

Structure functions at large Bjorken x and the Transition between perturbative and non-perturbative QCD

S. Liuti^{*}, N. Bianchi[†] and A. Fantoni[†]

^{*}*University of Virginia, Charlottesville, Virginia 22901, USA*

[†]*Laboratori Nazionali di Frascati dell'INFN, Via E. Fermi 40, 00044 Frascati (RM), Italy*

Abstract. We study both polarized and unpolarized proton structure functions in the kinematical region of large Bjorken x and four-momentum transfer of few GeV^2 , characterized by the phenomenon of parton-hadron duality between the smooth continuation of the deep inelastic scattering curve and the average of the nucleon resonances which dominate this region. We present results on a perturbative-QCD analysis using recent accurate data aimed at extracting the infrared behavior of the nucleon structure functions.

PACS: 13.60.Hb, 13.88.+e

INTRODUCTION

Parton-hadron duality, or the similarity between hadronic cross sections in the Deep Inelastic Region (DIS) and in the resonance region, encompasses a range of phenomena where one expects to observe a transmutation from partonic to hadronic degrees of freedom. It lies, therefore, at the very heart of Quantum ChromoDynamics (QCD), as the theory of strong interactions. A number of experiments were conducted, in fact, in the early days of QCD where it was shown that the *continuation* of the smooth curve describing different observables from a wide variety of reactions – structure functions, sum rules, $R(s)$, heavy meson decays... – at large four-momentum transfers/energies into the low momentum/energy region characterized by resonances, could be considered as an *average* of the resonances trend. A fully satisfactory theoretical description of this phenomenon, that became to be accepted as a “natural” feature of hadronic interactions, is still nowadays very difficult to obtain. Recent progress both on the theoretical and experimental side [1, 2], has however renovated and reinforced the hadronic physics community’s interest in this subject [3].

In this contribution, by conducting an analysis of the most recent polarized and unpolarized inclusive electron scattering data, we present evidence that standard Perturbative QCD (PQCD) approaches might not be adequate in order to describe parton-hadron duality. In particular, we unravel a discrepancy in the behavior of the extracted power corrections in the DIS and resonance regions, respectively.

COMPARISON BETWEEN DIS AND RESONANCE REGIONS

In this Section we define the key concepts and quantities in our analysis, namely what is meant by: *i) Continuation* of DIS curve into the resonance region; *ii) Average* over the resonances. Although these concepts are equivalently found in a number of different reactions, and in different channels (see *e.g.* [4] for a review), we concentrate on the proton structure functions for polarized, g_1 , and unpolarized, F_2 , electron scattering.

Continuation of DIS Curve

It is important to define exactly what one means by “continuation” of the DIS curve, in order to be able to define whether parton-duality can be considered to be fulfilled. The accuracy of current data allows us, in fact, to address the question of *what extrapolation from the large Q^2 , or asymptotic regime the cross sections in the resonance region should be compared to*. In principle any extrapolation from high to low Q^2 is expected to be fraught with theoretical uncertainties ranging from the propagation of the uncertainty on $\alpha_S(M_Z^2)$ into the resonance region to the appearance of different types of both perturbative and power corrections in the low Q^2 regime. All of these aspects need therefore to be evaluated carefully. In our approach we considered as essential ingredients for the analysis which is centered on the *large Bjorken x* behavior:

- Non-Singlet (NS) Parton Distribution Functions (PDFs) evolved at Next to Leading Order (NLO).
- The correct scale for the transverse momentum integration yielding the leading log approximation result [5, 6]
- Target Mass Corrections (TMCs) [7]

In Ref.[8] we performed an extensive study using all available parametrizations of PDFs which are pure DIS, extended to the measured x and Q^2 ranges by pQCD evolution. Definitions for both F_2 and g_1 in terms of PDFs are given *e.g.* in Ref.[8]. As shown in [8], the uncertainty due to the use of different parametrizations can be taken into account by a band that is currently smaller than the experimental one in the region of interest. A potential theoretical error in the extrapolation of the ratios to low Q^2 could be, however, generated by the error in $\alpha_S(M_Z^2)$. However, also in this case, because at large x DGLAP evolution involves only Non-Singlet (NS) distributions, there is very little uncertainty in the extrapolation of the initial pQCD distribution even to the low values of W^2 considered.

As noticed in a pioneering paper [5], the problem of resumming the large logarithm terms arising at large x can be accounted for by considering the correct definition of the upper limit of integration for the transverse momentum in the ladder diagrams defining the leading log approximation. This implies replacing Q^2 with $\approx \tilde{W}^2$, an invariant mass, in the evolution equations. Such a procedure was taken into account to obtain our results both in Refs.[8, 9], and in the current contribution.

Finally, TMCs need to be implemented. As a word of caution, we notice that since they apply as a series in the parameter: $4M^2x^2/Q^2$, one has to ensure that the kinematical

region considered is consistent with such an expansion (this question was addressed explicitly in [9]).

