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Hadroproduction Subprocesses**

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# New Preliminary Results on the Physics of Charm Hadroproduction Subprocesses

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## Abstract

This paper reviews the results and physics of two contributed papers to ICHEP94. Both papers relate to charm meson hadroproduction at Fermilab fixed target energies. The first (from E769) addresses the total forward cross section for charm mesons ( $D^\pm$  and  $D_s^\pm$ ) produced by  $\pi^\pm$ ,  $K^\pm$ , and proton beams. The second paper (from E791) deals with the asymmetries in the differential cross sections for charged D mesons produced in the forward direction by  $\pi^-$  beam.

The physics most directly related to the results of the E769 paper are the gluon distributions in the incident hadrons as well as perturbative QCD calculations of charm quark production and the charm quark mass. The E791 results address the details of the hadronization process after production of the charm quarks.

## 1. Introduction

QCD subprocess cross-sections for the creation of  $c\bar{c}$  pairs in high-energy parton interactions have been calculated perturbatively up to next-to-leading order (NLO). Convolution of these with the quark and gluon distribution functions of mesons and baryons allows for calculation of the total rate of charm production in hadronic collisions [1]. Fragmentation to particular charm final states, however, cannot be treated perturbatively, thus complicating the calculation of hadroproduction cross-sections for charm particles. For example, enhanced production in the forward hemisphere of particles which share a quark with the projectile particle (the leading-particle effect) is a feature of some phenomenological models [2,3] and indeed has been observed at levels not attributable to the underlying perturbative process of charm quark production [4-6]. Fermilab experiments E769 and E791 have new results [7,8 respectively] on these topics.

## 2. Comparison of Experiments E769 and E791

Table 1 gives a comparison of the major differences between E769 and E791. Both experiments took data using the Tagged Photon Spectrometer at Fermilab. The earlier experiment E769 focused on production issues, including dependence on incident particle type. This provides comparisons among charged pions, charged kaons and protons. The major upgrade for E791 was a massive increase in data handling capability [9] and higher beam energy, but without the E769 trigger enhancement of minority beam particles. E791 used only negative beam, while E769, in addition to its negative beam measurements, has made the first measurements of charm production with positive pions and positive kaons.

## 3. Forward $D^\pm$ and $D_s^\pm$ Cross-sections

E769's preliminary measurements of the  $D^\pm$  and  $D_s^\pm$  production cross-sections are listed in Table 2. Errors quoted for the  $D^\pm$  are statistical and systematic, in that order; only statistical errors are shown for the  $D_s^\pm$ .

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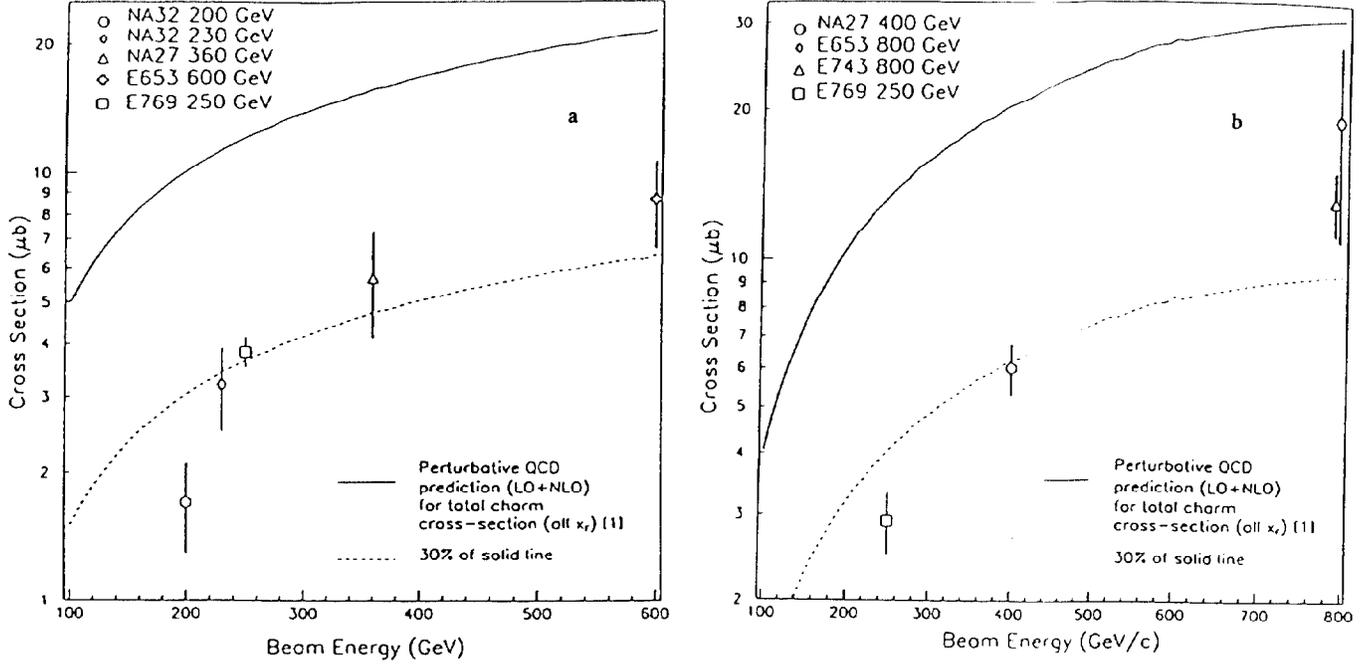


