Novel exposures of nuclear track emulsion to radioactive nuclei, neutrons and muons

P. I. Zarubin

The BECQUEREL Collaboration
Veksler and Baldin Laboratory for High Energy Physics
Joint Institute for Nuclear Research

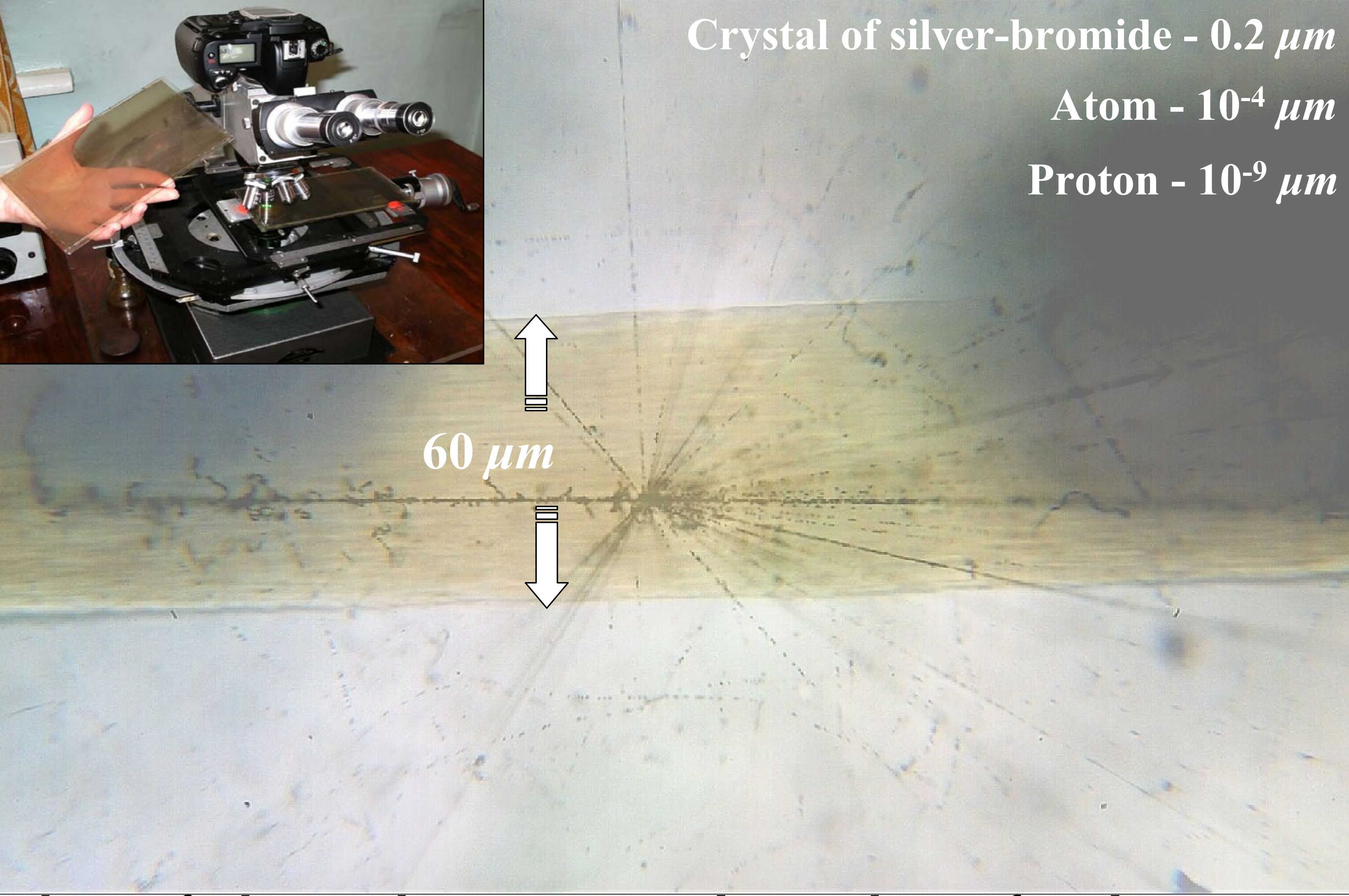
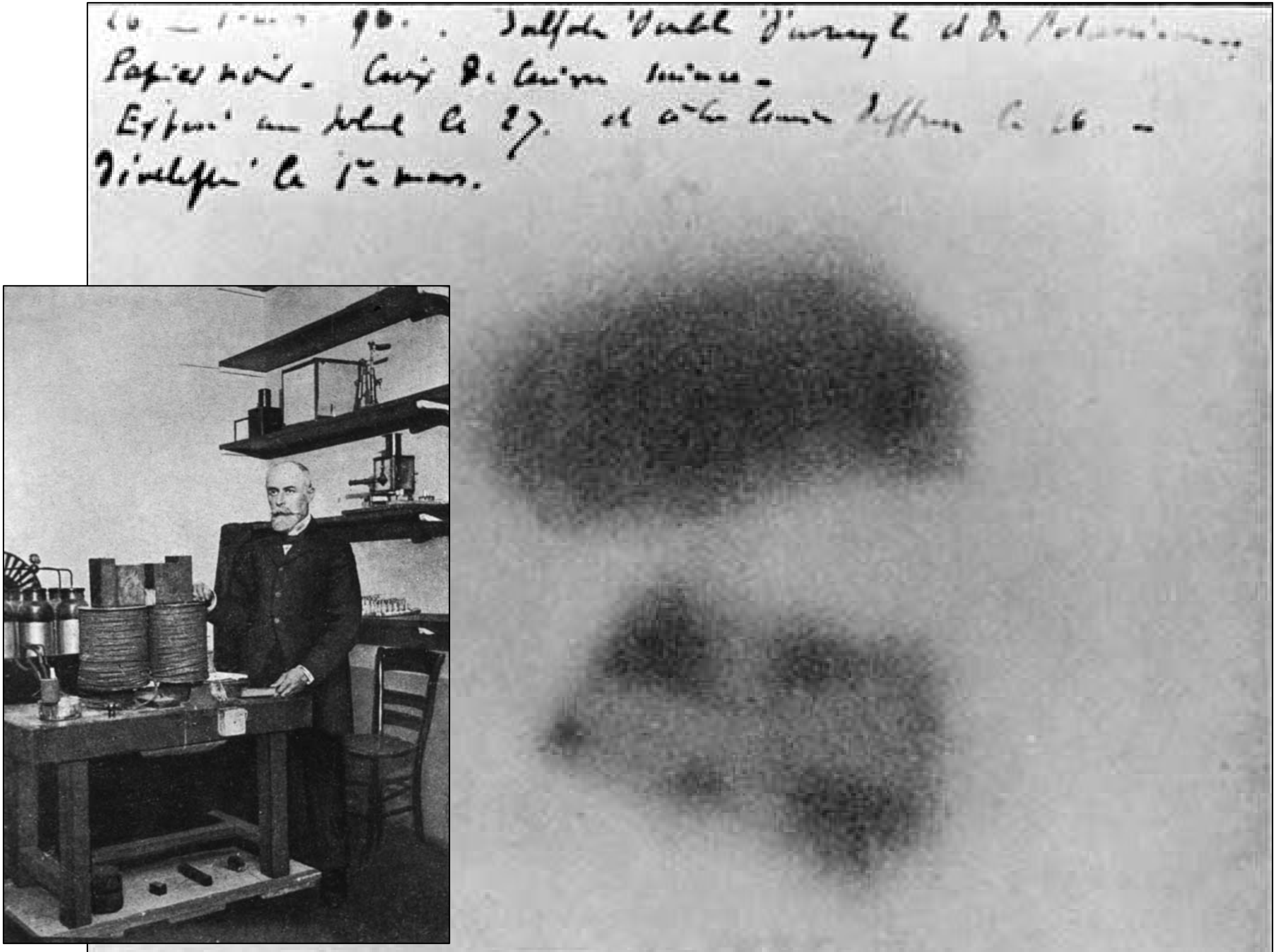
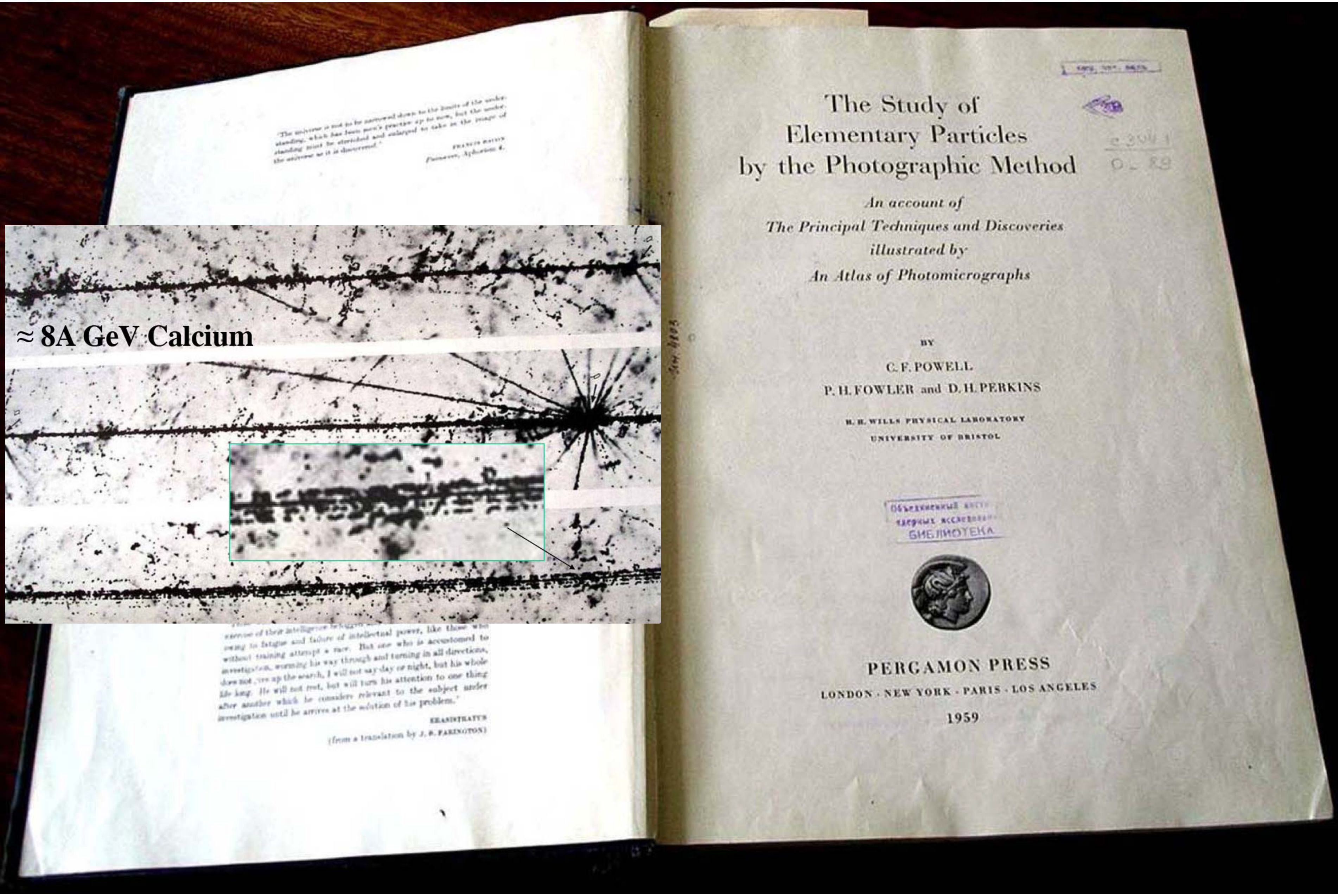


Photo of a human hair superposed on a photo of nuclear star produced by relativistic sulphur nucleus

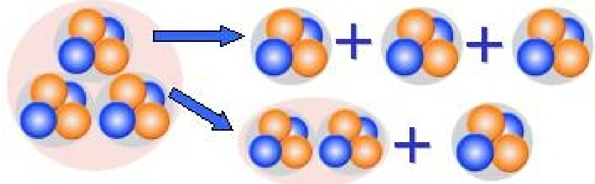

Sulfate double d'uranyle et de potassium.
Papier noir. Croix de cuivre mince.
Exposé au soleil le 27. et à la lumière diffuse le 26.
Développé le 1er mars.


≈ 8A GeV Calcium
The Study of
Elementary Particles
by the Photographic Method
An account of
The Principal Techniques and Discoveries
illustrated by
An Atlas of Photomicrographs
BY
C. F. POWELL
P. H. FOWLER and D. H. PERKINS
H. H. WILLS PHYSICAL LABORATORY
UNIVERSITY OF BRISTOL
PERGAMON PRESS
LONDON · NEW YORK · PARIS · LOS ANGELES
1959
БИБЛИОТЕКА

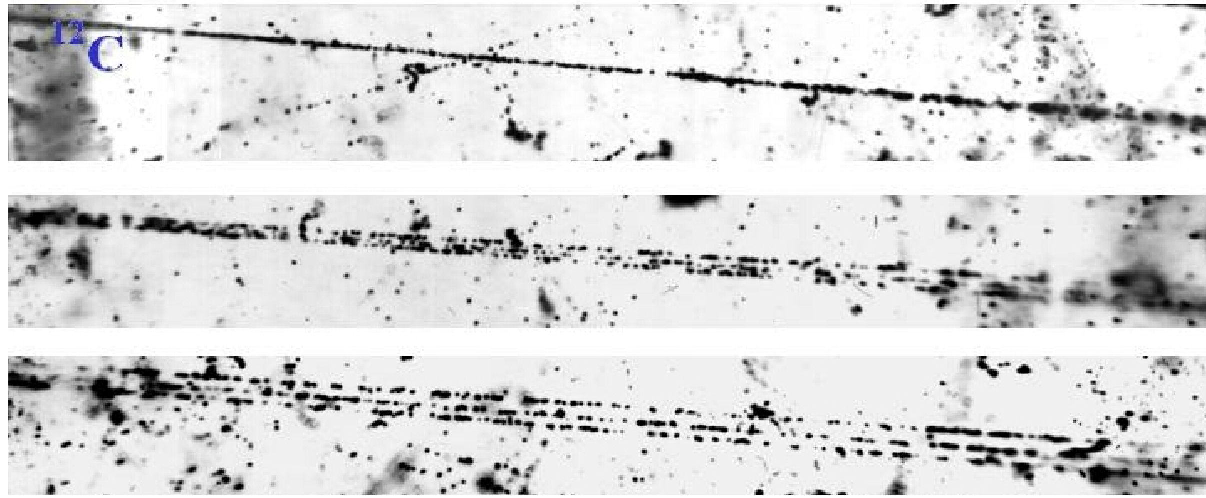
Lebedev PI (FIAN)

50-ies….

Advantages of relativistic fragmentation



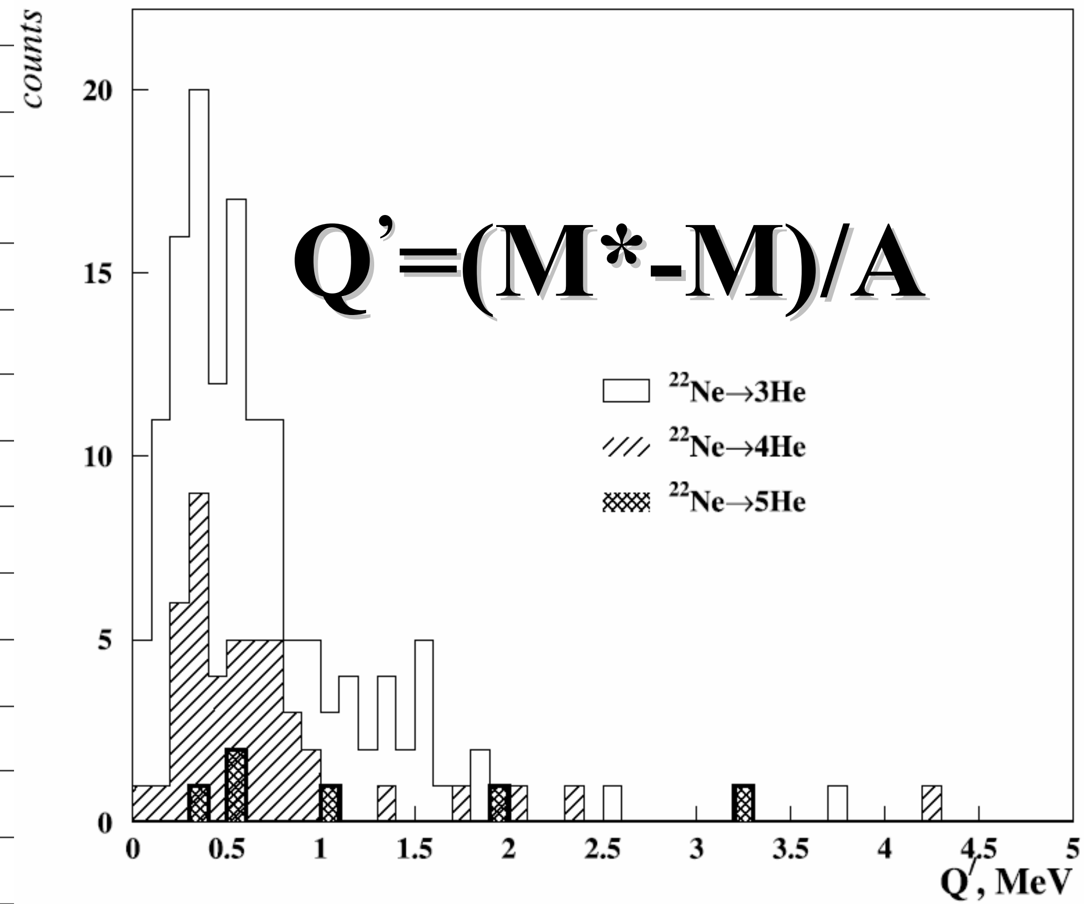
4.5A GeV/c ^{12}C
Coherent Dissociation



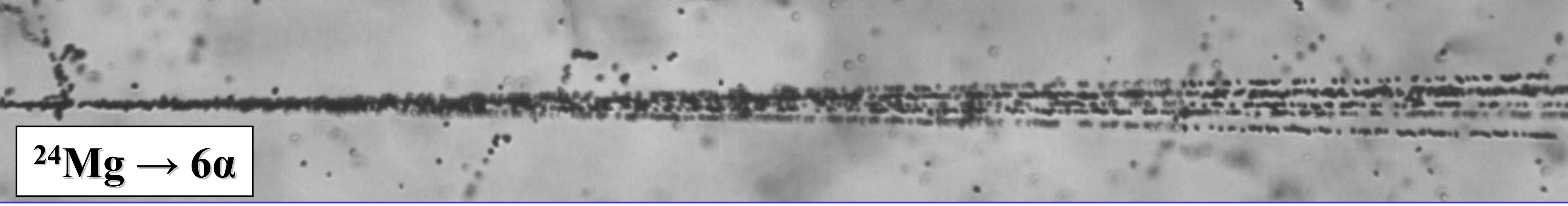
1. *a limiting fragmentation regime is set in,*
2. *the reaction takes shortest time,*
3. *fragmentation collimated in a narrow cone – 3D images,*
4. *ionization losses of the reaction products are minimum,*
5. *detection threshold is close to zero.*

