BECQUEREL PROJECT

Проект БЕККЕРЕЛЬ

Beryllium (Boron) Clustering Quest in Relativistic Multifragmentation

http://becquerel.jinr.ru

Study of light nuclei fragmentation in nuclear track emulsion and simulation in the Becquerel experiment

Denis Artemenkov,

VBLHEP, JINR

XXIV ISHEPP, 20.09.2018

BECQUEREL PROJECT

Проект БЕККЕРЕЛЬ

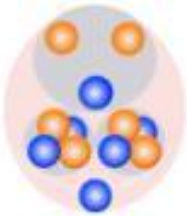
Beryllium (Boron) Clustering Quest in Relativistic Multifragmentation

http://becquerel.jinr.ru

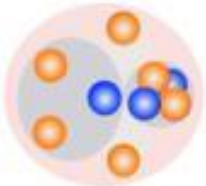
BECQUEREL at the JINR Nuclotron-NICA is devoted systematic exploration of clustering features of light stable and radioactive nuclei.

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.

^{12}N 11.0 ms

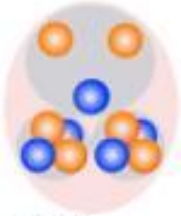


^{9}C 0.1265 s

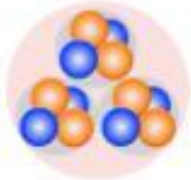


^{10}C 19.2 s

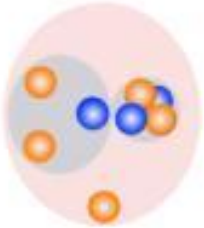
^{11}C 20.38 m



^{12}C 98.89 %

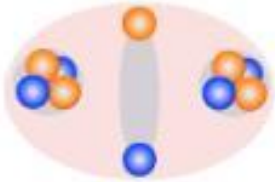


^{8}B 0.769 s

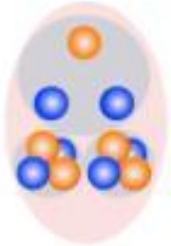


^{9}B 540 eV

^{10}B 19.8%



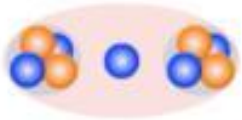
^{11}B 80.2 %



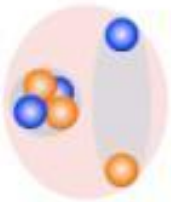
^{7}Be 53.3 d

^{8}Be 6.8 eV

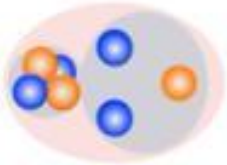
^{9}Be 100%



^{6}Li 7.5 %



^{7}Li 92.5 %



Eur. Phys. J. Special Topics **162**, 267–274 (2008)

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

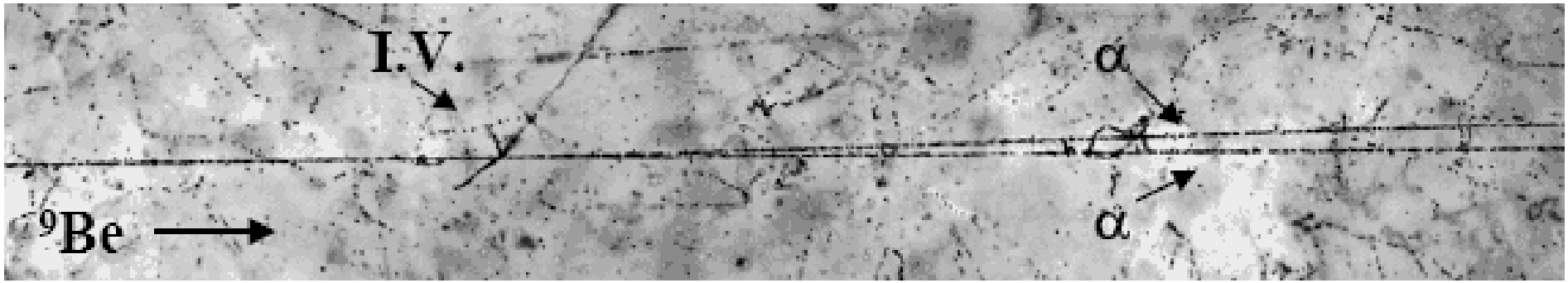
© 2010 г. Д. О. Кривенков[1)], Д. А. Артеменков[1)], В. Браднова[1)], С. Вокал[2)], П. И. Зарубин[1)*], И. Г. Зарубина[1)], Н. В. Кондратьева[1)], А. И. Малахов[1)], А. А. Моисеенко[3)], Г. И. Орлова[4)], Н. Г. Пересадько[4)], Н. Г. Полухина[4)], П. А. Рукояткин[1)], В. В. Русакова[1)], В. Р. Саркисян[3)],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

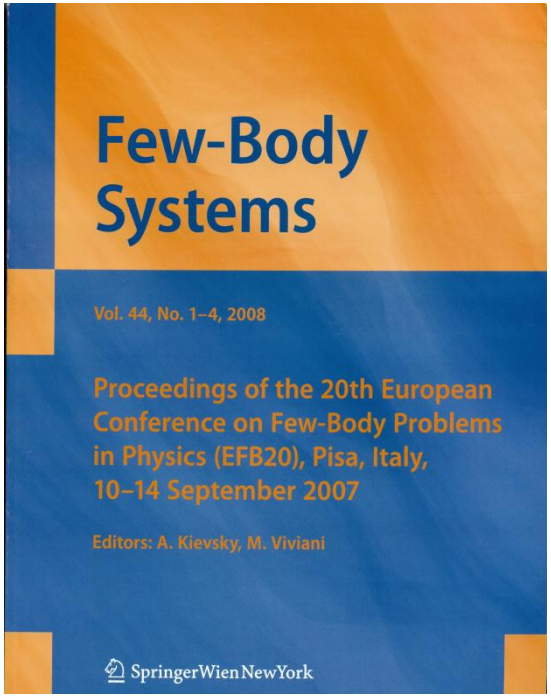
ЯДЕРНАЯ ФИЗИКА, 2010, том 73, № 12, с. 2166–2171

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)]





