сообщения
объединенного
института
ядерных
исследований
дубна

E2- 12439

V.I.Komarov , H.Müller

ON THE MECHANISM OF THE BACKWARD EMISSION OF FAST PROTONS IN HADRON-NUCLEUS INTERACTIONS AT INTERMEDIATE AND HIGH ENERGIES

1979

E2- 12439

V.I.Komarov , H.Müller*

ON THE MECHANISM OF THE BACKWARD EMISSION OF FAST PROTONS IN HADRON-NUCLEUS INTERACTIONS AT INTERMEDIATE AND HIGH ENERGIES

* Central Institute of Nuclear Research,
Rossendorf, GDR.

Комаров В.И., Мюллер Г.

E2 - 12439

О механизме эмиссии назад быстрых протонов в адрон-ядерных взаимодействиях при средних и высоких энергиях

Эмиссия назад быстрых протонов в адрон-ядерных взаимодействиях описывается простой моделью без привлечения аномально высоких импульсов или плотностей нуклонов в основном состоянии ядра-мишени. Предполагается, что инициирующие адроны рассеиваются на малые углы малонуклонными группами в ядре, сообщая им энергию возбуждения, достаточную для эмиссии быстрых протонов назад. Спектр возбуждения малонуклонных групп является их внутренней характеристикой при уровнях возбуждения, превышающих ≈ 100 МэВ. Обсуждается возможная универсальность таких спектров возбуждения.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1979

Komarov V.I., Müller H.

E2 - 12439

On the Mechanism of the Backward Emission of Fast Protons in Hadron-Nucleus Interactions at Intermediate and High Energies

The backward emission of fast protons in hadron-nucleus interactions is described by a simple model which does not include extremely high momentum components or anomalously high nuclear densities in the ground state of the target nucleus. The excitation spectrum of few-nucleon system in nuclei is proposed to be an internal characteristic of such systems, and a possible universality of the excitation spectrum is discussed.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1979

It is known, that fast protons are emitted from the target nucleus at angles larger than 90° in high-energy hadron-nucleus collisions. Inclusive spectra of these protons with energies larger than 30 MeV can be parametrized as follows:

$$E/(p_p^2\sigma_t)\cdot d\sigma/(d\Omega\, dp_p) = A_0 \exp(-A_1 p_p^2). \qquad (1)$$

(Here E and p_p are the energy and the momentum of the backward emitted fast protons, σ_t is the total cross section of hadron-nucleus interaction). The parameters A_0 and A_1 depend weakly on the type and the energy of the incident hadron h and the dependence of the slope parameter A_1 on the mass number A of the target nucleus is also a weak one (see refs. [1,2]). A similar behaviour of proton emission has been found at intermediate energies [3,4]. It is essential to note that with increasing initial energy T_0 A_1 asymptotically tends to $A_1^{as} \approx 10\text{-}15\ (\mathrm{GeV}/c)^{-2}$. In order to explain the observed dependences numerous rather different hypotheses have been developed (see, e.g., survey [5]). The majority of these hypotheses is based on assumptions about high intranuclear momenta [6], high densities [7] or mechanisms [8], which are specific for high-energy collisions (e.g., quark-parton ideas, fireball production). As many models are able to reproduce the properties of inclusive backward emission of fast protons, one may suppose that these models contain excess information for describing inclusive data. The question arises whether it is possible to describe these data at intermediate as well as at high energies from a single point of view without involving special hypothesis on the high momentum structure of nuclei.

