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Charm and Beauty Production from the Fermilab Fixed Target Program

Ray Stefanski

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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CHARM and BEAUTY PRODUCTION from the FERMILAB FIXED TARGET PROGRAM [a]

Ray Stefanski
Fermi National Accelerator Laboratory,
P.O. Box 500,
Batavia, Il 60510

Abstract

We present results from recent fixed target experiments at Fermilab. Heavy flavor production is studied by experiments using proton, photon, π^- and hyperon beams. The diversity of interactions provides a laboratory for the study of QCD through several different channels.

1 Introduction

Recent experimental results and developments in theory are beginning to form a coherent picture of heavy flavor production dynamics in fixed target experiments [1]. The data are described by Next-to-Leading-Order (NLO) QCD as well as nonperturbative effects involving fragmentation at large p_T and the intrinsic momentum of the interacting parton k_T. When more data are available, additional tuning of model parameters will be possible.

In this report, we present recent results from three Fermilab fixed-target charm production experiments:

1. E687: 220 GeV photon interactions in a 4 cm. beryllium target,

2. E781 (SELEX): 600 GeV hyperons interacting in a variety of thin targets,

3. E791: 500 GeV π^- on Pt and C targets.

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In addition, we report the E771 measurements of beauty production cross-sections measured for protons interacting in thin silicon targets.

Much of the analysis from the fixed target runs prior to 1994 is now nearing completion and will be published in the near future [2]. Some of the more recent results, taken during the 1996 fixed target run, will be reported here. In particular, we will report on charm production asymmetries and correlations, searches for rare or exotic states, and beauty production cross-sections.

2 Charm Production Asymmetry

The E791 collaboration has published results on charm production asymmetries [3] for strange charm mesons. Fig. 1 shows these results along with the previously measured non-strange charm results. Because of leading particle effects, the non-strange charm mesons should have a strong asymmetry, which is very evident from the figure. Because neither the target nor beam particle contain a strange quark, no asymmetry is expected for the strange charm meson production. The results reported by E791 are consistent with this picture.

The E687 collaboration has also published charm quark production asymmetries in photoproduction [4]. As seen in Fig. 2 they report an excess of anti-charm quarks at x_F near unity, and high p_t^2 consistent with a modified Lund [5] string model.

The SELEX Collaboration is reporting preliminary results. In Fig. 3, production asymmetries are shown for charm mesons and baryons produced by Σ^- and π^-. The relative production of charm to anti-charm is heavily dependent on the quark structure of the beam and target nucleons. From this data, we would conclude that SELEX has sufficient statistics to make important comparisons among Σ^-, and π^- data to probe PQCD.

From the figure, we can see that Σ^- and π^- production differ in several respects. The Σ^- interactions tend to produce Λ_c^+ about five times more often than $\overline{\Lambda}_c^-$. The π^- interactions also favor Λ_c^- but by a much smaller ratio. The D production shows the opposite behavior:

Both Σ^- and π^- interactions produce the negative D's more often. These are preliminary results.

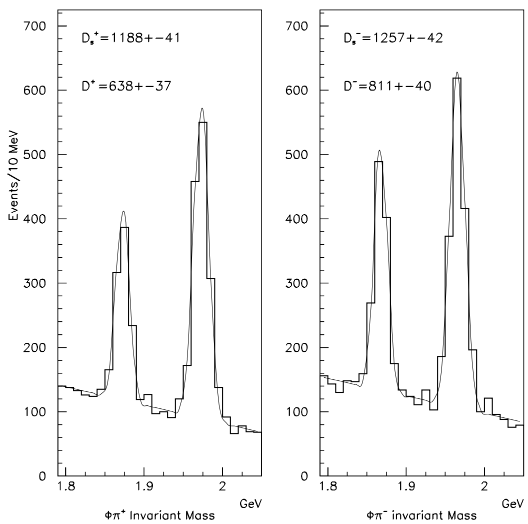

Figure 1: $K^+K^-\pi^-$ and $K^+K^-\pi^+$ invariant mass plots. The fits are to two Gaussian curves and a linear background. Typical cuts: (1)separation between primary and secondary vertex is $> 10\times$ experimental resolution, (2) impact parameter of the reconstructed momentum vector of the D_s candidate with respect to the primary vertex is > 40 microns, (3) tracks are closer to secondary vertex than primary vertex, and (4) no track in the event, except the three making the secondary vertex, passes within 10 microns of the secondary vertex.

