Search for unstable nuclear states in the fragmentation of Kr nuclei at 950 MeV/nucleon

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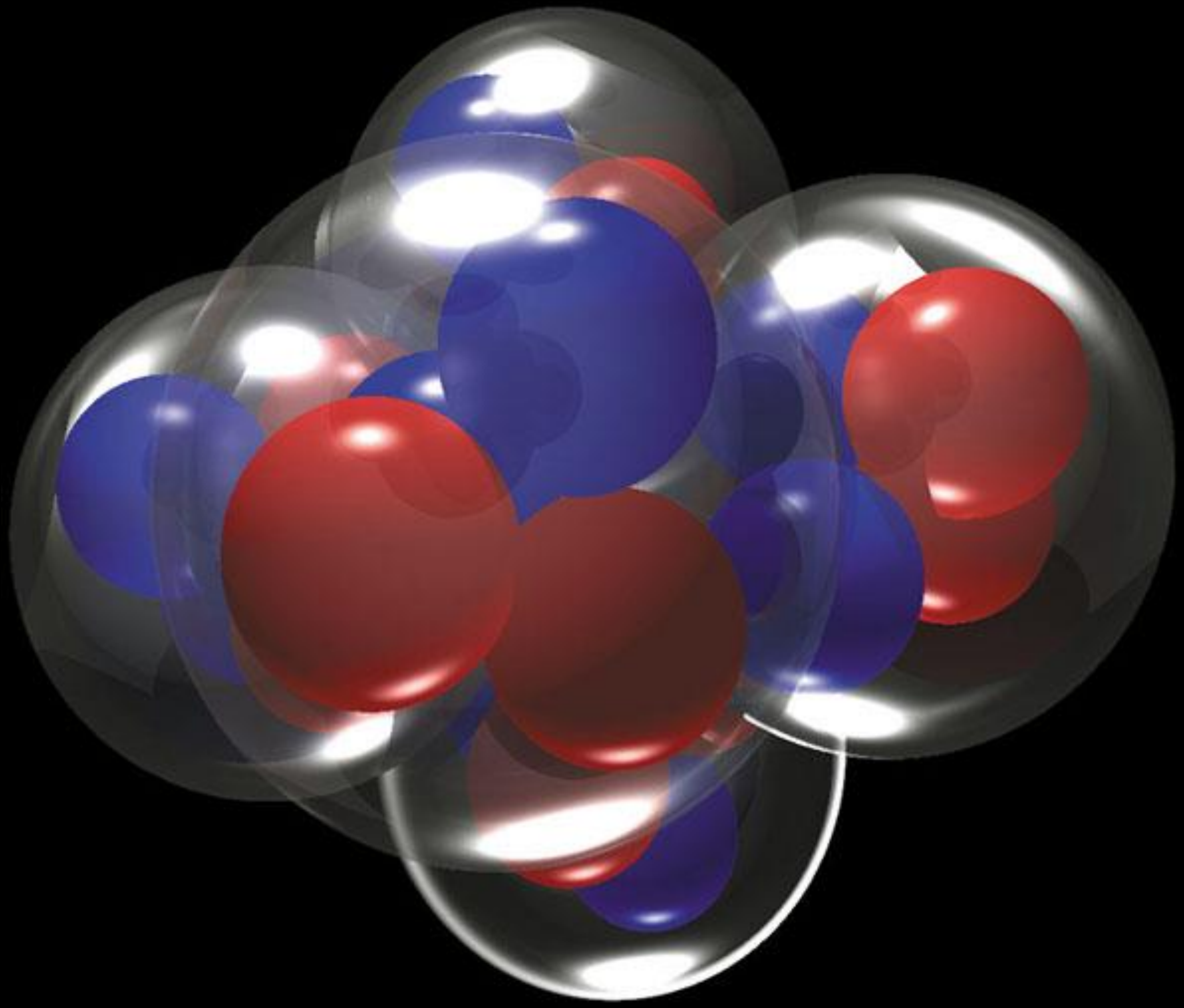
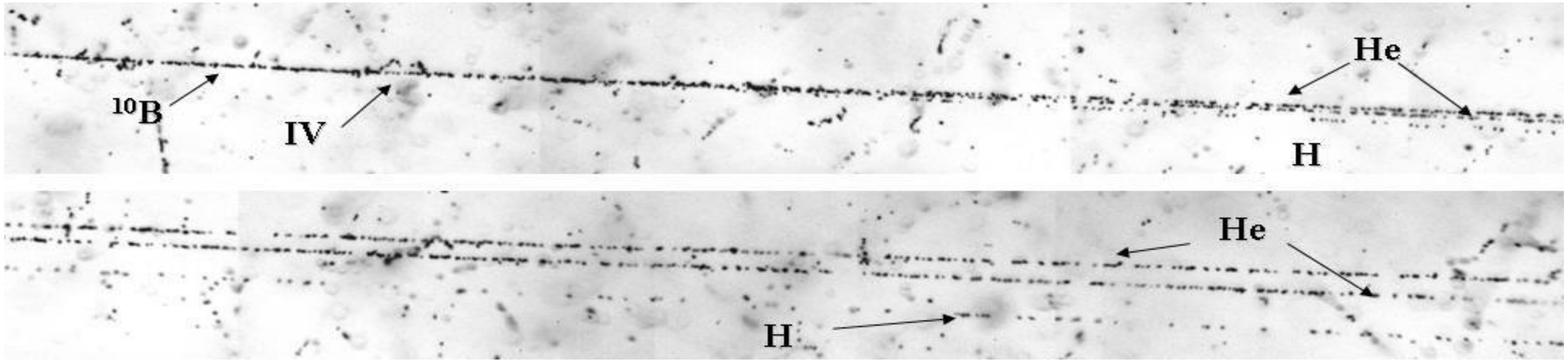


OUTLINE

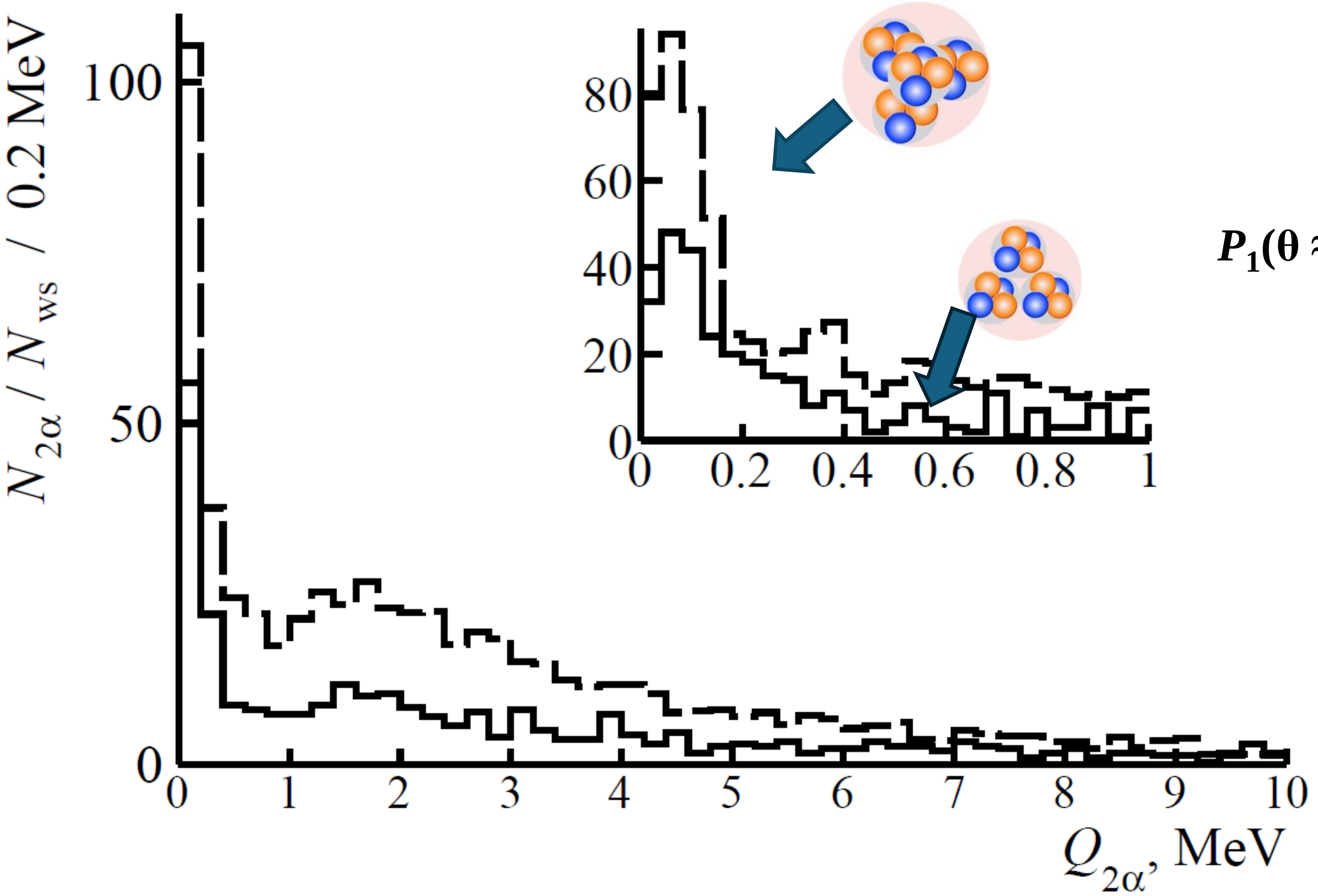
- Nuclear states in dissociation of light nuclei
- Fragmentation of Kr nuclei in NTE
- Topology of found events
- Reconstruction of unstable nucleus decay
- Prospect for the further analysis

