EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-PPE/92-39
4 March 1992

Study of the $\omega\pi^\circ$ system

D. Alde[3], B. Bencheik[4], F.G. Binon[7], M. Boutemeur[8], C. Bricman[2],
E.G. Chikovani[4,6], S.V. Donskov[1], M. Gouanère[4], S. Inaba[5], A.V. Inyakin[1],
V.A. Kachanov[1], G.V. Khaustov[1], E.A. Knapp[3], M. Kobayashi[5], A.V. Kulik[1],
G.L. Landsberg[1], A.A. Lednev[1], T. Nakamura[9], J.P. Peigneux[4], S.A. Polovnikov[1],
M. Poulet[4], Yu.D. Prokoshkin[1], S.A. Sadovsky[1], V.D. Samoylenko[1], P.M. Shagin[1],
A.V. Shtannikov[1], A.V. Singovsky[1], J.P. Stroot[2], V.P. Sugonyaev[1], M.D. Tabidze[6],
K.Takamatsu[5] and T. Tsuru[5]

IHEP[1] - IISN[2] - LANL[3] - LAPP[4] - KEK[5] Collaboration
(Joint CERN - IHEP experiment)

Abstract

The mass spectra of the $\omega\pi^\circ$ system, produced in $\pi^- p$ charge-exchange reactions at 38 GeV/c and 100 GeV/c, show a new neutral state with a mass of 2200 ± 20 MeV and a width of 260 ± 50 MeV. Like $\rho_3(1690)$, this meson, X(2200), is produced through one-pion-exchange. X(2200) J^{PC} is likely 1^{--}. It might be a $2\,^3D_1$ radial-orbital excitation of ρ°. Its production cross section falls with energy quadratically, in agreement with one-pion-exchange. The cross sections for $b_1(1235)$ and $\rho_3(1690)$ production have also been measured; their energy dependences have been determined.

(Submitted to Zeitschrift für Physik C)

---

1) Institute for High Energy Physics, Protvino, 142 284, Russia.
2) Institut Interuniversitaire des Sciences Nucléaires, B-1050 Brussels, Belgium.
3) Los Alamos National Laboratory, Los Alamos, NM 87544, USA.
4) Laboratoire d'Annecy de Physique des Particules, F-74019 Annecy-le-Vieux, France.
5) National Laboratory for High Energy Physics (KEK), Tsukuba, Ibaraki 305, Japan.
6) Institute of High Energy Physics, Tbilisi State University, Georgia.
7) Université Libre de Bruxelles, CP 229, B-1050 Brussels, Belgium.
8) CERN, CH-1211 Geneva 23, Switzerland.
9) Miyazaki University, Miyazaki 889-21, Japan.

The study of $\omega\pi^{\circ}$ systems produced in the charge-exchange reaction

$$\begin{array}{l} \pi^{-} p \rightarrow M^{\circ} n. \\ \qquad\quad \hookrightarrow \omega\pi^{\circ} \rightarrow \pi^{\circ}\pi^{\circ}\gamma \rightarrow 5\gamma \end{array} \qquad (1)$$

offers the possibility to investigate isovector $q\bar{q}$ mesons and to search for exotic states which do not contain strange quarks. This reaction has been studied previously at low energies [1,2].

The region of the mass spectrum above $\rho_3^{0}(1690)$ which has not yet been thoroughly investigated is the main subject of this work. Measurements have been carried out with 38 GeV/c pions at IHEP using the multiphoton hodoscope spectrometer GAMS-2000 [3] and with 100 GeV/c pions at CERN with GAMS-4000 [4].

The results of the analysis of the 100 GeV/c data have been preliminary reported [5]. Higher statistics have been accumulated during four 38 GeV/c runs in 1983, 1984 and 1987. This has allowed in particular a more thorough study of the high mass spectrum produced in reaction (1).

The experimental setup, measurement conditions, calibration technique and geometrical reconstruction of events have been described earlier [3,4,6]. Some additional cuts have been introduced to select $\omega\pi^{\circ}$ systems at 38 GeV/c. First, events with more than two out of ten possible 2γ combinations having an effective mass in a rather wide range around the π° mass ($50 \div 250$ MeV) have been rejected. Such a cut suppresses the background from multiphoton systems which have lost one or more gammas. It also excludes events in which the selection of the π° pair may be ambiguous. Second, events with two $\pi^{\circ}\gamma$ compatible combinations, that have a mass close to that of ω, have been excluded from further analysis. The ω mass interval for this cut is also chosen to be wide, $630 \div 930$ MeV. These two cuts eliminate the combinatorial background arising from misidentified ω or π°. Third, an energy threshold has been required for the free γ in the decay of ω to $\pi^{\circ}\gamma$ ($E_{\gamma} > 2$ to 3 GeV). This cut suppresses the background of $\pi^{\circ}\pi^{\circ}$ events associated with an additional noisy low energy gamma due to the high load of GAMS-2000 counters close to the beam [6].