^{22}Ne 3.22A GeV
4100 Inelastic Interactions

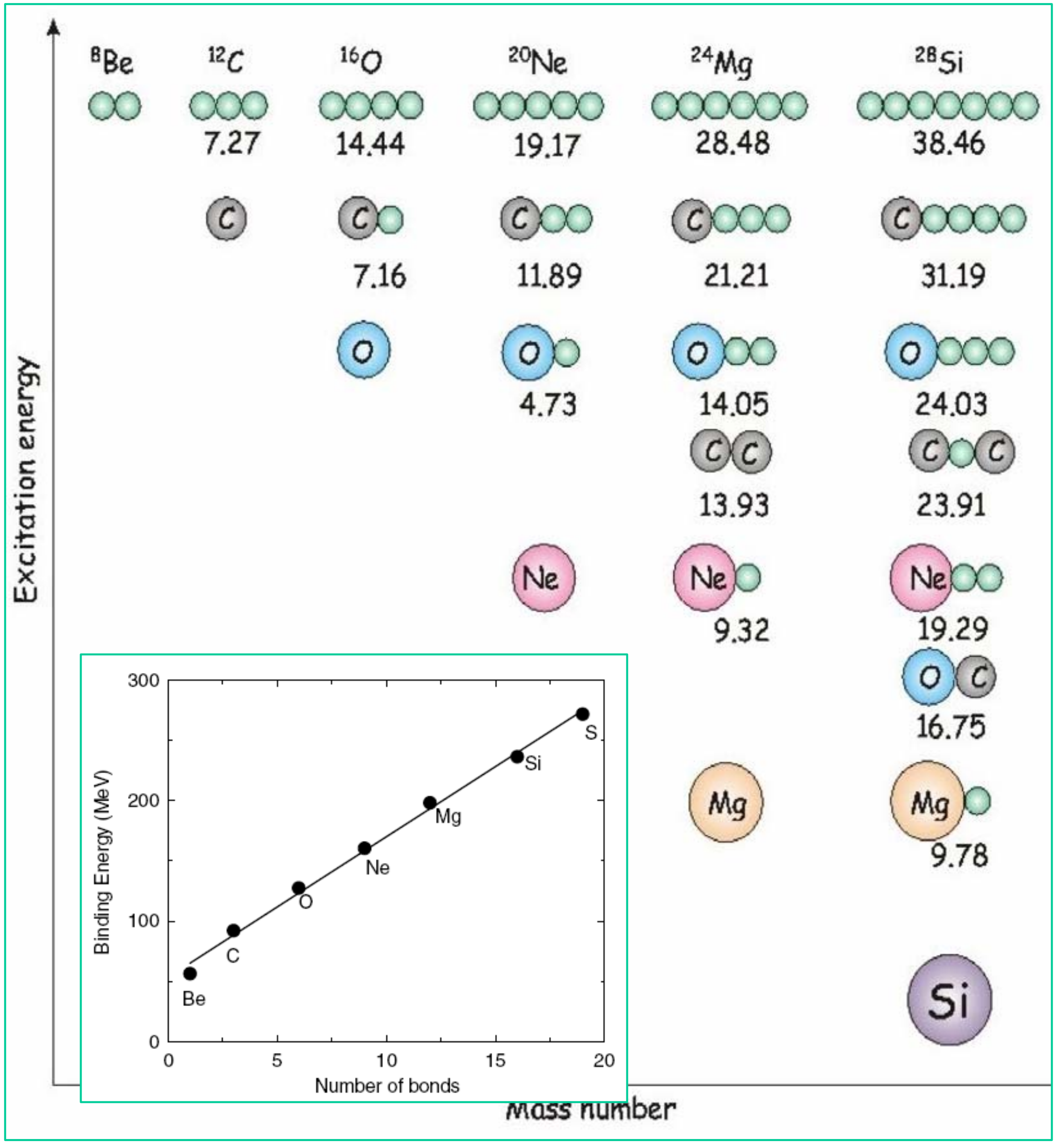
n_b	0	0	1	2	3	>3
n_g	0	1	0	0	0	0
F +H	26 (19.5)	9 (15.0)	13 (44.8)	2	-	1
O + He	54 (40.6)	19 (31.7)	2 (6.9)	-	1	
O + 2H	12 (9.0)	7 (11.7)	-	-	-	
N + He + H	12 (9.0)	7 (11.7)	4 (13.8)	1	-	
N + 3H	3 (2.3)	3 (5.0)	-	-	-	-
C + 2He	5 (3.8)	3 (5.0)	3 (10.3)			
C + 2He + 2H	5 (3.8)	3 (5.0)	3 (10.3)			
C + 4H	2 (1.0)	-	-			
B + Li +H	1 (0.8)	-	-			
B + 2He + H	2 (1.5)	1 (1.7)	-			
B + He + 3H	2 (1.5)	1 (1.7)	-			
B + 5H	1 (0.8)	-	1 (3.4)			
2Be + 2H	-	1 (1.7)	-			
Be + Li + 3H	1 (0.8)	-	-			
Be + 3He	2 (1.5)	-	-			
Be + He + 4H	1 (0.8)	-	-			
Li + 3He + H	-	1 (1.7)	-			
5He	3 (2.3)	-	1 (3.4)			
4He + 2H	1 (0.8)	5 (8.3)	2 (6.9)			



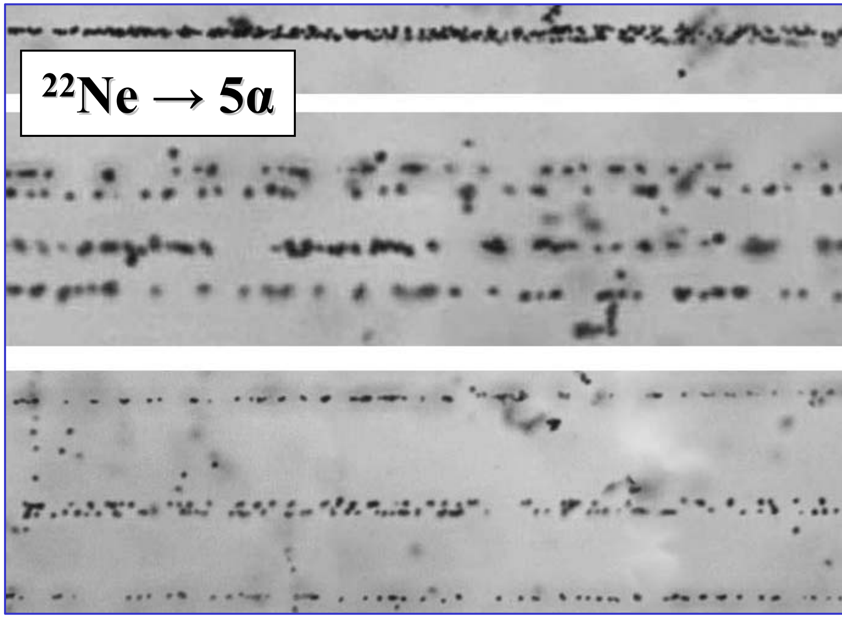
$$Q' = (M^* - M)/A$$



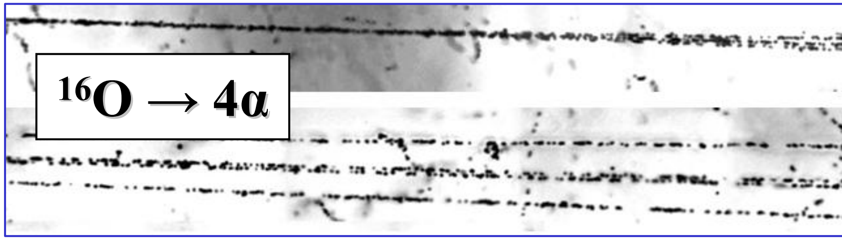
$^{24}Mg \rightarrow 6\alpha$



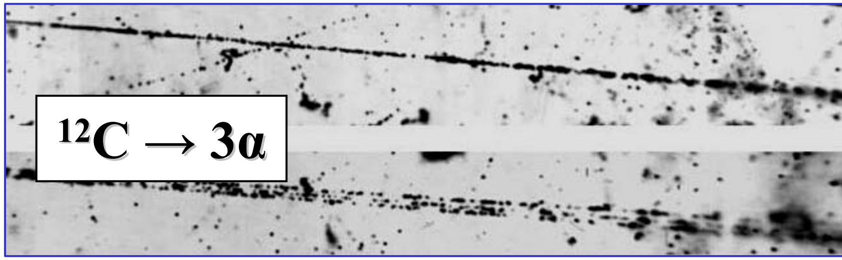
Excitation energy
Mass number
^{8}Be
^{12}C
^{16}O
^{20}Ne
^{24}Mg
^{28}Si
7.27
14.44
19.17
28.48
38.46
C
7.16
11.89
21.21
31.19
O
4.73
14.05
24.03
13.93
23.91
Ne
9.32
19.29
16.75
Mg
9.78
Si
Binding Energy (MeV)
Number of bonds
0
100
200
300
0
5
10
15
20
Be
C
O
Ne
Mg
Si
S



$^{22}Ne \rightarrow 5\alpha$



$^{16}O \rightarrow 4\alpha$

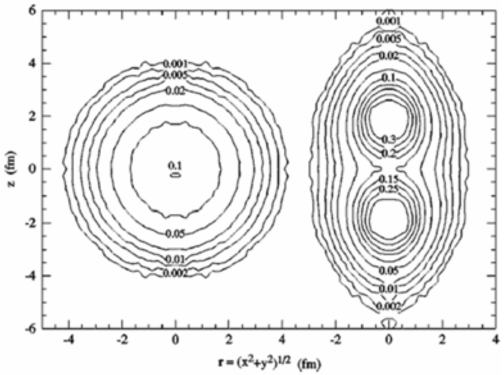


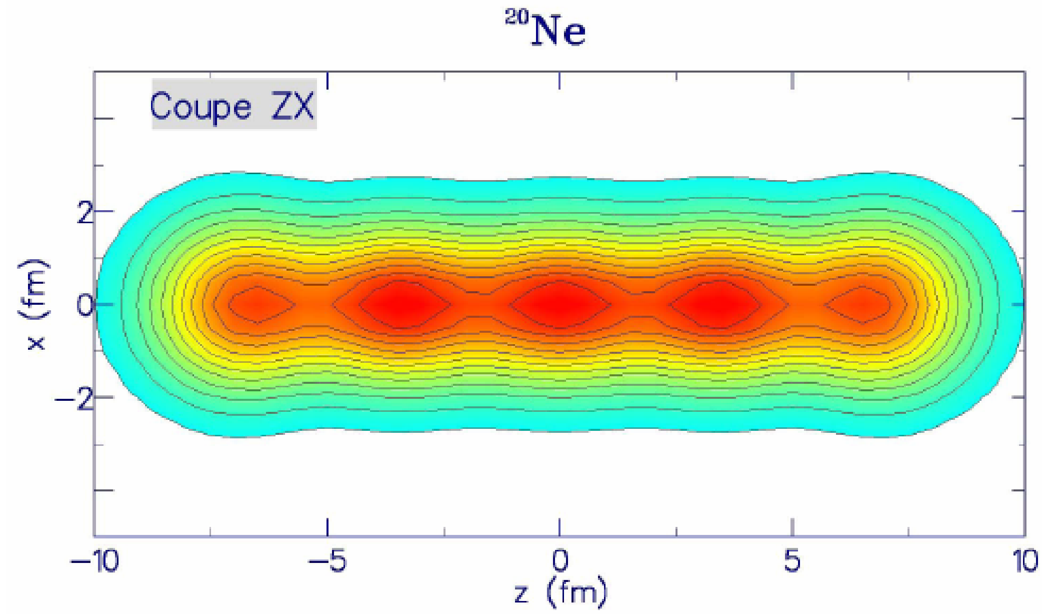
$^{12}C \rightarrow 3\alpha$

Alpha-Clusters in Nuclear Systems

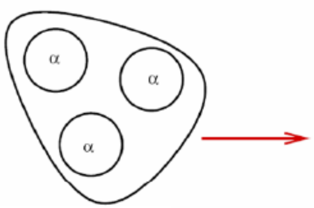
P. Schuck

Y. Funaki, H. Horiuchi, G. Röpke,
A. Tohsaki , W. von Oertzen and T. Yamada





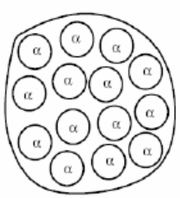
If O_2^+ in ^{12}C dilute $\alpha -$ state

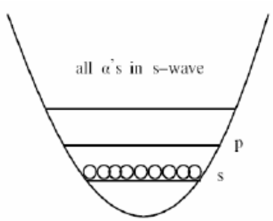


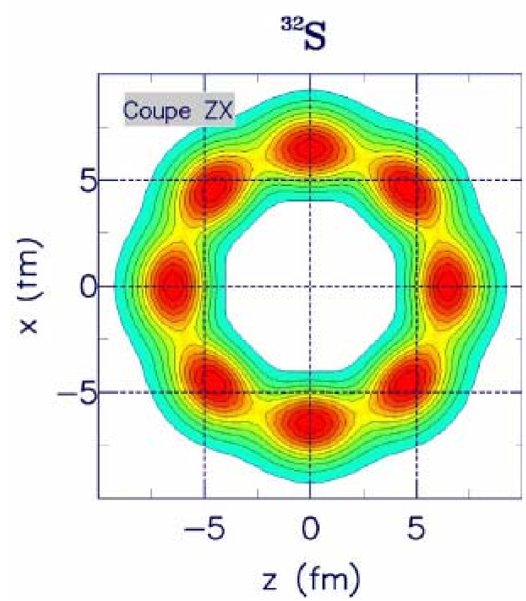
then α-condensate

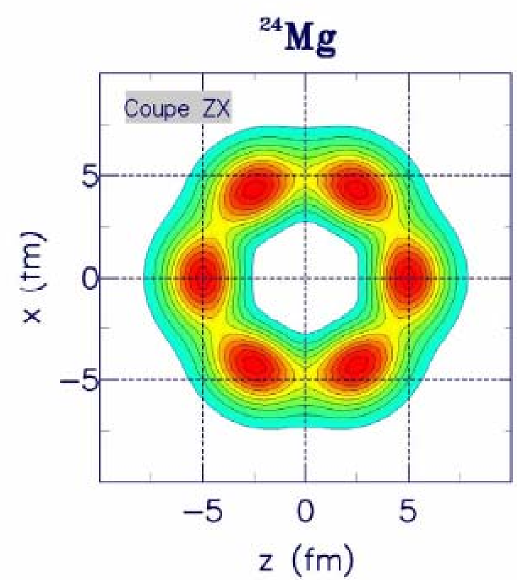
infinite matter $\rho_{crit} \sim \frac{\rho_0}{3}$

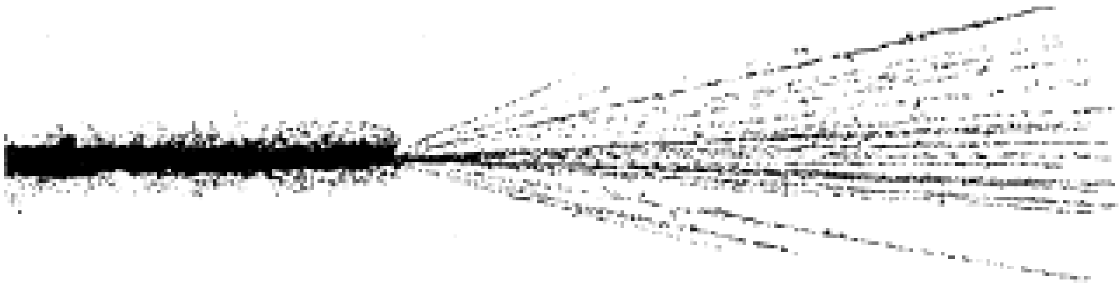
Conjecture: all n.α nuclei possess exited nα condensed state



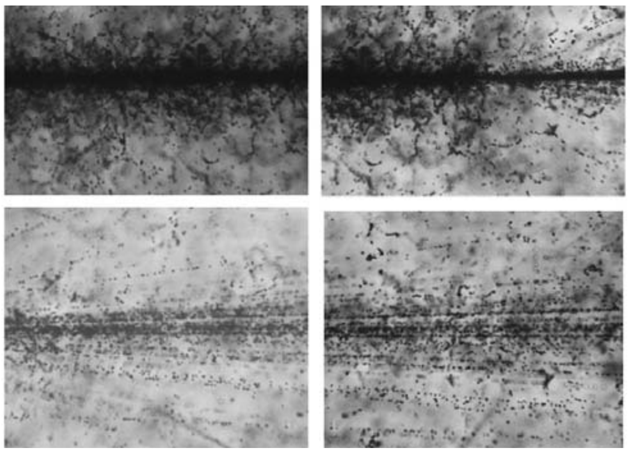




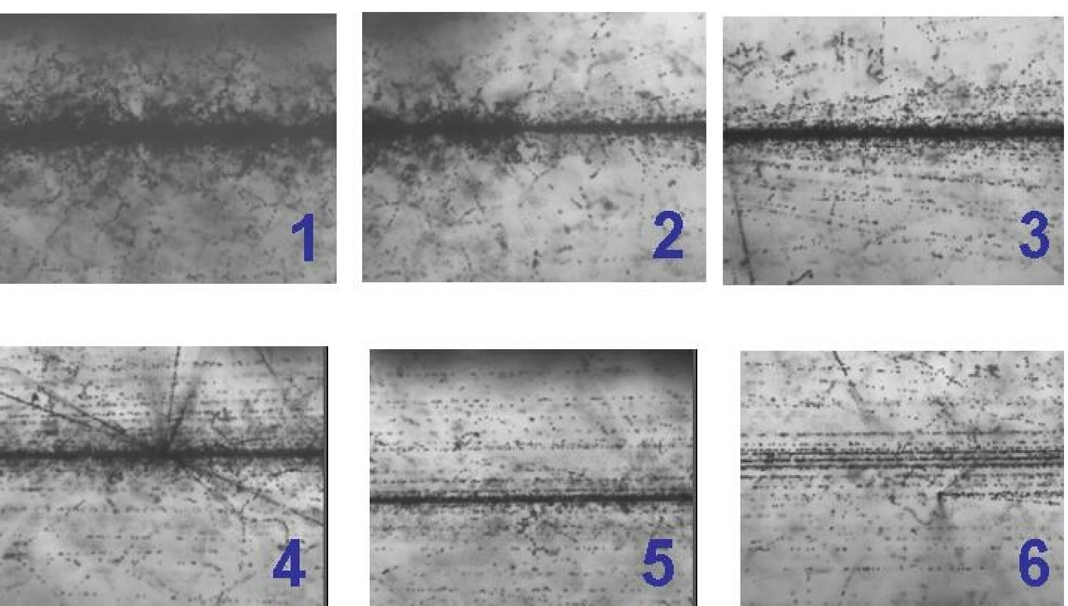




1A GeV U



10A GeV Au



160A GeV Pb

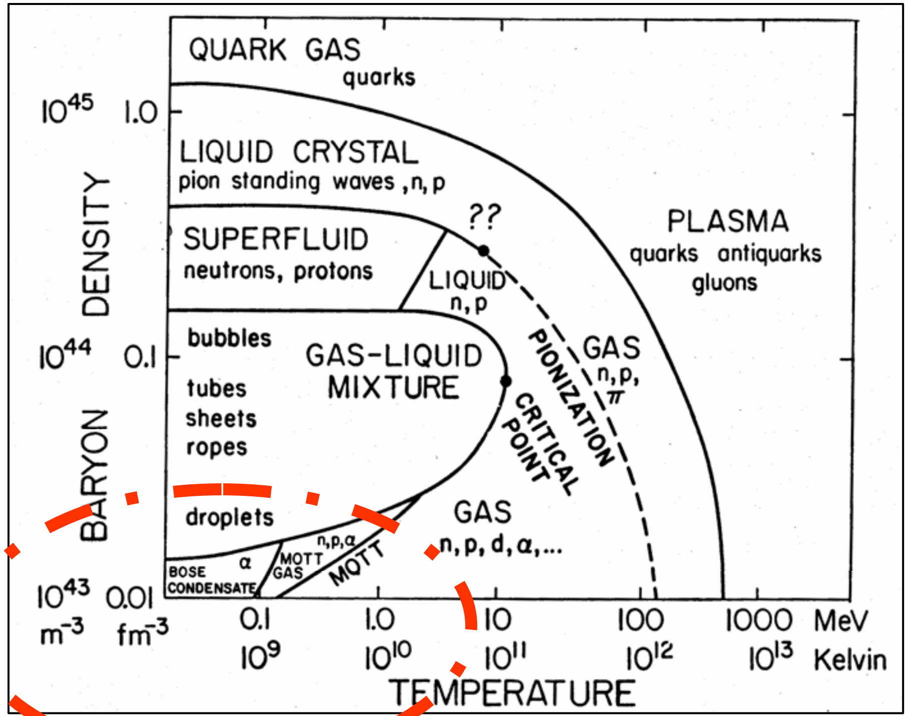

2

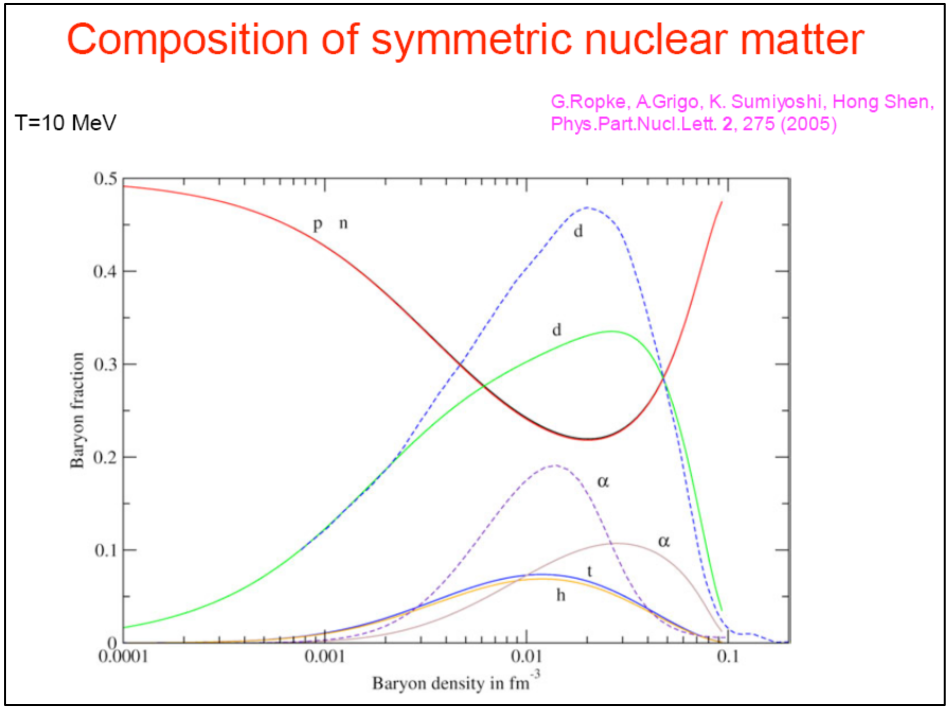
PHYSICAL REVIEW C VOLUME 41, NUMBER 6 JUNE 1990

Electromagnetic dissociation of relativistic heavy ions

W. J. Llope and P. Braun-Munzinger
Department of Physics, State University of New York at Stony Brook, Stony Brook, New York 11794

In particular, electromagnetic excitation of modes based on the nuclear giant dipole resonance (GDR) may lead to very exotic final states[1,2] in which neutrons oscillate against protons with a very large amplitude. The existence and decay mechanisms of such states is unknown at present. However, this electromagnetic process efficiently excites collective states so that little or no temperature is produced during the very short time scale (of order 1 fm/c) of the collision. One may thus hope to use this type of reaction to search for fragile, weakly bound exotic states such as multineutron clusters which might be formed in the decay of the possibly strongly excited multi-GDR states.





