Recent Crystal Ball Results On Resonance Formation in Photon-Photon Collisions

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Abstract

The Crystal Ball detector has been used to analyse the formation of resonances in photon-photon collisions. The $\pi_2(1670)$ resonance has been observed in the $3\pi^\circ$ final state, as well as the $\eta'(958)$ and $X(1900)$ resonances in the $\eta\pi^\circ\pi^\circ$ final state. The $X(1900)$ decay distributions are consistent with the assumption that it is the $J^{PC} = 2^{-+}$ η_2 meson. Preliminary analyses of the 8, 10 and 12γ final states are presented. The tensor meson $f_2(1270)$ is the most prominent structure in the energy dependence of the total cross section $\sigma(\gamma\gamma \to \pi^\circ\pi^\circ)$, but close investigation of the differential cross section indicates the presence of a sizeable S wave contribution. This observation is consistent with a broad scalar meson $f_0(1250)$, degenerate in mass with the f_2. Indications for the $f_0(975)$ mesons have been found, too.

Introduction

The Crystal Ball detector[1] is a nonmagnetic segmented NaI(Tl) calorimeter with spherical geometry. It has good energy resolution ($\sigma_E/E = 2.7\%/\sqrt[4]{E/GeV}$) and good angular resolution ($\sigma_\Theta = 3^\circ$ to 1°) for electromagnetically showering particles, combined with a solid angle coverage of 93 % of 4 π. Four layers of cylindrical proportional tubes were placed inside the calorimeter to detect charged particles. While operating at the DORIS-II e^+e^- collider between 1982 and 1986, an integrated luminosity of 255 pb^{-1} was collected at an average beam energy of 5 GeV. Due to rather low trigger thresholds ($E_{thres} \approx 1\%$ to $10\% \times \sqrt{s}$) and an excellent photon detection efficiency, this experiment is well suited for the study of all-photon final states which are produced in photon-photon ($\gamma\gamma$) collisions. The scattered leptons have not been detected (no-tag analysis), thus the transverse momentum distribution of the detected events peaks at very small values.

Formation of 2^{-+} Resonances in $\gamma\gamma \to \pi^\circ\pi^\circ\pi^\circ$ and $\gamma\gamma \to \eta\pi^\circ\pi^\circ$

The two-photon formation of the $\pi_2(1670)$ meson has been observed in the three-pion final state[1,2]. The Crystal Ball collaboration has found clear evidence for the decay chain $\pi_2 \to f_2(1270)\pi^\circ \to \pi^\circ\pi^\circ\pi^\circ$. The data are well described by $J^{PC} = 2^{-+}$, and the two-photon partial width has been measured to be[1]:

$$\Gamma_{\gamma\gamma}(\pi_2) = (1.41 \pm 0.23 \pm 0.28)\ \mathrm{keV}, \tag{1}$$

where the first error is statistical and the second systematic.

Recent analyses of the $\eta\pi\pi$ final state in $\gamma\gamma$ collisions by the Crystal Ball[3] and the CELLO collaborations[4] have found an enhancement of events at $M(\eta\pi\pi) \approx 1900\ \mathrm{MeV/c^2}$. Under the assumption that these events come from one resonance $X(1900)$, the Crystal Ball collaboration has analysed the decay angular distributions and the mass distributions of the $\eta\pi^\circ$ and $\pi^\circ\pi^\circ$ subsystems, and has compared them to various models. Spin-parity 2^- is favoured by the data, with the decay isobars $a_2(1320)\pi^\circ$ and $a_0(980)\pi^\circ$ in the following ratio:

$$BR\left(X \to \left\{\begin{array}{c} a_2\pi^\circ \\ a_0\pi^\circ \end{array}\right\} \to \eta\pi^\circ\pi^\circ\right) = \left\{\begin{array}{c} (70 \pm 20)\% \\ (30 \pm 20)\% \end{array}\right. \tag{2}$$

We assume that X is an $I = 0, J^{PC} = 2^{-+}$ resonance, but this assignment can not be proven unambigiously because of the small number of events. The resonance sits on top of a smoothly falling background. Its parameters have been determined to be:

$$\begin{array}{rcl} M(X) & = & (1876 \pm 35 \pm 50)\ \mathrm{MeV/c^2} \\ \Gamma_{tot}(X) & = & (228 \pm 90 \pm 34)\ \mathrm{MeV/c^2} \\ \Gamma_{\gamma\gamma}(X)\,BR(X \to \eta\pi^\circ\pi^\circ) & = & (0.9 \pm 0.2 \pm 0.3)\ \mathrm{keV}. \end{array} \tag{3}$$

