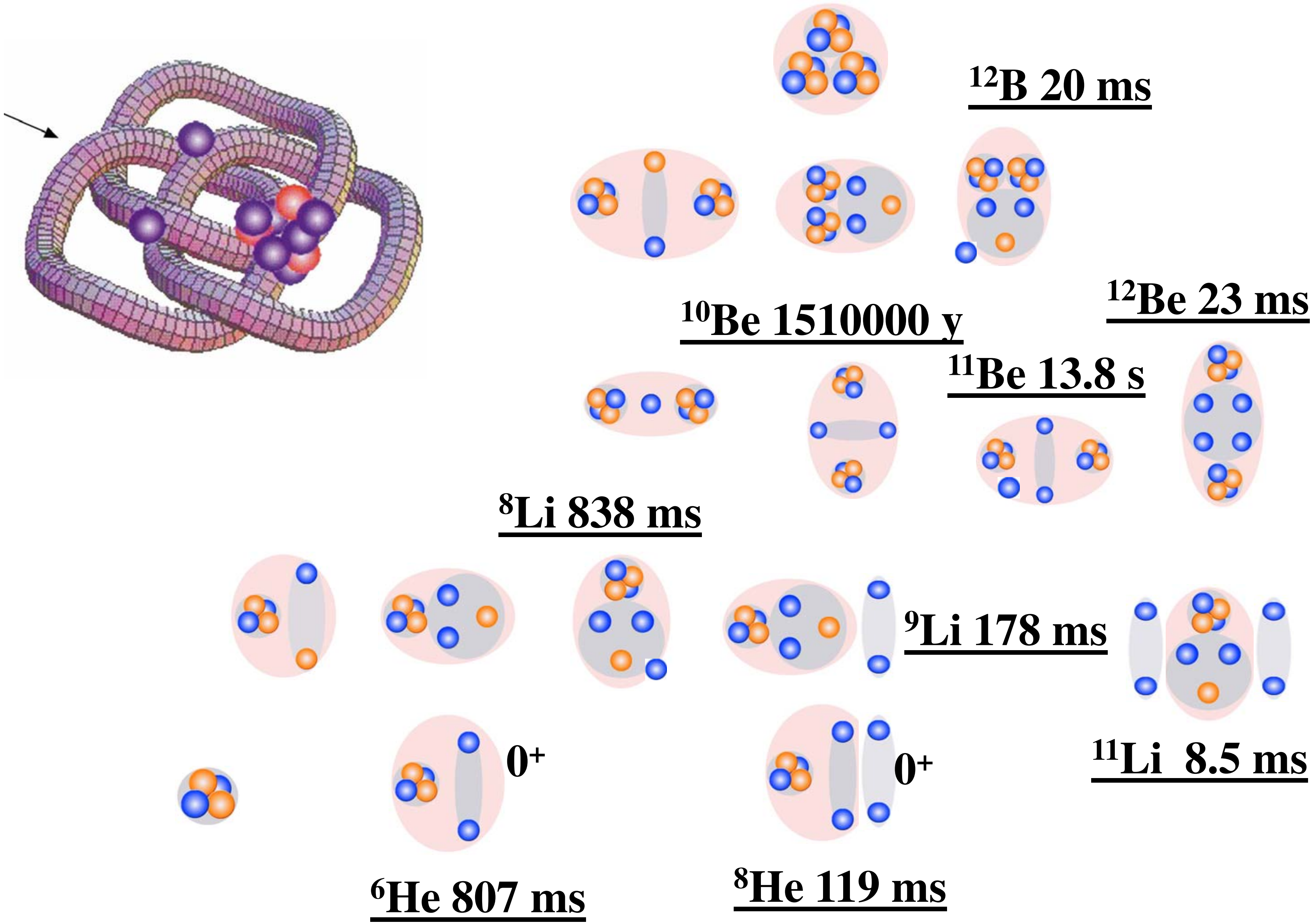
"Tomography" of nuclear structure in dissociation of relativistic nuclei

P. I. Zarubin

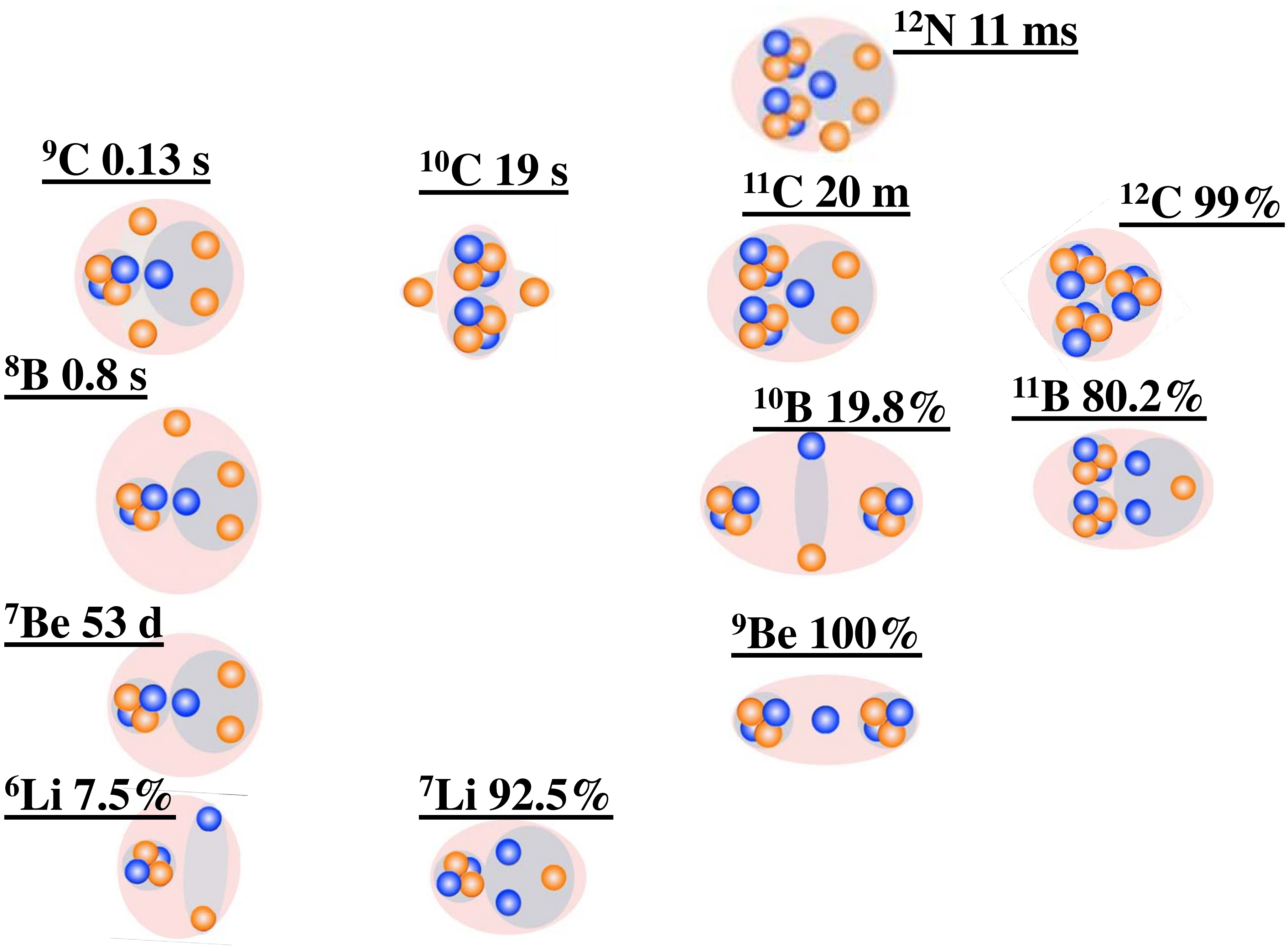
V. I. Veksler and A. M. Baldin Laboratory of High Energy Physics
Joint Institute for Nuclear Research, Dubna, Russia

The use of accelerated nuclei, including radioactive ones, qualitatively diversifies the spectroscopy of cluster systems. Configuration overlap of a fragmenting nucleus with finite cluster states manifested most fully in the dissociation at the periphery of the target nucleus with the excitation transfer near the cluster binding thresholds.

The definition of interactions as peripheral ones is simplified at energy above 1A GeV due to the collimation of the incident nucleus fragments. The detection thresholds disappear and the fragment energy loses in detector material are minimal. Thus, qualitatively new opportunities appear in the relativistic region for the study of cluster systems as compared with the low energy region.

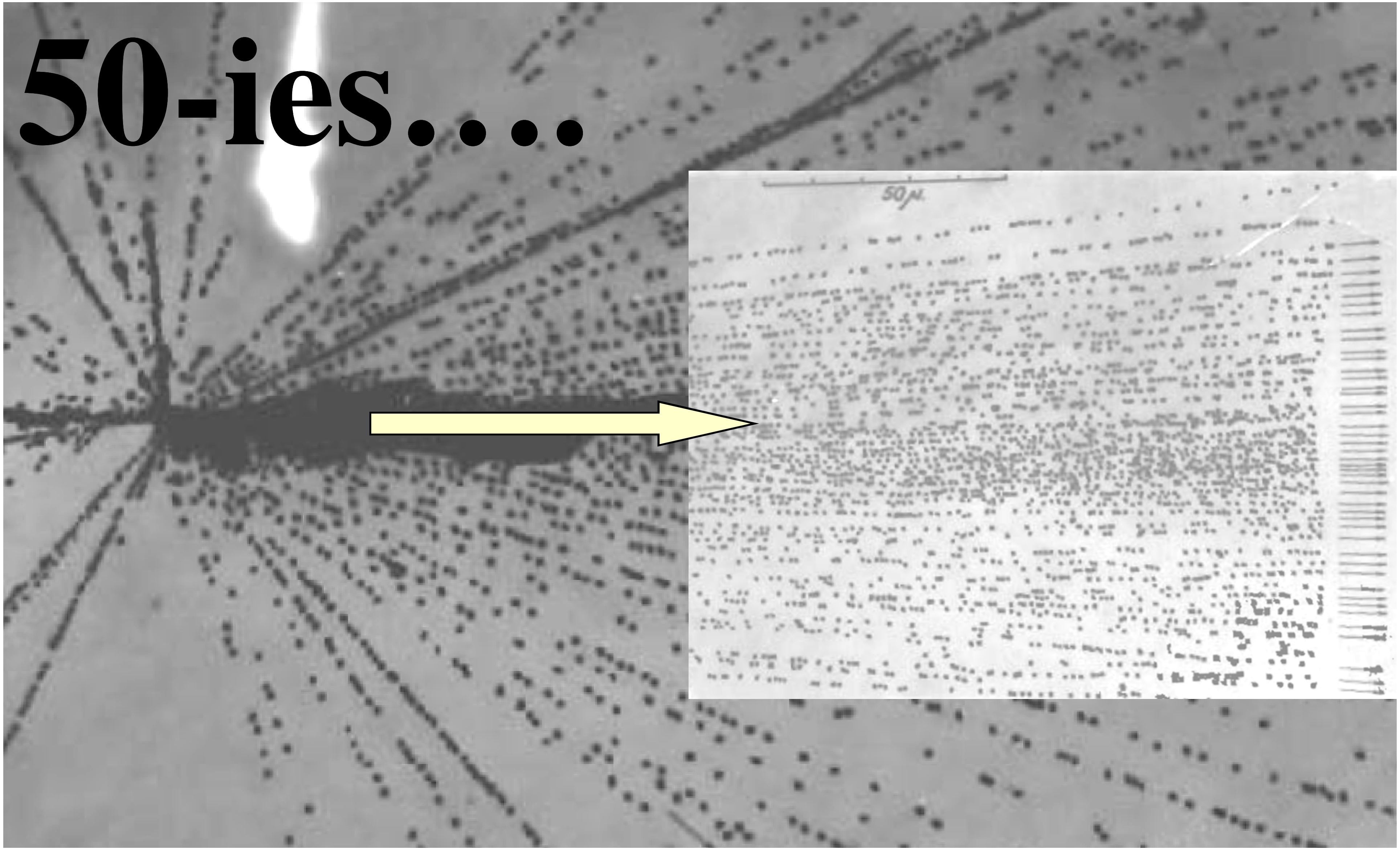


^{12}B 20 ms
^{10}Be 1510000 y
^{12}Be 23 ms
^{11}Be 13.8 s
^{8}Li 838 ms
^{9}Li 178 ms
0^{+}
0^{+}
^{11}Li 8.5 ms
^{6}He 807 ms
^{8}He 119 ms


^{12}N 11 ms
^{9}C 0.13 s
^{10}C 19 s
^{11}C 20 m
^{12}C 99%
^{8}B 0.8 s
^{10}B 19.8%
^{11}B 80.2%
^{7}Be 53 d
^{9}Be 100%
^{6}Li 7.5%
^{7}Li 92.5%

Lebedev PI (FIAN)

50-ies….



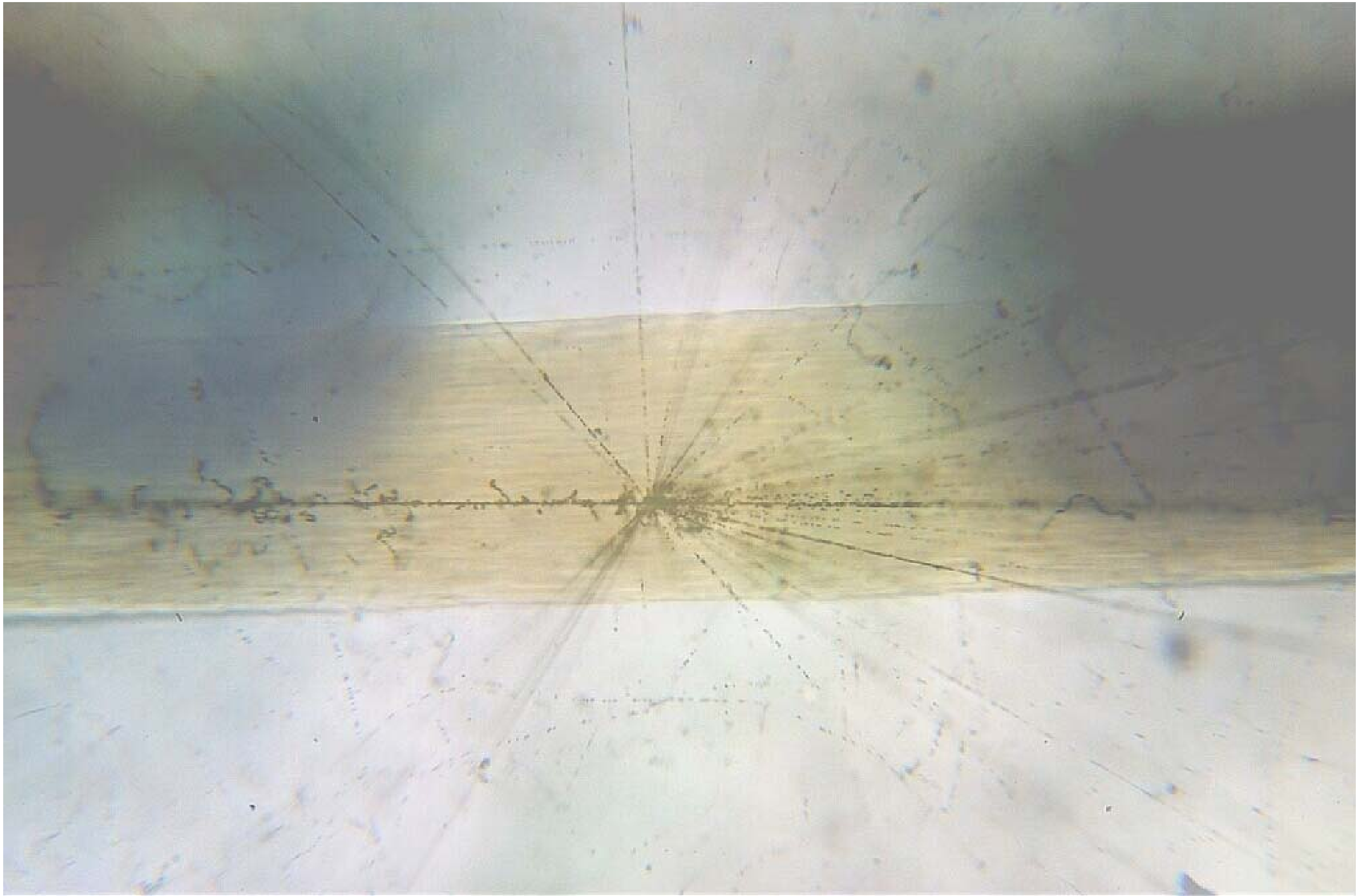
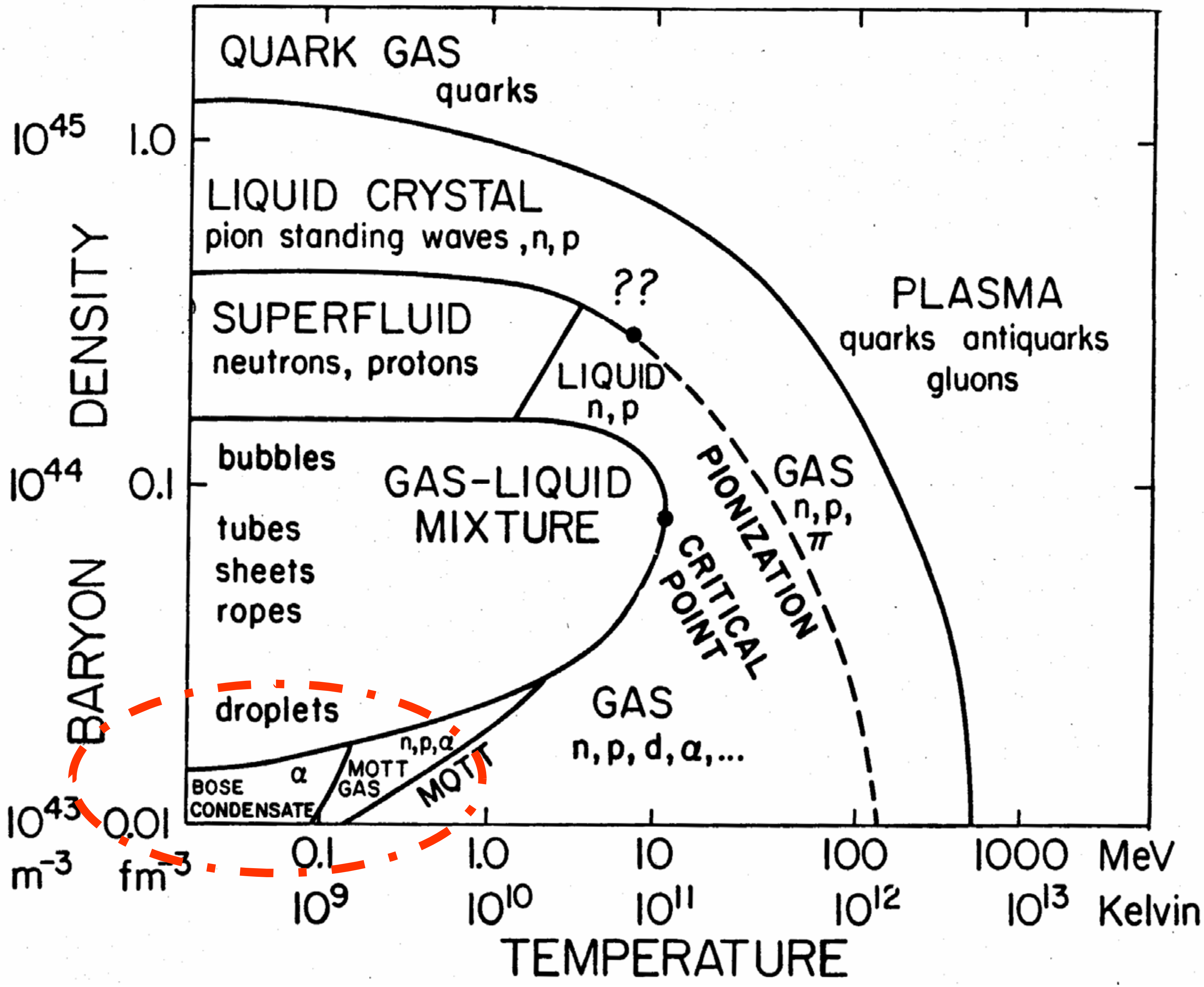
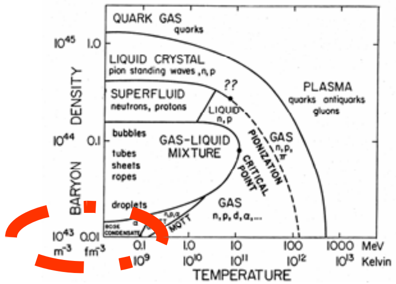


Photo of human hair superposed on nuclear star induced by relativistic sulphur nuclei in nuclear track emulsion



QUARK GAS
quarks
LIQUID CRYSTAL
pion standing waves ,n, p
SUPERFLUID
neutrons, protons
??
LIQUID
n, p
PLASMA
quarks antiquarks
gluons
bubbles
GAS-LIQUID
MIXTURE
tubes
sheets
ropes
droplets
PIONIZATION
CRITICAL POINT
GAS
n, p, π
GAS
n, p, d, α, ...
BOSE CONDENSATE
α
MOTT GAS
n,p,α
MOTT
BARYON DENSITY
10^45
1.0
10^44
0.1
10^43
0.01
m^-3
fm^-3
0.1
1.0
10
100
1000
MeV
10^9
10^10
10^11
10^12
10^13
Kelvin
TEMPERATURE


QUARK GAS
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n, p
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quarks antiquarks
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bubbles
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sheets
ropes
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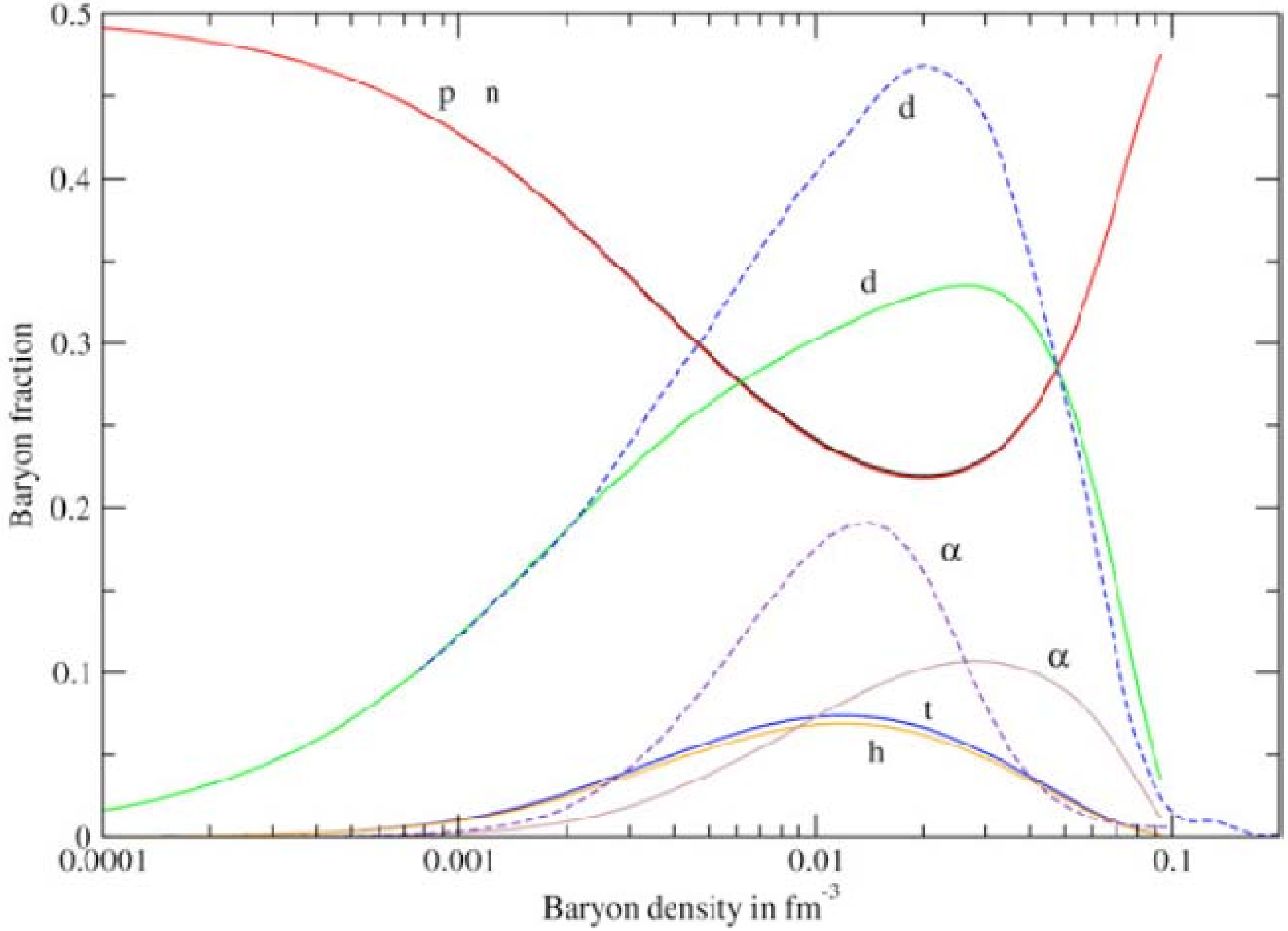
GAS-LIQUID
MIXTURE
CRITICAL POINT
PIONIZATION
GAS
GAS
n, p, d, α, ...
MOTT
BARYON DENSITY
TEMPERATURE
MeV
Kelvin

