High energy factorization predictions for $F_2^c$ at HERA

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High energy factorization predictions for $F_2^c$ are derived using BFKL resummations of leading logs for the proton structure functions at HERA. A theoretical non-perturbative uncertainty on the factorization scheme is taken into account by considering two different approaches for modelling the proton. The parameters are fixed by a fit of $F_2$ at small $x$. The resulting predictions for $F_2^c$ are in agreement with the data within the present error bars.

1 High energy factorization

$k_\perp$- (or high energy) factorization is a QCD factorization scheme suited for high-energy hard processes - and in particular for deep-inelastic $e^-p$ scattering - in the small $x$-regime. This scheme takes into account the resummation of the $(\alpha_s \log \frac{1}{x})^n$ terms in the QCD perturbative expansion of the structure functions.

Let us formulate $k_\perp$-factorization for the leptoproduction of a quark-antiquark pair of mass $M$ off a small size ("perturbative") target characterized by its gluon distribution. In this scheme, the inclusive transverse (resp. longitudinal) structure functions $F_T$ ($F_L$) can be expressed as follows:

$$F_{T,L}(Y,Q^2,M^2;Q_f^2) = \frac{1}{4\pi^2\alpha_{em}Q^2} \int_{Q_f}^{\infty} \frac{d^2k_\perp}{Q^2} \int_{0}^{\gamma} dy \, \hat{\sigma}_{\gamma \gamma^* T,L}(Y-y,q_\perp/M,k_\perp/M) \, F(y,k_\perp), \quad (1)$$

where $Q^2 = -q^2$ is the virtuality of the photon, $Q_f$ the factorization scale and $M$ the mass of the produced quarks. $Y$ represents the rapidity range available for the reaction. $F(y,k_\perp)$ is the unintegrated gluon distribution, which describes the probability of finding a gluon with longitudinal momentum fraction $z = e^{-y}$ and two-dimensional transverse momentum $k_\perp$ in the target. $q_\perp$ is the photon transverse momentum. $\hat{\sigma}_{\gamma \gamma^* T,L}$ is the hard cross section for (virtual)photon-(virtual)gluon fusion computed at order $\alpha_s \alpha_{em}$.

The final expression for the high-energy factorized structure function is most easily expressed as an inverse Mellin transform and reads:

$$F_{T,L}(Y,Q^2,M^2;Q_f^2) = e^2 \int \frac{d\gamma}{2\pi} \left( \frac{Q^2}{Q_f^2} \right)^\gamma h_{T,L}(\gamma;M^2) \, \frac{\mathcal{F}(Y,\gamma;Q_f^2)}{\gamma} \quad (2)$$

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where the coefficient functions $h_{T,L}(\gamma; M^2)$ represent the Mellin-transform of the off-shell (virtual) photon-(virtual) gluon cross section, in an approximation in which one neglects subleading terms in energy. One can find their expression in\textsuperscript{3} and\textsuperscript{4}.

$F(Y, \gamma; Q_f^2)$ is the Mellin-transform of the unintegrated gluon distribution $F(Y, k_{\perp})$ with respect to the transverse momentum of the gluon. It is assumed to satisfy the BFKL dynamics\textsuperscript{5}. Assuming a full factorization of the rapidity dependence, which is consistent with an asymptotic approximation for the coefficient functions, we obtain the following parametrization:

$$
\frac{F(Y, \gamma; Q_f^2)}{\gamma} = \omega(\gamma; Q_f^2) e^{\frac{\alpha_s N_c}{\pi} \chi(\gamma) Y},
$$

where $\chi(\gamma) = 2 \Psi(1) - \Psi(\gamma) - \Psi(1-\gamma)$. The function $\omega(\gamma; Q_f^2)$ will explicitly depend on the nature of the target, and has to be supplied by a model for an extended target like a proton, see next section.

2 Phenomenology

Let us introduce the model for the proton. Following the suggestion of ref.\textsuperscript{6}, one assumes the scaling form $\omega(\gamma; Q_f^2) = \omega(\gamma)(Q_f/Q_0)^{2\gamma}$, where $Q_0$ is a non-perturbative scale, independent of the mass $M$. With this assumption, the overall formula (2) does no more depend on the factorization scale $Q_f$.

We have shown in ref.\textsuperscript{4} that the behaviour of $\omega(\gamma)$ when $\gamma$ becomes large cannot be steeper than a polynomial. This constraint comes from the region where $k_{\perp}$ is large, i.e. where we expect rather a DGLAP evolution. Taking into account this constraint, we will now focus on two definite models relying on different formulations of the residue function $\omega(\gamma)$ at small $\gamma$. On the one hand, the model 1, with $\omega(\gamma) = C$(constant) corresponds to the factorization at the gluon level: all the perturbative content of $k_{\perp}$-factorization is kept. On the other hand, in model 2, we consider an input compensating the $1/\gamma$ pole of $h_{T}(\gamma; M^2)$: $\omega(\gamma) \sim \gamma C$ at small $\gamma$. This model corresponds to a factorization at the quark level\textsuperscript{7}, and was discussed in ref.\textsuperscript{4}. Both models lead to an expression for the proton structure functions depending on three free parameters, $C$, $\alpha_s$, and $Q_0$.

We determine these parameters for both models by a fit of $F_2 = F_T + F_L$ in their kinematical region of validity ($x \leq 10^{-2}$, moderate $Q^2$). Using the corresponding 103 experimental points given by the H1 collaboration\textsuperscript{8}, we fit our results (2) with the contribution of the three light quarks $u, d, s$ (assumed massless) and of the charm quark (mass $M_c$). The $F_2$-fit for the medium mass $M_c = 1.5$ GeV is displayed in figure 1, together with the predictions for its
charm component $F_2^c$. For model 1, the $\chi^2$ per point is always less than 0.9, while for model 2 it is even lower. For model 1, the value of $Q_0$ is around 330 MeV which is a typical non-perturbative scale for the proton. The value of the effective coupling constant in the BFKL mechanism $\alpha_s(0.07)$ is rather low. For model 2, the data for $F_2$ are also fairly well reproduced (see figure 1). Note that the value of $Q_0 \approx 1.2$ GeV is substantially higher and the effective coupling constant $\alpha_s$ is a bit larger ($\approx \alpha_s(M_Z)$).

The parameter free predictions$^4$ for $F_2^c$ obtained as an outcome of both of the considered models are in good agreement with ZEUS and H1 data$^9$, within the present experimental error bars, although model 2 predicts a significantly higher charm component. The predictions are also comparable to the next-leading order prediction$^10$ based on the GRV parton distribution set$^{11}$ which proves that $F_2^c$ cannot allow one to distinguish between the two approaches.

3 Conclusions

The high energy factorization scheme provides us with some good predictions for $F_2^c$ which are weakly dependent on the non-perturbative input, within the
present error bars on the data. However, one model predicts rather higher $F_2^c$. More precise data could help to distinguish between both models. A good parametrization for the total structure function $F_2$ was obtained (3 parameters only are required), but the low value obtained for the effective coupling constant $\alpha_s$ may be an indication of the strong next-leading order BFKL recently computed\textsuperscript{12}, which might have been taken into account effectively in these fits. Anyway, it seems not to spoil the $k_{\perp}$-factorization predictions.

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References