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INCLUSIVE SPECTRA AND THE ANGULAR DISTRIBUTION OF PROTONS EMITTED BACKWARDS IN THE INTERACTION OF 640 MEV PROTONS WITH NUCLEI

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Инклюзивные спектры и угловые распределения протонов, испускаемых назад при взаимодействии протонов 640 МэВ с ядрами

Инклюзивные спектры протонов, испускаемых с энергией от 60 до 145 МэВ при взаимодействии протонов 640 МэВ с ядром ^{12}C, измерены при семи лабораторных углах между 105° и 160°. В тех же условиях протонные спектры измерены под углом 140° с мишенями Be , Al , Cu и Pb. Обсуждается поведение структурной функции $E \cdot \sigma_t^{-1} \, d\sigma/d^3p$ при средних энергиях.

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Inclusive Spectra and the Angular Distribution of Protons Emitted Backward in the Interaction of 640 MeV Protons with Nuclei

The inclusive cross sections of protons emitted with energies from 60 to 145 MeV in the bombardment of ^{12}C by 640 MeV protons have been measured for seven laboratory angles from 105° to 160°. Under the same conditions proton spectra have been studied at 140° by using Be , Al , Cu and Pb targets. The behaviour of the structure function $E\sigma_t^{-1} \cdot d\sigma/d^3p$ at intermediate energies is discussed.

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

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The investigation of high energy hadron-nucleus reactions has shown that the inclusive particle spectra extend to essentially higher energies than predicted by the kinematics of free hadron-nucleon interaction. It is supposed that information on the short range correlation between nucleons [1] or on high momentum components of the wave function of the nucleus (see, e.g., ref. [2]) may be obtained from such spectra. The investigation of inclusive production of protons emitted in the backward hemisphere with energies higher than 30 MeV are of special interest. In fact the common interpretation of proton emission in the forward hemisphere cannot reflect the features of backward emission. So, the cascade model in its usual form is unable to describe the high energy component in the spectra of backward emitted protons. For incident energies lower than 100 MeV the description is possible only by taking into account the pre-equilibrium decay of highly excited intermediate states [3].

As already established in ref. [4], the inclusive spectra in the backward direction show the following peculiarities. The differential cross section in the relativistic invariant representation

$$f = E/(\sigma_t \cdot p^2) \cdot d^2\sigma/(d\Omega\, dp) \qquad (1)$$

is well reproduced by the dependence

$$f = A_0 \exp(-A_1 p^2), \qquad (2)$$

where f is the so-called structure function, σ_t is the total cross section (or the total inelastic cross section) of the hadron-nucleus interaction and $d^2\sigma/(d\Omega\, dp)$ is the inclusive differential cross section of the production of particles with a momentum p and a total energy E. The parameters A_0 and A_1 depend only weakly on the kind and the energy of incident hadrons as well as on the mass number A of target nuclei.

Here a question arises to which extent the function f may be accepted to be a universal one. At present the experimental data are very fragmentary, especially in the range of medium incident energies. Only recently cross sections for the production of p, d and t were measured at 180° in the proton-nucleus interaction at 600 MeV and 800 MeV [5]. The present paper concerns a measurement of the angular dependence of the differential cross section for the backward emission of protons from the interaction of 640 MeV protons with carbon nuclei.

Protons from 60 to 145 MeV were detected at seven angles from 105° to 160° with respect to the proton beam of the Dubna synchrocyclotron. A scintillation counter telescope measured the energy loss ΔT, the residual energy T and rejected particles

