

Global Analyses of Nuclear PDFs

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Abstract. A brief overview of the global DGLAP analyses of the nuclear parton distribution functions is given. Although all the current global nPDF sets describe $R_{F_2}^A(x, Q^2)$ well in the large- x region where the data exist, variations between their parton distributions can be substantial.

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Ever since it was observed about two decades ago that parton distribution functions (PDFs) of nuclei differ from those in the free proton, $f_i^A(x, Q^2) \neq f_i(x, Q^2)$, several analyses of the nuclear effects have been presented. Similarly to the case of the free proton PDFs, the nuclear PDFs (nPDFs) at an initial scale provide the nonperturbative input for the perturbative QCD analysis. Once they are known the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) evolution equations predict their behaviour at larger scales.

Although several DGLAP analyses [1, 2, 3, 4, 5, 6] exist, I will concentrate here only on the recent global ones where the initial distributions are based on the fit to the data, not on a model. Only three such analyses and their reanalyses currently exist, namely the ones by us, Eskola *et al.* (usually called as *EKS98* [7, 8]), Hirai *et al.* (*HKM* [9] and *HKN* [10]) and by de Florian and Sassot (*nDS* [11]). Along with these I will also present preliminary results of the reanalysis of our nPDFs (*EKS05* [12]).

The analyses of the nPDFs are performed much in the same way as those of the free PDFs. However, lack of data especially in the small- x region has kept the nPDF analyses less constrained than the free PDF ones. For example, whereas the recent PDF analyses have been performed in next-to-leading order (NLO) and some are currently being calculated in NNLO, only one global nPDF analysis, by de Florian and Sassot (nDS), is currently calculated in NLO.

Since the initial states of the global nPDF sets are based on the data they naturally describe well the structure function $F_2^A(x, Q^2)$ at large x where the most of the data lie. However, their nuclear modifications for the different parton flavours can vary greatly in some regions.

Nuclear effects are commonly defined through a ratio

$$R_i^A(x, Q^2) = \frac{f_i^A(x, Q^2)}{f_i(x, Q^2)}, \quad (1)$$

where f_i stands for parton distribution function for a parton type, $i = u, \bar{u}, d, \bar{d}, \dots, g$. However, due to lack of data one usually defines only some 3-5 ratios for the initial distributions: for valence (u and d together (EKS98), or separately (HKM, HKN, nDS)),

sea (\bar{u} and \bar{d} together (EKS98,HKM,HKN), or separately (nDS)) and gluon. These ratios are usually given for a bound proton.

The $R_{F_2}^A$ ratios are fairly well constrained in large- x region by the data from lepton-nucleus deep inelastic scattering (DIS). As valence quarks dominate the F_2 in this region, they also become well determined there. At mid- x the Drell-Yan (DY) dilepton data constrain the sea quark distributions together with the DIS data. For gluon distribution the only data constraints arise from the $\log Q^2$ slopes of the NMC data for $F_2^{\text{Sn}}/F_2^{\text{C}}$ [13] as shown in Refs. [7, 14]:

$$\frac{\partial R_{F_2}^A(x, Q^2)}{\partial \log Q^2} \approx \frac{10\alpha_s x g(2x, Q^2)}{27\pi F_2^D(x, Q^2)} \left\{ R_G^A(2x, Q^2) - R_{F_2}^A(x, Q^2) \right\}. \quad (2)$$

In addition to the data further constraints for the fits arise from the momentum, charge and baryon number conservation. Let us next take a look at these three analyses individually.

EKS98, EKS05: In the nPDF analysis by us, Eskola, Kolhinen, Ruuskanen and Salgado [7, 8] the $R_{F_2}^A(x, Q_0^2)$ distribution was first parametrized piecewise for each A and fitted to the data. The $R_{F_2}^A$ was then split to valence and sea part which were constrained by the DY data and baryon number conservation. Finally, the gluon distribution was constructed from the $R_{F_2}^A$ fit. The actual fits to the DIS and DY data were done by eye. However, later calculations with EKS98 prove $\chi^2 \approx 390$ for 503 data points, though the data set is slightly different than in the original analysis.

