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LIGHT HADRONS AS SEEN VIA TWO PHOTONS BY CELLO [1]

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ABSTRACT. This article reviews recent results on resonance formation in exclusive two photon reactions obtained with the CELLO detector at the (nowadays) low energy e^+e^- collider PETRA. A short survey of the characteristics of the two photon production mechanism is preceding a walk through the $J^{PC} = 0^{-+}, 0^{++}, 2^{++}, 2^{-+}$ and $1^{?+}$ multiplets, followed by a short note on new analyses of the 4π final states.

THE TWO PHOTON REACTION MECHANISM. The basic Feynman graph for the two photon reaction at e^+e^- storage rings is shown in fig.1. High energetic electrons and positrons each radiate off spacelike-virtual Bremsstrahlung photons (mainly low energetic and at small angles), which subsequently interact to form a final state X.

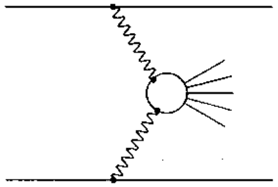

Figure 1: Feynman diagram of the two photon process in an e^+e^- reaction

The majority of events has too small lepton scattering angles to be detected ("tagged") in the forward calorimeters just around the beam pipe. The virtual photons of these "antitagged" events are restricted to small masses $Q^2 = -q^2$ and can be considered as "quasi-real" with the important consequence of being transversely polarised. The independently continuous energy spectra of the two photons lead to a continuum of invariant masses as well as boosts of the final state X along the beam axis. The Feynman graph can be split into two pieces, the purely QED and thus exactly calculable electron-photon vertices and the interesting $\gamma\gamma \to X$ vertex. A formalism exists which connects the measurable $e^+e^- \to e^+e^-X$ cross section to the interesting $\gamma\gamma \to X$ cross section [1]. The complicated kinematics leads to typically very low experimental acceptances which have to be calculated by detailed Monte Carlo simulations. Formed by two photons, the C parity of the final state X is positive. Due to the transversality of quasi real photons only the helicity states 0 and ± 2 can be produced, furthermore the Landau-Yang theorem [2] forbids the system X to have spin 1. In the single or double tag mode, however, with one or both of the photons being substantially off-shell, also helicity states ± 1 and spin 1 mesons can be formed. A quite large number of reviews of two photon physics results is existing, see e.g. [5].

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[1] Talk given at the 3rd Int. Conference on Hadron Spectroscopy, Ajaccio (France), Sept. 23 - 27, 1989

PSEUDOSCALAR MESONS. $\eta'(958)$. In a new analysis of the reaction $\gamma\gamma \to \pi^+\pi^-\gamma$ the η' radiative width is measured to be $\Gamma_{\gamma\gamma} = 3.7 \pm 0.2 \pm 0.4\,keV$, supporting the recent high statistics measurements which are below $4\,keV$. However, the many measurements are not compatible within their statistical errors, demonstrating that the 15 – 20% systematic uncertainties really limit the precision of present $\gamma\gamma$ experiments.

NO $\iota/\eta(1440)$. The pseudoscalar glueball candidate ι (now called $\eta(1440)$) has not been observed in the reaction $\gamma\gamma \to K^0_S K^\pm \pi^\mp$ [6], leading to an upper limit $\Gamma_{\gamma\gamma}(\eta(1440)) \cdot B(K\bar{K}\pi) < 1.2\,keV$. This result can also be given in terms of stickiness [7], defined as the ratio of the squared amplitudes of the gluon gluon coupling to the photon photon coupling of a resonance X. The latter probes the electric charge of the constituents, the former is sensitive to their colour charge and should be especially large if the gluons themselves are the valence constituents. For the pseudoscalar particles the stickiness ratio reads: $S_{\pi^0} : S_\eta : S_{\eta'} : S_\iota = 0.02 : 1 : 4 : > 80\,(95\%c.l.)$ using the CELLO limit alone. A combined analysis of all published experimental data [8] leads to the upper limit $\Gamma_{\gamma\gamma}(\eta(1440)) \cdot B(K\bar{K}\pi) < 0.75\,keV$ at 95% c.l. (incl. 20% systematic uncertainty) and a relative stickiness of more than 128! Although the experimental stickiness limit has been increased considerably, its implication becomes less clear due to new theoretical aspects: also radial excitations might have a smaller $\gamma\gamma$ coupling than previously expected due to a dynamical suppression by chiral symmetry [9]. Moreover, recent results from lattice gauge theory as well as the flux tube model point to glueball masses well above 2 GeV (except for the 0^{++}). Last not least, it is not clear whether the ι is in fact two states.

