Study of light nuclei cluster structure with nuclear track emulsion

Denis Artemenkov,

VBLHEP, JINR

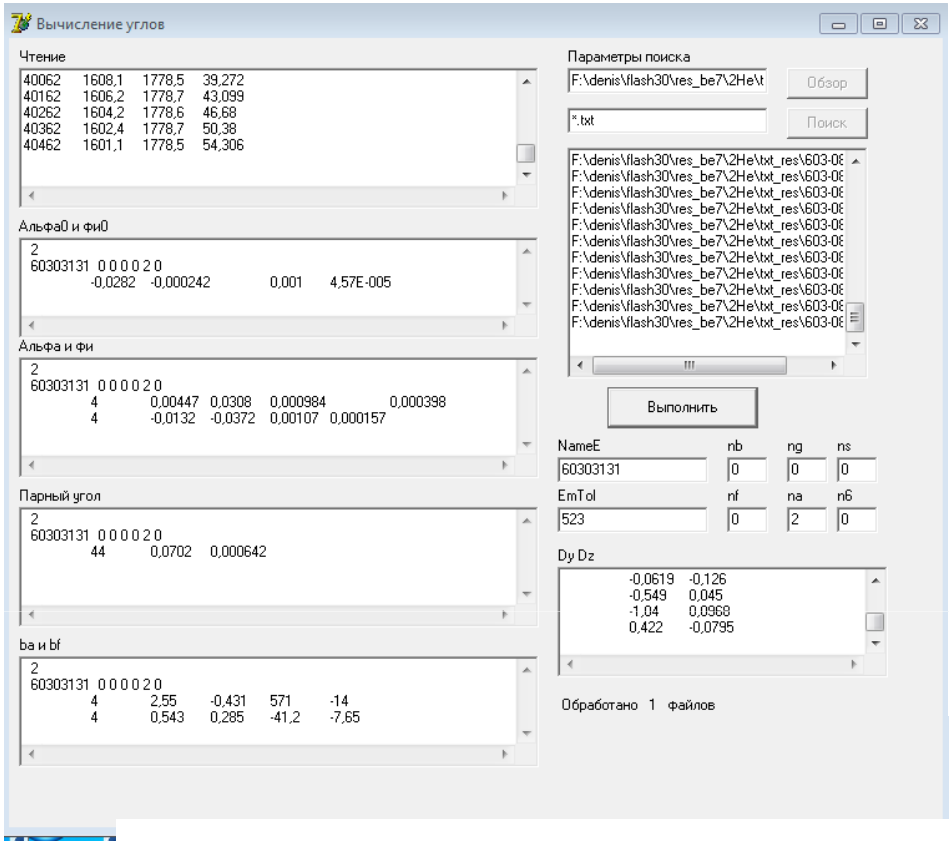
Predeal-Romania

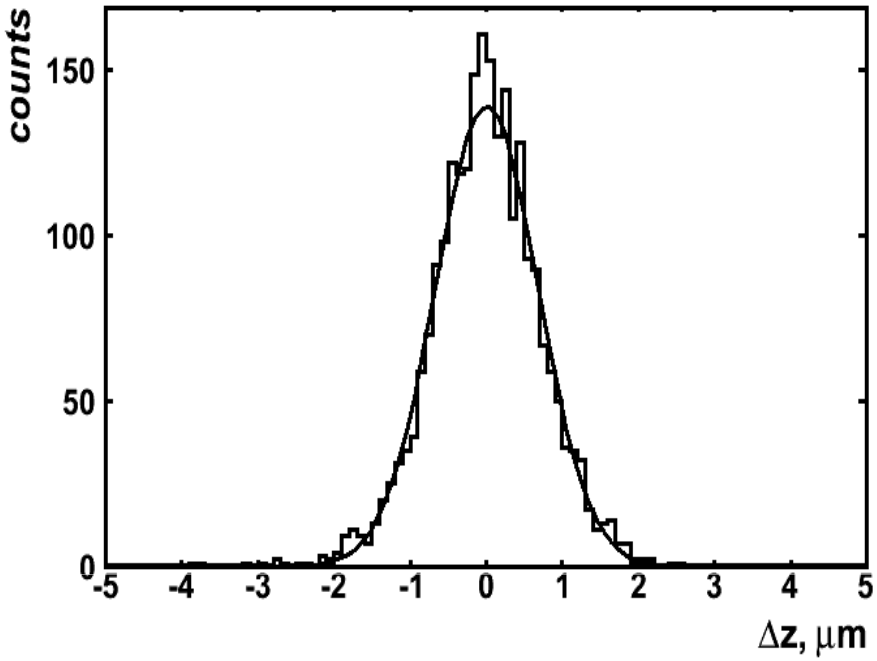
October 14-18, 2013

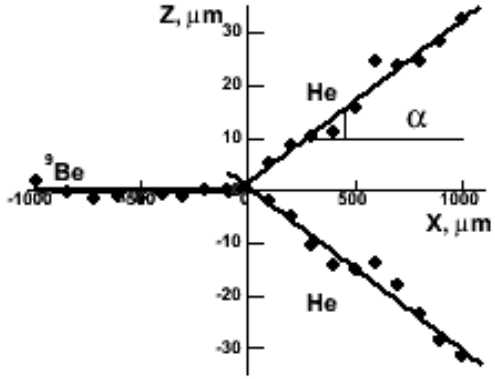
BECQUEREL at the JINR Nuclotron is devoted systematic exploration of clustering features of light stable and radioactive nuclei.

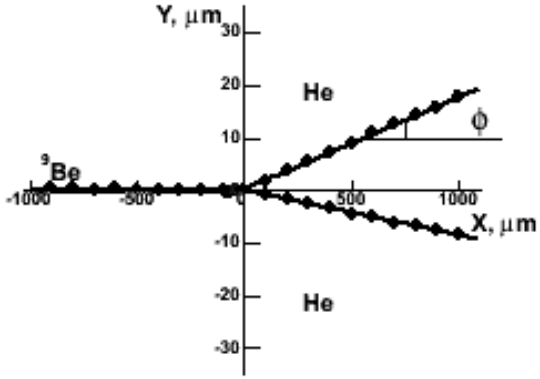
The fragmentation of a large variety of light nuclei was investigated using the emulsions exposed to few A GeV nuclear beams at JINR Nuclotron. A nuclear track emulsion is used to explore the fragmentation of the relativistic nuclei.

Angular measurements









Eur. Phys. J. Special Topics 162, 267–274 (2008)
© EDP Sciences, Springer-Verlag 2008
DOI: 10.1140/epjst/e2008-00802-0

THE EUROPEAN PHYSICAL JOURNAL SPECIAL TOPICS

Secondary nuclear fragment beams for investigations of relativistic fragmentation of light radioactive nuclei using nuclear photoemulsion at Nuclotron

P.A. Rukoyatkin[a], L.N. Komolov, R.I. Kukushkina, V.N. Ramzhin, and P.I. Zarubin

ISSN 1063-7788, Physics of Atomic Nuclei, 2008, Vol. 71, No. 9, pp. 1565–1571. © Pleiades Publishing, Ltd., 2008.

ELEMENTARY PARTICLES AND FIELDS
Experiment

Fragmentation of Relativistic Nuclei in Peripheral Interactions in Nuclear Track Emulsion*

D. A. Artemenkov[1)**], V. Bradnova[1)], M. M. Chernyavsky[2)], L. A. Goncharova[2)], M. Haiduc[3)], N. A. Kachalova[1)], S. P. Kharlamov[2)], A. D. Kovalenko[1)], A. I. Malakhov[1)], A. A. Moiseenko[4)], G. I. Orlova[2)], N. G. Peresadko[2)], N. G. Polukhina[2)], P. A. Rukoyatkin[1)], V. V. Rusakova[1)], V. R. Sarkisyan[4)], R. Stanoeva[5)], T. V. Shchedrina[1)], S. Vokál[1)], A. Vokálová[1)], P. I. Zarubin[1)***], and

Few Body Syst (2008) 44: 273–276
DOI 10.1007/s00601-008-0307-6
Printed in The Netherlands

Few-Body Systems

Detailed study of relativistic $^9Be \rightarrow 2\alpha$ fragmentation in peripheral collisions in a nuclear track emulsion*

D. A. Artemenkov**, D. O. Krivenkov, T. V. Shchedrina, R. Stanoeva, P. I. Zarubin

ЯДЕРНАЯ ФИЗИКА, 2009, том 72, № 4, с. 731 742

ЭЛЕМЕНТАРНЫЕ ЧАСТИЦЫ И ПОЛЯ

ЭЛЕКТРОМАГНИТНАЯ ДИССОЦИАЦИЯ РЕЛЯТИВИСТСКИХ ЯДЕР ^{8}B В ЯДЕРНОЙ ЭМУЛЬСИИ

© 2009 г. Р. Станоева[1),2)], Д. А. Артеменков[1)], В. Браднова[1)], С. Вокал[1),3)], Л. А. Гончарова[4)], П. И. Зарубин[1)*], И. Г. Зарубина[1)], Н. А. Качалова[1)], А. Д. Коваленко[1)], Д. О. Кривенков[1)], А. И. Малахов[1)], Г. И. Орлова[4)], Н. Г. Пересадько[4)], Н. Г. Полухина[4)], П. А. Рукояткин[1)], В. В. Русакова[1)], М. Хайдук[5)], С. П. Харламов[4)], М. М. Чернявский[4)], Т. В. Щедрина[1)]

ЯДЕРНАЯ ФИЗИКА, 2010, том 73, № 12, с. 2159–2165

ЭЛЕМЕНТАРНЫЕ ЧАСТИЦЫ И ПОЛЯ

КОГЕРЕНТНАЯ ДИССОЦИАЦИЯ РЕЛЯТИВИСТСКИХ ЯДЕР ^{9}C

© 2010 г. Д. О. Кривенков[1)], Д. А. Артеменков[1)], В. Браднова[1)], С. Вокал[2)], П. И. Зарубин[1)*], И. Г. Зарубина[1)], Н. В. Кондратьева[1)], А. И. Малахов[1)], А. А. Моисеенко[3)], Г. И. Орлова[4)], Н. Г. Пересадько[4)], Н. Г. Полухина[4)], П. А. Рукояткин[1)], В. В. Русакова[1)], В. Р. Саркисян[3)], Р. Станоева[1)], М. Хайдук[5)], С. П. Харламов[4)]

