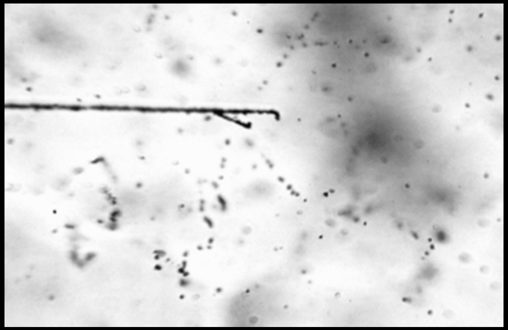
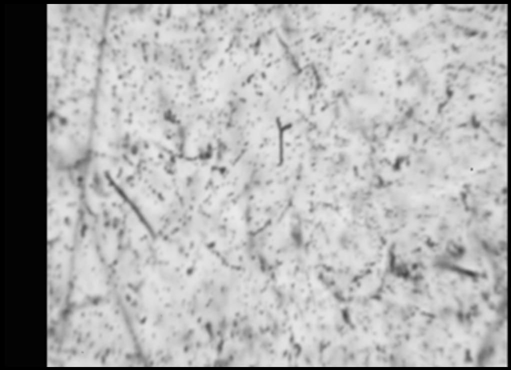
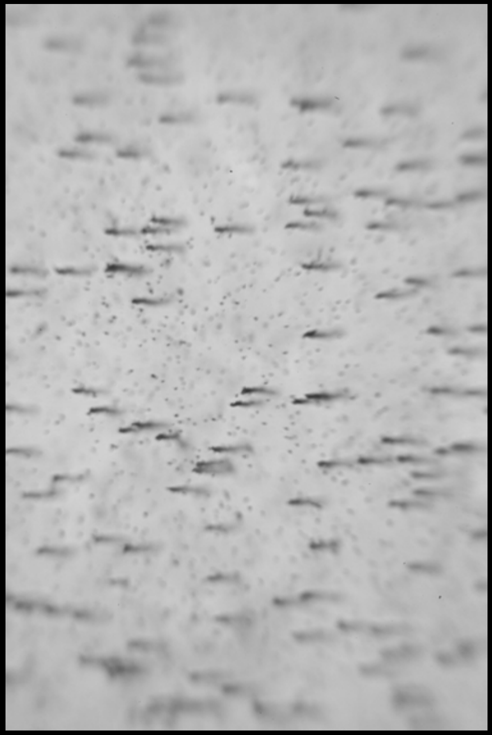
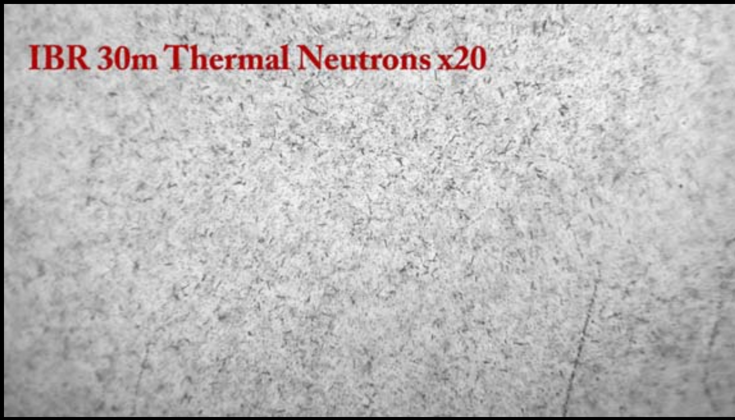
“Перспективы метода ядерной эмульсии в проблемах ядерной и нейтронной физики”

П. И. Зарубин

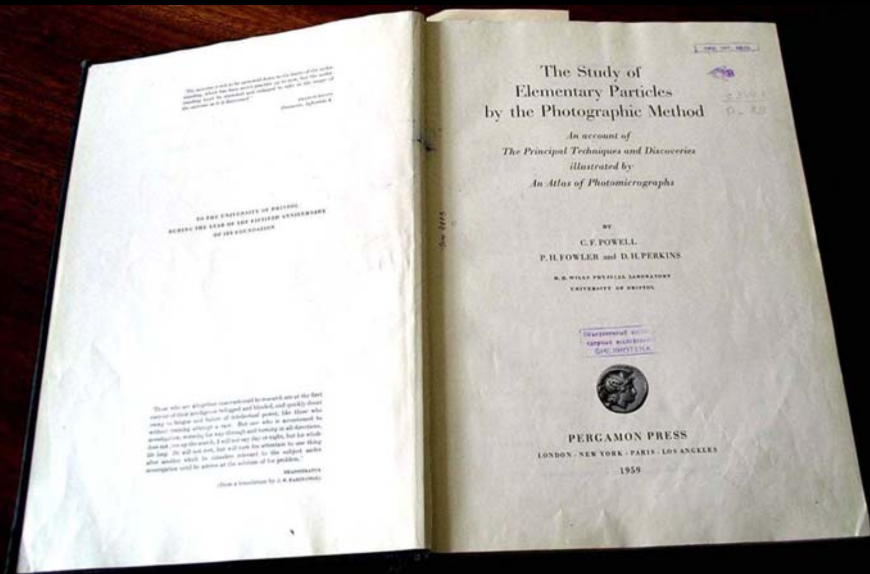








Лаборатория физики высоких энергий имени В. И. Векслера и А. М. Балдина ОИЯИ



Если не знаешь куда идти, оглянись назад, посмотри откуда пришел.

(индийская поговорка)

АКАДЕМИЯ НАУК СОЮЗА СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ РЕСПУБЛИК

ФИЗИЧЕСКИЙ ИНСТИТУТ им.П.Н.ЛЕБЕДЕВА

Рассекречен по Акту от 11.4.85г (Осипова)

[redacted]

Акт № А-60 от 4.4.55

Экз.№ 2

Акт № А-74 от 28/III 56г

К. Д. ТОЛСТОВ

ЗАМЕДЛЕНИЕ, ДИФФУЗИЯ и ЭНЕРГИЯ МЕДЛЕННЫХ НЕЙТРОНОВ ВНУТРИ и на ГРАНИЦЕ РАЗЛИЧНЫХ СРЕД.

Диссертация, представленная на соискание ученой степени кандидата физико-математических наук

(Перепечатано с некоторыми сокращениями 1957. ОИЯИ)

г.Москва, 1952 год.

ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

Лаборатория высоких энергий

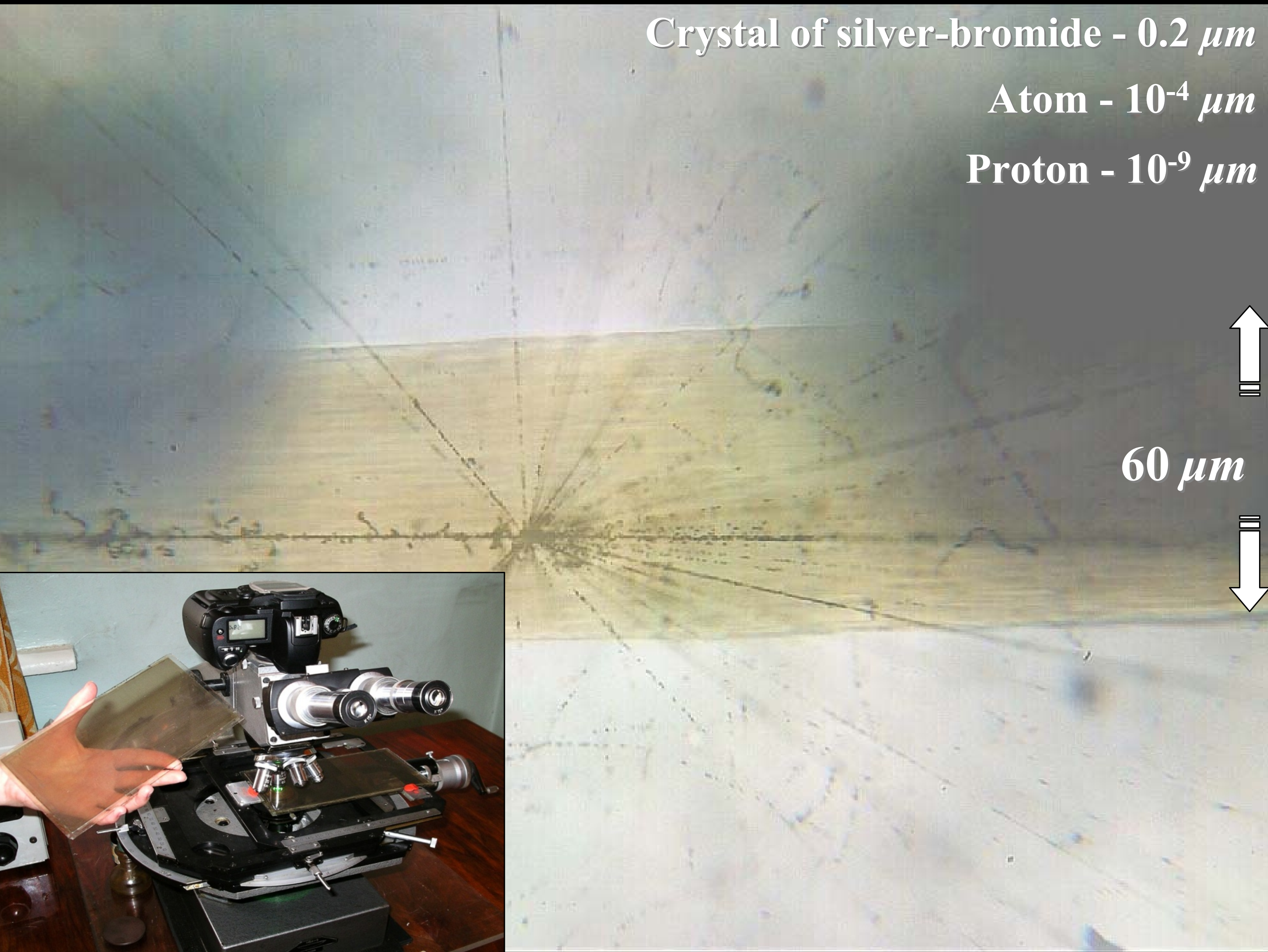
К.Д. Толстов

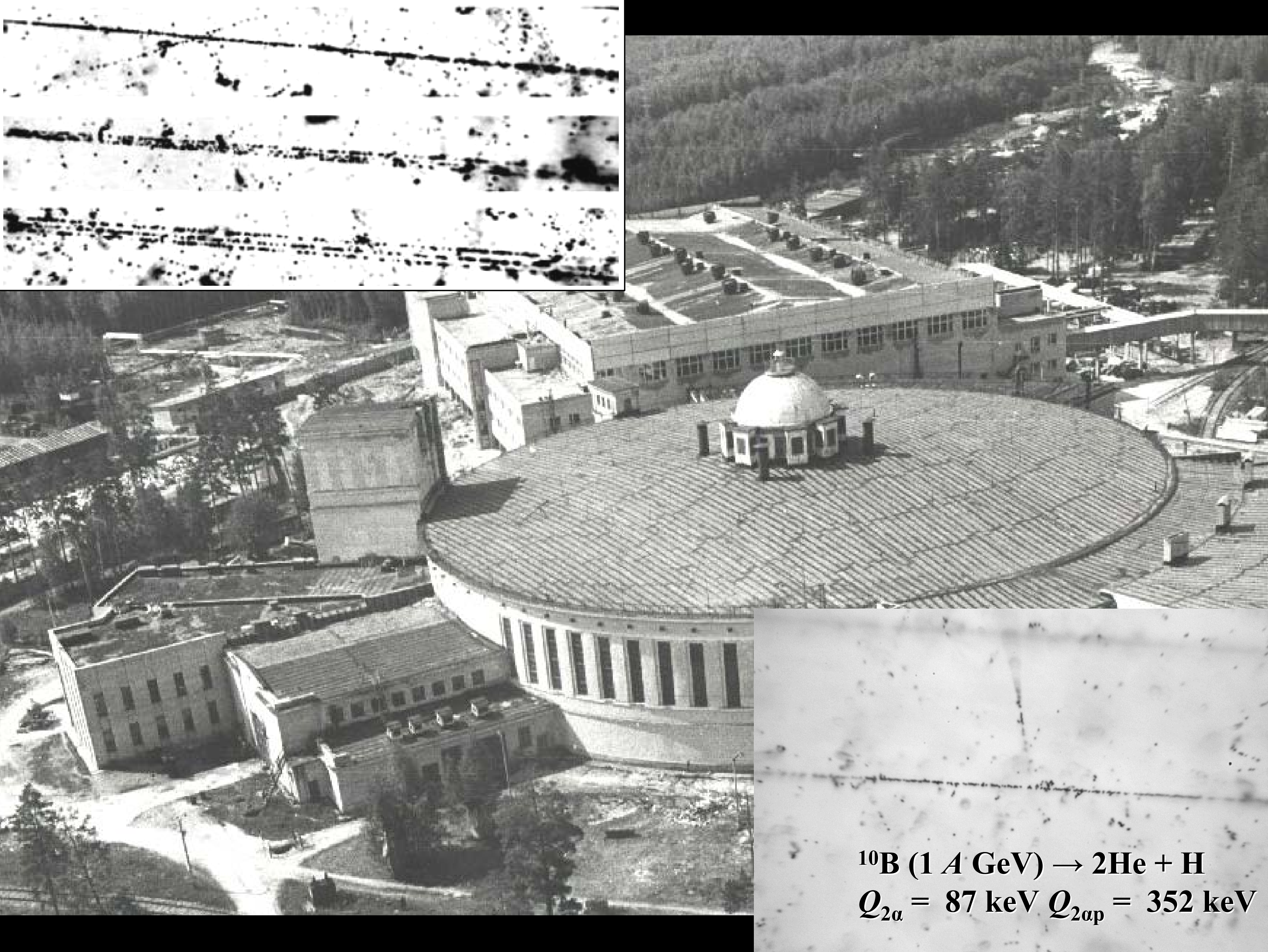
РЕЗУЛЬТАТЫ И НЕКОТОРЫЕ ПЕРСПЕКТИВЫ ФОТОЭМУЛЬСИОННЫХ ИССЛЕДОВАНИЙ ВЗАИМОДЕЙСТВИЯ ЧАСТИЦ И АТОМНЫХ ЯДЕР

Диссертация на соискание ученой степени доктора физико-математических наук

Дубна

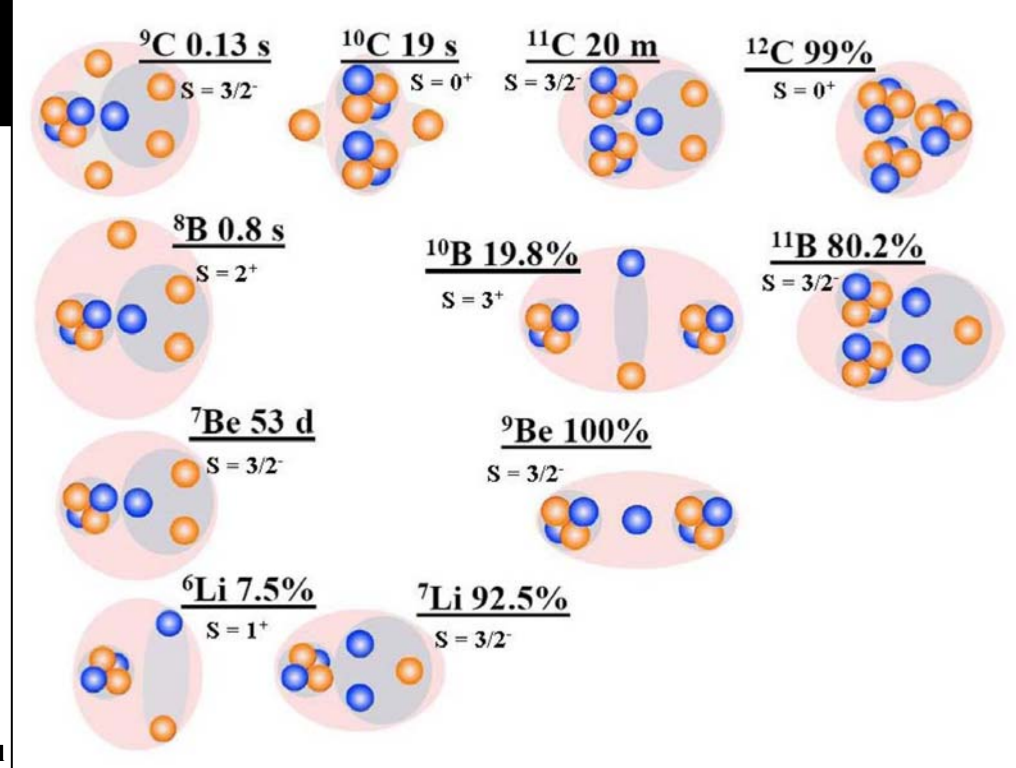
1966г.

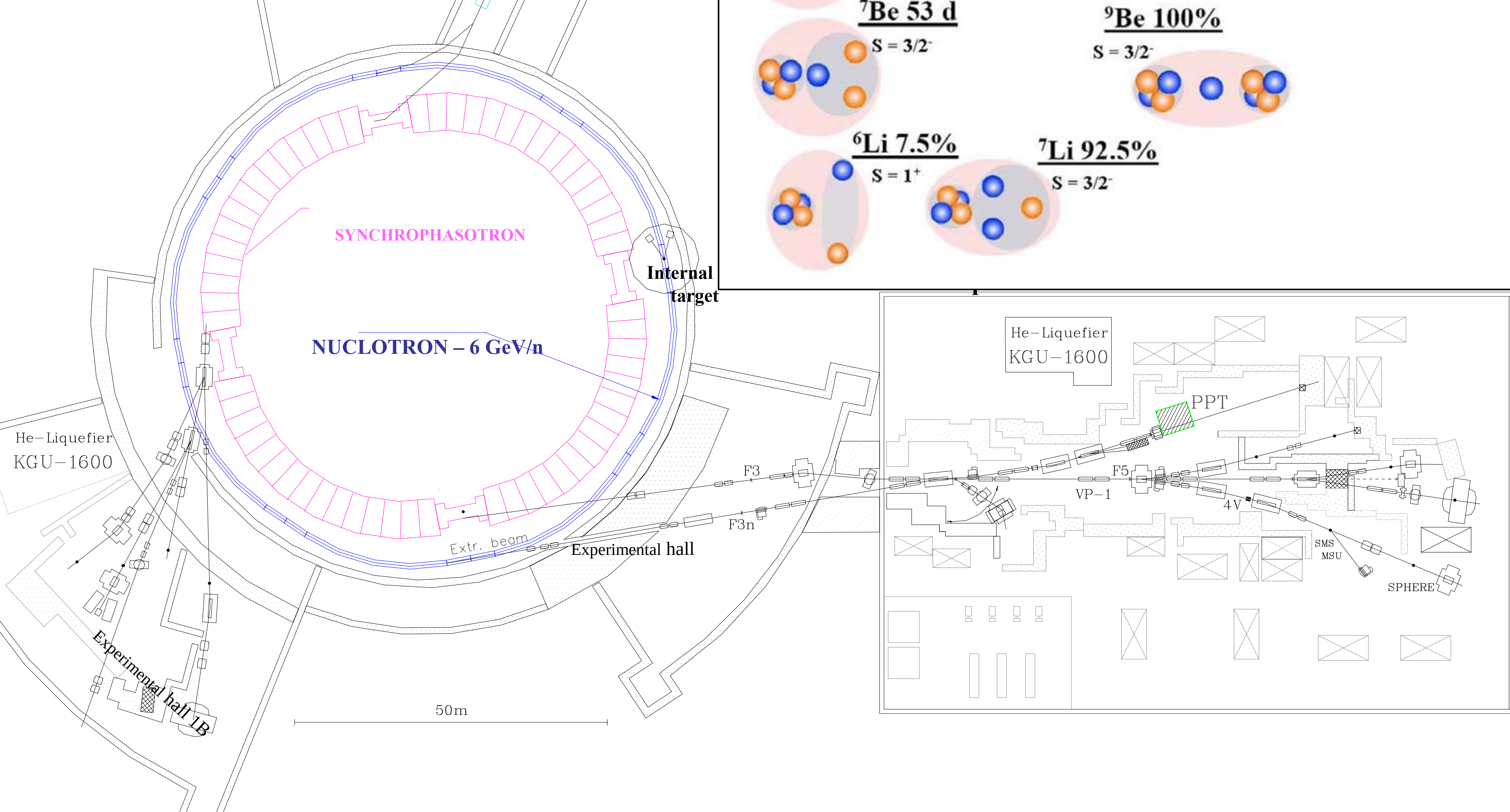

Crystal of silver-bromide - 0.2 μm
Atom - 10^{-4} μm
Proton - 10^{-9} μm
60 μm

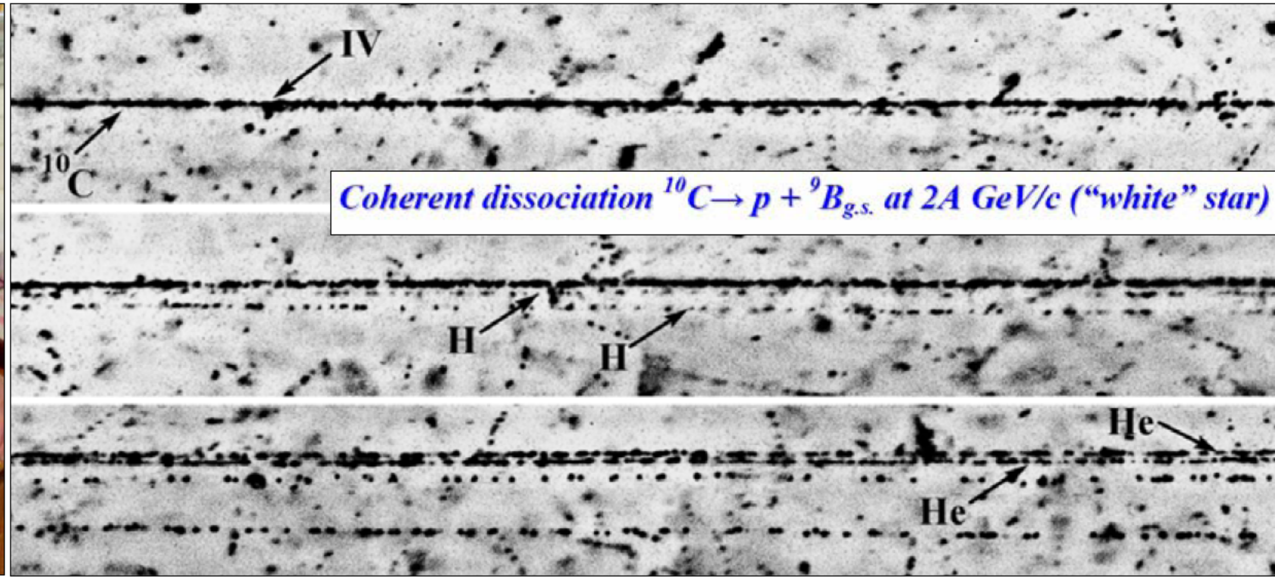


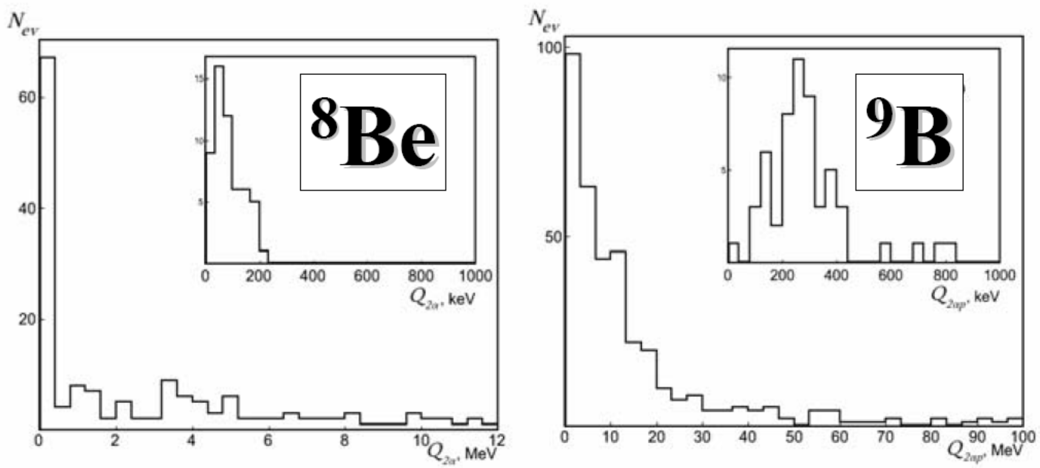
^{10}B (1 *A* GeV) → 2He + H
$Q_{2\alpha}$ = 87 keV $Q_{2\alpha p}$ = 352 keV


