QCD Photon Structure Functions at LEP

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The hadronic photon structure function from the LEP experiments will be reviewed. Since the 1998 Lund meeting new results from the ALEPH, L3 and OPAL collaborations have become available. The LEP data now cover a large range in x and Q^2. At high Q^2 the agreement with the theoretical predictions gets better.

1. INTRODUCTION

In the 1992 Zeuthen workshop on deep inelastic scattering (the forerunner of the DIS workshops) A. Vogt [1] had at hand only data from KEK, PEP and PETRA on F_2^γ to compare to theoretical predictions. The highest Q^2 value of the data then was at 100 GeV^2. LEP data have allowed to extend the Q^2 range by an order of magnitude (see Table 1). At the high values of Q^2 reached now, the quark parton model (QPM) or direct processes are dominant and compare to theory in a much cleaner way.

This review includes new (since 1998 conferences) results from ALEPH [2], L3 [3] and OPAL [4] as well as results from DELPHI [5].

The study of the hadronic structure of photon-photon interactions has up to now mostly been done for single tag events where the probe photon ($\gamma^*(q)$) is highly virtual and the target photon ($\gamma(p)$) quasi real (see Fig. 1).

This allows the determination of the $F_2^\gamma(x,Q^2)$ structure function from the deconvoluted cross section: $d^2\sigma_{e\gamma\to eX}/dxdQ^2 = 2\pi\alpha^2/xQ^4 \times [(1+(1-y)^2)F_2^\gamma(x,Q^2) - y^2F_L^\gamma(x,Q^2)]$. F_2^γ and F_L^γ depend on the helicity cross section σ_{ab} for virtual photon-photon collisions, where $a,b = L,T$ indicate longitudinal and transverse polarizations of the probe (target) photons: $F_2^\gamma \propto \sigma_{TT} + \sigma_{LT}$ and $F_L^\gamma \propto \sigma_{LT}$. Since $y^2F_L^\gamma$ is very small it can be neglected.

For double tag data σ_{LT} can no longer be neglected. Therefore, in this case an "effective" structure function is measured: $F_{eff}^\gamma \propto \sigma_{TT} + \sigma_{LT} + \sigma_{TL}$

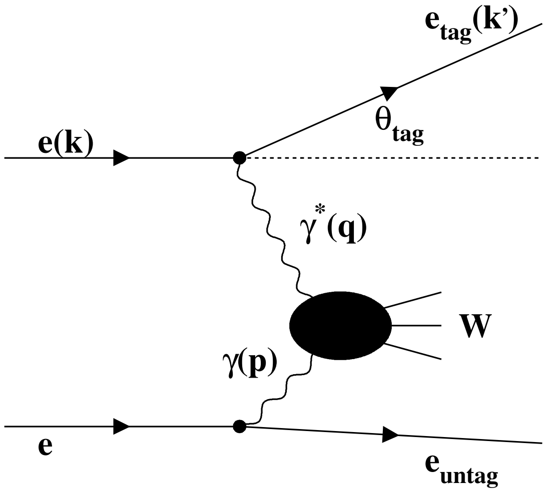

Figure 1. Single tag interaction.

2. MONTE CARLO DECONVOLUTION

Because of detector acceptance and efficiency effects, the deconvolution of the measured data depends quite strongly on Monte Carlo programs [6–10]. An improvement is obtained by using transverse momentum conservation: $W_{rec}^2 = (p_+^{e_{in}} - p_+^{e_{tag}})(\sum_i p_-^i) - |p_t^{e_{tag}}|^2$ which gives a reconstructed hadronic mass W_{rec} closer to the generated one (hashed histogram in Fig. 2).

