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Observation of double ϕ-meson production in the central region for the reaction $pp \rightarrow p_f (K^+K^-K^+K^-) p_s$ at 300 GeV/c.

WA76 Collaboration

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Abstract

The reaction $pp \rightarrow p_f (K^+K^-K^+K^-) p_s$ in which the $K^+K^-K^+K^-$ system is centrally produced has been studied at 300 GeV/c. $\phi\phi$ production has been observed and the ratio $\sigma(\phi K^+K^-)/\sigma(\phi\phi)$ is 1.0 ± 0.3. The cross-section for central production of $\phi\phi$ is found to be the same at 300 GeV/c and 85 GeV/c. An angular analysis of the $\phi\phi$ system favours $J^P = 2^+$ over 0^-.

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Studies of $\phi\phi$ production are of interest due to the suggestion that this channel could be a source of gluonic states. In particular, the OZI forbidden reaction

$$\pi^- p \to \phi\phi n \qquad (1)$$

has been studied at 22 GeV/c [1], and 16 GeV/c [2]. The fact that this reaction was only suppressed by a factor of $\approx 5^1$ relative to the OZI allowed reaction

$$\pi^- p \to \phi K^+ K^- n \qquad (2)$$

was interpreted [3] as evidence for the existence of bound gluon states decaying into $\phi\phi$. This led to a controversy about whether or not "double hairpin" reactions such as (1) are in fact OZI forbidden [4].

The OZI allowed reaction

$$K^- p \to \phi\phi\Lambda \qquad (3)$$

has been studied at 8.25 GeV/c [5] and 18.5 GeV/c [6] and its cross section has been found to be a factor of about 4 less than for the reaction

$$K^- p \to \phi K^+ K^- \Lambda. \qquad (4)$$

Thus it appears that reaction (1) is not OZI suppressed. In addition, the cross-section for $\phi\phi$ production in the π^- reaction, relative to the K^- reaction is suppressed by a factor of 5, whereas for single ϕ production there is a suppression factor of about 50.

A spin parity analysis of the $\phi\phi$ system in $\pi^- p$ [7] gives evidence for the observation of three $J^{PC} = 2^{++}$ states which constitute most of the $\phi\phi$ cross section, while the $\phi\phi$ observed in radiative J/ψ decay [8] is dominated by $J^{PC} = 0^{-+}$.

Experiment WA76 is designed to study exclusive final states formed in the reaction

$$pp \to p_f\,(X^0)\,p_s \qquad (5)$$

where the subscripts f and s indicate the fastest and slowest particles in the laboratory respectively and X^0 represents the central system that is presumed to be produced by double exchange processes. At high centre-of-mass energies these double exchange processes are believed to be dominated by Double Pomeron Exchange (DPE), where the Pomeron is thought to have a large gluonic content, leading to the conclusion that Pomeron-Pomeron scattering could be a source of gluonic states.

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[1] Throughout this paper a correction has been made for the unseen decay modes of the ϕ. The ratio of ≈ 10 quoted in [1] was for $\phi \to K^+K^-$ only.

The experiment has been performed using the CERN Omega Spectrometer at two incident beam momenta, 85 and 300 GeV/c, corresponding to centre-of-mass energies of $\sqrt{s}$ = 12.7 and 23.8 GeV respectively. Results on $\phi\phi$ production at 85 GeV/c have been published previously [9].

This paper presents results from the 300 GeV/c data and studies the energy dependence of central $\phi\phi$ production. Details of the layout of the apparatus, the trigger conditions and the data processing have been given in a previous publication [10]. The trigger was designed to enhance double exchange processes with respect to single exchange and elastic processes.

Events corresponding to the reaction

$$pp \rightarrow p_f (K^+K^-K^+K^-) p_s \qquad (6)$$

were selected from charge balancing six-prong events, using the momentum cuts |Missing p_x| < 20.0 GeV/c, |Missing p_y| < 0.16 GeV/c and |Missing p_z| < 0.06 GeV/c, where the x-axis is along the beam direction.

Information from Cerenkov counters was used to ensure that at least one of the centrally produced particles was a kaon or ambiguous kaon/proton and that none of the centrally produced particles was a positively identified pion. A pulse-height momentum correlation in a system of scintillation counters was used to ensure that the slow particle was a proton.

