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TWO PHOTON PROCESSES AT PETRA

by

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ABSTRACT

The analysis of two photon physics at the e^+e^- storage ring PETRA is reviewed. Higher order QED processes $e^+e^- \rightarrow e^+e^-e^+e^-(e^+e^-\mu^+\mu^-)$ have been measured in good agreement with the QED calculations. The production of the f^o resonance has been investigated and the radiative width has been determined. The total cross section $\sigma(Q^2,W)$ of the inelastic electron photon scattering has been studied in some detail. Evidence for the production of large P_T jets in the reaction $\gamma\gamma \rightarrow q\bar{q}$ is reported and a first measurement of the photon structure function in deep inelastic $e\gamma$ scattering is discussed.

INTRODUCTION

Long before the two photon reactions were investigated experimentally the scattering of light by light attracted the attention of many theorists. Already 1935 Euler and Kockel[1] calculated the elastic $\gamma\gamma$ scattering, a process which is forbidden in the classical notion of linear maxwell equations. With the high energy e^+e^- storage rings like PETRA and PEP very powerful photon sources are available which provide us with photons up to energies of 15 GeV and fluxes of the same order of magnitude as the initial e^+e^- beams. Because the total hadronic cross section is much larger for $\gamma\gamma \rightarrow X$ than for ee $\rightarrow X(\approx 300$ nb compared to $R\cdot 22\text{nb}/E^2)$ the 2 photon processes become more and more important, thus we are sometimes looking at the 1γ annihilation as a background to the 2γ reactions.

The basic diagram of the two photon reaction is shown in fig. 1. The two incoming particles radiate a photon predominantly at small angles to the beam and with small energies. These two photons react and produce a final state. Typically the 2γ events are measured in the following way: the final state is detected in a central detector, and the scattered electrons are detected in a separate device, a forward spectrometer, covering the range of $1^o - 10^o$ and $170^o - 179^o$ respectively.

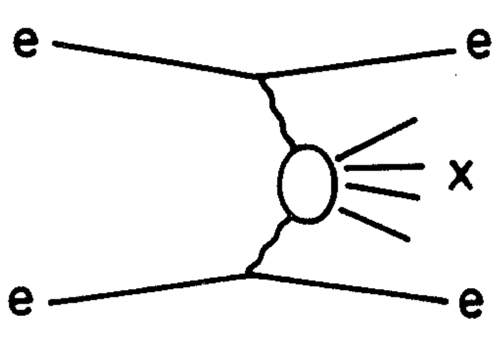

Fig. 1 basic diagram for the reaction ee $\rightarrow$ eex

None of the PETRA detectors has a 0^o tagging system. We distinguish between three experimental conditions:
1. 'double tag': both of the scattered electrons are detected, both photons are virtual: $Q^2 > 0.1$ GeV^2 for a typical PETRA detector ($-Q^2$ is the invariant mass squared of the photon). Though this condition was considered to be the only clean way of measuring 2γ phy-

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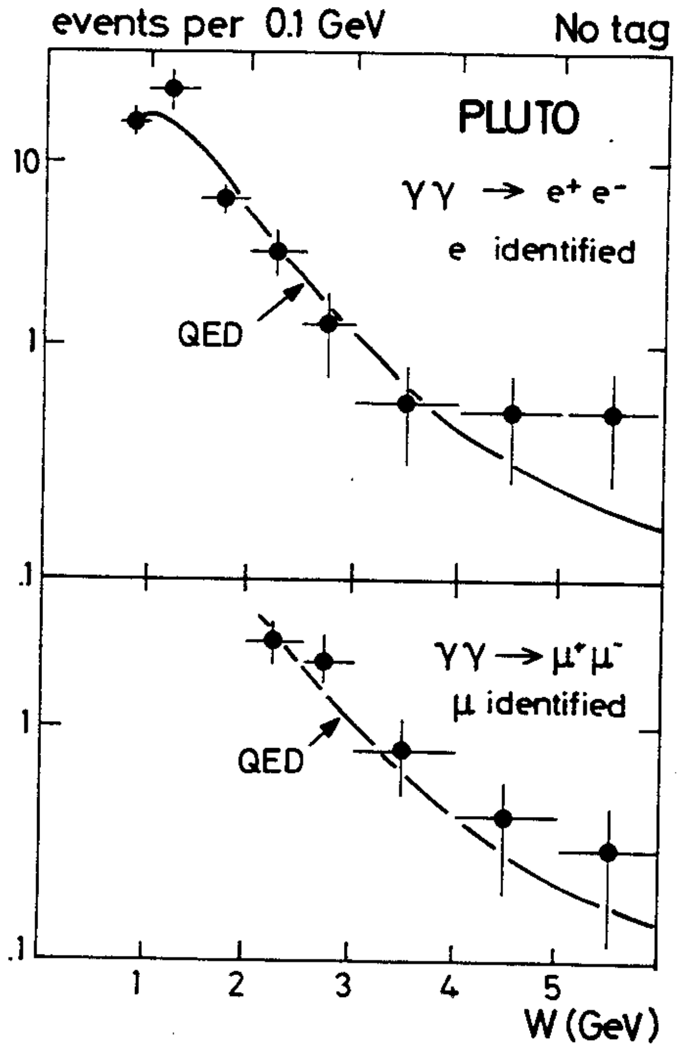


Fig. 2 Invariant mass distribution of the electron pairs and the μ pairs from the reaction γγ → ee(μμ)

sics a couple of years ago, there are no experimental results up to now. The double tag event rate is very small, and the interpretation is complicated, because in general 8 structure functions can contribute to the inclusive cross section.

