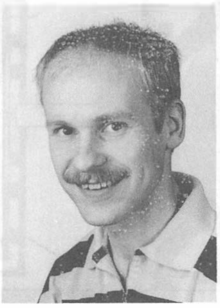
Evidence for the $\eta\eta'$ decay mode of an isoscalar scalar resonance

Ralf Hackmann
Johannes Gutenberg Universität
Institut für Physik
Staudinger Weg 7
D-55099 Mainz
representing the CRYSTAL BARREL-collaboration[1]



The CRYSTAL BARREL-collaboration investigates the spectrum of mesons produced in $\bar{p}p$ annihilation. We found three new scalar resonances; two isoscalar states at 1365 and 1500 MeV, respectively, and an isovector state at 1450 MeV. The resonance at 1500 MeV is observed to decay into $\pi^0\pi^0$, into $\eta\eta$, and into $\eta\eta'$. Preliminary results on $f_0(1500)$ production and decay are reported.

[1]C. Amsler, I. Augustin, C.A. Baker, B.M. Barnett, C.J. Batty, K. Beuchert, P. Birien, J. Bistirlich, P. Blüm, R. Bossingham, H. Bossy, K. Braune, J. Brose, D.V. Bugg, M. Burchell, T. Case, S.U. Chung, A. Cooper, K.M. Crowe, H.P. Dietz, S. v. Dombrowski, M. Doser, W. Dünnweber, D. Engelhardt, M. Englert, M.A. Faessler, C. Felix, G. Folger, R. Hackmann, R.P. Haddock, F.H. Heinsius, M. Herz, N.P. Hessey, P. Hidas, P. Illinger, D. Jamnik, Z. Jávorfi, H. Kalinowsky, B. Kämmle, T. Kiel, J. Kisiel, E. Klempt, M. Kobel, H. Koch, C. Kolo, K. Königsmann, M. Kunze, R. Landua, J. Lüdemann, H. Matthaey, M. Merkel, J.P. Merlo, C.A. Meyer, U. Meyer-Berkhout, L. Montanet, A. Noble, K. Peters, G. Pinter, S. Ravndal, A.H. Sanjari, E. Schäfer, B. Schmid, P. Schmidt, S. Spanier, C. Straßburger, U. Strohbusch, M. Suffert, D. Urner, C. Völcker, F. Walter, D. Walther, U. Wiedner, N. Winter, J. Zoll, B.S. Zou, Č. Zupančič

1 The Crystal Barrel detector

The Crystal Barrel detector [1] is set up at CERN at the LEAR complex. It is intended for mesons spectroscopy originating from antiproton–proton annihilation at rest or in flight. The detector setup is shown in figure 1.

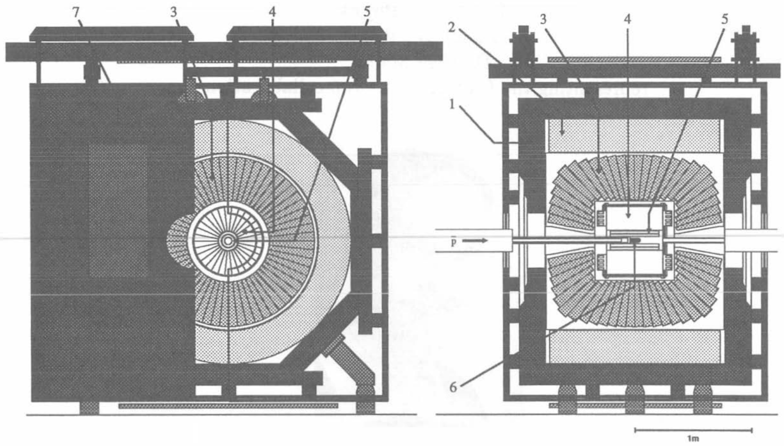


Figure 1: *The* Crystal Barrel *detector. Magnet yoke (1), magnet coils (2), CsI-calorimeter (3), JDC (4), proportional wire chamber (5), target (6), one half of the endplate (7).*

The sensitive components of the detector are embedded in a solenoidal magnetic field with a maximum field strength of 1.5 T. Antiprotons enter the liquid hydrogen target after passing beam defining counters. The incident momentum is 200 MeV/c, but can be changed up to the highest accessible momentum from LEAR (1.9 GeV/c). After entering the target the antiprotons slow down rapidly and form protonium atoms. These cascade down and annihilate. Charged annihilation products are detected and their tracks reconstructed in two multiwire proportional chambers and a jet drift chamber. The JDC is surrounded by an electromagnetic calorimeter consisting of 1380 crystal modules of thallium–doped cesium iodide. The calorimeter covers 98% of the total solid angle.

