SEARCH FOR ALPHA-CONDENSATE EFFECTS IN DISSOSIASION OF RELATIVISTIC NUCLEI

Andrei Zaitsev, JINR Dubna

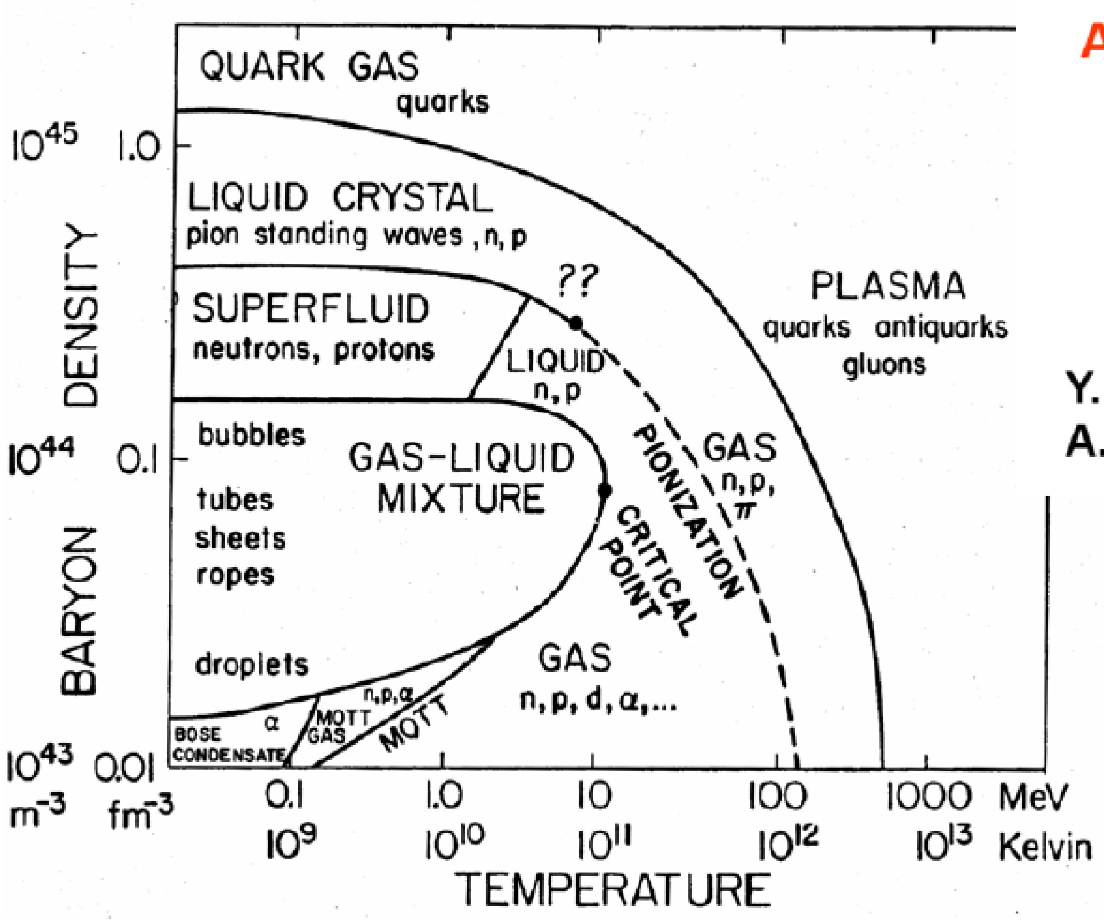
Outline

- **α-particle Bose-Einstein condensate;**
- **BECQUEREL Project:**
  - **Nuclear track emulsion;**
- ***N*α-states in relativistic dissociation;**
- **Summary.**

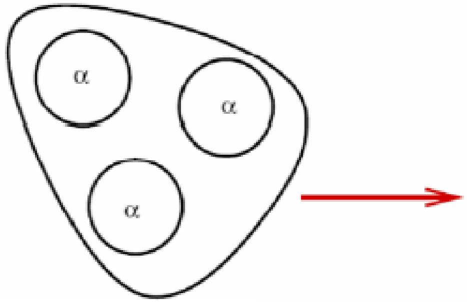
Alpha-Clusters in Nuclear Systems

P. Schuck

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



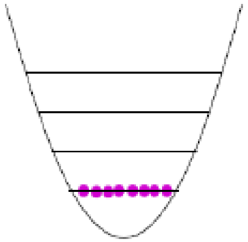
If 0_2^+ in ^{12}C dilute α – state,



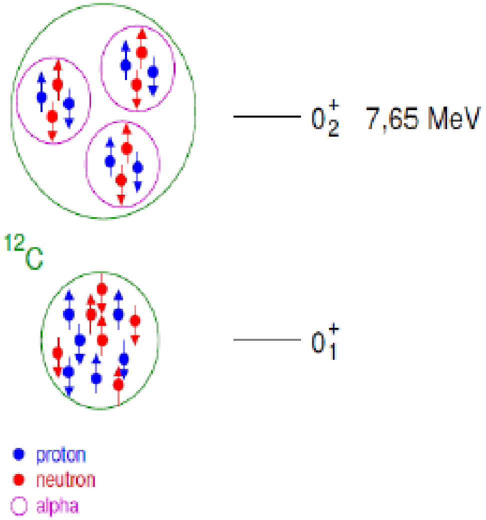
then α-condensate

infinite matter $\rho_{crit} \sim \frac{\rho_0}{3}$.

