On a Consistent Determination of α_s from Jet Rates in DIS

J. Chýla[a+], J. Rameš[a+]

[a] Institute of Physics, Na Slovance 2, Prague 8, 18040, Czech Republic
[+] Supported by grant No. A1010602 of the Grant Agency of the Academy of Sciences of CR

Abstract: For a theoretically consistent determination of α_s from jet rates in deep inelastic scattering the dependence on α_s of parton distribution functions is in principle as important as that of hard scattering cross–sections. For the kinematical region accessible at HERA we investigate in detail the numerical importance of these two sources of the α_s dependence of jet rates.

As QCD enters the stage of a truly quantitative theory, great emphasis is put on a precise determination of its basic parameter α_s, or equivalently $\Lambda_{\overline{\mathrm{MS}}}$, using different sorts of hard scattering processes in a broad range of kinematical conditions. The production of jets in DIS at HERA offers a possibility to investigate the running of $\alpha_s(\mu)$ in a single experiment. Recently both the H1 [1] and ZEUS [2] Collaborations have reported evidence for the running of $\alpha_s(\mu)$ obtained from the measurement of the quantity

$$R_{2+1}(Q^2) \equiv \frac{\sigma_{2+1}(Q^2)}{\sigma_{1+1}(Q^2)+\sigma_{2+1}(Q^2)}, \tag{1}$$

where σ_{k+1}, the cross–section for the production of k hard and one proton remnant jet, is given as

$$\sigma_{k+1}(Q^2, y_c, \Lambda) \equiv \sum_i \int_0^1 \mathrm{d}x f_i(x, M, \Lambda) C_{k+1,i}(Q, M, x, y_c, \Lambda). \tag{2}$$

In eq. (2), $f_i(x, M)$ denote parton distribution functions (PDF) of the proton evaluated at the factorization scale M, the sum runs over all parton species i, and

$$\begin{aligned} C_{2+1,i}(Q, M, x, y_c, \Lambda) &= a(\mu/\Lambda)\left[c^{(1)}_{2+1,i}(x, y_c) + a(\mu/\Lambda) c^{(2)}_{2+1,i}(Q/M, x, y_c)\right], && (3)\\ C_{1+1,i}(Q, M, x, y_c, \Lambda) &= c^{(0)}_{1+1,i}(Q, x) + a(\mu/\Lambda) c^{(1)}_{1+1,i}(Q/M, x, y_c). && (4) \end{aligned}$$

Using PROJET 4.1 [3] with the JADE jet algorithm and $y_c = 0.02$, the H1 Collaboration has obtained the following result $\alpha_s(M_Z, \overline{\mathrm{MS}})$

$$\alpha_s(M_Z, \overline{\mathrm{MS}}) = 0.123 \pm 0.012(\mathrm{stat.}) \pm 0.008(\mathrm{syst.}). \tag{5}$$

In Ref. [1] $\alpha_s(\mu, \overline{\mathrm{MS}})$ (or, equivalently, $\Lambda_{\overline{\mathrm{MS}}}$) was considered as a free parameter in the parton–level hard–scattering cross–sections $C_{k+1,i}$ but not in the parton distribution functions (PDF), for which the MRSH set was used. Theoretical consistency of this procedure has been frequently questioned. In Ref. [4] we have shown that the variation of Λ in PDF changes the ratio R_{2+1} by the same order as the variation of Λ in parton level cross–sections C_{k+1} and **must** therefore in principle be taken into account. We have also investigated the *numerical* importance of varying $\Lambda_{\overline{\rm MS}}$ in the PDF and in particular addressed the question under which conditions neglecting $\Lambda_{\overline{\rm MS}}$ in the PDF is *numerically* a good approximation for determining α_s from (1) at HERA. The main results are presented below. For details see Ref. [4].

