Pavel Zarubin "Overview of new exposures of nuclear track emulsion in the BECQUEREL experiment"

Preserving a status of a universal and inexpensive detector, the nuclear track emulsion (NTE) with unrivaled resolution and completeness ensures the observation of tracks beginning with fission fragments and down to relativistic particles.

Development of a study of formation of triplets of alpha particles in the Hoyle's state arising in dissociation of relativistic ^{12}C nuclei in a nuclear track emulsion is presented.

The analysis of layers transversely irradiated by muons with an energy of 160 GeV at CERN and about 2.5 GeV in the "muon torch" of the U-70 IHEP accelerator is in progress.

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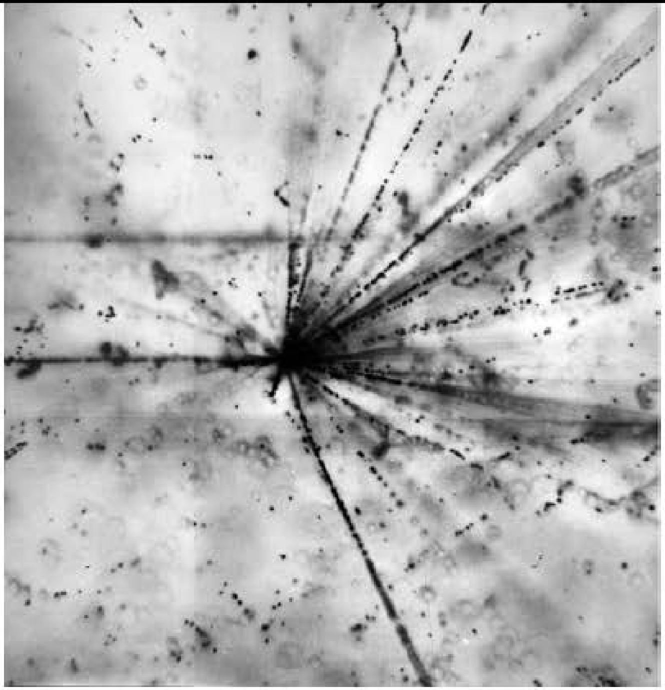

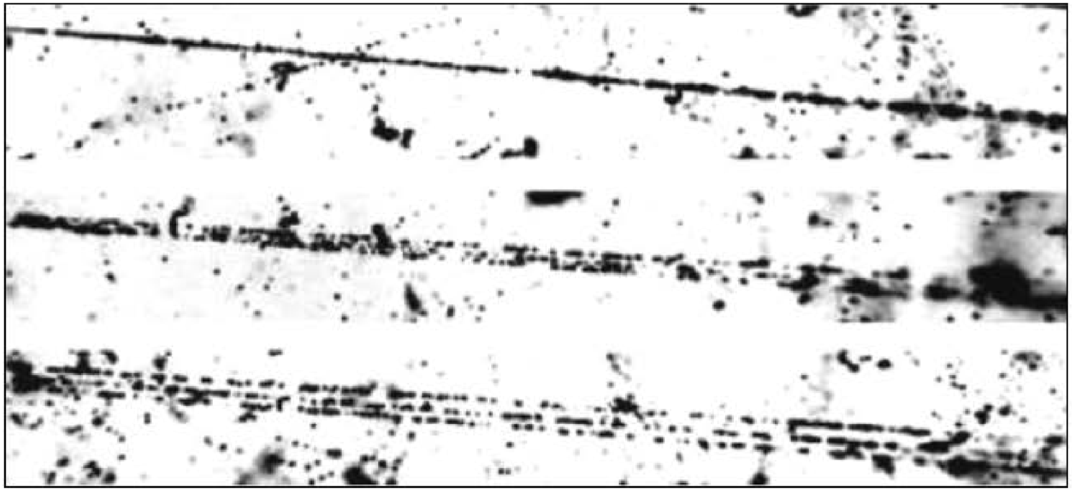


K. D. Tolstov


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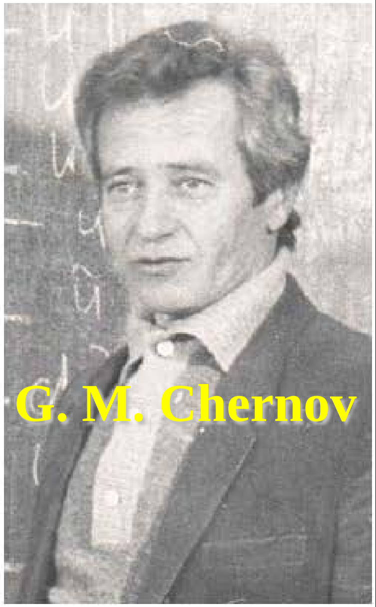
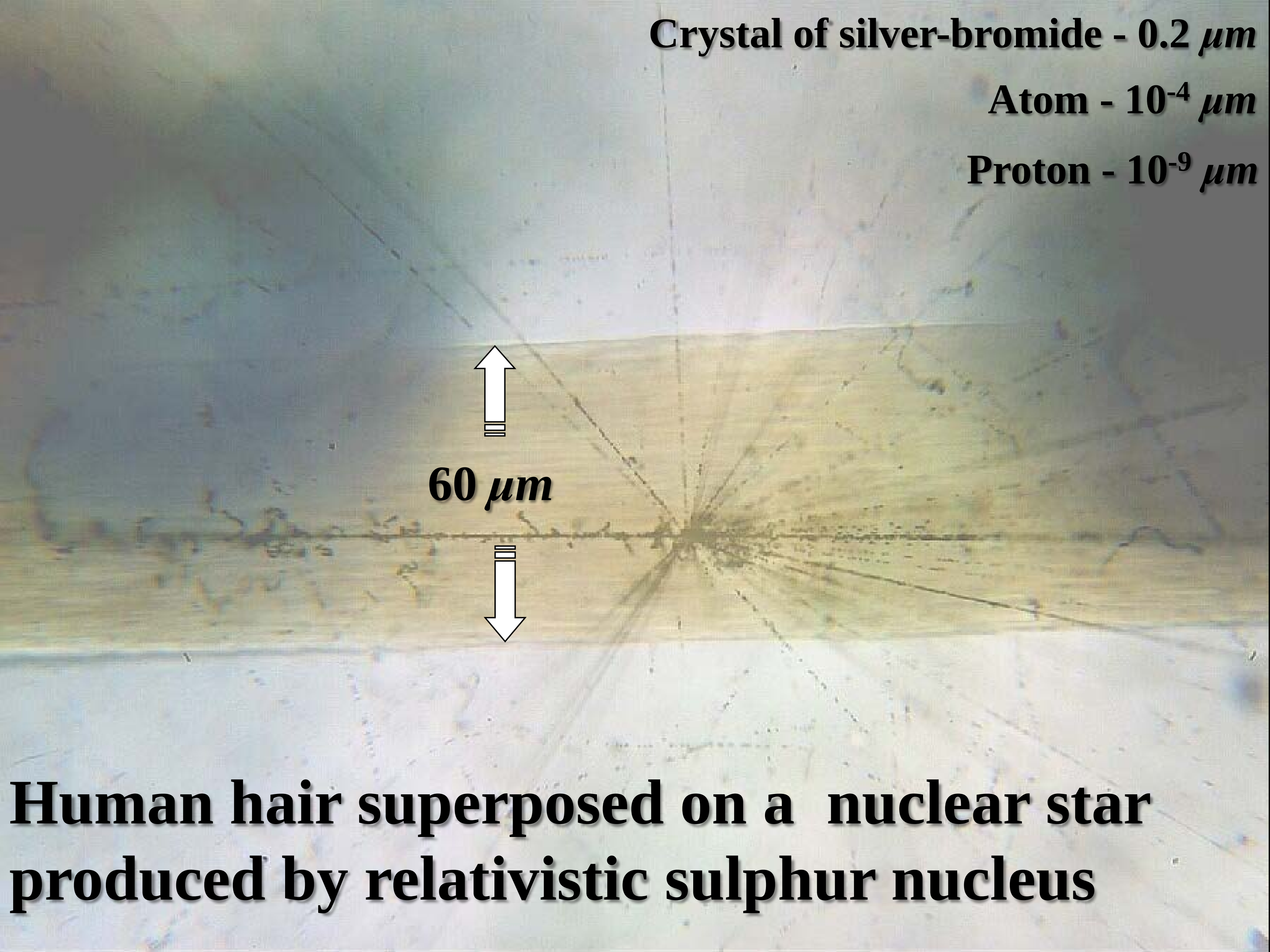
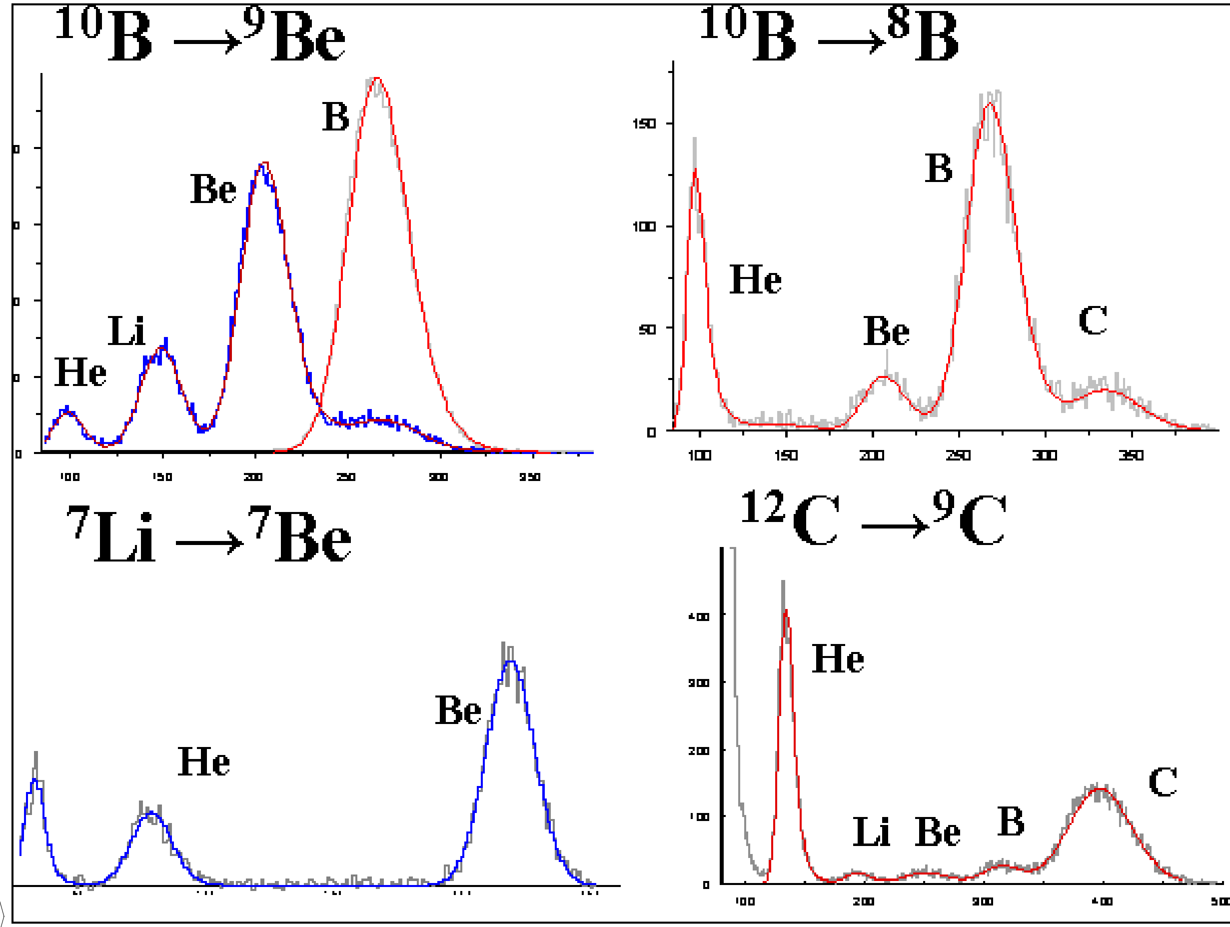

G. M. Chernov



Human hair superposed on a nuclear star produced by relativistic sulphur nucleus

The foundations of methods of measurements were laid at the beginning of studies on the physics of cosmic rays and, then, used widely beams of relativistic nuclei became available. For these purposes microscopes KSM-1 manufactured by Carl Zeiss (Jena) about half of century ago and still functioning well are applied in JINR.


