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Parton distributions in the photon from $\gamma^*\gamma$ and $\gamma^* p$ scattering

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Abstract

Leading order parton distributions in the photon are extracted from the existing F_2^γ measurements and the low-x proton structure function. The latter is related to the photon structure function by assuming Gribov factorization to hold at low x. The resulting parton distributions in the photon are found to be consistent with the Frankfurt–Gurvich sum rule for the photon.

1 Introduction

The notion of the photon structure function F_2^γ was introduced in analogy to the well known nucleon case. The first measurements of F_2^γ became available from e^+e^- collisions which could be interpreted as processes in which a highly virtual photon, of virtuality Q^2, probes an almost real target photon, with virtuality $P^2 \approx 0$.

While the proton structure function F_2^p has been well measured, F_2^γ data are poor and limited mainly to the high Bjorken–x region ($x > 0.05$) [1]. This limitation comes largely because it is not easy to measure $\gamma\gamma$ interactions at high center of mass energies, W.

The measured data of F_2^γ have been used to determine the quark distributions in the photon [2] in much the same way as the parton densities in the proton are determined [3]. However, contrary to the proton case, the gluon density in the photon is quite badly determined since no simple momentum sum rule can be applied. Recently, a sum rule for the virtual target photon case ($P^2 \neq 0$) has been devised by Gurvich and Frankfurt [4]. It can be extrapolated to the real photon case ($P^2 = 0$). Most of the presently known parameterization of the gluon in the photon, $xg^\gamma(x)$, violate this sum rule.

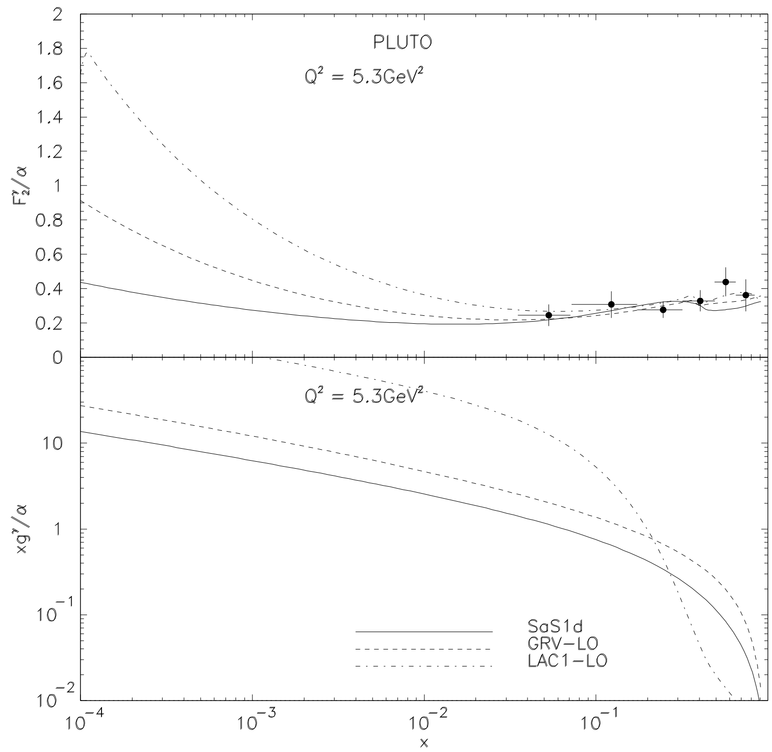

Figure 1: (a) Measured F_2^γ data at $Q^2 = 5.3$ GeV^2 (dots) together with some parton parameterizations (lines). (b) The gluon density distributions as obtained by the SaS (full line), GRV (dashed line) and LAC (dash-dotted line) parameterizations.

As one example of the present situation concerning parton distributions in the photon we show in figure 1a the measured data of F_2^γ at a probing virtuality of $Q^2 = 5.3$ GeV^2 as function of x [5]. The data show a slight decrease as x decreases. The curves are the different parameterizations [6, 7, 8], all of which give similar values in the region where they were fitted to the data. However they differ appreciably in the low–x region which is not constrained by the measurements. In figure 1b the inferred gluon density distribution at the same Q^2 is shown as function of x. The distributions of the different parameterizations differ in the whole x region.

