PHOTON STRUCTURE FUNCTION FROM L3 DATA*

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With the reaction $e^+e^- \to e^+e^-\gamma^*\gamma \to e^+e^- hadrons$, the L3 experiment at LEP has measured the hadronic photon structure function F_2^γ in a wide Q^2 and x range. The data are compared to other LEP experiments. Despite the high statistics and the small background contamination, the measurements are dominated by systematic uncertainties, mainly due poor agreement between the Monte Carlo models and the two-photon events.

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1. Introduction

At LEP, in the reaction $e^+e^- \to e^+e^-\gamma^*\gamma \to e^+e^- hadrons$, a photon γ^*, with a large virtuality, $Q^2 = -q^2 \sim 2E_{\rm tag}E_{\rm beam}(1-\cos\theta_{\rm tag})$, can be considered as a point-like probe investigating the partonic structure of the target photon γ, with four-momentum p and virtuality $P^2 = -p^2 \simeq 0$. The four-momentum q^2 of the hard photon is measured from the energy $E_{\rm tag}$, and polar angle $\theta_{\rm tag}$, of the scattered electron, while the second electron goes undetected and its polar angle is restricted to small values, "single-tag" events. The differential cross section, written in terms of the scaling variables $x = Q^2/(Q^2+W_{\gamma\gamma}^2+P^2)$ and $y = 1-(E_{\rm tag}/E_{\rm beam}\cos^2\theta_{\rm tag})$, is [1]:

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

The variable x depends on the two-photon center-of-mass energy $W_{\gamma\gamma}$, equal to the effective mass of the produced hadrons. The inelasticity y is small ($y < 0.3$) in the LEP kinematic regions and consequently only the photon structure function $F_2^\gamma(x,Q^2)$ contributes appreciably to the cross section.

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The photon structure function has been extensively studied at low-energy e^+e^-colliders and at LEP [2,3]. Recently the L3 measurements, summarised in Table I, have been completed [4][1].

TABLE I

The L3 measurements.

$\sqrt{s}$(GeV)	$\mathcal{L}$ (pb^{-1})	$\langle Q^2 \rangle$(GeV^2)	x interval	points
$\simeq 91$	140	1.9	0.002 – 0.1	6
		5.0	0.005 – 0.2	6
		120.	0.05 – 0.98	5
183	52	10.8	0.01 – 0.3	3
		15.3	0.01 – 0.5	4
		23.1	0.01 – 0.5	4
189 – 206	608	12.4	0.006 – 0.4	10
		16.7	0.006 – 0.467	11
		25.5	0.023 – 0.556	11

The quark parton model (QPM) gives definite predictions for F_2^γ, since the reaction $\gamma^*\gamma \to q\,\bar{q}$ is a QED process and QCD corrections are introduced via the DGLAP evolution equations. They necessitate the presence of gluon density as well as quark density in the photon. Many parameterisations of the parton density functions (pdf) of the photon where obtained by fitting the data before LEP ($\simeq$ 70 data points), they are documented in a recent review [5]. A new parameterisation (CJK) has been obtained using also published LEP data [6][2].

2. The data compared to Monte Carlo distributions

Tagged two-photon events are easily separated from annihilation by requiring a high energy electromagnetic cluster in the small angle calorimeter (Fig. 1(a)) and a limited energy deposit in the central calorimeters (Fig. 1(b)). The residual background, due to $e^+e^- \to e^+e^-\tau^+\tau^-$ and $e^+e^- \to q\,\bar{q}(\gamma)$ production, is small. The $W_{\rm vis}$ and $x_{\rm vis} = Q^2/(Q^2 + W^2_{\rm vis})$ distributions, presented in Fig. 2 for all selected data, are not perfectly reproduced by the available Monte Carlo's. The PYTHIA [7] and TWOGAM [8] model reproduce the shape of the data rather well, except at large values of $W_{\rm vis}$. PHOJET [9] presents a harder mass spectrum and predicts too many events for $x_{\rm vis} < 0.1$, it is, therefore, not used to extract F_2^γ.

[1] This last data analysis is due to Gyongyi Baksay.

[2] We thank Pawel Jankowski for providing us the CJK predictions for the photon structure function.