2 Data reduction

We analysed 16.8 million all–neutral events from $\bar{p}p$ annihilation at rest, taken with a trigger requiring an incident antiproton and no charged tracks in the wire chambers. From this data set we took those events with six photons in the final state, each having a minimum energy deposit of 20 MeV. An approximate completeness of the event is achieved by a cut on total energy and momentum. The subsequent four–constraint kinematical fit requiring energy and momentum conservation leaves $1.4 \cdot 10^6$ events .

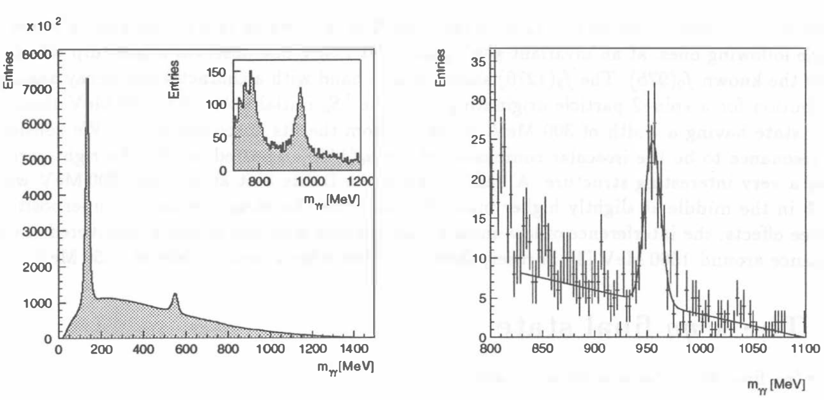


Figure 2: *The $\gamma\gamma$ invariant mass spectrum (left) after a 4C fit. The inset shows the η' region after rejecting π^0 and η events. The right picture shows the $\gamma\gamma$ effective mass spectrum of the hypothesis $\pi^0\eta\gamma\gamma$ after vetoing against all strong decay channels.*

The quality of the data at this stage is shown in figure 2, showing the $\gamma\gamma$–invariant mass. Each event enters the plot 15 times. One can see very clear signals from π^0 and η. The η' becomes more apparent after rejecting $\gamma\gamma$ mass combinations, which do not fall into mass windows around the π^0 or the η. An additional enhancement at around 760 MeV stems from events of the type $\pi^0\pi^0\omega$ with one photon from the ω decay undetected.

The data were then subjected to a list of 6C and 7C kinematical fits, where in addition the meson masses were imposed. We tried to fit all combinations of pseudoscalar mesons (π^0,η,η') as well as ω ($\omega \rightarrow \pi^0\gamma$). The decision as to which final state the event is attributed is made by a comparison of the corresponding confidence levels of the different hypotheses. The probability distributions are satisfactorily flat for all hypotheses under consideration.

It was also possible to isolate a signal from events of the type $\pi^0\eta\eta'$ by vetoing against all strong decay channels. This final state shows up in the $\gamma\gamma$ invariant–mass distribution of the fitted hypothesis $\pi^0\eta\gamma\gamma$ (figure 2). The peak at about the η' mass proves the existence of this final state. A fit to this signal with a gaussian function plus a linear background term gives an estimated number of observed events of 130 ± 14 of the type $\bar{p}p \rightarrow \pi^0\eta\eta'$ with any of the mesons decaying into two photons. In order to derive a branching ratio we used a full detector simulation program and checked the reconstruction efficiency. Thus we find

$$\mathrm{BR}(\bar{p}p \rightarrow \pi^0\eta\eta') = (2.5 \pm 0.5) \cdot 10^{-4}$$

3 The $3\pi^0$ Dalitz plot

The $3\pi^0$–decay–mode of the $\bar{p}p$-system is the strongest one in the 6 photon final state. The branching ratio is found to be

$$\mathrm{BR}(\bar{p}p \rightarrow \pi^0\pi^0\pi^0) = (6.3 \pm 1.0) \cdot 10^{-3}$$

