PHOTOPRODUCTION OF CHARMED D MESONS AT γ ENERGIES OF 40 - 70 GeV

Bonn¹-CERN²-Ecole Polytechnique³-Glasgow⁴-Lancaster⁵-Manchester⁶-
Orsay⁷-Paris VI⁸-Paris VII⁹-Rutherford¹⁰-Sheffield¹¹ Collaboration

D. Aston¹⁰, M. Atkinson¹⁰, R. Bailey¹¹, A.H. Ball⁶, B. Bouquet⁷,
G.R. Brookes¹¹, J. Bröring¹, P.J. Bussey⁴, D. Clarke¹⁰, A.B. Clegg⁵,
B. d'Almagne⁷, G. de Rosny³, B. Diekmann¹, A. Donnachie⁶, M. Draper⁴,
B. Drevillon³, I.P. Duerdoth⁶, J-P. Dufey², R.J. Ellison⁶, D. Ezra⁶,
P. Feller¹, A. Ferrer⁷, P.J. Flynn⁵, F. Frieze¹, W. Galbraith¹¹,
R. George⁸, S.D.M. Gill⁶, M. Goldberg⁸, S. Goodman⁸, M. Gorski^{7*},
W. Graves³, B. Grossetête⁹, P.G. Hampson⁶, K. Heinloth¹, R.E. Hughes-
Jones⁶, J.S. Hutton¹⁰, M. Ibbotson⁶, M. Jung¹, S. Katsanevas³,
M.A.R. Kemp¹⁰, F. Kovacs⁹, B.R. Kumar¹⁰, G.D. Lafferty⁵, J.B. Lane⁶,
J-M. Lévy⁸, V. Liebenau¹, J. Litt¹⁰, G. London⁸, D. Mercer⁶,
J.V. Morris¹⁰, K. Müller¹, D. Newton⁵, E. Paul¹, P. Petroff⁷, Y. Pons⁹,
C. Raine¹¹, F. Richard⁷, R. Richter¹, J.H.C. Roberts⁶, P. Roudeau⁷,
A. Rougé³, M. Rumpf³, M. Sené⁸, J. Six⁷, I. O. Skillicorn⁴,
J.C. Sleeman⁴, K.M. Smith⁴, C. Steinhauer¹, K.M. Storr⁵, R.J. Thompson⁶,
D. Treille², Ch. de la Vaissière⁸, H. Videau³, I. Videau³, A.P. Waite⁶,
A. Wijangco³, W. Wojcik^{7**}, J-P. Wuthrick³, T.P. Yiou⁸.

ABSTRACT

Inclusive $\bar{D}^0$ photoproduction is observed in $K^+\pi^-$ and $K^+\pi^-\pi^0$.

Evidence is presented for an associated production mechanism. Cross section estimates and limits are given for $\bar{D}$ and D mesons.

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* On leave of absence from Institute for Nuclear Research,
Warsaw, Poland.

** On leave of absence from University of Warsaw, Warsaw, Poland.

Since the first observation of charmed D mesons most of our knowledge of their properties has come from e^+e^- experiments⁽¹⁾. Although some evidence for their production has been reported in νp interactions⁽²⁾, there has been very little information about their hadroproduction⁽³⁾ or photoproduction⁽⁴⁾. In the case of photoproduction, our aim is to establish both the cross section and the production mechanism for charm. Specifically we wish to know whether charm is produced via a pair ($D\bar{D}$) or an associated production ($C\bar{D}$) mechanism. We report here on one aspect of our charm work, namely the study of D mesons observed through their decay into states containing a charged or neutral kaon.

The experiment was carried out using the Omega Spectrometer at the CERN SPS⁽⁵⁾. A tagged photon facility provided a beam of intensity $\sim 2 \times 10^5$ photons/burst over an energy range 20 - 70 GeV which interacted in a 67cm long liquid hydrogen target. The spectrometer trigger required at least four charged tracks at a plane 1.50m downstream of the centre of the target. About 70% of the data were obtained with this condition while for the remainder we demanded in addition a charged kaon in the final state. Charged kaons were identified between 5.7 and 19 GeV/c in an atmospheric pressure multi-cell Cerenkov counter. Protons and antiprotons were identified above 19 GeV/c and from their measured yield we estimate that they contribute to 30% of the kaon candidates. A lead glass wall and a scintillator array were used to detect photons and electrons; π^0 's could be identified if they had energy greater than 2 GeV.

