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NUCLEAR MODIFICATION IN THE STRUCTURE FUNCTION F_3

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ABSTRACT

Nuclear shadowing in the structure function F_3 is investigated as a possible test of shadowing models. The F_3 shadowing is studied in two different theoretical models: a parton-recombination model with Q^2 rescaling and an aligned-jet model. We find that predictions in these models differ completely in the small x region. It suggests that the F_3 shadowing could be used for discriminating among different models, which produce similar shadowing behavior in the structure function F_2.

1. Introduction

This talk is based on our investigation with R. Kobayashi in Ref. 1. Nuclear shadowing in the structure function F_2 has been studied extensively last several years.[2] There are various models in explaining the shadowing. These models include a traditional explanation in terms of vector-meson dominance and a new approach using parton interactions in nuclei. These viewpoints seem to be very different. The former model indicates that the virtual photon transforms into vector-meson states, which then interact with a target nucleus. Because the mesons interact predominantly in the nuclear surface, internal constituents are shadowed. On the other hand, the latter model is based on a parton picture. At small x, the localization size of a parton could exceed the average nucleon separation in a nucleus. Therefore, partons in different nucleons could interact, and these interactions are called parton recombinations. The recombinations are extra nuclear effects, which give rise to the nuclear shadowing.

These different models produce similar x dependence in the structure function F_2, so that we cannot distinguish among the models in comparison with experimental data. Various shadowing models may be tested by other quantities such as sea-quark and gluon distributions in nuclei.[3] In this paper, we propose that the structure function F_3 could be useful in determining the appropriate shadowing description. Namely, valence-quark distributions at small x are not well investigated and they could be used for determining the shadowing model. In order to find the possibility, two different models are employed for the shadowing. The first one is a parton model with parton recombination and Q^2 rescaling effects,[2] and the other is an aligned-jet model [4] which is an extension of the vector-meson-dominance model. Nuclear

*(URL) http://www.cc.saga-u.ac.jp/saga-u/riko/physics/quantum1/structure.html,
(Anonymous FTP) ftp://ftp.cc.saga-u.ac.jp/pub/paper/riko/quantum1.

modification of $F_3(x)$ in these models is explained in section 2.1. Then, we discuss whether or not the results are compatible with current experimental data. Experimental restrictions are estimated in section 2.2 and the results are compared with the theoretical predictions.

2. Shadowing in the structure function F_3

Nuclear modification of F_3 could be estimated from F_2 at medium and large x because valence-quark distributions dominate both structure functions. Hence, the essential point of our study is to investigate F_3 in the small x region. We neglect next-to-leading order corrections in F_3 for simplicity, so that F_3 is given by the valence-quark distributions: $F_3(x) = u_v(x) + d_v(x)$. Therefore, shadowing in F_3 indicates nuclear modification of the valence-quark distributions at small x. We explain theoretical and experimental situations in the following.

2.1. Model predictions

Because there is little theoretical study on the F_3 shadowing, existing theoretical predictions are limited at this stage. Among the models, we employ two very different ones for studying F_3.

The first one is a hybrid parton model with Q^2 rescaling and parton recombination effects.[2] The rescaling model was originally proposed as a model for explaining the medium x region, and the recombination as a model in the small x region. Combining these mechanism, we could explain nuclear structure functions F_2^A from small x (≈ 0.01) to large x (≈ 0.8). This unified model can be applied to the structure function F_3. According to the Q^2 rescaling model, nuclear structure functions $F_3^A(x, Q^2)$ are given by rescaling (increasing) Q^2 in the nucleon structure function $F_3^N(x, Q^2)$. Therefore, the ratio $R_3 \equiv F_3^A(x)/F_3^D(x)$ is smaller than unity at medium x as it explains the EMC effect in this region. Since the rescaling satisfies the baryon-number conservation $\int dx[u_v(x) + d_v(x)] = 3$, the ratio R_3 becomes larger than unity at small x. Parton-recombination contributions to $F_3(x)$ are rather contrary to those in the Q^2 rescaling model in the sense that the recombinations decrease the ratio at small x and increase it at medium and large x. The overall effects are shown by a solid line (model 1) in Fig. 1. It is interesting to note that the model predicts antishadowing at small x instead of shadowing. In this parton model, the F_3 shadowing differs distinctively from the F_2 one: $F_3^A(x)/F_3^N(x) \neq F_2^A(x)/F_2^N(x)$ at small x. In other words, valence-quark modification is different from the sea-quark one. However, there is a model which predicts F_3 shadowing similar to the F_2 one. An example is discussed in the following.

