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EVIDENCE FOR A 1^{-+} EXOTIC MESON

IHEP[1)] – IISN[2)] – LANL[3)] – LAPP[4)] Collaboration

(Joint CERN – IHEP experiment)

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Abstract

A non $q\bar{q}$, $J^{PC} = 1^{-+}$, $I^G = 1^-$ meson has been observed in the study of the exclusive reaction $\pi^- p \rightarrow \pi^0 \eta n$ at 100 GeV. Its mass is (1406 ± 20) MeV. Its width is (180 ± 30) MeV.

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Mesons in the constituent quark model are supposed to be bound $q\bar{q}$ states. This hypothesis is supported by the success of the SU(3) classification scheme through which most observed mesons are distributed in a series of nonets according to their quantum numbers. Some recently discovered light mesons seem to be in excess in their respective nonets but all have quantum numbers that are compatible with a two-quark structure. Theory is not yet in a measure to calculate the meson spectrum accurately, but it predicts the existence of mesons with a different structure, like gluonium made of two or three gluons, hybrids made of mixed quarks and gluons, as well as four-quark systems which might fill higher SU(3) representations. Such exotic states, which have no unambiguous characteristics except for the fact that some may have quantum numbers forbidden by strict conservation laws for $q\bar{q}$ systems, e.g. $J^{PC} = 0^{+-}, 0^{--}, 1^{-+}, 2^{+-}$, etc, have been intensively searched for.

The $\eta\pi$ system is the simplest channel where 1^{-+} states can be looked for. Results on the observation of the first exotic non $q\bar{q}$ vector meson in a high statistics study of the exclusive reaction

$$\pi^- p \to \eta\pi^0 n \quad (\eta\pi^0 \to 4\gamma) \tag{1}$$

are reported.

The experiment has been performed at the CERN SPS with a 100 GeV/c negative pion beam as a part of the GAMS programme. The main detector in these experiments is GAMS-4000, a hodoscopic, lead-glass, Cerenkov, electromagnetic calorimeter. The setup has been described previously [1]. Data have been collected for distances L between the liquid hydrogen production target and GAMS of 20 and 15 meters. Events with an isobar produced in the final state instead of a neutron are rejected by the guard system of counters surrounding the target.

The energy and impact point on GAMS of each gamma are determined through standard shower reconstruction procedures [1]. The $\eta\pi^0$ system has been studied through its 4γ decay. There are six combinations of two gamma pairs for each 4γ event.

The reaction $\pi^- p \to 4\gamma n$ is dominated by the production of π^0 pairs. Therefore, all events that are consistent with the two-pion hypothesis (the mass of 2γ pairs less than 300 MeV) are rejected. Of the remaining events, all that have one γ pair in the mass range 100 MeV $< M_{2\gamma} <$ 170 MeV and the other in the range 470 MeV < $M_{2\gamma}$ < 630 MeV are fit to reaction (1), fixing the masses of the neutron, the pion and the eta. Events that are fit with a CL > 0.1 are kept for further processing. The numbers of events is the final $\eta\pi^0$ sample are 11250 for L = 20 m data and 23193 for L = 15 m data.

The largest source of background is the production of $\eta\pi^0\pi^0$ systems whith both photons from a low energy π^0 escaping detection. Monte Carlo evaluations show that this background is about 5% in the low mass region of the spectrum (up to 1 GeV) and that it is smaller elsewhere.

The global detection efficiency, evaluated through Monte Carlo calculations, which include geometrical acceptance, reconstruction and fitting procedures and gamma energy detection threshold, depends only weakly on L. Fig. 1 shows the mass spectrum of fitted $\eta\pi^0$ events before and after correction for efficiency (the figures in this paper show the data taken with L = 15 m, i.e. 2/3 of the total statistics).

The |t| domain covered by the data extends up to 0.8 $(\mathrm{GeV/c})^2$. The |t| distribution of events in the 1.2 to 1.6 GeV mass range is peaked around |t| = 0.1 $(\mathrm{GeV/c})^2$. It has the shape expected for dominant ρ exchange in the production of $a_2(1320)$ [2,3].

A strong asymmetry between events with the η going either forward or backward in the Gottfried-Jackson frame of the $\eta\pi^0$ system is observed in the 1400 MeV mass range (fig. 2). This asymmetry, which had been already noticed previously [2], may only arise through the presence of an odd wave interfering with the visible $a_2(1320)$ peak.

