BECQUEREL PROJECT

Проект БЕККЕРЕЛЬ

Beryllium (Boron) Clustering Quest in Relativistic Multifragmentation

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Recent exposures of nuclear track emulsion to ^{8}He nuclei, fast and thermal neutrons and heavy ions.

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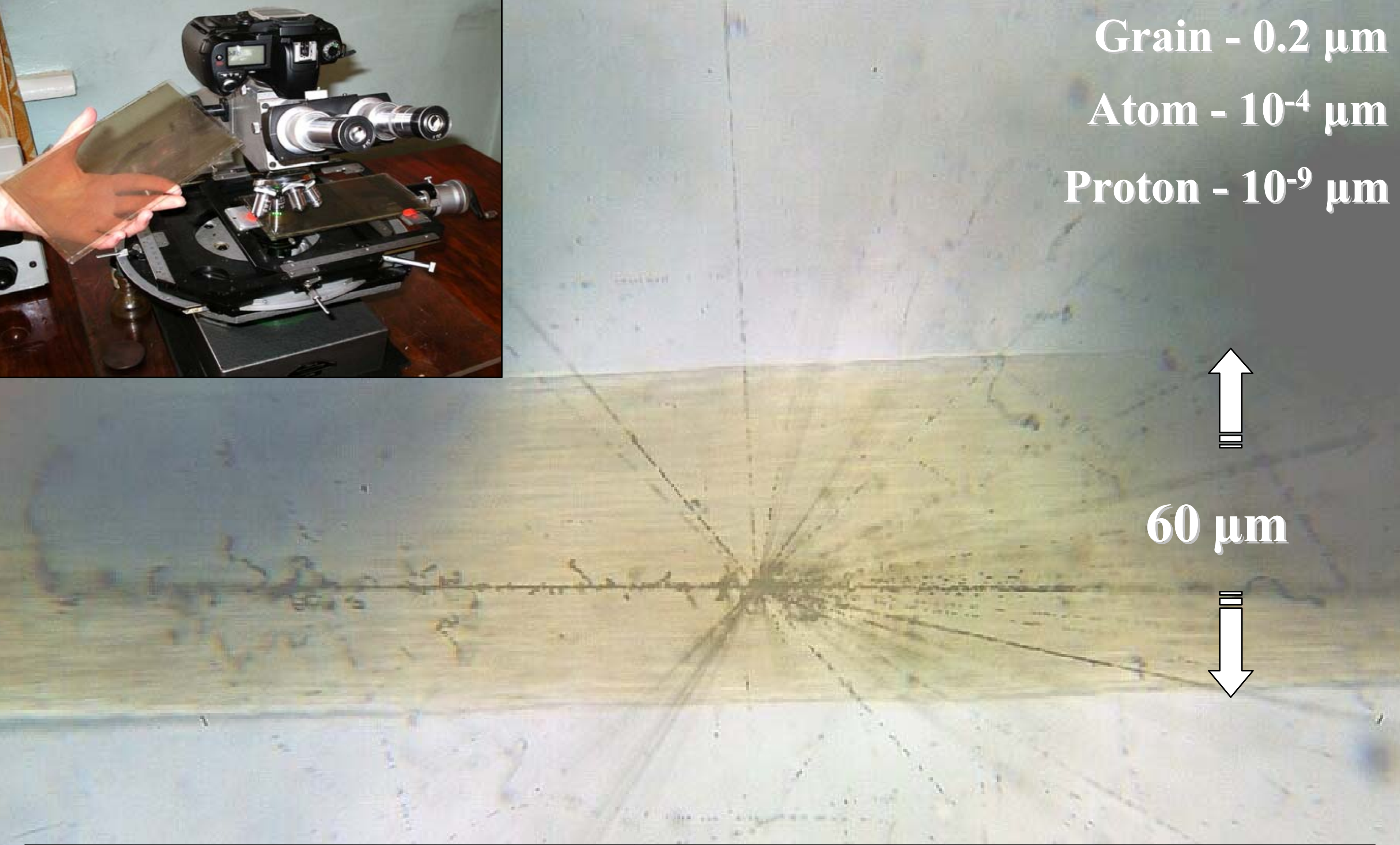
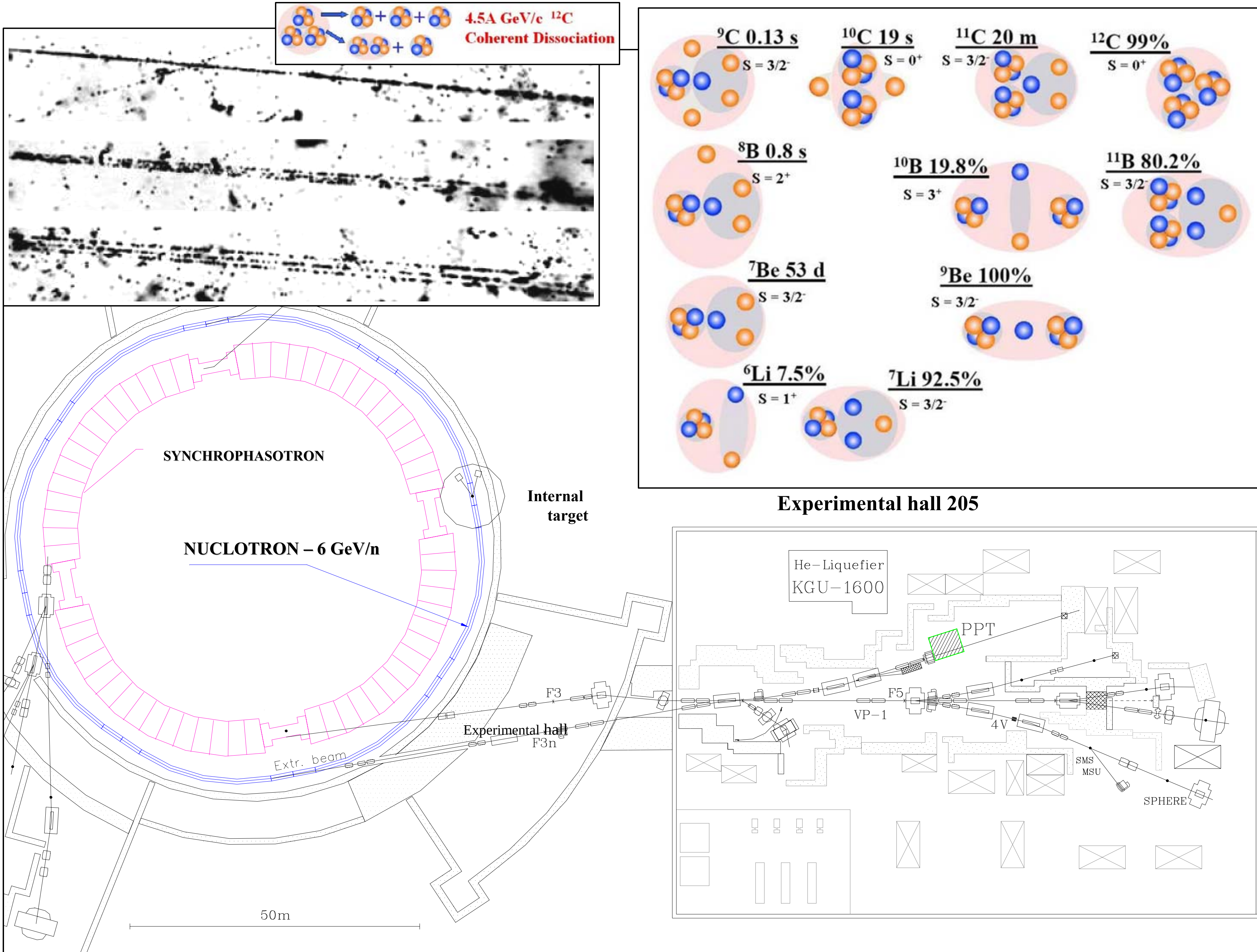
Featuring an excellent sensitivity and spatial resolution nuclear track emulsion (NTE) maintains the position of a universal and inexpensive detector for survey and exploratory research in microcosm physics. Use of this classical technique on the beams of modern accelerators and reactors turns out highly productive. In a number of important tasks the completeness of observations provided in NTE can not be achieved for electronic detection methods.

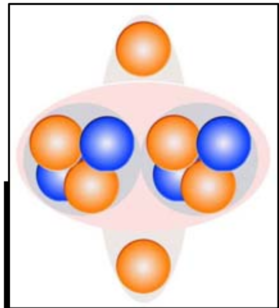
Physical analysis of exposures of test samples of reproduced NTE is presented. NTE is exposed to 60 MeV ^{8}He nuclei. Measurements of decays of ^{8}He nuclei stopped in NTE allow one to evaluate possibilities of α-spectrometry. Thermal drift of ^{8}He atoms is observed. Correlations of α-particles are studied on statistics of 400 events of splitting $^{12}C \rightarrow 3\alpha$ in NTE exposed to 14.1 MeV neutrons. In boron enriched NTE the angular and energy correlations of products of the reaction induced by thermal neutrons $n_{th} + {}^{10}B \rightarrow {}^{7}Li + (\gamma) + \alpha$ are studied. NTE was exposed to ions $^{86}Kr^{+17}$ и $^{124}Xe^{+26}$ of energy about 1.2 *A* MeV. Measurements of the heavy ion ranges of in NTE allowed one to determine their energy on a basis of the SRIM model.

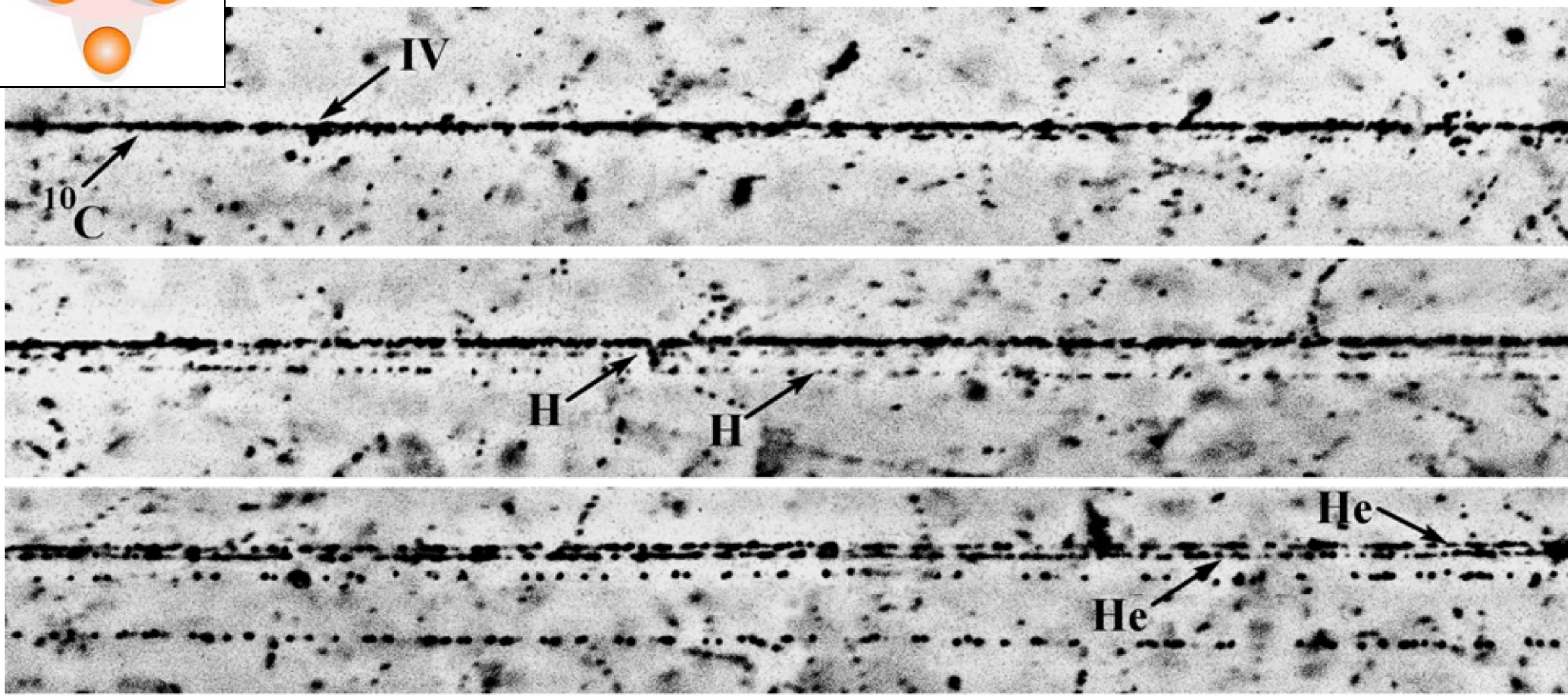


The spatial resolution of nuclear emulsion BR-2 (Russia) is 0.5 µm, and its sensitivity ranges from the most highly charged relativistic ions to singly charged relativistic particles. These features can be estimated in the photograph combining pictures of interaction of relativistic sulfur nucleus and human hair thickness of 60 µm. Both images were obtained under identical conditions using a microscope and a digital camera. It can be argued that nuclear emulsion gives the best projection of the events that occurred on microcosm scale.



