Higher twist effects in small x lepton-nucleus scattering

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We summarize the current information on the nuclear effects in inclusive high-energy lepton-nuclear scattering. We emphasize difficulties in extracting A-dependence of the parton densities at $x \leq 0.05$ due to the presence of the A-dependent higher twist effects in low Q^2 kinematics studies experimentally. We argue that the higher twist effects should be enhanced in the neutrino scattering both in the vacuum and the valence quark channels.

1. Introduction

Despite more than twenty years of studies of the inclusive deep inelastic nuclear scattering, there is very little direct information about the A-dependence of the parton densities.

Let us first summarize the current experimental situation.

Experiments with electron and muon beams produced high precision measurements of the ratios of total cross sections of lA scattering in a wide range of x [1]. σ_L is much smaller than σ_T for the whole x, Q^2 range covered in the DIS experiments, and the σ_L/σ_T ratio is consistent with being A-independent. As a result the current data provide high precision information on $R_A(x,Q^2) \equiv F_{2A}(x,Q^2)/F_{2N}(x,Q^2)$. R_A was studied in a large range of Q^2 for $x \geq 0.10$. It exhibits a precocious scaling and hence experiments in this kinematics measure A-dependence of the quark parton distribution functions (PDFs). The main effect in the $x \geq 0.4$ kinematics is the EMC effect which unambiguously demonstrates importance of the nonnucleonic degrees of freedom in nuclei. A moderate enhancement of $R_A(x,Q^2)$ ($\sim 5\%$ for $A \geq 40$) is observed. Since the Q^2 range is smaller at $x \leq 0.1$ it is not clear whether higher twist effects contribute in the lower end of the studied Q^2 interval in this case, for the review of the experimental data see [1].

An important information on the antiquark distributions comes from the measurements of the Drell-Yan process performed at $M_{\mu^+\mu^-} \geq 4GeV$[2]. The measurements find that $\bar{q}_A/\bar{q}_N$ is very close to one in most of the measured x range: $0.03 \leq x \leq 0.25$ with a small suppression at the smallest x covered in the experiment.

Measurements of $R_A(x,Q^2)$ at $x \leq 0.05$ demonstrate presence of a significant nuclear shadowing. However a strong correlation is present in the data between x and Q^2 and accurate data for $x \leq 0.01$ are available for $Q^2 \leq 2GeV^2$ only. Theoretical analyzes discussed below suggest that a significant part of the nuclear shadowing in the studied region originates from the higher twist effects.

Combing information on the lack of enhancement of the antiquark distribution and the enhancement of $R_A(x \sim 0.1)$ one finds that the valence quarks are enhanced at $x \sim 0.1$. Some enhancement is necessary to satisfy the baryon charge sum rule:

$$\int_0^A dx(V_A(x,Q^2) - AV_N(x,Q^2)) = 0. \quad (1)$$

However the enhancement appears to be larger than one necessary merely to compensate the EMC effect and hence indicates a need for the leading twist valence quark shadowing [3–6].

For gluons situation is more uncertain - the theoretical analyzes based on the QCD momentum sum rule implies that the fraction of total momentum carried by gluons in nuclei is practically the same as in a free nucleon [3,4]. Combing this with the expectation of the leading twist gluon

[1]We define x as $AQ^2/2(qp_A)$ which is slightly different from the convention adopted in the experimental analyzes of defining x as $Q^2/2q_0m$.

shadowing at least on the scale of the shadowing for F_2 results in a prediction of a gluon enhancement of the order of $10-20\%$ for $x \sim 0.1$ and $A \geq 40$ [3,4]. Two experimental observations appear to support this expectation. One is the NMC high precision measurement of the Q^2 dependence of the ratio of the cross sections of scattering off Tin and Carbon[7] which observes an increase of $F_{2Sn}(x,Q^2)/F_{2C}(x,Q^2)$ with increase of Q^2 consistent with the expectations of [4,6]. If interpreted as a leading twist effect it can be converted to the ratio of the gluon densities with a very small theoretical uncertainty[8] suggesting an enhancement of the gluons in Tin by about 10% as compared to Carbon. However the Q^2 range of the NMC data is rather limited and the higher twist effects may affect the analysis substantially. Besides an enhancement of a similar magnitude is expected for the Carbon/Deuteron ratio (since the shadowing for Carbon/Deuteron is about the same as for Tin/Carbon). However NMC does not observe an increase of R_C for the same kinematics. Another evidence for the gluon enhancement comes from the A-dependence of the inelastic J/ψ production as measured for the tin/carbon exposure [9]. Here an enhancement of yield off Tin is observed which is consistent with the leading twist interpretation of the inclusive data.

