E-meson in the reaction $\bar{\mathrm{p}}\mathrm{p} \rightarrow \pi^+\pi^-\pi^+\pi^-\eta$

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The E-meson, $\eta(1410)$, is observed in its decay into $\pi^+\pi^-\eta$, both via $\sigma\eta$ and via $a_0(980)\pi$. We do not find evidence for the $\eta(1295)$.

1. THE CRYSTAL BARREL EXPERIMENT AT LEAR

The data on reaction (1) were recorded with the Crystal Barrel detector at the LEAR at CERN.

$$\bar{\mathrm{p}}\mathrm{p} \rightarrow \pi^+\pi^-\pi^+\pi^-\eta \tag{1}$$

The data were recorded with a trigger requiring an antiproton stopping in the target and exactly 4 hits in the last two layers of the JDC. The trigger selected events with 4 long tracks in the JDC giving the best momentum resolution. $7.3 \cdot 10^6$ events were recorded under these trigger conditions. After kinematic fitting to the $\pi^+\pi^-\pi^+\pi^-\eta$ hypothesis imposing 5 constraints (energy and momentum conservation and the η mass) and a 10% confidence level cut we retained 6,026 events for reaction (1).
We find a branching ratio $BR(\bar{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-\eta) = (1.04 \pm 0.11) \cdot 10^{-2}$. The branching ratio includes the η' in the reaction $\bar{\mathrm{p}}\mathrm{p} \rightarrow \pi^+\pi^-\eta'$; $\eta' \rightarrow \pi^+\pi^-\eta$. Without the η' we find

$$BR(\bar{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-\eta) = (0.81 \pm 0.12) \cdot 10^{-2} \tag{2}$$

In the $\pi^+\pi^-\eta$ mass distribution (Fig. 1a) two signals are seen, the η' and the E-meson. The signal-to-background ratio can be improved by removing the η' (Fig. 1b).
To emphasize visible feature of the dynamics we construct a E-meson Dalitz plot. The Dalitz plot shown in Fig. 1(c) contains about 50 % background events. We observe two bands due to the $a_0(980)$ interfering with a $\pi\pi$ enhancement (the σ). The $a_0(980)$ is strongly asymmetric due to interference between the $a_0(980)\pi$ and $\eta\sigma$ decay modes. The Dalitz plot projection shown in Fig. 1(d) confirms these observations.

2. PARTIAL WAVE ANALYSIS

The $\pi^+\pi^-\pi^+\pi^-\eta$ data were analyzed using a maximum likelihood fit. The analysis was done in the helicity formalism in terms of the isobar model.
We start with amplitudes for the following reaction chains:

- $\bar{\mathrm{p}}\mathrm{p}(^1\mathrm{S}_0) \rightarrow \eta f_0(1370)$; $f_0(1370) \rightarrow \sigma\sigma$
  $f_0(1370) \rightarrow \rho\rho$

