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D-MESON PRODUCTION FROM 400 GEV/C P-P INTERACTIONS
EVIDENCE FOR LEADING DI-QUARKS?

LEBC-EHS Collaboration

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ABSTRACT

Results of fitting the differential distributions in x_F and p_T^2 of D-mesons produced in 400 GeV/c p-p interactions to the form:

$$\frac{d^2\sigma}{dx_F dp_T^2} \alpha (1-x_F)^n e^{-(\frac{p_T^2}{\langle p_T^2 \rangle})}$$

are discussed. The D^+ distribution is found to be relatively hard ($n = 3.1 \pm 0.8$, $\langle p_T^2 \rangle = 1.32 \pm 0.27$ $(GeV/c)^2$) and the $\bar{D}^0$ distribution relatively soft ($n = 8.1 \pm 1.9$, $\langle p_T^2 \rangle = 0.62 \pm 0.14$ $(GeV/c)^2$) compared to the average for all D's ($n = 4.9 \pm 0.5$, $\langle p_T^2 \rangle = 0.99 \pm 0.10$ $(GeV/c)^2$). It is suggested that these distributions could reflect the contribution of leading di-quarks in pp collisions. Comparison is made with the evidence for leading quarks in charm production in 360 GeV/c π^-p interactions.

The measurement of the D and $\bar{D}$ meson production distributions in pp interactions at 400 GeV/c ($\sqrt{s}$ = 27.4 GeV) has been reported in [1]. In this paper we present the results of fitting the production spectra of the different D-meson states and discuss their interpretation in terms of leading diquarks. Comparison is made with the evidence for leading quarks in charm production in π^-p collisions at 360 GeV/c previously reported [2].

The data were obtained from the CERN experiment NA27 in which direct detection of the charm decay topologies was achieved using the high resolution hydrogen bubble chamber LEBC. Downstream analysis of the decay products was provided by the European Hybrid Spectrometer (EHS) [3]. Interactions in LEBC producing more than two charged particles detected in a set of downstream PWC's triggered the data taking. The experiment has an unbiased acceptance for charm particles produced with $x_F > 0$. $D^\pm$ are separated from D_s and Λ_c by means of kinematic fits and π/K/p identification.

Following a trigger from the PWC's the bubble chamber laser illumination was delayed by 70 μs to allow the bubbles to grow to 20 μm which represents the two track resolution. The bubble density was 80 cm^{-1} giving typically 400 bubbles per track. After measurement, the track impact parameters were determined with a precision better than 2.5 μm in projection on the film plane. This is sufficient to associate tracks correctly to their vertices of origin according to the cuts and sample definition given in [1]. In Fig 1 we show a display of a pair of charged D-mesons as detected in LEBC.

The spectrometer was used to determine the momenta of charged particles to ∿0.5% within an acceptance of ∿120 mrad around the beam direction. This corresponds to nearly full acceptance for the decay products of D-mesons produced in the forward hemisphere of the overall centre-of-mass ($x_F > 0$). Charged particle identification is accomplished by means of a Silica Aerogel Cerenkov Counter, a helium Cerenkov Counter and the ionisation sampling large aperture drift chamber ISIS. Neutral particle detection is achieved with electromagnetic and neutral hadron calorimeters covering the forward x_F region. More details on the EHS performance are given in Ref [4].

The charm sample comes from a double scan of 1,015,000 pp interactions representing a sensitivity of (38.5±1.1) events/μb. The on-line charged particle multiplicity trigger had an efficiency of $98^{+2}_{-3}\%$ for pp interactions producing charm particles. After scanning and measurement (see [1,4] for scan details) we identified 324 pp interactions containing 425 clear charm decays, 57 decays with a charm signature but without a clear topology and 75 decays without a charm signature but paired with a charm decay in the same event (72% of the charm events have a detected pair).

