Exposures of nuclear track emulsion to light radioactive nuclei, neutrons and heavy ions

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XXII Baldin ISHEPP, 19.09.2014

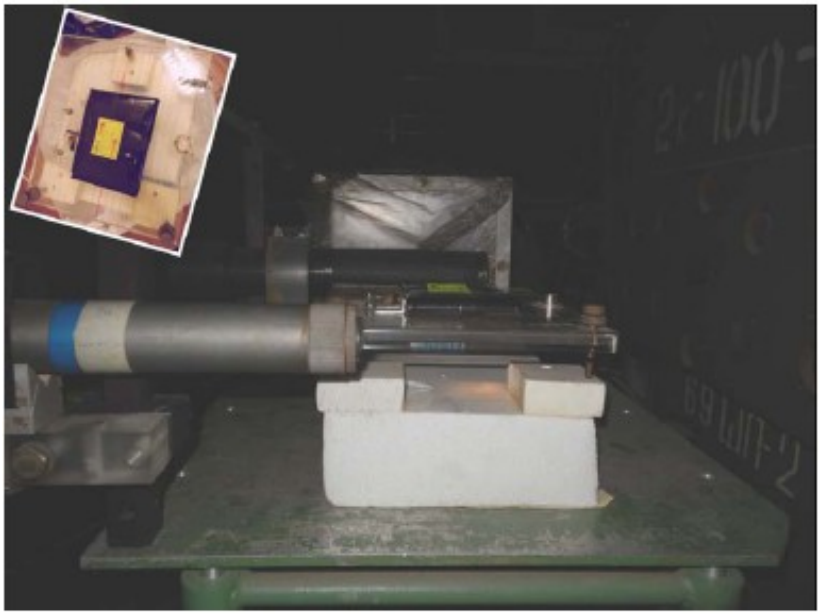
BECQUEREL PROJECT

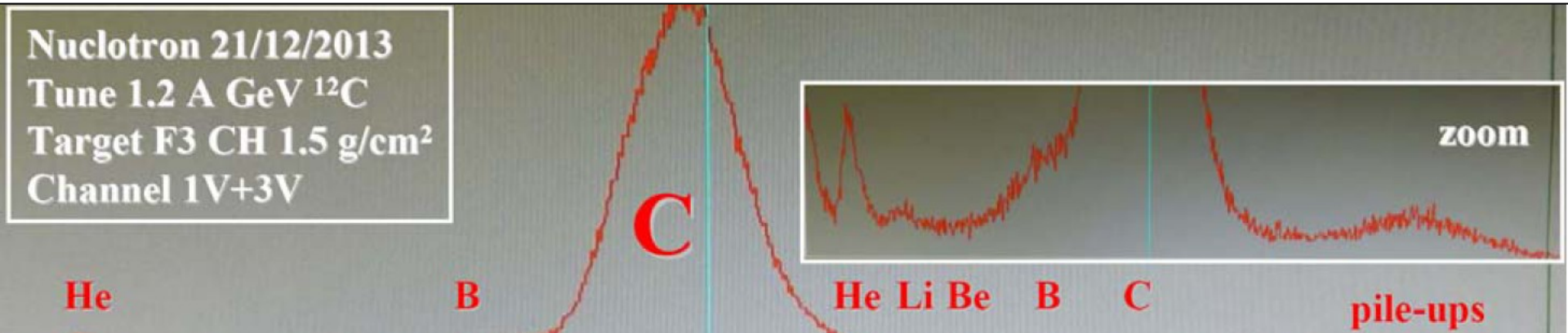
Проект БЕККЕРЕЛЬ

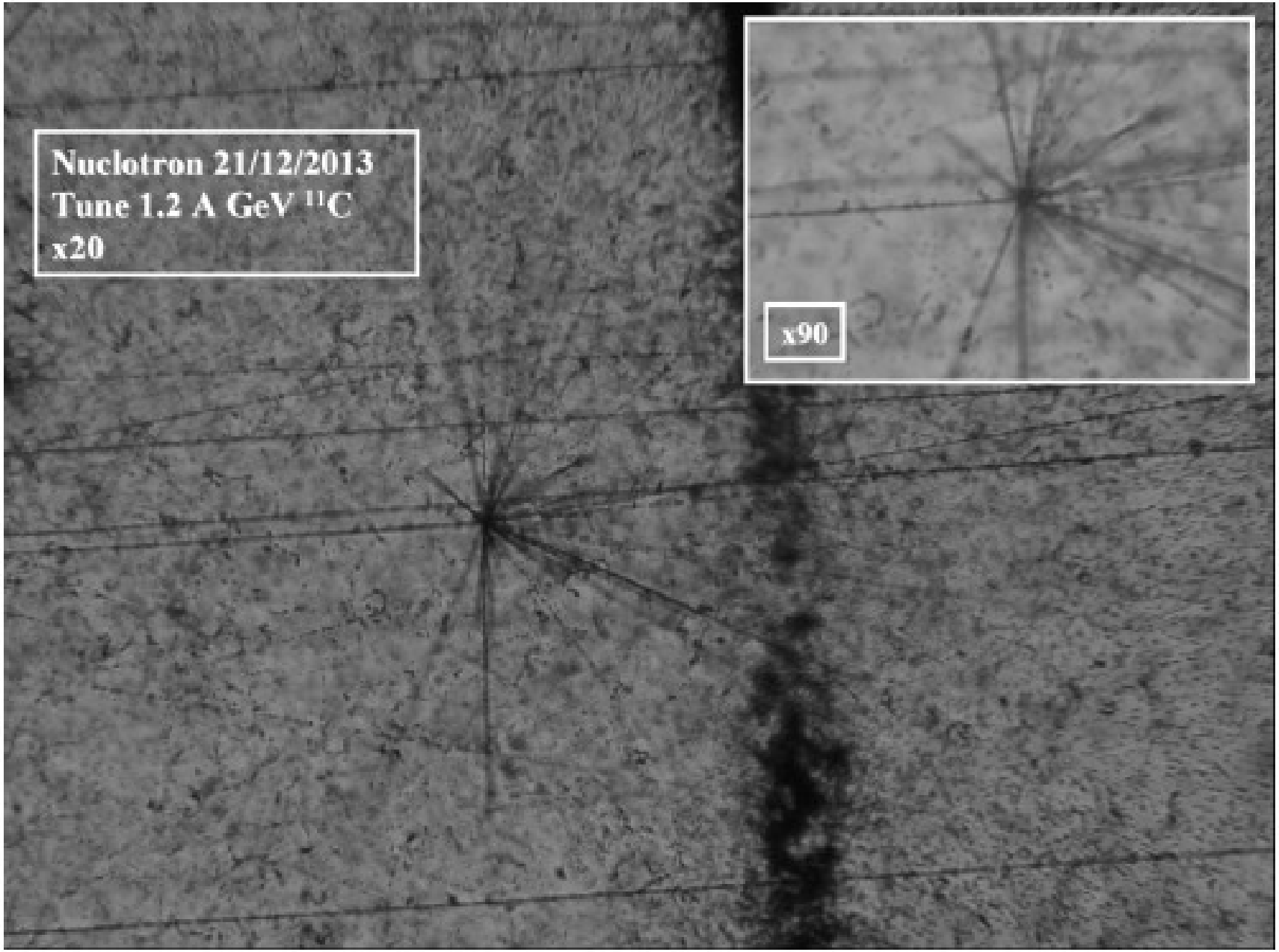
Beryllium (Boron) Clustering Quest in Relativistic Multifragmentation

http://becquerel.jinr.ru

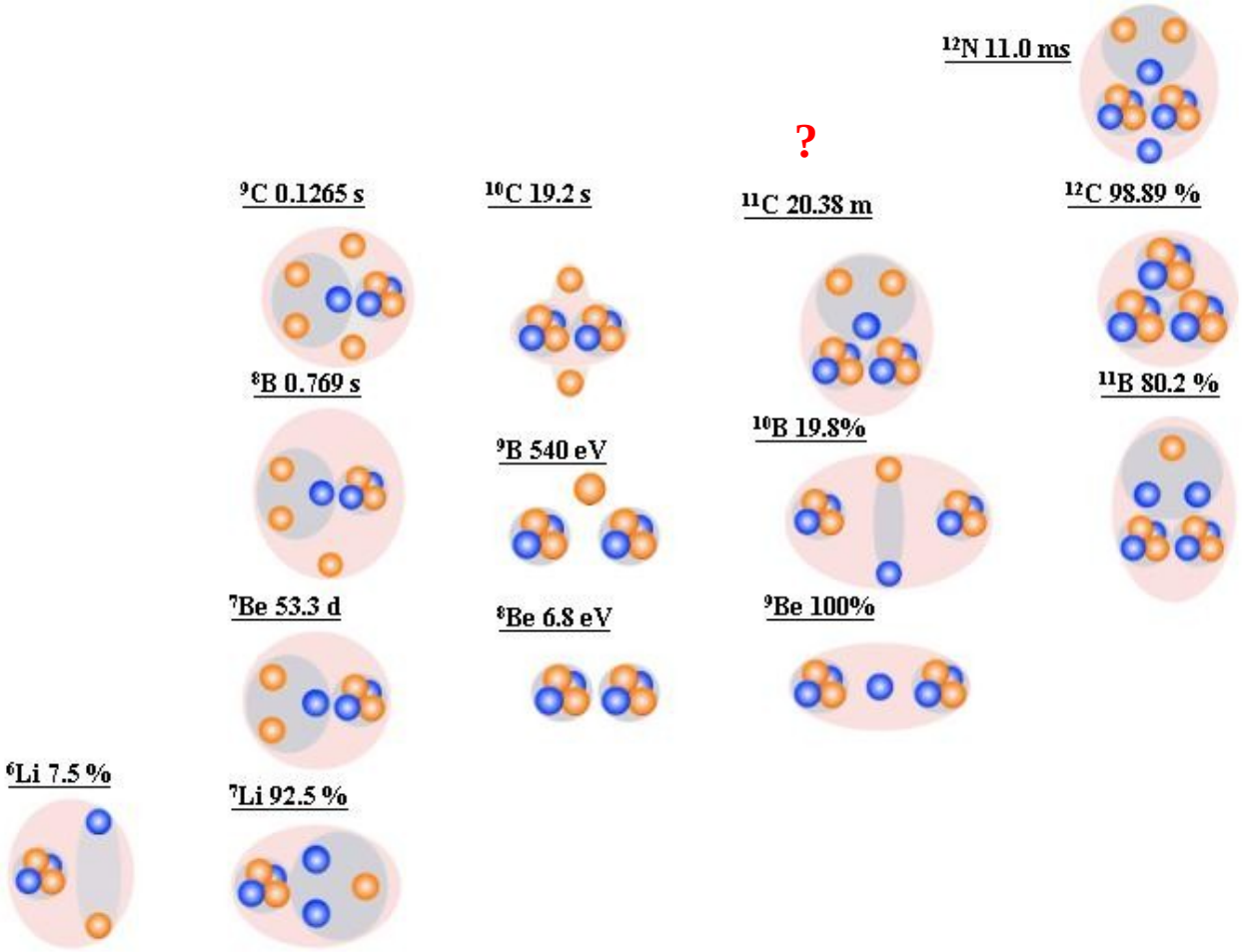
BECQUEREL at the JINR Nuclotron is devoted systematic exploration of clustering features of light stable and radioactive nuclei.






