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Stopped pion absorption on pp- and ^{3,4}He-clusters

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Abstract

Results on the research of spectra and yields of p, d, t formed in the reaction of stopped pion absorption by atomic nuclei are presented. Unique data on charged particle formation on 17 isotopes have been obtained in wide mass range (6 < A < 209). Empirical model is proposed that allows to describe A-dependence of primary proton yields (with 10-15% precision) and to estimate the ratio of the elementary widths of pion absorption on pn and pp pairs R' = 3.3±0.5.

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Keywords: pions; intermediate energies; absorption; protons; model

1. Introduction

Studies on spectra and yields of charged particles formed in the reaction of stopped pion absorption by nuclei allow improving our understanding of mechanisms of particle production in nuclear reactions at the intermediate energies (up to 1 GeV).

Several experimental works are dedicated to measure the energy spectra of particles produced in stopped pion absorption [1–9]. Nevertheless, the results of these works do not allow to obtain systematical set of data. Spectra measured in different works are extremely different. The high-energy part of spectra is of great interest because of its connection with primary particles, but results of such measurements are in contradiction.

In this paper the spectra and the yields of charged particles formed in the reaction are analyzed using the unique data set obtained in the experiment that was carried out on the PNPI RAS accelerator. Our phenomenological model

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[10] is applied to estimate the contributions of primary p, d, t particles. Obtained results allow to evaluate the ratio of the elementary widths of pion absorption on pn and pp pairs in the range of mass numbers 6 < A < 209.

2. Experiment

The experiment has been carried out on the pion channel of the PNPI RAS synchrocyclotron using the charged particle semiconductor spectrometer [11].

The pion beam with the momentum of 100 MeV/c passed through the carbon decelerator and two monitor surface-barrier Si(Au) detectors and then stopped in the 440 μm target that was installed on 45o angle with respect to the beam axis. Charged particles produced in the stopped pion absorption were registered by two multilayer telescopes. Taking into account the expected losses in non-sensitive layers, particle energies were evaluated as the sum of the energy losses in the detectors. The energy resolution was 0.6 MeV. Parameters of the monitor system were obtained using "living target" - Si detector with the equivalent thickness installed instead of the target). This allowed to reach high value of spectra normalization precision – 7% during all the experiment. Energy spectra of p (d, t) were measured in the range from 5 MeV (10 MeV) up to the kinematic thresholds of reactions. The stopped pion absorption by ^{6,7}Li, ^{9}Be, ^{10,11}B, ^{12}C, ^{28}Si, ^{40}Ca, ^{59}Co, ^{93}Nb, ^{114,117,120,124}Sn, ^{169}Tm, ^{181}Ta, ^{209}Bi nuclei was studied.

3. Model

For example, spectra of p, d, t emitted in stopped pion absorption on ^{12}C are shown on the Fig. 1.