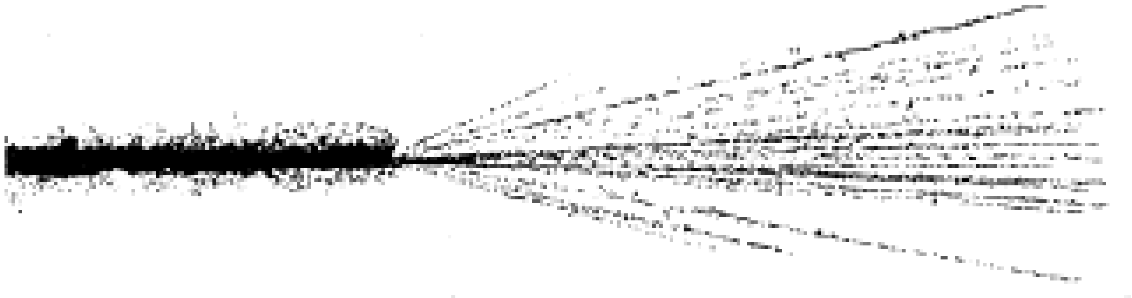

HADRON
STRUCTURE '11

Composition of symmetric nuclear matter

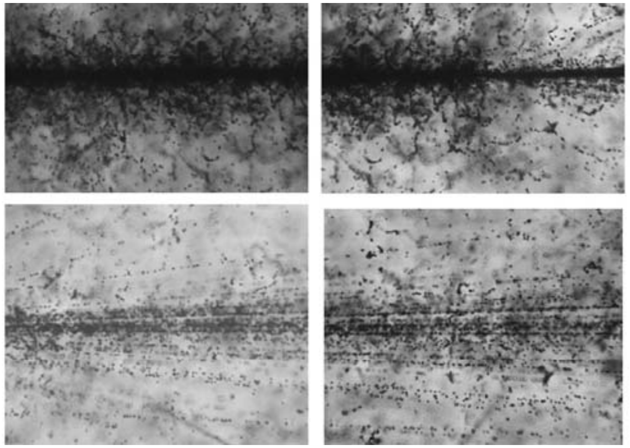
T=10 MeV

G.Ropke, A.Grigo, K. Sumiyoshi, Hong Shen,
Phys.Part.Nucl.Lett. **2**, 275 (2005)

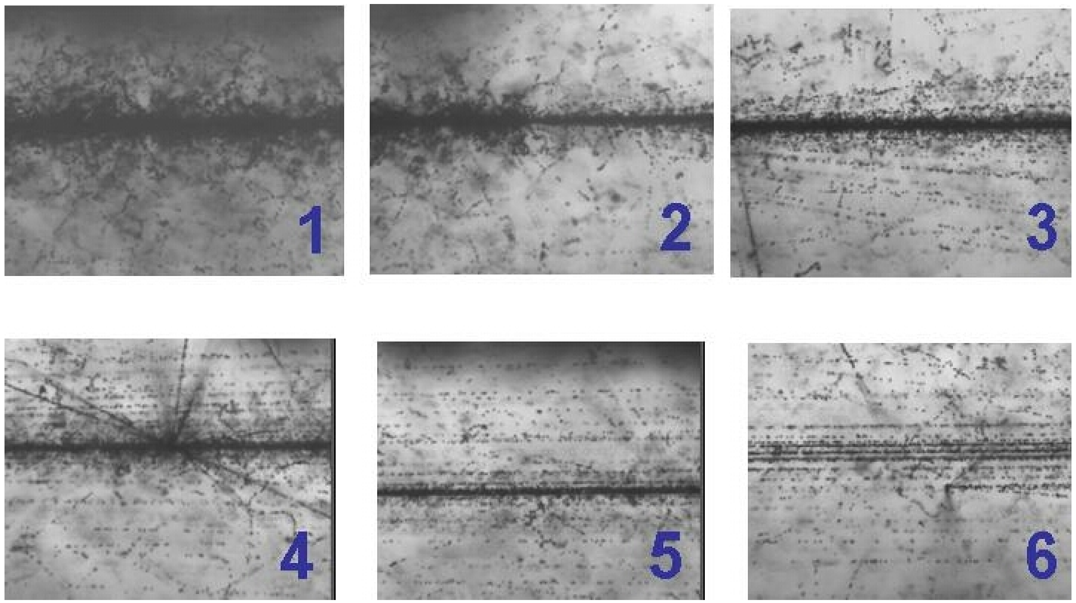




1A GeV U



10A GeV Au



160A GeV Pb

Dynamica ... rusts

Nuclear Theory ... N 47405

University ... 408

Dep

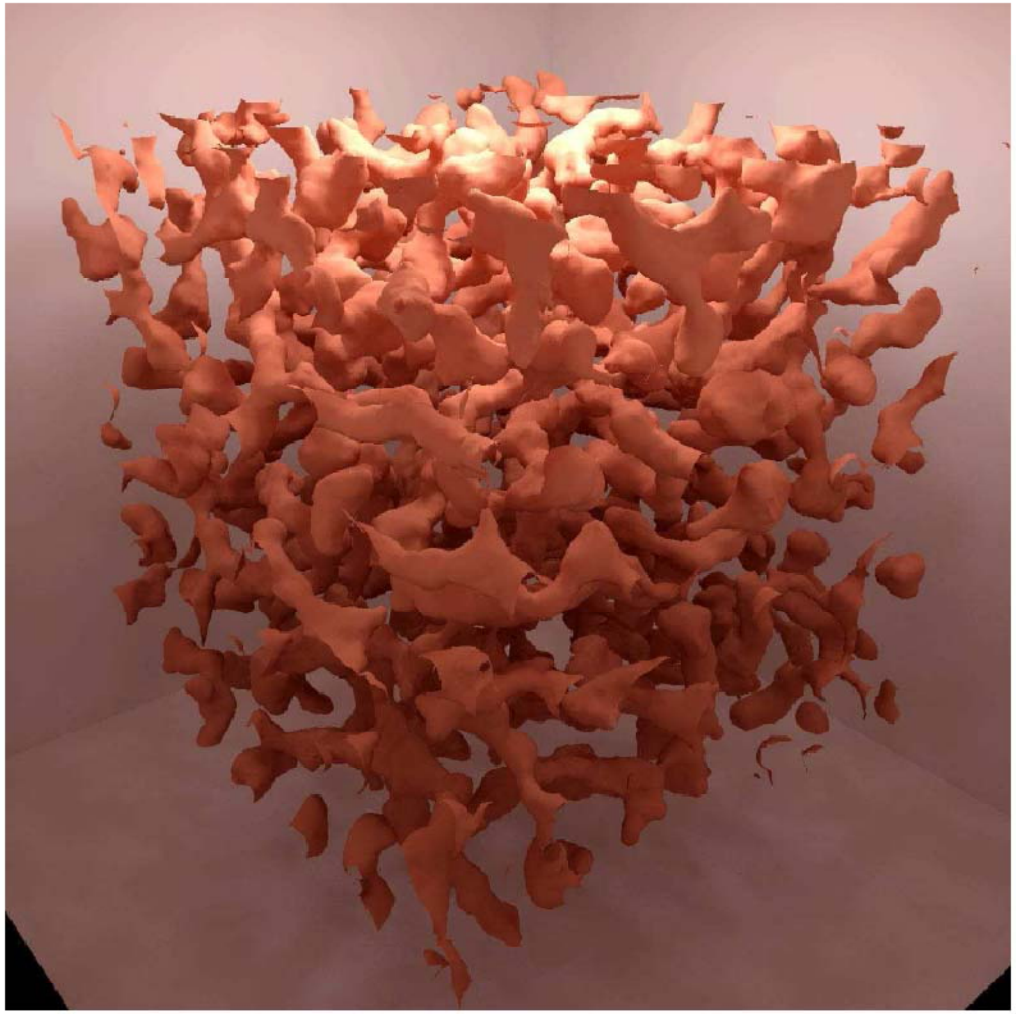


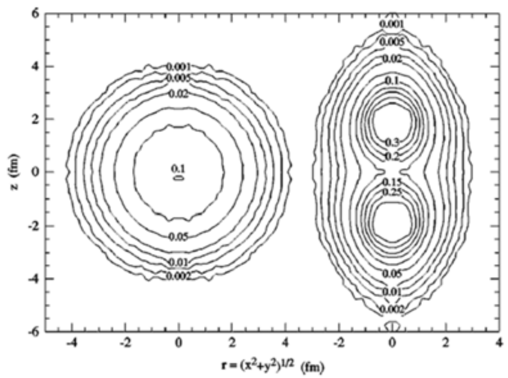
FIG. 1: (Color online) The 0.03 fm^{-3} proton density isosurface for one configuration of 100,000 nucleons at a baryon density of 0.05 fm^{-3}. The simulation volume is a cube of 126 fm on a side.

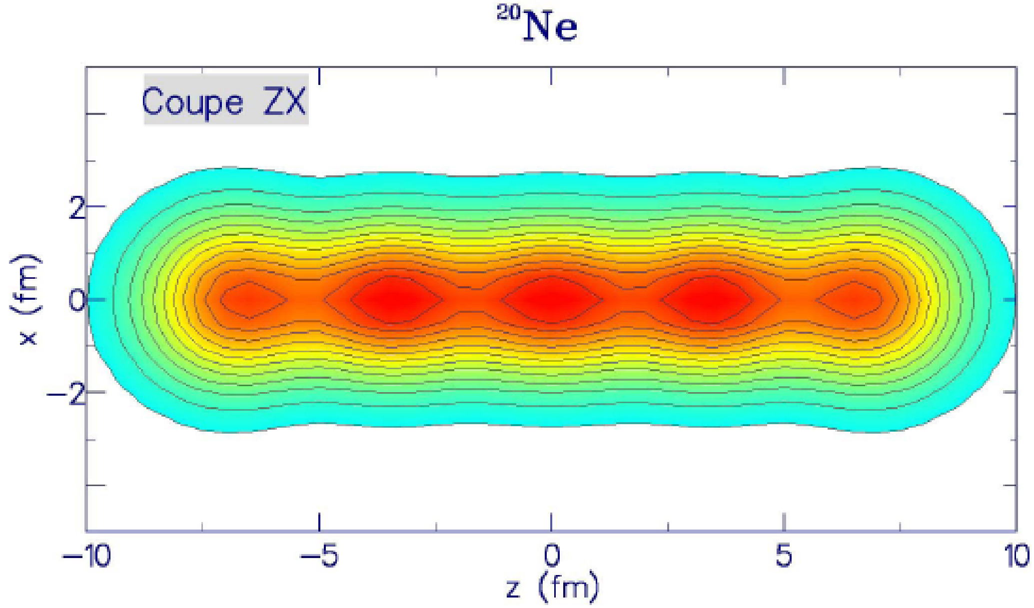
The nuclear p ... complex
shapes — is exp ... novae at
subnuclear dens ... ges from
the competition ... ion, the
nuclear pasta di ... ns could
have a strong in ... h stellar
environments. T ... ynamics
simulation invol ... classical
plasma oscillatio ... energies.
Yet this low-ene ... entative
heavy nucleus. ... likely to
be a density wav

Alpha-Clusters in Nuclear Systems

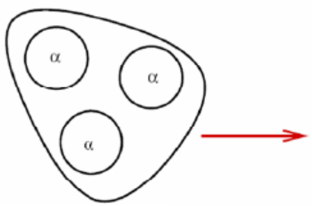
P. Schuck

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





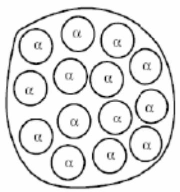
If O_2^+ in ^{12}C dilute $\alpha-$state

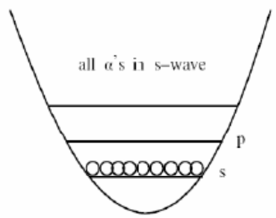


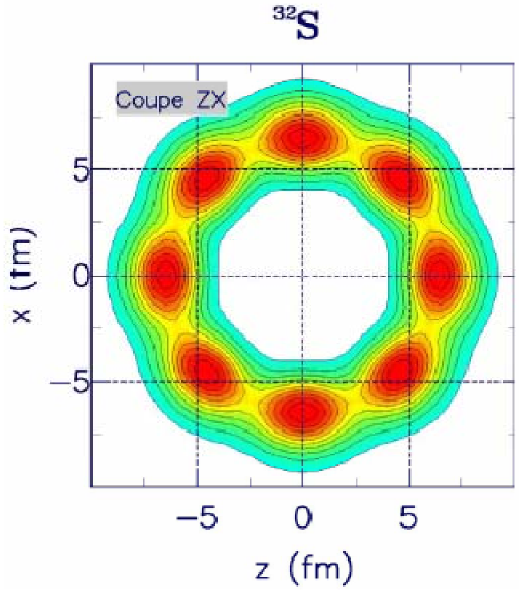
then α-condensate

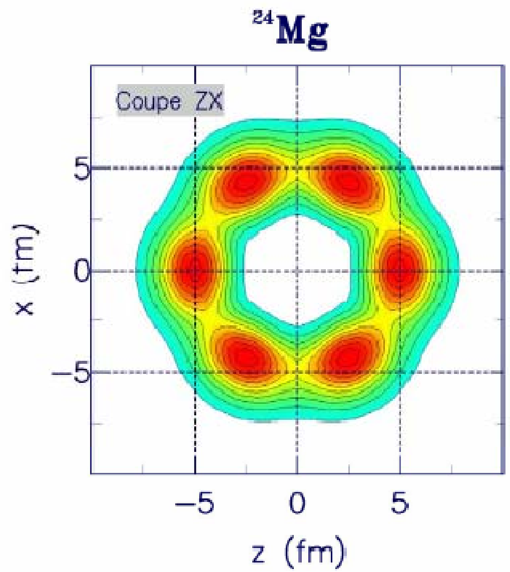
infinite matter $\rho_{\text{crit}} \sim \frac{\rho_0}{3}$

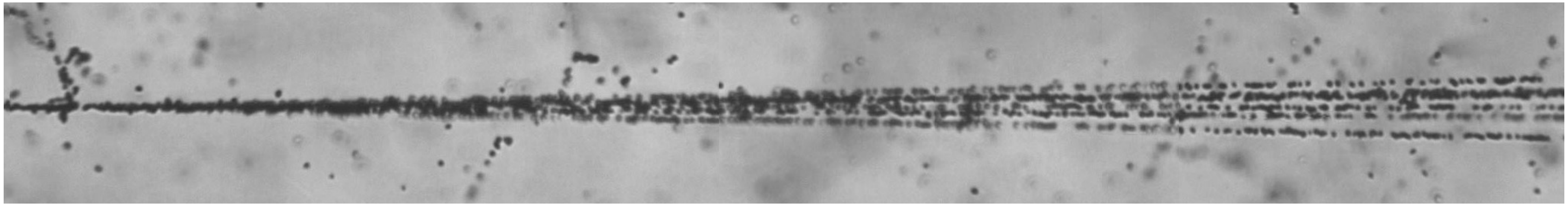
Conjecture: all n.α nuclei possess exited nα condensed state

