EXOTIC MESONS IN THE REACTION $p\bar{p} \rightarrow \pi^+\pi^-\pi^+\pi^-\eta$

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The results of a partial wave analysis of data on the reaction $\bar{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-\eta$ are presented. We found clearly evidence for the $\eta(1405)$ with mass (1407 ± 5) MeV and width (57 ± 9) MeV and evidence for the $\eta(1480)$ decaying into $\pi^+\pi^-\eta$ with mass 1490 MeV and a width of 80 MeV. No evidence for the $\eta(1295)$ was found.

Introduction

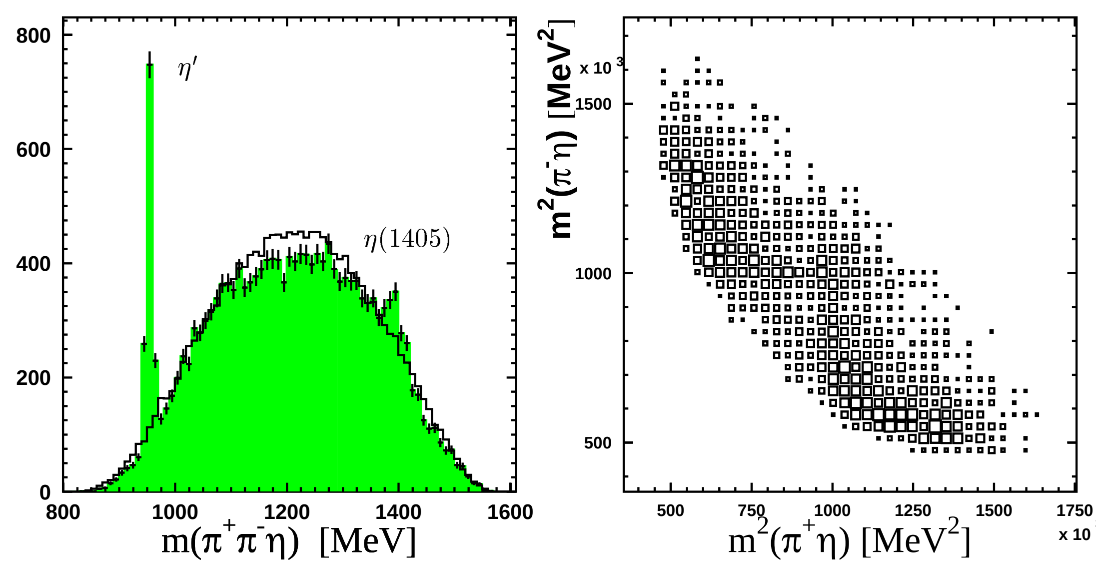
Gluons carry color charges and are members of a SU(3) color octet. They can bind to color singlets, so-called glueballs, or to $q\bar{q}g$-states, often called hybrids. A large number of experiments has been carried out to find such exotic particles, states beyond the quark model which are often called exotic even though they can have the same quantum numbers of quark-model states. It is hence difficult to decide, whether a state is pure $q\bar{q}$, exotic, or mixed.

The $\eta(1440)$, first called ι (greek: first) because it was believed to be the first glueball, is produced strongly in J/ψ decays where an enhancement of gluonic degrees of freedom is expected. This interpretation was supported by the similarity of the $\eta(1295)$ and $\pi(1300)$ masses suggesting ideal mixing. The corresponding $s\bar{s}$-state should carry a mass of about 1550 MeV. For this interpretation, the $\eta(1440)$ is too light and an exotic one was favored. A further hint against the $s\bar{s}$ interpretation of the $\eta(1440)$ was the fact that the $\eta(1440)$ was produced in π^-p but not in K^-p scattering.

After some years it turned out that the $\eta(1440)$ might be split into the $\eta(1400)$ and $\eta(1480)$. Nowadays three states close in mass are known — $\eta(1295)$, $\eta(1400)$, and $\eta(1480)$, — which cannot be all pure $q\bar{q}$-states. The question arises if one of these particles is exotic or whether there is another explanation.

