3 Meson Spectroscopy at LEAR with the Crystal Barrel

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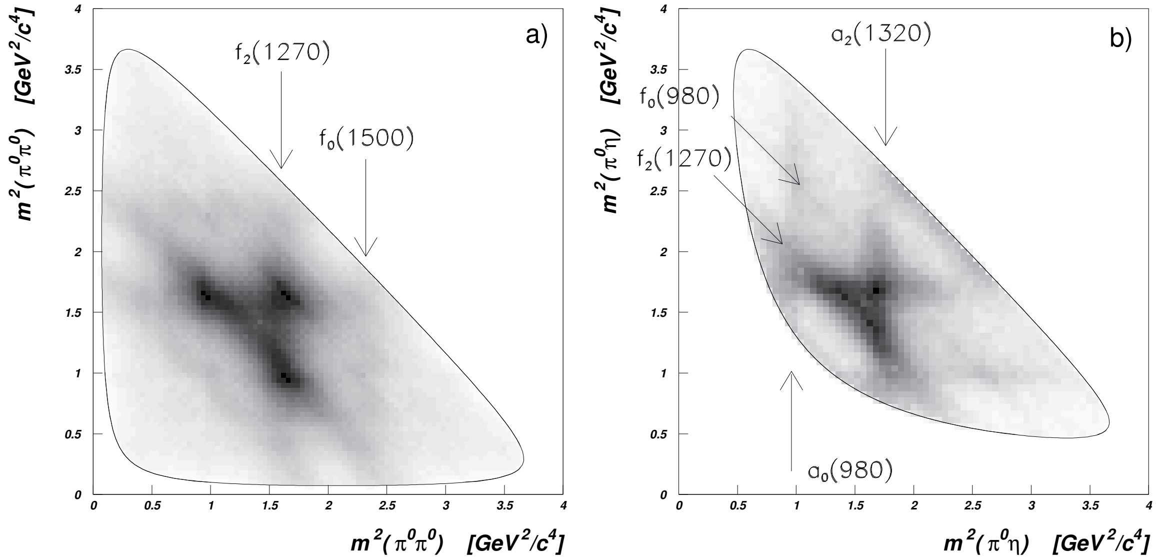
The Crystal Barrel experiment started data taking in late 1989 and was completed in autumn 1996 with the closure of LEAR. In 1998/99 we continued the data analysis. Details on the results achieved in the previous years can be found in a recent review [1].

Last year we reported the discovery of a meson $\hat{\rho}(1405)$ decaying to $\eta\pi$ with quantum numbers $J^{PC} = 1^{-+}$. This state was observed in the $\eta\pi$ P-wave in $\bar{p}n$ annihilation into $\pi^-\pi^0\eta$, using a liquid deuterium target [2]. Quantum number conservation implies that a meson with such quantum numbers does not couple to $q\bar{q}$ and is therefore exotic, e.g. made of two quarks and two antiquarks, or of $q\bar{q}$ pair with an excited gluon. Supportive evidence for this state has now been obtained from $\bar{p}p$ annihilations into $\pi^0\pi^0\eta$, using hydrogen gas at 12 atm [3]. Its mass (1360 ± 25 MeV) and width (220 ± 90 MeV) are compatible with our previous findings [2]. The properties of the E/ι meson decaying to $\eta\pi\pi$ that we studied earlier in the annihilation channel $\pi^+\pi^-\pi^0\pi^0\eta$ [4] were confirmed by analyzing the channel $2\pi^+2\pi^-\eta$ [5]. There is now evidence that the E/ι region contains two overlapping pseudoscalar mesons, one around 1410 MeV, decaying to $\eta\pi\pi$ and $K\bar{K}\pi$ via the intermediate state $a_0(980)\pi$, and one around 1470 MeV, decaying to $K^*\bar{K}$ [6]. The latter is probably the $s\bar{s}$ member of the radially excited pseudoscalar nonet while the former could be exotic. We will report in more details below on the annihilation channels $\pi^0\pi^0\omega$ and $\pi^0\eta\omega$ at rest analyzed by the Zürich group.