Similar selection criteria had also been applied to the 100 GeV/c data. The main difference is that the suppression of the combinatorial background relies on a choice based on a fit of each event with constraints on the masses of the decay particles amongst several possible channels ($\pi^{\circ}\pi^{\circ}\gamma$, $\pi^{\circ}\eta\gamma$, $\eta\eta\gamma$ etc.). The most probable channel is chosen. Only those $\pi^{\circ}\pi^{\circ}\gamma$ events in which the mass of at least one $\pi^{\circ}\gamma$ combination was found within the ω-range ($745 \div 825$ MeV) after the fit are kept as $\omega\pi^{\circ}$.

The efficiency of the ω selection procedure is illustrated in fig. 1. The ω-peak width is determined by the resolution of GAMS. This is equal to 50 MeV (FWHM) at 100 GeV/c and 100 MeV at 38 GeV/c. The peak-to-background ratio equals 5 on the average. It improves with increasing $\omega\pi^{\circ}$ mass (up to 15 for masses larger than 2 GeV, fig. 1b).

The $\omega\pi^{\circ}$mass spectrum in reaction (1) at 100 GeV/c (fig. 2a) has been obtained after background subtraction under the ω-peak in each 50 MeV $\omega\pi^{\circ}$ mass bin and correction for efficiency. It shows, alongside the well-known $b_1(1235)$ and $\rho_3(1690)$ mesons, a peak in the 2.2 GeV region which is more pronounced at low $|t|$ (fig. 2c). This 3.5 σ peak [5] is the first evidence of the presence of a vector meson that is approximately 300 MeV wide and has a mass of 2170 ± 30 MeV.

The $\omega\pi^{\circ}$ mass spectrum at 38 GeV/c (fig. 2b,d) has been obtained after a 4C-fit (the masses of the recoil neutron, of the two π° and ω being fixed) and correction for efficiency. It shows the same peak at 2.2 GeV with a much better statistical significance, larger than 10σ, for the low momentum transfer events. The peak (hereafter named X(2200)) contains 3500 ± 200 $\omega\pi^{\circ}$ events. The mass and width of X, evaluated by fitting the $\omega\pi^{\circ}$ mass spectrum of fig. 2d with two Breit-Wigner resonances and a polynomial continuum, are : $M = 2220 \pm 20$ MeV, $\Gamma = 240 \pm 60$ MeV (corrected for GAMS resolution).

Taking the 100 GeV/c data into account, the parameters of X are

$$\begin{aligned} M &= 2200 \pm 20 \text{ MeV}, \\ \Gamma &= 260 \pm 50 \text{ MeV}. \end{aligned} \tag{2}$$

The distribution of 4-momentum transfer squared (fig.3a), the angular distribution in the Gottfried-Jackson frame of reaction (1) and that in the ω helicity frame (fig.4) of the events in the X-peak have been studied.

The t-distributions of both ρ_3 and X events have been plotted after fitting the $\omega\pi^{\circ}$ mass spectrum at 38 GeV/c in each t-bin with the sum of a polynomial background and two Breit-Wigner resonances with the listed parameters of these two states. Both show a typical one-pion-exchange (OPE) exponential behaviour $|t| e^{bt}/(m_{\pi}^2 - t)^2$, with a slope

$$b = 7.2 \pm 0.8 \text{ (GeV/c)}^{-2} \tag{3}$$

for X, in good agreement with the slope for ρ_3 which is observed simultaneously (fig. 3a). A similar t-distribution is observed at 100 GeV/c in the X mass corridor.

These typical OPE distributions should be compared with those of b_1 (fig. 3b) obtained using the same bin-by-bin technique (at 38 GeV/c) or b_1 mass interval (at 100 GeV/c). The b_1 t-distribution follows an exponential function e^{ct} with

$$c = 3.4 \pm 0.2 \text{ (GeV/c)}^{-2}. \tag{4}$$

The assumption that OPE is the dominating mechanism in the X(2200) production is also confirmed by the isotropic Treiman-Yang angular distribution and by the characteristic angular distributions in the ω helicity frame (fig. 4). In the case of OPE without absorption, the following distributions are expected : $d\sigma/d\cos\theta_{\pi} \sim 1 + \cos^2\theta_{\pi}$, $d\sigma/d\phi_{\pi} \sim 1/2 + \cos^2\phi_{\pi}$ (here θ_{π}, ϕ_{π} define the π° direction in the $\omega \rightarrow \pi^{\circ}\gamma$ decay frame). The experimental data follow nicely these formulas.

The conclusion is that the observed $\omega\pi^\circ$ resonance, X(2220), is produced in reaction (1) through OPE exchange, which limits its quantum numbers to the following : $J^{PC} = 1^{--}, 3^{--}, ..., I^G = 1^+$.