2. 'single tag': only one of the electrons is measured and the other electron stays in the beam pipe, radiating an almost real photon ($< Q^2 > < 0.01$ GeV^2). Besides the fact that the event rate is higher than in the double tag condition, the interpretation is much clearer. We can regard this process as electroproduction off an almost real photon target. It should be noted that for this interpretation of the single tag events it is essential that one has a complete coverage of electron detection in θ between 1^o and 179^o to make sure that the second electron is scattered at small angles.

3. 'no tag': both electrons stay in the beam pipe, both photons are almost real. This is the (theoretically) most easy case, only one structure function contributes, and the measured cross section is only a function of W, the invariant mass of the final state X.

The common signature of all 2γ reactions is the small fraction of the total e^+e^- energy carried by the photons. This leads to only little energy in the central detector, which allows a clean separation from 1γ annihilation events.

TEST OF THE QED IN THE REACTIONS γγ → ee, μμ

The reaction ee → ee + lepton pairs can be completely calculated in QED. The measurement of a higher order QED process with an amplitude $\sim e^4$ as an isolated reaction (and not as usual as a radiative correction) is important by itself, although the Q^2 values involved are quite small. The QED reactions have been measured by four PETRA groups MARK J, JADE, PLUTO, TASSO, they all find consistency with QED calculations[2]. Fig. 2 shows the PLUTO results at 15.5 GeV beam energy in the no tag condition. Events with two prongs in the central detector and no additional showers were selected, where at least one of the tracks was identified as an electron or a muon. The curve drawn shows the QED expectations, neglecting radiative corrections. These radiative corrections are considered to be small (1-2%)[3].

PRODUCTION OF THE f^o MESON

Two photon reactions allow the production of the C = +1 resonances which are not accessable in the 1γ annihilation channel. One of the obvious candidates is the f^o because it has a large branching ratio of 55% into a clean final state. The reaction $\gamma\gamma \to f^o \to \pi^+\pi^-$ has been measured by PLUTO and TASSO in the no tag condition. As none of the detectors identifies the pions they select all 2 prong events and look for a signal in the invariant mass distribution above the QED expectation for electron pairs and muon pairs. Fig. 3a shows this distribution for the PLUTO detector with the QED subtracted data as an insert and Fig. 3b shows the TASSO data after QED subtraction. Both experiments show a clean peak around 1250 MeV. In order to determine the radiative width $\Gamma^{f^o}_{\gamma\gamma}$ from the number of events in the peak one has to make an assumption

