Parton Distributions in Nuclei

S. Kumano *

Department of Physics
Saga University
Saga 840, Japan

Plenary Talk given
at the International Symposium on Medium Energy Physics
Beijing, P. R. China, August 22–26, 1994

* Email: kumanos@himiko.cc.saga-u.ac.jp
to be published in proceedings
Parton Distributions in Nuclei

S. Kumano *
Department of Physics
Saga University
Saga 840, Japan

Abstract

We discuss two topics in this talk. One is a brief overview of nuclear parton distributions, and the other is SU(2)-flavor-symmetry breaking in nuclear antiquark distributions. First, we show that nuclear structure functions $F_A^2(x)$ could be explained in a $Q^2$ rescaling model with parton recombination effects. Then, nuclear gluon distributions are discussed in this parton model. We point out other interesting distributions for future investigations. Second, $\bar{u} - \bar{d}$ distributions in nuclei are discussed in order to shed light on nuclear modification of the $\bar{u} - \bar{d}$ distribution.

1. Overview of nuclear parton distributions

Modifications of the structure function $F_2(x)$ in nuclei were discovered by European Muon Collaboration (EMC effect). This effect has been an interesting topic because it may provide an explicit quark signature in nuclear phenomena. Most of these investigations discuss a “global” EMC effect in the sense that the effect is averaged over all constituents in a nucleus. However, it is interesting to investigate possible semi-inclusive or semi-exclusive processes for finding a “local” EMC effect [1] and possible relations between a local gluonic EMC effect and the $J/\psi$ suppression.

In recent years, many experimental data of $F_A^2(x)/F_D^2(x)$ are obtained in the small $x$ region, which is so called the shadowing region. There are theoretical attempts to explain the EMC effect in the medium-large $x$ region and the shadowing in the small $x$. However, most models investigated both regions separately, and enough effort has not been made for studying the structure function in the whole $x$ region. It is not straightforward to study a model which is valid in the wide $x$ region. An attempt to combine the medium-$x$ physics and the small-$x$ one in a dynamically consistent way is made in Ref. [2]. Our model is based on a parton model and is not on macroscopic nuclear physics (nuclear binding, Fermi motion, vector-meson dominance, and so on) explicitly. We simply incorporated two mechanism in our model: $Q^2$ rescaling and parton recombination. The rescaling has been used for explaining the EMC effect in the medium $x$ region and the recombination for the shadowing in the small $x$. We calculated nuclear parton distributions by using these ideas at small $Q^2$ and obtained distributions are evolved by using the Altarelli-Parisi equation.

As a result, we obtained reasonably good agreement with the experimental
data in the region \((0.005 < x < 0.8)\) as shown in Fig. 1. In the large \(x\) region, the ratio \((F^A_2(x)/F^D_2(x) > 1)\) is explained by quark-gluon recombinations, which produce results similar to those by the nucleon Fermi motion. In the medium \(x\) region, the EMC effect is mainly due to the \(Q^2\) rescaling mechanism in our model. In the small \(x\) region, shadowing effects are obtained by the parton recombinations. However, our shadowing at very small \(x(< 0.02)\) is very sensitive to the input gluon distribution.

\(Q^2\) variations of the nuclear structure function ratio \(F^{Ca}_2(x, Q^2)/F^{D}_2(x, Q^2)\) are calculated in our parton model. Calculated results are compared with the New Muon Collaboration (NMC) data in Fig. 2. Our theoretical results show small \(Q^2\) variation and are consistent with existing experimental data [2]. The detailed analysis of the \(Q^2\) evolution is still in progress [3].

We find that the model can explain experimental \(F^A_2(x)\) structure functions in the wide Bjorken–\(x\) range \((0.005 < x < 0.8)\). The structure function \(F_2(x)\) has been well investigated both experimentally and theoretically. However, there are nuclear structure functions, which are little understood. We summarize the current status of nuclear parton distributions in Table 1 in the Michelin style.

Because \(F_2(x)\) in the medium \(x\) is dominated by valence-quark distributions \([q_v(x)]\), we consider that \(q_v(x)\) at medium \(x\) is well known. On the other hand, \(q_v(x)\) at small \(x\) is not understood. We don’t know whether valence-quark shadowing is similar to the \(F_2\) shadowing. It could be very important to study the valence-quark shadowing by measuring \(F^A_3/F^D_3\) in neutrino experiments.

