1. SEARCH FOR A THRESHOLD ENHANCEMENT IN THE $\gamma p \rightarrow$ CHARMED BARYON + CHARMED MESON CROSS SECTION*

2. PHOTOPRODUCTION AND DECAY OF CHARMED PARTICLES IN γp INTERACTIONS AT 20 GEV

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ABSTRACT

In the first of these topics, upper limits to the cross section of reactions of the type $\gamma p \rightarrow \Sigma_c^{++} D^-$ just above threshold were obtained. These were found to be in the range 270 to 450 μb. In the second, a brief review of the important results obtained from a large photoproduction of charm experiment at 20 GeV is given.

1. SEARCH FOR A THRESHOLD ENHANCEMENT IN THE $\gamma p \rightarrow$ CHARMED BARYON + CHARMED MESON CROSS SECTION*

It has been suggested by Rubinstein and Stodolsky[1] that an enhancement of several microbarns in the cross section for $\gamma p \rightarrow$ charmed baryon + charmed meson exists a few hundred MeV above threshold. An enhancement of this type would provide a pure source of charmed baryons since it lies below the $D\bar{D}$ threshold. There is experimental evidence for such enhancements in photoproduced exclusive channels involving only light quarks[2,3], e.g. the cross section for $\gamma p \rightarrow \Delta^{++}\pi^-$ rises to 70 μb at 200 MeV above threshold. This enhancement is well described by the contact term model[3]. In this letter we present results from a search for an enhancement in the charm photoproduction cross section. The experiment was performed using the SLAC Hybrid Facility. The experimental details were similar in most respects to those used for the experiment on photoproduction of charm at 20 GeV described in reference 4.

The SLAC 1 m hydrogen bubble chamber was exposed to a photon beam with energy peaked at 10.5 GeV, which is 700 MeV above the $\gamma p \rightarrow D^-\Sigma_c^{++}$ threshold. The photon beam energy spectrum is shown in Fig. 1. The beam was produced by

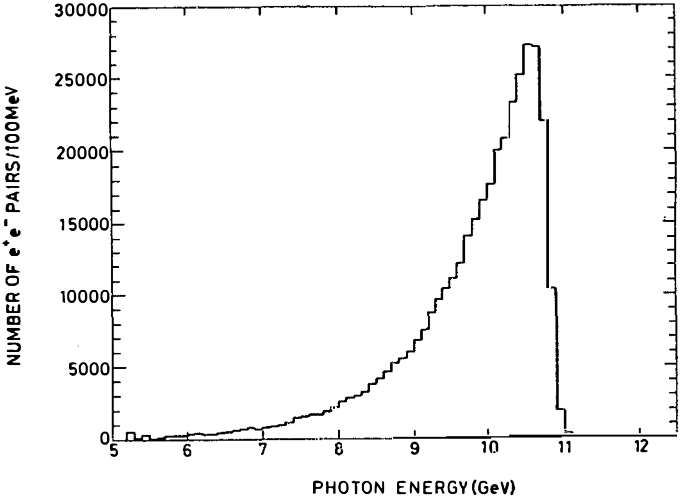

Fig. 1: The photon beam energy spectrum measured in an electron pair spectrometer located in front of the bubble chamber. This spectrum agrees with that obtained from a sample of 426 $\gamma p \rightarrow p\pi^+\pi^-$ events.

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* RL-84-032 and submitted to Physical Review Letters.

Compton scattering 532 nm laser light by a 23.5 GeV electron beam. It was operated at an intensity of 20 - 25 γ/pulse. A total of 98,000 pictures was taken, of which every tenth was untriggered.

In order to detect decays of charmed particles, a high resolution camera[5] having a resolution of 40 μm over a depth of field ±2 mm was used in addition to the normal 3-view camera. Every hadronic interaction was closely examined for multiprong decays of short-lived particles within 1.5 cm of the production vertex; 346 two-prong decays and one three-prong decay were found. All of these were compatible with decays of strange particles.