PHYSICAL REVIEW C **72**, 048801 (2005)

Multifragmentation reactions and properties of stellar matter at subnuclear densities

A. S. Botvina[1] and I. N. Mishustin[2,3]

[1]*Institute for Nuclear Research, Russian Academy of Sciences, RU-117312 Moscow, Russia*

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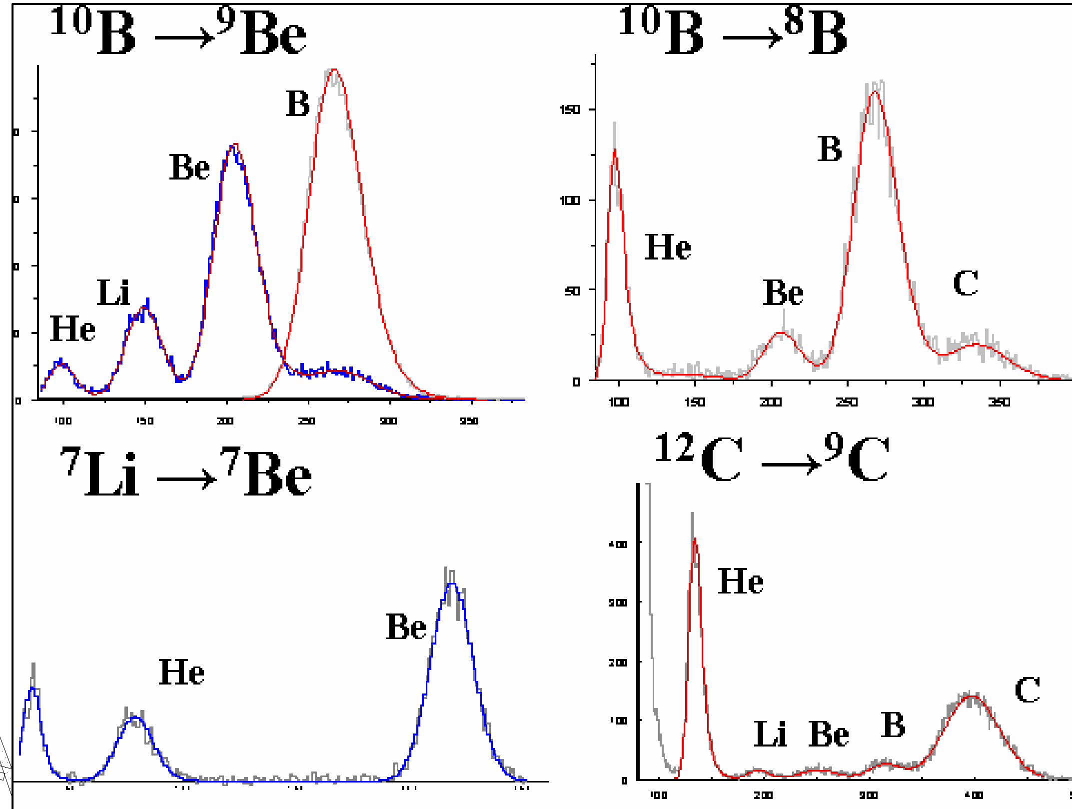
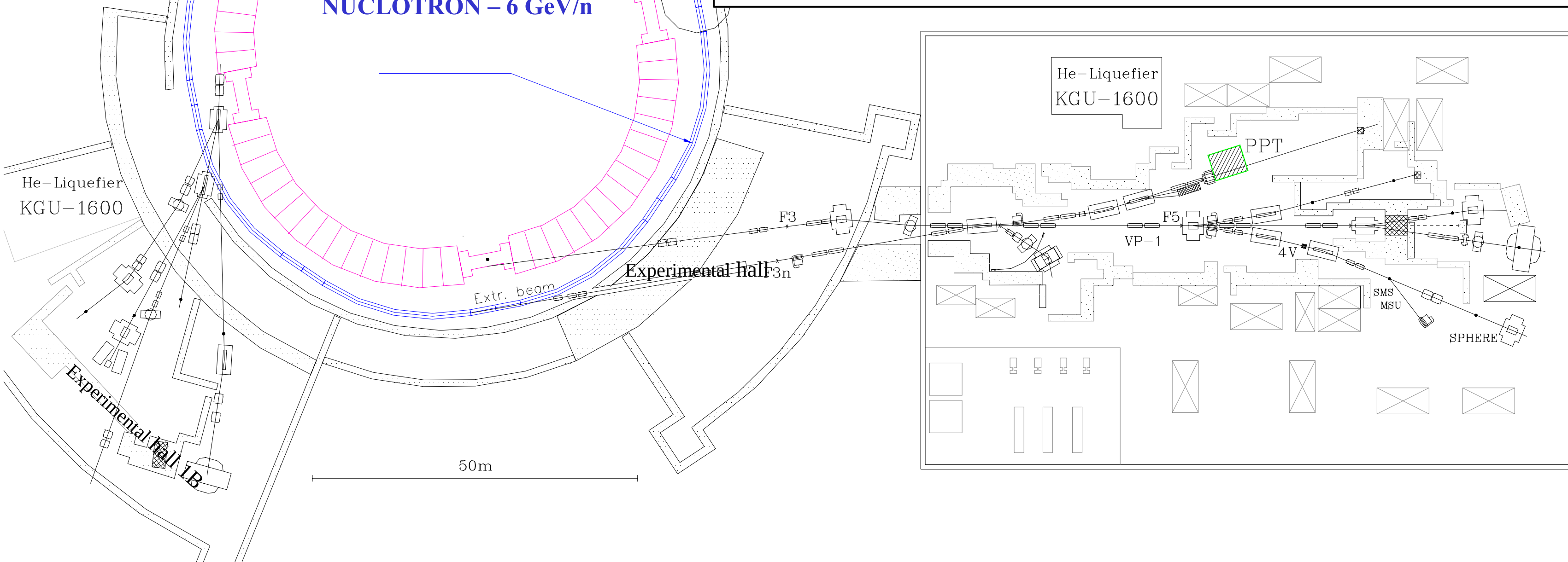
[3]*Kurchatov Institute, Russian Research Center, RU-123182 Moscow, Russia*

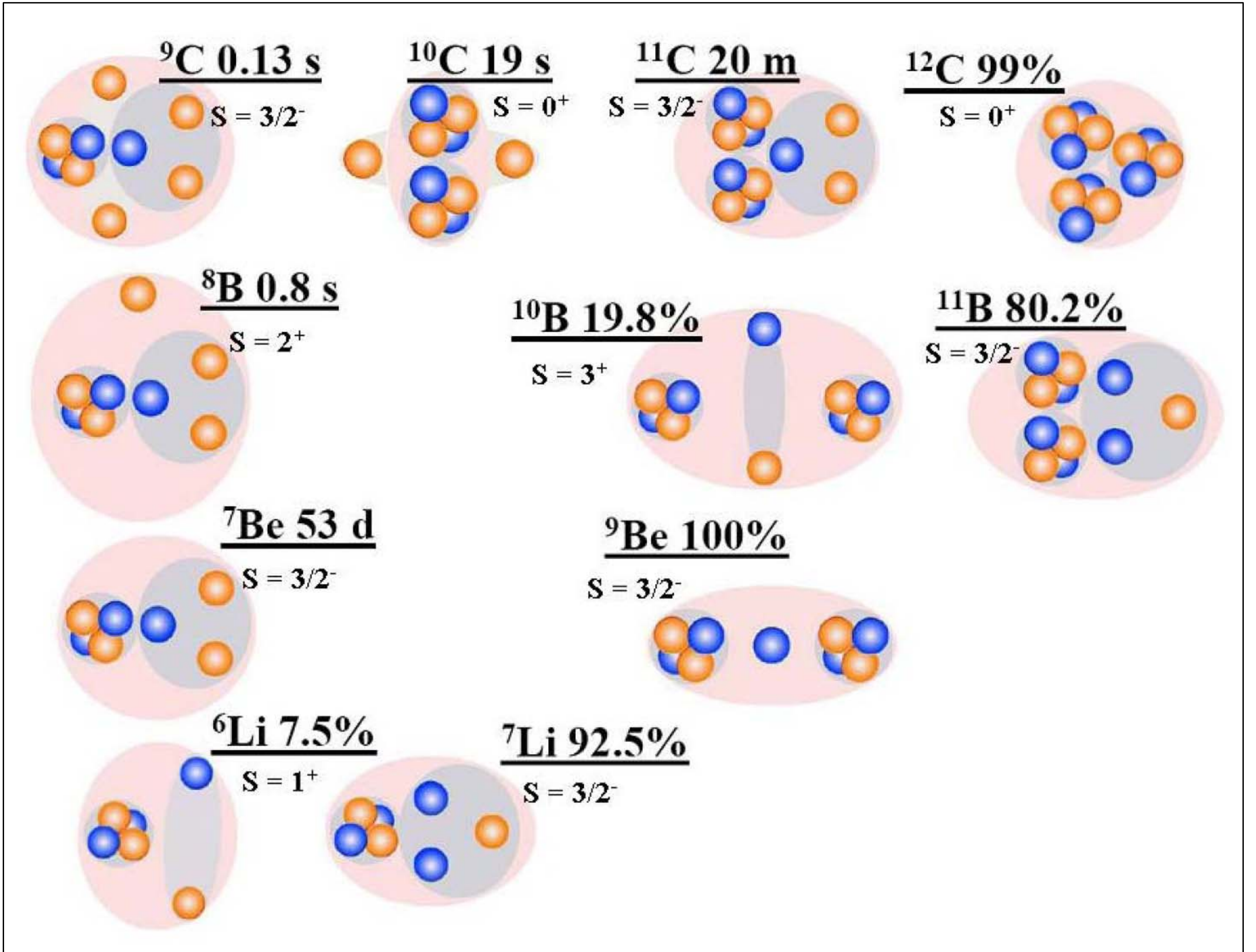
(Received 20 June 2005; published 24 October 2005)

We point out the similarity of thermodynamic conditions reached in nuclear multifragmentation and in supernova explosions. We show that a statistical approach previously applied for nuclear multifragmentation reactions can also be used to describe the electroneutral stellar matter. Then properties of hot unstable nuclei extracted from the analysis of multifragmentation data can be used to determine a realistic nuclear composition of hot supernova matter.

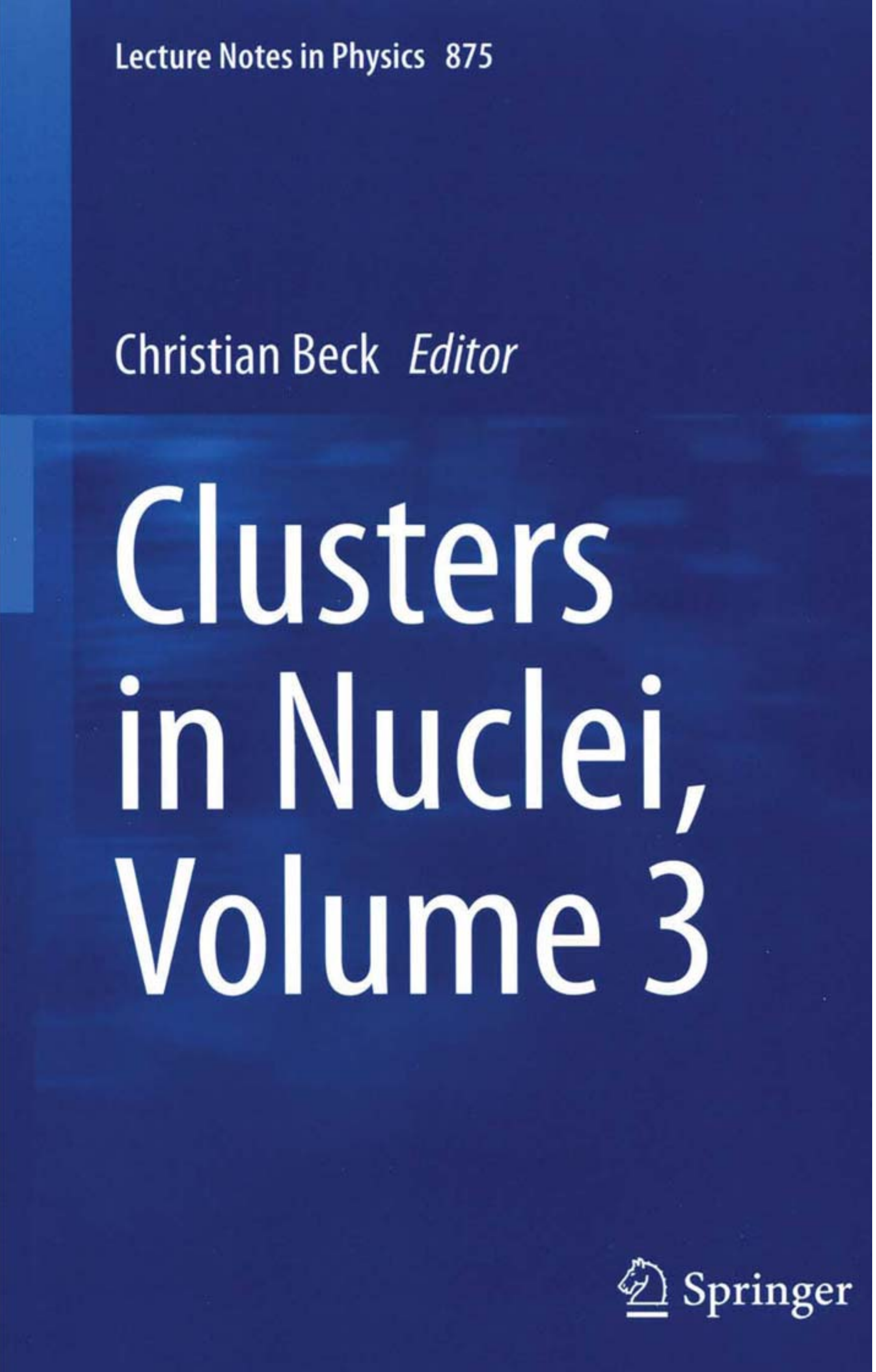

CO2 laser


$^{10}B \rightarrow {}^{9}Be$
He
Li
Be
B
$^{10}B \rightarrow {}^{8}B$
He
Be
B
C
$^{7}Li \rightarrow {}^{7}Be$
He
Be
$^{12}C \rightarrow {}^{9}C$
He
Li
Be
B
C


Linac LU-20
SYNCHROPHASOTRON
NUCLOTRON – 6 GeV/n
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



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-



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

P.I. Zarubin

3.1 Introduction

Collective degrees of freedom, in which groups of few nucleons behave as composing clusters, are a key aspect of nuclear structure. The fundamental "building blocks" elements of clustering are the lightest nuclei having no excited states—first of all, the ^{4}He nucleus (α particles) as well as the deuteron (d), the triton (t) and the ^{3}He nucleus (h, helion). This feature is clearly seen in light nuclei, where the number of possible cluster configurations is small (Fig. 3.1). In particular, the cluster separation thresholds in the nuclei of ^{7}Be, ^{6,7}Li, ^{11,10}B, ^{11,12}C and ^{16}O are below the nucleon separation thresholds. The stable ^{9}Be, and unbound ^{8}Be and ^{9}B nuclei have a clearly pronounced cluster nature. In turn, the cluster nuclei ^{7}Be, ^{7}Li, and ^{8}Be serve as cores in the isotopes ^{8}B and $^{9-12}$C. Descriptions of the ground states of light nuclei in the shell and cluster models are complementary. In the cluster pattern the light nuclei are represented as superpositions of different cluster and nucleon configurations. The interest in such states is associated with the prediction of their molecular-like properties [1, 2]. Nuclear clustering is traditionally regarded as the prerogative of the physics of nuclear reactions at low energies [3]. The purpose of these lecture notes is to present the potential of one of the sections of high-energy physics—relativistic nuclear physics—for the development of the concepts of nuclear clustering.

In the last decade, the concepts of ultracold dilute nuclear matter based on the condensation of nucleons in the lightest nuclei have been developed [4–7]. An α-particle Bose-Einstein condensate (αBEC) is considered as an analogue of atomic quantum gases [5, 7]. These developments put forward the problem of studying a variety of cluster ensembles and unbound nuclei as fundamental components of novel quantum matter. In a macroscopic scale coherent ensembles of clusters may play an

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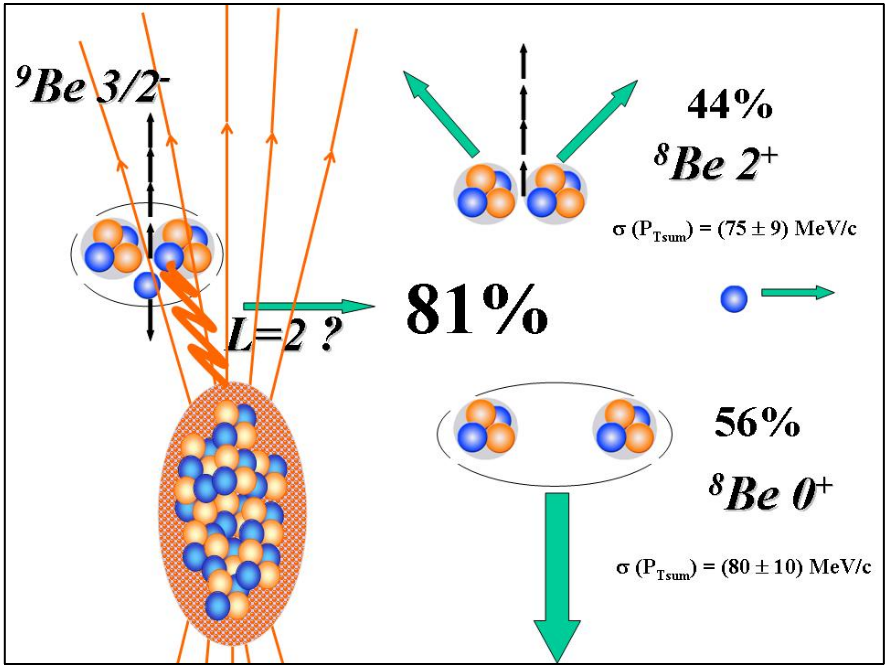
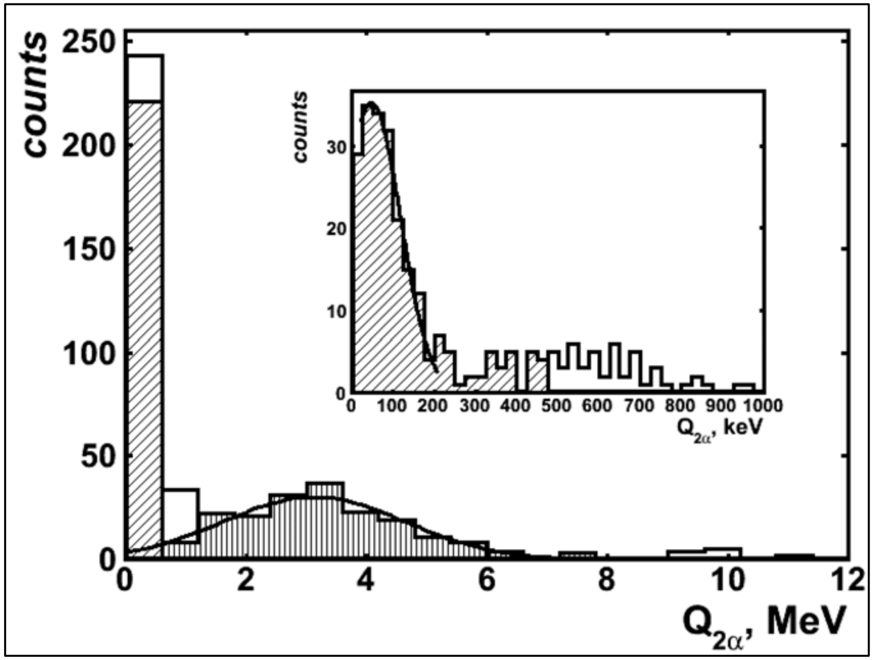
C. Beck (ed.), *Clusters in Nuclei, Volume 3*, Lecture Notes in Physics 875,
DOI 10.1007/978-3-319-01077-9_3,

