Recent Results on Two-Photon Processes from DESY

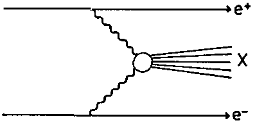
H. Kolanoski
University of Bonn, Fed. Rep. of Germany

Abstract

In this talk some recent results on two-photon scattering processes from DESY are presented, including results on the production of the charmonium state $\eta_c(2980)$, on the exclusive production of proton-antiproton pairs, on jet formation by two quasi-real photons, and on $\Lambda_{\overline{MS}}$ determinations from the structure function of the photon.

1 Introduction

Scattering of two photons can be observed at e^+e^- storage rings in the reaction (see diagram):



$$e^+e^- \rightarrow e^+e^-X$$

The photons producing the final state X are predominantly quasi-real with the scattered electrons going down the beam pipe. However, there is also a tail of large Q^2 photons which can be tagged by detecting the scattered electrons at some finite angle.

The analyses of the two-photon production of the η_c, of $p\bar{p}$ pairs, and of high p_t jets as described below have been done in the 'notag' mode, i.e. with quasi-real photons. A typical application of tagging is the study of the photon structure functions where one of the photons has a high Q^2 probing the structure of the usually quasi-real 'target photon'. Most recent results on the photon structure function F_2^γ will be presented.

Results on two-photon processes from the Crystal Ball experiment will be reported in another contribution to this meeting [1].

2 Observation of the Charmonium State η_c

The PLUTO collaboration for the first time measured the two-photon production of the charmonium state η_c [2]. In a data sample corresponding to an integrated luminosity of 45 pb^{-1} they searched for the reaction

$$\gamma\gamma \rightarrow \eta_c \rightarrow K_S^0 K^\pm \pi^\mp. \quad (1)$$

The K_S^0 's were observed via their $\pi^+\pi^-$ decay mode and identified by requiring that the $\pi^+\pi^-$ came from a secondary vertex separated from the primary e^+e^- collision point. The charged kaons and pions in reaction (1) were not identified. Therefore, both the $K^+\pi^-$ and the $K^-\pi^+$ assignments were tried leading to two entries per event in the $KK\pi$ invariant mass plot of Fig.1. In the η_c region, the difference in the $KK\pi$ invariant mass of these two combinations is smaller than the mass resolution of about 100 MeV.

The PLUTO group found 7 events in the η_c region distributed as expected from the detector resolution. The background in the η_c region is assumed to be negligible. From the observed 7 events the PLUTO group obtained for the product of the $\gamma\gamma$ width times the branching ratio into $K_S^0K^\pm\pi^\mp$:

$$\Gamma(\eta_c \rightarrow \gamma\gamma) \cdot B(\eta_c \rightarrow K_S^0 K^\pm \pi^\mp) = (0.5\ ^{+0.2}_{-0.15} \pm 0.1)\ keV$$

The TASSO collaboration searched for the two-photon production of the η_c in the same decay mode and with similar analysis methods. In particular the K_S^0 's were also identified by requiring a secondary vertex for the decay pions. The vertex finding procedure is still being improved and thus the following results are not yet final.

The $K_S^0K^\pm\pi^\mp$ invariant mass spectrum obtained by TASSO is shown in Fig.2. The mass resolution in the η_c region, $\sigma \approx 60$ MeV, is better than in the PLUTO experiment. However, the region around the η_c is not free of background. From a fit to the mass spectrum 6.6 $\pm$ 3.3 η_c events above background are found yielding the preliminary result:

$$\Gamma(\eta_c \rightarrow \gamma\gamma) \cdot B(\eta_c \rightarrow K_S^0 K^\pm \pi^\mp) = (1.2 \pm 0.6 \pm 0.4)\ keV$$

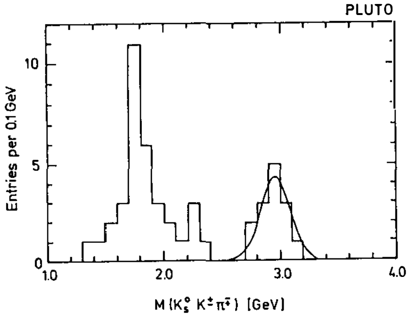


Figure 1:

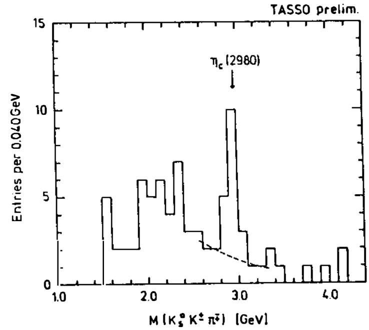


Figure 2:

Within the errors this result is in agreement with the PLUTO measurement.

