DEUTSCHES ELEKTRONEN – SYNCHROTRON

DESY 92–083
June 1992

CRYSTAL BALL Contributions to the 9th International Workshop on Photon-Photon Collisions, La Jolla, 23-26 March 1992

a) New Crystal Ball Data on Resonance Formation by $\gamma\gamma$–Collisions

b) Representation of Results on $\gamma\gamma$–Formation of Resonances by Helicity Amplitudes

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ISSN 0418-9833

NOTKESTRASSE 85 · D-2000 HAMBURG 52

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REPRESENTATION OF RESULTS ON $\gamma\gamma$-FORMATION OF RESONANCES BY HELICITY AMPLITUDES

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Abstract

It is suggested to use helicity amplitudes to represent the results of $\gamma\gamma$−formation of resonances. There exists a one-to-one relation to the $\gamma\gamma$ partial width $\Gamma_{\gamma\gamma}$ which is obtained from the Breit-Wigner fit to the resonance cross section. The advantage of using the helicity amplitude is that the phase space and the spin factor are separated and the helicity amplitude is directly proportional to the matrixelement of the hadronic transition.

1 Introduction

One of the fields of two-photon physics is the $\gamma\gamma$−formation of meson resonances R. The results of these measurements are the $\gamma\gamma$ partial widths, $\Gamma_{\gamma\gamma}(R)$, obtained from a fit of the measured cross section to a Breit-Wigner resonance shape. They may also be expressed by the branching ratio $BR_{\gamma\gamma}(R) = \Gamma_{\gamma\gamma}(R)/\Gamma_{tot}(R)$.

These numbers, $\Gamma_{\gamma\gamma}(R)$, do not allow an easy, intuitive ("anschaulich") interpretation of what they mean for hadron spectroscopy, i.e. which are the constituents of the hadron R and their wave functions. The main reason for this is that the phase space factor, strongly depending on the mass of the resonance, $M(R)$, is not divided out. To give you an example from another field of physics: One of the first things one has to learn studying β−decay is that the lifetime of a nucleus does not have a direct meaning for physics. One has to divide by phase space. The resulting number, called the ft−value, allows a direct physics interpretation. It is $(ft)^{-1} \sim (\text{coupling constant})^2 \times (\text{matrixelement})^2$.

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This contribution wants to point out that there exists a representation for $\Gamma_{\gamma\gamma}$ which fulfills the requirement mentioned above and which allows a quick, intuitive understanding of its meaning for physics interpretation. The representation is by helicity amplitudes. The author suggests to use them.

2 Theory of Helicity Amplitudes

The theory of the application of helicity amplitudes for $\gamma\gamma$ resonance formation has been presented in [1]. The idea of the deduction is repeated here.

We consider the $\gamma\gamma$–formation of a resonance R, decaying into n hadrons h,

$$\gamma\gamma \rightarrow R \rightarrow n \cdot h$$

and restrict ourselves to quasi-real γ's and unpolarized $e^{\pm}$–beams. The matrixelement is

$$M_{ab} = \epsilon_1^{\mu} \cdot \epsilon_2^{\nu} \cdot T_{\mu\nu} \cdot E_{J_z=a-b}^{\alpha_1 \ldots \alpha_n}$$

with

ϵ_1^{μ}, ϵ_2^{ν}	polarization vectors of the initial state photons
$E_{J_z=a-b}^{\alpha_1 \cdots \alpha_n}$	hadronic final state polarization tensor
a, b	helicities of intitial state γ's
α_i	spins of final state hadrons
λ	$\gamma\gamma$ helicity

The transition operator $T_{\mu\nu}$ is expanded in the helicity basis $H_{\mu\nu}$

$$T_{\mu\nu} = \sum_{\mu,\nu} F_{\lambda} \cdot H_{\mu\nu}.$$

The quantities F_{λ} are the helicity amplitudes. Other names given to them are helicity coupling constants or helicity form factors (the latter because they depend on the mass q^2 of the virtual photons, but this word should be reserved for the q^2–dependence normalized to 1 at $q_1^2 = q_2^2 = 0$). There is a one-to-one relation to the $\gamma\gamma$ partial width $\Gamma_{\gamma\gamma}$:

$$\Gamma_{\gamma\gamma}(R) = \frac{1}{16\pi \cdot (2J_R + 1) \cdot M_R} \cdot \sum |M_{ab}|^2$$

The use of the helicity basis suggests itself for $\gamma\gamma$–reactions because their helicity structure is simple: The initial state has either $\lambda = 0$ or $\lambda = 2$.

The advantages are:

1. The phase space factor is removed. The helicity amplitudes reflect directly the matrixelement, i.e. the overlap of the wavefunctions of the hadronic states. Similarly, the spin factor is separated out.

2. Upper limits for hadronic states which have not been seen in $\gamma\gamma$–formation can be understood intuitively by comparing the upper limit to the value of the helicity amplitude of an observed meson.