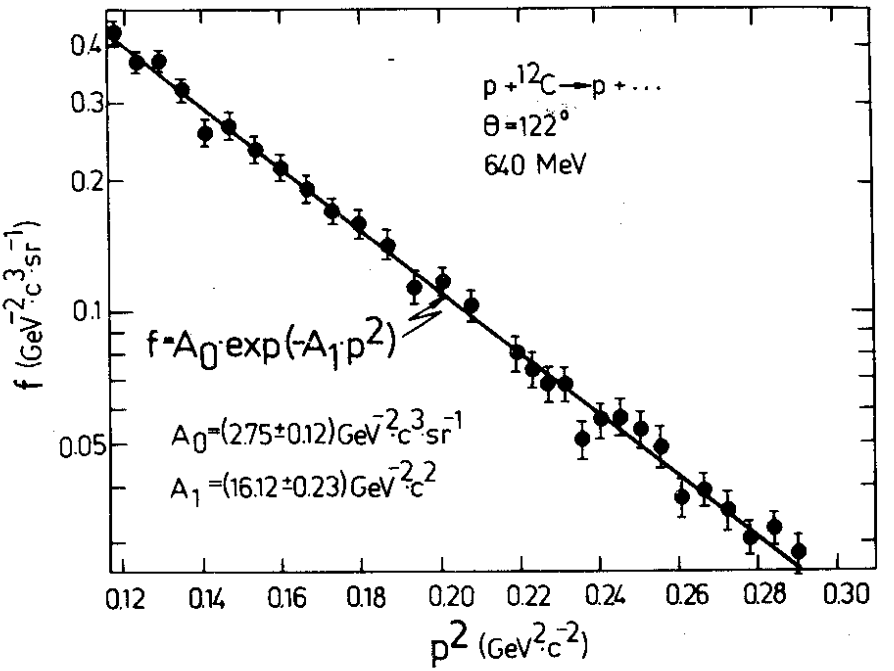

Fig. 1. Structure function f for an inclusive proton spectrum.

which passed through the T counter by an anticoincidence counter. The energy resolution amounted to about 10% and the solid angle to 0.1 sr. The differential cross sections were extracted by using a full Monte Carlo simulation. A typical energy spectrum is shown in fig. 1.

The measured spectra in representation (1) are fairly well described by function (2) for all the angles (see table 1). Here and below the total cross sections σ_t

Table 1

Angular dependences of the parameters A_0 and A_1 and the integral I, i.e., the cross section integrated from 60 to 145 MeV

θ degrees	A_0 $GeV^{-2}c^3\,sr^{-1}$	A_1 $GeV^{-2}c^2$	χ^2/f	I mb sr^{-1}
105	2.79±0.12	13.03±0.22	0.64	2.824±0.034
115	3.27±0.15	15.80±0.23	0.74	2.036±0.026
122	2.75±0.12	16.12±0.23	0.64	1.617±0.019
130	2.94±0.15	17.42±0.28	1.28	1.390±0.020
140	2.80±0.20	18.06±0.39	1.14	1.185±0.022
150	2.67±0.28	18.93±0.64	1.50	0.977±0.030
160	2.22±0.21	18.16±0.58	1.55	0.925±0.022

have been taken from ref.[6]. The error of absolute calibration amounts up to 15% and influences the parameter A_0 and the integrated cross section I but is not included in the quoted errors. As is also seen from table 1, the slope parameter A_1 of the inclusive cross section in the backward hemisphere increases with increasing angle. The angular dependences $A_0(\theta)$ and $A_1(\theta)$ were approximated by an expansion up to quadratic terms of $\cos\theta$. For A_0 the constant value 2.83±0.10 with $\chi^2/f = 3.1$ may be accepted too. A satisfying description of $A_1(\theta)$ is obtained only, if both the linear and the quadratic terms are included (see table 2). The angular distributions $A_1(\theta)$ were known only for pion-nucleus interactions. They are shown together with the present results in fig. 2. Proton spectra measured in the investigations of pion-production[7] were analysed in the present

Table 2

Fits of the angular dependence of the parameters A_0 and A_1 from table 1 by the expansion $A_i = a + b\cos\theta + c\cos^2\theta\ (i = 0, 1)$

	a	b	c	χ^2/f
A_0/ GeV^{-2} c^{3}sr^{-1}	2.28 ±0.55	-(2.9 ±2.1)	-(3.1 ± 1.8)	2.1
A_1/ GeV^{-2} c^2	8.4±1.0	-(21.4 ±4.0)	-(11.4 ±3.6)	1.8

study and the result is also shown in fig. 2 . For angles $\theta < 90°$ representation (2) holds too. In general the slope parameter $A_1(\theta)$ increases monotonously with increasing angle.

The dependence of the slope parameter A_1 on the incident energy is shown in fig. 3. In the interval from 1 to 10 GeV A_1 still decreases noticeably with increasing energy. The energy dependence of the parameter $A_1' = A_1 p_{max}^2$ is shown in the same figure. There p_{max} is the maximal momentum of a proton emitted at an angle of 140° in the reaction $p + 2N \rightarrow p +$ anything. By introducing the new parameter A_1' structure function (1) may be approximated by $f = A_0 \exp(-A_1' x^2)$ as a function of the relative variable $x = p/p_{max}$. Also the slope parameter A_1' defined in this way changes noticeably with the incident energy up to 10 GeV, as shown in fig. 3.

