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Saturation effects in low-x DIS structure functions and related hadronic total cross sections

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Abstract.
High-energy nucleon total cross sections are related to low-x DIS structure functions by using the additive quark model.

In the additive quark model, the hadron-hadron total cross section can be written as a product of the cross sections of the constituents, σ_{qq} [1, 2], *e.g.*

$$\sigma(s)^t_{pp} = \sigma_{qq}[n_V + n_S(s)]^2, \tag{1}$$

where n_V is the number of valence quarks and $n_S(s)$ is that of sea quarks, their number increasing with energy.

It was suggested in Refs. [1, 2] that the increasing number of sea quarks is related to the Bjorken scaling-violating contribution to the deep inelastic lepton-hadron structure function (DIS SF), namely to the momentum fraction of the relevant quarks given by the integral over the DIS structure function $F_2(x, Q^2)$. In Ref. [1] a simple model for the DIS structure function, known at those times, was used, resulting in the following expression for the total cross section, compatible with the data

$$\sigma(s)^t_{pp} = \sigma_{qq} n_V^2 (1 + 0.0.16\, \ell n(s/Q_0^2)), \tag{2}$$

where σ_{qq} is a free parameter, Q_0^2 was fitted to the DIS data, and $n_V = 3$.

In Ref. [2] the DIS SF was related to hadronic cross sections by means of finite-energy sum rules in Q^2.

The number of quarks in a reaction can be calculated from the SF by means of sum rules. see e.g. [3, 4].

In Ref. [5] following ansatz for the small-x singlet part (labelled by the upper index $S, 0$) of the proton structure function, interpolating between the soft (VMD, Pomeron) and hard (GLAP evolution) regimes was proposed:

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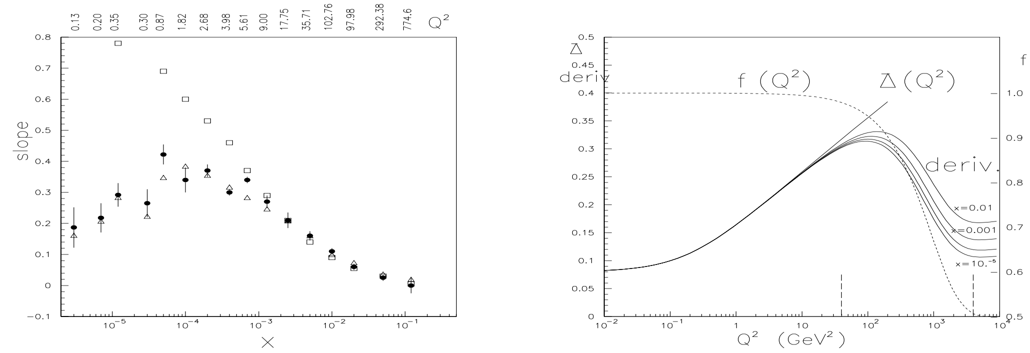

Figure 1. Slope of the structure function $F_2(x, Q^2)$.

$$F_2^{(S,0)}(x, Q^2) = A\left(\frac{Q^2}{Q^2 + a}\right)^{1+\widetilde{\Delta}(Q^2)} e^{\Delta(x,Q^2)}, \tag{3.1}$$

with the "effective power"

$$\widetilde{\Delta}(Q^2) = \epsilon + \gamma_1 \ell n\left(1 + \gamma_2 \ell n\left[1 + \frac{Q^2}{Q_0^2}\right]\right), \tag{3.2}$$

and

$$\Delta(x, Q^2) = \left(\widetilde{\Delta}(Q^2)\ell n \frac{x_0}{x}\right)^{f(Q^2)}, \tag{3.3}$$

where

$$f(Q^2) = \frac{1}{2}\left(1 + e^{-Q^2/Q_1^2}\right). \tag{3.4}$$

At small and moderate values of Q^2, the exponent $\widetilde{\Delta}(Q^2)$ (3.2) may be interpreted as a Q^2-dependent "effective Pomeron intercept", as shown in Fig. 1.

The function $f(Q^2)$ has been introduced in order to provide for the transition from the Regge behaviour, where $f(Q^2) = 1$, to the asymptotic solution of the GLAP evolution equation, where $f(Q^2) = 1/2$.