CO2 laser


^{9}C 0.13 s
S = 3/2^{-}
^{10}C 19 s
S = 0^{+}
^{11}C 20 m
S = 3/2^{-}
^{12}C 99%
S = 0^{+}
^{8}B 0.8 s
S = 2^{+}
^{10}B 19.8%
S = 3^{+}
^{11}B 80.2%
S = 3/2^{-}
^{7}Be 53 d
S = 3/2^{-}
^{9}Be 100%
S = 3/2^{-}
^{6}Li 7.5%
S = 1^{+}
^{7}Li 92.5%
S = 3/2^{-}

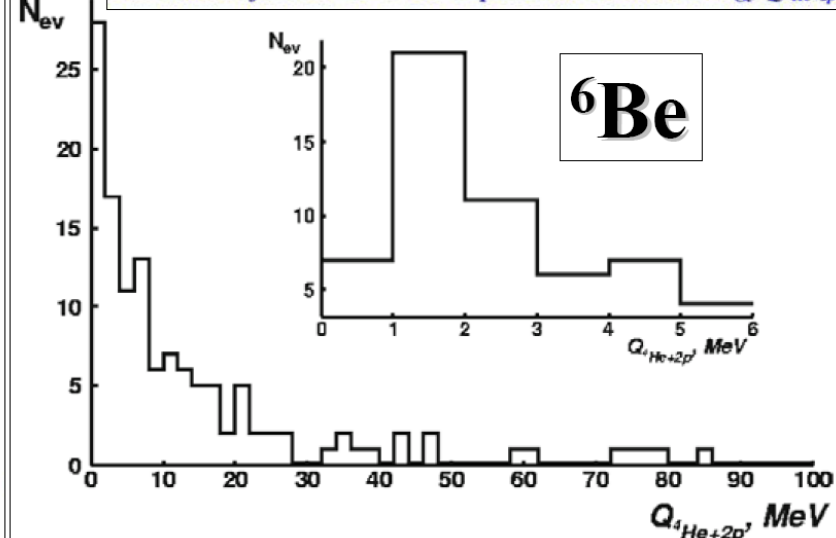

SYNCHROPHASOTRON
NUCLOTRON – 6 GeV/n
Internal target
He–Liquefier
KGU–1600
Extr. beam
Experimental hall
F3
F3n
Experimental hall 1B
50m
He–Liquefier
KGU–1600
PPT
F5
VP–1
4V
SMS
MSU
SPHERE





Distributions of the "white" stars $^{10}C \rightarrow 2\alpha + 2p$ over energy $Q_{2\alpha}$ of pairs 2α (a) and over $Q_{2\alpha p}$ of triples $2\alpha + p$ (b); on insertions – magnified distributions $Q_{2\alpha}$ and $Q_{2\alpha p}$.

Distribution of events $^{7}Be \rightarrow {}^{4}He + 2p$ over the excitation energy $Q_{^4He+2p}$



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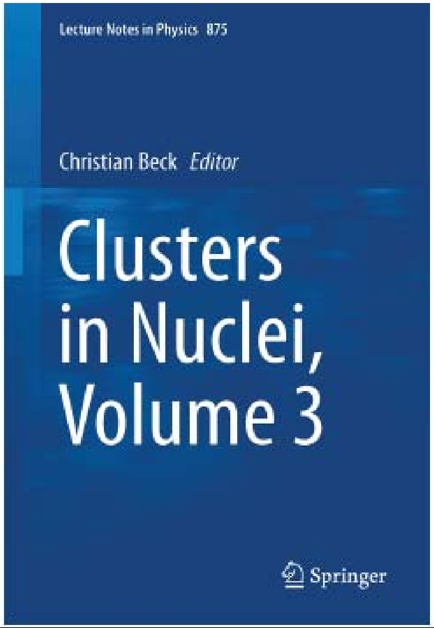
June 2015

Dear Christian Beck,

This report will provide you with transparent results on how your eBook has been performing on the market, as well as an update on the latest e-publishing developments.

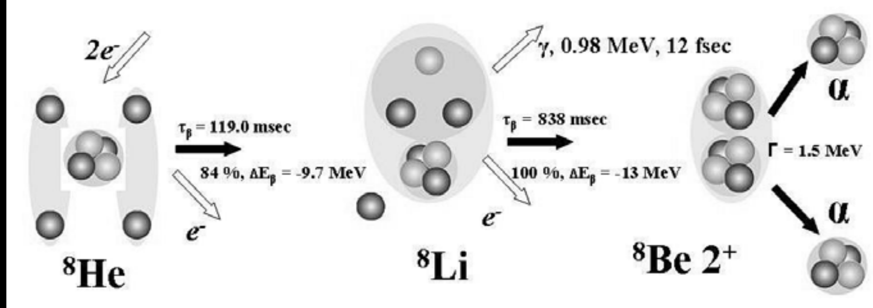
Year	Chapter Downloads
2014	1,151
2013	565



Chapter 3
"Tomography" of the Cluster Structure of Light Nuclei via Relativistic Dissociation

P.I. Zarubin

В рамках проекта БЕККЕРЕЛЬ проводятся облучения опытных образцов ЯЭ, производимые предприятием МИКРОН компании «ТД Славич». Образцы создаются путем полива ЯЭ слоями толщинами от 50 до 200 μм на стеклянную подложку. Эта ЯЭ соответствует ЯЭ с релятивисткой чувствительностью типа БР-2, производство которой прервалось около десяти лет назад. Облучения ЯЭ на ускорителях и реакторах, позволяют не только выполнить калибровку для перспективных проблем, но и сделать наблюдения, имеющие самостоятельную ценность. В свою очередь такие наблюдения дают развитие самой методу ЯЭ, поскольку стимулируют получения материала для развития автоматических микроскопов и образования. Воспроизведенная ЯЭ уже использовалась для спектрометрии по пробегам α-частиц, рожденных в ядерных реакциях и распадах. Опытные облучения направлены на общий контроль качества и чувствительности ЯЭ к релятивистским частицам, а также на сравнение пробегов ядер низких энергий со значениями, вычисляемыми в программах моделирования SRIM и GEANT4 .

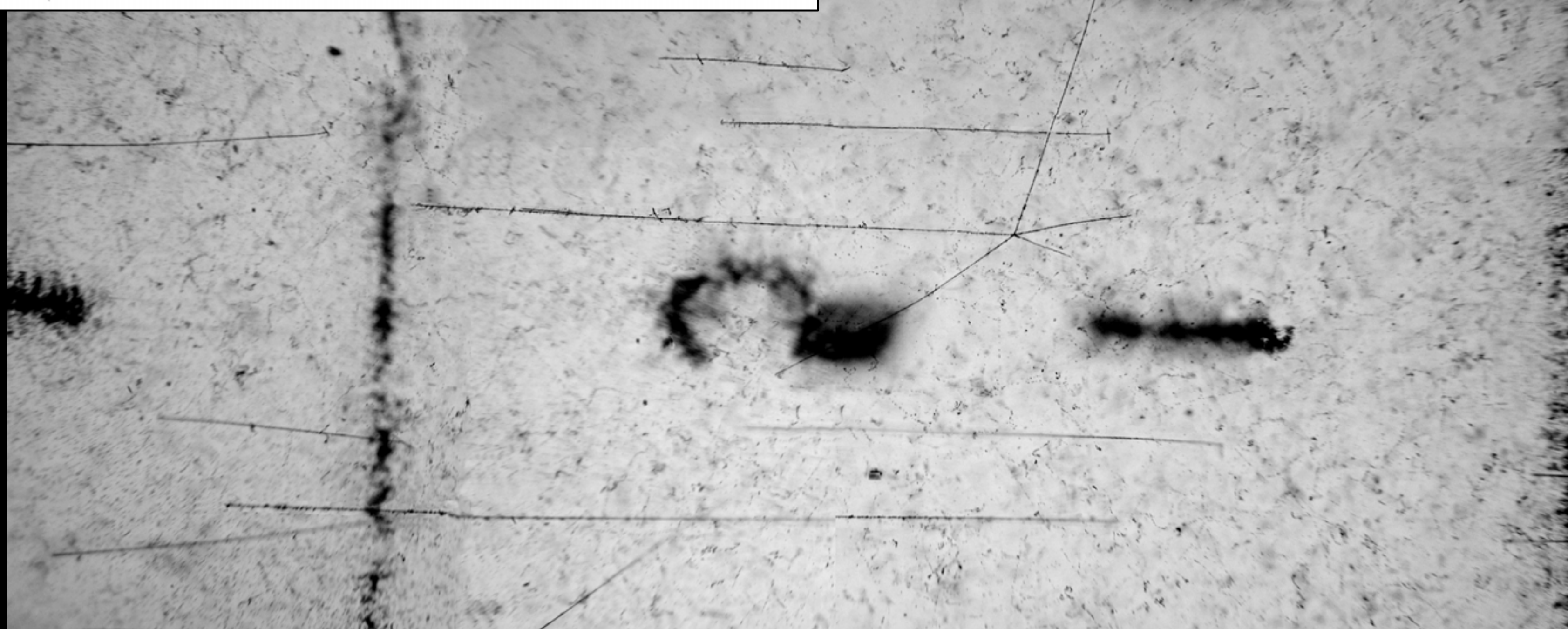


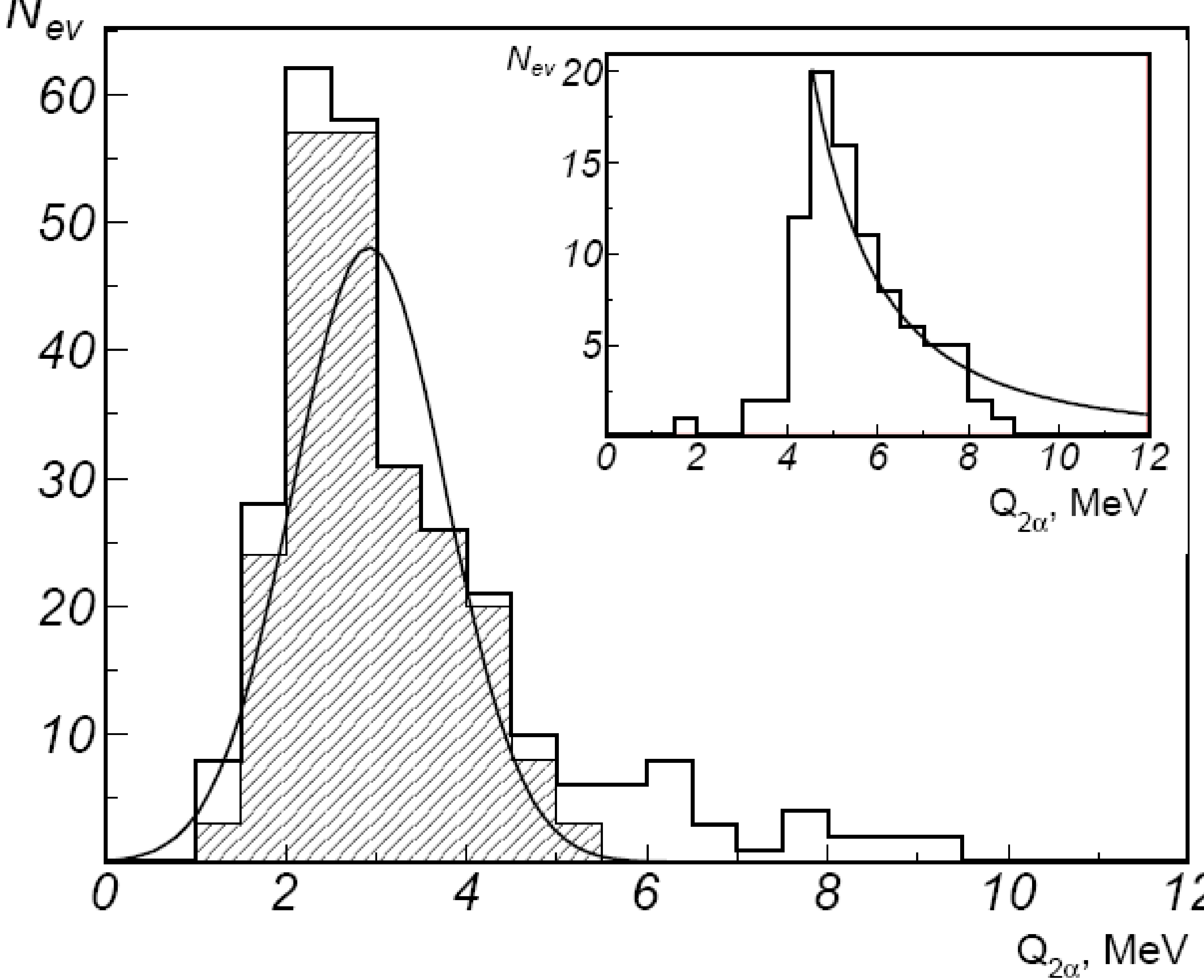
Облучение ядерной эмульсии ядрами ^{8}He на сепараторе ACCULINNA

Д. А. Артеменков[1], А. А. Безбах[1], В. Браднова[1], М. С. Головков[1], А. В. Горшков[1], П. И. Зарубин[1], И. Г. Зарубина[1], Г. Каминьски[1,2], Н. К. Корнегруца[1], С. А. Крупко[1], К. З. Маматкулов[1], Р. Р. Каттабеков[1], В. В. Русакова[1], Р. С. Слепнев[1], Р. Станоева[3], С. В. Степанцов[1], А. С. Фомичев[1], В. Худоба[1,4]

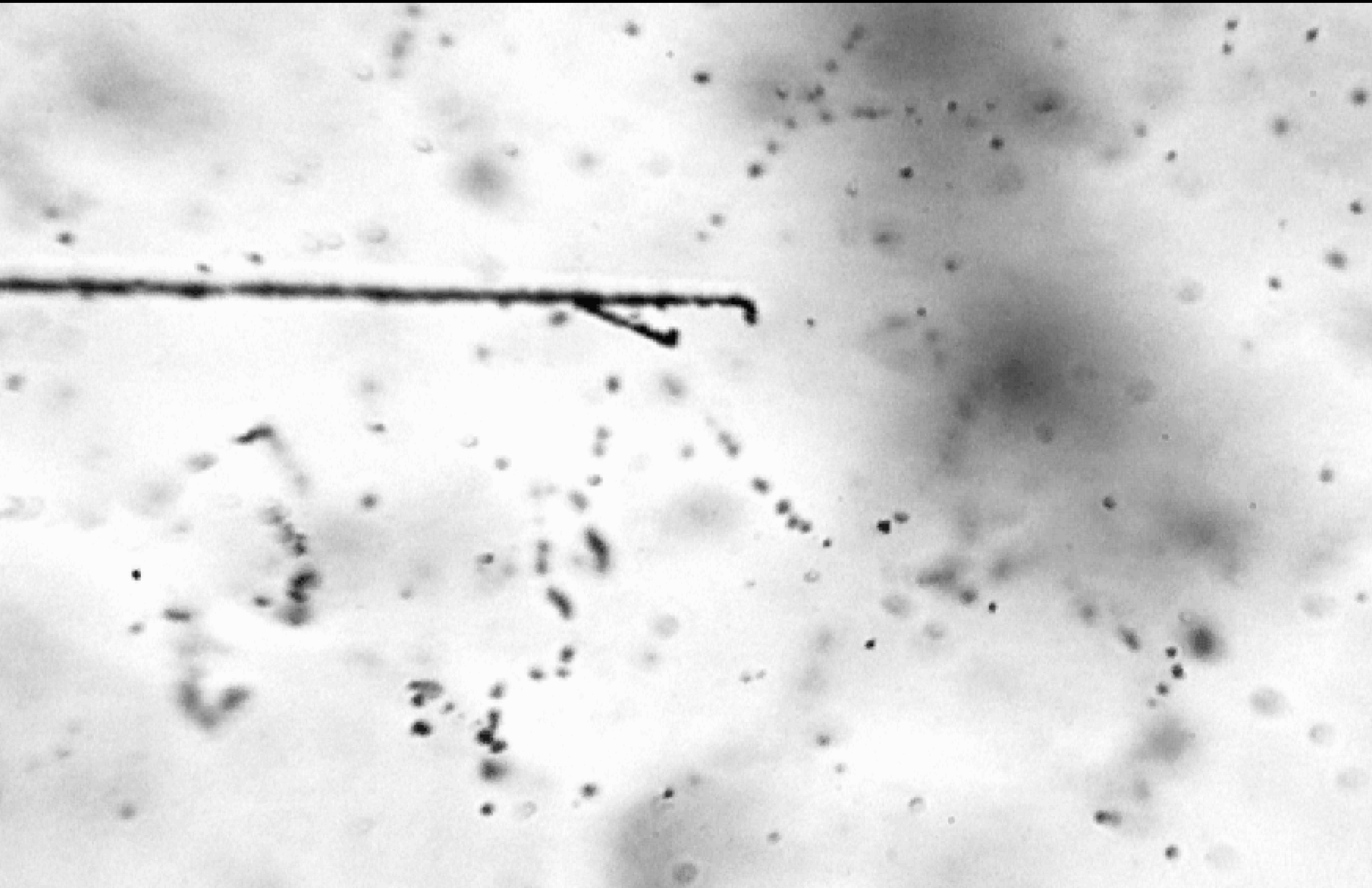
[1]Объединенный институт ядерных исследований, Дубна, Россия.
[2]Институт ядерной физики ПАН, Краков, Республика Польша
[3]Юго-западный университет, Благоевград, Болгария
[4]Институт физики, Университет Силезии, Опава, Чешская Республика

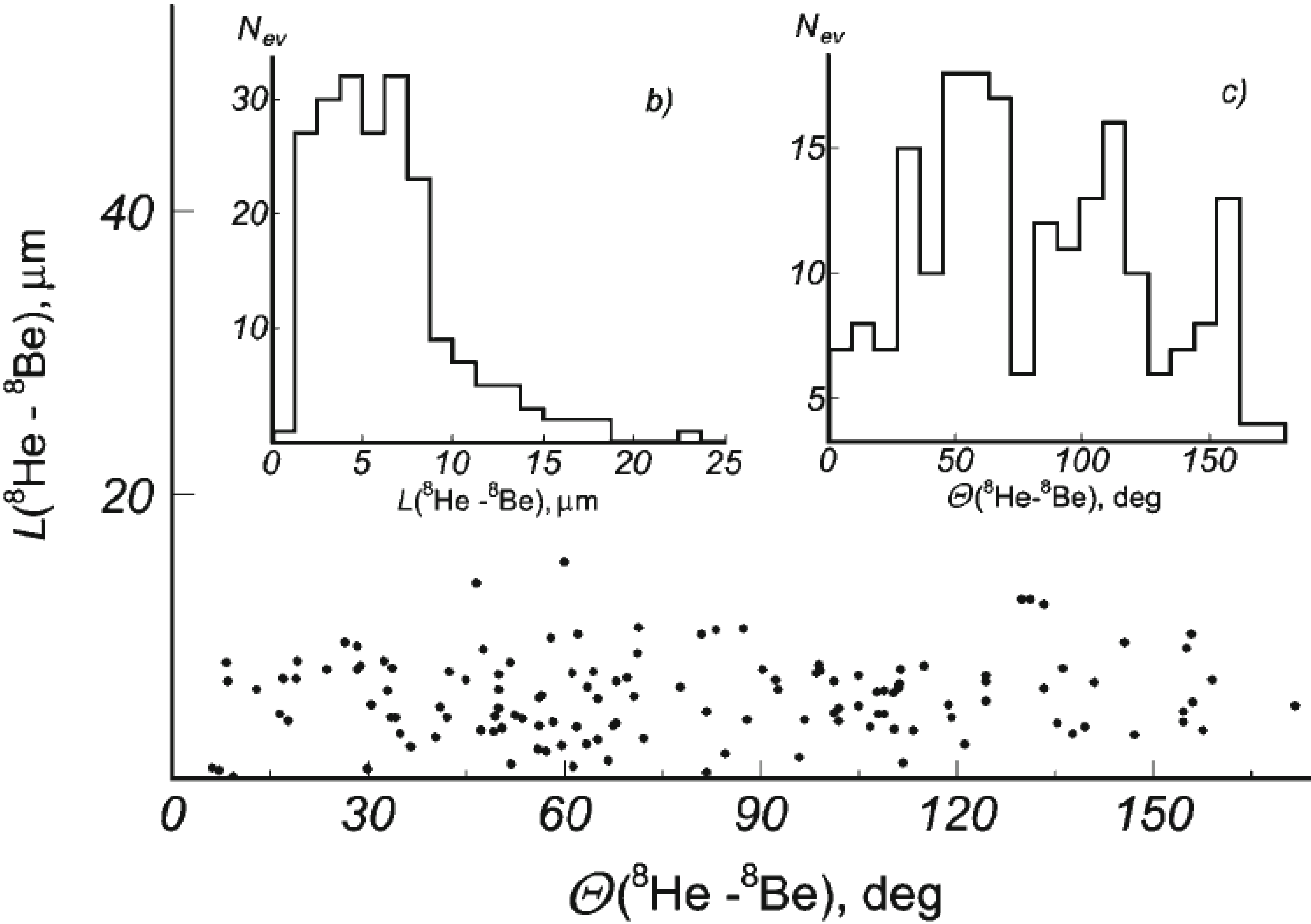
На сепараторе ACCULINNA ядерная эмульсия была облучена в пучке радиоактивных ядер ^{8}He с энергией 60 МэВ и обогащением около 80%. Измерения 278 распадов ядер ^{8}He, остановившихся в эмульсии, позволяют оценить возможности α-спектрометрии, а также впервые наблюдать дрейф атомов ^{8}He, термализованных в веществе.



