Comments on Electron-Deuteron Scattering at HERA.

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Abstract: While storing of deuterons in the HERA ring is relatively easy, designing precision measurements for electron-deuteron scattering turns out, as discussed in this note, to be difficult.

1 Electron-Deuteron scattering at low and high x

The deuteron structure function F_2^d can be expressed (following the notation of [1]) in terms of the proton structure function F_2^p and the neutron structure function F_2^n as follows:

$$2F_2^d = F_2^p + F_2^n - 2\delta_d, \tag{1}$$

where δ_d represents a correction, which includes the square of the double scattering amplitude as well as all interference terms of single and double scattering amplitudes. The structure functions F_2^d and F_2^p can be determined from the measured differential cross sections in ed and ep scattering. Their difference provides an important constraint on the nonsinglet structure function F_{NS} which describes the valence quark momentum distribution:

$$F_{NS} = F_2^p - F_2^n = 2(F_2^p - F_2^d) - 2\delta_d \tag{2}$$

The NMC collaboration has measured [2] the $F_2^p - F_2^d$ asymmetry in the $x \geq 10^{-2}$ region with a precision, which will be difficult to match at HERA, where, due to to the difference of the magnetic rigidities, protons and deuterons can not collide simultaneously with the same beam of electrons. In the region of $x \leq 10^{-2}$ and $Q^2 \geq\ 2\ GeV^2$ such a measurement can be done only at HERA. Can we reach satisfactory precision in this "exclusively HERA" x-region?

The expected $F_2^p - F_2^d$ difference, if extrapolated to low x using the NMC data, is below 0.01 [2] i.e. below 2 % of the $F_2^p(F_2^d)$ values. This difference is thus of the size of δ_d as calculated in [1]. The estimation of δ_d is however model dependent and to a large extent uncertain. Similarly, as has been pointed out in [3], there exists significant theoretical uncertainty of the low-x behavior of the F_{NS}. By measuring the $F_2^p - F_2^d$ difference at HERA one may hope to provide only weak constraint on the (δ_d, F_{NS}) plane. We are afraid, that by repeating the NMC "fully inclusive measurement", we shall be able neither to constrain the size of nuclear effects nor to provide a constraint on the F_{NS} sufficiently strong to improve the precision of determination of the gluon density at low x. Can we do better and try to pin down the size of δ_d by measuring the spectator nucleon?

2 Tagging of the spectator nucleon in the low-x electron-deuteron scattering

The effective longitudinal momentum distribution of nucleons bound in the deuteron stored at HERA at the energy of 820 GeV is shown in Fig. 1.