The method of Ehrlich et al. [11], modified for four tracks, has been used to compute the mass squared of the four central particles (assumed to be equal). The resulting distribution is shown in fig.1a, fitted with an exponential and a Gaussian, where a signal of the four kaon channel can be seen at 0.24 GeV^2. A cut on the mass squared of

$$0.18 < M^2 < 0.32 \text{ GeV}^2$$

has been used to select a sample of 4K events.

The four possible K^+K^- mass combinations are plotted in fig.1b, where a clear ϕ signal can be seen. A fit has been performed to this spectrum where the ϕ is represented by a Breit-Wigner convoluted with a Gaussian to represent the experimental resolution, and the background is described by

$$a(m-m_{th})^b \exp(-cm-dm^2)$$

where m is the K^+K^- mass, m_{th} is the threshold mass and a,b,c and d are fit parameters. This gave the following results

$$m(\phi) = 1019.1 \pm 0.8 \text{ MeV}$$

$$\sigma(\text{Gaussian}) = 3.3 \pm 0.5 \text{ MeV}$$

$$\Gamma(\text{Breit-Wigner}) = 4.22 \text{ MeV (fixed)}$$

The Feynman x_F distribution is shown in fig.1c for the ϕK^+K^- system and the central events lie within $|x_F| < 0.2$.

Fig. 2a shows the K^+K^- vs K^+K^- lego plot, which indicates strong $\phi\phi$ production. By selecting one K^+K^- mass to lie within a band around the ϕ mass (from 1.008-1.030 GeV) and plotting the effective mass of the other pair, the spectrum of fig. 2b was produced. The large ϕ signal with little background confirms the presence of a strong $\phi\phi$ signal.

The number of events in nine regions around the $\phi\phi$ position in the K^+K^- scatter plot are shown in fig.2c; no event has more than one entry in this region. From these numbers and applying a correction for the tails of the ϕ, the total number of $\phi\phi$ events is found to be 39 ± 8.

The $\phi\phi$ effective mass spectrum is shown in fig.3a for the events in the central bin of fig.2c, and shows an accumulation near threshold similar to that observed at 85 GeV/c [9]. The combined spectrum for 85 and 300 GeV/c is shown in fig.3b. The curve indicates the shape of the $\phi\phi$ mass spectrum observed in reaction (1) at 22 GeV/c [7], which consists of three 2^{++} states. The $\phi\phi$ mass distribution observed in central production is similar.

The angular distributions of the 4K system can be used to determine the spin-parity of the intermediate $\phi\phi$ state using a method formulated by Chang and Nelson [12] and Trueman [13]. Three angles have to be considered: the azimuthal angle χ, between the two ϕ decay planes and the two polar angles θ_1 and θ_2 of the K^+ decays in their respective ϕ rest frames relative to the ϕ momenta in the $\phi\phi$ rest frame.

For a $\phi\phi$ sample of unique spin-parity and free of background the distribution of χ takes the form

$$dN/d\chi \;=\; 1 + \beta\cos(2\chi)$$

where β is a constant which depends only on the spin-parity of the $\phi\phi$ system and is independent of its polarisation.

Similarly

$$dN/d\cos\theta \;=\; 1 + (\xi/2)(1 + \cos^2\theta) .$$

Values of β and ξ for different spin-parity states are given in table 1 [14]. Fig.4 shows the χ and $\cos\theta$ distributions for the 85 and 300 GeV/c data. The $\phi\phi$ system observed in radiative J/ψ decays is dominated by $J^P = 0^-$ while the $\phi\phi$ system observed in reaction (1) is dominated by $J^P = 2^+$. Curves corresponding to the distributions expected for states with $J^P = 0^-$ ($\beta = -1$, $\xi = -1$) and 2^+ (0,2) ($\beta = 1/15$, $\xi = 0$) are shown in fig.4. The data is more compatible with the 2^+ hypothesis than with the 0^-. A fit to the distributions has been performed in order to determine the values of β and ξ and gives

$$\text{85 GeV/c data :} \quad \beta = 0.3 \pm 0.2,\ \xi = -0.1 \pm 0.1$$

$$\text{300 GeV/c data :} \quad \beta = 0.3 \pm 0.2,\ \xi = 0.0 \pm 0.2$$

The two sets of parameters are similar and rule out the 0^- hypothesis. The acceptance has been calculated as a function of χ and $\cos\theta$ and does not change this conclusion.

