объединенный
институт
ядерных
исследований
дубна

E2-94-503

G.S.Averichev, Yu.A.Panebratsev, S.V.Razin,
E.I.Shahaliev, M.V.Tokarev

NUCLEAR EFFECT FOR BACKWARD PION PRODUCTION IN p-A INTERACTIONS[1]

Invited talk presented at the XII International Seminar on High Energy Physics, 12—17 September, Dubna, 1994

---

[1]Work supported in part by Russian Foundation of Fundamental Research under Grant No.94-02-06477

1994

1. Introduction

Experimental and theoretical investigations of the nuclear effect in deep - inelastic lepton - nucleus and proton - nucleus interactions are of increasing interest for the possibility to obtain general regularities of particle production under the transition from the non - cumulative to cumulative region and to determine nuclear quark structure functions.

A considerable progress has been reached in recent analysis of the experimental data in the deep - inelastic structure function ratio and new nuclear effects have been founded [1].

It was shown that

- the ratio $R^{A/D}(x,Q^2) = F_2^A/F_2^D$ is independent of Q^2 over the range of $0.001 < x < 0.7$, $0.01 < Q^2 < 200$ $(GeV/c)^2$;
- saturation effect in A-dependence is clearly observed;
- the crossover point $(x_0 : R^{A/D}(x_0,Q^2) = 1)$ does not depend on A;
- the quark distributions of all flavors are equally distorted by nuclear medium.

Note that the experimental data on the ratio $R^{A/D}(x,Q^2)$ cover in the main the region $x < 1$. The results of an analysis of the data show that the quark configurations in free and bounded nucleon are different each anothers [2]. The nuclear quark configurations can be explored only in the cumulative range $x > 1$ [3].

The new data for carbon nuclear structure function $F_2(x,Q^2)$ at x up to $x \simeq 1.3$ are presented by the BCDMS collaboration in [4]. Nevertheless the systematic analysis of nuclear effect based on these data is hard because a cross section in the range $x > 1$ falls very fast. In contrary to deep - inelastic processes cross sections in proton - nucleus collisions are much more numerous.

The calculated results of the ratio $R^{C/D}(x,Q^2)$ [1] with the theoretical deuteron structure function $F_2^D(x,Q^2)$ obtained in [5] show that the nuclear effect at $x > 1$ differs significantly from the ratio at $x < 1$.

The systematic investigations of the nuclear effects in the proton - nucleus interactions have been performed in the cumulative range in [6, 7, 8]. The measurements performed in JINR and ITEP show that the scale invariance universality for particle production in cumulative range takes place and confirm the hypothesis on locality of relativistic nuclear interactions [9]. It was found that the dependence of inclusive cross section $\rho_A^h(X)$ on the cumulative number X is an exponent one $\rho_A^h(X) \sim exp(-X/X_0)$. The A-dependence of the slope parameter X_0^{-1} demonstrates an asymptotic one for the various produced particles (π, K, p). It was concluded based on the data that quark configurations in heavy nuclei differ significantly from ones in light nuclei.

In the present paper the nuclear effect in the $p + A \to \pi + ...$ inclusive process at large backward scattering angles has been considered. The new experimental data [10] for nucleus deuterium obtained at Dubna Synchrophasotron have been used in this analysis. The dependence of the ratio $R^{A_1/A_2}(X)$ on cumulative number X has been investigated. The value of the slope parameter for the ratios $R^{A/D}(X)$ and $R^{A/He}$(X) in the cumulative range is determined and its A-dependence has been studied.

2. Set-up

The measurements have been carried out using the magnetic spectrometer DISC [11, 12] at Dubna Synchrophasotron. Input angle acceptance of the spectrometer was $\Omega(p) = 6 \cdot 10^{-4}$ (sr) and the impulse resolution was $\Delta p/p \simeq 0.1$. An interval of measured momentum of secondary particles ($\pi^{\pm}, K^{\pm}, p, d, t, He$) can be changed from 150 up to 1600 MeV/c and an interval of recording angles from 60° up to 168°. An identification of secondary particles, picked out by magnet - optical spectrometer channel, had been carried out using data about the time of flight on two bases 3.8m and 0.97m with precision ±260 ps and ionization losses of particles in scintillator counters and intensity of Cherenkov radiation of particles in two hard radiators.