In order to study production distributions we have selected a sample of 119 identified D-mesons with fully determined momenta and hence well defined x_F and p_T. We find 24 D^+, 27 D^-, 29 D^0, 22$\bar{D}^0$ and 16 $D^0/\bar{D}^0$ plus 1 $D^{\pm}$ ambiguous decays having $x_F > 0$. A detailed description of the selection procedure used to arrive at this sample and the associated weights is given in Ref [1]. The following cross-sections are determined for all x_F (see [1]):

$$\begin{aligned} \sigma(D) &= (16.2\pm2.0)\mu b \; ; \; \sigma(\bar{D}) = (14.0\pm1.8)\mu b \\ \sigma(D^0) &= (10.5\pm1.7)\mu b \; ; \; \sigma(\bar{D}^0) = (7.9\pm1.5)\mu b \\ \sigma(D^+) &= (5.7\pm1.0)\mu b \; ; \; \sigma(D^-) = (6.2\pm1.0)\mu b \end{aligned}$$

In Table 1 and Fig 2 we show the result of fitting the x_F distributions to both the non-invariant form $\frac{d\sigma}{dx_F} \alpha\ (1-x_F)^n$ and the invariant form $\frac{1}{E}\frac{d\sigma}{dx_F} \alpha\ (1-x_F)^m$ for $x_F > 0$. The non-invariant fit has also been performed for $x_F > 0.05$ to avoid any complications from the non-physical cusp at $x_F = 0$; however the results are essentially unchanged and are not shown.

These different fits lead to the same conclusions which can be summarised as:

- The D^- and D^0 distributions agree well with each other, and reflect the mean from all D's. The combined D^- and D^0 distributions yield
  $n \approx 5.5\pm1.0 \quad \langle p_T^2\rangle \approx 0.93\pm0.12\ (GeV/c)^2$

- The D^+ distributions are significantly harder
  $n \approx 3.1\pm0.8 \quad \langle p_T^2\rangle \approx 1.32\pm0.27\ (GeV/c)^2$

- the $\bar{D}^0$ distributions are significantly softer
  $n \approx 8.1\pm1.9 \quad \langle p_T^2\rangle \approx 0.62\pm0.14\ (GeV/c)^2$

- The invariant distributions show the same features.

The analysis of the D^0 and $\bar{D}^0$ distributions is complicated by the existence of the 16 ambiguous $D^0/\bar{D}^0$ decays which show a relatively hard x_F distribution. Assigning these decays to D^0 and $\bar{D}^0$ would bring the D^0 result closer to the D^+, and the $\bar{D}^0$ closer to the D^-. For example, if the 16 ambiguous $D^0/\bar{D}^0$ decays were split equally between D^0 and $\bar{D}^0$, then the resulting exponents for the complete samples of D^0 and $\bar{D}^0$ would be 5.1 and 6.5, respectively.

In contrast to our π^-p data [2], we do not see any leading particle effects associated with a single valence quark, which would have the effect of producing harder $\bar{D}$ than D mesons.

A possible physical explanation of our data can be found if we assume that the proton is composed of a quark and a di-quark, as suggested by other data (for example see Reference [5]). If the di-quark system is regarded as a single entity ($\bar{3}$ of colour) it will reappear as a constituent among the final state particles and on average will carry the larger fraction of the proton momentum. After production of the $c\bar{c}$ quarks by some hard scattering process, a colour singlet charm system can be formed by the combination of a $\bar{c}$-quark with a proton valence quark, or by a c-quark combining with the di-quark. This process could cause charm hadrons to be more leading than the anti-charm hadrons since the fast di-quark would tend to boost the charm hadron system to higher x_F.

If the di-quark is propagated into the final state and the production of low mass final states is preferred, then the data can be qualitatively understood. A (uu) di-quark can form a (uu)c combination and hence give rise to leading D^+ (Fig 3a). The pD^+ final state will be preferred over $\Delta^{++}D^0$ if the (uu)c combination is not too massive. The (ud)c combination will produce leading Λ_c (Fig 3b) or either nD^+ or pD^0 (Fig 3c). Again the low mass combinations are preferred. We have no a priori way to estimate the relative contributions of these diagrams.

In this experiment, ($\sqrt{s}$ = 27.4 GeV) we have no compelling evidence for leading Λ_c [6] which can only be produced in this model by diagram 3b. However, there is evidence for significant Λ_c production from ISR experiments [7] ($\sqrt{s}$ = 63 GeV), suggesting that at higher energies other diagrams may become important.

