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K.-H. Karch

Deutsches Elektronen-Synchrotron DESY, Hamburg

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Resonance Formation in $\gamma\gamma$–Collisions *

Karl-Heinz Karch
Deutsches Elektronen-Synchrotron DESY
D-2000 Hamburg 52, Germany
(Representing the Crystal Ball Collaboration)

Abstract

This article presents a compilation of the results on resonance formation in exclusive $\gamma\gamma$ reactions, obtained with the Crystal Ball detector at the DORIS-II storage ring.

Introduction

e^+e^- colliders provide a laboratory for the study of two-photon (or $\gamma\gamma$) reactions over a wide range of masses. The possible quantum numbers of states X that can be produced are limited. The C-parity of X is fixed to +1, and the Landau-Yang theorem [1] forbids the formation of states with spin 1, if the photons are quasi-real. The study of the $\gamma\gamma$–formation of resonances allows to probe their flavor content, because in the quark model of hadrons, the partial decay width to two photons is proportional to the fourth power of the constituent quark charges.

The analyses that are presented in this article, are no-tag experiments where the virtuality of the photons is restricted to very small values by requiring a balanced transverse momentum of the hadronic final state. Efficiencies between 0.5% and 5% are typical for these analyses.

The Crystal Ball (CB) detector [2] is a nonmagnetic segmented NaI(Tl) calorimeter with spherical geometry. It has good energy resolution for electromagnetically showering particles and good solid angle coverage. Four layers of cylindrical proportional tubes were placed inside the calorimeter to detect charged particles. An integrated luminosity of 255 pb^{-1} has been collected with the DORIS-II collider at an average beam energy of 5 GeV.

0^{-+} mesons

The π°, η and η' resonances have been detected in the reaction $\gamma\gamma \to \gamma\gamma$ [2]. The η has also been seen in the decay channel $\eta \to 3\pi^\circ \to 6\gamma$ [3] and the η' in $\eta' \to \eta\pi^\circ\pi^\circ \to 6\gamma$ [4,5] as well as $\eta' \to 10\gamma$ [6]. The measured two-photon widths are collected in table 1. No other known pseudoscalar resonances, like $\pi(1300)$, $\eta(1295)$ or $\eta(1440)$ have been observed. An upper limit on $\Gamma_{\gamma\gamma}BR(\eta\pi\pi)$ of 0.3 keV [4] has been set for masses between 1.3 and 1.5 GeV/c^2.

Using the CB $\Gamma_{\gamma\gamma}$ values and a ratio for the decay constant of the π° and of the SU(3) octet member η_8, $R_8 = f_{\pi^\circ}/f_{\eta_8} = 0.8$ [7], we determine the SU(3) mixing angle

$$\Theta_P = (-20.9 \pm 1.1)^\circ$$

and $R_1 = f_{\pi^\circ}/f_{\eta_1} = (0.96 \pm 0.01)$, where f_{η_1} is the singlet decay constant. We see that the pseudoscalar mesons are far from ideal mixing (35.3°), *i.e.* both the η and the η' contain appreciable amounts of strange quarks.

Table 1: Two-photon widths of pseudoscalar mesons

Meson	Final state	$\Gamma_{\gamma\gamma}$/keV	Reference
π°	$\gamma\gamma$	$(7.7 \pm 0.5 \pm 0.5)\cdot 10^{-3}$	[2]
η	$\gamma\gamma$	$(0.510 \pm 0.017 \pm 0.035)$	[2]
	$\pi^\circ\pi^\circ\pi^\circ$	$(0.488 \pm 0.034 \pm 0.065)$	[3] prel.
	CB-average	(0.508 ± 0.034)	
η'	$\gamma\gamma$	$(4.8 \pm 0.5 \pm 0.5)$	[2]
	$\eta\pi^\circ\pi^\circ$	$(4.53 \pm 0.29 \pm 0.51)$	[5] prel.
	CB-average	(4.64 ± 0.45)	
	10γ	$(5.5 \pm 1.0 \pm 0.7)$	[6] prel.
$\iota/\eta(1440)$	$\eta\pi^\circ\pi^\circ$	$< 0.3/BR(\eta\pi\pi)$ at 90% C.L.	[4]

0^{++} and 2^{++} mesons

In the reactions $\gamma\gamma \to \eta\pi^\circ \to 4\gamma$ [8] and $\eta\pi^\circ \to 8\gamma$ [6], we have observed the $a_0(980)$ and $a_2(1320)$ mesons and measured [8]:

$$\Gamma_{\gamma\gamma}(a_2) = (1.14 \pm 0.20 \pm 0.26)\ \text{keV}$$
$$\Gamma_{\gamma\gamma}(a_0)BR(a_0 \to \eta\pi) = (0.19 \pm 0.07^{+0.10}_{-0.26})\ \text{keV}.$$

The cross-section cannot be fitted by just these two resonances. Additionally, a continuum or another broad resonance is needed.