As a continuation for this work, we are currently performing a reanalysis of the nPDFs, with some more recent data included [12]. We have now also included a proper χ^2 analysis and use a Hessian method for the error estimates. Instead of parametrizing the $R_{F_2}^A$ as in EKS98, we now parametrize directly the nuclear effects in the initial valence, sea and gluon distributions. Although the results are still preliminary, they seem to resemble much the EKS98 ones and giving $\chi^2 \approx 390 - 400$ for 503 data points.

HKM, HKN: In their first analysis Hirai, Kumano and Miyama (HKM) [9] use the DIS, but not DY, data from several experiments. They composed two different fits, “quadratic” and “cubic” referring to the polynomial in the fit. These fits are performed for each A separately. The resulting valence ratios R_u^A and R_d^A are not given for bound proton but for an average nucleon in a nucleus. The calculated χ^2 of the fit is 583.7 (quadratic) and 546.6 (cubic) for 309 data points, or $\chi^2/d.o.f. = 1.93$ and 1.82, respectively. The nuclear effects show small antishadowing for the valence at small x . Sea and gluons are shadowed in small- x region, but antishadowed at larger values of x . Only valence shows an EMC effect (shadowing) at $x \sim 0.7$.

In the subsequent analysis by Hirai, Kumano and Nagai (HKN) [10], the DY data have been included along with some more DIS data. The statistical error analysis is also performed using a Hessian method. The general form of the fit is similar to the “cubic” form in HKM. The resulting distributions fit the small x region better, obviously due to the DY data and improved description of the sea quarks. Whereas valence and gluon behave much in the same way as in the HKM, the sea quarks now have a valence-like EMC effect at $x \sim 0.7$. The resulting $\chi^2 = 1489.8$ for 951 data points.

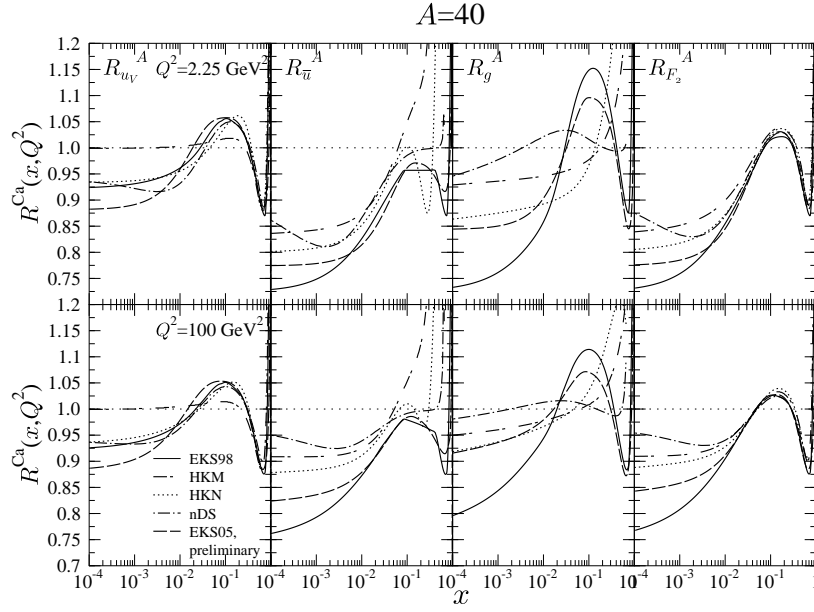


FIGURE 1. Ratios $R_{u_v}^A(x, Q^2)$, $R_{\bar{u}}^A(x, Q^2)$, $R_g^A(x, Q^2)$ and $R_{F_2}^A(x, Q^2)$ for $Q^2 = 2.25 \text{ GeV}^2$ (upper panels) and $Q^2 = 100 \text{ GeV}^2$ (lower panels) for $A = 40$ given by EKS98 (solid), HKM (double dashed), HKN (dotted) and nDS [NLO] (dotted-dashed). Preliminary EKS05 results are also shown (dashed).