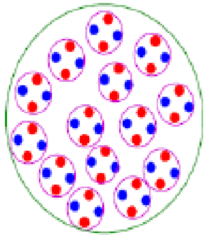
Bosons



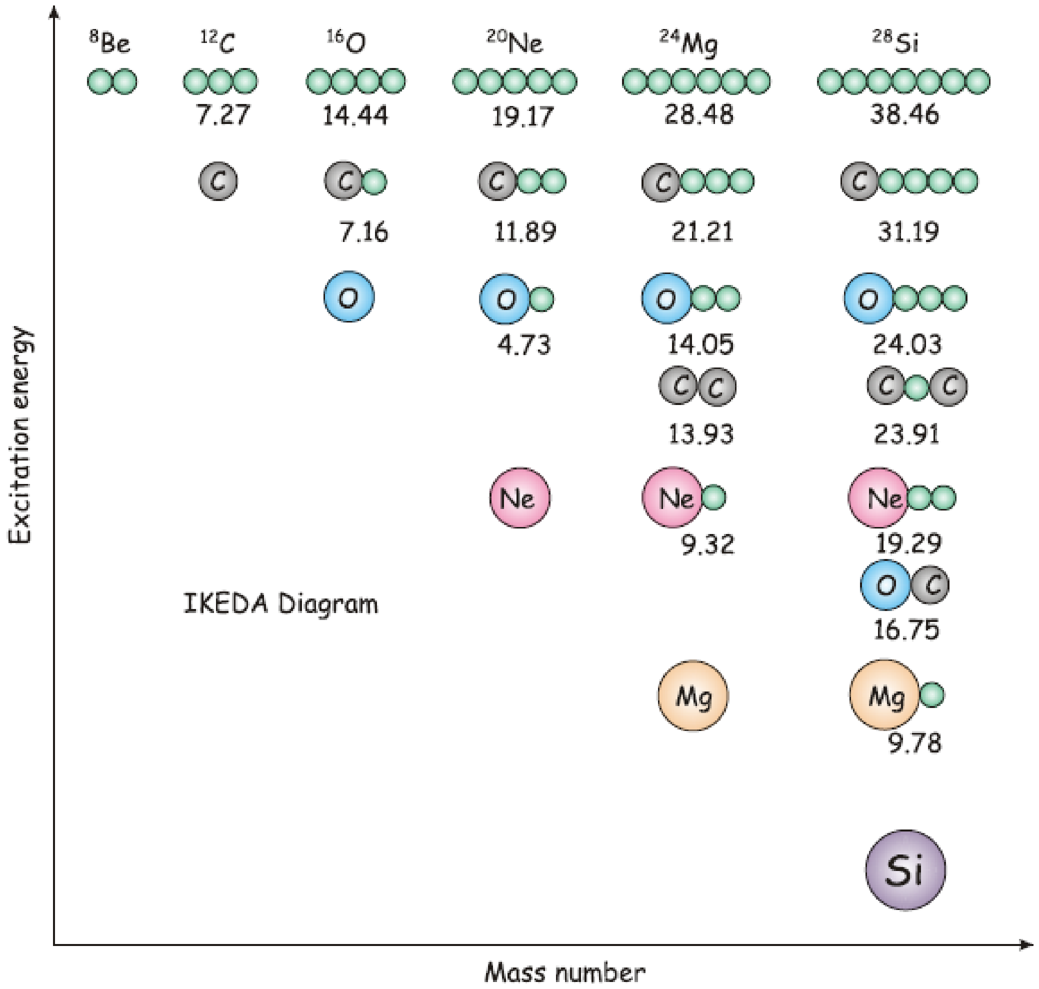
Back to nuclei

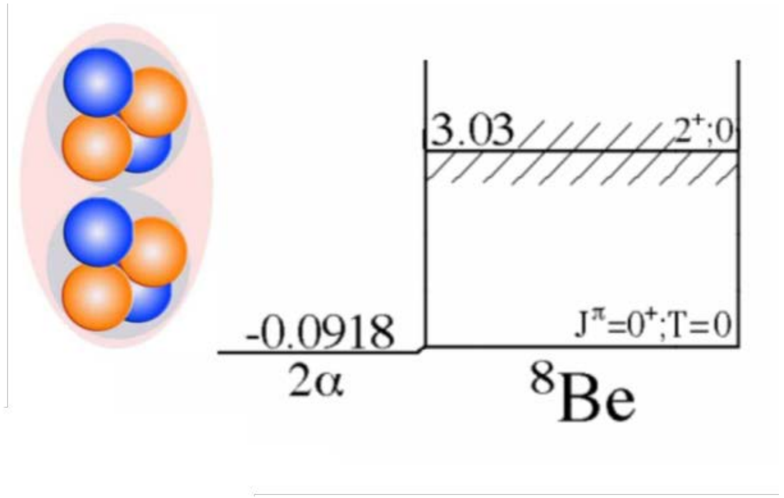


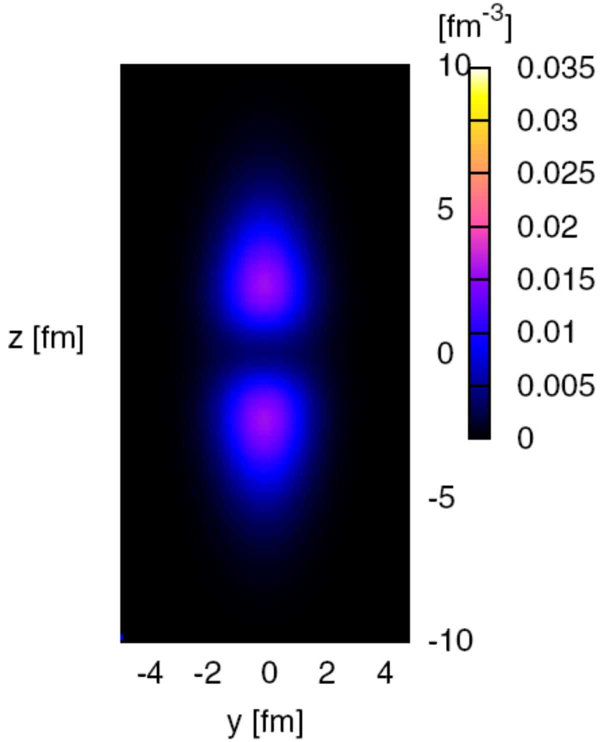
many α's
→ condensate



strong cluster phenomena in lighter nuclei



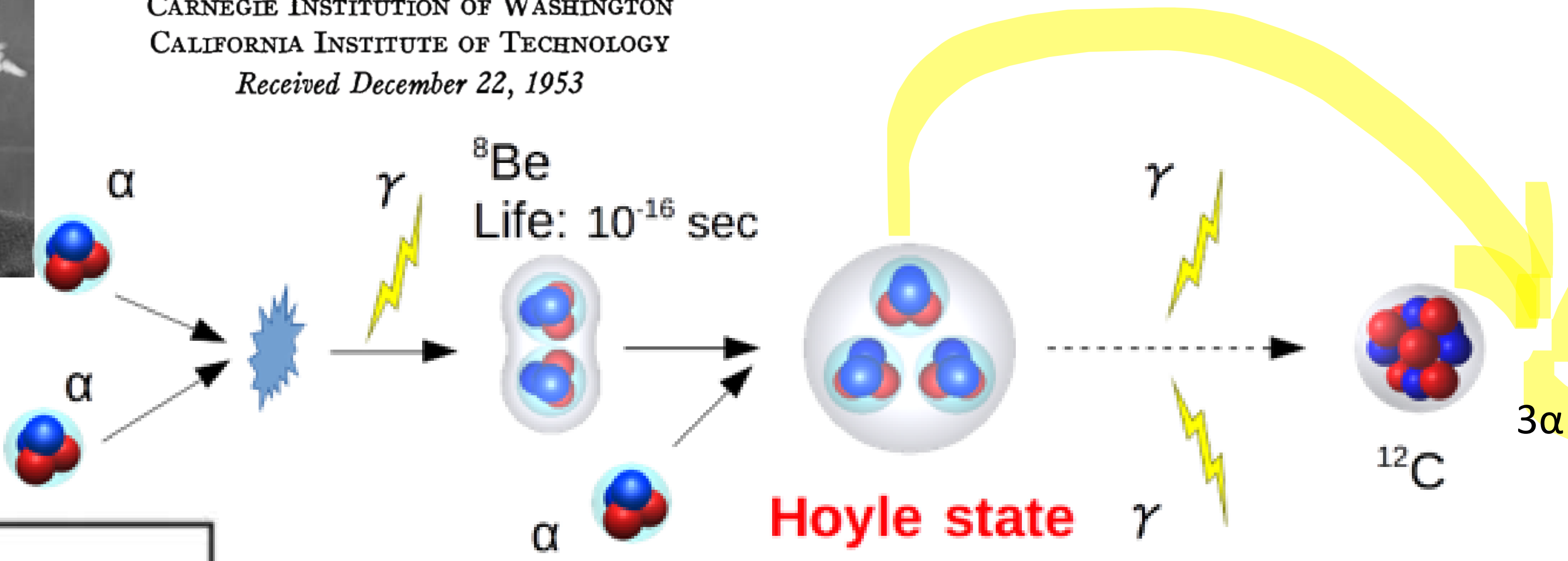


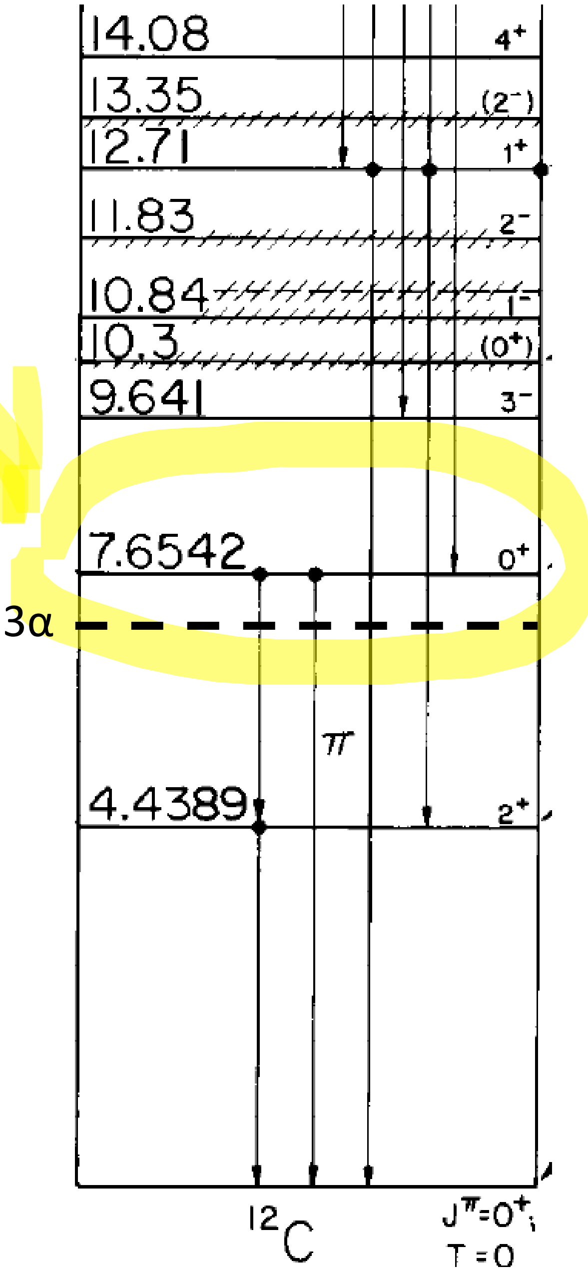


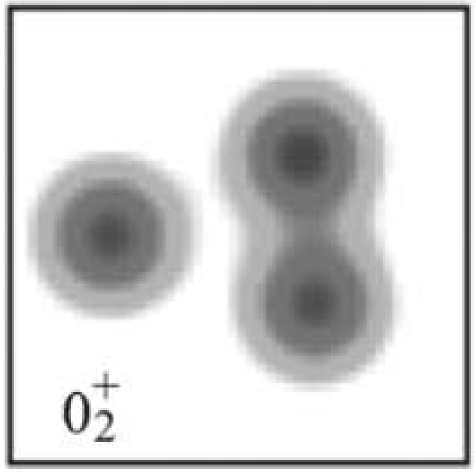
The "Ikeda diagram", showing the development of the cluster structure within α-conjugate nuclei when the excitation energy is increased.

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

F. Hoyle*
Mount Wilson and Palomar Observatories
Carnegie Institution of Washington
California Institute of Technology
Received December 22, 1953





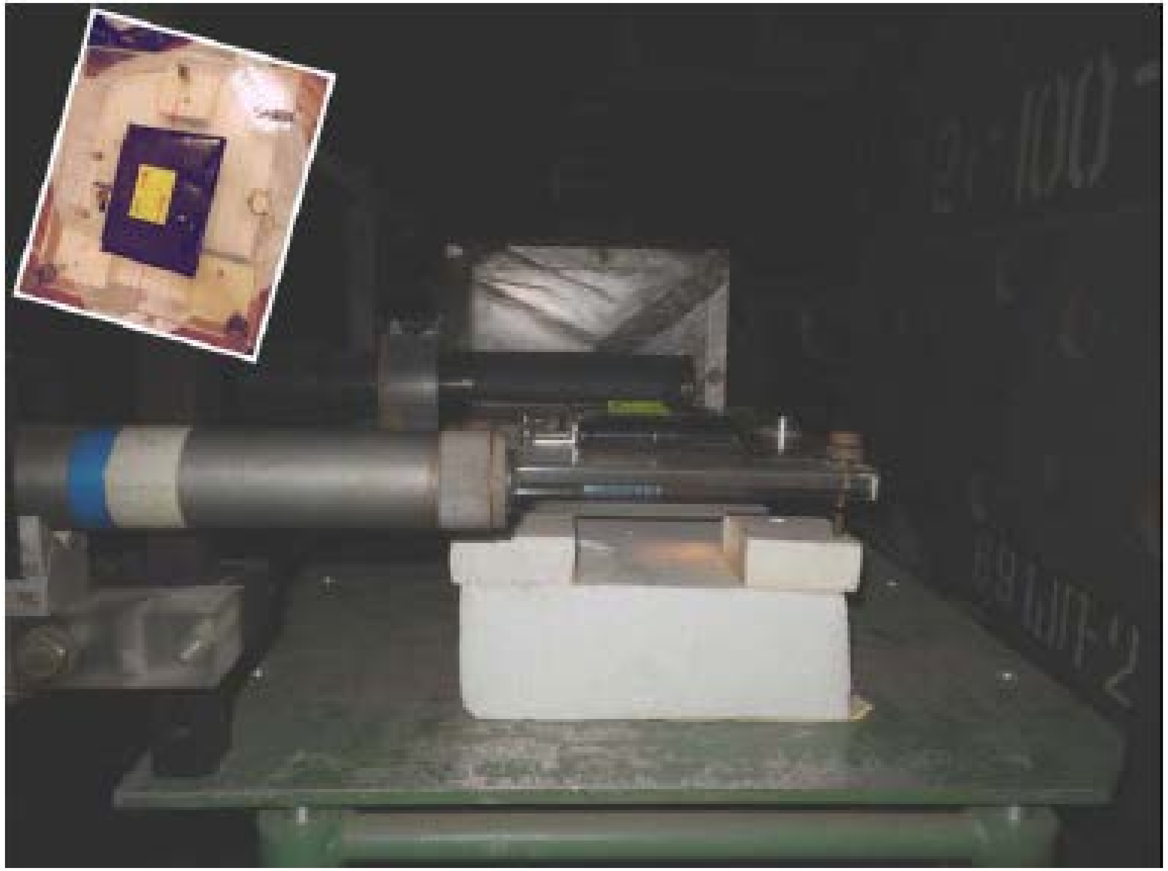


AMD density of HS

RADIUS - ?

STRUCTURE- ?

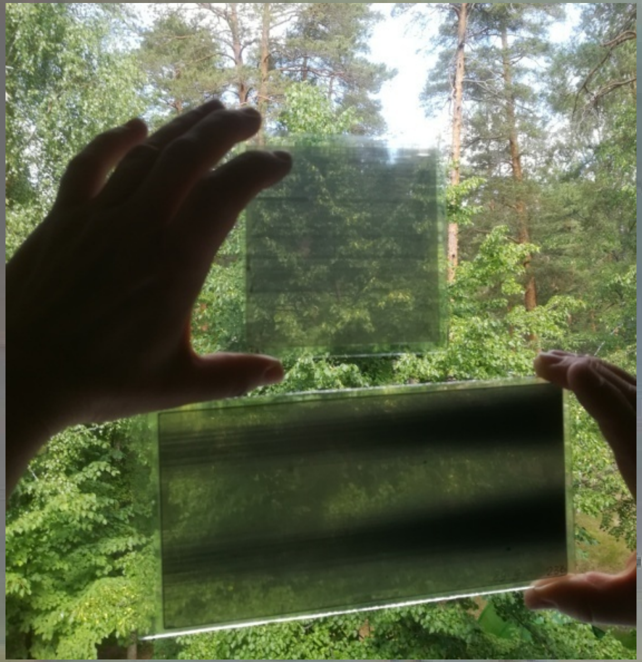
BECQUEREL Project at Nuclotron/NICA



Within the framework of the project, a systematic study of the cluster structure of light nuclei is carried out. The project is based on the analysis of layers of nuclear emulsion longitudinally irradiated in primary and secondary nuclear beams with an energy of about 1 *A* GeV.

