PHOTON STRUCTURE FUNCTION IN $\gamma\gamma$ COLLISIONS AT LEP

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A review of the leptonic and hadronic structure functions measured at LEP using the data collected by the ALEPH, DELPHI, L3 and OPAL detectors is given. The reactions $e^+e^- \rightarrow e^+e^-l^+l^-$ and $e^+e^- \rightarrow e^+e^-$ *hadrons* are studied in a single tag configuration for different values of the centre of mass energy, $\sqrt{s}$, between 91 GeV and 188 GeV.

1 Introduction

The study of the structure of the photon allows us to test the predictive power of QED and QCD. The photon couples to the electric charge and it reveals its structure in fluctuations into virtual lepton and quark pairs. The photon structure function can be experimentally measured by studying deep inelastic electron scattering on a target photon in e^+e^- colliders. Figure 1 shows the 'single-tag' configuration where the scattered electron (or positron) is detected at an angle $\theta_{tag} > \theta_0$, with a veto against a second tag anywhere in the detector.

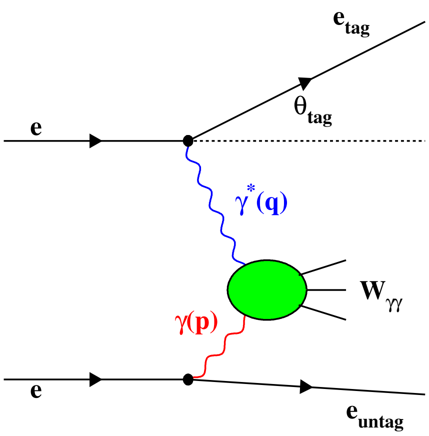


Figure 1: Kinematics of the 'single-tag'.

The cross section, to the lowest order in the electromagnetic coupling α, for this process where the quasi-real photon with four momentum p is probed by the virtual photon with four momentum q, is given by:

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[(1+(1-y)^2)F_2^\gamma(x,Q^2) - y^2 F_L^\gamma(x,Q^2)] \quad (1)$$

where F_2^γ, F_L^γ denote the structure functions of the quasi-real photon, $Q^2 = -q^2$ is the virtuality of the probe photon and x, y are the usual dimensionless variables of deep inelastic scattering $x = \frac{Q^2}{Q^2+P^2+W_{\gamma\gamma}^2}$ and $y = 1 - \frac{E_{tag}}{E_{beam}} \cos^2\theta_{tag}$. Here $W_{\gamma\gamma}$ is the invariant mass of the two photon final state and $P^2 = -p^2 \approx 0$ is the mass of the quasi-real target photon.

Since the scattered electron is detected at relatively small angles and high energies[a], y is so small that the measured cross section (1) is only sensitive to F_2^γ. However, the existence of the longitudinal component of the target photon can be estimated from the azimuthal correlations of lepton pairs produced via the two-photon interactions.

2 Leptonic Structure Function

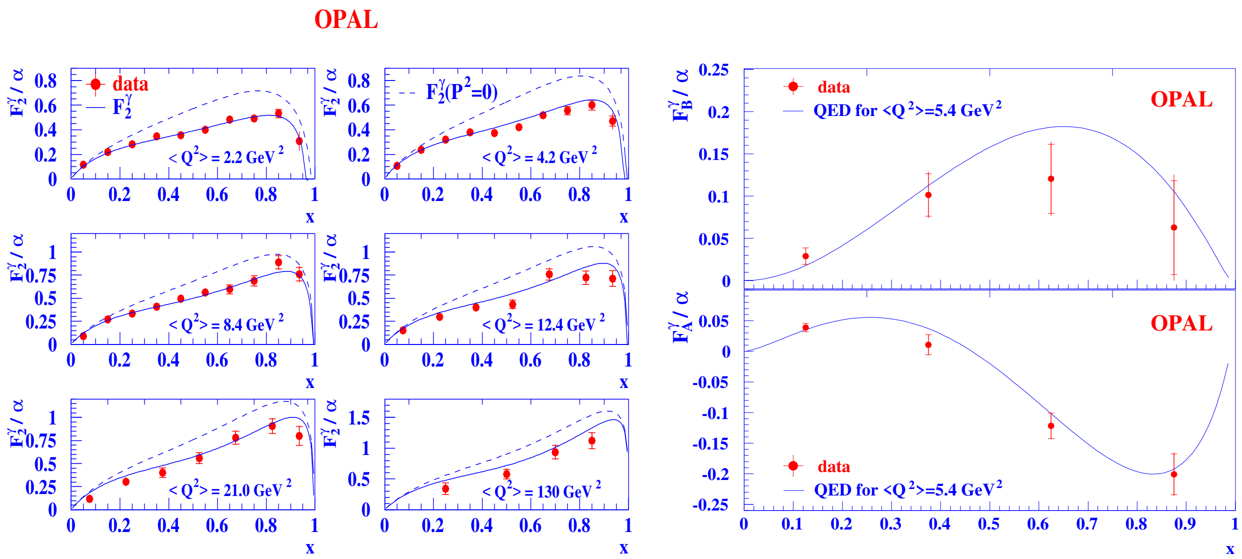
The leptonic structure function has been measured at LEP[1,2,3,4] and previously in other e^+e^- colliders[5,6,7] in the reaction $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$.

