Progress of the BECQUEREL Project in 2008-11 and Contribution to the Joint FAZA/BECQUEREL Project for 2012-2014

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The BECQUEREL Project (Beryllium (Boron) Clustering Quest in Relativistic Multifragmentation) at the JINR Nuclotron is devoted systematic exploration of clustering features of light stable and radioactive nuclei. A nuclear track emulsion is used to explore the fragmentation of the relativistic nuclei down to the most peripheral interactions - nuclear "white" stars. This technique provides a record spatial resolution and allows one to observe the 3D images of peripheral collisions. The analysis of the relativistic fragmentation of neutron-deficient isotopes has particular advantages owing to a larger fraction of observable nucleons.

The features of dissociation of ^{9}Be, ^{10}C, and ^{12}N nuclei of 1.2A GeV in nuclear track emulsion energy are presented. The data presented for the nucleus ^{9}Be can be considered as evidence that there is a core in its structure in the form of 0^{+} and 2^{+} states of the ^{8}Be nucleus having roughly equal weights. Events of coherent dissociation $^{9}C \rightarrow 3^{3}He$ associated with the rearrangement of the nucleons outside the α-clustering are identified. The charge fragment topology in the dissociation of ^{10}C and ^{12}N nuclei is obtained. Contribution of the unbound nucleus decays to the cascade process $^{10}C \rightarrow {}^{9}B \rightarrow {}^{8}Be$ is identified.

Continuation of the BECQUEREL project for the years 2012-14 will be mostly devoted to observational study of peripheral fragmentation of ^{10}C and ^{12}N nuclei in exposed emulsion. Production of unbound nuclei ^{6}Be, ^{7}B, ^{8}C and ^{11}N formed in the fragmentation of ^{7}Be, ^{8}B, ^{9}C and ^{12}N nuclei will be explored in the exposed emulsion. The investigation of the cluster degrees of freedom in the ^{7}Be and ^{10,11}B nuclei will be extended to a new level of statistics and detailed descriptions.

It is suggested to expose emulsion in a secondary ^{11}C beam prepared via a selection of products of charge exchange reaction $^{11}B \rightarrow {}^{11}C$. The project will support beam tests with heavy nuclei at the Nuclotron as well as other accelerators.

Introduction

The concepts of baryonic matter in a cold dilute phase with clustering of nucleons in the lightest nuclei ^{4}He, ^{3}He, ^{2}H and ^{3}H have been developed in the last decade. Theoretical developments carried out in this direction orient towards the study of cluster groups as integral quantum systems and give motivation to a new generation of experiments on cluster spectroscopy. Since the cluster states play the intermediate role in astrophysical processes, these studies assume the significance going beyond the framework of the nuclear structure problems.

The use of accelerated nuclei, including radioactive ones, qualitatively diversifies the spectroscopy of cluster systems. Configuration overlap of a fragmenting nucleus with finite cluster states manifested most fully in the dissociation at the periphery of the target nucleus with the excitation transfer near the cluster binding thresholds. The definition of interactions as peripheral ones is simplified at energy above 1A GeV due to the collimation of the incident nucleus fragments. The detection thresholds disappear and the fragment energy loses in detector material are minimal. Thus, qualitatively new opportunities appear in the relativistic region for the study of cluster systems as compared with the low energy region. An extensive collection of photographs of such interactions in nuclear track emulsion is gathered by the BECQUEREL collaboration [1].

Despite the fact that the potential of the relativistic approach to the study of nuclear clustering is recognized long ago, e-experiments were not be able to get closer to the required detailed observation of the relativistic fragment ensembles. The related pause has led to the BECQUEREL proposal to use the beam transport channels of the JINR Nuclotron for irradiation of nuclear track emulsion of the whole family of 1.2A GeV light nuclei, including radioactive ones [2]. Studies with relativistic neutron-deficient nuclei have special advantages due to more complete observations.