In order to compare the production rates for ϕK^+K^- and $\phi\phi$, the number of ϕK^+K^- events has been estimated. This was done by subtracting twice the number of $\phi\phi$ events from the total number of ϕ's observed in fig.1b, and gives 81$\pm$22 ϕK^+K^- events. The geometrical acceptance has been found to be similar for $\phi\phi$ and ϕK^+K^- production. After correcting for unseen decay modes of the ϕ, the ratio of cross sections is estimated to be

$$\sigma(\phi K^+K^-)/\sigma(\phi\phi) = 1.0 \pm 0.3$$

This compares with a value of 1.5$\pm$0.6 found in central production at 85 GeV/c [9].

Cross-sections for the reaction

$$pp \rightarrow p_f\,(\phi\phi)\,p_s \qquad (7)$$

at 85 and 300 GeV/c have been estimated to be 21$\pm$9 nb and 18$\pm$6 nb respectively for $0.0 < x_F < 0.2$. Geometrical acceptances, detector efficiencies and losses due to cuts and charged kaon decay have been taken into account.

In conclusion, $\phi\phi$ production has been observed in the central region in the reaction $pp \rightarrow p_f\,(K^+K^-K^+K^-)\,p_s$ at 300 GeV/c. The $\phi\phi$ mass spectrum shows an accumulation of events near threshold and is similar to that observed in reaction (1) at 22 GeV/c. An angular analysis of the $\phi\phi$ system shows that $J^P = 2^+$ is favoured over 0^-, although other waves cannot be ruled out. The ratio of ϕK^+K^- to $\phi\phi$ production is 1.0$\pm$0.3, which is similar to the value of 1.5$\pm$0.6 found in the same reaction at 85 GeV/c [9]. The cross-sections for $\phi\phi$ production at 85 and 300 GeV/c are the same within errors. This is consistent with the $\phi\phi$ system being produced by a double Pomeron exchange mechanism which predicts that the cross section should remain constant with centre-of-mass energy.

Table 1: The β and ξ values for different spins of the $\phi\phi$ system

J^P	L	S	β	ξ
0^+	0	0	2/3	0
0^+	2	2	1/3	1
0^-	1	1	−1	−1
1^-	1	1	0	1/2
1^+	2	2	0	1/2
2^+	0	2	1/15	0
2^+	2	0	2/3	0
2^+	2	2	2/21	3/14
2^-	1	1	−2/5	−1/10
2^-	3	1	−3/5	−2/3

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1. Figures

Fig. 1 a) The Ehrlich mass squared distribution for the four charged particles.

b) The K^+K^- mass spectrum (four combinations per event) The curve shows the result of a fit using a convoluted Breit-Wigner and Gaussian with a background described in the text.

c) x_F distribution for the ϕK^+K^- system, and the fast and slow particles

The shaded histogram is the x_F for the $\phi\phi$ central system.

Fig. 2 a) Lego Plot of one K^+K^- mass against the other (two entries per event)

b) K^+K^- effective mass of one K^+K^- combination after selecting the other to lie in the ϕ mass band.

c) Scatter table of one K^+K^- mass against the other in the $\phi\phi$ region.

Fig. 3 a) $\phi\phi$ effective mass spectrum for the 300 GeV/c data.