The sensitivity of the experiment was determined using the number of hadronic events found, the scanning and triggering efficiencies, and the known total hadronic cross section, σ_H, of 120 μb[6]. On a single scan the number of hadronic interactions examined, N_H, was 27,200. A third of the film was scanned twice. From this the single scanning efficiency for hadronic events, ε_H^{sc}, was determined to be (95 ± 1)%. In order to ensure high and uniform detection efficiency for charm events, the same cuts[7] were used in this experiment as in the 20 GeV experiment[4]. The single scan efficiency for charm events in the 20 GeV γp experiment passing cuts was (80 ± 5)%. This value was used to find the overall scanning efficiency, ε_c^{sc}, for charm events surviving all cuts in the present experiment. Allowing for the fraction of film scanned twice, ε_c^{sc} was computed to be (84 ± 5)%. This value of ε_c^{sc} is probably an underestimate as the optical resolution in the present experiment is considerably improved over that of the 20 GeV γp experiment and also because the confusion in the forward cone is greatly decreased at 10 GeV. This view is supported by the fact that the measured scanning efficiency for K^0's and Λ's decaying within 5 mm of the primary vertex was (92 ± 4)% in the present experiment. The triggering efficiency[8] for hadronic events, ε_H^T, was determined to be (66 ± 4)% from analysis of the untriggered film and also from the total photon flux. The triggering efficiency for charm events, ε_c^T, was studied by using Monte Carlo generated events with various production and decay channels and was estimated to be (70 ± 5)%. The sensitivity for charm events, s, is given by

$$s = \frac{N_H}{\sigma_H} \frac{\varepsilon_c^{sc}}{\varepsilon_H^{sc}} \frac{\varepsilon_c^T}{\varepsilon_H^T} = (213 \pm 24) \text{ events}/\mu\text{b}.$$

The number of charm events expected to be produced and to survive all cuts is given by $N_c = \chi s\bar{\sigma}_c$, where χ is the fraction of produced charm events which will survive the cuts, and $\bar{\sigma}_c = \int dE\ \sigma_c(E)\phi(E)$ is the overlap integral between the charm cross section as a function of photon energy, $\sigma_c(E)$, and the normalised photon flux, $\phi(E)$. The charm detection probability, χ, depends mainly on the decay branching ratios and the lifetimes. To estimate the value of χ, charm events were generated by a Monte Carlo program and all the cuts were applied to the generated events. The reactions considered were $\gamma p \to D^-\Sigma_c^{++}$ and $\gamma p \to D^{*-}\Sigma_c^{++}$. The lifetime values of $\tau_{D^o} = (6.8\ ^{+\ 2.3}_{-\ 1.8}) \times 10^{-13}$ s, $\tau_{D^\pm} = (7.4\ ^{+\ 2.3}_{-\ 2.0}) \times 10^{-13}$ s (as determined in our previous experiment[4]), $\tau_{\Lambda_c^+} = 2.2 \times 10^{-13}$ s and the $D^\pm$ multiprong branching ratio value of $B^\pm = 0.35 \pm 0.10$ were used. This gives $\chi = 0.13 \pm 0.05$ for $\gamma p \to D^-\Sigma_c^{++}$ and $\chi = 0.16 \pm 0.04$ for $\gamma p \to D_c^{*-}\Sigma^{++}$. The most important factors contributing to the errors in χ are the uncertainties in the multiprong branching ratio for charged decays and in the lifetimes, τ_{D^o} and $\tau_{D^\pm}$. The variation in χ due to changes in these parameters is demonstrated in Fig. 2 and 3. In the following $\chi = 0.14 \pm 0.05$ is used.

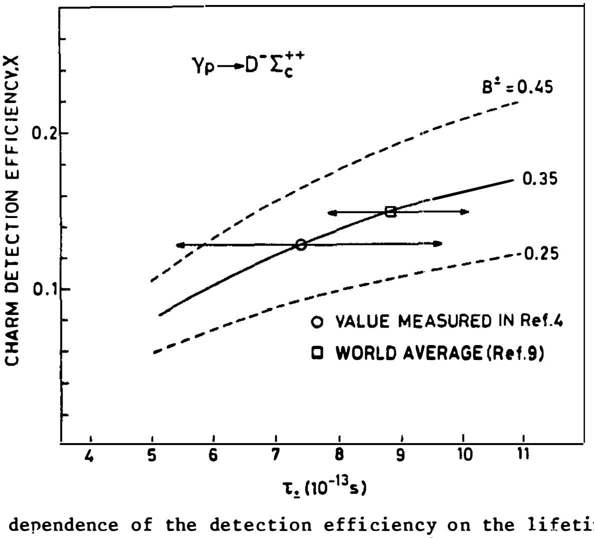

Fig. 2: The dependence of the detection efficiency on the lifetime of the charged D meson and its multiprong branching ratio for the reaction $\gamma p \to D^-\Sigma_c^{++}$ at 10.5 GeV.