For high Q^2 data (where most of the energy of an event is seen by the detector anyway) one can improve the agreement between reconstructed and generated variables even more by

Table 1
Kinematic range of published LEP data

	$\sqrt{s}$	Θ_{tag} range	Q^2 range	x
	GeV	mrad	GeV^2	
ALEPH	91	$65-2214$	$6-3000$	$0.005-0.970$
DELPHI	91	$43-135$	$4-30$	$0.005-0.977$
DELPHI	$161, 172, 183, 189$	$42-510$	$10-1000$	$0.01-0.60$
L3	91	$26-66$	$1.2-9$	$0.002-0.200$
L3	91	$200-600$	$40-500$	$0.05-0.98$
L3	183	$30-66$	$9-30$	$0.01-0.3$
OPAL	91	$27-55$	$1.1-6.6$	$0.0025-0.200$
OPAL	161	$33-55$	$11-41$	$0.02-0.60$
OPAL	172	$60-120$	$11-41$	$0.02-0.60$

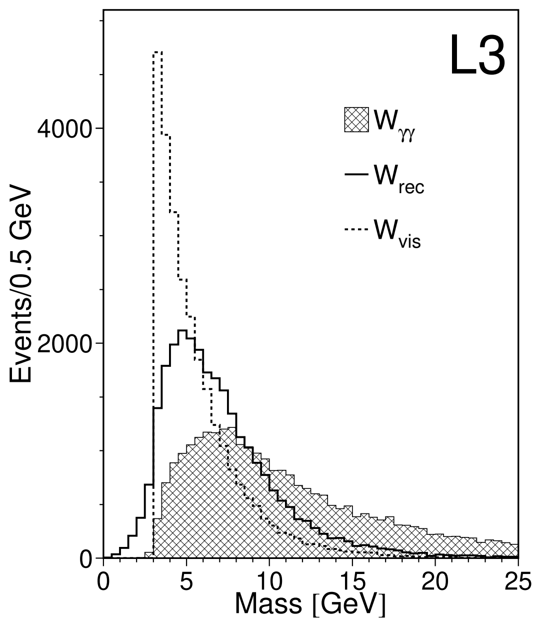

Figure 2. Comparison of W_{vis} and W_{rec} to the generated hadronic mass $W_{\gamma\gamma}$.

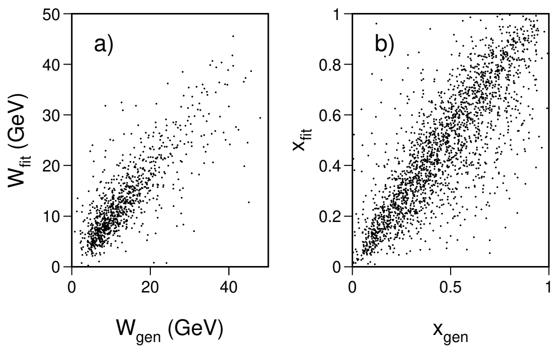

Figure 3. a) Correlation between fitted and generated hadronic mass, b) correlation between fitted and generated value of x.

use of kinematical fitting. This is demonstrated in Fig. 3 for the high Q^2 data from L3.

3. MEASUREMENT OF F_2^γ/α AT LEP

In the following, LEP results on F_2^γ/α are presented for low, medium and high values of Q^2. Each experiment has unfolded the data with a different Monte Carlo generator, viz. ALEPH and OPAL used HERWIG [8], DELPHI used TWOGAM [7] and L3 used PHOJET [10]. The question at low Q^2 is whether the rise of F_2^γ/α for small x as observed at HERA is seen in photon-photon interactions as well. Unfortunately, the data do not allow yet to draw such a conclusion (Fig. 4). Both the x-values reached and the data error bars are still too big. The high order GRV parametrization [11] fits the data best. The two curves from the SAS-1d parametrization [12] show that the inclusion of the virtuality $P^2 = -p^2$ of the target photon decreases the predictions.

