Pattern recognition of images
in nuclear emulsion and solid detectors experiments

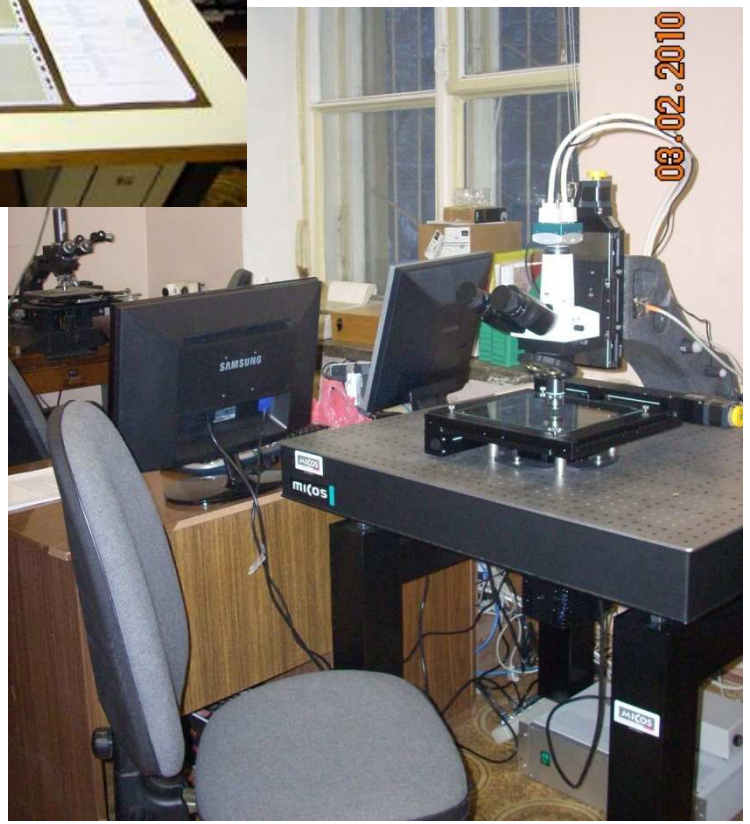
on PAVICOM facility

N. Starkov, Lebedev Physical Institute
Laboratory of elementary particles

PAVICOM 2
(X=12 cm, Y=10 cm)

PAVICOM 1
(X=80 cm, Y=40 cm)

PAVICOM 3
(OPERA)

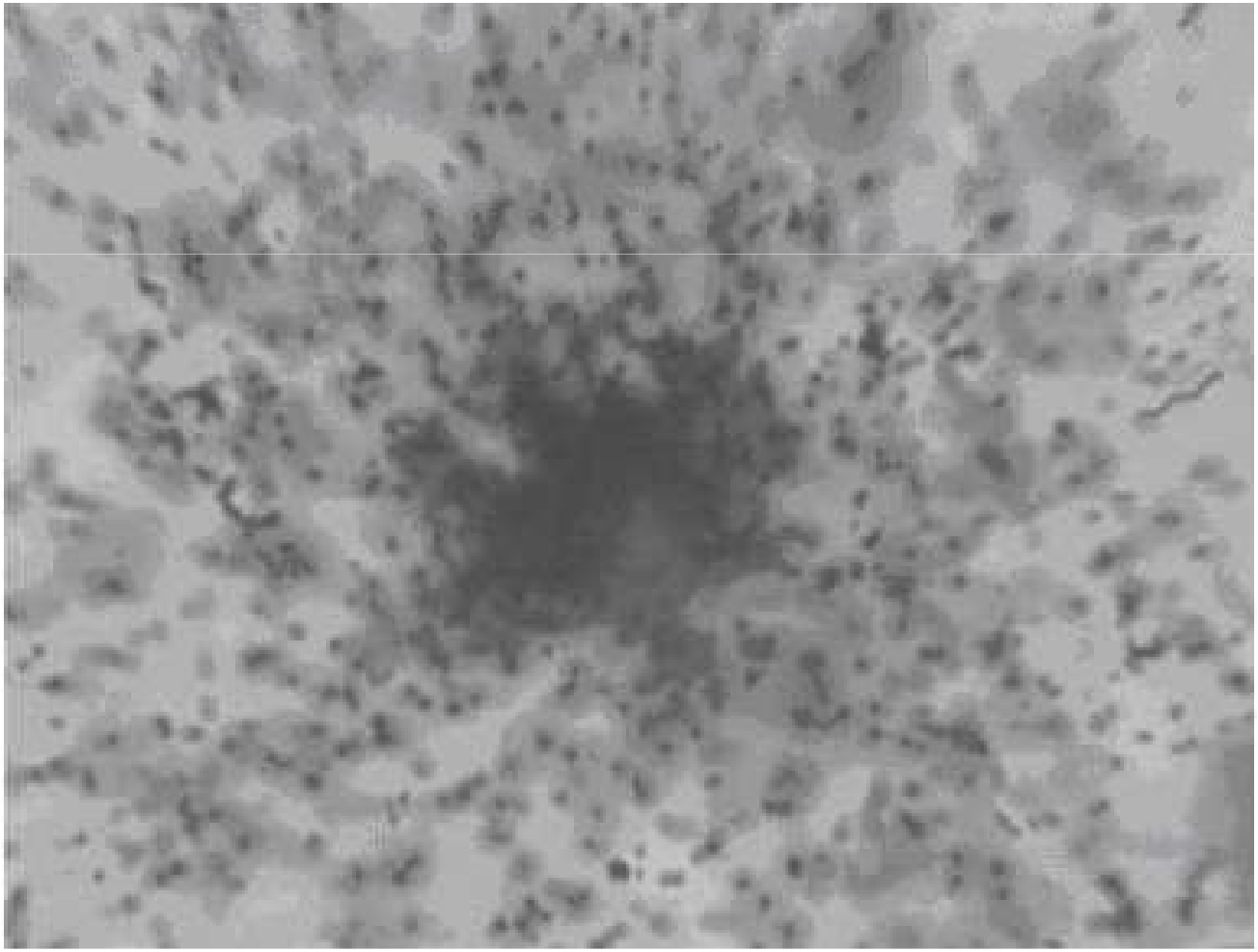


EMU-15.

Pb+Pb(fixed) 158 GeV/A (CERN SPS).

Multiplicity is about 1000 particles.

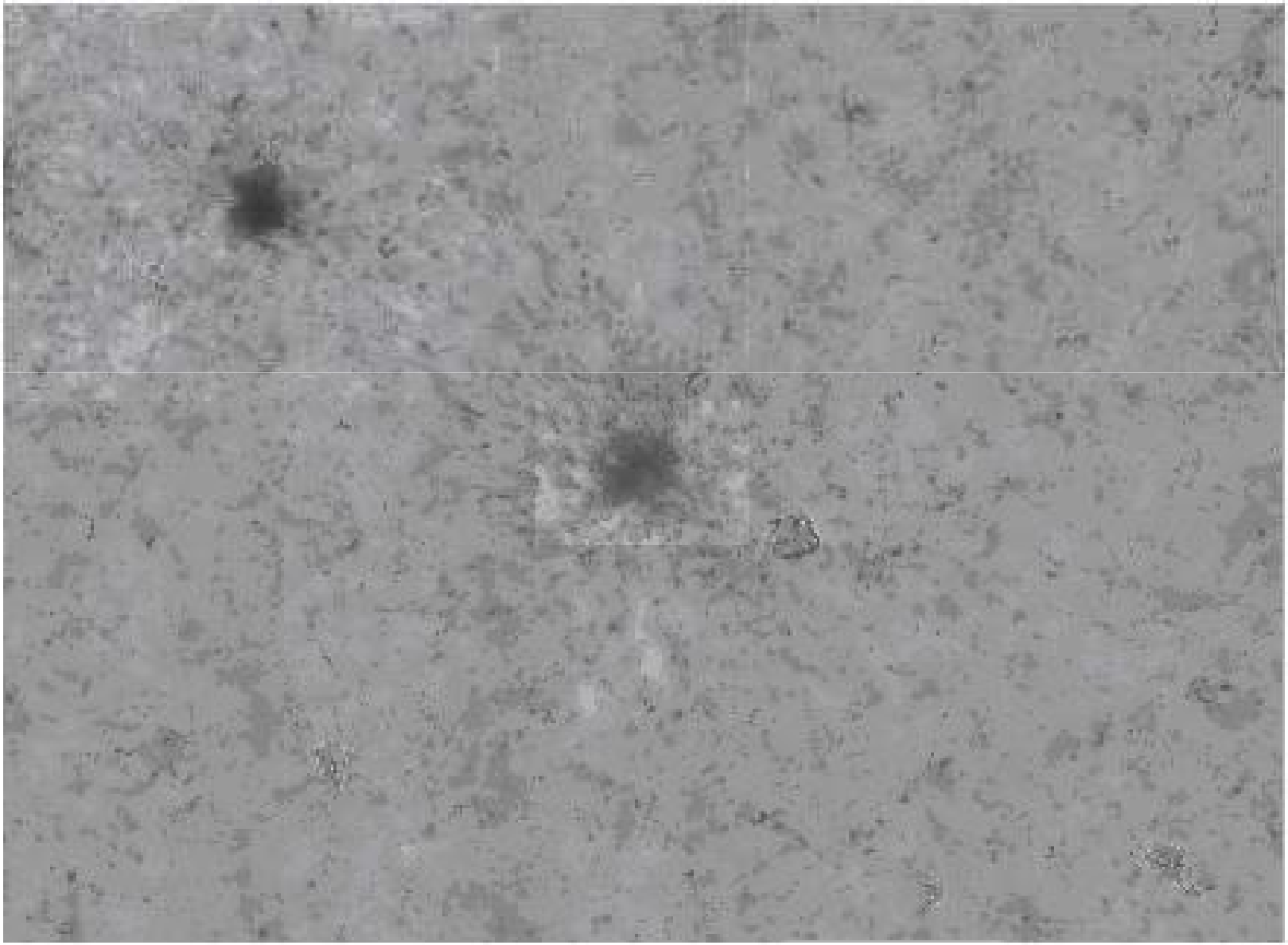
Central field of view



25 fields of view

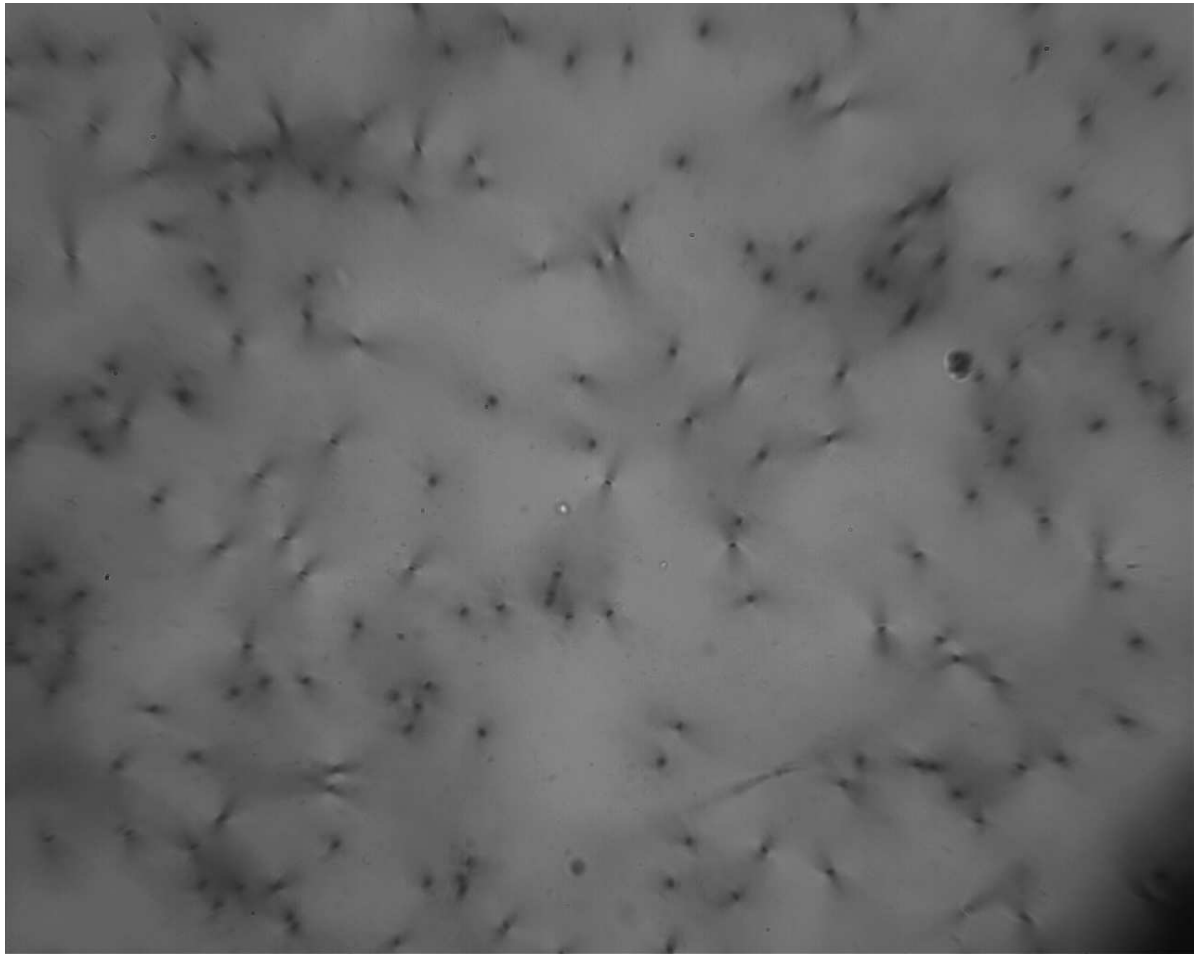
(track reconstruction, rapidity distribution)

60x80 mcm



Interaction of ^{6}He (E=60-20 МэВ) in emulsion

(tracks reconstruction, looking for of vertexes, kinematics)
320x280 mcm

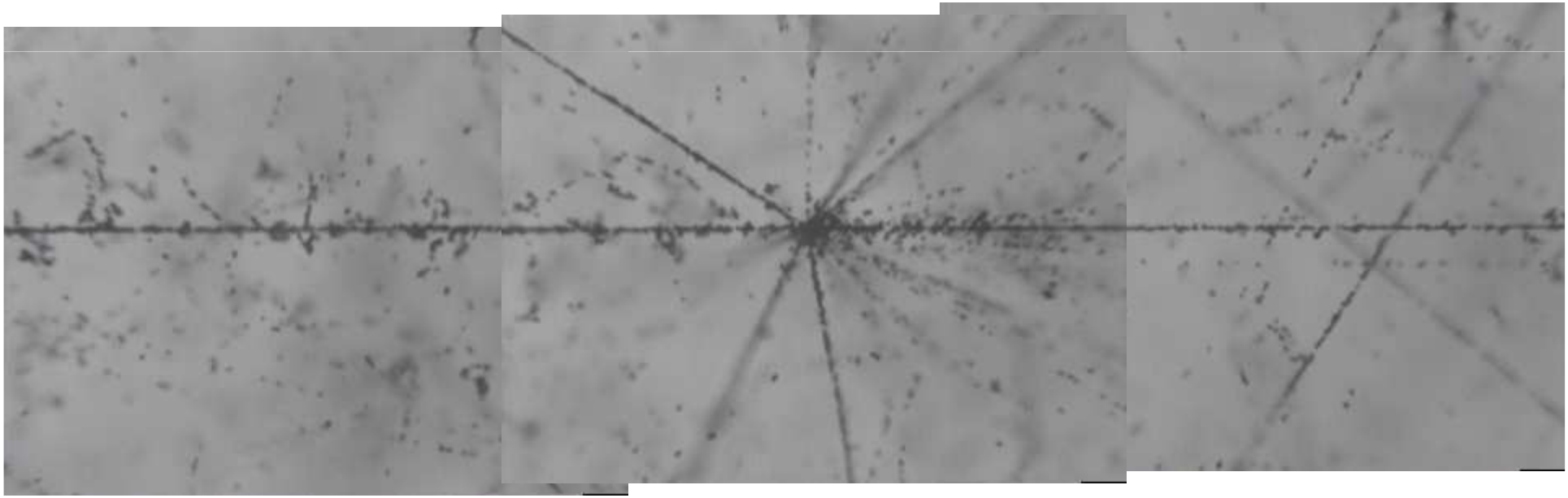


Trace of relativistic nucleus in thick emulsion

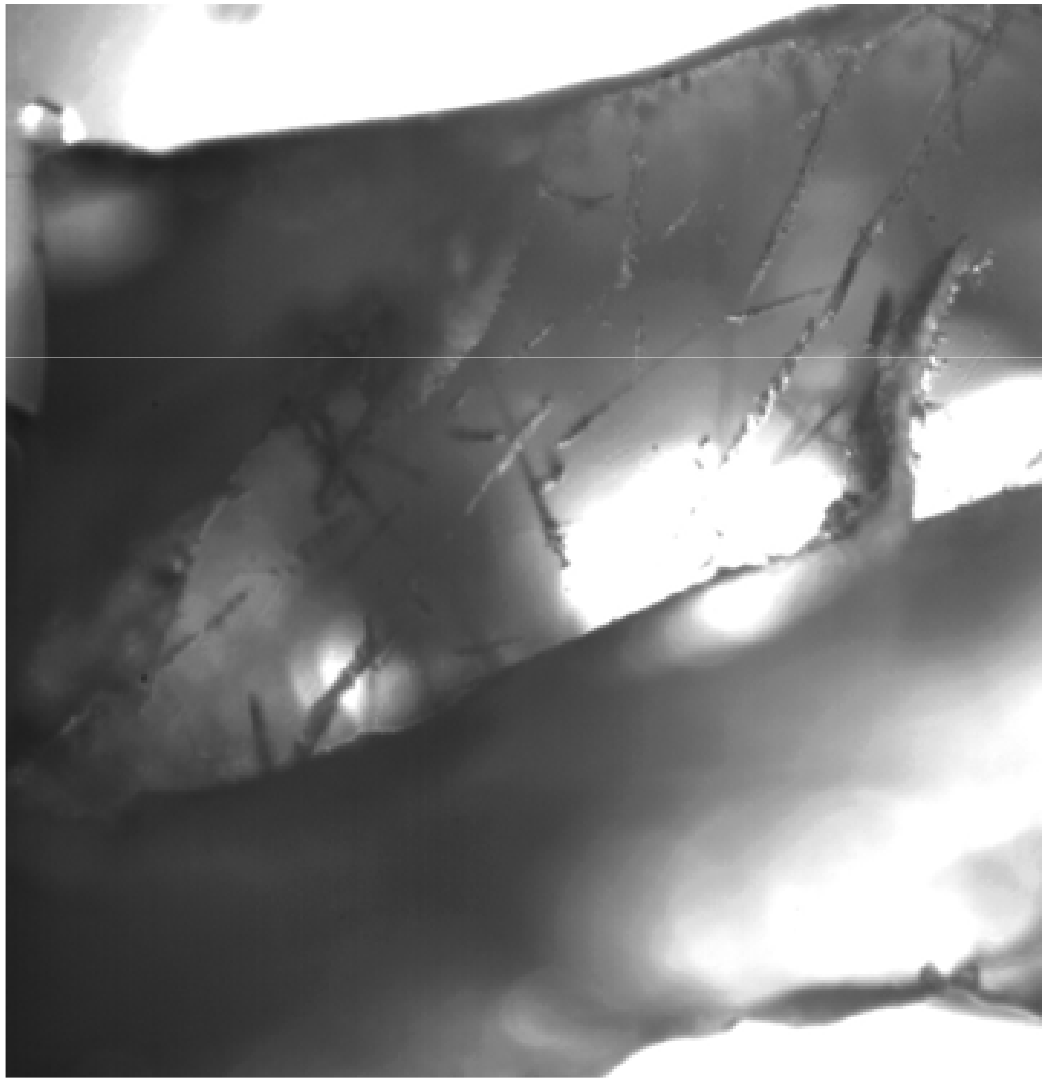
(thickness is 600 mcm)

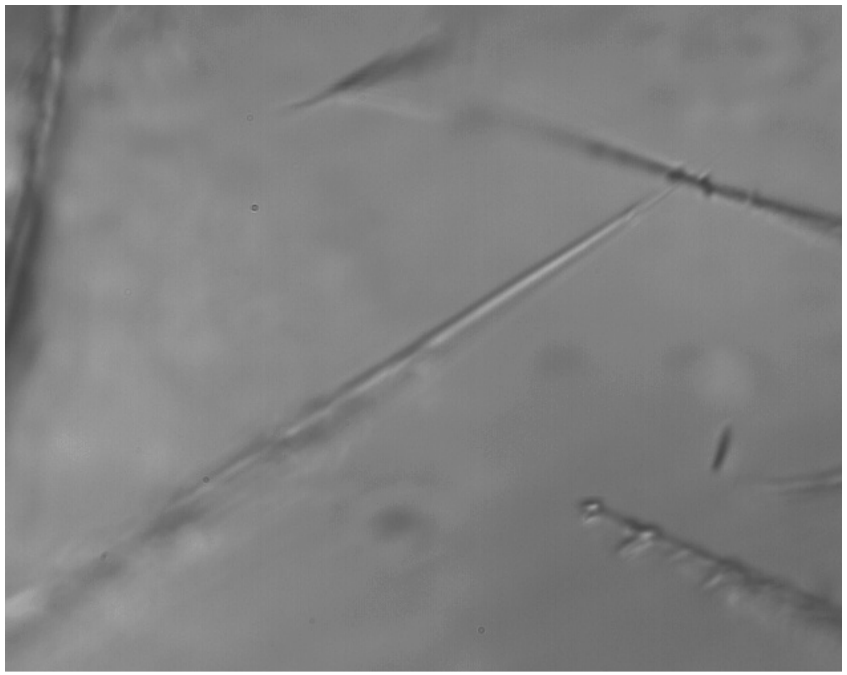
(definition of track characteristics and charge
of relativistic nuclei)

magnification is 40x



OLIMPIYA
Looking for of super heavy nuclei traces in olivine from meteorites
(track reconstruction, charge evaluation)

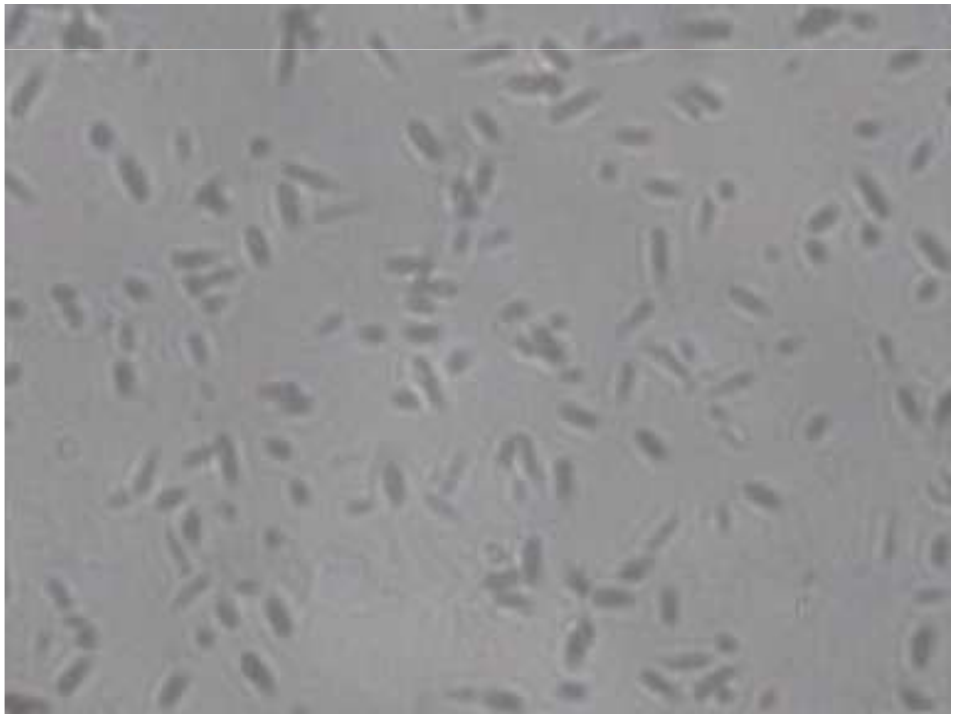


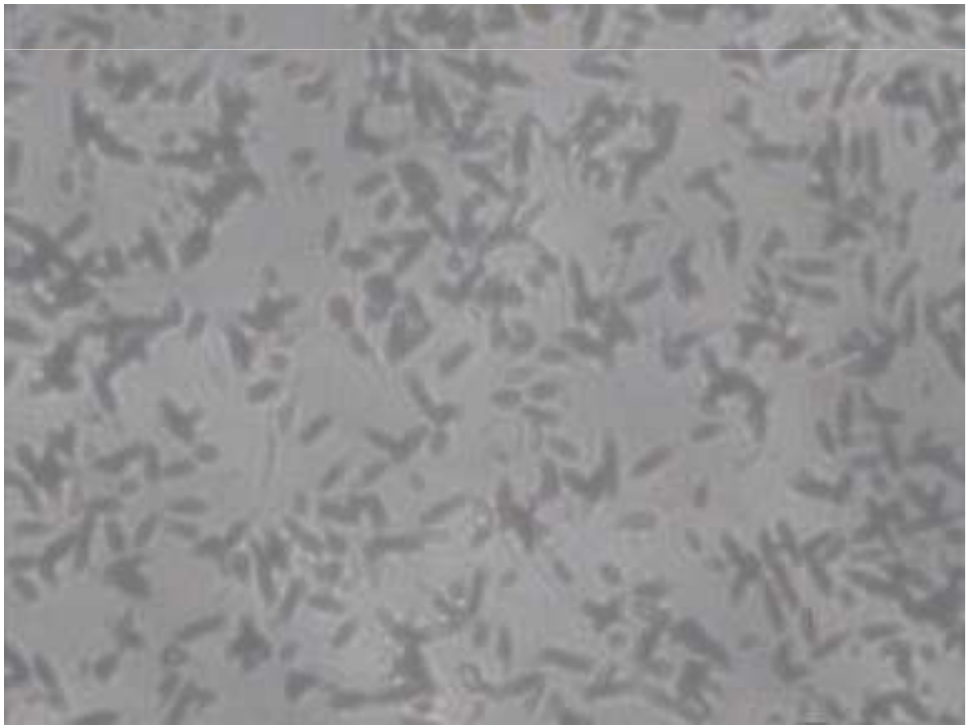


ENERGY+TRANSMUTATION

(evaluation of neutron flux using plastic detectors)

magnification is 20x

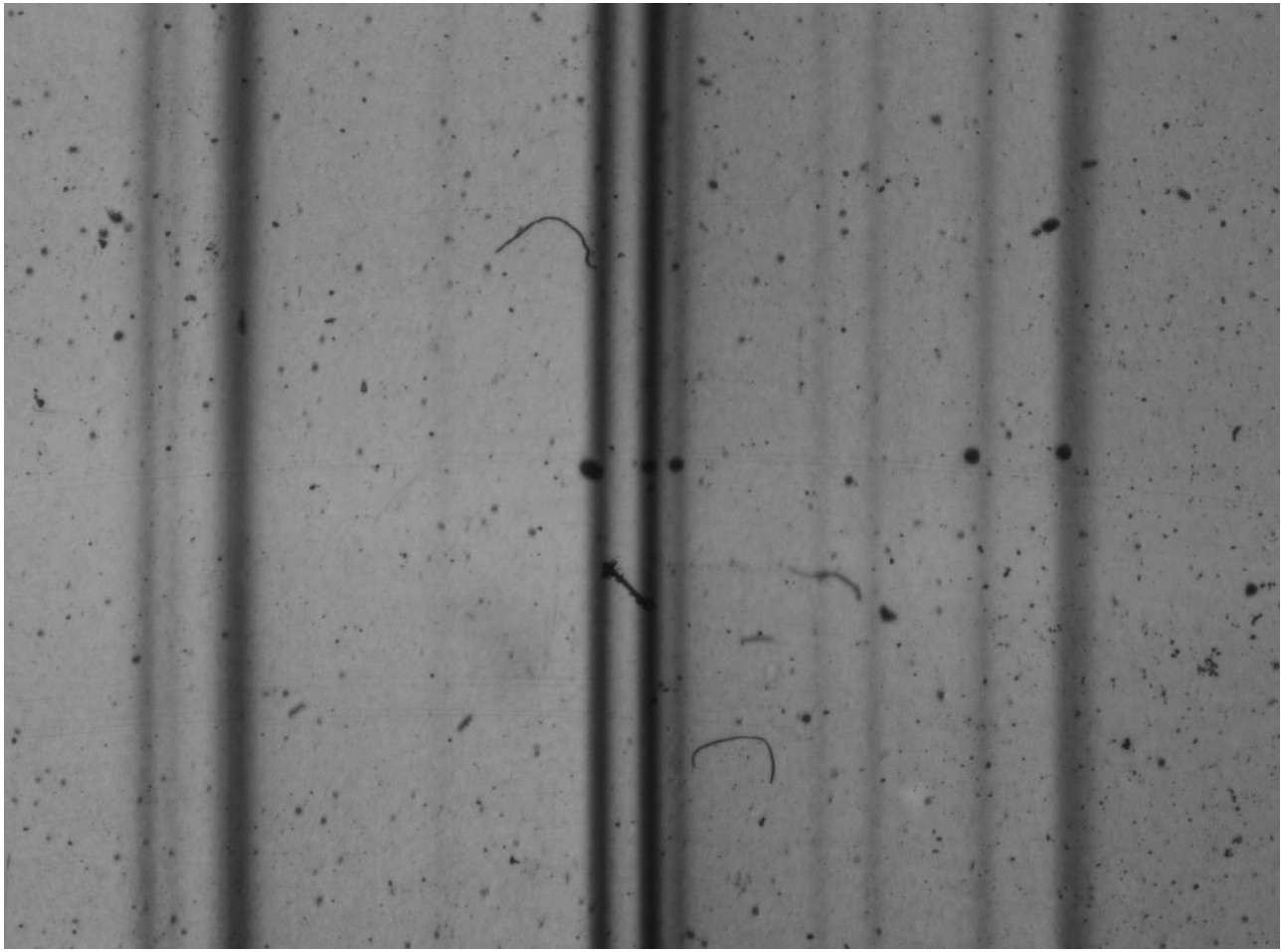




Investigation of inner conversion electrons of lanthanide nuclei

(line identification, looking for new lines)

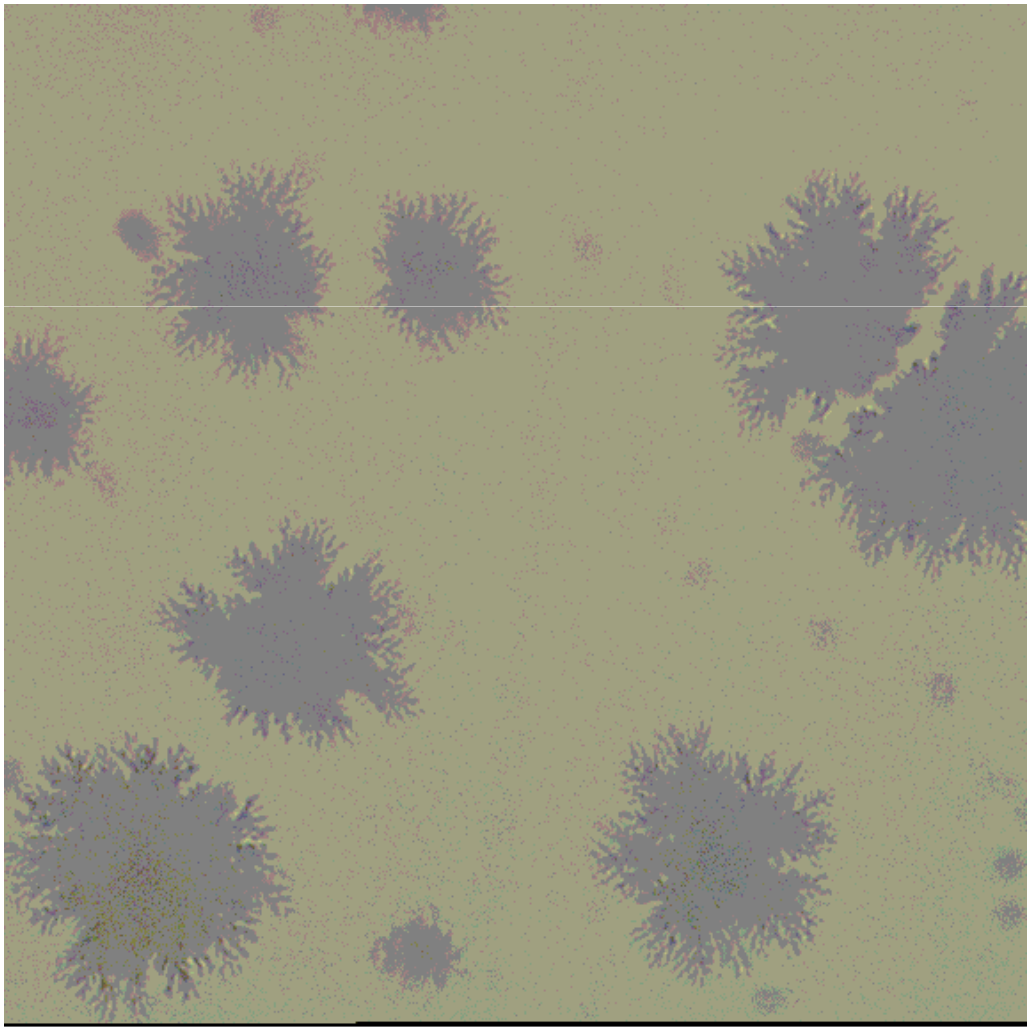
magnification is 8x



Traces of alpha particles in plastic after electro-chemical etching

(calculation of tracks number)

500x500 mcm



The list of image processing stages

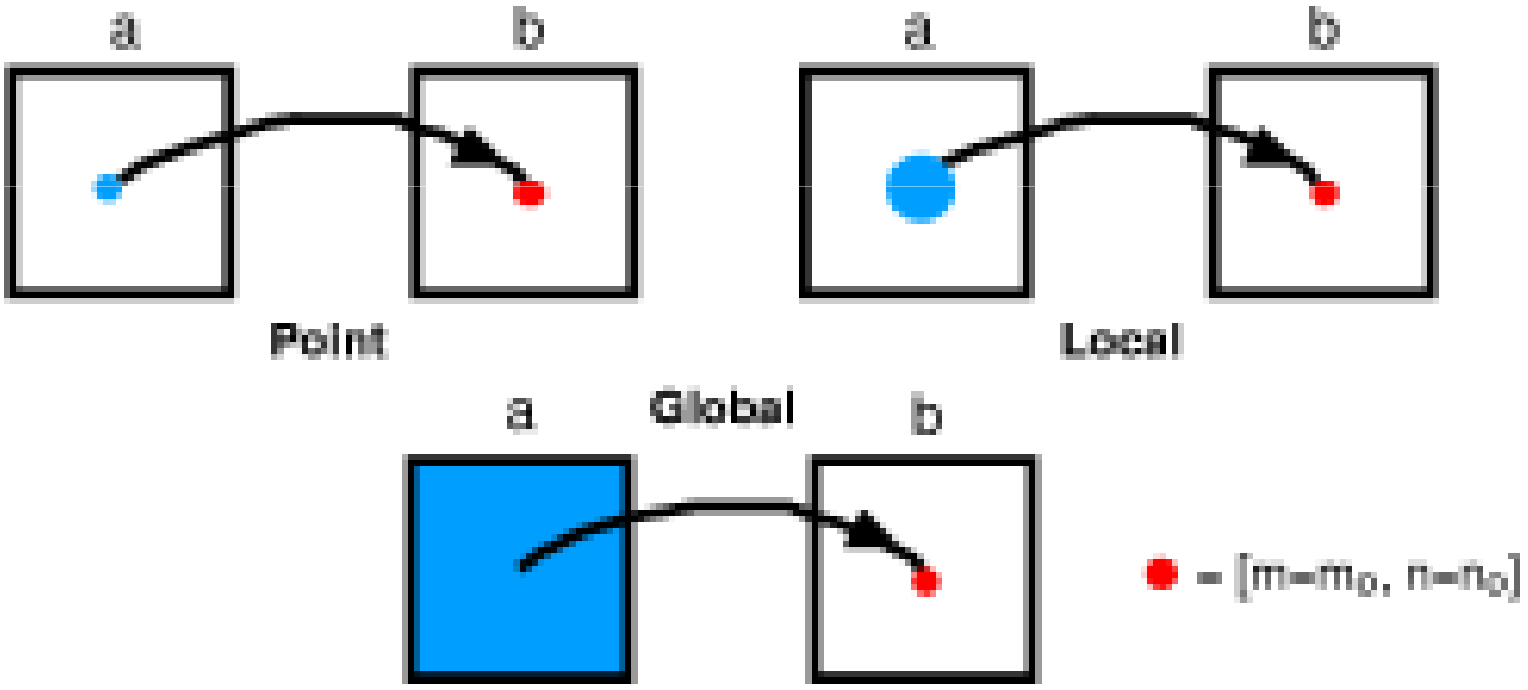
1. Preliminary transformation (filtering, logical operations, histogram analysis and go on).

