THE PHOTON STRUCTURE FUNCTION MEASUREMENTS FROM LEP

Richard Nisius, on behalf of the OPAL Collaboration
CERN, CH-1211 Genève 23, Switzerland

The present knowledge of the structure of the photon based on measurements of photon structure functions is discussed. This review is an update of [?] and covers QED structure functions and the hadronic structure function F_2^γ.

1 Introduction

One of the most powerful tools to investigate the internal structure of quasi-real photons is the measurement of photon structure functions in deep inelastic electron photon scattering at e^+e^- colliders. These measurements have by now a tradition of almost twenty years since the first F_2^γ was obtained by PLUTO [?]. The LEP accelerator is a unique place for the measurement of photon structure functions until a high energy linear collider is realised. It is unique because of the large coverage in Q^2 owing to the various beam energies covered within the LEP programme, and due to the high luminosities delivered to the experiments. Structure function measurements are performed by all four LEP experiments, however concentrating on different aspects of the photon structure. The main idea is that by measuring the differential cross section

$$\frac{d^2\sigma_{e\gamma\rightarrow eX}}{dxdQ^2} = \frac{2\pi\alpha^2}{x\,Q^4}\left[\left(1+(1-y)^2\right)F_2^\gamma(x,Q^2) - y^2 F_{\mathrm{L}}^\gamma(x,Q^2)\right] \qquad (1)$$

one obtains the photon structure function F_2^γ which is proportional to the parton content of the photon and therefore reveals the internal structure of the photon. Here Q^2 is the absolute value of the four momentum squared of the virtual photon, x and y are the usual dimensionless variables of deep inelastic scattering and α is the fine structure constant. In the region of small y studied ($y \ll 1$) the contribution of the term proportional to $F_{\mathrm{L}}^\gamma(x,Q^2)$ is small and it is usually neglected.

Because the energy of the quasi-real photon is not known, x has to be derived by measuring the invariant mass of the final state X, which consists of $\mu^+\mu^-$ pairs for $F_{\mathrm{k,QED}}^\gamma$, $k = 2, A, B$, and of hadrons created by a $\mathrm{q\bar{q}}$ pair in studies of F_2^γ. The invariant mass can be determined accurately in the case of $\mu^+\mu^-$ final states, and measurements of $F_{\mathrm{k,QED}}^\gamma$ are statistically limited. For hadronic final states the measurement of x is a source of significant uncertainties which makes measurements of F_2^γ mainly systematics limited.

2 The QED structure functions

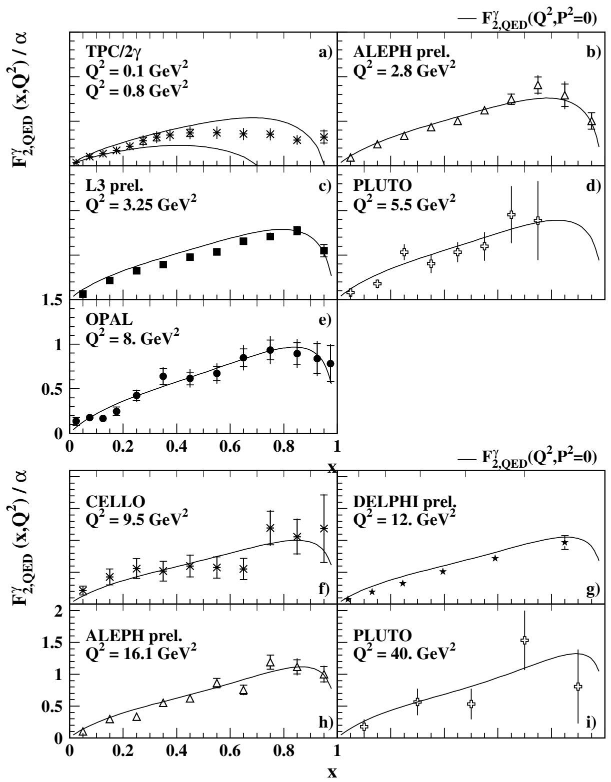

Figure 1: *The measurements of $F^{\gamma}_{2,\mathrm{QED}}$ as a function of x for various Q^2 compared to QED assuming $P^2 = 0$. The Q^2 values for the predictions are taken from the publications. If the data were unfolded to a given Q^2 this value is taken, if only the average Q^2 of the sample is given, c), this value is taken, and if no value at all is quoted the Q^2 range as obtained from the information of the event selection is shown, a). The quoted errors for g) are statistical only.*

Several measurements of QED structure functions have been performed by the LEP experiments. The $\mu^+\mu^-$ final state is such a clean environment that it allows for much more subtle measurements to be performed than in the case of hadronic final states. Therefore the investigation of QED structure functions not only serves as a test of QED but rather it is used to refine the experimentalists tools in a real but clean environment to investigate the possibilities of extracting similar information from the much more complex hadronic final states.

