Searching for stellar connections in relativistic nucleus fragmentation

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http://becquerel.jinr.ru/

Nuclear beams of energy higher than *1A* GeV are recognized as a novel opportunity for the nuclear structure explorations. Among all variety of the nuclear interactions the peripheral dissociation bears uniquely complete information about the excited nucleus states above particle decay thresholds.

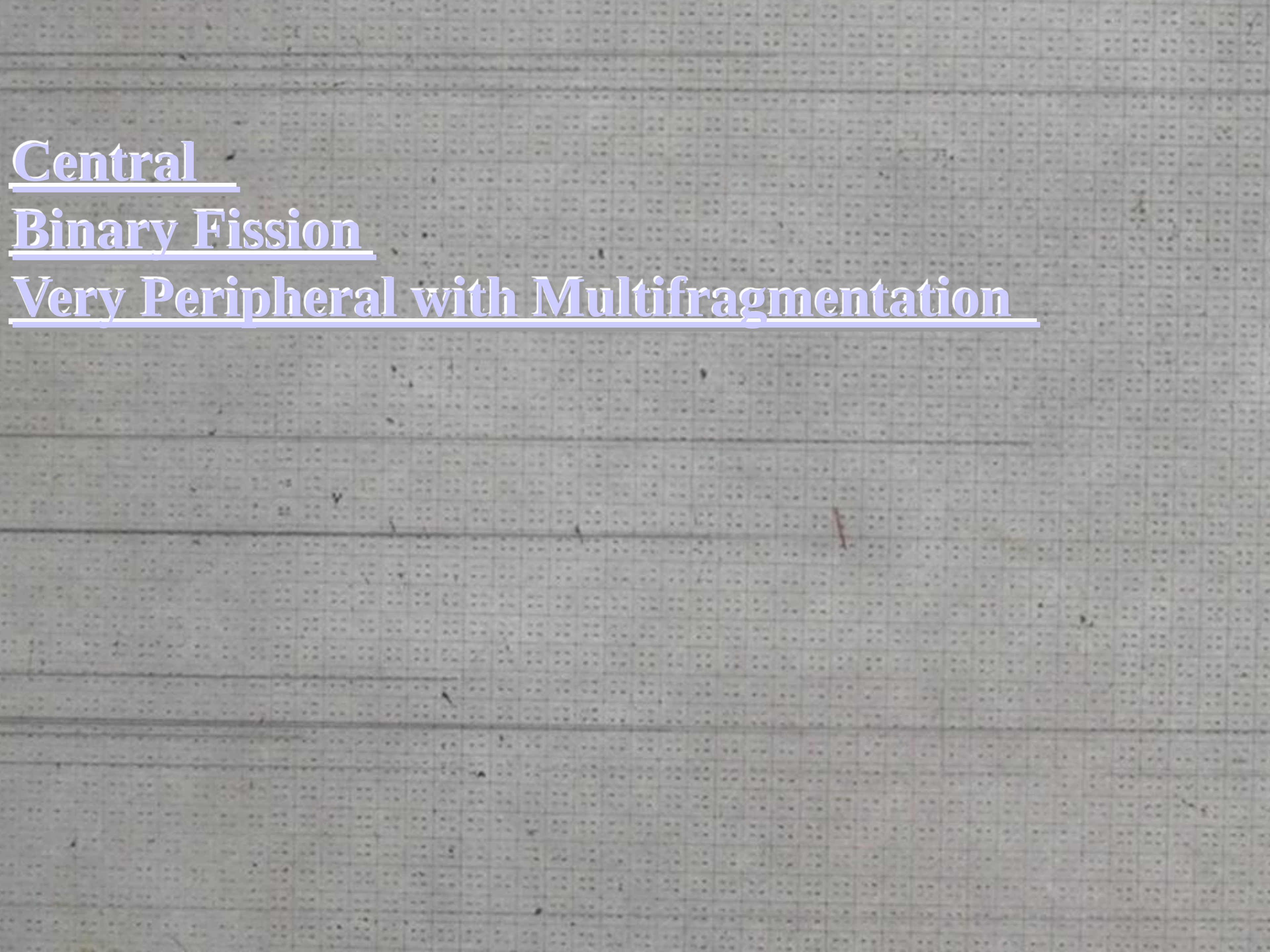
The BECQUEREL Project (Beryllium (Boron) Clustering Quest in Relativistic Multifragmentation) at the JINR Nuclotron is devoted systematic exploration of clustering features of light stable and radioactive nuclei. A nuclear track emulsion is used to explore the fragmentation of the relativistic nuclei down to the most peripheral interactions - nuclear "white" stars. This technique provides a record spatial resolution and allows one to observe the 3D images of peripheral collisions. The analysis of the relativistic fragmentation of neutron-deficient isotopes has special advantages owing to a larger fraction of observable nucleons.

Nuclear Track Emulsions

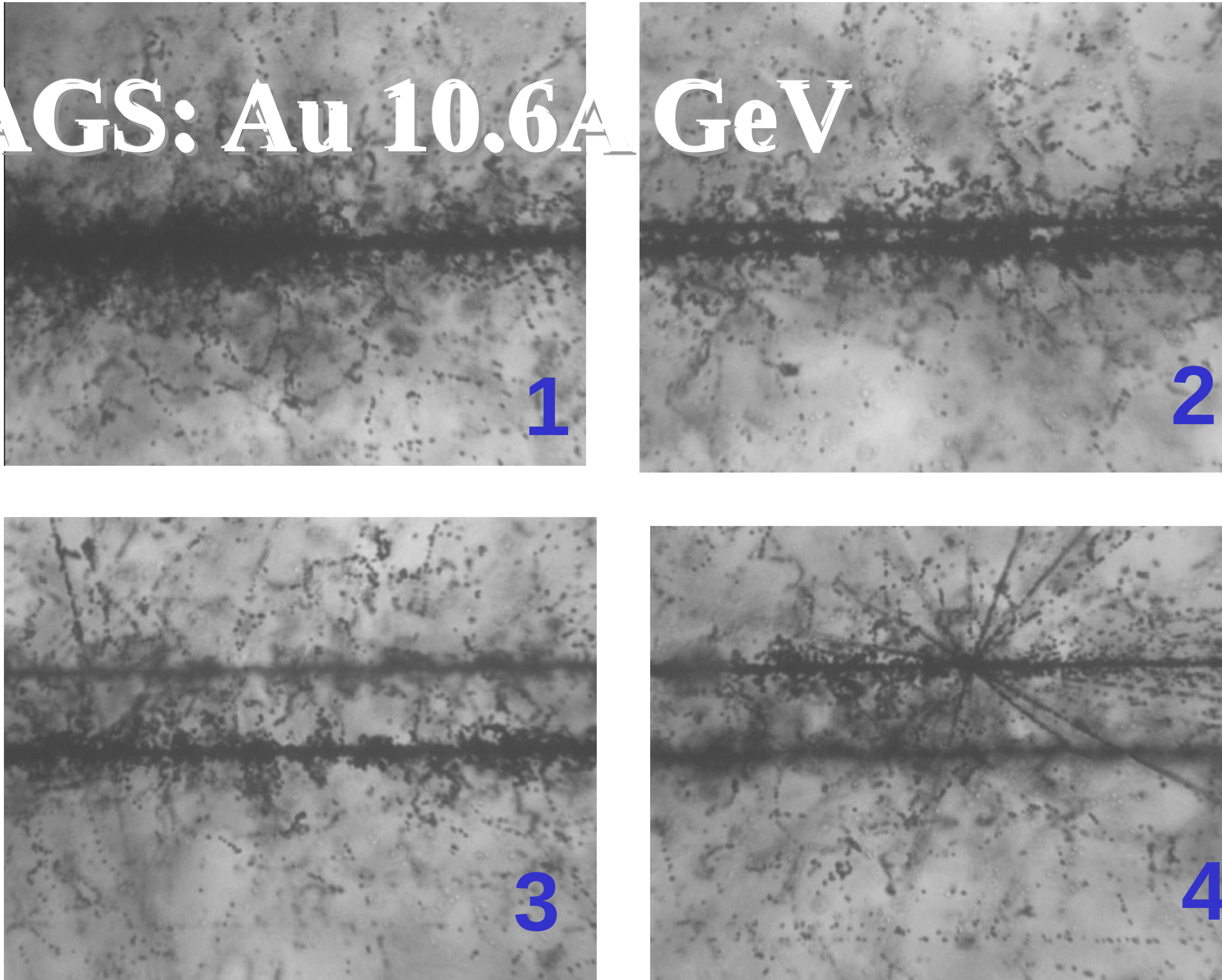
Superposition of microphotographs of interaction of relativistic nucleus ^{32}S and human hair taken with MBI-9 microscope and NIKON camera

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

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


Central
Binary Fission
Very Peripheral with Multifragmentation

AGS: Au 10.6A GeV



SPS: 158 A GeV/c Pb

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

Multifragmentation reactions and properties of stellar matter at subnuclear densities

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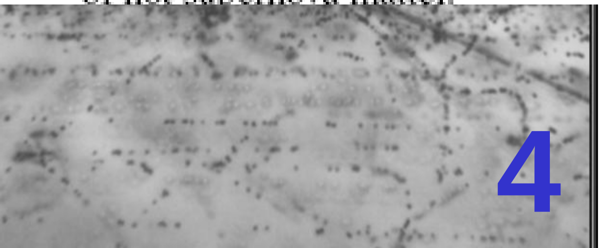
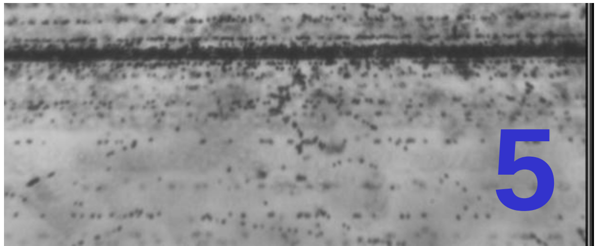
(Received 20 June 2005; published 24 October 2005)

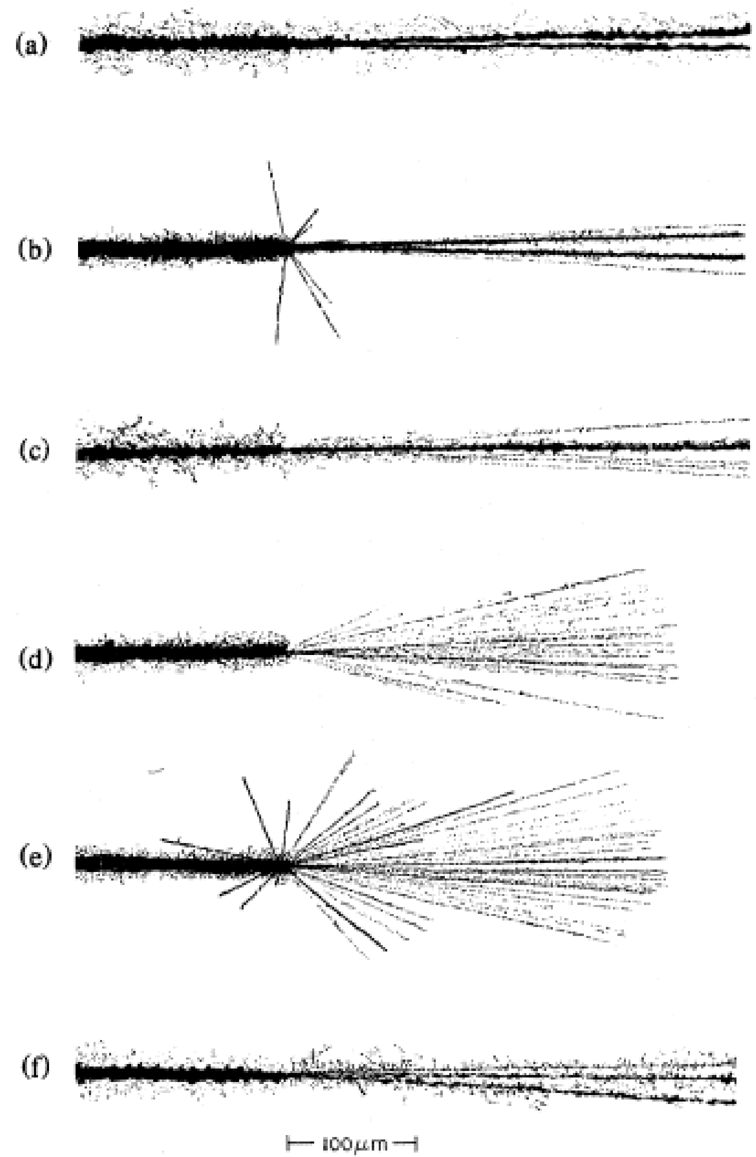
We point out the similarity of thermodynamic conditions reached in nuclear multifragmentation and in supernova explosions. We show that a statistical approach previously applied for nuclear multifragmentation reactions can also be used to describe the electroneutral stellar matter. Then properties of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





Nuclear collisions of uranium nuclei up to ~ 1 GeV/nucleon

E. M. Friedlander, H. H. Heckman, and Y. J. Karant



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Nuclear Instruments and Methods in Physics Research B 240 (2005) 863–870
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Neutron yields from 1 GeV/nucleon ^{238}U ion beams on Fe target

O. Yordanov, K. Gunzert-Marx, P. Adrich, T. Aumann, K. Bo
H. Emling, G. Fehrenbacher, F. Gutermuth, H. Iwase, H. Joha
K.L. Jones, A. Kovalov, T. Radon *, D. Schardt

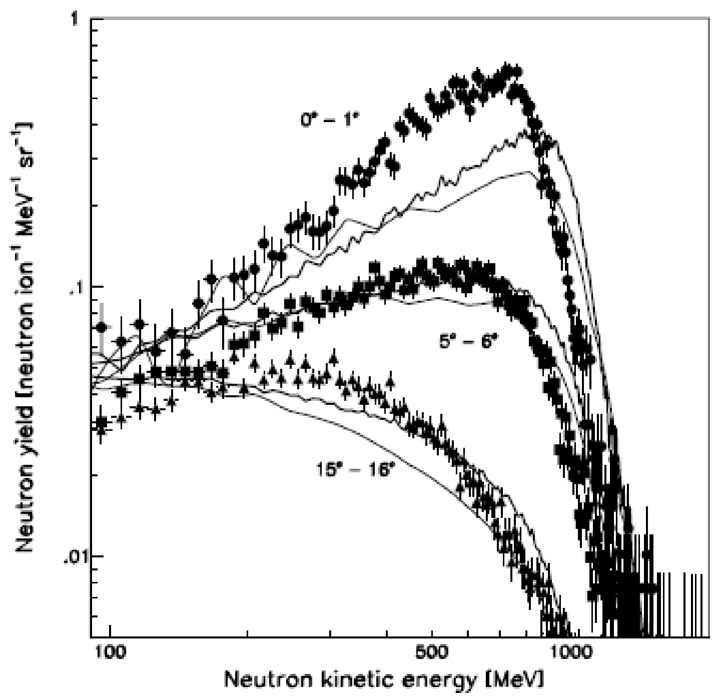


Fig. 3. Neutron yields versus neutron kinetic energy observed for a beam of ^{238}U (1 GeV/nucleon) on a thick Fe target at polar angles as indicated. Symbols denote the experimental data; thick (thin) lines represent results obtained with the FLUKA (PHITS) code.

