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Study of D^+ and D^- Feynman's x Distributions in π^--Nucleus Interactions at the SPS

WA82 Collaboration

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Abstract

Experiment WA82 studied charm production by a π^- beam of 340 GeV/c at the CERN Ω' spectrometer, using a silicon microstrip vertex detector and an impact parameter trigger. Results on the x_F distributions of D^+ and D^- mesons are presented and discussed. A clear excess of D^- over D^+, increasing at high x_F, is observed.

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One of the main open problems in charm physics is the relative importance of perturbative and non-perturbative QCD phenomena in the hadronic production of charm mesons. The nuclear dependence of charm hadroproduction and the longitudinal distributions of charm hadrons are two main benchmarks in this respect: perturbative QCD predicts a linear rise of the charm hadroproduction cross section with the mass number of the target nucleus, and if perturbative QCD alone were at play one would expect the x_F distributions for all charm hadrons to reproduce those of the c and $\bar{c}$ quarks, and therefore to be all very similar. We already reported on the nuclear dependence of charm hadroproduction in a previous paper [1]. In this letter we describe our results on the x_F distributions of D^+ and D^- mesons.

Experiment WA82 was run at the CERN Ω' spectrometer. The experiment was based on a silicon microstrip telescope, which allowed triggering and off-line detection of secondary vertices. The collected charm sample, consisting of about 3000 fully reconstructed decays, has allowed the study of the production and decay mechanisms of charm hadrons.

Beams of 340 GeV/c π^- or 370 GeV/c p were collided on a 2 mm thick target, which was divided vertically into two portions of different materials to allow the study of the nuclear dependence of charm hadroproduction. The π^- beam was used with a W/Si target ($1.8 \cdot 10^7$ triggers), and with a W/Cu target ($3 \cdot 10^7$ triggers). In addition, a proton beam run was performed on W/Si (10^7 triggers).

The silicon vertex detector [2] was 50 cm long and consisted of fourteen planes with pitches ranging from 10 μm to 50 μm. Eight additional 20 μm pitch planes were used as beam detector. The typical accuracy on the measurement of the position of secondary vertices was 500 μm (longitudinal) and 30 μm (transverse).

The microstrip detectors were placed inside the Ω' spectrometer, equipped with its standard multi-wire and drift chambers. The magnetic field intensity was 1.8 Tesla at the center of the Ω magnet. The accuracy on the measurement of momenta was $(dp/p)_{MEAS} \simeq 1.6 \cdot 10^{-4} p$ (p in GeV/c) , while the multiple scattering contribution was $(dp/p)_{SCAT} \simeq 10^{-3}$. The apparatus also featured a RICH detector and an electromagnetic calorimeter, which have not been used for the analysis presented in this paper.

Three vertex detector planes and two beam planes were also employed in the impact parameter trigger [3], which, working in the non-bending projection, selected events with at least one track with an impact parameter relative to the primary vertex in a range between 100 μm and 1000 μm. This trigger enriched the charm content of the recorded sample by a factor of about 15.

The full data sample has been used for the analysis presented in this paper. The analysis chain started with a filter program, selecting events with evidence for secondary vertices using only the microstrip information in the non-bending projection. The events thus selected were then passed through the full track and vertex reconstruction program. Some cuts were applied in order to clean up the samples: the primary vertex (PRIM) of the event had to be reconstructed inside the target region; the secondary vertex (SEC) had to be well separated from the primary vertex (at least 6 σ_{VTX} where $\sigma_{VTX} = \sigma_{PRIM} \oplus \sigma_{SEC}$) and from the target downstream edge (at least 3 σ_{SEC}). The reconstructed momentum of the secondary vertex had to point back to the primary vertex within 50 μm. In addition, for the $D^{\pm} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}$ channel, cuts were made on the proper life ($t_0 > 0.4$ ps) and on the $K^{\pm}$ center-of-mass decay angle ($cos\theta^{*}(K) > -0.96$), and vertices with an error on the calculated invariant mass bigger than 30 MeV/c^2 were rejected. The acceptance for D mesons of the apparatus, trigger and analysis chain extends to high x_F (as an example the x_F acceptance for $D^{+} \rightarrow K^{-}\pi^{+}\pi^{+}$ is shown in figure 1a).

