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CROSS SECTIONS AND SOME FEATURES OF CHARM PHOTOPRODUCTION AT γ ENERGIES OF 20-70 GeV

Photon Emulsion Collaboration

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† The authors wish to dedicate this work to the memory of their two friends and colleagues deceased recently.

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ABSTRACT

We report some results on charm photoproduction at γ energies ranging from 20 to 70 GeV. 36 events with pairs of charmed particles have been found in emulsions. The computed total cross section is (230 ± 57)nb/nucleon. Frequencies of different production channels and some distributions are presented and compared with the predictions from a photo-gluon fusion model with string fragmentation.

In this paper we present some results on cross sections and production mechanisms of charmed meson and baryon photoproduction on nuclei. The data were collected during the exposure of nuclear emulsions, coupled with the Omega Prime spectrometer, to a tagged beam of bremsstrahlung γ's with energies between 20 and 70 GeV at the CERN SPS (WA58 experiment).

The experimental method and the scanning procedure for finding the events with charmed particles are described elsewhere [1].

The sample selected for this paper consists of 36 events with both charmed particles seen in the emulsion. With this kind of selection it is possible to have a free background sample and also to compute exactly the correction factors due to the limited dimensions of the emulsion and to the scanning inefficiencies.

We tried to identify the nature and the momentum of both charmed particles. However, this was possible without any ambiguity only when all the decay products were detected by the spectrometer and could be associated to the secondary vertices.

If a neutral particle was among the decay products and was not detected by the spectrometer, two solutions were possible for the charmed particle momentum, making some hypothesis on the nature of the missing particle. In these cases we assigned to the particle a momentum which was given by the inverse of the mean value between the inverses of the two solutions. Sometimes from the energy conservation applied to the whole event it was possible to restrict the momentum indetermination.

When more than one hypothesis was possible, the Cabibbo favoured one was kept or the one with the highest probability on the basis of kinematical fits or Monte-Carlo analysis.

The 36 events selected in this way were classified as in table 1 ending thus with 38 D^o or $\bar{D}^o$, 21 $D^{\pm}$, 12 Λ_c^+ and 1 F^+.

In order to evaluate the total cross section for charm production, corrections had to be applied, owing to the various losses caused by the limited potential paths (for each charm a mean path of about 3 mm in emulsion is available), to scanning inefficiencies and to D decays in all neutral particles. The first two correction factors depend on the charm lifetimes.

We used for the lifetimes the following values (in units of 10^{-13} s) published as the world averages [2]: $\tau(D^o) = 4.1$, $\tau(D^{\pm}) = 9.3$, $\tau(\Lambda_c^+) = 2.3$ and $\tau(F^{\pm}) = 2.9$.

The correction factors were evaluated event-by-event on the basis of a Monte-Carlo, in which the charmed particles were generated with the momentum and angle distributions like those of the real events. The particles were then let decay with a proper time distribution in agreement with the corresponding lifetime. Afterwards we determined the number of events in which at least one charm decayed outside the emulsion and the number of events with a D^o decaying in all neutral products. Taking also into account the scanning efficiency for neutral D, which was evaluated experimentally in function of the distance from the primary vertex, a weight was attributed to each event.

A further correction was necessary because of the selection criteria adopted to scan the emulsions. The finding efficiency of an event depends on the number of tracks which the program reconstructed at the vertex and on the scanning area around the predicted vertex [1]. Moverover, in a fraction of the emulsions a high multiplicity selection was applied to the events to be searched for. To correct for these effects, we calculated another weight by taking the ratio between the numbers of events with a given multiplicity detected by the spectrometer and of those found in the scan. To each charmed event the corresponding weight was given according to its multiplicity.

At the end each event had a total weight corresponding to the product of the two calculated correction factors. Thus the 36 found events correspond to (302 ± 75) weighted events.