website: becquerel.jinr.ru

Nuclear emulsion technique



Hair - 60 μm

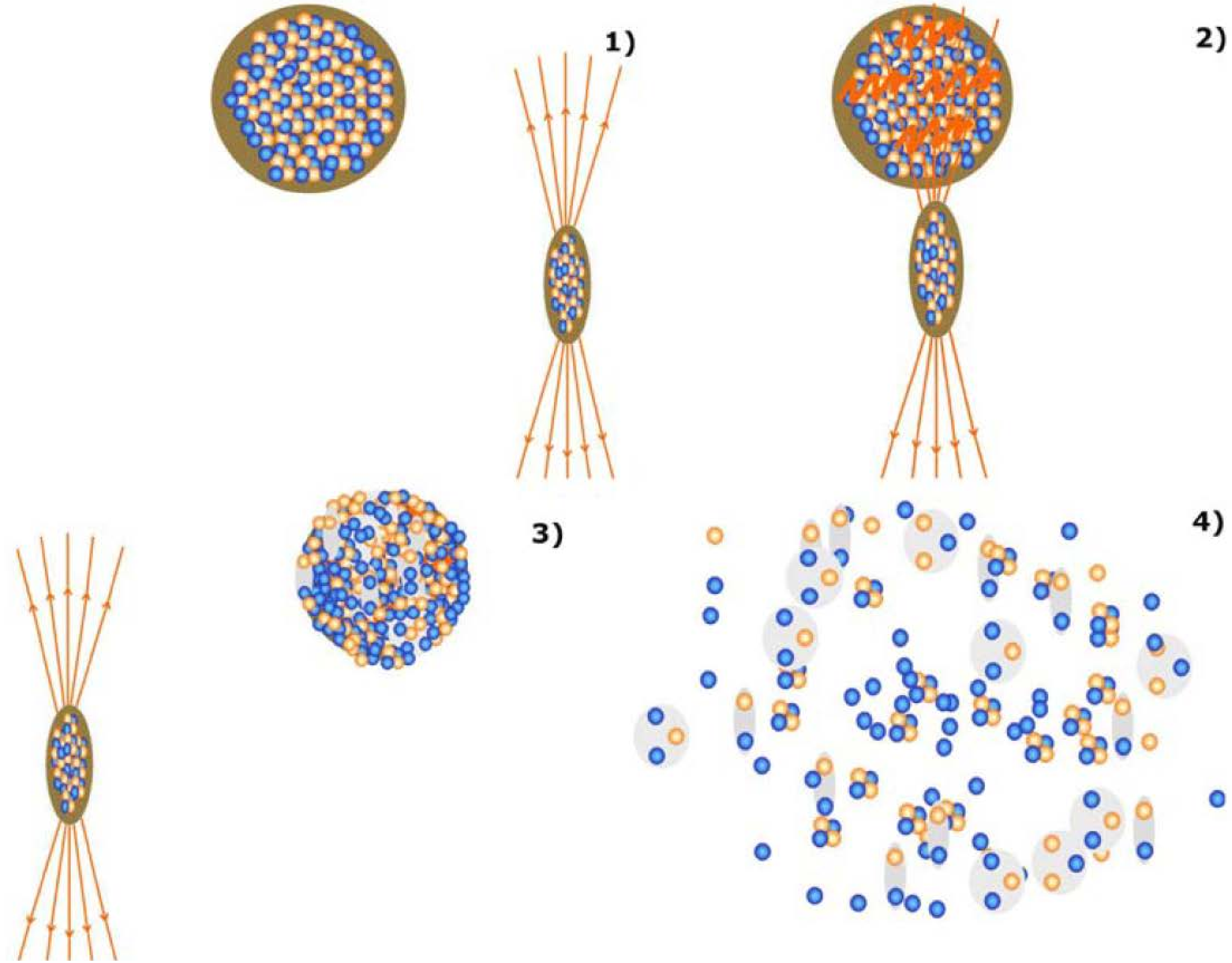
AgBr Crystal - 0.2 μm

Atom - 10^{-4} μm

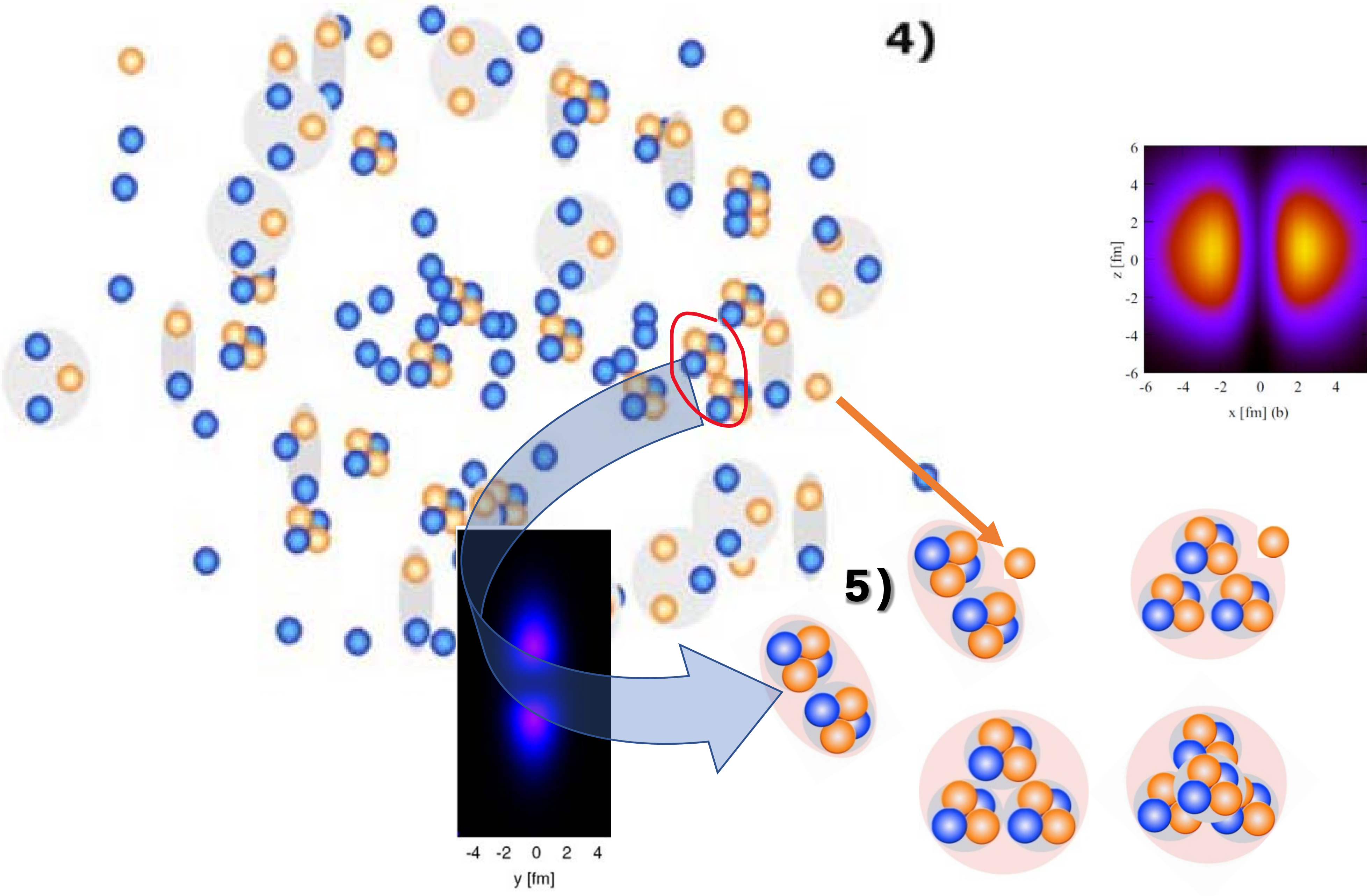
Proton - 10^{-9} μm

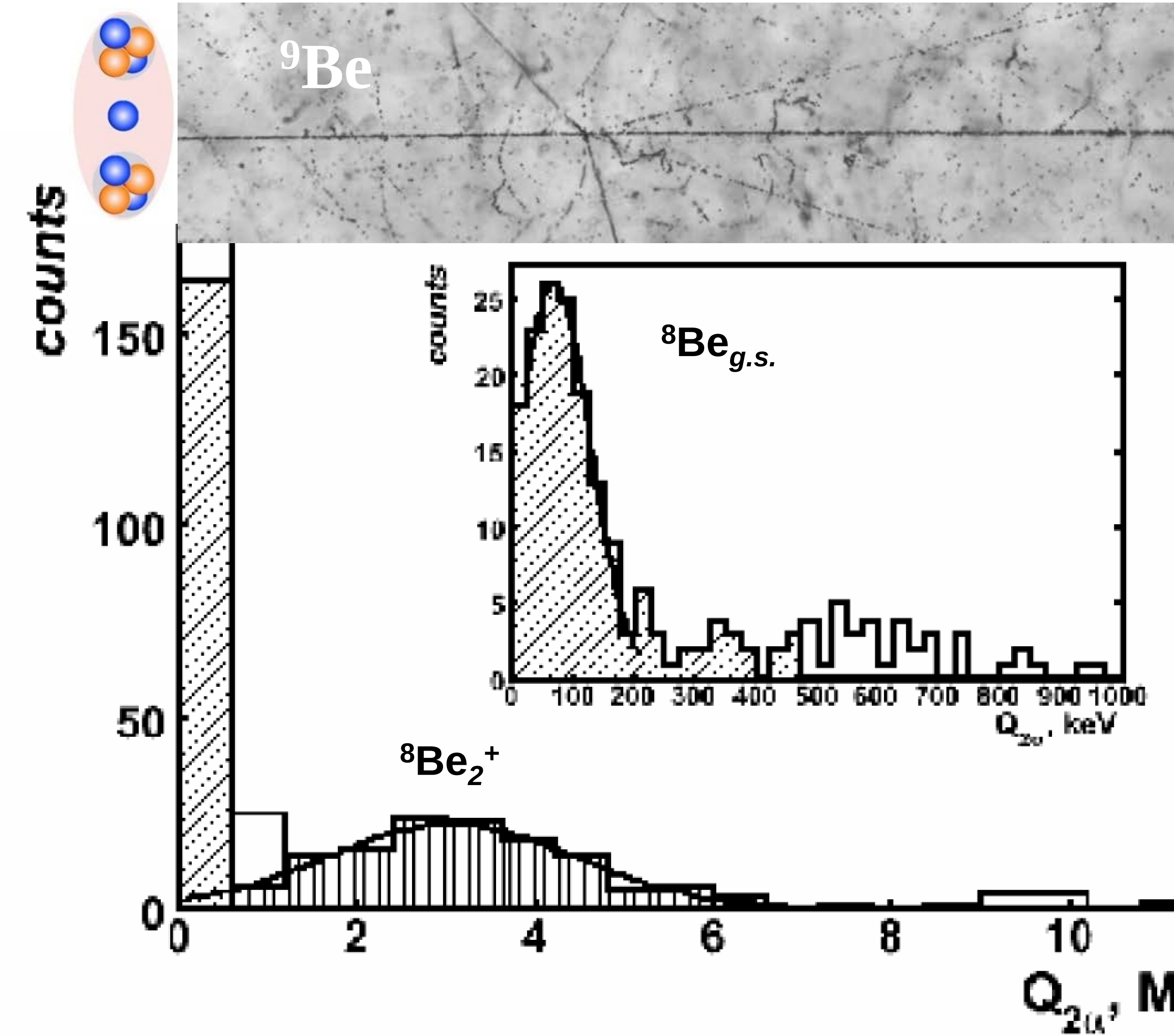
In general, the energy of a few-particle system Q is $Q = M^* - M$. M^* is the invariant mass defined by the sum of all products of *4*-momenta $P_{i,k}$ fragments: $M^{*2} = \sum(P_i \cdot P_k)$. Subtraction of mass M is a matter of convenience. The *4*-momenta $P_{i,k}$ are determined in the approximation of conservation of the initial momentum per nucleon. Then, the definition of Q comes down to determine the angles between the fragment emission directions.

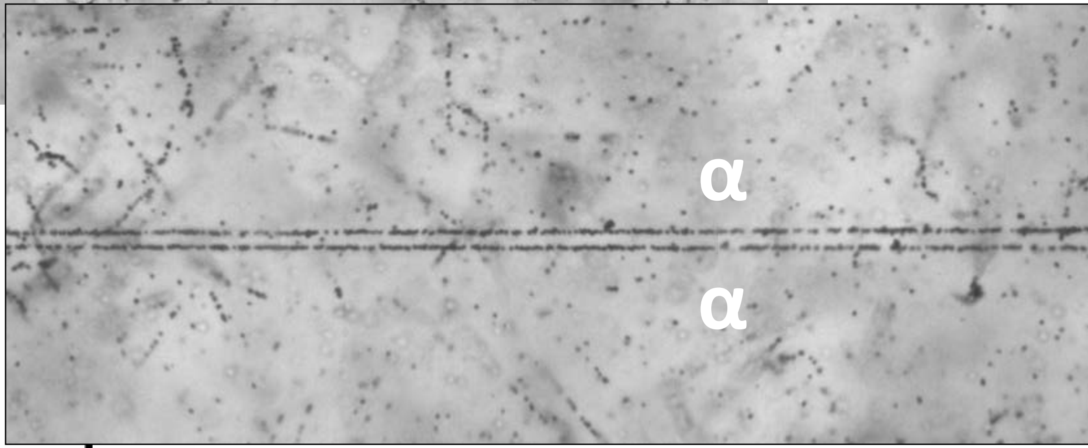
Clustering in relativistic dissociation of nuclei



