Measurements of the Photon Structure Function at LEP

A. De Roeck
CERN, 1211 Geneva 23, Switzerland

Abstract. In this contribution we discuss recent measurements by the LEP experiments on photon structure functions.

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1 Introduction

Photon structure functions are traditionally measured in $e\gamma$ scattering at electron-positron colliders. One of the electrons emits a photon which is almost on mass shell, and which is probed by a photon with virtuality $Q^2$ emitted by the second electron. The latter electron will be scattered within the acceptance of the detectors if the polar angle is larger than approximately 25 mrad, while the first electron will go undetected in the beam-pipe. Hence the signature is a so called single-tag event. For a recent review of the photon structure see [1].

Recent new data include measurements of $F_\gamma^2(x, Q^2)$, where $x$ is the Bjorken-$x$ value of the parton in the photon, from ALEPH and DELPHI; the charm structure function of the photon from OPAL; a first measurement of the electron structure function by DELPHI. New parton density parametrizations have been extracted using the (almost) complete data sets on $F_\gamma^2(x, Q^2)$, and an interesting extraction of $\alpha_s$ has been reported.

2 New ALEPH data on $F_\gamma^2(x, Q^2)$

ALEPH [2] reports a measurement of $F_\gamma^2(x, Q^2)$ based on 584.4 pb$^{-1}$, in the medium $Q^2$ range: at 17.3 GeV$^2$ and 67.3 GeV$^2$. The Tikhonov unfolding procedure was used to extract the data, and the results are shown in Fig. 1. The data are compatible with earlier measurements, but are more precise. In contrast to the proton, the structure function of the photon is predicted to rise linearly with the logarithm of the momentum transfer $Q^2$, and to increase with increasing Bjorken-$x$ [3]. The ALEPH data allows to check the rise of $F_\gamma^2(x, Q^2)$ with increasing $Q^2$: $F_\gamma^2(0.1 < x < 0.5, < Q^2 > = 17.3 \text{GeV}^2) = 0.41 \pm 0.01 \text{(stat.)} \pm 0.08 \text{(sys.)}$ and $F_\gamma^2(0.1 < x < 0.7, < Q^2 > = 67.2 \text{GeV}^2) = 0.52 \pm 0.01 \text{(stat.)} \pm 0.06 \text{(sys.)}$.

Fig. 1. Values of $F_\gamma^2(x, Q^2)/\alpha$ from ALEPH, compared to previous measurements and predictions of photon PDFs.

3 New DELPHI data on $F_\gamma^2(x, Q^2)$

DELPHI [4] presents new LEP1 and LEP2 data analyses based on 78 pb$^{-1}$ and 548 pb$^{-1}$ respectively. No unfolding procedure is used but the different cross section components are fitted to the data based on hadronic models. The LEP2 data are shown in Fig. 2. DELPHI chooses to present different $F_\gamma^2(x, Q^2)$ values calculated/corrected with different hadronic models, but do not give a single
measurement with a total error including the hadronic
uncertainty. Hence it is somewhat difficult to compare these
measurements with results from other experiments.

![Fig. 2.](image)

Fig. 2. $F_2^\gamma(x, Q^2)/x$ measurements at different $Q^2$ values,
using LEP2 data. The results are extracted from data using
TWOGAM (black points), PYTHIA (open triangles) and
PHOJET (open circles) and are compared to model predictions.

4 OPAL data on $F_2^{\gamma,c}(x, Q^2)$

OPAL reported end of last year on a new measurement
of the charm content of $F_2^\gamma(x, Q^2)$, namely $F_2^{\gamma,c}(x, Q^2)[5]$, which
depends directly on the gluon content of the
photon. The complete luminosity collected by OPAL during
the years 1997-2000 was used, namely 654.1 pb$^{-1}$. The measurement
is made in the $Q^2$ region of $5 < Q^2 < 100$
GeV$^2$. The decays $D^*+ \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$ and charge
conjugates, have been used. After selection cuts, exploiting
the small mass difference between the $D^*$ and the $D$
deckay, 55.3±11.0 signal events are selected. Divided in two
bins in $x$ gives 23.6±7.4 events for $x < 0.1$ and 31.4±8.1
events for $x > 0.1$.

Converting the number of events to a structure function
measurement and comparing this with QCD calcula-
tions, one finds that the high-$x$ region is well described
but the low-$x$ data is above the prediction. In the high-$x$
region the charm structure function is dominated by
the pointlike part of the cross section. If one subtracts
the NLO pointlike part from the low-$x$ data then the resulting
measurement of the hadronic part of the cross section for
$0.0014 < x < 0.1$ gives 34.5±14.3±6.9 pb with a theory
prediction of $7.7^{+1.2}_{-1.6}$ pb, i.e. the low-$x$ excess is about 2$\sigma$.

