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CHARM D-MESON PRODUCTION IN 360 GeV/c pp INTERACTIONS;
COMPARISON WITH π^- p AT THE SAME ENERGY

LEBC EHS Collaboration

Amsterdam¹-Brussels²-CERN³-Madrid⁴-Mons⁵-Nijmegen⁶-Oxford⁷-Padua⁸-Paris⁹-
Rome¹⁰-Rutherford¹¹-Serpukhov¹²-Stockholm¹³-Strasbourg¹⁴-Trieste¹⁵-
Turin¹⁶-Vienna¹⁷ Collaboration

M. Aguilar-Benitez³, W.W.M. Allison⁷, P. Bagnaia¹⁰, J. Bailly⁵,
G. Bertrand-Coremans², R. Bizzarri³, M. Boratav⁹, F. Bruyant³, D. Cauz¹⁵,
G. Ciapetti¹⁰, D. Crennell¹¹, E. Di Capua¹⁰, H. Dibon¹⁷, C. Dionisi¹⁰,
J. Dumarchez³, F. Etienne¹⁴, C. Fisher¹¹, Yu.V. Fisjak¹², S. Gentile³,
J. Hernandez⁴, P. Herquet⁵, S.O. Holmgren³, J. Hrubec³, P.T. Hughes⁷,
K.E. Johansson³, E.P. Kistenev¹², W. Kittel⁶, N. Kurtz³,
P. Ladron de Guevara³, J. Lemonne², H. Leutz³, P. Loverre¹⁰, L. Lyons⁷,
M. MacDermott¹¹, F. Marchetto¹⁶, F. Marzano¹⁰, M. Mazzucato⁸,
E. Menichetti¹⁶, M. Michalon-Mentzer¹⁴, A. Michalon¹⁴, T. Moa¹³,
L. Montanet³, G. Neuhofer³, S. Nilsson¹³, Yu.L. Petrovich¹², P. Pilette⁵,
C. Pinori⁸, G. Piredda¹⁰, A. Poppleton³, P. Poropat¹⁵, P. Porth¹⁷,
M. Regler¹⁷, S. Reucroft³, J. Richardson³, H. Rohringer¹⁷, P. Rossi⁸,
J. Salicio⁴, S. Tavernier², D. Toet¹, M.C. Touboul⁹, A.M. Touchard⁹,
C. Troncon¹⁵, L. Ventura⁸, P. Vilain², P.R.S. Wright³, L. Zanello¹⁰,
G.V. Zolobov¹², P. Zotto⁸ and G. Zumerle³,

- ¹ NIKHEF-H, Amsterdam, Netherlands
- ² I.I.H.E., Brussels, Belgium
- ³ CERN, European Organization for Nuclear Research, Geneva, Switzerland
- ⁴ Junta de Energia Nuclear, Madrid, Spain
- ⁵ Univ. de l'Etat, Faculté des Sciences, Mons, Belgium
- ⁶ University of Nijmegen, Netherlands
- ⁷ University of Oxford, Oxford, United Kingdom
- ⁸ University of Padua and INFN, Italy
- ⁹ LPNHE, Université Pierre et Marie Curie, Paris, France
- ¹⁰ University of Rome and INFN, Italy
- ¹¹ Rutherford Appleton Laboratory, Chilton, United Kingdom
- ¹² I.H.E.P., Serpukhov, USSR
- ¹³ University of Stockholm, Stockholm, Sweden
- ¹⁴ C.R.N., Strasbourg, France
- ¹⁵ University of Torino and INFN, Italy
- ¹⁶ University of Trieste and INFN, Italy
- ¹⁷ Inst. für Hochenergiephysik, Vienna, Austria

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ABSTRACT

Charm D-meson production in 360 GeV pp interactions has been studied using the high resolution hydrogen bubble chamber LEBC and the European Hybrid Spectrometer. D-mesons are produced with a differential cross section of the form

$$d^2\sigma/dx dp_T^2 \propto (1-x)^n \exp(-ap_T^2)$$

with $n = 1.8 \pm 0.8$ and $a = 1.1 \pm 0.3 \text{ (GeV/c)}^{-2}$ for the Feynman x and transverse momentum p_T behaviour. The inclusive single particle cross section for D and $\bar{D}$ is measured to be

$$\sigma(D/\bar{D}) = 56^{+25}_{-12} \text{ } \mu\text{b} \quad (\text{for all } x)$$

The $\Lambda_c \bar{D}$ cross section can be estimated to be $\sim 20 \text{ } \mu\text{b}$. No strong correlation is observed between $D\bar{D}$ pairs. The results are compared with results from a study of D-meson production in 360 GeV/c π^-p interactions also using LEBC-EHS.