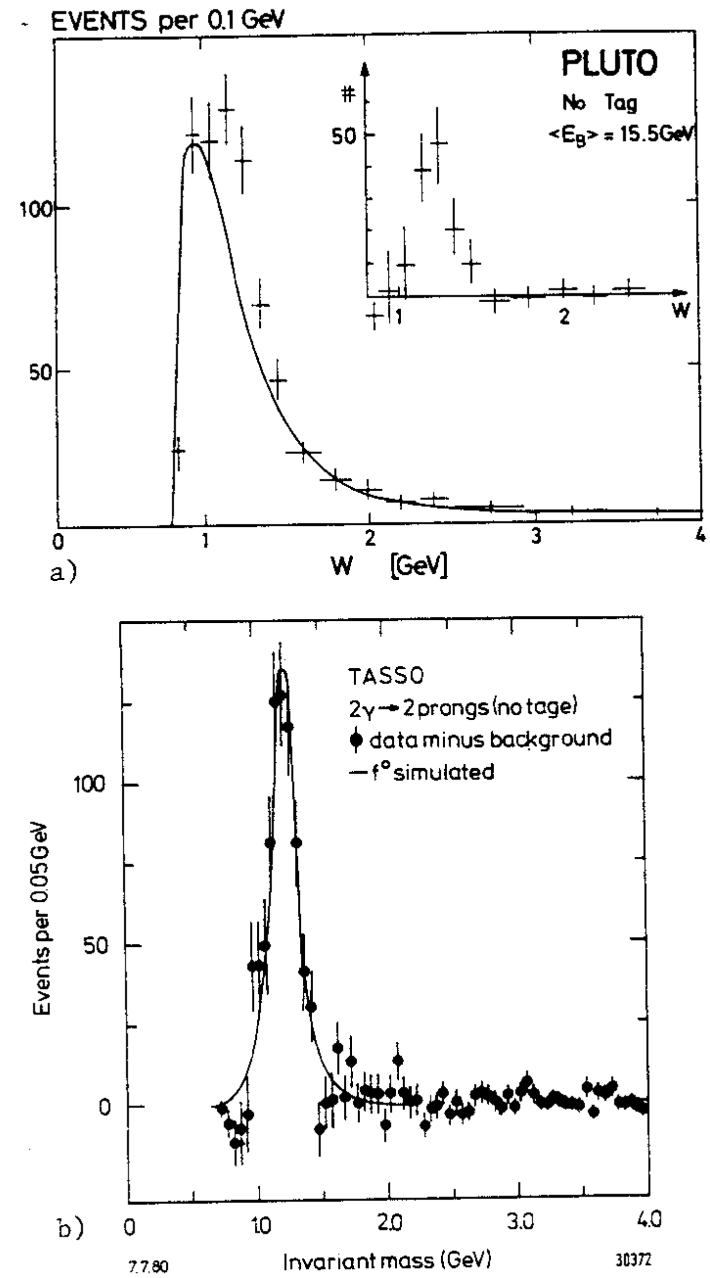


Fig. 3 Invariant mass distribution of the two prong events. The curve in 3a is an absolute QED prediction. The insert and the diagram from TASSO show the difference between data and QED background.

about the helicity amplitude for the f^o production[4] . Two amplitudes are possible, $\lambda = 0$ and $\lambda = 2$, which lead to about 50% different trigger efficiencies. Assuming $\lambda = 2$ we get:

$$\begin{aligned} \text{PLUTO} \quad \Gamma^{f^o}_{\gamma\gamma} &= (2.3 \pm .5\ (\text{stat.}) \pm .35\ (\text{syst.}))\ \text{keV} \\ \text{TASSO} \quad \Gamma^{f^o}_{\gamma\gamma} &= (4.1 \pm .4\ (\text{stat.}) \pm .6\ \ (\text{syst.}))\ \text{keV} \end{aligned} \tag{1}$$

Stretching the systematic errors the data agree, but one should note that the TASSO results are still preliminary.[11]

TOTAL CROSS SECTION FOR $\gamma\gamma$-HADRONS

The total cross section for multihadron production via two photons has been measured by PLUTO and TASSO with quite considerable statistics (ca. 1000 events). The data have been taken in the single tag mode allowing a study of the dependence of σ on W and Q^2, where Q^2 is determined from the scattered electron and W from the final state hadrons observed in the central detector. In the Vector Dominance Model (VDM) the Q^2 dependence of the cross section for transverse polarized photons is mainly given by a ρ pole form factor

$$\sigma_t(W,Q^2) = \sigma_{\gamma\gamma}(W)\ \left(\frac{m_\rho^2}{m_\rho^2 + Q^2}\right)^2 \tag{2}$$

A second term $\varepsilon\sigma_l$ for the longitudinal polarized photons is considered to be small[5]. $\sigma_{\gamma\gamma}(W)$, the cross section for two real photons can be estimated using Pomeron factorization and Resonance Regge duality[6]

$$\sigma_{\gamma\gamma}(W) = \sigma^{VDM}(W) = 240\text{nb} + \frac{270\text{nb.GeV}}{W} \tag{3}$$

Fig. 4 shows the PLUTO results for $\sigma_{\gamma\gamma}$ as a function of the visible invariant mass, W_{vis}, at 15.5 GeV beam energy. Above 3 GeV the shape agrees with the VDM predictions, where at small W the data are substantially higher. This could indicate the presence of non Regge terms[6] like the quark box diagram (Fig. 5) which would lead to the typical $1/W^2$ behaviour of point-like processes, although this assumption is debated[7]. Fig.6 shows the Q^2 behaviour for two

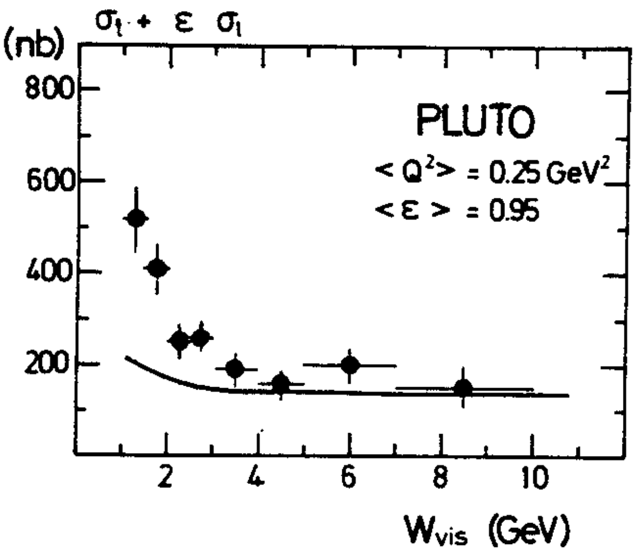


Fig.4 Total cross section vers. W_{vis}

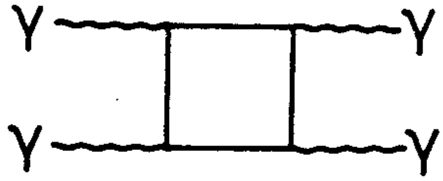


Fig.5 Quark box diagram

different invariant mass bins, both being consistent with the ρ pole form factor. For $W_{vis} > 3.5$ GeV one can assume that the total cross section is dominated by the VDM contribution. A separate fit of this

