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SOME SNAPSHOTS OF NEW CELLO AND CRYSTAL BALL RESULTS ON $\gamma\gamma$ REACTIONS *

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ABSTRACT

Two topics from recent experimental two- photon spectroscopy are presented which are of relevance even in the LEP era – the discovery of a new (probably 2^{-+}) resonance in $\gamma\gamma \to \eta\pi\pi$ by Crystal Ball and CELLO, and the measurements of the electromagnetic form factors of the π^0, η and η' by CELLO.

INTRODUCTION

Although (or maybe because) data taking at PETRA and the Crystal Ball has finished already some years ago, still very interesting physics is extracted from that data. All these analyses are very involved and require a detailed understanding of the underlying physics, the apparatus and its simulation. CELLO has contributed 13 papers to this conference [1-13], Crystal Ball 5 [14-18], which partly are published in the meantime.

Since it is completely impossible to review all of the papers on a few pages, I instead give an elementary and qualitative introduction to the merits of exclusive $\gamma\gamma$ physics and then concentrate on two topics of strong recent interest: the formation of 2^{-+} mesons (with orbital angular momentum 2 between the quarks) and the measurement of the pseudoscalar meson - photon transition form factors.

WHY EXCLUSIVE $\gamma\gamma$ PHYSICS?

Two photon formation of C- even meson resonances is an important tool for the analysis of their quark composition, their radiative widhts being proportional to the 4^{th} power of the constituents' charges. As such it plays an important role in the low energy frontier of QCD, the search and unambiguous classification of non- quark model particles (see e.g. [19-22]). A wealth of experimental data (see e.g. the reviews [23]) is existing on the two- photon widths of the pseudoscalar ($0^{-+}, L = 0, S = 0\, q\bar{q}$) and tensor mesons ($2^{++}, L = 1, S = 1\, q\bar{q}$), in good agreement with quark model expectations. Octet- singlet mixing angles derived from these measurements agree with those determined from other methods; the mid-80's change of the 0^{-+} mixing angle from $-10°$ to $\approx -20°$ was initiated by two photon experiments. The situation in the scalar sector is somewhat confused [24], mainly because of the controversial quark model assignment of the experimentally known states and probably strong unitarity corrections [24]. The small two- photon coupling of the well established S^* and δ (which according to the 1988 PDG name convention should be called $f_0(980)$ and $a_0(980)$ – if they were quark model states) is a good argument for interpreting them as 4 quark states or even $K\bar{K}$ molecules. No signs of glueball candidates have been found yet [25], supporting just this classification since the valence constituents are electrically neutral. However, also radial excitation candidates have not been found [25]. A place where it seems that a non-$q\bar{q}$ meson has been found is the spin 1 sector [25]: the $f_1(1420)$, clearly spin 1 from its peculiar production pattern (the signal is only seen if at least one photon is far off-shell, as expected from Yang's theorem [27] for spin 1 particles) has either positive parity – then there is one 1^{++} state too many – or negative parity – then it has exotic quantum numbers which cannot be built from two spin 1/2 quarks.

$\gamma\gamma$ FORMATION OF $J^{PC} = 2^{-+}$ STATES

The 2^{-+} nonet is not well known experimentally: apart from the strange members, only the charged substates of the isovector $\pi_2(1680)$ (the old A_3) have been seen, and the isoscalar states are completely unknown. In the quark model these mesons are spin