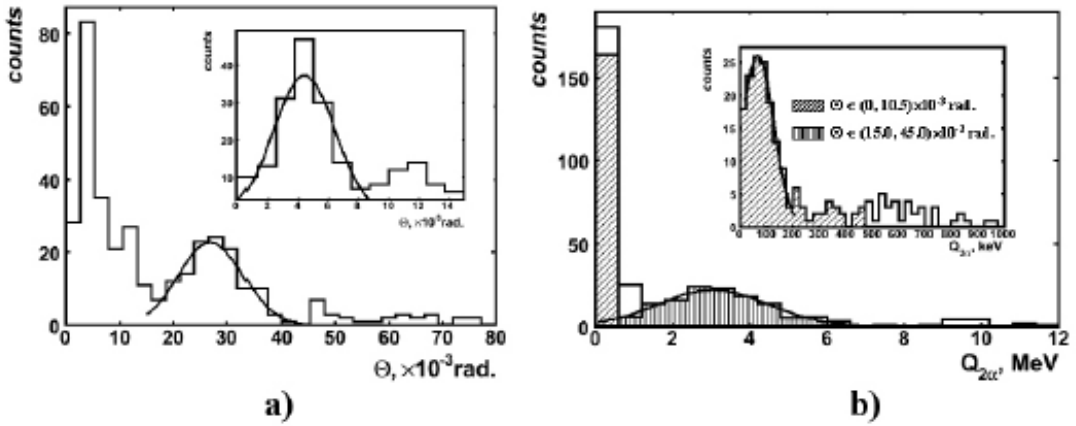
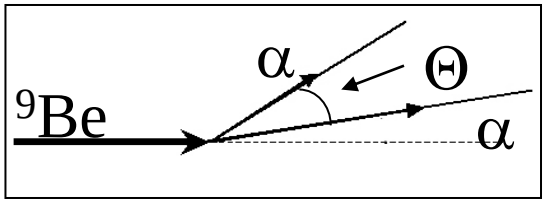
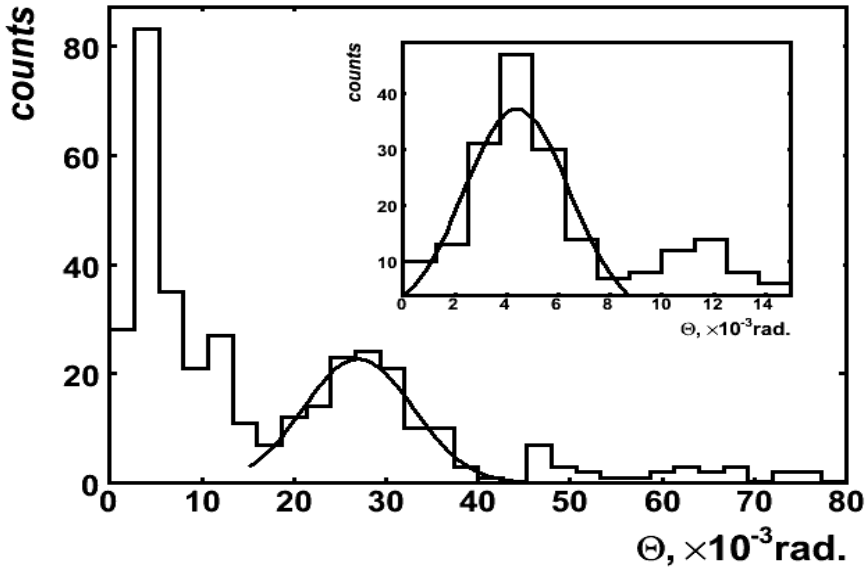


Figure 1. The opening Θ angle distribution of α particles in the ^{9}Be$\rightarrow 2\alpha$ fragmentation reaction at 1.2 A GeV energy. On the intersection: the Θ range from 0 to 15×10^{-3} rad.– a). The invariant energy $Q_{2\alpha}$ distribution of α particle pairs in the ^{9}Be$\rightarrow 2\alpha$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

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





Θ, mrad	$\langle\Theta\rangle$, 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.

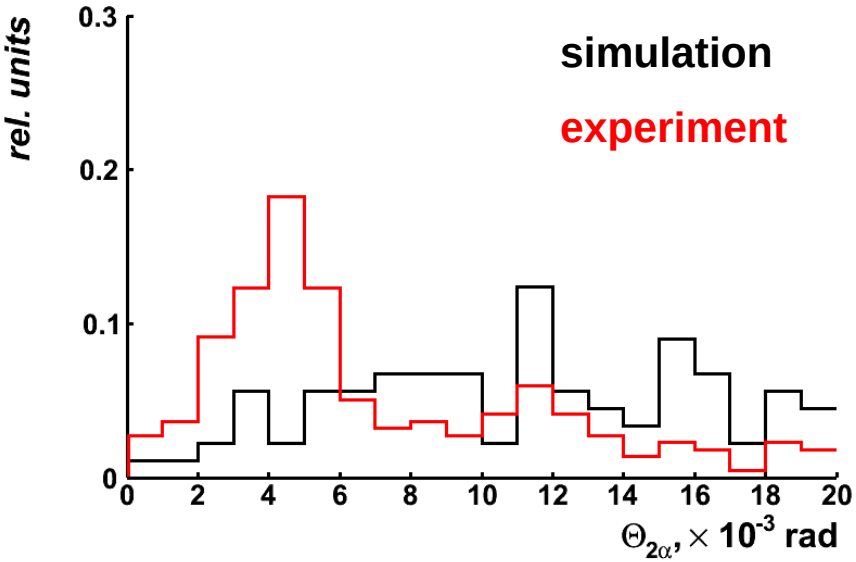
1. Y. L. Parfenova and Ch. Leclercq-Willain, «Hyperfine anomaly in Be isotopes and neutron spatial distribution: A three-cluster model for ^{9}Be», Phys. Rev. C 72, 054304 (2005).

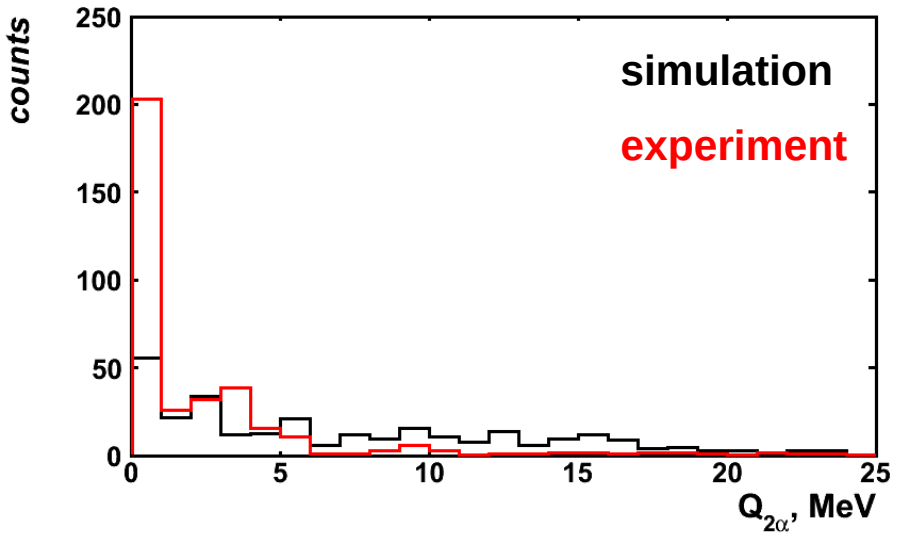
2. Y. L. Parfenova and Ch. Leclercq-Willain, «Hyperfine anomaly in Be isotopes in the cluster model and the neutron spatial distribution», Phys. Rev. C 72, 024312(2005)

