LU TP 95–21
hep-ph/9509264
August 1995

Low- and High-Mass Components of the Photon Distribution Functions*

Torbjörn Sjöstrand
Department of Theoretical Physics, University of Lund,
Sölvegatan 14A, S-223 62 Lund, Sweden
and
Gerhard A. Schuler
Theory Division, CERN
CH-1211 Geneva 23, Switzerland

Abstract
Four new parton distributions of the photon are presented, with a description of theory choices, properties and applications.

*To appear in the Proceedings of the International Europhysics Conference on High Energy Physics, Brussels, Belgium, July 27 – August 2, 1995.

1 Introduction

This is a brief presentation of ref. 1. Related references may be found on the non-perturbative constraints on the photon structure function[2], on photoproduction[3] and on $\gamma\gamma$ physics[4].

There is already available many parton distribution function sets of the photon[5, 6, 7, 8, 9, 10, 11], so why produce more ones? A few reasons:

- The choice of theoretical ansatz is ambiguous, so there is more room to play than e.g. for the proton.
- The data are very incomplete and uncertain, so there is a need for contrasting parametrizations.
- Compared with previous studies, we put more emphasis on the subdivision of the distributions into several components of different physical nature. This is required for a detailed modelling of γp and $\gamma\gamma$ hadronic final states, and for a sophisticated eikonalization approach to the relation between jet and total cross sections.
- Our ansatz allows a closed-form extension to the parton distributions of a (moderately) virtual photon.

2 Physics Assumptions and Fits

Photons obey a set of inhomogeneous evolution equations, where the inhomogeneous term is induced by $\gamma \to \mathrm{q}\overline{\mathrm{q}}$ branchings. The solution can be written as the sum of two terms,

$$f_a^{\gamma}(x,Q^2) = f_a^{\gamma,\mathrm{NP}}(x,Q^2;Q_0^2) + f_a^{\gamma,\mathrm{PT}}(x,Q^2;Q_0^2) \ , \tag{1}$$

where the former term is a solution to the homogeneous evolution with a (non-perturbative) input at $Q = Q_0$ and the latter is a solution to the full inhomogeneous equation with boundary condition $f_a^{\gamma,\mathrm{PT}}(x,Q_0^2;Q_0^2) \equiv 0$. One possible physics interpretation is to let $f_a^{\gamma,\mathrm{NP}}$ correspond to $\gamma \leftrightarrow V$ fluctuations, where $V = \rho^0, \omega, \phi, \ldots$ is a set of vector mesons, and let $f_a^{\gamma,\mathrm{PT}}$ correspond to perturbative ("anomalous") $\gamma \leftrightarrow \mathrm{q}\overline{\mathrm{q}}$ fluctuations. The discrete spectum of vector mesons can be combined with the continuous (in virtuality k^2) spectrum of $\mathrm{q}\overline{\mathrm{q}}$ fluctuations, to give

$$\begin{aligned} f_a^{\gamma}(x,Q^2) = & \sum_V \frac{4\pi\alpha_{\mathrm{em}}}{f_V^2} f_a^{\gamma,V}(x,Q^2) \\ & + \frac{\alpha_{\mathrm{em}}}{2\pi} \sum_{\mathrm{q}} 2e_{\mathrm{q}}^2 \int_{Q_0^2}^{Q^2} \frac{\mathrm{d}k^2}{k^2} f_a^{\gamma,\mathrm{q}\overline{\mathrm{q}}}(x,Q^2;k^2) \ , \end{aligned} \tag{2}$$

where each component $f^{\gamma,V}$ and $f^{\gamma,\mathrm{q}\overline{\mathrm{q}}}$ obeys a unit momentum sum rule.

Beyond this fairly general ansatz, a number of choices has to be made, as described in the following.

What is Q_0? A low scale, $Q_0 \approx 0.6$ GeV, is favoured if the V states above are to be associated with the lowest-lying resonances only. Then one expects $Q_0 \sim m_\rho/2$–m_ρ. Furthermore, with this Q_0 one obtains a reasonable description of the total γp cross section, and continuity e.g. in the primordial $k_\perp$ spectrum. Against this choice speaks worries that perturbation theory may not be valid at such low Q, or at least that higher-twist terms appear in addition to the standard ones. Alternatively one could therefore pick a larger value, $Q_0 \approx 2$ GeV, where these worries are absent. One then needs to include also higher resonances in the vector-meson sector, which adds some arbitrariness, and one can no longer compare with low-Q data. We have chosen to prepare sets for both these (extreme) alternatives.

