Статус проекта БЕККЕРЕЛЬ и планы

П. И. Зарубин

The second edition of "State of The Art in Nuclear Cluster Physics" Workshop

A great deal of research work has been performed in the field of alpha clustering since the pioneering discovery of molecular resonances in the excitation functions for $^{12}C+^{12}C$ scattering. The aim of the series of SOTANCP Workshops is to further discuss the many facets of clustering in nuclear physics facing some of the greatest challenges and opportunities in the years ahead.

The second Workshop **"State Of The Art in Nuclear Cluster Physics"** (SOTANCP2 that took place on 25-28 May, 2010 at the Université Libre de Bruxelles (Brussels, Belgium) was organized by P. Descouvemont, J.-M. Sparenberg and M. Dufour. The first workshop was held in Strasbourg, France, in 2008 (*Nuclear Physics News*, Vol. **18**, No. 3). This second workshop was dedicated to Daniel Baye (see photo) on the occasion of his 65^{th} birthday. As in Strasbourg the scope of the second workshop, mostly informal, brought together different groups, both theoretical and experimental, involved in the study of "Clusters in Nuclei".

The purpose of SOTANCP2 was to promote the exchange of ideas and discuss new developments in Clustering Phenomena in Nuclear Physics. Applications in Condensed Matter and Nuclear Astrophysics were also presented. The various aspects of the main topics of SOTANCP2 were divided into eight sections, each highlighting an area where open questions have emerged over recent years:

- Cluster Structure of Stable and Unstable Nuclei, including Haloes
- Alpha Clustering and Nuclear Molecules
- Clusters in Nuclear Astrophysics
- Clustering Aspects of Nuclear Reactions, including Reactions and Molecular States
- Alpha Condensates and Analogy with Condensed Matter Approaches
- Cluster Radioactivity
- Clusters in Hypernuclei
- Cluster in Superheavy Nuclei

The Workshop attracted 88 participants from some 21 different countries from all the continents (Africa, Asia, Australia, Europe, North-America and South-America,). It should be noticed that a large number of our japanese colleagues have travelled to Europe to attend the meeting. The formats of the sessions were such that a sufficient amount of time was available for both discussions and questions.

Eighteen invited Talks of 25 minutes duration were presented by distinguished colleagues in their respective area of expertise as part of the 16 plenary sessions. As the

2^{nd} Workshop on
"State of the Art in Nuclear Cluster Physics" SOTANCP2

Université Libre de Bruxelles, Belgium
May 25-28, 2010

http://pntpm4.ulb.ac.be/sotancp2

ULB

organizers wished to make it possible to present as many as possible of the contributions in oral form, sixty one 20- and 15-minute talks were also given in the four days of the meeting. The most recent developments of clustering in nuclear structure were presented primarily for light stable and unstable nuclei (Y. Suzuki, M. Freer, M. Milin, T. Neff, K. Kato, N. Timofeyuk, R. Raabe). Alpha-particle condensation and the search for an equivalent Hoyle state in nuclei heavier than ^{12}C were among the highlights (T. Kawabata, Y. Funaki, N. Itagaki) that have been the most actively discussed. Various microscopic cluster-model approaches (S. Aoyama, E. Hiyama, Y. Fujiwara) to the understanding of hypernuclei and four nucleon scattering were also presented. Whereas D. Baye proposed a very nice overview of cluster-model descriptions of collisions, very recent experimental results have been reported for collisions for incident energies ranging from the Coulomb barrier (P. Figuera, M. Rodriguez-Gallardo) to the Fermi energy (J. Natowitz) up to relativistic energies (P. Zarubin). The study of clustering effects in reaction mechanisms has gained a renewed interest with available radioactive ion beam facilities.

The Workshop was sponsored from both Fonds National de la Recherche Scientifique (FNRS) and Université Libre de Bruxelles (ULB). The details of the Workshop program (including the slides of the talks) may be found in http://pntpm4.ulb.ac.be/sotancp2. The Proceedings, in a form of peer-reviewed papers of most of the orally presented talks, will be presented in a forthcoming issue of the *International Journal of Modern Physics* E.

Owing to the interest shown by the community and the potential for future research in clustering in nuclei, the members of the International Advisory Committee have agreed to consider SOTANCP as a series of meetings to complement the traditional CLUSTER Conferences (Cluster2012 will be organized by our hungarian colleagues in Debrecen). Japan being the country where Nuclear Cluster Physics is the most active, we look forward to the new and exciting work that will be presented at the third "SOTANCP Workshop" to be held in Yokohama in 2014.

Chistian Beck (IPHC/DRS et Université de Strasbourg, France),
Pierre Descouvemont (Université Libre de Bruxelles, Belgique),
Jean-Marc Sparenberg (Université Libre de Bruxelles, Belgique),
Marianne Dufour (IPHC/DRS et Université de Strasbourg, France)

The purpose of SOTANCP2 was to promote the exchange of ideas and discuss new developments in Clustering Phenomena in Nuclear Physics. Applications in Condensed Matter and Nuclear Astrophysics were also presented. The various aspects of the main topics of SOTANCP2 were divided into eight sections, each highlighting an area where open questions have emerged over recent years:

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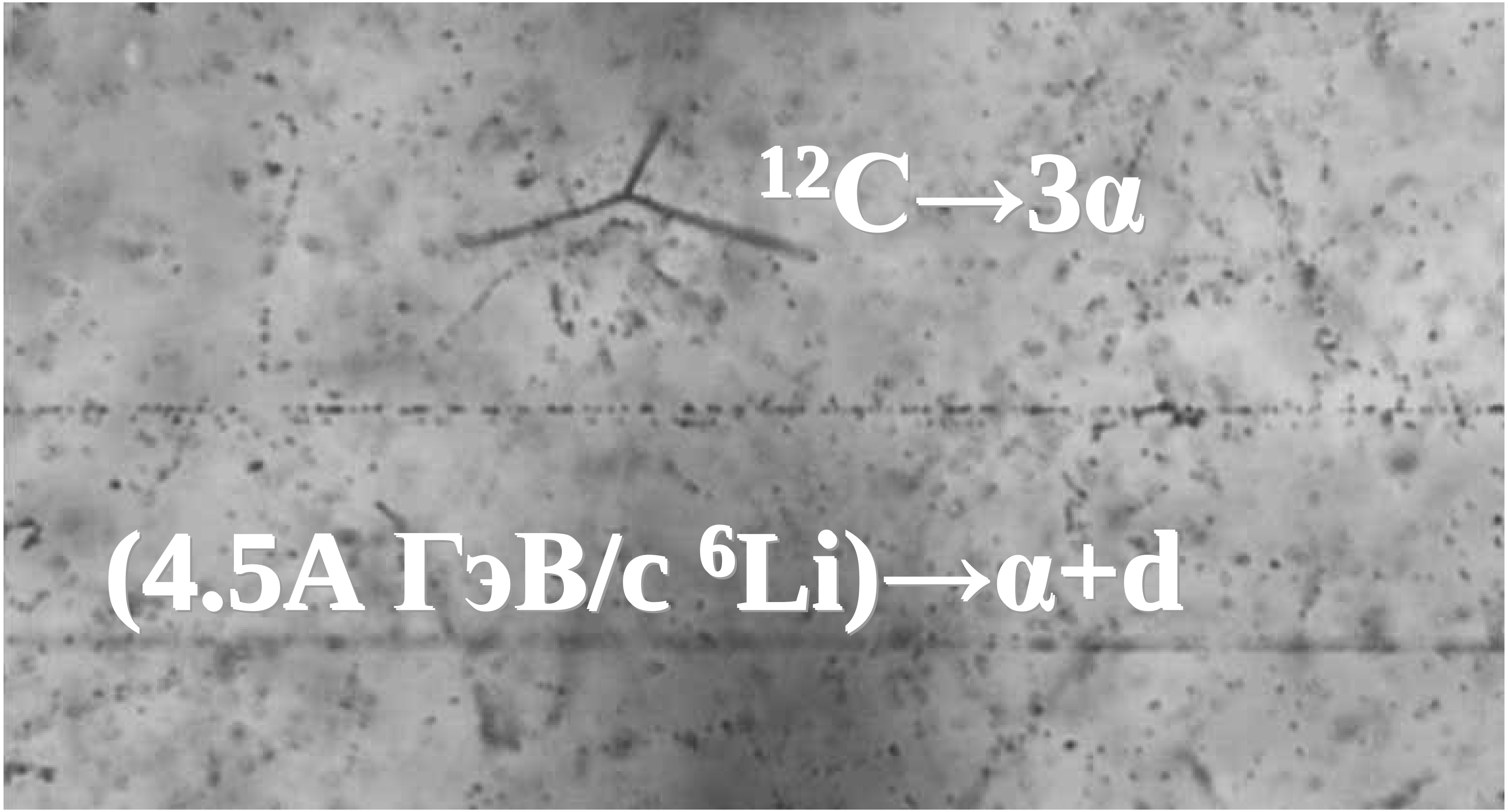
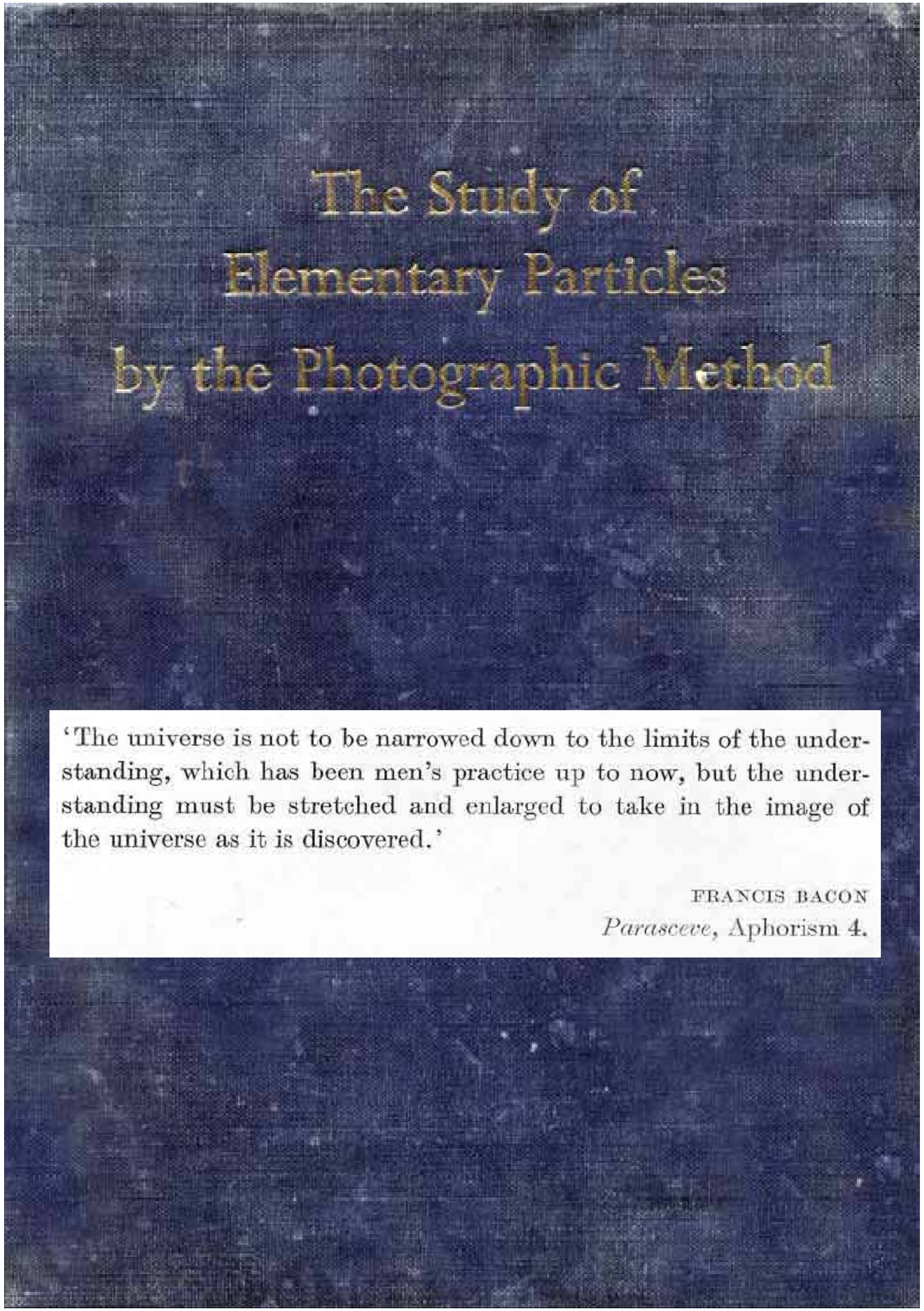
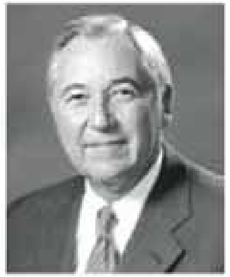

$^{12}C \to 3\alpha$
$(4.5A$ ГэВ/с $^{6}Li) \to \alpha + d$



'The universe is not to be narrowed down to the limits of the understanding, which has been men's practice up to now, but the understanding must be stretched and enlarged to take in the image of the universe as it is discovered.'

FRANCIS BACON
Parasceve, Aphorism 4.





The Study of Elementary Particles by the Photographic Method

An account of
The Principal Techniques and Discoveries
illustrated by
An Atlas of Photomicrographs

BY
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H. H. WILLS PHYSICAL LABORATORY
UNIVERSITY OF BRISTOL

PERGAMON PRESS
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1959

ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

1-92-77

ЗАРУБИН
Павел Игоревич

УДК 539.172.8

РЕДКИЕ ПРОЦЕССЫ В КУМУЛЯТИВНОМ РОЖДЕНИИ ЧАСТИЦ ПРИ ВЗАИМОДЕЙСТВИИ РЕЛЯТИВИСТСКИХ ЯДЕР

Специальность: 01.04.16 - физика ядра и элементарных частиц

Автореферат диссертации на соискание ученой степени кандидата физико-математических наук

Дубна 1992

Работа выполнена в Лаборатории высоких энергий Объединенного института ядерных исследований.

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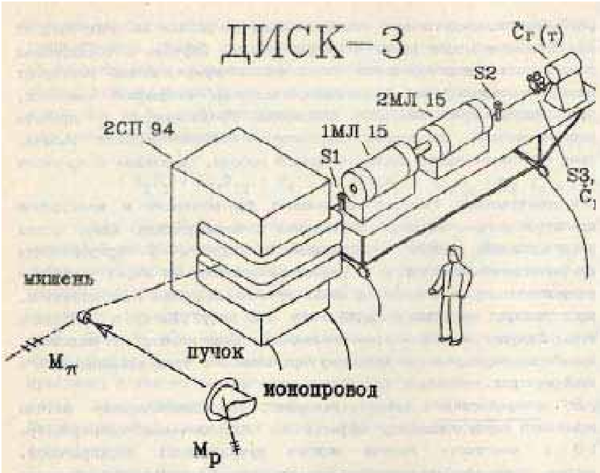
доктор физико-математических наук — Ставинский Алексей Валентинович

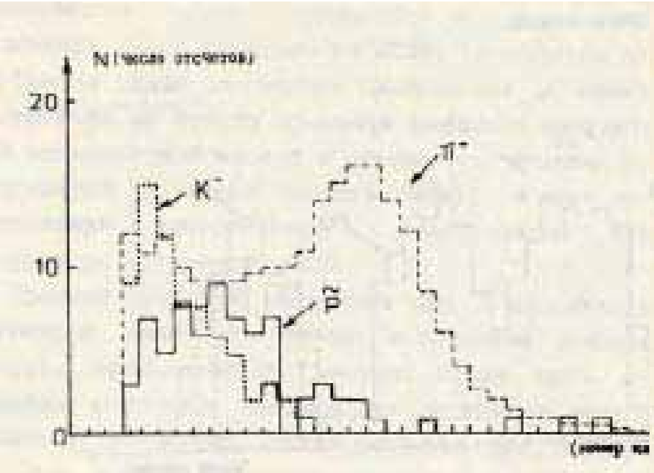
Защита состоится "____" __________ 1992 года в _____ час. на заседании специализированного совета Д-047.01.02 при Лаборатории высоких энергий Объединенного института ядерных исследований, Дубна, Московской области, конференц-зал ЛВЭ.

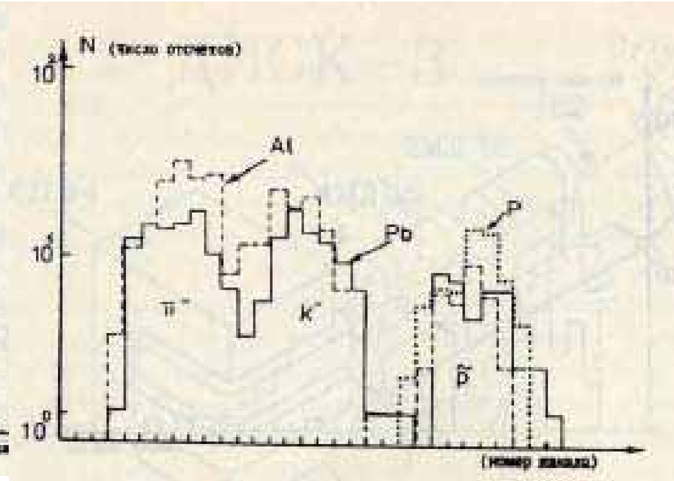
С диссертацией можно ознакомиться в библиотеке ЛВЭ ОИЯИ.

Автореферат разослан "____" __________ 1992 года.

Ученый секретарь
специализированного совета — М.Ф.Лихачев







First observation in photographic emulsion of an event attributed to the creation and annihilation of an anti-proton

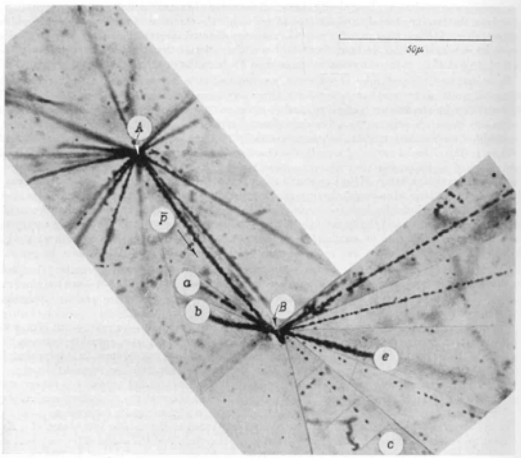


PLATE 12–1

Ilford G5 emulsion. AMALDI *et al.* (1955).