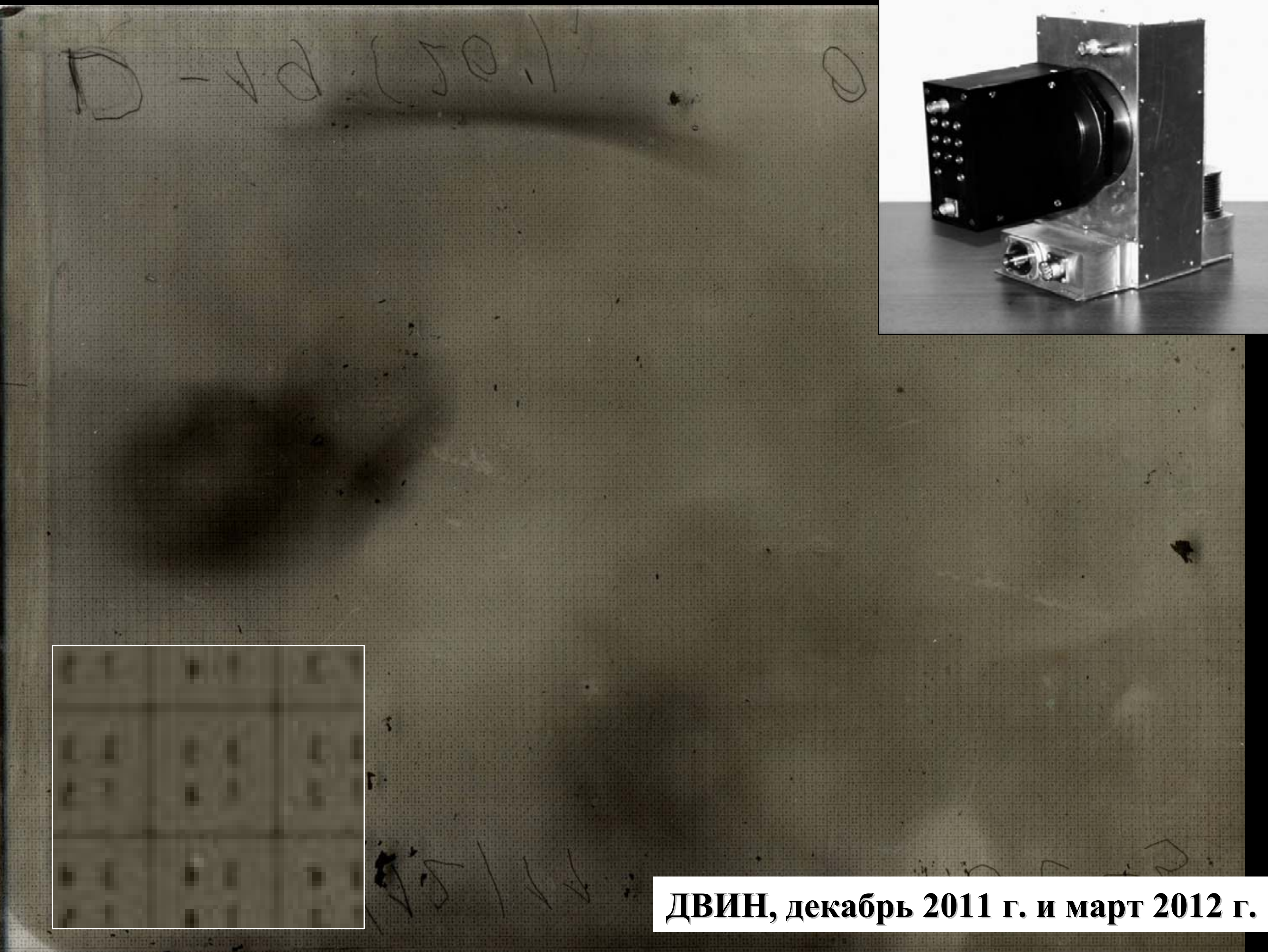


N_{ev}
60
50
40
30
20
10
0
2
4
6
8
10
12
$Q_{2\alpha}$, MeV
N_{ev}
20
15
10
5
0
2
4
6
8
10
12
$Q_{2\alpha}$, MeV

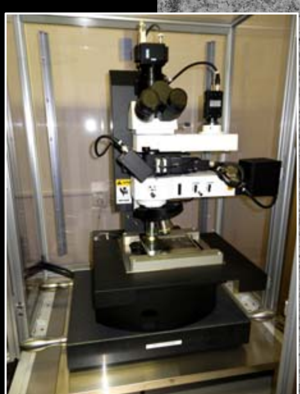


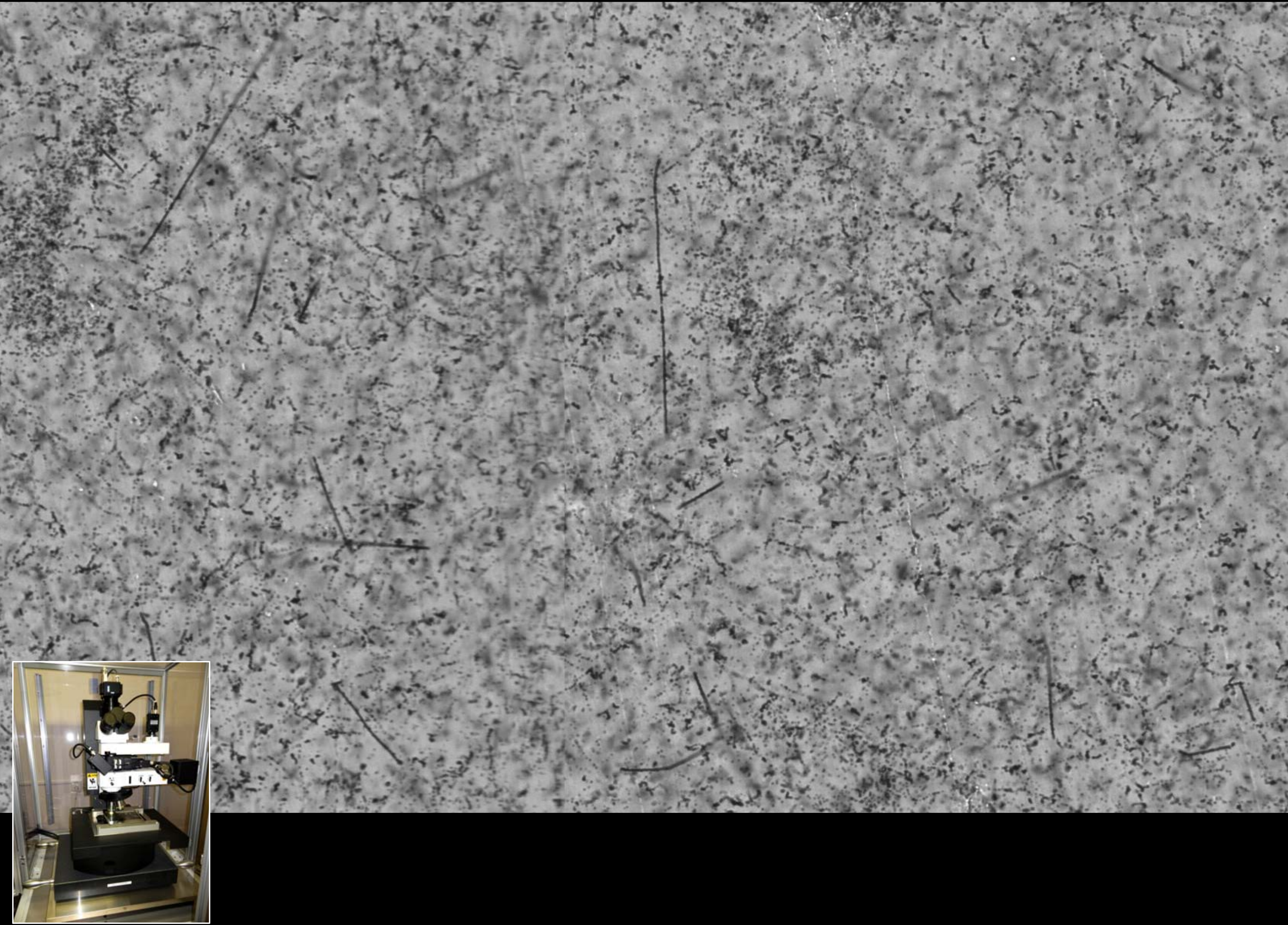


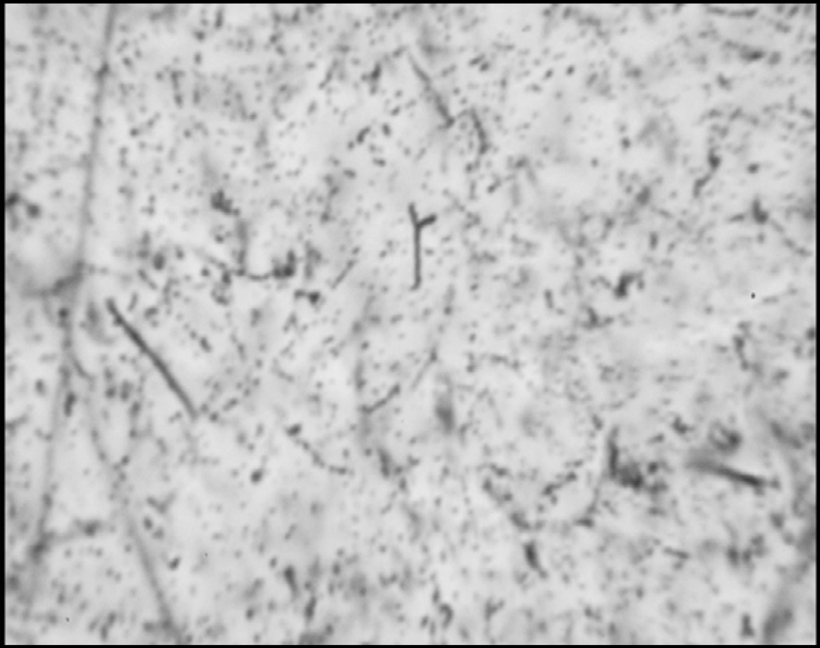
b)
c)
N_ev
L(8He - 8Be), μm
Θ(8He-8Be), deg
Θ(8He - 8Be), deg

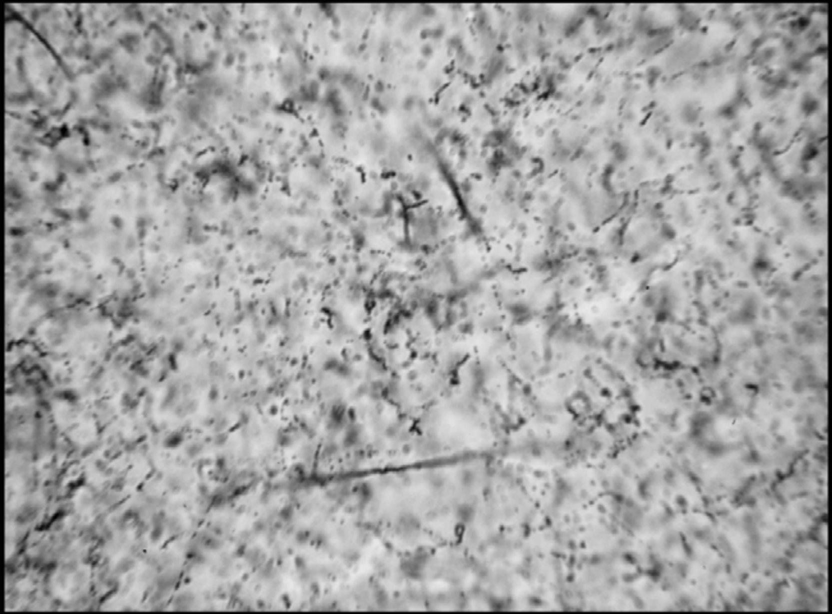


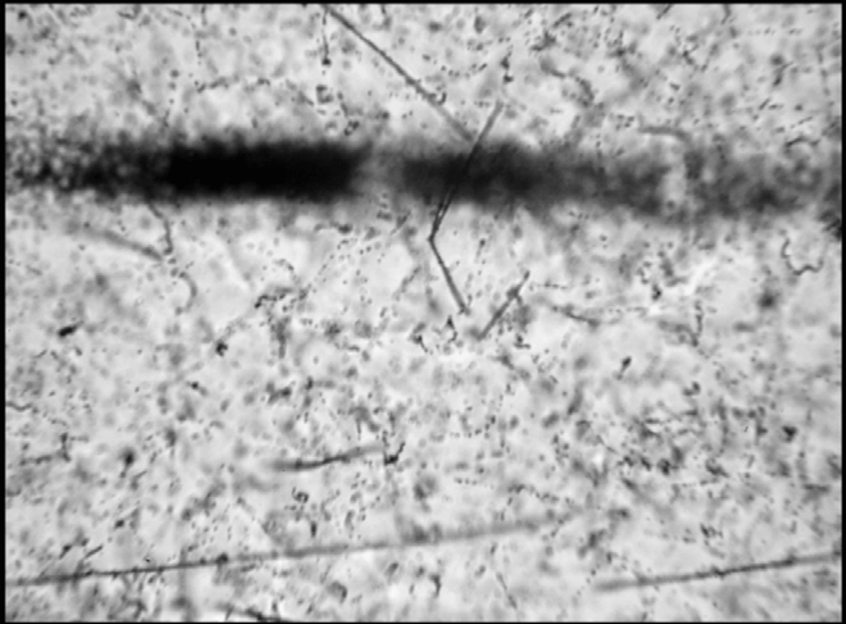
ДВИН, декабрь 2011 г. и март 2012 г.

