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# Production Asymmetries in $x_f$ and $P_t^2$ for $D^\pm$ mesons

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### Abstract

Non-zero asymmetries have been reported in  $x_f$  distributions of leading and non-leading charmed mesons produced from hadronic beams. Production models have also been proposed that would explain these asymmetries and make predictions on how these asymmetries will depend on  $P_t^2$ . We present differences in leading and non-leading  $D$  charged meson production as a doubly differential function of both  $P_t^2$  and  $x_f$ . This information is from the preliminary analysis of 1/3 of the data from Fermilab experiment E791. It was taken during the 1991-2 fixed target run using a 500 GeV/c  $\pi^-$  beam incident on a segmented target.

## 1 The Detector

The results given in this paper come from the 1991/92 run of fixed target experiment E791 at Fermilab. The experiment used a 500 GeV/c  $\pi^-$  beam on a segmented nuclear target. The detector was the Tagged Photon Spectrometer, an open geometry multiparticle spectrometer and has been described elsewhere [1]. A key element of the detector for this analysis was the 23 planes of silicon micro-strip detectors which provided excellent primary and secondary vertex resolution ( $\sim 350\mu$  longitudinally,  $\sim 20\mu$  transverse to the beam). The target consisted of 1 platinum and 4 carbon foils, each approximately 0.58% interaction lengths thick. The foils were placed  $\sim 1.5$ cm apart so that a large fraction of the secondary vertices from charm decay would fall outside the foils.

Another key element of the E791 experiment was the fast and efficient data acquisition computer and electronics system [2]. The computer system consisted of 42 parallel micro-processors with large separate memory storage for buffering data during the spill. The front end electronics were designed for a fast readout time of  $50\mu$ sec. This system allowed E791 to use a very open trigger consisting of only a clean primary interaction with a mild transverse energy requirement. Over 20 billion events were recorded on 24,000 8mm tapes.

The reconstruction of this large data set will be completed by late summer on parallel processing computer farms in 4 locations: Kansas State University, University of Mississippi, Fermilab and Centro Brasileiro de Pesquisas Fisicas in Brazil.

## 2 The Physics

Previous experiments [3,4] have seen asymmetries in the hadronic production of charmed mesons. By asymmetries, we mean that a particular charmed meson may have a different production distribution from its anti-particle partner. The specific case we will be studying in this paper is the one in which the  $D^-$  meson has a *harder*  $x_f$  distribution than the  $D^+$  meson. We will also show initial results on the comparison of their  $P_t^2$  distributions.

In studying the physics of asymmetries in charm meson production, we are actually studying two different processes which may affect our data. The first process is how  $c$  and  $\bar{c}$  quarks are produced during the interaction. The second process is how those quarks progress to form hadronic states visible to our detector. Various models and theories have been proposed which ascribe production asymmetries to one or both of these processes.

The first place to look to explain any asymmetries seen is in standard perturbative QCD. NLO calculations [5] predict for a  $\pi^-$  beam a small increase in mesons

containing a  $\bar{c}$  quark over those containing  $c$  quarks in the very forward direction. This effect is much smaller than that seen in data[3].

Another possible explanation of the asymmetry is the Lund “string fragmentation” model that effects the formation of the visible particles. 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[6]. This causes charmed mesons with a light quark in common with the incoming beam (“Leading Particles”) to have a harder  $x_f$  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. Comparisons of this model to data have been made by previous experiments [3,4].

A third possible model which would affect the production distributions for charmed hadrons is that of intrinsic charm [7]. Here, a virtual  $c\bar{c}$  pair is formed in the incoming beam particle and is knocked onto mass shell during a small percentage of the interactions. A recent publication on this model compares its predicted results to past  $x_f$  data distributions. It also predicts how these asymmetries will look as a function of  $P_t^2$ .

### 3 Method of Analysis

In E791’s case, with a  $\pi^-$  beam, the most copious leading charmed mesons should be the  $D^0$ ,  $D^-$  and  $D^{*-}$ . One might set out to study the directions in which these particles are produced in comparison with their non-leading counterparts, the  $\bar{D}^0$ ,  $D^+$  and  $D^{*+}$ . Unfortunately, a large fraction of the  $D^0$ ’s (typically 1/3 of those observed) may have been produced by the  $D^{*+} \rightarrow D^0\pi^+$  decay process. The original  $D^{*+}$  is actually a *non*-leading particle. Therefore the  $D^0$ ’s seen come from a mixture of leading and non-leading processes, making the study a bit more complex. This document will study only the  $D^+/D^-$  comparisons although  $D^{*+}/D^{*-}$  comparisons are soon to follow.