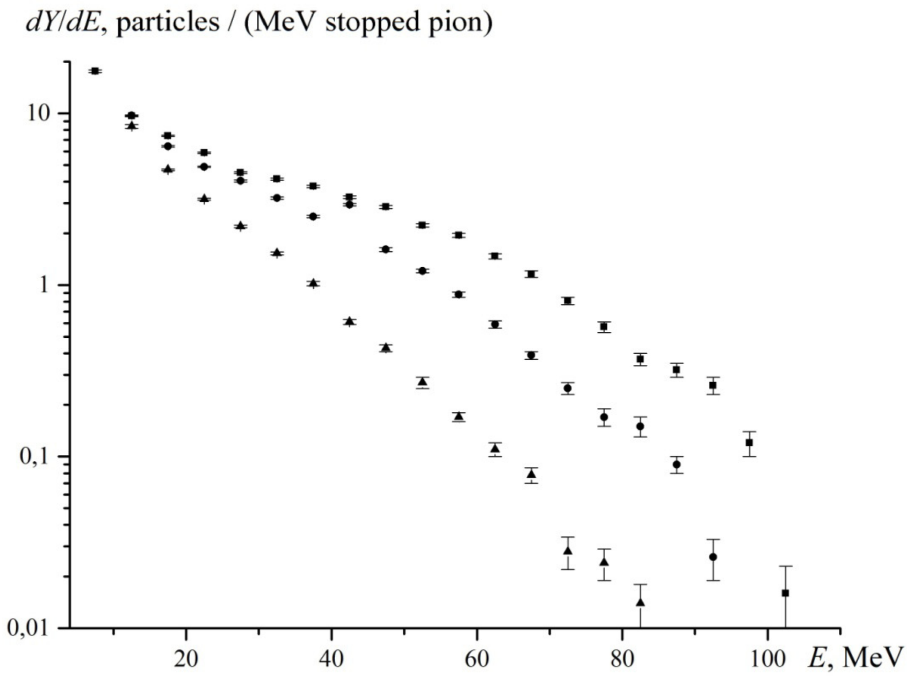

Fig. 1. Spectra of p (squares), d (circles), t (triangles) emitted in stopped pion absorption on ^{12}C nuclei.

Shapes of the most of the spectra are similar to the presented one.

The exceptions are the spectra of tritons produced in the pion absorption on the ^{6,7}Li and ^{9}Be nuclei: there is a distinctive peak associated with pion alpha-absorption in the energy range of 30 ÷ 40 MeV.

In order to analyze spectra we developed the phenomenological model [10] taking considering the charged particle formation during three stages of the reaction:

$$\left(\frac{dY}{dE}\right)_{full} = \left(\frac{dY}{dE}\right)_{prime} + \left(\frac{dY}{dE}\right)_{neq} + \left(\frac{dY}{dE}\right)_{ev} \quad (1),$$

where "prime" part is the spectrum of primary p (d, t) emitted in pion absorption on intranuclear cluster pp (^{3,4}He); "neq" — the spectrum of preequilibrium particles formed during the intranuclear cascade; "ev" — the spectrum of particles emitted during the process of evaporation from the nuclear surface after the thermodynamical equilibrium has been established in the nucleus.

The model allowed to describe all measured p, d, t spectra successfully ($\chi^2/n \approx 1$, where n is the number of degrees of freedom). For example, the description of the spectrum of protons formed in pion absorption on ^{28}Si is shown on Fig. 2.

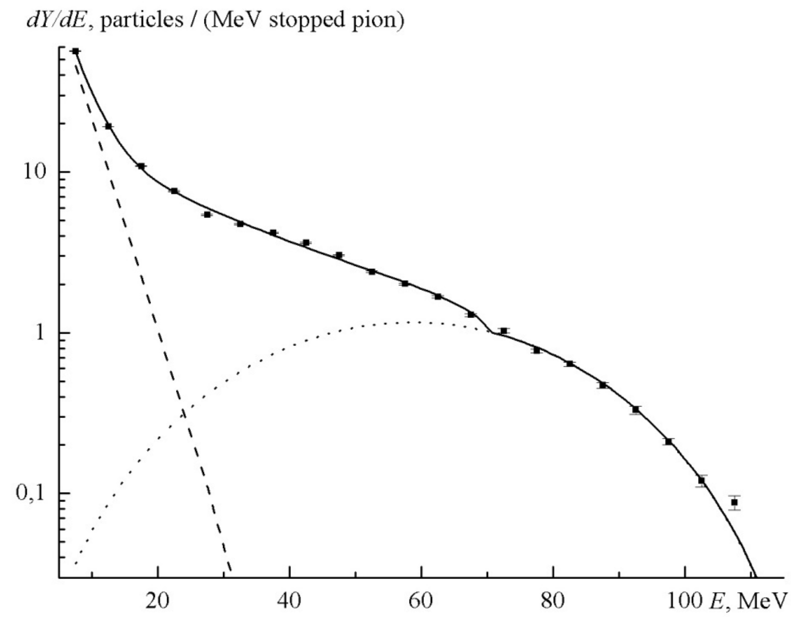

Fig. 2. Spectrum of protons produced in pion absorption by ^{28}Si. The solid line – full description, dashed line – evaporative part, dash-dot line – primary part

4. Analysis

The estimation of different contributions in the spectra of charged particles allows to estimate the total amount of particles formed in all stages (partial yields):

$$Y = \int_{E_{min}}^{E_{max}} \frac{dY}{dE} dE \qquad (2)$$

We obtained that the contribution of protons emitted directly from the pion absorption on pp-pairs is 20% from the total yield in average. The contribution of the pion absorption on the ^{3}He cluster in total yield of the deuterons is 20%. The contribution of particles formed in the pion absorption on ^{4}He is 5% from the total triton yield.

