Color Transparency or the Standard Inelastic Shadowing?∗

Boris Kopeliovich†
Max-Planck Institut für Kernphysik, Postfach 103980, 69029 Heidelberg, Germany

Jan Nemchik‡
Dipartimento di Fisica Teorica, Università di Torino I-10125, Torino, Italy

Abstract

The standard first-order inelastic correction (IC) well known in the pre-QCD era, causes a rising $Q^2$-dependence of nuclear transparency in the quasielastic electron scattering, $A(e, e'p)A'$, at moderate $Q^2$, similar to what is supposed to be the onset of color transparency (CT). Although IC is a part of the whole pattern of CT, it contains no explicit QCD dynamics. Evaluation of this correction is based on experimental data on diffraction dissociation and is independent of whether CP phenomenon exists or not. The growth of nuclear transparency is numerically comparable with the expected signal of CT up to about $Q^2 \approx 20 \text{ GeV}^2$. Analogous effect in $A(p, 2p)A'$ reaction is estimated as well.

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†On leave from Joint Institute for Nuclear Research, Laboratory of Nuclear Problems, Dubna, 141980 Moscow Region, Russia. E-mail: bzk@dxnhd1.mpi-hd.mpg.de
‡On leave from Institute of Experimental Physics SAV, Solovjevova 47, CS-04353 Kosice, Slovakia
Recent failure of the NE18 experiment at SLAC \cite{1} to observe the onset of color transparency (CT) in $(e,e'p)$ reaction has excited interest to the baseline for such a study. It was realized that even the Glauber model predictions have a substantial uncertainty. Nevertheless, a nearly $Q^2$-independent nuclear transparency is expected in the Glauber approximation, what makes it possible to single out the $Q^2$-dependent onset of CT effects \cite{2, 3}.

We call Glauber eikonal approximation an approach disregarding any off diagonal diffractive rescatterings of the ejectile, which itself is supposed to be just a proton even in the primary interaction of the electron with a bound proton.

It is known since Gribov’s paper \cite{4}, that the Glauber model should be corrected for inelastic shadowing at high energies. The very existence and the numerical evaluations of the inelastic shadowing effect was nicely confirmed by the high precision measurements of the total cross sections of interaction of neutrons \cite{5} and neutral K-mesons \cite{6} with nuclei. Due to the inelastic corrections (IC) the total cross section turns out to be smaller, i.e. nuclear matter is more transparent, than is expected in the Glauber approximation. Important for further discussion is the rising energy dependence of nuclear transparency due to the growth of IC. An example is shown in fig.1. The data for $n-Pb$ total cross section as function of energy are compared with the Glauber approximation corrected or not for the IC, evaluated in \cite{5, 7}.

According to these results one can expect that nuclear matter becomes more transparent at higher $Q^2$ because the ejectile energy correlates with $Q^2$, $\nu = Q^2/2m_N$. Such a rising $Q^2$-dependent nuclear transparency can imitate the CT effects which are expected to manifest themselves as a monotonous growth of nuclear transparency with $Q^2$.

At this point it worth reminding that CT is a particular case of Gribov’s inelastic shadowing, provided that QCD dynamics tunes many elastic and inelastic diffractive rescatterings to cancel each other in the final state interaction \cite{8, 9} at high $Q^2$. Therefore, one may think that there is no sense in picking up only one IC from many others, which all together build up CT. However, searching for CT effects one should first of all ask himself what happens if CT phenomenon does not exist; for instance, if the ejectile in $(e,e'p)$ on a bound nucleon is not a small-size wave packet, but is a normal proton. Even in this case the IC shown schematically in fig. 2, makes the nuclear matter more transparent than is predicted by the
Figure 1: Data on $n - Pb$ total cross section (ref. \[5\] and references therein). The dashed curve is corresponds to the Glauber approximation. The solid line shows the effect of inclusion of the first order IC to the total cross section as it is calculated in ref. \[5\] Glauber model.

Figure 2: Cartoon showing $A(e, e'p)A'$ reaction with eikonal elastic final state interactions (a) and with diffractive production of inelastic intermediate state (b)

This first order IC corresponds to the diffractive production of inelastic intermediate states by the ejectile proton while it propagates through the nucleus. The proton waves
with and without this correction interfere with each other, while the contributions from
different production points add up incoherently because the momentum transfer
in the \((e, e'p)\) reaction is too large. It is important that IC has a positive relative sign,
provided that all diffraction amplitudes are imaginary, as was demonstrated in [10, 11, 12].
The resulting nuclear transparency reads,

\[
T r(Q^2) = \int d^2b \int_{-\infty}^{\infty} dz \rho(b, z) \exp[-\sigma^{NN}_m \int_{z}^{\infty} dz' \rho(b, z')] \times \\
\left[ 1 + 4\pi \int dM^2 \frac{d\sigma}{dM^2 dt}\big|_{t=0} F_A^2(b, z, q_L) \right]^2
\]

Here \(b\) and \(z\) are the impact parameter and longitudinal coordinate of the bound proton
which absorbs the virtual photon. \(\sigma^{NN}_m\) is inelastic \(NN\) cross section. We assume that
the \((e, e'p)\) cross section is integrated over the transverse momentum of the ejectile proton
relative to the photon direction. \(T(b) = \int_{-\infty}^{\infty} dz \rho(b, z)\) is the nuclear thickness function.
\(d\sigma/dM^2 dt\big|_{t=0}\) is the forward cross section of single diffraction dissociation in \(NN\) interaction.
\(F_A(b, z, q_L)\) is the nuclear longitudinal form factor [7],

\[
F_A(b, z, q_L) = \int_{z}^{\infty} dz' \rho(b, z') e^{iz'q_L},
\]

where \(q_L = (M^2 - m_N^2)/2\nu\) is the longitudinal momentum transfer in the diffraction disso-
ciation. This form factor leads to the \(Q^2\)-dependence of nuclear transparency.

