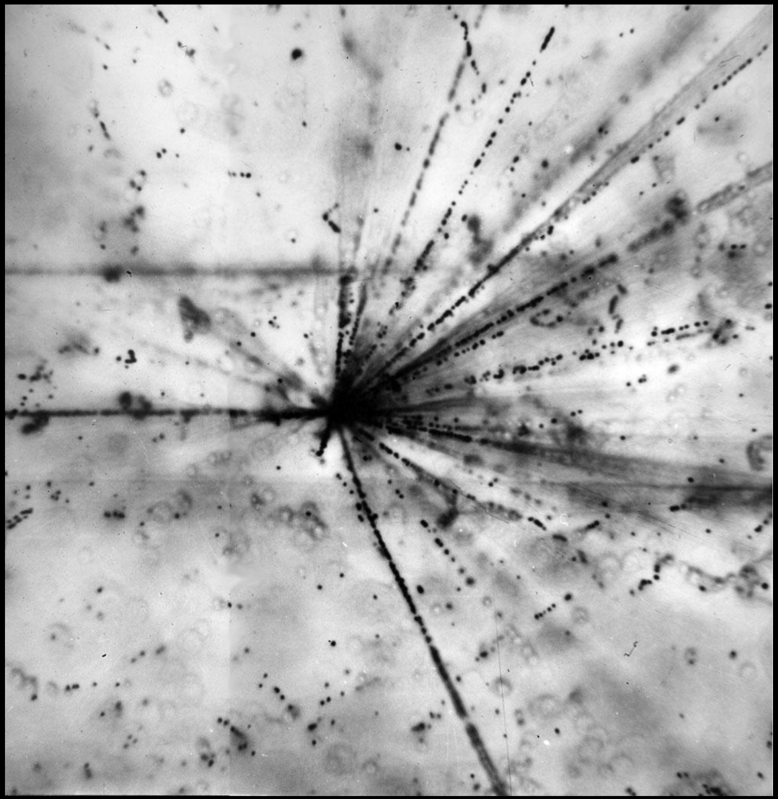
Pavel Zarubin "Highlights of Unstable States in Relativistic Dissociation of Light Nuclei"



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Joint Institute for Nuclear Research, Dubna

International Journal of Modern Physics E | Vol. 33, No. 12, 2441015 (2024)

| Nucleus-2024: Fundament...

Free Access

Highlights of unstable states in relativistic dissociation of light nuclei in nuclear emulsion

D. A. Artemenkov, N. K. Kornegrutsa, N. G. Peresadko, V. V. Rusakova, A. A. Zaitsev,

P. I. Zarubin, and I. G. Zarubina

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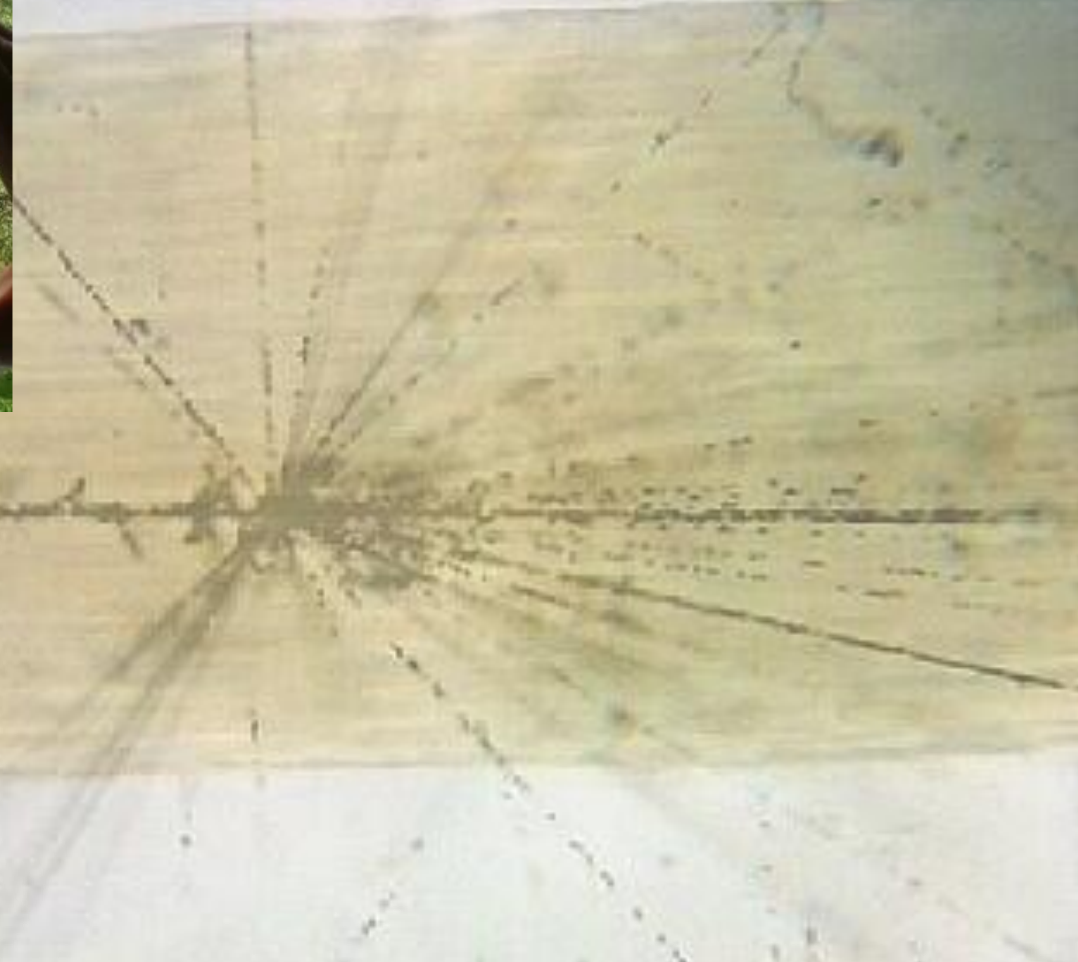
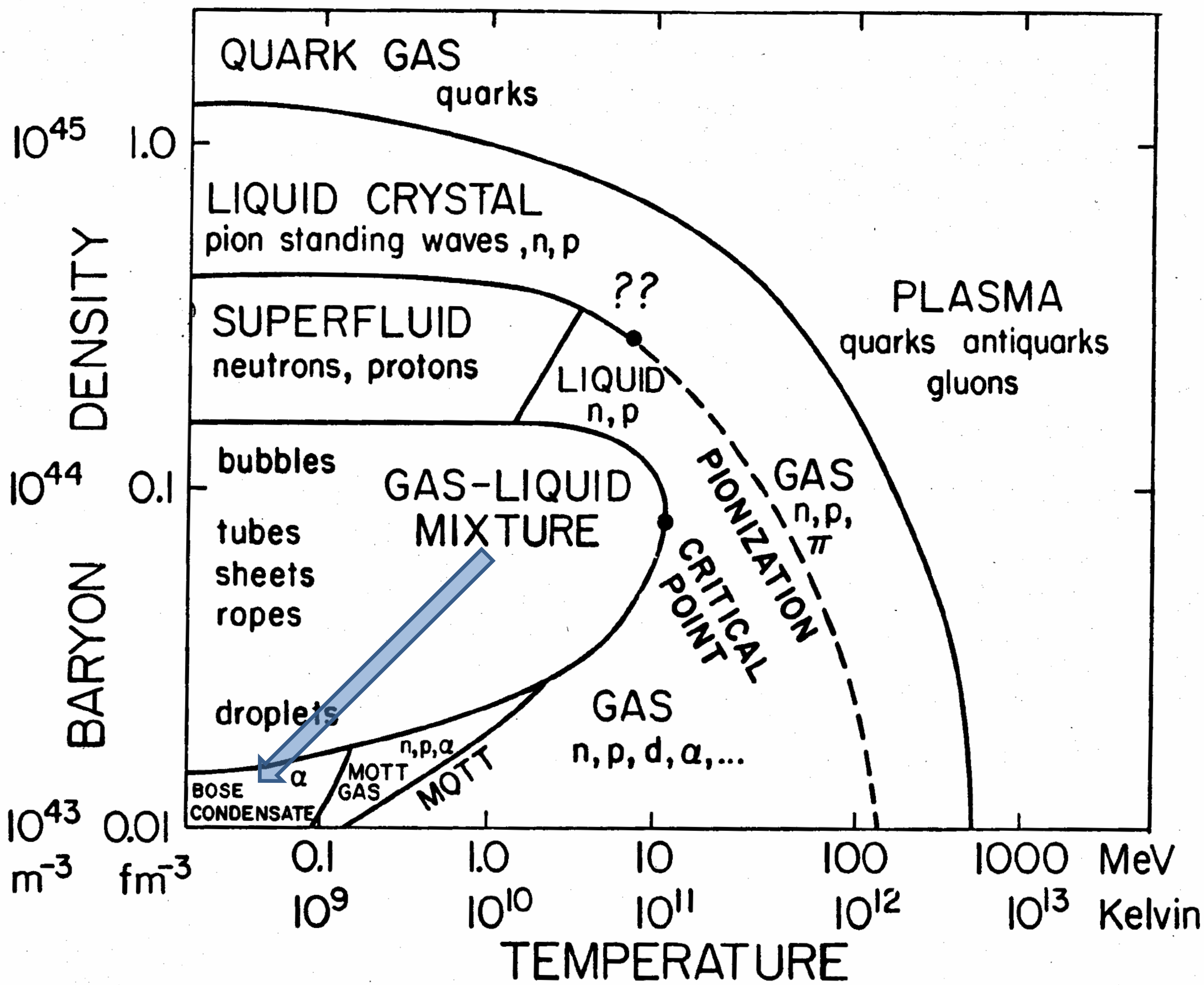


Hair - 60 μm

AgBr Crystal - 0.2 μm

Atom - 10^{-4} μm

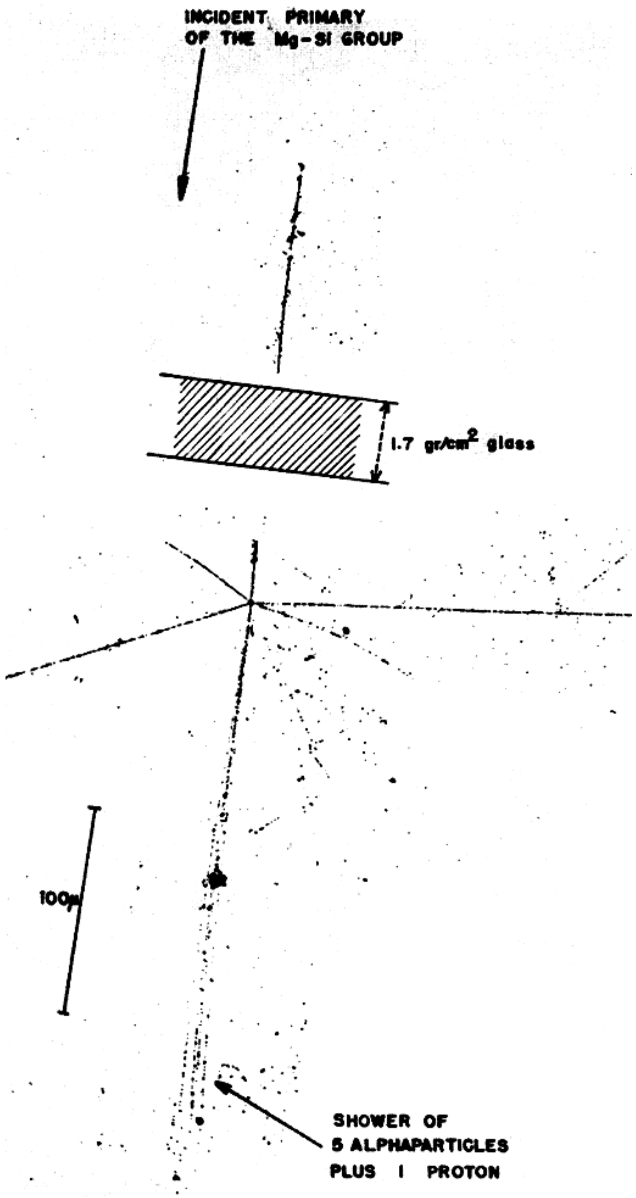
Proton - 10^{-9} μm


QUARK GAS
quarks
LIQUID CRYSTAL
pion standing waves ,n, p
SUPERFLUID
neutrons, protons
??
LIQUID
n, p
PLASMA
quarks antiquarks
gluons
bubbles
GAS-LIQUID
MIXTURE
tubes
sheets
ropes
droplets
PIONIZATION
CRITICAL
POINT
GAS
n, p,
π
GAS
n, p, d, α, ...
α
BOSE
CONDENSATE
MOTT
GAS
n,p,α
MOTT
10^{45}
1.0
10^{44}
0.1
10^{43}
0.01
m^{-3}
fm^{-3}
BARYON DENSITY
0.1
1.0
10
100
1000
MeV
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
Kelvin
TEMPERATURE

PHYSICAL REVIEW VOLUME 77, NUMBER 1

The Heavy Nuclei of the Primary Cosmic Radiation

H. L. Bradt and B. Peters
University of Rochester, Rochester, New York
(Received September 9, 1949)



The Study of Elementary Particles by the Photographic Method

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

BY
C. F. POWELL
P. H. FOWLER and D. H. PERKINS
H. H. WILLS PHYSICAL LABORATORY

PERGAMON PRESS
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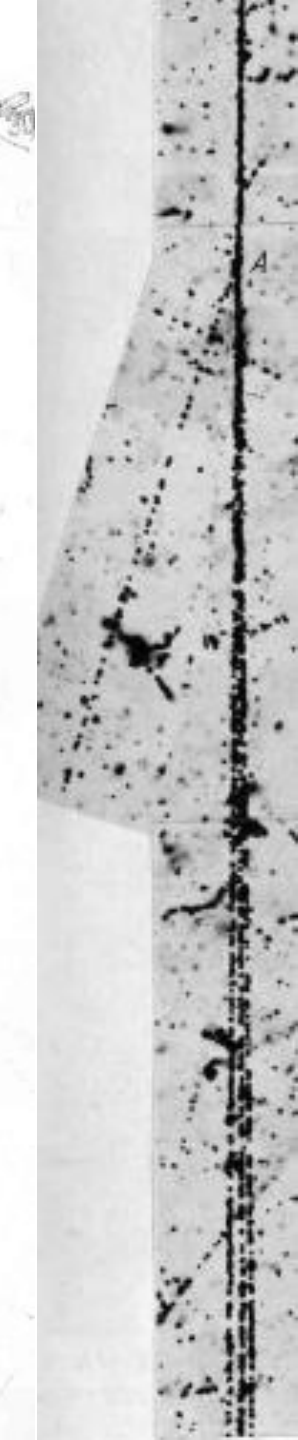
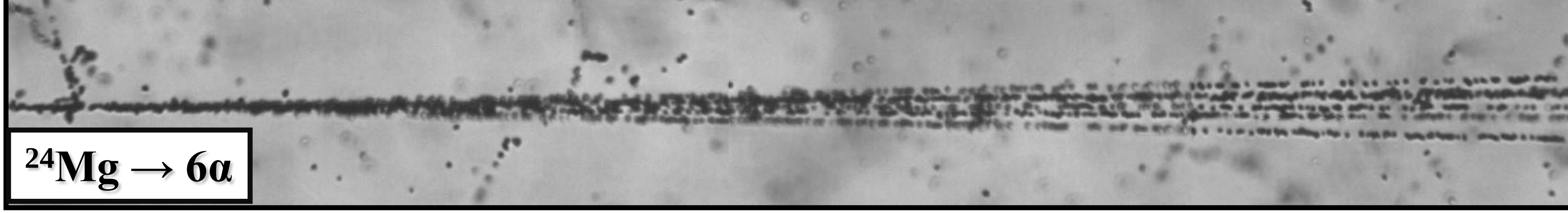
1959