The method of nuclear track emulsion provides a uniquely complete observation of multiple fragment systems produced in dissociation of relativistic nuclei. Approximate conservation of the initial momentum per nucleon by relativistic fragments is used in the kinematical analysis of the events to compensate the lack of momentum measurements. The fragmenting system excitation can be defined as $Q = M^{*} - M$, where M^{*} is the invariant mass and M – the projectile mass or total fragment mass. The value M^{*} is defined by the relation $M^{*2} = (\Sigma P_j)^2 = \Sigma(P_i \cdot P_k)$, where $P_{i,k}$ 4-momenta fragments i and the k, determined in the approximation of the conservation of the primary momentum value per nucleon.

The most valuable events of coherent dissociation of nuclei in narrow jets of light and the lightest nuclei with a net charge as in the initial nucleus, occurring without the production of fragments of the target nuclei and mesons (the so-called "white" stars), comprise a few percent among the observed interactions. The data on this phenomenon are fragmented, and the interpretation is not offered. The dissociation degree of light O, Ne, Mg and Si, and as well as heavy Au, Pb and U nuclei may reach a complete destruction to light and the lightest nuclei and nucleons, resulting in cluster systems of an unprecedented complexity. The dissociation dynamics of heavy nuclei can be grounded on dissociation peculiarities established for light nuclei.

Already it is established that final states of relativistic He fragments effectively correlate with the clustering in the nuclei ^{12}C, ^{6}Li [5], and ^{9}Be [3]. The described approach is used in the BECQUEREL Project to study the drip line nuclei ^{7}Be [4], ^{8}B [5], ^{9}C [6], ^{10}C and ^{12}N [7-9]. Until now ^{11}C exposure waits to be performed. The summary on dissociation features of ^{9}Be, ^{9,10}C, and ^{12}N nuclei will be presented in the present paper as well as plans for further analysis.

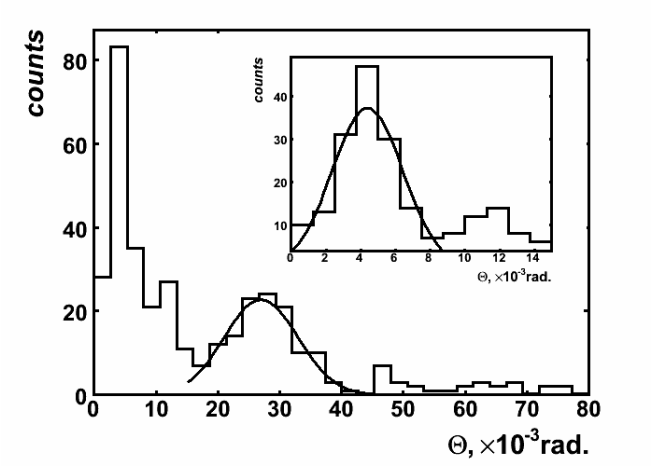

Fig. 1. The distribution of events ^{9}Be → 2α on the opening angle Θ; in the inset - enlarged distribution of events in the region $0 < \Theta_n < 10.5$ mrad

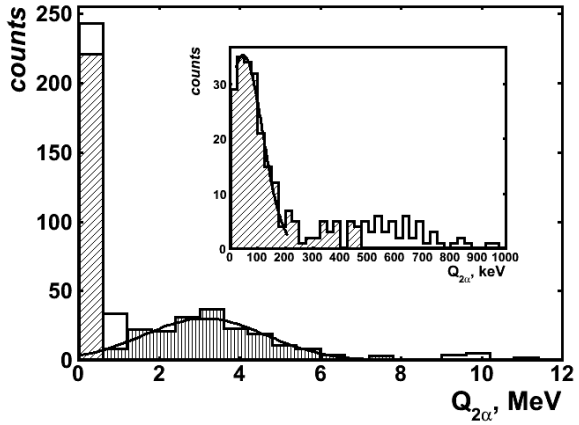

Fig. 2. Distribution of events ^{9}Be → 2α on the energy $Q_{2\alpha}$ of α-particle pairs; obliquely hatched histogram - events with Θ_n; vertically hatched histogram - events with Θ_w; in the inset - enlarged distribution of events on $Q_{2\alpha}$ at angles Θ_n; solid histogram - total distribution

