CONSTRAINTS FOR NUCLEAR GLUON DENSITIES FROM DIS DATA

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The $Q^2$ dependence of the ratios of nuclear structure functions $F_{2n}$ is studied by performing QCD evolution of nuclear parton distribution functions. The log $Q^2$ slope of these ratios is very sensitive to the nuclear gluon distribution function. Taking different parametrizations, we show that the NMC data on the $Q^2$ dependence of $F_{2n}^{\text{Sn}}/F_{2n}^{\text{C}}$ rule out the case where nuclear shadowing (suppression) of gluons at $x \sim 0.01$ is much larger than the shadowing observed in the ratio $F_{2n}^{\text{A}}/F_{2n}^{\text{D}}$. We also take into account modifications to the DGLAP evolution by including gluon fusion terms and see that the effect is small at present energies, and, in any case, a strong gluon shadowing is not favored. The region studied ($x \sim 0.01$) is the most relevant for RHIC multiplicities.

The nuclear parton distribution functions (nPDFs) are an essential ingredient in calculations of hard processes involving nuclei. In the framework of the QCD improved parton model it is possible to extract the nPDFs from experiments of DIS and to use them for other processes in $AB$ collisions. In this framework, a set of nPDFs, or equivalently, nuclear corrections to PDFs in nucleons, has been obtained.\textsuperscript{[1,2,3]} There are, however, some uncertainties in the determination of the initial conditions for the $Q^2$ evolution due to the lack of experimental data. For instance, gluons and sea quarks are not constrained\textsuperscript{4} in the EMC region. Also, it is a common belief that nuclear gluon distributions are very weakly constrained by experimental data at small $x$. The situation would be similar to that of nucleon PDFs before HERA measured the rapid increase of $F_2$ as $x \to 0$. However, we have shown\textsuperscript{5} that within the leading twist (LT), lowest order (LO) DGLAP framework, the DIS data provide enough constraints to rule out very strongly shadowed gluon distributions in the region $x \gtrsim 0.01$. The key experimental information comes from the $Q^2$ dependence of the ratios $F_{2n}^{\text{Sn}}/F_{2n}^{\text{C}}$ measured by the NMC Collaboration\textsuperscript{6}. 
In the case that the dominant contribution to total multiplicities comes from jets or minijets, as has been proposed, the measurements of $N_{ch}$ done at RHIC give direct information about the initial gluon distributions in nuclei. This has been used in Ref. 3 to parametrize the gluon distribution function in the HIJING model. As a result, a strong gluon shadowing has been proposed in order to compensate the large multiplicity obtained in the original model.

In previous works we have determined a set of nPDFs (named EKS98) by using available data of $F_2^A(x, Q^2)$ and Drell-Yan cross sections in nuclear scatterings as constraints. The iterative procedure is very similar to that in global fits of parton distributions of the free proton. As a result the nPDFs become fixed at an initial scale $Q_0^2$, and the evolution to $Q^2 > Q_0^2$ is given by the DGLAP equations. The nuclear case is more complicated as a new variable ($A$) is present. Moreover, as the amount of data does not allow to fix the nuclear ratios for each parton species

$$R_i^A(x, Q^2) = \frac{f_i^A(x, Q^2)}{f_i(x, Q^2)}, \quad i = g, u_v, d_v, \bar{u}, \ldots,$$

in an unambiguous way, some assumptions were imposed in addition to the constraints from the momentum sum rule (that, roughly speaking fixed the amount of antishadowing for gluons) and baryon number conservation. The assumptions include the saturation of the shadowing at small values of $x$ and the existence of an EMC effect for gluons and sea quarks at large $x$.

Notice that the DGLAP evolution imposes some constraints to nuclear gluons, just in the same way as it does in the global analysis with nucleons. In particular for small values of $x$, LO DGLAP equations give

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

So, the slope of the $Q^2$ evolution of the ratio $F_2^A / F_2^D$ is related to the difference of the nuclear ratio in gluons and $F_2$ (notice, however, the factor $2x$ in $R_g$). As $R_g^A(x, Q^2)$ is measured experimentally, data on the $Q^2$ evolution of the ratios $R_g^A$ constrain $R_g$ once DGLAP evolution is taken into account. In particular, the experimental data from the NMC Collaboration show that $F_2^A / F_2^C$ increases as $Q^2$ increases at small values of $x$. For this reason, $R_g^A$ cannot be much smaller that $R_g^A$ in order for the slope to be positive. We have studied different parametrizations for the initial ratios, and shown this fact by performing the DGLAP evolution without making use of the approximation (2). We will see that the result is in agreement with the argument above.

The initial conditions of the four parametrizations studied can be seen in Fig. 1. Notice that the HPC and the new–HIJING parametrizations are $Q^2$ independent. They are used here as initial conditions for evolution. HKM is based on DGLAP evolution, but the NMC data on $Q^2$ dependence of $F_2^A / F_2^C$ and DY data have not been taken into account. We think that this is the main reason for the difference in gluons and sea quarks as compared with EKS98.

As can be seen from the figure, all the parametrizations give similar results for quarks at the values of $x$ where experimental data exist. However, the largest uncertainties are in the gluon distribution function, the extreme case being the new parametrization introduced in HIJING which suggests a very strong shadowing. We will make use of this parametrization to demonstrate that a very strong shadowing for gluons is ruled out based on the experimental data on the experimental data on the $Q^2$ dependence of $F_2^A / F_2^C$. For that we perform the DGLAP evolution of the nPDFs given by these parametrizations for Sn and C and, then, compute the ratios. In Fig. 2 we present the result of this analysis. It is clear that the strong gluon shadowing case is in complete disagreement with the data as it presents a negative slope, while all the others are positive.

One could argue, however, that the non–linear terms (expected to be present in evolution equations at high enough density) could change this conclusion. In order to check this possibility,
Figure 1: Initial ratios $R_1^A(x, Q_0^2)$ at $Q_0^2 = 2.25 \text{ GeV}^2$ of Pb, for valence quarks (solid), sea quarks (dashed) and gluons (dotted) from the four different parametrizations used.

we repeat the $Q^2$ evolution using the same initial conditions but now taking into account the gluon–fusion terms computed by Mueller and Qiu. In this case, the evolution is modified as can be seen in Fig. 3. Including these non–linear terms the slopes become always smaller (even more negative in the case of strong gluon shadowing). So we can conclude that using the presently available experimental data, a strong gluon shadowing is ruled out at $x > 0.01$ in the present framework.

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Figure 2: Comparison of the calculated and measured $Q^2$ dependence of the ratio $F_{2n}^n/F_{2c}^C$. The NMC data are shown with statistical errors only. The results for EKS98 (solid lines) and HKM (dotted-dashed) are from the corresponding global DGLAP analyses. The $Q^2$ dependence of the HPC (dashed) and HIJING (dotted) cases is obtained from the DGLAP evolution with initial conditions similar to Fig. 1.

Figure 3: The scale dependence of the ratio $F_{2n}^n/F_{2c}^C$ calculated using DGLAP evolution with MQ corrections, and compared with the NMC data. Initial conditions for nuclear effects are taken from EKS98 (solid lines), HPC (dashed) and HIJING (dotted) parametrizations.