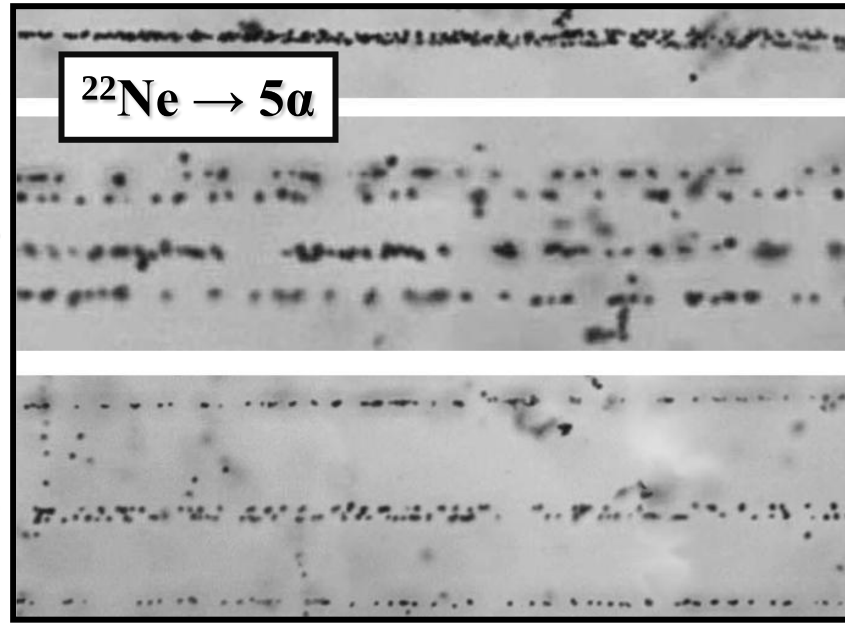


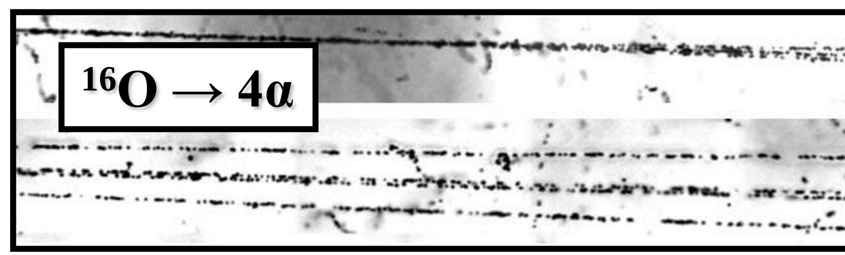


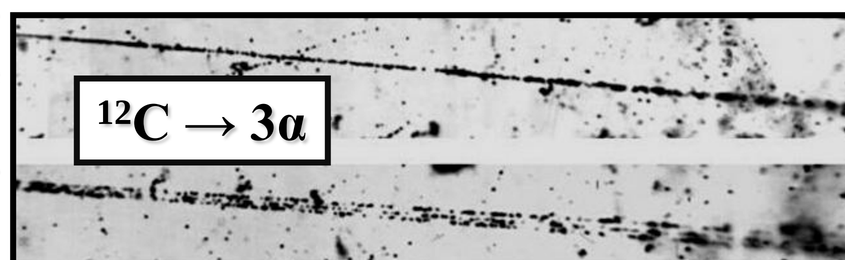
The fragmentation of relativistic nuclei observed in its entirety only in nuclear emulsion (NTE) serves as a source of ensembles of the lightest nuclei of interest to modern nuclear physics and nuclear astrophysics. NTE allows one to study such ensembles with record angular resolution and identification He and H isotopes.

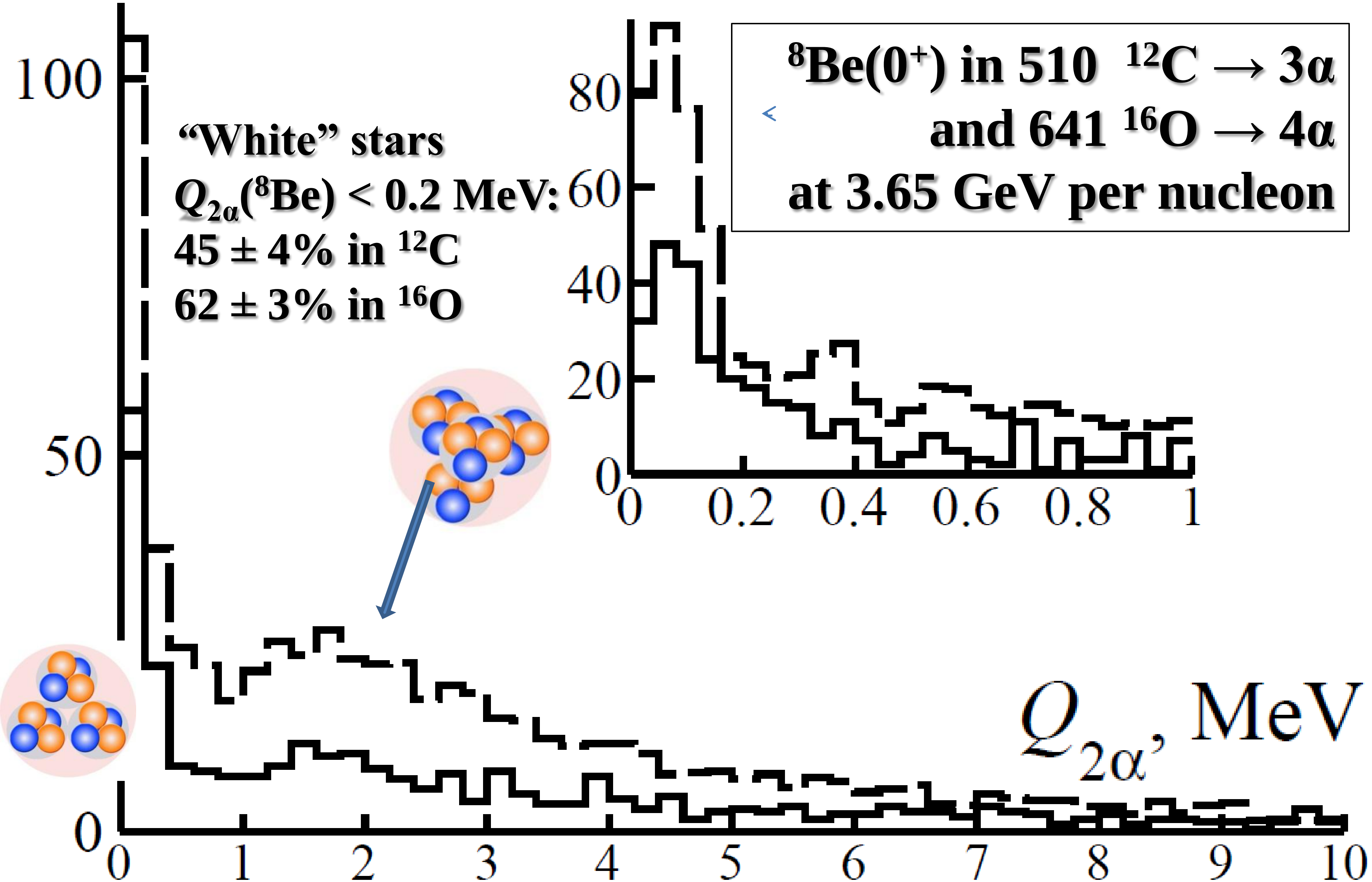
Electronic experiments in this direction run into fundamental difficulties due to the quadratic dependence of ionization on the charges of the nuclei, extremely small angular divergence of relativistic fragments, and, often, an approximate coincidence in magnetic rigidity with the beam nuclei. Therefore, the NTE method retains its uniqueness in the relativistic fragmentation cone.

The intense "tracks" in the photos splits into the He track pairs with the opening angles of about $2 \cdot 10^{-3}$ rad corresponding to decays of the unstable ^{8}Be nucleus. Their observation testify to the completeness of observations across the spectrum of cluster excitations.