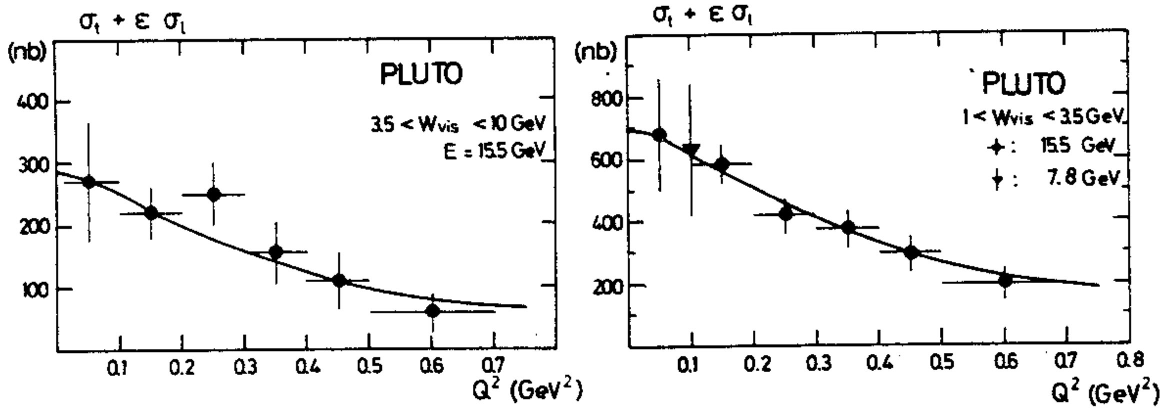


Fig. 6 Total cross section as a function of Q^2 for two different W_{vis} bins

W region results in $\sigma(W) = (1.21 \pm .13)\cdot \sigma^{VDM}(W)$. Finally the whole data sample is fit by the ansatz:

$$\text{PLUTO:} \qquad \sigma(W) = A \cdot \sigma^{VDM}(W) + B/W^2 \qquad (4)$$

in order to account for the enhancement at low W_{vis}.[5] The data from TASSO are fit by a slightly different ansatz:[11]

$$\text{TASSO:} \qquad \sigma(W) = A + B/W \qquad (5)$$

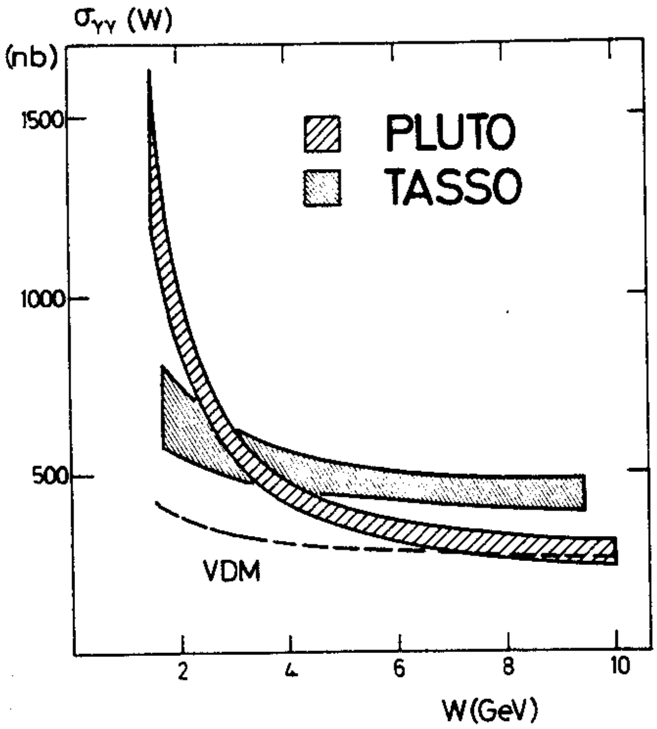


Fig. 7 Unfolded total cross section versus W

whereas both groups assume the same Q^2 behaviour (Eq.2). The fit results are represented by the hatched bands in Fig. 7 with an additional systematic error of 25%. The two experiments agree on average but differ very clearly in the shape of the curves. In comparing the two results one should note the following facts:

1. The trigger efficiency of an hadronic event is about 25% thus leading to a correction factor of about 4, quite in contrast to the 1 photon cross section, where the corrections are a few percent only.

2. Due to particle losses the visible invariant mass is always smaller than W. The correction $W_{vis} \to W$ is done by an unfolding procedure

which needs a specific ansatz. (The PLUTO data can also be fit by an ansatz A + B/W, resulting in a somewhat flatter cross section.)

3. There are two major differences in the analysis of the two experiments: a) PLUTO uses single tags only where TASSO includes the double tags, b) TASSO uses charged particles only where PLUTO includes the neutrals, leading to a smaller correction $W_{vis} \to W$.

HARD SCATTERING PROCESSES

Though the gross features of the total cross section are well described by the VDM picture there is certainly room for additional processes; especially the PLUTO data seem to suggest a contribution from the pointlike photon quark coupling (Fig. 5). A possibly better way to look for this pointlike coupling is the study of hard scattering processes (Fig. 8).