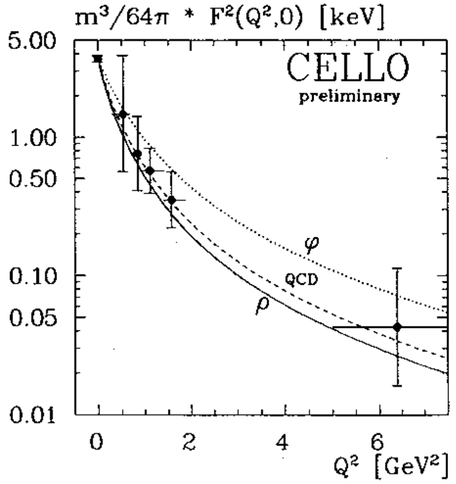

Figure 2: $\eta'\gamma$ transition form factor as function of Q^2.

$0^{-+}\gamma$ TRANSITION FORM FACTORS. The coupling of a pseudoscalar meson to two photons is described by the amplitude $T_{\mu\nu} = i \cdot \varepsilon_{\mu\nu\alpha\beta} \cdot q_1^\alpha q_2^\beta \cdot F(Q_1^2, Q_2^2)$ in terms of a single form factor. Resonance formation in the single tag mode allows to measure the Q^2 dependence of the form factor. Currently the form factors of all three ground state pseudoscalars are investigated by CELLO and will be published soon. The result for the η' in the $\rho\gamma$ decay mode lies between a single ρ and a single ϕ pole as predicted by vector dominance models and is consistent with a QCD calculation[10]. The statistics of this measurement will be increased by including the $\eta\pi^+\pi^-$ decay modes with the η decaying into $\gamma\gamma$, $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\gamma$. Also exclusive $\eta(548)$ production is seen in single tag $\pi^+\pi^-\pi^0/\gamma$, the preliminary form factor looking much like the η' one. For the first time also a $\pi^0\gamma$ transition form factor measurement in the spacelike region is underway, with results expected in the very near future. The analysis of these events with only two photons in the liquid argon calorimeter in addition to a forward tag demands careful control of trigger and reconstruction efficiencies as well as (e.g.) beam-gas background which is relatively straightforward in the presence of charged tracks.

TENSOR MESONS - AND SCALARS UNDERNEATH ? The coupling of tensor (i.e. $J^{PC} = 2^{++}$) mesons to two photons is described by 5 independent form factors. In the untagged mode (i.e. for (quasi-) real photons) only two of them contribute, they can be chosen to describe the coupling to helicity 0 and ± 2, respectively. Thus, for tensor mesons one has to measure the radiative width as well as the helicity structure which can be inferred from angular distributions. In the absence of azimuthal angular information in an untagged $\gamma\gamma$ experiment an important piece of analytical power is lost, e.g. the spherical harmonics Y_J^λ describing the decay into two pseudoscalars are not orthogonal after ϕ integration. So a pure Y_2^2 angular distribution can be mimicked by a suitable linear combination of Y_0^0 and Y_2^0. If, as advocated by quark model calculations and some recent experimental evidence in partial wave analyses, the LS splitting is small, and tensor and scalar mesons are almost mass degenerate, this can lead to serious misinterpretations. Former results on the helicity structure in untagged two photon reactions thus have to be interpreted with care. Another consequence of the ϕ integration is that helicity 2 states do not interfere with helicity 0 states.

