High Energy Physics and Nuclear Physics

Volume 14, Number 1

Investigation of the Nuclear Shadowing Effect in the Small x Region

Zhong Chasheng, Shen hongqing
(Nanjing Normal University, Nanjing)

Shen Jianping, Li Guanglie
(Institute of High Energy Physics, Chinese Academy of Sciences, Beijing)

In this paper, we analyse the spatially overlapping behaviour of the sea quarks of neighboring nucleons in nuclei in the small x region and give a relation between the nuclear shadowing factor $R(x, Q^2, A)$ and the spatially overlapping factor $\Delta V_A(x)/V_A(x)$. By using this nuclear shadowing factor $R(x, Q^2, A)$, we calculate the ratios of the average nuclear structure function and obtain ^{12}C, ^{63}Cu and ^{116}Sn, to the deuteron structure function and obtain nuclei which yield a better agreement between the calculated results and the experimental data.

The recent experimental data of the European Muon Collaboration (EMC)[1] show that the nuclear shadowing effect in the small x region has two distinct features: (1) it depends weakly on Q^2; (2) the critical value of x, x_m, at which it occurs, increases with the mass number A. These two features cannot be explained by the original vector-meson dominance model[2]. Of late, Close and Roberts[3] explained the nuclear shadowing effect by the gluon redistribution theory proposed by Mueller and Qiu[4]. Their theory has obtained some better results. But, it is well known that the gluon redistribution theory of Mueller and Qiu encounters computational difficulties at the large gluon density. Thus, the nuclear shadowing factor $R(x, Q^2, A)$ given by their theory is valid only for the case of the small gluon density. However, Close and Roberts describe the whole nuclear

---

Supported by the National Natural Science Foundation of China.
Received on June 13, 1989.

shadowing course just with this nuclear shadowing factor. Therefore, their results distinctly deviate from the experimental data in the very small x region. At present, this problem has not yet been solved.

In this paper, by analyzing the behavior of the sea-quarks in nuclei we shall point out that in the small x region a portion of the sea quarks evoluates into gluons due to the spatial overlapping and the interaction between the sea quarks from neighboring nucleons in the nucleus. It makes the sea quarks and gluons in the nucleus redistribute, thus leading to the nuclear shadowing effect. We have analyzed the spatially overlapping factor $\Delta V_A(x)/V_A(x)$ of the sea quarks and obtained a dependence of x_n on the mass number A. Furthermore, we have given a proportional relation between the nuclear shadowing factor $R(x, Q^2, A)$ and the spatially overlapping factor $\Delta V_A(x)/V_A(x)$ of the sea-quarks, and calculated the ratios of the average nuclear structure functions for the nuclei ^{12}C, ^{63}Cu and ^{116}Sn to the deuteron structure function. The results fit the experimental data very well.

To describe the course of occurrence of the nuclear shadowing effect, we define the effective radius of the nucleon

$$r(R) = \left[\frac{4}{3}\pi\rho_N(R)\right]^{-1/3}. \tag{1}$$

where

$$\rho_N(R) = \frac{\rho_0}{1 + e^{(R-C)/Z}}, \tag{2}$$

is the nucleon density distribution in the nucleus. The parameters C and Z are taken from Ref.[5], ρ_0 is determined by the normalization condition

$$\int_0^\infty \rho_N(R)\cdot 4\pi R^2 dR = A, \tag{3}$$

Thus, in the infinite momentum frame, the longitudinal size of a nucleon is about $\Delta Z_N \sim 2r(R)m/P$, where m and P are the mass and momentum of the nucleon. The occupied volume of the nucleon in the nuclei is

$$V_N(R) \sim \frac{4}{3}\pi r^3(R)m/P. \tag{4}$$

According to the Pauli exclusion principle, the longitudinal size of a sea-quark with the momentum xP is $\Delta Z_s \sim 1/xP$, then the occupied volume of the sea-quark in the nucleus is

$$V_s(x, R) \sim \pi r^2(R)/xP. \tag{5}$$

One can see from Eqs.(4) and (5) that when x is very small, the sea-quarks from neighboring nucleons in nucleus will overlap spatially. In the overlapping space, the sea-quarks from different nucleons interact with each other and some of the sea-quarks evolute into gluons. It makes the number of sea-quarks decrease, thus leading to the nuclear shadowing effect. Obviously, there is a relation between the nuclear shadowing effect thus produced and the spatially overlapping factor $\Delta V_A(x)/V_A(x)$ of the sea-quarks in nucleus, where

$$\Delta V_A(x) = \int_0^{R_0} \frac{\pi r^2(R)}{P} \left[\frac{1}{x} - \frac{4}{3} mr(R)\right] \rho_s(R) 4\pi R^2 dR, \tag{6}$$

$$V_A(x) = \int_0^{\infty} \frac{\pi r^2(R)}{xP} \rho_s(R) 4\pi R^2 dR. \tag{7}$$

The upper limit R_0 of the integration in Eq.(6) is determined by the condition: $V_s(x, R) > V_N(R)$, and $\rho_s(R)$ is the original density distribution of the sea quarks given by

$$\rho_s(R) = \bar{q}_s^N \rho_N(R). \tag{8}$$

where $\rho_N(R)$ is the nucleon density distribution and $\bar{q}_s^N$ the fraction of the sea quarks in the nucleon, which is independent of R.