Invariant mass peaks were fitted with gaussian shapes, and charm candidates were selected by invariant mass cuts of ± 2 fitted standard deviations (typically $\sigma_M = 7$ to 9 MeV/c^2) around the fitted central value. The amount of background under the peaks was estimated by straight line fits. The results of two such fits are shown in figure 1b/c.

If the longitudinal distributions for charm mesons were to follow those of the produced charm quarks, i.e. if non-perturbative phenomena were negligible, the x_F distributions for all D mesons should be similar, and in particular independent of the D meson light quark content.

Early results from NA27 [4,5] indicated enhancement of leading charmed mesons (charmed mesons containing a beam valence quark) at high x_F in π^{-}-proton reactions.

This "leading particle effect" has also been seen by a beam dump experiment [6]. More recently the results of experiment NA32 [7], too, suggested a difference in the x_F distributions between leading and non-leading D mesons in $\pi^- -$ Cu interactions. Both charged and neutral charmed mesons have been used in those analyses.

With a π^- $(\bar{u}d)$ beam, D^+ $(c\bar{d})$ is non-leading, and D^- $(\bar{c}d)$ is leading. The D^0 $(c\bar{u})$ and the $\bar{D}^0$ $(\bar{c}u)$ can be unambiguously considered as respectively leading and non-leading only in the case of direct production; if instead they are produced in resonance decay, their leading/non-leading character may be inverted (as for example in the decay $D^{*+}(c\bar{d}) \rightarrow D^0(c\bar{u}) + \pi^+(u\bar{d})$). This ambiguity cannot occur in the $D^\pm$ case, as $D^{*0} \rightarrow D^+\pi^-$ decays are forbidden by energy conservation, and the remaining $D^{*+} \rightarrow D^+\pi^0$ and $D^{*+} \rightarrow D^+\gamma$ decays conserve the "leading-ness" of the charmed meson. For this reason only D^+ and D^- samples have been used in our analysis.

As we are working with a nuclear target, and there have been some indications that the nuclear dependence parameter α $(\sigma \propto A^\alpha)$ decreases at high x_F in proton interactions for hidden charm hadroproduction [8], we studied $\alpha(D)$ as a function of x_F for our charm sample and saw no indication of a decrease of $\alpha(D)$ with x_F within our errors [1]. In the following we shall therefore discuss our results within a model for hadron-nucleon interactions.

For the x_F distributions study, the D^+ and D^- candidates samples have been selected with $\pm 2\sigma_M$ cuts on the invariant mass distributions. Background samples have been defined as the contents of the two sidebands in the $K^-\pi^+\pi^+$ and $K^+\pi^-\pi^-$ invariant mass distributions ranging from 1740 MeV/c^2 to 1830 MeV/c^2 and from 1900 MeV/c^2 to 2000 MeV/c^2, normalized to the amount of background under the D^+ and D^- peaks. The contribution of this background was then subtracted from the D^+ and D^- candidates x_F distributions. The $D^\pm$ sample thus selected consists of 322 ± 20 $D^+ \rightarrow K^-\pi^+\pi^+$ on a background of 57 and 449 ± 23 $D^- \rightarrow K^+\pi^-\pi^-$ on a background of 51 from π^- interactions, and 92 ± 11 $D^\pm \rightarrow K^\mp\pi^\pm\pi^\pm$ on a background of 12 from p interactions.

After acceptance correction, the ratio of D^- over D^+ at positive x_F for the π^-

beam sample is:

$$\frac{D^-}{D^+} = 1.34 \pm 0.13$$

The $(D^- - D^+)/(D^- + D^+)$ versus x_F distribution (figure 2) shows that this excess of D^- over D^+ increases with x_F. A combined χ^2 - run test [9] indicates that the probability that the D^- and D^+ normalised distributions be two random samplings of the same limit distribution is less than 1%.

