Clustering features of light neutron-deficient nuclei in nuclear fragmentation

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VBLHEP, JINR

NUCLEUS-2015

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BECQUEREL at the JINR Nuclotron is devoted systematic exploration of clustering features of light stable and radioactive nuclei.

The fragmentation of a large variety of light nuclei was investigated using the emulsions exposed to few A GeV nuclear beams at JINR Nuclotron. A nuclear track emulsion is used to explore the fragmentation of the relativistic nuclei.

Ongoing emulsion experiments

Experiments	Country	Area	Gel weight (dry)	Producer	Film/ Gel	Status	Special requirements
OPERA experiment	International	100,000 m^2	~30,000kg	Fuji	Film	Produced	Refreshing function.
Double Hyper nuclei	Japan		a few 1000 kg	**Not decided**	Gel	Doing R&D	For thick type emulsion
Balloon cosmic-ray	Japan	10 m^2	3 kg	Fuji	Film	Produced	
Dark Matter	Japan, Italy		1 kg (1-2 year)	Nagoya / to be done	Gel	Doing R&D	crystal size ~ 10nm
Muon radiography single experiment. ~10 experiments	Bern, Italy, Japan	a few m^2/exp. ~ 50m^2 /total	a few kg/exp 15 kg/total	Fuji or Nagoya	Film	Produced or to be produced.	
Medical applications hadron therapy basic study beam study Proton radiography Dosimetry R&D	 Japan Bern Bern Bern	 10 m^2 1 m^2 1 m^2 5 m^2	 3 kg 0.3kg 0.3kg 1.5 kg	 Fuji / done Fuji / done Fuji /	 Film Film Film Film	 Produced Produced Produced Produced	

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DOI: 10.1140/epjst/e2008-00802-0

THE EUROPEAN PHYSICAL JOURNAL SPECIAL TOPICS

Secondary nuclear fragment beams for investigations of relativistic fragmentation of light radioactive nuclei using nuclear photoemulsion at Nuclotron

P.A. Rukoyatkin[a], L.N. Komolov, R.I. Kukushkina, V.N. Ramzhin, and P.I. Zarubin

ISSN 1063-7788, Physics of Atomic Nuclei, 2008, Vol. 71, No. 9, pp. 1565–1571. © Pleiades Publishing, Ltd., 2008.

ELEMENTARY PARTICLES AND FIELDS
Experiment

Fragmentation of Relativistic Nuclei in Peripheral Interactions in Nuclear Track Emulsion*

D. A. Artemenkov[1)**], V. Bradnova[1)], M. M. Chernyavsky[2)], L. A. Goncharova[2)], M. Haiduc[3)], N. A. Kachalova[1)], S. P. Kharlamov[2)], A. D. Kovalenko[1)], A. I. Malakhov[1)], A. A. Moiseenko[4)], G. I. Orlova[2)], N. G. Peresadko[2)], N. G. Polukhina[2)], P. A. Rukoyatkin[1)], V. V. Rusakova[1)], V. R. Sarkisyan[4)], R. Stanoeva[5)], T. V. Shchedrina[1)], S. Vokál[1)], A. Vokálová[1)], P. I. Zarubin[1)***], and

Few Body Syst (2008) 44: 273–276
DOI 10.1007/s00601-008-0307-6
Printed in The Netherlands

Few-Body Systems

Detailed study of relativistic ^{9}Be → 2α fragmentation in peripheral collisions in a nuclear track emulsion*

D. A. Artemenkov**, D. O. Krivenkov, T. V. Shchedrina, R. Stanoeva, P. I. Zarubin

ЯДЕРНАЯ ФИЗИКА, 2009, том 72, № 4, с. 731–742

ЭЛЕМЕНТАРНЫЕ ЧАСТИЦЫ И ПОЛЯ

ЭЛЕКТРОМАГНИТНАЯ ДИССОЦИАЦИЯ РЕЛЯТИВИСТСКИХ ЯДЕР ^{8}B В ЯДЕРНОЙ ЭМУЛЬСИИ

© 2009 г. Р. Станоева[1),2)], Д. А. Артеменков[1)], В. Браднова[1)], С. Вокал[1),3)], Л. А. Гончарова[4)], П. И. Зарубин[1)*], И. Г. Зарубина[1)], Н. А. Качалова[1)], А. Д. Коваленко[1)], Д. О. Кривенков[1)], А. И. Малахов[1)], Г. И. Орлова[4)], Н. Г. Пересадько[4)], Н. Г. Полухина[4)], П. А. Рукояткин[1)], В. В. Русакова[1)], М. Хайдук[5)], С. П. Харламов[4)], М. М. Чернявский[4)], Т. В. Щедрина[1)]

ЯДЕРНАЯ ФИЗИКА, 2010, том 73, № 12, с. 2159–2165

ЭЛЕМЕНТАРНЫЕ ЧАСТИЦЫ И ПОЛЯ

КОГЕРЕНТНАЯ ДИССОЦИАЦИЯ РЕЛЯТИВИСТСКИХ ЯДЕР ^{9}C

© 2010 г. Д. О. Кривенков[1)], Д. А. Артеменков[1)], В. Браднова[1)], С. Вокал[2)], П. И. Зарубин[1)*], И. Г. Зарубина[1)], Н. В. Кондратьева[1)], А. И. Малахов[1)], А. А. Моисеенко[3)], Г. И. Орлова[4)], Н. Г. Пересадько[4)], Н. Г. Полухина[4)], П. А. Рукояткин[1)], В. В. Русакова[1)], В. Р. Саркисян[3)], Р. Станоева[1)], М. Хайдук[5)], С. П. Харламов[4)]

ЯДЕРНАЯ ФИЗИКА, 2010, том 73, № 12, с. 2166–2171

ЭЛЕМЕНТАРНЫЕ ЧАСТИЦЫ И ПОЛЯ

ОБЛУЧЕНИЕ ЯДЕРНОЙ ЭМУЛЬСИИ В СМЕШАННОМ ПУЧКЕ РЕЛЯТИВИСТСКИХ ЯДЕР ^{12}N, ^{10}C И ^{7}Be

© 2010 г. Р. Р. Каттабеков[1),2)], К. З. Маматкулов[1),3)], Д. А. Артеменков[1)], В. Браднова[1)], С. Вокал[4)], Д. М. Жомуродов[1),3)], П. И. Зарубин[1)*], И. Г. Зарубина[1)], З. А. Игамкулов[1),3)], Н. В. Кондратьева[1)], Н. К. Корнегруца[1)], Д. О. Кривенков[1)], А. И. Малахов[1)], Г. И. Орлова[5)], Н. Г. Пересадько[5)], Н. Г. Полухина[5)], П. А. Рукояткин[1)], В. В. Русакова[1)], Р. Станоева[1),6)], М. Хайдук[7)], С. П. Харламов[5)]