The second model is the aligned jet model in Ref. 4. This model is based on the vector-meson dominance model, which indicates that the virtual photon transforms

into vector meson states and they interact with the target. The propagation length of the hadronic fluctuation could exceed the average nucleon separation in a nucleus at small x, and shadowing occurs due to multiple scatterings. In the aligned-jet model, the virtual photon transforms into a $q\bar{q}$ pair, which then interacts with the target. However, the only $q\bar{q}$ pair aligned in the direction of γ (W) interacts in a similar way to the vector-meson interactions with the target. The model predication for the F_3 shadowing is shown by a solid curve (model 2) in Fig. 1. This shadowing is very similar to the F_2 shadowing: $F_3^A(x)/F_3^N(x) \approx F_2^A(x)/F_2^N(x)$ at small x. It is because the $q\bar{q}$ pair interacts with sea and valence quarks in the similar way. The model curve is obtained by the aligned-jet-model together with the baryon-number conservation. Their study to combine the shadowing mechanism with the medium x physics, such as the nuclear binding, is still in progress.

As far as we know, these are only two papers which discuss the F_3 shadowing explicitly. Obviously, other model predictions should be investigated in future in comparison with the above estimates. We examine whether these model predications are compatible with current experimental data in the following.

2.2. Experimental restriction and comparison

It is rather surprising that both model predications are opposite at small x even though both results are very similar in the F_2 shadowing. This fact suggests that the F_3 shadowing could be used for discriminating among various models. We can at least rule out one of the above models by accurate experimental measurements.

The structure function F_3 is measured in neutrino interactions. Because the process is a weak interaction, most data are taken by using nuclear targets with large mass number. In order to learn about the nuclear modification, the ratio $F_3^A(x)/F_3^D(x)$ should be taken. Unfortunately, available deuteron data are not accurate enough to investigate 10–20% effects. There is little experimental information on the F_3 shadowing from neutrino data, so that we estimate a current experimental restriction on the F_3 shadowing by using F_2^A/F_2^D ($\equiv R_2$) data at medium x and the baryon number conservation.

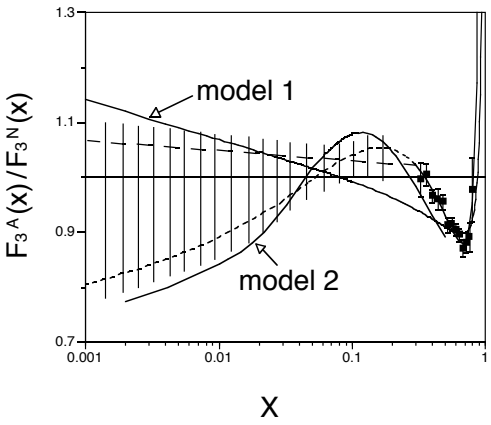

Fig. 1 Shadowing in $F_3(x)$.

In finding the restriction, we neglect next-to-leading-order effects and assume $R_3 = R_2[\equiv F_2^A(x)/F_2^D(x)]$ in the region $x \geq 0.3$ because valence-quark distributions dominate both structure functions. We employ SLAC R_2^{Ca} data, which are fitted by a

smooth curve. This curve is extrapolated into the small x region. The only guideline is to satisfy the baryon-number conservation. First, a straight line in the logarithmic x is simply drawn from x=0.3 as shown by the dashed line in Fig. 1 so as to satisfy the conservation. Second, the curve is smoothly extrapolated into the small x region so as to satisfy the conservation by allowing about 6% antishadowing at $x = 0.1 - 0.2$. The result is the dotted curve in Fig. 1. The first line is roughly the upper limit of nuclear modification, and the second curve is roughly the lower bound. The shaded area between these curves is the area of possible nuclear modification, which is allowed by present experimental data of R_2 and the baryon-number conservation.

It is noteworthy that the first parton-model (model 1) prediction is roughly equal to the upper bound curve, and the aligned-jet model (model 2) prediction is to the lower bound curve. So the models are two extreme cases, which are both acceptable in our present knowledge. We have not investigated the details of other model predictions. However, it is very encouraging to investigate the (anti)shadowing phenomena of F_3 in the sense that the observable could be useful in discriminating among different models, which produce similar results in the F_2 shadowing.

3. Conclusions

We have investigated nuclear modification of the structure function F_3. In particular, the F_3 shadowing at small x is studied in two different theoretical models: the parton-recombination with Q^2 rescaling and the aligned-jet model. These models predict very different shadowing behavior, namely antishadowing in the first model and shadowing in the second model. Therefore, it is in principle possible to rule out one of these models by measuring the ratio F_3^A/F_2^D. However, current experimental data are not accurate enough to probe the F_3 shadowing. Our investigation is merely intended to shed light on the model difference in F_3 at this stage. Much detailed theoretical and experimental investigations have to be done in the near future.

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