The Pythia [10] event generator qualitatively reproduces this effect as a hadronization effect in the Lund string fragmentation model: at our energies the $\bar{d}$ quark necessary for building a D^+ meson must essentially be produced by string fragmentation. On the contrary a d quark in the forward hemisphere is often present in the final state as a spectator quark from the beam π^-. There are therefore additional ways for producing a D^-, particularly at high x_F, near to the projectile rapidity.

The $(D^- - D^+)/(D^- + D^+)$ distributions from WA82 and from Pythia are compared in figure 2. The exact shape of the effect is not reproduced by the generator, which also predicts too large an integral value of the excess of D^- over D^+ (a factor 2, compared with our measured 1.34 ± 0.13).

The D^+ and D^- acceptance corrected x_F distributions measured by WA82 are compared with the Pythia predictions in figures 3a and 3b respectively. Also shown are the $c/\bar{c}$ distributions from next-to-leading-order (NTLO) QCD calculations [11] (whose shape is compatible with that of the Pythia leading-order + parton shower $c/\bar{c}$ ones, not shown). The Pythia D^+ and the NTLO c quark x_F distributions are very similar, apart from a small deviation at high x_F. Both are compatible with our data within the experimental accuracy. A much more marked deviation of the Pythia charmed hadron distribution from the NTLO charmed quark distribution, due to the mechanism outlined above, is visible in the D^- case. WA82 D^- data agree better with the Pythia distribution.

As a cross-check we have studied the relative abundances of the D^{*+} and D^{*-} mesons, for which the quark content is the same as for the $D^\pm$, so that a similar effect is expected. $D^{*+} \rightarrow D^0\pi^+$ (+ charge conjugate) were obtained selecting events with a D^0 vertex pointing back to the primary vertex within 50 μm, and a primary vertex π^+ such that the mass difference $\Delta M = M(D^0\pi^+) - M(D^0)$ was within 2 MeV/c^2 of the nominal $D^{*+} - D^0$ mass difference. The D^0 mesons, reconstructed in the decay channels $K^-\pi^+$ and $K^-\pi^-\pi^+\pi^+$, were required to have an invariant mass within 15 MeV/c^2 of the nominal D^0 mass. The sample thus selected consists of 84 ± 9 D^{*+} and 150 ± 12 D^{*-} from π^- interactions. Here, too, an excess is present: the D^{*-}/D^{*+} ratio, corrected for acceptance, is 1.8 ± 0.3 for positive x_F.

In the proton beam case, too, a slight excess of D^- over D^+, due to the valence d quark content of the proton, is expected. We measured an integral value of the D^-/D^+ ratio for positive x_F of 1.2 ± 0.3.

In conclusion, we have studied the x_F distributions of D^+ and D^- mesons in $\sqrt{s} \simeq$ 25 GeV π^- - nucleus interactions. A clear excess of D^- over D^+, increasing towards high x_F, is observed. The ratio D^-/D^+ at positive x_F is 1.34 ± 0.13, and the probability that the two x_F distributions be random samplings of the same limit distribution is less than 1%. Comparison with theory shows that non-perturbative effects are probably required to explain the relative abundance and the longitudinal distributions of the different charmed mesons.