In Fig 4(a,b) we compare the x_F distribution of the $\bar{c}$ states ($D^-/\bar{D}^0$) with that of the D^+. Note that the hard D^+ distribution is accompanied by large $\langle p_T^2 \rangle$. Only a fraction of all D^+ is expected to be produced via the leading di-quark mechanism, however a two component fit to the D^+ distribution is not justified with the statistics available. A contribution of about 25% of leading D^+ (with $n = 1$) would suffice to produce the observed effect. In Fig 4(c,d) we recall the results of D production from the 360 GeV/c $\pi^- p$ interactions [2]. The potentially leading states [$D^0(c\bar{u})$ and $D^-(\bar{c}d)$] have a harder distribution than the non-leading states [$\bar{D}^0(\bar{c}u)$ and $D^+(c\bar{d})$]. Even though statistics are limited there is a clear similarity which can be taken as supporting evidence for leading di-quarks (uu or ud) in pp collisions and leading quarks ($\bar{u}$ or d) in $\pi^- p$ collisions.

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TABLE 1

Fits to $\frac{d\sigma}{dx_F} \alpha (1-x_F)^n$ and to $\frac{1}{E}\frac{d\sigma}{dx_F} \alpha (1-x_F)^m$ for $x_F > 0$

	Number of Decays	n	m	$\langle p_T^2\rangle$ $(GeV/c)^2$
All D	119	4.9±0.5	3.2±0.6	0.99±0.10
D^+	24	3.1±0.8	1.8±0.7	1.32±0.27
D^-	27	5.4±1.2	3.5±0.9	1.04±0.20
D^0	29	5.5±1.2	3.8±0.9	0.82±0.14
$\bar{D}^0$	22	8.1±1.9	6.2±1.4	0.62±0.14
D_{ambig}	17	3.9±1.1	2.9±0.9	0.93±0.30
$[D^+ + D^0]$	53	4.2±0.8	2.7±0.6	1.04±0.14
$[D^- + \bar{D}^0]$	49	6.6±1.1	4.6±0.8	0.84±0.12

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FIGURE CAPTIONS

1. A D^+, D^- event observed in the high resolution bubble chamber LEBC. The picture shows a display of the HPD digitisings of bubble centres with the scale expanded in the transverse direction.

2. Differential cross sections in x_F and p_T^2 ($x_F > 0$) for D^+, $\bar{D}^0$, D^- and D^0 decays.

   The curves correspond to fits of the form:

   $$\frac{d\sigma}{dx_F} \alpha (1-x_F)^n \text{ and } \frac{d\sigma}{dp_T^2} \alpha \exp [-bp_T^2]$$

3. Diagrams contributing to forward charm production via leading di-quarks from the incident proton.

4. Comparison between data showing possible leading diquarks (D^+) in p-p interactions and leading quarks (D^-, D^0) in π^-p interactions. In both cases the leading combinations are compared with non-leading combinations.