Normalized spherical harmonic moments $<Y_{\ell m}>$ have been evaluated from the measured angular distributions $I(\Omega)$ in each mass bin using a maximum likelihood method [4]:

$$I(\Omega) = N \sum_{\ell} \{ <Y_{\ell 0}> \mathrm{Re}Y_{\ell 0}(\Omega) + 2 \sum_{m>0} <Y_{\ell m}> \mathrm{Re}Y_{\ell m}(\Omega)\} \quad (2)$$

where $\Omega \equiv \theta,\phi$ are the polar and azimutal angle of the η in the Gottfried-Jackson frame of the $\eta\pi^0$ system and N is the number of events. Significant moments are shown on fig. 3. All moments with $\ell > 4$ and/or $m > 2$ are compatible with zero, indicating the absence of significant contributions from waves other than S, P and D.

The helicity amplitudes have been obtained in each mass bin by solving the system of equations which relates them to the moments [5]. There is no ambiguity as both solutions corresponding to the choice of different Barrelet zeros [5,6] are identical within the errors. Phases of the natural parity amplitudes have been evaluated relative to the P_+ phase and those of unnatural parity amplitudes relatively to the D_0 phase. Both P_+ and D_- are structureless. Fig. 4 shows the different P and D amplitudes and phases.

The P_0,D_0 and D_+ amplitudes have been fit with Breit-Wigner functions superposed on a quadratic background and P_+ with a polynomial. The structures in D waves above 1.6 GeV and the S wave amplitude will be discussed in a forthcoming paper.

The $a_2(1320)$ state is readily visible in the mass spectrum. It dominates the D wave. The relative phase variation between P_+ and D_+ shows the resonating behaviour expected for $a_2(1320)$. A P_0 wave resonance is seen at about 1400 MeV. Its phase relative to D_0 undergoes a variation compatible with the presence of two neighbouring resonances.

The sensitivity of the experiment is (1.6 ± 0.3) pb/event, obtained by normalisation to the measured cross section for the exclusive production of η [1]. This leads to a measured $a_2(1320)$ production cross section $\sigma(\pi^- p \rightarrow a_2 n)$ of (395 ± 80) nb at 100 GeV, using the known tabulated value for $BR(a_2 \rightarrow \eta\pi^0)$. Using measuments of this cross section at lower energies [2], one sees that it scales down with momentum like p^{-b} where $b = 2.05 \pm 0.2$, as expected. This gives further confidence in the overall consistency of the data.

The parameters of $a_2(1320)$ and of the new P state are given in the Table.

The quantum numbers of this new meson are $J^{PC} = 1^{-+}$ and $I^G = 1^-$. It is the first observation of a meson that can in no way be a $q\bar{q}$ state because of its quantum numbers. There being no nomenclature yet for such a state, the name M(1405) is proposed. Being an isovector, it cannot be a glueball. Two interpretations have been proposed : that M(1405) is an hybrid state containing a valence gluon, $gq\bar{q}$ [7], or it is a four-quark state [8]. The measurement of its branching ratio into $\eta'\pi^0$ might shed light on the question. The discovery of other exotic states should now be firmly expected.

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TABLE: Parameters of the resonances

Name	Wave	Mass (MeV)	Γ (MeV)	σ.BR (nb)	
M(1405)	P_0	1406 ± 20	180 ± 30	9 ± 2	
$a_2(1320)$	D_0	1308 ± 20	163 ± 30	40 ± 10	57 ± 12
	D_+	1301 ± 20	114 ± 20	17 ± 6	

REFERENCES

[1] D.Alde et al., Nucl. Phys. B269 (1986) 485 and references therein.

[2] W.D.Apel et al., Nucl. Phys. B193 (1981) 269 and references therein.

[3] D.Alde et al., Phys.Lett. 198B (1987) 286.

[4] G.Grayer et al., Nucl. Phys. B75 (1974) 189.

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

[6] E.Barrelet, Nuovo Cim. 8A (1972) 331;
A.Gersten, Nucl. Phys. B12 (1969) 537.

[7] F.Close and H.Lipkin, Phys.Lett. 196B (1987) 245.