4.5A GeV/c 12C
Coherent Dissociation
9C 0.13 s
S = 3/2-
10C 19 s
S = 0+
11C 20 m
S = 3/2-
12C 99%
S = 0+
8B 0.8 s
S = 2+
10B 19.8%
S = 3+
11B 80.2%
S = 3/2-
7Be 53 d
S = 3/2-
9Be 100%
S = 3/2-
6Li 7.5%
S = 1+
7Li 92.5%
S = 3/2-
SYNCHROPHASOTRON
Internal target
NUCLOTRON – 6 GeV/n
Experimental hall 205
He-Liquefier
KGU-1600
PPT
F3
F5
VP-1
4V
Experimental hall
F3n
Extr. beam
SMS
MSU
SPHERE
50m



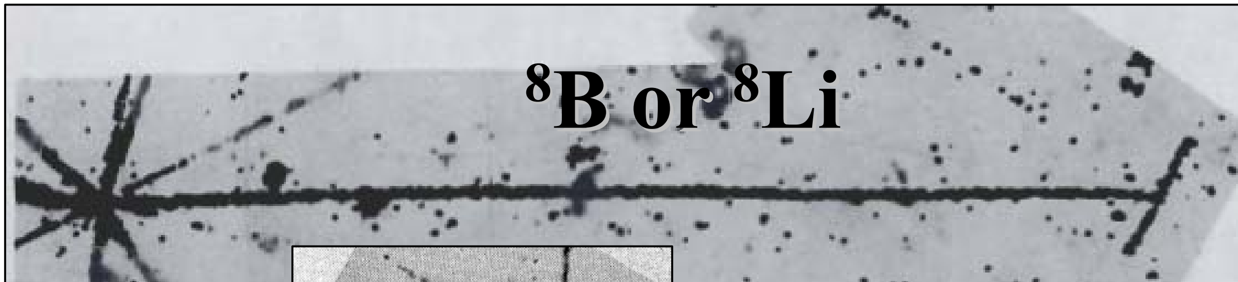


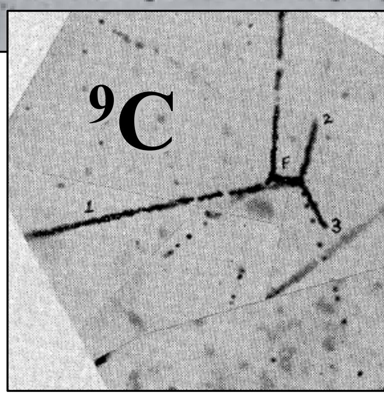
Coherent dissociation $^{10}C \rightarrow p + {}^{9}B_{g.s.}$ at 2A GeV/c. The interaction vertex (IV) in which a group of fragments formed is marked on the top photo. Further, one can distinguish two H (middle photo) and two He fragments (bottom photo). The most remote track is originated in the dissociation $^{10}C \rightarrow {}^{9}B_{g.s.} + p$. The other tracks correspond to the decay of the unbound ^{9}B nucleus. The pair of the He tracks corresponds to the following decay of another unbound ^{8}Be nucleus.

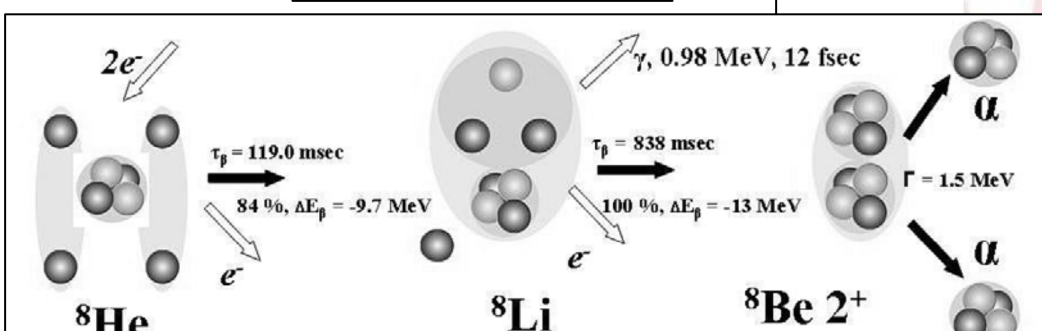
In the framework of the BECQUEREL project NTE samples produced by the Micron workshop which is part of the Slavich Company are irradiated. Samples are manufactured by pouring of NTE layers of 50 to 200 micrometers on glass substrates. The main features of this NTE are close to NTE BR-2 which provided sensitivity to relativistic particles. Production NTE BR-2 was carried out over four decades and finished about ten years ago. The reproduced NTE was already used for a spectrometry of α-particles over ranges.

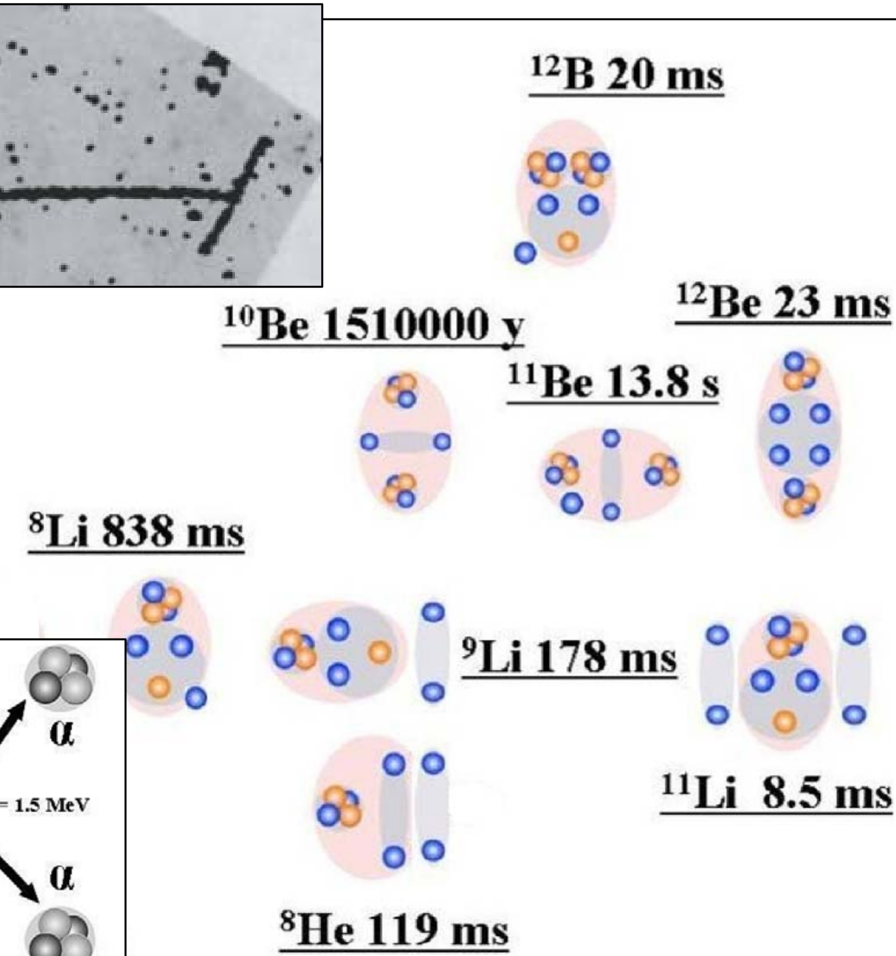
^{8}He nuclei stopped in nuclear track emulsion

There is a possibility to study 2α- and 3α-particle decays of some light nuclei by implanting them into a detector. In this respect, NTE is worthy to be used as well. In NTE, the directions and ranges of the beam nuclei, as well as slow products of their decays can be measured, which provides a basis for spectrometry. Nowadays, when used with sufficiently pure secondary beams, NTE appears to be an effective means for studies of such decays.

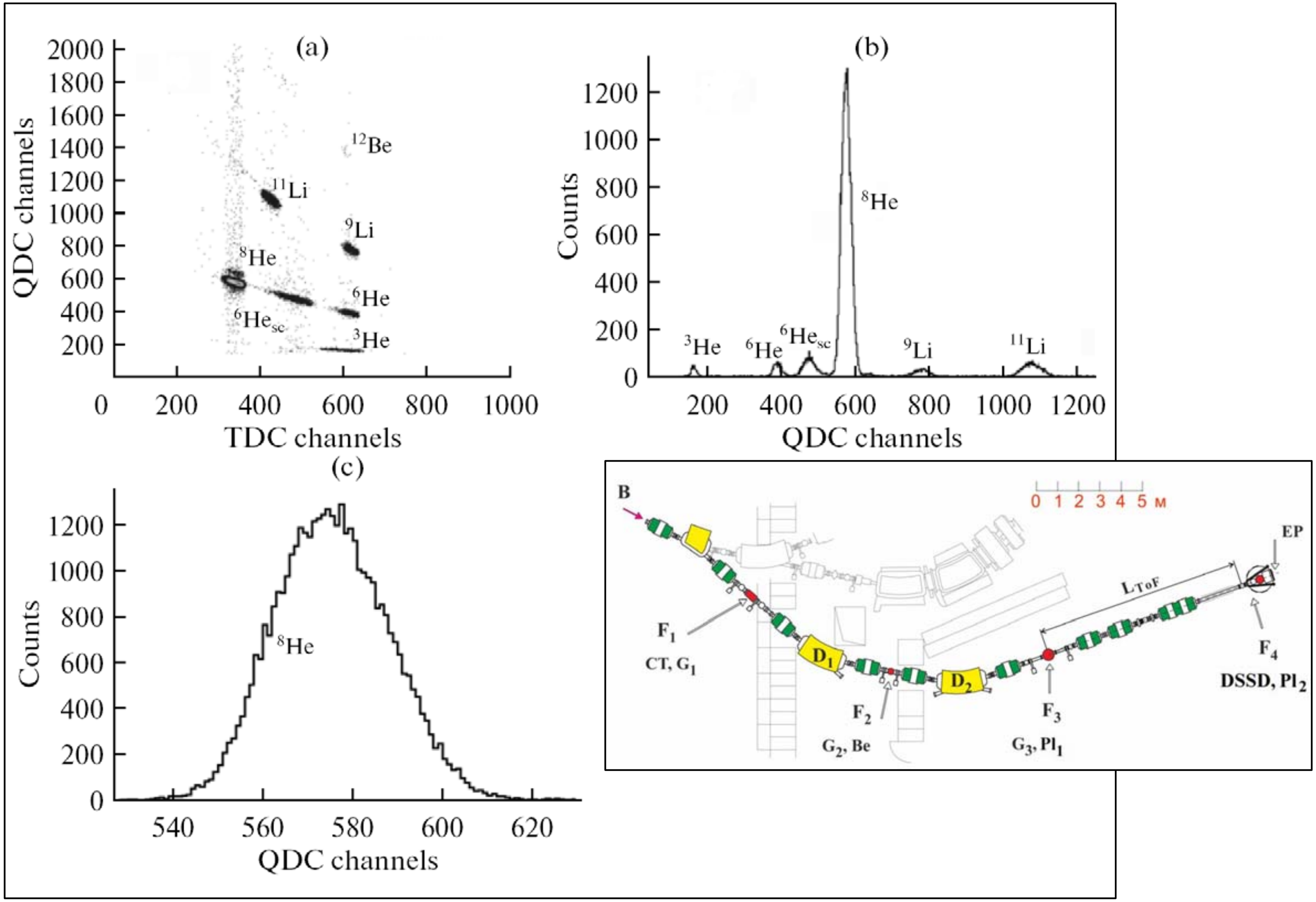




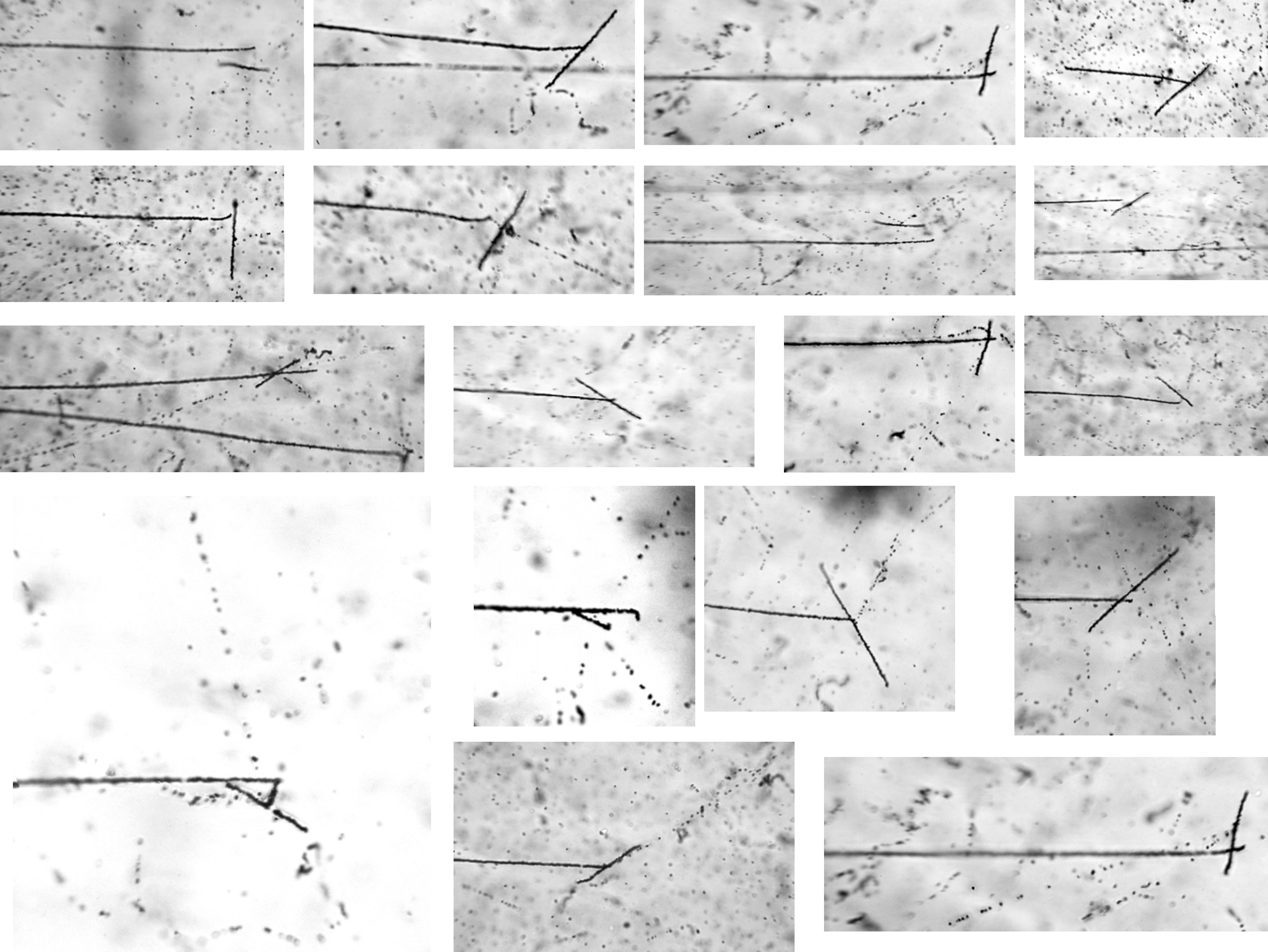




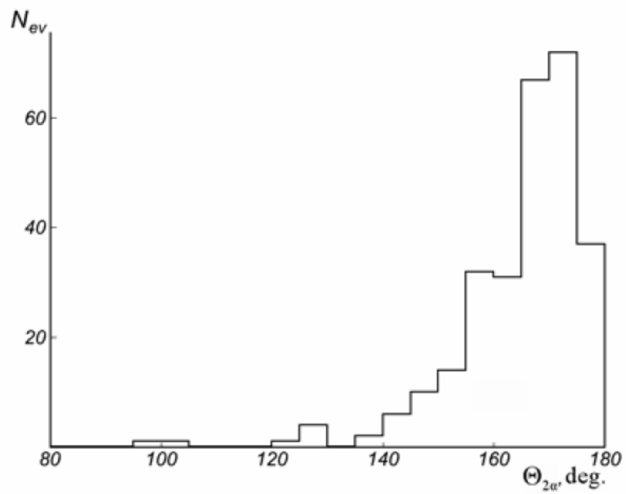
Exposure of NTE to nuclei ^{8}He of energy of 60 MeV is performed at the fragment separator ACCULINNA in the G. N. Flerov Laboratory of Nuclear Reactions, JINR.