Using isospin invariance the $K^0_S K^\pm \pi^\mp$ branching ratio is 1/3 of the $K\overline{K}\pi$ branching ratio which has been measured by the Mark III group to be [3]:

$$B(\eta_c \rightarrow K\overline{K}\pi) = (6.1 \pm 2.2)\,\%. \tag{2}$$

This value has been obtained using the branching ratio $B(J/\psi \rightarrow \gamma\eta_c) = (1.27 \pm 0.36)\,\%$ measured with the Crystal Ball [4].

With the Mark III value for $B(\eta_c \rightarrow K\overline{K}\pi)$ one obtains for the $\gamma\gamma$ width of the η_c from the two experiments:

$$\Gamma(\eta_c \rightarrow \gamma\gamma) = (25 \pm 14)\ keV \quad (PLUTO)$$
$$\Gamma(\eta_c \rightarrow \gamma\gamma) = (59 \pm 41)\ keV \quad (TASSO)$$

An ISR experiment searching for the reaction $p\overline{p} \rightarrow \eta_c \rightarrow \gamma\gamma$, obtained the upper limit [5]:

$$\Gamma(\eta_c \rightarrow \gamma\gamma) < 7\ keV \quad (95\%\ c.l.).$$

A theoretical estimate can be obtained by relating the $\gamma\gamma$ width of the η_c to the leptonic width of the J/ψ. Assuming equal wave functions for the spin singlet and triplet charmonium states yields

$$\Gamma(\eta_c \rightarrow \gamma\gamma) = 3\, e_c^2 \cdot \Gamma(J/\psi \rightarrow e^+e^-)$$

With the measured leptonic width of the J/ψ this gives $\Gamma(\eta_c \rightarrow \gamma\gamma) \approx 6\ keV$. QCD sum rule calculations indicate that this value could be even smaller [6]. Thus the η_c rates observed by the PLUTO and TASSO groups seem to be rather large. For example, using the ISR upper limit and the branching ratio (2) at face value TASSO should see less than 0.8 events of reaction (1).

3 Two-Photon Production of Proton-Antiproton Pairs

One of the most complicated processes which have been calculated by perturbative QCD methods is the exclusive production of hadron pairs by two photons [7]. Measurements of charged pion and kaon pair production (pions and kaons not separated) by the PLUTO and Mark II groups are in good agreement with these calculations for $\gamma\gamma$ invariant masses,

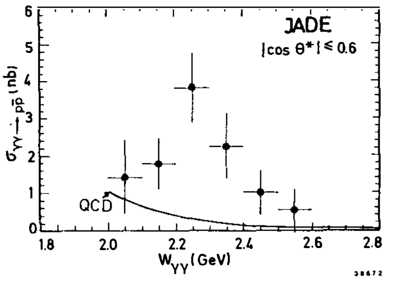


Figure 3:

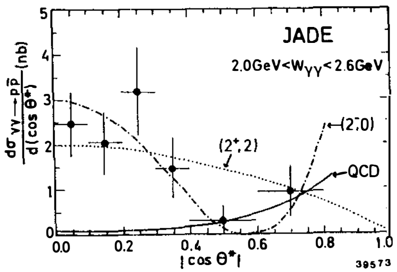


Figure 4:

$W_{\gamma\gamma}$, above about 2 GeV [8]. The TASSO group [9] found that the cross section for proton-antiproton pair production,

$$\gamma\gamma \rightarrow p\bar{p}, \tag{3}$$

in a similar $W_{\gamma\gamma}$ range (2 to 3 GeV) is much larger than predicted by the QCD calculations of Farrar et al. [10].

The TASSO measurement has now been confirmed by the JADE group which analysed $p\bar{p}$ production in a $W_{\gamma\gamma}$ range from 2.0 to 2.6 GeV [11]. The protons and antiprotons have been identified by the energy loss in the JADE jet chamber. Good separation of protons from pions and kaons is possible for momenta up to 1 GeV. In a data sample corresponding to an integrated luminosity of about 84 pb^{-1} 41 $p\bar{p}$ events have been found. The cross section of reaction (3) in the c.m.s. angular range $|cos\Theta^*| < 0.6$ is shown as a function of $W_{\gamma\gamma}$ in Fig.3. The data are compared to a QCD curve [10] which lies much below the data. The JADE group emphasizes an apparent peaking of the cross section around 2.25 GeV as indicative for a possible resonance formation. However, the TASSO measurement, while statistically in agreement with the JADE data, does not exhibit this shape.