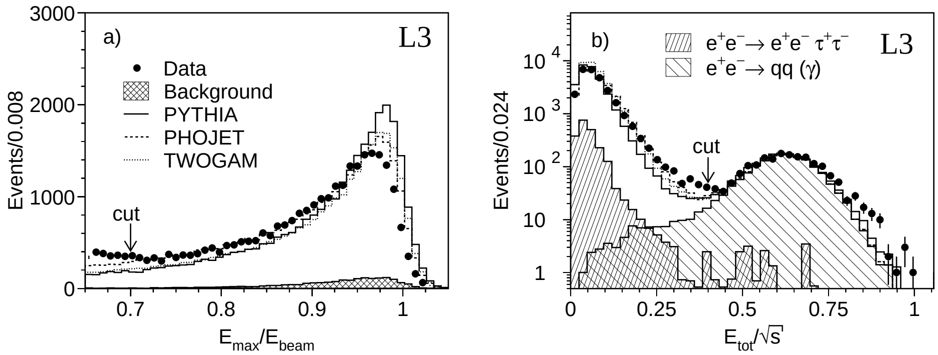


Fig. 1. (a) Distribution of the highest energy clusters in the forward electromagnetic calorimeters for the tagged electron. (b) Total energy in the central calorimeters.

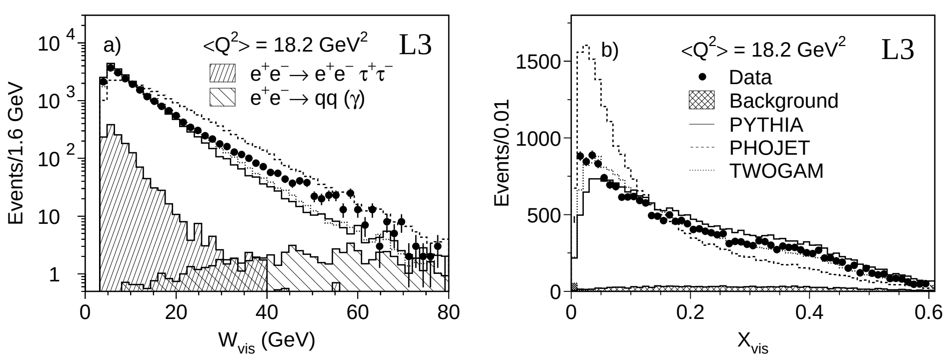
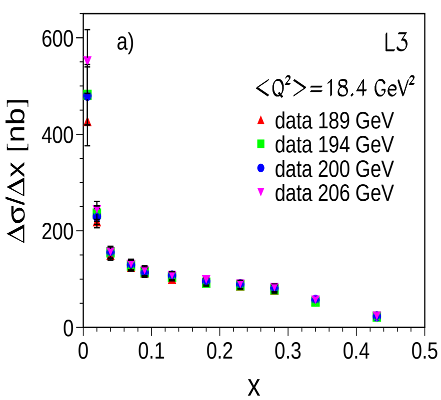


Fig. 2. Distribution of (a) the visible mass of the two-photon system and of (b) the visible x for all selected events compared to Monte Carlo predictions.

3. Cross sections and extraction of F_2^γ

The cross section $\Delta\sigma/\Delta x$ as a function of x (Fig. 3(a)) is measured for each $\sqrt{s}$ interval. A Bayesian unfolding procedure [10] is used to relate the measured x_{vis} to the true value of x and to correct the data for the detector acceptance and efficiency. The average value of the cross sections obtained with the PYTHIA and TWOGAM generators are used. Three main sources of systematic uncertainties are considered: the selection procedure, the trigger efficiency and the Monte Carlo model. Their values, added in quadrature, are larger than the statistical uncertainty of the data. In order to obtain the photon structure function $F_2^\gamma\,/\alpha$, the measured cross section is divided by the target–photon flux and the cross section of Eq. (1), calculated analytically by the program GALUGA [11], setting $F_2^\gamma = 1$ and F_L^γ to the QPM value. The contribution of radiative corrections to the cross section is also subtracted using the program RADCOR [12].