By means of some simple operations, we get

$$\frac{\Delta V_A(x)}{V_A(x)} = \frac{1}{W_3} \left[W_2 - \frac{20x}{3} (9A)^{-1/3} y_0^3 W_1^{1/3}\right]. \tag{9}$$

with

$$W_1 = \int_0^{\infty} \frac{y^2 dy}{1 + e^{(y-C)/Z}},$$

$$W_2 = \int_0^{y_0} \frac{y^2 dy}{[1 + e^{(y-C)/Z}]^{1/3}},$$

$$W_3 = \int_0^{\infty} \frac{y^2 dy}{[1 + e^{(y-C)/Z}]^{1/3}},$$

$$y_0 = C + Z \ln \left[\left(\frac{3}{20x}\right)^3 \cdot \frac{A}{2W_1} - 1\right].$$

By setting $\Delta V_A(x)/V_A(x) = 0$, we can obtain the critical value of Bjorken variable x, x_n, at which the nuclear shadowing effect occurs. One can see from Eq.(9) that in our model the value of x_n depends distinctly on the mass number A. We calculate the values of x_n for nuclei ^{12}C, ^{63}Cu and ^{116}Sn. The obtained results are 0.123, 0.132 and 0.135, respectively.

Furthermore, we define the nuclear shadowing factor

$$R(x, Q^2, A) = 1 - K_A(Q^2)\Delta V_A(x)/V_A(x). \quad (0 < x < x_n) \tag{10}$$

Since the experimental data show that the nuclear shadowing effect depends weakly on Q^2, the parameter $K_A(Q^2)$ can be considered as Q^2 independent. Thus, in the $0 < x < x_n$ region, the distribution of sea-quarks in the nucleus can be expressed by

$$q_s^A(x, Q^2) = R(x, Q^2, A) q_s^N(x, Q^2). \tag{11}$$

where $q_s^N(x, Q^2)$ is the probability distribution of the sea-quarks in free the nucleon.

To make a comparison with the experimental data, we calculate the ratios of the average nuclear structure functions for the nuclei ^{12}C, ^{63}Cu and ^{116}Sn to the deuteron structure function:

$$R^{A/D}(x, Q^2) = F_2^A(x, Q^2)/F_2^D(x, Q^2). \tag{12}$$

where the deuteron structure function is taken from Ref.[6]. By considering the nuclear shadowing effect and the EMC effect together, $F_2^A(x, Q^2)$ can be expressed as

$$F_2^A(x, Q^2) = \frac{5}{18} x q_v^N(x, \xi(Q^2)Q^2) + \frac{2}{9} R(x, Q^2, A) x q_s^N(x, \xi(Q^2)Q^2). \tag{13}$$

where, in order to compare with the results of Close and Roberts[3], we employ the Q^2 resealing mechanism to describe the EMC effect and take the values of the resealing parameters, $\xi(Q^2)$ and Q^2, also from Ref.[3]. $q_v^N(x, Q^2)$ and $q_s^N(x, Q^2)$, taken from Ref.[7], are the probability distributions of valence and sea quarks in the free nucleon, respectively. For the above three nuclei, the parameters K_A in $R(x, Q^2, A)$ are taken as 0.5, 0.5 and 0.65, respectively. The calculated results (solid curves) are shown in Fig.1. The dashed curves in Fig.1 are the results of Close and Roberts. It can be seen from Fig.1 that our results can fit the experimental data better than that of Close and Roberts, especially in the very small x region.

To sum up, the description of the nuclear shadowing effect with the spatial overlapping between the sea-quarks from neighboring nucleons in the nucleus can explain not only the A-dependence of the critical values of x, xn, at which the nuclear shadowing effect occurs, but also obtain a good agreement between the calculated values of $R^{A/D}(x, Q^2)$ for the nuclei ^{12}C, ^{63}Cu and ^{116}Sn and the experimental data, especial in the very small x region. Therefore, we come to the

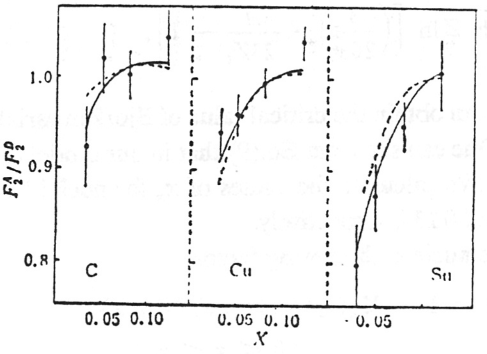

FIG. 1

The comparison between the calculated ratios $R^{A/D}(x, Q^2)$ and the experimental data for nuclei: ^{12}C, ^{63}Cu and ^{116}Sn (the solid curves are our calculated results; the dashed curves are the results of Close and Roberts).

conclusion that the spatially overlapping and the evolution of the sea-quarks from neighboring nucleons in the nucleus might be the main cause of the nuclear shadowing effect.

REFERENCES

[1] J. Ashman et al., *Phys. Lett.* **B202**(1988)603.

[2] S. J. Brodsky, F. E. Close and J. F. Gunion, *Phys. Rev.* **D6**(1972)177.

[3] F. E. Close and R. G. Roberts, Preprint, RAL-88-058.

[4] A. H. Mueller and J. Qiu, *Nucl. Phys.* **B268**(1986)427; J. Qiu, *Nucl. Phys.* **B291**(1987)746; E. L. Berger and J. Qiu, *Phys. Lett.* **B206**(1988)141.

[5] C. W. de Jaeger et al., *At. Data Nucl. Data Tables*, **14**(1974)476.

[6] W. B. Atwood and G. B. West, *Phys. Rev.* **D7**(1973)773; L. L. Frankfurt and M. I. Strikman, *Phys. Lett.* **76B**(1978)333.

[7] D. W. Duke and J. E. Owens, *Phys. Rev.* **D30**(1984)49.