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SPIN-PARITY ANALYSIS OF THE E MESON CENTRALLY PRODUCED IN THE REACTIONS $\pi^+ p \to \pi^+(K_1^0 K^\pm K^\mp)p$ AND $pp \to p(K_1^0 K^\pm \pi^\mp)p$ AT 85 GeV/c

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ABSTRACT

Results are presented of a spin-parity analysis on a sample of ~ 1000 E mesons centrally produced in the reactions $(\pi^+/p)p \to (\pi^+/p)(K_1^0 K^\pm \pi^\mp)p$ at 85 GeV/c. The E quantum numbers are determined to be $J^{PC} = 1^{++}$. Its decay in this channel is consistent with being 100% into $K^*\bar{K}$ + c.c. and no evidence is seen for a $\delta\pi$ decay mode where $\delta \to K\bar{K}$. The mass and width were determined to be M = (1425 ± 2) MeV and Γ = (62 ± 5) MeV.

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The apparently different spin-parity assignments being found for the enhancements in $(K\bar{K}\pi)^o$ mass spectra around 1.42 GeV have aroused considerable interest due to the possibility of one of them being a glueball state. The first observation of an enhancement, in the $K_1^oK^\pm\pi^\mp$ system produced in $p\bar{p}$ annihilations at rest [1,2], was called the E meson and had favoured spin-parity $J^{PC} = 0^{-+}$. Subsequently a similar enhancement in mass and width was observed in the reaction $\pi^-p \rightarrow K_1^oK^\pm\pi^\mp n$ at 3.9 GeV [3]. Here, a spin-parity analysis showed the state to be $J^{PC} = 1^{++}$ with the $K^*\bar{K}$ decay mode dominant. At about the same time an enhancement was observed in the decays $\psi \rightarrow \gamma(K_1^oK^\pm\pi^\mp)$ [4] and $\psi \rightarrow \gamma(K^+K^-\pi^o)$ [5] whose mass and width were similar to the above observations. However, in this case [5], a spin-parity analysis favoured $J^{PC} = 0^{-+}$ with the decay being mainly via $\delta\pi$ (where $\delta \rightarrow K\bar{K}$). Against the $J^{PC} = 0^{-+}$ assignment is the observation that no $\eta\pi\pi$ final state decay mode has yet been seen in spite of the reported large branching ratio into $\delta\pi$.

The experimental situation is therefore not clear and it was with the idea of providing additional information in this region and of searching for possible signs of glueball states that experiment WA76 at the CERN SPS, a study of the characteristics of exclusive central meson production, was undertaken.

The layout of the Ω' spectrometer used for this experiment is shown in Fig. 1 and it was designed in order to enhance the double exchange graphs (Double Pomeron, Regge-Pomeron, Regge-Regge) with respect to single Pomeron (diffractive) or single Regge exchange.

The positively charged H1 beam (45% p, 47% π) in the West Area was incident on a 60 cm long hydrogen targer and two Cerenkov counters in the beam allowed positive identification of the pions and protons.

The trigger required:

a) A fast particle defined by a hit in the counter A(54 x 60 cm^2) placed after Cerenkov C_2, ≥ 1 hit in a single plane of the forward MWPCs T_2 and T_3 and no hit in the beam veto counter A_0;

b) A slow particle defined by demanding one hit on any of the fourteen horizontal slabs of the Slow Proton Counter (SPC), (56×88 cm^2), and ≥ 1 hit on a single plane of the MWPCs situated on one side of the target. In addition, a hit was demanded in the side of the box counter (TS), surrounding the target, which was nearest the SPC.

c) In order to reduce the backward diffraction or excitation no hit was requested in the other three sides of the box TS counter which was left open at its front end to allow particles produced centrally to escape downstream.

d) To reduce the forward diffraction or excitation no hit was requested in two counters (DFC) of dimensions (30×60 cm^2) which were placed either side of the beam and just downstream of drift chamber 2 (DC2).

e) Elastic events were vetoed by demanding a forward multiplicity of ≥ 2 in the "A3" MWPC outside the beam region.

f) In addition to the above conditions (called a π trigger) a K/p trigger was imposed to select events having a negatively or positively charged kaon or proton by demanding correlated hits in the hodoscopes H_1, H_2 and H_3 along with no correlated light in the appropriate region of the multicell Cerenkov counters C_1 and C_2. The Cerenkov counters C_1 and C_2 were filled with Freon 114 and CO_2, respectively, resulting in threshold for π/K/p of 2.8/9.8/18.8 GeV/c for C_1 and 5.0/17.4/33.0 GeV/c for C_2. An air bag was placed inside C_1 in the beam region in order to reduce the multiple scattering on the fast track.