Nuclotron 21/12/2013
Tune 1.2 A GeV ^{11}C
x20
x90

Motivation

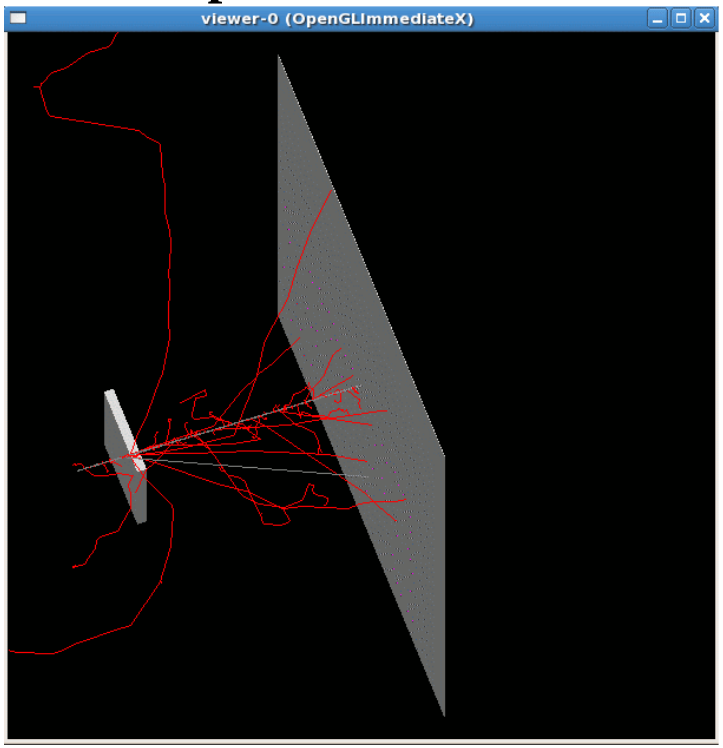


The fragmentation of a large variety of light nuclei was investigated using the emulsions exposed to few A GeV nuclear beams at JINR Nuclotron. A nuclear track emulsion is used to explore the fragmentation of the relativistic nuclei.

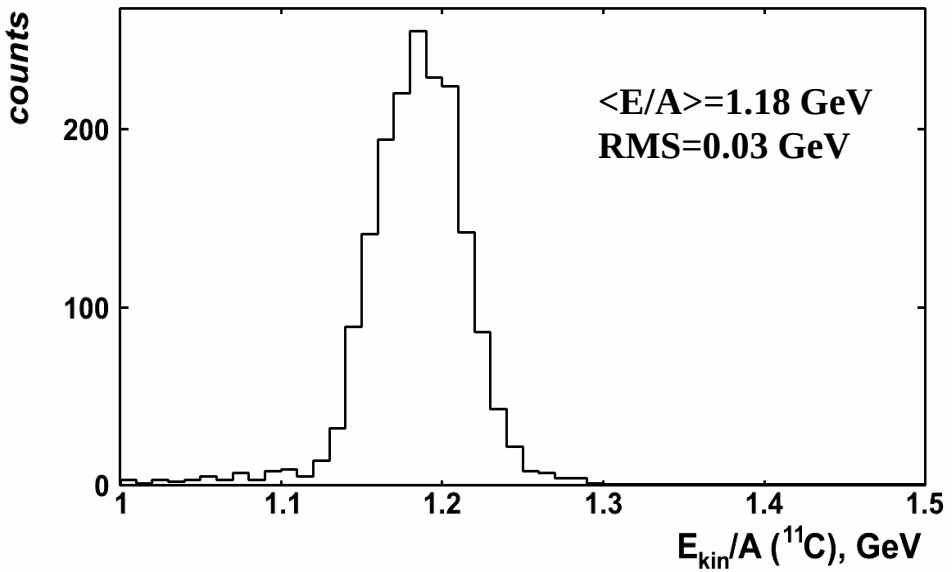
Proposal on exposures of NTE to beam of ^{11}C nuclei at 1.2 A GeV

based on:

- **results of Becquerel project for carbon isotopes (^{9}C, ^{10}C, ^{12}C)**
- **P.A. Rukoyatkin et al., "Secondary nuclear fragment beams for investigations of relativistic fragmentation of light radioactive nuclei using nuclear photoemulsion at Nuclotron", http://arxiv.org/abs/1210.1540**

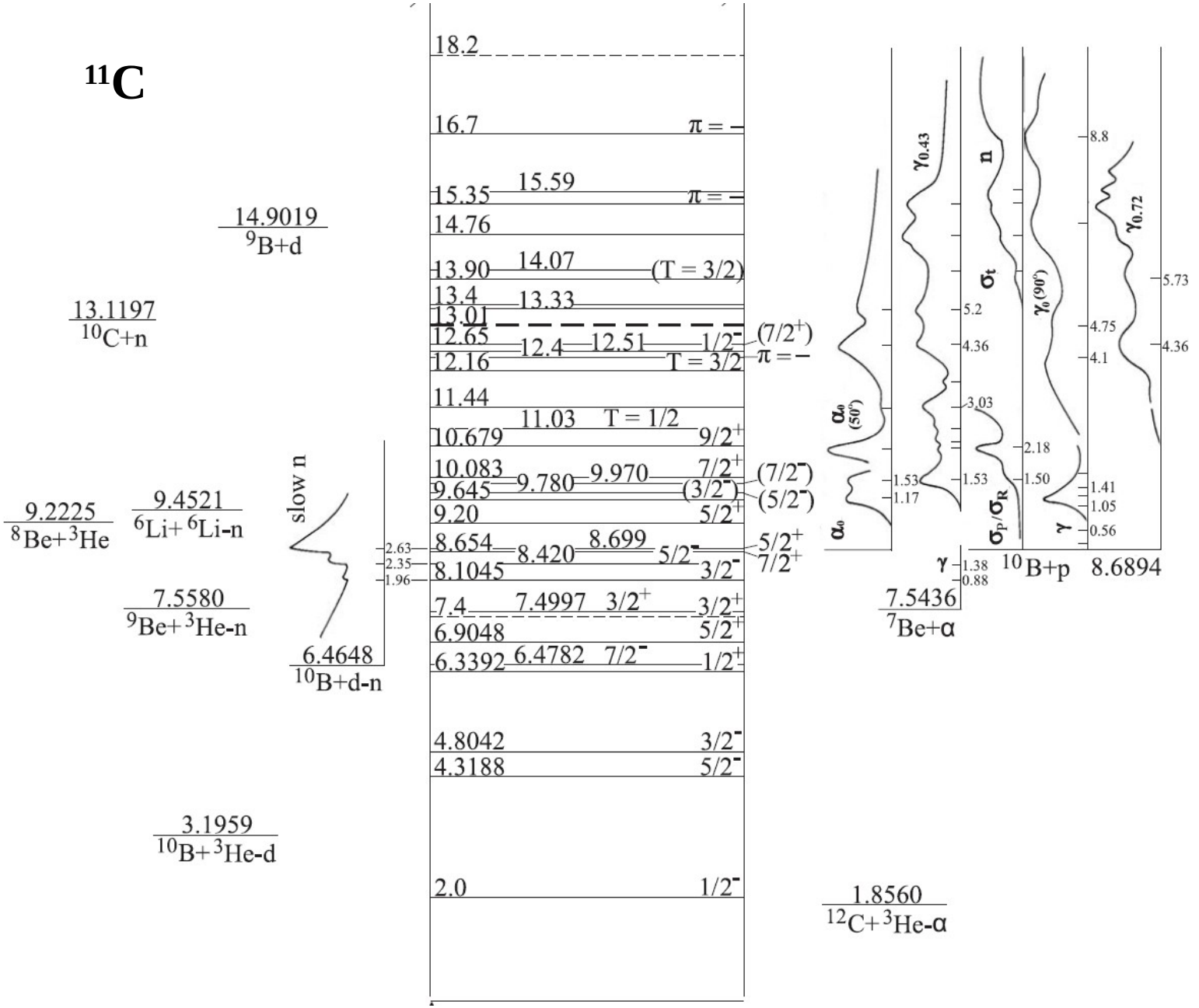


1810 nuclei of ^{11}C produced from $5 \cdot 10^4$ of ^{12}C



Polyethylene target (thickness - 1 cm) irradiated by ^{12}C nuclei with 1.2 A GeV. Used CHIPS physics list, and G4_POLYETHYLENE target (Geant4). All equipment located in air.

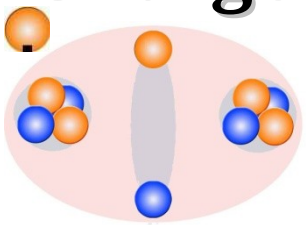
^{11}C

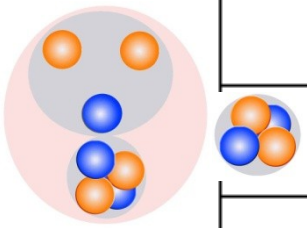


http://www.tunl.duke.edu/nucldata/figures/11figs/11_05_2012.pdf

Charge topology of ^{11}C fragmentation

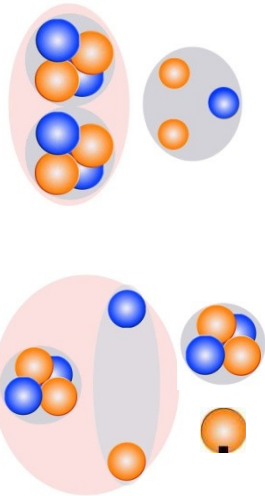
8.7 MeV





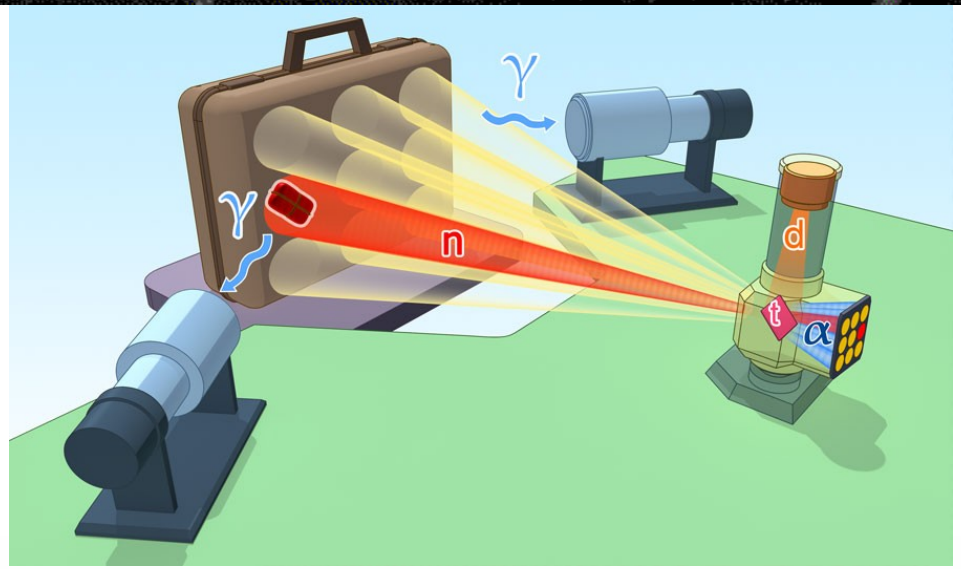
B + H	5 (8 %)
^{7}Be + He	11 (18 %)
3He	10 (16 %)
2He + 2H	26 (42 %)
He + 4H	4 (7 %)
Li + He + H	3 (5 %)
6H	3 (5 %)