Annihilation of an artificially produced anti-proton

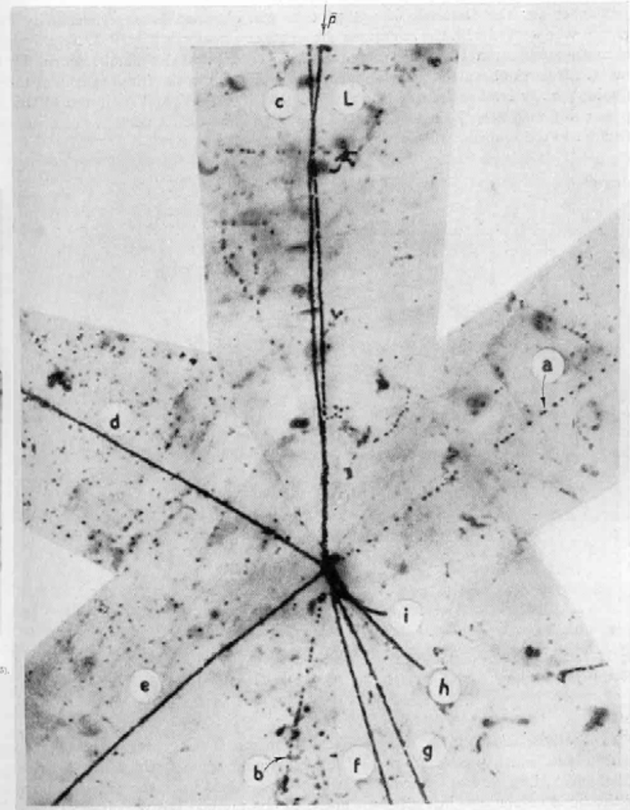


PLATE 12–1

rd G5 emulsion. CHAMBERLAIN *et al.* (1956a).

Annihilation of an anti-proton

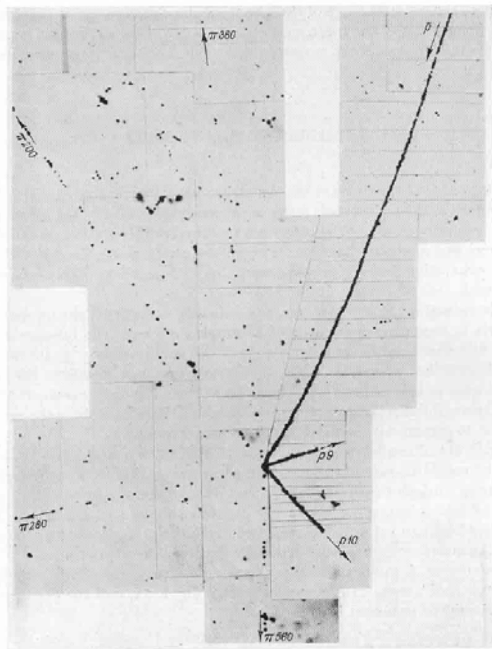
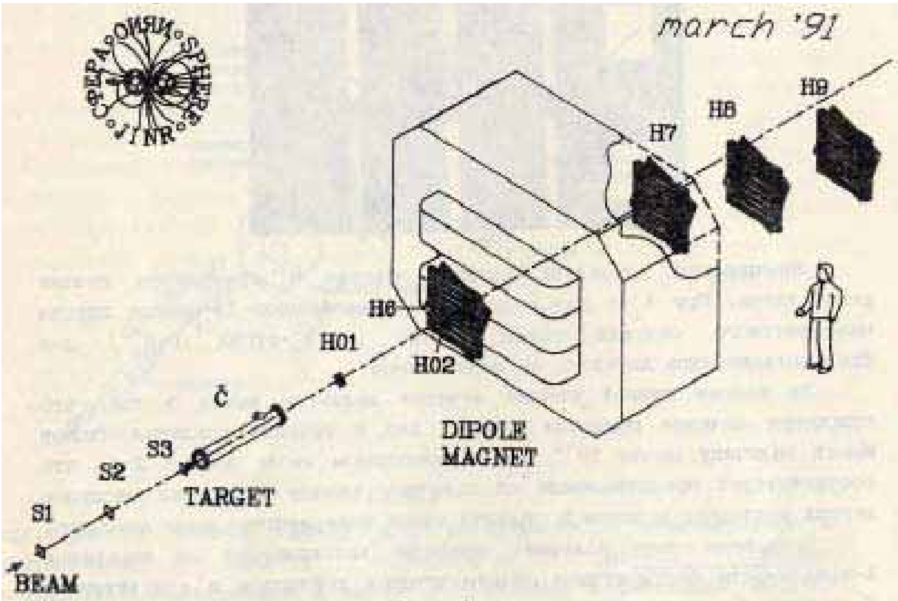
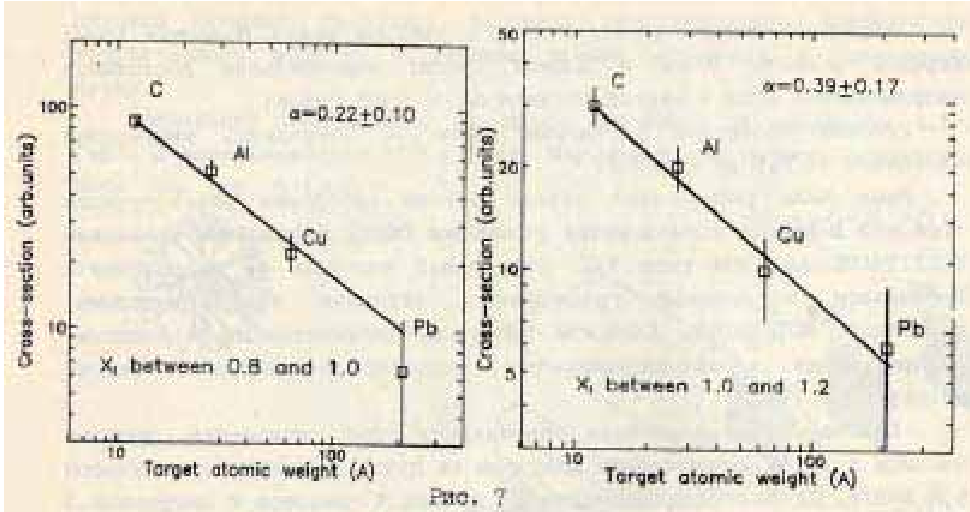


PLATE 12–3

Ilford G5 emulsion. BIRGE *et al.* (1956)



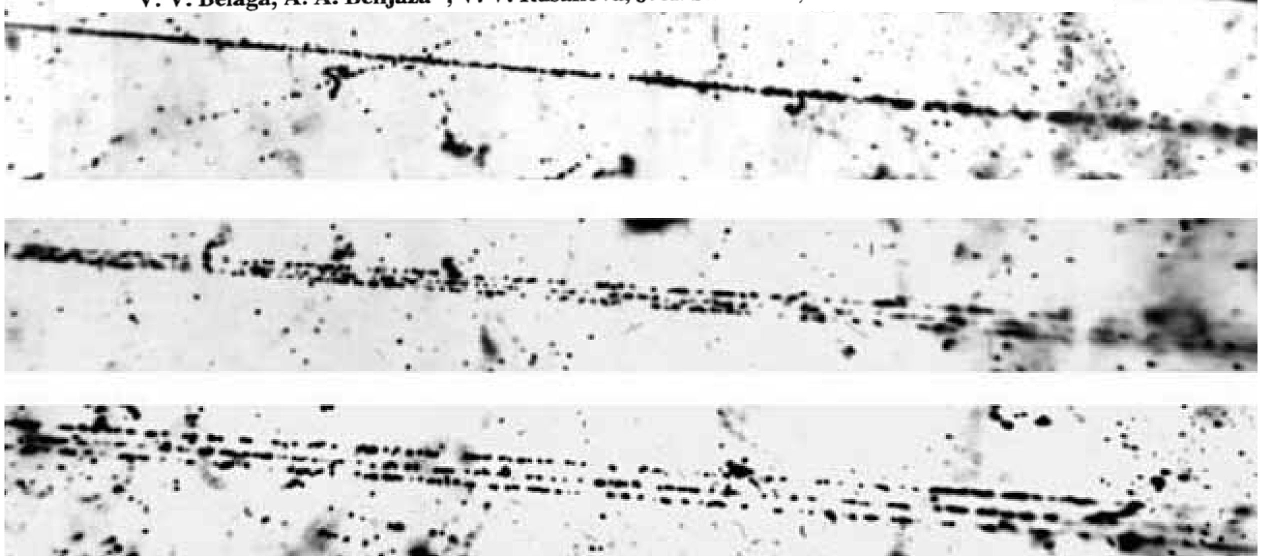


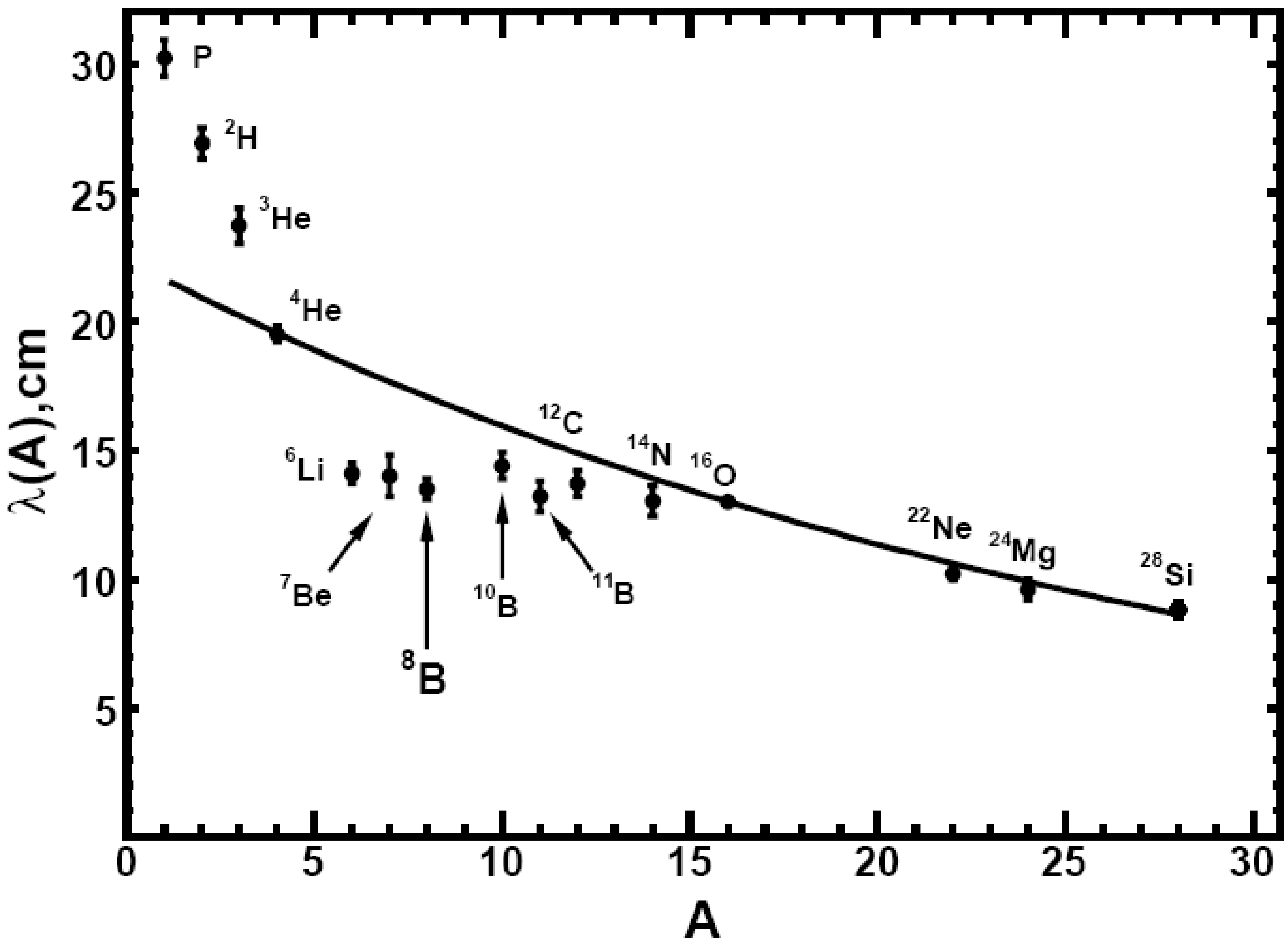
Physics of Atomic Nuclei, Vol. 58, No. 11, 1995, pp. 1905 - 1910. Translated from Yadernaya Fizika, Vol. 58, No. 11, 1995, pp. 2014 - 2020.

ELEMENTARY PARTICLES AND FIELDS
Experiment

Coherent Dissociation $^{12}C \rightarrow 3\alpha$ in Lead-Enriched Emulsion at 4.5 GeV/*c* per Nucleon

V. V. Belaga, A. A. Benjaza[1)], V. V. Rusakova, J. A. Salamov[2)], and G. M. Chernov





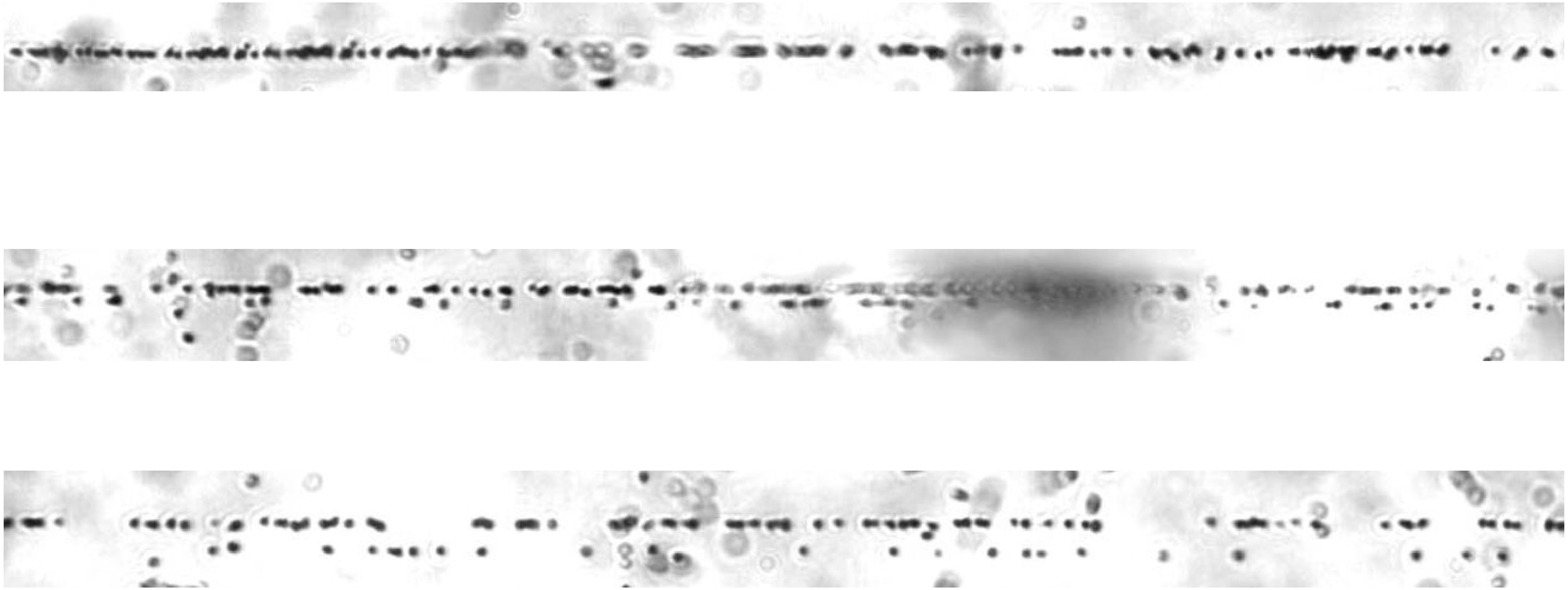
λ(A),cm
A
30
25
20
15
10
5
0
5
10
15
20
25
30
P
2H
3He
4He
6Li
7Be
8B
10B
11B
12C
14N
16O
22Ne
24Mg
28Si

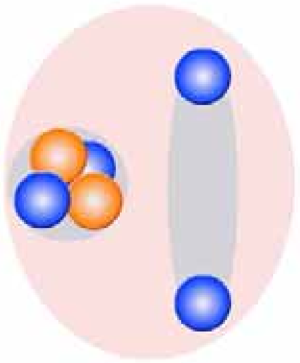
Physics of Atomic Nuclei, Vol. 62, No. 8, 1999, pp. 1378–1387. Translated from Yadernaya Fizika, Vol. 62, No. 8, 1999, pp. 1461–1471.