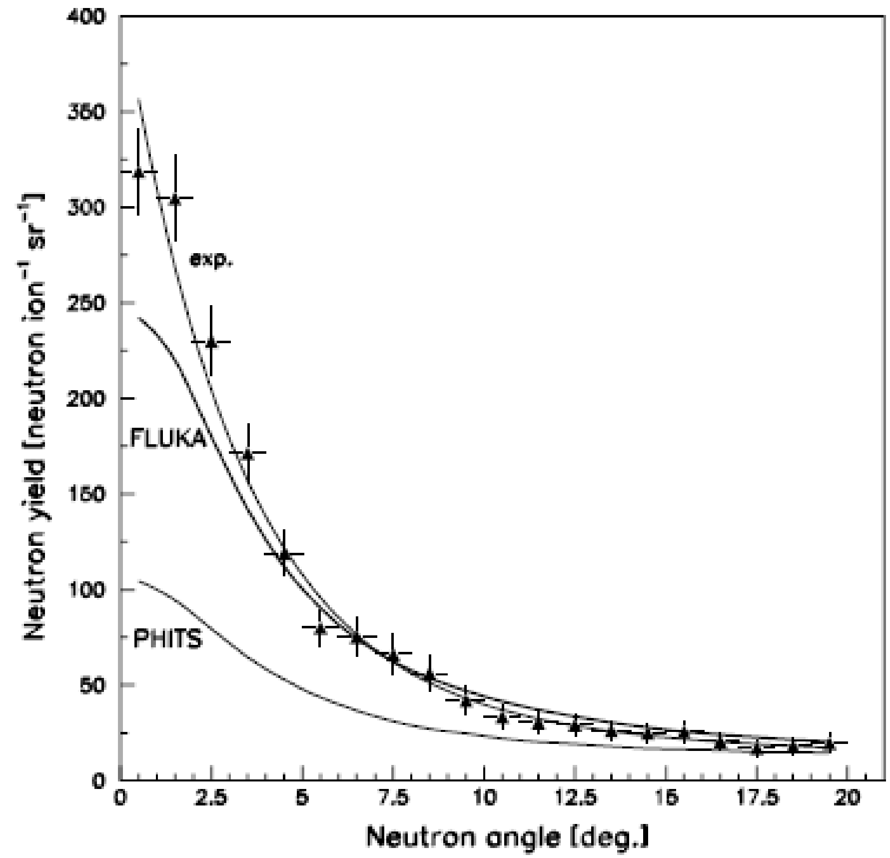
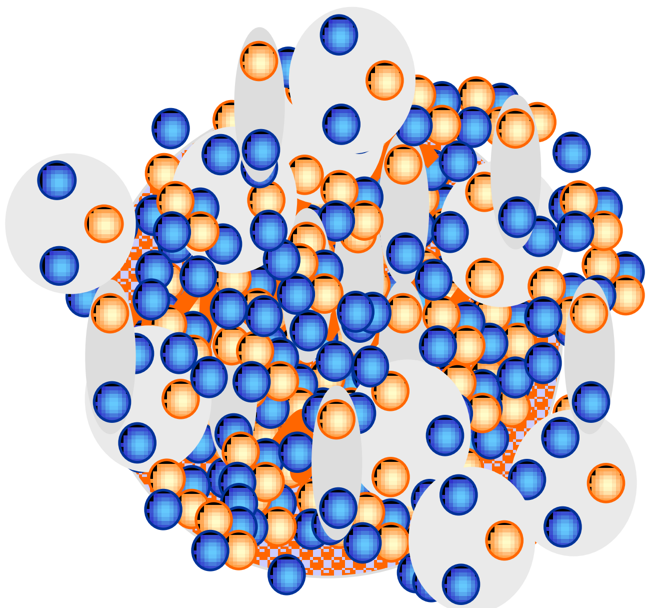
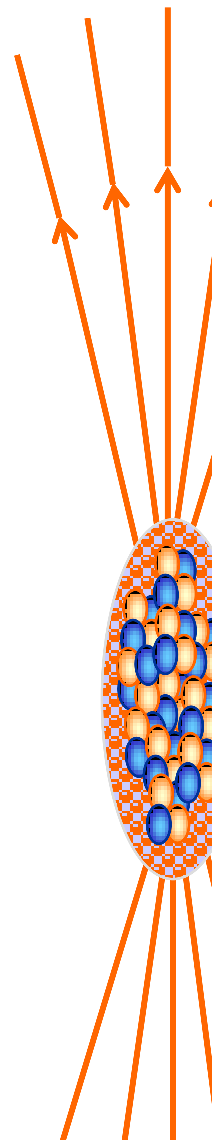
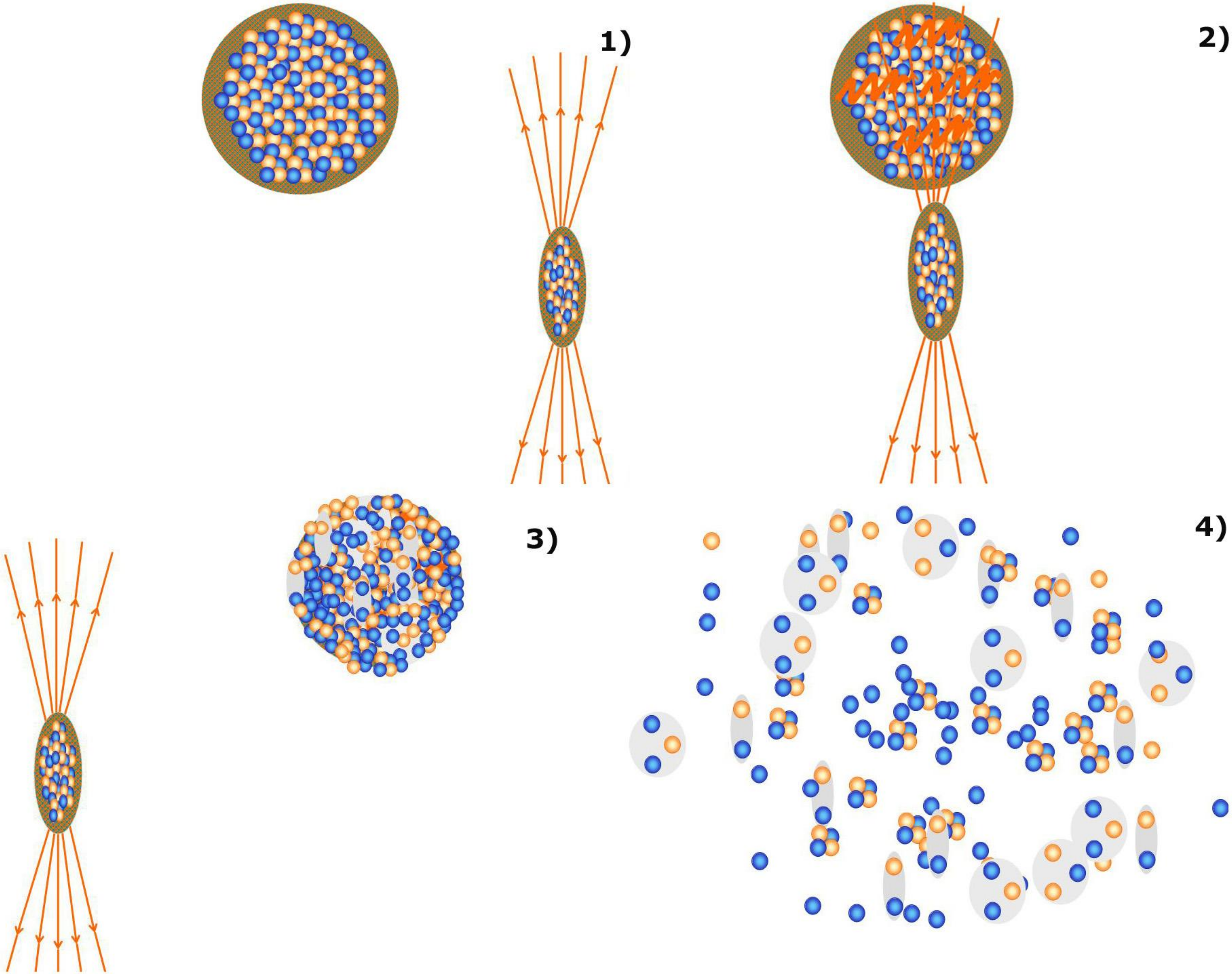


Fig. 4. Angular distribution of neutron yield. Experimental results (symbols) are compared to results from the FLUKA and PHITS codes and an empirical parameterization with the sum of two exponential curves (exp).

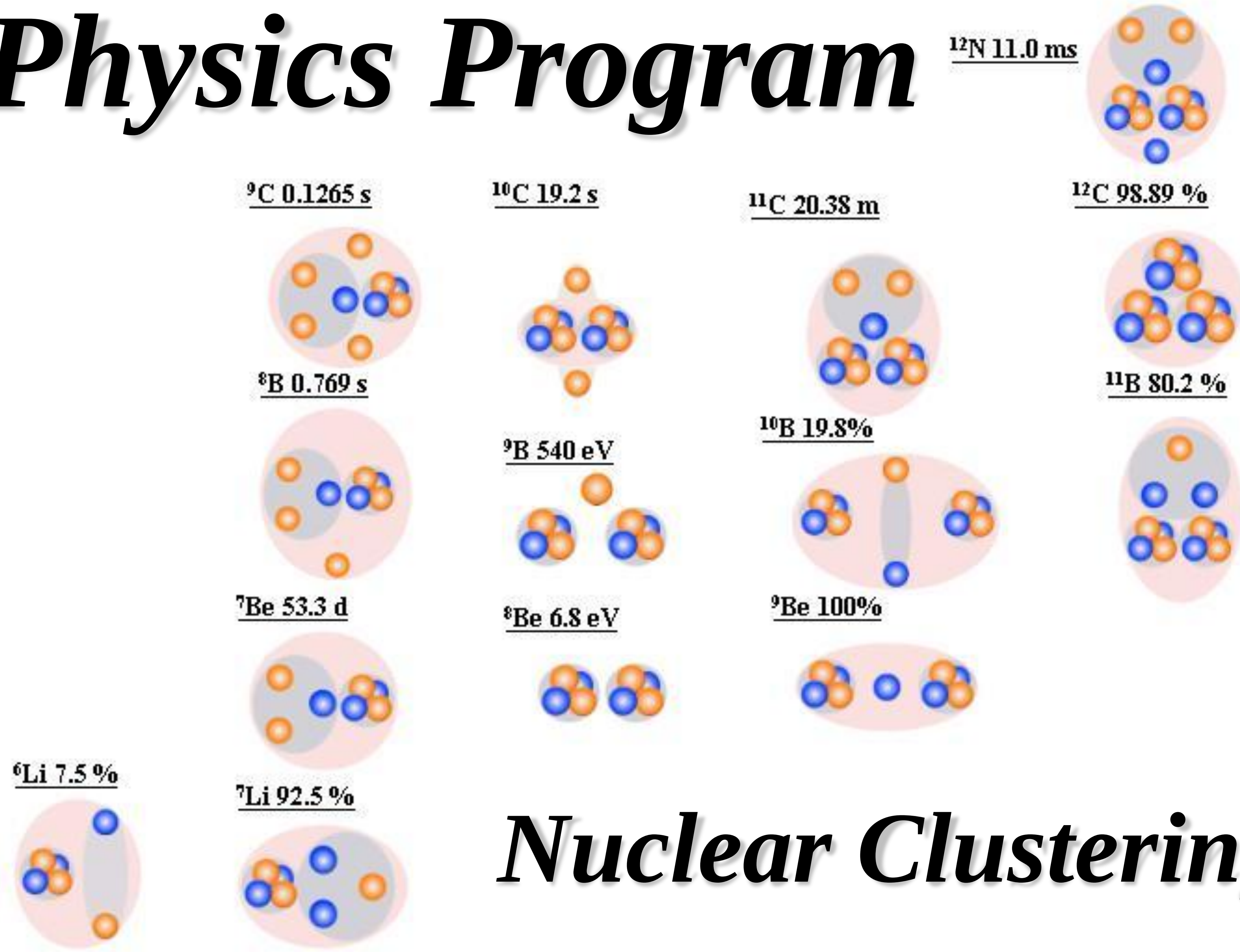

2





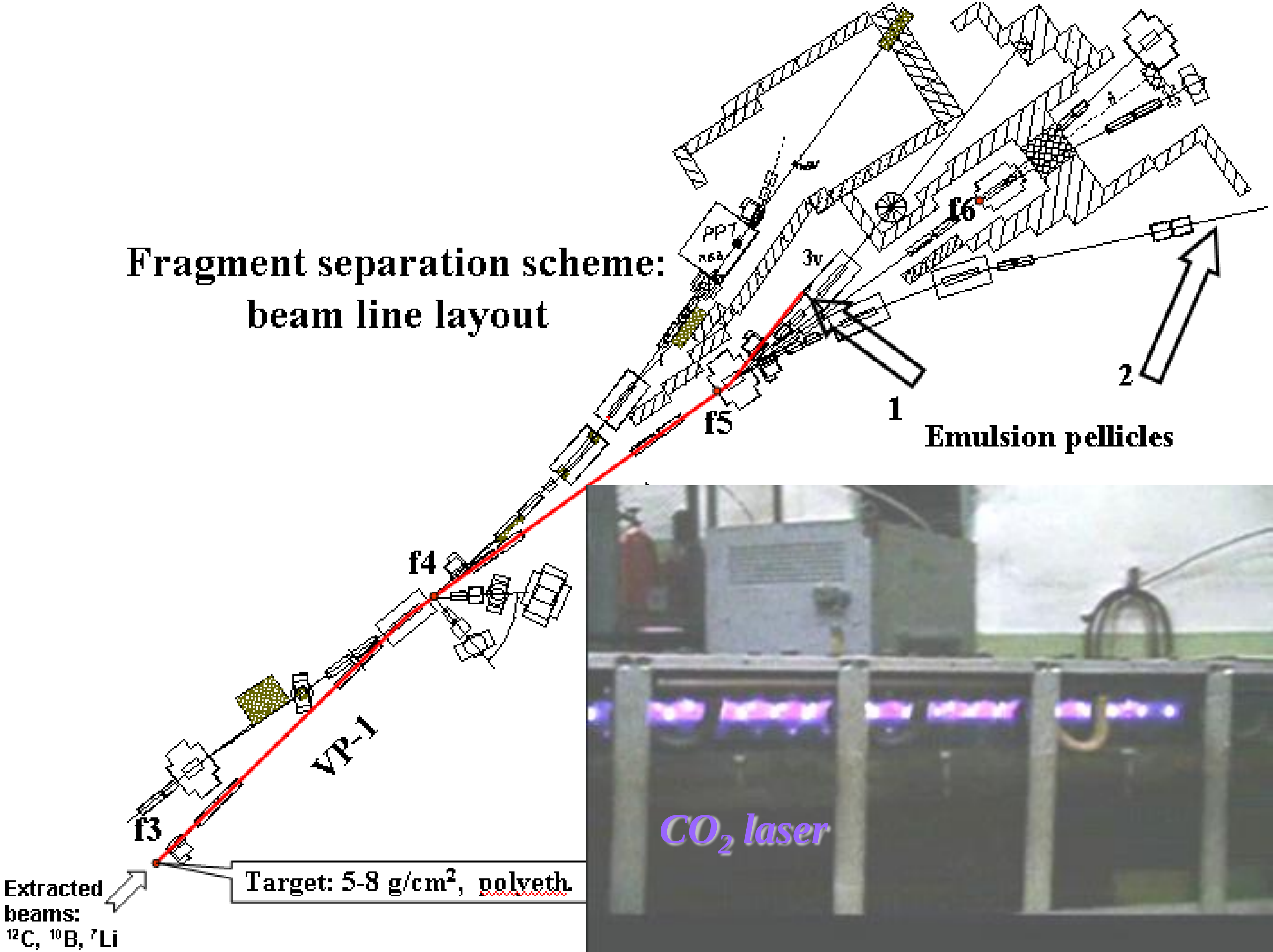

1)
2)
3)
4)

