Peripheral fragmentation of relativistic nuclei in nuclear track emulsion

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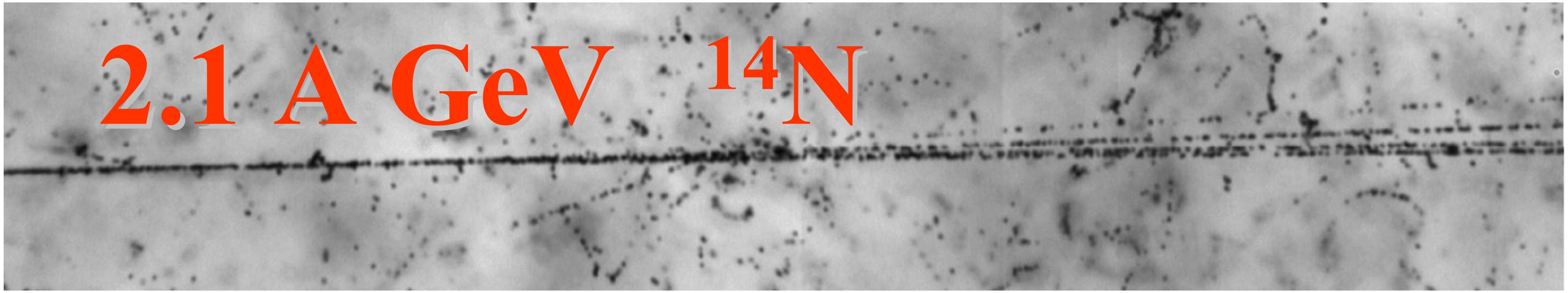
http://becquerel.jinr.ru/

2.1 A GeV ^{14}N

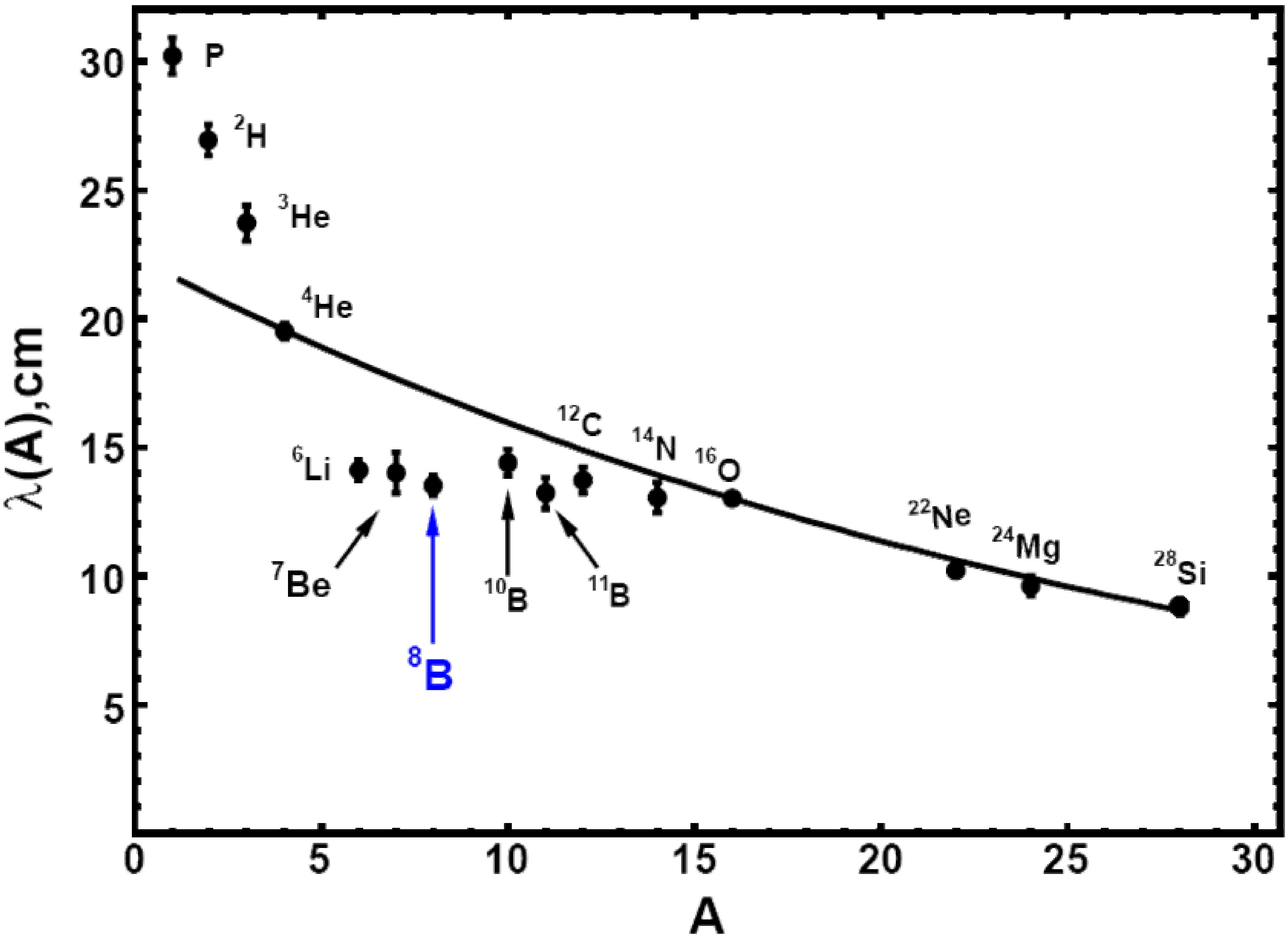


The BECQUEREL Project (Beryllium (Boron) Clustering Quest in Relativistic Multifragmentation) at the JINR Nuclotron is devoted systematic exploration of nucleonic clustering of light stable and radioactive nuclei. Among all variety of the nuclear interactions the peripheral dissociation bears uniquely complete information about multiple cluster states.

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.

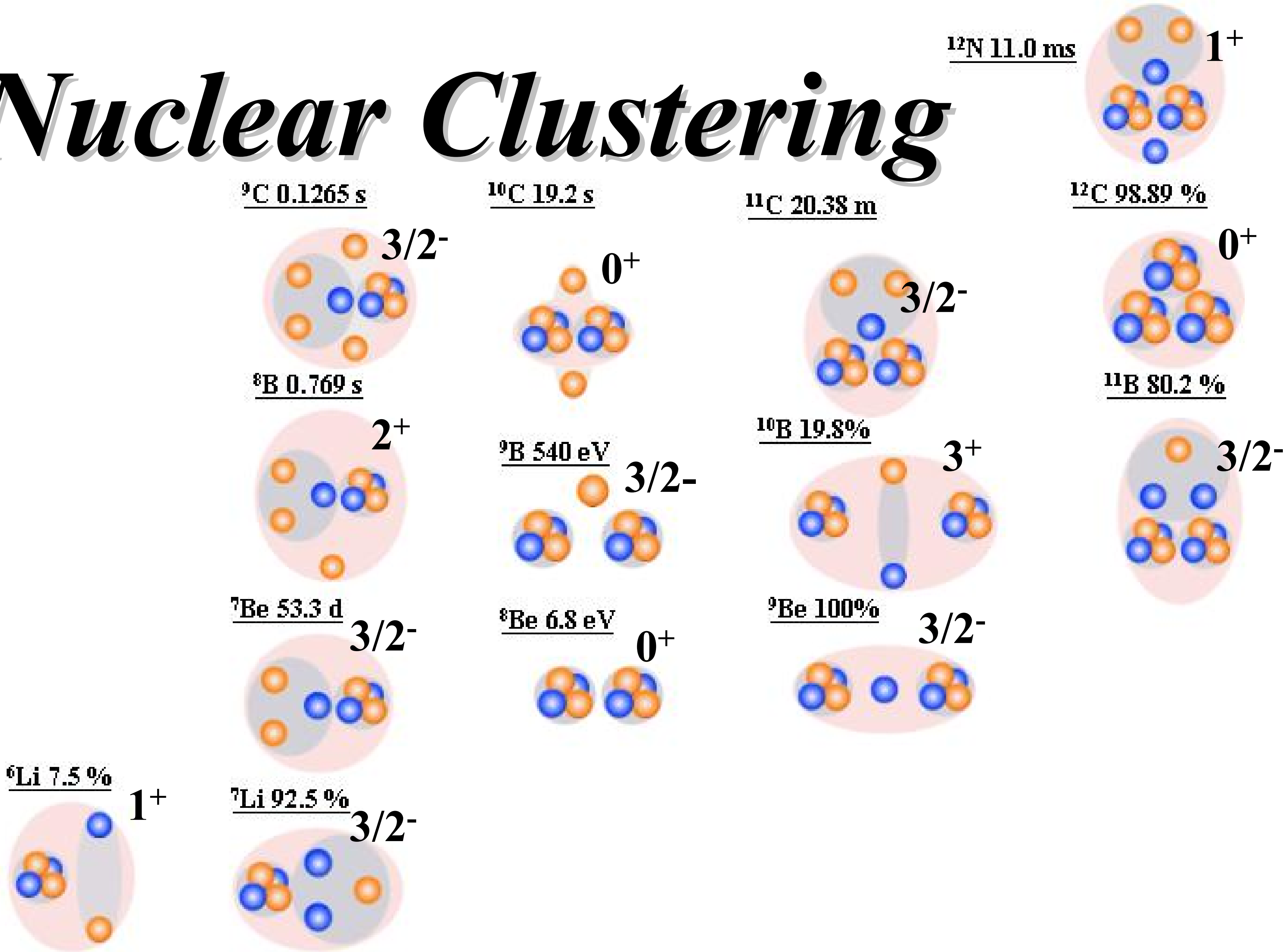
0.5 μm resolution, identification of charges and H&He isotopes

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

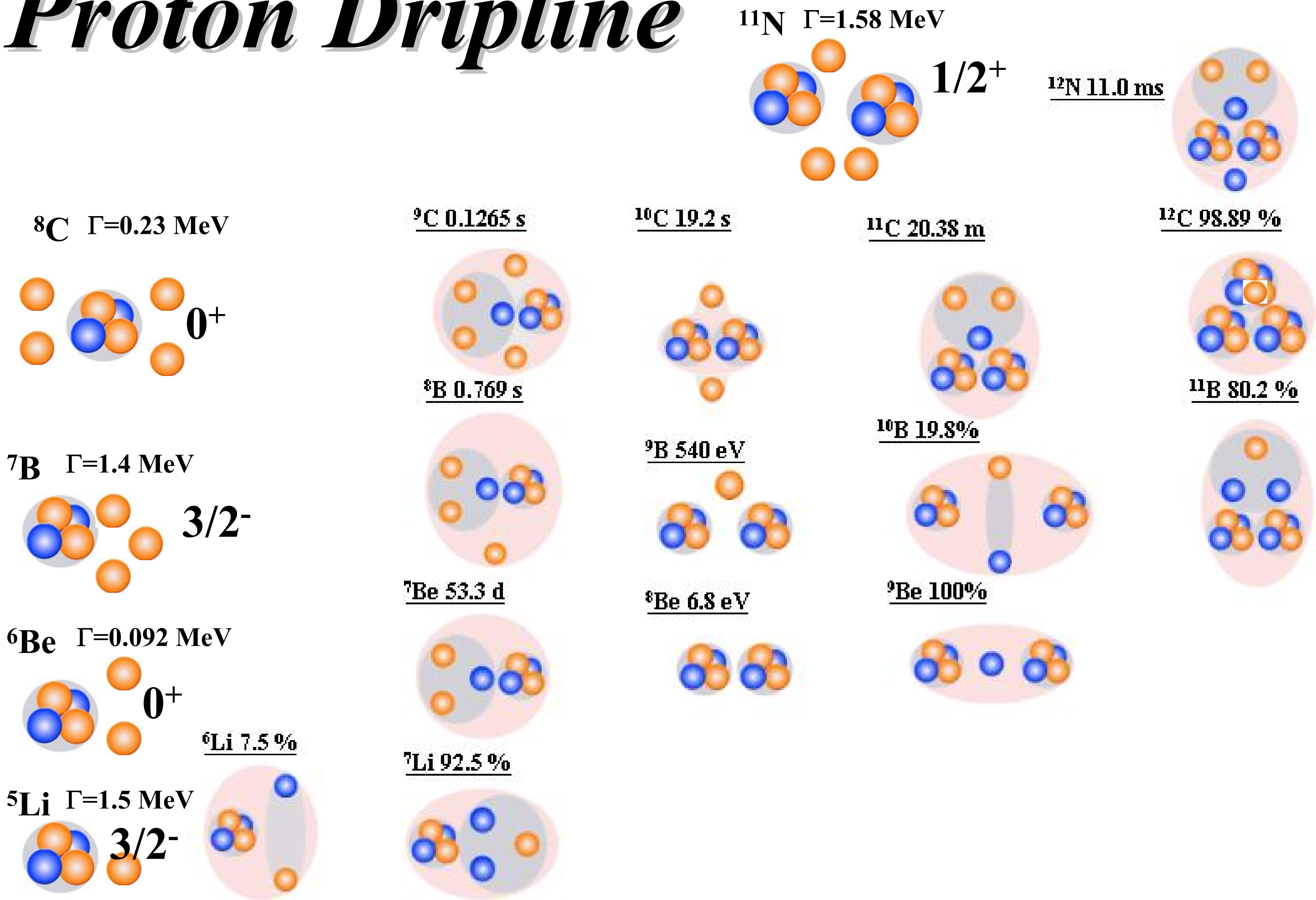


λ(A),cm
A
30
25
20
15
10
5
0
5
10
15
20
25
30
P
2H
3He
4He
6Li
7Be
8B
10B
11B
12C
14N
16O
22Ne
24Mg
28Si