Role of the Nuclear and Electromagnetic Interactions in the Coherent Dissociation of the Relativistic ^7Li Nucleus into the $^3H + ^4He$ Channel

N. G. Peresadko, V. N. Fetisov, Yu. A. Aleksandrov, S. G. Gerasimov, V. A. Dronov, V. G. Larionova, E. I. Tamm, S. P. Kharlamov

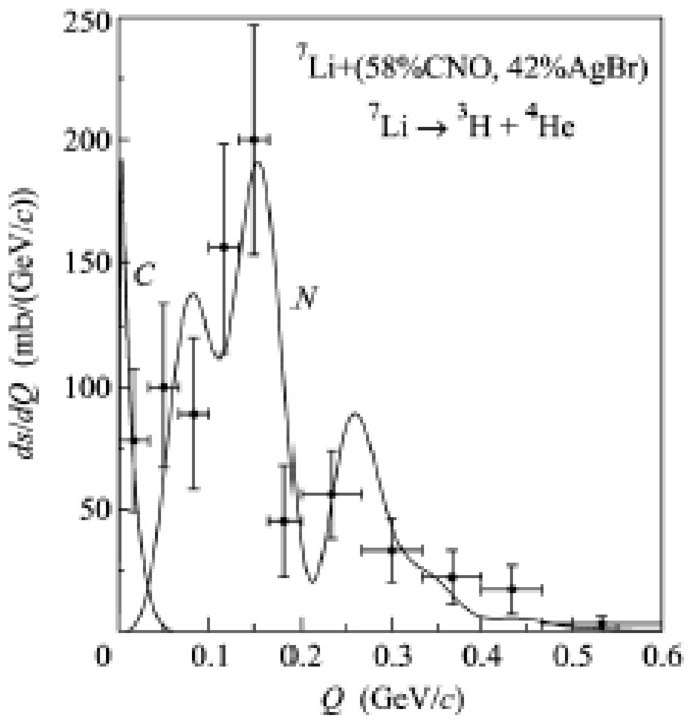


FIG. 1: Experimental and theoretical cross sections for (*C*) Coulomb and (*N*) nuclear diffraction dissociations of the ^{7}Li nuclei.

http://arxiv.org/pdf/1110.2881.pdf

$$^{12}C \rightarrow 3\alpha$$

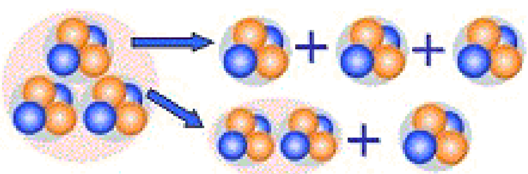
Physics of Atomic Nuclei, Vol. 58, No. 11, 1995, pp. 1905 - 1910. Translated from Yadernaya Fizika, Vol. 58, No. 11, 1995, pp. 2014 - 2020.

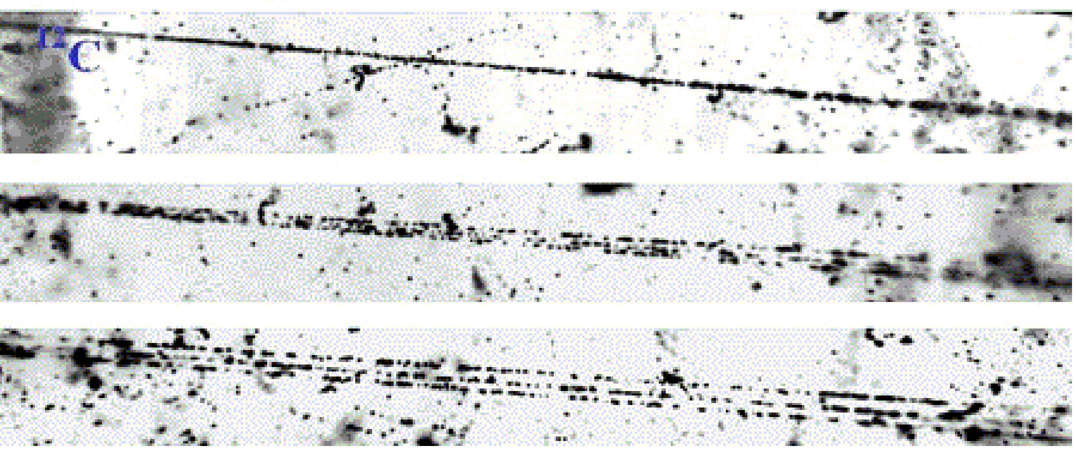
ELEMENTARY PARTICLES AND FIELDS
Experiment

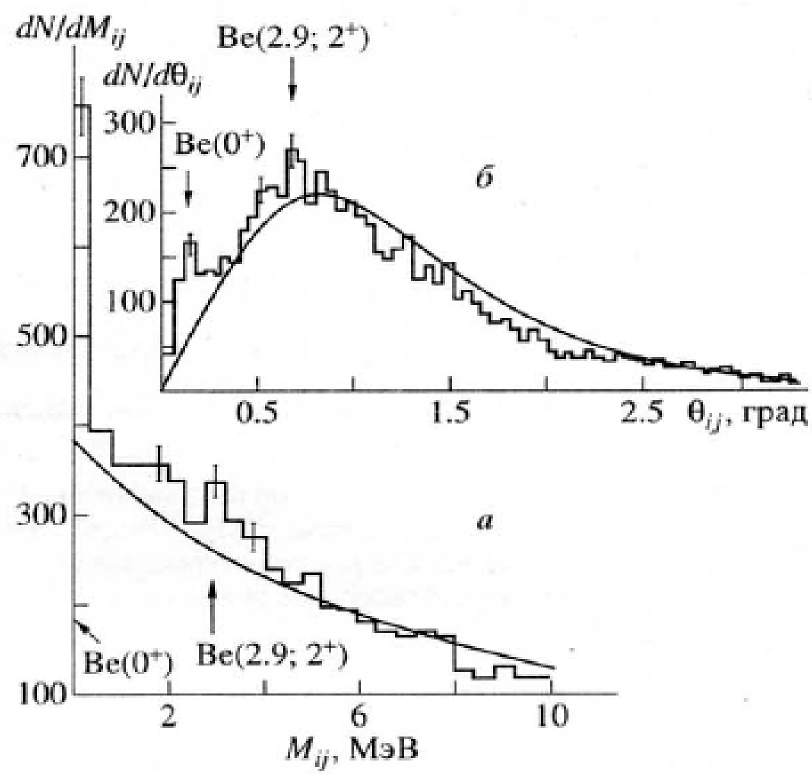
Coherent Dissociation $^{12}C \to 3\alpha$ in Lead-Enriched Emulsion at 4.5 GeV/*c* per Nucleon

