

## Search for exotic cluster configurations in $^{14}\text{C}$ nucleus

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**Abstract.** The analysis of 2-dimensional Dalitz' diagram, measured in  $^{14}\text{C}(\pi^-, \text{pd})\text{X}$  reaction, allowed to distinguish the pion absorption by  $^3\text{p}$  intranuclear cluster and to obtain an indication on the existence of  $^3\text{p} + ^{11}\text{Li}$  configuration in  $^{14}\text{C}$  nucleus. Highly excited states of  $^{12,13}\text{Be}$  isotopes were found with the energy of  $E_x \approx 30$  MeV for the first time. It was shown that these states decay as follows  $^{12}\text{Be}^* \rightarrow \text{p} + ^{11}\text{Li}$  and  $^{13}\text{Be}^* \rightarrow \text{d} + ^{11}\text{Li}$ .

### 1. Introduction

Carbon isotope  $^{14}\text{C}$  is of interest for the study of light neutron-rich nuclei. The Antisymmetrized Molecular Dynamics (AMD) model predicts  $^{14}\text{C}_{\text{g.s.}}$  to be a system of “ $3\alpha + 2n$ ” [1]. This structure manifests itself as a triangle of alpha particles and neutrons between [2]. Information about the structure of  $^{14}\text{C}$  is also important in studies for the heavier carbon isotopes;  $^{14}\text{C}$  is “core” for them [3].

Stopped pion absorption is a multinucleon process, so this reaction is useful in order to search clusters in nuclei. In this paper, we look for indications of the existence of “ $^3\text{p} + ^{11}\text{Li}$ ” configuration in the ground state of  $^{14}\text{C}_{\text{g.s.}}$ . For this purpose, we performed the analysis of the results of correlation measurements of  $^{14}\text{C}(\pi^-, \text{pd})\text{X}$  reaction. The search method is based on the allocation of the events of quasi-free pion absorption by intranuclear cluster  $^3\text{p}$  ( $\pi^- + ^3\text{p} \rightarrow \text{p} + \text{d}$ ), where the residual nucleus  $^{11}\text{Li}$  is a “spectator”. Earlier, this method allowed to obtain indications on the existence of “ $^3\text{He} + ^6\text{He}$ ” configuration in  $^9\text{Be}$  [4] and “ $^5\text{Li} + ^6\text{He}$ ” - in  $^{11}\text{B}$  [5].

Analysis of the inclusive measurements of  $^{14}\text{C}(\pi^-, \text{p})\text{X}$  and  $^{14}\text{C}(\pi^-, \text{d})\text{X}$  allows to search for highly excited states of the beryllium isotopes  $^{12,13}\text{Be}$ . Information about these states is of interest in studies of cluster resonances and its decays, as well as of the deformation of nuclear systems. Research of cascade channels of pion absorption  $\pi^- + ^{14}\text{C} \rightarrow \text{d} + ^{12}\text{Be}^* \rightarrow \text{d} + \text{p} + ^{11}\text{Li}$  and  $\pi^- + ^{14}\text{C} \rightarrow \text{p} + ^{13}\text{Be}^* \rightarrow \text{p} + \text{d} + ^{11}\text{Li}$  can provide data on excited levels and rare cluster decays of  $^{12,13}\text{Be}$ . Earlier, we used this method to found lithium decay modes  $^8\text{Li} \rightarrow \text{t} + ^5\text{He}$  [6] and  $^9\text{Li} \rightarrow \text{t} + ^6\text{He}$  [7].

### 2. Search for “ $^3\text{p} + ^{11}\text{Li}$ ” configuration in $^{14}\text{C}$ nucleus

Search for “ $^3\text{p} + ^{11}\text{Li}$ ” configuration was carried out in the correlation measurements of  $^{14}\text{C}(\pi^-, \text{pd})\text{X}$  reaction. Results were obtained with a beam of low energy  $\pi^-$ -mesons (LEP) using two-arm semiconductor spectrometer [8]. The contribution of the impurity  $^{12}\text{C}$  in  $^{14}\text{C}$  target was subtracted, using the procedure described in [9]. This method is based on measurements of  $^{12}\text{C}(\pi^-, \text{pd})\text{X}$  obtained in the same experimental run. The data obtained are presented in figure 1 as 2-dimensional distribution