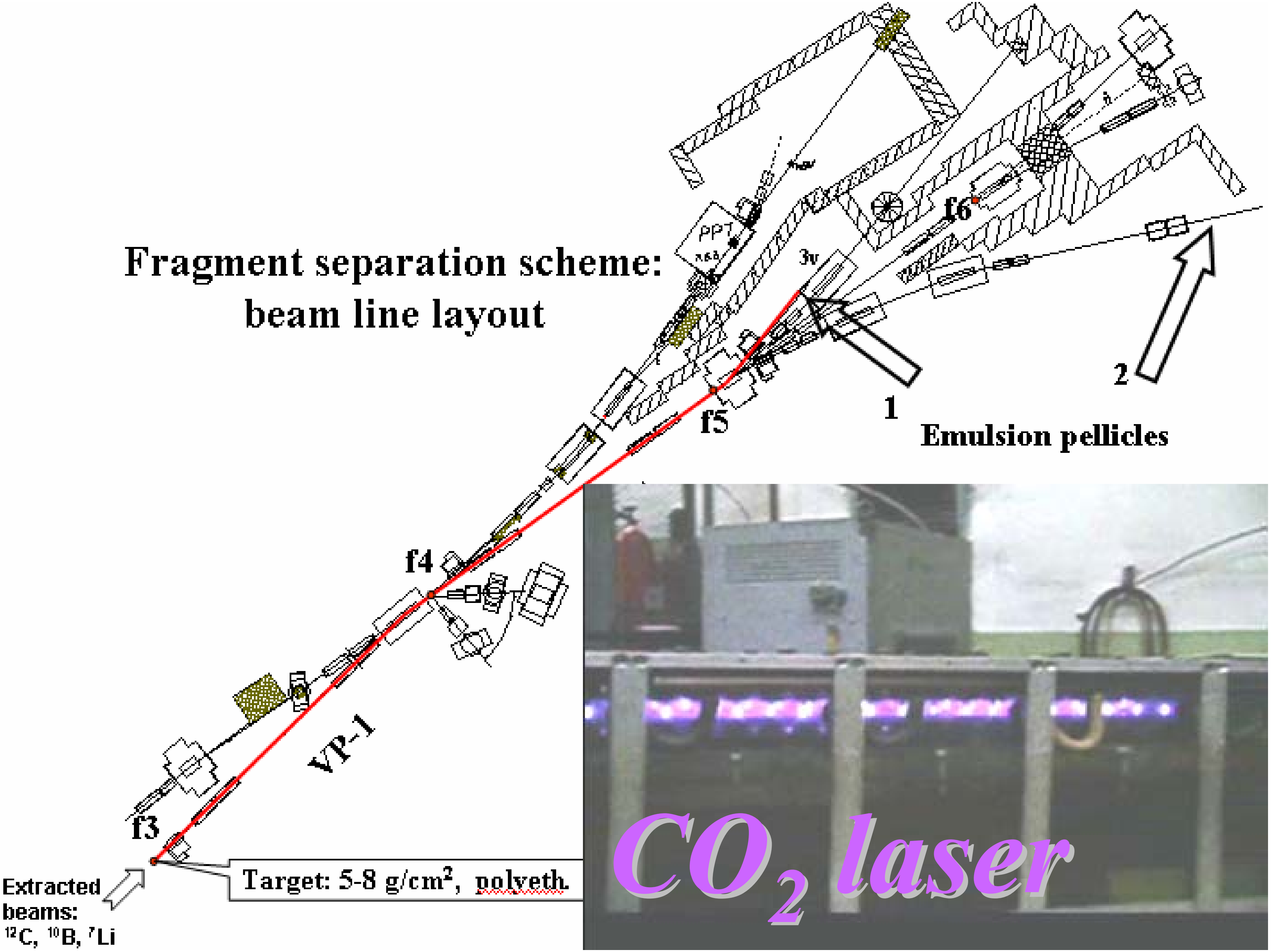
Nuclear Clustering

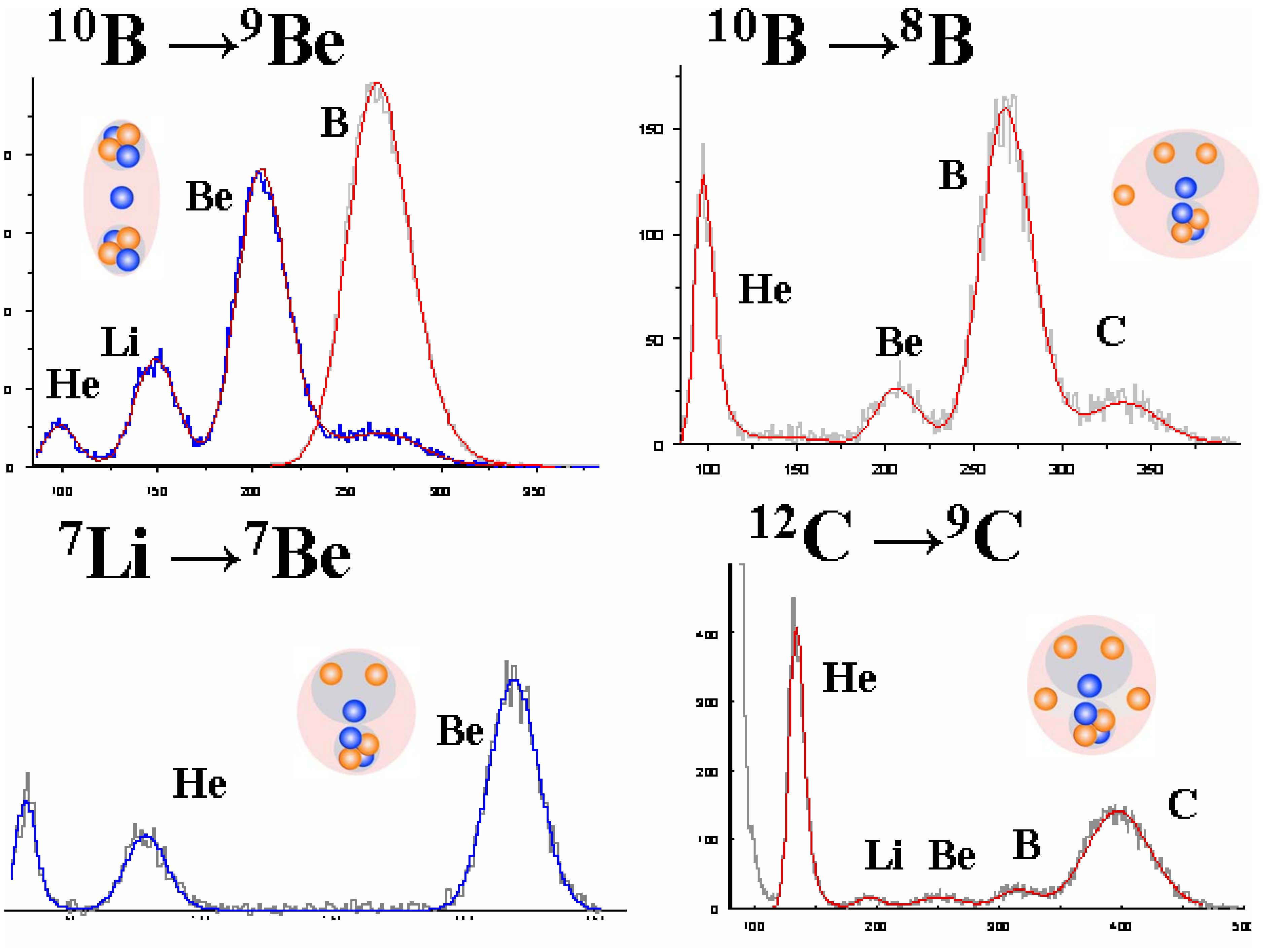


Proton Dripline

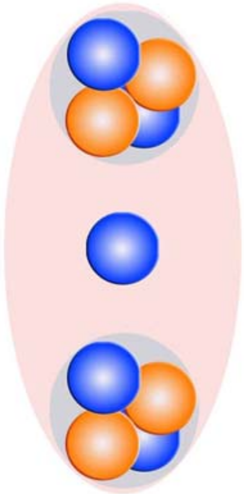


Fragment separation scheme: beam line layout



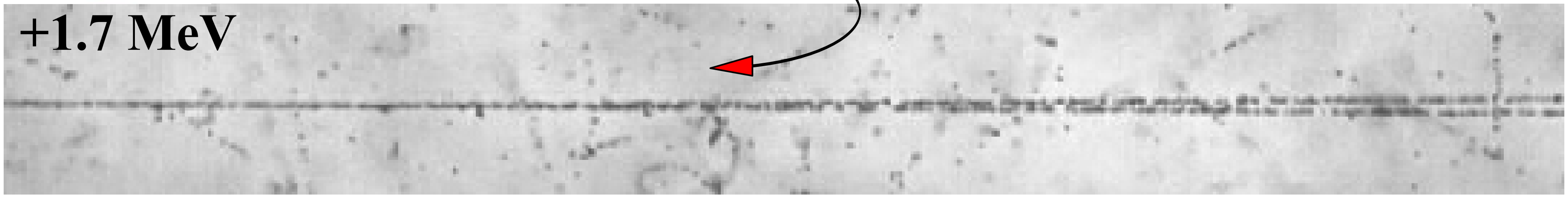


10B →9Be
B
Be
Li
He
100
150
200
250
300
350
10B →8B
150
100
50
0
He
Be
B
C
100
150
200
250
300
350
7Li →7Be
He
Be
12C →9C
400
300
200
100
0
He
Li
Be
B
C
100
200
300
400
500

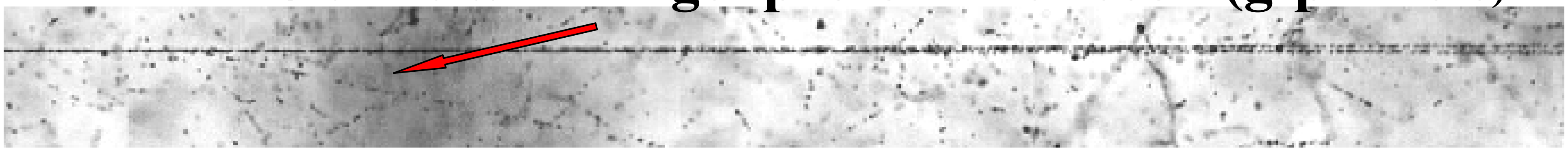


370 events 1.2 A GeV
$^{9}Be \rightarrow 2He$

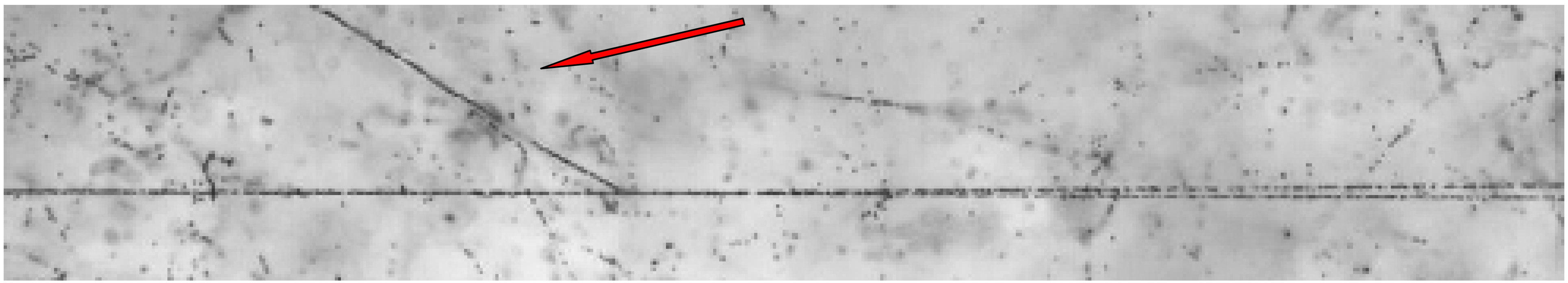
144 "white" stars



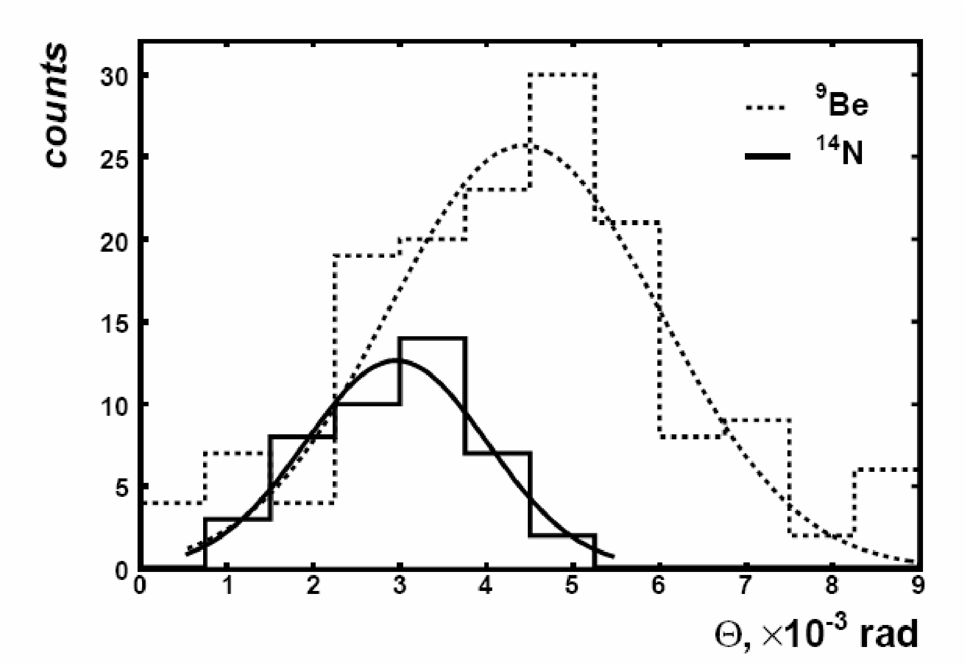
27 stars with target proton like recoil (g-particle)

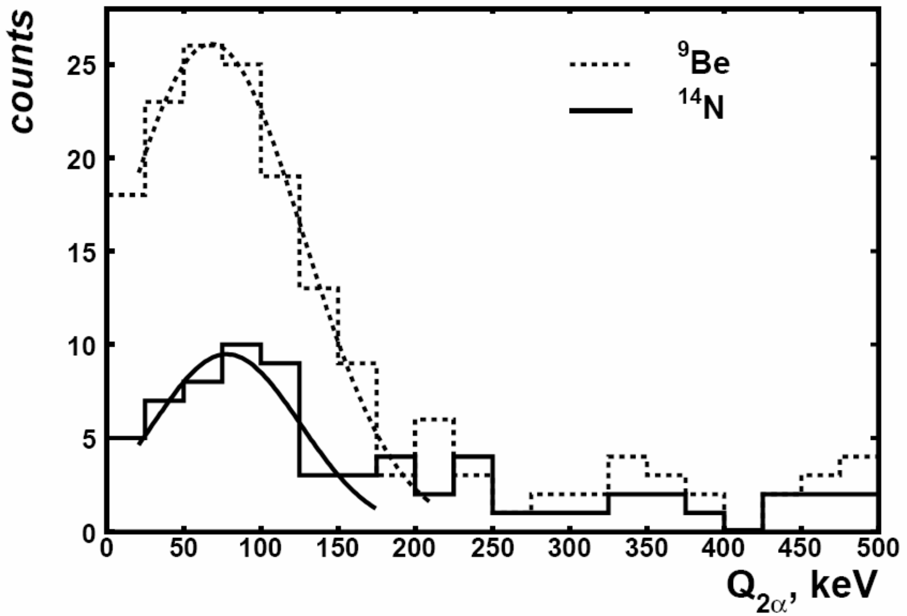


39 stars with heavy fragment of target nucleus (b-particle)



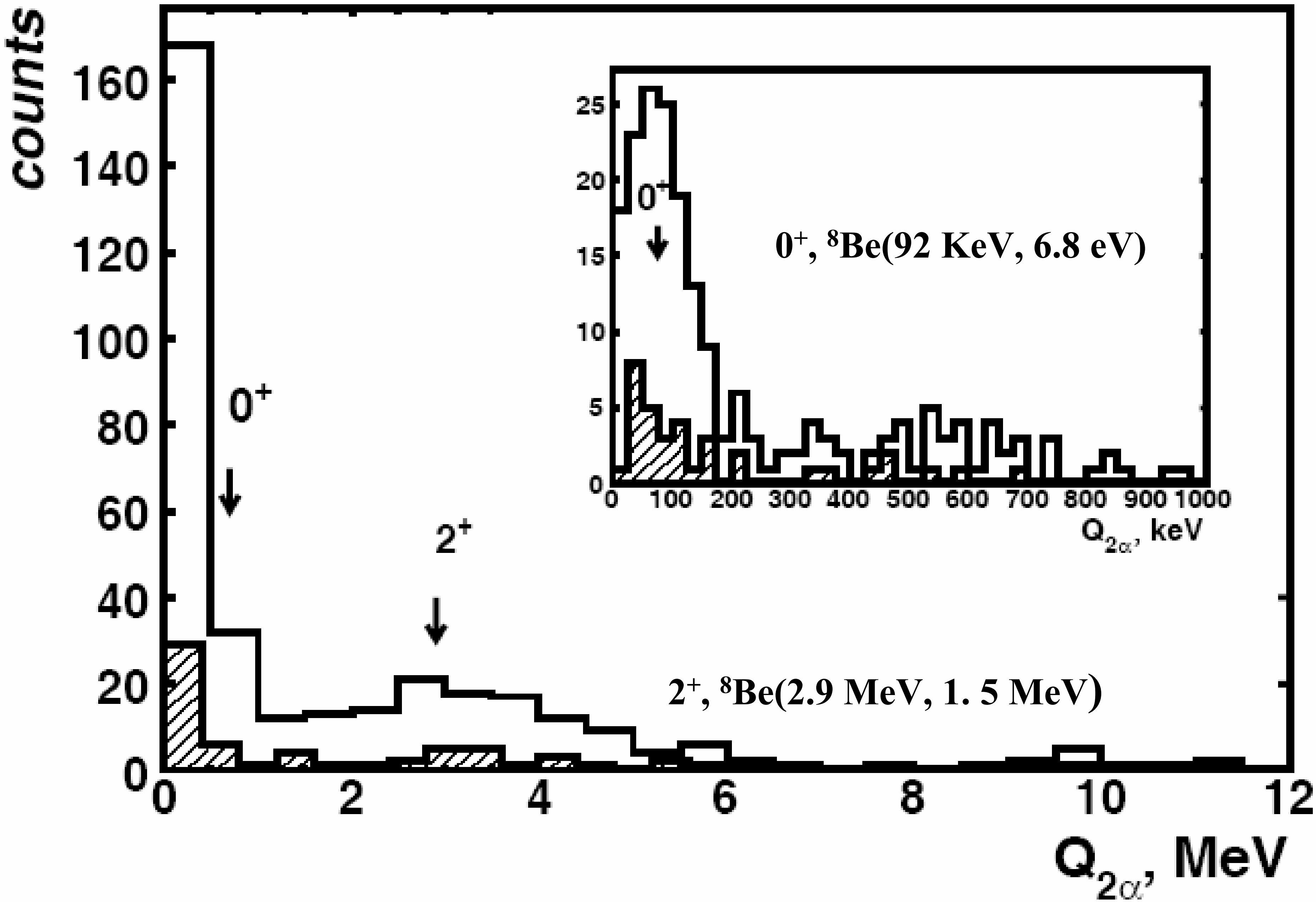
$^{14}N \to {}^{8}Be(0^+) + He + X \to 3He + X$, $p_0(^{14}N) = 2.86A$ GeV/c
$^{9}Be \to {}^{8}Be(0^+) + X \to 2He$, $p_0(^{9}Be) = 1.95$ A GeV/c





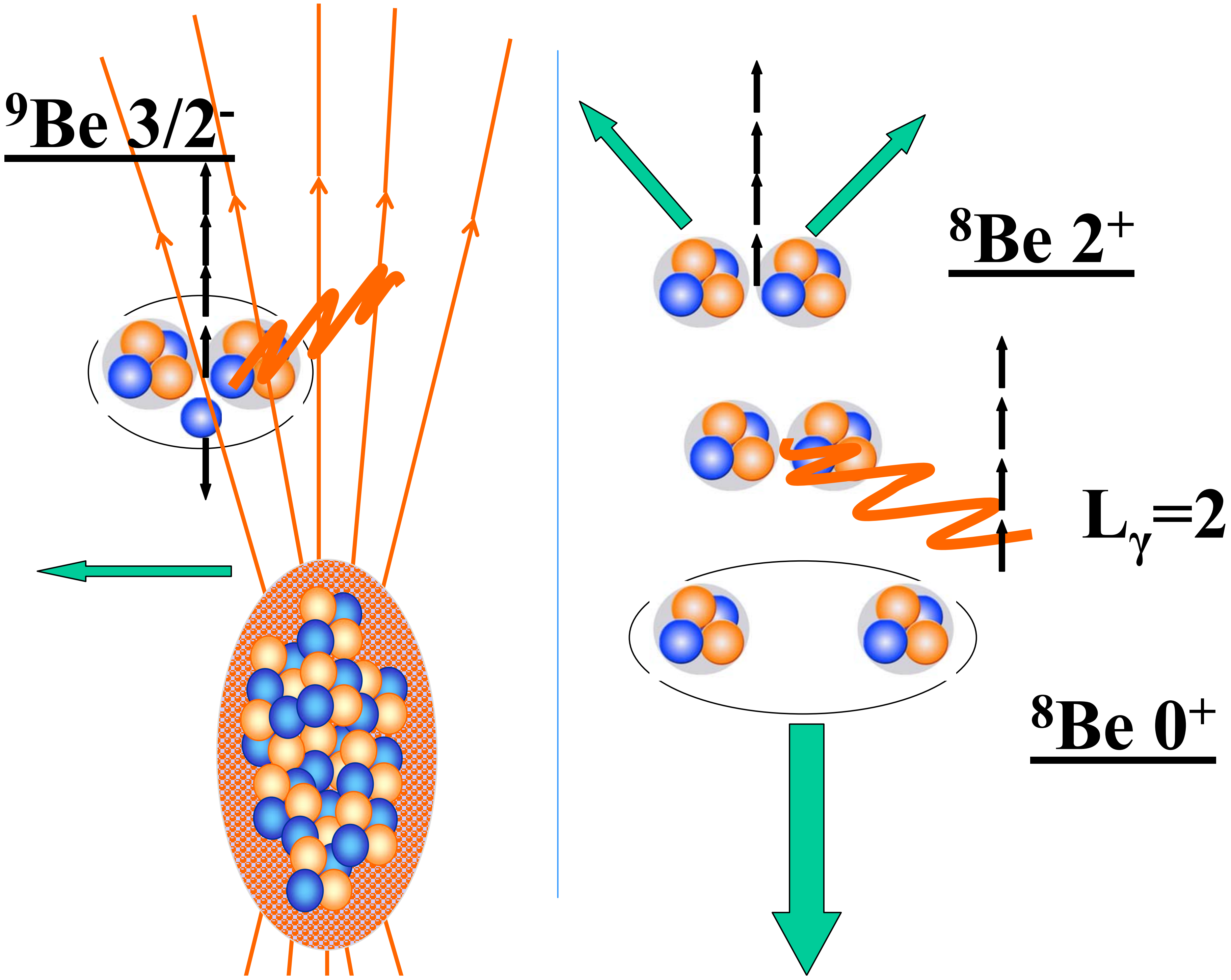
$\langle\Theta(^{14}N \to {}^{8}Be + X)\rangle = (2.96 \pm 0.18)$ mrad;
$\langle\Theta(^{9}Be \to {}^{8}Be + X)\rangle = (4.43 \pm 0.14)$ mrad;