1. Data Selection

The data are taken at the Low-Energy-Antiproton-Ring at LEAR at CERN. Low energy antiprotons (200 MeV/c) are extracted and stopped in a liquid hydrogen target. The annihilation products are then detected with



(a) (b)

Fig. 1. *a* — the $\pi^+\pi^-\eta$ invariant mass combinations — Data: bars, phase space (solid line). *b* — the symmetrized Dalitz plot of the decay $\eta(1440) \rightarrow \pi^+\pi^-\eta$

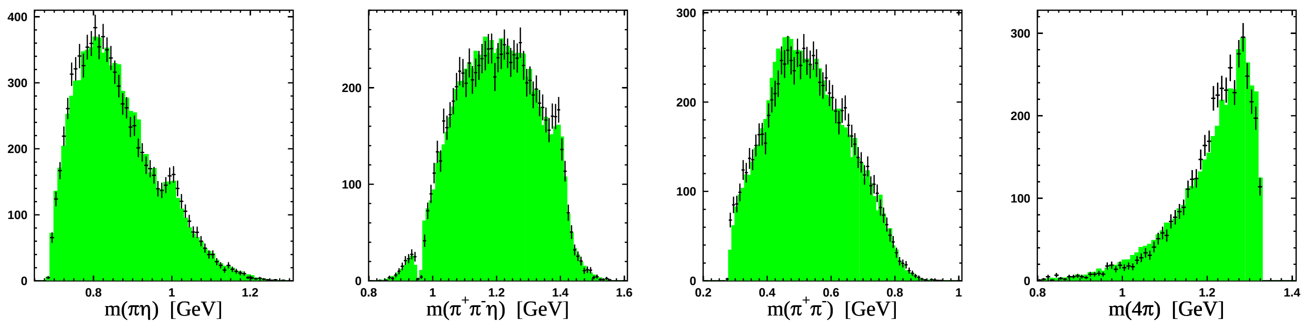


Fig. 2. Result of our reference fit: invariant mass distributions $m(\pi\eta)$, $m(\pi^+\pi^-\eta)$, $m(\pi^+\pi^-)$ and $m(4\pi)$. Data: error bars, Fit: shaded region

the Crystal Barrel detector, which has been described in [9]. The target is surrounded by a pair of cylindrical multi-wire proportional chambers (PWC's) and a 23-layer cylindrical drift chamber (JDC). The JDC is surrounded by a 1380 crystal CsI(Tl) barrel calorimeter. The crystals point towards the target center and the calorimeter covers polar angles between 12° and 168° degrees and 2π in azimuth. The useful acceptance for shower detection is 95% of 4π.

In Fig. 1,*a*, we show the $\pi^+\pi^-\eta$ invariant mass combinations and the phase distribution. The most striking feature is the η'-peak, while the $\eta(1400)$ is also visible. Fig. 1,*b* shows the Dalitz plot of the reaction $\eta(1400) \to \pi^+\pi^-\eta$. The decay $\eta(1440) \to a_0(980)\pi$ is visible in the structure along the $\pi\eta$-axes. A partial wave analysis extracts all other contributions to the Dalitz plot, which are not clearly visible.

1.1. Partial Wave Analysis

The $\pi^+\pi^-\pi^+\pi^-\eta$ data are analyzed using a maximum likelihood fit. In p$\bar{\text{p}}$-annihilation at rest, 90% of all events stem from $^1S_0$ or $^3S_1$ initial states. Therefore, only these two states and the $^3P_0$-state are included in the analyses described here. We start with amplitudes for the following reaction chains:

- p$\bar{\text{p}}$ $(^1S_0)\to\eta f_0(1370)$; $f_0(1370)\to\sigma\sigma$
  $f_0(1370)\to\rho\rho$
- p$\bar{\text{p}}$ $(^1S_0)\to\sigma\eta(1410)$; $\eta(1410)\to a_0(980)\pi$
  $\eta(1410)\to\sigma\eta$
- p$\bar{\text{p}}$ $(^1S_0)\to\pi a_0(1450)$; $a_0(1450)\to a_0(980)\sigma$
- p$\bar{\text{p}}$ $(^3S_1)\to\rho f_1(1285)$; $f_1(1285)\to a_0(980)\pi$
  $f_1(1285)\to\sigma\eta$
- p$\bar{\text{p}}$ $(^3P_0)\to\eta f_1(1285)$; $f_1(1285)\to\rho\rho$

We refer to this compilation as our reference fit. Its comparison with data is demonstrated in Fig. 2. It is emphasized that the fit does not optimize the χ^2 for distributions like the ones shown here; instead a likelihood fit is made using the full 11-dimensional space.