$f_2(1270)$. CELLO can observe the $f_2(1270)$ in the reaction $\gamma\gamma \to \pi^+\pi^-$. To overcome the problems with the large electron and muon pair background a particle identification method making extensive use of the fine grained information from the liquid argon calorimeter has been developped [11], and preliminary results have been presented [12]. Since then many systematic checks of tracking efficiencies and corresponding improvements in the detector Monte Carlo simulation have been made. The data are consistent with a pure helicity ± 2 formation, however remember the warning given above. Presently an amplitude analysis taking into account constraints from unitarity and continuity in $W_{\gamma\gamma}$ is underway. A key challenge is to prove or disprove the suggestion of a large scalar component under the $f_2(1270)$ [13], and to explore the S^* region. Results are to be expected soon.

$a_2(1320)$. In a new analysis of the reaction $\gamma\gamma \to \pi^+\pi^-\pi^0$ [14] in two data samples (fully reconstructed and one of the π^0 decay photons missing) the a_2 radiative width is determined to be $\Gamma_{\gamma\gamma}(a_2) = 1.00 \pm 0.07 \pm 0.19\,keV$, in accord with previous measurements.

Large statistics, the relatively low background as well as the exploition of the maximal angular information (the correlation of the Euler angles $\cos\beta$ and γ describing the orientation of the decay plane in the $\gamma\gamma$ helicity frame, α is not measureable without tag) allows us to perform a precise measurement of the helicity structure of a_2 formation. The result is that no helicity 0 is needed at all, and an upper limit of $R^{(0)} = \Gamma^{(0)}_{\gamma\gamma}/\Gamma_{\gamma\gamma} < 8.2\%$ at $95\% c.l.$ (incl. systematic uncertainties due to background angular distributions) is obtained. This is the most stringent limit on the helicity 0 fraction of a tensor meson produced in real two photon collisions, and for the first time makes it possible to distinguish between different dynamical models. Through combination with previous measurements it can be improved to 7.7%. The lowest order gauge invariant and Bose symmetric Born term amplitude predicts a helicity ratio $\Gamma^{(2)}_{\gamma\gamma}/\Gamma^{(0)}_{\gamma\gamma} = 6:1$, i.e. $R^{(0)} = 1/7 = 14.3\%$ [15]. Such a value is now excluded at a level of more than 3.5 standard deviations. The present measurement thus argues in favour of quark model and sum rule approaches which predict a tiny or even vanishing $R^{(0)}$.

An important point has to be realised in the interpretation of this result: Since the decay of a scalar particle to $\rho\pi$ is forbidden by parity, there is no danger of confusing spin 2, helicity 2 with some linear combination of spin 2, helicity 0 and spin 0. Thus this limit has to be taken seriously as it stands!

BUT NO NARROW $a_0(1300)$. The just given argumentation does not hold for the $\eta\pi$ decay of the a_2, where indeed a scalar underneath could contribute - and evidence for a narrow $a_0(1300)$ with almost identical mass and width is presented by GAMS [16] at this conference! CELLO is not able to detect the final state $\pi^0\eta$, but Crystal Ball [17] and JADE [18] have data on this reaction. Their combined result on $\Gamma_{\gamma\gamma}(a_2)$ is $1.06 \pm 0.20\,keV$. Thus the world average measured in the $\rho\pi$ decay mode, $0.94 \pm 0.09\,keV$ (stat. and syst. errors added in quadrature), leaves some space for a scalar component. However, the Crystal Ball angular distribution is well described by almost only spin 2, helicity 2 - though some "non-resonant" (see below) background is present. Our null- result for the helicity 0 contribution justifying an incoherent ansatz, an upper limit on $\Gamma_{\gamma\gamma}(a_0(1300))$ can be derived by fitting the published angular distribution of Crystal Ball and demanding consistency between the different a_2 decay modes. The most conservative (concerning the angular distribution of the background under the a_2/a_0 signal) 95% c.l. limit is $\Gamma_{\gamma\gamma}(a_0(1300)) \cdot B(a_0(1300) \to \eta\pi) < 0.44\,keV$ for a narrow (GAMS-type) a_0, or the ratio $\Gamma_{\gamma\gamma}(a_0)/\Gamma_{\gamma\gamma}(a_2) < 0.50/B(a_0 \to \eta\pi)(95\% c.l.)$.