How handle the direct contribution? Unlike the p, the γ has a direct component where the photon acts as an unresolved probe. In the definition of F_2^γ this adds a component C^γ, symbolically

$$F_2^\gamma(x,Q^2) = \sum_{\mathrm{q}} e_{\mathrm{q}}^2 \left[f_{\mathrm{q}}^\gamma + f_{\overline{\mathrm{q}}}^\gamma \right] \otimes C_{\mathrm{q}} + f_{\mathrm{g}}^\gamma \otimes C_{\mathrm{g}} + C^\gamma \; . \tag{3}$$

Since $C^\gamma \equiv 0$ in leading order, and since we stay with leading-order fits, it is permissible to neglect this complication. Numerically, however, it makes a non-negligible difference. We therefore make two kinds of fits, one DIS type with $C^\gamma = 0$ and one $\overline{\mathrm{MS}}$ type including the universal part of C^γ[9].

How deal with heavy flavours, i.e. mainly charm? When jet production is studied for real incoming photons, the standard evolution approach is reasonable, but with a lower cut-off $Q_0 \approx m_{\mathrm{c}}$ for $\gamma \to \mathrm{c}\overline{\mathrm{c}}$. Moving to deep inelastic scattering, $\mathrm{e}\gamma \to \mathrm{e}X$, there is an extra kinematical constraint: $W^2 = Q^2(1-x)/x > 4m_{\mathrm{c}}^2$. It is here better to use the "Bethe-Heitler" cross section for $\gamma^*\gamma^* \to \mathrm{c}\overline{\mathrm{c}}$. Therefore two kinds of output is provided. The parton distributions are calculated as the sum of a vector-meson part and an anomalous part including all five flavours, while F_2^γ is calculated separately from the sum of the same vector-meson part, an anomalous part and possibly a C^γ part now only covering the three light flavours, and a Bethe-Heitler part for c and b.

Should ρ^0 and ω be added coherently or incoherently? In a coherent mixture, $\mathrm{u}\overline{\mathrm{u}} : \mathrm{d}\overline{\mathrm{d}} = 4:1$ at Q_0, while the incoherent mixture gives $1:1$. We argue for coherence at the short distances probed by parton distributions. This contrasts with long-distance processes, such as $\mathrm{e}\gamma \to \mathrm{e}V$.

What is Λ_{QCD}? The data are not good enough to allow a precise determination. Therefore we use a fixed value $\Lambda^{(4)} = 200$ MeV, in agreement with conventional results for proton distributions.

In total, four distributions are presented[1], based on fits to available data:

- SaS 1D, with $Q_0 = 0.6$ GeV and in the DIS scheme.
- SaS 1M, with $Q_0 = 0.6$ GeV and in the $\overline{\mathrm{MS}}$ scheme.
- SaS 2D, with $Q_0 = 2$ GeV and in the DIS scheme.
- SaS 2M, with $Q_0 = 2$ GeV and in the $\overline{\mathrm{MS}}$ scheme.

Fig. 1 compares these distributions at one Q^2 value.

The code for the parametrizations is freely available, e.g. on the web:
`http://thep.lu.se/tf2/staff/torbjorn/lsasgam`

The parametrizations above can be used also for photons with a virtuality $P^2 \neq 0$. This is done by introducing dipole factors $m_V^4/(m_V^2 + P^2)^2$ for the VMD components, by changing the lower cut-off of the anomalous integral from Q_0^2 to $\max(Q_0^2, P^2)$, and by using the proper off-shell expressions for Bethe-Heitler cross sections etc.

3 Summary

Above are presented four new sets of parton distributions and structure functions of the photon[1]. Owing to the subdivision of the distributions into different physics components, it is now possible to construct detailed models of γp and $\gamma\gamma$ events. These models are presented elsewhere[3, 4], with further work in progress.