This year most of the analysis efforts concentrated on the large samples collected with antiprotons in flight at various antiproton momenta between 600 and 1940 MeV/c. In particular we have searched for the $f_2(2220)$, a 2^{++} glueball candidate reported in radiative J/ψ decay [6], by varying the beam momenta in small steps and looking for a peak in the cross section for $\bar{p}p \to \eta\eta$ and $\pi^0\pi^0$. No signal was observed [7]. We have also reported the first evidence for a new $q\bar{q}$ meson with a mass of 1660 MeV, the first radial excitation of the $a_2(1320) \to \eta\pi$ meson, observed in the annihilation channel $\pi^0\eta\eta$ with 1940 MeV/c incident antiprotons [8].

3.1 Annihilation in flight into three neutral pseudoscalars

Identifying the $s\bar{s}$ meson of the ground state scalar meson nonet is one of the most important issues in light quark spectroscopy which bear on the interpretation of the $f_0(1500)$ meson as the ground state scalar glueball [9]. This state is predicted in the 1700 MeV mass region where a meson, $f_J(1710)$ with controversial spin J (0 or 2), has been observed in previous experiments. This state cannot be produced in $\bar{p}p$ annihilation at rest as it lies too close to the $\bar{p}p$ threshold. On the other hand, the analysis of annihilation data in flight is complicated by the large number of contributing partial waves which increases rapidly with antiproton momentum. The Zürich group is therefore analyzing data at 900 MeV/c incident momentum, corresponding to a center of mass energy of 2050 MeV. We are searching for new scalar and tensor mesons [10] in the annihilation channels $3\pi^0$, $\pi^0\pi^0\eta$ and $\pi^0\eta\eta$ that led to our discovery of $f_0(1500)$ and $a_0(1450)$, but with stopped antiprotons [11]. These channels were reconstructed by selecting 0-prong events with six detected photons.



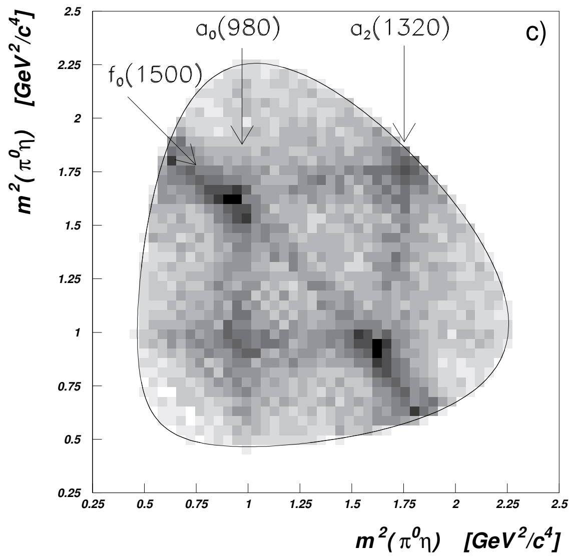


Figure 3.1: Dalitz plots for $\pi^0\pi^0\pi^0$ (a) (6 entries/event), $\pi^0\pi^0\eta$ (b) (2 entries/event) and $\pi^0\eta\eta$ (c) (2 entries/event) at 900 MeV/c. The event density increases from white to black.

With stopping antiprotons the coordinate of the annihilation vertex along the beam axis was distributed within a few 100 μm of the target center due to the low momentum (200 MeV/c) and the excellent momentum resolution of the incident beam. It was therefore assumed to lie at the center of the detector for all events. For annihilation in flight, however, the vertex distribution was spread uniformly along the full length (4 cm) of the hydrogen target. Since for neutral events the vertex coordinates could not be observed directly, we had first to develop a kinematic fitting algorithm using the mass constraints of the decaying π^0 and/or η as well as energy and momentum conservation [10].