The angular distributions in the Gottfried-Jackson frame have been fitted with the sum of a constant background and the theoretical distributions expected for J = 1 and for J = 3 in OPE. In this model, which does not take into account a possible interference of X(2200) with the background and with the ρ_3 "tail", the fit favours the hypothesis $J^{PC} = 1^{--}$. It is incompatible with spin 3 (fig. 4a).

Further evidence that the X(2200) spin is not 3 is shown on fig. 5 (38 GeV/c data). Here the $\omega\pi^\circ$ spectrum that includes selected events with $0.3 < |\cos \theta_{GJ}| < 0.6$, an interval where the contribution of the 3^{--} wave is small, shows a X peak that is considerably enhanced with respect to ρ_3 and the continuum.

The peak also manifests itself within the $0.2 < |\cos \theta_{GJ}| < 0.4$ range, situated in the vicinity of zeros of the 5^{--} wave. The angular distribution (fig. 4a) does not exclude a small contribution of the 5^{--} wave (at a level less than 1/4 of that of the 1^{--} wave). Such a wave in the 2.2 GeV to 2.5 GeV mass region might be due to $\rho_5^0(2350)$. Contributions of this meson as well as of $\rho_1^0(1700)$ to the $\omega\pi^\circ$ mass spectrum will be evaluated in the partial wave analysis of the whole set of the GAMS data currently in progress.

The cross section of the X meson production in reaction (1) is equal to

$$\sigma(\pi^- p \to X\, n) \bullet BR(X \to \omega\pi^\circ) = \begin{cases} 120 \pm 25 \text{ nb} & \text{at } 38 \text{ GeV/c}, \\ \\ 20 \pm 6 \text{ nb} & \text{at } 100 \text{ GeV/c}. \end{cases} \qquad (5)$$

The cross section decreases with energy quadratically, in agreement with OPE.

The observed resonance is a serious candidate for a $J^{PC} = 1^{--}, I^G = 1^+$ multiplet. It might be a radial and orbital 2^3D_1 excitation of ρ°. In the Godfrey-Isgur model [7], such a meson would have a mass near 2150 MeV (cf. e.g. [8]). A similar value (M = 2200 ± 60 MeV) follows from the Veneziano formula [9] for the fourth ρ° excitation [10]. The predictions of these two models together with experimental data are shown in fig.6. The possible existence of a 1^{--} state around 2.15 GeV had also been suggested in an analysis of the $\pi\pi$ system [11].

A preliminary analysis of the ρ_3 production in reaction (1) has been performed. The $\cos\theta_{GJ}$ distributions both for 38 GeV/c and 100 GeV/c are presented in fig. 7. They are well fitted by the spin-3 OPE curve plus a small constant term. The parameters of the ρ_3 resonance determined from the 38 GeV/c and 100 GeV/c data,

$$M = 1690 \pm 20 \text{ MeV}, \Gamma = 230 \pm 30 \text{ MeV}, \qquad (6)$$

are in agreement with the tabulated values, excluding the narrow width found in some older experiments [12].

The measured ρ_3 production cross section

$$\sigma(\pi^- p \rightarrow \rho_3 n) \bullet BR(\rho_3 \rightarrow \omega\pi^\circ) = \begin{cases} 0.8 \pm 0.2\ \mu b & \text{at } 38\ \text{GeV/c}, \\ \\ 0.15 \pm 0.04\ \mu b & \text{at } 100\ \text{GeV/c}, \end{cases} \qquad (7)$$

together with the low-energy cross section [13], considering the different branching ratios [12], fits the OPE quadratic energy dependence well in the momentum range from 10 GeV/c to 100 GeV/c : $\sigma \sim s^{-\alpha/2}$, $\alpha = 2.0 \pm 0.3$.

The high-$|t|$ region of reaction (1) is dominated by $b_1(1235)$ production. The b_1 parameters obtained from the 38 GeV/c and 100 GeV/c data,

$$M = 1235 \pm 15\ \text{MeV},\ \Gamma = 160 \pm 30\ \text{MeV}, \qquad (8)$$

agree with the tabulated values [12]. The b_1 production cross section values,

$$\sigma(\pi^- p \rightarrow b_1 n) \bullet BR(b_1 \rightarrow \omega\pi^\circ) = \begin{cases} 1.0 \pm 0.2\ \mu b & \text{at } 38\ \text{GeV/c}, \\ \\ 0.28 \pm 0.07\ \mu b & \text{at } 100\ \text{GeV/c}, \end{cases} \qquad (9)$$

together with previous data at 8.45 GeV/c [2] show an energy decrease with a slope $\alpha = 1.50 \pm 0.25$.

The 100 GeV/c mass spectrum of the $\omega\pi^\circ$ events measured with $|t| > 0.2\ (\text{GeV/c})^2$ suggests a bump near 1.4 GeV [5]. It is not confirmed by the 38 GeV/c data.