2. Clustering (extraction, characteristics calculations).

3. Division of clusters into classes (tracking and other).

4. Informative analysis according to physical task.

Three kinds of preliminary image transformation



Linear filters:

$$P'_{mn} = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} P_{mn} \cdot h_{m-i,n-j}$$

Smoothing

$$h_{cinc}[j,k] = \frac{1}{21}\begin{bmatrix} 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 0 \end{bmatrix} ; \frac{1}{81}\begin{bmatrix} 1 & 2 & 3 & 2 & 1 \\ 2 & 4 & 6 & 4 & 2 \\ 3 & 6 & 9 & 6 & 3 \\ 2 & 4 & 6 & 4 & 2 \\ 1 & 2 & 3 & 2 & 1 \end{bmatrix}$$

Laplasian

$$[\mathbf{h}] = \begin{vmatrix} -1 & -2 & -3 & -2 & -1 \\ -2 & 2 & 5 & 2 & -2 \\ -3 & 5 & 20 & 5 & -3 \\ -2 & 2 & 5 & 2 & -2 \\ -1 & -2 & -3 & -2 & -1 \end{vmatrix}$$

Gradient

1. Usual

$$[\mathbf{h}_x] = \frac{1}{3}\begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$

$$[\mathbf{h}_y] = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}$$

2. Sobel's

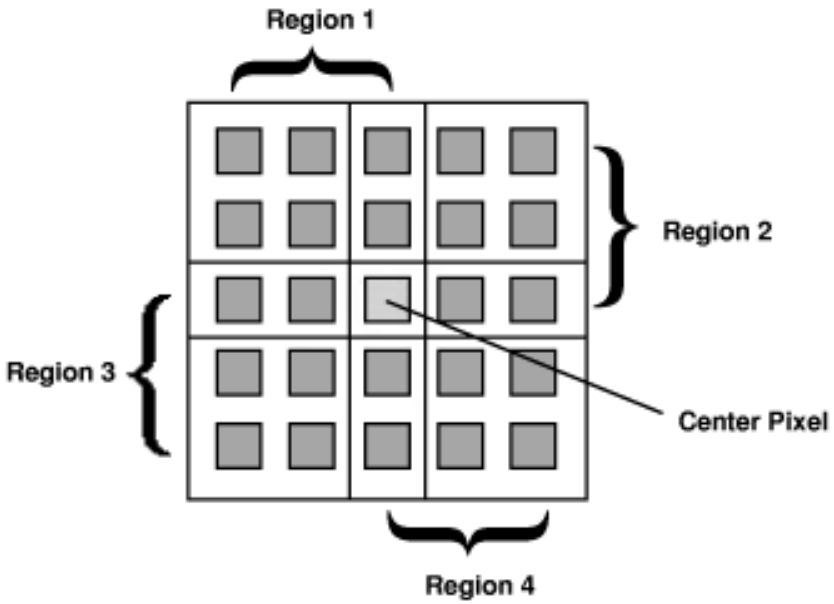
$$[\mathbf{h}_x] = \frac{1}{4}\begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

$$[\mathbf{h}_y] = \frac{1}{4}\begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

Nonlinear transformation

$$T_{ij}^{new} = T_{ij}^{old} + K_{br} \cdot F_{br}(T_{ij}^{old})$$ Brightness,

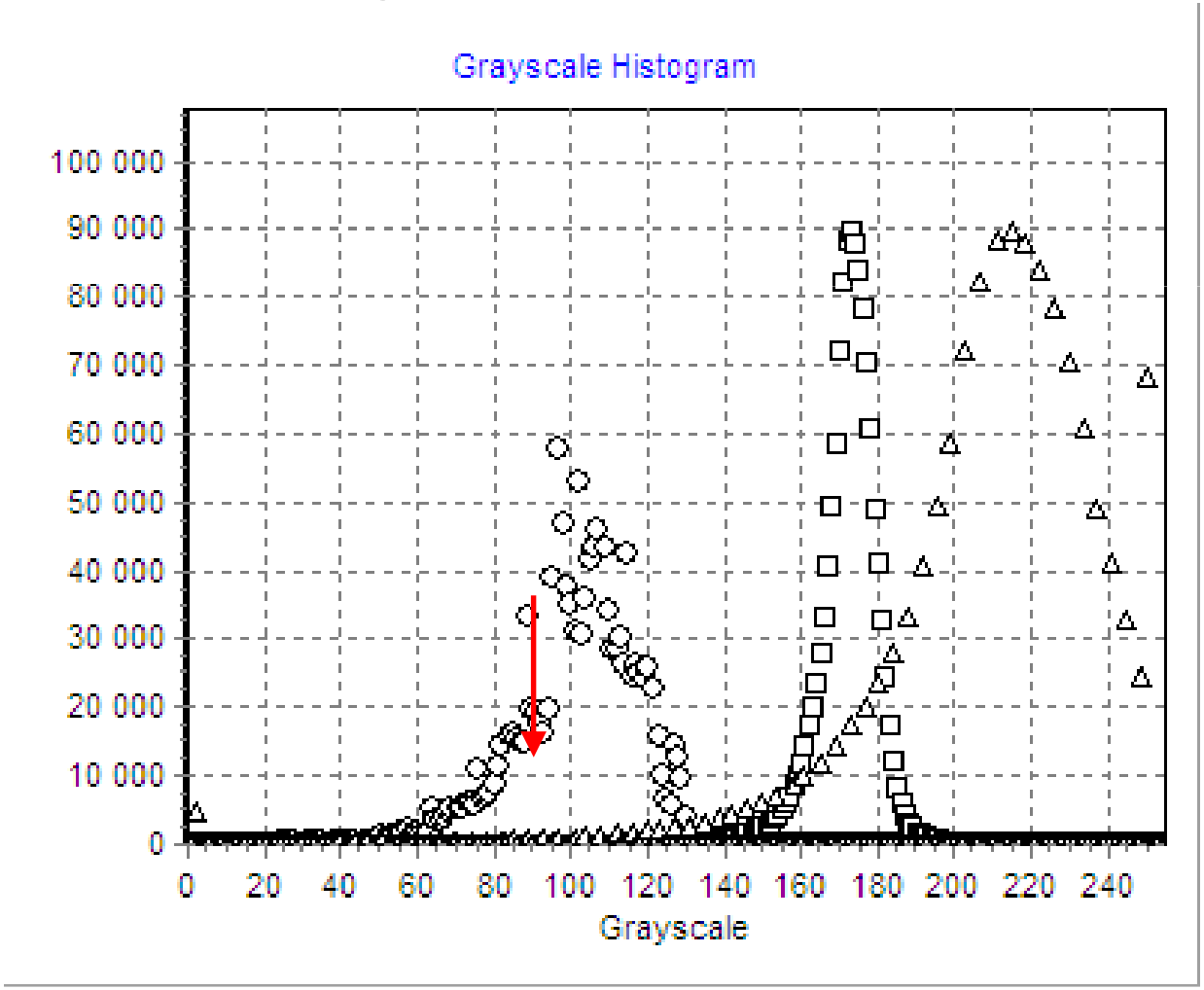
$$T_{ij}^{new} = T_{ij}^{old} + K_{con} \cdot F_{con}(T_{ij}^{old} - T^{fix})$$ Contrast



Kuwahara's nonlinear filtre

Brightness histogram (^{6}He):

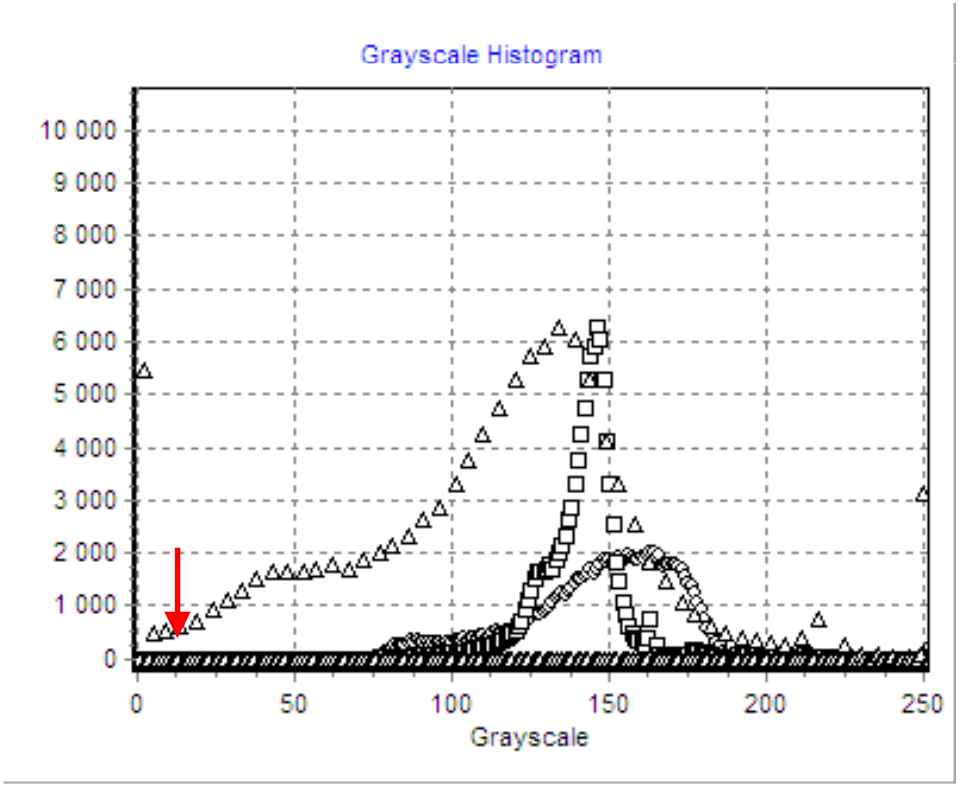
circle - initial image,
rectangle – after filtering,
triangle – after filtering and contrast.



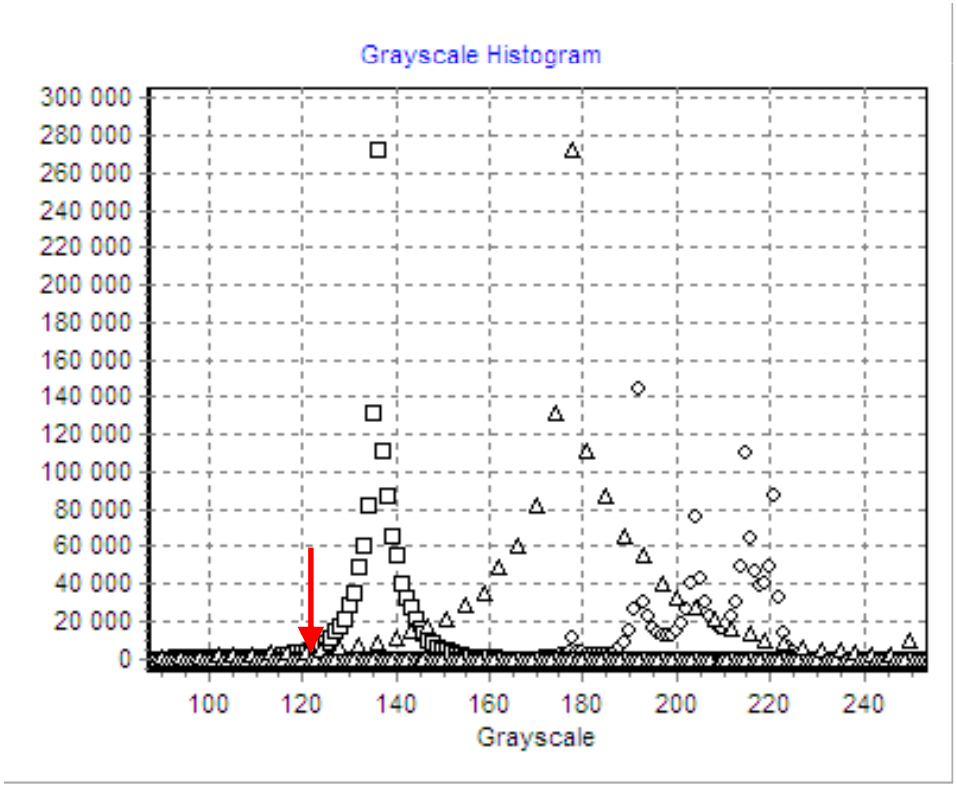
Brightness histogram

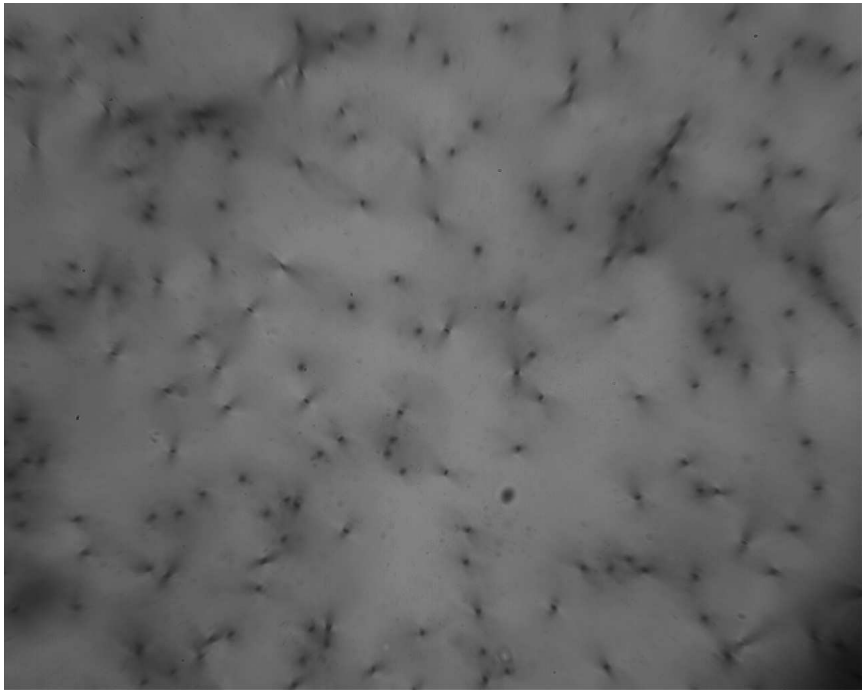
circle - initial image,
rectangle – after filtering,
triangle – after filtering and contrast.

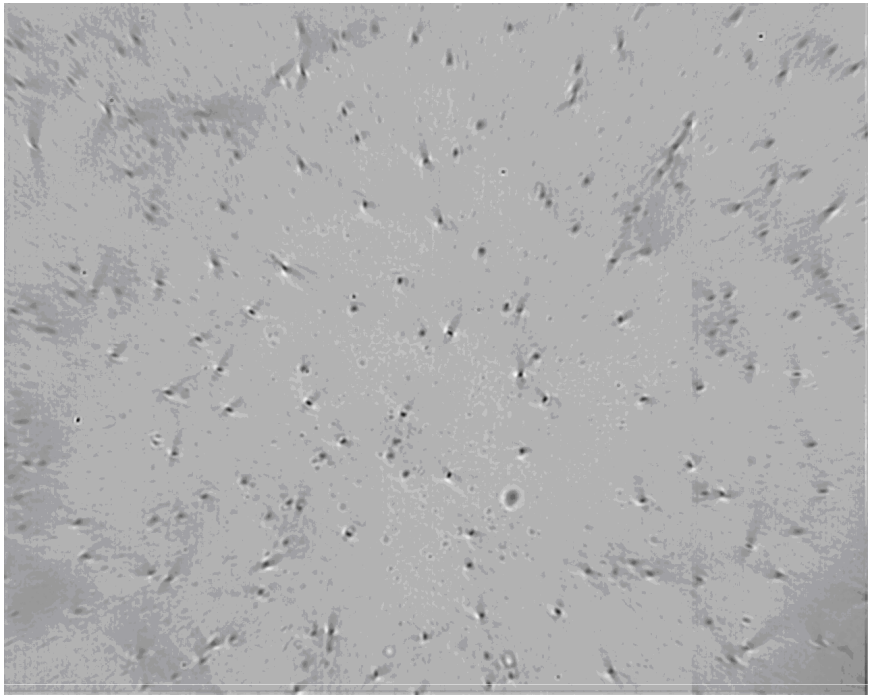
EMU-15

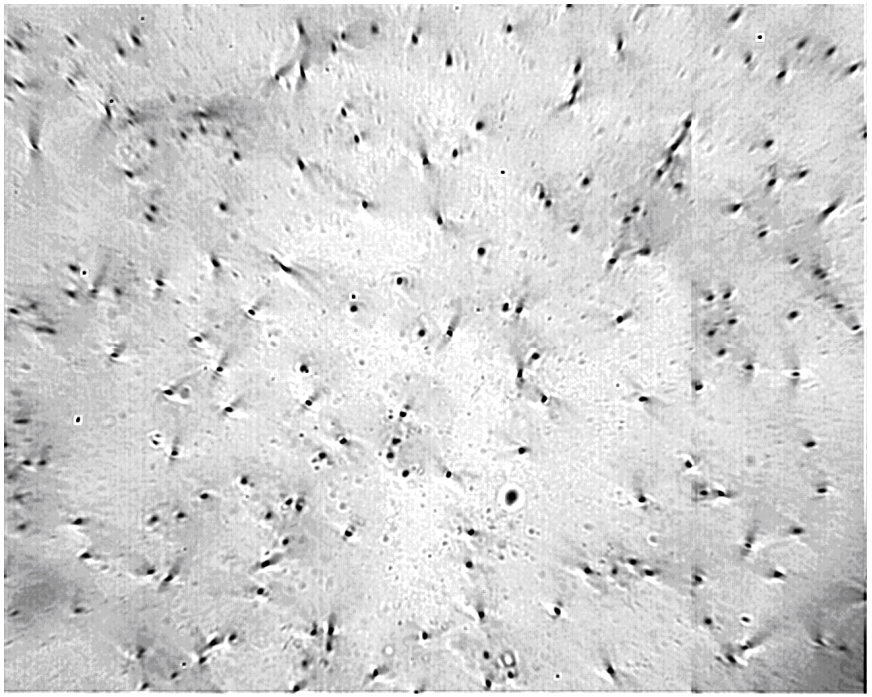


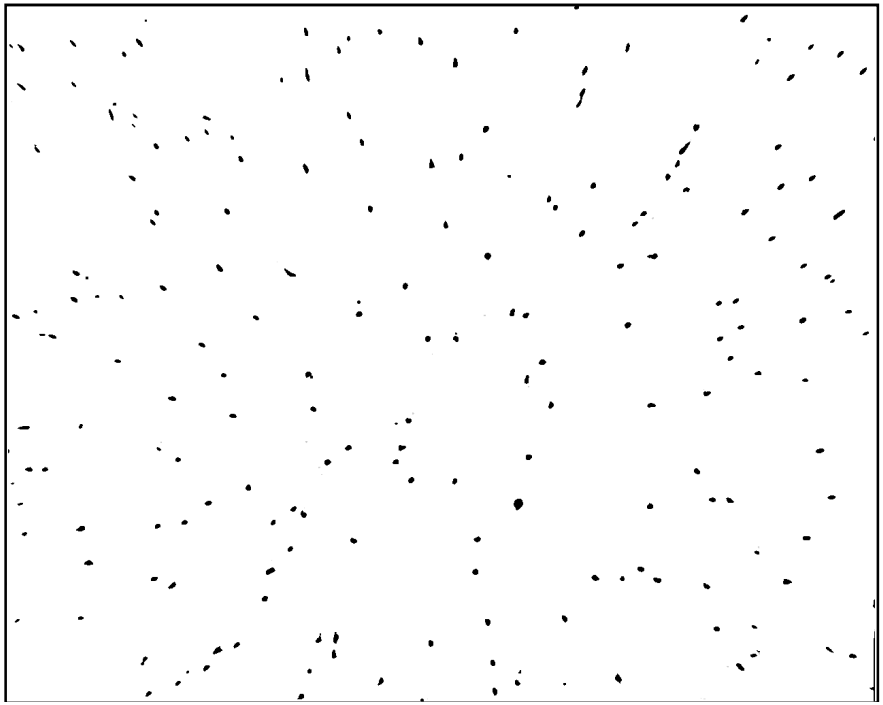
OPERA



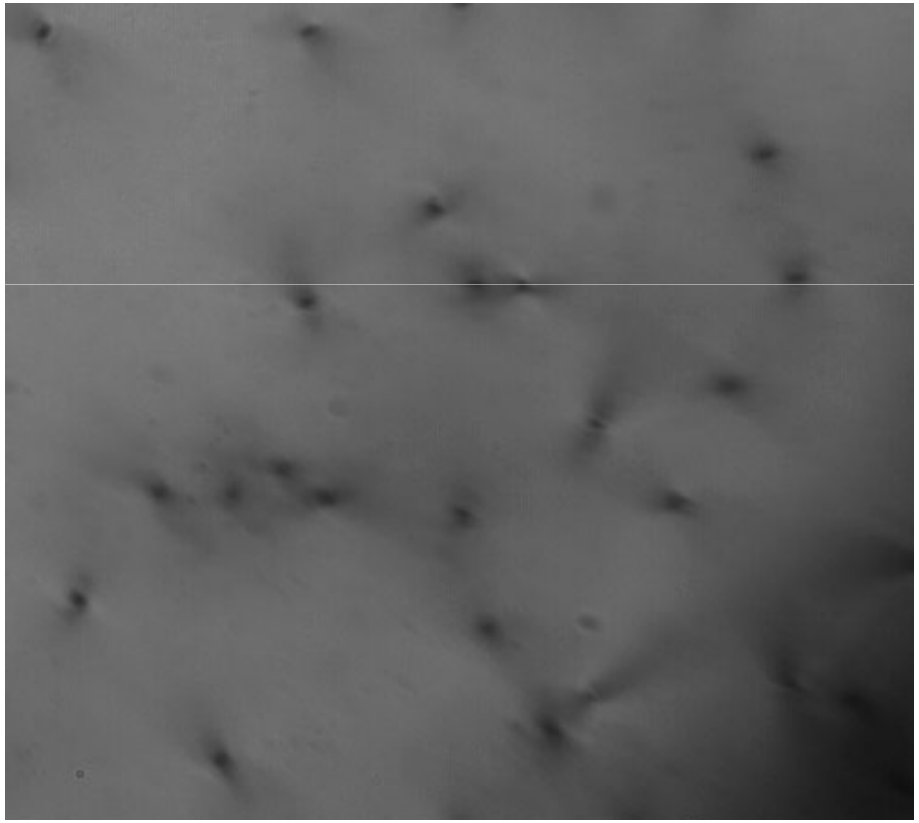


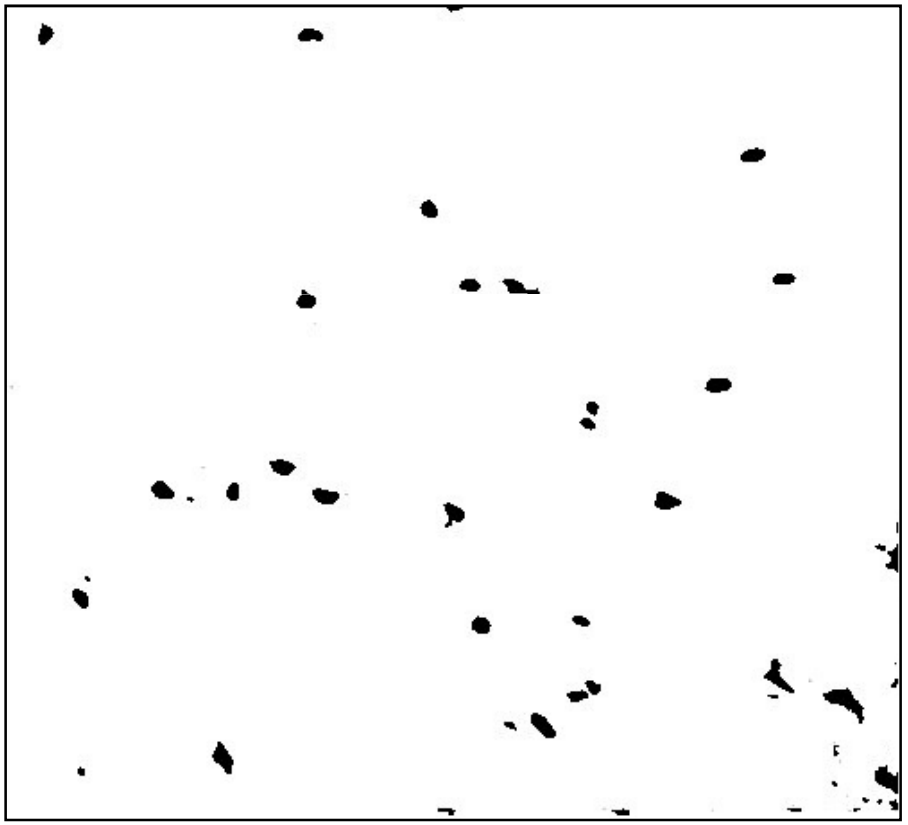






Clusters extraction from dark backgroud

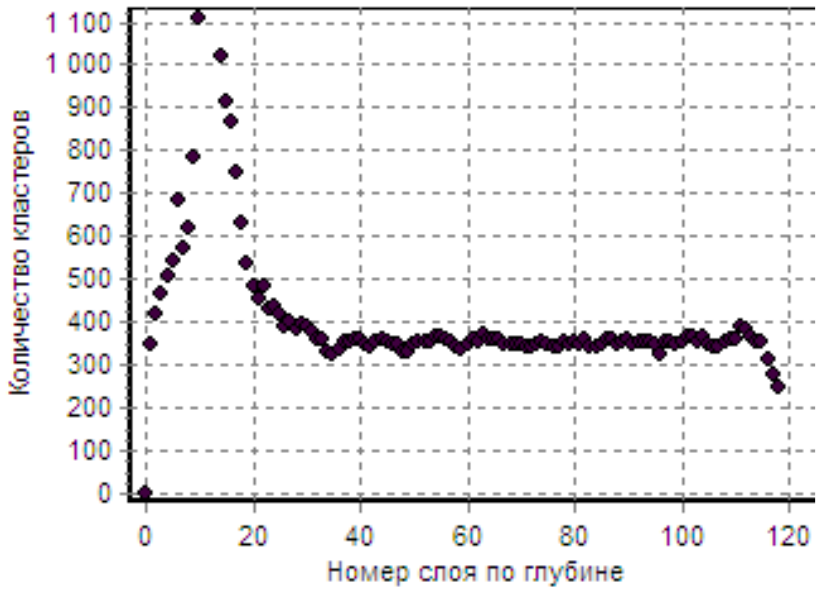


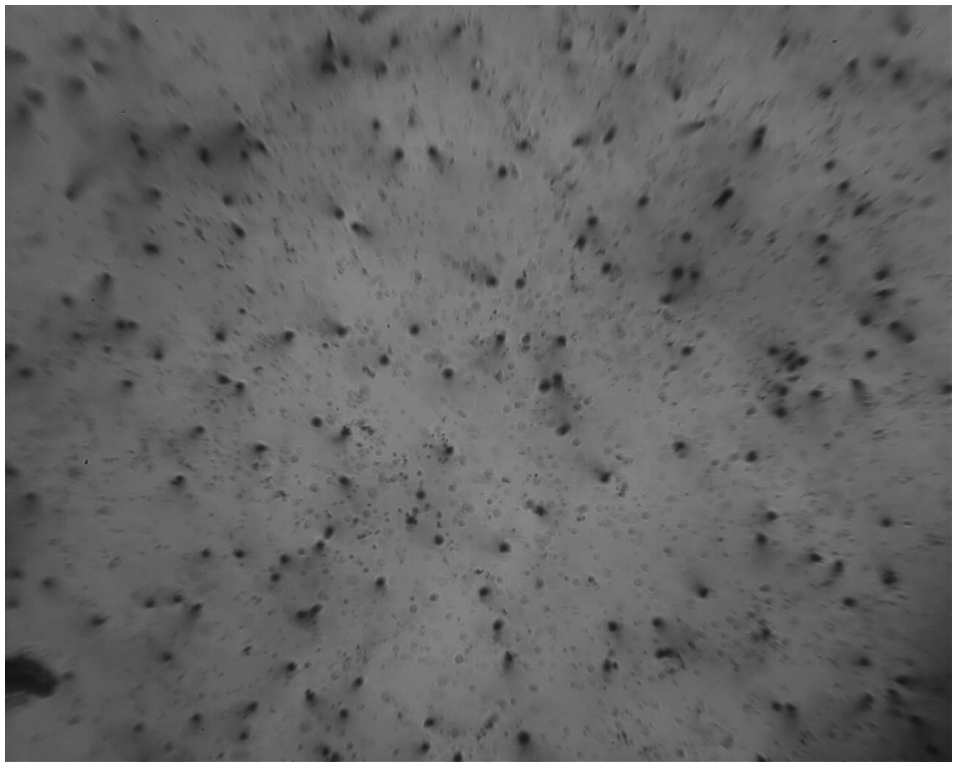


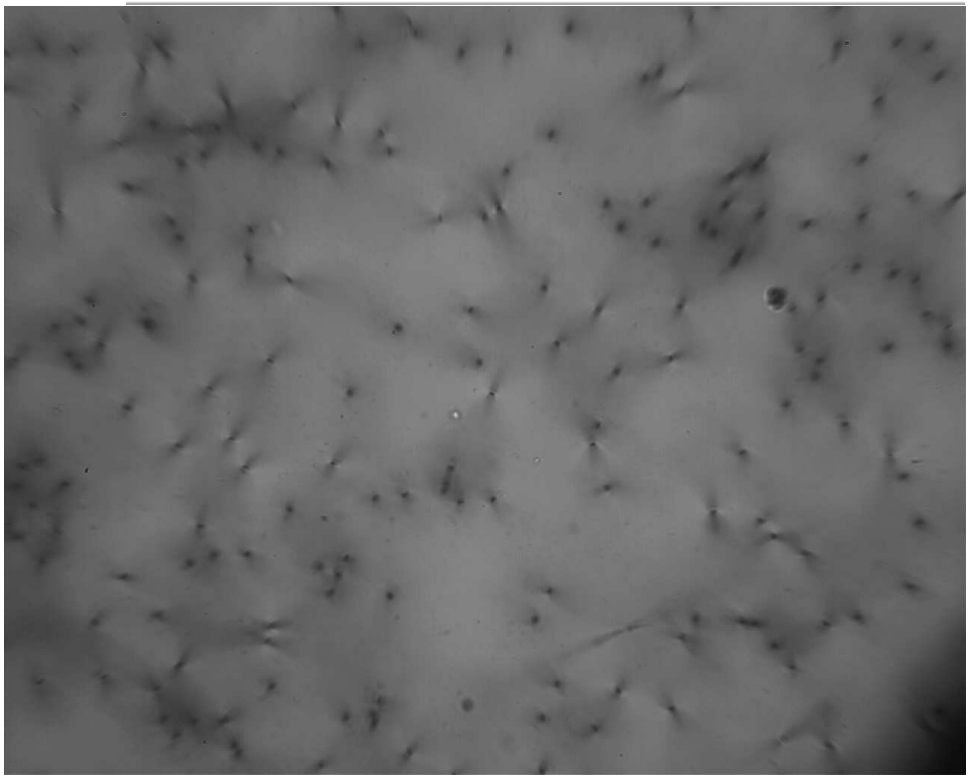
Large thickness emulsion (600 mcm)

(different image properties is a result of irregular development)

=> Variable threshold and track characteristics

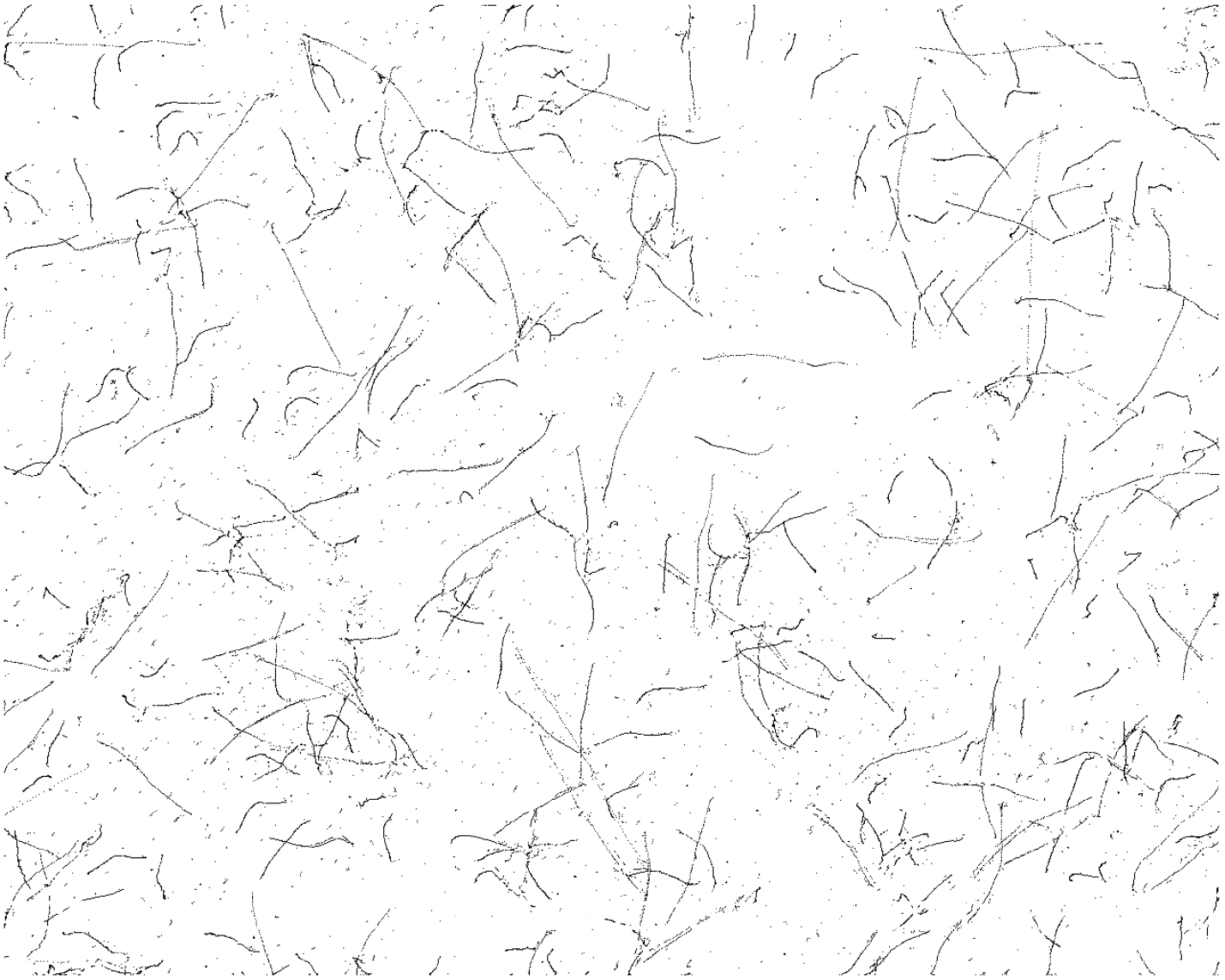




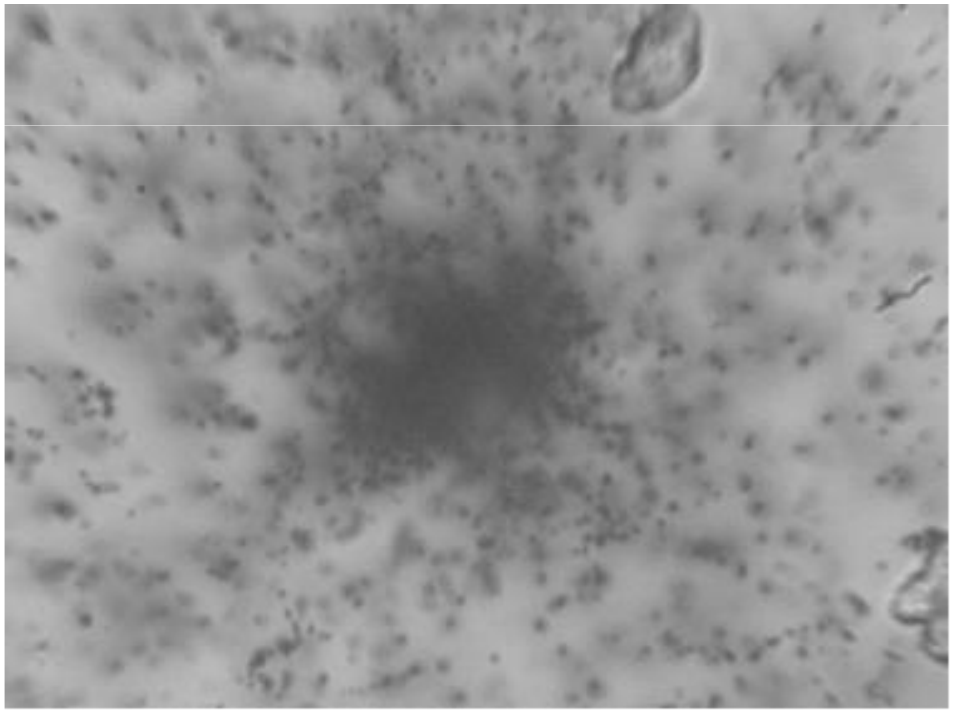


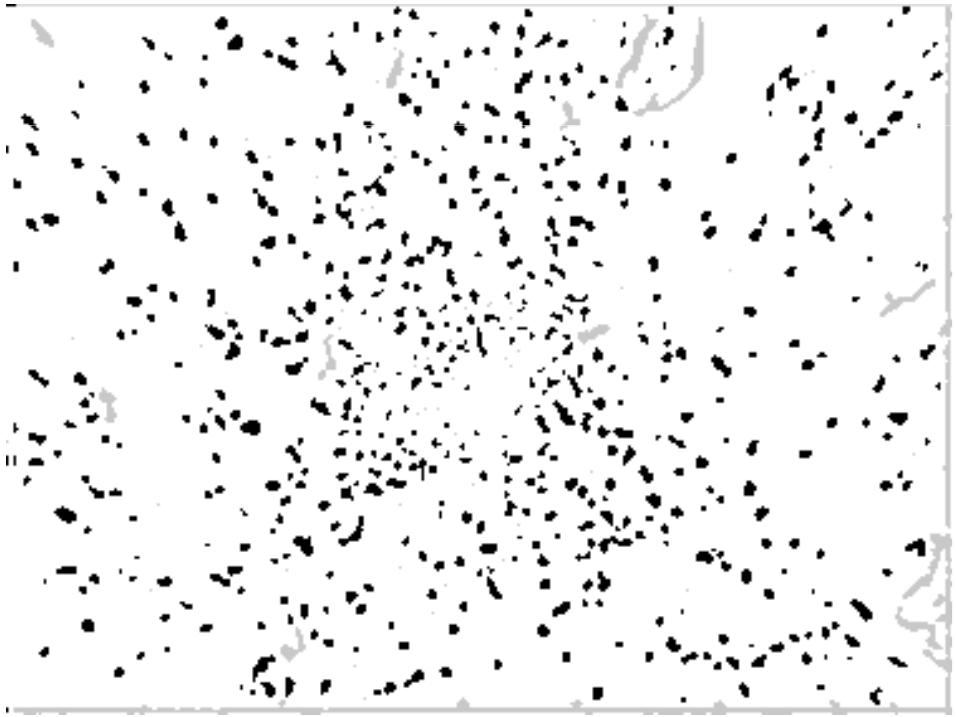
The result of clustering.