Comparing this ratio with the quark model prediction of 15/4, the branching ratio must be lower than 13.3%. This however is unlikely, since $\eta\pi$ is expected to dominate over the $\eta'\pi$ and $K\bar{K}$ decay modes (as for the a_2), and $\rho\pi$, accounting for $70.1 \pm 2.7\%$ for the a_2, is forbidden. Thus the $\eta\pi$ branching ratio could easily be as large as 50%. This means that either (a) the quark model prediction is not to be taken too literally (then it also should not be used for S^*/δ identification as $4q$ states or $K\bar{K}$ molecules) *or* (b) there is no narrow mass degenerate $a_0(1300)$ à la GAMS. However, both $\gamma\gamma \to \eta\pi^0$ analyses show a large "non-resonant background" below the δ and a_2 resonances. With only neutral particles in the final state, there is no Born term contribution, and isospin 1 final state interactions only can create $\eta\pi$ via the not very large K^+K^- intermediate state. There is no reason why this "continuum" should not be due to a very broad $q\bar{q}$ scalar resonance. An angular analysis of the JADE data could further clarify this topic.

$f_2'(1530)$ - AND NO $f_0'(1530)$. The $f_2'(1530)$ has been seen in the reaction $\gamma\gamma \to K^0_S K^0_S$ with a radiative width of $\Gamma_{\gamma\gamma}(f_2(1530)) \cdot B(K\bar{K}) = 0.11^{+0.03}_{-0.02} \pm 0.02\,keV$[19]. In this analysis destructive $f_2 - a_2$- interference has been observed, in accord with quark model predictions. A combined angular analysis of PLUTO [20] and CELLO data leads to an upper limit for the scalar $s\bar{s}$ candidate $\Gamma_{\gamma\gamma}(f_0'(1530)) \cdot B(K\bar{K}) < 0.7\,keV$ $(95\% c.l.)$[21]. This limit is not strong enough to shed any doubt on the existence of the scalar particle.

NO $\Theta/f_2(1720)$. There is no indication of $f_2(1720)$ in the reaction $\gamma\gamma \to K^0_S K^0_S$ [19], leading to the $95\% c.l.$ upper limit of $\Gamma_{\gamma\gamma}(f_2(1720)) \cdot B(K\bar{K}) < 0.22\,keV$ allowing arbitrary interference with the $f_2'(1530)$ and arbitrary helicity structure, improving to $0.06\,keV$ neglecting interference and assuming helicity 2. These strong limits in principle confirm a glueball interpretation. However, at this conference it became clear that the spin assignment is still uncertain, a scalar interpretation cannot be ruled out.

THE PSEUDOTENSOR $\pi_2(1670)$. In the final state $\pi^+\pi^-\pi^0$ evidence for the 2^{-+} meson π_2 (the old A_3) has been obtained by identifying the $f_2\pi$ decay mode [14]. A large interference term between the $\rho\pi$ and $f_2\pi$ decay modes complicates the numerical evaluation of the $\gamma\gamma$ width. The best description of the data is given by constructive interference, which leads to the radiative width of $0.8 \pm 0.3(stat.)\,keV$. Neglecting interference, the value is increased to $1.3 \pm 0.3(stat.) \pm 0.3(syst.)keV$, in agreement with the preliminary Crystal Ball result [22] in the final state $3\pi^0$ which is almost free of interference complications.

SPIN 1 MESONS. Two spin 1 states are seen in $\gamma\gamma$ experiments, with only low statistics, but consistently in 5 experiments reporting. Their spin 1 nature is identified by the presence in the single tag mode and the simultaneous absence in the no tag mode, a behaviour expected due to the Landau-Yang theorem. In the last year no more information has become available, such that the discussion in [8] is still completely up to date. Here we only list the numerical results which are not really radiative widths (which are zero), but some limits taking into account the known Q^2 behaviour at $Q^2 = 0$ proportional to the squared coupling constant (see e.g.[8]). The $f_1(1285)$ is seen in the final state $\eta\pi\pi$ [23] ($\tilde{\Gamma}_{\gamma\gamma} = 7.2 \pm 2.2 \pm 2.4\,keV$ using a ρ pole, preliminary), the $f_1(1420)$ in $K_S^0 K^\pm \pi^\mp$ [6] ($\tilde{\Gamma}_{\gamma\gamma} \cdot B(K\bar{K}\pi) = 3.0 \pm 0.9 \pm 0.7\,keV$ using a ρ pole, $1.4 \pm 0.4 \pm 0.3\,keV$ using a ϕ pole), and an upper limit on $f_1(1530)$ ($\tilde{\Gamma}_{\gamma\gamma} \cdot B(K\bar{K}\pi) < 1.0\,keV$ for a ϕ pole) has been established [6]. The parity of the $f_1(1420)$ is not yet unambiguously settled, but its exotic nature is evident: As a 1^{++} it would be extra in the nonet (and too light for a radial excitation), and a 1^{-+} cannot be built by two spin 1/2 quarks. In the latter case a dynamic suppression of the coupling to the LT as compared to the TT polarisation state is necessary to describe the data [8,24].