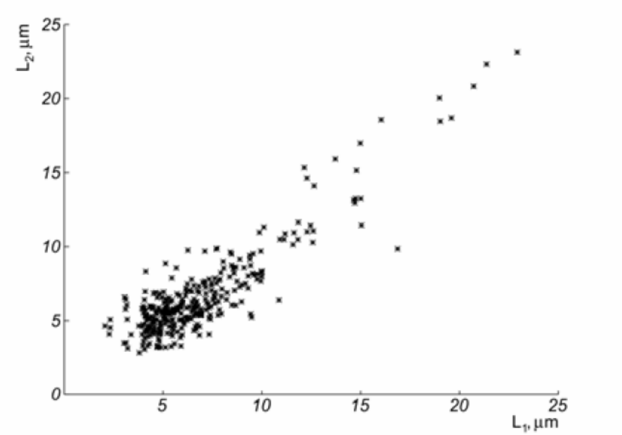
Composition of the beam produced at the ACCULINNA separator tuned to the ^{8}He isotope from the fragmentation of the ^{18}O nuclei with energy of 35 MeV/nucleon on the ^{12}C target. (a) Identification of particles by the silicon detector and from the time of flight; (b) spectra of energy lost by all beam particles in the silicon detector 1 mm thick; and (c) energy loss of ^{8}He nuclei alone. The sum of counts in (b) and (c) was used to find the beam enrichment in ^{8}He nuclei.



The coordinates of the decay vertices and stops of decay α-particles were determined for "hammers" of 136 "whole" and 142 "broken" events. In "broken" events the decay points were determined by extrapolating the electron track. The emission angles and the ranges of α-particles were obtained on this basis.



Distribution over $\Theta_{2\alpha}$ in α-pairs.



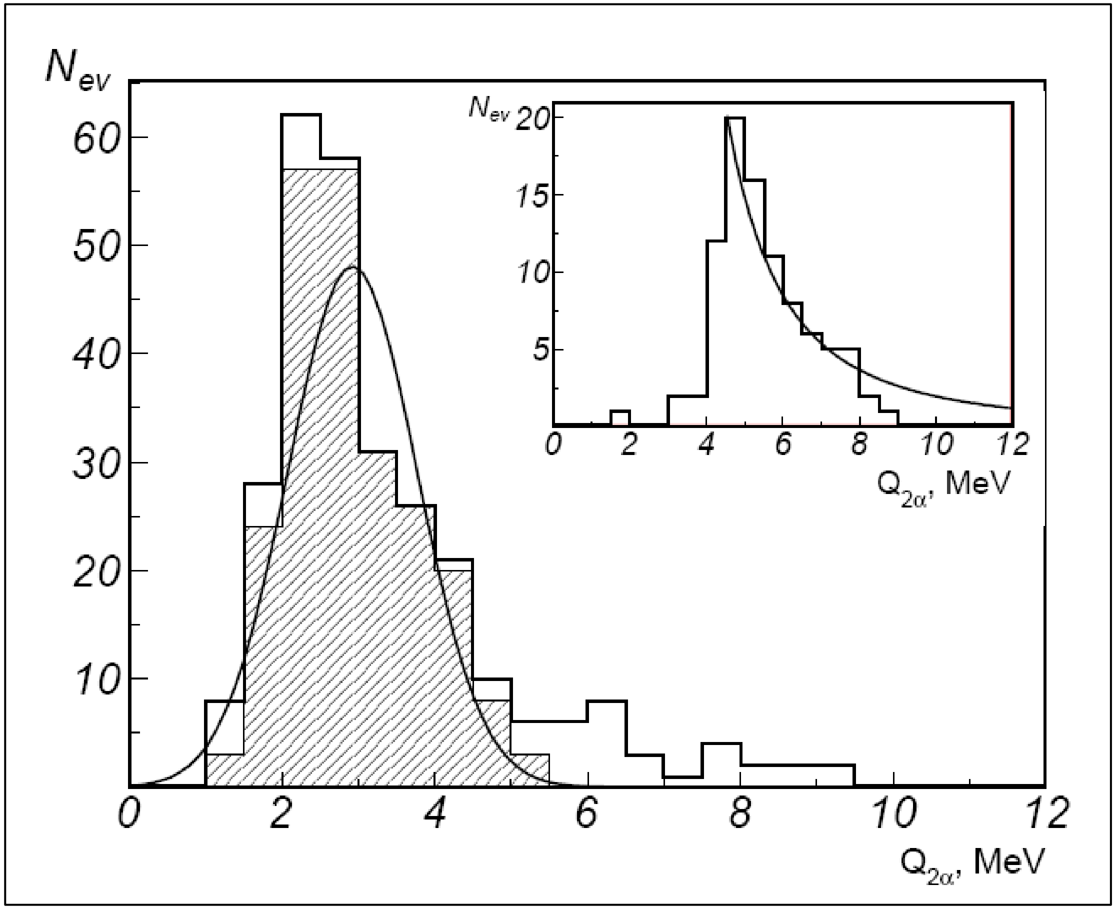
Distrbution of ranges L_1 and L_2 in α-pairs.

The distribution of the opening angles of α-particle pairs has a mean value $<\Theta_{2\alpha}> = (164.9 \pm 0.7)^o$ at rms $(11.6 \pm 0.5)^o$. Some kink of "hammers" is defined by the momenta carried away by eν-pairs.

The dependence of the α-particle ranges L_α and their energy values are determined by spline interpolation of calculations in the SRIM model.

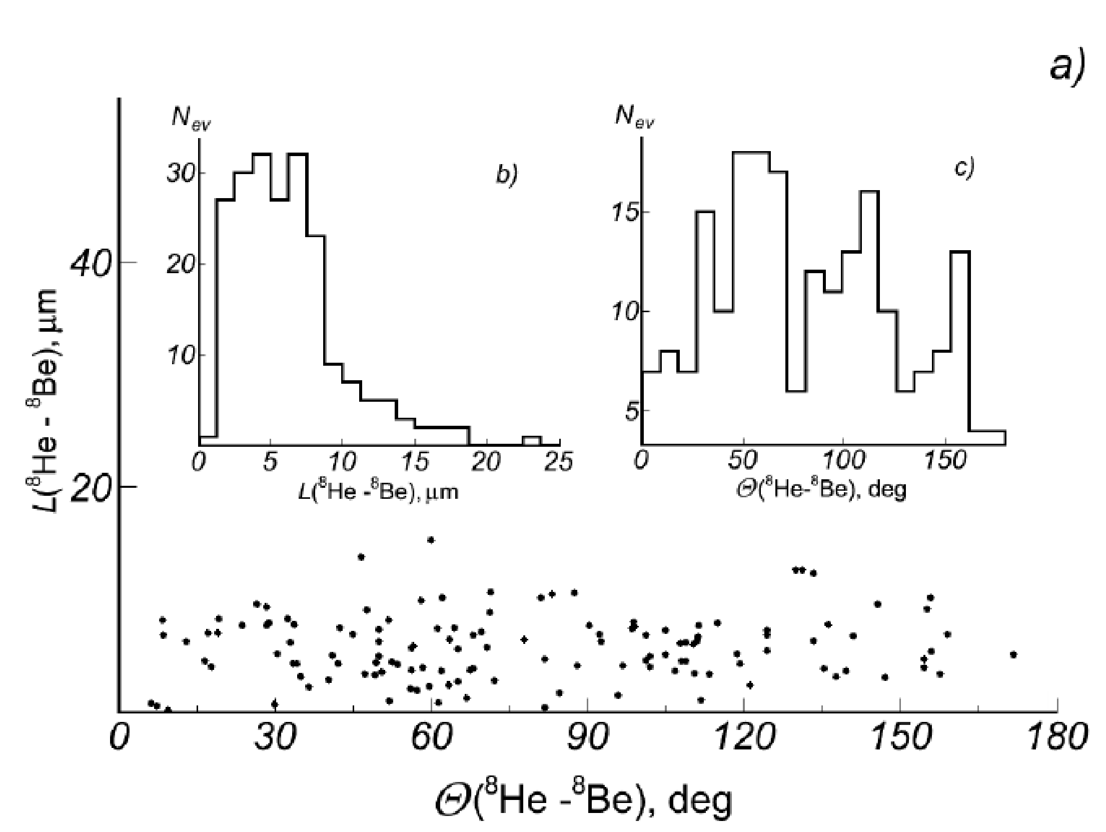
The mean value of the α-particle ranges is (7.4 ± 0.2) μm at rms (3.8 ± 0.2) μm. This value corresponds to a mean kinetic energy $<E(^4He)> = (1.70 \pm 0.03)$ MeV at rms 0.8 MeV. Correlation of ranges L_1 and L_2 of α-particles in pairs is clearly manifested. The distribution of the range differences $L_1 - L_2$ has rms 2.0 μm.

Knowledge of the energy and emission angles of α-particles allows one to derive the energy distribution of α-decays $Q_{2\alpha}$. The invariant variable Q is defined as the difference between the invariant mass of a final system M⋆ and the mass of a primary nucleus M, that is, Q = M⋆ –M, M⋆ is defined as the sum of all products of the 4-momenta P_i of fragments, that is, $M^{*2} = (\sum P_i)^2$. In a case of an α-particle pair *i* is equal just 1 and 2.



Distribution on energy $Q_{2\alpha}$ of 278 pairs of α-particles; hatched histogram correspond to condition of selection of events L_1 and L_2 <12.5 μm, Θ > 145˚; line Gaussian. On the insertion: $Q_{2\alpha}$ distribution of additional 98 α-pairs having L_1 and L_2 > 12.5 μm.

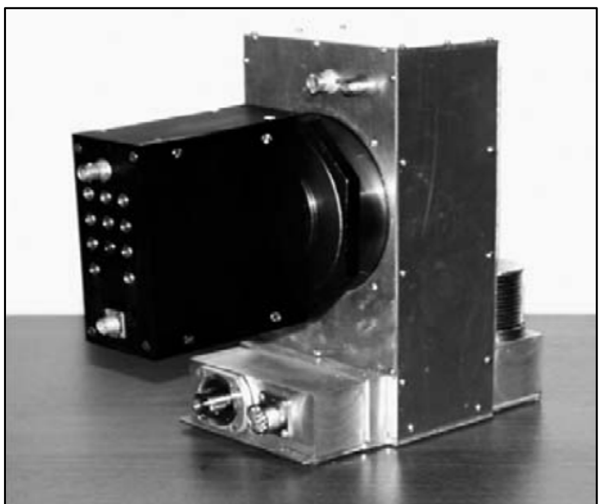
In the 142 "broken" events the distances $L(^8He\text{-}^8Be)$ between the stopping points of the ^8He ions and the decay vertices as well as the angles Θ (8He-8Be) between directions of arrivals of the ions and directions from the stopping points of the ions towards the decay vertices are defined. Uniformity of distributions of events over these parameters and absence of a clear correlation indicate on a thermal drift of the atoms ^8He. The mean value of $L(^8He\text{-}^8Be)$ amounting to (5.8 ± 0.3) μm at rms (3.1 ± 0.2) μm, can be associated with a mean range of atoms ^8He. The low value of a mean speed of the atoms ^8He defined as ratio of the mean value of $L(^8He\text{-}^8Be)$ to the half-life of the nucleus ^8He supports a pattern of diffusion.



Distribution of the distances $L(^8He\text{-}^8Be)$ between the stopping points of the ^8He ions and the decay vertices *vs* the angles $\Theta(^8He\text{-}^8Be)$ between directions of arrivals of the ions and directions from the stopping points of the ions to the decay vertices (a); insertions: projected histograms for $L(^8He\text{-}^8Be)$ (b) and $\Theta(^8He\text{-}^8Be)$ (c).