$^{10}B \rightarrow {}^{9}Be$
He
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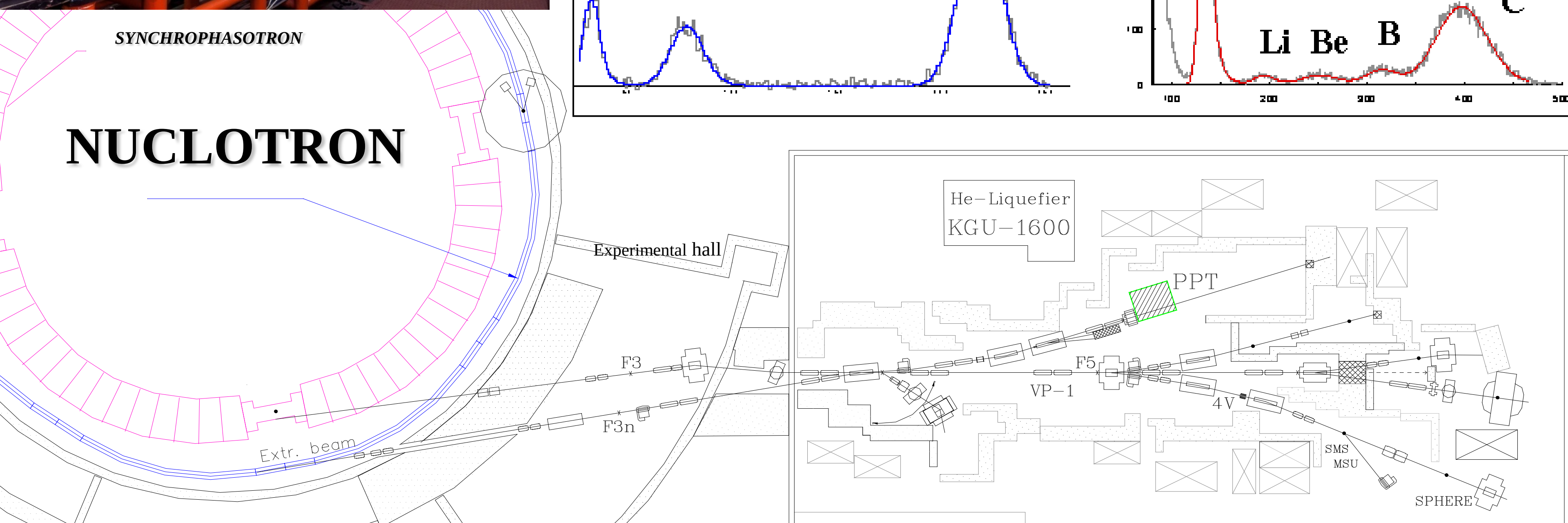
SYNCHROPHASOTRON
NUCLOTRON
Experimental hall
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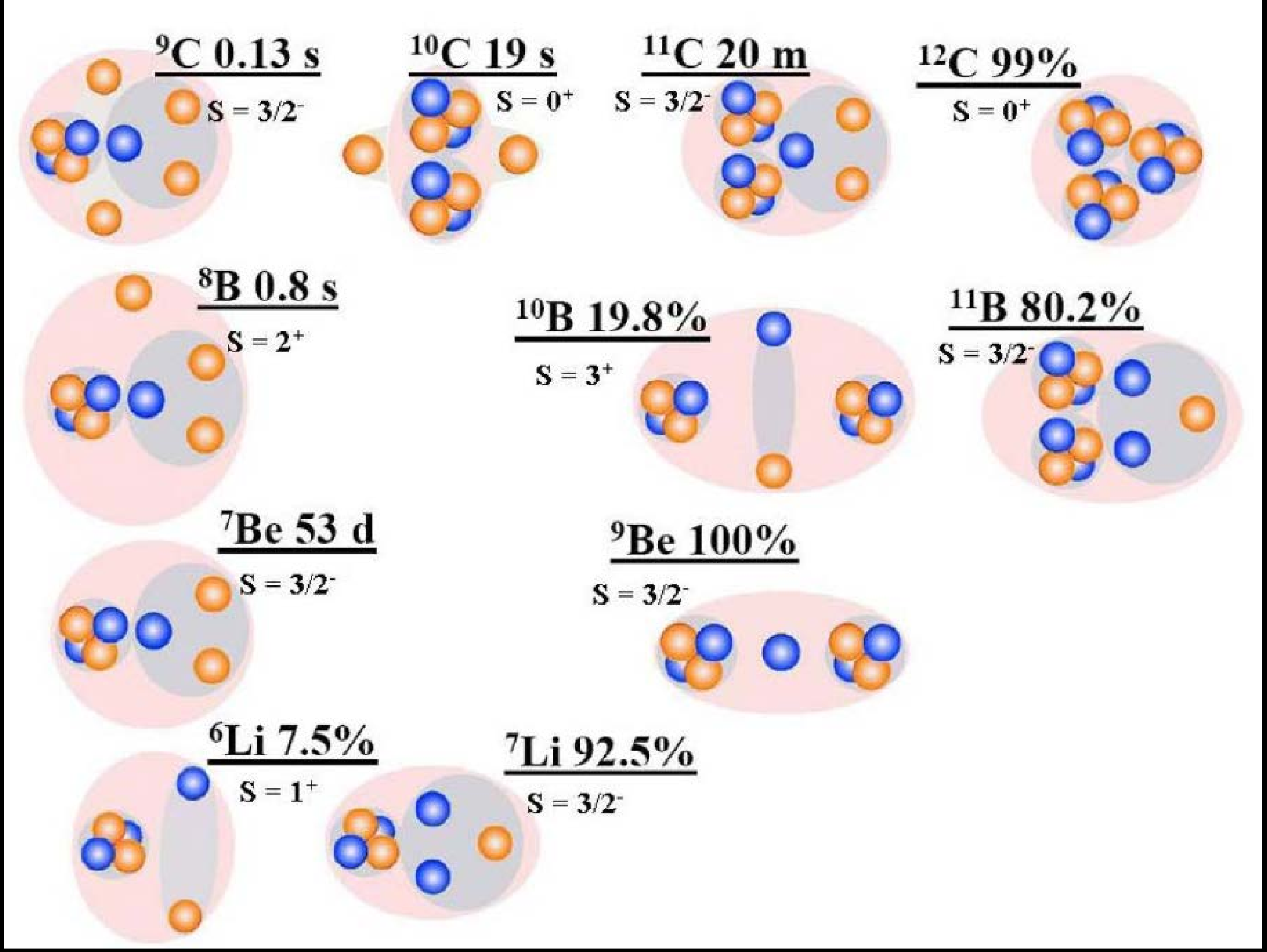
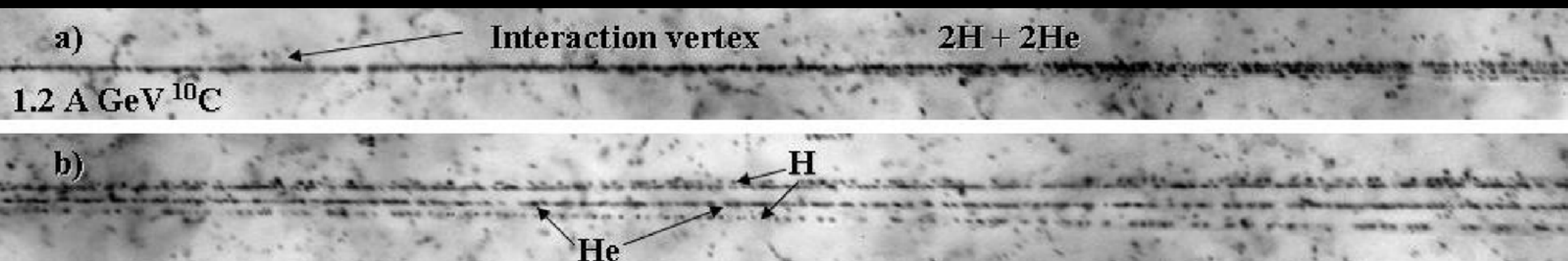
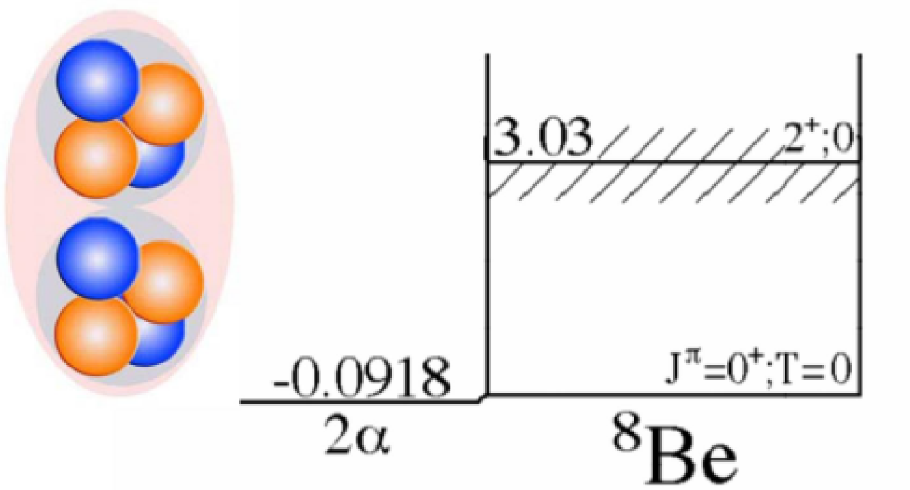


Exposures of nuclear track emulsion (NTE) to newly formed beams of relativistic nuclei, which began in the 1970s at the JINR Synchrophasotron of and LBL Bevalac (Berkeley, USA), since the early 2000s have found a continuation at the JINR Nuclotron in the BECQUEREL Experiment. A topical application of the NTE technique consists in studying the structure of light nuclei including radioactive ones on a basis of advantages of the relativistic approach. Distributions of peripheral interactions of studied nuclei over channels of dissociation into relativistic charged fragments convey features of their structure. This possibility is lacking in electronic experiments. The NTE makes it possible to observe the breakdown of nuclei up to a coherent dissociation, in which the target nuclei are not visibly destroyed in an obvious way.

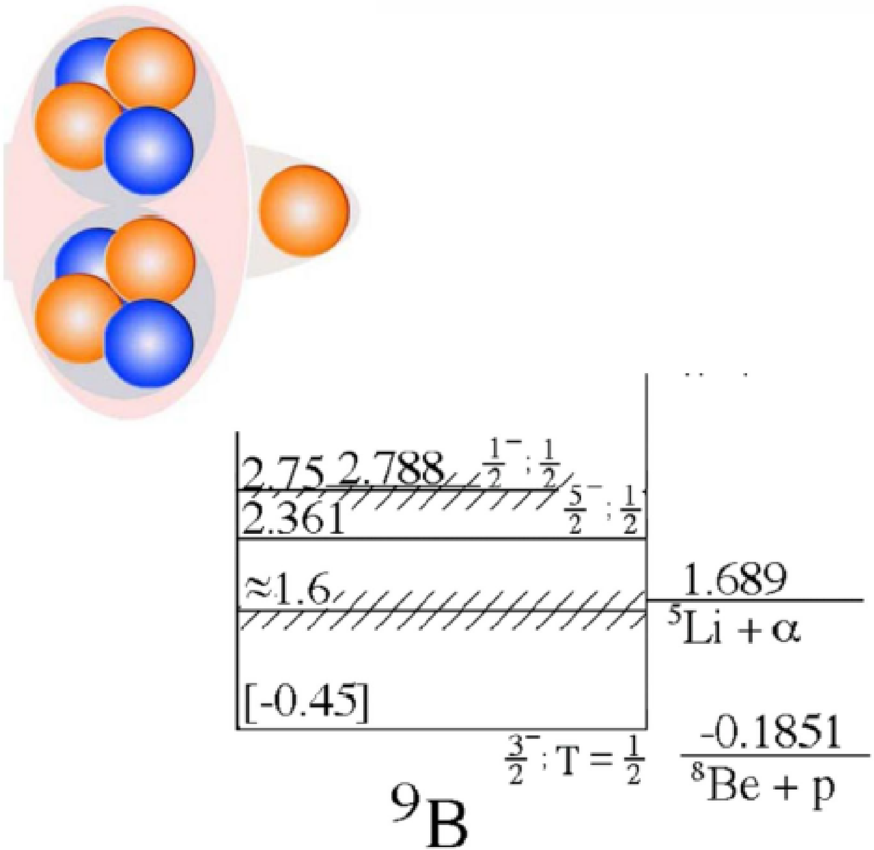
Channel	^{12}C	^{11}C	^{10}C	^{9}C
B + H		6 (5 %)	1 (0.4 %)	15 (14 %)
Be + He		18 (13 %)	6 (2.6 %)	
Be + 2H				16 (15 %)
3He	100 (100 %)	25 (17 %)	12 (5.3 %)	16 (15 %)
2He + 2H		72 (50 %)	186 (82 %)	24 (23 %)
He + 4H		15 (11 %)	12 (5.3 %)	28 (27 %)
Li + He + H		5 (3 %)		
Li + 3H			1 (0.4 %)	2 (2 %)
6H		3 (2 %)	9 (4 %)	6 (6 %)



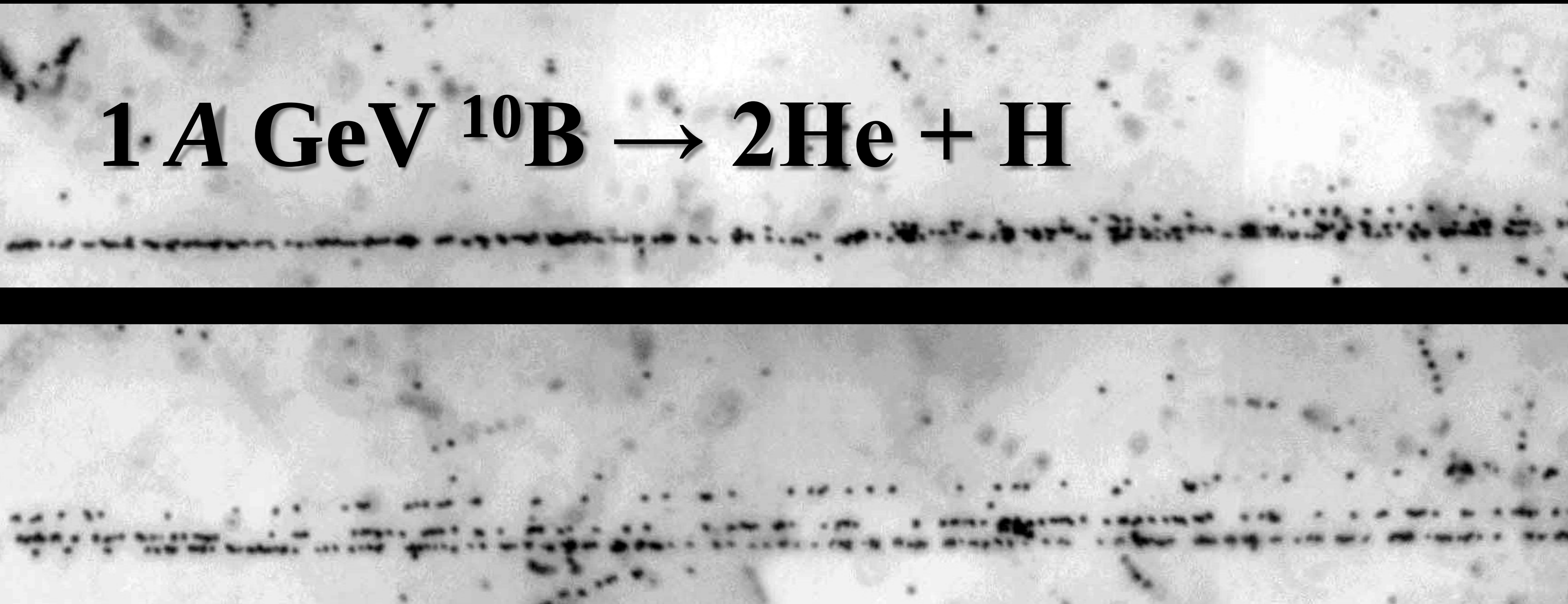
Events of this kind, called "white" stars, account for several percent of a total number of interactions. They are the most valuable for interpreting the structure, since in them distortion of an initial state of a nucleus that experiences dissociation can be considered minimal. Among the key results of the BECQUEREL experiment is determination of contribution of unstable ^{8}Be and ^{9}B nuclei in dissociation of relativistic nuclei ^{10,11}C and ^{10}B. Meaning of this fact is as follows. As is known, nucleosynthesis involving ^{8}Be and ^{9}B is suppressed due to absence of the bound ground states. Nevertheless, this circumstance does not prevent the substantial contribution of ^{8}Be and ^{9}B.



