PROGRESS ON GLOBAL ANALYSIS FOR DETERMINING PARTON DISTRIBUTION FUNCTIONS IN NUCLEI

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Nuclear parton distribution functions are determined by a global analysis of nuclear data on structure functions F_2^A and Drell-Yan cross sections σ_{DY}^{pA}. Nuclear modifications are expressed by a number of parameters, which are determine by a χ^2 analysis of the data. We explain the obtained nuclear PDFs and uncertainties. A useful code is provided to calculate the nuclear PDFs.

1. Introduction

Structure functions have been measured in lepton-nucleon deep inelastic scattering (DIS) processes. They are expressed in terms of coefficient functions and parton distribution functions (PDFs). The coefficient functions are calculated in perturbative Quantum Chromodynamics (QCD); however, the PDFs are not precisely calculated by theoretical methods because they are related to a nonperturbative aspect. We need to extract this information from experimental measurements.

The unpolarized PDFs in the nucleon have been investigated for a long time, and they are now established in the wide region from very small Bjorken variable x to relatively large x. However, their nuclear modifications are not well investigated although they are becoming increasingly important, for example, in the studies of heavy-ion and neutrino reactions in order to investigate quark-gluon plasma physics and neutrino oscillation.

A global χ^2 analysis was first reported in Ref. 1, and then uncertainties of the nuclear PDFs were estimated in Ref. 2. The nuclear modifications are expressed by a number of parameters, which are determined by an analysis of DIS and Drell-Yan data. Then, uncertainties of the modifications are estimated by the Hessian method. Since the last publication, we have been working on a better description of mass-number (A) dependence and also on a next-to-leading order (NLO) analysis.[3] Here, we report our global analysis for the nuclear PDFs.

2. Analysis method

Because the nucleonic PDFs have been determined well, it is more practical to investigate their nuclear modifications rather than the nuclear PDFs themselves. We express such nuclear modifications by a number of parameters at a fixed Q^2 point ($\equiv Q_0^2$):[1,2]

$$f_i^A(x, Q_0^2) = w_i(x, A, Z)\, f_i(x, Q_0^2),$$
$$w_i(x, A, Z) = 1 + \left(1 - \frac{1}{A^\alpha}\right) \frac{a_i + b_i x + c_i x^2 + d_i x^3}{(1-x)^{\beta_i}}, \tag{1}$$

where $f_i^A(x, Q_0^2)$ and $f_i(x, Q_0^2)$ indicate nuclear and nucleonic PDFs, respectively, for the parton type i, so that the function w_i indicates its nuclear modification. For the parton type, we investigate up- and down-valence quark distributions (u_v, d_v), antiquark distribution ($\bar{q}$), and gluon distribution (g). The initial scale is taken Q_0^2=1 GeV^2. It should be noted that the nuclear PDFs at very large x ($x > 1$) cannot be described by the parametrization in Eq.(1) because the nucleonic PDFs vanish at $x > 1$. If such large-x data will become available in the deep inelastic region, the functional form should be reconsidered.

The parameters in Eq.(1) are determined to fit experimental data with nuclear targets by minimizing the total χ^2:

$$\chi^2 = \sum_j \frac{(R_j^{data} - R_j^{theo})^2}{(\sigma_j^{data})^2}, \tag{2}$$

where R_j indicates a ratio of nuclear-structure functions or Drell-Yan cross sections: $F_2^A/F_2^{A'}$ or $\sigma_{DY}^{pA}/\sigma_{DY}^{pA'}$. We use available data in the region, $Q^2 \geq 1$ GeV^2. Because there are three obvious constraints: charge, baryon-number, and momentum conservation, three parameters are fixed by these conditions. Experimental data are taken in various Q^2 points, so that the distributions at Q_0^2 in Eq.(1) are evolved to the experimental Q^2 points by the DGLAP evolution equations. Uncertainties of nuclear PDFs are calculated by the Hessian method. Details of the analysis and error-estimation methods are explained in Refs. 1 and 2.

3. Results

The nuclear PDFs are determined in the leading order (LO)[1,2] and their uncertainties are calculated in the previous version.[2] Typical results are shown in Fig.1 for the calcium nucleus at Q^2=1 GeV^2. The nuclear modifications for the valence-quark, antiquark, and gluon distributions are shown together with their uncertainty bands.

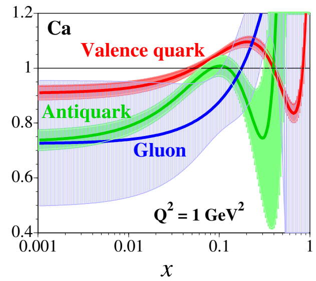

Figure 1. Nuclear modifications of the PDFs in the calcium nucleus are shown at Q^2=1 GeV^2. Their uncertainties are shown by the bands.

We have been investigating the nuclear PDFs since the publication in Ref.2, especially on a better description of the A dependence and also on a NLO analysis.[3] In the previous works,[1,2] the nuclear dependence is simply assumed to be proportional to $1 - 1/A^{1/3}$ as shown in Eq.(1). This is too simple to describe whole nuclei especially small-size ones. A possible improvement is to allow explicit A dependence in the parameters a, b, c, and d in Eq.(1). Furthermore, NLO effects are included in the global analysis. The results are briefly explained, but numerical results are not shown in this paper because recent results are still preliminary. In the previous analysis,[2], we obtain χ^2/d.o.f.=1.58. Assigning the A dependence in the parameters a, b, c, and d, we are getting χ^2/d.o.f.$\sim$ 1.1 in a NLO analysis, whereas the fit is slightly worse in the LO. The significant reduction of the χ^2 value indicates that the nuclear dependence is much improved. However, the obtained PDFs and their uncertainties are similar to Fig.1.

The valence-quark distributions are well determined from small x to large x. Because of the F_2^A data, the valence distributions are determined at large x. The smaller-x region is constrained by the charge and baryon-number conservations, even though there is no data to fix the valence distributions at small x. The antiquark distributions are determined at small x ($x \sim 0.01$) because of the shadowing data of F_2^A. They are also determined at $x \sim 0.1$ due to the Fermilab Drell-Yan data, which indicate small nuclear modifications for the antiquark distributions. However, they have large uncertainty at $x > 0.2$, and this region should be investigated by future experiments, for example, at the J-PARC facility.[4]

The gluon distributions have large uncertainties in the whole x region. This is because there is almost no data which is sensitive to the nuclear gluon distributions. There are scaling violation data for $F_2^A/F_2^{A'}$, for example, by the NMC and HERMES collaborations. However, they are not accurate enough to probe the gluon distributions. Our preliminary analysis seems to indicate that inclusion of the NLO effects does not much improve the situation because the data are not accurate to reflect the NLO gluonic effects. Obviously, we need precise data on the scaling violation and possibly on other measurements such as jet and direct-photon production processes.

We are finalizing our recent analysis for a new set of nuclear PDFs with uncertainties.[3] A new version will become available in the near future.

4. Summary

The parton distribution functions in nuclei have been determined by analyzing the data for nuclear structure functions F_2^A and Drell-Yan cross sections. In particular, we investigated a better description of nuclear dependence and NLO effects. The fit is significantly improved by assigning explicit A dependence in the parameters. However, the nuclear gluon distributions cannot be accurately determined even if the NLO effects are included. A code is supplied to calculate the obtained PDFs for an arbitrary nucleus at given x and Q^2.

Acknowledgements

S.K. was supported by the Grant-in-Aid for Scientific Research from the Japanese Ministry of Education, Culture, Sports, Science, and Technology. T.-H.N. was supported by the JSPS Research Fellowships for Young Scientists.

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