The total cross section for charm photoproduction was obtained from the ratio between the number of weighted charmed events and the number of hadronic events generated in the emulsions as calculated from the known γ dose and assuming a hadronic cross section $\sigma_{\gamma A} = 115\ A^{0.9}$ μb at our energies [1]. If we assume a linear A dependence for the charm production, we obtain

$$\sigma = (230 \pm 57)\text{nb/nucleon}.$$

The error is the statistical one. Using the lifetime values (in units of 10^{-13} s) calculated from our data [3]: $\tau(D^0) = 3.6$, $\tau(D^{\pm}) = 5.0$ and $\tau(\Lambda_c^+) = 2.3$, the total cross section decreases of about 14%.

Fig. 1 shows the charm production cross section as a function of the energy of the incident γ (real or virtual) for different experiments of charm photoproduction and muoproduction. The value determined in our experiment is in excellent agreement with the prediction obtained by the photon-gluon fusion model [5]. The $D\bar{D}$ channel corresponds to (70 ± 21)% of the total cross section and the other relevant channel $\bar{D}\Lambda_c^+$, to (28 ± 13)%.

The possible production of the D^* ($\bar{D}^*$) resonance was also investigated by the decay mode into $D^0\pi^+$ ($D^0\pi^-$). In fact the decay modes, where π^0 or γ are present in the final state, are affected in our experiment by the limited angular acceptance of the electromagnetic detector. The ($D^0\pi^-$) and ($D^0\pi^+$) mass distributions are shown in fig. 2. In the first mass spectrum a peak at the value of the $\bar{D}^*$ mass stands clearly over the background, while no statistically significant signal is present in the ($D^0\pi^+$) mass distribution. Estimating that the peak contains about 100 weighted events and by using for the branching ratio $B(D^* \to D^0\pi^+)$ the value (0.49 ± 0.08) [9], we obtain that the D^{*-} production in our experiment corresponds to (68 ± 34)% of the total cross section.

We also investigated the production of the Σ_c^{++} baryonic resonance. In the $\Lambda_c^+\ \pi^+$ mass spectrum some mass combinations occur at the Σ_c^{++} mass value but there is not any clear signal over the background from which we can extract a significant cross section.

The more relevant features of the $D\bar{D}$ and $\bar{D}\Lambda_c^+$ channels were studied by looking over the Feynman x of the charms, the z ratio between the two charms total energy and the incident γ energy, and the p_T of the charm pair. The possible correlation between the two charmed particles can be analyzed by the ϕ angle defined by

$$\cos\phi = \frac{\vec{p}_{T_1} \times \vec{p}_{T_2}}{|\vec{p}_{T_1}||\vec{p}_{T_2}|}$$

where $\vec{p}_{T1}$ and $\vec{p}_{T2}$ are the transverse momenta.

The charm x_F distributions are shown in fig. 3. In the $D\bar{D}$ channel the D and $\bar{D}$ distributions are alike, and indicate a central production. In the $\bar{D}\Lambda_c^+$ channel the $\bar{D}$ is mainly produced at $x > 0$, while the Λ_c^+ is mainly produced at $x < 0$.

Fig. 4 shows the distributions of the z variable and of the ϕ angle. The behaviour of z indicates that the charms take on the average 60% of the incident γ energy. The p_T^2 distributions of the charm pairs are well fitted by exponential functions. The fits give $\langle p_T^2\rangle = (1.7 \pm 0.1)\ (\mathrm{GeV}/c)^2$ for $D\bar{D}$ and $\langle p_T^2\rangle = (0.9 \pm 0.1)(\mathrm{GeV}/c)^2$ for $\bar{D}\Lambda_c^+$.

The photo-gluon fusion model seems to account for the value of the total cross section at our energy. We tried to compare the more important characteristics of the two channels with the predictions of a particular photon-gluon fusion model [10]. According to it, the creation process of the $\bar{c}$ and c quarks in the γ interaction with a gluon emitted by a quark of the nucleon is followed by the creation of strings between the $\bar{c}$ and the quark of the target nucleon and between the c and the remaining diquark. For simplicity in our calculations we have assumed for the gluon distribution the form $(1-x_2)^5/x_1$ and for the quark distribution the form $x_2(1-x_2)^2$. The product of these functions gives the probability of finding a gluon which carries an x_1 fraction of the nucleon momentum and a quark with an x_2 fraction of the remaining momentum.

