# Impact of large-x resummation on parton distribution functions

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**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.

**Keywords:** Resummation, parton distribution functions
**PACS:** 12.38.Bx, 12.38.Cy

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 $\overline{\rm MS}$ coefficient functions with the NLO PDF set CTEQ6M [5]. We consider $Q^2 = 31.62$ 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 $\Delta = (F_2^{\rm res} - F_2^{\rm NLO})/F_2^{\rm NLO}$ (Fig. 1b). We note that the 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

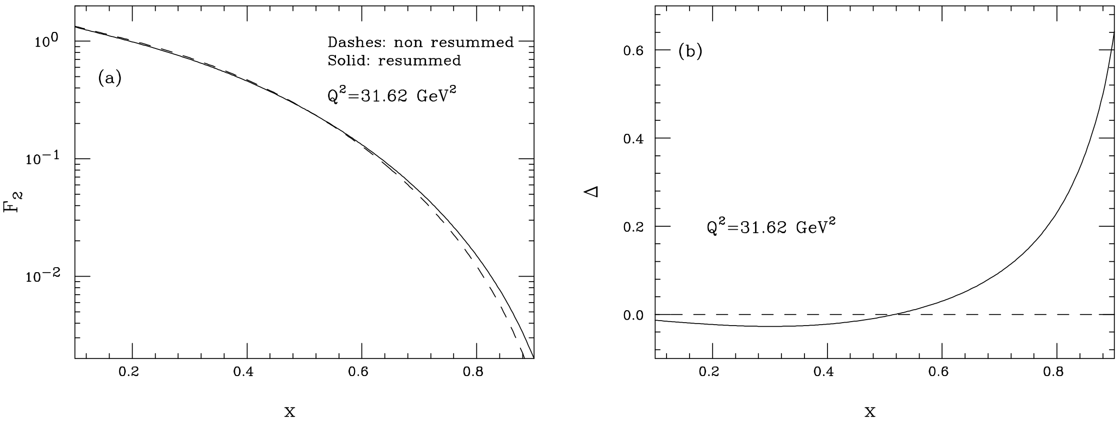


**FIGURE 1.** (a): CC structure function $F_2(x)$ using NLO (dashes) and NLL-resummed (solid) coefficient functions, at $Q^2 = 31.62$ GeV$^2$; (b): relative difference $\Delta = (F_2^{\rm res} - F_2^{\rm NLO})/F_2^{\rm NLO}$

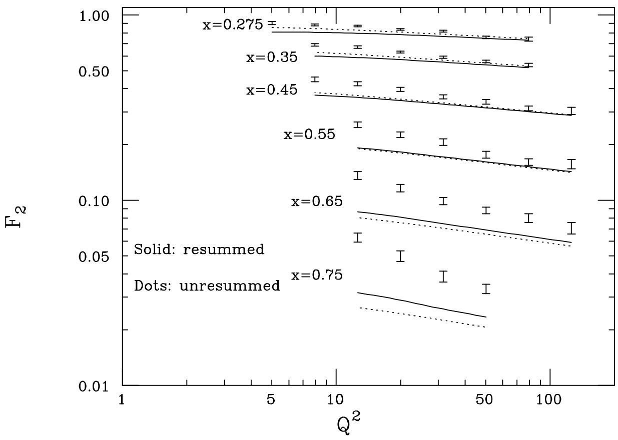


**FIGURE 2.** Comparison of NuTeV data on the CC structure function $F_2(x,Q^2)$ with a theoretical prediction using CTEQ6M PDF's and NLO (dots) or NLL-resummed (solid) coefficient functions.

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 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 $F_2^q(x) = F_2(x) - F_2^g(x) = Ax^{-\alpha}(1-$