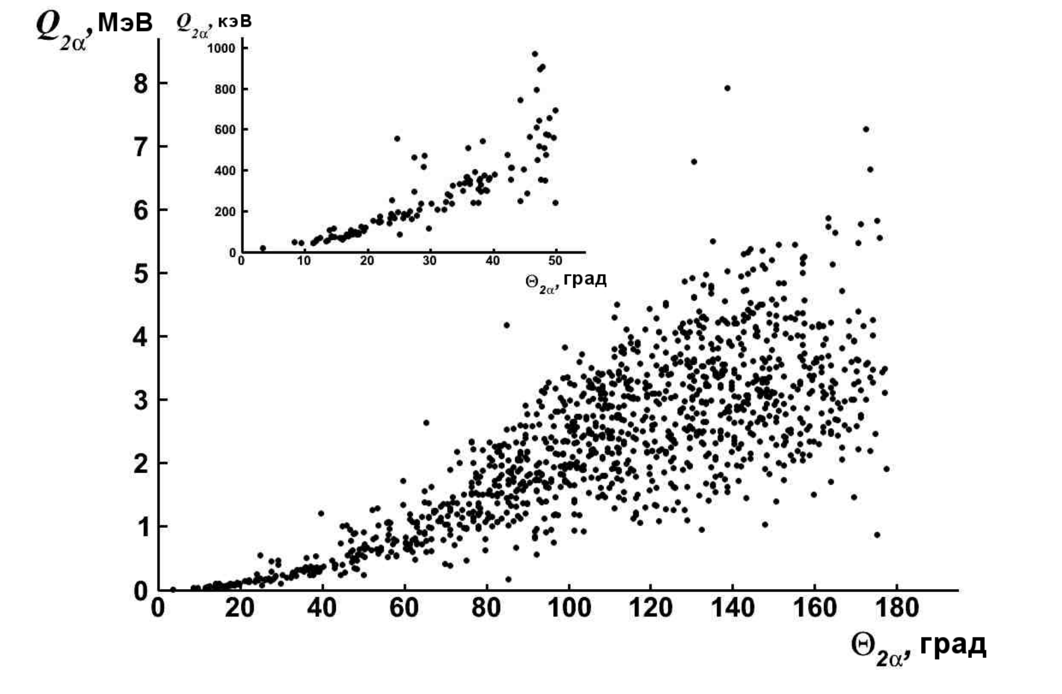



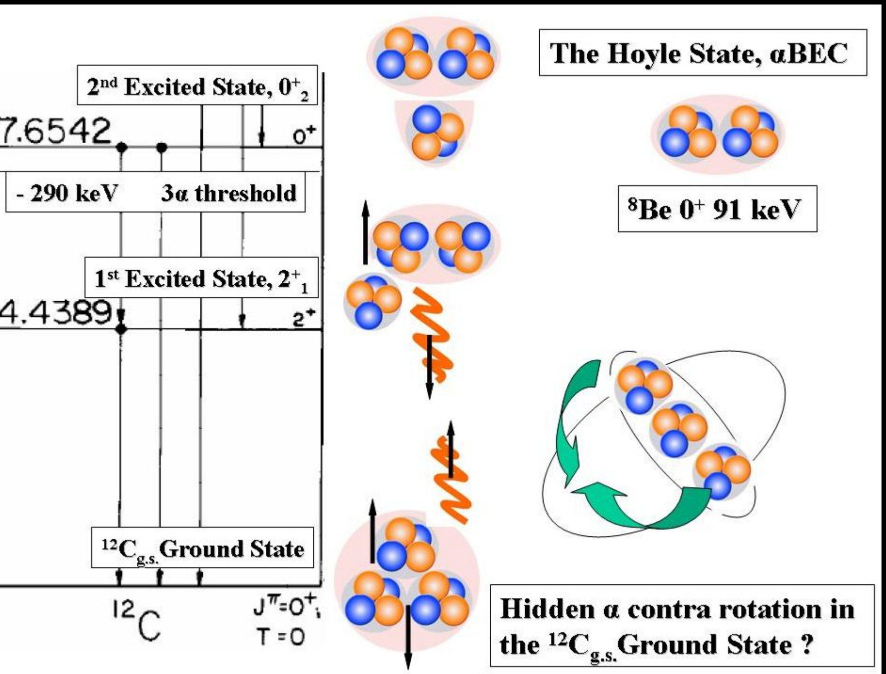


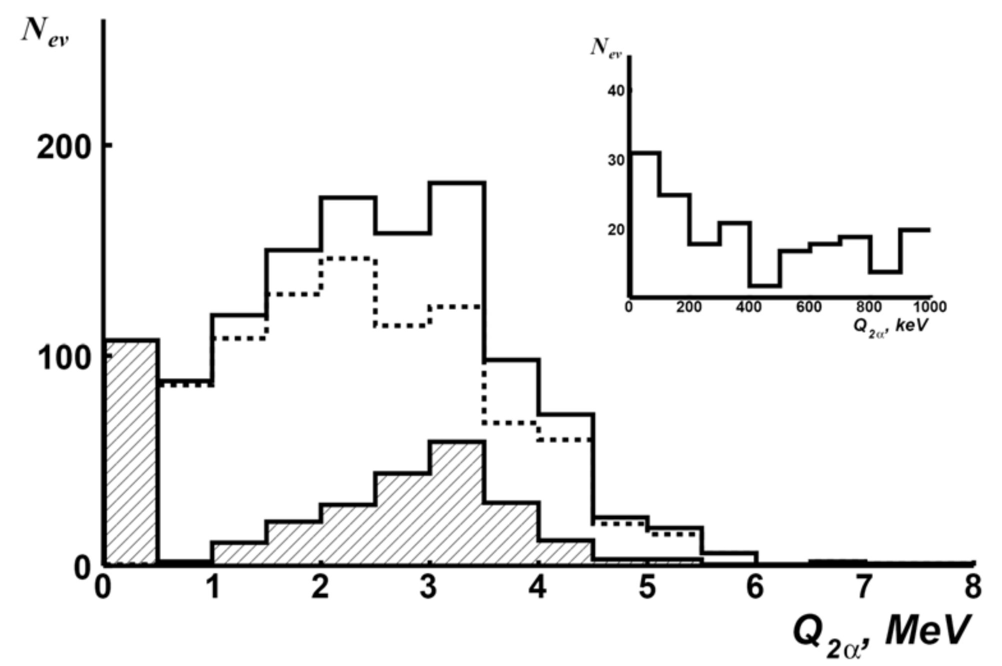


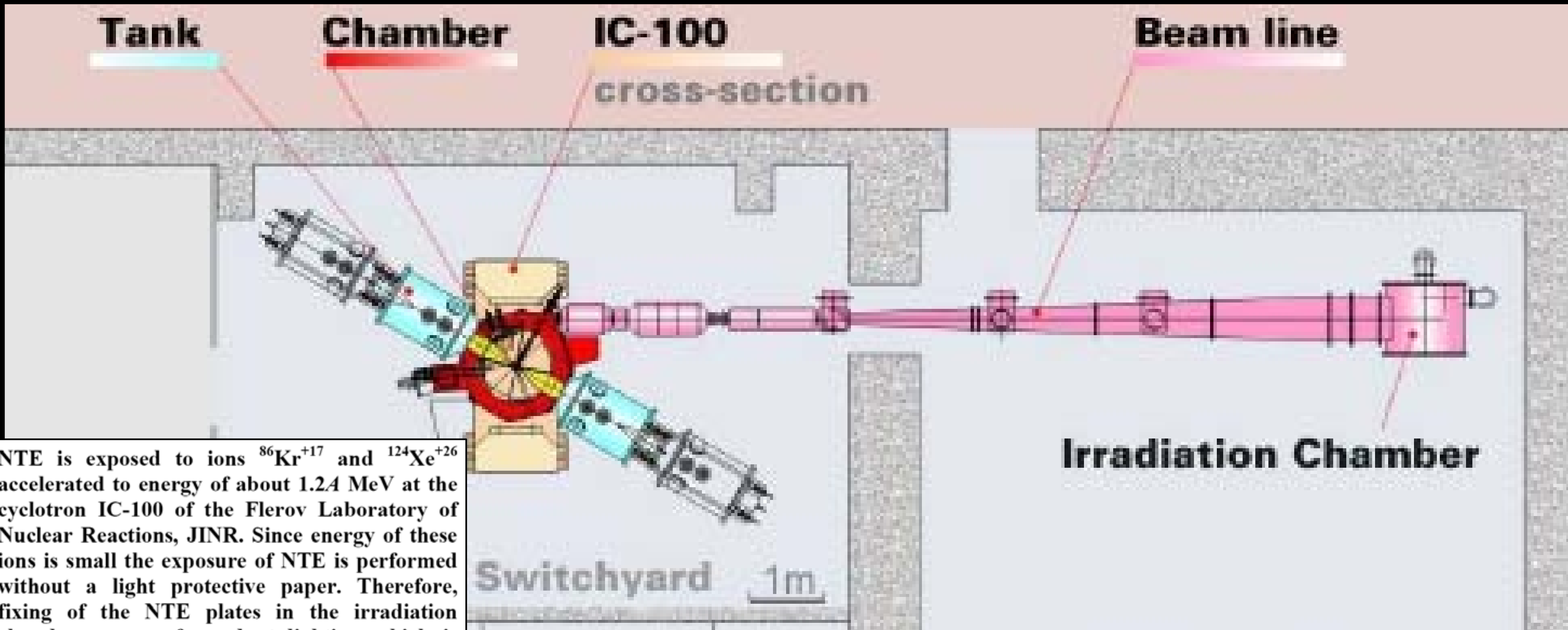




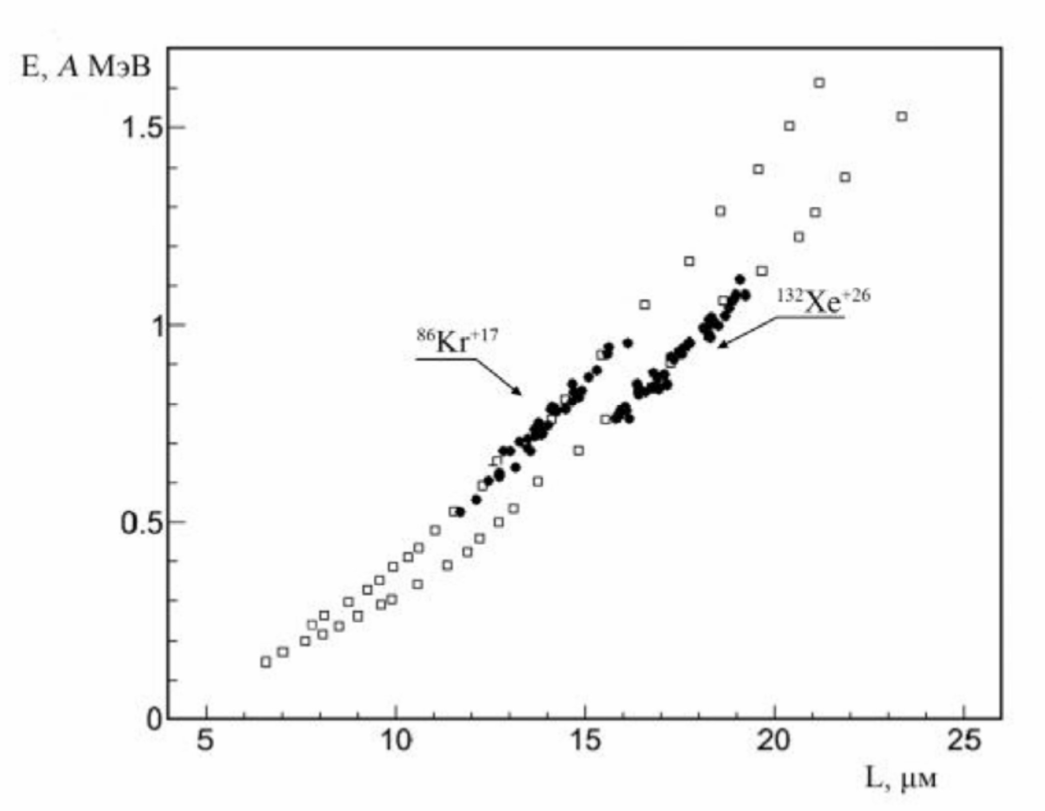

$Q_{2\alpha}$, МэВ
$Q_{2\alpha}$, кэВ
$\Theta_{2\alpha}$, град
$\Theta_{2\alpha}$, град


2nd Excited State, 0+2
7.6542
0+
- 290 keV
3α threshold
1st Excited State, 2+1
4.4389
2+
12Cg.s. Ground State
12C
Jπ=0+1
T=0
The Hoyle State, αBEC
8Be 0+ 91 keV
Hidden α contra rotation in the 12Cg.s. Ground State ?

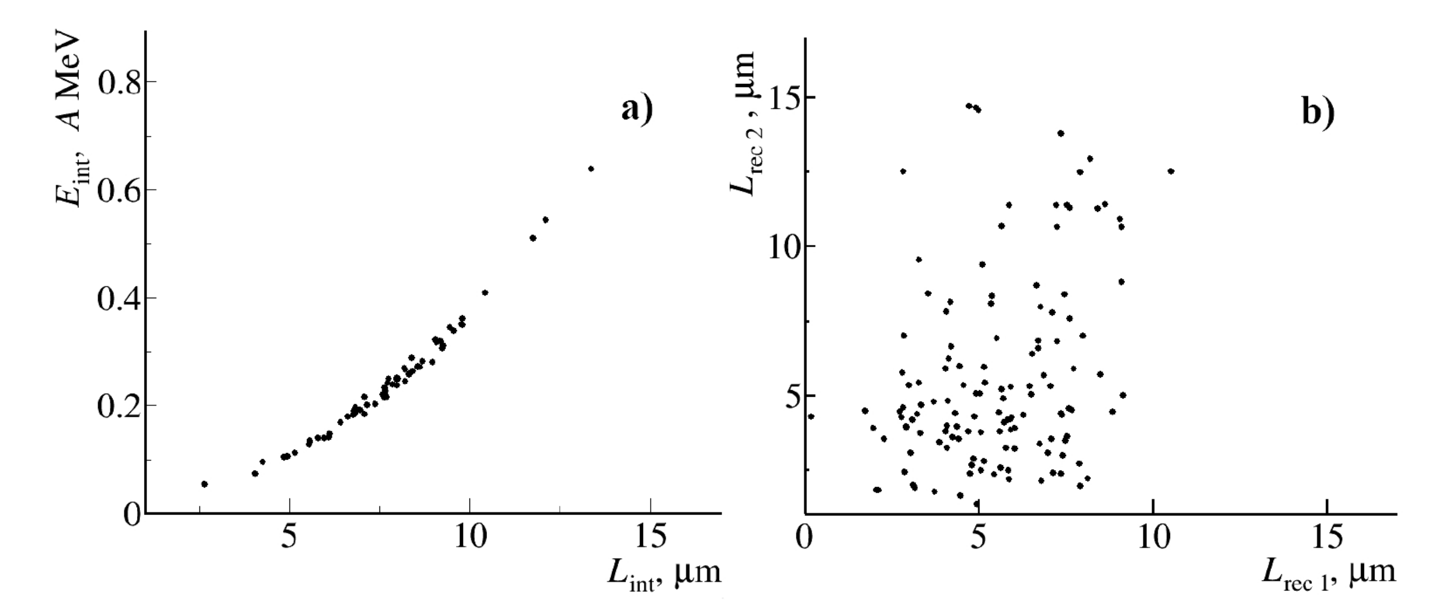

N_{ev}
$Q_{2\alpha}$, MeV
N_{ev}
$Q_{2\alpha}$, keV



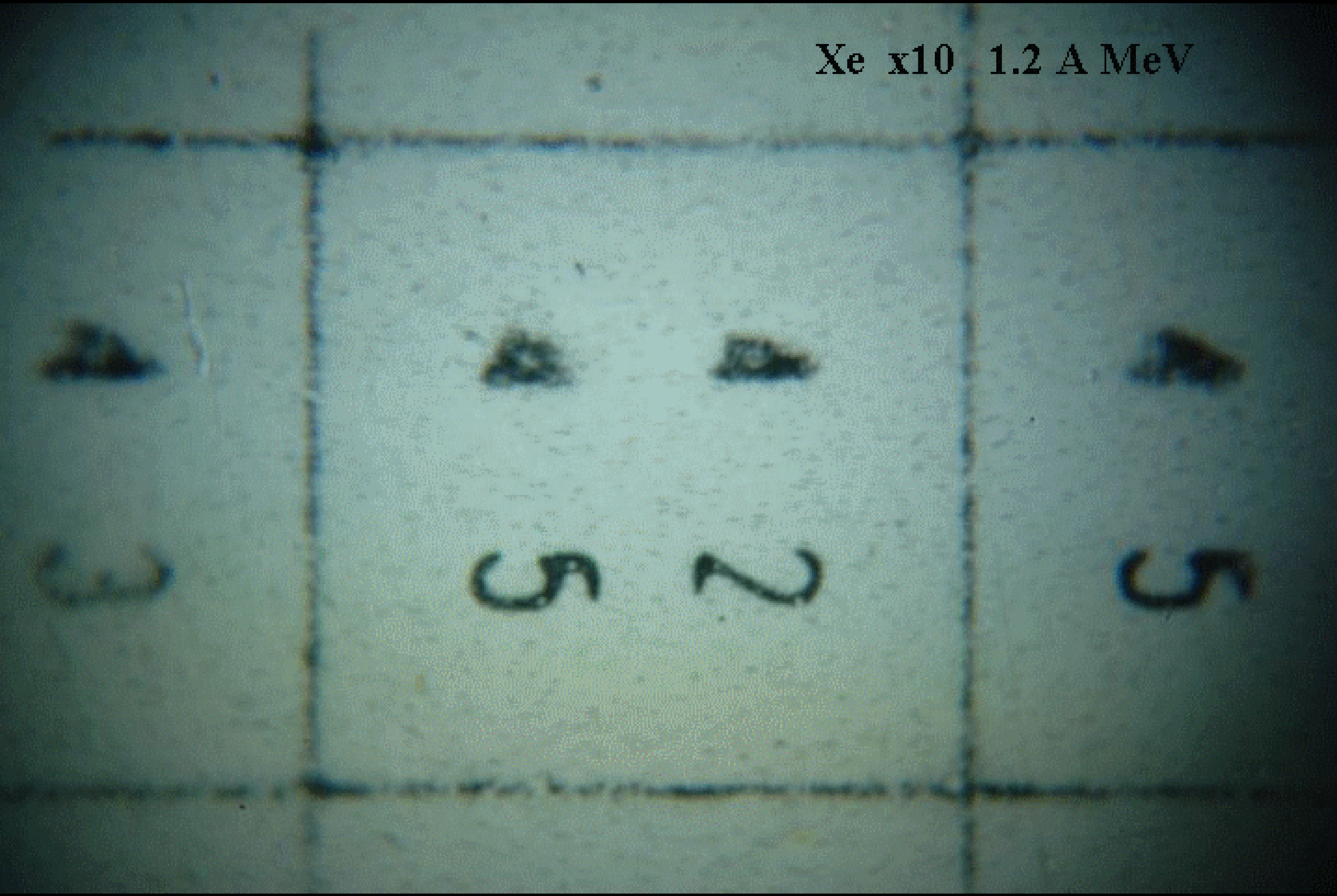
NTE is exposed to ions $^{86}Kr^{+17}$ and $^{124}Xe^{+26}$ accelerated to energy of about 1.2*A* MeV at the cyclotron IC-100 of the Flerov Laboratory of Nuclear Reactions, JINR. Since energy of these ions is small the exposure of NTE is performed without a light protective paper. Therefore, fixing of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



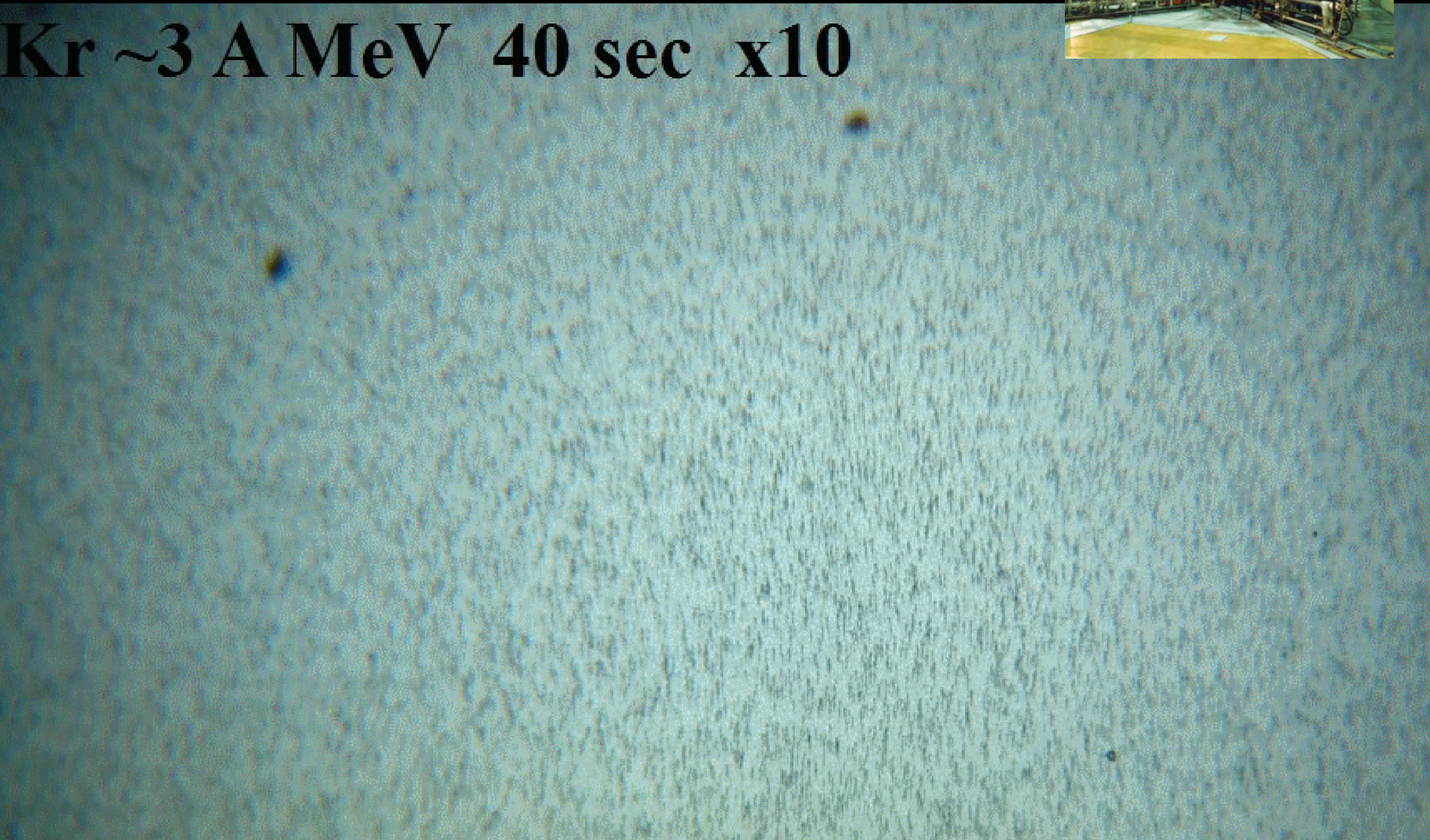
E, A МэВ
1.5
1
0.5
0
5
10
15
20
25
L, μм
$^{86}Kr^{+17}$
$^{132}Xe^{+26}$

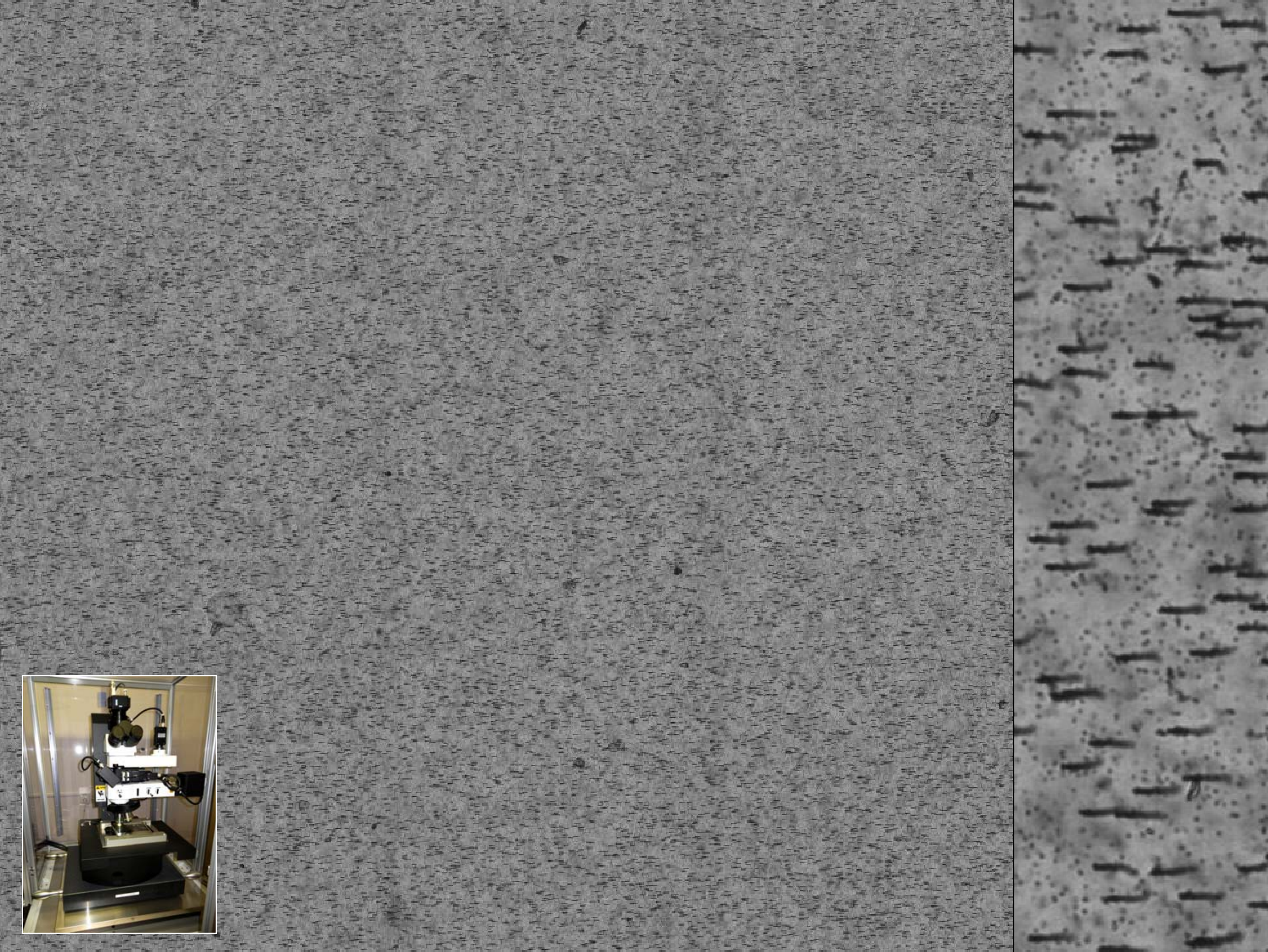


a)
E_{int}, A MeV
0.8
0.6
0.4
0.2
0
5
10
15
L_{int}, μm
b)
$L_{rec\ 2}$, μm
15
10
5
0
5
10
15
$L_{rec\ 1}$, μm