Obtained results are used to develop a model in order to describe the primary proton yields and to calculate these values in reactions of the pion absorption on nuclei with any A, Z.

We assume that the value of the yield Y^p_{prime} is proportional to the probability of the pion absorption on pp-pair [12 – 14] and thus can be described as follows:

$$Y^p_{prime} = C_p \cdot \frac{\exp(-\beta_p \cdot A^{1/6})}{1 + 2N \cdot R'/(Z-1)} \qquad (3),$$

where C_p, β_p – parameters which are independent on A, Z, N; R' – ratio of the ratio of the elementary widths of pion absorption on pn and pp pairs; $\exp(-\beta_p A^{1/6})$ – the probability of the primary proton leaving nucleus without further interactions.

In Fig. 3 the results of calculations using formula (3) are compared to Y^p_{prime} with $\beta_p = 0.5$ и $C_p = 0.14$.

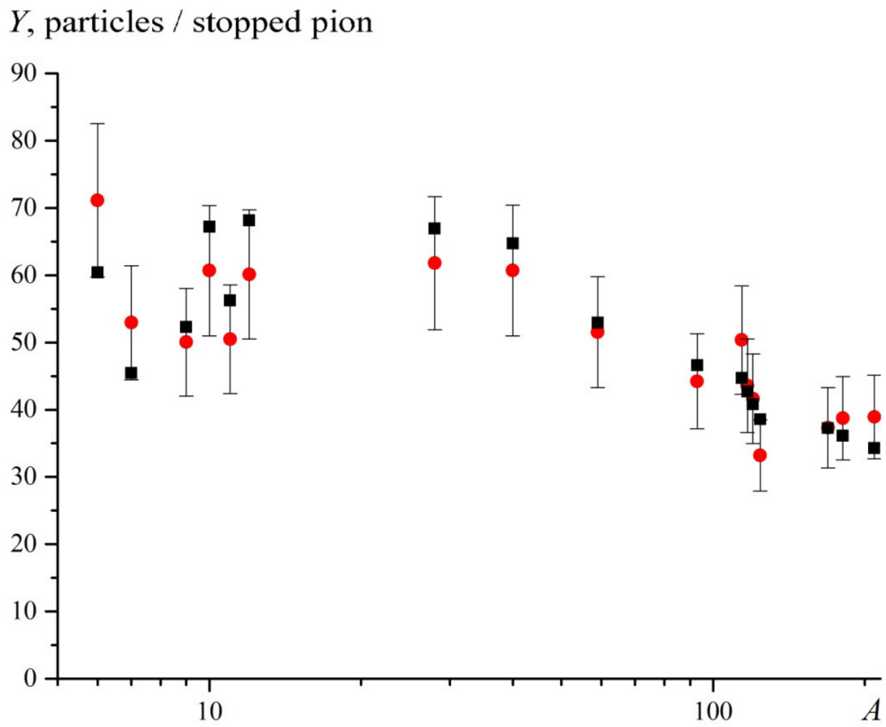

Fig. 3. Proton yields: circles — primary part (1), squares — calculations via (3)

The values of these parameters are chosen to achieve the best agreement with the data. The empirical formula (3) reproduces well the A-dependence of the primary proton yields throughout all the studied range of mass numbers with the error about 15%.

We obtained the value of the parameter R' = 3.3 ± 0.5. This result is in a good agreement with work [15] where authors analyzed the inclusive and correlation measurements of spectra of protons produced in pion absorption on ^{9}Be, ^{12}C, ^{28}Si, Cu and Ge.

5. Conclusions

It is shown that the contribution of pp-, ^{3}He-, ^{4}He-cluster absorption in p, d, t formation is 20%, 20%, 5% respectively. A-dependence of the primary proton yields is successfully described in the range of mass numbers $6 < A < 209$ using the developed phenomenological model. Based on the obtained result, the ratio of the ratio of the elementary widths of pion absorption on pn and pp pairs was estimated as R' = 3.3 ± 0.5.

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