Observation of a narrow meson with a mass of 1750 MeV which decays into two η mesons

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A meson with a small width which is produced in $\pi^- p$ collisions and which decays into an $\eta\eta$ pair has been discovered. The experiment was carried out with the GAMS-2000 multiphoton hodoscopic spectrometer in the pion beam at the Serpukhov accelerator at a momentum of 38 GeV/c. The mass of this new meson state is 1755 ± 8 MeV, and its width does not exceed 50 MeV. The spin and parity are $J^{PC} = 0^{++}$ or, less probably, 2^{++}. The isospin and G-parity are 0^+. The production cross section, σBR, has been found to be 3.5 ± 1.5 nb. The t dependence of the cross section is described by $\exp(\bar{b}t)$ with a slope $\bar{b} = 3.8 \pm 1.5$ $(\text{GeV}/c)^{-2}$.

This experiment was carried out to pursue the study of $\eta\eta$ systems in the reaction

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

which was begun with the experiments of Ref. 1. Those earlier experiments revealed a scalar $G(1590)$ meson with the characteristic properties of a glueball.[2–6] The measurements were carried out with the GAMS-2000 multiphoton hodoscopic spectrometer.[7] The apparatus and the analysis procedure are described in detail in Refs. 1, 2, and 7–9.

Data on reaction (1) were obtained in two month-long operating sessions of the spectrometer in a pion beam with a momentum of 38 GeV/c extracted from the Serpukhov accelerator. One session was carried out in the same geometry as in the first study[1] (the distance between the liquid-hydrogen target and the GAMS-2000 calorimeter, which determines the acceptance of the spectrometer, was $L = 4.2$ m). In the second session, the acceptance was increased through a reduction of the distance L to 3.4 m and through the use of a wide-aperture guard system consisting of sandwich counters with reradiation of light.[10]

The total number of $\eta\eta$ events detected was five times that in the preceding experiment.[1] The result was to make it possible to move to a large momentum transfer, up to $|t| \approx 1$ $(\text{GeV}/c)^2$, and to carry out a search for mesons which decay into $\eta\eta$ pairs in this region.

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To distinguish the rare process in (1) from events with four γ rays in the final state, we use the procedure described in Refs. 1 and 6. The background level is insignificant, even at a large momentum transfer. For further analysis we selected 45 000 events.

The overwhelming majority of these events were concentrated at small values of $|t|$, where reaction (1) is dominated by one-pion exchange (OPE), a large number of resonances $[\epsilon, f, G(1590), h]$ form, and the mass and angular distributions of the $\eta\eta$ systems correspondingly have a complex structure.[1,6] With increasing momentum transfer, the contribution of these resonances disappears, and at $|t| \gtrsim 0.2\ (\mathrm{GeV}/c)^2$ the dependence of the angular distribution on the mass $M_{\eta\eta}$ becomes monotonic.

At and above this value of $|t|$, we can clearly see a narrow peak in the mass spectrum of the $\eta\eta$ system at 1750 MeV (Fig. 1). This peak was observed independently in the two measurement sessions. It is clearly visible in different, nonoverlapping intervals of t.

The mass of this new meson state is found to be

$$M = 1755 \pm 8\,\mathrm{MeV}. \tag{2}$$

The measured width of the peak is the same as the instrumental resolution of the spectrometer. From the data obtained, we find the intrinsic width of the resonance to be

$$\Gamma < 50\,\mathrm{MeV}. \tag{3}$$

Figure 2 shows the (integral) distribution in t of events near the (1750) peak.

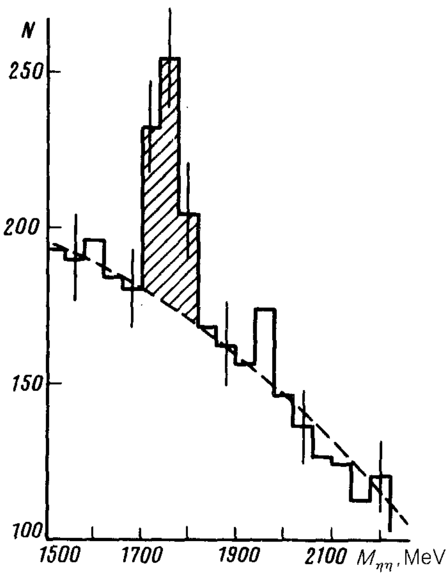

FIG. 1. Measured spectrum of the $\eta\eta$ systems in reaction (1) at $|t| > 0.35\ (\mathrm{GeV}/c)^2$. Here N is the number of events in the interval $\Delta M_{\eta\eta} = 40$ MeV; the dashed line is a polynomial fit of the spectrum outside the (1750) peak.