9.2 MeV



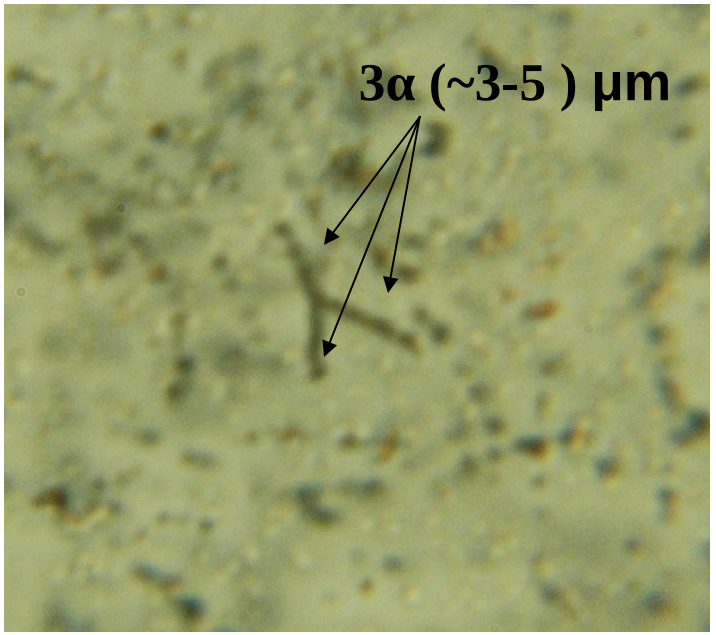
7.6 MeV

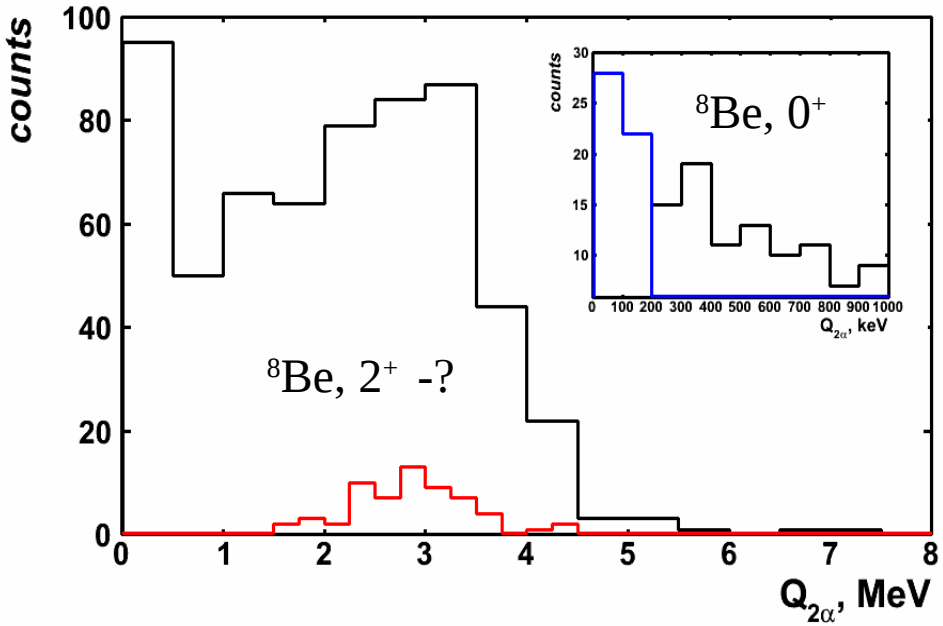
http://becuerel.jinr.ru/miscellanea/C11/11C.html



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

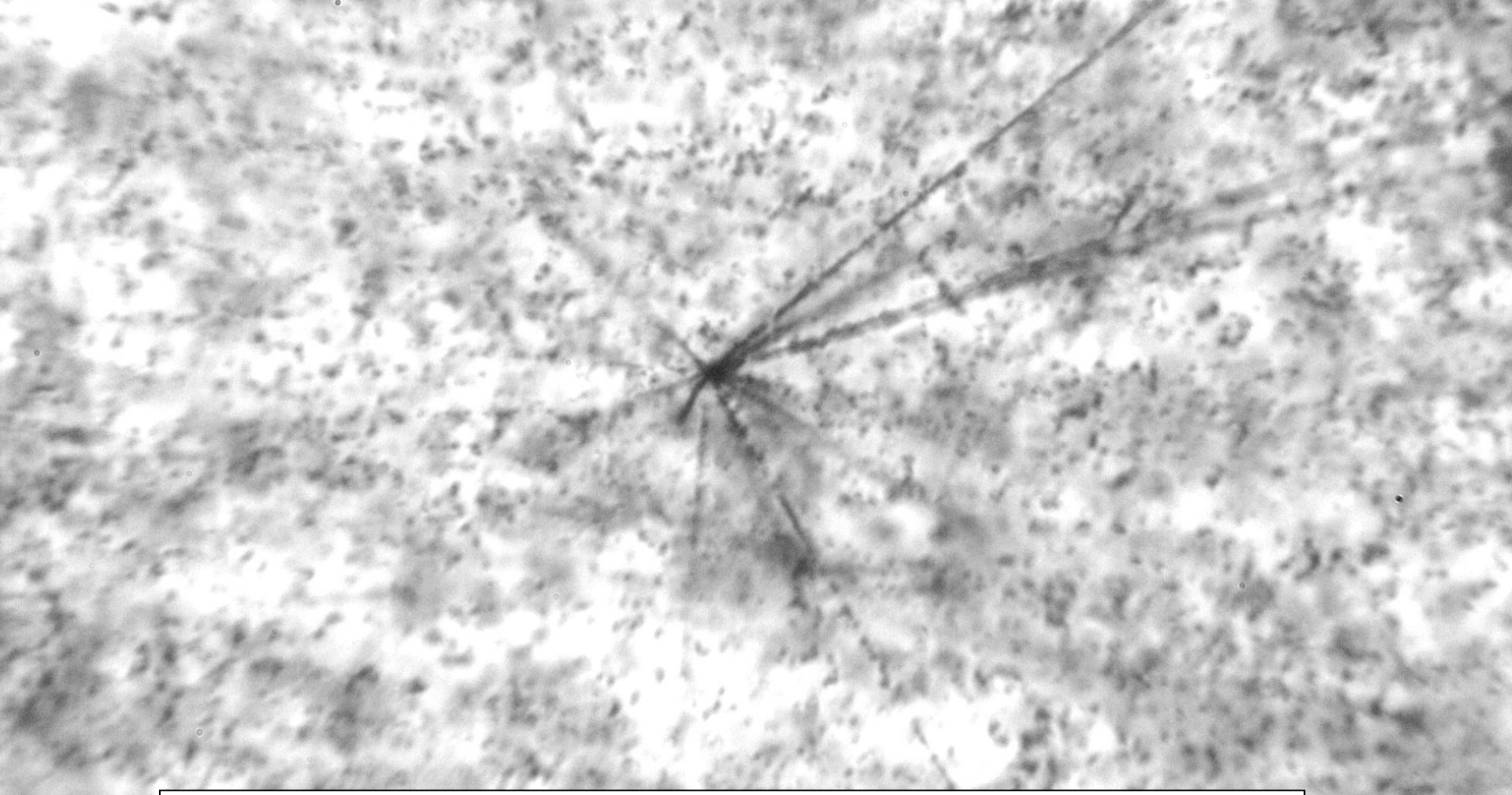
DVIN - explosives detector on the basis of fast tagged neutron method for complex program for population safety in transport





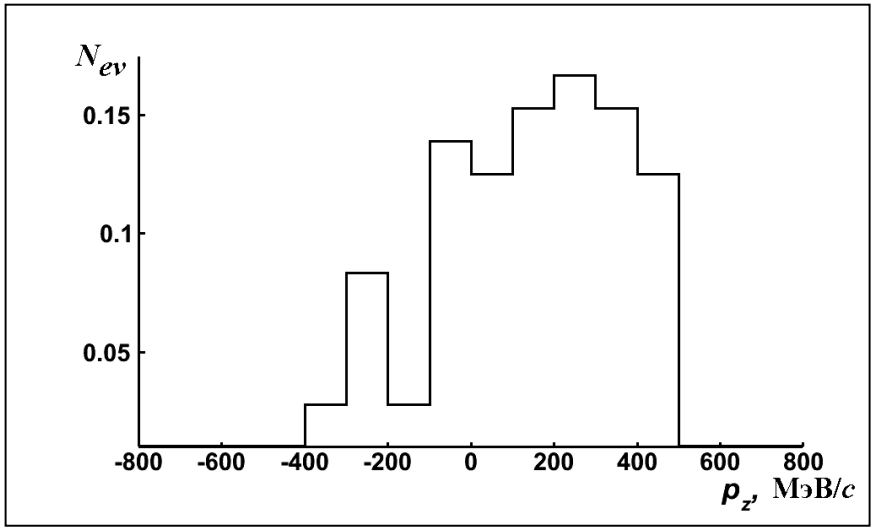
$$M_{2\alpha} = \left[2\left(m_\alpha^2 + E_{\alpha 1}E_{\alpha 2} - p_{\alpha 1}p_{\alpha 2}\cos(\Theta_{12})\right)\right]^{\frac{1}{2}}$$

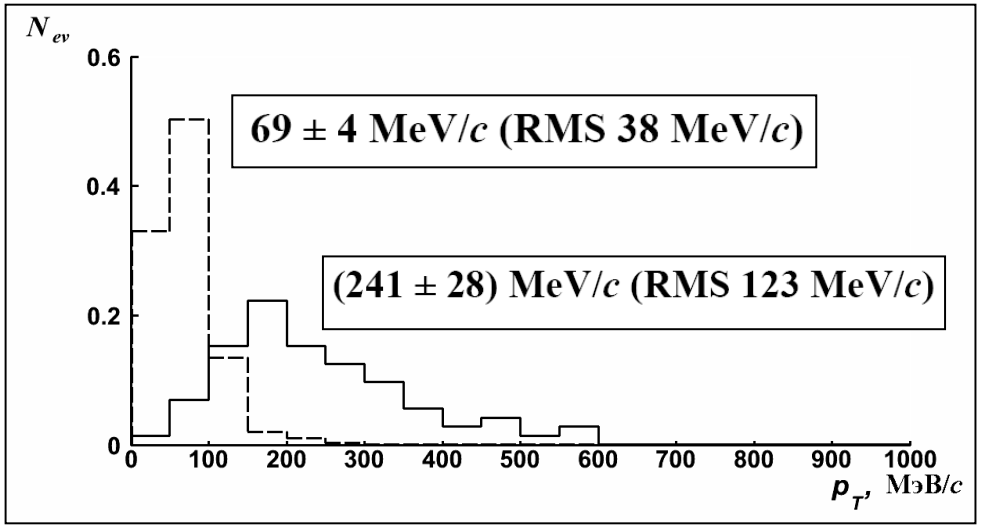
$$Q_{2\alpha} = M_{2\alpha} - 2\cdot m_\alpha$$