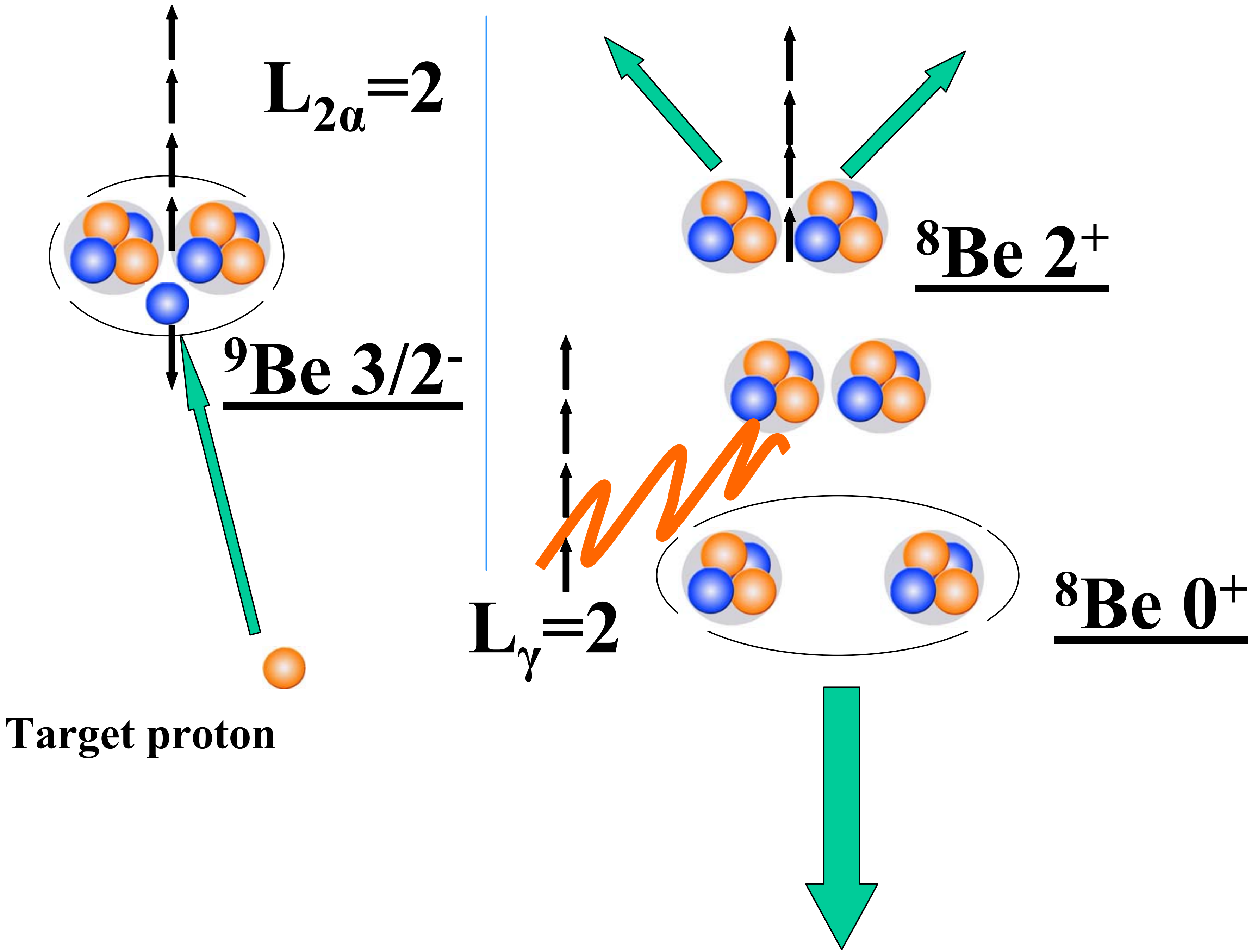
$\langle Q_{2\alpha}(^{14}N \to {}^{8}Be + X)\rangle = (67.8 \pm 14.1)$ keV;
$\langle Q_{2\alpha}(^{9}Be \to {}^{8}Be + X)\rangle = (77.8 \pm 13.9)$ keV.



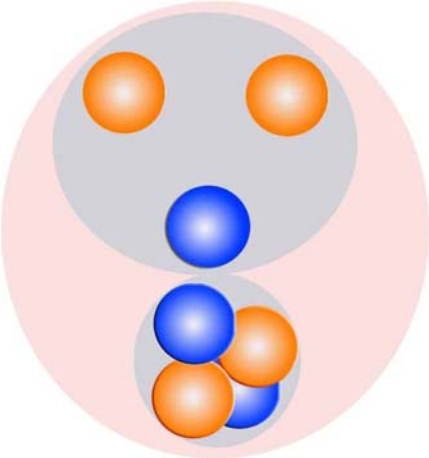
counts
Q$_{2\alpha}$, MeV
0$^+$
2$^+$
2$^+$, ^{8}Be(2.9 MeV, 1. 5 MeV)
0$^+$, ^{8}Be(92 KeV, 6.8 eV)
Q$_{2\alpha}$, keV

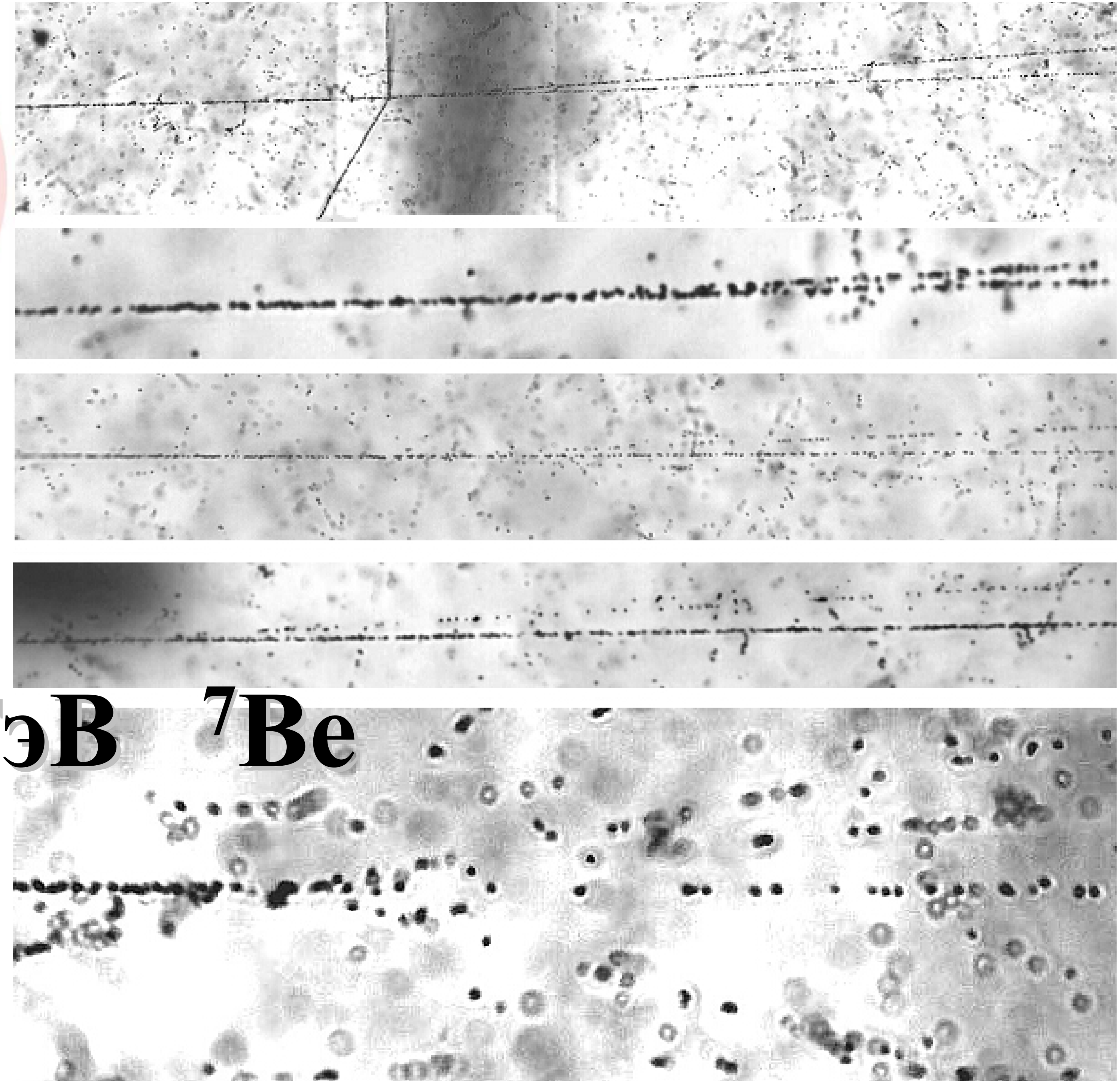
n_b	0	0	1	2	3	4	5
n_g	0	1	0	0	0	0	0
$Q_{2\alpha}$ <1 MeV	98	10	21	8	1	3	1
$<P_T^{2\alpha}>$, MeV/c	133±16	166±40	154±14				
1 MeV$<Q_{2\alpha}<$4 MeV	33	10	14	3	2	1	-
$<P_T^{2\alpha}>$, MeV/c	127±15	195±54	178±23				
4 MeV$<Q_{2\alpha}$	13	7	4	2	2	3	1
$<P_T^{2\alpha}>$, MeV/c	202±31	232±42	281±51				


^{9}Be 3/2$^-$
^{8}Be 2$^+$
L_γ=2
^{8}Be 0$^+$



L2α=2
9Be 3/2-
Target proton
8Be 2+
Lγ=2
8Be 0+





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

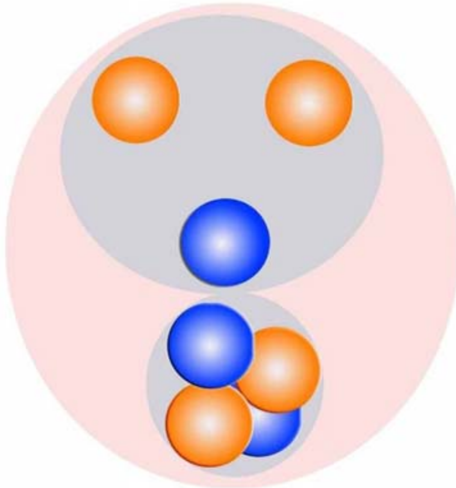
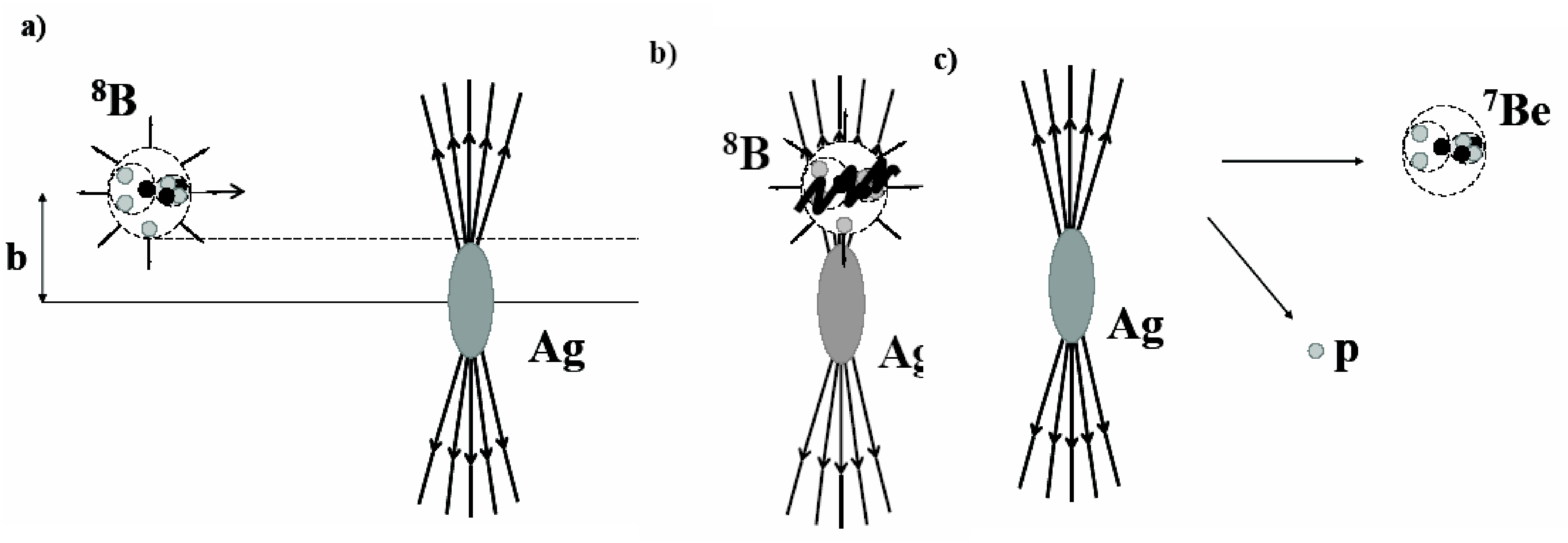


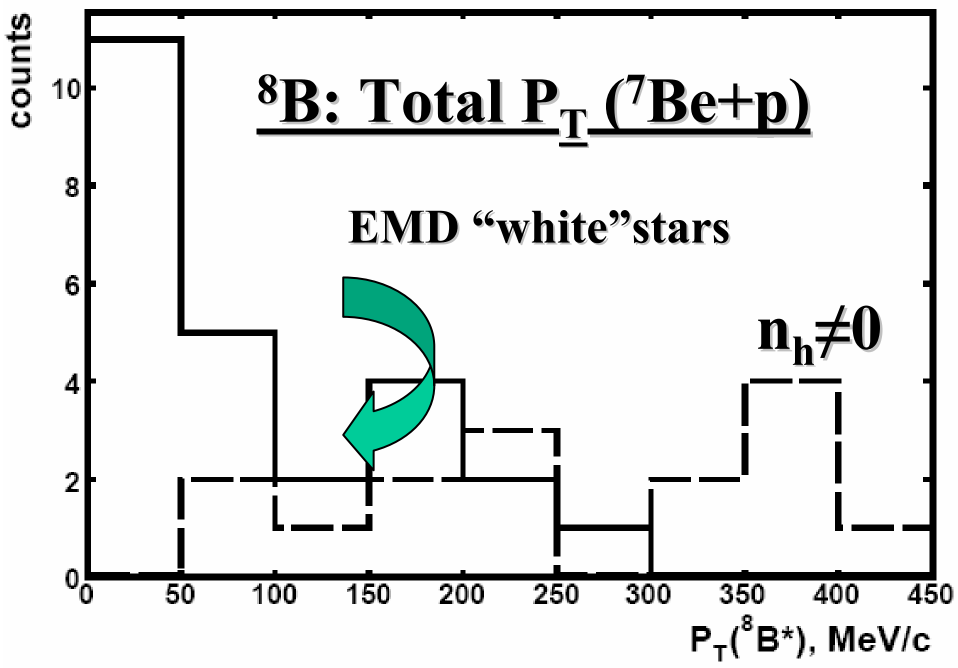
Diagram of peripheral dissociation of relativistic ^{8}B nucleus in EM field of Ag nucleus



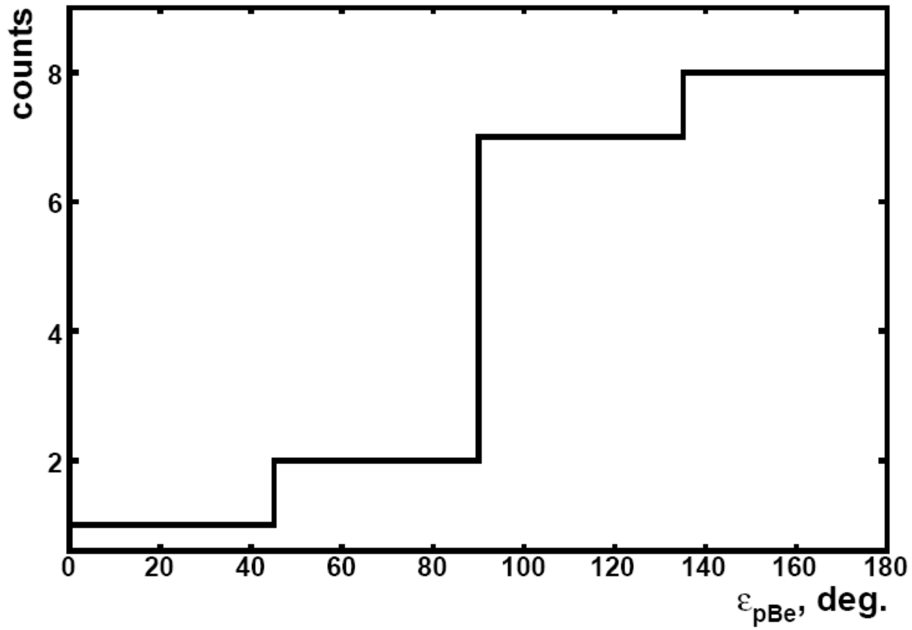
Nearer approach of the nuclei with an impact parameter (a), absorption of quasireal photon by ^{8}B nucleus (b), ^{8}B dissociation on fragment pair - p and ^{7}Be (c).

^{8}B (1.2 A GeV) → ^{7}Be + p

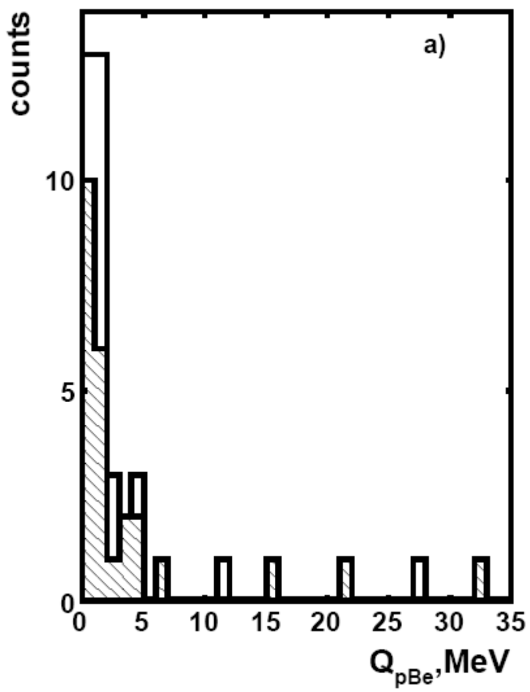
	Q_{min} (^{10}B), МэВ	N_{ws} (^{10}B)	% (^{10}B)	Q_{min} (^{8}B), МэВ	N_{ws} (^{8}B)	% (^{8}B)
2He+H	6.0	30	73	1.724	14	27
He+3H	25	5	12	8.6	12	23
Be+H	6.6	1	2	0.138	25	48
B		-	-		1	2
Li+He	4.5	5	13	3.7	-	-



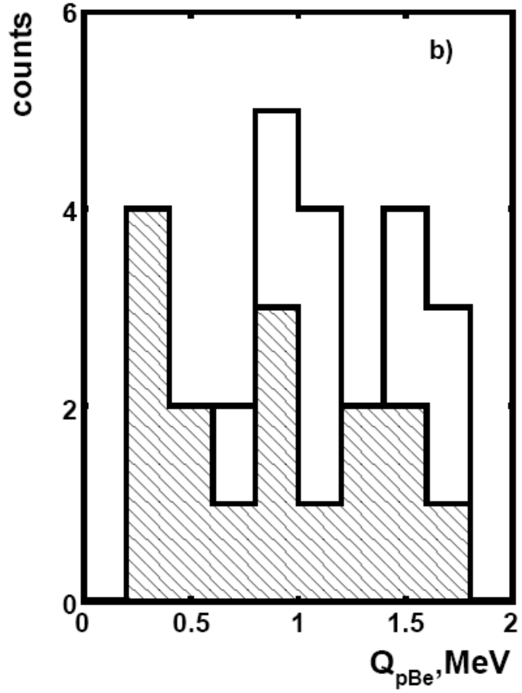
counts
^{8}B: Total P_T (^{7}Be+p)
EMD "white"stars
$n_h \neq 0$
$P_T(^{8}B^*)$, MeV/c



counts
ε_{pBe}, deg.