The authors would like to thank D.C. Peaslee for useful discussions. They are also thankful to CERN, IHEP, IISN, KEK, LANL, and LAPP directorates for their support to the GAMS programme.

References

[1] S.Fukui et al., Phys. Lett. B257 (1991) 241.

[2] K.Edwards et al., Proc. XIX Int. Conf. on High Energy Physics, No.120, Tokyo, 1978.

[3] F.Binon et al., Nucl. Instr. and Meth. A248 (1986) 86; Cherenkov detectors and their applications in science and technics, p.149, Nauka, Moscow, 1990.

[4] D.Alde et al., Nucl. Phys. B269 (1986) 485; Yad.Fiz. 44 (1986) 120.

[5] B.Bencheikh, Thesis. LAPP-T-90/04, Annecy-le-Vieux, 1990; M.Boutemeur and J.P.Peigneux, Hadron mass spectrum Rheinfels workshop, 1990, Nucl. Phys. B (Proc. Suppl.) 21 (1991) 159.

[6] D.Alde et al., Phys. Lett. B182 (1986) 105; Pis'ma JETP 44 (1986) 441; Yad.Fiz. 49 (1989) 1021; Phys. Lett. B216 (1989) 451.

[7] S.Godfrey, N.Isgur, Phys. Rev. D32 (1985) 189.

[8] S.U.Chung, Preprint BNL 40599, 1987.

[9] G.Veneziano, Nuovo Cimento 57 (1968) 190.

[10] D.C.Peaslee, Surveys in High Energy Physics 6 (1988) 37; HADRON 89, Ajaccio. Ed. Frontières (1990) 255.

[11] B.R.Martin, D.Morgan, Nucl. Phys. B176 (1980) 355.

[12] J.J.Hernandez et al., Particle Data Group, Phys. Lett. B239 (1990) VII.24,50.

[13] G.Costa et al. Nucl. Phys. B175 (1980) 402.

Figure captions

Fig. 1 Identification of ω produced in reaction (1) events.

a) Mass spectrum of $\pi^\circ\gamma$ systems after identification of one π° (100 GeV/c data, 38 GeV/c spectrum is similar);

b) idem for 38 GeV/c in the 2100 MeV < $M_{\pi^\circ\pi^\circ\gamma}$ < 2350 MeV range. Arrows indicate the PDG value of the ω mass. Curves show the results of the fit.

Fig. 2 Mass spectrum of the $\omega\pi^\circ$ system.

a,c) 100 GeV/c, all events and $|t| < 0.04$ (GeV/c)^2 events.

b,d) 38 GeV/c, all events and $|t| < 0.05$ (GeV/c)^2 events. Here and further data are shown corrected for the mass and angular dependent efficiency. The curves are the sums of a polynomial background and three Breit-Wigner functions, respectively for b_1 and ρ_3 with their tabulated parameters and for X(2200) with the measured parameters.

e) Id., after continuum and ρ_3 subtraction.

Fig.3 a) The t-distributions (arbitrary units) of the $\omega\pi^\circ$ events for X(2200) (histogram) and ρ_3 (open circles) at 38 GeV/c and for ρ_3 at 100 GeV/c (crosses). The curve shows the t-dependence for OPE with the exponential slope (3).

b) The same for b_1. The straight line has the slope (4).

Fig. 4 Angular distributions in the X-peak region.

a,b) Distributions in the Gottfried-Jackson frame at 38 GeV/c (histogram) and 100 GeV/c (crosses) fitted with the sum of a constant background and OPE functions for $J^{PC} = 1^{--}$ (solid curve). The behaviour of the 3^{--} wave is shown by a dashed curve (the fit gives zero contribution for this wave).

c,d) Distributions in the ω helicity frame at 38 GeV/c fitted simultaneously with the distributions in fig. 4a,b (cf.text for curves definition).

Fig. 5 38 GeV/c mass spectrum of the $|t| < 0.05$ (GeV/c)^2 $\omega\pi^\circ$ events in the $0.3 < |\cos\theta_{GJ}| < 0.6$ range where the J = 3 contribution is small.

Fig. 6 Comparison of the experimental data with theoretical models. Dots with error bars are experimental points, open circles are Godfrey-Isgur predictions [7]. Straight lines show the Veneziano formula prediction [9] corresponding to the slope 1.07 ± 0.07 GeV^2.

Fig. 7 Same as in fig. 4a but for the ρ_3 region.