A possible explanation for the state $X(1900)$ is that it is the η_2, an isoscalar partner of the π_2. Predictions have been obtained with quark model calculations[5] for the mass, total width and decay modes of the η_2 which are in agreement with our data. However, the two-photon width may be a problem: Recent $q\bar{q}$–potential model calculations[6] have found values which are in agreement with data for the 2^{++} mesons, but are two to three orders of magnitude too small for the π_2. If these calculations are correct, new explanations for the π_2 and $X(1900)$ have to be found.

Analysis of $\gamma\gamma \to 8,\ 10,\ 12\gamma's$

In an attempt to understand the background in the 6γ final state of the $\eta\pi^\circ\pi^\circ$ analysis, the Crystal Ball data have been searched for 8, 10 and 12 γ final states, which are created in $\gamma\gamma$ collisions. The well established reactions $\gamma\gamma \to \eta\pi^\circ$ and $\gamma\gamma \to \eta\pi^\circ\pi^\circ$, as well as the yet unobserved reaction $\gamma\gamma \to \eta\eta$, might contribute in those cases, where the η decays to $3\pi^\circ$. If two, four or six photons escape detection, these events are background sources for the 6γ final state. A large part of the events between 1100 MeV/c^2 and 1500 MeV/c^2 in the $\eta\pi^\circ\pi^\circ$ analysis can be explained by these processes.

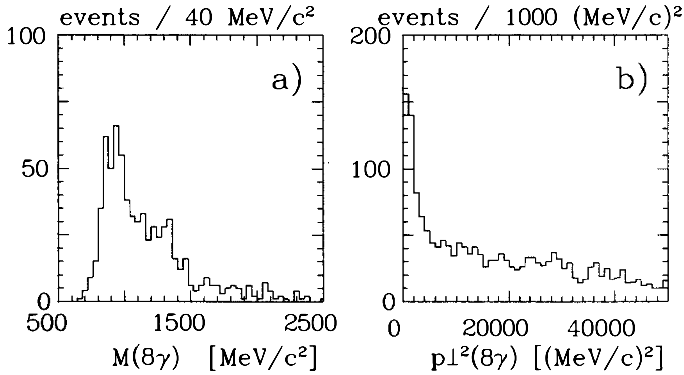

Figure 1: Invariant mass spectrum (a), with $p_t < 100$ MeV/c, and p_t^2 spectrum (b) for events with 8 photons.

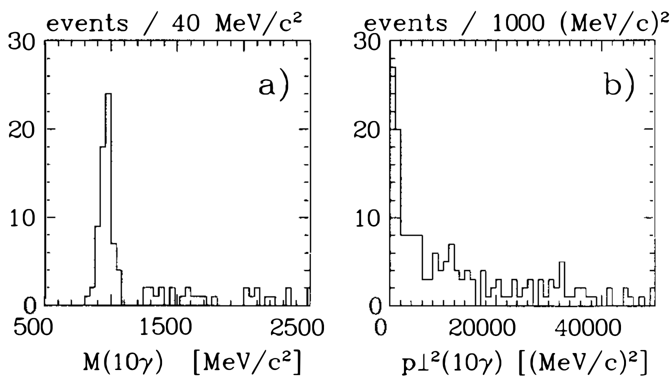

Figure 2: Invariant mass spectrum (a), with $p_t < 100$ MeV/c, and p_t^2 spectrum (b) for events with 10 photons.

The mass spectrum of events with 8 and 10 photons, which are well contained in the detector, and which have $p_t < 100$ MeV/c, are presented in Figs. 1a) and 2a), respectively. Because of the large combinatorial background, no attempt has been made to identify η's or π°'s. The corresponding p_t^2 spectra, without the cut on p_t, are displayed in Figs. 1b) and 2b). In both cases, an enhancement towards $p_t^2 = 0$ is evident, as expected for $\gamma\gamma$ formation.