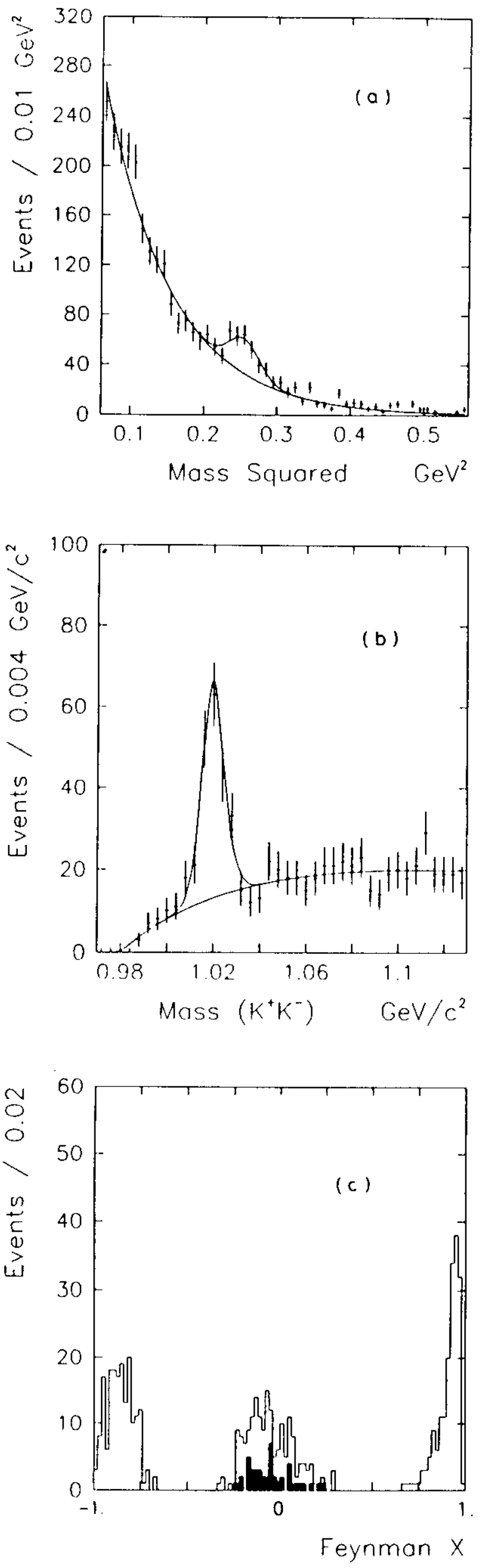
b) $\phi\phi$ effective mass spectrum for the combined 85 and 300 GeV/c data. The curve superimposed is described in the text.

Fig. 4 The χ and $\cos\theta$ distributions for

a),b) the 85 GeV/c data and

c),d) the 300 GeV/c data.

The superimposed curves represent the 2^+ (0,2) (solid) and $0-$ (broken) waves.



Events / 0.01 GeV²
(a)
Mass Squared GeV²
Events / 0.004 GeV/c²
(b)
Mass (K⁺K⁻) GeV/c²
Events / 0.02
(c)
Feynman X