ЯДЕРНАЯ ФИЗИКА, 2010, том 73, № 12, с. 2166–2171

ЭЛЕМЕНТАРНЫЕ ЧАСТИЦЫ И ПОЛЯ

ОБЛУЧЕНИЕ ЯДЕРНОЙ ЭМУЛЬСИИ В СМЕШАННОМ ПУЧКЕ РЕЛЯТИВИСТСКИХ ЯДЕР ^{12}N, ^{10}C И ^{7}Be

© 2010 г. Р. Р. Каттабеков[1),2)], К. З. Маматкулов[1),3)], Д. А. Артеменков[1)], В. Браднова[1)], С. Вокал[4)], Д. М. Жомуродов[1),3)], П. И. Зарубин[1)*], И. Г. Зарубина[1)], З. А. Игамкулов[1),3)], Н. В. Кондратьева[1)], Н. К. Корнегруца[1)], Д. О. Кривенков[1)], А. И. Малахов[1)], Г. И. Орлова[5)], Н. Г. Пересадько[5)], Н. Г. Полухина[5)], П. А. Рукояткин[1)], В. В. Русакова[1)], Р. Станоева[1),6)], М. Хайдук[7)], С. П. Харламов[5)]

Role of the Nuclear and Electromagnetic Interactions in the Coherent Dissociation of the Relativistic ^{7}Li Nucleus into the ^{3}H + ^{4}He Channel

N. G. Peresadko, V. N. Fetisov, Yu. A. Aleksandrov, S. G. Gerasimov, V. A. Dronov, V. G. Larionova, E. I. Tamm, S. P. Kharlamov

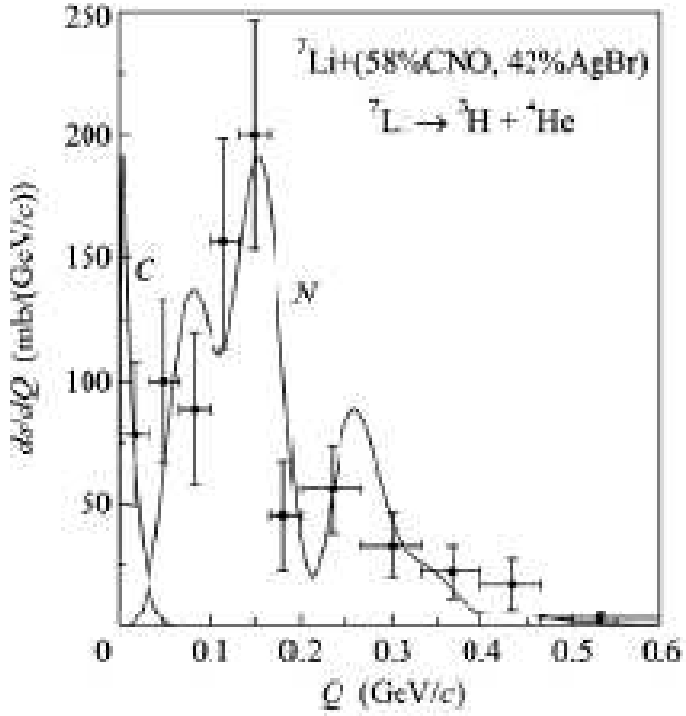


FIG. 1: Experimental and theoretical cross sections for (C) Coulomb and (N) nuclear diffraction dissociations of the ^{7}Li nuclei.

http://arxiv.org/pdf/1110.2881.pdf

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

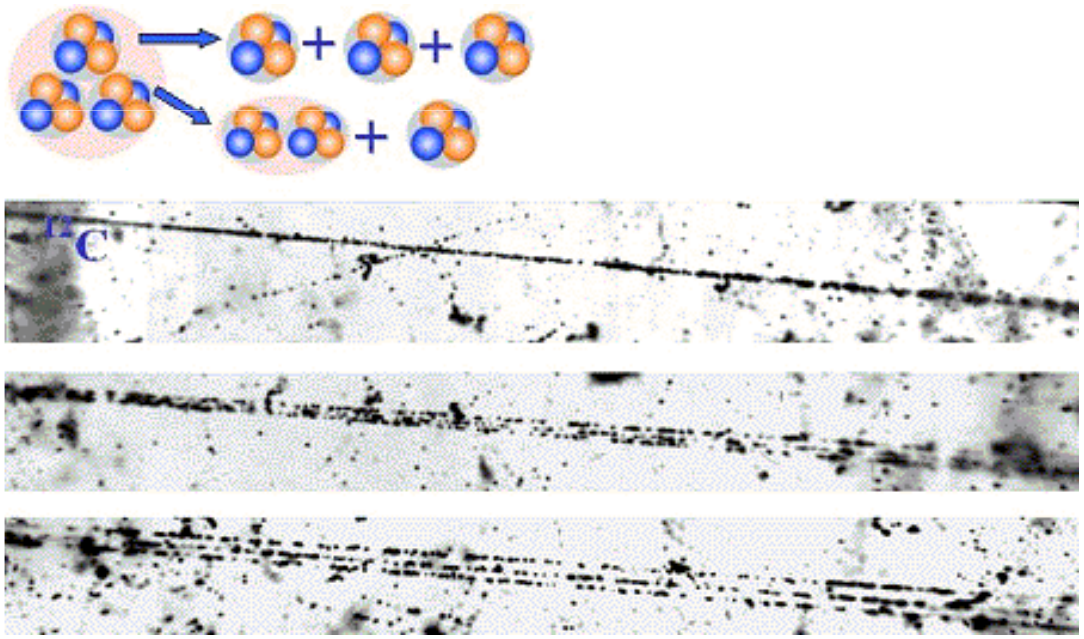
Physics of Atomic Nuclei, Vol. 58, No. 11, 1995, pp. 1905 - 1910. Translated from Yadernaya Fizika, Vol. 58, No. 11, 1995, pp. 2014 - 2020.

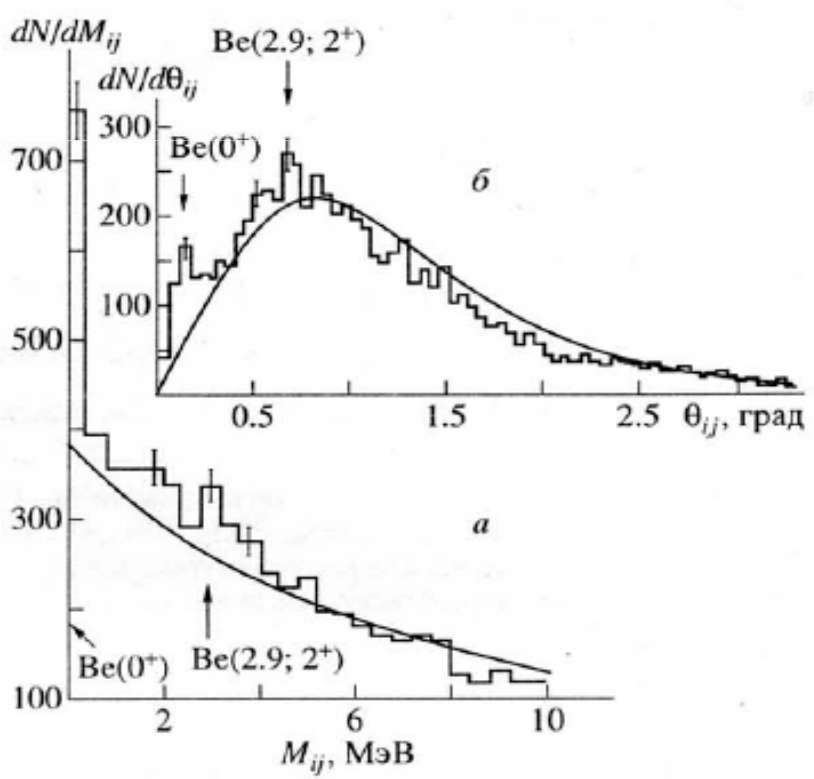
ELEMENTARY PARTICLES AND FIELDS
Experiment

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

$^{12}C \rightarrow 3\alpha$, 3.65 A GeV



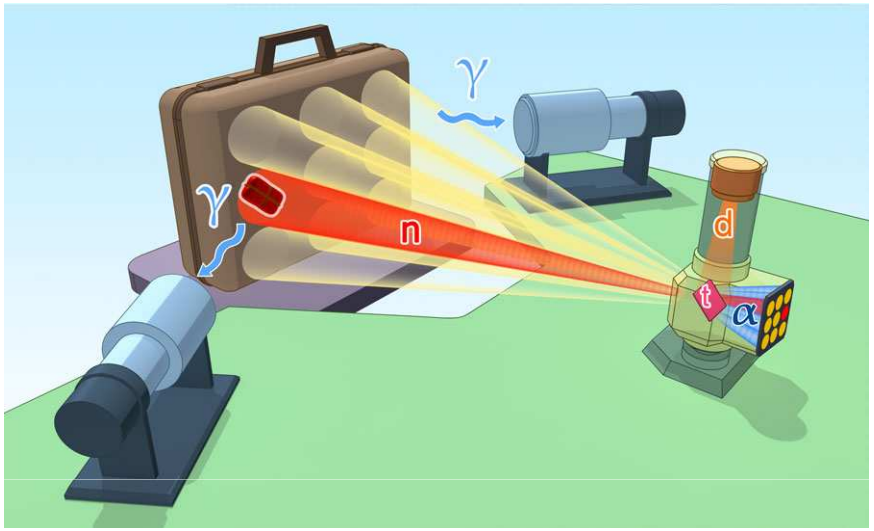


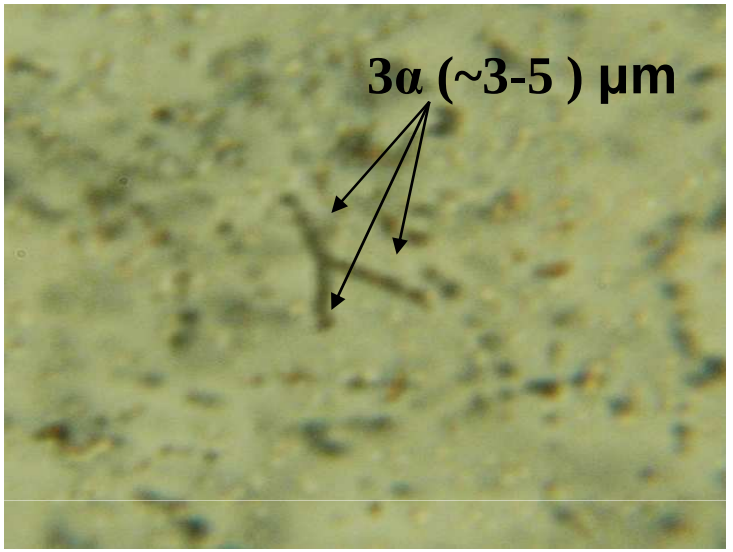
(PAVICOM image)