[8] M.S.Chanowitz, Phys.Lett. 187B (1987) 409.

FIGURE CAPTIONS

Fig.1 Invariant mass spectrum of $\eta\pi^0$ events measured with a target-to-GAMS distance of 15 m in mass bins of 35 MeV :

a) full line histogram : raw data;

b) dashed histogram : after correction for acceptance;

c) points : recalculated from the fit of angular distribution ($\sqrt{4\pi}$ N $< Y_{00} >$).

Fig.2 Forward-backward asymmetry, i.e. $(N_F - N_B)$ where $N_F(N_B)$ is the number of η going forward (backward) in the Gottfried-Jackson frame of the $\eta\pi^0$-system

Fig.3 The unnormalized moments $< \ell . m > \equiv \sqrt{4\pi}$ N $< Y_{\ell m} >$ of significant waves versus the mass of the $\eta\pi^0$ system.

Fig.4 Upper two rows : intensities of P and D waves (in 10^3 events/35 MeV), and lower row : relative phases (radians) of P and D waves versus the $\eta\pi^0$ mass.

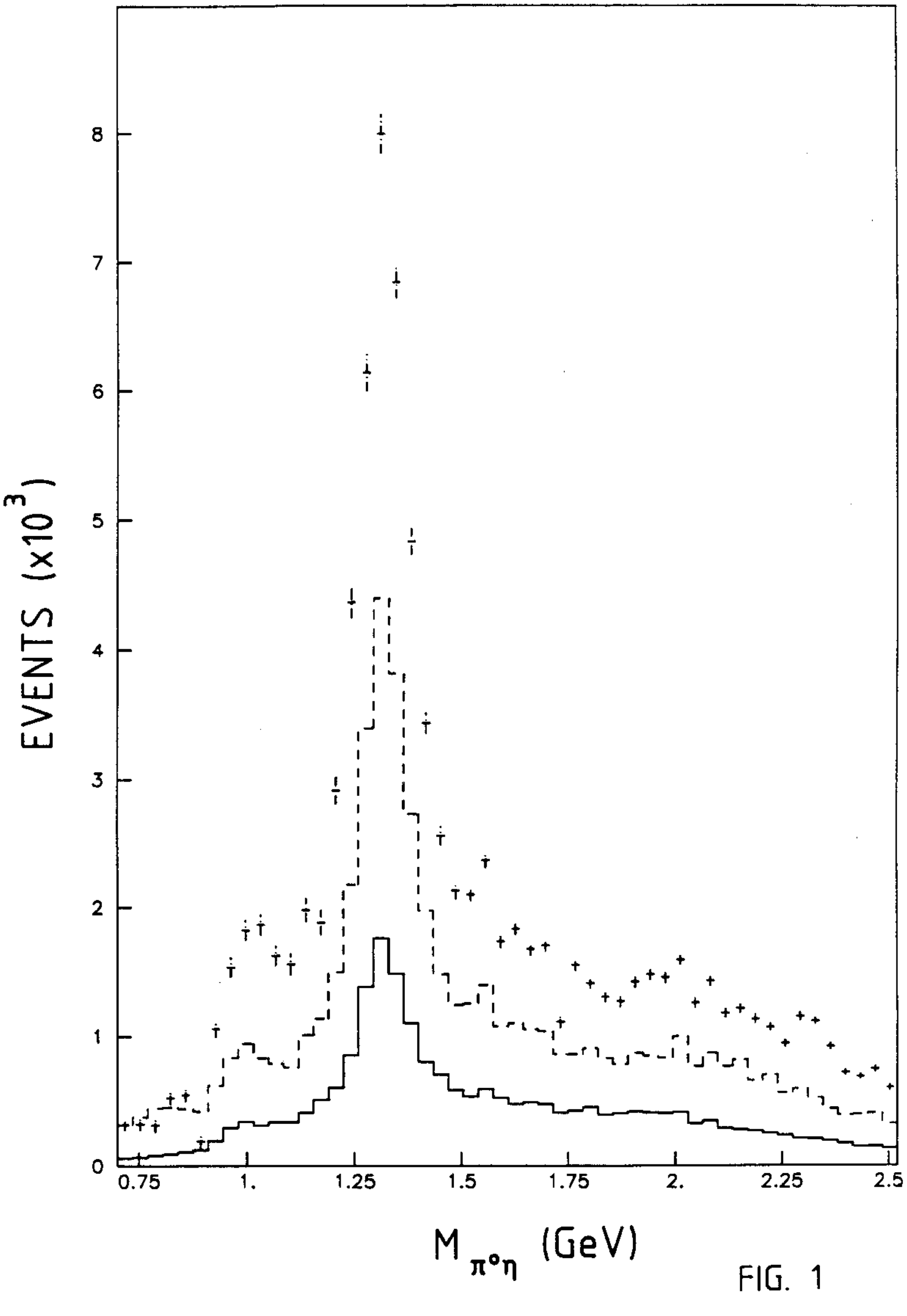