In this paper the inclusive proton emission from the reaction

$$h + A \to p(\theta > 90^\circ,\ T_p > 30\,\mathrm{MeV}) + X \qquad (2)$$

is considered under the following assumptions:

a) the hadron h interacts with a group of several nucleons of the target nucleus and is scattered preferably at small forward angles. As a result of the interaction momentum is transferred to the few-nucleon system (FNS) and its invariant mass is increased:

$$h + [kN] \to h' + [kN]^* . \qquad (3)$$

(Further such an increase is called as the FNS excitation). Protons are emitted backwards during the decay of these excited $[kN]^*$ systems:

$$[kN]^* \to p + N_1 + N_2 + \dots + N_{k-1} . \qquad (4)$$

In the calculations it is assumed that the decay (4) proceeds in a statistical way.

b) The relative probability of increasing M^{inv} by a certain quantity ΔM^{inv} does not depend on the type and the energy of the incident hadron. The excitation probability distribution over ΔM^{inv} ("the excitation spectrum" - $W_k(\Delta M^{inv})$ is an intrinsic property of the FNS which takes part in process (2), and a $W_k(\Delta M^{inv})$ depends weakly on k and the target mass number A for values $\Delta M^{inv} \lesssim 100$ MeV. In our calculations the following excitation spectrum $W_k(\Delta M^{inv})$ has been used

$$W_k(\Delta M^{inv}) = \exp(-\Delta M^{inv}/M_{exc})/(1-\exp(-E_k^{max}/M_{exc}), \qquad (5)$$

where M_{exc} is a specific parameter characterizing the excitation probability, while E_k^{max} is the maximum value of excitation energy, kinematically accessible in process (3). If one assumes that the FNS excitation in the energy region of interest occurs via the excitation of nucleons of the FNS (i.e., first of all, via the excitation of the Δ(1232)-resonance or pion production in the intermediate states), it is quite natural to use for the parameter M_{exc} a value near the pion mass.

c) Process (3) has a quasi-diffractional character, i.e., the scattering of the hadron h approaches the diffractional one with increasing energy T_0. (The invariant momentum transferred by the hadron for a fixed ΔM^{inv} tends with increasing T_0 to the corresponding value for the elastic $h + [kN]$ scattering). Therefore, the probability for the hadron scattering at the angle θ^* in the c.m.s. with the momentum p_k^* has been assumed in a form to describe the main peak of the diffraction scattering on a black sphere with

radius $a = 1.81\, k^{1/3} R_{c2}$:

$$W_k(\theta^*) = \exp(-(\theta^* p_k^* k^{1/3} R_{c2})^2) \qquad (6)$$

(R_{c2} is a free parameter of the model).

d) The total cross section of interaction (3) is determined with an accuracy up to a constant factor $\mathcal{P}$ by the geometrical section of FNS $[kN]$ and the combinatorial probability of finding it in the nucleus:

$$\sigma_{kA} = \mathcal{P} \pi (k^{1/3} R_c + \sqrt{\sigma_{hN}/\pi})^2 (A/k!)(R_k/R_0)^{3(k-1)} \exp(-(R_k/R_0)^3), \qquad (7)$$

where σ_{hN} is the total cross section of hN interaction, R_0 and R_c are the parameters determining the nucleus radius $R_A = A^{1/3} R_0$ and cluster radius $R_k = k^{1/3} R_c$. We assume the average FNS density to be close to the average nuclear density ($R_c = R_0$). A Gaussian distribution with the standard deviation $\sigma_F(k) = \sqrt{k/2} \cdot 90$ MeV/c has been used for the momentum distribution of the FNS in the nucleus. Secondary interactions of the hadron or outgoing protons in the nucleus are not taken into account.

The proton spectra are calculated as the sum $d^3\sigma/d\vec{p}_p = \sum_{k=2}^{k_{max}} d^3\sigma_k/d\vec{p}_p$ where $d^3\sigma_k/d\vec{p}_p = (\sigma_{kA}/R_k^{FM})(d^3R_k^{FM}/d\vec{p}_p)$. The integral of the phase space R_k^{FM} and its derivative were found by the recurrent kinematic formulae of the Kopylov-Byckling-Kajante type (see ref. [9]). Weight functions (having the meaning of a squared matrix element of process) in the form of (5), (6) were introduced into the integral of the phase space, and the FNS momentum distribution in the target nucleus was taken into account. The integration was performed by using the Monte-Carlo method.