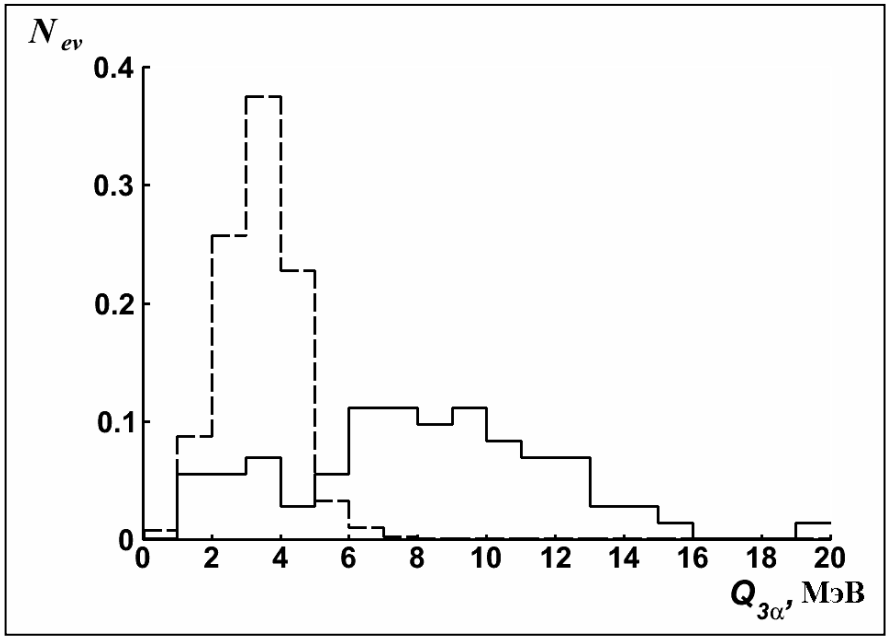


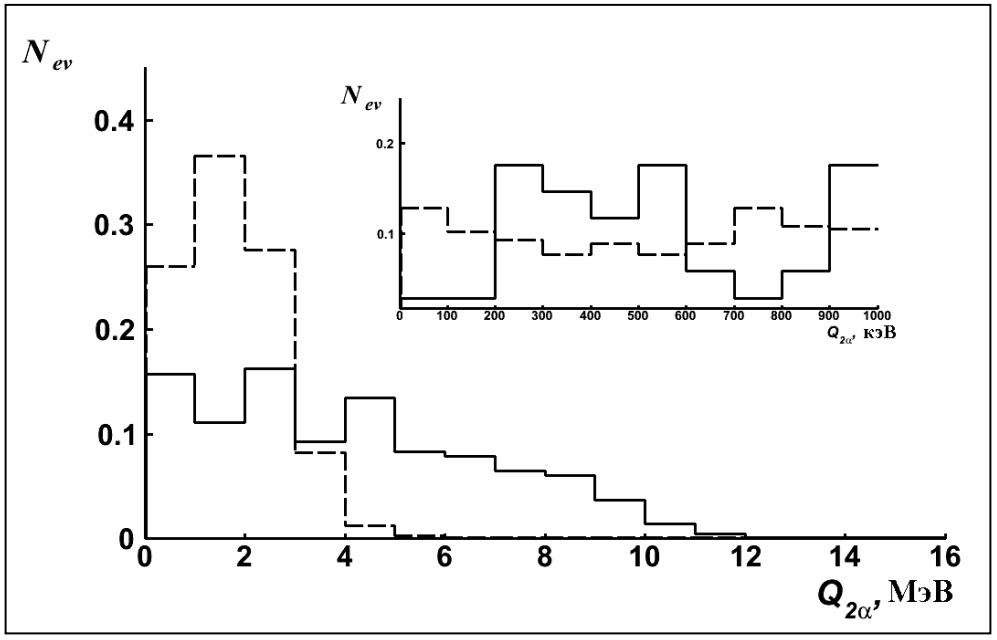
EXPOSURE TO μ-MESONS

Deep inelastic scattering of ultrarelativistic μ-mesons is a recognized approach to study the parton structure of nucleons and nuclei. Exposure of NTE to these particles allows one to perform a study of nuclear multifragmentation under a purely electromagnetic probe. Multiphoton exchanges or transitions of virtual photons to vector mesons leading to nuclear interactions may serve as the mechanisms of fragmentation. NTE has been irradiated at CERN by μ-mesons of energy of 160 GeV. Earlier such an exposure hasn't been carried out. The purpose of this irradiation was a study of experimental downloads near a beam axis and the preliminary assessment of the nature of interactions μ-mesons.



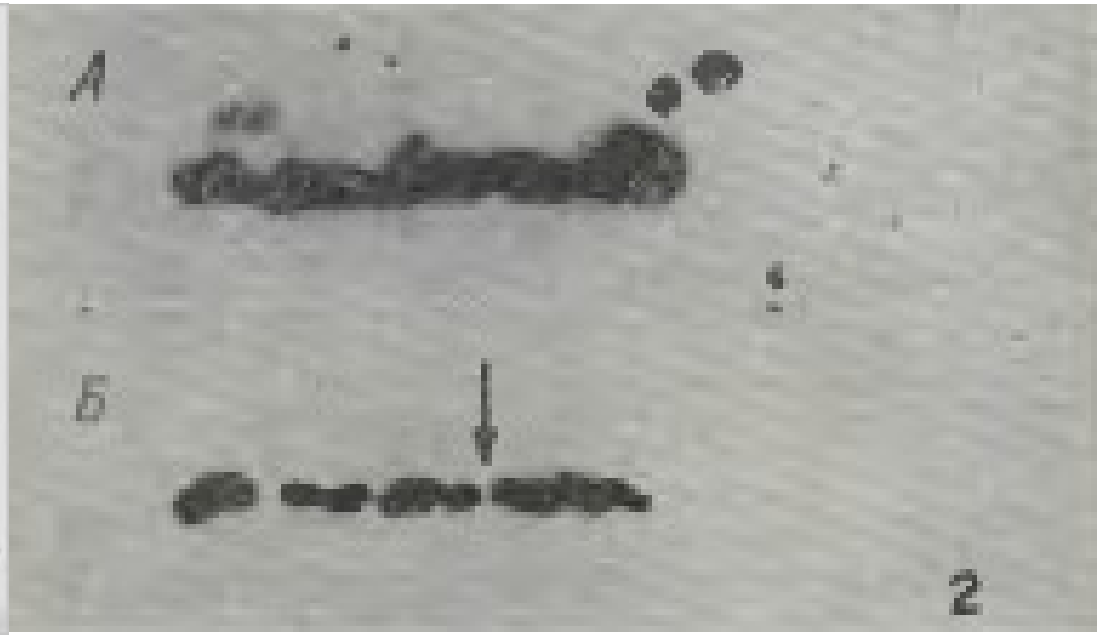






72 stars containing only a triple of *b*-particles stopped in NTE are assigned to the disintegration μ + ^{12}C → 3*α* and compared with the case *n*(14.1 MeV) + ^{12}C → 3*α* + *n*.