The high resolution hydrogen bubble chamber, LEBC, has been used in association with the European Hybrid Spectrometer to study charm particle production in 360 GeV/c π^-p and 360 GeV/c pp interactions. In this paper we give results on D-meson production from the proton exposure based on 500,000 pictures with 181,799 interactions. D-meson production by 360 GeV/c pions is reported in the preceding paper [1]. In both experiments data taking was triggered using a simple minimum-bias interaction trigger derived from a set of scintillators. Details of the geometrical acceptance and the scanning weights are given in ref. [1]. The sensitivity of the proton exposure was 7.3 evts/ μ b. EHS and LEBC are described in refs [2,3].

The mean charged multiplicity for events with a charm particle is 8.4 ± 0.9 . This agrees with the overall inelastic multiplicity of 8.9 [4]. For event identification if there exists a $D/F/\Lambda_c$ ambiguity the D-hypothesis is chosen if it is Cabibbo favoured, otherwise the decay is a candidate for Λ_c/F . A total of 29 reconstructed D-mesons were observed together with 3 unambiguous $F^\pm$ and 3 ambiguous Λ_c^+/F^+ decays. We have two events with reconstructed pairs of $D\bar{D}$ -mesons.

Cross sections for $D^\pm$ and $D^0/\bar{D}^0$ are estimated from the observed decays $D^\pm \rightarrow K^\pm \pi^\mp \pi^\pm$ with branching ratio $(4.6 \pm 1.1)\%$, $D^0/\bar{D}^0 \rightarrow K^\pm \pi^\mp$ $(2.4 \pm 0.4)\%$, $D^0/\bar{D}^0 \rightarrow K^\pm \pi^\mp \pi^0$ $(9.3 \pm 2.8)\%$ and $D^0/\bar{D}^0 \rightarrow K^\pm \pi^\mp \pi^+ \pi^-$ $(4.5 \pm 1.3)\%$ [5]. Using the weighted events we find the inclusive single D/ $\bar{D}$ cross section to be (for all x)

$$\sigma(D/\bar{D}) = 56^{+25}_{-12} \mu\text{b} \quad (9 \text{ decays})$$

where we have applied symmetry about $x = 0$ for the pp system.

The inclusive single particle cross sections are: $\sigma(D^-) = 26^{+25}_{-8} \mu\text{b}$ (3 decays), $\sigma(D^+) = 11^{+25}_{-4} \mu\text{b}$ (1 decay), $\sigma(D^0) = 3^{+7}_{-1} \mu\text{b}$ (1 decay) and $\sigma(\bar{D}^0) = 16^{+13}_{-5} \mu\text{b}$ (4 decays). The cross sections for $\bar{c}$ and c production are

$$\sigma(D^-/\bar{D}^0) = 42^{+23}_{-8} \mu\text{b} \quad (7 \text{ decays})$$

$$\sigma(D^+/\bar{D}^0) = 14^{+18}_{-4} \mu\text{b} \quad (2 \text{ decays})$$

If we assume the D-mesons are either produced in pairs or in association with Λ_c^+ we can estimate the $D\bar{D}$ and $\Lambda_c \bar{D}$ cross sections separately. The difference between the $\bar{c}$ and c cross sections shows an excess of $\bar{c}$ states which can be interpreted as due to $\Lambda_c \bar{D}$ in which the Λ_c^+ is not detected. We then estimate:

$$\sigma(D\bar{D}) = 14^{+18}_{-4} \text{ } \mu\text{b} \text{ and } \sigma(\Lambda_c \bar{D}) = 28^{+21}_{-12} \text{ } \mu\text{b}$$

Alternatively, with slightly better statistics but more assumptions, we can use the distribution of all decays between D and $\bar{D}$ states. We observe $8D^-$, $8\bar{D}^0$, $6D^0$, $6D^+$ and $1D^0/\bar{D}^0$ ambiguous, which gives the ratio $\bar{D}/D = 1.3 \pm 0.5$. This reflects the $\bar{c}/c$ ratio at production if we assume that D and $\bar{D}$ states are produced with the same x distribution and hence have the same average weights. Within statistics this assumption is valid. Using this result together with the single $D/\bar{D}$ inclusive cross section we estimate $\sigma(D\bar{D}) = 24^{+9}_{-5} \text{ } \mu\text{b}$ and $\sigma(\Lambda_c \bar{D}) = 8^{+10}_{-8} \text{ } \mu\text{b}$.