Values of the parameters R_{c2} and $\mathcal{P}$ have been obtained by comparing the calculated spectrum with the experimental one for the reaction $p + {}^{12}C \to p + X$ at 640 MeV and $\theta = 122°$ (ref. [4]). Fig. 1 shows the results of this comparison with $R_{c2} = 0.25$ fm and $\mathcal{P} = 0.141$*. With this values the angular dependence of A_1 has been calculated which is close to the experimental one (Fig. 2a), and the scaling character of the energy dependence of this parameter is reproduced too (Fig. 2b). The calculated values of A_0 , A_1 are stable to the variation of the parameters used in the calculations, as shown in the Table.

* In ref. [18] the parameter $\mathcal{P}$ value was indicated wrongly.

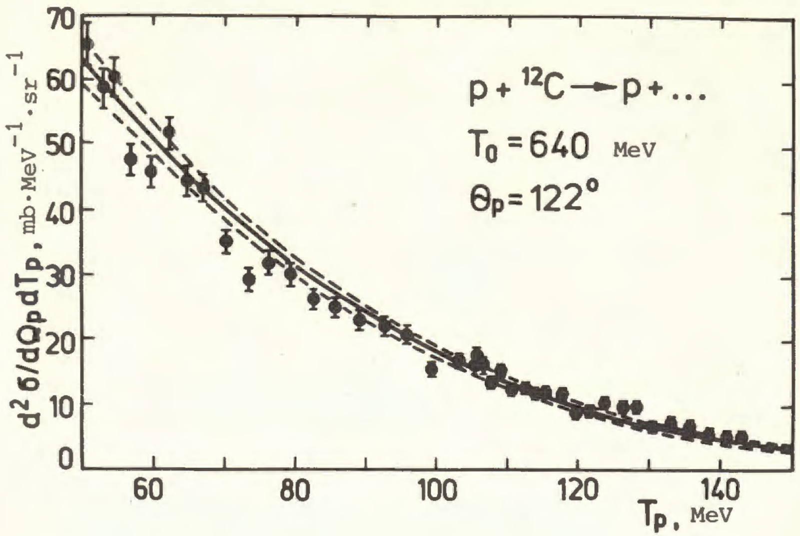

Fig. 1. Proton energy spectrum. Curve with corridor of error-calculation, points - experiment [4].

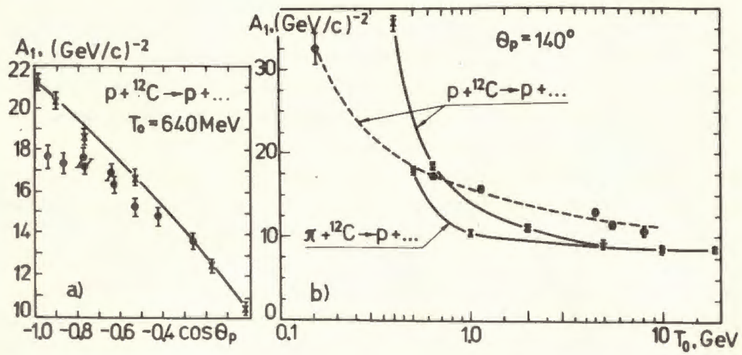

Fig. 2. Angular (a) and energy (b) dependence of the slope parameter A_1. x - calculation, • - experiment (refs. in [4]), 50 MeV $< T_p <$ 150 MeV.