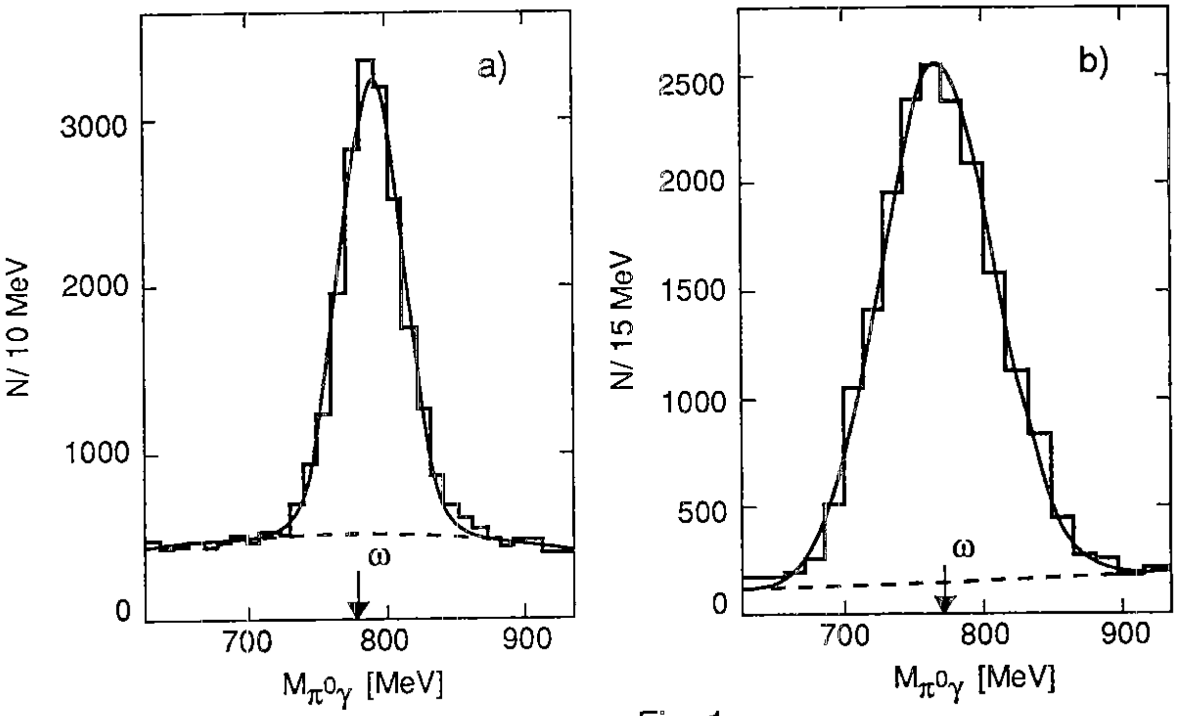
a)
b)
N/ 10 MeV
N/ 15 MeV
3000
2000
1000
0
2500
2000
1500
1000
500
0
ω
ω
700
800
900
700
800
900
$M_{\pi^0\gamma}$ [MeV]
$M_{\pi^0\gamma}$ [MeV]

Fig. 1

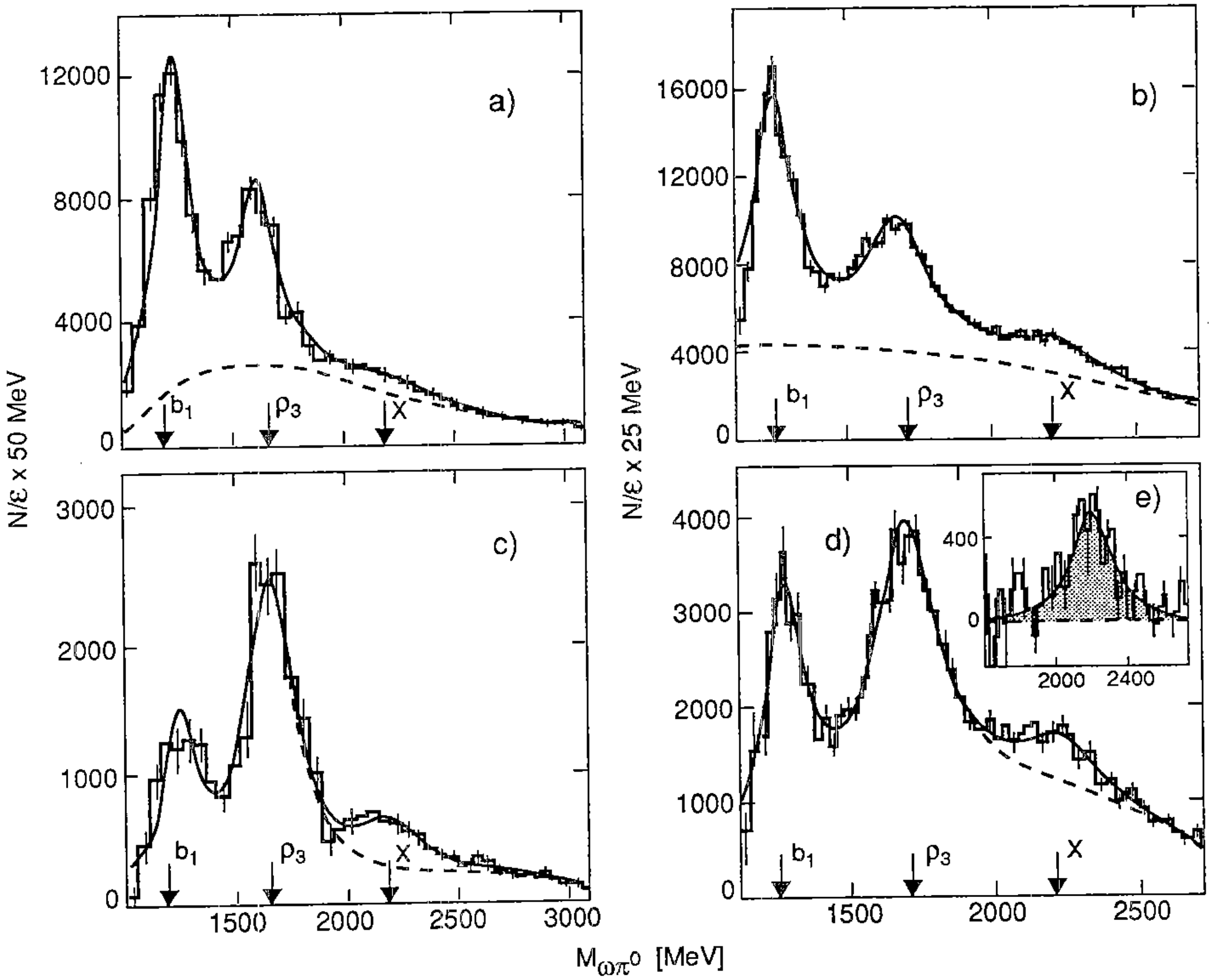
a)
b)
c)
d)
e)
N/ε x 50 MeV
N/ε x 25 MeV
12000
8000
4000
0
16000
12000
8000
4000
0
3000
2000
1000
0
4000
3000
2000
1000
0
400
0
2000
2400
b_1
ρ_3
X
1500
2000
2500
3000
1500
2000
2500
$M_{\omega\pi^0}$ [MeV]

