

ԵՐԵՎԱՆԻ ՖԻԶԻԿԱՅԻ ԻՆՍՏԻՏՈՒՏ
ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ

ЕФИ-537(24)-82

S.R.GEVORKYAN, H.R.GULKANYAN

ON THE POSSIBILITY OF DEFINING THE TIME OF TRANSITION
OF QUARKS TO HADRONS FROM THE EXPERIMENTS WITH NUCLEI

ԵՐԵՎԱՆ 1982 ԵՐԵՎԱՆ

ЕФИ-537(24)-82

С.Р.ГЕВОРКЯН, Г.Р.ГУЛКАНЯН

О ВОЗМОЖНОСТИ ОПРЕДЕЛЕНИЯ ВРЕМЕНИ ПЕРЕХОДА КВАРКОВ
В АДРОНЫ ИЗ ЭКСПЕРИМЕНТОВ НА ЯДРАХ

В работе рассмотрена возможность перехода кварка (дикварка) в адрон внутри ядра. Получены простые выражения, позволяющие при сравнении с экспериментальными данными по инклюзивным спектрам быстрых адронов, рожденных недифракционно во взаимодействии лептонов и адронов высоких энергий с ядрами, оценивать среднее время адронизации кварков (дикварков) и сечения их взаимодействия с нуклонами. Показано, что существующие экспериментальные данные недостаточны для независимого определения этих параметров. Приводятся соображения о том, что наиболее информативными для извлечения указанных параметров являются процессы глубоко неупругого лепторождения, и на конкретном примере лепторождения пионов и каонов оценена необходимая для этого точность эксперимента.

Ереванский физический институт

Ереван 1982

HEP-537(24)-82

S.R.GEVORKYAN, H.R.GULKANYAN

**ON THE POSSIBILITY OF DEFINING THE TIME OF TRANSITION
OF QUARKS TO HADRONS FROM THE EXPERIMENTS WITH NUCLEI**

The possibility of transition of the quark (diquark) into a hadron within the nucleus is considered. Simple expressions are obtained which, when comparing with experimental data on the inclusive spectra of fast hadrons produced nondiffractively in the interaction of high-energy leptons and hadrons with nuclei, allow to estimate the mean time of quark (diquark) hadronization and the cross sections of their interaction with nucleons. The experimental data available are shown to be insufficient for the independent definition of these parameters. The processes of deep inelastic leptonproduction are shown to be the most informative ones for the definition of the above parameters, and on the concrete example of pion and kaon leptonproduction the required accuracy of the experiment is estimated.

Yerevan Physics Institute

Yerevan 1982

EDM-537(24)-82

YEREVAN PHYSICS INSTITUTE

S.R.GEVORKYAN, H.R.GULKANYAN

ON THE POSSIBILITY OF DEFINING THE TIME OF TRANSITION
OF QUARKS TO HADRONS FROM THE EXPERIMENTS WITH NUCLEI

Yerevan 1982

The progress recently achieved in the understanding of processes of high-energy particles interaction with nuclei is first of all due to the realization of the fact that in these processes the composite (quark) structure of hadrons is manifested. Among the most popular models used for the description of processes of multiple production on nuclei are the ones based on the additive quark model (AQM) [1].

In AQM the hadron is presented as a system of spatially separated objects - valence quarks, each surrounded by a cloud of gluons and quark-antiquark pairs. When the hadron interacts with the nucleus, it is assumed that quarks propagate within the nucleus, and the hadrons are formed of them out of the nucleus. This assumption is based on the fact that the time of the quark transition to hadron increases linearly with energy $\tau \sim E/\mu^2$ and at fairly high energies, when $\tau \gg R$ the hadron formation occurs out of the nucleus [2]. However, this assumption seems to require an additional verification. The propagation of free quarks on large distances agrees difficultly with the confinement hypothesis, and, therefore, the linear increase of τ with energy doesn't seem obvious [3]. Besides, at quark ener-

gies of several GeV the times of their formation are comparable with the dimensions of nuclei, and, therefore, it is necessary to take into account the possibility of their transition to hadrons within the nucleus.