The cross-section for $\pi^\circ\pi^\circ$ production has been measured from threshold [9]. The low-mass continuum is well described by a unitarized Born-term model [10]. The dominant feature of the cross-section is the $f_2(1270)$, for which we have measured [9]:

$$\Gamma_{\gamma\gamma}(f_2) = (3.19 \pm 0.26 \pm 0.29)\ \text{keV}.$$

In a new analysis [6], the full data sample has been used, and a higher efficiency has been achieved in the $\pi^\circ\pi^\circ$ mass range from 0.8 to 2.5 GeV/c^2. In addition to the large f_2 signal, the analysis of the angular distributions shows evidence for

*Talk presented at the Joint International Lepton-Photon Symposium & Europhysics Conference on High Energy Physics, Geneva, July 25 – August 1, 1991 scalar states. We interpret this as indications for the $f_0(975)$ and an additional broad scalar resonance, the $f_0(1250)$, in the f_2 region. A fit to the differential cross-section gives the following preliminary results:

$$\begin{aligned}\Gamma_{\gamma\gamma}(f_0(975)) &= (0.25 \pm 0.10)\ \text{keV}\\ \Gamma_{\gamma\gamma}(f_0(1250)) &= (3.4 \pm 0.8)\ \text{keV}\\ \Gamma_{\gamma\gamma}(f_2(1270)) &= (3.1 \pm 0.2)\ \text{keV}\end{aligned}$$

Only statistical errors are reported. In this analysis, it was assumed that the f_2 is produced only with total helicity $\lambda = 2$ [11,12,13].

Using the published CB values for $\Gamma_{\gamma\gamma}$ of the a_2 and the f_2, and the world average for the $f_2'(1525)$ [14], we determine the SU(3) mixing angle for the tensors (here assuming $R_8 = 1$)

$$\Theta_T = (31.6 \pm 1.7)^\circ$$

and $R_1 = f_{a_2}/f_{f_1} = (0.96 \pm 0.08)$. The tensor mesons are almost ideally mixed, and the data are compatible with nonet symmetry ($f_{f_1} \simeq f_{f_8}$).

In the reaction $\gamma\gamma \to \eta\eta \to 4\gamma$, (6 ± 4) events were found in the $f_2(1270)$ region, where (3.4 ± 1) are expected. Another (4 ± 2.5) events are found between 1.6 and 1.9 GeV/c^2. Attributing these events to the $\Theta/f_2(1720)$, we find

$$\Gamma_{\gamma\gamma}(\Theta/f_2(1720))BR(\Theta/f_2(1720) \to \eta\eta) < 0.05\ \text{keV},$$

at 90% CL, if the Θ is indeed a 2^{++} state. For a possible scalar Θ [15], the limit is

$$\Gamma_{\gamma\gamma}(\Theta/f_0(1720))BR(\Theta/f_0(1720) \to \eta\eta) < 0.3\ \text{keV}.$$

Between 1.5 and 1.7 GeV/c^2 there are four $\eta\eta$ events. Attributing them to the $G/f_0(1590)$, an upper limit of

$$\Gamma_{\gamma\gamma}(G/f_0(1590))BR(G/f_0(1590) \to \eta\eta) < 0.17\ \text{keV}$$

can be set at 90% CL. No events in the $G/f_0(1590)$ region were found in $\gamma\gamma \to \eta'\eta$, amounting to

$$\Gamma_{\gamma\gamma}(G/f_0(1590))BR(G/f_0(1590) \to \eta'\eta) < 0.92\ \text{keV},$$

again at 90% CL.

2^{-+} mesons

The $\pi_2(1670)$ has been observed in the reaction $\gamma\gamma \to 3\pi^\circ$ [16]. The chain decay $\pi_2(1670) \to f_2(1270)\pi^\circ$ has been identified in the $M(\pi^\circ\pi^\circ)$ distribution and the two-photon width measured to be

$$\Gamma_{\gamma\gamma}(\pi_2(1670)) = (1.41 \pm 0.23 \pm 0.28)\ \text{keV}.$$

Furthermore, in the analysis of the reaction $\gamma\gamma \to \eta\pi^\circ\pi^\circ$ [17], an enhancement of about 30 events was found between 1.6 and 2.2 GeV/c^2. We attribute these

events to the formation and decay of a new broad resonance $X(1900)$. The analysis of the angular distributions favors negative parity, but spin $J = 0$ and 2 cannot be discriminated. The $M(\eta\pi^\circ)$ distribution is best fitted with a mixture of $a_0(980)$ and $a_2(1320)$. Possibly, this resonance could be a 2^- state, the isoscalar η_2 partner of the π_2. Assuming $J^P = 2^-$ and decay via $a_2(1320)\pi$, we find:

$$\Gamma_{\gamma\gamma}(X(1900))BR(X(1900) \to \eta\pi\pi) = (0.9 \pm 0.3 \pm 0.2)\ \text{keV}.$$

Discussion

Five years after the end of data taking, we now have an almost complete set of measurements of those final states, that are accessible with the CB detector (*i.e.* the final states with 2, 4, 6, 8 and 10 photons). The formation of the well established mesons π°, η, η', f_2, a_2 and π_2 has been observed. A highlight of our analyses is the observation of the new state $X(1900)$, which could be the predicted η_2. The measured two-photon widths of the π_2 and $X(1900)$ are much larger than predicted in quark-model calculations [18], although recent calculations [19], incorporating relativistic effects, predict values that are closer to our measurements.

No positive evidence was found for the formation of the radial excitations of the pseudoscalar mesons or the $\iota/\eta(1440)$. The situation is less clear for the glueball candidates $G/f_0(1590)$ and $\Theta/f_2(1720)$. Some events have been found in the $\eta\eta$ final state, but not enough to establish signals. For these states, as for the scalar mesons, new experiments with larger data samples are needed to find answers for the remaining open questions. Exploring the mass range above 2 GeV/c^2 will also profit from new experiments.

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