EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EP 89-23
31 January 1989

A spin-parity analysis of the $f_1(1285)$ and $f_1(1420)$ mesons centrally produced in the reaction $pp \to p_f(K^0{}_S K^{\pm}\pi^{\mp})p_s$ at 300 GeV/c.

WA76 Collaboration

T.A. Armstrong [4,*], M. Benayoun [5], W. Beusch [4], I.J. Bloodworth [3], M. Caponero [2], J.N. Carney [3], R. Childs [3], B.R. French [4], B. Ghidini [2], Y. Goldschmidt-Clermont [4,7], A. Jacholkowski [4], J. Kahane [5], J.B. Kinson [3], A. Kirk [3], K. Knudson [4], V. Lenti [2], Ph. Leruste [5], A. Malamant [5], J.L. Narjoux [5], F. Navach [2], A. Palano [2], E. Quercigh [4], N. Redaelli [4,**], L. Rossi [4,***], M. Sené [5], R. Sené [5], H.R. Shaylor [3], M. Stassinaki [1], M.T. Trainor [4], G. Vassiliadis [1], O. Villalobos Baillie [3], M.F. Votruba [3], G. Zito [2] and R. Zitoun [6]

Abstract

Results are presented of an analysis of the reaction $pp \to p_f(K^0{}_S K^{\pm}\pi^{\mp})p_s$ at 300 GeV/c. Clear $f_1(1285)$ and $f_1(1420)$ signals are seen. A spin parity analysis shows that both are consistent with being 1^{++} states. The $f_1(1420)$ is found to decay only to $K^*\bar{K}$ and no 0^{-+} or 1^{+-} waves are required to describe the data. The production of the $f_1(1285)$ as a function of energy is not the same as that for the $f_1(1420)$ whose cross section is found to be constant with energy.

Submitted to Physics Letters B

---

[1] Athens University, Physics Department, Athens, Greece
[2] Dip. di Fisica dell'Università and Sez. INFN, Bari, Italy
[3] University of Birmingham, Physics Department, Birmingham,U.K.
[4] CERN, CH-1211 Geneva 23, Switzerland
[5] Collège de France, Paris, France
[6] LPNHE, Universités de Paris VI et VII, Paris, France
[7] Deceased

[*] Present address: Pennsylvania State University, University Park, USA
[**] Present address: INFN and Dip. di Fisica, Milan, Italy
[***] Present address: INFN and Dip. di Fisica, Genoa, Italy

At present there is some uncertainty as to the number of states present in the $(K\bar{K}\pi)^0$ mass spectrum around 1.4 GeV. The interest in this region is that one of these states could be a glueball or hybrid state [1]. A state is observed in radiative J/ψ decays with a mass of 1.46 GeV and a spin parity analysis favours 0^{-+} [2]. A spin 1 object is observed in two photon physics with a mass of 1.42 GeV [3]. In hadronic experiments both a 0^{-+} state [4], and a 1^{++} state [5] [6] have been observed with a mass of 1.42 GeV. The 1^{++} state, the $f_1(1420)$ (E), was thought to be the $s\bar{s}$ isoscalar member of the 1^{++} nonet. However, it is not seen in K^- incident experiments where instead an object with $J^{PC} = 1^{++}$ is observed at 1.526 GeV [7]. It has been suggested that this last state, the D′(1530), is the $s\bar{s}$ member of the 1^{++} nonet. If so, then a possible explanation of the state at 1.42 GeV is that it is a gluonic or four quark state [8].

This paper provides further information about this problem by studying the centrally produced exclusive final states formed in the reaction

$$pp \rightarrow p_f (K^0_S K^\pm \pi^\mp) p_s \qquad (1)$$

at 300 GeV/c, where the subscripts f and s indicate the fastest and slowest particles in the laboratory respectively. A comparison is made with data from the same channel at 85 GeV/c [6].

The data come from experiment WA76 which has been performed using the CERN Omega Spectrometer. Details of the layout of the apparatus, the trigger conditions and the data processing have been given in a previous publication [9].