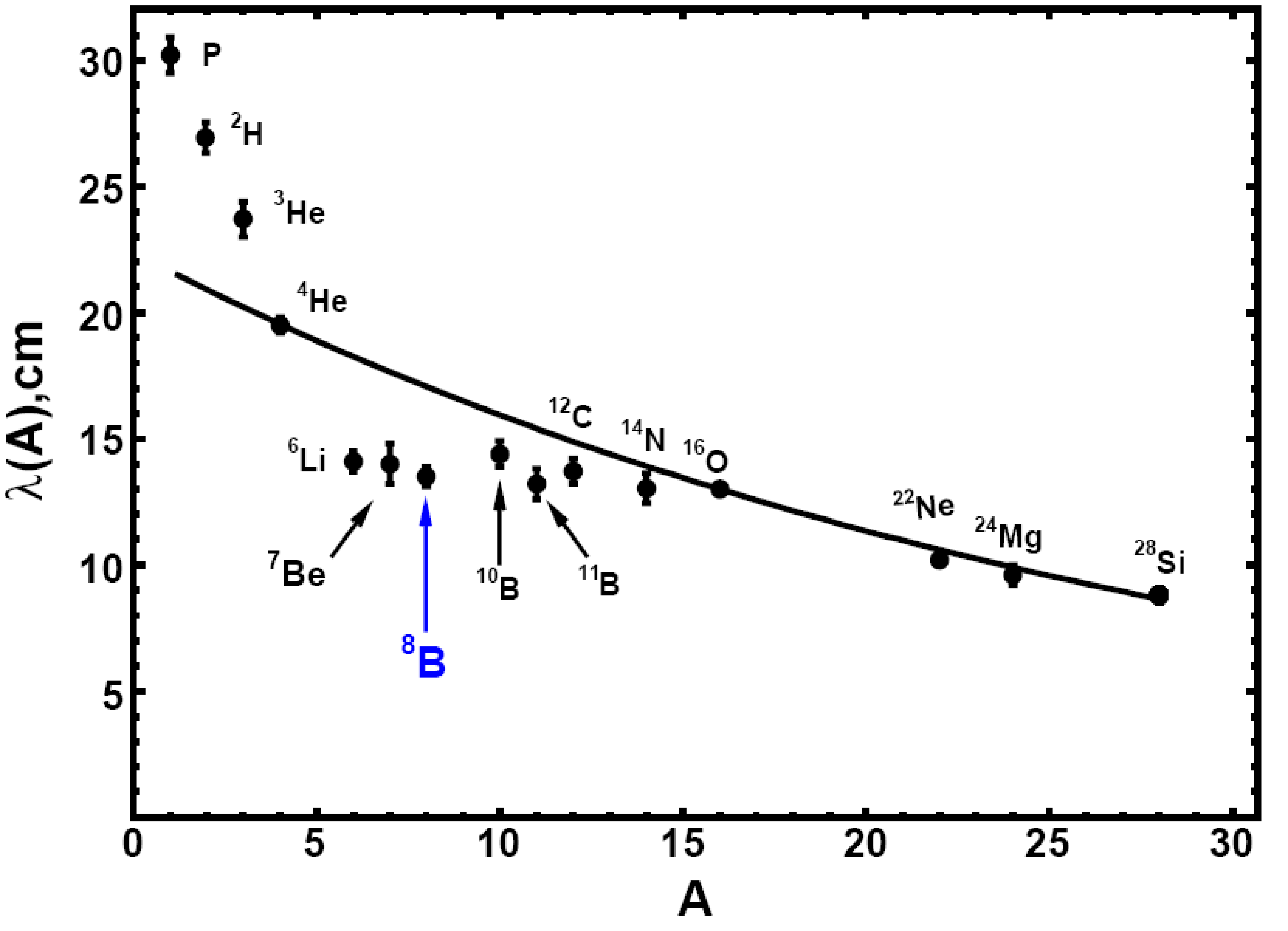
Physics Program



Nuclear Clustering

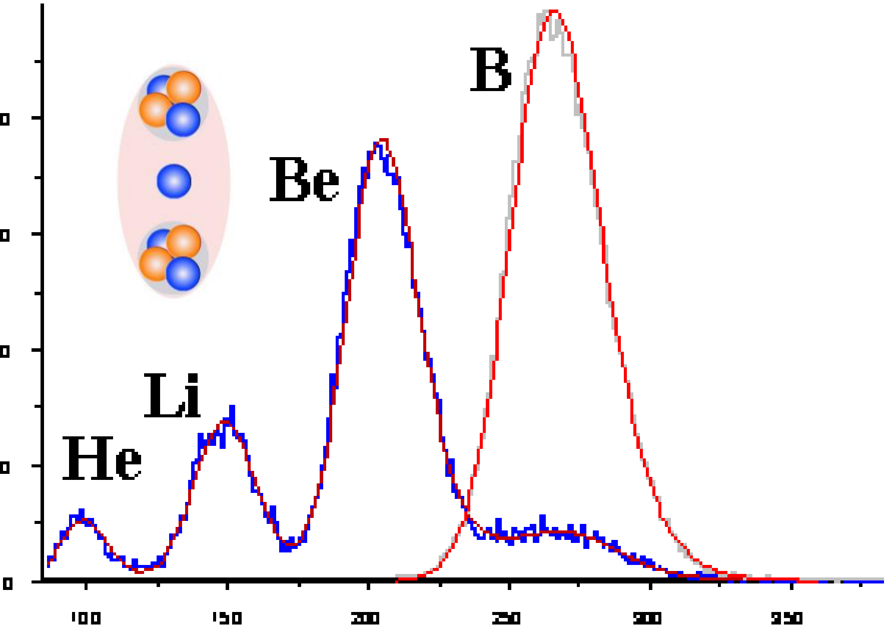
Fragment separation scheme: beam line layout



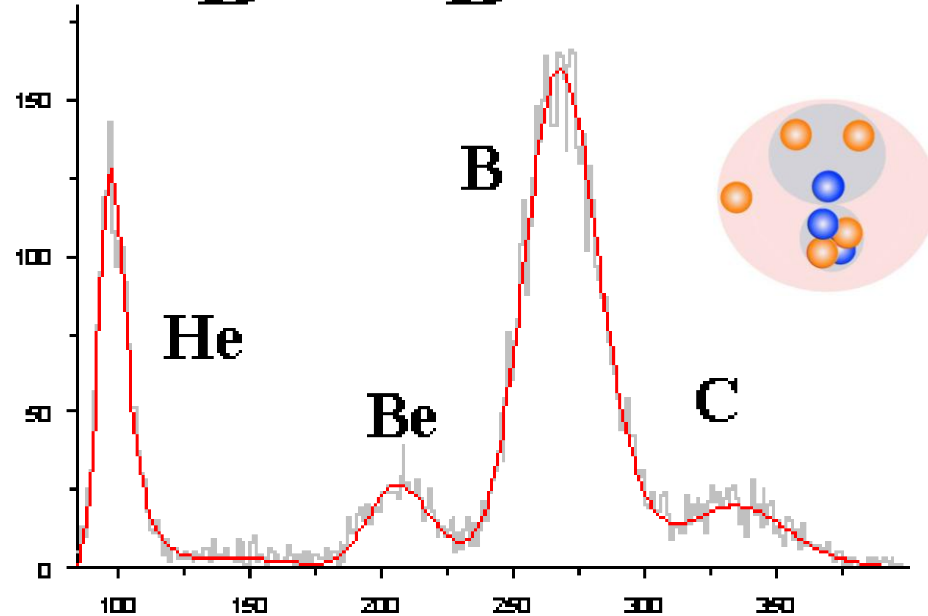


30
25
20
15
10
5
0
5
10
15
20
25
30
λ(A),cm
A
P
2H
3He
4He
6Li
7Be
8B
10B
11B
12C
14N
16O
22Ne
24Mg
28Si

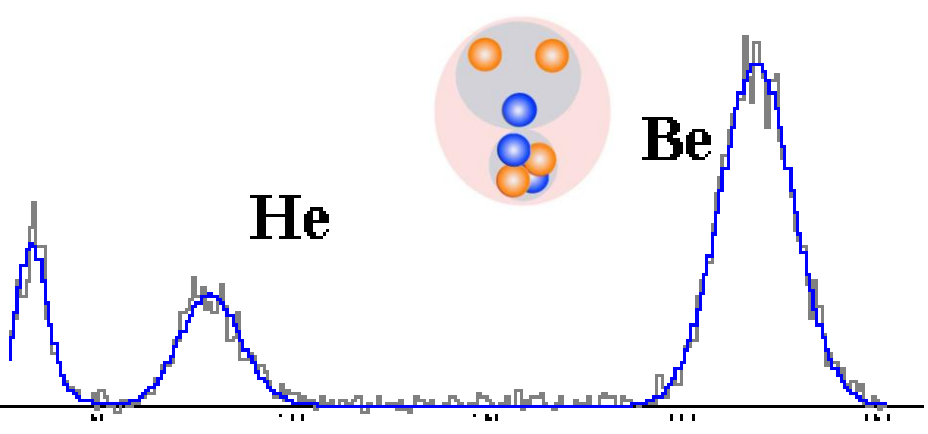
$^{10}B \rightarrow {}^{9}Be$



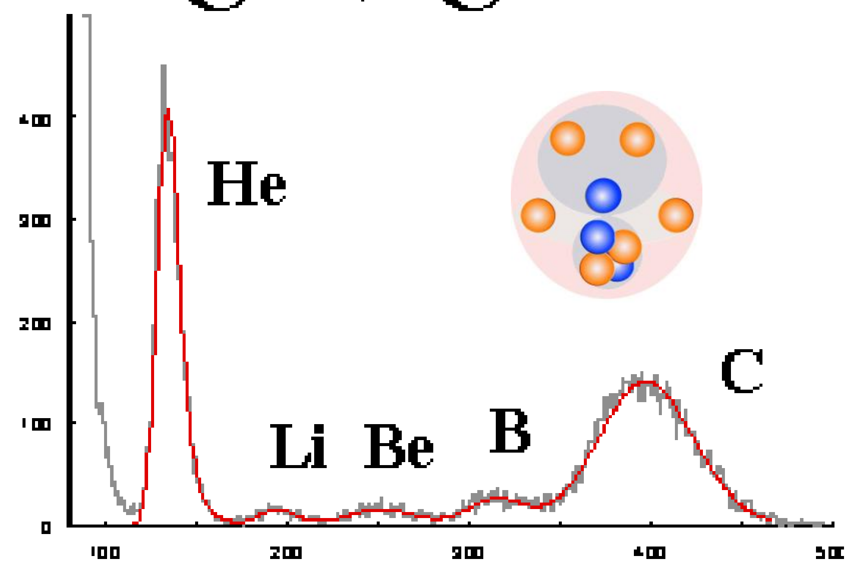
$^{10}B \rightarrow {}^{8}B$

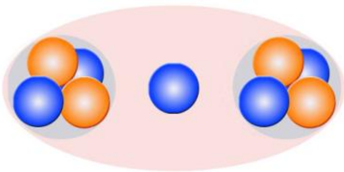


$^{7}Li \rightarrow {}^{7}Be$



$^{12}C \rightarrow {}^{9}C$

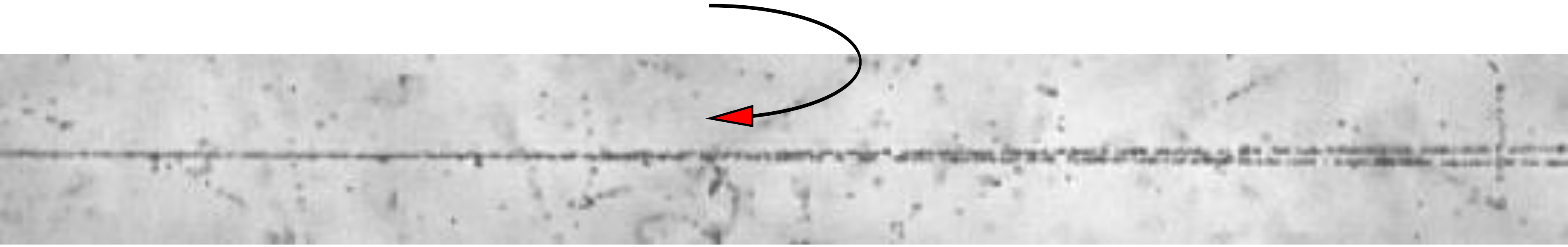




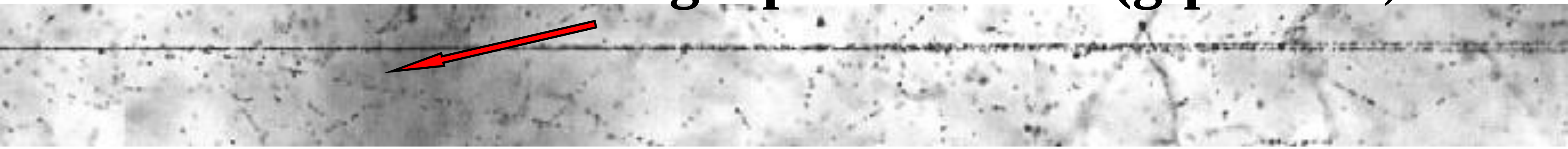
370 events 1.2 A GeV $^{9}Be \rightarrow 2He$

+1.7 MeV

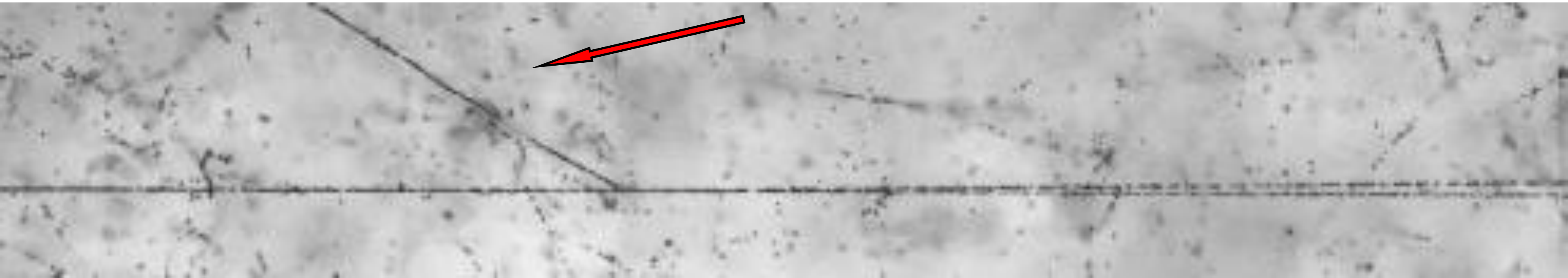
144 “white” stars

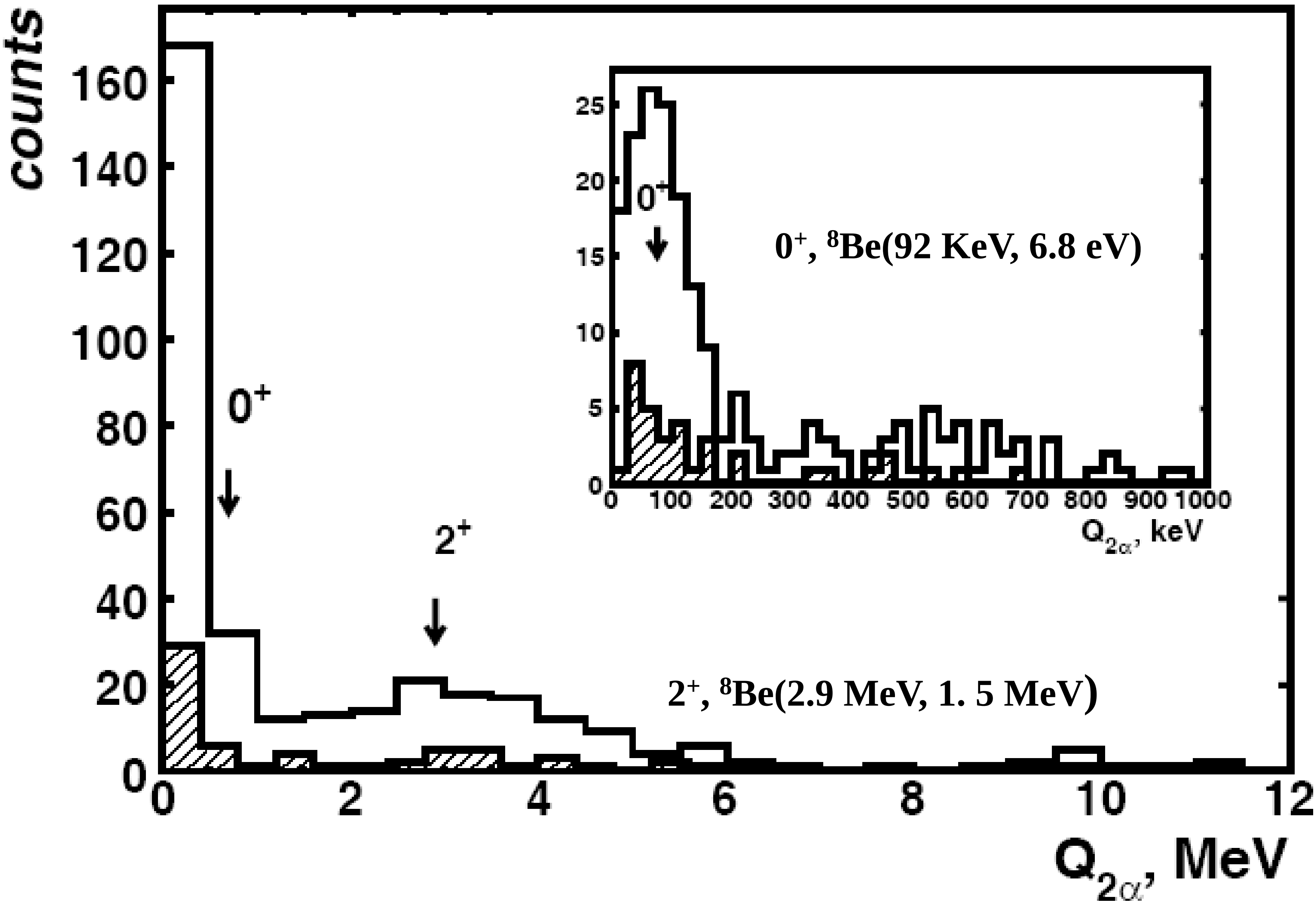


27 stars with target proton recoil (g-particle)



