D MESON BRANCHING RATIOS AND HADRONIC CHARM PRODUCTION CROSS SECTIONS

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ABSTRACT

A determination of branching ratios for D meson decays into all charged particle final states is reported. The values obtained: $(D^{\pm} \rightarrow K^{\mp} \pi^{\pm} \pi^{\pm} / \text{all } D^{\pm}) = (14 \pm 6)\%$ and $(\bar{D}^0/D^0 \rightarrow K^{\pm} \pi^{\mp} \pi^+ \pi^- / \text{all } \bar{D}^0/D^0) = (10 \pm 4)\%$, are higher than those currently accepted. This result, if confirmed, implies a corresponding reduction in the accepted values for some total cross section measurements. Revised inclusive cross sections for D meson production in the forward hemisphere in π^-p and pp interactions at 360 GeV/c, are presented.

Charm particle decay vertices have been detected in the high resolution hydrogen bubble chamber LEBC and the decay products analysed downstream using a preliminary configuration of the European Hybrid Spectrometer (EHS), which allowed γ detection but had very limited particle identification capabilities [1]. Data were taken with incident 360 GeV/c π^- (7.8 ev/ μ b) and 360 GeV/c p (7.3 ev/ μ b). The bubble chamber film has been subjected to 2 independent scans plus a physicist check scan. After measurement, the charm decays were selected (from a large background consisting mostly of strange particle decays) by a procedure described elsewhere [2,3]. The final sample consists of 72 events containing 103 detected charm decays. For 77 of these, the kinematic constraints are sufficient to establish the acceptable decay mode. However, the lack of particle identification and the generally large number of possible π^0 combinations lead to a high degree of ambiguity in the interpretation of the events. This problem does not strongly affect the determination of D meson lifetimes [2] nor the shape of inclusive D meson production spectra [3] but is more critical when attempting to determine branching ratios. For this reason, a different approach is used in this analysis, which aims to determine D meson branching ratios to decay modes consisting entirely of charged particles. It is based on a sub-sample consisting of 25 3-prong decays (C3), 15 2-prong (V2) and 10 4-prong decays (V4), for which all charged decay products are reconstructed in the spectrometer.

Before proceeding to the evaluation of branching ratios and cross sections we note that the results on lifetimes^(*) and production x_F and p_T distributions from this sample are entirely consistent with the previously published results.

We further note that the symbol D^0 is used in general to denote both D^0 and $\bar{D}^0$.

(*) In particular, the $D^\pm$ and D^0 lifetimes are, for the previous data [2] and present data, respectively, the following:

$$\tau(D^\pm) = (8.4^{+3.5}_{-2.2}) \times 10^{-13} \text{ s and } (9.9^{+5.7}_{-3.0}) \times 10^{-13} \text{ s}$$

$$\tau(D^0) = (4.1^{+1.3}_{-0.9}) \times 10^{-13} \text{ s and } (3.7^{+2.0}_{-1.1}) \times 10^{-13} \text{ s}$$

An important feature of the spectrometer is that the acceptance for the charged particles from the decay of charmed particles is only weakly dependent on the number of associated neutrals. This is shown in fig. 1(a) where we plot the probability that all charged particles are within the acceptance, as a function of the x_F of the D meson. The acceptance rises sharply at $x_F \approx 0$ and does not depend significantly on the decay mode or on any detailed internal dynamics of the decay (such as K^* or ρ intermediate states, etc). Fig. 1(b) shows equivalent acceptance curves for V2 and V4 decays.

Consider now the specific decay modes:

(a) $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$

In fig. 2 we plot the effective mass for the 3 charged particles assuming that the Cabibbo favoured assignment of the kaon applies. A Cabibbo favoured $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$ signal is clearly seen, estimated as 8 decays on a background of ~ 1 .

Kinematic fits have been made to all events. This procedure includes an additional constraint (p_T balance in the decay), which would in general be violated if a neutral particle were missing. Decays with a fit probability larger than 10^{-2} for the hypothesis $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$ are shaded in fig. 2(a) and confirm the interpretation of the events in the peak.

