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THE PHOTON STRUCTURE AT MEDIUM x AND Q^2 IN DEEP INELASTIC eγ SCATTERING AT $\sqrt{s_{\rm ee}} = 91-172$ GeV

RICHARD NISIUS, for the OPAL Collaboration

CERN, PPE Division, CH-1211 Geneve 23, Switzerland

New measurements are presented for the photon structure function $F_2^\gamma(x,Q^2)$ at four values of Q^2 between 9 and 59 GeV^2 based on data taken with the OPAL detector at $\mathrm{e^+e^-}$ centre-of-mass energies of 161$-$172 GeV, with a total integrated luminosity of 18.1 pb^{-1}. The evolution of F_2^γ with Q^2 in bins of x is determined, in the Q^2 range from 1.86 to 135 GeV^2, using data taken at centre-of-mass energies of 91$-$172 GeV. The slope $\alpha^{-1}\mathrm{d}F_2^\gamma/\mathrm{d}\ln Q^2$ in the range $0.1 < x < 0.6$ is measured to be $0.10 \pm 0.02^{+0.05}_{-0.02}$.

1 Introduction

The measurement of the photon structure function F_2^γ and in particular of its evolution with the momentum transfer squared, Q^2, is a classic test of perturbative QCD [1]. The large range of Q^2 values accessible at the $\mathrm{e^+e^-}$ collider LEP makes it an ideal place to study this evolution.

The results presented in this paper are based on data taken by the OPAL detector at $\mathrm{e^+e^-}$ centre-of-mass energies $\sqrt{s_{\rm ee}}$ around the mass of the $\mathrm{Z^0}$ (denoted by $\sqrt{s_{\rm ee}} = 91$ GeV) [2,3] and on new measurements of F_2^γ in the Q^2 range from 6 to 100 GeV^2, using data recorded in 1996 for $\sqrt{s_{\rm ee}} = 161 - 172$ GeV. This measurement is an extension of the analysis of F_2^γ detailed in [2] using basically the same methods to analyse the singly-tagged two-photon events.

In the singly-tagged region the process $\mathrm{e^+e^-} \to \mathrm{e^+e^-} +$ hadrons can be regarded as deep inelastic scattering of an $\mathrm{e^\pm}$ on a quasi-real photon. The cross-section for this process is expressed as

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

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 studied here $(y \ll 1)$ the contribution of the term proportional to $F_{\rm L}^\gamma(x,Q^2)$ is small and neglected.

Because the energy of the quasi-real photon is not known, x has to be derived from the hadronic final state. This leads to a dependence of F_2^γ on the modelling of the hadronic final states by the Monte Carlo generators.

2 Data Selection and Background Contribution

The measurement of $F_2^\gamma(x,Q^2)$ involves the determination of x and Q^2 which are obtained from the four-vectors of the tagged electron and the hadronic final state using $Q^2 = 2\,E_\mathrm{b}\,E_\mathrm{tag}\,(1-\cos\theta_\mathrm{tag})$ and $x = \frac{Q^2}{Q^2+W^2+P^2}$. Here E_tag and θ_tag are the energy and polar angle of the observed electron, E_b is the beam energy and W is the invariant mass of the hadronic system. P^2 is much smaller than Q^2 and W^2 and it is neglected in the calculation.

The events are divided into two samples depending on the detector components in which the scattered electron is observed, the SW sample and the FD sample. The SW (FD) samples require a large energy deposit $E_\mathrm{tag} \geq 0.775(0.60)\,E_\mathrm{b}$ in the ranges $33 \leq \theta_\mathrm{tag} \leq 55$ $(60 \leq \theta_\mathrm{tag} \leq 120)$ mrad of polar angle, and a hadronic system with at least three tracks and a visible hadronic mass in the range $2.5 \leq W_\mathrm{vis} \leq 40$ GeV. To ensure the scattering on a quasi-real photon, an antitag requirement $E_\mathrm{at} \leq 0.08\,E_\mathrm{b}$ is applied in the hemisphere opposite to the tagged electron. With these cuts 879 and 414 events, with average squared momentum transfers $\langle Q^2\rangle$ of approximately 11 GeV^2 and 41 GeV^2 are selected in the SW and FD samples. The accessible x ranges for the two samples are $0.004 < x < 0.76$ and $0.012 < x < 0.94$. The trigger efficiency is evaluated from the data to be above 95% for the SW sample and essentially 100% for the FD sample.