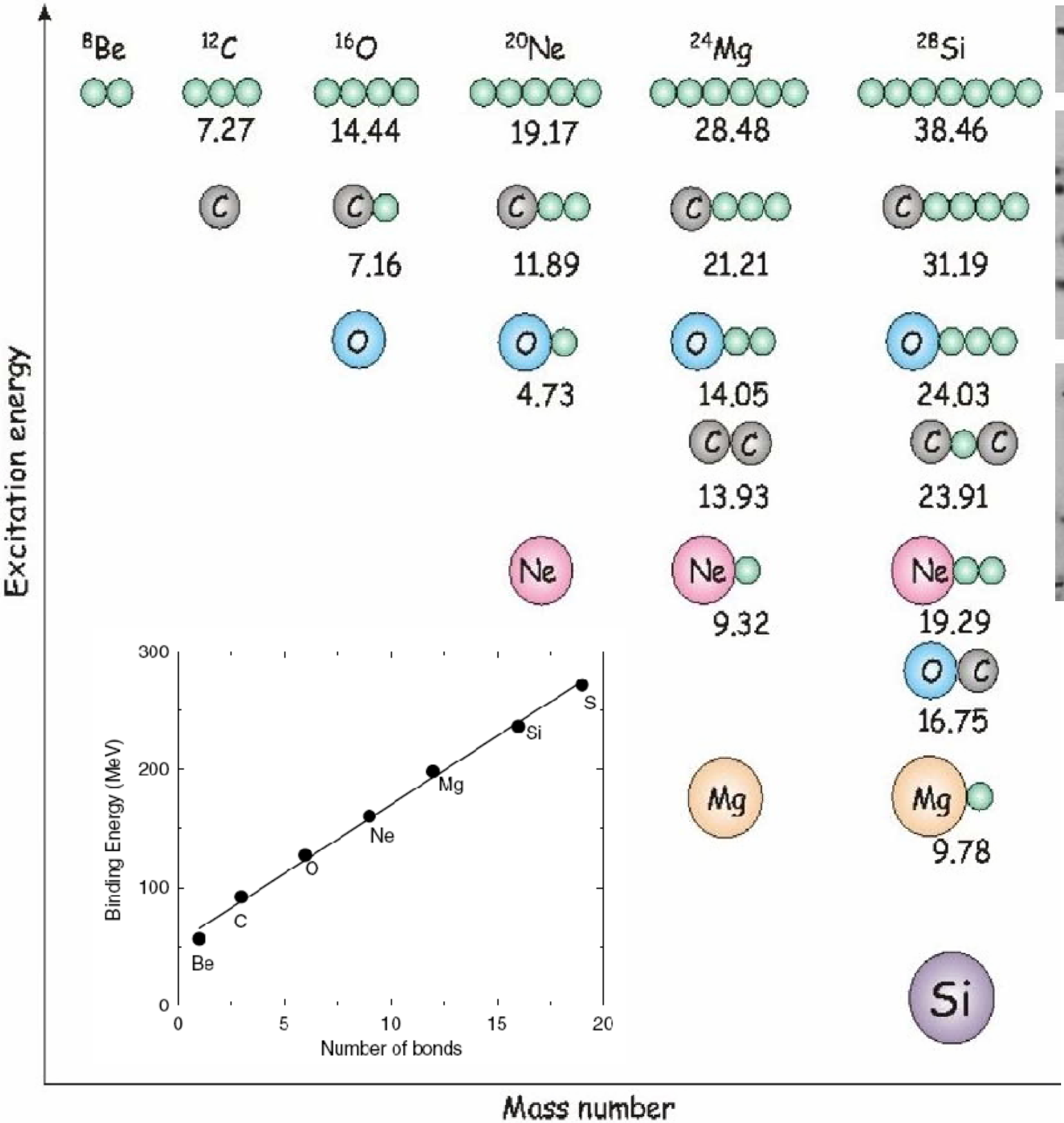


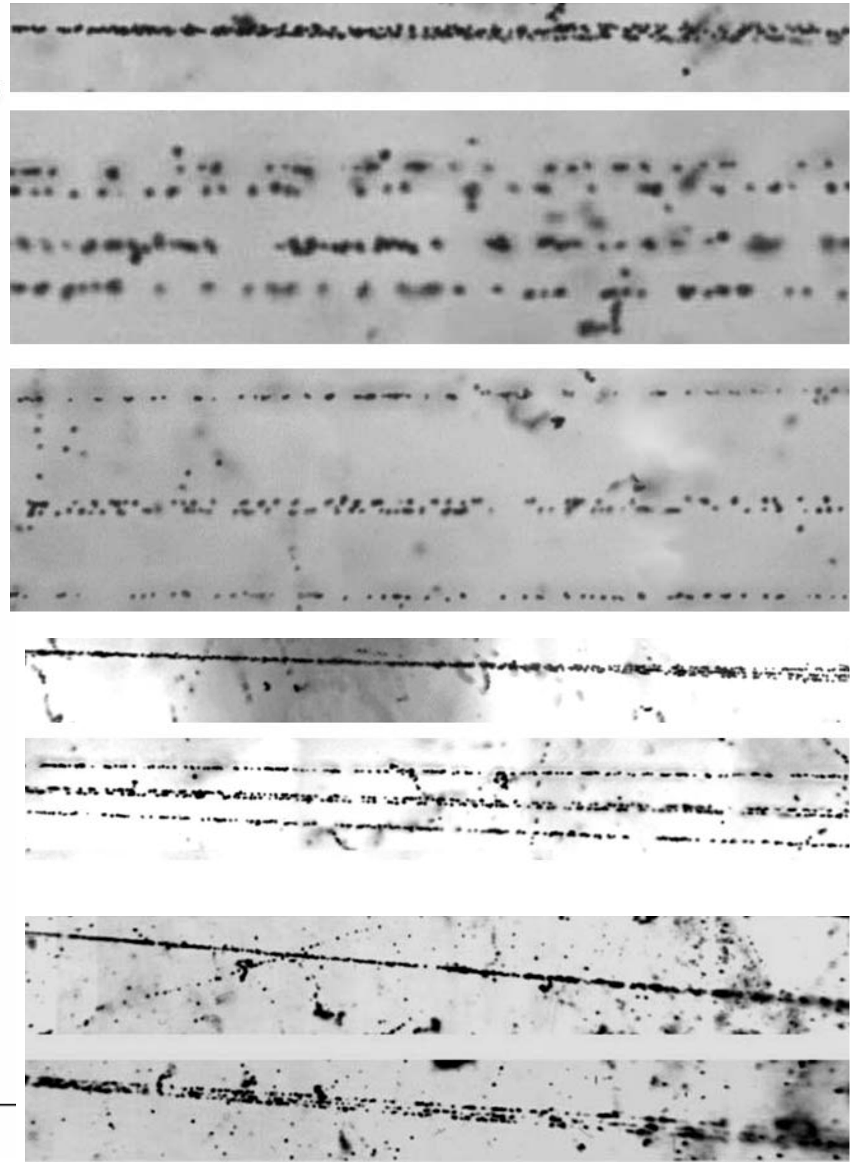








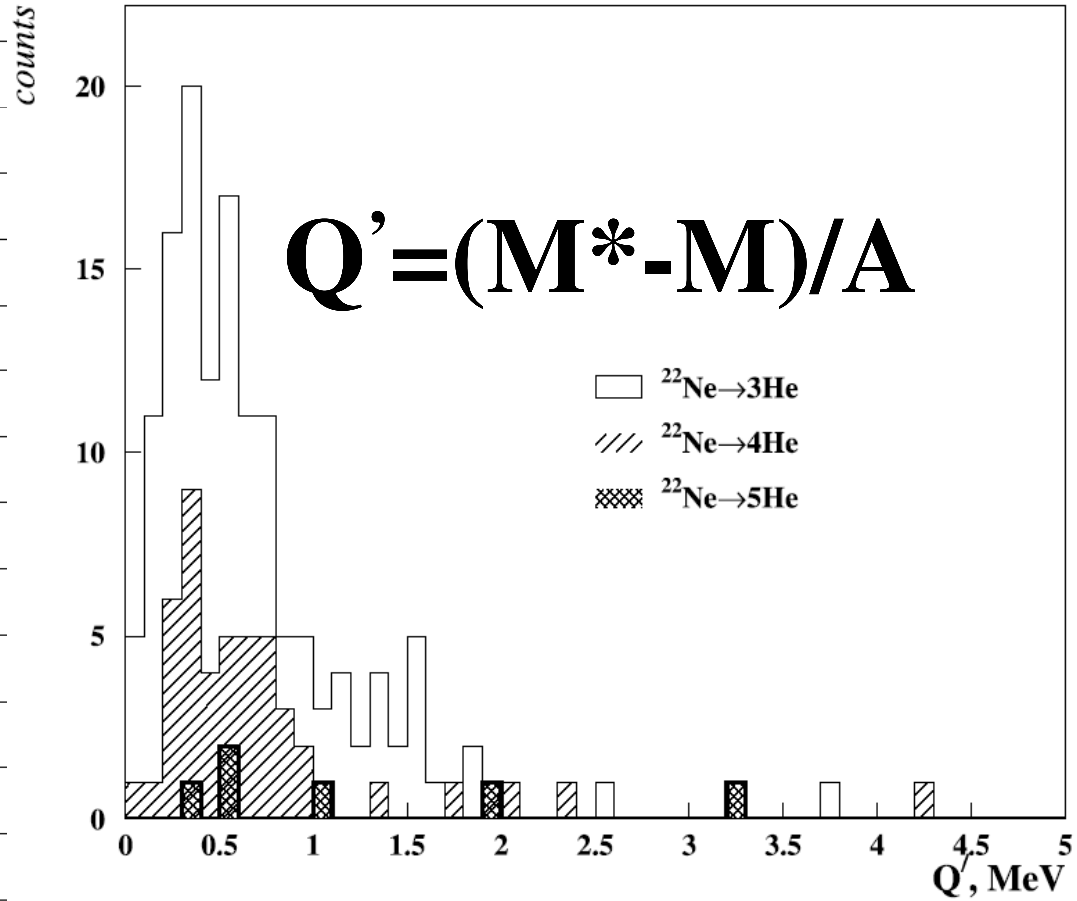

Excitation energy
8Be
12C
16O
20Ne
24Mg
28Si
7.27
14.44
19.17
28.48
38.46
7.16
11.89
21.21
31.19
4.73
14.05
24.03
13.93
23.91
9.32
19.29
16.75
9.78
C
O
Ne
Mg
Si
Binding Energy (MeV)
Number of bonds
Be
C
O
Ne
Mg
Si
S
Mass number

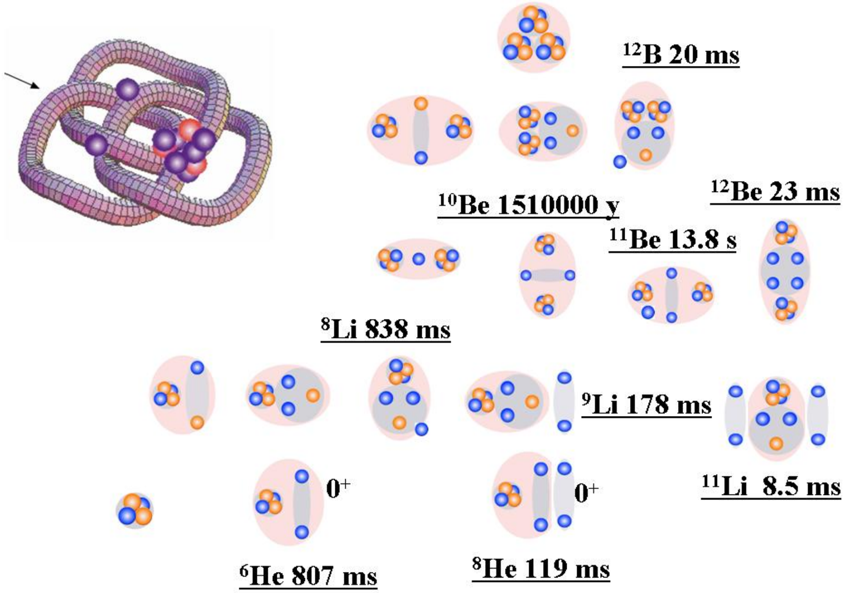


^{22}Ne 3.22A GeV
4100 Inelastic Interactions

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)			

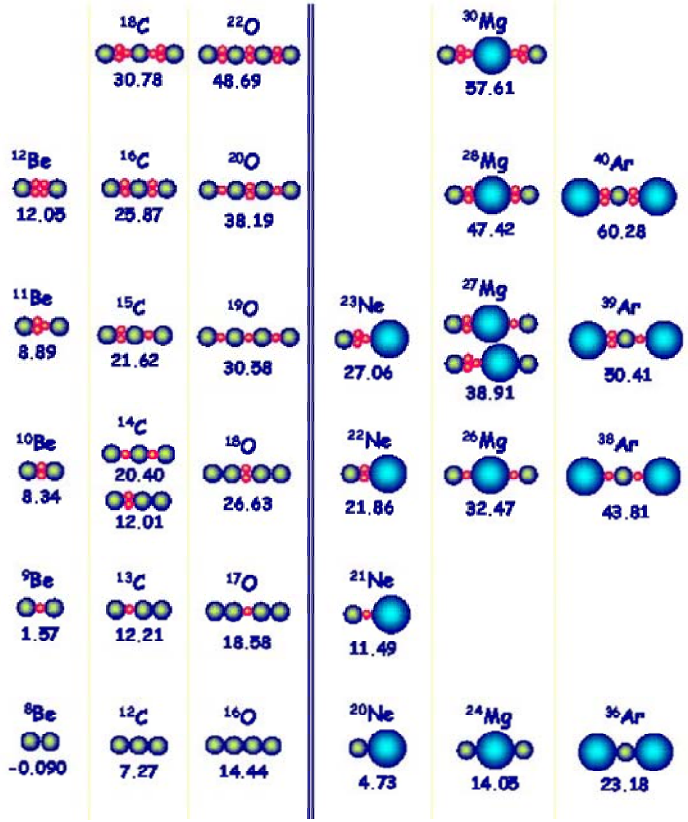
$$Q' = (M^* - M)/A$$



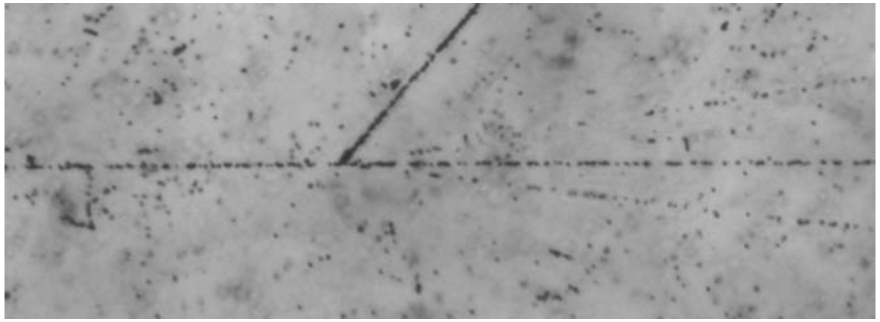


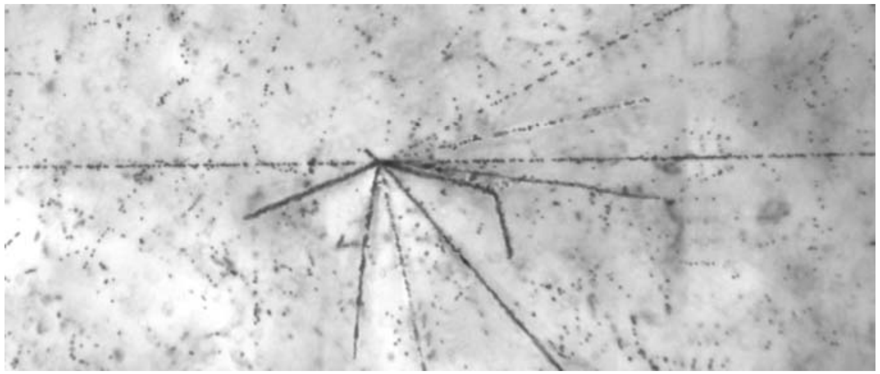
^{12}B 20 ms
^{10}Be 1510000 y
^{12}Be 23 ms
^{11}Be 13.8 s
^{8}Li 838 ms
^{9}Li 178 ms
^{11}Li 8.5 ms
0^+
0^+
^{6}He 807 ms
^{8}He 119 ms

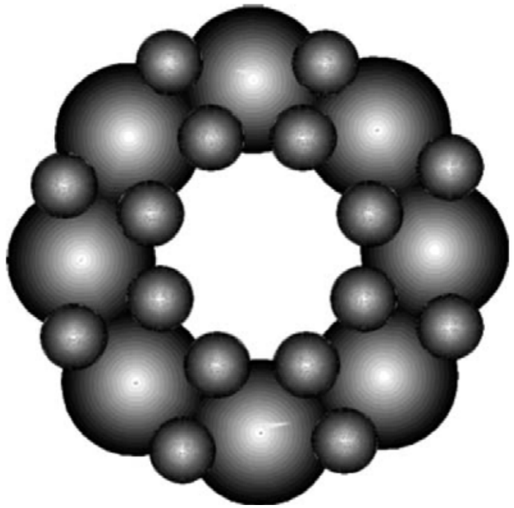
von Oertzen

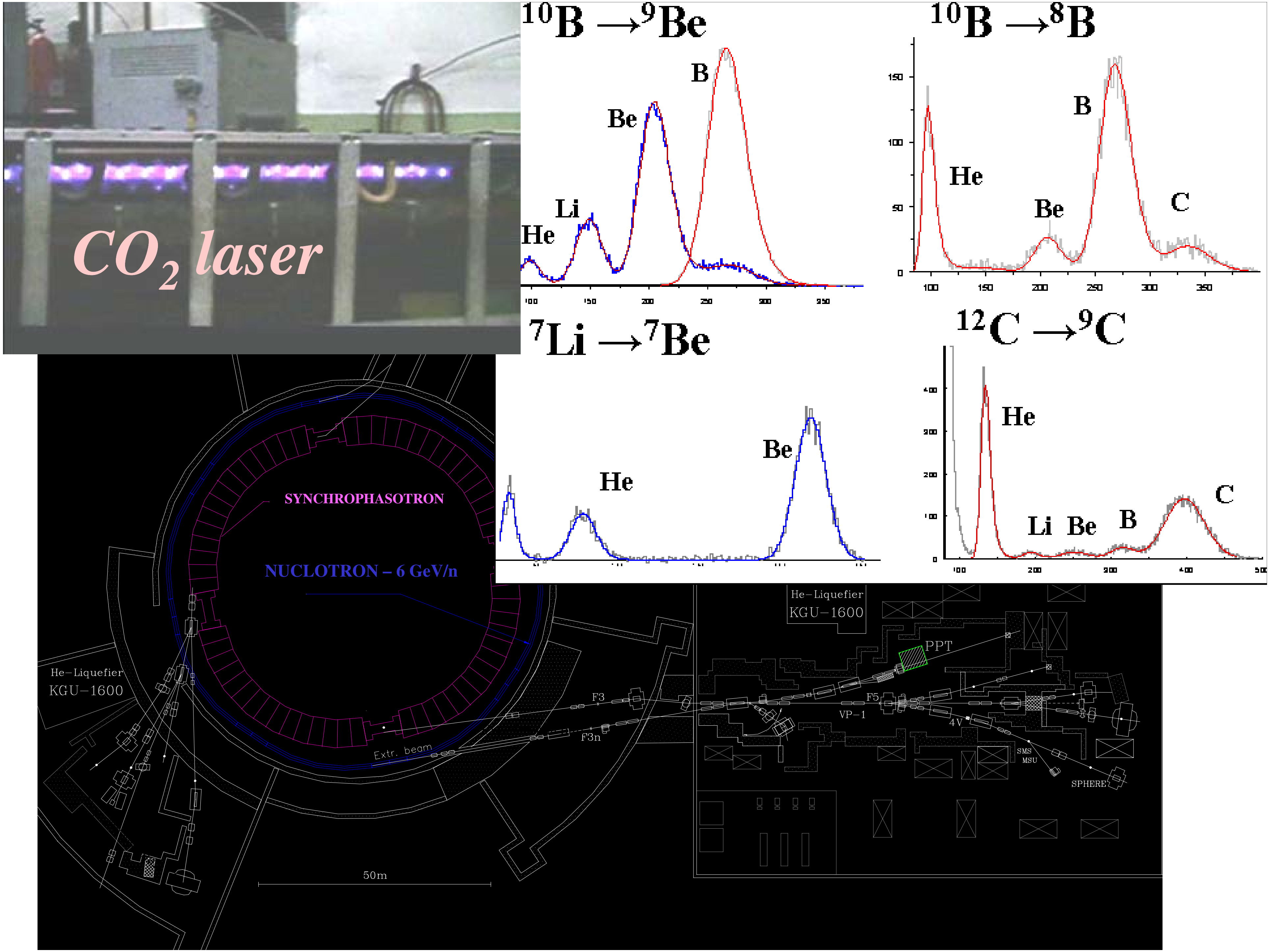


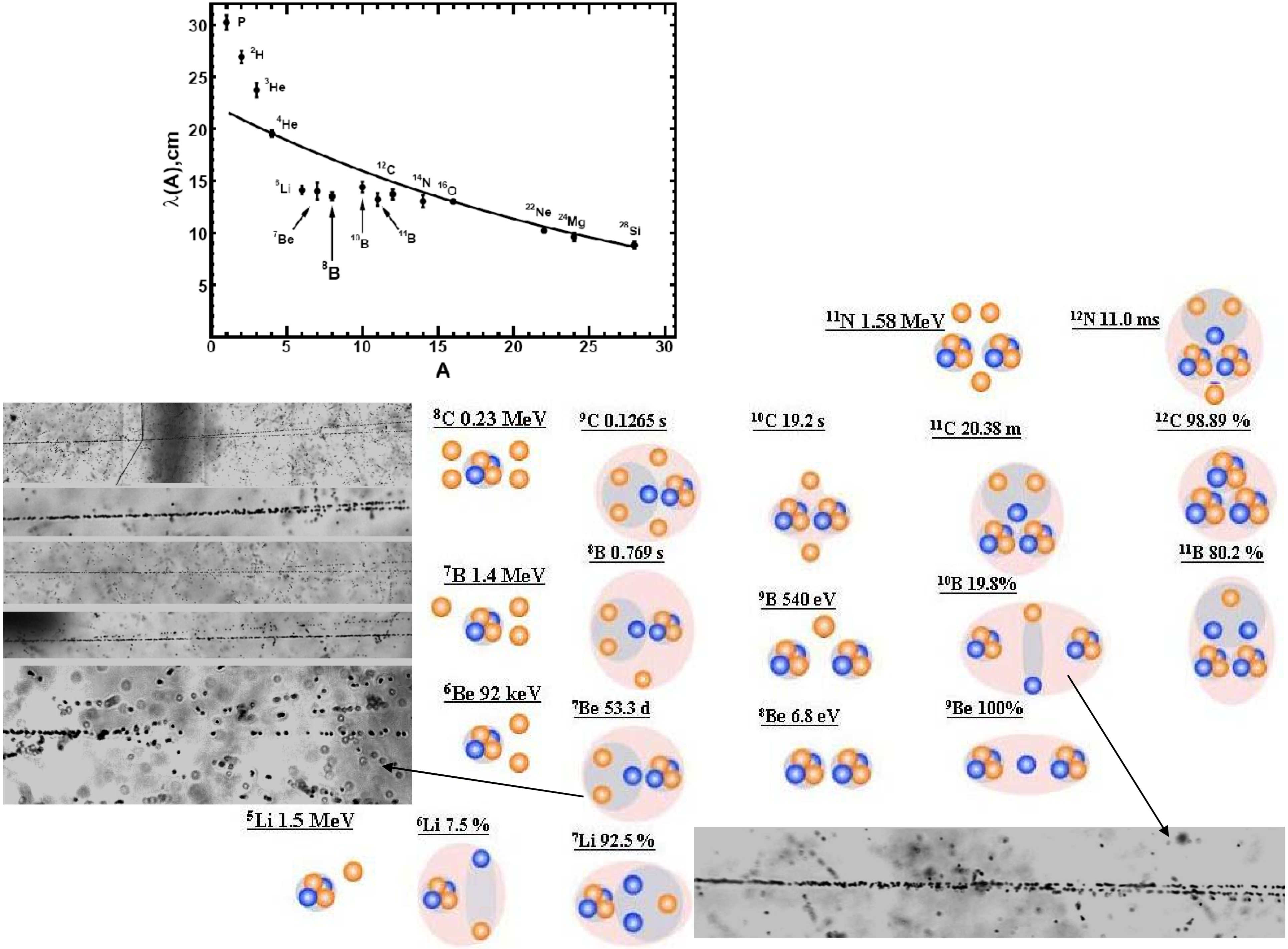
^{18}C
30.78
^{22}O
48.69
^{30}Mg
57.61
^{12}Be
12.05
^{16}C
25.87
^{20}O
38.19
^{28}Mg
47.42
^{40}Ar
60.28
^{11}Be
8.89
^{15}C
21.62
^{19}O
30.58
^{23}Ne
27.06
^{27}Mg
38.91
^{39}Ar
50.41
^{10}Be
8.34
^{14}C
20.40
12.01
^{18}O
26.63
^{22}Ne
21.86
^{26}Mg
32.47
^{38}Ar
43.81
^{9}Be
1.57
^{13}C
12.21
^{17}O
18.58
^{21}Ne
11.49
^{8}Be
-0.090
^{12}C
7.27
^{16}O
14.44
^{20}Ne
4.73
^{24}Mg
14.05
^{36}Ar
23.18



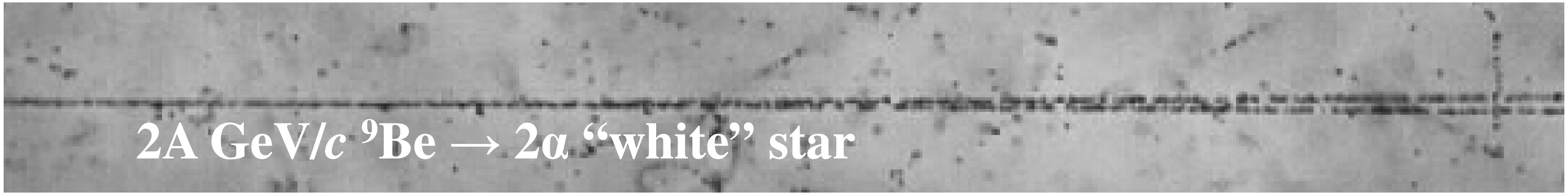




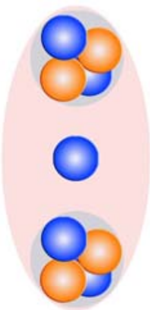

CO_2 laser
$^{10}B \rightarrow {}^{9}Be$
He
Li
Be
B
$^{10}B \rightarrow {}^{8}B$
He
Be
B
C
$^{7}Li \rightarrow {}^{7}Be$
He
Be
$^{12}C \rightarrow {}^{9}C$
He
Li
Be
B
C
SYNCHROPHASOTRON
NUCLOTRON – 6 GeV/n
He–Liquefier
KGU–1600
He–Liquefier
KGU–1600
PPT
F3
F3n
F5
VP–1
4V
Extr. beam
SMS
MSU
SPHERE
50m

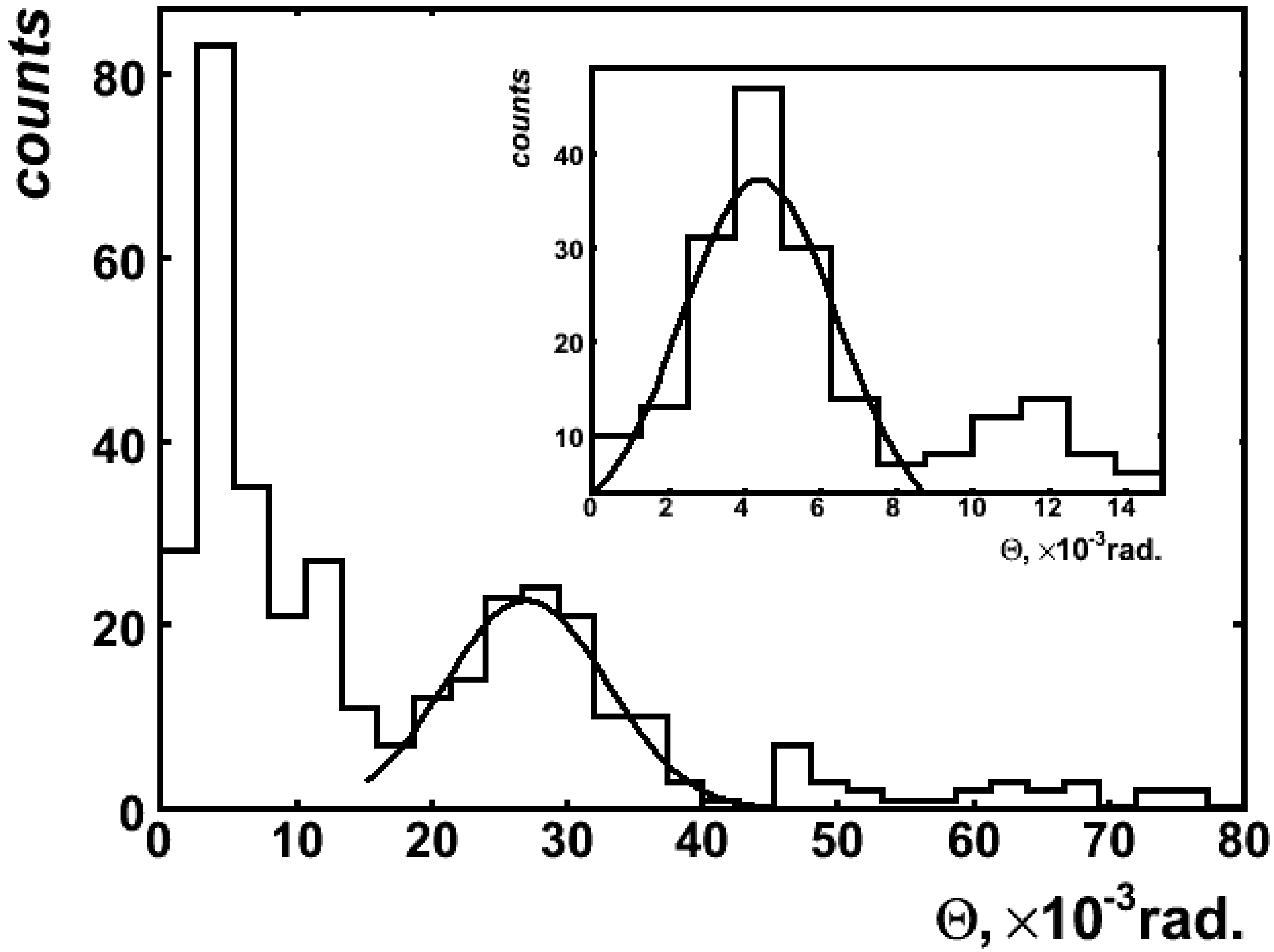


λ(A),cm
A
P
^{2}H
^{3}He
^{4}He
^{6}Li
^{7}Be
^{8}B
^{10}B
^{11}B
^{12}C
^{14}N
^{16}O
^{22}Ne
^{24}Mg
^{28}Si
^{11}N 1.58 MeV
^{12}N 11.0 ms
^{8}C 0.23 MeV
^{9}C 0.1265 s
^{10}C 19.2 s
^{11}C 20.38 m
^{12}C 98.89 %
^{7}B 1.4 MeV
^{8}B 0.769 s
^{9}B 540 eV
^{10}B 19.8%
^{11}B 80.2 %
^{6}Be 92 keV
^{7}Be 53.3 d
^{8}Be 6.8 eV
^{9}Be 100%
^{5}Li 1.5 MeV
^{6}Li 7.5 %
^{7}Li 92.5 %