E_x (MeV ± keV)	$J^\pi; T$	Γ_{cm} (keV)	Decay
g.s.	$0^+; 0$	5.57 ± 0.25 eV [i]	α
3.03 ± 10 [i]	$2^+; 0$	1513 ± 15 [i]	α
[i,j]	2^+		
11.35 ± 150 [i]	$4^+; 0$	≈ 3500[b]	α

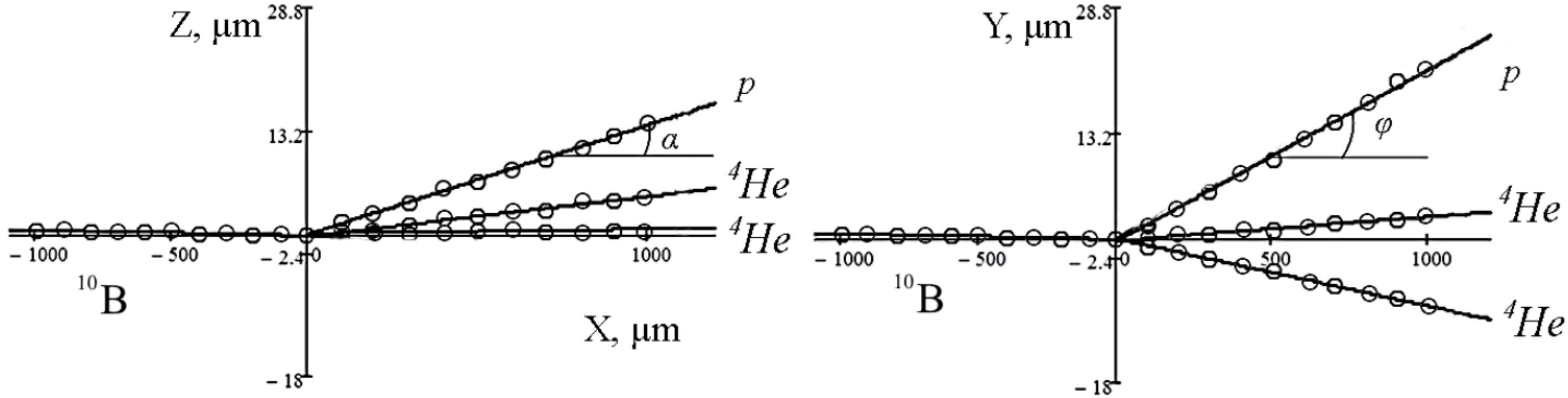


E_x [a] (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay
g.s.	$\frac{3}{2}^-; \frac{1}{2}$	0.54 ± 0.21	p
≈ 1.6 [b]			p, (α)
2.361 ± 5	$\frac{5}{2}^-; \frac{1}{2}$	81 ± 5	p, α
2.75 ± 300 [c]	$\frac{1}{2}^-; \frac{1}{2}$	3130 ± 200	p
2.788 ± 30	$\frac{5}{2}^+; \frac{1}{2}$	550 ± 40	p, α
4.3 ± 200 [d]		1600 ± 200	
6.97 ± 60	$\frac{7}{2}^-; \frac{1}{2}$	2000 ± 200	p
11.65 ± 60 [e]	$(\frac{7}{2})^-; \frac{1}{2}$	800 ± 50	p

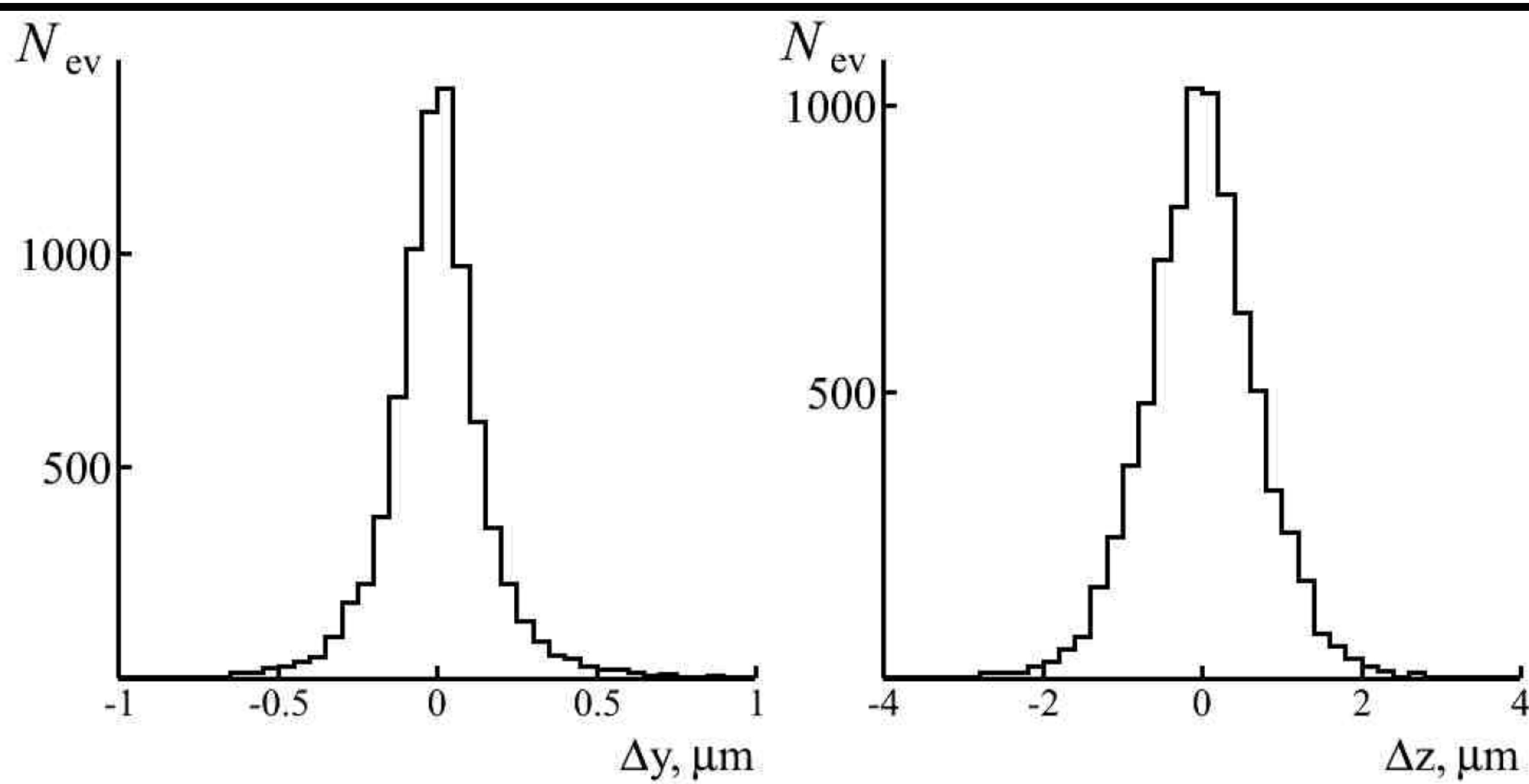


In general, energy of a few-particle system Q can be defined as difference between the invariant mass of the system M^* and a primary nucleus mass or a sum of masses of the particles M, that is, $Q = M^* - M$. M^* is defined as the sum of all products of 4-momenta $P_{i,k}$ fragments $M^{*2} = (\Sigma P_j)^2 = \Sigma(P_i P_k)$. Subtraction of M is a matter of convenience and Q is also named an invariant mass. Reconstruction of Q makes possible to identify decays unstable particles and nuclei.

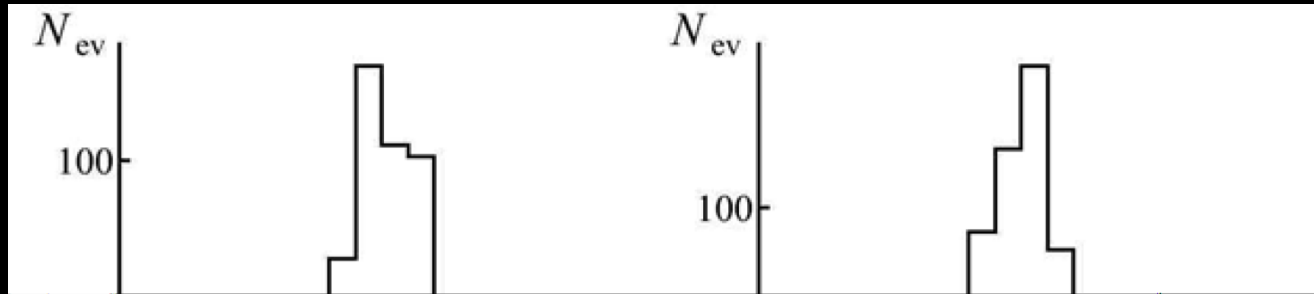
For the most part, fragments of a relativistic nucleus are contained in a narrow cone of the polar angle θ, which is estimated as $\theta = 0.2/P_0$, where the factor 0.2 GeV/c is determined by the spectator-nucleon transverse momentum, while P_0 is the momentum of the accelerated-projectile nucleon. The fragment 4-momenta $P_{i,k}$ in the cone can be determined in assumption of conservation of momentum per nucleon by fragments of a projectile (or its velocity). This approximation is well grounded when primary energy above 1 A GeV.

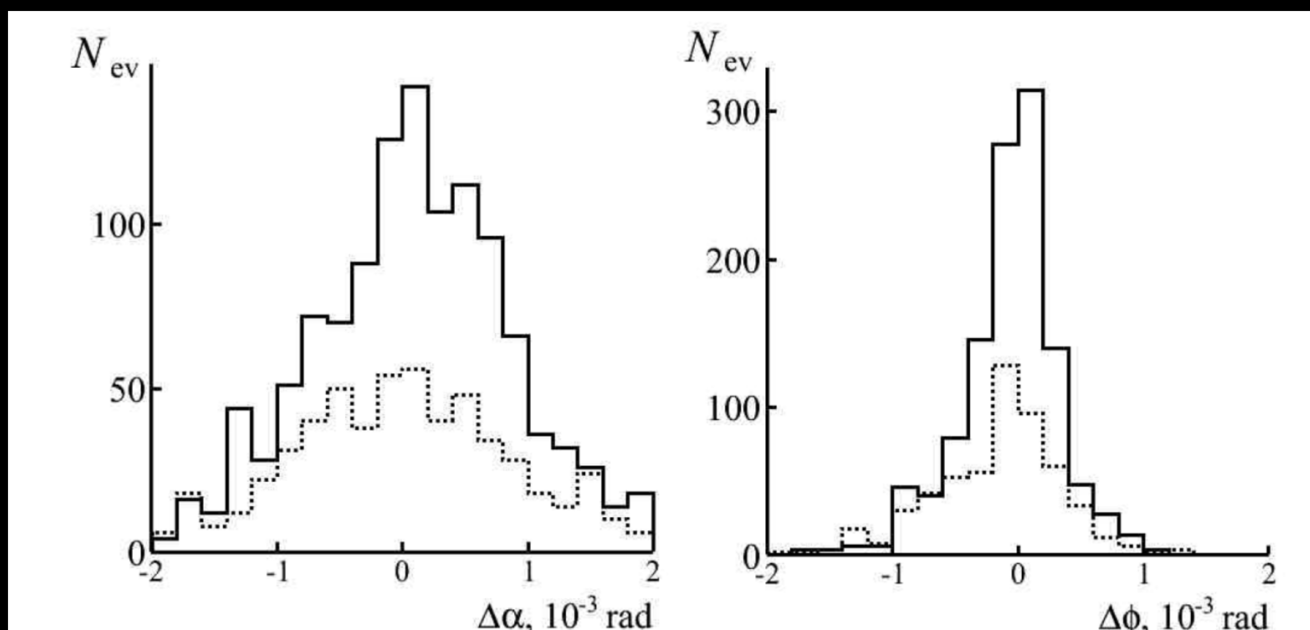


Example of restored directions in event $^{10}B \rightarrow 2He + H$ over vertical and planar planes.



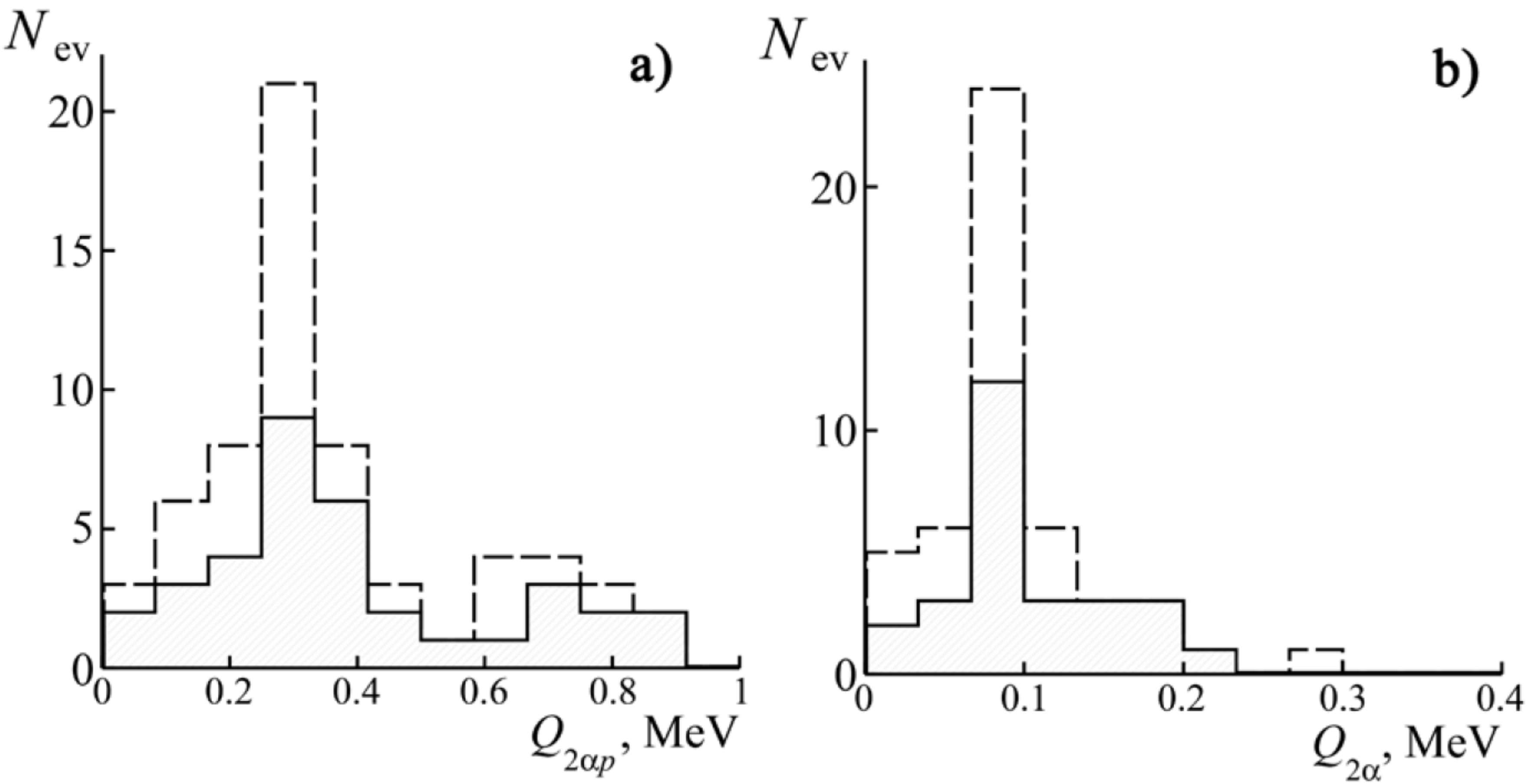
Distributions of residuals Δ*y* and Δ*z* of fitting of coordinates of H and He tracks in events $^{10}B \rightarrow 2He + H$.