(projection of all CM of clusters from 120 layers)

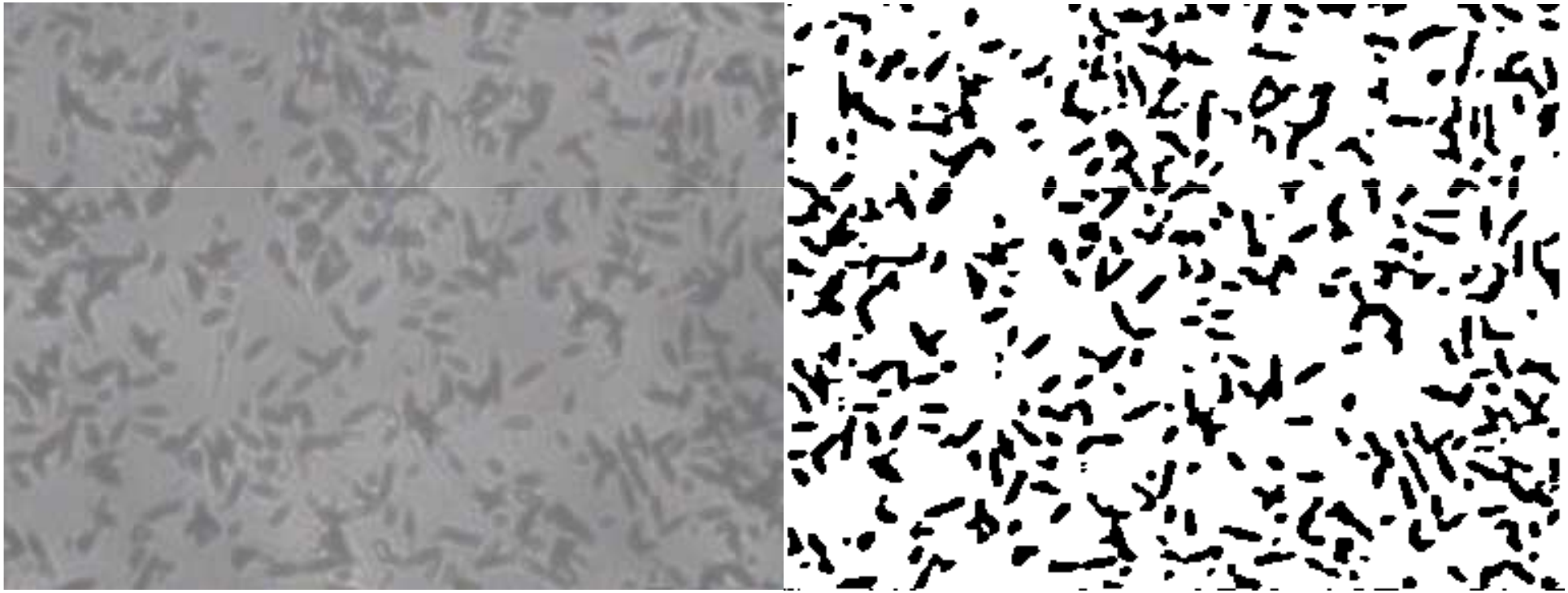


Clustering of EMU-15 image



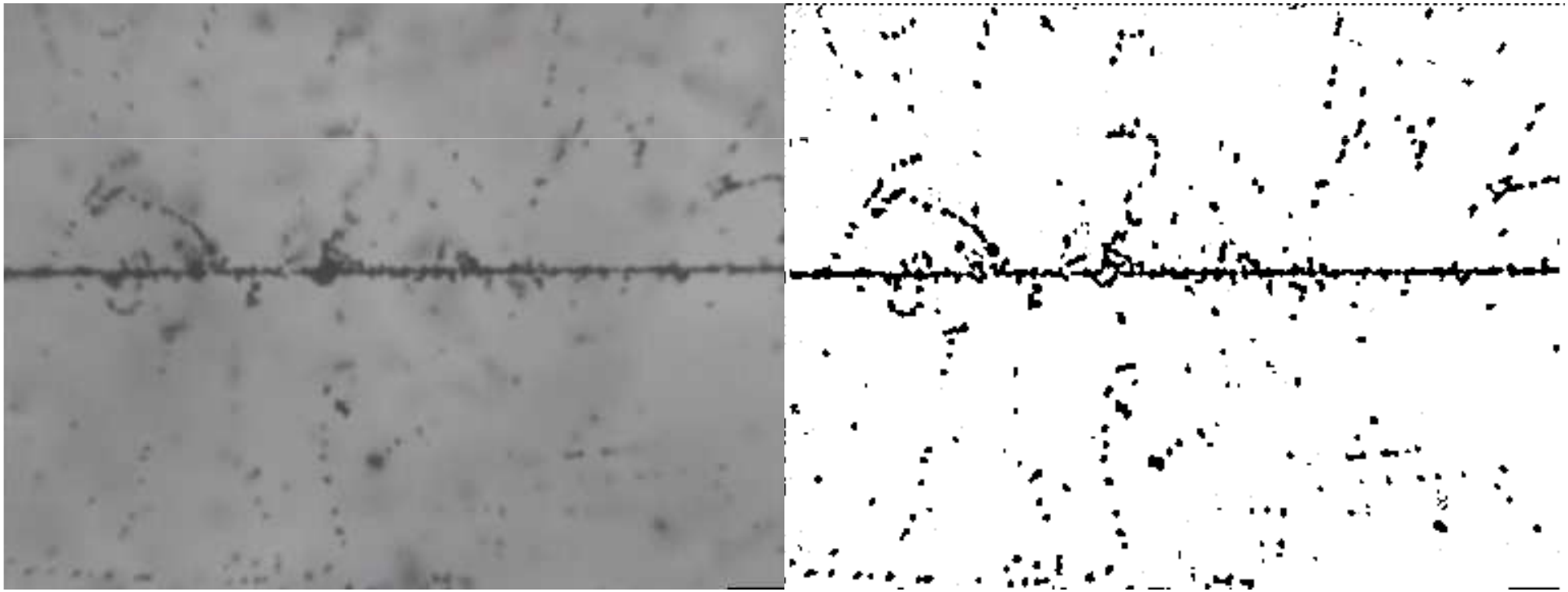


Clustering of Energy+Transmutation image

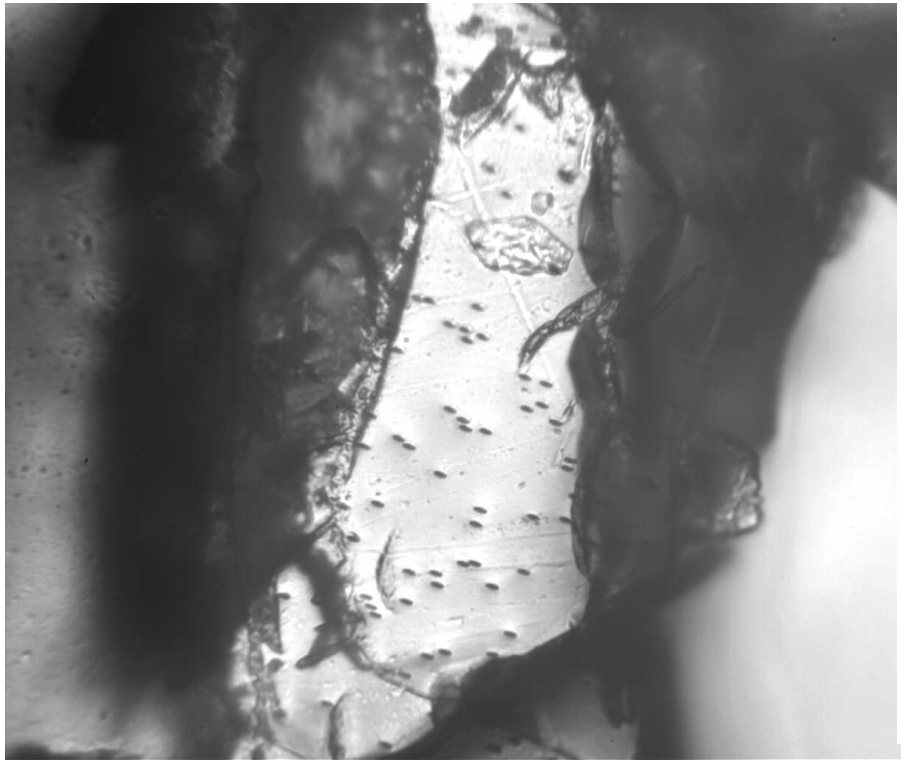


(many tracks intersect each other)

Clustering of longitudinal track in thick emulsion

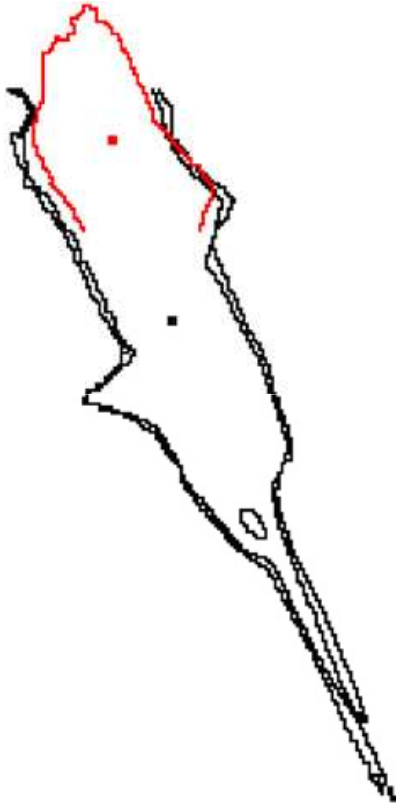


Particularity of olivine from meteorites processing

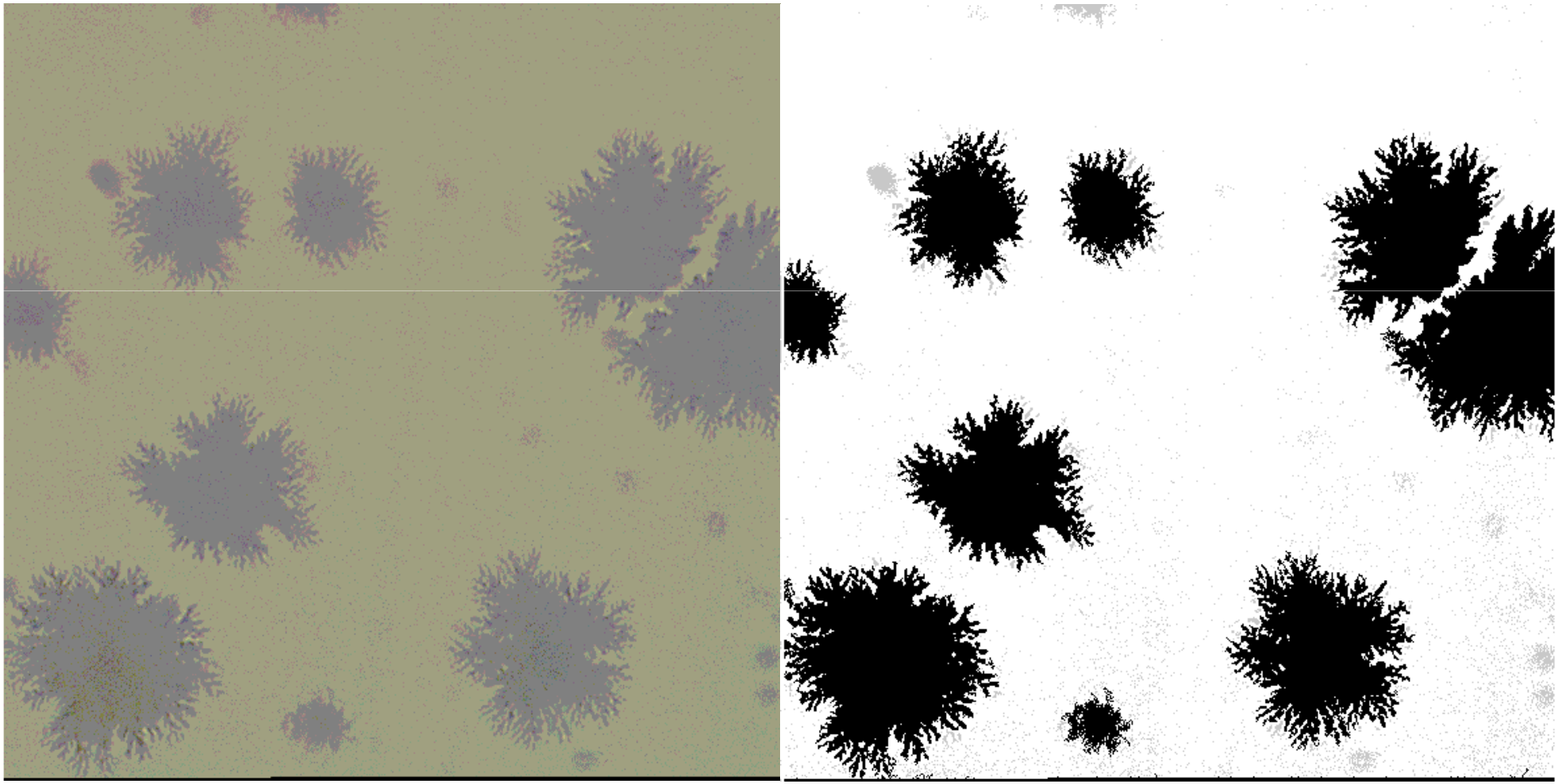


Extraction of processing area when there is large noise area

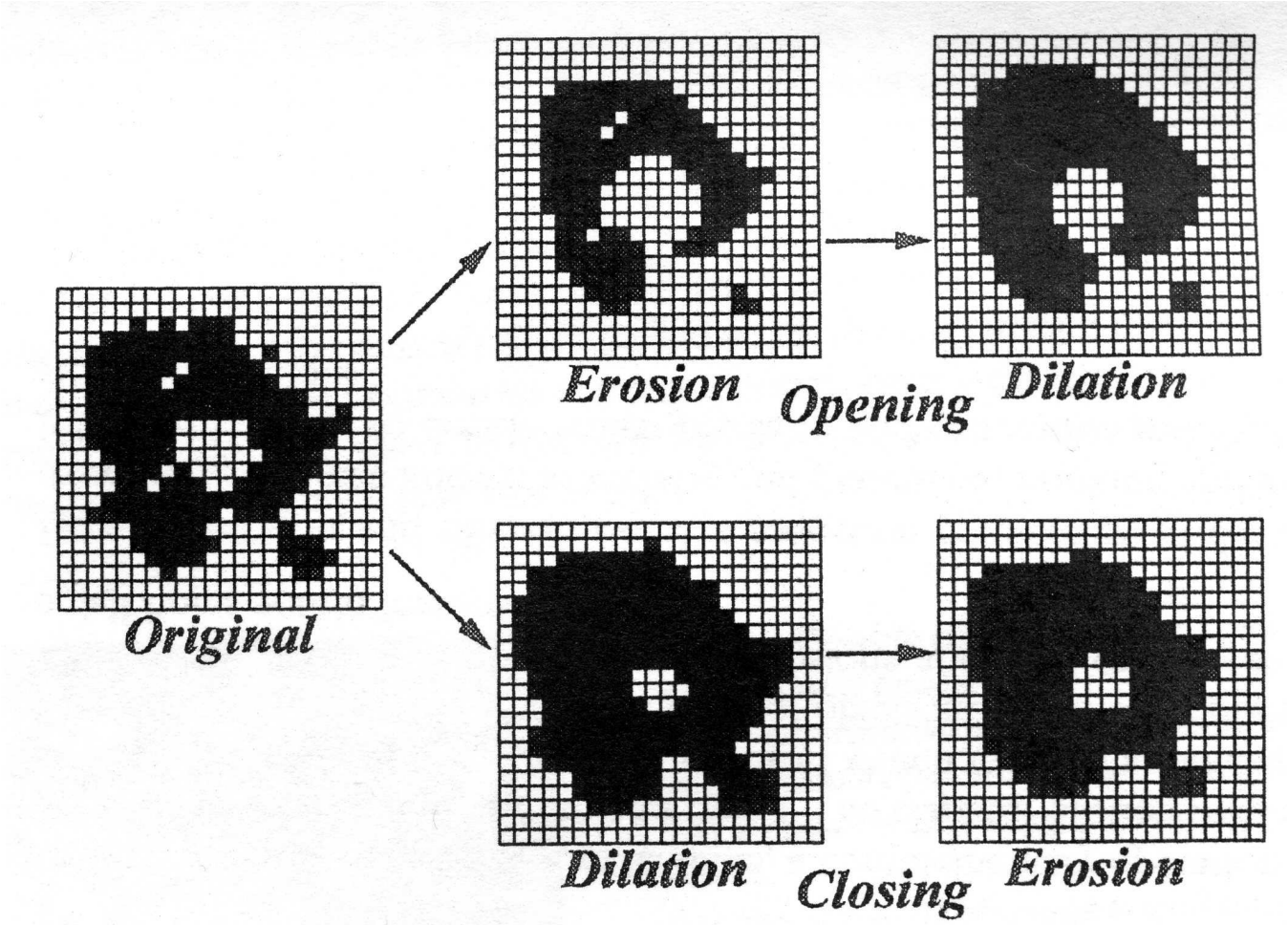
Extraction of complicated track (heavy nucleus trace in olivine)



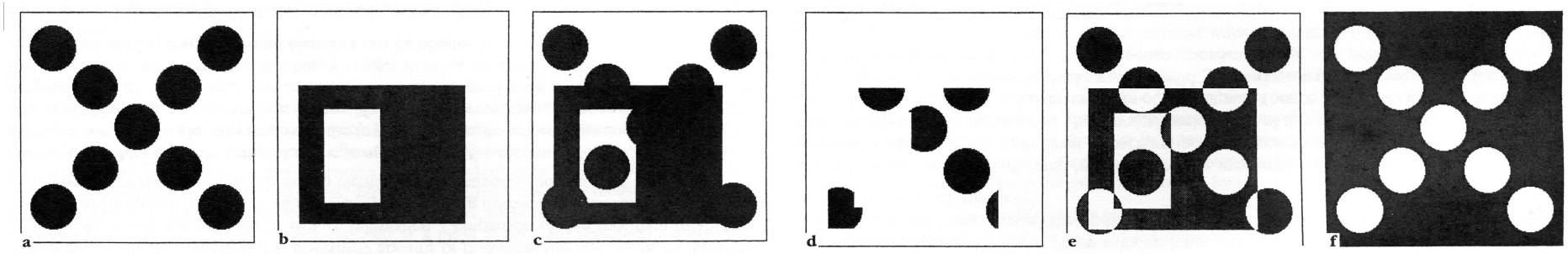
Clustering of tracks having very complicated form



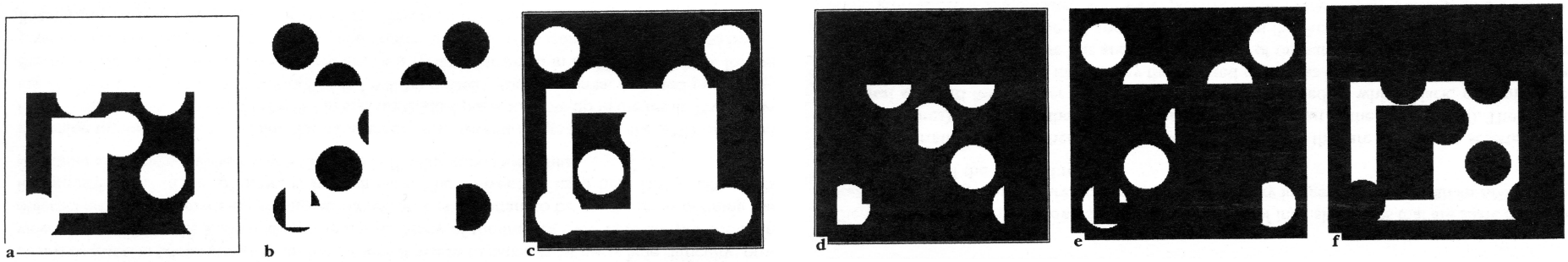
Additional correction of clusters form



Binary (logical) operations with images



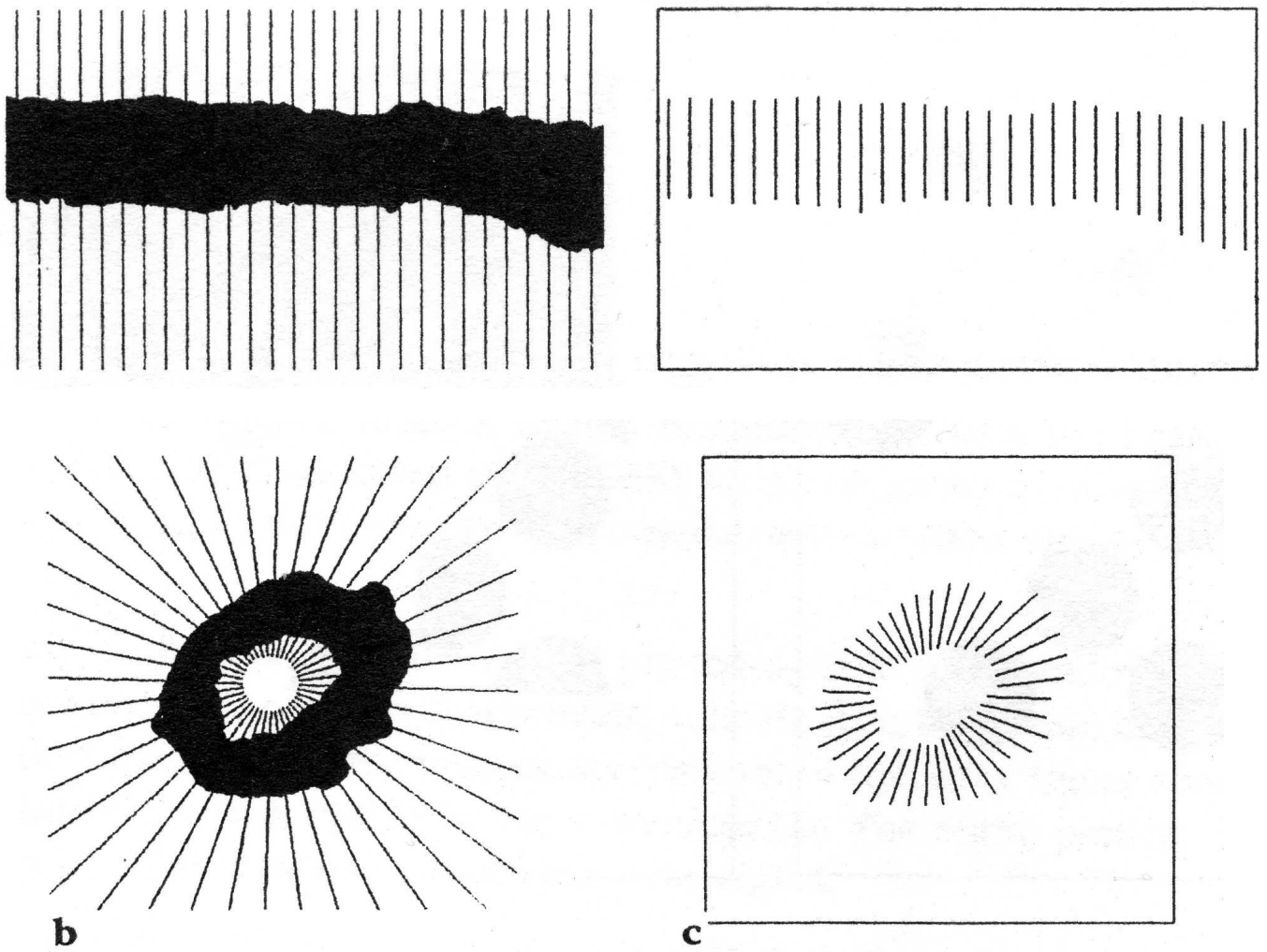
A B A Or B A And B A exOr B Not A



Not A) And B (Not A) And (Not B) (Not A) Or B

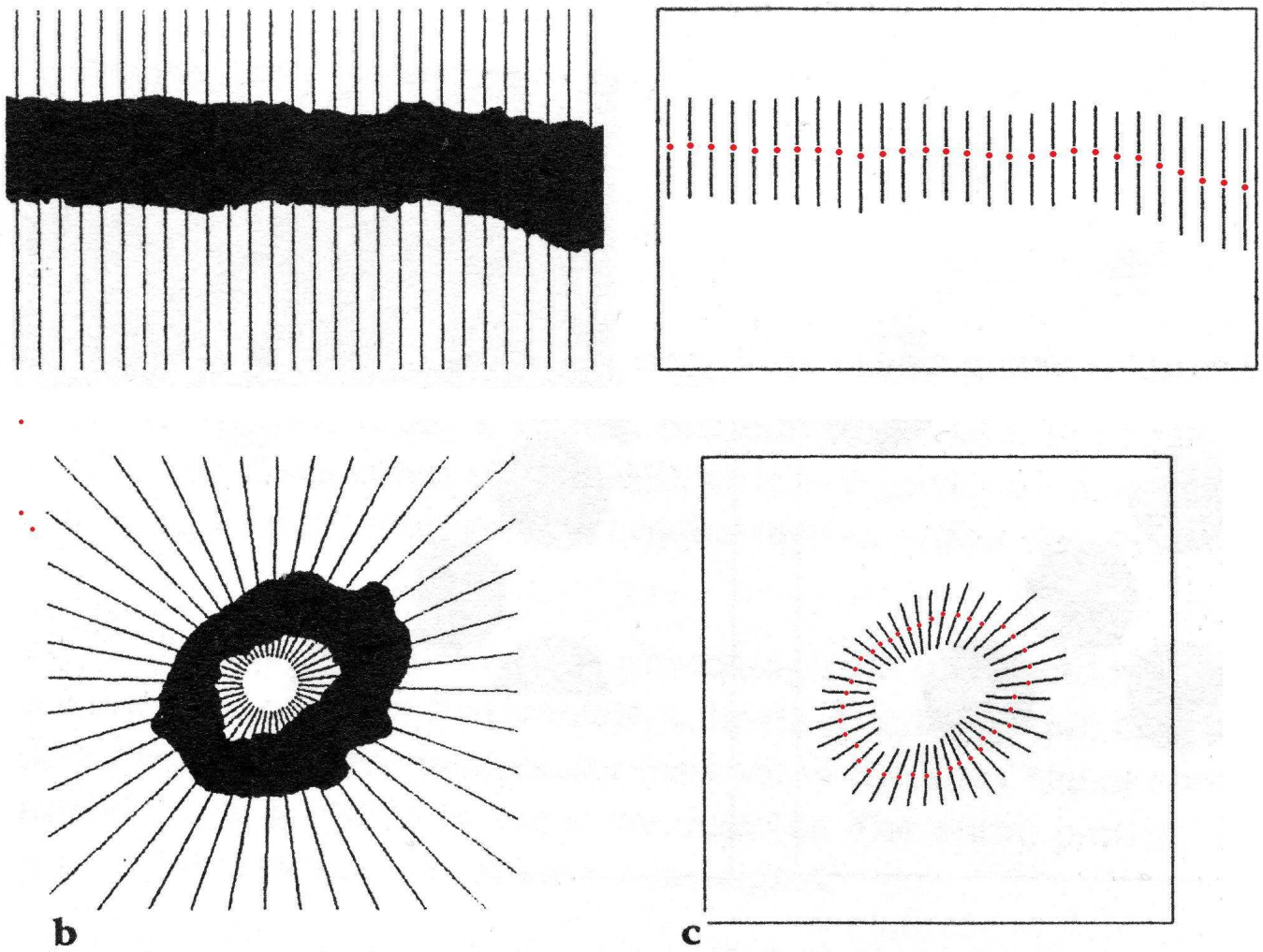
A And (Not B) Not(A And B) A And (Not B)

Use of logical operations to define geometrical characteristics



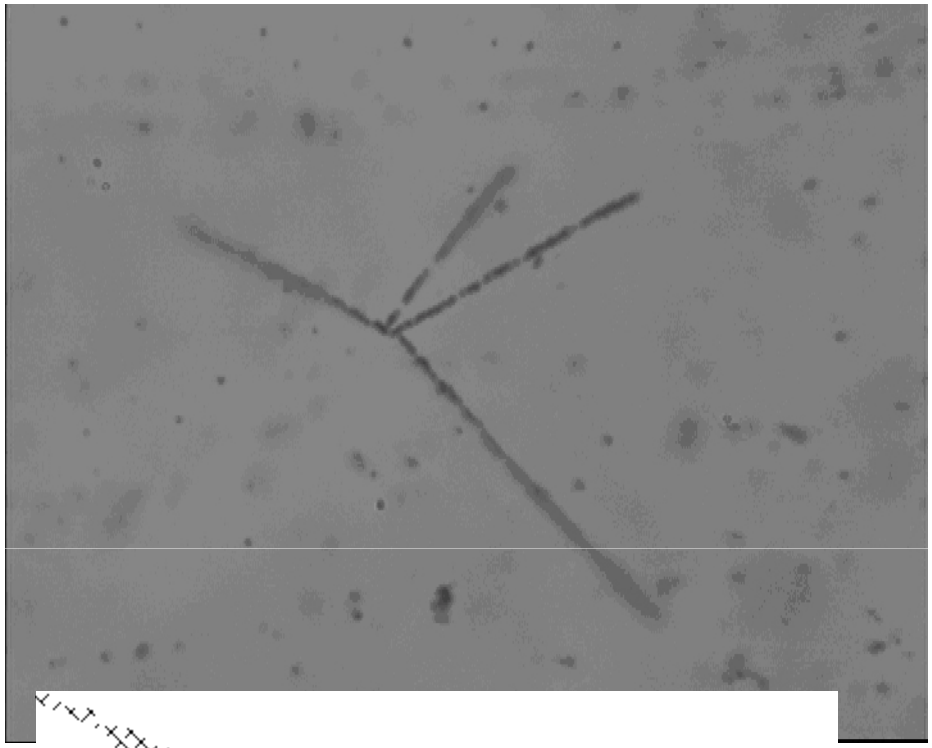
В более сложных случаях используются другие методы.

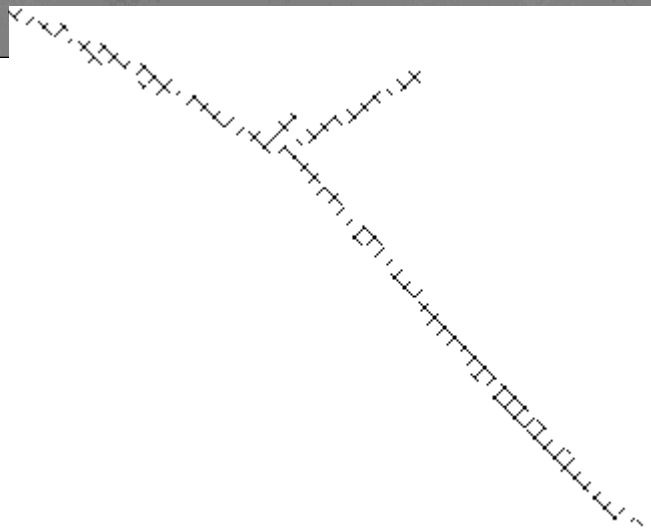
Use of logical operations to define geometrical characteristics (axis, skeleton …)

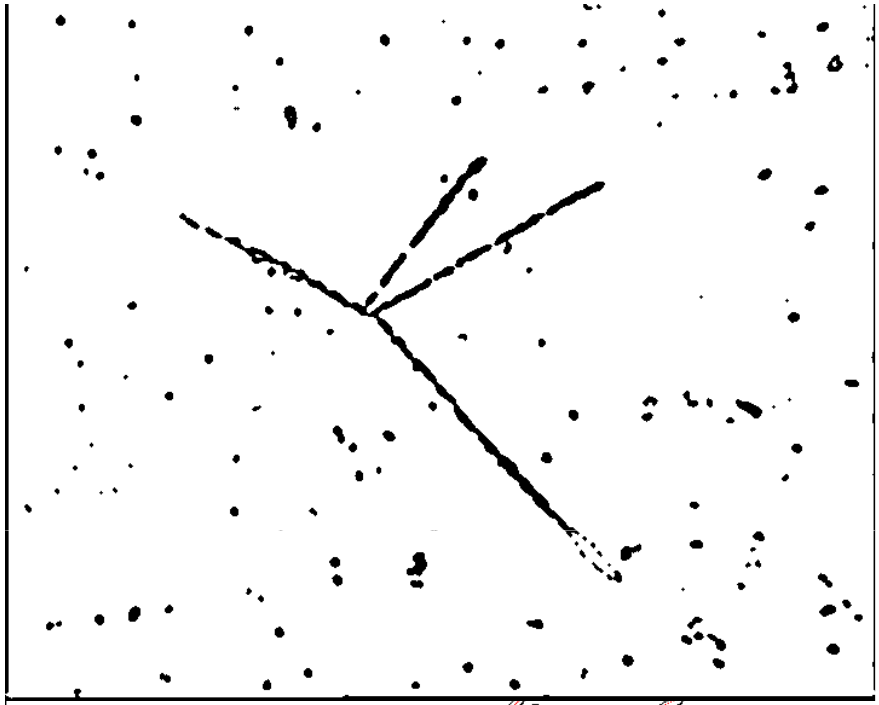


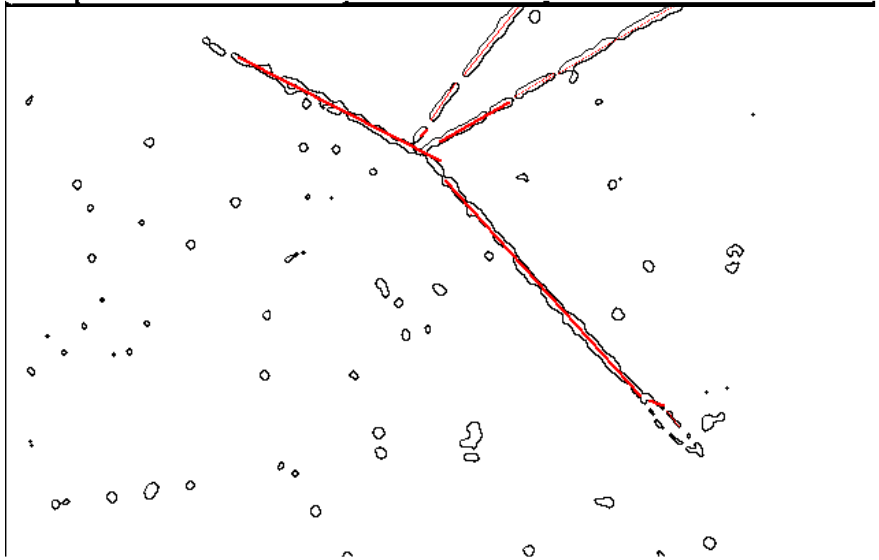
В более сложных случаях используются другие методы.