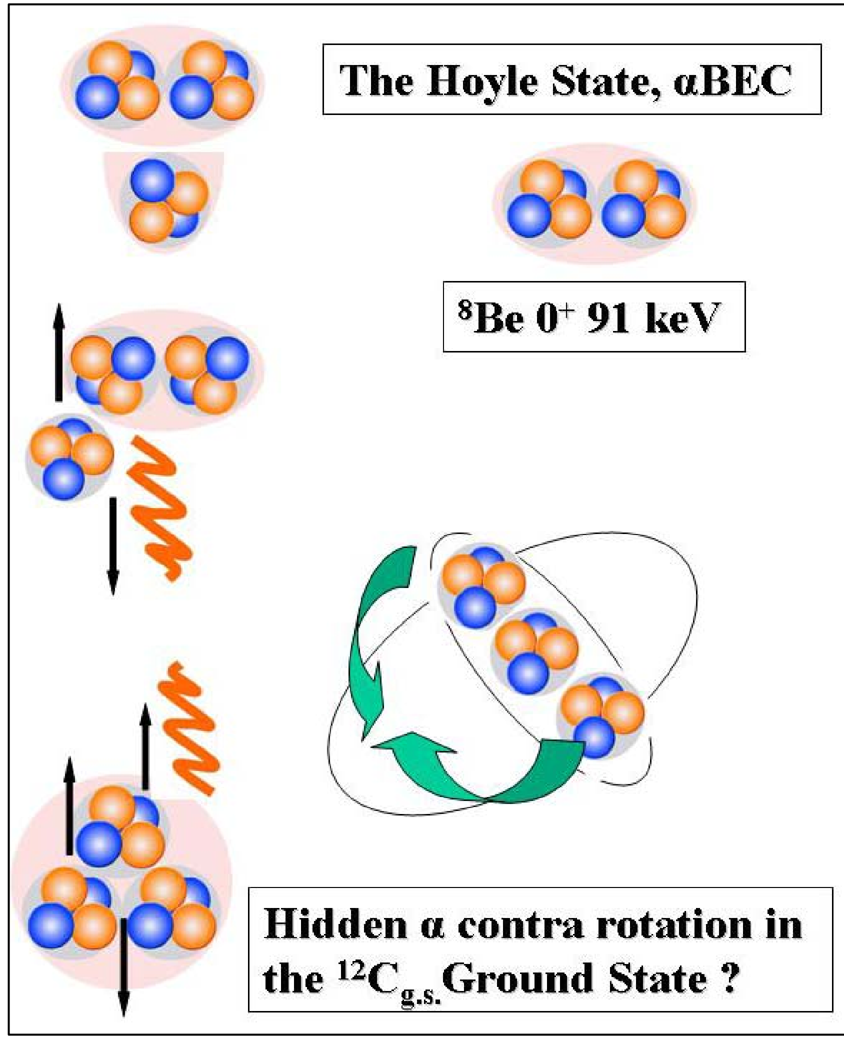
Correlations of α-particles in splitting of ^{12}C nuclei by neutrons of energy of 14.1 MeV

Nuclear track emulsion (NTE) exposed to neutrons of energy of 14.1 MeV produced in a low energy reaction $d + t \rightarrow n + \alpha$ allows one to study the ensembles of triples of α-particles produced in disintegrations of carbon nuclei of NTE composition. Energy transferred to α-particles is sufficient to measure their ranges and directions and, at the same time, it remains below the thresholds of background channels. Such an approach to the experimental study emerged with the advent of neutron generators. An initial objective of this analysis was limited to α-calibration of NTE, recently reproduced by the Slavich Company. A significant number of α-triples of the reaction ^{12}C$(n,n')3\alpha$ reached 1200 in a short time made it possible to analyze it on a large statistics as well as to create a commonly available bulk of experimental data. This bulk is useful for a direct comparison with the α-cluster models of the ^{12}C nucleus.

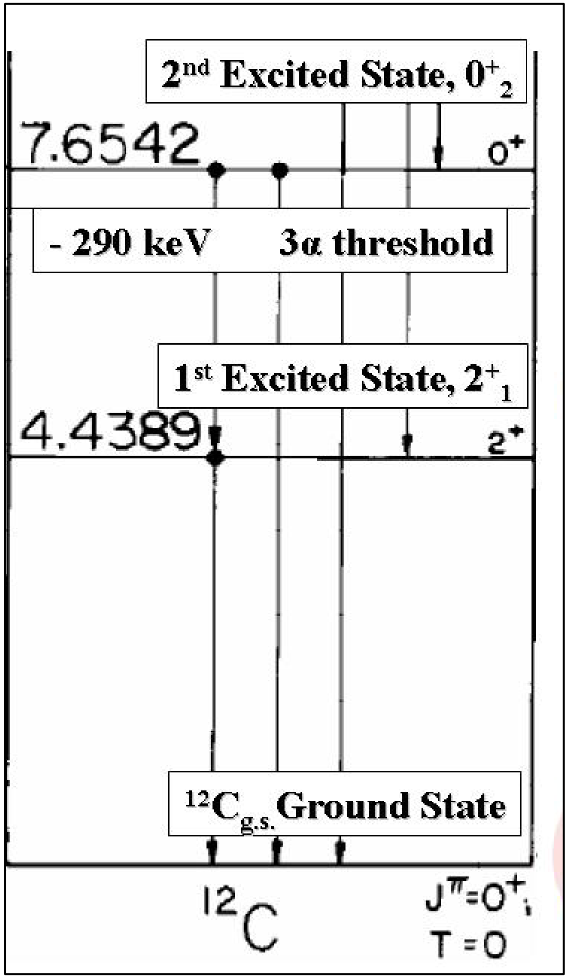


Exposure of NTE to neutrons of energy 14.1 MeV was performed on one of devices DVIN of an applied destination. A neutron generator of the device provided a flow of $5\cdot10^7$ neutrons/s in the full solid angle. The NTE stack was placed on a top cover of the device DVIN approximately 10 cm above a tritium target.

Traditionally the nucleus ^{12}C is regarded as a "laboratory" for the development the α-particle clustering concepts. It is a possible that in the ground state of $^{12}C_{g.s.}$ there are two pairs of α-clusters with orbital angular momenta equal to 2 (D-wave). In this case the basic configurations are ^{8}Be nuclei in the first excited state 2^+. In a classical pattern one may imagine a rotation in opposite directions of two α-clusters with angular momenta equal to 2 around a common center represented by a third α-cluster. Then the remaining combination of two α-clusters should correspond to the ground state of the nucleus ^{8}Be with spin and parity 0^+ (S-wave). As a result the superposition of the pair states in the ensemble of three α-clusters leads to a zero spin in $^{12}C_{g.s.}$. Naturally, this simplified model requires a quantum-mechanical consideration. Nevertheless, its validity should be confirmed by an intensive formation of states $^{8}Be_{2+}$ and $^{8}Be_{g.s.}$ with a predominance of the former one in reactions of knocking of α-particles from ^{12}C nuclei.

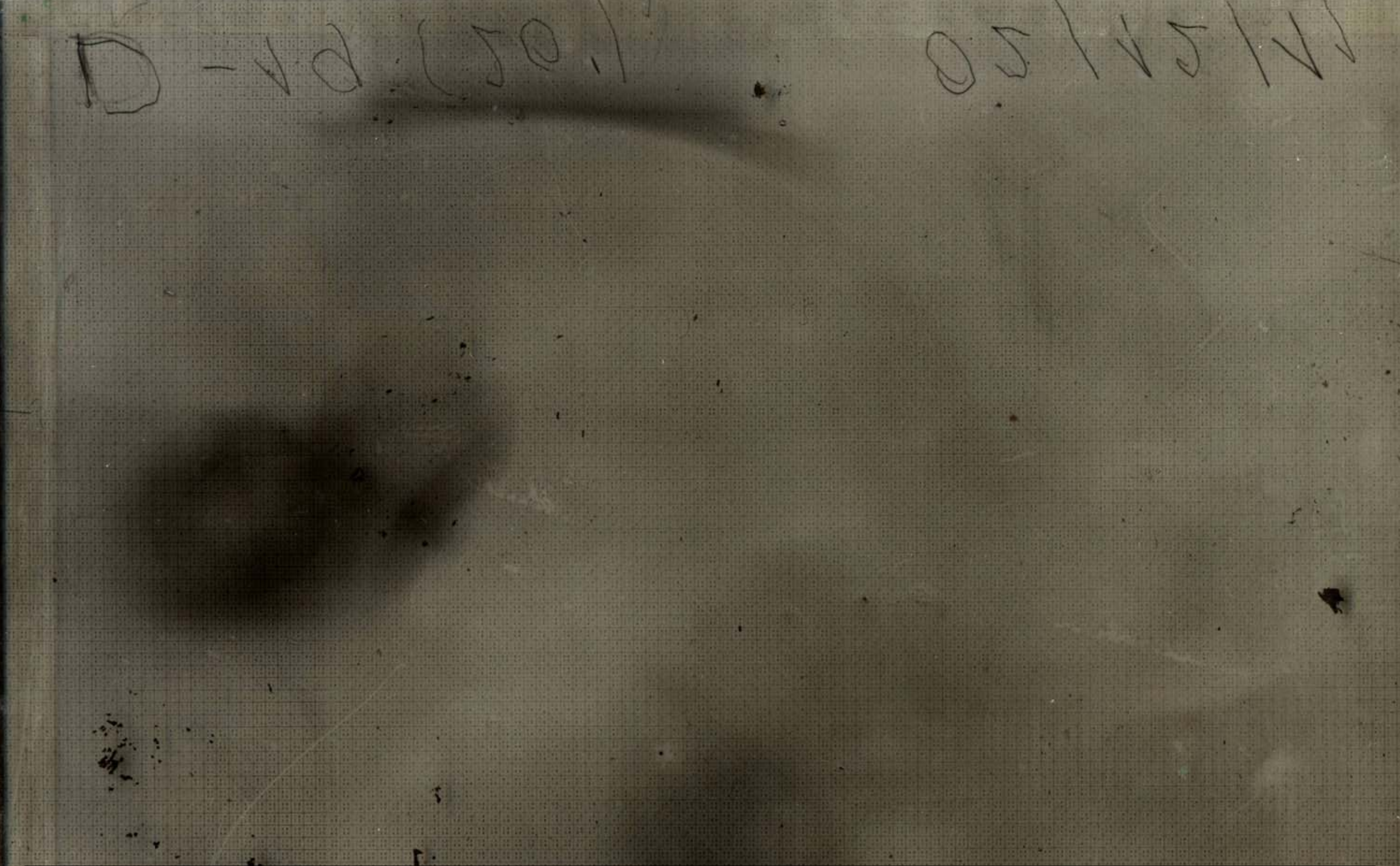


The ratio of the yields of α-particle pairs through the states $^{8}Be^{2+}$ and $^{8}Be_{g.s.}$ in disintegrations of nuclei ^{12}C not accompanied by a transfer of the angular momentum is a key parameter which should reflect the spin-cluster structure $^{12}C_{g.s.}$. Analysis of interactions in NTE exposed to neutrons of energy near the threshold of the ^{12}C splitting allows one to determine this and other characteristics of the reaction $^{12}C(n,n')3\alpha$.



Importance of the discussed structure is determined not only by interest to describe $^{12}C_{g.s.}$, but also the fact that it is the starting configuration for the reverse process of generating 3α-particle ensembles in the Hoyle state. It is assumed that this state after $^{8}Be_{g.s.}$ is a Bose-Einstein condensate consisting of α-particles with zero angular momentum. Its identification in breakups of ^{12}C allows one to advance to generation of condensate states of larger number of α-particles. Fundamental aspect seems related to the fact that in order to recreate the condensate it is necessary to "evacuate" two hidden rotations $^{12}C_{g.s.}$. We note that in this respect the Coulomb dissociation of a nucleus on a heavy nucleus appears to be the most suitable process since few photon exchanges in it are possible.

Such a concept does not contradict the mechanism of the synthesis of the nucleus ^{12}C accepted in nuclear astrophysics. Fusion of a triple of α-particles occurs through its second excited state 0^+_2 (the Hoyle state) located on 270 keV above the breakup threshold $^{12}C \rightarrow 3\alpha$. Basically, each pair of α-particles in it corresponds to $^{8}Be_{g.s.}$. In the transition $0^+_2 \rightarrow 2^+_1$ with emission of a photon to the first excited state of ^{12}C, which is bound one, an α-pair in the D-wave should arise in a 3α ensemble in order to provide conservation of the angular momentum. The subsequent transition to $^{12}C_{g.s.}$, which is also accompanied by emission of a photon leads to the formation of another α-particle pair in the D-wave state. This pair should have an opposite angular momentum with respect to the first pair to ensure zero spin value of the ground state $^{12}C_{g.s.}$. Thus, the nucleus $^{12}C_{g.s.}$ does acquire polarization. Figuratively being expressed it does conserve an "invisible rotation".



The stack consisted of several layers of NTE BR-2 of size of 9 to 12 cm^2 at thickness of 107 μm poured onto glass plates of thickness of 2 mm. The neutron generator gave rise to an irreducible background of X-ray radiation. This background was detected by the NTE layers with decreasing brightness as the absorption in the glasses grows which allowed one to select layers with a low X-ray backlighting.

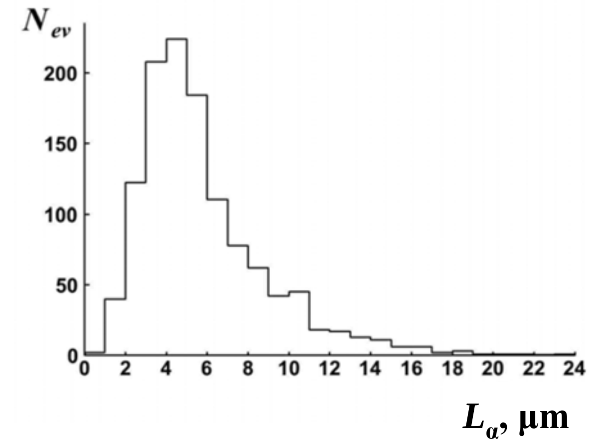


Fig. 1. Distribution of α-particles over ranges L_α.

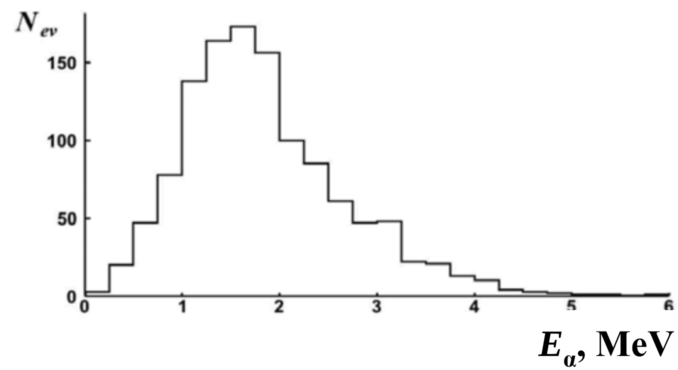


Fig. 2. Distribution of α-particles over energy E_α.

