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THE *E*-MESON AND OTHER GLUEBALL CANDIDATES*

Ulrike Thoma

representing the Crystal Barrel Collaboration

Institut für Strahlen-und Kernphysik der Universität Bonn
Nußalle 14-16, 53115 Bonn, Germany

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The $\iota(1440)$ also called E-meson has been discussed as glueball candidate since many years. In $\bar{p}p \to \pi^+\pi^-\pi^+\pi^-\eta$ the $\iota(1440)$ is clearly observed but no evidence was found for the $\eta(1295)$. The non-observation of the $\eta(1295)$ in $\bar{p}p$-annihilation with the expected yield questions its interpretation as radial excitation of the η and therefore also the nature of the $\iota(1440)$. Another glueball candidate is the $f_0(1500)$. The investigation of the different 4π-decay modes of the scalar states may be crucial to clarify if a scalar glueball exists below 2 GeV. In order to do so four different 5π-final states have been investigated. The data are clearly dominated by the scalar isoscalar interaction. At least to scalar states are needed, the $f_0(1370)$ and the $f_0(1500)$. The first state decays dominantly into 4π, while the 4π-decays of the $f_0(1500)$ represent about half of its total width.

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The possibility that gluonic excitations of hadronic matter may exist is perhaps one of most fascinating topics in hadron spectroscopy. A particle which has been discussed as glueball candidate since many years is the $\iota(1440)$ also called E-meson. It was observed as a prominent peak in radiative J/Ψ decays [1] and was believed to be the first glueball. This conjecture was supported by the masses of the $\eta(1295)$ and of the $\pi(1300)$ suggesting ideal mixing and demanding the $s\bar{s}$ state to have a mass of $\sim$ 1550 MeV. The PDG suggests a 2^1S_0 nonet consisting of $K(1460)$, $\pi(1300)$, $\eta(1295)$ and the $\iota(1440)$, called $\eta(1440)$. But as $s\bar{s}$-state its mass is too low, and one does not understand why the $\eta(1440)$ is produced with π^--beams but not

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with K^--beams. In addition there is evidence for a splitting of the $\eta(1440)$ into two states at 1405 and at 1480 MeV [2]. Three states in mass region of 200 MeV cannot all be $q\bar{q}$-states. To clarify the experimental situation the reaction $\bar{p}p \to \pi^+\pi^-\pi^+\pi^-\eta$ has been investigated at LEAR by stopping antiprotons in liquid H_2 and by observing the final state with the Crystal Barrel detector. The data (Fig. 1) evidence the $f_1(1285)$, decaying into 4π, the $a_0(980)$, the η' and the $\eta(1440)$, respectively. A partial wave analysis