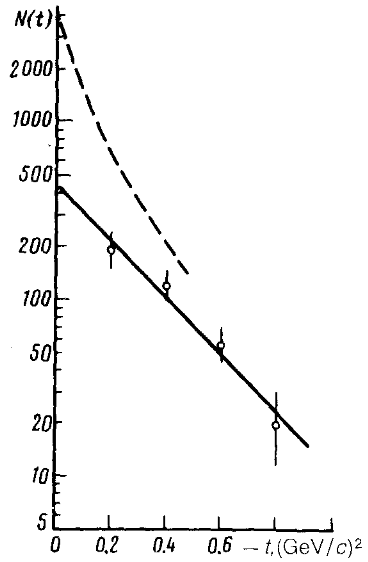

FIG. 2. Integral t distribution of $\eta\eta$ events in the (1750) peak, $N(t) = \int^{t} (dN/dt)dt$. Points—experimental results; straight line—the function $N(t) \sim \exp(bt)$, $b = 3.8$ $(\text{GeV}/c)^{-2}$; dashed curve—t dependence for the $G(1590)$ meson [one-pion exchange; $b = 10$ $(\text{GeV}/c)^{-2}$ at $t \approx 0$, and $b = 6.5$ $(\text{GeV}/c)^{-2}$ at $|t| = 0.4$ $(\text{GeV}/c)^2$].[1,6]

This distribution can be described by the exponential function $\exp(\bar{b}t)$ with the slope

$$\bar{b} = 3.8 \pm 1.5 \ (\text{GeV}/c)^{-2}. \quad (4)$$

This result corresponds to an interaction region with smaller dimensions than those of other mesons which are produced in reaction (1) by the OPE mechanism, for which the typical value at small values of $|t|$ is $\bar{b} \approx 10$ $(\text{GeV}/c)^2$. Consequently, the observed meson state is not manifested in the mass spectrum at $t \approx 0$, where it is masked by other mesons, which are produced more intensely [$G(1590)$, etc.; Fig. 2].

At $|t| \gtrsim 0.3$ $(\text{GeV}/c)^2$ the angular distribution of the $\eta\eta$ systems in reaction (1) depends weakly on the mass, as we have already mentioned. With increasing $|t|$, this distribution becomes more nearly isotropic. By virtue of the smooth dependence of the angular distributions on $M_{\eta\eta}$, we can determine the angular distribution for the (1750) peak by a method of subtraction in adjacent mass intervals. Figure 3 shows the angular distribution for the decay $M^0 \to \eta\eta$ in (1) in the Gottfried-Jackson system. In

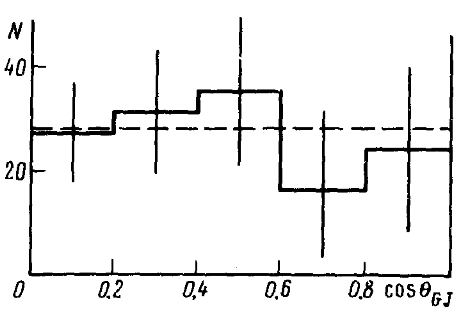

FIG. 3. Distribution of $\eta\eta$ events at the (1750) peak in the polar angle of the decay in the Gottfried-Jackson system at $|t| > 0.35$ $(\text{GeV}/c)^2$. The dependence of the detection efficiency ϵ on θ_{GJ} has been taken into account. The distribution has been normalized in such a way that its integral is equal to the number of measured events (150).

plotting this distribution, we allowed for the detection efficiency ϵ, which depends only slightly on the decay angle[1] θ_{GJ}.

Only even states are possible in the $\eta\eta$ system. The isotropy of the angular distribution in Fig. 3 is evidence of a spin and parity $J^{PC} = 0^{++}$, although a 2^{++} state is not ruled out (but is less likely). The other quantum numbers of this meson—its isospin and G-parity—are fixed: $1^G = 0^+$.

This new meson, for which we are introducing the designation $X(1750)$, is distinguished by not only its small total width but also its very small production cross section in the reaction $\pi^- p \to X(1750)n$:

$$\sigma VR\,[X\,1750) \to \eta\eta] = 3.5 \pm 1.5 \text{ nb} \quad (5)$$

[extrapolated over the region $0.2 < |t| < 1$ $(\text{GeV}/c)^2$ to $t = 0$; Fig. 2]. This production cross section is significantly smaller than those of other known mesons at these energies. The observation of a decay into η mesons may be evidence that the $X(1750)$ meson has a significant valance gluon component.[3] In analyzing the nature of this meson it is useful to recall the existence of yet another narrow state, with a mass of[11] 2220 MeV.

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