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

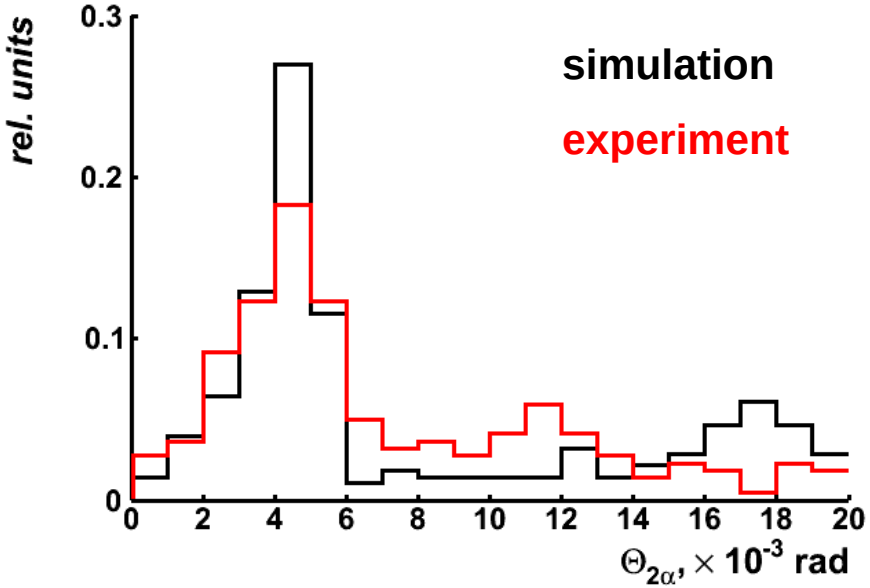
Geant4+QMD

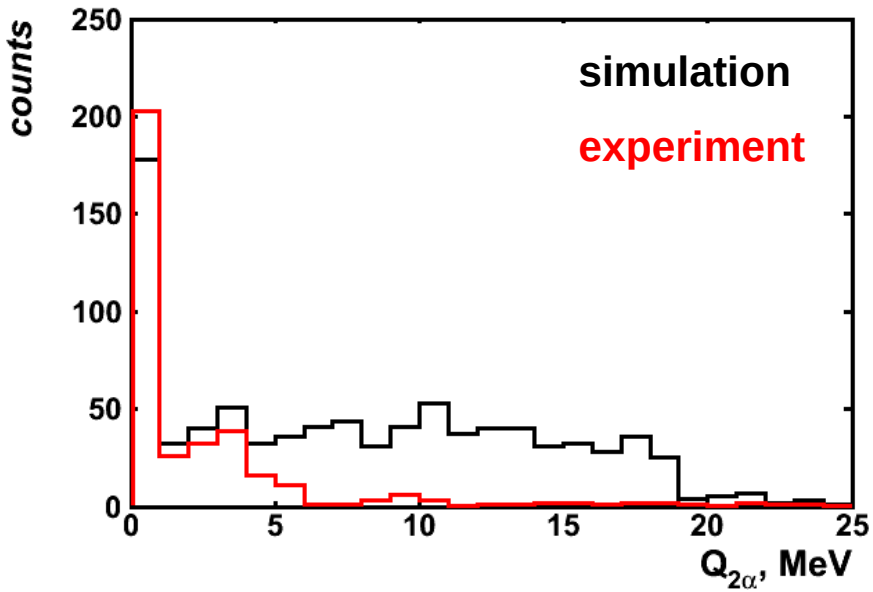
$$M_{2\alpha} = \left[2\left(m_{\alpha}^{2} + E_{\alpha 1}E_{\alpha 2} - p_{\alpha 1}p_{\alpha 2}\cos(\Theta_{12})\right)\right]^{\frac{1}{2}}, \quad Q_{2\alpha} = M_{2\alpha} - 2 \cdot m_{\alpha}$$





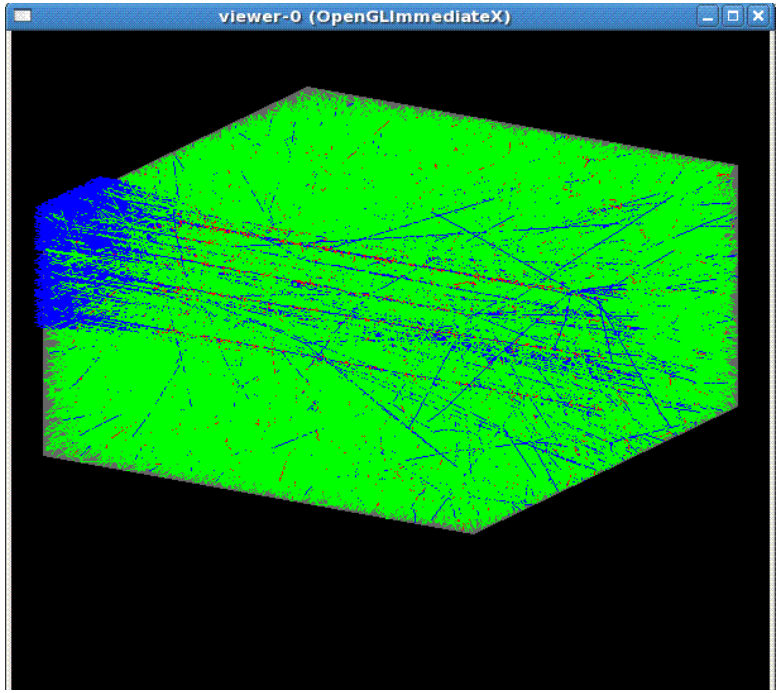
Geant4+BinaryLightIonReaction





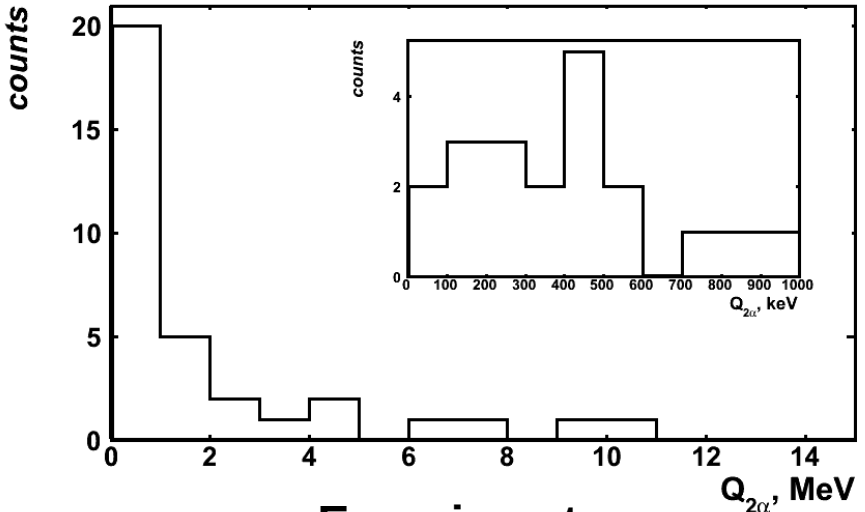
Modeling of ^{10}C fragmentation in NTE (with Geant4)