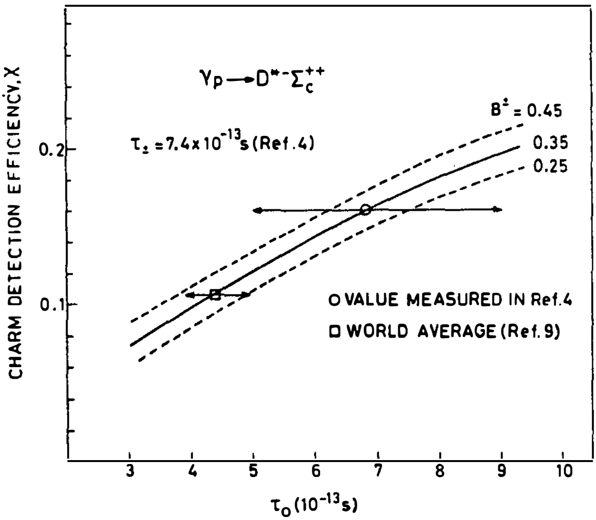

Fig. 3: The dependence of the detection efficiency on the lifetime of the neutral D meson and the multiprong branching ratio of the charged D meson for the reaction $\gamma p \rightarrow D^{*-}\Sigma_c^{++}$ at 10.5 GeV.

No charm candidates were detected in this experiment. Taking into account the uncertainties in s and χ, an upper limit to $\bar{\sigma}_c$ was calculated:

$$\bar{\sigma}_c < 94 \text{ nb (90\% CL)}.$$

The average charm cross section, $\bar{\sigma}_c$, is related to the maximum value of the charm cross section near threshold, σ_c^{max}, by $\bar{\sigma}_c = f\sigma_c^{max}$, where the degradation factor f is given by

$$f = \int dE \; \frac{\sigma_c(E)}{\sigma_c^{max}} \; \phi(E)$$

and clearly depends on the shape of $\sigma_c(E)$. It was assumed that $\sigma_c(E)/\sigma_c^{max}$ has the same dependence on energy above threshold as the contact term cross section for $\gamma p \rightarrow \Delta^{++}\pi^-$. Table 1 shows the degradation factors and resulting 90% confidence level upper limits to σ_c^{max} for the four channels considered.

Channel	Degradation Factor	90% CL Upper Limit on σ_c^{max}(nb)
$\gamma p \rightarrow D^- \Sigma_c^{++}(2440)$	0.28	340
$\gamma p \rightarrow D^- \Sigma_c^{++}(2510)$	0.35	270
$\gamma p \rightarrow D^{*-} \Sigma_c^{++}(2440)$	0.35	270
$\gamma p \rightarrow D^{*-} \Sigma_c^{++}(2510)$	0.21	450

Table 1: The degradation factors and 90% confidence limits on σ_c^{max} for the production of Σ_c^{++} of masses 2440 and 2510 MeV.

The results given in Table 1 indicate that if there is any enhancement in the charm cross section near threshold it is less than approximately 0.3 μb per channel, much smaller than the suggested several microbarns[1]. There are several possible explanations for this, including the following. Firstly, the enhancement could have a very different shape or position to those considered. Secondly, the effective strong coupling constant in the charm case may be smaller than that obtained using simple SU(4) symmetry considerations. Thirdly, the phenomenological Lagrangian formalism used in the contact term model may have to be modified by a form factor, leading to a reduction in the effective coupling strength.

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7) Briefly, decays were rejected if they were within 500 μm of the primary vertex or if no track had a projected impact distance greater than 110 μm and no second track greater than 40 μm, or if they could be due to strange particle decays or photon conversions.

8) The trigger for this experiment was altered from that of Ref. 4) by lowering the energy threshold for the lead glass counters to allow for the lower beam energy.

9) C. Jarlskog, Proceedings of the International Europhysics Conference on High Energy Physics, Brighton, July 1983, p.768, (published by Rutherford Appleton Laboratory, Didcot, UK).

2. PRODUCTION AND DECAY OF CHARMED PARTICLES IN γp INTERACTIONS AT 20 GEV

The following is a very brief summary of the most pertinent results obtained from the first phase of a large photoproduction experiment performed with the SLAC Hybrid Facility. A full description of the experiment and the results are contained in RL-83-123 and have been submitted to Physical Review.

a) **Lifetimes of Charmed Particles:**

i) $\tau_{D^0} = 6.8 {}^{+2.3}_{-1.8} \times 10^{-13}s$

based on 22 decays (11 2-prong and 11 4-prong).

ii) $\tau_{D^\pm} = 7.4 {}^{+2.3}_{-2.0} \times 10^{-13}s$

based on 21 decays (7 positive decays and 14 negative, 20 3-prong and 1 5-prong)

b) **Cross Section:**

The total inclusive cross section for charm (in the production reaction $\gamma p \rightarrow$ charmed particle + anticharmed particle + anything) was found to be $\sigma_{charm} = 56 {}^{+24}_{-23}\ \mu b$.

