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Nuclear Dependence of Charm Production by a 340 GeV π^- beam

The WA82 Collaboration

Dedicated to the memory of our friend and colleague Francis Muller

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Abstract

Charmed mesons, produced on silicon, copper and tungsten by 340 GeV π^-, have been identified as peaks in invariant mass distributions. The comparison of the yields of charmed particles originating from interactions in Si, Cu and W allows the mass number dependence of the charm hadroproduction cross section to be measured. Assuming the usual parametrization $\sigma_c = \sigma_0 A^\alpha$, we find $\alpha = 0.92 \pm 0.06$ for charmed mesons with $< x_F >= 0.24$. We do not find any decrease of α with increasing x_F in contrast to the case of the production of particles containing only light quarks.

The cross section for particle production on a nuclear target of mass number A is usually parametrized as:

$$\sigma(A) = \sigma_0 A^{\alpha} \qquad (1)$$

where $\sigma(A)$ is the nuclear cross-section, $\sigma_0 = K\sigma(p)$ is proportional to the proton cross section and α is a parameter. In the hadroproduction of particles containing only light quarks α is observed to decrease with x_F from ~ 0.75 at $x_F = 0$ to ~ 0.45 at $x_F = 1$ [1] and to increase with p_T [2].

The importance of determining α for charm is two-fold:

(a) To establish if perturbative QCD is applicable in the case of charm (the QCD parton model predicts the charm cross section to be an incoherent sum of elementary processes on partons and hence proportional to the number of quarks in the nucleon, that is $\alpha \sim 1$).

(b) To reconcile the results of charm hadroproduction experiments performed with different target materials [3].

Previous A-dependence measurements of the charm hadroproduction cross section σ_c give conflicting indications: a measurement based on the comparison of two bubble chamber experiments [4] favours $\alpha \sim 1$ but with large errors, while beam dump experiments [5] based on the measurement of lepton yields which need large and model dependent correction factors, favour $\alpha \sim 0.75$.

In this paper we report on a study which compares charm hadroproduction in targets of silicon, copper and tungsten. The experiment has been performed at the Ω Spectrometer at CERN using a beam of 340 GeV π^-. Details of the apparatus, of the data processing and of the trigger requirements have been given in previous publications [6]. Here we simply recall the features that are most relevant to this analysis.

The experiment is based on the detection and measurement of secondary vertices. Charm events are produced by interactions of 340 GeV π^- in a 2 mm thick target composed of two different materials placed side by side along the z axis, where z is the vertical coordinate transverse to the beam direction. The beam illuminates the two halves of the target simultaneously thus eliminating several possible sources of systematic uncertainty. Part of the data have been taken using Si and W as target materials, part using Cu and W.

Tracks and vertices are precisely reconstructed by means of a telescope made of 23 silicon microstrip detectors that complements the track information provided by the Ω Spectrometer. Typical errors on transverse (longitudinal) vertex position are of 10 (500) μm while the error on momentum measurement is $\frac{\Delta p}{p^2} \sim 10^{-4}$ GeV^{-1} [6]. The acceptance of the apparatus is such that charmed particles can be reconstructed only for positive x_F.

Events are accepted only if:

a) the primary vertex (VTX1) lies inside the target within $2\sigma_1$(σ_1 being the error on the VTX1 position);

b) at least one secondary vertex (VTX2) is found downstream of the target and upstream of the first microstrip detector (5.6 cm distant from the target centre). The tolerance here is $3\sigma_2$(σ_2 being the error on the VTX2 position);

c) the distance between VTX1 and VTX2 exceeds $6\sigma_{12}$ (where $\sigma_{12} = (\sigma_1^2 + \sigma_2^2)^{1/2}$).

d) the sum of the momenta of the tracks associated with a secondary vertex points back to the primary vertex within 60 μm.

In this analysis the invariant mass of the set of tracks associated with each secondary vertex is calculated without using particle identification. For the two-prong vertices we thus assume both the $K\pi$ and πK combinations, for the three-prong vertices the Cabibbo favoured $K\pi\pi$ combination is taken and for the four-prong vertices the four possible $K\pi\pi\pi$ combinations are taken. Charmed mesons appear as peaks in the above invariant mass distributions as shown in figure 1 (a) to (c). We similarly look, in the same data sample, for $K^0_S \to \pi^+\pi^-$ and we find the signal shown in figure 1 (d); this signal was used as a check in the analysis we describe below.