Xe x10 1.2 A MeV

Flerov Laboratory





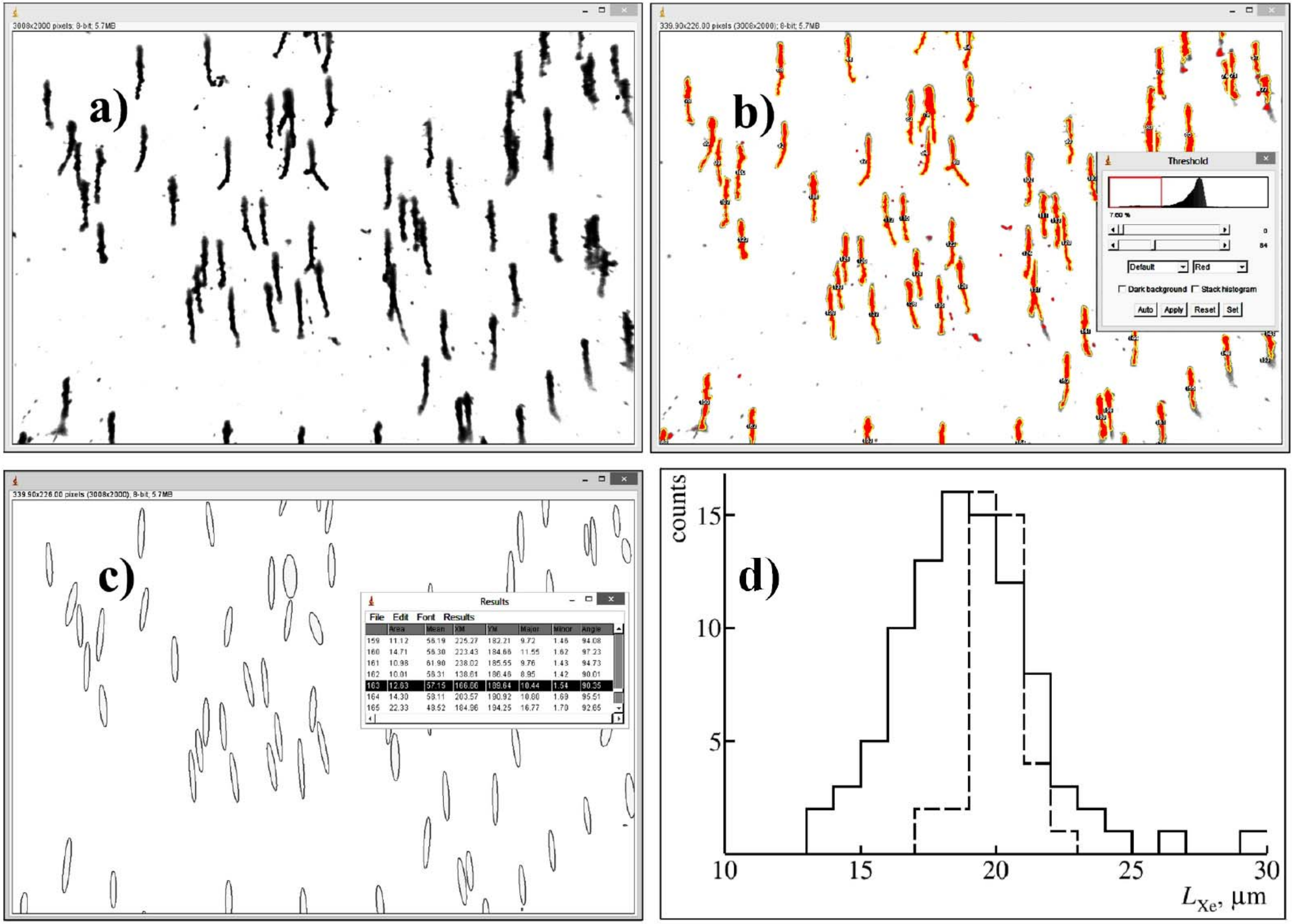
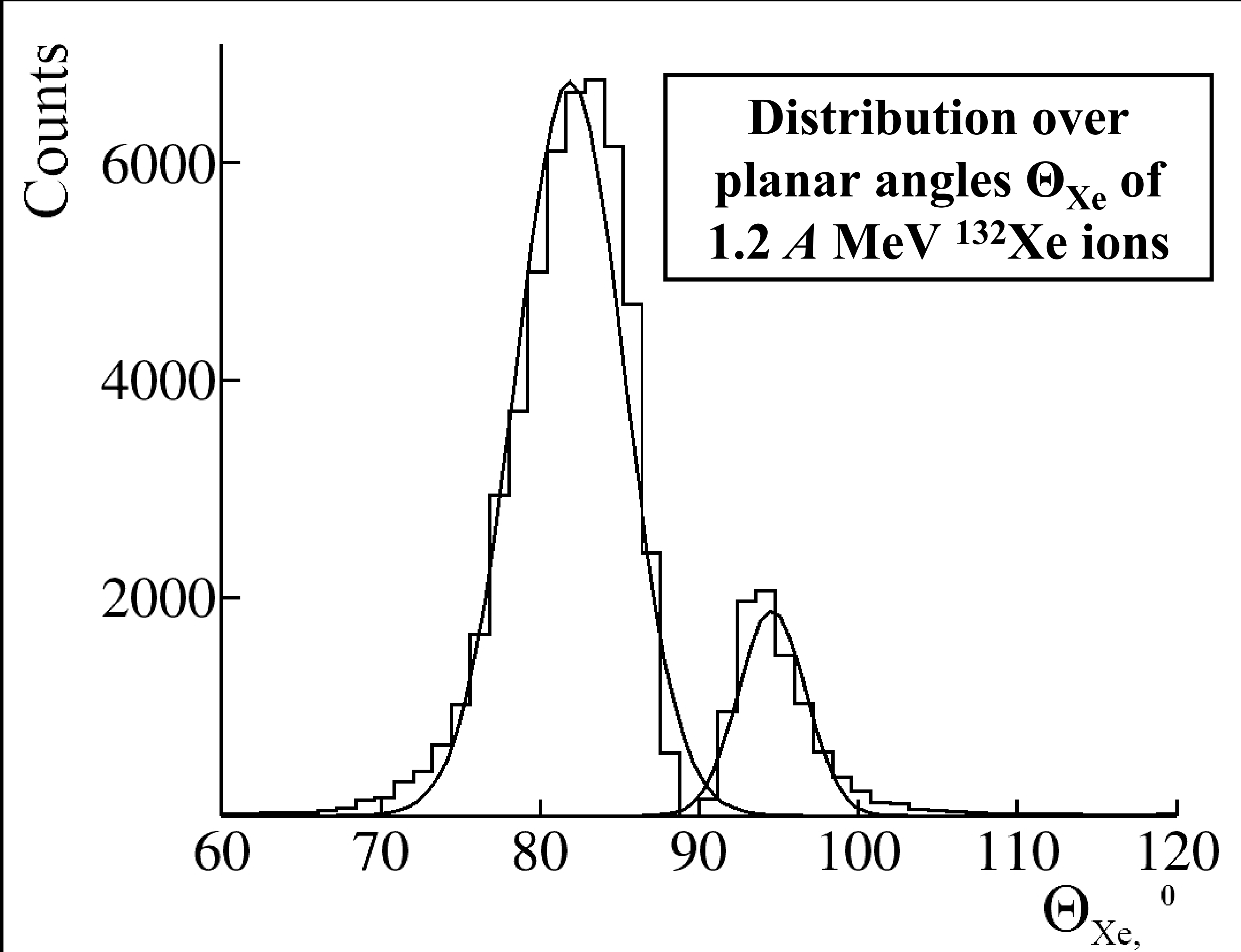
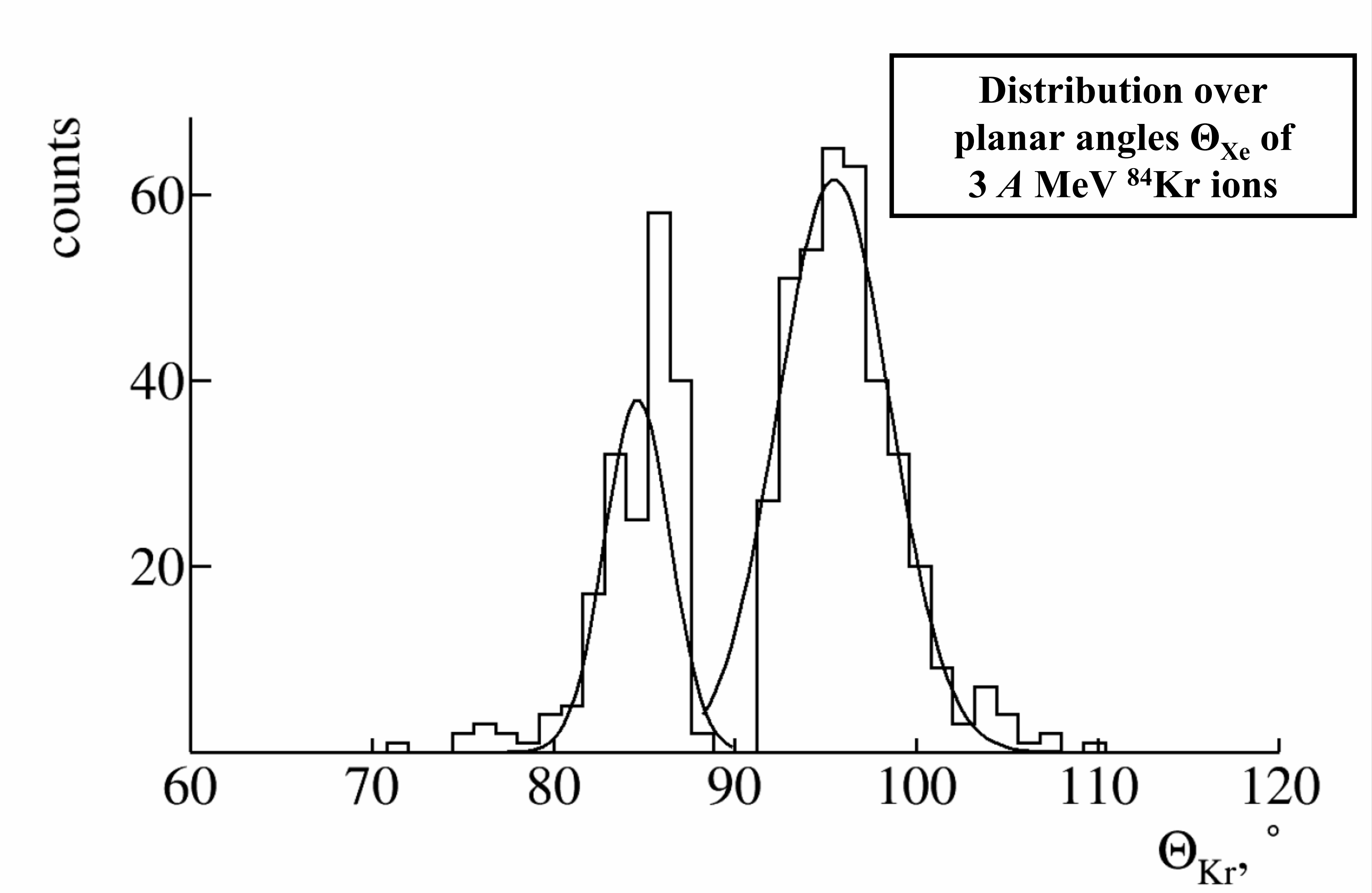


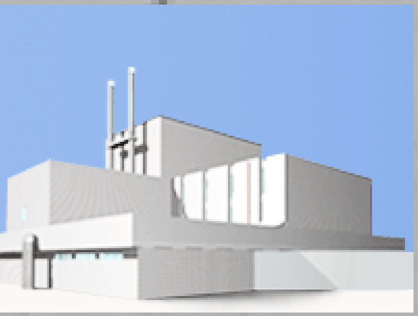
Fig. 5. Stages of computer analysis: (a) initial close-up, (b) finding of track images, (c) description of them as ellipses and (d) ion range distribution in computer (solid line) and manual (dashed line) analysis.

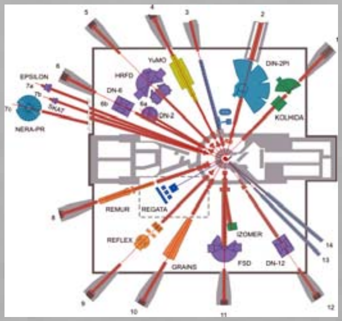

Distribution over
planar angles Θ_{Xe} of
1.2 *A* MeV ^{132}Xe ions
Counts
6000
4000
2000
60
70
80
90
100
110
120
$\Theta_{Xe,}$ ^{0}



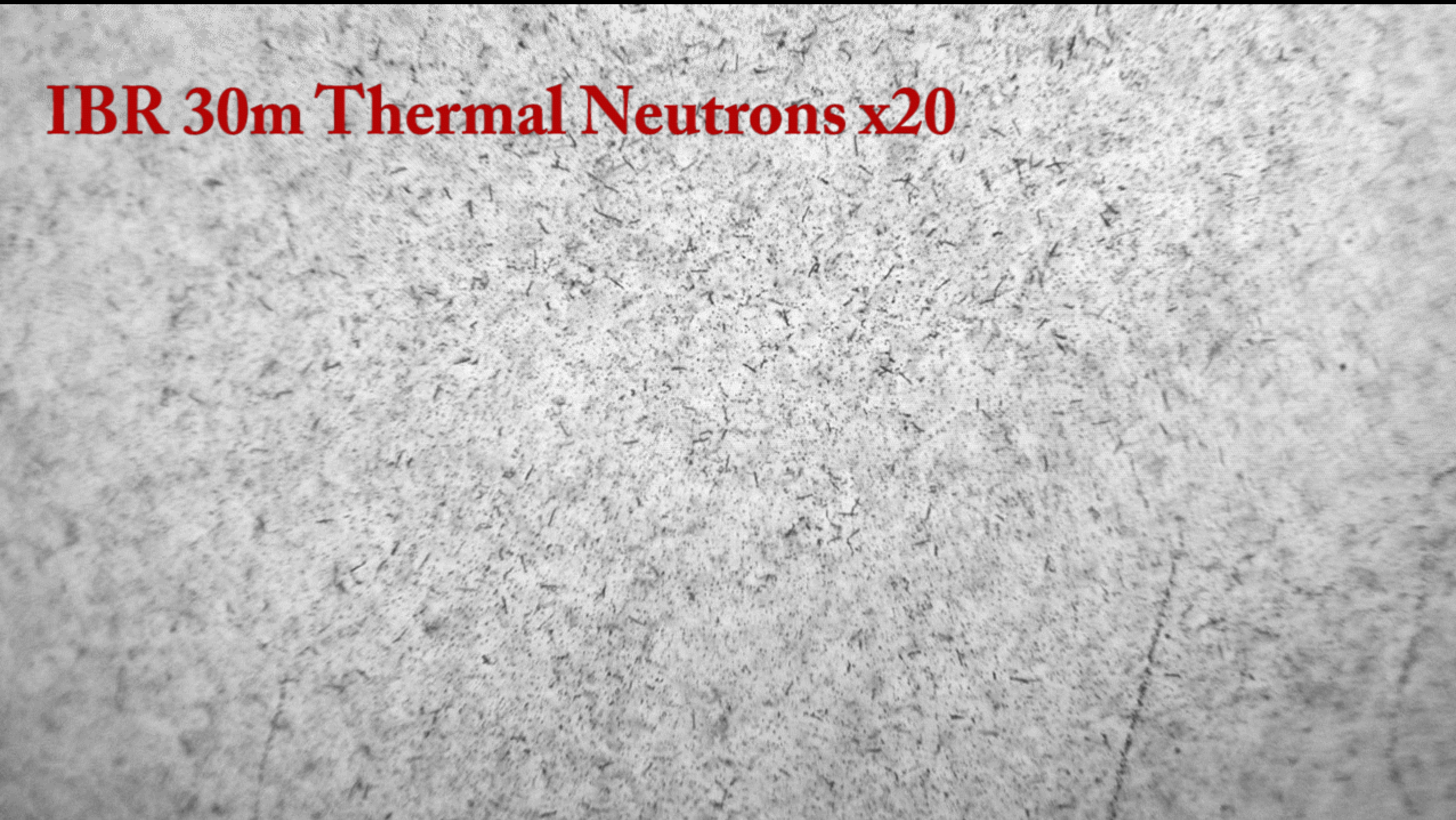
Distribution over
planar angles Θ_{Xe} of
3 *A* MeV ^{84}Kr ions
counts
60
40
20
60
70
80
90
100
110
120
Θ_{Kr}, °

JINR IBR-2 Pulsed Reactor

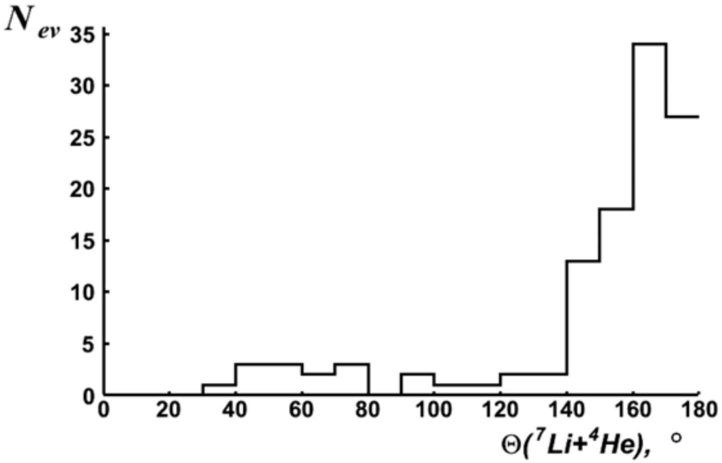




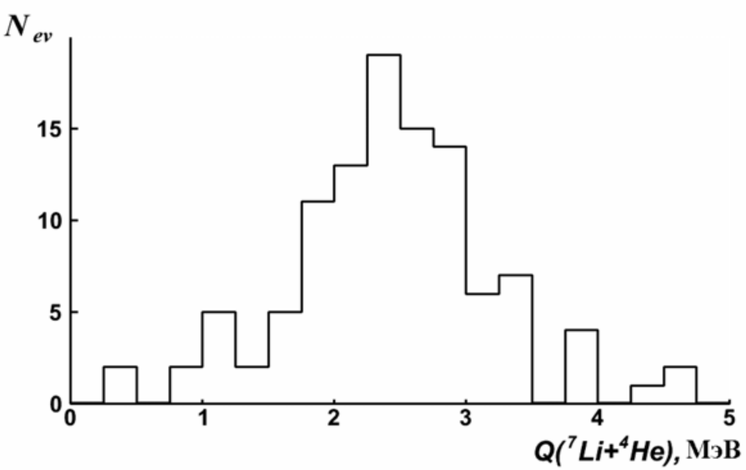
26CB-2/3


IBR 30m Thermal Neutrons x20

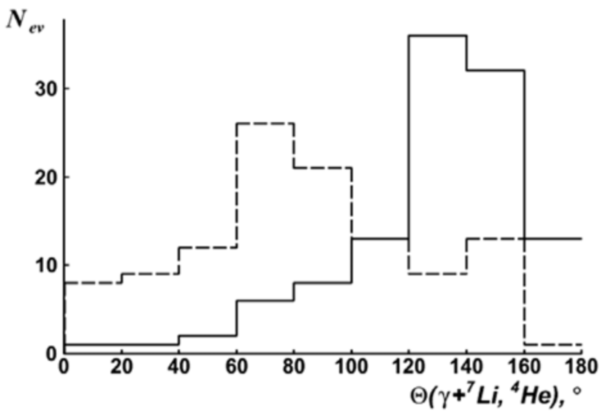

IBR-2 thermal neutrons (no boron) x20



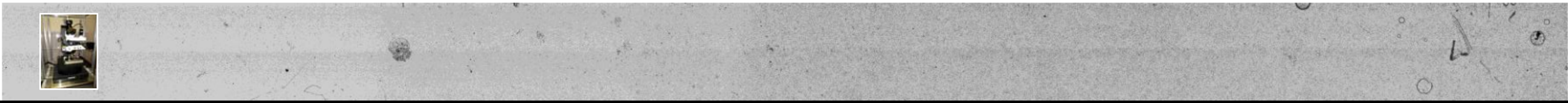
Directions of emission aren't collinear in pairs as a consequence of emission of γ-rays. A value of the average opening angle $\Theta(^7Li + {}^4He)$ is $(148 \pm 14)^o$ (RMS 35^o). There are several events $\Theta(^7Li + {}^4He) < 90^o$ in the distribution $\Theta(^7Li + {}^4He)$.

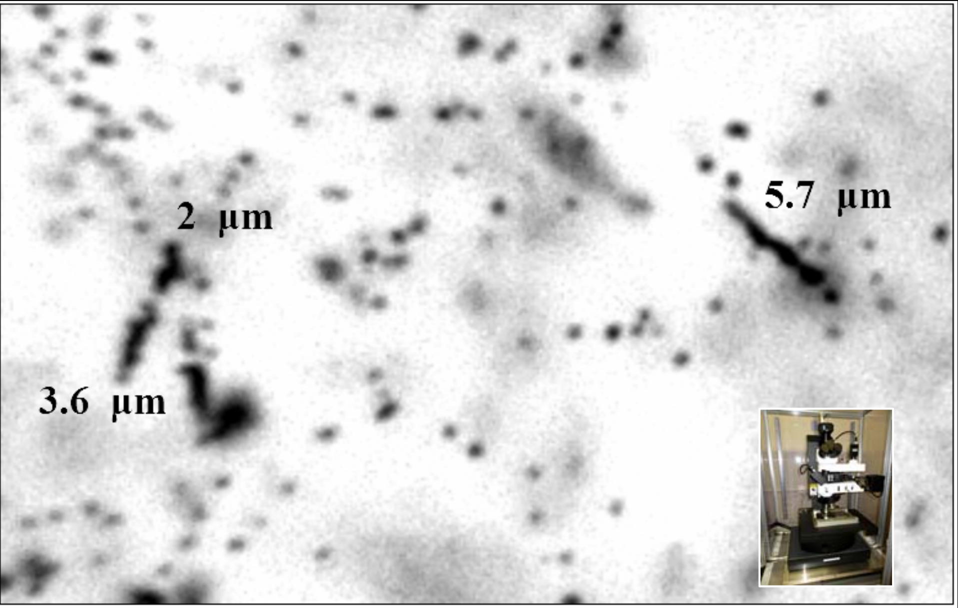


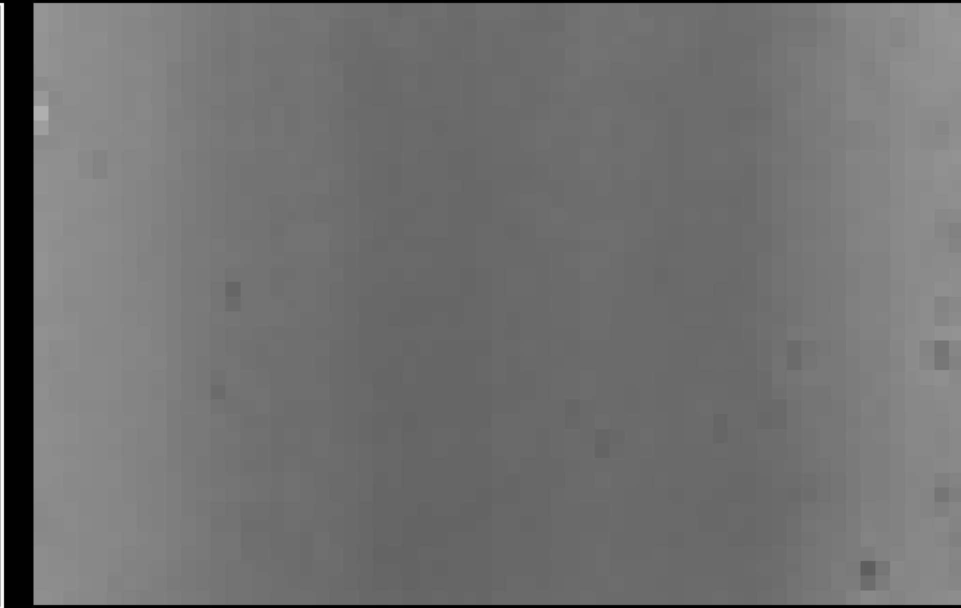
The simulation program SRIM allows one to evaluate the kinetic energy of the nuclei by measuring lengths of tracks. Knowledge of energy and emission angles allows to obtain the energy distribution $Q(^7Li + {}^4He)$ of pairs of ^7Li and ^4He nuclei. The variable Q is defined as the difference between the invariant mass of the final M^* and the mass of the decaying nucleus M. $Q = M^* - M$. M^* is defined as the sum of all products of the 4-momenta Pi, k fragments, i.e., $M^{*2} = (\Sigma P_j)^2$. Its relativistic-invariant character allows one to compare disparate data in 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 $\Theta(\gamma + {}^7Li)$ of angles between 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 anti-correlation. It is characterized by the average value of $\Theta(\gamma + {}^7Li)$ $(128 \pm 3)^o$ (RMS 31^o) and a 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