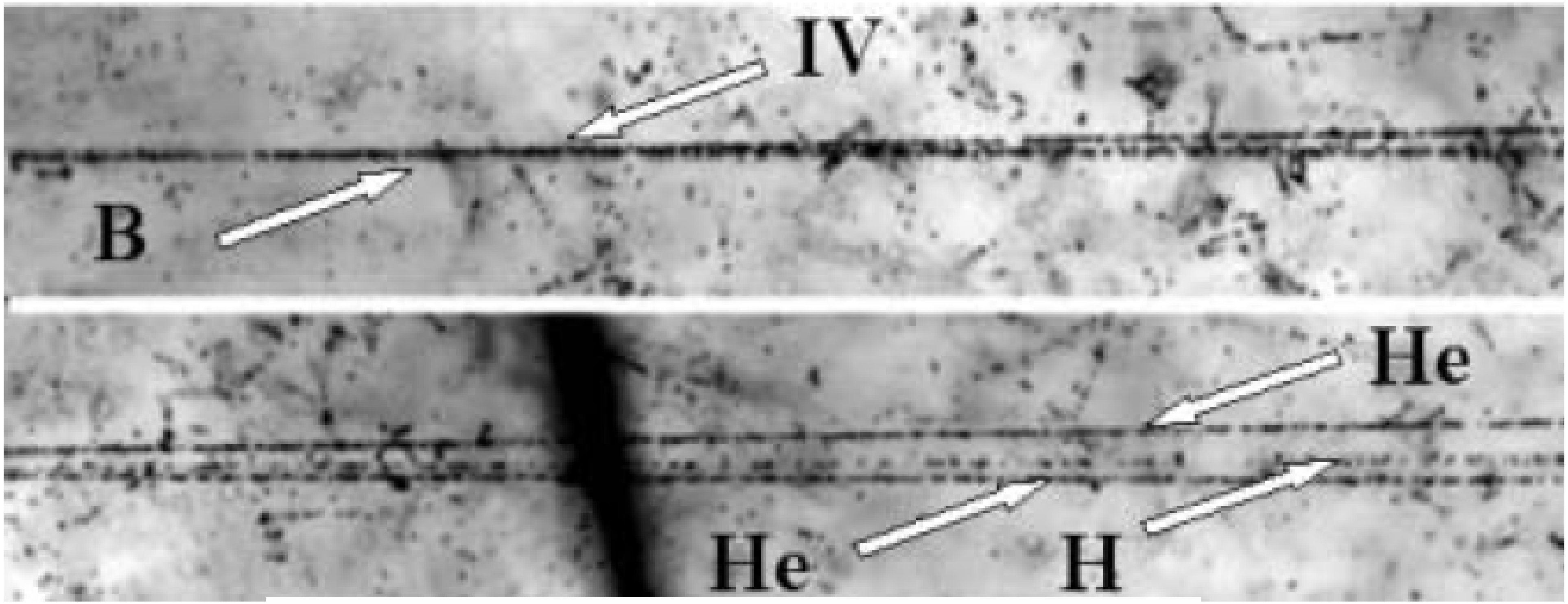


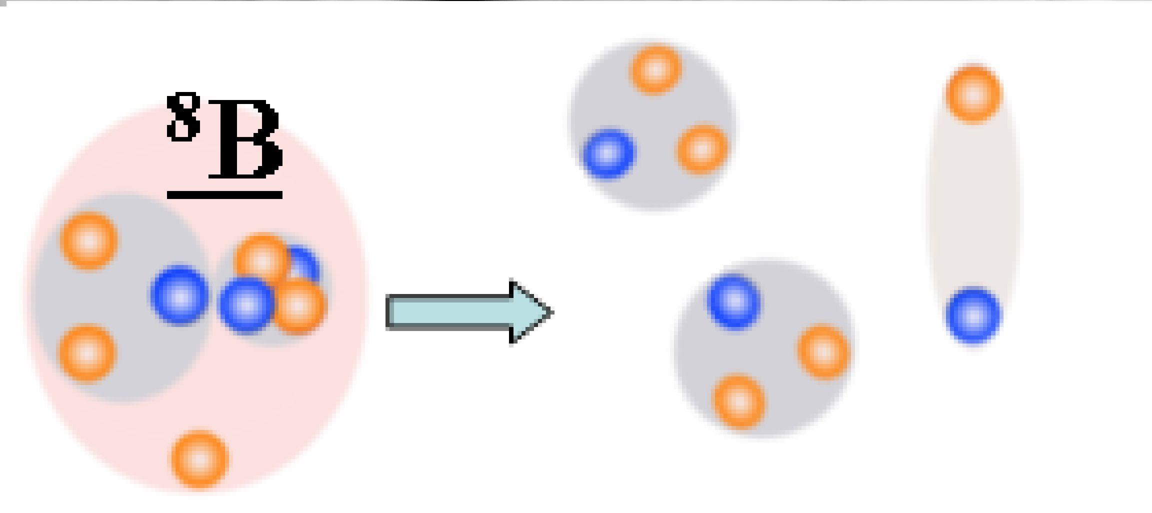
counts
a)
Q_{pBe},MeV

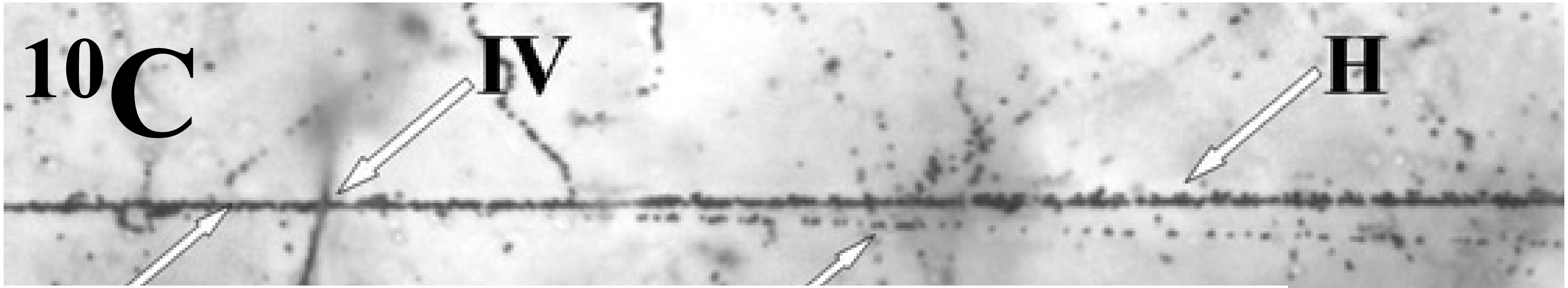


counts
b)
Q_{pBe},MeV

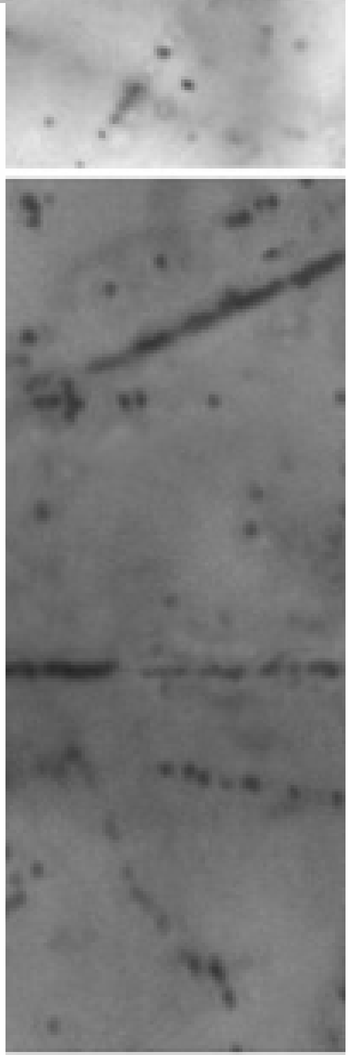
^{8}B (1.2A GeV) → 2He + H

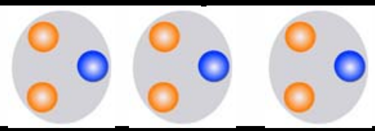


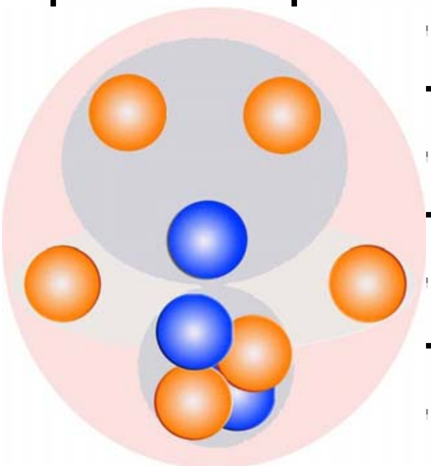




N_z					N_{ws}	N_{tf}
5	4	3	2	1		
-	-	-	1	5	-	1
-	-	-	2	3	1	-
-	-	-	2	2	3	5
-	-	-	1	4	-	10
-	-	-	-	6	-	2
-	-	-	2	1	-	5

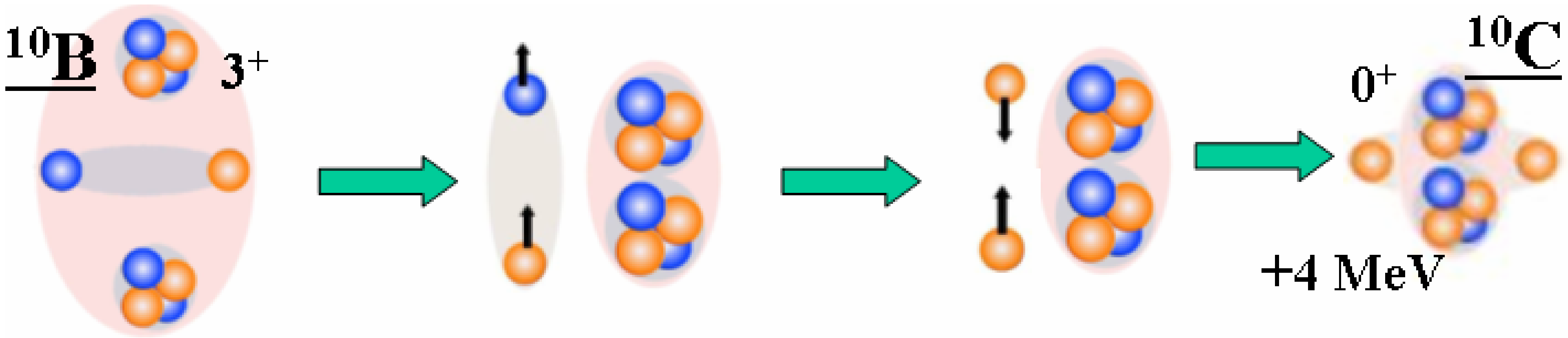


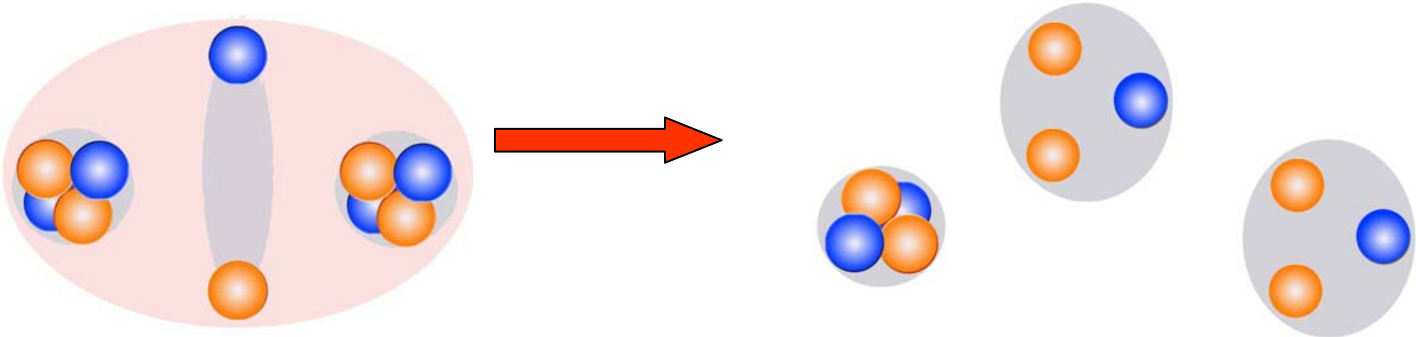
Z_{fr}						N_{ws}
6	5	4	3	2	1	
-	1	-	-	-	1	11
-	-	1	-	-	2	16
-	-			3	-	13
		1	-	1	-	1
		-	1	1	1	2
		-	1	-	3	2
		-	-	1	4	22
				2	2	21
				-	6	5



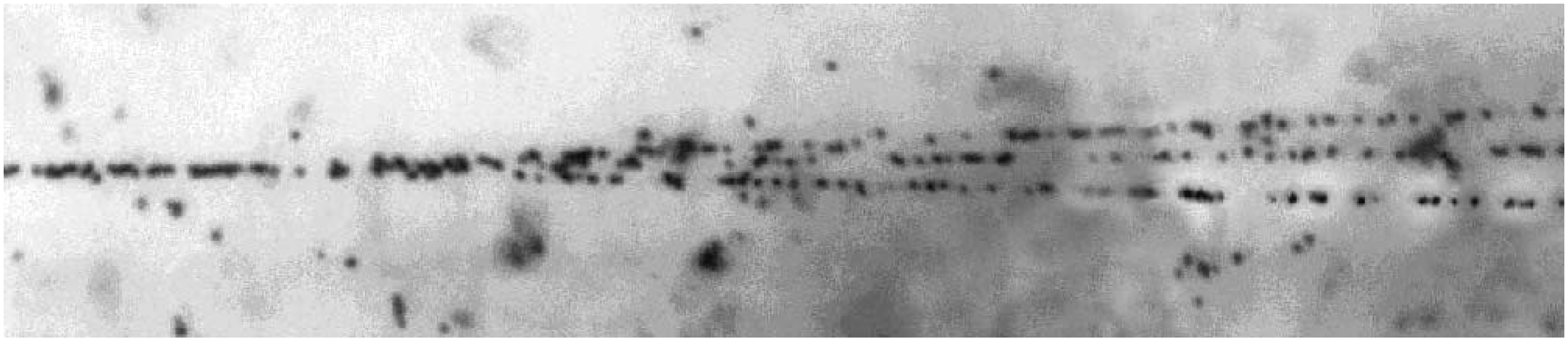
^{9}C exposure

Suggested ^{10}C Exposure

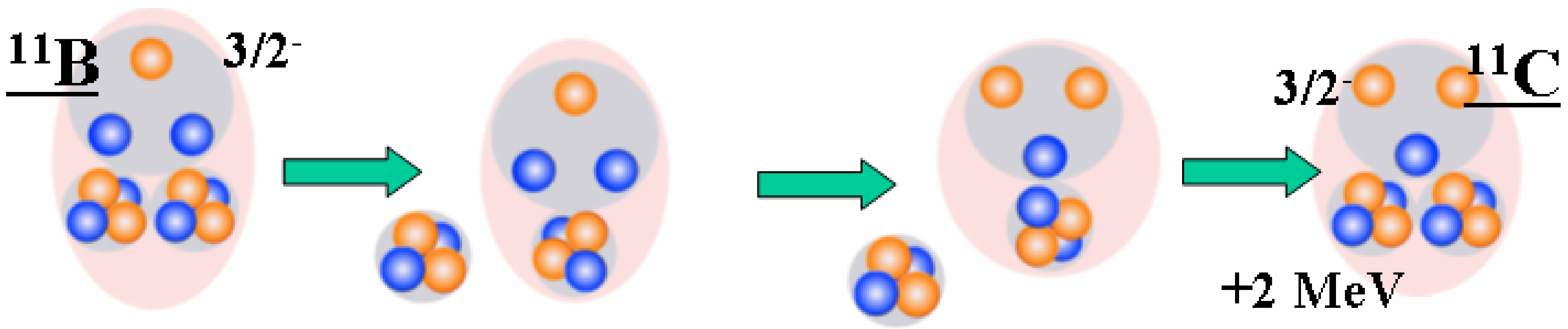




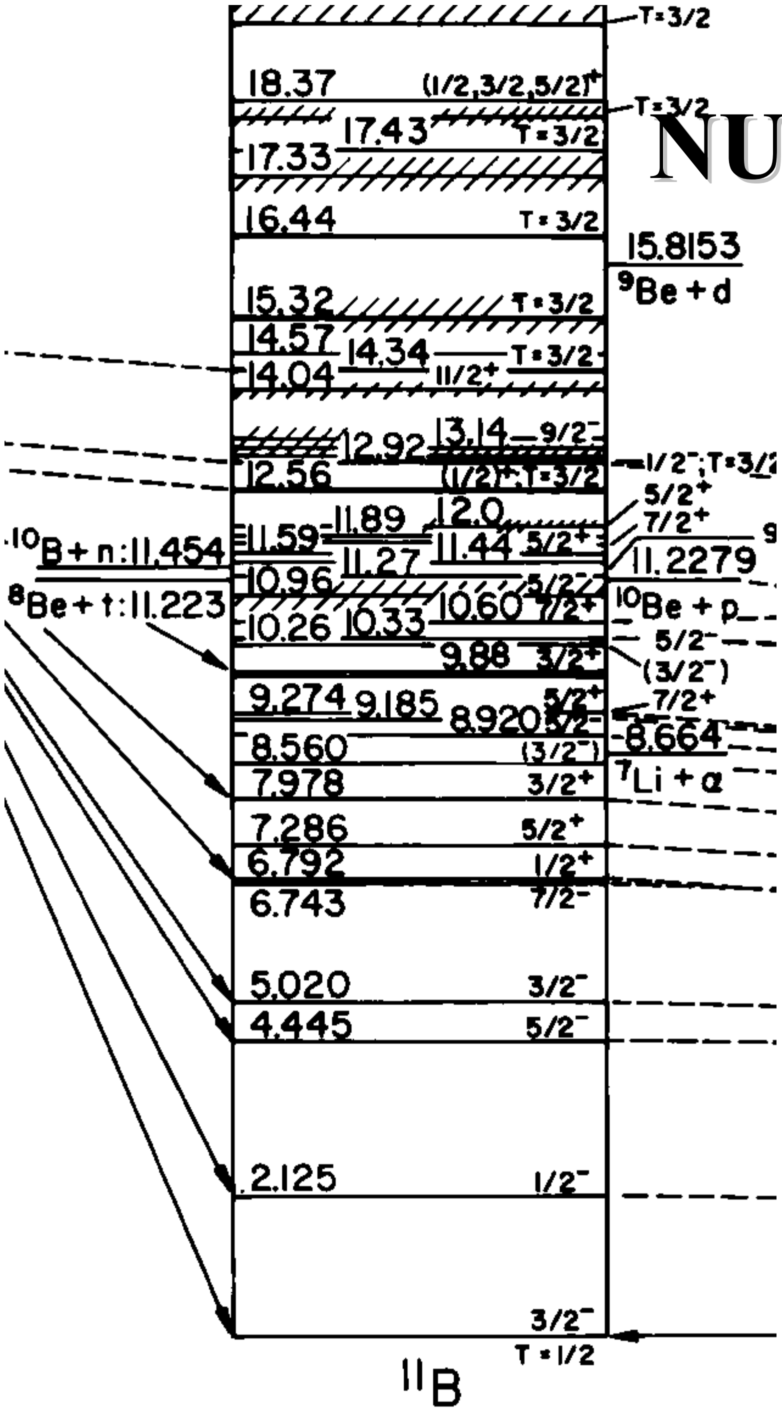
1.0 A GeV $^{10}B \rightarrow 2\,^{3}He + ^{4}He$