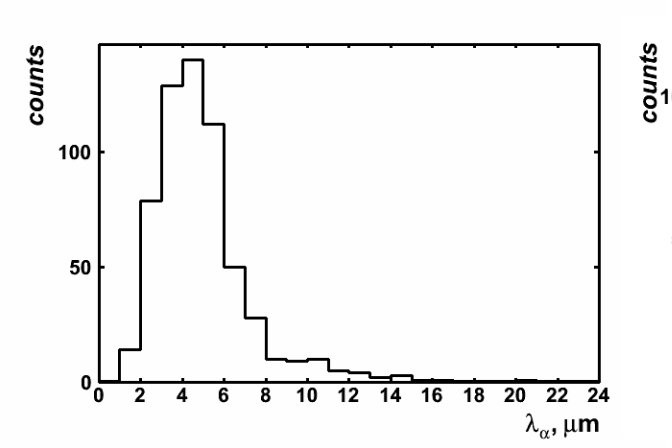
$^{12}C(n,n')3\alpha$, E_n = 14.1 MeV

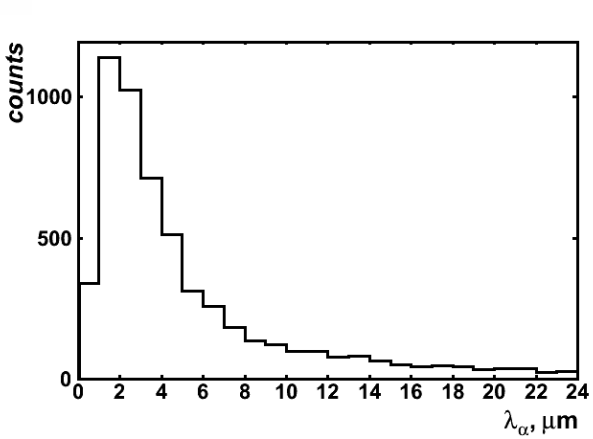
http://neutrontech.ru

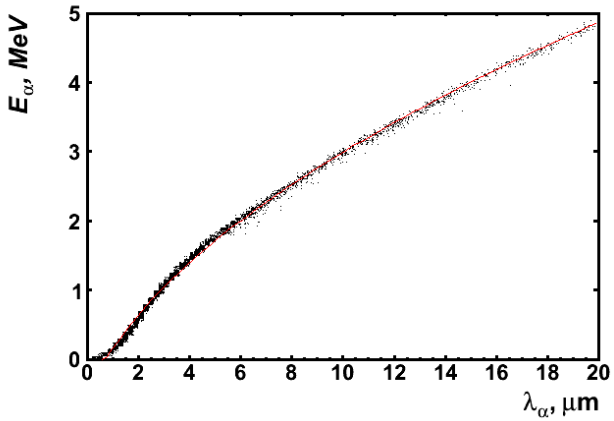
DVIN - explosives detector on the basis of fast tagged neutron method for complex program for population safety in transport





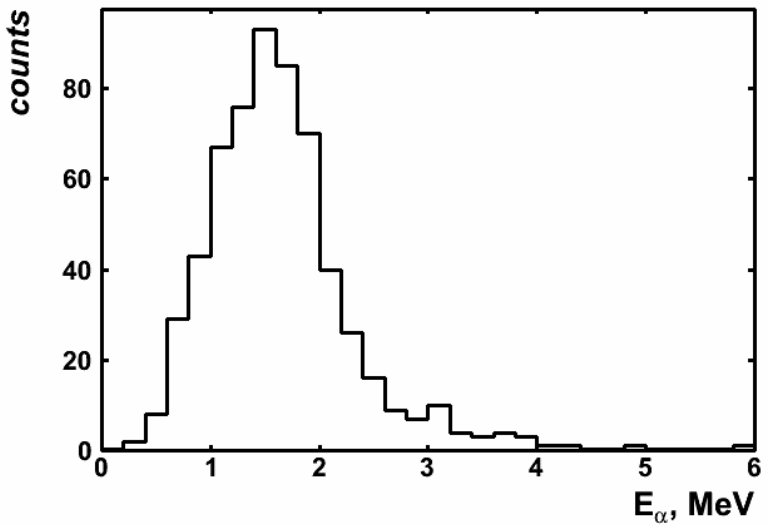


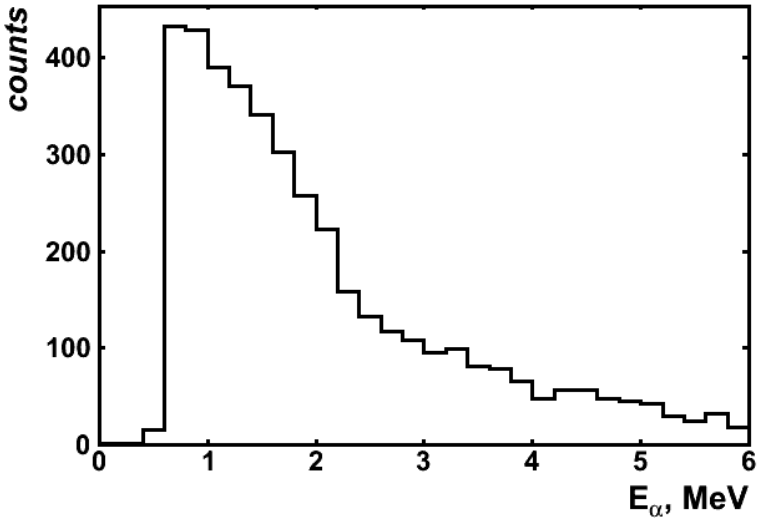




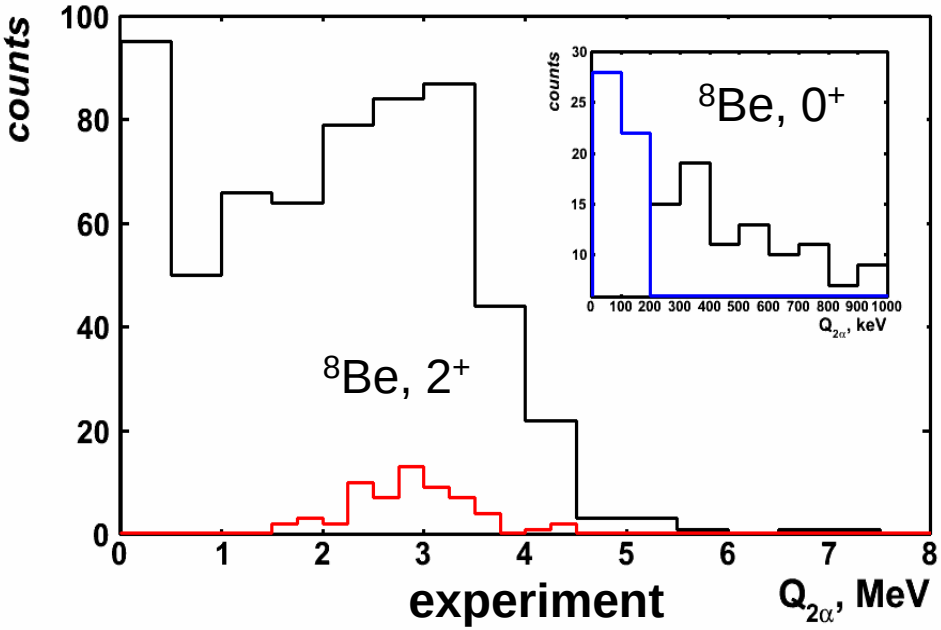
experiment

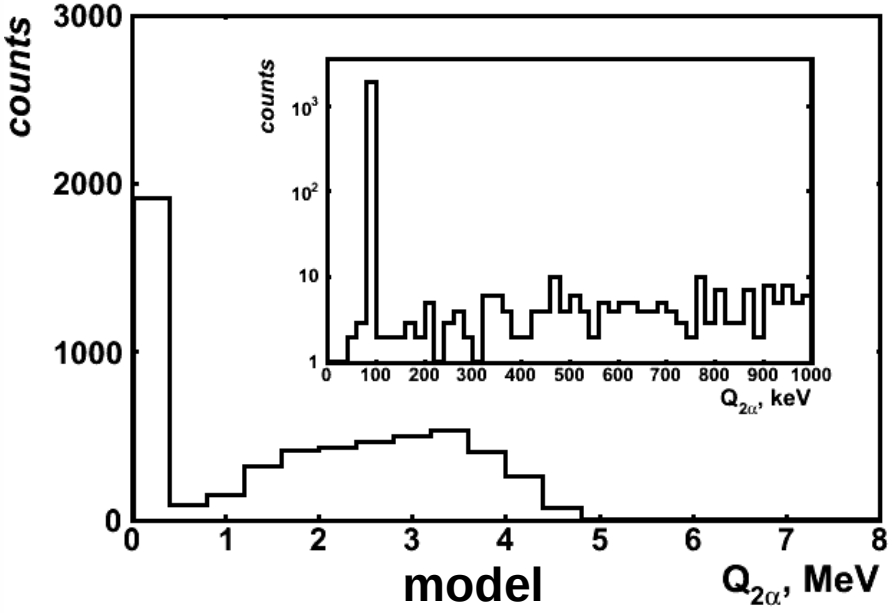
model (Geant4, CHIPS list)





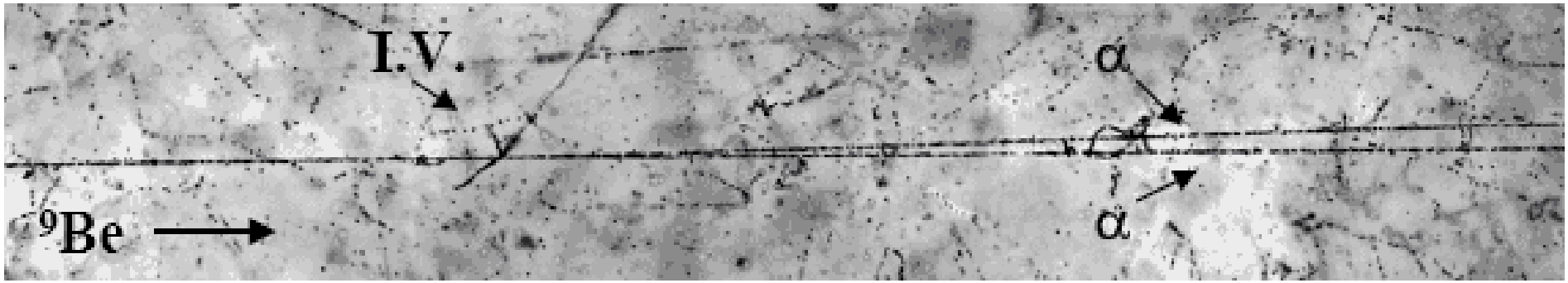
$$M_{2\alpha} = \left[2\left(m_\alpha^2 + E_{\alpha 1}E_{\alpha 2} - p_{\alpha 1}p_{\alpha 2}\cos(\Theta_{12})\right)\right]^{\frac{1}{2}}, \quad Q_{2\alpha} = M_{2\alpha} - 2\cdot m_\alpha$$