Events are assigned to a given target material according to the z-coordinate of the primary vertex. The distributions along z of primary vertices for K^0_S and D^0 events are shown in figure 2 for the Si/W target. In order to avoid wrong assignments a 180 μm wide horizontal band at the boundary between the two materials is excluded. The number of charmed mesons in Si, Cu and W are then determined by maximum likelihood fits to the invariant mass distributions. The signal peaks are fitted with Gaussians and the backgrounds with a third order polynomials. As an example the fits for the decay $D^\pm \to K^\mp\pi^\pm\pi^\pm$ in Si, Cu and W are shown in figure 3. The number of D mesons that we reconstruct are 102 ± 13 in silicon, 528 ± 32 in copper and 1017 ± 35 in tungsten.

In order to perform the calculation of α as defined in eq.(1) we must know:

a) the beam flux on the two sides of the target

b) the biases due to the trigger, to the event reconstruction and to the analysis.

The flux correction has been measured using beam events that have been recorded interleaved with the experimental triggers. The error on the ratio of the fluxes is $3 \cdot 10^{-3}$ and it does not therefore contribute appreciably to the error on the α measurement.

To correct for the trigger, the reconstruction and the analysis biases we have developed a detailed Monte Carlo. Charm events were generated by a combination of FRITIOF 6 [7] for the nuclear, low p_T part and PYTHIA 5.4 [8] for the perturbative QCD part. Simulation of hadronization and decays was done by JETSET 7.3 [9]. Events of the type $\pi^- A \to K^0_S X$ or $\pi^- A \to C\overline{C}X$ were generated, where $A = Si, Cu$, or W and C is the charmed hadron under study. The decay channel of C is fixed whereas the nature and the decay channel of the charmed partner $\overline{C}$ are distributed according to measured cross sections and branching ratios. The phase space distributions for all particles are those emerging from the Lund programs. The detector simulation was done with a GEANT 2 [10,11] program which includes all important effects like inefficiency, noise, scattering, pair production, secondary interactions, etc.. GEANT outputs were then passed through a trigger simulator and through the same program chain used for the analysis of the real data. K^0_S events were generated by FRITIOF 6 and then treated in the same way as the charm events.

To control our procedure, we have first performed the calculation of α for the K^0_S sample and we obtain

$$\alpha(K^0_S) = 0.72 \pm 0.02 \qquad \text{for} \quad < x_F >= 0.05$$

in good agreement with published data [1,12].

The same procedure, applied to the charm sample, gives

$$\alpha(D) = 0.92 \pm 0.06 \qquad \text{for} \quad < x_F >= 0.24$$

The error is dominated by the statistics, and the systematic uncertainty arising from Monte Carlo corrections is small and is included in the quoted error.

Separate measurements for the three decay channels we have considered, give: $\alpha(\overline{D}^0 \rightarrow K^{\mp}\pi^{\pm}) = 1.03 \pm 0.11, \alpha(D^{\pm} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}) = 0.84 \pm 0.08, \alpha(\overline{D}^0 \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}\pi^{\mp}) = 0.93 \pm 0.11$.

There have been some indications that α may decrease with x_F in charm production by pions [13]. Decrease of α with x_F has been also recently observed in J/ψ production by protons[14]. However, as shown in Figure 4, our data do not indicate, within the present statistical accuracy, any decrease of $\alpha(D)$ with x_F which is similar to what has been reported for J/ψ production by pions [15].

In conclusion, the present data obtained with a 340 GeV π^- beam, indicate that σ_c increases faster with the mass number than the production cross section of hadrons containing only light quarks. The value of the α parameter we measure for open charm production by pions is compatible with that predicted by perturbative QCD and agrees with the value obtained for hidden charm production by protons [14], and by pions [15]. No statistically significant decrease of α with x_F is observed.

REFERENCES

[1] D.S.Barton et al., Phys. Rev. D 27 (1983) 2580.

[2] L.Kluberg et al., Phys. Rev. Lett. 38 (1977) 670.

[3] S.P.K.Tavernier, Rep. on Progr. in Phys. 50 (1987) 1439.

[4] H.Cobbaert et al., Zeitschr. für Phys. C36 (1987) 577.

[5] M.E.Duffy et al., Phys. Rev. Lett. 55 (1985) 1816.

H.Cobbaert et al., Phys. Lett.B 191 (1987) 456.

[6] M.Adamovich et al., IEEE Trans. Nucl. Sci. 37 (1990) 236.

M.Adamovich et al., Nucl. Instr. and Meth. in Phys. Res. A309 (1991) 401.