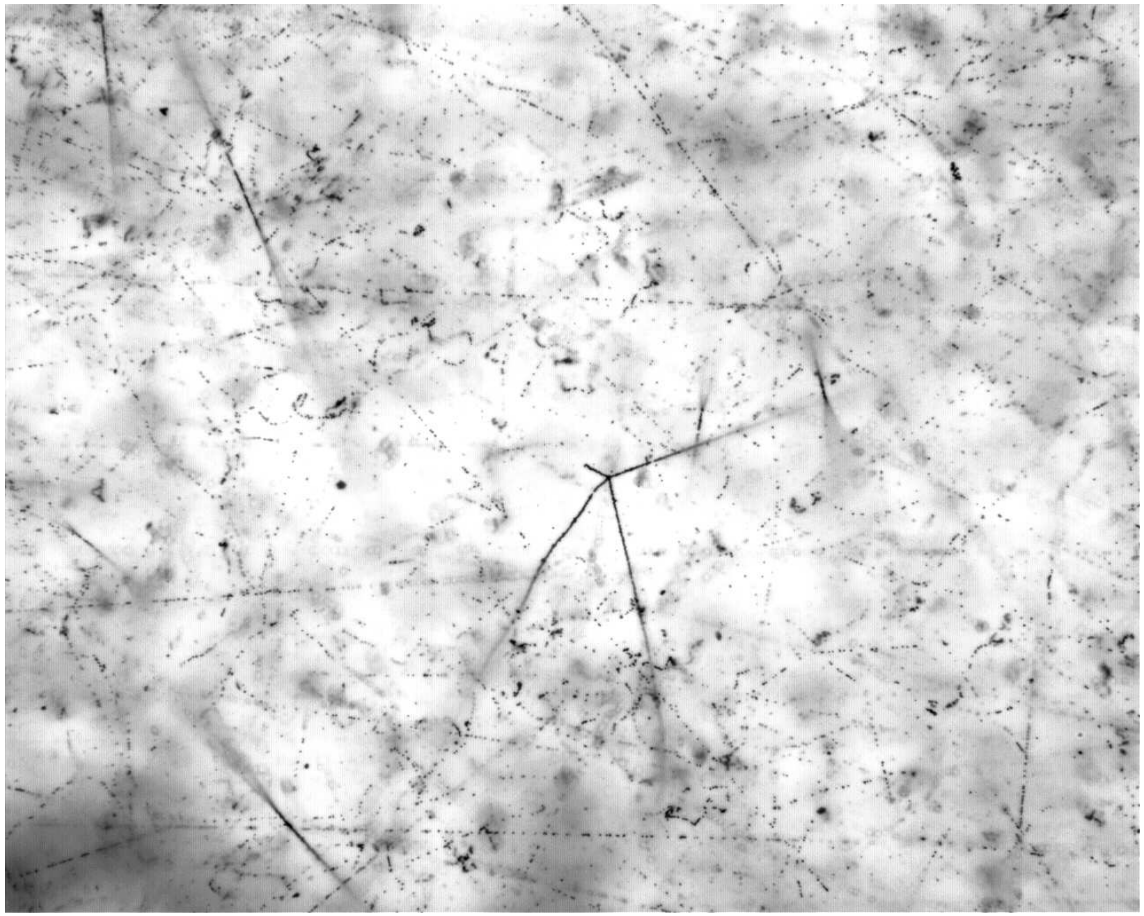
The Extraction of a nuclear star rays using auxiliary grid

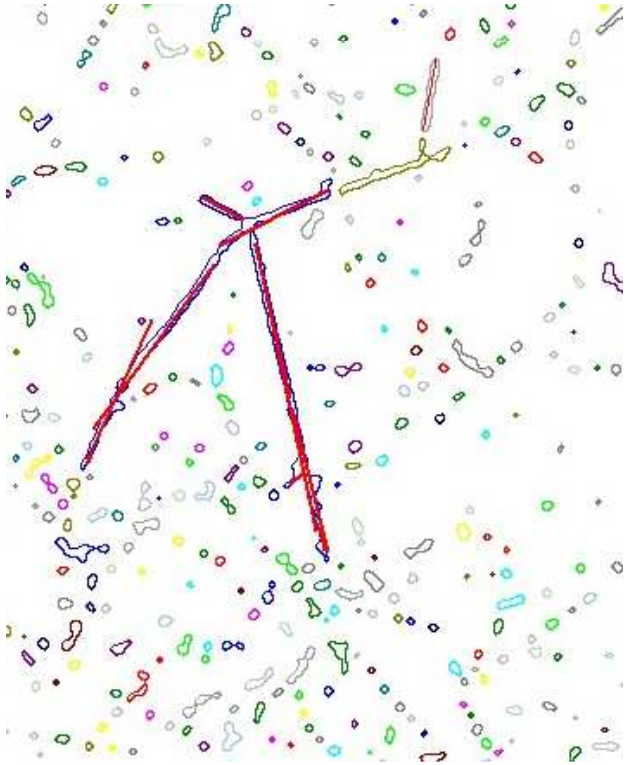




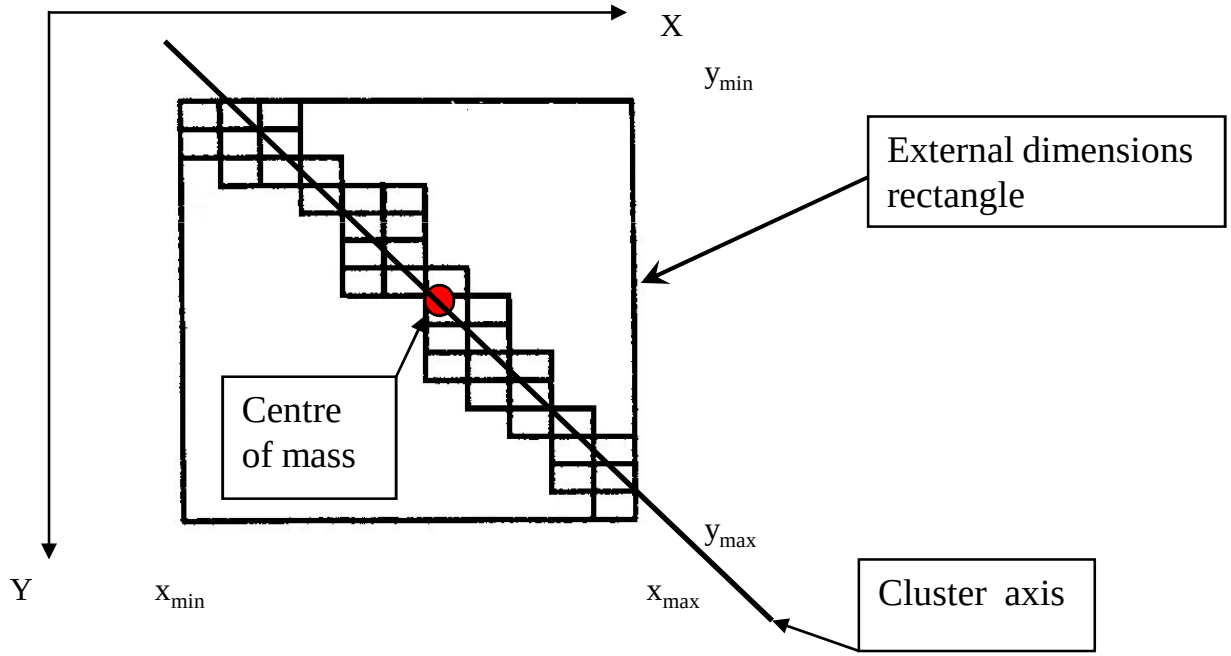






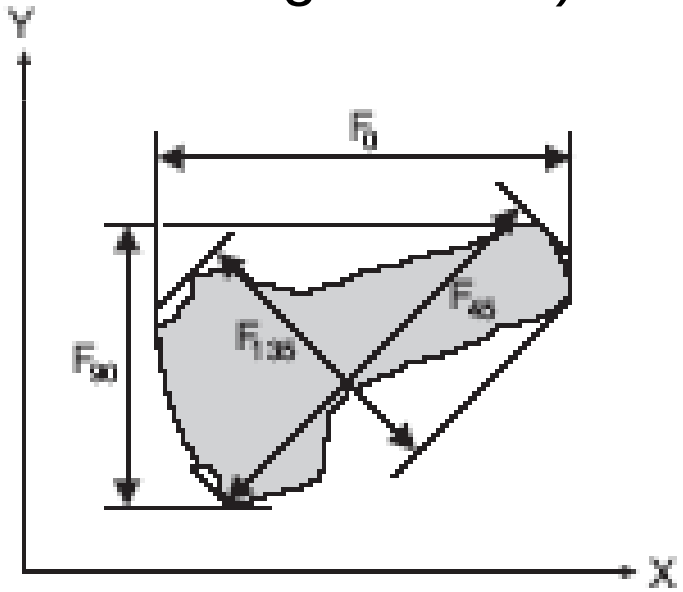


Cluster's axis, length and width

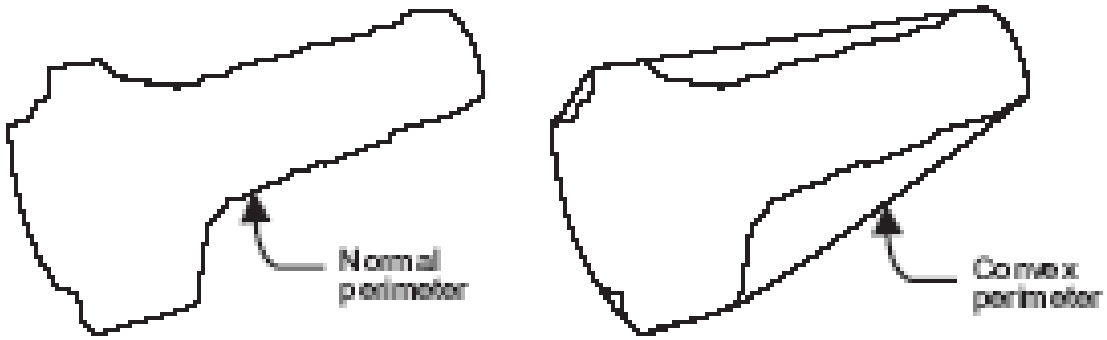


Other geometrical characteristics

Ferret's diameters (distance between two tangent lines)



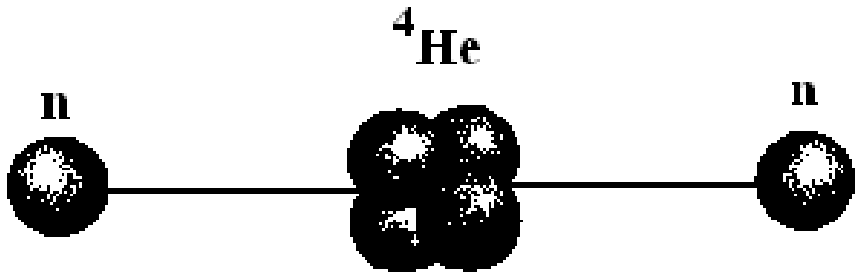
Usual and convex perimeter



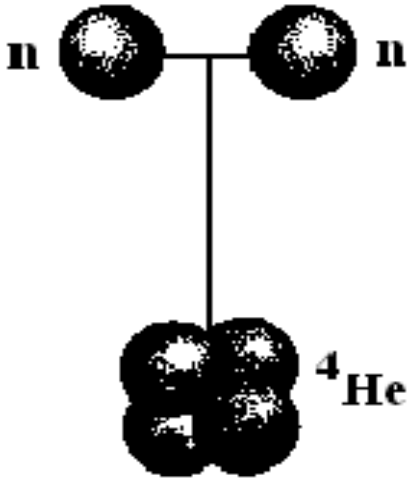
The investigation of ^{6}He interaction in emulsion

It is possible the existence of two configurations of additional neutrons

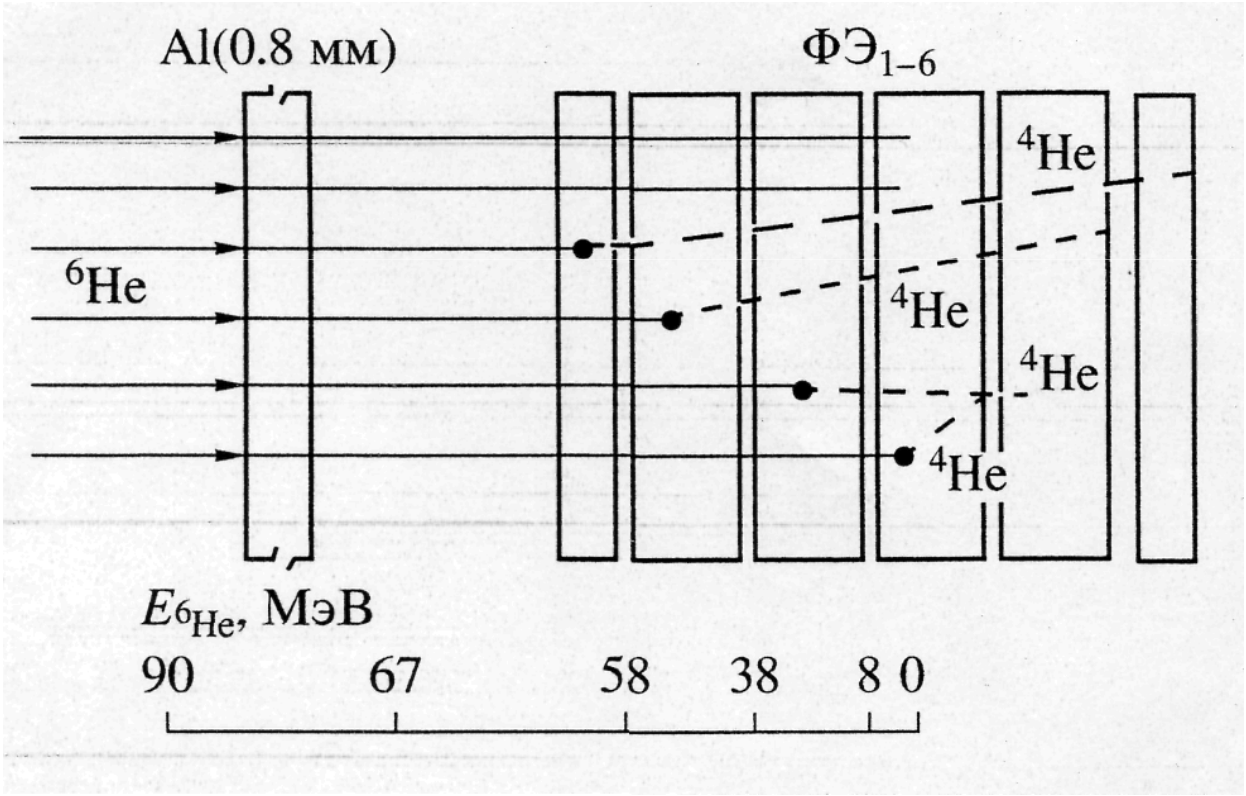
cigar-like



dineutron



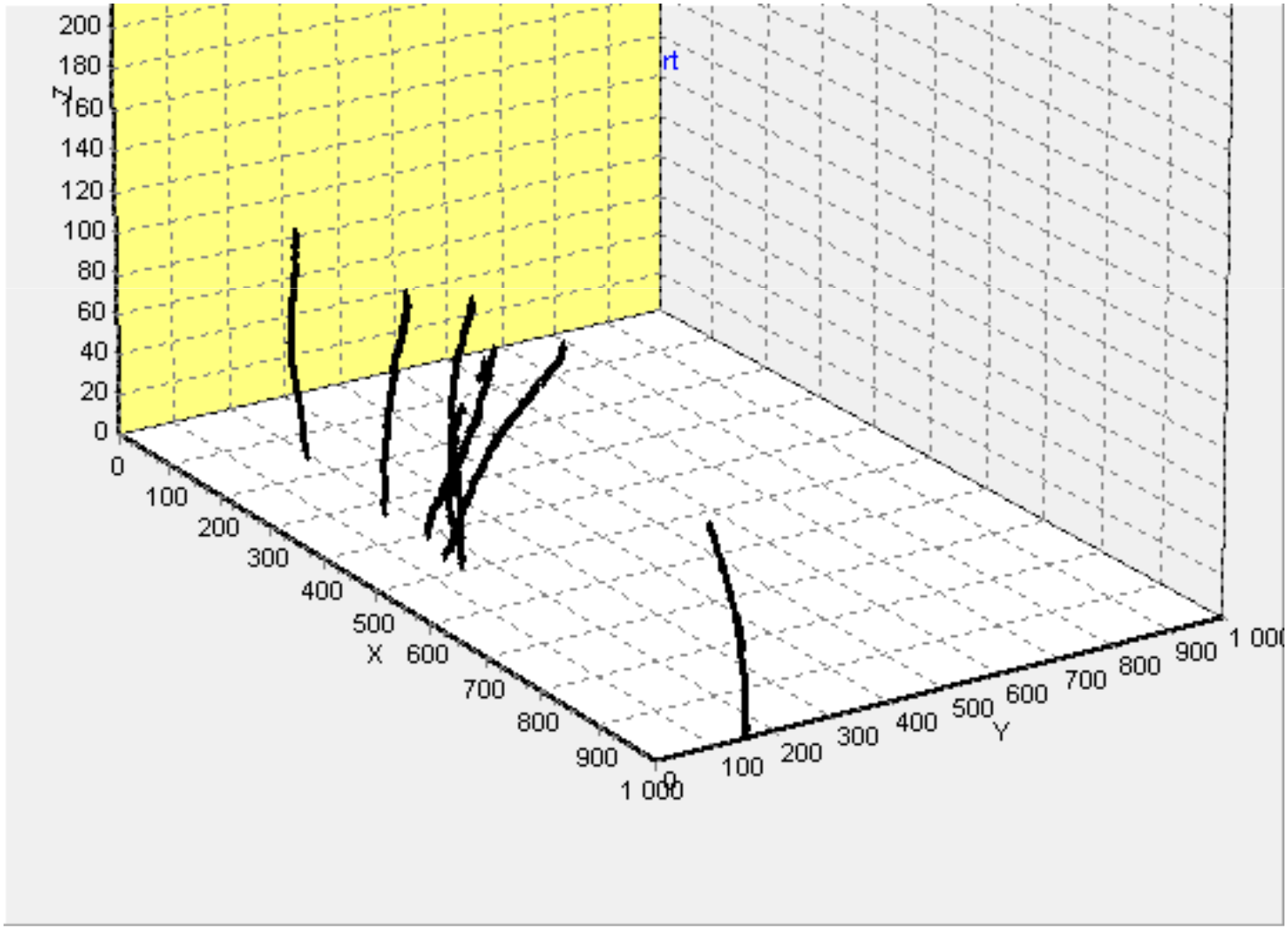
The schema of experiment



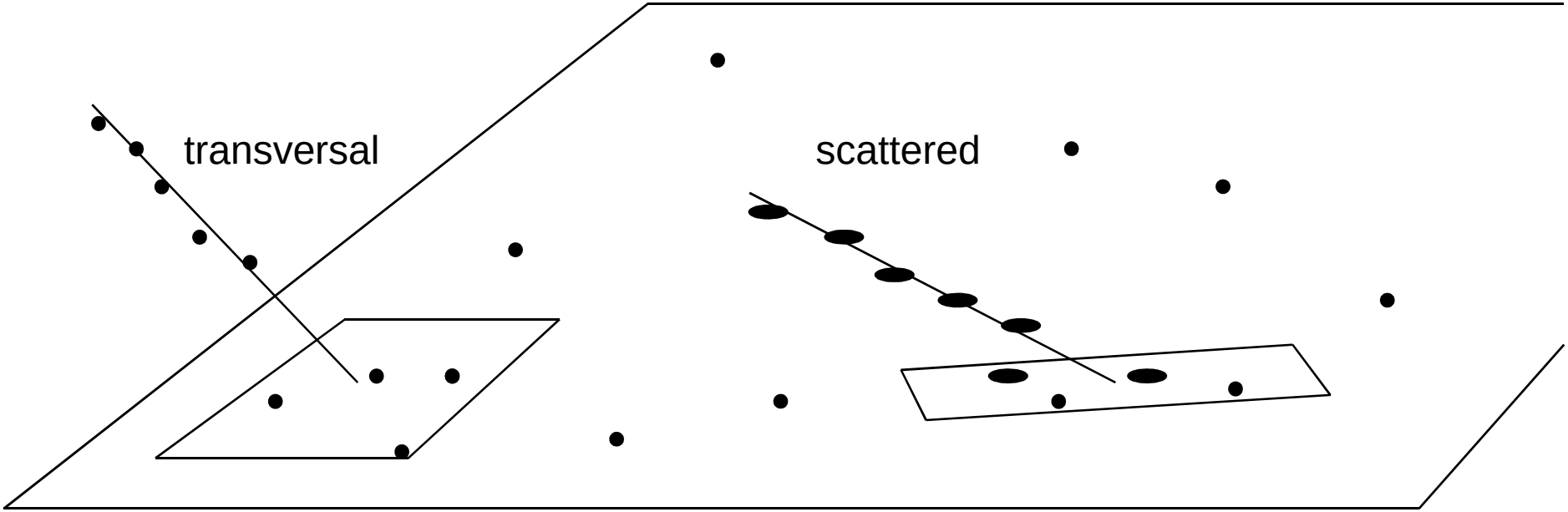
Analysis of interactions

- Clusters alignment in three dimension space (tracking)
- Search of vertexes
- Geometrical reconstruction of interaction
- Reconstruction of kinematics

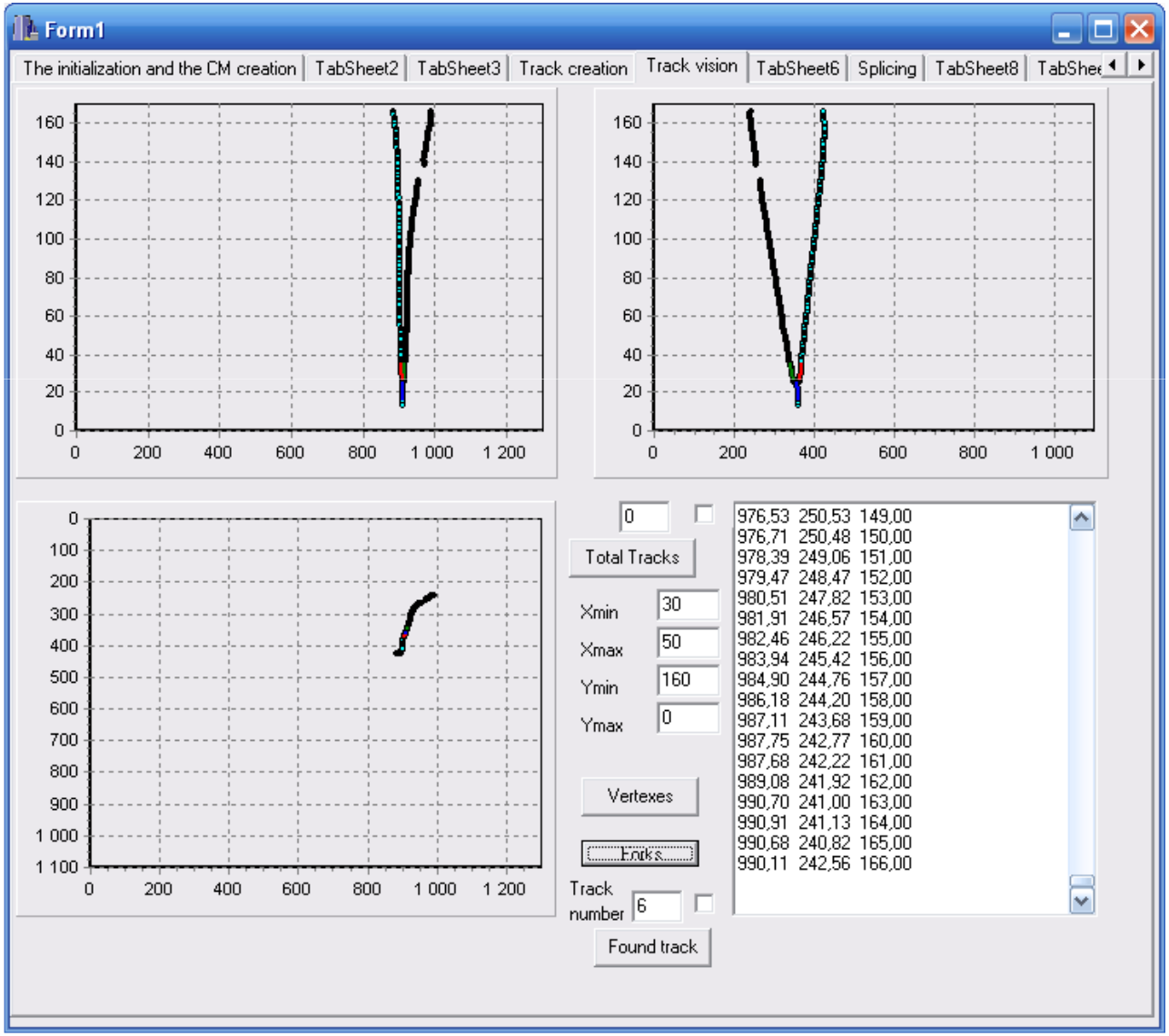
Most part of tracks are bent due distorsion



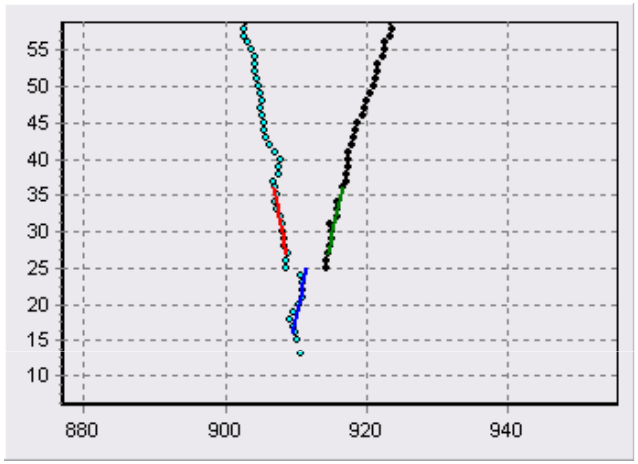
Algorithm of track prolongation
(sliding window)



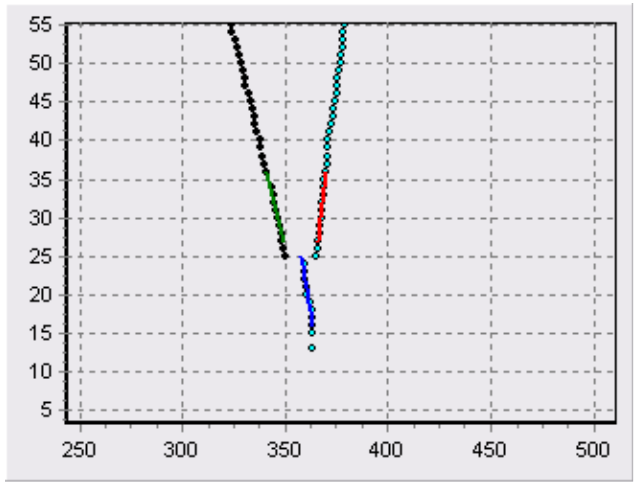
One vertex of ^{6}He+p=>He+(pnn)



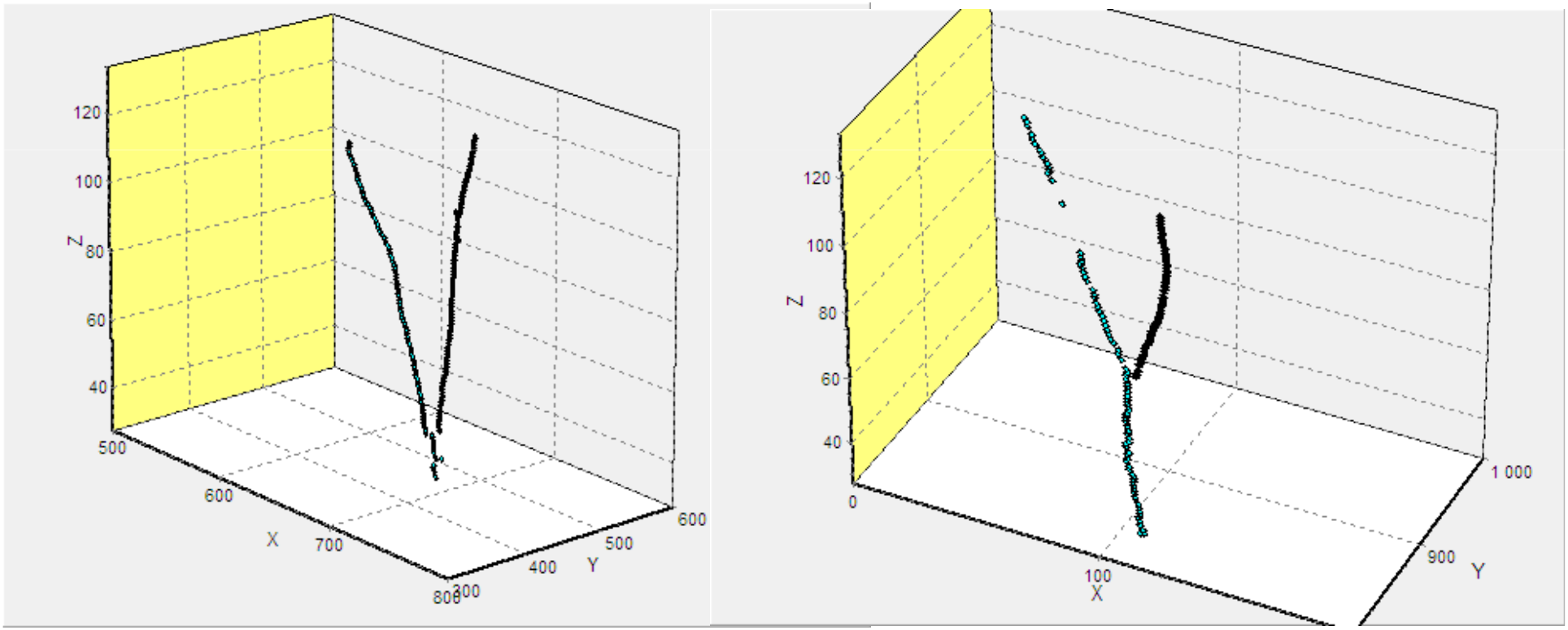
XZ



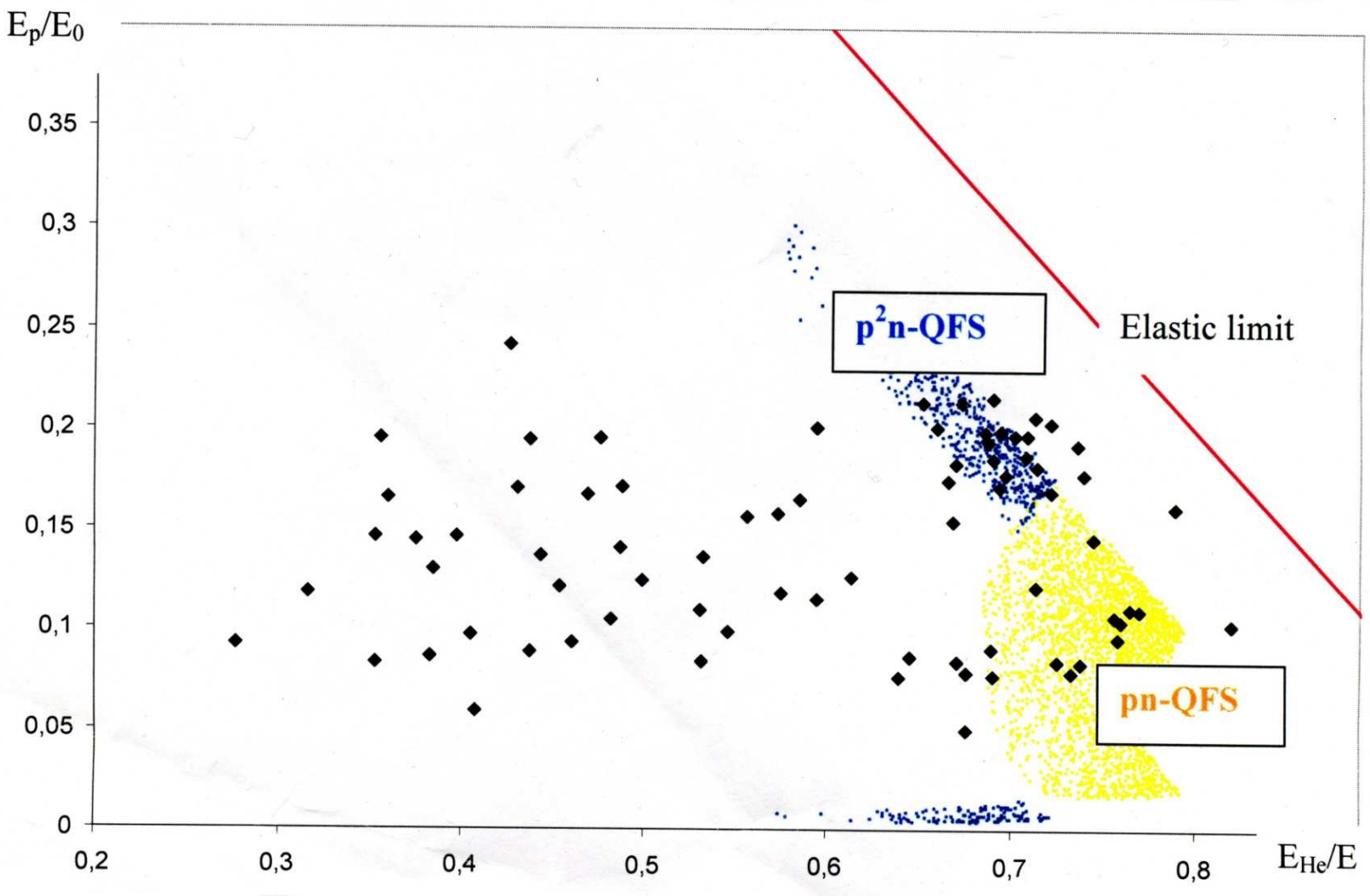
YZ



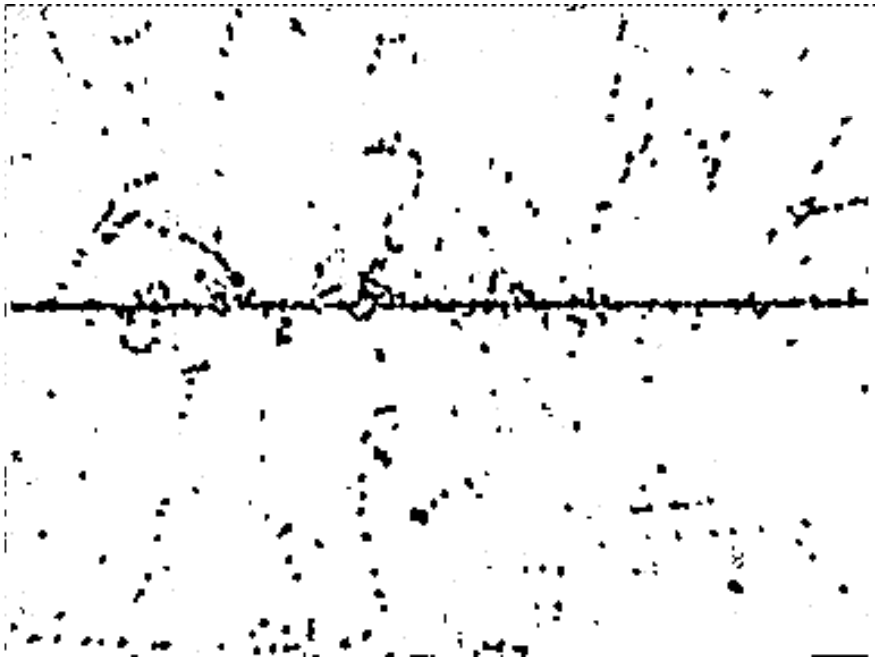
Three dimensional representation

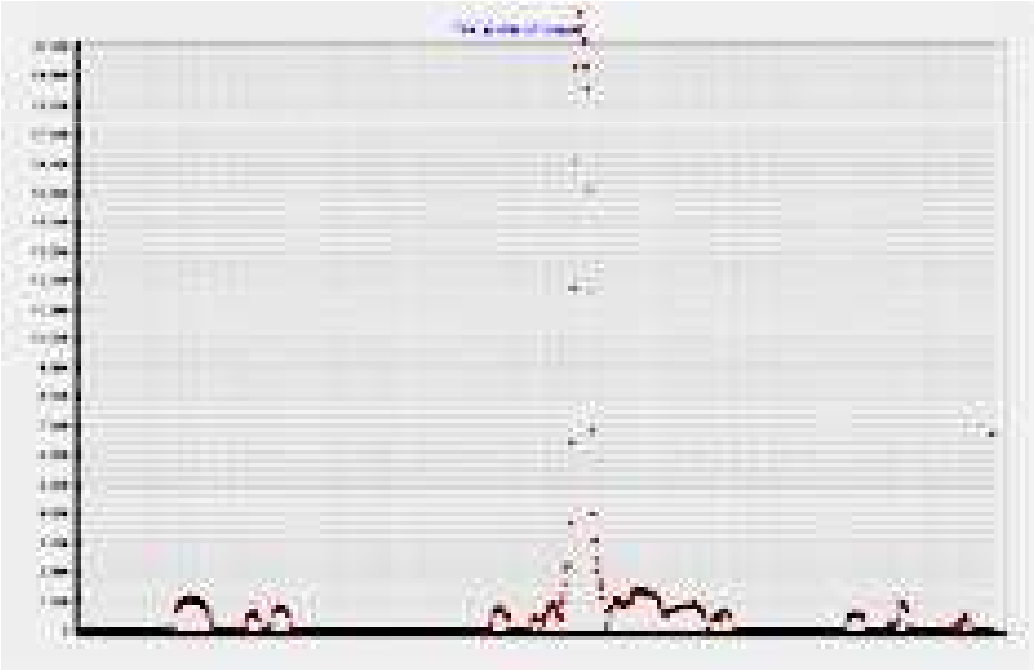


Kinematical areas of reactions

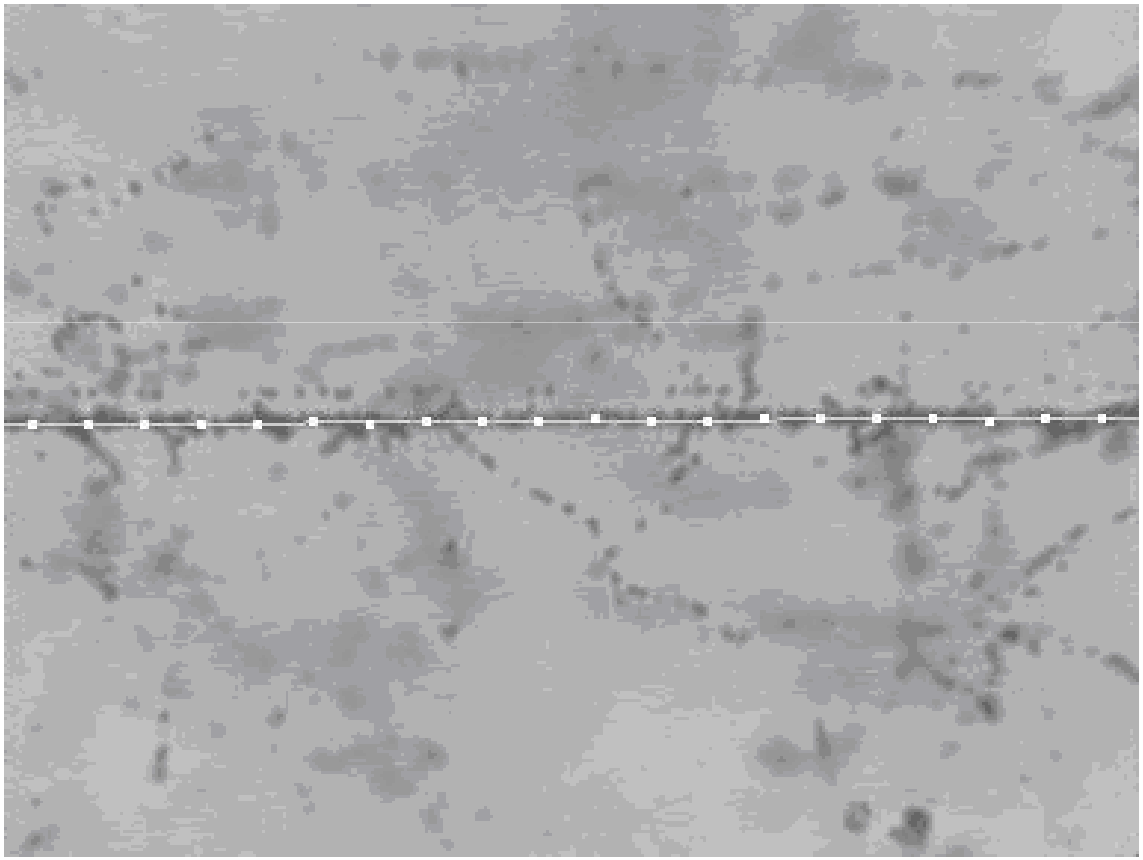


The method of automatic charge measurement (relativistic nuclei in thick emulsion)