In order to clarify to which extent approximation (2) is independent on the target mass number A, spectra were measured at 140° with Be , Al , Cu and Pb targets. All

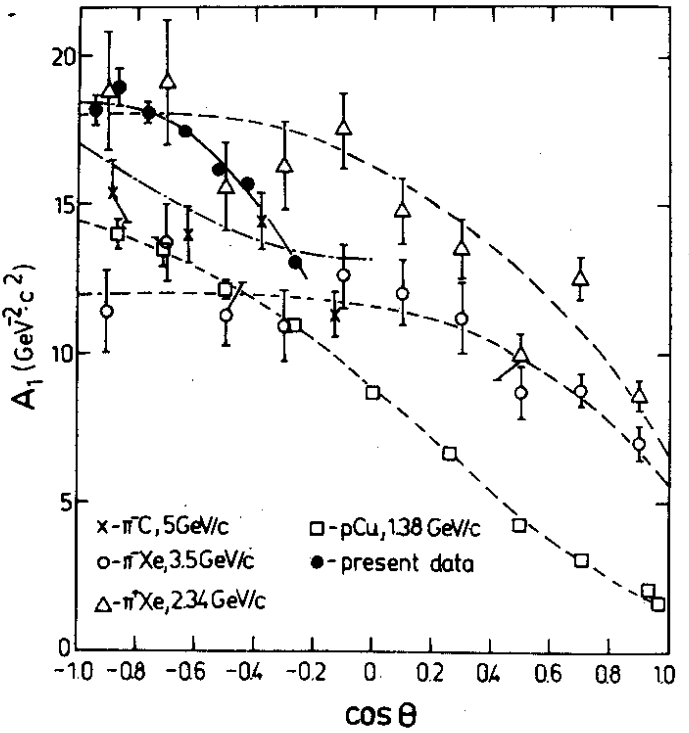

Fig. 2. Angular dependence of the slope parameter A_1 in the hadron-nucleus interactions. The energy intervals of the inclusive protons were 71-225 MeV (□)[7], 47-163 MeV (×)[8], 50-200 MeV (o)[9] and 30-150 MeV (Δ)[10]. Dashed lines are drawn to guide the eye. The full line represents the fit given in table 2. The dashed-dotted line is a fit taken from ref.[8] with $A_1 = a + c \cdot \cos^2\theta$.

of them are again fairly well described by function (2). The parameters A_0 and A_1 depend strongly on A for light nuclei, but weakly for A > 30 (see fig. 4).

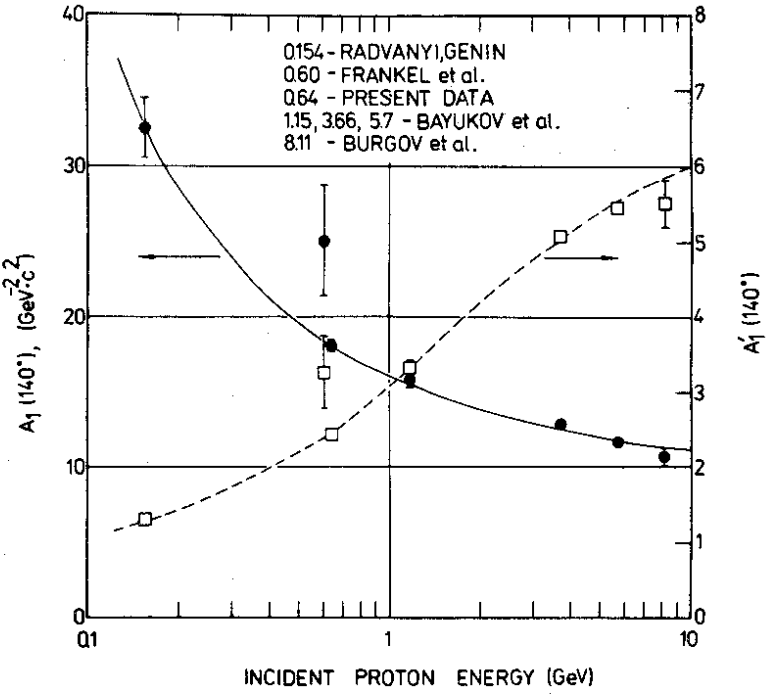

Fig. 3. Dependence of the slope parameters A_1 (•) and A_1' (□) on the incident energy in the reaction $p + {}^{12}C \to p + \ldots$ at 140°. The data of Radvanyi and Genin[11] were recalculated from 120°. The quoted error at 600 MeV contains uncertainties in the extrapolation from 180° and in the recalculation of the data of Frankel et al.[5] from a representation different from eq. (2). The curves are drawn to guide the eye.