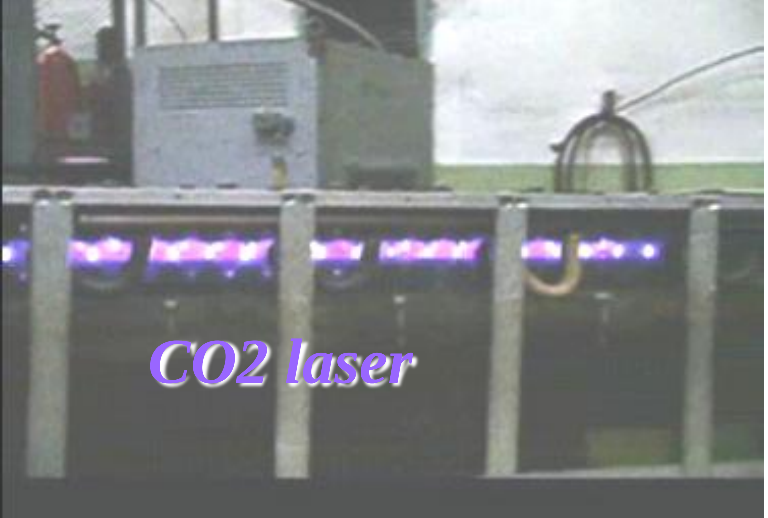


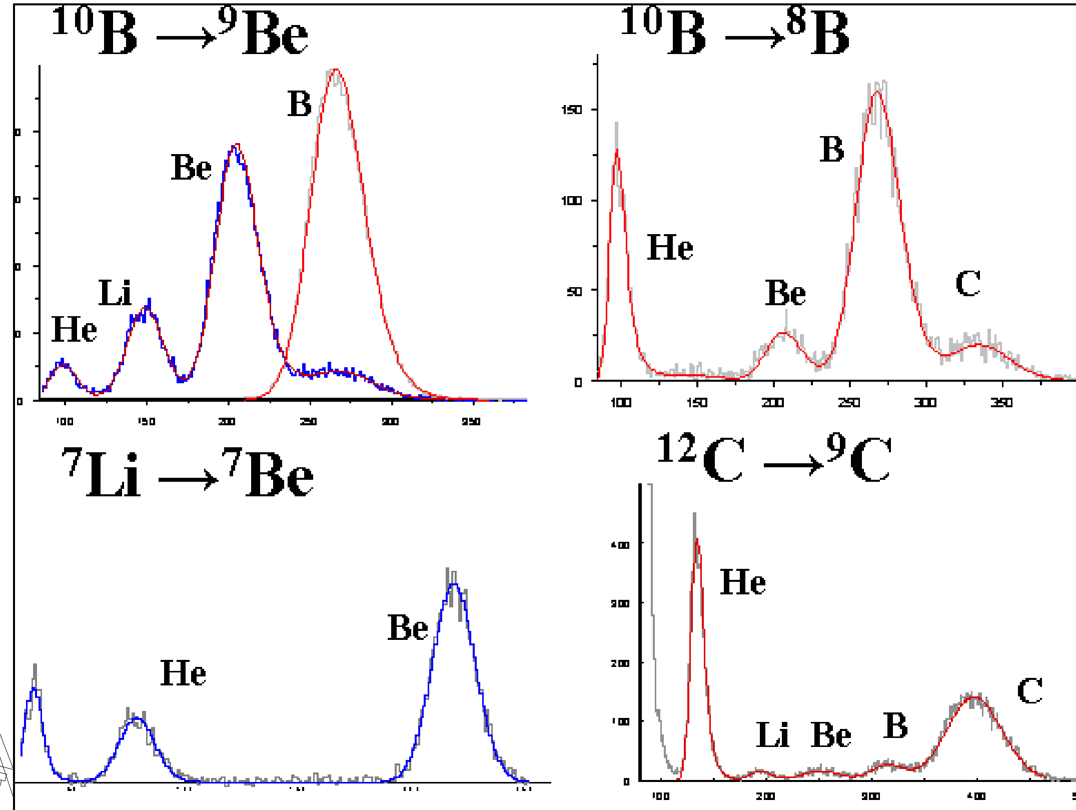


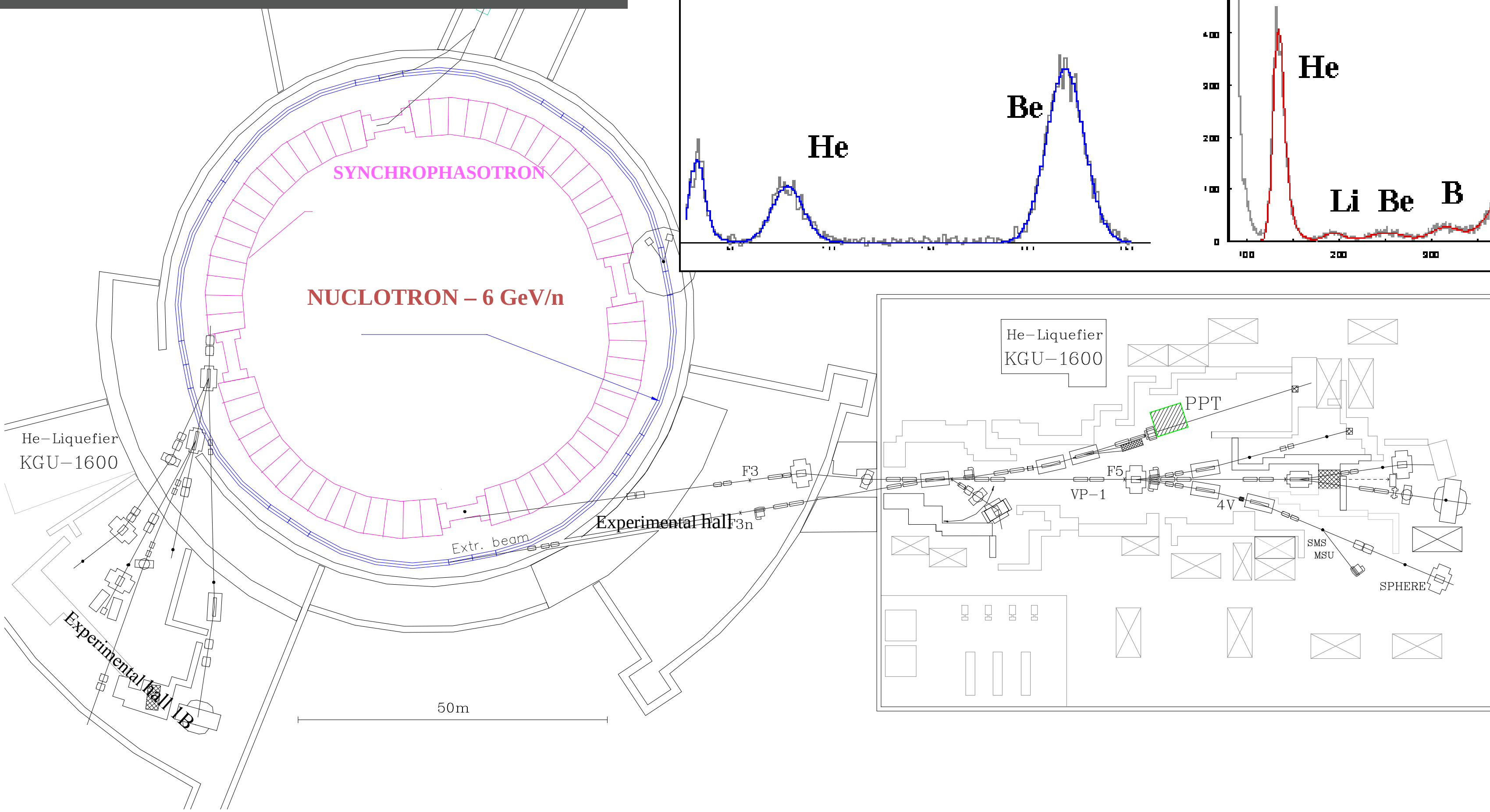


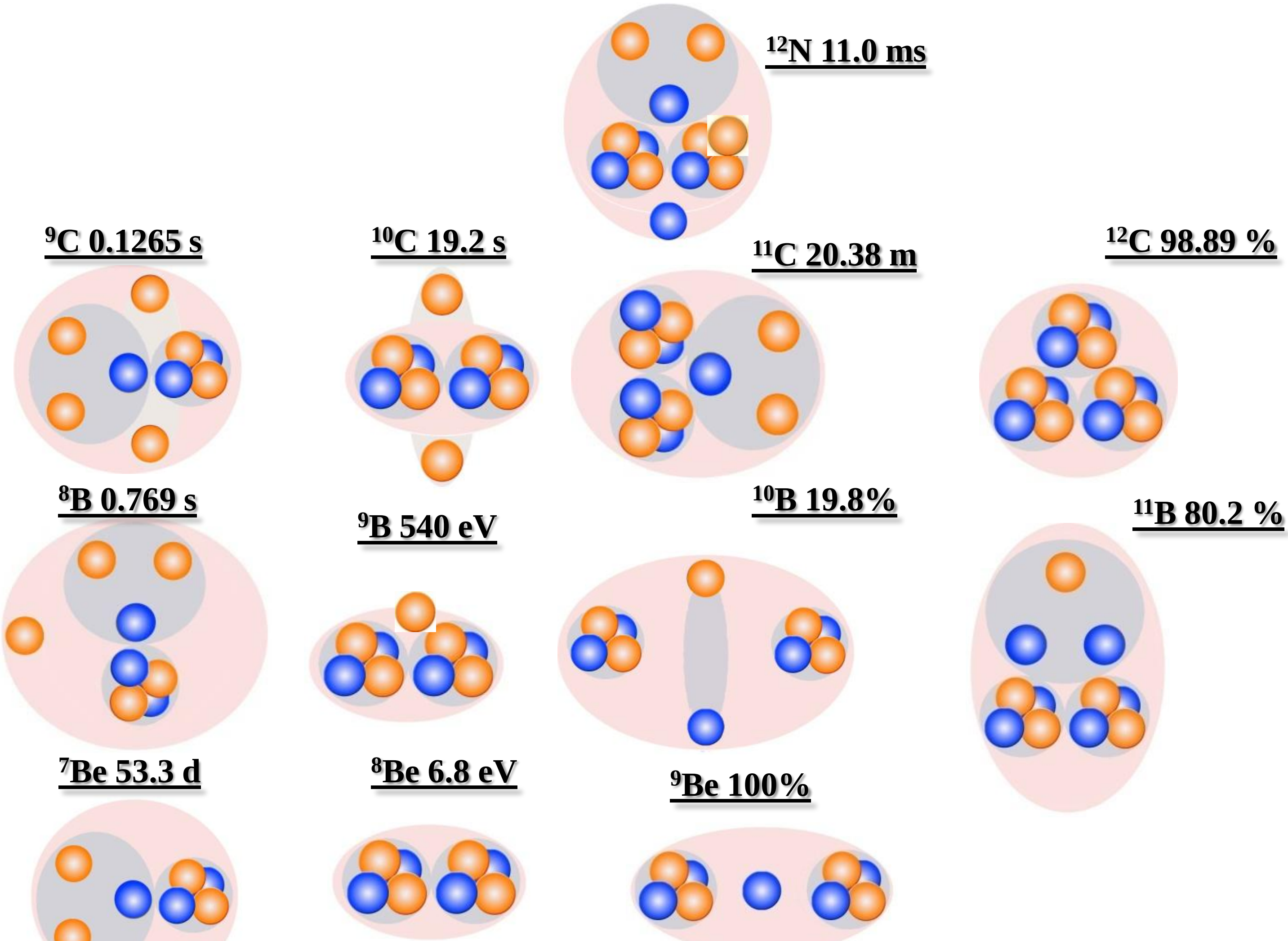


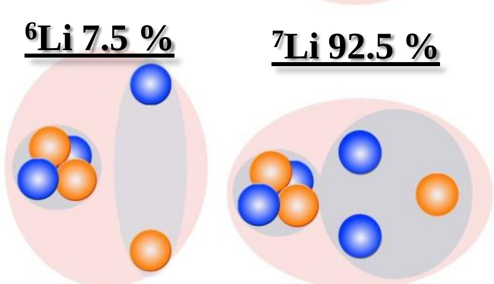
$Q = M^* - M$. M^* is defined by the sum of all products of *4*-momenta $M^{*2} = \sum(P_i \cdot P_k)$.


CO2 laser


$^{10}B \rightarrow {}^{9}Be$
He
Li
Be
B
$^{10}B \rightarrow {}^{8}B$
He
Be
B
C
$^{7}Li \rightarrow {}^{7}Be$
He
Be
$^{12}C \rightarrow {}^{9}C$
He
Li
Be
B
C

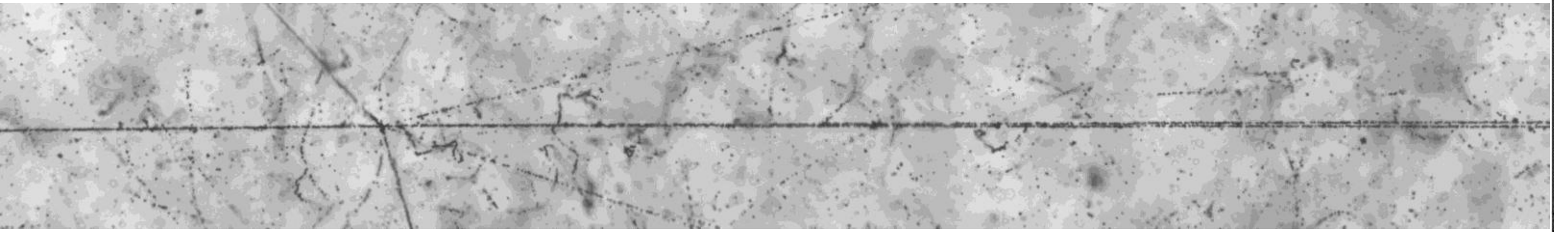

SYNCHROPHASOTRON
NUCLOTRON – 6 GeV/n
He–Liquefier
KGU–1600
Extr. beam
Experimental hall
F3
F3n
Experimental hall 1B
50m
He–Liquefier
KGU–1600
PPT
F5
VP–1
4V
SMS
MSU
SPHERE

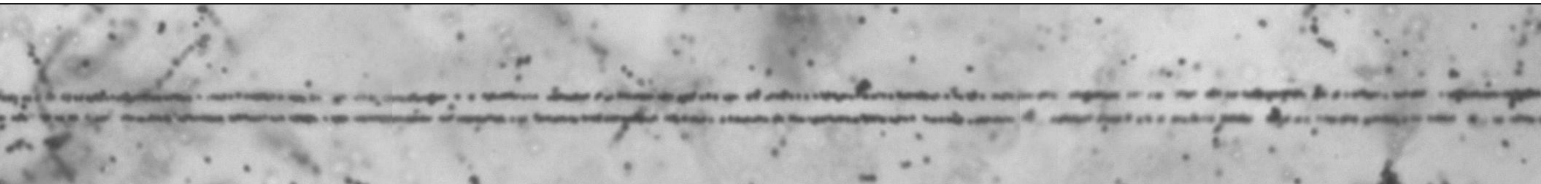


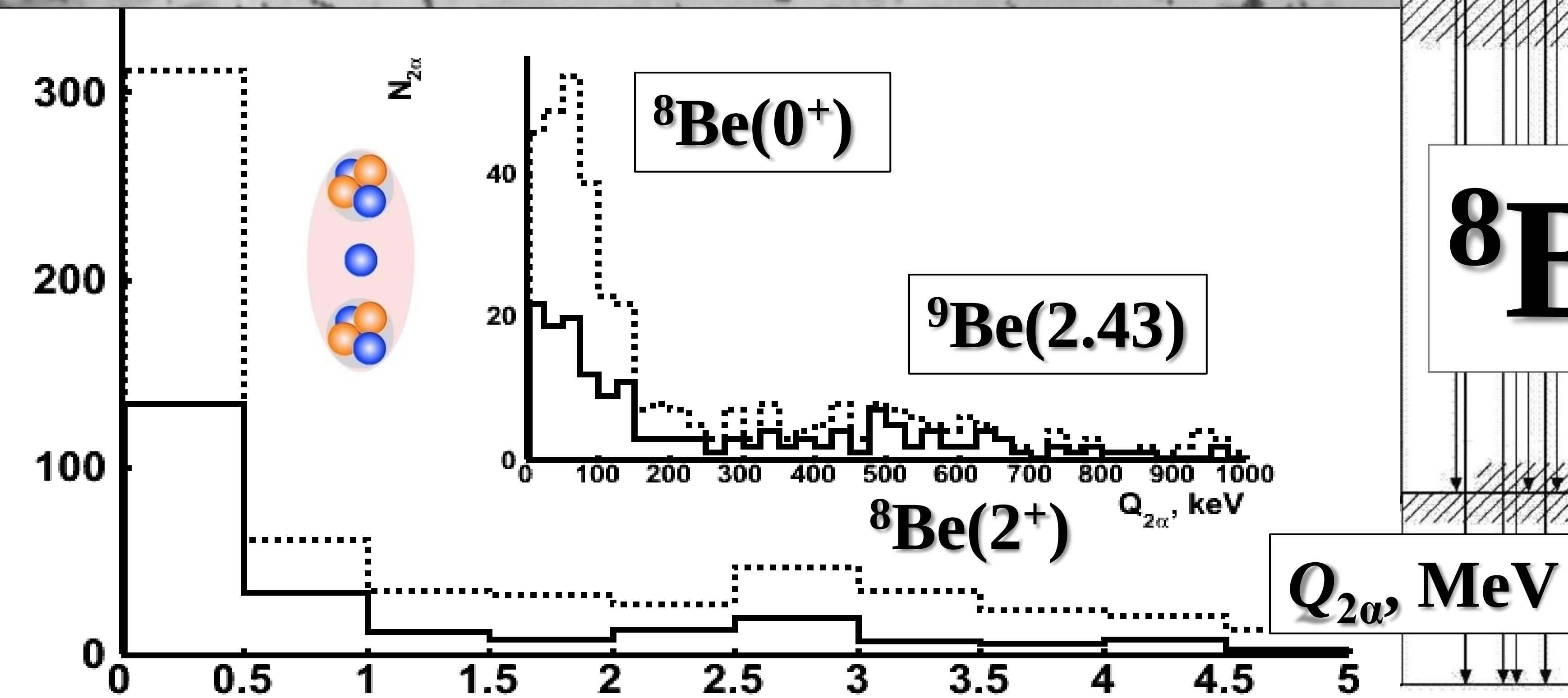


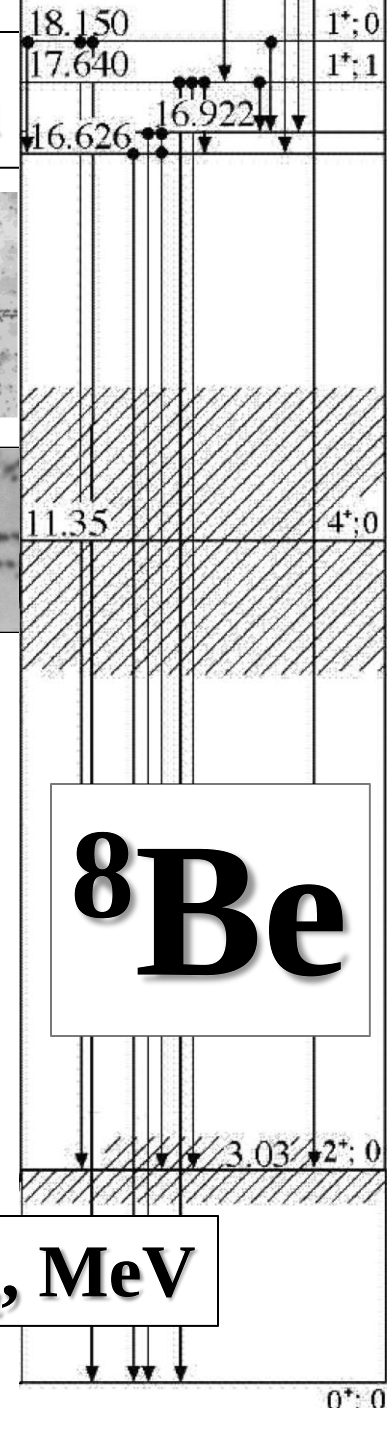
Since 2000s nuclear track emulsion is used to study clustering of light stable and radioactive nuclei in the relativistic approach in the BECQUEREL experiment at the JINR Nuclotron. The features of the nuclei ^{7,9}Be, ^{8,10,11}B, ^{10,11}C, ^{12,14}N appeared in the probabilities of their dissociation channels. In dissociation of isotopes ^{10}B, ^{10}C, and ^{11}C, decays ^{9}B → ^{8}Be are identified