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singlet states ($S = 0$) with two units of orbital angular momentum. In potential model calculations their $\gamma\gamma$ couplings are sensitive to the second derivative of the $q\bar{q}$ wave function at the origin. The discovery of the neutral π_2 in quasi real two photon scattering into 3 pion final states by Crystal Ball [15] and CELLO [3] and the surprisingly large radiative width in the order of 1-1.5 keV have triggered interest into the search for the isoscalar partner(s), of which the mainly non-strange should have a radiative width around 3 keV from SU(3) expectations. Given the dominant (S-wave) $\pi_2 \to f_2\pi$ branching fraction, a large decay mode of the hypothetical η_2 could be $a_2\pi$, which decays into $\eta\pi\pi$ as well as 4π. The latter "suffers" from a huge (and still not unambigously understood) positive parity cross section, making the former the better candidate for an η_2 search. CELLO [4] has looked into the $\eta\pi^+\pi^-$ channel and, after an optimization of the low energy photon reconstruction procedure in the liquid argon calorimeter, found evidence for ηs in the $\pi^+\pi^-\pi^0$ and $\gamma\gamma$ decay modes (Fig. 1). The cross section, shown in Fig. 2, shows a resonance like behaviour, with the parameters $m = 1850 \pm 50 MeV$, $\Gamma \approx 360\, MeV$, and $(2J+1)\cdot\Gamma_{\gamma\gamma}\cdot B(\eta\pi\pi) = 15 \pm 5\, keV$ (preliminary). In parallel, Crystal Ball [14] has seen this object in the decay mode $\eta\pi^0\pi^0$ reconstructed from exclusive $\gamma\gamma \to 6\gamma$ events. The mass spectrum is shown in Fig. 3. Many beautiful tests convincingly demonstrate that the events between the η' and say $1.6\, GeV$ are due to background, but the events around $1.9\, GeV$ are clearly genuine exclusive $\gamma\gamma \to \eta\pi^0\pi^0$ [14]. The parameters given by Crystal Ball are $M(X) = 1.876 \pm 0.035 \pm 0.045\, GeV$, $\Gamma_{tot}(X) = 0.229 \pm 0.090 \pm 0.033\, GeV$, and $(2J+1)\cdot\Gamma_{\gamma\gamma}(X)\cdot BR(\eta\pi\pi) = 4.5 \pm 1.0 \pm 1.5\, keV$. A likelihood test of the decay kinematic distributions cannot be fully conclusive, given the small statistics available. However, both experiments report consistency with $2^{-+} a_2\pi$, as expected for the isoscalar partner of the π_2. Positive parities are not favoured, but $0^{-+} f_0\eta$ also gives a quite good description. The possibility of more than one state contributing cannot be ruled out at all, and acceptances are quite different for different interpretations, such that the parameters given above have to be taken with care. A recent quark model calculation by Cahn et al. [28] predicts very small values for $\Gamma_{\gamma\gamma}$ in the order of $0.001 - 0.01\, keV$ for pseudotensor $q\bar{q}$ states. If this turns out to be true, one needs other interpretations for the signals usually assigned to π_2 and η_2. In the flux tube model, hybrid states with correct quantum numbers and decay characteristics are predicted in this mass range [29]. It will be interesting how the situation develops.

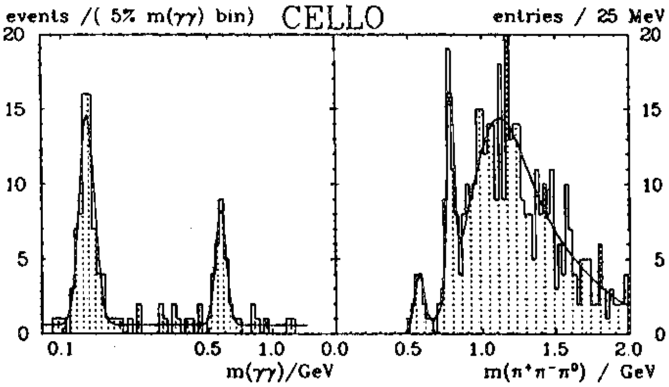

Figure 1: Evidence for η production in invariant $\gamma\gamma$ (left) and $\pi^+\pi^-\pi^0$ (right) masses recoiling against a $\pi^+\pi^-$ pair

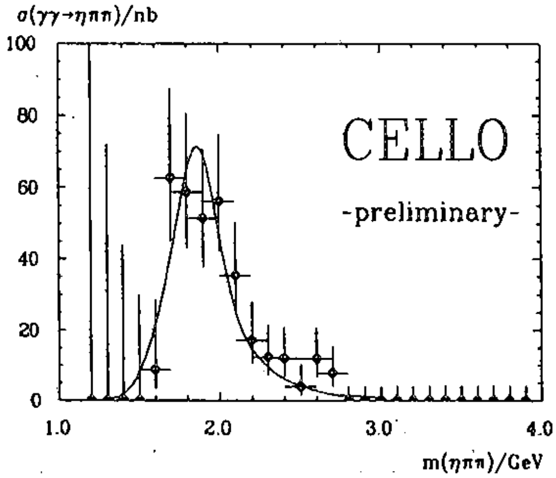

Figure 2: Topological cross section for $\gamma\gamma \to \eta\pi^+\pi^-$.