Reaction (1) has been isolated from the sample of events having four outgoing tracks plus a reconstructed V^0 by first imposing on the components of missing momentum the cuts $|\Delta P_x| < 20.0$ GeV/c, $|\Delta P_y| < 0.16$ GeV/c and $|\Delta P_z| < 0.08$ GeV/c, where the x axis is along the beam direction. The $\pi^+\pi^-$ mass distribution for the V^0's shows a clear K^0 signal which was selected by requiring $0.475 < m(\pi^+\pi^-) < 0.52$ GeV.

Reaction (1) was then selected from this sample by using energy conservation. A cut of $|\Delta| \leq 1.6$ (GeV)^2 was used, where

$$\Delta = MM^2(p_f\, p_s) - M^2(K^0_S K^\pm \pi^\mp) .$$

In addition Cerenkov compatibility was required.

These cuts gave 28.8 % of the events with an ambiguous $K^0{}_S K^{\pm}\pi^{\mp}$ assignment. The Ehrlich mass [10] has been calculated for the V^0 and one of the charged particles assuming the other to be a pion. A clear peak is observed in the Ehrlich mass spectrum (not shown) at the kaon mass squared and suitable cuts were applied to select out the $K^0{}_S K^+\pi^-$ and $K^0{}_S K^-\pi^+$ channels.

Fig.1 shows the $K^0{}_S K^{\pm}\pi^{\mp}$ effective mass spectrum (3808 events) where the events that still have an ambiguous $K^{\pm}\pi^{\mp}$ mass assignment are plotted twice (6.8 % of the events). A fit to this spectrum, using two simple Breit-Wigners and a background of the form $a(m-m_{th})^b \exp(-cm-dm^2)$ (where m is the $K^0{}_S K^{\pm}\pi^{\mp}$ mass, m_{th} is the threshold mass and a,b,c,d are fit parameters), yields masses and widths of

$$M_1 = 1278 \pm 2 \text{ MeV} \qquad \Gamma_1 = 25 \pm 4 \text{ MeV}$$

$$M_2 = 1429 \pm 3 \text{ MeV} \qquad \Gamma_2 = 58 \pm 8 \text{ MeV}.$$

A Dalitz plot analysis of the $K^0{}_S K^{\pm}\pi^{\mp}$ mass spectrum has been performed by using Zemach tensors and a standard isobar model [11]. Fits to the $f_1(1285)$ region (1.25 − 1.32 GeV, 200 events) have been performed using amplitudes describing the 0^{-+}, 1^{++}, and 2^{-+} states decaying through $\delta\pi$, where the δ has been described in terms of the Flatté formalism [12]. The fits show that the best solution is for 70 ± 6 % 1^{++} $\delta\pi$ with 30 % phase space background, which is consistent with the amount found from a fit to the mass spectrum. Therefore we conclude that we are observing the $f_1(1285)$ and that no other wave is required by the fit. This agrees with the results obtained at 85 GeV/c [6].

Fig.2 shows the Dalitz plot for the events in the $f_1(1420)$ region defined as $1.37 \le M(K^0{}_S K^{\pm}\pi^{\mp}) \le 1.49$ GeV together with the $K\pi$ and $K\overline{K}$ projections. There are 671 events in the plot. Well defined K^* bands can be seen but there is no enhancement near threshold in the $K\overline{K}$ spectrum.

The $f_1(1420)$ region has been fitted in 40 MeV slices from 1.33 to 1.69 GeV so that the background can also be studied. Different combinations of 22 waves, with $J \le 2$, decaying to $\delta\pi$ and $K^*\overline{K}$ have been used. Full interference between waves having the same spin-parity has been allowed. Interference was also allowed between the 1^{++} and 1^{+-} $K^*\overline{K}$ waves.

The fit shows that the $1^{++}(K^*\bar{K})$ is the dominant wave in the $f_1(1420)$ region. The addition of 0^{-+} or any other waves up to J equals 2 does not increase the Likelihood significantly. The results of the fit including only 0^{-+} and 1^{++} S waves, in addition to phase space, is shown in fig.3. If the $f_1(1420)$ region is defined as $1.37 \leq M(K^0_S K^{\pm}\pi^{\mp}) \leq 1.49$ GeV then the percentage of each wave present is

0^{-+}	(3 ± 2) %
1^{++} S	(56 ± 4) %

Therefore it is concluded that the 0^{-+} waves are consistent with zero and only the 1^{++} wave is needed. A fit with 1^{++} and phase space only gives

1^{++} S	(58 ± 4) %

with 42 % background which is consistent with the amount found from a fit to the total mass spectrum. The result of a Monte Carlo simulation based on the results of the fit is shown superimposed on the Dalitz plot projections in figs. 2b,c,d and shows good agreement.