712 ^{9}Be → 2α at 1.2 GeV per nucleon

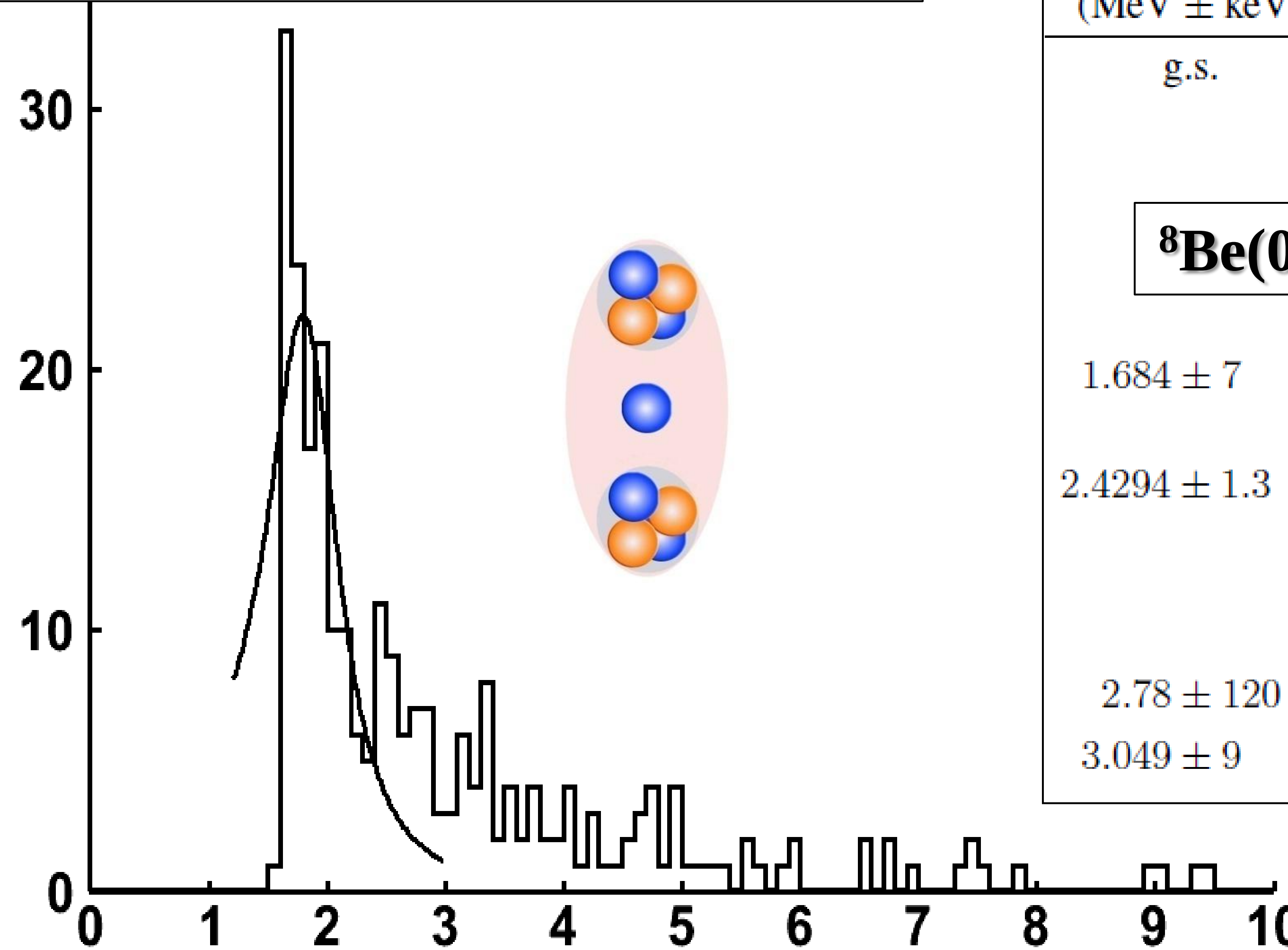








$^9Be^*(1.684)$ in $^9Be \to 2\alpha$



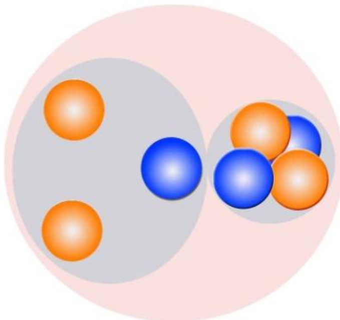
$Q_{2\alpha n}$, MeV

E_x (MeV ± keV)	$J^\pi; T$	Γ_{cm} (keV)
g.s.	$\frac{3}{2}^-; \frac{1}{2}$	
1.684 ± 7	$\frac{1}{2}^+$	217 ± 10
2.4294 ± 1.3	$\frac{5}{2}^-$	0.78 ± 0.13
2.78 ± 120	$\frac{1}{2}^-$	1080 ± 110
3.049 ± 9	$\frac{5}{2}^+$	282 ± 11

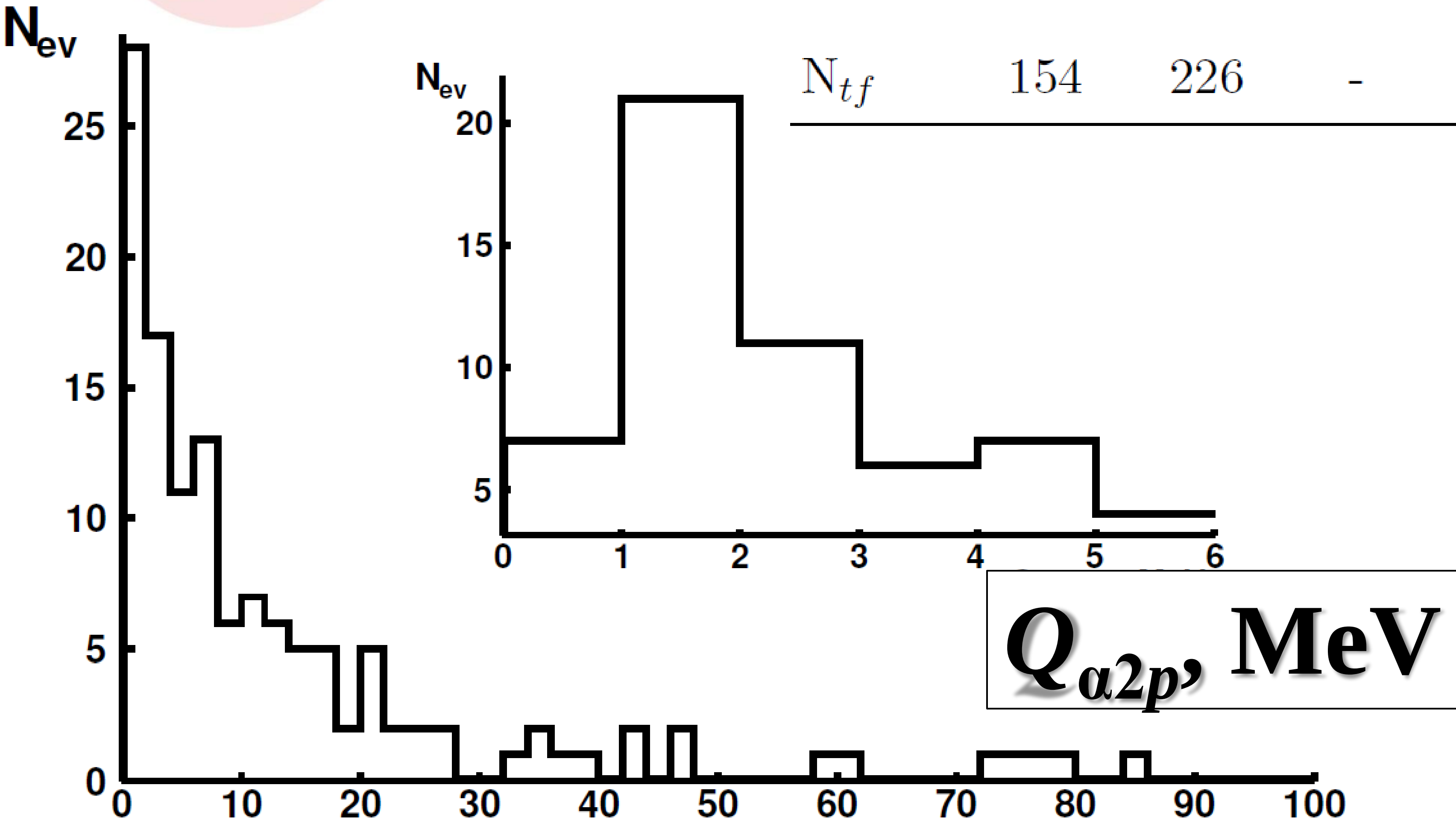
$^8Be(0^+)n$ 1.665 MeV

$\langle P_{T2\alpha}\rangle$ in $^9Be \to 2\alpha$ is about 10 MeV/c per nucleon is several times less than the Fermi momentum (100-200 MeV/c). P_{Tn} carried away by neutrons can be estimated and, then, $Q_{2\alpha n}$. The resonance 1.80 ± 0.01 MeV consistent with $^9Be^*(1.684)$. contributing 33 ± 4% to $^9Be \to {}^8Be(0^+)$. $^9Be(2.43)$ is than 4% of $^9Be \to 2\alpha$.

^{6}Be(1.37) in ^{7}Be dissociation at 1.2 GeV per nucleon

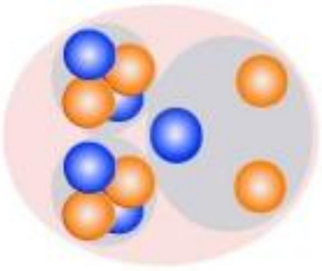


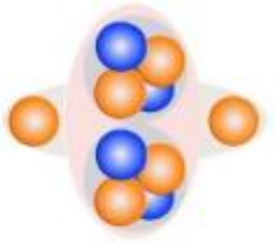
Channel	2He	He + 2H	4H	Li + H
N_{ws}	115	157	14	3
N_{tf}	154	226	-	-

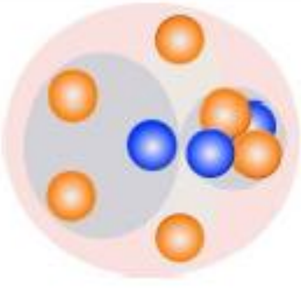


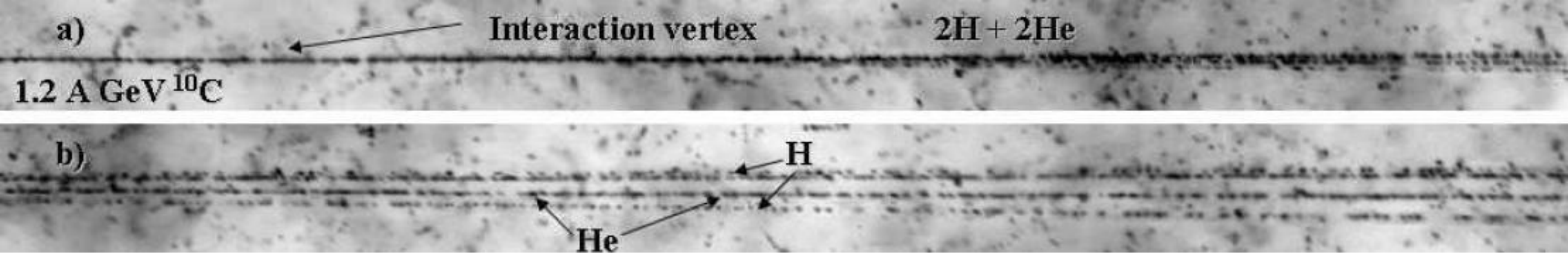
Coherent dissociation (or "white" stars) at 1.2 GeV per nucleon

	^{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	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 %)