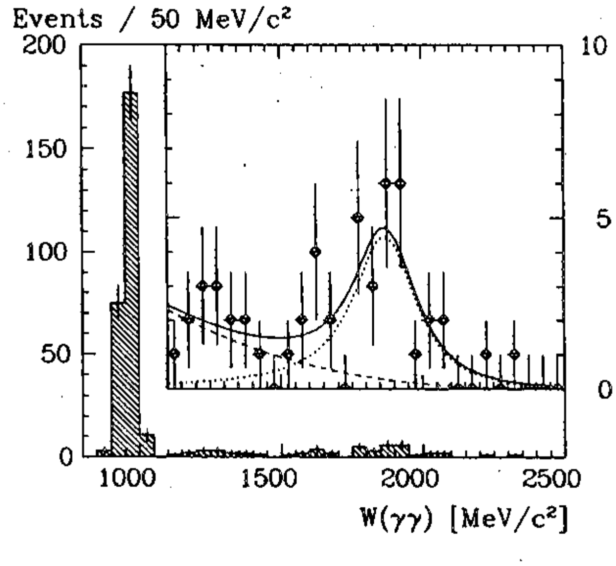

Figure 3: Crystal Ball data on $\gamma\gamma \to \eta\pi^0\pi^0$.
The histogram is the invariant mass distribution of selected events. The insert shows the distribution of events with $1100\, MeV/c^2 < W_{\gamma\gamma} < 2500\, MeV/c^2$. The full line is the fit to the data, the dotted line is the Breit-Wigner and the dashed line is the background.

ELECTROMAGNETIC FORM FACTORS OF π^0, η AND η'

In Quantum Electro- Dynamics (QED) one can compute electromagnetic transition amplitudes from first principles. Possible deviations from the expected behaviour are parameterized in terms of *vertex form factors*, scalar functions of Lorentz scalar quantities (e.g. invariant masses). Form factors are expected to be constant for pointlike particles, deviations may be created by finite size effects or strong final state interactions. Hadrons clearly are extended and composite objects, such that severe deviations from constancy are expected, as is well known for the nucleon electric and magnetic form factors and the (charged) pion form factor. The latter, describing the $\gamma^*\pi^+\pi^-$ vertex, is known to be dominated by the ρ resonance in the timelike region (for positive photon "mass squares" $q^2 > 0$), and is well approximated by the ρ pole tail also in the spacelike region ($q^2 < 0; Q^2 := -q^2 > 0$). This has lead to the hypothesis of Vector Meson Dominance (VMD), suggesting that photons interact with hadrons largely via intermediate virtual vector meson states. A pole form (from the vector meson propagator) is a natural parameterization of the Q^2 dependence: $F(Q^2) \propto 1/(1 + Q^2/\Lambda^2)$, where Λ can be identified with the vector meson mass (in the timelike region also the imaginary part $(-im\Gamma)$ due to its finite life time has to be taken into account). In the spacelike region, cross sections are smaller than the QED prediction; the slope b of the form factor at $Q^2 = 0$ can be interpreted as the effective mean charge radius of the pion: $r = \sqrt{6 \cdot b}$. Thus finite size effects and vector meson dominance both are dual descriptions of the low Q^2 behaviour. C parity conservation forbids the existence of an analogous vertex for neutral pions. The electromagnetic

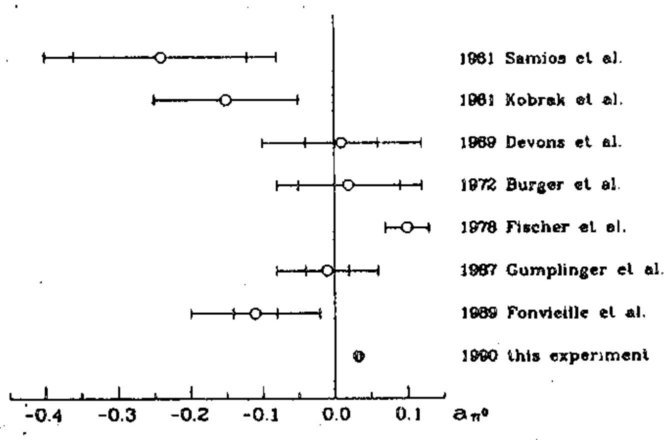

Figure 4: Measured values of the π^0 form factor slope parameter $a = b \cdot m_{\pi^0}^2$ from [31] and [7]. The inner error bars denote statistical, the outer total errors.

