Diffraction and Shadowing in Deep-Inelastic Scattering from Nuclei[1]

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Abstract: Shadowing effects in deep-inelastic photon and lepton scattering from deuterium probe the mass spectrum of diffractive photo- and leptoproduction from nucleons. For heavier nuclear targets diffractive hadron-nucleon transition amplitudes can be studied in addition. At small $Q^2 \lesssim 1\,GeV^2$, as in the recent data from the NMC and E665 collaboration, shadowing is due to the coherent interaction of low mass vector mesons. Nuclei at HERA would yield the opportunity to investigate shadowing effects at large Q^2 where the diffractive excitation and coherent multiple interaction of heavy hadronic states is important.

Diffractive photo- and leptoproduction of hadrons from nucleons and shadowing effects in high energy (virtual) photon-nucleus scattering processes are closely related [1]. Their connection is displayed most clearly if one considers the scattering of high energy (virtual) photons from deuterium. The total photon-deuteron cross section can be split into two parts. First, it receives contributions from incoherent photon scattering off single nucleons inside the deuteron. This yields twice the photon-nucleon cross section. Secondly, at high photon energies $\nu > 3\,GeV$, or for lepton scattering at small values of the Bjorken variable $x < 0.1$, the photon can interact coherently with both nucleons inside the target. This double scattering process reduces the total photon-deuteron cross section, i.e. causes shadowing. It is driven by the diffractive excitation of the photon on the first nucleon into a hadronic state X, which subsequently interacts with the second nucleon and converts into the outgoing photon. Neglecting the real part of the diffractive photon-nucleon amplitude one obtains the double scattering correction to the total photon-deuteron cross section [1]:

$$\delta\sigma_{\gamma^* d} = -4\pi \int_{4m_\pi^2}^{W^2} dM_X^2 \, \left.\frac{d^2\sigma_{\gamma^* N\to XN}}{dM_X^2\,dt}\right|_{t\approx 0} \mathcal{F}_d(k_L). \tag{1}$$

Here $\frac{d^2\sigma_{\gamma^* N\to XN}}{dM_X^2\,dt}|_{t\approx 0}$ is the forward differential cross section for diffractive photoproduction of hadrons with invariant mass M_X. The latter requires a minimal momentum transfer $k_L = (Q^2 + M_X^2)/2\nu$ parallel to the momentum of the incident photon. Contributions with a momentum transfer k_L larger than the inverse of the typical target size are suppressed by the longitudinal deuteron form factor $\mathcal{F}_d(k_L)$. As a consequence, shadowing from diffractive excitation of large mass intermediate states will only be seen at sufficiently high photon energies ν.

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High precision data on shadowing in deep-inelastic lepton-nucleus scattering have recently become available from experiments at CERN (NMC) and Fermilab (E665) [2]. To investigate which diffractively excited hadronic states dominate the observed shadowing, one has to know the diffractive leptoproduction cross section (see Eq.(1)). However, in the kinematic regime of the NMC and E665 experiments such data are available only for the resonance region, $M_X^2 \lesssim 3\,GeV^2$. Nevertheless, since in these fixed target experiments the average momentum transfer is small ($\overline{Q^2} < 1\,GeV^2$) for small values of $x < 0.005$, we may, for a qualitative analysis, study shadowing effects for real photon beams at corresponding photon energies $50\,GeV < \nu < 300\,GeV$. Here the diffractive photoproduction cross section is measured in the region $4m_\pi^2 < M_X^2 < 18\,GeV^2$ [3]. At $M_X^2 \lesssim 3\,GeV^2$ it receives large contributions from vector mesons, while for $M_X^2 > 4\,GeV^2$ it drops like $\sim M_X^{-2}$. This is consistent with the expected Regge behaviour $\frac{d^2\sigma}{dM_X^2 dt}|_{t\approx 0} \sim M_X^{-2} \approx M_X^{-2\alpha_P(0)}$, where $\alpha_P(0)$ is the intercept of the pomeron trajectory, $\alpha_P(t=0) \approx 1.08$. In Fig.1 we show the shadowing correction for deuterium, $\delta\sigma_{\gamma d}$, caused by the diffractive excitation of all kinematically allowed hadronic states and compare it with the contribution from low mass vector mesons. We observe that vector mesons are dominant for photon energies $\nu < 300\,GeV$. This is in agreement with results from the generalized vector meson dominance model [4], where it is found that the shadowing observed by NMC and E665 is mainly due to the coherent multiple scattering of low mass vector mesons. Also note that according to Regge phenomenology, the diffractive photoproduction cross section rises as $W^{4(\alpha_P(0)-1)}$ which leads to an increase of the shadowing correction proportional to $\nu^{2(\alpha_P(0)-1)} \approx \nu^{0.16}$.