Figure 1. Measurements of (a)  $\sigma_{x_F > 0}(\pi^- N \rightarrow D^\pm X)$  and (b)  $\sigma_{x_F > 0}(p N \rightarrow D^\pm X)$  versus beam energy. The curves are for total charm quark production, i.e., all  $x_F$ .

Description	Experiment E769	Experiment E791
Years Data Taken	1987-8	1991-2
Beam Energy	250 GeV	500 GeV
Beam Particle ID	Cerenkov, TRD	none
Targets	W, Cu, Al, Be	Pt, C
No. of Events	400 M	20,000 M
Data Set Size	1.5 TBytes	50 TBytes
Recon. Decays	4,000	>200,000

Table 1. Comparisons of Fermilab experiments E769 and E791.

Beam, B	$\sigma_{x_F > 0}(BN \rightarrow D^\pm X)$	$\sigma_{x_F > 0}(BN \rightarrow D_s^\pm X)$
$\pi^-$	$3.8 \pm 0.3 \pm 0.2$	$1.9 \pm 0.4$
$\pi^+$	$3.9 \pm 0.4 \pm 0.4$	$2.9 \pm 0.9$
$K^-$	$2.8 \pm 0.5 \pm 0.8$	$3.5 \pm 1.3$
$K^+$	$3.1 \pm 0.4 \pm 0.4$	$2.8 \pm 1.1$
$p^+$	$2.9 \pm 0.4 \pm 0.2$	$< 1.9(90\%c.l.)$

Table 2. Each cross section is in microbarn/nucleon and is for the sum of mesons observed in the forward hemisphere, the particles and the antiparticles.

Branching fractions from the 1992 Review of Particle Properties [10] were used; their errors are not included.

For both the  $D^\pm$  and  $D_s^\pm$ , no significant differences in beam particle and antiparticle-induced cross-sections are observed. Also consistent with being equal are the  $\pi$  and  $K$  induced cross-sections, suggesting that the gluon distribution functions of the two mesons are similar. Additionally, fragmentation of charm to  $D_s^\pm$

is not greatly suppressed with respect to  $D^\pm$  at this energy. Nor is  $D_s^\pm$  production enhanced by having the appropriate strange quark in the projectile. This lends support to the dominance of gluon-gluon fusion in the theory.

In Figures 1(a) and 1(b), respectively, E769 results for  $\pi^-$  and  $p$  induced  $D^\pm$  production are displayed alongside previous measurements. Assuming a constant  $D^\pm$  fragmentation rate, the energy dependence of  $D^\pm$  production can be compared to the theoretical predictions for all charm, as shown in the figures. Given this, it appears that the steepness of the data points vs energy with respect to the theoretical curves points to too hard gluon distributions and/or too low an effective charm quark mass in the parameterizations used in the theoretical calculations.

#### 4. Production Asymmetries

Previous experiments [4,6] have seen asymmetries in the hadronic production of charmed mesons. Mesons which have a light quark in common with the incoming beam ("leading particles") have a harder momentum spectrum than those which do not ("non-leading particles"). In the case of E791, with its  $\pi^- (d\bar{u})$  beam, the  $D^- (d\bar{c})$  is leading and the  $D^+ (\bar{d}c)$  is non-leading.

Next to leading order PQCD calculations [1] predict, for a  $\pi^-$  beam, only a very small excess in  $\bar{c}$  quarks relative to  $c$  quarks in the very forward direction. This effect is much smaller than that seen in data.