Scanning of layers performed on microscopes MBI-9 was aimed at 3α-disintegrations. In 400 events of 3α-disintegration selected among the found 1200 ones measurements of angles relative to plane of a NTE layer and its surface as well as their lengths were at a KSM microscope performed for all α-particle tracks. The only condition for the selection of the events was fullness of measure. Distribution over ranges of α-particles L_α (Fig. 1) has an average value $\langle L_\alpha \rangle$ = (5.8 ± 0.2) μm at RMS (3.3 ± 0.1) μm. This distribution has an asymmetric shape described by the Landau distribution. Directly associated with it the distribution over energy of α-particles E_α (Fig. 2) defined by ranges L_α in the SRIM model has an average value $\langle E_\alpha \rangle$ = (1.86 ± 0.05) MeV with RMS (0.85 ± 0.03) MeV.

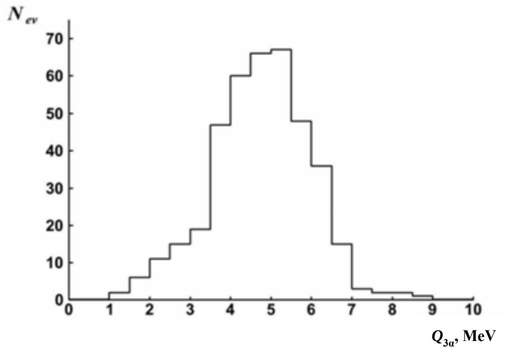
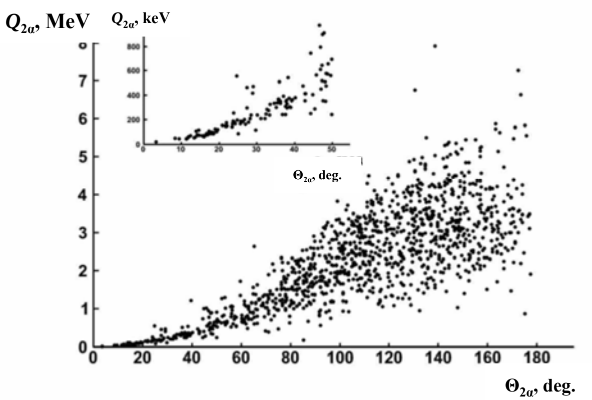


Fig. 3. Distribution triples of α-particles over energy $Q_{3\alpha}$.



Fig, 4. Correlation over energy $Q_{2\alpha}$ and opening angles $\Theta_{2\alpha}$

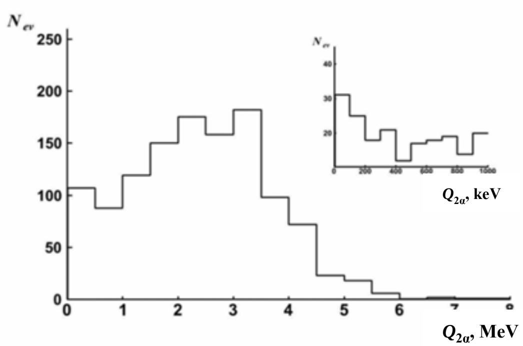


Fig. 5. Distribution pairs of α-particles over energy $Q_{2\alpha}$.

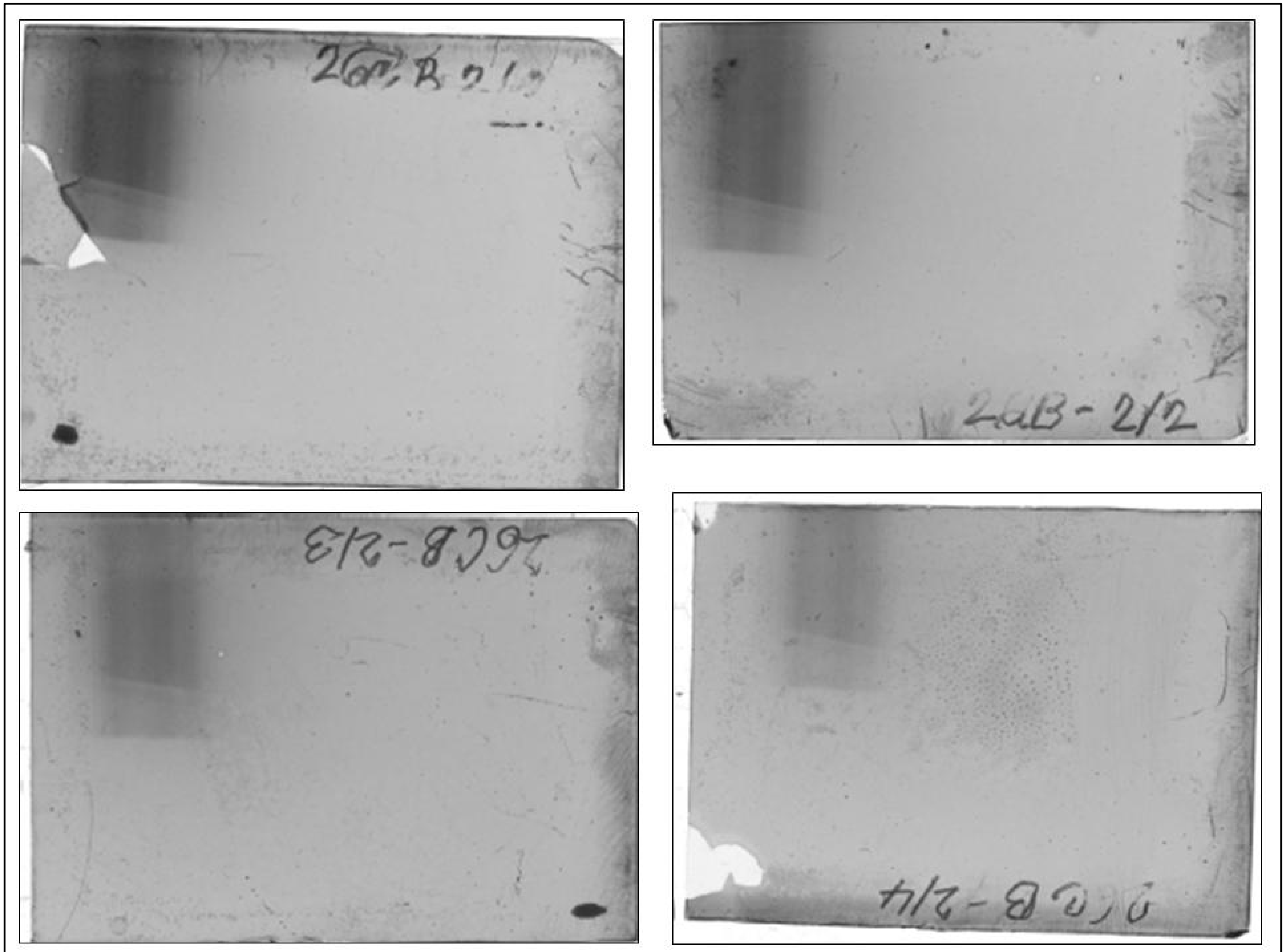
Determination of angles and energy values versus ranges allows one to determine the energy $Q_{2\alpha}$ of pairs and triples $Q_{3\alpha}$ of α-particles. Distribution over $Q_{3\alpha}$ (Fig. 3) is concentrated in the range of excitations of the ^{12}C nucleus which is below thresholds of separation of nucleons. The used method does not resolve levels of ^{12}C while the Hoyle state is not shown, as expected, for the reaction of α-particle knocking out.

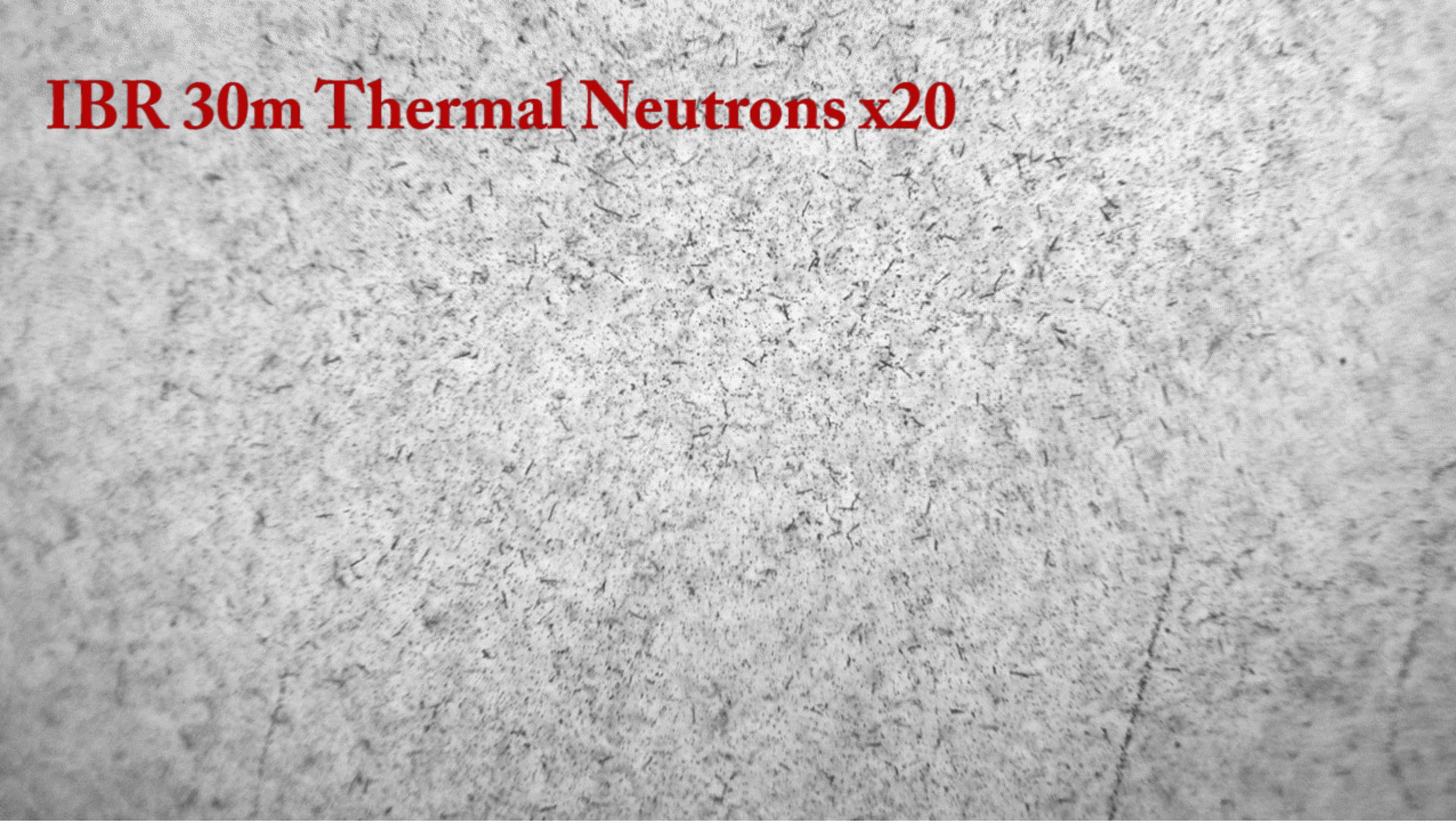
Correlation over energy $Q_{2\alpha}$ and opening angles $\Theta_{2\alpha}$ in α-particle pairs reveals features of the ^{8}Be nucleus (Fig. 4). The region of large opening angles $\Theta_{2\alpha} > 90^o$ is corresponding to $Q_{2\alpha}$ of $^{8}Be_{2+}$, while $\Theta_{2\alpha} < 30^o$ - $^{8}Be_{g.s.}$. Distribution over $Q_{2\alpha}$ points to these states (Fig. 5). Its right side meets the shape expected from the decay through $^{8}Be_{2+}$. Condition $Q_{2\alpha} < 200$ keV has allowed to allocate 56 decays $^{8}Be_{g.s.}$.

For $^{8}Be_{g.s}$ the total momentum distribution is rather narrow and characterized an average value of (208 ± 4) MeV/*c* with RMS (30 ± 3) MeV/*c*. Estimate of the average total momentum for 212 pairs of α-particles which are the most appropriate to $^{8}Be_{2+}$ is (130 ± 3) MeV/*c* with RMS (43 ± 2) MeV/*c*. Thus, the distribution over the total momentum for $^{8}Be_{2+}$ is much softer and relatively wider.

In general, these data indicate the presence of a superposition of states 0^+ and 2^+ of the nucleus ^{8}Be in the ground state of ^{12}C, and $^{8}Be_{2+}$ dominates.

Exposure to thermal neutrons. Adding of boric acid in NTE allows one to solve practical problems for thermal neutron beams (n_{th}) – specify their profiles and flows. Enrichment of NTE with boron makes it possible to observe charged products of the reaction $n_{th} + {}^{10}B \rightarrow {}^{7}Li + (\gamma) + {}^{4}He$. This reaction giving an output of energy of 2.8 MeV occurs with a probability of about 93% with the emission of γ-ray of energy of 478 keV by the ^{7}Li nucleus from a single excited state. Samples of NTE prepared with the addition of boric acid were exposed to thermal neutrons n_{th} for 30 min in the channel #1 of the reactor IBR-2 of JINR.





The selected duration allowed one to avoid an overexposure and perform coordinate measurements of tracks of 112 events ^{7}Li + ^{4}He at KSM microscope with a 90× magnification objective. Due to a distinct difference in the ionization of the reaction products, the coordinates of its vertices are determined with an accuracy of 0.5 - 0.8 μm. The average length of tracks of Li nuclei was (3.1 ± 0.3) μm (RMS 0.8 μm) at an average thickness of (0.73 ± 0.02) μm (RMS 0.05 μm), and for tracks of ^{4}He nuclei (5.5 ± 0.5) μm (RMS 1.1 μm) and (0.53 ± 0.01) μm (RMS 0.04 μm), respectively.