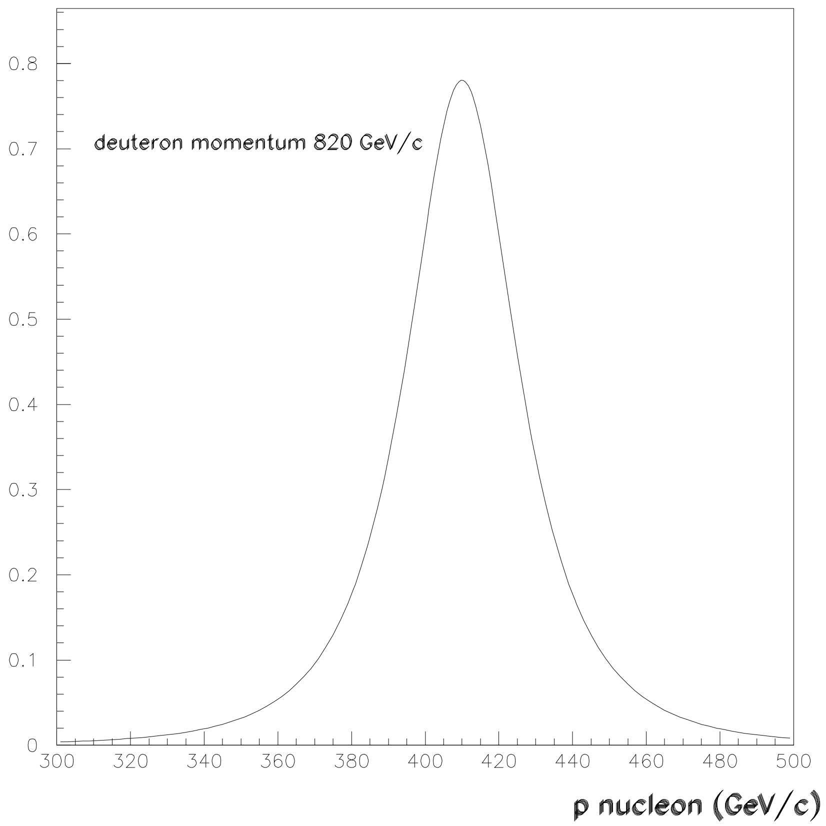

Figure 1: *Distribution of the effective longitudinal momentum of nucleons in the deuteron.*

We have used in the calculation the "Bonn wave function" of the deuteron. If an electron scatters off the proton the above distribution represents the longitudinal momentum distribution of the spectator neutron and vice versa. Can we tell, on the event by event basis, which nucleon has interacted by measuring the longitudinal momenta of the nucleons? The relative change of the longitudinal momentum of the nucleon which has interacted with an electron can be expressed by the following formula:

$$\frac{\delta p_z}{p_z} \simeq x(1 + \frac{M_X^2}{Q^2}), \tag{3}$$

where x is the Bjorken variable, Q^2 is the 4-momentum transfer from the electron to the deuteron and M_X stands for the mass of the hadronic system, excluding the scattered nucleon and the spectator nucleon. In this formula we neglected the transverse momentum of the interacting nucleon. For the large x values the change of the nucleon longitudinal momentum is large and the spectator can be tagged unambigously. This is no longer the case in the low

x region (e.g. the nucleon of the effective initial momentum of 420 GeV/c gets its momentum reduced by 10 GeV in the interaction in which $x = 10^{-3}$ and $M_X^2/Q^2 = 30$). Such a change of the longitudinal momentum is significantly smaller than the momentum spread of the spectator and the interacting nucleon can not be identified unambigously in such a case.

Can we improve the efficiency of the spectator tagging by measuring not only the longitudinal momentum but, as well, the transverse momentum of the nucleons? In Fig. 2 we show the

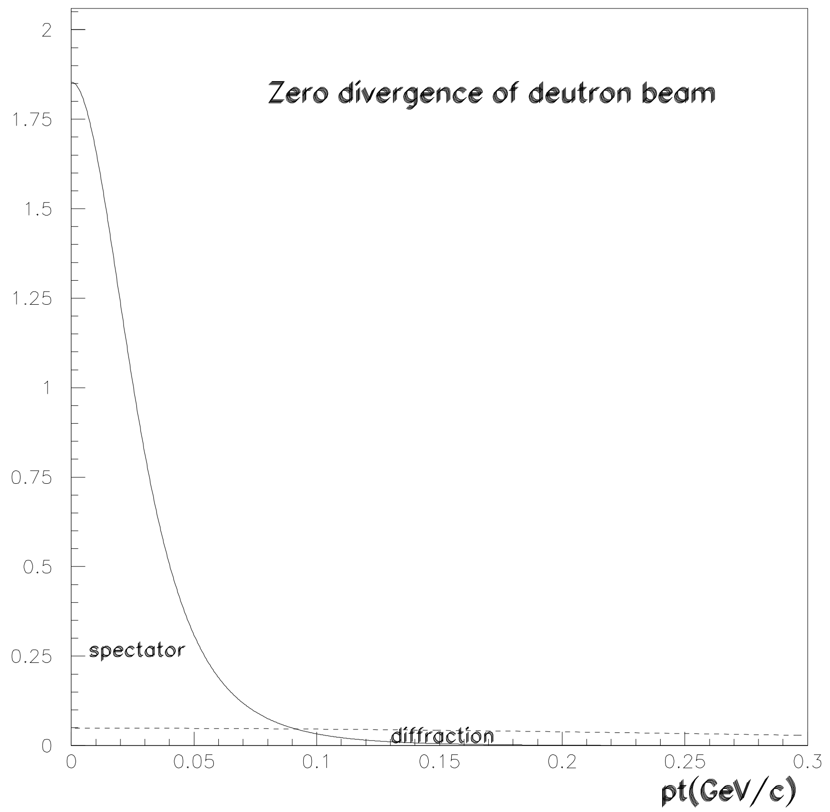

Figure 2: *The p_t spectra of the spectator and the diffractively scattered nucleon for a "pencil-like beam".*

