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# ON MECHANISM OF PROTON EMISSION IN KINEMATIC REGION FORBIDDEN FOR FREE PARTICLE SCATTERING

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# ON MECHANISM OF PROTON EMISSION IN KINEMATIC REGION FORBIDDEN FOR FREE PARTICLE SCATTERING

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О механизме испускания протонов в область, кинематически запрещенную для рассеяния свободных частиц

В рамках каскадной модели с учетом процесса предравновесной эмиссии частиц анализируется выход быстрых протонов в заднюю полусферу в протон-ядерных реакциях при $T_0$ = 640 МэВ. Отмечается слабая чувствительность инклюзивных распределений к специфике механизма реакции, необходимость проведения корреляционных экспериментов и измерения поляризации рождающихся быстрых частиц.

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On Mechanism of Proton Emission in Kinematic Region Forbidden for Free Particle Scattering

The backward yield of high energy protons in proton-nucleus reactions at T = 640 MeV is investigated in the framework of the cascade model taking account of the preequilibrium particle emission. A weak sensitivity of the inclusive distributions to the specific reaction mechanism and a need of correlation and polarization measurements are noted.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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In the past few years the particle emission in a kinematic region inaccessible to scattering from a free nucleon has drawn a growing attention. It can be expected that the information obtained will shed light on the most deep nuclear transformations and help to understand the mechanism of large momentum transfer. In particular, the precise measurements at the Los Alamos meson factory and at the Dubna synchrocyclotron are of great importance where high energy protons at large (near 180°) angles were investigated in the $p + A \to p' + ...$ reaction induced by protons with energy $T_0 = 0.6-0.8$ GeV [1,2].

Several mechanisms were proposed to interpret these fast particles. Amado and Woloshyn [3] relate the fast backward proton production to the existence of high-momentum component of nuclear wave function (Fig. 1a). To describe the experimental inclusive spectra, they need to postulate the exponential fall-off of the internal momentum distribution of nucleons what extends up to about 1.2 GeV/c. This case corresponds to the two-body kinematics of the elastic quasi-free scattering. A mechanism of elastic scattering on a correlated group of N nucleons ("correlated cluster") is treated by Fujita (see Fig. 1b). Earlier a similar mechanism of nuclear scattering due to fluctuation of nuclear density has been suggested by D.I.Blokhintsev [5] and further developed in works [6] to explain the production of cumulative mesons and protons but at higher energies of the bombarding hadron. The exchange

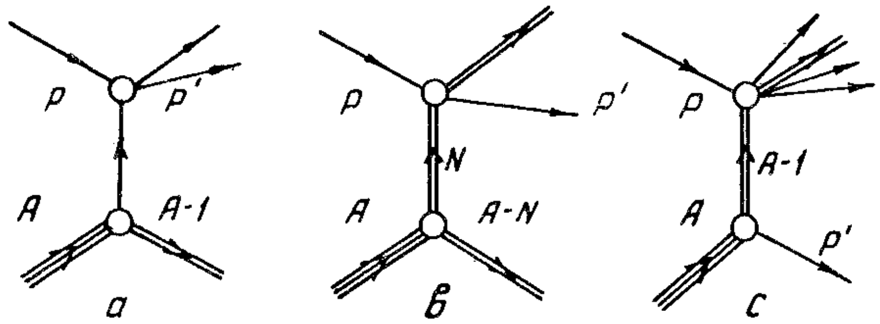


Fig. 1. Diagrams for production mechanism of fast backward going proton, p′ .

mechanism pictured in Fig. 1c was proposed by Weber and Miller /7/. Here, the enhancement of the backward particle emission is achieved due to the fact that the process amplitude is proportional to the cross section of the particle interaction with (A-1)-nucleus. Note should be made that all these models consider only single-particle scattering process and neglect the effects of rescattering and final state interaction, nevertheless, they succeed to fit the shape of experimental proton spectra.