V. V. Belaga, A. A. Benjaza[1)], V. V. Rusakova, J. A. Salamov[2)], and G. M. Chernov

$^{12}C \to 3\alpha$, 3.65 A GeV



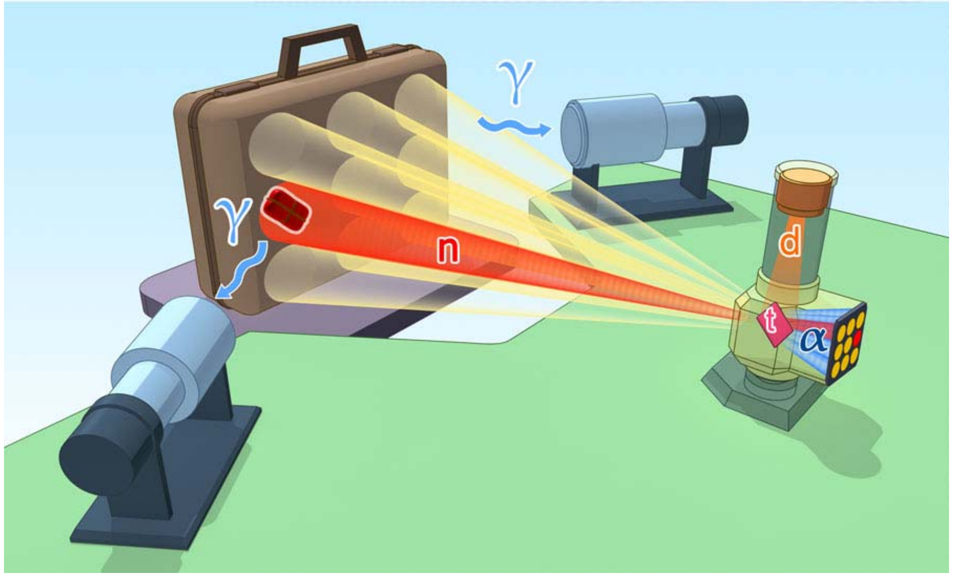




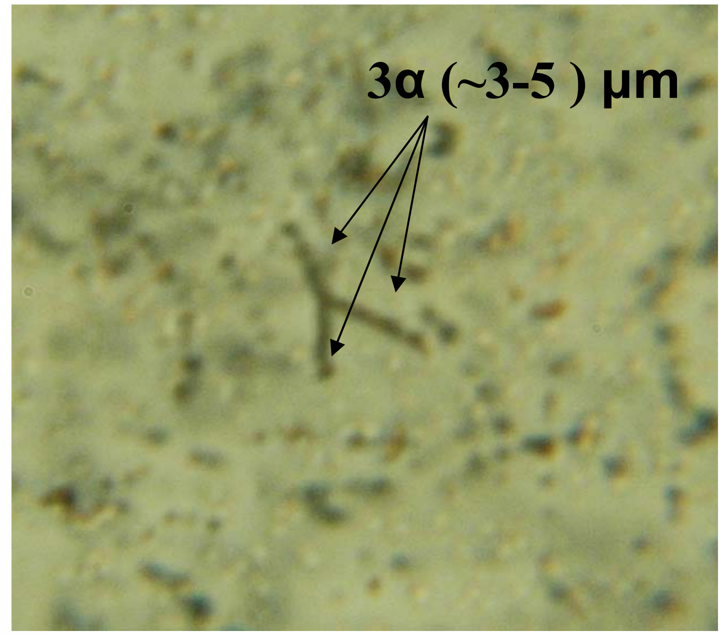
(PAVICOM image)

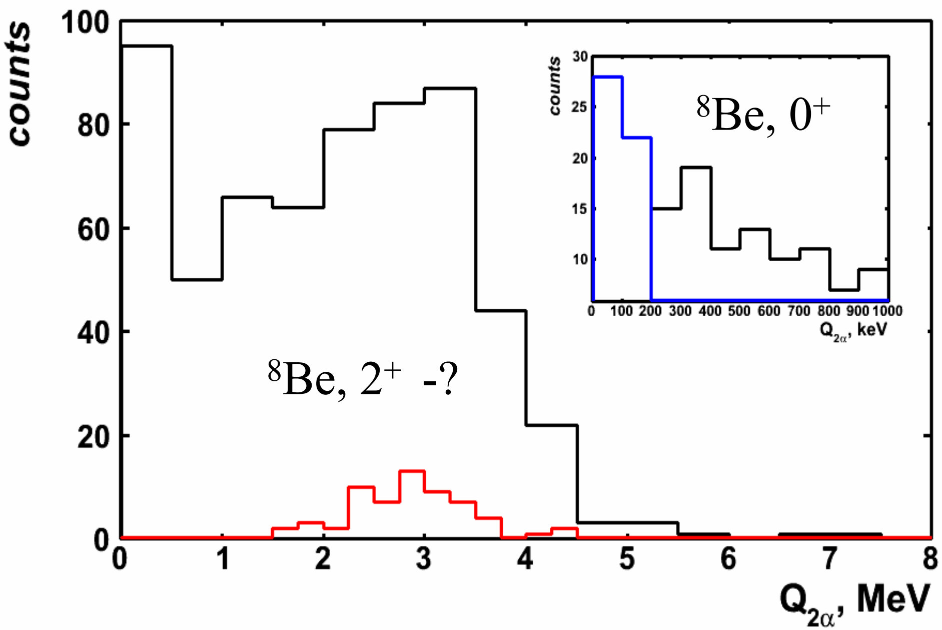
http://neutrontech.ru

$^{12}C(n,n')3\alpha$, $E_n = 14.1$ MeV



DVIN - explosives detector on the basis of fast tagged neutron method for complex program for population safety in transport



