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ON THE OBSERVATION OF THE DIRECT REACTION $^{12}C(p, 3p)$ AT AN ENERGY OF 640 MEV

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О наблюдении прямой ядерной реакции $^{12}C(p,3p)$ при энергии 640 МэВ

Методом сцинтилляционной спектрометрии измерен спектр масс частиц, испускаемых назад при квазисвободном выбивании вперед протонных пар из ядра углерода протонами 640 МэВ. Экспериментально показано, что ранее измеренное дифференциальное сечение выбивания вперед двух быстрых протонов, сопровождающееся эмиссией частицы назад, может быть отнесено к прямой реакции типа (p,3p). Зависимость счета тройных совпадений протонов от угла между протонами, выбиваемыми вперед, обнаруживает широкое распределение по относительному импульсу в этой паре.

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On the Onservation of the Direct Reaction $^{12}C(p,3p)$ at an Energy of 640 MeV

The mass spectrum of backward emitted particles has been measured in the quasifree knock-out of a proton pair emitted forward from carbon nuclei at an incident proton energy of 640 MeV. As the experiment shows, the earlier investigated differential cross section for the forward knock-out of two fast protons and the simultaneous backward emission of a light particle can be attributed to the direct reaction of type (p,3p). The dependence of the counting rate of triple coincidences on the angle between the forward knocked out protons indicates a broad distribution of relative momenta within the proton pair.

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

Communication of the Joint Institute for Nuclear Research. Dubna 1978

In ref. /1/ it has been reported on the observation of the knock-out of two fast protons from the nucleus ^{12}C by 640 *MeV* protons at small angles to the beam in coincidence with a backward emitted proton. The conditions for the particle detection in ref. /1/ were chosen in accordance with the kinematics of the quasifree scattering of an incident proton on two protons in the nucleus at the lab. angle $\gamma_3 = 122°$ (see *fig. 1*). For the angles

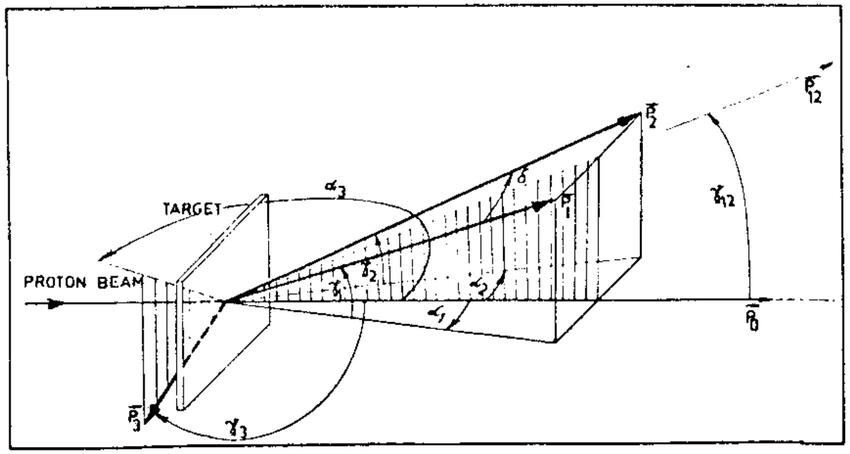

Fig. 1. Geometrical conditions of the experiments. $\vec{P}_1$, $\vec{P}_2$, $\vec{P}_3$ *are momenta of the detected protons in the final state of the reaction.* γ_i *are angles between the momenta* $\vec{P}_i$ *and their projection into the horizontal plane determined by the beam.*

$\alpha_1 = \alpha_2 = 9°$, $\gamma_1 = \gamma_2 = 12°$, and $\alpha_3 = 180°$ it follows from the kinematics of the scattering

$$p_0 + [2p] \rightarrow p_1 + p_2 + p_3 \quad (1)$$

that the energies of both forward emitted protons are $T1 = T2 = 270$ *MeV* and that the backward emitted proton has the energy $T3 = 72$ *MeV* if the Fermi-motion is neglected. Therefore, in the experiment of ref./1/ the differential cross section for the emission of three protons was measured on the conditions given in *table 1*. The forward emitted protons were definitely identified, but the appearance of backward emitted particles heavier than protons such as deuterons with $T_d > 20$ *MeV*, tritons with $T_t > 24$ *MeV*, ^3He with $T_{^3He} > 53$ *MeV*, and ^4He with $T_\alpha > 59$ *MeV* could not be excluded.

There is an experimental evidence for such light fragments only in inclusive measurements (see, e.g., ref./2/). The appearance of deuterons in the inclusive spectra is treated in ref./3/ as the pick-up of a neutron by the backward scattered proton inside the same nucleus. That could happen after process (1) too. Light fragments

Table 1

Conditions for the detection of three protons in the experiment of ref./1/. Forward telescopes 1 and 2 are identical.

Telescope	Energies/MeV	Angles/deg.			
		α_i	$\Delta\alpha_i$ a)	γ_i	$\Delta\gamma_i$ a)
1,2	$260 < T_i < 335$	9	±4	12	±4
3	$32 < T3 < 98$	180	±31	122	±31

a) $\Delta\alpha_i$ and $\Delta\gamma_i$ mean the aperture of the i- th telescope.