The fits have been repeated using a Dalitz plot analysis where the combinations are plotted according to their strangeness rather than their charge. The best fit is again found to be for 58 % 1^{++} $K^*\bar{K}$ and no other wave is required.

It has been suggested [13] on the basis of a fit to the Dalitz plot projections only, that the $f_1(1420)$ region is dominated by a $J^{PC} = 1^{+-}$ wave. We have tested this hypothesis on the present data and find a Ln(Likelihood) of 44 for the 1^{+-} wave compared to 85 for the 1^{++} wave. Therefore, we conclude that no 1^{+-} wave is required by the data.

In order to study how the $f_1(1285)$ and $f_1(1420)$ behave as a function of centre-of-mass energy the ratio, R, of the number of $f_1(1285)$ to $f_1(1420)$ events at 85 and 300 GeV/c has been calculated. The mass spectra at both energies have been corrected for geometrical acceptance, which is smoothly varying with effective mass, and have been fitted using two Breit-Wigners of fixed mass and width. The masses and widths used come from a fit to the combined 85 and 300 GeV/c spectrum. A cut of $|x_F| < 0.15$ has been placed on the Feynman x of the central system to select a region for which the acceptance is good for both experiments and gives

$$\text{at } 85 \text{ GeV/c} \qquad R = 0.58 \pm 0.07$$

$$\text{at } 300 \text{ GeV/c} \qquad R = 0.34 \pm 0.03$$

This suggests that the energy dependence of the $f_1(1285)$ production is different from that of the $f_1(1420)$.

The cross sections for the $f_1(1285)$ and $f_1(1420)$ have been calculated under our trigger conditions taking into account losses due to detector inefficiencies and tails on cuts. The cross sections for $|x_F| < 0.15$ are

$$85 \text{ GeV/c} : \sigma(f_1(1285)) = 230 \pm 70 \text{ nb} \qquad \sigma(f_1(1420)) = 400 \pm 120 \text{ nb}$$

$$300 \text{ GeV/c} : \sigma(f_1(1285)) = 135 \pm 40 \text{ nb} \qquad \sigma(f_1(1420)) = 400 \pm 110 \text{ nb}$$

These results indicate that the $f_1(1285)$ cross section decreases with incident momentum while the $f_1(1420)$ cross section remains constant.

In conclusion clear $f_1(1285)$ and $f_1(1420)$ signals are seen with masses and widths

$$f_1(1285) \quad m = 1278 \pm 2 \text{ MeV} \quad \Gamma = 25 \pm 4 \text{ MeV},$$

$$f_1(1420) \quad m = 1429 \pm 3 \text{ MeV} \quad \Gamma = 58 \pm 8 \text{ MeV}.$$

A spin parity analysis shows that both are 1^{++} states. The $f_1(1285)$ is found to decay via $\delta\pi$ while the $f_1(1420)$ is found to decay only to $K^*\bar{K}$, no 0^{-+} or 1^{+-} waves being required to describe the data. The energy dependence for the production of the $f_1(1285)$ is not the same as that for the $f_1(1420)$ and it is found that the cross section for the $f_1(1420)$ remains constant as a function of incident momentum.

References

[1] M.S.Chanowitz, Proceedings of the Second Int. Conf. on Hadron Spectroscopy 16 – 18 April 1987, KEK, Tsukuba, Japan.

[2] C.Edwards et al., Phys. Rev. Lett. **49** (1982) 259.

[3] H.Aihara et al., Phys. Rev. Lett. **57** (1986) 2500.
G.Gidal et al., Phys. Rev. Lett. **59** (1987) 2016.

[4] P.Baillon et al., Nuovo Cimento **50A** (1967) 393.
A.Birman et al., Phys. Rev. Lett. **61** (1988) 1557.
M.G.Rath et al., Phys. Rev. Lett. **61** (1988) 802.

[5] C.Dionisi et al., Nucl. Phys. **B169** (1980) 1.

[6] T.Armstrong et al., Phys. Lett. **146B** (1984) 273.
T.Armstrong et al., Z. Phys. C. 34 (1987) 23.