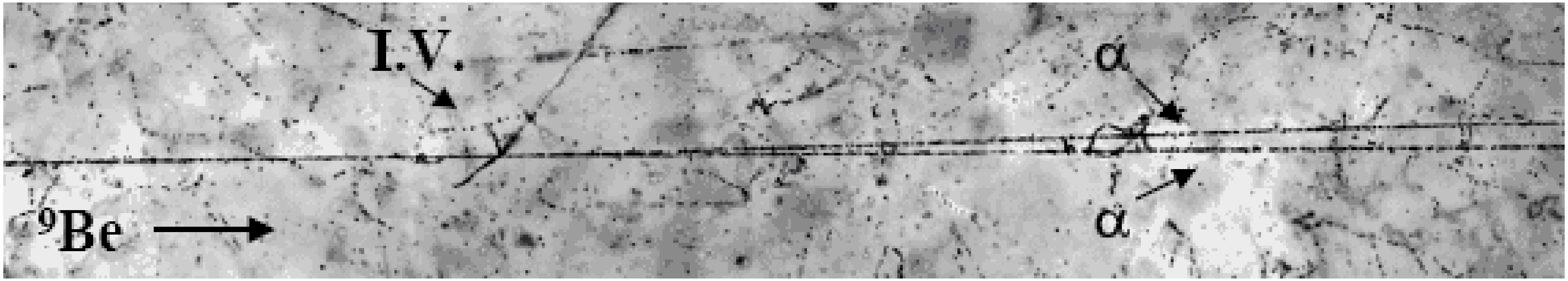


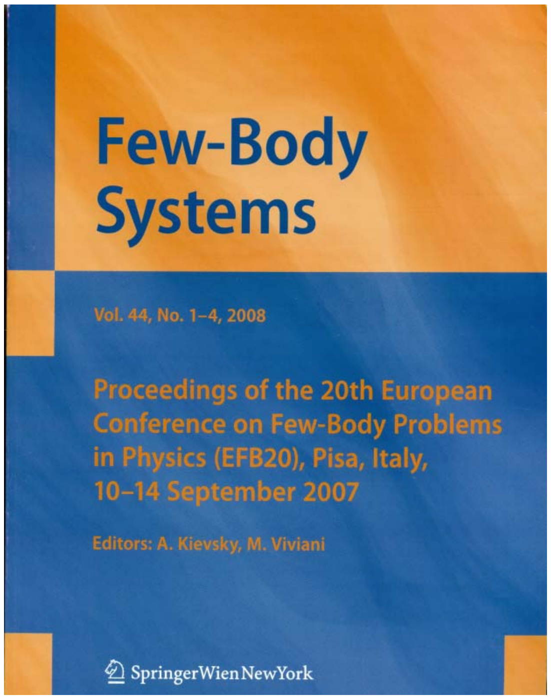
$$M_{2\alpha} = \left[2\left(m_\alpha^2 + E_{\alpha 1}E_{\alpha 2} - p_{\alpha 1}p_{\alpha 2}\cos(\Theta_{12})\right)\right]^{\frac{1}{2}}$$

$$Q_{2\alpha} = M_{2\alpha} - 2\cdot m_\alpha$$

$$^{9}Be \rightarrow 2\alpha$$

(1.2 A GeV)





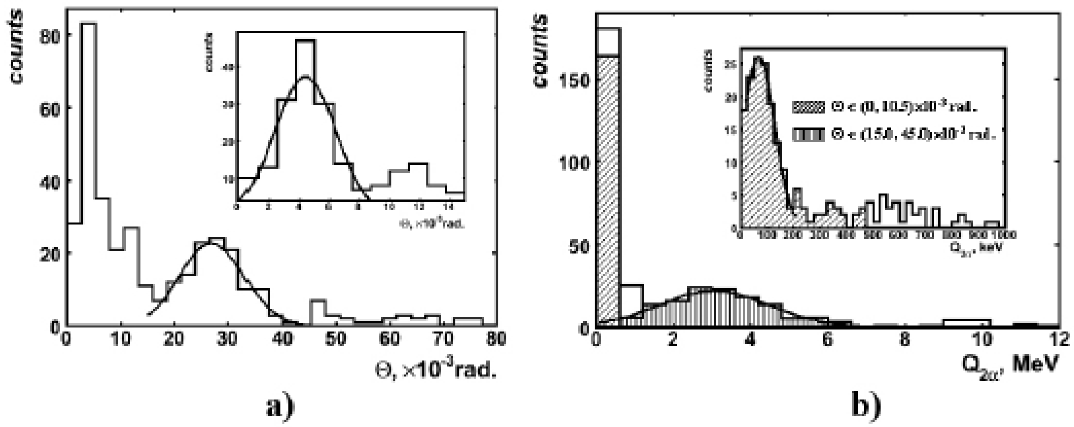
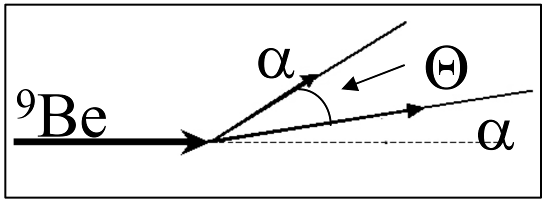
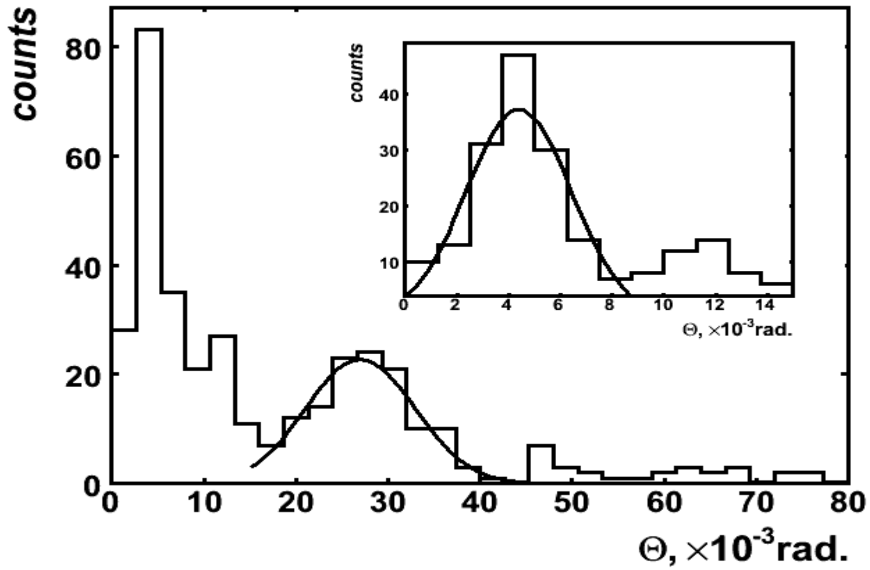