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

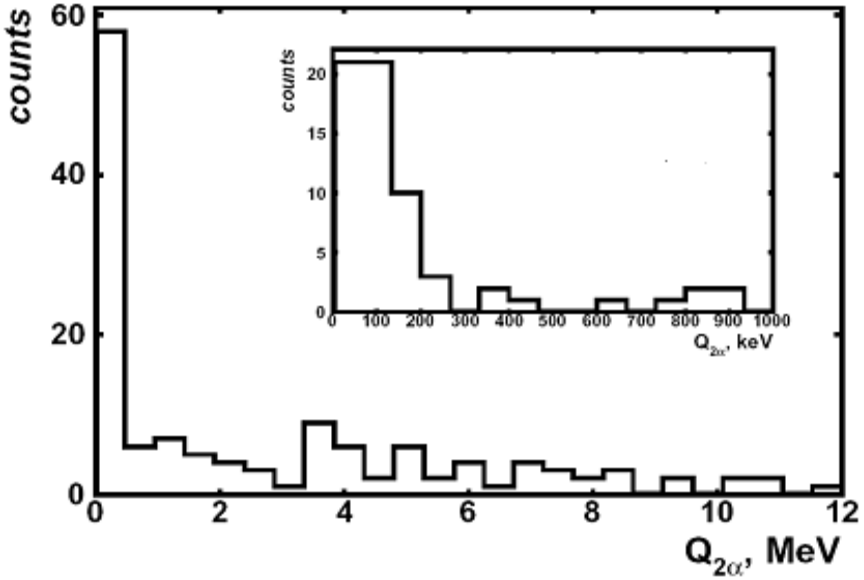


$$Q_{2\alpha} = M_{2\alpha} - 2 \cdot m_{\alpha}$$

Model (CHIPS)