In the absence of particle identification the possible backgrounds contributing to this peak are (1) a reflection of F or Λ_c decays and (2) D-meson decays to final states containing neutral particles. Both backgrounds have been investigated with Monte-Carlo studies which show that they can contribute at most a fraction of an event in the D peak mass region. An empirical investigation is also possible by plotting the Cabibbo unfavoured combinations (2 per event). Background effects will populate the D meson mass bin in both Cabibbo favoured and Cabibbo unfavoured distributions. The Cabibbo favoured with the Cabibbo unfavoured distribution subtracted is shown in fig. 2(b). Assuming the true Cabibbo unfavoured branching ratio to be zero we find a similar number of $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$ decays. An invariant mass plot of events not in the $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$ peak shows no evidence of a signal in either $F^\pm \rightarrow K^\pm K^\mp \pi^\pm$ or $\Lambda_c^+ \rightarrow p K^- \pi^+$.

(b) $D^0 \rightarrow K^\pm \pi^\mp \pi^+ \pi^-$ and $D^0 \rightarrow K^\pm \pi^\mp$

In figs 3(a) and 3(b) we show the $K^\pm \pi^\mp \pi^+ \pi^-$ (4 combinations per event) and the $K^\pm \pi^\mp$ (2 combinations per event) mass distributions. Since both D^0 and $\bar{D}^0$ solutions are always possible we cannot investigate the kaon ambiguity using the Cabibbo unfavoured combinations. For the V2 decays it is clear from the plot that there is negligible background in the vicinity of the D^0 mass. The grouping of 4 combinations near the D^0 mass actually corresponds to 3 events. In the V4 decays 7 out of the 10 events have at least one mass combination in the D^0 mass bin and six of them have a kinematic fit to a 4-body decay. A Monte-Carlo study of the channels contributing to the V4 topology reproduces well the $K^\pm \pi^\mp \pi^+ \pi^-$ mass plot if we assume 6 genuine $D^0 \rightarrow K^\pm \pi^\mp \pi^+ \pi^-$ decays. The only topological backgrounds arise from misinterpreted D^0 decays such as $D^0 \rightarrow K^0 \pi^+ \pi^+ \pi^- \pi^-$ and $D^0 \rightarrow K^\pm \pi^\mp \pi^+ \pi^- \pi^0$ with unseen neutral particles. Neither of these modes will give a peak at the D mass if interpreted as $D^0 \rightarrow K^\pm \pi^\mp \pi^+ \pi^-$ and the Monte-Carlo shows that they can contribute at most one event in the D^0 mass region.

We conclude that our sample contains:

3 $D^0 \rightarrow K^\pm \pi^\mp$ events and 6 $D^0 \rightarrow K^\pm \pi^\mp \pi^+ \pi^-$ events.

To evaluate the branching ratio of a specific decay mode relative to all channels having the same charged topology we must compare the detection efficiency at the scanning level for charm decays with and without neutral particles. This problem has already been studied in detail in a previous publication [2] where the event scanning weights were found to be nearly independent of the number of neutral particles in the decay. Monte-Carlo studies of the variation of the impact parameter distribution show a correction of < 10% which would tend to decrease the branching ratio. On the other hand, from the curves of fig. 1 it can be seen that the slight variation of the charged particle acceptance with the number of neutrals represents a < 10% upwards correction to the branching ratios when averaged over the observed x_F distribution. Therefore, these two small corrections tend to cancel.

We can thus write

$$\frac{D^{\pm} \rightarrow K^{\mp} \pi^{\pm} \pi^{\pm}}{D^{\pm} \rightarrow 3\text{-prongs}} = (32^{+12}_{-10})\%$$

assuming that our total C3 sample contains only $D^{\pm}$ decays, and for the V4 decays:

$$\frac{D^0 \rightarrow K^{\pm} \pi^{\mp} \pi^+ \pi^-}{D^0 \rightarrow 4\text{-prongs}} = (60^{+18}_{-20})\% .$$

Because of the small statistics and the obviously greater problems of strange particle background subtraction we are less confident in our result for the V2 $D^0 \rightarrow K^{\pm} \pi^{\mp}$ mode.