This result tends to favour photon-gluon fusion models over vector meson dominance or quark-quark fusion models.

c) Λ_c^+ **production:**

No uniquely identified Λ_c^+ decays were found. Of the seven positive decays, five were kinematically ambiguous between D^+ and Λ_c^+. However, indirect evidence was found for some Λ_c^+ production.

This came from two separate sources:

i) Six Λ decays were seen on frames containing charm decays. If there were no correlation between charm decay and Λ production, 1.4 Λ's would be expected. The excess of Λ's seen over those expected can be readily explained by some Λ_c^+ production and decay.

ii) Using the signs of identified kaons and assuming the decays to be D-mesons with no Cabibbo suppressed modes, 18 of the 28 decays were assigned to be D^- or $\bar{D}^\circ$ and 10 as D^+ or D°. From this there is evidence for a component of $\Lambda_c^+ \bar{D}X$ production.

Putting this together with some evidence from events where pairs of $D^\circ\bar{D}^\circ$ were seen, the fraction of $\Lambda_c\bar{D}X$ production is <u>35 ± 20%</u>.

d) D^* **Production:**

No constrained $D^{\pm *} \rightarrow D^\circ + \pi^\pm$ decays were found. Some weak evidence for $D^{\pm *}$ production was found by looking at the total sample of constrained and unconstrained D° decays and calculating the mass difference between the invariant mass of the charged tracks from the decay vertex and this mass together with a single charged pion from the production vertex. For real $D^{\pm *}$ this mass difference peaks at ~ 146 MeV/c^2 just like fully constrained events, however there is a tail towards high masses. Eighty five percent of all real $D^{*\pm} \rightarrow D^{\circ}\pi^{\pm}$ have a mass difference of less than 200 MeV/c^2 when calculated in this manner. Seven events were found with mass differences less than 200 MeV/c^2 compared to 2.8 predicted as background from a $D\bar{D}$ production Monte Carlo programme. Correcting for the branching ratio $D^{*\pm} \rightarrow D^{\circ}\pi^{\pm}$ and the efficiency for detecting D° decays, we obtain 0.17 ± 0.11 $D^{*\pm}$ particles produced per charm event.

e) **$F^{\pm}$ Production:**

No evidence for $F^{\pm}$ production was found in this experiment. However an ambiguity between $D^{\pm}$ and $F^{\pm}$ exists by which decays when interpreted as Cabibbo favoured $D^{\pm}$, peaked at the $D^{\pm}$ mass and when interpreted as $F^{\pm}$, peaked at ~ 2030 MeV/c^2. There was other evidence in the experiment that the majority of the charged decays were $D^{\pm}$. The moral of this is that to establish an $F^{\pm}$ signal among a large number of $D^{\pm}$ decays, very good particle identification is necessary.

f) **$D^{\pm}$ Branching Ratios:**

The following table shows the branching ratios obtained from this experiment compared to those given in the Particle Data Group tables. Due to the low statistics the measurements are very imprecise, however the $D^{\pm} \rightarrow K^{\mp}\pi\pi$ branching ratio appears to be rather larger than previous measurements.

Table I

Branching Ratios into Various Final States

Channel	Number of Decays Observed		Detection Efficiency	Branching Ratio (%) [a]	Particle Data Group Value (%)
$D^+ \to K^-\pi^+\pi^+$	1	8	0.49	11 ± 4	4.6 ± 1.1
$D^- \to K^+\pi^-\pi^-$	7				
$D^+ \to \bar{K}^\circ\pi^+\pi^+\pi^-$	0	1	0.13	5 ± 5	8.4 ± 3.5
$D^- \to K^\circ\pi^-\pi^-\pi^+$	1				
$D^\circ \to K^-\pi^+$	1	1	0.38	3 ± 3	2.4 ± 0.4
$\bar{D}^\circ \to K^+\pi^-$	0				
$D^\circ \to K^-\pi^-\pi^+\pi^+$	2	4	0.51	8 ± 4	4.5 ± 1.3
$\bar{D}^\circ \to K^+\pi^+\pi^-\pi^-$	2				
$D^\circ \to \bar{K}^\circ\pi^+\pi^-$		1	0.06	18 ± 18	4.2 ± 0.8
$\bar{D} \to K^\circ\pi^+\pi^-$					

a) The calculation of the branching ratio used the branching ratios of D° and $D^\pm$ into multiprongs, B° (multiprongs) = 0.87 ± 0.05; $B^\pm$ (multiprongs) = 0.35 ± 0.10.