A further improvement of this measurement can only
be achieved if also the other LEP experiments will have a
go at it.

![Fig. 3.](image)

Fig. 3. The electron structure function averaged in the region
of $Q^2 = 20-30$ GeV$^2$.

5 Electron structure function

A few years ago it was argued [6] that one could circum-
vent some of the dominant systematics of present photon
structure function measurements, namely the necessity to
measure and use the hadronic final state to reconstruct
the kinematic variable $x$, by making a measurement of the
electron structure instead. Here the emitted real photon
is considered as part of the structure of the electron. The
kinematics of the process can be reconstructed from the
scattered electron, and no unfolding procedure is neces-
sary. Furthermore no correction due to the small but finite
virtuality of the target photon is needed. On the downside
the rapid falling photon flux with increasing photon en-
ergy is now absorbed in the measurement (instead of being
factorized out as for the photon structure function case)
and obscures the sensitivity to the QCD dynamics of the
photon structure. Furthermore the radiative corrections
can become quite large.

DELPHI has presented a first preliminary measure-
ment [7], shown in Fig. 3. The electron structure function
falls rapidly with increasing $z$ (= the Bjorken-$x$ w.r.t. the
electron) as expected. The measurements are consistent with
the $F_2^\gamma(x, Q^2)$ results, but within the large error bars
no significant increased sensitivity to the underlying dy-
namics is seen: the predictions of the different models are
much closer to each other than in the case of the photon
structure function. It constitutes however an important
cross check of the photon structure function measurement,
and it is noted [7] that the statistical uncertainties on this
measurement may be better understood.
A summary of the world data is shown in Figs 4 and 5. The first Figure shows the data in different $Q^2$ bins as function of $x$. It contains in total over 50 measurements in the kinematical range $0.001 < x < 0.9$ and $1.9 < Q^2 < 780$ GeV$^2$.

In Fig. 5 the data are shown in different $x$ bins as function of $Q^2$. A fit of the form $F^2(x, Q^2) = a + b \ln(Q^2/\Lambda^2)$ gives $b$ values of $0.061 \pm 0.003, 0.095 \pm 0.008$ and $0.135 \pm 0.013$, for $x$ ranges of $0.01 - 0.1, 0.2 - 0.3$ and $0.4 - 0.6$ respectively, and $\Lambda = 0.2$ GeV. Hence there is a significant increase of the slope with increasing $x$.

7 Parton distributions and $\alpha_s$

Using all $F^2(x, Q^2)$ data measured at LEP, apart from the new data reported in this paper, recently new parton distributions and an extraction of the strong coupling constant $\alpha_s$ have been reported.

LO parton distributions were reported in [8]. These PDFs were radiatively generated, and use the ACOT (and FFNS) heavy flavour scheme. NLO densities are in progress.

Fits to the $F^2(x, Q^2)$ data to extract $\alpha_s$ were reported in [9]. Two different extractions have been made. The first uses data with $x > 0.45, Q^2 > 59$ GeV$^2$, and $\alpha_s$ is fitted directly from its logarithmic asymptotic behaviour. The result (NLO/MV) is $\alpha_s = 0.1183 \pm 0.0050 (\text{exp})^{-0.0029 (\text{theo})}$. The second fit uses all data but makes a 5 parameter fit, one of which is $\alpha_s$. The result of this fit is $\alpha_s = 0.1198 \pm 0.0028 (\text{exp})^{-0.0034 (\text{theo})}$. The results are consistent with each other and the precision is interesting in view of the total precision of the world data $\alpha_s = 0.1172 \pm 0.0020$ [10].

8 Outlook and conclusion

In the near future what can we still expect from LEP? OPAL works on a low-$x$ analysis for $F^2(x, Q^2)$ and $F^2(z, Q^2)$ using the complete statistics; L3 plans an analysis in the full kinematical plane using the complete LEP statistics, and ALEPH may possibly perform an analysis with the full data sample at high $Q^2$.

On the longer term, an extension of the present kinematic region and improved quality of the data can be expected only at a future linear collider [1] or photon collider [11]. At a photon collider the coverage and precision can be of similar quality as the one of today’s proton measurements.

In summary the structure of the photon is now measured in the kinematical range of $0.001 < x < 0.9$ and $1.9 < Q^2 < 780$ GeV$^2$. The precision has been improving over the years. The charm structure function measurement can become significant if the data of all experiments will be analysed and combined. A first extraction of the electron structure function has been presented.

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