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The Photon Structure Function at Small-x

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Abstract

It is shown that recent small–x measurements of the photon structure function $F_2^\gamma(x, Q^2)$ by the LEP–OPAL collaboration are consistent with parameter–free QCD predictions at all presently accessible values of Q^2.

Recently the OPAL collaboration [1] at the CERN–LEP collider has extended the measurements of the photon structure function $F_2^\gamma(x,Q^2)$ into the small–x region down to $x \simeq 10^{-3}$, probing lower values of x than ever before. The observed rise of F_2^γ towards low values of x, $x < 0.1$, is in agreement with general QCD renormalization group (RG) improved expectations. It has, however, been noted that the rising small–x data at lower scales $Q^2 \simeq 2 - 4$ GeV^2 lie above the original QCD expectations anticipated almost a decade ago [2, 3].

It is the purpose of the present note to demonstrate that more recent and updated parameter–free QCD predictions [4] for $F_2^\gamma(x,Q^2)$ are in general also consistent with the OPAL small–x measurements at all presently accessible values of Q^2.

Before presenting our results it is instructive to recapitulate briefly the main differences between the original GRV$_\gamma$ [2] approach to the photonic parton distributions and the more recent parameter–free predictions of GRS [4]. In the latter approach a coherent superposition of vector mesons has been employed, which maximally enhances the u–quark contributions to F_2^γ, for determining the hadronic parton input $f_{\rm had}^\gamma(x,Q_0^2)$ at a GRV–like [5] input scale $Q_0^2 \equiv \mu_{\rm LO}^2 = 0.26$ GeV^2 and $Q_0^2 \equiv \mu_{\rm NLO}^2 = 0.40$ GeV^2 for calculating the (anti)quark and gluon distributions $f^\gamma(x,Q^2)$ of a real photon in leading order (LO) and next–to–LO (NLO) of QCD. Furthermore, in order to remove the ambiguity of the hadronic light quark sea and gluon input distributions of the photon (being related to the ones of the pion, $f^\pi(x,Q_0^2)$, via vector meson dominance), inherent to the older GRV$_\gamma$ [2] and SaS [3] parametrizations, predictions [6] for $\bar{q}^{\,\pi}(x,Q^2)$ and $g^\pi(x,Q^2)$ have been used by GRS [4] which follow from constituent quark model constraints [7]. These latter constraints allow to express $\bar{q}^{\,\pi}$ and g^π entirely in terms of the experimentally known pionic valence density and the rather well known quark–sea and gluon distributions of the nucleon [6], using most recent updated valence–like input parton densities of the nucleon. Since more recent DIS small–x measurements at HERA imply somewhat less steep sea and gluon distributions of the proton [5], the structure functions of the photon will therefore also rise less steeply in x [4] than the previous GRV$_\gamma$ [2] ones as will be seen in the figures shown below. In this way one arrives at truly parameter–free predictions for the structure functions and parton distributions of the photon.

In Figs. 1 and 2 we compare the more recent GRS predictions [4] and the older GRV$_\gamma$ results [2] with the recent small–x OPAL measurements [1] and, for completeness, some relevant L3 data [8] are shown as well. The parameter–free LO– and NLO–GRS expectations are confirmed by the small–x OPAL data at all (small and large) experimentally accessible scales Q^2. This is in contrast to the GRV$_\gamma$ and SaS results which at LO are somewhat below the data at small Q^2 in Fig. 1 and seem to increase too strongly at small x in NLO, in particular at larger values of Q^2 as shown in Fig. 2. The main reason for this latter stronger and steeper x–dependence in LO and NLO derives from the assumed vanishing (pionic) quark–sea input at $Q_0^2 = \mu^2_{\rm LO,NLO}$ for the anti(quark) distributions of the photon as well as from relating the hadronic gluon input of the photon directly to its (pionic) valence distribution [2, 9]. This is in contrast to the more realistic (input) boundary conditions employed by GRS [4, 6].