Dissociation ^{9}Be → 2α

In order to justify the application of the relativistic fragmentation in the study of Nα-system spectroscopy it was suggested to investigate the dynamics of the formation of α-particle pairs at a high statistical level and under the simplest conditions (without combinatorial background) which are provided in the relativistic fragmentation ^{9}Be → 2α. Due to the low neutron separation threshold, the ^{9}Be dissociation can serve as a convenient source of unstable ^{8}Be nuclei. As is known, the ^{8}Be nucleus has a distinct separation between the ground 0^+, the first 2^+ and the second 4^+excited states. It appears to be interesting to test a hypothesis about the possibility of observing relativistic nucleus ^{8}Be in the 0^+ and 2^+ states when removing a neutron from the 2α + n system of the ^{9}Be nucleus. Observation of these states in the spectrum of opening angles Θ of relativistic α-particle pairs can serve as a test of the spectroscopic capabilities. The decays of relativistic nuclei ^{8}Be → 2α via the 0^+ ground state are identified as α-particle pairs belonging to the characteristic region of the smallest opening angles $\Theta_{2\alpha}$, limited at the momentum 2A GeV/c by the condition $\Theta_{2\alpha} < 10.5$ mrad.

The secondary ^{9}Be beam was obtained by fragmentation of accelerated ^{10}B nuclei. When scanning the exposed emulsion 500 events ^{9}Be → 2α in a fragmentation cone of 0.1 rad have been found. About 81% α-pairs form roughly equal groups on $\Theta_{2\alpha}$: “narrow" ($0 < \Theta_n < 10.5$ mrad) and “wide” ($15.0 < \Theta_w < 45.0$ mrad) ones (Fig. 1). The Θ_n pairs are consistent with ^{8}Be decays from the ground state 0^+, and pairs Θ_w - from the first excited state 2^+. The Θ_n and Θ_w

fractions are equal to 0.56 ± 0.04 and 0.44 ± 0.04. These values are well corresponding to the weights of the ^{8}Be 0^{+} and 2^{+} states $\omega_{0+} = 0.54$ and $\omega_{2+} = 0.47$ in the two-body model n - ^{8}Be, used to calculate the magnetic moment of the ^{9}Be nucleus.

For the coherent dissociation ^{9}Be → 2α + n, the average value of the total α-pair transverse momentum is equal to $\langle P_{Tsum} \rangle \approx 80$ MeV/c in correspondence with the Goldhaber statistical model. So, it can be assigned to the average transverse momentum carried away by neutrons. For the ^{9}Be coherent dissociation through the ^{8}Be 0^{+} and 2^{+} states there is no differences in the values $\langle P_{Tsum} \rangle$, which points to a "cold fragmentation" mechanism. The whole complex of these observations may serve as an evidence of the simultaneous presence of the ^{8}Be 0^{+} and 2^{+} states with similar weights in the ground state of the nucleus ^{9}Be.

Coherent dissociation of ^{9}C nuclei

One can expect that the pattern established for the ^{7}Be and ^{8}B nuclei is reproduced for nucleus ^{9}C with the addition of one or two protons. In addition, the emergence of a 3^{3}He ensemble becomes possible. An intriguing hypothesis is that in the nuclear astrophysical processes the 3^{3}He system can be a 3α-process analog

A secondary beam, optimized for ^{9}C nucleus selection was formed by fragmentation of accelerated ^{12}C nuclei. It was important in this irradiation to avoid overexposure by the accompanying flux of ^{3}He nuclei. The intensity ratio of the nuclei with charges $Z_{pr} = 6$ and 2 amounted to 1 : 10. This factor has limited statistics and made the scan for ^{9}C interactions much more labor demanding.