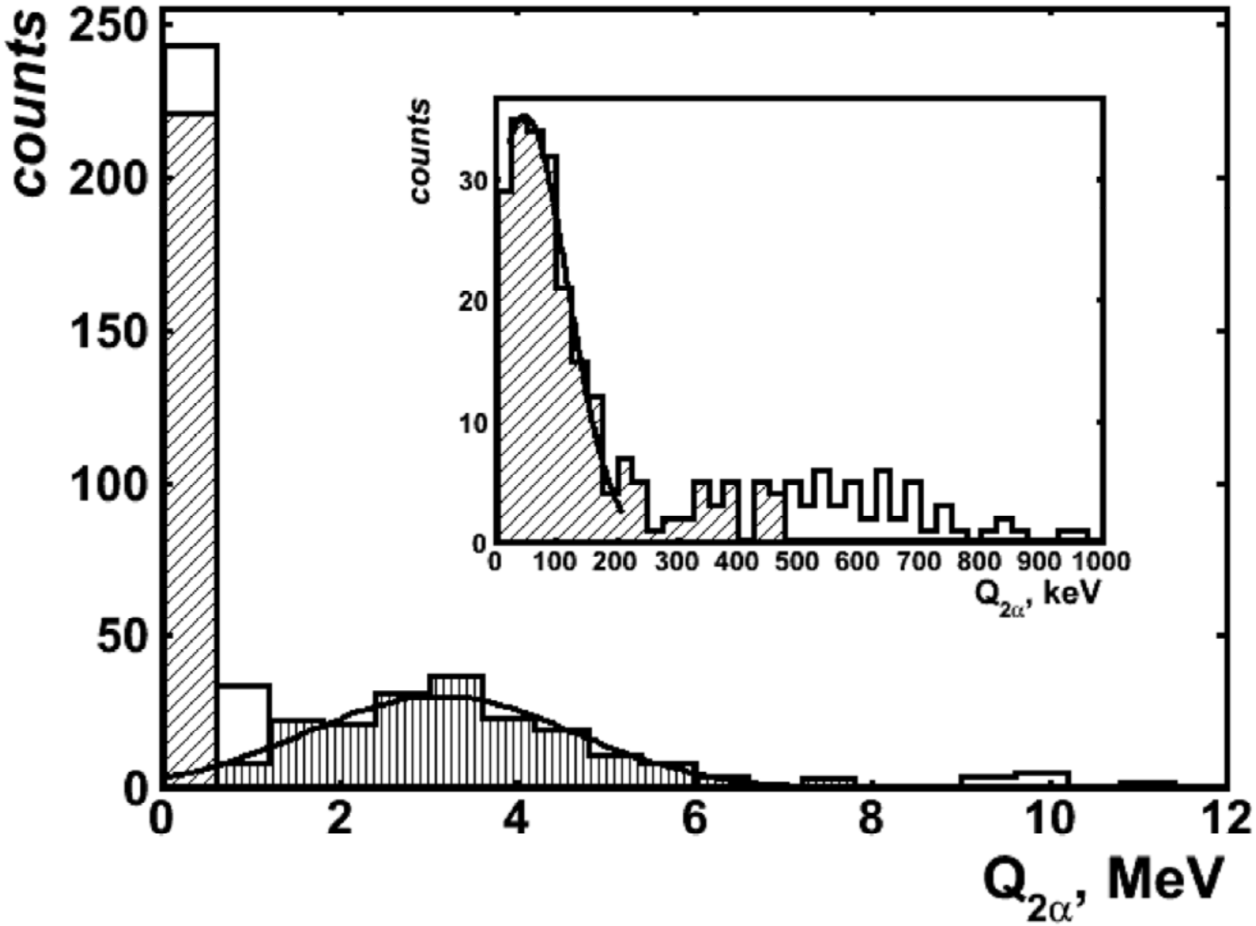


2A GeV/c ^{9}Be → 2α "white" star

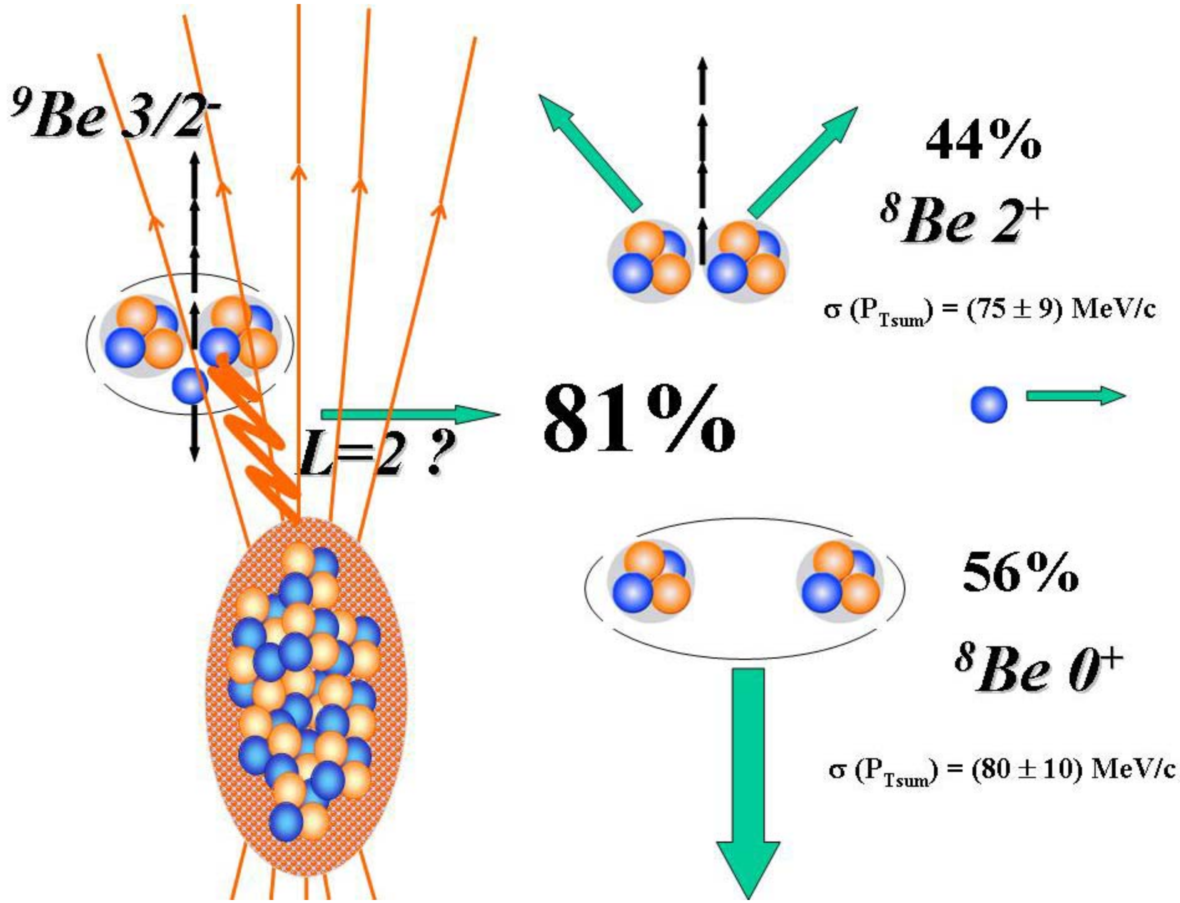


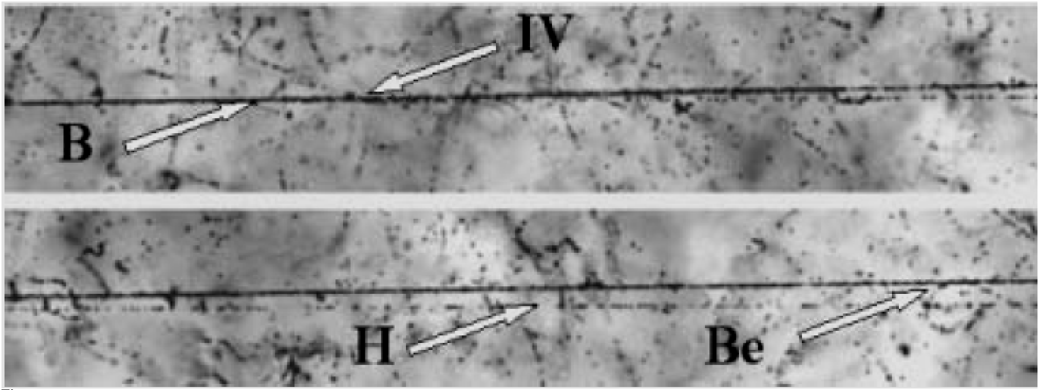


The secondary ^{9}Be beam was obtained by fragmentation of accelerated ^{10}B nuclei. When scanning the exposed emulsion 500 events $^{9}Be \rightarrow 2\alpha$ in a fragmentation cone of 0.1 rad have been found. About 81% α-pairs form roughly equal groups on $\Theta_{2\alpha}$: "narrow" ($0 < \Theta_n < 10.5$ 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.

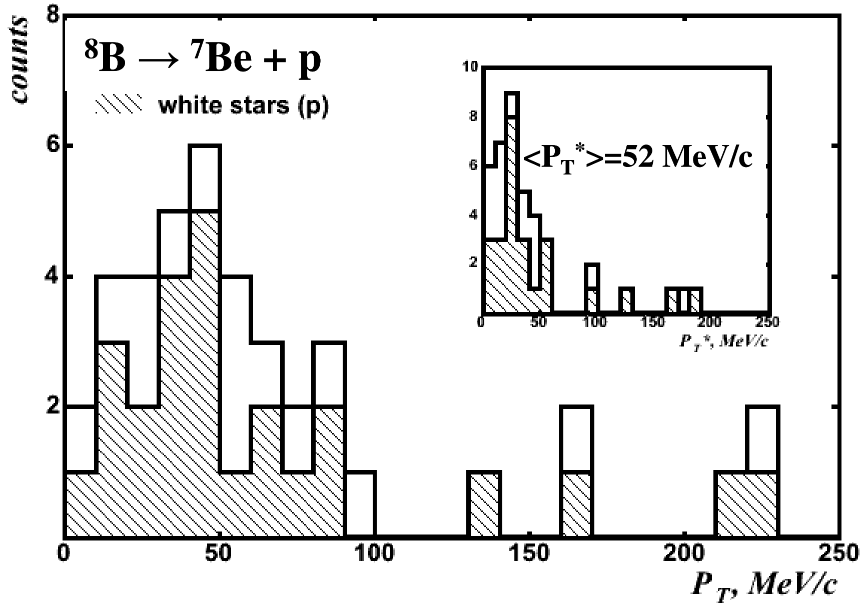


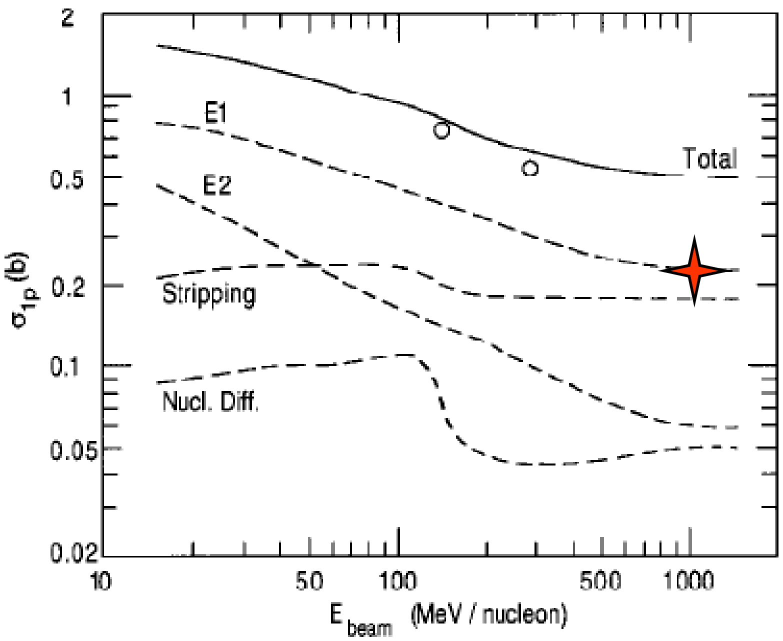
For the coherent dissociation ^{9}Be → 2α + n, the average value of the total α-pair transverse momentum is equal to $\langle P_{Tsum} \rangle \approx 80$ MeV/c in correspondence with the Goldhaber statistical model. So, it can be assigned to the average transverse momentum carried away by neutrons. 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.

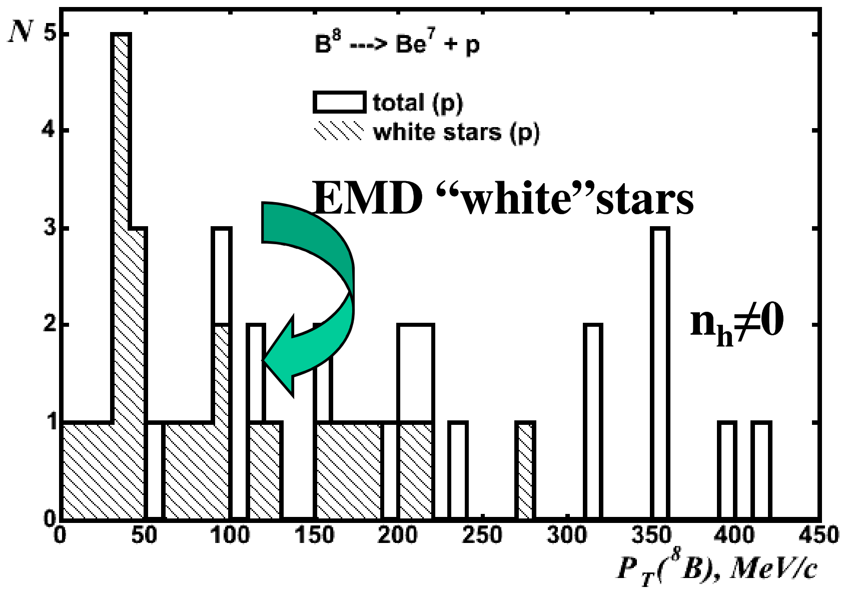


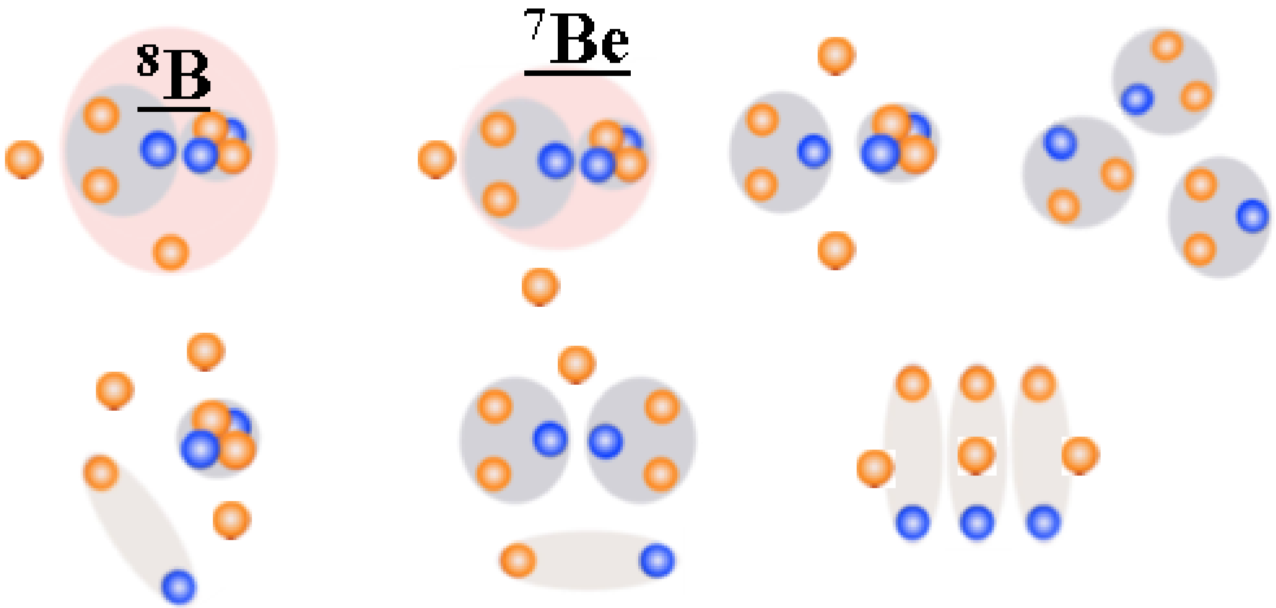


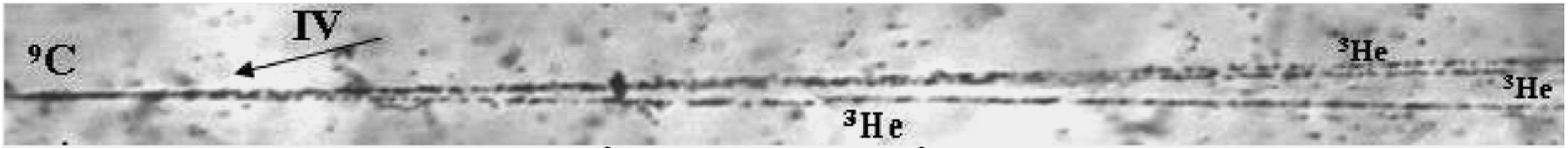
	Q_{min} (^{10}B), МэВ	N_{ws} (^{10}B)	% (^{10}B)	Q_{min} (^{8}B), МэВ	N_{ws} (^{8}B)	% (^{8}B)
2He+H	6.0	30	73	1.724	14	27
He+3H	25	5	12	8.6	12	23
Be+H	6.6	1	2	0.138	25	48
B		-	-		1	2
Li+He	4.5	5	13	3.7	-	-





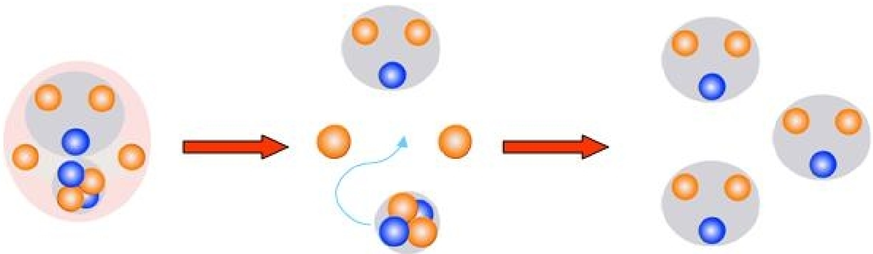


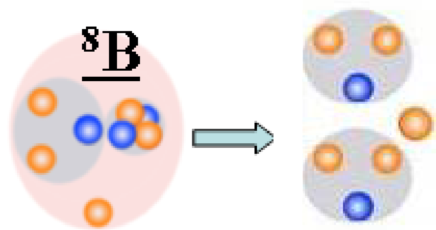


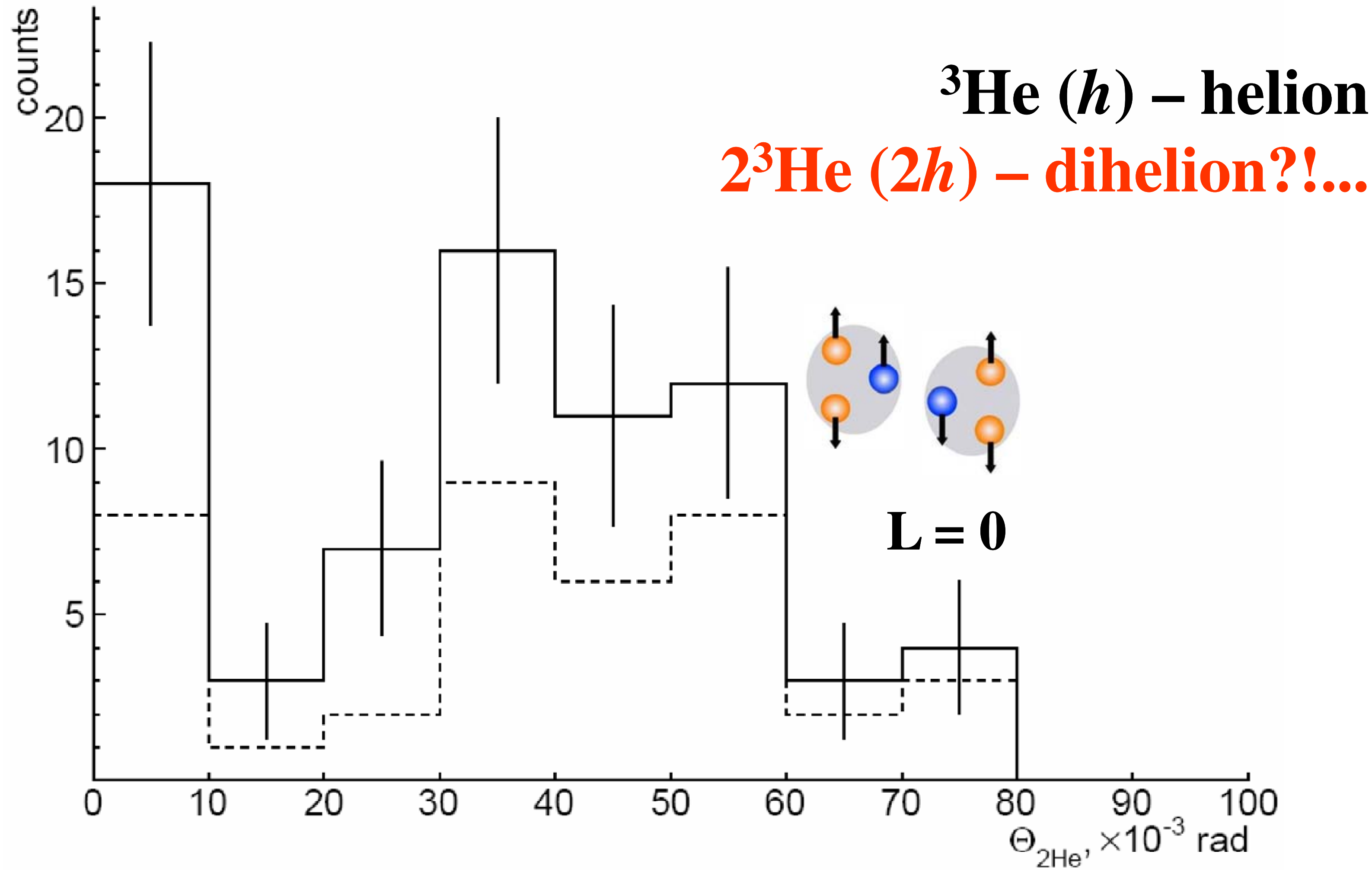


Macro photo of “white” star of ^{9}C dissociation to 3 ^{3}He nuclei in nuclear track emulsion; the interaction vertex IV is shown by the arrow.