By using the fragmentation functions suggested in ref. [5], we obtained the curves drawn on the histograms in figs 3 and 4. The general behaviour of x_F and z distributions is reasonably reproduced if one takes into account the simplicity of the assumptions in the model.

The model we used does not foresee any particular correlation between the directions of the charm transverse momenta except those coming from the phase space. The experimental data behaviour seems to deviate significantly from the predictions.

We have also used the Lund Monte-Carlo program implemented by the photo-gluon interaction for charm production and by string fragmentation [11]. The distributions we have obtained are similar to the previous ones. But the Lund Monte-Carlo gives also the possibility to calculate the frequencies of the different channels. We have used a low value for the probability of diquark creation in the strings in agreement with ref. [12]. The program has been further implemented by the fact that our data do not show D^{*+} production. We have obtained the frequencies reported in table 1 and compared with the experimental ones. The agreement is very good. The assumption on the diquark probability accounted for the $\bar{\Lambda}_c$ absence in our experiment. It is interesting to notice that the Lund program with an independent fragmentation model gives almost the same number of Λ_c and $\bar{\Lambda}_c$, in complete disagreement with our data.

To summarize, we studied the charm photoproduction at energies of the incident γ ranging from 20 to 70 GeV. The resulting total cross section is σ = (230 ± 57) nb/nucleon. The $D\bar{D}$ channel amounts to the (70 ± 21)% of the total, while the $\bar{D}\Lambda_c^+$ channel is (28 ± 13)%. The D^{*-} production is (68 ± 34)% of the total cross sections. The analysis of the production mechanism was carried out by studying the distributions of the x_F, of the z variable and of the ϕ angle between the transverse momenta of the two charms. These distributions were compared with those predicted by a photo-gluon fusion model. In this model the hadronisation of the charm quarks takes place through string fragmentation. The agreement between the predicted distributions and the data is reasonably good. The Lund Monte-Carlo program with string fragmentation gives similar results and accounts for the frequencies of the different channels.

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TABLE 1

Channels	$\bar{D}^0 D^0$	$\bar{D}^0 D^+$	$D^- D^0$	$D^- D^+$	$\bar{D}^0 \Lambda_c^+$	$D^- \Lambda_c^+$	$D^- F^+$
Number of events	10	6	5	2	7	5	1
Fraction of total cross section (%)	30 ± 13	23 ± 13	5 ± 3	12 ± 11	22 ± 12	6 ± 3	2 ± 2
Lund model	28	25	9	7	20	8	1