2. Results

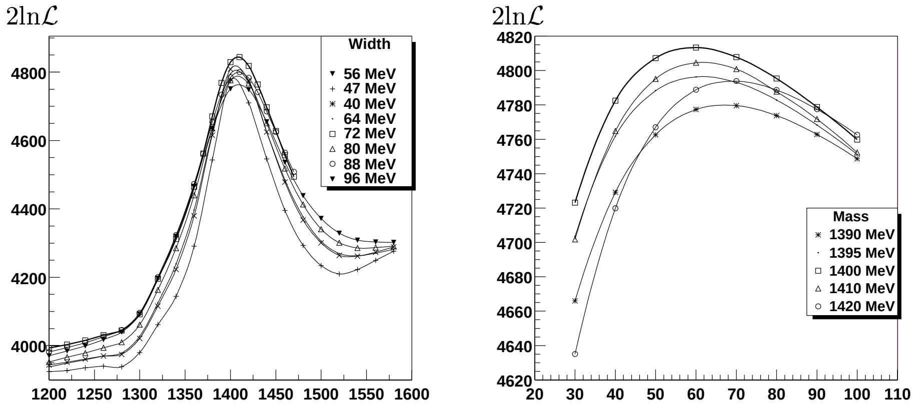
Starting from our reference fit, we search for a optimum mass of a pseudoscalar resonance using different widths. Fig. 3,*a* shows the log likelihood as a function of the assumed mass. The need for a pseudoscalar state at 1400 MeV is obvious. No bump or local maximum around 1295 MeV or 1480 MeV is visible.

In Fig. 3,*b*, the local maximum of $\eta(1400)$ is explored by plotting the likelihood as a function of width for fixed masses. Likelihood changes in 2 ln $\mathcal{L}$ smaller than 9 correspond to 3σ intervals. We deduce

$$M = (1407 \pm\ 5)\ \text{MeV} \qquad \text{and} \qquad \Gamma\ = (57 \pm\ 9)\ \text{MeV} \tag{1}$$

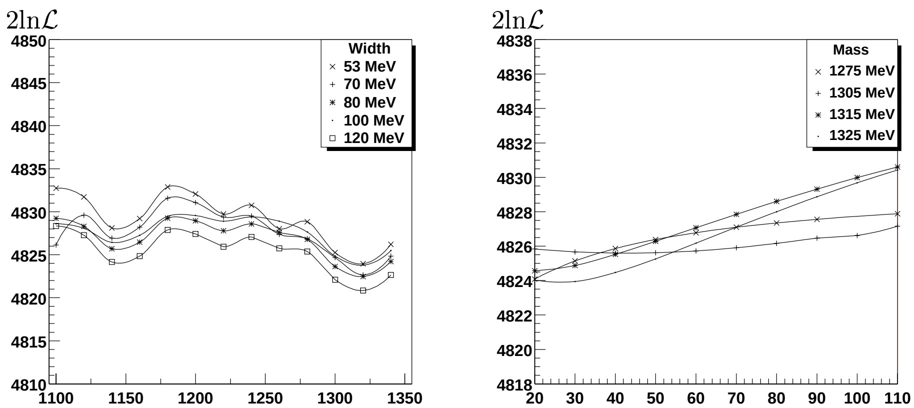
which agrees very well with the PDG averages of (1405 ± 5) and (56 ± 7) MeV, respectively. The branching ratio for the decay chain p$\bar{\text{p}}$ $\to \pi^+\pi^-$E; E$\to \pi^+\pi^-\eta$, is determined to $(1.64 \pm 0.46)\cdot 10^{-3}$. We find destructive inference between the two decay chains and a phase of $158° \pm 12°$. We deduced the following parameters:

$$\begin{aligned} &\text{M} = (1407 \pm 5)\ \text{MeV}, \\ &\Gamma = (57 \pm 9)\ \text{MeV}, \\ &\frac{BR(\eta(1400)\to a_0\pi)}{BR(\eta(1400)\to\sigma\eta)} = 0.6 \pm 0.1, \\ &\phi = 158° \pm 12°. \end{aligned}$$