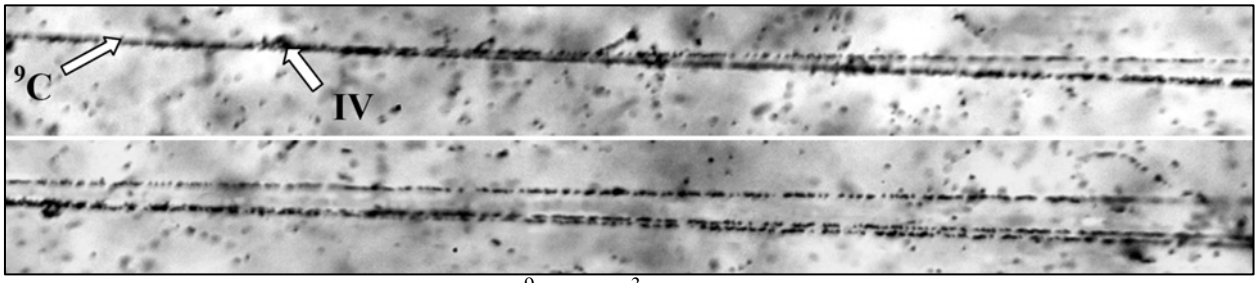

Fig. 3. Macro photograph of a ^{9}C → 3^{3}He "white" star at an energy of 1.2 GeV per nucleon. The upper photograph shows the dissociation vertex IV and a fragment jet in a narrow cone; moving along the jet, one can see three He relativistic fragments (lower photograph).

Among the total number of "white" stars N_{ws}, detected in this exposure, 15 events ^{9}C → ^{8}B + p and 16 events ^{7}Be + 2p are found. Statistics in the channels 2He +2 H (24), He +4 H (28) and 6H (6) well corresponds to the ^{7}Be core dissociation. The event fraction ^{9}C → 3^{3}He (16) was found to be the same as that of the channels ^{9}C → ^{8}B + p and ^{7}Be + 2p. The latter fact can point to a significant admixture of a virtual 3^{3}He state in the ^{9}C ground state. This component can give a contribution to the ^{9}C magnetic moment, which has an abnormal value in terms of the shell model.

On a possible observation of "dihelion"

Thus, population of the three ^{3}He nucleus state is observed in the ^{9}C coherent dissociation with 14% probability. Its origin can be caused by a virtual regrouping of a neutron from the ^{4}He cluster to form ^{3}He clusters as well as the presence of the 3^{3}He component in the ^{9}C ground state. In the second variant, the probability of the 3^{3}He ensemble production points to the significance of this deeply bound configuration in the wave function of the ^{9}C ground state.The mechanism of the ^{9}C coherent dissociation in the channels with nucleon separation and the 3^{3}He channel is a nuclear diffractive interaction which is established on the basis of measurements of the total transverse momentum (a few hundred MeV/c) transferred to the fragment ensembles.

Correlated ^{3}He pairs with opening angles Θ_{2He} less than 10^{-2} rad are detected in the channel $^9C \rightarrow 3^3He$ (Fig. 3). This observation indicates to a possible existence of a 2^3He resonant state with the decay energy about 140 keV. In the same way the formation of ^{8}Be nuclei is reliably manifested in the production of ^{4}He pairs with extremely small opening angles in the relativistic dissociation of $^9Be \rightarrow 2^4He$ and $^{10}C \rightarrow 2^4He + 2p$. Significant probability of coherent dissociation $^9C \rightarrow 3^3He$ makes it an efficient source for search for an analog of the unbound ^{8}Be nucleus among the ^{3}He pairs. In what follows, a rather unexpected and potentially important feature of the spectrum Θ_{2He} of ^{3}He pairs produced in the dissociation of ^{9}C and ^{8}B nuclei, is given.