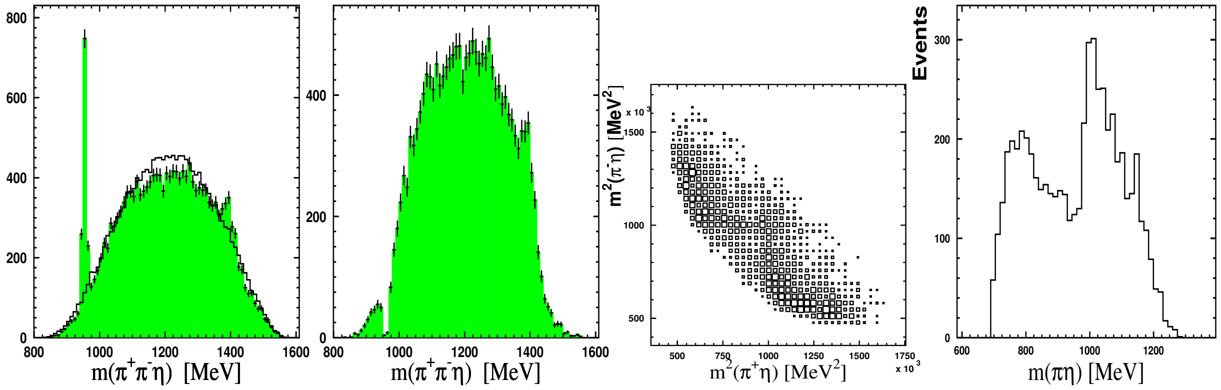

Figure 1. (a): Invariant mass distributions m($\pi^+\pi^-\eta$), (b): m($\pi^+\pi^-\eta$) with η' anti-cut, (c): the E-Meson Dalitz plot and its projection m($\pi\eta$) (d). Shaded areas with error bars in (a) correspond to data and the solid line represent the phase space.

- $\bar{\mathrm{p}}\mathrm{p}(^1\mathrm{S}_0)\rightarrow\sigma\eta(1410)$; $\eta(1410)\rightarrow a_0(980)\pi$
  $\eta(1410)\rightarrow\sigma\eta$
- $\bar{\mathrm{p}}\mathrm{p}(^1\mathrm{S}_0)\rightarrow\pi a_0(1450)$; $a_0(1450)\rightarrow a_0(980)\sigma$
- $\bar{\mathrm{p}}\mathrm{p}(^3\mathrm{S}_1)\rightarrow\rho f_1(1285)$; $f_1(1285)\rightarrow a_0(980)\pi$
  $f_1(1285)\rightarrow\sigma\eta$
- $\bar{\mathrm{p}}\mathrm{p}(^3\mathrm{S}_1)\rightarrow\eta b_1(1235)$; $b_1(1235)\rightarrow\rho\sigma$
- $\bar{\mathrm{p}}\mathrm{p}(^3P_0)\rightarrow\eta f_1(1285)$; $f_1(1285)\rightarrow\rho\rho$

We refer to this fit as our reference fit. Its comparison with data is demonstrated in the figures 2.

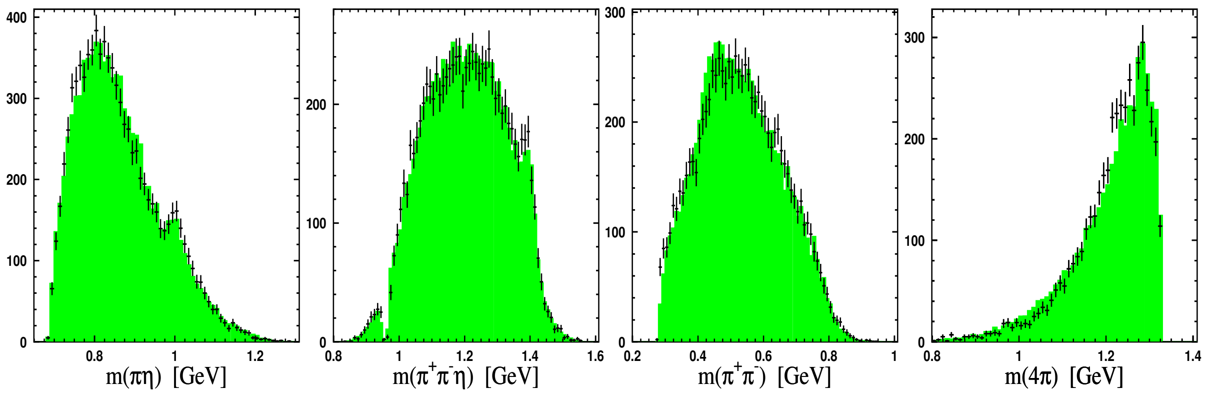

Figure 2. Result of the partial wave analysis: invariant mass distributions m($\pi\eta$), m($\pi^+\pi^-\eta$), m($\pi^+\pi^-$) and m(4π). Data: line with error bars, Fit: shaded region.

