NEW RADIATIVELY GENERATED LO QUARK (u, d, s, c, b) AND GLUON DENSITIES IN REAL PHOTON*

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New, radiatively generated, LO quark (u, d, s, c, b) and gluon densities in real photon are presented. We [1] perform a global fit, based on LO DGLAP evolution equations, to all available data for the structure function $F_2^\gamma(x, Q^2)$. We adopt a new theoretical approach called ACOT(χ) to deal with heavy quark thresholds (CJKL model). For comparison we perform a standard fit using the Fixed Flavour Number Scheme ($\mathrm{FFNS}_{\mathrm{cjkl}}$ model), updated with respect to previous fits of this type. We show the superiority of the CJKL model over the $\mathrm{FFNS}_{\mathrm{cjkl}}$ one and other LO parton parametrizations for $F_2^\gamma(x, Q^2)$. Both our models describe equally well the gluon density extracted from HERA data.

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Is there a need for a new parton parametrization of the real photon? Our [1] motivation for its construction is twofold. On the one hand, there is a vast amount of new data on $F_2^\gamma(x, Q^2)$ that has not been used: eg. two recent parametrizations: GRV [2] and GRS [3] used respectively about 70 and 130 experimental points, while at present a total of 208 independent $F_2^\gamma(x, Q^2)$ points exist. On the other hand, there are discrepancies between the theoretical calculations and experimental results for some processes of heavy quarks production initiated by real photons. Let us just mention here the D^* and D_s meson inclusive photoproduction or D^* meson production with associated dijets [4] at HERA as examples. Disagreement is even more profound for the open beauty production in both HERA [5] and LEP [6].

Our analysis especially focuses on the heavy quark contributions to the $F_2^\gamma(x, Q^2)$. We apply a new theoretical Variable Flavour Number Scheme

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(VFNS) approach proposed for heavy flavour production in *ep* collision in [7], denoted as ACOT(χ). For comparison we perform a standard FFNS fit as well. Since these approaches are based on very distinct schemes and need different evolution programs we will refer to them as to two models, CJKL (ACOT(χ) type) and $\mathrm{FFNS_{cjkl}}$ models, respectively.

Our approach is based on the GRV one [2], introduced in year '92. We solve the DGLAP equations through Mellin moments $g^n(Q^2) = \int_0^1 x^{n-1} g(x,Q^2)dx$ and inverse Mellin transformation. Equations have the following form then: $\frac{df_i^{\gamma,n}(Q^2)}{d\ln Q^2} = \frac{\alpha}{2\pi}k_i^n(x) + \frac{\alpha_s(Q^2)}{2\pi}P_{ij}^n f_j^{\gamma,n}(Q^2)$, where $L = \alpha_s(Q^2)/\alpha_s(Q_0^2)$, P_{ij} and k_i are the LO splitting functions (k_i arises from the Parton Model process $\gamma\gamma^* \to q\bar{q}$), Q_0^2 is the scale where the evolution starts. In the following we will skip the subscripts i,j denoting different partons.

Solution to the DGLAP equations is divided into so called point-like (PL) and hadron-like (had) parts:

$$
\begin{aligned}
f^{\gamma,n}(Q^2) &= f_{\mathrm{had}}^{\gamma,n}(Q^2) + f_{\mathrm{PL}}^{\gamma,n}(Q^2), \quad f_{\mathrm{had}}^{\gamma,n}(Q^2) = L^{-2P^n/\beta_0} f^{\gamma,n}(Q_0^2),\\
f_{\mathrm{PL}}^{\gamma,n}(Q^2) &= \frac{4\pi}{\alpha_s(Q^2)}\frac{1}{1-2P^n/\beta_0}\frac{\alpha}{2\pi\beta_0}\left[1-L^{1-2P^n/\beta_0}\right]k^n. \qquad (1)
\end{aligned}
$$

In this analysis as in GRV'92 starting scale of the evolution has been chosen to be small, $Q_0^2 = 0.25\ \mathrm{GeV}^2$. Point-like contribution is calculable without any further assumptions while the hadronic part needs an input distribution. The Vector Meson Dominance (VMD) model can be utilized for this purpose, $f_{\mathrm{had}}^{\gamma}(x,Q_0^2) = \sum_V \frac{4\pi\alpha}{\hat{f}_V^2} f_V(x,Q_0^2)$, with $\hat{f}_V^2$ calculated from the $\Gamma(V \to e^+e^-)$ width. Usually vector mesons V taken into account are the light ρ, ϕ and ω mesons. Often they are represented only by the ρ meson, while other mesons are accounted for by a single parameter κ. We adopt this approach and our hadronic input densities take form: $f_{\mathrm{had}}^{\gamma}(x,Q_0^2) = \kappa\frac{4\pi\alpha}{\hat{f}_\rho^2} f_\pi(x,Q_0^2)$. In GRV'92 the ρ parton densities are approximated with the pionic ones. We directly fit parameters for ρ meson to the F_2^γ experimental data. We apply simplest model with only valence and gluon input distributions: $xv_\rho(x,Q_0^2) = N_v x^\alpha (1-x)^\beta$, $\quad xG_\rho = N_g x v_\rho(x,Q_0^2)$. We use two constraints. First comes from the restriction that in any meson only one pair of valence quark exists, so: $\int_0^1 v_\rho(x,Q_0^2)dx = 1$. Second represents the energy-momentum sum rule for the meson: $\int_0^1 x(2v_\rho(x,Q_0^2) + G_\rho(x,Q_0^2))dx = 1$. In the fit we have 3 independent parameters α, β and κ.