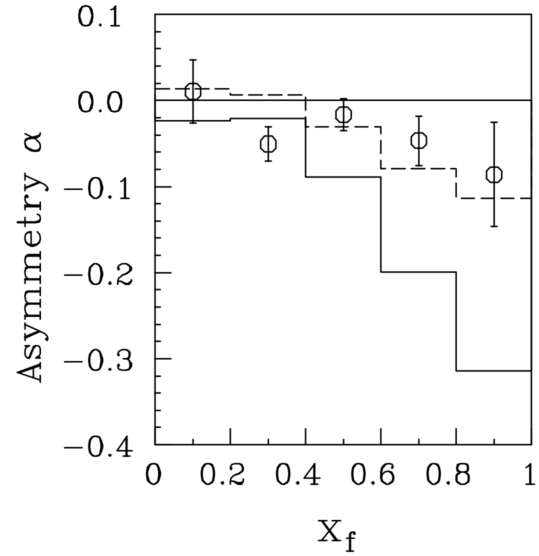

Figure 2: Variations of the production asymmetry $\alpha = \frac{N_c - N_{\bar{c}}}{N_c + N_{\bar{c}}}$ as a function of x_F for the decay mode $D^+ \to K^-\pi^+\pi^-$ from E687.

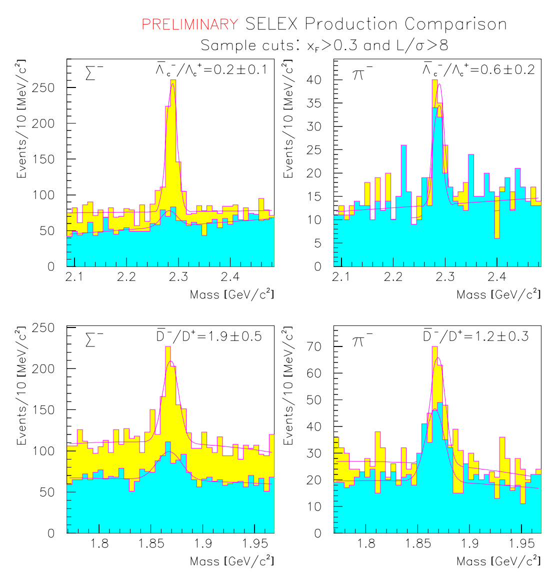

Figure 3: The charm baryon particle/anti-particle production asymmetry from SELEX looks very different for π^-, and Σ^- beams. The more copiously produced particles are shown by the lightly shaded bins, the particles with relatively less production probability are shown by the darkly shaded bins.

3 Charm Particle Correlations

E791 will soon complete the analysis of nearly 800 fully reconstructed charm pairs (mesons). Because each pair is fully reconstructed, an analysis can be carried out to search for correlations in kinematic variables of one charm meson relative to those of the other. Such correlations can greatly constrain charm production models.

One of the variables that can be studied in this way is the acoplanarity, or azimuthal angle ϕ around the beam axis. Both the difference $\Delta\phi$ and sum $\Sigma\phi$ of the charm pair can be computed. In the absence of correlations, these distributions would be completely flat. If the charm pair is produced back-to-back, as predicted in Leading Order (LO) QCD, the $\Delta\phi$ would be a spike at 180°, whereas $\Sigma\phi$ would still be flat. The $\Sigma\phi$ reflects the azimuthal symmetry of the detector, and cannot show structure if the detector acceptance is uniform in ϕ.

In Fig. 4 are shown the results from E791. The $\Delta\phi$ distribution shows correlations, but not to the degree predicted by LO QCD. All three of the QCD models incorporating higher order contributions which were compared to the data in the figure still favor greater correlation than seen in the data. This may be an indication that still higher order terms will be required to account for the correlations in the data.