Pattern recognition and geometrical reconstruction were carried out using the program ROMEO⁽⁶⁾. We obtained 30,000 events with a K_S^0 with the requirement that the K_S^0 vertex be separated from the main vertex by at least 4cm. We estimate that there is less than 20% contamination of the K_S^0 sample and that our efficiency for identification of K_S^0 is $\sim 60\%$. The K_S^0 mass spectrum is centred at the nominal value and has a FWHM of 9 MeV.

To reduce combinatorial background and still have a good acceptance for D mesons we excluded poorly measured tracks and charged pions with momentum

less than 500 MeV/c. In view of the momentum cut-off for π^0 and charged K's, we have only considered beam momenta above 40 GeV/c to keep some acceptance for centrally produced D's. With these selections we obtained 300,000 events with a kaon, corresponding to an integrated luminosity of 44 evts/nb.

We have plotted mass distributions for all charged and neutral final states $K(m\pi)$ where $m = 1, 2$ or 3 . The bin width and bin centre are chosen to maximize any excess from the D in two bins; this choice is determined by our knowledge of the mass resolution and from the published D mass. To estimate the excess in these two bins, we use a third degree polynomial fit for the background. The calculated resolutions, given in Table I, have been checked with K_S^0 for charged particles and with π^0 and η for neutrals.

The inclusive mass spectra given in Fig. 1 show evidence for $\bar{D}^0$ in the $K^+\pi^-$ and in the $K^+\pi^-\pi^0$ modes. The two mass spectra when added give a $\bar{D}^0$ signal of ~ 5 standard deviations. The absence of a corresponding D signal could indicate that associated production ($C\bar{D}$) dominates. In $C\bar{D}$ events, the proton from the C decay is likely to have a momentum below 19 GeV/c and so be identified as a K^+ . Using events with an apparent second K^+ a considerable reduction of the number of combinations is obtained and with this selection we find that the signal/background ratios for $K^+\pi^-$ and $K^+\pi^-\pi^0$ improve (Fig. 2). For the decays involving K_S^0 , the above selection of an extra K^+ does not isolate the $C\bar{D}$ channel; nevertheless after selecting a K^+ a signal is observed in $K_S^0\pi^+\pi^-$ (Fig. 2).

We consider now the cross section for charm production. This requires a determination of the acceptance which is essentially dependent upon the longitudinal momentum distribution of the D meson. For the photon energies considered (> 40 GeV) we find that the acceptances for the $K^+\pi^-$ and the $K^+\pi^-\pi^0$ channels have a different dependence in the Feynman x_D^* variable. To obtain a consistent cross section for charm using these two channels, it is necessary to assume that $\bar{D}^0$ are mainly produced with positive x_D^* and so we have taken the x_D^* distribution to be flat between -0.1 and 0.5. With this assumption we obtain the $B\sigma$ values listed in Table II.

The $K^+\pi^-$ channel has a nearly flat acceptance for positive x_D^* ; consequently we can determine an essentially model-independent inclusive $\bar{D}^0$ cross section from this channel:

$$\sigma_{\bar{D}^0} = 525 \pm 140 \text{ nb}$$

using

$$\text{BR}(\bar{D}^0 \rightarrow K^+\pi^-) = 2.6 \pm 0.4\%$$

This error is statistical only but includes the error in the D branching ratio; uncertainties in acceptances and in efficiencies are not included and are estimated to be $\sim 20\%$.

From SPEAR results⁽⁷⁾ we expect the charmed baryon to decay predominantly via a proton and so we take a branching ratio for C into proton of 50%. Assuming that the C is more centrally produced than the $\bar{D}$ and taking x_C^* flat between -0.3 and 0.3, we find that about 25% of the $C\bar{D}$ events should give a K^+/p identified in our Cerenkov. Using these hypotheses, we are able to extract from our data a model-dependent cross section for $\bar{D}^0$ production via $\gamma p \rightarrow C\bar{D} X$ of:

$$\sigma_{\bar{D}^0} = 525 \pm 160 \text{ nb}$$

The two results for the $\bar{D}^0$ cross section agree, implying that most $\bar{D}^0$ are produced via associated production.

