

## Yields of p, d, t formed in stopped pion absorption by intranuclear clusters

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**Abstract.** Results of the study of spectra and yields of p, d, t formed in stopped pion absorption by nuclei are presented. Data on charged particle formation have been obtained for 17 isotopes in wide atomic mass range ( $6 < A < 209$ ). Empirical model was proposed to describe A-dependences of primary p, d, t yields.

### 1. Introduction

Study of charged particle formation in the reaction of stopped pion absorption by nuclei allows to gain insight into mechanisms of particle production in nuclear reactions at the intermediate energies (up to 1 GeV) as well as understanding of cluster structures of nuclei. Because of energy and momentum conservation, pion absorption is multinucleon process. The particles formed in such processes are referred to as “primary” ones and their spectra and yields may be connected to properties of intranuclear structures. Therefore A-dependences of yields of the primary particles are of great interest.

Energy spectra of particles produced in this reaction were measured in many experimental works [1-9]. Nevertheless, these results cannot be used to obtain systematic set of data because of significant differences in the absolute normalization, especially in the high-energy region ( $E > 70$  MeV), which is known to be populated mostly by primary particles.

In this work the yields of charged particles p, d, t are analyzed using the unique set of data. These data were obtained in the PNPI RAS experiment. Phenomenological model [10] was applied to estimate the contributions of primary particles.

### 2. Experiment details

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

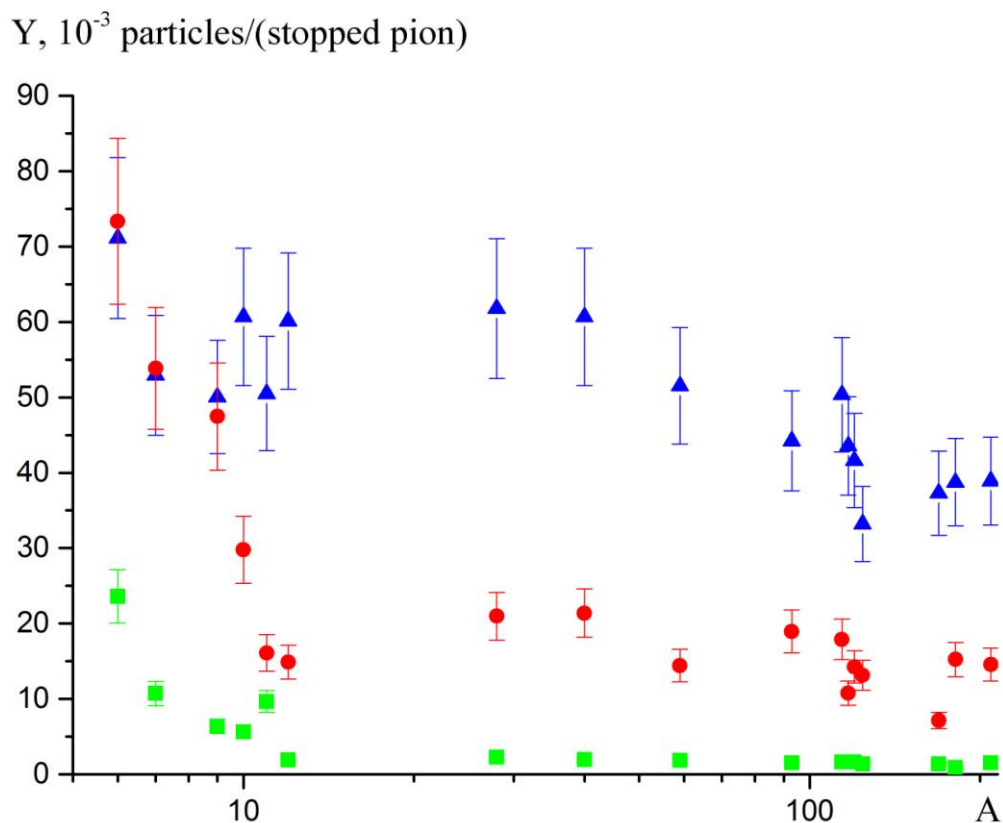
The pion beam with the momentum of 100 MeV/c passed through the carbon moderator and two monitor surface-barrier Si(Au) detectors and then stopped in the 440  $\mu\text{m}$  thick target installed on 45° angle with respect to the beam axis. Charged particles produced by absorption in the target were detected by two multilayer telescopes. The energy resolution was 0.6 MeV. Application of the “active target” method [10] permitted high precision of the spectra normalization – 7% throughout the experiment. The energy spectra of p (d, t) were measured in the range from 5 MeV (10 MeV) to the kinematic thresholds of reactions. The measurements were carried out on large set of target  ${}^6\text{Li}$ ,  ${}^9\text{Be}$ ,



$^{10,11}\text{B}$ ,  $^{12}\text{C}$ ,  $^{28}\text{Si}$ ,  $^{40}\text{Ca}$ ,  $^{59}\text{Co}$ ,  $^{93}\text{Nb}$ ,  $^{114,117,120,124}\text{Sn}$ ,  $^{169}\text{Tm}$ ,  $^{181}\text{Ta}$ ,  $^{209}\text{Bi}$ .

### 3. Results and analysis

The measured spectra showed similar smooth declining form [10]. The exceptions were triton spectra measured on light nuclei, where there is a distinct peak possibly connected to pion absorption by alpha-clusters. All spectra were successfully described using our phenomenological model [10]. It then allowed to estimate contributions of different processes in the total particle formation and thus to calculate corresponding yields for each of studied nuclei. These results were used to obtain A-dependences of yields of primary particles, which are presented in the figure 1 for p, d and t.