Fragmentation topology of relativistic carbon nuclei

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 %)



Peripheral interaction of relativistic boron nucleus with a nucleus from NTE with the production of the two helium and one hydrogen fragments.



$$P_1(\theta \approx 0^{o}) = P_0$$

$$P_x = P_0 \cdot A \cdot cos(\alpha)cos(\phi)$$

$$P_y = P_0 \cdot A \cdot cos(\alpha)sin(\phi)$$

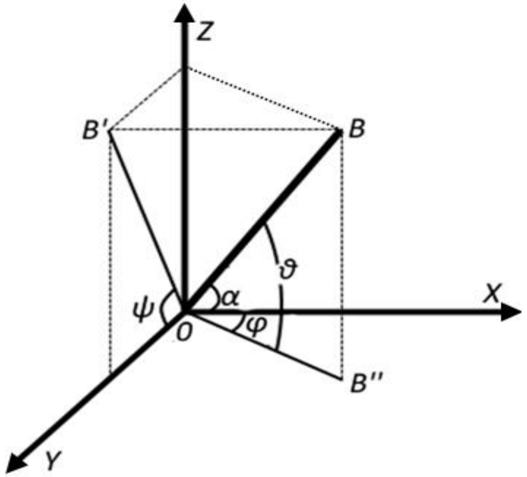
$$P_z = P_0 \cdot A \cdot sin(\alpha)$$

$$E_1 = \sqrt{P_0^2 \cdot A^2 + m_1^2}$$

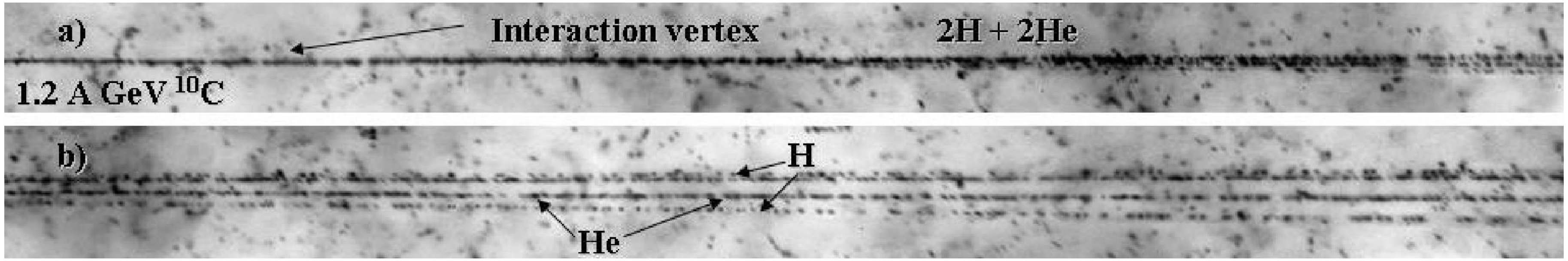
$$\Theta_{12} = \frac{P_{x1} \cdot P_{x2} + P_{y1} \cdot P_{y2} + P_{z1} \cdot P_{z2}}{P_1 \cdot P_2}$$

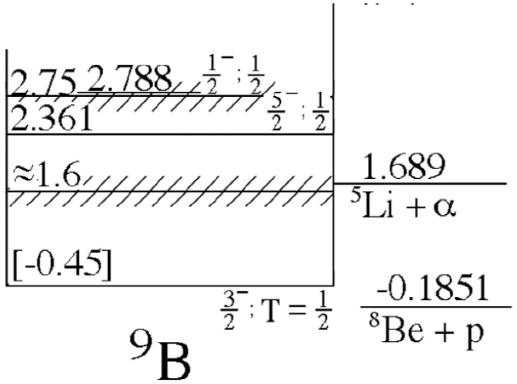
$$\mathfrak{M} = \sqrt{\left(\sum_{i=1}^{n} E_i\right)^2 - \left(\sum_{i=1}^{n} p_i\right)^2}$$

$$Q = \mathfrak{M} - \sum_{i=1}^{n} m_i$$

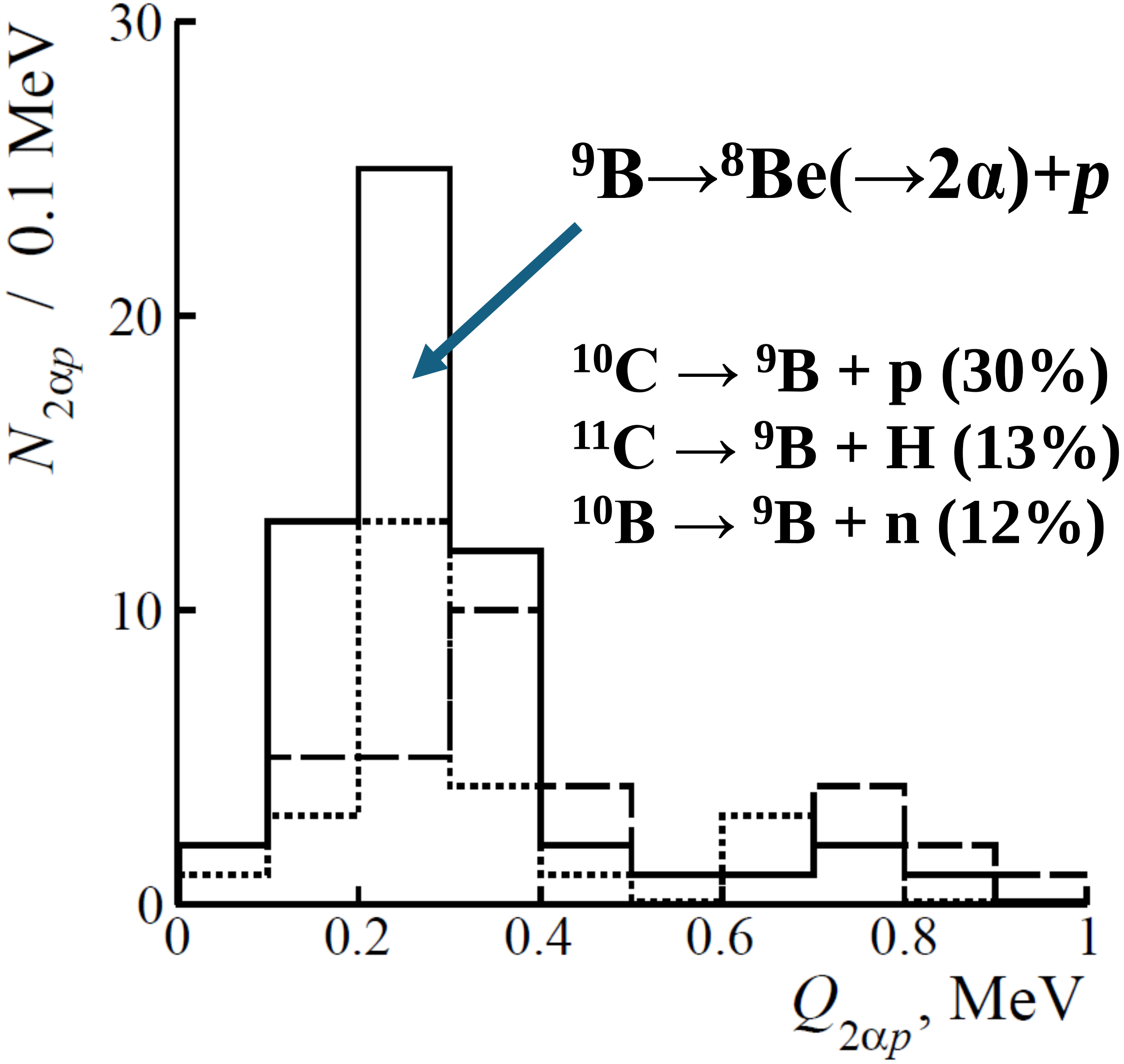


Selected under the cleanest conditions, the criterion $Q_{2\alpha}(^{8}Be) < 0.2$ MeV includes the accepted approximations, the kinematic ellipse of the ^{8}Be decay, and the resolution of angular measurements. Its application allows us to determine the ^{8}Be contribution to the statistics of “white” stars equal to **45 ± 4%** for $^{12}C \rightarrow 3\alpha$ and **62 ± 3%** for $^{16}O \rightarrow 4\alpha$