We have no unambiguous Λ_c^+ decay directly detected. Of the three Λ_c/F ambiguous events one is $\Lambda_c^+ \rightarrow pK^- \pi^+$ and is within the selection criteria for weights. One genuine decay in this mode, branching ratio $(2.2 \pm 1.0)\%$ [5], corresponds to a cross section of $\sim 40 \text{ } \mu\text{b}$.

Consider now the analysis of the distribution in the Feynman variable x ($= 2 p_L^*/\sqrt{s}$). It is difficult to detect leading particle effects in the pp interactions, if they exist, because the only truly leading particle that can occur is the Λ_c which takes 2 out of the 3 valence quarks of the proton. Leading Λ_c have been reported to be observed at ISR [6]. Leading $\bar{D}^0$ or D^- are expected [7] to show a $(1-x)^3$ behaviour. Central production with no valence quarks should account for D^0 , D^+ and $F^\pm$ production and a $(1-x)^5$ distribution is predicted.

The distributions in Feynman x for the observed D-mesons are shown in fig 1; 1(a) shows the D^- and $\bar{D}^0$, 1(b) the D^0 and D^+ and 1(c) the $D + \bar{D}$ distribution. Fig. 1(d) shows the integral distribution for all D-states together plotted logarithmically. A differential distribution of the form $d\sigma/dx \propto (1-x)^n$ appears as a line of slope $(n+1)$. A maximum likelihood

fit to the full data, assuming a form $(1 - x)^n$, yields $n = 1.8 \pm 0.8$. We do not observe any difference between the production of D^- and $\bar{D}^0$ on the one hand and D^+ and D^0 on the other. Both distributions are consistent with $(1 - x)^2$.

The results of the parallel analysis of the 360 GeV $\pi^- p$ data [1] shows evidence for leading quark effects in the $D^-/\bar{D}^0$ states in addition to a central component consisting of a mixture of all $D/\bar{D}$ states. The x distribution in the pp data also suggests leading rather than central production. However, there is no distinction in terms of the quark content in this case. The distribution, fig. 1(d), could have some two component structure even in pp.

We can compare the strange particle x distributions with those observed for charm mesons in the $\pi^- p$ data [1] and the pp data presented here and thereby compare the dynamics of c and s quark production. The results for $K/\bar{K}$ production have been obtained by A.E. Brenner et al. [8] by a fit to the invariant cross sections for $K/\bar{K}$ production in the range $0.2 < x < 0.7$. We also give a comparison with the predictions of the modified quark counting rules of J.F. Gunion [9] and the applications to D-meson production by F. Halzen [7]. The experimental data for pp and $\pi^- p \rightarrow K/\bar{K}$ are taken at 100 and 175 GeV and use invariant cross sections. The value of n shows little energy dependence [10]. The main features of the data are given in table 1. Only rough comparisons can be made because of the different parametrizations used and large errors on the charm data. However, there are clear differences between $D/\bar{D}$ and $K/\bar{K}$ production for pp interactions.

The integral p_T^2 distribution is shown in fig. 2. The form of the p_T^2 distribution is the same as found for D production in $\pi^- p$ [1]. The overall production distribution has the form

$$\frac{d^2\sigma}{dx dp_T^2} \propto (1 - x)^n \exp(-ap_T^2)$$

with $n = 1.8 \pm 0.8$ and $a = 1.1 \pm 0.3 \text{ (GeV/c)}^{-2}$.

There are two events in which both members of a D-meson pair are reconstructed. Fig. 3 shows the c.m.s. rapidity distribution of both the single D-mesons and the two pairs. In the $\pi^- p$ data we observe a clear

correlation in rapidity between $D\bar{D}$ pairs; no such correlation is observed in the proton data where we observe mostly single D-mesons. A possible explanation is that the pairs have a large rapidity gap such that one member of the pair is usually in the backward hemisphere and hence not reconstructed. Under this assumption the mean rapidity gap must be greater than 1.2. Part of the single $\bar{D}$ -mesons could also come from $\Lambda_c \bar{D}$ production with an undetected Λ_c as was discussed earlier.

