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EVIDENCE FOR A 1.9 GeV MESON DECAYING INTO $\eta\eta'$

IHEP¹⁾ - IISN²⁾ - LANL³⁾ - LAPP⁴⁾ Collaboration

(Joint CERN - IHEP experiment)

D.Alde ³⁾, F.G.Binon ^{2,5)}, C.Bricman ^{2,5)}, S.V.Donskov ¹⁾, M.Gouanère ⁴⁾, A.V.Inyakin ¹⁾,
V.A.Kachanov ¹⁾, G.V.Khaustov ¹⁾, E.A.Knapp ³⁾, A.V.Kulik ¹⁾, A.A.Lednev ¹⁾, J.P.Peigneux ⁴⁾,
Yu.D.Prokoshkin ¹⁾, Yu.V.Rodnov ¹⁾, S.A.Sadovsky ¹⁾, V.D.Samoylenko ¹⁾, P.M.Shagin ¹⁾,
A.V.Shtannikov ¹⁾, A.V.Singovsky ¹⁾, J.P.Stroot ^{2,5)} and V.P.Sugonyaev ¹⁾

Abstract

Evidence for a new meson decaying into $\eta\eta'$ has been found in 38 GeV π^-p charge-exchange interactions. The mass and the width of this meson are (1917 ± 15) MeV and $(90 + 35/-50)$ MeV, respectively. Possible spin and parity assignments are $J^{PC} = 0^{++}$, 1^{-+} or 2^{++} , isospin and G-parity are $I^G = 0^+$. The t-dependence of the differential cross section follows an exponential behaviour e^{bt} with a small slope: $b = (2 \pm 1) (\text{GeV}/c)^{-2}$. Upper limits on its decay into $\pi\pi$, $\eta\eta$ and $K\bar{K}$ suggest an exotic interpretation of this meson.

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¹⁾ Institute for High Energy Physics, Serpukhov, USSR.

²⁾ Institut Interuniversitaire des Sciences Nucléaires, Belgium.

³⁾ Los Alamos National Laboratory, New Mexico, USA.

⁴⁾ Laboratoire d'Annecy de Physique des Particules, France.

⁵⁾ Mailing address : CERN, EP Division, 1211 Geneva 23, CH.

A systematic study of neutral mesons which decay into pseudoscalar mesons is pursued in the GAMS programme in a search for new states [1]. $\eta\eta'$ -systems produced in π^-p charge-exchange reactions have already been studied in the region of small momentum transfer where one-pion exchange (OPE) dominates. The number of measured $\eta\eta'$ events having since been increased by an order of magnitude, it has been possible to investigate the region of higher $|t|$ values, where OPE influence is decreasing fast and where other processes, with exchange of heavier particles, starts to contribute. The presence in this region of $X(1750)$ decaying into $\eta\eta$ [2] enhances the interest of high momentum transfer studies.

The measurements have been performed with 38 GeV/c pions at the IHEP proton synchrotron. The multiphoton hodoscope spectrometer GAMS-2000 was used in particular to detect 4γ final states produced in the exclusive reaction:

$$\begin{array}{c} \pi^- p \rightarrow M^0 n \\ \quad \downarrow \\ \quad \eta\eta' \rightarrow 4\gamma \end{array} \quad (1)$$

Data have been accumulated during three runs. The same geometrical configuration with a distance $L = 4.2$ m between GAMS-2000 and the liquid hydrogen target was used for two of these. The acceptance was increased for the third run by enlarging the opening of the guard-system and by reducing L to 3.4 m.

The experimental setup and the data analysis procedures have been described elsewhere [2],[3].

Events of the low yield reaction (1) ($BR(\eta' \rightarrow 2\gamma) \cdot BR(\eta \rightarrow 2\gamma) = 0.9\%$) are unambiguously identified up to the largest momentum transfer (Fig.1). In order to reduce the background in the analysis of the $\eta\eta'$ -systems, a cut has been applied on the χ^2 resulting from the fit of each individual gamma-shower profile [2] (such a cut was not necessary for the study of the more intensively produced $\eta\eta$ -system). In this way, 1200 events have been identified instead of 250 events in a first study [4].

