DGLAP analyses of nPDF: constraints from data

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Abstract. We explain how the constraints from present experimental data can be used to obtain the nPDF in the framework of LO DGLAP evolution. We will also compare the only two available sets of this type and comment on the important information that neutrino factories could provide.

1. Introduction

Parton distribution functions (PDF) are needed to compute hard processes in hadronic and nuclear collisions. The method to obtain the PDF from experimental data is well established in the case of the free proton: the initial distributions at Q_0^2 are evolved by the DGLAP equations [1] to larger Q^2 and fitted to available data. The data from deep inelastic lepton-proton scattering (DIS) are of main importance in these analyses. The nuclear structure functions F_2^A measured in DIS experiments differ from those of the free nucleons. Definining the ratio vs. deuterium, $R_{F_2}^A(x,Q^2) = \frac{1}{A}F_2^A(x,Q^2)/(\frac{1}{2}F_2^D(x,Q^2))$, several nuclear effects can be distinguished: shadowing ($R_{F_2}^A < 1$) at small values of x, antishadowing ($R_{F_2}^A > 1$) at intermediate x and EMC effect ($R_{F_2}^A < 1$ again) and Fermi motion at large x. The nuclear effects in F_2^A translate in nuclear PDF (nPDF) which are modified from the ones of the free proton. The goal then is to obtain a set of nPDF following the well established procedure used for the free proton. In practice, a set of ratios of the PDF in bound and free protons, $R_i^A(x,Q^2) = f_i^A(x,Q^2)/f_i^p(x,Q^2)$ for $i = g,\ u_V,\ d_V,\ \bar{u}\ldots$, are extracted for a known set of the free proton PDF $f_i^p(x,Q^2)$.

2. EKRS analysis

The main problem in the nuclear case is the lack of experimental data. The DGLAP analysis of EKRS, which lead to the set EKS98 [2], uses several sets of DIS data on F_2^A (see [2] for the refs.) and data on the Drell-Yan (DY) process measured in pA collisions [3]. Some other sets of data could be very helpful in constraining the nuclear effects for different parton flavours, e.g. charm production to constrain gluons. However, so far they are not included in [2] because of large error bars (open charm in pA) or the presence of final state nuclear effects (charmonium in pA). Further constraints which are used are momentum and baryon number sum rules. At an initial scale, chosen as

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$Q_0^2 = 2.25$ GeV^2, the ratios for valence quarks $R_V^A(x, Q_0^2)$ (same for u_V^A and d_V^A), sea quarks $R_S^A(x, Q_0^2)$ (same for $\bar{u}^A$, $\bar{d}^A$ and $\bar{s}^A$) and gluons $R_g^A(x, Q_0^2)$ are obtained in the following way:

- At large values of x ($x \gtrsim 0.3$) valence quarks dominate, and the data on $R_{F_2}^A$ fix the ratio R_V^A but do not constrain the ratio R_S^A. There are no constraints for the nuclear gluons, either, in this region. For consistency of the DGLAP evolution, it is assumed that $R_S^A \approx R_V^A$, and that a similar EMC effect also exists in R_g^A already at Q_0^2.
- At intermediate values of x ($0.04 \lesssim x \lesssim 0.3$) both DIS and DY data constrain the ratios R_V^A and R_S^A. The use of DY data [3] is essential in order to fix the relative strength of the valence and sea quark modifications, as DIS alone cannot distinguish between them. The baryon number sum rule imposes also constraints to R_V^A. The gluon ratio R_g^A is constrained at $0.02 \lesssim x \lesssim 0.2$ by the NMC data on the Q^2 dependence of the ratio $F_2^{\rm Sn}/F_2^{\rm C}$ [4], and by momentum conservation. A 20% antishadowing is found for gluons at $x \sim 0.1$.
- At small values of x ($x \lesssim 0.04$), F_2 is dominated by sea quarks, so DIS data constrains mainly R_S^A. The ratio R_V^A is fixed by baryon number conservation and turns out to be larger (less shadowing) than R_S^A. At $x \lesssim 0.005$, where no information from data is obtained in the region $Q^2 \gtrsim 1$ GeV^2, a saturation of the shadowing ($R_{F_2}^A \to const.$) is assumed. This phenomenon has been observed but only at $Q^2 \ll 1$ GeV^2. At the initial scale, $R_g^A \approx R_{F_2}^A$ is assumed at $x \lesssim 0.01$, which leads to positive $\log Q^2$ slopes for F_2^A (observed at $x \sim 0.01$ [4]).