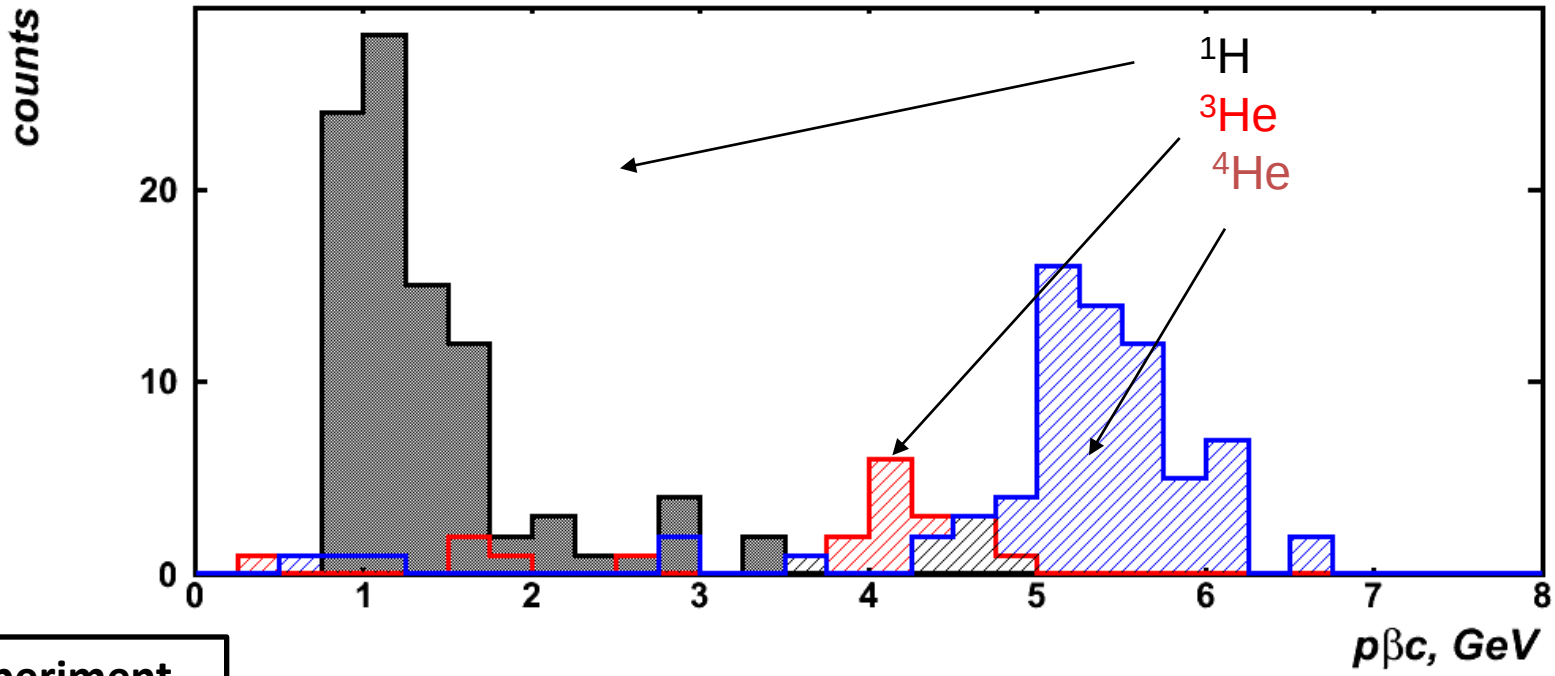


Experiment

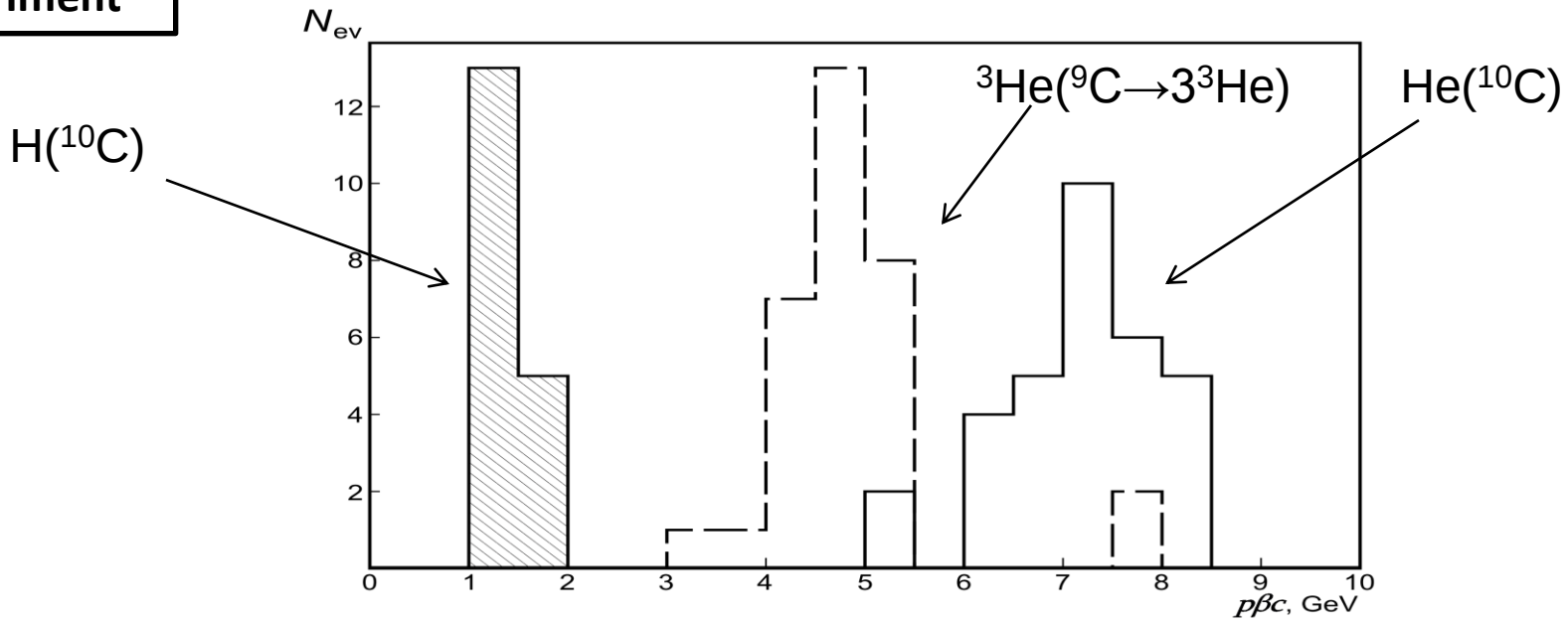


$^{10}C + Em \rightarrow 2\alpha + 2p$

Model

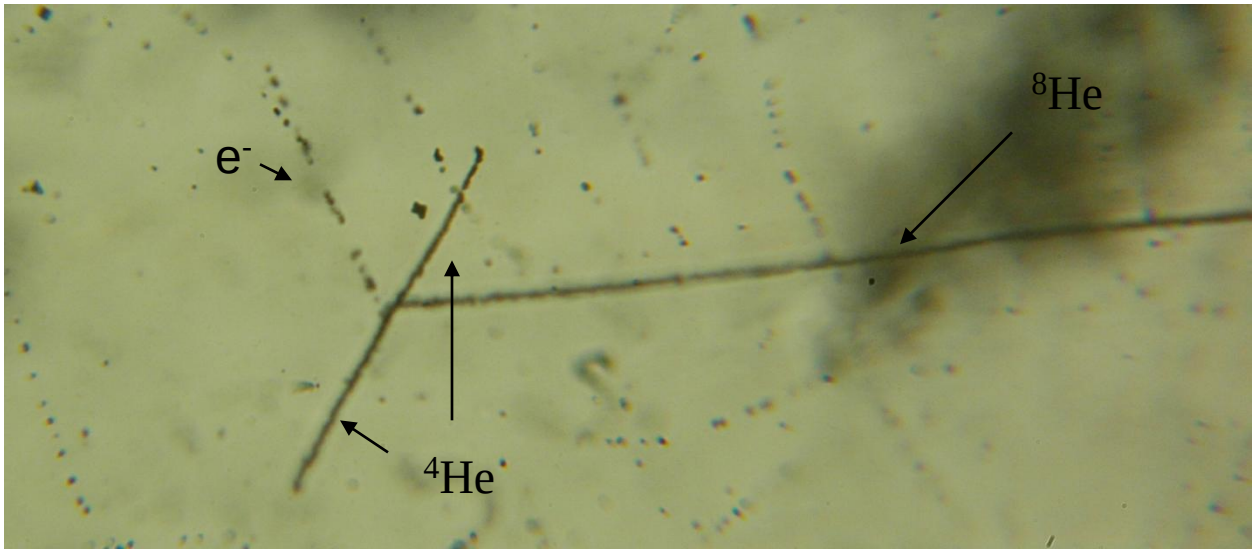


Experiment



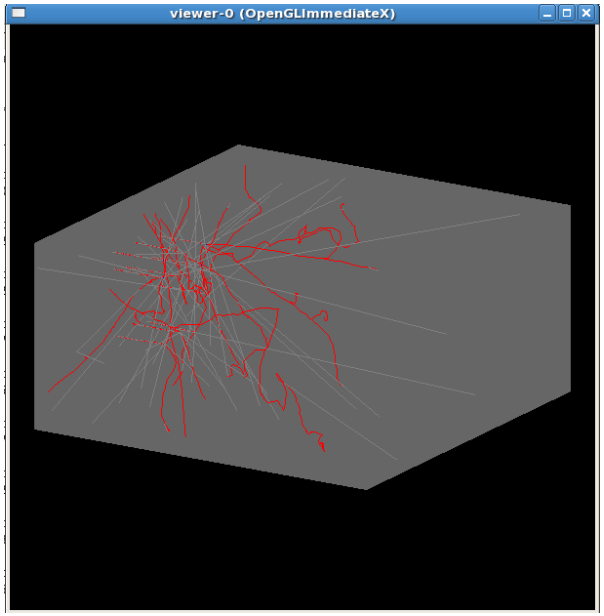
$$^{8}He \xrightarrow{\beta} {}^{8}Li \xrightarrow{\beta} {}^{8}Be \rightarrow 2\alpha$$