Figure 1. The opening Θ angle distribution of α particles in the $^{9}Be \to 2\alpha$ fragmentation reaction at 1.2 A GeV energy. On the intersection: the Θ range from 0 to 15×10^{-3} rad.– a). The invariant energy $Q_{2\alpha}$ distribution of α particle pairs in the $^{9}Be \to 2\alpha$ fragmentation reaction at 1.2 A GeV energy. On the intersection: the $Q_{2\alpha}$ range from 0 to 1 MeV –b).

Opening angle distribution of two α-particles

$^9Be \to 2\alpha$





Θ, mrad	*<Θ>, mrad*	*σ_Θ, mrad*	**Fraction (Events)**
Θ_n (0 - 10.5)	*4.4 ± 0.2*	*2.1 ± 0.2*	*0.56 ± 0.04 (164)*
Θ_w (15.0 – 45.0)	*27.0 ± 0.6*	*5.9 ± 0.6*	*0.44 ± 0.04 (130)*

Fractions of events Θ_n and Θ_w demonstrate compliance with weights 0^+ and 2^+ states of a ^8Be core, adopted in the two-body model, $\omega_{0+} = 0.535$ and $\omega_{2+} = 0.465$ [1,2]. They indicate the presence of these states as components of the ground state of the ^9Be nucleus.

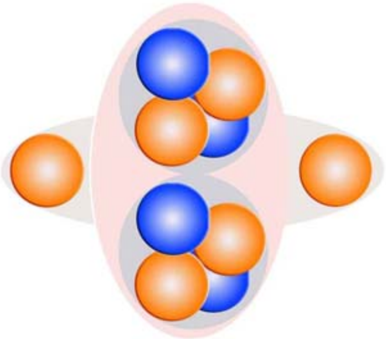
1. Y. L. Parfenova and Ch. Leclercq-Willain, «Hyperfine anomaly in Be isotopes and neutron spatial distribution: A three-cluster model for ^{9}Be», Phys. Rev. C 72, 054304 (2005).

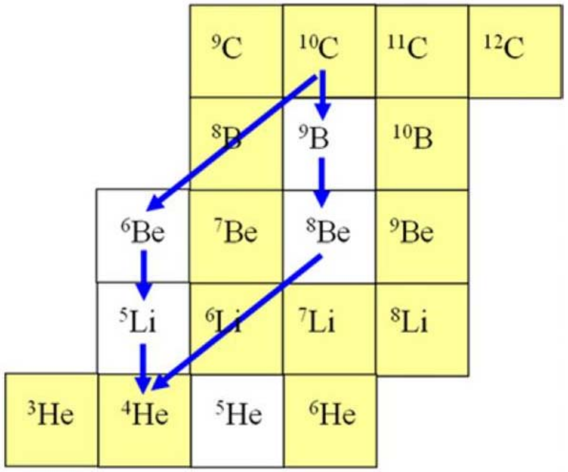
2. Y. L. Parfenova and Ch. Leclercq-Willain, «Hyperfine anomaly in Be isotopes in the cluster model and the neutron spatial distribution», Phys. Rev. C 72, 024312(2005)

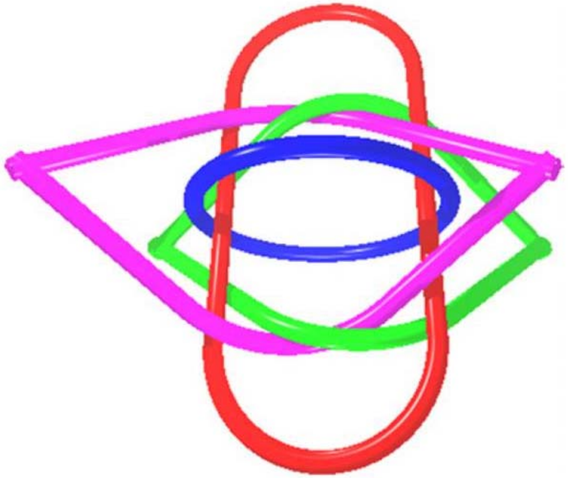
$$^{10}C \rightarrow 2\alpha + 2p$$

(1.2 A GeV)