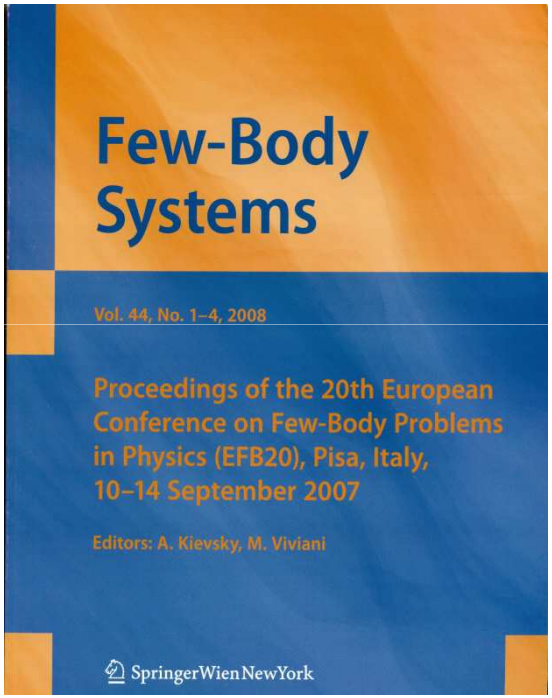




$^{9}Be \rightarrow 2\alpha$

(1.2 A GeV)





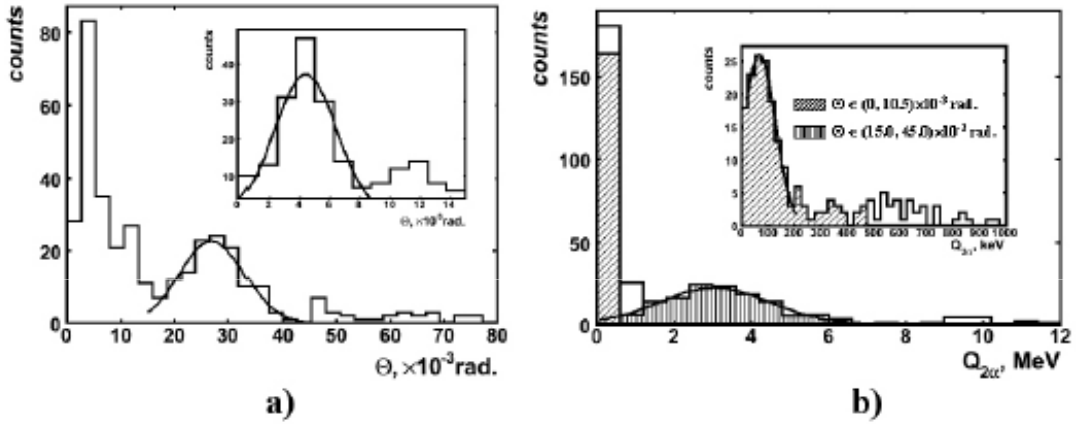
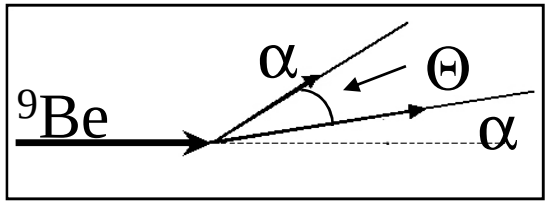
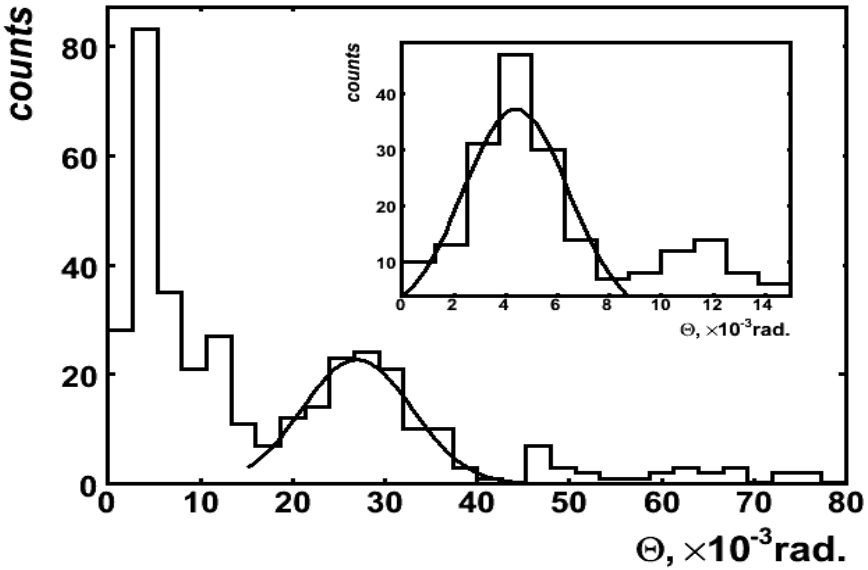


Figure 1. The opening Θ angle distribution of α particles in the ^{9}Be$\rightarrow 2\alpha$ fragmentation reaction at 1.2 A GeV energy. On the intersection: the Θ range from 0 to 15×10^{-3} rad.– a). The invariant energy $Q_{2\alpha}$ distribution of α particle pairs in the ^{9}Be$\rightarrow 2\alpha$ fragmentation reaction at 1.2 A GeV energy. On the intersection: the $Q_{2\alpha}$ range from 0 to 1 MeV –b).

Opening angle distribution of two α-particles

$^{9}Be \rightarrow 2\alpha$





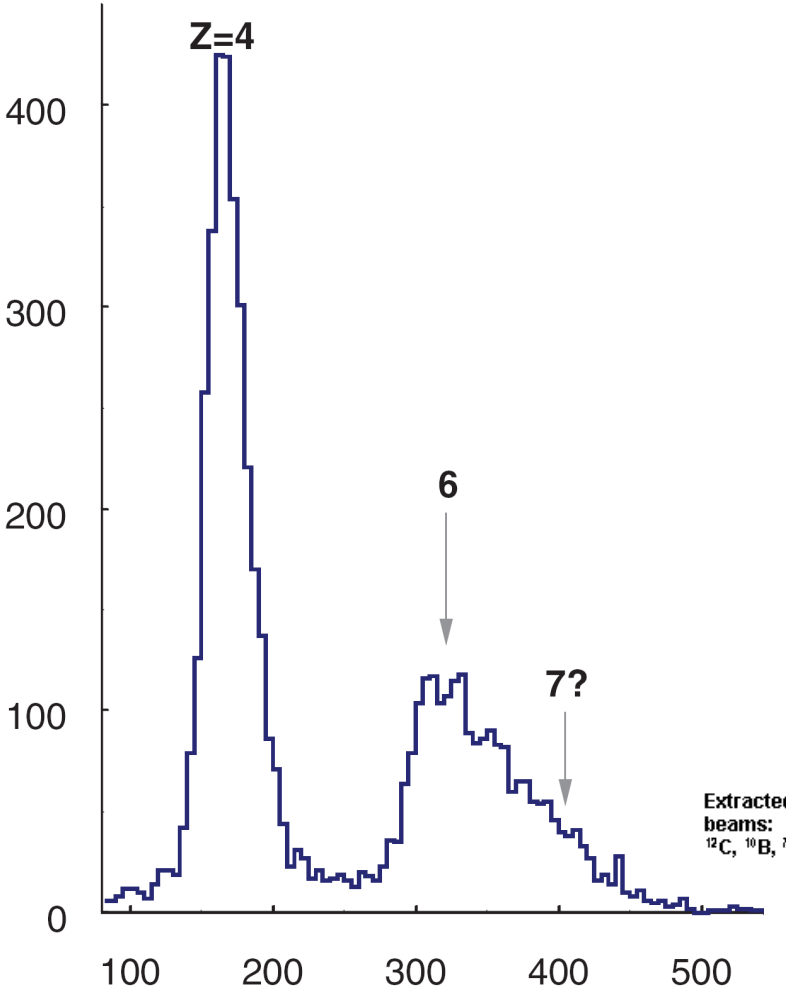
Θ, mrad	$<\Theta>$, mrad	σ_{Θ}, mrad	Fraction (Events)
Θ_n (0 - 10.5)	4.4 ± 0.2	2.1 ± 0.2	0.56 ± **0.04** (164)
Θ_w (15.0 – 45.0)	27.0 ± 0.6	5.9 ± 0.6	0.44 ± **0.04** (130)

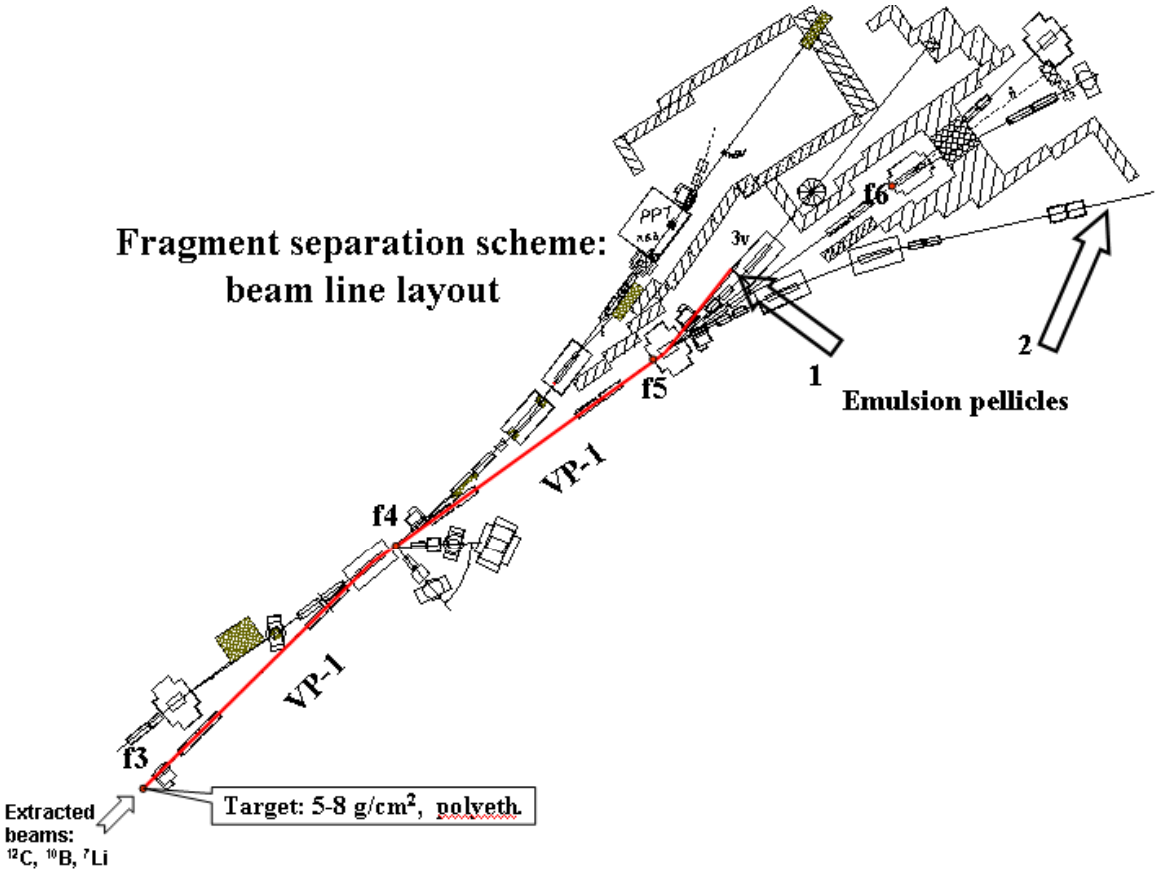
Fractions of events Θ_n and Θ_w demonstrate compliance with weights 0^+ and 2^+ states of a ^8Be core, adopted in the two-body model, $\omega_{0+} = 0.535$ and $\omega_{2+} = 0.465$ [1,2]. They indicate the presence of these states as components of the ground state of the ^9Be nucleus.