[7] Ph.Gavillet et al., Z.Phys C. **16** (1982) 119.
D.Aston et al., Nucl. Phys. **B301,** (1988) 525.

[8] F.E.Close, Rutherford preprint RAL – 87 – 072.
D.Caldwell, Mod. Phys. Lett. **A2** (1987) 771.

[9] T.A. Armstrong et al., Nucl. Instr. and Methods A274 (1989) 165.

[10] R.Ehrlich et al., Phys. Rev. Lett. **20** (1968) 686.

[11] Ch.Zemach, Phys. Rev. **133B** (1964) 1201.
C.Dionisi et al., Nucl. Phys. **B169** (1980) 1.

[12] S.M.Flatté, Phys. Lett. **63B** (1976) 224.

[13] J.Iizuka et al., Phys. Rev. **D36** (1987) 1422.

1. Figures

Fig. 1 $K^0{}_SK^{\pm}\pi^{\mp}$ mass distribution. The superimposed curve is the result of the fit described in the text.

Fig. 2 a) Dalitz plot with b),c) $K\pi$ and d)$K\bar{K}$ projections for the mass region $1.37-1.49$ GeV. The superimposed curve corresponds to the Monte Carlo simulation using 58 % 1^{++} S wave.

Fig. 3 Result of the Dalitz plot analysis.