2.1. The E-meson

Starting from our reference fit we search for the optimum mass of a pseudoscalar resonance having a width of 55 MeV. 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. The local

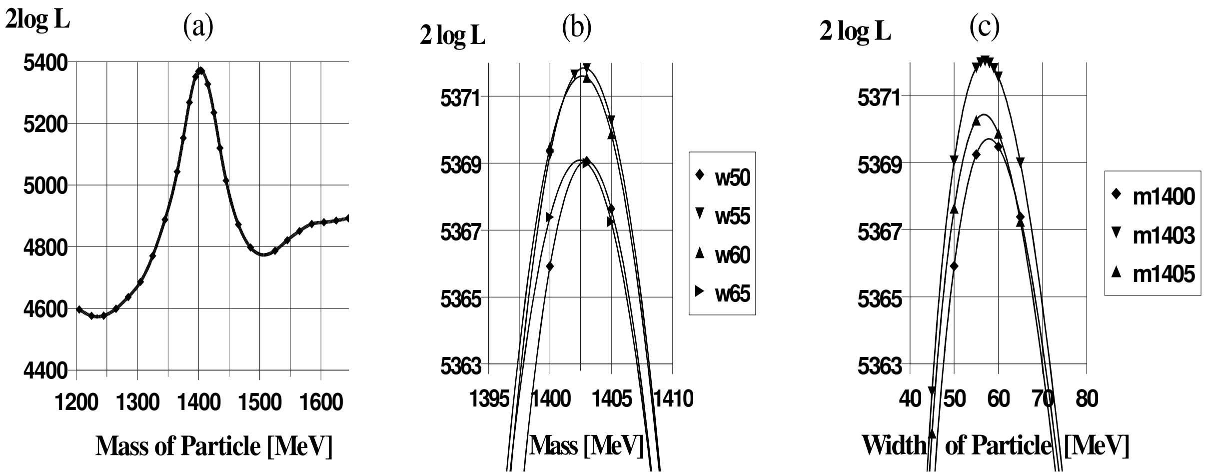

Figure 3. (a): Scan for a 0^+0^{-+} resonance with a fixed width of 55 MeV, (b) scan for the E-meson with fixed widths of 50 - 65 MeV and with fixed masses of 1400 - 1405 MeV (c) for $3\sigma = 9$ (in 2 log L).

maximum is explored by plotting the likelihood as a function of mass for fixed widths or as a function of width for fixed masses. The two plots are displayed in Fig. 3(b,c) for likelihood changes less than 9 (corresponding to 3σ intervals). We deduce

$$M = 1403 \pm\ 6\ \text{MeV}\ ; \qquad \Gamma\ = 57 \pm\ 9\ \text{MeV} \tag{3}$$

which agree very well with the PDG averages of 1405 ± 5 and 56 ± 7 MeV. For the branching ratio for the decay chain $\bar{p}p \rightarrow \pi^+\pi^- E$; $E \rightarrow \pi^+\pi^-\eta$ we derive a branching ratio of $(1.1 \pm 0.1) \cdot 10^{-3}$.
The ratio r_E of the branching ratios for decay into $a_0(980)\pi$ and into $\eta\sigma$ and phase angle between two decay modes are varied. They optimise for

$$r_E = 0.85 \pm\ 0.24\ ; \qquad \phi\ = 192.6^\circ \pm\ 23.2^\circ \tag{4}$$

The result is consistent with $\phi = 180^\circ$, i.e. with destructive interference of the two decay modes. This destructive interference can be seen in the E-meson Dalitz plot (Fig. 1 c,d) where a sharp rise at the $a_0(980)$ peak mass is observed.

2.2. Search for further η resonances

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 to the $\pi^+\pi^-\pi^+\pi^-\eta$ final state is less than $3 \cdot 10^{-5}$, 30 times smaller than the

contribution of the E-meson.
We also performed likelihood scans. For the nominal $\eta(1295)$ width the likelihood as a function of the mass of a second η-resonance shows a strange behaviour with 3 peaks and a dip (see Fig. 4 a). At low masses there is a peak at 1260 MeV of insignificant strength.