Another possible explanation of the asymmetry is inherent in the Lund "string fragmentation" model [11]. In this model, forward momentum is added to the produced heavy quarks as they combine with the remnant light quarks from the incoming beam particle. As implemented in the model, the string connections cause the leading particles to have a harder momentum spectrum than non-leading particles. However, unlike the data, the default parameters in the model give a large asymmetry, even at low momentum. The shape matches the asymmetry better if the number of  $D^+$  produced is forced to match the number of  $D^-$ .

A third possible source of asymmetry is intrinsic charm [3]. Here, a virtual  $c\bar{c}$  pair in the incoming beam particle is knocked onto the mass shell in a small percentage of the interactions. The recent publication in reference 3 compares its predicted results to past data and predicts asymmetries as a function of transverse momentum. The prediction for the asymmetry versus longitudinal momentum matches the data. However, equality of the overall  $D^+$  and  $D^-$  production is put into the prediction by hand and the prediction depends on selected phenomenological parameters.

One can also study production asymmetries for  $D^0$ 's and  $D^*$ 's. For the  $D^0$ 's, however, a large fraction of the  $D^0$ 's (typically 1/3 of those observed) are produced by the  $D^{*+} \rightarrow D^0\pi^+$  decay process. The original  $D^{*+}$  is actually a *non-leading* particle. Therefore, the observed  $D^0$ 's come from a mixture of leading and non-leading processes, making the study more complex.

A produced charm meson may be described by its  $z_F$ , the scaled longitudinal momentum (Feynman  $x$ ), and its  $P_t$ , transverse momentum. In order to show small differences in distributions in different  $z_F$  and  $P_t$  regions, an asymmetry parameter is calculated for each region. For a  $\pi^-$  beam, this parameter,  $A$ , is defined as:

$$A \equiv \frac{N_{D^-} - N_{D^+}}{N_{D^-} + N_{D^+}}$$

where  $N_D$  is the number of that meson produced within that  $z_F$  or  $P_t$  bin. (Note that since the acceptance for  $D^+$  and  $D^-$  is nearly the same in the detectors,  $A$  is independent of the acceptance values.)

The new preliminary E791  $D^\pm$  forward asymmetries are very similar to the earlier WA82 and E769 published results. However, E791 has more than an order of magnitude more data, even in the reported 1/3 of their total data sample ( $9363 \pm 96 D^\pm$  vs  $863 \pm 32 D^\pm$  from WA82 and  $919 \pm 37 D^\pm$  and  $600 \pm 30 D^\pm$  from E769). Thus, E791 can examine, for example, the  $P_t^2$  asymmetry distribution in restricted regions of  $z_F$ . PYTHIA-LUND predicts a slight increase in  $A$  with increasing  $P_t^2$ . The intrinsic charm model predicts a maximum at  $P_t^2$  of zero, decreasing with  $P_t^2$ . The effect would be strongest in mesons with large values of  $z_F$  in

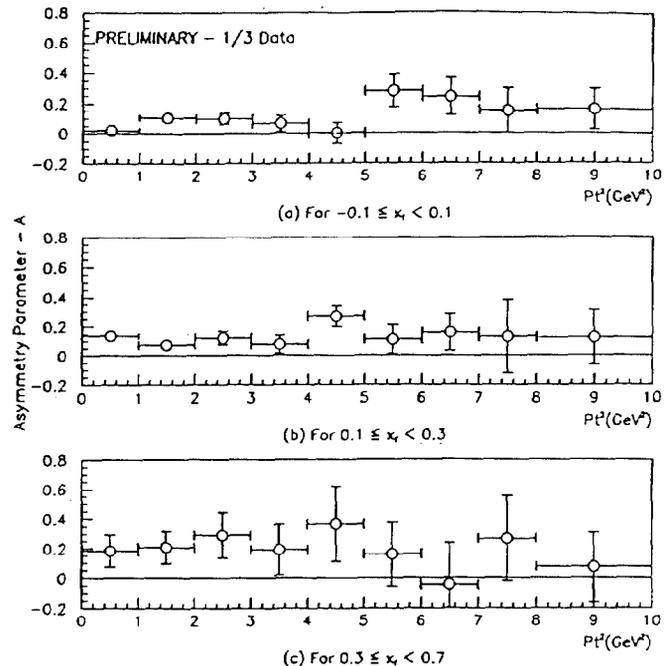


Figure 2. Asymmetry vs  $P_t^2$  in various regions of  $z_F$ .

both models. Figure 2 shows the value of  $A$  vs  $P_t^2$  for different regions of  $z_F$ . The data does not match either prediction.

## 5. Acknowledgements

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