The differential cross section obtained by JADE averaging over the whole $W_{\gamma\gamma}$ range is shown in Fig.4. The cross section seems to be enhanced around 90°. By comparing the region below and above $|cos\Theta^*| = 0.4$ the JADE group finds that the χ^2 probability for the angular distribution being isotropic is less than 0.1%. The TASSO group also observed a slight preference for large angles, but their result is much less significant, partly because they cover a smaller angular range. In a preliminary study the TPC/$\gamma\gamma$ collaboration found in a similar $W_{\gamma\gamma}$ region also some enhancement at large angles while for larger $W_{\gamma\gamma}$ they observed rather a peaking in the forward direction [8].

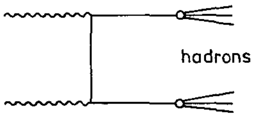
An enhancement in the angular distribution around 90° is suggestive for resonance production as it can hardly be explained by another production mechanism. E.g., the QED Born term for the coupling of two photons to proton-antiproton pairs yields a flat angular distribution near threshold and develops a forward peak with increasing energy. This is also expected for any non-resonant hadronic production mechanism and, in particular, is also predicted by the QCD calculations.

The angular distribution observed by JADE can be reproduced by J=2 states. For the lowest orbital angular momenta in the $\gamma\gamma$ initial state one can assume that the $\gamma\gamma$ helicities are dominantly $\lambda=\pm2$ for $J^P = 2^+$ states and $\lambda=0$ for $J^P = 2^-$ states. The corresponding angular distributions are shown as the dotted ($J^P = 2^+, \lambda = 2$) and the dashed-dotted ($J^P = 2^-, \lambda = 0$) curves in Fig.4. For $J^P = 2^-$ the $p\bar{p}$ state can occur in spin states S=0 and S=1. The shown curve is for S=0; S=1 is not in agreement with the data.

In summary we can conclude that around 2.5 GeV $p\bar{p}$ production is definitely not yet in the continuum region described by perturbative QCD. Possible resonance formation can be tested analysing the angular distribution. However, this task requires better statistics than available today.

4 Jet Production by Two Quasi-Real Photons

In the Born approximation hadron production by two photons proceeds via quark pair production according to the diagram below. The coupling of the photons to quarks is in this case purely electromagnetic and the ratio of hadron production to muon pair production, $R_{\gamma\gamma}$, is given by the charges of the quarks with different flavour f and colour c:



$$R_{\gamma\gamma} = \frac{1}{3} \sum_f (\sum_c e_{fc}^2)^2.$$

The standard fractionally charged quark (FCQ) model and the Han-Nambu model of integrally charged quarks yield $R_{\gamma\gamma}$ values which differ by about a factor of 3 ($R_{\gamma\gamma}$ is 34/27 for the FCQ and 10/3 for the ICQ model including u,d,s,c quarks). In a gauge invariant formulation of the ICQ model $R_{\gamma\gamma}$ can be even larger due to additional couplings to charged gluons [12]. In this model with broken $SU(3)_{color}$ symmetry, gluons acquire masses resulting in a form factor suppression of all non-color-singlet contributions to $R_{\gamma\gamma}$. Thus the difference between the FCQ and ICQ models will be damped for virtual photons by a factor proportional to

$$\frac{M_{gluon}^2}{M_{gluon}^2 + Q^2}$$

Hence scattering of two quasi-real photons is best suited to distinguish between these models.

In contrast to one-photon annihilation processes the two-photon Born diagram describes hadron production only for large momentum transfers along the virtual quark line corresponding to large transverse momenta of the quarks and the fragmentation products. Recent calculations indicate that the QCD corrections to the Born term (K-factor) are small [13], [14]. Furthermore, also the contributions of higher order QCD processes are predicted to be small for transverse momenta of hadrons above about 1 to 2 GeV. The more surprising was the observation by the TASSO group that the yield of high-p_t hadrons produced by quasi-real photons (no-tag experiment) was about 3 to 4 times larger than expected from the Born diagram [15]. An excess of two-jet events with p_t^{jet} values above about 1.5 GeV was also observed by the PLUTO group [16]. This excess was found to decrease with increasing Q^2 of one of the photons so that at Q^2 above about 12 GeV^2 consistency with the Born term was reached.