The reactions

$$\pi^+ p \rightarrow \pi^+ (K_1^0 K^\pm \pi^\mp) p \ , \tag{1}$$

and

$$pp \rightarrow p (K_1^0 K^\pm \pi^\mp) p \ , \tag{2}$$

were isolated from the four-prong events which had in addition an associated reconstructed V^0.

Momentum balancing events were selected by requiring:

(a) the effective mass of the two pions at the V^o vertex to lie inside the K^o mass region: viz. $0.475 < m(\pi^+\pi^-) < 0.520$ GeV;

(b) $|\text{missing } p_z| < 0.08$ GeV;

(c) $|\text{missing } p_y| < 0.20$ GeV;

(d) $|\text{missing } p_x| < 4.00$ GeV.

Since the efficiency of the geometrical reconstruction program for finding V^o vertices decreases near the main vertex a cut was applied to the events of the form: (decay distance (cm) X K^o mass/K^o momentum) > 0.4.

Reactions (1) and (2), "4C" events, were selected from the total sample of the events with no missing neutrals by making use of the Cerenkov information and by requiring that

$$\Delta = |\text{missing mass}^2(\pi^+/pp) - m^2(K_1^oK^\pm\pi^\mp)| < 1.5 \text{ GeV}^2 \quad .$$

The Cerenkov information (when available) was used in order to reduce the internal π/K ambiguity by rejecting the combinations which were incompatible with the mass assignment hypothesis.

The total number of isolated events is 5999 of which 35% belong to reaction (1) and 65% to reaction (2). Of these 5999 events 4623 have one combination and 1376 have two combinations.

The Feynman x distribution of the selected $K_1^oK^\pm\pi^\mp$ system [6] is concentrated mainly in the central region (i.e. $|x_F| < 0.25$).

The $K_1^oK^\pm\pi^\mp$ effective mass spectra for reactions (1) and (2) are shown in figs 2(a) and 2(b) and the combined spectrum in fig. 2(c). Two clear signals may be seen in the D and E region over a relatively small background. A better separation between signal and background is obtained by asking for a positively identified kaon or ambiguous kaon/proton assignment and gives the spectrum shown in fig. 3(a).

A fit of this spectrum using a background of the form $a(m-m_{th})^b \times \exp(-cm-dm^2)$, (where m is the $K_1^0K^{\pm}\pi^{\mp}$ mass, m_{th} is the $K_1^0K^{\pm}\pi^{\mp}$ threshold mass and a,b,c,d are fit parameters) and two simple non-relativistic Breit-Wigners gives the following values of mass and width for the two enhancements:

$$m(D) = (1.279 \pm 0.002)\mathrm{GeV} \qquad \Gamma(D) = (32 \pm 3)\mathrm{MeV},$$
$$m(E) = (1.425 \pm 0.002)\mathrm{GeV} \qquad \Gamma(E) = (62 \pm 5)\mathrm{MeV}.$$

The experimental resolution which was not taken into account in the fit is $\sigma = \pm$ 4 MeV and $\sigma = \pm$ 6 MeV at the D and E masses, respectively.

The geometrical acceptance of the apparatus has been evaluated on the Dalitz plot of the $K_1^0K^{\pm}\pi^{\mp}$ system as a function of its mass. The events were rotated isotropically in the laboratory system, translated along the hydrogen target and the K^0 was allowed to decay exponentially with its proper lifetime. Each track was traced through the apparatus and the trigger conditions were applied to the event.

The resulting acceptance is essentially flat in the regions of the D and E. All the Dalitz plot fits which we have performed gave essentially identical results with and without acceptance corrections. In what follows we refer only to the unweighted fits.

The method used in this analysis is a standard isobar model which makes use of the Zemach tensor method [7]. The $\delta(K\bar{K})$ resonance has been parametrized as a coupled channel Breit-Wigner as given in refs [8,9] i.e., $m(\delta) = 0.981$ GeV, $\Gamma(\delta \to \eta\pi) = 55$ MeV, $g^2_\eta/g^2_K = 2/3$, and the K^* resonance as a relativistic p-wave Breit-Wigner according to the Particle Data Group (PDG) values [10].