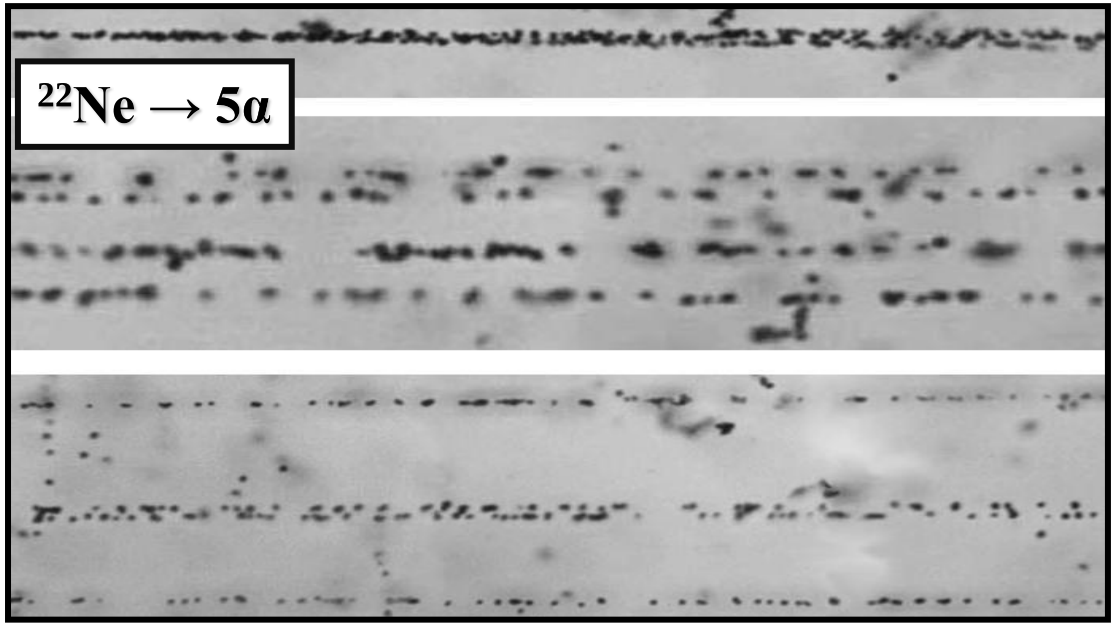


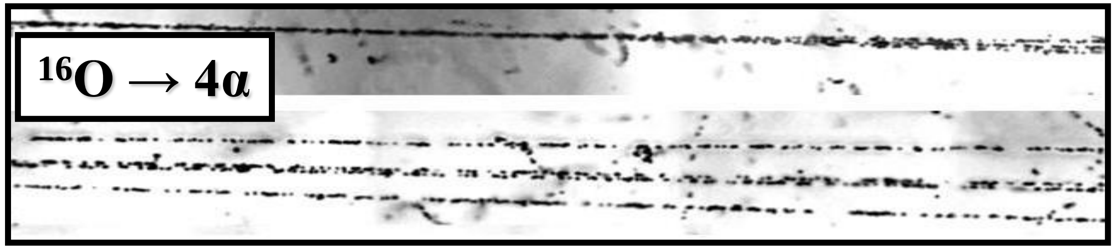
The ground state of the ^{9}B nucleus is higher than the ^{8}Be*p* threshold by 185 keV, and its width 0.54 keV, also indicates that it is a long-lived state.



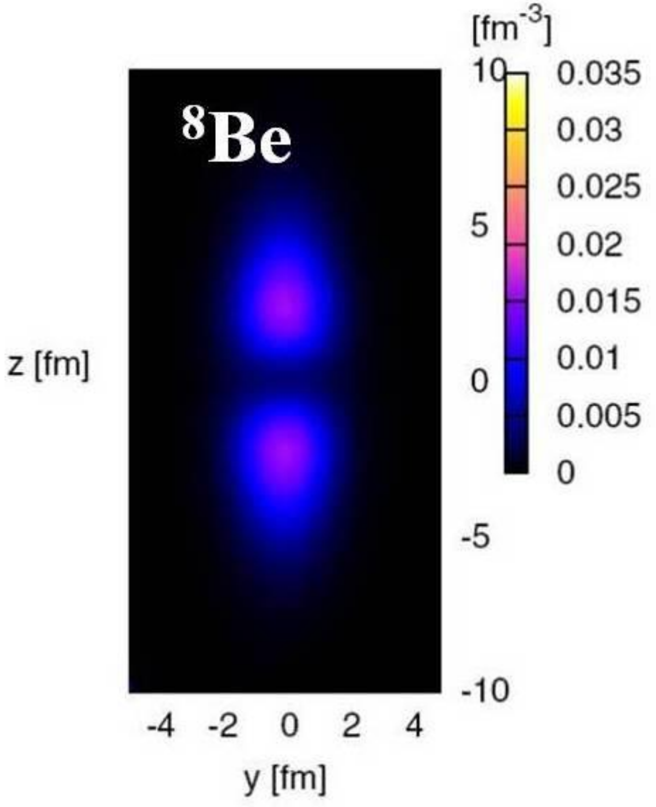
Distribution of number of 2*αp* triples $N_{2\alpha p}$ over invariant mass $Q_{2\alpha p}$ (< 1 MeV) in coherent dissociation $^{10}C \rightarrow$ 2He2H (solid) and dissociation $^{11}C \rightarrow$ 2He2H (dots) and $^{10}B \rightarrow$ 2HeH (dashed).

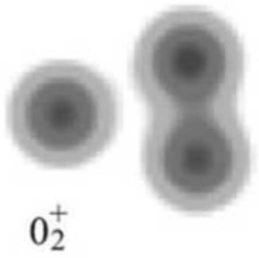
Events of peripheral dissociation, reflecting the individual characteristics of incident nuclei, are observed in nuclear energy as often and completely as central impacts. They indicate the fundamental possibility of studying the nuclear structure in the cone of relativistic fragmentation. However, in this aspect, the use of traditional magnetic spectrometers with coordinate and scintillation detectors turned out to be very limited. The difficulties that have arisen are due to the dramatic difference in the ionization of the beam nuclei and relativistic fragments with their extremely small angular divergence, and, often, an approximate coincidence in magnetic rigidity. For these reasons, measurements were carried out with the registration of relativistic fragments as close in charge as possible to the nucleus under study.



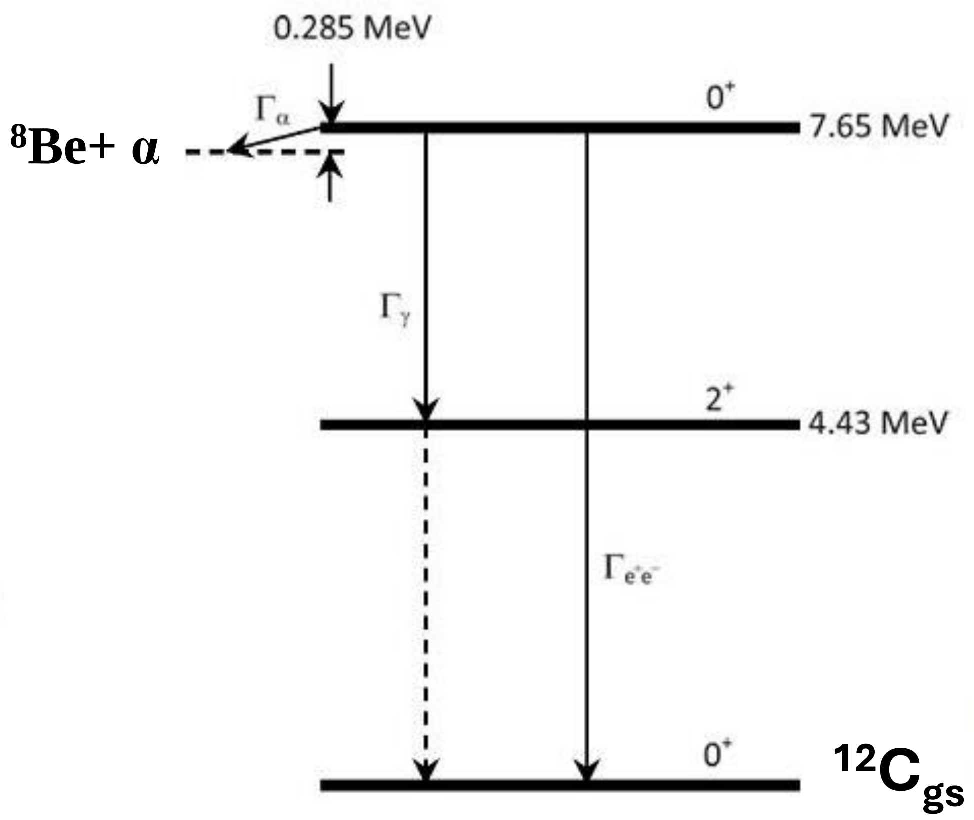


The Hoyle state is the second excited state of ^{12}C at **378 keV** above the 3α threshold. The ^{8}Be nucleus inevitably appears among products of ^{9}B and Hoyle state decays.