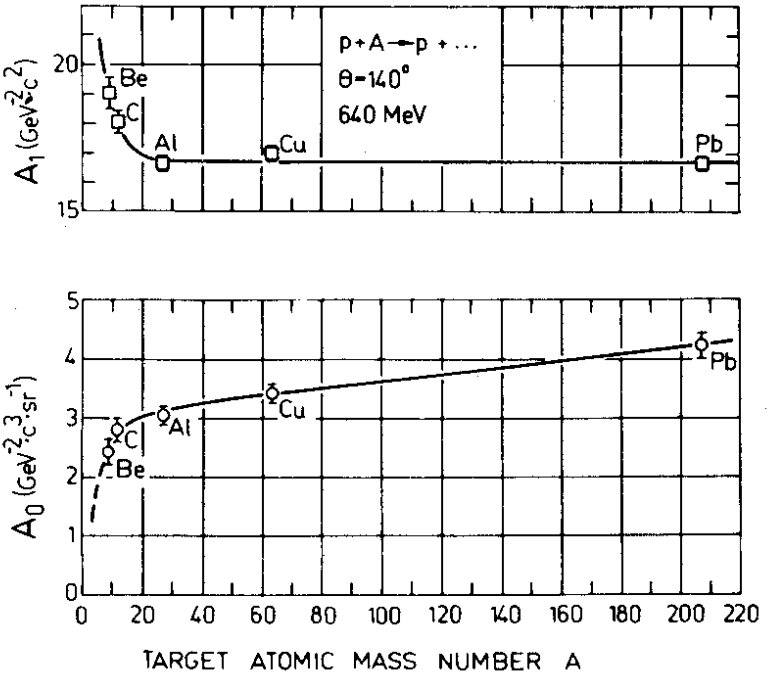

Fig. 4. Dependence of the parameters A_0 and A_1 on the target mass number A.

The only published calculation, ref. [2], on inclusive backward proton production is based on the hypothesis of an exponential course of the nucleon momentum distribution in the nucleus at the momenta of about 0.5 to 1.2 GeV/c. To compare the present data with the calculated ones the values of A_0 and A_1 were extrapolated to 180° using the fits of table 2. The difference in the incident energy (600 MeV-calculation, 640 MeV - present experiment)

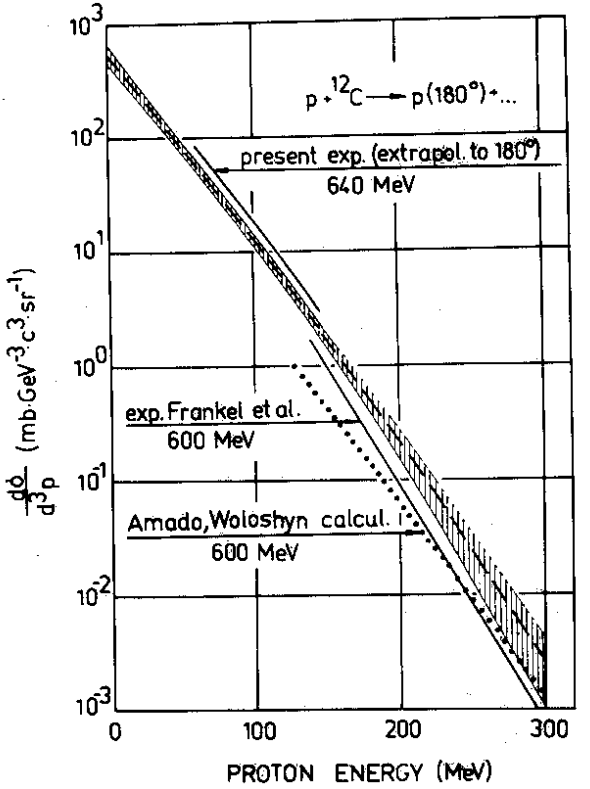

Fig. 5. Comparison of experimental data (the present ones and from ref. /5/) with the calculation in ref. /2/. The present data recalculated for 180° and 600 MeV are shown by the dashed line.

was estimated to lower A_0 by a factor of 0.72. In this way $\tilde{A}_0 = (700 \pm 110)$ mb sr^{-1} GeV^{-2}c^3 were obtained. The dependence

$$d\sigma/d^3p = \tilde{A}_0 E^{-1} \exp(-A_1 p^2) \qquad (3)$$

describes the inclusive proton cross sections in a broad range of energies, as shown in fig. 5, and does not contradict the reasoning given in ref. /2/.

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