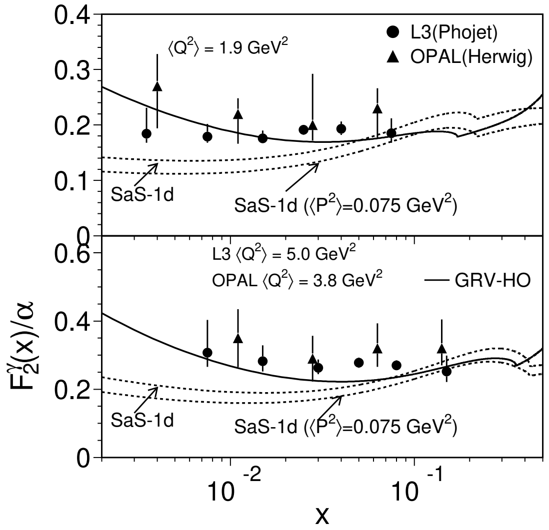

Figure 4. F_2^γ/α at low Q^2 from L3 and OPAL.

The target photon virtuality is measured in double tag events. In Fig. 5 F_2^γ/α from 456 ± 24 single tag events and F_{eff}^γ/α from 43 ± 7 double tag events from L3 are shown as a function of x. For F_2^γ/α the predictions agree for $x > 0.4$ for all parametrizations, viz. AGF [13], GRV [11] and LRSN [14]. In the case of the double tag structure function F_{eff}^γ/α the data are somewhat higher than the QPM and GRS predictions. The latter one is a modification of the F_2^γ structure function from GRS [15] (denoted by GRS F2 in Fig. 5) with TL and LL contributions from QPM added to it.

For the higher Q^2 bins (Fig. 6 and Fig. 7) the agreement of the parametrizations with the data gets better. In the highest Q^2 bin the predictions of the quark parton model (QPM) describe the

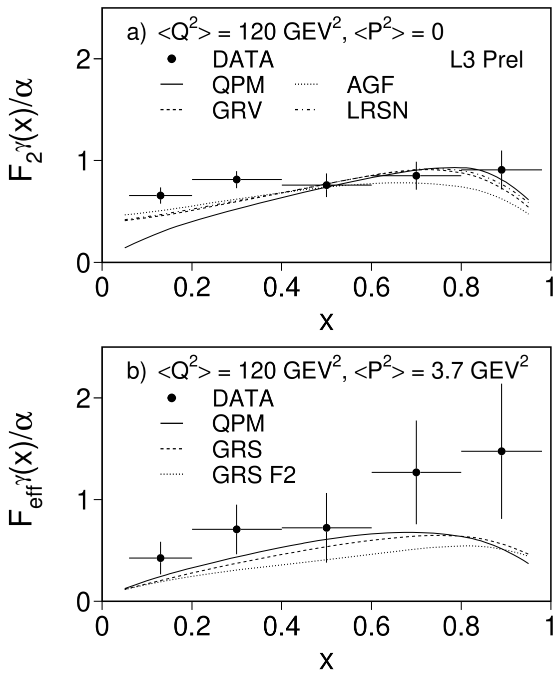

Figure 5. a) F_2^γ/α at $Q^2 = 120$ GeV^2 and $P^2 = 0$ from single tag events, b) F_{eff}^γ/α at $Q^2 = 120$ GeV^2 and $P^2 = 3.7$ GeV^2 from double tag events.

data well except at small values of x where contributions from resolved processes are needed to be included. It should be noted that the data points at large values of Q^2 are obtained by averaging over a wide range in Q^2. In the case of the ALEPH data, $\langle Q^2 \rangle = 284$ GeV^2 is the mean over $30 < Q^2 < 3000$ GeV^2.

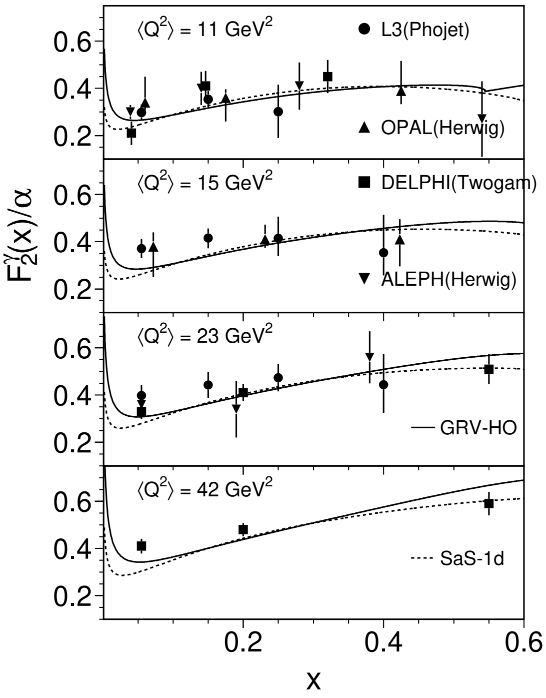

Figure 6. F_2^γ/α at medium Q^2 from LEP.