Table 2

Conditions for the present experiment. Compare *table 1*.

Telescope	Energies/MeV	Angles/deg.			
		α_i	$\Delta\alpha_i$	γ_i	$\Delta\gamma_i$
1,2	$235 < Ti < 310$	a)	±4	12	±4
3	T3 = 35 ... 105	180	±29	122	±29

a) $\alpha_1 = \alpha_2$ were varied from 7.5° up to 32.1° (see *fig. 3*).

could originate also in the reaction $^{12}C(p,2p)^{11}B^*$ by the following decay of the highly excited states of ^{11}B. Although such an emission should be less intensive than the proton one, the actual ratio of backward emitted protons to heavier fragments for the process of forward knocked out proton pair production must be measured.

For this purpose the third scintillation counter telescope (see ref./1,4/) was improved to determine the energy loss of backward emitted particles in the first counter and the residual energy in the second one. (The $(\Delta T, T)$-spectrometer was successfully used already in the investigation of inclusive proton spectra in ref./5/). As is shown in *table 2*, the experimental conditions in the present investigation are very close to those of ref./1/. In the following the results of the first data analysis are shown and discussed.

The measured mass spectrum of the backward emitted particles is shown in *fig. 2*. The mass scale is arbitrarily normalized to give mass channel 64 for protons in case of the correct energy calibration of both counters in the $(\Delta T, T)$ -spectrometer. The spectrum includes all events measured at different angles $\alpha_1 = \alpha_2$ for the forward knocked out proton pair. The negative channel contents

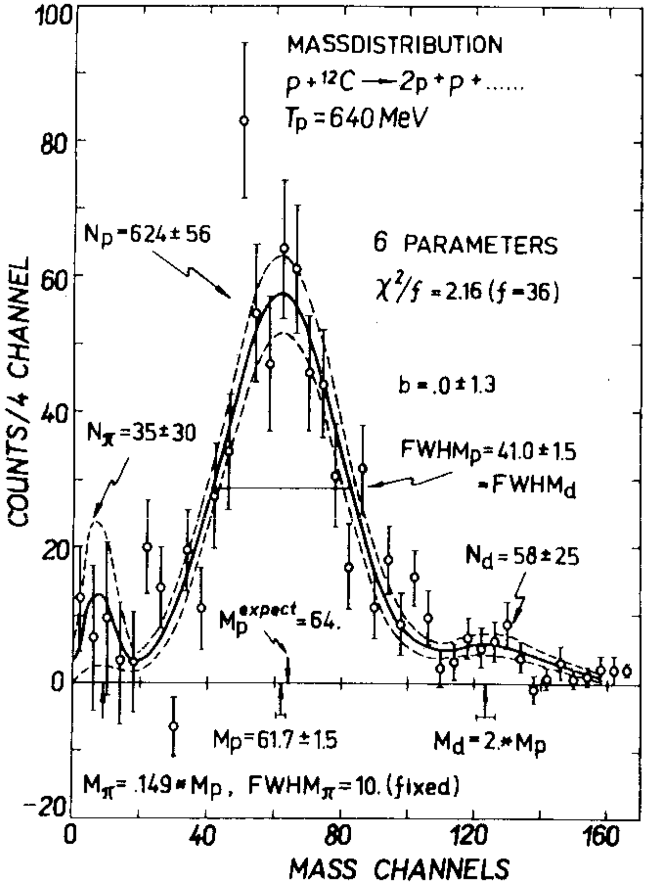

Fig. 2. Experimental mass spectrum of the backward emitted particles in coincidence with a forward emitted proton pair. The curve shows fit number 6 of table 3 by expression (2).

arise from the subtraction of the accidental coincidence background (for the procedure see ref. [4]).

The experimental mass distribution $n(M)$ was fitted by the expression

$$n(M) = \frac{C}{\sqrt{\pi}} \left\{ \frac{N_\pi}{FWHM_\pi} \exp\left[-\left(C\,\frac{M-M_\pi}{FWHM_\pi}\right)^2\right] + \frac{N_p}{FWHM_p} \exp\left[-\left(C\,\frac{M-M_p}{FWHM_p}\right)^2\right] + \frac{N_d}{FWHM_d} \exp\left[-\left(C\,\frac{M-M_d}{FWHM_d}\right)^2\right]\right\} + b\,\exp(-M/\mu) \qquad (2)$$

with $C = 2\sqrt{\ln(2)}$. Besides the three Gaussians for pions, protons and deuterons, the exponential term is included for taking into account a possible low background. The numbers of pions, protons and deuterons N_π, N_p, N_d, the intensity b of the background, the proton peak position M_p, and the $FWHM_p$ in expression (2) were taken as free parame-