Averaging Procedure

Resonant data can be averaged over, according to different procedures We considered the following complementary methods:

$$I(Q^2) = \int_{x_{\min}}^{x_{\max}} F_2^{\text{res}}(x, Q^2) dx \quad (1)$$

$$M_n(Q^2) = \int_0^1 dx \xi^{n-1} \frac{F_2^{\text{res}}(x, Q^2)}{x} p_n \quad (2)$$

$$F_2^{\text{ave}}(x, Q^2(x, W^2)) = F_2^{\text{Jlab}}(\xi, W^2) \quad (3)$$

where F_2^{res} is evaluated using the experimental data in the resonance region ¹. In Eq.(1), for each Q^2 value: $x_{\min} = Q^2/(Q^2 + W_{\max}^2 - M^2)$, and $x_{\max} = Q^2/(Q^2 + W_{\min}^2 - M^2)$. W_{\min} and W_{\max} delimit either the whole resonance region, *i.e.* $W_{\min} \approx 1.1 \text{ GeV}^2$, and $W_{\max}^2 \approx 4 \text{ GeV}^2$, or smaller intervals within it. In Eq.(2), ξ is the Nachtmann variable [10], and $M_n(Q^2)$ are Nachtmann moments [10]; p_n is a kinematical factor [10]. The r.h.s. of Eq.(3), $F_2^{\text{Jlab}}(\xi, W^2)$, is a smooth fit to the resonant data [1], valid for $1 < W^2 < 4 \text{ GeV}^2$; F_2^{ave} symbolizes the average taken at the $Q^2 \equiv (x, W^2)$ of the data.

After describing our program to address quantitatively all sources of theoretical errors started in [9, 8], we finally, in Fig. 1 we present our main result, namely extraction of the dynamical Higher Twist (HT) terms from the resonance region, and we compare them to results obtained in the DIS region [11, 12]. A clear discrepancy marking perhaps a *breakdown of the twist expansion* at low values of W^2 is seen for the unpolarized structure function, F_2 (upper panel). More data at large x are needed in order to draw conclusion for the polarized structure function, g_1 .

ACKNOWLEDGMENTS

This work is supported by the U.S. Department of Energy grant no. DE-FG02-01ER41200.

REFERENCES

1. I. Niculescu *et al.*, Phys. Rev. Lett. **85**, 1186 (2000).
2. A. Airapetian *et al.* [HERMES Collaboration], Phys. Rev. Lett. **90**, 092002 (2003)
3. <http://www.lnf.infn.it/conference/duality05/>

¹ Similar formulae hold for the polarized structure function, g_1 .

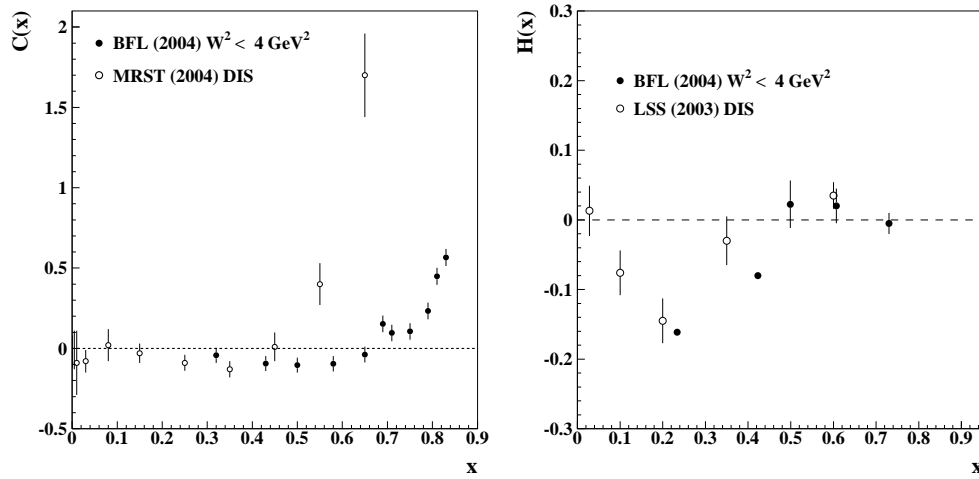


FIGURE 1. Comparison of HT contributions for both the structure function F_2 (left panel) and the polarized structure function g_1 (right panel) in the DIS and resonance regions, respectively. The full circles are the values obtained in the resonance region [8]. For F_2 these are compared with extractions using DIS data, from [11]. For g_1 they are compared to the extraction from [12]. Notice that we show our results in a factorized model for F_2 , and in a non-factorized one for g_1 for a consistent comparison with [11, 12].

4. W. Melnitchouk, R. Ent and C. Keppel, Phys. Rept. **406**, 127 (2005)
5. S. J. Brodsky and G. P. Lepage, SLAC-PUB-2447, *Presented at Summer Inst. on Particle Physics, SLAC, Stanford, Calif., Jul 9-20, 1979*
6. R. G. Roberts, Eur. Phys. J. C **10**, 697 (1999)
7. H. Georgi and H. D. Politzer, Phys. Rev. D **14**, 1829 (1976);
8. N. Bianchi, A. Fantoni and S. Liuti, Phys. Rev. D **69**, 014505 (2004)
9. S. Liuti, R. Ent, C. E. Keppel and I. Niculescu, Phys. Rev. Lett. **89**, 162001 (2002)
10. O. Nachtmann, Nucl. Phys. B **63**, 237 (1973).
11. A. D. Martin, R. G. Roberts, W. J. Stirling and R. S. Thorne, Eur. Phys. J. C **35**, 325 (2004)
12. E. Leader, A. V. Sidorov and D. B. Stamenov, Phys. Part. Nucl. Lett. **1**, 229 (2004), *and references therein*