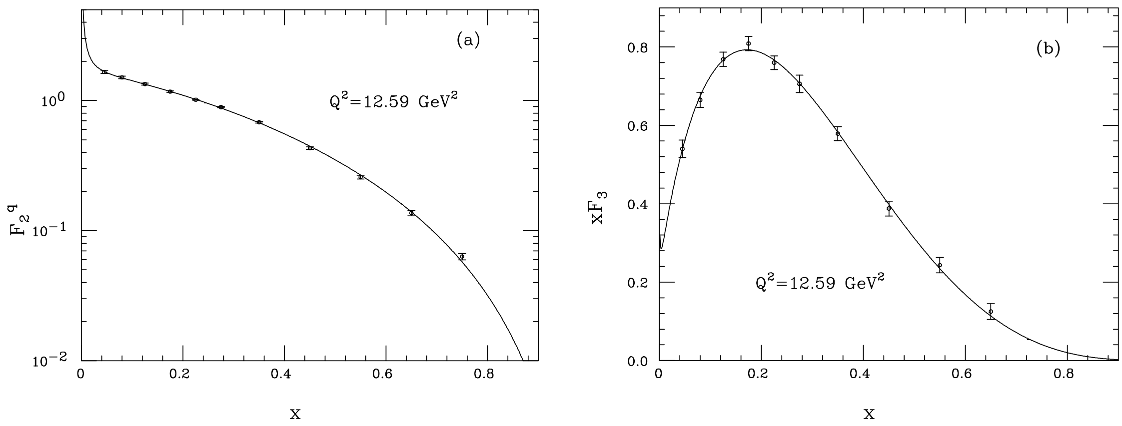


**FIGURE 3.** NuTeV data and best-fit curves at $Q^2 = 12.59$ GeV$^2$ for $F_2^q$ (a) and $xF_3$ (b).

$x)^\beta(1+bx)$; $xF_3(x) = Cx^{-\rho}(1-x)^\sigma(1+kx)$. The best-fit parameters and the $\chi^2$ 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 $D$, $\gamma$ and $\delta$, along with the $\chi^2$/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 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

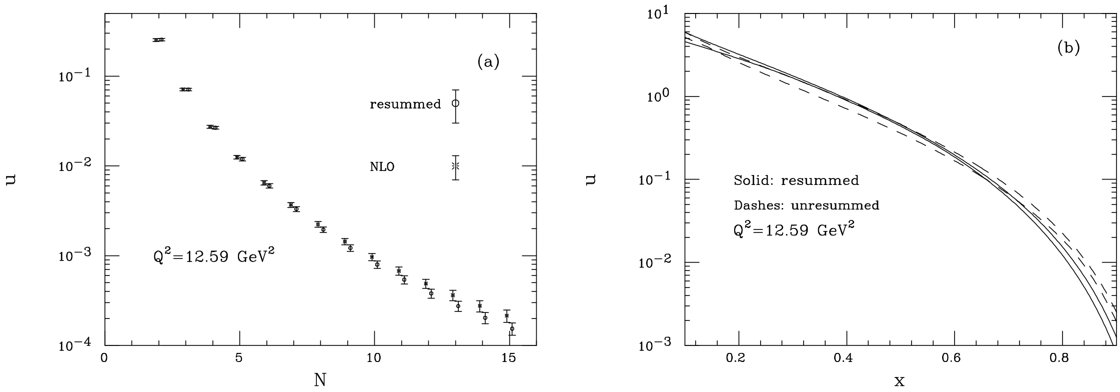


**FIGURE 4.** NLO and resummed up quark distribution at $Q^2 = 12.59\ \mathrm{GeV}^2$ in moment (a) and $x$ (b) spaces. Following [9], in $x$ space, we have plotted the edges of a band corresponding to a prediction at one-standard-deviation confidence level (statistical errors only).

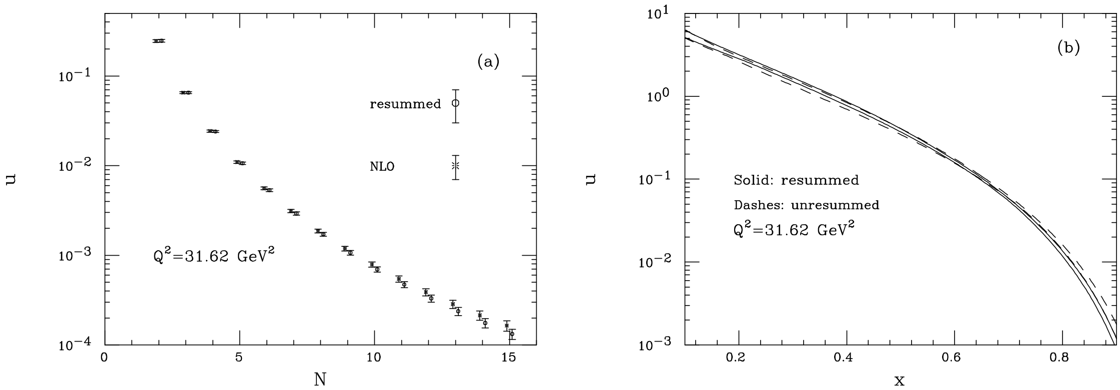


**FIGURE 5.** The same as in Fig. 4, but at $Q^2 = 31.62\ \mathrm{GeV}^2$.

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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