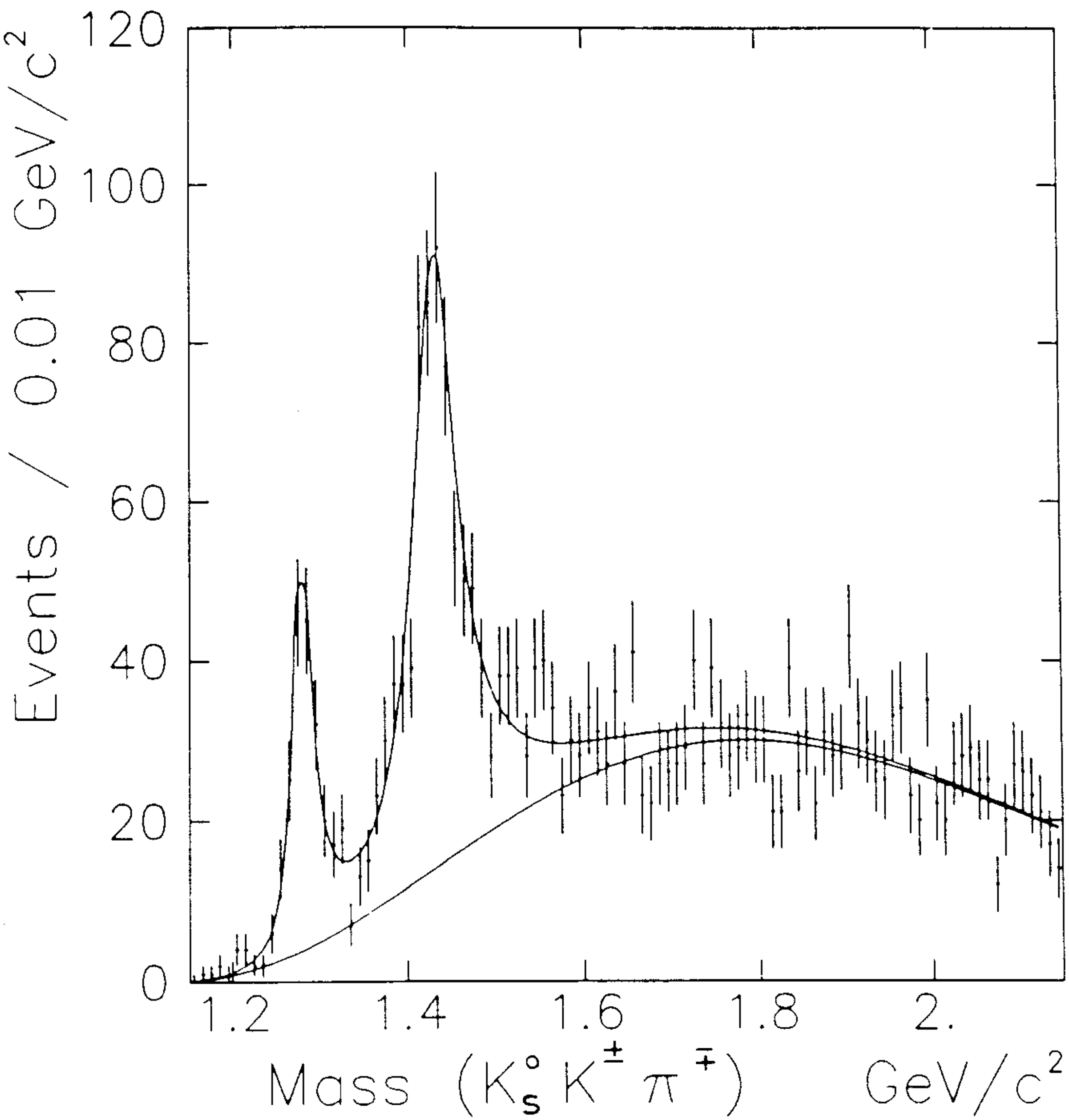

120
100
80
60
40
20
0
Events / 0.01 GeV/c²
1.2
1.4
1.6
1.8
2.
Mass ($K^\circ_s K^\pm \pi^\mp$) GeV/c²