Sea-quark distributions \([q_s(x)]\) are dominant in \(F_2(x)\) at small \(x\), so that we know the behavior of \(q_s(x)\) at small \(x\). In the region of \(x = 0.1 - 0.2\), we have Fermilab-E772 Drell-Yan data which indicates small nuclear modifications of the sea distribution in the iron nucleus. However, the situation is not very clear if we look at the Drell-Yan data in the carbon and calcium nuclei. We need accurate data especially the data which show the \(A\) dependence. Furthermore, it is very interesting to investigate sea-quark shadowing at RHIC. At this stage, the Fermilab Drell-Yan data are not shown in the shadowing region \((x < 0.03)\).
Nuclear gluon distributions are also not understood. The only explicit experimental data are those obtained by the NMC in muon-induced $J/\psi$ productions, but accuracy is not good enough to test 10% effects. Currently, two-jet events are being analyzed by the Fermilab muon group for investigating gluon shadowing. This group may produce interesting results. In future, proposed RHIC direct-photon experiment should clarify the gluon-shadowing problem.

Table 1 Status of nuclear parton distributions.

We investigate gluon distributions in the carbon and tin nuclei by using the $Q^2$ rescaling model with parton recombination effects. We obtain strong shadowing in the small $x$ region due to the recombinations. The ratio $G_A(x)/G_N(x)$ in the medium $x$ region is typically 0.9 for medium size nuclei. At large $x$, the ratio becomes large due to gluon fusions from different nucleons.

Calculated gluon distributions are compared with the NMC data for $G_{Sn}(x)/G_C(x)$ in Fig. 3. The dashed curve shows recombination results with the cutoff for parton leaking $z_0=0$ and the solid (dash-dot) curve shows combined results of the $Q^2$ rescaling and the recombinations with $z_0=0$ ($z_0 = 2$ fm). Comparisons with NMC data for $G_{Sn}(x)/G_C(x)$ indicate that more accurate experimental data are needed for testing the model.

Fig. 3 Nuclear gluon distributions [4].

[Summary] We find that nuclear structure functions $F_2(x, Q^2)$ can be explained in the wide $x$ range by using a parton model with $Q^2$-rescaling and parton-recombination effects. The model is extended to studies of nuclear gluon distributions. We need detailed theoretical and experimental analyses of nuclear sea-quark and gluon distributions. Furthermore, valence-quark distributions at small $x$ could be interesting for studying nuclear shadowing mechanism.
2. SU(2)-flavor-symmetry breaking in nuclear antiquark distributions

Violation of the Gottfried sum rule was suggested by the NMC in deep inelastic muon scattering. It indicates that antiquark distributions in the nucleon are not SU(2)-flavor symmetric $[\bar{u}(x) \neq \bar{d}(x)]$. As an independent test, Drell-Yan data for the tungsten target have been used for examining the flavor asymmetry. However, nuclear effects are possibly significant because the tungsten is a heavy nucleus. If the nuclear modification is very large, the Drell-Yan analysis cannot be directly compared with the NMC result. We discuss the SU(2)-flavor-asymmetric distribution $(\bar{u} - \bar{d})_A$ in nuclei, especially in the tungsten nucleus.

We investigate whether there exists significant modification of the $\bar{u} - \bar{d}$ distribution in nuclei in a parton recombination model [5]. It should be noted that a finite $\bar{u} - \bar{d}$ distribution is theoretically possible in nuclei even if the sea is $SU(2)_f$ symmetric in the nucleon. In neutron-excess nuclei such as the tungsten, there exist more $d$-valence quarks than $u$-valence quarks, so that more $\bar{d}$-quarks are lost than $\bar{u}$-quarks are due to parton recombinations in the small $x$ region. In a parton-recombination picture, partons in different nucleons could interact in a nucleus. This is an extra effect which does not exist in a single nucleon. In discussing antiquark distributions in nuclei, this effect should be taken into account properly. Even if the nucleon sea is SU(2) flavor symmetric, it is interesting to find that a finite flavor asymmetric distribution can be obtained in a nucleus:

$$
x[\Delta \bar{u}(x) - \Delta \bar{d}(x)]_A = \varepsilon \frac{4K}{9} x \int_0^1 dx_2 \, x \bar{u}^*(x) \, x_2 [u_v(x_2) - d_v(x_2)] \, \frac{x^2 + x_2^2}{(x + x_2)^4},
$$

where $u_v(x)$ and $d_v(x)$ are $u$ and $d$ valence-quark distributions in the proton, the neutron-excess parameter $\varepsilon$ is defined by $\varepsilon = \frac{N-Z}{N+Z}$, and $K$ is given by $K = 9A^{1/3}\alpha_s(Q^2)/(2R_0^3Q^2)$ with $R_0=1.1$ fm. The physics meaning of the finite distribution is as follows. In a neutron-excess nucleus ($\varepsilon > 0$), the $d_v$ quark number is larger than the $u_v$ quark one. Hence, more $\bar{d}$ quarks are lost than $\bar{u}$ quarks in parton recombination processes. The modification of the flavor-asymmetric distribution is directly proportional to the neutron-excess parameter.

We evaluate Eq. (1) with the input parton distributions MRS-D0 (1993) in the tungsten nucleus $^{184}_{74}W_{110}$. The $SU(2)_f$-symmetric-sea distribution in the nucleon is used by setting $\Delta = 0$ in the MRS-D0 distribution. Obtained results are shown in Fig. 4, where the solid curve shows the $x[\Delta \bar{u} - \Delta \bar{d}]_A$ distribution (per nucleon) of the tungsten nucleus in Eq. (1). As expected in a neutron-excess nucleus, the parton recombinations produce a finite $SU(2)_f$-breaking antiquark distribution even if they are $SU(2)_f$ symmetric in the nucleon. Furthermore, it is a positive contribution to $\bar{u} - \bar{d}$ because of the $d$-valence-quark excess over $u$-valence in the neutron-excess nucleus.
The situation is changed if the $SU(2)_f$ asymmetric distribution is used as the input distribution as shown by the dashed curve in Fig. 4. In this case, $\bar{q}G \to \bar{q}$ contributions become larger than $q\bar{q} \to G$ ones, and obtained results are much different. The whole contribution becomes negative at small $x$ due to the $\bar{d}$-excess over $\bar{u}$ in the proton. On the contrary, we find $\bar{u}$-excess over $\bar{d}$ in the larger $x$ region ($x > 0.05$).

Fig. 4 Nuclear modification of $\bar{u}(x) - \bar{d}(x)$ [5].

[Summary] We find that a finite flavor-breaking distribution in a nucleus ($[\bar{u}(x) - \bar{d}(x)]_A \neq 0$) is possible even though it is symmetric in the nucleon ($\bar{u}(x) - \bar{d}(x) = 0$). Because the Drell-Yan experiments are in progress at Fermilab, nuclear effects on the flavor asymmetric distribution could be an interesting topic for future theoretical and experimental investigations.

Acknowledgment

S. K. would like to thank the Yamada Science Foundation for their financial support for his participating in this conference. This research was partly supported by the Grant-in-Aid for Scientific Research from the Japanese Ministry of Education, Science, and Culture under the contract number 06640406.

* Email: kumanos@himiko.cc.saga-u.ac.jp.

References

[1] S. Kumano and F. E. Close, Phys. Rev. C41, 1855 (1990); S. Kumano, in Proceedings of the International Workshop on Gross Properties of Nuclei and Nuclear Excitations, Hirschegg, Austria, Jan. 20–25, 1992, edited by H. Feldmeier.
[2] S. Kumano, Phys. Rev. C48, 2016 (1993) & C50, 1247 (1994).
[3] R. Kobayashi, M. Konuma, and S. Kumano, preprint SAGA-HE-63-94, submitted for publication; M. Miyama and S. Kumano, research in progress.
[4] S. Kumano, Phys. Lett. B298, 171 (1993).
[5] S. Kumano, preprint SAGA-HE-67-94, submitted for publication.
This figure "fig1-1.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9410207v1