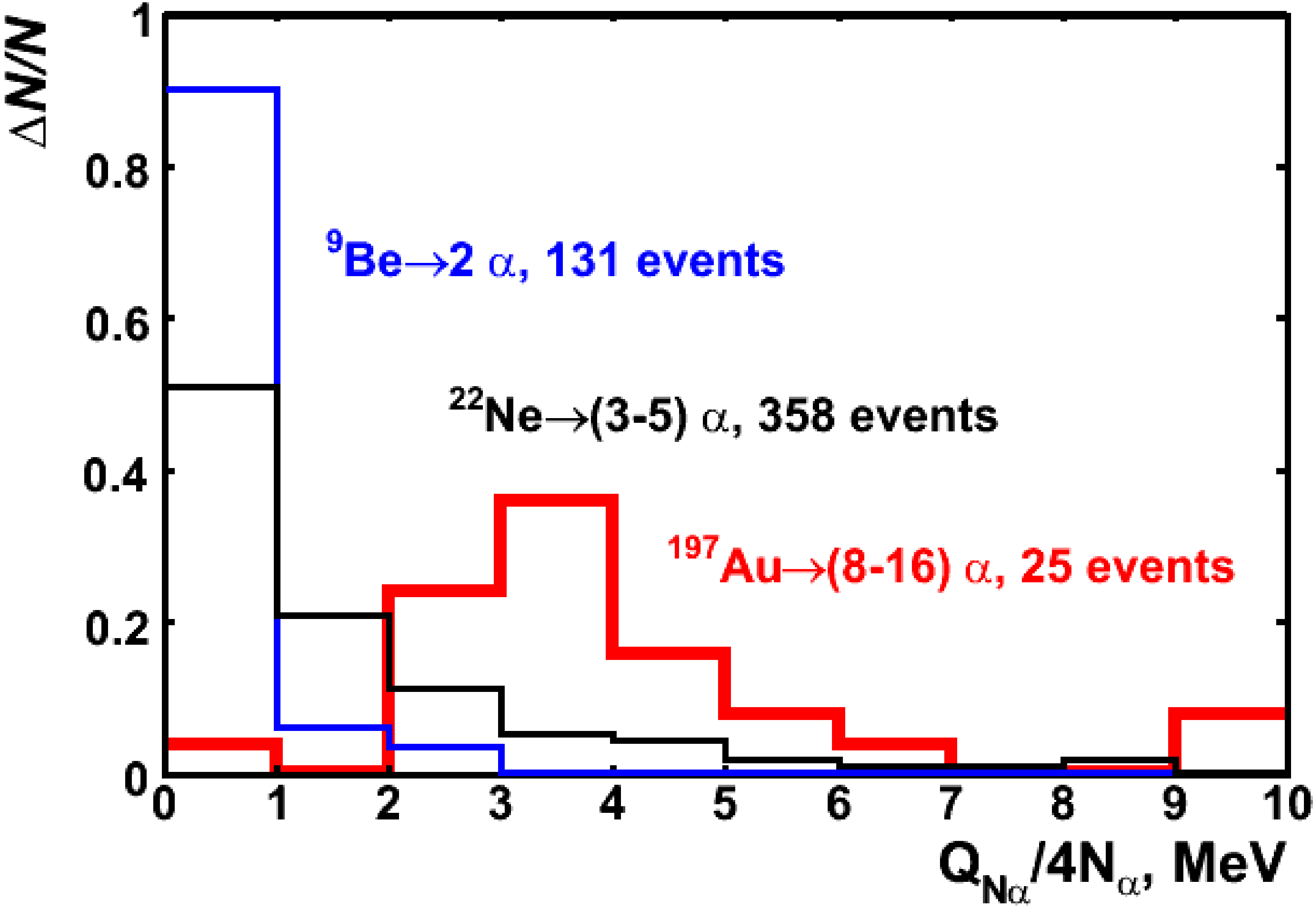
39 stars with heavy fragment of target nucleus (b-particle)

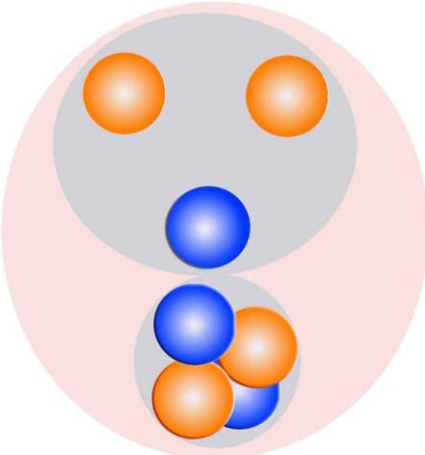


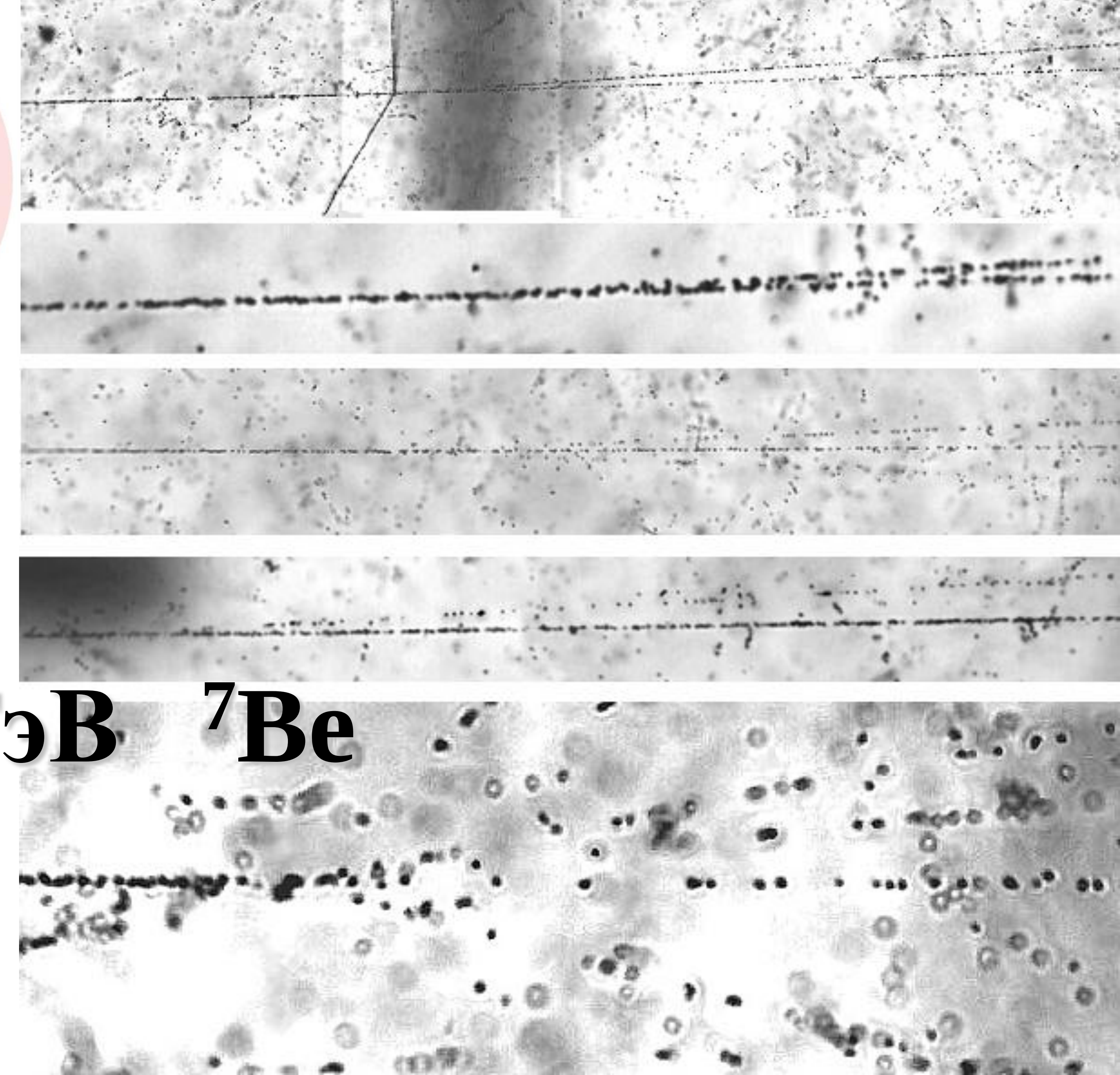


counts
0⁺
2⁺
0⁺, ⁸Be(92 KeV, 6.8 eV)
2⁺, ⁸Be(2.9 MeV, 1. 5 MeV)
Q2α, keV
Q2α, MeV

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



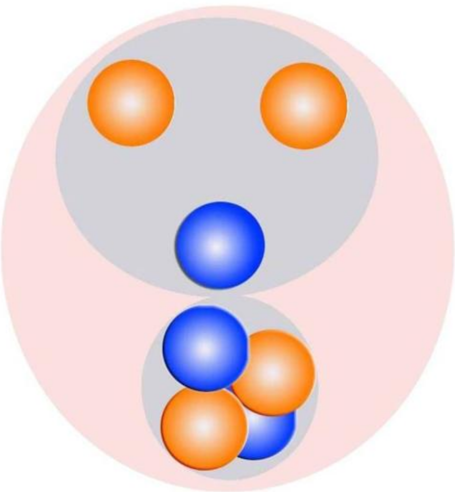




1.2A ГэВ ^{7}Be

TABLE III: ^{7}Be fragmentation channel (number of events)

MeV	Channel	2He	2He	He+2H	He+2H	4H	4H	Li+H	Li+H	Sum
		$n_b=0$	$n_b>0$	$n_b=0$	$n_b>0$	$n_b=0$	$n_b>0$	$n_b=0$	$n_b>0$	
1.6	^{3}He+^{4}He	30	11							41
	^{3}He+^{3}He	11	7							18
	^{4}He+2p			13	9					22
6.9	^{4}He+d+p			10	5					15
	^{3}He+2p			9	9					18
	^{3}He+d+p			8	10					18
25.3	^{3}He+2d			1						1
21.2	^{3}He+t+p			1						1
	3p+d					2				2
	2p+2d					1				1
5.6	^{6}Li+p							9	3	12
	Sum	41	18	42	33	2	1	9	3	149



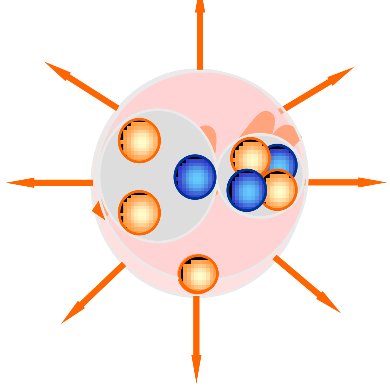
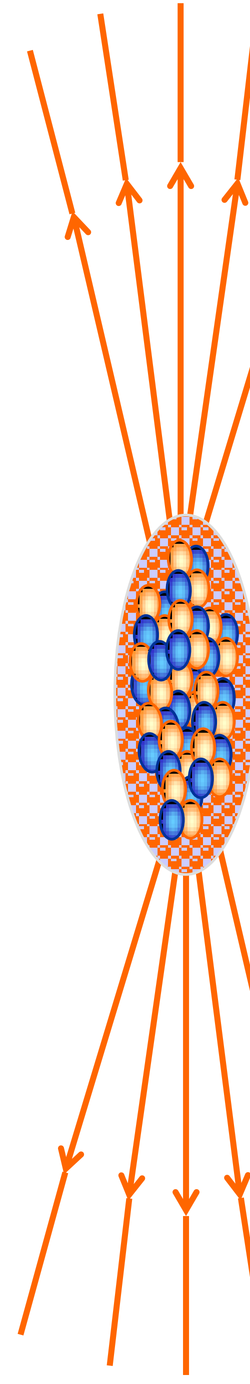
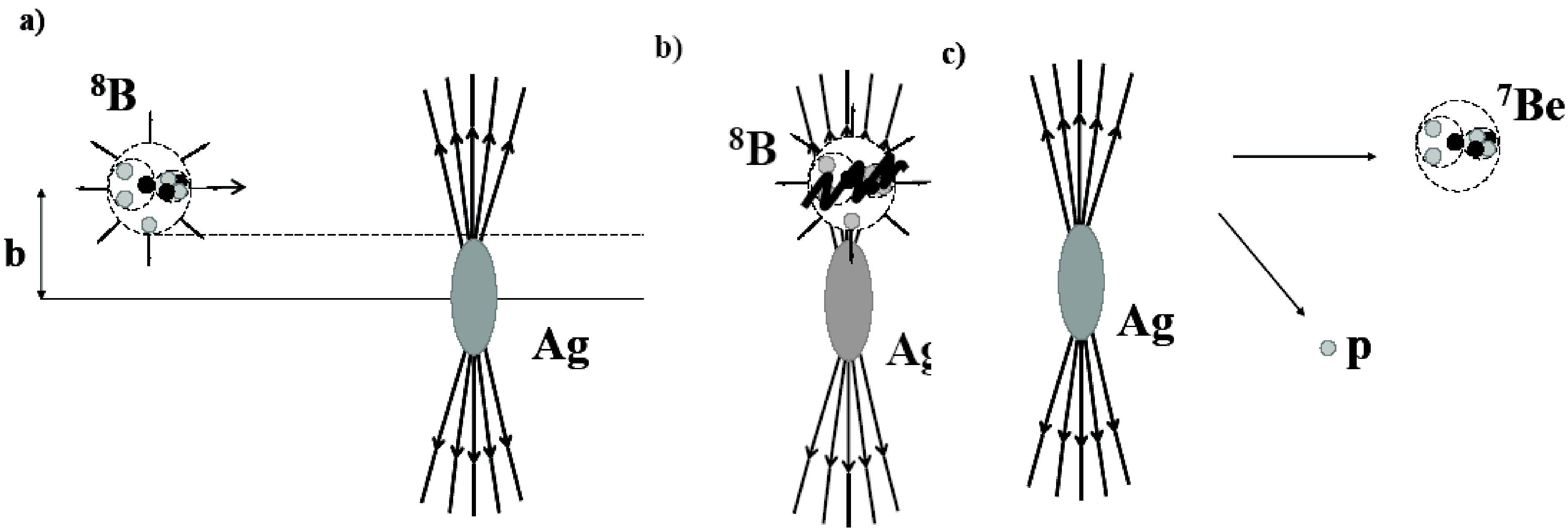