Clustering in relativistic dissociation of nuclei







D.A. Artemenkov et al.,

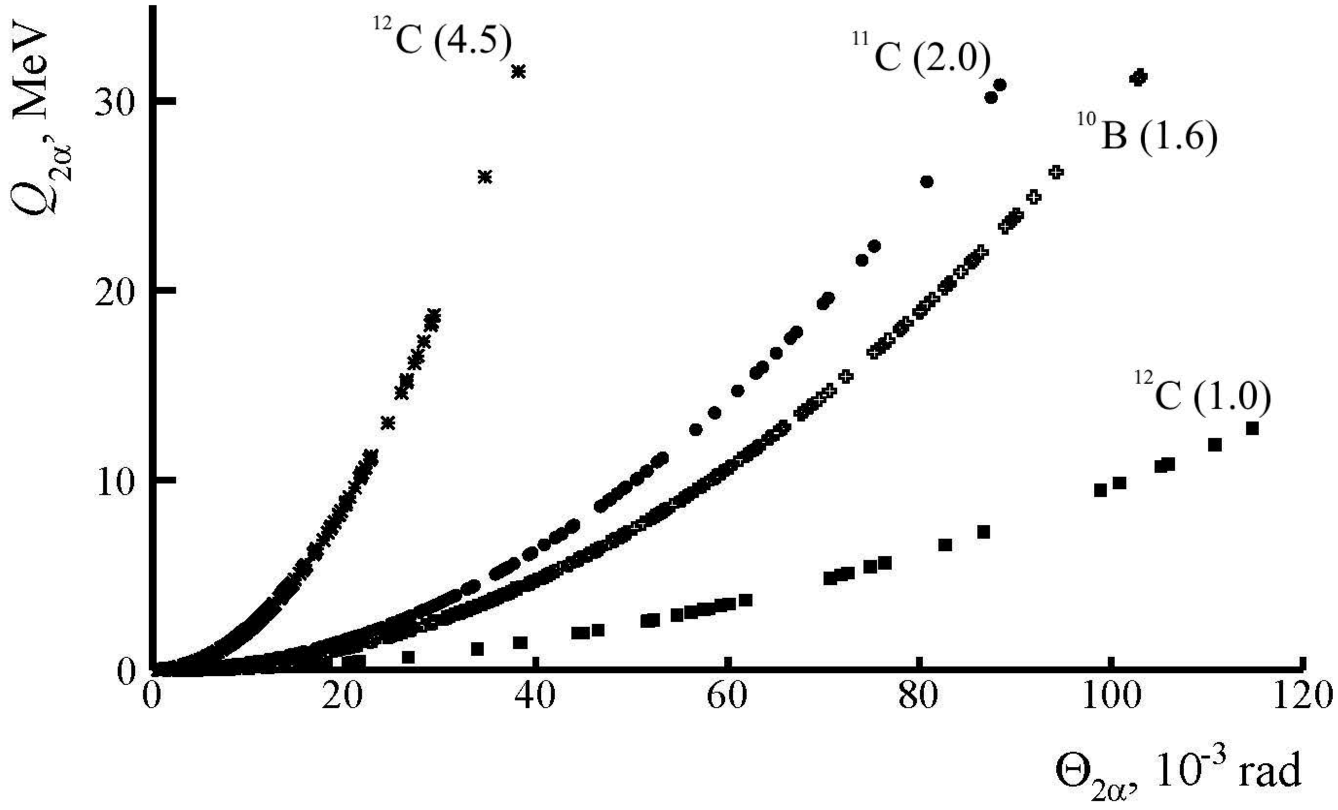
Eur. Phys. J. A 56 (2020)

The distribution over $Q_{2\alpha}$ of 2α-pairs ($N_{2\alpha}$ = 500), including "white" 2α-stars (N_{ws} = 198), indicates the condition $Q_{2\alpha}(^8Be) < 0.2$ MeV. Then the fraction of decays ^{8}Be 36 ± 3 and 41 ± 5%, respectively. Two "influxes" are worth to be mentioned around 0.6 and 3 MeV. The first of them corresponds to the decay via the ^{9}Be 2.43 MeV excitation, and the second one corresponds to the decay from the first excited state $^8Be_{2+}$.

Unstable ^{8}Be nucleus in dissociation of light relativistic nuclei

Nucleus (P_0, A GeV/c)	$\langle\Theta_{2\alpha}\rangle$ (RMS), mrad ($Q_{2\alpha}$ < 300 keV)	$\langle Q_{2\alpha}\rangle$ (RMS), keV
^{12}C (4.5)	2.1 ± 0.1 (0.8)	109 ± 11 (83)
^{16}O (4.5)	1.8 ± 0.3 (0.6)	81 ± 2 (50)
^{22}Ne (4.1)	1.9 ± 0.1 (0.8)	82 ± 5 (52)
^{14}N (2.9)	2.9 ± 0.2 (1.9)	120 ± 10 (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)	4.8 ± 0.3 (1.9) 5.3 ± 0.5 (1.5)	77 ± 7 (40) 68 ± 17 (42)
^{11}C (2.0) → ^{9}B → ^{8}Be	4.5 ± 0.3 (1.3)	94 ± 15 (86)
^{10}B (1.6)	5.9 ± 0.2 (1.6)	101 ± 6 (46)
^{10}B (1.6) → ^{9}B → ^{8}Be	5.6 ± 0.3 (1.3)	105 ± 9 (47)
^{12}C (1.0)	10.4 ± 0.5 (3.9)	107 ± 10 (79)

$$Q_{2\alpha} = \sqrt{2\cdot[m_\alpha^2 + E_\alpha^2 - \vec{P}_{\alpha 1}\cdot\vec{P}_{\alpha 2}]} - 2\cdot m_\alpha$$



The dependence of the calculated invariant masses of α-pairs $Q_{2\alpha}$ on the angles of $\Theta_{2\alpha}$ expansion into them in the events of dissociation *^{12}C*, *^{11}C* and *^{10}B* nuclei; the momentum values are indicated in brackets (*A* GeV/*c*).

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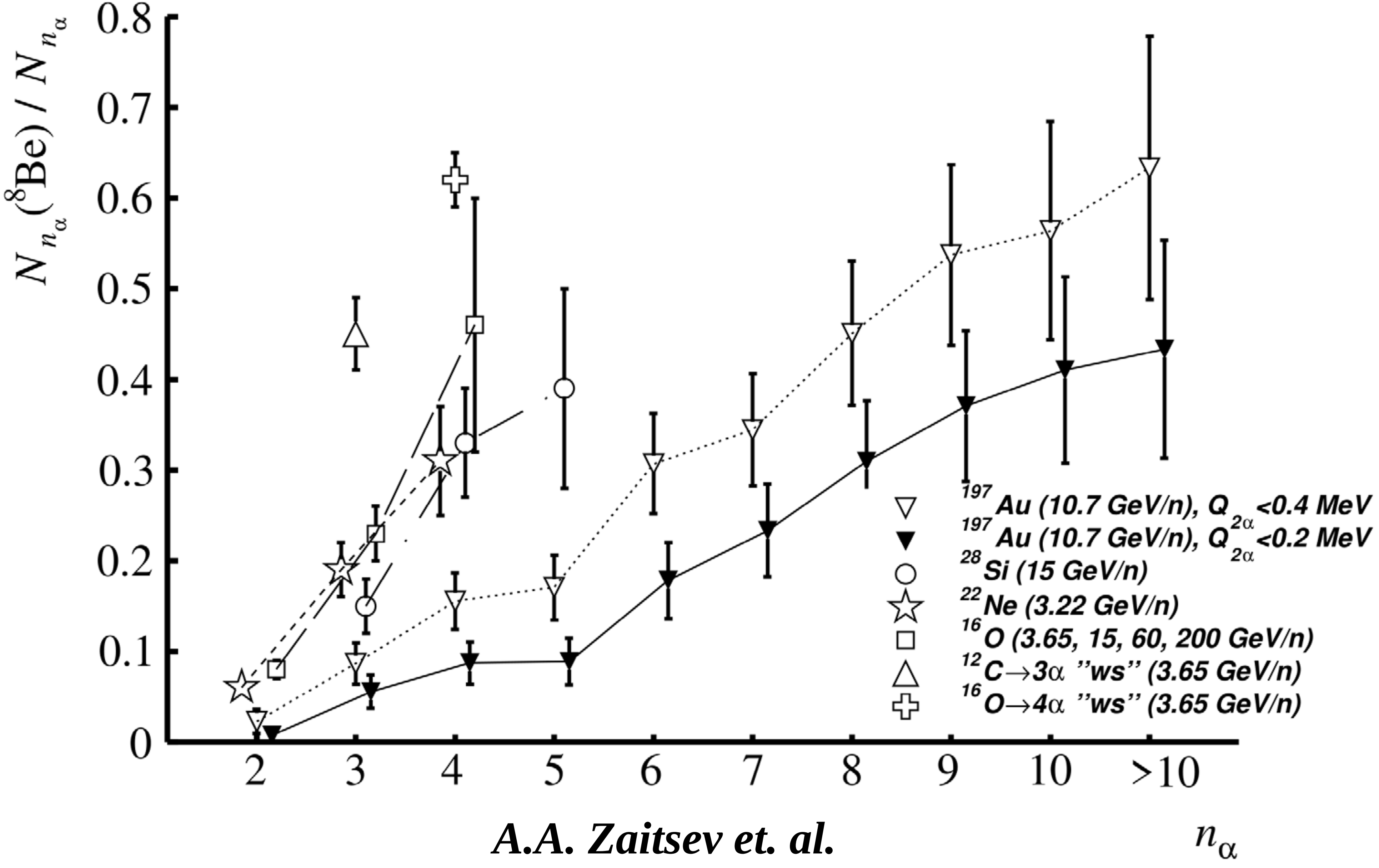
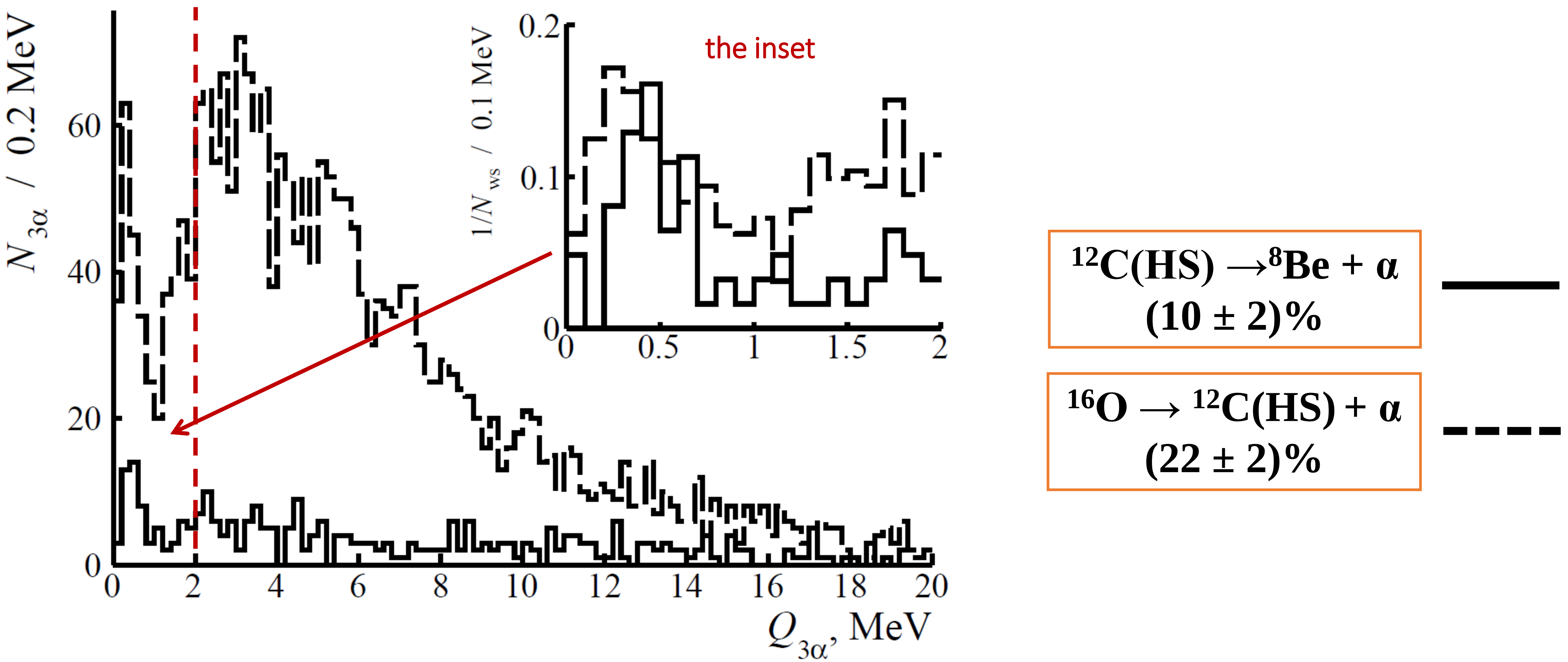
Correlation in ^{8}Be nucleus formation and α-particle multiplicities



A.A. Zaitsev et. al.