In the study of 2A GeV/c ^{9}C interactions it is found that the probability of the 3^{3}He coherent dissociation is roughly coincides with the values for the channels with the separation of one or a pair of nucleons. Due to a significant probability of the channel ^{9}C → 3^{3}He, 2^{3}He pairs with opening angles up to 10^{-2} rad are found as well as for ^{8}B interactions with the neutron knock out. This observation indicates the possible existence of a 2^{3}He resonance just near the threshold.



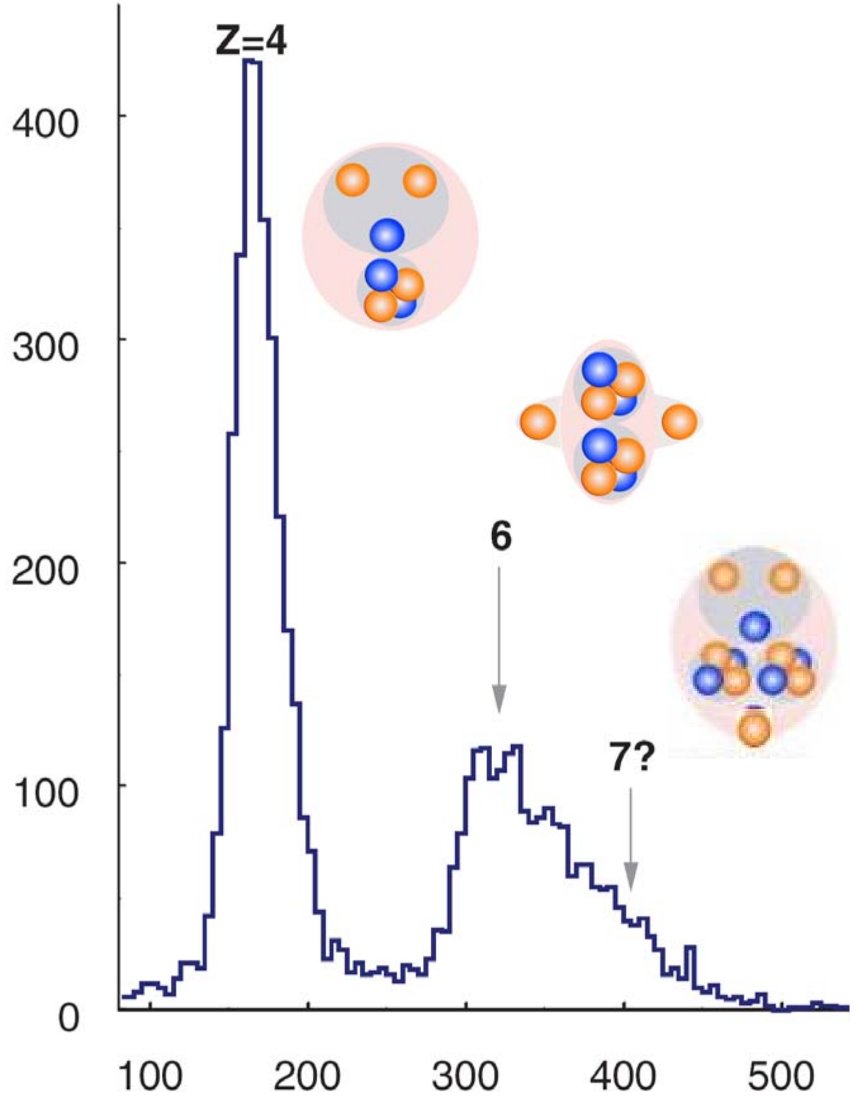




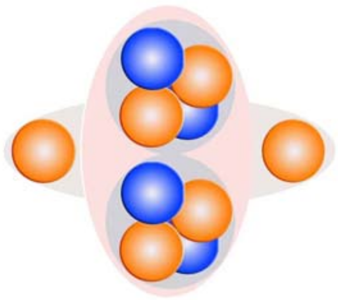
Total distribution of opening angles Θ_{2He} between the relativistic He fragments in the "white" stars ^{9}C → 3^{3}He and in events ^{8}B → 2He + H with the formation of target nucleus fragments or meson; dotted line indicates the "white" stars contribution.

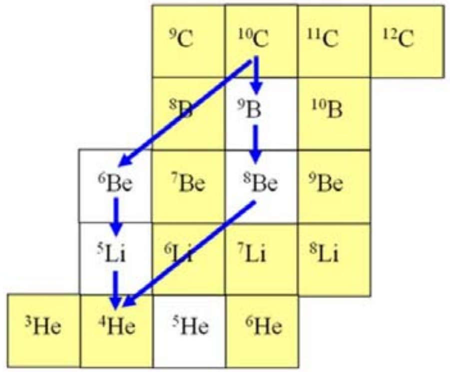
Exposure of emulsion to a mixed beam of relativistic ^{12}N, ^{10}C, and ^{7}Be nuclei

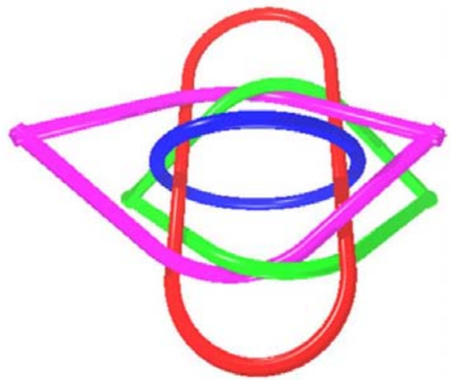
Generation of ^{12}N and ^{10}C nuclei is possible in charge exchange and fragmentation reactions of accelerated ^{12}C nuclei [3]. The charge to weight ratio Z_{pr}/A_{pr} differs by only 3% for these nuclei, while the momentum acceptance of the separating channel is 2 - 3%. Therefore, their separation is not possible, and the ^{12}N and ^{10}C nuclei are simultaneously present in the secondary beam, forming a so-called beam "cocktail". The contribution of ^{12}N nuclei is small in respect to ^{10}C ones in accordance with the cross sections for charge transfer and fragmentation reactions. Also, the beam contains ^{7}Be nuclei, differing by Z_{pr}/A_{pr} from ^{12}N nuclei only by 2%.



Nuclear track emulsion is exposed to a mixed beam of ^{12}N, ^{10}C and ^{7}Be nuclei formed by means of primary 1.2A GeV ^{12}C nucleus beam. The initial scanning phase consisted in visual search of beam tracks with charges Z_{pr} = 1, 2 and $Z_{pr} > 2$. The ratio of beam tracks with charges Z_{pr} = 1, 2 and $Z_{pr} > 2$ is found to be equal ≈ 1 : 3 : 18. Thus, the contribution of ^{3}He nuclei dramatically decreased compared with the ^{9}C irradiation, which radically raised the event search efficiency. The scanning along the total length of primary tracks in emulsion layers that was equal to 924.7 m revealed 6144 inelastic interactions, including 516 "white" stars.







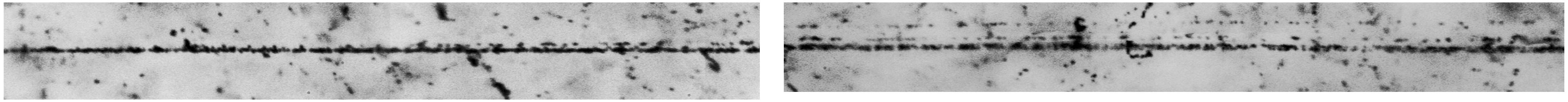
The ^{10}C nucleus is the only example of the system, which has the “super-boromean” properties, since the removal of one of the four clusters in the 2α + 2p structure leads to an unbound state.

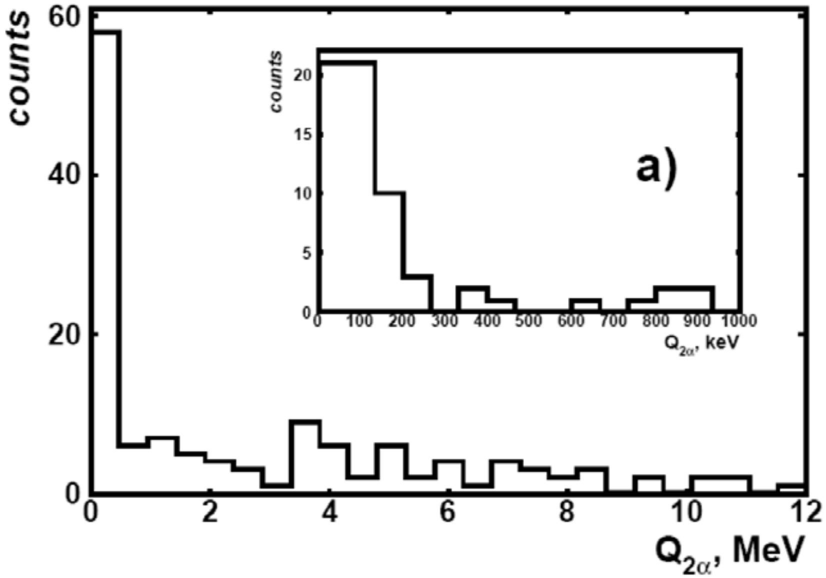
Distribution of the number of “white” stars, N_{ws}, and the number of events involving the production of target fragments, N_{tf}, with respect to $\sum Z_{fr} = 6$ channels

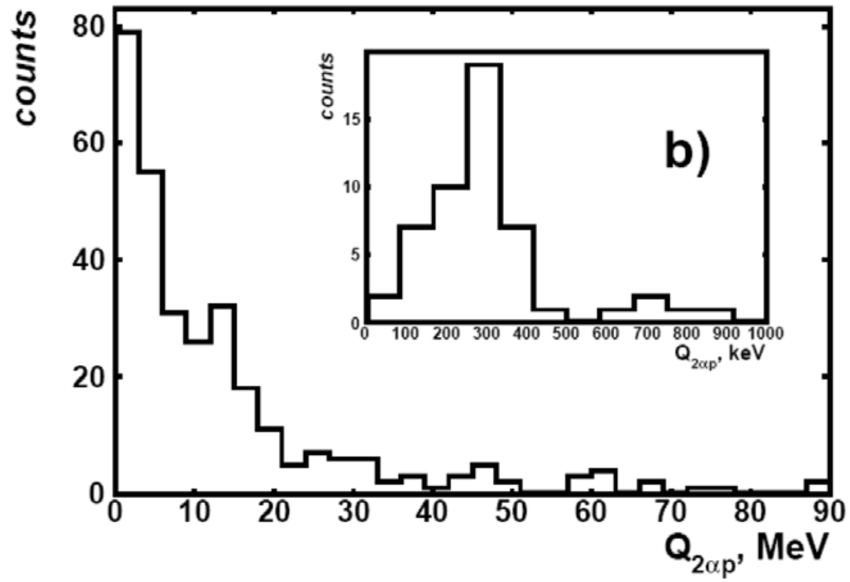
$\sum Z_{fr} = 6$	C	2He + 2H	He + 4H	6H	3He
N_{ws}	-	159	16	8	11
N_{tf}	27 (^{9}C)	211	76	16	11

For "white" stars N_{ws} with charge topology $\sum Z_{fr} = 6$ the most probable channel is represented by events 2He + 2H, which might be expected for the isotope ^{10}C. The channel He + 4H is found to be suppressed, as in the ^{10}C case it is required to overcome the high threshold of the α-cluster break up. Besides, events are observed in the channel ^{10}C $\rightarrow$ 3He.

Production of ^{8}Be and ^{9}B nuclei in ^{10}C dissociation



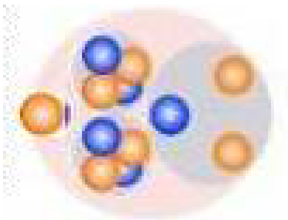


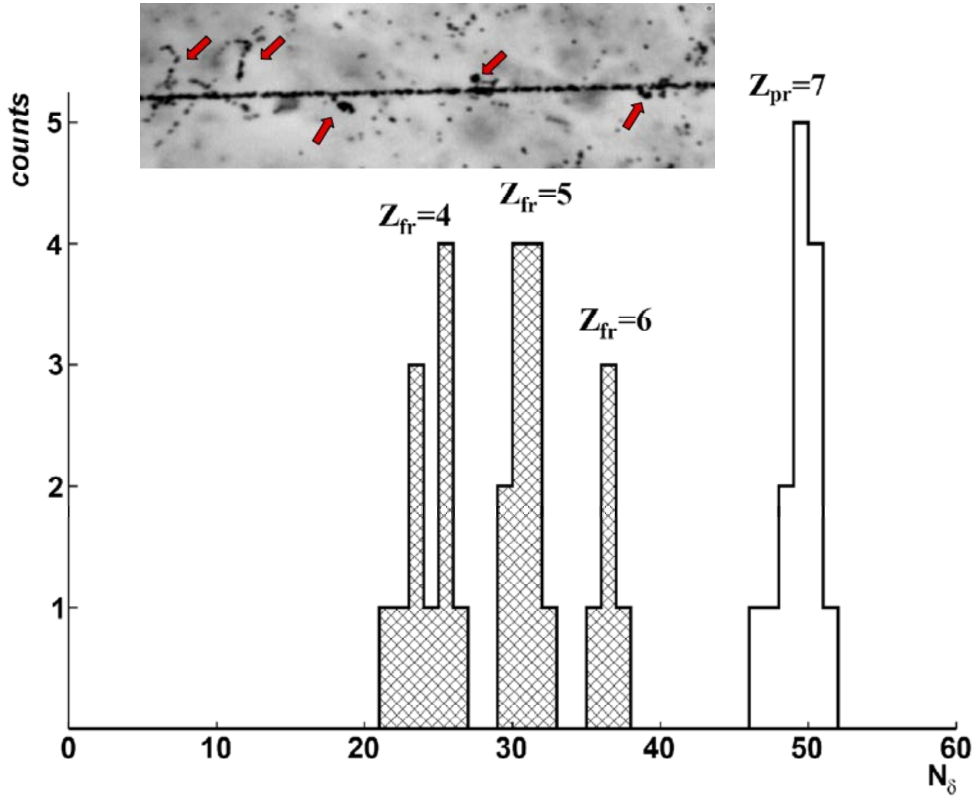


a) Distribution of the number of "white" stars $2\alpha + 2p$ versus excitation energy $Q_{2\alpha}$ of the α-pairs. In the inset a zoom over the $Q_{2\alpha}$ distribution is shown. b) Distribution of the number of "white" stars $2\alpha + 2p$ versus excitation energy $Q_{2\alpha p}$ of triples $2\alpha + p$. In the inset a zoom over the $Q_{2\alpha p}$ distribution is shown.

In 63 events the $Q_{2\alpha}$ value does not exceed 500 keV (inset a)). For them, the average value is $\langle Q_{2\alpha}\rangle \approx 110 \pm 20$ keV and the mean-square scattering $\sigma = 40$ keV, which well corresponds to the decays of the ^{8}Be 0^+ ground state. The unbound ^{9}B nucleus can be another major product of the ^{10}C coherent dissociation. The $Q_{2\alpha p}$ values for one of two possible 2α + p triples do not exceed 500 keV in 58 events (inset b)). The average value for these triples is $\langle Q_{2\alpha p}\rangle = 250 \pm 15$ keV with rms $\sigma = 74$ keV.

Coherent dissociation of ^{12}N nuclei





The particular feature of the ^{12}N nucleus consists in the low proton separation threshold (600 keV). Furthermore, the dissociation can occur through the channels $\alpha + {}^{8}B$ (8 MeV), $p + {}^{7}Be + \alpha$, as well as into more complicated ensembles with the ^{7}Be core break.

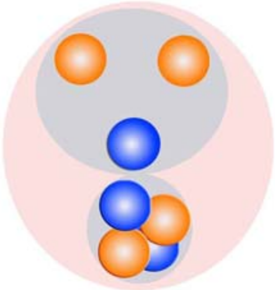
In this irradiation 41 "white" stars N_{ws} with $Z_{pr} = 7$ and $\sum Z_{fr} = 7$ are found, corresponding to the dissociation of ^{12}N nuclei. About half of the events contain a fragment $Z_{fr} > 2$, clearly differing from the cases of nuclei ^{14}N and ^{10}C.

Distribution of the number of "white" stars, N_{ws}, with respect to the channels $\sum Z_{fr} = 7$ and $Z_{pr} = 7$

C + H	^{8}B + He	^{7}Be+He+H	^{8}B+2H	^{7}Be+3H	3He + H	2He + 3H	He +5H
5	6	6	5	5	2	10	2

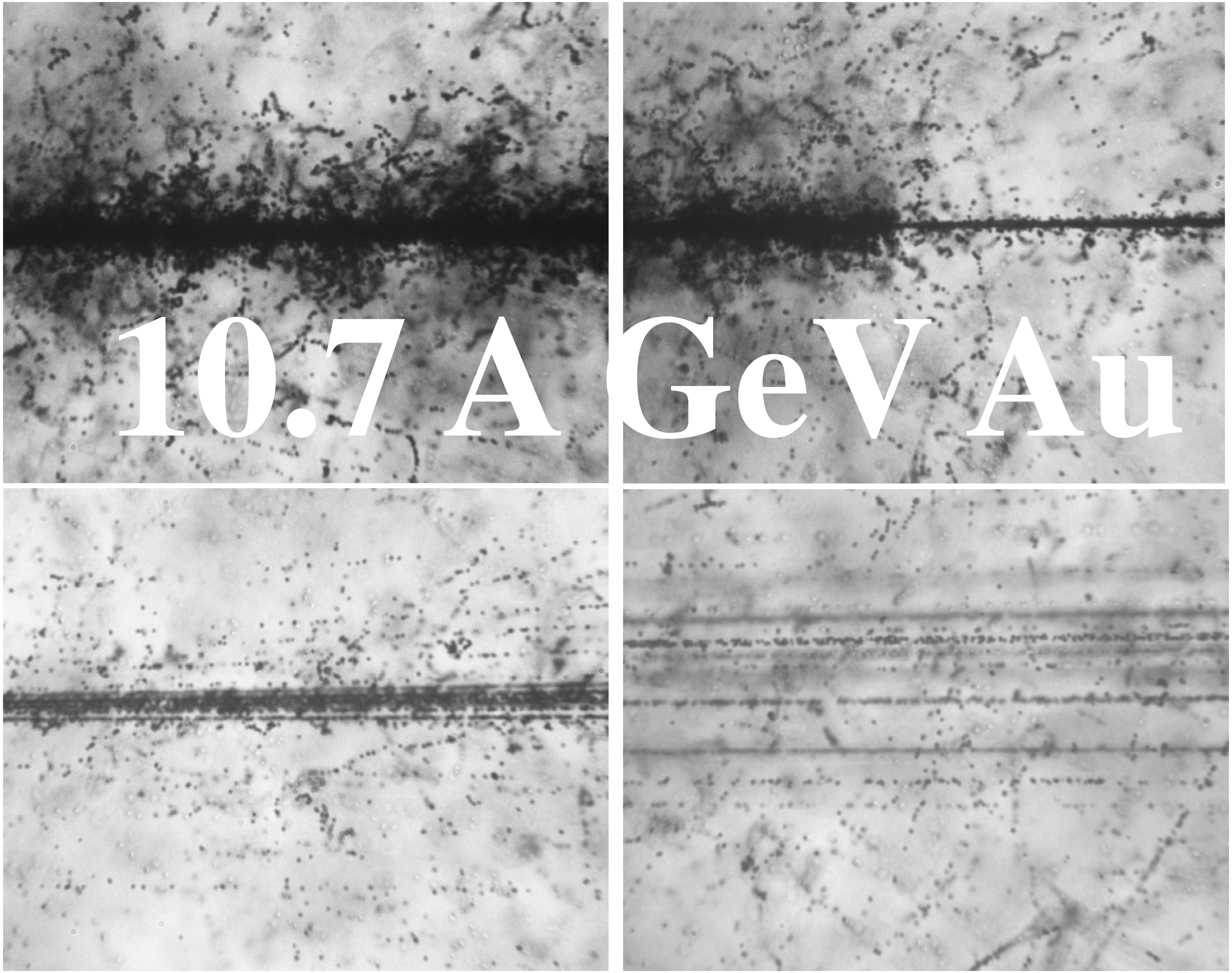
High statistics analysis of ^{7}Be dissociation

The BECQUEREL Collaboration performed irradiation of nuclear track emulsion in a mixed beam of ^{12}N, ^{10}C and ^{7}Be nuclei. Thus, there are new opportunities with regard to the issue of "dihelion" based on the analysis of the found about 400 "non-white" stars ^{7}Be $\rightarrow$ 2^{3}He with knocking out of a neutron and the formation of fragments of target nuclei or mesons, as in the case of ^{8}B $\rightarrow$ 2He + H. Thus, the indication to the existence of "dihelion" will be reviewed using a significantly larger statistics.