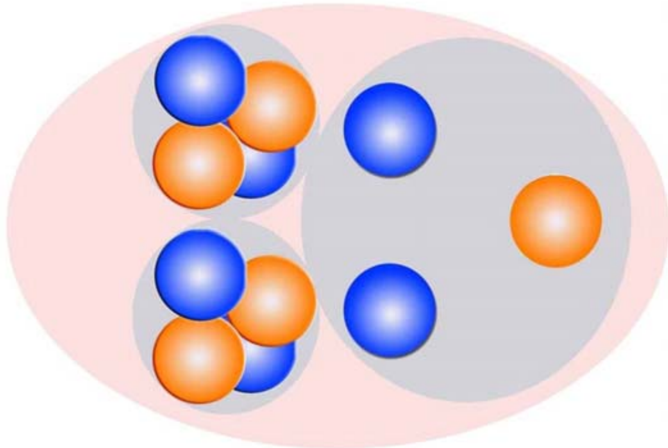


Suggested ^{11}C Exposure

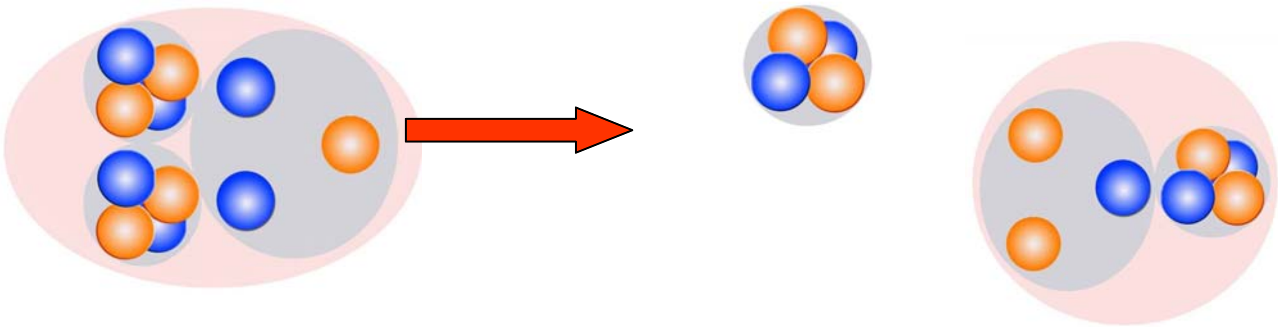


NUCLOTRON:1.2A GeV ^{11}B

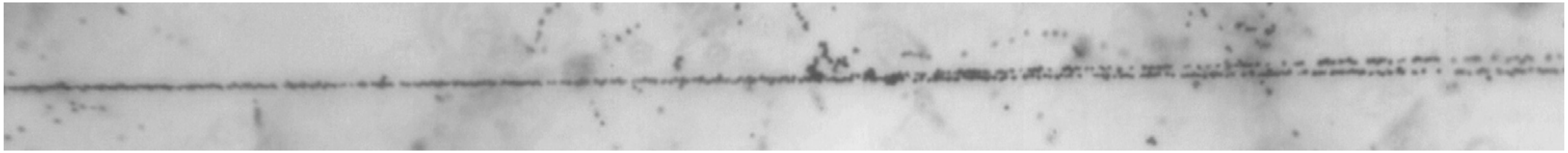


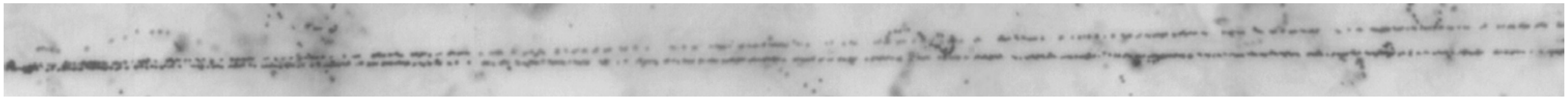


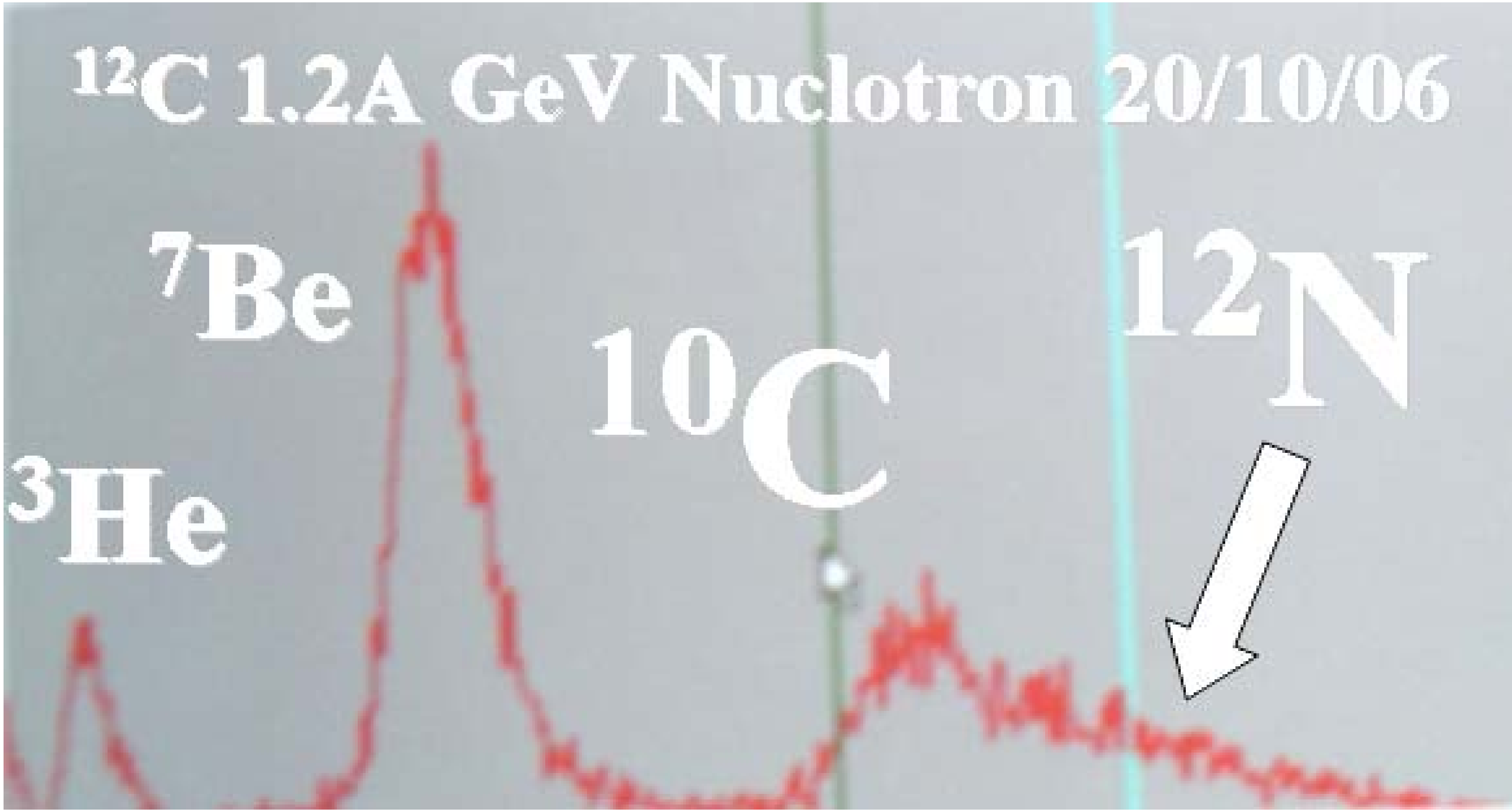
$N_{Z=5}$	$N_{Z=4}$	$N_{Z=3}$	$N_{Z=2}$	$N_{Z=1}$	N_{ws}	N_{tf}
1					1	1
	1			1	2	9
		1	1		0	3
		1		2	0	5
			1	3	5	12
			2	1	13	30
				5	0	0
Total:					**21**	**60**



2.0 A GeV $^{11}B \rightarrow {}^{4}He + {}^{7}Be$

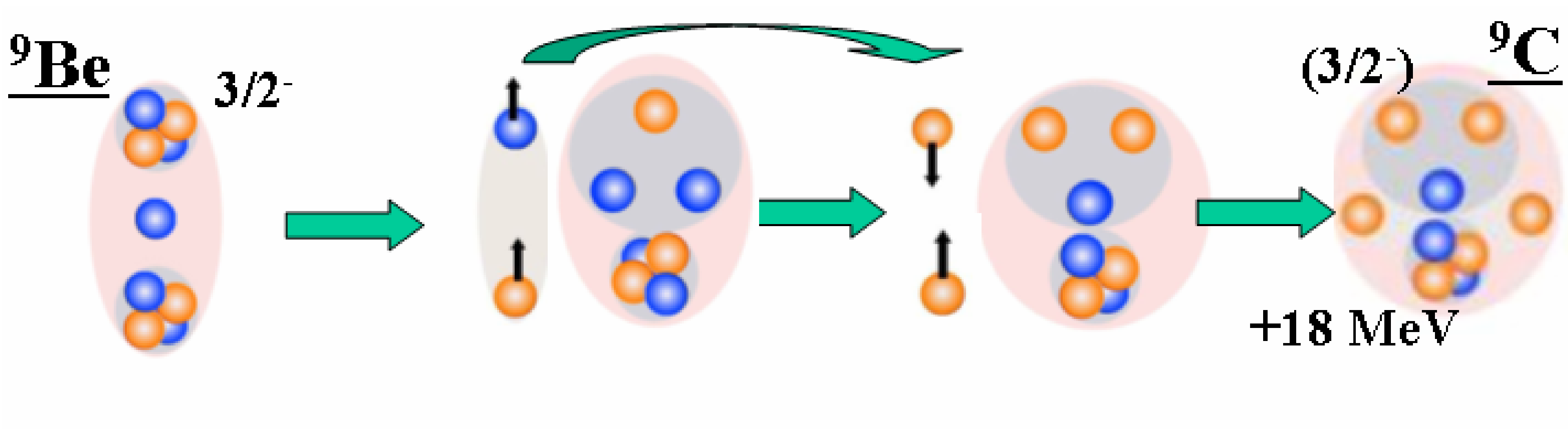


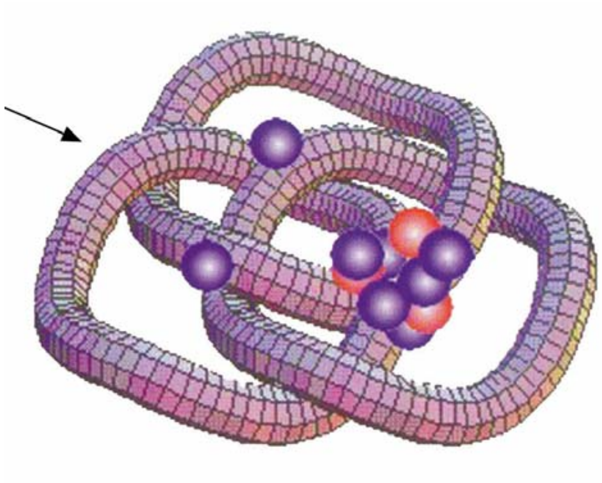


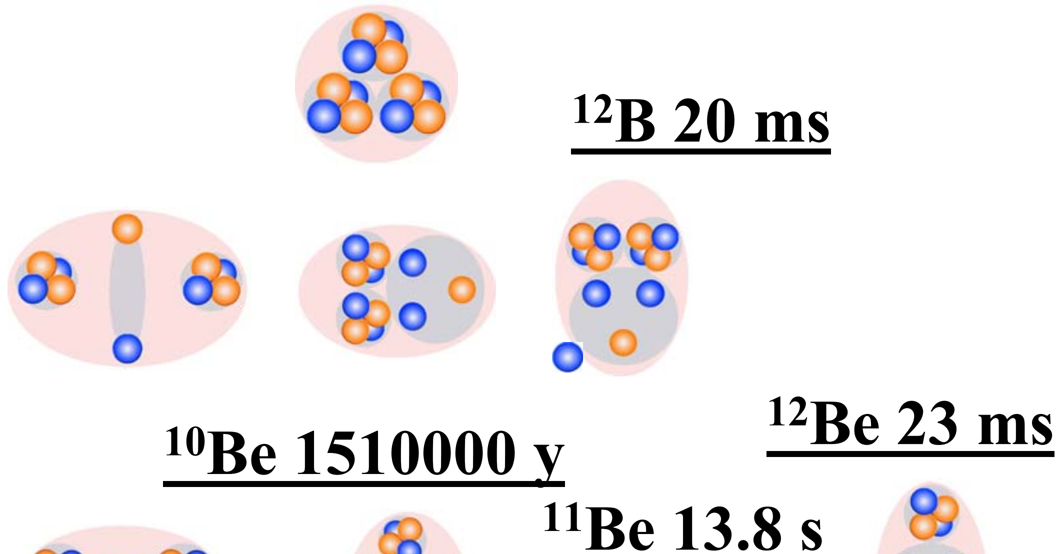


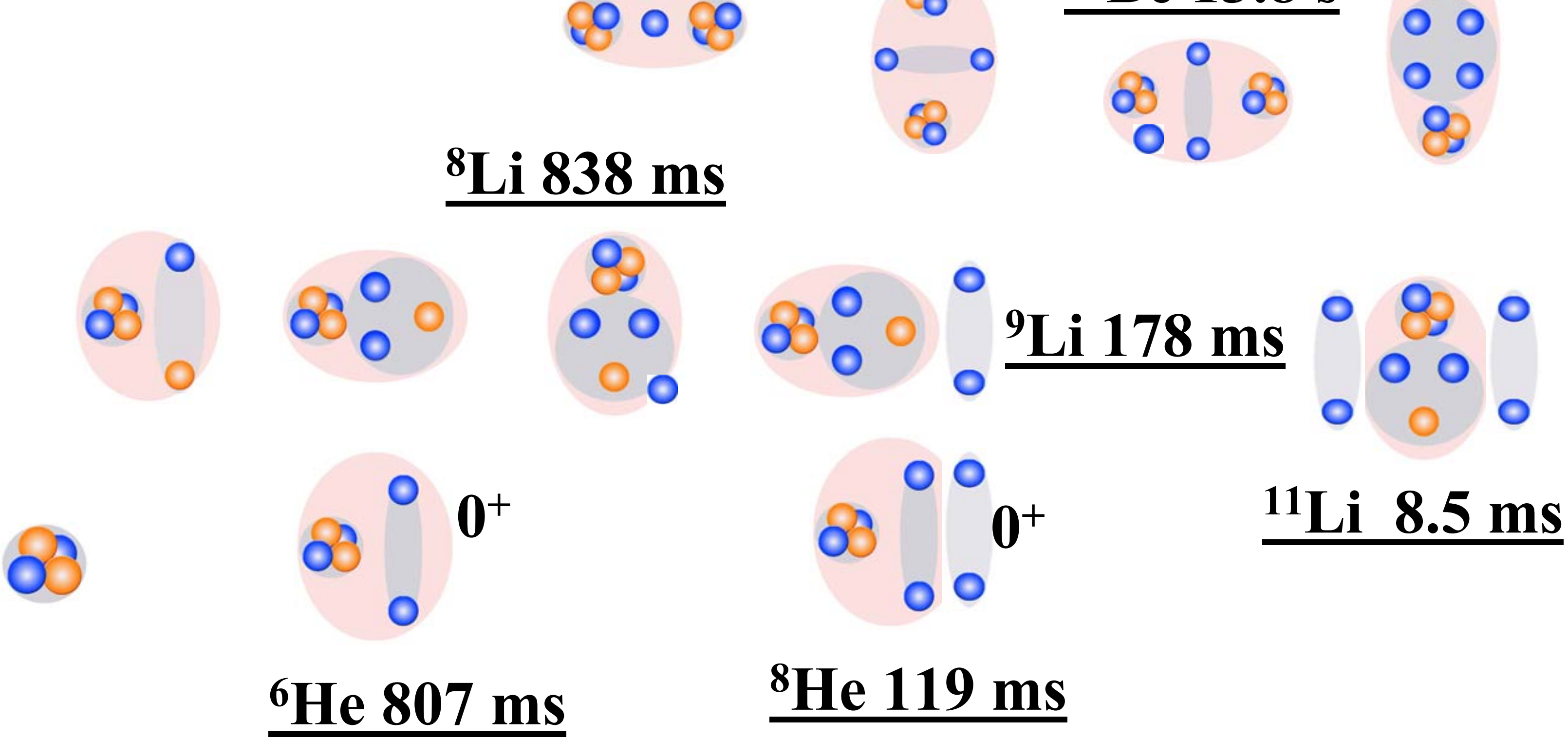
$$Z_{pr}/A_{pr} = 5/12\ {}^{12}C \rightarrow {}^{12}N$$