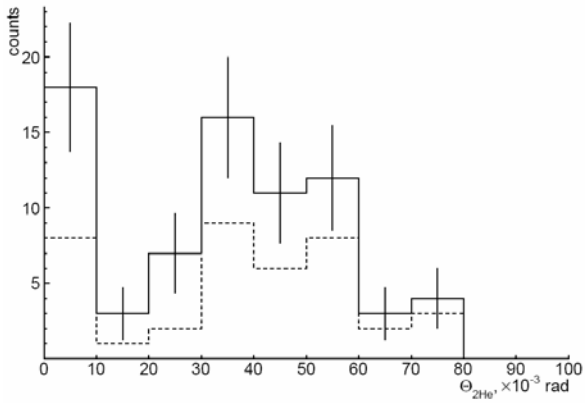

Fig. 4. Total distribution of opening angles Θ_{2He} between the relativistic He fragments in events $^8B \rightarrow 2He + H$ with the formation of fragments of target nuclei or mesons and in the "white" stars $^9C \rightarrow 3^3He$; dotted line indicate the contribution of the "white" stars

In the Fig. 4 the dotted line shows the distribution Θ_{2He} for "white" stars $^9C \rightarrow 3^3He$. Its main part, corresponding to 30 pairs, is described by a Gaussian distribution with mean values $\langle\Theta_{2He}\rangle = (46 \pm 3)\cdot10^{-3}$ rad. and RMS 16·10-3 rad. In addition, thanks to excellent spatial resolution eight 2^3He pairs within $\Theta_{2He} < 10^{-2}$ rad are reliably observed. These pairs form a special group with a mean value $\langle\Theta(2^3He)\rangle = (6 \pm 1)\cdot10^{-3}$ rad and RMS $3\cdot10^{-3}$, which is obviously beyond the previous description.These values correspond to the average relative energy $\langle Q(2^3He)\rangle = (142 \pm 35)$ keV at 100 keV RMS. The parameter $Q(2^3He)$ was defined as the difference between the invariant mass of the pair and the double ^{3}He mass assuming that the fragments conserve the ^{9}C momentum per nucleon.

Additional search for the resonance 2^3He is carried our in the events of peripheral dissociation $^8B \rightarrow 2He + H$. In this case, inelastic interactions with target nucleus fragments or produced mesons are selected in order to enhance the effect. This condition provides the selection of interactions with knocking of a neutron out of the ^{4}He cluster in the ^{8}B nucleus. The resulting distribution $\Theta(2^3He)$ in the figure also includes a separate group of narrow pairs with parameters $\Theta(2^3He)\rangle = (4.5 \pm 0.5)\cdot10^{-3}$ rad and RMS $1.5 \cdot 10^{-3}$ rad, corresponding to the case of "white" stars $^9C \rightarrow 3^3He$.

The total distribution for both the options presented in the figure, makes the indication to the existence of the resonance 2^3He near threshold more reliable. Moreover, the question arises about the nature of the broad peak with a maximum of $\Theta(2^3He)$ about $(40 – 50)\cdot10^{-3}$ rad. It is possible that in this $\Theta(2^3He)$ region the 2^3He system shows its similarity with the first excited 2^+ state of the ^{8}Be nucleus.

Exposure of emulsion to a mixed beam of relativistic ^{12}N, ^{10}C, and ^{7}Be nuclei