Fig. 1

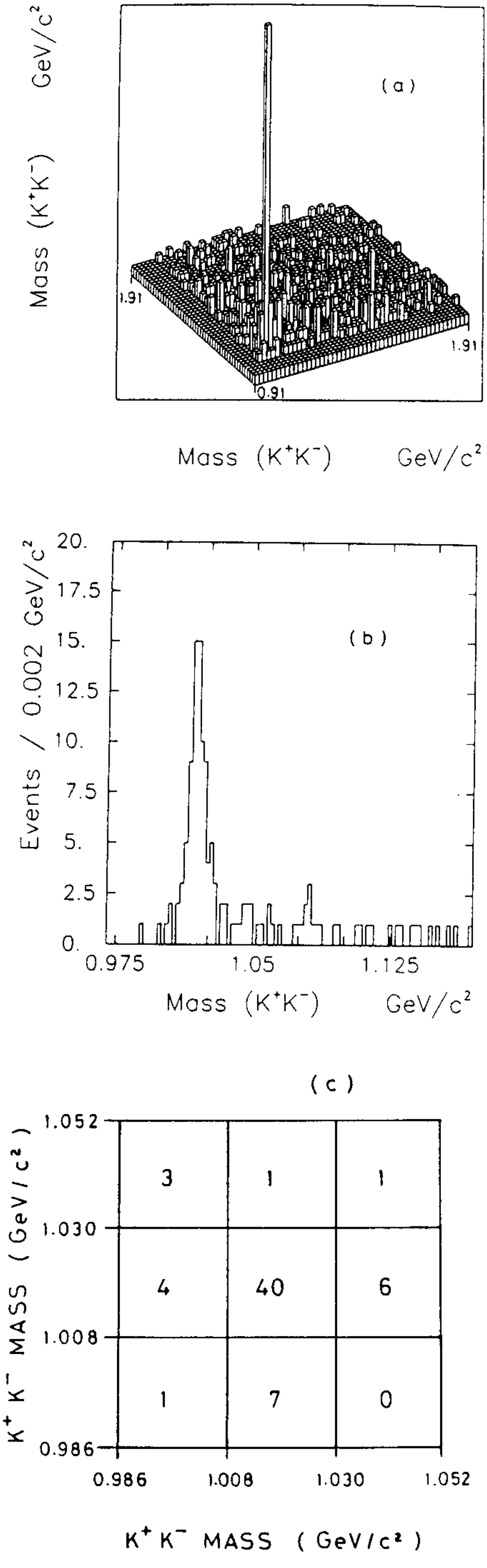
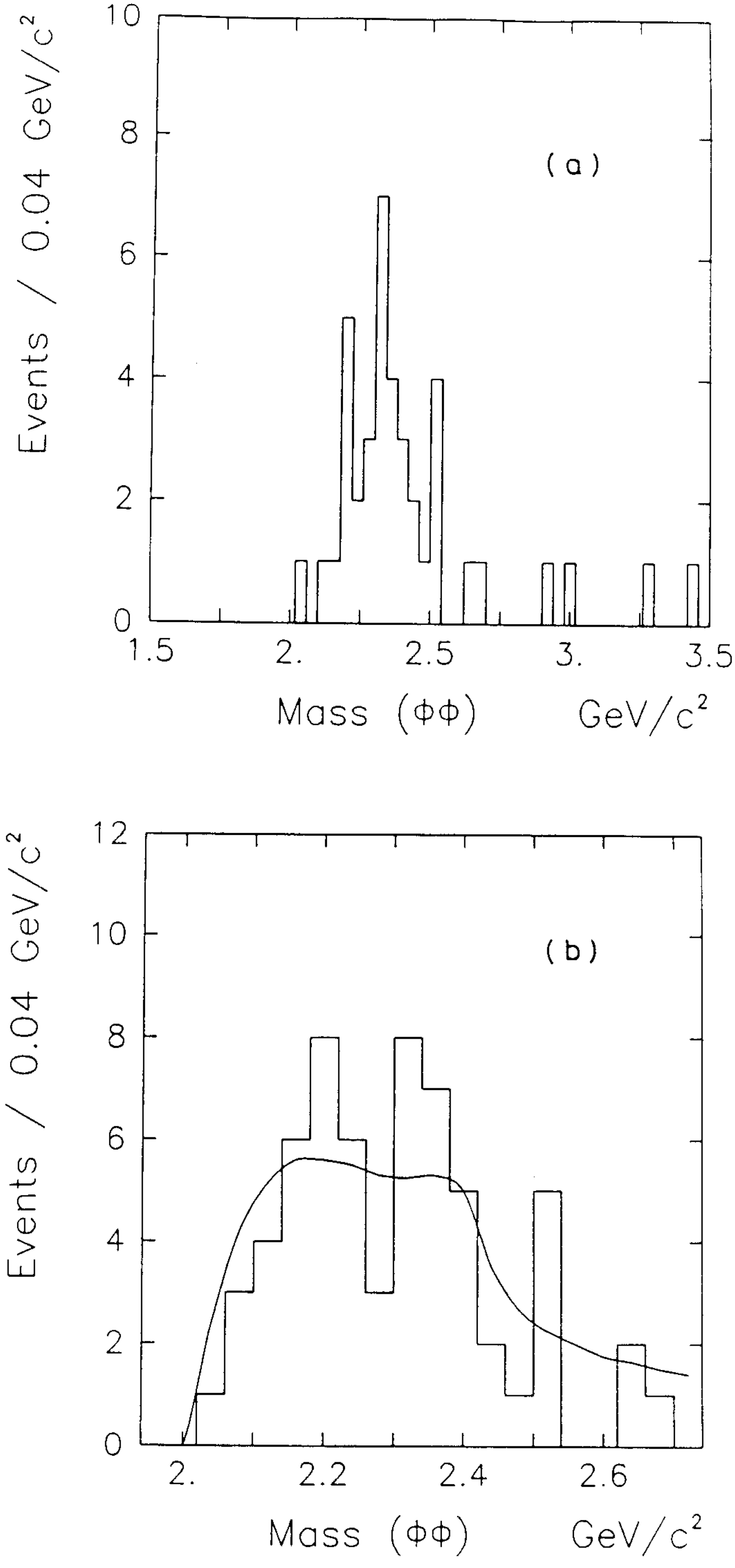

(a)
Mass (K^+K^-) GeV/c^2
1.91
1.91
0.91
Mass (K^+K^-) GeV/c^2
(b)
Events / 0.002 GeV/c^2
20.
17.5
15.
12.5
10.
7.5
5.
2.5
0.
0.975
1.05
1.125
Mass (K^+K^-) GeV/c^2
(c)
K^+K^- MASS (GeV/c^2)
1.052
1.030
1.008
0.986
3
1
1
4
40
6
1
7
0
0.986
1.008
1.030
1.052
K^+K^- MASS (GeV/c^2)