Therefore understanding of the higher twist effects in the lepton-nucleus scattering remains a very important question. The recent NuTeV data aimed at a high precision determination of the Weinberg angle have added impetus to such studies.

2. Theory of the leading twist nuclear shadowing for the vacuum channel

It is well known that the physics of deep inelastic scattering changes at small x due to the increase of the essential longitudinal distances with decrease of x roughly $\propto 1/x$. As a result a virtual photon when fluctuating to a hadronic configuration, propagates distances, $l_c \sim 1/2m_N x$, exceeding internucleon distances in nuclei and ultimately the nucleus diameter. As a result it can interact coherently with two, three, ... $A^{1/3}$ nucleons, leading to a phenomenon of nuclear shadowing in DIS.

It was demonstrated by Gribov[10] that there exists a deep connection between phenomenon of nuclear shadowing and phenomenon of diffraction in the scattering off a free nucleon. The relation is especially simple and practically model independent if the interactions with two nucleons only is taken into account (which is reasonable for moderate $x \geq 0.01$ when the coherence length, l_c is significantly smaller than the nuclear size.

The shadowing correction arising from the coherent interaction with any two nucleons of the nuclear target with the atomic mass number A, $\delta F_{2A}^{(2)}$ (the superscript (2) serves as a reminder that only the interaction with two nucleons is accounted for), is expressed in terms of the proton diffractive structure function $F_2^{D(4)}$ (the superscript (4) indicates dependence on four kinematic variables) as a result of the generalization of the Gribov result to include the real part of the diffractive amplitude[11]. This does not require decomposition over twists and is therefore valid even for the case of real photon interactions

$$\delta F_{2A}^{(2)}(x,Q^2) = \frac{A(A-1)}{2} 16\pi \mathcal{R}e \left[\frac{(1-i\eta)^2}{1+\eta^2} \int d^2b \int_{-\infty}^{\infty} dz_1 \int_{z_1}^{\infty} dz_2 \int_x^{x_{I\!P,0}} dx_{I\!P} \times F_2^D(4)(\beta, Q^2, x_{I\!P}, t)\Big|_{t=t_{\min}} \rho_A(b,z_1)\rho_A(b,z_2) e^{ix_{I\!P} m_N (z_1-z_2)} \right], \quad (2)$$

with η the ratio of the real to imaginary parts of the diffractive scattering amplitude; z_1, z_2 and $\vec{b}$ the longitudinal (in the direction of the incoming virtual photon) and transverse coordinates of the nucleons involved (defined with respect to the nuclear center); β, $x_{I\!P}$ and t the usual kinematic variables used in diffraction. In particular, we use $\beta = x/x_{I\!P}$. Equation (2) uses the fact that the t-dependence of the elementary diffractive amplitude is much weaker than that given by the nuclear wave function, and, hence, $F_2^D(4)$ can be approximately evaluated at $t = t_{\min} \approx 0$. All information about the nucleus is encoded in the nucleon distributions $\rho_A(b,z_i)$. Finally, $x_{I\!P,0}$ is a cut-off parameter ($x_{I\!P,0} = 0.1$ for quarks and $x_{I\!P,0} = 0.03$ for gluons), effectively accounts for antishadowing effects, see discussion in [17].

The origin of all factors in Eq. (2) can be readily seen by considering the corresponding forward double rescattering Feynman diagram (see Fig. 1), which accounts for the diffractive production of intermediate hadronic states by the incoming virtual photon:

