SEARCH FOR DECAY OF THE ^{7}Be NUCLEUS IN ^{8}B NUCLEUS DISSOCIATION

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ABSTRACT

The fragmentation of light relativistic nuclei can be studied in detail by the technique of nuclear track emulsions. The registration of all charged particles and their identification enable one to explore the isotopic composition of fragments and the projectile fragmentation channels. In the present paper results of an analysis of decay of the ^{7}Be nucleus in dissociation of ^{8}B nuclei are presented and a comparative analysis of the experimental data with the Monte Carlo model calculations is made. The paper is illustrated with characteristic images, obtained by means of a microscope, equipped with a CCD camera.

Keywords: *Monte Carlo modelling, nuclear track emulsion technique, peripheral interactions of nuclei.*

INTRODUCTION

The nuclear emulsion is unique in its composition including the Br, Ag and H nuclei in comparable concentrations. This allows to be compared fragmentation patterns of different origins. Under the same conditions it is possible to observe very peripheral break-up in the electromagnetic field on a heavy target nucleus as well as in collisions with target protons. Thanks to this, we can only study peripheral interactions.

Since the nuclear track emulsion method provides the most detailed observation of the interaction pattern [1, 2], it is the most suitable for studying the relativistic fragmentation of neutron-deficient light nuclei. Its traditional task is to outline the nuclear interaction model on the base on a limited sample of statistical data to plan better future experiments involving different detectors. The limitations of the analyzed data are compensated to some extent by the inability to fully observe of the fragment's composition within other methods.

First Stanoeva et al. studied the nucleus ^{8}B by the nuclear track emulsion method [3]. This made it possible to deduce detailed information about all dissociation channels that were observed in the experiment. Microphotographs of such events were presented in article [4]. An example of the interaction of projectile nuclei in a nuclear track emulsion is shown in Fig. 1.

This work is based on the experimental material devoted to the comparative analysis of the characteristics of reaction $^{8}B \rightarrow {}^{7}Be + p$ and is a natural extension of the work [3].

EXPERIMENTAL

Nuclear emulsions were irradiated with relativistic ^{8}B nuclei at beam energy of 1.2 A GeV (JINR Nuclotron). Rukoyatkin et al. present detailed information concerning the approach of the beam of relativistic ^{8}B nuclei obtaining [6]. Events were searched by microscope scanning on the emulsion plates.

In the used BR-2 photo emulsion, single- and double-charged relativistic particles are visually