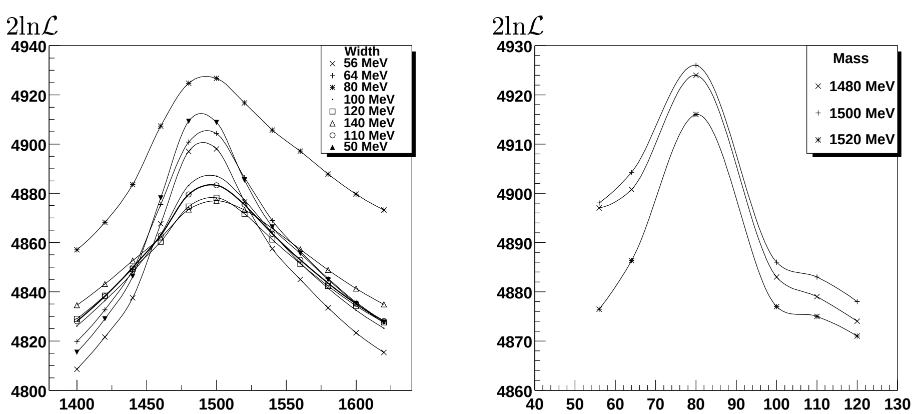
(a) (b)

Fig. 3. *a* — scan for a 0^+0^{-+} resonance with a fixed widths, *b* — width-scan between 30—100 MeV with fixed masses



(a) (b)

Fig. 4. *a* — mass-scan for an additional 0^+0^{-+} resonance with fixed widths, *b* — width-scan with fixed masses



(a) (b)

Fig. 5. *a* — mass-scan for an additional 0^+0^{-+} resonance with fixed widths, *b* — width-scan with fixed masses

2.1. Search for Further η *Resonances*

$\eta(1295)$ has precisely known parameters. Mass and width are known with an accuracy of a few MeV. Hence we tried to introduce this meson in addition to the $\eta(1405)$ with its PDG values. The likelihood ($2\ln\mathcal{L}$) increases by 3 for 4 additional parameters, a marginal change only.

We try to scan the mass region for an additional 0^{-+}-resonance between 1100—1350 MeV for different widths (Fig.4,a). No structure is visible. The likelihood change over the whole range is very small. Scanning the width shows a smoothly rising behaviour but no maximum(Fig. 4,b).

These observations lead us to conclude that we have no evidence for the $\eta(1295)$.

2.1.1. η(1480)

$E(1440)$ is possibly split into a low-mass $\eta(1400)$ and a high mass $\eta(1480)$ [1]. Adding an additional pseudoscalar resonance improves the fit by 100 in $2\ln\mathcal{L}$. The scan in mass shows a clear maximum at 1490 MeV (Fig. 5,b). The width optimizes for 80 MeV.

3. Summary and Discussion

The $E\to\pi^+\pi^-\eta$ decay is clearly established in our data. Mass and width of the E-meson are fully compatible with previous determinations of these quantities and the E-meson decays with approximately equal rates via $a_0(980)\pi$ and $\eta\sigma$ into $\eta\pi\pi$, compared quite well with our previous finding [4, 7, 5, 8] . We searched for $\eta(1295)$ but did not find any evidence for its production in $p\bar{p}$ annihilation. Even if $f_1(1285)$ is excluded from the fit, there is no evidence for $\eta(1295)$. The fit improves significantly if $\eta(1480)$ is included.

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ЕКЗОТИЧНІ МЕЗОНИ В РЕАКЦІЇ $p\bar{p}\to\pi^+\pi^-\pi^+\pi^-\eta$

Й. Райнарт

Р е з ю м е

Наведено результати аналізу даних з реакції $\bar{p}p\to\pi^+\pi^-\pi^+\pi^-\eta$ на основі розкладу за парціальними хвилями. Безумовно, ми знайшли підтвердження експериментальних даних і для реакцій $\eta(1405)$ частинок масою (1407 $\pm$ 5) МеВ і шириною (57 $\pm$ 9) МеВ, і для реакцій $\eta(1480)$ частинок в розкладі $\pi^+\pi^-\eta$ масою 1490 МеВ та шириною 80 МеВ. Але для частинок $\eta(1295)$ не було знайдено жодного підтвердження.

ЭКЗОТИЧЕСКИЕ МЕЗОНЫ
В РЕАКЦИИ $p\bar{p}\to\pi^+\pi^-\pi^+\pi^-\eta$

Й. Райнарт

Р е з ю м е

Представлены результаты анализа данных о реакции $\bar{p}p\to\pi^+\pi^-\pi^+\pi^-\eta$ на основе разложения по парциальным волнам. Безусловно, мы нашли подтверждения экспериментальных данных и для реакций $\eta(1405)$ частиц массой (1407 $\pm$ 5) МэВ и шириной (57 $\pm$ 9) МэВ, и для реакций $\eta(1480)$ в разложении $\pi^+\pi^-\eta$ с массой 1490 МэВ и шириной 80 МэВ. Но для $\eta(1295)$ не было найдено ни одного подтверждения.