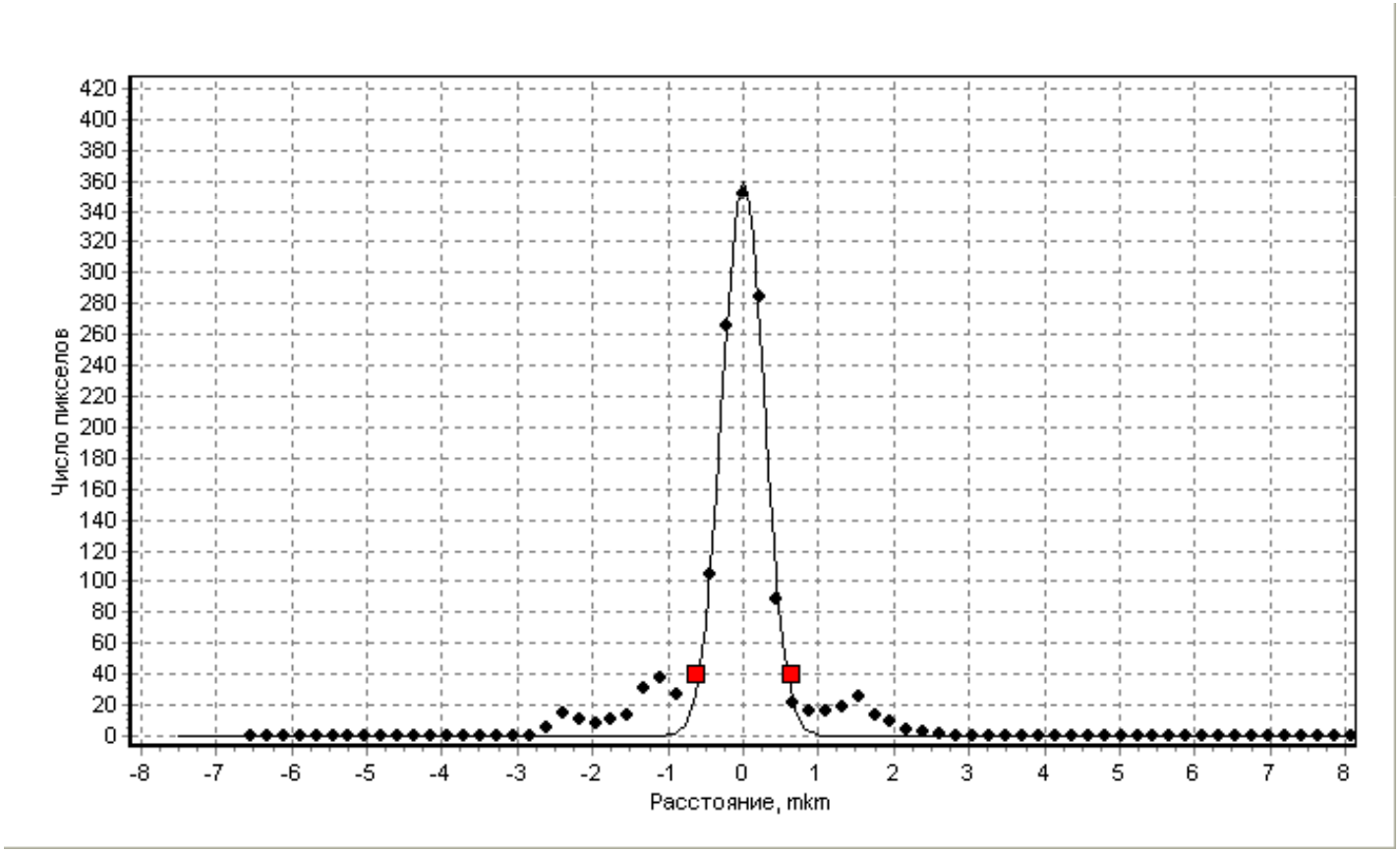


The axis creating
(20 auxiliary vertical strips)



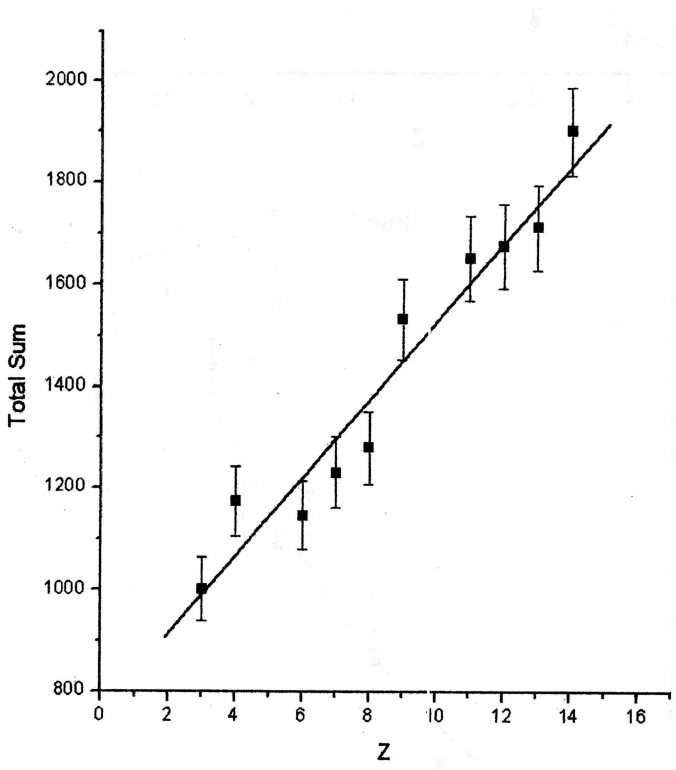
Dependence of the pixels number on their distance to axis

(only those clusters belong to track which are crossed by axis)

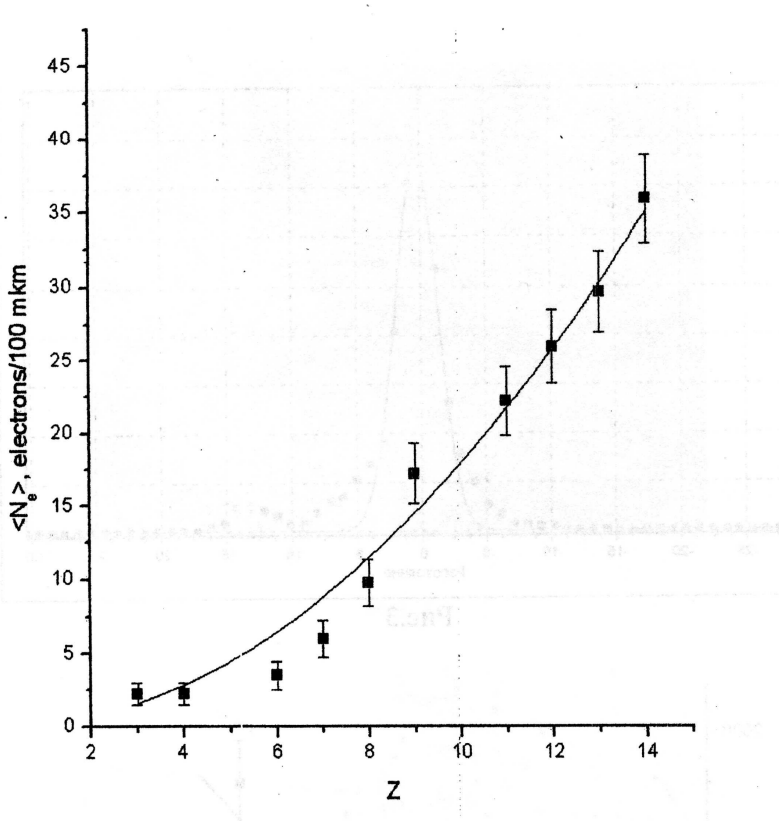


Calibrating curves

Total number of pixels of track

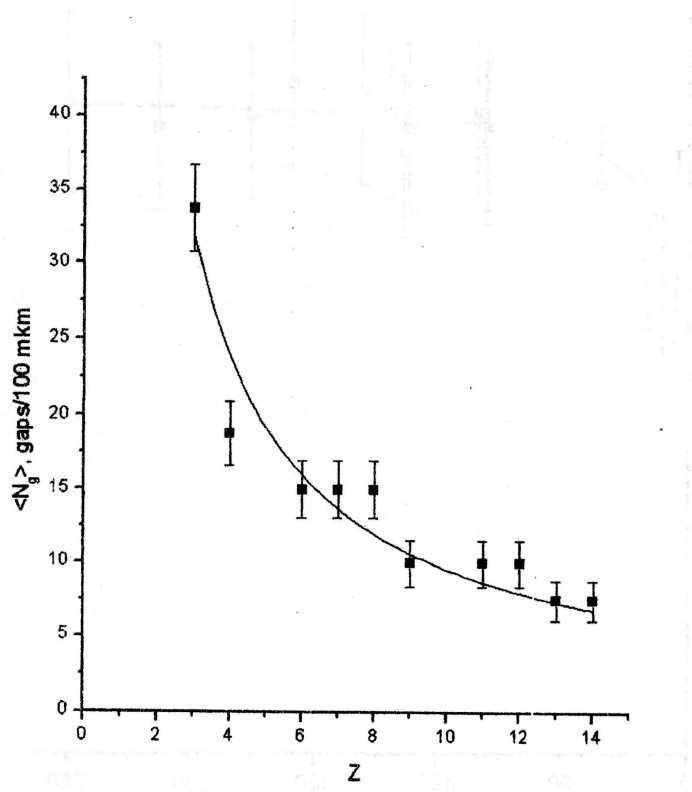


Number of delta electrons

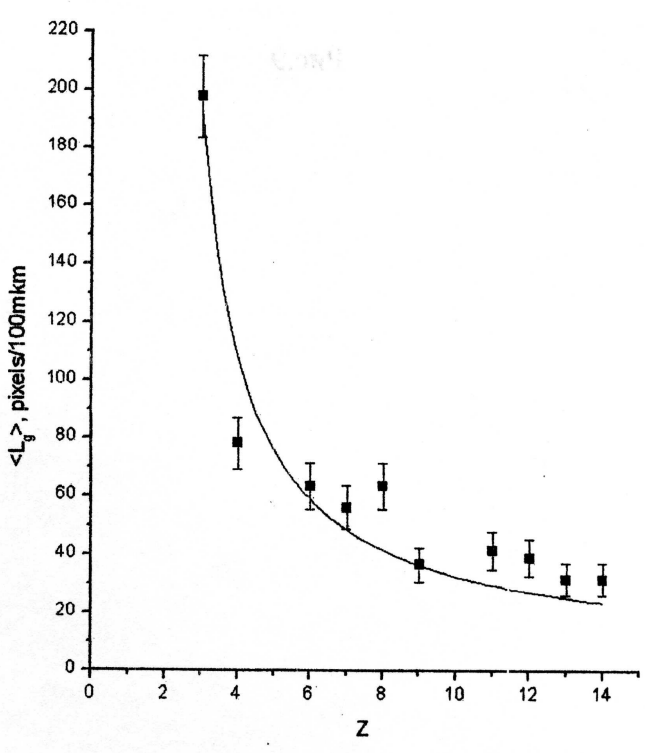


Calibrating curves
(light nuclei)

Number of gaps between track clusters



Total length of gaps

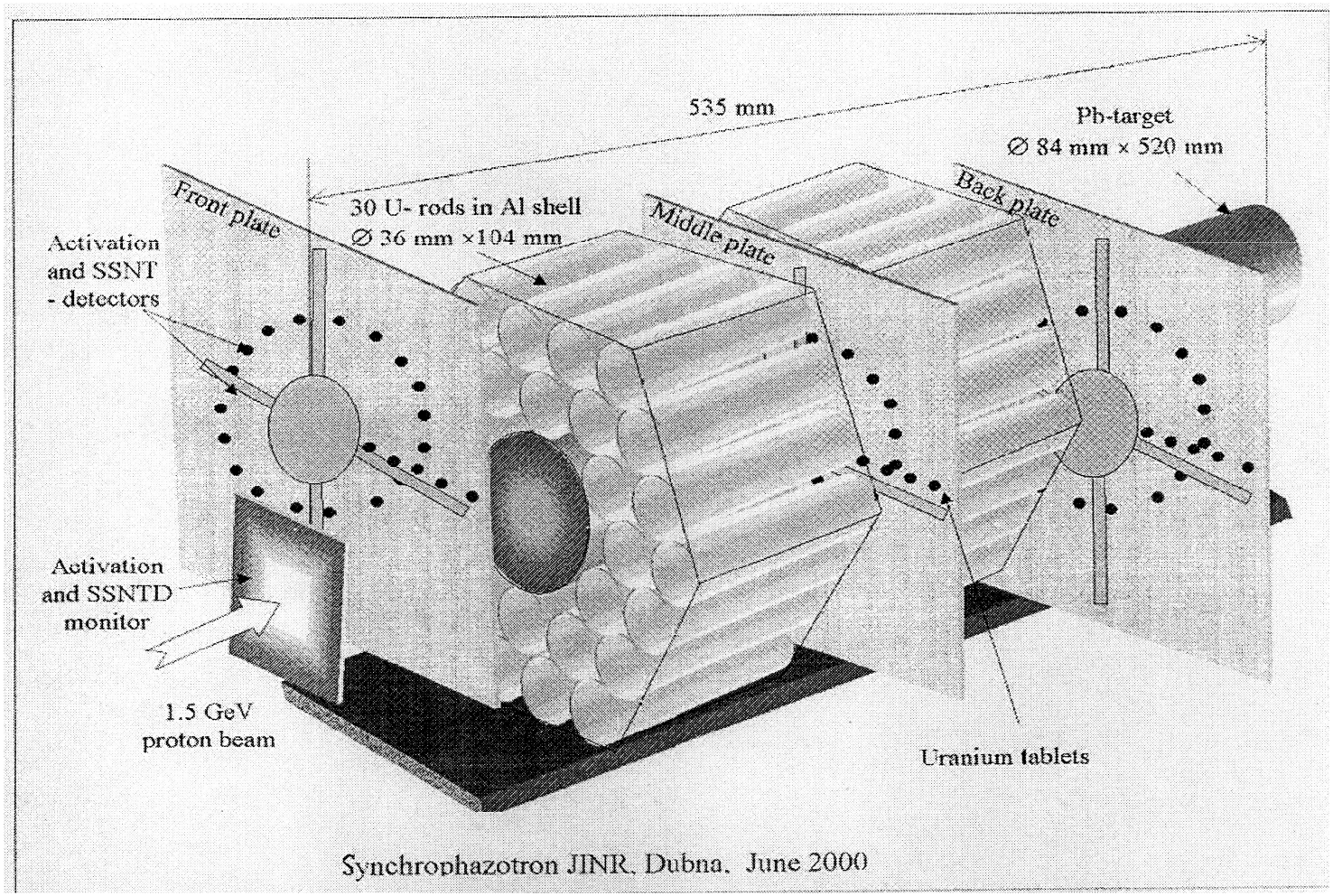


Comparison of handle and automatic measurements of charges

Event number	Handle		Automatic	
	projectile	fragment	projectile	fragment
174-43/153 90-39	12	10	12.2±0.4	10.2±0.3
174-43/174 80-48		5		4.9±0.3
174-43/180 67-52	12		12.2±0.4	10.2±0.3
174-43/88 44-55	12	6	12.2±0.4	6.6±0.5
174-43/169 75-48	10		9.7±0.6	4.2±0.9
174-43/129 48-39	10	6	9.3±0.6	5.9±0.4
174-43/59 08-68	14	13	14±0.5	13.3±0.5

Processing of “Energy-Transmutation” experiment data

Initializing of uranium decay with neutrons produced in inelastic proton interaction with lead target. Measurement of neutron flux from decay process.



Neutron flux is connected with number of radiator nuclei fragments.

=> Measurement of fragments traces in plastic detector

The problem: many tracks cross each other when flux is large

Solution: use fuzzy logic approach

Usual logic:

a=b => Yes (true) or No (falls)

Fuzzy logic:

With probability P a=b

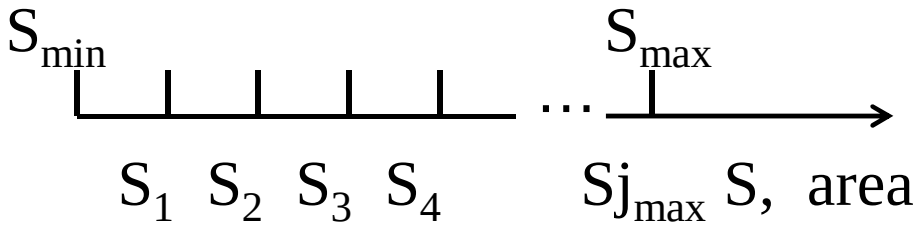
With probability 1-P $a \neq b$

Use probable description of crossing tracks number

Variable is the cluster area S_{CL}.

But the S_{CL} can corresponds to different tracks number

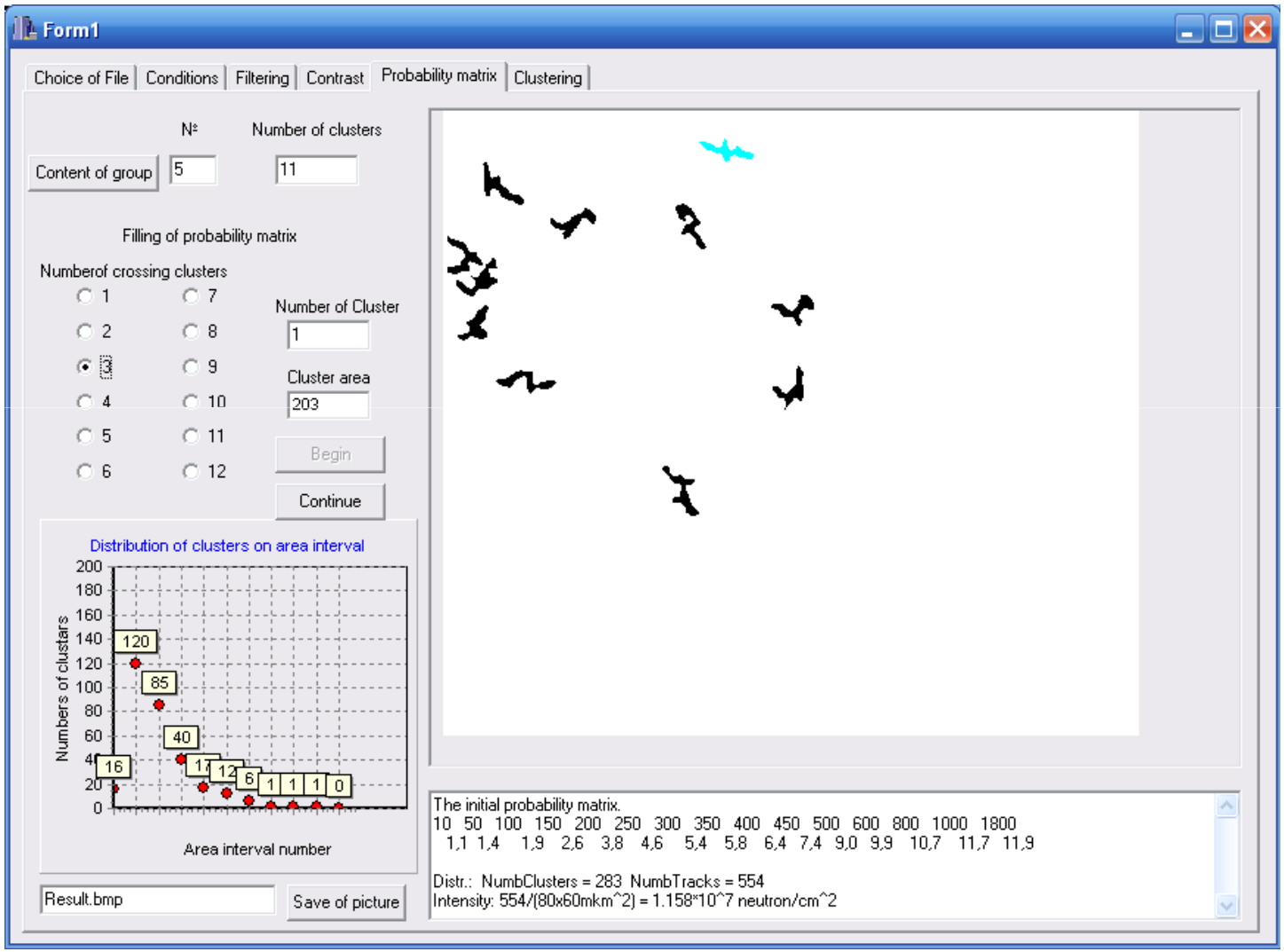
=> Probability matrix W is defined :



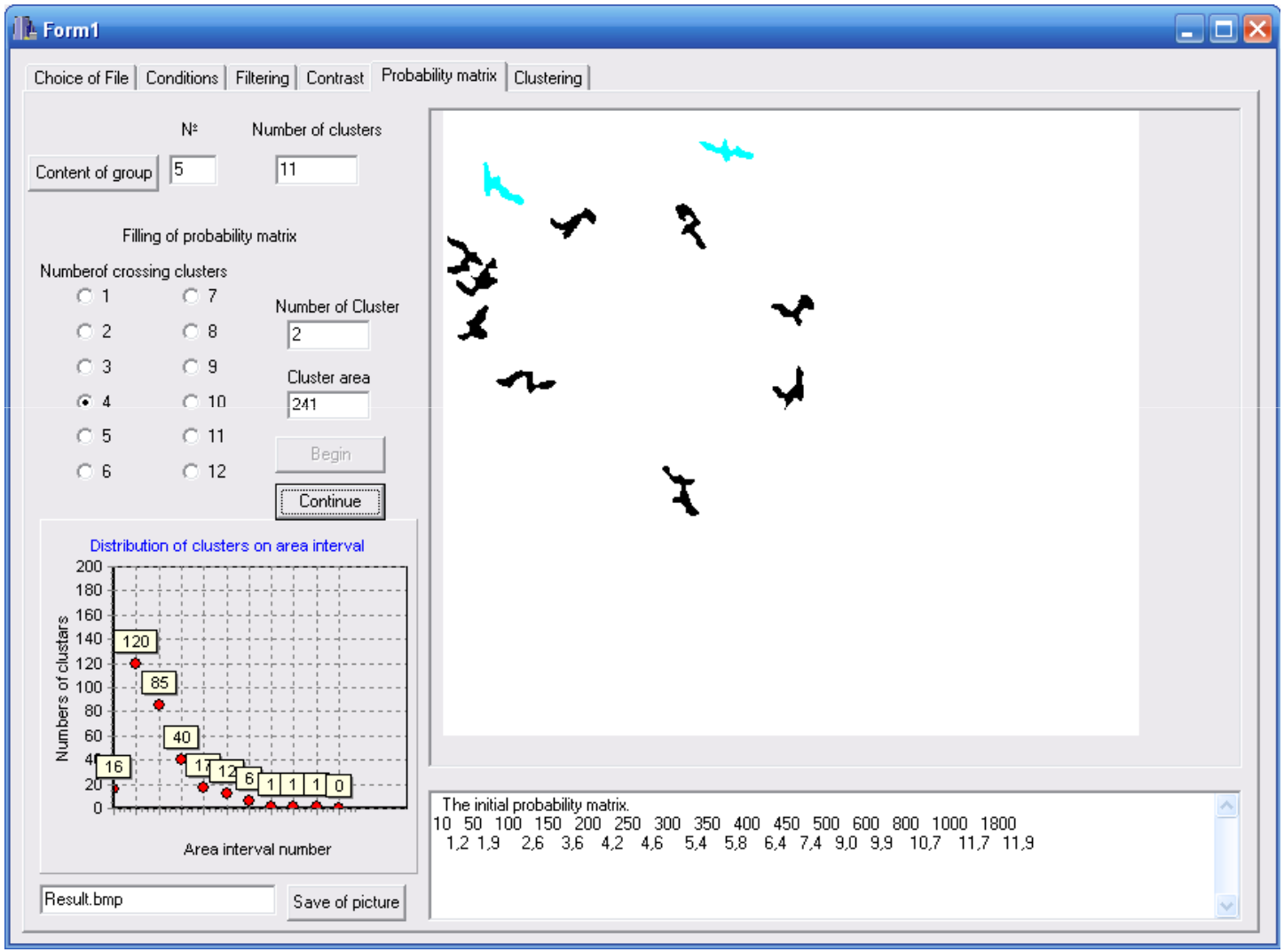
$$W(N, S_j), \qquad S_j \in (S_{\min}, S_{\max}), \qquad 1 \le j \le j^{\max}; 1 \le N \le N^{\max}$$

$$\hat{N}(S_j) = \sum_{N=1}^{N^{\max}} N \cdot W(N, S_j); \qquad \overline{N} = \sum_{j=1}^{j^{\max}} n_j \cdot \hat{N}(S_j)$$

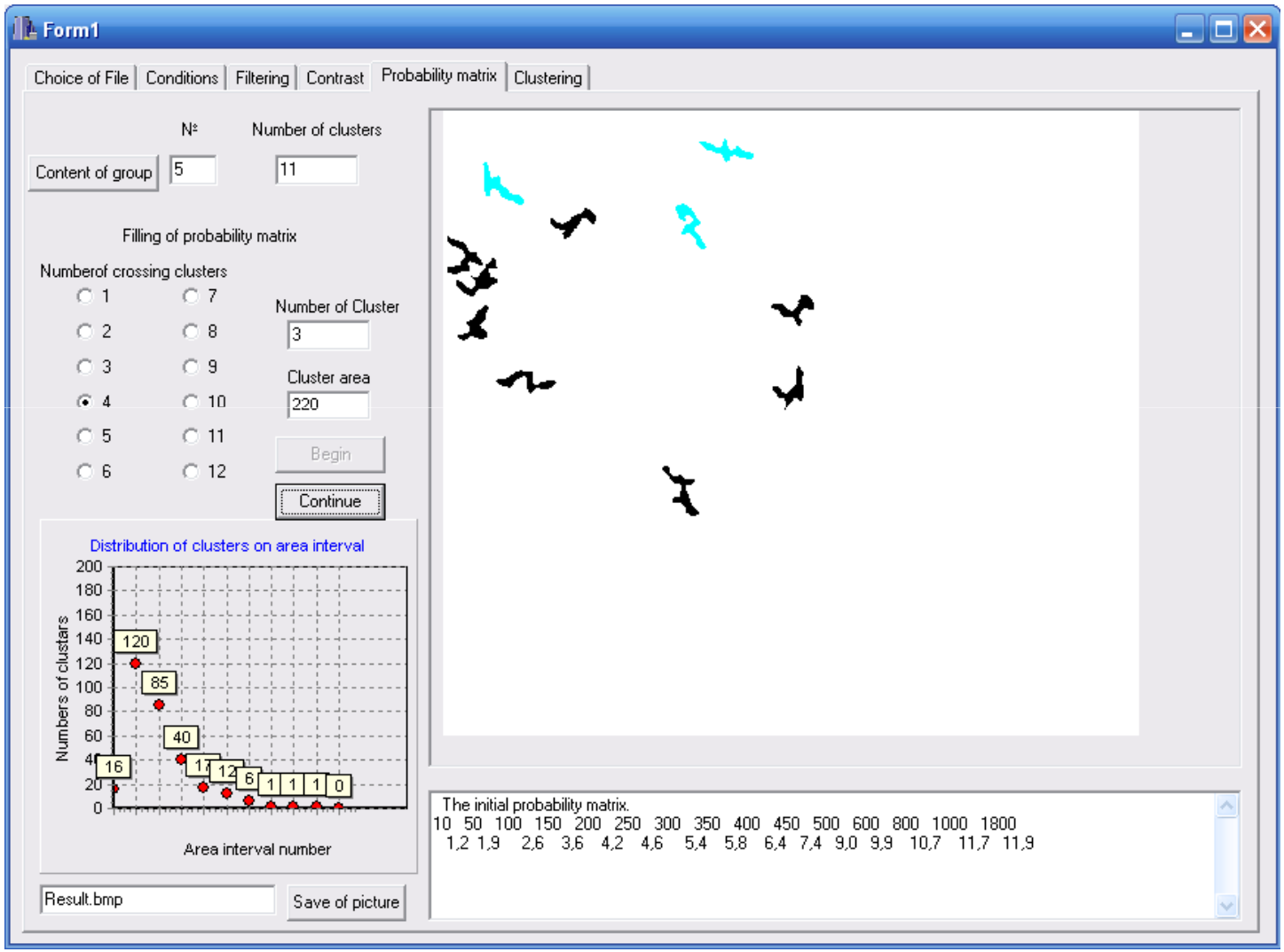
The dialog window for training procedure



The dialog window for training procedure



The dialog window for training procedure



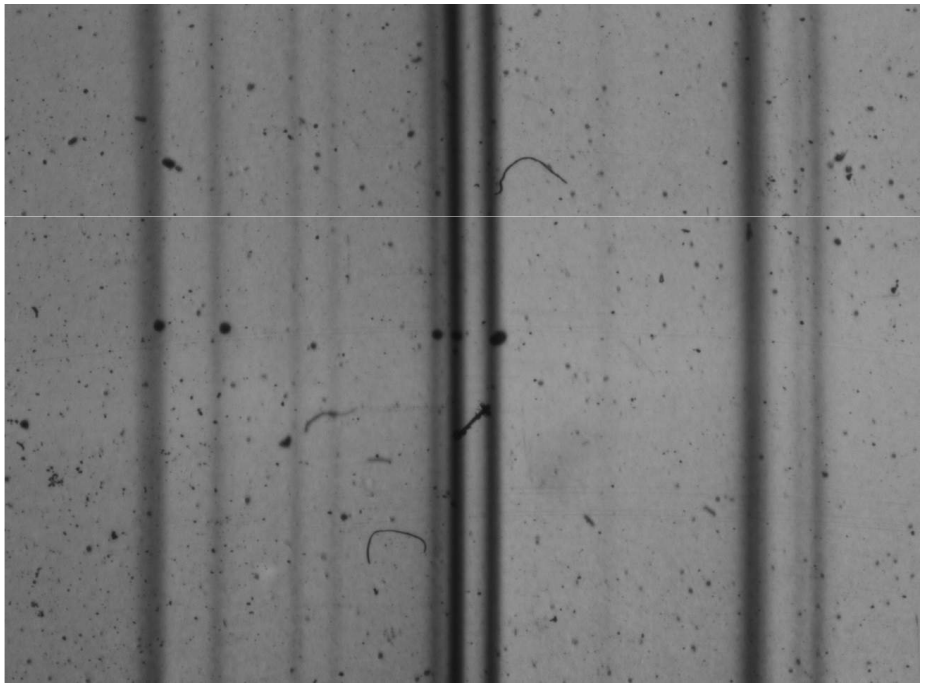
Result:

There are 283 clusters. It corresponds to 554 tracks.

==> The flux is ~ 1,15 10^7 fragments/cm^2.

Investigation of spectra of inner-conversion electrons

(lanthanides isotopes of Er, Ho, Dy, Gd …).



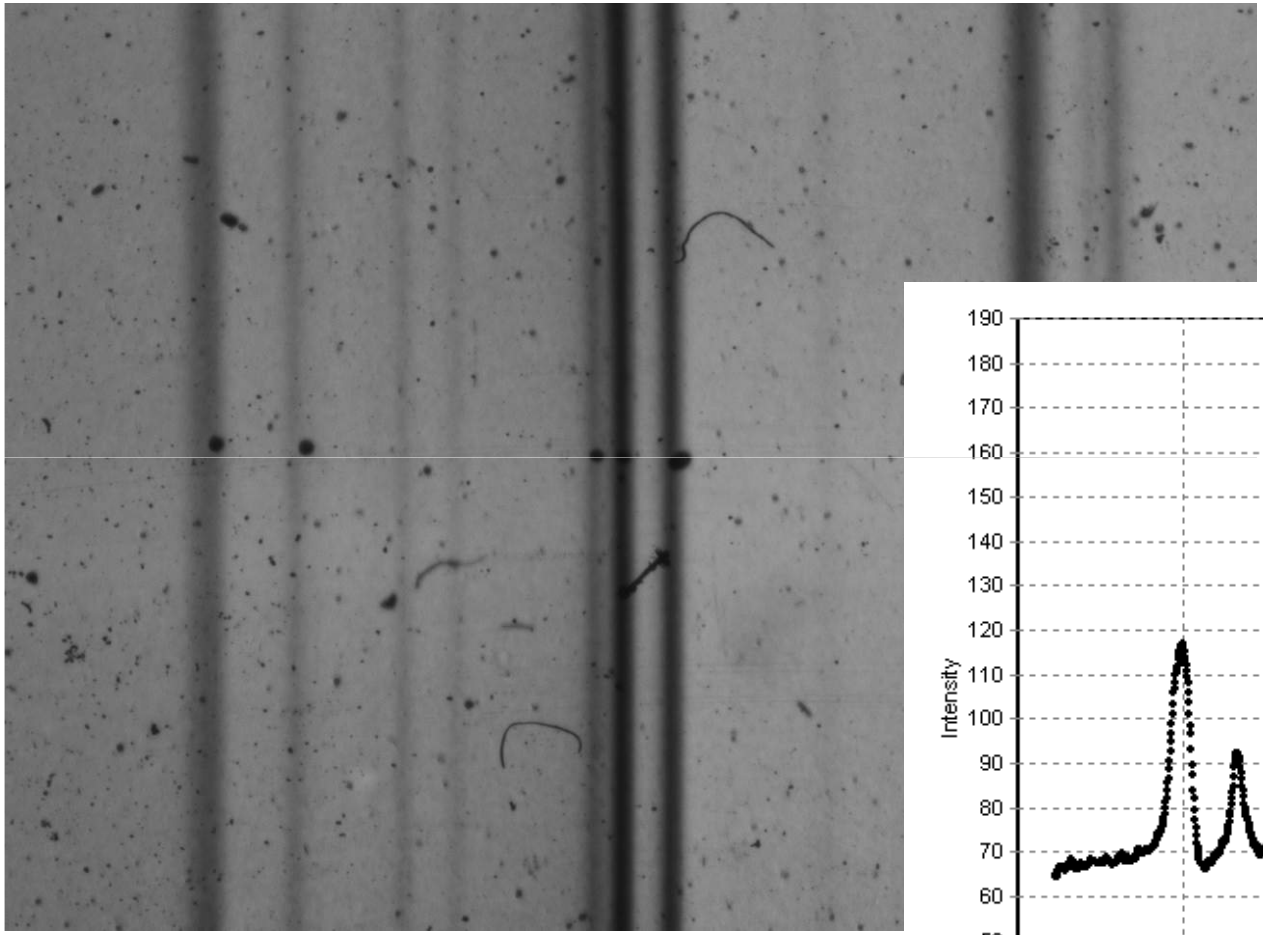
1. Preliminary filtering is not used because it is necessary to compare brightness of lines but filters change it.