E687 have published [6] acoplanarity distributions for photoproduction. One result is given in Fig. 5. As can be seen, there also exists a deviation from the correlation that would be predicted by NLO QCD, but to a lesser extent than is apparent in the E791 data for π^- production. In either case, higher order terms seem to be needed in PQCD to explain the correlations.

Fig. 6 gives additional information for $\Delta\phi$ and Σp_t^2 from the E791 data, along with comparison to the three models. In this analysis, the data are divided into bins, in $\Delta\phi$ and Σp_t^2, and compared. It can be seen from the figure that at high Σp_t^2 the pairs tend to lie in the $\Delta\phi$ bins near 180° and therefore exhibit more LO behavior. The predictions of the models are similar to data, but do not agree with the data in detail. The three sets of theoretical predictions are:

1. the distributions of $c\bar{c}$ pairs from a next-to-leading-order perturbative QCD calculation by Mangano, Nason and Ridolfi [7,8];
2. PYTHIA/ JETSET Monte-Carlo distributions of $c\bar{c}$ pairs [9], which use a parton-shower model to include higher-order perturbative effects [10]; and
3. PYTHIA/ JETSET Monte-Carlo distributions of $D\overline{D}$ pairs [9], which use the Lund string model to transform $c\bar{c}$ pairs to $D\overline{D}$ pairs[12,13].

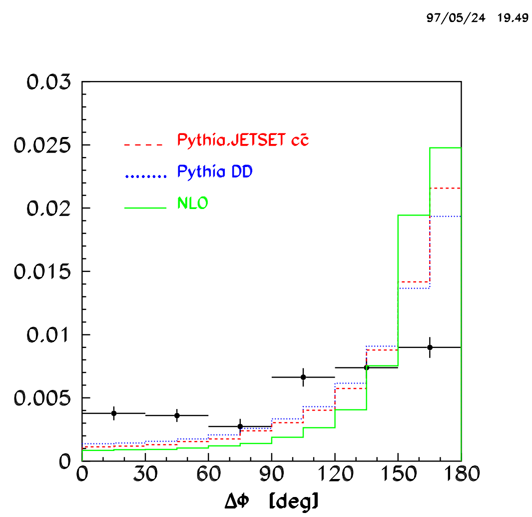

Figure 4: Charm-pair $\Delta\phi$ and $\Sigma\phi$ distributions; •, weighted data as described in ——, NLO QCD prediction; - - - -, PYTHIA/JETSET $c\bar{c}$ prediction; ········, PYTHIA/JETSET $D\overline{D}$ meson prediction.

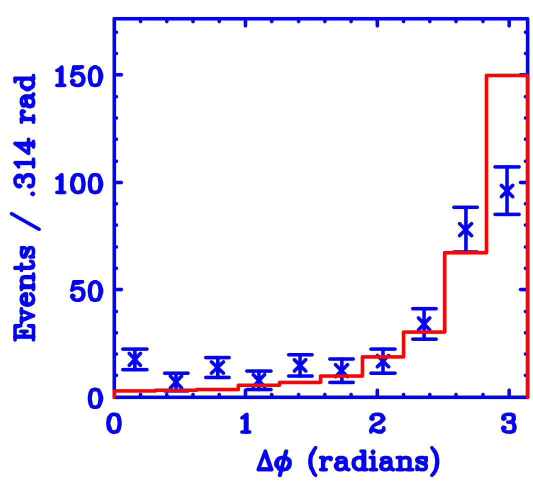

Figure 5: Background subtracted acoplanarity distribution $\Delta\phi$ for fully reconstructed $D\overline{D}$ pairs compared to Monte Carlo. (solid histogram)

4 Excited Charm Baryon States

E687 reports [14] the observation of the Ξ_c^{*+} state decaying into $\Xi_c^0\pi^+$ with $\Xi_c^0 \to \Lambda\overline{K}^0\pi^+\pi^-$ and $\Lambda K^-\pi^+\pi^+\pi^-$. 47 ± 11 candidate events were observed for the Ξ_c^{*+} state and the mass was measured to be $177.1 \pm 0.5 \pm 1.1$ Mev/c^2 above the Ξ_c^0 mass. The Ξ_c^0 mass was measured to

