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STUDY OF $\pi^- p \to \eta' \eta n$ IN A SEARCH FOR GLUEBALLS

IHEP[1]-IISN[2]-LAPP[3] Collaboration

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ABSTRACT

$\eta'\eta$ pair production in the charge-exchange reaction $\pi^- p \to \eta'\eta n$ has been observed and studied in a search for glueballs with the 38 GeV/c pion beam of the 70 GeV IHEP accelerator. The γ-rays from the decay $\eta'\eta \to 4\gamma$ were detected with the hodoscope spectrometer GAMS-2000. The $\eta'\eta$ events in the mass range from threshold up to 1.8 GeV are decays of the scalar G(1590)-meson which has been already observed in its $\eta\eta$ decay mode. The measured ratio of the partial widths of the $G \to \eta'\eta$ and the $G \to \eta\eta$ decay channels is 2.7 ± 0.8 in agreement with the value expected for glueball.

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1. INTRODUCTION

During the last two years, experiments on the search for bound gluon states (glueballs) have been intensively pursued [1]. The occurence of such states without quarks as a pure gluonic state of matter is one of the most important predictions of quantum chromodynamics.

A very attractive way of searching for glueballs lies in the study of $\eta\eta$ and $\eta'\eta$ systems which may be favoured final states of glueball decays [2]. Already a tensor meson, θ (1700) $[I^G(J^P)C = 0^+(2^+)+]$ decaying into an eta pair has been discovered. It is interpreted as a glueball candidate [3]. The scalar G(1590)-meson $[0^+(0^+)+]$ also decaying in $\eta\eta$ is another possible glueball [4].

The study of other G (1590) decay channels is of great interest, particularly $G \rightarrow \eta'\eta$. Would the G(1590) meson be of gluonic nature, the ratio of decay probabilities in both $\eta\eta$ and $\eta'\eta$ channels could be theoretically predicted rather precisely [5]

$$2 \lesssim \frac{BR(G \rightarrow \eta'\eta)}{BR(G \rightarrow \eta\eta)} \lesssim 3.7 \qquad (1)$$

The present experiment has been made with the aim of measuring neutral meson states decaying into $\eta'\eta$ pairs in the mass region up to 1.8 GeV.

2. EXPERIMENTAL PROCEDURE

The set-up has been described previously [4,6]. The measurements have been made in a 38 GeV/c negative pion beam. Charge-exchange processes leading to neutral final states which ultimately decay into photons have been detected

$$\pi^- p \rightarrow M^0 n, \quad M^0 \rightarrow k\gamma \qquad (2)$$

The photons were measured in the hodoscope spectrometer GAMS-2000.

Events with all kinds of multiplicities are recorded including those of multiplicity k = 4 which would be produced by decays of the type:

$$M^0 \rightarrow \eta'\eta, \quad \eta'\eta \rightarrow 4\gamma \qquad (3)$$

and which have the same topology as have events in the reaction $\pi^- p \rightarrow \eta\eta\, n$ through which G(1590) was discovered in the same set-up [4].

The reaction $\pi^- p \to \eta' \eta\, n$ has not been observed before. The difficulty lies in the low decay probability $\eta' \eta \to 4\ \gamma$ $(7 \cdot 10^{-3})$ and the large combinatorial background from the processes of π^0 and η pair production which are three orders of magnitude more abundant.

3. REACTION $\pi^- p \to \eta' \eta\, n$

The following criteria have been used to suppress the background contribution to events of reaction (2) with k = 4 multiplicity, selected by the reconstruction program [6]:

(a) the effective mass of each pair of gammas $M_{\gamma_i \gamma_j}$ should be larger than 180 MeV in order to eliminate neutral pions [4];

(b) events with both pairs of gammas in the η-meson range from 450 MeV to 650 MeV are rejected in order to exclude the reaction $\pi^- p \to \eta\eta\, n$.

These criteria dramatically decrease the background and allow to securely identify events (3) in reaction (2). Fig. 1b shows the mass spectrum of one gamma pair $\gamma_3\gamma_4$ on the condition that the mass of the other pair $\gamma_1\gamma_2$ lies inside the η mass range (470 MeV $< M_{\gamma_1\gamma_2} <$ 650 MeV). Fig. 1c shows the analogous distribution for the mass $M_{\gamma_1\gamma_2}$ when the second pair $\gamma_3\gamma_4$ has the mass of η' (870 MeV $< M_{\gamma_3\gamma_4} <$ 1080 MeV). In both spectra, η and η' meson peaks are distinctly present, in contrast with the mass spectrum of all arbitrary pairs $M_{\gamma_i\gamma_j}$ (fig. 1a). The background under the η' peak is about 20%. It is negligeably small under the η peak.