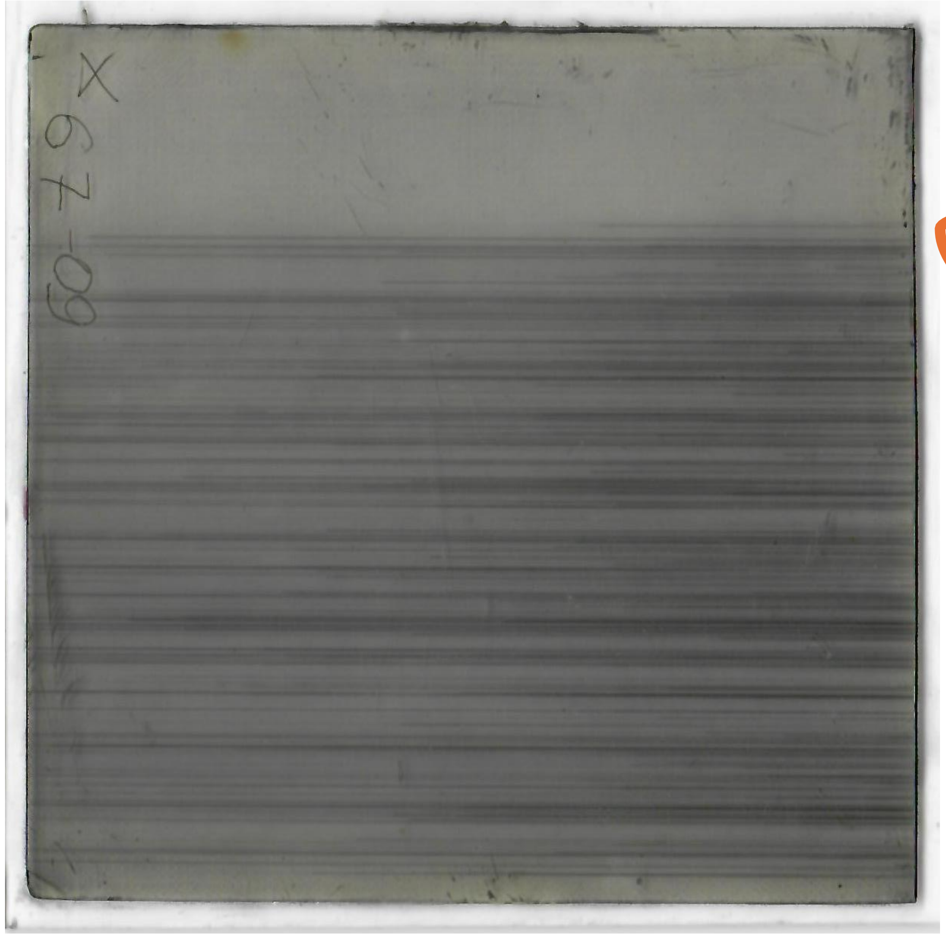


The Hoyle state

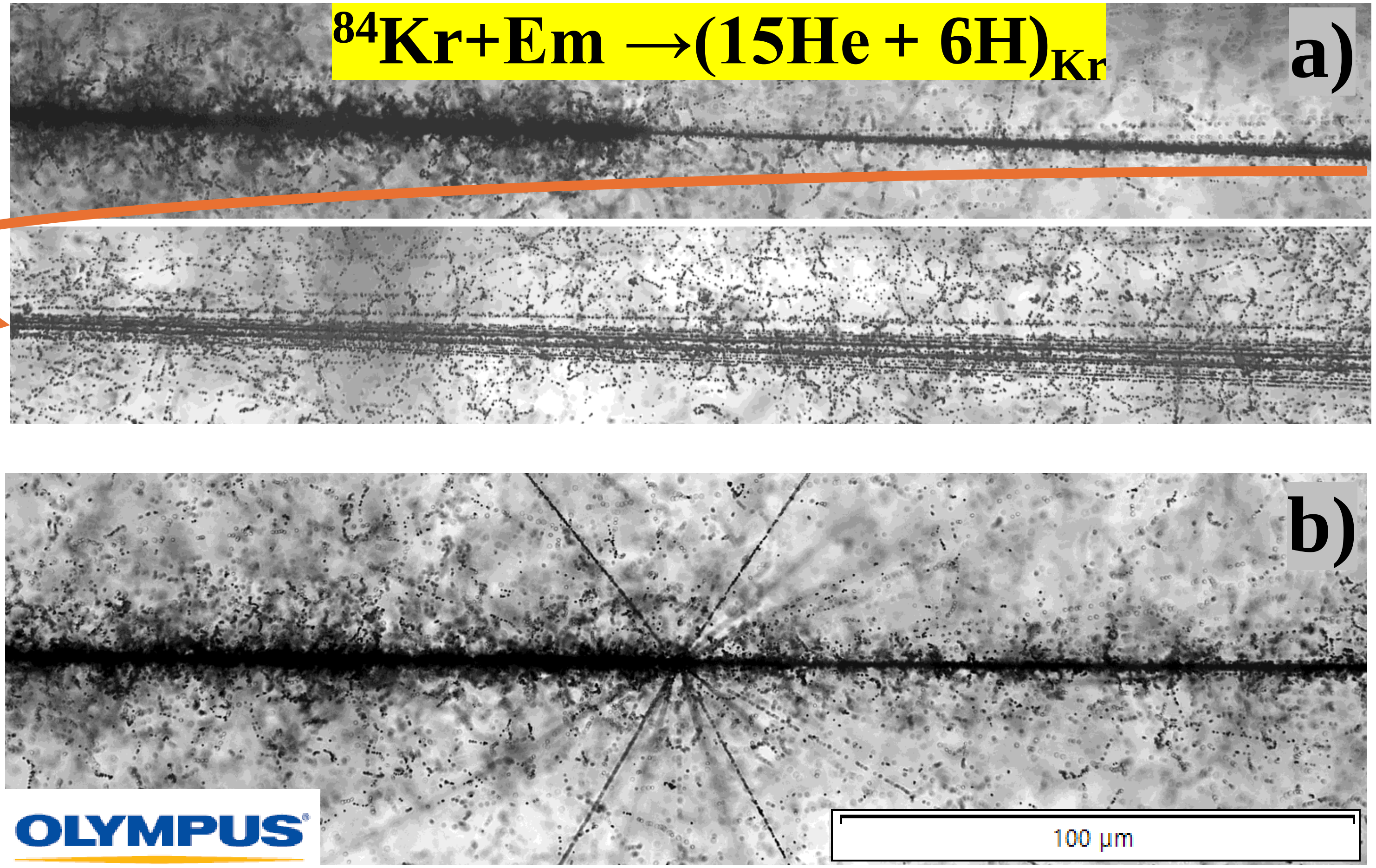


An isolated position of the Hoyle state at the beginning of the ^{12}C excitation spectrum and its width 9.3 eV render its 3α analog of ^{8}Be. The synthesis of ^{12}C in the red-giant medium is possible via the fusion reaction $3\alpha \rightarrow \alpha^{8}Be \rightarrow ^{12}C(0^+_2) \rightarrow ^{12}C$ ($+2\gamma$ or e^+e^- with a probability of about 10^{-4}). A further synthesis via the fusion reaction $\alpha^{12}C \rightarrow ^{16}O\gamma$ through a ^{16}O level at an appropriate energy is forbidden in parity. This is the circumstance that determines the relative abundances of ^{12}C and ^{16}O, as well as the survival of ^{12}C under the astrophysical conditions of helium burning. However, the synthesis of ^{16}O is possible through the sequence $^{12}C^{12}C \rightarrow ^{12}C^{12}C(0^+_2) \rightarrow ^{16}O^{8}Be$.

^{84}Kr nucleus interactions in NTE at 950 MeV/nucleon



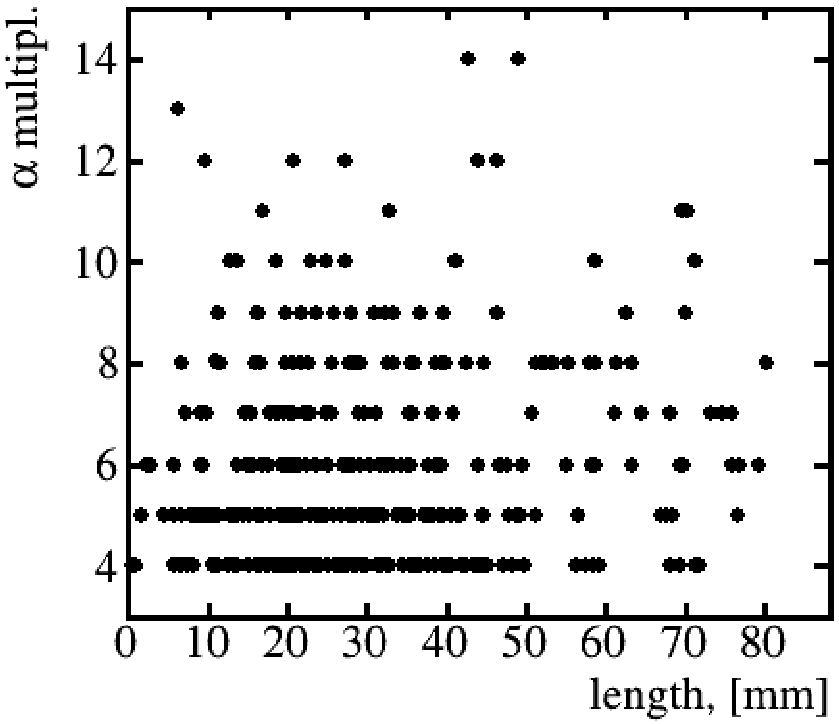
NTE plate exposed by Kr nucleus beam at GSI.

