Diffraction in DIS on nuclear targets

N.N.Nikolaev[a,b,c], W.Schäfer[b], B.G.Zakharov[c], V.R.Zoller[d]

[a] ITKP, Universität Bonn, Nußallee 14-16, Bonn D-53115, FRG
[b] Inst. f. Kernphysik, KFA Jülich, D-52425 Jülich, FRG
[c] L.D.Landau Inst. Theor. Physics, Kosygina 2, 117334 Moscow, Russia
[d] Inst. Theor. exp. Physics, B.Cheremushkinskaya 25, 117259 Moscow, Russia

Abstract: We discuss the implications of a strong enhancement of diffraction for multiproduction in DIS off nuclear targets. The predicted effects are large and observable at HERA. We present the prediction of a large tensor structure function $b_2(x)$ of the deuteron which does not vanish at small x.

Diffractive DIS on nuclei is a huge effect

At the DESY Mini School in May 1994 one of the present authors (NNN) presented a prediction of a strong nuclear enhancement of diffractive DIS (DDIS), which on a strongly absorptive nuclei must reach $f_D \sim 50\%$ of the total DIS rate [1]! The participants may remember how it has been ridiculed by fellow experimentalists as an utterly useless prediction and at the Round Table discussion some of the fellow theorists stated it must be wrong. It took slightly more than a year for a serious discussion on the electron-nucleus option at HERA to be on the floor.

The detailed evaluation of nuclear enhancement of DDIS is published in [2]. The argument for the enhancement goes as follows: The microscopic QCD mechanism of DDIS is a grazing, quasielastic scattering of multiparton Fock states of the photon on the target proton, which is best described viewing these Fock states as systems of color dipoles spanned between quarks, antiquarks and gluons [3]. The crucial finding is that for transverse photons DDIS is dominated by the contribution from soft dipoles $r \sim 1/m_f$, still the $1/Q^2$ leading twist behavior of σ_T^D is a rigorous QCD result [3]. The rest of the story is simple: DDIS on nuclei essentially amounts to an elastic (coherent DDIS) and small admixture of quasielastic (incoherent DDIS) scattering of soft dipoles off a target nucleus. For soft dipoles and strongly absorbing targets

$$\sigma^D \sim \sigma^{ND} \sim \frac{1}{2}\sigma^{tot}. \tag{1}$$

Here ND stand for the non-diffractive and/or non-LRG DIS. In the conventional A^α parameterization of nuclear cross sections, we find $\alpha \approx 0.9$ for the total DIS at moderately small $x \sim 10^{-3}$ (or $\alpha \approx -0.1$ for the structure function per bound nucleon) and very large $\alpha_{coh}^D \approx$0.25-0.3 for the coherent DDIS per bound nucleon. Finally, for the incoherent DDIS per bound nucleon we predict $\alpha_{inc}^D \approx -0.4$. For the reference, for the carbon target $\sigma_{coh}^D : \sigma_{inc}^D \approx 2.2 : 1$.

Coherent DDIS $eA \to e'XA$ is at work for $x, x_{\mathbf{IP}} \lesssim 0.1 \cdot A^{-1/3}$ which is precisely the kinematical range of the eA collisions at HERA. What are the consequences of this striking nuclear enhancement of DDIS? Are they observable at HERA?

DDIS and A^α physics in multiproduction off nuclei

The multiproduction off nuclei is usually discussed in terms of the normalized Feynman z and/or (pseudo)rapidity η distributions $R(z) = [dn/dz]_A/[dn/dz]_N$ and $R(\eta) = [dn/d\eta]_A/[dn/\eta]_N$. In the hadron-nucleus collisions, the more hadronlike is a hadron, i.e., larger is σ_{tot}^{hN} the stronger is the shadowing in σ_{tot}^{hA}, the higher is the average multiplicity, the larger is $R(\eta) > 1$ at mid-rapidity, the stronger is nuclear attenuation of the projectile fragments $R(z \sim 1) < 1$, the stronger is the hadronic activity in the target nucleus region (for the review see [4]. We predicted a striking reversal of this trend when going from pointlike photons in the nonshadowing (NS) region of $x \gtrsim 0.1$ to the hadronlike photons in the shadowing (SH) region of small $x \lesssim 0.03 - 0.01$ [2].