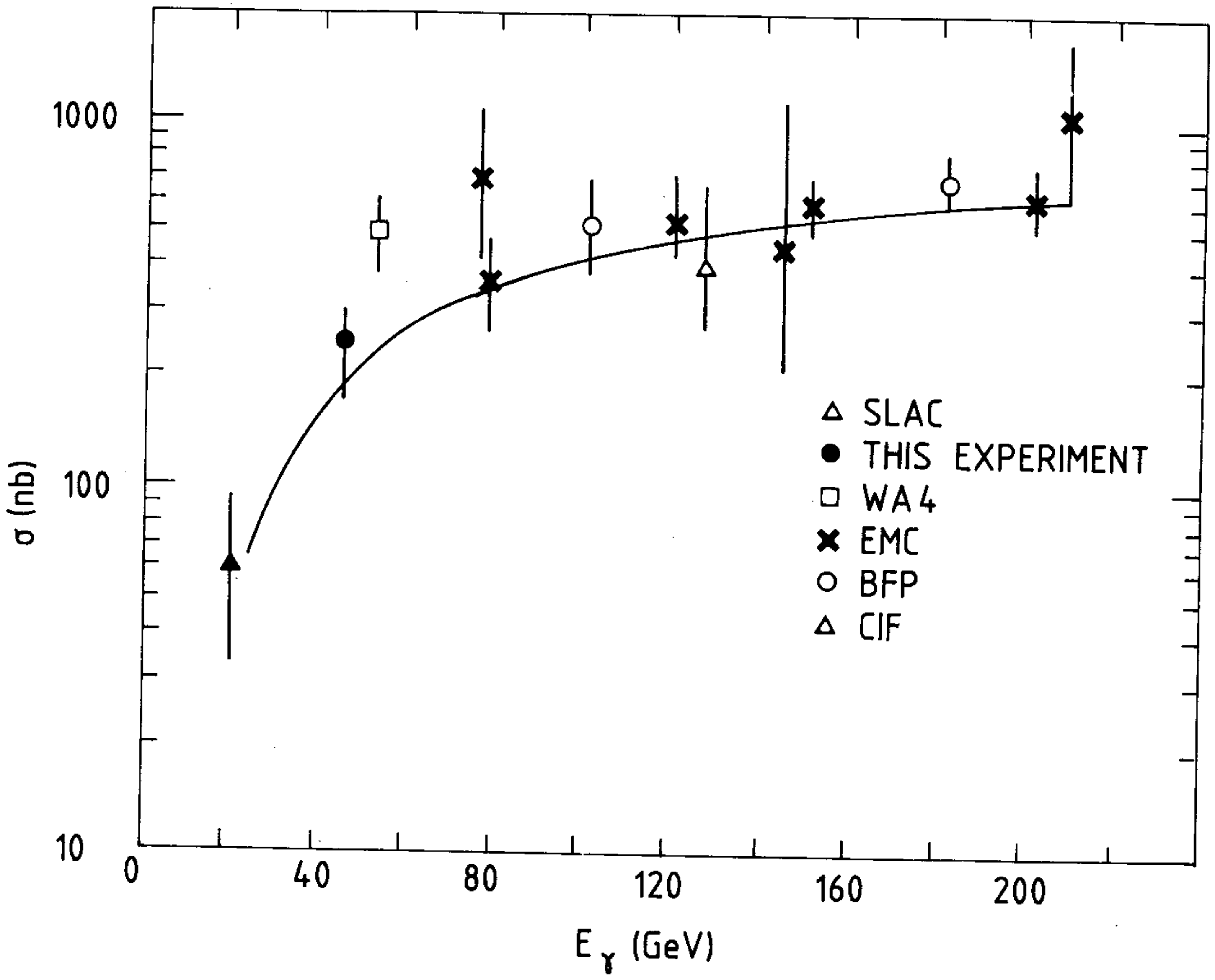
FIGURE CAPTIONS

Fig. 1 The total charm photoproduction cross section as a function of photon energy. The data are taken from refs [4-8]. The curve is the prediction of the photon gluon fusion model. In our experiment the error bars take into account the systematic error due to the lifetimes.

Fig. 2 Weighted distributions of $\bar{D}^{o}\pi^{-}$ and $D^{o}\pi^{+}$ masses.