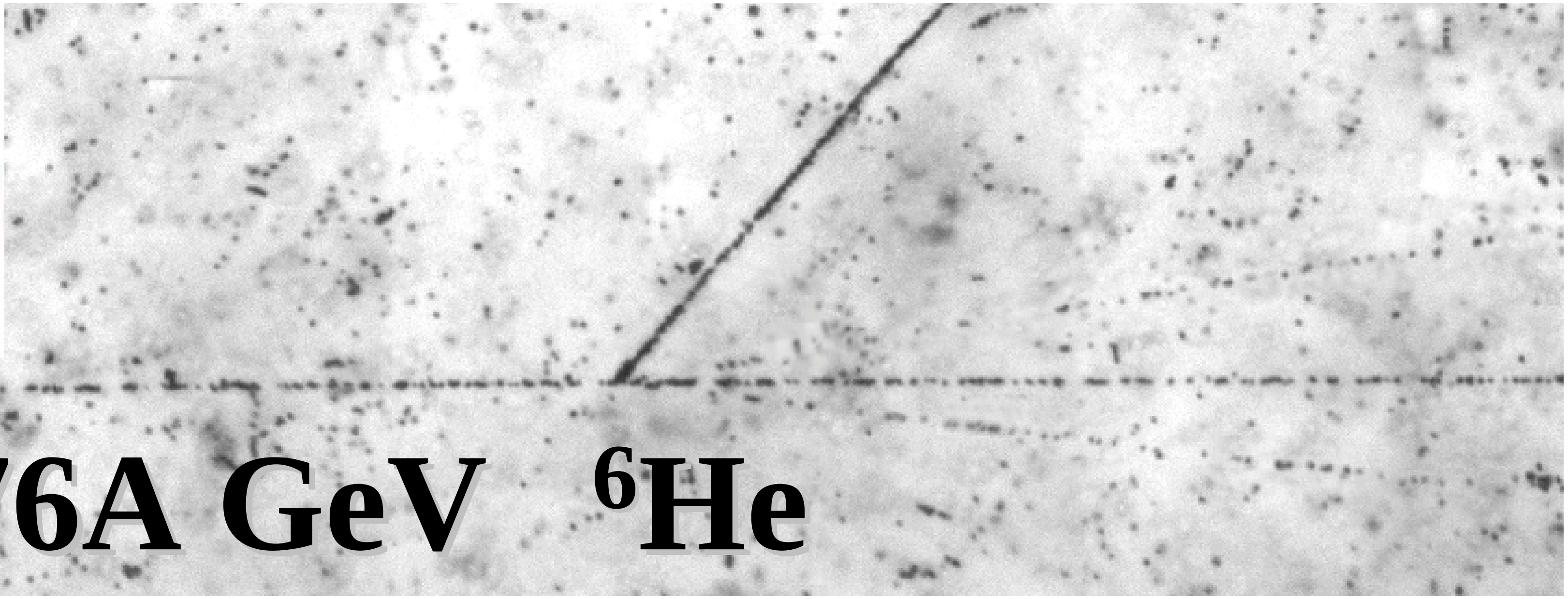
ELEMENTARY PARTICLES AND FIELDS
Experiment

Interactions of Relativistic ^{6}Li Nuclei with Photoemulsion Nuclei

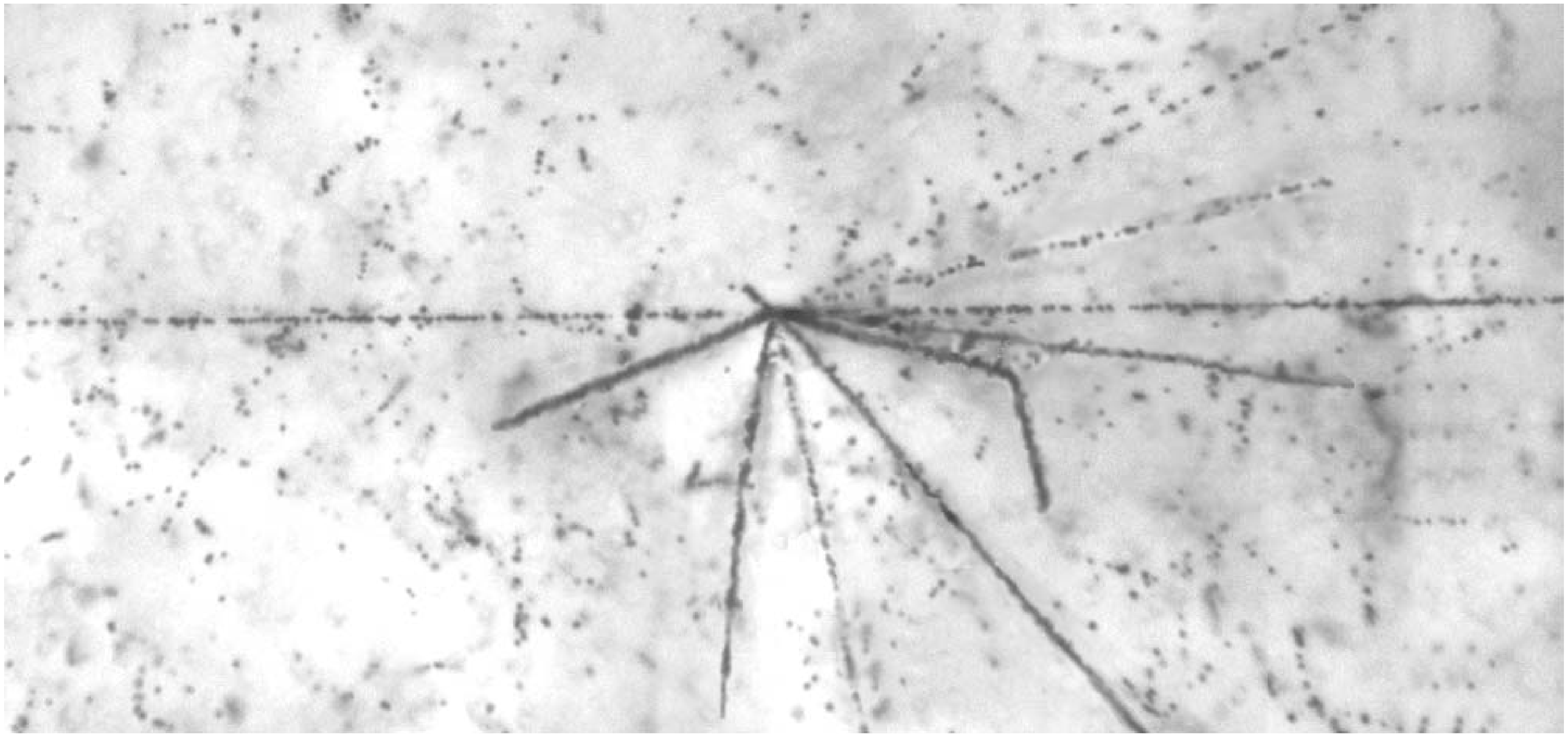
M. I. Adamovich, V. G. Bogdanov[1)], I. A. Konorov, V. G. Larionova, N. G. Peresadko, V. A. Plyushchev[1)], Z. I. Solovyeva[1)†], and S. P. Kharlamov







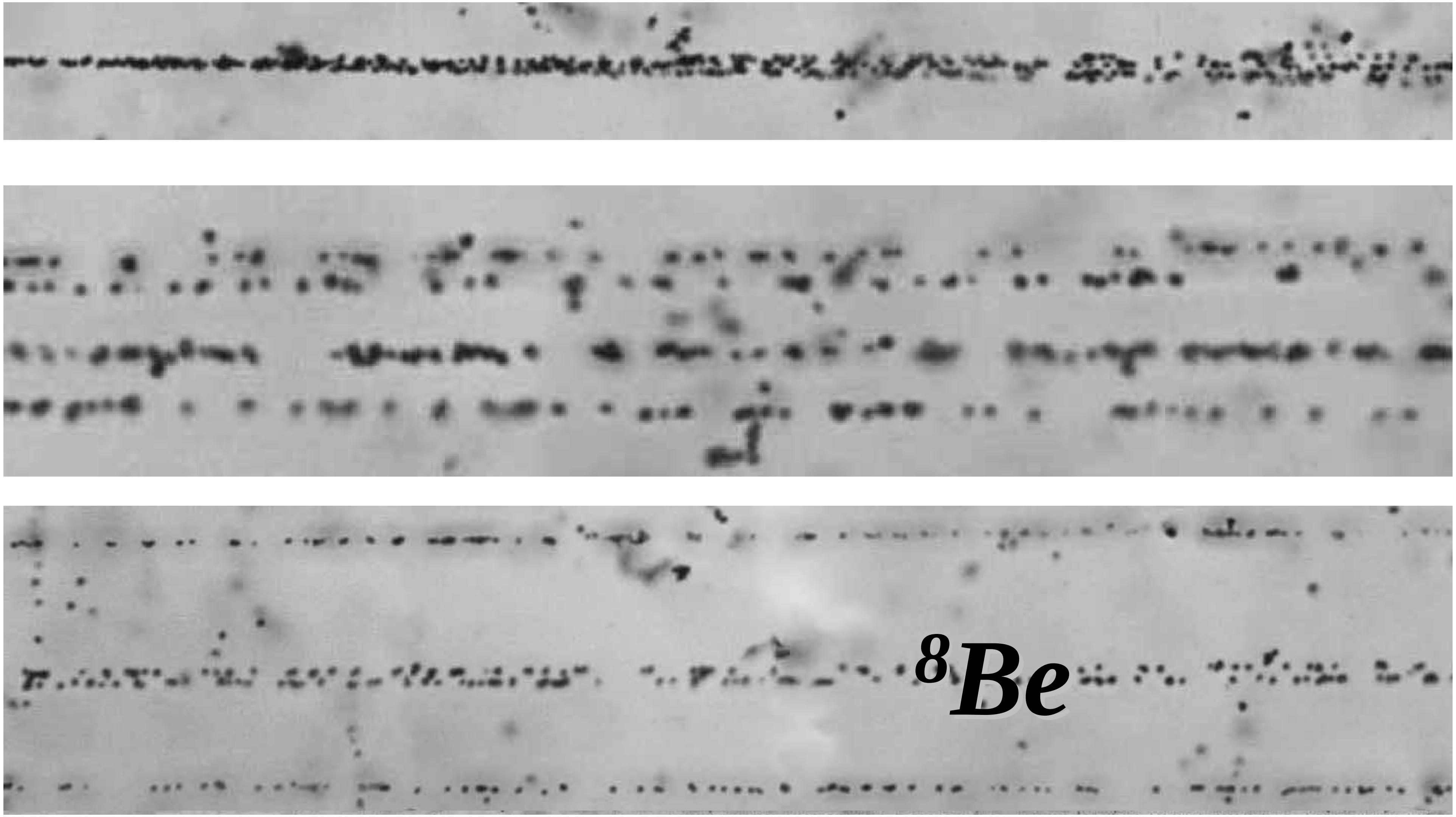
2.76A GeV ^{6}He

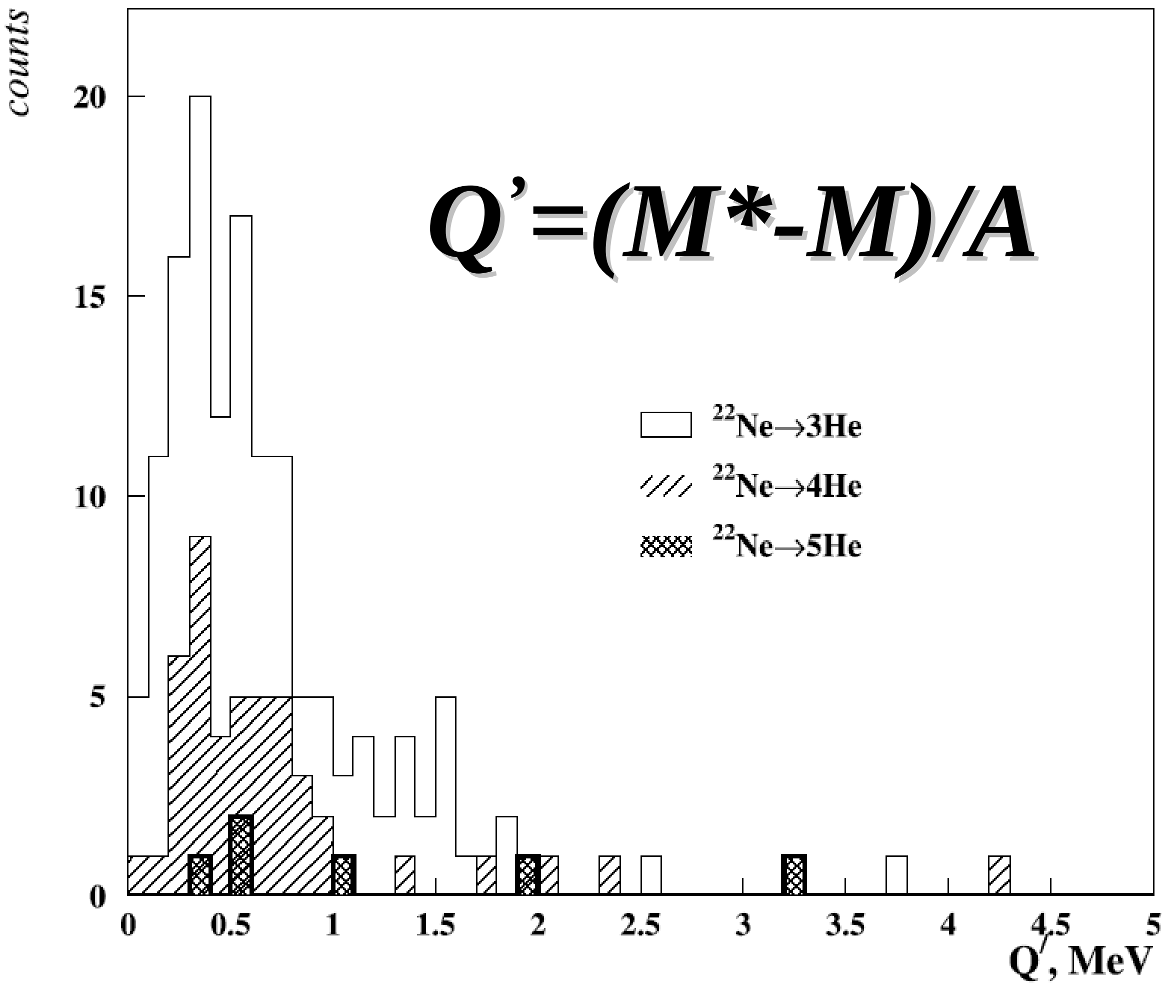


^{22}Ne 3.22A GeV
4100 Inelastic Interactions

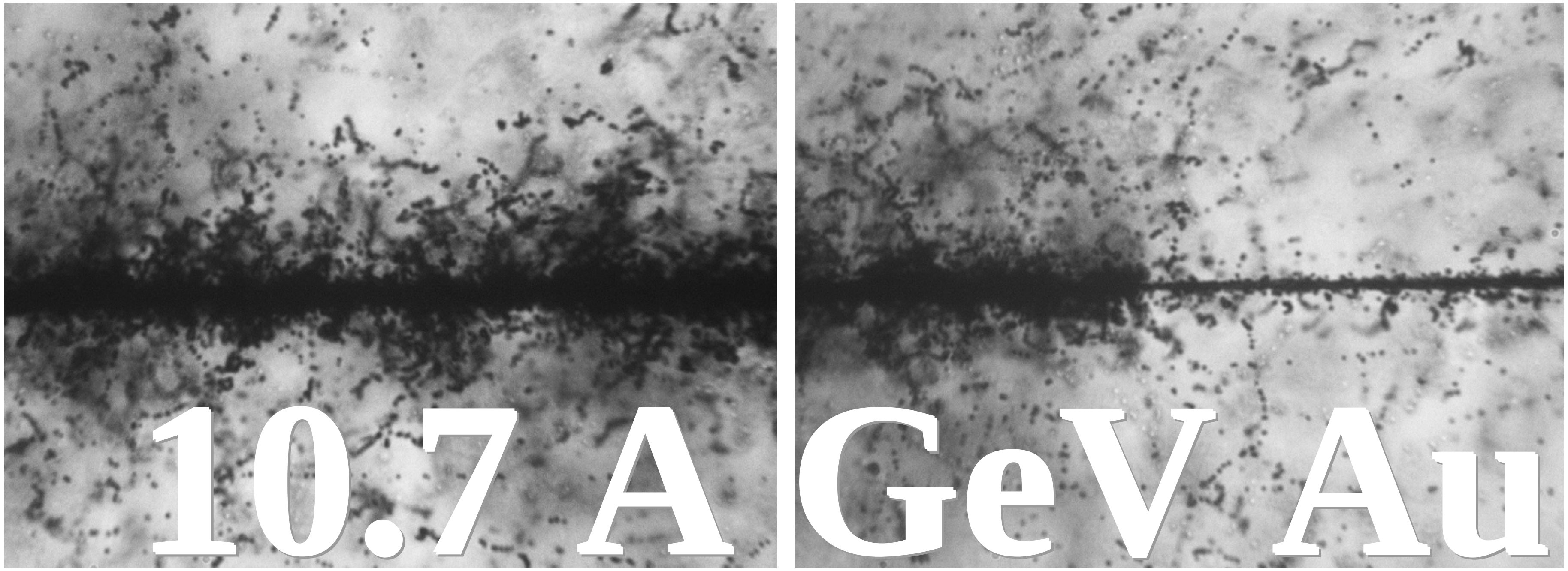
n_b n_g	0 0	0 1	1 0	2 0	3 0	>3 0
F +H	26 (19.5)	9 (15.0)	13 (44.8)	2	-	1
O + He	54 (40.6)	19 (31.7)	2 (6.9)	-	1	1
O + 2H	12 (9.0)	7 (11.7)	-	-	-	-
N + He + H	12 (9.0)	7 (11.7)	4 (13.8)	1	-	-
N + 3H	3 (2.3)	3 (5.0)	-	-	-	-
C + 2He	5 (3.8)	3 (5.0)	3 (10.3)	1	-	-
C + 2He + 2H	5 (3.8)	3 (5.0)	3 (10.3)	-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

3.65A GeV $^{20}Ne \rightarrow 5\alpha$





Among *4100* events it was found *3* "white" stars $^{22}Ne \to 5\alpha$. Of them, in *2* "golden" events the α particle tracks are contained even within a 1^o cone. For these two events the value of *Q'* is estimated to be as low as *400 - 600 keV* per nucleon. The detection of such "ultracold" 5α states is a serious argument in favor of the reality of the phase transition of α clusterized nuclei to the dilute Bose gas of α particles. It gives a special motivation to explore lighter $n\alpha$ systems as potential "building blocks" of the dilute α particle Bose gas.