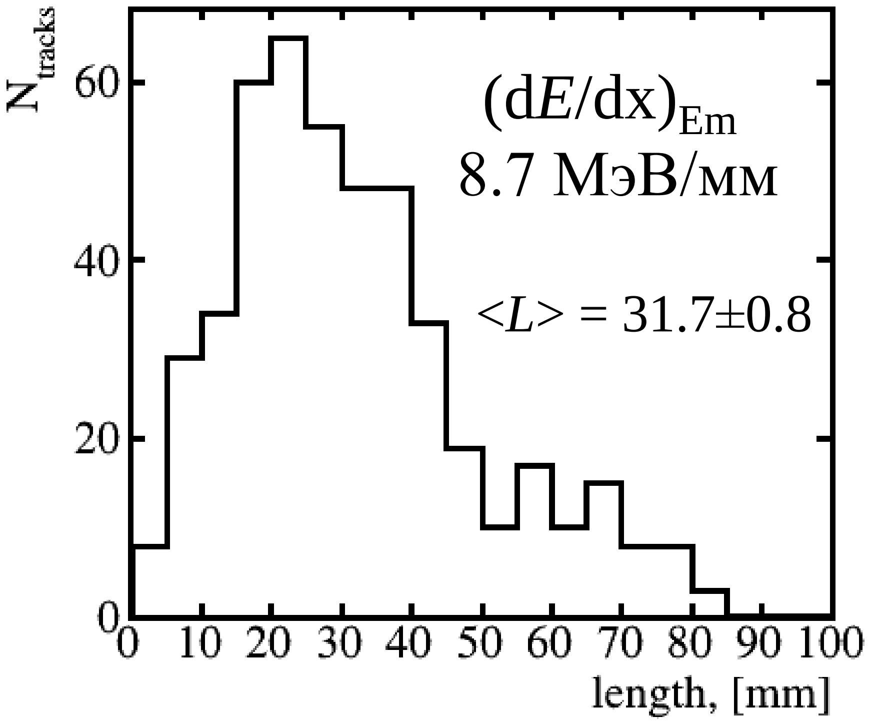


a) Peripheral interaction of Kr projectile nucleus with a NTE nucleus, without produced mesons and fragments of the target nucleus. This type of interaction is called “white” stars.
b) Interaction of Kr nucleus with a large impact parameter, as a result of which fragments of the target nucleus are observed.

Multiplicity of alpha particles (nα) in found events depending on the type of event: "white" star (N_{ws}) and with visible target fragments (N_{tf})

nα	3	4	5	6	7	8	9	10	nα>10	**nα>3**
N_{tf}	66	83	75	48	24	27	9	5	2	**273**
N_{ws}	29	21	25	11	8	11	8	5	10	**99**
TOTAL	95	104	100	59	32	38	17	10	12	**372**





Right: Distribution of the multiplicity of produced α-particles depending on the coordinate of the event vertex in the volume of the nuclear emulsion.

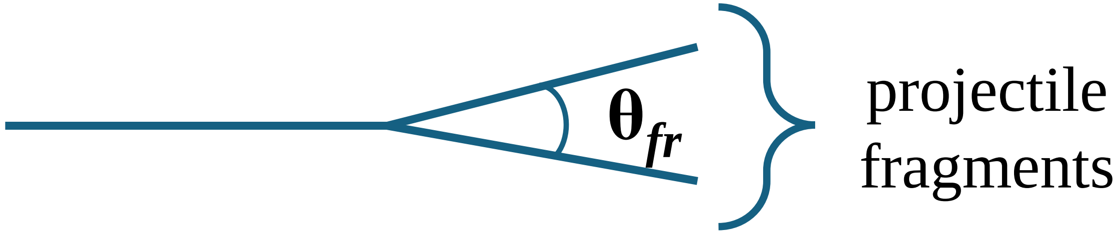
Left: Distribution of events over the free path of Kr nuclei to the interaction vertex.

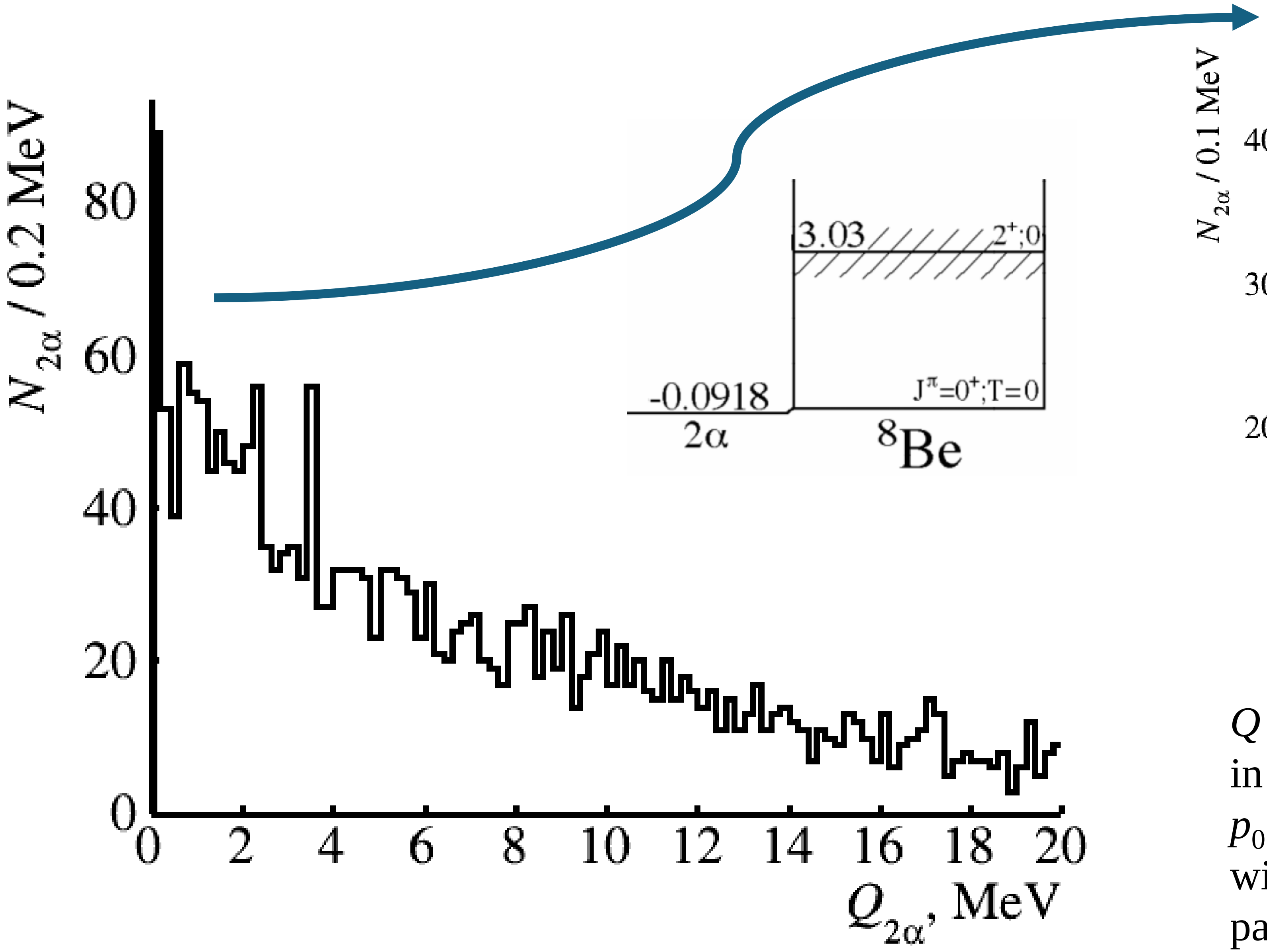
Average multiplicity of projectile hydrogen fragments with the number of alpha particles in the «white» stars (*ws*) and with target fragment events (*tf*)

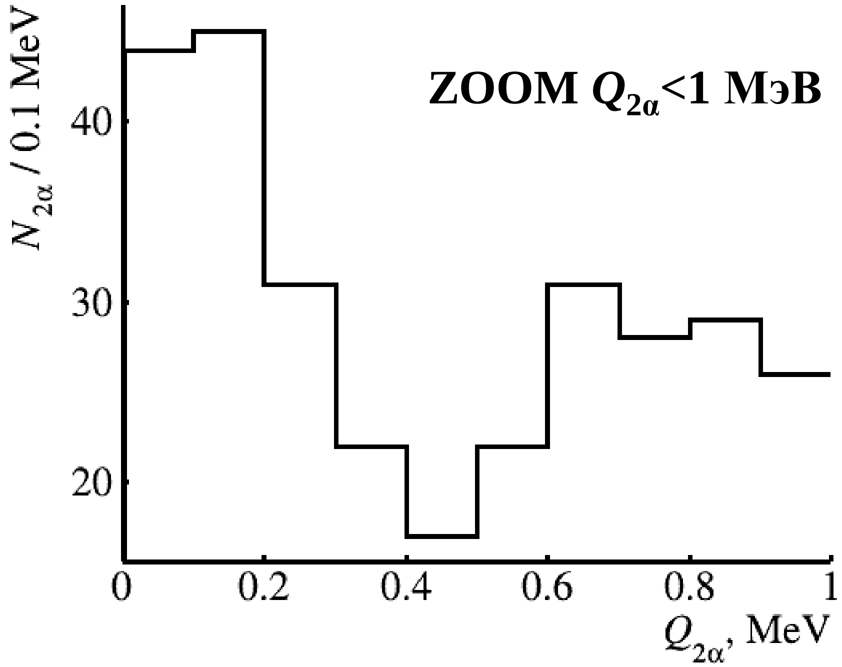
$n\alpha$	$\langle nH_{proj.} \rangle_{tf}$	$\langle nH_{proj.} \rangle_{ws}$
3	3.5	6.6
4	3.9	9.0
5	4.3	9.0
6	5.6	11.3
7	5.9	12.2
8	6.0	11.3
$n\alpha > 8$	3.8	6.4