2. The sum of vertical pixels amplifies useful signal and reduces noise.

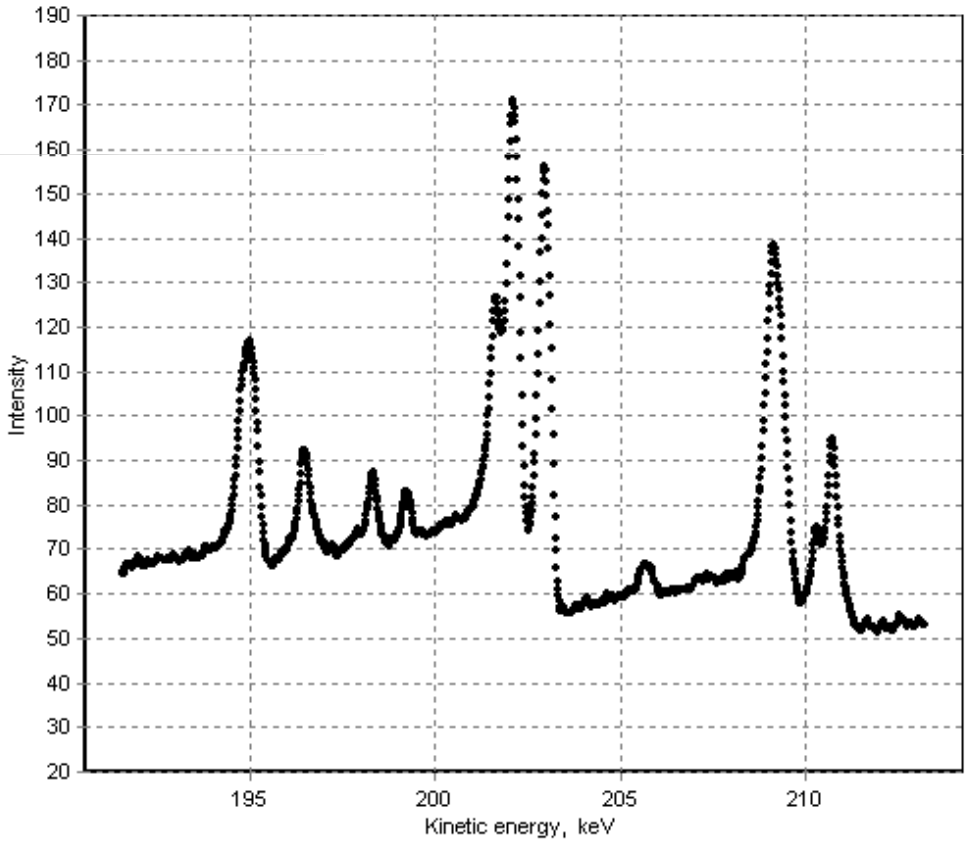
3. Noise: spots, scratches, non-uniform of illumination.

Investigation of spectra of inner-conversion electrons

(isotopes of Er, Ho, Dy, Gd …).

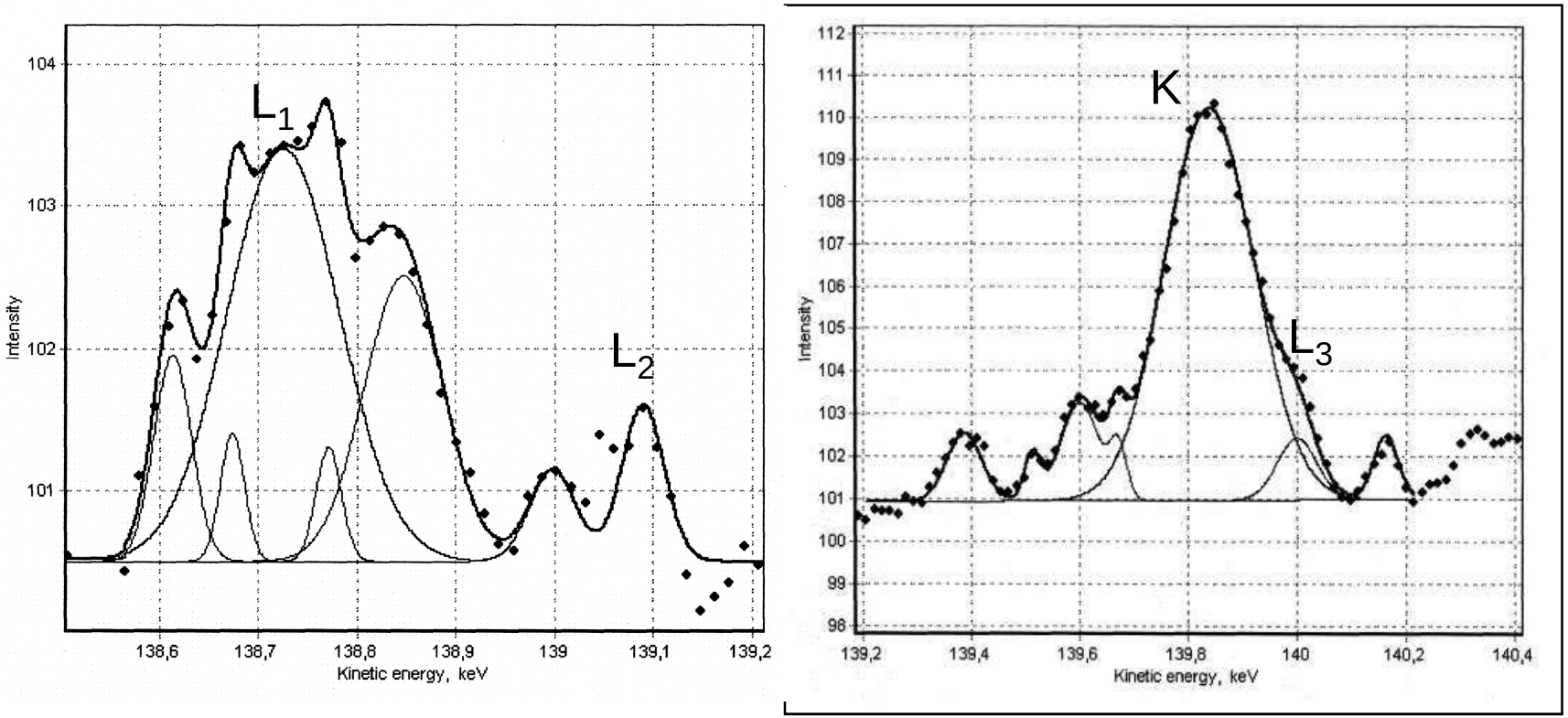


There are 40 fields of view of such kind

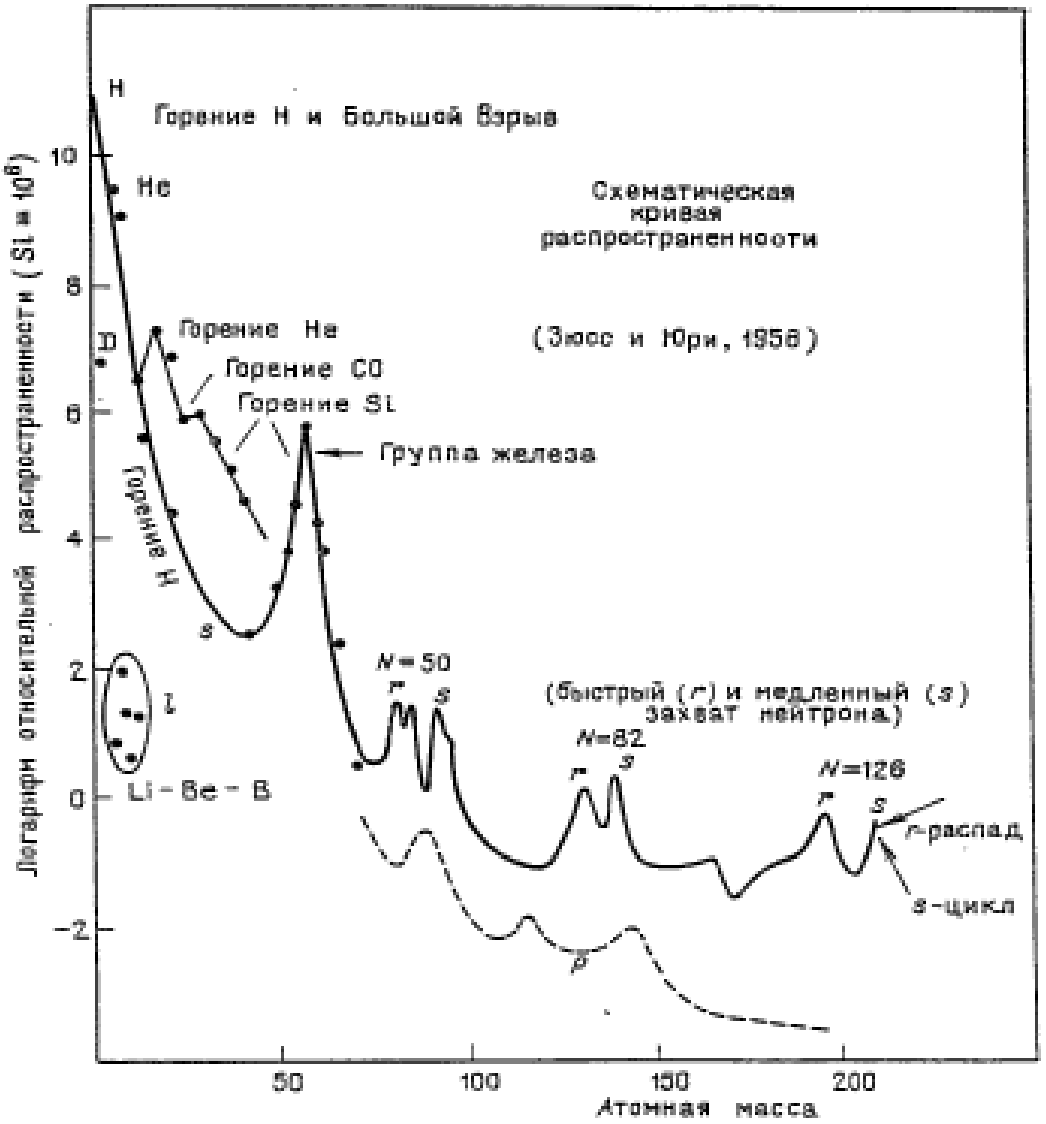


Identification of lines L_1, L_2, L_3 ICN of ^{161}Ho

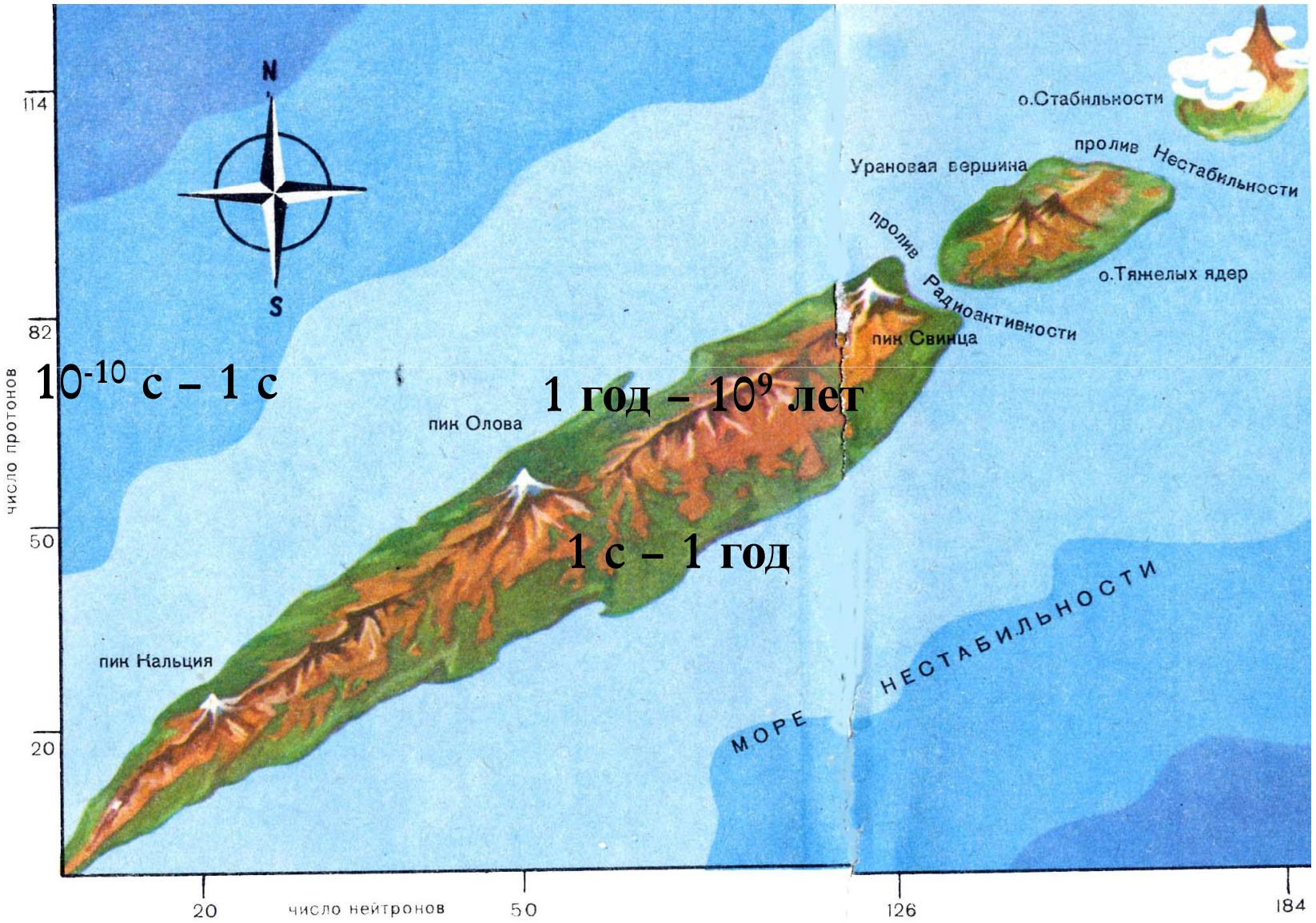
(L_2, L_3 are new; known line K scales of energy)



Investigation of olivine from meteorites
Study of charge spectrum super heavy nuclei in space



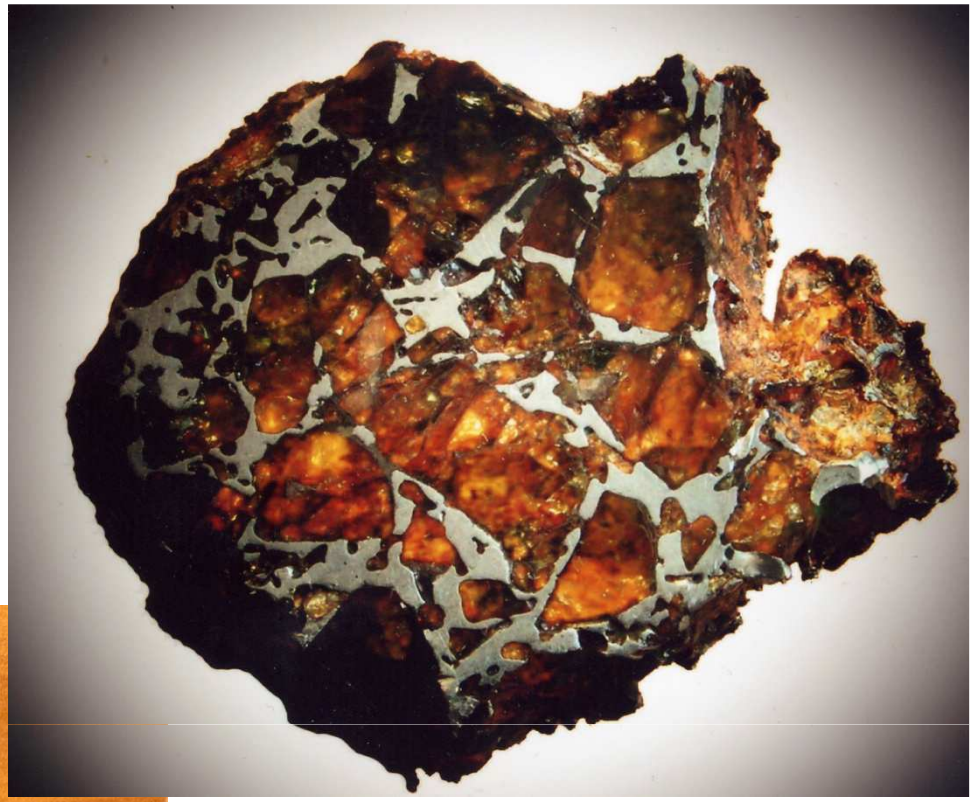
The position of stability island (neutron-proton coordinates)



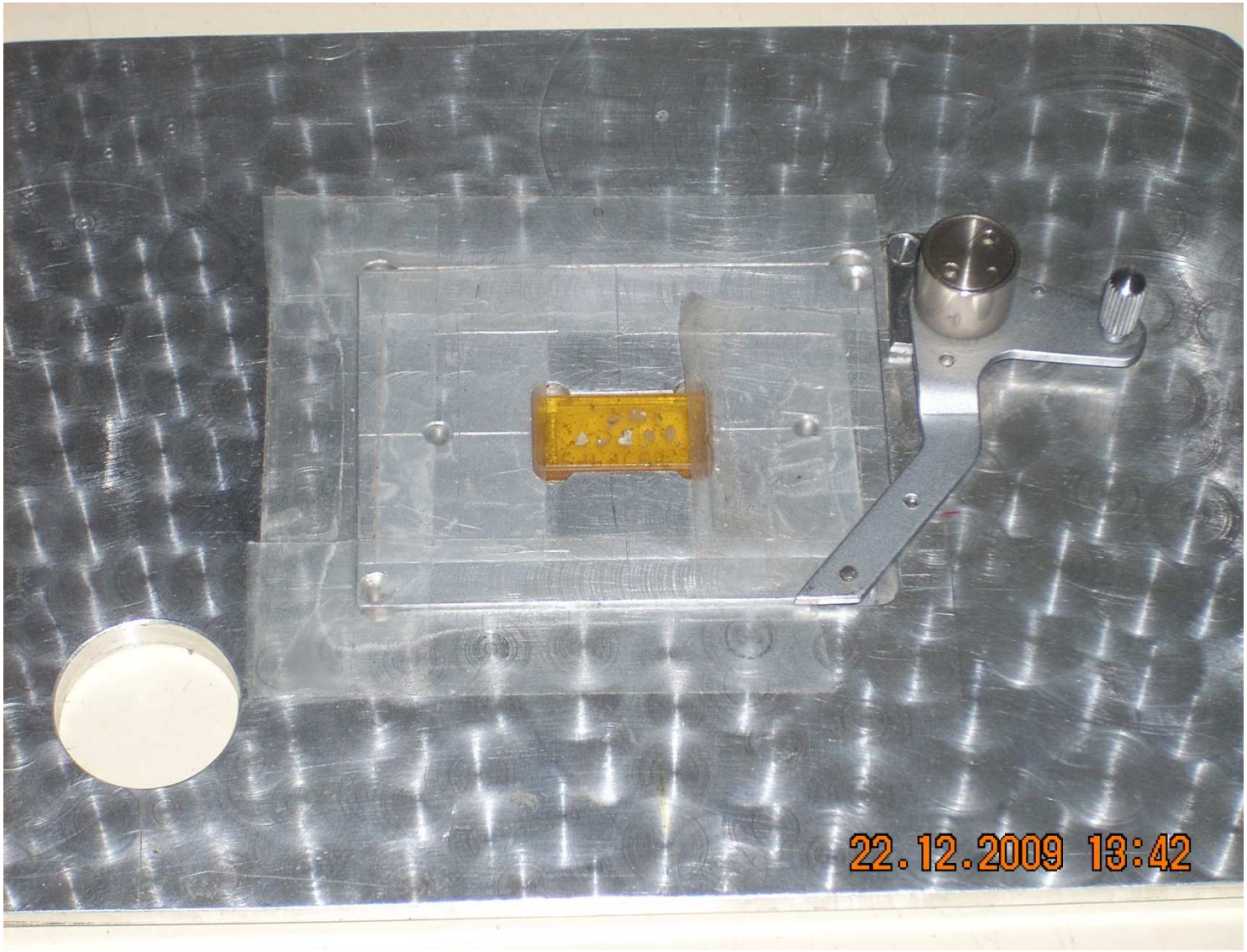
«OLIMPIYA»

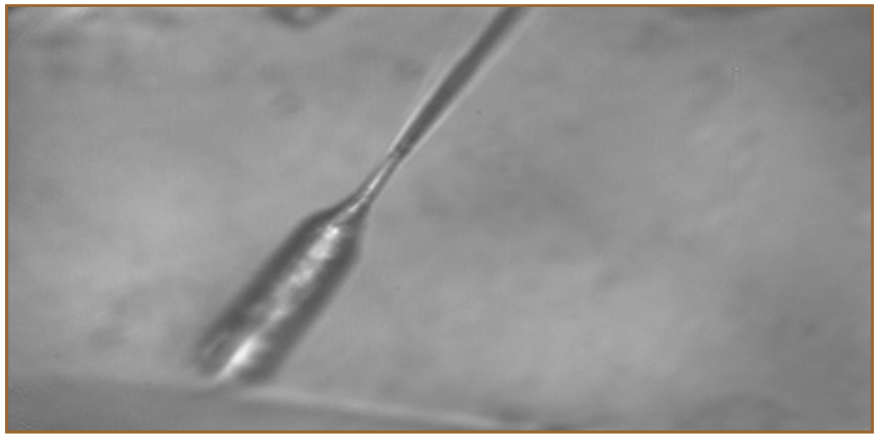
«ОЛИПИЯ»

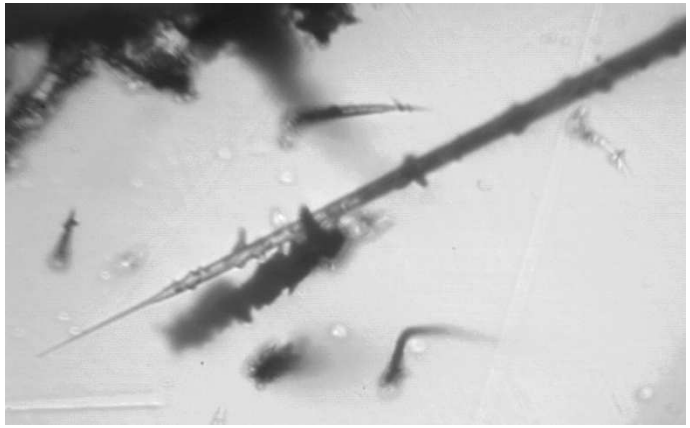
(«ОЛИвины из Метеоритов – Поиск тяжелых и сверхтяжелых Ядер»)

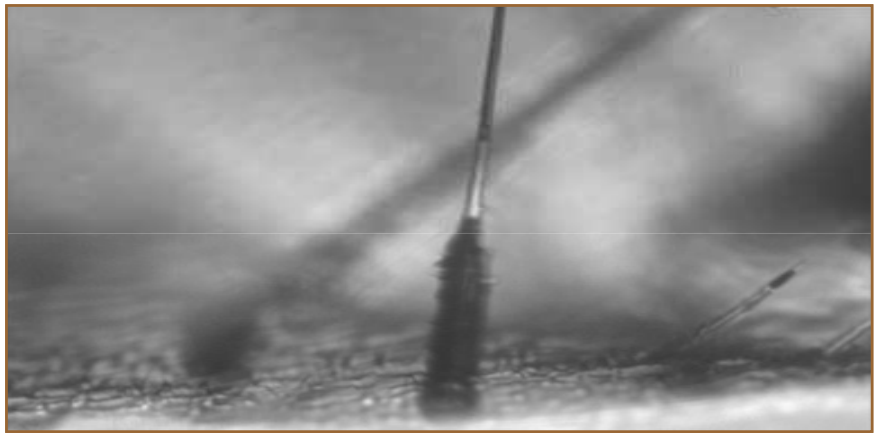


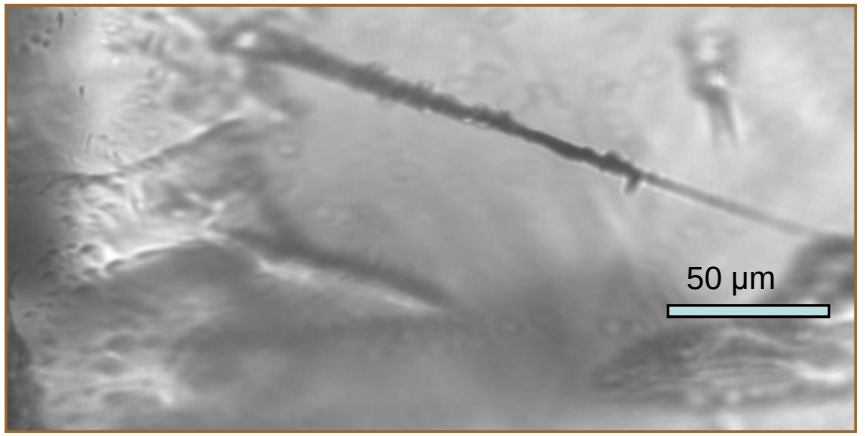
Epoxy tablet with olivine crystalls



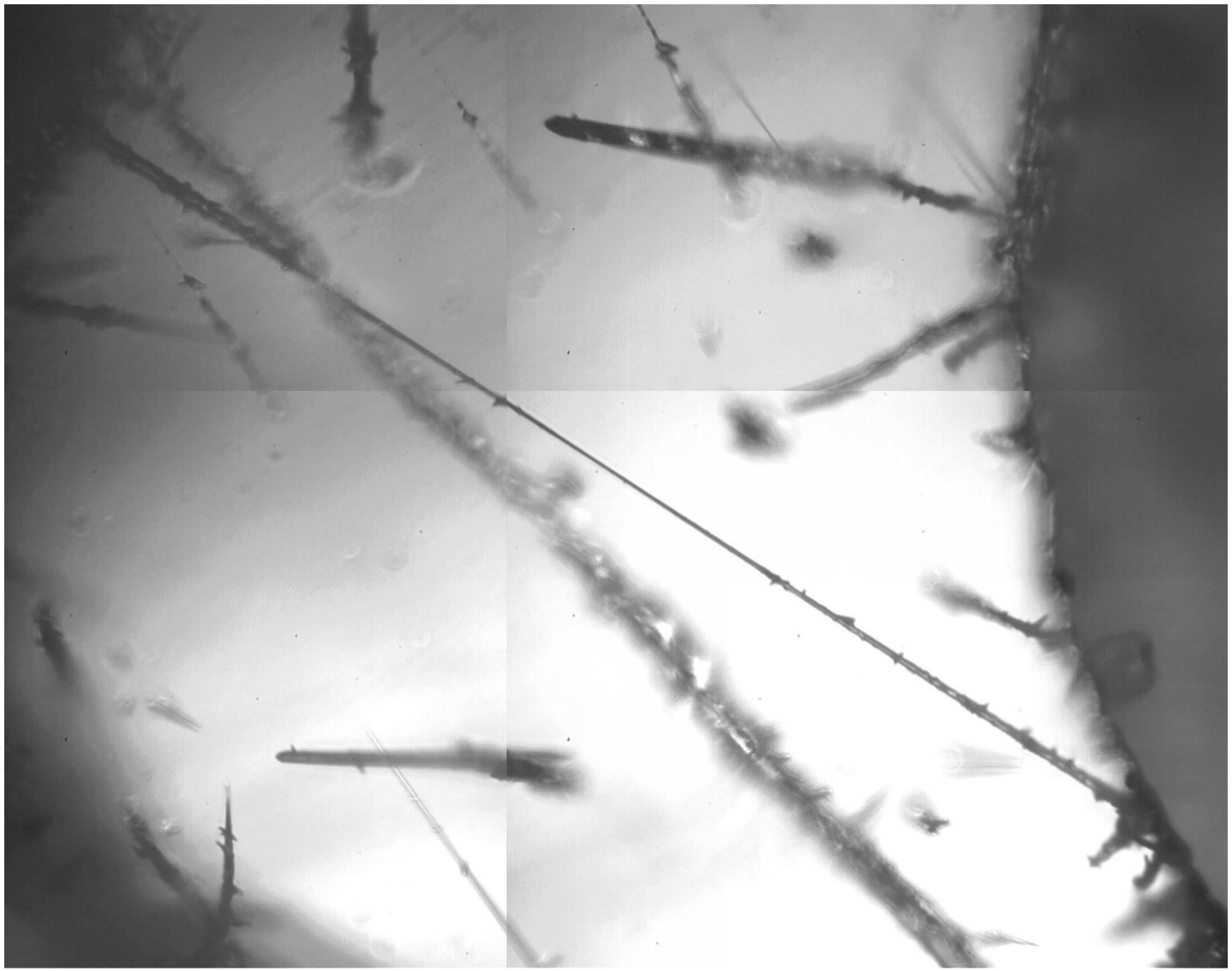






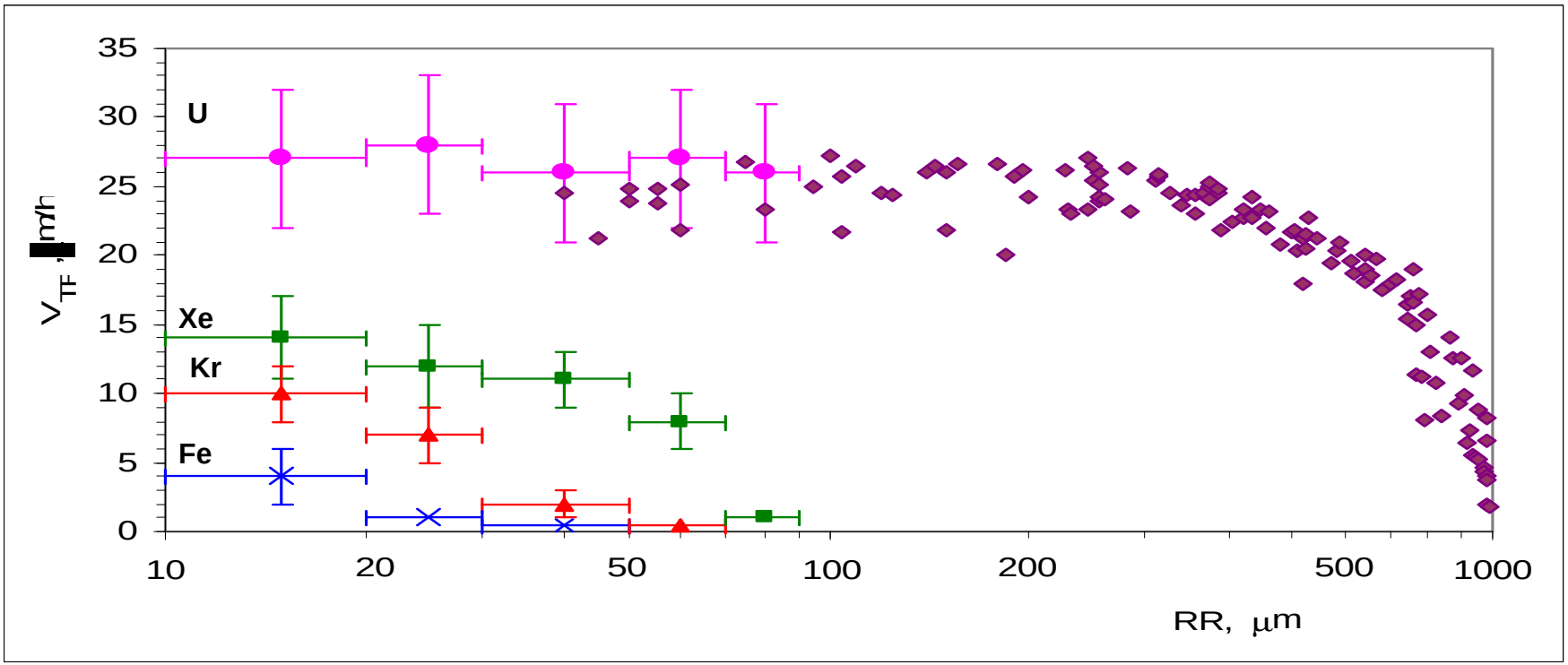

50 µm

Sample of very long track (L>700 mcm; Z>70)



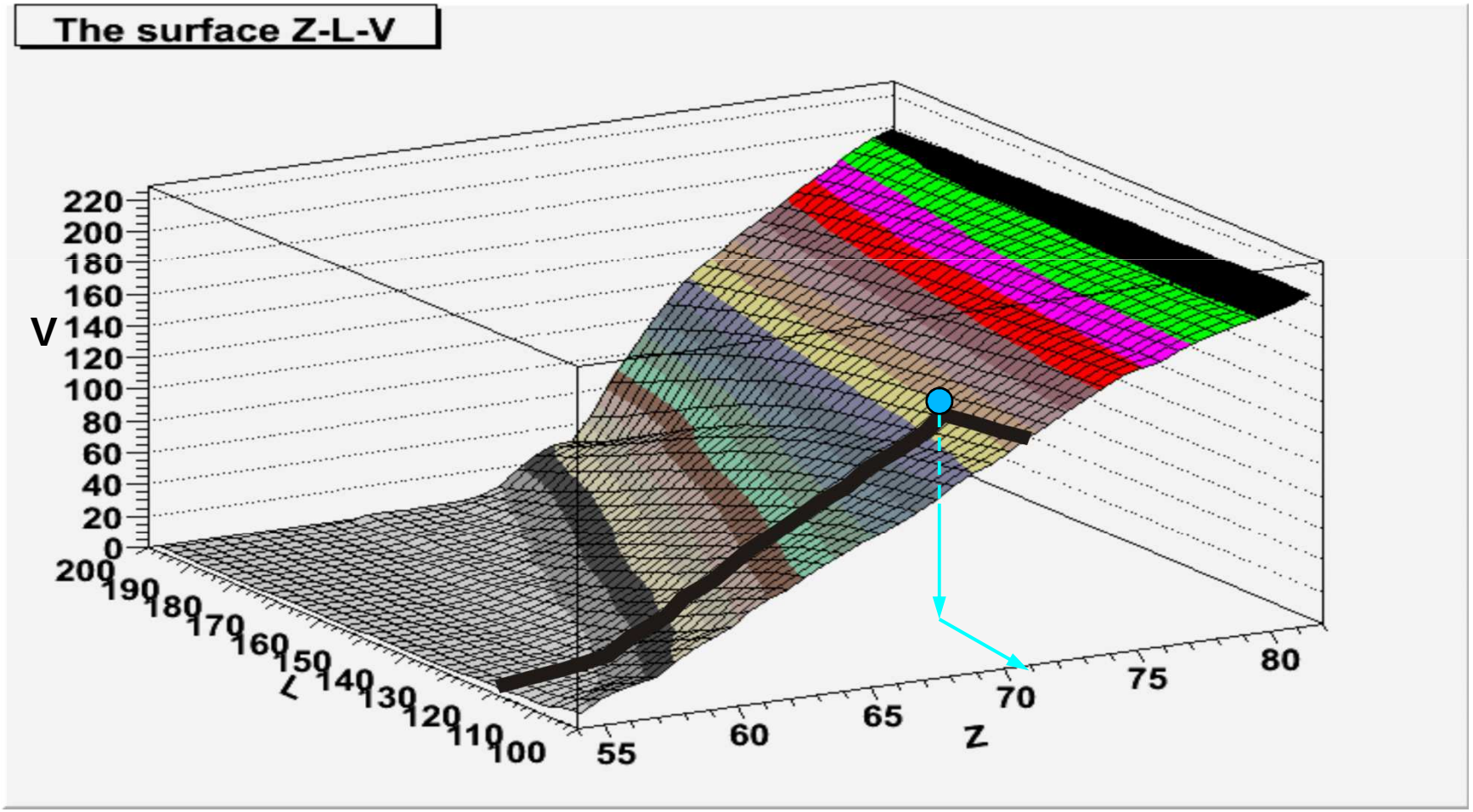
Track-etch rate (V_{TR}) in the pallasite Marjalahti olivine crystals from accelereted Kr, Xe and U ions and Fe cosmic ray nuclei

Ion	E, MeV/nucl	V_{TR} (μm/h) at RR (μm)				
		15 ± 5	25 ± 5	40 ± 10	60 ± 10	80 ± 10
Fe	>5	4 ± 2	~0.1	~0.05	–	–
Kr	10.2	10 ± 2	7 ± 2	2 ± 1	~0.1	–
Xe	11.4	14 ± 3	12 ± 3	11 ± 2	8 ± 2	≤1
U	11.4	27 ± 5	28 ± 5	26 ± 5	27 ± 5	26 ± 5

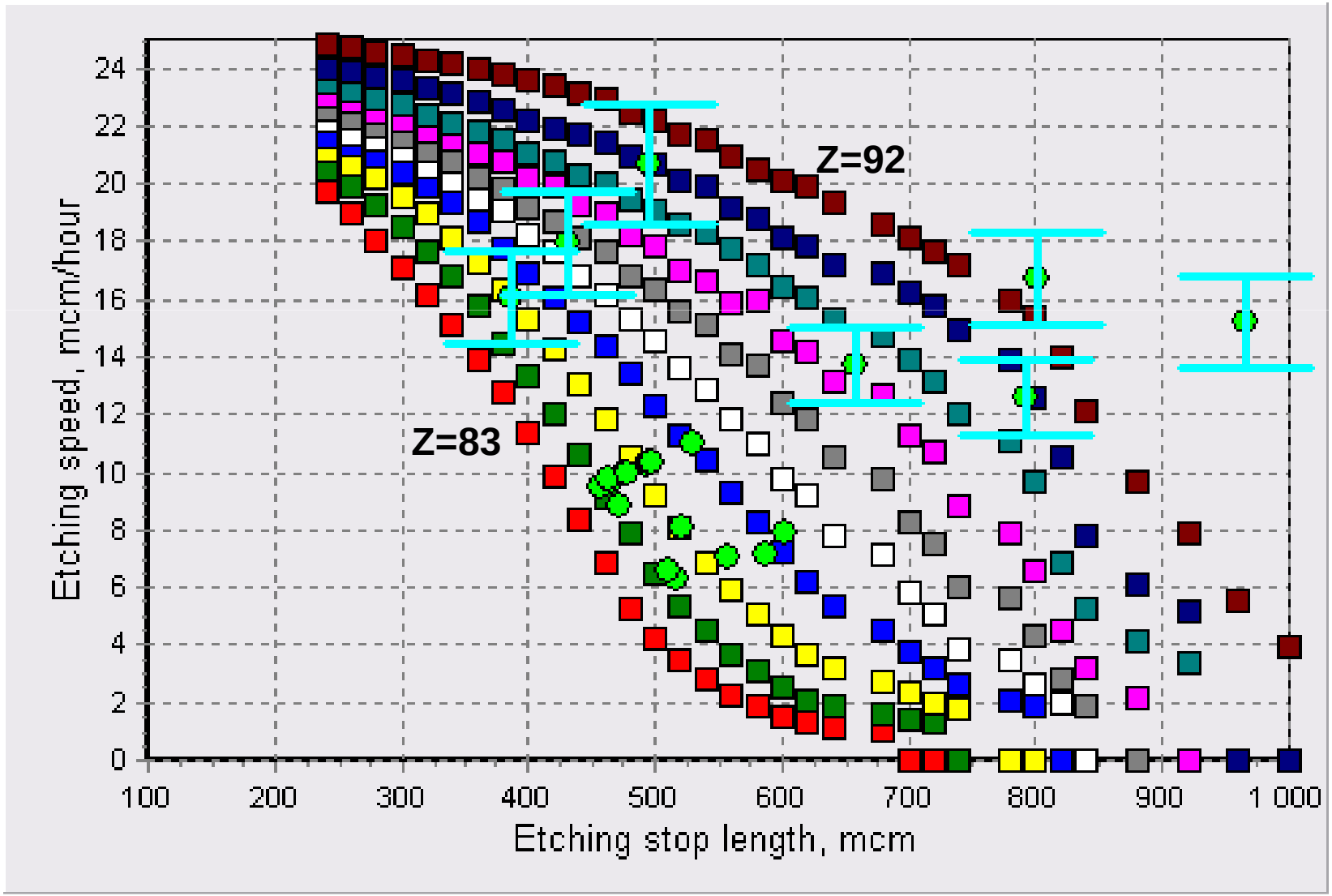


Measured V_{TR} values at the certain residual range (RR) of accelerated Kr, Xe and U ions and GCR Fe nuclei in olivine crystals from the Marjalahti pallasite
Data for U at RR>100 μm by Perron and Maury, 1986

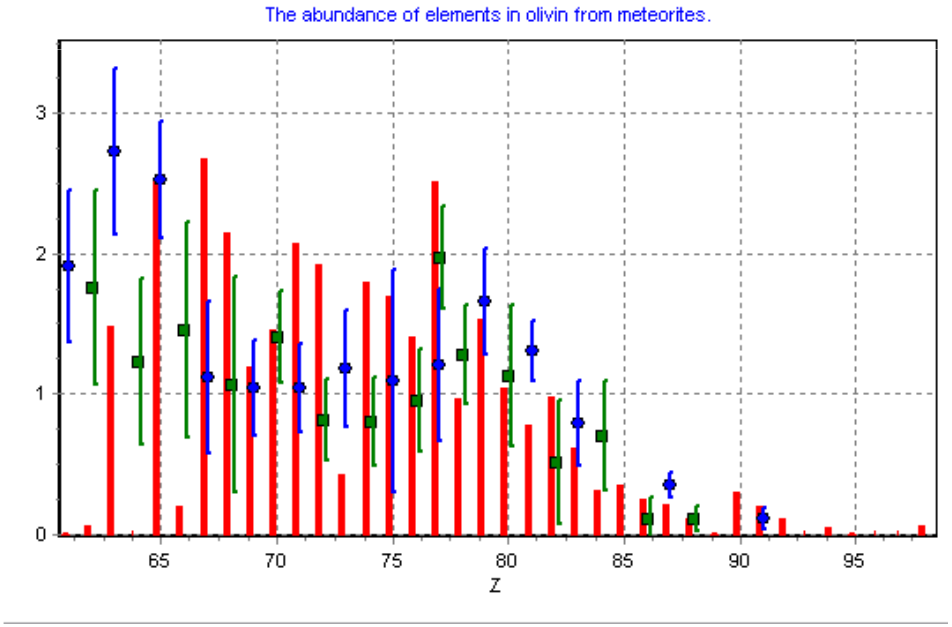
Dependence between charge Z, track length L and etch rate V.