The next chapter explains these advantages with the example of the $J^{PC} = 0^{-+}$ mesons.

The table below shows the relation between the measured $\Gamma_{\gamma\gamma}$ and the helicity amplitudes for various spins and helicities. The helicity amplitude has a dimension which varies with spin and helicity.

J^P	λ	$\Gamma_{\gamma\gamma}$
0^-	0	$\frac{1}{64\pi} \cdot M_R^3 \cdot F_0^2$
2^+	2	$\frac{1}{80\pi} \cdot \frac{1}{M_R} \cdot F_2^2$
2^+	0	$\frac{1}{240\pi} \cdot M_R^3 \cdot F_0^2$
0^+	0	$\frac{1}{16\pi} \cdot \frac{1}{M_R} \cdot F_0^2$
2^-	0	$\frac{1}{120\pi} \cdot M_R^3 \cdot F_0^2$

3 The Helicity Amplitudes of Pseudoscalar Mesons

Figure 1 shows the helicity amplitudes for the $J^{PC} = 0^{-+}$ pseudoscalar mesons $\pi^{\circ}(135)$, $\eta(549)$, and $\eta'(958)$ together with the upper limits for other states which have not been observed by $\gamma\gamma$–formation (known or not known).

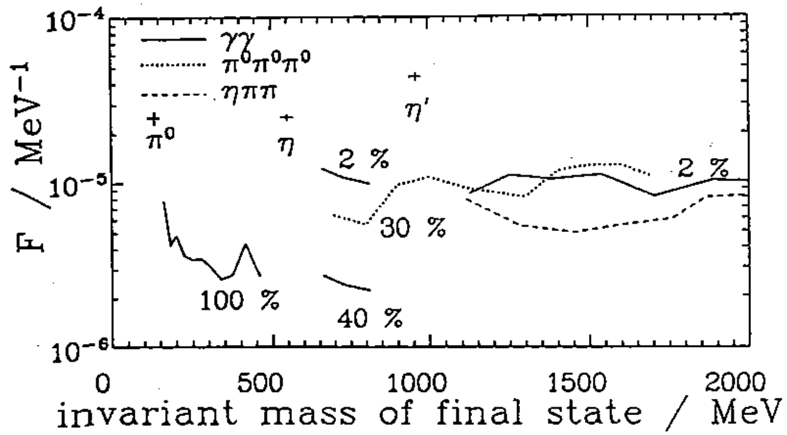

Figure 1: The helicity amplitudes for pseudoscalar mesons.

While $\Gamma_{\gamma\gamma}$ for π°, η, η' is ~ 7 eV ~ 500 eV and ~ 4 keV, respectively, their helicity matrixelements are very similar:

$$F(\pi^\circ) \approx F(\eta) \approx \frac{3}{4}F(\eta') \approx 3.7 \cdot F(\eta_c).$$

No other pseudoscalar state X has been observed in the decay channels $X \to \gamma\gamma$, $\to \pi^\circ\pi^\circ\pi^\circ$ and $\to \eta\pi^\circ\pi^\circ$ [2]. Upper limits have been derived for $\Gamma_{\gamma\gamma} \cdot BR$. Assumptions on the branching ratio have to be made. For figure 1 the following guesses (which indicate limits) have been made:

$X \to \gamma\gamma$	BR	$= 100\%$	between π° and η
$\to \gamma\gamma$		$= 40\%$ or 2%	between η and η'
$\to \gamma\gamma$		$= 2\%$	above η'
$\to \pi^\circ\pi^\circ\pi^\circ$		$= 30\%$	maximum because of isospin
$\to \eta\pi^\circ\pi^\circ$		$= 30\%$	maximum because of isospin

Of special interest are the candidates for radial excitations of π° and η. We find

$$F(\pi(1300)) \leq 0.3 \cdot F(\pi^\circ)$$

$$F(\eta(1275) \leq 0.3 \cdot F(\eta).$$

Mark-II has given a limit for $\gamma\gamma$–formation of the glueball candidate $\iota/\eta(1440)$. From their value one gets

$$F(\iota/\eta(1440)) \leq 0.15 \cdot F(\pi^\circ).$$

This representation of upper limits for candidates for radially excited mesons and for glueballs shows that improvements for these numbers are highly needed.

It should be mentioned that for the calculation of the flavor mixing angle always the correction for phase space has been made.

4 Summary

Two-photon physics became an important tool for experimental hadron spectroscopy. Photons couple to charges, i.e. to the quark constituents of hadrons. So $\gamma\gamma$–formation of mesons contributes centrally to advancing hadron spectroscopy to hadron microscopy.

An easy, intuitive understanding of the experimental results is important. The use of helicity amplitudes to represent the data can help.

Acknowledgement

I would like to thank all the collaborators over the years on getting data with the Crystal Ball detector and analyzing them. Among those who specialized on two-photon physics I want to mention especially K. Wacker, H. Marsiske, B. Muryn, and K.-H. Karch.

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