The ^{10}C nucleus is the only example of the system, which has the "super-boromean" properties, since the removal of one of the four clusters in the 2α + 2p structure leads to an

unbound state. The particular feature of the ^{12}N nucleus consists in the low proton separation threshold (600 keV). Furthermore, the dissociation can occur through the channels α + ^{8}B (8 MeV), p + ^{7}Be + α, as well as into more complicated ensembles with the ^{7}Be core break. Generation of ^{12}N and ^{10}C nuclei is possible in charge exchange and fragmentation reactions of accelerated ^{12}C nuclei. The charge to weight ratio Z_{pr}/A_{pr} differs by only 3% for these nuclei, while the momentum acceptance of the separating channel is 2 - 3%. Therefore, their separation is not possible, and the ^{12}N and ^{10}C nuclei are simultaneously present in the secondary beam, forming a so-called beam "cocktail". The contribution of ^{12}N nuclei is small in respect to ^{10}C ones in accordance with the cross sections for charge transfer and fragmentation reactions. Also, the beam contains ^{7}Be nuclei, differing by Z_{pr}/A_{pr} from ^{12}N nuclei only by 2%.

Due to the momentum spread ^{3}He nuclei can penetrate in the separating channel. For neighboring ^{8}B, ^{9}C and ^{11}C nuclei the difference by Z_{pr}/A_{pr} from ^{12}N is about 10%, which leads to suppression in these isotopes. Identification of ^{12}N nuclei can be performed by δ-electron counting along the beam tracks. In the ^{10}C case, relying on the charge topology of the produced "white" stars it is necessary to be sure that the neighboring carbon isotope contribution is small. These considerations provided the justification to expose nuclear track emulsion in a mixed beam of ^{12}N, ^{10}C and ^{7}Be nuclei.

Nuclear track emulsion is exposed to a mixed beam of ^{12}N, ^{10}C and ^{7}Be nuclei formed by means of primary 1.2A GeV ^{12}C nucleus beam. The initial scanning phase consisted in visual search of beam tracks with charges Z_{pr} = 1, 2 and Z_{pr}> 2. The ratio of beam tracks with charges Z_{pr} = 1, 2 and Z_{pr} > 2 is found to be equal ≈ 1 : 3 : 18. Thus, the contribution of ^{3}He nuclei dramatically decreased compared with the ^{9}C irradiation, which radically raised the event search efficiency. The scanning along the total length of primary tracks in emulsion layers that was equal to 924.7 m revealed 6144 inelastic interactions, including 516 "white" stars.

The presence of fragments Z_{fr} > 2 makes the charge identification of beam Z_{pr} and secondary Z_{fr} tracks necessary. For the calibration the average density of δ-electrons N_{δ} was measured along the beam tracks, which produced the "white" stars 2He + 2H, 2He and He + 2H, and also stars with fragments Z_{fr} > 2 (^{12}N candidates). Thus, the correlation between the charge topology ΣZ_{fr} and N_{δ} was established which permitted to determine beam track charges Z_{pr} and the fragment charges Z_{fr} > 2.

The pattern of the ^{12}N and ^{10}C dissociation seems to be self-consistent, and the performed exposures have prospects for increasing "white" star statistics. At the current stage one can derive some conclusions about the ^{12}N and ^{10}C clustering what follows below.

Coherent dissociation of ^{10}C and ^{12}N nuclei

For "white" stars N_{ws} with charge topology $\sum Z_{fr}$ = 6 the most probable channel is represented by events 2He + 2H, which might be expected for the isotope ^{10}C (Table 1). The channel He + 4H is found to be suppressed, as in the ^{10}C case it is required to overcome the high threshold of the α-cluster break up. Besides, events are observed in the channel ^{10}C → 3He.

Table 1. Distribution of the number of "white" stars, N_{ws}, and the number of events involving the production of target fragments, N_{tf}, with respect to $\sum Z_{fr}$ = 6 channels

$\sum Z_{fr}$ = 6	C	2He + 2H	He + 4H	6H	3He
N_{ws}	-	159	16	8	11
N_{tf}	27 (^{9}C)	211	76	16	11

Coherent dissociation of ^{12}N nuclei

In this irradiation 41 "white" stars N_{ws} with Z_{pr} = 7 and $\sum Z_{fr}$ = 7 are found, corresponding to the dissociation of ^{12}N nuclei. About half of the events contain a fragment Z_{fr} > 2, clearly differing from the cases of nuclei ^{14}N and ^{10}C (Table 2).