In order to take into account this effect, let's first consider the process of electroproduction of fast hadrons on nuclei at large masses Q^2 of virtual photon. The probability that the quark-parton knocked out by the virtual photon from the nucleon located in nucleus at the point with the coordinate (\vec{b}, z_1) , will reach the point (\vec{b}, z_2) , where it will transform into a hadron (and neither the quark, nor the formed hadron will suffer inelastic interactions in the nucleus), is given by the following expression:

$$W_q^h = \frac{1}{A} \int \rho(\vec{b}, z_1) \exp \left\{ -\sigma_q \int_{z_1}^{z_2} \rho(\vec{b}, z) dz - \sigma_h \int_{z_2}^{\infty} \rho(\vec{b}, z) dz \right\} \times P_{qh}(z_2 - z_1) \Theta(z_2 - z_1) dz_1 \frac{d^2 b}{\tau} \quad (1)$$

Here $\rho(z)$ is the one-particle nuclear density; $\sigma_{q(h)}$ is the inelastic cross section of the knocked out quark (hadron) interaction with the nucleon, and $P_{qh}(z)$ is the probability that the quark doesn't transform into a hadron by moving away from the "parent" nucleon at a distance z . Let's parametrize this probability in the form $P_{qh} = e^{-z/\tau}$, where τ is the mean time (distance) of the transition of the quark to a hadron ($\hbar = c = 1$). When obtaining (1), no distinction was made between the electroproduction on protons and neutrons, the consideration of which is trivial.

The integrals in (1) over the longitudinal coordinates

are taken analytically in the approximation of the nuclear density constant:

$$\rho(z) = \begin{cases} \rho_0 = \frac{3A}{4\pi z_0^3} & \text{at } z < z_0 \\ 0 & \text{at } z \geq z_0 \end{cases}$$

where z_0 is the nuclear effective radius. (It is obvious that this approximation is not decisive for the future). Then a simple expression is obtained for W_q^h :

$$W_q^h = \frac{1}{A} \left[\frac{N(0, \epsilon_h) - N(0, \epsilon_q)}{\tau \rho_0 (\epsilon_h - \epsilon_q)} + N(0, \epsilon_q) \right] \quad (2)$$

where

$$\epsilon_h = \epsilon_q + \frac{1}{\tau \rho_0} \quad N(0, \epsilon) = \int \frac{1 - \exp\{-2\epsilon \rho_0 \sqrt{z_0^2 - b^2}\}}{\epsilon} d^2b \quad (3)$$

In the kinematic region, where the hadron obtains almost all the energy of virtual photon (quark), W_q^h is the ratio of inclusive spectra on the nucleus and on the nucleon

$$W_q^h = \frac{1/A \, d\epsilon^h/d^3p}{d\epsilon^N/d^3p}$$

It is easy to ensure that in the limiting by τ cases from (1) and (2) follow the well known expressions for the relation of inclusive cross sections in the mentioned region

$$W_q^h = \begin{cases} \frac{1}{A} N(0, \epsilon_h) & \tau = 0 \\ \frac{1}{A} N(0, \epsilon_q) & \tau = \infty \end{cases} \quad (4)$$

The expressions (1) and (2) are not applicable in the case, when the hadron obtains a relatively small fraction of the vir-

tual photon energy; in this case it is necessary to allow for the corrections connected with the multiple inelastic rescattering of quark and hadron in the nucleus, whose contribution is increased with the decrease of the virtual photon energy fraction transferred to the hadron. In this work no attempts are made to calculate these corrections since their estimation is connected with considerable uncertainty, first of all due to the lack of data on quark-nucleon inclusive cross sections [4].

The problem of the quarks transition to hadrons in the nucleus was discussed in ref. [5]. The basic expression (4) for the probability obtained in it differs from the expression (1) of this work and has the form

$$W_q^h = \frac{1}{A} \int d^2b dz \rho(b, z) \left[1 - G_q \int_z^\infty P_{qh}(z'-z) \rho(b, z') dz' - G_h \int_z^\infty (1 - P_{qh}(z'-z)) \rho(b, z') dz' \right]^{A-1}$$

Such a representation is physically incorrect. Indeed, expanding this expression we shall obtain a series, in the n-th order of which there will be a probability for quarks transition to a hadron in the n-th order, though the very sense of W_q^h is that the quark is transformed into a hadron once and only once.