$$\mathbf{\sin \theta_{\mathit{fr}} \sim \mathit{p_{fr}}/\mathit{P_0}}$$

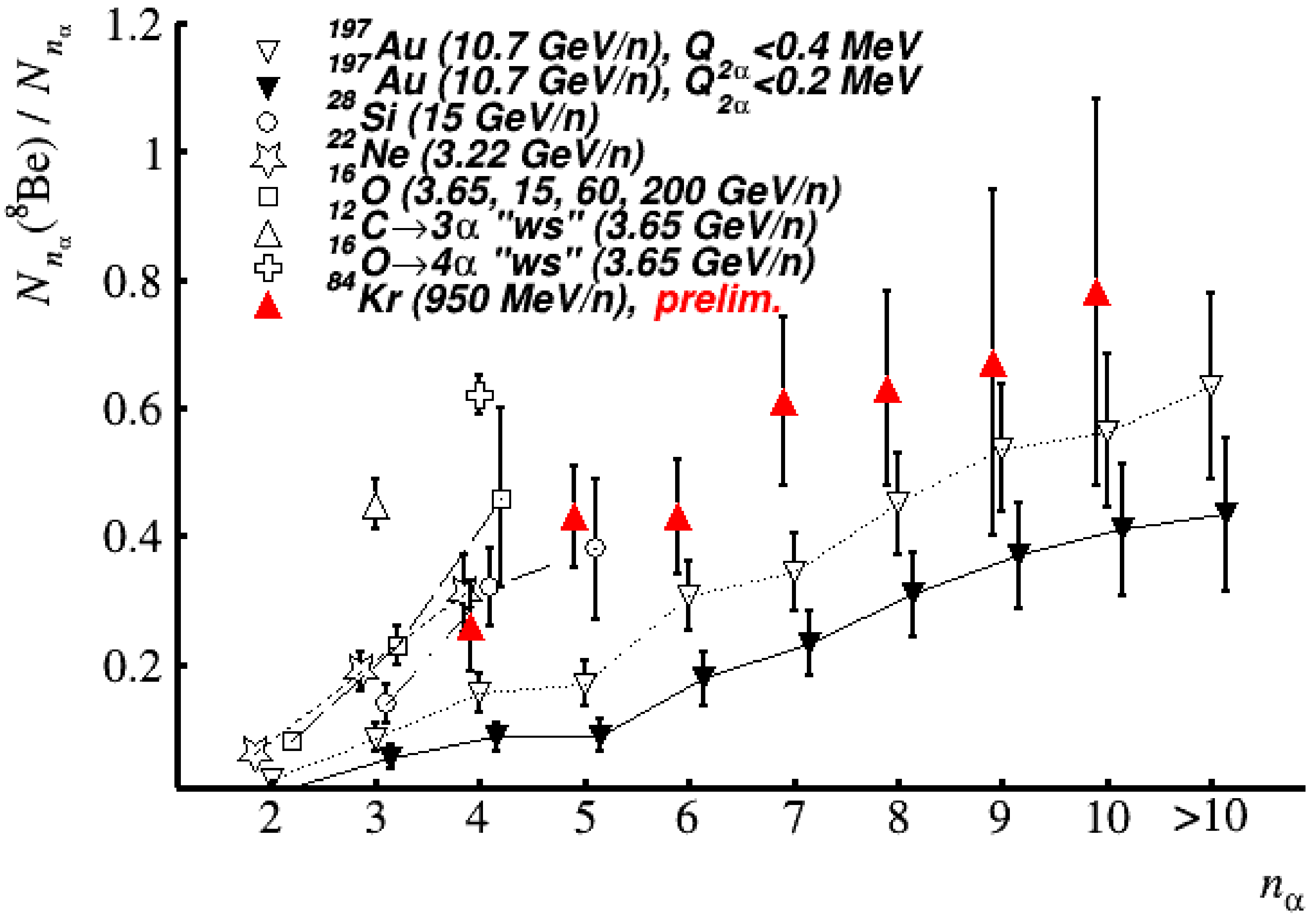
$$p_{fr} = 0.2 \text{ ГэВ}/c$$





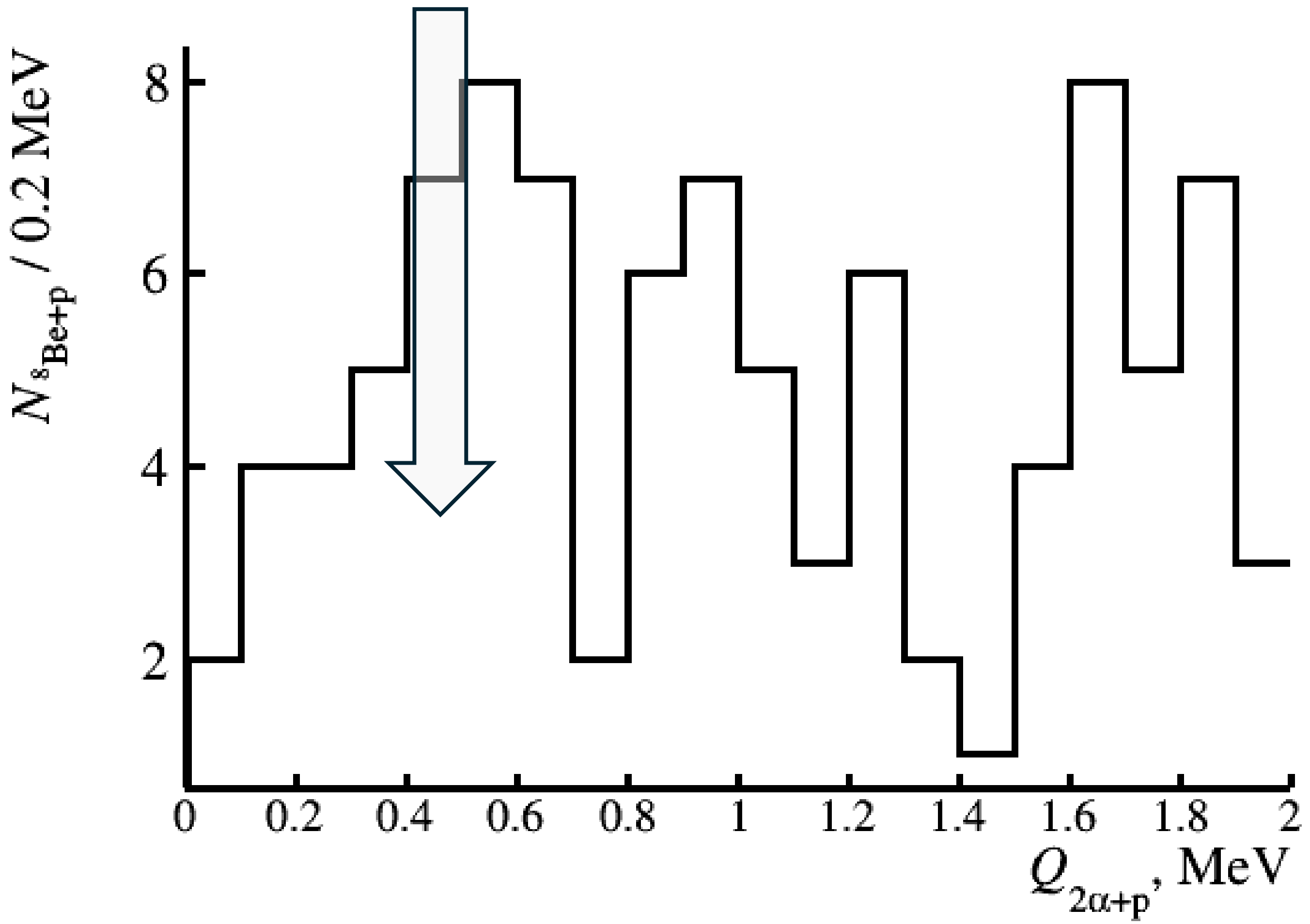


Q value distribution of α-particle pairs in Kr→(4-10)α events with correction p_0 = 0.8*p(L). The number of events with at least one ^{8}Be (number of ^{8}Be pairs) for $Q_{2\alpha}$<0.4 MeV is **96 (17)**, for $Q_{2\alpha}$<0.2 MeV – **68 (9)**.