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

Multifragmentation reactions and properties of stellar matter at subnuclear densities

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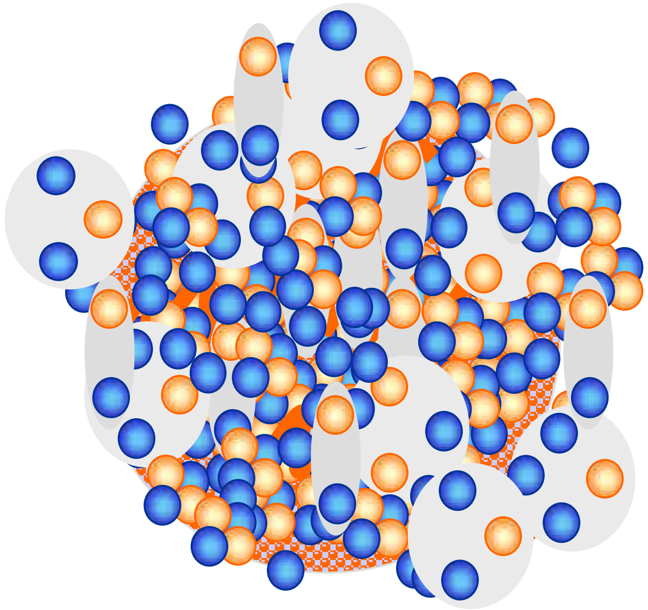
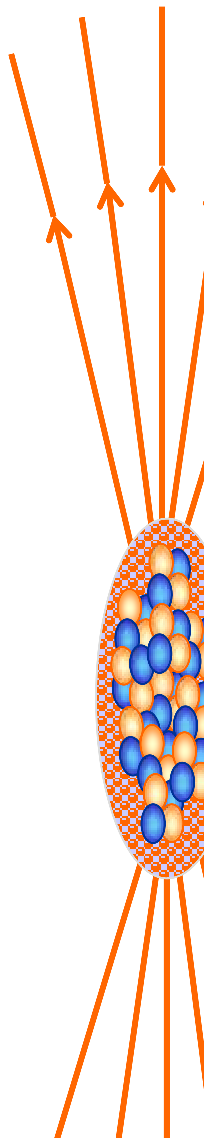
[1] *Institute for Nuclear Research, Russian Academy of Sciences, RU-117312 Moscow, Russia*

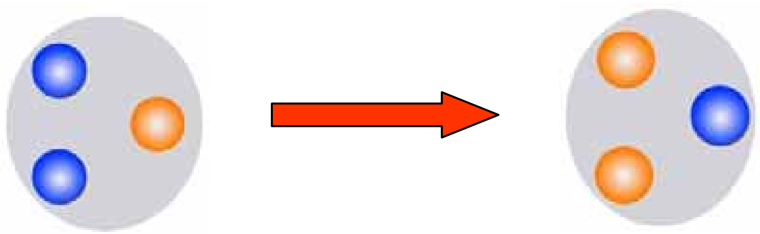
[2] *Frankfurt Institute for Advanced Studies, J.W. Goethe University, D-60438 Frankfurt am Main, Germany*

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

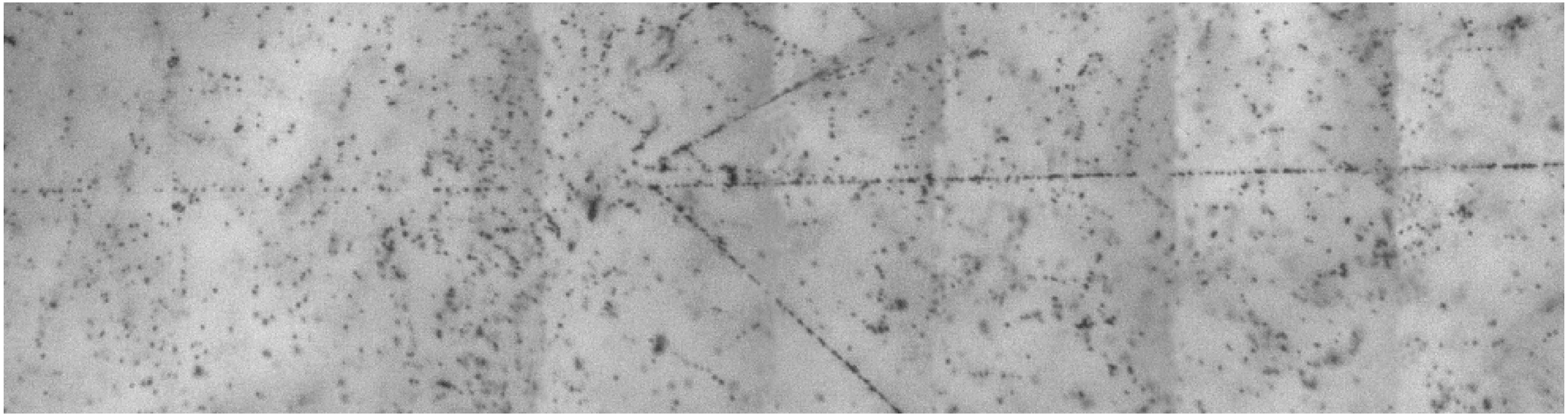
(Received 20 June 2005; published 24 October 2005)

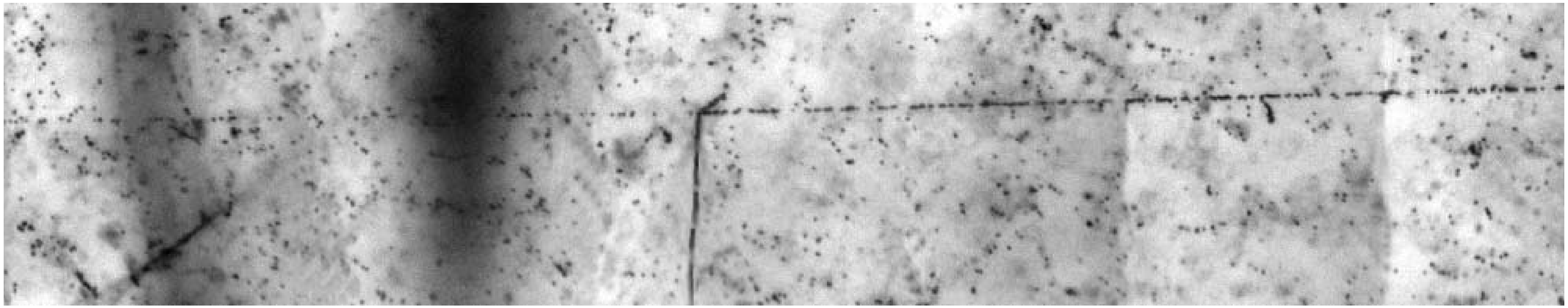
We point out the similarity of thermodynamic conditions reached in nuclear multifragmentation and in supernova explosions. We show that a statistical approach previously applied for nuclear multifragmentation reactions can also be used to describe the electroneutral stellar matter. Then properties of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

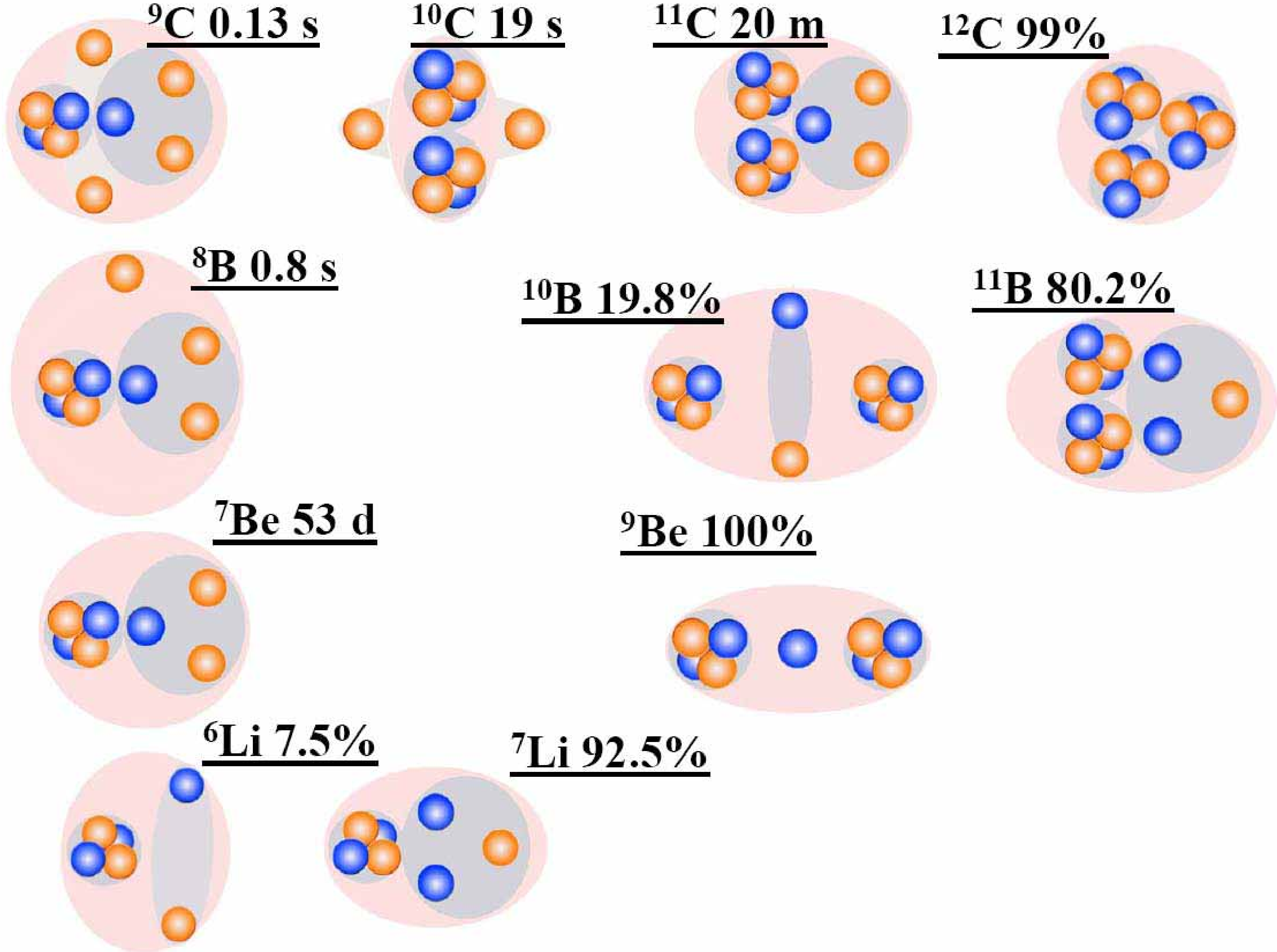





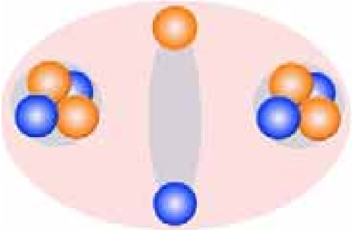
SPT: 2.76A GeV $^{3}H \rightarrow {}^{3}He$



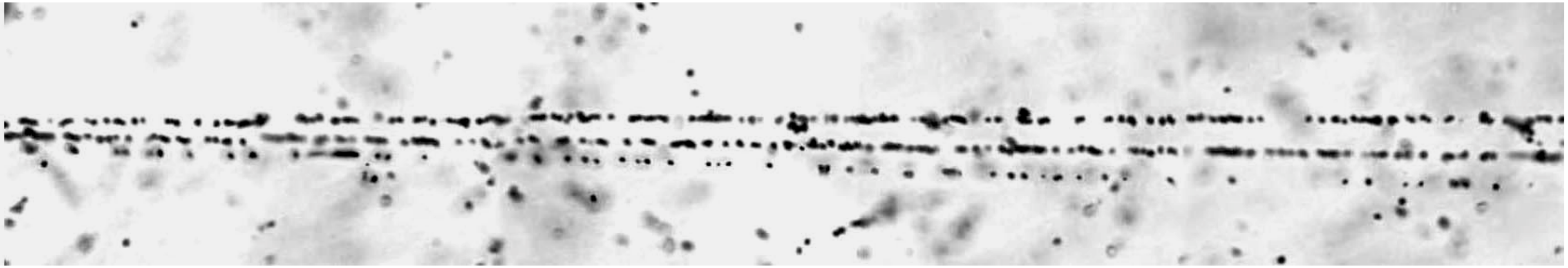




^{9}C 0.13 s
^{10}C 19 s
^{11}C 20 m
^{12}C 99%
^{8}B 0.8 s
^{10}B 19.8%
^{11}B 80.2%
^{7}Be 53 d
^{9}Be 100%
^{6}Li 7.5%
^{7}Li 92.5%



1A GeV ^{10}B

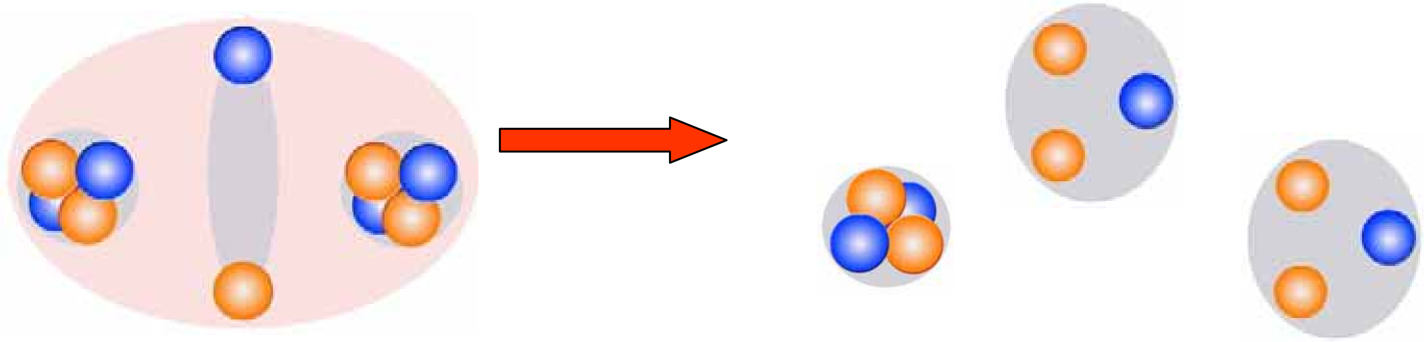


2He + H (6 MeV) - 73% Li + He (4.5 MeV) - 12% ^{9}Be + p (6.6 MeV) - 2%

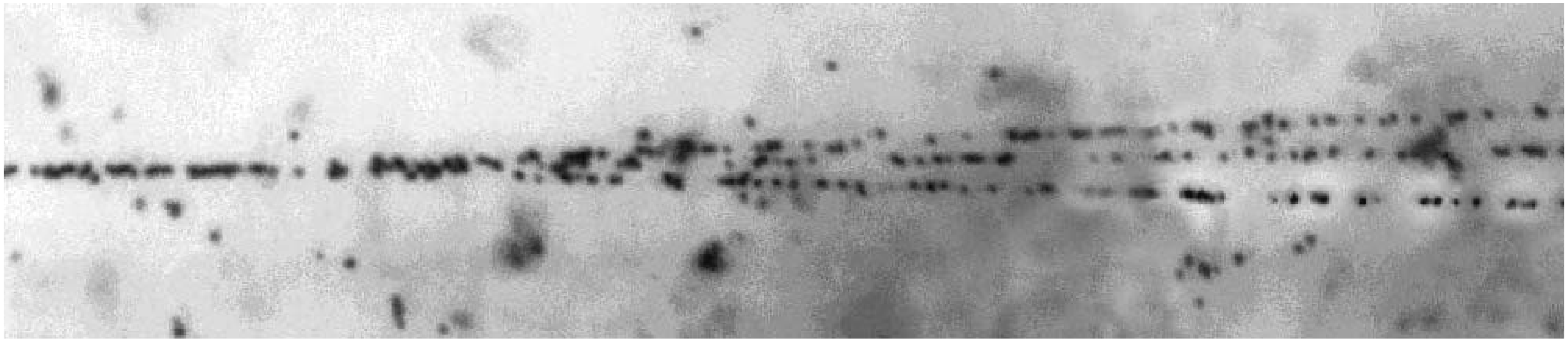
Peripheral dissociation of ^{10}B and ^{11}B nuclei is studied. In both cases it points to a leading role of three-body channels *2He + H*.

Deuteron clustering is established for or the coherent dissociation of ^{10}B and the nuclei ^{11}B – triton one.

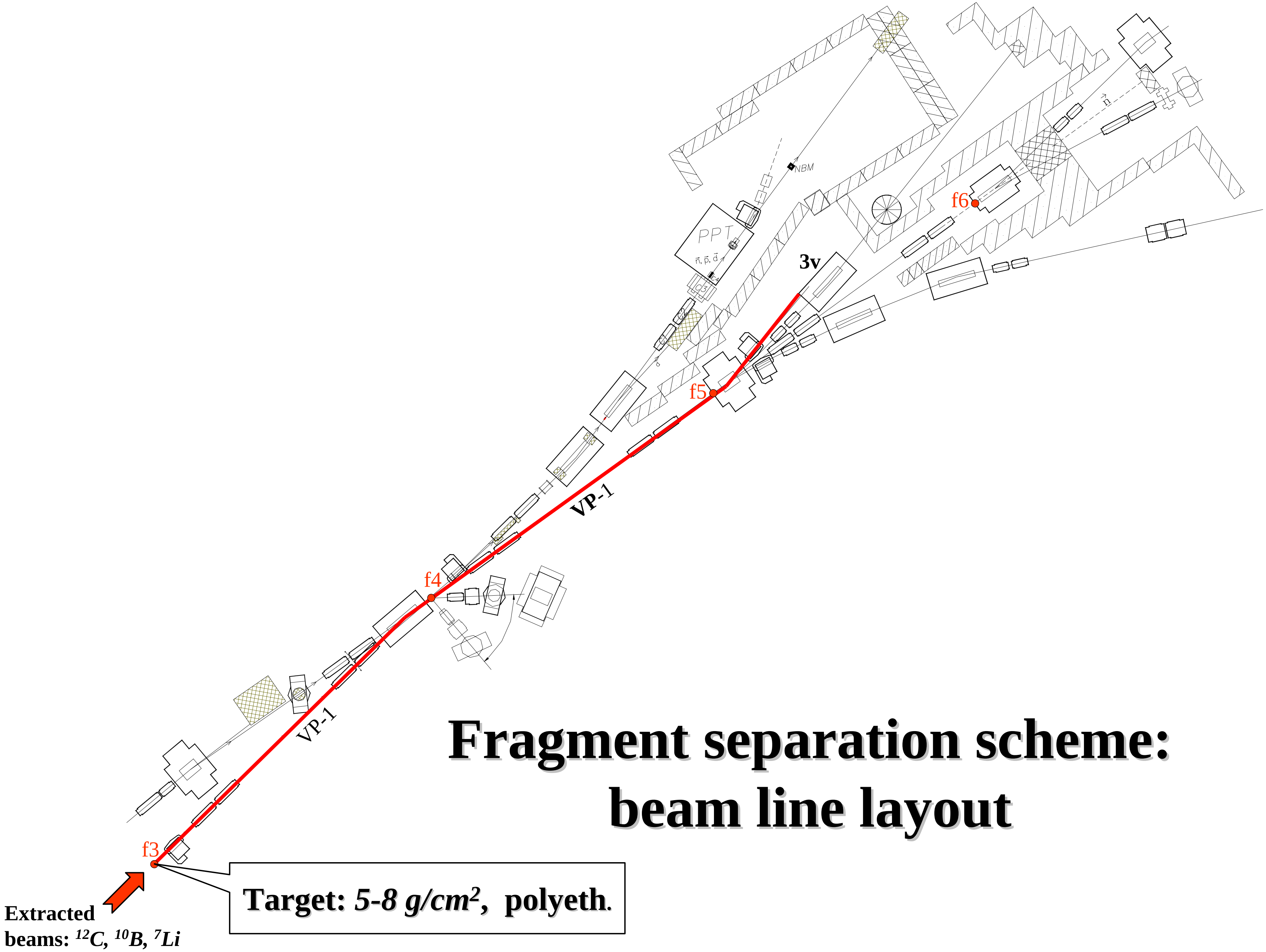
For the first time the events of coherent charge exchange of $^{11}B \rightarrow {}^{7}Be + {}^{4}He$ are observed in the absence of events in the three-body channel indicating the sensitivity of the relativistic dissociation to structural characteristics of mirror nuclei.