^{10}C



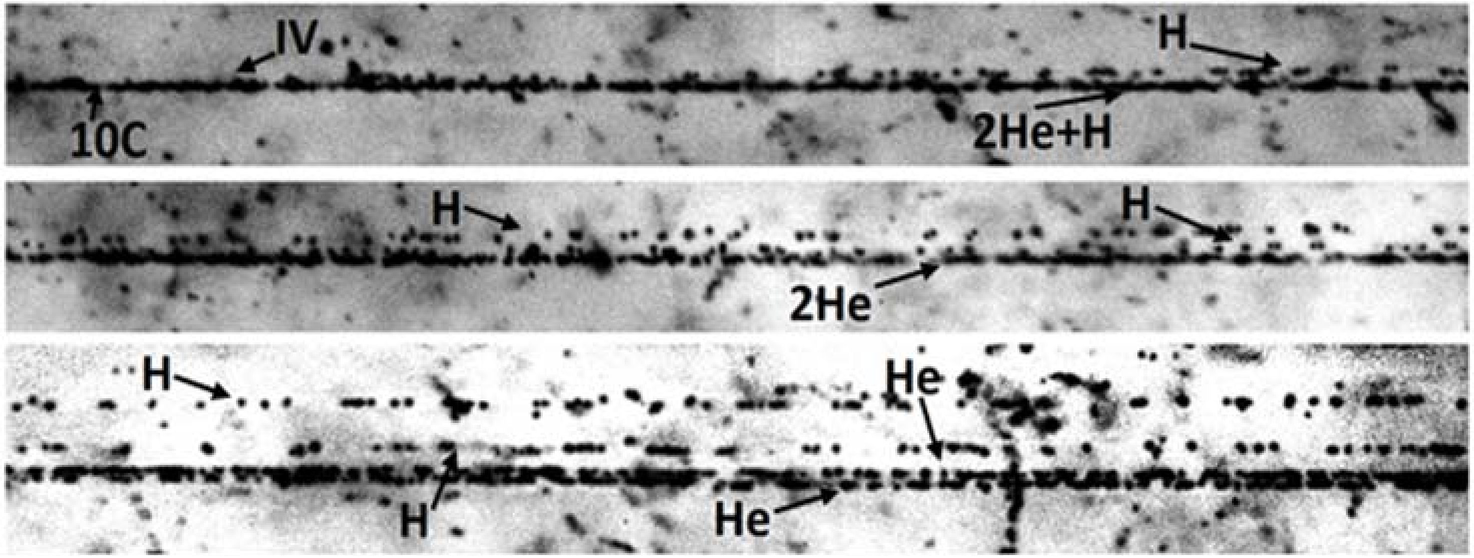




Charge-topology distribution of fragments from white stars, N_{ws}, where the total charge of relativistic fragments is $\sum Z_{fr} = 6$, and from $\sum Z_{fr} = 6$ events, N_{tf}, accompanied by target fragments or product mesons

Channel	N_{ws}, %	N_{tf}, %
2He + 2H	186 (81.9)	361 (57.6)
He + 4H	12 (5.3)	160 (25.5)
3He	12 (5.3)	15 (2.4)
6H	9 (4.0)	30 (4.8)
Be + He	6 (2.6)	17 (2.7)
B + H	1 (0.4)	12 (1.9)
Li + 3H	1 (0.4)	2 (0.3)
$^{9}C + n$	–	30 (4.8)

$^{10}C \rightarrow {}^{9}B + p \rightarrow {}^{8}Be + 2p$ *(25-30%)*



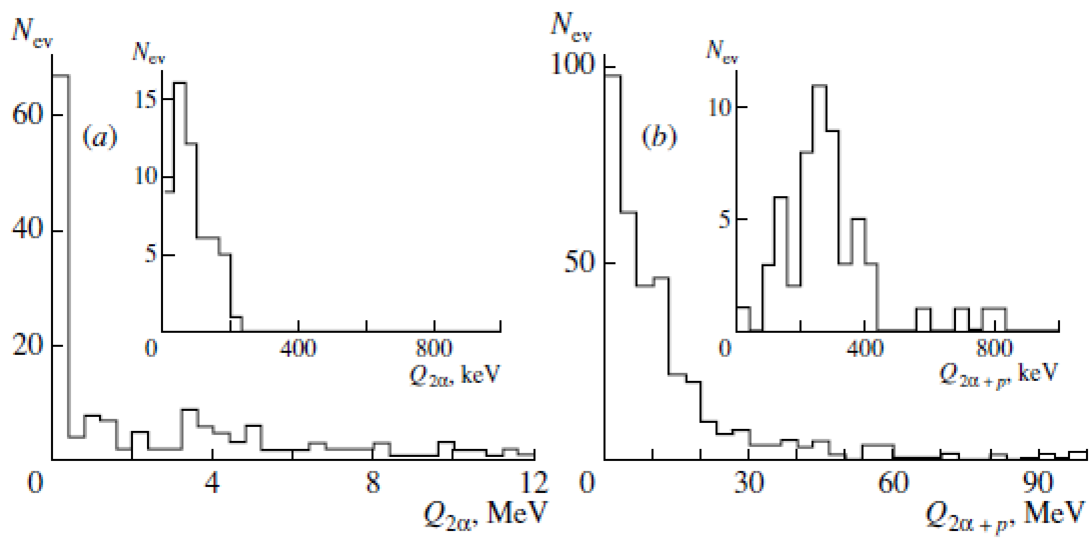


Fig. 6. Distributions of $^{10}C \rightarrow 2\alpha + 2p$ events with respect to the (*a*) energy $Q_{2\alpha}$ of alpha-particle pairs and (*b*) energy $Q_{2\alpha p}$ of the $2\alpha + p$ three-particle systems. The insets show enlarged distributions of $Q_{2\alpha}$ and $Q_{2\alpha p}$.

Исследование изотопов углерода в проекте Беккерель

^{9}C

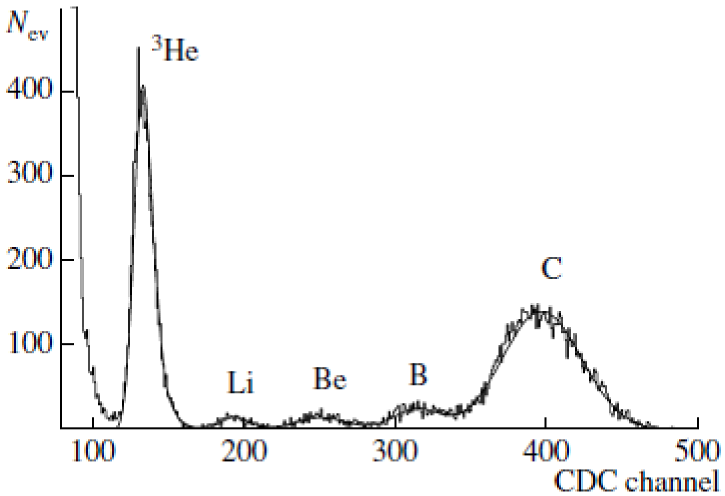


Fig. 1. Charge spectrum of nuclei from the $^{12}C \to {}^{9}C$ fragmentation process in the case where the secondary beam is tuned to the value of $Z_{pr}/A_{pr} = 2/3$.