The direction of a produced meson may be described by its  $x_f$  and  $P_t$  values. In order to show small differences in these values over many different  $x_f$  and  $P_t$  regions, an asymmetry parameter is calculated for each region. 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  $x_f$  or  $P_t$  bin. (Note that since the acceptance for  $D^+$  and  $D^-$  is the same in our detector,  $A$  is independent of the acceptance values.)

This asymmetry was plotted vs  $x_f$  by both WA82[3] and E769[4]. Both these experiments saw increasing  $A$  with increasing  $x_f$ . E769 went further and plotted  $A$  vs  $P_t^2$ . There, the asymmetry appeared positive and constant over the  $P_t$  region

studied. Both these experiments were limited by their statistics. WA82 used  $863 \pm 32 D^\pm$ . E769 used  $919 \pm 37 D^\pm$  and  $600 \pm 30 D^{*\pm}$ .

In addition to the  $x_f$  distributions, E791 can use its high statistics ( $9363 \pm 96$  used here) to plot the asymmetries vs  $P_t^2$  for different regions of  $x_f$ . This will allow us to compare to predictions made for the intrinsic charm model [7].

## 4 Data Set and Analysis

The results shown in this paper come from the analysis of approximately 1/3 of the total E791 data set. Figure 1 shows the resulting mass peak from the decay of  $D^\pm \rightarrow K2\pi$ . A much larger sample of  $D^\pm$  can be produced if the background level is allowed to increase.

In this paper, the asymmetry parameter,  $A$ , is calculated directly from data with no correction for detector acceptance. To ensure that no acceptance correction was required, Monte Carlo software simulation of our detector was used. This test showed that the value of  $A$  calculated from the reconstructed simulated events was equal to the generated value of  $A$  within errors. We also tested to see if any slight systematic errors in reconstruction such as misalignment or miscalculation of the magnetic field would change the calculated  $A$  value. There were no significant changes noted.

Throughout the rest of this paper, the errors shown will be statistical errors only.

## 5 Results

Figures 2(a) and 2(b) show the value of  $A$  for the E791  $D^\pm$  mesons plotted vs.  $x_f$  and  $P_t^2$  respectively. Figure 2(b) is consistent with both a flat distribution in  $P_t^2$  and one which slightly rises with increasing  $P_t^2$ . PYTHIA predicts a slight increase in  $A$  with increasing  $P_t^2$ .

Figure (3) shows the value of  $A$  vs  $P_t^2$  for different regions of  $x_f$ . The intrinsic charm model predicts a maximum at  $P_t^2$  of zero and decreasing with  $P_t^2$ . This effect would be strongest in mesons with large values of  $x_f$ [7]. There are no indications of such an increase in figure 3(c), although we are limited by statistics.

## 6 Future Analysis

The ability to see changes in  $A$  with  $P_t^2$  as shown in figure 2(b) show the value of a high statistics hadro-productions charm experiment. At the same time, the limited high  $x_f$  statistics shown in figure 3(c) show the need for an even larger sample. Completing the analysis of our entire data set and including  $D^{*\pm}$  decays will allow us to make more definitive statements about various models. At the same time we can increase the range of  $x_f$  examined.

The study of  $D_s$  and  $\Lambda_c$  decays in our data should give us a possible test for the cause of the changing value of  $A$ . In the case of the meson, neither  $D_s$  or  $\bar{D}_s$  contain a quark in common with our  $\pi^-$  beam. In the baryon case, *both*  $\Lambda_c$  and  $\bar{\Lambda}_c$  contain quarks in common with the beam particle. In both cases, there should have no “leading particle” effect.

Finally, we will complete our studies of possible systematic errors in our analysis.