This measurement provides not only a QED test but also an experimental check for the procedures used in the study of the hadronic photon structure function.

L3 and OPAL have analysed the full set of data collected between 1991 and 1995 at $\sqrt{s} = 91$ GeV[3,4] for the kinematical ranges described in table 1. The leptonic structure function measured by OPAL is shown in figure 2 (a) for different bins of Q^2. The results are in good agreement with the QED prediction for a target photon of virtuality $P^2 = 0.05$ GeV^2.

Table 1: Kinematic ranges of the selected $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ events.

$\sqrt{s}$=91 GeV		$\mathcal{L}$	θ_{tag}	Q^2	x
Exp	Detector	pb^{-1}	mrad	GeV^2	
L3	Lumi Cal	93.7	25-68	1.4-7.6	0-1
OPAL	SW Cal.	67.4	28-55	1.5-7	0-1
	Forward	81.3	60-120	6-30	0-1
	Endcap	129.1	210-540	70-400	0-1



(a) (b)

Figure 2: (a) $F_{2,\mathrm{QED}}^\gamma$ in Q^2 bins. The dashed line corresponds to $P^2 = 0$. (b) The structure functions F_A and F_B from azimuthal correlations.

The study of the $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ cross section as a function of the azimuthal angle χ between the scattered electron and the μ direction, provides information on the longitudinal

[a] Typically $E_{tag} > 0.5\ E_{beam}$

component of the probe photon [8,9]. The data are well described by the form $dN/d\chi = A_1(x) + A_2(x)\cos\chi + A_3(x)\cos 2\chi$ where the coefficients A_i are related to the polarisation states of the two photons, $A_2 \sim F_A$ and $A_3 \sim F_B$. The interference term between longitudinal and transverse photons, measured by the structure function F_A, is small, but significantly non-zero.

3 Hadronic Structure Function

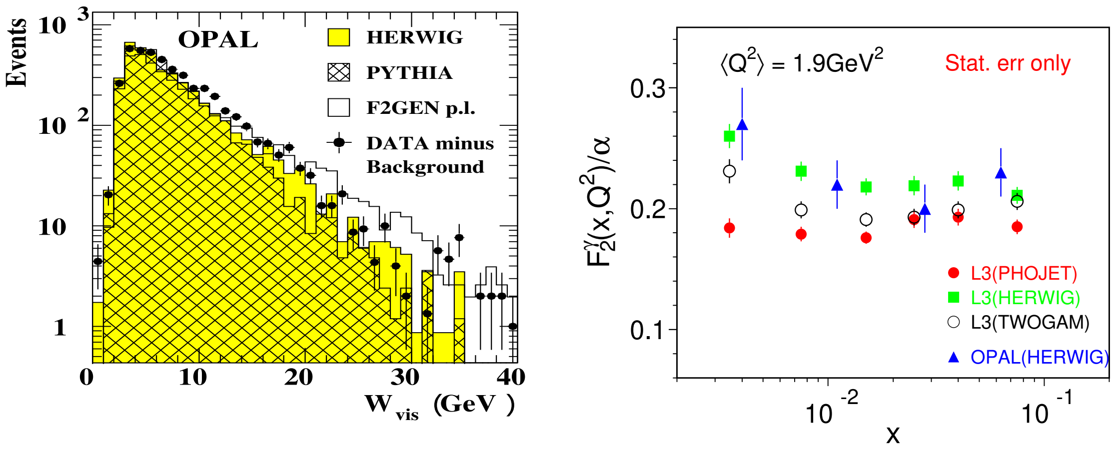
The hadronic structure function can be divided into two parts: a point-like coupling of the photon to the quark-antiquark pair (Quark Parton Model) and a second where the photon couples to the hadronic system via a virtual vector meson (ρ, ω, Φ, J/Ψ,...).