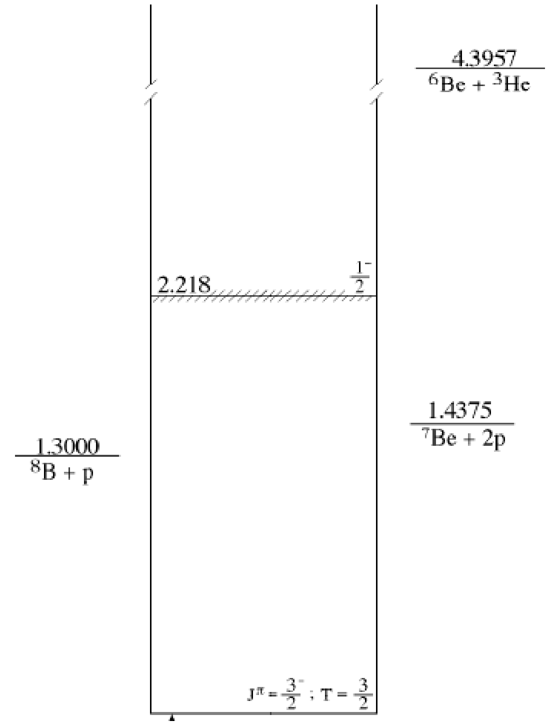
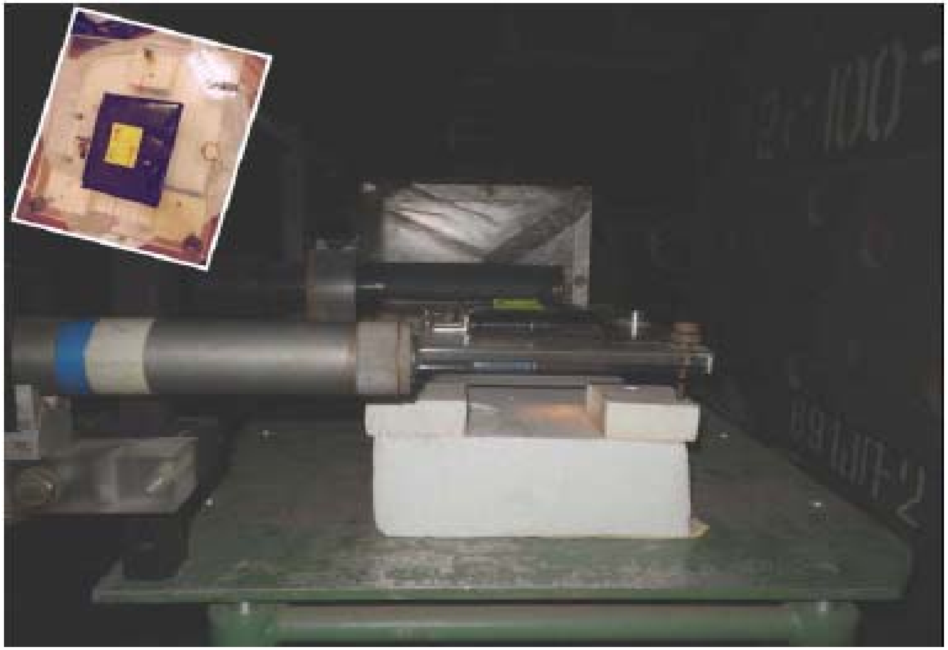


Table 1. Distribution of the number of "white" stars, N_{ws}, and the number of events involving the production of target fragments, N_{tf}, with respect to $\sum Z_{fr} = 6$ channels

Channel	B + H	Be + 2H	3He	Be + He	Li + He + H	Li + 3H	2He + 2H	He + 4H	6H
N_{ws}	15	16	16	4	2	2	24	28	6
N_{tf}	51	47	9	7	11	8	54	80	16