Table

Parameter (x)	Accepted value	$\frac{(\Delta A_0/A_0)}{(\Delta x/x)}$	$\frac{(\Delta A_1/A_1)}{(\Delta x/x)}$
M_{exc}	0.14 GeV	-1.4	-0.7
R_0	1.1 fm	2.7	-0.4
R_c	1.1 fm	0.6	-0.2
R_{c2}	0.25 fm	0.2	0.06
$\wp$	0.141	1	0

Thus, the main characteristics of the inclusive data at intermediate and high energies can be explained by using simple assumptions about nuclear properties and reaction mechanism. The results are found to be weakly dependent on the details of the exact form of functions (5) and (6), since the observed spectrum is a complex composition of partial spectra from FNS with different k (Fig. 3). The statistical character of inclusive spectra is a consequence of numerous possibilities for proton emission with a certain $\vec{p}_p$ value: various values of k ($2 \le k \le k_{max} = 6-8$), decay (3), Fermi motion of the centre-of-mass of the [kN]-group. It should also be noted that measured spectra are influenced by distortions not taken into account in our calculations: multiple hadron interactions in the nucleus, partial transfer of the FNS energy to the residual nucleus and final-state interactions of protons emerging from the nucleus.

In models, proposed so far for the interpretation of inclusive spectra, short range correlations between nucleons in the initial state of the nucleus and elastic rescattering in the final state are taken into account (see, e.g., refs.[6,7,10,11]). Our calculations indicate that inelastic processes with nucleon excitations during the interaction may be important too. This conclusion is supported by the following facts. For elastic backward pd-scattering at intermediate energies the great significance of diagrams with a pion in the intermediate state has been shown in ref.[12]. The authors of ref.[13] have found a considerable contribution of the Δ-isobar excitation to the amplitude of this process. The important role of the virtual pion exchange and the resonance production in the intermediate state of the process

$$p + d \to p\,(\theta > 90^\circ) + p + n$$

has been proved in refs.[14,15]. From calculations in the framework of the cascade model[16] it follows that for process (2) at intermediate energies inelastic interactions of the incident hadron with intranuclear nucleons are of decisive importance. Thus, our assumption on the significant role of FNS excitation occurring through nucleon excitation seems to be quite natural.

The combined account of nucleon correlations (in the initial and final states) and nucleon excitations makes this problem too difficult for a detailed analysis (e.g., by taking into account a certain set of Feynmann graphs). Therefore, a phenomenological description of FNS excitation seems to be reasonable. As seen from the above calculations, the inclusive data do not allow to extract exact information on the excitation spectrum. However, definite channels (3) with the leading hadron h' can be separated and studied in exclusive and semi-exclusive measurements (see, e.g., ref.[17]). By selecting such channels one can study both the

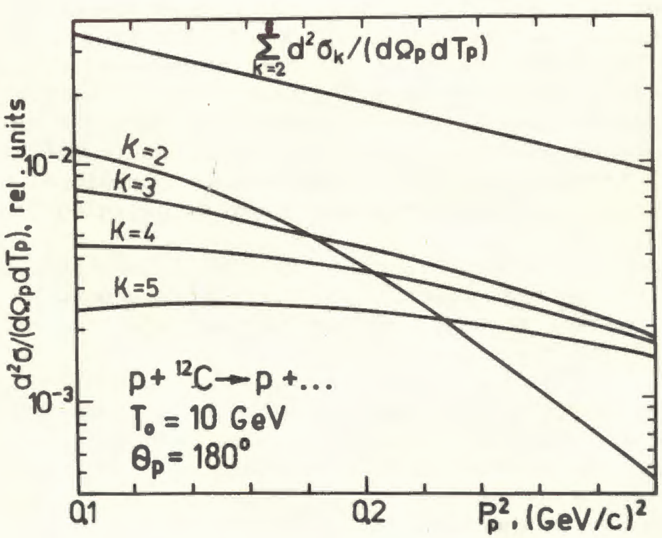

Fig. 3. Components of the calculated spectrum differing by the number of nucleons k in the few-nucleon group.