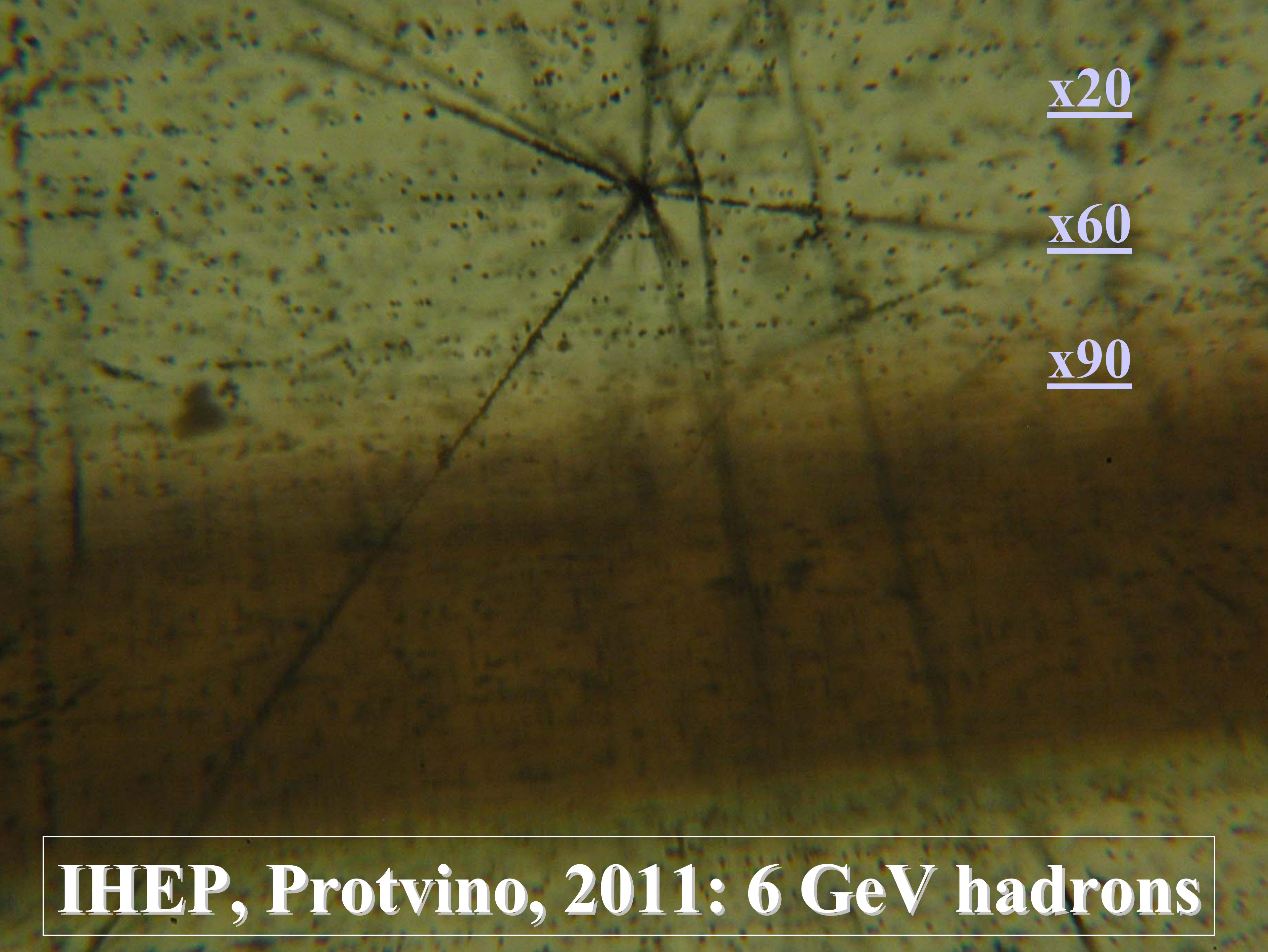
2A GeV/c ^{9}Be → 2α "white" star

The secondary ^{9}Be beam was obtained by fragmentation of accelerated ^{10}B nuclei. When scanning the exposed emulsion 500 events ^{9}Be → 2α in a fragmentation cone of 0.1 rad have been found. About 81% α-pairs form roughly equal groups on $\Theta_{2\alpha}$: "narrow" ($0 < \Theta_n < 10.5$ mrad) and "wide" ($15.0 < \Theta_w < 45.0$ mrad) ones. The Θ_n pairs are consistent with ^{8}Be decays from the ground state 0^+, and pairs Θ_w - from the first excited state 2^+. The Θ_n and Θ_w fractions are equal to 0.56 ± 0.04 and 0.44 ± 0.04. These values are well corresponding to the weights of the ^{8}Be 0^+ and 2^+ states $\omega_{0+} = 0.54$ and $\omega_{2+} = 0.47$ in the two-body model n - ^{8}Be, used to calculate the magnetic moment of the ^{9}Be nucleus.





For the coherent dissociation ^{9}Be → 2α + n, the average value of the total α-pair transverse momentum is equal to $\langle P_{Tsum} \rangle \approx 80$ MeV/c in correspondence with the Goldhaber statistical model. So, it can be assigned to the average transverse momentum carried away by neutrons. For the ^{9}Be coherent dissociation through the ^{8}Be 0^+ and 2^+ states there is no differences in the values $\langle P_{Tsum} \rangle$, which points to a "cold fragmentation" mechanism. The whole complex of these observations may serve as an evidence of the simultaneous presence of the ^{8}Be 0^+ and 2^+ states with similar weights in the ground state of the nucleus ^{9}Be.

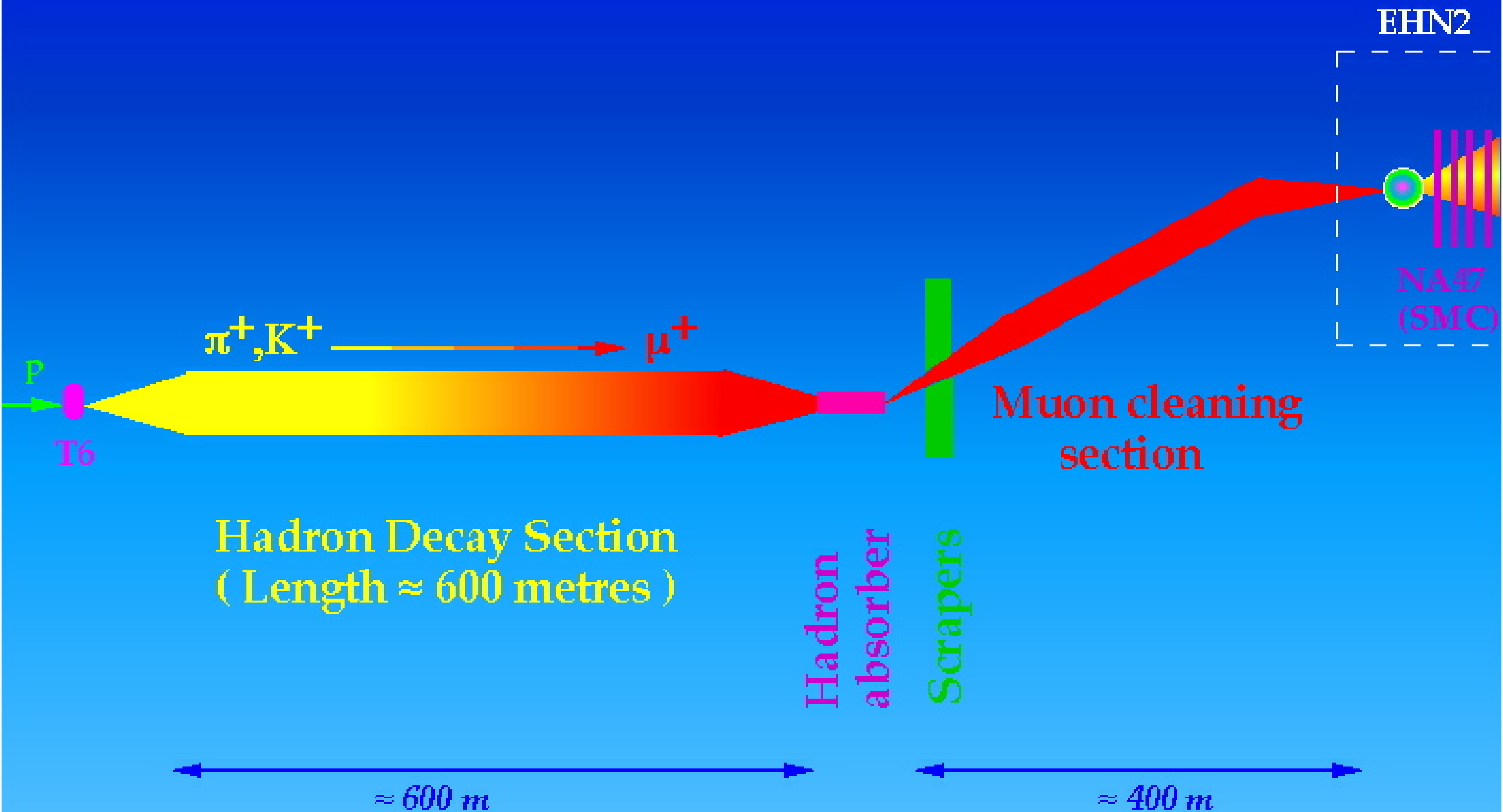


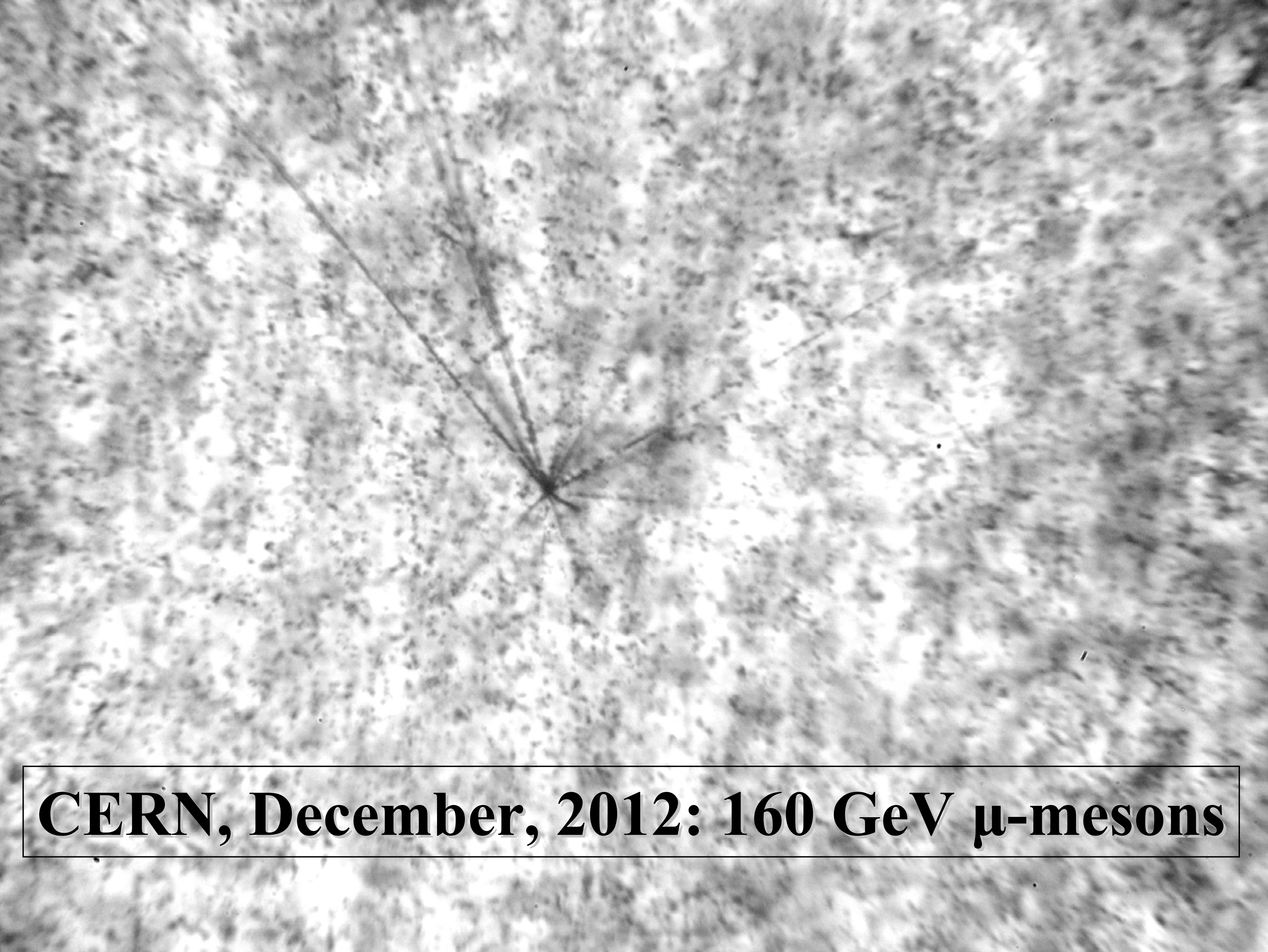
IHEP, Protvino, 2011: 6 GeV hadrons

Request for irradiation to a high-energy muon beam

- Until now, a high-energy muon exposure has not been conducted, which is a notable omission in survey observations of high-energy particle interactions.
- Meanwhile, the use of the muon, which is an electromagnetic probe, facilitates the interpretation of the phenomenon of nuclear multiple fragmentation.
- Moreover, the unexplored effects of multiphoton exchange may occur in the formation of muon stars associated with the destruction of heavy nuclei of emulsion.
- In addition to the nuclear dynamics, the muon interactions associated with the electron-positron pair formation in strong electromagnetic fields of heavy nuclei can be studied.
- It is also important that the images of the investigated events will complement the nuclear photo collection begun in the classic book by Powell, Fowler and Perkins.
- In terms of applications the received material will be very valuable for the development of systems of automatic search for nuclear interactions, as well as for university education.

THE M2 MUON BEAM
(FOR NA47 - SMC)





CERN, December, 2012: 160 GeV μ-mesons

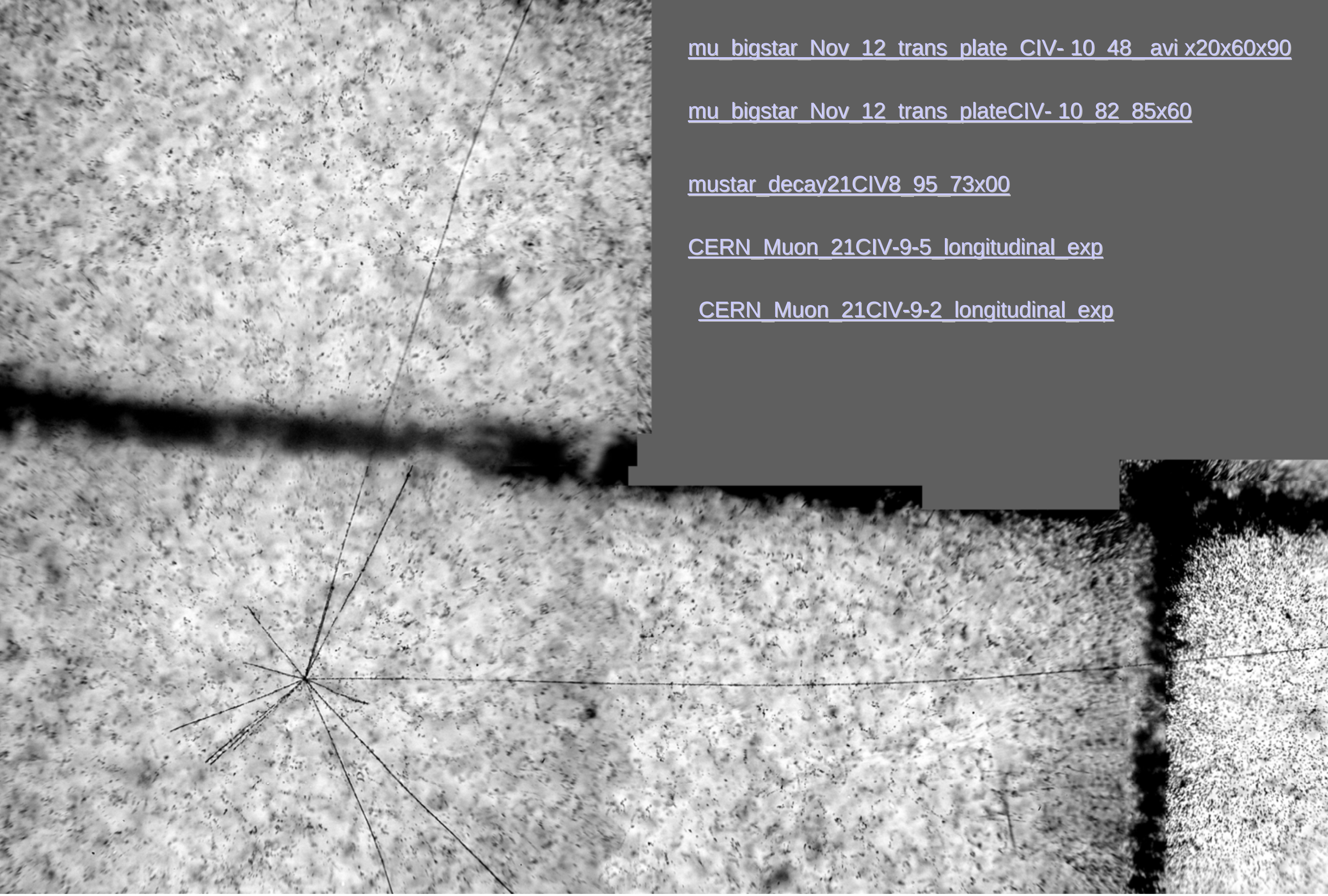
mu_bigstar_Nov_12_trans_plate_CIV- 10_48_ avi x20x60x90

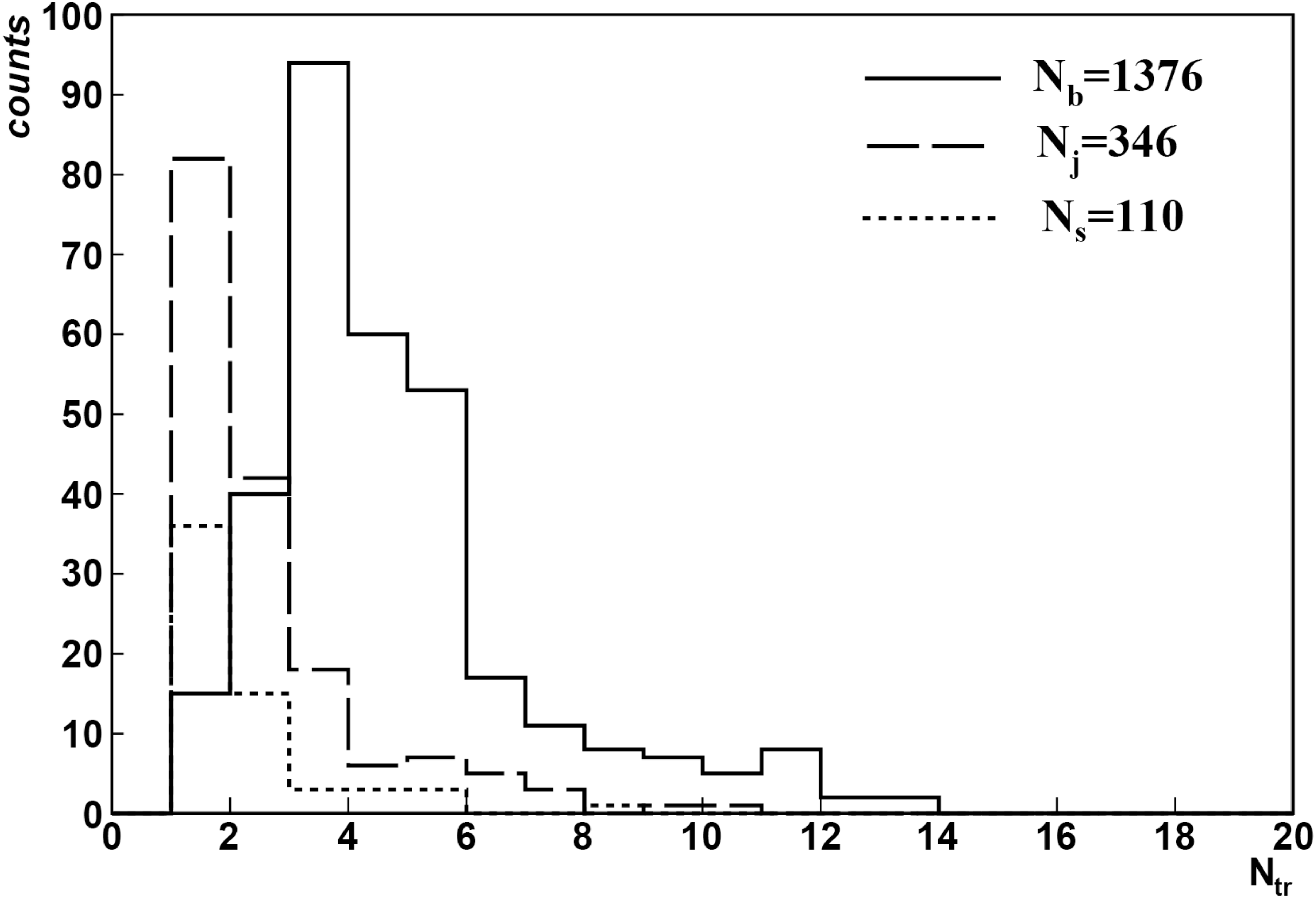
mu_bigstar_Nov_12_trans_plateCIV- 10_82_85x60