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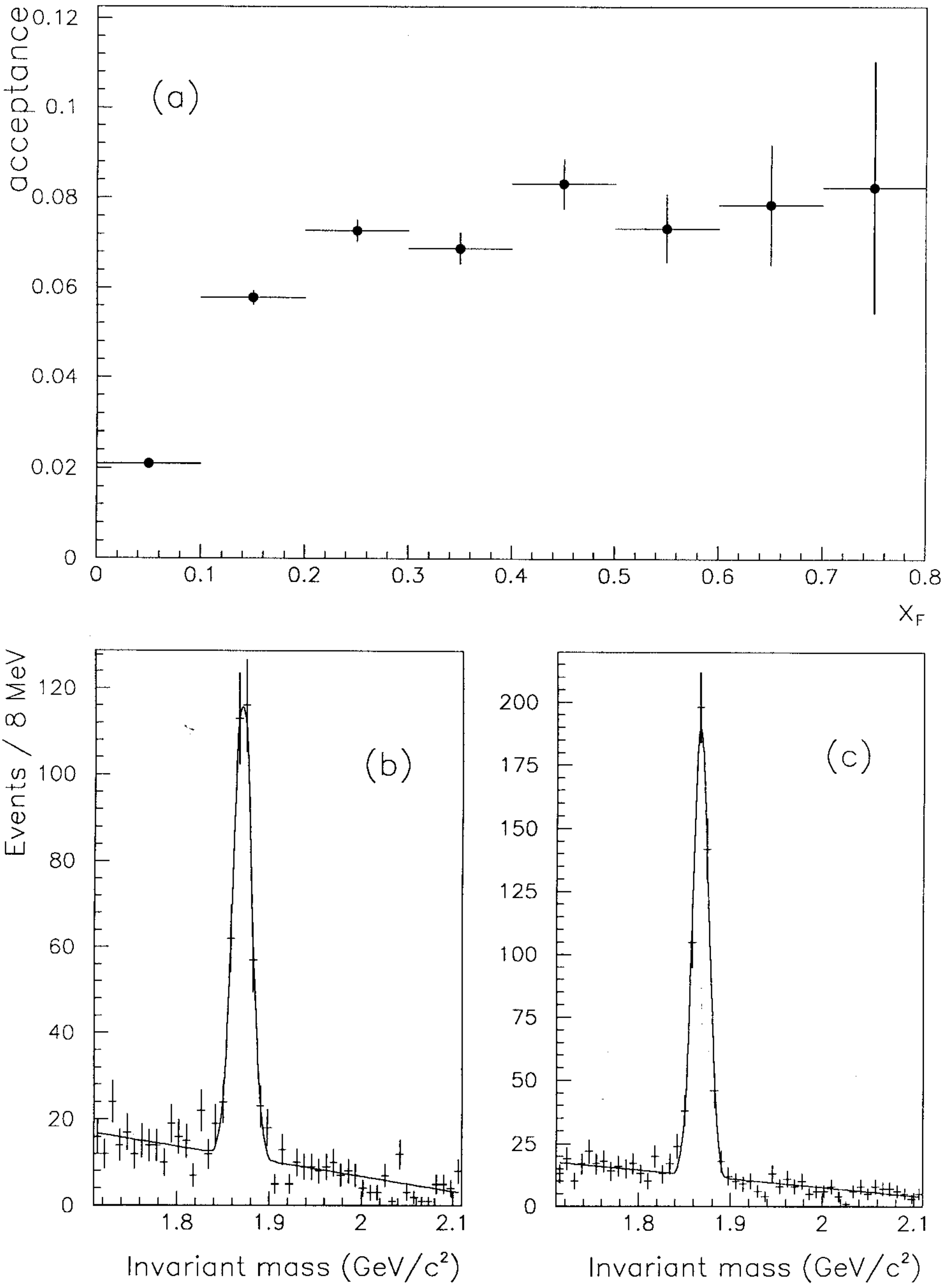
Figure Captions

Fig. 1 x_F acceptance for $D^+ \rightarrow K^-\pi^+\pi^+$ (a), invariant mass distributions for a sample of $D^+ \rightarrow K^-\pi^+\pi^+$ (b) and a sample of $D^- \rightarrow K^+\pi^-\pi^-$ (c).

Fig. 2 $(D^- - D^+)/(D^- + D^+)$ asymmetry (π^- data).

Fig. 3 x_F distributions from π^- interactions, a) D^+, b) D^-.



acceptance
(a)
0
0.02
0.04
0.06
0.08
0.1
0.12
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
X_F
Events / 8 MeV
(b)
0
20
40
60
80
100
120
1.8
1.9
2
2.1
Invariant mass (GeV/c^2)
(c)
0
25
50
75
100
125
150
175
200
1.8
1.9
2
2.1
Invariant mass (GeV/c^2)

