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Clustering pattern of light nuclei in peripheral dissociation above 1 A GeV

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Abstract. Status of nuclear clustering studies based on fragmentations of light nuclei with energy above 1 A GeV in nuclear emulsions is sketched.

Fragmentation of relativistic nuclei provides an excellent "laboratory" to explore the transition of nuclei from the ground state to a gas-like phase composed of nucleons and few-nucleon clusters having no excited states, i.e. d, t, ^{3}He, and α. The research challenge is to find indications for the formation of quasi-stable or loosely bound systems significantly exceeding the sizes of the fragments. Search for such states on the nuclear scale is of undoubted interest since they can play a role of intermediate states ("waiting stations") for a stellar nuclear fusion due to dramatically reduced Coulomb repulsion. The fragmentation features might assist one to disclose the scenarios of few-body fusions as processes inverse to fragmentation.

The fragmentation of a large variety of light nuclei was investigated using the emulsions exposed to few A GeV nuclear beams at JINR [1 and Ref. herein]. In this energy range, the pattern of the relativistic fragmentation loses sensitivity either to the collision energy or to the particular properties of a target nucleus. As an illustration, a 3.65 A GeV ^{28}Si fragmentation in emulsion is shown in Fig. 1. The tracks of relativistic fragments remain in an emulsion sufficiently long for a 3D event image to be reconstructed. A system of 6 He fragments within a narrow cone is of particular interest. The cone is defined by the ratio of the transverse Fermi momentum to the primary nucleus one. The identification of relativistic H and He isotopes in emulsion is possible via the determination of the mean angle of multiple scattering. The excitation energy is defined by a fragment multiplicity, the masses, and the emission angles. It can be estimated as the difference between the invariant mass of the fragmenting system and the mass of the primary nucleus that amounts to not more than 1 MeV per nucleon of the fragment.

The common topological feature for fragmentation of the Ne, Mg, Si, and S nuclei consists in a suppression of binary splitting to fragments with charges larger than 2. The growth of the fragmentation degree is revealed in an increase of the multiplicity of singly and doubly charged fragments up to complete dissociation with increasing of excitation. This circumstance shows in an obvious way on a domination of the multiple cluster states having high density over the binary states having lower energy thresholds.

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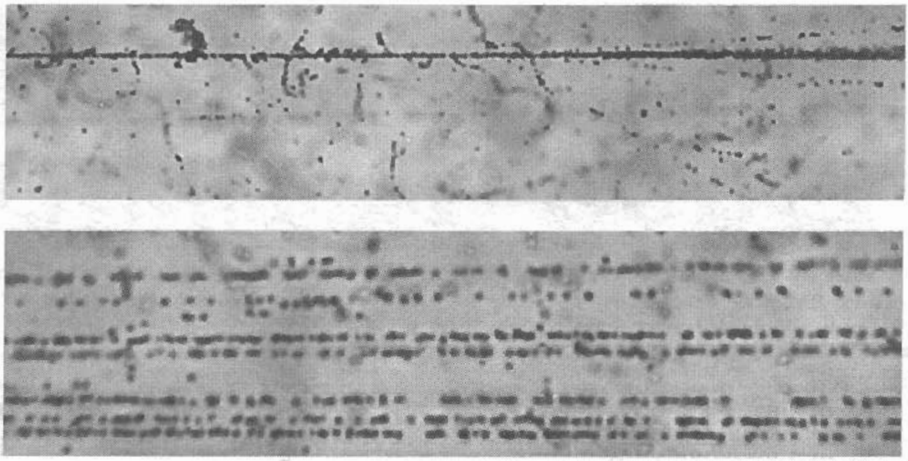

FIGURE 1. Event of a 3.65 A GeV ^{28}Si fragmentation in a peripheral interaction with an emulsion nucleus. In the upper photo one can see the interaction vertex, singly charged participant-nucleons, a produced meson pair, and the fragment jet collimated in a narrow angular cone. The jet is composed of a separate He fragment, an H fragment (product of α cluster direct interaction with meson pair production), a very narrow He pair (^{8}Be→2α), and a very narrow He triple (^{12}C*→3α) (lower photo).

Formation of systems involving the α, d and t nuclei is being studied for a relativistic fragmentation of ^{6,7}Li, ^{10,11}B, ^{12}C, ^{14}N and ^{16}O nuclei. The role of the deuteron as a cluster is especially pronounced in the "white" stars of ^{6}Li nuclei at an energy of 3.65 A GeV (^{6}Li*→dα – 74%, ^{6}Li*→^{3}Het – 13%, ^{6}Li*→tdp – 13%). The topology of "white" stars was investigated for ^{10}B nuclei at the energy of 1.0 A GeV. The fraction of the ^{10}B*→dαα decays is 40% of the events with a charge topology 2+2+1 (80% of final states with a charge 5). The contribution of the channel ^{10}B*→d^{8}Be→dαα is estimated to be 18±3%. It may be concluded that the direct 3-body decays with "white" stars 2+2+1 configuration play a crucial role.

