Status of CCFM - un-integrated gluon densities

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New fits of the unintegrated gluon density obtained from CCFM evolution to HERA $F_2(x, Q^2)$ data are presented. Also predictions of the unintegrated gluon density of the real photon are presented.

1 The CCFM splitting function

A general review on small x physics and CCFM evolution can be found in [1]. The original CCFM splitting function is given by :

$$P_{gg}(z, \bar{q}, k_\perp) = \frac{\bar{\alpha}_S(\bar{q}^2)}{1-z} + \frac{\bar{\alpha}_S(k_\perp^2)}{z}\Delta_{ns}(z, \bar{q}^2, k_\perp) \tag{1}$$

with $\bar{q} = q(1-z)$ and with the non-Sudakov form factor Δ_{ns} defined as:

$$\begin{aligned} \log \Delta_{ns}(z_i, \bar{q}^2, k_\perp) &= -\bar{\alpha}_S \int_z^1 \frac{dz'}{z'} \int \frac{dq^2}{q^2} \cdot \Theta(k_\perp - q)\Theta(q - z'\bar{q}) \\ &= -\bar{\alpha}_S \int_z^1 \frac{dz'}{z'} \int_{(z'\bar{q})^2}^{k_\perp^2} \frac{dq^2}{q^2} \end{aligned} \tag{2}$$

Here only the singular terms $1/z$ and $1/(1-z)$ were included and for simplicity the scale in the running α_s was not treated in the same way for the small and large z part.

Due to the angular ordering a kind of random walk in the propagator gluon $k_\perp$can be performed. For values of $k_\perp < k_\perp^{cut}$ the non-perturbative region is entered, which is avoided in a strictly $q_\perp$-ordered evolution (DGLAP). The region of small $k_\perp$ is characterized by α_s and the parton density being large, and collective phenomena, like gluon recombination or saturation might play a role. At such small $k_\perp$ the total cross section is expected to rise only weakly with energy, equivalently to a constant $xG(x, Q)$ for small x and Q. A practical treatment is therefore to fix $\alpha_s(\mu)$ to $\alpha_s(Q_0) \sim 0.6$ for $\mu < Q_0$. Until $k_\perp > k_\perp^{cut}$ is reached, no gluon emissions are allowed, but energy-momentum conservation is properly treated. In the **JS** unintegrated gluon density [2], the soft region was defined by $k_\perp^{cut} = 0.25$ GeV. In the new sets presented here, $k_\perp^{cut} = Q_0$ was chosen, with Q_0 being the collinear cut for the real emissions (the scale for resolvable branchings).

Following the arguments in [1], it was investigated in [3] to change the scale in α_s to $q^2(1-z)^2$ everywhere, in $1/z$ part of the splitting function as well as in the non-Sudakov form factor. From eq.(2) it is obvious, that a special treatment of the soft region (and the lower integration limit) is needed, because q' can become very small and even $q' < \Lambda_{qcd}$ at small values of z'. The problematic region in the non-Sudakov form factor in eq.(2) is avoided by fixing $\alpha_s(\mu)$ for $\mu < 0.9$ GeV [1, 3]:

$$\begin{aligned} \log \Delta_{ns} &= -C_a \cdot \int_{z_1}^{z_0} \frac{dz'}{z'} \int_{(z'\bar{q})^2}^{k_t^2} \frac{dq^2}{q^2} \frac{1}{\log(q/\Lambda_{qcd})} \\ &\quad -\bar{\alpha}_S(q_{cut}) \int_{z}^{z_c} \frac{dz'}{z'} \int_{(z_c\bar{q})^2}^{k_t^2} \frac{dq^2}{q^2} \Theta(z_c - z) \end{aligned} \tag{3}$$

with $C_a = 36/(33-2n_f)$ and n_f being the number of active flavours. The integration limits are defined by $z_c = q_{cut}/\bar{q}$, $q_{cut} = 0.9$ GeV and $z_1 = \max(z, z_c)$. However in practical application we observe only a small effect from changing the scale of the small z part from $k_\perp$to $q_\perp$.

At very high energies, the $1/z$ term in P_{gg} will certainly be dominant. However, at present colliders the non-singular terms, as suggested in [1] should also be included:

$$P_{gg}(z, \bar{q}, k_\perp) = \bar{\alpha}_S\left(k_\perp^2\right)\left(\frac{(1-z)}{z} + \frac{z(1-z)}{2}\right)\Delta_{ns} + \bar{\alpha}_S(\bar{q}^2)\left(\frac{z}{1-z} + \frac{z(1-z)}{2}\right). \tag{4}$$

As already mentioned before, the change of the scale in α_s from $k_\perp$to $q_\perp$does not produce significant differences. For simplicity, $k_\perp$is still taken as the scale for the small z part in the non-Sudakov form factor.