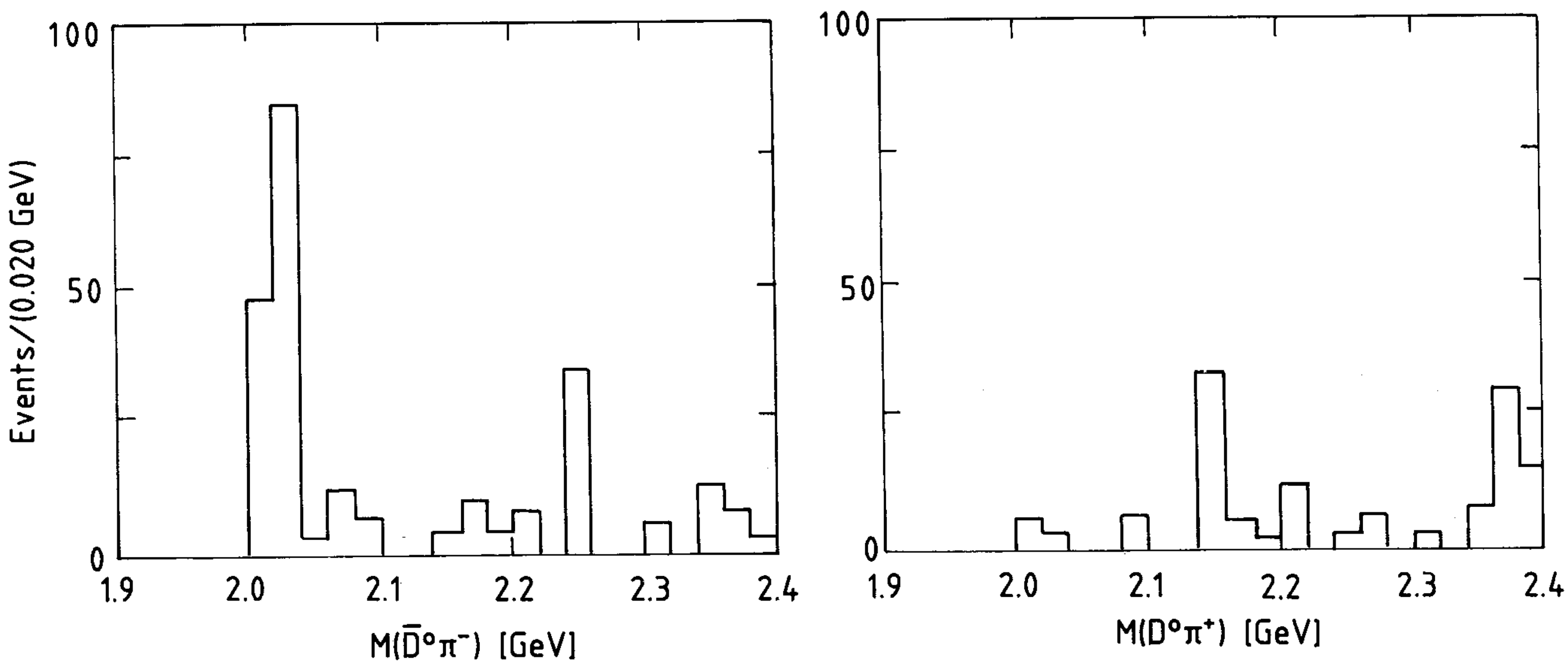
Fig. 3 Weighted distributions of x_F for $D\bar{D}$ channel (left) and $\bar{D}\Lambda_c^+$ channel (right). The curves are the predictions of a photon gluon fusion model with string fragmentation.

Fig. 4 Weighted distributions of the z and of the correlation angle ϕ for the $D\bar{D}$ channel (left) and for the $\bar{D}\Lambda_c^+$ channel (right). The curves are the predictions of a photon gluon fusion model with string fragmentation.



1000
100
10
0
40
80
120
160
200
σ (nb)
E γ (GeV)
SLAC
THIS EXPERIMENT
WA 4
EMC
BFP
CIF

Fig. 1



Events/(0.020 GeV)
100
50
0
1.9
2.0
2.1
2.2
2.3
2.4
M($\bar{D}^o\pi^-$) [GeV]
M($D^o\pi^+$) [GeV]