Fig. 2

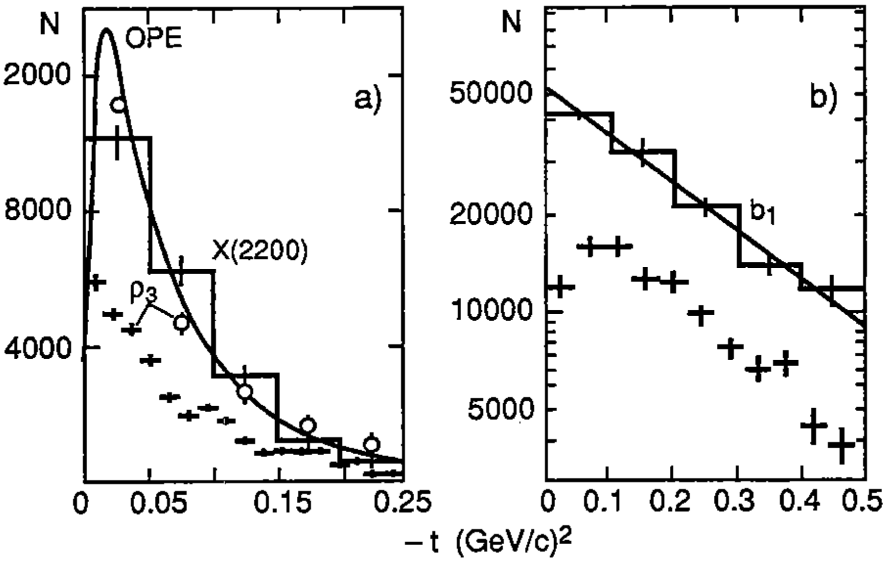
N
OPE
12000
8000
4000
a)
X(2200)
ρ_3
0
0.05
0.15
0.25
N
50000
20000
10000
5000
b)
b_1
0
0.1
0.2
0.3
0.4
0.5
$-t$ (GeV/c)^2

