CERN-PH-TH/2005-118

Impact of large-x resummation on parton distribution functions [1]

G. Corcella* and L. Magnea†

*CERN, Department of Physics, Theory Division, CH-1211 Geneva 23, Switzerland
† Università di Torino and INFN, Sezione di Torino, Via P. Giuria 1, I-10125, Torino, Italy

Abstract. We investigate the effect of large-x resummation on parton distributions by performing a fit of Deep Inelastic Scattering data from the NuTeV, BCDMS and NMC collaborations, using NLO and NLL soft-resummed coefficient functions. Our results show that soft resummation has a visible impact on quark densities at large x. Resummed parton fits would therefore be needed whenever high precision is required for cross sections evaluated near partonic threshold.

A precise knowledge of parton distribution functions (PDF's) at large x is important to achieve the accuracy goals of the LHC and other high energy accelerators. We present a simple fit of Deep Inelastic Scattering (DIS) structure function data, and extract NLO and NLL-resummed quark densities, in order to establish qualitatively the effects of soft-gluon resummation.

Structure functions $F_i(x,Q^2)$ are given by the convolution of coefficient functions and PDF's. Finite-order coefficient functions present logarithmic terms that are singular at $x=1$, and originate from soft or collinear gluon radiation. These contributions need to be resummed to extend the validity of the perturbative prediction. Large-x resummation for the DIS coefficient function was performed in [1, 2] in the massless approximation, and in [3, 4] with the inclusion of quark-mass effects, relevant at small Q^2.

Soft resummation is naturally performed in moment space, where large-x terms correspond, at $\mathscr{O}(\alpha_s)$, to single ($\alpha_s \ln N$) and double ($\alpha_s \ln^2 N$) logarithms of the Mellin variable N. In the following, we shall consider values of Q^2 sufficiently large to neglect quark-mass effects. Furthermore, we shall implement soft resummation in the next-to-leading logarithmic (NLL) approximation, which corresponds to keeping terms $\mathscr{O}(\alpha_s^n \ln^{n+1} N)$ (LL) and $\mathscr{O}(\alpha_s^n \ln^n N)$ (NLL) in the Sudakov exponent.

To gauge the impact of the resummation on the DIS cross section, we can evaluate the charged-current (CC) structure function F_2 convoluting NLO and NLL-resummed $\overline{\mathrm{MS}}$ coefficient functions with the NLO PDF set CTEQ6M [5]. We consider $Q^2 = 31.62\ \mathrm{GeV}^2$, since it is one of the values of Q^2 at which the NuTeV collaboration collected data [6]. In Fig. 1 we plot $F_2(x)$ with and without resummation (Fig. 1a), as well as the normalized difference $\Delta = (F_2^{\mathrm{res}} - F_2^{\mathrm{NLO}})/F_2^{\mathrm{NLO}}$ (Fig. 1b). We note that the

[1] Talk given by G. Corcella at DIS 2005, XIII Workshop on Deep Inelastic Scattering, April 27–May 1, 2005, Madison, WI, U. S. A.