The angle χ is defined as the azimuthal angle between the plane spanned by the muon pair and the plane spanned by the incoming quasi-real photon and the deep inelastically scattered electron. This angle has been used to extract structure functions of the photon, $F^{\gamma}_{\mathrm{A,QED}}$ and $F^{\gamma}_{\mathrm{B,QED}}$, which can not be assessed by the cross section measurement, which is dominated by the contribution of $F_{2,\mathrm{QED}}^{\gamma}$. Azimuthal correlations based on χ were investigated by ALEPH (prel.) [?], L3 (prel.) [?] and OPAL [?], and $F_{2,\mathrm{QED}}^{\gamma}$ has been obtained by all four experiments. Figure **??** shows the world summary of the $F_{2,\mathrm{QED}}^{\gamma}$ measurements [?,?,?,?,?,?,?]. The measurements are nicely described by the QED predictions. The LEP data are precise enough to study the effect of the small virtuality P^2 of the quasi-real photon [?,?].

3 The hadronic structure function F_2^{γ}

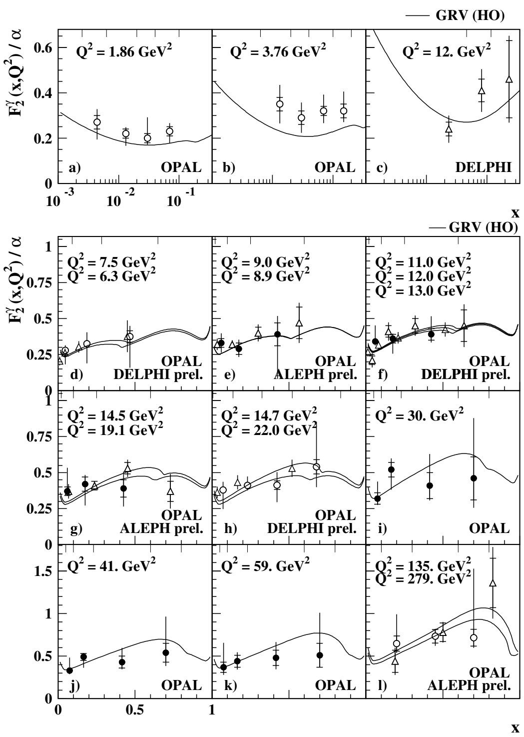

Figure 2: *The measurements of F_2^{γ} as a function of x unfolded on a logarithmic x scale, a)–c), or on a linear x scale, d)–l), compared to the prediction of the GRV (HO) parametrisation. The OPAL data at 11* GeV^2 *(41* GeV^2*) are the combined data from 9 and 14.5* GeV^2 *(30 and 59* GeV^2*). The inner error bar is the statistical error and the outer the quadratic sum of statistical and systematic error. (ALEPH, DELPHI triangles, OPAL circles)*

The measurement of F_2^{γ} has attracted a lot of interest at LEP over the last years. The LEP collaborations have measured F_2^{γ} in the range $0.0025 < x \lesssim 1$ and $(1.86 < Q^2 < 279)$ GeV^2, the largest region of phase space ever studied [?,?,?,?,?]. This work has also encountered some difficulties [?,?] which were not considered in older determinations of F_2^{γ}. Two distinct features of the photon structure are investigated. Firstly the shape of F_2^{γ} is measured as a function of x at fixed Q^2. Particular emphasis is put on measuring the low-x behaviour of F_2^{γ} in comparison to F_2^{p} as obtained at HERA. Secondly the evolution of F_2^{γ} with Q^2 at medium x is investigated. This evolution is predicted by QCD to be logarithmic. In general F_2^γ is found to rise smoothly towards large x and there is some weak indication for a possible rise at low x for $Q^2 < 4$ GeV^2, as shown in Fig **??**. Compared to the status of[?] there is a new preliminary measurement from L3 available[?] which complements the OPAL measurement at $Q^2 < 5$ GeV^2. The two measurements nicely agree in normalisation and due to some improvements in the modelling of the hadronic final state by the Monte Carlo models and a different treatment of systematic errors the preliminary L3 measurement seems to suffer less from systematic uncertainties than the first measurement at low-x from OPAL.

All measurements are satisfactorily described (except in Fig **??**b) by several of the existing F_2^γ parametrisation, e.g. GRV[?,?] and SaS[?]. Experimentally there seems to emerge an inconsistency between the OPAL[?], L3[?] and PLUTO[?] data on one hand and the TPC[?] data on the other hand at $Q^2 \approx 4$ GeV^2, see[?,?].