The dominant background source is $\gamma^\star\gamma \rightarrow$ leptons. These processes were simulated with the Vermaseren program. The background contribution from $\gamma^\star\gamma \rightarrow \tau^+\tau^-$ events is 36.0 ± 1.8 (29.0 ± 2.2) and the $\gamma^\star\gamma \rightarrow \mathrm{e^+e^-}$ process contributes 16.8 ± 1.2 (9.1 ± 0.9) events to the SW (FD) samples.

3 Modelling of the Hadronic Final State

The data are compared to the HERWIG [4] and PYTHIA [5] Monte Carlo models and to the more specialised F2GEN generator [6]. The data are described reasonably well by the models for global hadronic variables such as the visible hadronic mass, the visible neutral energy, and the charged multiplicity, but there are serious discrepancies in the hadronic energy flow especially at $x_\mathrm{vis} \leq 0.1$, between the data and any of the models at all rapidities [2,7].

4 The Determination of F_2^γ

F_2^γ is determined as a function of x from the x_vis distribution using the method of regularised unfolding [8], Fig. 1. The figures also show F_2^γ evaluated at the

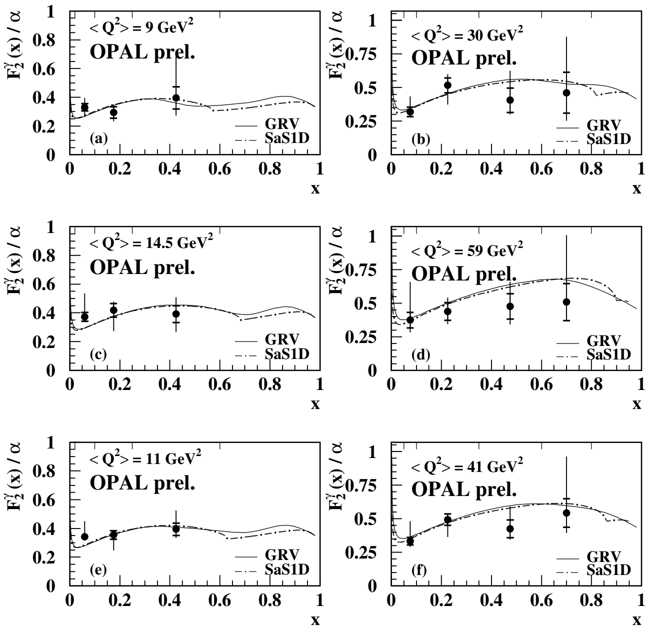

Figure 1: The measurement of F_2^γ as a function of x in bins of Q^2.

corresponding values of $\langle Q^2 \rangle$ for the GRV [9] and the SaS1D [10] parton density parametrisation, in each case including the expected contribution from massive charm quarks. The value of F_2^γ/α is given at the centre of the x bin. The bin sizes are indicated by the vertical lines at the top of the figure. The error bars show both the statistical error alone and the full error, given by the quadratic sum of statistical and systematic errors. The F_2^γ values presented here are not corrected for the fact that P^2 is not strictly equal to zero, because this correction is uncertain as it depends strongly on the model chosen [11,2].

The estimation of the systematic error includes three parts: the variation of the compositions of signal and background events in the sample, the use of different F_2^γ structure functions assumed in the Monte Carlo samples, and the different modelling of the formation of the hadronic final state. The systematic error assigned to the result, which is taken as the maximum deviation of any unfolding result from the central values, is dominated by the model uncertainties. The results on F_2^γ as a function of x are well described by the GRV and SaS1D predictions in all Q^2 ranges.

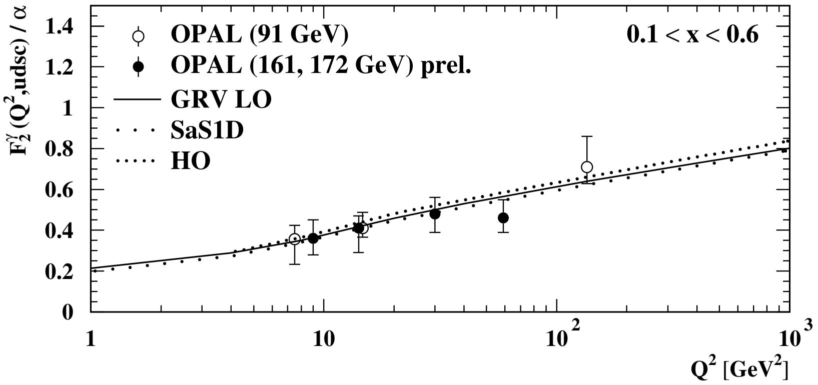

Figure 2: The evolution of F_2^γ as a function of Q^2 for $0.1 < x < 0.6$.