Table 2. Distribution of "white" stars, N_{ws}, with respect to the channels $\sum Z_{fr} = 7$ and $Z_{pr} = 7$

C + H	^{8}B + He	^{7}Be+He+H	^{8}B+2H	^{7}Be+3H	3He + H	2He + 3H	He +5H
5	6	6	5	5	2	10	2

High statistics analysis of ^{7}Be dissociation

The BECQUEREL Collaboration performed irradiation of nuclear track emulsion in a mixed beam of ^{12}N, ^{10}C and ^{7}Be nuclei. Thus, there are new opportunities with regard to the issue of "dihelion" based on the analysis of the found about 400 "non-white" stars $^{7}\text{Be} \rightarrow 2^{3}\text{He}$ (Table 3) with knocking out of a neutron and the formation of fragments of target nuclei or mesons, as in the case of $^{8}\text{B} \rightarrow 2\text{He} + \text{H}$. Thus, the indication to the existence of "dihelion" will be reviewed using a significantly larger statistics.

Table 3. Distribution of the number of "white" stars, N_{ws}, and the number of events involving the production of target fragments, N_{tf}, with respect to $\sum Z_{fr} = 4$ channels

$\sum Z_{fr} = 4$	2He	He+2H	4H
N_{ws}	95	116	14
N_{tf}	371	554	16

However, it is possible that the "dihelion" formation is due to the presence of the 2^{3}He component in the ^{9}C and ^{8}B structures. In principle, in a lighter ^{7}Be nucleus such a component can be suppressed, this means that the "dihelion" formation can be suppressed as well. Therefore, it is important to search for the 2^{3}He resonance with high statistics exactly in low energy ^{9}C and ^{8}B beams. At the same time, pointing to the existence of "dihelion", our observation motivates the search for a mirror state of a pair of nuclei ^{3}H - "ditriton".

In 63 events the $Q_{2\alpha}$ value does not exceed 500 keV (inset in Fig 5a)). For them, the average value is $\langle Q_{2\alpha} \rangle \approx 110 \pm 20$ keV and the mean-square scattering $\sigma = 40$ keV, which well corresponds to the decays of the ^{8}Be 0^{+} ground state. The unbound ^{9}B nucleus can be another major product of the ^{10}C coherent dissociation. The $Q_{2\alpha p}$ values for one of two possible $2\alpha + p$ triples do not exceed 500 keV in 58 events (inset in Fig. 5b)). The average value for these triples is $\langle Q_{2\alpha p} \rangle = 250 \pm 15$ keV with rms $\sigma = 74$ keV.

In addition, excitations $\alpha + 2p$ are studied on the remaining statistics of "white" stars 2He + 2H beyond ^{9}B decays. In the spectrum of $Q_{\alpha 2p}$, there is no clear signal of ^{6}Be decays [12], and its estimated contribution does not exceed 20%. This aspect deserves further analysis taking the proton angular correlations into account.

Summary of research program for years 2012-2014

The BECQUEREL Collaboration exposed nuclear track emulsion to a mixed beam of ^{12}N, ^{10}C and ^{7}Be nuclei and performed accumulation of statistics. Continuation of the BECQUEREL project for the years 2012-14 will be mostly devoted to observational study of peripheral fragmentation of relativistic nuclei ^{10}C and ^{12}N in nuclear track emulsion.

Paired protons can have the meaning of a covalent pair in the ^{10}C molecular-like system with two-center potential $\alpha + 2p + \alpha$. Verification of these assumptions will be made in the correlation analysis of the pairs of $2p$, 2α and αp, and then for more complex configurations with unstable nuclei, i. e. $p + {}^{9}\text{B}$, $2p + {}^{8}\text{Be}$ and $\alpha + {}^{6}\text{Be}$.