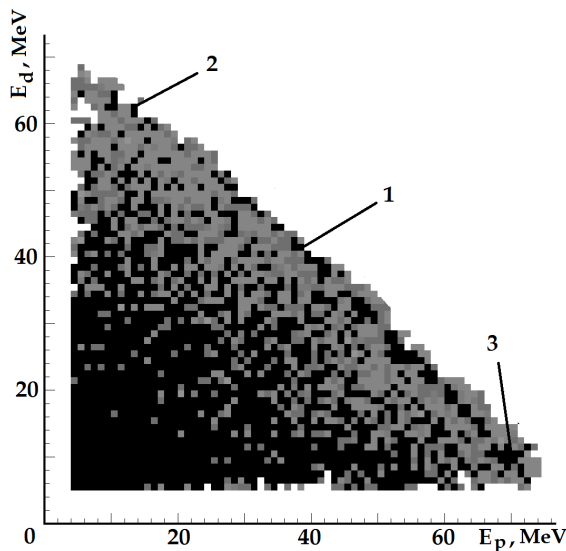
of the kinetic energies of pd-pairs (Dalitz' diagram). On the kinematic boundary of the plot one can see the following areas with the formation of three particles in the final state:

1 –  $15 \text{ MeV} \leq E_d \leq 50 \text{ MeV}$ ,  $30 \text{ MeV} \leq E_p \leq 60 \text{ MeV}$  - quasi-free pion absorption by intranuclear cluster  ${}^3\text{p}$  ( $\pi^- + {}^3\text{p} \rightarrow \text{p} + \text{d}$ ); where the momentums  $p_p \approx p_d$ , and the residual nucleus  ${}^{11}\text{Li}$  does not take part in the reaction;

2 –  $E_d \approx 65 \text{ MeV}$ ,  $E_p \leq 15 \text{ MeV}$  corresponding to 2-body reaction channel  $\pi^- + {}^{14}\text{C} \rightarrow \text{d} + {}^{12}\text{Be}^*$  with the following decay  ${}^{12}\text{Be}^* \rightarrow \text{p} + {}^{11}\text{Li}$ ;

3 –  $E_p \approx 70 \text{ MeV}$ ,  $E_d \leq 10 \text{ MeV}$  corresponding to 2-body reaction channel  $\pi^- + {}^{14}\text{C} \rightarrow \text{p} + {}^{13}\text{Be}^*$  with the following decay  ${}^{13}\text{Be}^* \rightarrow \text{d} + {}^{11}\text{Li}$ .

In order to distinguish the reaction channels, responsible for the increase in population density in the region 1 on Dalitz' diagram, we considered the missing-mass spectrum ( $MM$ ) shown in figure 2. The reference point here is the mass of  ${}^{11}\text{Li}_{\text{g.s.}}$ . Peak in the area of  $MM \approx 0 \text{ MeV}$  is due to 3-body channel of  ${}^{14}\text{C}(\pi^-, \text{pd}){}^{11}\text{Li}$  reaction with the formation of the ground and the first excited state of  ${}^{11}\text{Li}$  with  $E_x = 0.9 \pm 0.1 \text{ MeV}$ . Analysis shows that the events lying in the range of  $-1.0 \text{ MeV} < MM < 2.0 \text{ MeV}$  populate mainly the region 1 in figure 1. This indicates that the dominant contribution in forming low-lying states of  ${}^{11}\text{Li}$  is quasi-free absorption channels.

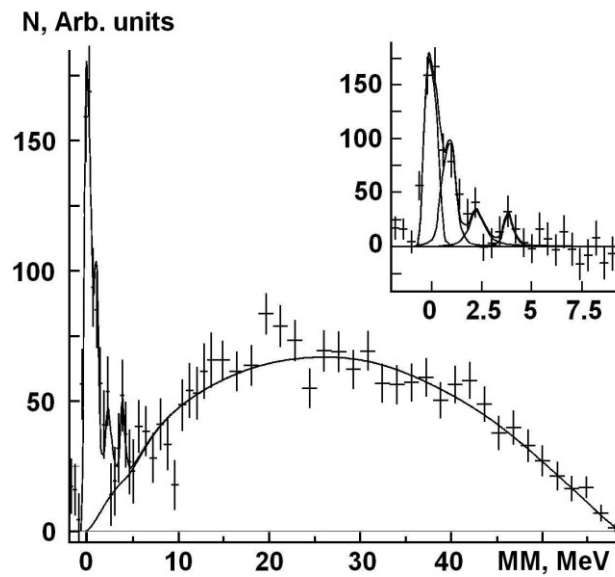


**Figure 1.** Experimental 2-dimensional distribution of events for  ${}^{14}\text{C}(\pi^-, \text{pd})X$  reaction. The darker points on the chart correspond to more events.