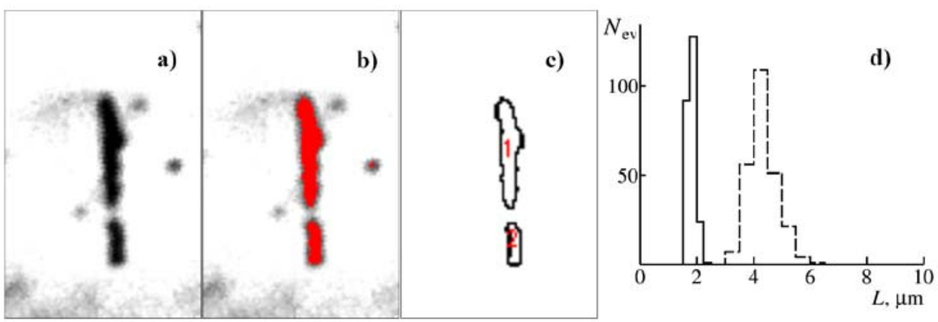
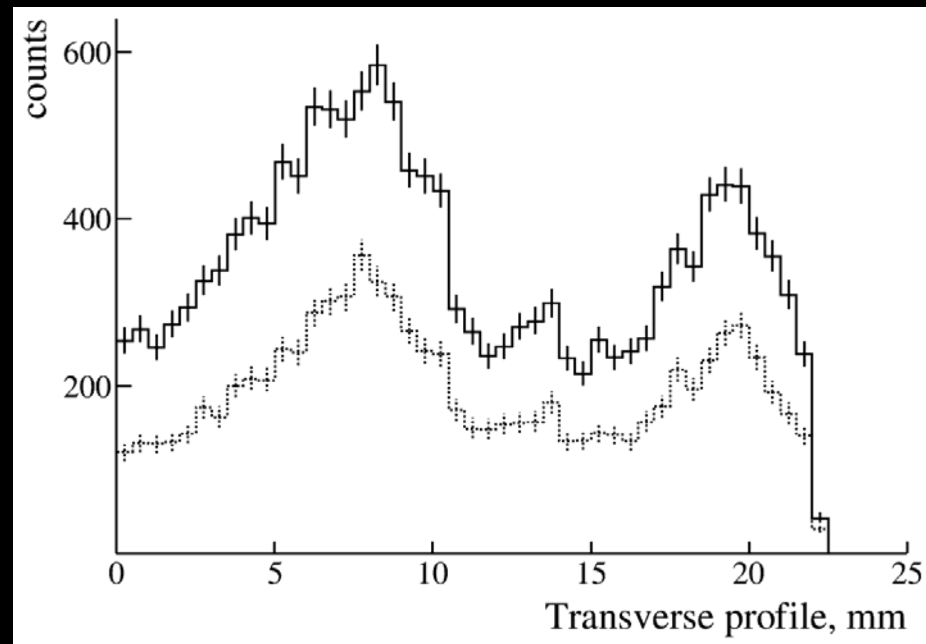
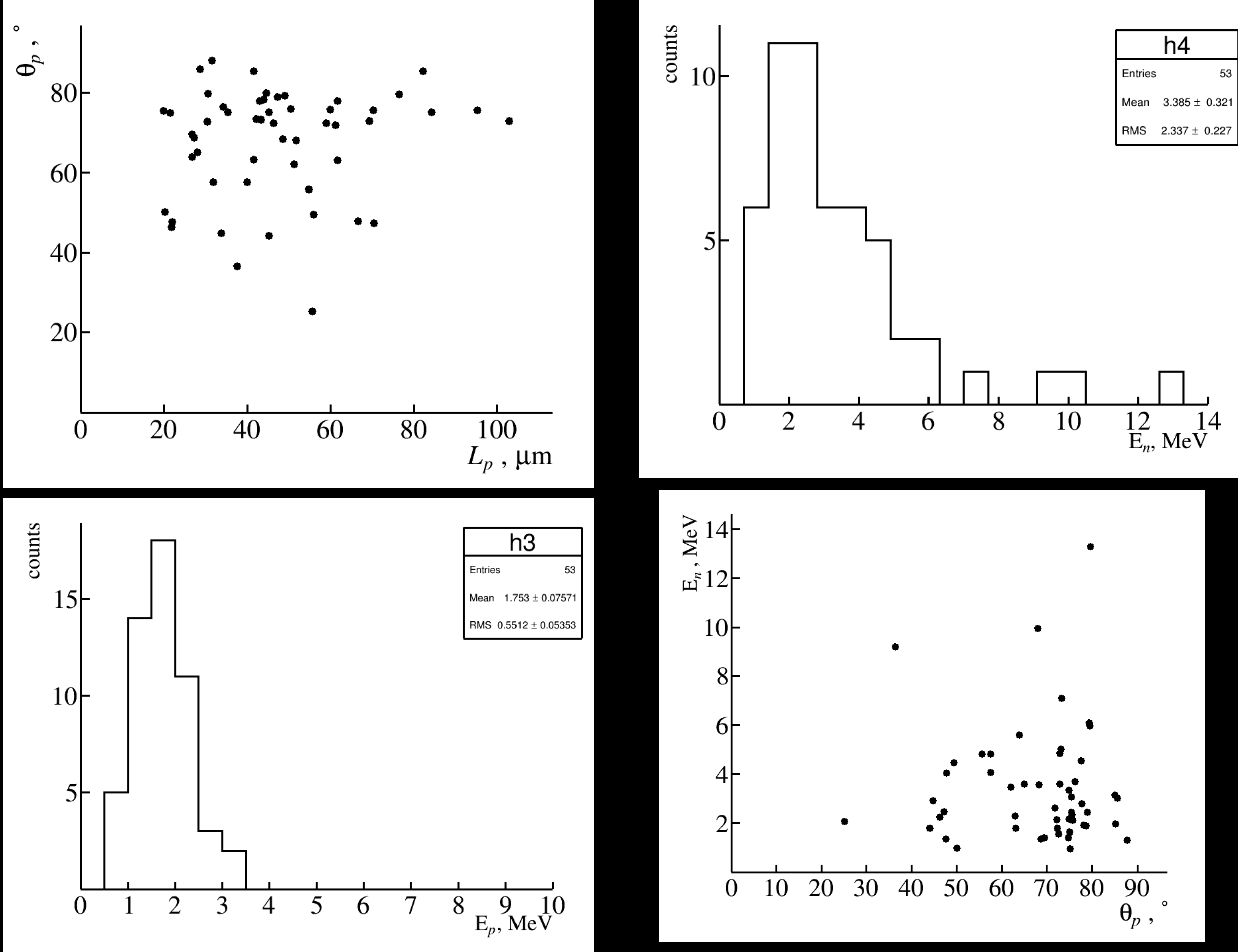


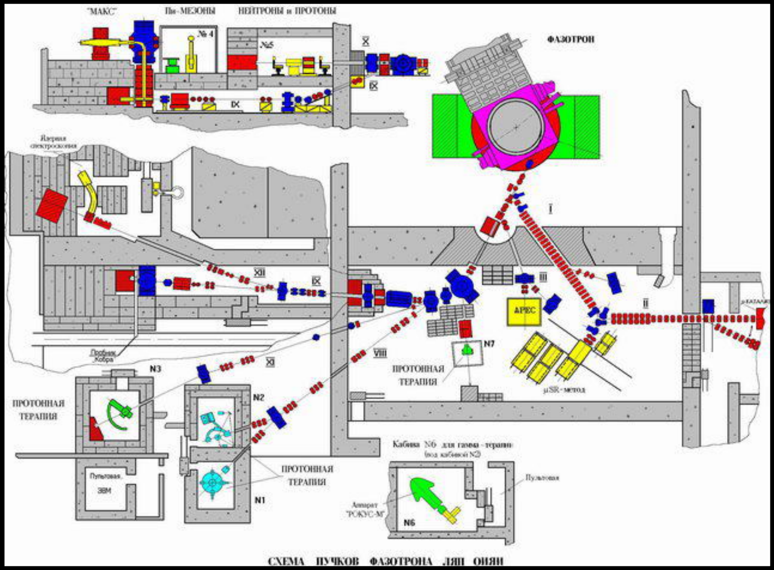
Figure 3. Example of disintegration of boron nucleus by thermal neutron to the Li and He n_{th} (a) and steps of image recognition via the ImageJ program (a-c). Distribution of mean range of Li (solid line) and He (dotted line) (d).

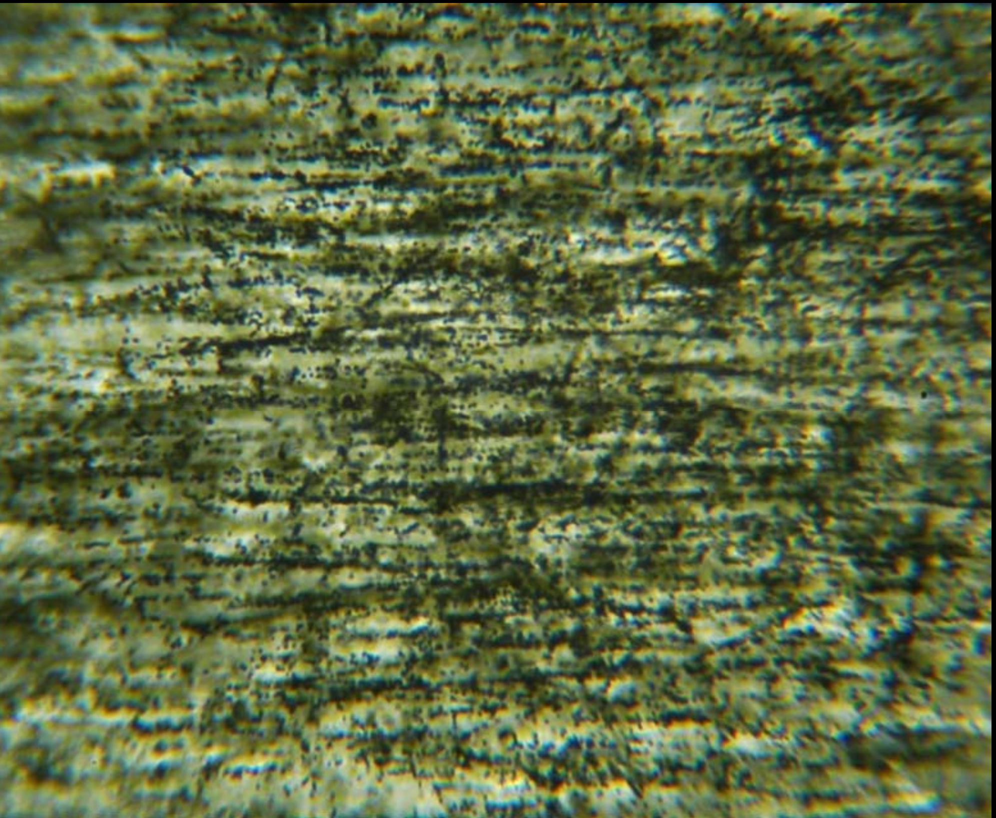


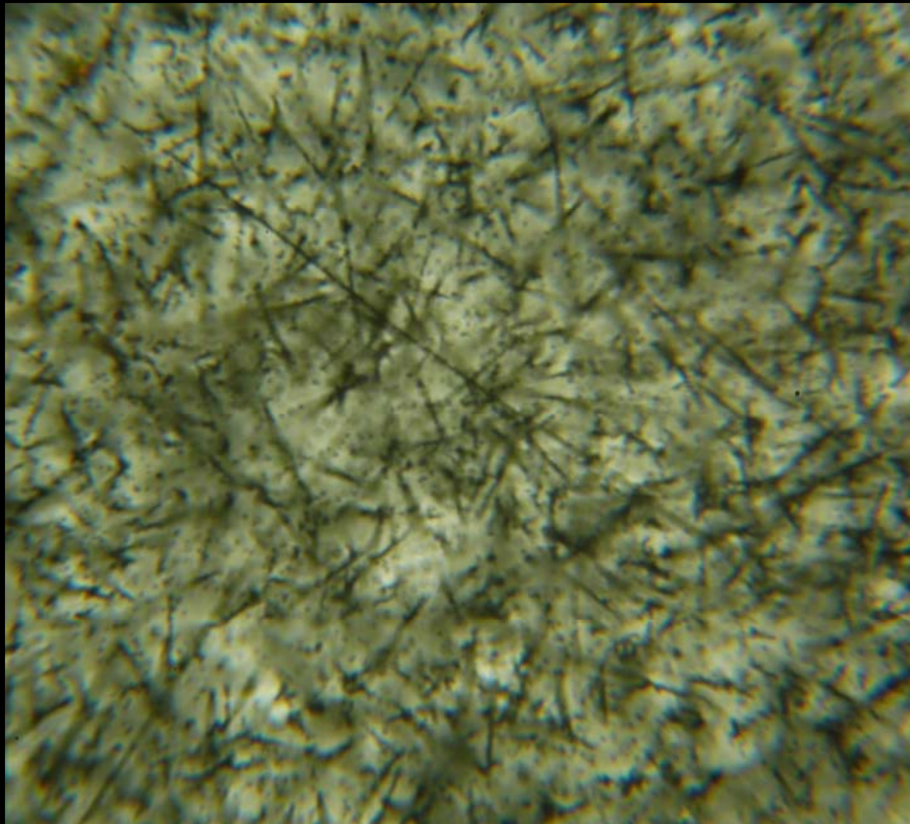


θ_p , °
L_p , μm
counts
h4
Entries 53
Mean 3.385 ± 0.321
RMS 2.337 ± 0.227
E_n, MeV
counts
h3
Entries 53
Mean 1.753 ± 0.07571
RMS 0.5512 ± 0.05353
E_p, MeV
E_n , MeV
θ_p , °


Электросила
им. С.М.Кирова


"МАКС"
Пи-МЕЗОНЫ
НЕЙТРОНЫ и ПРОТОНЫ
№ 4
№5
ФАЗОТРОН
Ядерная спектроскопия
АРЕС
N7
ПРОТОННАЯ ТЕРАПИЯ
μSR-метод
N3
ПРОТОННАЯ ТЕРАПИЯ
N2
ПРОТОННАЯ ТЕРАПИЯ
N1
Пультовая ЭВМ
Кабина N6 для гамма-терапии (под кабиной N2)
Пультовая
Аппарат "РОКУС-М"
N6
СХЕМА ПУЧКОВ ФАЗОТРОНА ЛЯП ОИЯИ





On the New Fission Processes of Uranium Nuclei

TSIEN SAN-TSIANG, HO ZAH-WEI, R. CHASTEL, AND L. VIGNERON
Laboratoire de Chimie Nucléaire du Collège de France, Paris, France
February 13, 1947

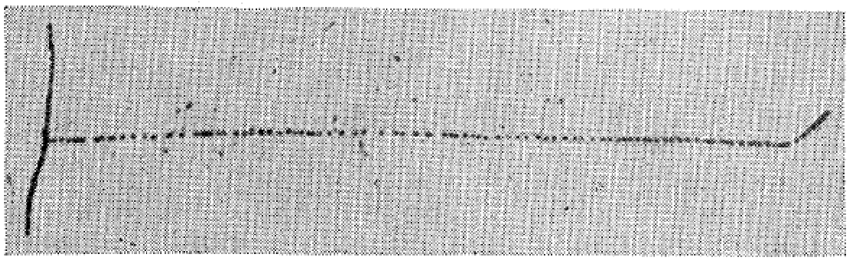


FIG. 1. Ternary fission: third fragment—mass≈9, range=17 cm air equivalent.

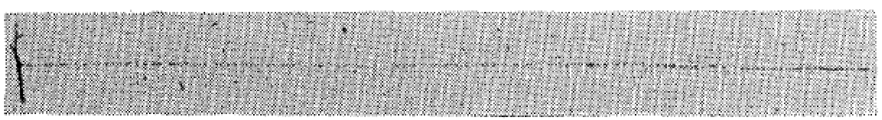


FIG. 2. Ternary fission: third fragment—mass≈6, range=44 cm air equivalent. The two branches on one of the heavy fragments are caused by nuclear collisions.

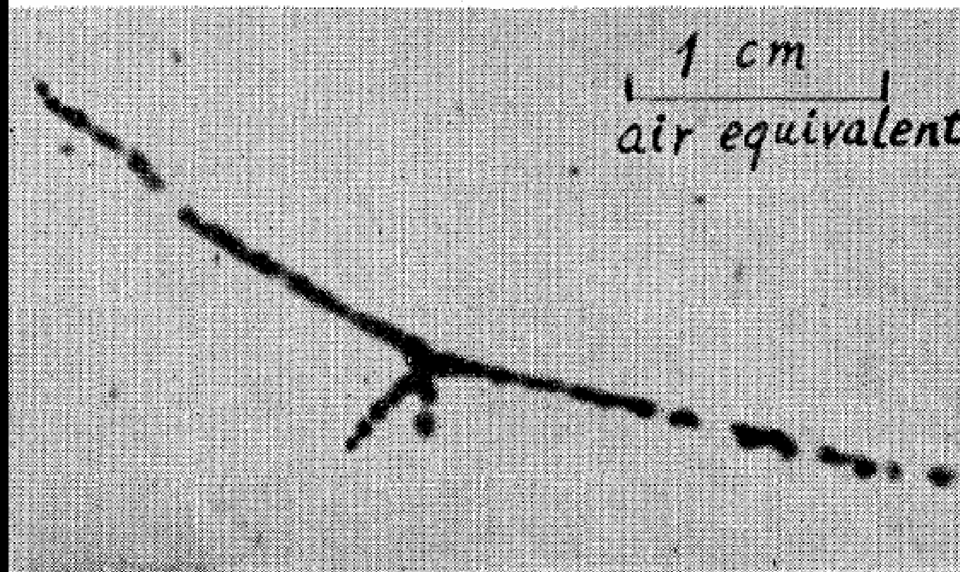


FIG. 4. Quaternary fission.

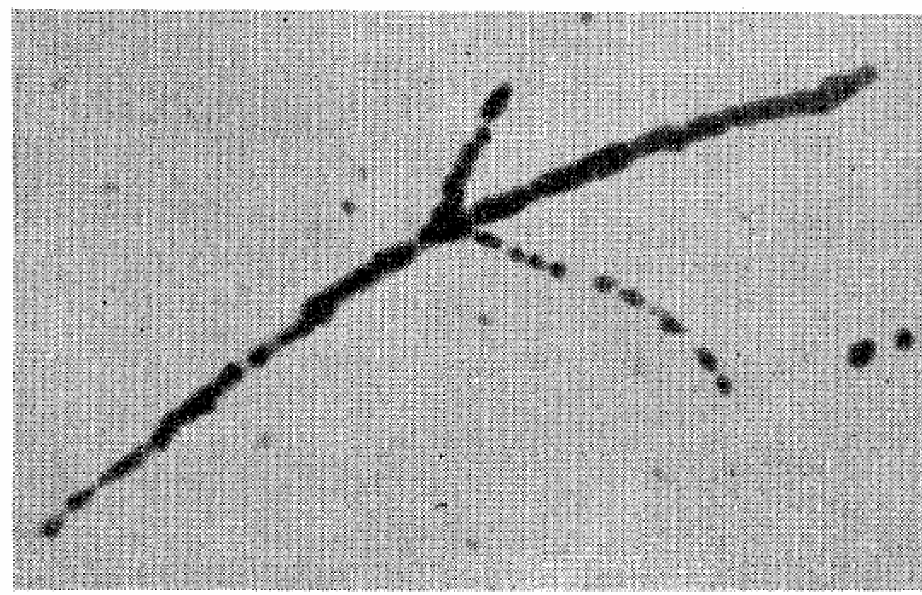


FIG. 5. Quaternary fission. (In same scale as Fig. 4.)