In Ref. [4] we have developed a procedure for varying $\Lambda_{\overline{\rm MS}}$ in PDF while keeping certain parameters specifying the initial conditions for the GLAP evolution equations fixed. It should be emphasized that this procedure *does not* use fixed boundary conditions at a finite initial M_0. It exploits in a crucial way the parametrization of the solutions of GLAP equations by means of the evolution distance

$$s \equiv \ln\left(\frac{\ln(M/\Lambda)}{\ln(M_0/\Lambda)}\right) \doteq \ln\left(\frac{\alpha_s(M_0/\Lambda)}{\alpha_s(M/\Lambda)}\right). \tag{6}$$

In our studies we have used several of the GRV parametrizations [5]. All the results reported below were obtained using the PROJET 4.1 generator [3]. To quantify the dependence of R_{2+1} on Λ separately in hard scattering cross–sections and PDF we considered it as a function of Q^2, y_c and two independent Λ–parameters, denoted as $\Lambda^{\rm hsc}$ and $\Lambda^{\rm pdf}$, respectively, and defined

$$V(Q^2, y_c, r, s) \equiv \frac{R_{2+1}(Q^2, y_c, \Lambda^{\rm pdf} = s, \Lambda^{\rm hsc} = r)}{R_{2+1}(Q^2, y_c, \Lambda^{\rm pdf} = r, \Lambda^{\rm hsc} = s)}. \tag{7}$$

Considered as a function of s for fixed r, eq. (7) quantifies the relative importance of varying Λ in the PDF (described by R_{2+1} in the numerator) and in hard scattering cross–sections (described by R_{2+1} in the denominator). To a good approximation, eq. (7) is a linear function of s for any fixed Q^2, y_c, r. We therefore fitted $V(Q^2, y_c, r, s)$ by a linear function of s and defined

$$W(Q^2, y_c, r) \equiv \frac{{\rm d}V^{fit}(Q^2, y_c, r, s)}{{\rm d}s}, \tag{8}$$

which, by construction, is an s–independent function of Q^2, y_c and r. Positive W means that the variation of Λ in the PDF is more important than that in the hard scattering cross–sections, while for negative W the situation is opposite. The simulations were done at both the leading and next–to–leading order and for 12 values of Q^2 (equidistant in $\ln Q^2$ between 5 and 10^4 GeV^2), 5 values of $\Lambda^{\rm pdf}$ or $\Lambda^{\rm hsc}$ (equal to $0.1, 0.2, 0.3, 0.4$ and 0.5 GeV), 3 values of $y_c = 0.01, 0.02, 0.04$ and two options concerning cuts on final jets (with no cuts as well as with the cuts as used in Ref. [1]). The main results are displayed in Figs. 1,2 and summarized below:

1. For Q^2 below about 40 GeV^2 the variation of Λ is more important in the PDF than in the hard–scattering cross-sections, while above 40 GeV^2 the situation is reversed.
2. Above $Q^2 \approx 10^3$ GeV^2 the variation of Λ in PDF becomes negligible.
3. The preceding conclusions depend only weakly on y_c.
4. the “cross–over” point Q^2_{cr}, where $W(Q^2_{cr}, y_c, r) = 0$, is at higher values of $Q^2_{cr} \sim 50 - 200$ GeV^2 and depends more sensitively on y_c, than at the NLO,
5. the relative importance of varying Λ in PDF is larger at the LO,
6. the difference between the LO and NLO results increases with increasing y_c.
7. the H1 cuts result in a significant reduction of the sensitivity to $\Lambda_{\overline{\rm MS}}$ in PDF in low Q^2.