The evolution of F_2^γ with Q^2, Fig **??**, has been studied using the large lever arm in Q^2, and also by comparing various ranges in x within one experiment[?]. Unfortunately the different experiments quote their results for different ranges in x which makes the comparison more difficult because the predictions for the various ranges in x start to be significantly different for $Q^2 > 100$ GeV^2, as can be seen in Fig **??**. The measurements are consistent with each other and a clear rise of F_2^γ with Q^2 is observed. It is an interesting fact that

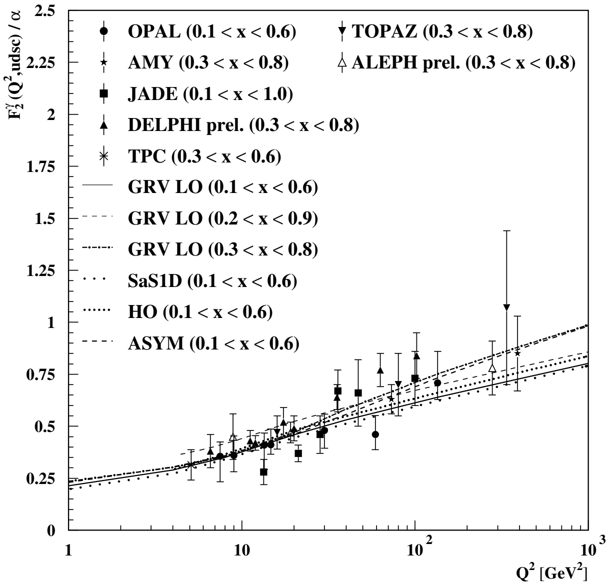

Figure 3: *Summary of the measurements of F_2^γ at medium x without subtraction of the charm contribution compared to several theoretical predictions taking into account the various ranges in x.*

this rise can be described reasonably well ($\mathcal{O}(15\%)$ accuracy) by the leading order asymptotic solution [?] for F_2^γ as predicted by perturbative QCD for $\alpha_s(M_z^2) = 0.128$ as detailed in [?].

4 Conclusion

Informations on the photon structure in a large range in Q^2 and x have been obtained based on structure function measurements at LEP. All observations are consistent with the QED and QCD predictions. The future LEP2 programme will allow to extend the study of the photon structure up to $Q^2 \approx 1000$ GeV^2.

References

1. R. Nisius, *contributed paper to ICHEP97, Jerusalem*, hep-ex/9712012.
2. PLUTO Collab., C. Berger et al., Phys. Lett. **107B**, 168–172 (1981).
3. ALEPH Collab., *contributed paper to Photon 97, Egmond aan Zee.*
4. L3 Collab., *contributed paper to ICHEP97, Jerusalem.*
5. OPAL Collab., K. Ackerstaff et al., Z. Phys. **C74**, 49–55 (1997).
6. CELLO Collab., H. J. Behrend et al., Phys. Lett. **126B**, 384–390 (1983).
7. TPC/2γ Collab., M. P. Cain et al., Phys. Lett. **147B**, 232–236 (1984).
8. PLUTO Collab., C. Berger et al., Z. Phys. **C27**, 249–256 (1985).
9. OPAL Collab., R. Akers et al., Z. Phys. **C60**, 593–600 (1993).
10. DELPHI Collab., P. Abreu et al., Z. Phys. **C69**, 223–234 (1996).
11. OPAL Collab., K. Ackerstaff et al., Z. Phys. **C74**, 33–48 (1997).
12. OPAL Collab., K. Ackerstaff et al., Phys. Lett. **B411**, 387–401 (1997).
13. OPAL Collab., K. Ackerstaff et al., Phys. Lett. **B412**, 225–234 (1997).
14. DELPHI Collab., *contributed paper to Photon 97*, Egmond aan Zee.
15. ALEPH Collab., *contributed paper to ICHEP97, Jerusalem.*
16. L3 Collab., *these proceedings.*
17. M. Glück, E. Reya, and A. Vogt, Phys. Rev. **D45**, 3986–3994 (1992).
18. M. Glück, E. Reya, and A. Vogt, Phys. Rev. **D46**, 1973–1979 (1992).
19. G. A. Schuler and T. Sjöstrand, Z. Phys. **C68**, 607–623 (1995).
20. PLUTO Collab., C. Berger et al., Phys. Lett. **142B**, 111–118 (1984).
21. TPC/2γ Collab., H. Aihara et al., Z. Phys. **C34**, 1–13 (1987).
22. E. Witten, Nucl. Phys. **B120**, 189–202 (1977).