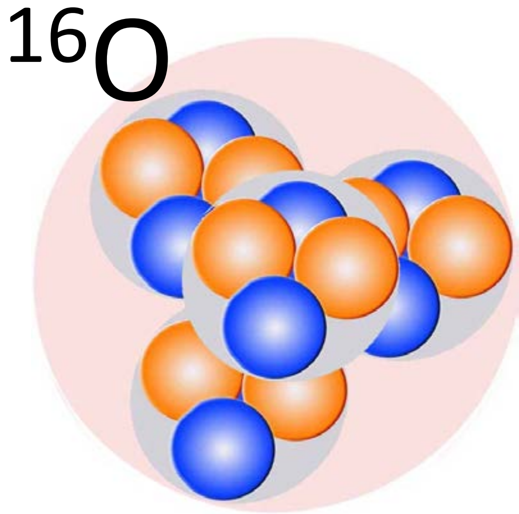
Phys. Let. B 820, 136460 (2021)

3α-particle events – Hoyle state

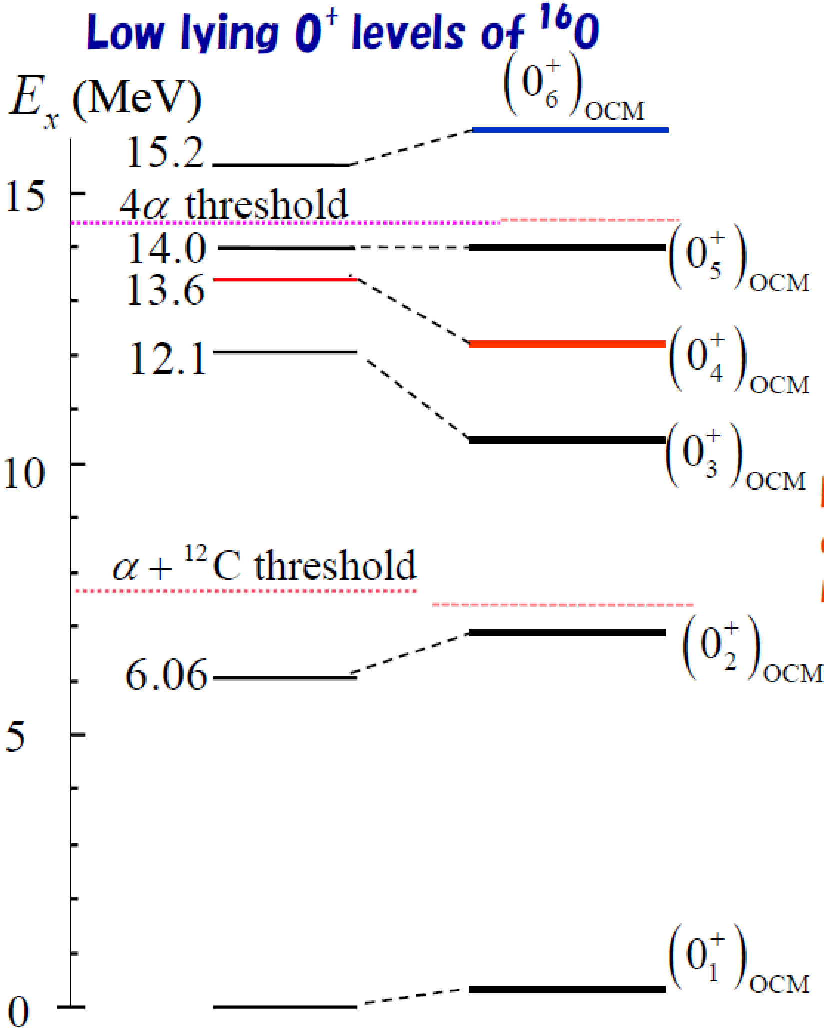


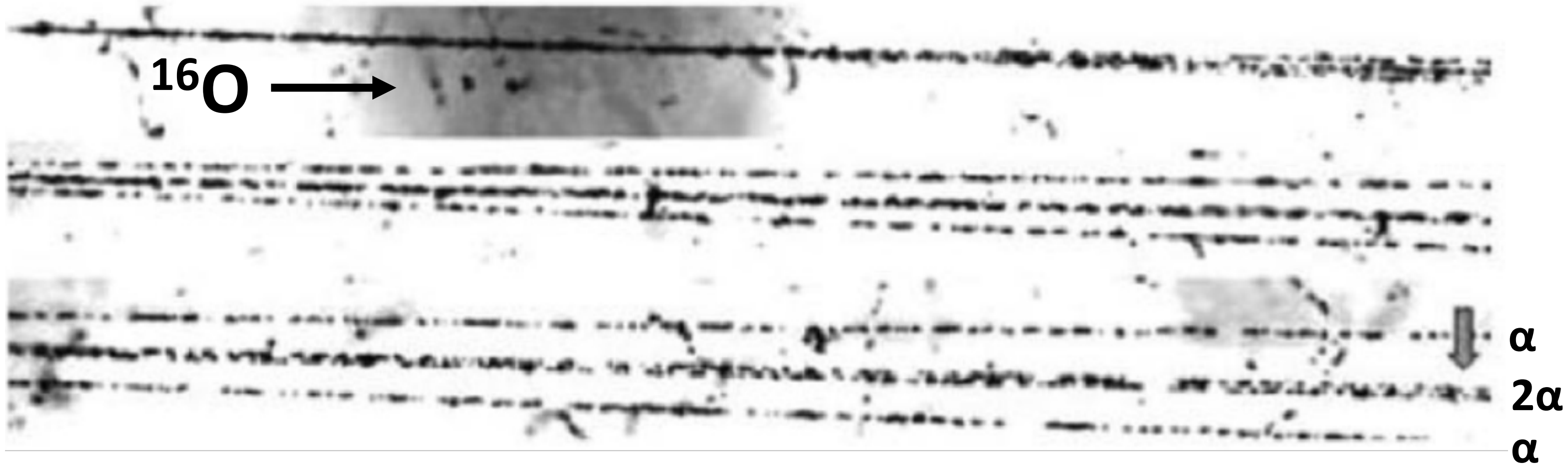
Distribution of the number of 3α-triplets $N_{3\alpha}$ over the invariant mass $Q_{3\alpha}$ of 316 "white" stars: ^{12}C → 3α (solid) and 641 "white" stars: ^{16}O → 4α (dashed) at 3.65 *A* GeV; the inset: the enlarged view of distributions in the region of $Q_{3\alpha}$ < 2 MeV normalized to the number of "white" N_{ws} stars in the both cases. The obtained ratios: $N_{HS}(^{12}C)/N_{8Be}(^{12}C) = 0.36 \pm 0.06$ и $N_{HS}(^{16}O)/N_{8Be}(^{16}O) = 0.35 \pm 0.04$.

Observation of Nα states in heavier nuclei



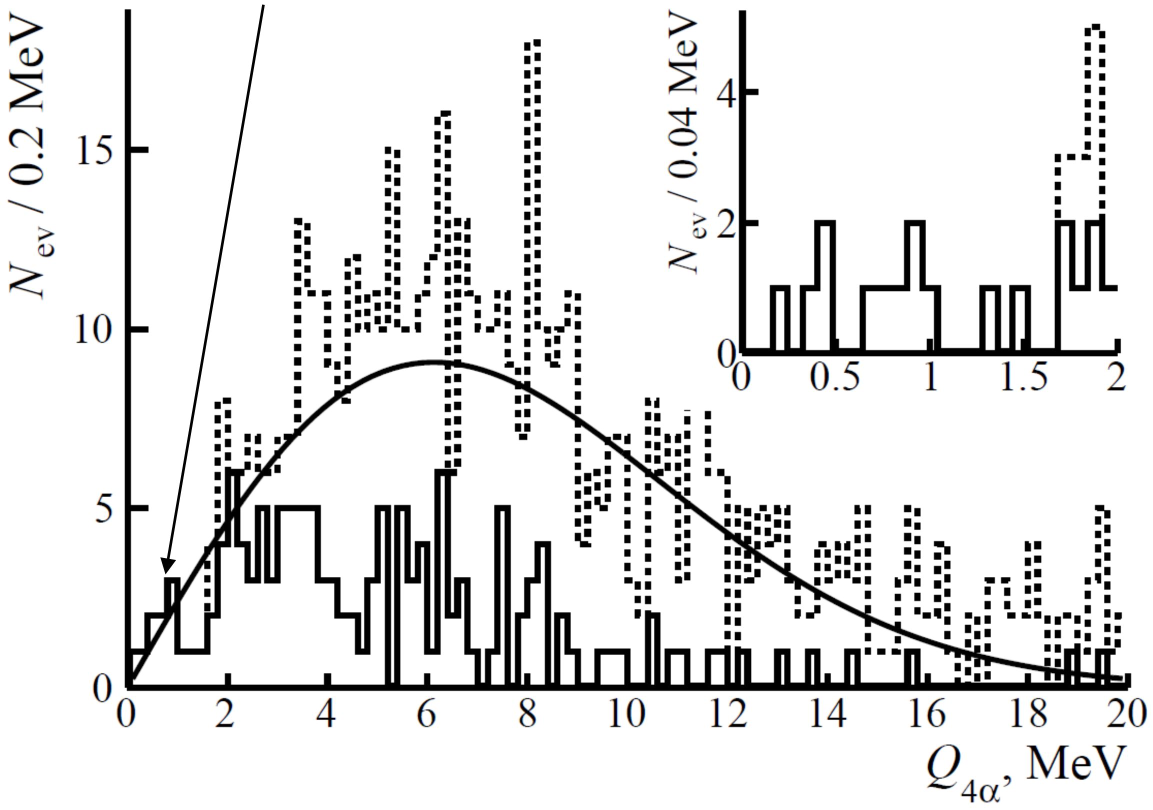
E_x (MeV ± keV)	J^π; T	K^π	$\Gamma_{c.m.}$ or τ_m (keV)	Decay
14.620 ± 20	$4^{(+)}$		490 ± 15	α
14.660 ± 20	5^-	0^-	670 ± 15	α
14.8153 ± 1.6	6^+; 0		70 ± 8	α
14.926 ± 2	2^+		54 ± 5	p, α
15.097 ± 5	0^+		166 ± 30	p, α
15.196 ± 3	2^-; 0		63 ± 4	p, α
15.26 ± 50	2^+; (0)		300 ± 100	p, α