4. MASS SPECTRUM AND ANGULAR DISTRIBUTIONS

The kinematical characteristics of the $\eta'\eta$ systems produced in the reaction $\pi^- p \to \eta' \eta\, n$ have been determined by a 3C fit of the selected events fixing $M_{\gamma_1\gamma_2} = m_\eta$, $M_{\gamma_3\gamma_4} = m_{\eta'}$ and the recoil neutron mass. The detection efficiency ε has been evaluated with the method in Refs. [4,6] using a data base of real showers. It does practically depend neither on the mass of the $\eta'\eta$ system, nor on the decay angle in the Gottfried-Jackson frame.

The mass spectrum of $\eta'\eta$ is given on Fig. 2. It shows a fast increase very near the kinematical threshold, as expected for the decay $G(1590) \to \eta'\eta$.

In the explored mass region near the threshold, $M_{\eta'\eta} < 1.8$ GeV, S waves dominate, the contribution of higher waves being decreased by the barrier factor [4]. This is confirmed by the isotropic angular distribution of Fig. 3. It also fixes the quantum numbers of the scalar $\eta'\eta$ system: $0^+(0^+)+$.

$\pi^- p \to \eta'\eta\, n$ events are concentrated in the small emission angle region. The shape of their t-distribution is characteristic of one-pion exchange. It is similar to that obtained in the reaction producing the G(1590) meson decaying into $\eta\eta$ [4]. It is described by $d\sigma/dt \sim t(t-m_\pi^2)^{-2}\exp(bt)$ with $b \simeq 5(\mathrm{GeV/c})^{-2}$.

5. G(1590) → η'η and G(1590) → ηη DECAYS

The $\eta'\eta$ mass spectrum has been fitted with a Breit-Wigner distribution of the form

$$\frac{d\sigma}{dM} = \frac{A}{(M-\bar{M})^2+(\Gamma/2)^2} \cdot \frac{q(M)}{q(\bar{M})} \qquad (4)$$

where $q(M) = [M^2-(m_{\eta'}+m_\eta)^2]^{1/2}\,[M^2-(m_{\eta'}-m_\eta)^2]^{1/2}/2M$ is the phase space ($M = M_{\eta'\eta}$) and $\bar{M}$, Γ and A are free parameters (Fig. 2). It gives the following best values of the parameters:

$$\bar{M} = (1568 \pm 33)\ \mathrm{MeV}$$
$$\Gamma = (260 \pm 60)\ \mathrm{MeV}. \qquad (5)$$

The width Γ is evaluated taking into account the instrumental resolution $\sigma_M \sim 25$ MeV ($\sigma_M/M \sim 1.5\%$). These values are in good agreement within the experimental error limits with those of the mass and the width of the G(1590)-meson ($M_G = (1592 \pm 25)$MeV, $\Gamma_G = (210 \pm 40)$MeV) [4].

So all measured characteristics (quantum numbers, resonance mass and width, t dependence of the cross-section) of the observed $\eta'\eta$ events are consistent with those of G(1590). This allows to conclude that the decay mode

$$G(1590) \to \eta'\eta \qquad (6)$$

has been observed.

The ratio of G decay rates through $\eta'\eta$ and through $\eta\eta$ evaluated from the data of this experiment and of the previous one [4]

$$\frac{BR(G \to \eta'\eta)}{BR(G \to \eta\eta)} = 2.7 \pm 0.8 \qquad (7)$$

is in agreement with the value predicted by the already mentioned model in which the G(1590)-meson is described as a glueball with a small quark admixture [5].

If one takes into account the relative phase spaces, the $\eta'\eta$ decay channel of G(1590) is enhanced by a factor 7 compared to the $\eta\eta$ decay channel which is itself several times enhanced compared to the $\pi\pi$ and KK channels. This is a characteristic feature of glueball.