Emulsion stacks were exposed to 1.23 A GeV ^{7}Be nuclei. 27 "white" stars having only two prongs with the charge topology 2+2 were found. The ^{7}Be*→α^{3}He decay is identified in 22 events. In the latter, 5 events are due to the ^{7}Be*→(n) ^{3}He^{3}He decay. In the case of 36 events with 2+1+1 topology, 20 tracks with Z=2 were identified as ^{3}He and 16 tracks - as ^{4}He. Thus, a ^{3}He clustering in ^{7}Be relativistic excitation is shown and the next round of tasks, as to whether this kind of nuclear clustering is revealed in heavier neutron-deficient nuclei, might be attacked.

In 2004, emulsion stacks were exposed to 1.3 A GeV ^{9}Be, ^{8}B, and ^{9}C nuclei. The clear production of "white" stars with α particle pairs is initiated in the ^{9}Be fragmentation with removal of a loosely bound neutron (fig. 2). An analysis of the data will allow one to conclude about clustering in the ^{9}Be nucleus and extent experience of ^{8}Be identification in n-^{8}Be, n-^{8}Be*, and αnα excitations.

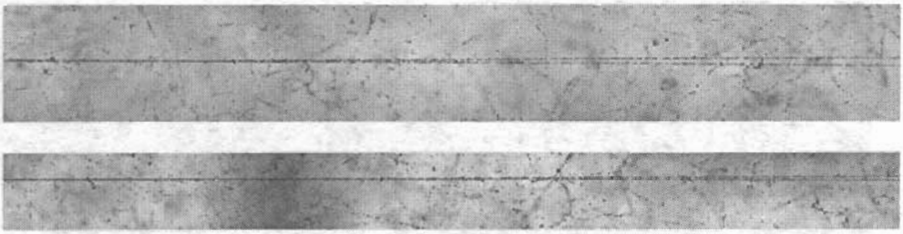

FIGURE 2. Examples of the events of the peripheral ^{9}Be in emulsion at 1.3 A GeV: a splitting to two He fragments (upper photo) without target nucleus excitation or visible recoil and to two He fragments with a recoil proton (lower photo).

It is planned to determine the relative probabilities of $^{8}B^{*}\to p^{7}Be$, $p^{3}He\alpha$, $pp^{6}Li$, and $ppd\alpha$. There arises a possibility of studying the decays $^{7}B\to ppp\alpha$ and $p^{3}He^{3}He$ since a nuclear stability border gets crossed in the $^{8}B\to{}^{7}B$ fragmentation. In the relativistic case such decays would be appearing as narrow jets convenient for a analysis.

The priority task is to establish the probability of $^{9}C^{*}\to 3^{3}He$ decays with respect to $^{9}C^{*}\to p^{8}B$, $pp^{7}Be$. The inverse processes $^{3}He^{3}He^{3}He\to pp^{3}He\alpha\to{}^{9}C$ are similar to 3α fusions but produce a significantly higher energy output. A decay to a ^{9}B nucleus that is not a bound one, results in the $^{9}B\to p\alpha\alpha$ decay. Thus, in a stellar medium, initially composed of the ^{3}He, a workout of ^{4}He can proceed. In fragmentation $^{9}C\to{}^{8}C$, a crossing of the stability boundary takes place once more and $^{8}C^{*}\to pppp\alpha$ and $pp^{3}He^{3}He$ decays can be explored. It is suggested to form ^{10,11}C beams to explore the ^{3}He role in ^{10,11}C 3-body decays and to extent the "3He" process ($^{3}He^{3}He\alpha$, $^{3}He\alpha\alpha$).

To conclude, emulsions exposed to light relativistic nuclei provide a unique basis for studies of few body nuclear systems with minimal experimental distortions and interpretation sophistications. Thank to the best spatial resolution and the full solid angle acceptance provided by nuclear emulsions, such an approach allows one to obtain observations reflecting cluster-like features in decays of light nuclear structures. Observations of projectile fragmentation open up new opportunities to explore excited nuclear states above particle decay thresholds up to complete dissociation. Such states might play a role of intermediate quantum states in a fusion of more than two nuclei in stellar processes. More images reflecting capabilities of emulsion technique of this can be found via the Web [2].

REFERENCES

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2. Web site of the BECQUEREL Project, *http://becquerel.lhe.jinr.ru.*