Search for Structure in the Mass Region 2220 to 2240 MeV/c² in a $\bar{p}p \rightarrow \pi^0\pi^0, \eta\pi^0, \eta\eta$ Formation Experiment

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Results of a search for narrow resonances in a $\bar{p}p$ formation experiment with the Crystal Barrel Detector at LEAR are presented. The cross sections for $\bar{p}p \rightarrow \pi^0\pi^0, \eta\pi^0$ and $\eta\eta$ are determined for annihilation at 9 momenta in the region $\sqrt{s} = 2222 - 2240$ MeV/c². No indication for the formation of a $\xi(2230)$ is found. Breit-Wigner fits, assuming a resonance width of 5-20 MeV/c², yield the upper limits $B(\bar{p}p \rightarrow \xi) B(\xi \rightarrow \pi^0\pi^0) < (7.5 - 5) \cdot 10^{-5}$ and $B(\bar{p}p \rightarrow \xi) B(\xi \rightarrow \eta\eta) < (3.0 - 2.2) \cdot 10^{-5}$ at 95% CL.

1. Introduction

First observations of the $\xi(2230)$ were reported by the Mark III [1] collaboration in the decays $J/\Psi \rightarrow \gamma K_s K_s$ and $J/\Psi \rightarrow \gamma K^+ K^-$. The mass was determined to be (2230 ± 15) MeV/c², the width $(26_{-16}^{+20} \pm 17)$ MeV/c² and $J^{PC} = (\text{even})^{++}$. A subsequent measurement of the same channels by the DM2 collaboration at Orsay [2] however gave no confirmation of a narrow resonance. In the following years the $\xi(2230)$ was searched for in a variety of final states and reactions including peripheral production and $\bar{p}p$ annihilation but no clear picture emerged [3] [4]. Recently the BES collaboration, analyzing J/Ψ decays, claim to have rediscovered the $\xi(2230)$ not only in the decay to $K_s K_s$ and $K^+ K^-$ but also in non strange decay modes such as $\pi^+ \pi^-$, $\pi^0 \pi^0$ and also $\bar{p}p$, with masses all lying around 2230 MeV/c² and widths around 20 MeV/c² [4] [5]. The relative strengths of these decays as measured by BES appear to be almost flavor blind with values of the product branching $B(J/\Psi \rightarrow \gamma \xi) \cdot B_{\text{out}}$ ranging from $2 \cdot 10^{-5}$ to $6 \cdot 10^{-5}$. This result together with the narrow width of the resonance makes the $\xi(2230)$ a candidate for the 2^{++} glueball which is predicted in this mass region by theoretical models. The potential glueball nature of the ξ and its reported $\bar{p}p$ coupling stimulated the present search in a $\bar{p}p$ formation experiment. Figure 1 shows the scan region of this experiment together with the masses deduced from the previously reported evidence for the $\xi(2230)$.

2. Data Selection

The Crystal Barrel Detector allows full reconstruction of neutral and charged particles over almost 4π as described in detail in [6]. The scan data was taken at 9 different momenta of the incoming $\bar{p}$ ranging from 1412 MeV/c to 1461 MeV/c; the corresponding center of mass energies of the $\bar{p}p$ system being $\sqrt{s} = 2222$ MeV/c² to 2240 MeV/c². For each scan point an average of $6 \cdot 10^5$ events were taken with a trigger requiring no charged

Figure 1. Masses and statistical errors of previous measurements of the $\xi(2230)$ together with the Crystal Barrel scan region

tracks in the final states and the total energy sum of the CsI-crystals in the calorimeter lying in an appropriate window.

Events with exactly 4 photons in the CsI calorimeter, satisfying energy and momentum conservation, were selected in the first step. The $\eta\eta$, $\pi^0\pi^0$ and $\eta\pi^0$ final states were identified using cuts on the invariant masses of the 2 γ pairs. Optionally a kinematical fit on the final state was made, the agreement of these two selection methods being within 5%. The background was studied in the experimental data and in Monte Carlo simulations of various channels such as $\omega\pi^0$, $\omega\eta$, $3\pi^0$ and was found to contribute in total less than 1%. The final samples after the kinematic fit consisted of about 11000 events of the type $\pi^0\pi^0$, 350 events of the type $\eta\eta$ and 3000 of the type $\eta\pi^0$ for each scan point.

The normalization was done by counting of the incoming $\bar{p}$'s with a beamcounter telescope and recording of the DAQ lifetime. The various rates from this telescope were also used to perform checks on the beam quality such as correct beam position and focus. Additional checks on the normalization covered analyses of runs with different lifetimes, beam rates and triggers. As a result a common systematic error of 10% is assigned to the data. Quality checks of the data showed problems for the normalization of the scan point at 1429 MeV/c² incoming beam momentum. To circumvent this problem in the present context, cross sections at this point were normalized to the yield for $\bar{p}p \rightarrow \pi^0\pi^0\pi^0$. For this normalization the average $\pi^0\pi^0\pi^0$ cross section was determined for the other scan points, and it was assumed that this channel is non resonant. This assumption is justified for the present search of an isospin zero resonance since $\pi^0\pi^0\pi^0$ is a pure isospin 1 state.