**Figure 1.** Yields of primary p ( $\blacktriangle$ ), d ( $\bullet$ ), t ( $\blacksquare$ ).

The yields are used to develop a set of expressions in order to describe the yields of the primary particles. The empirical relations can then be used as a generalization of our results on the entire mass number region.

We assume that the value of the yield  $Y_{prime}^p$  is proportional to the probability of the pion absorption on pp-pair [12 – 14]. Thus, assuming that absorption by heavier clusters is insignificant, A-dependence can be described as follows:

$$Y_{prime}^p = C_p \cdot \frac{\exp(-\beta_p \cdot A^{1/6})}{1 + 2N \cdot R'/(Z-1)}, \quad (1)$$

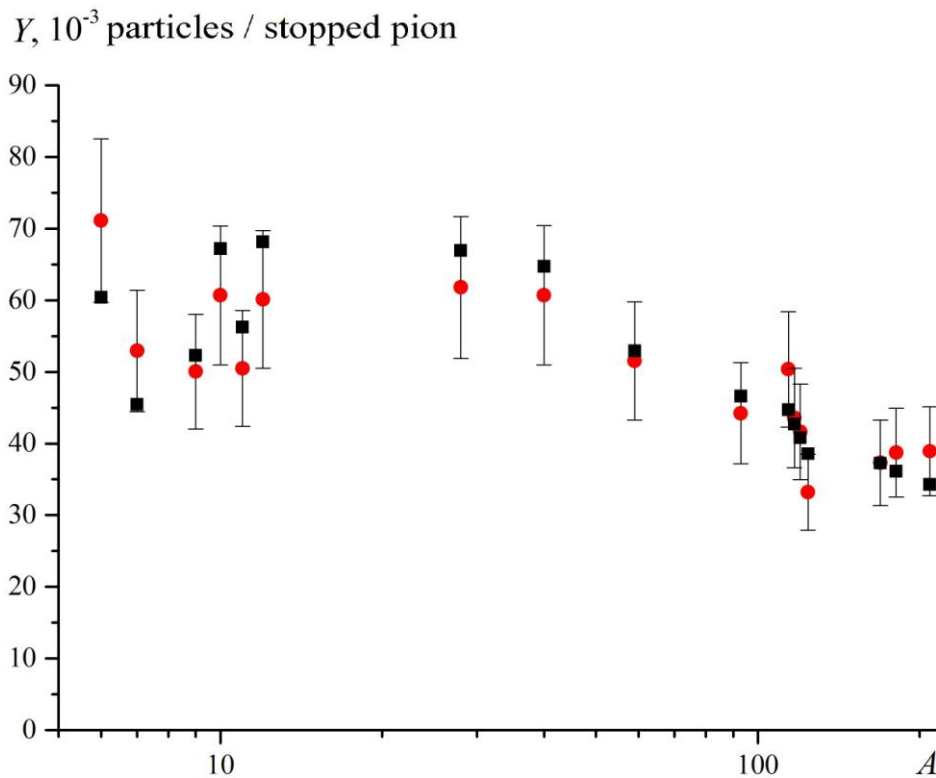
where  $C_p$  – free parameter.

$R'$  is the ratio of the elementary widths of the pion absorption on pn and pp pairs. We supposed it to be independent of parameters of the target nucleus in the range  $6 < A < 209$ .

The factor  $\exp(-\beta_p A^{1/6})$  is the probability for the primary particle to leave nucleus without interactions, where  $\beta_p$  is a parameter dependent only on the type of primary particle.

In figure 2 the results of calculations using relation (1) are compared to primary proton yields with  $\beta_p = 0.5$  и  $C_p = 0.14$ . The values of these parameters are chosen to achieve the best agreement with the data. The empirical expression (1) reproduces well the A-dependence of the primary proton yields throughout all the studied range of mass numbers with the error  $\sim 15\%$ . The value of the ratio of the elementary widths is  $R' = 3.3 \pm 0.5$ . 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  $^9\text{Be}$ ,  $^{12}\text{C}$ ,  $^{28}\text{Si}$ , Cu and Ge.

Such result provides an estimation of important physical parameter  $R'$  and allows to determine the yields of primary protons in the reaction of pion absorption on any nucleus.



**Figure 2.** Proton yields: ● — primary part, ■ — calculations via (1).

Similar method is used to derive expressions for d and t A-dependences of yields of d and t. Probability of the primary d or t leaving the nucleus without further interactions is taken in the similar exponential form with  $\beta$  parameter chosen separately for each particle type. The estimation of the probability of pion absorption on corresponding clusters ( $^3\text{He}$ ,  $^4\text{He}$ ) is much more complicated than in the case of protons, so simple empirical expressions were chosen which provided the best agreement with the data. Expressions for d and t yields are:

$$Y_{pr}^d = C_d \frac{Z(Z-1)N}{A-3} \exp(-\beta_d A^{1/6}), \quad (2)$$

$$Y_{pr}^t = C_t \frac{Z(Z-1)N(N-1)}{(A-4)^2} \exp(-\beta_t A^{1/6}). \quad (3)$$

These relations reproduce primary d and t yields with ~15% precision, but only for medium and heavy nuclei from the mass number range of  $28 < A < 209$ . For the light nuclei satisfactory description was not obtained, possibly because of their complex cluster structure.

#### 4. Conclusions

A-dependences of the yields of the primary p, d and t were described with an accuracy of ~ 15% over the wide range of mass numbers:  $6 < A < 209$  for protons,  $28 < A < 209$  for deuterons and tritons.

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