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)

^{12}N (in mixed beam of ^{12}N+^{10}C+^{7}Be at 1.2 A GeV), 2006





http://arxiv.org/abs/1310.2080

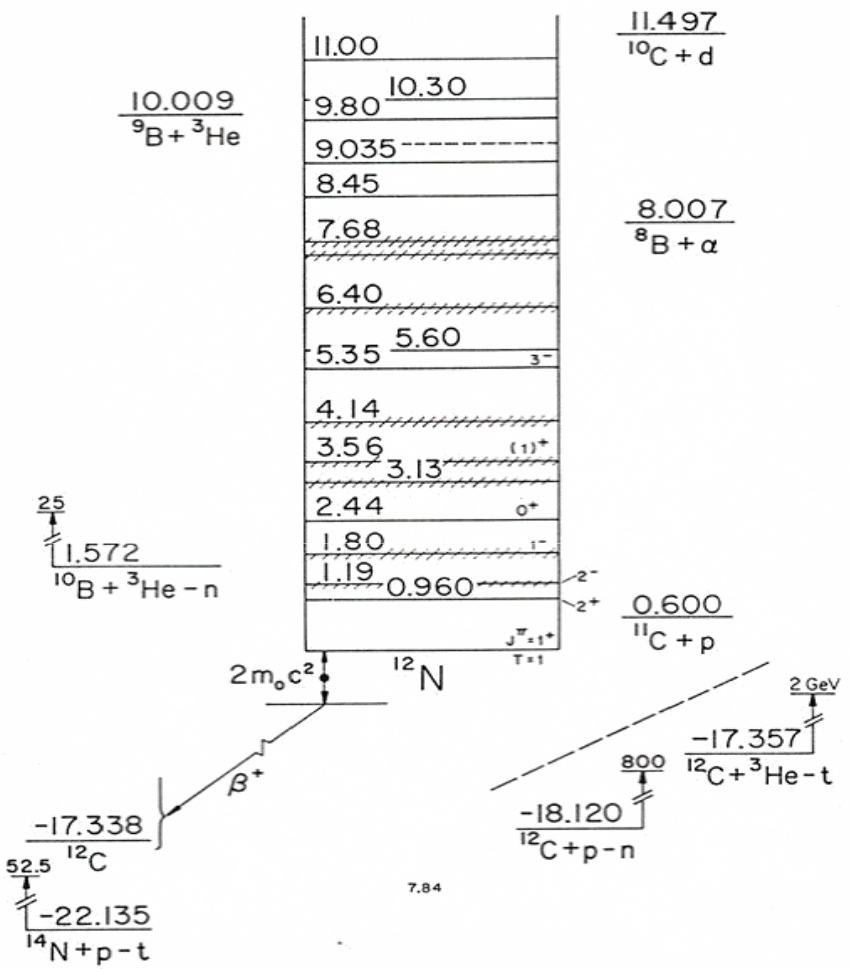


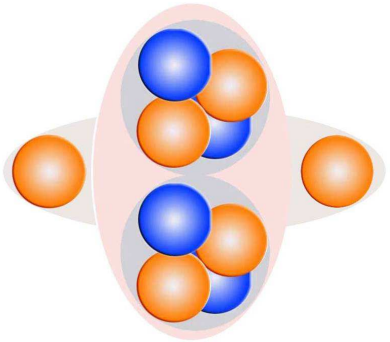
Table 2. Distribution of the number of white stars (N_{ws}) among the dissociation channels where the total charge of fragments is $\sum Z_{fr} = 7$ and where the measured charge of the beam track is $Z_{pr} = 7$

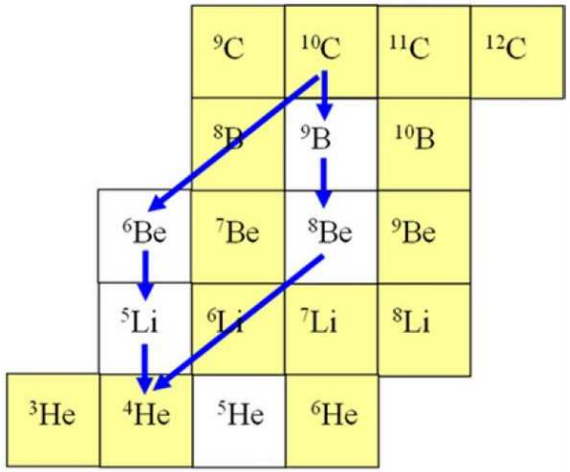
Channel	N_{ws}	
	$\theta_{fr} < 11°$	$\theta_{fr} < 6°$
He + 5H	9	2
2He + 3H	24	12
3He + H	2	2
^{7}Be + 3H	10	5
^{7}Be + He + H	9	8
^{8}B + 2H	11	9
^{8}B + He	3	3
C + H	4	4
$\sum$	72	45

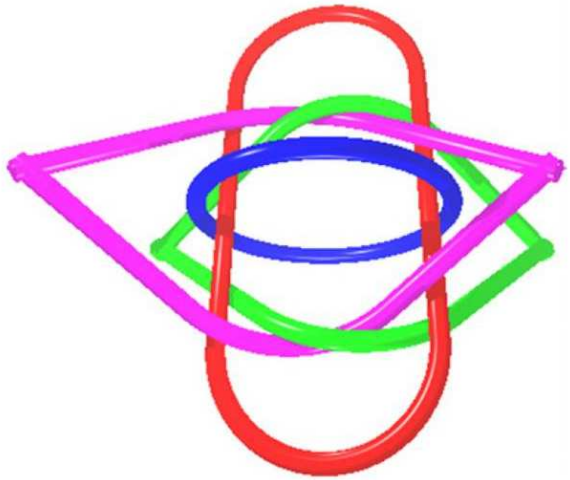
$$^{10}C \rightarrow 2\alpha + 2p$$

(1.2 A GeV)

^{10}C



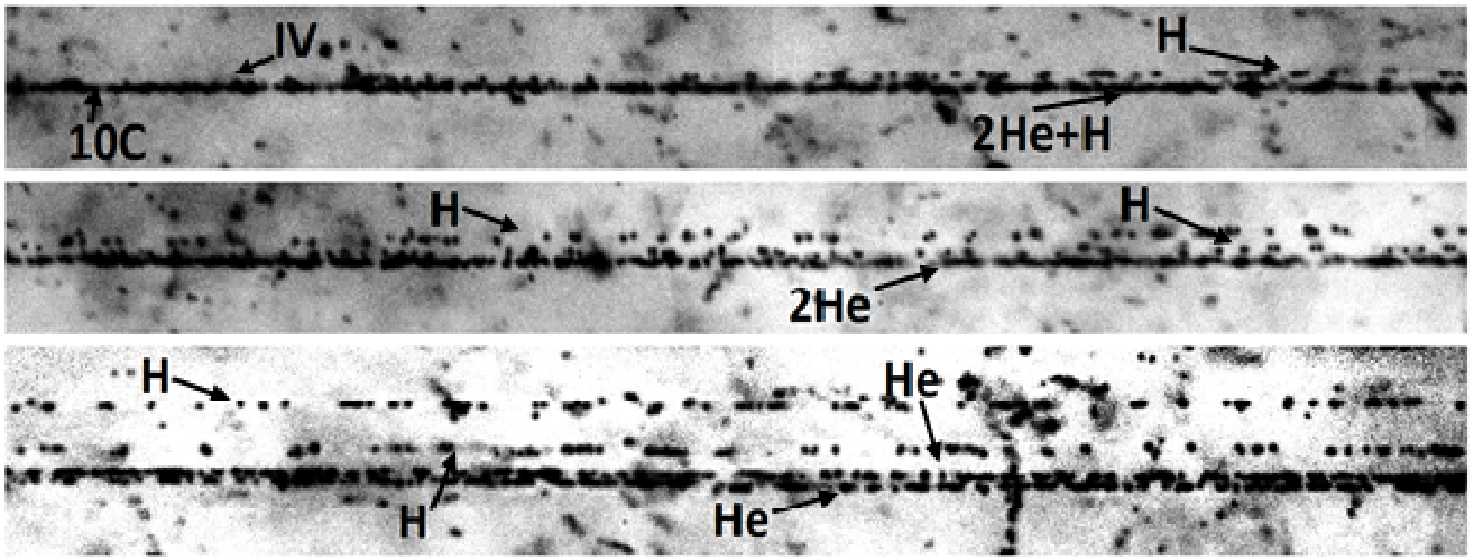




Charge-topology distribution of fragments from white stars, N_{ws}, where the total charge of relativistic fragments is $\sum Z_{fr} = 6$, and from $\sum Z_{fr} = 6$ events, N_{tf}, accompanied by target fragments or product mesons