[7] B.Nilsson-Almqvist and E.Stenlund, Comp. Phys. Comm. 43 (1987) 387.

[8] T.Sjostrand and M.Bengtsson, Comp. Phys. Comm. 43 (1987) 367.

[9] H.U.Bengtsson and T.Sjostrand, Comp. Phys. Comm. 46 (1987) 43.

[10] R.Brun et al., GEANT User Guide and Reference Manual, CERN-DD/EE/83-1.

[11] J.C.Lassalle and F.Carena, OMGEANT Manual, CERN-DD/EE/79-1.

[12] P.Skubic et al. Phys. Rev. D 18 (1978) 3115.

[13] M.Mac Dermott and S.Reucroft, Phys. Lett. B 184 (1987) 108.

[14] D.M.Alde et al. Phys. Rev. Lett. 66 (1991) 133.

[15] S.Kartik et al. Phys. Rev. D vol.41, n.1 (1990) 41

FIGURE CAPTIONS

Fig.1 - Charm signals used in this analysis:

a) $K^{\pm}\pi^{\mp}$

b) $K^{\pm}\pi^{\mp}\pi^{\mp}$

c) $K^{\pm}\pi^{\mp}\pi^{\mp}\pi^{\pm}$

d) $K^0_S \to \pi^+\pi^-$ signal. Only the K^0_S decaying in front of the silicon detector telescope are considered.

Fig.2 - z-distribution of primary vertices in the target made of silicon and tungsten for the K^0_S and the $D^0 \to K^{\mp}\pi^{\pm}$ samples.

Fig.3 - Invariant mass distributions of $D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$ and their fits (see text for details) for interactions in the target made of (a) tungsten and (b) silicon and in the target made of (c) tungsten and (d) copper.

Fig.4 - The parameter α for charm production as measured in three x_F intervals.