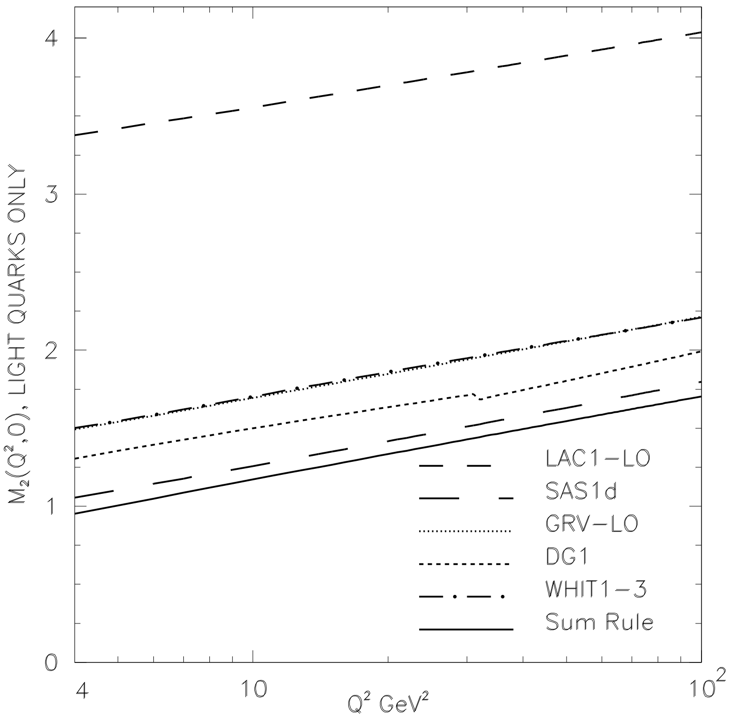

Figure 2: The Frankfurt–Gurvich sum rule for the photon (full line) as function of Q^2 for the real photon case, together with that obtained from different parton parameterization, as shown in the figure.

In figure 2 we present the quantity $M_2(Q^2, 0)$ which is constrained by the Frankfurt–Gurvich sum rule in the real photon case, as function of Q^2, for the case of light quarks only. As can be seen, only the SaS parameterization [8] is close to the expectations of the sum rule [4].

In the present note we use Gribov factorization [9] as suggested in [10] to constrain the behaviour of F_2^γ at low x from the data of F_2^p. We then use this extended set of data to extract the parton distributions in the photon.

2 Gribov factorization

Gribov factorization [9] is based on the assumption that at high energies the total cross section of two interacting particles is determined by the property of the universal pomeron trajectory. This implies relations between total cross sections of various interacting particles. In particular, the Gribov factorization can be used [9, 11] to relate the total $\gamma\gamma$ cross section, $\sigma_{\gamma\gamma}$, with that of photoproduction, $\sigma_{\gamma p}$, and that of pp, σ_{pp}, all at the same center of mass energy squared W^2. Using the assumption made in [10] that at low–x Gribov factorization is applicable also for virtual photons, one can relate the proton and the real photon structure functions in a simple way [10]:

$$F_2^\gamma(x,Q^2) = F_2^p(x,Q^2)\frac{\sigma_{\gamma p}(W^2)}{\sigma_{pp}(W^2)}. \tag{1}$$

Relation (1) allows the use of well measured quantities like total cross sections and proton structure function data to predict the values of the photon structure function in the region of low–x where equation (1) is expected to be valid. Since this is also the region where direct measurements of the photon structure function are difficult and not available, the use of (1) provides a way to 'obtain' F_2^γ 'data' and use them as an additional source, on top of the direct measurements of F_2^γ , to extract information on the parton distributions in the photon.