In the 8γ sample, a rather large background is present, but indications for the $a_0(980)$

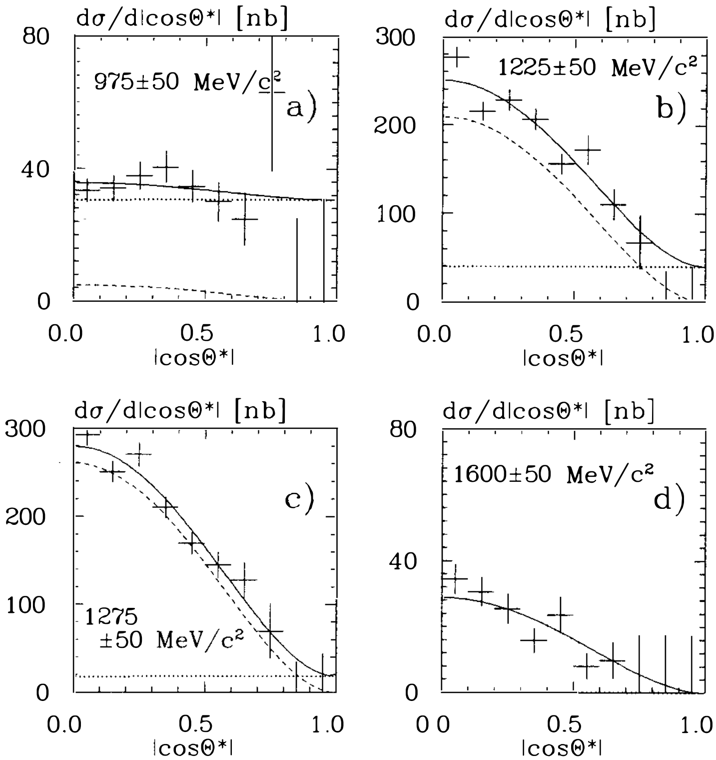

Figure 3: Differential cross section for four different mass intervals. The intervals are indicated in the figures. Crosses are data, the dashed curve is the D_2-wave contribution, the dotted curve the $S-$wave contribution and the full curve is the sum. The fit interval is $|\cos\Theta^*| < 0.7$.

$(f_0(975), f_0(1250))$, and one Breit-Wigner for the $f_2(1270)$ to drive the D_2 wave. Typical fit results are displayed as curves in Fig. 4. These fits give the following resonance parameters:

$$\left.\begin{array}{rcl} \Gamma_{\gamma\gamma}(f_0(975)) & = & (0.25 \pm 0.10)\ \mathrm{keV} \\ \Gamma_{tot}(f_0(1250)) & = & (250 \pm 90)\ \mathrm{MeV} \\ \Gamma_{\gamma\gamma}(f_0(1250))BR(f_0(1250) \to \pi^\circ\pi^\circ) & = & (1.2 \pm 0.3)\ \mathrm{keV} \\ \Gamma_{\gamma\gamma}(f_2(1270)) & = & (3.1 \pm 0.2)\ \mathrm{keV} \end{array}\right. \quad \text{(preliminary)}. \qquad (5)$$

The systematic errors have not yet been determined.

The numbers in (5) are in agreement with our previously published results and upper limits. The possible broad scalar resonance $f_0(1250)$ with large $\Gamma_{\gamma\gamma}$ is in nice agreement with the combined (re-)analysis of CELLO and MARK-II data by Feindt and Harjes[10], as well as with the rather elaborate analysis of Crystal Ball and MARK-II data by Morgan and $a_2(1320)$ mesons are visible in the mass spectrum. The 10γ sample is dominated by a peak of some 50 events at the $\eta'(958)$ mass. Monte Carlo studies give a detection efficiency of 0.3%. The number of events can be converted into a value for the two-photon partial width of the η'

$$\Gamma_{\gamma\gamma}(\eta') = (5.5 \pm 1.0 \pm 0.7)\ \mathrm{keV}\ \ \text{(preliminary)}, \tag{4}$$

which is of about the same magnitude as found in previous measurements. Some 20% background may still be present (see Fig.3b). No evidence has been found for the $\gamma\gamma$ formation of 12γ final states.