At present there is only one experimental work [6], where the inclusive spectra of hadrons in electroproduction on nuclei at large $Z_h^{c.m.} = P_{||} / P_{max}$ were investigated ($P_{||}$ is the longitudinal momentum, P_{max} is the maximum possible momentum of the hadron in c.m.s. of the virtual photon and target nucleon).

In fig. 1 the experimental data at $Z_h^{c.m.} = 0.8^*$ and the results of calculations by the formula (2) at various values of

σ_q and τ are presented. When making the calculations we have assumed that $\sigma_h = \sigma_{qN}^{in} = 20$ mb, since the suppressing number of detected in the experiment hadrons are pions.

Since in the experiment [6] no noticeable dependence of inclusive spectra on the invariant energy $S = 4P_{max}^2$ was observed and the presented data were averaged over S , we hadn't assumed any dependence of τ on the quark energy. If in fact there is such a dependence then τ may be considered as some averaged value.

The nuclear density ρ_0 for each nucleus has been chosen in such a way that the effective numbers $N(0, \delta)$, calculated by the formula (3), coincide with the values $N(0, \delta)$, calculated at the real (Fermi) density of the nucleus.

As seen from fig. 1, the description of experimental data is satisfactory in both limiting cases, when $\tau \gg \tau_3$ (formula (4)) and σ_q is approximately 10 mb, and at not large (several fermi) values of τ and practically zero cross sections of the "knocked out" quark interaction with the nucleon $\sigma_q = 0$; a similar description is achieved at intermediate values of σ_q and the appropriate selection of τ . Thus, from the available experimental data on electroproduction it is impossible to estimate independently τ and σ_q . We think that in order to obtain such an estimate it is necessary to carry out exact measurements of inclusive spectra of hadrons of various types (e.g. pions and kaons) differing from each other by the value of inelastic cross sections of the interaction with nucleons. The curves in fig. 2 calculated for this case by the formula (2) show that by means of exact measurement

(with a several per cent error) of the pion yield ratio R_A^{π} , for instance, on the lead nucleus to the deuterium yield $R_{Pb}^{\pi} = \frac{(1/208) d\sigma_{Pb}^{\pi}}{(1/2) d\sigma_D^{\pi}}$ and the ratio R_A^K / R_A^{π} for the yield of pions and kaons would make the exponential estimation of the values τ and ϵ_q much less indefinite. The curves in fig. 2 are calculated for the energy region of the detected hadron of several GeV, where the inelastic cross sections of the interaction of K^+ -meson and pion with nucleons essentially differ from each other ($\sigma_{KN}^{in} = 15$ mb, $\sigma_{\pi N}^{in} = 22.5$ mb).

It should be emphasized that the reaction of deep inelastic leptonproduction seems to us a more informative process for the investigation of properties of coloured quark systems than those of hadroproduction. This is determined by the following circumstances. It has been noted above that in order to exclude (or reduce to the minimum) the corrections on the quark (diquark) multiple interactions, it is desirable to investigate the hadron inclusive spectrum in kinematic region where it obtains almost the whole energy of the incident hadron (the Feynman variable is $X_F \sim 1$). Generally, in this region a contribution is made by diffraction-type processes (to which the parameter τ is not connected directly), the experimental separation of which isn't quite unambiguous. Besides, as distinct from the processes of deep inelastic electroproduction, where knowing fairly exactly the energy of "knocked out" quark, we can select the events without multiple inelastic collisions in nucleus, the model-independent (or at least, weakly depending on the model) information on the energy of the quark (diquark) to which the produced hadron is genetically connected, is lack-

ing in the hadroproduction processes. Further on, in hadroproduction processes the expressions for inclusive spectra are more sensitive to the details of nucleon distribution in nucleus than the expressions (1) and (2). Indeed, consider the production of fast hadrons on nuclei with hadrons composed of K compound quarks ($K = 2$ for π , $K = 3$ for N). If we assume that the spectator mechanism makes the main contribution in the region $X_F \sim 1$, then it is easy to obtain for W_q^h in the reaction $hA \rightarrow h'X$ an expression similar to (2):

$$W_q^h = \frac{\sigma_h}{\sigma_{hA}^{prod}} \left[\frac{N(\sigma_h, \sigma_{h'}) - N(\sigma_h, \sigma_\tau)}{\tau \rho_0 (\sigma_\tau - \sigma_{h'})} + N(\sigma_h, \sigma_\tau) \right] \quad (5)$$

where $\sigma_h(h')$ are inelastic cross sections of the initial (final) hadron interaction with the nucleon; $\sigma_\tau = (K-1)\sigma_q + 1/\tau \rho_0$ and

$$N(\sigma_1, \sigma_2) = \int \frac{\exp\{-2\sigma_1 \rho_0 \sqrt{z_3^2 - b^2}\} - \exp\{-2\sigma_2 \rho_0 \sqrt{z_3^2 - b^2}\}}{\sigma_2 - \sigma_1} d^2b \quad (6)$$