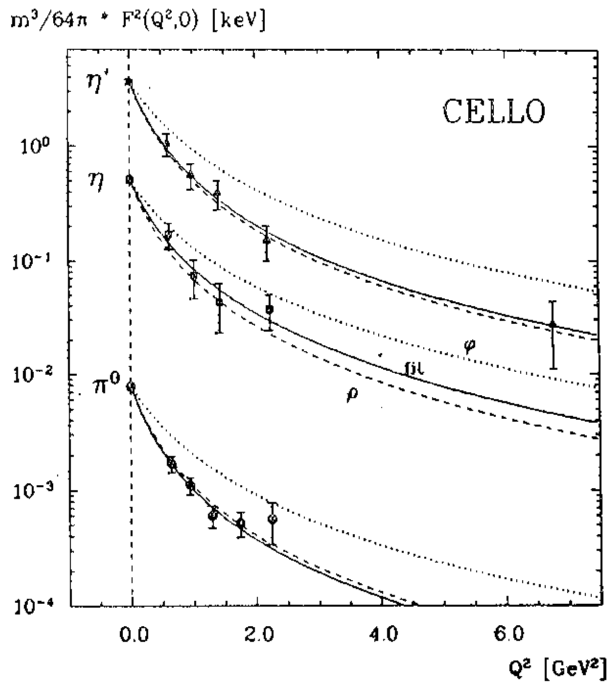

Figure 5: Q^2 dependence of the pseudoscalar meson-photon transition form factors. The ordinate is normalized such that the $Q^2 = 0$ point corresponds to the radiative width in keV.

structure of the neutral pion can however be accessed in the coupling to *two* photons. This 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 *transition form factor* $F(Q_1^2, Q_2^2)$. Here we are interested in the case $Q_2^2 = 0$, i.e. the Q^2 dependence of the transition of a π^0 to a real photon initiated by a virtual photon of mass Q^2. Experimentally, this form factor can be accessed by two methods: in the timelike region (for $-Q^2 = q^2 = (2m_e)^2 - m_{\pi^0}^2$) using conversion decay experiments ("Dalitz" decays $\pi^0 \rightarrow e^+e^-\gamma$) (see the review by Landsberg [30]), and in the spacelike region by single tag two photon experiments [7]. Here one measures the π^0 formation rate as a function of Q^2 in the process $e^+e^- \rightarrow e^+e^{-\prime}\gamma\gamma^*(Q^2) \rightarrow e^+e^{-\prime}\pi^0$ at an e^+e^- storage ring, where the incoming electron is scattered to a large, observable angle ("tag") allowing the reconstruction of the photon's virtuality Q^2, whereas the positron emits a quasi real photon and remains unobserved in the beam pipe (or vice versa). Analogous measurements are possible for the other neutral pseudoscalar mesons, the η and η'. Both of these are already known to follow roughly a ρ pole, from measurements in the spacelike and timelike region (for a bibliography see [7]). The π^0 form factor is hithero more or less unknown: Conversion decay experiments performed during 30 years [31] could not even decide on the sign of the form factor slope at $Q^2 = 0$ (Fig. 4). From a theoretical point of view, many different ansatzes (VDM, quark model, current algebra, QCD interpolation) clearly need a positive slope (with respect to q^2, i.e. negative w.r.t. Q^2), and a verification of the latest negative slope measurement [32] would be desasterous [33]. The results of the new comprehensive analysis of the π^0, η and η' form factors in the spacelike region by the CELLO experiment (for experimental details see [7,34]) are shown in Fig. 5. With the help of the much larger lever arm in this experiment, the confusing situation in the π^0 case is clearly resolved (Fig. 4), and in good agreement with theoretical expectations. Pole masses (effective interaction radii) are measured to be 748 ± 30 MeV (0.65 ± 0.03 fm) for the π^0, 839 ± 63 MeV (0.58 ± 0.04 fm) for the η, and 794 ± 44 MeV (0.61 ± 0.03 fm) for the η'.