- The combinatoric factor $A(A-1)/2$ is the number of the pairs of nucleons involved in the rescattering process.
- The factor 16π provides the correct translation of the differential diffractive to the total rescattering cross section (see the definition later), as required by the Glauber theory [12].
- The factor $(1-i\eta)^2/(1+\eta^2)$ is a correction for the real part of the diffractive scattering amplitude $\mathcal{A}$. Since the shadowing correction is proportional to $(Im\mathcal{A})^2$, while the total diffractive cross section is proportional to $|\mathcal{A}|^2$, the factor $(1-i\eta)^2/(1+\eta^2)$ emerges naturally, when one expresses nuclear shadowing in terms of the total diffractive cross section (diffractive structure function).
- The integration over the positions of the nucleons is the same as in the Glauber theory. Since the recoil of the nucleons is neglected, both involved nucleons have the same transverse coordinate $\vec{b}$.
- The integration over $x_{I\!P}$ represents the sum over the masses of the diffractively produced intermediate states.
- In order to contribute to nuclear shadowing (not to break the nucleus), the virtual photon should interact with the nucleons diffractively. The product of the two diffractive amplitudes (depicted as shaded blobs in Fig. 1) gives the diffractive structure function of the nucleon $F_2^{D(4)}$.)
- The effect of the nucleus is given by the nucleon densities $\rho_A(b,z_i)$. For the sufficiently heavy nuclei that we consider, nucleon-nucleon correlations can be neglected and the nuclear wave function squared can be approximated well by the product of individual $\rho_A(b,z_i)$ for each nucleon (the independent particle approximation).
- The factor $e^{ix_{I\!P} m_N (z_1-z_2)}$ is a consequence of the propagation of the diffractively produced intermediate state between the two nucleons involved.

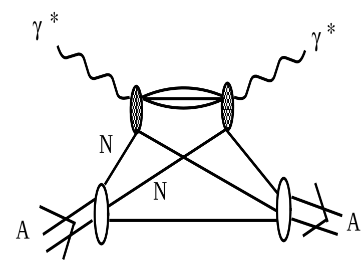

Figure 1. The forward γ^*-nucleus rescattering amplitude, which gives the principal contribution to nuclear shadowing.

Step 2. The QCD factorization theorems for inclusive [13] and hard diffractive DIS [14] can be used to relate the structure functions in Eq. (2) to the corresponding – inclusive and diffractive – parton distribution functions[15–17]. Since the coefficient functions (hard scattering parts) are the same for both inclusive and diffractive structure functions, the relation between the shadowing correction to nuclear PDFs (nPDFs) and the proton diffractive PDFs is given by an equation similar to Eq. (2). The shadowing correction to the nPDF of flavor j, $f_{j/A}$, $\delta f_{j/A}^{(2)}$, is related to the nucleon diffractive PDF $f_{j/N}^{D(4)}$ of the same flavor

$$\delta f_{j/A}^{(2)}(x,Q^2) = \frac{A(A-1)}{2} 16\pi \mathcal{R}e \left[\frac{(1-i\eta)^2}{1+\eta^2} \right. \\ \times \int d^2b \int_{-\infty}^{\infty} dz_1 \int_{z_1}^{\infty} dz_2 \int_x^{x_{I\!P,0}} dx_{I\!P} \\ \times f_{j/N}^{D(4)}(\beta,Q^2,x_{I\!P},t)\big|_{t=t_{\min}} \rho_A(b,z_1)\rho_A(b,z_2)$$

$$\times e^{ix_{I\!P} m_N (z_1 - z_2)} \Bigg] . \quad (3)$$

Equation (3) is very essential in several ways. Firstly, it enables one to evaluate nuclear shadowing for each parton flavor j separately. Secondly, since the diffractive PDFs obey leading twist QCD evolution, so does the shadowing correction $\delta f_{j/A}^{(2)}$. This explains why the considered theory can be legitimately called the leading twist approach. Since Eq. (3) is based on the QCD factorization theorem, it is valid to all orders in α_s. Hence, if $f_{j/N}^{D(4)}$ is known with the next-to-leading order (NLO) accuracy, as is the case for the used H1 parameterization for $f_{j/N}^{D(4)}$, we can readily make predictions for NLO nPDFs.