FIG. 1

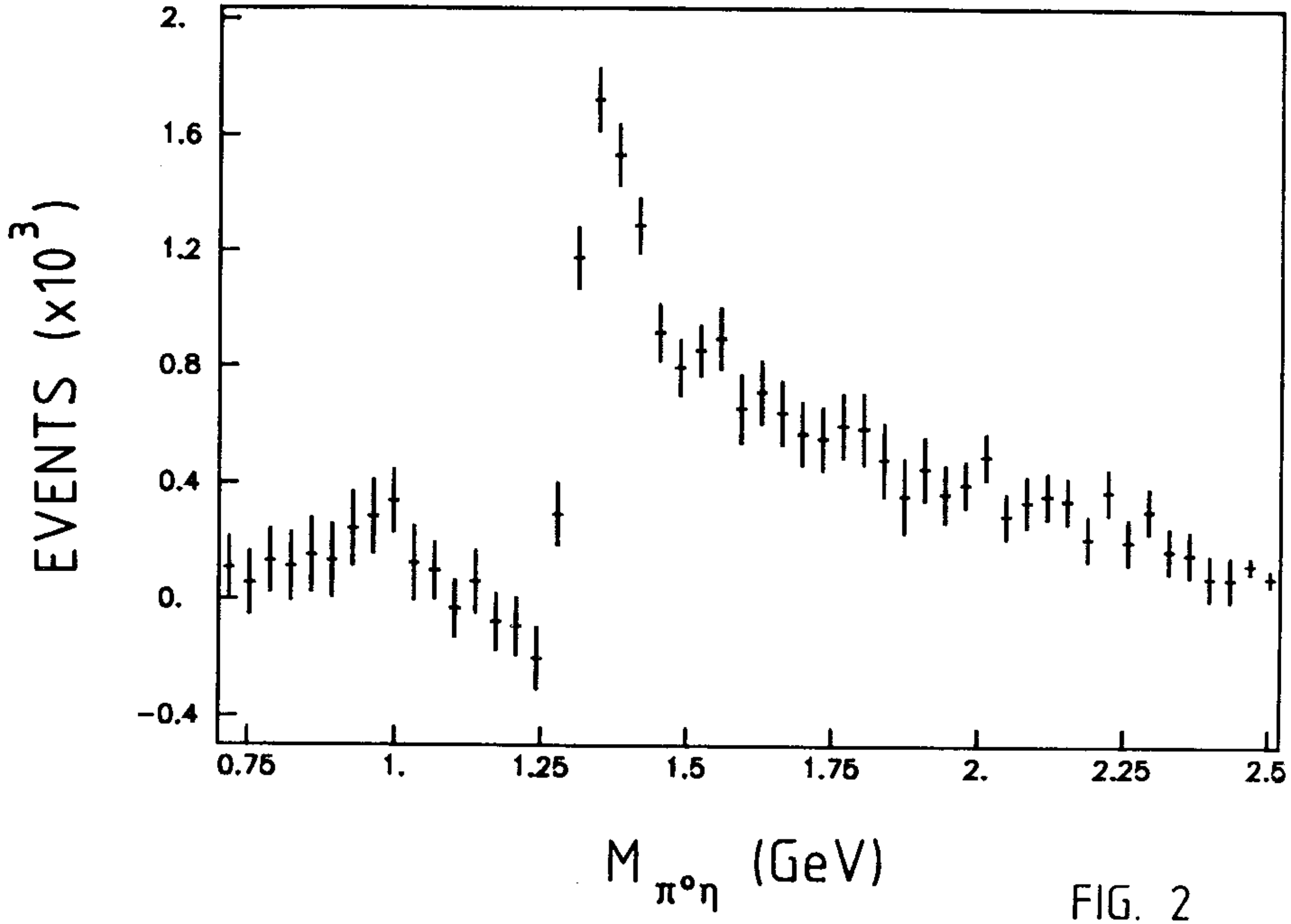


FIG. 2

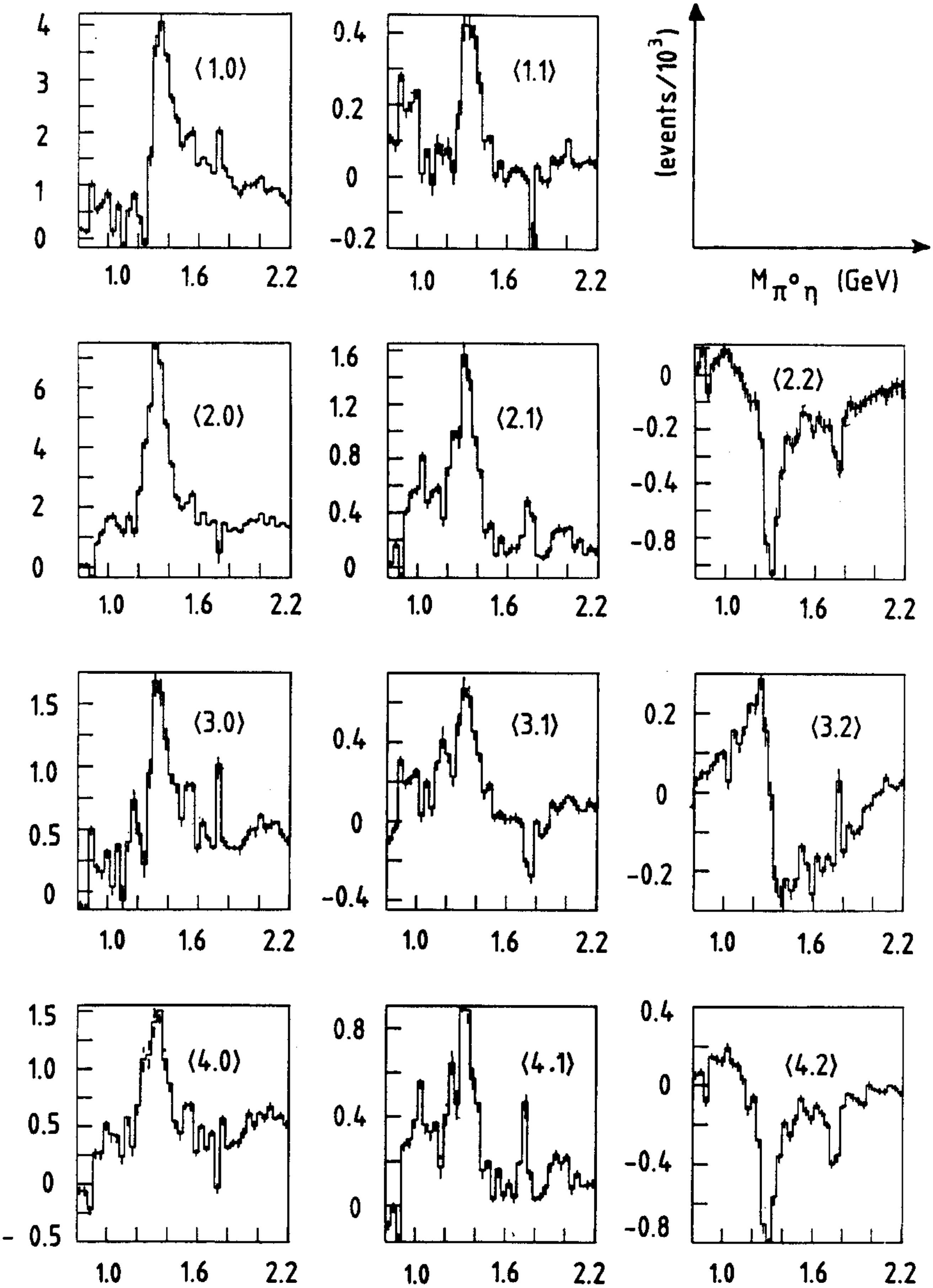
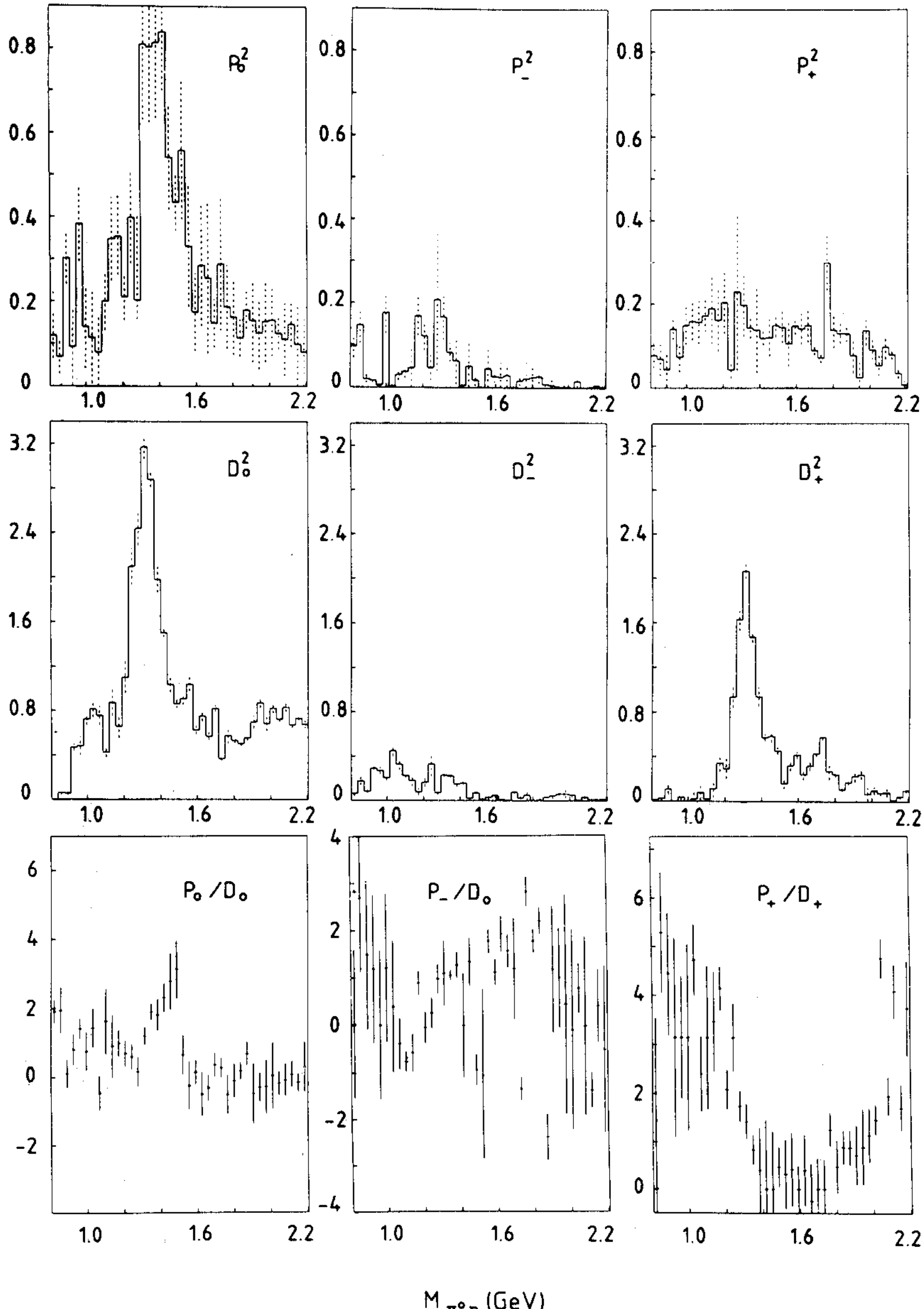


FIG. 3



P_0^2
P_-^2
P_+^2
D_0^2
D_-^2
D_+^2
P_0/D_0
P_-/D_0
P_+/D_+
0.8
0.6
0.4
0.2
0
3.2
2.4
1.6
0.8
6
4
2
-2
-4
1.0
1.6
2.2
$M_{\pi^0\eta}$ (GeV)

FIG. 4