The energy calibration of the CsI barrel was performed by adjusting the measured photon energies to match the π^0 mass, assuming that the average vertex position (target center) coincided with the detector center. However, in preliminary analyses of in-flight data the total energy deposited by the photons was 3% smaller than expected from the LEAR $\bar{p}$ momentum. This was recently traced to the erroneous calibration procedure, as events with charged tracks indicated a substantial mismatch between the target and detector centers.

This displacement occurred during the modifications in the target geometry required for runs in flight. The calibration parameters had therefore to be recalculated and the in-flight data reprocessed entirely.

The data at 900 MeV/c were collected by vetoing charged particles from the microvertex detector and by the inner layers of the drift chamber. From the sample of 17 million annihilations into 0-prong one obtains about 3 million annihilations into 6γ. The minimum cluster energy for γ-detection was set to 20 MeV. The kinematic fit leads to about 5×10^5 $3\pi^0$, 1.5 $\times10^5$ $\pi^0\pi^0\eta$ and 2×10^4 $\pi^0\eta\eta$ events. The sizes of these samples are comparable to those obtained earlier at rest. The corresponding Dalitz plots are shown in fig. 3.1. Apart from the well known mesons one observes a clear signal from $f_0(1500)$ in $3\pi^0$ and $\pi^0\eta\eta$. There is no striking signal from any narrow state like $f_J(1710) \to \eta\eta$ or $\pi^0\pi^0$ in the 1700 MeV region. These are not necessarily bad news, however, since a pure $s\bar{s}$ state cannot be produced in $\bar{p}p$ annihilation, assuming no strange quarks in the proton. The absence of a spin zero $f_J(1710)$ in our data would argue against this state having a substantial admixture of glue or other quark flavours than strangeness in its wave function. A detailed partial wave analysis is in progress [10].

3.2 Annihilation at rest into $\pi^0\pi^0\omega$ and $\pi^0\eta\omega$

These channels are being studied in the 7γ final state where $\omega \to \pi^0\gamma$ and $\pi^0(\eta) \to \gamma\gamma$ [12]. They have been studied earlier by Crystal Barrel [13, 14], albeit with much lower statistics. The channel $\pi^0\pi^0\omega$ is interesting to search for scalar mesons decaying into $\pi^0\pi^0$ and for vector mesons decaying into $\omega\pi^0$, the channel $\pi^0\eta\omega$ to look for axial vectors decaying into $\omega\eta$.