In the Fixed Flavour Number Scheme $\mathrm{FFNS_{cjkl}}$ model only gluon and light quark densities exist (three 'active' flavours in the photon). The heavy quark (h) contributions to the $F_2^\gamma(x,Q^2)$ are described by lowest order $\gamma^\star(Q^2)\gamma \to h\bar{h}$ (Bethe–Heitler) cross-section. Those contributions appear provided that the centre-mass energy of the $\gamma^\star\gamma$ system, W, fulfills a kinematic threshold condition $W \gtrsim 2m_h$.

The CJKL model bases on the new ACOTχ description, [7], which we for the very first time apply to the photon structure function analysis. This approach combines the FFNS and Zero-mass Variable Flavour Number Scheme in which all quarks are treated as massless. For the light quark contributions to F_2^γ we take: $F_2^\gamma(x,Q^2)|_{u,d,s} = x\sum_{i=1}^{2\times 3} e_i^2 q_i^\gamma(x,Q^2)$, while for heavy quarks we include following terms:

$$F_2^\gamma(x,Q^2)|_{c,b} = \sum_{h=c,b}^{2\times 2}\left[x e_h^2 q_h^\gamma(x,Q^2) + F_{2,h}^\gamma(x,Q^2)|_{\rm direct} + F_{2,h}^\gamma(x,Q^2)|_{\rm resolv}\right].$$

The $F_{2,h}^\gamma|_{\rm direct}$ is the Bethe–Heitler term while the $F_{2,h}^\gamma|_{\rm resolv}$ contribution corresponds to the $\gamma^\star G \to h\bar{h}$ process. By including them we double count some contributions with heavy quarks which are already contained by the DGLAP equations for $q_h^\gamma(x,Q^2)$. Therefore from the above sum we must subtract the following terms:

$$F_2^\gamma(x,Q^2)|_{\rm subtr.} =$$
$$x\sum_{h=c,b}^{2\times 2}\ln\frac{Q^2}{m_h^2}\left[3e_h^4\frac{\alpha}{2\pi}(x^2+(1-x)^2) + e_h^2\frac{\alpha_{\rm s}}{2\pi}\int_x^1\frac{dy}{y}P_{qG}\left(\frac{x}{y}\right)G^\gamma(y,Q^2)\right].$$

The first term is an exact solution of the equation $\frac{dq_h^\gamma(x,Q^2)}{d\ln Q^2} = \frac{\alpha}{2\pi}e_h^2 k(x)$, a part of the DGLAP equations. The second term is an approximated solution for

$$\frac{dq_h^\gamma(x,Q^2)}{d\ln Q^2} = \frac{\alpha_{\rm s}(Q^2)}{2\pi}\int_x^1\frac{dy}{y}\left[P_{qG}(\frac{x}{y})G^\gamma(y,Q^2)\right].$$

Further we need to ensure that terms containing heavy quark h disappear when $W\to 2m_h$. The problem emerges for the heavy quark densities q_h^γ and subtraction terms. These terms do not naturally disappear at the threshold. This problem can be cured if instead of x we use the χ variable defined as $\chi \equiv x(1+4m_h^2/Q^2)$ [7]. This way we force vanishing at the threshold of the heavy quark distributions and of the second term of the subtraction contribution (the integral). Unfortunately unlike for proton in case of the photon structure function we are left with the term corresponding to the Bethe–Heitler $F_{2,h}^\gamma|_{\rm direct}$ contribution which now takes form proportional to $\chi^2+(1-\chi)^2$. Obviously this expression does not vanish for $\chi\to 1$. In the region of large Q^2 the change of variables is irrelevant.

Fits of the parameters of both models to the all existing F_2^γ experimental points were performed with use of the MINUIT procedure [8]. References to the experimental data used and plots of the fits can be found in [1].

First table gives fitted parameters for our two models. In two first columns total χ^2 and χ^2 per degree of freedom calculated for 208 $F_2^\gamma(x,Q^2)$ points are shown. Further the obtained values of three independent parameters of fits are given. Finally in two last columns the N_v and N_{gl} parameters computed using the constraints described above are presented.