ФОТОГРАФИЧЕСКАЯ
РЕГИСТРАЦИЯ
ИОНИЗИРУЮЩИХ
ИЗЛУЧЕНИЙ

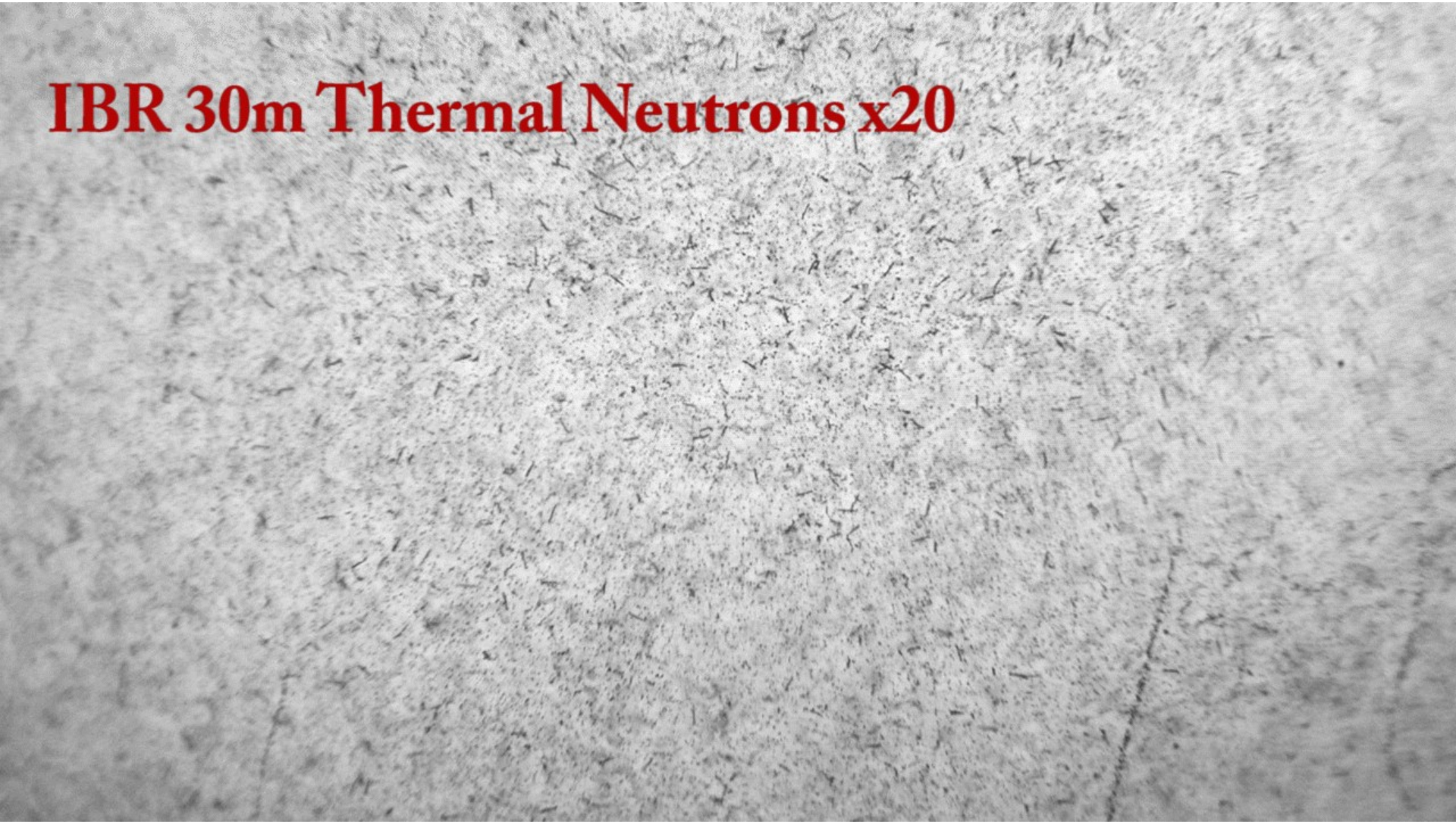


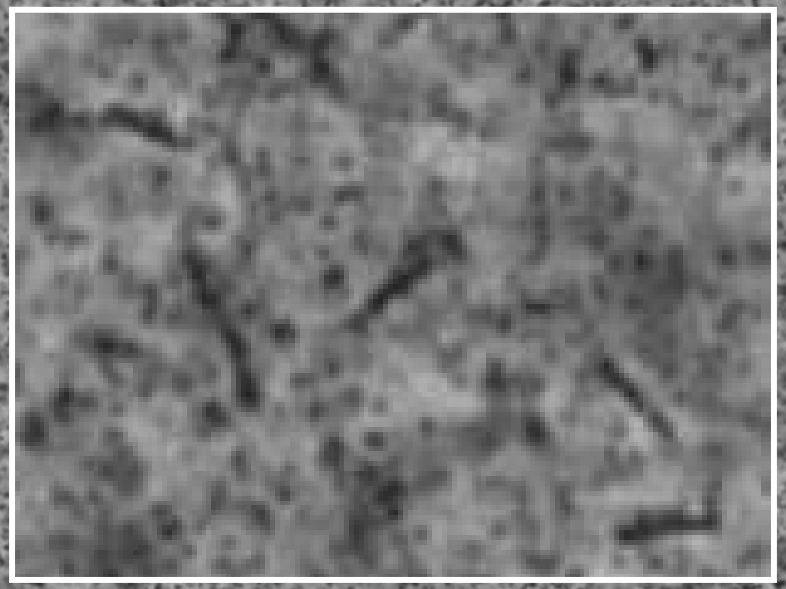
БОР

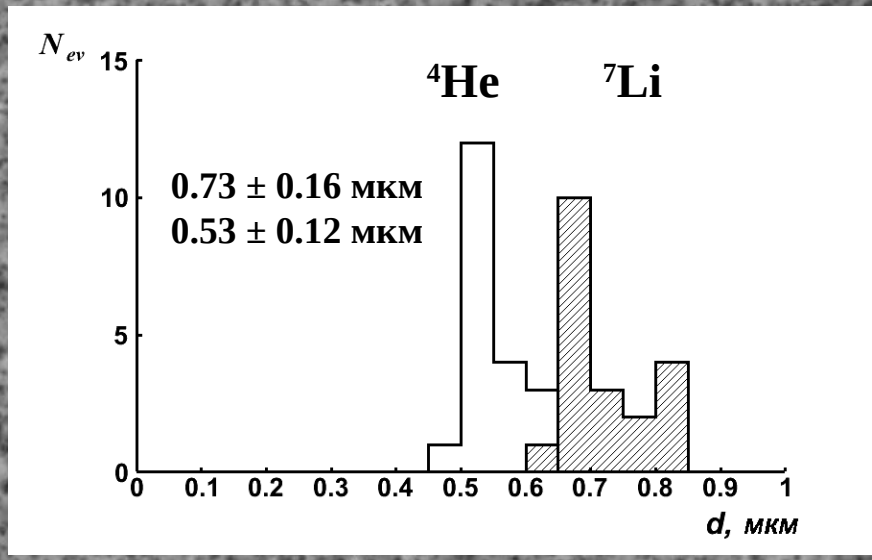
Расщепление бора тепловыми нейтронами

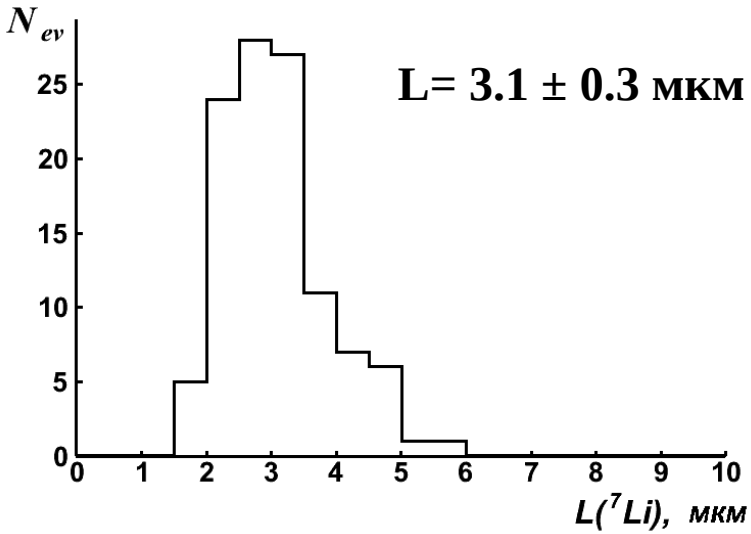
$$_5B^{10} + {}_0n^1 \rightarrow {}_2He^4 + {}_3Li^{7*}$$

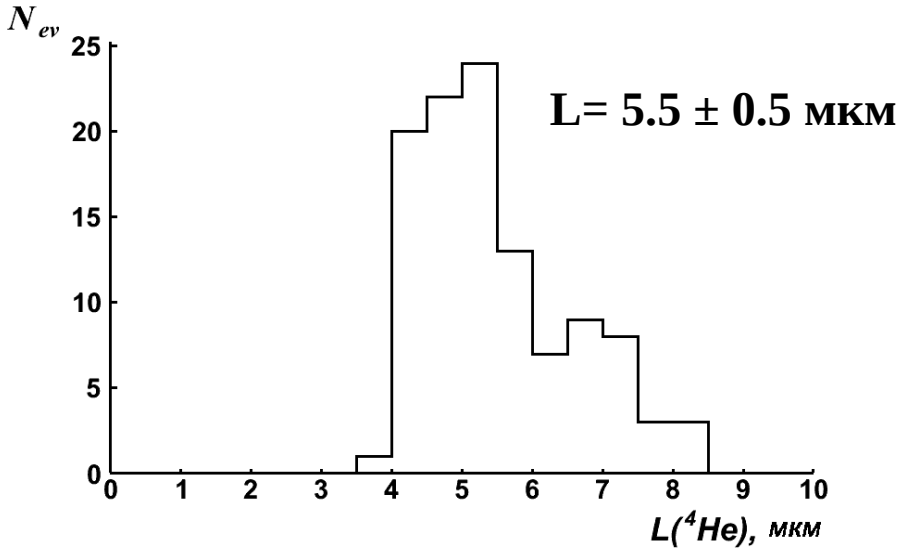
приводит к испусканию α-частицы и образованию ядра лития в возбужденном состоянии с энергией 478 *кэв* [53]. В этом случае, так же как и в предыдущей реакции, ядро отдачи лития поглощает значительную часть кинетической энергии, и ионизирующие способности $_2He^4$ и $_3Li^7$ отличаются слишком мало, чтобы их можно было распознать путем нормального проявления.


IBR 30m Thermal Neutrons x20




N_{ev}
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
d, мкм
⁴He
⁷Li
0.73 ± 0.16 мкм
0.53 ± 0.12 мкм





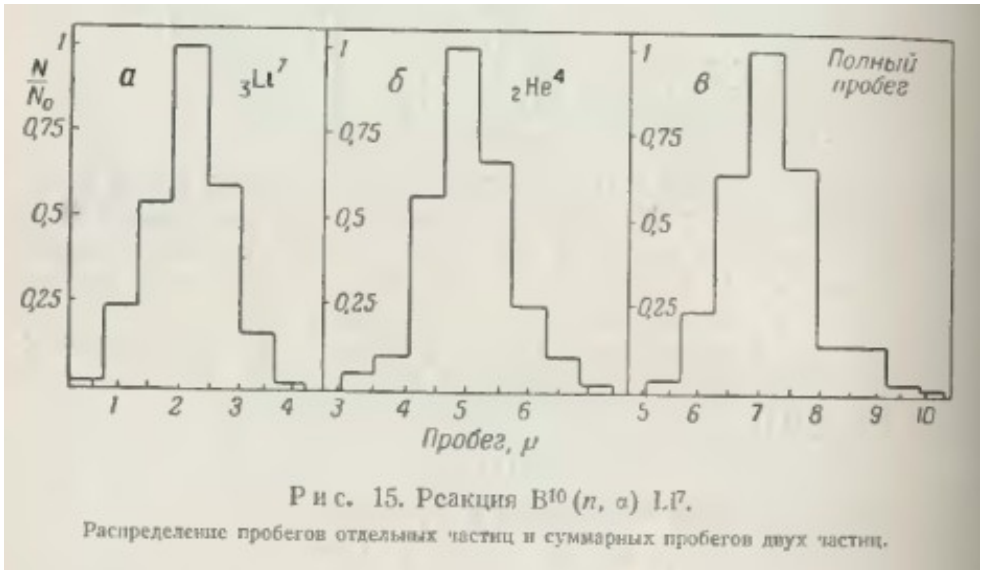
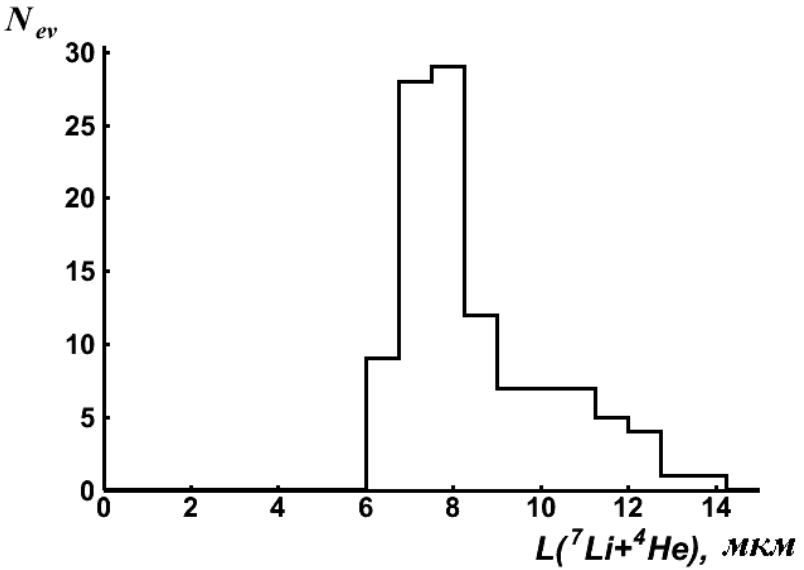
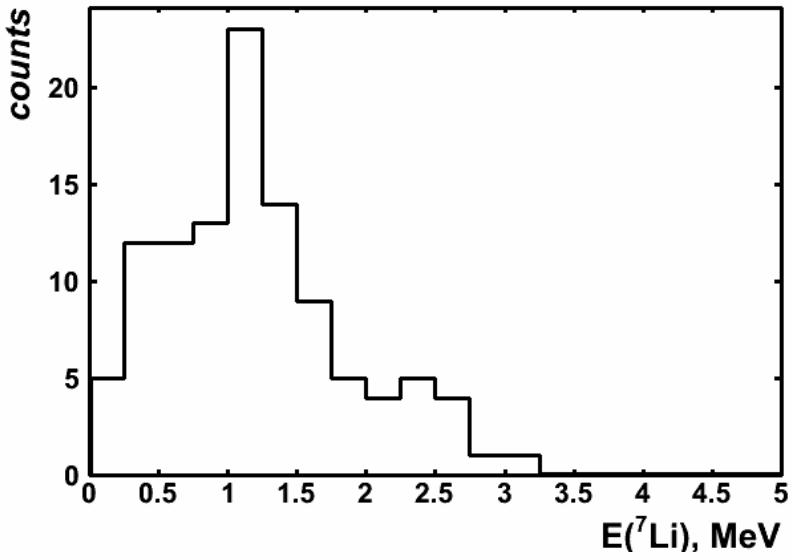
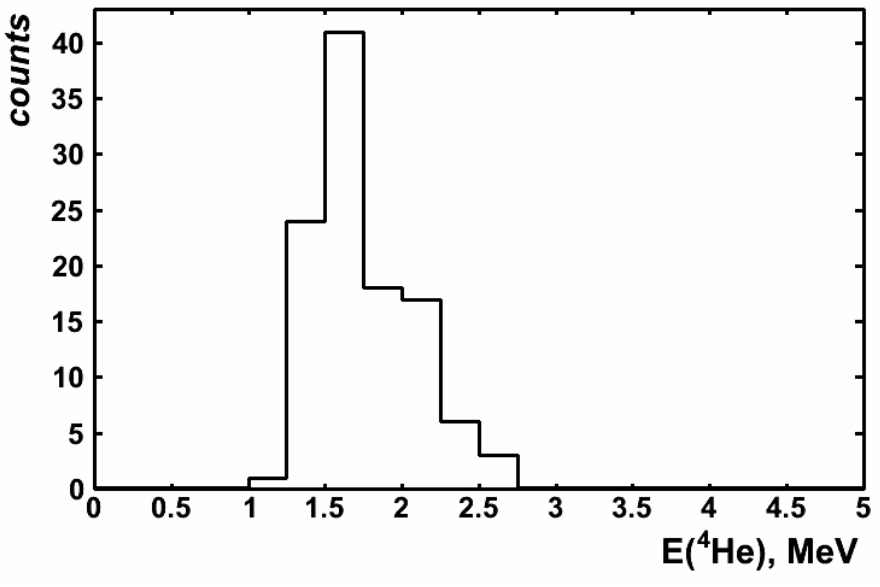