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

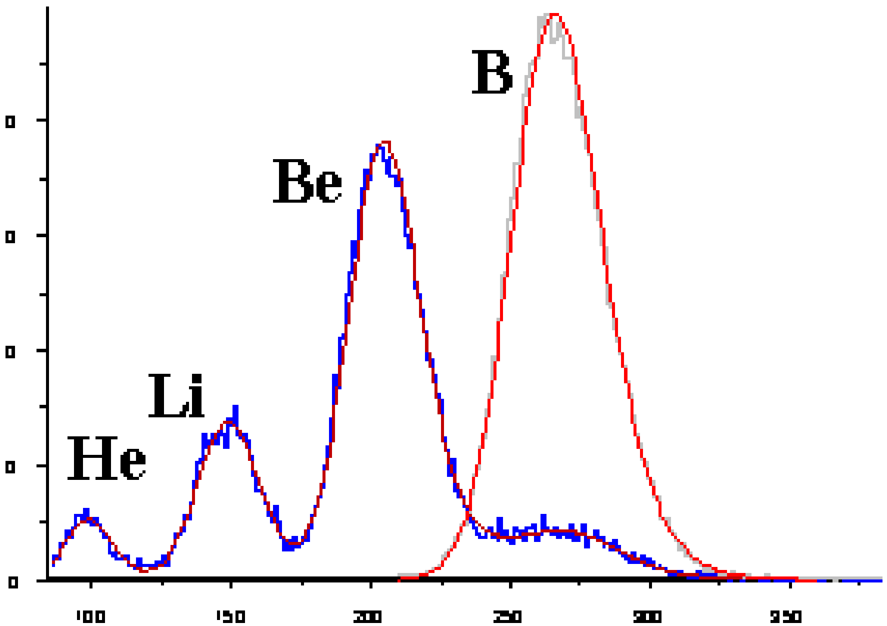


Fragment separation scheme: beam line layout

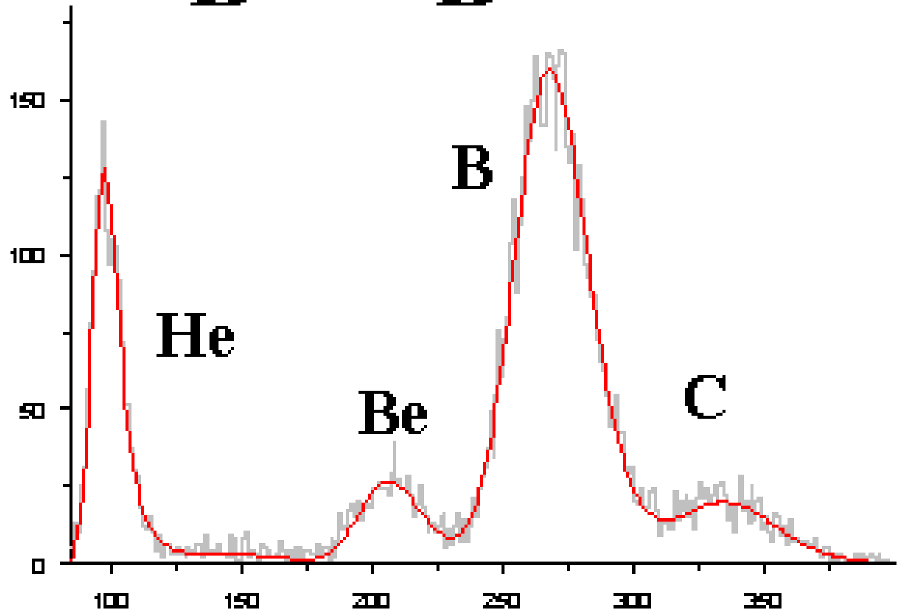


Target: ***5-8 g/cm²*****, polyeth.**

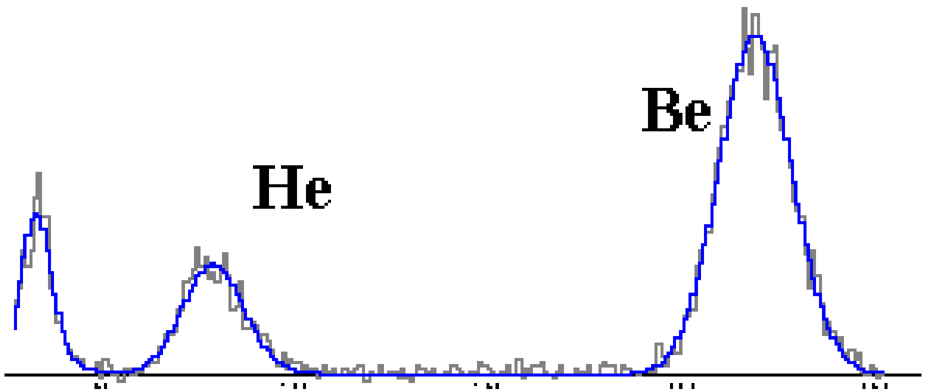
$^{10}B \rightarrow {}^{9}Be$



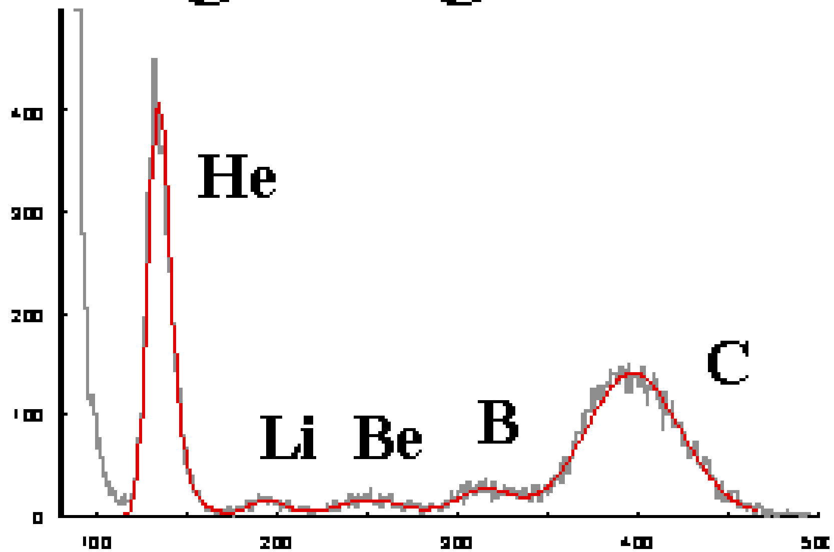
$^{10}B \rightarrow {}^{8}B$

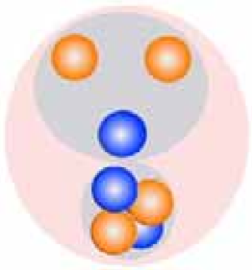


$^{7}Li \rightarrow {}^{7}Be$



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





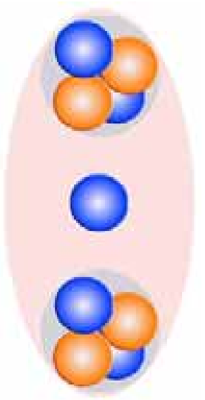
1.2A GeV ^{7}Be

	^{4}He + ^{3}He	^{3}He + ^{3}He	^{4}He + 2p	^{4}He + d + p	^{3}He + 2p	^{3}He + d + p	^{3}He + 2d	^{3}He + t + p	3p + d	2d + 2p	^{6}Li + p
$n_h = 0$	30	11	13	10	9	8	1	1	2	-	9
$n_h > 0$	11	7	9	5	9	10	-	-	1	-	3

The coherent dissociation of ^{7}Be nuclei is mainly attributable to two-cluster structure ^{3}He + ^{4}He.

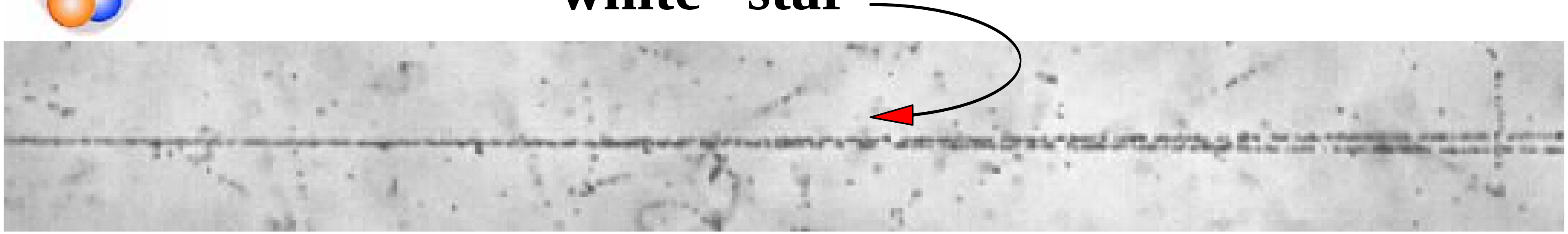
^{3}He clusters contribution is twice of the ^{4}He one, indicating the strong manifestation of ^{3}He clustering in relativistic processes.

This type of clustering is most pronounced in channel ^{4}He + ^{3}He in coherent dissociation of ^{7}Be nuclei, not accompanied by the emission of neutrons

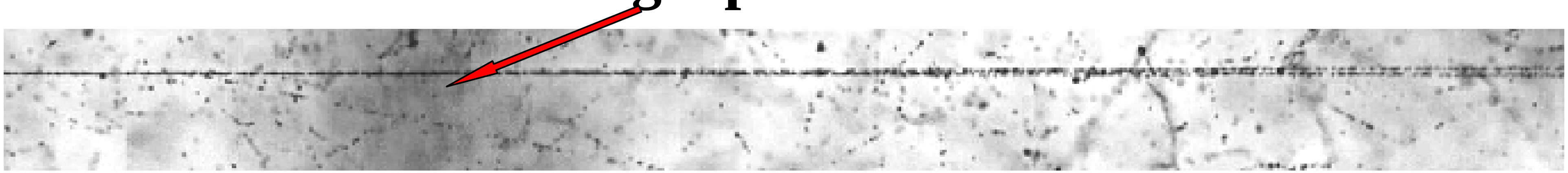


1.2A GeV ^{9}Be

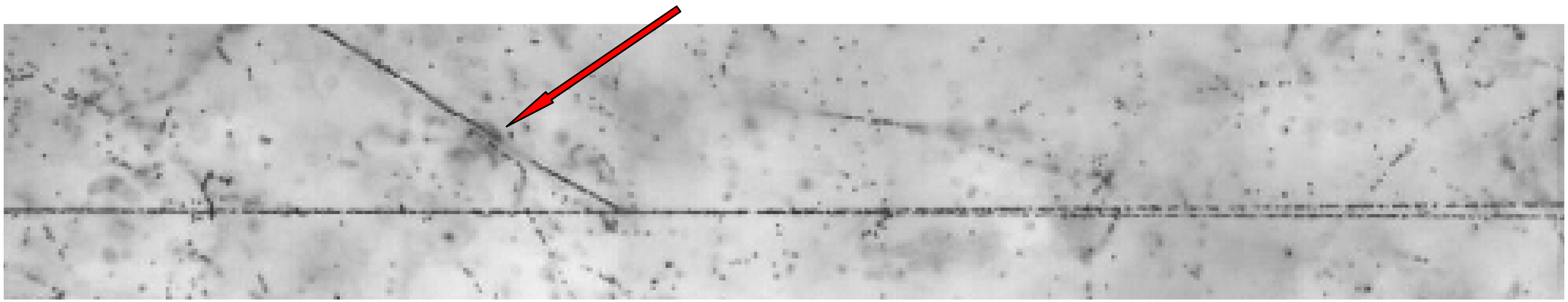
"white" star

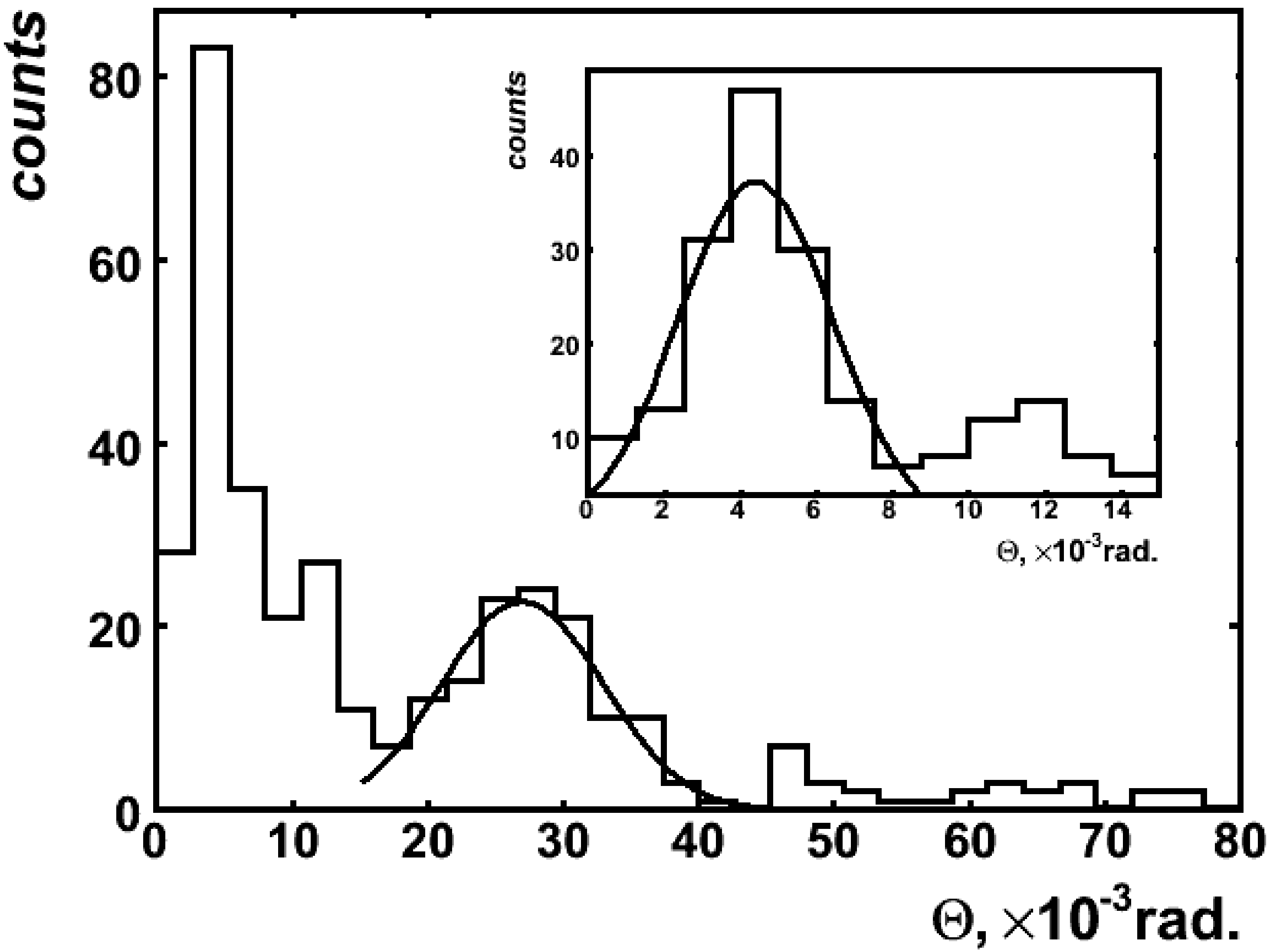


star with target proton like recoil

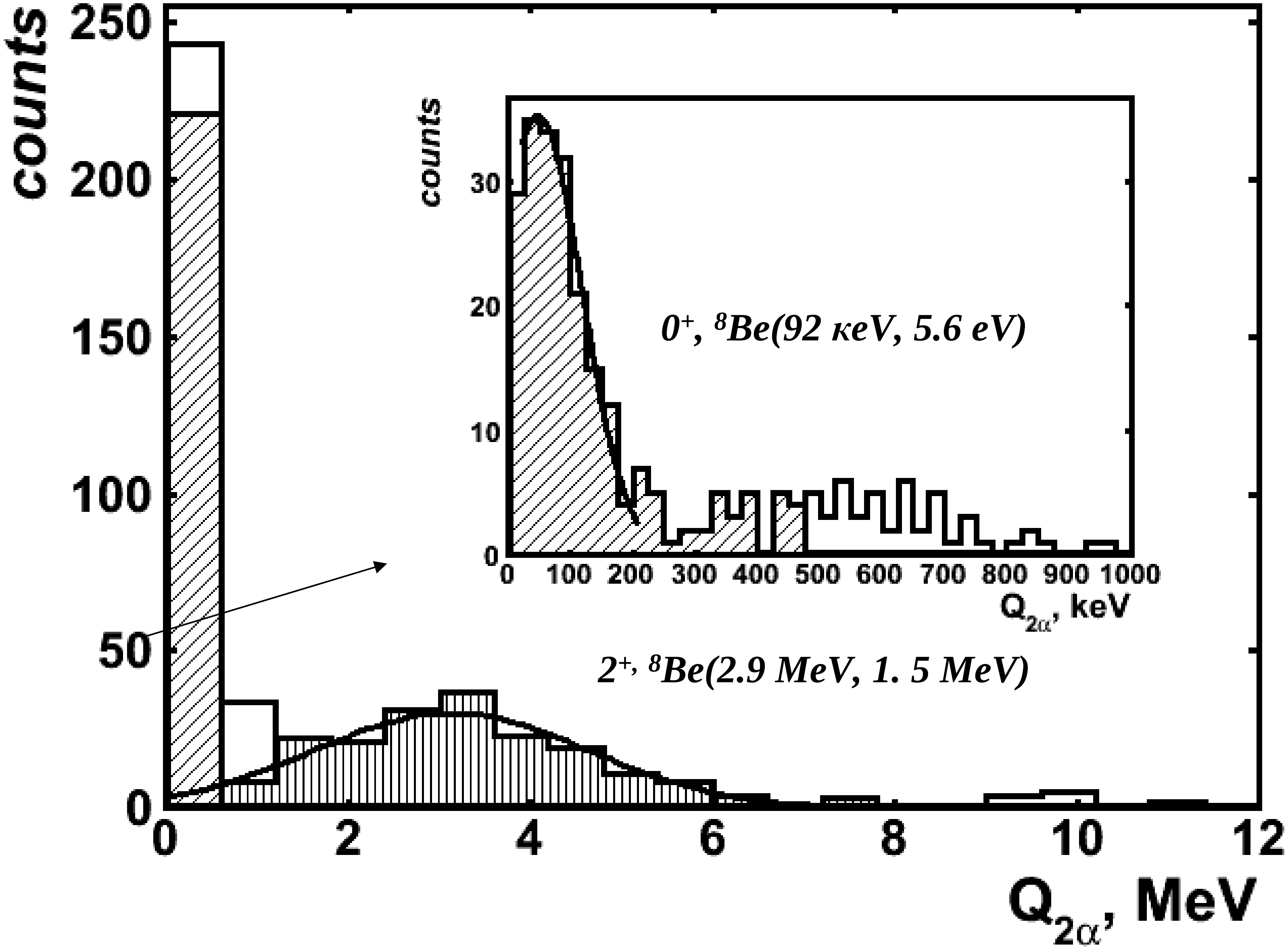


Star with heavy fragment of target nucleus (b-particle)