3 Results

We have used data on F_2^γ in order to obtain the parton distributions in the photon, in a similar way to the procedure used in [6]. We have applied a leading order evolution equation, using four flavours, and assumed the following simple parameterization forms for the partons, at a starting scale of $Q_0^2 = 4$ GeV^2:

$$xq(x) = K_{sup} A e_q^2 (1+Bx) x^C \tag{2}$$
$$xg(x) = A_g x^{B_g}(1-x)^{C_g} \tag{3}$$

where K_{sup} is a suppression factor, having the value 1 for u and d quarks, and $K_{sup} = 0.3$ for s and c quarks. The charge of the quarks is denoted by e_q and A, B, C, A_g, B_g and C_g are parameters to be determined from a fit to the F_2^γ data.

We have used all available data on F_2^γ together with the indirect 'data' obtained through relation (1). The latter was obtained by using the data of the proton structure function [1] for $x \leq 0.01$. For the total photoproduction cross section and the total pp cross sections, we used the Donnachie–Landshoff parameterizations [12], which give a good representation of the total cross section data. For the measured F_2^γ data, we used as errors the statistical and systematical errors added in quadrature. For the 'data' as obtained through relation (1) we used an additional systematic error of 3% as an estimate of the uncertainty coming from assuming the Gribov factorization to hold also for the virtual photon case at low–x.

The parameters in (2) and (3) were determined from a best fit to the data. We used 247 data points and obtained a χ^2 value of 172. The results of the best fit are displayed in figure 3. The directly measured photon structure function data appear as full points, while the data obtained through the use of the Gribov factorization are displayed as open triangles. We displayed the F_2^γ data of $Q^2 = 5.09$ (TPC/2γ), 5.1 (TOPAZ) and 5.3 (PLUTO) GeV^2 in the same figure