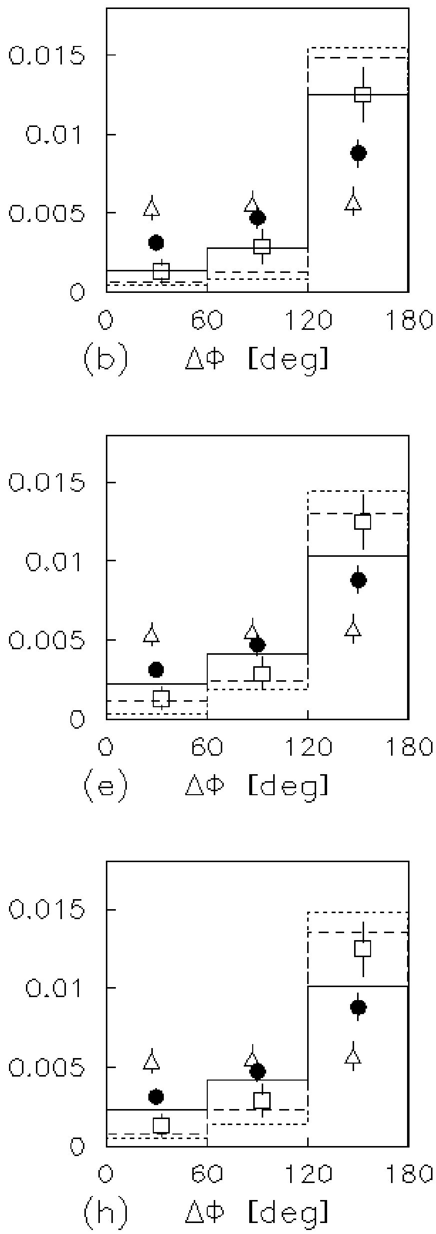

Figure 6: (b) Experimental $\Delta\phi$ distribution for each Σp_t^2 bin compared to the NLO QCD predictions. Each $\Delta\phi$ distribution is normalized such that the integral over $\Delta\phi$ equals one. (e) Same as (b) for the PYTHIA/JETSET $c\overline{c}$ prediction. (h) Same as (b) for the PYTHIA/JETSET $D\overline{D}$ prediction. Symbols are weighted data; lines are theory predictions. △ & —— come from the low bin; • & - - - - come from the middle bin; □ & ········ come from the high bin.

be $2470.0 \pm 2.8 \pm 2.6$ Mev/c^2. This measurement substantially confirms the initial observation made by the CLEO collaboration [15].

In Fig. 7 we give the two-dimensional scatter plot of the mass difference versus the mass of the Ξ_c^0. The narrow signal is evident in the $M(\Xi_c^0\pi^+) - M(\Xi_c^0)$ scatter plot. The narrow peak is very evident in the projections given in (b) and (c) of the figure.

The decay modes of the Ξ_c^0 baryon to $\Lambda\overline{K}^0\pi^+\pi^-$ and $\Lambda\pi^+\pi^+\pi^-$ were not previously observed.

5 Beauty

E771 [16] took data with 800 GeV/c proton-silicon interactions and a di-muon trigger. The run time was limited, although the average interaction rate was high for an open geometry spectrometer: about 2 MHz. When the results of two methods of analysis are combined, the following preliminary cross-section is obtained:

$\sigma(b\overline{b}) = 42^{+20}_{-13}(\text{stat.})^{+7}_{-7}(\text{syst.})$ nb/nucleon.

As can be seen in Fig. 8, this cross-section is on the high side of the NLO predictions. It also is higher by 2.4σ than the previously reported result from E789 [17].

The experimental results and the theoretical predictions for beauty production in pion interactions are also shown in the figure. Data and theory are in qualitative agreement, but much more work remains to reduce the uncertainty in both measurement and theory.