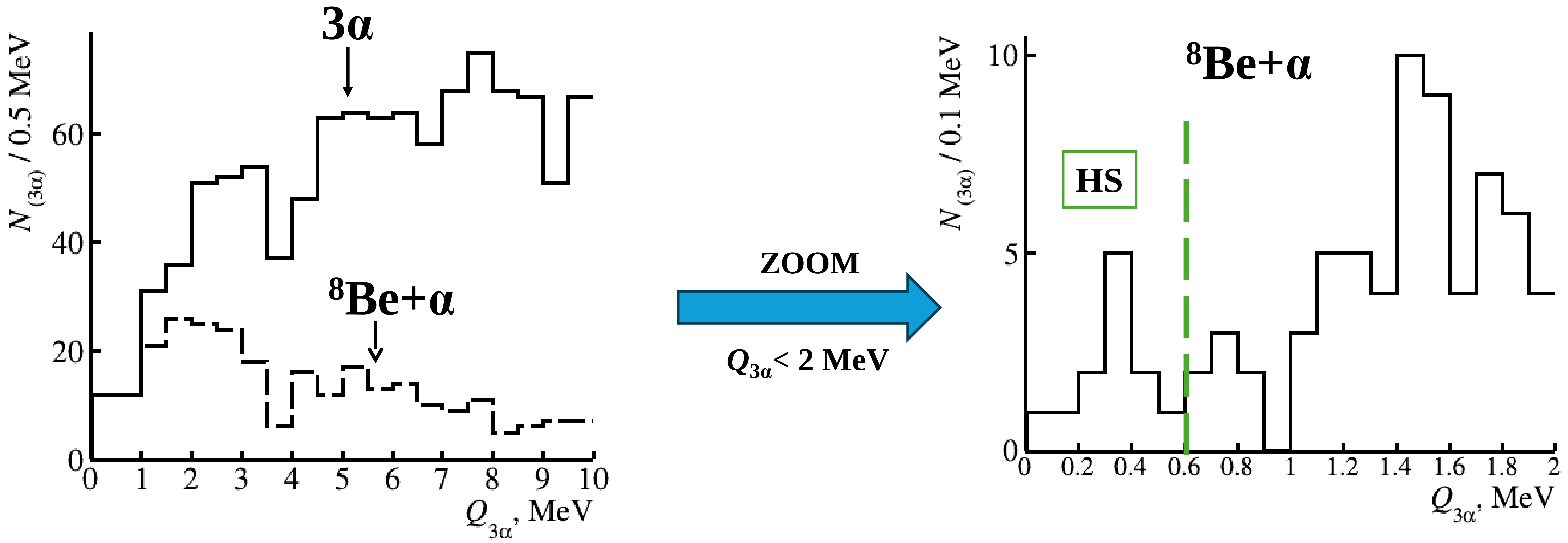


Dependence of relative contribution of $N_{n\alpha}(^8Be)$ decays to statistics of $N_{n\alpha}$ events with α-particle multiplicity nα in relativistic fragmentation of C, O, Ne, Si, and Au nuclei; marked "white" stars $^{12}C \rightarrow 3\alpha$ and $^{16}O \rightarrow 4\alpha$ (WS); points are slightly shifted from values of n_α and are connected by dotted line.

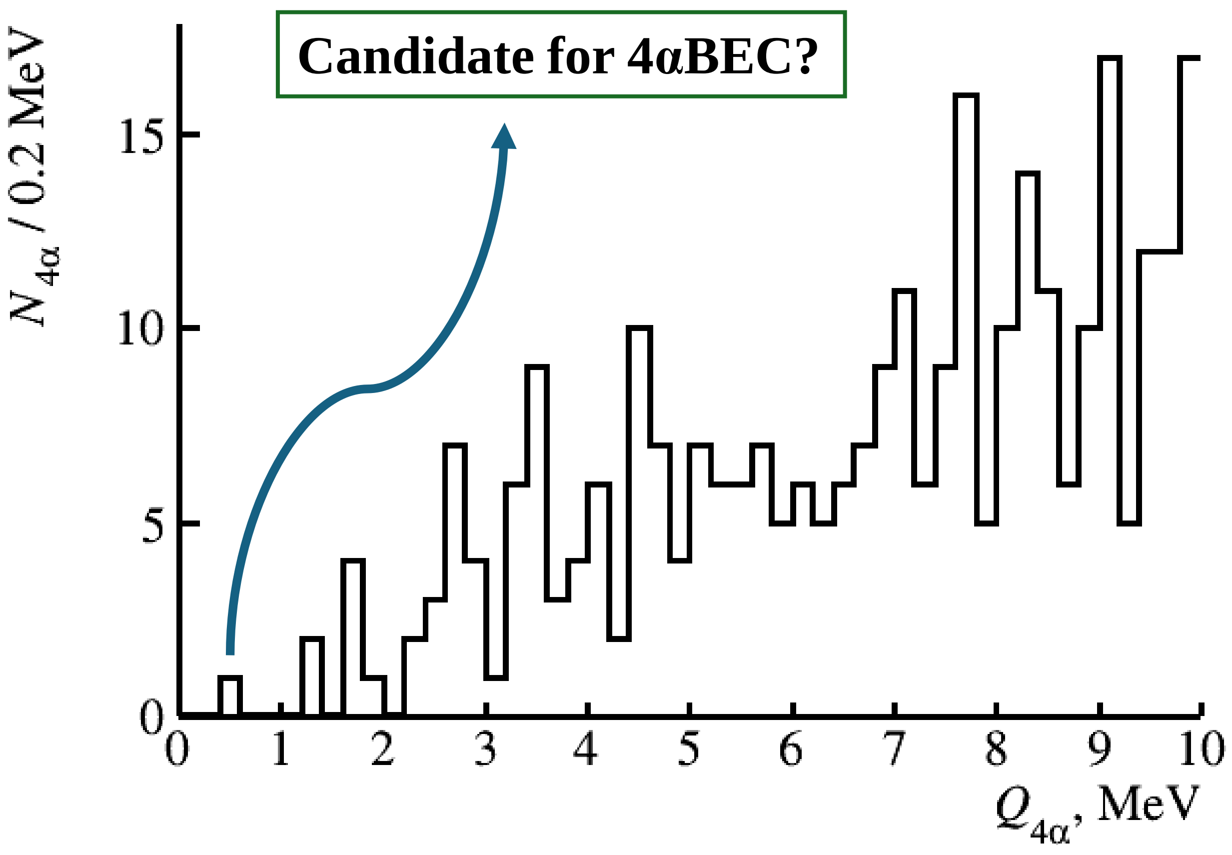
^{9}B decays?



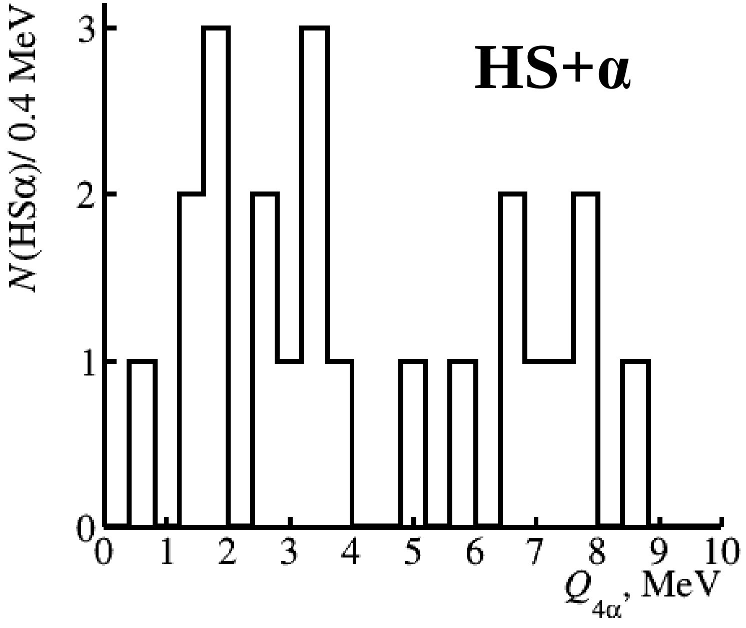
Distribution over Q value for triples $2\alpha+p$, in events with identified of the ^{8}Be nucleus decays with the condition $Q_{2\alpha}< 0.4$ MeV

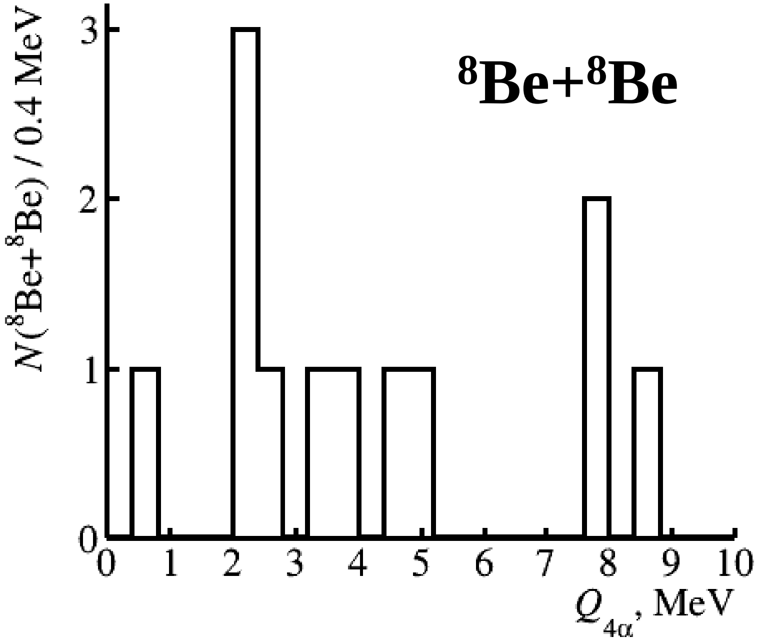


Q value distribution of α-particle triplets in Kr→(4-10)α events. Number of events satisfying the soft condition $Q_{3\alpha}$ < 0.6 MeV – **11 events**



Distribution over Q value of 4α-particles.
Event $Q_{4\alpha} < 1$ MeV (nα = 6):
$\mathbf{Q_{4\alpha} = 0.584}$ **MeV**