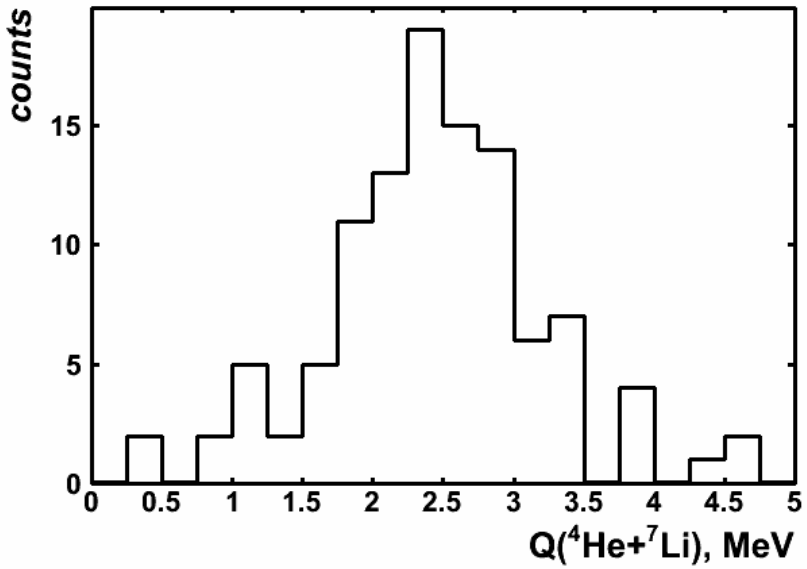
Рис. 15. Реакция $B^{10}(n, \alpha)\ Li^7$.

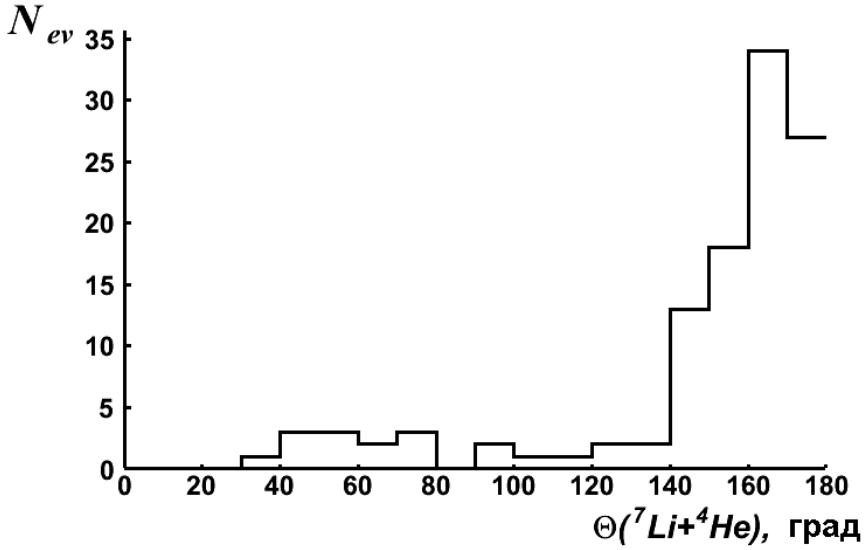
Распределение пробегов отдельных частиц и суммарных пробегов двух частиц.




counts
E(7Li), MeV


counts
E(4He), MeV


counts
Q(4He+7Li), MeV


Nev
Θ(7Li+4He), град

In the energy range of nuclei several MeV per nucleon, there is a possibility of implantation of radioactive nuclei into detector material. Of course, in this approach daughter nuclei are investigated rather than the nuclei themselves. In this respect it is worth mentioning the known, although somewhat forgotten, possibilities of NTE (Nuclear Track Emulsion) for the detection of slow radioactive nuclei. More than half a century ago, alpha tracks from the decay of ^{8}Be nuclei through the first excited state 2^{+} of about 2.0 MeV were observed. They occurred in the alpha decays of stopped ^{8}Li.

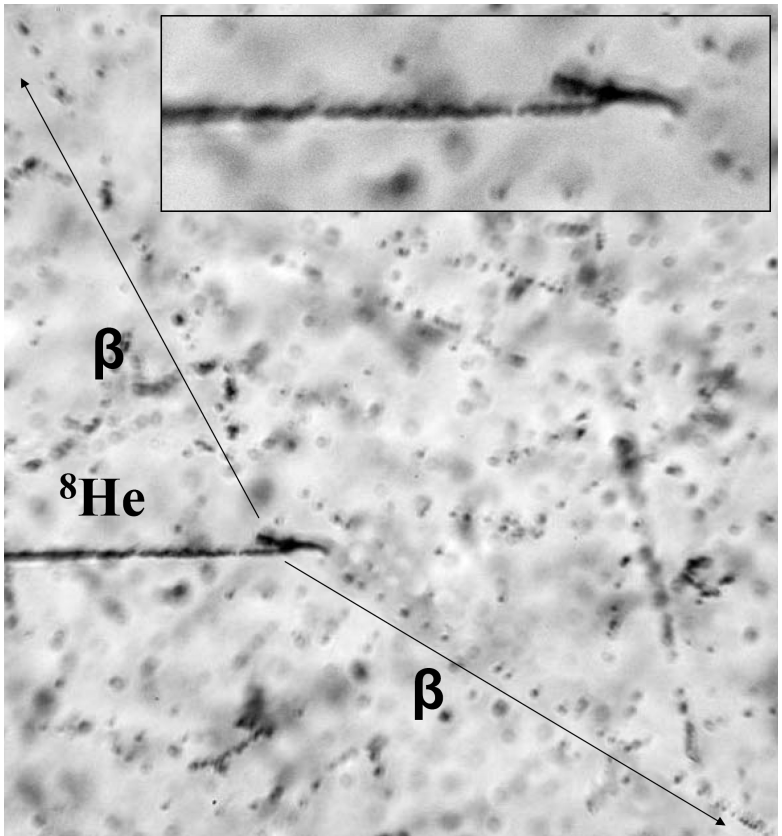
PHYSICAL REVIEW VOLUME 99, NUMBER 1 JULY 1, 1955

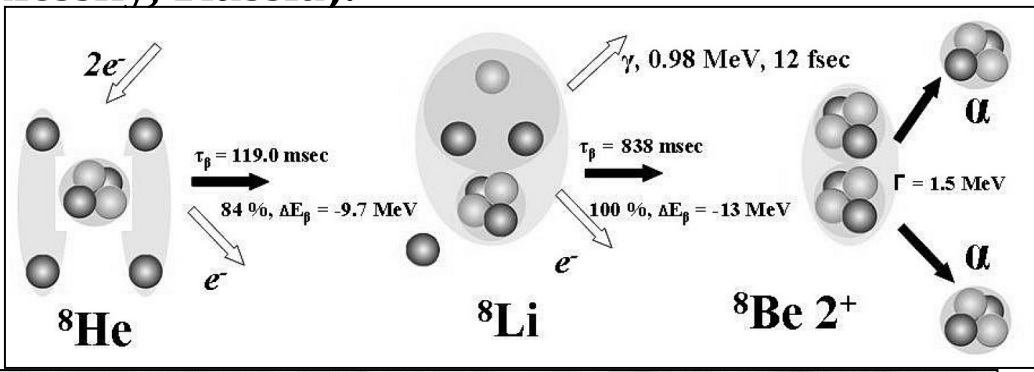
Alpha Spectrum in the Decay of Li^{8}†

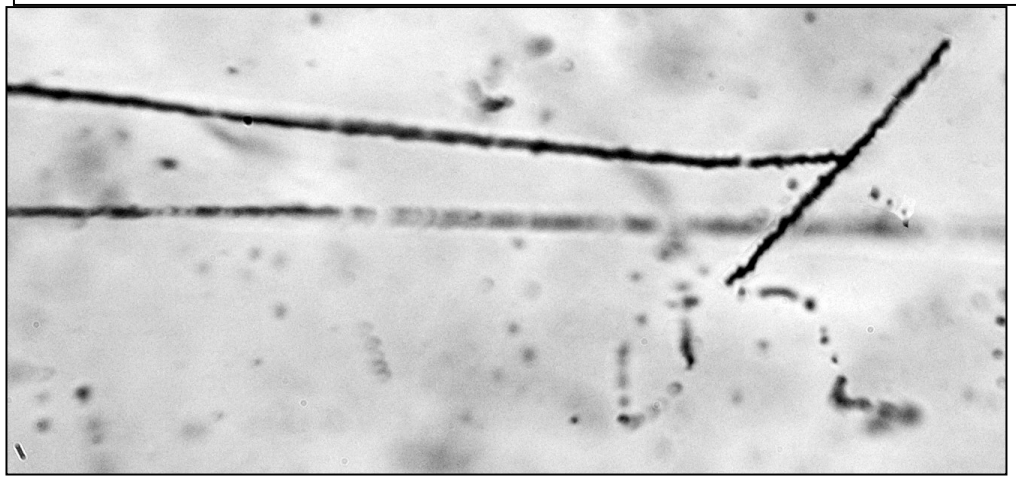
R. T. Frost* and S. S. Hanna
Department of Physics, The Johns Hopkins University, Baltimore, Maryland
(Received February 28, 1955)

The alpha-particle spectrum in the successive beta-alpha decay of Li^{8} was observed with magnetic analysis from 1 to 6.5 Mev, corresponding to excitation energies in Be^{8} from 2 to 13 Mev. The only definite structure in the spectrum corresponds to the well-known broad state at 2.9 Mev.

In March 2012 NTE was exposed at the Flerov Laboratory of Nuclear Reactions (JINR) at the ACCULINNA spectrometer (http://aculina.jinr.ru/). 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).