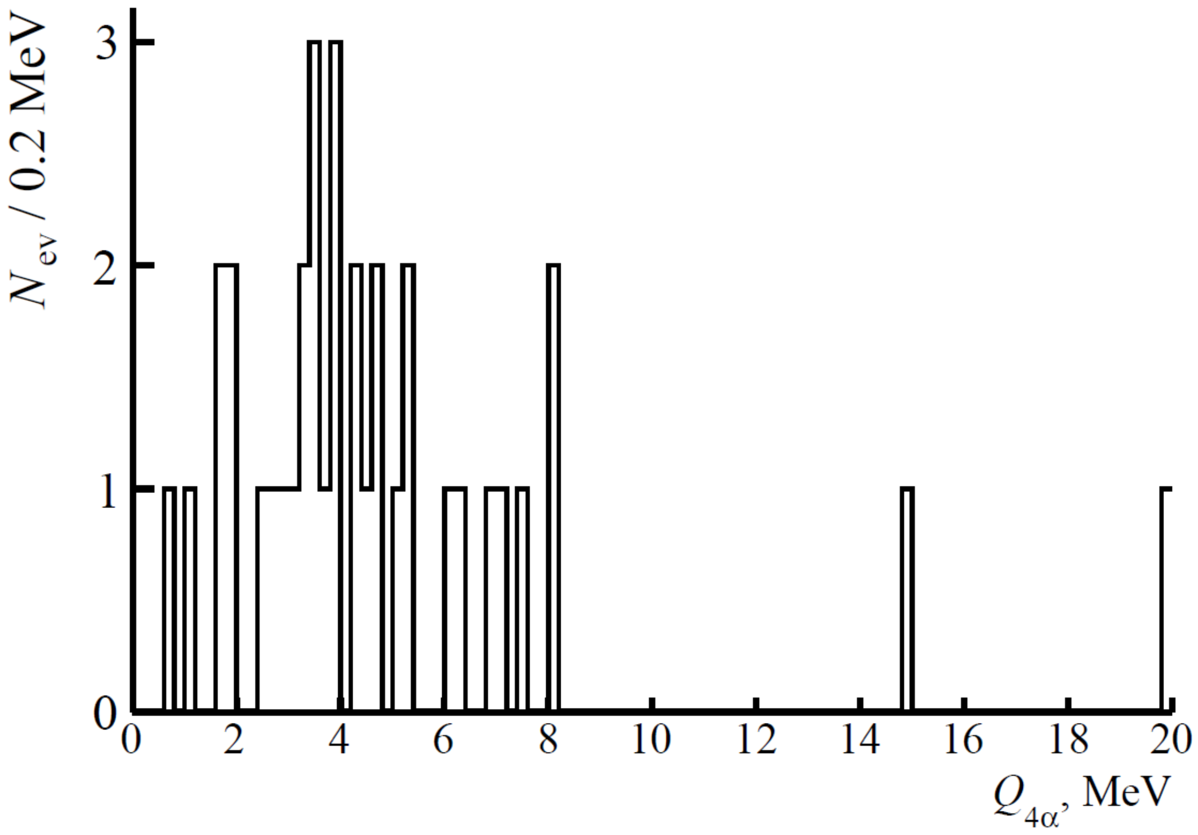




α-four events in ^{16}O

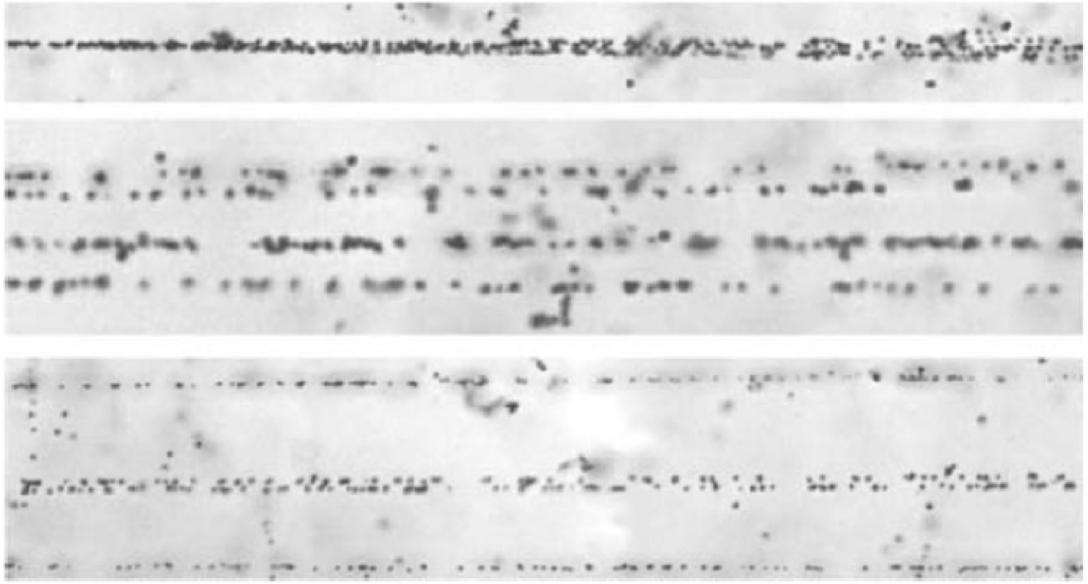
$^{16}O(0^+_6) \rightarrow {}^{12}C^*(\rightarrow 3\alpha) + \alpha$ – (7 ± 1) %

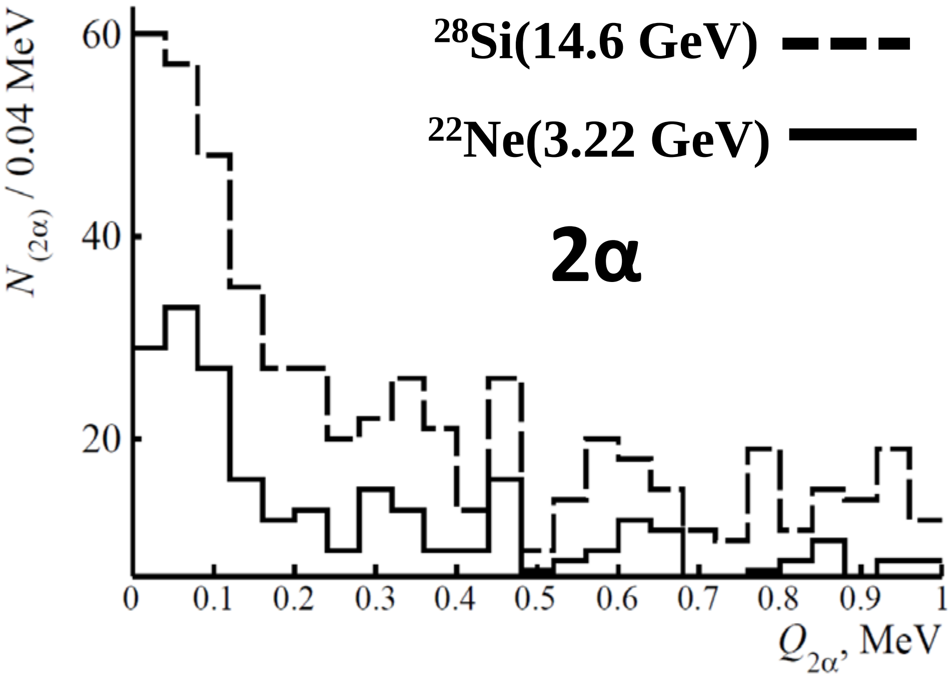


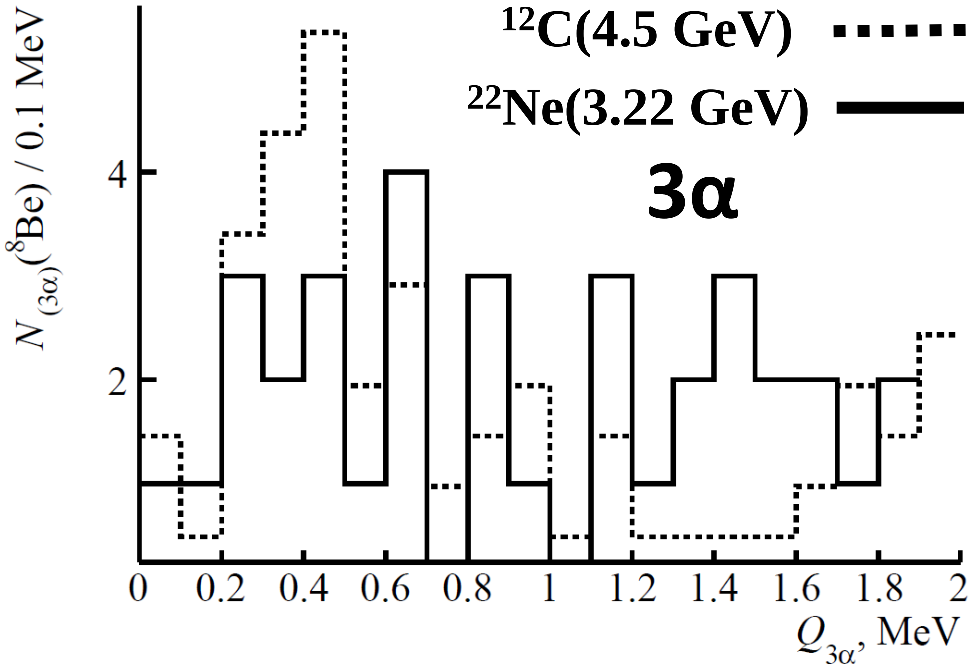


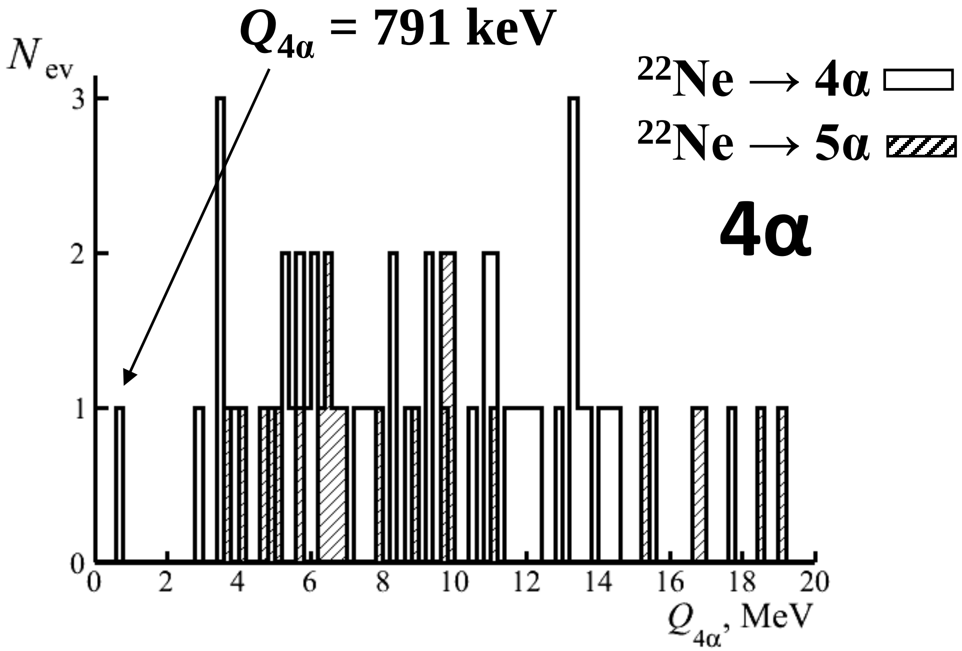
HS can occur as a result of α decay of the 0^+_6 excitation of the ^{16}O nucleus. The distribution of "white" $^{16}O \rightarrow 4\alpha$ stars over the invariant mass of 4α-quartets $Q_{4\alpha}$ (left) is described by the Rayleigh distribution with $\sigma_{Q4\alpha}$ = (6.1 ± 0.2) MeV. The condition $Q_{3\alpha}$ (HS) < 700 keV shifts the $Q_{4\alpha}$ distribution and indicates 9 events: $Q_{4\alpha}$ < 1 MeV with $\langle Q_{4\alpha} \rangle$ at (RMS) = 624 ± 84 (252) keV. The contribution of ^{16}O (0^+_6) → α + HS decays is estimated to be equal to 7 ± 2% to normalize on HS. It can be concluded that the direct dissociation of α + HS dominates in the formation of HS.