Indeed, in coherent DDIS the target nucleus remains in the ground state, there is vanishing hadronic activity in the nucleus region and coherent DDIS falls into the LRG category. Incoherent DDIS also contributes to LRG events but the fraction of incoherent DDIS rapidly decreases with A [2]. Because the DDIS rate increases at small x, hadronic activity in the nucleus region must decrease with the decreasing x, i.e., for more hadronlike photons. The predicted [2] effect is large, $\sim 30\%$, and has been fully confirmed by the E665 μXe scattering data [5]. The very sharp t distribution permits an unambiguous selection coherent DDIS. HERA experiments can extend these measurements to a much smaller x and higher Q^2 on a broad range of nuclei.

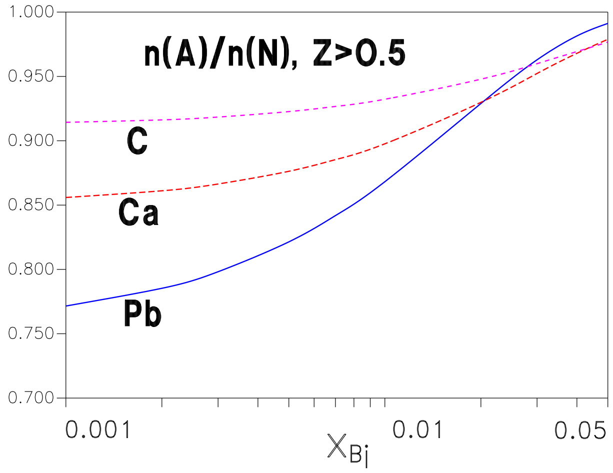

Figure 1: *Our predictions for attenuation of forward hadrons in ND DIS off nuclei as a function of* x_{bj}.

Now consider $R(z)$ for the generic, DDIS/ND unseparated, DIS off a nucleus. The very forward hadrons with $z \sim 1$ are predominantly the diffraction dissociation products [6]. It is precisely the part of the phase space usually discussed in terms of the fragmentation of the isolated struck quark and the Landau-Pomeranchuck-Migdal effect (for the quantum theory of the LPM effect see [7]). Our point is that DDIS completely invalidates this interpretation in the SH region of small x. Indeed, because of (1) for *heavy, strongly absorbing* nuclei we predict a *universality* of the z-distributions, $R(z) = 1$, which derives from the nuclear enhancement of DDIS, the Landau-Pomeranchuck effect is irrelevant for this prediction. The corrections to $R(z) = 1$ for slight nuclear distortions of the mass spectrum in DDIS must be marginal with one subtle exception: because of the M^2 dependent factorization scale [8] and related effects of color transparency [9] DDIS into small masses $M^2 \ll Q^2$ the vector mesons included will have a much steeper A^α dependence with the exponent $\alpha \approx$1.35-1.4. Therefore, in the narrow region of $z \to 1$ to which only the small mass excitations can contribute, we predict $R(z) > 1$!