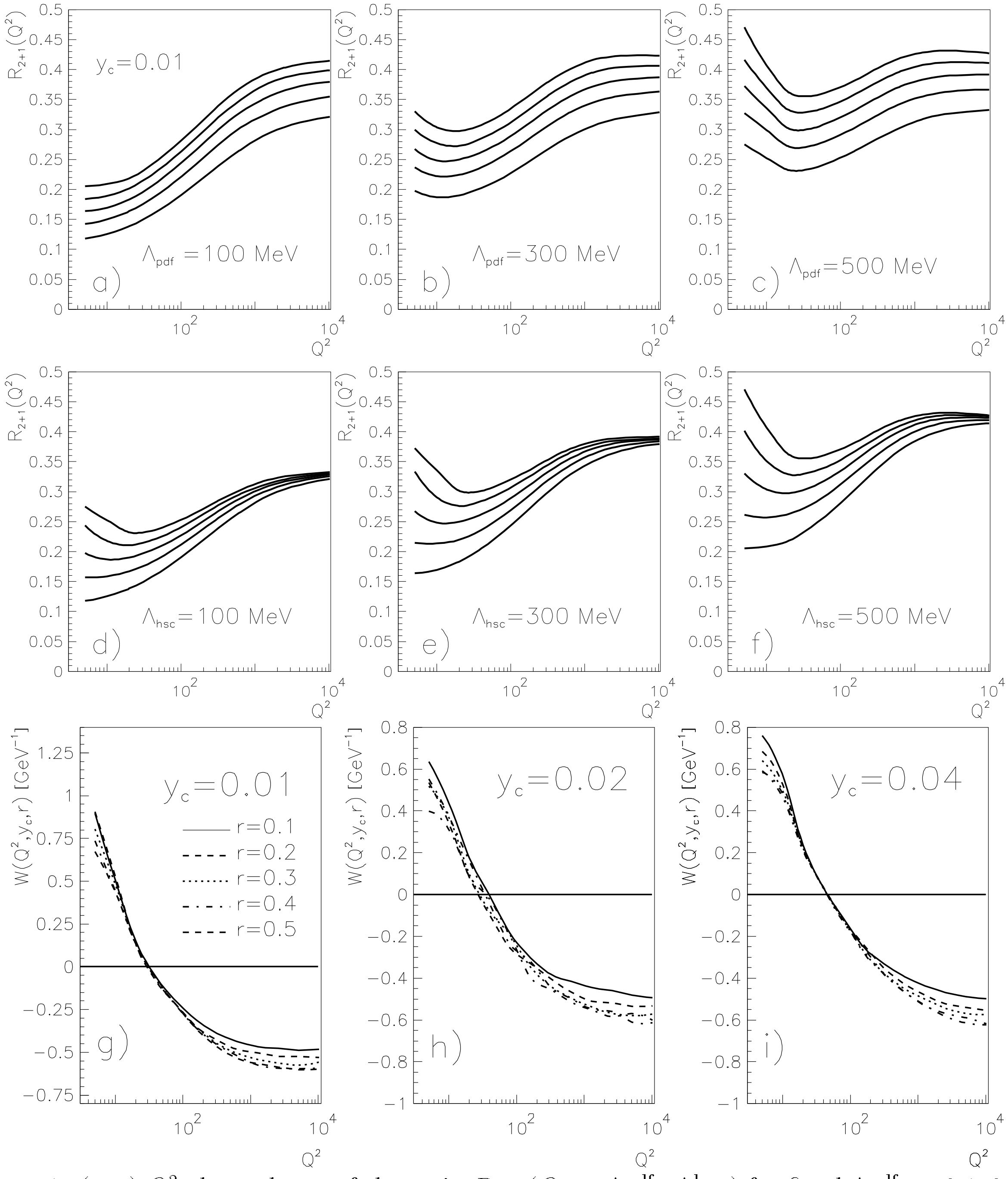

Figure 1: (a–c) Q^2–dependence of the ratio $R_{2+1}(Q, y_c, \Lambda^{\rm pdf}, \Lambda^{\rm hsc})$ for fixed $\Lambda^{\rm pdf} = 0.1, 0.3, 0.5$ GeV and five values of $\Lambda^{\rm hsc} = 0.1, 0.2, 0.3, 0.4, 0, 5$ GeV. (d–f) The role of $\Lambda^{\rm pdf}$ and $\Lambda^{\rm hsc}$ is reversed. No cuts were applied in evaluating R_{2+1} and $y_c = 0.01$. In all plots the curves are ordered from below according to increasing $\Lambda^{\rm hsc}$ (in a–c) or $\Lambda^{\rm pdf}$ (in d–f). (g-i): The quantity $W(Q^2, y_c, r)$ as a function of Q^2 for five values of r (given in GeV) and $y_c = 0.01, 0.02, 0.04$. All curves correspond to the case of no cuts.