Step 3. Equation (3) is derived in the approximation of the low nuclear thickness and it takes into account only the interaction with two nucleons of the target. The effect of the rescattering on three and more nucleons can be taken into account by introducing the attenuation factor $T(b, z_1, z_2)$ (see for example Ref. [18]),

$$T(b, z_1, z_2) = e^{-(A/2)(1-i\eta)\sigma_{\text{eff}}^j \int_{z_1}^{z_2} dz \rho_A(b,z)} , \quad (4)$$

where the meaning of σ_{eff}^j should become clear after the following discussion. Let us consider sufficiently small values of Bjorken variable x such that the factor $e^{ix_{I\!P} m_N (z_1 - z_2)}$ in Eq. (3) can be neglected. Then, introducing σ_{eff}^j as

$$\sigma_{\text{eff}}^j(x, Q^2) = \frac{16\pi}{f_{j/N}(x, Q^2)(1 + \eta^2)} \times \int_x^{x_{I\!P,0}} dx_{I\!P} f_{j/N}^{D(4)}(\beta, Q^2, x_{I\!P}, t)\big|_{t = t_{\min}} , \quad (5)$$

Eq. (3) can be written in the form equivalent to the usual Glauber approximation

$$\delta f_{j/A}^{(2)}(x, Q^2) \approx \frac{A(A-1)}{2}(1 - \eta^2)\sigma_{\text{eff}}^j(x, Q^2) \times f_{j/N}(x, Q^2) \int d^2b \int_{-\infty}^{\infty} dz_1 \times \int_{z_1}^{\infty} dz_2 \rho_A(b, z_1)\rho_A(b, z_2) , \quad (6)$$

where $f_{j/N}$ is the proton inclusive PDF. Therefore, it is clear that thus introduced σ_{eff}^j has the meaning of the rescattering cross section, which determines the amount of nuclear shadowing in the approximation of Eq. (6). Hence, it is natural to assume that the same cross section describes rescattering with the interaction with three and more nucleons, as postulated by the definition of the attenuation factor $T(b, z_1, z_2)$ by Eq. (4). In the language of Feynman diagrams, the assumed form of the attenuation factor implies that the diffractively produced intermediate state rescatters elastically (i.e. we neglect fluctuations into the diffractive state with different mass) with the same cross section on all remaining nucleons of the target.

After introducing the attenuation factor into Eq. (3), the complete expression for the shadowing correction, $\delta f_{j/A}$, becomes

$$\delta f_{j/A}(x, Q^2) = \frac{A(A-1)}{2} 16\pi \mathcal{R}e \Bigg[\frac{(1 - i\eta)^2}{1 + \eta^2} \times \int d^2b \int_{-\infty}^{\infty} dz_1 \int_{z_1}^{\infty} dz_2 \int_x^{x_{I\!P,0}} dx_{I\!P} \times f_{j/N}^{D(4)}(\beta, Q^2, x_{I\!P}, t_{\min})\rho_A(b, z_1)\rho_A(b, z_2) \times e^{-(A/2)(1-i\eta)\sigma_{\text{eff}}^j \int_{z_1}^{z_2} dz \rho_A(b,z)} \times e^{ix_{I\!P} m_N (z_1 - z_2)} \Bigg] . \quad (7)$$

This is our master equation (see Ref.[17] for the expression containing contribution of the non-vacuum channels), which we used to derive our numerical predictions for the amount of nuclear shadowing in nPDFs and structure functions at the starting evolution scale $Q_0^2 = 4$ GeV^2, which are then evolved to larger Q^2 scales using the NLO QCD evolution equations. As mentioned above, the double rescattering term can be calculated using Eq. (3) at any Q^2. However, the quasieikonal approximation employed in Eq. (7) is best justified at low $Q^2 \sim Q_0^2$, where fluctuations in the strength of the interaction are smaller (see the discussion in Ref. [16]). The QCD evolution equations automatically account for the proper increase of the fluctuations of the effective cross section around its average value σ_{eff}^j with an increase of Q^2. This important effect is omitted if one attempts to apply Eq. (7) at $Q^2 > Q_0^2$ with a

Q^2-dependent $\sigma^j_{eff}(Q^2)$.

3. Higher twist effects in $\gamma^* A$ scattering.

As was already mentioned in the introduction the shadowing of F_{2A} is observed only for relatively small Q^2. Besides, there is a strong correlation of x and Q^2 in the relevant kinematic region of $x \leq 0.01$, $Q^2 \leq 2$ GeV^2. In this kinematic region theoretical calculations of shadowing based on the Gribov theory connecting diffraction in electron nucleon scattering and shadowing in eA scattering describe the data well, see e.g.[19–21]. However, in these analyzes the vector meson contribution to diffraction which is a higher twist effect was found to be substantial. This suggests that the higher twist effects in shadowing maybe important. At the same time importance of the vector meson contribution cannot be considered by itself as a proof of the presence of the higher twist effects in the shadowing since the vector meson contribution could be dual to the contribution of the continuum as it happens for example in the case of inclusive DIS.