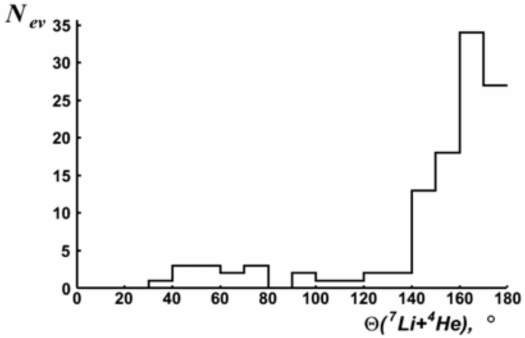


Fig. 1. Distribution over the opening angle $\Theta(^7Li + {}^4He)$ for pairs of ^7Li and ^4He nuclei produced by thermal neutrons in 112 events $n_{th} + {}^{10}B \rightarrow {}^7Li + (\gamma) + {}^4He$.

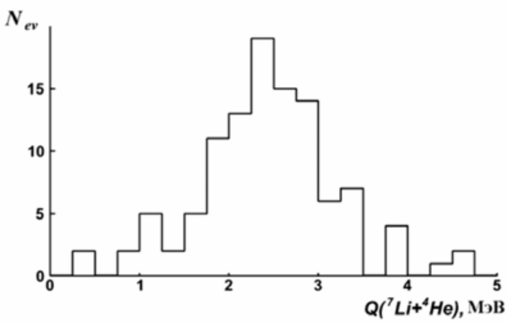


Fig. 2. Distribution over the energy $Q(^7Li + {}^4He)$ for pairs of ^7Li and ^4He nuclei produced by thermal neutrons in 112 events $n_{th} + {}^{10}B \rightarrow {}^7Li + (\gamma) + {}^4He$.

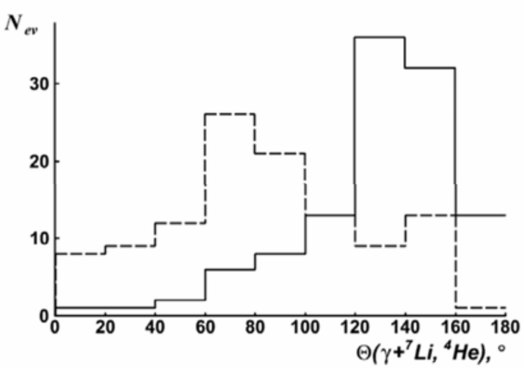


Fig. 3. Distribution over the angle $\Theta(\gamma + {}^7Li, {}^4He)$ between the calculated directions of emission of γ-quanta and the directions of emission for of ^7Li and ^4He nuclei (solid and dashed histogram, respectively) produced by thermal neutrons in 112 events $n_{th} + {}^{10}B \rightarrow {}^7Li + (\gamma) + {}^4He$.

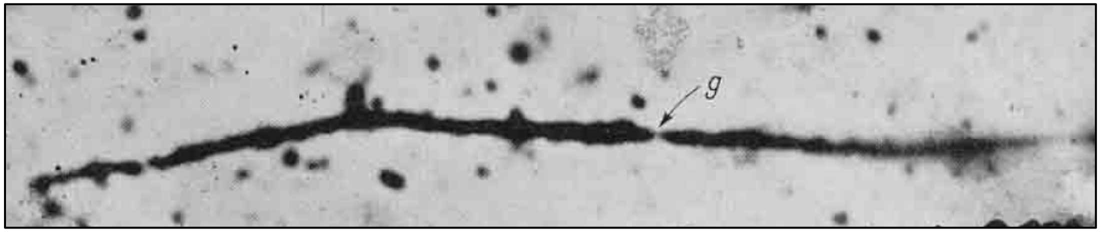
The directions of emission in pairs aren't collinear as a consequence of emission of γ-rays (Fig. 1). A value of the average opening angle $\Theta(^7Li + {}^4He)$ is $(148 \pm 14)^o$ (RMS 35^o). There are several events $\Theta(^7Li + {}^4He) < 90^o$ in the distribution $\Theta(^7Li + {}^4He)$. Their origin may be associated with a visually indistinguishable scattering of α-particles on initial parts of escape from the reaction vertices.

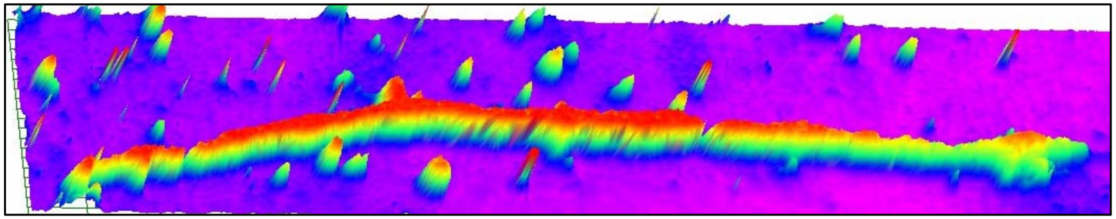
The simulation program SRIM allows one to evaluate the kinetic energy of nuclei by measuring the lengths of tracks. Knowledge of the energy and emission angles enables one to obtain the energy distribution $Q(^7Li + {}^4He)$ of pairs of ^7Li and ^4He nuclei (Fig. 2). The variable Q is defined as a difference between the invariant mass of the final M^* and the mass of the decaying nucleus M. $Q = M^* - M$. M^* is defined as a sum of all products of the 4-momenta $P_{i,k}$ fragments, i.e., $M^{*2} = (\Sigma P_j)^2$. Its relativistic-invariant character makes it possible to compare various data by a unified manner. The average value of $Q(^7Li + {}^4He)$ which amounted to 2.4 ± 0.2 MeV (RMS 0.8 MeV), match the expected one taking into account the energy carried away by γ-quanta.

The distribution over the angle $\Theta(\gamma + {}^7Li)$ between the directions of emission of γ-quanta computed according to the condition of conservation of momentum and the directions of emission of the nuclei ^7Li shows a clear anticorrelation (Fig. 3). It is characterized by the average value of $\Theta(\gamma + {}^7Li)$ $(128 \pm 3)^o$ (RMS 31^o) and the coefficient of asymmetry with respect to the angle of 90^o equal to 0.75 ± 0.07. In the case of ^4He nuclei the average value of $\Theta(\gamma + {}^4He)$ was $(84 \pm 4)^o$ (RMS 40^o), with a coefficient of asymmetry of 0.14 ± 0. 01.

EXPOSURE TO HEAVY IONS. Of interest is the application of NTE in the physics of ternary fission. Spontaneous fission of ^{252}Cf or fission of ^{235}U initiated by thermal neutrons is a source of search for molecular-like nuclear systems. Emission of fission fragments may turn out to be a collinear one. In the decay of 3-body system one of the heavy fragments can enthrall the light one. NTE enables one to investigate correlation down to smallest angles between the directions of emission of the fragments of a collinear ternary fission. It is assumed that NTE will be exposed to fission fragments by contacting with a film on which the explored isotope is plated.

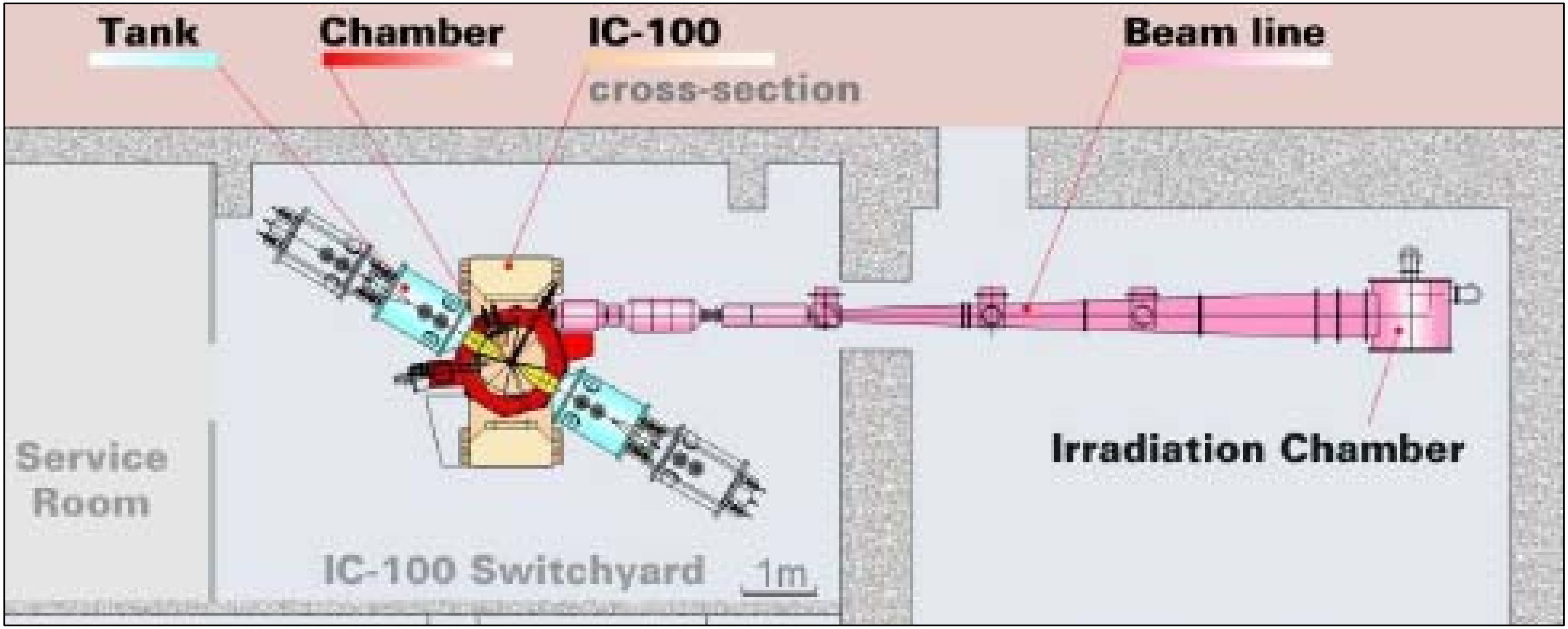
It is necessary to calibrate the ranges and estimate the angular resolution for the greatest variety of heavy ions of a known energy which are implanted in NTE. It is important to advance the energy calibration to values below the Coulomb barrier of nuclear reactions. Experience of spectrometry of heavy nuclei by ranges will be useful in search for hypothetical particles of the dark matter.



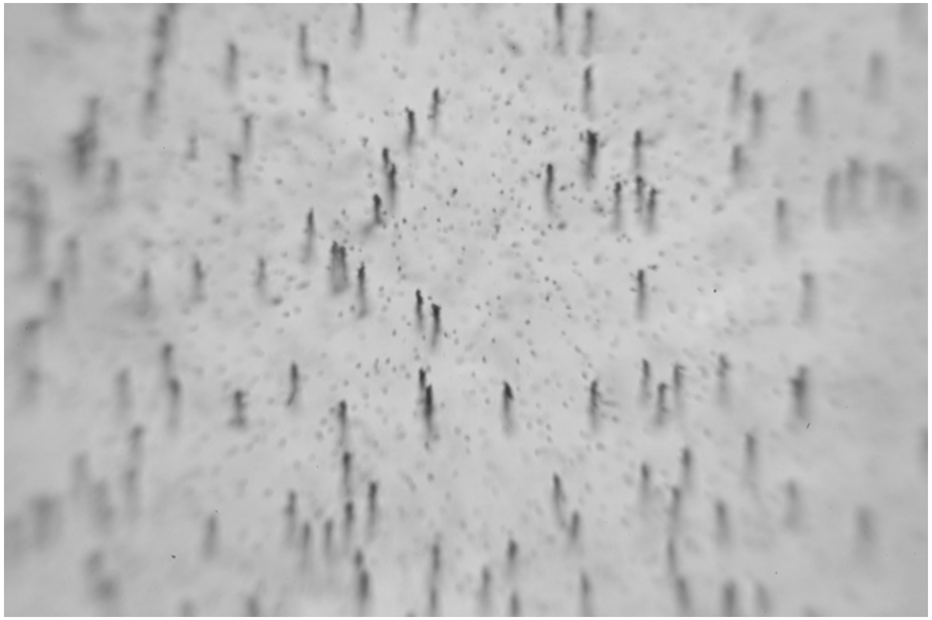
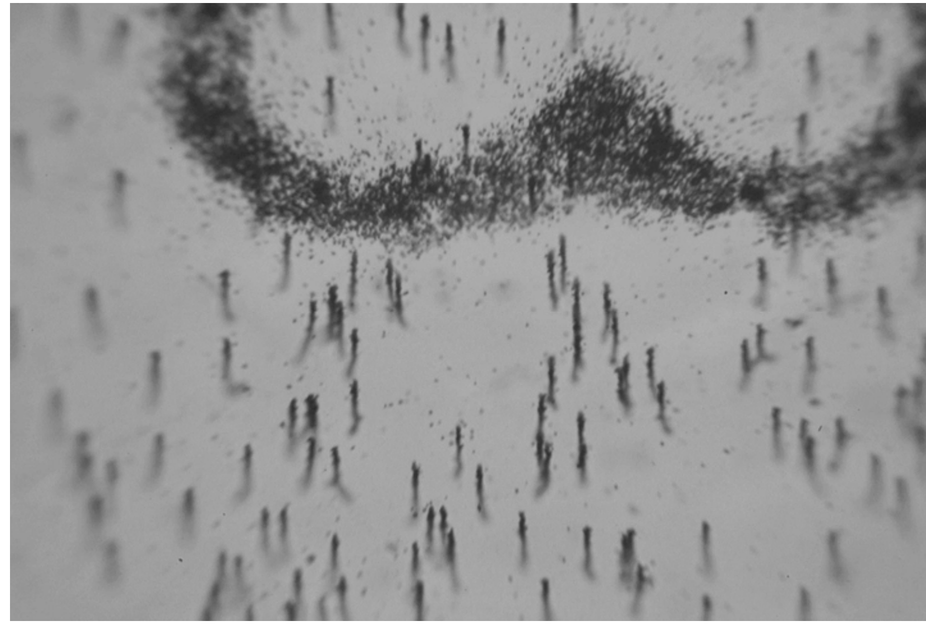