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

$^{10}C \rightarrow {}^{9}B+p \rightarrow {}^{8}Be+2p$ *(25-30%)*



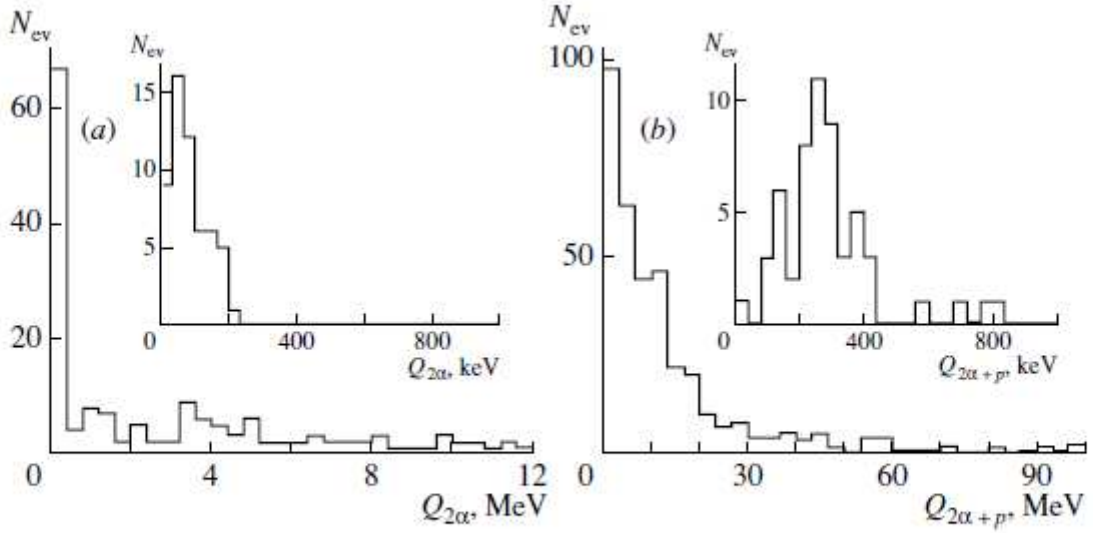
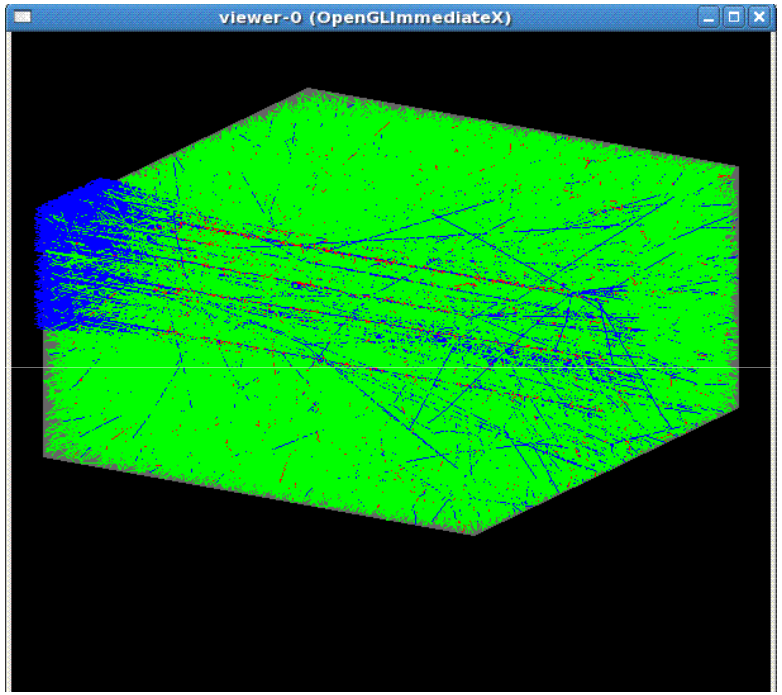


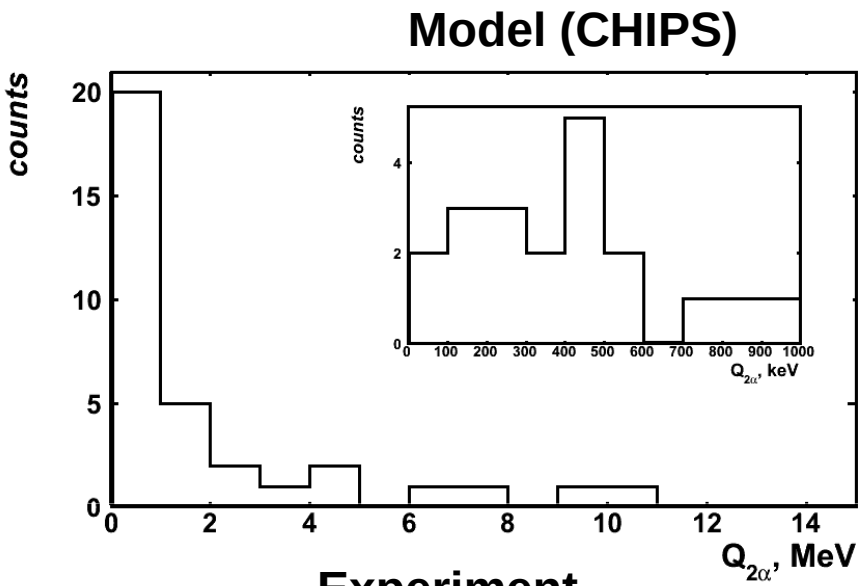
Fig. 6. Distributions of $^{10}C \rightarrow 2\alpha + 2p$ events with respect to the (a) energy $Q_{2\alpha}$ of alpha-particle pairs and (b) energy $Q_{2\alpha p}$ of the $2\alpha + p$ three-particle systems. The insets show enlarged distributions of $Q_{2\alpha}$ and $Q_{2\alpha p}$.

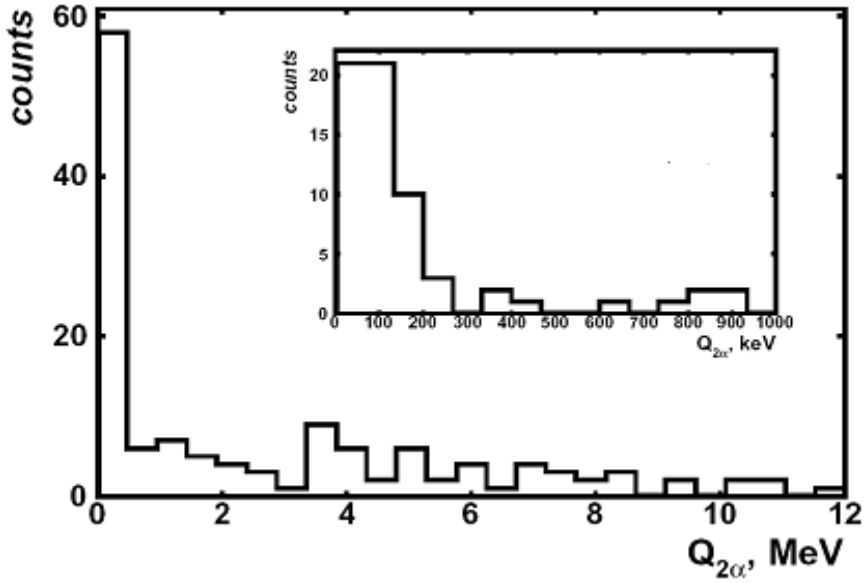
Modeling of ^{10}C fragmentation with Geant4

$$^{10}C + Em \rightarrow 2\alpha + 2p$$



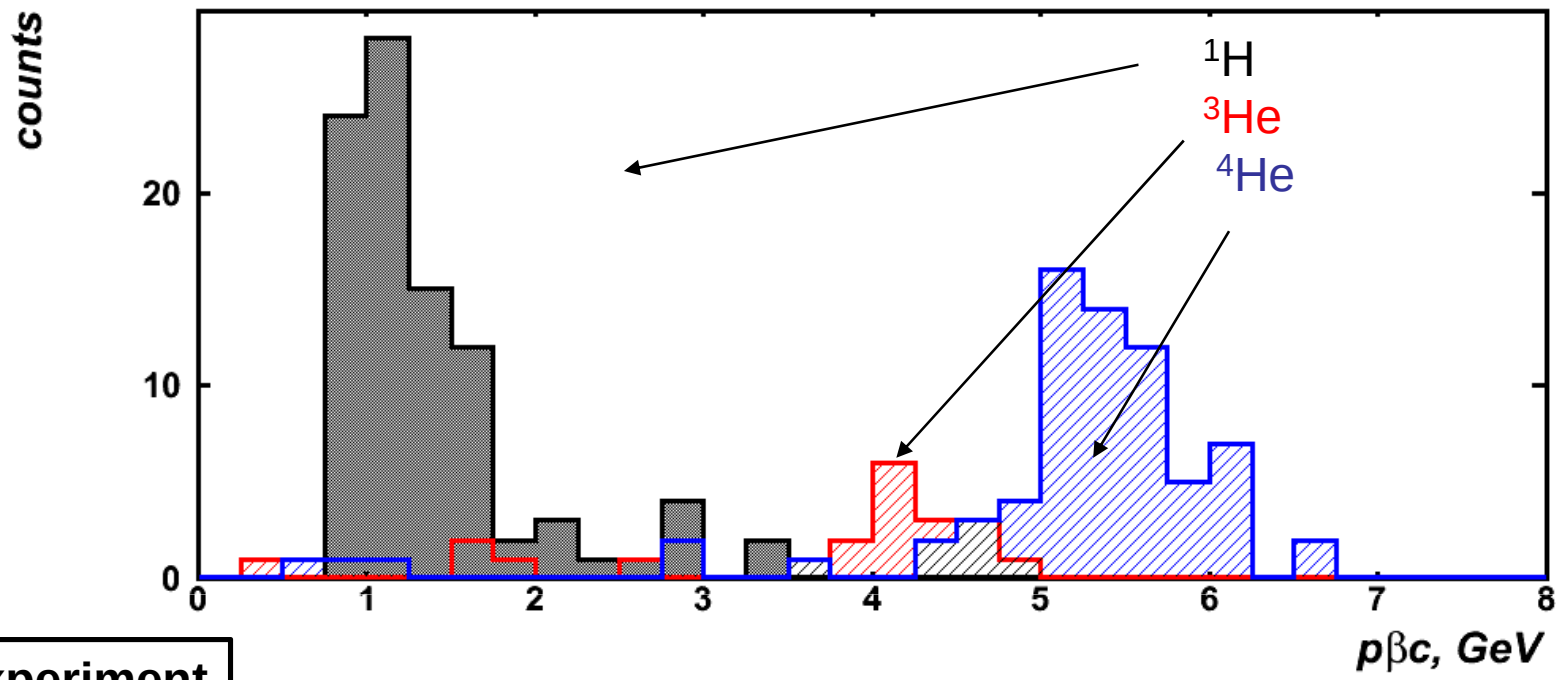
$$Q_{2\alpha} = M_{2\alpha} - 2 \cdot m_{\alpha}$$