(Charge Exchange)^2

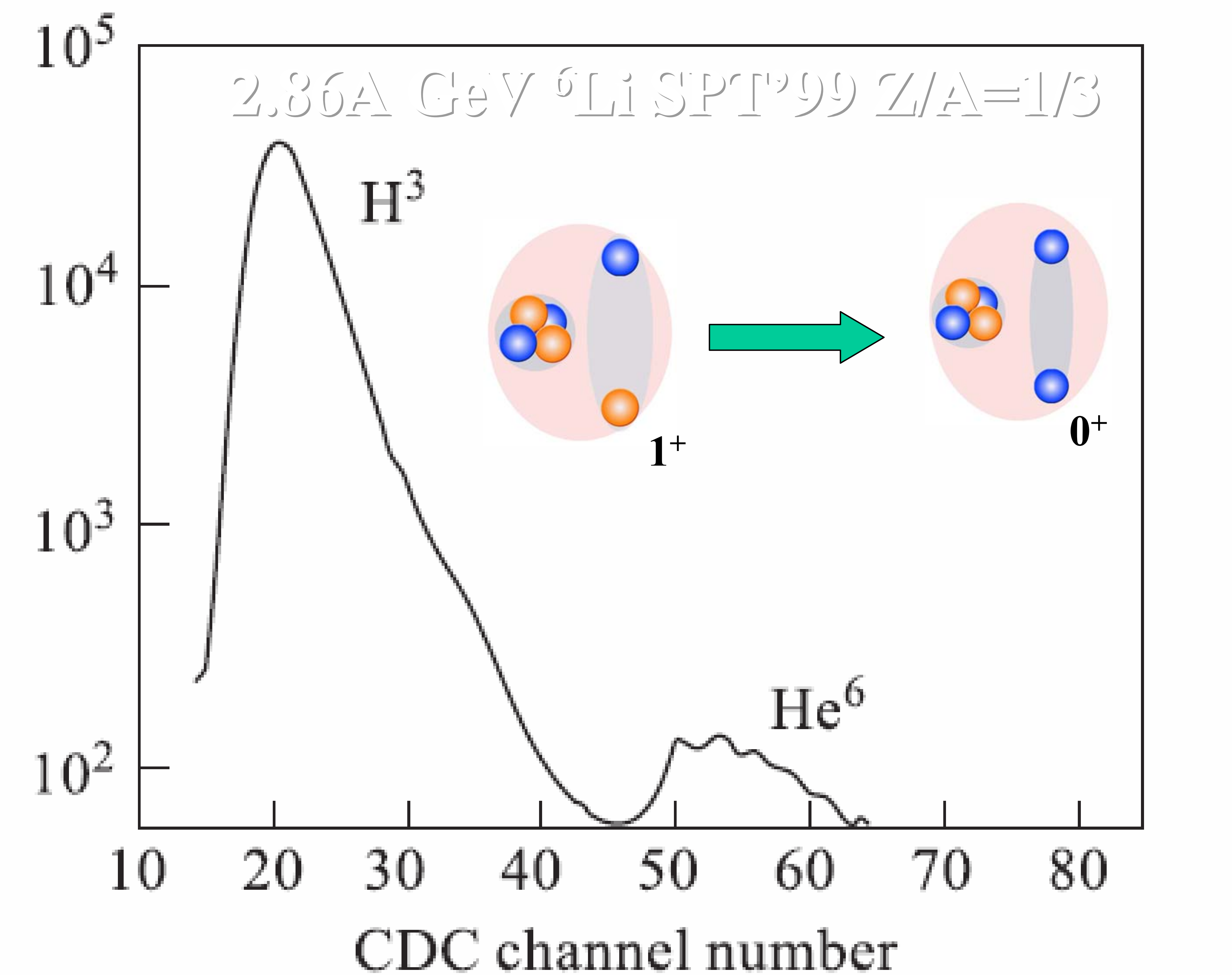




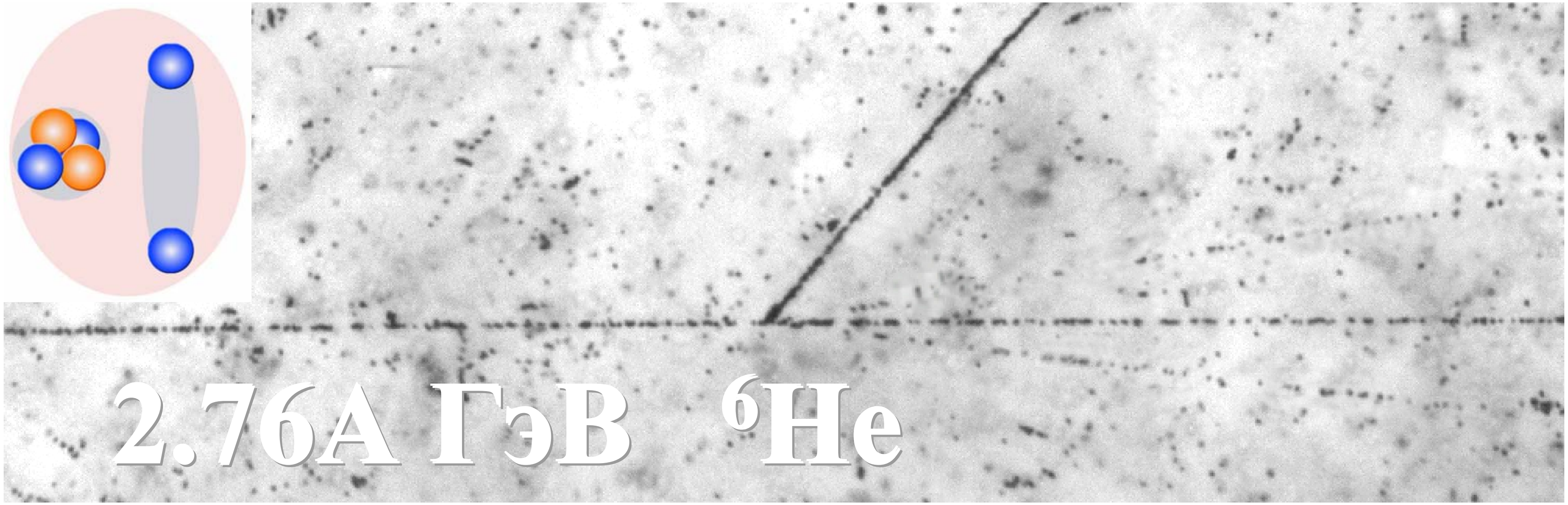


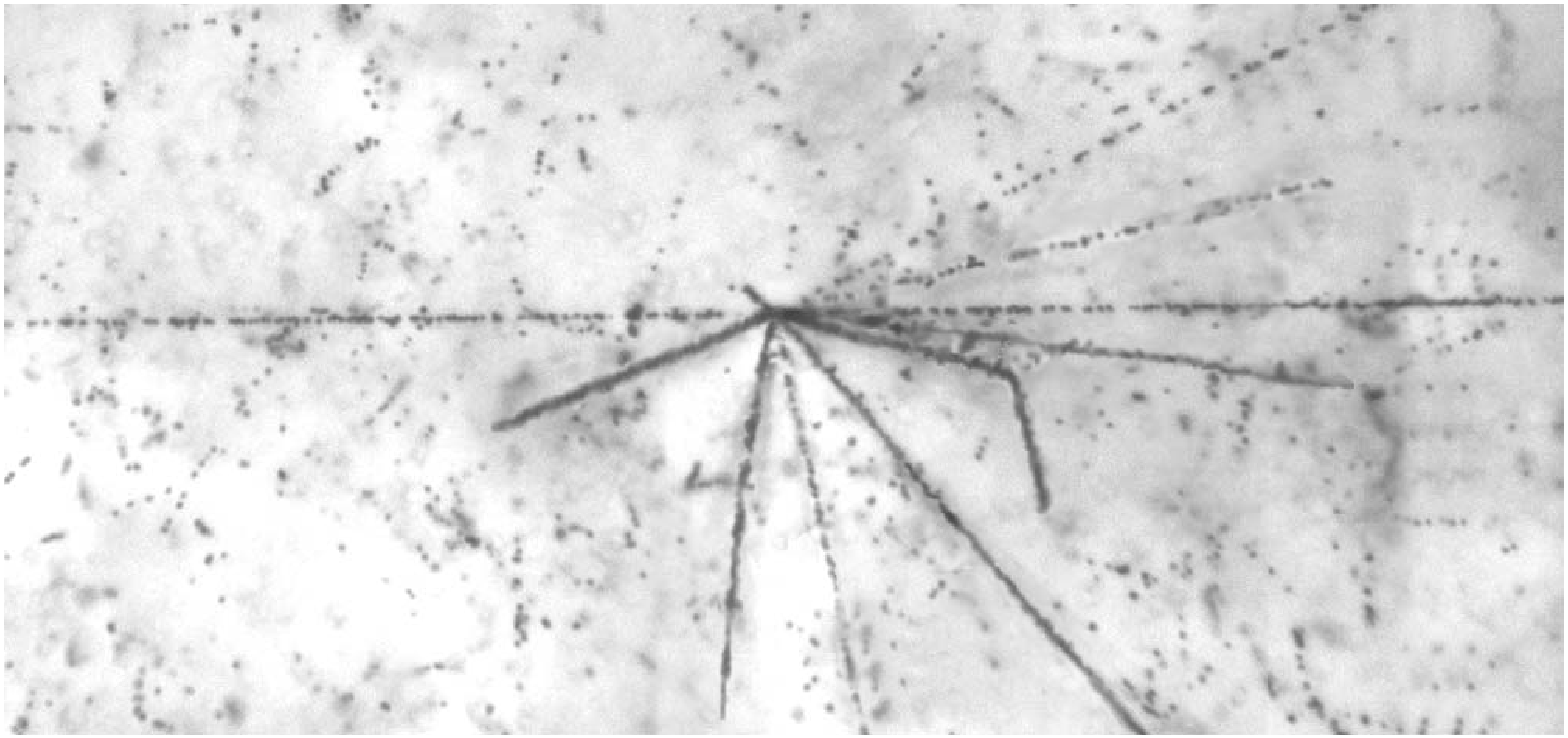


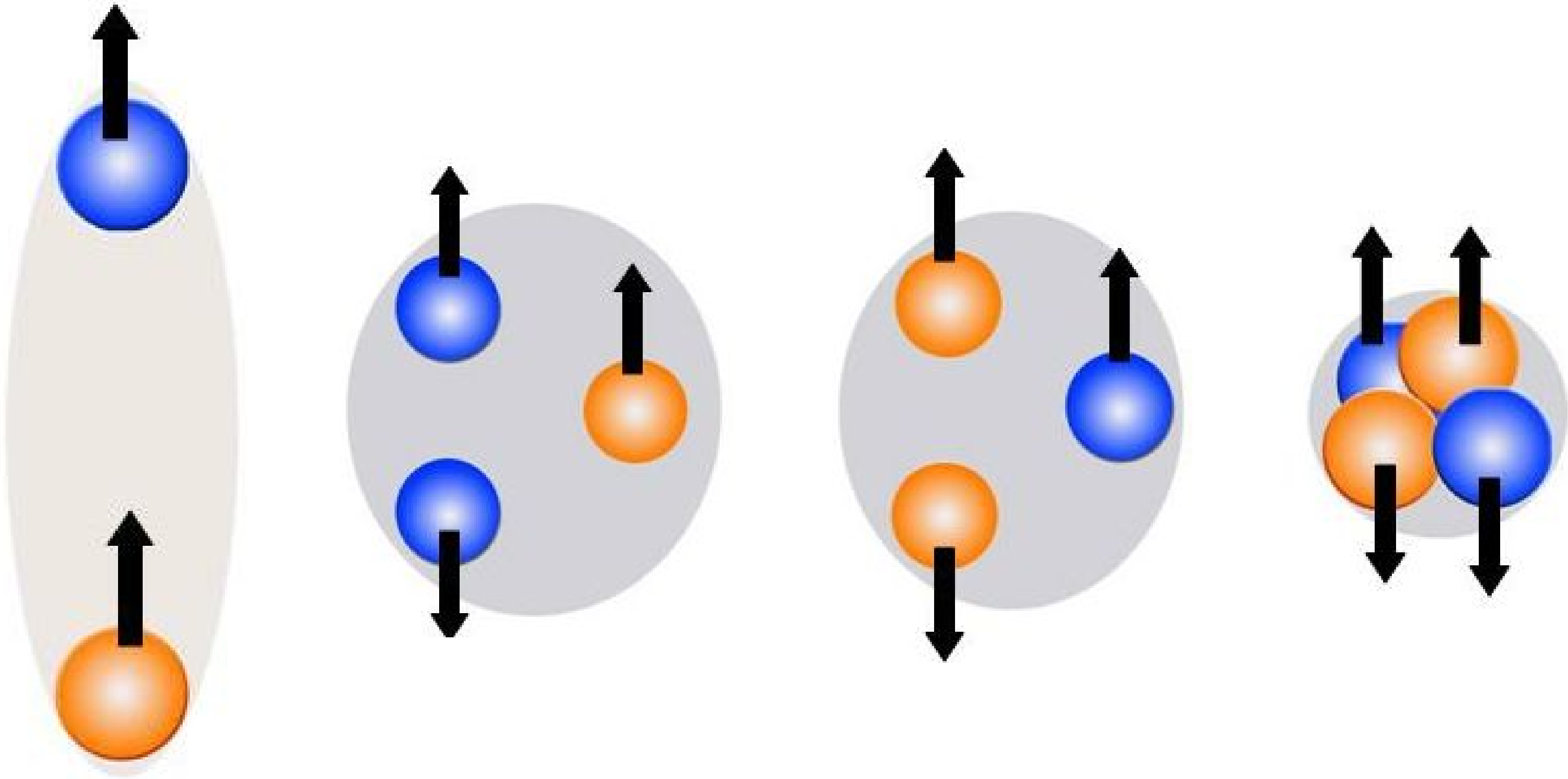
^{12}B 20 ms
^{10}Be 1510000 y
^{12}Be 23 ms
^{11}Be 13.8 s
^{8}Li 838 ms
^{9}Li 178 ms
0^+
0^+
^{11}Li 8.5 ms
^{6}He 807 ms
^{8}He 119 ms



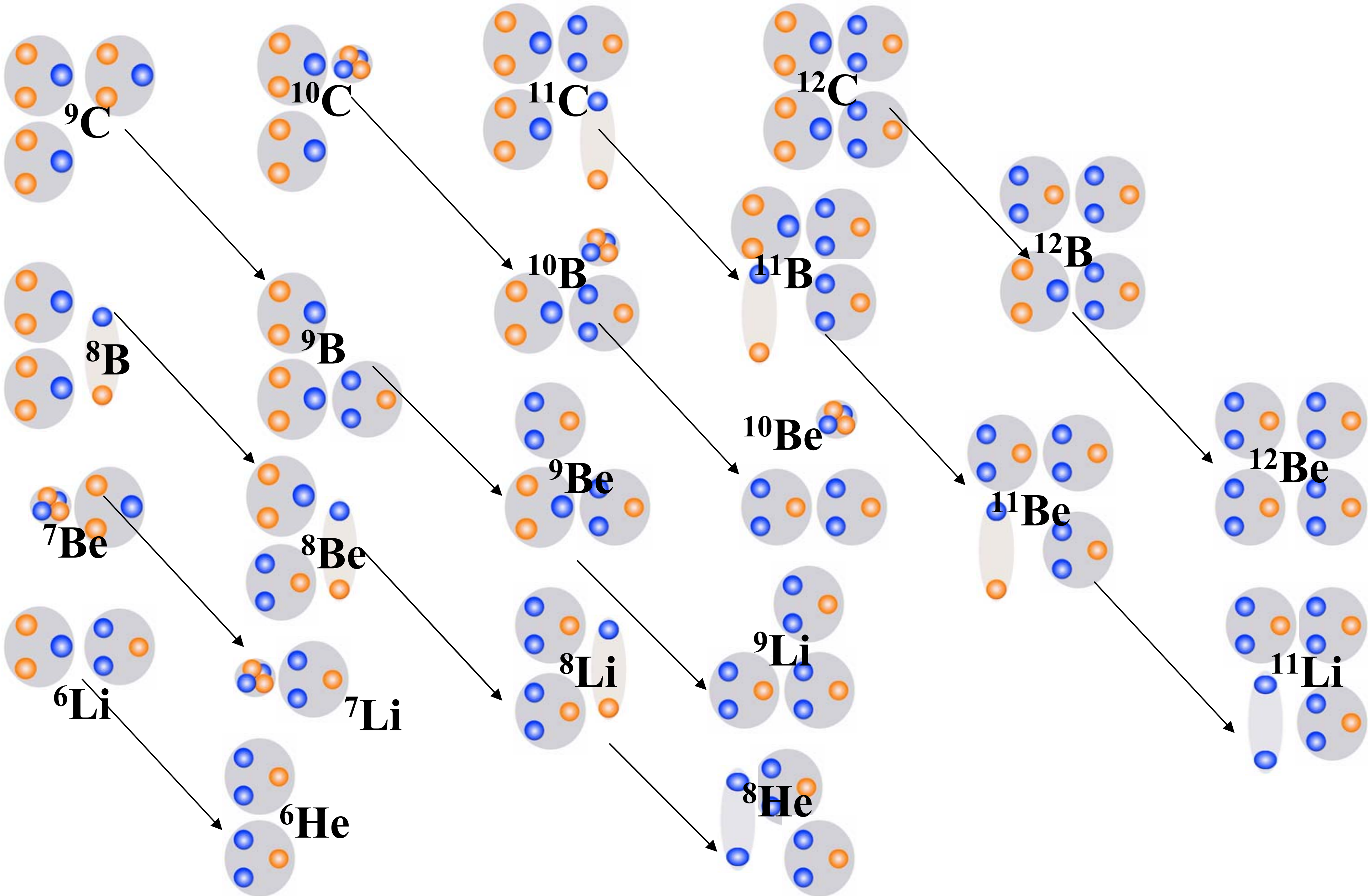
2.86A GeV 6Li SPT'99 Z/A=1/3
H3
He6
1+
0+
10
20
30
40
50
60
70
80
CDC channel number