Fig. 3

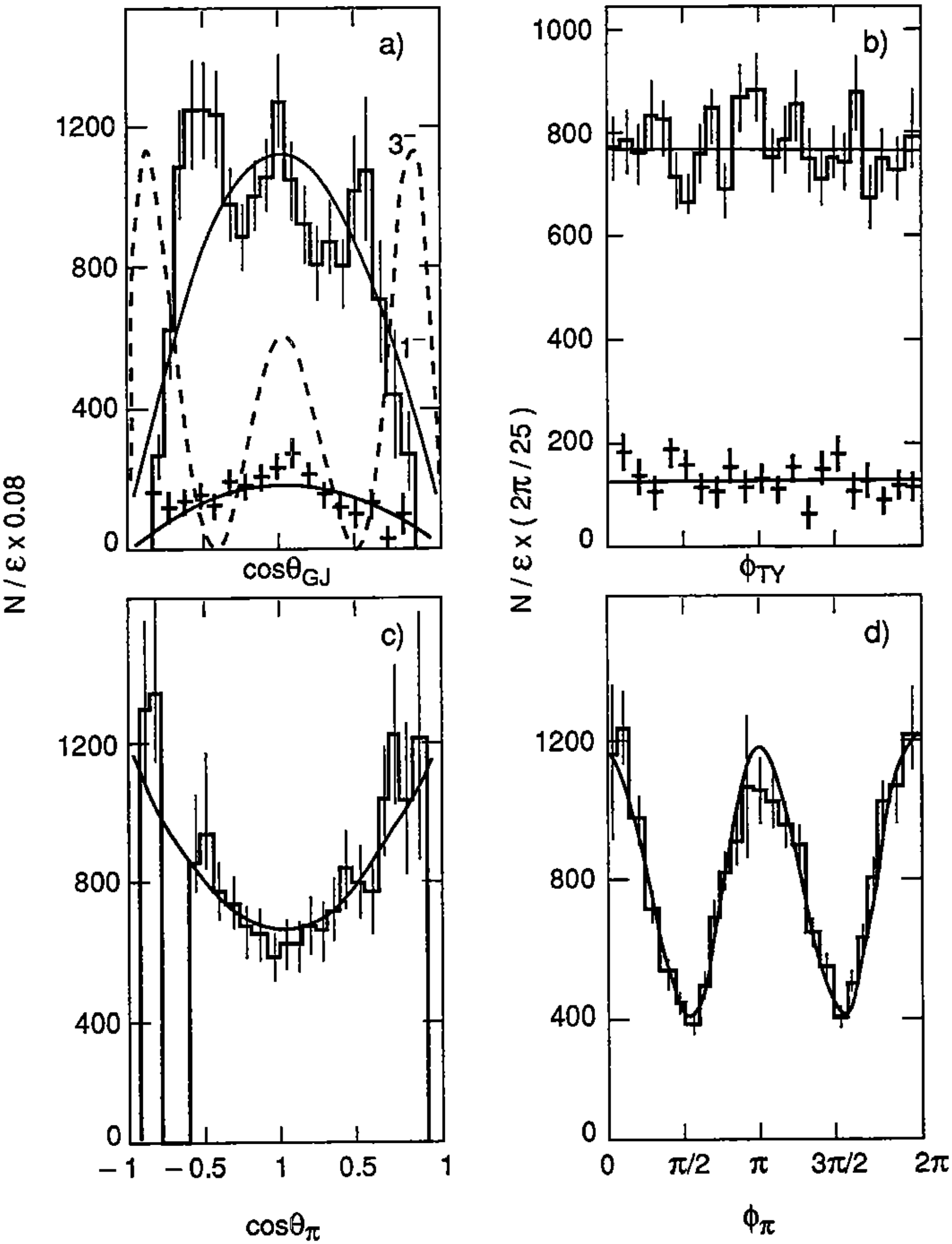
a)
1200
800
400
0
3^-
1^-
$\cos\theta_{GJ}$
b)
1000
800
600
400
200
0
ϕ_{TY}
$N/\varepsilon \times 0.08$
$N/\varepsilon \times (2\pi/25)$
c)
1200
800
400
0
−1
−0.5
1
0.5
1
$\cos\theta_\pi$
d)
1200
800
400
0
0
π/2
π
3π/2
2π
ϕ_π