Distribution of errors in determining dip (α) and planar (φ) angles for fragments He (solid) and H (dotted) in events $^{10}B \rightarrow 2He + H$.

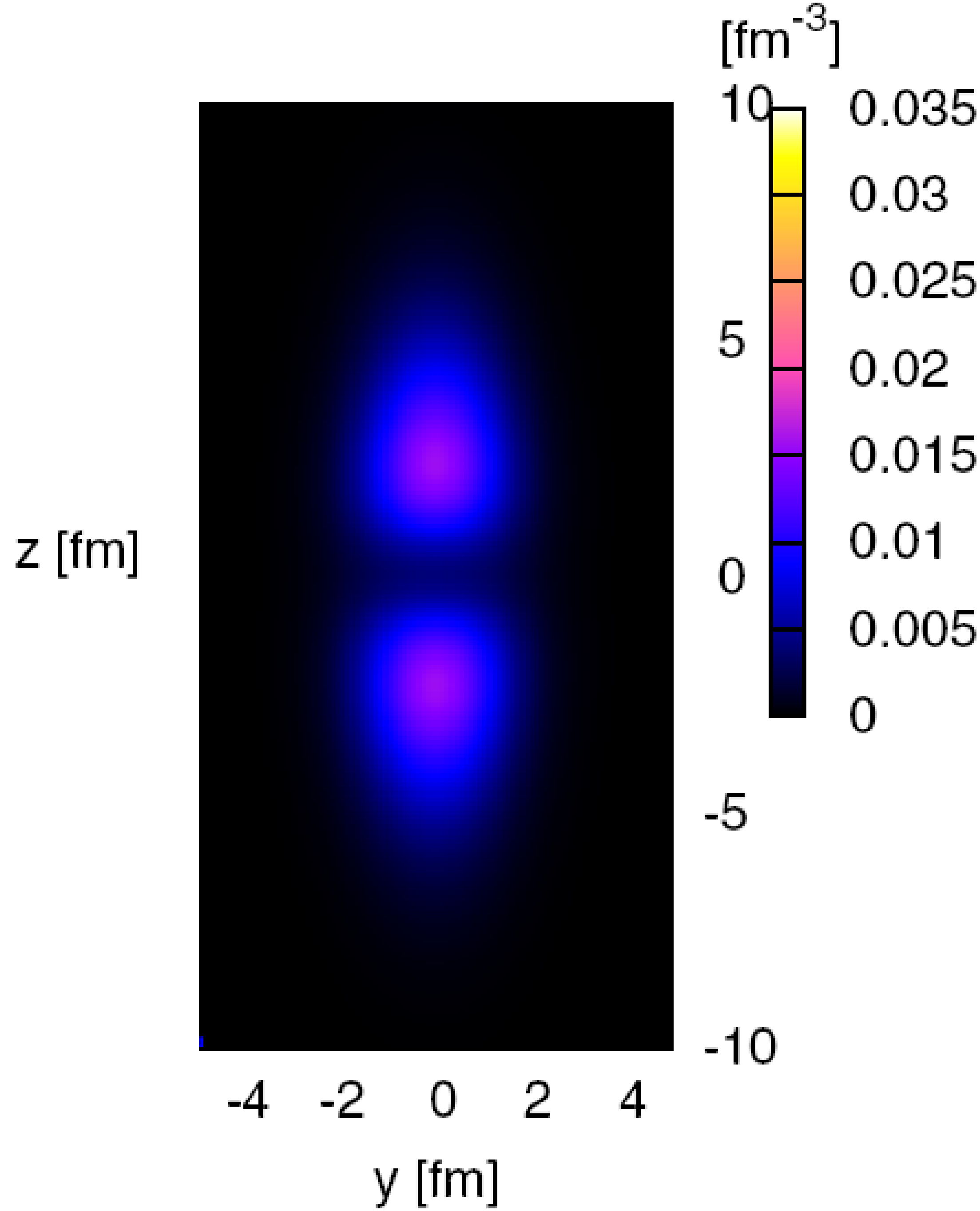
Reconstruction of values $Q_{2\alpha p}$ and $Q_{2\alpha}$ for the ^{10}B and ^{11}C fragmentation is presented in the range which is relevant for ^{9}B. In these cases the ^{9}B decays serves as source of ^{8}Be. The distribution mean values (RMS) $\langle Q_{2\alpha p} \rangle = 265 \pm 14$ (100) keV and $\langle Q_{2\alpha} \rangle = 91 \pm 7$ (53) keV match the accepted values and expected resolution. The condition 200 keV < $Q_{2\alpha}$ is a practical cut-off for ^{8}Be identification.



Distributions of triples $2\alpha p$ over invariant mass $Q_{2\alpha p}$ (a) for fragmentation ^{10}B → 2He + H at 1.6 *A* GeV/*c* (solid) and ^{11}C → 2He + 2H at 2.0 A GeV/*c* (added, dashed) and $Q_{2\alpha}$ of α-pairs in the range 400 keV < $Q_{2\alpha p}$ identified in these events (b); statistics of 99 events ^{10}B → 2He + H and 212 events ^{11}C → 2He + 2H.

Nucleus (P_0, *A* GeV/*c*)	$<\Theta_{2\alpha}>$ (RMS), 10^{-3} rad ($Q_{2\alpha} < 300$ keV)	$<Q_{2\alpha}>$ (RMS), keV
^{12}C (4.5)	2.1 ± 0.1 (0.8)	109 ± 11 (83)
^{14}N (2.9)	2.9 ± 0.2 (1.9)	119.6 ± 9.5 (72)
^{9}Be (2.0)	4.4 ± 0.2 (2.1)	86 ± 4 (48)
^{10}C (2.0)	4.6 ± 0.2 (1.9)	63 ± 7 (83)
^{11}C (2.0)	4.7 ± 0.3 (1.9)	77 ± 7 (40)
^{11}C(2.0) → ^{9}B → ^{8}Be		94 ± 15 (86)
^{10}B (1.6)	5.9 ± 0.2 (1.6)	101 ± 6 (46)
^{10}B(1.6) → ^{9}B → ^{8}Be		105 ± 9 (47)
^{12}C (1.0)	10.4 ± 0.5 (3.9)	107 ± 10 (79)

Nucleus	$<Q_{2\alpha p}>$, (RMS), keV ($Q_{2\alpha p} < 400$ keV)
^{10}B	249 ± 19 (91)
^{10}C	254 ± 18 (96)
^{11}C	273 ± 18 (82)



[fm-3]
10
5
0
-5
-10
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
z [fm]
-4
-2
0
2
4
y [fm]

ON NUCLEAR REACTIONS OCCURRING IN VERY HOT STARS. I. THE SYNTHESIS OF ELEMENTS FROM CARBON TO NICKEL

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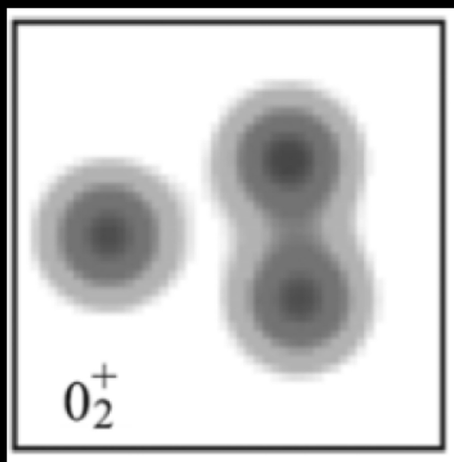
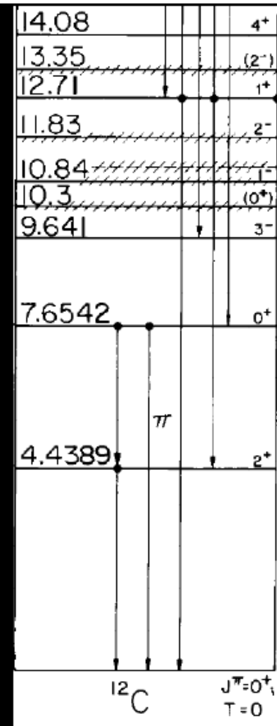
Received December 22, 1953

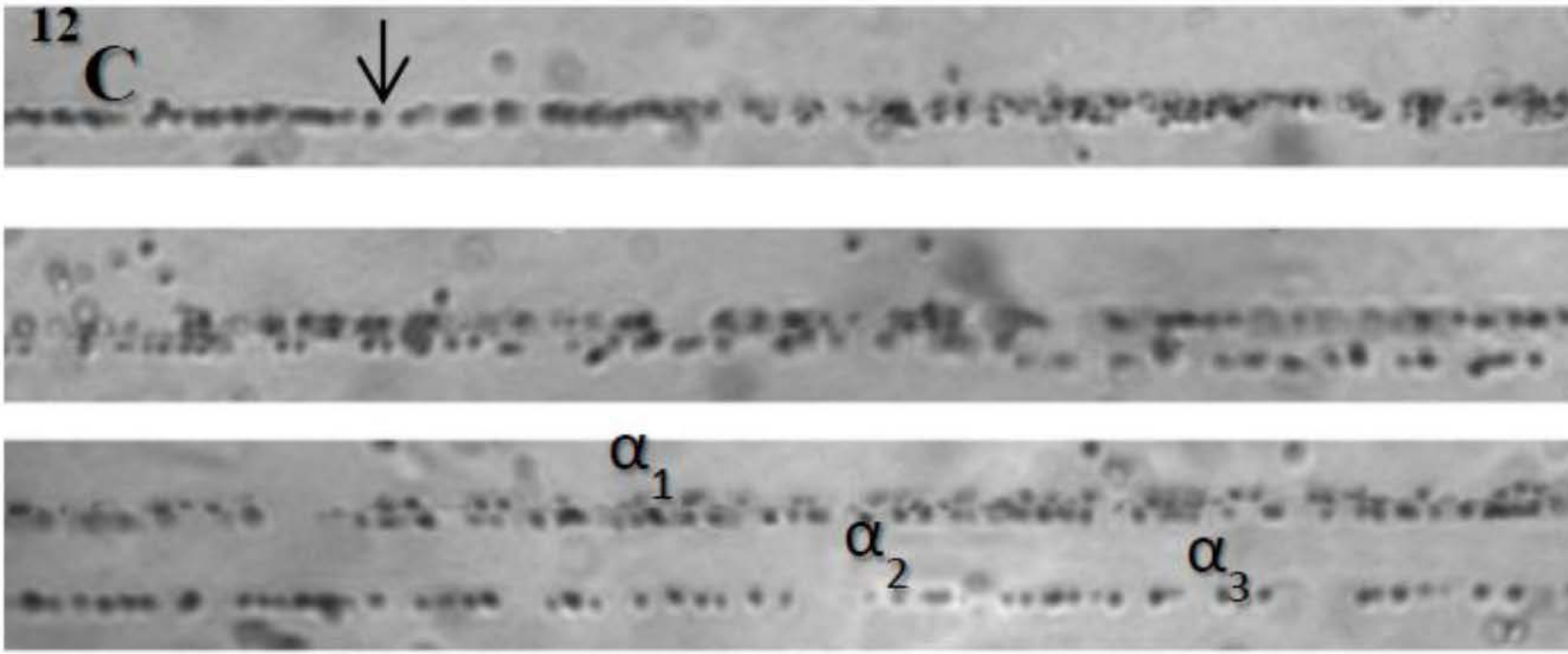




E_x in ^{12}C (MeV ± keV)	J^π ; T	$\Gamma_{c.m.}$ (keV)	Decay
g.s	0^+; 0	-	stable
4.43891 ± 0.31	2^+; 0	$(10.8 \pm 0.6) \times 10^{-6}$	γ
7.6542 ± 0.15	0^+; 0	$(8.5 \pm 1.0) \times 10^{-3}$	γ, π, α

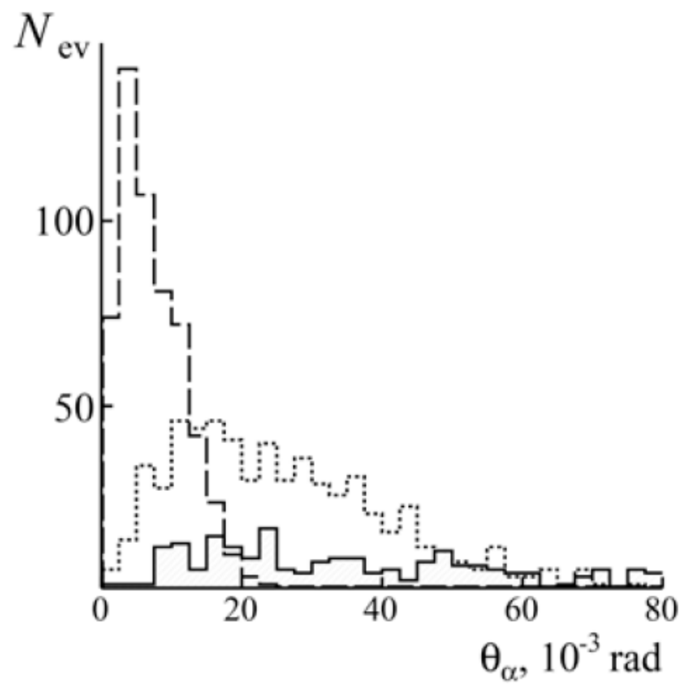
The second excited state of the ^{12}C nucleus is is named after the astrophysicist F. Hoyle who postulated its existence to explain the prevalence of the ^{12}C isotope. Following an accurate prediction of the HS energy it was experimentally confirmed that the ^{12}C nucleus has the excited state located at only 378 keV above the mass threshold of the three α particles. Although it is unstable, its width is only 8.5 eV. Such a value indicates that the HS lifetime is comparable with the values for ^{8}Be or π^0-meson. Observation of HS at a contrast of relativistic energy and the minimum possible energy stored by 3α-ensembles can demonstrate HS as a nuclear-molecular object similar to ^{8}Be. First of all it is necessary to establish the very possibility of HS appearance in the relativistic fragmentation.