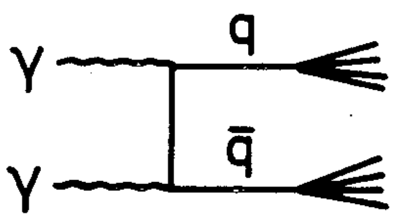


Fig. 8 pointlike photon quark coupling

There are two cases of interest:
1. the exchanged quark is highly virtual. This leads to the production of two coplanar but non collinear jets with large transverse momenta, a process which cannot occur in the VDM picture, but which can easily be related to the μ pair production:

$$R_{\gamma\gamma} = \frac{\sigma\ \gamma\gamma \to q\bar{q}}{\sigma\ \gamma\gamma \to \mu\mu} = 3\ \Sigma\ e_q^4\ (1 + O(\alpha_s)) \approx \frac{34}{27} \text{ for } q = udsc \qquad (6)$$

2. one of the photons is highly virtual. The process can be understood as deep inelastic electron photon scattering, thus probing the hadronic structure of the photon.

The part of the photon structure function, resulting from the pointlike γq coupling can be calculated from first principles in QCD[8,9].

PRODUCTION OF LARGE P_T JETS

A good candidate for a two photon jet event, seen in the PLUTO detector, is shown in Fig. 9. Similar events are also seen by CELLO and TASSO. For a quantitative analysis PLUTO selected all events (single tag + no tag) with 3 GeV < W_{vis} < 9 GeV. The P_T^2 distribution of the charged particles of these events shows a very pronounced tail (Fig. 10), which can be partly explained by the process $\gamma\gamma \to q\bar{q}$ including charm quarks (full curve). In a further step the particles are ordered into two non collinear jets by maximizing the twoplicity T_2 (=Thrust along 2 different axis). Fig. 11 shows that the tail in the P_T distribution is entirely due to the jetlike events (T_2 > .75), whereas the transverse momenta for the more isotropic events (T_2 < .75) are limited.

A crucial test of the production mechanism is the P_T behaviour of the partons in the underlying hard scattering process which can be studied by the P_T distribution of the jets. For the process $\gamma\gamma \to q\bar{q}$ we expect P_T^{-4} whereas higher twist terms[9] like $\gamma\gamma \to q\bar{q}$ meson, where a meson is involved in the basic hard process should be $\sim P_T^{-6}$. Fig. 11 shows the P_T distribution of the jets, compared with the Monte Carlo expectation for $\gamma\gamma \to q\bar{q}$ including u d s c quarks. Obviously the data show a steeper fall off than the quark model, showing good agreement only above $P_T^2 = 7.5$ GeV^2. At moderate P_T there is room for other contributions (like $q\bar{q}$ meson) but up to now there is no positive evidence for these processes because for invariant masses below 9 GeV it seems to be very