A duration of signals from shaper and time diagrams have been determined using the condition for time measurements on the base 3.8 m: the value of the time must be in interval from 12 ns ($\beta = 1$) up to 92 ns ($\beta = 0.16$). So it was possible to detect pions, kaons, protons and barion fragments at the same time.

A relative intensity of accelerated particles has been measured by means of two monitoring systems of scintillator telescopes which were calibrated by measuring of secondary activity in carbon in polistirol foil (C_8H_8) irradiated in the place where target is situated with precision $\pm(5 \div 7)\%$.

The 8.9 (GeV/c) proton beam extracted from the accelerator with intensity up to $\sim 10^{11}$ particles per pulse with pulse length of $0.4s$ and repetition rate of $0.1Hz$ fell on cryogenic liquid deuterium target [13] with effective thickness about 1 (g/cm^2). The 96% part of target is formed from the effective deuterium material and only 4% part is a material of target vessel. The time of work without adding of deuterium was more than 100 hours.

The possible systematic uncertainty of the measured invariant cross section $Ed^3\sigma/dq^3$ is estimated to be about ±15%.

3. Nuclear effect in the $p + A \to \pi + ...$ process

We shall describe the nuclear effect in the $p+A \to \pi + ...$ process by the inclusive cross section ratio in dependence on the cumulative number X (Stavinsky variable [14])

$$R^{A_1/A_2}(X) = \frac{1}{A_{eff}} \cdot \frac{\rho^{\pi}_{A_1}(X)}{\rho^{\pi}_{A_2}(X)}. \qquad (1)$$

Here $\rho^{\pi}_{A}(X) \equiv Ed^3\sigma/dq^3$ is the inclusive cross section.

The physical mean of the variable X is the minimal mass of a target (A), in unit nucleon mass, needed for production of a particle h with the momentum q and the emission angle θ_h in according with the 4-momentum conservation law for the $p + A \to h + ...$ reaction.

The variable X for the π- meson production in the process is defined as follows

$$X = \frac{2(k_1k_2) - m_3^2}{(k_1k_2) - (k_2k_3) - m_1m_2}. \qquad (2)$$

Here k_1, k_2, k_3 and m_1, m_2, m_3 are the 4-momenta and masses of proton, nucleus and secondary pion, respectively. The factor A_{eff} takes into account the difference between pion cross section on proton ρ^{π}_p and neutron ρ^{π}_n and is defined by the expression

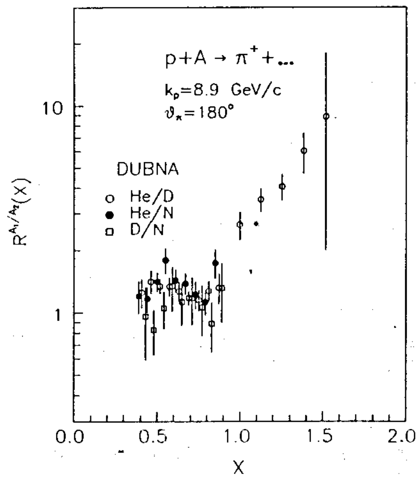

Figure 1. Dependence of the inclusive cross section ratio $R^{A_1/A_2}(X)$ for the $p + A \to \pi^+ + ...$ process on the cumulative number X. The experimental data are taken from [17].