Fig. 2



Events / 0.04 GeV/c²
(a)
0
2
4
6
8
10
1.5
2.
2.5
3.
3.5
Mass (ΦΦ) GeV/c²
Events / 0.04 GeV/c²
(b)
0
2
4
6
8
10
12
2.
2.2
2.4
2.6
Mass (ΦΦ) GeV/c²

Fig. 3

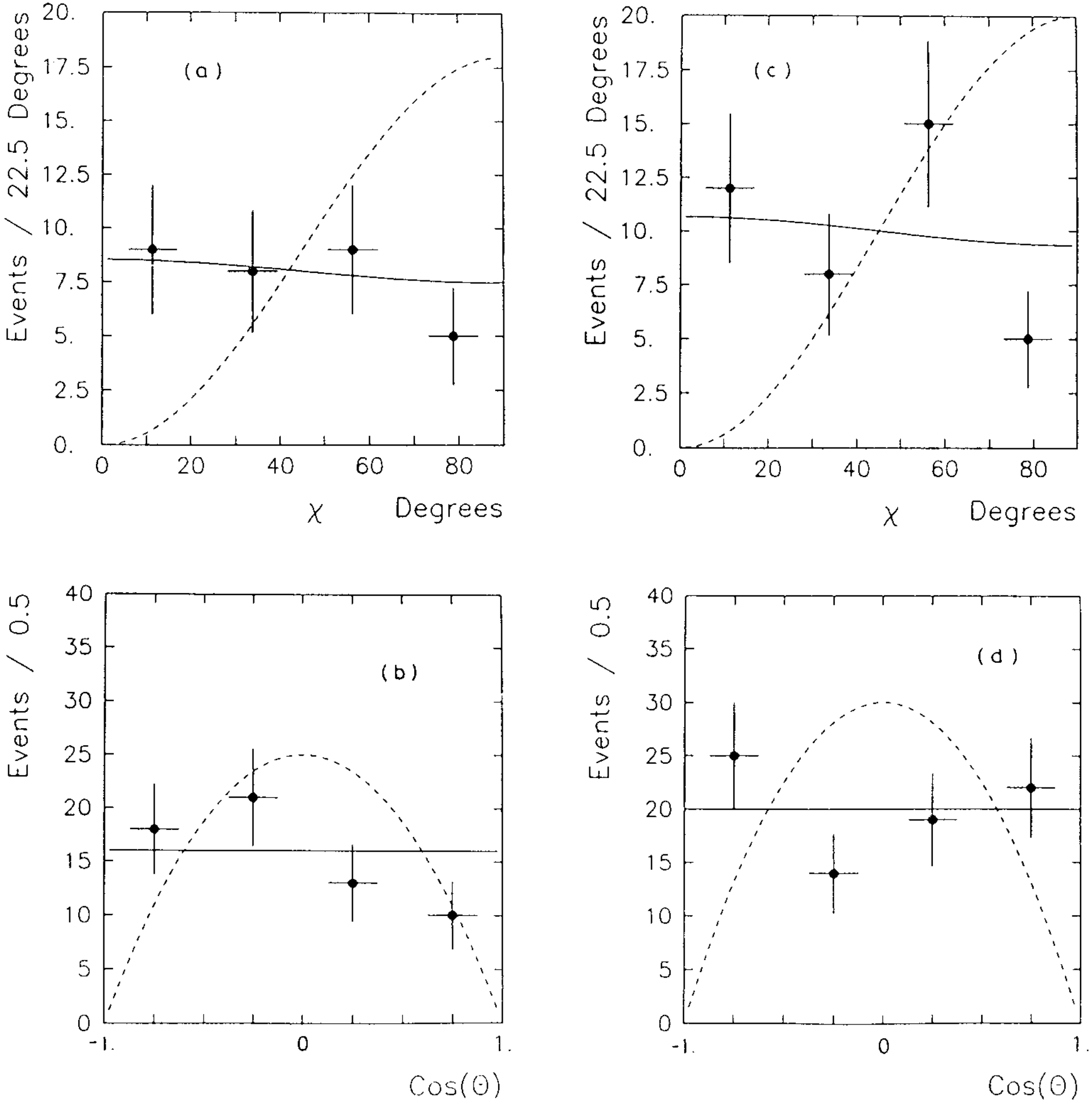


Fig. 4