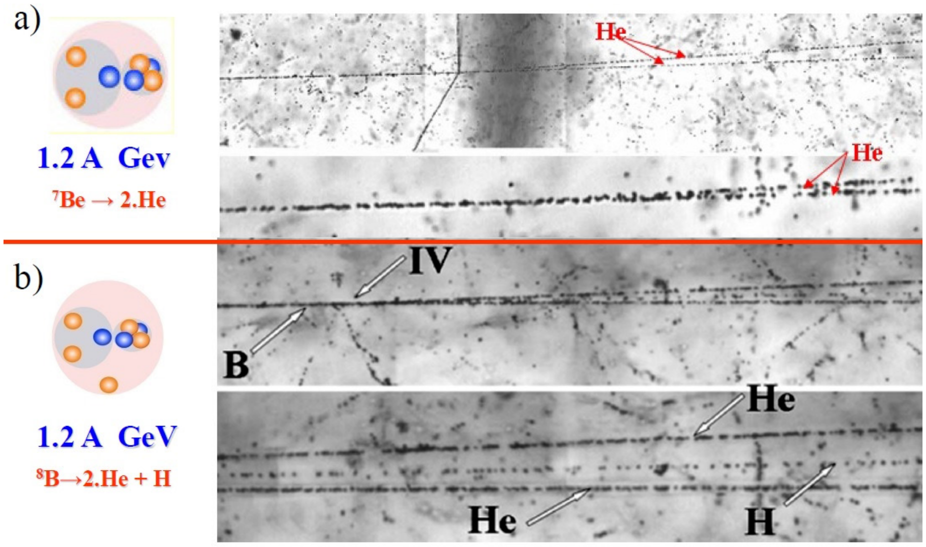

Fig. 1. Peripheral interactions in a nuclear track emulsion of: (a) a 1.2 A GeV $^{7}Be \rightarrow 2He$ [5]. Following the direction of the fragment jet, it is possible to distinguish 2 doubly charged fragments. (b) a 1.2 A GeV $^{8}B \rightarrow 2He + H$. On the bottom microphotograph, when we follow the direction of the fragment jet, it is possible to distinguish 3 charged fragments - one with a charge equal to 1 (the central track) and 2 doubly charged fragments.

identified, since the 1-fold ionization of relativistic single-charged particles is reliably distinguished from the 4-fold ionization of particles with charge 2. Nuclei with charges $Z \geq 3$ are determined by the method of calculating the δ - electrons (N_δ) per unit length of the investigated track. Taking into account the possible differences in the conditions of development of nuclear photo emulsions, the tracks left by particles with the same charge value can have different numbers of N_δ in different plates. Even in the same plate, the number of N_δ for the same particles lying at different depths can differ. Therefore, before determining the charges of the fragments, a corresponding calibration (approximation) is made. For this, N_δ of the tracks left by particles of known charge are counted. Knowing N_δ for $Z = 1$ and $Z = 2$, one can easily calculate the expected values of N_δ for multi-charged particles ($Z \geq 3$). The semi-empirical relation: the number of δ-electrons per unit length (the δ-electron density) – charge can be written as follows: $N_\delta = aZ^2 + b$, where N_δ is the number of δ-electrons in the track of the relativistic particle of unit length, Z - the electric charge of the nucleus.

In Fig. 2 is shown the distribution of the number of δ-electrons. The data from this experiment is compared with results obtained in the study of ^{9}C nuclei (50 events - shaded histogram). The curve shown is an approximation by the sum of four Gaussian functions. The main part of the interactions found are with a charge of the primary trace equal to 5. The figure shows that there are small impurities from other nuclei in the beam, corresponding to the spectrum obtained by the Nuclotron.

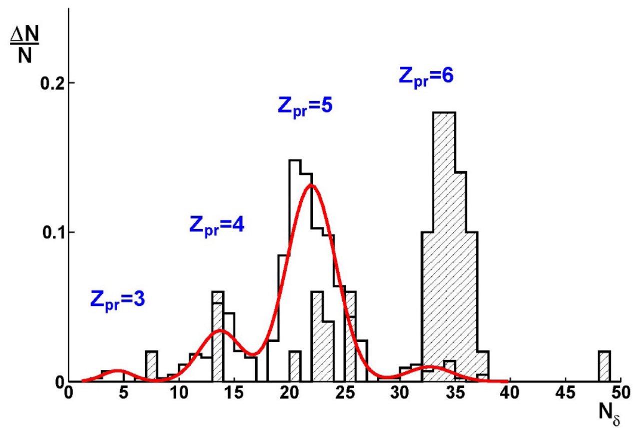

Fig. 2. Distribution of the number of δ-electrons. The experimental data is compared with a distribution of the number of δ-electrons over 1 mm of length of tracks of beam particles that induced interactions in beam ^{9}C nuclei (50 events - shaded histogram). The curve shown is an approximation by the sum of four Gaussian functions.

A detailed distribution of the ^{8}B dissociation over the fragment configurations $\sum Z_{fr}$ and the numbers of the target fragments n_b and n_g is given in [3]. The main conclusion is that the contribution of the dissociation channel $^8B \to {}^7Be + p$ is dominant in events that do not involve the production of target nucleus fragments or mesons. Information about the branching ratios for dissociation modes featuring a high multiplicity has been obtained. Among the events with $\sum Z_{fr} = 5$, the channels 2He + H (Fig. 1) and He + 3H can observe, which saturate about 70 % for the number of events involving the target fragments (N_{tf}) and about 50 % for the number of events of the type "white" star (N_{ws}). The dissociation of the ^7Be core in the ^8B nucleus bears resemblance to the dissociation of a free nucleus ^7Be. Irradiation details and a special analysis of interactions in the BR-2 emulsion are presented in refs. [3, 5]. We have no chance to present here a full description of all experimental procedures.