Tracks due the fission of uranium. The fragment on the left has collided with a nucleus in the emulsion to produce a forked track

Fission of thorium accompanied by emission of light particle

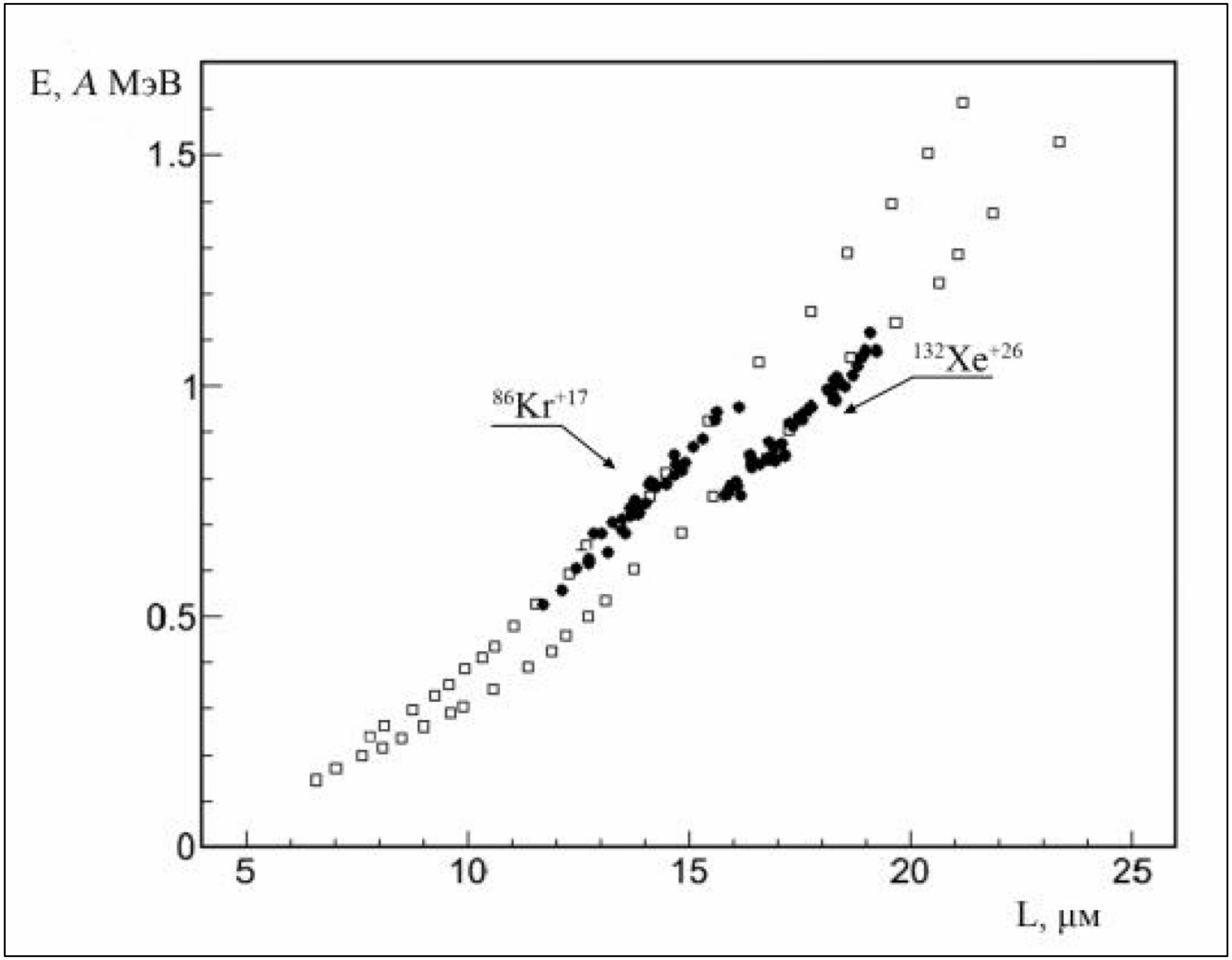


NTE is exposed to ions $^{86}Kr^{+17}$ and $^{124}Xe^{+26}$ accelerated to energy of about 1.2 *A* MeV at the cyclotron IC-100 of the Flerov Laboratory of Nuclear Reactions, JINR. Since energy of these ions is small the exposure of NTE is performed without a light protective paper. Therefore, fixing 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.

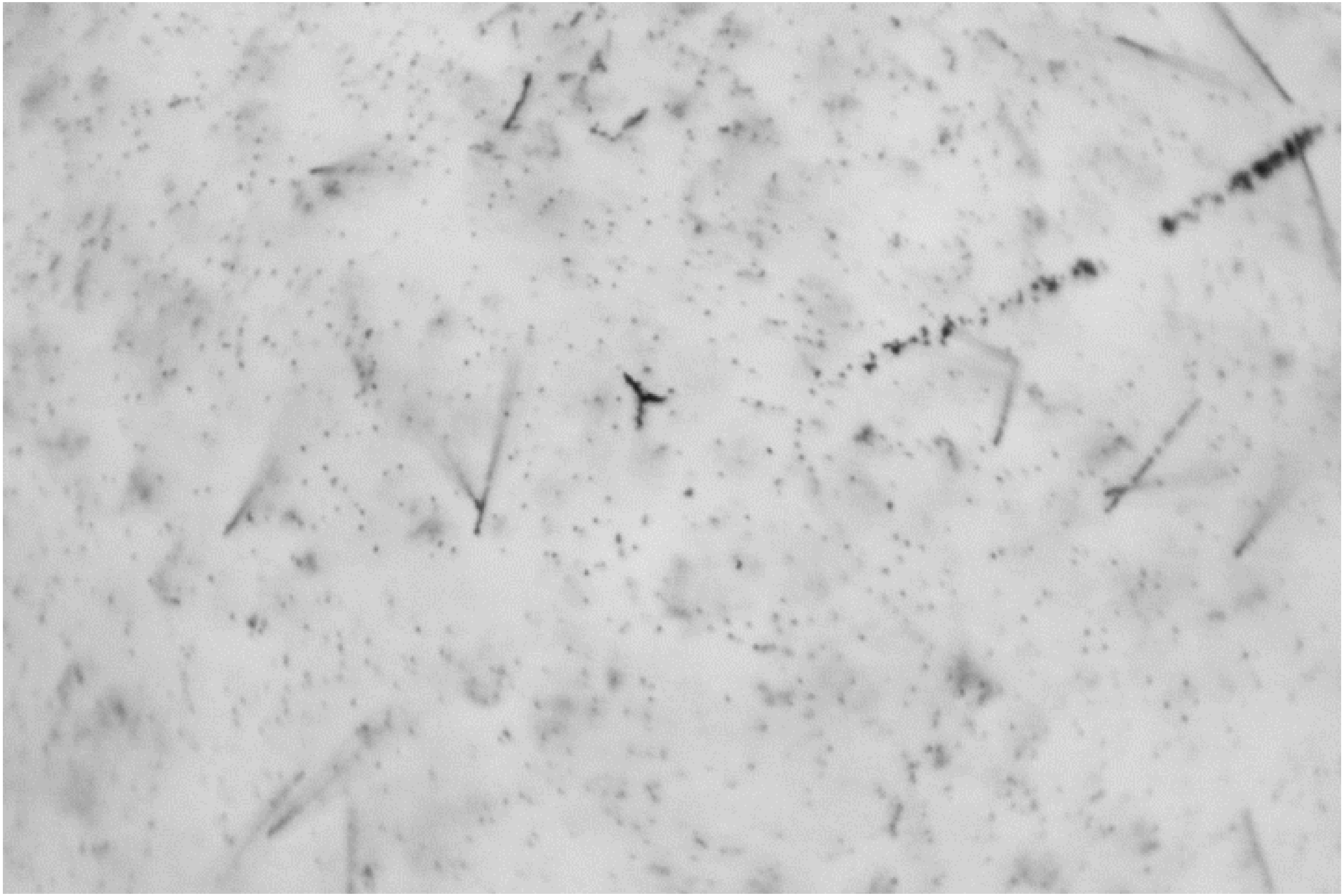
 

Measurements of the track lengths of ions stopped without scattering in the NTE layer are performed on a microscope KSM with 90-fold magnification of the objective. Average ranges of tracks without scattering for Kr ions is (14.3 ± 0.15) μm (RMS 0.9 μm) and for Xe ions – (17.5 ± 0.1) μm (RMS 1.0 μm) which are close to the values calculated by the model SRIM - for Kr (18.5 ± 1.3) μm (RMS 1.3 μm) and Xe – (20.1 ± 2.2) μm (RMS 1.3 μm).

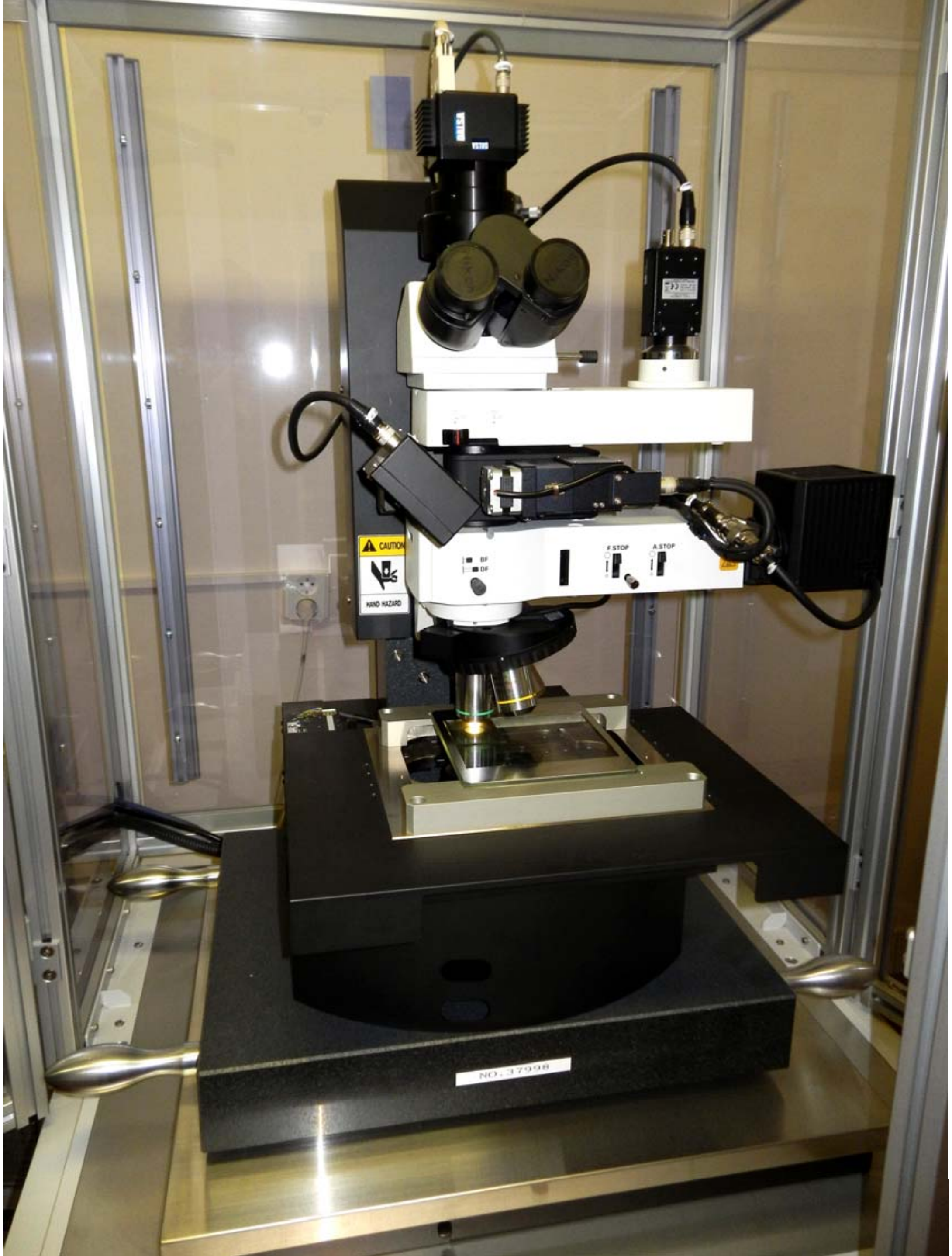
Many of primary tracks are completed by “knees” or “forks” as a result of scattering by nuclei composing NTE. At braking before scattering energy of ions is reduced to an order of magnitude smaller than the Coulomb barrier. On the basis of detailed measurements of coordinates it is supposed to identify observed recoil nuclei and extend the study of energy resolution to extremely low energy. This aspect is important for future calibration of NTE of submicron resolution designed for searching for dark matter particles.