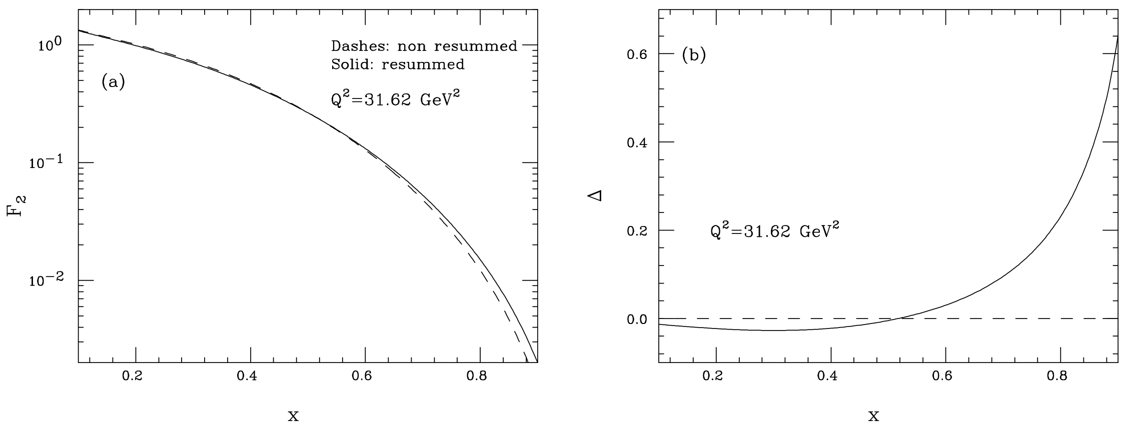

FIGURE 1. (a): CC structure function $F_2(x)$ using NLO (dashes) and NLL-resummed (solid) coefficient functions, at $Q^2 = 31.62$ GeV^2; (b): relative difference $\Delta = (F_2^{\rm res} - F_2^{\rm NLO})/F_2^{\rm NLO}$

effect of the resummation is an enhancement of F_2 for $x > 0.6$. Such an enhancement is compensated by a decrease at smaller x: the resummation, in fact, does not change the first moment of F_2, since we include in the Sudakov exponent only terms $\sim \ln^k N$, which vanish for $N = 1$. Our predictions for F_2 at different values of Q^2 can be compared with

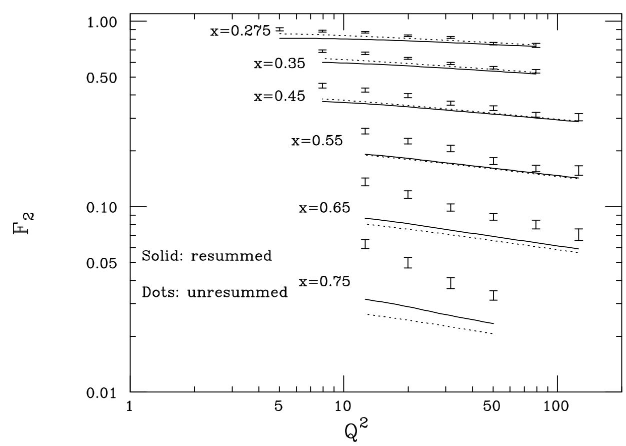

FIGURE 2. Comparison of NuTeV data on the CC structure function $F_2(x,Q^2)$ with a theoretical prediction using CTEQ6M PDF's and NLO (dots) or NLL-resummed (solid) coefficient functions.

NuTeV data at large x. The results of the comparison are shown in Fig. 2: although the resummation moves the prediction towards the data, we are still unable to reproduce the large-x data. Several effects are involved in the mismatch: at very large values of x, power corrections will certainly play a role. Moreover, we have used so far a parton set (CTEQ6M), extracted by a global fit which did not account for the NuTeV data. Rather, data from the CCFR experiment [7], which disagree at large x with NuTeV [6], were used. The discrepancy has recently been described as understood [8]; however, it is not possible to draw any firm conclusion from our comparison.

We wish to reconsider the CC data in the context of an indipendent fit. We shall use NuTeV data on $F_2(x)$ and $xF_3(x)$ at $Q^2 = 31.62$ GeV^2 and 12.59 GeV^2, and extract