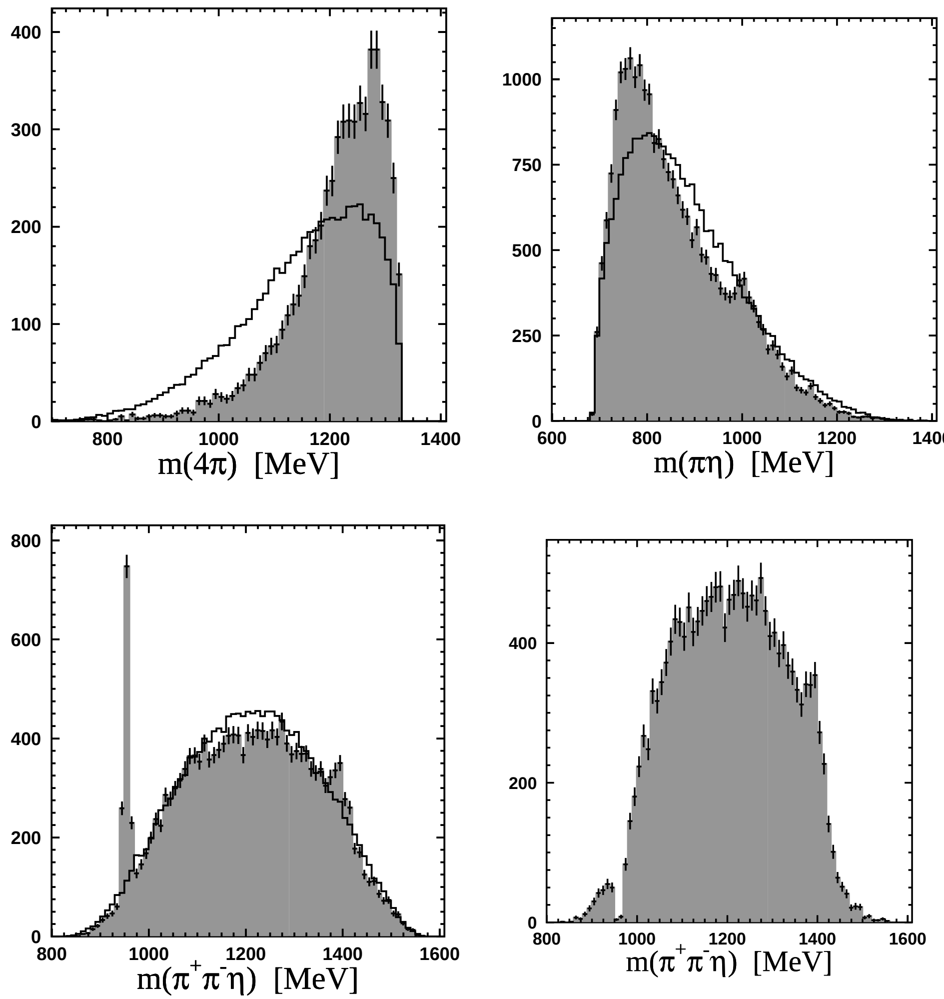

Fig. 1. Invariant masses of the $\bar{p}p \to \pi^+\pi^-\pi^+\pi^-\eta$ data set. The shaded distribution with the error bars shows the data, the line the phase space distribution. The last plot shows the $\pi^+\pi^-\eta$ invariant mass after an η'–anti-cut.

was performed within the isobar model. The following amplitudes have been introduced:

$$\begin{array}{lllllll}
\bar{p}p(^1S_0) & \to & f_0(1370)\eta, & f_0(1370) & \to & (\pi\pi)_S(\pi\pi)_S,\ \rho\rho,\ \pi(1300)\pi,\ a_1\pi \\
\bar{p}p(^1S_0) & \to & \eta(1440)(\pi\pi)_S, & \eta(1440) & \to & a_0(980)\pi,\ (\pi\pi)_S\eta \\
\bar{p}p(^1S_0) & \to & a_0(1440)\pi, & a_0(1450) & \to & a_0(980)(\pi\pi)_S \\
\bar{p}p(^3S_1) & \to & f_1(1285)\rho, & f_1(1285) & \to & a_0(980)\pi,\ (\pi\pi)_S\eta \\
\bar{p}p(^3S_1) & \to & b_1(1235)\eta, & b_1(1235) & \to & \rho(\pi\pi)_S \\
\bar{p}p(^3P_1) & \to & f_1(1285)\eta, & f_1(1285) & \to & \rho\rho
\end{array}$$

For the $\eta(1440)$ we found a mass of 1403 ± 6MeV and a width of 57 ± 9MeV in good agreement with the values given in the PDG [2]. The local variation in $2\ln(\mathcal{L})$ is shown in Fig. 2(a). A clear maximum is observed.

The $\iota(1440)$ is possibly split into a low-mass $\eta(1405)$ and a high mass $\eta(1480)$. A scan searching for an additional high mass state is shown in Fig. 2(b). There seems to be some evidence for an $\eta(1480)$, but the change in $2\ln(\mathcal{L})$ is small and we do not claim evidence for a splitting of the $\iota(1440)$. We also searched for further η-states in our data. The $\eta(1295)$ has precisely defined parameters. Mass and width are known with an accuracy of a few MeV. Hence we tried to introduce this meson with its PDG values. The likelihood increases by 24 for 4 additional parameters, a marginal change only. The contribution is less than (3×10^{-5}), 30 times smaller than the contribution of the $\eta(1405)$. Even if the $f_1(1285)$ is omitted, there is no evidence for the $\eta(1295)$. Likelihood scans (Fig. 2(c), (d) do not show any maximum in mass and width. These observations lead us to conclude that we have no evidence for the $\eta(1295)$. The non-observation of the $\eta(1295)$ in $\bar{p}p$-annihilation is unexpected if one assumes that the particle is the radial excitation of the η. The $\eta(1295)$ was also never observed in radiative J/Ψ-decays. A comparison of the branching fractions for $\bar{p}p\to\pi(1300)\sigma$ and $\bar{p}p\to\eta(1295)\sigma$ or $\bar{p}p\to\eta(1440)\sigma$ shows that only $\eta(1440)\sigma$ is produced at a rate one would expect from $\bar{p}p\to\pi(1300)\sigma$ (BR $\sim3\times10^{-3}$). This may indicate that not the $\eta(1295)$ but the $\eta(1440)$ is the radial excitation of the η. This assignment also gives a natural explanation of its splitting into two states: in the decay mode $\eta(1440)\to a_0(980)\pi$ two structures appear; the transition operator has a zero due to a node in the wave function [3]. In the decay mode $\eta(1440)\to K^*K$ only one peak is observed. Here the transition operator has no zero [3]. This could also give an explanation for the observation of the $\eta(1440)$ in experiments with π^- beams and its non-observation in experiments with K^--beams even if the $\eta(1440)$ decays dominantly in $K\bar{K}\pi$. The particle is dominant an $(u\bar{u}+d\bar{d})$-state but its decay into $a_0\pi$ is suppressed due to a node in the wave function. We interprete the $\eta(1440)$ as radial excitation of the η; the $\eta(1295)$ is supernumerous.