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REFERENCES

1. CELLO Coll. H.J. Behrend et al.: *Global Properties of Pion Production in the Reaction* $\gamma\gamma \to 3\pi^+3\pi^-$, contr. paper #534, Phys. Lett. B 245 (1990) 298
2. CELLO Coll. H.J. Behrend et al.: *ρ^0 Production in the Reaction $\gamma\gamma \to 3\pi^+3\pi^-$ and Search for $\gamma\gamma \to \rho^0\rho^0(1700)$*, contr. paper #536, DESY 90-066 (1990)
3. CELLO Coll. H.J. Behrend et al.: *$a_2(1320)$ and $\pi_2(1670)$ Formation in the Reaction $\gamma\gamma \to \pi^+\pi^-\pi^0$*, contr. paper #538, Z. Phys. C 46 (1990) 583
4. CELLO Coll. H.J. Behrend et al.: *Observation of a Resonant Structure in the Reaction $\gamma\gamma \to \eta\pi^+\pi^-$*, contr. paper #533
5. CELLO Coll. H.J. Behrend et al.: *Cross Section Measurement and Spin- Parity Analysis of the Reaction $\gamma\gamma \to \omega\rho$*, contr. paper #537
6. CELLO Coll. H.J. Behrend et al.: *A Study of the Reaction $\gamma\gamma \to \pi^+\pi^-$*, contr. paper #532
7. CELLO Coll. H.J. Behrend et al.: *A Measurement of the π^0, η and η' Electromagnetic Form Factors*, contr. paper #531, DESY 90-110 (1990)
8. CELLO Coll. H.J. Behrend et al.: *Measurement of the Photon Structure Function $F_2(x, Q^2)$ at Q^2 from 3 to 60 GeV^2*, contr. paper #481
9. CELLO Coll. H.J. Behrend et al.: *Properties of Inclusive Jet Production in Hadronic $\gamma\gamma$ Interactions*, contr. paper #450
10. CELLO Coll. H.J. Behrend et al.: *$D^{*\pm}$ Production in e^+e^- Annihilations at 35 GeV*, contr. paper #535
11. CELLO Coll. H.J. Behrend et al.: *Intermittency in Multihadronic e^+e^- Annihilations at 35 GeV*, contr. paper #529; M. Feindt, these proceedings
12. CELLO Coll. H.J. Behrend et al.: *Limits on Electron Compositeness from Bhabha Scattering*, contr. paper #479
13. CELLO Coll. H.J. Behrend et al.: *Limits on Compositeness of Quarks and Leptons from e^+e^- Annihilation*, contr. paper #480
14. Crystal Ball Coll. K. Karch et al.: *Observation of a New $\eta\pi^0\pi^0$ Resonance at 1.9 GeV/c^2 and Measurement of the η' in Two-Photon Scattering*, contr. paper #196, DESY 90-068 (1990)
15. Crystal Ball Coll. D. Antreasyan et al.: *First Observation of $\gamma\gamma \to \pi_2 \to \pi^0\pi^0\pi^0$*, contr. paper #159, DESY 90-054 (1990)
16. Crystal Ball Coll. C. Bieler et al.: *Measurement of π^0 and η Meson Production in e^+e^- Annihilation at $\sqrt{s}$ near 10 GeV*, contr. paper #506, DESY 90-086 (1990)
17. Crystal Ball Coll. D. Antreasyan et al.: *Observation of the Exclusive Decay $B \to e\nu D^*$ and Search for $B \to e\nu\pi^0$*, contr. paper #158, DESY 90-038 (1990)
18. Crystal Ball Coll. D. Antreasyan et al.: *Limits on Axion and Light Higgs Boson Production in $\Upsilon(1S)$ Decays*, contr. paper #609, DESY 90-094 (1990)
19. T.H. Burnett and S.R. Sharpe, *Non-Quark-Model Mesons*, DOE-40423-04, to be published in Ann. Rev. Nucl. Part. Sci.
20. M.S. Chanowitz, LBL-29347, to be published in Procs. PANIC XII, MIT 1990
21. Procs. BNL Workshop on Glueballs, Hybrids and Exotic Hadrons, Upton, New York 1988, AIP Conference Proceedings No. 185
22. Procs. III. Int. Conference on Hadron Spectroscopy, Ajaccio (France) 1989, éditions Frontières
23. M. Poppe, Int. J. Mod. Phys. 1 (1986) 545; H.Kolanoski, P.Zerwas, in *High Energy Electron and Positron Physics*, editors A. Ali and P. Söding, p.695; G. Gidal (in[21]); articles in Proc. VIII. International Workshop on Photon Photon Collisions, Shoresh,Israel, 1988, World Scientific
24. M. Feindt, J. Harjes, talks given at Rheinfels '90 Workshop on the Hadron Mass Spectrum, St. Goar (FRG) Sept. 1990
25. M. Feindt, in [21,22]
26. J.K. Bienlein, in [21]
27. L.Landau, Dokl.Akad.Nauk.SSSR 60(1948)207; C.N.Yang, Phys.Rev. 77(1950)242
28. J.D. Anderson, M.H. Austern, R.N. Cahn, LBL-29059 (1990)
29. S. Godfrey, in [21]
30. L.G.Landsberg, Phys.Rep. 128 (1985) 301
31. Particle Data Group, *Review of Particle Properties*, Phys.Lett. B204 (1988)
32. H. Fonvieille et al., Phys. Lett. B 233 (1989) 65
33. L. Bergström, Stockholm Univ. Preprint USITP-90-04
34. J.H. Peters, Ph.D. thesis, DESY FCE-90-01 (1990)