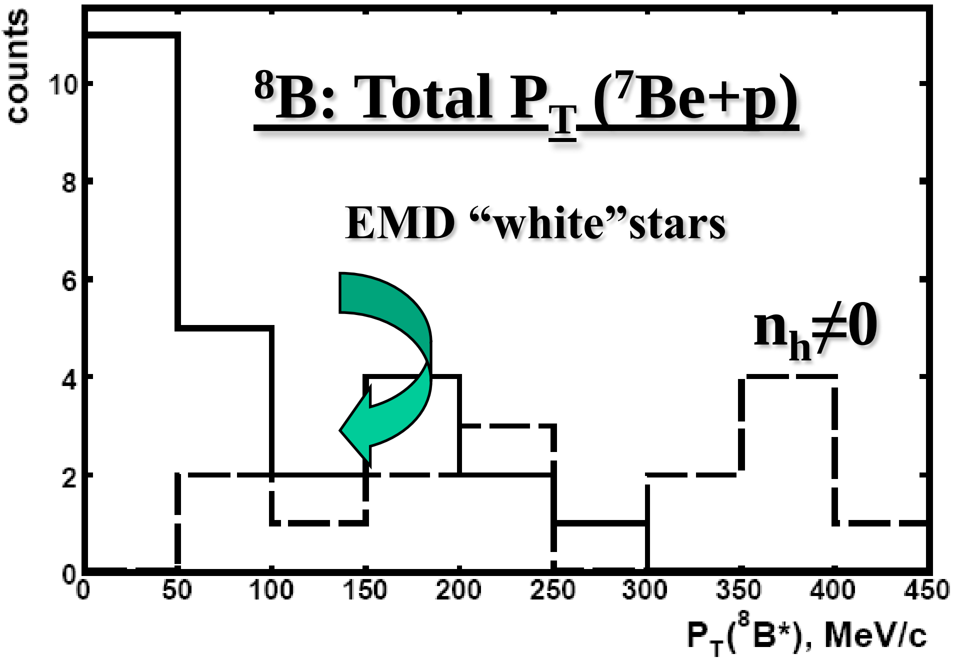
Diagram of peripheral dissociation of relativistic ^{8}B nucleus in EM field of Ag nucleus



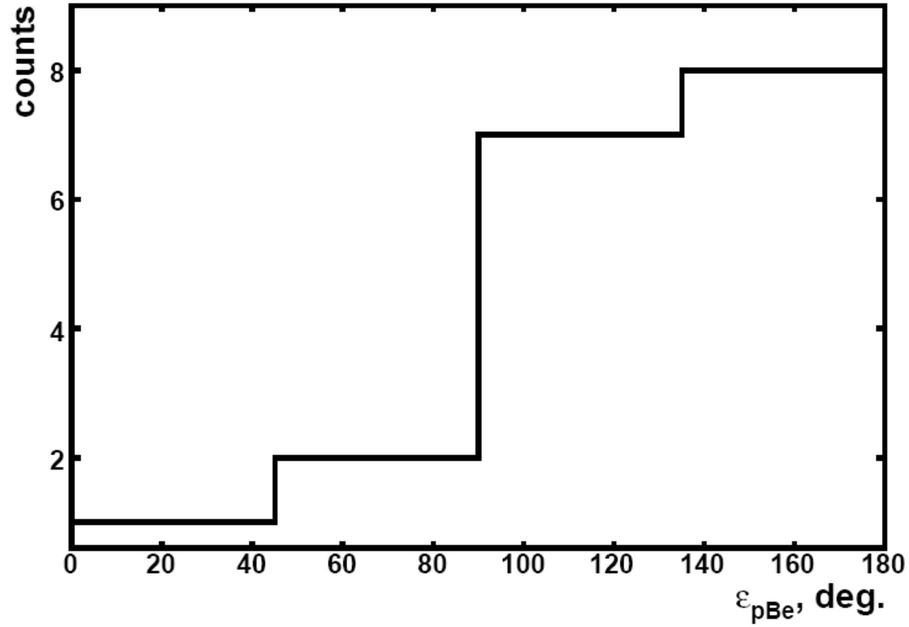
Nearer approach of the nuclei with an impact parameter (a), absorption of quasireal photon by ^{8}B nucleus (b), ^{8}B dissociation on fragment pair - p and ^{7}Be (c).

^{8}B (1.2 A GeV) → ^{7}Be + p

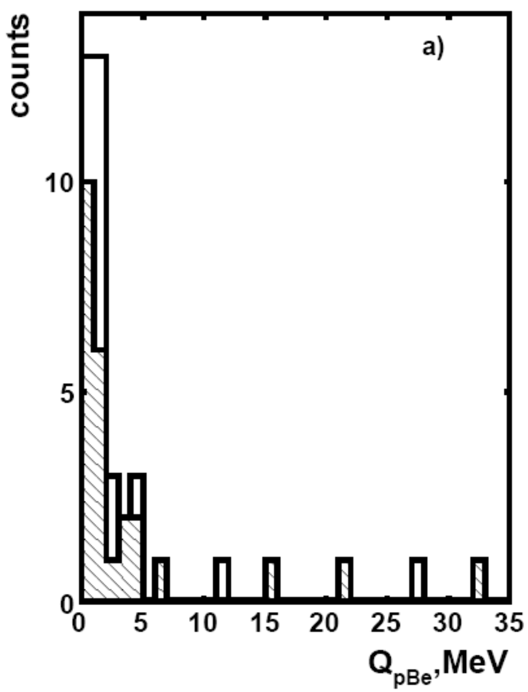
	Q_{min} (^{10}B), МэВ	N_{ws} (^{10}B)	% (^{10}B)	Q_{min} (^{8}B), МэВ	N_{ws} (^{8}B)	% (^{8}B)
2He+H	6.0	30	73	1.724	14	27
He+3H	25	5	12	8.6	12	23
Be+H	6.6	1	2	0.138	25	48
B		-	-		1	2
Li+He	4.5	5	13	3.7	-	-



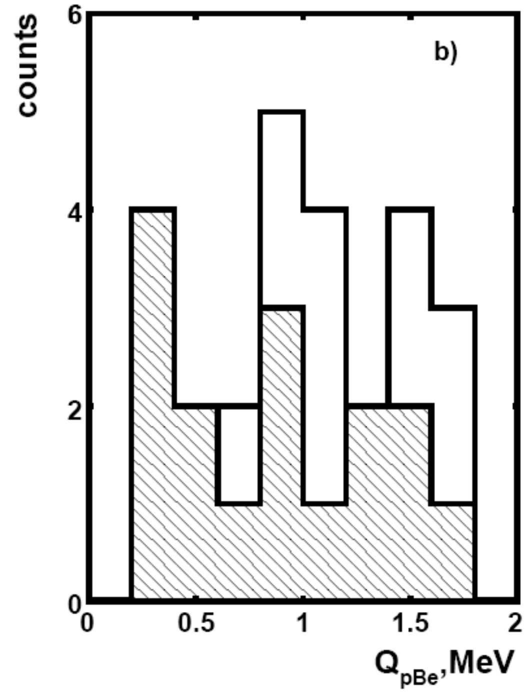
⁸B: Total P_T (⁷Be+p)
EMD “white”stars
n_h≠0
counts
0
2
4
6
8
10
0
50
100
150
200
250
300
350
400
450
P_T(⁸B*), MeV/c



counts
2
4
6
8
0
20
40
60
80
100
120
140
160
180
ε_pBe, deg.

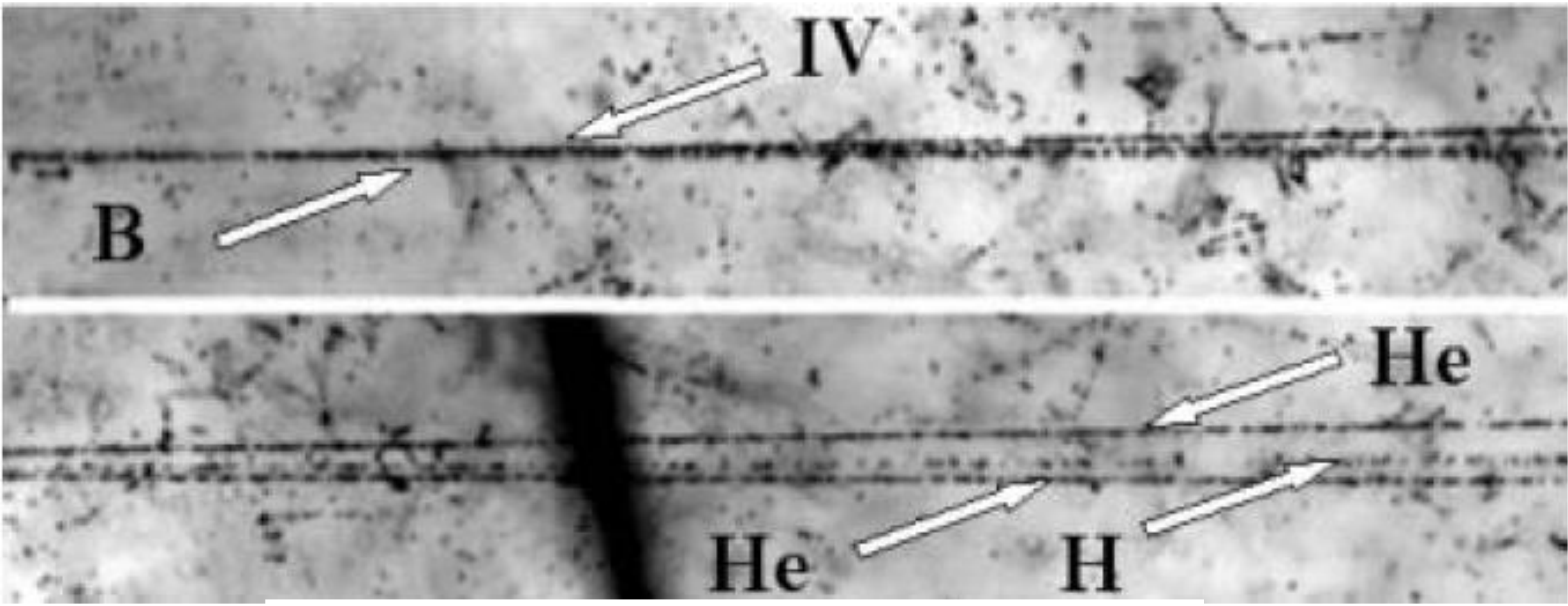


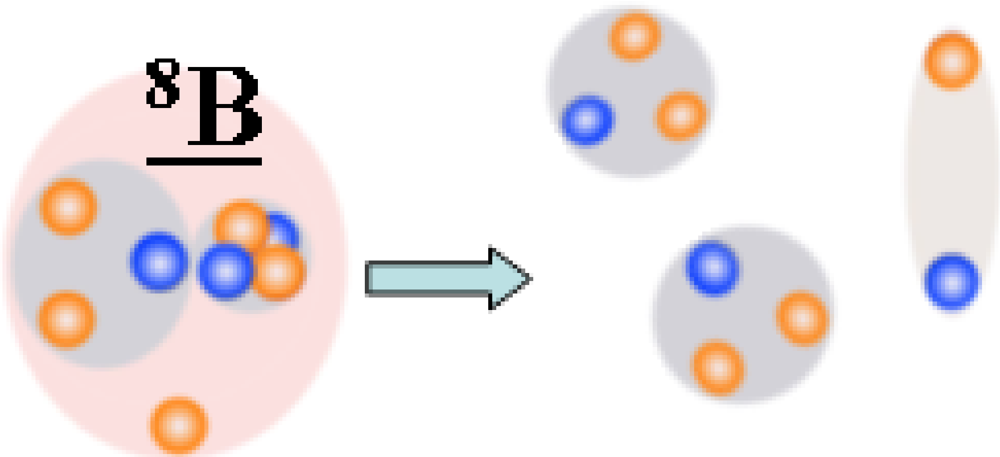
a)
counts
0
5
10
0
5
10
15
20
25
30
35
Q_pBe,MeV



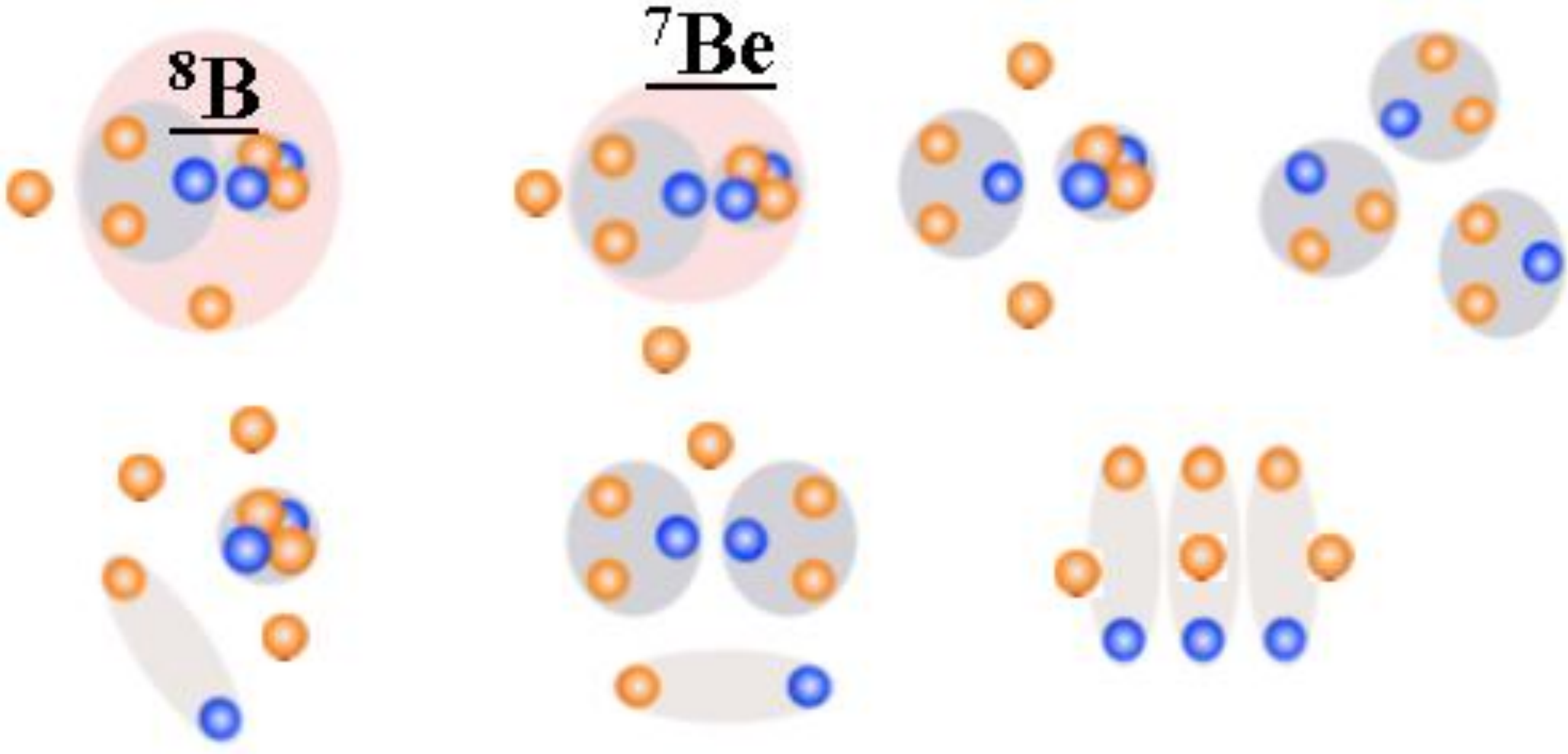
b)
counts
0
2
4
6
0
0.5
1
1.5
2
Q_pBe,MeV