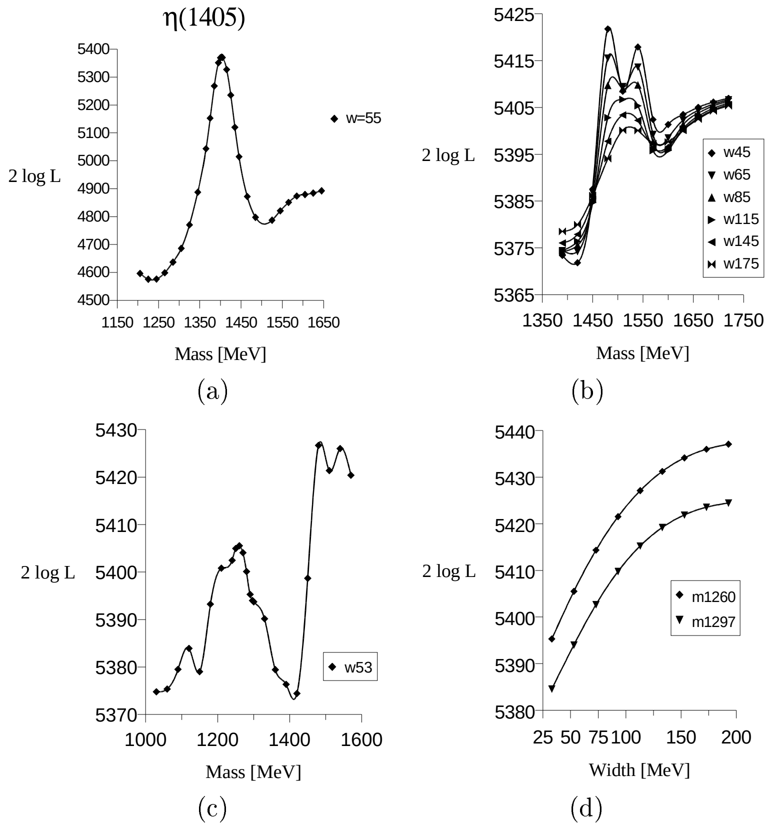

Fig. 2. (a) scan for a single 0^+0^{-+}-resonance, (b) scan for an additional η-state of higher mass. (c), (d) Scan for an additional 0^+0^{-+} resonance at lower mass. In the mass scan (c) the PDG value for the width of the $\eta(1295)$ is used, in the scan of the width (d) two curves for two different η-masses are shown ($m_{\rm PDG}$=1297 MeV).

In lattice gauge theories the lightest glueball is predicted to have scalar quantum numbers and a mass of about $1.73\,{\rm GeV}/c^2$ [4]. The existence of more scalar isoscalar mesons than the quark model can host has led to speculations that a glueball has intruded into the spectrum of scalar quarkonia and mixes with them, thus producing the states observed in the mass range below $2\,{\rm GeV}/c^2$ [5, 6]. Different mixing schemes *e.g.* [5, 6] allow an explanation of the observed decays of the $f_0(1500)$ into two pseudoscalar mesons even though the glueball content of the $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$ are quite different in these models. Experimental information on decay modes for these states may be helpful to decide which of these models is correct. Indeed, calculations exist which show that the determination of the different 4π decay modes might be crucial to shed light on this mixing scheme [7, 8].

In order to investigate the different 4π decay modes of the scalar states, $(\pi\pi)_S(\pi\pi)_S$, $\rho\rho$, $\pi(1300)\pi$ and $a_1\pi$, we have investigated four different 5π-final states: $\bar{p}p \to 5\pi^0$, $\bar{p}n \to \pi^- 4\pi^0$, $\bar{p}p \to \pi^+\pi^- 3\pi^0$, $\bar{p}n \to \pi^+ 2\pi^- 2\pi^0$.

From these datasets we found an $f_0(1370)$ with a mass of 1395 ± 40 MeV$/c^2$ and a width of 275 ± 55 MeV$/c^2$ and an $f_0(1500)$ with mass and width compatible with previous findings. For the $f_0(1370)$ the 4π-decay modes clearly dominate, while for the $f_0(1500)$ they represent about half of its total width. Assuming that all decay modes of the two states are known the partial decay widths of the states can be calculated. They are given in Table I. To our knowledge there is so far no model which explains all the decay modes of the two scalar states in a consistent way.

TABLE I

Partial widths Γ_i (in MeV) of $f_0(1370)$ and $f_0(1500)$ for decays into 2 pseudoscalar particles and into 4 pions assuming that all decay modes are observed (preliminary). The error of the total width is included in the errors for the partial widths. The pseudoscalar branching ratios to calculate the partial widths are taken from [9–11]

	Γ_{tot}	$\sigma\sigma$ $\pi\pi$	$\rho\rho$ $\eta\eta$	$\pi^*\pi$ $\eta\eta'$	$a_1\pi$ $K\bar{K}$
$f_0(1370)$	275 ± 55	120.5 ± 49.0 21.7 ± 9.9	62.2 ± 28.8 0.41 ± 0.27	41.6 ± 22.0	14.1 ± 7.2 (7.9 ± 2.7) to (21.2 ± 7.2)
$f_0(1500)$	130 ± 30	18.6 ± 12.5 44.1 ± 15.4	8.9 ± 8.2 3.4 ± 1.2	35.5 ± 29.2 2.9 ± 1.0	8.6 ± 6.6 8.1 ± 2.8

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