Fig.2

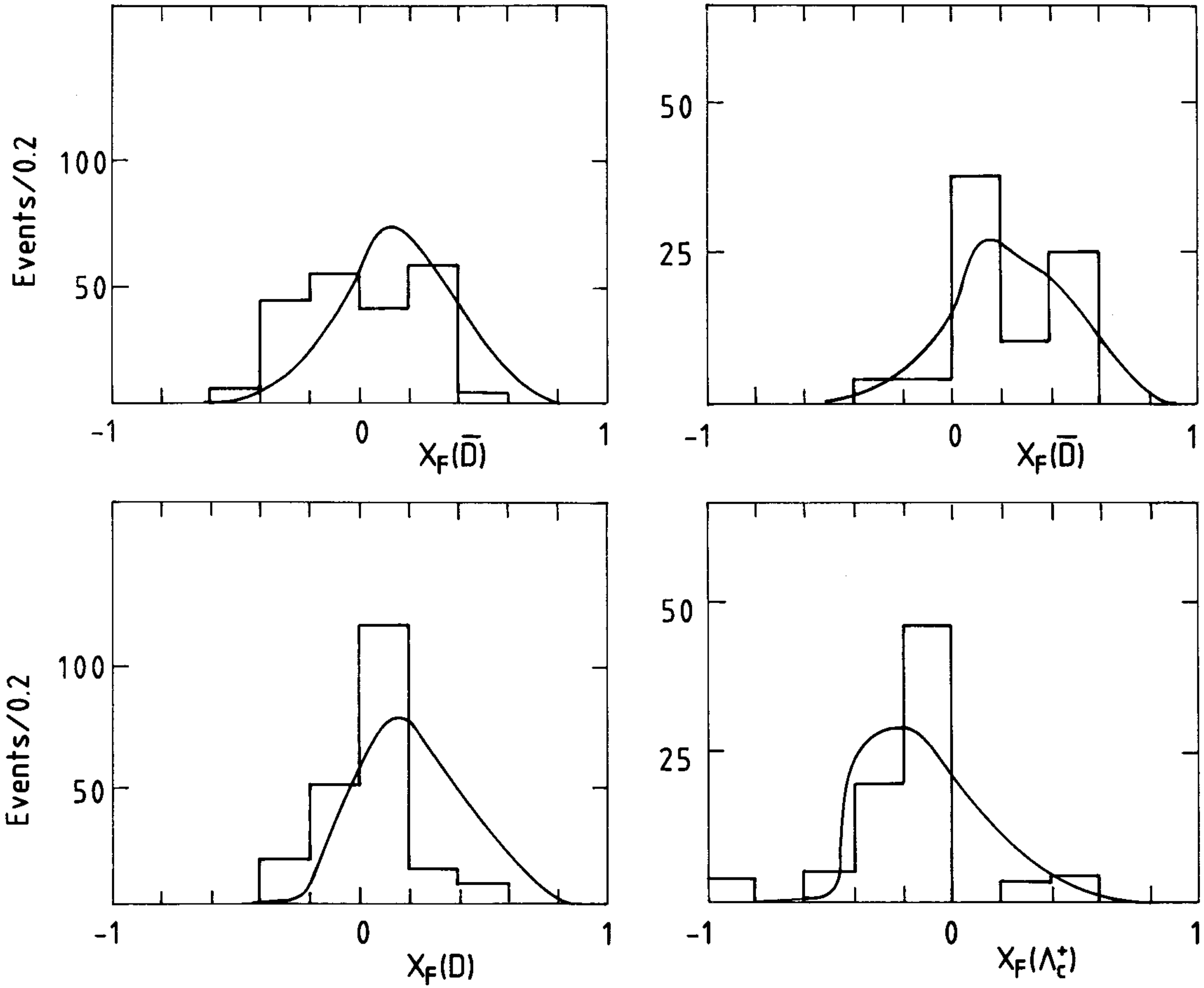

Events/0.2
100
50
-1
0
1
X_F(D̄)
50
25
-1
0
1
X_F(D̄)
Events/0.2
100
50
-1
0
1
X_F(D)
50
25
-1
0
1
X_F(Λc+)