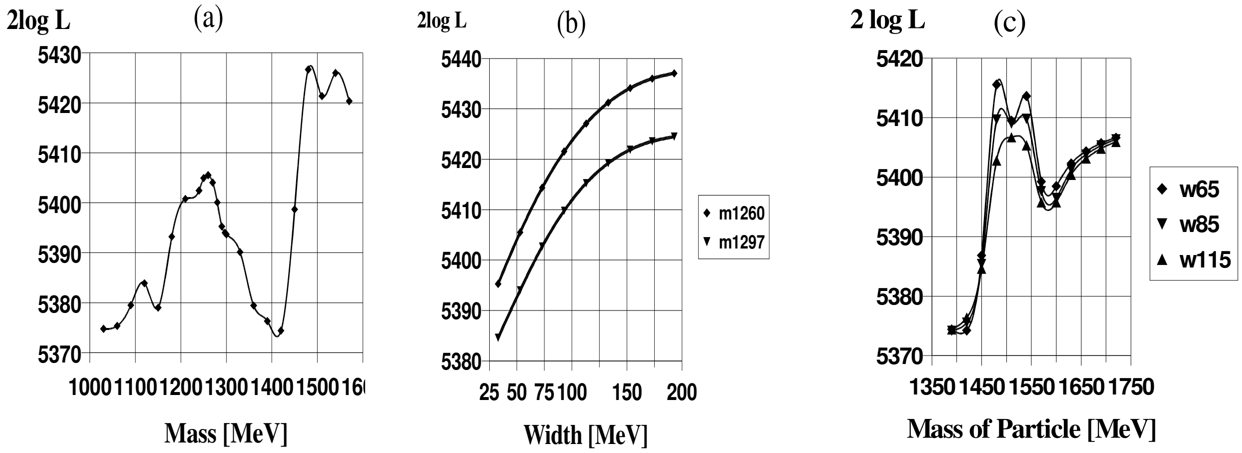

Figure 4. (a): Scan for an additional $0^{+}0^{-+}$ resonance with fixed width of 53 MeV and with fixed masses of 1260 and 1297 MeV (b), scan for $\eta(1470)$ with fixed width (c).

When a scan using this mass is made to optimise the width (see Fig. 4 b), no maximum is found, the likelihood continues to increase with width. These observations lead us to conclude that we have no evidence for the $\eta(1295)$.

The $E/\iota(1440)$ is possibly split into a low-mass $\eta(1410)$ and a high mass $\eta(1470)$ [1]. We searched for an additional high-mass state and find indeed some evidence for it: for a width of 65-85 MeV the scan optimizes for a mass of 1480 MeV (Fig. 4 c). The likelihood change is 28. If a $\eta(1470)$ exists, it contributes to the $4\pi\eta$ channel by $(2.6 \pm 0.5) \cdot 10^{-4}$.

3. SUMMARY

The $E \rightarrow \pi^{+}\pi^{-}\eta$ decay is clearly established in our data. Mass and width of the E-meson are fully compatible with previous determinations of these quantities. We confirm our previous finding[2] that the E-meson decays with approximately equal rates via $a_0(980)\pi$ and $\eta\sigma$ into $\eta\pi\pi$.

We searched for the $\eta(1295)$ but did not find evidence for its production in $\bar{p}p$ annihilation. Also when the $f_1(1285)$ is excluded from the fit there is no $\eta(1295)$. There is evidence that the $E/\iota(1440)$ could be split into a $\eta(1410)$ and a $\eta(1470)$.

REFERENCES

1. C. Caso *et al*, European Physical Journal **C 3** 396 (1998)
2. C. Amsler *et al*, Phys. Lett. **B 358** 389 (1995)