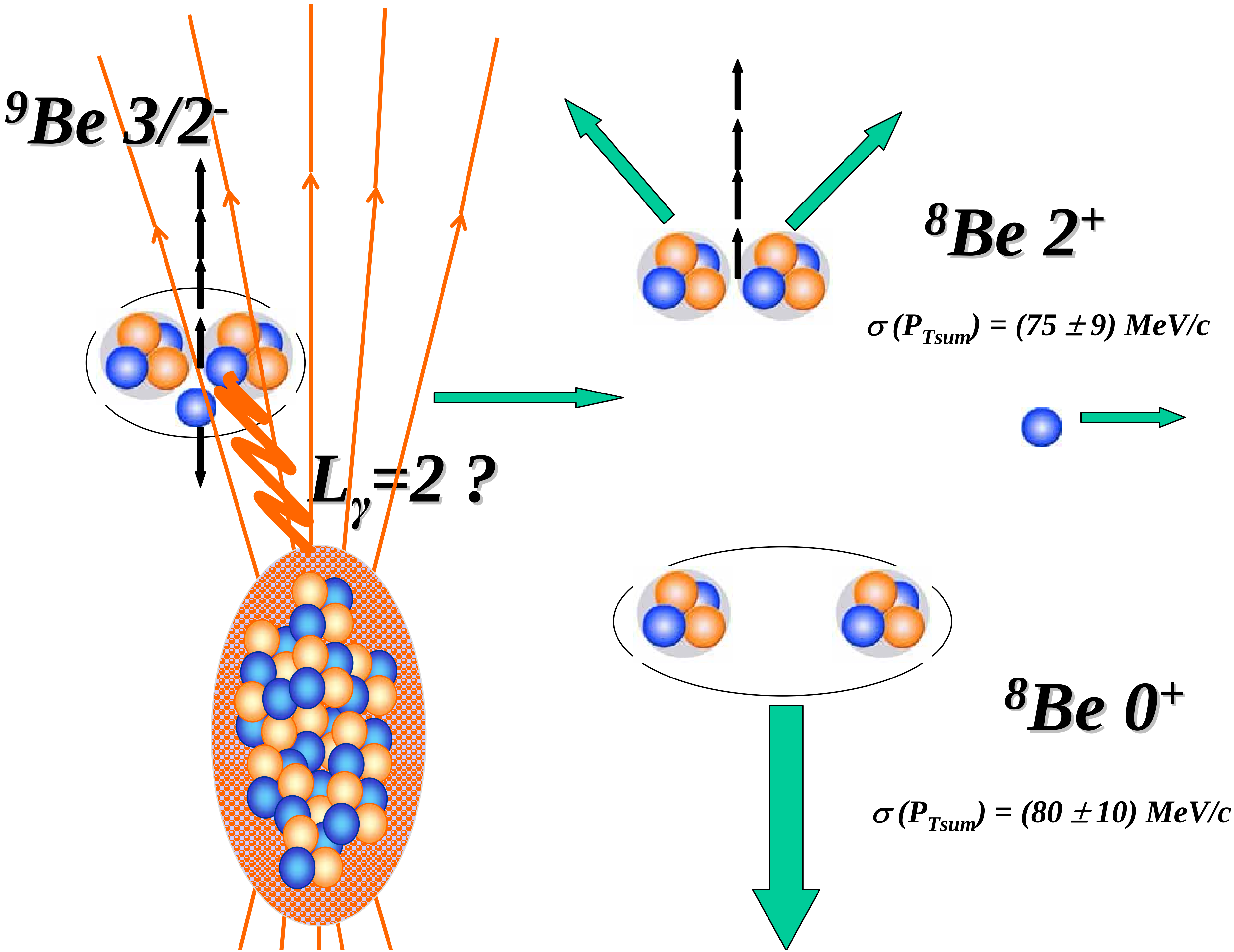




81% **of the events on the value of opening angle** ***Θ*** **form two roughly equal groups - "narrow" α-pairs** ***$0 < \Theta_{n(arrow)} < 10$ mrad*** **and "wide" ones** ***$15 < \Theta_{w\ (ide)} < 45$ mrad***



72% **of the events of fragmentation** ^{9}***Be*** **→** ***2α*****, proceed through intermediate states** ***0***$^{+}$ **and** ***2***$^{+}$ **of** ^{8}***Be*** **nucleus. A two-peak structure in the distribution of opening angles Θ arises due to this circumstance.**



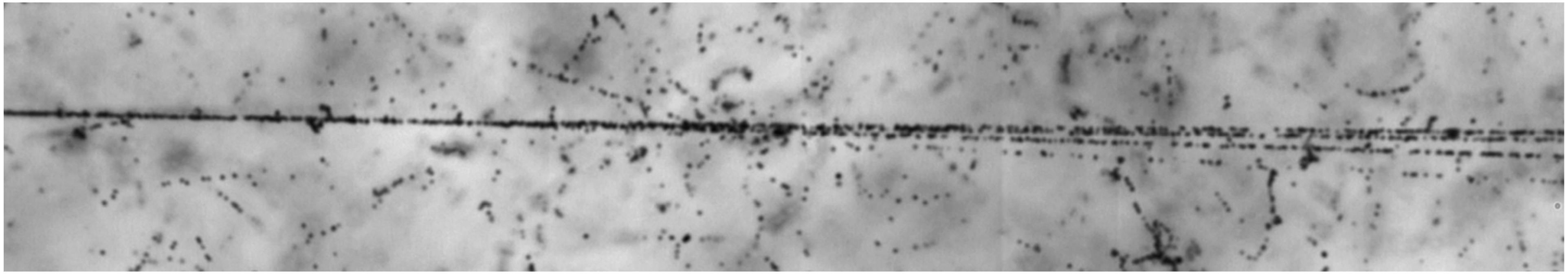
$^{9}Be\ 3/2^{-}$
$L_{\gamma}=2$?
$^{8}Be\ 2^{+}$
$\sigma(P_{Tsum}) = (75 \pm 9)$ MeV/c
$^{8}Be\ 0^{+}$
$\sigma(P_{Tsum}) = (80 \pm 10)$ MeV/c

Θ, *mrad*	*<Θ>*, *mrad*	σ_Θ, *mrad*	Fraction (Events)
Θ_n (0 - 10.5)	4.4 ± 0.2	2.1 ± 0.2	0.56 ± 0.04 (164)
Θ_w (15.0 – 45.0)	27.0 ± 0.6	5.9 ± 0.6	0.44 ± 0.04 (130)

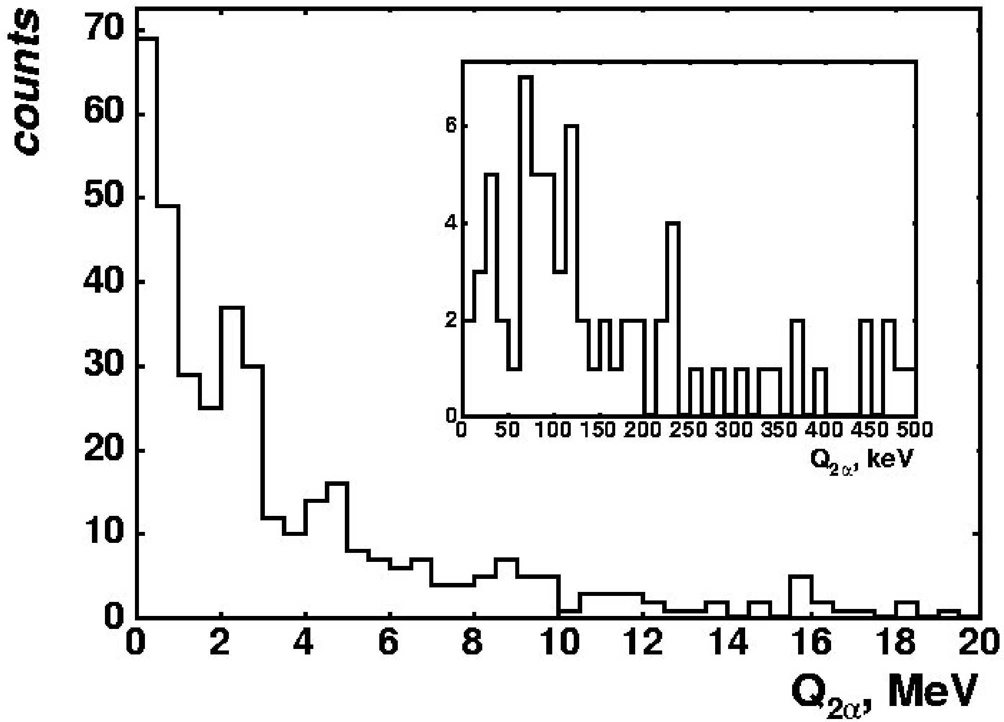
Fractions of events Θ_n and Θ_w demonstrate compliance with weights 0^+ and 2^+ states of a ^8Be core, adopted in the two-body model, $\omega_{0+} = 0.535$ and $\omega_{2+} = 0.465$ [1,2]. They indicate the presence of these states as components of the ground state of the ^9Be nucleus.

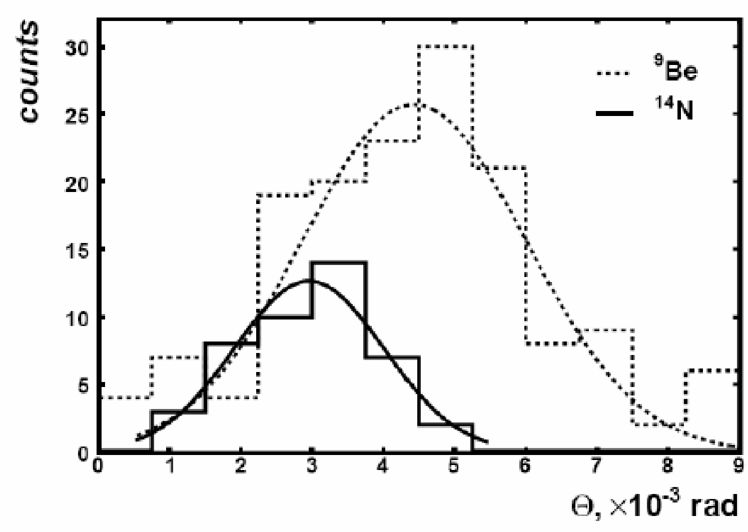
1. Y. L. Parfenova and Ch. Leclercq-Willain, «Hyperfine anomaly in Be isotopes and neutron spatial distribution: A three-cluster model for ^{9}Be», Phys. Rev. C 72, 054304 (2005).

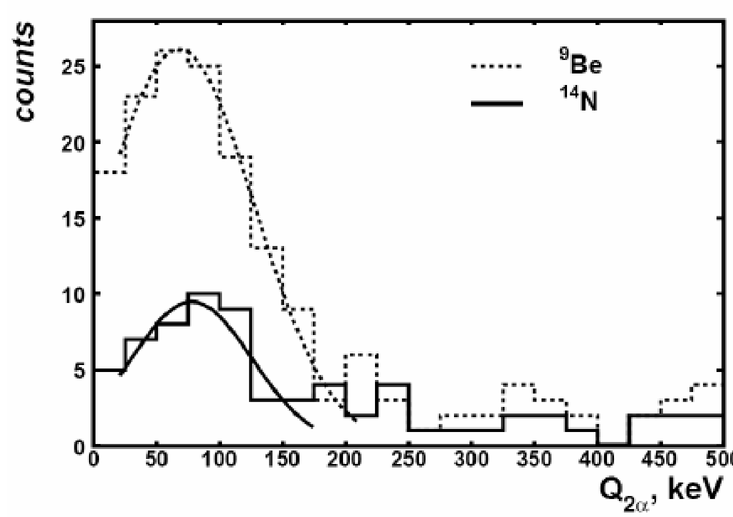
2. Y. L. Parfenova and Ch. Leclercq-Willain, «Hyperfine anomaly in Be isotopes in the cluster model and the neutron spatial distribution», Phys. Rev. C 72, 024312(2005)