^{8}B (1.2A GeV) → 2He + H

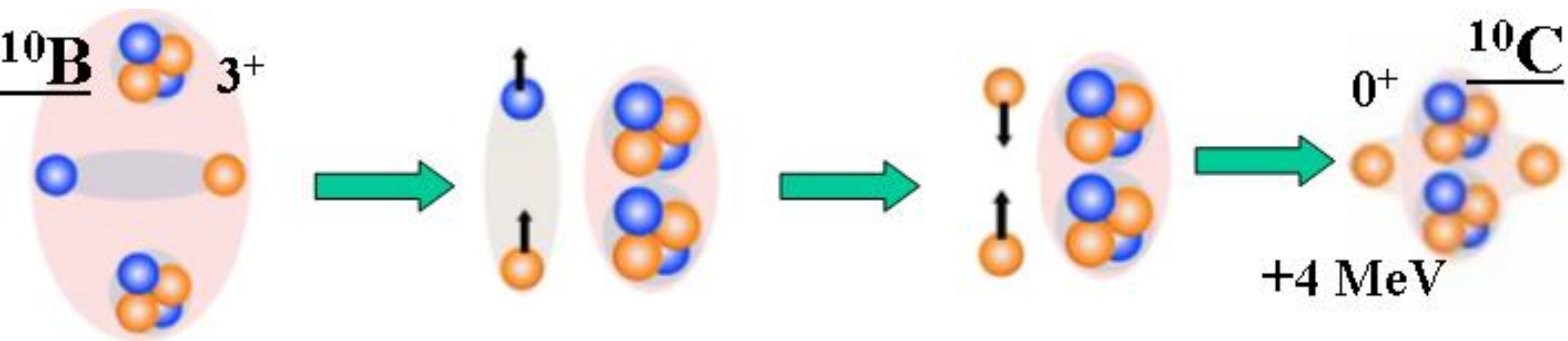




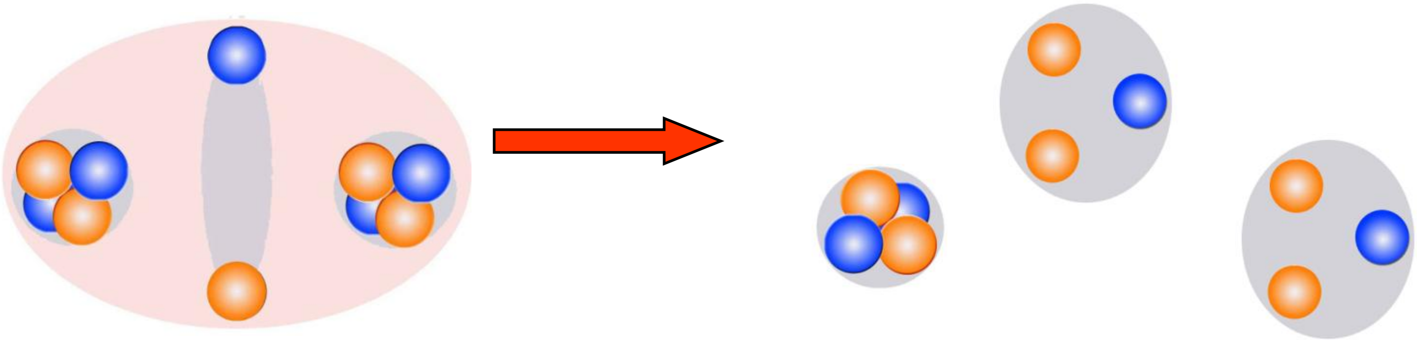
Major task:
analysis of ^9C exposure



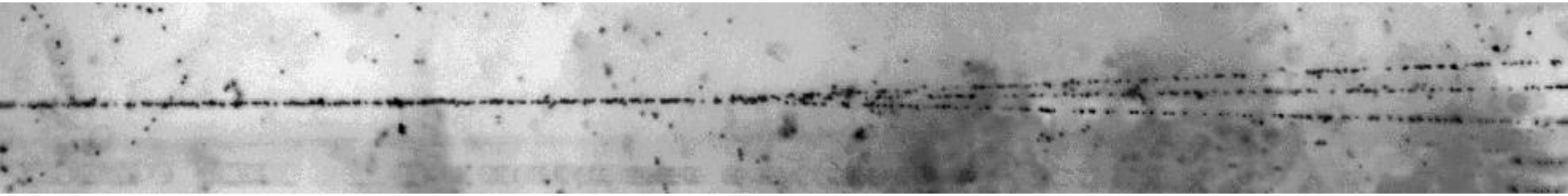
Облучение эмульсии ядрами ^{10}C

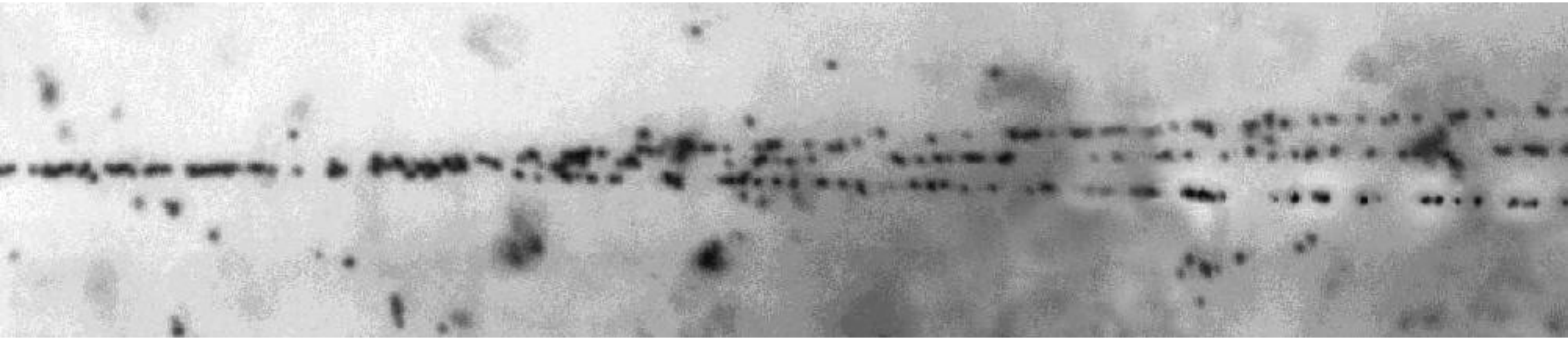


N_z					N_{ws}	N_{tf}
5	4	3	2	1		
-	-	-	1	5	-	1
-	-	-	2	3	1	-
-	-	-	2	2	3	5
-	-	-	1	4	-	10
-	-	-	-	6	-	2
-	-	-	2	1	-	5

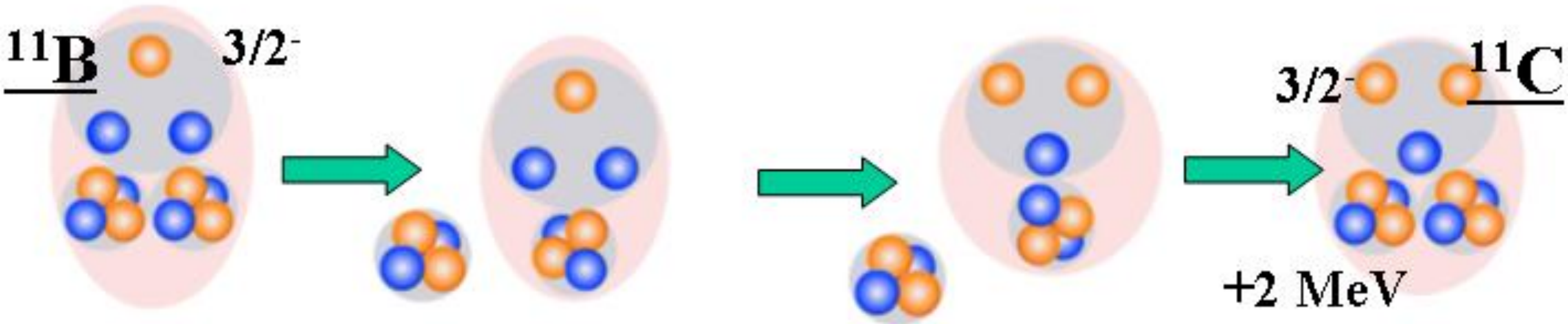


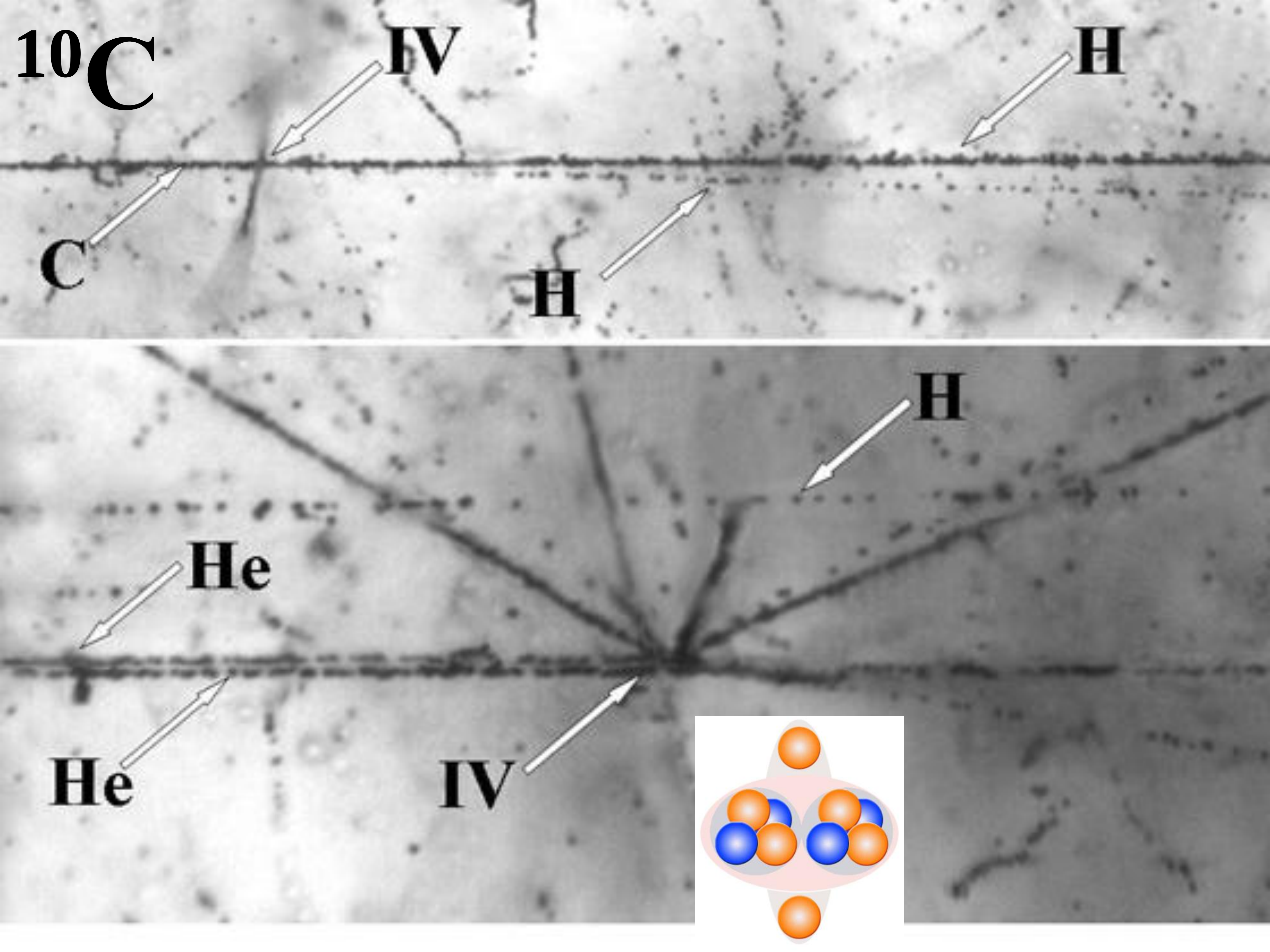
1.0 A ГэВ $^{10}B \rightarrow 2\,^{3}He + ^{4}He$



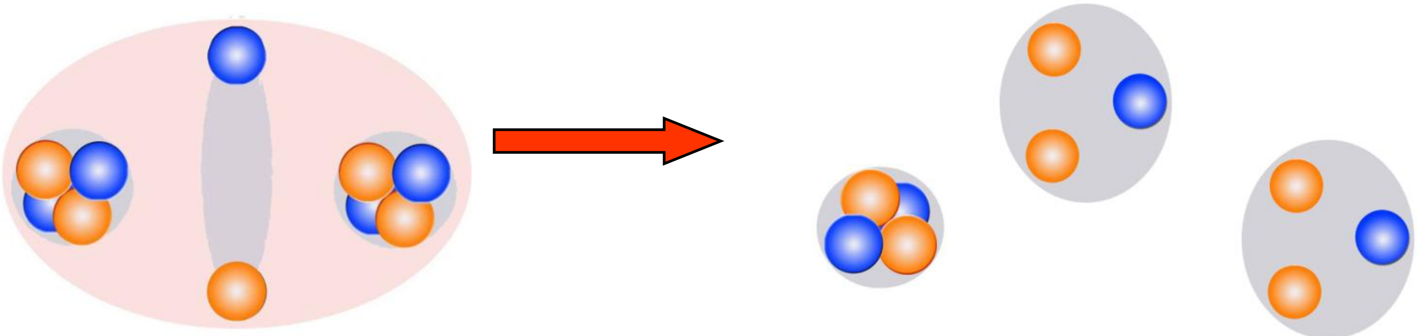


Облучение эмульсии ядрами ^{11}C

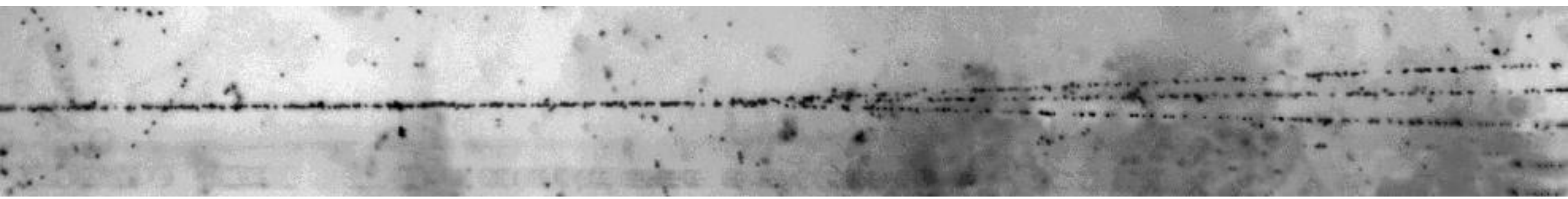




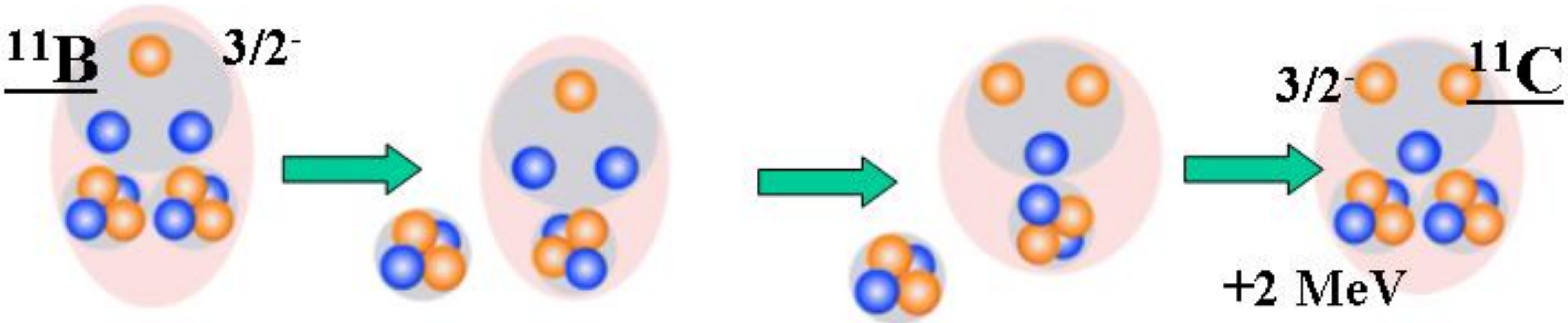
^{10}C
IV
H
C
H
H
He
He
IV



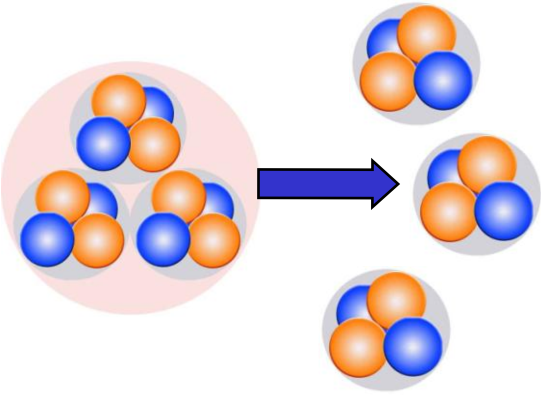
1.0 A ГэВ $^{10}B \rightarrow 2\,^{3}He + ^{4}He$