We find 712,000 events of this type of reaction. The features of this Dalitz plot in figure 3 are the following ones: at an invariant $\pi^0\pi^0$–mass of ≈ 1 GeV one observes a faint dip which is due to the known $f_0(975)$. The $f_2(1270)$ shows up as a band with a characteristic decay angular distribution for a spin–2 particle originating from the $^1S_0$ initial state. At 1365 MeV there is a 0^{++} state having a width of 300 MeV. It results from the fits described below. We consider this resonance to be the isoscalar companion of the $a_0(1450)$ reported in [2]. The right corner shows a very interesting structure. A band crossing the Dalitz plot at around 1500 MeV with a blob in the middle at slightly higher mass. We attribute this structure to the superposition of three effects: the interference of low–mass $\pi\pi$ amplitudes with the recently discovered scalar resonance around 1500 MeV [3]. Further, there is evidence for a tensor state at 1550 MeV.

4 The $\pi^0\eta\eta$ final state

The $\pi^0\eta\eta$ final state has a branching ratio

$$\mathrm{BR}(\bar{\mathrm{p}}\mathrm{p}\rightarrow\pi^0\eta\eta) = (2.1 \pm 0.4)\cdot 10^{-3}$$

We find 31,000 events of this final state decaying into six photons. The Dalitz plot is shown in figure 3.

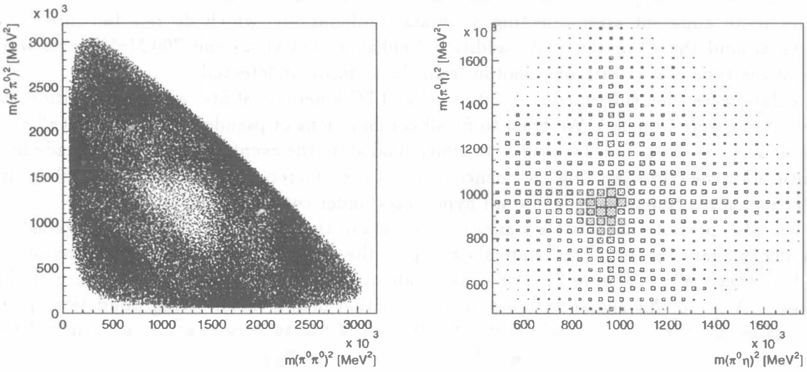


Figure 3: *The Dalitz plots of the reactions* $\bar{p}p\rightarrow\pi^0\pi^0\pi^0$ *(left) and* $\bar{p}p\rightarrow\pi^0\eta\eta$ *(right)*

The most prominent feature is the cross–like structure right in the middle of the Dalitz plot. These bands arise from $a_0(980)\rightarrow\pi^0\eta$. In $\eta\eta$ the situation is more involved. The analysis reveals the presence of a scalar state at 1365 MeV. A further scalar state is observed at 1500 MeV which we assume to be the same object as seen in $3\pi^0$. Furthermore a small tensor contribution around 1520 MeV is needed.

5 Threshold enhancement in $\eta\eta'$

The $\pi^0\eta\eta'$ Dalitz-plot (see figure 4) contains 158 events, which are concentrated in the lower right corner of the plot. The feedthrough of 35 events from possible background channels can be quantitatively described via Monte Carlo simulations. The enhancement could be due to the $a_2(1320)$ decaying into $\pi^0\eta'$, but since we do not observe the $a_2(1320)$ in $\pi^0\eta\eta$ we conclude that the enhancement must be produced from a resonance decaying into $\eta\eta'$.

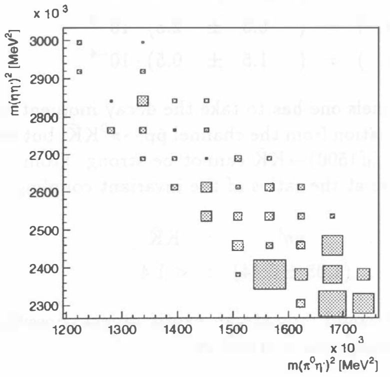


Figure 4:
Dalitz plot of the rare decay channel $\pi^0\eta\eta'$.