^{22}Ne 3.22 *A* GeV

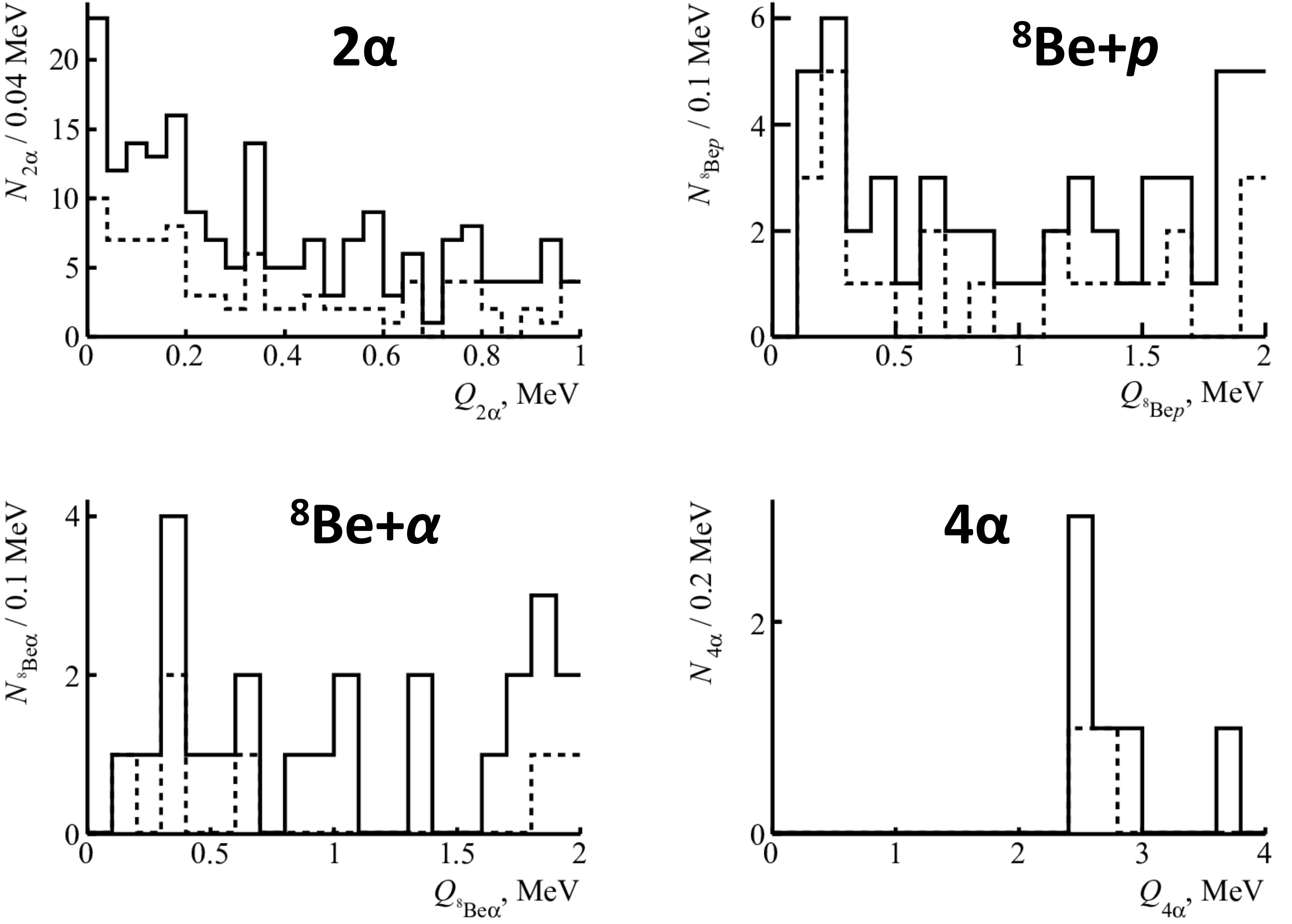






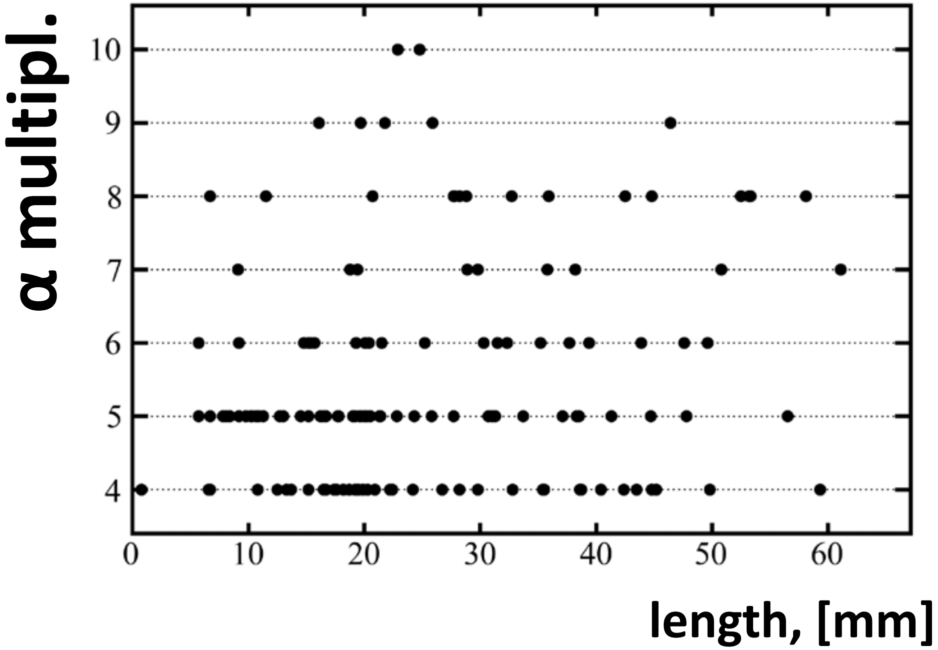


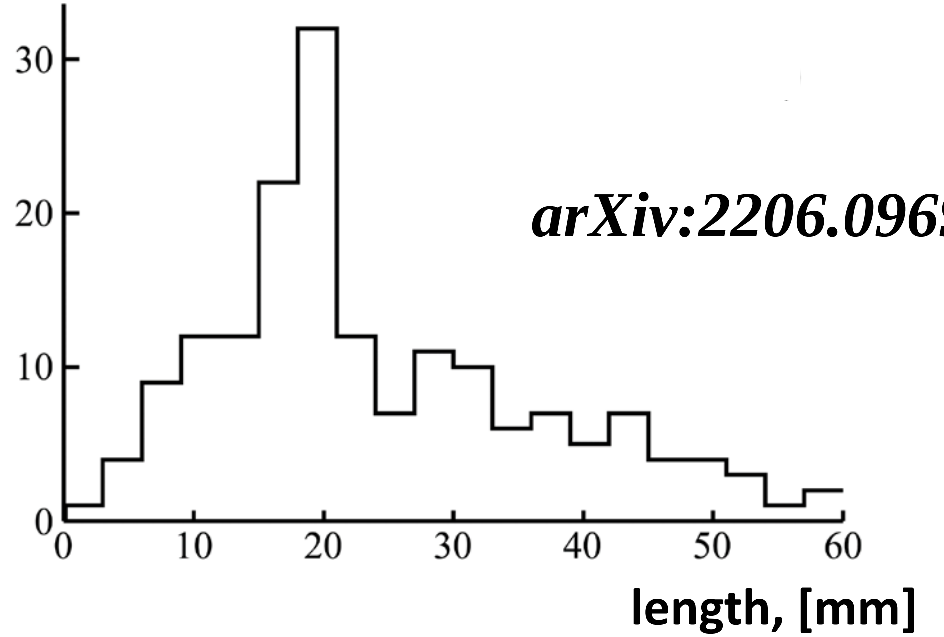
Relativistic dissociation of ^{28}Si nuclei



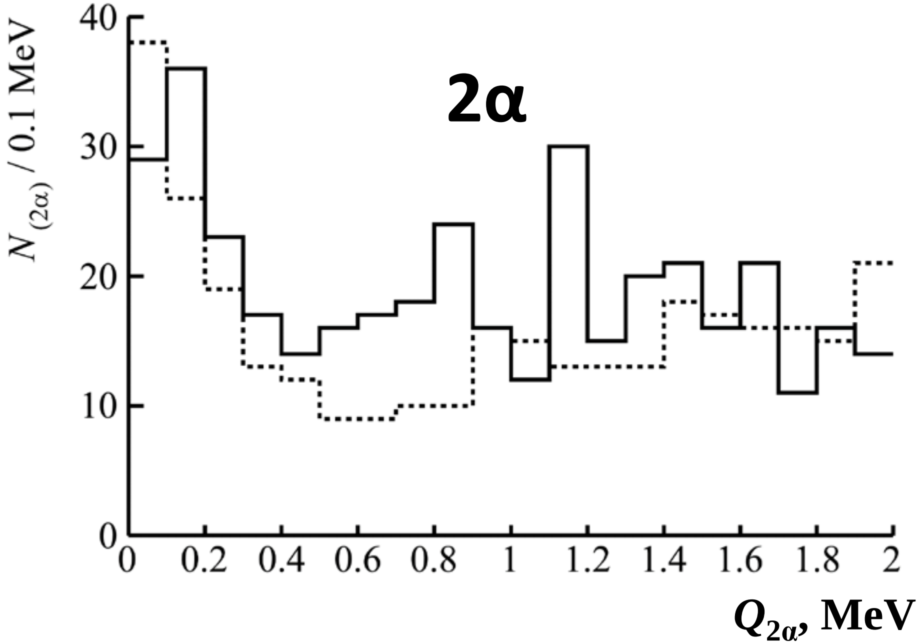
D.A. Artemenkov et al Eur. Phys. J. A (2020) 56:250

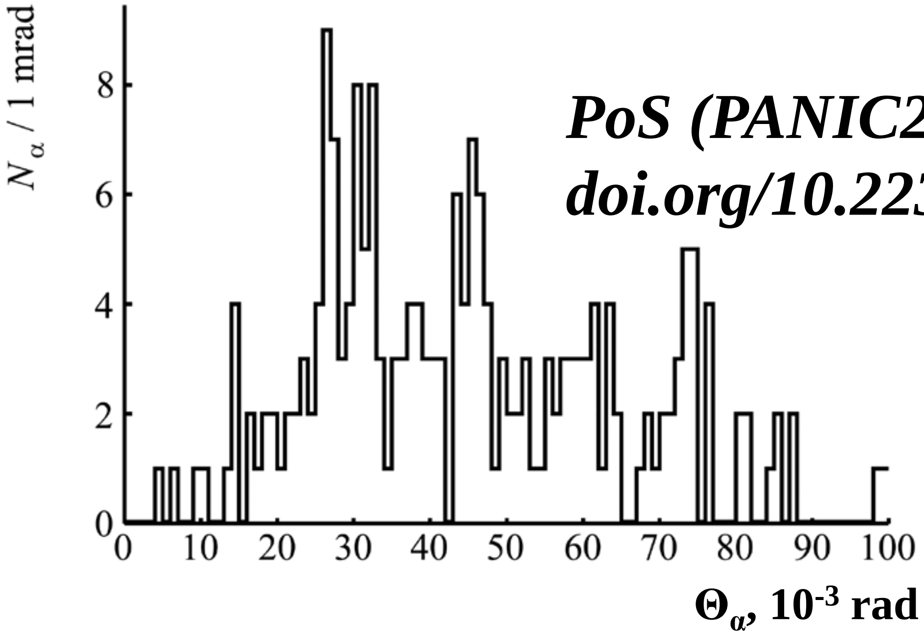
Searching for Nα states in ^{84}Kr dissociation





arXiv:2206.09690v1 [nucl-ex]





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Searching for Nα states in ^{84}Kr dissociation