The invariant mass spectrum of the selected $\eta\eta'$ -systems is shown on Fig.2. A peak is observed near threshold. It is identified with $G(1590)$. It quickly disappears when $|t|$ increases. Simultaneously, a peak around 1.9 GeV shows up more and more significantly with increasing $|t|$, bearing witness of a new meson state. This peak is observed in all three runs.

The mass of this resonance, determined from the fit of the spectrum on Fig. 2c, is:

$$M = (1917 \pm 15) \text{ MeV} \quad (2)$$

The measured width of the peak at half maximum is $(110 \pm 33) \text{ MeV}$. Taking into account the instrumental resolution (see below), the width of this meson, for which the name X(1920) is proposed, is:

$$\Gamma = (90^{+35}_{-50}) \text{ MeV} \quad (3)$$

The efficiency of the gamma selection by their associated χ^2 (Table 1) has been determined from the analysis of η -pairs with the same topology as the events of reaction (1). It is practically independent on the energy of the gammas. The global detection efficiency of $\eta\eta'$ events and the mass resolution of the spectrometer have been obtained by Monte Carlo [2]. The efficiency shows only a weak dependence on t and on the $\eta\eta'$ mass.

Table 1: Efficiency and resolution of the spectrometer at $M_{\eta\eta'} = 1.92 \text{ GeV}$

Run	1	2	3
L(m)	4.2	3.4	4.2
γ reconstruction efficiency (χ^2 cut)	0.72	0.45	0.64
Geometrical acceptance	0.26	0.29	0.26
Mass resolution fwhm (MeV)	55	65	55

Fig. 3 shows that the t -dependence of the differential cross section for the production of X(1920) in reaction (1) is quite different from the characteristic OPE distribution which is concentrated in a region of $|t|$ below $0.2 (\text{GeV}/c)^2$. It follows an exponential law $d\sigma/dt \sim e^{bt}$ with a slope

$$b = (2 \pm 1) (\text{GeV}/c)^{-2} \quad (4)$$

which is nearly the same as that found for X(1750).

The distribution of $\eta\eta'$ events in the region of the X(1920) peak and the corresponding detection efficiency ε are shown on Fig. 4 as a function of the polar decay angle in the Gottfried-Jackson frame. The angular distribution becomes more and more isotropic when $|t|$ increases, which is an indication that the spin of X(1920), if aligned, is not large: $J \leq 2$. The $\eta\eta'$ -system has positive C-parity and its parity P is given by $(-1)^J$ so that possible quantum numbers for X(1920) are $J^{PC} = 0^{++}, 1^{-+}$ or 2^{++} . Its other quantum numbers, $I^G = 0^+$, are defined by the observed decay mode.

Taking into account the efficiency and the measured t -dependence (Fig. 3), the production cross section of X(1920) in reaction (1) at 38 GeV/c is:

$$\sigma(\pi^- p \rightarrow X(1920)n) \cdot \text{BR}(X(1920) \rightarrow \eta\eta') = (15 \pm 5) \text{ nb} \quad (5)$$

This result has been obtained after normalization to the reaction $\pi^- p \rightarrow \eta\eta n$ (40 times more intense) of which the cross section had been previously measured [2].

The following 90 % C.L. limit may be put on the decay $X(1920) \rightarrow \eta\eta$ which has not been observed experimentally [2]:

$$\text{BR}(X(1920) \rightarrow \eta\eta) / \text{BR}(X(1920) \rightarrow \eta\eta') < 1/10 \quad (6)$$

X(1920) is neither observed in the channel $\pi^0\pi^0$ (Fig.5) at the same low level:

$$\text{BR}(X(1920) \rightarrow \pi^0\pi^0) / \text{BR}(X(1920) \rightarrow \eta\eta') < 1/10 \quad (7)$$

With the mass spectrum of $K_S^0 K_S^0$ -systems measured with the ITEP magnetic spectrometer [6] one may evaluate the following limit²:

$$\text{BR}(X(1920) \rightarrow K_S^0 K_S^0) / \text{BR}(X(1920) \rightarrow \eta\eta') < 1/15 \quad (8)$$

² From these data and the data [2] one gets also the limit $\text{BR}(X(1750) \rightarrow K_S^0 K_S^0) / \text{BR}(X(1750) \rightarrow \eta\eta) < 1/2$.

