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

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ABSTRACT

$\eta' \eta$ pair production in the charge-exchange reaction $\pi^- p \rightarrow \eta' \eta n$ 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 $\eta' \eta \rightarrow 4\gamma$ 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 $G \rightarrow \eta' \eta$ and the $G \rightarrow \eta \eta$ 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 occurrence 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, $\theta(1700)$ [$I^G(J^P)C = 0^+(2^+) +$] 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]

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

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

$$\pi^- p \rightarrow M^0 n \quad (2)$$

$\downarrow$
 $k\gamma$

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:

$$M^0 \rightarrow \eta'\eta \quad (3)$$

$\downarrow$
 4γ

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 $\pi^- p \rightarrow \eta' \eta n$ has not been observed before. The difficulty lies in the low decay probability $\eta' \eta \rightarrow 4 \gamma$ ($7 \cdot 10^{-3}$) 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 $\pi^- p \rightarrow \eta' \eta n$

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 $\pi^- p \rightarrow \eta \eta n$.

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 ($470 \text{ MeV} < M_{\gamma_1 \gamma_2} < 650 \text{ MeV}$). 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' ($870 \text{ MeV} < M_{\gamma_3 \gamma_4} < 1080 \text{ MeV}$). 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 negligibly small under the η peak.

4. MASS SPECTRUM AND ANGULAR DISTRIBUTIONS

The kinematical characteristics of the $\eta' \eta$ systems produced in the reaction $\pi^- p \rightarrow \eta' \eta n$ 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 $G(1590) \rightarrow \eta' \eta$.

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: $0^+(0^+)_{++}$.

$\pi^- p \rightarrow \eta' \eta n$ 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 $b \approx 5(\text{GeV}/c)^{-2}$.

5. G(1590) $\rightarrow \eta' \eta$ and G(1590) $\rightarrow \eta\eta$ DECAYS

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

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

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:

$$\begin{aligned} \bar{M} &= (1568 \pm 33) \text{ MeV} \\ \Gamma &= (260 \pm 60) \text{ MeV.} \end{aligned} \quad (5)$$

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 ($M_G = (1592 \pm 25) \text{ MeV}$, $\Gamma_G = (210 \pm 40) \text{ MeV}$) [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

$$G(1590) \rightarrow \eta' \eta \quad (6)$$

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]

$$\frac{\text{BR}(G \rightarrow \eta'\eta)}{\text{BR}(G \rightarrow \eta\eta)} = 2.7 \pm 0.8 \quad (7)$$

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 $\pi^- p \rightarrow \eta' \eta n$ from the threshold (arrow) to $1.83 \text{ GeV}/c^2$. In this figure and in the next one, N has been corrected for efficiency ($\epsilon \sim 0.25$). 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. $1.51 \text{ GeV} < M_{\eta' \eta} < 1.83 \text{ GeV}$. $\theta_{GJ} = 0$ corresponds to the trajectory of η' along the beam direction.

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FIG. 1

FIG. 2

FIG. 3