The current material for the HS search is a set 200 μm NTE pellicles on 2 mm glass of size 9 to 12 cm which is irradiated longitudinally ^{12}C nuclei at initial momentum P_0 = 1 A GeV/c. This exposure was performed recently in the medical-biological beam of the Institute of High Energy Physics (Protvino). This ^{12}C beam has energy of about 400 A MeV and used for medical and biological studies. 2% irradiation homogeneity is provided by application of two rotating electrostatic wobblers. The steps taken in December 2016 and April 2017 resulted in the controllable irradiation with a particle density at the area of irradiation of 2000−4500 nuclei/cm^2.

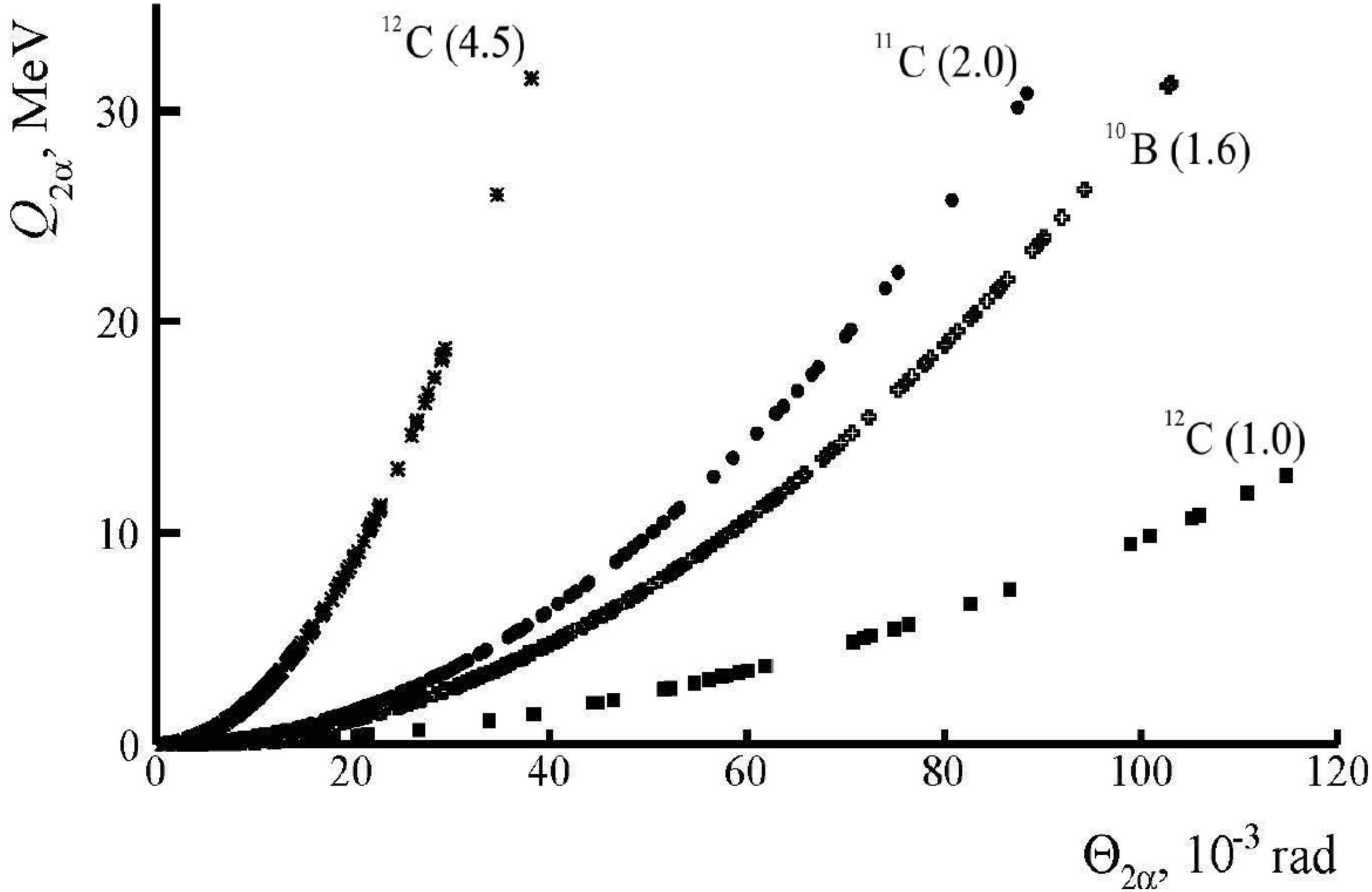


Consecutive frames of coherent dissociation $^{12}C \rightarrow 3\alpha$ at 1 *A* GeV/*c* ("white" star); arrow indicate interaction vertex; grain sizes are about 0.5 μm. Accelerated search for 3α-events the developed pellicles is carried out by scanning along bands that are transverse to the beam direction. By May 2018, 86 $^{12}C \rightarrow 3\alpha$ events, including 36 "white" stars, are found and measured in exposure at IHEP (Protvino).

Measurements made in the 90s in NTE layers exposed to ^{12}C beam at momentum P_0 = 4.5 *A* GeV/*c* at the JINR Synchrophasotron are available for 72 (G.M. Chernov's group, Tashkent) and 114 "white" stars $^{12}C \rightarrow 3\alpha$ (A.Sh. Gaitinov's group, Alma-Ata) as a legacy of the emulsion community. At that time, the HS problem was not set. Fig. shows jointly distributions of α-particles at both momentum values over the polar emission angle θ_α. They are described by the Rayleigh distribution with the parameters $\sigma_{\theta\alpha}$ equal to 27 ± 3 (1.0 *A* GeV/*c*) and 6.5 ± 0.6 (4.5 *A* GeV/*c*) corresponding to a simple inverse relationship between P_0 и $\sigma_{\theta\alpha}$. In addition, Fig. shows data on He fragments for the 2.0 *A* GeV/c ^{11}C dissociation where the ^4He isotope dominates.

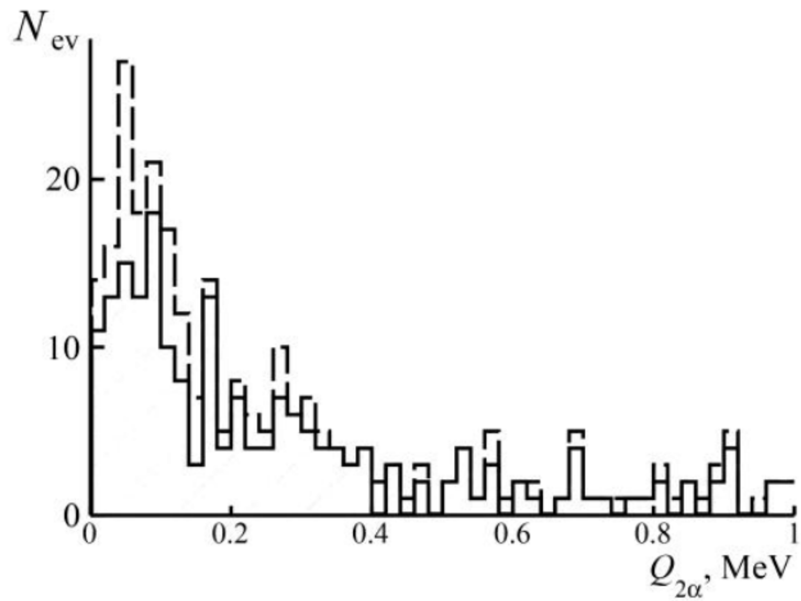


Distribution over polar angle θ_α of relativistic He fragments in exposures at 4.5 (dashed) and 1 A GeV/*c* (solid) ^{12}C and 2.0 *A* GeV/*c* ^{11}C (dotted).



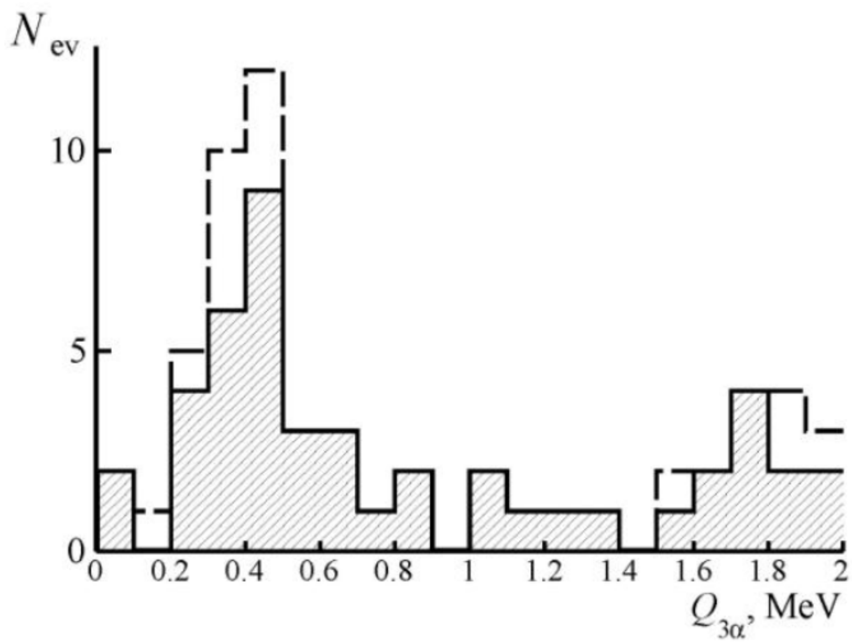
Dependence of calculated invariant masses of α-pairs $Q_{2\alpha}$ over opening angles in them $\Theta_{2\alpha}$ in events of dissociation of ^{12}C, ^{11}C and ^{10}B nuclei; momentum values are indicated in parentheses (A GeV/c).

The $Q_{2\alpha}$ distributions obtained on a basis of angular measurements of events $^{12}C \rightarrow 3\alpha$ at two values P_0 are presented jointly. Both are distributions do not differ within statistics. The region $Q_{2\alpha}$ < 200 keV contains a peak pressed to the origin which corresponds to decays of ^8Be. Although the ^8Be signal is present the $Q_{2\alpha}$ distribution appears to be significantly wider.



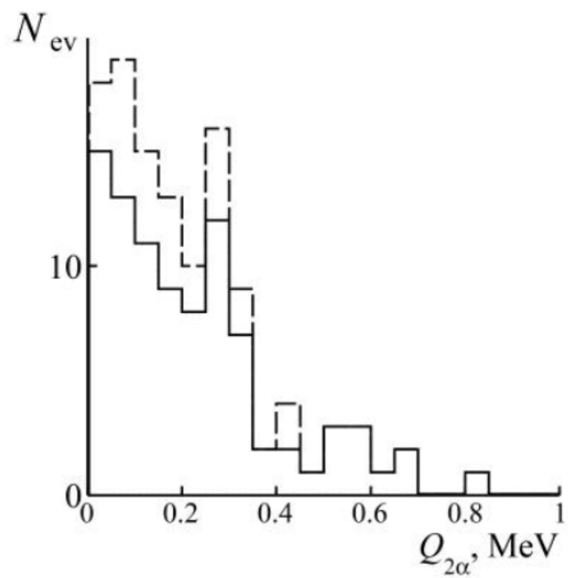
Distribution of α-pairs over invariant mass $Q_{2\alpha}$ < 1 MeV in the dissociation $^{12}C \rightarrow 3\alpha$ at 4.5 (solid) and 1 *A* GeV/*c* (added).

In the $Q_{3\alpha}$ distribution over the invariant mass of the α-triples there is a peak in the region $Q_{3\alpha} < 1$ MeV where HS decays could be reflected. For events at 4.5 *A* GeV/*c* the mean value for the events at the peak $<Q_{3\alpha}>$ (at RMS) is 441 ± 34 (190) keV, and at 1 A GeV/c, respectively, 346 ± 28 (85) keV. According to the "soft" condition $Q_{3\alpha} < 1$ MeV in the 4.5 *A* GeV/*c* exposure 30 (of 186) events can be attributed to HS and 9 (of 86) including 5 "white" stars (of 36) in 1 *A* GeV/*c* exposure.



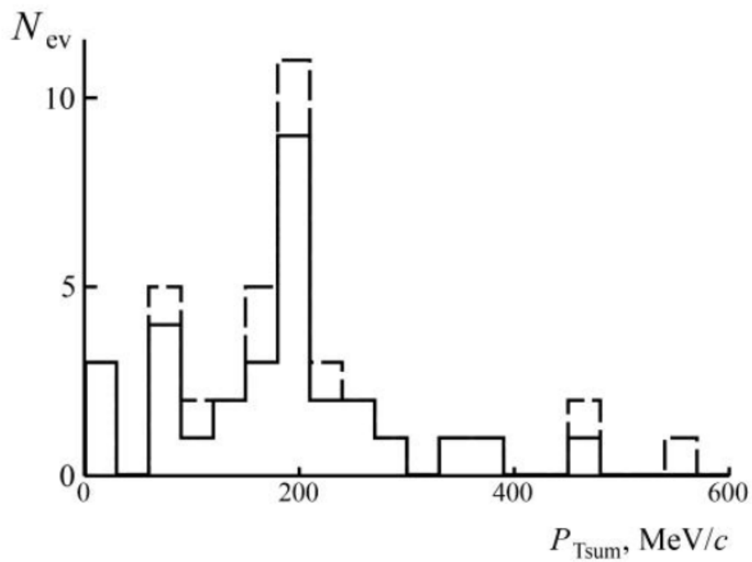
Distribution of α-triples over invariant mass $Q_{3\alpha} < 2$ MeV in dissociation of $^{12}C \rightarrow 3\alpha$. at 4.5 *A* GeV/*c* (solid) and 1 *A* GeV/c (added).

When selecting α-pairs from α-triples that correspond to the HS criterion $Q_{3\alpha} < 1$ MeV the $Q_{2\alpha}$ distribution acquires the form shown in Fig. The average value $\langle Q_{2\alpha} \rangle$ (RMS) is 210 ± 15 (156) keV. The distribution form becomes wider and separation of the ^{8}Be peak in the region $Q_{2\alpha} < 200$ keV is impossible. This change is caused by the increased contribution of non-^{8}Be-resonance α pairs of HS decays masking the ^{8}Be signal. In turn, this circumstance makes unattainable a more detailed analysis of the HS inner structure. It characterizes a limitation of our approach to penetrate in the HS structure. Nevertheless, it is concluded that HS is observed in a relativistic dissociation $^{12}C \rightarrow 3\alpha$. with probability about 10-15%.