Table I gives upper limits for $\bar{D}$ decay channels produced via $C\bar{D}$; these were calculated at the three standard deviation level taking into account the expected resolutions. This level was chosen to ensure that with a probability of 85% the excess will not drop below 2σ by random fluctuations. In Table II are summarized purely inclusive limits for D and $\bar{D}$ channels.

Systematic effects influencing the above results could arise from the multiplicity requirement in our trigger. No correction has been made for such effects, because unless charm events have a very specific behaviour (which is not indicated by e^+e^- data), the correction is likely to be small, given that we trigger on more than 60% of the total cross section.

Our result on the charm cross section allows some discrimination between the wide variety of theoretical models⁽⁸⁾. Perturbative QCD calculations for our energy range generally give a smaller cross section than we observe, but correcting the theoretical prediction to allow for the energy dependence of the ψ cross section⁽⁹⁾, one can get better agreement with our measurement. One should also recall that we have only measured the cross section for $\bar{D}^0$ production; we note however that $\bar{D}^0$ production seems to dominate over D^0 production, in a similar way to the observed excess of K^+ over K^- in photoproduction.

In conclusion, we find that the $\bar{D}^0$ photoproduction cross section is $\sim 0.5\%$ of the total hadronic cross section and that $\bar{D}$ mesons are produced mainly through associated production.

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TABLE I

$\bar{D}$ cross-sections from events with an additional "p"

Decay channel	Detection efficiency %	Expected FWHM (MeV)	Fitted mass (MeV)	No. of events* or 3 σ limit	B σ (nb)
$K^+ \pi^-$	42	20	1866 ± 5	60 ± 17	13.5 ± 4
$K^+ \pi^- \pi^0$	5	36	1856 ± 11	63 ± 19	108 ± 33
$K^+ \pi^- \pi^+ \pi^-$	28	20		< 122	< 40
$K^+ \pi^- \pi^-$	34	20		< 94	< 26
$K^0 \pi^-$	19	30		< 33	< 17
$K^0 \pi^+ \pi^-$	17	30	$1852 \quad 12$	66 ± 19	39 ± 11

The quoted errors on B σ are statistical only.

The values for the detection efficiencies do not include the acceptance for the proton from the C baryon, estimated to be $\sim 25\%$.

* This number comes from the two bins in which a signal would be expected (see text), corrected for resolution loss.

TABLE II

Inclusive D photoproduction cross sections

	Decay channel	Fitted mass (MeV)	No. of events [*] or 3 σ limit	B σ (nb)
$\bar{D}$	$K^+ \pi^-$	1863.5 ± 2.5	238 ± 58	13.5 ± 3.5
	$K^+ \pi^- \pi^0$	1861 ± 7	215 ± 67	94 ± 30
	$K^+ \pi^- \pi^+ \pi^-$		< 470	< 39
	$K^+ \pi^- \pi^-$		< 302	< 22
D	$K^- \pi^+$		< 167	< 9.5
	$K^- \pi^+ \pi^0$		< 172	< 75
	$K^- \pi^+ \pi^+ \pi^-$		< 383	< 32
	$K^- \pi^+ \pi^+$		< 294	< 20

* This number comes from the two bins in which a signal would be expected (see text), corrected for resolution loss.

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FIGURE CAPTIONS

Fig. 1:

Inclusive mass spectra for $K_{\pi}^{+}\pi^{-}$ and $K_{\pi}^{+}\pi^{+}\pi^{0}$ channels. The superimposed curves are obtained from a third degree polynomial fit to the background plus a Breit-Wigner having a width given by the expected mass resolution for the signals.

Fig. 2:

Events with an additional K^{+} candidate are selected; one of the K^{+} is assumed to be a proton (see text).

The following cuts have been applied to all the events:

$E_{\gamma} > 40 \text{ GeV}$, $P_{\pi}^{\pm} > 500 \text{ MeV/c}$, $P_{\pi}^{0} > 2.5 \text{ GeV/c}$.

Fig. 1

Fig. 2