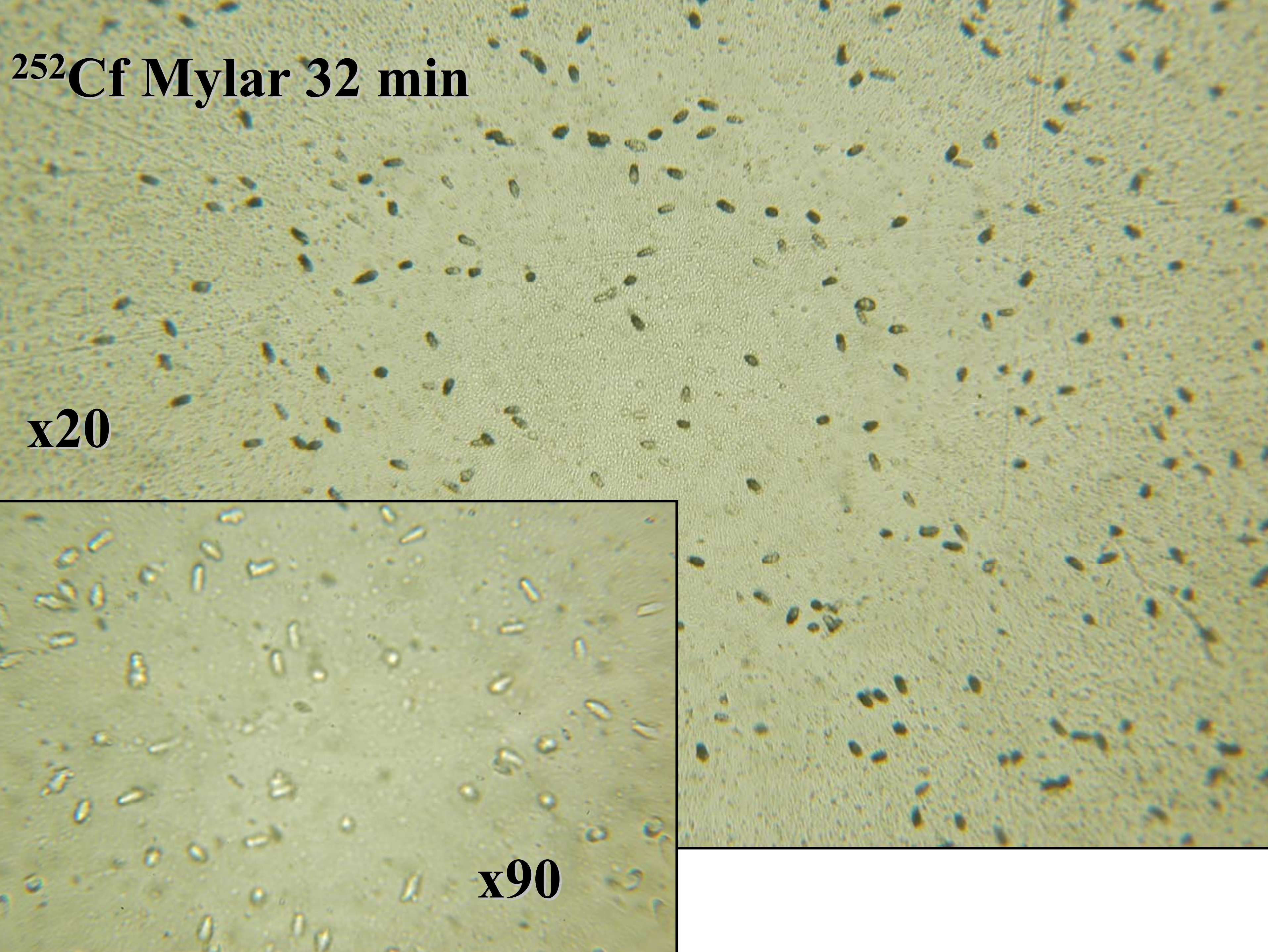


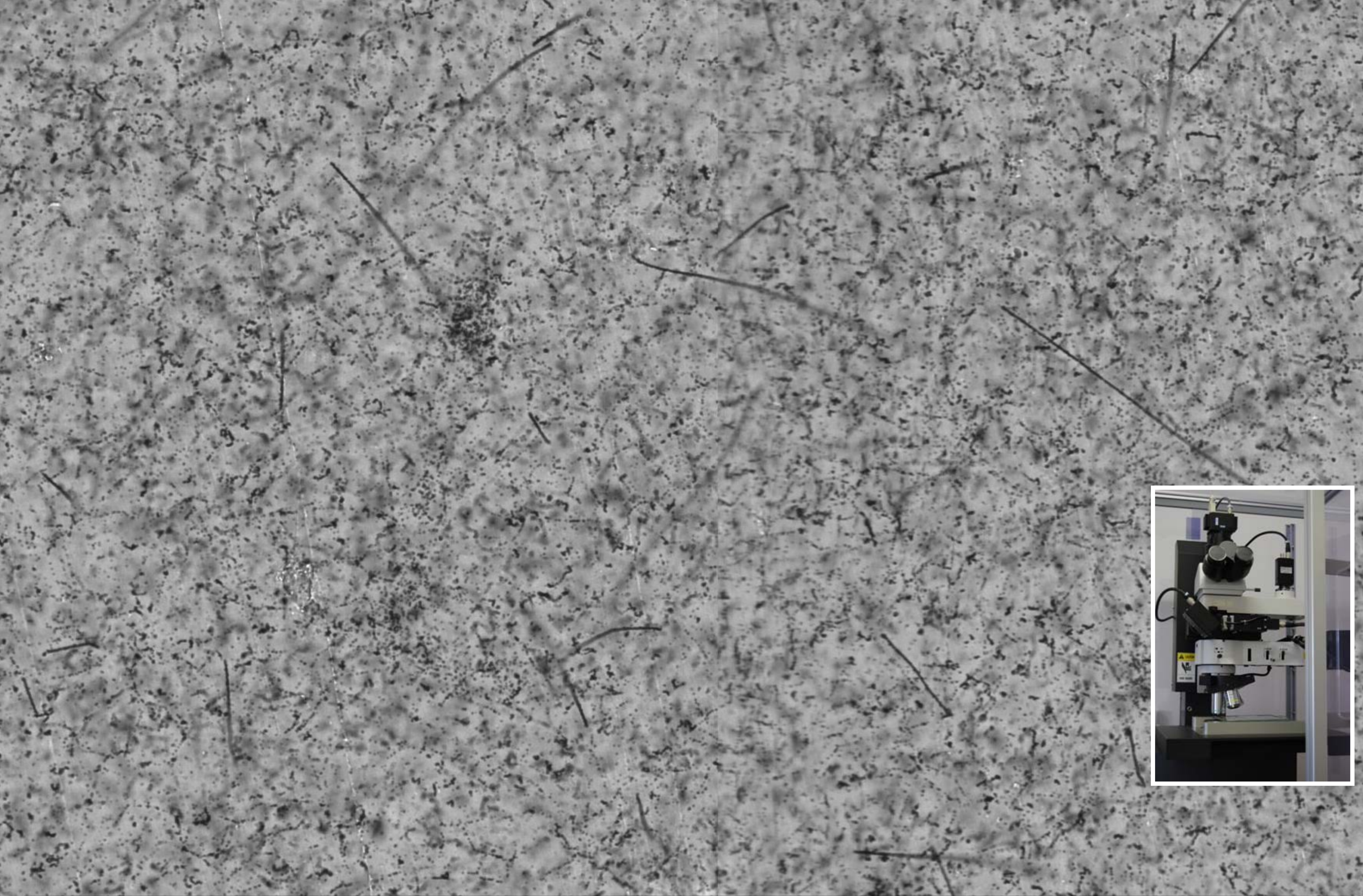
On the basis of spline-interpolation of range-energy calculations measurements of the ion ranges allow one to estimate their kinetic energy using the SRIM model. Its average values amounted for Kr was (0.74 ± 0.01) *A* MeV (RMS 0.1 *A* MeV) and for Xe – (0.92 ± 0.01) *A* MeV (RMS 0.1 *A* MeV). The average values which are below the expected ones show that it is necessary to make modeling more accurate. The average angle of implantation into the NTE layer for Kr ions is $(43.8 \pm 0.6)^0$ (RMS 4^0) and for Xe ions – $(44.7 \pm 0.6)^0$ (RMS 4^0) which corresponds to the orientation angle of the NTE plate with respect to the beam axis.



Currently, NTE exposed to a ^{252}Cf source giving mainly α-particles and spontaneous fission fragments (6% probability) and, for the sake of comparison, to a source ^{241}Am giving only α-particles is analyzed.


CAUTION
HAND HAZARD
F.STOP
A.STOP
NO.37998


^{252}Cf Mylar 32 min
x20
x90

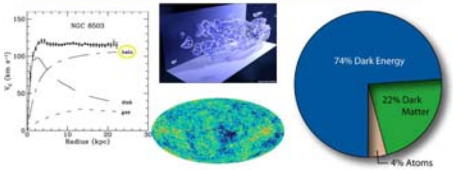


NTE is comparable to a liquid hydrogen target on density of hydrogen. Therefore, the main background is presented by recoil protons. Overlaying of tracks that would be imitating 3α-disintegrations was reduced to a negligible level by choice of the exposure time of 40 min.

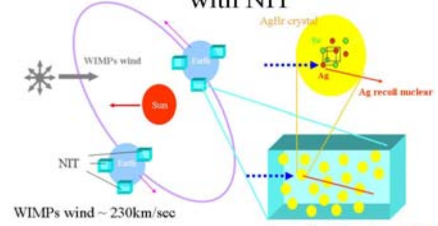
Evidence of Dark Matter

- Rotation velocity of Galaxy
- Gravitational Lens
- Cosmic Microwave Background(CMB)

etc



Principle for Detection of WIMPs with NIT



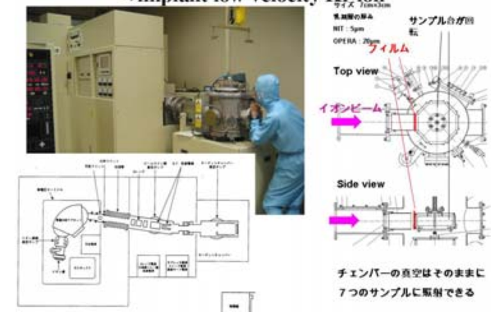
WIMPs wind ~ 230km/sec

Recoil energy ~ 100keV

(if WIMPs mass ~ 100GeV)

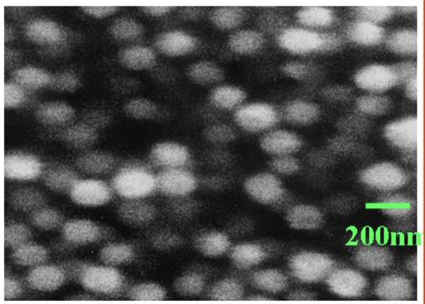
Range of recoil nuclear ~ 100nm

Recoil nuclear test of NIT ⇒implant low velocity Kr ion



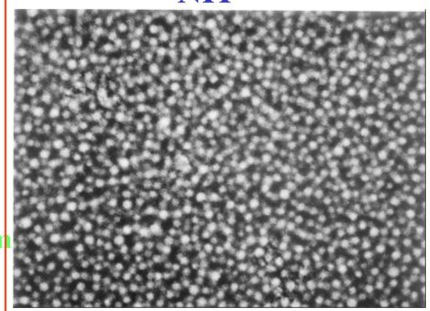
High resolution emulsion (Nano Imaging Tracker:NIT)

OPERA



OPERA:AgBr crystal size ~200nm
2.3 AgBr/μm

NIT



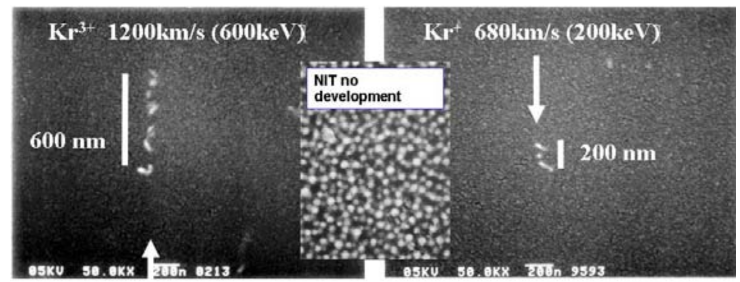
NIT:AgBr crystal size ~40nm
11 AgBr/μm

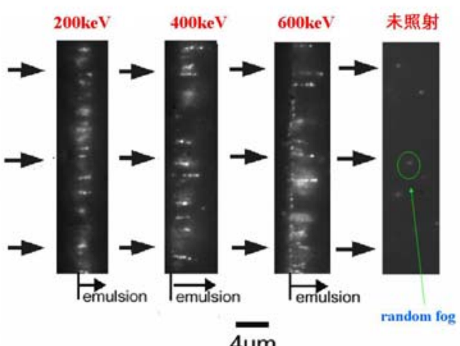
5 times resolution for OPERA!

Tracking test by low velocity Kr

Supposition **Br** recoil

SEM image

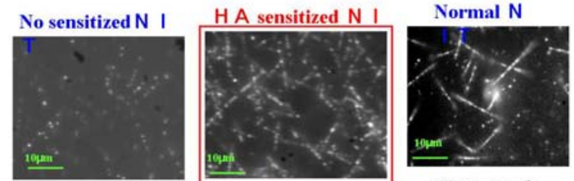




Sensitivity control of NIT

Halogen Accepter sensitized ⇒sensitivity between no sensitized NIT and normal NIT

No sensitized NIT | HA sensitized NIT | Normal NIT



※αray track

β・γrejection power(^{241}Am γray test)

⇒**Rejection < 10E-5 (manual determination)**

CONCLUSIONS

These test exposures are aimed primarily at an overall quality control and sensitivity of NTE to relativistic particles as well as at the comparison of the ranges of slow strongly ionizing nuclei of low energy with the values computed in the simulation program SRIM.

Exposures of the reproduced NTE on beams of modern accelerators and reactors allow one not only to perform range-energy calibration for the future, but also to make physical observations and draw conclusions that are valuable in itself.

In turn, these exposures stimulate the development of the NTE method because they provide a new material for progress of automated microscopes and nuclear physics education.

The present report combines the results of the analysis of recent exposures of NTE to ^{8}He nuclei, thermonuclear and thermal neutrons and very low heavy ions. Such a variety of experiments are related to a common methodical use of the new NTE for coordinate measurements of tracks of length from a few to tens of microns.

Video materials on the interactions studied in NTE are available via the page Miscellanea of website http://becquerel.jinr.ru/.

The authors consider it their pleasant duty to thank the colleagues whose contributions made it possible to carry out the series of exposures for 2011-2013. The use of new samples of NTE became possible thanks the full support of the project curator O. I. Orurk (the JSC "Slavich Company") as well as the creative work of the staff of the department MICRON of this company Yu. A. Berezkina, A. V. Kuznetsov and L. V. Balabanova (Pereslavl Zalesky). Great methodological assistance in the reproduction of NTE technology provided by A. S. Mikhailov (the Moscow kinovideoinstitut).

The JINR staff members provided the NTE samples irradiation of: S. B. Borzakov – at the IBR-2 thermal neutron beam, O. M. Ivanov - at the cyclotron IC-100, O. P. Gavrishchuk, G. V. Mescheryakov and A. S. Nagaytsev – at the μ-meson beam at CERN.

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