Clearly these small–x measurements imply that the photon must contain [1] a dominant hadron–like component at low x, since the simple direct 'box' cross section (based on the subprocess $\gamma^*(Q^2)\gamma \to q\bar{q}$) yields $F^\gamma_{2,\rm box} \to 0$ as $x \to 0$, in contrast to the data for $x < 0.1$ in Figs. 1 and 2. The QCD RG–improved parton distributions of the photon are thus essential for understanding the data on $F_2^\gamma(x, Q^2)$, with its dominant contributions deriving from $q^\gamma(x, Q^2) = \bar{q}^{\,\gamma}(x, Q^2)$. It would be also interesting and important to extend present measurements [10, 11] of the gluon distribution of the photon, $g^\gamma(x, Q^2)$, below the presently measured region $0.1 \lesssim x < 1$ where similarly $g^\gamma(x < 0.1,\, Q^2)$ is expected to be also somewhat flatter [4] in the small–x region than previously anticipated [2].

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Figure Captions

Fig. 1. Comparison of the parameter–free GRS predictions [4], the previous GRV_γ [2] and SaS [3] results for $F_2^\gamma(x,Q^2)$ with the recent OPAL (1.9 GeV^2) small–x measurements [1] at two fixed lower scales Q^2. The previous OPAL (1.86 GeV^2) [1] and L3 [8] data are also displayed.

Fig. 2. As in Fig. 1 but at two fixed scales Q^2. The recent OPAL small–x data are taken from Ref. [1].