The aim of this paper is to elucidate to what extent one needs certain specific mechanisms for describing the observed protons in a kinematic region forbidden for free particle scattering and to study the sensitivity of the characteristics to the interaction mechanism considered. Here, we shall limit ourselves to the energy region $T_0 < 1$ GeV.

Our analysis is based upon the Dubna version of the conventional cascade model of nuclear reactions. In ref. /8/ it is compared to other versions of the intranuclear cascade model at energies $T_0$ below the meson production threshold. In the energy region under consideration, $T_0 = 0.6 - 0.8$ GeV, it is necessary to allow for the process of $\pi$-meson



production that is performed in the same way as in ref. /9/. This model is shown to describe quite well overall distributions of secondaries at an energy of the incident hadron $T_0 \lesssim 3$-5 GeV /10,11/.

It should be particularly noted that the intranuclear cascade model does not take into account the clusterization of nuclear nucleons and exchange effects; besides, the energy spectrum of nuclear constituents is limited by the value of Fermi energy. Therefore, noticeable deviations might be expected between cascade model predictions and experiment for characteristics of this highly restricted kinematical region. It would seem that in this case the only mechanism of high energy particle production at large angles is the rescattering process. It is of interest to estimate the contribution of this "background" effect to the characteristics in question. Moreover, the cascade model enables us to predict the absolute values for proton cross sections and does not require any additional data or special normalization of its results.

As is seen from Figs. 2 and 3, the "background" protons with T=60-140 MeV contribute essentially to the measured cross sections, even at maximal T. The calculated slope of energy spectra turns out to be close to experimental one, as well. Thus, in the framework of the cascade model the fast proton yield at $\theta = 140°$ has a correct A-dependence, $d\sigma/d^3p \sim A$. Also, it reproduces the change in inclusive spectra with the observation angle.

From results presented in Fig. 4 it follows that at an energy of the incident proton $T_0 \simeq 0.7$ GeV the yield of fast nucleons in the angular range $\theta > 120°$ through the elastic rescattering only is negligible. The main contribution to the backward scattering of energetic protons comes from the process of double-, triple- and even quadrupole-interactions with $\pi$-meson production in one of them. A special analysis showed that in the most part of these events the produced pion is absorbed