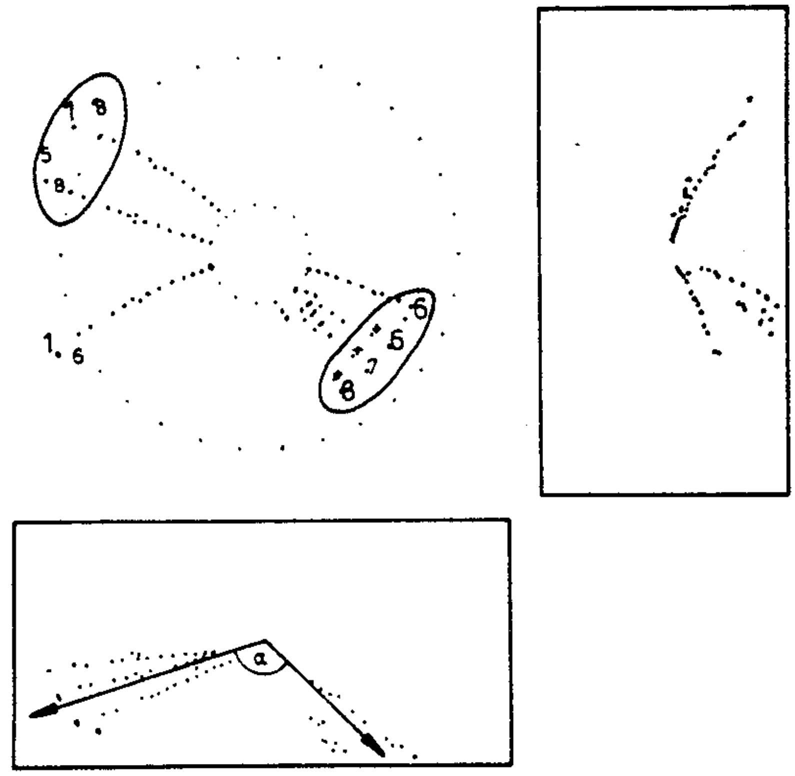


Fig. 9 example of a two photon initiated two jet event

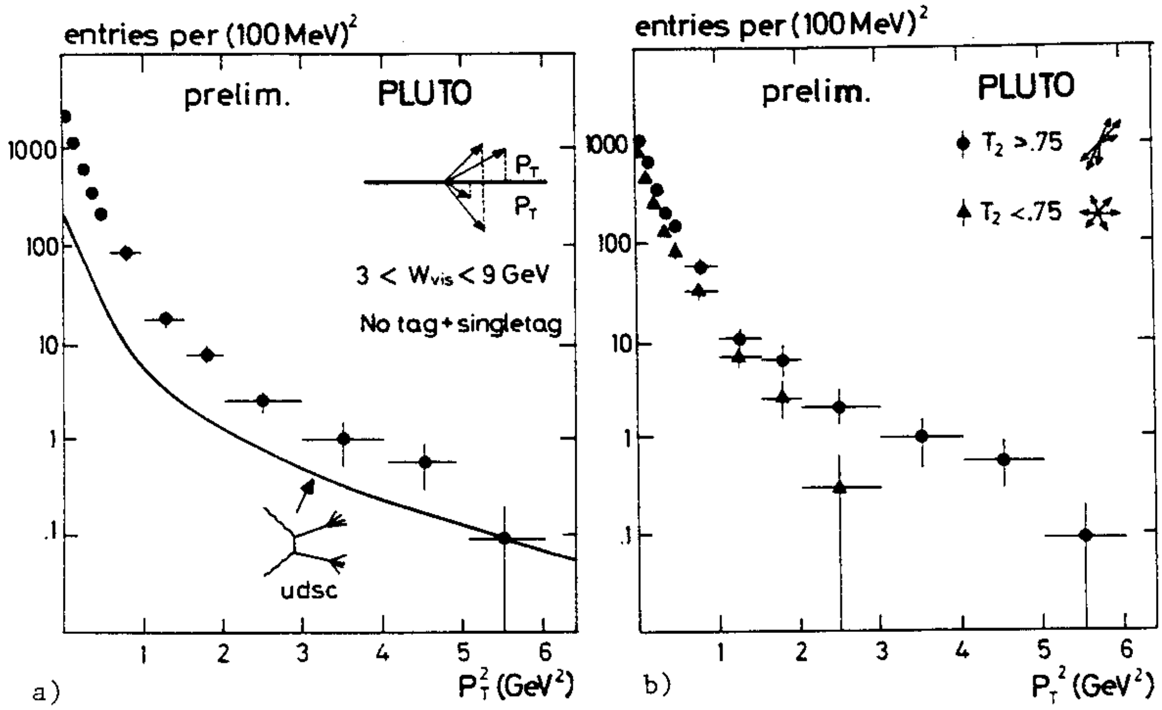
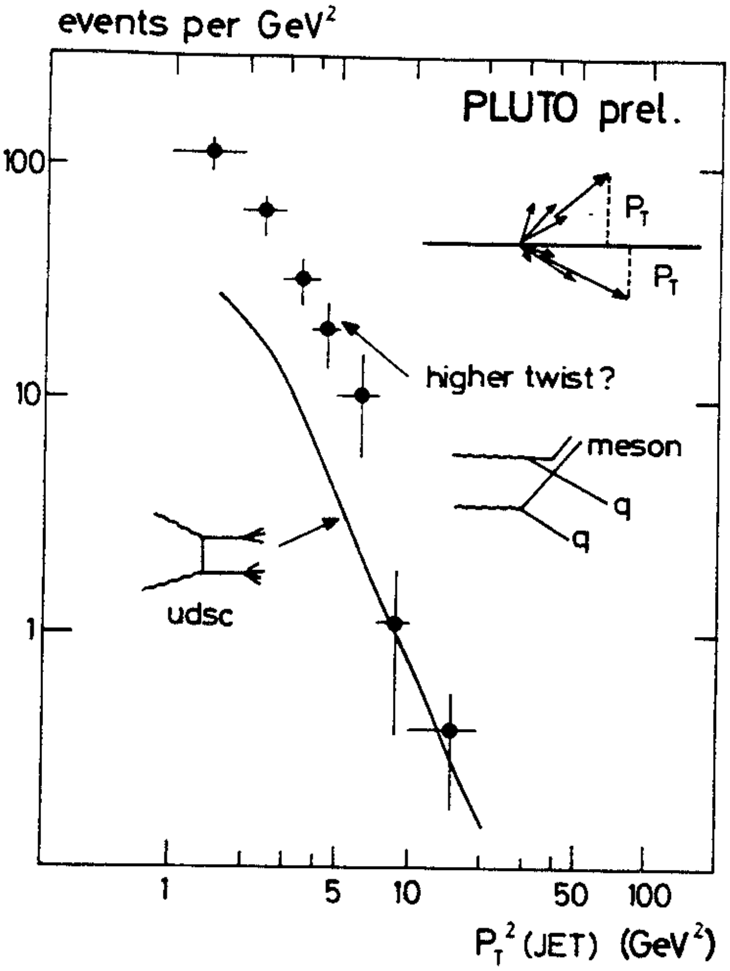


Fig. 10 transverse momenta of all charged particles with respect to the beam (a), and for different twoplicity values (b)



hard to distinguish between a $q\bar{q}$ and a qq meson final state. A Monte Carlo analysis, including higher twist terms and diffractive hadron production is under work.