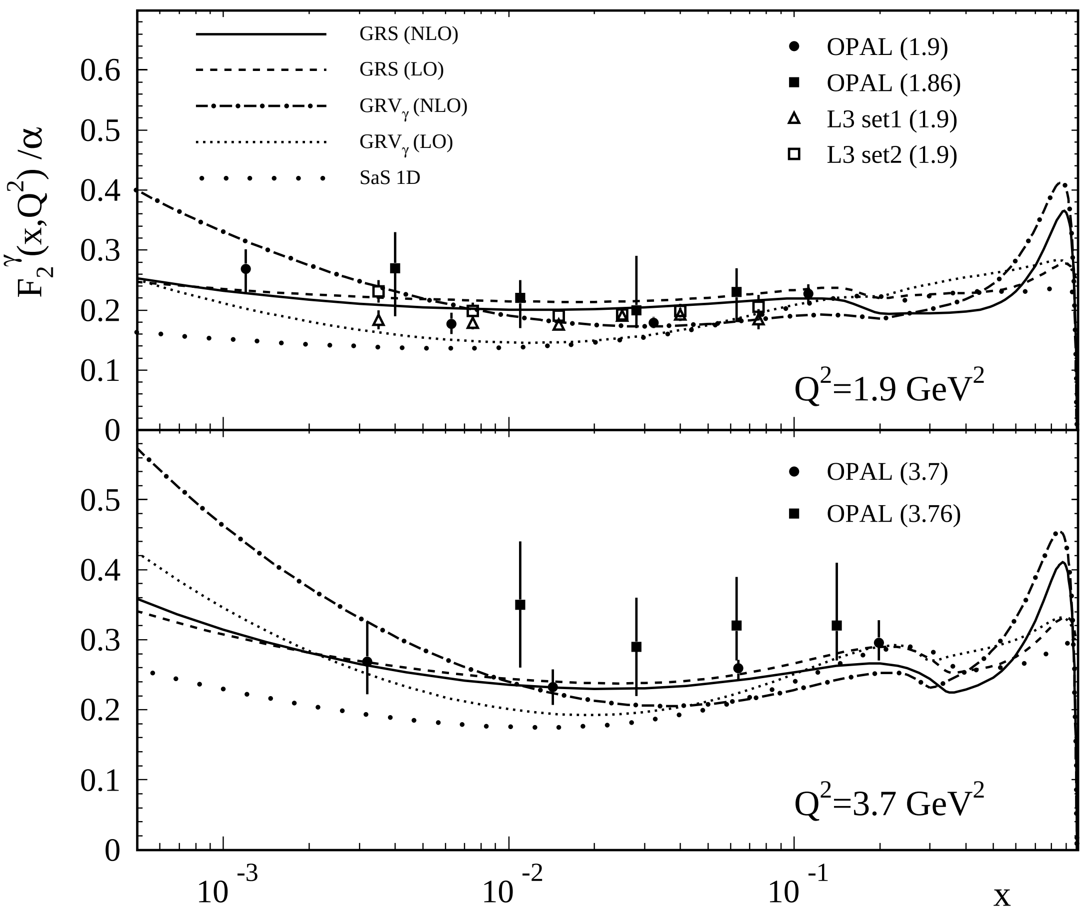
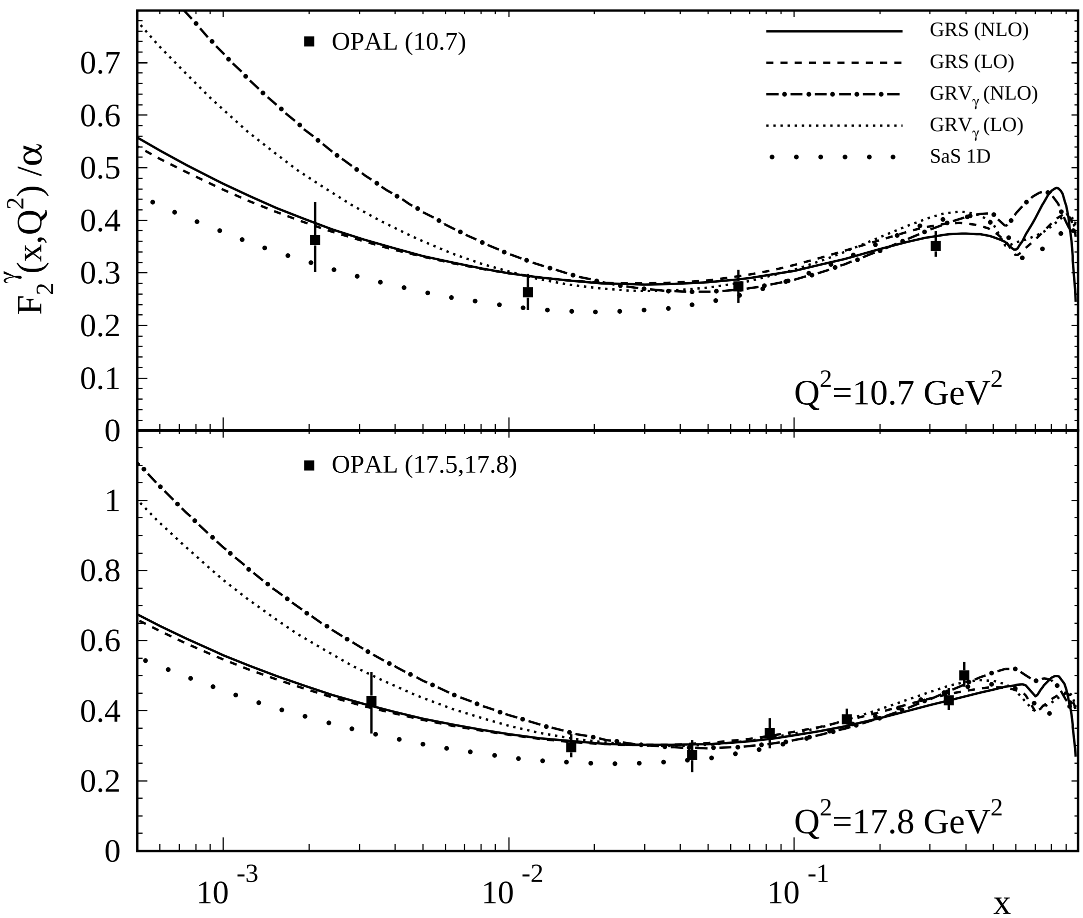

GRS (NLO)
GRS (LO)
GRV$_\gamma$ (NLO)
GRV$_\gamma$ (LO)
SaS 1D
OPAL (1.9)
OPAL (1.86)
L3 set1 (1.9)
L3 set2 (1.9)
$F_2^\gamma(x,Q^2)/\alpha$
Q^2=1.9 GeV^2
OPAL (3.7)
OPAL (3.76)
Q^2=3.7 GeV^2
x

Fig. 1



OPAL (10.7)
GRS (NLO)
GRS (LO)
GRV$_\gamma$ (NLO)
GRV$_\gamma$ (LO)
SaS 1D
$F_2^\gamma(x,Q^2)/\alpha$
Q^2=10.7 GeV^2
OPAL (17.5,17.8)
Q^2=17.8 GeV^2
x

Fig. 2