Fig. 4

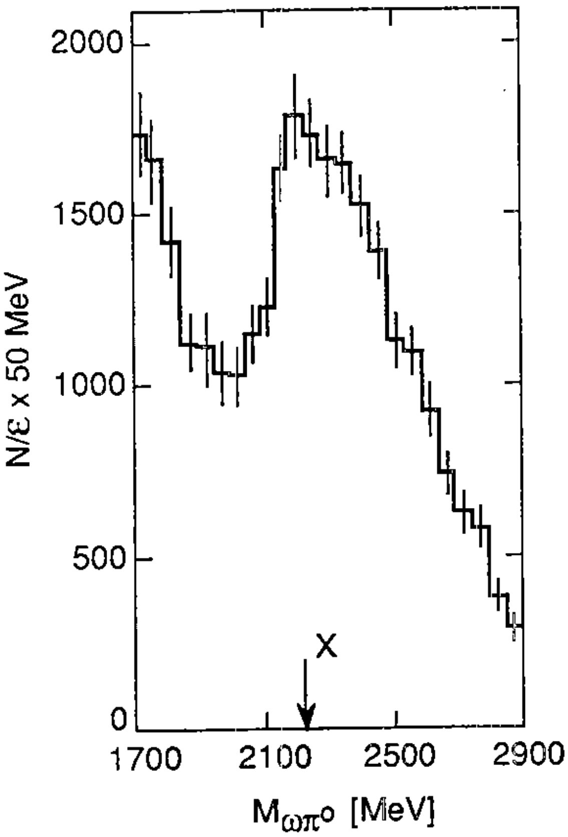

Fig. 5

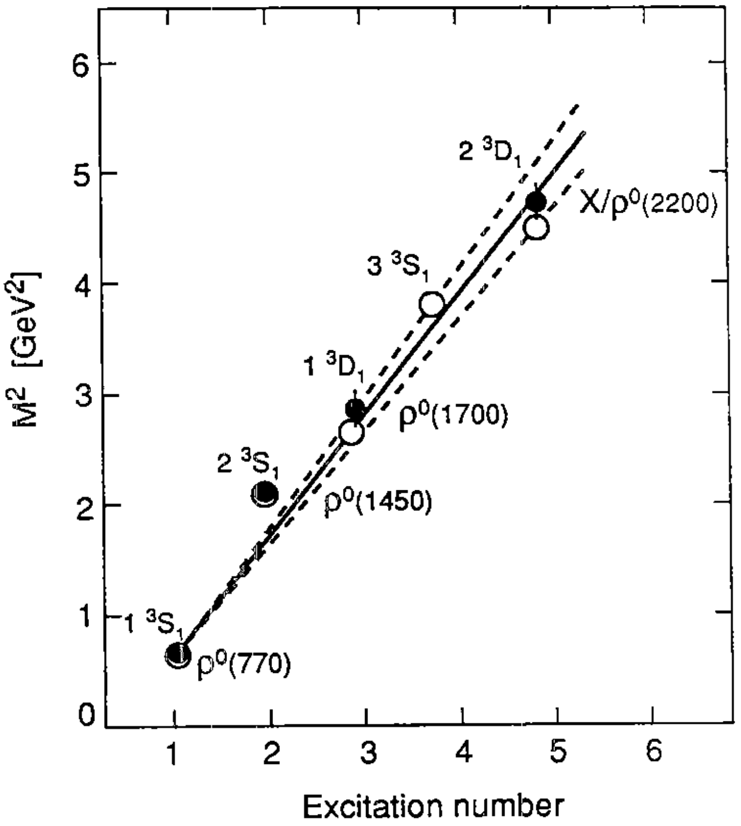

Fig. 6

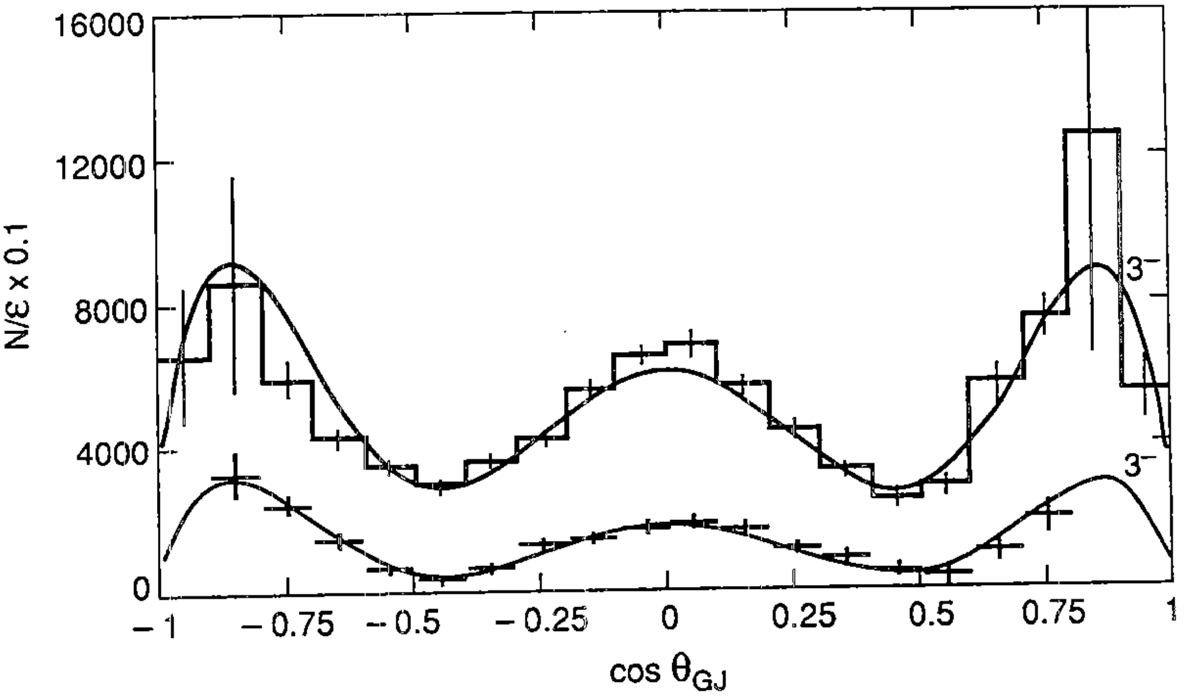

Fig. 7