Fig.1

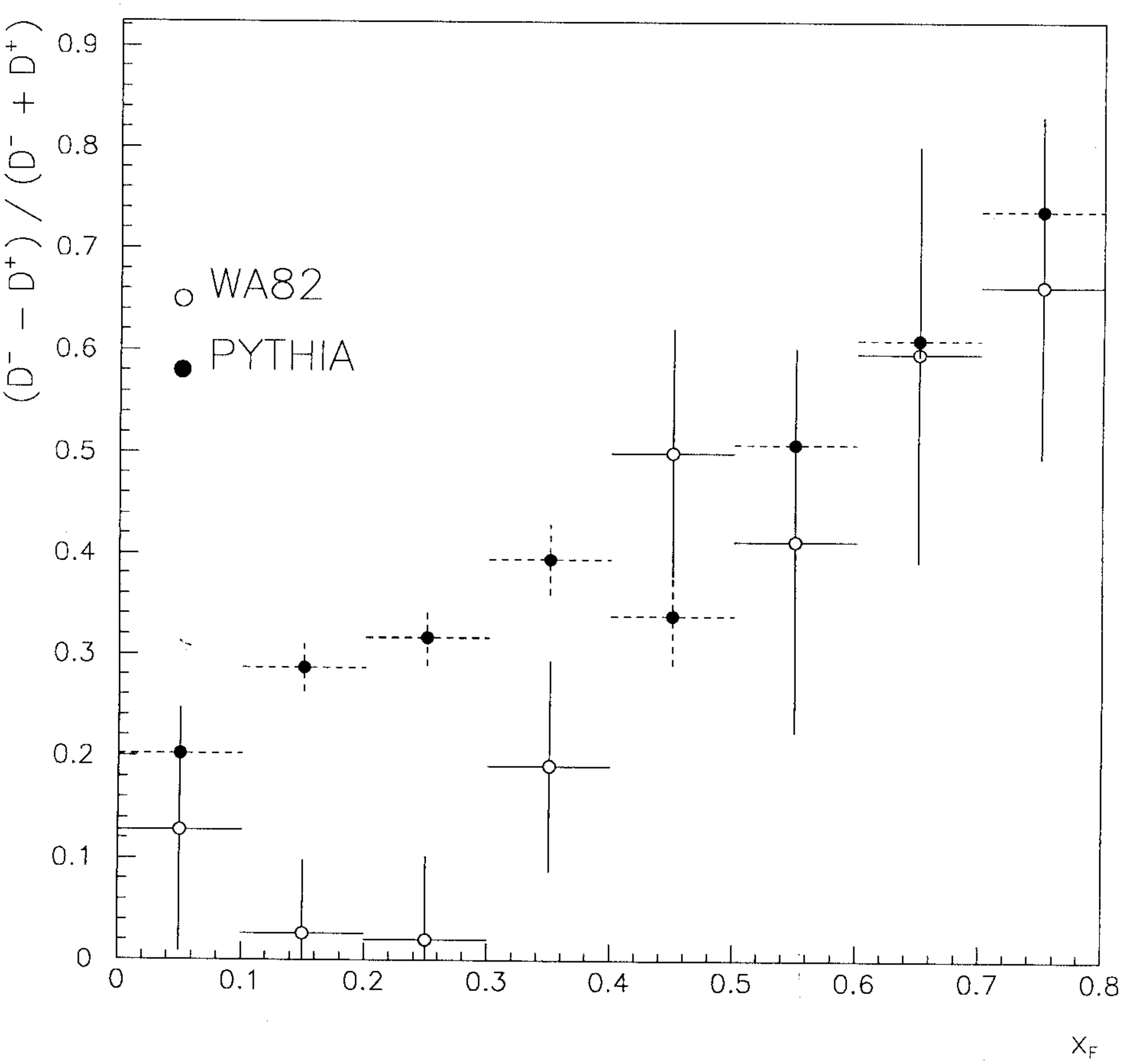

(D⁻ − D⁺) / (D⁻ + D⁺)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
○ WA82
● PYTHIA
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
X_F