The form of the likelihood function used is

$$L = \prod_n [\sum_i \alpha_i |A_G^{JP}|^2 + (1 - \sum_i \alpha_i)] ,$$

where α_i are the frequency parameters to be adjusted, and the sum runs over different J^P possibilities. It is implicitly assumed that all the amplitudes are normalized. The A_G^{JP} terms represent the coherent waves.

The G parity which determines the interference between $K^*\bar{K}$ and $\bar{K}^*K$ has been fixed to +1 [3] and waves belonging to the same spin-parity were allowed to interfere with arbitrary phase.

Reactions (1) and (2) do not show any difference in the Dalitz plot behaviour so that in what follows the data of the two reactions have been added together. In order to test the above δ representation we started by fitting the Dalitz plot of the D meson region, defined as $1.25 < m(K^0_1K^{\pm}\pi^{\mp}) < 1.32$ GeV (604 events). The fits clearly favour the 1^+ assignment for the D meson ($\ell n(L) = 267$) against the 0^- assignment ($\ell n(L) = 200$). The result of these fits is shown in fig. 4(a) on the $K\bar{K}$ projection and this result gives us confidence that the δ representation is able to describe satisfactorily the data in the D region.

The Dalitz plot for the E region, defined as $1.37 < m(K^0_1K^{\pm}\pi^{\mp}) < 1.49$ GeV (1520 events) is shown in fig. 3(b).

We initially used a set of waves corresponding to the states (0^-, 1^+) including $\delta\pi$ and $K^*\bar{K}$. The result of such a fit requires the 1^+(d) wave to be consistent with zero, and the 0^- wave to be small (~ 7%). Exclusion of the 1^+(d) wave leaves the likelihood value intact ($\ell n(L) = 416$) and again requires only a small contribution from the 0^- wave. A fit performed by using only 1^+ ($\delta\pi = 2 \pm 2\%$ and $K^*\bar{K}(s) = 98\%$) gives the best representation of the data ($\ell n(L) = 412$) assuming a single resonance to be present in this region. The result of such a fit is superimposed on the real data in figs 4(b-d) (full line).

Attempting a fit with a 0^- state ($\delta\pi$ and $K^*\bar{K}$) gives a likelihood value ($\ell n(L) = 321$) several orders of magnitude smaller than the 1^+ fit. The result of such a fit is shown superimposed on the real data in figs 4(b-d) (dashed line). We have also tried the 2^{-+} quantum numbers assignment but this assumption ($\ell n(L) = 380$) is also excluded by the fit.

The amount of the fitted background (34%) in the 1^+ hypothesis is consistent with that found by fitting the mass spectrum of fig. 2(c). The addition of incoherent K^* waves does not significantly improve the fit and their contributions remain always less than 5%.

Fits with G = -1 which would give negative interference between the two K^*s have been tried but give a bad description of the data.

We thus find a quantum number assignment for the E meson, of $J^{PC} = 1^{++}$ with dominant $K^*\bar{K}$ + c.c. decay mode (consistent with being 100%). This result is in disagreement with that found in refs [2] and [5] and in agreement with the result of ref. [3].

In conclusion we have performed an analysis of the reactions $(\pi^+/p)p \rightarrow (\pi^+/p)(K_1^0K^{\pm}\pi^{\mp})p$ at 85 GeV/c where the $K_1^0K^{\pm}\pi^{\mp}$ is produced centrally in the c.m. system. We observe clear signals of the D and E mesons with masses and widths m(D) = (1.279 ± 0.002)GeV, Γ(D) = (32 ± 3)MeV, m(E) = (1.425 ± 0.002)GeV, Γ(E) = (62 ± 5)MeV. A Dalitz plot analysis of the E meson yields the quantum numbers assignment $J^{PC} = 1^{++}$ and shows that the E meson observed in the $K_1^0K^{\pm}\pi^{\mp}$ system decays ~ 100% via the $K^*\bar{K}$ + c.c. mode there being no evidence for a $\delta\pi$ decay mode. This absence of a $\delta\pi$ decay mode is in agreement with the non-observation of the $\eta\pi\pi$ decay mode of the E meson in the same experiment [6].

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FIGURE CAPTIONS

Fig. 1 Layout of the Ω' spectrometer as used in the present experiment.