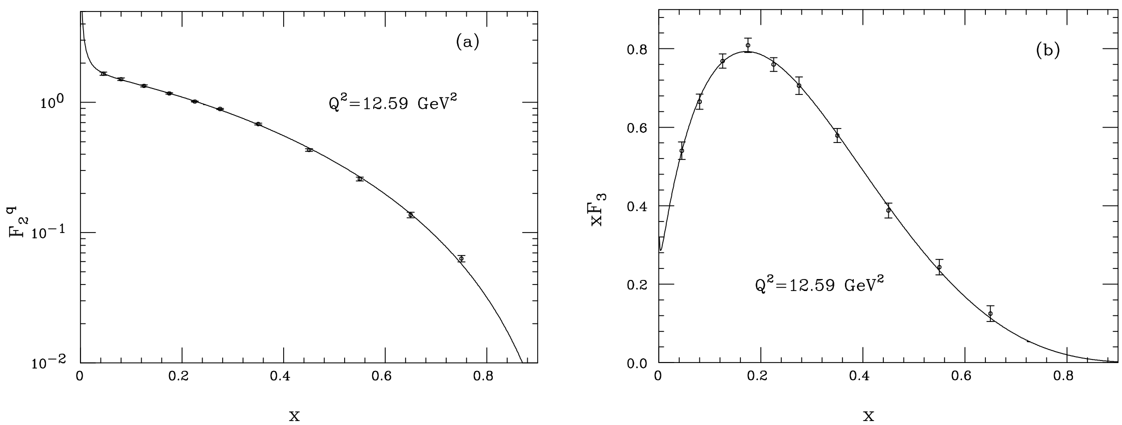

FIGURE 3. NuTeV data and best-fit curves at $Q^2 = 12.59$ GeV^2 for F_2^q (a) and xF_3 (b).

NLO and NLL-resummed quark distributions from the fit. F_2 contains a gluon-initiated contribution F_2^g, which is not soft-enhanced and is very small at large x: we can therefore safely take F_2^g from a global fit, e.g. CTEQ6M, and limit our fit to the quark-initiated term F_2^q. We choose a parametrization of the form $F_2^q(x) = F_2(x) - F_2^g(x) = Ax^{-\alpha}(1-x)^{\beta}(1+bx)$; $xF_3(x) = Cx^{-\rho}(1-x)^{\sigma}(1+kx)$. The best-fit parameters and the χ^2 per degree of freedom are quoted in [9]. In Fig. 3, we present the NuTeV data on $F_2(x)$ and $xF_3(x)$ at $Q^2 = 12.59$ GeV^2, along with the best-fit curves. Similar plots at $Q^2 = 31.62$ GeV^2 are shown in Ref. [9].

In order to extract individual quark distributions, we need to consider also neutral current data. We use BCDMS [10] and NMC [11] results, and employ the parametrization of the nonsinglet structure function $F_2^{\rm ns} = F_2^p - F_2^D$ provided by Ref. [12]. The parametrization [12] is based on neural networks trained on Monte-Carlo copies of the data set, which include all information on errors and correlations: this gives an unbiased representation of the probability distribution in the space of structure functions.

Writing F_2, xF_3 and $F_2^{\rm ns}$ in terms of their parton content, we can extract NLO and NLL-resummed quark distributions, according to whether we use NLO or NLL coefficient functions. We assume isospin symmetry of the sea, i.e. $s = \bar{s}$ and $\bar{u} = \bar{d}$, we neglect the charm density, and impose a relation $\bar{s} = \kappa\,\bar{u}$. We obtain a system of three equations, explicitly presented in [9], that can be solved in terms of u, d and s. We begin by working in N-space, where the resummation has a simpler form and quark distributions are just the ratio of the appropriate structure function and coefficient function. We then revert to x-space using a simple parametrization $q(x) = Dx^{-\gamma}(1-x)^{\delta}$.

