Shadowing in the deuteron

B. Badełek[ab] and J. Kwieciński[c]

[a] Institute of Experimental Physics, Warsaw University, ul.Hoża 69, PL-00 681 Warsaw, Poland
[b] Department of Physics, Uppsala University, Box 530, S-751 21 Uppsala, Sweden
[c] Institute of Nuclear Physics, ul.Radzikowskiego 152, PL-31 342 Cracow, Poland

Abstract: Shadowing correction to the deuteron structure function is calculated in the HERA kinematic region. The double interaction formalism relating the shadowing to inclusive diffractive processes is used. Both the vector meson and parton contributions are considered for low and high Q^2 values. The QCD corrections with parton recombination are included for high Q^2.

Accelerating deuterons at HERA will give an opportunity to rise a precision of the QCD analysis of the structure functions (F_2^d contains almost completely a flavour singlet quark distributions) and to measure the neutron structure function, F_2^n (and thus the flavour non-singlet $F_2^p - F_2^n$). To these aims, shadowing in the deuteron has to be quantified in a wide interval of kinematic variables. Shadowing in the deuteron, *per se* a very interesting low x phenomenon, is well established experimentally, observed in the low Q^2 (including the photoproduction) and in the large Q^2 region and apparently only weekly dependent on Q^2 [1]. In this paper we summarise the results of our earlier studies of the deuteron shadowing [2], updated and adapted to the HERA kinematics.

The deuteron structure function F_2^d is related in the following way to F_2^p, F_2^n and to the shadowing term δF_2^d, which is non-negligible for x less than, say, 0.1:

$$2F_2^d(x,Q^2) = F_2^p(x,Q^2) + F_2^n(x,Q^2) - 2\delta F_2^d(x,Q^2). \tag{1}$$

(F_2^d and δF_2^d are normalised per nucleon).

The shadowing term $\delta F_2^d(x,Q^2)$ is related through the (double) pomeron exchange to the diffractive structure function, $\partial^2 F_2^{diff}/\partial\xi\partial t$

$$\delta F_2^d(x,Q^2) = \int d^2\mathbf{k}_\perp \int_{\xi_0}^1 d\xi S(k^2) \frac{\partial^2 F_2^{diff}}{\partial\xi\partial t} \tag{2}$$

where $S(k^2)$ is the deuteron form factor. We define $\xi = 2kq/p_d q$ where k, q and p_d are the four momenta of the pomeron, virtual photon and of the deuteron respectively; $\xi_0 = x(1 + M_{x0}^2/Q^2)$ where M_{x0}^2 is the lowest mass squared of the diffractively produced hadronic system. We also have $t \cong -k_\perp^2 - k_{||}^2$ where $k_{||}^2 = M^2\xi^2$ with M being equal to the nucleon mass. The integration over ξ corresponds to the integration over M_x^2 where M_x is the mass of the diffractively produced system. The region of low M_x^2 is dominated by the diffractive production of low mass vector

mesons which is assumed to be described by the vector meson dominance mechanism. In this model the contribution of the vector mesons to the nuclear shadowing is

$$\delta F_{2v}^d = \frac{Q^2}{4\pi} \sum_v \frac{M_v^4 \delta\sigma_v^d}{\gamma_v^2 (Q^2 + M_v^2)^2} \tag{3}$$

where the sum extends over the low mass vector mesons ρ, ω and ϕ. M_v are the masses of the vector mesons v and γ_v can be obtained from the leptonic widths of the vector mesons. The double scattering cross section $\delta\sigma_v^d$ is obtained from the Glauber model, with the energy–dependent vector meson–nucleon cross sections. The contribution of large M_x^2 corresponds to the partonic mechanism of shadowing, δF_{2p}^d, which is related to the partonic content of the pomeron. We used the parametrization of parton distributions in a pomeron from ref. [3] which was constrained to describe the data on deep inelastic diffraction from HERA [4].

Results of the calculations of $\delta F_2^d(x, Q^2)$ are shown in fig.1.