In our experiment, the coordinate method of angular measurements was used. The emission angles of secondary relativistic particles relative to the primary particle (polar θ and azimuthal ψ) were measured using a special measuring microscope for nuclear research KSM-1 from Zeiss. Since the microscope is designed to measure momentum of high-energy particles by multiple Coulomb scattering, then the noise of the microscope when measuring the coordinates of the tracks can be ignored. It is worth noting that there are situations where angular measurements cannot be taken. This is most often associated with the location of the event in the emulsion. For example, the "star" is too close to the edge of the record, etc. Further, we assume that the conditions for the measurement are favourable.

RESULTS AND DISCUSSION

Fig. 3 shows the distributions of the emission angle θ for projectile fragments of charge equal to 1 (Fig. 3a) and equal to 4 (Fig. 3b) for the channel $^7Be + p$. The distributions are mostly concentrated in the area of small values. The mean value of the emission angle θ for fragments with charge $Z_{fr} = 1$ (40 events - shaded histogram) is $<\theta_p> = (34 \pm 5) \times 10^{-3}$ rad and RMS = 29 × 10^{-3} rad. For $Z_{fr} = 4$ fragments, the average value is $<\theta_{Be}> = (10.5 \pm 1.0) \times 10^{-3}$ rad and RMS = 7×10^{-3} rad. The obtained experimental values for the average values of the emission angle θ reflects very well the difference in the mass of the fragments. The experimental data are compared with a distribution of the emission angle θ for projectile fragments of charge $Z_{fr} = 1$ (Fig. 3a) and $Z_{fr} = 4$ (Fig. 3b)

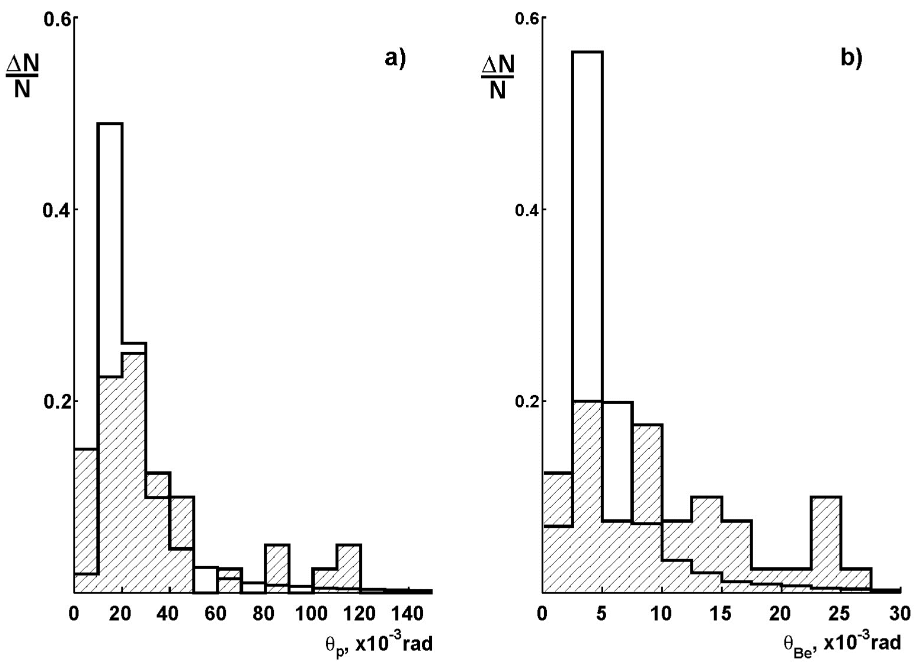

Fig. 3. Distribution of the polar emission angle θ in the reaction $^8B \to {}^7Be + p$ (Monte Carlo modeling) for target-nucleus fragments of charge (a) $Z_{fr} = 1$ and (b) $Z_{fr} = 4$. The shaded part of the histogram represents the contribution of all events in the reaction $^8B \to {}^7Be + p$ (40 events - experiment).