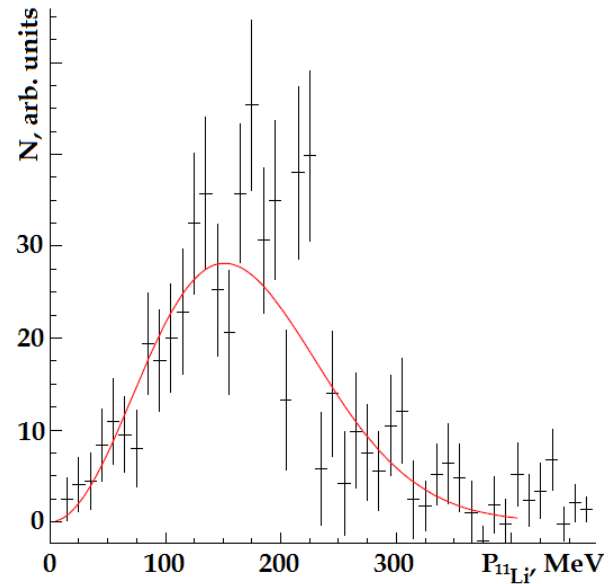
Additional evidence of “ ${}^3\text{p} + {}^{11}\text{Li}$ ” cluster configuration in  ${}^{14}\text{C}$  can be obtained from the momentum distribution of the residual nucleus  ${}^{11}\text{Li}$ , shown in figure 3. Satisfactory description of the peak observed in the region of small values of the momentum was achieved in the approximation of a harmonic oscillator:

$$F(p) \sim (p/p_F)^2 \exp(-(p/p_F)^2). \quad (1)$$

The best agreement with the experimental data is achieved with  $p_F \approx 150 \pm 10 \text{ MeV} / c$ . This value is typical for intranuclear Fermi motion of clusters, which proves a significant contribution of quasi-free pion absorption by  ${}^3\text{p}$  cluster:  $\pi^- + {}^3\text{p} \rightarrow \text{p} + \text{d}$ .



**Figure 2.** Missing mass spectrum for  $^{14}\text{C}(\pi^-, \text{pd})X$  reaction. Dots with error bars are the experimental data, the curve is the total fit.

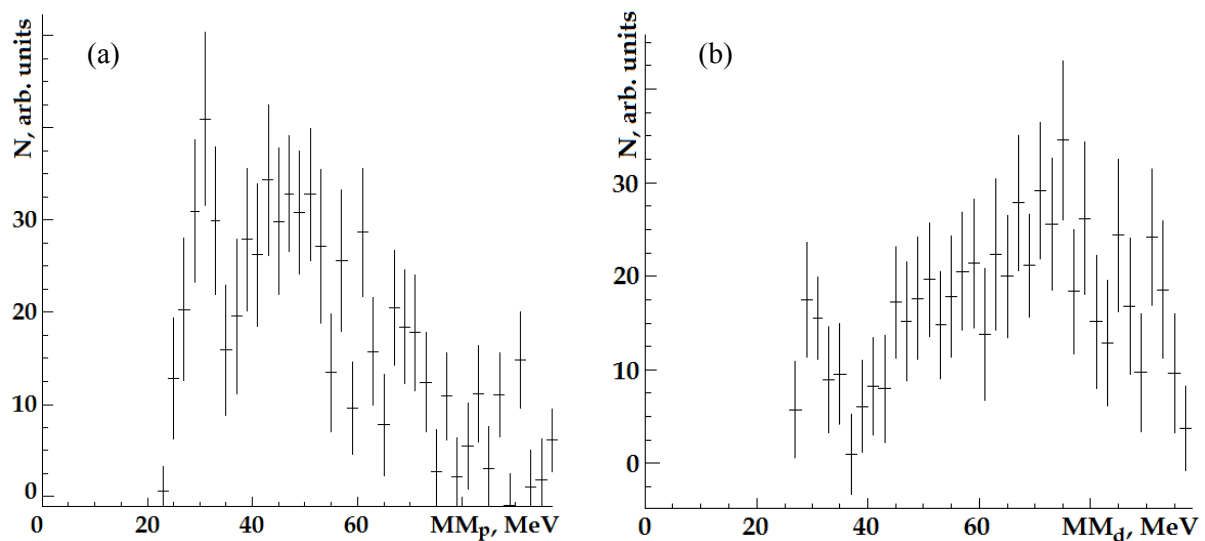


**Figure 3.** The momentum distribution of the residual nucleus  $^{11}\text{Li}$  from  $^{14}\text{C}(\pi^-, \text{pd})X$  reaction for  $-1.0 \text{ MeV} < MM < 2.0 \text{ MeV}$  events. Dots with error bars are the experimental data, the curve is the description of the spectrum using (1).