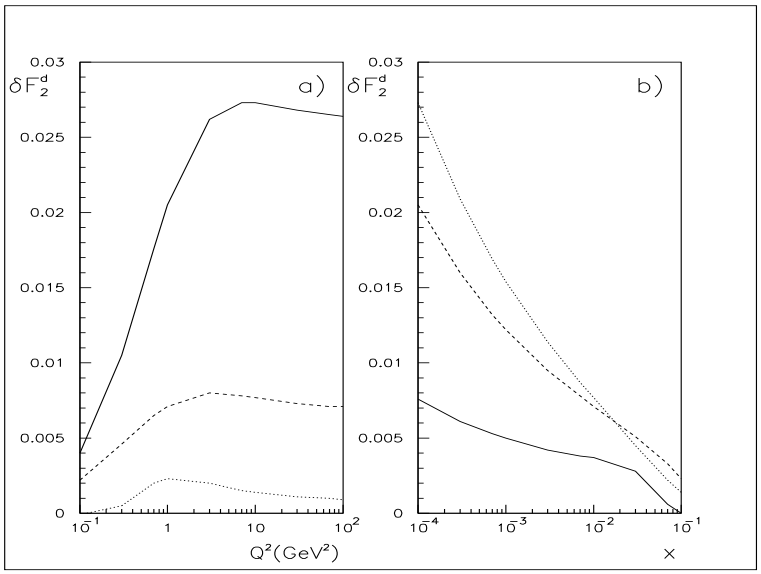

Figure 1: *Shadowing contribution, $\delta F_2^d(x, Q^2)$, to the deuteron structure function; a) continuous line: x=0.0001, broken line: x=0.01, dotted line: x=0.1; b) continuous line: Q^2=0.2 GeV^2, broken line: Q^2=1 GeV^2, dotted line: Q^2=10 GeV^2.*

In fig.2 plotted is the quantity $2F_2^d(x, Q^2)/F_2^p(x, Q^2) - 1$ which in the absence of shadowing would be just equal to $F_2^n(x, Q^2)/F_2^p(x, Q^2)$ and is often referred to as a ratio of neutron and proton structure functions. The F_2^d has been calculated according to eqs (1) and (2) where the structure functions for the proton and the neutron were calculated according to a model [5]. In this model the contributions from both the parton model with QCD corrections suitably extended to the low Q^2 region and from the low mass vector mesons were taken into account.

The model describes the data fairly well. Thus a quantitative method to obtain the shadowing contribution to the deuteron structure function is available. It should be used in extracting the neutron structure function from the F_2^d and F_2^p measurements as well as in the QCD analysis including, in particular, measurements of F_2^d. A shadowing model of ours, extended to encompass the meson exchange effects, [9], gives the same results for the δF_2^d. Other approaches, generally similar to ours, [10], predict larger values of the effect.

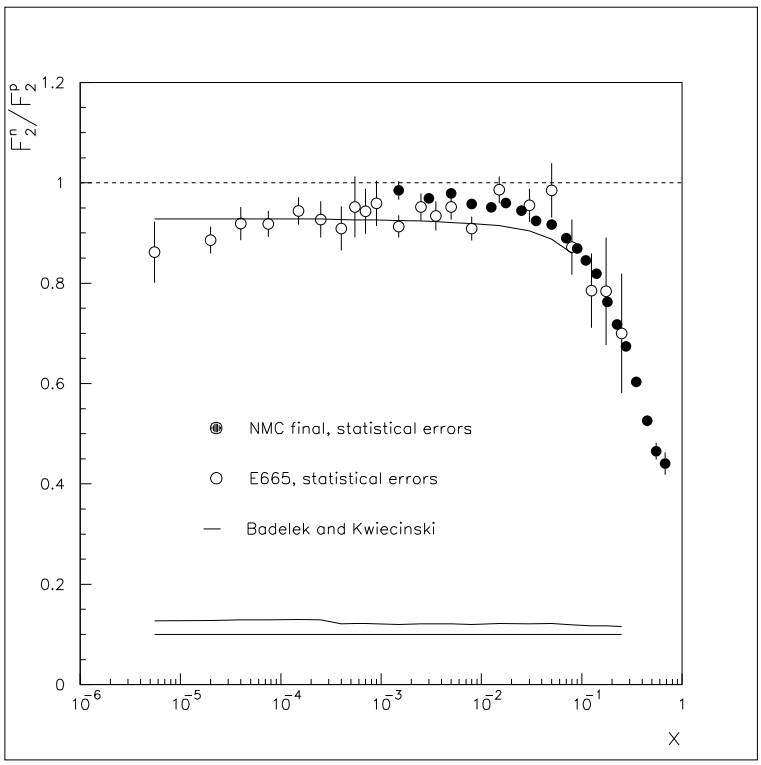

Figure 2: $F_2^n/F_2^p = 2F_2^d/F_2^p - 1$ *as a function of* x. *The line shows a result of our calculations, [2], with MRS(A), [6], as asymptotic function. Data come from the E665, [7] and from the NMC, [8]. Errors are statistical, band at the bottom shows the magnitude of the E665 systematic uncertainty.*

The curve in fig.2 has been calculated for the (x, Q^2) points corresponding to the E665 experiment results, i.e. at lowest values of x, $x \sim 10^{-5}$, $Q^2 \sim 0.005$ GeV^2. It would be desirable to measure the shadowing in the region of similarly low values of x but at higher scales in order to check its possible Q^2 dependence (anticipated to be weak). This would be possible uniquely at HERA.