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FIGURE CAPTIONS

Fig.1 a) Effective mass spectrum of γ pairs in reaction (2) for events with a multiplicity of k = 4 (6 entries for one event). Arrows show the tabulated masses of η and η';

b) Idem for one pair ($\gamma_3\gamma_4$) when the mass of the other pair ($\gamma_1\gamma_2$) is in the η mass range shown by arrows;

c) Idem for $M_{\gamma_1\gamma_2}$ when $M_{\gamma_3\gamma_4}$ is in the η' mass range shown by arrows.

Fig. 2 $\eta'\eta$ mass spectrum produced in reaction $\pi^-p \to \eta'\eta n$ from the threshold (arrow) to 1.83 GeV/c^2. In this figure and in the next one, N has been corrected for efficiency ($\varepsilon \sim 0.25$). The full line is a Breit-Wigner fit (4) with parameters (5). The dashed line is the phase space normalized to the number of events in the measured mass interval.

Fig. 3 Polar angular distribution of $\eta'\eta$ decay in the Gottfried-Jackson frame. 1.51 GeV < $M_{\eta'\eta}$ < 1.83 GeV. $\theta_{GJ} = 0$ corresponds to the trajectory of η' along the beam direction.

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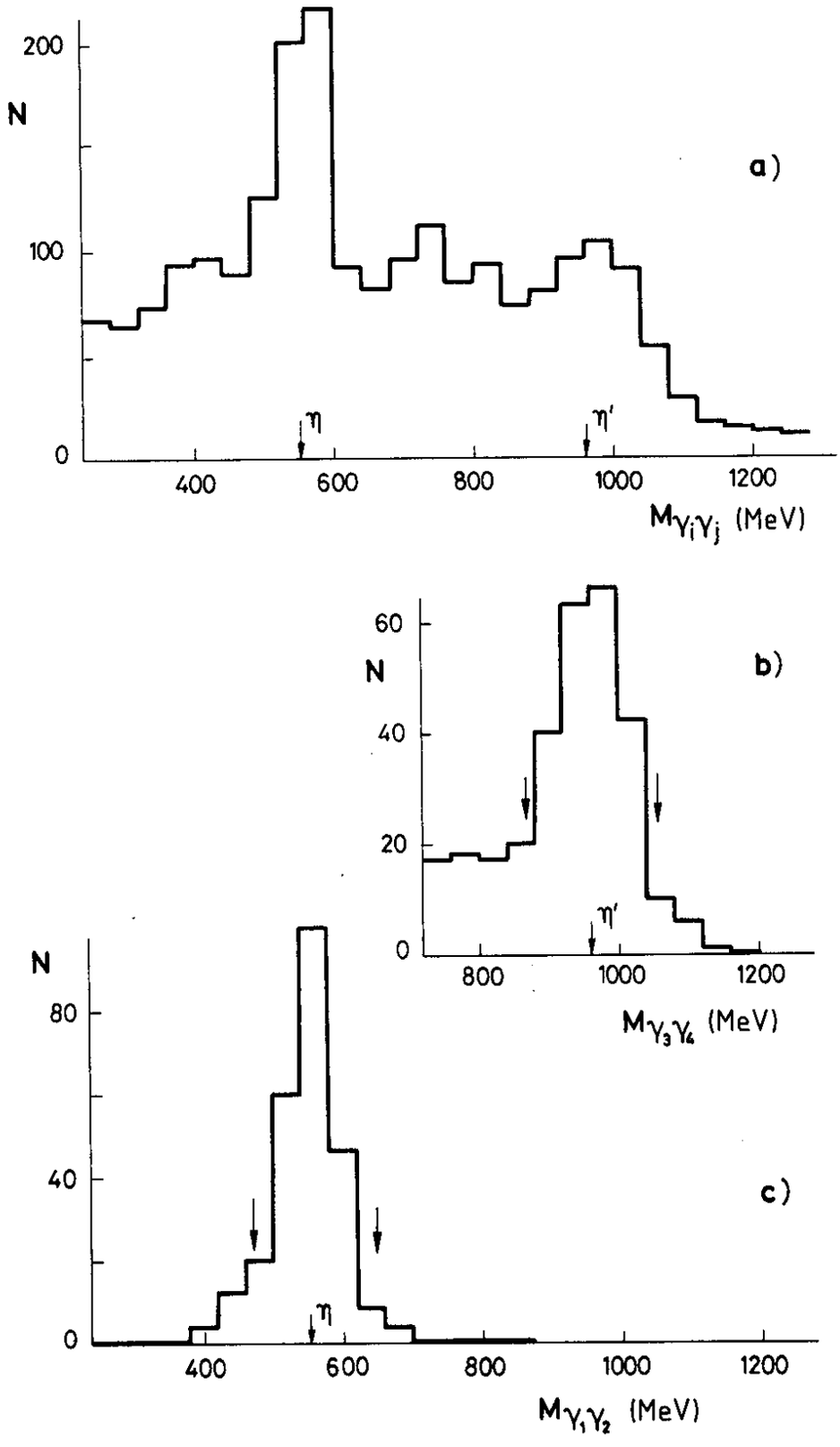
200
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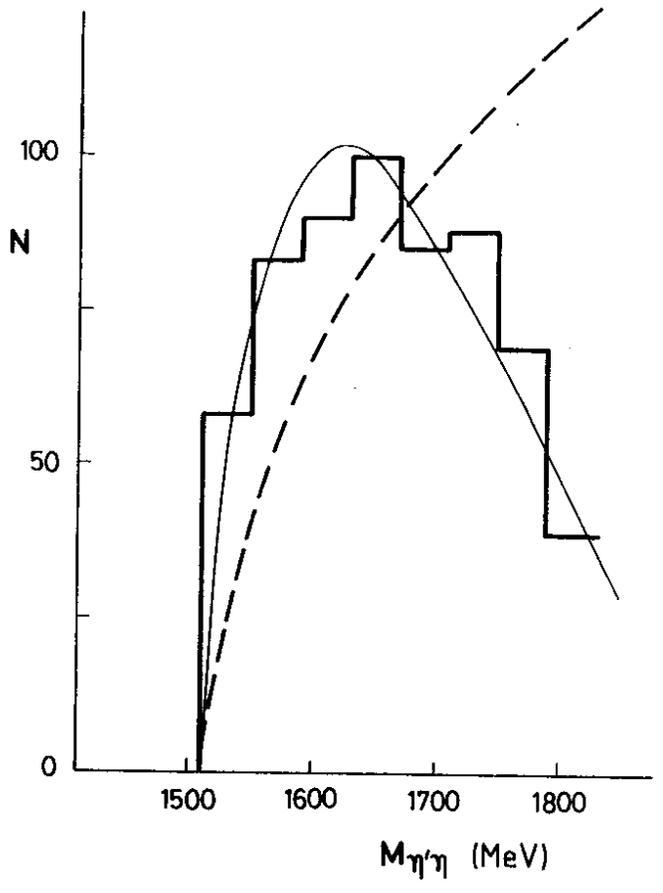
$M_{\gamma_1\gamma_2}$ (MeV)