Fig.3

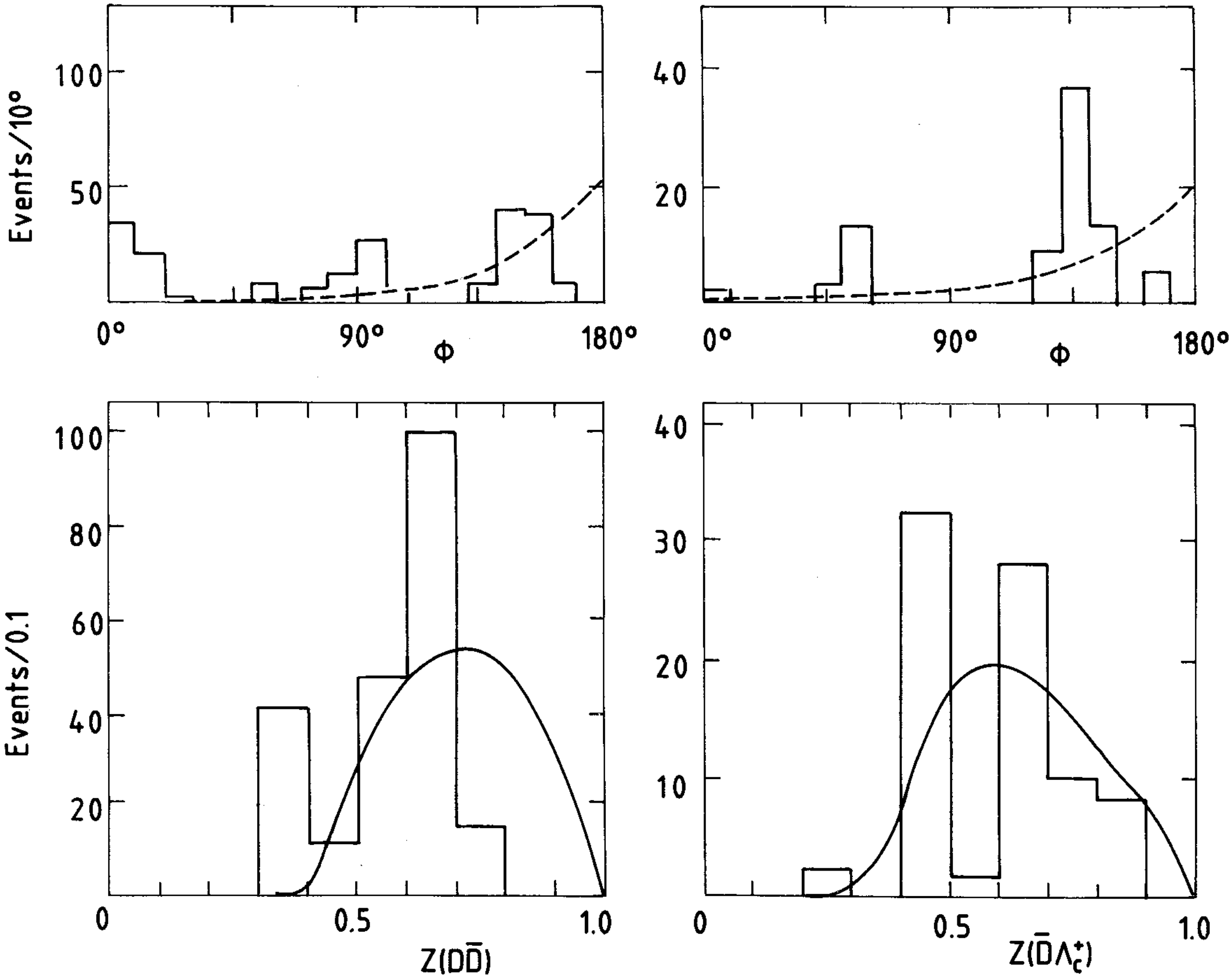

Events/10°
100
50
0°
90°
Φ
180°
40
20
0°
90°
Φ
180°
Events/0.1
100
80
60
40
20
0
0.5
1.0
Z(DD̄)
40
30
20
10
0
0.5
1.0
Z(D̄Λc+)

Fig.4