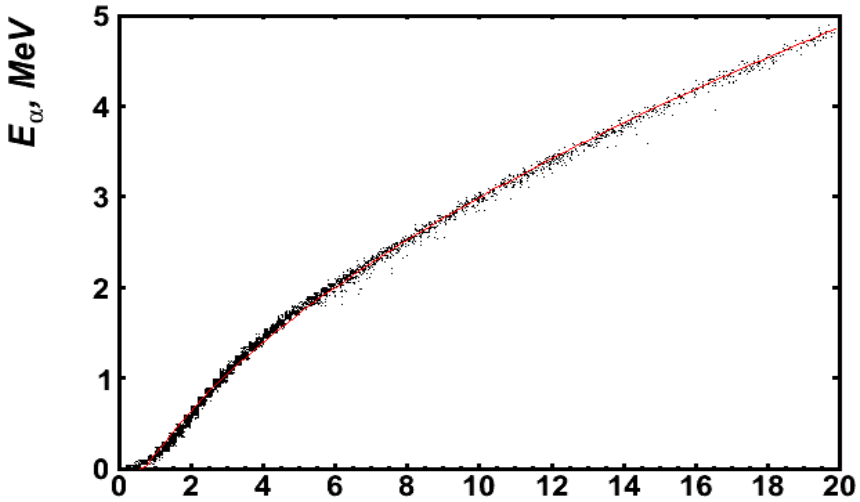
In March 2012 NTE was exposed at the Flerov Laboratory of Nuclear Reactions (JINR) at the ACCULINNA spectrometer. The beam in use was enriched by 7 A MeV ^{8}He nuclei. A 107 μm thick NTE pellicle was oriented at a 10° angle during irradiation, which provided approximately a five-fold effective thickness increase. For 10 minutes of irradiation, statistics of about 2 thousand of such decays was obtained. It is pleasant to note that the used NTE have been recently reproduced by the enterprises «Slavich» (Pereslavl-Zalessky, Russia).



Data modeling and nature

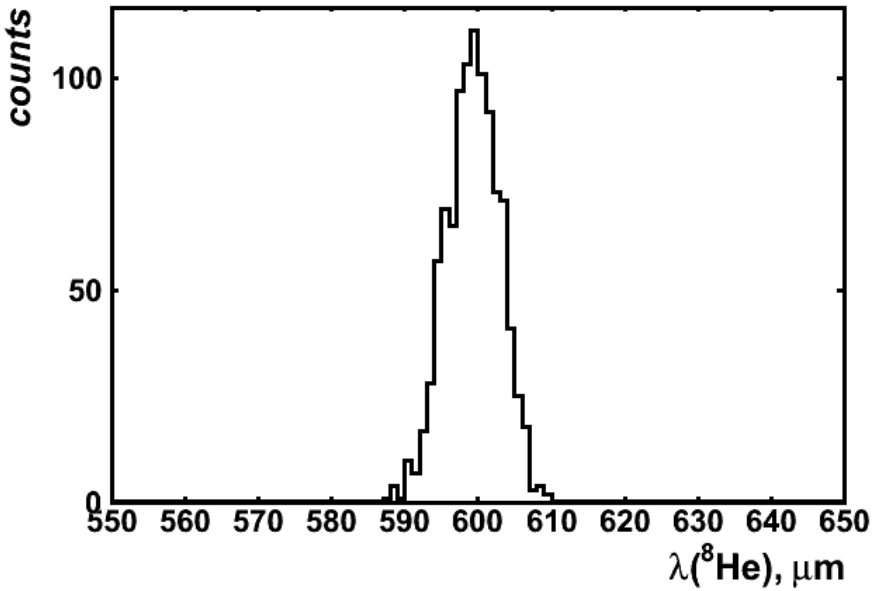
Radioactive Decay (Geant4)

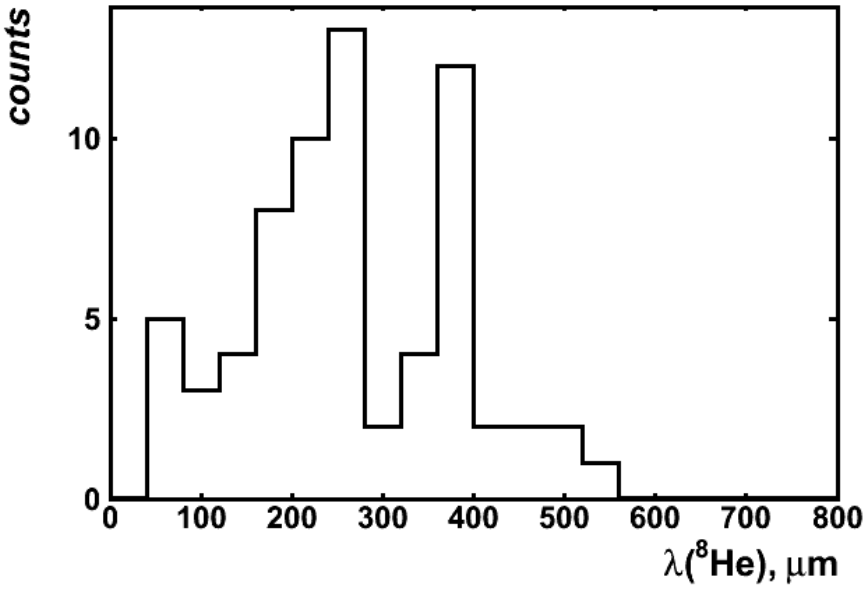




Track length / kinetic energy curve for alpha fragments (Geant4)