## 7 References

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Figure 1. E791 -  $D^{*+} \rightarrow k\pi\pi$

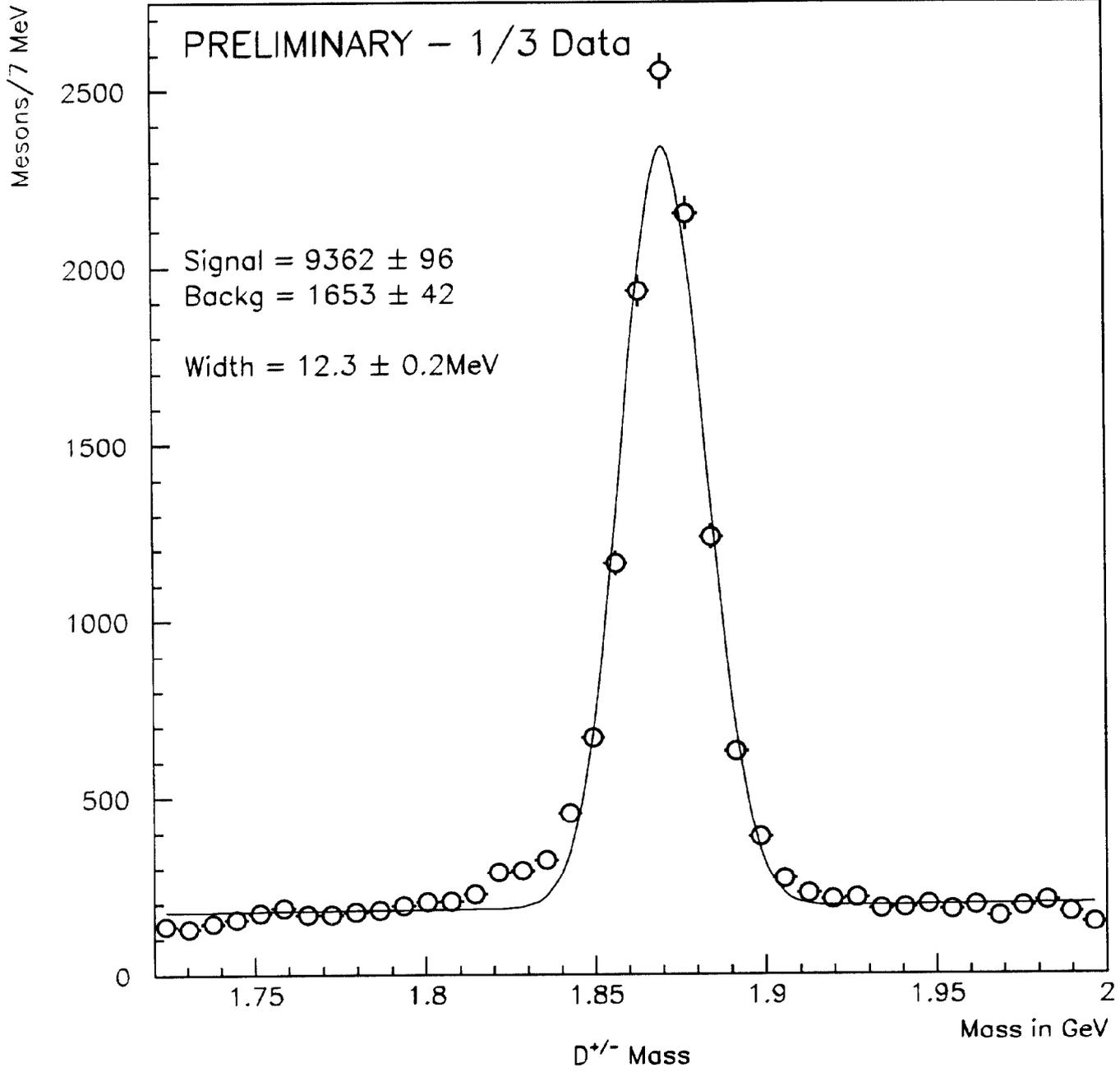
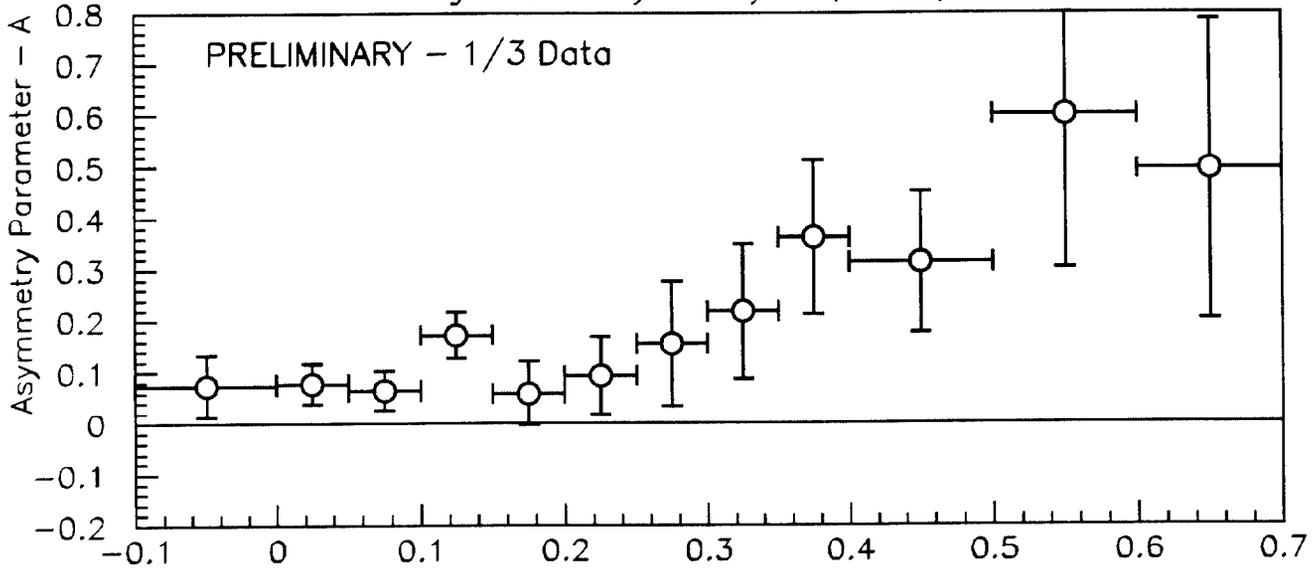