The observed Q^2 and p_t dependence can be explained by the gauged ICQ model. However, before accepting this non-standard model of quarks and gluons, more experimental tests can be made. The PLUTO group recently investigated the topology of events produced by two quasi-real photons (no-tag experiment) [17]. Using a thrust algorithm they divided each event into two jets. In Fig.5 the ratio of the observed number of jets to the one expected

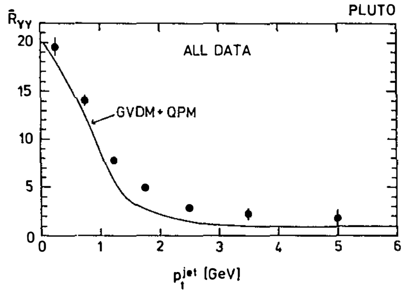


Figure 5:

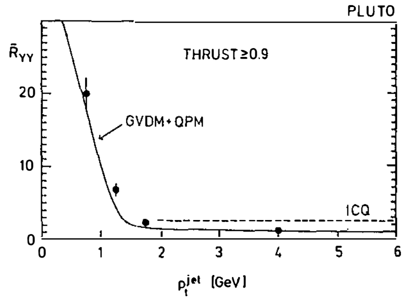


Figure 6:

from the Born term, $\tilde{R}_{\gamma\gamma}$, is plotted versus the jet transverse momentum, p_t^{jet}. The large excess at small p_t^{jet} is explained by a VMD model which is, however, unable to describe the excess persisting above about 2 GeV where the Born term is expected to dominate. An inspection of the thrust distribution shows that the average thrust of large-p_t jets is smaller than expected from the Born term. Including only events with a thrust larger than 0.9 (Fig.6) yields $\tilde{R}_{\gamma\gamma}$= 1.2±0.3 for $2 < p_t^{jet} < 6$ GeV. Thus the 'naive' Han-Nambu model of integer quark charges ($\tilde{R}_{\gamma\gamma}$= 2.65) is excluded by more than 4 standard deviations. Using the same data the PLUTO group had already published an upper limit for the gluon mass [18]:

$$M_{gluon} < 5\, MeV \quad (95\%\ c.l.).$$

As reported at this meeting, experimental results on high energy Compton scattering and on the production of two prompt photons in pion-nucleon scattering also strongly support the model of fractionally charged quarks.

Thus the ICQ model is not likely to be the right explanation for the excess of large-p_t jets (or hadrons) which, according to the PLUTO finding, are produced in less jetty events. Aurenche et al. [14] suggest that a modified VMD contribution, as derived from photoproduction data, could make a significant contribution even at large p_t . The p_t distribution of inclusive hadrons measured by TASSO may just be explainable by adding such a VMD estimate on top of the Born term and the QCD corrections [19].

The PLUTO group finds that the event topology and the p_t distributions can be qualitatively described by adding contributions from a QCD process which leads to four-jet final states (two high-p_t jets and two beam pipe jets). It has to be studied further if a quantitative description can be achieved by summing all leading QCD diagrams.

5 The Structure Function of the Photon

The hadronic structure of a photon can be probed in collisions of a high-Q^2 photon with a quasi-real 'target photon'. In such an experiment the virtual photon is tagged by detecting the scattered electron at a large angle. The $\gamma\gamma$ invariant mass, $W_{\gamma\gamma}$, is determined from the hadronic system observed in the detector.

The structure function $F_2^\gamma(x, Q^2)$ of the photon has been calculated perturbatively in leading and next-to-leading order QCD [20]. Imposing the so-called 'asymptotic boundary

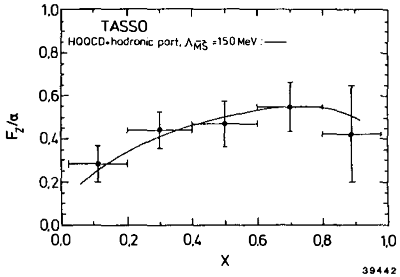


Figure 7:

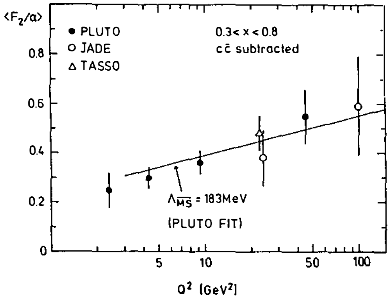


Figure 8:

condition', i.e. requiring F_2^γ to approach the Born term for $\gamma\gamma \to q\bar{q} \to$ *hadrons* at large Q^2, allows to calculate F_2^γ absolutely. The pointlike, perturbatively calculable part of the structure function yields the Q^2 dependence

$$F_2^\gamma \sim \ln \frac{Q^2}{\Lambda^2} \tag{4}$$

with Λ being the QCD scale parameter. The hadronic component of the photon cannot be calculated perturbatively and is usually estimated by the VMD model. Several groups at DESY determined Λ employing relation (4) as obtained by higher order QCD calculations.