Fig. 2 (a) $K_1^oK^{\pm}\pi^{\mp}$ effective mass for reaction (1);

(b) $K_1^oK^{\pm}\pi^{\mp}$ effective mass distribution for reaction (2).

(c) The sum of (a) and (b).

Fig. 3(a) $K_1^oK^{\pm}\pi^{\mp}$ effective mass distribution for reactions (1) and (2) requiring a K/p identification. The superimposed curve is the result of the fit described in the text.

(b) Dalitz plot for the E region.

Fig. 4 (a) D region. Projection of the Dalitz plot on the $K\bar{K}$ mass axis.

(b) E region. Projection of the Dalitz plot on the (Kπ) neutral axis.

(c) E region. Projection of the Dalitz plot on the (Kπ) charged axis.

(d) E region. Projection of the Dalitz plot on the KK mass axis.

The solid line corresponds to the 1^{++} fit, the broken line to the 0^{-+} fit.

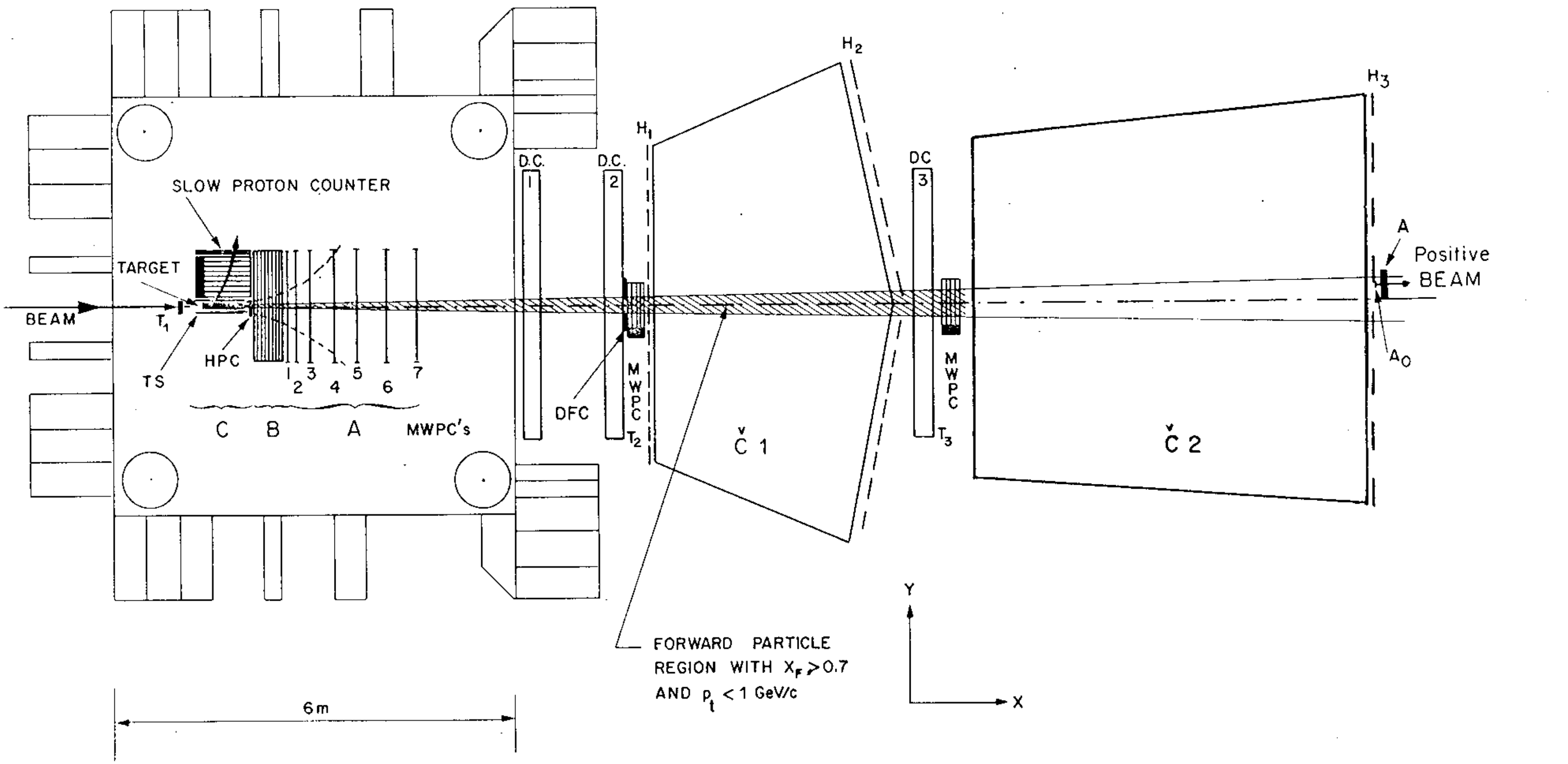

SLOW PROTON COUNTER
TARGET
BEAM
T1
TS
HPC
1
2
3
4
5
6
7
C
B
A
MWPC's
D.C.
1
D.C.
2
DFC
MWPC
T2
H1
Č 1
H2
DC
3
MWPC
T3
Č 2
H3
A
Positive
BEAM
A0
FORWARD PARTICLE
REGION WITH X_F > 0.7
AND p_t < 1 GeV/c
Y
X
6m