mustar_decay21CIV8_95_73x00

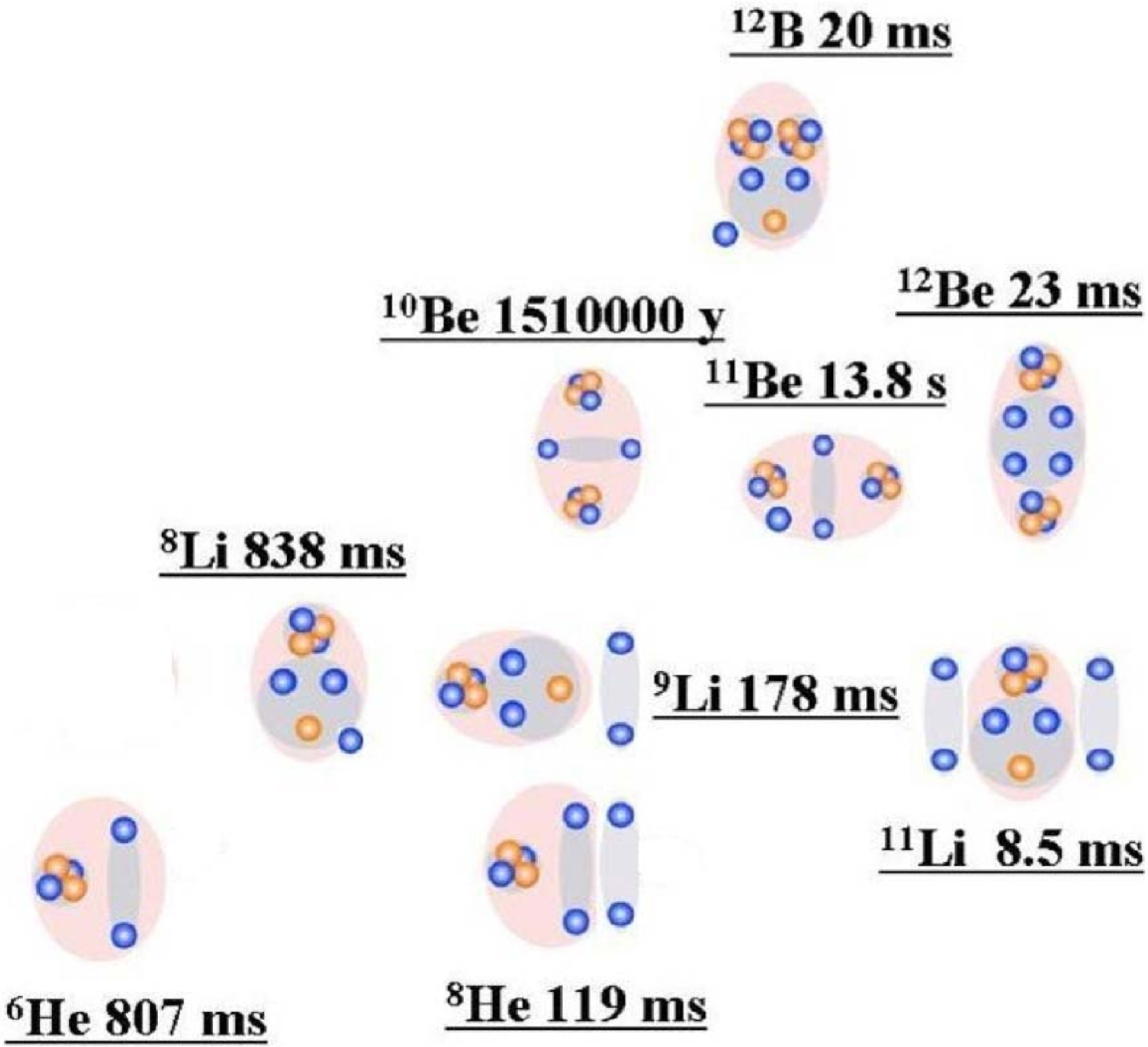
CERN_Muon_21CIV-9-5_longitudinal_exp

CERN_Muon_21CIV-9-2_longitudinal_exp

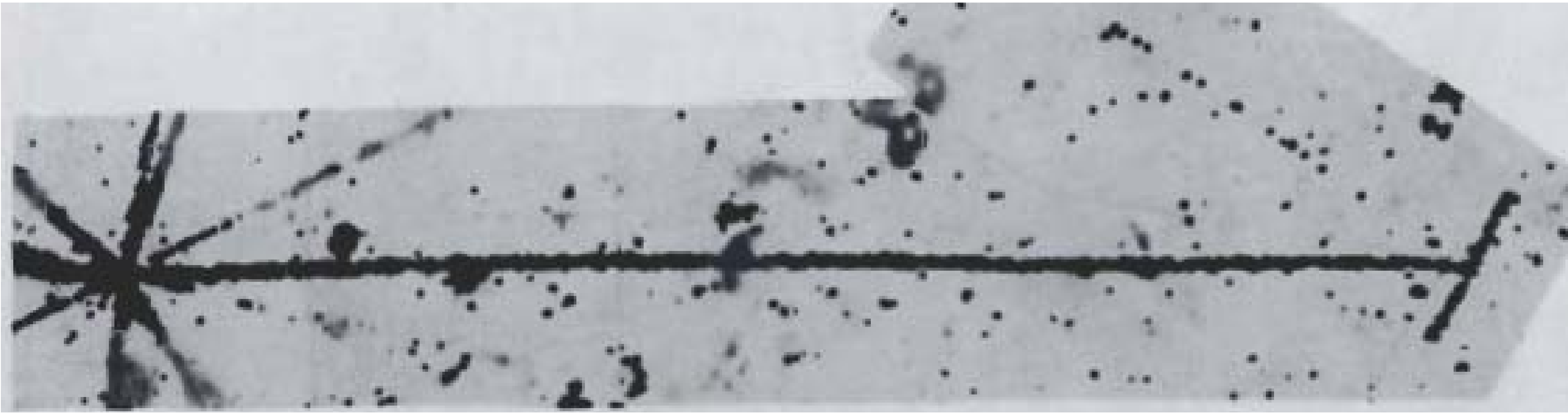


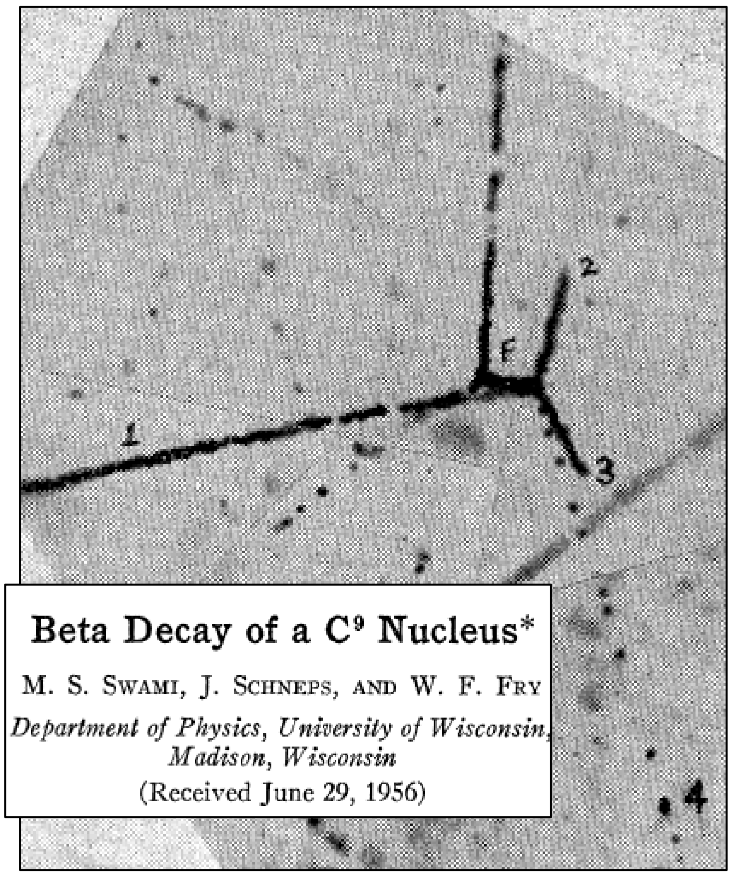


counts
N_b=1376
N_j=346
N_s=110
N_tr
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20



12B 20 ms
10Be 1510000 y
12Be 23 ms
11Be 13.8 s
8Li 838 ms
9Li 178 ms
11Li 8.5 ms
6He 807 ms
8He 119 ms



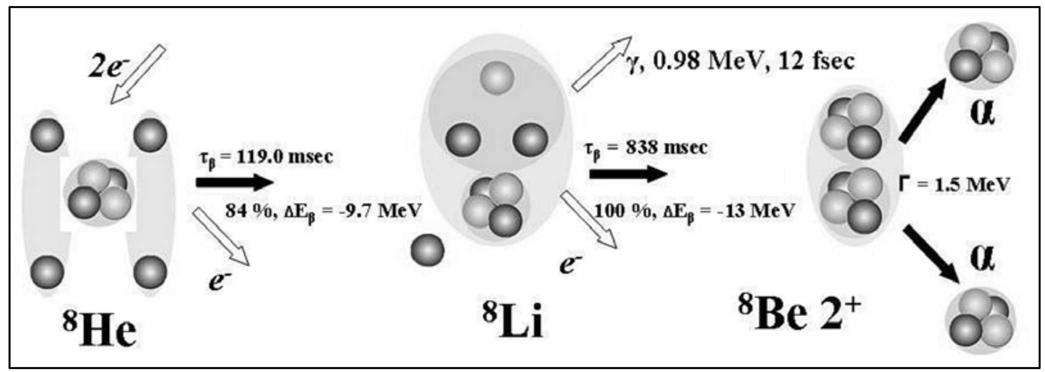


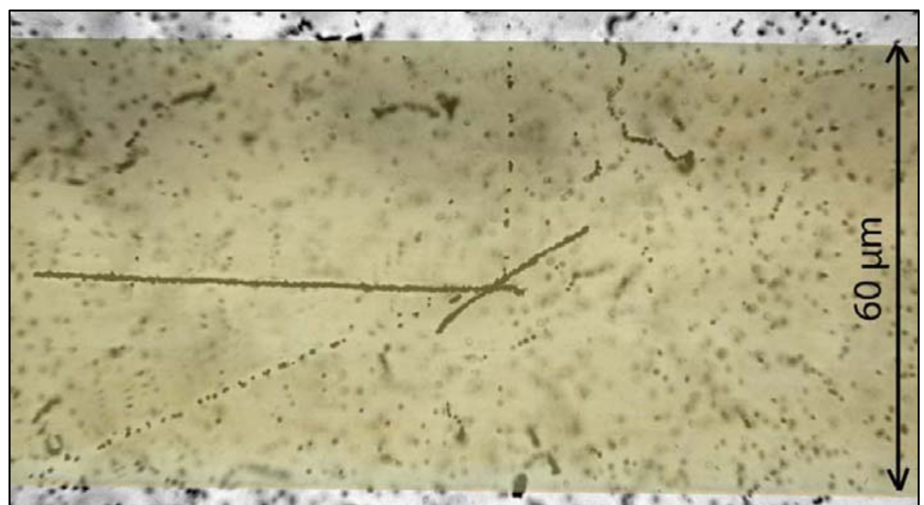
Beta Decay of a C^9 Nucleus*

M. S. SWAMI, J. SCHNEPS, AND W. F. FRY

Department of Physics, University of Wisconsin, Madison, Wisconsin

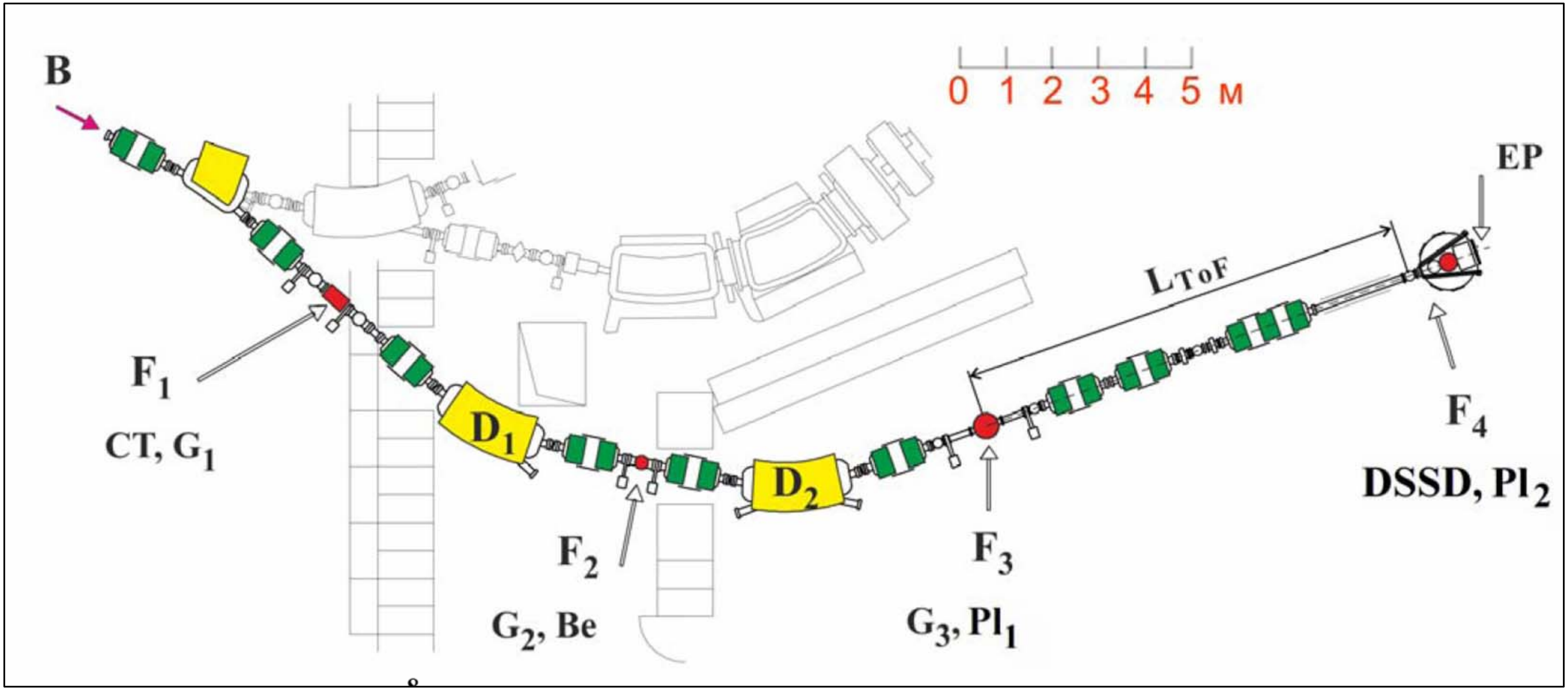
(Received June 29, 1956)