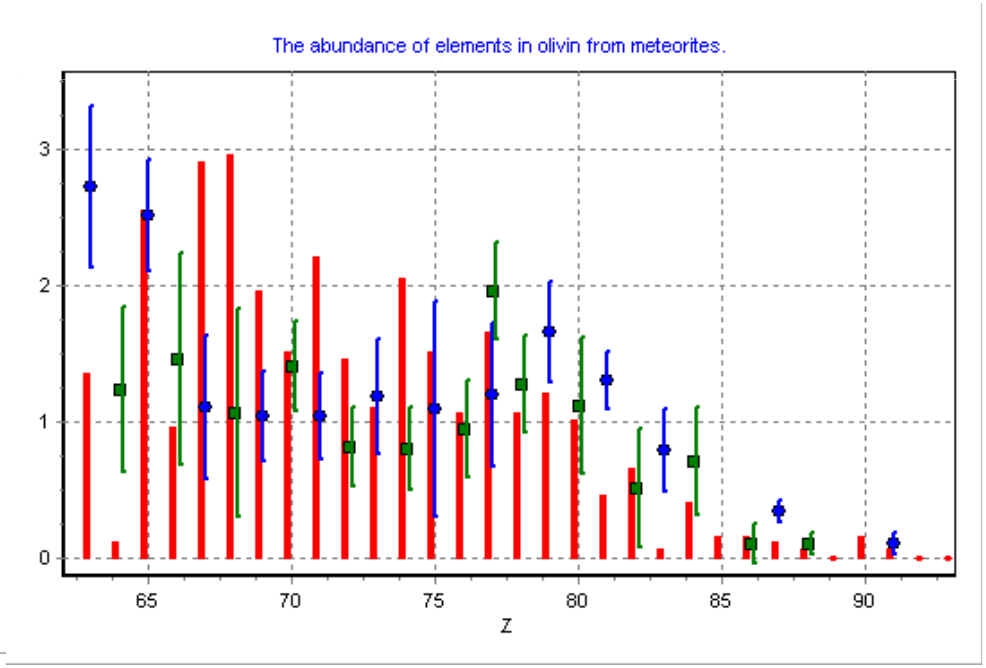


The result of heavy nuclei processing
Z` > 83



Abundance of super heavy nuclei in comparison with Ariel 6 – o and HEAO 3 - □ data. (Abundance of Fe = 10^6)





Besides three nuclei where found whose charge is more 100.

Our calculations give estimation

$106 < Z < 130$
Lifetime > 3000 years

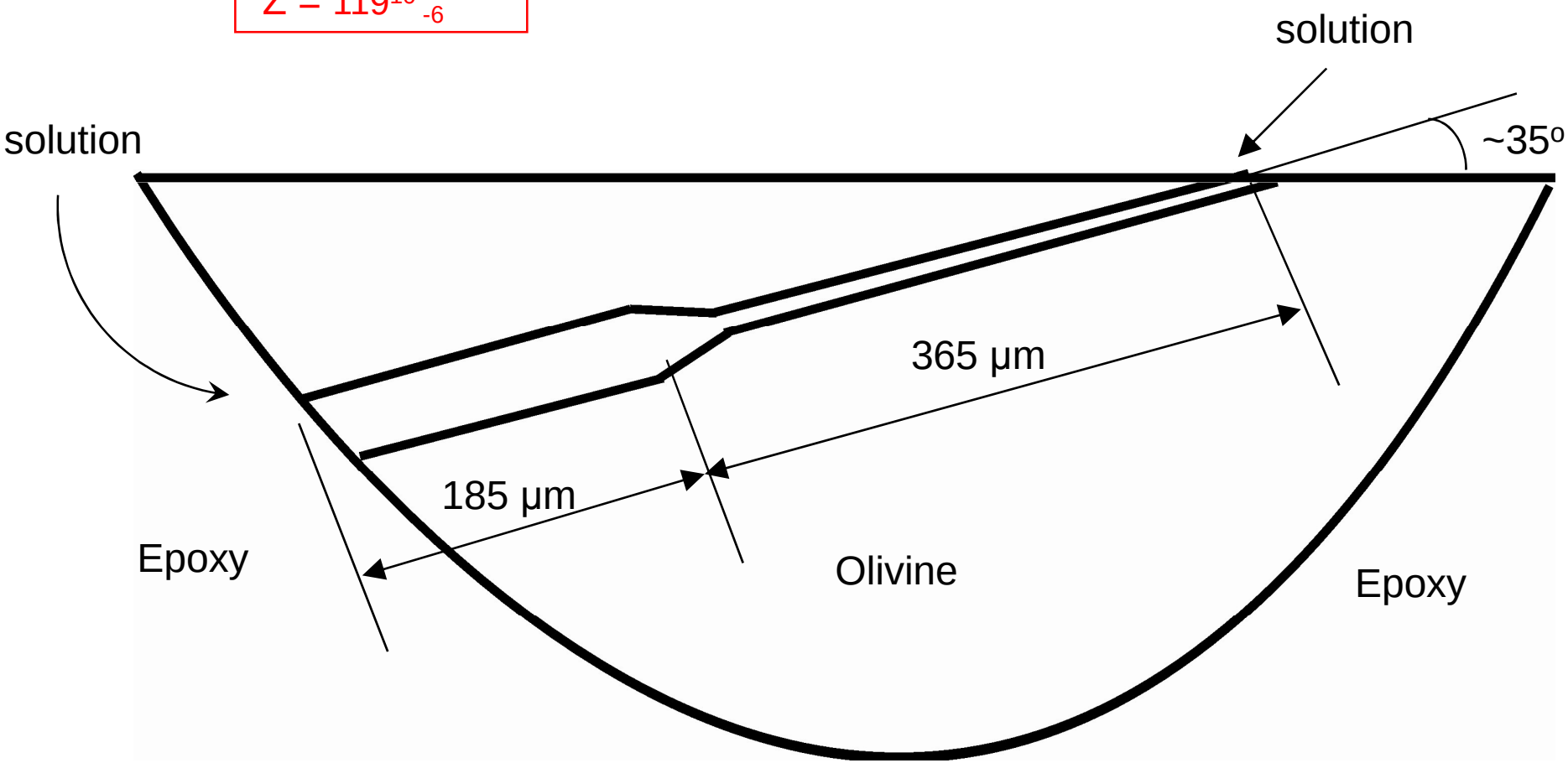
The charge of one of them is defined more exactly

The total track length in olivine is ~550 μm. The etch time is 8 hours.

But the etch solution can reach to track from both sides.

⇒ The minimum etch rate is about 35 μm/h

$Z = 119^{10}{}_{-6}$

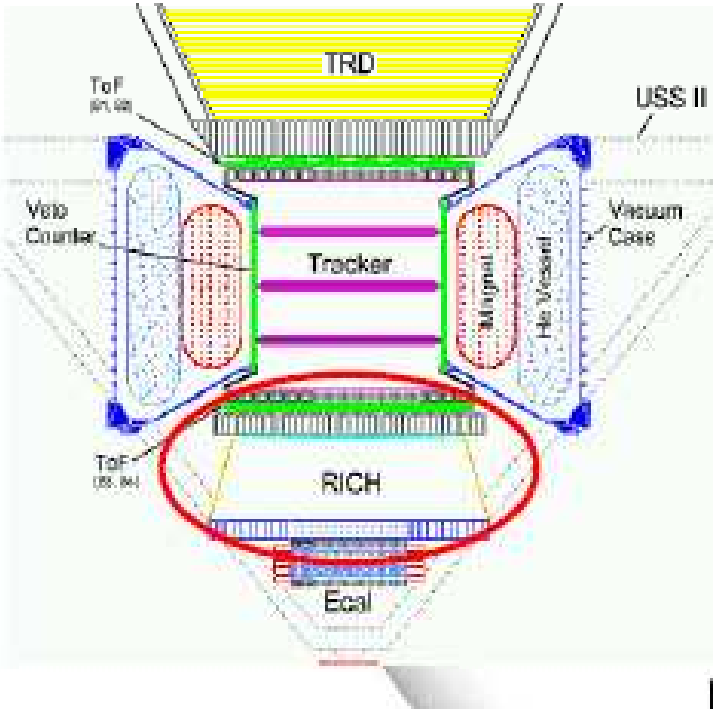


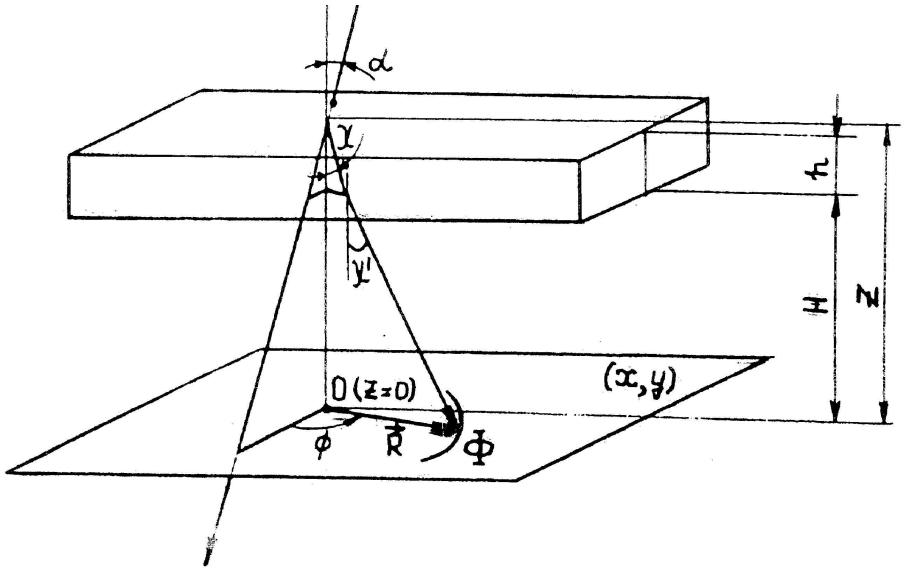
Обработка данных RICH-детектора с помощью нейронной сети

(определение заряда и скорости)

Alpha Magnetic Spectrometer

(AMS)

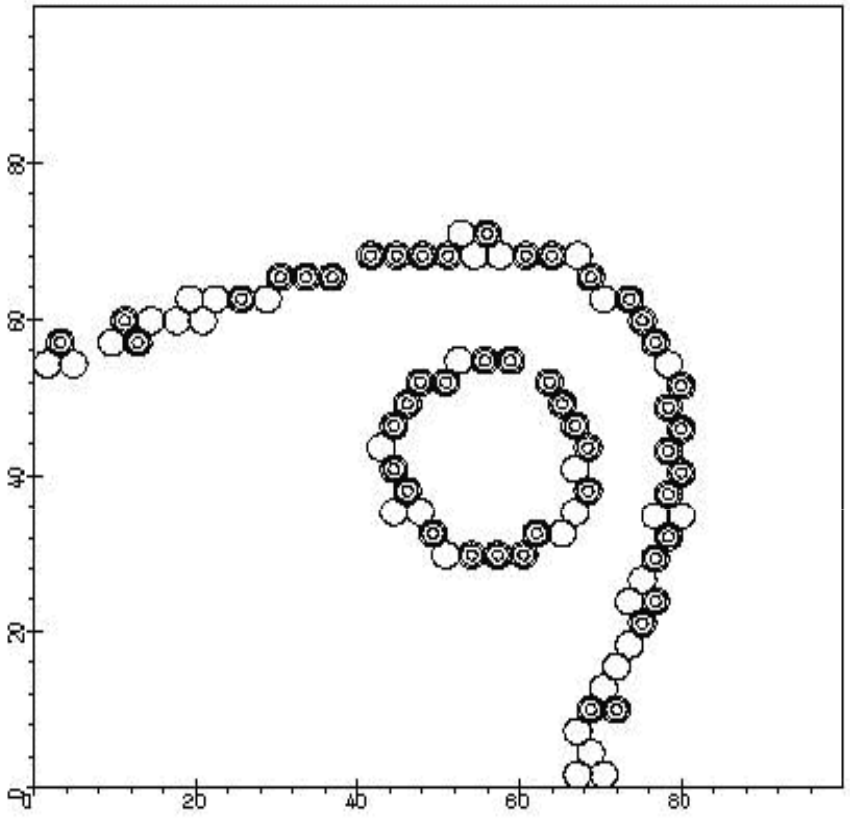


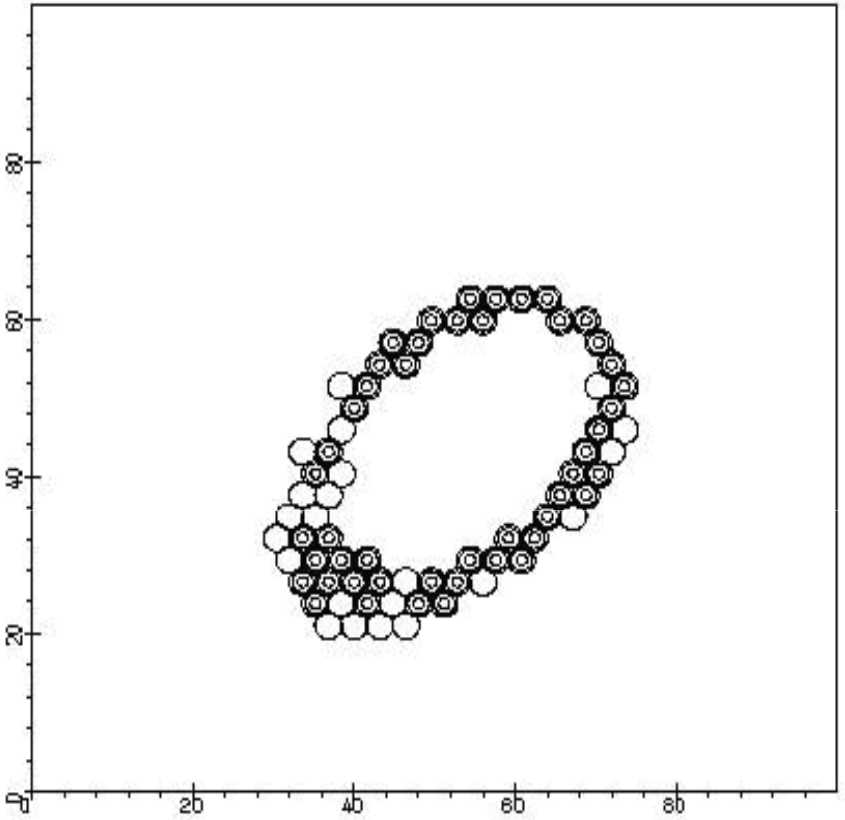


$\cos(\chi)=1/(\beta n) \quad (\beta n>1)$

$$d^2N/d\lambda dx = (2\pi/137)\cdot(Ze)^2\,(1 - 1/\beta^2 n^2(\lambda))\cdot/\lambda^2$$

Результат работы RICH-детектора

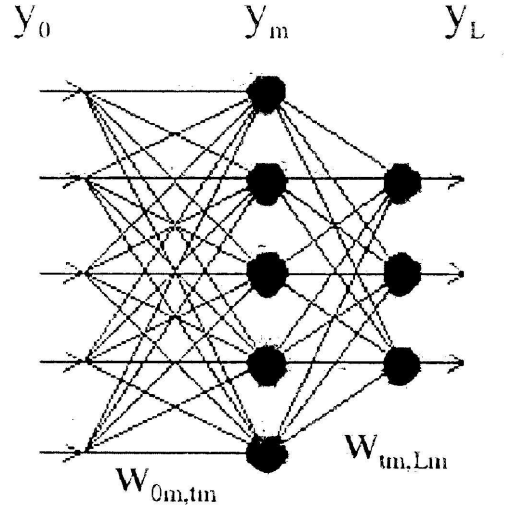




Необходимые данные: координаты точки входа частицы (x, y, углы θ, φ), амплитуда и координаты сработавших ФЭУ.

Принцип работы нейронной сети Хопфилда

(обучение с обратным распространением ошибки)



$$s_{j,m} = f\left(\sum_{i=1}^{N_{m-1}} s_{i,m-1} \cdot W_{j,m;i,m-1} - b_{j,m}\right)$$

$$f(x) = (1+e^{-x})^{-1}$$

Входной вектор: полная амплитуда, ширина фигуры, образуемой сработавшими ФЭУ, и азимутальный угол φ

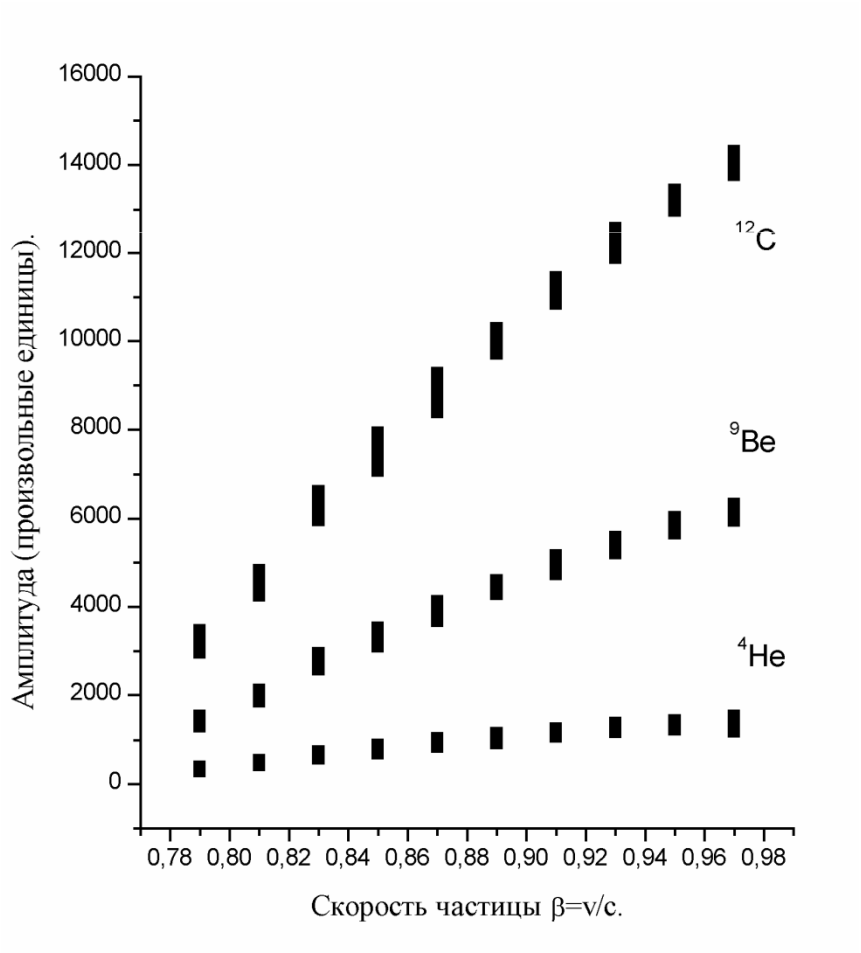
Выходной вектор: заряд, скорость

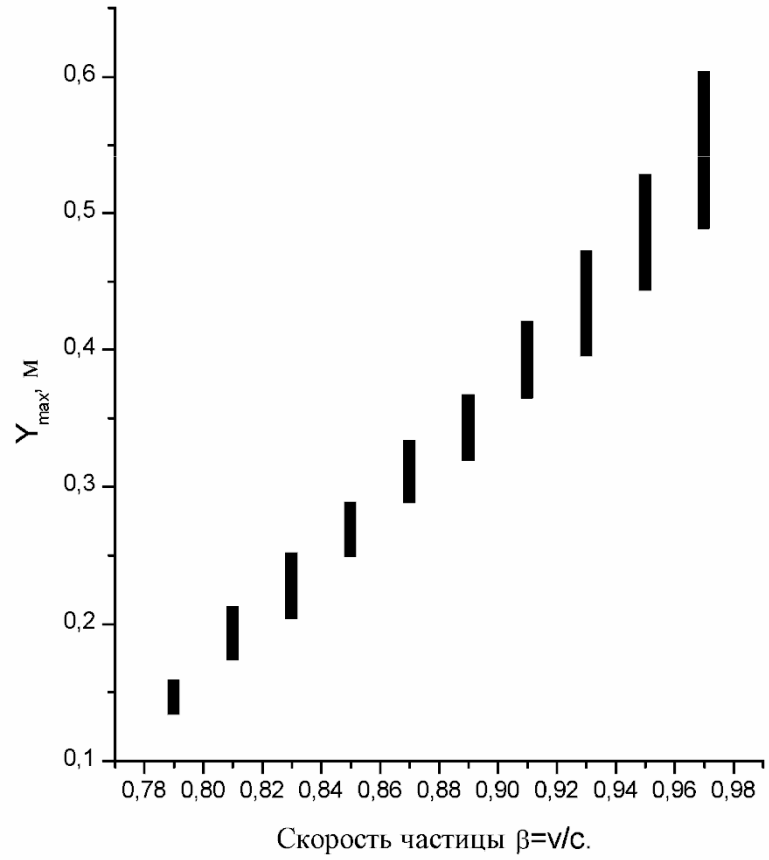
Не нужно решать обратную задачу

Входной вектор: полная амплитуда и координаты сработавших ФЭУ, азимутальный угол φ

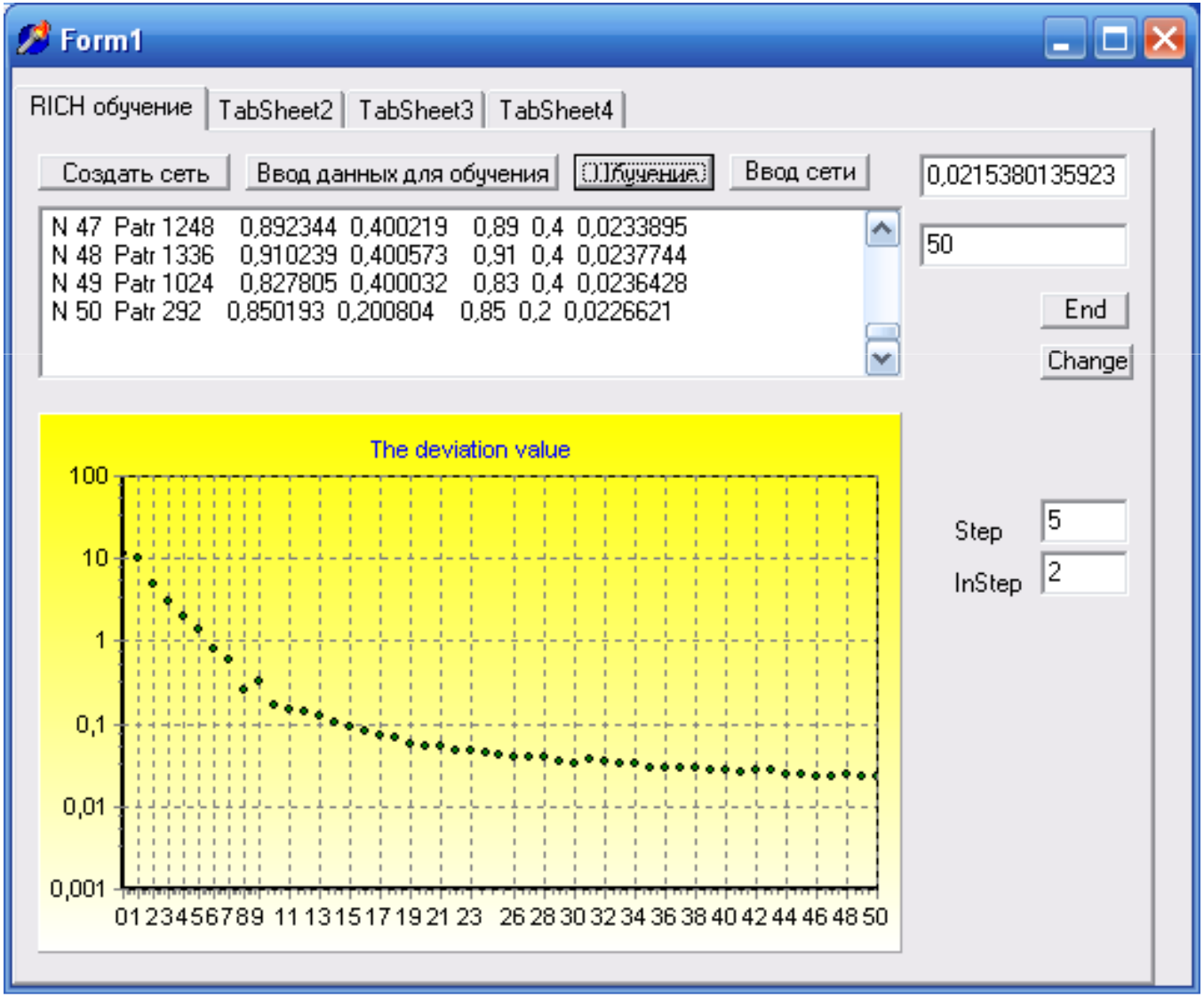
Выходной вектор: заряд, скорость

Обучение: 2400 событий (3 заряда, 10 скоростей)

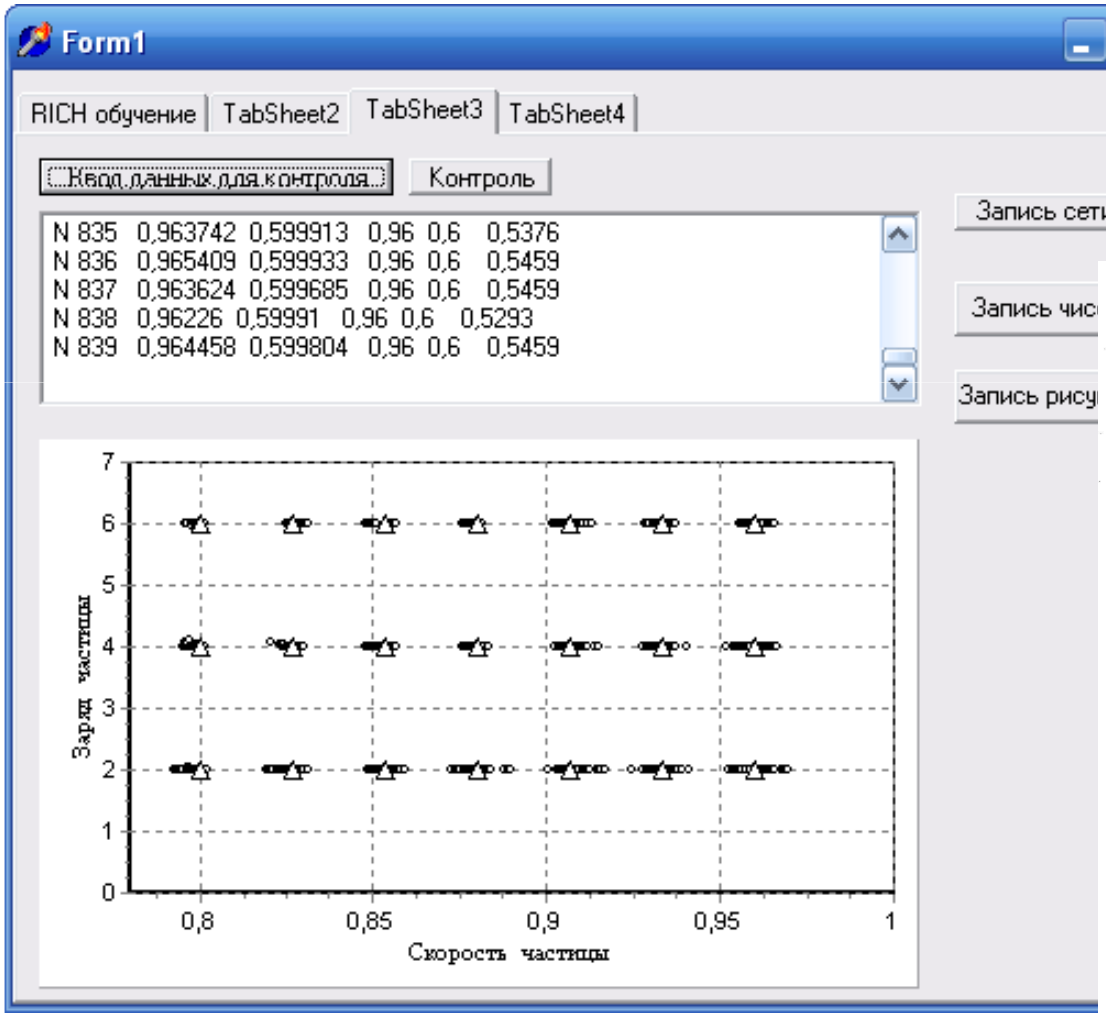


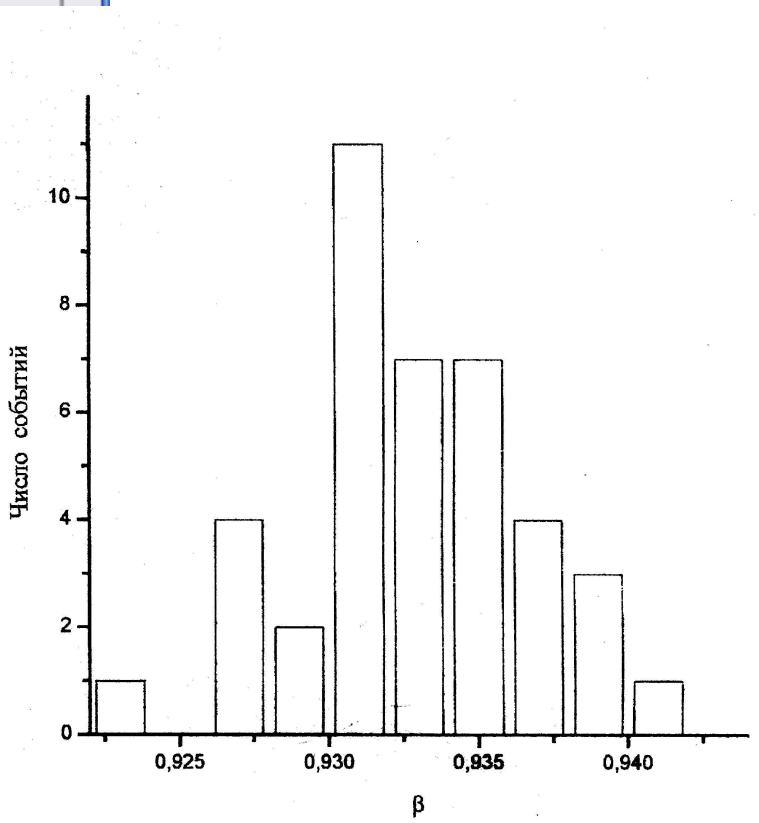


Окно пользовательской программы

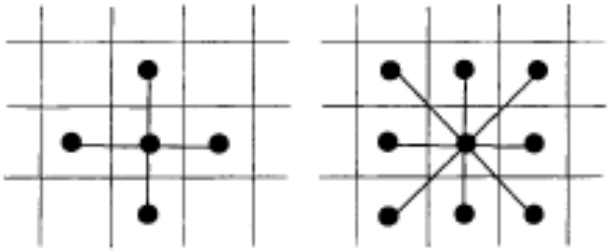


Результат распознавания 840 контрольных событий
(точность по Z ~ 100 %, по β ~ 96%)



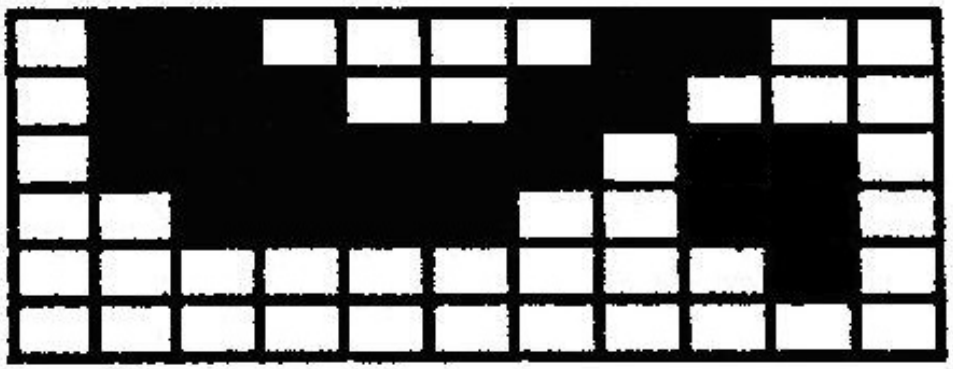


Выделение кластеров и определение их характеристик



Два типа смежности кластеров

Алгоритм выделения кластера

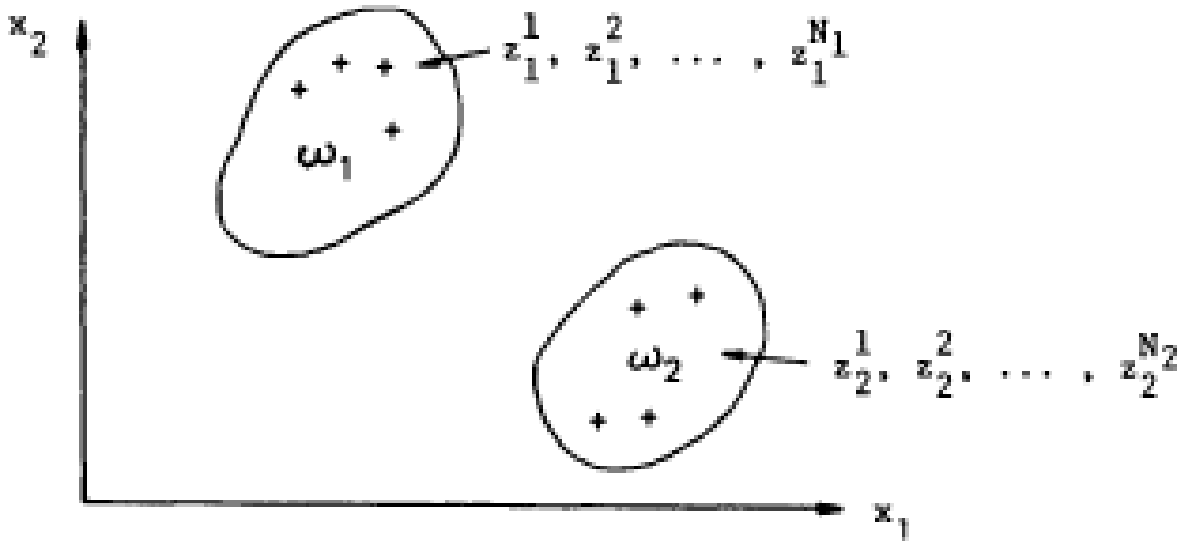


0	1	1	0	0	0	0	2	2	0	0
0	1	1	1	0	0	2	2	0	0	0
0	1	1	1	1	1	2	0	0	3	0
0	0	1	1	1	1	0	0	3	3	0
0	0	0	0	0	0	0	0	0	3	0
0	0	0	0	0	0	0	0	0	0	0

Пространство признаков

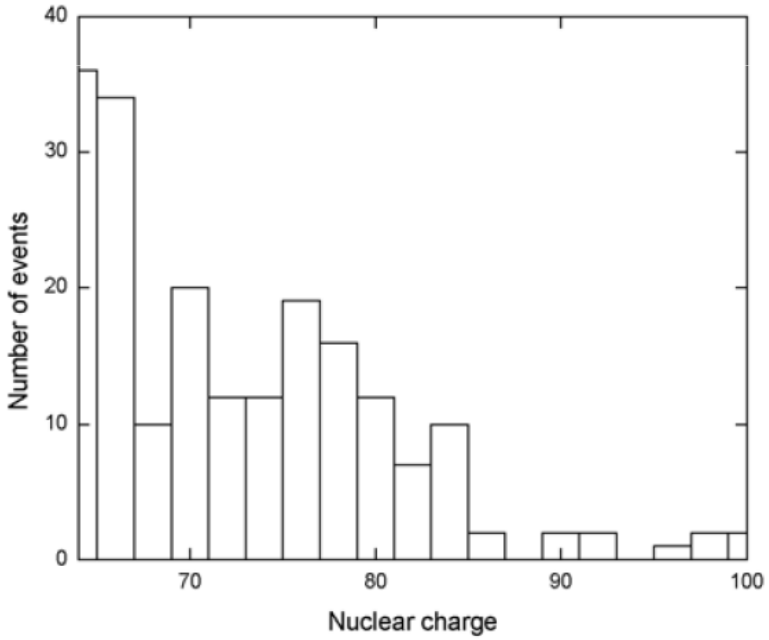
Эффективность обработки изображений решающим образом зависит от правильного выбора характеристик кластеров, подлежащих дальнейшему анализу.