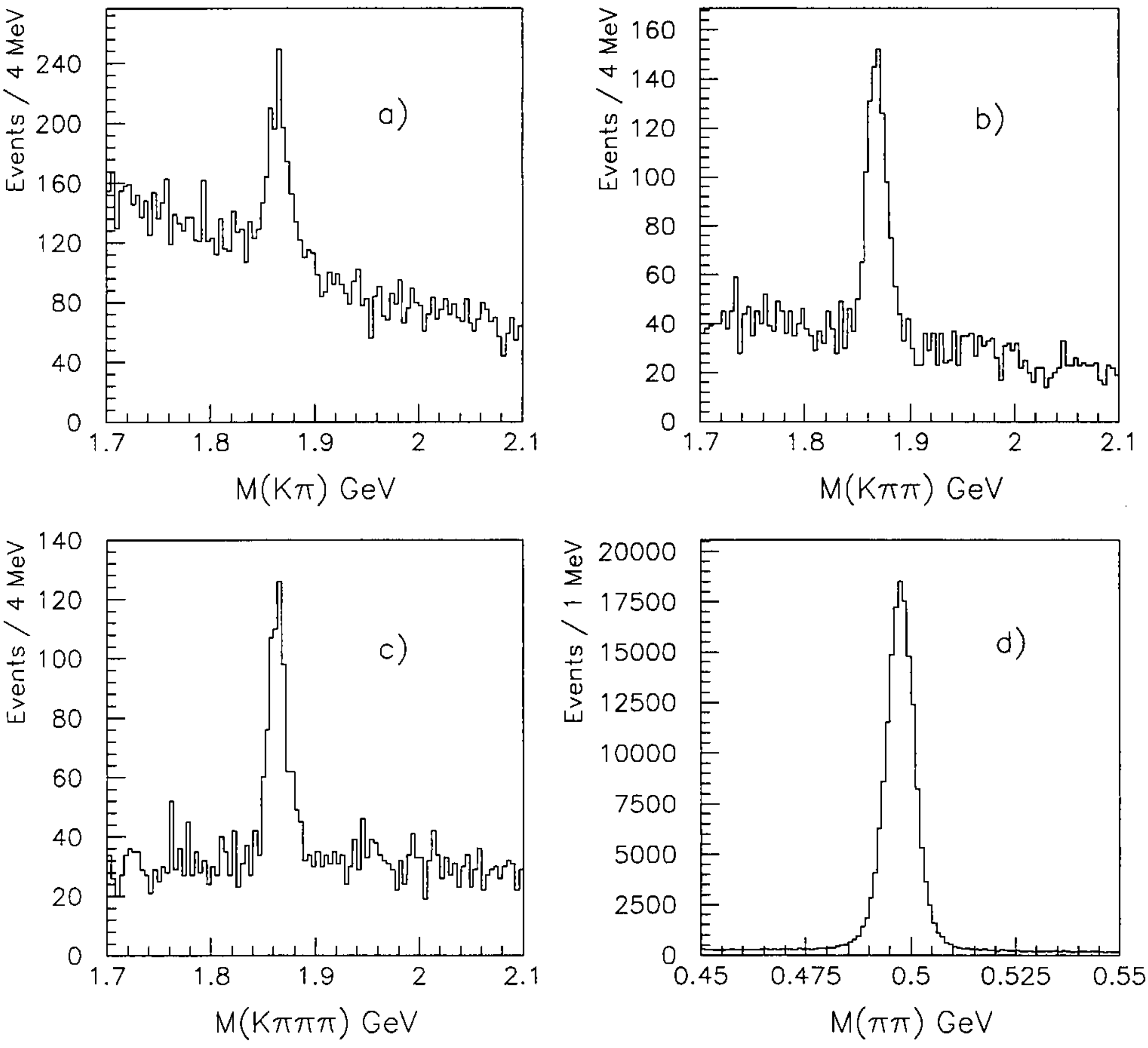
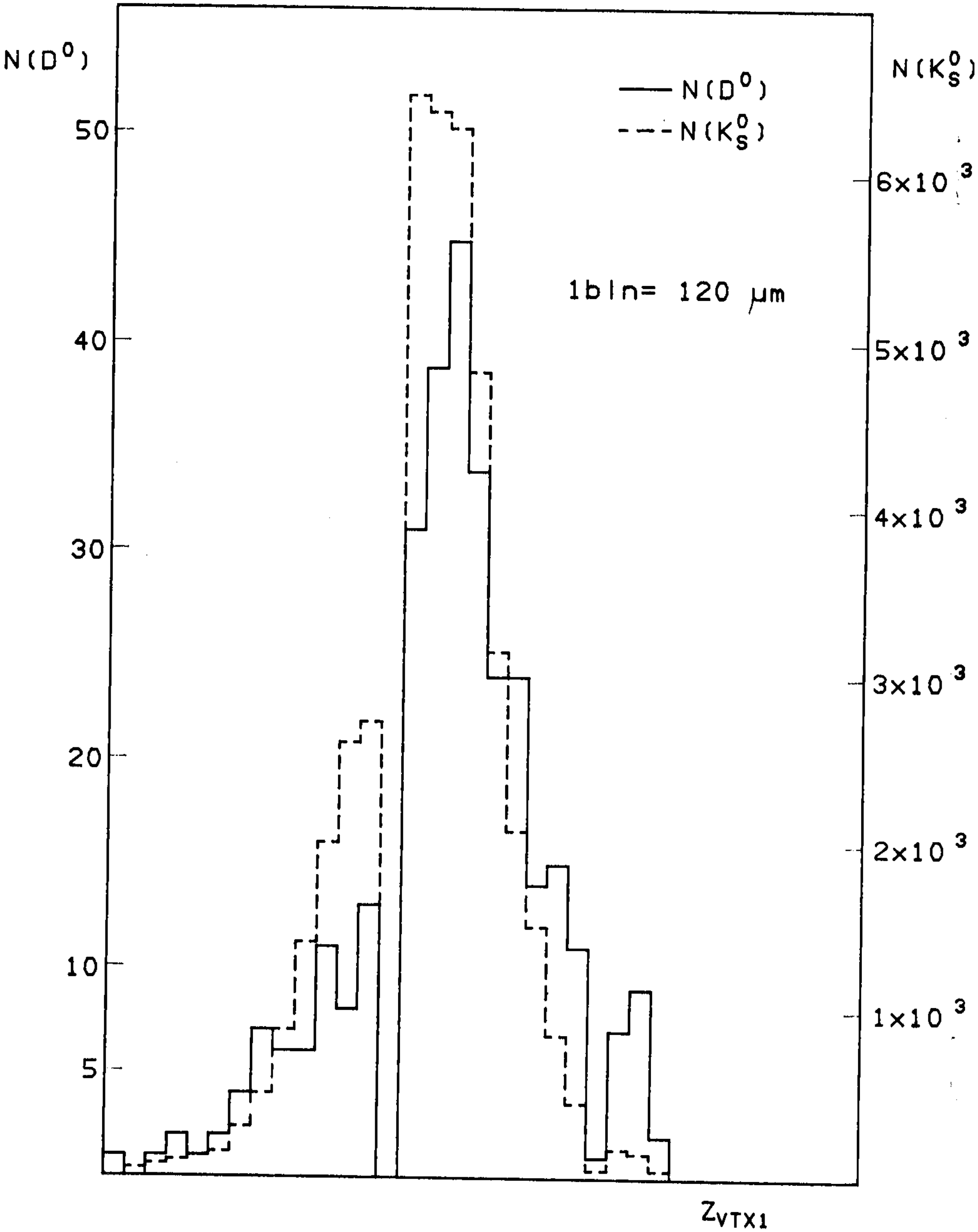