6 Analysis method

We made a coupled channel analysis of the final states $\pi^0\pi^0\pi^0$ and $\pi^0\eta\eta$ using a K-matrix formalism [4] in an extension to production processes. The coupling is achieved with the K-matrix which we use in its Lorentz-invariant form

$$K = \sum_\alpha \frac{g^0_{\alpha i} g^0_{\alpha j} B^l_{\alpha i}(q, q_\alpha) B^l_{\alpha j}(q, q_\alpha)}{m^2_\alpha - m^2}$$

Here the factors $g^0_{\alpha i}$ are the coupling constants of the resonance α to the channel i. The functions $B^l_{\alpha i}(q, q_\alpha)$ are angular momentum barrier factors. The resonance position is characterized by the K-matrix pole m_α, which is in general different from the mass of the resonance which has to be determined by tranforming the K-matrix pole position to the T-matrix pole position. Following the idea of [5] the production process can be included using a so-called P-vector.

$$P = \sum_\alpha \frac{\beta^0_\alpha g^0_{\alpha i} B^l_{\alpha i}(q, q_\alpha)}{m^2_\alpha - m^2}$$

Then the transition amplitude F is constructed by multiplying the P-vector with a propagator term

$$F = (I - iK\rho)^{-1} P\,,$$

where ρ is the usual two-body phase-space factor. The coupled-channel fit also includes the $\pi\pi$ scattering data [6] by fitting these to the T-matrix simultaneously. T is given by

$$T = (I - iK\rho)^{-1} K$$

7 Results

We investigated 6–photon final states and observed in the $3\pi^0$ and $\pi^0\eta\eta$ Dalitz plot the same scalar resonance at 1500 MeV. In addition we observed a resonance in the same mass region decaying into $\eta\eta'$. The following conclusions assume the $\eta\eta'$–resonance to be the same object as the one decaying into $\pi^0\pi^0$ and $\eta\eta$. The branching ratios of this scalar resonance $f_0(1500)$ after correcting for the decay branching ratios into $\gamma\gamma$ and isospin 1 of the pion are

$$\begin{array}{lllllll} \mathrm{BR}(\bar{p}p & \rightarrow & \pi^0 f_0(1500), f_0(1500) & \rightarrow & \pi\pi &) = (& 38.0 \pm 10.0) \cdot 10^{-4} \\ \mathrm{BR}(\bar{p}p & \rightarrow & \pi^0 f_0(1500), f_0(1500) & \rightarrow & \eta\eta &) = (& 6.3 \pm 2.8) \cdot 10^{-4} \\ \mathrm{BR}(\bar{p}p & \rightarrow & \pi^0 f_0(1500), f_0(1500) & \rightarrow & \eta\eta' &) = (& 1.5 \pm 0.5) \cdot 10^{-4} \end{array}$$

In order to get the decay ratios to the different channels one has to take the decay momentum of the $f_0(1500)$ into account. We await further information from the channel $\bar{p}p \rightarrow \pi^0 K\bar{K}$, but we know from bubble chamber data that the coupling $f_0(1500) \rightarrow K\bar{K}$ cannot be strong. From [7] we get an upper limit (90% CL) only. Then we arrive at the ratios of the invariant couplings

$$\begin{array}{lllllllll} f_0(1500) & \rightarrow & \pi\pi & : & \eta\eta & : & \eta\eta' & : & K\bar{K} \\ & & 3 & : & (0.72 \pm 0.37) & : & (1.05 \pm 0.44) & : & < 1.4 \end{array}$$

This behaviour is not typical for a $\bar{q}q$ resonance. It could indicate an exotic object, possibly the scalar glueball predicted at this mass in lattice gauge calculations [8].

References

[1] E. Aker et al. (Crystal Barrel Collaboration), Nucl. Instr. Meth. **A321**(1992)69

[2] C. Amsler et al. (Crystal Barrel Collaboration), "Observation of a new $I^G(J^{PC}) = 1^-(0^{++})$ resonance at 1450 MeV", submitted to Phys. Lett. **B**

[3] V. V. Anisovich et al. (Crystal Barrel Collaboration), Phys. Lett. **B323**(1994)233

[4] S. U. Chung et al., Partial wave analysis in K–matrix formalism, submitted to Zeitschrift für Physik **C**

[5] I. J. R. Aitchison, Nucl. Phys. **A189**(1972)417

[6] G. Grayer et al., Nucl. Phys. **B75**(1974)189
L. Rosselet, Phys. Rev. **D15**(1977)574

[7] L. Gray et al., Phys. Rev. **D27**(1983)307

[8] C. Michael and M. Teper, Nucl. Phys **B314**(1989)347