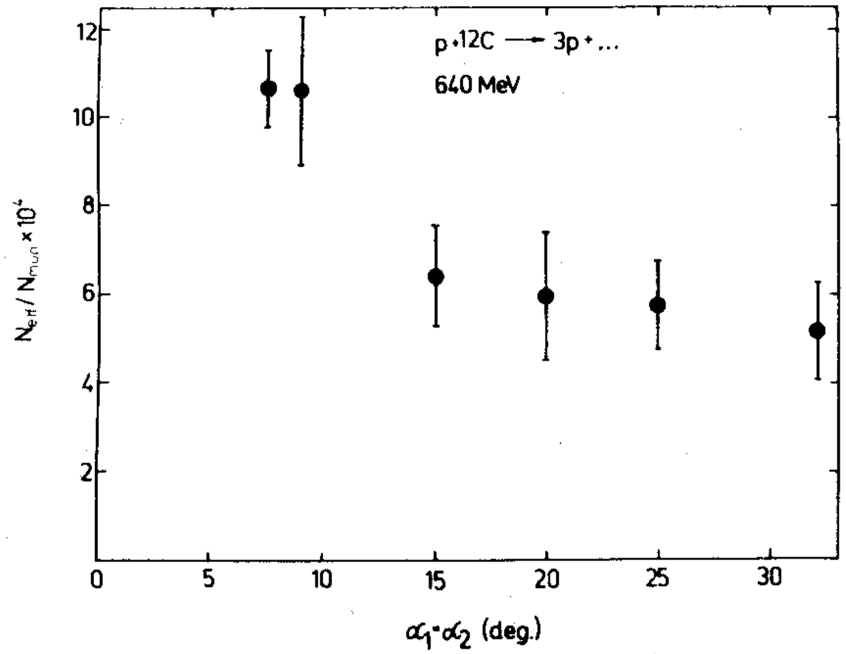

Fig. 3. Dependence of the number of triple proton coincidences in the reaction $^{12}C(p,3p)$ *on the angles* $\alpha_1 = \alpha_2$.

Table 3

Results of different fits of the experimental mass spectrum in *fig. 2* by the expression (2). For fits 1 to 5 were used $FWHM_\pi = .344\,FWHM_p$ and $FWHM_d = 1.54\,FWHM_p$. For fit 6 (see *fig. 2*) $FWHM_\pi = 10$ channels and $FWHM_d = FWHM_p$ were taken.

Fit Nr	N_π	N_p	N_d	M_p a)	$FWHM_p$ a)	β b)	μ a)	χ^2/f
1	40±34	607± 57	79±41	61.4±1.2	38.5±3.5	.0±1.6	∞	2.22
2	44±39	613± 75	74±49	61.1±1.6	38.8±3.9	.0±4.7	160/1	2.18
3	90±77	693±141	106±75	60.2±2.5	42.8±6.0	.0±15.	160/2	3.15
4	31±53	585± 88	52±28	61.4±1.9	37.6±4.4	.7±11.	160/3	2.09
5	19±51	571± 71	51±21	61.5±1.8	36.6±3.9	4.±11.	160/4	2.08
6	35±30	624± 56	58±25	61.7±1.5	41. ±1.5	.0±1.3	∞	2.16

a) In units of mass channels.
b) In units of counts/channel.

ters. The positions M_π and M_d of the pion and deuteron peaks were related to M_p by their known mass ratios. The widths for pions and deuterons were taken to be proportional to the proton width $FWHM_p$. The ratios of the widths were evaluated by a Monte-Carlo simulation.

Some results with different values of the parameter μ in the last term of expression (2) and of a fit with changed $FWHM_\pi$ and $FWHM_d$ values are shown in *table 3*. These different conditions for the fits do not influence both the values of N_p and N_d within their errors. (Fit number 6 of *table 3* is shown in *fig. 2*).

The proton peak dominates in all the fits and is actually situated near channel 64. About 94% of all events are doubtless protons. The nuclei heavier than protons give rather a small contribution to the mass spectrum. Deuterons still appear with a statistical confidence of about 90%, whereas heavier fragments are not observed at a level of about 1% of the proton quantity. Therefore, the differential cross section reported in ref. /1/ in fact can be attributed to the (p,3p) reaction.

The number of triple proton coincidences from the reaction (p,3p) on the conditions presented in *table 2* is shown in *fig. 3* versus the angles $\alpha_1 = \alpha_2$ of the forward knocked out proton pair. The number of coincidences decreases only weekly from 7.5° to 32.1°. This range of angles corresponds to a change of the relative momentum Δ_{12} between the protons in the knocked out proton pair in its center of mass system from 200 to 730 *MeV/c* and to a range of invariant mass $M_{12}^{eff} c^2$ from 1887 to 2013 *MeV*. That means that the backward emission of protons takes place with a wide distribution of the relative momenta between the nucleons of the knocked out proton pair. This result is incompatible with the model for the backward emission of protons by a simple quasielastic scattering of the incoming proton on a correlated cluster, which is not destroyed in the interaction (see ref. /6/). Besides the quasielastic backward scattering of the protons, which give rise to the forward knock-out of bound particles such as d , t , ^3He and ^4He (see ref. /7/), there is further backward emission of the protons together with forward outgoing nucleons, which have a high relative momentum in their center of mass system.

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