2.76A ГэВ ^{6}He

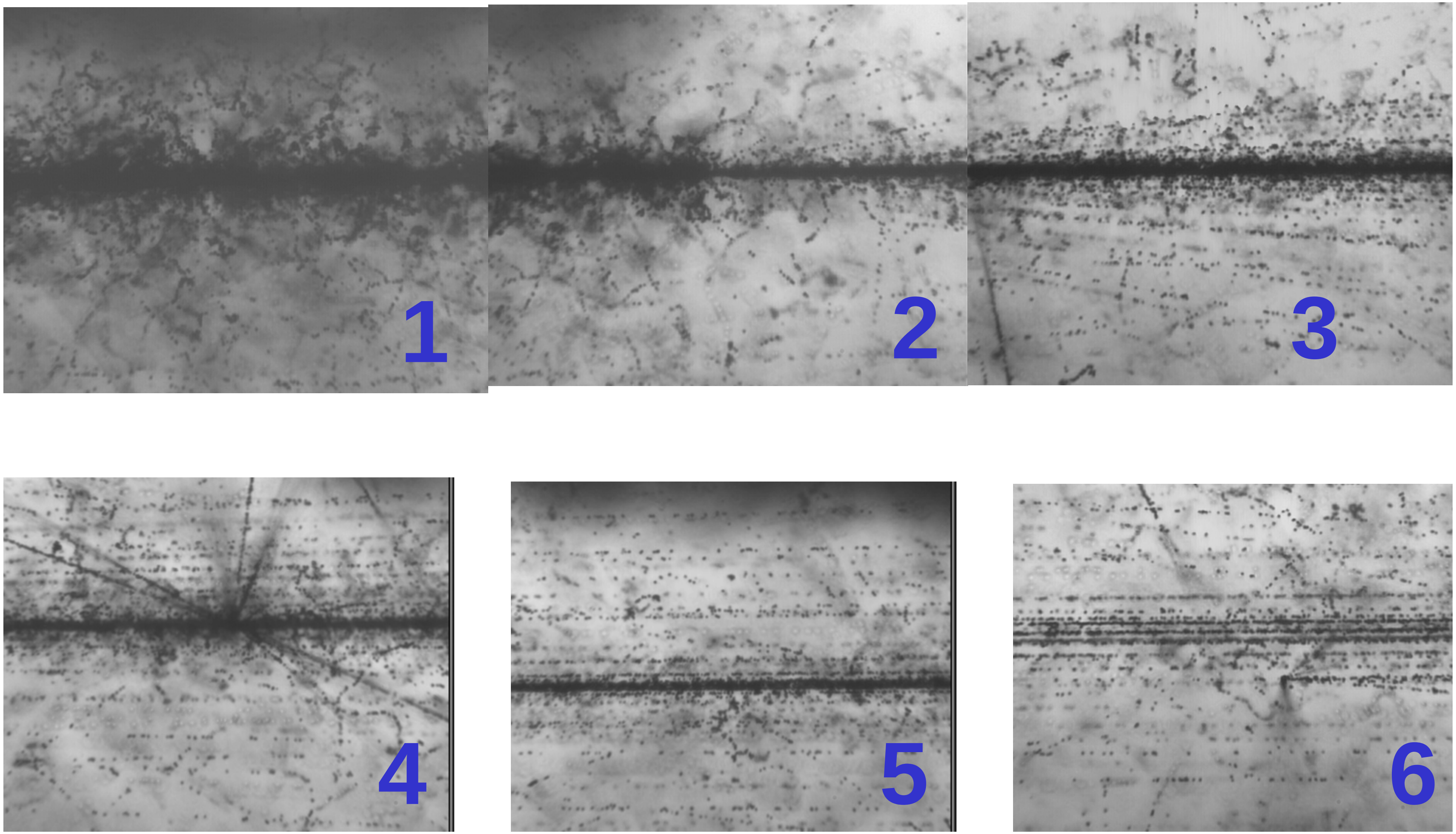


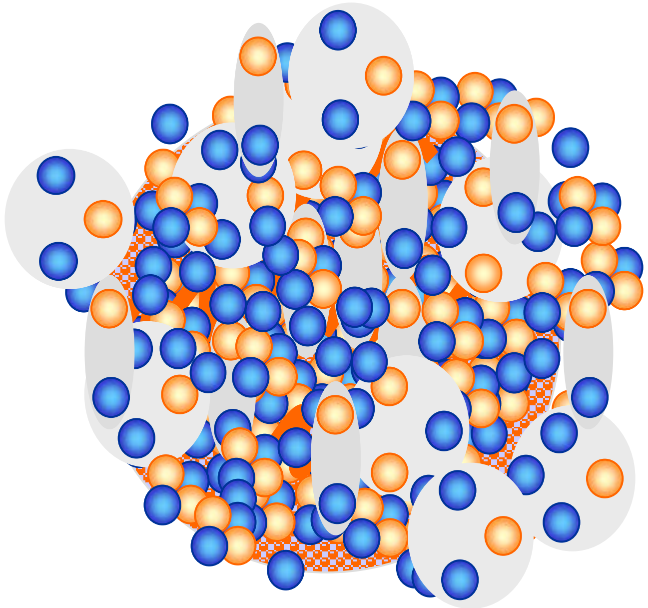
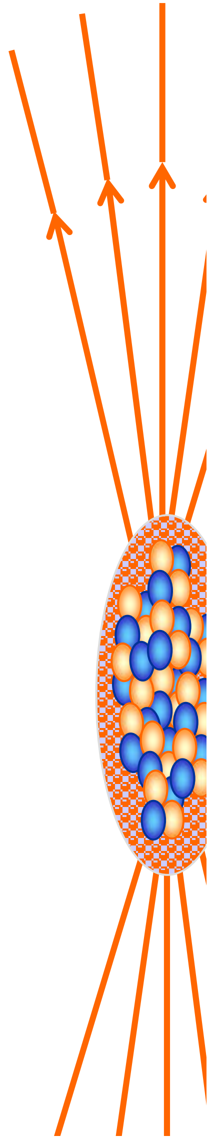


Multiply mirrored states?



SPS: 158 A GeV/c Pb



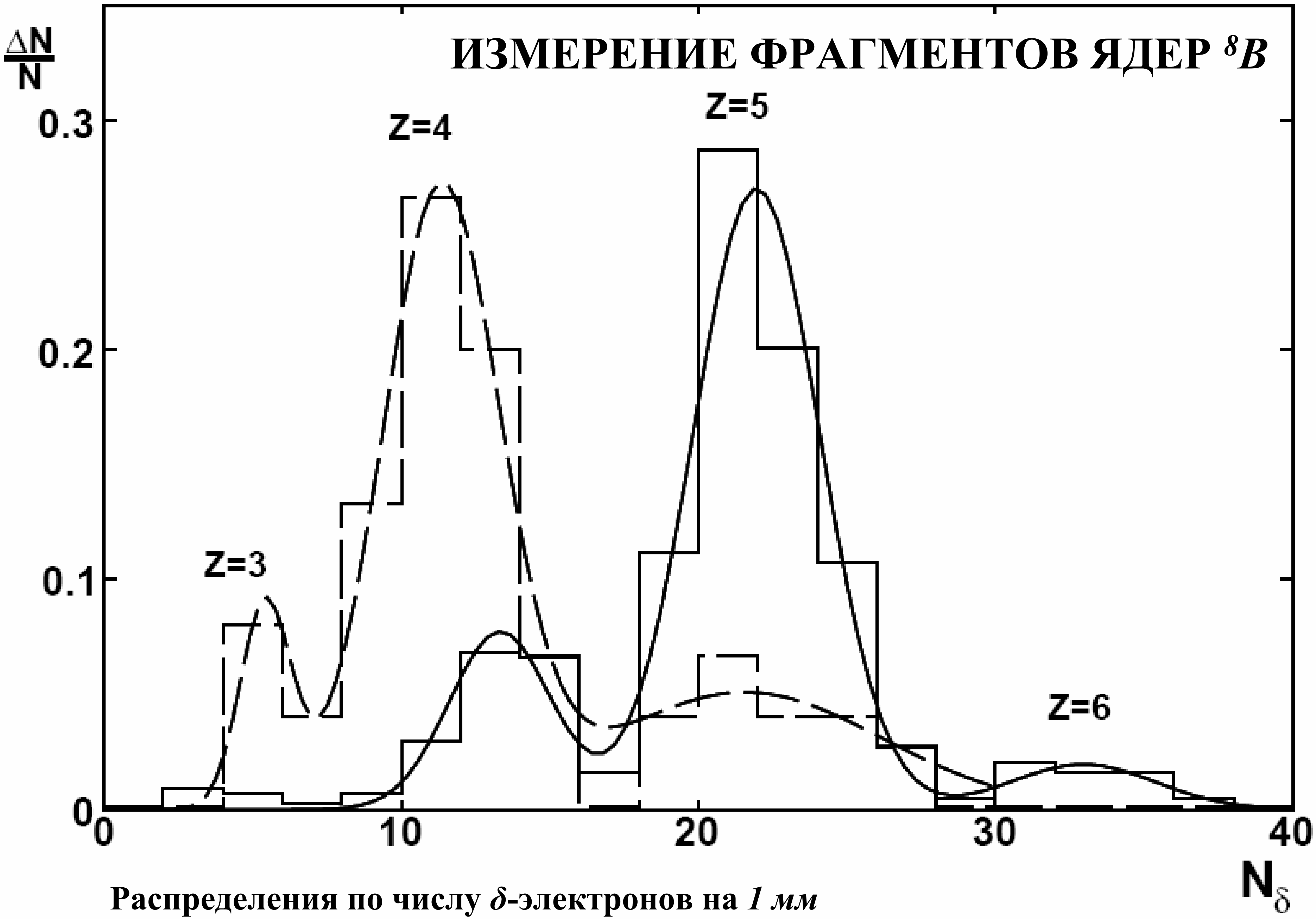



CONCLUDING REMARKS

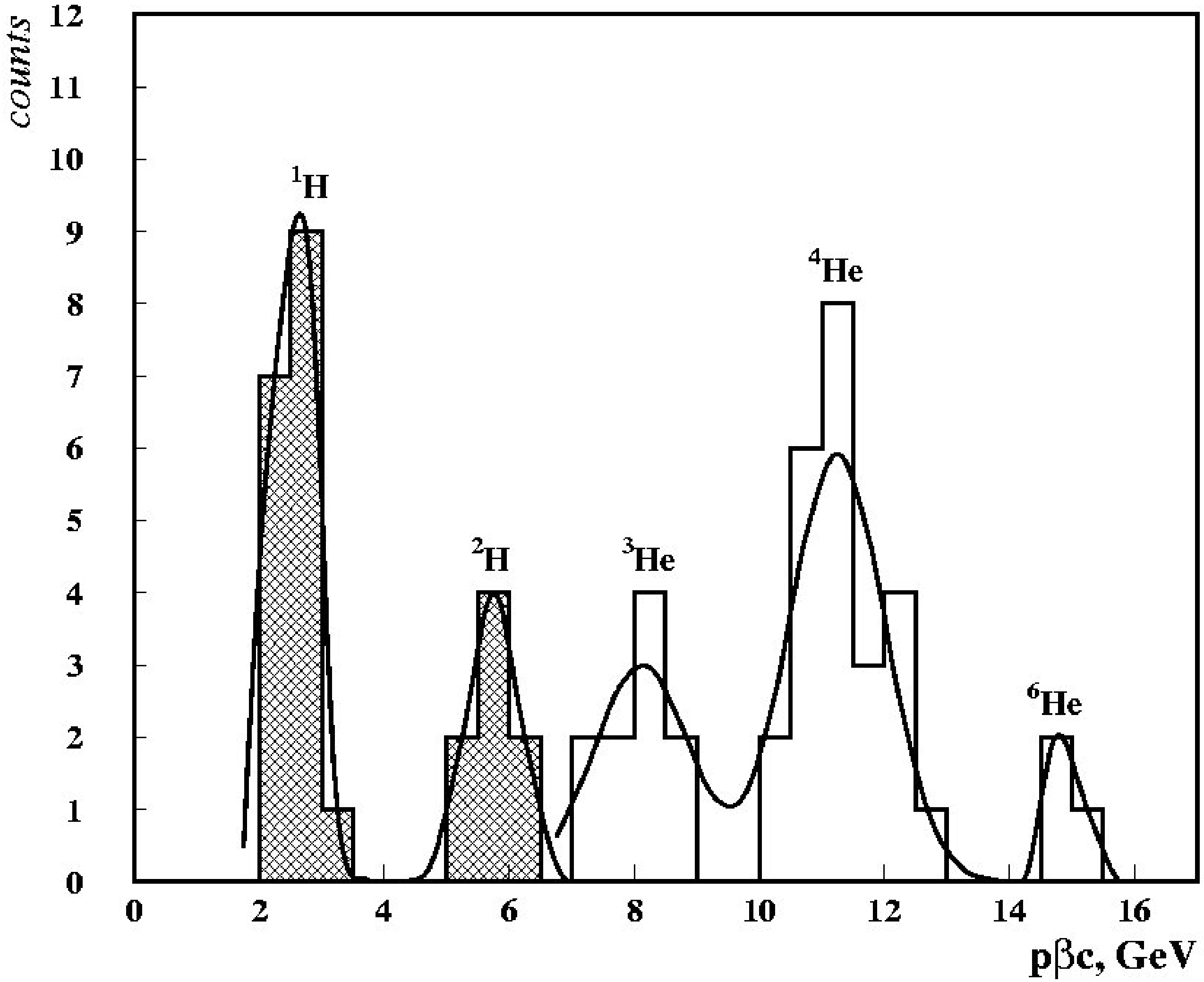
The presented observations serve as an illustration of prospects of the Nuclotron for nuclear physics and astrophysics researches. In spite of an extraordinarily large distinction from the nuclear excitation energy the relativistic scale does not impede investigations of nuclear interactions down to 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.

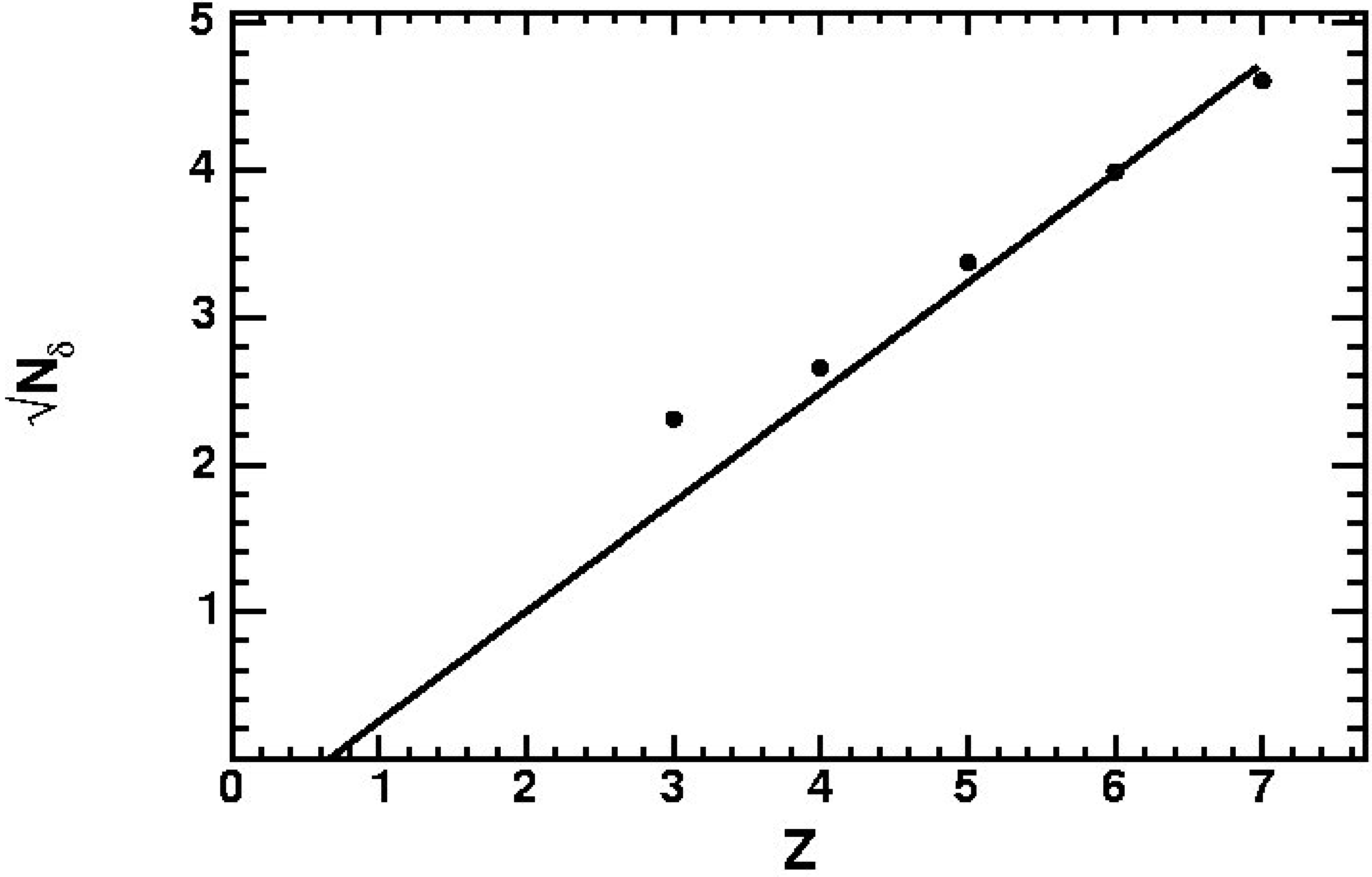
Due to a record space resolution the emulsion technique provides unique entirety in studying of light nuclei, especially, neutron-deficient ones. Providing the 3D observation of narrow dissociation vertices this classical technique gives novel possibilities of moving toward more and more complicated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



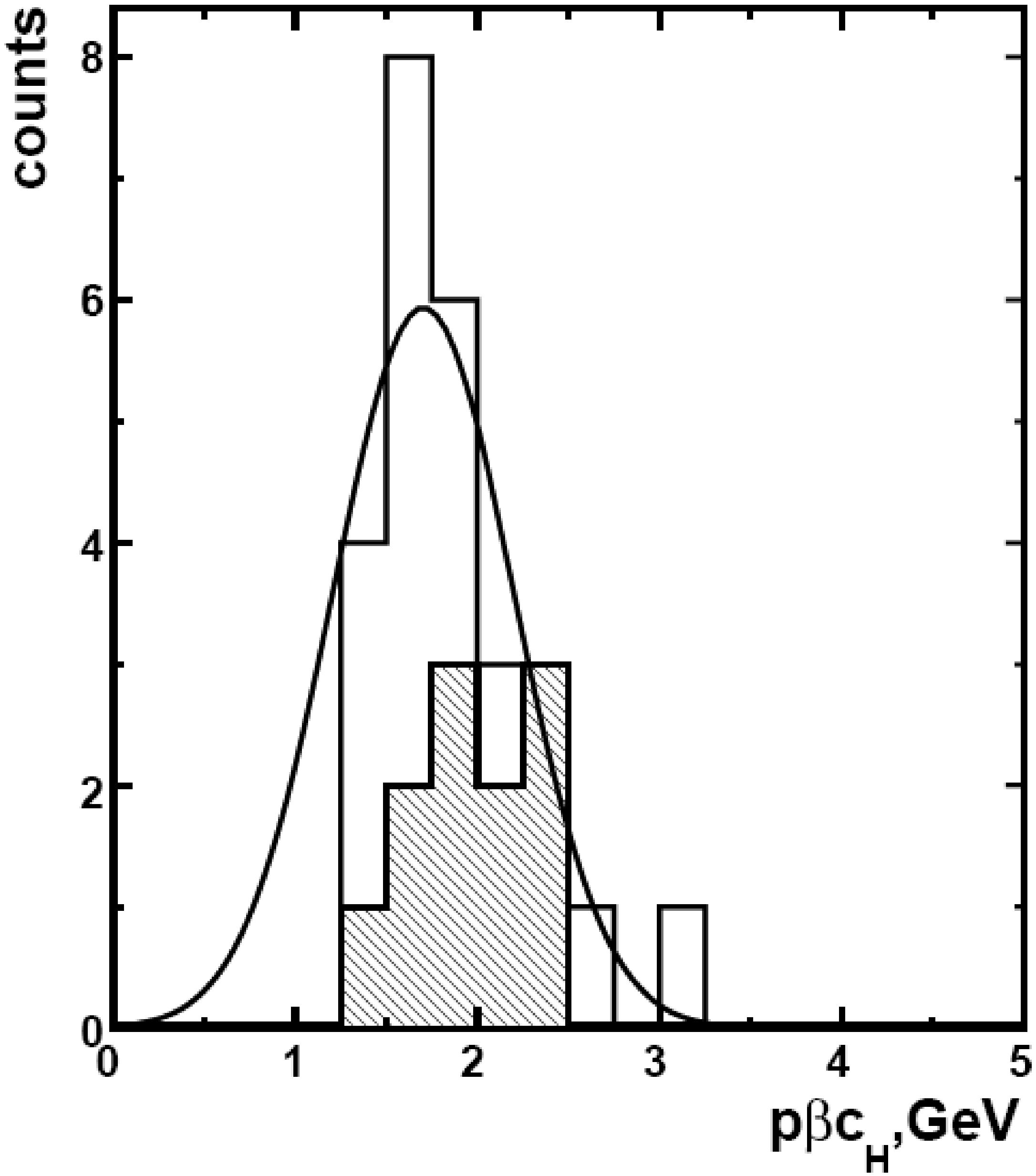
Распределения по числу *δ*-электронов на *1 мм* следов пучковых частии релятивистских фрагментов с зарядами $Z_{fr} > 2$.