Fig. 1

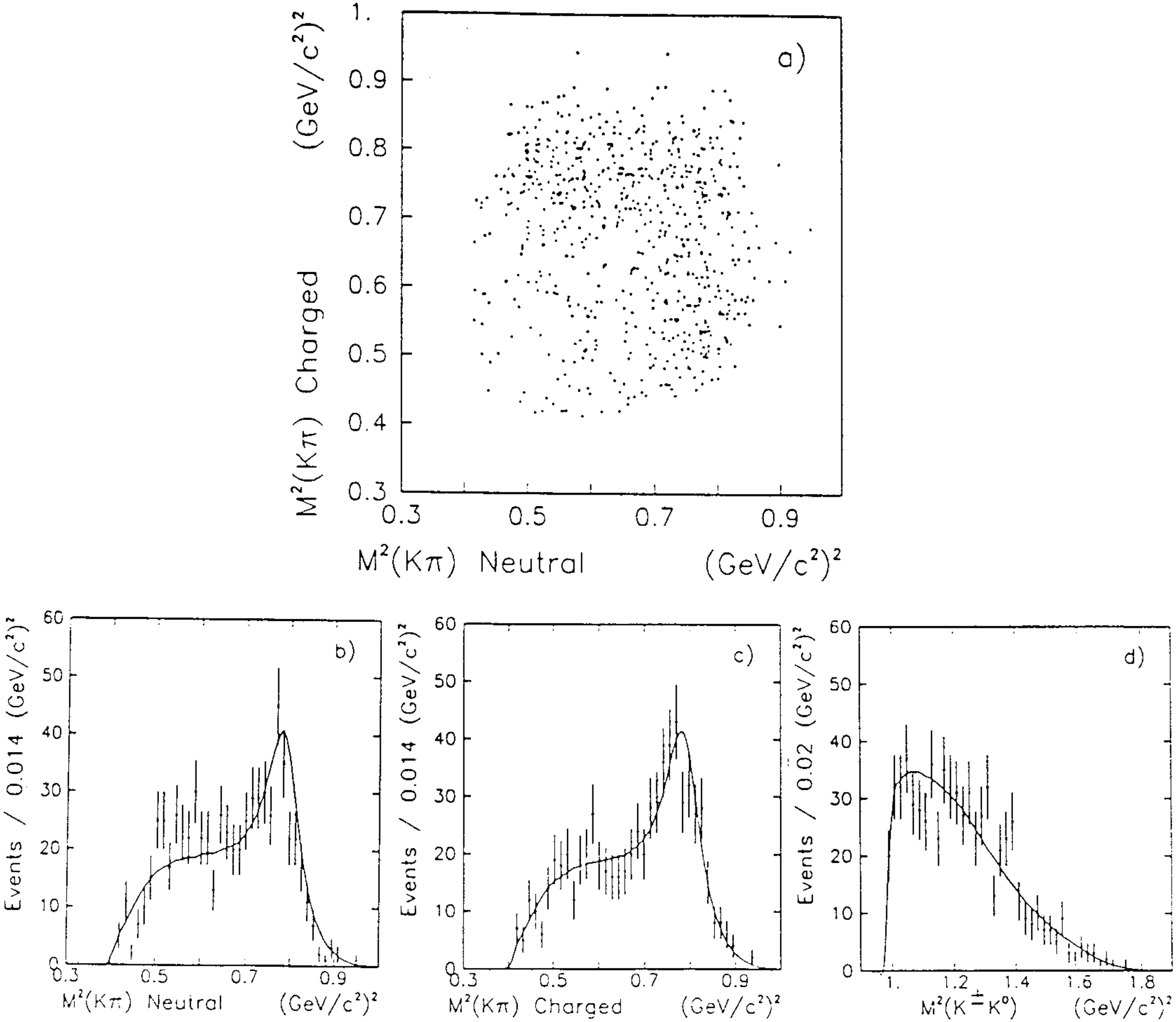
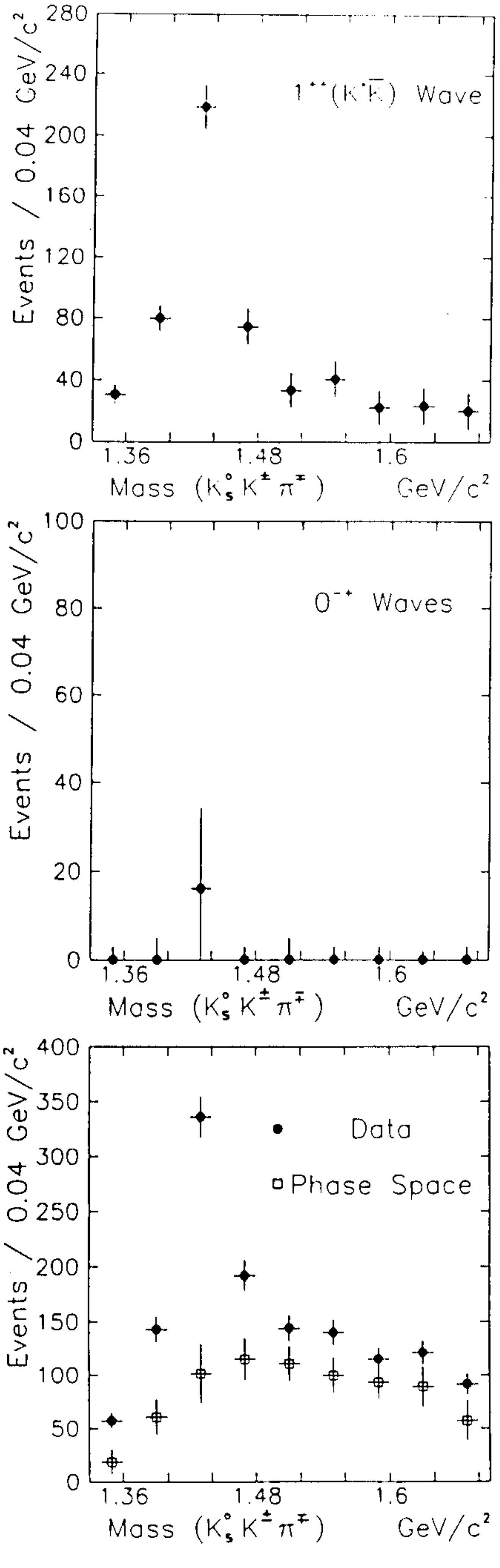

a)
$M^2(K\pi)$ Charged $(GeV/c^2)^2$
$M^2(K\pi)$ Neutral $(GeV/c^2)^2$
b)
Events / 0.014 $(GeV/c^2)^2$
$M^2(K\pi)$ Neutral $(GeV/c^2)^2$
c)
Events / 0.014 $(GeV/c^2)^2$
$M^2(K\pi)$ Charged $(GeV/c^2)^2$
d)
Events / 0.02 $(GeV/c^2)^2$
$M^2(K^{\pm}K^0)$ $(GeV/c^2)^2$

Fig. 2



$1^{++}(K^*\bar{K})$ Wave
0^{-+} Waves
Data
Phase Space
Events / 0.04 GeV/c²
Mass ($K_s^0 K^{\pm} \pi^{\mp}$) GeV/c²

Fig. 3