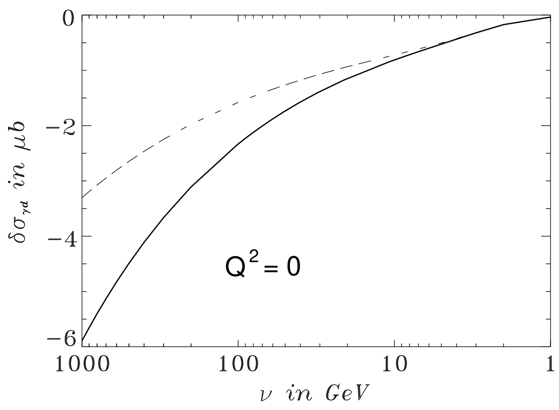

Figure 1: *Shadowing correction $\delta\sigma_{\gamma d}$ in high energy photon-deuterium scattering. The dashed line shows the contribution from low mass vector mesons.*

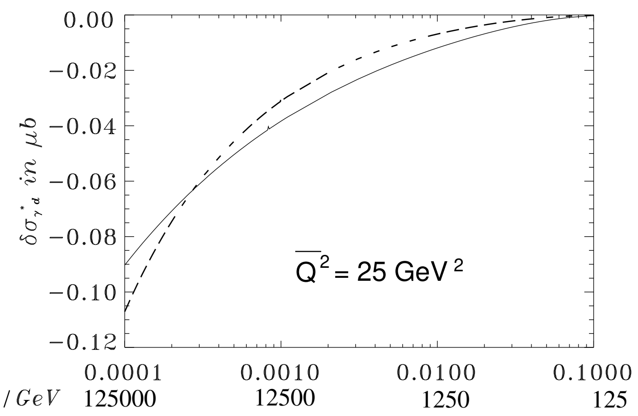

Figure 2: *Shadowing correction $\delta\sigma_{\gamma^* d}$ for deep-inelastic scattering form deuterium at $\overline{Q^2} = 25\,GeV^2$. For the full (dashed) line the diffractive leptoproduction cross section from H1 (ZEUS) was used.*

At large momentum transfers, $Q^2 \gtrsim 10\,GeV^2$, the situation is different. Here shadowing is caused by the coherent interaction of heavy hadronic states. This can be shown by using recent data on diffractive leptoproduction from nucleons measured at the HERA collider [5]. They cover the kinematic region of large $\overline{Q^2} \gtrsim 10\,GeV^2$ and very small x ($10^{-4} < x < 0.02$). However, the dependence of the production cross section on t, the momentum transfer to the nucleon target, is not yet available. We construct the forward diffractive production cross section by assuming a t-dependence similar to diffractive hadron-hadron collisions. Vector meson contributions to the diffractive cross section are strongly suppressed, e.g. $\sigma(\gamma^* N \to \rho N) \approx 1/Q^{4.2}$ [6]. At large masses one finds $\frac{d^2\sigma}{dM_X^2 dt}|_{t\approx 0} \sim (Q^2 + M_X^2)^{-a}$, where $a \approx 1.3$ (H1) or $a \approx 1.3$–1.5 (ZEUS) respectively. In Fig.2 we show the shadowing correction $\delta\sigma_{\gamma^* d}$ calculated for $\overline{Q^2} = 25\,GeV^2$ and $a = 1.3(1.5)$. We observe that the vector meson contribution to shadowing is negligible in this kinematic regime. The main effect is caused by large mass hadronic states: $M_X^2 \sim Q^2$. The energy dependence of the calculated shadowing effect is proportional to ν^{a-1}.

To conclude: We have investigated the relation between shadowing effects in deep-inelastic scattering from nuclei and diffractive photo- and leptoproduction from free nucleons. We find that the momentum transfer Q^2 selects the diffractive states which dominate the observed shadowing effect. As a consequence shadowing as observed in recent measurements of the NMC and E665 collaboration is controlled by the coherent multiple scattering of low mass vector mesons. If nuclei would become available at the HERA collider, shadowing effects could be explored at large $Q^2 \gtrsim 10\,GeV^2$, where the high mass tail of the diffractive production cross section is relevant. Therefore the investigation of shadowing effects in deep-inelastic scattering from deuterium over a large range of Q^2 probes the M_X^2- and Q^2-dependence of the diffractive leptoproduction cross section. For heavier nuclear targets shadowing is sensitive not only to double scattering but also to the multiple interaction of diffractively excited hadronic states. This offers the possibility to study both diagonal and off-diagonal diffractive hadron-nucleon amplitudes.

References

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