The use of the theory of the leading twist shadowing allows to address this question. Recently, we performed detailed analysis of the predictions of the leading twist shadowing incorporating the current information from HERA both for the region of $x_{I\!P}$ where vacuum channel dominates and from higher $x_{I\!P}$. We included uncertainties related to the real part of the diffractive amplitude due to the non-vacuum contribution. Since the leading twist evolution starts at the initial scale $Q_0^2 = 4$ GeV^2 we had to evolve backward from our initial scale $Q_0^2 = 4$ GeV^2 down to $Q^2 = 3$ GeV^2 (at lower Q^2, the numerical accuracy of our calculations becomes worse), and then evaluate $F_2^A/(AF_2^N)$ at fixed $Q^2 = 3$ GeV^2 for the first five NMC data points with $Q^2 < 3$ GeV^2. The results of the comparison are presented in Fig. 2. One can see from Fig. 2 that the agreement with the data at low x is poor. Of course, one might argue that we are comparing our predictions at $Q^2 = 3$ GeV^2 (this is as low as we could go and have trustworthy QCD evolution results) to the data with much lower Q^2 values: the first five NMC points presented in Fig. 2, the average values of Q^2 are

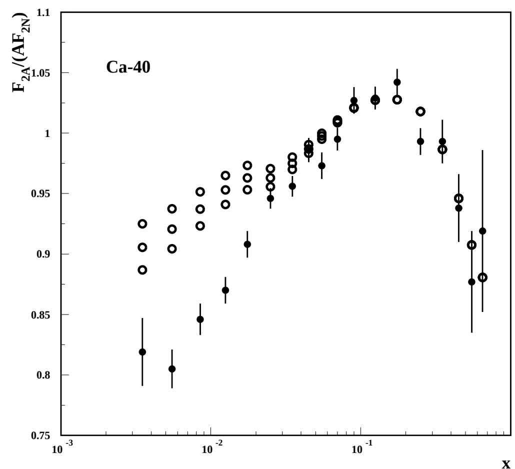

Figure 2. Comparison of the leading twist theory results (open circles) to the NMC data on ^{40}Ca [22] (filled circles). Three sets of open circles correspond to three values of the diffractive slope B_q in Eq. (7): $B_q = (8.3, 7.2, 6.1)$ GeV^{-2}. First five open circles correspond to the fixed $Q^2 = 3$ GeV^2, all other have the same Q^2 as the corresponding data point.

$\langle Q^2 \rangle = (0.60, 0.94, 1.4, 1.9, 2.5)$ GeV^2. However, even if we consider the scenario with the maximally possible nuclear shadowing (the choice of $\eta_{I\!R} = \eta_{I\!P}$), or evolve down to $Q^2 = 2$ GeV^2, the agreement with the NMC low-x does not improve. Therefore, since our approach to nuclear shadowing includes the entire leading twist contribution to the nuclear shadowing correction to the nuclear structure function F_2^A, and the contribution of the $N \geq 3$ rescattering which has a small model dependence is not important in the discussed kinematics) the disagreement with the NMC low-x data compels us to conclude that *the low-x NMC data [22] contain significant higher twist effects, which contribute 40÷50% to the nuclear shadowing correction to F_2^A.*

As a check of the consistency of this analysis with analyzes of the groups which described the data using as input the HERA diffractive data we compared the LT parametrization of $F_2^{D(3)}(\beta, Q^2)$ with the HERA data at $Q^2 \leq 2GeV^2$. We found that these fits very significantly underestimate the diffractive cross section which for $\beta \geq 0.4$ (dominating in this case in the shadowing integral) is predominantly due to the vector meson contribution. This provides a strong evidence for the lack of the resonance- continuum duality in the diffractive interactions and implies that indeed a large part of the nuclear shadowing observed by NMC is due to the higher twist effects.

Currently several groups started programs of extracting nuclear PDFs from the fits to the nuclear data [6,23]. So far these analyzes were based on the assumption that the higher twist contributions are not important in the kinematics of the NMC data (which dominate the fits). Our analysis suggests that this is not a very safe assumption.

