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Selex results on $D_s^{\pm}$, $D^{\pm}$, $D^{*\pm}$ and $D^0/\bar{D}^0$ production

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The SELEX experiment (E781) is a 3-stage magnetic spectrometer for a high statistics study of hadroproduction of charm baryons out to large x_F using 650 GeV/c Σ^-, π^- and p beams. The main features of the spectrometer are: a high precision silicon vertex system; powerful particle identification provided by TRD and RICH; forward decay spectrometer; and 3-stage lead glass photon detector. Preliminary results on asymmetry for $D_s^{\pm}$, $D^{\pm}$, $D^{*\pm}$ and $D^0/\bar{D}^0$ produced by Σ^-, π^- beams at $x_F > 0.2$ are presented. The results show significant non-perturbative effects that are not explained by any present model.

1. Motivation of charm hadroproduction measurements

The QCD factorization theorem for heavy particle production states that production is described by the distribution function of the incident parton, the parton cross section and the heavy quark fragmentation function [1]. The parton cross section at Leading Order (LO) predicts no asymmetry between c and $\bar{c}$ fragments. Asymmetries are generated at next-to-leading order (NLO) but they are too small to account for the experimental results. Fixed target hadroproduction experiments have observed large asymmetries in production of charmed baryons as well as charmed mesons. These asymmetries are known as "the leading particle effect" since the charmed hadrons which have a valence parton in common with the beam hadron are produced in great number in the forward region. Several phenomenological models of hadronization have been proposed. One class of models is based on the string fragmentation mechanism: PYTHIA Monte Carlo [2] and the Quark-String-Gluon model (QSGM) [3,4]. In PYTHIA the charm quarks hadronize into a charmed meson or baryon by the decay of a color string connected to the partons in the beam remnants. Predictions of the aymmetries are sensitive to the model for the beam remnants as well as other PYTHIA parameters. In the QSGM the charmed hadrons are produced by an exchange of a chain of quarks between the beam and the target. In this model a parameter of the leading fragmentation function dependence of valence quark on z as well as the content of sea quarks in the beam must be fit by the data. A qualitative explanation of the leading particle effect is given also by heavy quark recombination with a light parton that participates in the hard-scattering process [5–7]. Another class is based on the intrinsic charm (IC) in the nucleon; it predicts smaller asymmetries than are observed [8].

More experimental data, using different incident hadrons (π, p and Σ^-), may help the understanding of the charm hadroproduction and they probe the non perturbative effects as well as $O(\Lambda_{QCD}/m_c)$ corrections. In particular a study of D^* meson production can evidence the role played by the beam in the charmed meson spin.

2. The Selex spectrometer

The SELEX experiment at Fermilab is a 3-stage magnetic spectrometer. The 600 GeV/c Hyperon beam of negative polarity contains roughly equal fractions of Σ and π. The positive beam is composed of 92% of protons and the rest π's. Beam particles are identified by a Transi-

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	$D^{+(*)}/D^{-(*)}$ $(c\bar{d})/(\bar{c}d)$	$D^0/\bar{D}^0$ $(c\bar{u})/(\bar{c}u)$	D_s^+/D_s^- $(c\bar{s})/(\bar{c}s)$
$\pi^-(d\bar{u})$	NL / L	L / NL	NL / NL
$\Sigma^-(dds)$	NL / L	NL / NL	NL / L

Table 1
Leading (L) and non-leading (NL) particles for $D^{*\pm}$, $D^\pm$, $D^0/\bar{D}^0$ and $D_s^\pm$ according to the quark beam and the charm particle content.

tion Radiation detector (BTRD). The spectrometer was designed to study charm production in the forward hemisphere with good mass and decay vertex resolution for charm momentum in a range of 100-500 GeV/c. The vertex region is composed of 5 targets (2 Cu and 3 C). The total target thickess is 5% of λ_{int} for protons and the targets are separated by 1.5 cm. Downstream of the targets there are 20 silicon planes with a strip pitch of 20-25 μm disposed in X,Y,U and V views. The M1 and M2 magnets effect a momentum cutoff of 2.5 GeV/c and 15 GeV/c respectively. A RICH detector, filled with Neon at room temperature and pressure, provides a single track ring radius resolution of 1.4% and 2σ K/π separation up to about 165 GeV/c. A computational filter uses tracks identified by the RICH and linked to the vertex silicon by the PWCs to make a full reconstruction of the secondary vertex. Events consistent with only a primary vertex are rejected. A layout of the spectrometer can be found elsewhere [9]. The charm trigger is very loose. It requires a valid beam track, two tracks of charge opposite to the beam with momentum $>$ 15 GeV/c, two high momentum tracks linked to the Silicon vertex detector, and unconnected to all other tracks from the primary vertex. We triggered on about 1/3 of all the inelastic interactions. About 1/8 of them are written on the tape for a final sample of about $0.9 \cdot 10^9$ events. In the analysis secondary vertices were reconstructed if the χ^2 of all tracks was inconsistent with single primary vertex. The RICH detector labelled all particles above 25 GeV/c and it gives a good separation π/K for track momentum of 100 GeV/c, typical momenta for charm decay tracks (p,K). All data reported here resulted from a first pass