Fig. 8 shows the evolution of the LEP structure functions with Q^2 for three bins in x to be in good agreement with QCD.

Finally, Fig. 9 displays the Q^2 evolution of data from LEP and from the lower energy colliders for larger x bins, corroborating the previous statement.

4. CONCLUSIONS

LEP has improved the measurement of the structure functions significantly. At high Q^2 the data agree well with QCD.

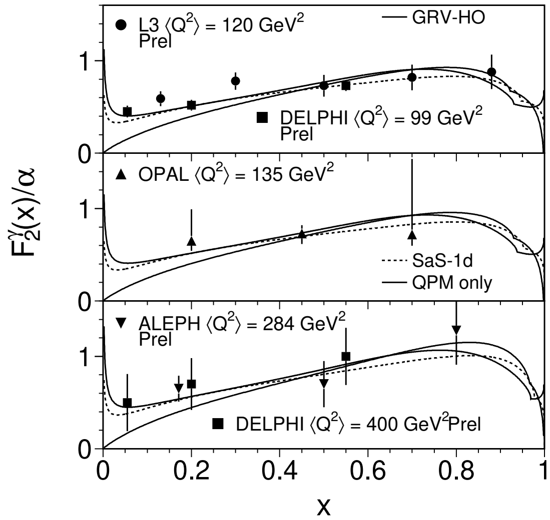

Figure 7. F_2^γ/α at high Q^2 from LEP.

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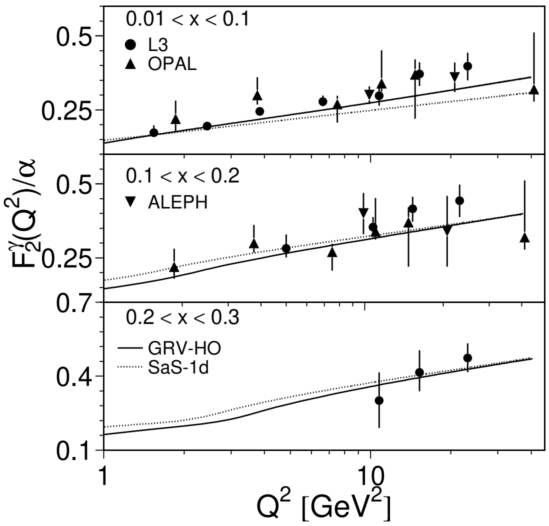

Figure 8. F_2^γ/α from LEP versus Q^2.

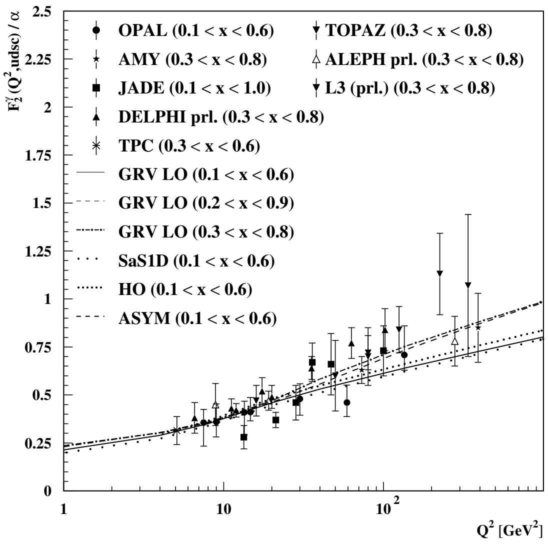

Figure 9. World data of F_2^γ/α versus Q^2.

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