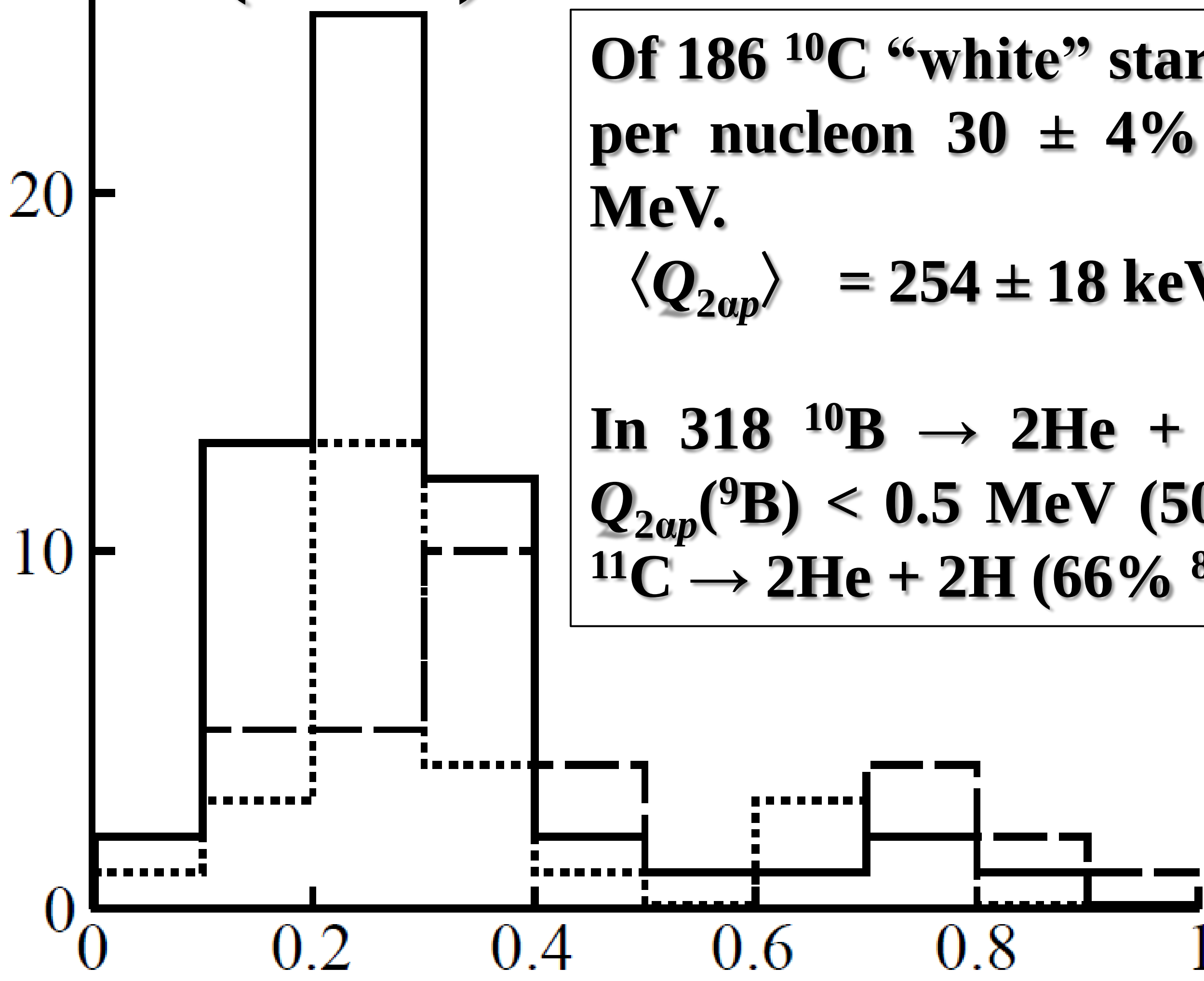








^{9}B(0.185) in dissocaition of ^{10}C, ^{11}C and ^{10}B



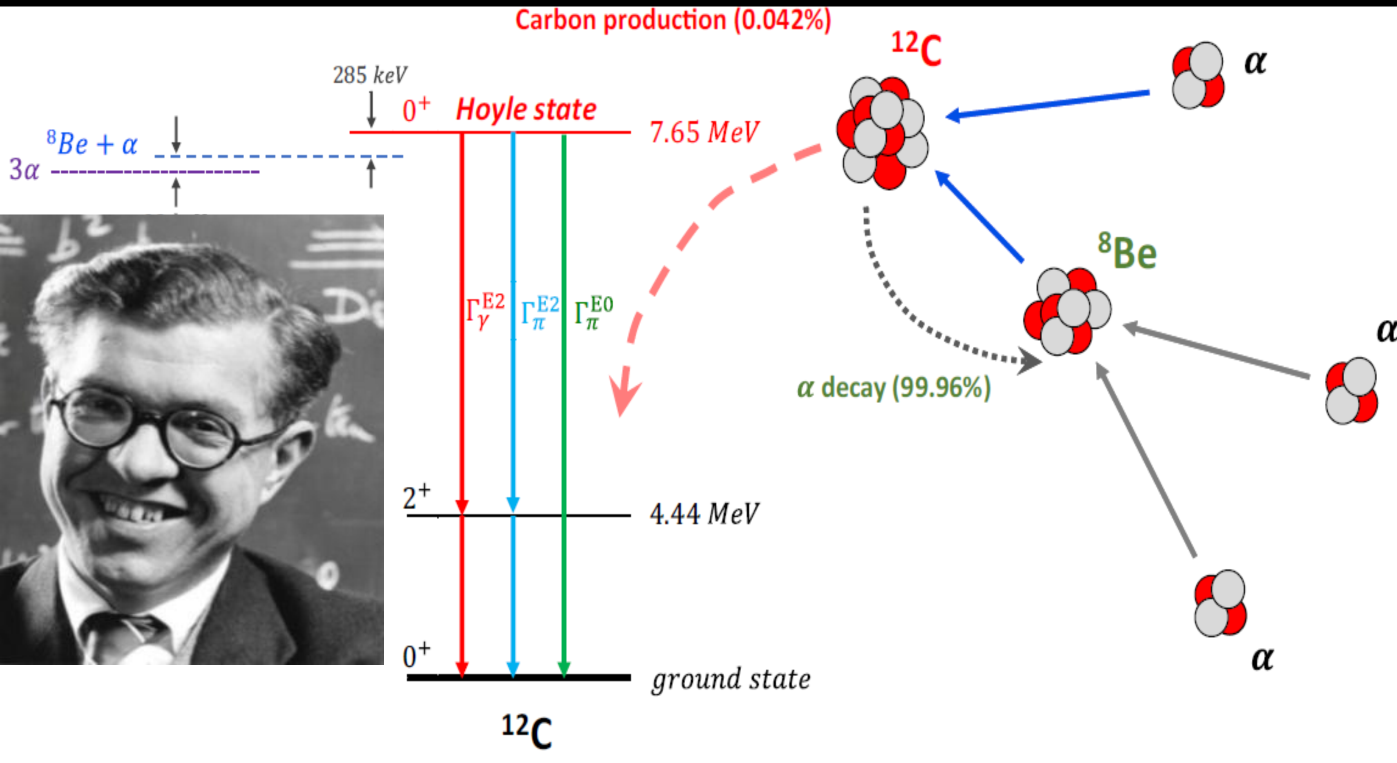
Of 186 ^{10}C "white" stars 2He + 2H. at 1.0 GeV per nucleon 30 ± 4% satisfy $Q_{2\alpha p}(^{9}B) < 0.5$ MeV.

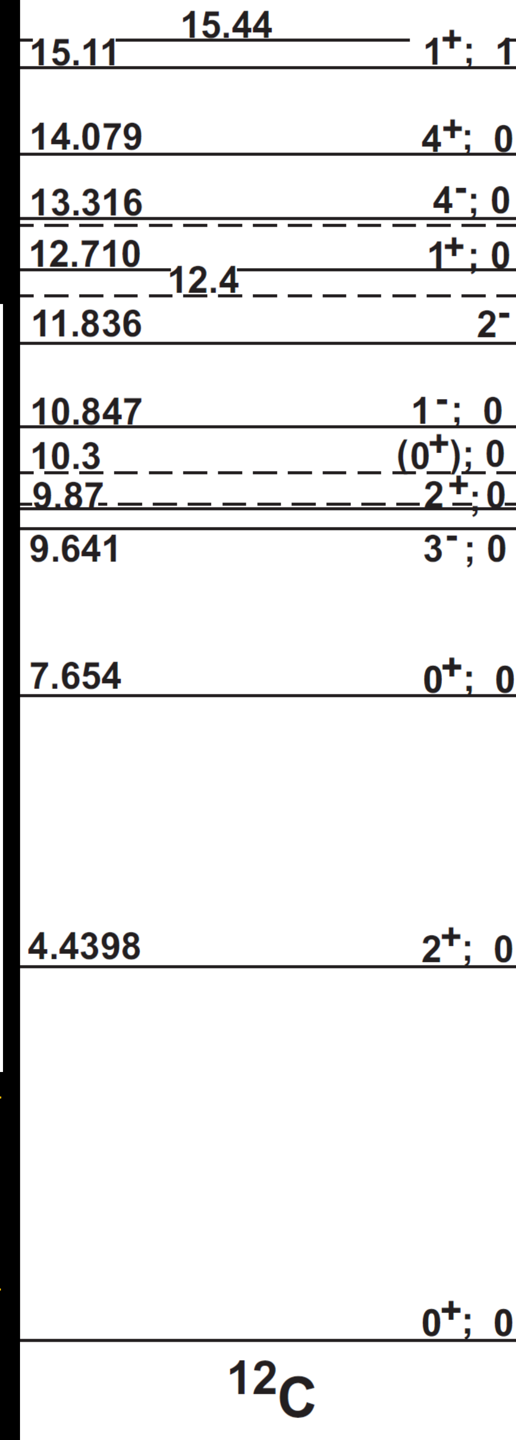
$\langle Q_{2\alpha p} \rangle$ = 254 ± 18 keV RMS 96 keV.

In 318 ^{10}B → 2He + H stars, 20 decays of $Q_{2\alpha p}(^{9}B) < 0.5$ MeV (50% ^{8}Be) and 22 in 154 ^{11}C → 2He + 2H (66% ^{8}Be) were identified.

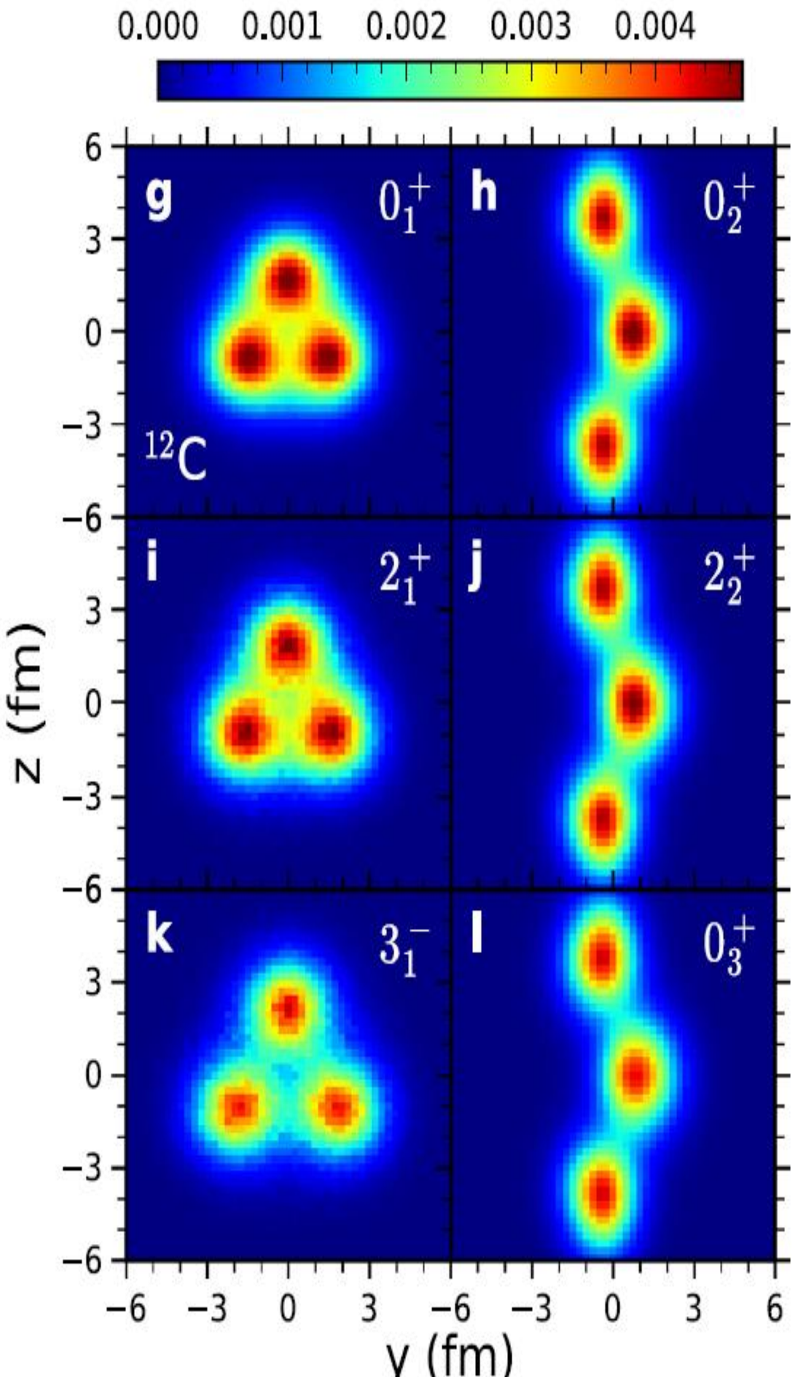
$Q_{2\alpha p}$, MeV

The Hoyle state





The Hoyle state is the second excited state $^{12}C(0^+_2)$ at 378 keV above the 3α threshold. The $^{8}Be(0^+)$ inevitably appears in ^{9}B and Hoyle state decays. The isolated position of $^{12}C(0^+_2)$ at the beginning of the excitation spectrum and the width of 9.3 eV indicate it as a 3α analogue $^{8}Be(0^+)$.



nature communications

Article

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Emergent geometry and duality in the carbon nucleus

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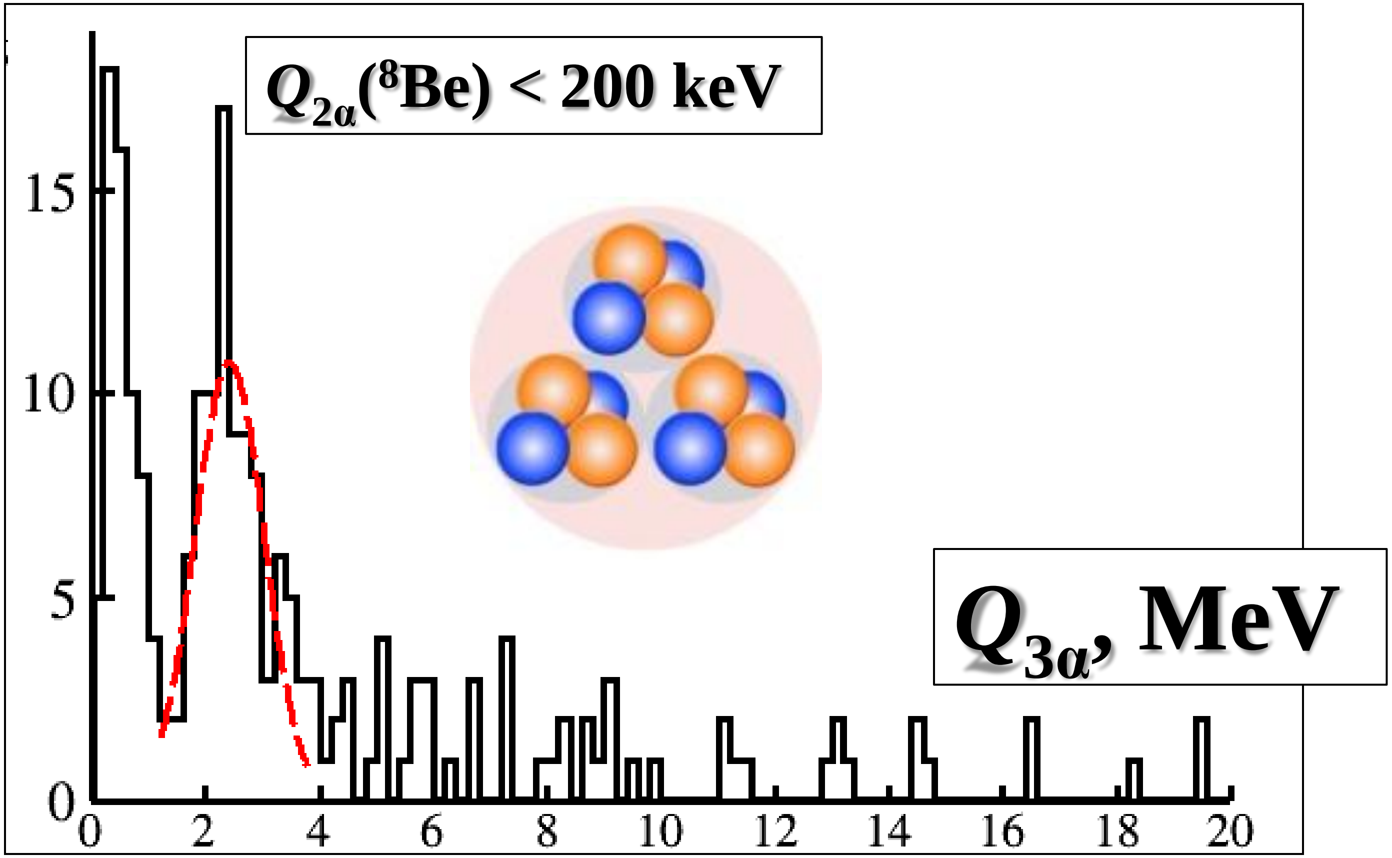
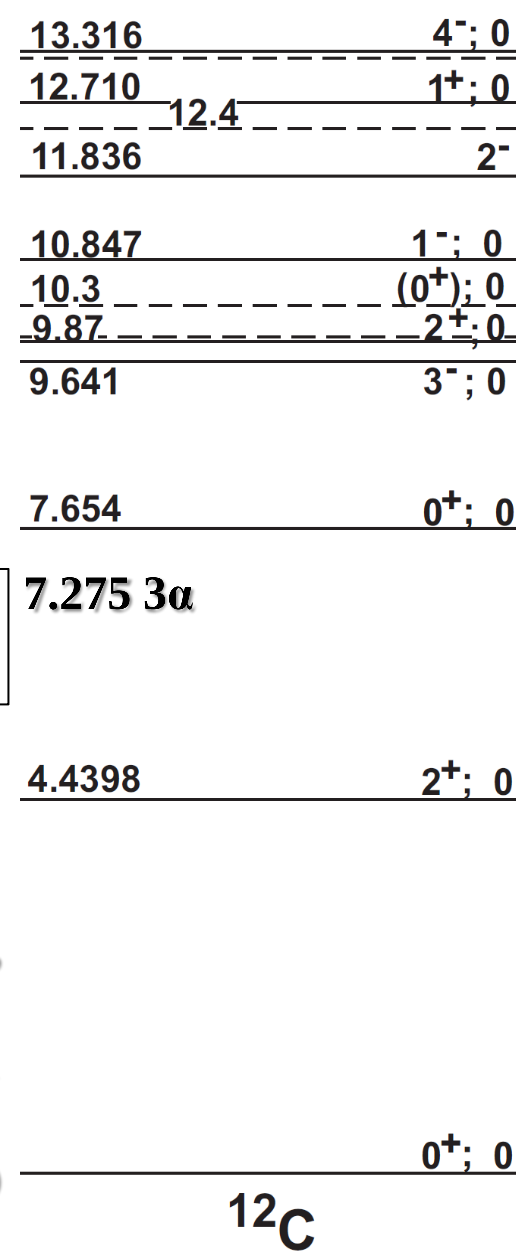
Shihang Shen[1], Serdar Elhatisari[2,3], Timo A. Lähde[1,4], Dean Lee[5], Bing-Nan Lu[6] & Ulf-G. Meißner[1,2,4,7]

The carbon atom provides the backbone for the complex organic chemistry composing the building blocks of life. The physics of the carbon nucleus in its predominant isotope, ^{12}C, is similarly full of multifaceted complexity. Here we provide a model-independent density map of the geometry of the nuclear states of ^{12}C using the ab initio framework of nuclear lattice effective field theory. We find that the well-known but enigmatic Hoyle state is composed of a "bent-arm" or obtuse triangular arrangement of alpha clusters. We identify all of the low-lying nuclear states of ^{12}C as having an intrinsic shape composed of three alpha clusters forming either an equilateral triangle or an obtuse triangle. The states with the equilateral triangle formation also have a dual description in terms of particle-hole excitations in the mean-field picture.