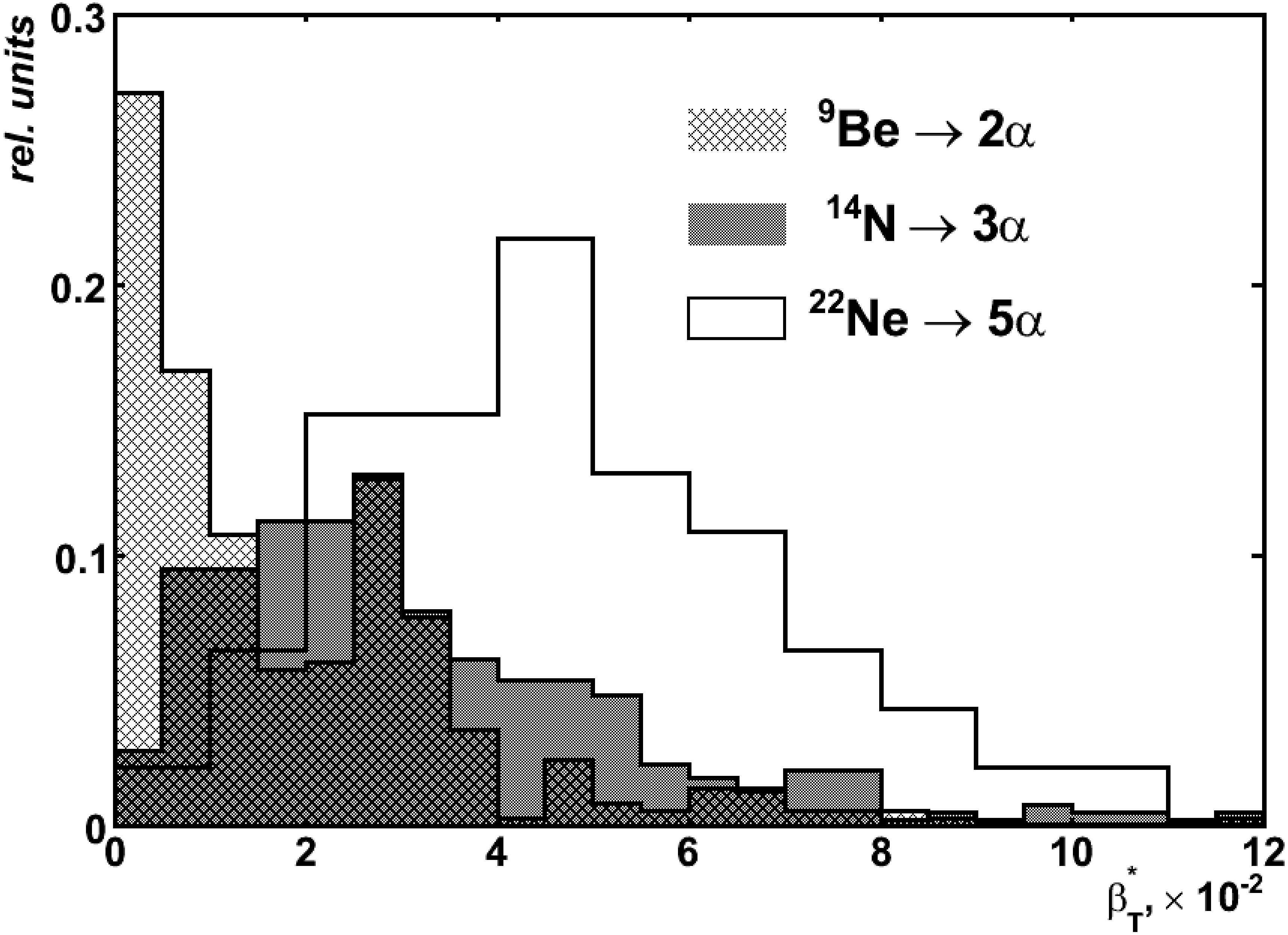


2A GeV ^{14}N

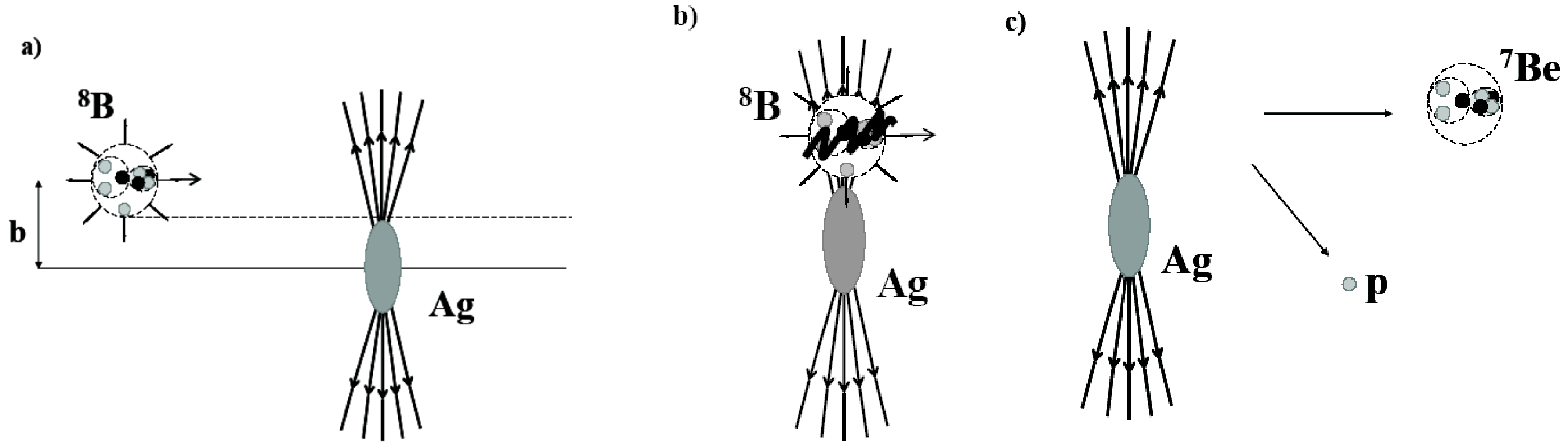

counts
Q2α, MeV
Q2α, keV


counts
9Be
14N
Θ, ×10-3 rad

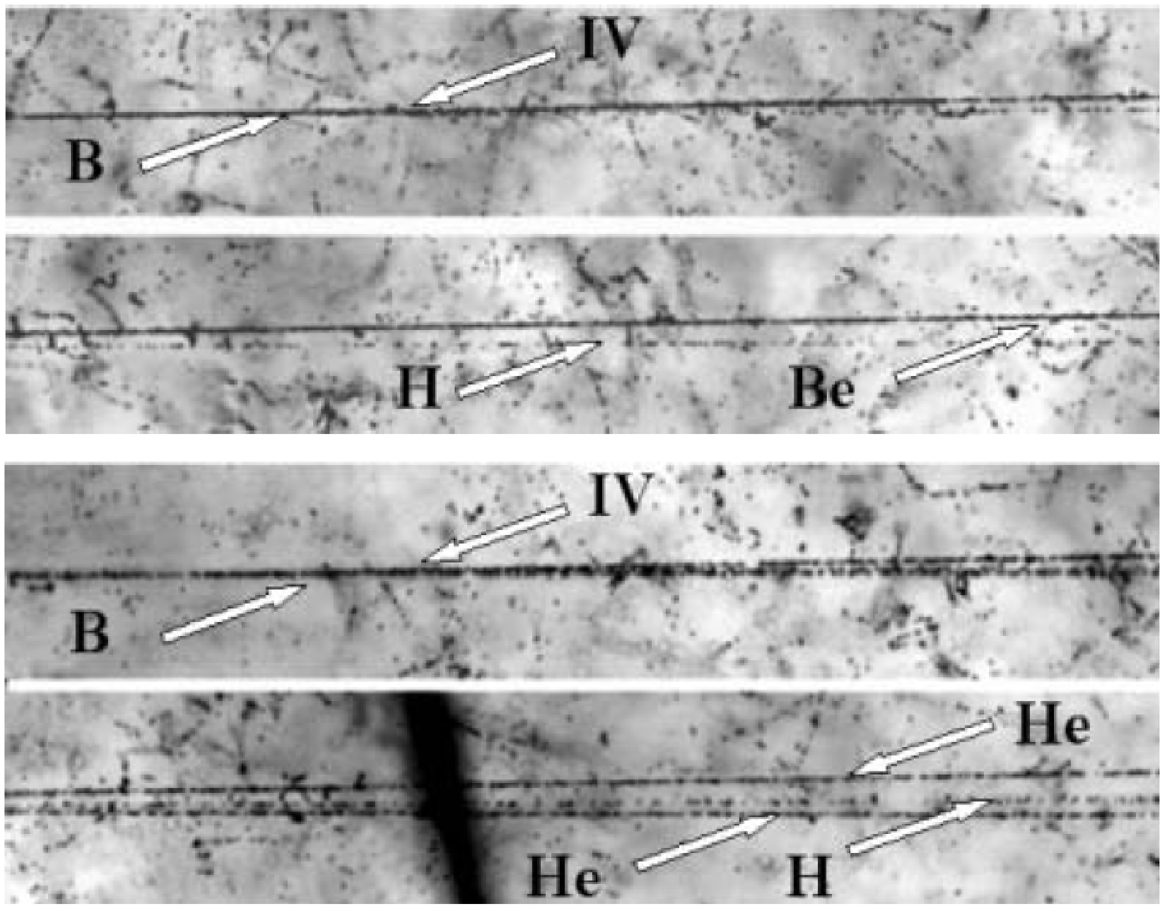

counts
9Be
14N
Q2α, keV

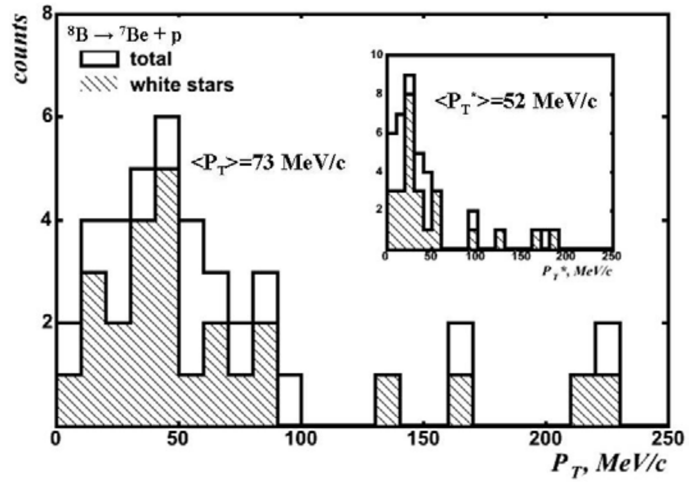


rel. units
0.3
0.2
0.1
0
0
2
4
6
8
10
12
^{9}Be → 2α
^{14}N → 3α
^{22}Ne → 5α
β^{*}_{T}, × 10^{-2}


a)
^{8}B
b
Ag
b)
^{8}B
Ag
c)
Ag
^{7}Be
p

1.2A GeV ^{8}B

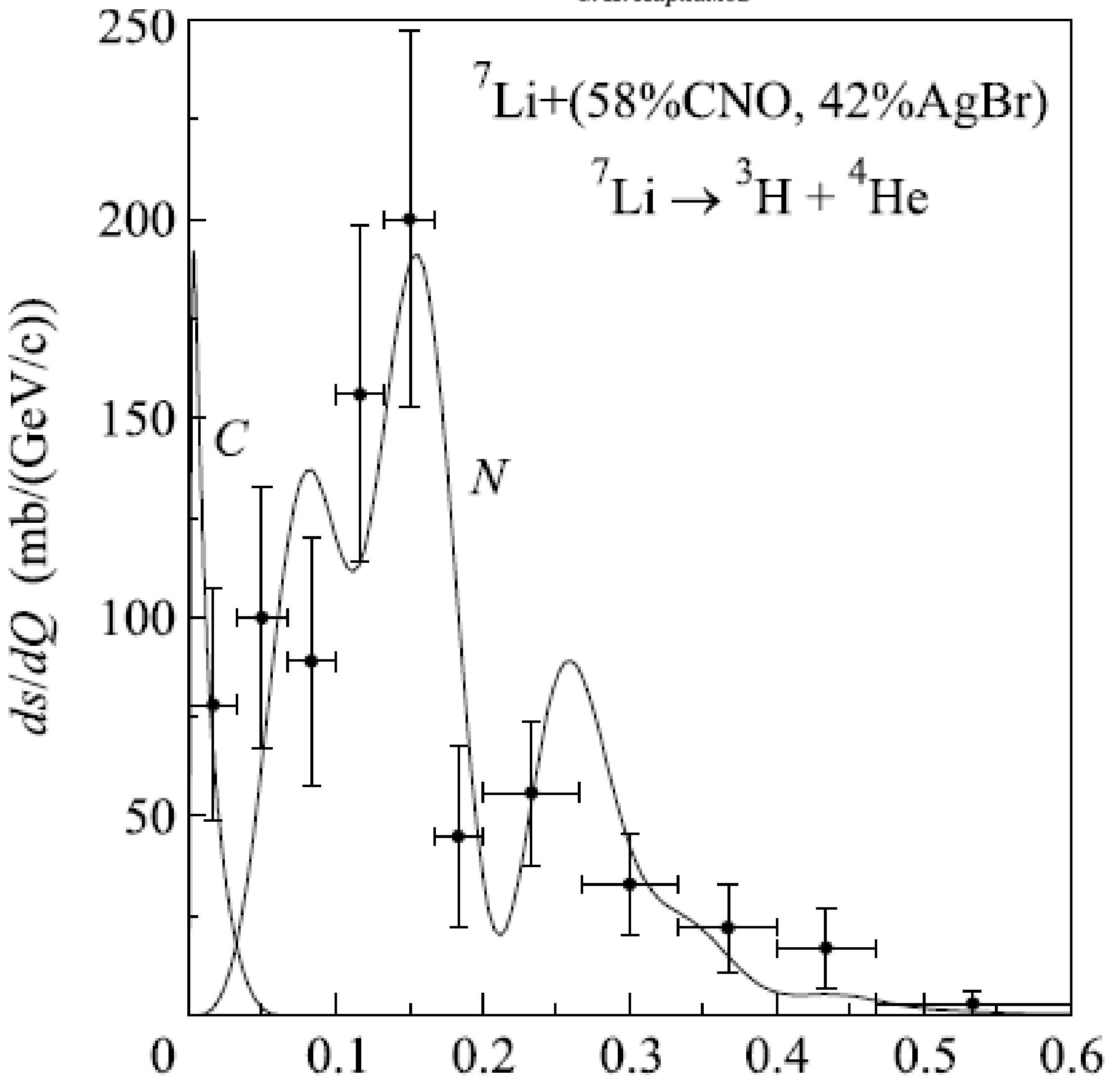

IV
B
H
Be
IV
B
He
He
H


$^8B \rightarrow {}^7Be + p$
total
white stars
counts
$<P_T>$=73 MeV/c
$<P_T^*>$=52 MeV/c
P_T^*, MeV/c
P_T, MeV/c

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

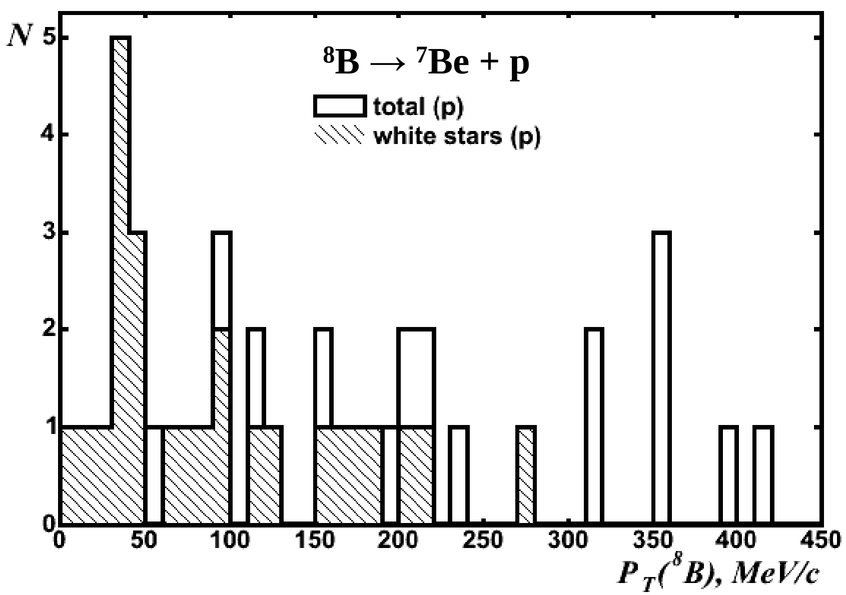
Роль ядерного и электромагнитного взаимодействий в когерентной диссоциации релятивистского ядра ^{7}Li по каналу ^{3}H + ^{4}He

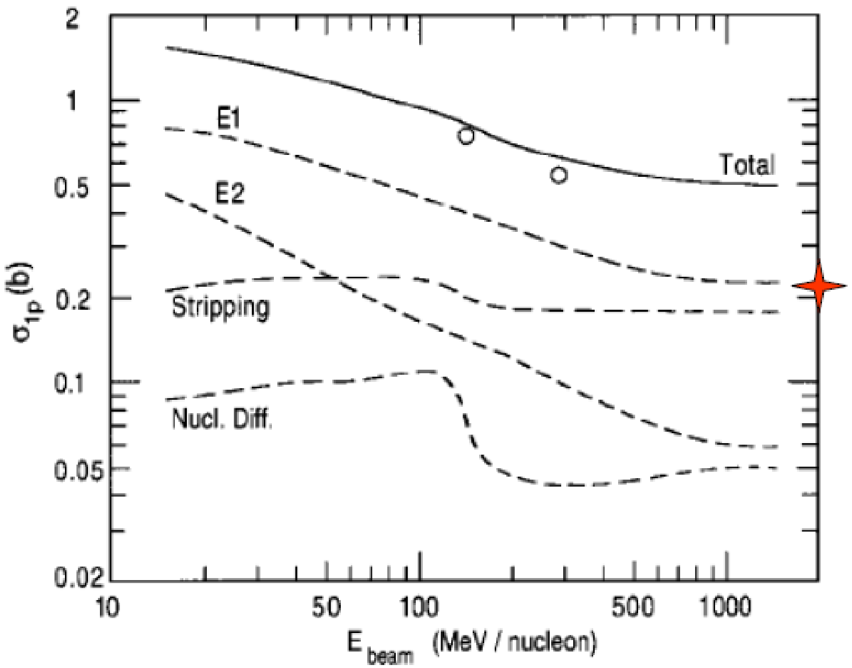
Н. Г. Пересадько, В. Н. Фетисов[1]*, Ю. А. Александров, С. Г. Герасимов, В. А. Дронов, В. Г. Ларионова, Е. И. Тамм, С. П. Харламов*



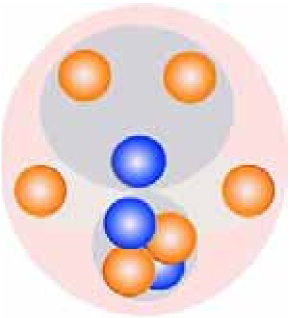
P$_T$ (^{7}Li), GeV/*c*

	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	-	-



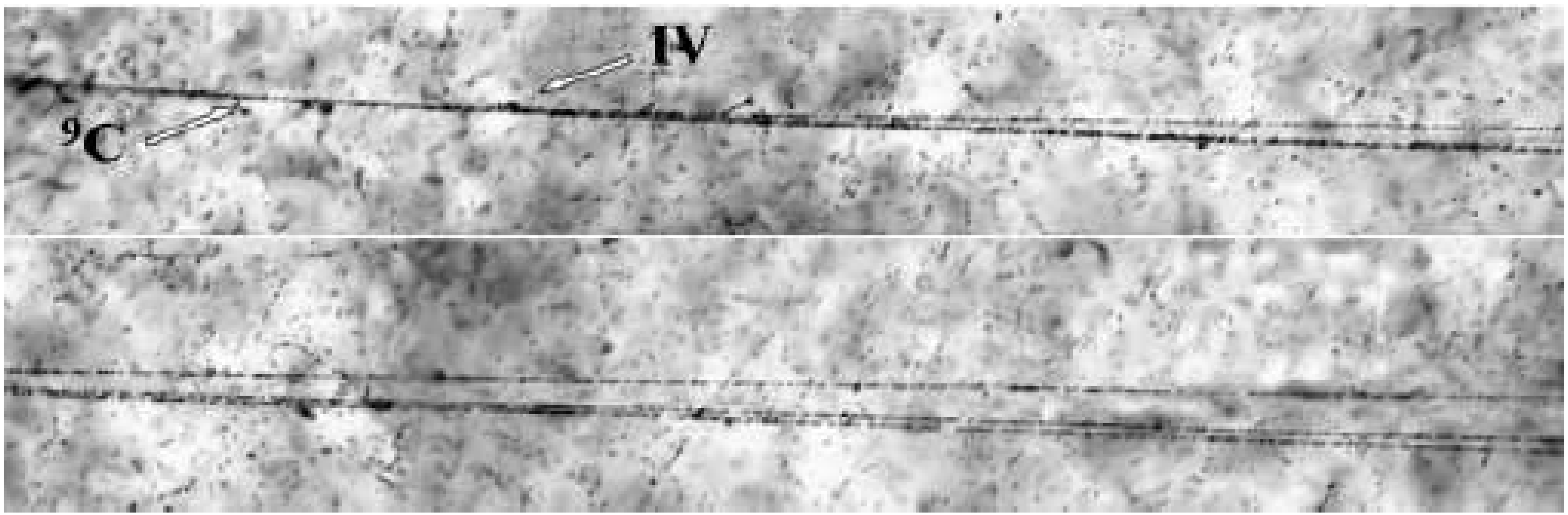


COHERENT DISSOCIATION OF RELATIVISTIC ^9C NUCLEI

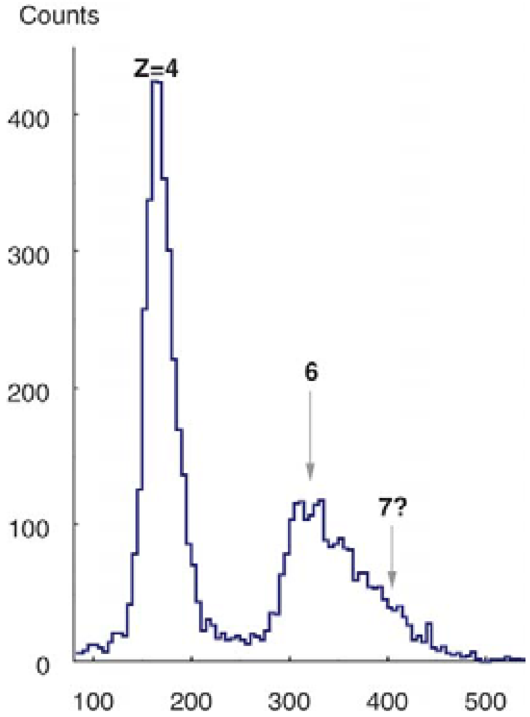


The contribution of the dissociation channel $^9C \rightarrow {}^8B + p$ and $^9C \rightarrow {}^7Be + 2p$ is most important in events that do not involve the production of target-nucleus fragments or mesons ("white" stars). It can be concluded that in the peripheral ^9C dissociation the picture hitherto obtained for ^8B and ^7Be with the addition of one or two protons, respectively, is reproduced. The dissociation events $^9C \rightarrow 3{}^3He$ accompanied by neither target fragments of the nucleus target nor charged mesons are observed.