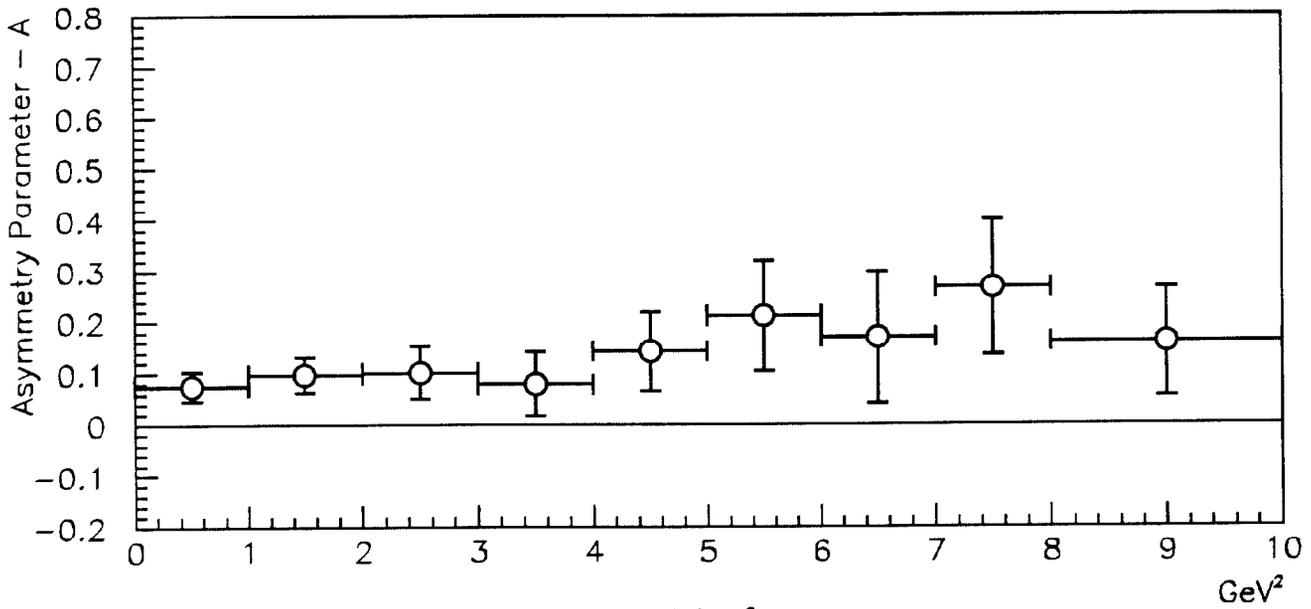


Figure 2. - Asymmetry vs  $x_f$  and  $P_t^2$



(a)  $x_f$



(b)  $P_t^2$

Figure 3 – Asymmetry vs  $Pt^2$  for Different  $x_f$  Regions