It should be mentioned that the validity of this method of determining Λ is theoretically controversial [21]. The problems arise from the separation of the hadronic and the pointlike piece of the photon. Using calculations in which these pieces are not separated the experimental sensitivity to Λ is lost.

The latest results on $F_2^\gamma(x,Q^2)$ have been obtained by the TASSO [22] and PLUTO [19] groups. The TASSO group determined $F_2^\gamma(x,Q^2)$ at an average Q^2 of 23 GeV^2. Figure 7 shows the measured structure function with the charm contribution (estimated by the Born term) subtracted. The charm contribution is assumed to be not sensitive to Λ since in this case the relevant scale may be set by the charm quark mass rather than Λ. The subtracted structure function is compared to the sum of a higher order QCD calculation with $\Lambda_{\overline{MS}} = 150$ MeV and a hadronic piece estimated by VMD. Above about x=0.3 the VMD contribution is small and the structure function is sensitive to Λ. The measured structure function is equally well described if the pointlike QCD part is replaced by the quark-parton model prediction using constituent quark masses (pure QED couplings).

The PLUTO group determined the structure function $F_2^\gamma(x,Q^2)$ in a wide range of Q^2 values [19]. Figure 8 shows the measured Q^2 dependence averaged over the x range from 0.3 to 0.8. Also shown are data points from TASSO [22] and JADE [23]. The measurements are compared to higher order QCD calculations for $\Lambda_{\overline{MS}} = 183$ MeV. Note that the Λ value is determined by the absolute height rather than the slope of the curve.

Taking the average of all $\Lambda_{\overline{MS}}$ determinations from F_2^γ by DESY groups yields (statistical and systematic errors have been combined in quadrature) [19]:

$$\Lambda_{\overline{MS}} = (193 \pm 43)\ MeV.$$

References

[1] R.Clare, presented at the XXIst Rencontre de Moriond, Les Arcs, March 16 - 22, 1986
[2] PLUTO Coll., Ch.Berger et al., Phys.Lett.167B (1986) 120
[3] Mark III Coll., R.M.Baltrusaitis et al., Phys.Rev.D33 (1986) 629
[4] J.E.Gaiser et al., SLAC-PUB-3899 (1985)
[5] R704 Coll., C.Baglin et al., paper contributed to the Kyoto Conf. (see [19])
[6] L.J.Reinders, H.R.Rubinstein and S.Yazaki, Phys.Lett.113B (1982) 411
[7] S.J.Brodsky and G.P.Lepage, Phys.Rev.D24 (1981) 1808
[8] H.Kück, Proc. of the $\gamma\gamma$ Workshop, Lake Tahoe (1984)
[9] TASSO Coll., M.Althoff et al., Phys.Lett.130B (1983) 449
[10] G.Farrar, E.Maiana and F.Neri, Nucl.Phys. B259 (1985) 702
[11] JADE Coll., W.Bartel et al., DESY 86-043 (1986)
[12] R.M.Godbole et al., Phys.Lett.142B (1984) 91
[13] F.Khalafi, P.V.Landshoff and W.J.Stirling, Phys.Lett.130B (1983) 215
[14] P.Aurenche et al., Z.Phys.C29 (1985) 423
[15] TASSO Coll., M.Althoff et al., Phys.Lett.138B (1984) 219
[16] PLUTO Coll., Ch.Berger et al., Z.Phys.C26 (1984) 191
[17] PLUTO Coll., Ch.Berger et al., to be published
[18] PLUTO Coll., Ch.Berger et al., Z.Phys.C29 (1985) 499
[19] H.Kolanoski, Proc. of the Lepton-Photon Symposium, Kyoto, 1985
[20] E.Witten, Nucl.Phys.B120 (1977) 189; W.A.Bardeen and A.J.Buras, Phys.Rev.D20 (1979) 166; D.W.Duke and J.F.Owens, Phys.Rev.D22 (1980) 2280.
[21] M.Drees, M.Glück, K.Grassie and E.Reya, Z.Phys.C27 (1985) 587
[22] TASSO Coll., M.Althoff et al., DESY 86-026 (1986)
[23] JADE Coll., W.Bartel et al., Phys.Lett.121B (1983) 203; Z.Phys.C24 (1984) 231;