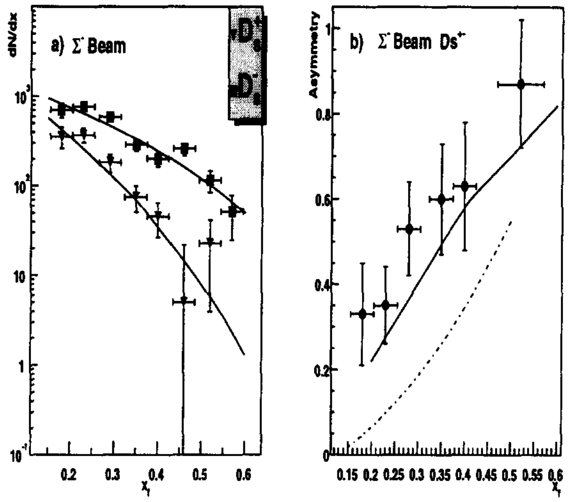

Figure 1. a) Yields versus x_F for $D_s{}^-$ and $D_s{}^+$ from Σ^- beam; b) Production asymmetry as function of x_F from Σ^- beam. In Fig. b) solid and dotted-dashed lines are the predictions from the QSGM [4] and the IC model [8] respectively.

through the data.

3. $D_s^\pm$, $D^\pm$, $D^{*\pm}$ and $D^0/\bar{D}^0$ asymmetry from Σ^- beam

The hadroproduction asymmetry used in this analysis is defined as: $A = (\sigma_L - \sigma_{NL})/(\sigma_L + \sigma_{NL})$ where L is the leading particle and NL the non-leading particle according to the valence content of the produced charmed particle as summarized in Table 1. The data yields were corrected by geometrical acceptance and reconstruction efficiency. The efficiency rises from x_F greater than 0.2 to a maximum at 0.4 and it remains high at x_F equal to 0.6. The efficiency difference for particle and antiparticle is less than 2%.

3.1. $D_s{}^\pm$

After all the cuts and acceptance corrections, the resulting $D_s^\pm$ yields as functions of x_F are shown in Fig. 1a. It shows that for the Σ^- beam values of the $D_s{}^-$ production is favoured over D_s^+ at all x_F. This difference increases at large x_F, which means that the D_s^- carries more of the beam momentum compared to D_s^+. Figure 1b displays the $D_s^{\pm}$ acceptance corrected asymmetry as function of x_F for Σ^- beam; There is a significant asymmetry which increases as x_F increases. Using the π^- beam no asymmetry is found. No charge bias in the asymmetry due to the trigger hodoscope requirement has been observed in studies of these data.

3.2. $D^{*\pm}$, $D^{\pm}$ and $D^0/\bar{D}^0$

The D^* and D mesons have the same valence quark content and the S=1 and S=0 respectively. The $D^{*\pm}(2010)$ has been identified by reconstructing the decay chain $D^{*+} \to D^0\pi^+$. The cut applied to decay vertex are described in Ref.[12]. The added track was assumed to be a pion and a mass difference $\Delta M = M(D^0\pi^+) - M(D^0)$ was determined. A signal region was defined as $141 < \Delta M(\mathrm{MeV}/c^2) < 150$. Fig. 2a shows that the integral yield favours the leading D^{*-} but its x_F distribution becames steep for $x_F > 0.3$. Instead, as shown in Fig. 2a,b the D^* and the $D^{\pm}$ x_F distributions from Σ^- have a different behaviour, in contrast to the $D^{*\pm}$ and $D^{\pm}$ x_F distribution measured with π^- beam by WA92 and E791 esperiments [11,10] . That suggests the d quark structure function is different in π^- and Σ^- beam or the fragmentation function depends on the spin of picked up d-quark or dd quarks. Instead the $D^{\pm}$ and D^0 asymmetry from Σ^- is small for both as shown in Fig. 3a,b. For $D^{\pm}$ we expect a large asymmetry at large x_F. The small asymmetry measured is further evidence of noleading mechanism is operative in the production of a particle having spin 0 by dd valence quarks.

The SELEX results add more details to the observed asymmetry in earlier data from the WA89 experiment where the charm production was studied in a 340 GeV/c Σ^- [11].