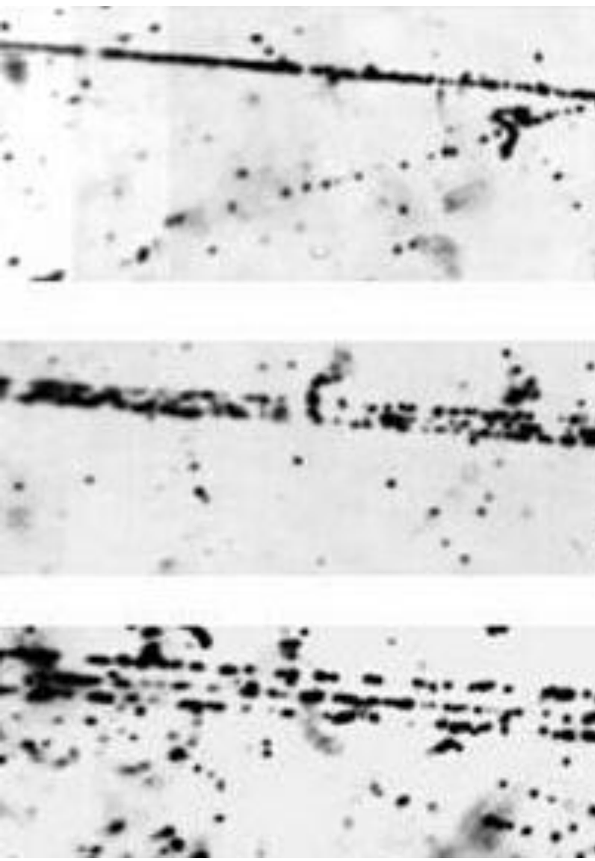


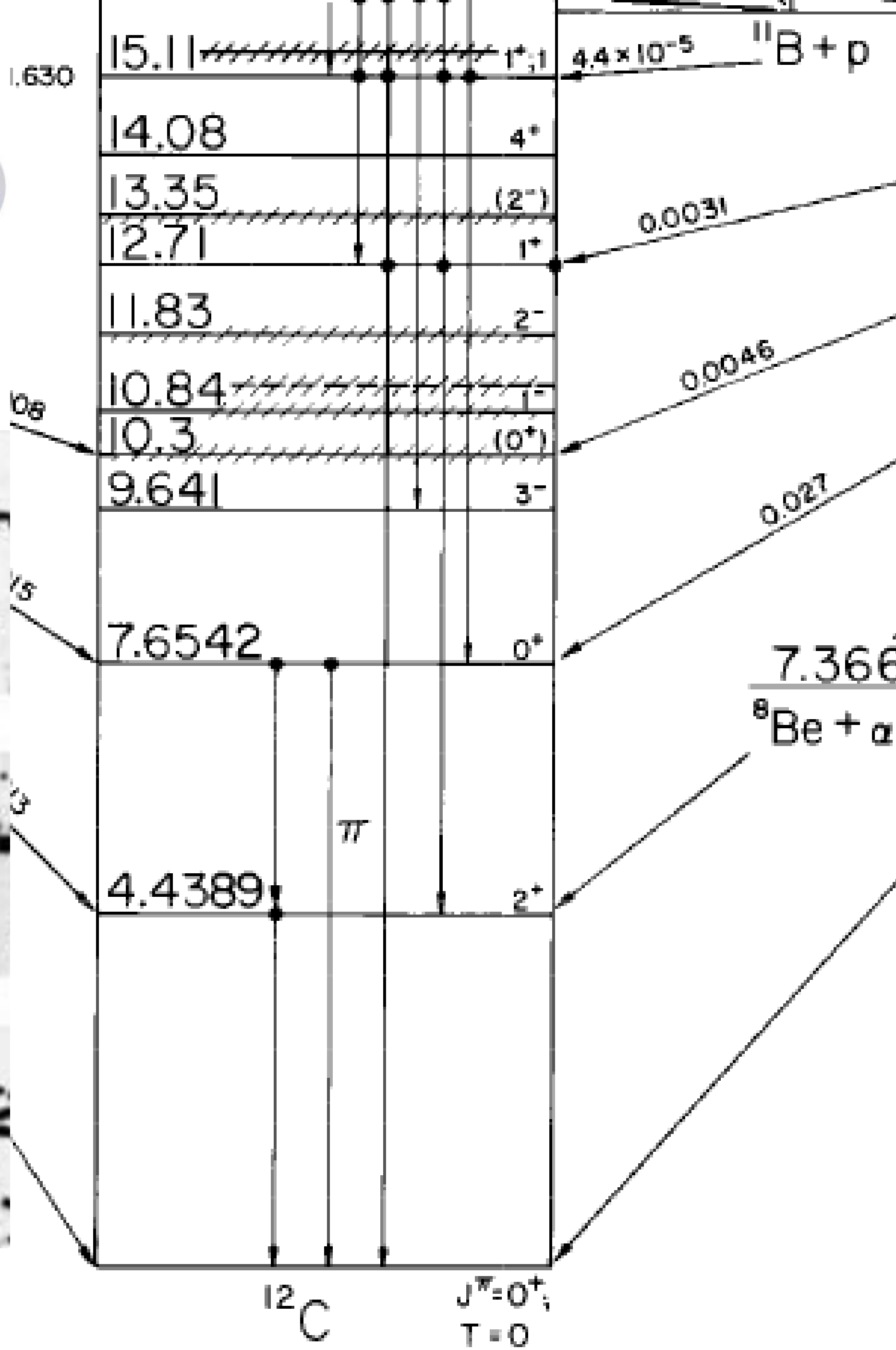
Suggested ^{11}C exposure

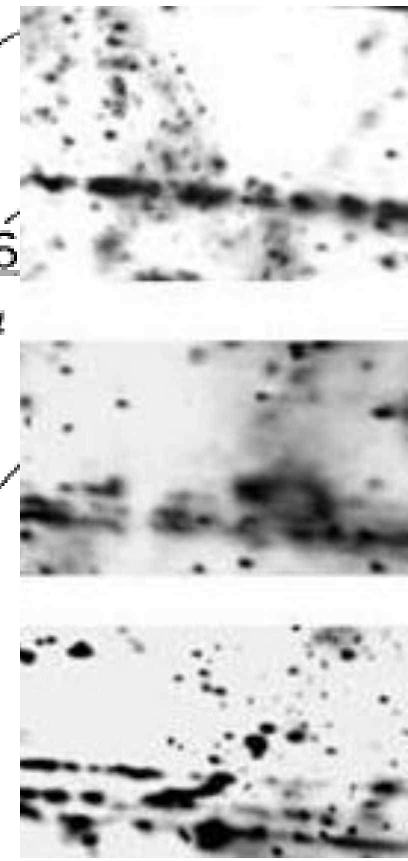


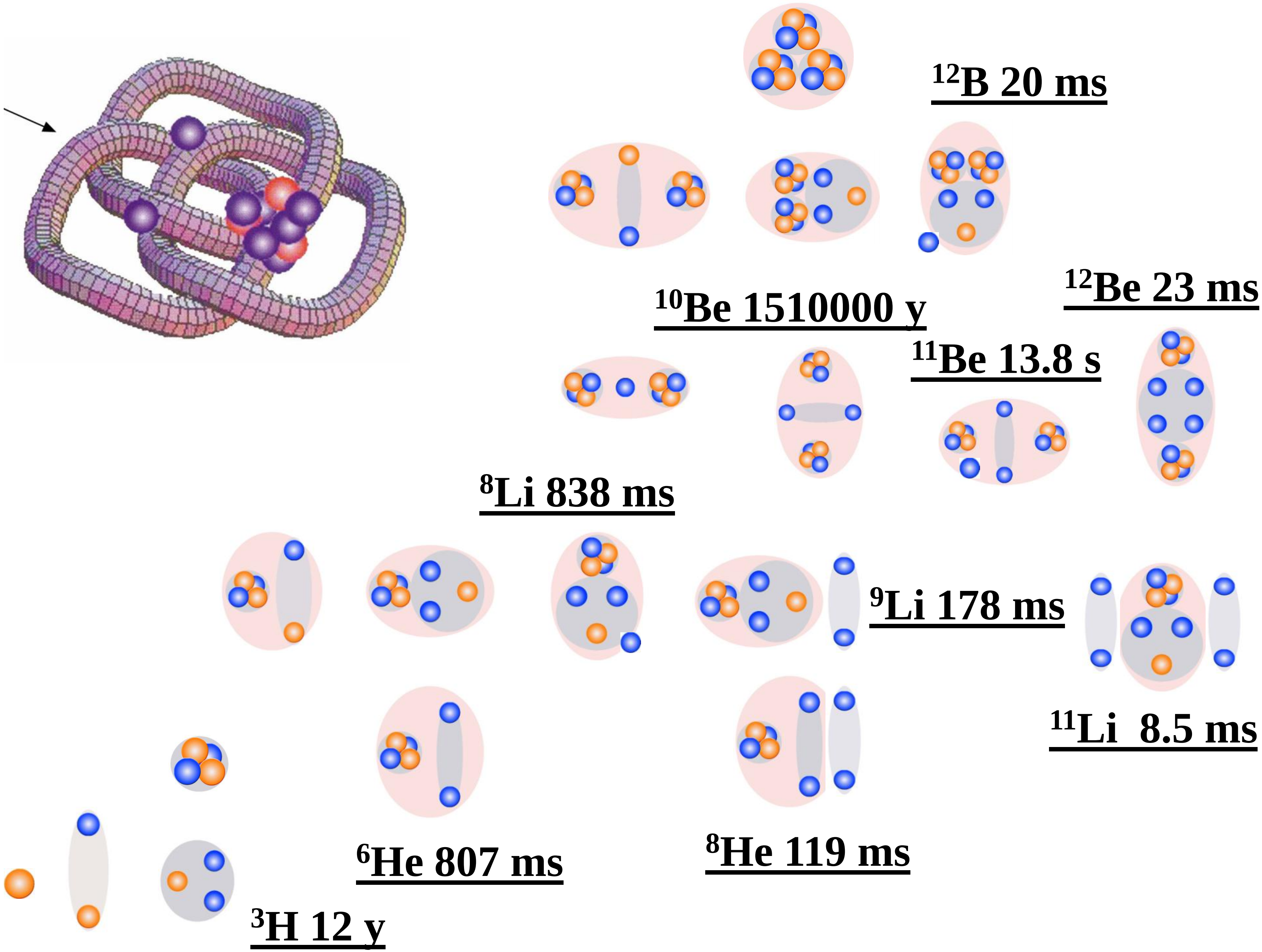
$^{12}C \to 3\alpha$



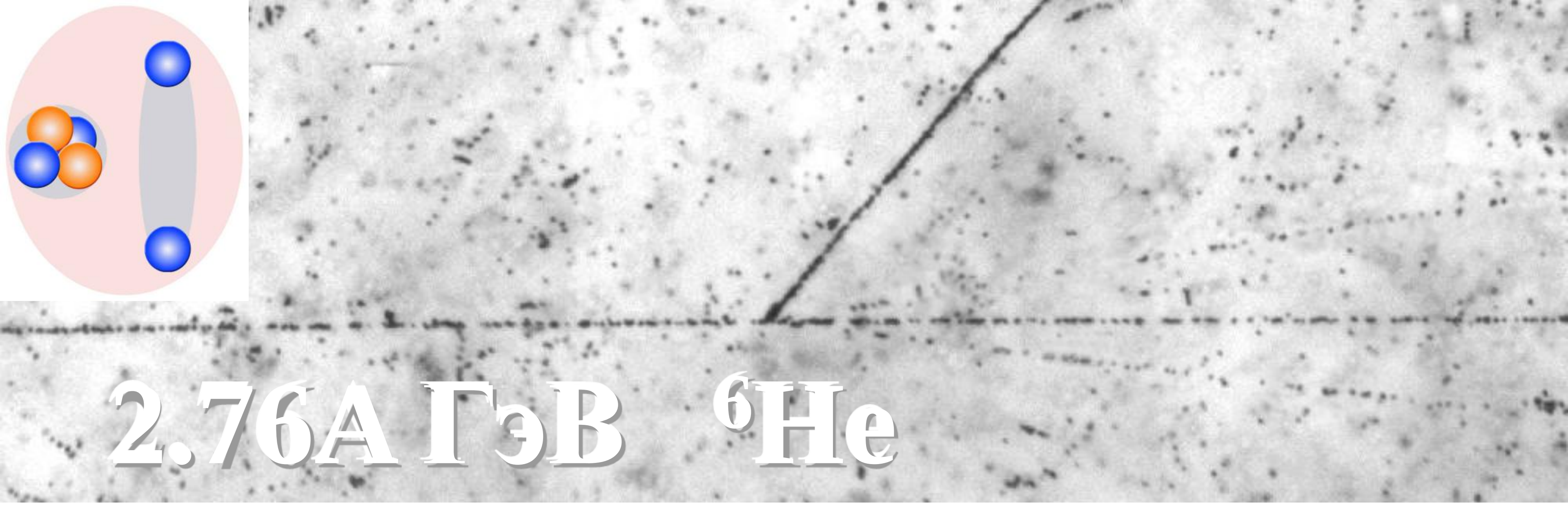




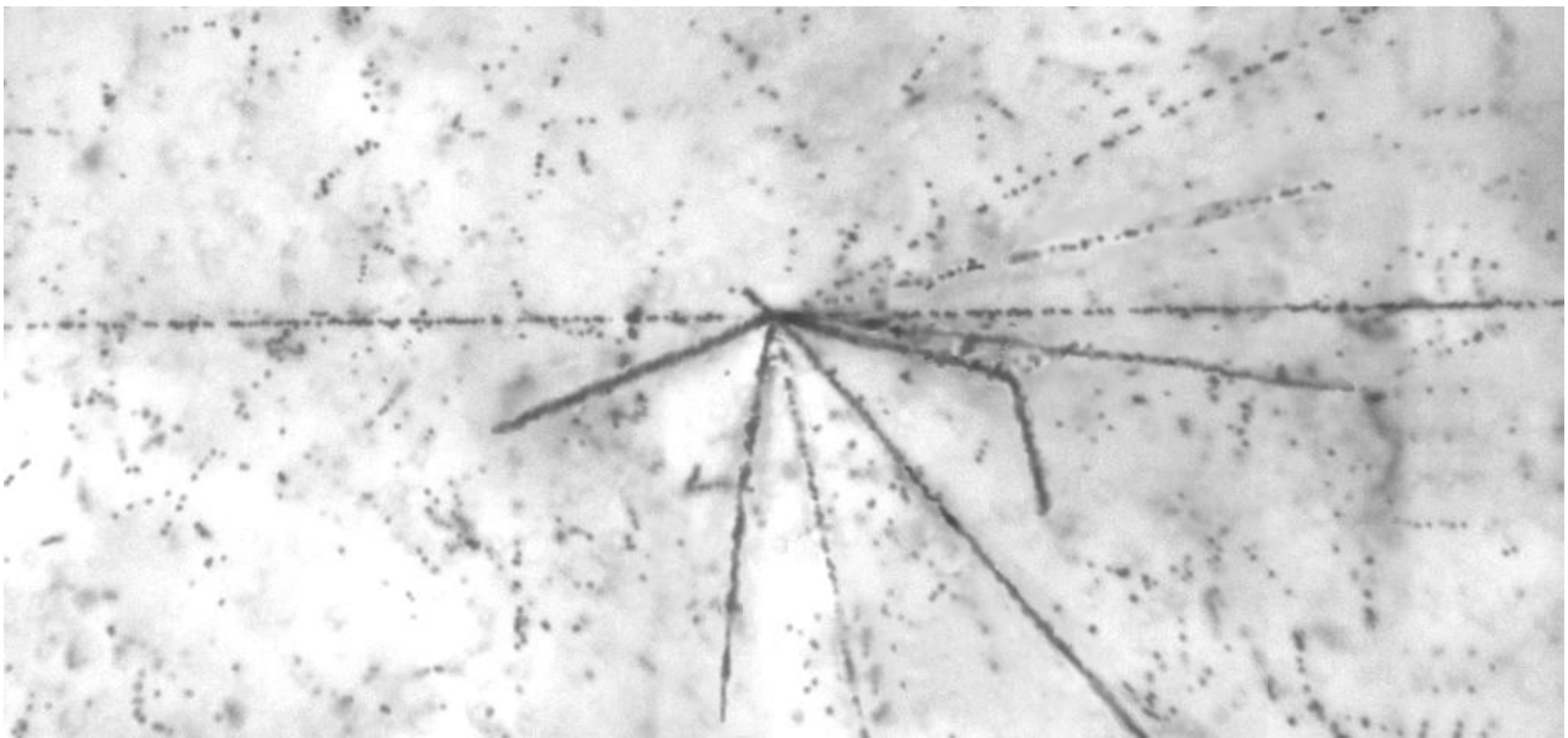


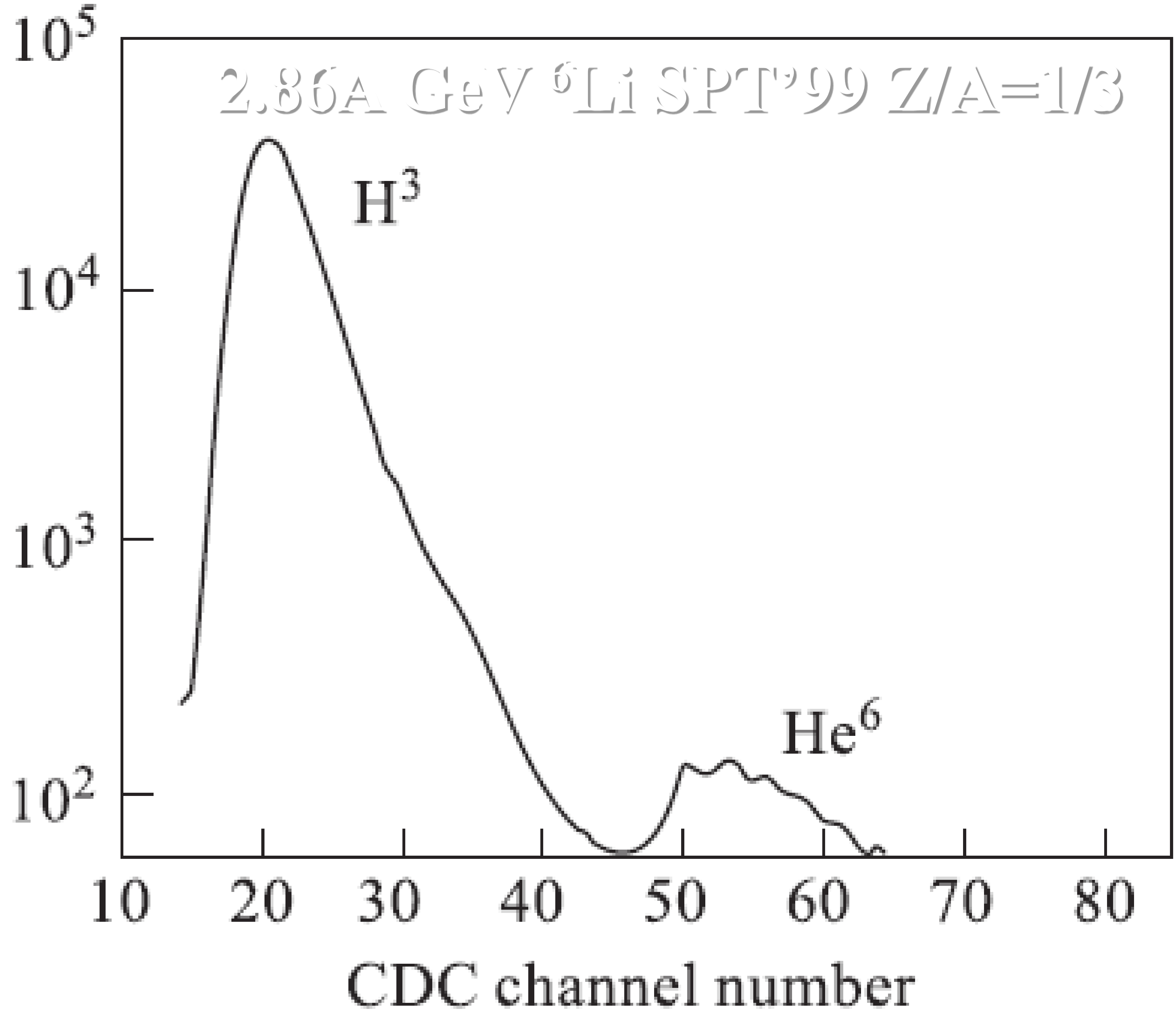


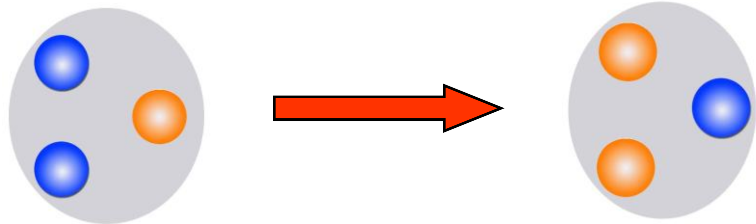
^{12}B 20 ms
^{10}Be 1510000 y
^{12}Be 23 ms
^{11}Be 13.8 s
^{8}Li 838 ms
^{9}Li 178 ms
^{11}Li 8.5 ms
^{6}He 807 ms
^{8}He 119 ms
^{3}H 12 y



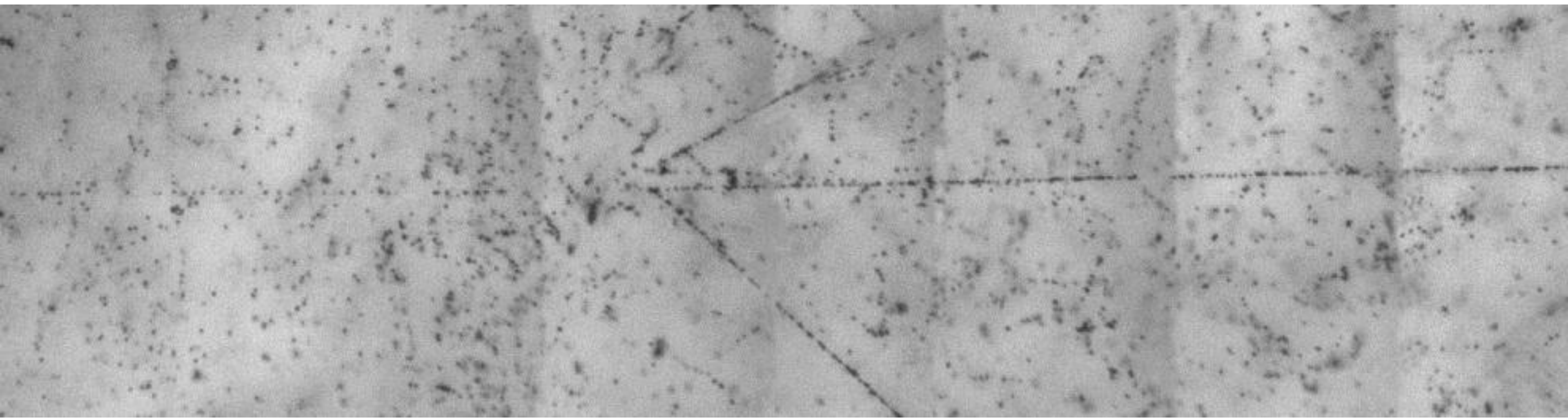
2.76A ГэВ ^{6}He

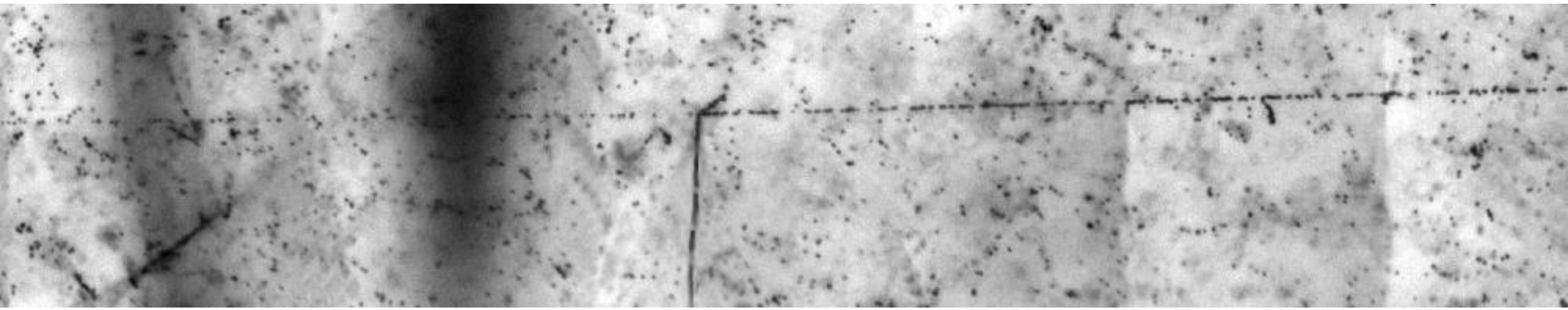



2.86A GeV ^{6}Li SPT'99 Z/A=1/3
H^3
He^6
10^5
10^4
10^3
10^2
10
20
30
40
50
60
70
80
CDC channel number



SPT: 2.76A GeV $^{3}H \to {}^{3}He$



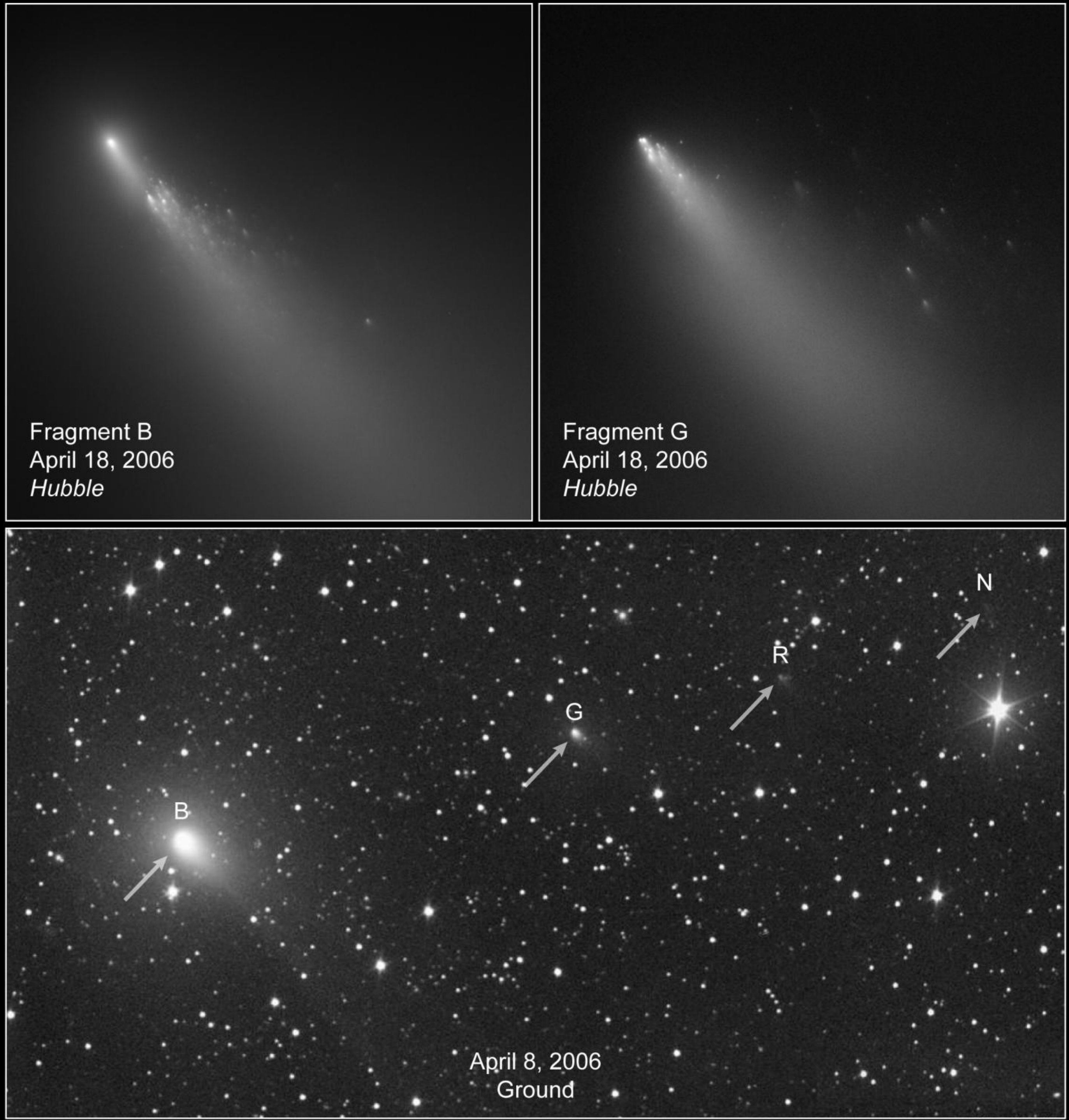


CONCLUDING REMARKS

The presented observations serve as an illustration of prospects of the Nuclotron for nuclear physics and astrophysics researches. In spite of an extraordinarily large distinction from the nuclear excitation energy the relativistic scale does not impede investigations of nuclear interactions down to energy scale typical for nuclear astrophysics, but on the contrary gives advantages. The major one of them is the possibility of principle of observing and investigating multi-particle systems.

The investigations with light nuclei provide a basis for challenging studies of increasingly complicated systems *He – H - n* produced via multifragmentation of heavier relativistic nuclei in the energy scale relevant for nuclear astrophysics. In this respect, the motivated prospects are associated with a detailed analysis of the already observed fragment jets in the events of EM&Diffractive dissociation of *Au* nuclei at *10.6A* GeV and *Pb* nuclei at *160A* GeV.

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. Therefore this technique deserves upgrade, without changes in its detection basics, with the aim to speed up the microscope scanning for rather rare events of peripheral dissociation.


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