Разделение двух классов ω_1 и ω_2 в пространстве признаков x_1 и x_2.

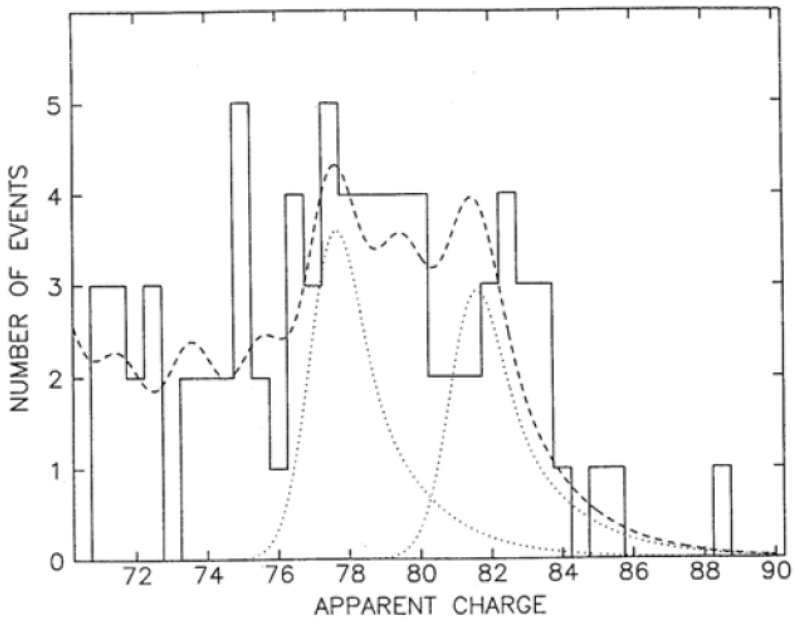


Skylab; E.K. Shirk, P.B. Price; 1978 Z≥65. Спутник, 430 км, 230 дней,

пластик (стопки лексана)

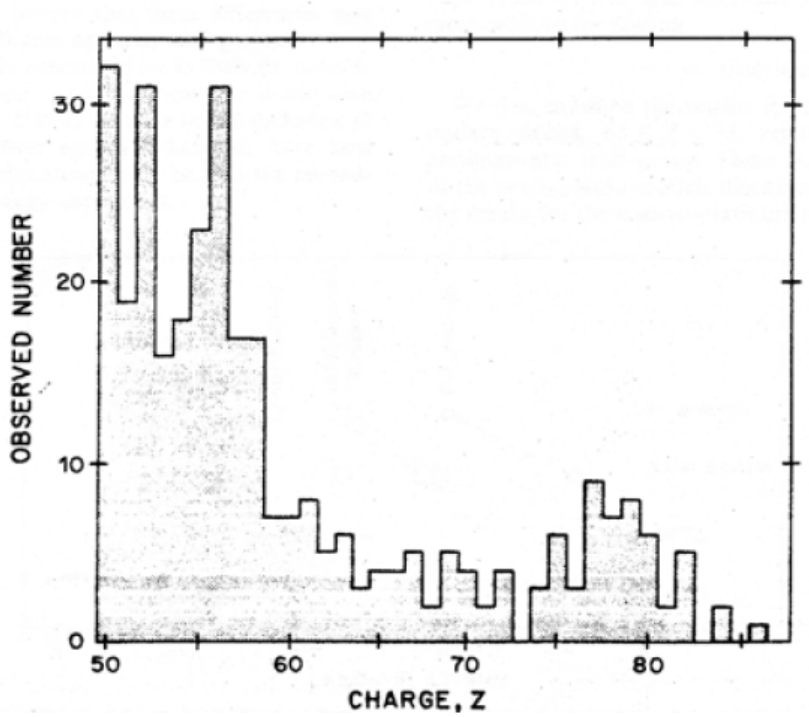


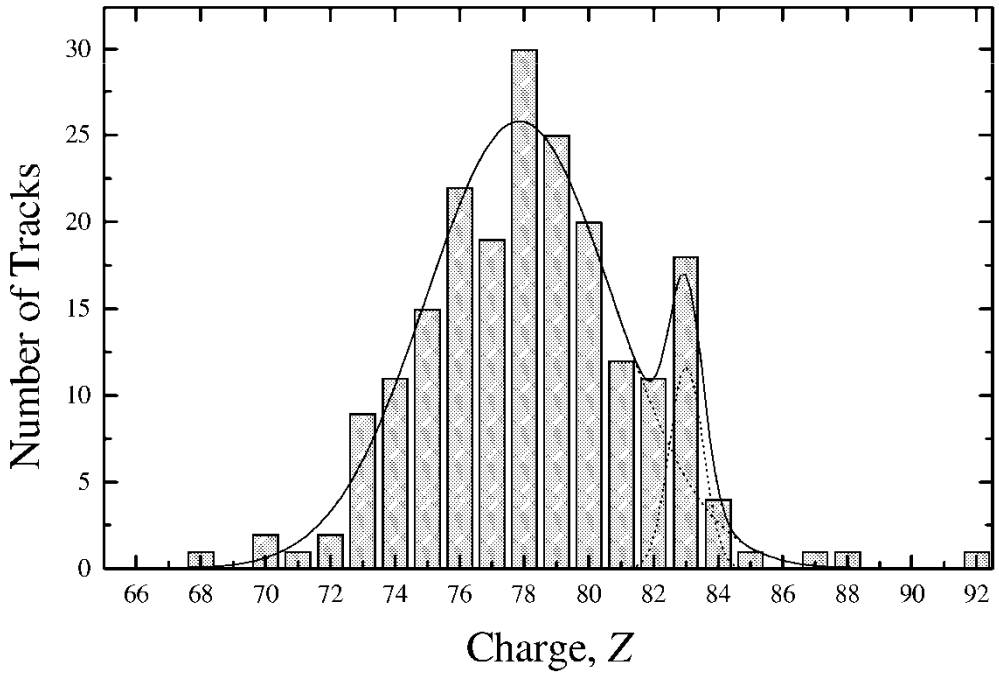
Ariel 6; P.H. Fowler et al. 1987 Z≥70. Спутник, 625 км, 427 дней, электроника



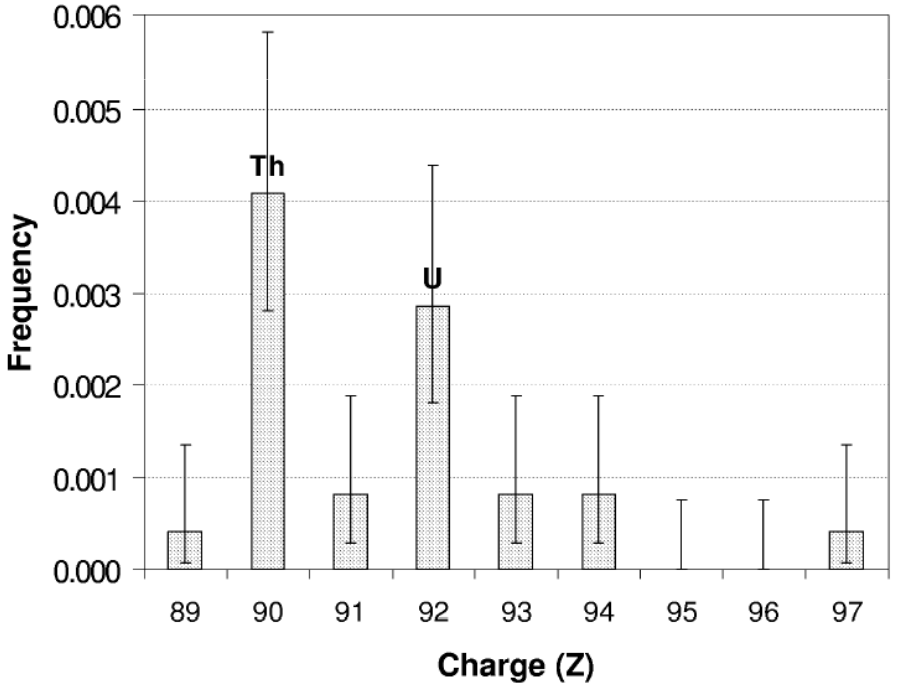
HNE (HEAO 3); W.R. Binns et al. 1989 Z≥50. Спутник, 495 км, 454 дня, электроника

UHCRE; C. Domingo, J. Font et al. 1995 Z≥68. Спутник, 450 км, 6 лет, пластик (стопки лексана)

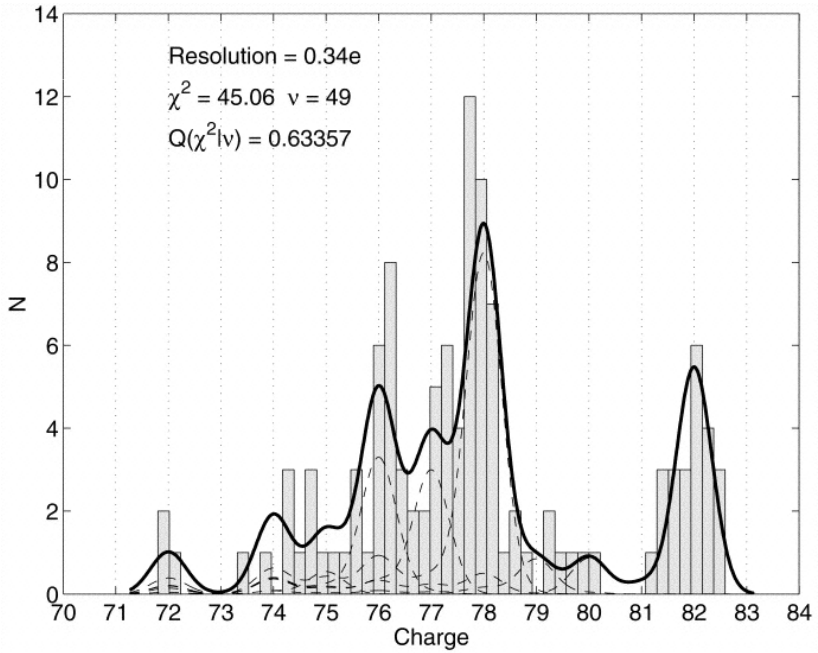




UHCRE; J. Donelly, ICRC-2001

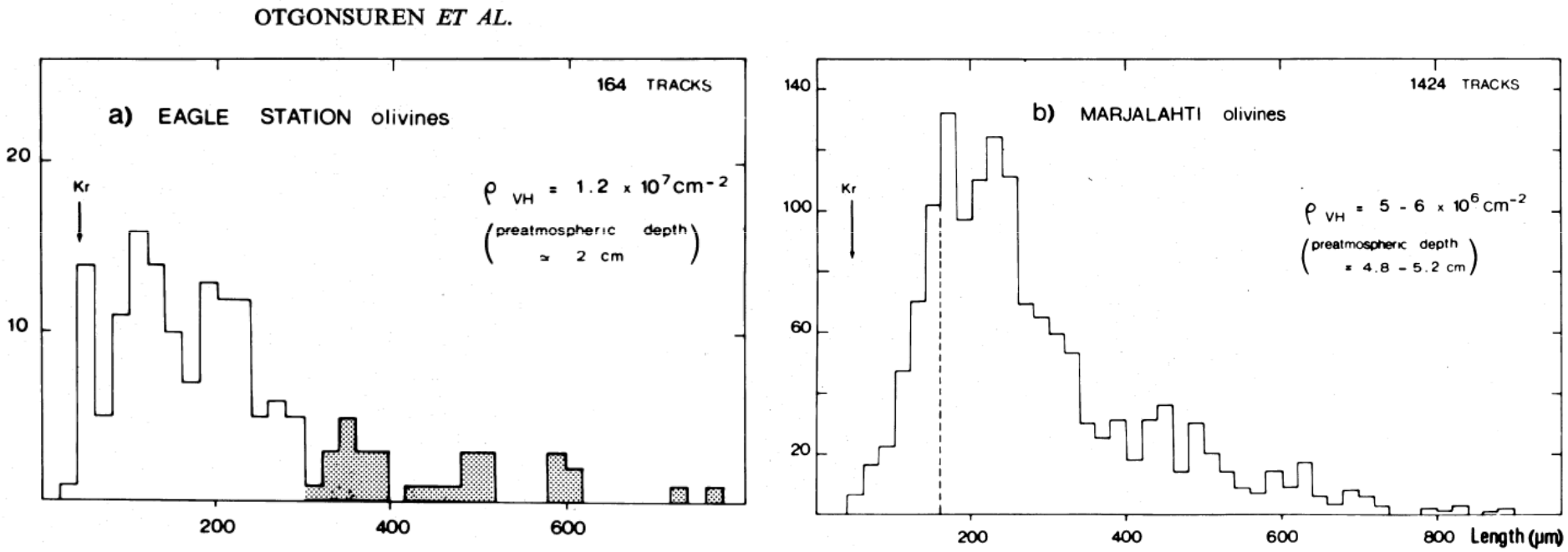


Trek; B. A. Weaver, A. J. Westphal. Станция "Мир", 5 лет, 450 км, стопки стёкол



Перелыгин (ОИЯИ): травление кристаллов оливина из метеоритов методом трек в треке.

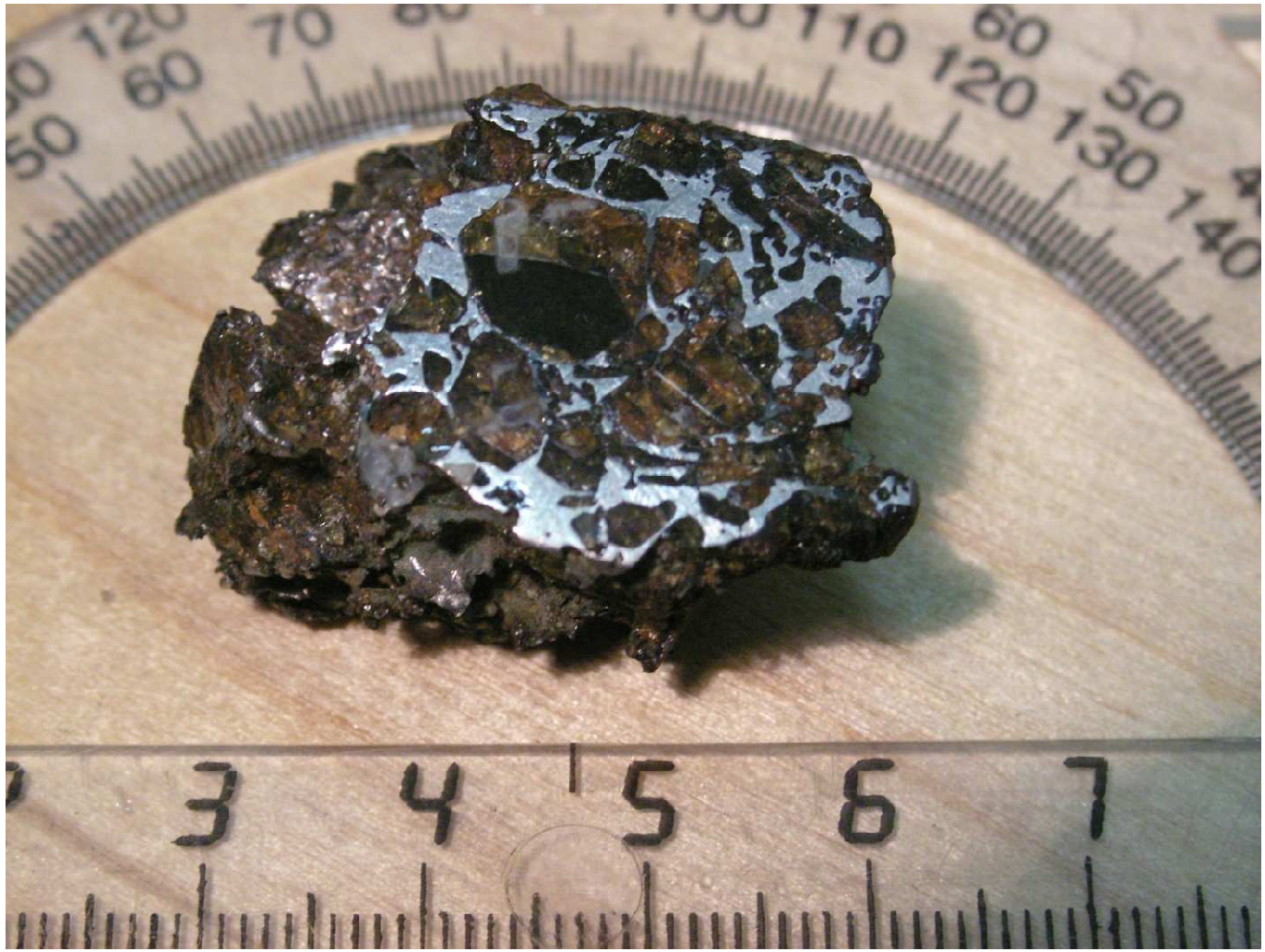
Начало работ 1975



Позднее дополнили метод предварительным отжигом

Метеорит Eagle Station (США 1880 г.).

Размер ~ 25 см. Вес ~ 38 кг. 300 млн лет



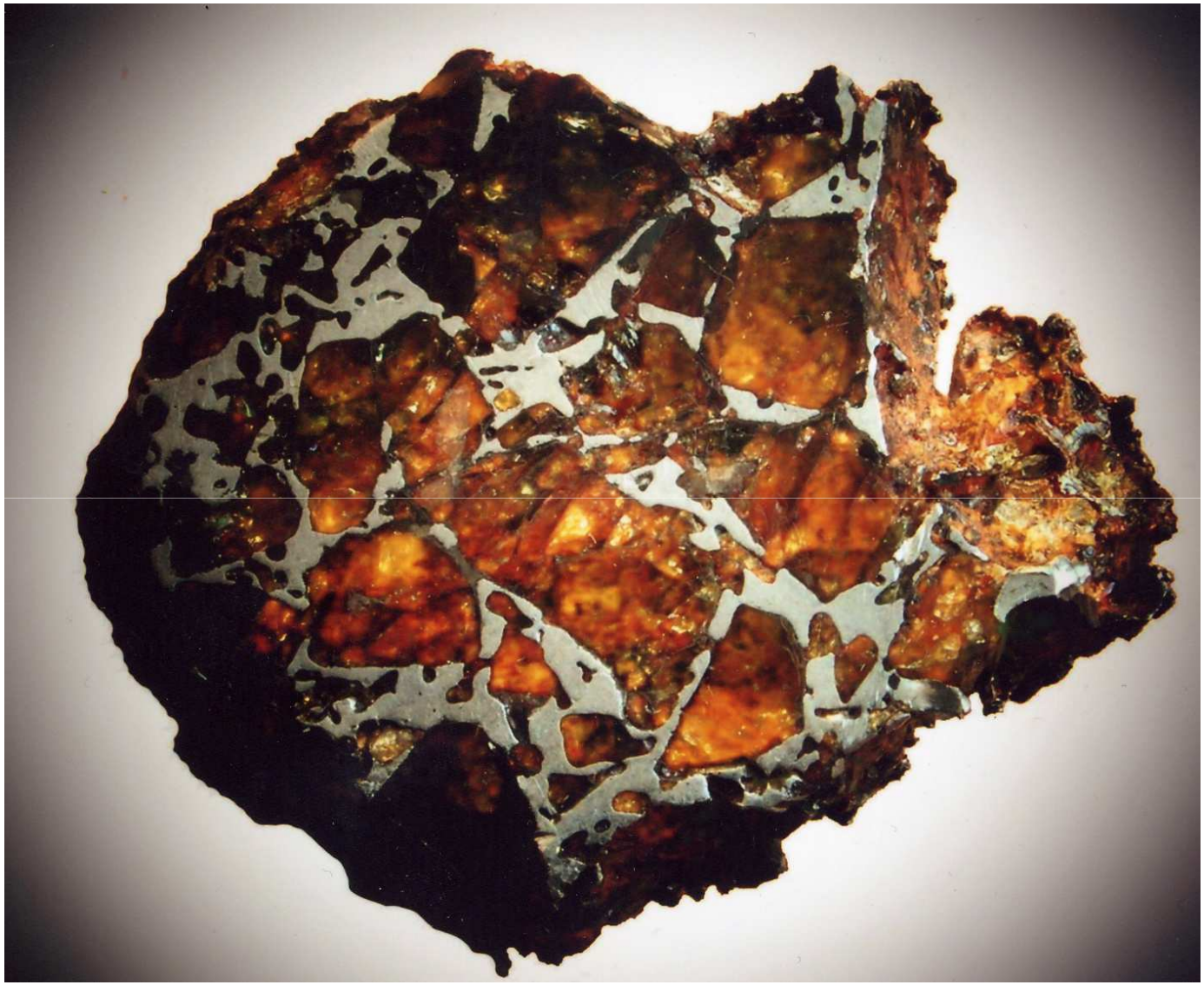
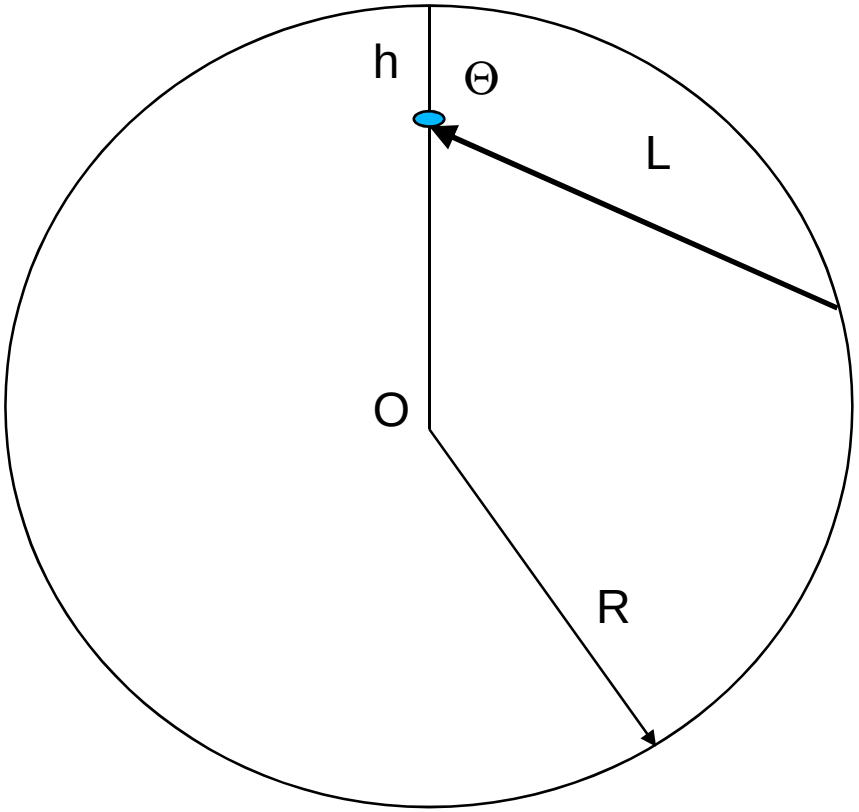
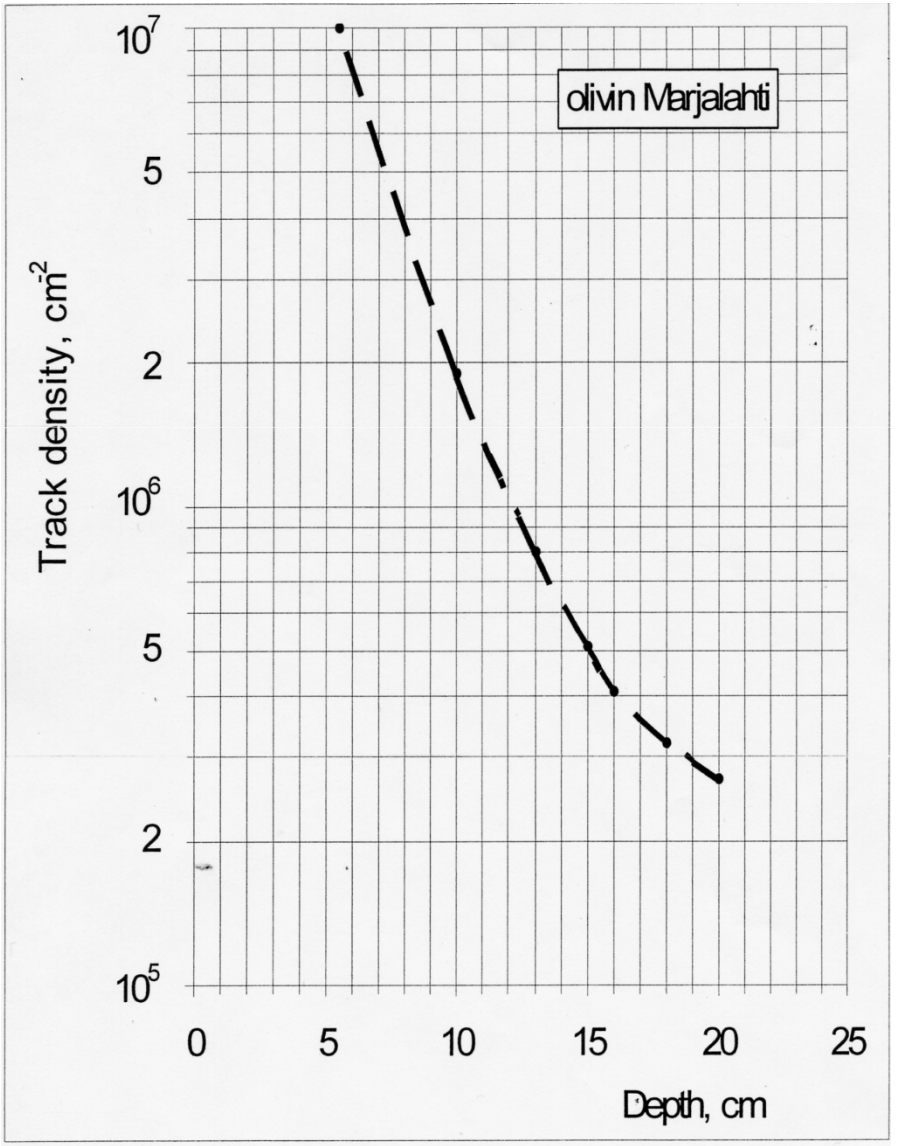
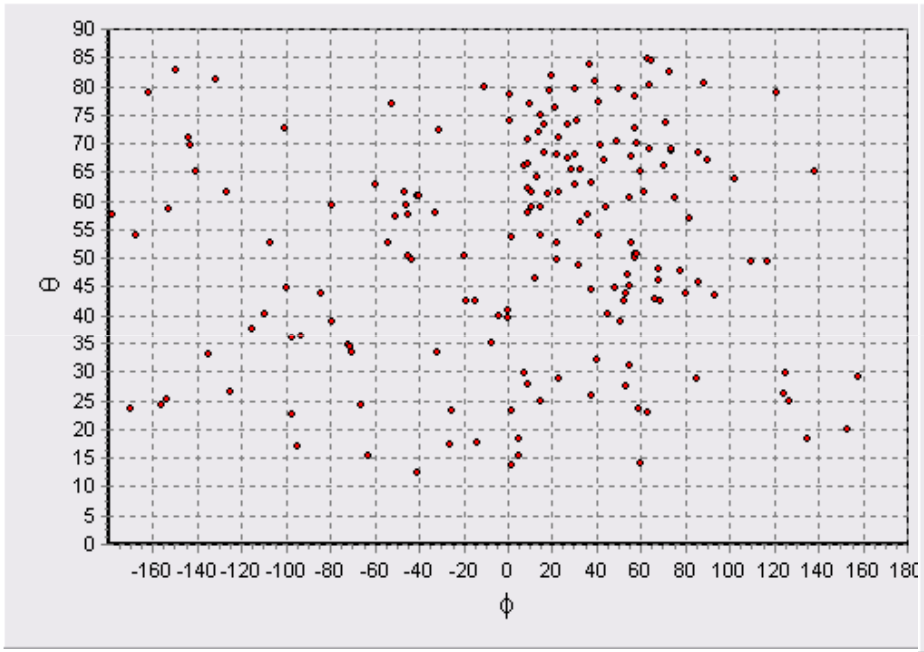


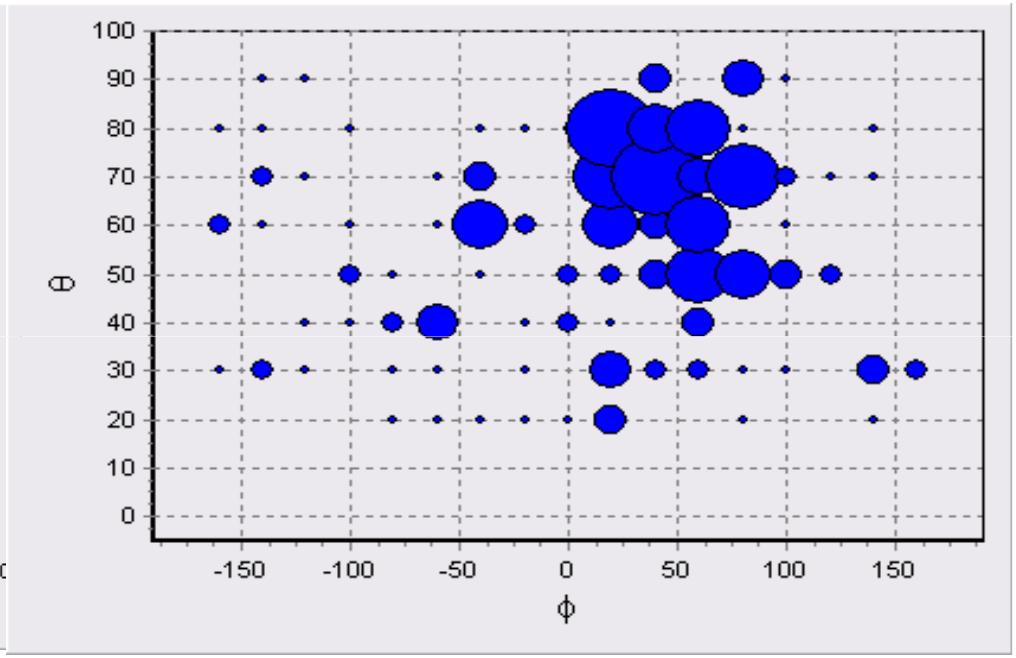
Схема оценки энергии первичной частицы

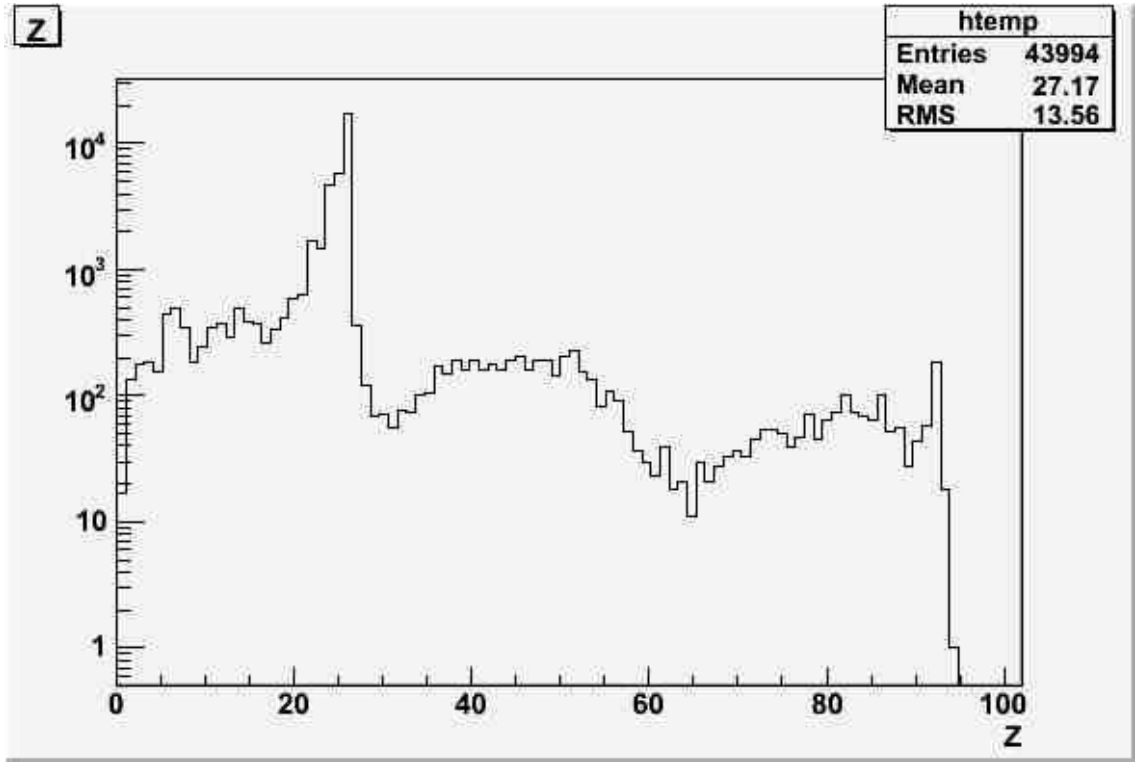




Распределение направлений треков тяжёлых ядер на плоскости углов θ и φ в образце оливина






Z
htemp
Entries 43994
Mean 27.17
RMS 13.56
10^4
10^3
10^2
10
1
0
20
40
60
80
100
Z