The ND DIS is the counterpart of inelastic hadron-nucleus scattering and our principal prediction is that nuclear effects in ND events must be similar to those seen in $\pi A, pA$ collisions: $R_{ND}(z) < 1$ at $z \sim 1$ and $R(\eta) > 1$ in the mid-rapidity region. In particular, hadronic final states will be a superposition of subprocesses with the ν-fold average multiplicity (ν cut pomerons along the lines reviewed in [4]. Only the $\nu = 1$ subprocesses contribute to production of large-z particles. In Fig. 1 we show the expected x dependence of nuclear attenuation of forward hadrons with $z > 0.5$, in the parameterization $R(z) \approx A^{\alpha(z)}$ for the very forward hadrons and for a sufficiently small $x \sim 10^{-3} - 10^{-4}$ we predict $\alpha(z) \sim -0.15$. For the central, mid-rapidity region we predict $R(\eta) \sim A^{0.15}$. The mean multiplicities in the ND DIS are dominated by central production and must exhibit similar A dependence. Such a strong nuclear effects can easily be observed at HERA.

Nuclear enhancement of coherent DDIS implies enhancement of low multiplicities, whereas the enhancement of central production implies the enhancement of high multiplicities. Consequently, we predict a substantial broadening of the multiplicity distributions, although the overall nuclear increase of the average multiplicities can be relatively weak.

DDIS and the tensor spin structure functions of the deuteron

For DIS of *unpolarized* leptons off the spin-1 deuterons one can define the tensor spin structure function [10]

$$b_2(x,Q^2) = \frac{1}{2}\left[F_2^+(x,Q^2) + F_2^-(x,Q^2) - 2F_2^0(x,Q^2)\right] ,$$

where $+, -, 0$ refer to the deuteron spin projection on for instance the $\gamma^* D$ collision axis. One can similarly define the longitudinal tensor structure function $b_L(x,Q^2)$.

In the usually discussed impulse approximation the tensor parton densities vanish for the S-wave bound state. The $S-D$ interference makes the nucleon momentum distributions and folding corrections to structure functions different for $\pm, 0$ polarizations, but at moderately small x the corresponding tensor asymmetry is a per mill and even smaller effect and vanishes at $x \to 0$ [11].

An interesting finding is that an order in magnitude larger tensor spin structure function is generated by DDIS via shadowing corrections [12]. Our point is that nuclear shadowing depends on the alignment of nucleons in the deuteron, which because of the $S-D$ interference is different for $\pm$ and 0 polarization states. The striking finding is that unlike all other spin asymmetries which are well known to vanish in the limit $x \to 0$, the tensor spin asymmetry is finite and even rises at small x. Besides the spin-alignment dependent shadowing for DDIS, another source of the tensor asymmetry is DIS off pions in the deuteron. The number of pions in the deuteron also depends on the deuteron spin state. Our predictions for the tensor asymmetry are shown in Fig. 2. The pion effects have a sign opposite to that of the diffractive NS effects and dominate at $x \gtrsim 10^{-2}$, diffractive NS takes over at $x \lesssim 10^{-2}$.

We predict a nonvanishing $b_L(x,Q^2)$. Typically, the ratio $R_{LT} = b_L/b_2 \sim 0.2$ and is very similar to the familiar ratio σ_L/σ_T for the nucleon target.

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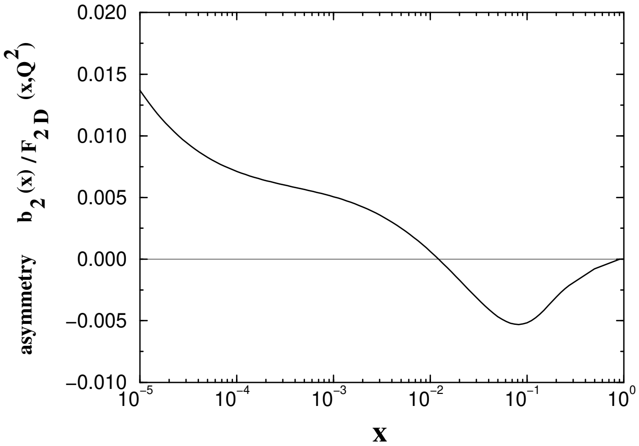

Figure 2: *Our predictions for the tensor asymmetry in DIS of unpolarized leptons off tensor polarized deuterons ($Q^2 = 10$ GeV^2).*

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