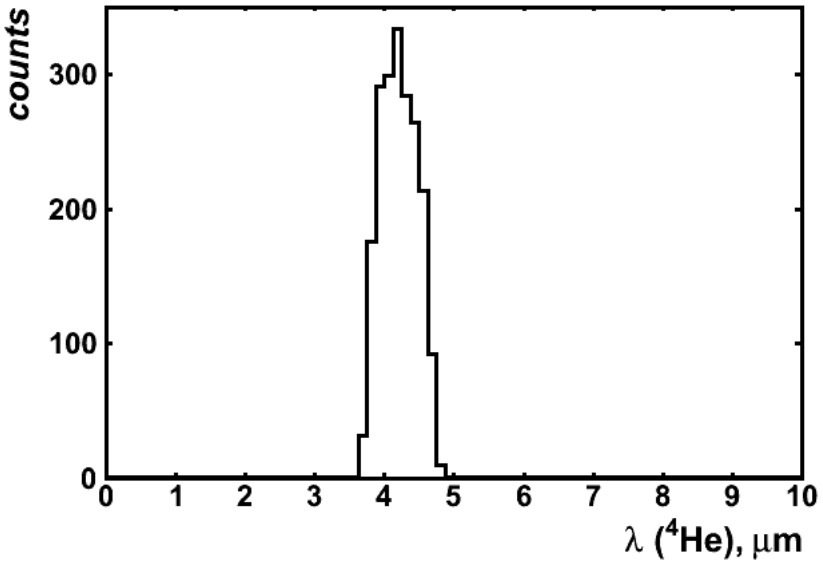
^{8}He at 7 A MeV

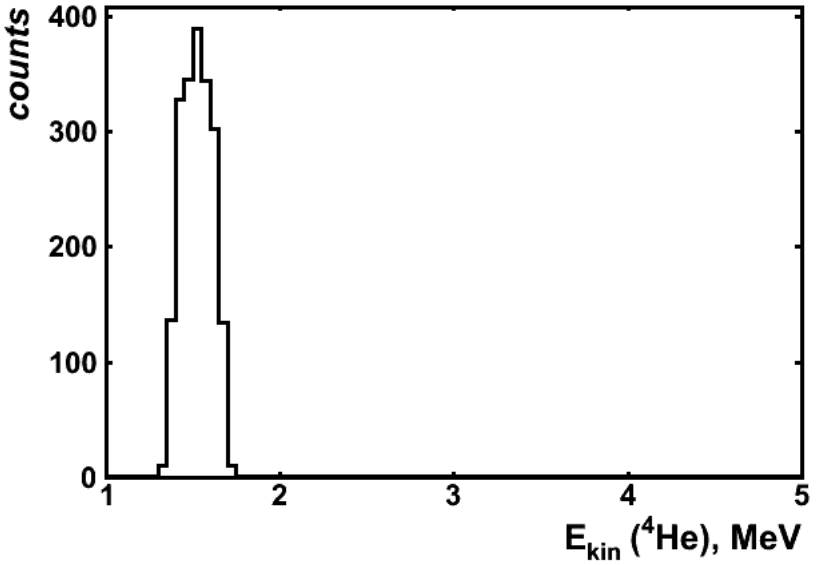




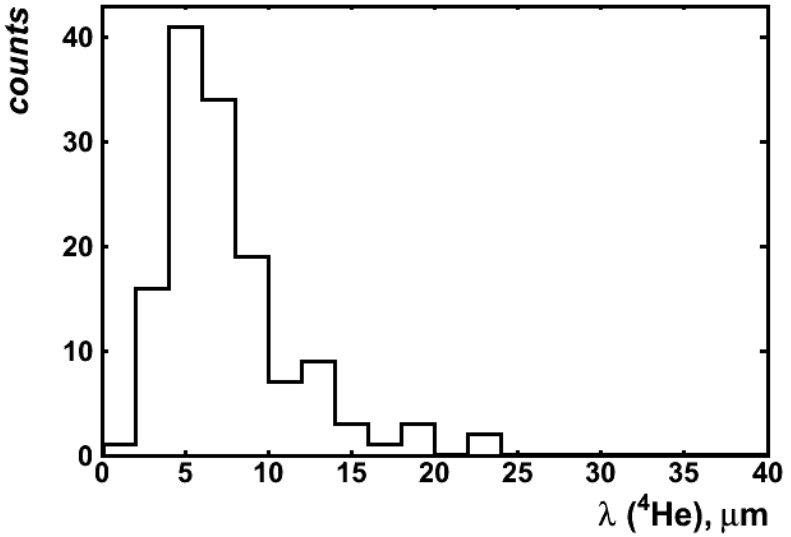
Track length and kinetic energy

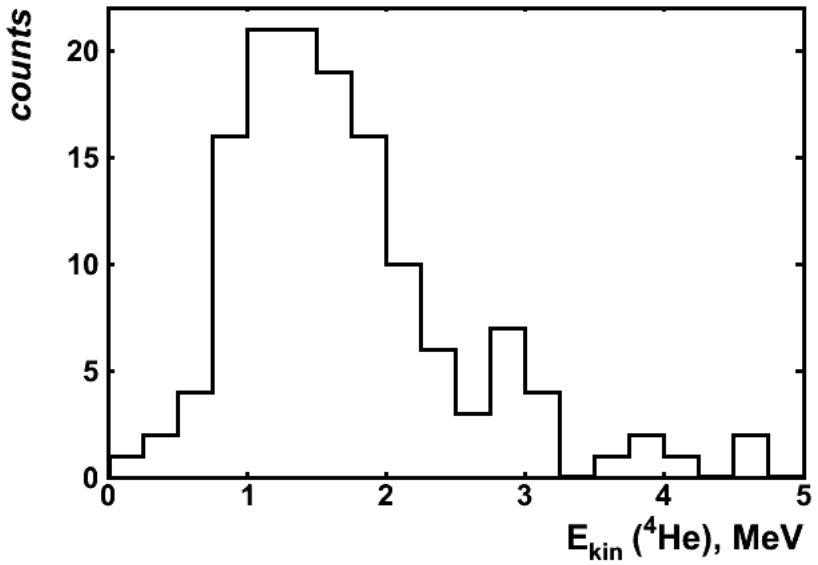
Radioactive Decay (Geant4)





Experiment





АНАЛИЗ ОБЛУЧЕНИЯ ЯДЕРНОЙ ЭМУЛЬСИИ ТЕПЛОВЫМИ НЕЙТРОНАМИ

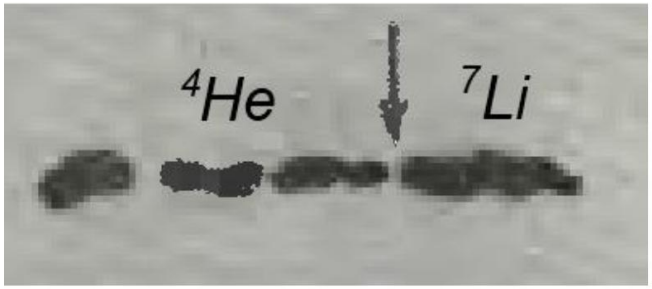


Рисунок 3 – Пример события расщепление тепловыми нейтронами ядра атома бора. На рисунке отчетливо можно различить треки ядер ^{4}He и ^{7}Li.

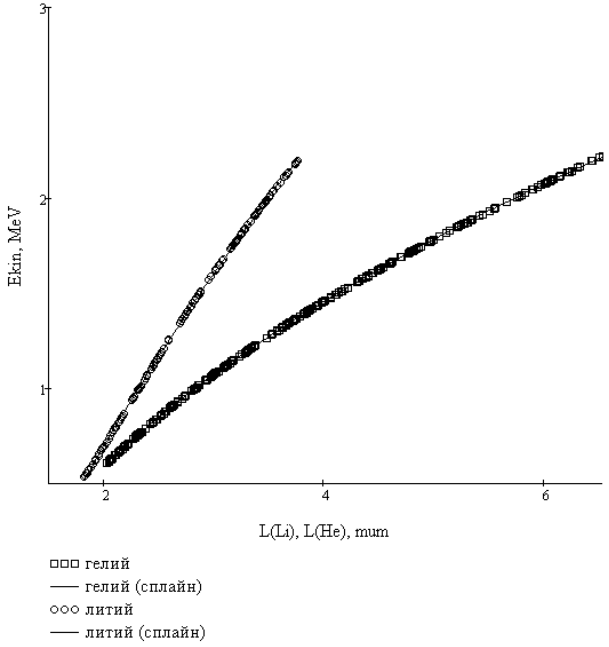


Рисунок 7 – Зависимость длина трека/кинетическая энергия фрагмента, полученная на основе моделирования и используемая для интерпретации экспериментальных данных