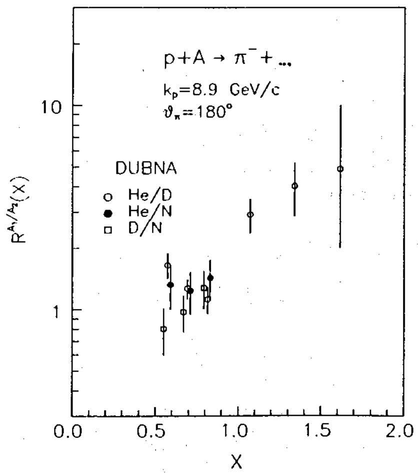

Figure 2. Dependence of the inclusive cross section ratio $R^{A_1/A_2}(X)$ for the $p + A \to \pi^- + ...$ process on the cumulative number X. The experimental data are taken from [17].

$$A_{eff} = \frac{n_1 \rho_n^\pi + p_1 \rho_p^\pi}{n_2 \rho_n^\pi + p_2 \rho_p^\pi}, \quad (3)$$

where $n_1(n_2)$ and $p_1(p_2)$ are numbers of neutrons and protons in nucleus $A_1(A_2)$.

We shall consider in according with the isospin symmetry that the $\rho_n^{\pi^+} = \rho_p^{\pi^-}$. Then the expression for the factor A_{eff} can be written as

$$A_{eff} = \frac{p_1 R_p^{\pi^+/\pi^-} + n_1}{p_2 R_p^{\pi^+/\pi^-} + n_2}. \quad (4)$$

The ratio $R_p^{\pi^+/\pi^-} = \rho_p^{\pi^+}/\rho_p^{\pi^-}$ of inclusive cross section for π^+ and π^- - mesons in $p-p$ interaction can be parametrized by the function $1 + 4X$ in the range $0 < X < 1$. This parametrization is in good agreement with the experimental data [15]. In the range $X > 1$ the factor A_{eff} we define as follows : $A_{eff} = p_1/p_2$.

4. Results and discussion

The experimental data [10, 16, 17] for the $p + A \to \pi + ...$ inclusive process for target nuclei p, D, He, Al and Pb at the incident proton momentum $k_p = 8.9\ GeV/c$ and the pion registration angle $\theta_\pi = 168°, 180°$ over the pion momentum region $q_\pi = (150 \div 900)\ MeV/c$ have been analyzed.

The experimental values of the ratio $R^{A_1/A_2}(X)$ in dependence on the cumulative number X for nuclei $A_1 = D, He$ and $A_2 = N, D$ are shown in Figure 1. One can see that the ratio $R^{A/N}(X)$ is approximately constant

$$R^{A/N} = const \geq 1 \quad (5)$$

over a non - cumulative range of $X < 1$. A similar ratio $R^{He/N}(x)$ for deep - inelastic lepton - nucleus scattering is less than 1 over a range $0.5 < x < 1$ [2].

Note that the ratio $R^{He/N}(X)$ is systematically larger than one for a deuteron. It can be considered as an evidence that the pion production in more dense nuclear matter medium is enhanced. In the cumulative range ($X > 1$) the exponential behaviour of the ratio $R^{He/N}(X)$ is observed

$$R^{He/D} \sim exp\ (\alpha \cdot X). \quad (6)$$

The sharp change of regime begins at $X \simeq 0.8$. The value of slope parameter α is defined to be $\alpha = 2.93 \pm 0.38$.

The kinematic conditions of the experiment have been such that the contribution of rescattering mechanism was extremely small. Therefore one can consider that the energy transferring process from few nucleons (at $X > 1$) to produced particle is due to hard scattering of an incident proton on non-nucleon configurations of target nuclei. So the results for π - mesons production at $X > 1$ show that non-nucleon configurations on which pions produced differ significantly in the light nuclei - deuterium and helium.