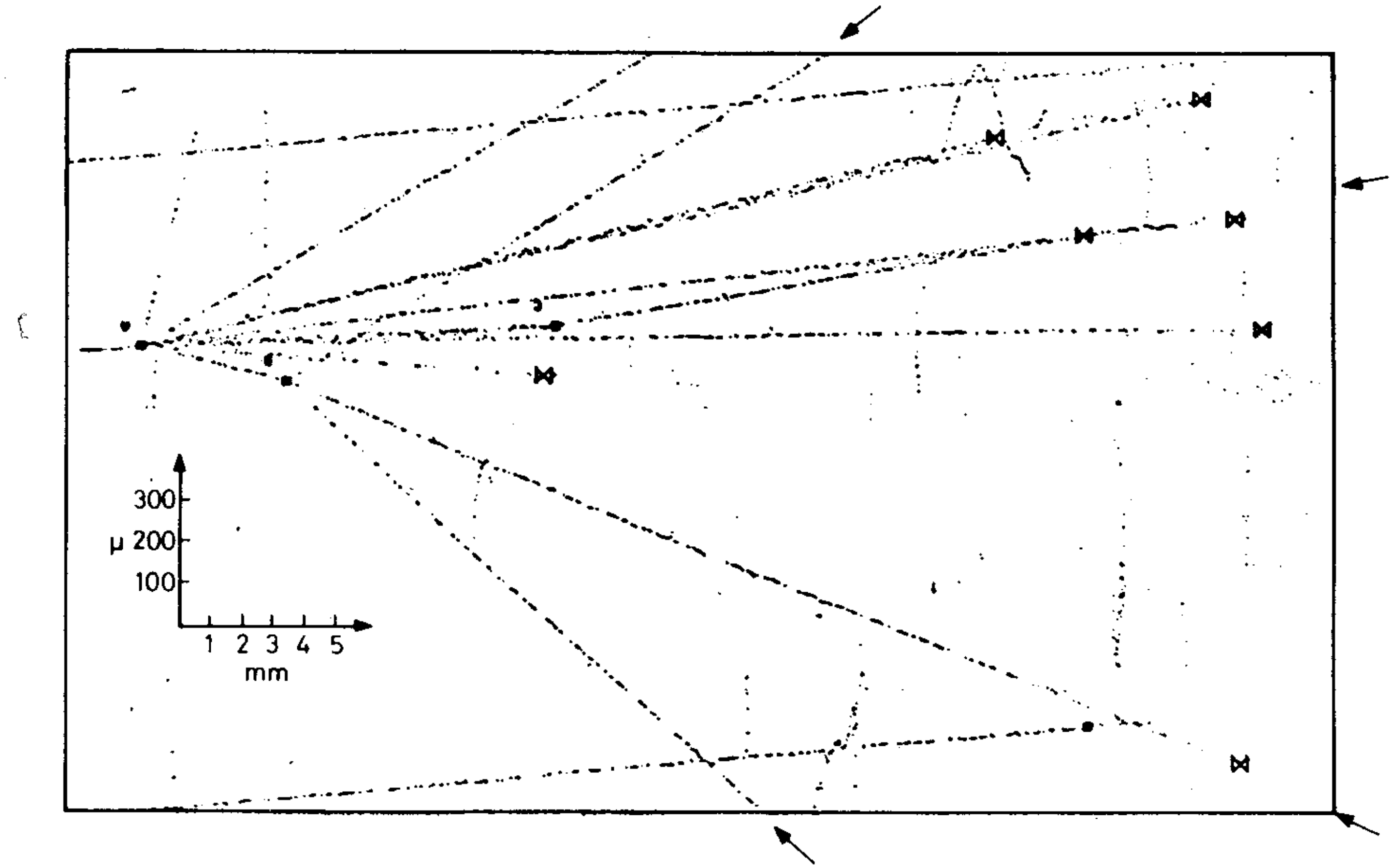


Fig. 1

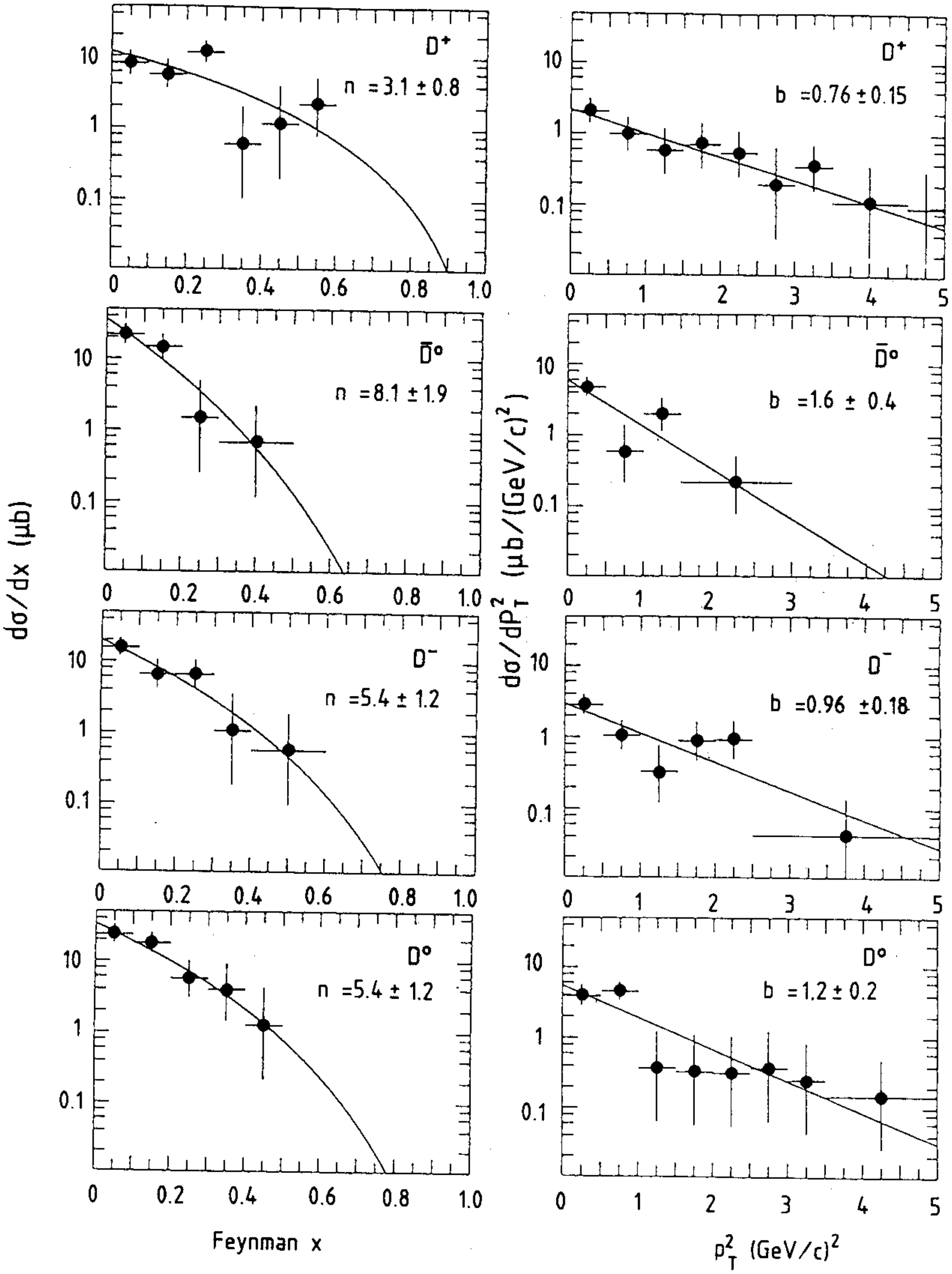

dσ/dx (μb)
dσ/dP$_T^2$ (μb/(GeV/c)^2)
D⁺
n =3.1 ± 0.8
b =0.76 ± 0.15
D̄°
n =8.1 ± 1.9
b =1.6 ± 0.4
D⁻
n =5.4 ± 1.2
b =0.96 ±0.18
D°
n =5.4 ± 1.2
b =1.2 ± 0.2
10
1
0.1
0
0.2
0.4
0.6
0.8
1.0
1
2
3
4
5
Feynman x
p$_T^2$ (GeV/c)^2