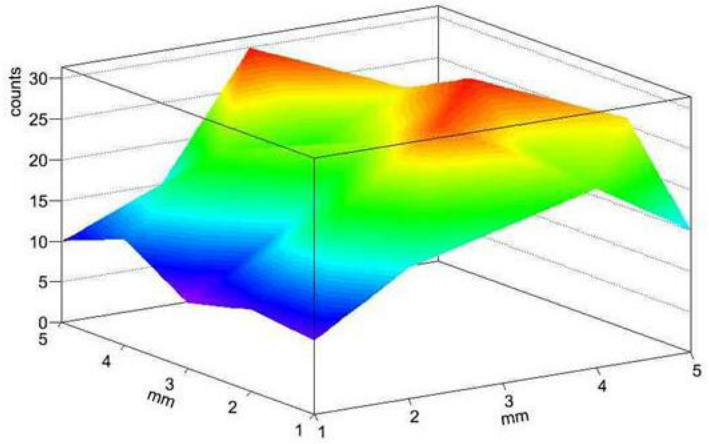


Рисунок 8 – График распределения плотности событий ядерной реакции по объему ядерной эмульсии

$$j = \frac{N_{вз}}{N \cdot \sigma \cdot t}$$

σ≈3900 барн

Study of nuclear multifragmentation induced by ultrarelativistic μ-mesons in nuclear track emulsion

D A Artemenkov[1,2], V Bradnova[1], E Firu[3], N K Kornegrutsa[1], M Haiduc[3], K Z Mamatkulov[1], R R Kattabekov[1], A Neagu[3], P A Rukoyatkin[1], V V Rusakova[1], R Stanoeva[4], A A Zaitsev[1,5], P I Zarubin[1,5] and I G Zarubina[1,5]

[1] Joint Institute for Nuclear Research, Dubna, Russia
[2] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia
[3] Institute of Space Science, Magurele, Romania
[4] South-Western University, Blagoevgrad, Bulgaria
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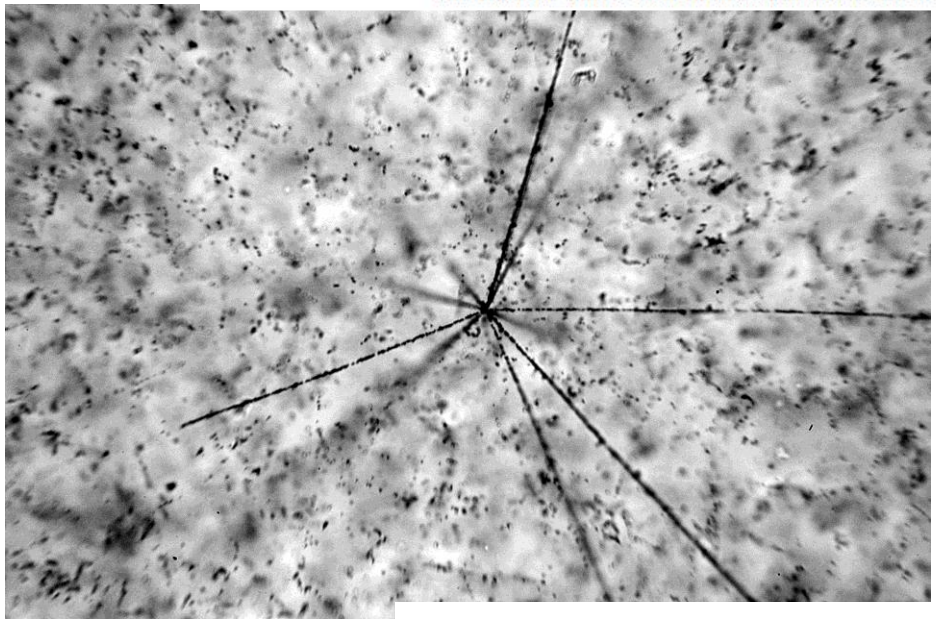
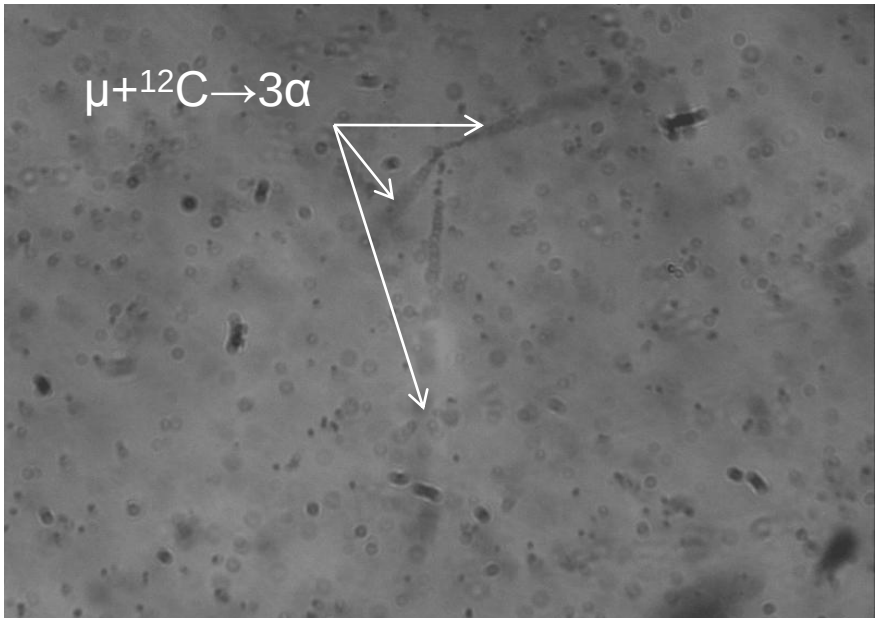
Abstract. Exposures of test samples of nuclear track emulsion were analyzed. The formation of high-multiplicity nuclear stars was observed upon irradiating nuclear track emulsions with ultrarelativistic muons. Kinematical features studied in this exposure of nuclear track emulsions for events of the muon-induced splitting of carbon nuclei to three α-particles are indicative of the nuclear-diffraction interaction mechanism.





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Summary

The presented observations serve as an illustration of prospects of the Nuclotron-NICA 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.

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

The report presents preliminary results of the study of multifragmentation of ^{12}C(from target) under the influence of ultra relativistic muons. These materials are available on our website Becquerel (http://becquerel.jinr.ru).

Thank you for your attention!