Apparently, the ^{11}C nucleus does not manifest itself as a ^{12}N core in spite of low energy of proton binding. To clarify the nucleon clustering in the ^{12}N nucleus it is required to increase statistics and to identify H and He isotopes by multiple scattering measurements.

Besides, there are new opportunities based on an analysis already found 400 "non-white" stars ^{7}Be with regard to the issue of "dihelion". Structure of unbound nuclei ^{6}Be, ^{7}B, ^{8}C and ^{11}N formed in the fragmentation of ^{7}Be, ^{8}B, ^{9}C and ^{12}N nuclei will be explored by using of the exposed emulsion.

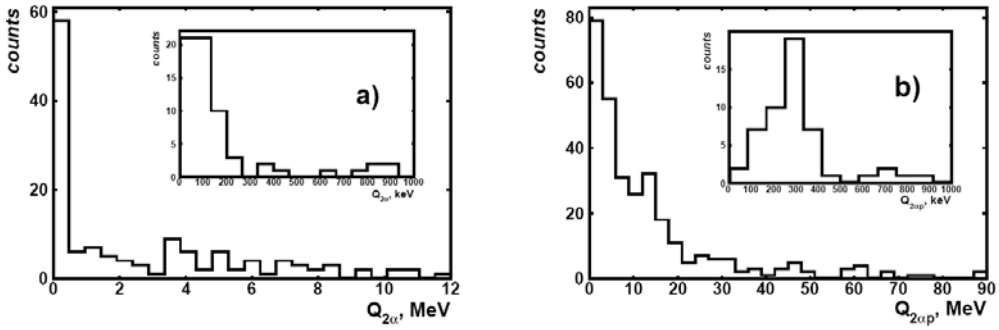

Fig. 5, a) Distribution of the number of "white" stars 2α + 2*p* versus excitation energy $Q_{2\alpha}$ of the α-pairs. In the inset a zoom over the $Q_{2\alpha}$ distribution is shown. b) Distribution of the number of "white" stars 2α + 2*p* versus excitation energy $Q_{2\alpha p}$ of triples 2α + *p*. In the inset a zoom over the $Q_{2\alpha p}$ distribution is shown.

The investigation of the cluster degrees of freedom in the ^{7}Be and ^{10,11}B nuclei will be extended to a new level of statistics and detailed descriptions. Observation of the simultaneous presence of the ^{8}Be 0^{+} and 2^{+} states with similar weights in the ground state of the nucleus ^{9}Be raises the problem of research 2α-particle correlations in ^{10,11} B and ^{10}C fragmentation with high statistics to identify the role of ^{8}Be 2^{+} state in them.

Of a fundamental interest is the search for effects depending on the charge of parent nucleus for relativistic ^{11}B and ^{11}C nuclei which demands new exposure. Nuclotron beam time requested is approximately 60 hours per year.

The main tasks include:

1. Investigation of peripheral nuclear fragmentation ^{10}C on the statistics 500 interactions
2. Investigation of peripheral nuclear fragmentation ^{12}N on the statistics 100 interactions
3. Search 2^{3}He-resonance in the peripheral nuclear fragmentation ^{9}C, ^{8}B, ^{7}Be on the statistics 200 pairs of 2^{3}He
4. Irradiation of nuclear emulsion in the secondary beam containing the isotope ^{11}C, formed by exchange reaction of the accelerated nuclei
5. Studies 2α-particle correlations in ^{10,11}B fragmentation in statistics 200 interactions
6. Studies of ^{28}Si and ^{32}S clustering at a new level of statistics and detailed descriptions
7. Irradiation of nuclear emulsions by ^{11}C and heavy relativistic nuclei

Recent publications

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4. D. A. Artemenkov, T. V. Shchedrina, R. Stanoeva, and P. I. Zarubin, AIP Conf. Proc., 912, 78(2007); arXiv:0704.0384.
5. Stanoeva R. et al., Phys. At. Nucl., 72, 690 (2009); arXiv:0906.4220.
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