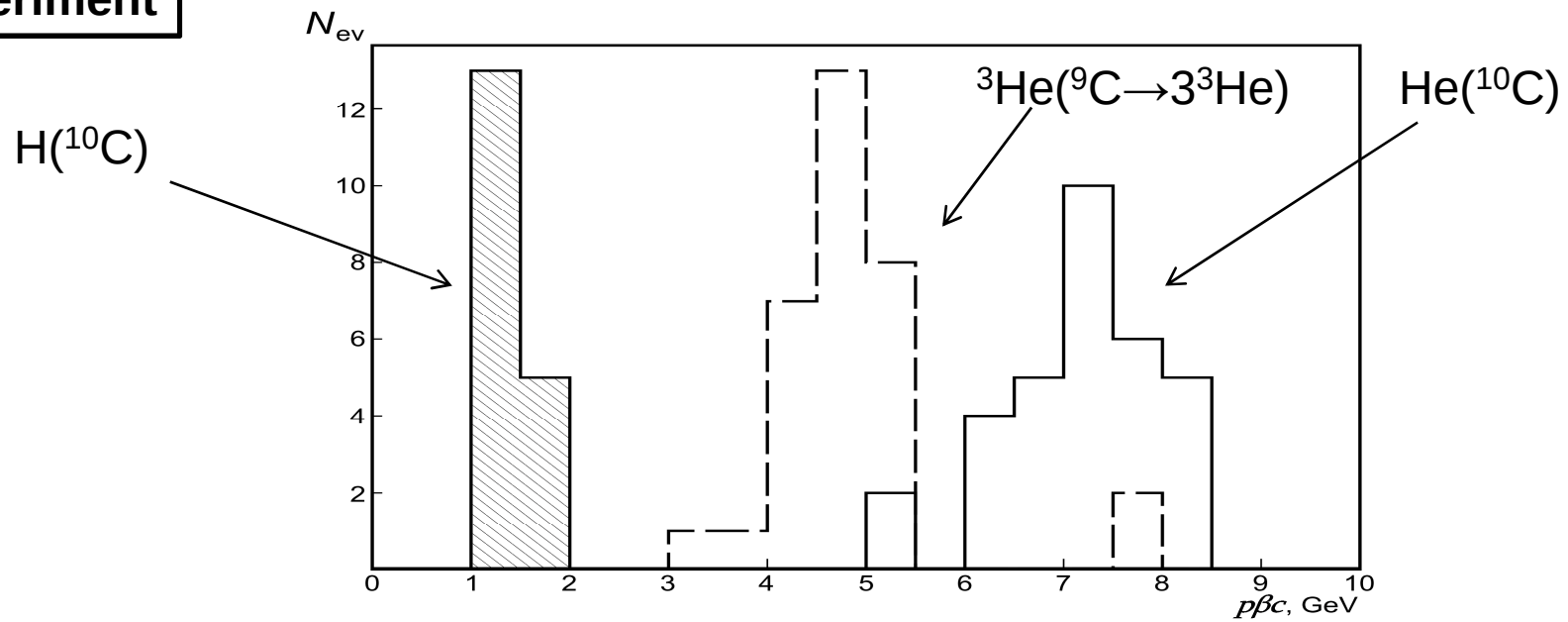


$^{10}C + Em \rightarrow 2\alpha + 2p$

Model



Experiment

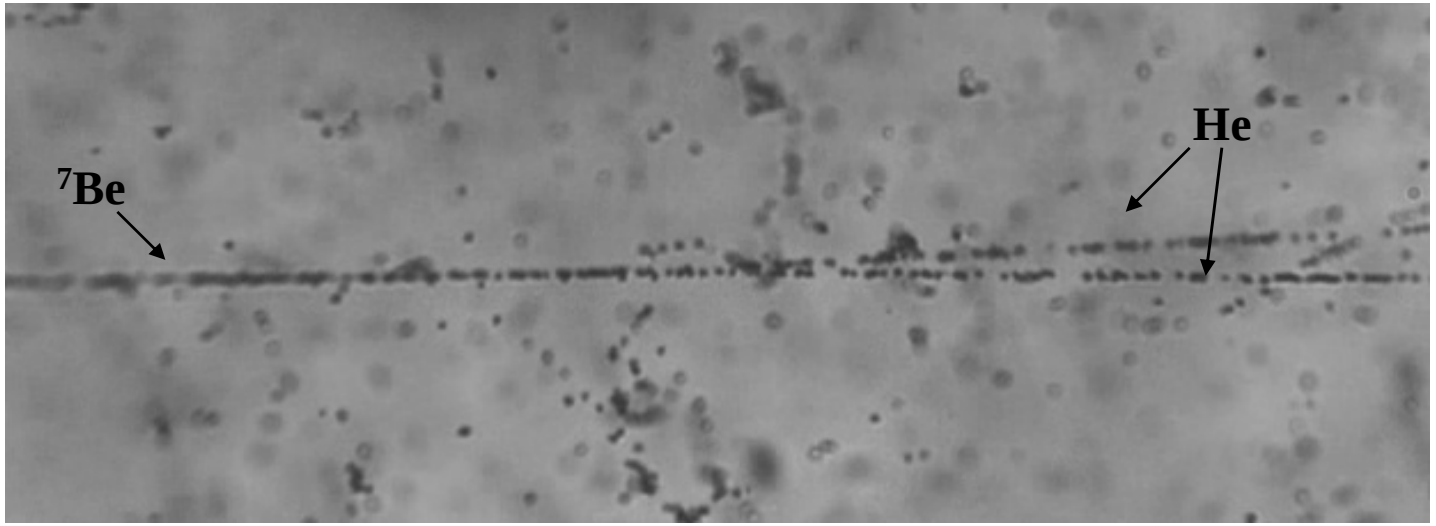


$^{7}Be \rightarrow \alpha + {}^{3}He$ ($2\,{}^{3}He$)

$^{7}Be \rightarrow {}^{6}Be \rightarrow \alpha + 2p$

(1.2 A GeV)

$^{7}Be \rightarrow 2He$



Channel	2He		Total event number
	n_b=0	n_b>0	
$^{4}He+^{3}He$	32	24	56
$^{3}He+^{3}He$	14	9	23

Fragmentation channel	2He		Total event number
	$n_b = 0$	$n_b > 0$	
$^{4}He + ^{3}He$	30	11	41
$^{3}He + ^{3}He$	11	7	18

$^{12}C \rightarrow ^{7}Be$ ($^{12}N+^{10}C+^{7}Be$ at 1.2 A GeV, 2006)

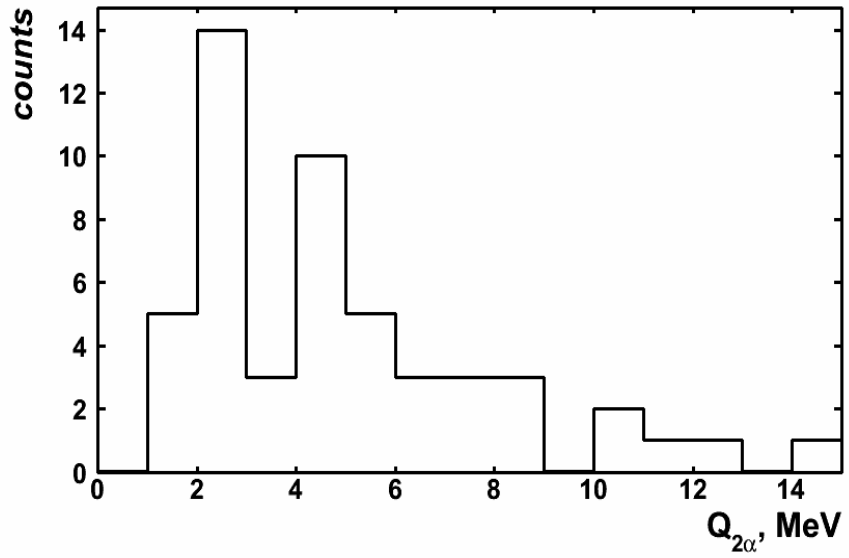
$^{7}Li \rightarrow ^{7}Be$ (1.2 A GeV, 2004)

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

$^{12}C \rightarrow {}^{7}Be$
($^{12}N + {}^{10}C + {}^{7}Be$ at 1.2 A GeV)
2006



$^{7}Li \rightarrow {}^{7}Be$
(1.2 A GeV)
2004

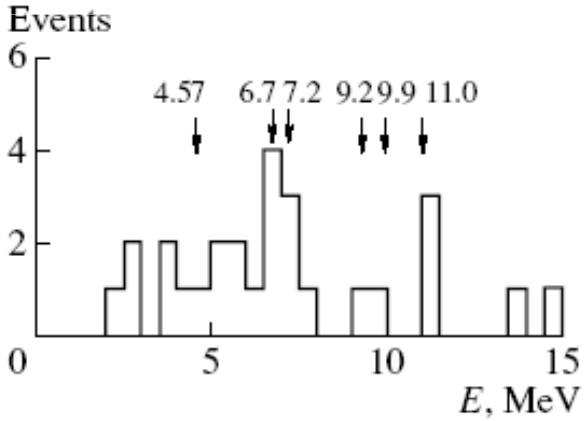
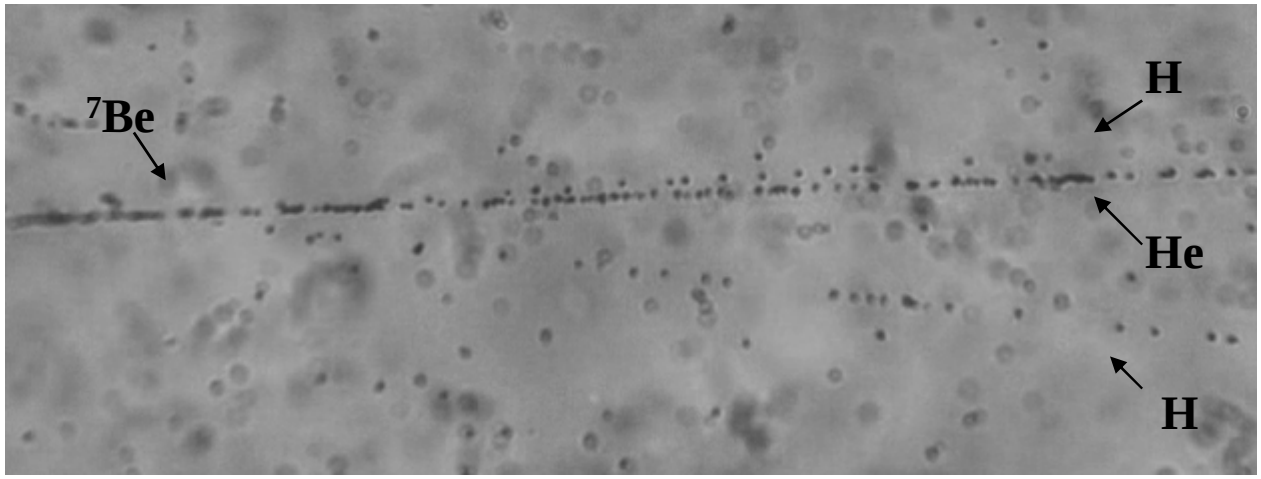


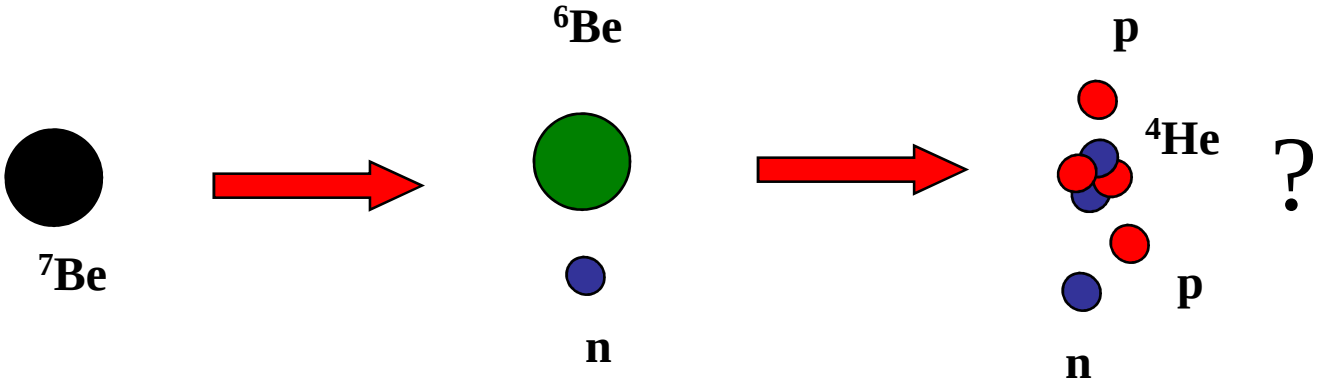
Fig. 2. Distribution of the $^{4}He + {}^{3}He$ events in E. The numbers near the arrows are the excitation energies in the ^{7}Be nucleus in MeV.