The data are consistent with previous LEP measurements [3], considering the large systematic errors (Fig. 3(b)). We can notice, however, that the large dispersion of the experimental measurements must be mainly attributed to different analysis procedures and different generators used to unfold the data. A comparison of the data with the existing parameterisations, as obtained with the PDFLIB library [13], shows that our data are not well described by the leading-order parton density functions. As for the high-order pdf's, GRV [14] shows the best agreement with the data.



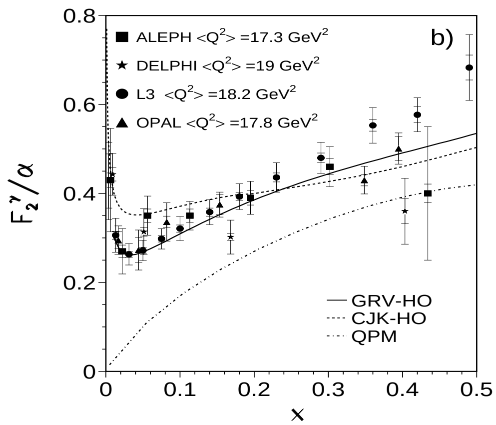


Fig. 3. (a) The cross section as a function of x for different $\sqrt{s}$ values. (b) The photon structure function as measured by the LEP experiments at $\langle Q^2 \rangle \simeq 18$ GeV^2. The predictions of the high-order parton density functions GRV and CJK are shown as well as the QPM prediction for $\gamma\gamma \to q\,\bar{q}$.

Considering all LEP measurements, the Q^2 evolution is studied from 1.5 GeV^2 to 120 GeV^2 in the low-x region, $0.01 \leq x \leq 0.1$, and from 9.9 GeV^2 to 780 GeV^2 in the higher-x region, $0.1 < x \sim 0.6$. The data are presented in Fig. 4 together with the GRV and CJK high-order predictions. The $\ln Q^2$ evolution of F_2^γ is well established, a simple $a + b \ln Q^2$ fit represents the LEP data:

x region	a	b	CL
$0.01 \leq x \leq 0.1$	0.132 ± 0.007	0.069 ± 0.004	8 %
$0.1 \leq x \simeq 0.6$	0.04 ± 0.04	0.142 ± 0.012	14 %

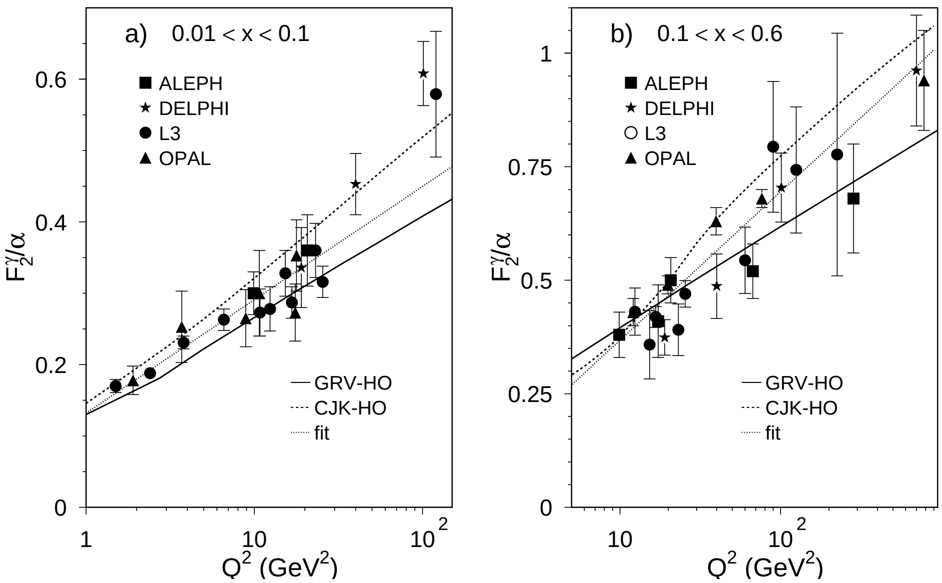


Fig. 4. The photon structure function as measured by the LEP experiments for two x-intervals.The predictions of the high-order parton density functions GRV and CJK are shown as well as the results of a fit to the data of the function $a + b \ln Q^2$.

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