Distribution of α-pairs over invariant mass $Q_{2\alpha}$ in the HS like decays ($Q_{3\alpha} < 1$ MeV) in dissociation of $^{12}C \rightarrow 3\alpha$. at 4.5 (solid) and 1 A GeV/c (added).

The angular measurements make it possible to conclude about the dynamics of the HS appearance according to the distribution of α-particle triples over their total transverse momentum P_{Tsum}. Its average value <P_{Tsum}> (RMS) is equal to 190 ± 19 (118) MeV/*c* corresponding to the nuclear-diffraction mechanism. In the case of electromagnetic dissociation on Ag and Br nuclei composing NTE the limitation is expected to be P_{Tsum} < 100 MeV/*c* [9]. It is surprising that such a "fragile" formation of three α-particles as HS can arise in relativistic collisions as an ensemble which is "bouncing off" with the transverse momentum P_{Tsum} characteristic for strong interactions rather than electromagnetic ones.

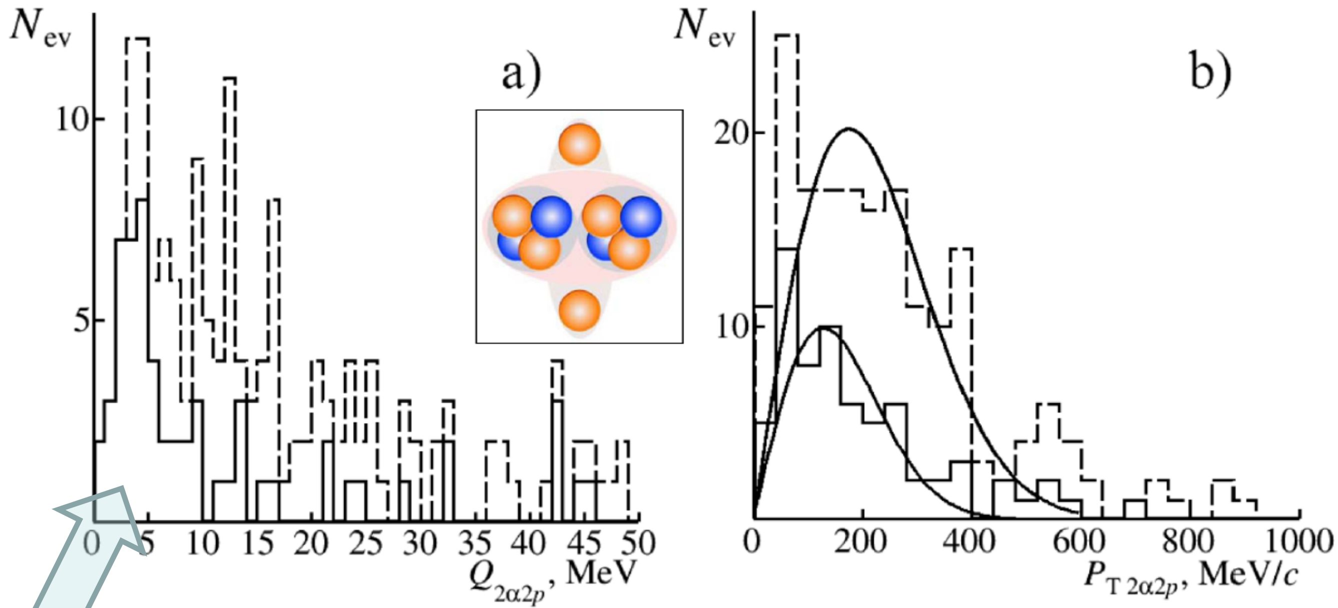


Distribution of α-triples of HS like decays ($Q_{3\alpha}$ < 1 MeV) over total transverse momentum <P_{Tsum}> in dissociation $^{12}C \rightarrow 3\alpha$ at 4.5 (solid) and 1 *A* GeV/*c* (added).

Conclusions

HS is identified at 4.5 and 1 *A* GeV/*c* on the basis of the most precise measurements in NTE performed by different researchers on different exposures that are separated in time by two decades. In itself, this fact demonstrates the thoroughness of the NTE method. As a result of the studies шt can be concluded that HS is observed with a contribution of about 10-15%. However, the method does not allow one to investigate the features of the HS decay. Reconstruction of HS on the invariant mass of relativistic α-triples can be used to study processes with the HS formation as an integral object at large momenta and for other fragmenting nuclei, except for ^{12}C.

It is possible that HS can not be reduced to only the excitation of ^{12}C but can manifest itself as a universal object in the fragmentation of heavier nuclei, similarly to ^{8}Be. In this respect, the closest source of HS is the ^{14}N nucleus. Even more convenient are the ^{13}N and ^{13}C nuclei whose beams can be formed in the ^{14}N fragmentation. It can be expected that the nuclear-molecular objects ^{8}Be and HS will become reference points for the search for more complex states of sparse nuclear matter in the relativistic approach.

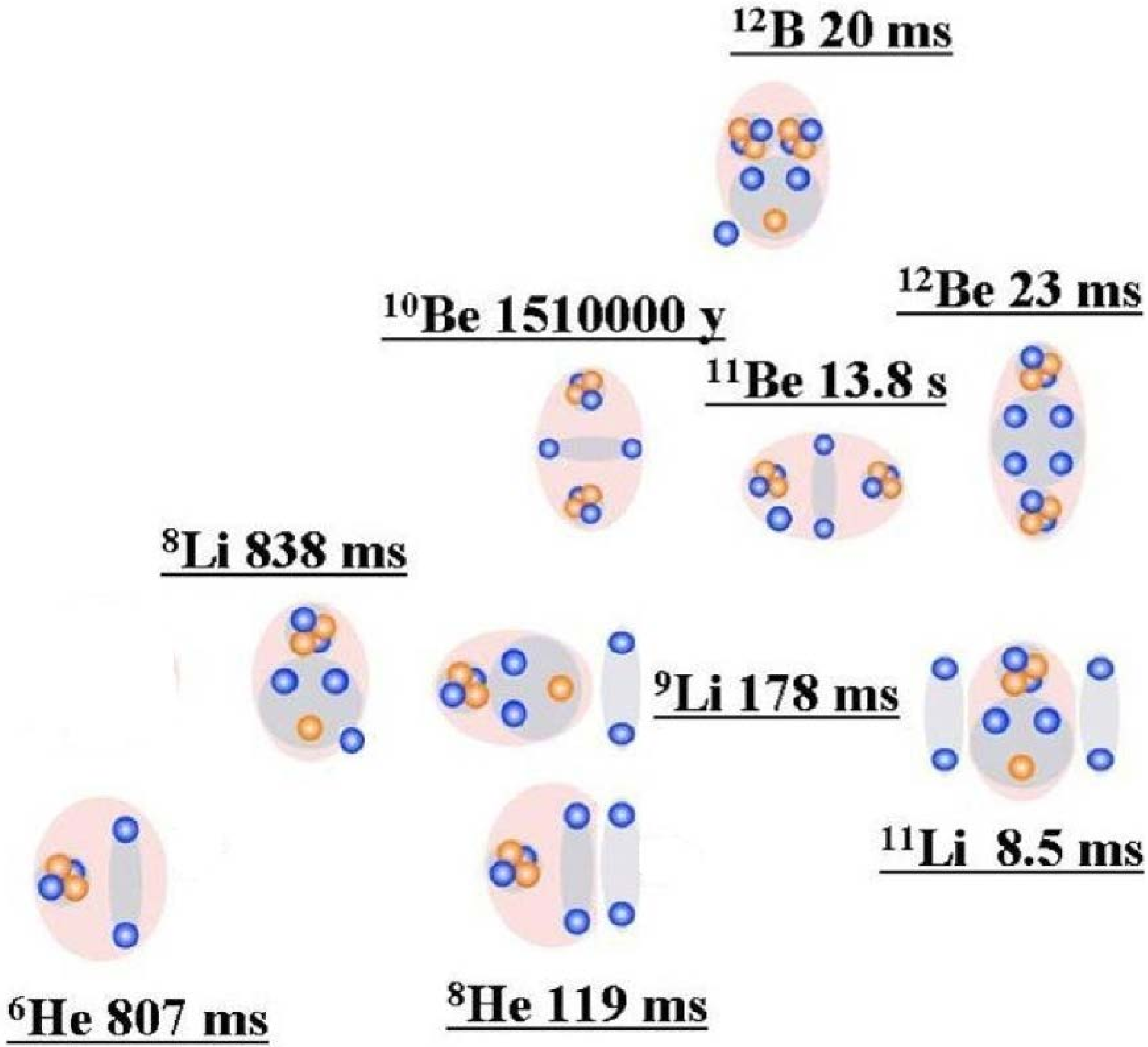


Distributions of all "white" stars $^{10}C \rightarrow 2He + 2H$ (dashed histogram) and the ones with the presence of $^{8}Be_{g.s.}$ (^{9}B) (solid histogram) over energy $Q_{2\alpha 2p}$ (a) and total transverse momentum $P_{T2\alpha 2p}$ (b).

Selection of the ^{10}C "white" stars accompanied by $^{8}Be_{g.s.}$ (^{9}B) leads to appearance in the excitation energy distribution of $2\alpha 2p$ "quartets" of the distinct peak with a maximum at 4.1 ± 0.3 MeV. Distribution over the total momentum of $^{8}Be_{g.s.}2p$ ensembles is described by a Rayleigh function with the parameter 127 ± 16 MeV/c. A single $2\alpha 2p$ "white" star in which both $2\alpha p$ triples correspond to a ^{9}B decay is observed.

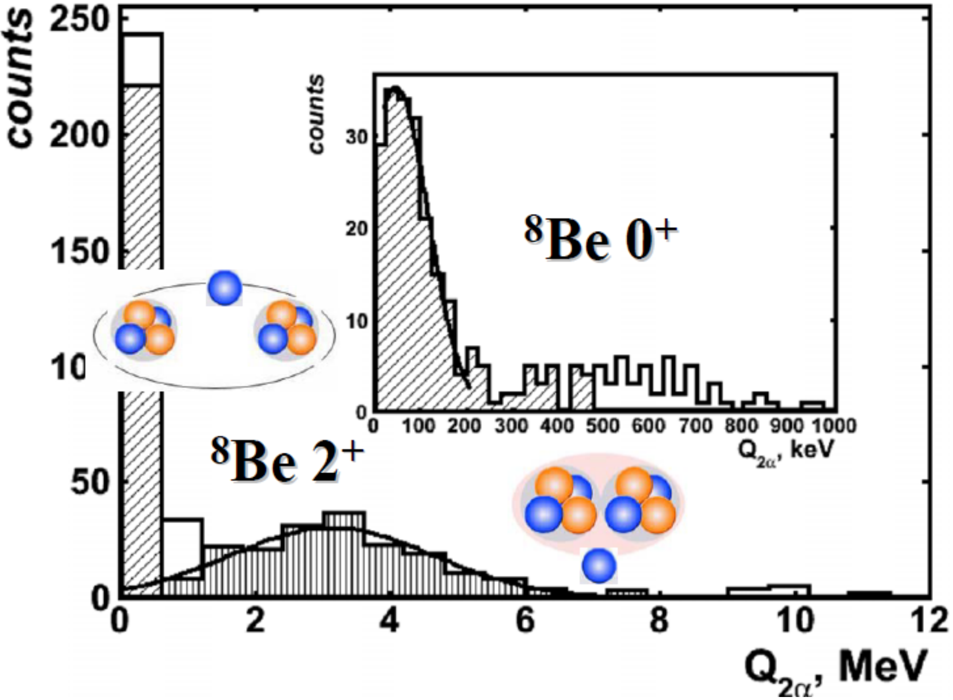
The distribution on the charge configurations of relativistic fragments $\Sigma Z_{fr} = 6$ of ^{10}C fragmentation events for "white" stars N_{ws} and collisions with produced mesons, target fragments or protons N_{tf}

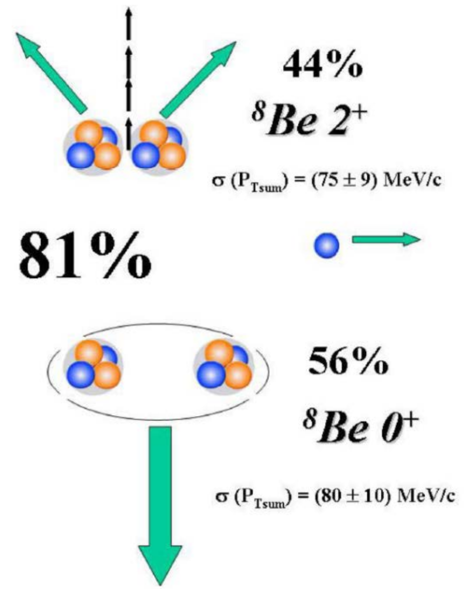
	2He+2H	He+4H	3He	6H	Be+He	B+H	Li+3H	C+n
N_{ws} (%)	186 (81.9)	12 (5.3)	12 (5.3)	9 (4.0)	6 (2.6)	1 (0.4)	1 (0.4)	
N_{tf} (%)	361 (57.6)	160 (25.5)	15 (2.4)	30 (4.8)	17 (2.7)	12 (1.9)	2 (0.3)	30 (4.8)



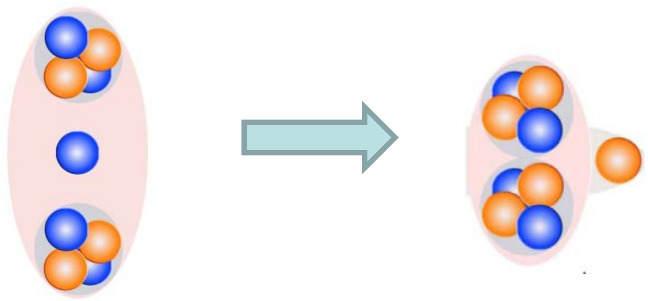
^{12}B 20 ms
^{10}Be 1510000 y
^{12}Be 23 ms
^{11}Be 13.8 s
^{8}Li 838 ms
^{9}Li 178 ms
^{11}Li 8.5 ms
^{6}He 807 ms
^{8}He 119 ms