nDS: The global nPDF analysis by de Florian and Sassot (nDS) [11] is so far the only one performed in NLO. In this analysis PDFs are defined using the convolution method, $f_i^A(x, Q_0^2) = \int_x^A \frac{dy}{y} w_i(y, A) f_i(\frac{x}{y}, Q_0^2)$, which enables evolution in the Mellin space. The advantages of this approach are that the calculations are faster and more straightforward, as well as that the x dependence of nPDFs is strongly correlated to that of free PDFs. The total χ^2 obtained is 316.35 for LO and 300.15 for NLO for 420 data points. The main difference between LO and NLO results are in sea and gluon distributions at small x , small Q^2 and large A . As the χ^2 values suggest, LO fit describes the data almost equally well as the NLO one. This fact is reported to arise from the rather restricted Q^2 range of the data as well as the absence of the data strongly dependent to gluon distribution.

Compared to the other analyses, the largest difference is in the gluon distribution, which is much less shadowed than e.g. in EKS98. The authors have tried another parametrization with stronger gluon shadowing, but they report the results to be worse.

Comparison between the nuclear effects of different sets are shown in Fig. 1 for $A = 40$ and for $Q^2 = 2.25$ and 100 GeV^2 . As seen in the figure, $R_{F_2}^A$'s calculated using different nPDF sets coincide in the large x region. Also valence quarks become well determined in large x . However, in other regions the differences between the sets can be large. In order to constrain the fits more properly, especially at small x , more data would be needed. As pointed out earlier and shown in Fig. 2, currently only the $\log Q^2$ slopes of NMC data for $F_2^{\text{Sn}}/F_2^{\text{C}}$ give constraints to gluon distributions. Probes sensitive to nuclear gluon PDFs, such as the charm production, would thus be crucial for more accurate analysis.

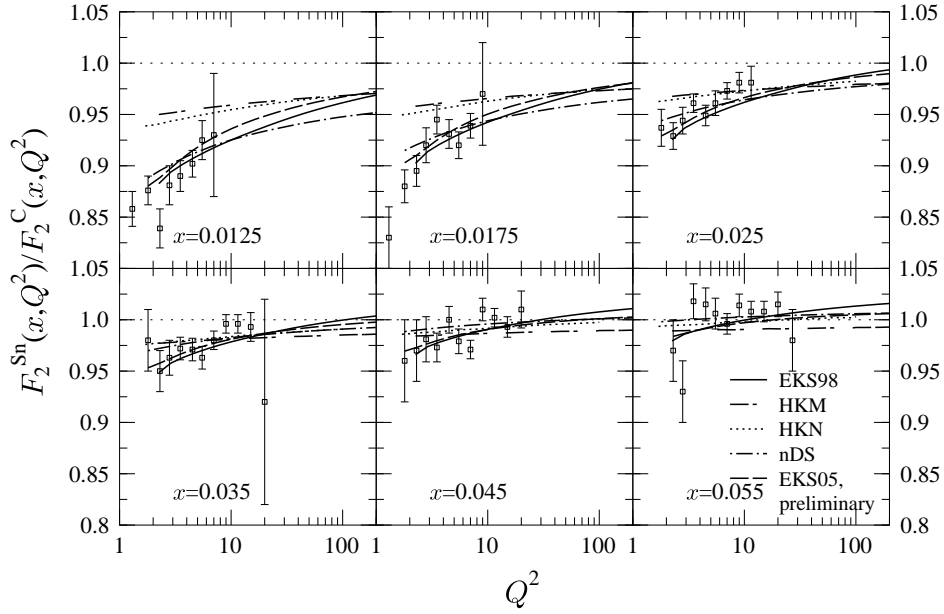


FIGURE 2. Calculated $F_2^{\text{Sn}}/F_2^{\text{C}}$ ratios compared to the NMC data [13] for a few small x values.

In future analyses data on structure function F_3 could also provide more information on the u_v^A vs d_v^A ratio and the valence shadowing.

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