It is also worth noting that the HT shadowing may extend to higher x than the leading twist shadowing. Indeed the characteristic coherence length in the case of the vector meson contribution, $l_c = 2\frac{\nu}{Q^2+m_V^2}$, is somewhat larger than the average l_c for $Q^2 > m_V^2$. Also, there seem to be no reasons for the enhancement effects which damp shadowing in the leading twist as a consequence of presence of the baryon and momentum sum rules. Hence a new systematic study of the eA scattering at $x \sim 0.05 \div 0.1$, $Q^2 \leq 4GeV^2$ would be highly desirable.

4. Valence quark channel and Higher twist effects in neutrino scattering

Valence quark shadowing constitutes one of the biggest puzzles of the DIS scattering off nuclei at small x. Indeed, the aligned jet model produced a very reasonable description of the magnitude of the nuclear shadowing in the sea channel [3,24] at intermediate Q^2. It is perfectly consistent with the dominance of the soft mechanism of the diffraction in the $\gamma^* N$ scattering at such Q^2. Consequently, one may expect that the valence quark channel corresponding to the exchange of

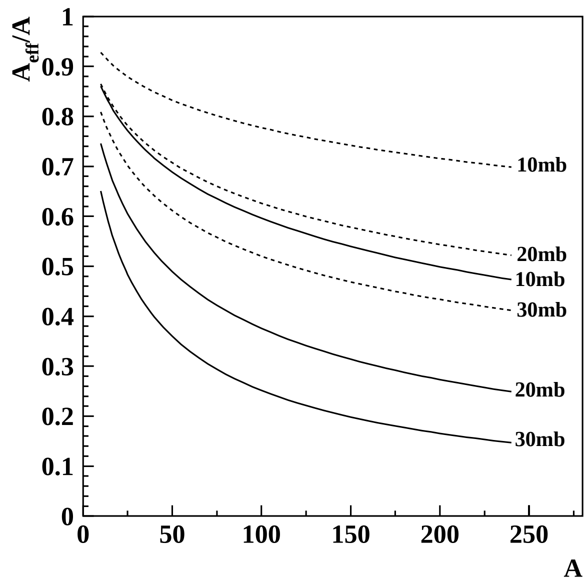

Figure 3. Comparison of shadowing in the valence channel (solid curves) and sea channel (dashed curves) for different values of σ_{eff}.

a non-vacuum $I\!R$-Reggeon is due to the difference of the interaction of aligned jets where a quark is fast or an antiquark is fast. In this case using the eikonal approximation we can estimate shadowing in the valence channel as [3]:

$$\frac{V_A(x, Q_0^2)}{V_N(x, Q_0^2)} = \int T(b) \exp(-T(b)\sigma_{eff}/2), \qquad (8)$$

where σ_{eff} is the average cross section of the interaction of the aligned jets. Eq.8 leads to a much larger shadowing for $A \geq 10$ than the corresponding equation for the sea channel even if σ_{eff} is a factor of two smaller than for the sea channel where it is about 20 mb, see Fig.3. Qualitatively the reason is that in the limit of strong absorption difference of the cross sections is determined by the scattering off the edge of the nucleus and hence $\propto A^{1/3}$ rather than $\propto A^{2/3}$ as in the case of the total cross sections.

A large shadowing in the valence channel leads a large enhancement of V_A at larger x to satisfy the conservation of the baryon charge as given by Eq.(1) [3]. However the combined analysis of the E772 Drell-Yan and the NMC data seems not support such large effect. It is not clear whether including higher twist effects at smaller x would help, since the required suppression of the shadowing effect is at least a factor of two - three. More likely possibility is that the onset of the leading twist shadowing regime is delayed to smaller x, with the enhancement spread over a larger range of x. This calls for a systematic studies of the A-dependence of $F_3(x, Q^2)$ at $x \leq 0.1$.

The leading twist formalism can be formally extended to calculate LT shadowing due to interaction with two nucleons by noticing that in this case a diagram corresponding to attachment of two Pomerons to the target nucleons has to be substituted by an interference diagram of Fig. 4 where a non-vacuum Reggeon is attached to one of the nucleons. The enhancing factor of two present in the eikonal in this language is due to the lack of the identity of two exchanges. The suppression as compared to the Pomeron case can come from a strong suppression of the quark contribution in the structure function of the Pomeron exchange. Overall this problem requires further studies and will be considered elsewhere.