PRELIMINARIES ON $\gamma\gamma \longrightarrow \pi^+\pi^-2\pi^0$. The reaction $\gamma\gamma \rightarrow \pi^+\pi^-2\pi^0$ has already been analysed by CELLO, it showed evidence for charged ρ pair creation [25]. This final state may however also contain other intermediate states like $a_1\pi$ and $a_2\pi$, both of them predicted to strongly couple to $q\bar{q}g$ hybrid states, and the latter a main decay mode of the yet undetected η_2, the isoscalar partner of the $J^{PC} = 2^{-+}$ π_2 meson (see above). In order to search for such states, the analysis was extended to final states with only 3 or 2 photons instead of all 4 from the two π^0s, whose momenta were then approximated by kinematic fitting. From Monte Carlo simulations we know that the far majority of events are reconstructed in these topologies, especially at low invariant masses. Selecting on charged intermediate ρs and corresponding a_1 or a_2 bands in the 3π masses, the resulting mass spectrum shows two structures, one around $1.53\,GeV$ and the other around $1.8\,GeV$. Without such cuts there is only a slight indication of structure above a large smooth background. However, if the events are weighted according to some (Bose-symmetrised) $a_2\pi$ or $a_1\pi$ amplitude squares, the same structures clearly emerge out of the flat background, showing that they have a different distribution in phase space. Some problems have to be clarified before definite conclusions can be drawn: First it is not unambiguously clear that the final state really is $\pi^+\pi^-\pi^0\pi^0$ if only two photons are reconstructed, and second, we found that for the lower mass state the expected mass resolution using this procedure strongly depends on the decay dynamics, such that the real width must be very small and not all J^Ps and decay modes could lead to such a narrow enhancement. It remains to be seen whether these states, if confirmed, have any relation to the recently announced 4π resonances of WA76 [26], or the enhancement seen in a single tag two photon reaction by TPC/2γ [27]. After the conference we also looked into our single tagged data, which require a larger minimum tag angle than those of TPC/2γ. Up to now we could not find any resonance-like structure. Further work on this topic is necessary.

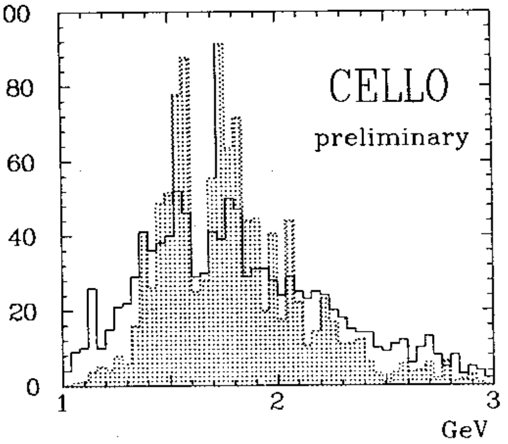

Figure 3: Preliminary invariant $\pi^+\pi^-2\pi^0$ mass spectrum without cuts (solid), weighted with squared $(0^-)2^{-+}\,a_1\pi$ matrix element (shaded).

We now also search for corresponding structures in the 4 charged pion final state where statistics is higher and no resolution problems exists. However, this reaction is dominated by the large $\rho^0\rho^0$ enhancement, and the identification of $a_2\pi$ or $a_1\pi$ above this background requires a full partial wave analysis.

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