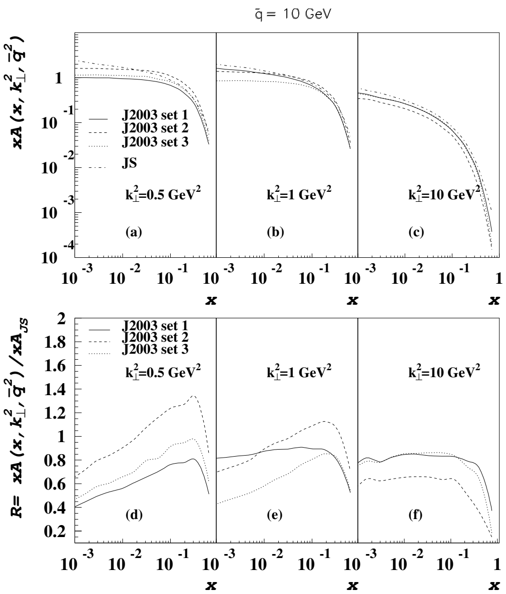

Figure 1: *Comparison of the different sets of unintegrated gluon densities obtained from the CCFM evolution as described in the text. In $(a - c)$ the unintegrated gluon density is shown as a function of x for different values of $k_\perp$ at a scale of $\bar{q} = 10$ GeV. In $(d - f)$ the ratio $R = \frac{x\mathcal{A}(x,k_\perp^2,\bar{q}^2)}{x\mathcal{A}(x,k_\perp^2,\bar{q}^2)_{\rm JS}}$ as a function of x for different values of $k_\perp$ is shown.*

2 Unintegrated gluon density of the Proton

The CCFM evolution equations have been solved numerically [2] using a Monte Carlo method. Three new sets (**J2003 set 1 - 3**, details are given in Tab. 1) of unintegrated gluon densities were determined and compared to the previous one **JS** [2]. The input parameters were fitted to describe the structure function $F_2(x, Q^2)$ in the range $x < 5 \cdot 10^{-3}$ and $Q^2 > 4.5$ GeV^2 as measured at H1 [4, 5] and ZEUS [6, 7]. Set **JS** [2] was fitted only to $F_2(x, Q^2)$ of Ref. [4]. A comparison of the different sets of CCFM unintegrated gluon densities is shown in Fig. 1. It is clearly seen, that the treatment of the soft region, defined by $k_\perp < k_\perp^{cut}$ influences the behavior at small x and small $k_\perp$. It is interesting

set	P_{gg}	Q_0	$k_\perp^{cut}$ (GeV)	χ^2/ndf
JS [2]	eq.(1,2)	1.40 GeV	0.25	$1197/248 = 4.8$
J2003 set 1	eq.(1,2)	1.33 GeV	1.33	$321/248 = 1.29$
J2003 set 2	eq.(4)	1.18 GeV	1.18	$293/248 = 1.18$
J2003 set 3	eq.(3)	1.35 GeV	1.35	$455/248 = 1.83$

Table 1: The different settings of the CCFM unintegrated gluon densities. In **J2003 set 2** and **J2003 set 3** the lower integration limit in the non-Sudakov form factor is changed from eq.(2) to $((z_c q)^2)$. In the last column, the χ^2/ndf to HERA F_2 data [4, 5, 6, 7] is given (for $x < 5 \cdot 10^{-3}$ and $Q^2 > 4.5$ GeV^2).

to note, that the change of the scale form $k_\perp$ to $q_\perp$ in **J2003 set 2** is visible only in the small $k_\perp$ region, whereas at larger $k_\perp$ **J2003 set 1** and **J2003 set 3** agree reasonably well. In Tab. 1 the parameters of the CCFM unintegrated gluon densities are summarized and also the χ^2 of the fits are shown.

3 Unintegrated gluon density of the Photon

We use the same parameter settings as given in Tab. 1, to calculate the CCFM unintegrated gluon density of the real photon. For the input gluon density at the scale Q_0 we chose GRV set [8], which also determined the normalization. The set corresponding to **J2003 set 2** is used in CASCADE 1.2 [9] to calculate heavy quark production in $\gamma\gamma$ reactions and are compared with the measurements at LEP (Fig. 2). Charm production is reasonably well described, whereas bottom production falls below the measurement. The prediction obtained in $k_\perp$-factorization is only slightly larger than that obtained in the collinear approach at NLO.

Acknowledgments

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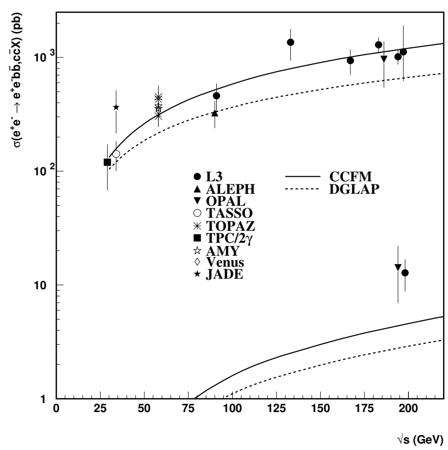

Figure 2: *The cross section for heavy quark production obtained with* CASCADE *using the CCFM unintegrated gluon density of the photon compared to measurements in $\gamma\gamma$ collisions.*

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