HERA might also permit detection of the shadowing modifications due to the QCD effects: (mild) logarithmic scaling violations induced by the QCD evolution and recombination of partons from *different* nucleons in the deuteron [2]. Influence of these effects on δF_2^d is shown in fig.3.

Fortran codes to calculate $\delta F_2^d(x, Q^2)$ and $F_2^d/F_2^p(x, Q^2)$ are available upon request from *badelek@fuw.edu.pl*.

This research has been supported in part by the Polish Committee for Scientific Research, grant number 2 P03B 184 10.

References

[1] B. Badełek and J. Kwieciński, Rev. Mod. Phys. (in print).

[2] B. Badełek and J. Kwieciński, Nucl. Phys. **B370** (1992) 278; Phys. Rev. **D50** (1994) R4.

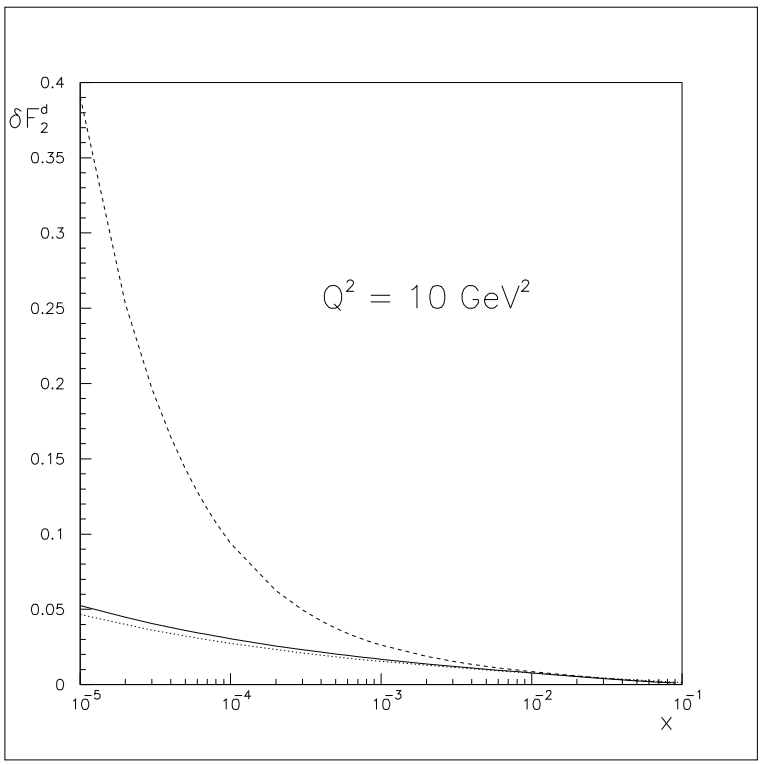

Figure 3: *QCD effects in the δF_2^d for Q^2=10 GeV^2. Dotted curve marks the results without- and continuous one – with the QCD evolution starting from Q_0^2=4 GeV^2. The dotted line shows the effect of the QCD evolution with the recombination terms in the evolution equations. Gluon distribution was assumed as given by the parametrization of Glück, Reya and Vogt, [11].*

[3] K. Golec-Biernat and J. Kwieciński Phys. Lett. **B353** (1995) 329.

[4] ZEUS Collaboration, M. Derrick et al., Phys. Lett. **B315** (1994) 228; **B338** (1994) 483. H1 Collaboration, T. Ahmed et al., Nucl. Phys. **B429** (1994) 477; Phys.Lett. **B348** (1995) 681.

[5] J. Kwieciński and B. Badełek, Z. Phys. **C43** (1989) 251;
B. Badełek and J. Kwieciński, Phys. Lett. **B295** (1992) 263.

[6] A.D. Martin, W.J. Stirling and R.G. Roberts, Phys. Rev. **D50** (1995) 6734.

[7] E665 Collaboration, M.R. Adams et al., Phys. Rev. Lett. **75** (1995) 1466.

[8] NMC, E.M. Kabuss, presented at DIS96, Rome, Italy.

[9] W. Melnitchouk and A.W. Thomas, Phys. Rev. **D47** (1993) 3783.

[10] See e.g. N.N. Nikolaev and B.G. Zakharov, Z. Phys. **C49** (1991) 607; V. Barone et al., Phys. Lett. **B321** (1994) 137; V.R. Zoller, Phys. Lett. **B279** (1992) 145.

[11] M. Glück, E. Reya and A. Vogt, Z. Phys. **C67** (1995) 433.