$^8B + p$	$^7Be + 2p$	$2He + 2H$	$He + 4H$	$6H$	$^6Li + 3p$	$3{}^3He$
15	*16*	*24*	*28*	*6*	*2*	*16*



EXPOSURE OF NUCLEAR TRACK EMULSION IN THE MIXED BEAM OF RELATIVISTIC NUCLEI ^{12}N – ^{10}C – ^{7}Be

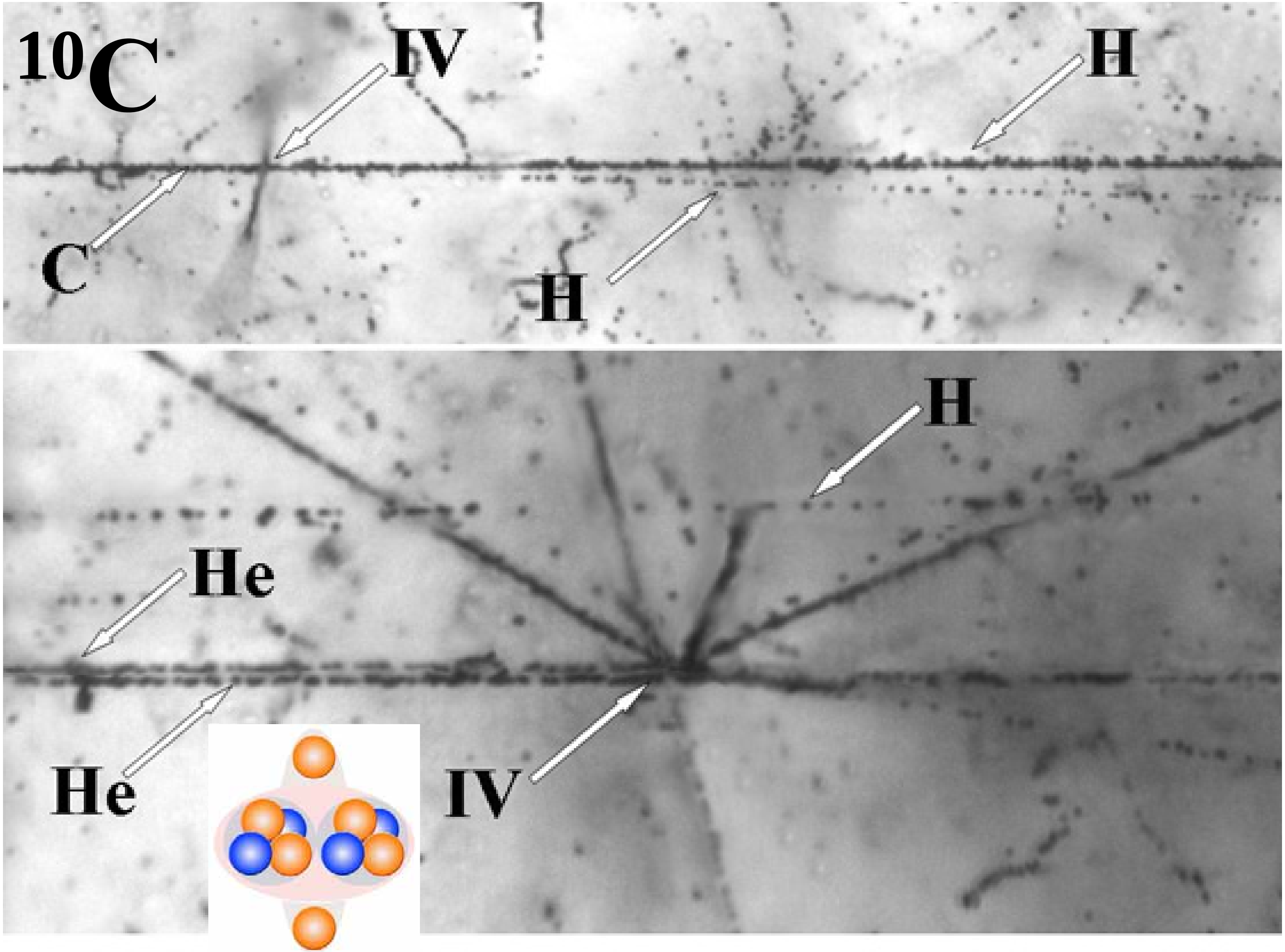


Nuclear track emulsion exposed to a mixed beam of relativistic nuclei ^{12}N, ^{10}C and ^{7}Be which was formed in the charge exchange and fragmentation reactions of the primary nuclei ^{12}C with momentum *2A GeV/c* accelerated at the JINR Nuclotron.

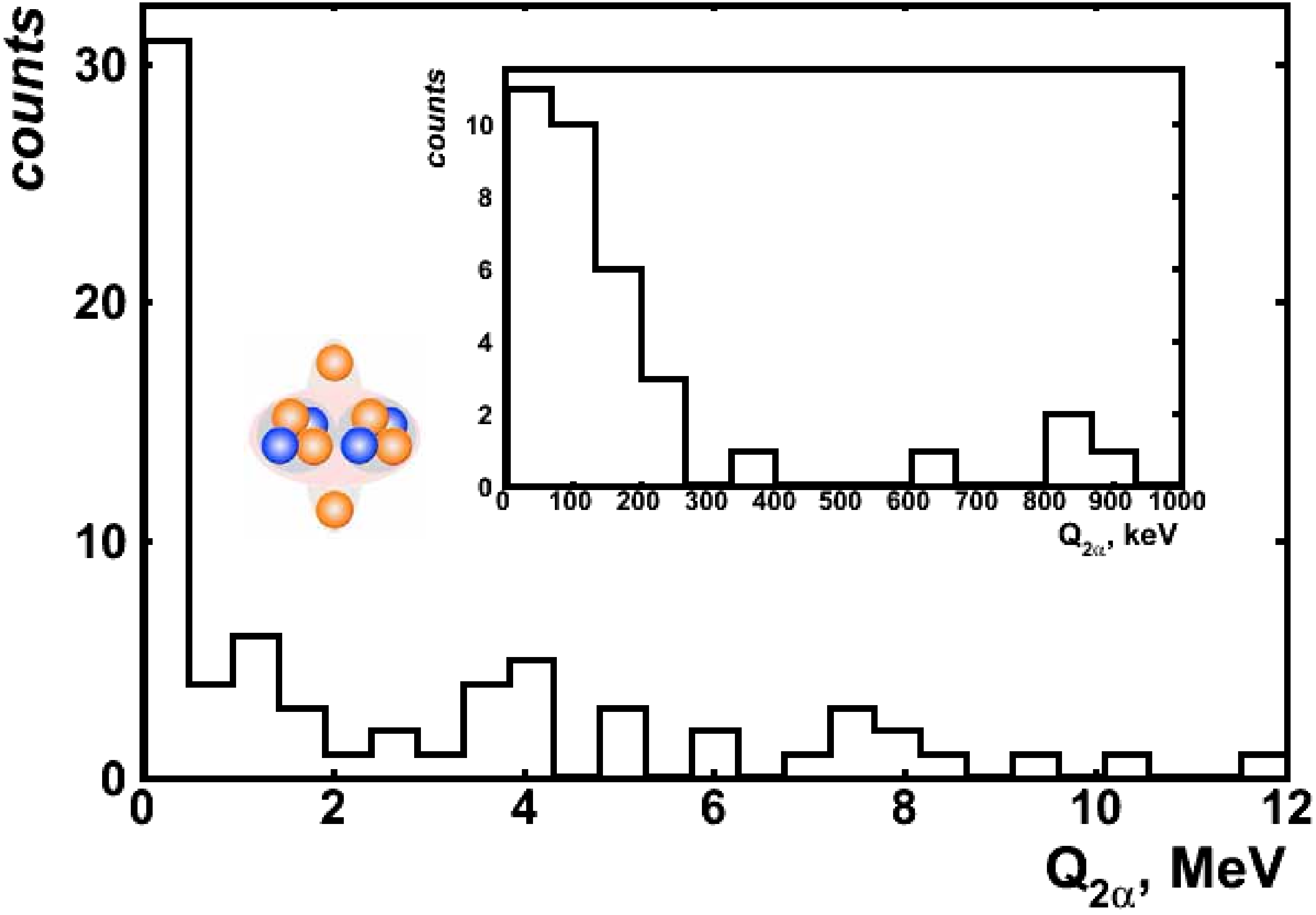
Projectile nucleus and secondary fragment charges are identified for the most peripheral collisions which occur without the production of target nucleus fragments and charged mesons. These data indicate the dominance of ^{10}C beam nuclei and the presence of ^{12}N ones.

«White» star statistics

$^{11}C + p$	$^{8}B + 2H$	$^{7}Be + 3H$	$2He + 2H$	$He + 4H$	$^{8}B + H$	$^{7}Be + He$	$^{7}Be + 2H$
1	3	7	91	14	1	5	3



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



counts
30
20
10
0
0
2
4
6
8
10
12
$Q_{2\alpha}$, MeV
counts
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
900
1000
$Q_{2\alpha}$, keV

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.

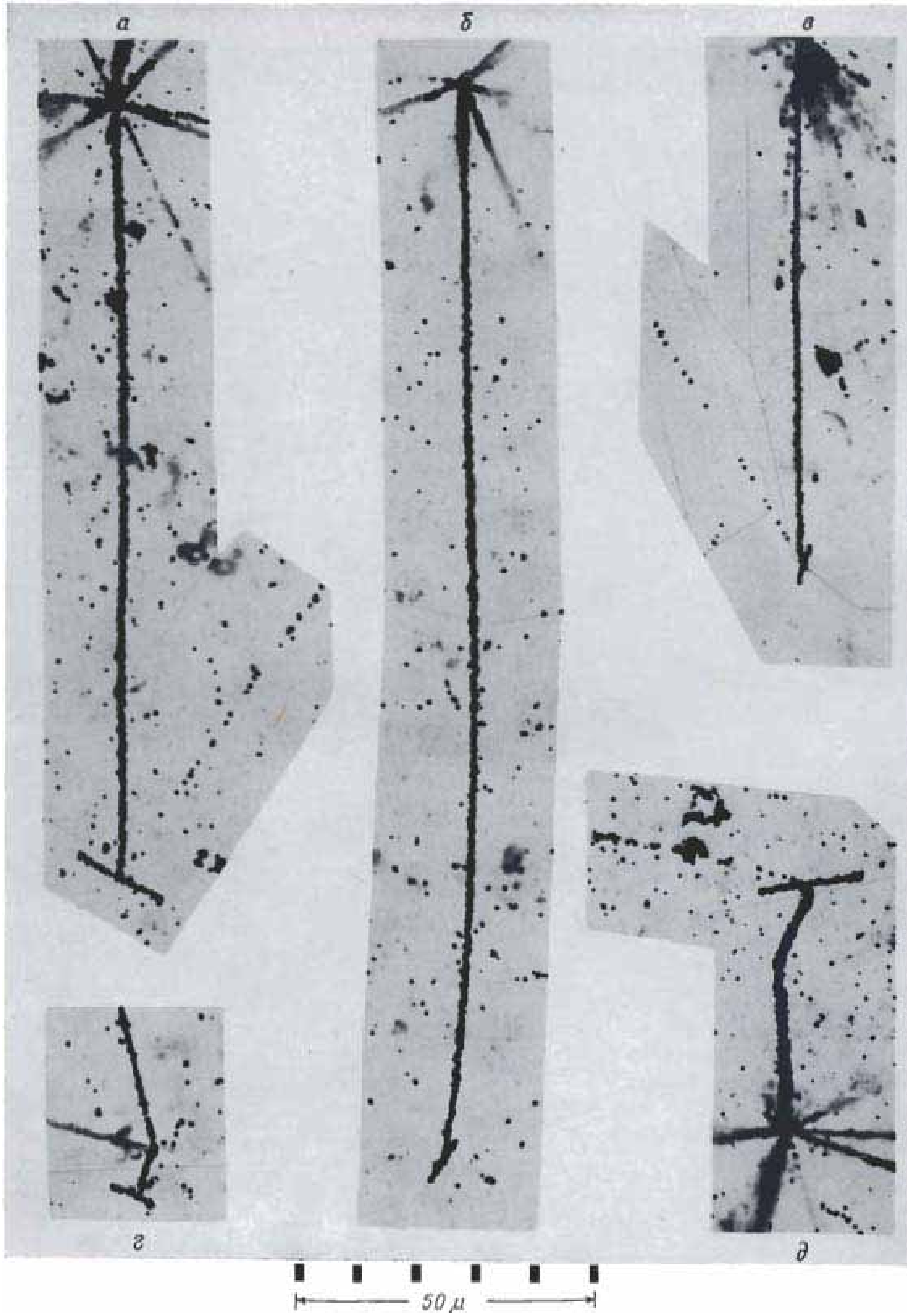
Due to a record space resolution the emulsion technique provides unique entirety in studying of light nuclei, especially, neutron-deficient ones. Providing the 3D observation of narrow dissociation vertices this classical technique gives novel possibilities of moving toward more and more complicated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

The results of an exclusive study of the interactions of relativistic ^{9}Be and ^{8}B nuclei lead to the conclusion that the known features of their structure are clearly manifested in very peripheral dissociations.

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.

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)

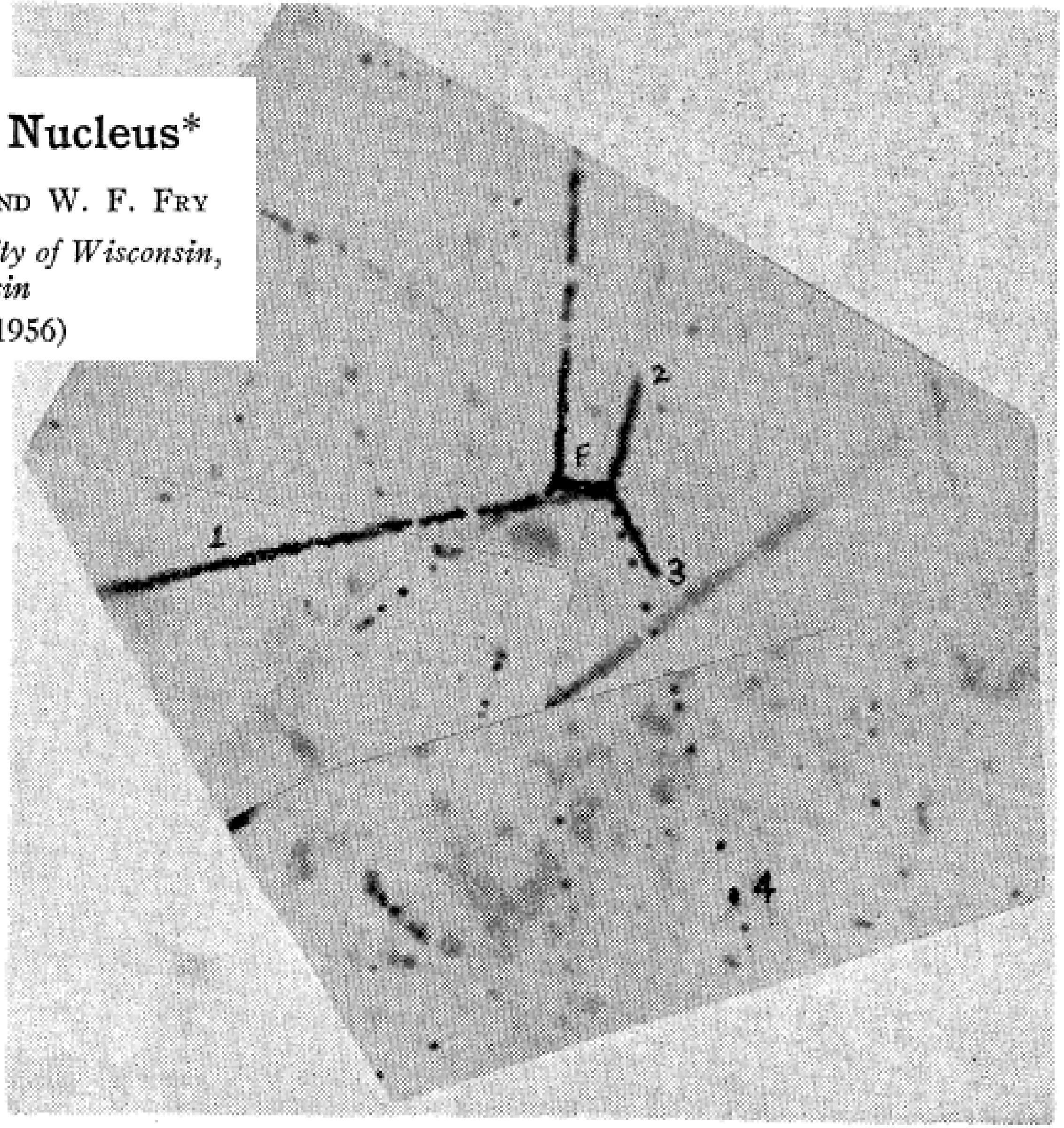
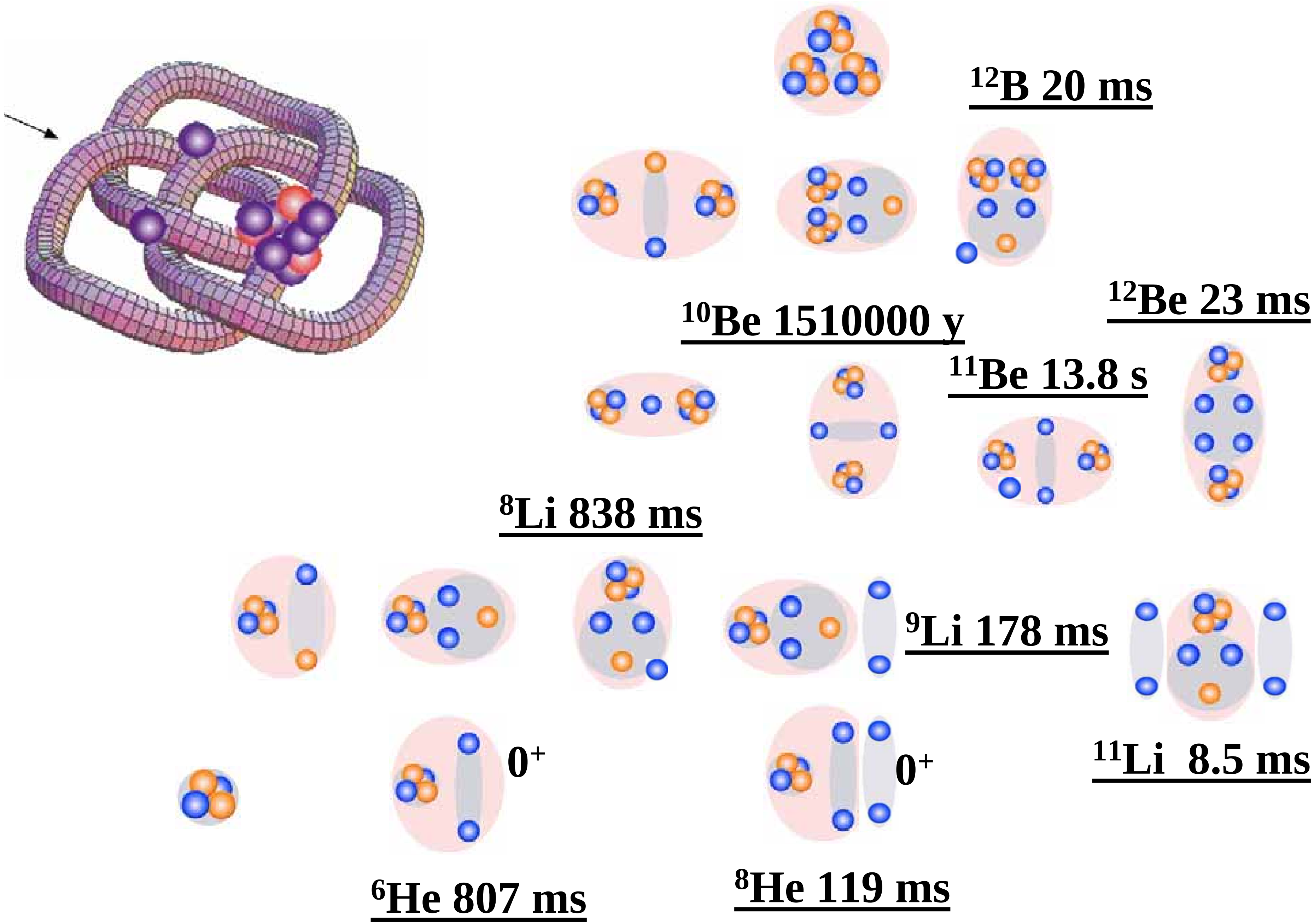


Fig. 1. A photograph of an event interpreted as the beta decay of C^9. The C^9 nucleus (track *F*) was produced in star (*A*) and disintegrated into a proton, two alpha particles, and a positron (tracks 1, 2, 3, and 4, respectively).



^{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