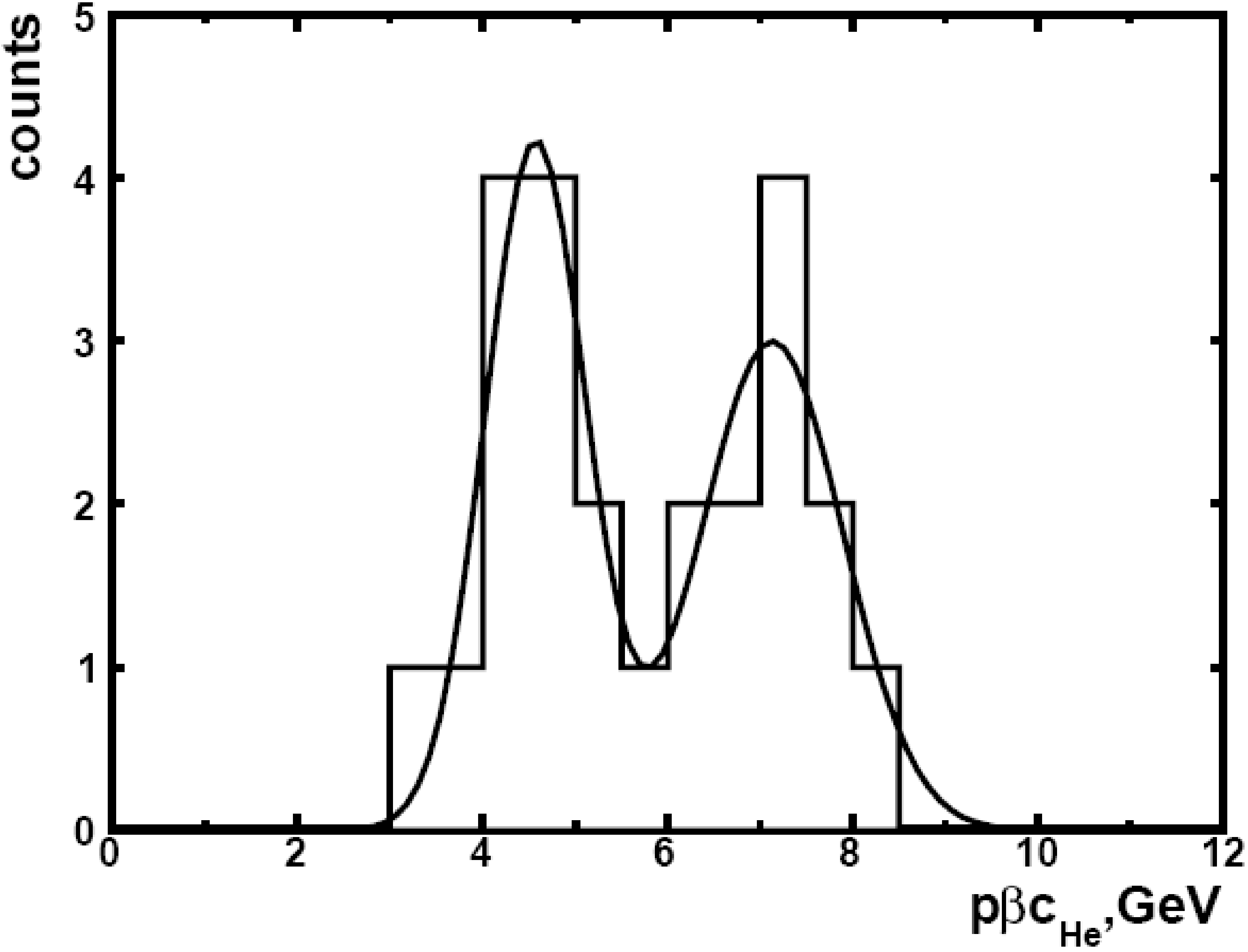
Распределение одно- и двухзарядных фрагментов ядра *^{14}N* по измеренным значениям *pβc* в канале диссоциации *3He*+*H*.



Зависимость квадратного корня среднего числа *δ*-электронов <*Nδ*> на 100 мкм длины следа от величины предполагаемого заряда фрагмента-спектатора Z_{rf}.



Распределение однозарядных фрагментов ядра *^{8}B* по измеренным значениям *pβc* в каналах диссоциации *Be + H* и *2He+H*) Заштрихованная часть гистограммы относится к каналу *2He + H*.



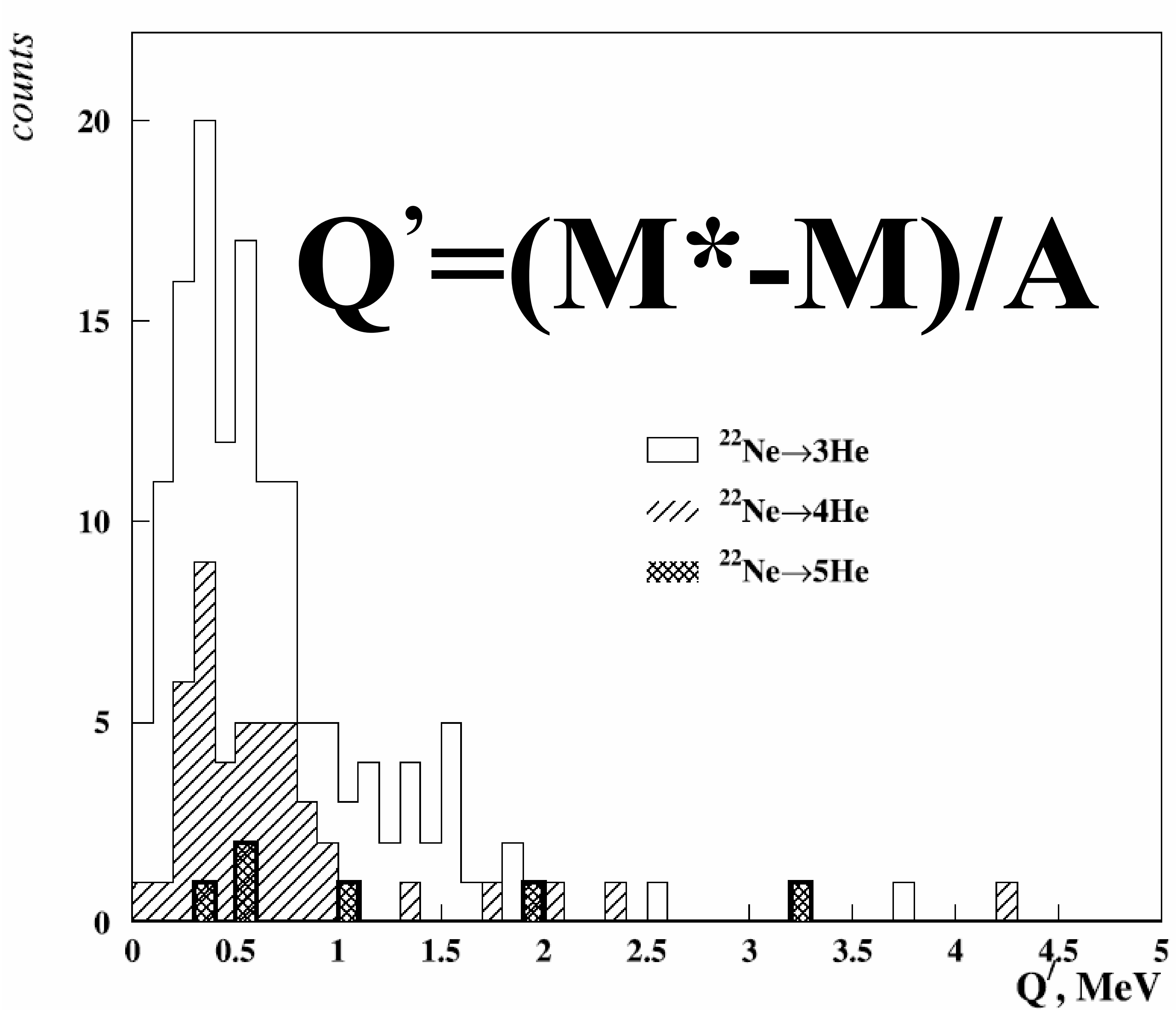
Распределение двухзарядных фрагментов ядра ^{8}B по измеренным значениям $p\beta c$.

$$^{7}\mathrm{Li} \to {}^{4}\mathrm{He} + {}^{3}\mathrm{H} \quad \langle p_T^{*} \rangle = 108 \pm 2\ \text{МэВ}/c$$

$$^{7}\mathrm{Be} \to {}^{4}\mathrm{He} + {}^{3}\mathrm{He} \quad \langle p_T^{*} \rangle = 147 \pm 5\ \text{МэВ}/c$$

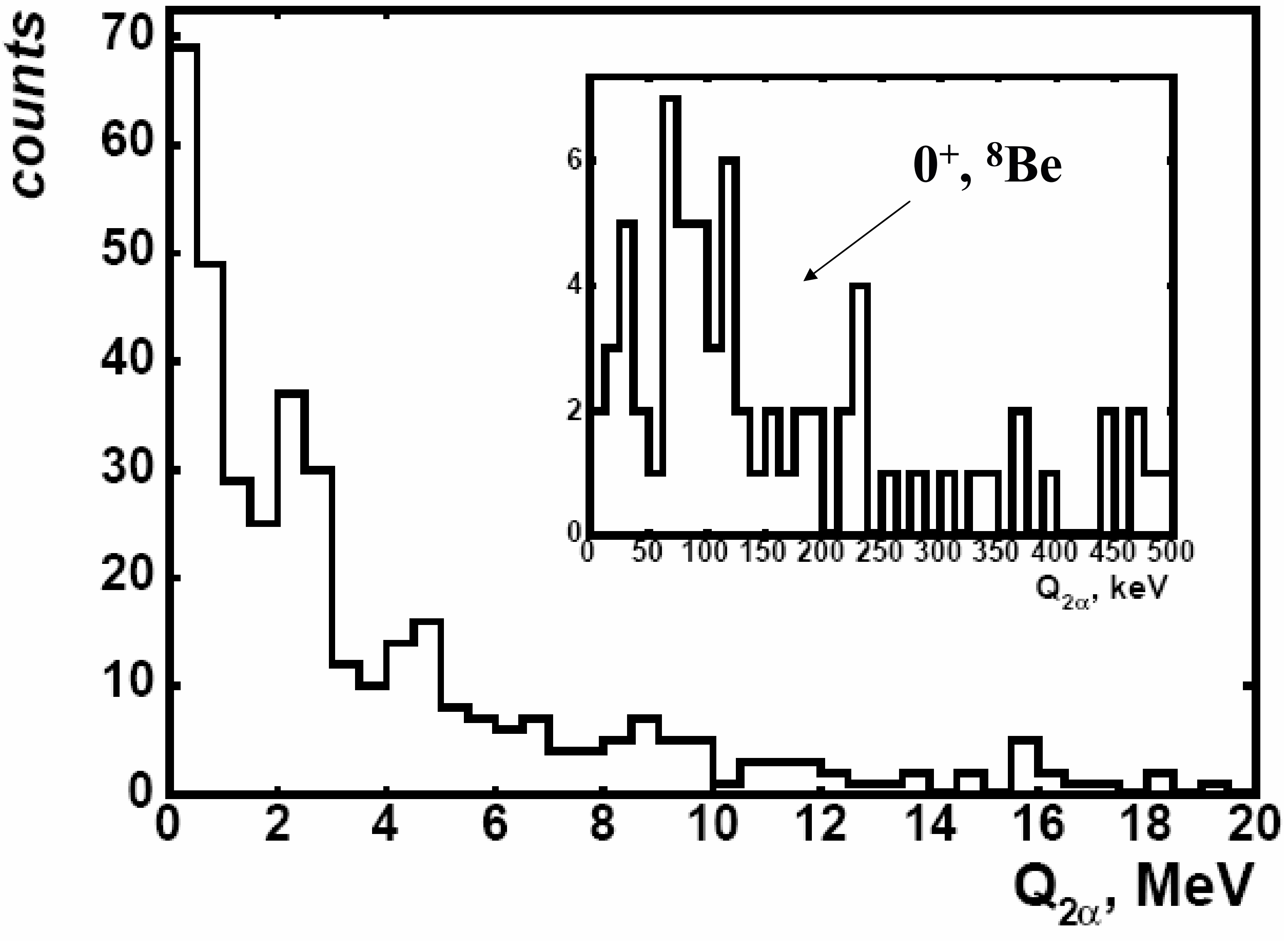
$$\langle T^{*} \rangle \sim \langle p_T^{*} \rangle^{2}$$

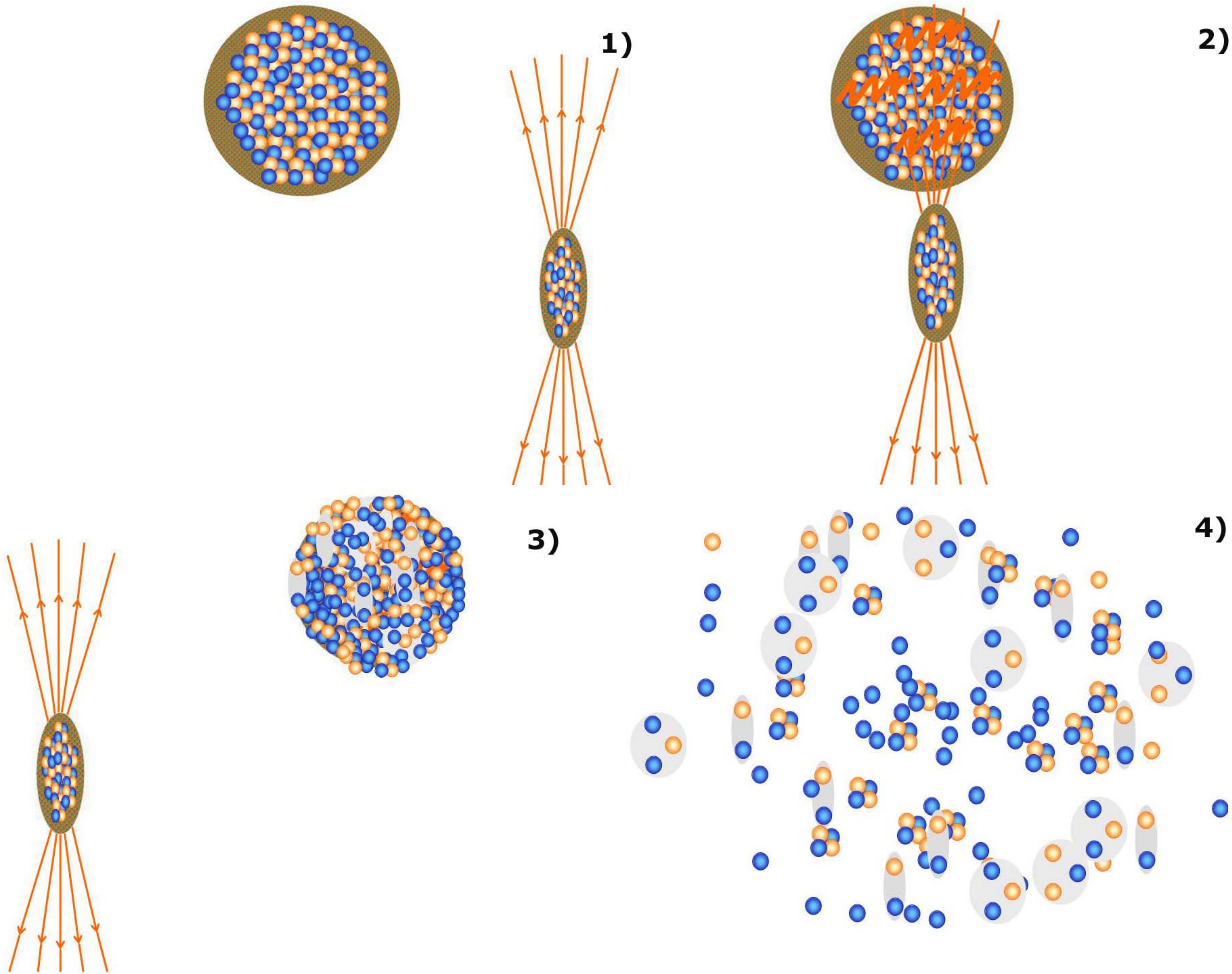
Отношение ≈ 2, т. е. Кулон



Q'=(M*-M)/A
counts
20
15
10
5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Q', MeV
²²Ne→3He
²²Ne→4He
²²Ne→5He

$Q_{2\alpha}$ $^{14}N \rightarrow 3\alpha + X$




1)
2)
3)
4)

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