PHYSICAL REVIEW VOLUME 121, NUMBER 1 JANUARY 1, 1961

Tripartition in the Spontaneous-Fission Decay of Cf^{252}†

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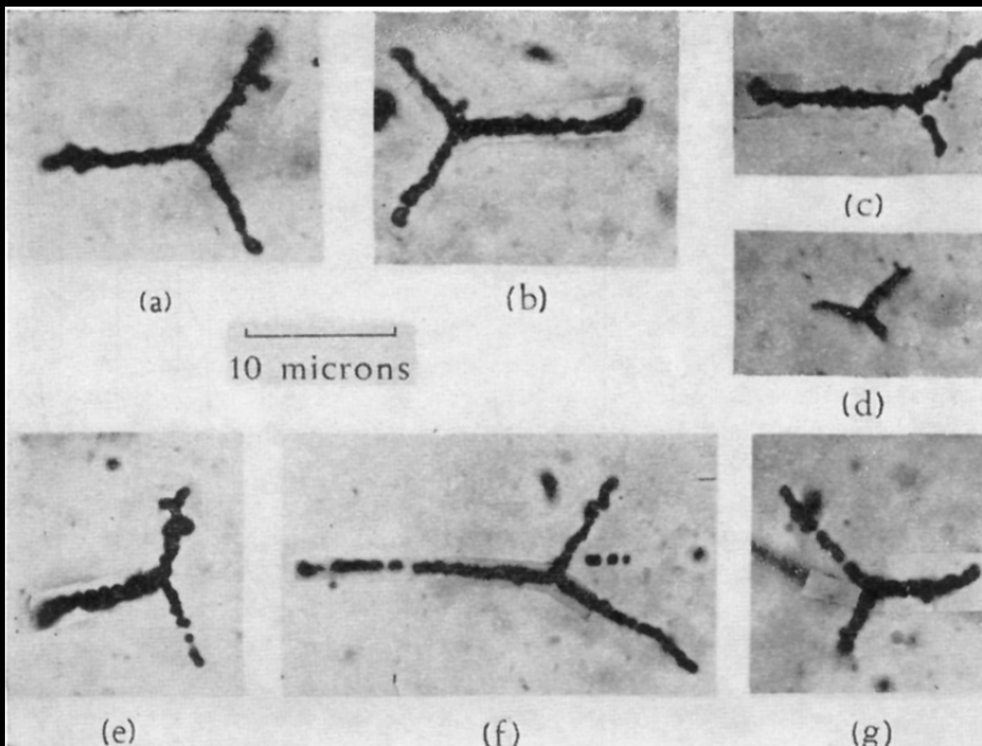
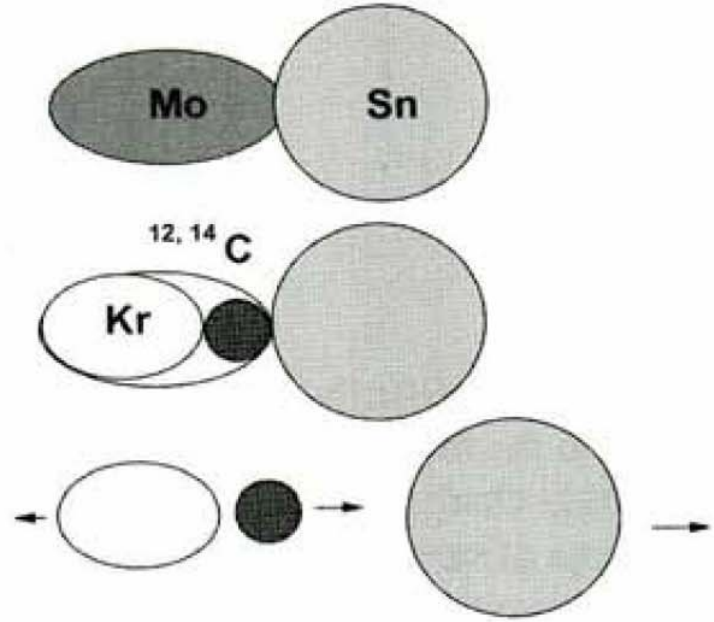


To make such a development purposeful it is necessary to focus on such a topical issue of nuclear physics the solution of which can be reduced to simple tasks of recognition and measurement of tracks in NTE to be solved with the aid of already developed programs. One of the suggested problems is a search for the possibility of a collinear cluster tri-partition. The existence of this phenomenon could be established in observations of such a type of ternary fission of heavy nuclei in which a lightest fragment is emitted in the direction of one of the heavy fragments.

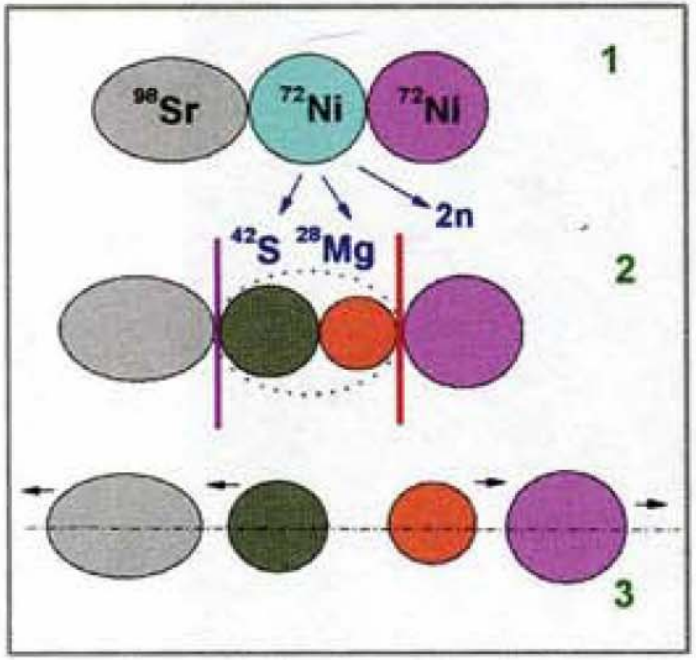
Despite distinct observability of fission fragments they can not be fully identified in NTE. However, NTE is valuable due to combination of the best angular resolution and maximum sensitivity. Besides, it is possible to measure the lengths and thicknesses of tracks, and, thus, to classify the fragments. As an initial stage, to provide statistics of ternary _ssions it is suggested to analyze a sufficient NTE area exposed to ^{252}Cf source with an appropriate density of tracks of α-particles and spontaneous fission fragments. Such an approach will be developed by a NTE with an admixture of the ^{252}Cf isotope. Another option is exposure of NTE manufactured with a ^{235}U isotope addition by thermal neutrons.

Fig. 6.19 Illustration of the scenario of collinear cluster tripartition



Of interest is 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 for search of molecular-like nuclear systems. Emission of fission fragments may prove 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 directions of emission of fragments of a collinear ternary fission.

Fig. 6.33 Presumable scenario of one mode of collinear multi-body decay



Before scission: chain of three magic clusters

Clustering of the middle nucleus, double rupture (sequential fission) which sets free the constituents (^{42}S, ^{28}Mg) of the middle molecule (^{72}Ni)

All the partners of the decay fly apart almost collinearly

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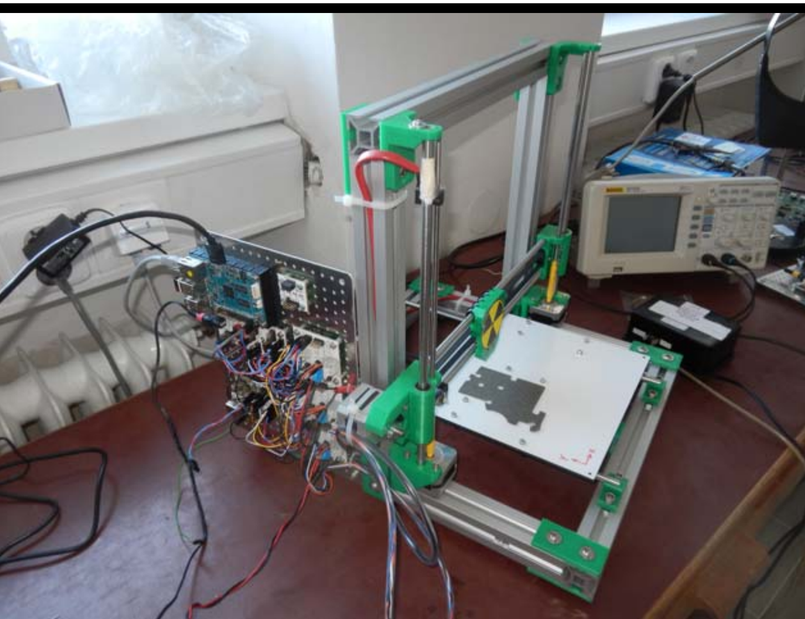
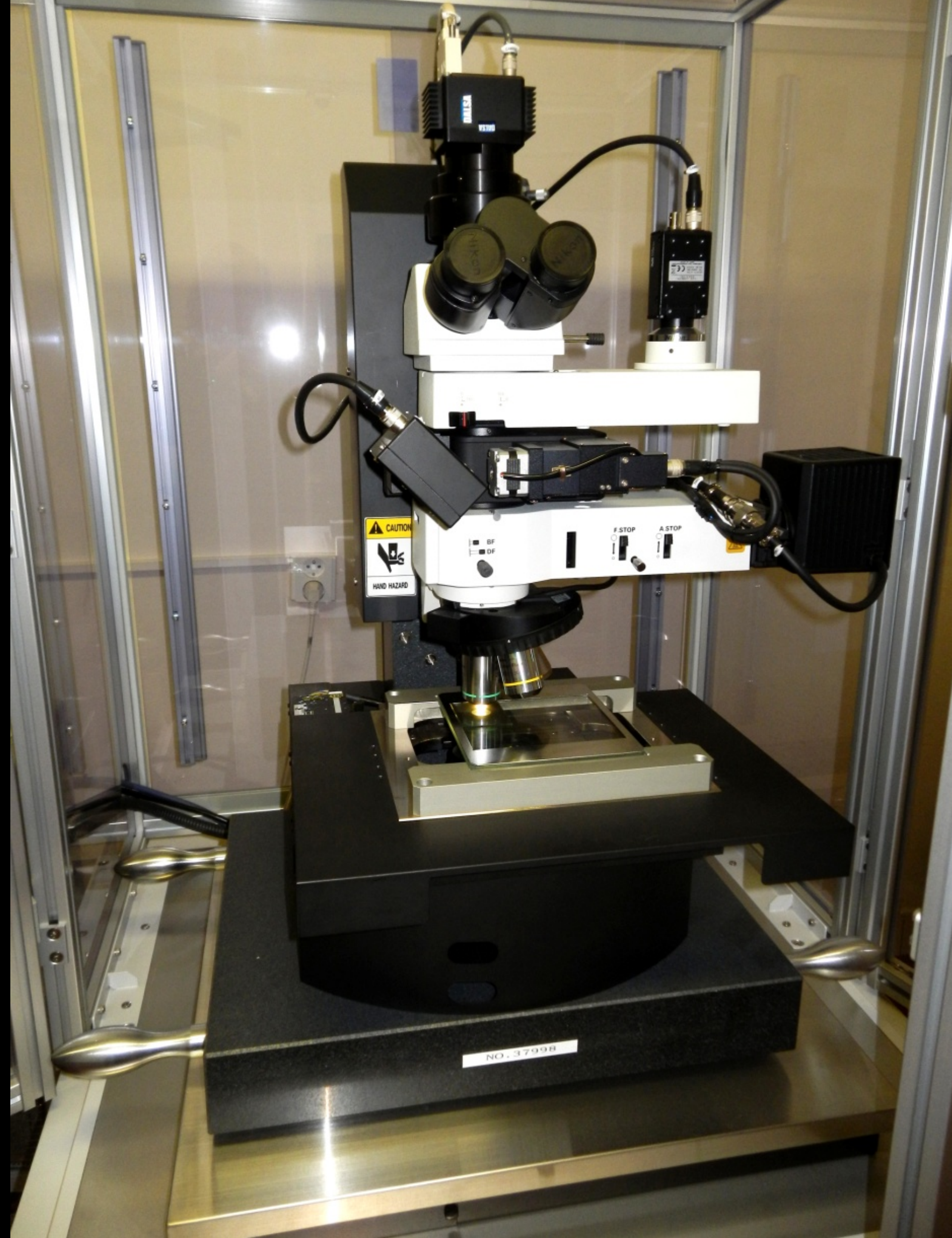
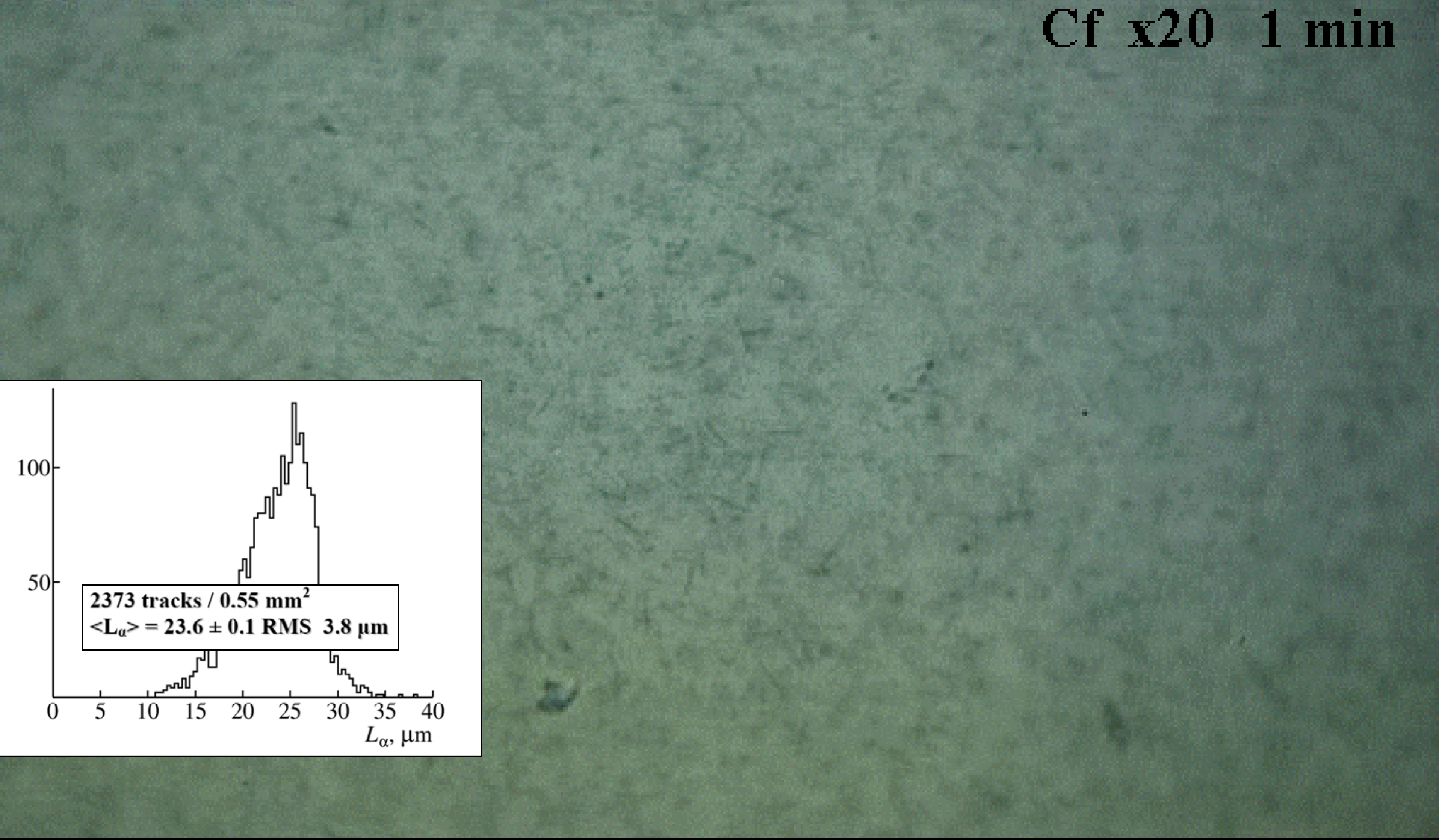
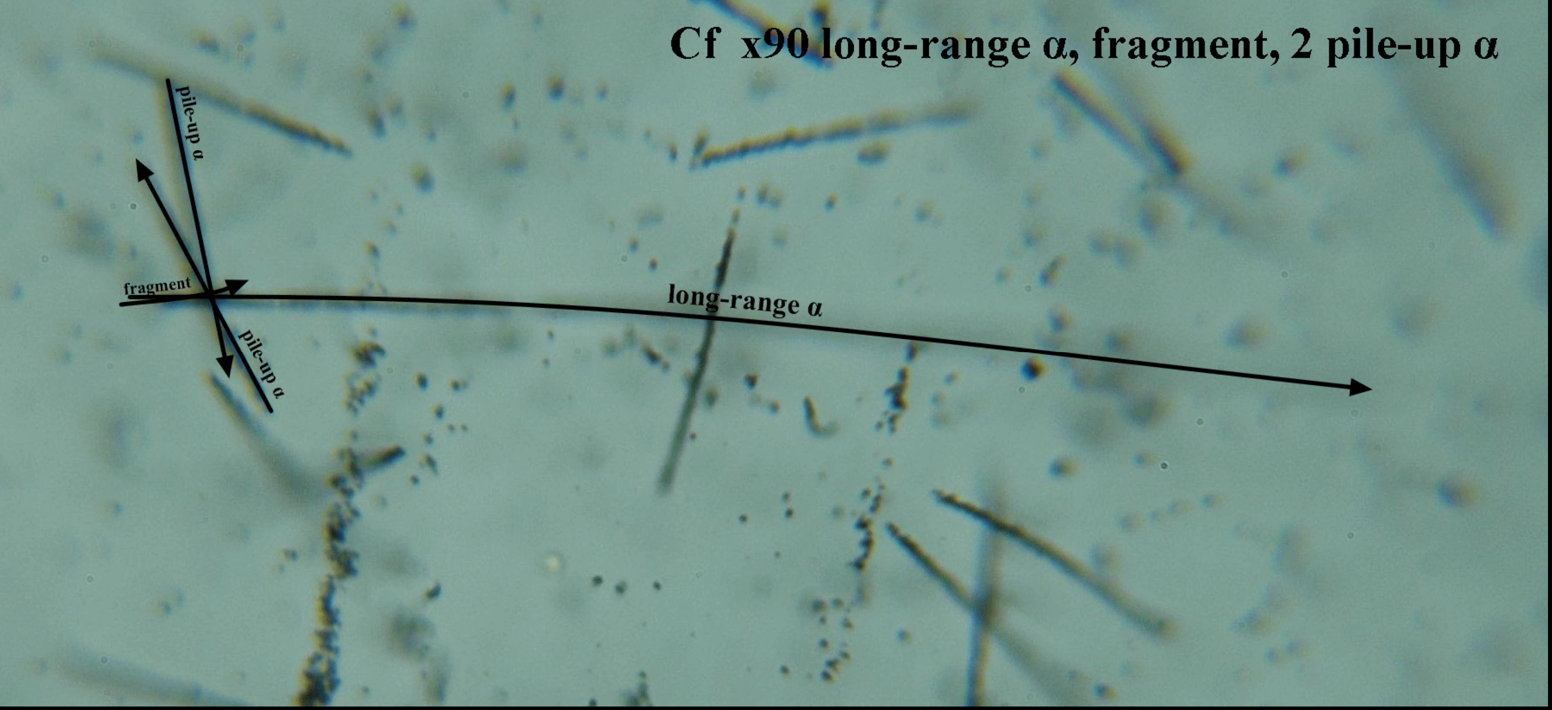
A large-scale NTE scanning is suggested to be performed on the microscope HSP-1000 of the Department of radiation dosimetry (DRD) of Nuclear Physics Institute of the Academy of Czech Republic. The use of the NTE resolution will be full if the microscope will be adapted to operate with lenses of the highest magnification. Development of algorithms for automatic search and analysis of short tracks of heavy ions in NTE will be required. On the experimental side, ion ranges in NTE must be calibrated in the α-decay and fission energy scale. Progress of the preparatory phase of the proposed study is summarized below.







Surface exposures of NTE samples in DRD were performed by a manually moving ^{252}Cf source. Most likely, the ^{252}Cf isotope decays by emission of α-particles of energy of 5-6 MeV, the tracks of which mainly populate an exposed sample. This isotope also undergoes a spontaneous fission to a pair or even triple of fragments with probabilities of 3%, and about 0.1%, respectively. For comparison an NTE sample was exposed to a ^{241}Am source emitting only α-particles in the same energy range. Since the ranges of decay products are small the source exposures are performed without a light protective paper in a darkroom when illuminated with red light.


Cf x90 long-range α, fragment, 2 pile-up α
pile-up α
fragment
long-range α
pile-up α


Cf x90 3 fragments,
long-range α

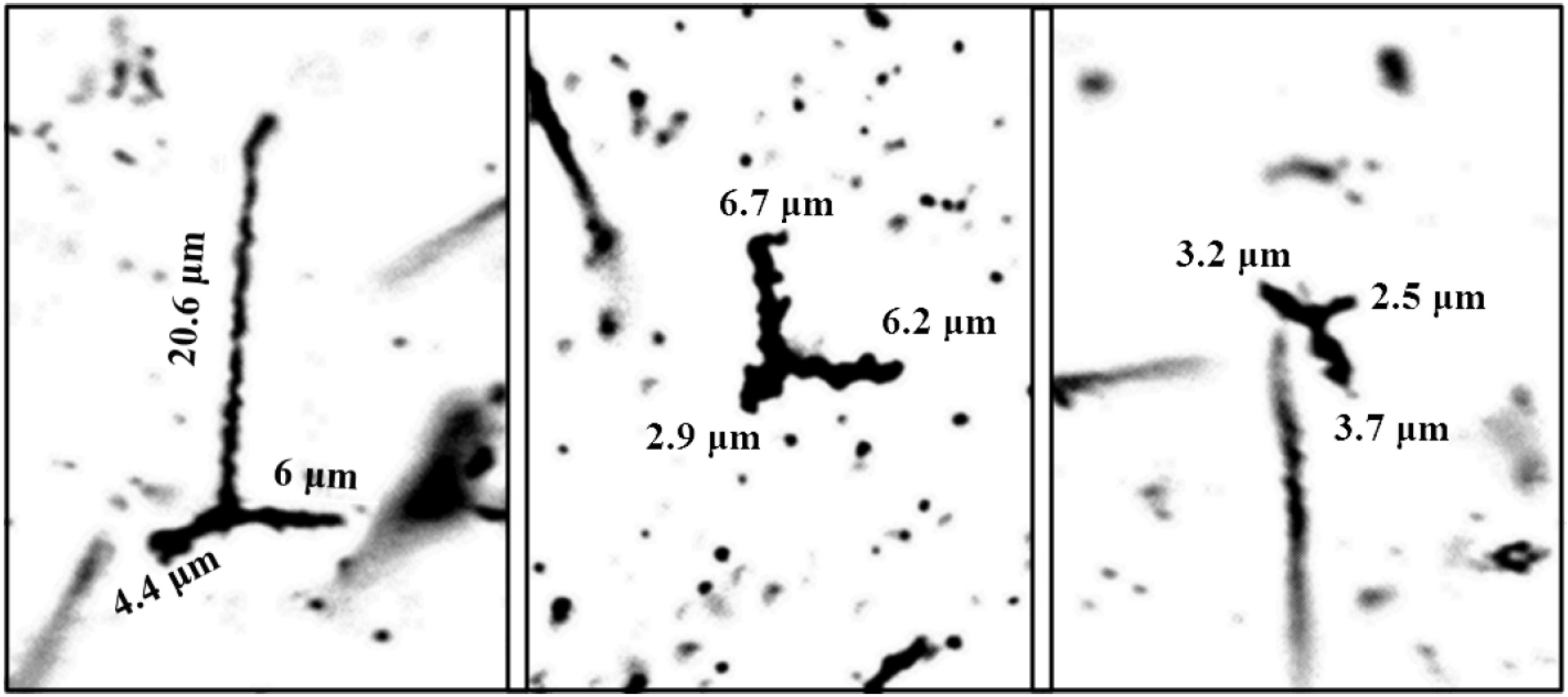


Figure 1. Examples of observed events of ternary fission; track lengths are specified. Left photo: long-range α-particle (long arrow), fragment (middle arrow). Mid and right photo: three fragment tracks.