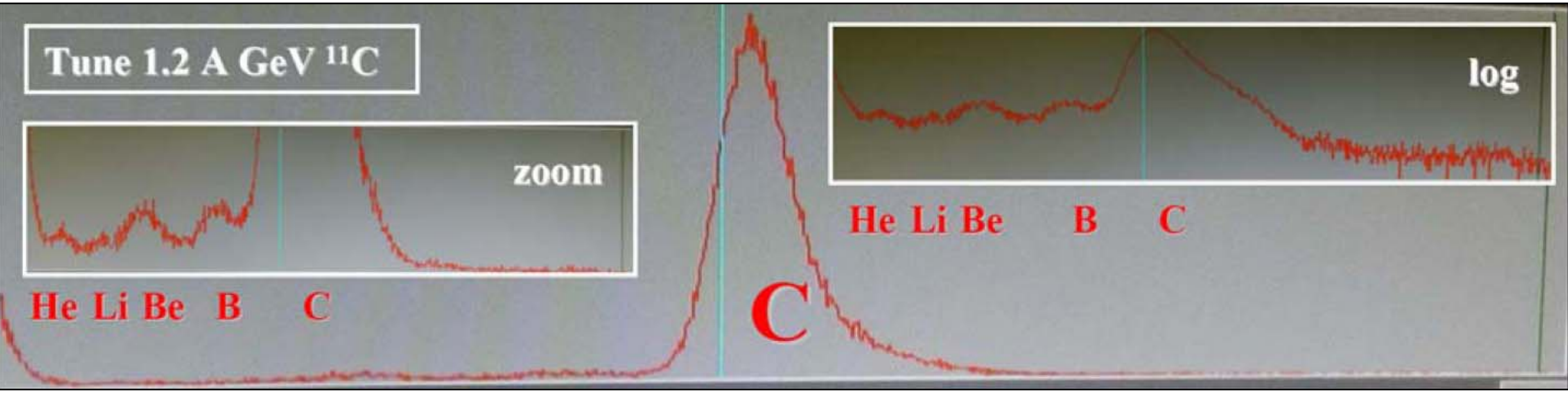
http://arxiv.org/abs/1104.2439

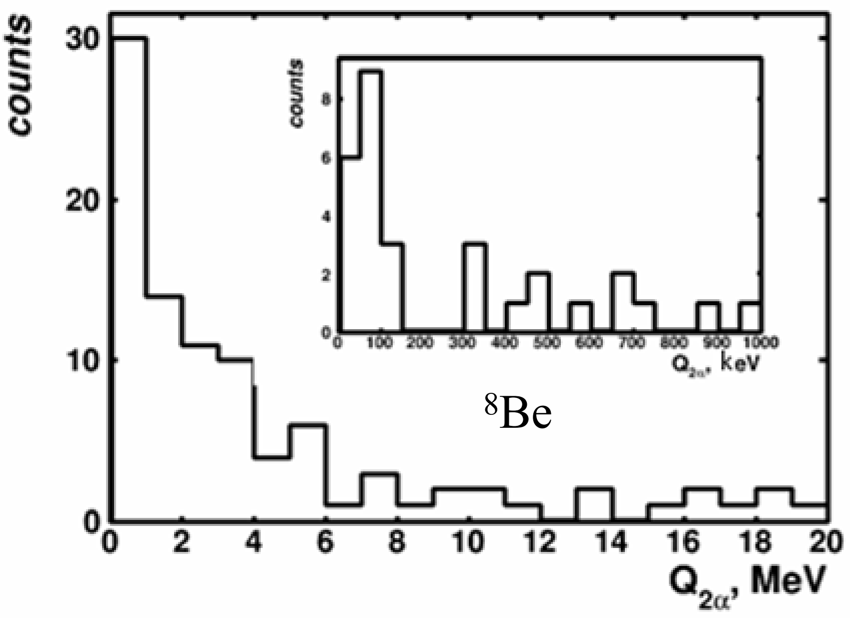
The exposure of NTE pellicles by relativistic ^{11}C 1.2 A GeV nuclei was held at the JINR Nuclotron Dec. 2014.



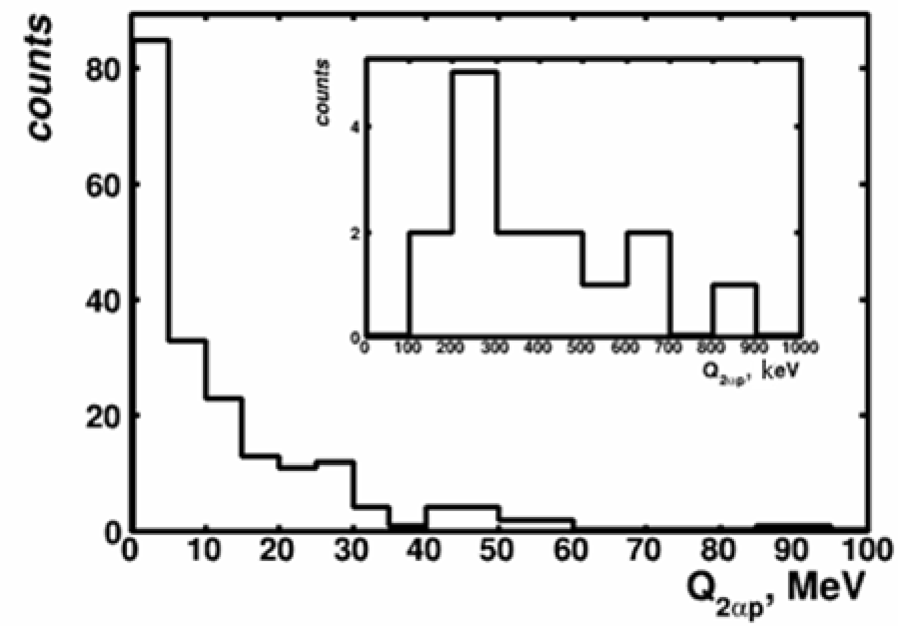
The observed channels of fragmentation ^{11}C nuclei

Channels	"White" stars	With emulsion nuclei fragments
6H	3 (2%)	10 (4%)
B + H	6 (3%)	7 (3%)
He + 4H	15 (9%)	44 (17%)
Li + He + H	5 (3%)	17 (7%)
Be + He	18 (10%)	26 (10%)
2He + 2H	72 (41%)	140 (53%)
3He	25 (14%)	19 (7%)





(a)



(b)

The distribution of events of the channel $^{11}C \rightarrow 2\alpha + 2p$ by excitation energy: $Q_{2\alpha}$ pairs α-particles in the inset - enlarged distribution $Q_{2\alpha}$ (a); $Q_{2\alpha+p}$ triples $2\alpha + p$, in the inset - enlarged distribution $Q_{2\alpha+p}$ (b).

Summary

The presented observations serve as an illustration of prospects of the Nuclotron and NTE for nuclear physics researches.

Due to a record space resolution the emulsion technique provides unique entirety in studying of light nuclei, especially, neutron-deficient ones. Providing the 3D observation of narrow dissociation vertices this classical technique gives novel possibilities of moving toward more and more complicated nuclear systems.

The results of an exclusive study of the interactions of relativistic ^{9}***Be,*** ^{10,12}***C nuclei lead to the conclusion that the known features of their structure are clearly manifested in very peripheral dissociations.***

Thank you for your attention!

CLUSTERING FEATURES OF LIGHT NEUTRON-DEFICIENT NUCLEI IN NUCLEAR FRAGMENTATION

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Nuclear track emulsion (NTE) is still retaining its exceptional position as a means for studying the structure of diffractive dissociation of relativistic nuclei owing to the completeness of observation of fragment ensembles and owing to its record spatial resolution. Separation of products of fragmentation and charge-exchange reactions of accelerated stable nuclei make it possible to create beams of radioactive nuclei. A unification of the above possibilities extends the investigation of the clustering phenomena in light radioactive proton-rich nuclei. Conclusions concerning clustering features are based on the probabilities for observing of dissociation channels and on measurements of angular distributions of relativistic fragments.

At the JINR Nuclotron exposures of NTE stacks of (NTE) are performed at energy above 1 *A* GeV to the beams of isotopes Be, B, C and N, including radioactive ones [1–3]. In general, the results confirm the hypothesis that the known features of light nuclei define the pattern of their relativistic dissociation. The probability distributions of the final configuration of fragments allow their contributions to the structure of the investigated nuclei to be evaluated. These distributions have an individual character for each of the presented nuclei appearing as their original “autograph”. The nuclei themselves are presented as various superpositions of light nuclei-cores, the lightest nuclei-clusters and nucleons. Recent data on pattern of diffractive dissociation of the nuclei ^{9}C, ^{10}C, ^{11}C and ^{12}N will be discussed in this context.

1. P.I.Zarubin // Lect. Notes in Phys, Springer. 2013. V.875. P.51.
2. D.A.Artemenkov *et al.* // Few-Body Systems. V.50. Issue 1-4. P.259.
3. D.A.Artemenkov *et al.* // Few-Body Systems. 2008. V.44. P.273.