The change of the regime behaviour of the $R^{He/D}$ ratio with increasing X can be considered as an evidence that another production mechanism is involved. One can see that the change of regime starts at $X \simeq 0.8$ and it is lower than the kinematic boundary

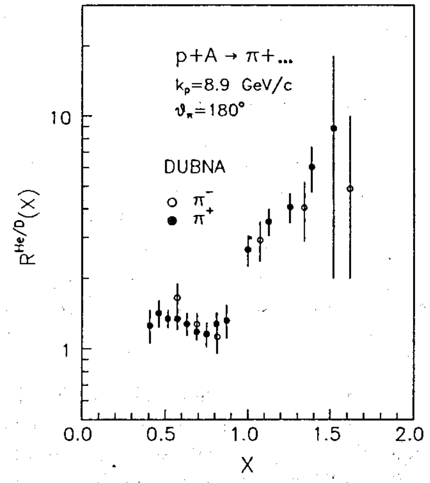

Figure 3. Dependence of the inclusive cross section ratio $R^{He/D}(X)$ for the $p + A \to \pi^\pm + ...$ process on the cumulative number X. The experimental data are taken from [17].

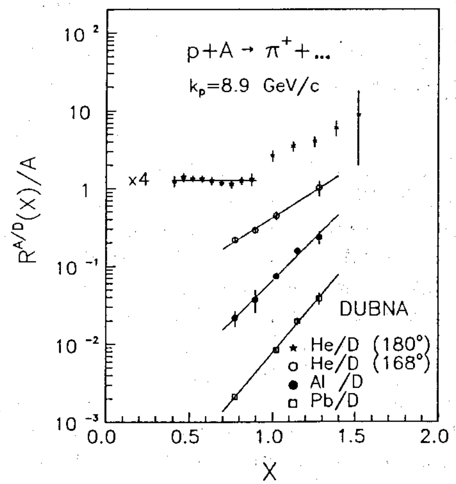

Figure 4. Dependence of the inclusive cross section ratio $R^{A/D}(X)$ for the $p + A \to \pi^+ + ...$ process on the cumulative number X for some nuclei $A = He, Al, Pb$ and the pion scattering angle $\theta = 180°, 168°$. The experimental data for $\rho_D^{\pi^+}$ are taken from [10].

for free nucleon - nucleon interaction. Therefore one can assume that the result is due to the enhancement effect connected with nuclear medium.

The ratio $R^{A_1/A_2}(X)$ for the $p+A \to \pi^- + ...$ process for nuclei $A_1 = D, He$, $A_2 = N, D$ is displayed in Figure 2. The ratios are similar to ones obtained for π^+ - meson both for the non-cumulative and cumulative range.

Figure 3 shows the dependence of the ratio $R^{He/D}$(X) for π^+ and π^- - mesons on X. One can see that the ratios coincide with each others.

In the quark cluster model it is assumed that the nucleus structure function is expressed via momentum distributions of quarks in clusters and clusters in nucleus. So far as we observed π^+ and π^- - meson produced at $X > 1$ therefore the coincidence of the ratios of $R^{He/D\to\pi^+} \simeq R^{He/D\to\pi^-}$ can be an evidence that the nuclear matter changes similarly quark distributions of all flavours. A similar result for deep - inelastic process at $x < 1$ have been concluded in [1].

Figure 4 shows the ratio $R^{A/D}(X)$ for target nuclei He, Al, Pb. The experimental data for He, Al, Pb and D are taken from [17] and [10], respectively. It is seen that the ratios $R^{He/D}$ for the registration angles $\theta = 168°$ and $180°$ at $X > 1$ are practically equal.

The X-dependence of the $R^{A/D}(X)$ ratio for heavy nuclei demonstrates the exponent increase $\sim exp\ (\alpha \cdot X)$ over a cumulative range like one for the light nuclei D, He.

The values of the slope parameter α are presented in the Table. We would like to note that the parameter α under the transition from Al to Pb changes slower than for the transition from He to Al. The results can be considered as the evidence that quark configurations in Al and Pb differ insignificantly over a range of $1 < X < 1.3$.