A comparison of these cross sections with literature gives about a factor 2 difference to the $\pi^0\pi^0$ values of Dulude et al. [7] at a neighboring beam momentum of 1389 MeV/c (see Fig. 2), but a reasonable agreement with Hasan et al. [8] (at 1550 MeV/c) for the reaction $\bar{p}p \rightarrow \pi^+\pi^-$ was found.

Figure 2. Differential cross section for $\bar{p}p \rightarrow \pi^0\pi^0$ at 1412 MeV/c incoming momentum ($\sqrt{s} = 2222.1 \text{ MeV}/c^2$). Dots are the measured Crystal Barrel values, the solid line refers to the measurement by Dulude et al. [7]. As usual the cross section refers to events, i.e. only the π^0 's in the forward hemisphere are counted.

3. Results

Figure 2 shows the acceptance corrected angular distribution for one scan point for the reaction $\bar{p}p \rightarrow \pi^0\pi^0$. For comparison the measurement of Dulude et al. is included in the plot. The cross sections integrated over the range $0 < \cos(\theta) < 0.7$ for $\pi^0\pi^0$ and $\eta\eta$ are given in Figure 3 and for the reaction $\bar{p}p \rightarrow \eta\pi^0$ in Fig. 4. In both reactions no enhancements from a narrow resonance are visible.

For further investigation a Legendre decomposition using the angular distributions of the $\pi^0\pi^0$ final state was made. Taking into account the quantum numbers of the final states only even Legendres up to $\ell = 8$ were used. Inspecting the fit parameters of this decomposition as a function of energy, none of them gives evidence for a narrow resonance. However the relative $\ell = 6, 8$ contributions increase monotonically over the investigated range, as may be expected for large scale structure.

Figure 3. Cross sections for $\bar{p}p \rightarrow \pi^0\pi^0$ and $\bar{p}p \rightarrow \eta\eta$ integrated over $0 < \cos(\theta) < 0.7$ for all 9 scan points. All points are normalized to the incoming $\bar{p}$ rate (filled symbols) except for 2227.9 MeV/c² (open symbols) which were cross-normalized to $\bar{p}p \rightarrow \pi^0\pi^0\pi^0$ (see text). The statistical errors are about as large as the symbols. The additional systematic error of the absolute cross section amounts to 10%.

Figure 4. As above but for $\bar{p}p \rightarrow \eta\pi^0$.

To extract upper limits for the product branchings $B(\bar{p}p \rightarrow \xi) \cdot B(\xi \rightarrow \pi^0\pi^0)$ and $B(\bar{p}p \rightarrow \xi) \cdot B(\xi \rightarrow \eta\eta)$ a fit of the excitation function was made using a Breit-Wigner of the form

$$\sigma(\sqrt{s}) = (2J + 1) \cdot \frac{\pi}{k^2} \cdot \frac{B_{\text{in}} B_{\text{out}} \Gamma_{\text{tot}}^2}{(\sqrt{s} - M)^2 + \Gamma_{\text{tot}}^2/4}$$

with

$$B_{\text{in}} = B(\bar{p}p \rightarrow \xi)$$

and

$$B_{\text{out}} = B(\xi \rightarrow \pi^0\pi^0) \text{ or } B_{\text{out}} = B(\xi \rightarrow \eta\eta) \quad .$$

Figures 5 and 6 show the 95% confidence levels for $B_{\text{in}}B_{\text{out}}$ as a function of the resonance mass for fixed widths of 5, 10 and 20 MeV/c^2 .

Figure 5. 95% confidence upper limit for a Breit-Wigner fit to the excitation function of $\bar{p}p \rightarrow \pi^0\pi^0$ with widths fixed at 5, 10 and 20 MeV/c^2 .

From these fits the following upper limits (corresponding to $\Gamma = 5 \text{ MeV}/c^2$) are set: $B(\bar{p}p \rightarrow \xi) \cdot B(\xi \rightarrow \pi^0\pi^0) < 7.5 \cdot 10^{-5}$ and $B(\bar{p}p \rightarrow \xi) \cdot B(\xi \rightarrow \eta\eta) < 3.0 \cdot 10^{-5}$ referring to 95% CL and resonance mass in the measured range 2222 - 2240 MeV/c^2 . Using these results together with the product branchings of BES [5] [4] one arrives at

$$B(\bar{p}p \rightarrow \xi) < 5 \cdot 10^{-3} \quad ,$$

$$B(\xi \rightarrow \pi^0\pi^0) < 1.5 \cdot 10^{-2} \quad ,$$

Figure 6. 95% confidence upper limit for a Breit-Wigner fit to the excitation function of $\bar{p}p \rightarrow \eta\eta$ with widths fixed at 5, 10 and 20 MeV/c^2 .

$$B(J/\Psi \rightarrow \gamma\xi) > 3 \cdot 10^{-3} .$$

Since $B(J/\Psi \rightarrow \gamma\xi) = \sum_k B_{\text{in}} \cdot B_{\text{out}}^k$, the sum over all possible decay modes, and the sum over the measured decay modes from BES accounts for only $2 \cdot 10^{-4}$, our result implies that other strong decay modes of the hypothetical resonance exist which have to make up for the order of magnitude difference. Hence our result is hard to reconcile with the existence of a narrow $\xi(2230)$.

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