Fig. 1

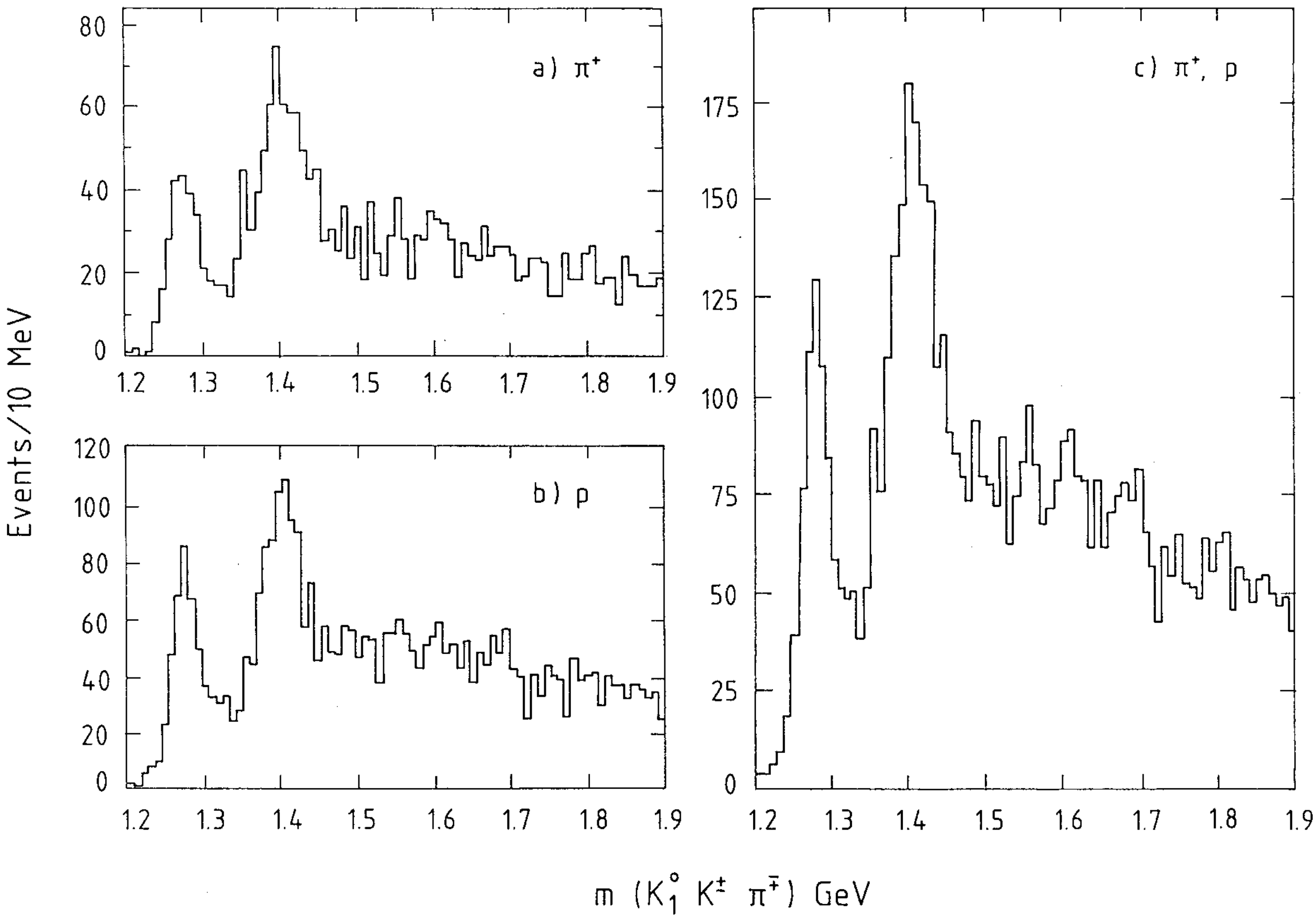


Fig. 2

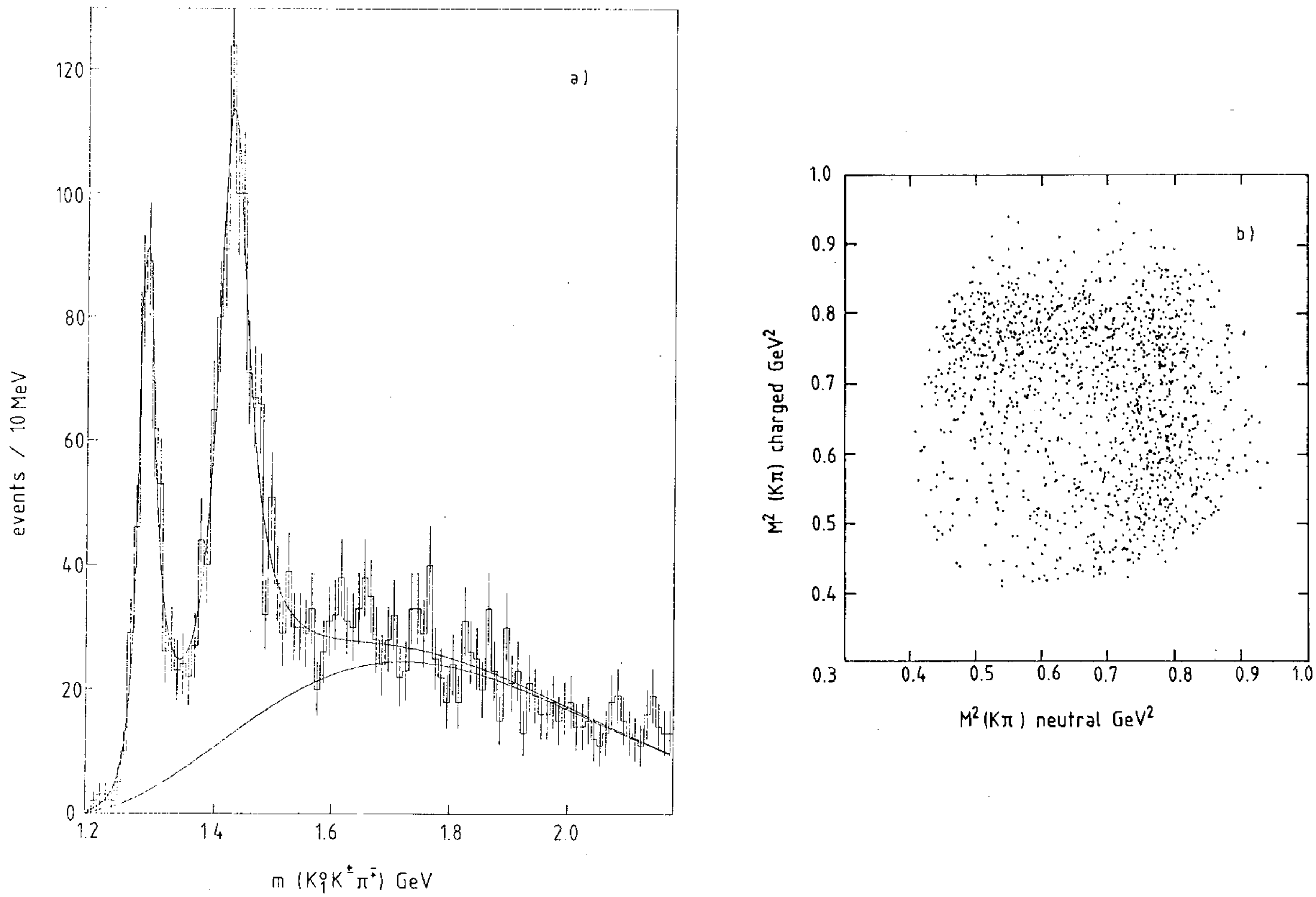
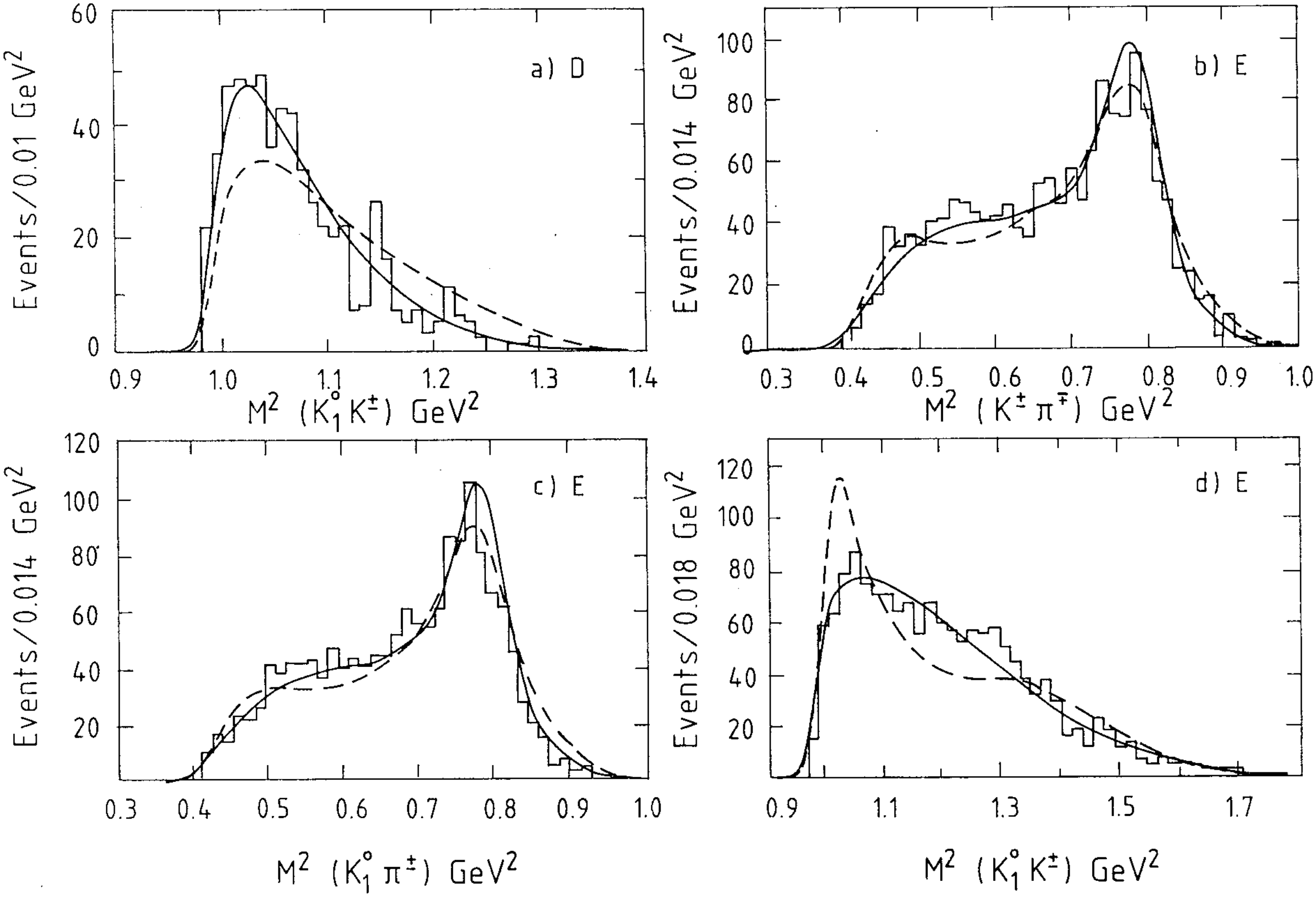

a)
events / 10 MeV
$m\ (K^0_1 K^{\pm} \pi^{\mp})$ GeV
b)
$M^2\ (K\pi)$ charged GeV^2
$M^2 (K\pi)$ neutral GeV^2

Fig. 3



a) D
Events/0.01 GeV²
M² (K₁° K±) GeV²
b) E
Events/0.014 GeV²
M² (K± π∓) GeV²
c) E
Events/0.014 GeV²
M² (K₁° π±) GeV²
d) E
Events/0.018 GeV²
M² (K₁° K±) GeV²

Fig. 4