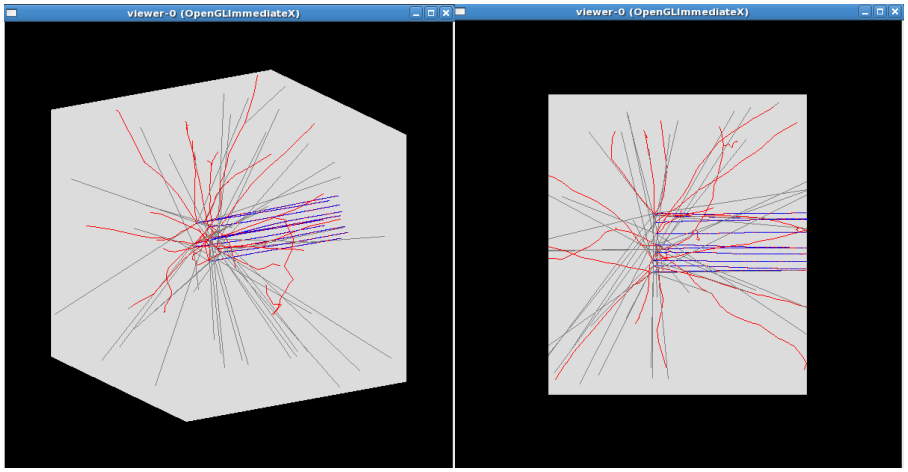




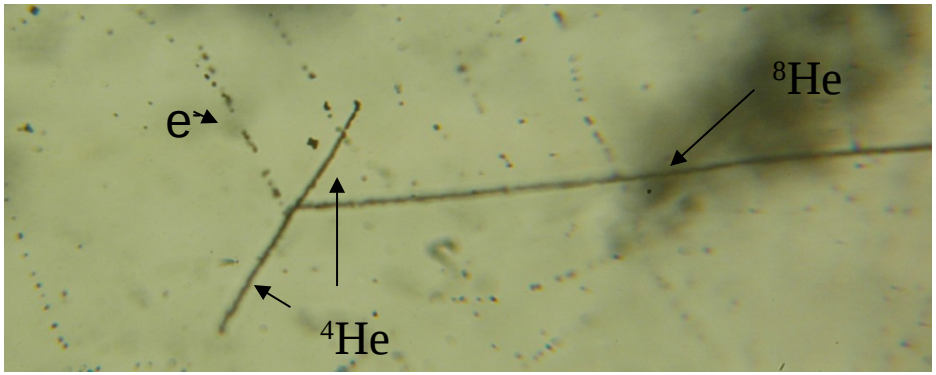


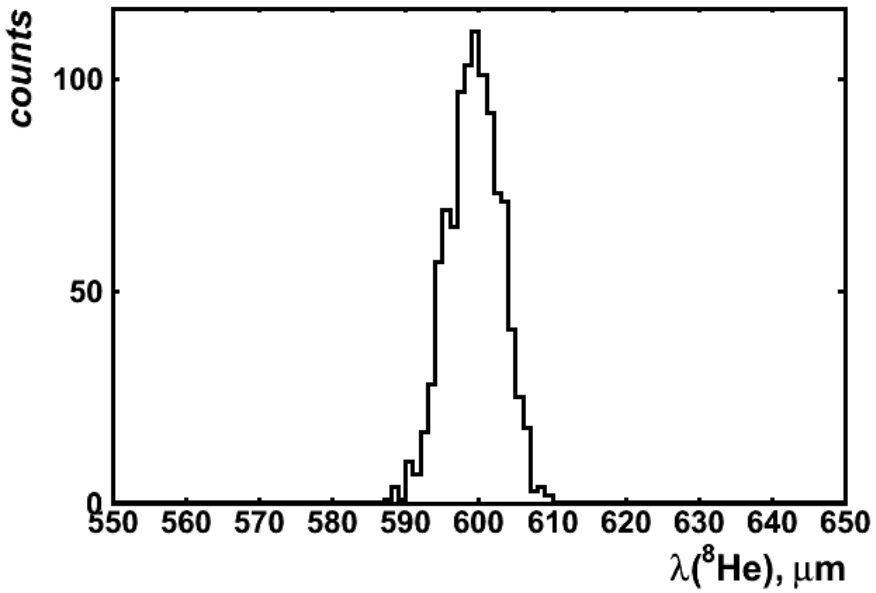
Data modeling and experiment (^{8}He at ≈7 A MeV)

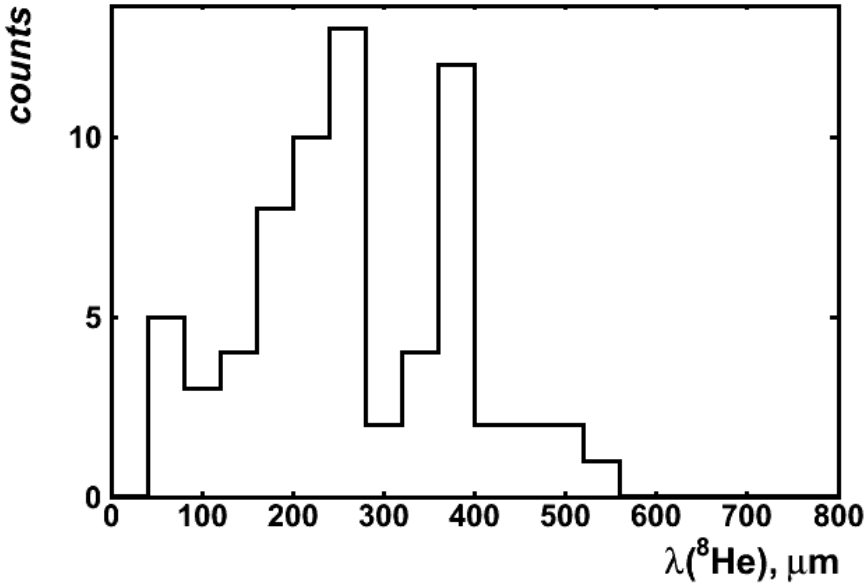
Radioactive Decay (Geant4)

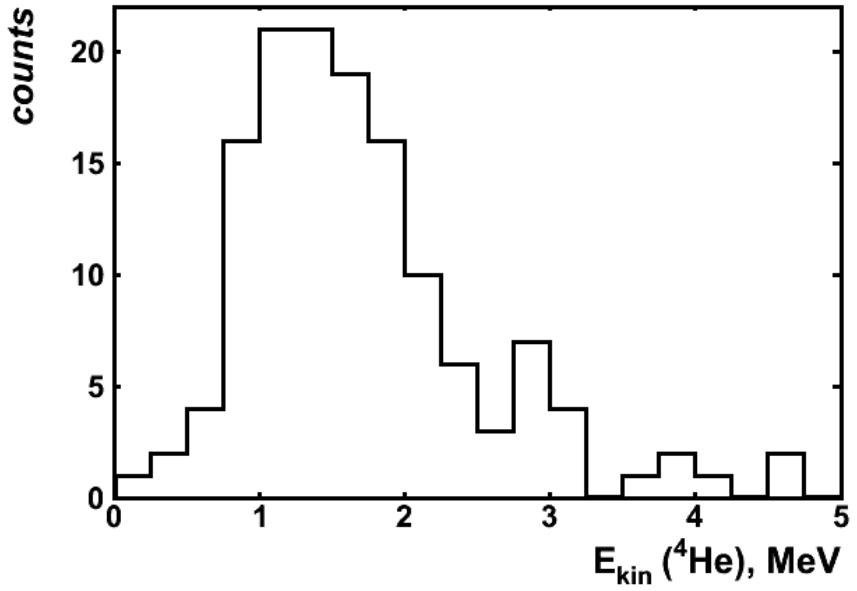


Experiment









Alpha spectrum from

(our experiment)

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

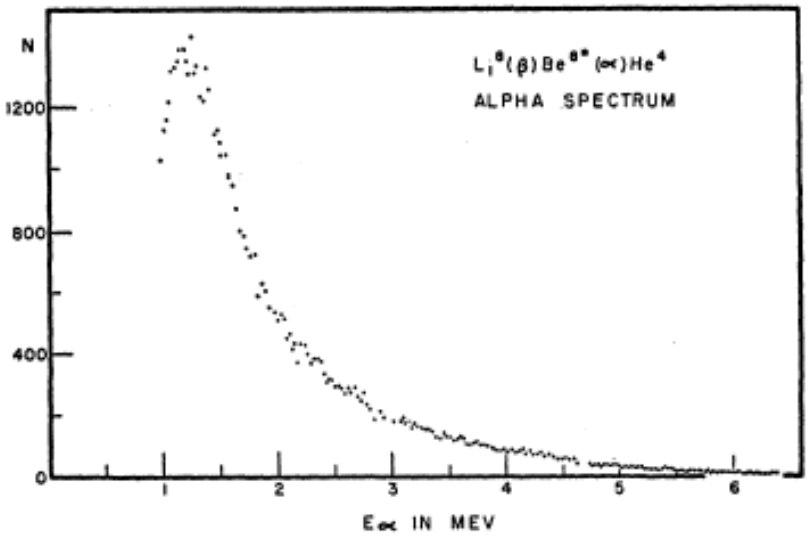


FIG. 1. Alpha spectrum from $Li^8(\beta)Be^{8*}(\alpha)He^4$. The vertical intensity scale is arbitrary. The numbers given indicate approximately the actual number of particles counted for the points below 3 Mev. Above 3 Mev the actual count is about twice that indicated by the numbers.