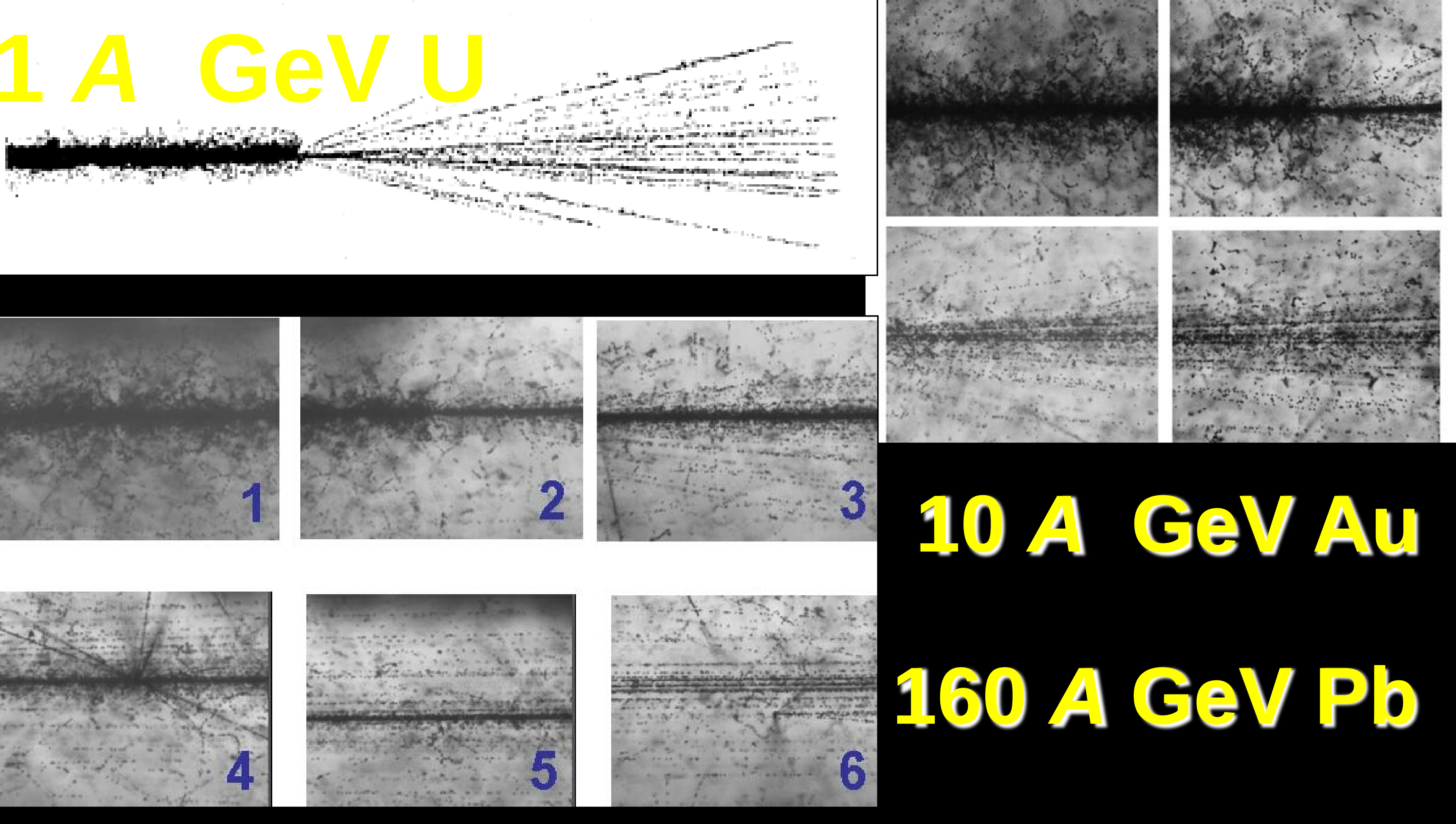
2A GeV/*c* ^{9}Be → 2α “white” star





Search for charge exchange ^{9}Be → ^{9}B (in progress)





The studies of light nuclei are only the first steps toward complex cluster-nucleon ensembles He – H – n produced in the dissociation of heavy nuclei. The question that has to be answered is what kind of physics underlies the "catastrophic" destruction shown in Fig. Events of multiple fragmentation of relativistic nuclei down to a complete destruction into the lightest nuclei and nucleons without visible excitation of target nuclei were reliably observed in NTE for Au and Pb and even U projectile nuclei. The existence of this phenomenon is certain. It is possible that it confirms the essential role of the long-range quantum electrodynamics interaction. The charges of heavy nuclei make possible multiphoton exchanges and transitions in many-particle states.

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Inelastic Muon Interactions in Nuclear Emulsion at 2.5 and 5.0 GeV (*).

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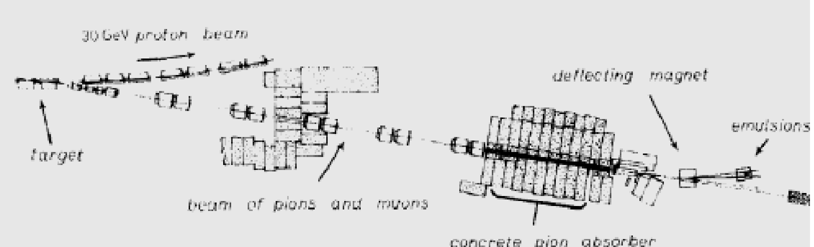
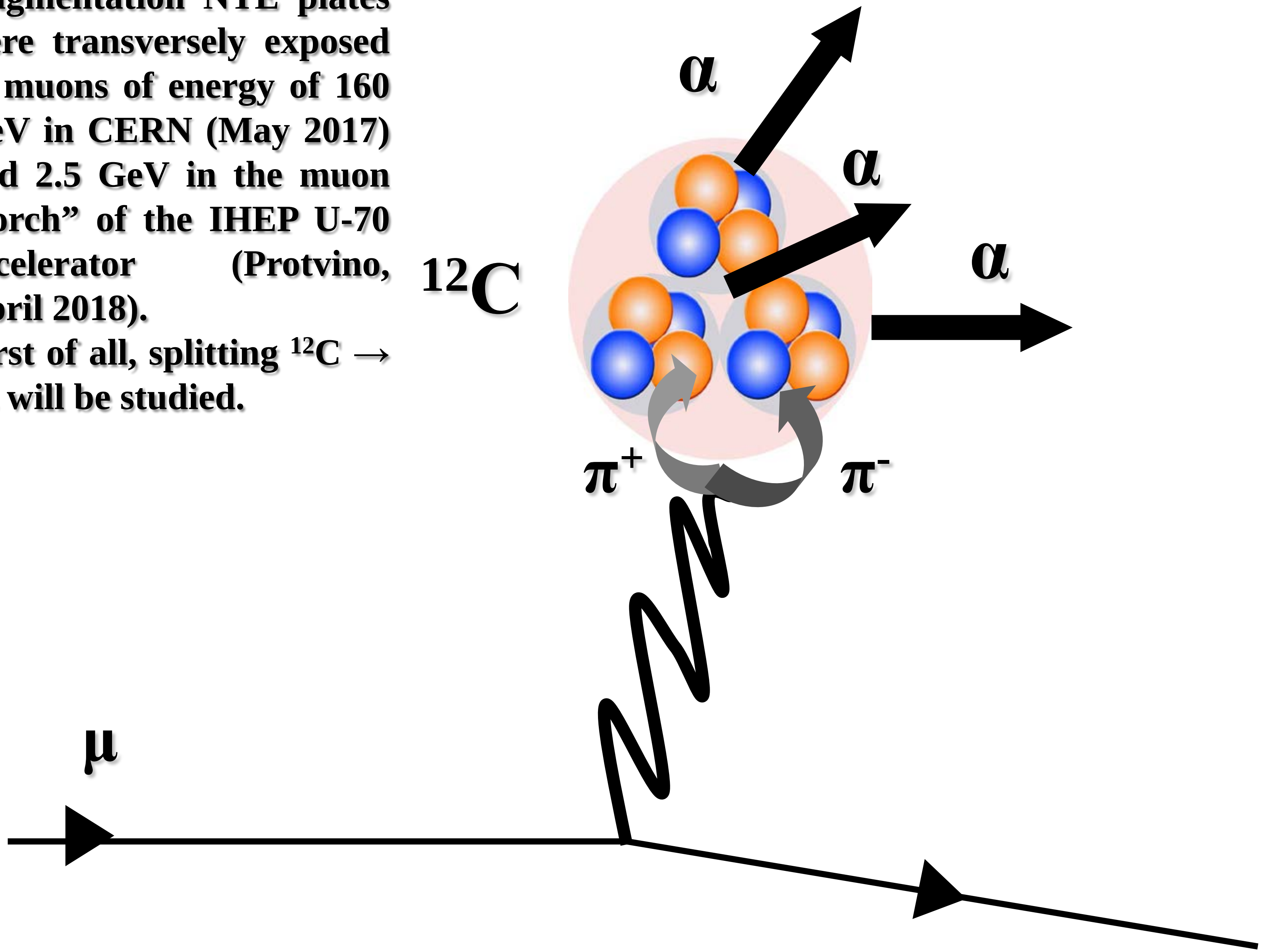
(ricevuto il 25 Maggio 1965)



Event No.	Muon defl. angle degrees	Type of interaction (d) $n_b + n_g + n_s$	Event No.	Muon defl. angle degrees	Type of interaction (d) $n_b + n_g + n_s$	Event No.	Muon defl. angle degrees	Type of interaction (d) $n_b + n_g + n_s$
1	< 0.3	3 + 2 + 2	41	< 0.3	2 + 0 + 0	81	0.8	3 + 1 + 1
2	< 0.3	2 + 1 + 1	42	0.6	2 + 0 + 0	82	< 0.3	3 + 1 + 0
3	> 10.0	16 + 3 + 2	43	1.1	1 + 1 + 0	83	0.4	5 + 0 + 0
4	0.6	3 + 1 + 0	44	1.3	3 + 0 + 0	84	1.9	4 + 1 + 0
5	(a)	3 + 0 + 0	45	(a)		85	< 0.3	1 + 1 + 0
6	0.9	3 + 1 + 1	46	1.2	3 + 1 + 2	86	< 0.3	3 + 0 + 0
7	0.3	1 + 1 + 1	47	< 0.3	2 + 0 + 0	87	3.9	4 + 1 + 0
8	(a)	1 + 2 + 0	48	0.8	6 + 3 + 2	88	2.7	7 + 1 + 1
9	0.3	3 + 1 + 1	49	2.5	4 + 1 + 0	89	7	1 + 1 + 0
10	< 0.3	2 + 1 + 0	50	1.1	1 + 1 + 0	90	< 0.3	2 + 1 + 0
11	1.3	7 + 2 + 0	51	< 0.3	3 + 1 + 0	91	0.6	2 + 0 + 0
12	2.2	2 + 0 + 1	52	< 0.3	2 + 1 + 0	92	< 0.3	2 + 1 + 0
13	(a)	2 + 0 + 0	53	< 0.3	3 + 0 + 0	93	0.3	5 + 1 + 0
14	5.5	2 + 1 + 0	54	0.9	4 + 0 + 0	94	(*)	7 + 0 + 0
15	< 0.3	2 + 0 + 1	55	0.4	1 + 1 + 0	95	0.9	2 + 0 + 0
16	4.2	3 + 0 + 0	56	1.8	3 + 0 + 1	96	3.2	2 + 0 + 0
17	< 0.3	2 + 1 + 0	57	< 0.3	6 + 1 + 0	97	0.8	2 + 0 + 0
18	< 0.3	3 + 1 + 0	58	0.4	10 + 1 + 0	98	< 0.3	3 + 0 + 0
19	2.8	5 + 1 + 0	59	0.5	3 + 1 + 0	99	(*)	2 + 1 + 0
20	0.8	5 + 3 + 0	60	(c)	2 + 1 + 0	100	< 0.3	2 + 3 + 0
21	1.1	2 + 1 + 0	61	< 0.3	2 + 0 + 0	101	(*)	3 + 1 + 0
22	> 10.0	2 + 1 + 0	62	0.4	3 + 0 + 0	102	0.8	1 + 1 + 0
23	< 0.3	2 + 0 + 0	63	< 0.3	7 + 0 + 0	103	< 0.3	3 + 1 + 0
24	0.6	2 + 1 + 0	64	(*)	2 + 0 + 0	104	0.8	1 + 1 + 0
25	< 0.3	3 + 2 + 0	65	(*)	5 + 0 + 0	105	< 0.3	7 + 1 + 0
26	< 0.3	1 + 0 + 1	66	1.2	5 + 0 + 0	106	0.3	1 + 1 + 0
27	4.4	2 + 2 + 1	67	< 0.3	3 + 1 + 0	107	0.9	4 + 0 + 0
28	(a)	4 + 0 + 0	68	0.8	5 + 0 + 0	108	4	6 + 0 + 0
29	1.0	6 + 2 + 0	69	> 10	9 + 4 + 2	109	0.8	2 + 1 + 0
30	< 0.3	1 + 1 + 0	70	3.4	4 + 0 + 0	110	< 0.3	4 + 2 + 0
31	1.2	4 + 1 + 0	71	0.4	7 + 1 + 0	112	< 0.3	2 + 0 + 0
32	0.4	1 + 2 + 0	72	< 0.3	3 + 0 + 1	111	< 0.3	2 + 0 + 0
33	< 0.3	2 + 0 + 0	73	4.3	2 + 0 + 1	113	< 0.3	4 + 0 + 0
34	1.0	2 + 1 + 0	74	2.8	7 + 1 + 0	114	< 0.3	2 + 0 + 0
35	6.8	5 + 2 + 4	75	< 0.3	2 + 1 + 0	115	> 10	13 + 4 + 1
36	7.1	2 + 1 + 1	76	4.2	3 + 0 + 0	116	0.4	4 + 0 + 0
37	0.3	1 + 1 + 0	77	(b)	6 + 1 + 1	117	0.3	4 + 0 + 2
38	< 0.3	1 + 1 + 0	78	2.6	3 + 1 + 0	118	0.6	2 + 0 + 0
39	< 0.3	1 + 1 + 0	79	1.3	1 + 1 + 1	119	1.4	5 + 1 + 3
40	9.1	4 + 2 + 0	80	< 0.3	4 + 0 + 0	120	4.8	5 + 3 + 0

In order to study the origin of nuclear multiple fragmentation NTE plates were transversely exposed to muons of energy of 160 GeV in CERN (May 2017) and 2.5 GeV in the muon "torch" of the IHEP U-70 accelerator (Protvino, April 2018).