The hadronic structure function has been measured at LEP [10,11,12,13] in the ranges of x and Q^2 shown in table 2. Due to the increase of the centre of mass energy of LEP with respect to previous experiments [14,15,16,17,18] lower values of x can be reached as $W_{\gamma\gamma}$ is larger for a fixed Q^2.

Table 2: Kinematic range of the selected $e^+e^- \to e^+e^-$hadrons events.

Exp	$\sqrt{s}$	θ_{tag}	Q^2	x
	GeV	mrad	GeV^2	
L3	91	26-700	1.2-500	0.002-0.98
L3	183	30-66	9-30	0.01-0.3
OPAL	91	27-55	1.1-6.6	0.0025-0.2
OPAL	161,172	33-120	6-100	0.02-0.6
ALEPH	91	65-2215	6-3000	0.005-0.97
DELPHI	91	43-135	40-30	0.005-0.977
DELPHI	161-188	42-610	10-1000	0.01-0.8

The variable x must be determined from the effective mass, W_{vis}, of all detected particles. Due to the limited detector acceptance $W_{vis} < W_{\gamma\gamma}$ therefore the data need to be unfolded using the Monte Carlo simulation. Because of this it is extremely important that the Monte Carlo reproduces well the particle distributions observed in the detector. Figure 3 (a) shows the distribution