Topological branching ratios can be estimated from the published SPEAR data [4,5,6]. Making an approximate correction for the $K^0 \rightarrow \pi^+ \pi^-$ decays included in the published data we estimate:

$$\begin{aligned} D^{\pm} \text{ decay} &= (54 \pm 10)\% \text{ 1-prong}; (43 \pm 10)\% \text{ 3-prong}; (3 \pm 3)\% \text{ 5-prong} \\ D^0 \text{ decay} &= (14 \pm 4)\% \text{ 0-prong}; (67 \pm 8)\% \text{ 2-prong}; (17 \pm 4)\% \text{ 4-prong}; \\ &\quad (2 \pm 2)\% \text{ 6-prong.} \end{aligned}$$

We therefore find the following branching ratios:

$$\begin{aligned} \frac{D^{\pm} \rightarrow K^{\mp} \pi^{\pm} \pi^{\pm}}{\text{all } D^{\pm}} &= (14^{+6}_{-5})\% \\ \frac{D^0 \rightarrow K^{\pm} \pi^{\mp} \pi^+ \pi^-}{\text{all } D^0} &= (10 \pm 4)\% . \end{aligned}$$

If the unfitted C3 sample contains a contribution from $F^{\pm}$ and Λ_c^+ decays then the branching ratio for $D^{\pm}$ will have been underestimated. Although we have no evidence for $F^{\pm}$ or Λ_c^+ in our sample the $D^{\pm} \rightarrow K^{\mp} \pi^{\pm} \pi^{\pm}$ result should therefore strictly be regarded as a lower limit. These values can be compared with the current world average values of $(4.6 \pm 1.1)\%$ and $(4.5 \pm 1.3)\%$ respectively [7].

For both channels our results are bigger than, although not statistically incompatible with, the current world average. Either we have a large positive fluctuation in the number of decays into all charged particles or the current branching ratios should be revised upwards. In either case it is inappropriate to use the events of these exclusive channels to estimate the production cross sections. We therefore prefer to derive the D meson production cross sections using the topological branching ratios [4,5,6] at present better known. This method requires a sample of events of each topology (C3, V4) with controlled losses and negligible contamination. Losses are evaluated using a Monte-Carlo technique to derive expected distributions in the decay parameters L (length) and $y = L \sin \theta_d$ (impact parameter), where θ_d is the angle of the secondary particle relative to the direction of the decaying particle. The inputs to the Monte-Carlo are the particle lifetimes, x_F and p_T distributions, all of which have been measured [3]. Because of the good acceptance for $x_F > 0$ the results are in fact insensitive to the exact form of the x_F distribution. We use:

$$\frac{dN}{dx_F dp_T^2} \propto (1 - |x_F|)^3 \exp(-1.1 p_T^2)$$

at production (with p_T in GeV/c) and $\tau(D^{\pm}) = 9.10^{-13}$ s, $\tau(D^0) = 4.10^{-13}$ s.

The minimum detectable impact parameter is set at 25 μm in space. This value is 2.5 times the standard deviation of the measured impact parameter distribution for a sample of non-charm events. Typical distributions are shown in fig. 4 for all C3 decays with at least two tracks having $y > 25 \mu\text{m}$. Within the sample, the agreement with the Monte-Carlo is good both in the shape of the distributions and in the ratio of expected numbers of events in the categories with 3 and 2 tracks having $y > 25 \mu\text{m}$. The sample with 0 or 1 track with $y > 25 \mu\text{m}$ is affected by losses and therefore we prefer not to use it in the cross section computation. From our Monte-Carlo study we expect 25% of the original sample to be in this category, and that the remaining losses are negligible. The impact parameter distribution does not depend significantly on the number of associated neutrals.

We observe 22 C3 decays having all tracks in the spectrometer and having at least 2 tracks with $y > 25 \mu\text{m}$. Four decays have one track not fully reconstructed. Three of the 22 have measured charged particle momenta too small to ensure that the decaying particle was produced at positive x_F and are not used in the evaluation of the cross section for $x_F > 0$. Their possible contribution is included in the error. The remaining sample is divided into 9 events in the π^-p exposure (6-ve, 1+ve, 2 unknown charge) and 10 in the pp exposure (7-ve, 3+ve).

Similarly we observe 10 V4 decays with 3 or 4 tracks having $y > 25 \mu\text{m}$; 9 of them produced at positive x_F , 4 in π^-p and 5 in pp.

To evaluate cross sections we must apply correction factors to take account of losses and cuts. For both C3 and V4 topologies we have a factor of 1.2 due to scanning efficiency and spectrometer acceptance losses above $x_F = 0$. To take account of decays with more than one track having $y < 25 \mu\text{m}$ we estimate from the Monte-Carlo a correction factor of 1.25 for C3 and 2.1 for the V4 decays. For the C3 topology there is an additional factor of 1.1 to take account of cuts [2] introduced to reject strange particles. We therefore have an overall correction factor of 1.65 to the number of C3's and 2.5 to the number of V4's.