Fig.2

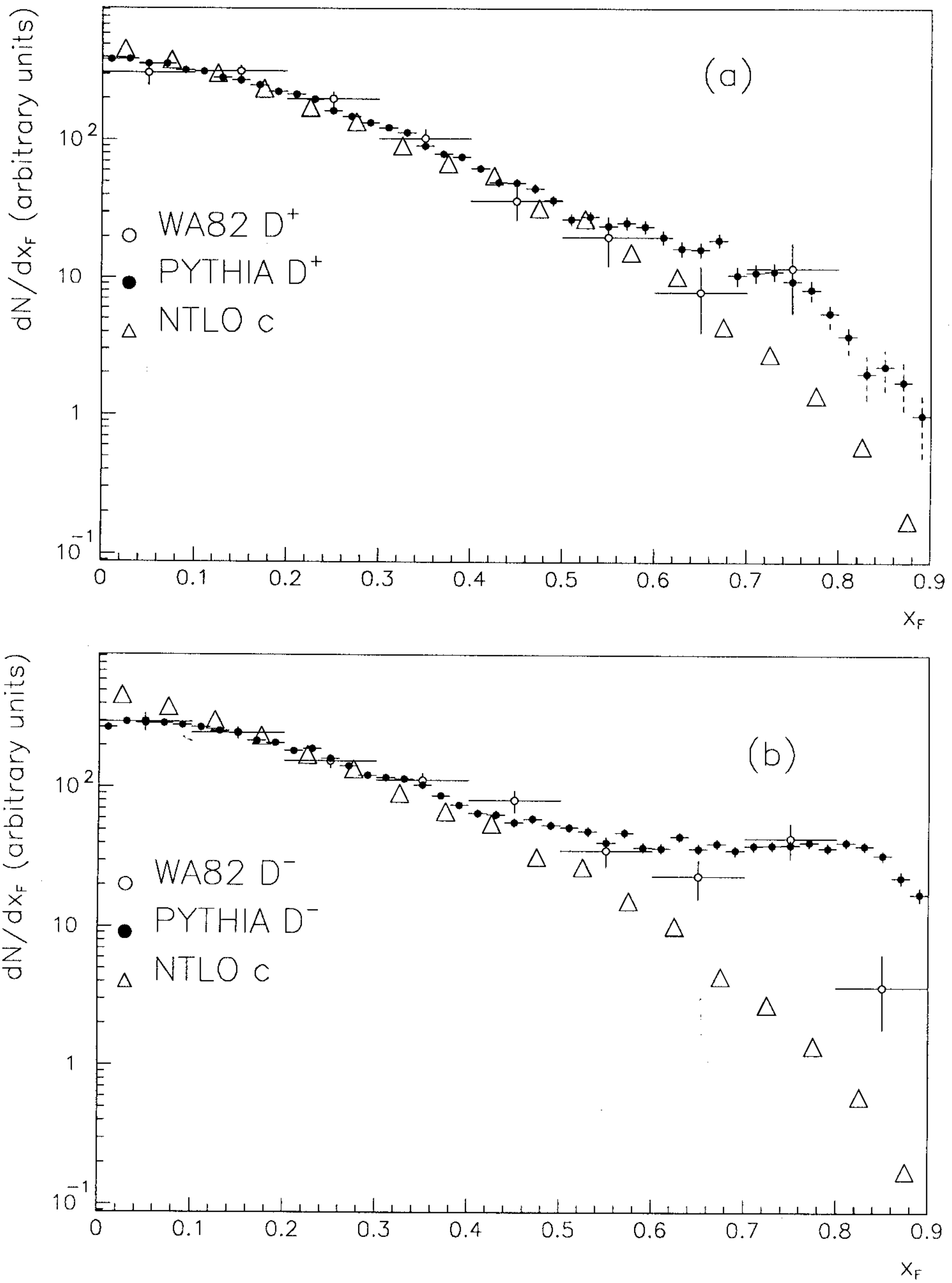

(a)
dN/dx$_F$ (arbitrary units)
10^2
10
1
10^{-1}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x$_F$
WA82 D$^+$
PYTHIA D$^+$
NTLO c
(b)
dN/dx$_F$ (arbitrary units)
10^2
10
1
10^{-1}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x$_F$
WA82 D$^-$
PYTHIA D$^-$
NTLO c

Fig.3