As it is easy to see, the well known limiting cases [2] are obtained from (5):

$$W_q^h = \begin{cases} \frac{\sigma_h}{\sigma_{hA}^{prod}} N(\sigma_h, \sigma_{h'}) & \tau = 0 \\ \frac{\sigma_h}{\sigma_{hA}^{prod}} N(\sigma_h(K-1), \sigma_q) & \tau = \infty \end{cases} \quad (7)$$

One can present the effective numbers (6) in the form

$$N(\sigma_1, \sigma_2) = \frac{\sigma_2}{\sigma_2 - \sigma_1} N(0, \sigma_2) - \frac{\sigma_1}{\sigma_2 - \sigma_1} N(0, \sigma_1) \quad (8)$$

Apparently, for calculations by the formula (5) the effective

numbers $N(0, \epsilon)$ should be known more exactly than for calculations by the formula (2) (electroproduction).

It follows from the abovesaid that the extraction of the parameters τ and σ_q from the experimental data on hadroproduction requires additional model-dependent assumptions.

In conclusion let's illustrate the application of the expression (5) on the example of the reaction $pA \rightarrow \Lambda X$ the experimental data on which [7] are today the most exact among the nondifraction processes on nuclei in the region of large X_F . Just as in the case of electroproduction, the parameters τ and σ_q can't be independently defined from these data. They can be described, for instance, in two limiting cases $\tau \gg \tau_0$, $\sigma_{2q} = 10$ mb and $\tau = 5.7f$, $\sigma_{2q} = 0$. Note that from the analysis of data on other hadronic processes in ref. 2 the authors have obtained another estimate: $\sigma_{2q} = 20$ mb at $\tau \gg \tau_0$. Thus, the available experimental data on hadroproduction and deep inelastic electroproduction do not allow to independently estimate the parameters characterizing the space-time picture of the quark (diquark) transition to a hadron. More detailed investigations are needed, especially on leptoproduction of hadrons.

The authors would like to thank G.V.Grigoryan, S.G.Matinyan and N.N.Nikolaev for useful discussions.

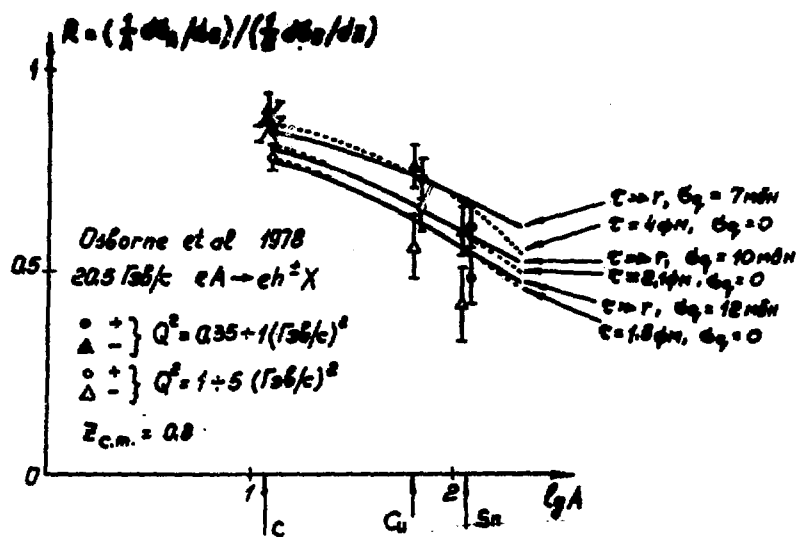


Figure Captions

Fig. 1 Comparison of experimental data on electroproductive with estimations by the formula (2).