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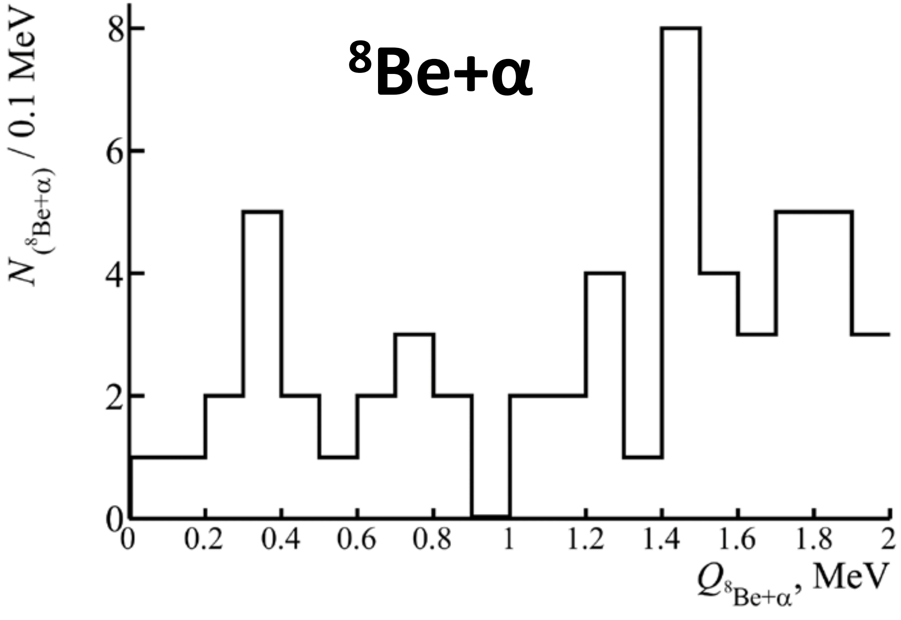
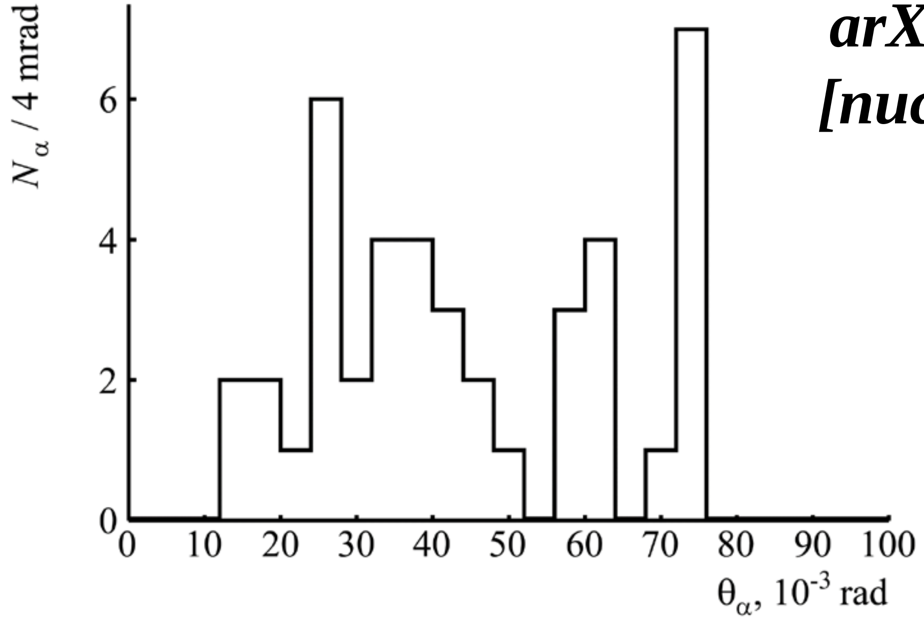
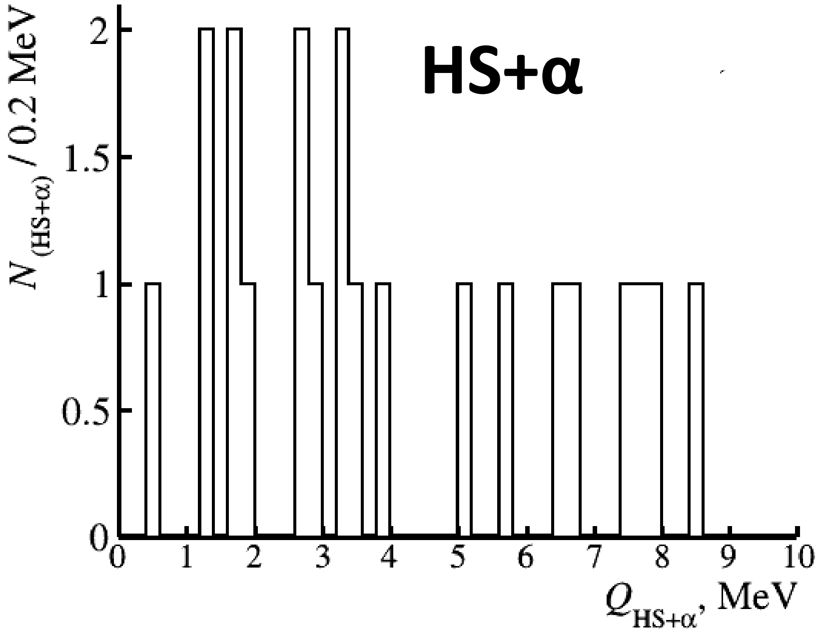
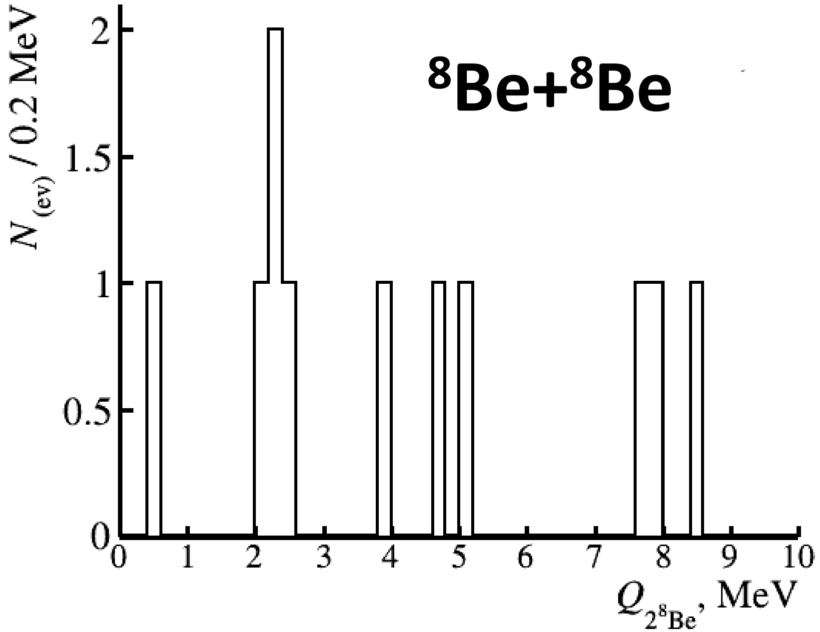


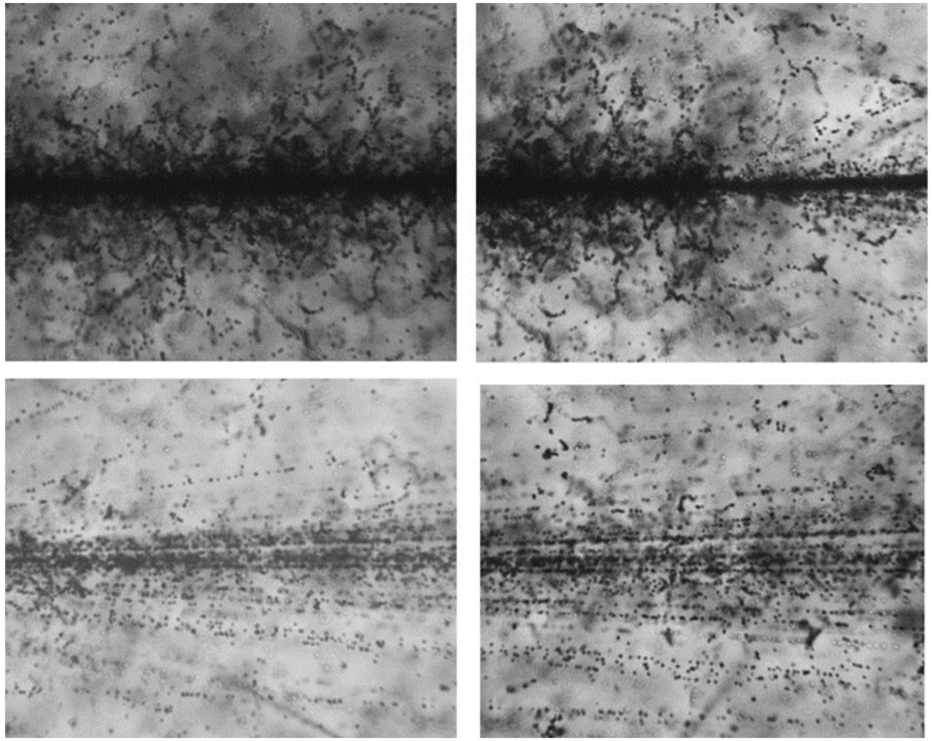


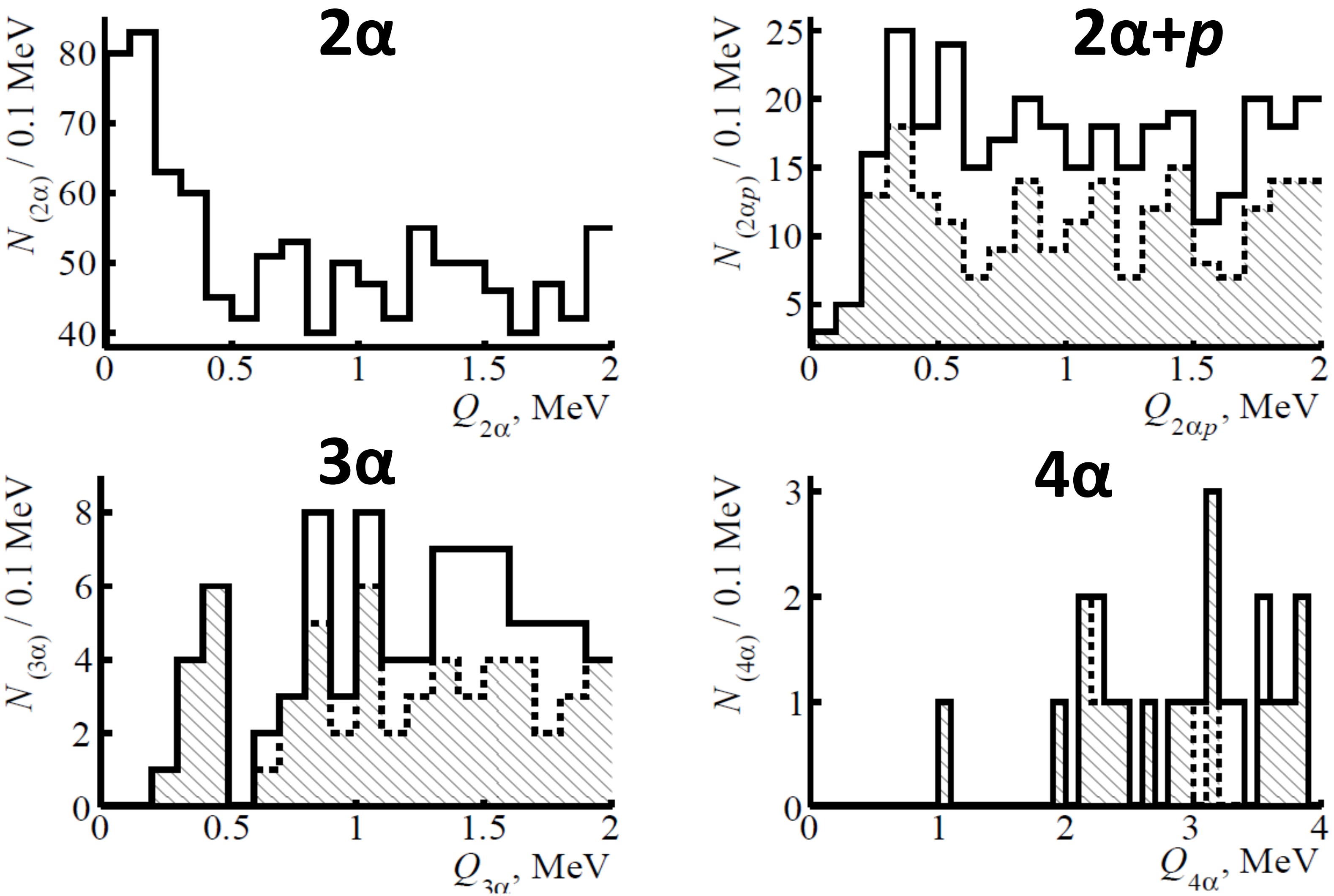




arXiv:2206.09690v1 [nucl-ex]

Au 10.7 *A* GeV





1316 interactions of 10.7 *A* GeV Au; **160 α-pairs $Q_{2\alpha}$ < 0.2 MeV; 40 events with 2α*p*-triplets $Q_{2\alpha p}$ < 0.5 MeV (^{9}B); 12 events with α-triplets $Q_{3\alpha}$ < 0.7 MeV (Hoyle state); 1 event with α-quartet $Q_{4\alpha}$ = 1 MeV.**

Summary

- **Existing experimental data on interactions of the relativistic nuclei have allowed us to determine the contribution of unstable nuclei ^{8}Be and the Hoyle state to the dissociation of the relativistic nuclei.**
- **The presented results of our analysis have indicated a relative enhancement of the ^{8}Be contribution to the increasing number of relativistic α-particles per event.**
- **The main goal of our future experiments is to explain the connection between the appearance of ^{8}Be and HS and the multiplicity of α-ensembles and search for the decays of the ^{16}O(0^{+}_{6}) state.**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