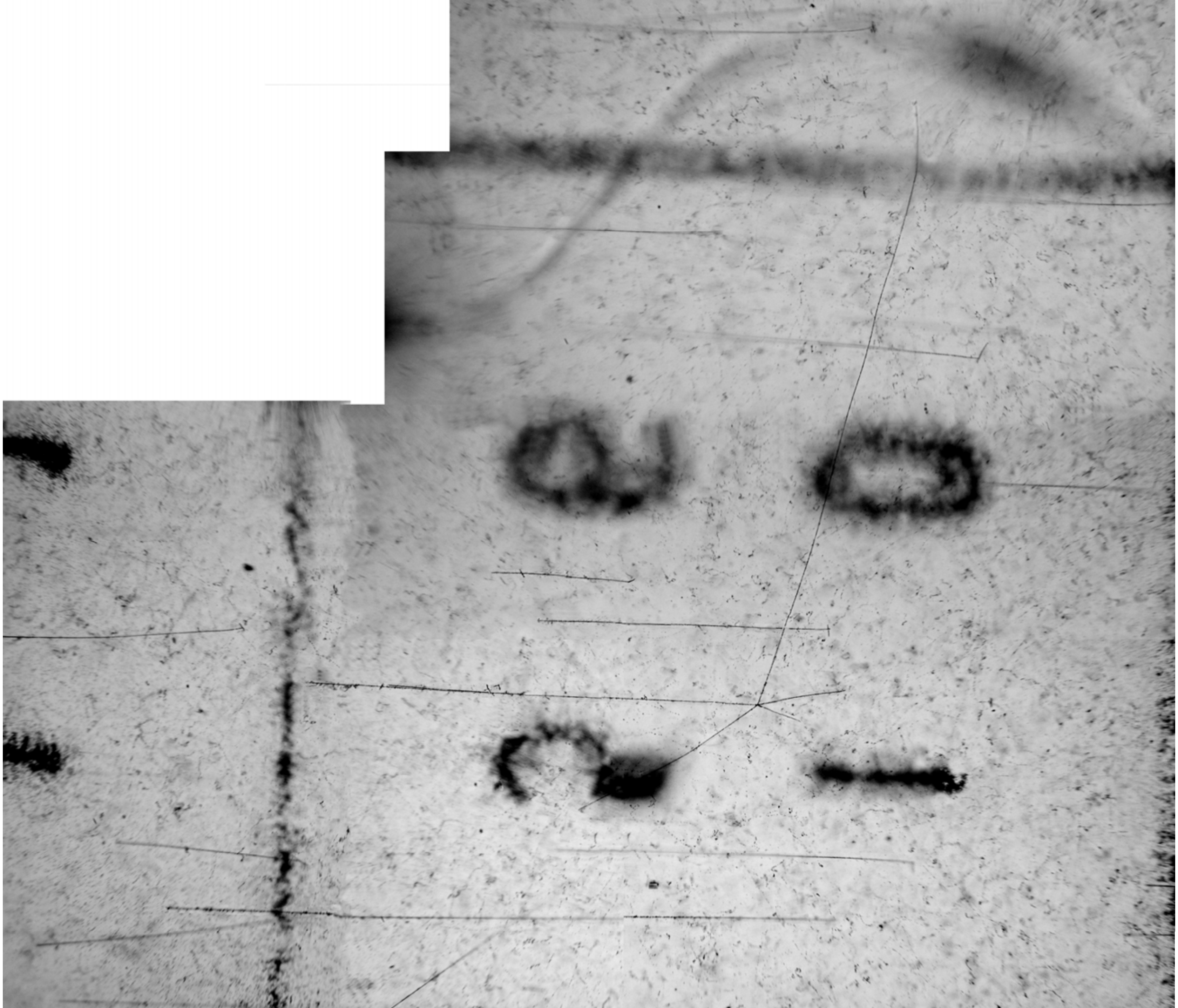


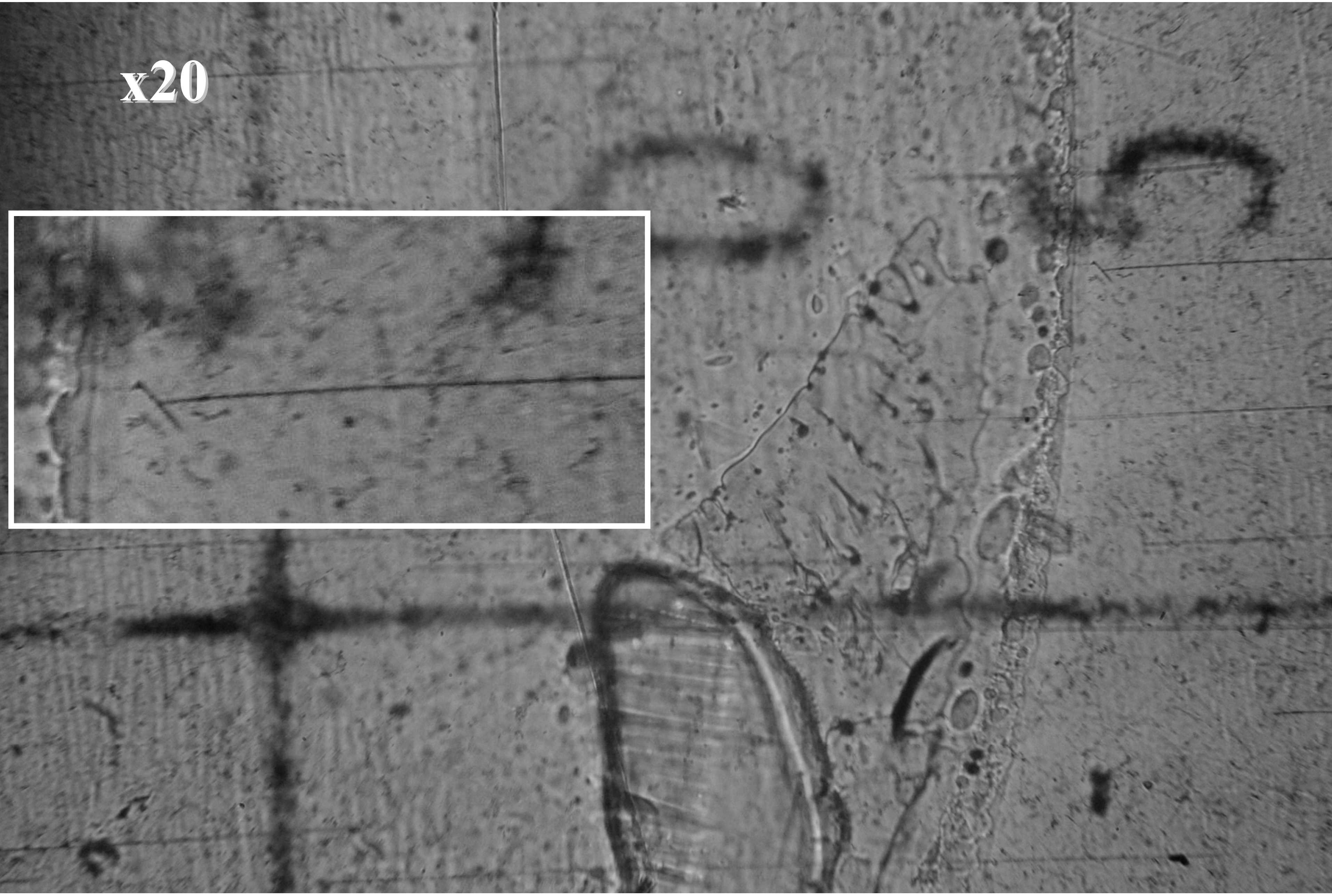


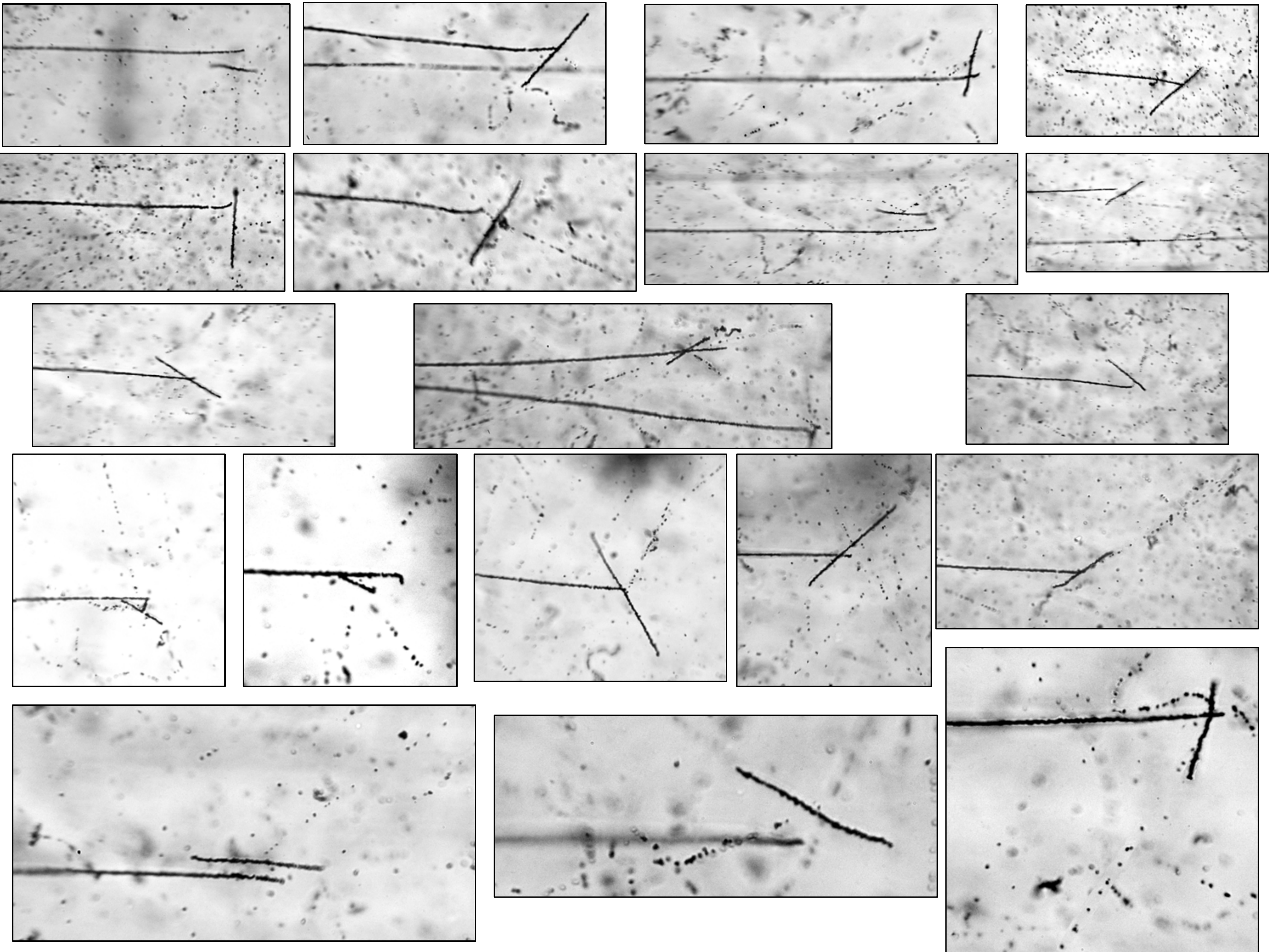
Flerov Laboratory

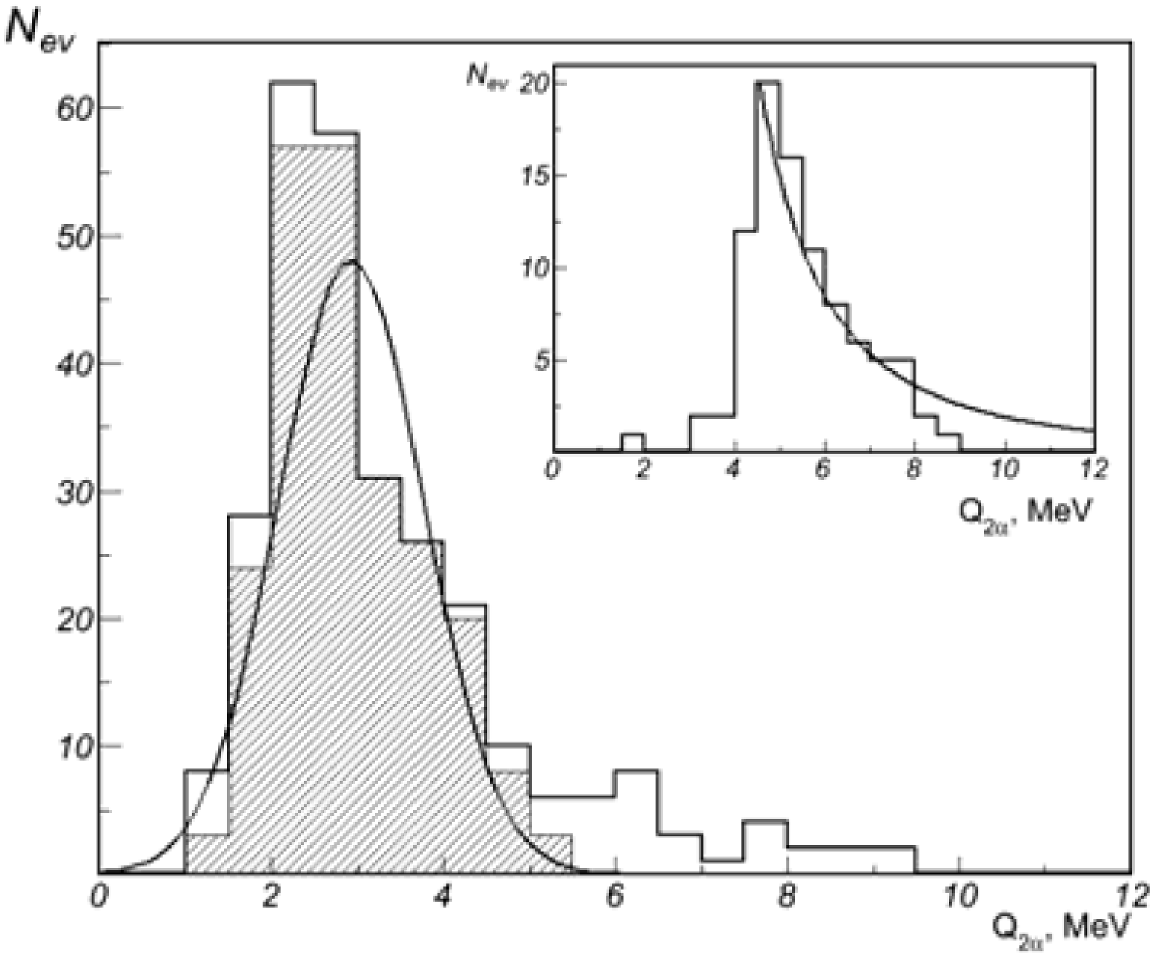
Flerov Laboratory
The ACCULLINA Fragment Separator

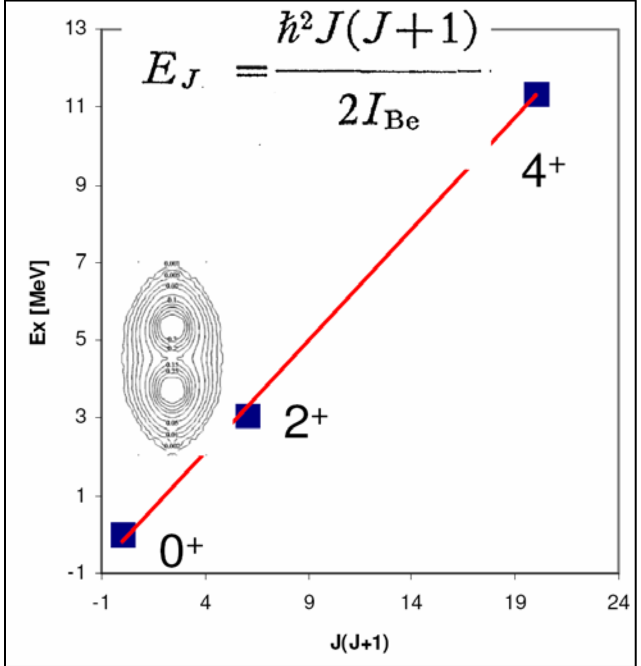





x20







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, $\Theta > 145^0$; line – Gaussian. On the insertion: $Q_{2\alpha}$ distribution of additional 98 α-pairs having L_1 and $L_2 > 12.5$ μm.

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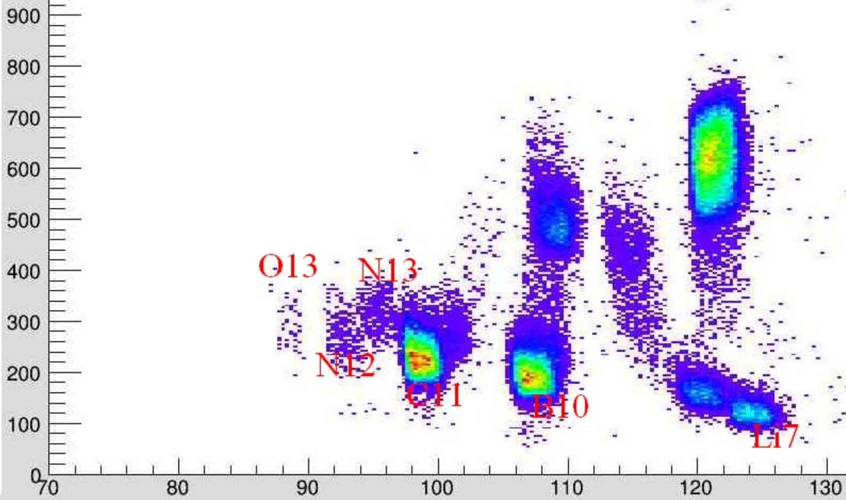
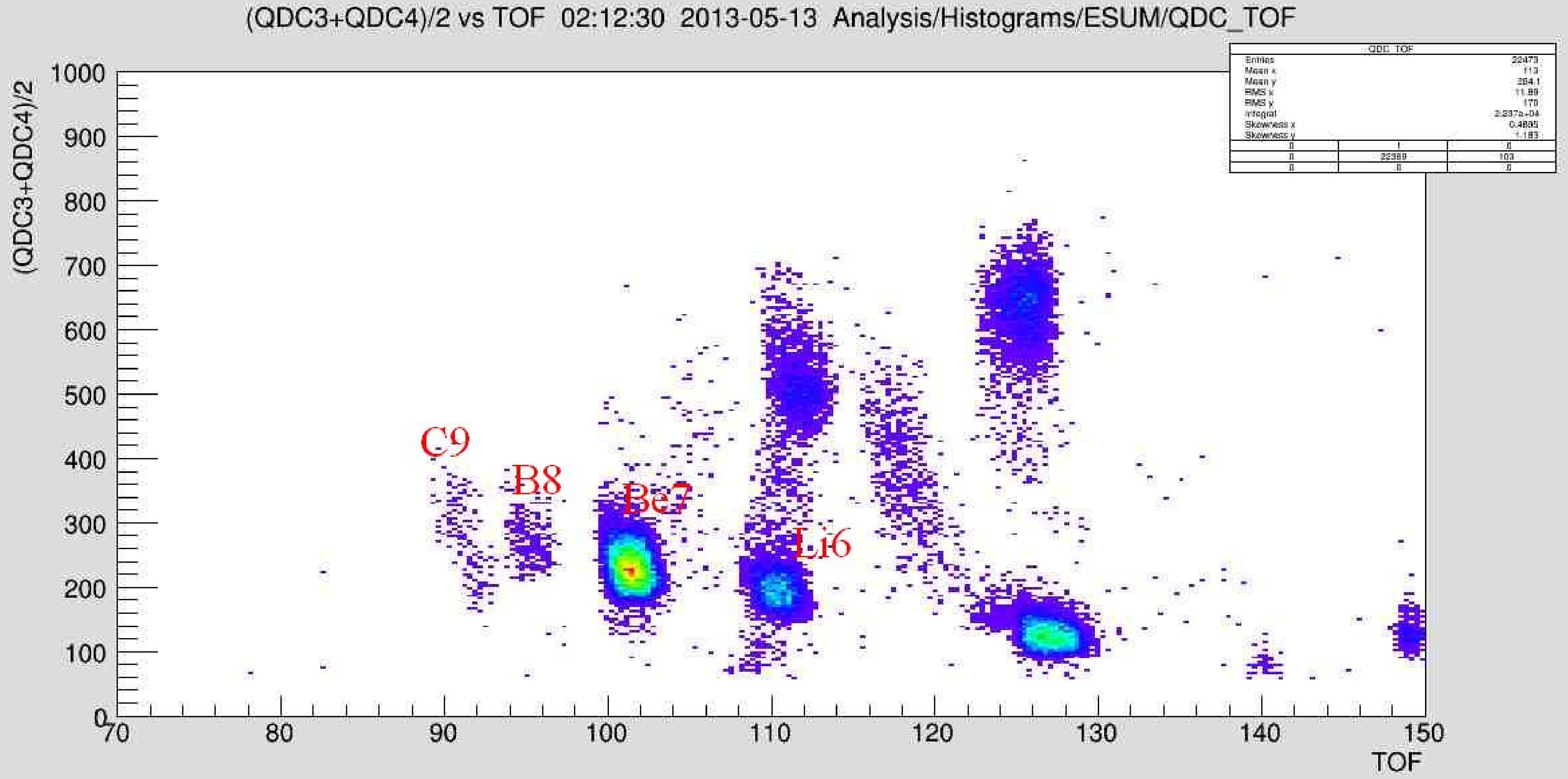
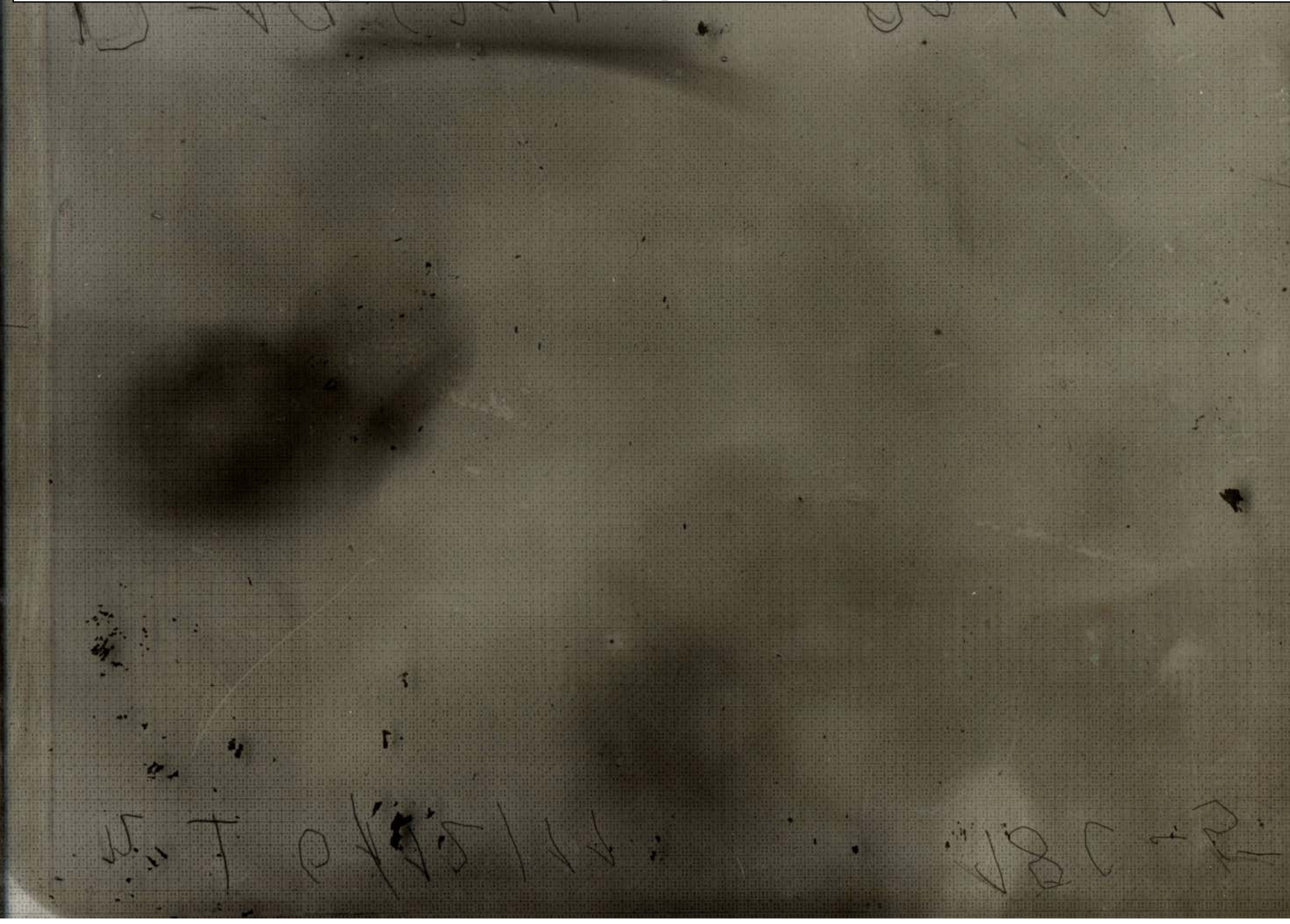




Correlations of α-particles in splitting of ^{12}C nuclei by 14.1 MeV neutrons

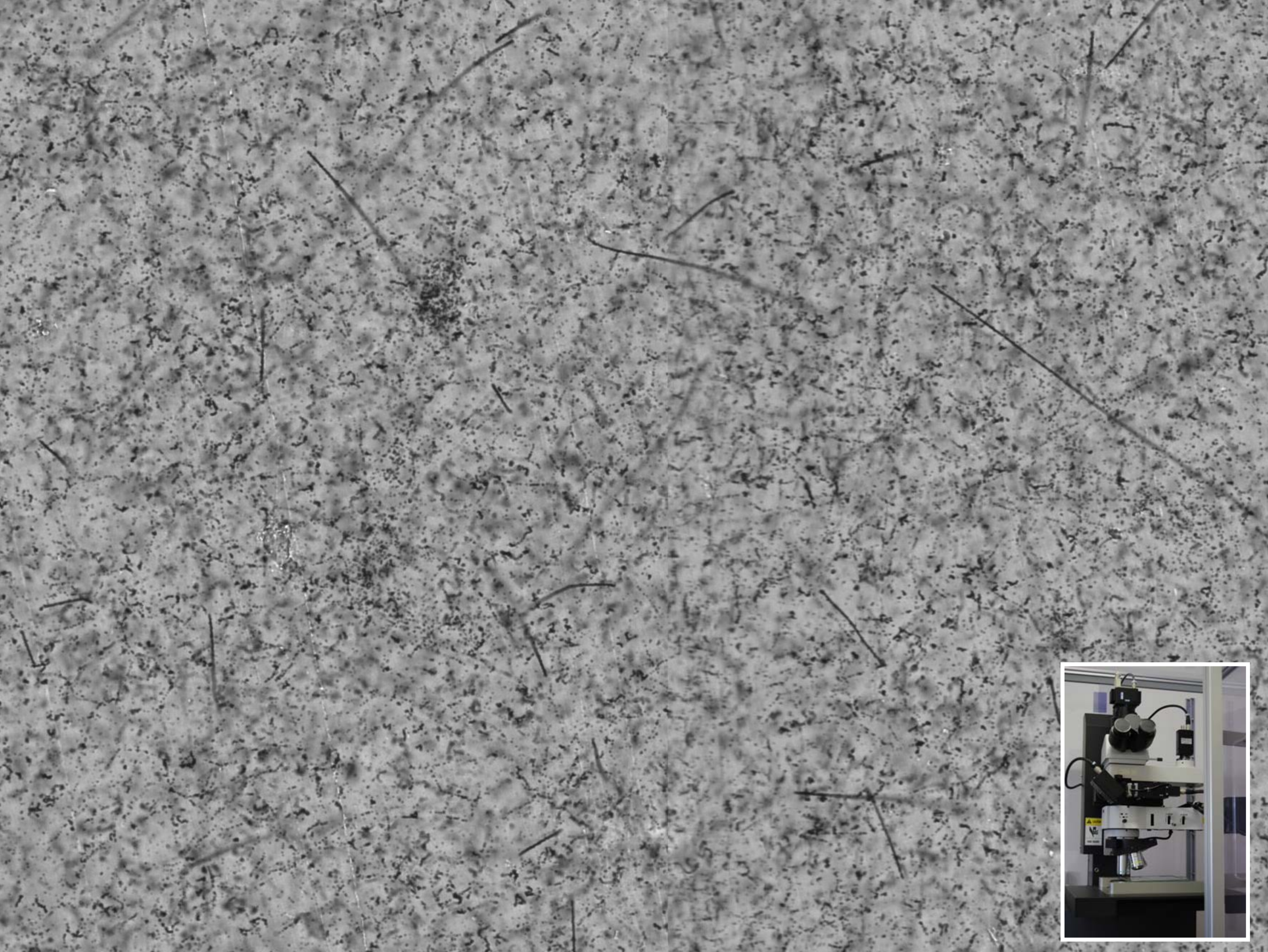
Correlations of α-particles in splitting of ^{12}C nuclei by 14.1 MeV neutrons



Department of Radiation Dosimetry
Nuclear Physics Institute
Academy of Sciences of
Czech Republik