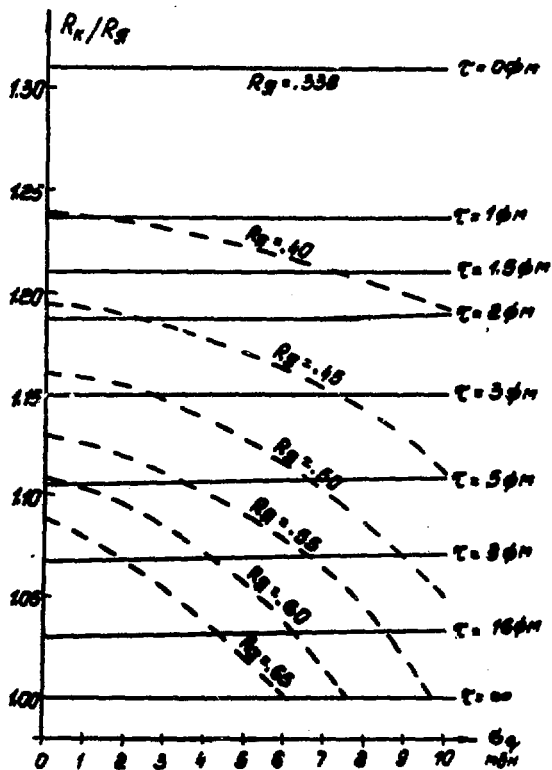


Fig. 2 Dependence of relative yields of K^+ -mesons and pions

$$\frac{R_K}{R_\pi} = \left(\frac{d\sigma_{\pi K}}{d\Omega} \right)_{K^+} / \left(\frac{d\sigma_{\pi\pi}}{d\Omega} \right)_\pi$$

on σ_q at fixed values of τ - solid lines, and R_π - dotted lines at $\Sigma_h \sim i$. The simultaneous measurement of R_π and ratio R_K/R_π allows to independently estimate τ and σ_q (see the text).

References

1. Nikolaev N.N. Quarks in the Interaction of High Energy Leptons, Photons and Hadrons with Nuclei. Uspekhi Fizicheskikh Nauk, 1981, vol. 134, p. 370.
2. Anisovich V.V. The Constituent Quarks and Partons in Soft Processes. Proc. 14th LINPh, Winter School, 1979, vol. 1.
3. Dar A., Takagi F. Attenuation and Recombination of Quarks in Nuclear Matter. Phys. Rev. Lett., vol.44,p.768.
Bialas A. Particle Production from Nuclear Targets and the Structure of Hadrons. FERMILAB-PUB-78/75-THY, 1978.
4. Anderson B. et al. Leptoproduction of Hadrons on Nuclei. Phys. Lett., 1979, vol. 83B, p. 379.
Bialas A., Bialas E. Determination of Quark-Nucleon Inclusive Cross Section from Leptoproduction of Hadrons in Nuclear Targets. Phys. Rev., 1980, vol. D21, p. 675.
5. Bialas A. Attenuation of High Energy Particles Leptoproduced in Nuclear Matter. Acta Physica Polonica, 1980, vol. B11, p. 475.
6. Osborne L.S. et al. Electroproduction of Hadrons from Nuclei. Phys. Rev. Lett., 1978, vol. 40, p. 1624.
7. Heller K. et al. Inclusive Production of Hyperons by 300 GeV Protons: A-Dependence. Phys. Rev., 1977, vol. D16, p. 2737.

The manuscript was received 27 January 1982.



С.Р. ГЕВОРКЯН , Г.Р. ГУЛКАНЯН

**О ВОЗМОЖНОСТИ ОПРЕДЕЛЕНИЯ ВРЕМЕНИ ПЕРЕХОДА КВАРКОВ
В АДРОНЫ ИЗ ЭКСПЕРИМЕНТОВ НА ЯДРАХ
(на английском языке, перевод Л.Н. Багдасаряна)
Ереванский физический институт**

Тех. редактор А.С. Абрамян

Заказ 167

ВФ- 05175

Тираж 299

Препринт БФН

Формат издания 60x84/16

Подписано к печати 14/IV-82г. 1,0уч.изд.л. Ц. 10 к.

**Издано Отделом научно--технической информации
Ереванского физического института, Ереван-36, пер.Маржаряна 2**

индекс 3624