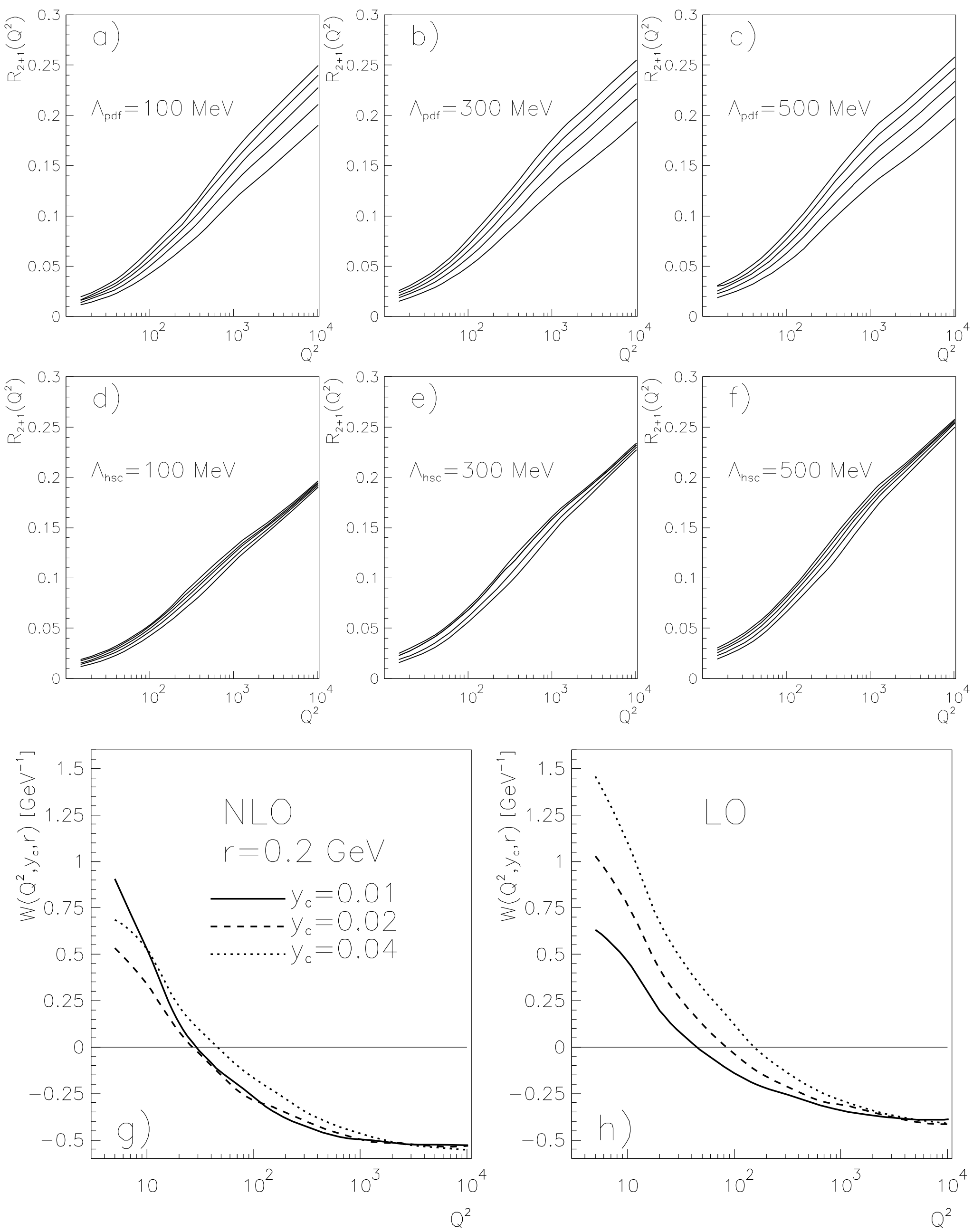

Figure 2: (a–f): The same as in Fig. 1a–f but for the H1 acceptance cuts. (g–h): Q^2–dependence of $W(Q^2, y_c, r = 0.2)$ for three values of y_c at the NLO (g) and LO (h) and no cuts.

References

[1] H1 Collab., T. Ahmed et al., Phys. Lett. **B 309** (1995) 415.

[2] ZEUS Collab., M. Derrick et al., Phys. Lett. **B 363** (1995) 201.

[3] D. Graudenz, Comput. Phys. Commun. **92** (1995) 65.

[4] J. Chýla, J. Rameš, PRA-HEP/96-01, hep-ph/9604265.

[5] M. Glück, E. Reya and A. Vogt, Z. Phys. **C 67** (1995) 433.