For a given initial condition, LO DGLAP evolution is done. Then, comparing with the data at different Q^2, the best initial distributions are obtained through a recursive procedure. The resulting initial ratios at Q_0^2 can be seen in Figure 1.

3. Comparison with other approaches

For the moment there is only one global DGLAP analysis on the nPDF similar to EKRS [2], that of HKM [6, 7]. Figure 1 shows a comparison of the EKS98 and HKM results for the ratios R_V^A, R_S^A and R_g^A at $Q^2 = 2.25$ GeV^2. The difference between the results follows from the fact that the data on the DY process [3] and on the Q^2 dependence of F_2^A [4] are not used as contraints in the HKM analysis.

The DY data set is important in the EKRS analysis in fixing R_V^A and R_S^A at intermediate x: the DIS data forces $R_V^A > 1$ at $x \sim 0.1$ and, as the the DY cross sections show almost no nuclear effects (in x_2) there, the ratio R_S^A is bound to be less than one (no antishadowing for sea quarks). In this conference, preliminary results from the HKM analysis with the DY data included were presented [7]. As a result, a better agreement with EKS98 was found.

The Q^2-dependence of the structure function F_2 is very sensitive to the gluon distribution at small values of x. LO DGLAP evolution of the nPDF gives [5] $\partial R_{F_2}^A(x, Q^2)/\partial \log Q^2 \sim R_g^A(2x, Q^2) - R_{F_2}^A(x, Q^2)$. NMC has measured [4] positive $\log Q^2$ slopes for the ratio $F_2^{\rm Sn}/F_2^{\rm C}$. This implies that within the DGLAP framework gluon shadowing cannot be much stronger than that in F_2^A in the measured region $x \gtrsim 0.01$. Also too weak a gluon shadowing is outruled [5] by the NMC data.

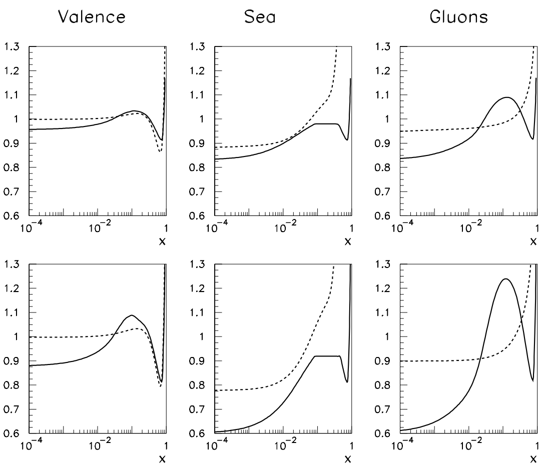

Figure 1. EKS98 (solid lines) and HKM (dashed lines) nuclear modifications for valence, sea and gluon distributions in Pb and C at $Q^2 = 2.25$ GeV^2.

4. Improvements from neutrino DIS data

DIS experiments with neutrino and antineutrino projectiles could measure [8]

$$F_2^{\nu p} = 2x\,(\bar{u} + d + s + \bar{c}) \qquad F_2^{\bar{\nu} p} = 2x\,\left(u + \bar{d} + \bar{s} + c\right)$$
$$xF_3^{\nu p} = 2x\,(-\bar{u} + d + s - \bar{c}) \qquad xF_3^{\bar{\nu} p} = 2x\,\left(u - \bar{d} - \bar{s} + c\right)$$

with similar relations for neutrons. Different flavors could then be disentangled and some of the uncertainties discussed above (e.g. valence at small x and sea at large x) would become more directly constrained by data. This would allow for a more detailed analysis of the nPDF. Moreover, the valence/sea separation at medium x would be measured and could be compared with the results from DY data. This would test the universality of the nPDF. Measuring sea and valence quark distributions in νA experiments would also shed more light on some open questions of QCD in nuclei, such as the probability interpretation of the (n)PDF [9].

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