Figure 2 shows the measurement of $F_2^\gamma(Q^2)/\alpha$ as a function of Q^2 in the region $0.1 < x < 0.6$ together with the results obtained in [2]. The results of the two analyses at very different centre-of-mass energies, which use different detector components to measure the deep inelastic scattered electron for similar Q^2 values, are consistent. A clear increase of F_2^γ/α with Q^2 is observed in the data, in agreement with the QCD predictions. The data are compared to the LO GRV and the SaS1D parametrisations, and to a higher order (HO) prediction based on the HO GRV parametrisations for light quarks and on the charm contribution calculated in [12], as described in more detail in [2].

A fit to the OPAL data in the Q^2 range 7.5–135 GeV^2 using a linear function of the form $a + b\ln(Q^2/\mathrm{GeV}^2)$, where a and b are parameters which do not depend on x, yields:

$$F_2^\gamma(Q^2)/\alpha = (0.16 \pm 0.05^{+0.17}_{-0.16}) + (0.10 \pm 0.02^{+0.05}_{-0.02})\ \ln\ Q^2/\mathrm{GeV}^2\,,$$

where the first error is statistical and the second systematic.

The measurement is consistent with results obtained by other experiments [13,14], Fig. 3a. The data are usually compared without referring to the different x ranges studied by the experiments. Based on the GRV parametrisation it is shown that the predictions for $Q^2 > 100$ GeV^2 are significantly different for the various x ranges.

QCD predicts a positive scaling violation of F_2^γ which varies in size as a function of x. To study this variation in $\alpha^{-1}\mathrm{d}F_2^\gamma/\mathrm{d}\ln Q^2$, the data in the Q^2 range 1.86–135 GeV^2 are analysed using the same x ranges for all data. Fig. 3b shows the measurement in comparison to the HO calculation. The

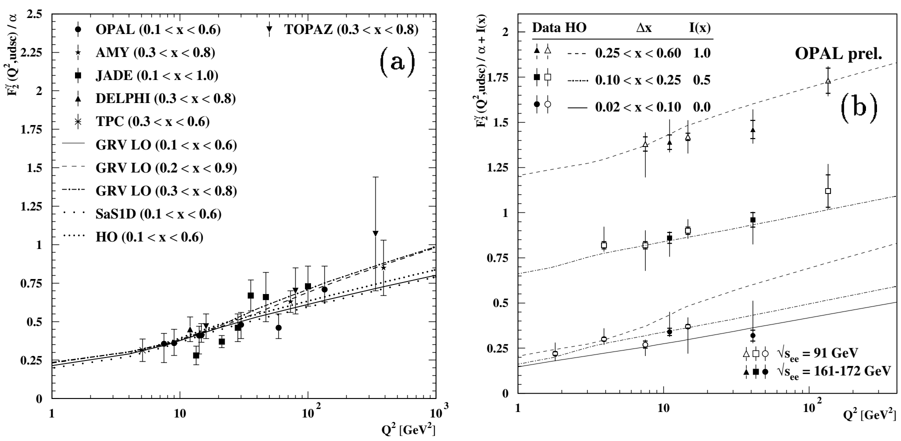

Figure 3: The evolution of F_2^γ with Q^2 in several bins in x compared to other measurements and theoretical predictions.

changes in slope of the predictions for Q^2 below 15 GeV^2 is caused by the charm threshold. The results from [2,3] are only rebinned in x but not reanalysed. They consistently extend the measurement into the region of low x and low Q^2. For fixed Q^2 and varying x the data in general lie closer together than the prediction, and the agreement between the prediction and the data is best for the range $0.10 < x < 0.25$. In order to experimentally observe the variation of $\alpha^{-1}\mathrm{d}F_2^\gamma/\mathrm{d}\ln Q^2$ with x more data and a reduced systematic error are needed.