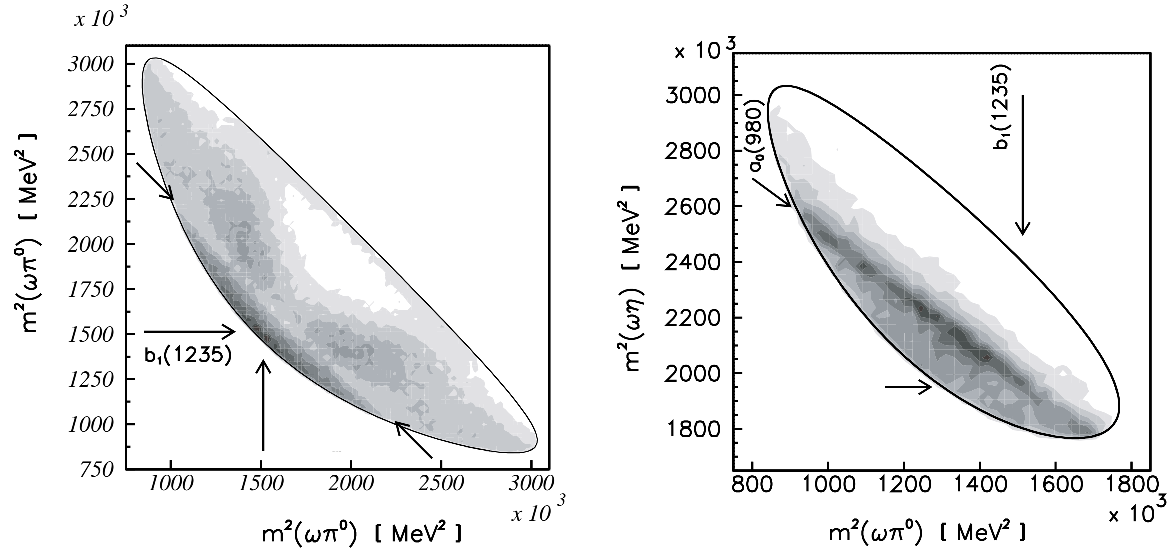


Figure 3.2: Left: Dalitz plot for $\pi^0\pi^0\omega$ at rest (136'023 events, two entries per event). The diagonal arrows mark the valley due to $f_0(980)$ in the $\pi\pi$ invariant mass spectrum. Right: Dalitz plot for $\pi^0\eta\omega$ (34'064 events). The horizontal arrow shows the region where a new state is required by the fit (see next figure).

In this final analysis we selected from our full sample of 2×10^7 0-prong events in liquid hydrogen at rest about 1.6 million events with 7γ. The events were then submitted to a kinematic fit to the hypotheses $\pi^0\pi^0\omega$ and $\pi^0\eta\omega$ (8 constraints fits). The acceptances were studied by Monte Carlo simulation. The reconstruction efficiency was 12.4 %, respectively 20.6 %. The annihilation frequencies were determined to be $(2.8 \pm 0.3 \pm 0.4)\%$ and $(1.1 \pm$

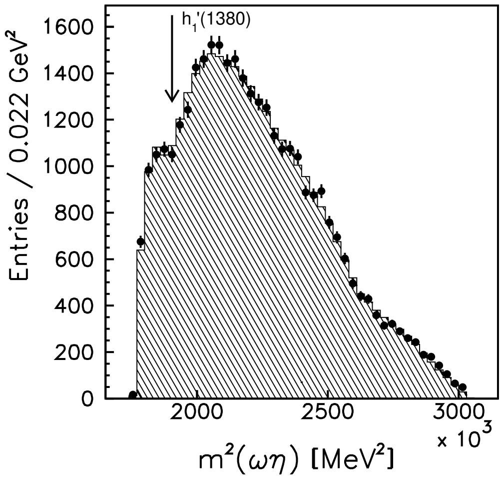


Figure 3.3: $\eta\omega$ mass distribution. The hatched histogram is the fit result including $h_1'(1380)$.

$0.1 \pm 0.3)$% of all annihilations, respectively, where the first error is statistical and the second is systematical.

The Dalitz plots are shown in fig. 3.2. The $\pi^0\pi^0\omega$ Dalitzplot is dominated by the production of $b_1(1235) \to \omega\pi$, by the $\pi\pi$ S-wave and by the tail of the $f_2(1270) \to \pi\pi$ (accumulation of events at the lower edge). A background of about 9% is due to the $4\pi^0$ final state with one missing (undetected) photon. In contrast to our earlier work [13] we are now also fitting the angular distribution (θ and ϕ) of the decay photon in the rest frame of the $\omega \to \pi^0\gamma$, in addition to the $\omega\pi^0$ invariant masses. Substantial improvements were also made in the spin analysis procedure [12]. The diagonal valley around 1000 MeV in fig. 3.2 is due to $f_0(980) \to \pi\pi$. This dip which could not be described satisfactorily before is now fully understood using our K-matrix formalism.

The $\pi^0\eta\omega$ Dalitz plot is dominated by the production of $b_1(1235)$ and $a_0(980) \to \eta\pi$. In contrast to our earlier work [14] the $a_0(980)$ is now described by a K-matrix taking into account the unobserved $K\bar{K}$ decay mode which leads to an asymmetric mass distribution. The new feature is the observation of an enhancement in the $\omega\eta$ distribution just above threshold (fig. 3.2). This peak is consistent with a 1^{+-} isoscalar meson at 1380 MeV, decaying to $\omega\eta$. The $s\bar{s}$ partner of the $h_1(1170)$ is not well established. A signal, $h_1'(1380)$, was reported in K^-p interactions [15] and also by Crystal Barrel [16], however in the $K^*\overline{K}$ decay mode. A detailed partial wave analysis is in progress [12].

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