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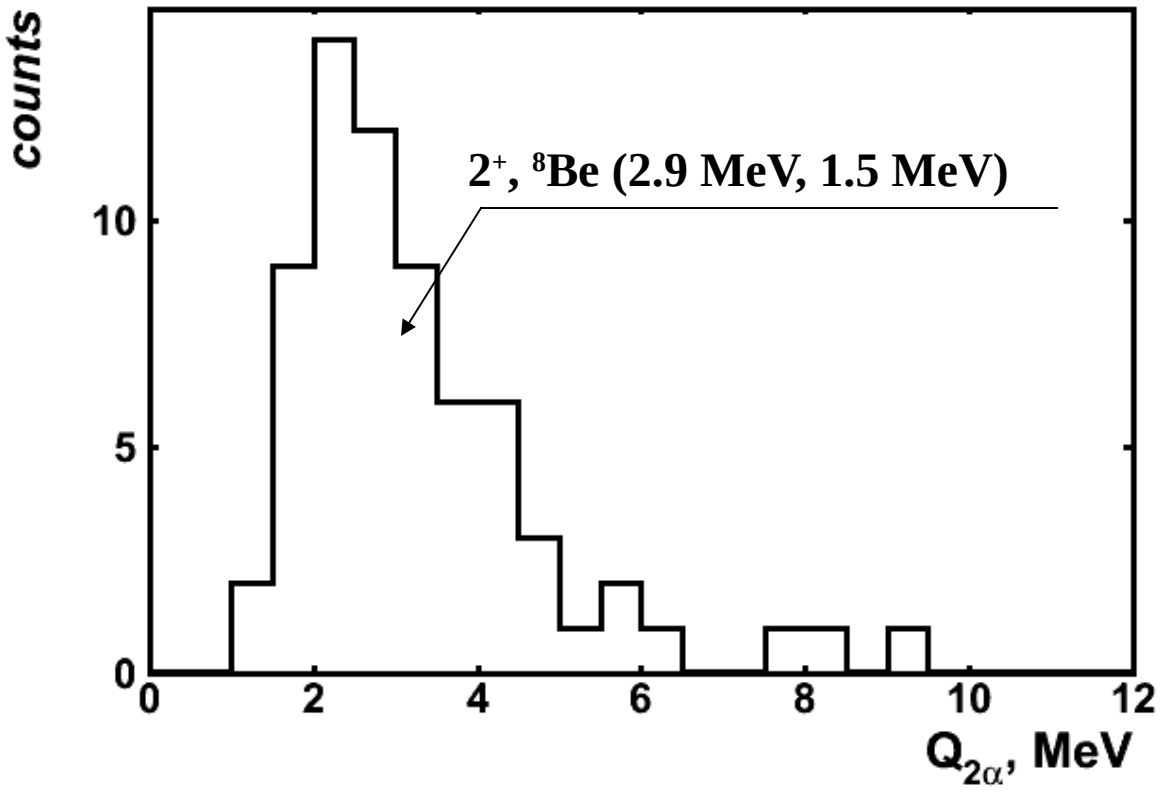
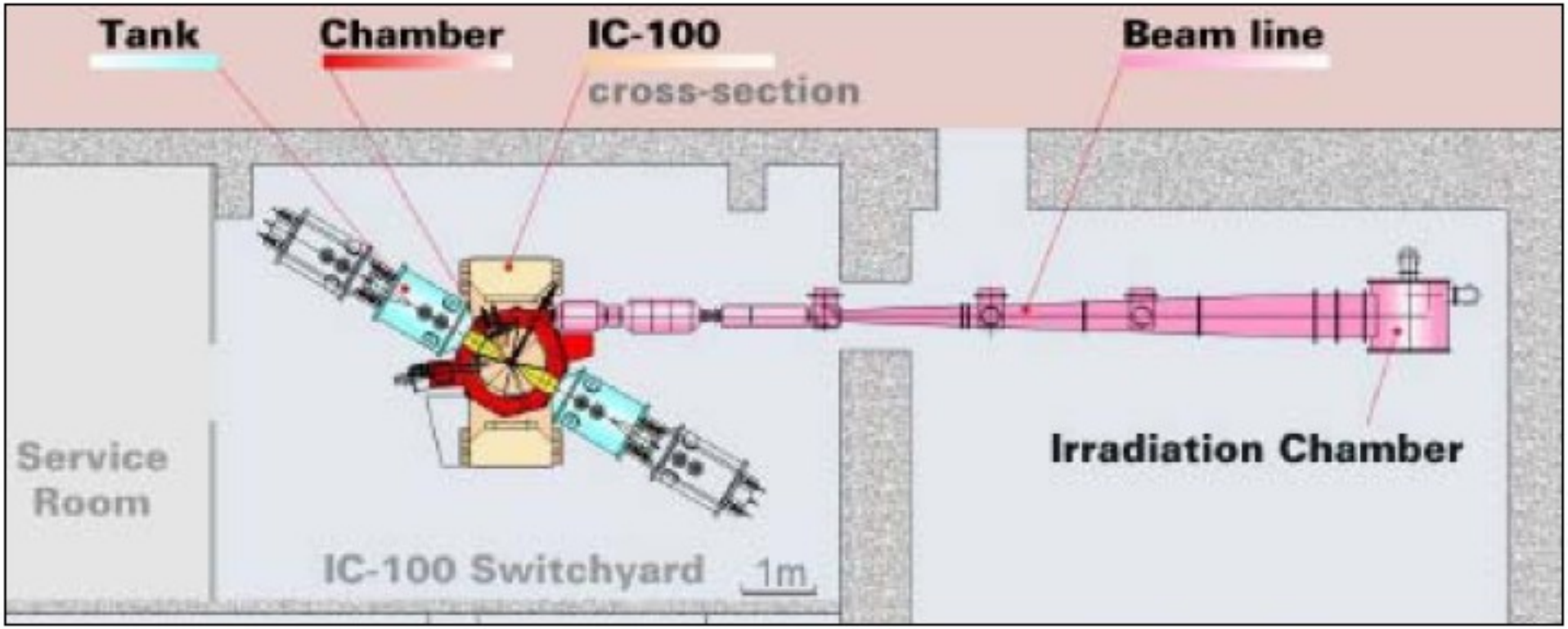
$$^{8}He \xrightarrow{\beta} {}^{8}Li \xrightarrow{\beta} {}^{8}Be \rightarrow 2\alpha$$ **at ~7 A MeV**

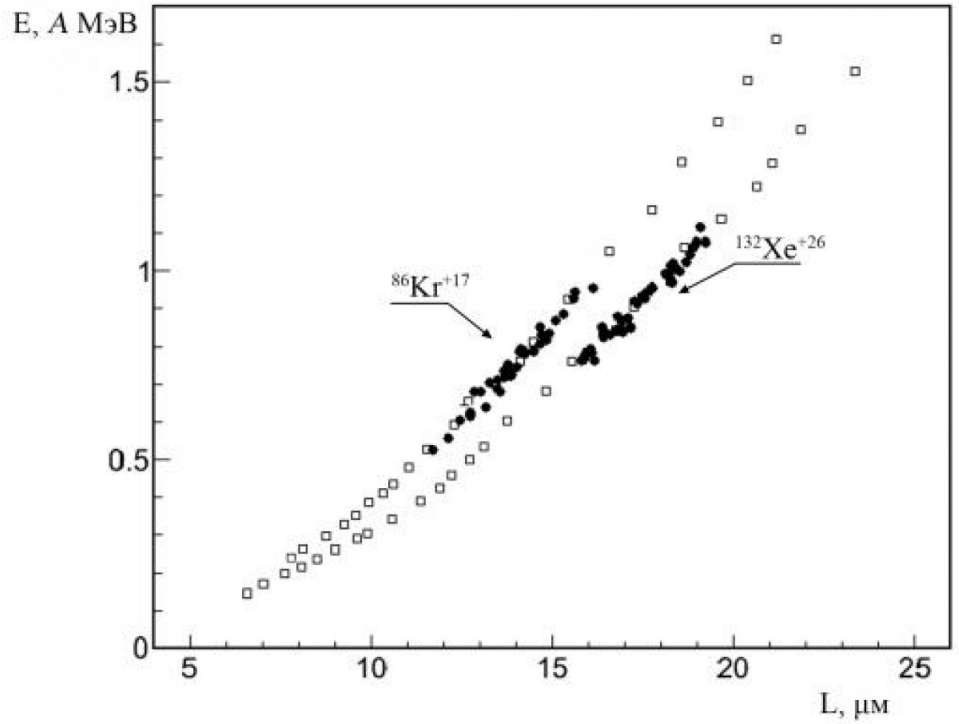
$$M_{2\alpha} = \left[2\left(m_{\alpha}^{2} + E_{\alpha 1}E_{\alpha 2} - p_{\alpha 1}p_{\alpha 2}\cos(\Theta_{12})\right)\right]^{\frac{1}{2}}$$

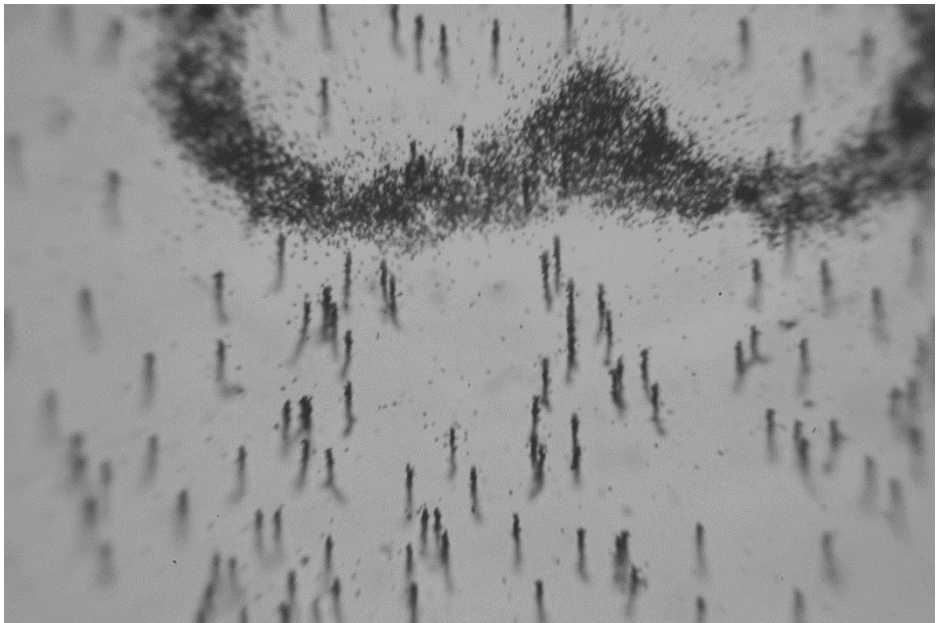
$$Q_{2\alpha} = M_{2\alpha} - 2 \cdot m_{\alpha}$$





NTE is exposed to ions $^{86}Kr^{+17}$ and $^{124}Xe^{+26}$ accelerated to energy of about 1.2 *A* MeV at the cyclotron IC-100 of the Flerov Laboratory of Nuclear Reactions, JINR. Since energy of these ions is small the exposure of NTE is performed without a light protective paper. Therefore, fixing of the NTE plates in the irradiation chamber was performed at a light which is ordinary for a photographic laboratory. For 5 seconds of exposure the track density amounted to about 10^5 - 10^6 cm^{-2}. The NTE layers with an inclination angle of 45 ° to the beam axis which provided observation of ion stops.


E, A МэВ
1.5
1
0.5
0
5
10
15
20
25
L, μм
$^{86}Kr^{+17}$
$^{132}Xe^{+26}$



Summary

- ***The presented observations serve as an illustration of prospects of the Nuclotron and NTE for nuclear physics researches.***
- ***The possibilities of nuclear track emulsion for study of fragmentation of relativistic ^{11}C nuclei is shown.***
- ***In the energy range of nuclei several MeV per nucleon, there is a possibility of implantation of radioactive nuclei (^{8}He) into detector material.***
- ***The possibilities of NTE for study with neutrons and muons are shown.***
- ***Demonstrated the possibilities of the newly reproduced nuclear emulsion for research with heavy ions at extremely low energies (^{86}Kr and ^{132}Xe).***

Thank you for your attention!

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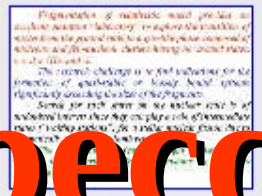


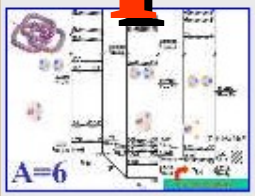



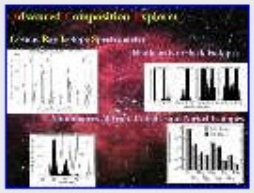
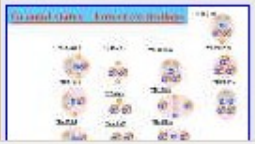

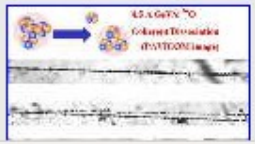


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