$^{12}C(0^+_2)$ and $^{12}C\ (3^-)$ in 510 $^{12}C \to 3\alpha$





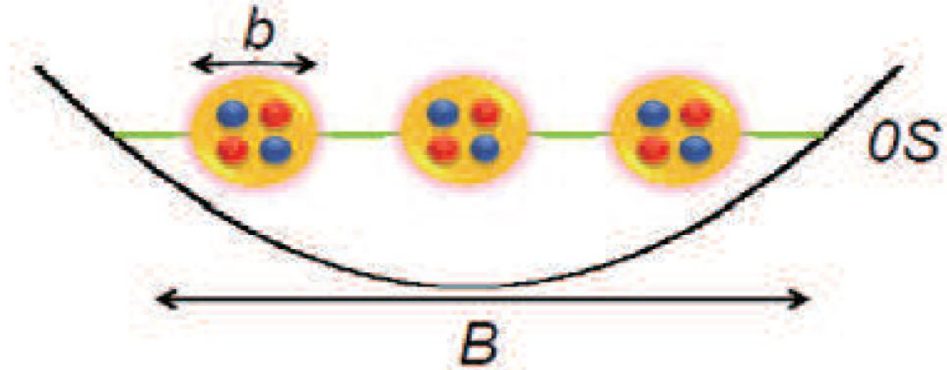
The 1st peak $\langle Q_{3\alpha}\rangle$ (RMS) = 417 ± 27 (165) keV is $^{12}C(0^+_2)$, and the 2nd $\sigma(Q_{3\alpha})$ = 2.4 ± 0.1 MeV – $^{12}C(3^-)$.

The contributions of $^8Be(0^+)$, $^{12}C(0^+_2)$ and $^{12}C(3^-)$ are 43 ± 4, 11 ± 2, 19 ± 2%.

The contribution to $^8Be(0^+)$ of $^{12}C(0^+_2)$ is 26 ± 4%, and $^{12}C(3^-)$ is 44 ± 6% and their ratio is 0.6 ± 0.1.

Alpha-Clusters in Nuclear Systems

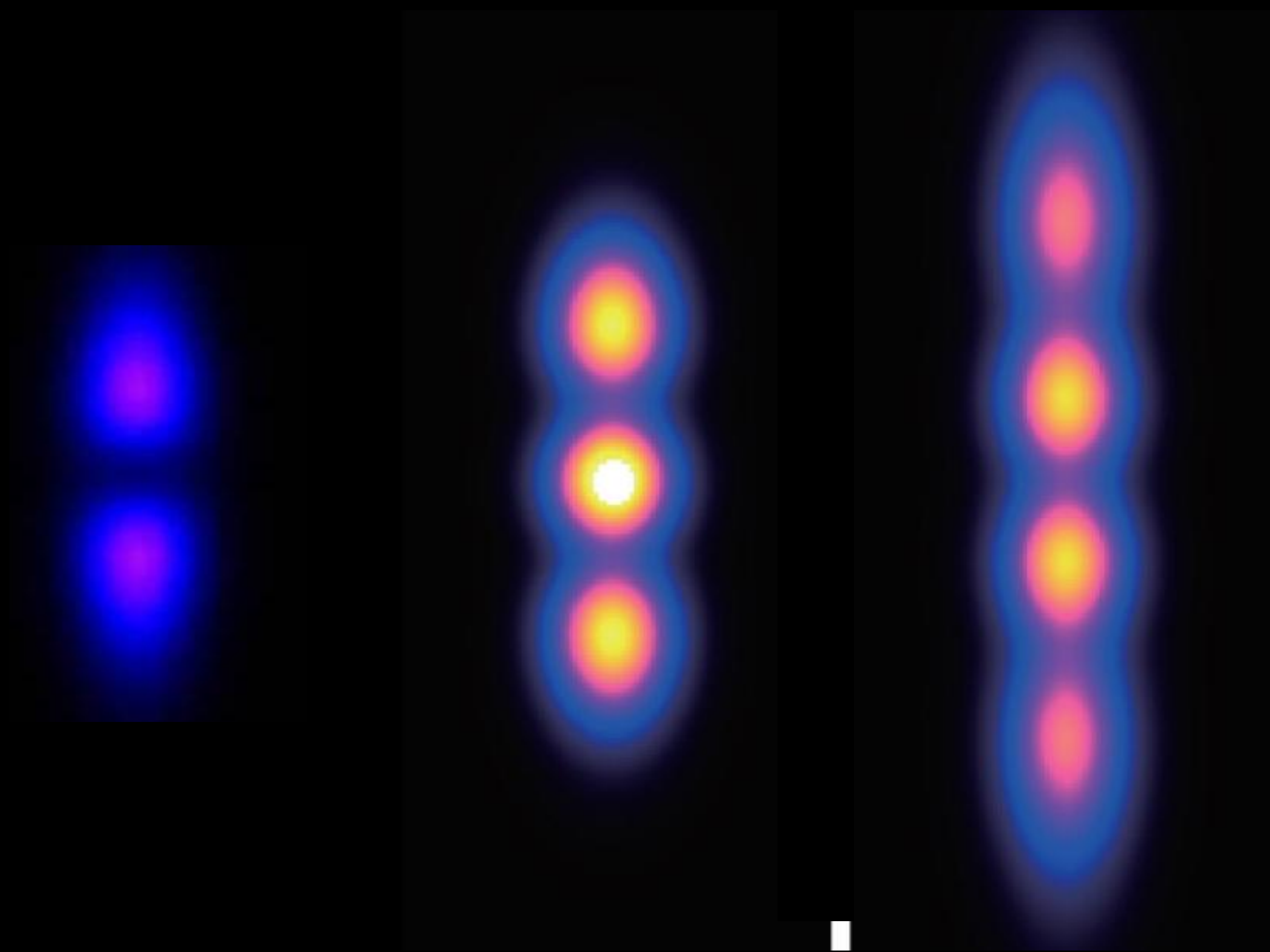
P. Schuck



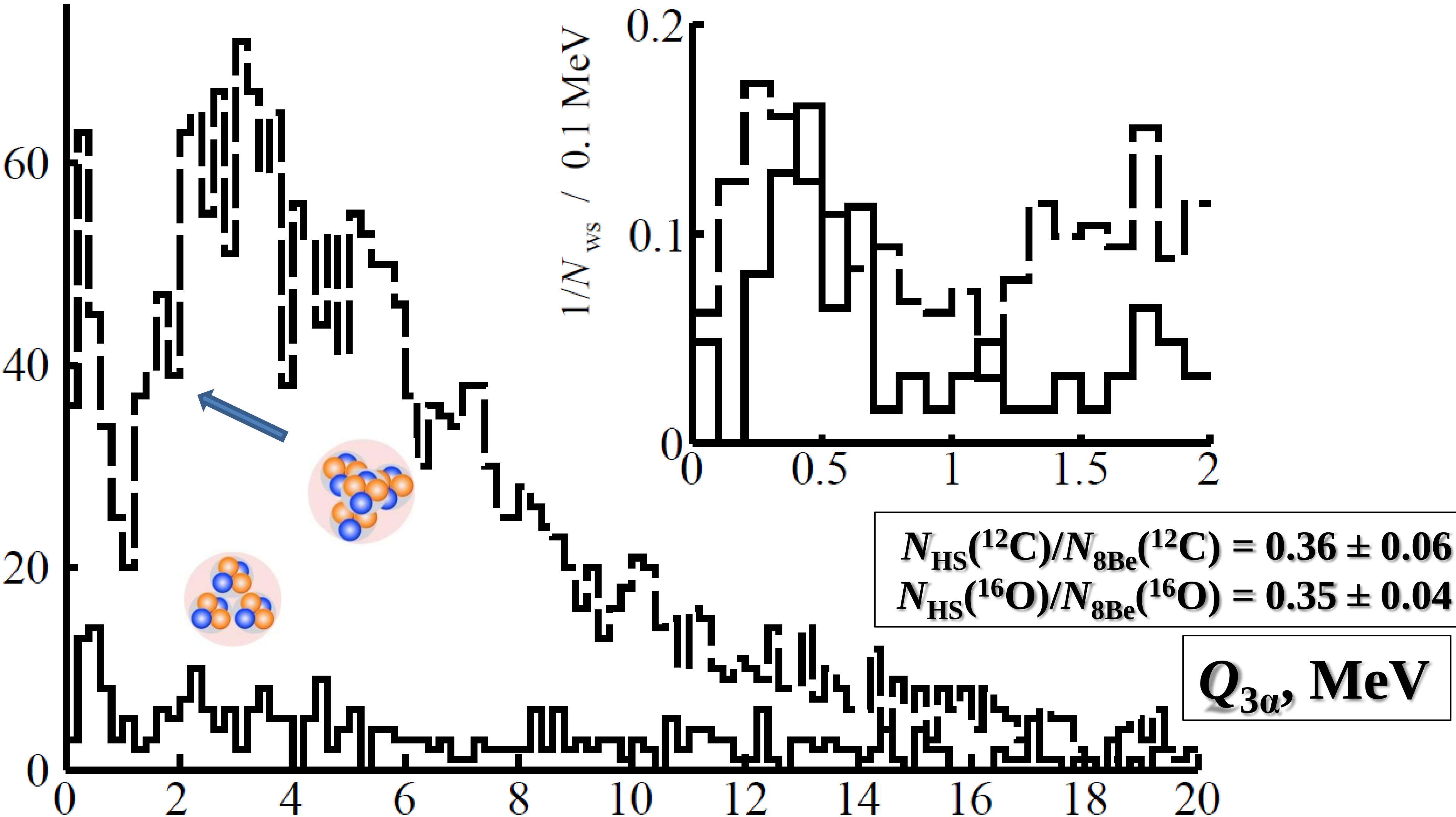
Y. Funaki, H. Horiuchi, G. Röpke,
A. Tohsaki , W. von Oertzen and T. Yamada

A current focus is on the concept of α-particle Bose-Einstein condensate (αBEC) – the S-wave α-particle state right above threshold. ^{8}Be(0^+) is being described as 2αBEC, and the ^{12}C(0^+_2) or Hoyle as 3αBEC. Suggesteded as 4αBEC ^{16}O(0^+_6) at 660 keV can sequentially decay via α^{12}C(0^+_2) or 2^{8}Be(0^+).

$^{8}Be(0^{+})$ $^{12}C(0^{+}_{2})$ $^{16}O(0^{+}_{6})$

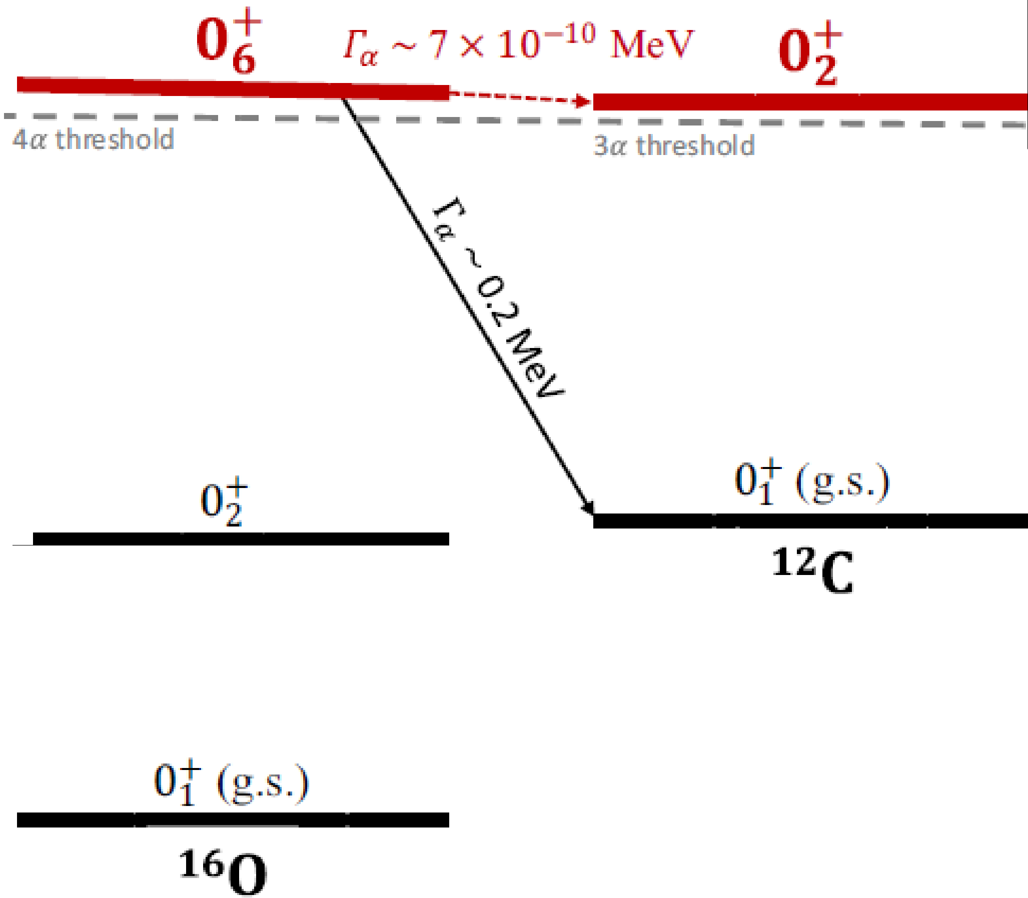


$^{12}C(0^+_2)$ in 641 "white" stars $^{16}O \to 4\alpha$

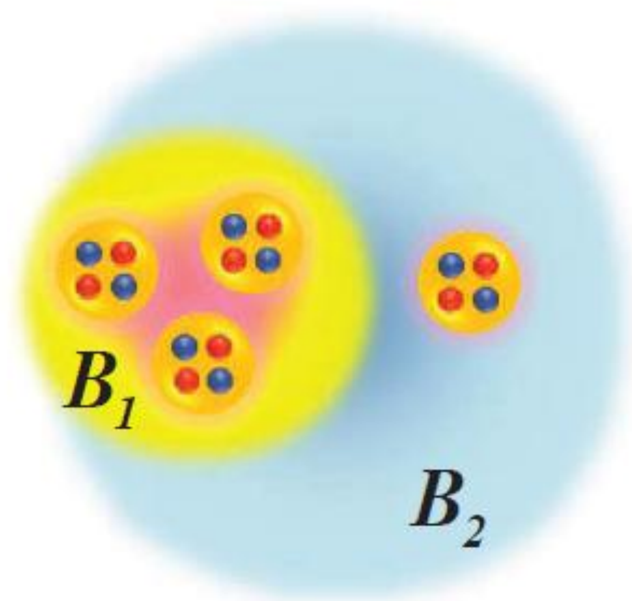


Distribution of the number of 3α-triples $N_{3\alpha}$ over the invariant mass $Q_{3\alpha}$ of 316 "white" stars $^{12}C \to 3\alpha$ (solid) and 641 "white" stars $^{16}O \to 4\alpha$ (dashed) at 3.65 *A* GeV. The α-particle enhancement $^{8}Be(0^+)$ and $^{12}C(0^+_2)$ allows to assume the fusion $2\alpha \to {}^{8}Be(0^+)\alpha \to {}^{12}C(0^+_2)\alpha \to {}^{16}O(0^+_6)$.