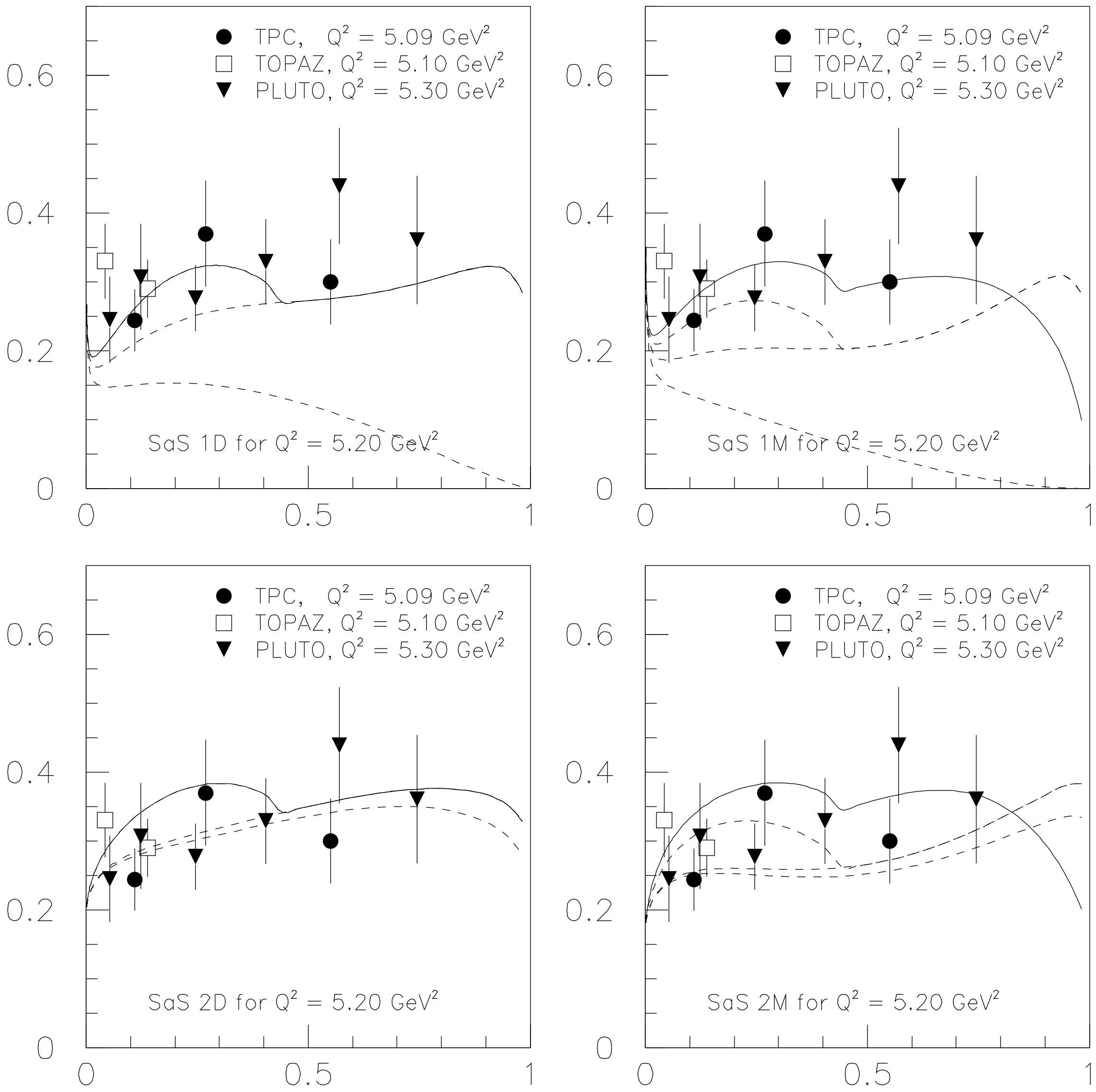

Figure 1: Subdivision of the full F_2^γ parametrization by component, compared with data at $Q^2 \approx 5.2$ GeV^2. The total F_2^γ (except for an overall factor α_{em}) is shown by the full curve. The lowest dashed curve gives the VMD contribution, and the next lowest the sum of VMD and anomalous ones. The third dashed curve, which coincides with the full curve for the DIS fits, gives the sum of VMD, anomalous and Bethe–Heitler terms. For the $\overline{\mathrm{MS}}$ fits, the full curve additionally contains the contribution of the C^γ term. Note that this last term is negative at large x.

References

[1] G.A. Schuler and T. Sjöstrand, CERN–TH/95–62 and LU TP 95–6, to appear in *Zeit. Phys.* **C**.

[2] G.A. Schuler, Regensburg preprint TPR–95–15.

[3] G.A. Schuler and T. Sjöstrand, *Phys. Lett.* **B300** (1993) 169,. *Nucl. Phys.* **B407** (1993) 539.

[4] G.A. Schuler and T. Sjöstrand, in *Two-Photon Physics from DAΦNE to LEP200 and Beyond*, World Scientific, Singapore, 1994, Eds. F. Kapusta and J. Parisi, p. 163.

[5] M. Drees and K. Grassie, *Zeit. Phys.* **C28** (1985) 451.

[6] H. Abramowicz, K. Charchula and A. Levy, *Phys. Lett.* **B269** (1991) 458..

[7] M. Glück, E. Reya and A. Vogt, *Phys. Rev.* **D46** (1992) 1973.

[8] L.E. Gordon and J.K. Storrow, *Zeit. Phys.* **C56** (1992) 307.

[9] P. Aurenche, M. Fontannaz and J.-Ph. Guillet, *Zeit. Phys.* **C64** (1994) 621.

[10] K. Hagiwara, M. Tanaka, I. Watanabe and T. Izubuchi, *Phys. Rev.* **D51** (1995) 3197.

[11] J.H. Field, F. Kapusta and L. Poggioli, *Phys. Lett.* **B181** (1986) 362,. *Zeit. Phys.* **C36** (1987) 121.