement in statistics in FOCUS over E687 for semileptonic decays is extremely interesting for the study of form factors and comparisons with theory.

5 Preliminary Results from SELEX

SELEX is a new experiment at Fermilab taking its first data in the 1996-1997 Fixed Target Run. It uses a $\Sigma^-(sdd)$ beam and the leading particle effect to try to preferentially produce charm strange baryons in the forward (high x_F) region. In the leading particle effect, charm particles produced in the high x_F region preferentially carry a valence quark from the beam particle. So with a $\pi^-(\bar{u}d)$ beam there should be more $D^-(\bar{c}d)$ produced than $D^+(c\bar{d})$ as seen by E791 [16], and with a $\Sigma^-(sdd)$ beam this asymmetry should be even larger, (naively by roughly a factor of two) and this is seen by SELEX [4]. SELEX are still finalizing their reconstruction code and in particular are still working on Ξ_c and Ω_c^0 reconstruction, so although this leading particle effect would predict preferential production of Ξ_c and Ω_c^0 this has not yet been confirmed in SELEX. Early pre-preliminary signals for D and Λ_c^+ from about 50% of their data sample shown in Figure 5 show that they get a mass resolution of about 10 MeV/c^2. This is comparable with other mod-

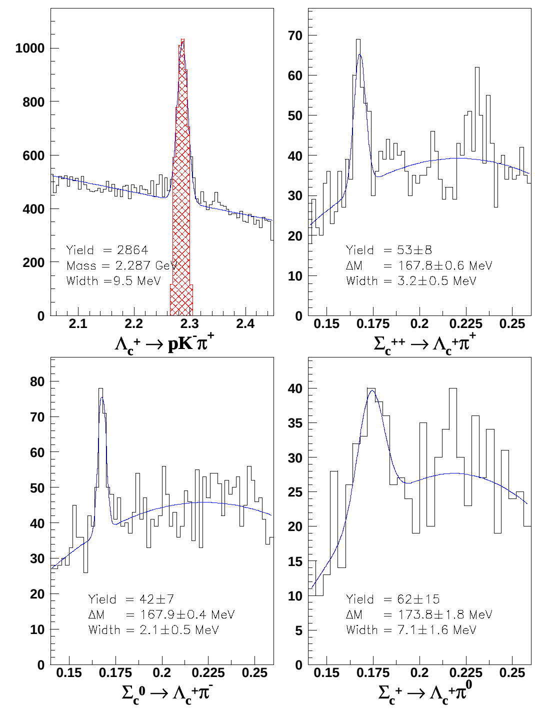

Figure 4: Preliminary signals for $\Lambda_c^+ \to pK^-\pi^+$ and $\Sigma_c^{++,0,+} \to \Lambda_c^+\pi^{+,-,0}$ from about 15% of the FOCUS data.

ern charm experiments, and they also have excellent vertex and proper time resolutions comparable to E687, E791 and FOCUS. SELEX cannot yet make projections of the size of their final charm sample as their reconstruction still has improvements which might increase the efficiency by as much as a factor of three. Due to their good mass and vertex resolution and their excellent particle identification [3] coupled with the leading particle effect in production, one can be hopeful that SELEX will be very competitive in the study of charm baryon decays as well as having some interesting production physics results.

6 Conclusions

The Fermilab Fixed Target program has in the past produced many of the world's best charm physics results. With the success of the last run in 1996-1997, the Fermilab experiments FOCUS, E835 and SELEX will continue to lead the world in the area of charm physics.

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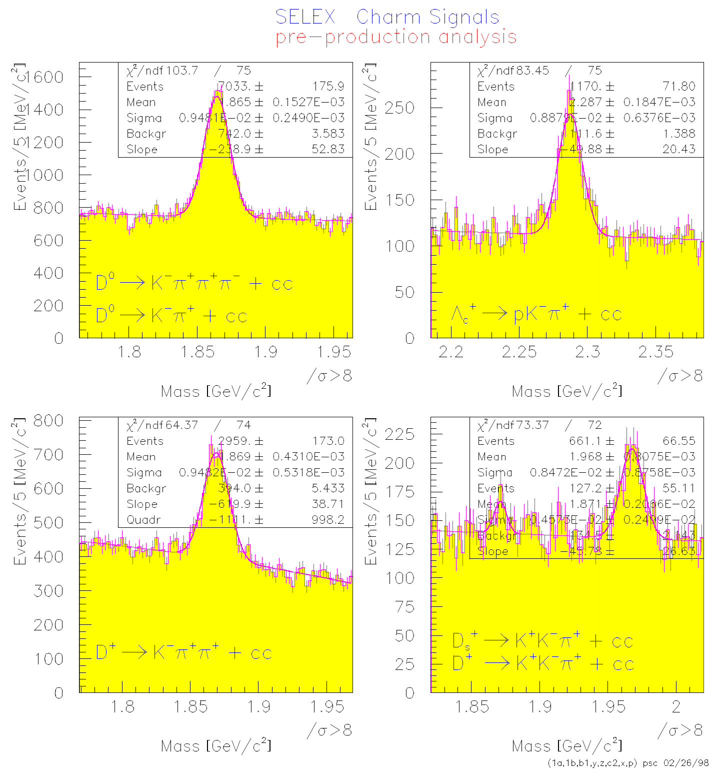

Figure 5: SELEX Pre-preliminary signals for $D^0 \to K^-\pi^+$, $K^-3\pi$; $D^+ \to K^-\pi^+\pi^+$; $\Lambda_c^+ \to pK^-\pi^+$; and $D^+, D_s^+ \to K^-K^+\pi^+$.

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