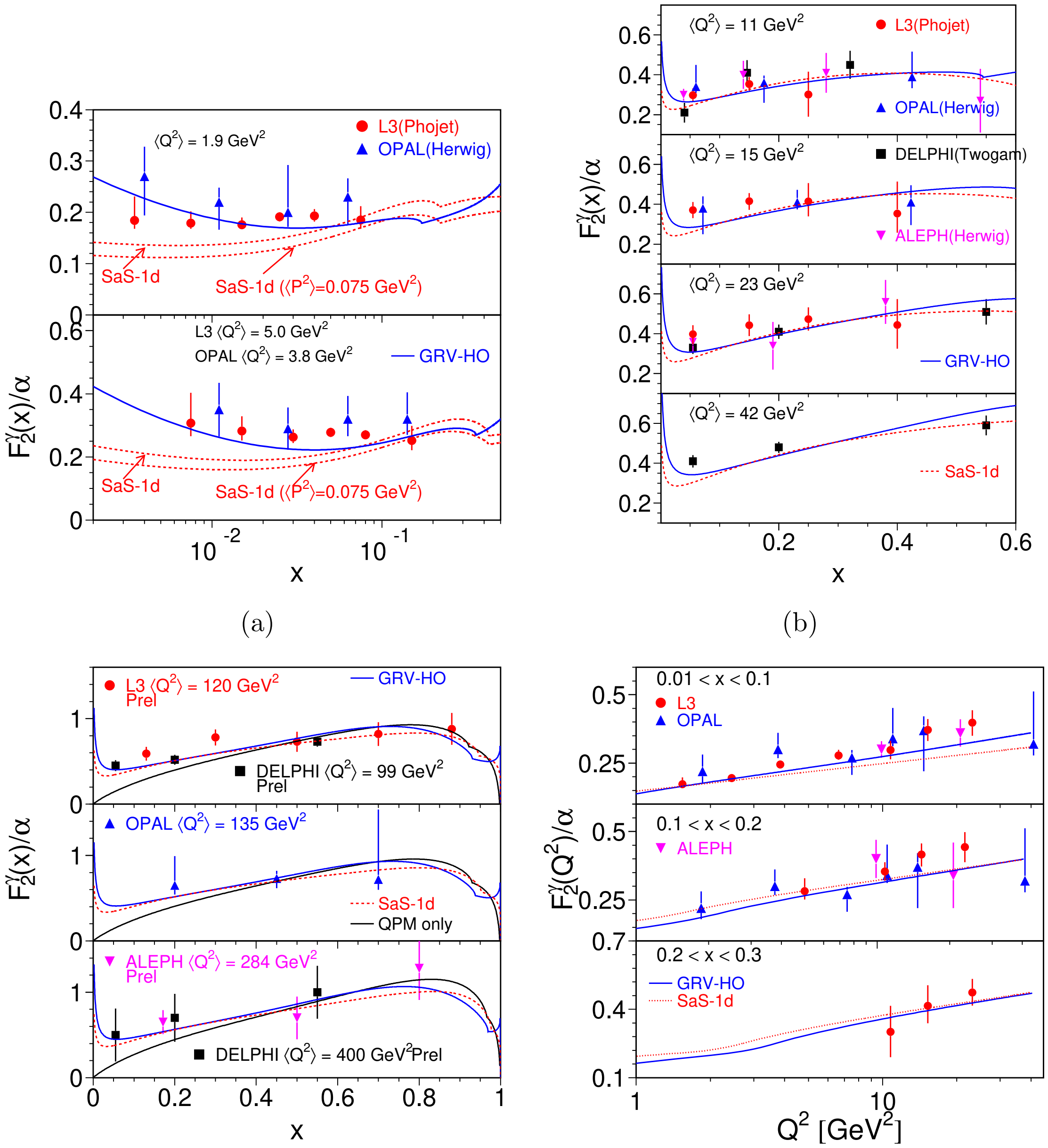


(a) (b)

Figure 3: (a) Comparison of W_{vis} reconstructed in data with different Monte Carlos, (b) F_2^γ dependence on the Monte Carlo modelling.

of W_{vis} for data and several Monte Carlos, and 3 (b) the large variations on the measured F_2^γ, mainly at low x and low Q^2, depending on the model chosen to unfold the data. The L3 and OPAL results are similar if the same Monte Carlo is used.

Figure 4 shows F_2^γ measured at LEP by L3 (PHOJET [22]), OPAL (HERWIG [24]), DELPHI (TWOGAM [23]) and ALEPH (HERWIG [24],QPM+VDM). The largest uncertainty in F_2^γ comes from the Monte Carlo modelling and it is estimated by unfolding the data with different Monte Carlos [b]. At low and medium values of Q^2 (fig. 4 (a) and (b)) data agree with GRV-HO and SaS-1d parametrisations in the range $x > 0.1$, but at low x the data are higher than expected. These differences are larger if the virtuality of the target photon is considered in the theoretical predictions. For high Q^2 (fig. 4 (c)) data are well reproduced by the Quark Parton Model except



(c) (d)

Figure 4: (a) Distribution of generated, reconstructed and visible invariant mass, (b) comparison of W_{vis} reconstructed in data with different Monte Carlos, (c) F_2^γ dependence on the Monte Carlo modelling.

at low values of x where the resolved processes need to be considered. Finally figure 4 (d) shows the Q^2 evolution of the structure function, in agreement with the QCD prediction.

[b]This error is estimated in different ways by each experiment (see ref. [10,11,12,13]).

Conclusions

The hadronic photon structure function is measured at LEP in the range $0.002 < x < 0.977$ and $1.2\ \mathrm{GeV}^2 < Q^2 < 3000\ \mathrm{GeV}^2$. The precision of the measurement is limited by the Monte Carlo models at low values of x and Q^2. Quark Parton Model alone is not sufficient to describe the data at low x.

Acknowledgements

I would like to thank all the LEP colleagues for their contribution, in particular J.H. Field, M. Kienzle-Focacci and C.H. Lin.

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