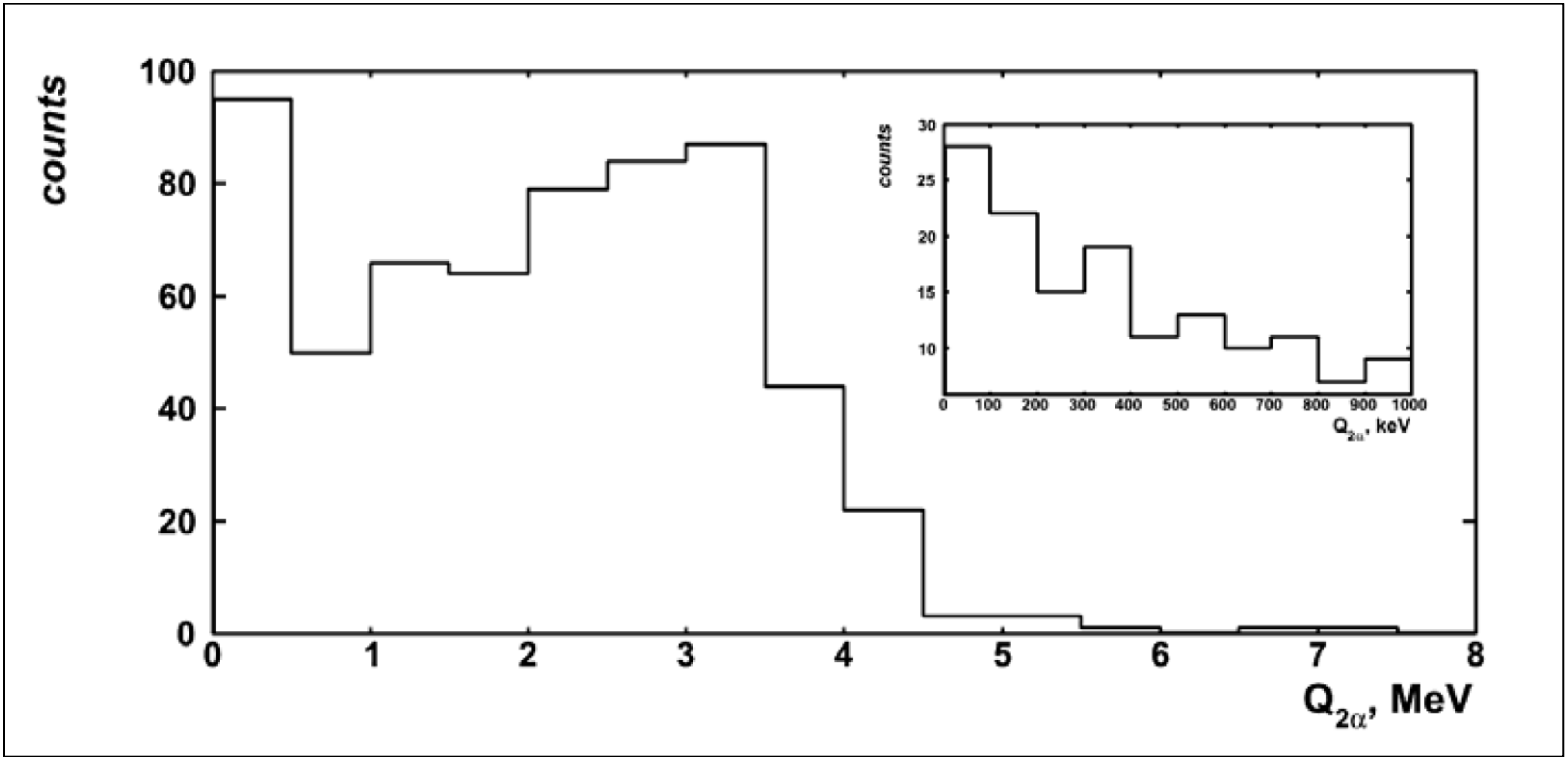
Microscope HSP-1000

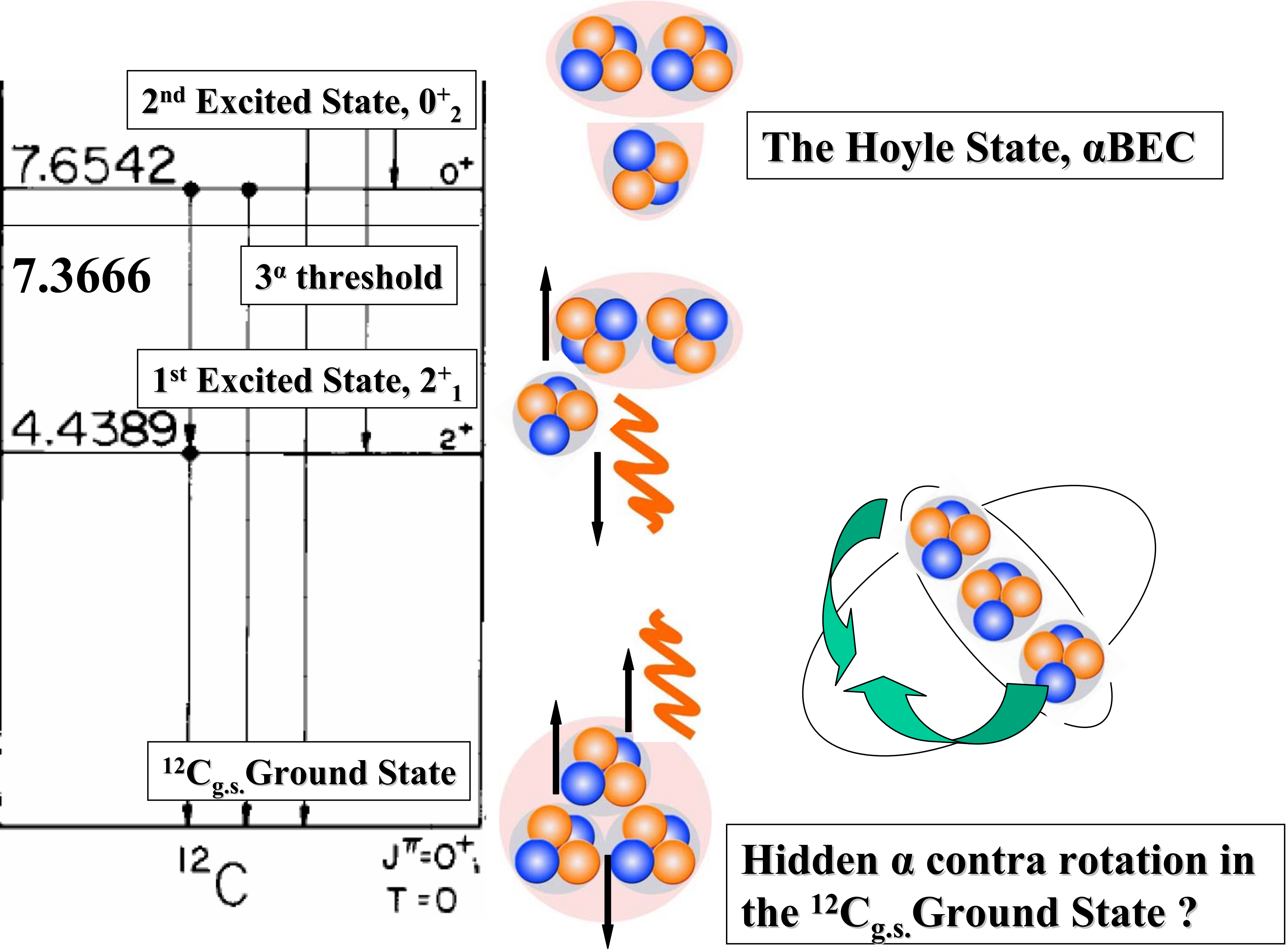
High speed wide area imaging microscope HSP-1000 manufactured by SEIKO Precision was purchased by the Department of Radiation Dosimetry in 2009. A high-resolution line scannerr instead of a CCD camera acquires and digitizes samples with autofocus and high speed micro positioning up to 50 times faster than similar systems with CCD cameras. A computer controlled mechanism with x-y-z stage movement allows for clear image acqusition of objects with very uneven thickness at high speed.



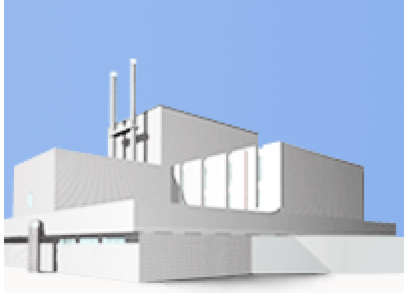
Correlations of α-particles in splitting of ^{12}C nuclei by 14.1 MeV neutrons

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

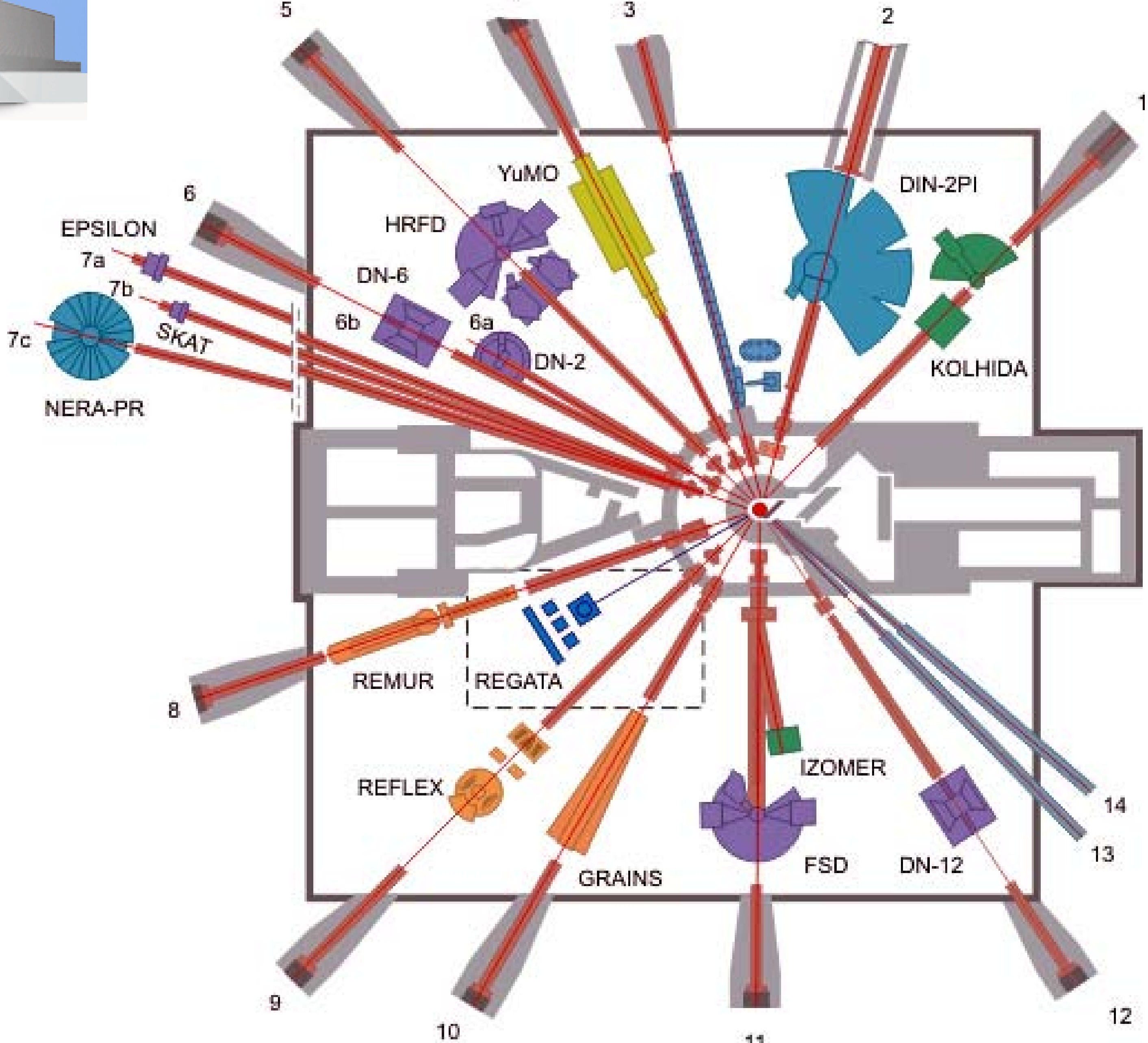




2nd Excited State, 0+2
7.6542
0+
7.3666
3α threshold
1st Excited State, 2+1
4.4389
2+
12Cg.s. Ground State
12C
Jπ=0+;
T=0
The Hoyle State, αBEC
Hidden α contra rotation in the 12Cg.s. Ground State ?