The most unusual property of X(1920) is the strong suppression of its decays into $\pi\pi$ and $K\bar{K}$. A $ss\bar{s}$ structure is excluded for this state by the limit (8). Its weak coupling to the $\pi\pi$ -system could be an indication of a large gluonic component [7].

The strong suppression (6) of the $\eta\eta$ channel relatively to the $\eta\eta'$ one is also worth consideration. Taking into account that when X(1920) decays into $\eta\eta'$ the momentum is 1.4 times smaller than in the $\eta\eta$ case, one obtains from (6) a ratio³ for the decay matrix elements squared $|T|^2$:

$$\frac{|T(X(1920) \rightarrow \eta\eta')|^2}{|T(X(1920) \rightarrow \eta\eta)|^2} > \begin{cases} 14 & \text{if } J=0 \\ 50 & \text{if } J=2 \end{cases} \quad (9)$$

A much stronger limit is obtained from (7) on $T(X(1920) \rightarrow \pi^0\pi^0)$.

States similar to the scalar meson G(1590) can be explained in the framework of the gluon deco-
loration model [7] but the ratio (9) is not as large for G(1590) (≈ 7) and, furthermore, though its esti-
mated coupling to the $\pi\pi$ channel is weak ($BR \approx 3\%$ [7]) nevertheless it clearly manifests itself in
the production mechanism (OPE dominated) [1], [2] So, X(1920) and G(1590) are not analo-
gous-systems.

The peculiarities of X(1920) would find a natural explanation if this state had the quantum num-
bers $J^{PC} = 1^{-+}$ which are not allowed for $q\bar{q}$ -systems. Mesons with such quantum numbers cannot
decay into $\pi\pi$, $\eta\eta$ or $K\bar{K}$. They also cannot be produced by the OPE mechanism. In this case X(1920)
would be exotic : $q\bar{q}g$, $q\bar{q}q\bar{q}$...and its similarity with the X(1750) meson, also produced at large mo-
mentum transfers, is only superficial.

In conclusion, the unusual production and decay properties of X(1920) might be understood if it
had a non- $q\bar{q}$ structure, being either a glueball (0^{++} or 2^{++}) or a meikton or a 4-quark state (1^{-+}).

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³ If $J=4$ the limit obtained for (9) reaches 150 (!).

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Figure captions

Fig.1 a) Invariant mass spectrum of one γ -pair after the other has been identified as a η' ($\eta' \rightarrow \gamma_3\gamma_4$); b) same as a) but when the second pair has been identified as a η ($\eta \rightarrow \gamma_1\gamma_2$); c) and d) same as a) and b) but for $0.35 < |t| < 0.6 \text{ (GeV/c)}^2$ and $1850 < M_{4\gamma} < 1990 \text{ MeV}$.

Fig.2 Invariant mass spectrum of $\eta\eta'$ -systems produced in reaction (1) in various $|t|$ -domains in $(\text{GeV/c})^2$: a) $\{0, 0.6\}$, b) $\{0.2, 0.6\}$, c) $\{0.35, 0.6\}$. The arrows point to the mass value of G(1590) [8] and of X(1920).

Fig.3 Differential t -distribution of the $\eta\eta'$ events in the region of the X(1920) peak. The dashed curve is the OPE t -dependence: $d\sigma/dt \sim t(t-m_\pi^2)^{-2}e^{bt}$ with $b = 6 \text{ (GeV/c)}^{-2}$.

Fig.4 Angular distribution, corrected for the efficiency ε (dashed curve), in the Gottfried-Jackson frame of the $\eta\eta'$ events for various lower cuts on t in $(\text{GeV/c})^2$ (upper t bound: $|t| < 0.6 \text{ (GeV/c)}^2$). $1860 \text{ MeV} < M_{\eta\eta'} < 1980 \text{ MeV}$. Histograms are normalized so that the total number of measured $\eta\eta'$ events is conserved.

Fig.5 Mass spectrum of $\pi^0\pi^0$ -systems produced in the reaction $\pi^-p \rightarrow \pi^0\pi^0n$ with $0.35 < |t| < 0.6 \text{ (GeV/c)}^2$, measured with the GAMS-2000 spectrometer (see also [1]).

Fig.1

Fig. 2

Fig. 3

Fig. 4

Fig. 5