At the same time is seems natural that for small virtualities soft exchanges should dominate. In this case, similar to the case of vacuum channel, two-body processes due to exchange of the non-vacuum Reggeons should dominate (the same ones which generate the nonsinglet contribution for the total cross section). For such processes the eikonal approximation for the screening of the non-vacuum exchanges should be a reasonable approximation. Thus it should extend to rather large x as there are no compensating effects from the baryon charge conservation. Also, it should be substantially larger than at high Q^2 where the data indicate it to be small for $x \leq 0.05$ and absent for higher x. At the same time in difference from the vacuum channel the ratio of the two-body and inclusive channels decreases with x as $x^{1/2}$ leading to similar decrease of the shadowing with decrease of x. Hence we conclude that *significant higher twist shadowing effects are expected in the valence quark channels.*

We have argued above that a significant higher twist shadowing is present for F_{2A} in the virtual photon-nucleus scattering. Similar effects should be present in the case of low Q^2 neutrino scattering. In fact, it follows from the the Adler theorem[25] that in the limit of very small Q^2:

$$\frac{\sigma^{\nu+A\rightarrow\mu+X}(E_\nu, Q^2)}{\sigma^{\nu+A\rightarrow\mu+X}(E_\nu, Q^2)} = \frac{\sigma_{tot}(\pi A)}{\sigma_{tot}(\pi N)}. \tag{9}$$

Since the shadowing for $\sigma_{tot}(\gamma A)$ is known to be smaller than for $\sigma_{tot}(\pi A)$ by about $20 \div 30\%$ we conclude that for sufficiently low Q^2 neutrino scattering the higher twist shadowing should be larger than for the photon case.

In conclusion, we have demonstrated that higher twist shadowing effects should be enhanced for $x \leq 0.1$ in the (anti)neutrino-nucleus scattering both in the case of F_3 and F_2 structure functions making it very interesting to perform detailed experimental studies of the A-dependence of of $\nu(\bar{\nu})-A$ in this kinematics. Such studies would help also to understand a possible difference between the higher twist effects in the neutral and charged current weak interactions which was suggested to be of relevance for determination of the Weinberg angle from the NuTeV experiment, see discussion in [26].

Such studies are likely to be possible within the framework of the the intermediate energy neutrino program discussed at this workshop.

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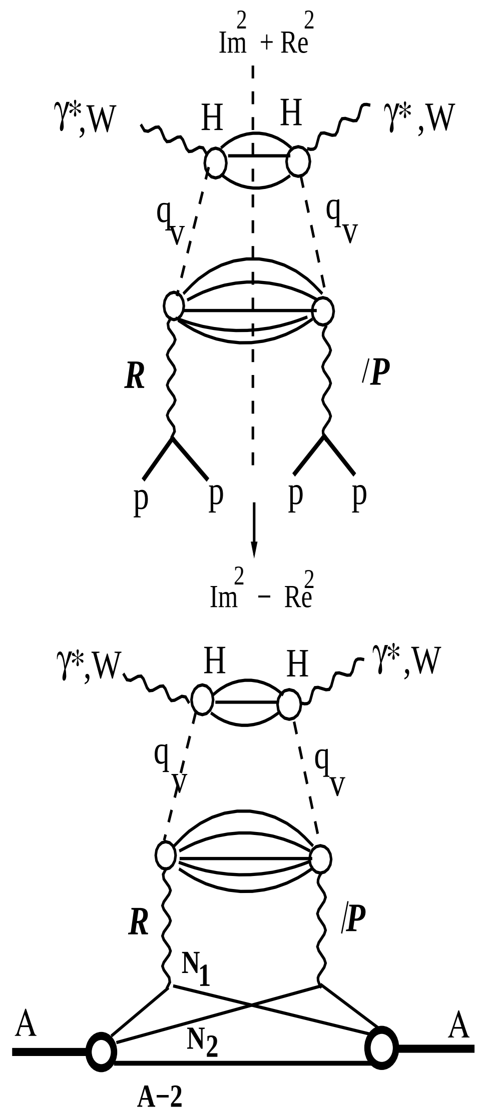

Figure 4. Leading twist diagram contributing to valence quark shadowing.