Table. The slope parameter α of the $R^{A_1/A_2}(X) = C \cdot exp\ (\alpha \cdot X)$ ratio

A_1/A_2	He/D	Al/D	Pb/D
α	2.93 ± 0.38	4.91 ± 0.44	6.11 ± 0.62

Figure 5 shows the X-dependence of the ratios $R^{A/D}(X)$, $R^{A/He}(X)$ for nuclei $= Al$ and Pb. The slope parameter α for $R^{Pb/A}(X)$ decreases with increasing an atomic number A. So the results confirm the conclusion on similarity of quark configurations in heavy nuclei. It was shown in [8] that the ratio of nucleus cross sections $\rho^{\pi}_{A_1}$ and $\rho^{\pi}_{A_2}$ normalized per nucleon for middle and heavy nuclei is about unit and is independent of X in a cumulative range. This is the consequence of the $\sim A^1$-dependence for the cumulative pion production and the universality of spectrum slope parameter expressed in the variable X.

The nuclear effect in the $p + A \to \pi(119°) + ...$ process for heavy nuclei $A = Be, Al, Cu, Ta$ at $X > 1$ has been analyzed in [6, 7], too. The experiment has been performed at incident proton energy $10, 14$ (GeV) and the secondary pion momentum $q_\pi = 0.6 - 1.62$ (GeV/c). It was founded that the ratio $R^{A_1/A_2}(X)$ demonstrates the exponent behaviour and does not manifest the regularity around the integer number X predicted in [18] and connected with two nucleon correlations.

The A-dependence of slope parameter $\alpha(A)$ of the $R^{A/A_1}(X) = C \cdot exp\ (\alpha \cdot X)$ ratio is shown in Figure 6. The dependence of $\alpha(A)$ demonstrates some asymptotic behaviour with increasing A.

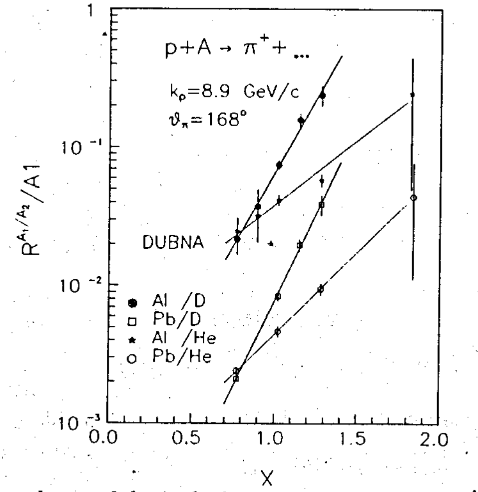

Figure 5. Dependence of the inclusive cross section ratio $R^{A_1/A_2}(X)$ for the $p + A \to \pi^+ + ...$ process on the cumulative number X for some nuclei $A_1 = Al, Pb$ and $A_2 = D, He$. The experimental data are taken from [10, 17].

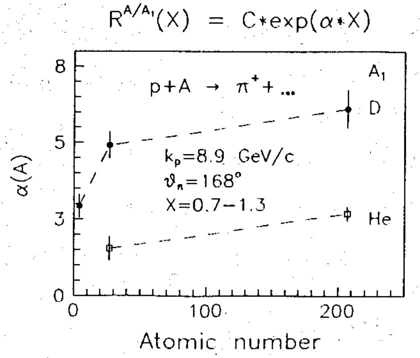

Figure 6. A-dependence of the slop parameter α of the ratio $R^{A_1/A_2}(X)$ for some nuclei $A_1 = He, Al, Pb$ and $A_2 = D, He$. The lines are drawn by hand. The experimental data are taken from [10, 17].

5. Conclusions

1. The nuclear effect in the $p + A \to \pi + ...$ process at large backward registration angle θ_π is investigated. It is found that cross section ratio $R^{A_1/A_2}(X)$ differs significantly in the cumulative and non - cumulative ranges.