15.095 keV   Γ = 165 keV

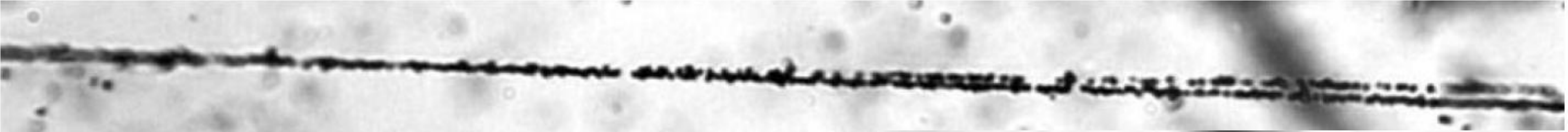


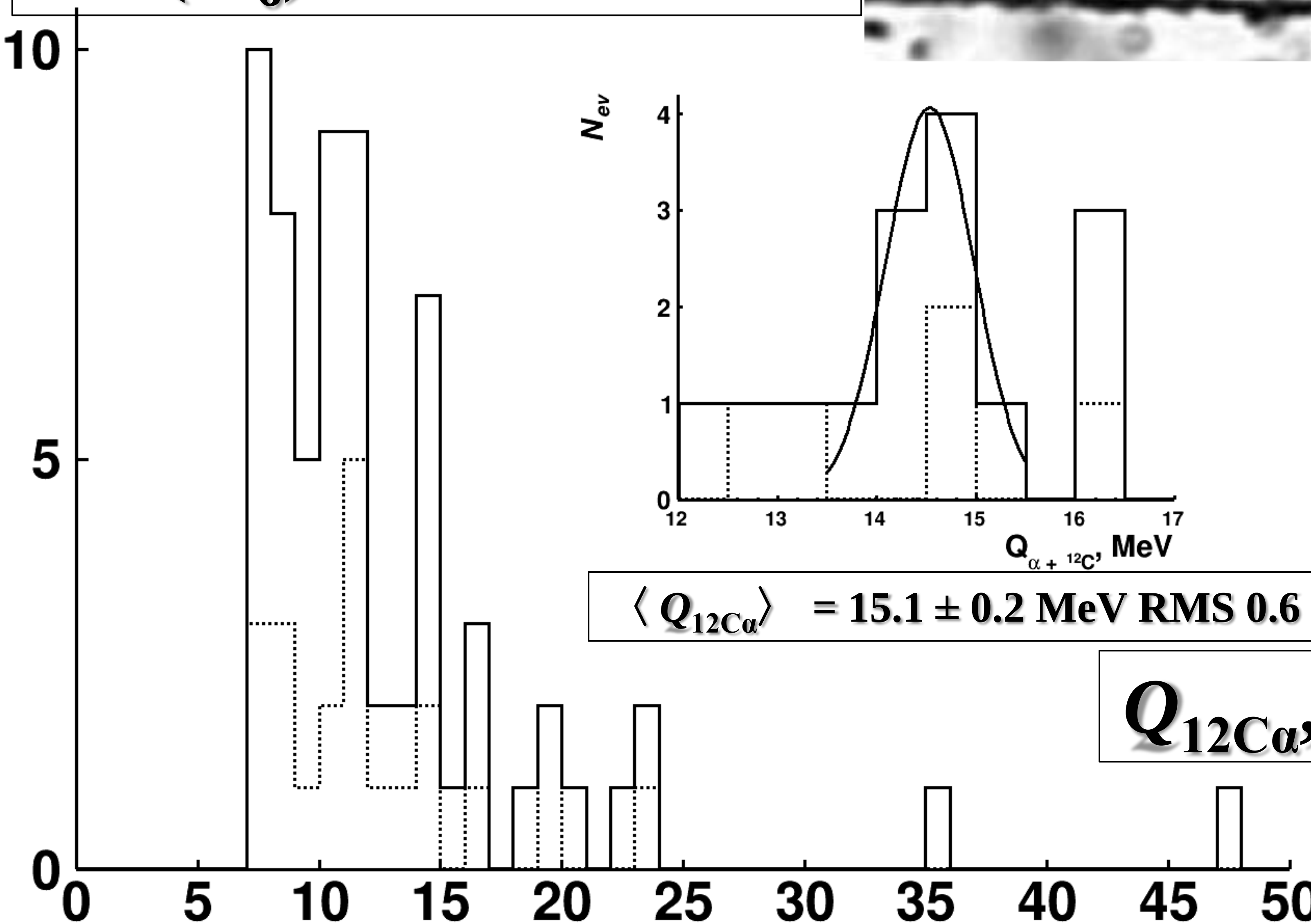
Just 296 keV !



The coexistence decays $^{16}O(0^+_6) \rightarrow {}^{12}C(0^+_2)\alpha$ and $^{12}C\alpha$ cannot be ruled out. The duality requires both decay modes to be examined.

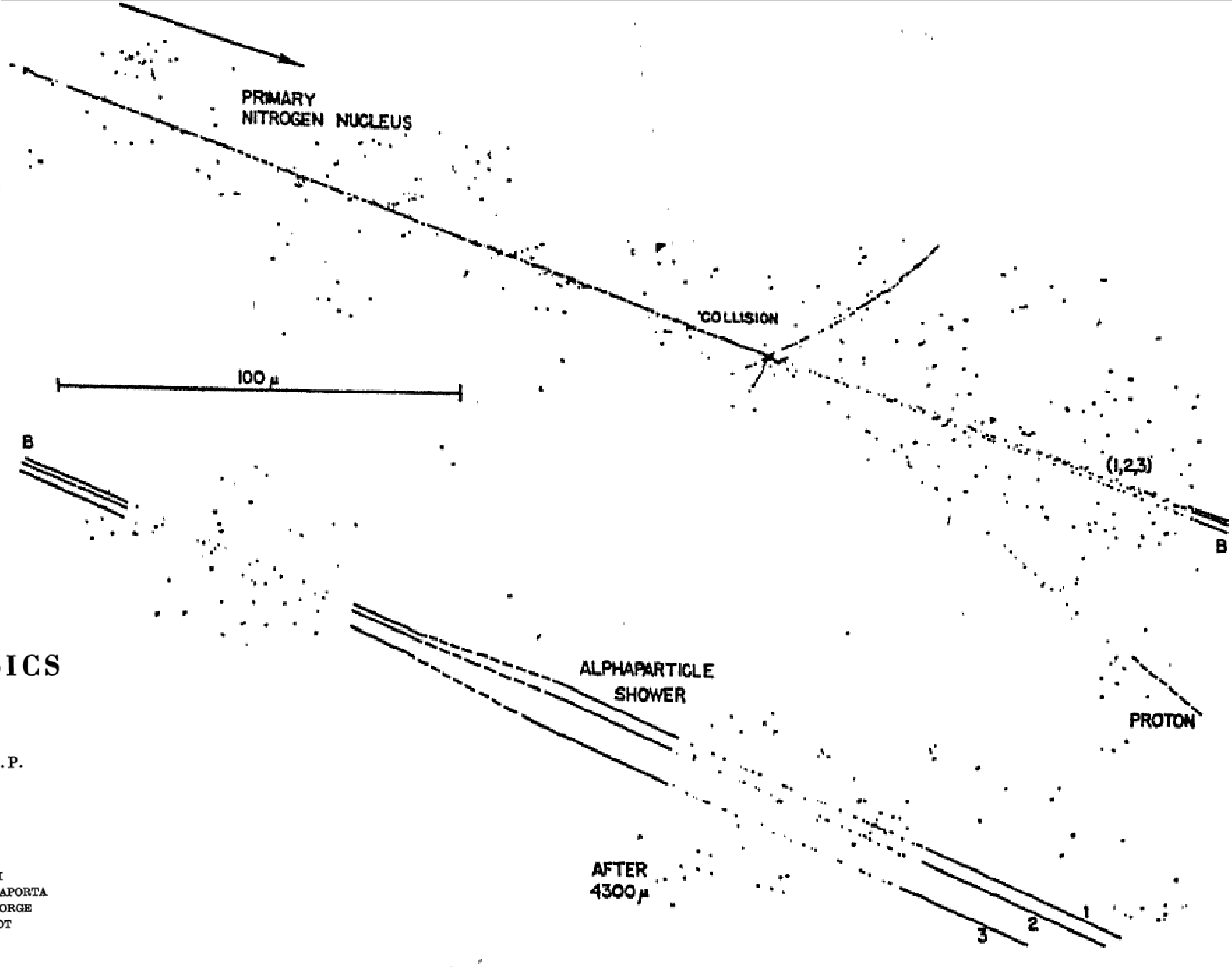
$^{16}O(0^+_6)$ in $^{16}O \rightarrow {}^{12}C\alpha$?