Table 1. Mean values of emission angles < θ > and transverse momenta of protons < P_T> in reactions $^8B \rightarrow {}^7Be + p$ and 2He + p. N_{ws} - the number of "white" stars; N_{tf} - the number of events involving the target fragments; $N_{ws} + N_{tf}$ - the number of all peripheral events; N - the number of events.

channel	N_{ws}			N_{tf}			$N_{ws} + N_{tf}$		
	< θ >, 10^{-3} rad	< P_T>, MeV/c	N	< θ >, 10^{-3} rad	< P_T>, MeV/c	N	< θ >, 10^{-3} rad	< P_T>, MeV/c	N
Be + H	33 ± 6	66 ± 12	25	35 ± 7	69 ± 15	15	34 ± 5	67 ± 9	40
2·He + H	51 ± 8	101 ± 16	13	39 ± 5	78 ± 10	37	42 ± 4	84 ± 9	50

that induced interactions in Monte Carlo modeling. We suppose that the relativistic fragments ^7Be and p were formed because of the decay of the excited nucleus $^8B^*$. Any particle collision problem can be reduced to a decay problem. First, particles ^8B and X merge into one particle 0 (or $^8B^*$), and then the particle breaks up into particles ^7Be and p. This is an imaginary particle that is introduced for convenience only. This particle is assigned momentum and energy. The effective mass of the ^8B + X system is $M_0 = \sqrt{E_0^2 - p_0^2}$. The process of decay of $^8B^*$ nucleus into particles ^7Be and p is generated in its rest system. During the calculation, the determination of the maximum phase volume was used.

The calculation of the transverse momenta P_T of fragments with mass number A_{fr} is based on the results of the emission angle measurements and an approximate ratio $P_T \approx A_{fr}P_0 \sin\theta$, where A_{fr} is the mass number of a fragment, θ its emission angle and P_0 the momentum per ^8B nucleon (P_0 = 2.0 A GeV/c). In essence, the P_T distributions for protons produced in all peripheral interactions $^8B \rightarrow {}^7Be + p$ and 2He + p are similar, which may indicate the independence of fragmentation of the proton to the core nucleus ^7Be. Table 1 contains a summary of the mean values of emission angles <0> and transverse momenta of protons < P_T >, generally confirms the similarity distributions.

Figure 4 presents the distribution of the total transverse momentum P_T ($^8B^*$) of ^7Be + p pairs produced in all peripheral interactions $^8B \rightarrow {}^7Be + p$: (solid-line histogram) Monte Carlo modeling and (dashed-line histogram) experiment. After comparing these two distributions, we can make the conclusion that the made condition P_T ($^8B^*$) < 150 MeV/c, allows an effective separation of the kinematic region that is characteristic of the production of the interactions $^8B \rightarrow {}^7Be + p$, which do not involve the production of target nucleus fragments or mesons ("white" stars).

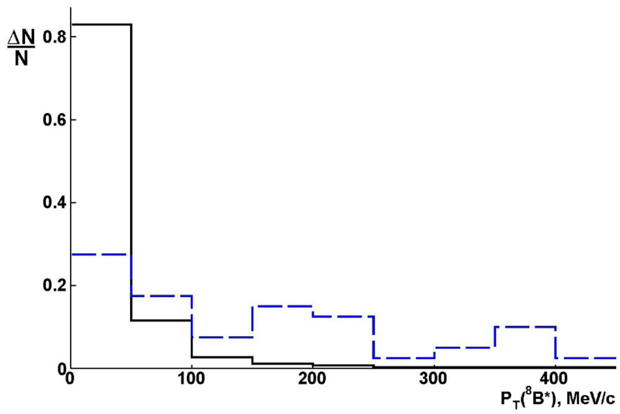

Fig. 4. Distribution of the total transverse momentum P_T ($^8B^*$) of ^7Be + p pairs produced in the reaction $^8B \rightarrow {}^7Be + p$: (solid-line histogram) Monte Carlo and (dashed-line histogram) experiment (40 events).