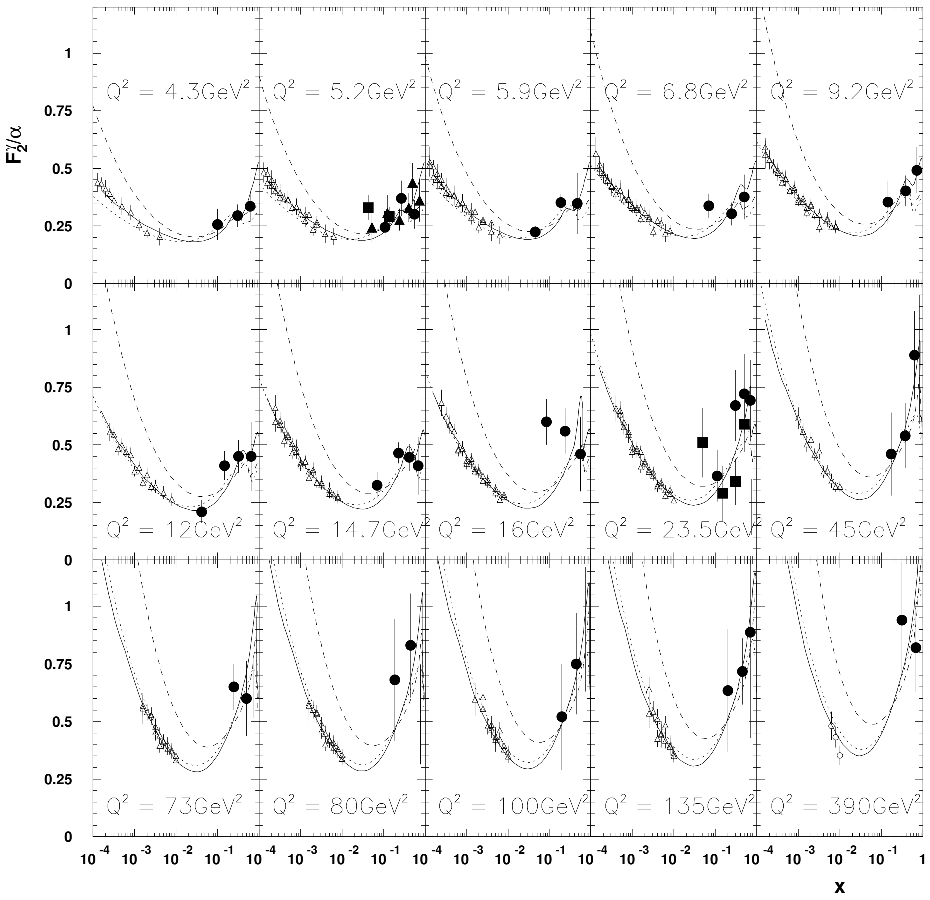

Figure 3: The photon structure function as function of x for fixed Q^2 values as indicated in the figure. The full points are the direct measurements and the open triangles are those obtained from F_2^p through the Gribov factorization relation (1). The full line is the result of the present fit as described in the text, the dashed line is that of the GRV–LO parameterization, and the dotted line is that of SaS.

labeled 5.2 GeV^2. We also show the data of Q^2 of 23 (TASSO) and 24 (JADE) GeV^2 in one bin of $Q^2 = 23.5$ GeV^2. All the low–x data coming from the proton structure function have been scaled to the value of Q^2 which is indicated in the figure. The solid curves are the results of the present parameterization. For comparison we show as dashed lines the results of the GRV-LO [7] parameterization which differ substantially from the present parameterization in the low–x region. The dotted lines are the resulta of the SaS [8] parameterization, which are very close to those of the present parameterization.

The photon structure function data exhibit a minimum in the range $10^{-2} < x < 10^{-1}$, which is broad at lower Q^2 and gets sharper as Q^2 increases. The increase of F_2^γ with decreasing x is not surprising since it is an outcome of the factorization assumption which uses the proton structure function data.

The results of the new parameterization, which give a good fit to the data in the whole x region, can be confronted with the expectations of the Frankfurt–Gurvich sum rule. This constraint was not used in the fit but left in order to test the parameterization. The sum rule using the new parameterization agree with the theoretical expectations within 5%. The only other parameterization which is close to fulfil the expected sum rule is that of SaS [8].

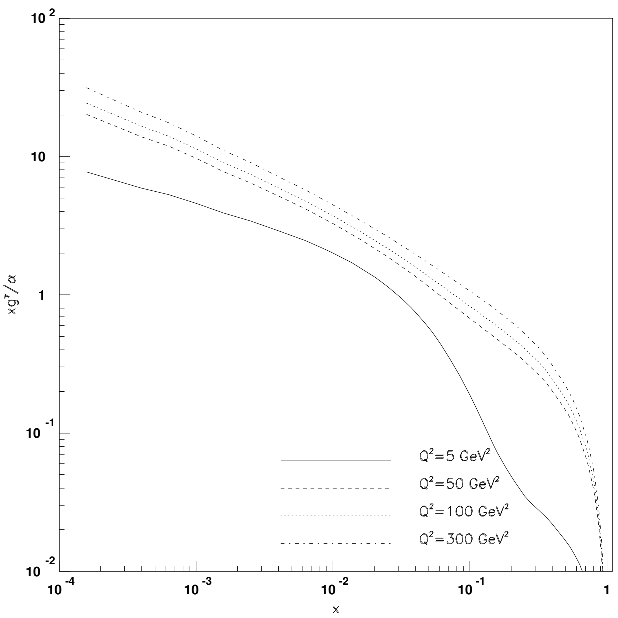

Figure 4: The gluon momentum distribution in the photon as function of x, for fixed values of Q^2, as calculated from the present parameterization.

In figure 4 we present the gluon momentum density as calculated from the form (3) as function of x, for a few fixed values of Q^2. The gluon density increases as x decreases. One sees also the increase of the gluon momentum density with Q^2, at a given value of x. This is a reflection of the feature that the photon structure function has a positive scaling violation at all values of x, contrary to the proton case.

4 Conclusions

We have extracted the leading order parton distributions in the photon by using the existing F_2^γ measurements and the low–x proton structure function. The latter is related to the photon structure function by assuming Gribov factorization to hold at low x. The resulting parton distributions in the photon fulfil the Frankfurt–Gurvich sum rule for the photon.

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