Fig. 11 transverse momenta of the jets

DEEP INELASTIC eγ SCATTERING

The precise measurement of the photon structure function might turn out to be one of the best testing grounds of QCD. The situation is quite different from nucleon scattering where the structure function cannot be calculated but only the (small!) QCD corrections can. In the case of the photon the structure function is completely dominated by the perturbative part. The Born term as well as the higher order corrections can be calculated in QCD. In the leading log approximation we get

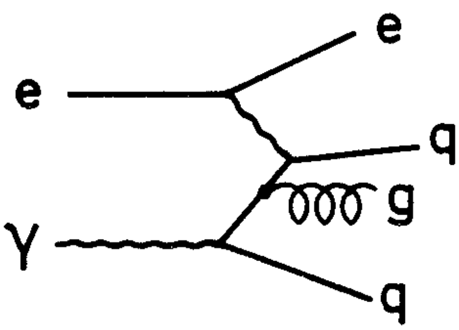


Fig. 12 effect of gluon bremsstrahlung to $F_2(x)$

$$F_2^{Born} = 2xF_T = \frac{\alpha}{\pi}\,\Sigma e_q^4\, x\,(x^2+(1-x)^2)\,\ln\frac{Q^2}{\Lambda^2} \quad (7)$$

F_2^{Born} shows two interesting features: it grows with x, quite in contrast to the VDM expectation ($F_2^{VDM} \sim 1-x$) and shows a strong scale breaking effect $\sim \ln Q^2/\Lambda^2$. The effect of higher order QCD corrections can be easily understood in a simple picture: The electron scatters on a quark which has lost part of it's momentum ($p_q = x \cdot p_\gamma$) by radiating a gluon. This cancels part of the increase of F_2.

There are first data on the photon structure function from PLUTO.

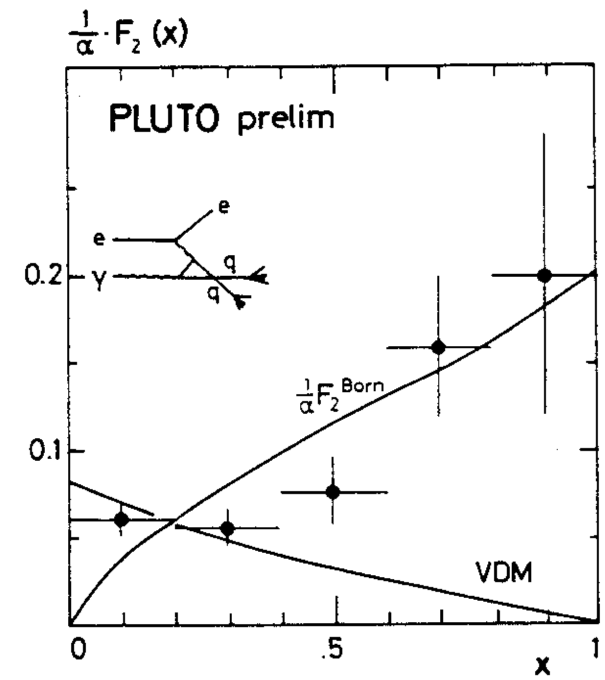


Fig. 13 hadronic structure function of the photon

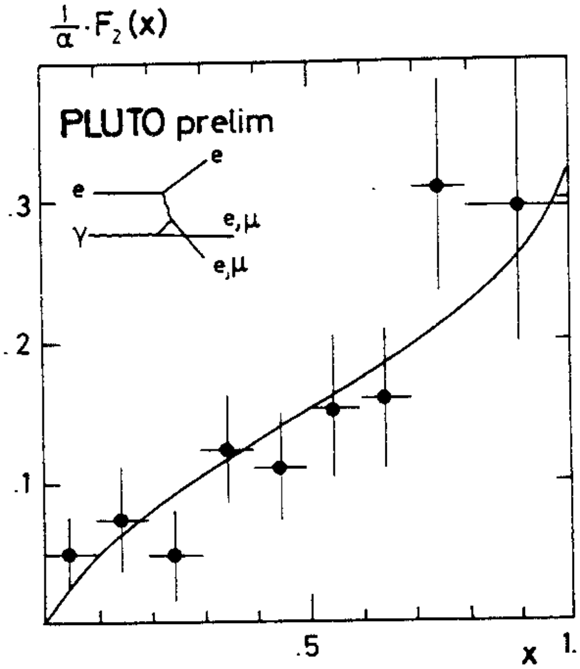
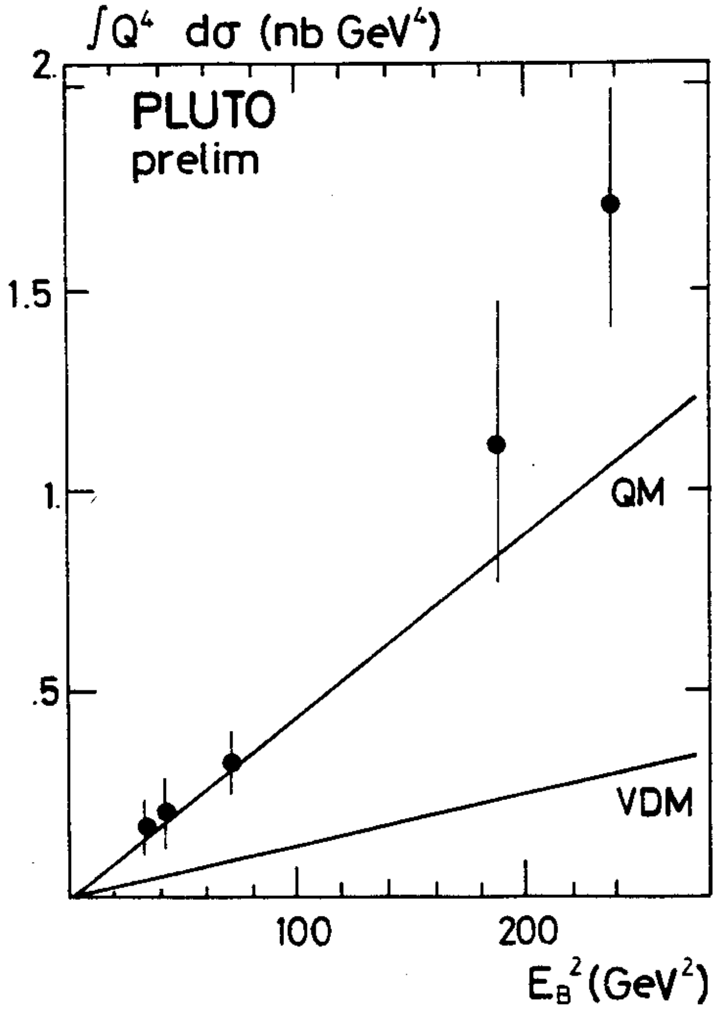