5 Summary and Conclusion

Data from the OPAL experiment at LEP have been used to study the hadronic structure of the photon. A slightly better agreement between the predictions for the hadronic energy flow of the various models and the data in the region $0.1 < x_{\mathrm{vis}} < 0.6$ is found for the data taken at $\sqrt{s_{\mathrm{ee}}} = 161 - 172$ GeV, than for the data collected at $\sqrt{s_{\mathrm{ee}}} = 91$ GeV. For $x_{\mathrm{vis}} < 0.1$ significant differences [2] persist, as the data prefer a more pointlike angular distribution of the final state hadrons than assumed in either HERWIG or PYTHIA, and for $x_{\mathrm{vis}} > 0.6$ the statistical precision is insufficient to draw firm conclusions.

Using the data at $\sqrt{s_{\mathrm{ee}}} = 161 - 172$ GeV the photon structure function $F_2^\gamma(x, Q^2)$ has been unfolded as a function of x in four Q^2 intervals, with mean momentum transfers $\langle Q^2 \rangle = 9$, 14.5, 30 and 59 GeV^2. Using data at $\sqrt{s_{\mathrm{ee}}} = 91 - 172$ GeV the evolution of F_2^γ with Q^2 in the range

$0.10 < x < 0.60$ has been measured to be $F_2^\gamma(Q^2)/\alpha = (0.16 \pm 0.05^{+0.17}_{-0.16}) + (0.10 \pm 0.02^{+0.05}_{-0.02}) \ln(Q^2/\mathrm{GeV}^2)$, where the first error is statistical and the second systematic. The slope $\alpha^{-1}\mathrm{d}F_2^\gamma/\mathrm{d}\ln Q^2$, based on the OPAL data alone is significantly different from zero and consistent with the logarithmic evolution of F_2^γ with Q^2 expected from QCD. The variation of the positive scaling violation of F_2^γ with varying x was studied in three ranges in x, $0.02 - 0.10$, $0.10 - 0.25$ and $0.25 - 0.60$. The QCD prediction is in agreement with the data, but the accuracy of the data is insufficient to show a significantly different slope of F_2^γ for the ranges in x studied.

The data, over the x and Q^2 range studied, are equally well described by several of the available parton density parametrisations, including the GRV and SaS1D parametrisations used in this analysis.

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References

1. E. Witten, *Nucl. Phys.* B **120**, 189 (1977).
2. OPAL Collab., K. Ackerstaff et al., *Z. Phys.* C **74**, 33 (1997).
3. OPAL Collab., J. Bechtluft these proceedings.
4. G. Marchesini *et al.*, *Comp. Phys. Comm.* **67**, 465 (1992); CERN 96-01, Physics at LEP2, (1996) Vol. 2, p. 213.
5. T. Sjöstrand, *Comp. Phys. Comm.* **82**, 74 (1994); CERN 96-01 Physics at LEP2, (1996) Vol. 2, p. 218.
6. A. Buijs *et al.*, *Comp. Phys. Comm.* **79**, 523 (1994).
7. J. A. Lauber *et al.*, these proceedings.
8. V. Blobel, DESY-84-118, 1984; CERN 85-09.
9. M. Glück, E. Reya and A. Vogt, *Phys. Rev.* D **46**, 1973 (1992); M. Glück, E. Reya and A. Vogt, *Phys. Rev.* D **45**, 3986 (1992).
10. G. A. Schuler and T. Sjöstrand, *Z. Phys.* C **68**, 607 (1995).
11. M. Glück, E. Reya and M. Stratmann *Phys. Rev.* D **51**, 3220 (1995); G. A. Schuler and T. Sjöstrand, *Phys. Lett.* B **376**, 193 (1996).
12. E. Laenen *et al.*, *Phys. Rev.* D **49**, 5753 (1994).
13. Ch. Berger and W. Wagner, *Phys. Rep.* **146**, 1 (1987).
14. TPC/2γ Collab., H. Aihara *et al.*, *Z. Phys.* C **34**, 1 (1987); TPC/2γ Collab., H. Aihara *et al.*, *Phys. Rev. Lett.* **58**, 97 (1987); DELPHI Collab., P. Abreu *et al.*, *Z. Phys.* C **69**, 223 (1996); JADE Collab., W. Bartel *et al.*, *Z. Phys.* C **24**, 231 (1984); TOPAZ Collab., K. Muramatsu *et al.*, *Phys. Lett.* B **332**, 477 (1994).