FIG. 2

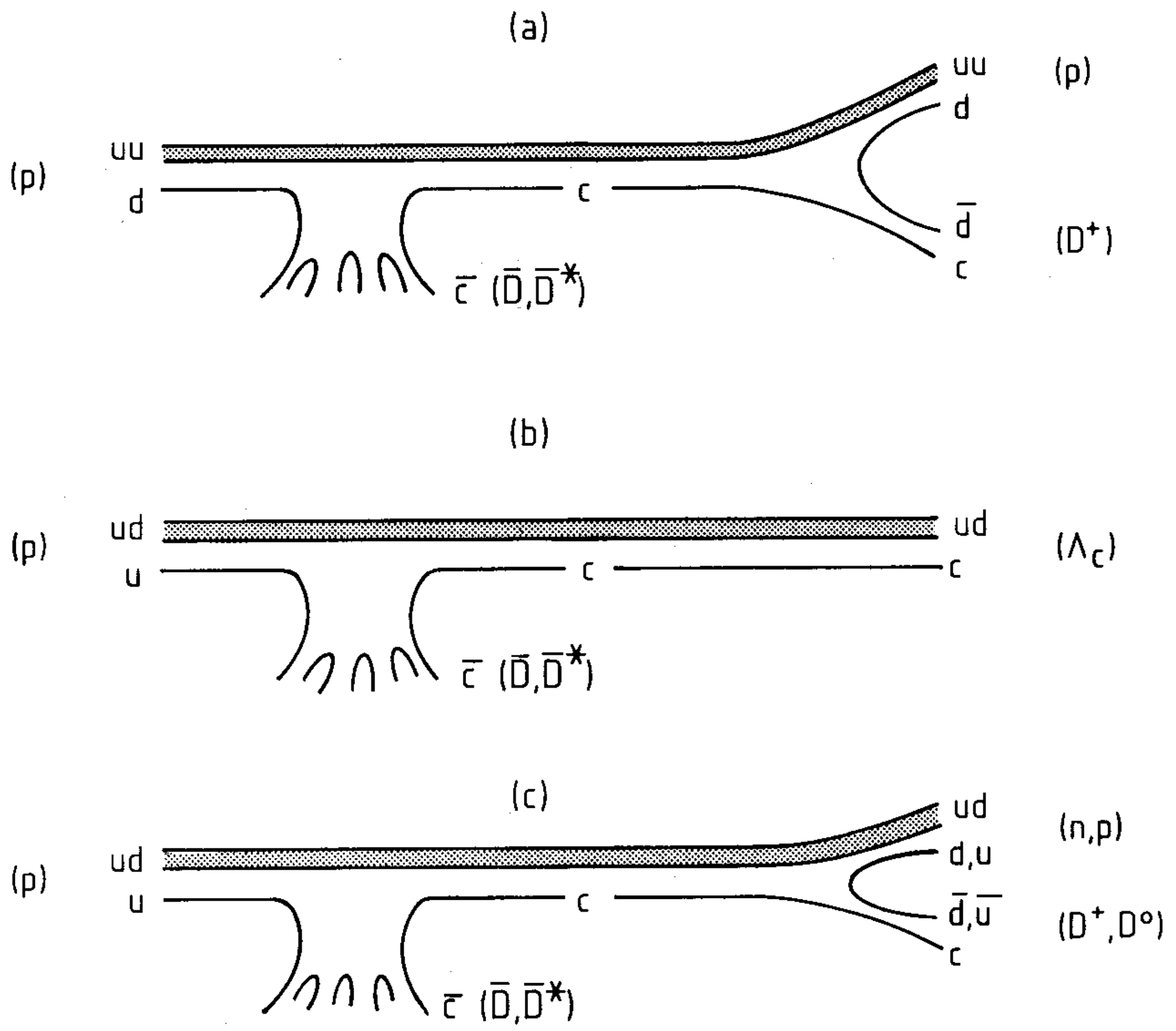
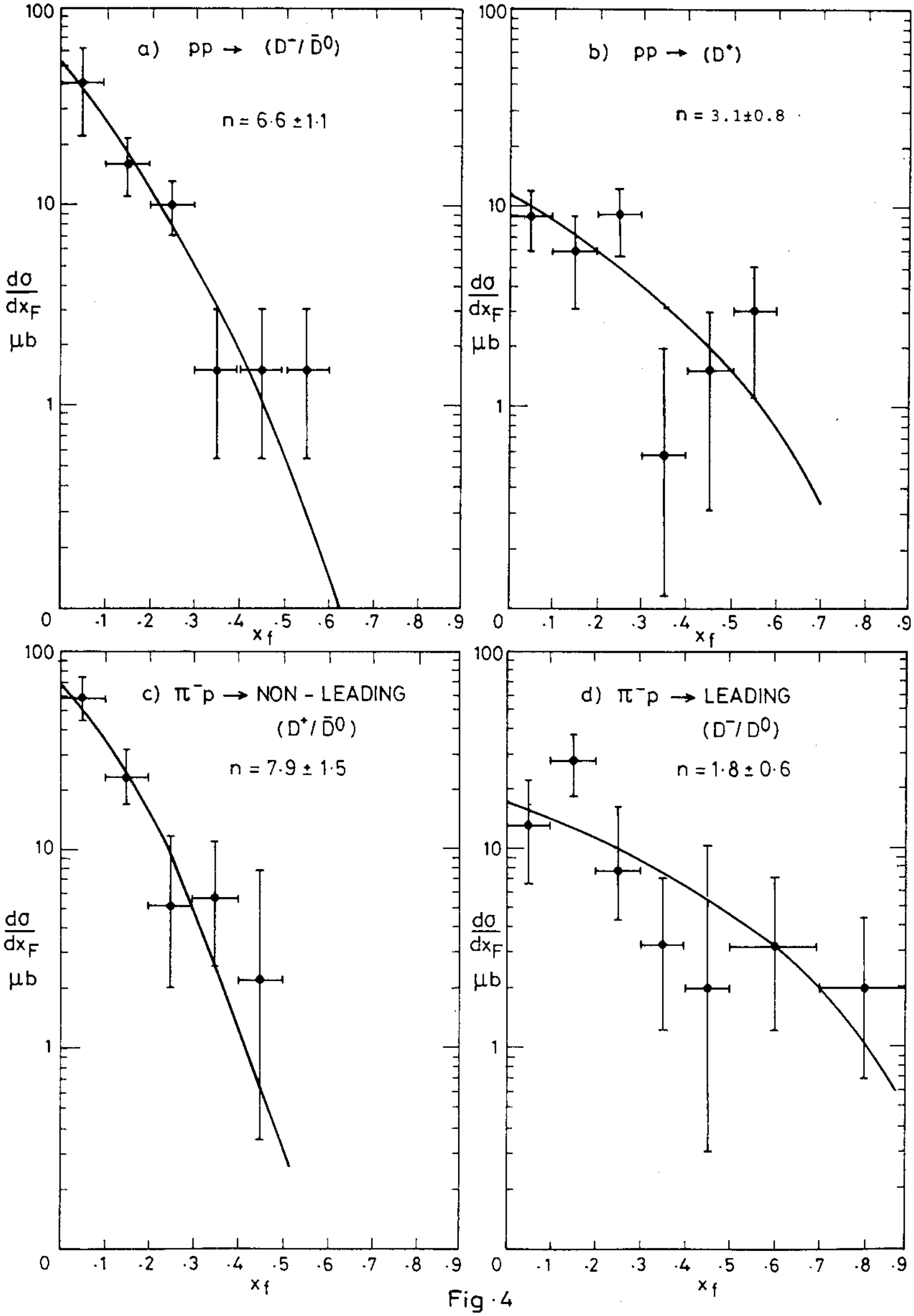

(a)
(p)
uu
d
c
$\bar{c}$ ($\bar{D}$,$\bar{D}^*$)
uu
d
$\bar{d}$
c
(p)
(D$^+$)
(b)
(p)
ud
u
c
$\bar{c}$ ($\bar{D}$,$\bar{D}^*$)
ud
c
(Λ_c)
(c)
(p)
ud
u
c
$\bar{c}$ ($\bar{D}$,$\bar{D}^*$)
ud
d,u
$\bar{d}$,$\bar{u}$
c
(n,p)
(D$^+$,D°)

FIG. 3


a) pp → (D⁻/D̄⁰)
n = 6·6 ±1·1
b) pp → (D⁺)
n = 3.1±0.8
c) π⁻p → NON - LEADING (D⁺/D̄⁰)
n = 7·9 ± 1·5
d) π⁻p → LEADING (D⁻/D⁰)
n = 1·8 ± 0·6
dσ/dx_F μb
x_f
100
10
1
0
·1
·2
·3
·4
·5
·6
·7
·8
·9

Fig·4