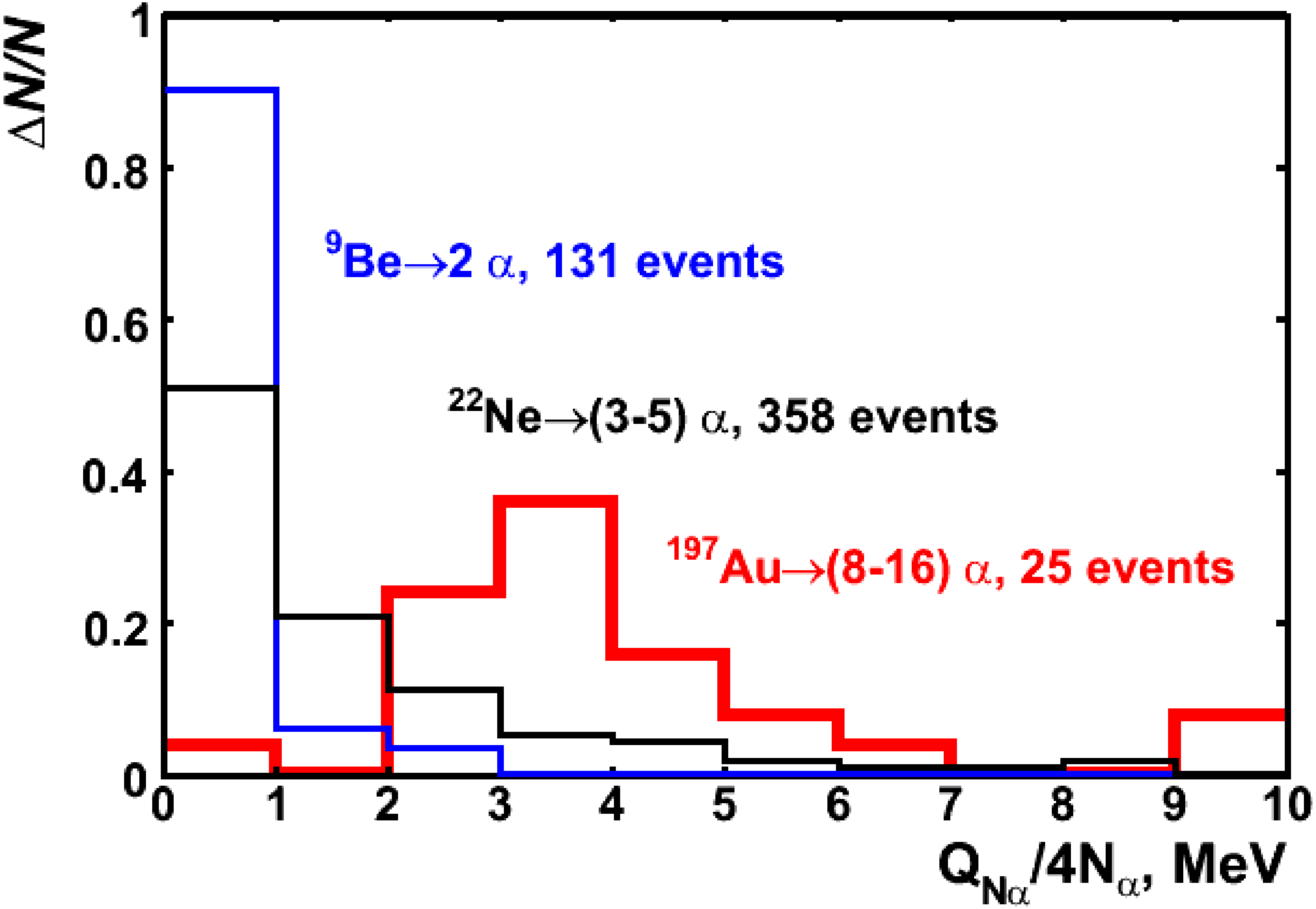


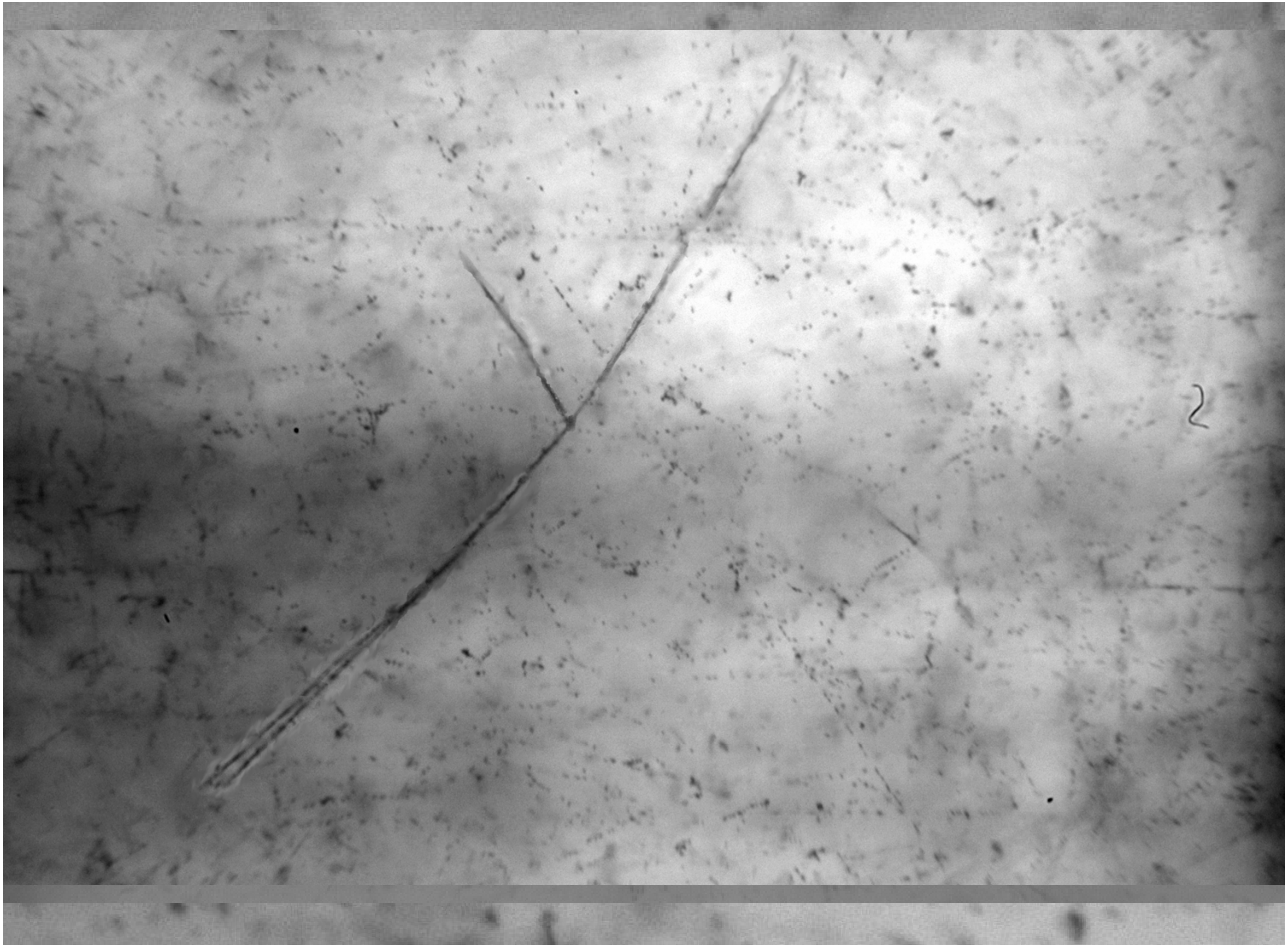
Distribution of the number of "white" stars, N_{ws}, and the number of events involving the production of target fragments, N_{tf}, with respect to $\sum Z_{fr} = 4$ channels

$\sum Z_{fr} = 4$	2He	He+2H	4H
N_{ws}	95	116	14
N_{tf}	371	554	16


10.7 A GeV Au

1.2A GeV ^{9}Be   3.22A GeV ^{22}Ne   10.7A GeV ^{197}Au

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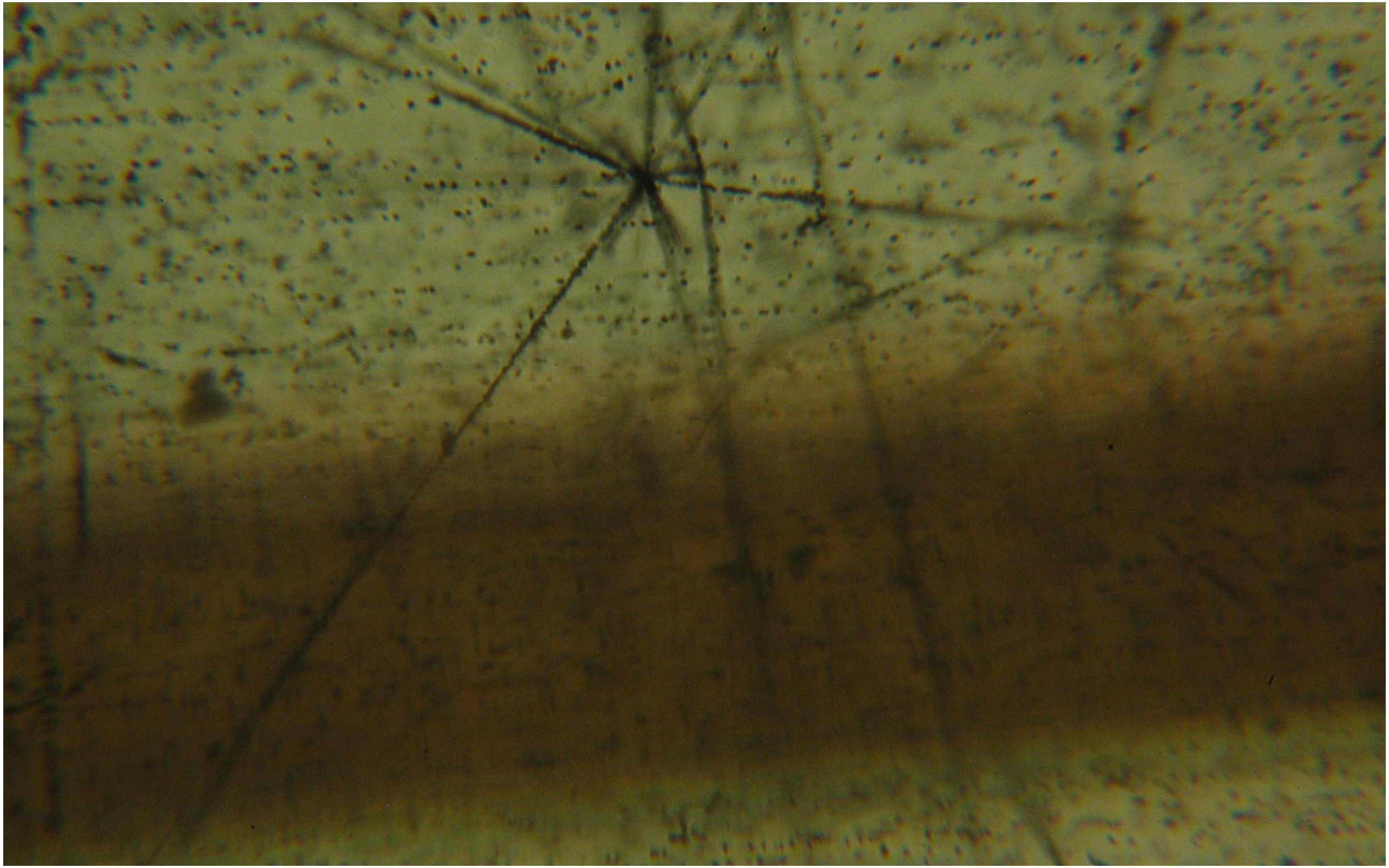
PHYSICAL REVIEW C VOLUME 41, NUMBER 6 JUNE 1990

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.



Macrophoto of nuclear star induced by 5 GeV hadron in nuclear track emulsion and human hair

Conclusions

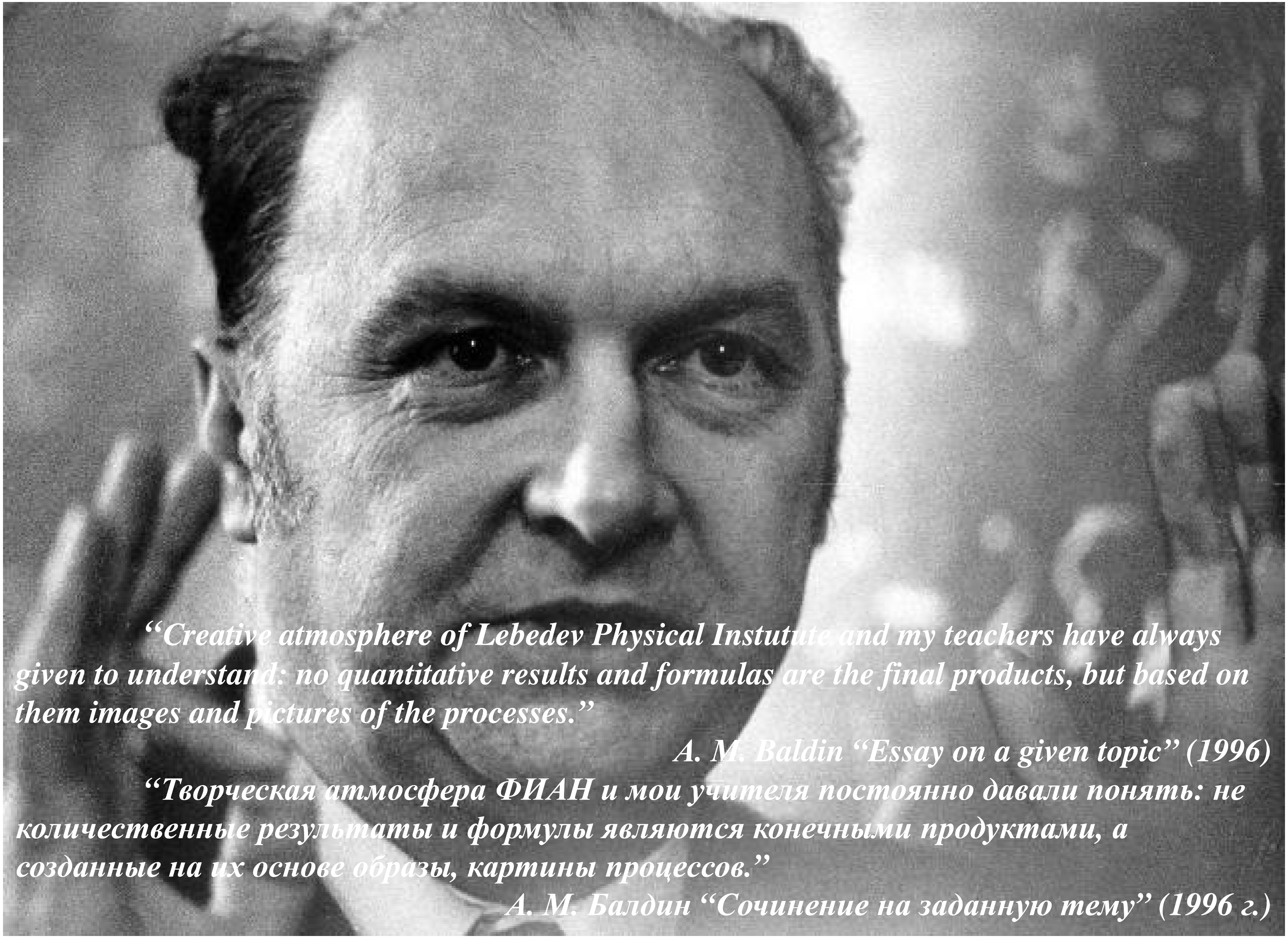
The presented observations serve as an illustration of prospects of the Nuclotron for nuclear physics and astrophysics researches. The relativistic energy scale does not impede investigations of nuclear interactions down to energy scale relevant for nuclear astrophysics, but on the contrary gives advantages for investigation of multi-particle systems.

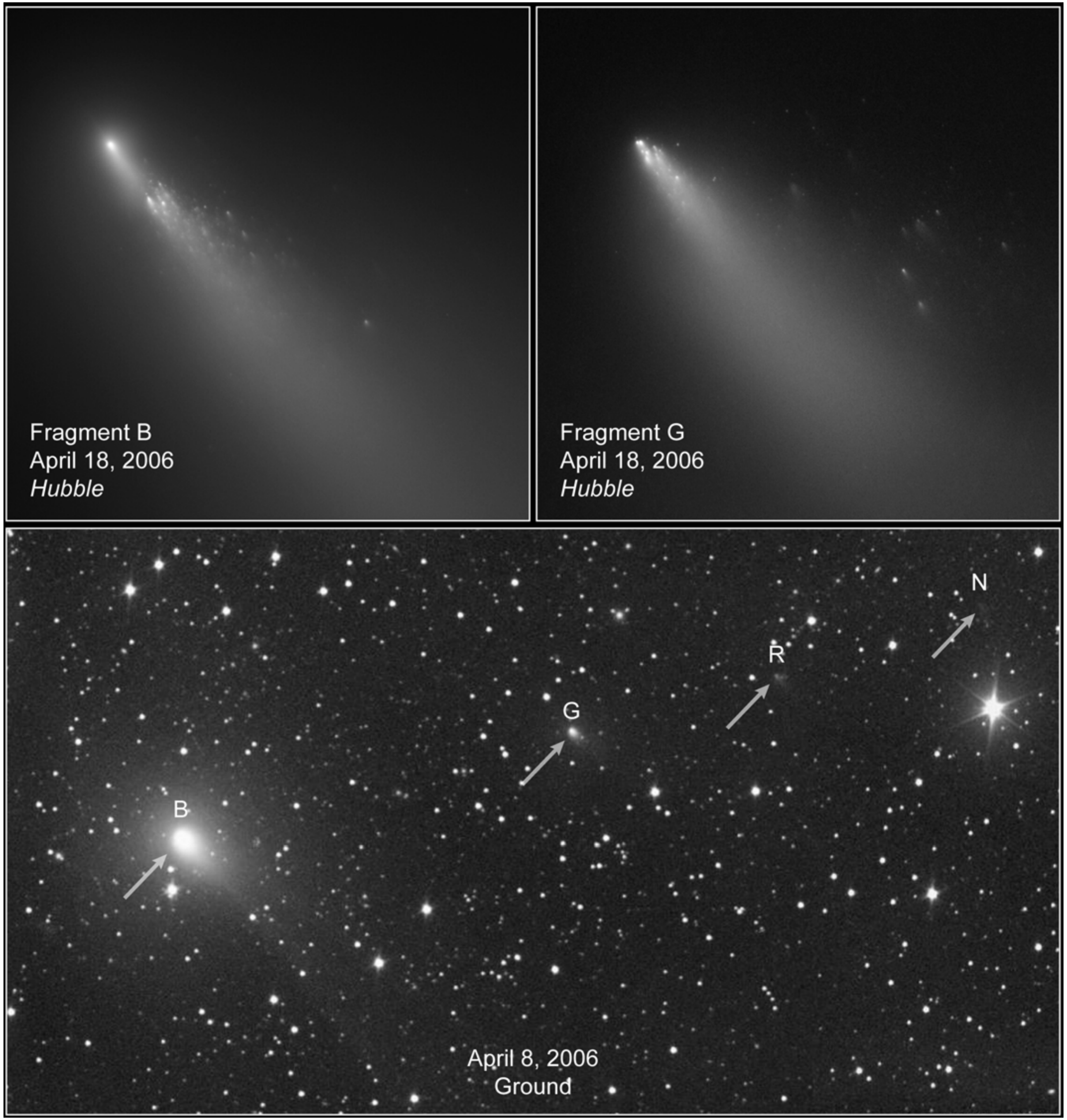
Due to a record space resolution the emulsion technique provides unique entirety in studying of light nuclei, especially, neutron-deficient ones. Providing the 3D observation of narrow dissociation vertices this classical technique gives novel possibilities of moving toward more and more complicated nuclear systems.

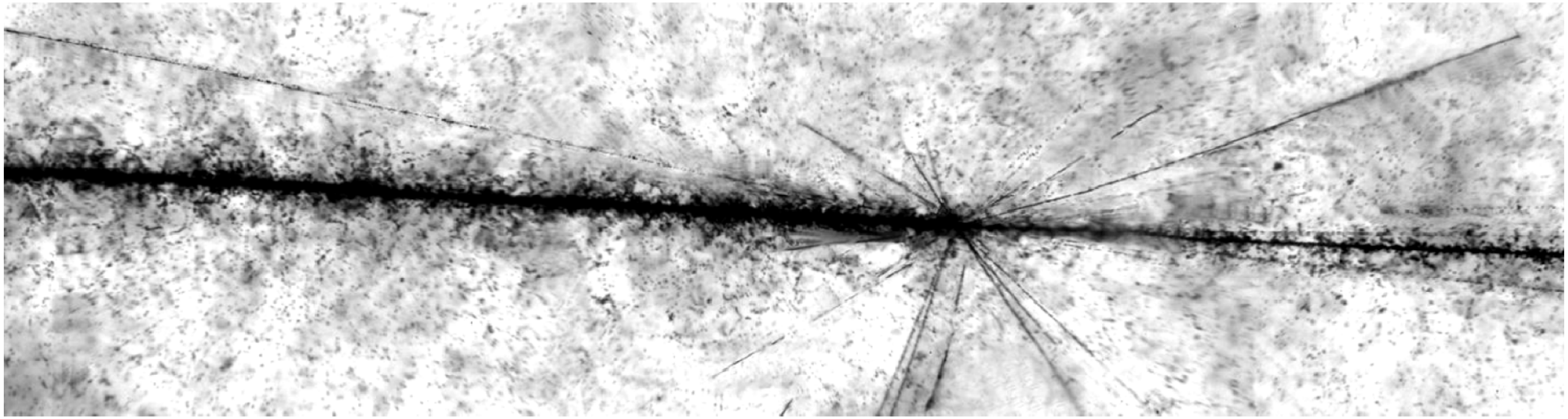
The results of the light nucleus study lead to the conclusion that their structure dominates in very peripheral dissociations while some unknown features are clearly observed

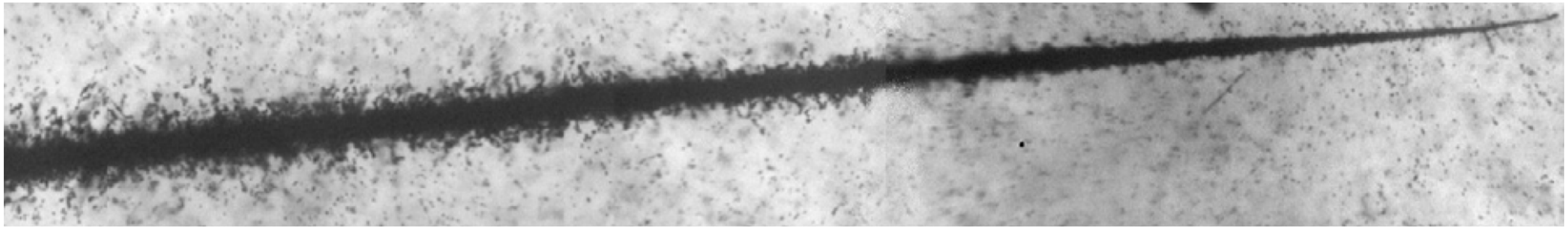
The investigations with light nuclei provide a basis for challenging studies of increasingly complicated systems *He – H - n* produced via complete fragmentation of heaviest relativistic nuclei.

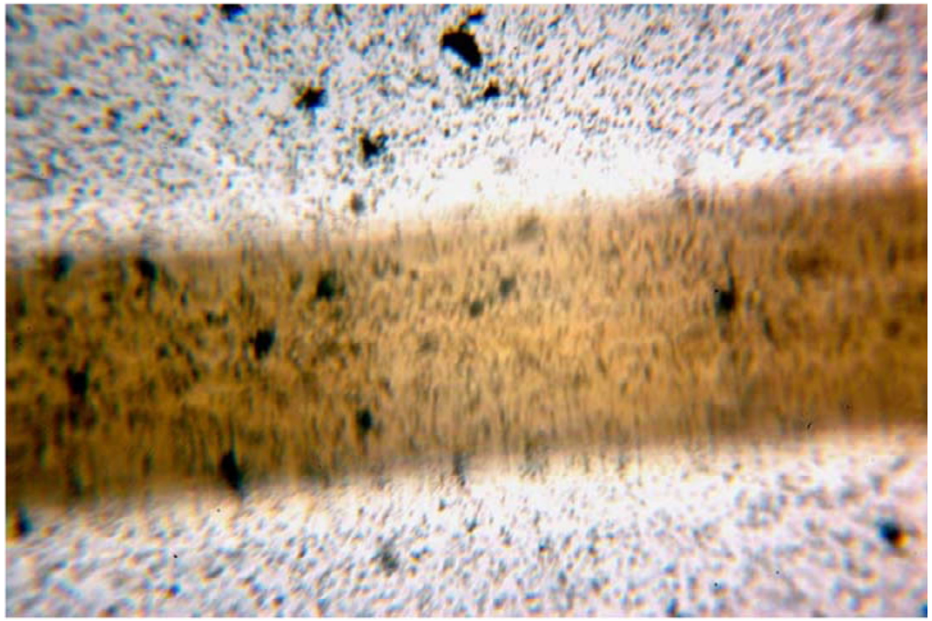
Long and bright road is ahead for nuclear researches using HEP techniques. Nuclear imaging continue to inspire our imagination.