By comparison with the results of the study of D-meson production in $\pi^- p$ at 360 GeV/c given in ref. [1] we have the following conclusions:

- The inclusive single D cross sections in the $x > 0$ region are

$$\sigma(D/\bar{D}) = 28 \begin{smallmatrix} + 12 \\ - 6 \end{smallmatrix} \mu\text{b for } pp \quad (\sqrt{s} = 26 \text{ GeV})$$

$$\sigma(D/\bar{D}) = 40 \begin{smallmatrix} + 15 \\ - 8 \end{smallmatrix} \mu\text{b for } \pi^- p$$

- Assuming symmetry in the pp system we have two estimates of the $D\bar{D}$ and $\Lambda_c \bar{D}$ pair cross sections and taking the average we obtain

$$\sigma(D\bar{D}) = 19 \begin{smallmatrix} + 13 \\ - 5 \end{smallmatrix} \mu\text{b} \quad \text{and} \quad \sigma(\Lambda_c \bar{D}) = 18 \begin{smallmatrix} + 15 \\ - 10 \end{smallmatrix} \mu\text{b} \quad (\text{all } x)$$

- In pp the distribution in Feynman x is leading with slope $n = 1.8 \pm 0.8$ but no correlation exists with the D-meson types. The indications of leading D-meson production in $\pi^- p$ are found both in the Feynman x distribution and the distribution of D-meson types by quark content.
- Both $\pi^- p$ and pp D-meson production are consistent with a simple exponential p_T^2 distribution having slope $a = 1.1 \pm 0.3 \text{ (GeV/c)}^{-2}$ corresponding to $\langle p_T^2 \rangle = 0.9 \pm 0.2 \text{ (GeV/c)}^2$.
- Differences exist between the inclusive production distributions for $D/\bar{D}$ and $K/\bar{K}$ in pp interactions suggesting different production mechanisms for $c\bar{c}$ and $s\bar{s}$ pairs.
- A correlation in rapidity between charm particle pairs is observed in the $\pi^- p$ data. In the pp data the numbers of reconstructed single decays and pairs suggest larger rapidity gaps between D and $\bar{D}$.

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TABLE 1

Comparison of inclusive $D/\bar{D}$ and $K/\bar{K}$ production. The coefficients n in $d\sigma/dx$ (or invariant cross section for $K/\bar{K}$) $\propto (1-x)^n$ are also compared with the predictions of the modified quark counting rules [7,9]. Both coefficients are given for predictions with two components in the distribution.

$pp \rightarrow D/\bar{D}$	Exp. slope ^(a)	Theory	$pp \rightarrow K/\bar{K}$	Exp. slope ^(b)	Theory
$D^- (\bar{c}d)$	2	(5, 3)	$K^0 (\bar{s}d)$	"central" ^(c)	4
$\bar{D}^0 (\bar{c}u)$	2	(5, 3)	$K^+ (\bar{s}u)$	3	3
$D^0 (c\bar{u})$	2	5	$K^- (s\bar{u})$	5	5
$D^+ (c\bar{d})$	2	5	$\bar{K}^0 (s\bar{d})$	"Central" ^(c)	4
$\pi^- p \rightarrow D/\bar{D}$	Exp. slope	Theory	$\pi^- p \rightarrow K/\bar{K}$	Exp. slope	Theory
$D^- (\bar{c}d)$	(6, 1)	(5, 1)	$K^0 (\bar{s}d)$	"central" ^(c)	1
$\bar{D}^0 (\bar{c}u)$	6	5	$K^+ (\bar{s}u)$	2	3
$D^0 (c\bar{u})$	(6, 1)	(5, 1)	$K^- (s\bar{u})$	2	1
$D^+ (c\bar{d})$	6	5	$\bar{K}^0 (s\bar{d})$	"Central" ^(c)	1

(a) The errors are 2 ± 1 , 6 ± 3 and 1 ± 1 .

(b) The errors on the measured values are small.

(c) K_s^0 data refs [4,11].

FIGURE CAPTIONS

- Fig. 1 The weighted and unweighted (crosses) distributions of Feynman $x = (2p_L^*/\sqrt{s})$ for (a) D^- , $\bar{D}^0$, (b) D^+ , D^0 , (c) all events and (d) integral, weighted distribution for all events.
- Fig. 2 The integral, weighted distribution of transverse momentum squared.
- Fig. 3 The centre of mass rapidities of D-mesons for (a) pairs, (b) singles.

Fig. 1

Fig. 1(d)

Fig. 2

Fig. 3