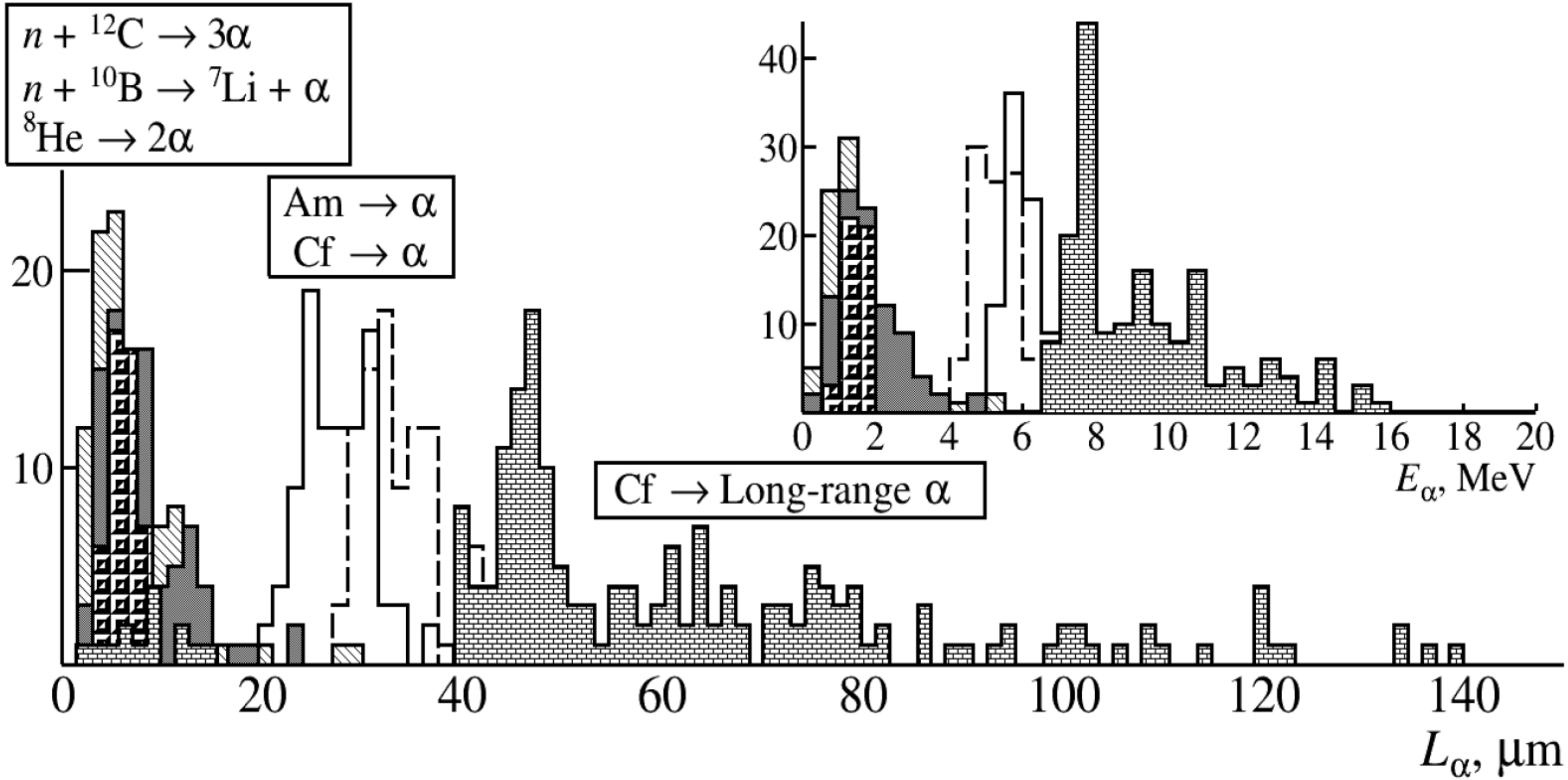
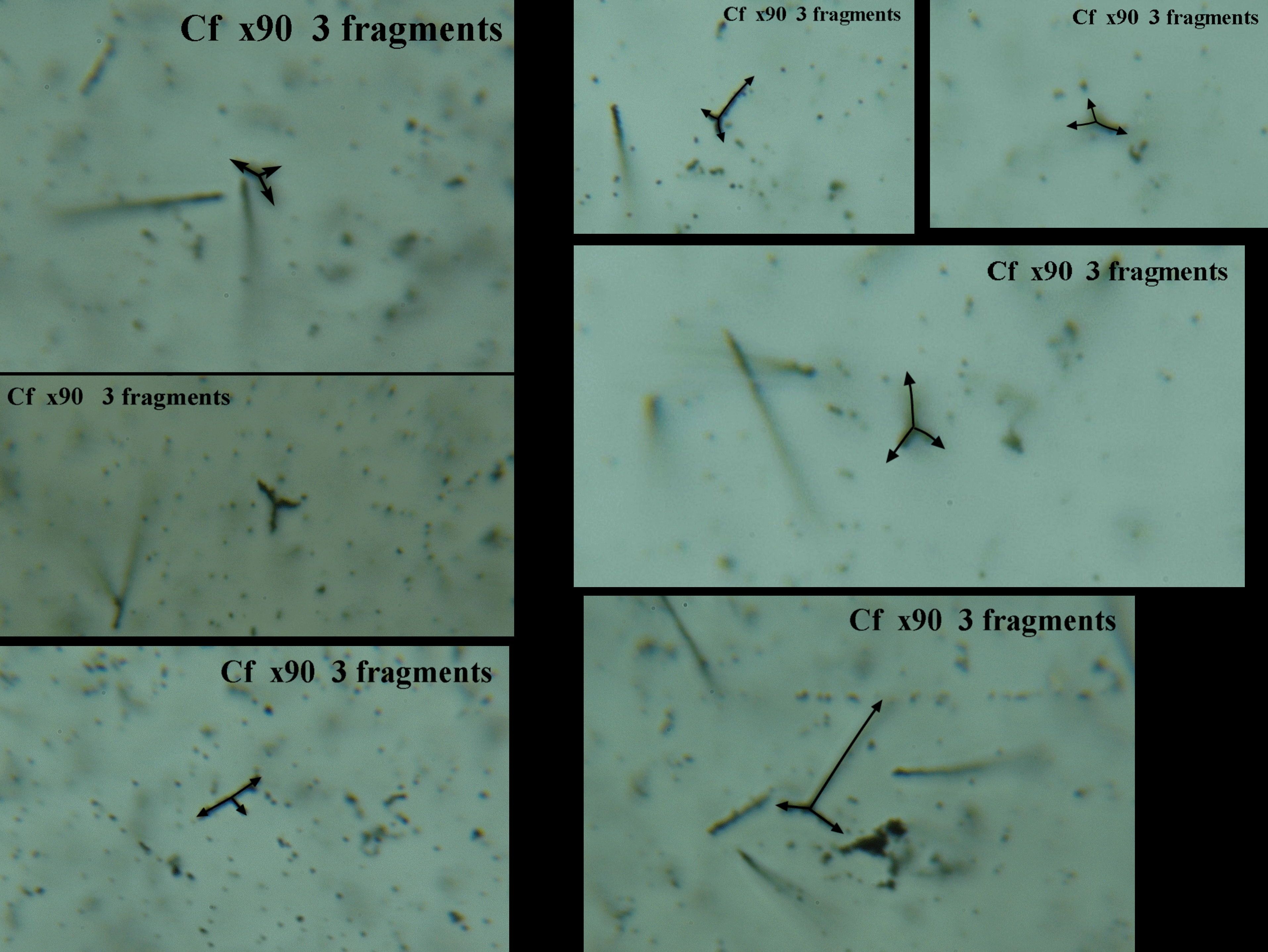


Fig. 1. Distributions of α-particle ranges: n(14.1 MeV) + $^{12}C \rightarrow 3\alpha$ (obliquely-shaded), $^{8}He \rightarrow 2\alpha$ (gray), n_{th} + $^{10}B \rightarrow {}^{7}Li + \alpha$ (black dot), Cf $\rightarrow \alpha$ (solid), Am $\rightarrow \alpha$ (dotted histogram), Cf $\rightarrow$ long-range α (brick-shaded); the inset: corresponding of α-particle energy estimated via spline-interpolation of range-energy calculations in the SRIM model.


Cf x90 3 fragments
Cf x90 3 fragments
Cf x90 3 fragments
Cf x90 3 fragments
Cf x90 3 fragments
Cf x90 3 fragments
Cf x90 3 fragments

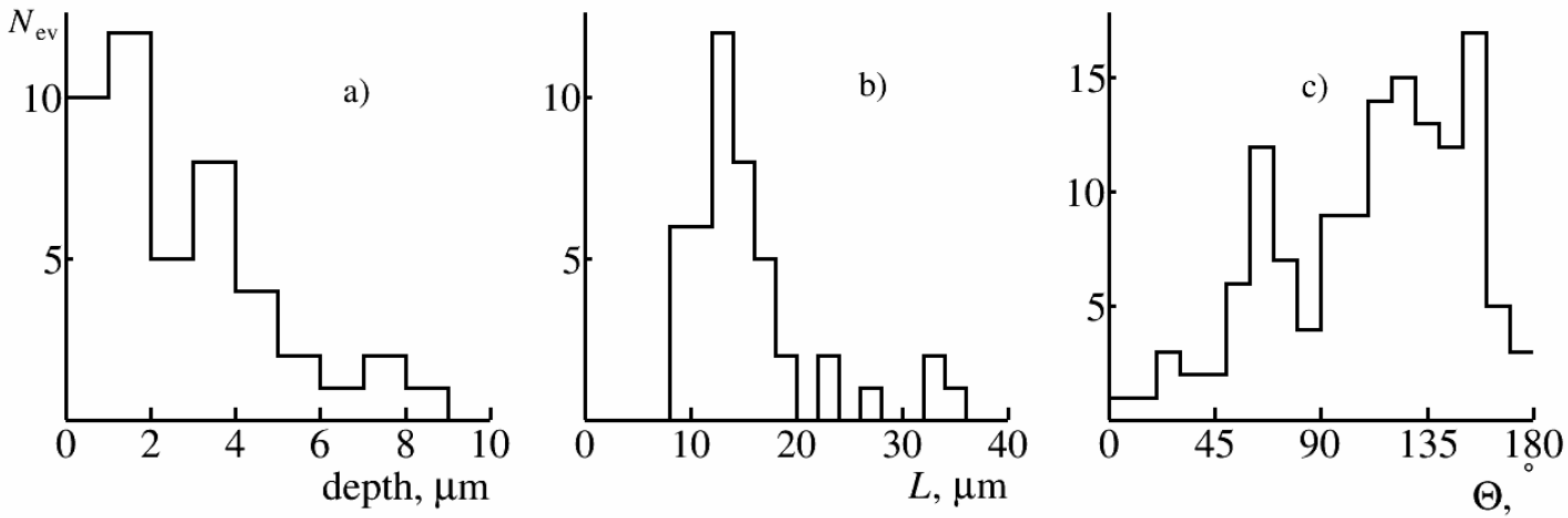


Figure 2. Distributions for the ^{252}Cf fissions into three fragments over depth in NTE layer (a), amount ranges of three fragments (b) and opening angles between fragments (c).

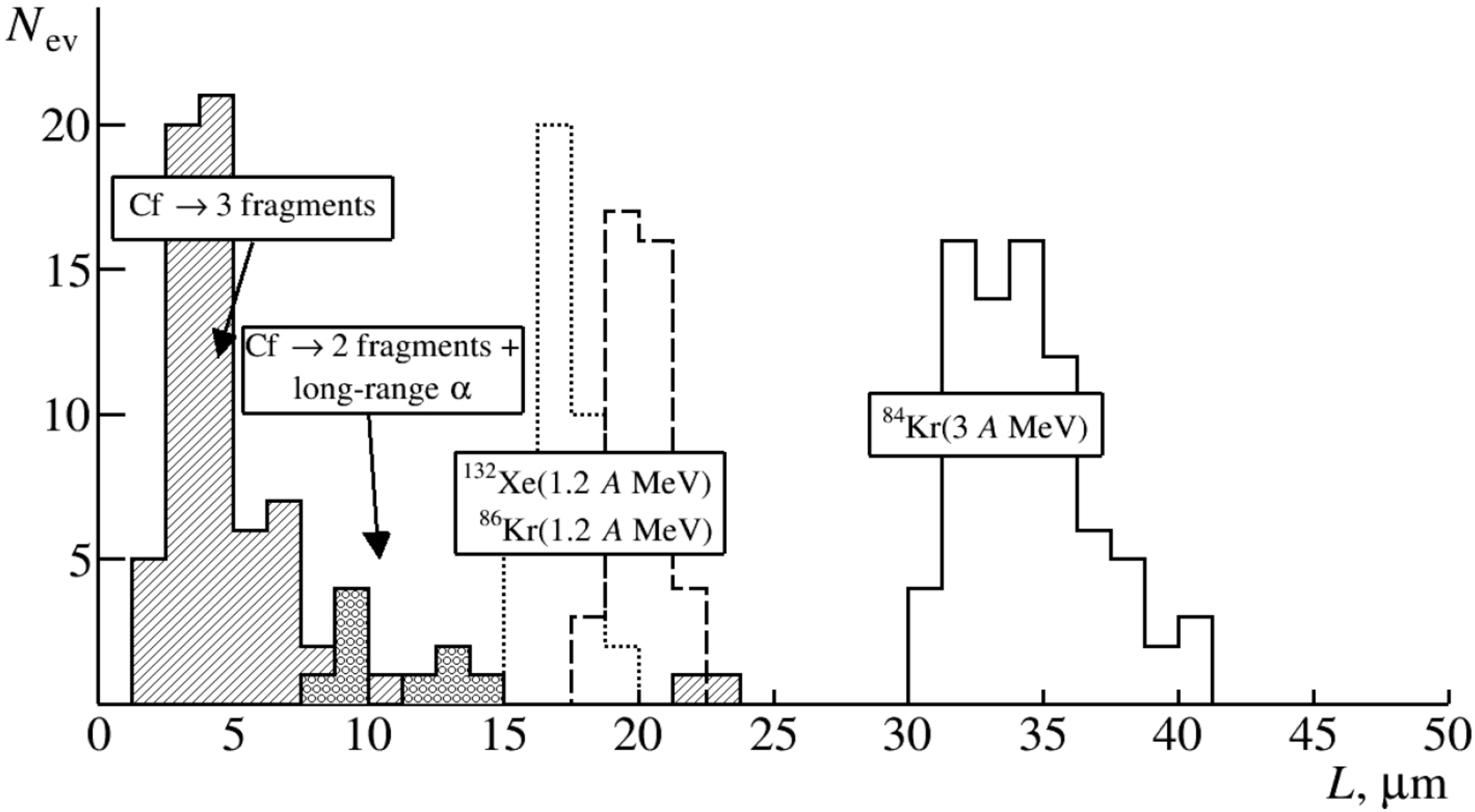
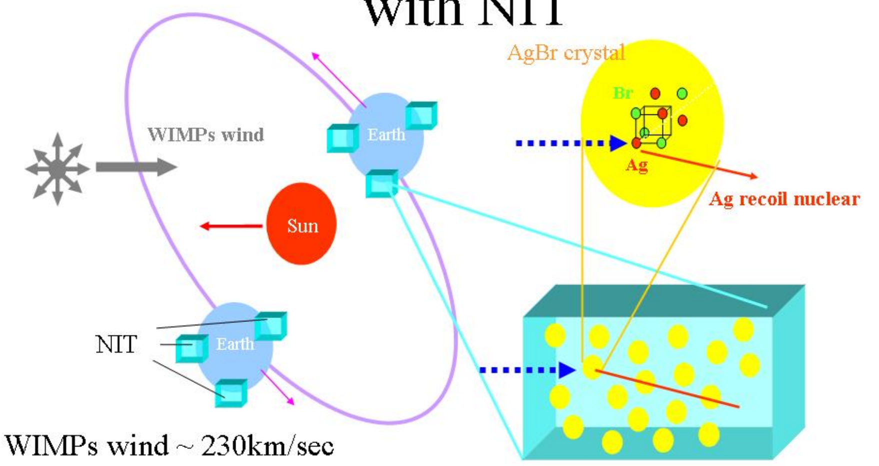


Fig. 2. Distributions of ranges of ions ^{86}Kr, ^{132}Xe, ^{84}Kr and in decays Cf → 3 fragments and Cf → 2 fragments + long-range α.

Principle for Detection of WIMPs with NIT



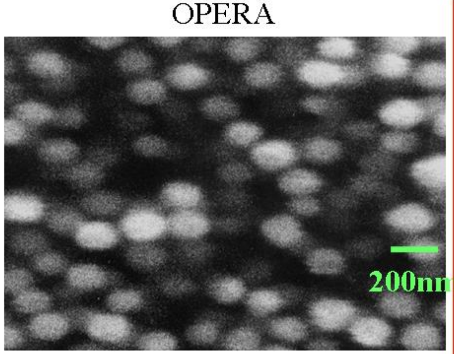
WIMPs wind ~ 230km/sec

Recoil energy ~ 100keV

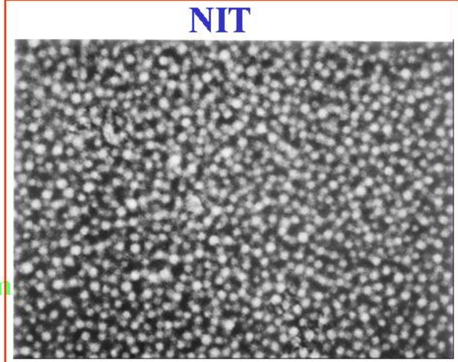
Range of recoil nuclear ~ 100nm

(if WIMPs mass ~ 100GeV)

High resolution emulsion (Nano Imaging Tracker:NIT)



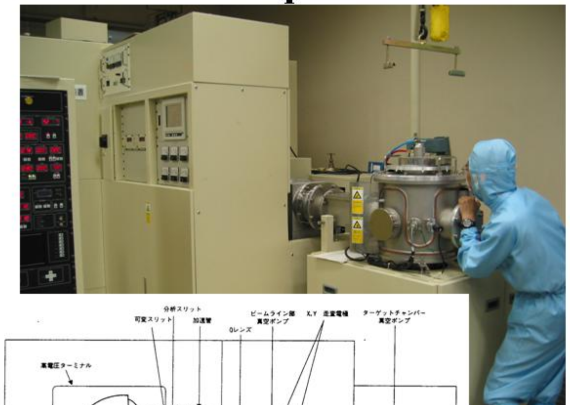
OPERA:AgBr crystal size ~200nm
2.3 AgBr/μm

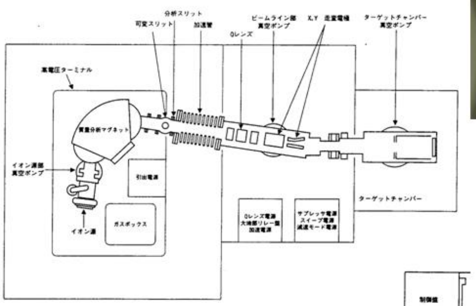


NIT:AgBr crystal size ~40nm
11 AgBr/μm

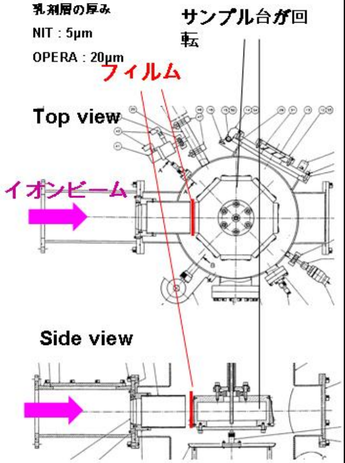
5 times resolution for OPERA!

Recoil nuclear test of NIT ⇒implant low velocity Kr ion





サイズ　7cm×3cm
乳剤層の厚み
NIT : 5μm
OPERA : 20μm

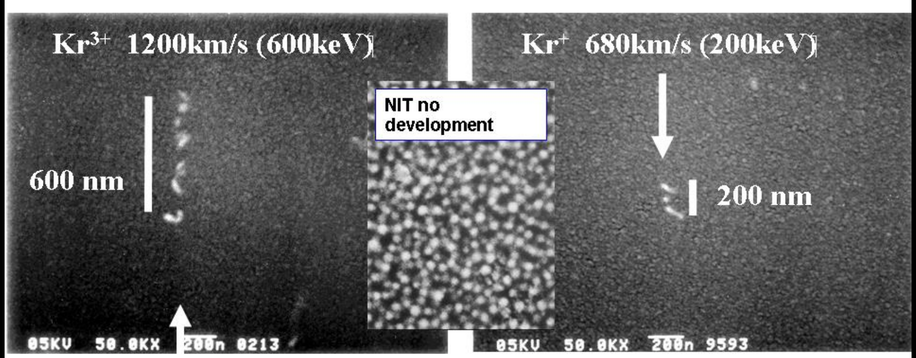


チェンバーの真空はそのままに
７つのサンプルに照射できる

Tracking test by low velocity Kr

Supposition **Br** recoil

SEM image



Conclusions

The stated task of analyzing extremely rare events of the ternary fission is reduced to finding planar triples of nuclear fragments. Beginning at a common vertex and being randomly directed their tracks should have an extent of from 1 to 10 μm. Computer analysis of images will allow one to select the decays for a perfect manual analysis.

Automation of search for ternary fission events will drastically reduce the most time-demanding stage and will help to focus the manual analysis on already found events. Thus, manual and automatic analyses complement each other.

When the time of the NTE exposure is controlled the computer analysis can be applied in a desired scale and the diversity of tracks with estimation of ion energy, both to ion beam profilometry and to α-dosimetry with random track directions.

In general, the synergy of modern radioactive sources, NTE proven metrology and advanced microscopy seems to be a promising prospect for α-radioactivity and nuclear fission research. It can be assumed that ions of transfermium elements will be implanted some when in NTE. Their bright decays can be found as common vertices of few α-particles and fission fragments. This perspective emphasizes the fundamental value of preservation and modernization of the NTE technique.

Thus, the present study focused on the NTE return in practice of nuclear experiment will serve as a prototype of solution of an impressive variety of problems. Macro photos of the discussed exposures and videos based on them are available on the BECQUEREL project website.