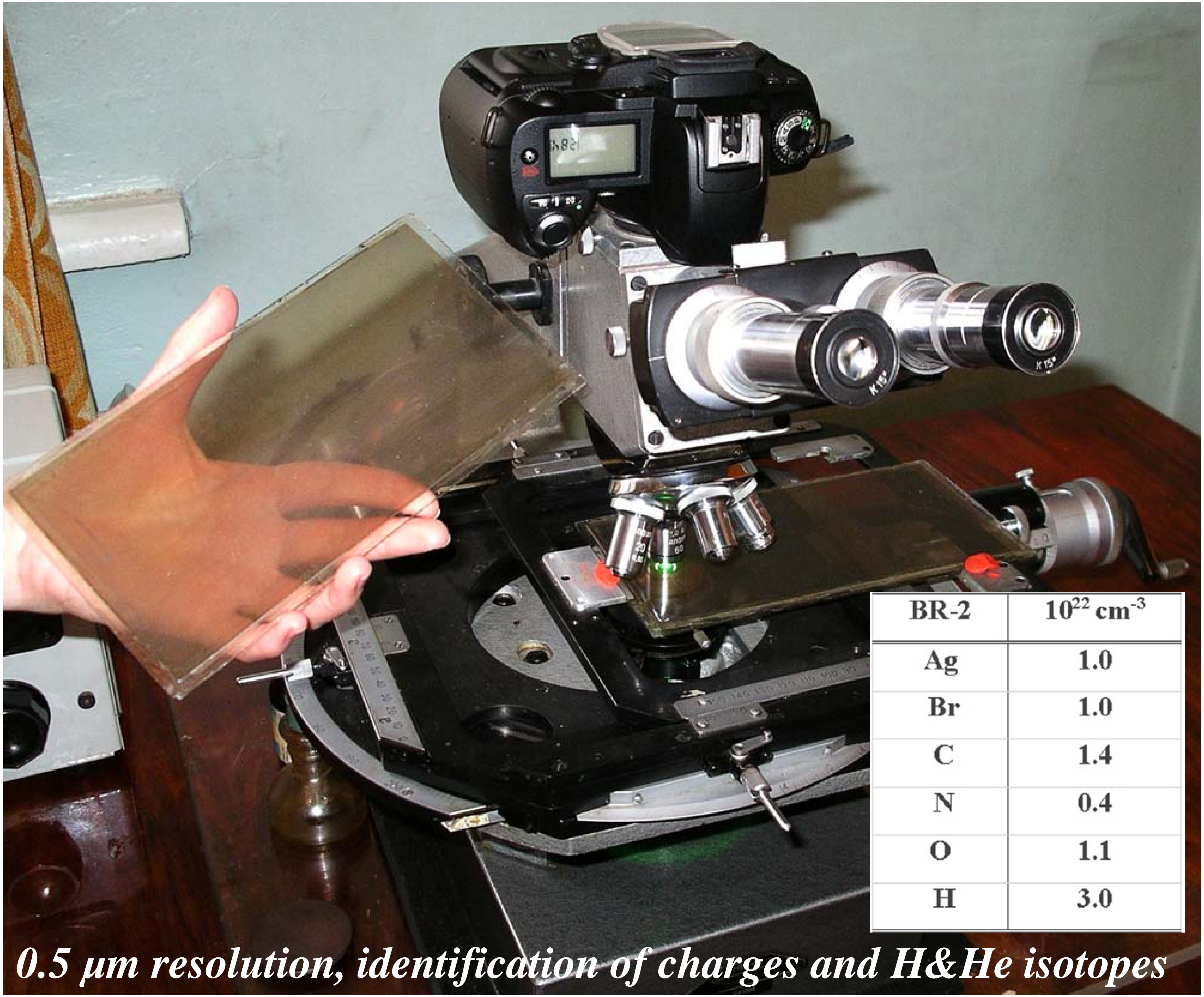

“Creative atmosphere of Lebedev Physical Institute and my teachers have always given to understand: no quantitative results and formulas are the final products, but based on them images and pictures of the processes.”
A. M. Baldin “Essay on a given topic” (1996)
“Творческая атмосфера ФИАН и мои учителя постоянно давали понять: не количественные результаты и формулы являются конечными продуктами, а созданные на их основе образы, картины процессов.”
А. М. Балдин “Сочинение на заданную тему” (1996 г.)


Fragment B
April 18, 2006
Hubble
Fragment G
April 18, 2006
Hubble
N
R
G
B
April 8, 2006
Ground



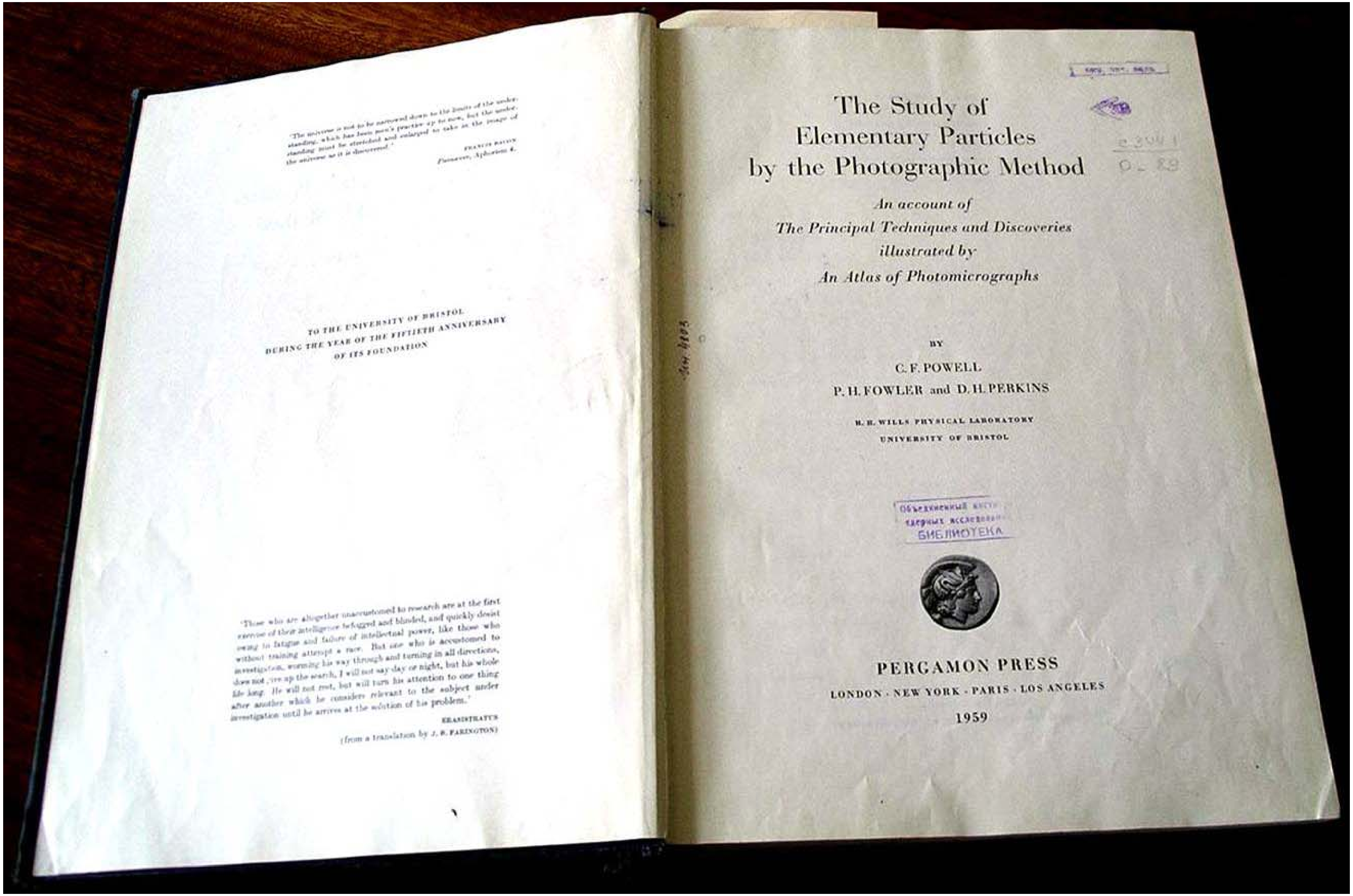






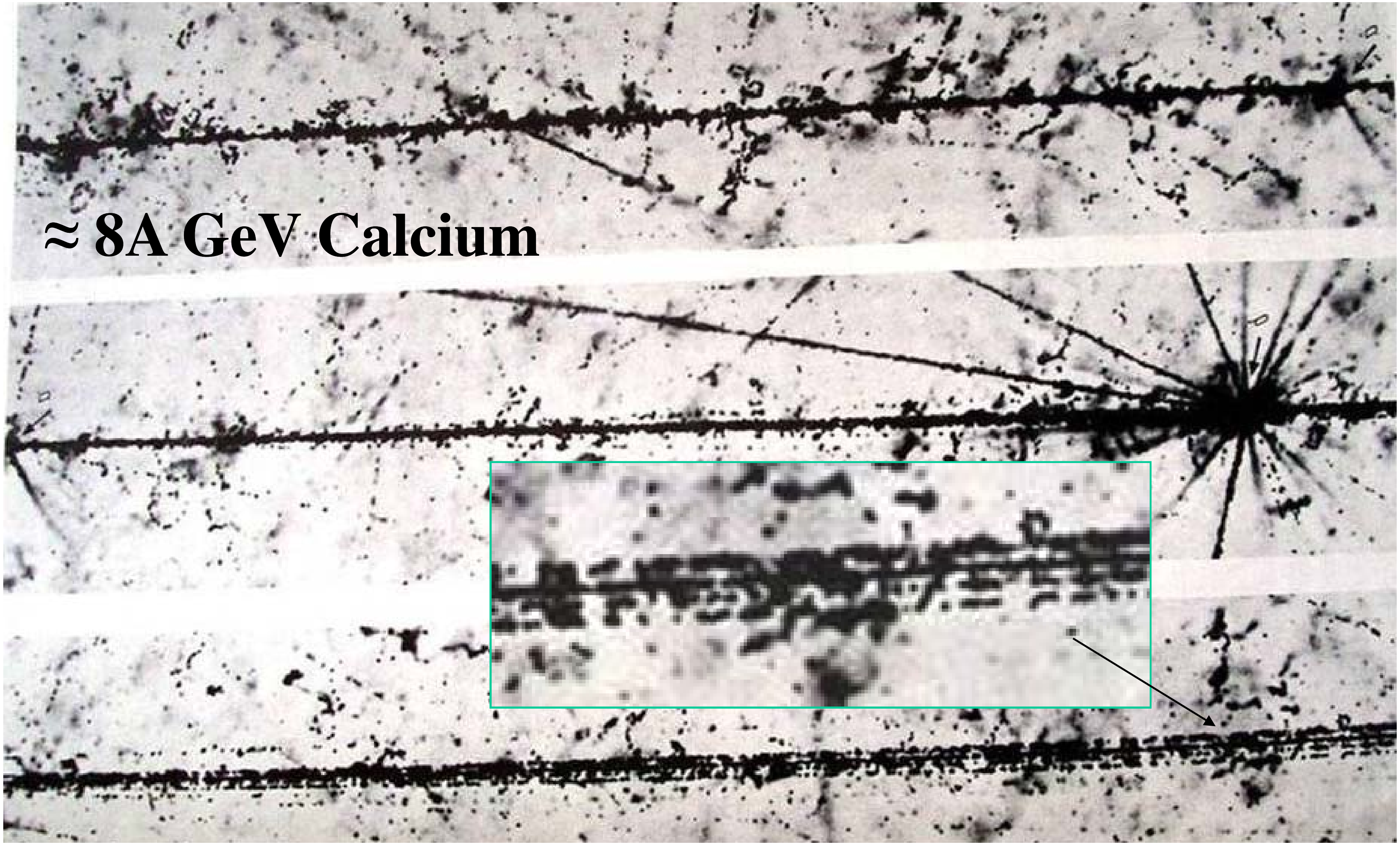
BR-2	10^{22} cm^{-3}
Ag	1.0
Br	1.0
C	1.4
N	0.4
O	1.1
H	3.0

0.5 μm resolution, identification of charges and H&He isotopes



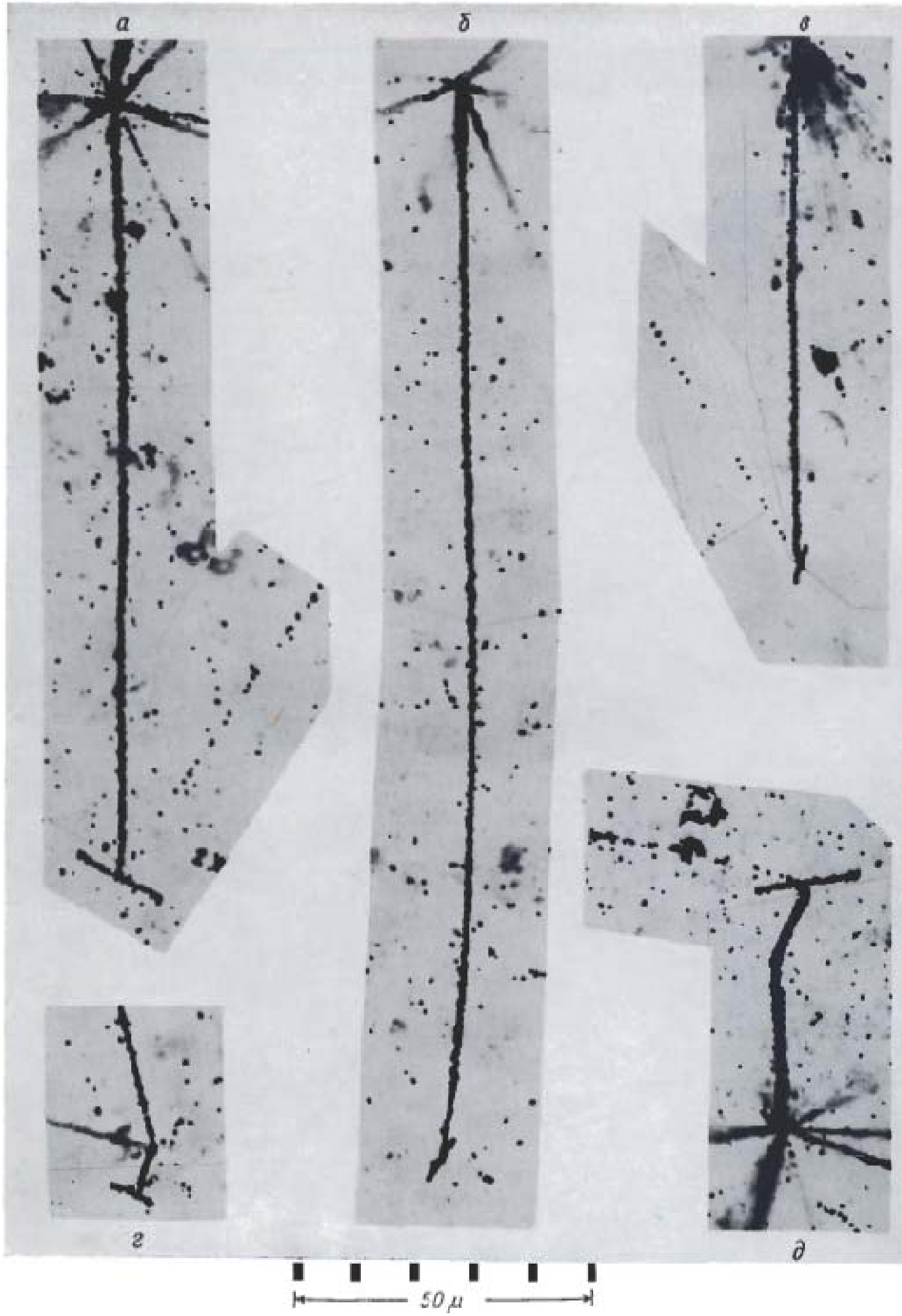
The unique collection of images in the "Emulsion Bible" by Powell, Fowler, and Perkins.

Interactions of relativistic nuclei of galactic origin



Hammer tracks in cosmic ray events:

^{8}Be produced in β-delayed decay of stopped ^{8}B and ^{8}Li



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)

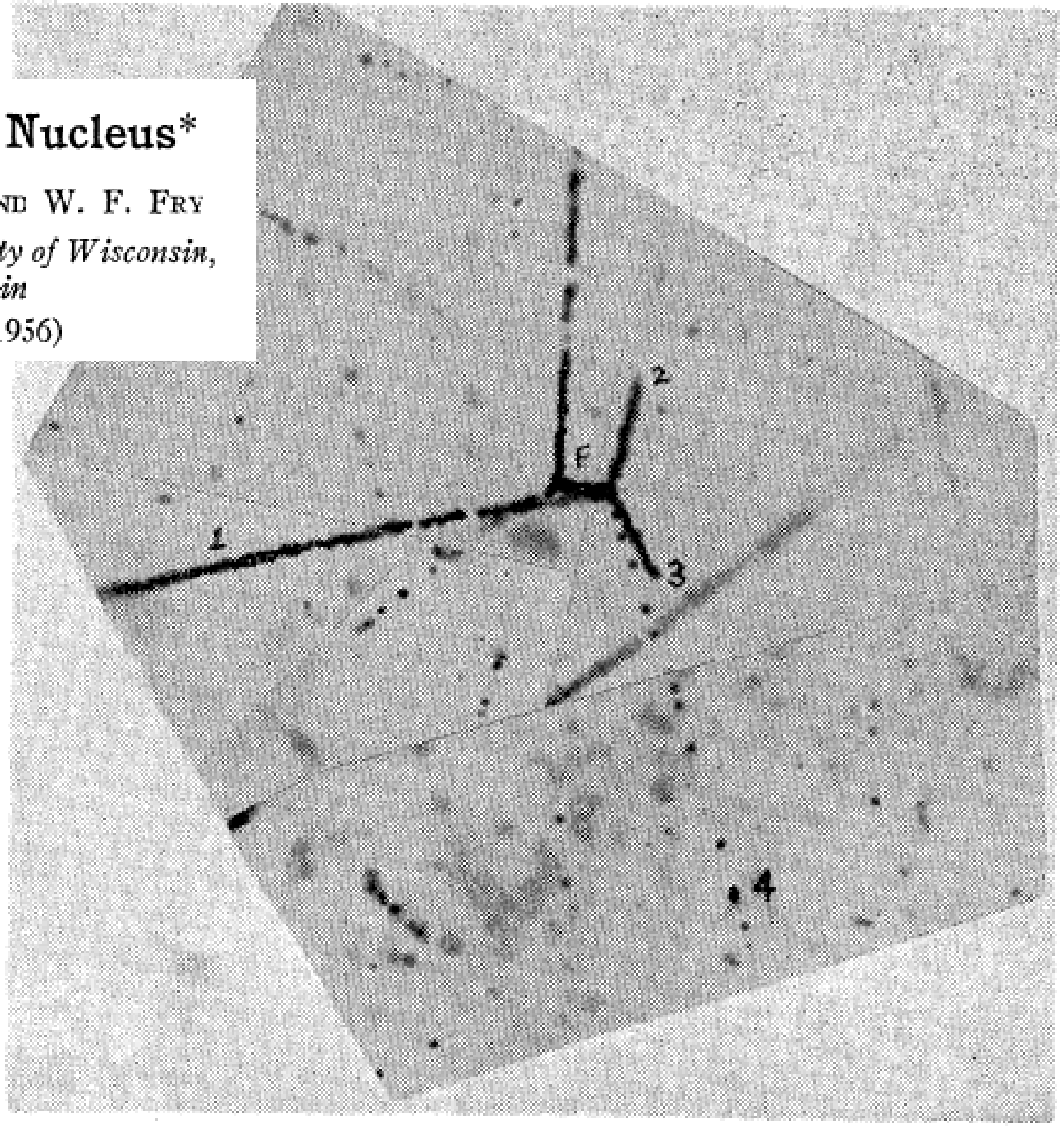
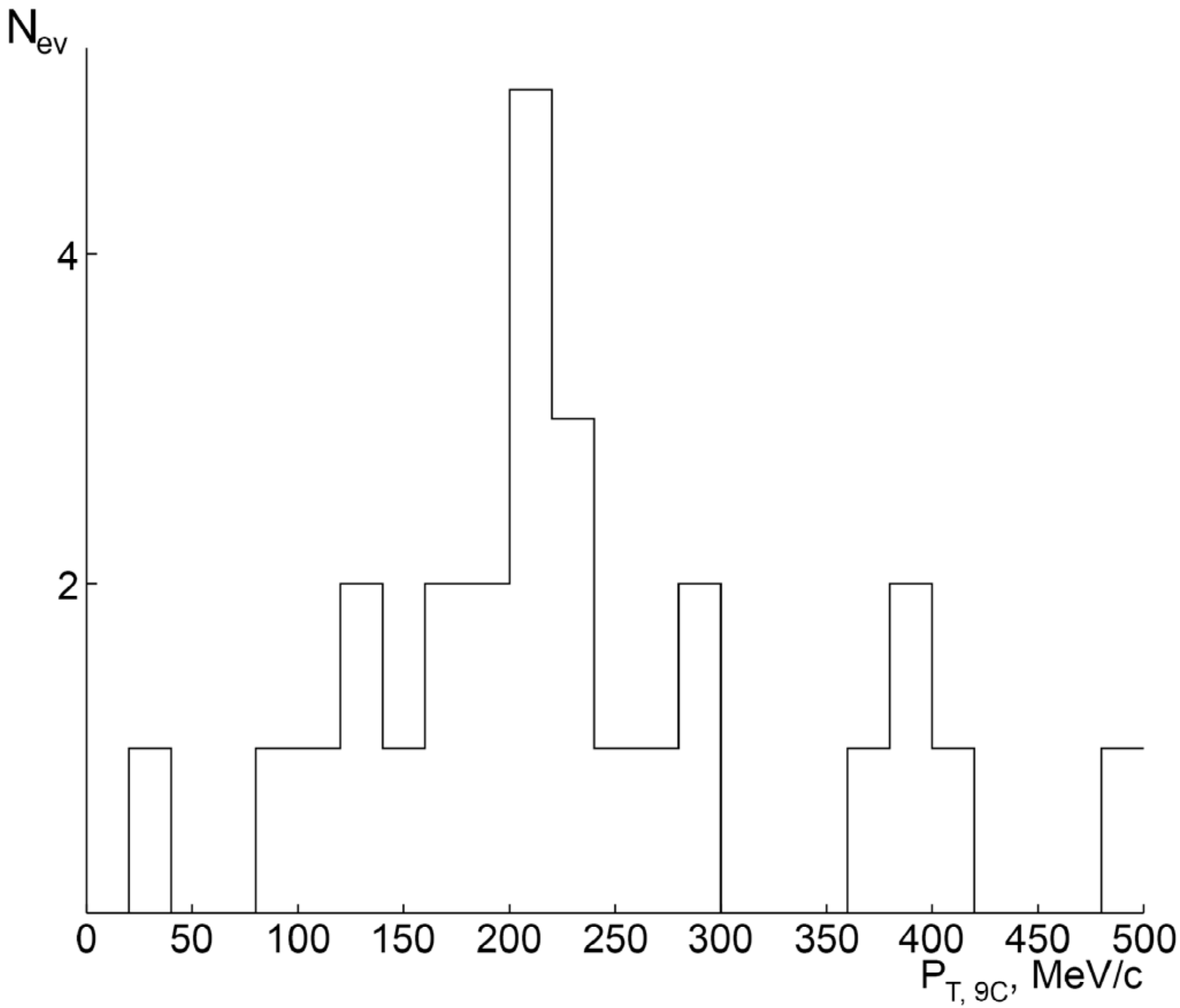
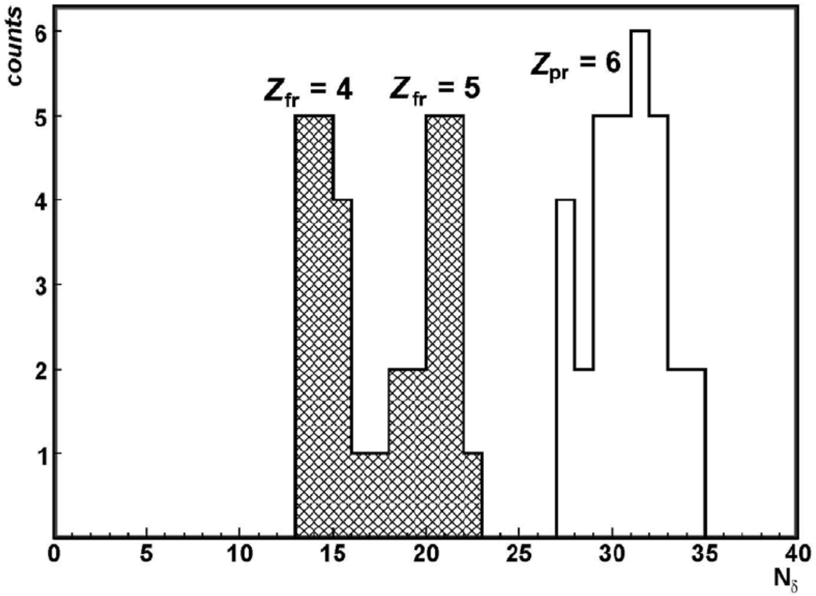


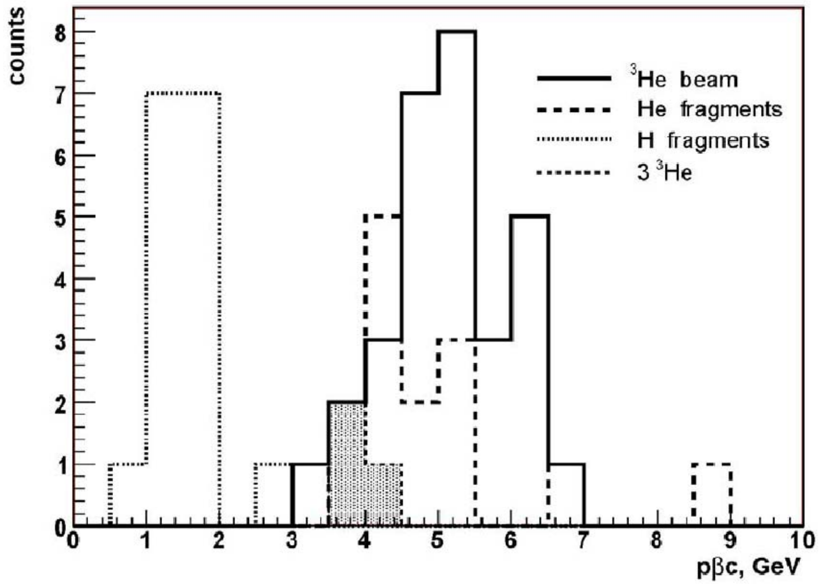
Fig. 1. A photograph of an event interpreted as the beta decay of C^9. The C^9 nucleus (track *F*) was produced in star (*A*) and disintegrated into a proton, two alpha particles, and a positron (tracks 1, 2, 3, and 4, respectively).