$\langle Q_{12C\alpha} \rangle = 15.1 \pm 0.2$ MeV RMS 0.6 MeV

$Q_{12C\alpha}$, MeV



PROGRESS

IN

COSMIC RAY PHYSICS

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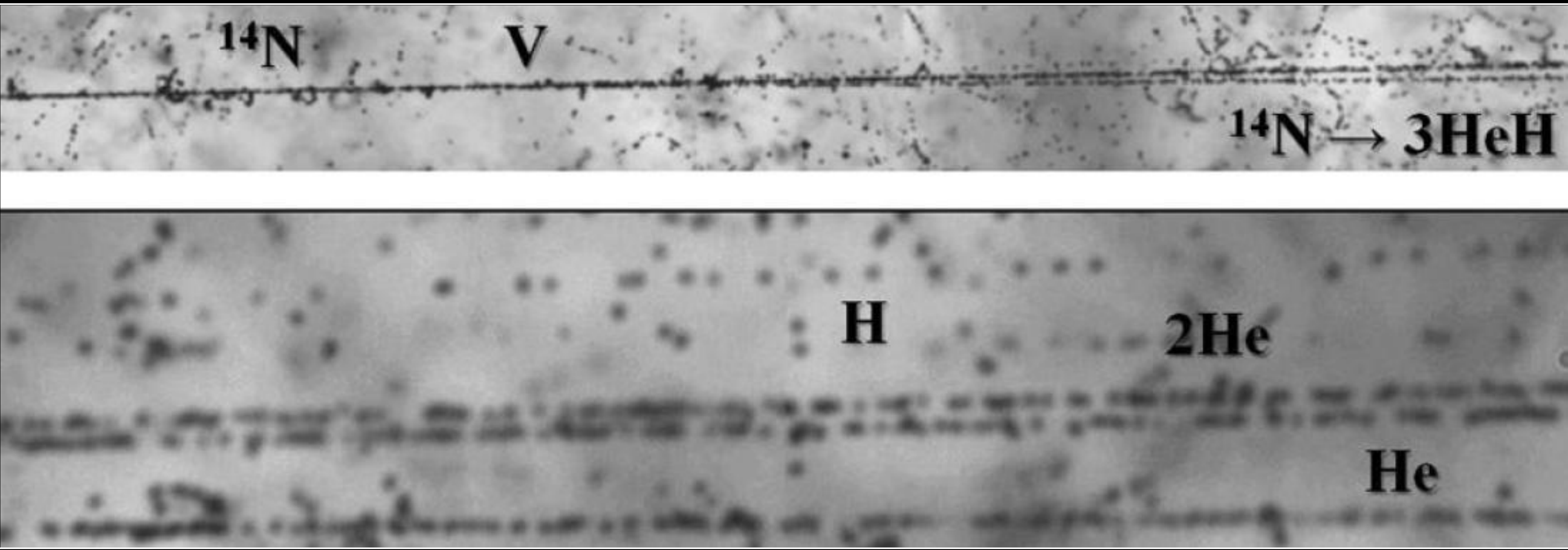
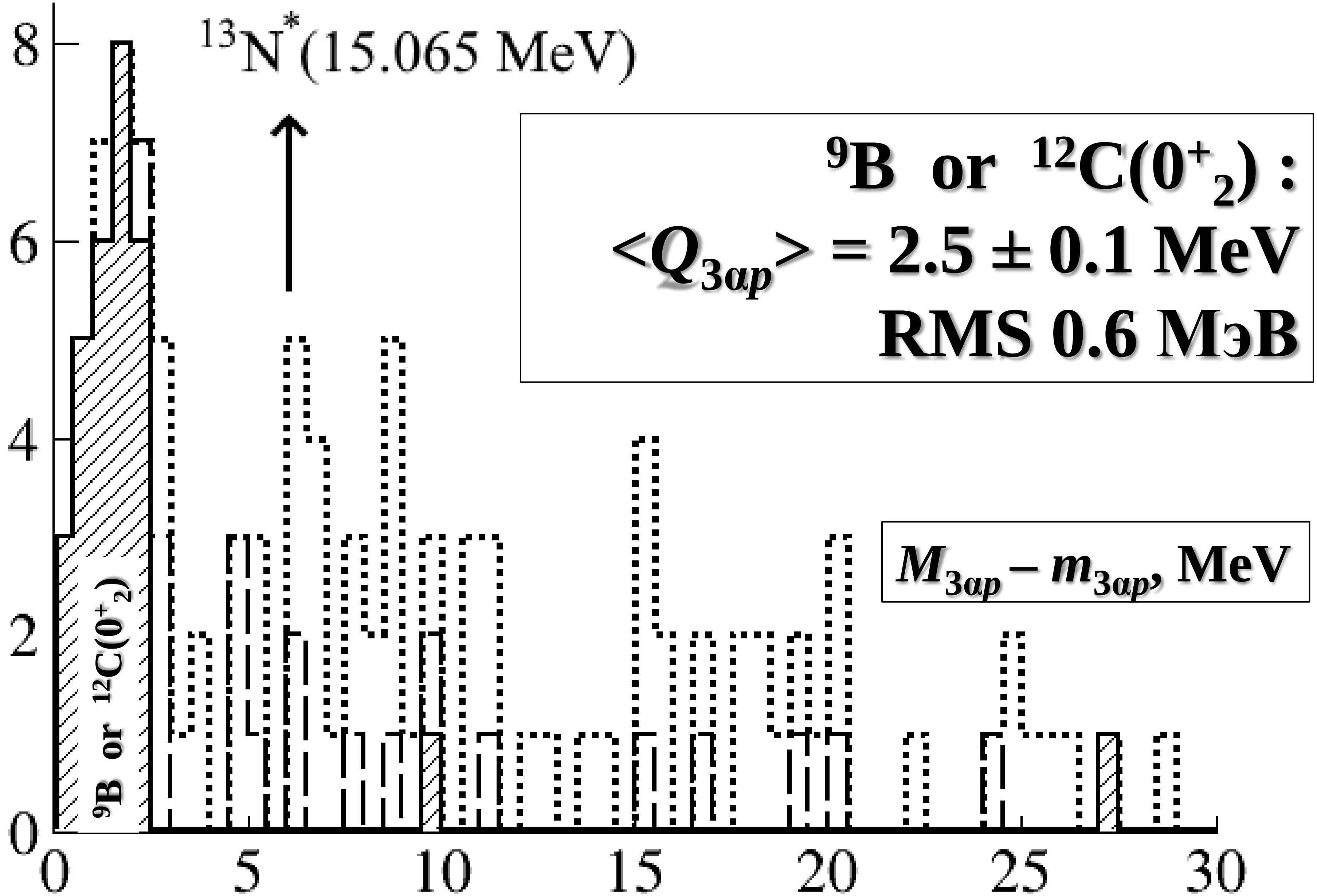
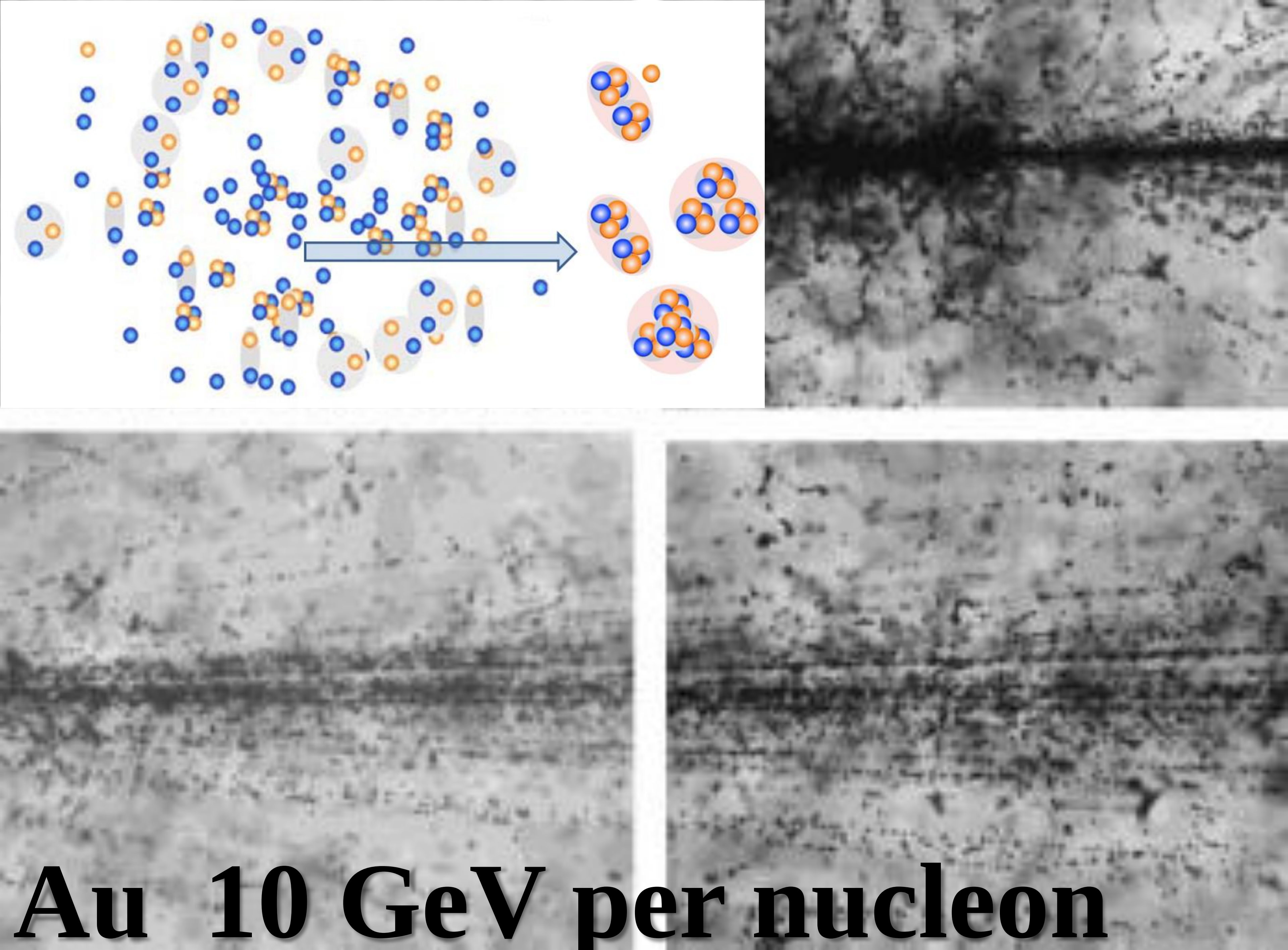
Search for ^{9}B and ^{12}C(0^+_2) in 128 ^{14}N → 3αp at 2 GeV per nucleon



The channel ^{14}N → 3αp presents a half of peripheral interactions with the transfer of the primary charge to the fragmentation cone. It is a common source of ^{8}Be(0^+), ^{9}B and ^{12}C(0^+_2). Transverse scanning of emulsion layers found 226 ^{14}N → 3αp stars which 128 are measured including 29 “white” stars.

$^{14}N \to 3\alpha p$ at 2 GeV per nucleon





Au 10 GeV per nucleon

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Correlation in formation of ^{8}Be nuclei and α-particles in fragmentation of relativistic nuclei

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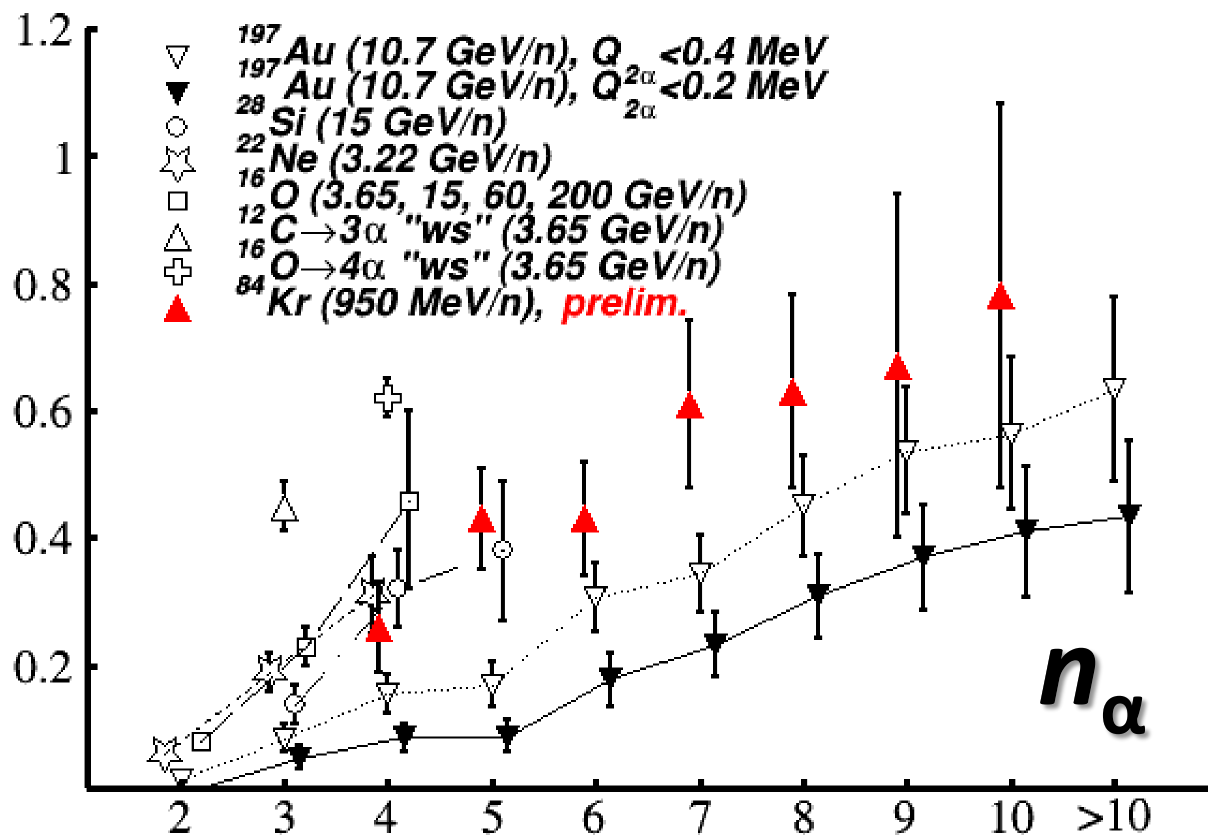
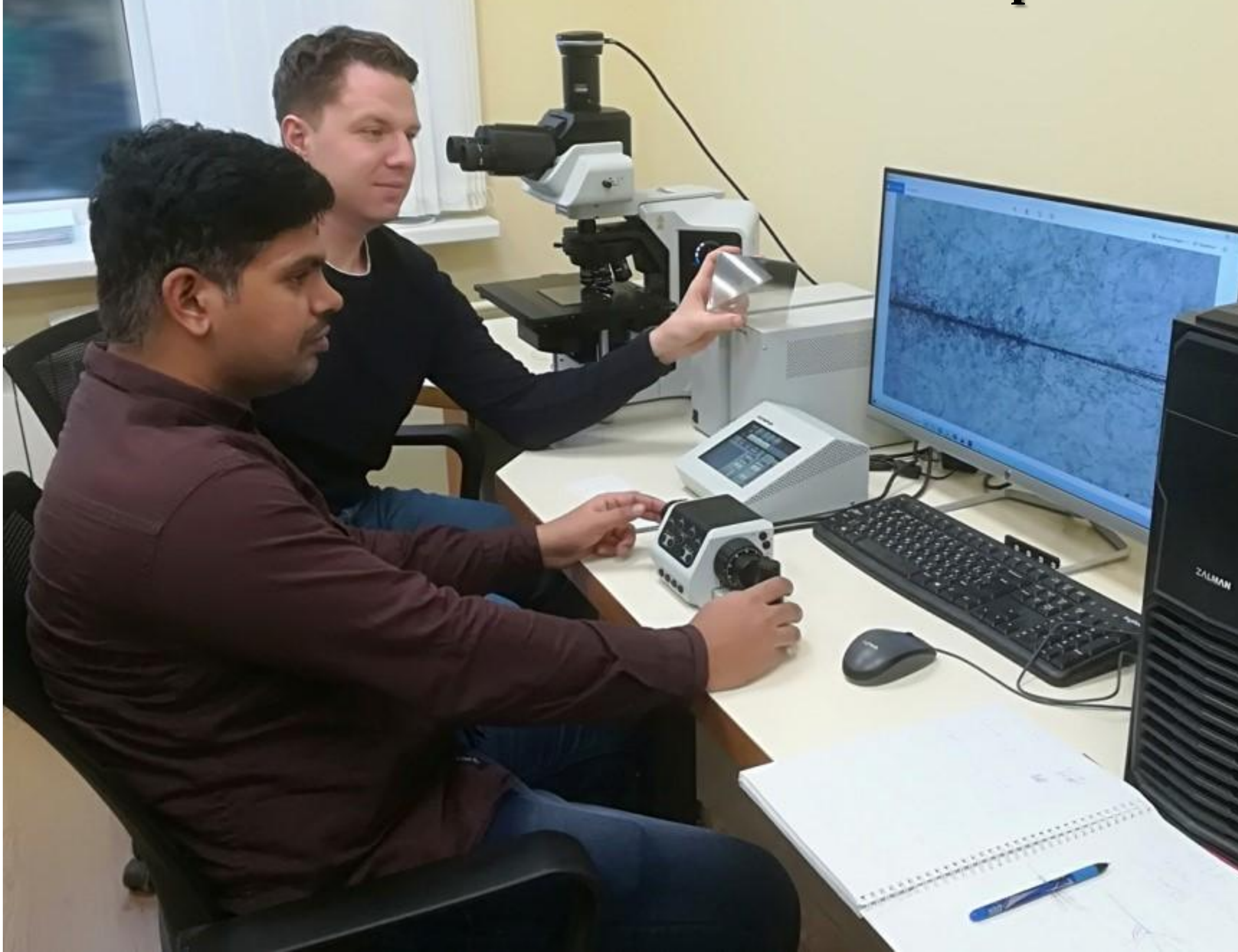
$N_{n_\alpha}(^8\mathrm{Be}) / N_{n_\alpha}$



Nuclotron December 2022 ^{124}Xe 3.8 GeV per nucleon



Highlights of Highlights

Productivity of the nuclear emulsion method in studies nuclear clustering and states of the lowest density and temperature is confirmed.

Determination of the invariant masses from the fragment emission angles assuming conservation of momentum per nucleon of the parent nucleus allowed identifying the decays of ^{8}Be(0^{+}), ^{8}Be(2^{+}), ^{9}Be(1.7), ^{9}B, ^{6}Be, ^{12}C(0^{+}_{2}), and ^{12}C(3^{-}).

The observations of ^{8}Be(0^{+}) and ^{12}C(0^{+}_{2}) points out that conditions of nuclear astrophysics can be reproduced in the relativistic fragmentation.

Despite relativistic scale unstable states may emerge in final state interactions of lowest energy nuclear physics.

Progress in microscope image analysis opens up new horizons to the method in nuclear structure studies.

Such a development stays on foundations laid in cosmic ray physics more than seven decades ago.


Trento 2019

Если не знаешь куда идти,
оглянись назад,
посмотри откуда пришел.
(индийская поговорка)

If you do not know where to go,
look back,
look at where you came from.
(Indian saying)