2. It was observed that the dependence of the ratio $R^{A/D}(X)$ on the cumulative number X demonstrates the sharp increasing $\sim exp(\ \alpha \cdot X)$ starting at $X \simeq 0.8$.

3. It was found the coincidence of the ratios $R^{He/D\to\pi^+} \simeq R^{He/D\to\pi^-}$ both in the cumulative and non-cumulative ranges.

4. The new data on slope parameter $\alpha(A)$ for the $p + D \to \pi(168°) + ...$ process give some evidence on an asymptotic behaviour of α on an atomic number A.

Acknowledgments

We would like to thank G.A.Leksin, A.V.Stavinsky, G.I.Smirnov and V.V.Vechernin for useful discussions. This work has been supported in part by the Russian Foundation of Fundamental Research under Grant No. 94-02-06477.

References

1. Smirnov G.I., Preprint JINR, D1-94-278, Dubna, 1994 .
2. Michele Arneodo, Preprint CERN-PPE/92-113, 16 June 1992.
3. Baldin A.M., CERN Courier, **24** (1984) 19.
4. Benvenuti A.C. et al., Preprint JINR, E1-93-133, Dubna, 1993.
5. Braun M.A.,Tokarev M.V., Particles and Nuclei **22** (1991), 1238.
6. Boyarinov S.V. et al., Sov.J.Nucl.Phys. **46** (1987) 1472.
7. Boyarinov S.V. et al., In: Proc. XI Intern. Seminar on High Energy Physics Problems, JINR, D1, 2-88-652, Dubna, v.1, p.219
8. Baldin A.M., Panebratsev Yu.A., Stavinsky V.S., DAN USSR 279 (1984) 1352.
9. Baldin A.M., Brief Communication on Physics, AN USSR, 1 (1971) 35.
10. Averichev G.S. et.al., In: Proc. Intern. Symp."DUBNA DEUTERON-93",Dubna, Russia,14-18 September, 1993, 12p.
11. Averichev G.S. et al., JINR Rapid Communication No.4[37]-89, Dubna, 1989, p.5.
12. Avericheva T.V. et al., Preprint JINR, 1-11317, Dubna, 1978.
13. Borzunov Yu.T., Golovanov L.B. et al., JINR Communication 8-83-191, Dubna, 1983.
14. Stavinsky V.S., JINR Communication P2-9528, Dubna, 1976.
15. Johnson J.R. et al., Phys. Rev. **D17** (1978) 1292.
16. Baldin A.M., et.al., Preprint JINR, P1-11168, Dubna, 1977.
17. Baldin A.M., et.al., Preprint JINR, E1-82-472, Dubna, 1982.
18. Frankfurt L.L., Strikman M.I., Phys. Rep. **76** (1981) 215.

Received by Publishing Department
on December 26, 1994.

Аверичев Г.С. и др. E2-94-503

Ядерный эффект в рождении пионов назад в p-A взаимодействиях

Анализируются новые экспериментальные данные об инклюзивных сечениях рождения π-мезонов назад в p-D взаимодействиях. Исследуется ядерный эффект в реакции $p + A \to \pi + \ldots$ в кумулятивной ($X > 1$) и некумулятивной ($X < 1$) областях. Сделано заключение, что полученные результаты для зависимости отношения инклюзивных сечений $R^{A/D}$ от кумулятивного числа X дают указание о важной роли ненуклонных конфигураций при взаимодействии ядерных конституентов в кумулятивной области.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1994

Averichev G.S. et al. E2-94-503

Nuclear Effect for Backward Pion Production in p-A Interactions

The new experimental data on inclusive backward π-meson production in p-D interactions were analyzed. The nuclear effect in the $p + A \to \pi + \ldots$ processes in the cumulative ($X > 1$) and non-cumulative ($X < 1$) ranges is investigated. It was concluded that the obtained results for the dependence of the cross section ratio $R^{A/D}$ on the cumulative number X give the evidence on an important role of non-nucleon configurations in the interaction of the nuclear constituents in a cumulative range.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1994