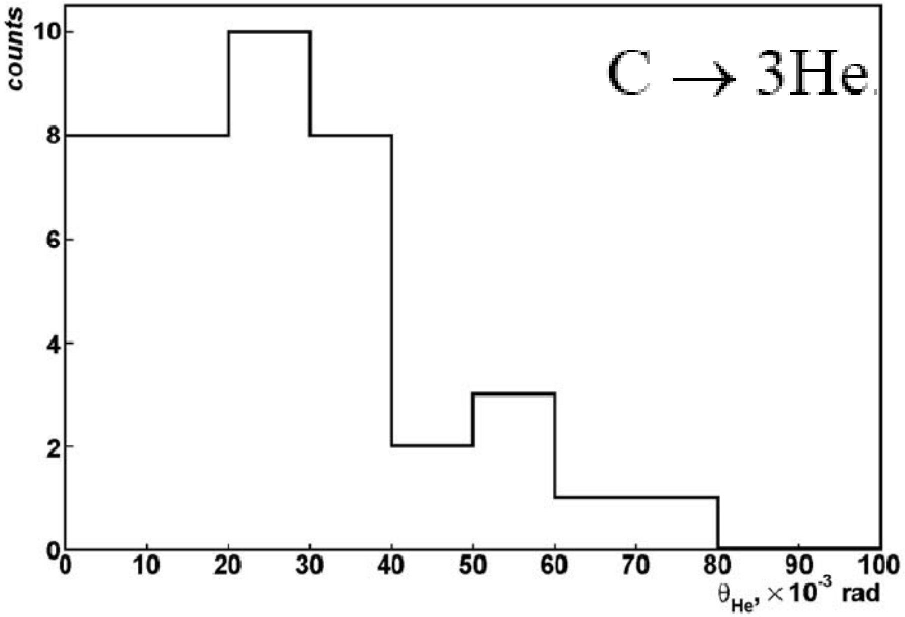
N_ev
4
2
0
50
100
150
200
250
300
350
400
450
500
P_T, 9C, MeV/c



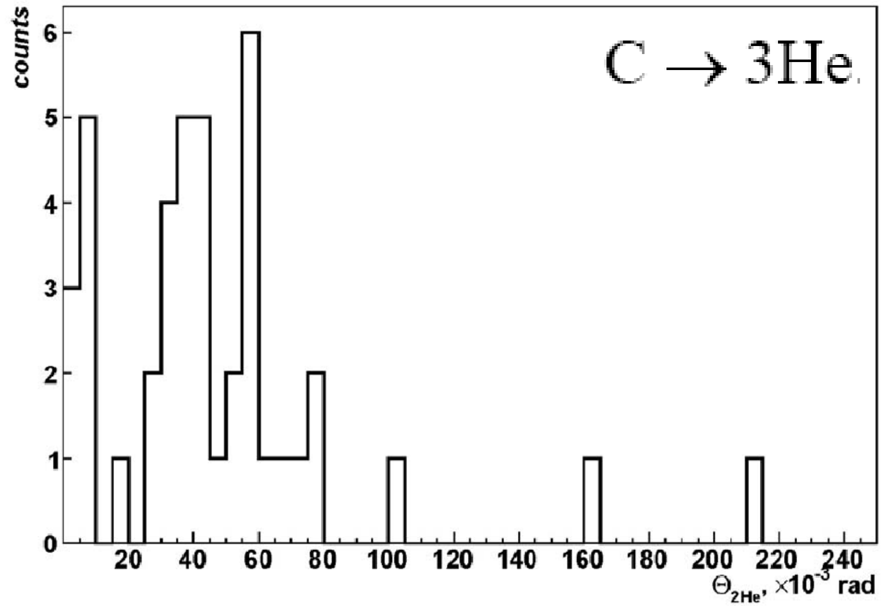
δ -electrons density for beam particles and relativistic fragments with charges $Z_{fr} > 2$ from "white" stars $\sum Z_{fr} = 5 + 1$ and $4 + 1 + 1$



pβ*c* for beam ^{3}He nuclei, H fragments of the "white" stars $\sum Z_{fr} = 5 + 1$ and $4 + 1 + 1$, He fragments of the "white" stars 3He and from the 3^3He event



Polar angles θ for doubly charged fragments in the "white" stars C → 3He

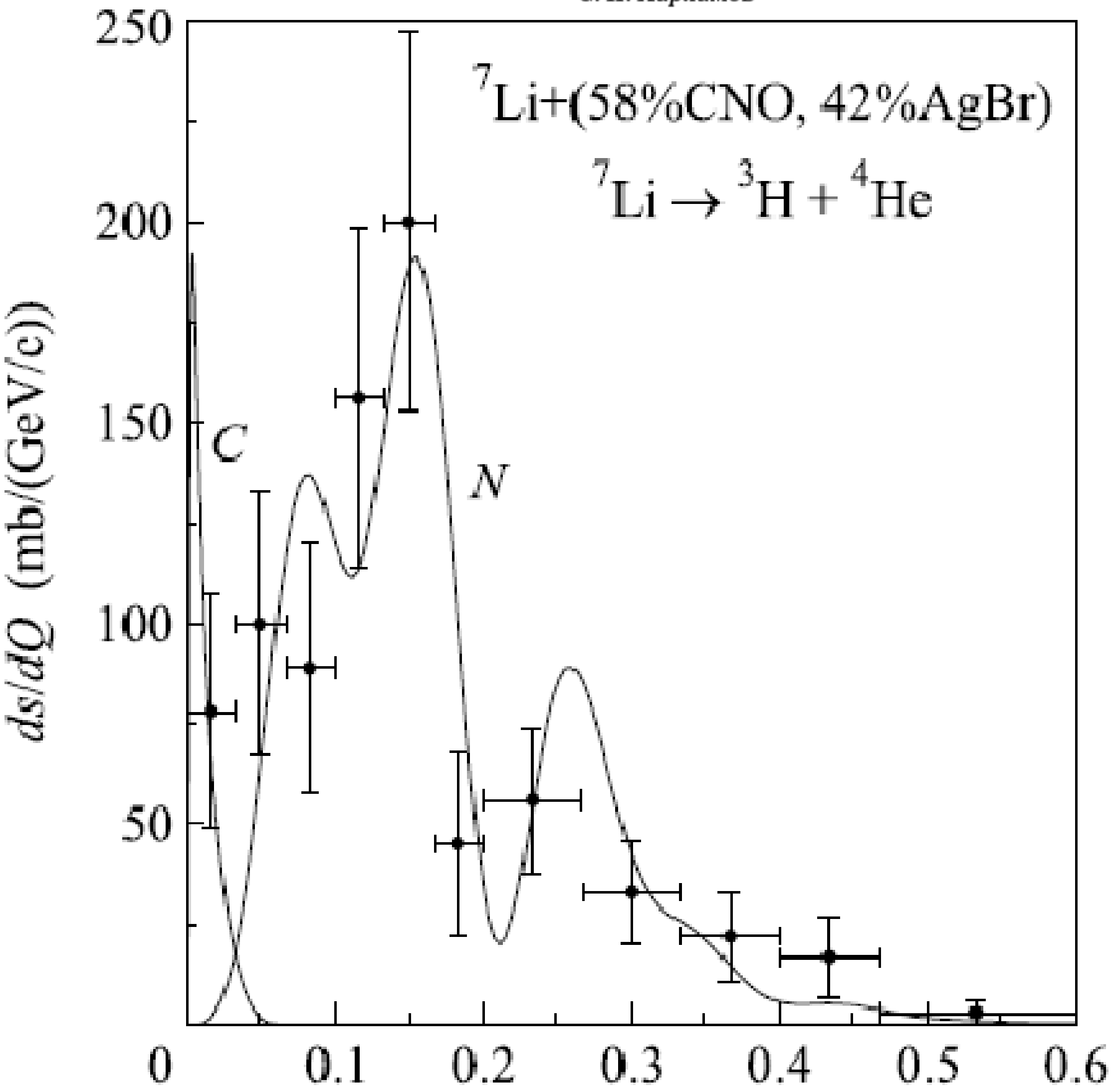


Opening angles Θ_{2He} between fragments in the "white" stars C → 3He

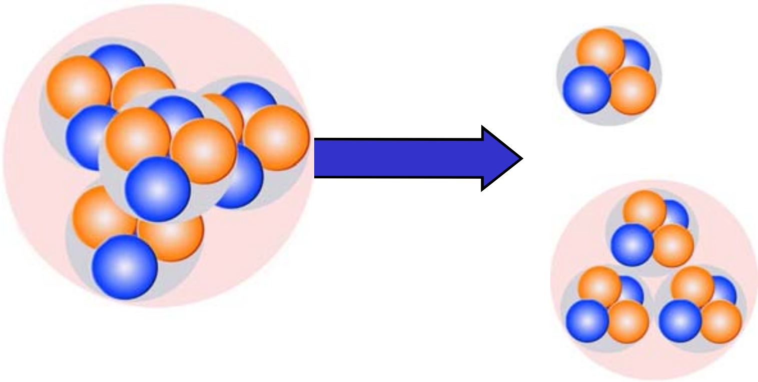
Письма в ЖЭТФ, том 88, вып. 2, с. 83 – 87

Роль ядерного и электромагнитного взаимодействий в когерентной диссоциации релятивистского ядра ^{7}Li по каналу ^{3}H + ^{4}He

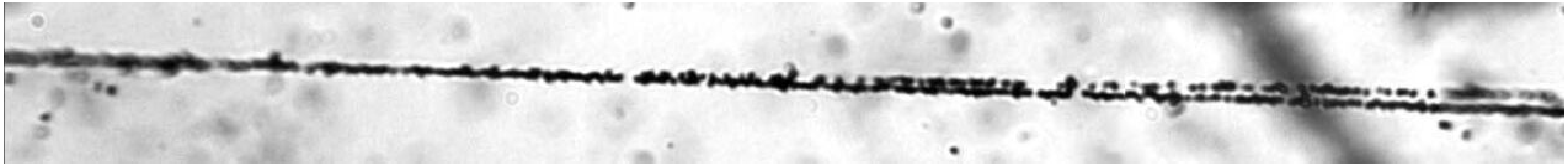
Н. Г. Пересадько, В. Н. Фетисов[1], Ю. А. Александров, С. Г. Герасимов, В. А. Дронов, В. Г. Ларионова, Е. И. Тамм, С. П. Харламов

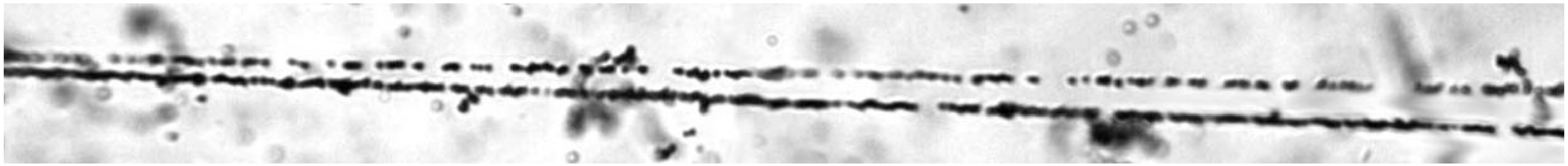


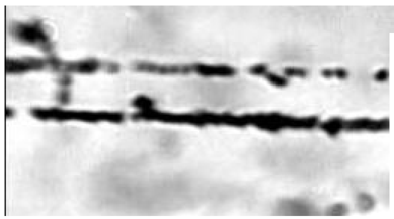
P_T (^{7}Li), GeV/c



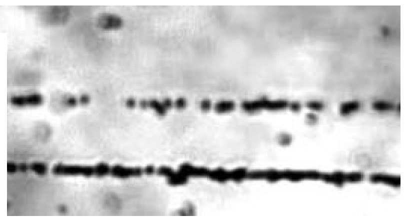
4.5 A GeV/c ^{16}O





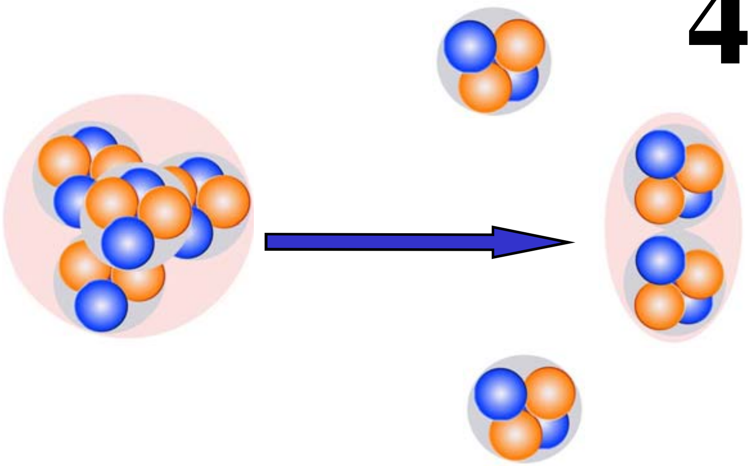


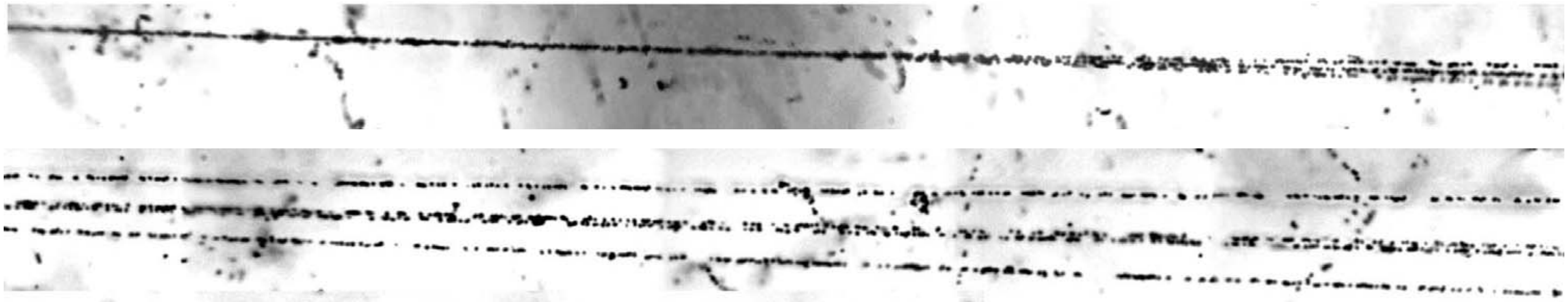
$Z_{fr} > 3$	N	C	C	B	B	Be	Be	-	-
$N_{Z=1}$	1	-	2	3	1	-	2	-	2
$N_{Z=2}$	-	1	-	-	1	2	1	4	3
N_{ev}	18	21	7	2	10	1	1	9	3



4.5A GeV/c 641 events

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





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
(Received 12 January 1990)

A framework is developed for the quantitative analysis of the electromagnetic dissociation of relativistic nuclei. This includes treatment of multiple excitations of the giant dipole resonance, coupled with calculations of the fragmentation probabilities in the framework of the statistical model.

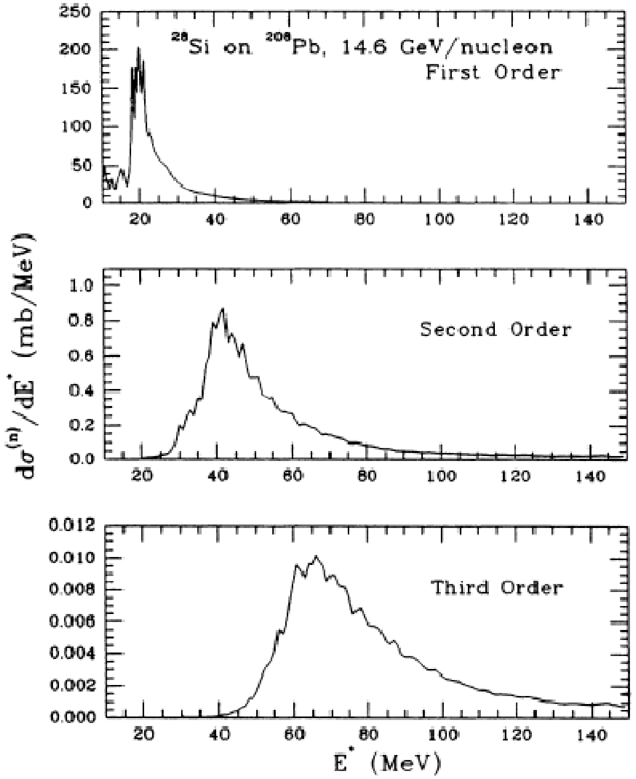


FIG. 3. The total differential Coulomb excitation cross sections for ^{28}Si on ^{208}Pb at $E_{\rm lab}/A = 14.6$ GeV for the first-, second-, and third-order processes.

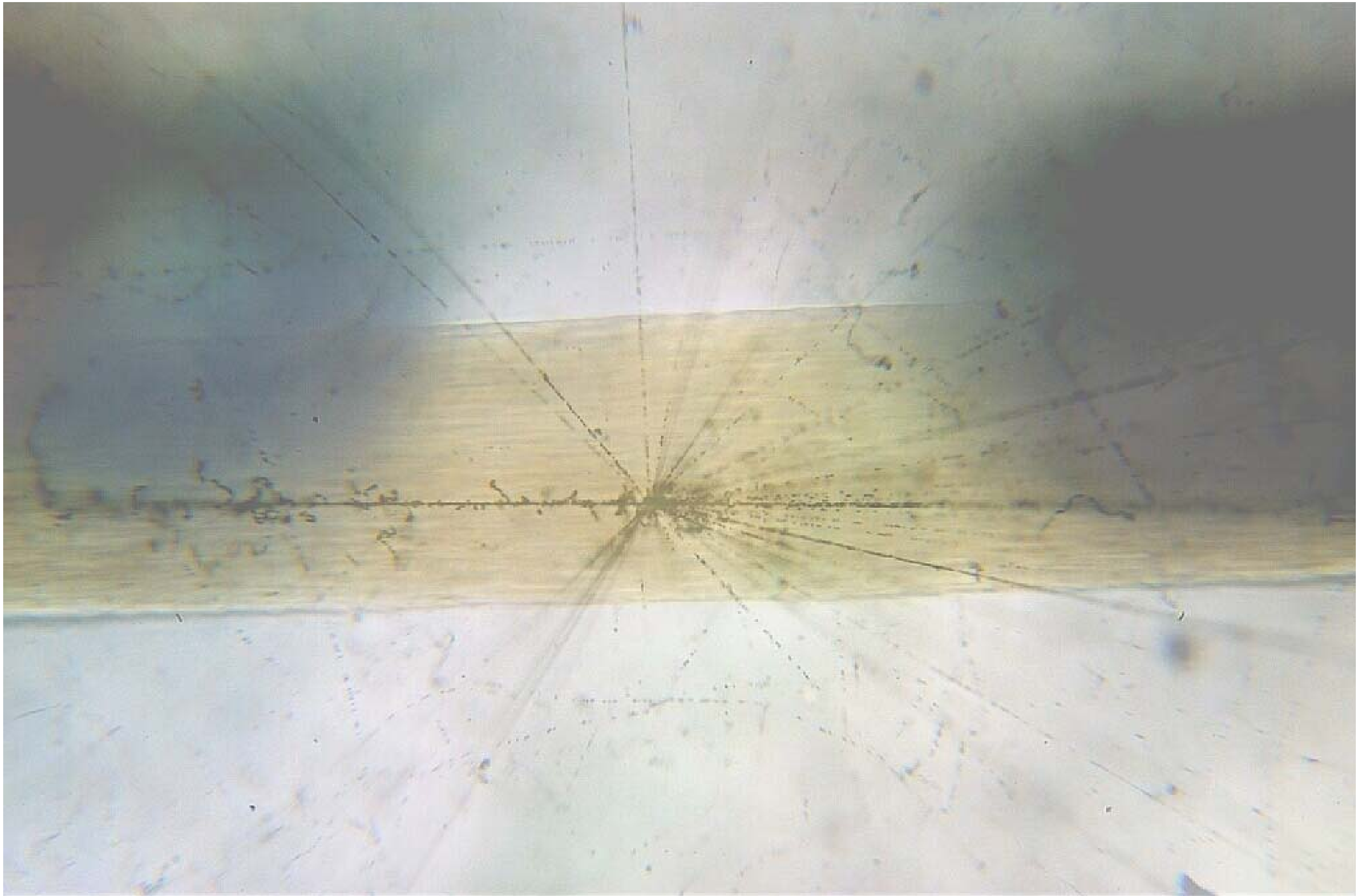


Photo of human hair superposed on nuclear star induced by relativistic sulphur nuclei in nuclear track emulsion