$k_{\perp}$-FACTORIZATION PREDICTIONS FOR $F_2^c$ AT HERA

S. MUNIER

Service de Physique Théorique, CEA, CE-Saclay
F-91191 Gif-sur-Yvette Cedex, France

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 $e^\mp p$ 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:

$$F_{T,L}(Y, Q^2, M^2; Q_f^2) = \frac{1}{4\pi^2 \alpha_{em} Q_f^2} \int_{Q_f} d^2k_{\perp} \int_0^\infty dy \hat{\sigma}_{\gamma^* g,T,L}(Y, q_{\perp}/M, k_{\perp}/M) F(y, k_{\perp}),$$

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. $\hat{\sigma}_{\gamma^* g,T,L}$ 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:

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

$^a$Talk presented at the DIS98 workshop, Brussels, April 1998.
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 3 and 4.

\( F(Y, \gamma; Q^2_f) \) 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. Assuming a full factorization of the rapidity dependence, which is consistent with an asymptotic approximation for the coefficient functions, we obtain the following parametrization:

\[
\frac{F(Y, \gamma; Q^2_f)}{\gamma} = \omega(\gamma; Q^2_f) e^{\frac{\alpha_s}{\pi} \chi(\gamma) Y},
\]

(3)

where \( \chi(\gamma) = 2\Psi(1) - \Psi(\gamma) - \Psi(1-\gamma) \). The function \( \omega(\gamma; Q^2_f) \) 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. 6, one assumes the scaling form \( \omega(\gamma; Q^2_f) = \omega(\gamma)(Q_f/Q_0)^{2\gamma} \), 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. 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 \( h_{T,L}(\gamma; M^2) \): \( \omega(\gamma) \sim C \gamma \) at small \( \gamma \). This model corresponds to a factorization at the quark level, and was discussed in ref. 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 \((x \leq 10^{-2}, \text{moderate } Q^2)\). Using the corresponding 103 experimental points given by the H1 collaboration, we fit our results 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 $F_c^2$. 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 $Q_0 \simeq 1.2$ GeV is substantially higher and the effective coupling constant $\alpha_s$ is a bit larger ($\simeq \alpha_s(M_Z)$).

The parameter free predictions for $F_c^2$ obtained as an outcome of both of the considered models are in good agreement with ZEUS and H1 data 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 based on the GRV parton distribution set which proves that $F_c^2$ cannot allow one to distinguish between the two approaches.

3 Conclusions

The high energy factorization scheme provides us with some good predictions for $F_c^2$ which are weakly dependent on the non-perturbative input, within the
present error bars on the data. However, one model predicts rather higher $F_2$. 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.

Acknowledgments

The material of this contribution is the result of a collaboration with R. Peschanski. We also thank S. Catani for fruitful suggestions, H. Navelet and Ch. Royon for stimulating discussions and comments. This work was supported in part by the EU Fourth Framework Programme ‘Training and Mobility of Researchers’, Network ‘Quantum Chromodynamics and the Deep Structure of Elementary Particles’, contract FMRX-CT98-0194 (DG 12 - MIHT).

References

1. S. Catani, M. Ciafaloni, F. Hautmann, *Nucl. Phys.* **B366** (1991) 135.
2. J. C. Collins, R. K. Ellis, *Nucl. Phys.* **B360** (1991) 3.
   E. M. Levin, M. G. Ryskin, Yu. M. Shabelskii, A. G. Shuvaev, *Sov. J. Nucl. Phys.* **53** (1991) 657.
3. S. Catani, *Z. Phys.* **C75** (1997) 665.
4. S. Munier, R. Peschanski, *hep-ph/9802230*, to appear in *Nucl. Phys. B*.
5. V. S. Fadin, E.A. Kuraev and L.N. Lipatov, *Phys. Lett.* **B60** (1975) 50; I. I. Balitsky and L.N. Lipatov, *Sov. J. Nucl. Phys.* **28** (1978) 822.
6. H. Navelet, R. Peschanski, Ch. Royon, S. Wallon, *Phys. Lett.* **B385** (1996) 357.
7. N. N. Nikolaev, B. G. Zakharov, *Phys. Lett.* **B332** (1994) 184.
8. H1 Coll., T. Ahmed et al., *Phys. Lett.* **B348** (1995) 681; ZEUS Coll., M. Derrick et al., *Z. Phys.* **C68** (1995) 569.
9. H1 Coll., C. Adloff et al., *Z. Phys.* **C72** (1996) 593; ZEUS Coll., J. Breitweg et al., *Phys. Lett.* **B407** (1997) 402.
10. B. W. Harris and J. Smith, *Nucl. Phys.* **B452** (1995) 109.
11. M. Glück, E. Reya and A. Vogt, *Z. Phys.* **C67** (1995) 27.
12. V.S. Fadin, L.N. Lipatov, M. Ciafaloni, G. Camici, *hep-ph/9802290*, *hep-ph/9803038*.