FNS excitation spectrum and the hadron angular distribution in process (3). If hadron scattering is of coherent quasi-diffractional character, one should expect that the angular distribution of h' has the width $\Delta\theta_k \approx (p_k^* k^{1/3} R_{c2})^{-1}$. The assumption on the possibility to describe the FNS excitation spectra for various target nucleus and incident particles by the same function[18], can be checked experimentally: the ΔM^{inv} distributions can be measured directly at least for light nuclei in a large number of various reactions in which FNS suffer large momentum transfer and high excitation. The assumption on the identity of the excitation spectra for different few-nucleon systems may be accepted evidently only for the qualitative description of inclusive data. In general, one may expect that FNS excitation spectrum depends on the FNS spin-isospin state. As a consequence of such a universality of the excitation spectra, one can expect, e.g., an unambiguous coupling between the slope parameters of fast proton spectra and of the spectra of fragments (${}^2H$, ${}^3H$, ${}^3He$, ${}^4He$) emitted backwards in hadron-nucleus reactions. The emission of these fragments may occur via the following channels:

$$[kN]^* \to \begin{array}{l} {}^2H + N_1 + N_2 + \ldots + N_{k-2} \\ {}^3H + N_1 + N_2 + \ldots + N_{k-3} \\ \ldots\ldots\ldots\ldots , \end{array} \qquad (7)$$

along with the dominating channel (4).

In conclusion we add a further example of the connection between the reactions via the FNS excitation spectrum. The spectra of fast pions from the reaction

$$d + A \to \pi\,(0^\circ) + X \qquad (8)$$

can be coupled with the spectra of energetic protons emitted in the reaction

$$h + d \to h' + N + p\,(180^\circ)$$

if the dominating mechanism of these reactions includes the decays

$$[np]^* \to \left\{ \begin{array}{l} \pi\,(0^\circ) + N + N \\ p\,(180^\circ) + n . \end{array} \right.$$

The authors express their gratitude to Prof. V.V.Balashov, L.L.Frankfurt, G.A.Lykasov, M.I.Strikman and V.D.Toneev for helpful discussions of the probems touched upon in this paper.

REFERENCES

1. *Leksin G.A. "Nuclear Scaling", MIFI, M., 1975.*
2. *Baldin A.M. Fiz. elem. chastits. at. yadra, 1977, 8, p.429.*
3. *Frankel S. et al. Phys.Rev.Lett., 1976, 36, p.642.*
4. *Komarov V.I. et al. Phys.Lett., 1977, 69B, p.37.*
5. *Frankfurt L.L., Strikman M.I. Proc. of XIII Winter School of Physics. Leningrad Inst. of Nucl.Phys., 1978.*
6. *Amado R.D. and Woloshyn R.M. Phys.Rev.Lett., 1976, 36, p.1435.*
7. *Burov V.V. et al. Phys.Lett., 1977, 67B, p.46.*
8. *Efremov A.V. JINR, E2-9529, Dubna, 1976; Bogatskaya I.G. et al. Yad. fiz., 1978, 27, p.856.*
9. *Kopylov G.I. JINR, E-528, Dubna, 1960; Byckling E., Kayanti K. "Kinematics of Elementary Particles", M.,1975.*
10. *Woloshyn R.M. Nucl.Phys., 1978, A306, p.333.*
11. *Fujita T., Hufner J. Nucl.Phys., 1979, A314, p.317.*
12. *Craigie N.S., Wilkin C. Nucl.Phys., 1969, B14, p.477.*
13. *Kondratyuk L.A., Lev F.M. Yad. fiz., 1977, 26, p.294.*
14. *Amelin N.S., Lykasov G.I. Yad.fiz., 1978, 28, p.1528.*
15. *Kopeliovich V.B., Radomanov V.D. JINR, P2-11938, Dubna, 1978.*
16. *Gudima K.K. et al. JINR, E2-11307, Dubna, 1978.*
17. *Komarov V.I. et al. JINR, E1-9460, Dubna, 1976; JINR, E1-111354, Dubna, 1978.*
18. *Komarov V.I., Müller H. JINR, P2-12208, Dubna, 1979; Pis'ma v JETHP, 1979, 29, No. 8.*

Received by Publishing Department
on May 5 1979.