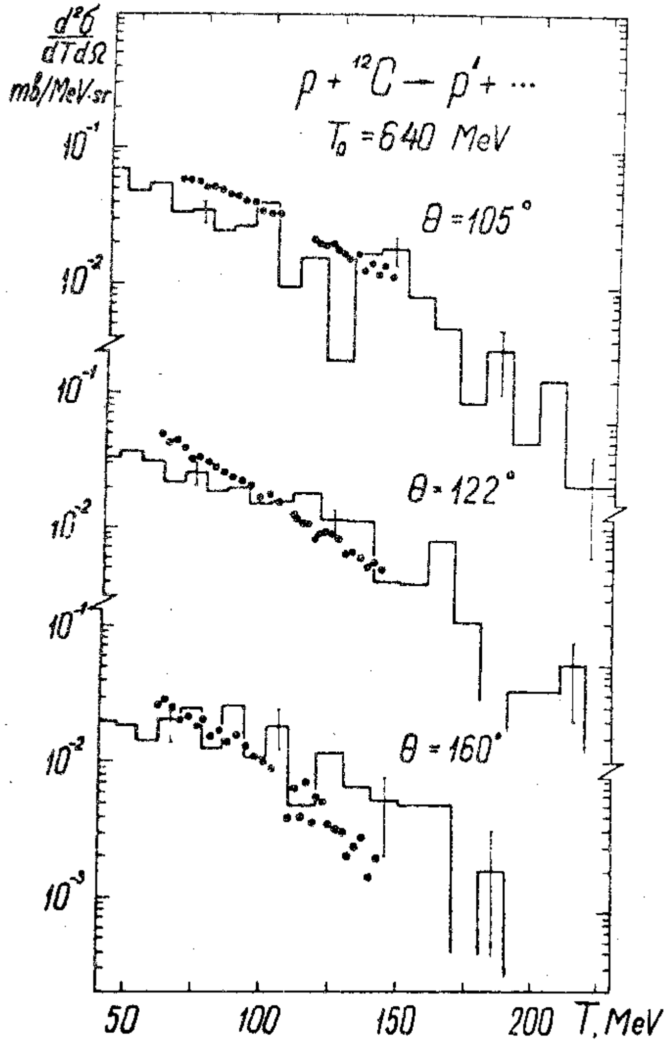


Fig. 2. Inclusive proton spectra; histograms are calculated within our cascade model, experimental points are from ref. /2/.

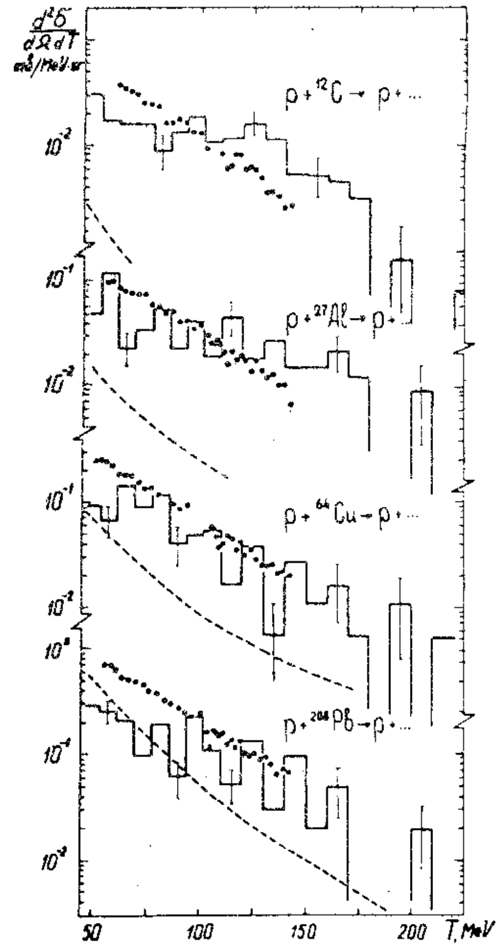


Fig. 3. Inclusive spectra of protons ejected at the angle $\theta = 140°$. The incident proton energy $T_0 = 640$ MeV. Histograms are cascade model results, points–experiment /2/. Contribution of the preequilibrium proton emission is shown by dashed lines (see the text).