First of all, splitting $^{12}C \rightarrow 3\alpha$ will be studied.



n (14.1 MeV) + $^{12}C \rightarrow 3\alpha$

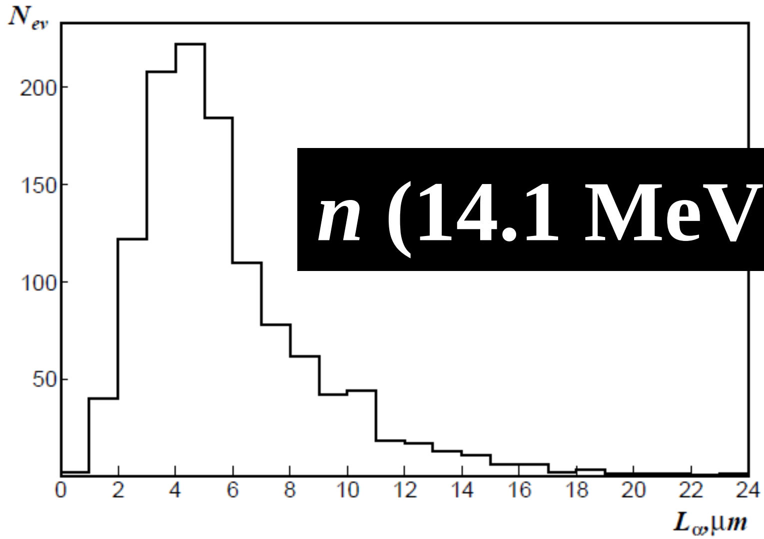


FIG. 1: Distribution of α-particles over ranges L_α.

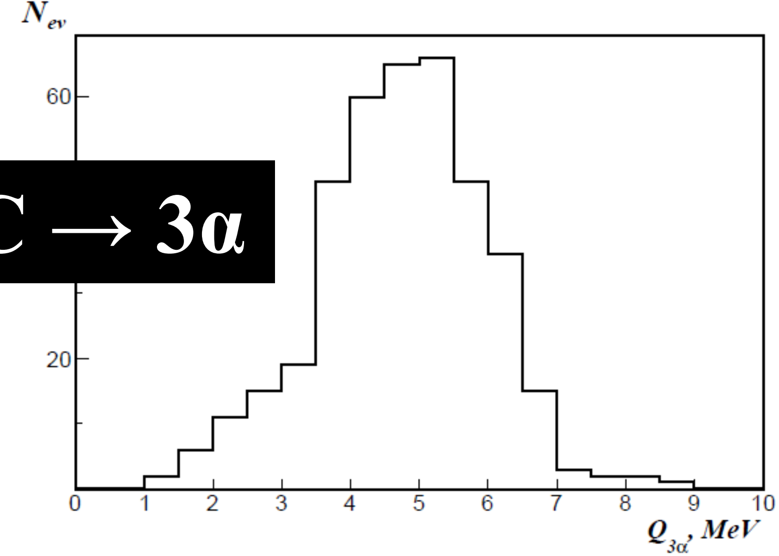


FIG. 3: Distribution triples of α-particles over energy $Q_{3\alpha}$.

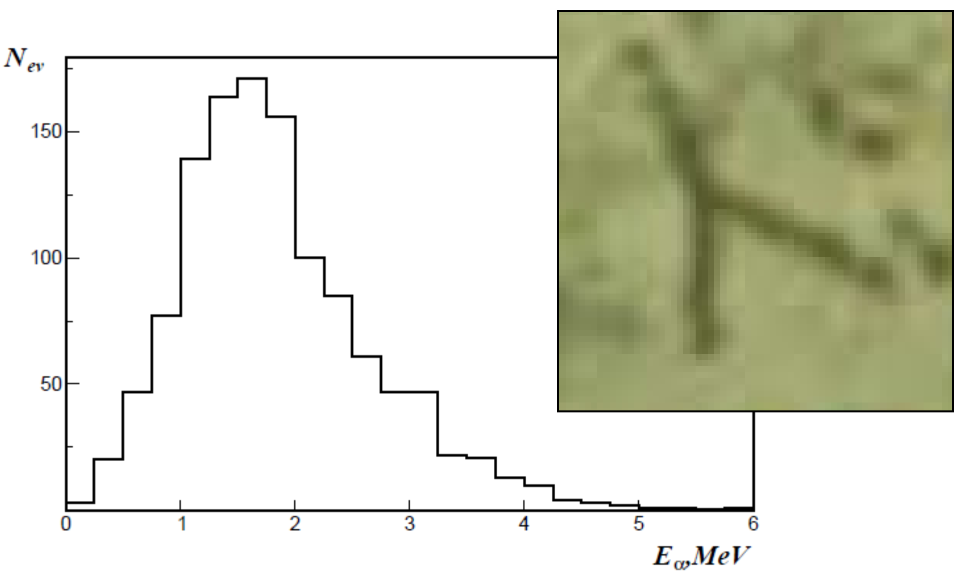


FIG. 2: Distribution of α-particles over energy E_α.

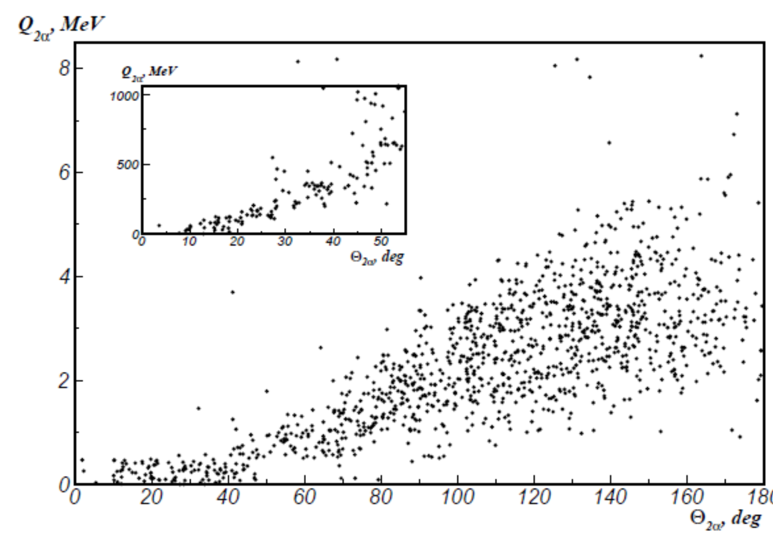


FIG. 4: Correlation over energy $Q_{2\alpha}$ and opening angles $\Theta_{2\alpha}$ in α-particle pairs.

Study of nuclear multifragmentation induced by ultrarelativistic μ-mesons in nuclear track emulsion

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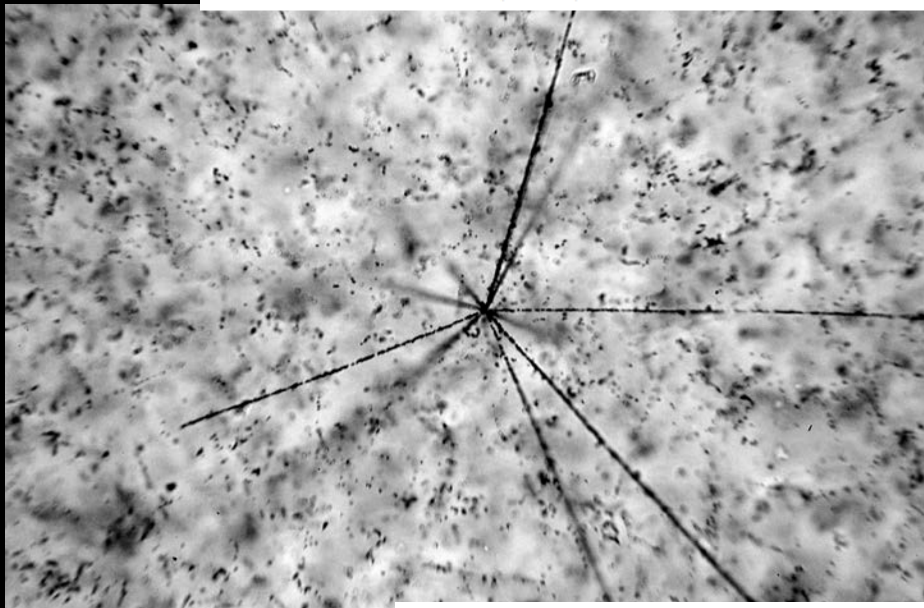
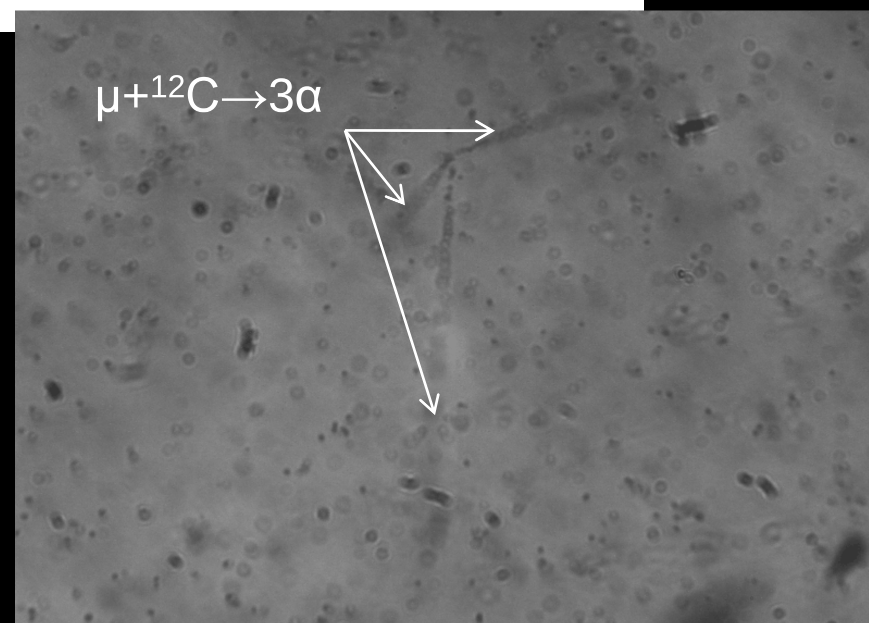
Abstract. Exposures of test samples of nuclear track emulsion were analyzed. The formation of high-multiplicity nuclear stars was observed upon irradiating nuclear track emulsions with ultrarelativistic muons. Kinematical features studied in this exposure of nuclear track emulsions for events of the muon-induced splitting of carbon nuclei to three α-particles are indicative of the nuclear-diffraction interaction mechanism.





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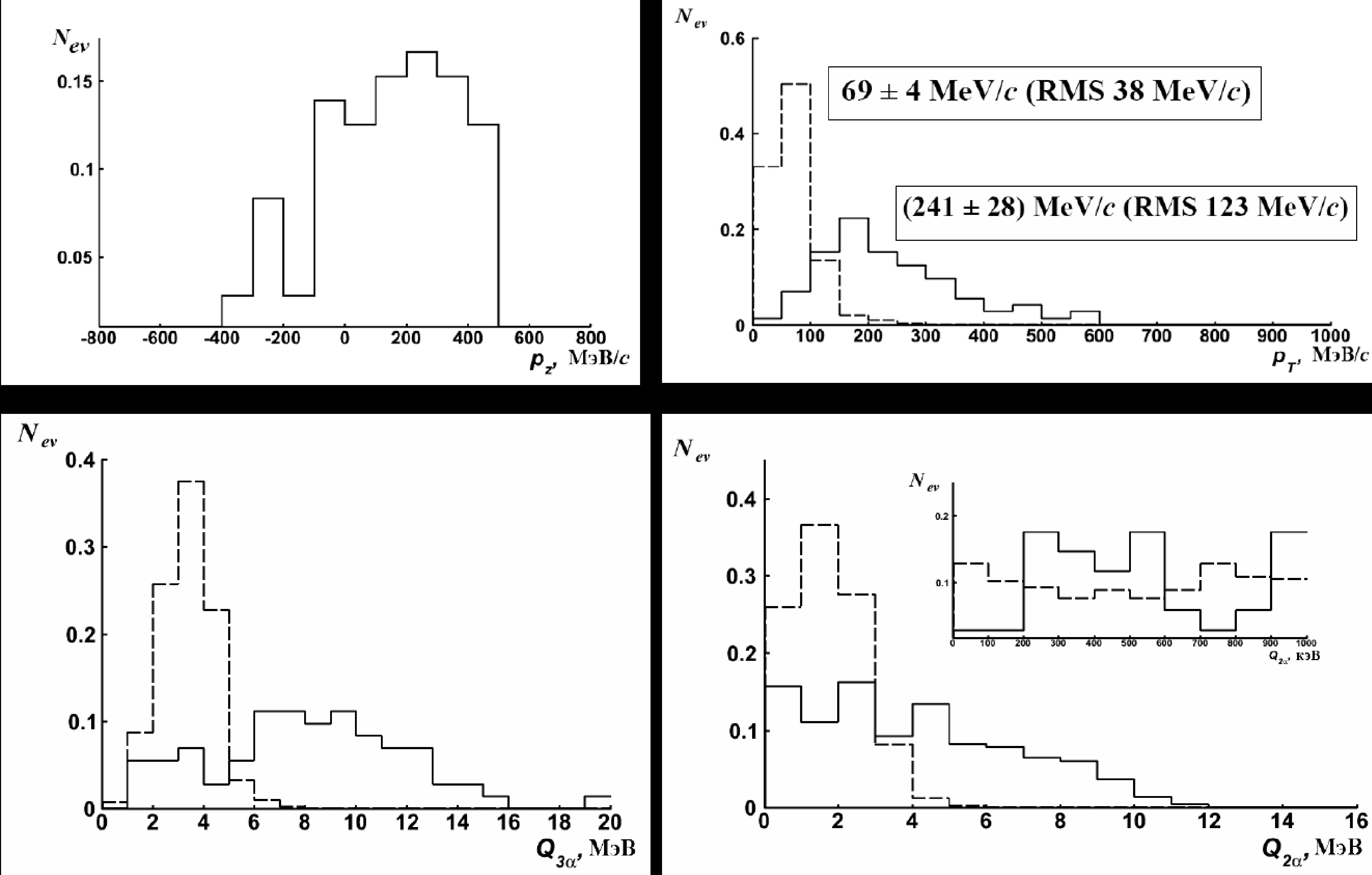

72 stars containing only a triple of *b*-particles stopped in NTE are assigned to the disintegration $\mu + {}^{12}C \rightarrow 3\alpha$ and compared with the case n(14.1 MeV) $+ {}^{12}C \rightarrow 3\alpha + n$.

Three stacks of 10 layers with an emulsion thickness 1000 μm and 3 of 10 layers with a thickness of 200 μm are irradiated perpendicular to the beam. Nearby monitor is 8 × 8 cm^2. The fluences are 9.3 × 10^6, 45 × 10^6, and 57 × 10^6. The average energy of muons is 2.5 GeV on average.

3 stacks (2 of 10 layers 100 microns and 1 of 10 200 microns) are irradiated in the hadrons beam: pions - 60%, protons - 35% and kaons - 5%.