4. $D^{\pm}$ and $D^0/\bar{D}^0$ asymmetry from π^- beam

SELEX has measured also the $D^{\pm}$ and $D^0/\bar{D}^0$ asymmetry from π^- beam. Fig 4a shows a moderate asymmetry as function of x_F for charged D

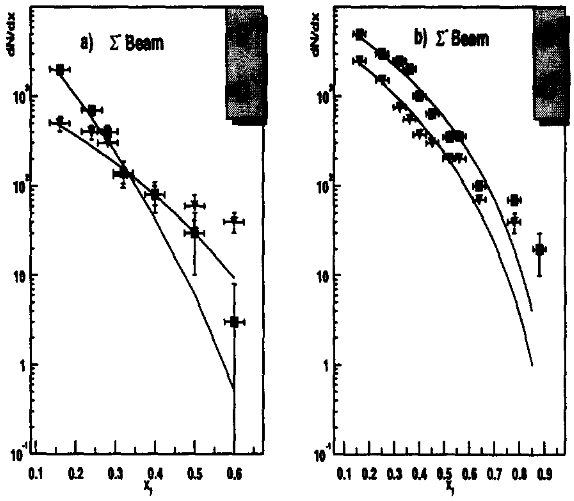

Figure 2. a),b): Yields versus x_F for $D^{*\pm}$ and $D^{\pm}$ respectively from Σ^- beam.

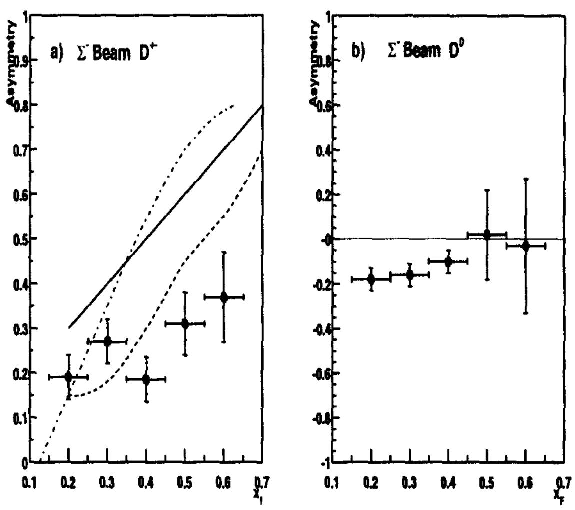

Figure 3. a),b) : Production asymmetry as function of x_F for $D^{\pm}$ and $D^0/\bar{D}^0$ respectively from Σ^- beam. In Fig. a) solid, dashed and dotted-dashed lines are the predictions from the QSGM [4], the recombination model [5] and the IC model [8] respectively.

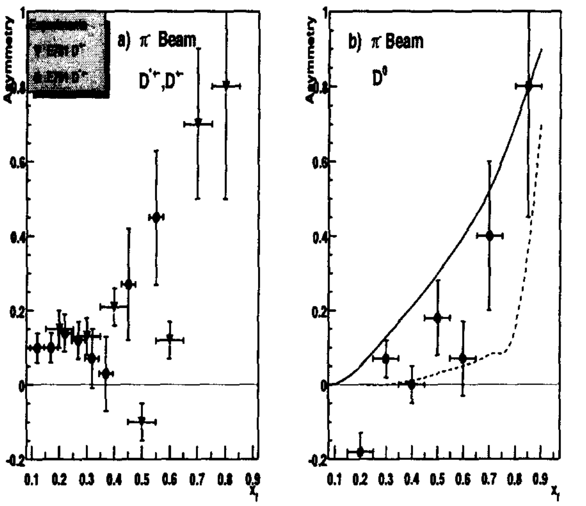

Figure 4. a),b) Production asymmetry as function of x_F for $D^{\pm}$ and $D^0/\bar{D}^0$ respectively from π^- beam. In Fig. a) $D^{\pm}$ asymmetry is compared to $D^{*\pm}$ distribution measured by E791. In Fig. b) the solid and dashed lines are the prediction from the QSGM [4] and the heavy-quark recombination model [5] respectively.

mesons in the x_F range (0.2,0.6). These results are in agreement to the $D^{*\pm}$ asymmetry results obtained by E791 experiment. The dotted line in Fig. 4a is the tuned for E791 PYTHIA prediction; it does not reproduces the data. Fig. 3b shows the $D^0/\bar{D}^0$ asymmetry as function of x_F. Also in this case we do not see a large asymmetry production as predicted by different models.No D^* removal is made in the data shown in Fig. 4b.

5. SUMMARY

The SELEX experiment finds clear production asymmetry at large x_F for $D_s{}^{\pm}$ from Σ^- beam and $D^0/\bar{D}^0$ from π^- beam. The different behaviour on x_F distribution between $D^{*\pm}$ and $D^{\pm}$ produced by the Σ^- beam suggests that its *dd* valence quarks content plays a different role in the creation of a Spin 1 or Spin 0 particle when it is compared to the $D^{*\pm}$ and $D^{\pm}$ production obtained by the π^- beam where only one *d* valence quark is present. A comparison between SELEX and E791 data on $D^{*\pm}$, $D^{\pm}$ asymmetry from π^- beam shows a good agreement between them at $x_F < 0.5$.

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