CONCLUSIONS

The method discussed in this paper preserves unique opportunities for studying the structural features of light relativistic nuclei. The traditional task of the nuclear track emulsion method is to outline the nuclear-interaction pattern based on a limited statistical data sample to plan better future complicated experiments featuring various detectors. Limitations on the statistics subjected to analysis are compensated to some extent by the impossibility of completely observing the composition of fragments within other methods.

Monte Carlo modeling of the $^8B \rightarrow {}^7Be + p$ reaction in the paper is used because the contribution of this dissociation channel is dominant in events that do not involve the production of target-nuclei fragments or mesons ("white" star), which is the main conclusion in article [3]. Independent fragmentation of the proton to the main ^7Be nucleus is also observed. An analysis of angular correlations in all peripheral events from the experiment and in events involving Monte Carlo modeling made it possible to validate selections of events of the electromagnetic dissociation process $^{8}B \rightarrow {}^{7}Be + p$ in the total transverse momentum of fragments, which agrees with the experimental results.

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REFERENCES

1. C.F. Powell, P.H. Fowler, D.H. Perkins, The Study of Elementary Particles by the Photographic Method, London - New York: Pergamon Press, 1959.
2. W.H. Barkas, Nuclear Research Emulsions. New York - London: Academic Press, 1963.
3. R. Stanoeva, D.A. Artemenkov, V. Bradnova, S. Vokál, L.A. Goncharova, P.I. Zarubin, I.G. Zarubina, N.A. Kachalova, A.D. Kovalenko, D.O. Krivenkov, A.I. Malakhov, G.I. Orlova, N.G. Peresadko, N.G. Polukhina, P.A. Rukoyatkin, V.V. Rusakova, M. Haiduc, S.P. Kharlamov, M.M. Chernyavsky, T.V. Shchedrina, Electromagnetic dissociation of relativistic ^{8}B nuclei in nuclear track emulsion, Physics of Atomic Nuclei, 72, 4, 2009, 690-701.
4. D.A. Artemenkov, V. Bradnova, M.M. Chernyavsky, L.A. Goncharova, M. Haiduc, N.A. Kachalova, S.P. Kharlamov, A.D. Kovalenko, A.I. Malakhov, A.A. Moiseenko, G.I. Orlova, N.G. Peresadko, N.G. Polukhina, P.A. Rukoyatkin, V.V. Rusakova, V.R. Sarkisyan, R. Stanoeva, T.V. Shchedrina, S. Vokal, A. Vokalova, P.I. Zarubin, I.G. Zarubina, Fragmentation of relativistic nuclei in peripheral interactions in nuclear track emulsion, Physics of Atomic Nuclei, 71, 9, 2008, 1565-1571.
5. N.G. Peresadko, Yu.A. Aleksandrov, V. Bradnova, S. Vokál, S.G. Gerasimov, V.A. Dronov, P.I. Zarubin, I.G. Zarubina, A.D. Kovalenko, V.G. Larionova, A.I. Malakhov, P.A. Rukoyatkin, V.V. Rusakova, S.P. Kharlamov, V.N. Fetisov, Fragmentation channels of relativistic ^{7}Be nuclei in peripheral interactions, Physics of Atomic Nuclei, 70, 7, 2007, 1226-1229.
6. P.A. Rukoyatkin, L.N. Komolov, R.I. Kukushkina, and V.N. Ramzhin, Beams of relativistic nuclear fragments at the nuclotron accelerator facility, Czech. J. Phys., Supplement C56, 2006, 379-384.