TABLE I

Model	χ^2 (208 pts)	χ^2/DOF	κ	α	β	N_v	N_{gl}
$\mathrm{FFNS_{cjkl}}$	471	2.30	1.726	0.465	0.127	0.504	1.384
CJKL	431	2.10	1.125	0.843	2.359	2.435	2.982

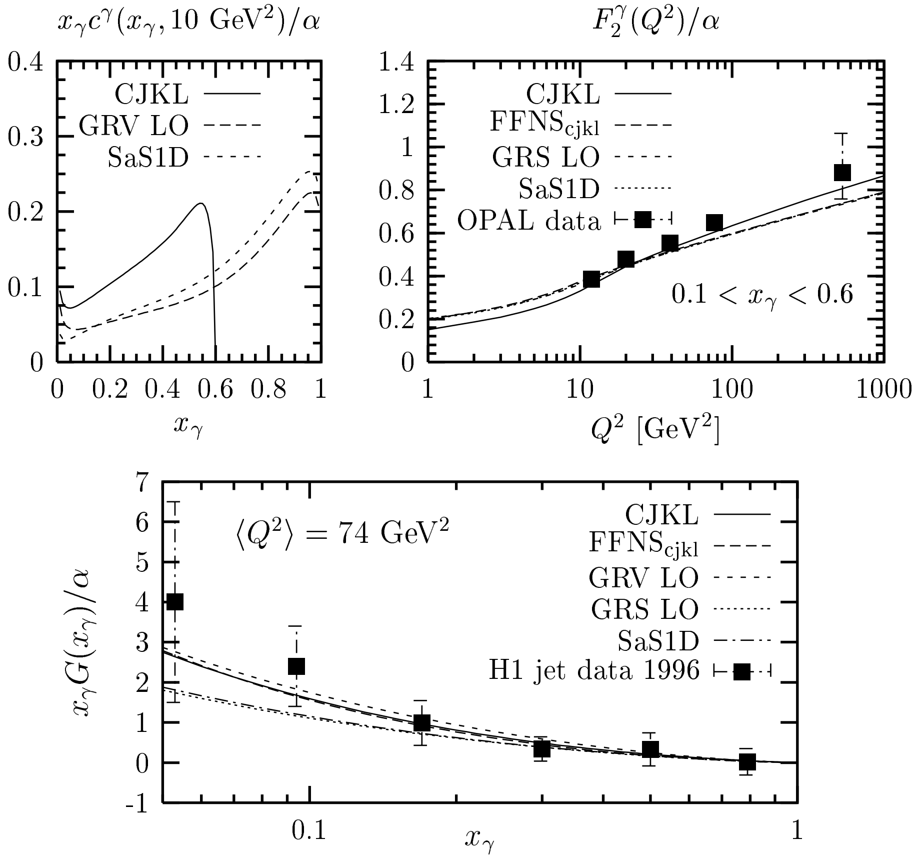
In second table the quality of our fits is compared with the results of the GRS LO [3] and SaS1D [9] parametrizations. The comparison is performed for the set of data excluding the points with $Q^2 < 0.26$ GeV^2 (required by the GRS parametrization). The CJKL model gives best fit in terms of χ^2 but one has to keep in mind that GRS LO and SaS1D parametrizations were fitted to other sets of data.

TABLE II

Model	χ^2 (205 pts)	χ^2/DOF	Model	χ^2 (205 pts)	χ^2/DOF
SaS1D	657	3.25	$\mathrm{FFNS_{cjkl}}$	442	2.19
GRS LO	499	2.43	CJKL	406	2.01

First figure shows the improved threshold behavior of the charm quark density obtained in our CJKL model at $Q^2 = 10$ GeV^2 in comparison to predictions of other parametrizations. Second figure presents prediction for the $F_2^\gamma(x,Q^2)$ averaged over $0.1 < x < 0.6$ region compared with the recent OPAL data [10] and with the GRS LO and SaS1D results. We observe that apart from the CJKL results other parametrizations predict similar logarythmic shape of the $F_2^\gamma(Q^2)$ dependence. The CJKL model describes these data slightly better than other parametrizations.

As an independent test of our results we compare the gluon distributions of CJKL and $\mathrm{FFNS_{cjkl}}$ models with the ones measured by the H1 collaboration in the *ep* dijet production [11]. Third figure shows the obtained gluon density at $Q^2 = 74$ GeV^2 compared to results of our two models and of other parametrizations. Both CJKL and $\mathrm{FFNS_{cjkl}}$ models agree with the GRV LO result which gave so far best agreement with the H1 data.



In conclusion, new parametrization of the real photon structure based on the LO DGLAP equations has been presented. New experimental data has been used to perform a global fit. New VFNS scheme, ACOT(χ), has been applied to the photon case for the very first time. Improved threshold behavior of the heavy quarks contributions is obtained. More details and comparisons can be found in [1]. Also a a simple analytic parametrization of our model is given there. A fortran program can be obtained at the web page `http://www.fuw.edu.pl/~pjank/param`. Work on the NLO parton densities is already in progress.

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