FIG. 1


100
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1500
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1700
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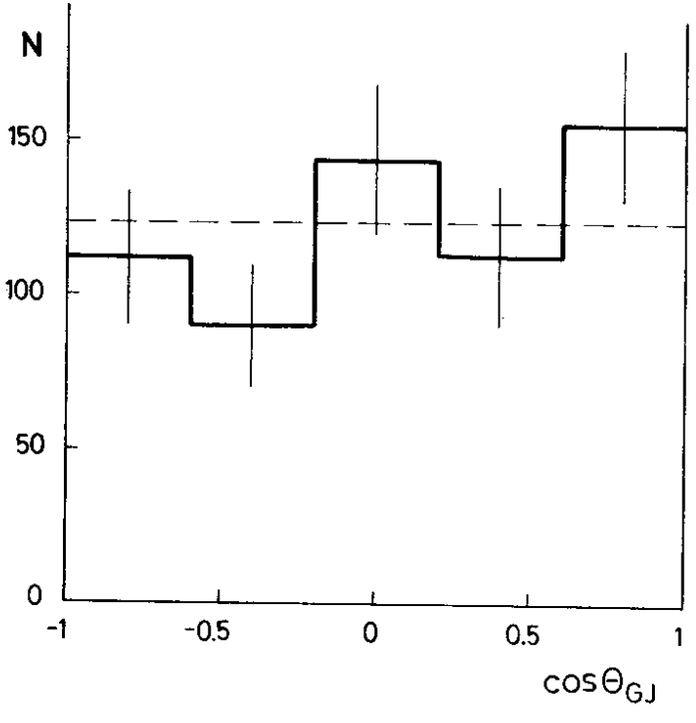
$M_{\eta'\eta}$ (MeV)

FIG. 2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-1
-0.5
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0.5
1
$\cos\Theta_{GJ}$

FIG. 3