In Ref. [5] the above singlet SF was appended by a non-singlet part, important at large values of x. The parameters were fitted to the DIS data in a wide range of x and Q^2.The values of the fitted parameters are: $A = 0.1623$, $a = 0.2916$ GeV^2, $\gamma_2 = 0.01936$, $Q_0^2 = 0.1887$ GeV^2, $Q_1^2 = 916.1$ GeV^2; $x_0 = 1$, $\epsilon = 0.08$, $\gamma_1 + 2.4$ were fixed (by QCD-related arguments). The resulting fits and more details can be found in Ref. [5].

The proton-proton total cross section is cast by integrating Eqs. (3) between $x = 0$ and $x = 1$. At high energies, only the singlet part of the SF, Eqs. (3) (the "Pomeron") is relevant. Integration can be

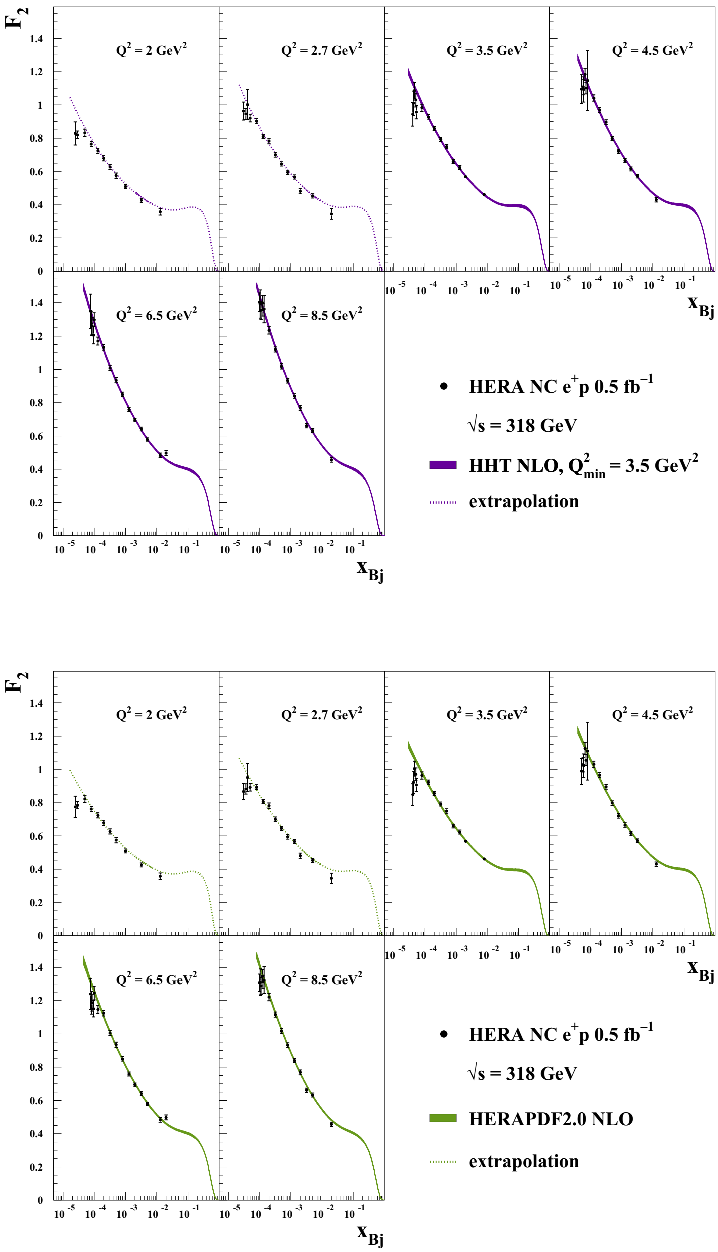

Figure 2. HHT (top) and HERAPDF2.0 (bottom) NLO predictions of the F_2 structure function at $Q^2_{\mathrm{min}} = 3.5\,\mathrm{GeV}^2$, compared to extracted values. For more details, see Ref. [7].

performed numerically. The result is in reasonable agreement with the data on pp total cross sections, including those from the LHC.

The operator-product expansion beyond leading twist has diagrams in which two, three or four gluons may be exchanged in the t-channel such that these gluons may be viewed as recombining. This recombination could lead to gluon saturation. The colour-dipole framework also inspired a phenomenological model of saturation by Golec–Biernat–Wüsthoff (GBW), in which the onset of saturation is characterised as the transition from a "soft" to a "hard" scattering regime. This occurs along a "critical line" in the x_{Bj}, Q^2 plane.

Recently new results on low-x DIS parton distrubutions (PDF and SF) have appeared [6, 7]; they show an intriguing change of regime towards smallest values of x (Fig. 2) - possible saturation effect?

We intend to investigate its impact on the asymptotic behaviour of the total cross sections.

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