$$Q_{^{4}He+^{3}He} = M_{^{4}He+^{3}He} - m_{^{4}He} - m_{^{3}He} + 1{,}59\,MeV$$

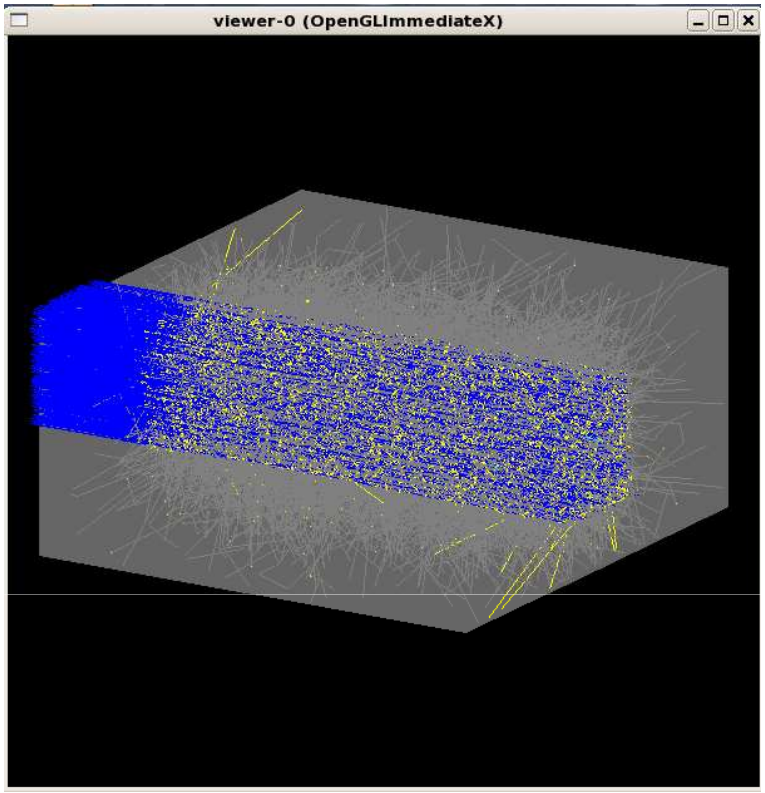
$^{7}Be \rightarrow He + 2H$



$^{7}Be \rightarrow {}^{6}Be + n \rightarrow {}^{4}He + 2{}^{1}H + n$



Data modeling of ^{7}Be EM dissociation at 1.2 A GeV

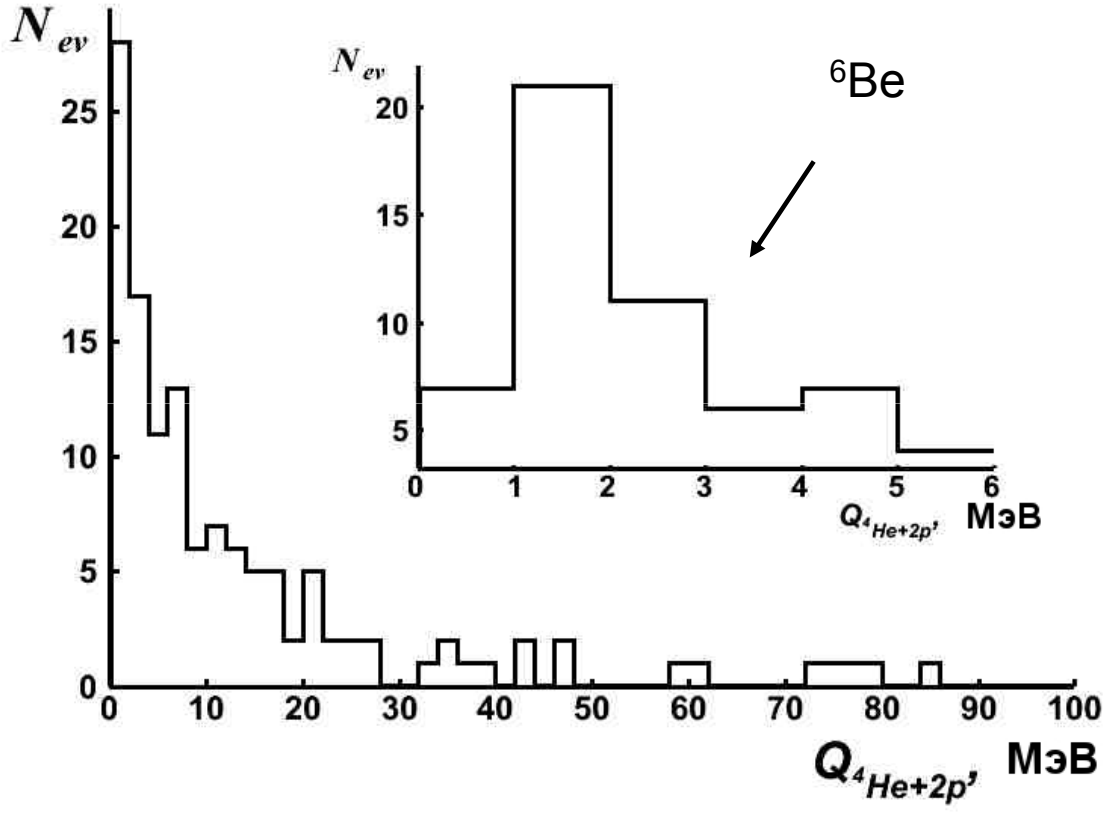


G4EMDissociation
G4EMDissociationCrossSection
Started: 3000 of ^{7}Be nuclei at 1.2 A GeV
Produced: 7 events of ^{7}Be→^{6}Be+n;

^{6}Be

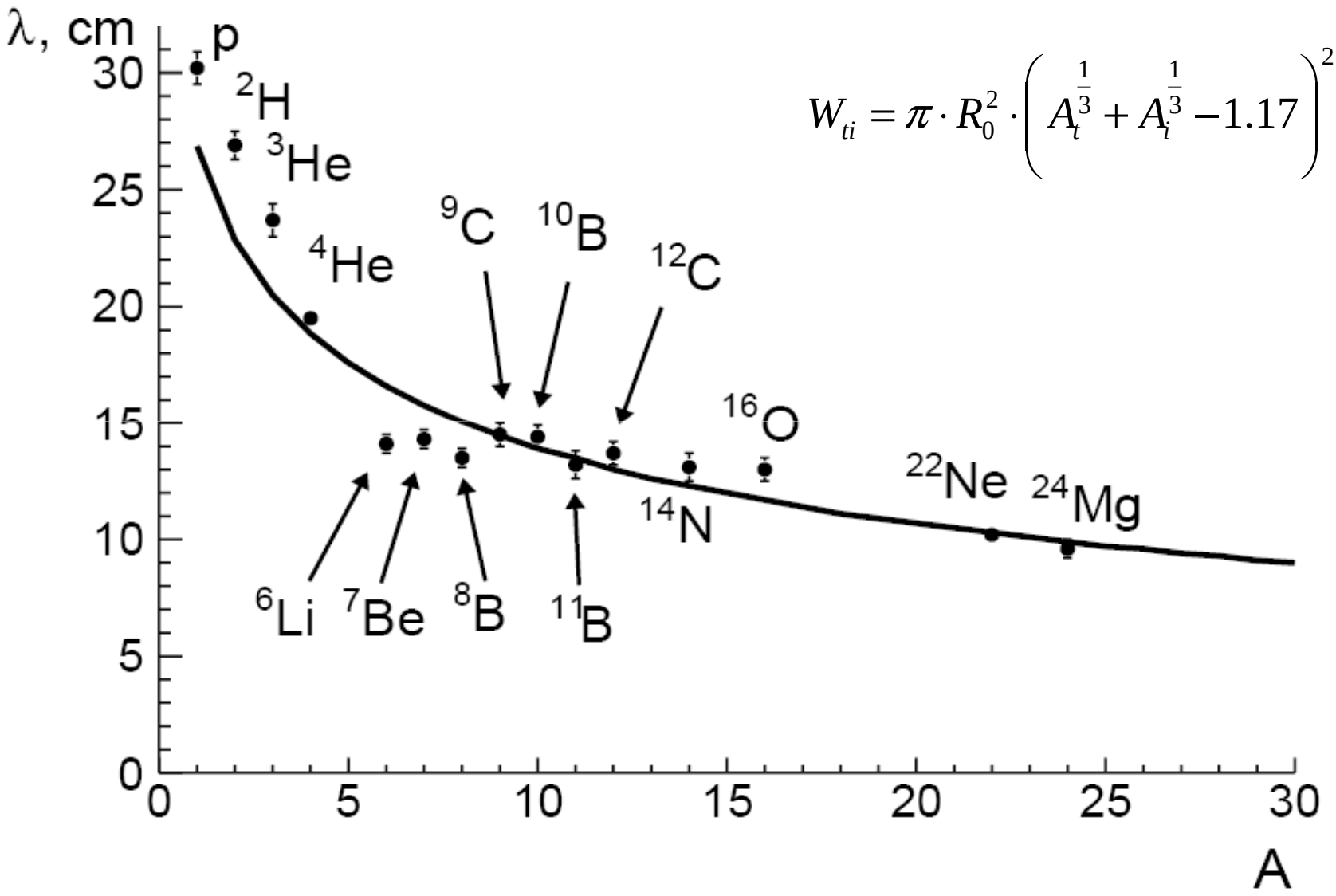
Atomic Mass: 6.0197258 ± 0.0000059 amu
Excess Mass: 18374.465 ± 5.468 keV
Binding Energy: 26924.058 ± 5.468 keV
Spin: 0+
Half life: 92 keV ($5.0 \cdot 10^{-6}$ fs)
Mode of decay: 2 Proton to He-4
Decay energy: 1.372 MeV

$$^{7}Be \rightarrow {}^{6}Be \rightarrow {}^{4}He + 2\,p$$



$$Q_{^4He+2p} = M_{^4He+2p} - m_{^4He} - 2m_p$$

Mean free path of studied nuclei in NTE



$$W_{ti} = \pi \cdot R_0^2 \cdot \left(A_t^{\frac{1}{3}} + A_i^{\frac{1}{3}} - 1.17 \right)^2$$

Summary

The presented observations serve as an illustration of prospects of the Nuclotron and NTE for nuclear physics researches.

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

The results of an exclusive study of the interactions of relativistic ^{7,9}Be, ^{10,12}C nuclei lead to the conclusion that the known features of their structure are clearly manifested in very peripheral dissociations.

Thank you for your attention!