Fig. 14 leptonic structure function of the photon



120 hadronic events were selected with a single tag at relatively large angles ($\theta = 70$–250 mrad), resulting in a Q^2 of 1 - 15 GeV^2 ($\langle Q^2 \rangle = 5$ GeV^2). This allows to measure the structure function up to $x = 0.95$. The result is shown in Fig.13, and is compared with the Born term (Eq.7) and the predictions from the VDM. It is evident that the VDM cannot account for the steep increase above $x = 0.4$. It would be very interesting to measure deviations from the Born term due to QCD corrections at $x \to 1$ in a high statistics experiment but that is not yet possible. On the other hand the scale breaking factor $\ln Q^2/\Lambda^2$ varies by a factor of 3 in the given Q^2 range, and might be

Fig. 15 Q^4 weighted total cross section versus the beam energy acquired visible even with low statistics. As a test of the method, the 'leptonic structure function' was determined with the same procedure but using only two prong final states ($ee,\mu\mu$). The result in Fig.14 shows good agreement with the QED expectation. It is quite exciting to see that hadronic final states with low mass and low multiplicity seem to be produced by the same mechanism as lepton pairs.

One can finally do a global scaling test by integrating over the structure function. If F_2 is a function of x only one can easily show:

$$\int Q^4 \frac{d\sigma}{dxdy} \; dxdy \sim E^2 \qquad (8)$$

Scaling is predicted in VDM and (approximately) in the quark model, but with different slopes. Fig.15 shows the PLUTO data compared to the two models (m_g = 300 MeV was used in the QM). At large beam energies, corresponding to large Q^2, the data seem to exceed the QM predictions. This could already indicate the presence of scale breaking effects, but with the present statistics this is not conclusive.

CONCLUSIONS

An enormous progress has been made in two photon physics in the last two years. The photon appears, if we don't look too deep inside, as a vector meson. But the VDM obviously doesn't tell us the whole story: if we investigate the photon at very short distances it exhibits a 'hard component'. The analysis of the hard scattering processes with high statistics will be a good testing ground of QCD.

REFERENCES

1. H. Euler and B. Kockel, Naturwiss. 23, 246 (1935).
2. D.P. Barber et al., Phys. Rev. Lett. 43, 1915 (1979).
   PLUTO Collaboration, Ch. Berger et al., Phys. Lett. 94B, 254 (1980).
3. G. Cochard, Invited Talk given at the International Workshop on $\gamma\gamma$ Collisions, Amiens (1980).
4. J. Babcock, J.L. Rosner, Phys. Rev. D14, 1286 (1976).
5. Ch. Berger, Invited Talk given at the International Workshop on $\gamma\gamma$ Collisions, Amiens (1980), PITHA 80/07 (1980).
   PLUTO Collaboration, Ch. Berger et al., DESY 80/94 (1980), to be published in Phys. Lett..
6. M. Greco, Y. Srivastava, Nuovo Cim. 43A, 88 (1978).
7. J. Gunion, Invited Talk given at the International Workshop on $\gamma\gamma$ Collisions, Amiens (1980), SLAC-PUB-2503 (1980).
8. E. Witten, Nucl. Phys. B120, 189 (1977).
   C.H. Llewellyn Smith, Phys. Lett. 79B, 83 (1978).
9. S.J. Brodsky et al., Phys. Rev. D19, 1418 (1979).
10. P. Zerwas, Phys. Rev. D10, 1485 (1974).
11. E. Hilger, Invited Talk given at the International Workshop on $\gamma\gamma$ Collisions, Amiens (1980), DESY 80/75 (1980).