Using the topological branching ratios [4,5,6] we derive the following inclusive single $D^\pm$ cross sections for $x_F > 0$:

$$\sigma(\pi^-p \rightarrow D^\pm + X) = (4.5^{+2.2}_{-1.4}) \mu\text{b}$$

$$\sigma(pp \rightarrow D^\pm + X) = (5.3^{+2.4}_{-1.6}) \mu\text{b}$$

again on the assumption that F and Λ_c decays do not contribute to the C3 sample. These cross sections should in principle be regarded as upper limits for $D^\pm$ production due to the possible contribution of unfitted F and Λ_c decays to the C3 topology.

For the $D^0/\bar{D}^0$ cross sections with $x_F > 0$ we find

$$\sigma(\pi^- p \rightarrow D^0/\bar{D}^0 + X) = (7.7^{+7.2}_{-3.5}) \mu b$$

$$\sigma(pp \rightarrow D^0/\bar{D}^0 + X) = (10.2^{+7.9}_{-4.3}) \mu b.$$

In our previous publications [3] we gave significantly higher values derived using the world average D^0 and $D^\pm$ branching ratios [7]. The previous estimates for the inclusive single D cross sections for $x_F > 0$ were 40 μb in πp and 28 μb in pp . Using topological branching ratios instead, the cross section estimates are reduced by a factor ≈ 2 . This difference is due to the enhanced branching ratios for the exclusive topologies as compared to the world averages. If for example in [3] we would have used a branching ratio of $14 \pm 6\%$ as found in the present experiment instead of the world average of $(4.6 \pm 1.1)\%$ for the $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$ mode a central value of 6 μb would have been estimated for the forward hemisphere $\sigma(pp \rightarrow D^\pm X)$ cross section.

In conclusion, our data suggest that the branching ratios to the simple final states $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$, and $D^0/\bar{D}^0 \rightarrow K^\mp \pi^\pm \pi^\pm$, might have to be revised upwards by a factor ~ 2 . If this is indeed the case many of the published cross sections should be revised downwards by a similar factor.

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REFERENCES

- [1] M. Aguilar-Benitez et al., Nucl. Instr. and Methods 205 (1983) 79.
- [2] M. Aguilar-Benitez et al., Phys. Lett. 122B (1983) 312.
- [3] M. Aguilar-Benitez et al., Phys. Lett. 123B (1983) 98;
M. Aguilar-Benitez et al., Phys. Lett. 123B (1983) 103.
- [4] I. Peruzzi et al., Phys. Rev. Lett. 39 (1977) 1301.
- [5] R.H. Schindler et al., Phys. Rev. D24 (1981) 78.
- [6] G.H. Trilling, Phys. Reports 75 (1981) 57.
- [7] M. Roos et al., "Review of Particle Properties", Phys. Lett. 11B (1982).

FIGURE CAPTIONS

Fig. 1 Acceptance for charged decay products from D meson decays as a function of x_F of the D meson at production.

Fig. 2 (a) Effective mass distribution for 3-prong charged decays for the Cabibbo favoured assignment of the kaon (i.e. the decay prong having opposite charge to the incoming D is assigned to the K mass and the other prongs are treated as pions).

Events giving a kinematic fit to the Cabibbo favoured decay $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$ are shaded.

(b) The Cabibbo favoured distribution with the Cabibbo unfavoured distribution subtracted. Note that in this plot the Cabibbo favoured peak produces an additional negative peak below the D mass by reflection in the Cabibbo unfavoured combination.

Fig. 3 (a) Effective mass distribution for 4-prong neutral decays (V4). Because of the possible assignment of the kaon there are four combinations per event. Events giving a kinematic fit to $\bar{D}^0/D^0 \rightarrow K^\pm \pi^\mp \pi^\pm \pi^\mp$ are shaded. Of the 10 events plotted 6 give an acceptable kinematic fit and appear in the $D^0/\bar{D}^0$ mass peak.

(b) Effective mass distribution for 2-prong neutral decays (V2). There are 2 combinations per event. Events fitting $D^0/\bar{D}^0 \rightarrow K^\mp \pi^\pm$ are shaded.

Fig. 4 Distributions of length L and impact parameter $L \sin \theta_d$ for 3-prong charged decays having 2 or 3 tracks with impact parameter greater than 25 μm . The histogram represents the data and the full curve the Monte-Carlo.

Fig. 1

Fig. 2

Fig. 3

Fig. 4