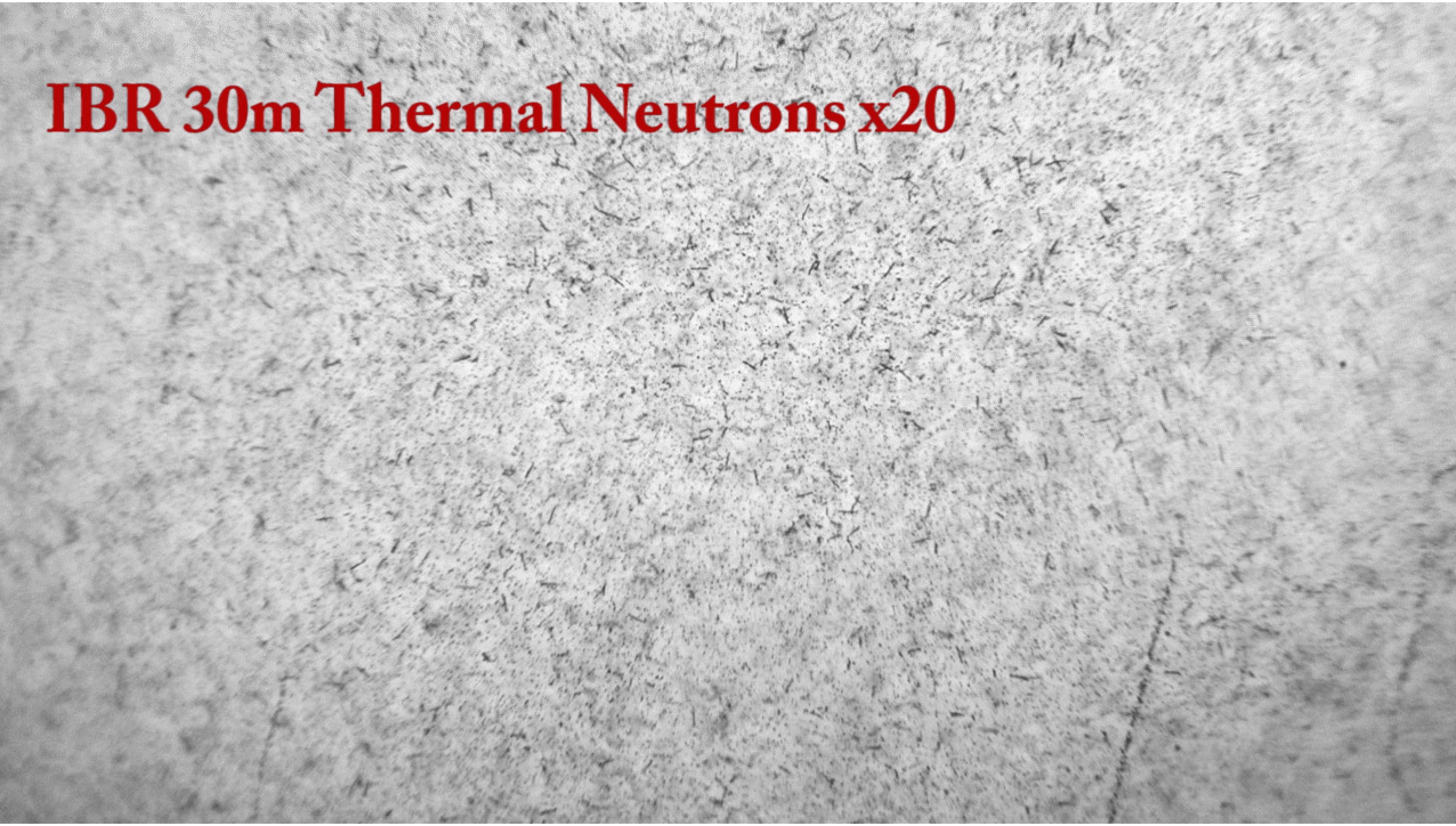


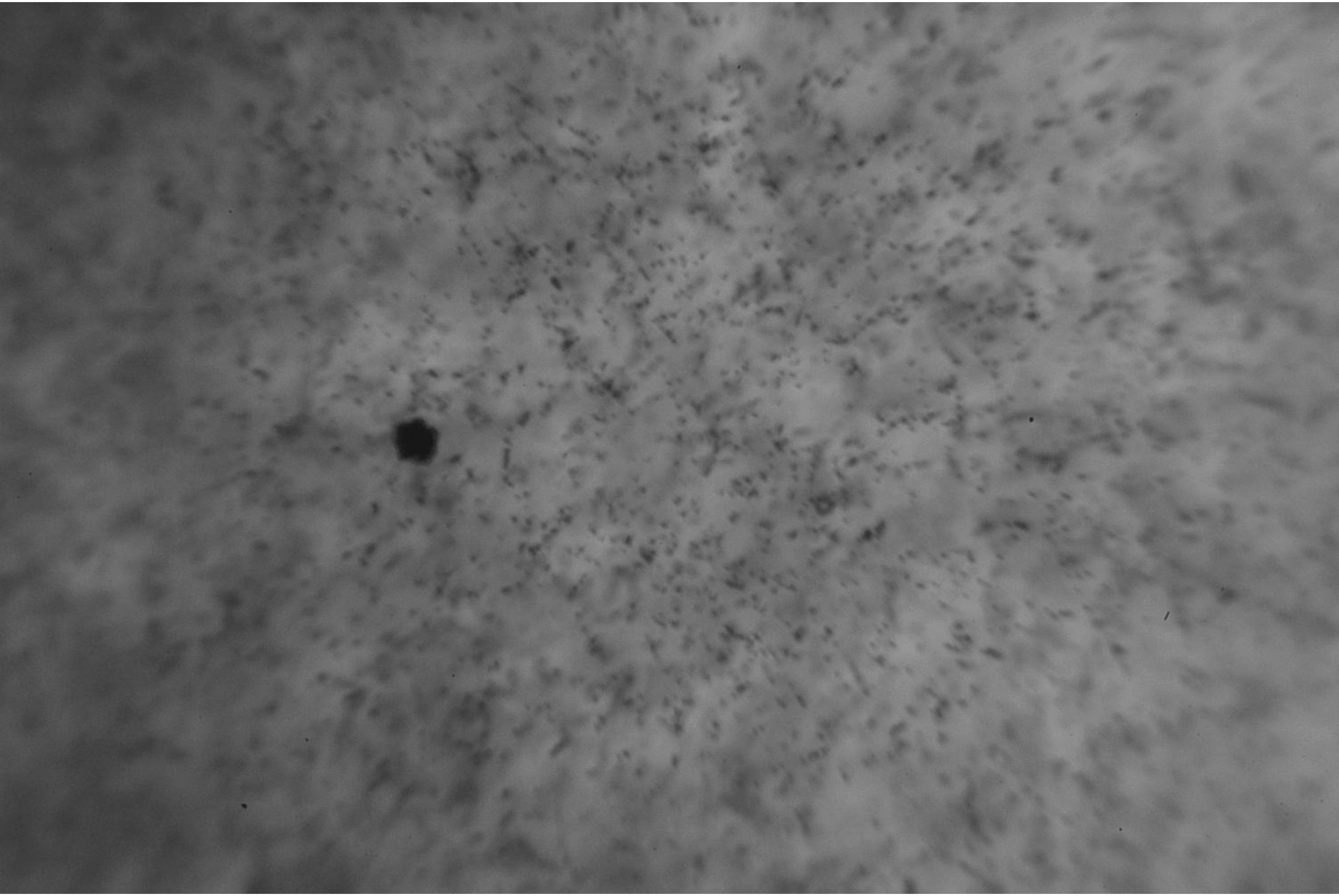
JINR IBR-2 Pulsed Reactor

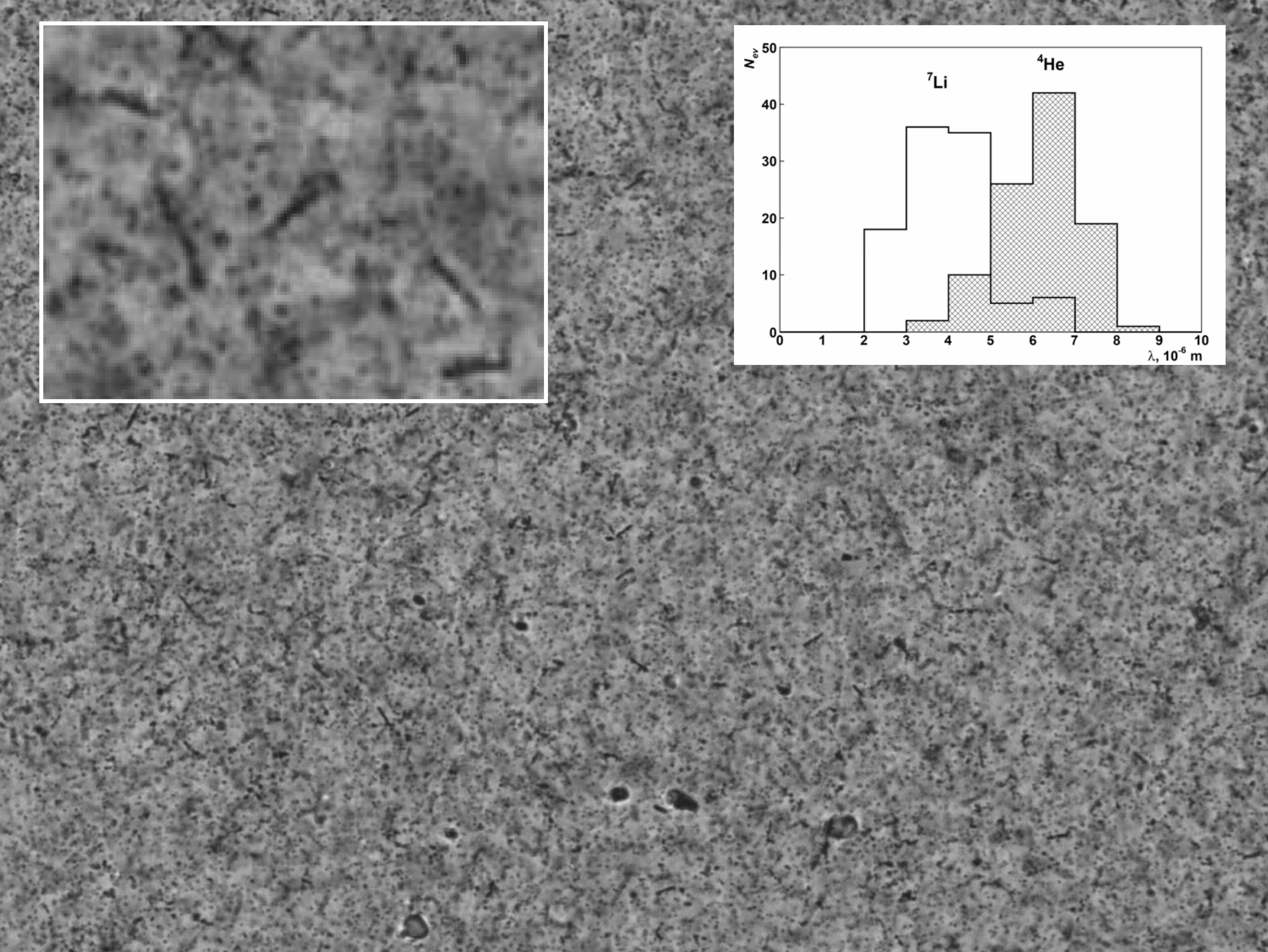



2aB - 2/2

IBR 30m Thermal Neutrons x20

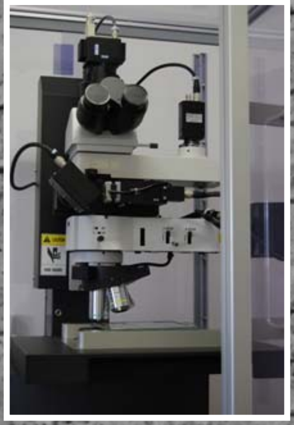


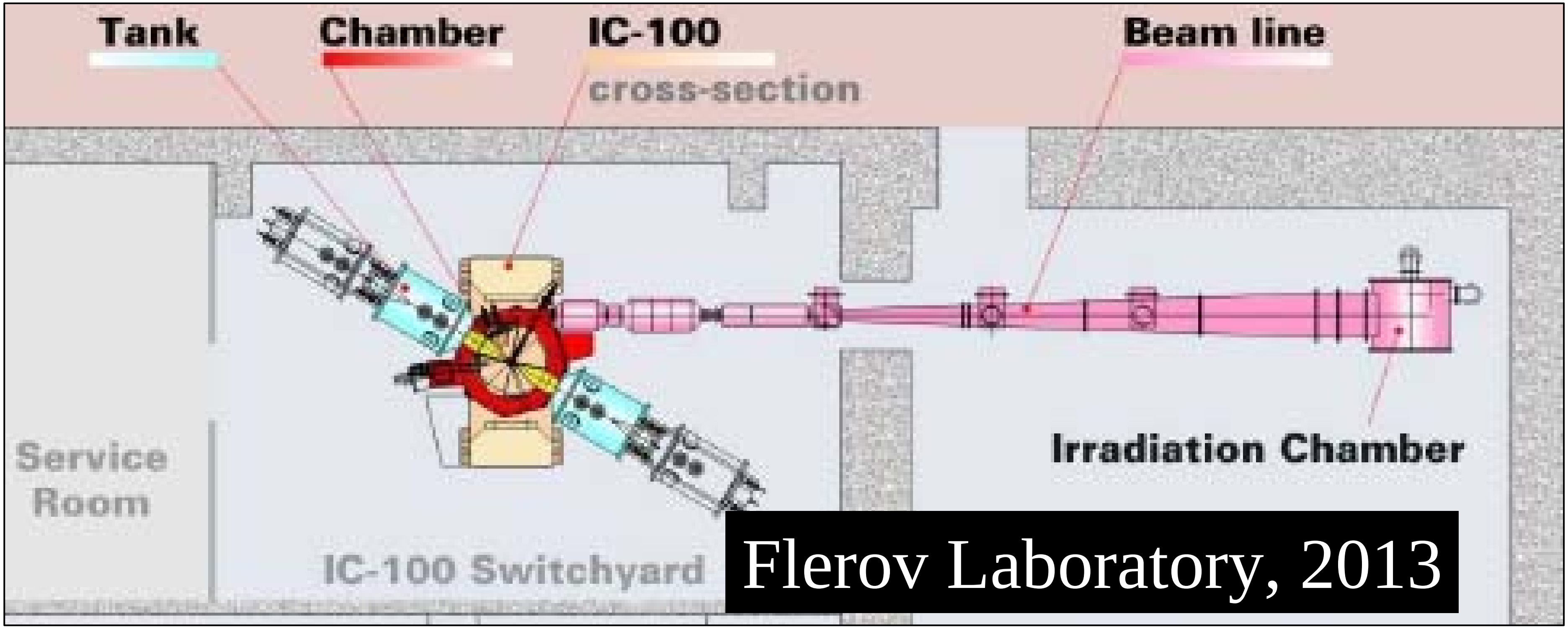



N_{ev}
^7Li
^4He
0
10
20
30
40
50
0 1 2 3 4 5 6 7 8 9 10
λ, 10^{-6} m

Implantation of Kr and Xe ions

At the accelerator complex IC-100 a nuclear track emulsion is exposed to beams of ions $^{86}Kr^{+17}$ and $^{132}Xe^{+26}$ with energy of about 1.2 *A* MeV. Measured ranges and scattering angles of Kr and Xe ions are compared with the values calculated in the model SRIM.





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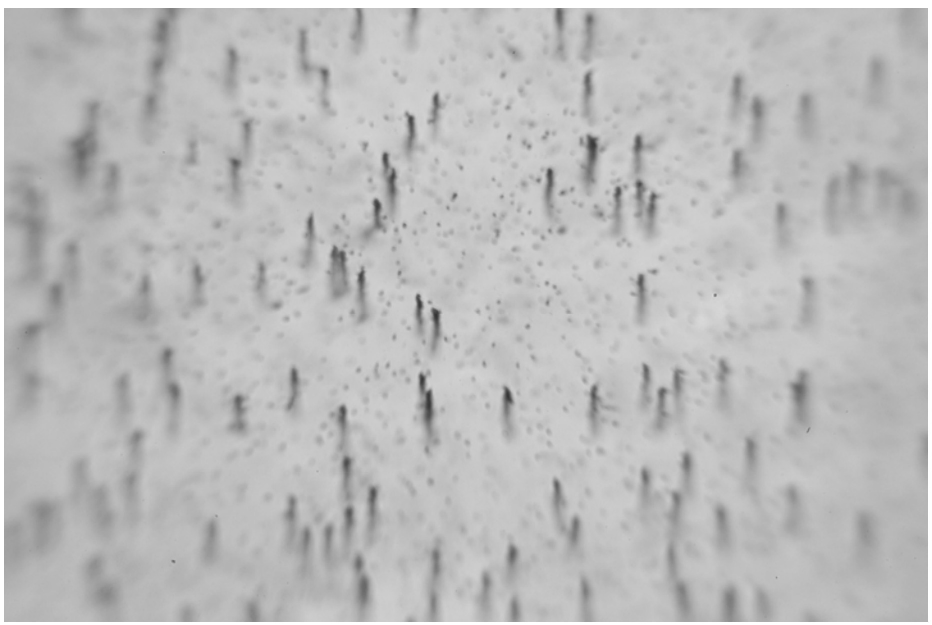
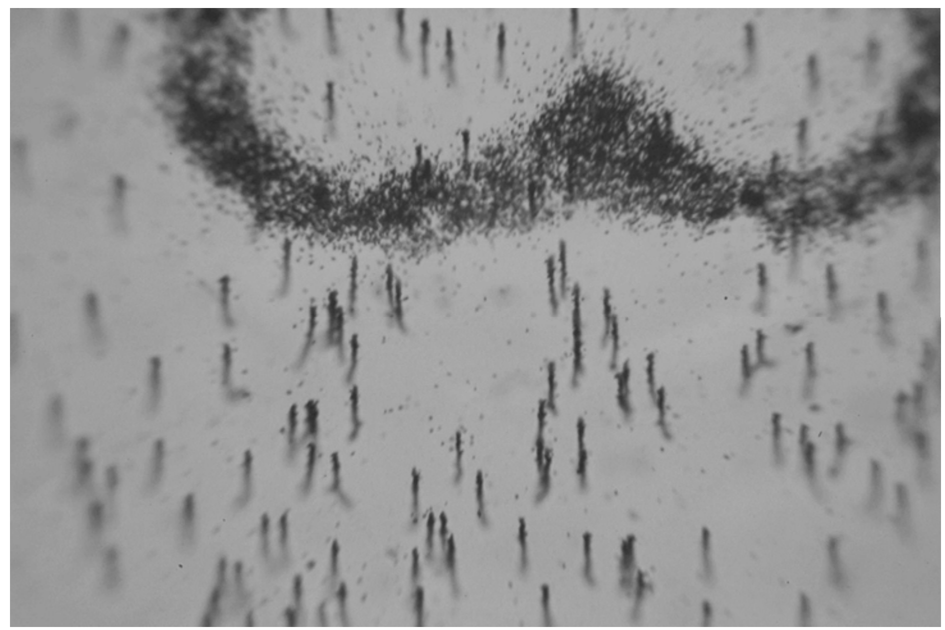
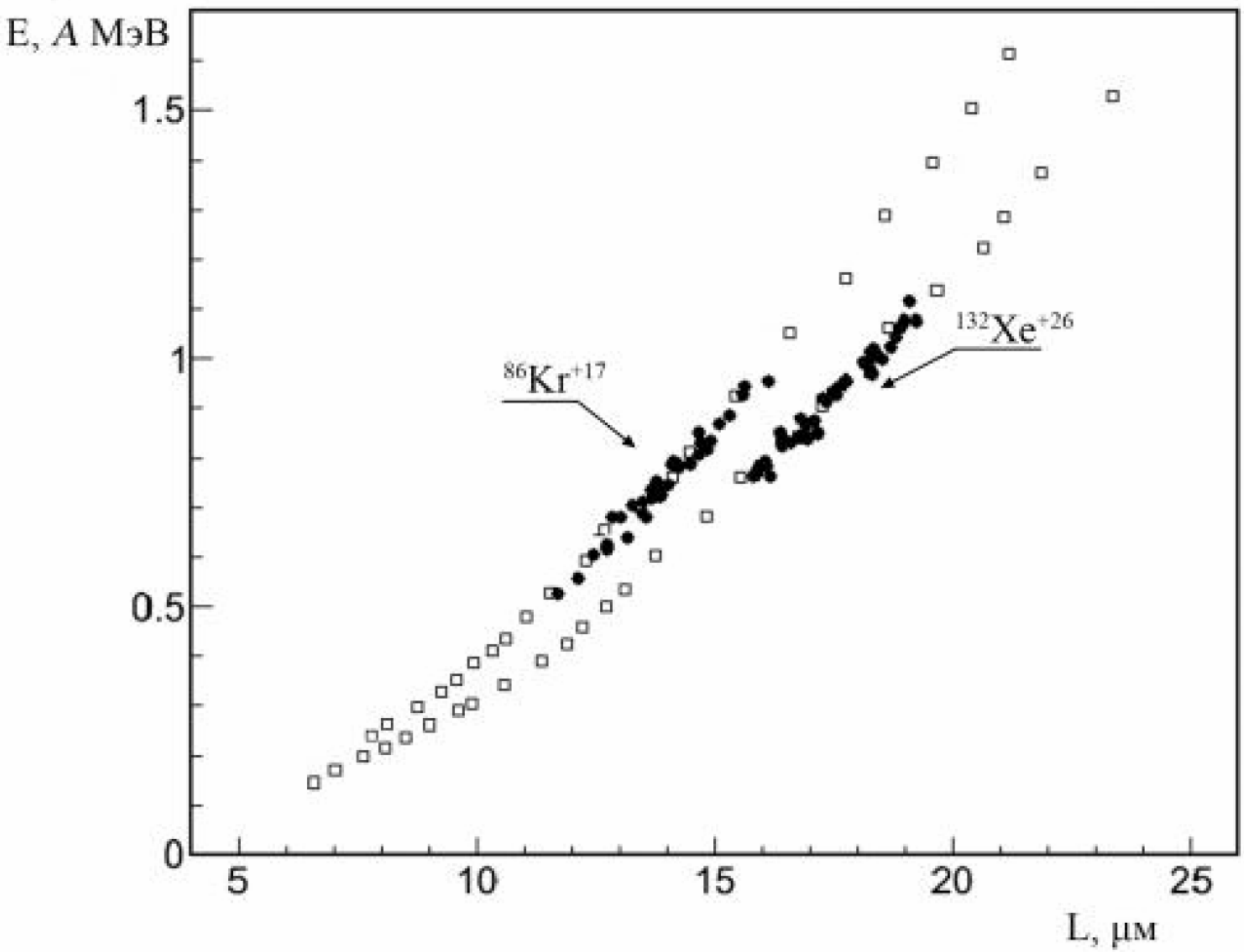
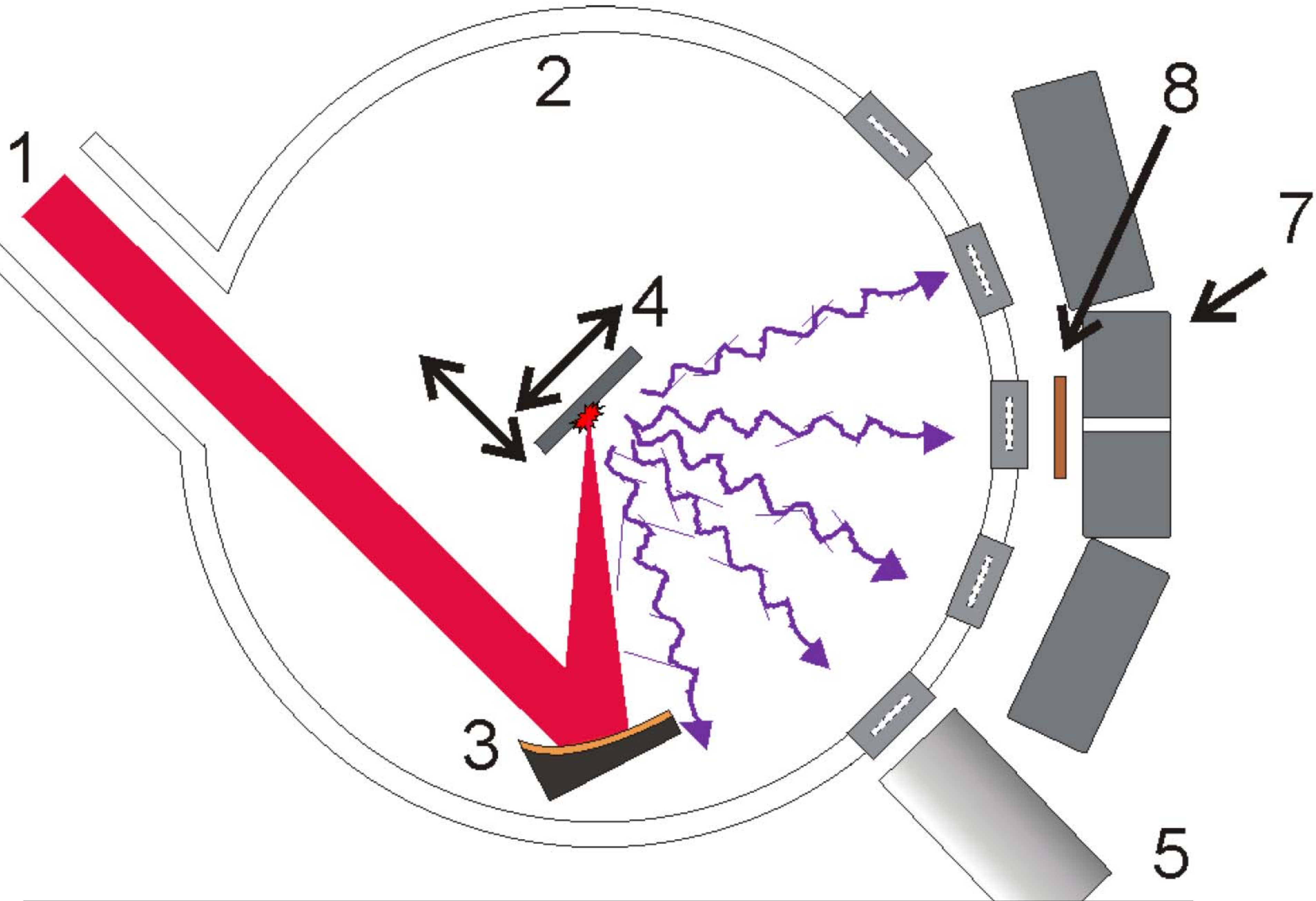
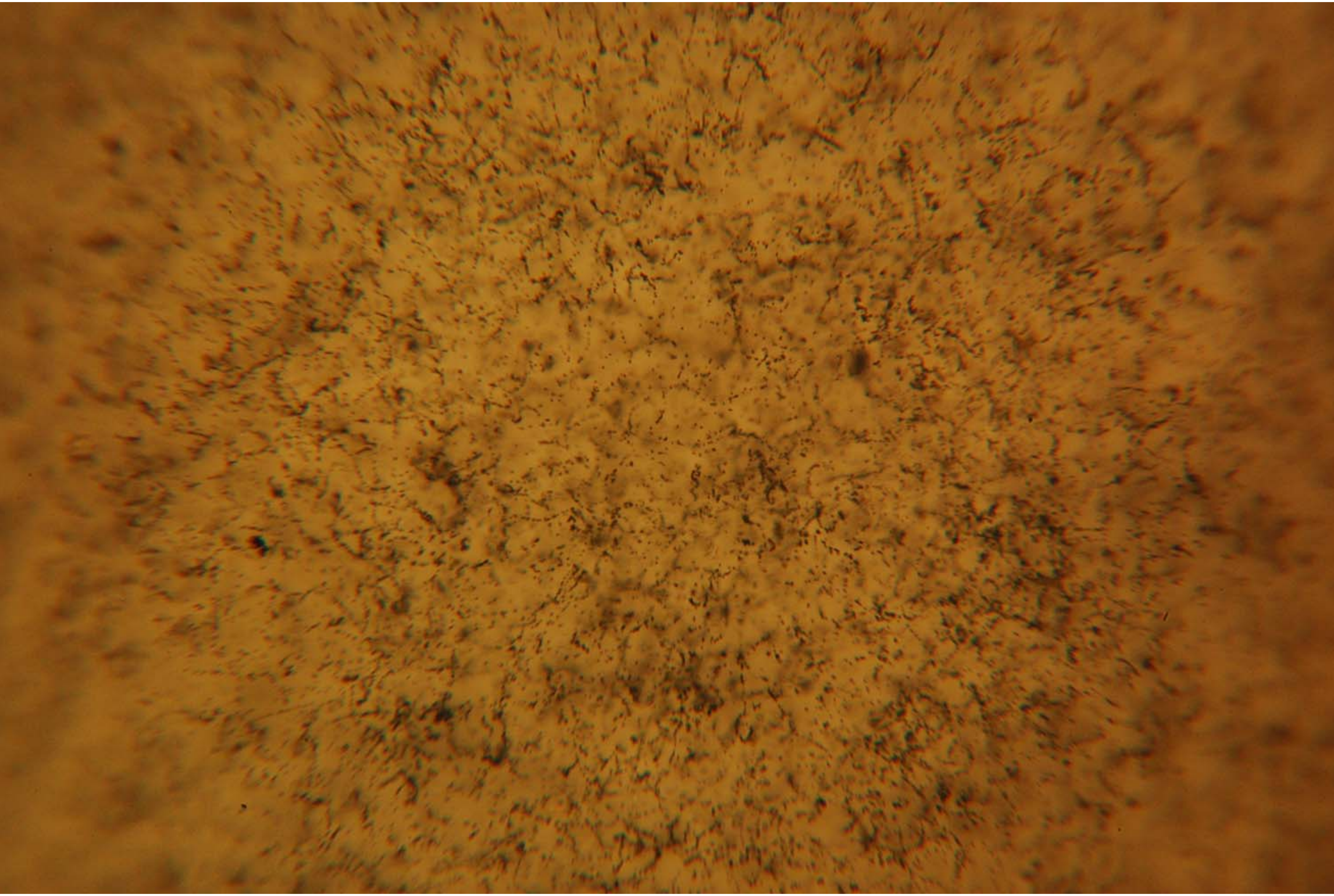





E, A МэВ
1.5
1
0.5
0
5
10
15
20
25
L, μм
86Kr+17
132Xe+26



Femtosecond Laser , Laser Center Moscow State University



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

(индийская поговорка)

If you do not know where to go, look back, look at where you came from.

(Indian saying)