a)
Events / 4 MeV
M(Kπ) GeV
b)
Events / 4 MeV
M(Kππ) GeV
c)
Events / 4 MeV
M(Kπππ) GeV
d)
Events / 1 MeV
M(ππ) GeV

Fig. 1



N(D0)
N(K0S)
N(D0)
N(K0S)
50
40
30
20
10
5
6x10 3
5x10 3
4x10 3
3x10 3
2x10 3
1x10 3
1bln= 120 μm
ZVTX1

Fig. 2

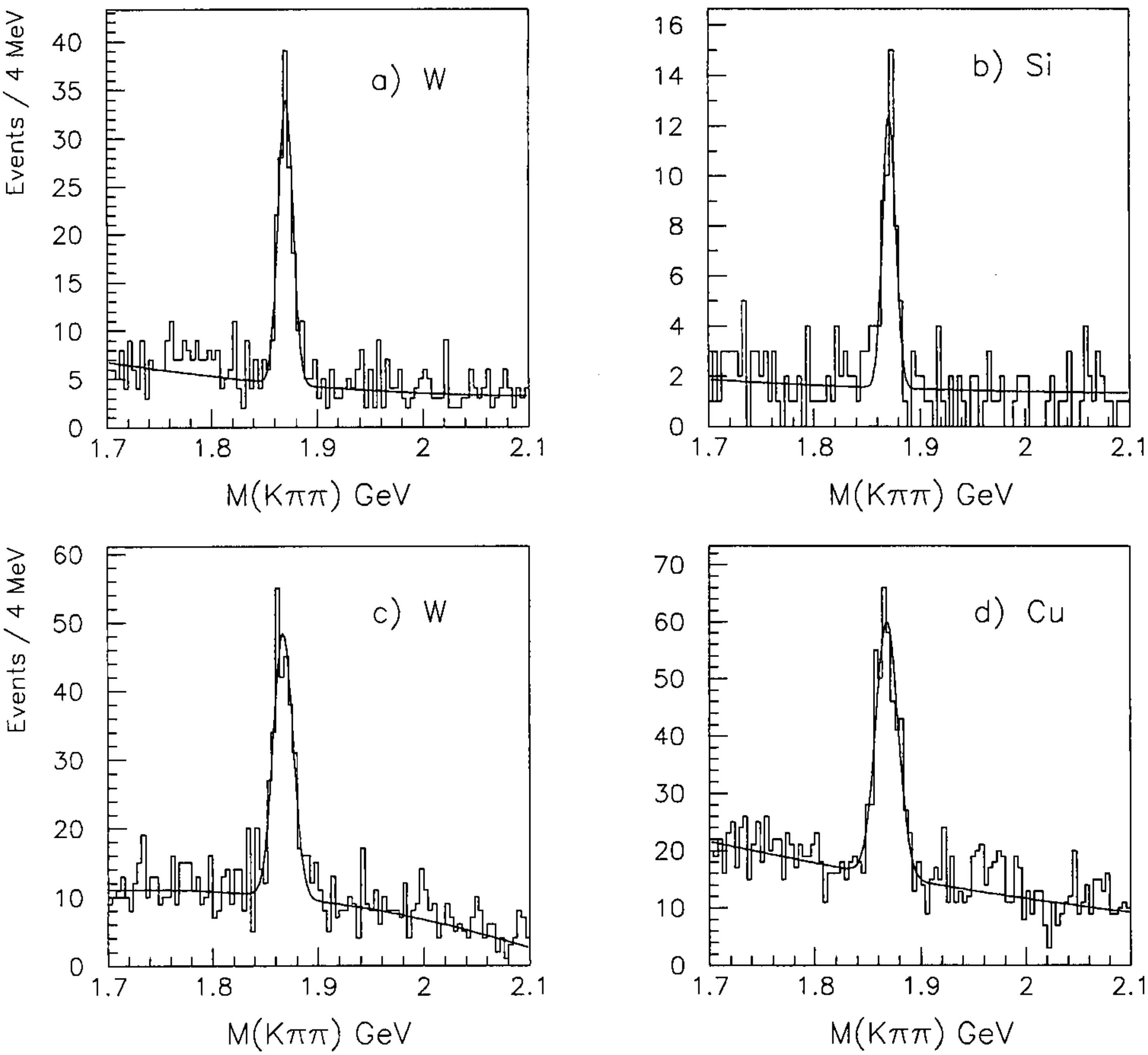


Fig. 3

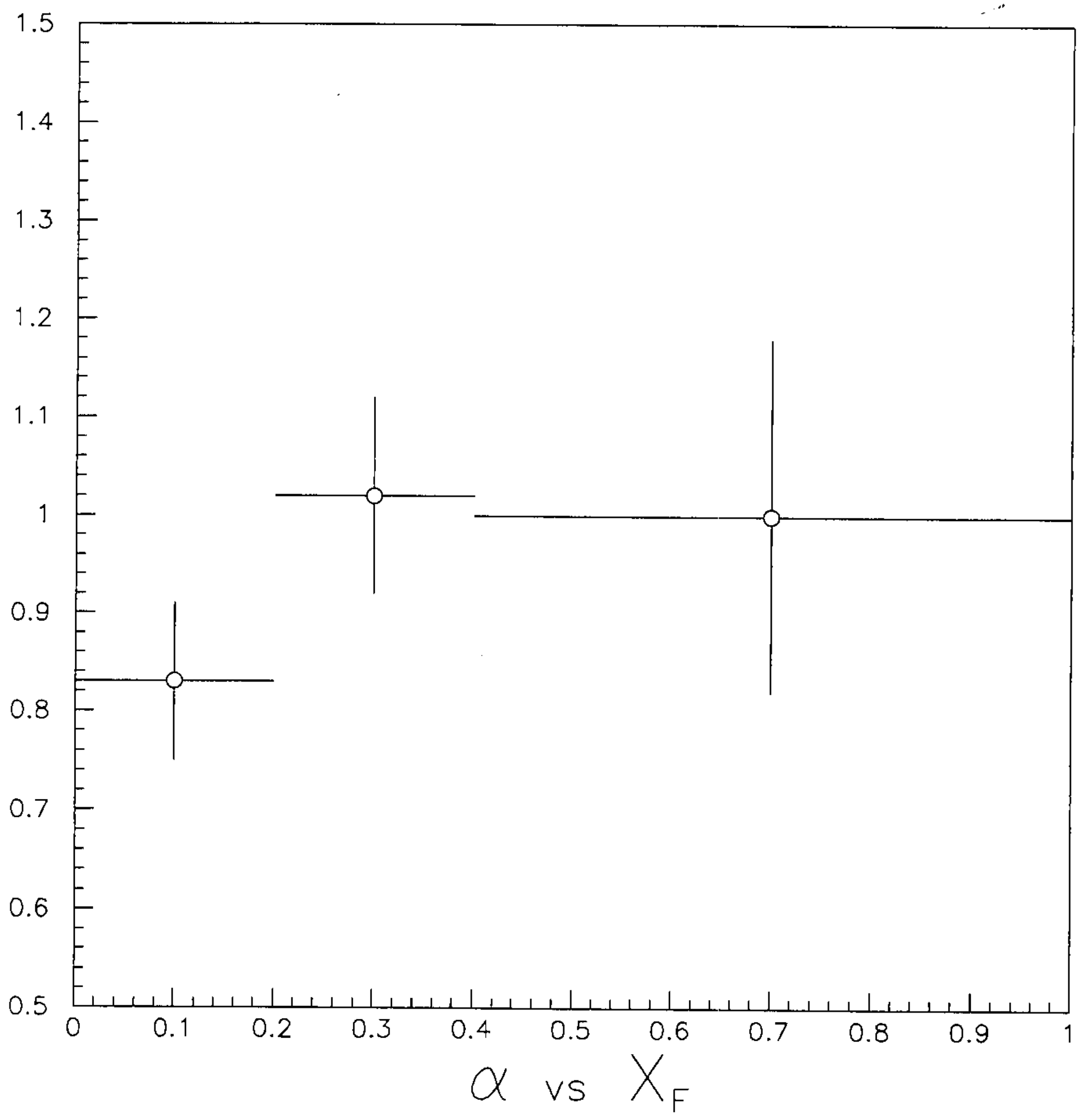


Fig. 4