6 Summary

In this report we've summarized some of the more recent heavy flavor production results from the Fermilab fixed target program. Measurement of the charm production asymmetry from E791 for D_s shows no asymmetry, consistent with the QCD prediction. E791 also presented new data for charm particle production correlations. The data are not readily explained by the models. An excited charm baryon state was measured and reported by E687, confirming the previous observation by CLEO, and identifying two new decay modes. The FOCUS collaboration, using an modified E687 apparatus, expects 15 times more charm and as many as 10,000 reconstructed $D\overline{D}$ events. The new experiment

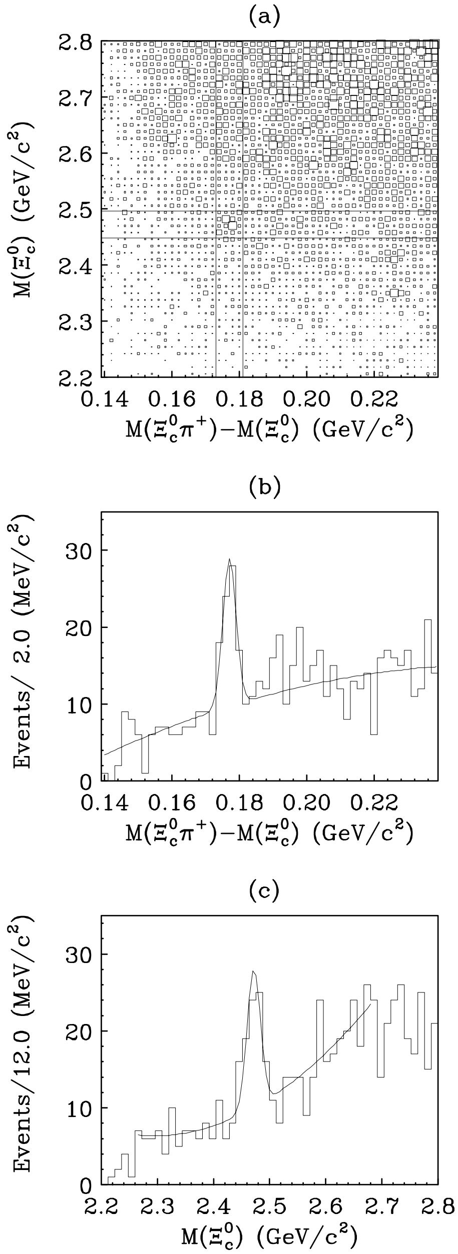

Figure 7: (a) shows a 2-D scatter plot of the mass difference, $M(\Xi_c^0\pi^+)-M(\Xi_c^0)$, versus the mass of Ξ_c^0, $M(\Xi_c^0)$. Signal events are clustered in a small box where the vertical and horizontal bands cross. (b) shows a projection by selecting events within two horizontal lines. This plot shows the mass difference distribution revealing a clear signal around $\Delta M = 177 MeV/c^2$. (c) shows an invariant mass distribution obtained by selecting events within the two vertical lines. This plot shows a clear signal for the Ξ_c^0 baryon.

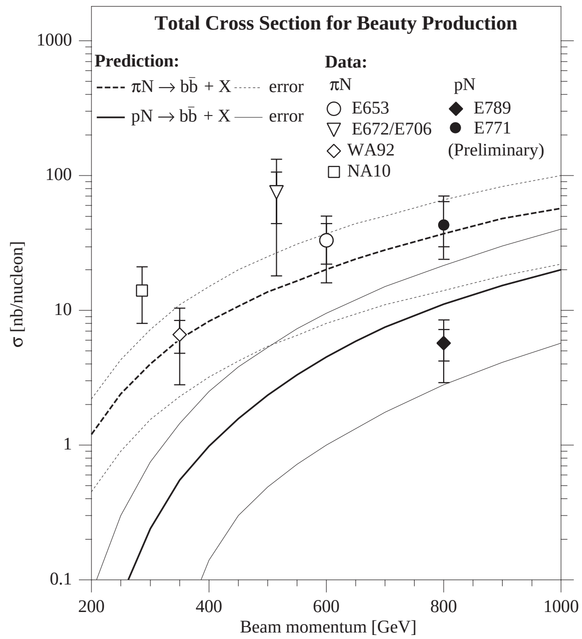

Figure 8: Comparison of beauty production cross-sections in πN, and pN interactions from experiment[18] and QCD predictions[19].

E781 (SELEX) has preliminary data with Σ^-, and π^-. For beauty production, the preliminary cross-section obtained from E771 suggests that further work will be needed to understand beauty production at fixed target energies.

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