Analysis of $\gamma\gamma \to \pi^\circ\pi^\circ$

The reaction $\gamma\gamma \to \pi^\circ\pi^\circ$ can be analysed more easily than the reaction $\gamma\gamma \to \pi^+\pi^-$, as no huge QED ($\gamma\gamma \to e^+e^-, \mu^+\mu^-$) background has to be subtracted. Furthermore, there is no Born term contribution to the $\pi^\circ\pi^\circ$ final state, thus it is easier to extract resonance parameters. We have analysed this reaction using the full data sample of the Crystal Ball experiment. Compared to the previously published analysis[7], we have gained a factor of 2.5 in luminosity, but due to higher trigger thresholds, the analysis can reconstruct $\pi^\circ\pi^\bullet$ events only for $M(\pi^\circ\pi^\circ) > 800$ MeV/c^2. The selection efficiency was raised by a factor of 2.5 by including events in which the decay photons of a π° merge into one energy deposition. The π°'s can be reconstructed up to $E_\pi \approx 1.5$ GeV, and discriminated from single photon showers, by analysing the lateral distribution of the energy in the calorimeter; the second moment of the energy distribution is proportional to the squared mass of the decaying system. Thus, we have selected events with $p_t < 125$ MeV/c and two, three or four neutral energy depositions. Events with four energy depositions have been accepted, if two pairs of energy depositions (photons) were found, whose invariant mass $m_{\gamma\gamma}$ were compatible with the π° mass. Events with three energy depositions were required to have one $m_{\gamma\gamma}$ combination, which was compatible with m_{π°, and one high eneregtic ($E > 500$ MeV) deposition, which had the shape of an overlapping shower. Finally, the events with two high energetic depositions were required to be compatible with two overlapping showers.

We have found some 7100 $\pi^\circ\pi^\circ$ events. The background has been measured to be about 150 events. The majority of the events is clustered between 1100 and 1400 MeV/c^2, i.e. in the region of the well known $f_2(1270)$ resonance. In Fig. 3 we present the differential cross section $d\sigma(\gamma\gamma \to \pi^\circ\pi^\circ)/d|\cos\Theta^*|$ for various mass intervals. Θ^* is the polar angle between the beam axis and one π°, measured in the $\gamma\gamma$ rest frame. The measured total cross section $\sigma(\gamma\gamma \to \pi^\circ\pi^\bullet)$, for $|\cos\Theta^*| < 0.7$, is displayed in Fig. 4.

There is an unresolvable ambiguity in the angular analysis of $\gamma\gamma \to \pi^\bullet\pi^\circ$: without polarized beams the cross section exhibits no Φ dependence and thus any helicity-2 component can be expressed as a coherent sum of helicity-0 amplitudes[8]. However, Li, Close and Barnes[9] have shown that the spin-2, helicity-0 amplitude should be suppressed in $\gamma\gamma$ reactions. Thus we have fitted the differential cross section in each mass bin by a sum of spin-0 (S wave) and spin-2, helicity-2 (D_2 wave) intensities for $|\cos\Theta^*| < 0.7$. A large $S-$wave contribution is found in the bin centered at 975 MeV/c^2, which can be attributed to the $f_0(975)$. Dominance of the D_2 wave is found everywhere between 1000 and 1800 MeV/c^2, but a sizeable S wave is present up to 1350 MeV/c^2. This observation is consistent with a broad scalar resonance $f_0(1250)$.

To extract the maximum information from the data, we have employed a 2-dimensional fit to $d^2\sigma/dM_{\pi\pi}d|\cos\Theta^*|$. Two Breit-Wigner functions were used to drive the S wave

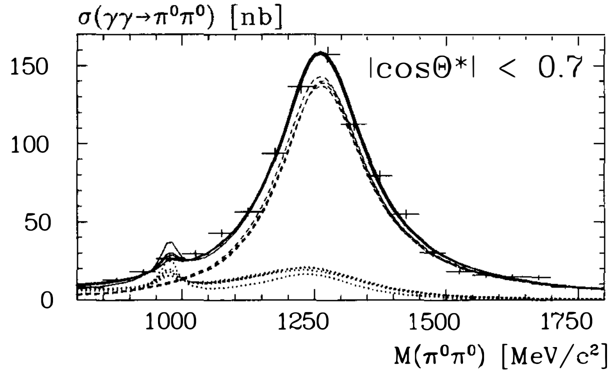

Figure 4: Total cross section $\sigma(\gamma\gamma \rightarrow \pi^{\circ}\pi^{\circ})$ for $|\cos\Theta^{*}| < 0.7$. Crosses are data, dashed curves are the D_2−wave contributions, dotted curves the S−wave contributions and the full curve is the sum. The various curves have been obtained by shifting the mass bins by 12.5 MeV/c^2.

and Pennington[11]. Probably Chanowitz' conjecture[12] that the "true" scalar mesons are degenerate in mass with the corresponding tensors is correct.

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