Note that we assume in (1) that the cross section is integrated over the angle between
the proton and the virtual photon momenta (see [13]).

One can find in [5] a detailed calculation of IC to the nuclear total cross section. We use
the same parameterization of the data on \(d\sigma/dM^2 dt\) as in [3] and the realistic nuclear density
from [14] to calculate expression (1). Following refs. [3, 5, 7] we assume that the inelastic
intermediate states attenuate in nuclear medium with the same inelastic cross section as the
proton. The predicted growth of nuclear transparency with \(Q^2\) in \(Pb(e, e'p)\) is compared in
fig. 3 with what is expected to be a onset of CT [13]. We use \(\sigma^{NN}_m = 33 \text{ mb}\) in order to
have the same transparency in the Glauber approximation as in ref. [13]. We see that these
two mechanisms, one with and another one without CT dynamics predict about the same
magnitude of deviation from the Glauber model up to about \(Q^2 \approx 20 \text{ GeV}^2\). It is especially
difficult to disentangle the real CT effects and the first-order IC because of a substantial model-dependence of the theoretical predictions for CT. In order to detect reliably a signal of CT one needs $Q^2$ at least of a few tens of $GeV^2$. As different from CT, the growth of transparency provided by the first IC saturates at high $Q^2$ at quite a low level.

\[ \begin{align*}
\text{Figure 3: Comparison of the Glauber model (dashed line) with the model} & \text{ incorporating with CT (solid curve – CT) and with our calculation} \\
\text{of the first-order IC using eq.(1) (solid curve – no CT)}
\end{align*} \]

Our calculations are compared with the data from the NE18 experiment at SLAC \[ \text{in fig. 4. In order to be more realistic we use the data on} \sigma_{in}^{NN} \text{ from ref. [16] which exhibit a decreasing energy-dependence at low energies (compare with [24]). Of course, more sophisticated calculations may consider the effects of Fermi motion \[ \text{[11, 17, 18]}, \text{ few-nucleon correlations \[ \text{[19, 18, 20, 21, 22]}, \text{ accuracy of the closure approximation \[ \text{[23], etc. We try to escape these complications to make the presentation simpler. The relative contribution of IC is expected to be nearly independent of the details of nuclear structure.} \]

Note that we predict a bigger effect of inelastic shadowing than that in total hadron-nucleus cross sections \[ \text{[3]. In the latter case case it is a correction to the small exponential term in the elastic amplitude which is subtracted from unity, while in the present case we deal with a net transparency effect.} \]
Figure 4: Comparison of the Glauber model (dashed line) and of the results of our calculations of the standard first-order IC, eq. (1), (solid line) with the data from the NE18 experiment [1].

Note that the same problems are inherent in the quasielastic hadron scattering off nuclei, for instance, \(A(p, 2p)A'\). We expect a growth of nuclear transparency due to the standard IC in this reaction as well. The effect of the first IC was taken into account in all three proton legs and evaluated using the formula analogous to eq. (1) and the realistic energy-dependent inelastic nucleon cross section,

\[
Tr(p, 2p) = \int d^2b \int_{-\infty}^{\infty} dz \rho(b, z) \exp \left[ -\sigma_{in}^{NN} \int_{-\infty}^{\infty} d'z' \rho(b, z') \right] \times \\
\exp \left[ -\sigma_{in}^{NN} \int_{-\infty}^{\infty} d'z' \rho(b, z') \right] \left[ 1 + 4\pi \int dM^2 \frac{d\sigma}{dM^2dt} \bigg|_{t=0} \left| \int_{-\infty}^{\infty} d'z' \rho(b, z') e^{2iz'q_L} \right|^2 \right] \times \\
\left[ 1 + 4\pi \int dM^2 \frac{d\sigma}{dM^2dt} \bigg|_{t=0} \left| \int_{-\infty}^{\infty} d'z' \rho(b, z') e^{iz'q_L} \right|^2 \right]^2 \]  

The results for lead are plotted in fig. 5 in comparison with the data from the BNL experiment [2]. Of course we do not pretend to fit to the data, which, we believe, is
difficult to explain within any known realistic model. Fig.5 demonstrates the size of the effect due to the first-order IC.

Figure 5: The data from the Brookhaven experiment ref. [25] vs the Glauber model prediction (dashed curve) and including the first order IC. eq. (3) (solid curve). We took into account the energy dependence of $\sigma_{pp}^{in}$

To conclude, we estimated the first-order IC, which causes a growth of nuclear transparency with $Q^2$ in quasielastic scattering of electrons and hadrons off nuclei and can imitate the expected onset of CT up to $Q^2 \sim 20 \text{ GeV}^2$. In fact, this correction grows with the ejectile/projectile energy, which correlates with $Q^2$. The evaluation of this IC is independent of our ideas about QCD dynamics of hard interaction since it is based only on the data on diffractive dissociation. Although this correction is a part of the total CT pattern, it survives any modifications of the underlying dynamics and should be considered as a baseline for CT studies. One can reliably disentangle this contribution and the real CT effect only at $Q^2$ of a few tens of $\text{GeV}^2$, where the former saturates, but CT provides a growth of nuclear transparency up to unity.

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