Figs. 4–5 show the effect of the resummation on the up-quark distribution at $Q^2 = 12.59$ and 31.62 GeV^2, in N- and x-space respectively. The best-fit values of D, γ and δ, along with the χ^2/dof, can be found in [9]. The impact of the resummation is noticeable at large N and x: there, soft resummation enhances the coefficient function and its moments, hence it suppresses the quark densities extracted from structure function data. In principle, also d and s densities are affected by the resummation; the errors on their moments, however, are too large for the effect to be statistically significant. In [9] it was also shown that the results for the up quark at 12.59 and 31.62 GeV^2 are consistent with

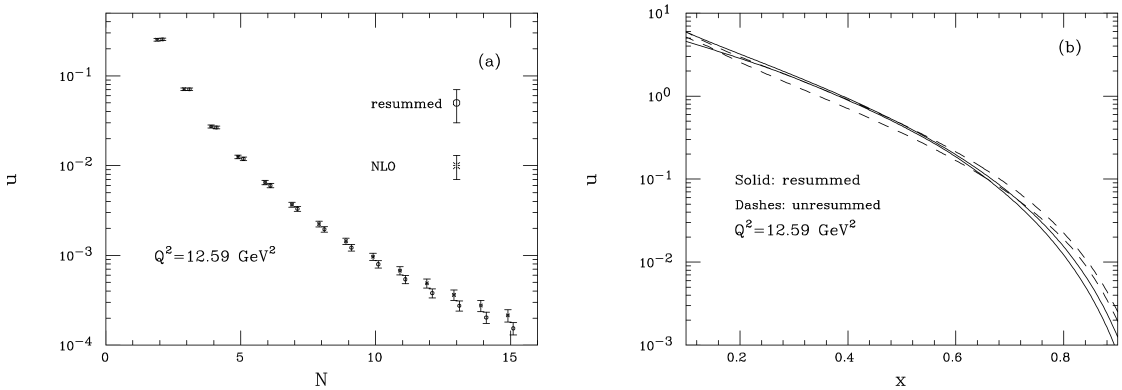

FIGURE 4. NLO and resummed up quark distribution at $Q^2 = 12.59$ GeV^2 in moment (a) and x (b) spaces. Following [9], in x space, we have plotted the edges of a band corresponding to a prediction at one-standard-deviation confidence level (statistical errors only).

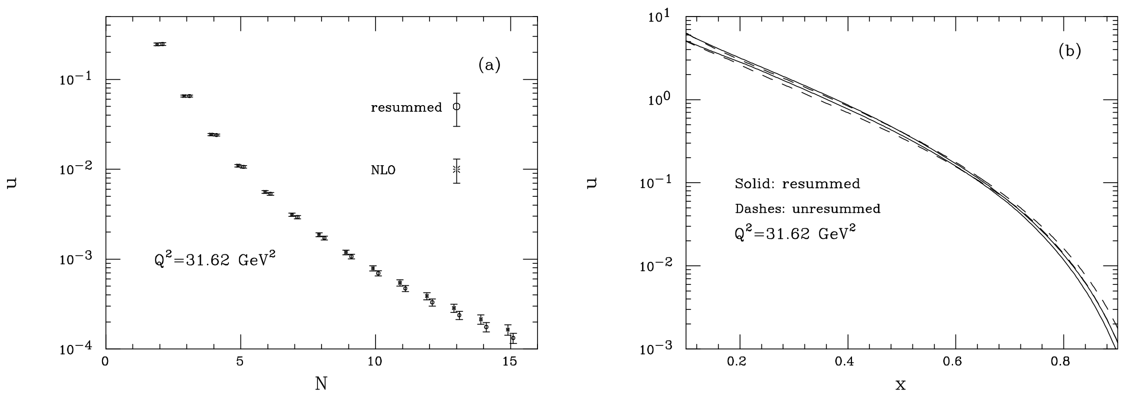

FIGURE 5. The same as in Fig. 4, but at $Q^2 = 31.62$ GeV^2.

NLO perturbative evolution.

In summary, we have presented a comparison of NLO and NLL-resummed quark densities extracted from large-x DIS data. We found a suppression of valence quarks in the $10-20\%$ range at $x > 0.5$, for moderate Q^2. We believe that it would be interesting and fruitful to extend this analysis and include large-x resummation in the toolbox of global fits. Our results show in fact that this would be necessary to achieve precisions better than 10% in processes involving large-x partons.

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