distribution dN/dp_t^2 of the spectator nucleon ploted as a function of its transverse momentum, p_t, for a fraction of events, in which its longintudinal momentum is contained within $\pm 10\%$ of the peak value of Fig. 1. By doing this selection we choose a specific configuration of nucleons in the deuteron in which nucleons move perpendicularly to the incoming electron direction. We show, as well, for comparison, the corresponding distribution for diffractively scattered nucleon. The distributions are significantly diferent allowing for a clean identification of the spectators in the $p_t \leq 50\ MeV$ domain and diffractively scattered nucleons in the $p_t \geq 150\ MeV$ domain. If however, we include in the calculation the effect of intrinsic divergence of the deuteron beam, than the identification efficiency deteriorates significantly (both diffractive and spectator nucleons contribute to the whole p_t domain shown in Fig. 3). The plot presented in Fig. 3 corresponds to the mini β optics with the p_t spread at the interaction point of $\sqrt{60^2 + 170^2}$ MeV/c. It is clear that it will be difficult to achieve, in the "shape fit", 1 % precision of subtraction of the diffractive contribution. We thus conclude that within the presently considered

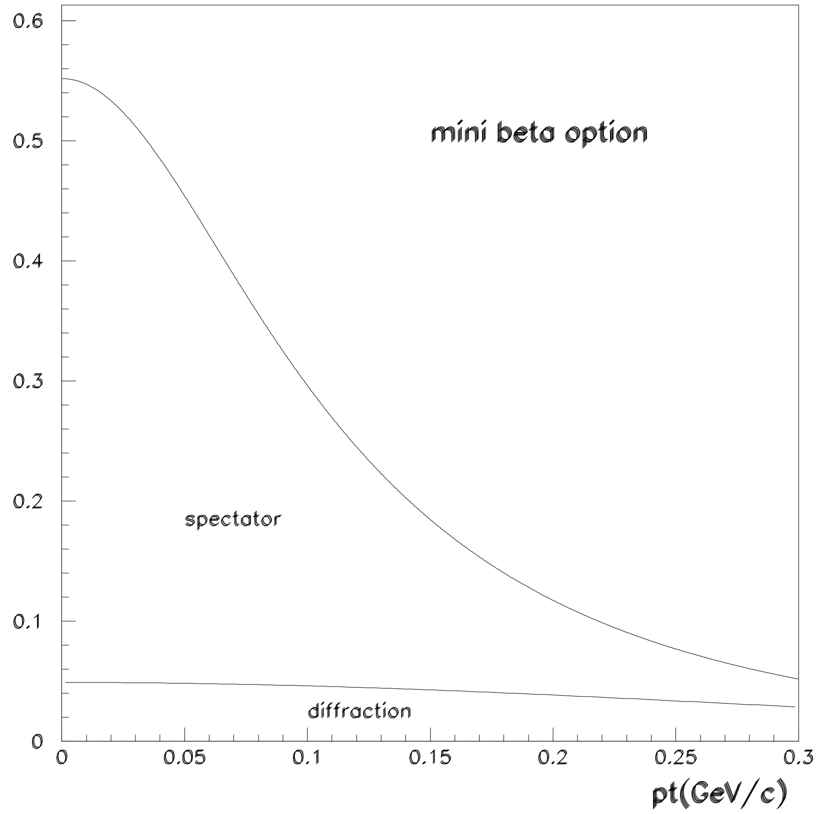

Figure 3: *The p_t spectra of the spectator and the diffractively scattered nucleon for the mini β optics.*

collision optics it will be difficult to resolve the the nuclear effects with respect to the effects of low x behavior of the nonsinglet structure function at the satisfactory level of precision.

Acknowledgements

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References

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