Thus, the analysis of the spectra shown in figure 2-3, suggests the presence of the configuration “ $^3\text{p} + ^{11}\text{Li}$ ” in  $^{14}\text{C}$  nucleus. The properties of the intranuclear  $^{11}\text{Li}$  system may be different from those of the isotope  $^{11}\text{Li}$  in a free state.

### 3. Search for rare cluster decays of $^{12,13}\text{Be}$

In order to find highly excited states of  $^{12,13}\text{Be}$  beryllium isotopes we analyzed  $MM$  spectra of  $^{14}\text{C}(\pi^-, \text{p})X$  and  $^{14}\text{C}(\pi^-, \text{d})X$  reactions, presented in figure 4. The spectra were obtained for the events from the areas 2 and 3 on the Dalitz’ diagram (figure 1).



**Figure 4.** Missing mass spectra for: a)  $^{14}\text{C}(\pi^-, \text{p})X$  (the reference points is the mass of  $^{12}\text{Be}_{\text{g.s.}} + \text{n}$ ); b)  $^{14}\text{C}(\pi^-, \text{d})X$  (the reference points is the mass of  $^{12}\text{Be}_{\text{g.s.}}$ ).

The peaks in figure 4 are due to the 2-body reaction channels where the excited states of beryllium decay as  $^{12(13)}\text{Be} \rightarrow \text{p(d)} + ^{11}\text{Li}$  (threshold is 23.20 (20.97) MeV). One can clearly see in both spectra the broad structure in the region of  $\text{MM} \approx 30$  MeV. Due to the lack of statistics, this structure cannot be interpreted as a manifestation of one or more excited levels.

Highly excited states of  $^{12}\text{Be}$ , decay into  $\text{p} + ^{11}\text{Li}$ , were also observed in [10]. The authors describe the experimental spectrum with two excited levels with  $E_x = 25.0$  MeV and 28.0 MeV [10]. The average value of the peak position ( $E_x \approx 30$  MeV), observed on figure 4b, is slightly higher than in [10], however, we do not exclude the presence of  $E_x = 28.0$  MeV state in our spectrum.

The existence of highly excited  $^{13}\text{Be}$  levels is first observed in our measurements. Note that the decay  $^{13}\text{Be} \rightarrow \text{d} + ^{11}\text{Li}$  is also observed for the first time.

#### 4. Conclusion

Search for rare cluster configuration in  $^{14}\text{C}$  nucleus was carried out in the correlation measurements of the stopped pion absorption reaction  $^{14}\text{C}(\pi^-, \text{pd})\text{X}$ . A study of 2-dimensional energy distribution for the particles (p, d) made possible to distinguish 2-body ( $\pi^- + ^{14}\text{C} \rightarrow \text{p(d)} + ^{13(12)}\text{Be}^*$ ) and 3-body ( $\pi^- + ^{14}\text{C} \rightarrow \text{p} + \text{d} + ^{11}\text{Li}$ ) reaction channels. Analysis of the 3-body channel, allowed to identify the pion absorption by a system of 3 protons ( $\pi^- + ^3\text{p} \rightarrow \text{p} + \text{d}$ ). This result points out on the presence of the configuration “ $^3\text{p} + ^{11}\text{Li}$ ” in  $^{14}\text{C}$  nucleus. The properties of the intranuclear  $^{11}\text{Li}$  system may be different from those of the isotope  $^{11}\text{Li}$  in a free state. We also investigated the cascade reaction channels  $\pi^- + ^{14}\text{C} \rightarrow \text{d(p)} + ^{12}\text{Be} \rightarrow \text{d(p)} + \text{p(d)} + ^{11}\text{Li}$ . The indications on highly excited states of  $^{12,13}\text{Be}$  with the energies  $E_x \approx 30$  MeV were obtained for the first time.

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