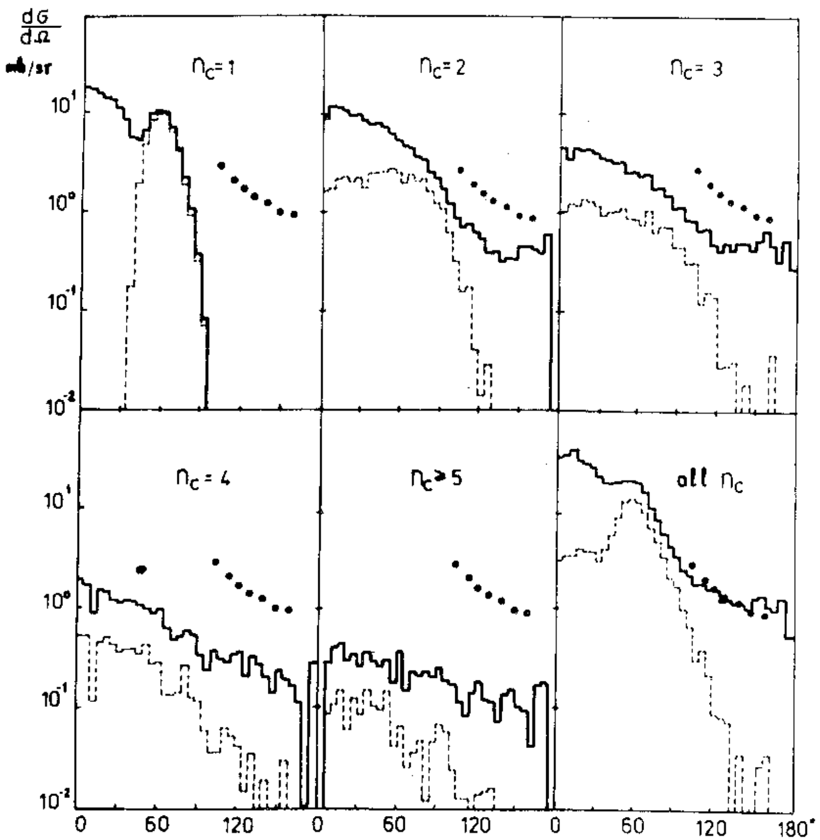


Fig. 4. Angular distributions of protons in energy "window" 60 MeV $\leq T \leq$ 140 MeV suffered from $n_c$ collisions inside the nuclear target $^{12}C$, the incident proton energy being 640 MeV. The solid and dashed histigrams are cascade model results for all events and for the case when only elastic intranuclear collisions occur, respectively. Experimental points are related to the sum over all $n_c$ /8/.

by the quasi-deuteron pair resulting in the fast protons which leave the nucleus immediately or after rescatterings.



The simplest way to account for effects of final state interactions may be achieved within the preequilibrium approach to nuclear reactions /12/. The cascade-exciton model developed in ref. /13/ allows one to estimate the preequilibrium particle emission in high-energy nucleon-nucleus collisions. In the framework of this model the reaction proceeds in three stages: cascade, preequilibrium and equilibrium. Results of cascade calculations determine the initial state (i.e., the number of excited particle-holes and excitation energy) of the excited nuclear system whose further development up to attainment of the statistical equilibrium is traced in terms of the exciton model of the preequilibrium decay. As was noted earlier /13,14/, the preequilibrium component contributes essentially to the hard part of backward emission spectra of nucleons and complex particles. Fig. 3 shows the estimated cross sections of the preequilibrium proton emission. It is noteworthy that for heavy nuclei the fraction of fast protons emitted at the preequilibrium stage is comparable with the cascade component and the slope of the preequilibrium spectrum is close to the experimental one. The measured protons correspond to the sum of these two components, therefore for such targets as Cu and Pb (see Fig. 3) there is agreement for energy spectra in both the shape and the absolute value. In a sense, the mechanism under consideration is "background", trivial. The contributions of indicated specific mechanisms (Fig. 1) can be estimated as a difference between experimental points and the calculated "background".

The results obtained do not imply, of course, that nucleon-nucleus interaction physics is completely covered by the mechanism of independent particle-particle collisions inside the nucleus. But more strict kinematic constraints and analysis of more "delicate" characteristics of nuclear reaction are required to establish unambiguously the interaction mechanism and especially its absolute contribution. In this aspect we think that inclusive particle distributions feel weakly the specific features of reaction mechanism. Apparently, to have a more convincing evidence for the existence of the specific interaction mechanism, the correlation and polarization measurements are needed.

In conclusion one should note that the results obtained allow certain qualitative predictions on the nature of secondary proton polarization to be made without detailed calculations. Indeed, it can be expected that in the mechanism of independent particle-particle collisions the polarization should correlate with the polarization in the elementary act of elastic nucleon-nucleon scattering and with the number of quasifree elastic collisions. Then, as it follows from Fig. 4, the maximum polarization can be expected nearby the peak of quasifree scattering, the polarization degree being changed much lesser passing from 60° to 90° than from 90° and 120° where the relative contribution of elastic rescattering is small.

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