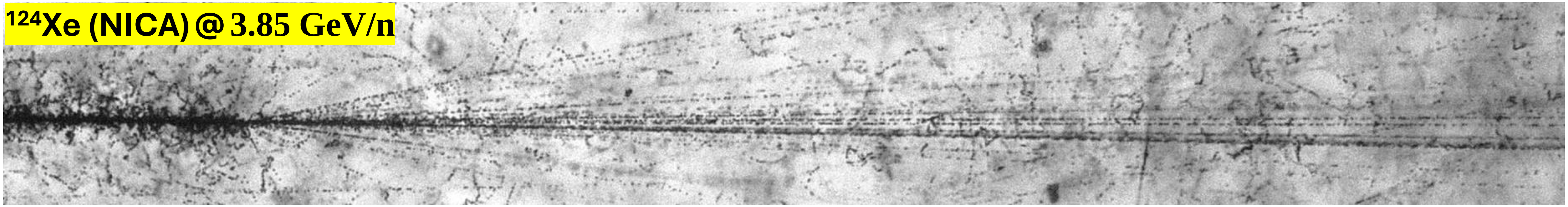


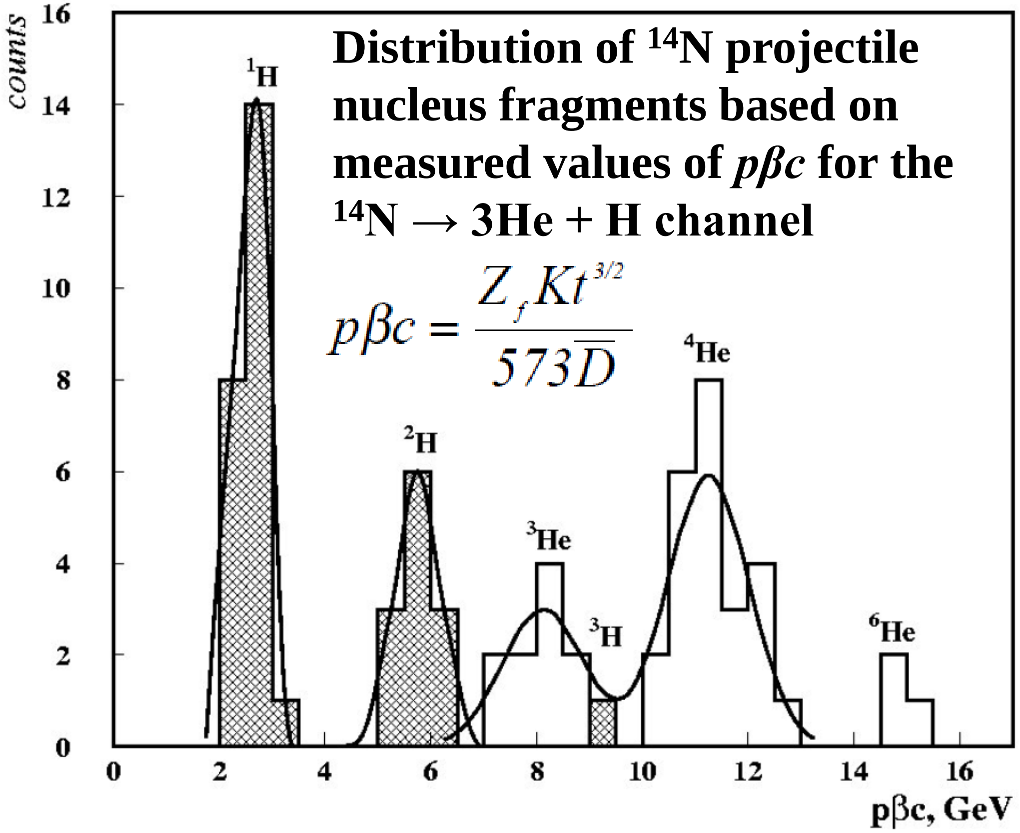
Reconstructed decay sequence: ^{16}O → HS(→^{8}Be+α) + ^{8}Be → 4α

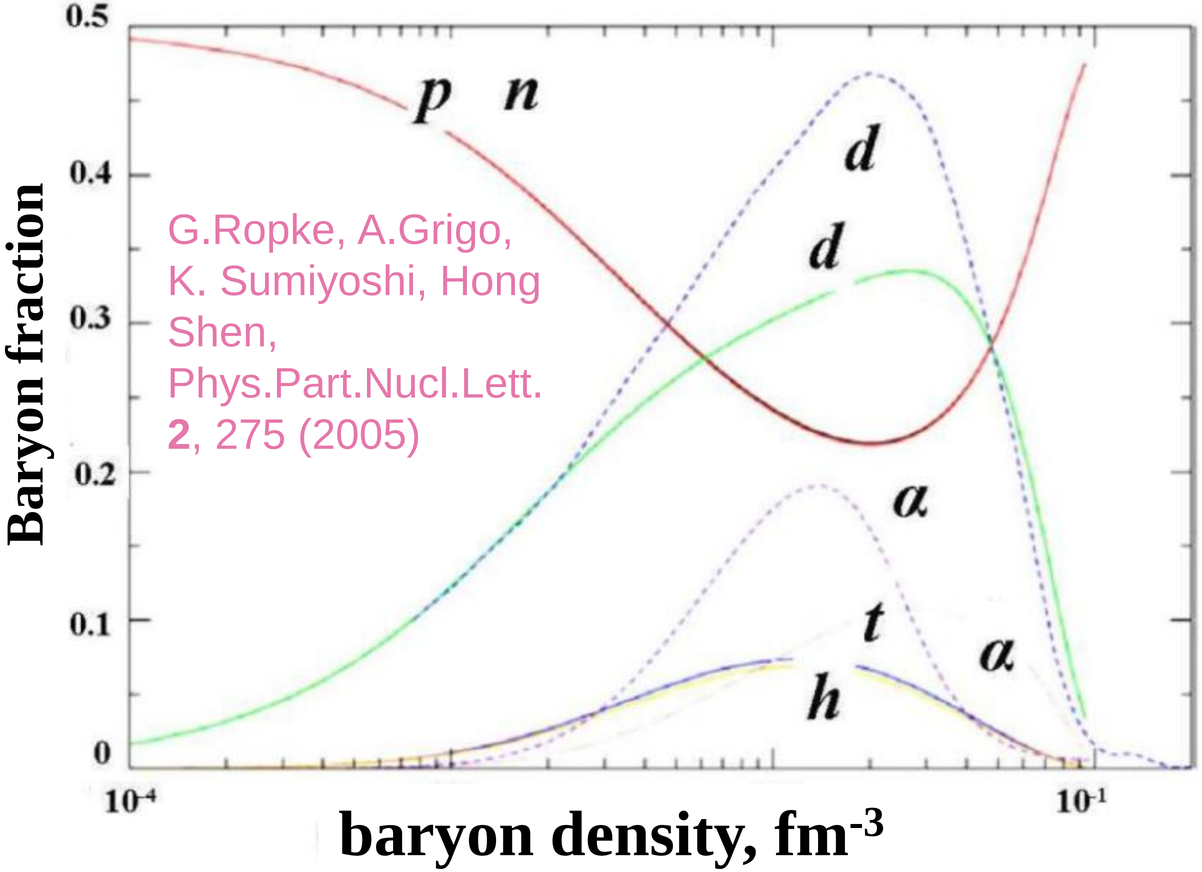
Alpha particle multiplicity in events with identified ^{8}Be and HS decays in Kr fragmentation

$n\alpha$	4	5	6	7	8	9-13
$N_{n\alpha}$	40(69)*	50(54)	21(27)	10(19)	15(12)	7(3)
$N_{n\alpha}/N_{ev}$,%	7.9 ± 1.0	6.2 ± 0.9	3.1 ± 0.6	2.2 ± 0.5	1.4 ± 0.4	0.4 ± 0.2
$N_{n\alpha}(\geq 1^{8}\mathrm{Be})$	5(15)	16(10)	12(13)	4(10)	11(8)	4(3)
$N_{n\alpha}(\geq 1^{8}\mathrm{Be})/N_{n\alpha}$, %	19 ± 5	25 ± 6	52 ± 13	48 ± 16	70 ± 21	70 ± 35
$N_{n\alpha}(2^{8}\mathrm{Be})$	0	2	2	1	5	2
N_{HS}	1	2	1	1	2	2

* Data from the EMU01 collaboration are shown in parentheses


124Xe (NICA) @ 3.85 GeV/n


Distribution of 14N projectile nucleus fragments based on measured values of pβc for the 14N → 3He + H channel
$p\beta c = \frac{Z_f K t^{3/2}}{573\overline{D}}$
counts
pβc, GeV
1H
2H
3He
3H
4He
6He
0
2
4
6
8
10
12
14
16


Baryon fraction
baryon density, fm-3
G.Ropke, A.Grigo, K. Sumiyoshi, Hong Shen, Phys.Part.Nucl.Lett. 2, 275 (2005)
p
n
d
d
α
t
α
h
0.5
0.4
0.3
0.2
0.1
0
10-4
10-1

Conclusion

- Analysis of multiple fragmentation of the krypton nucleus at the energy of 950 MeV/n is carried out using the NTE method.
- Using the existing statistics with the production of (3-10) alpha particles per event, the decays of unstable nuclear states ^{8}Be and HS were reconstructed. The presented data are the first contribution to the targeted search for 4αBEC states.
- The relative contributions of unstable nuclear states from the multiplicity of alpha particles in the final state are analyzed.
- There is enough NTE layers, the transverse scanning of which makes it possible to increase the statistics of krypton interactions by at least 3 times from the existing one.
- Recently unique material has been obtained for studying of multiple states of α-particles and nucleons in Xe nucleus interactions with NTE at the energy of 3.85 GeV/n.

Thank you for your attention!

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