Search for cluster states in medium-heavy nuclei

Burnaby – F. Wu, C. Andreoiu, P. Spagnoletti

Orsay – C. Petrache, A. Astier, P. Jodidar, A. Courbe

Padova – D. Mengoni et al.

Legnaro – J. J. Valiente-Dobon et al.

Lanzhou – G. Song, B. F. Lv et al.

Cluster states in ^{212}Po from an EUROBALL experiment

Production of ^{212}Po

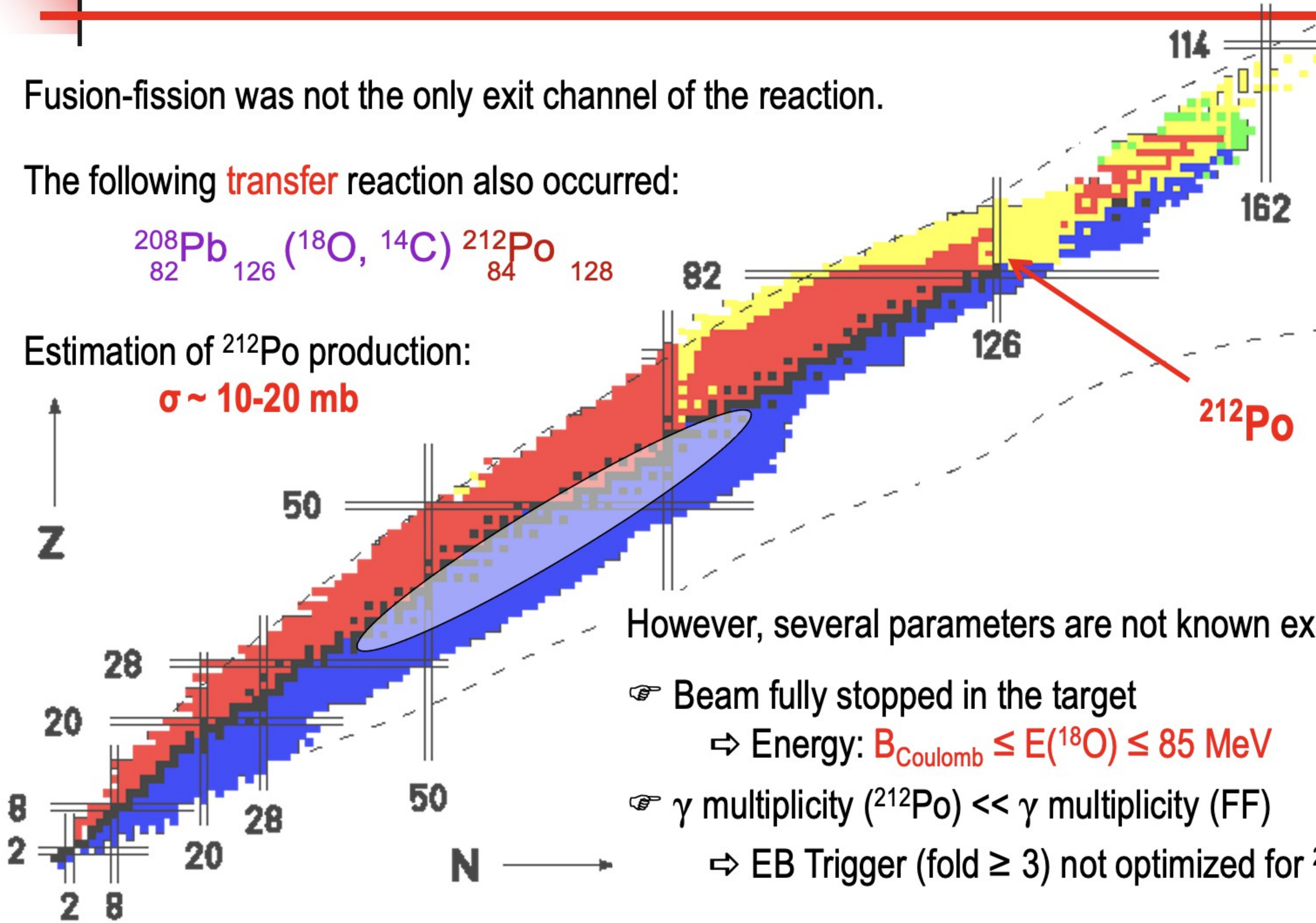
Fusion-fission was not the only exit channel of the reaction.

The following transfer reaction also occurred:

$$^{208}_{82}\mathrm{Pb}_{126}\,(^{18}\mathrm{O},\,^{14}\mathrm{C})\,^{212}_{84}\mathrm{Po}_{128}$$

Estimation of ^{212}Po production:

σ ~ 10-20 mb

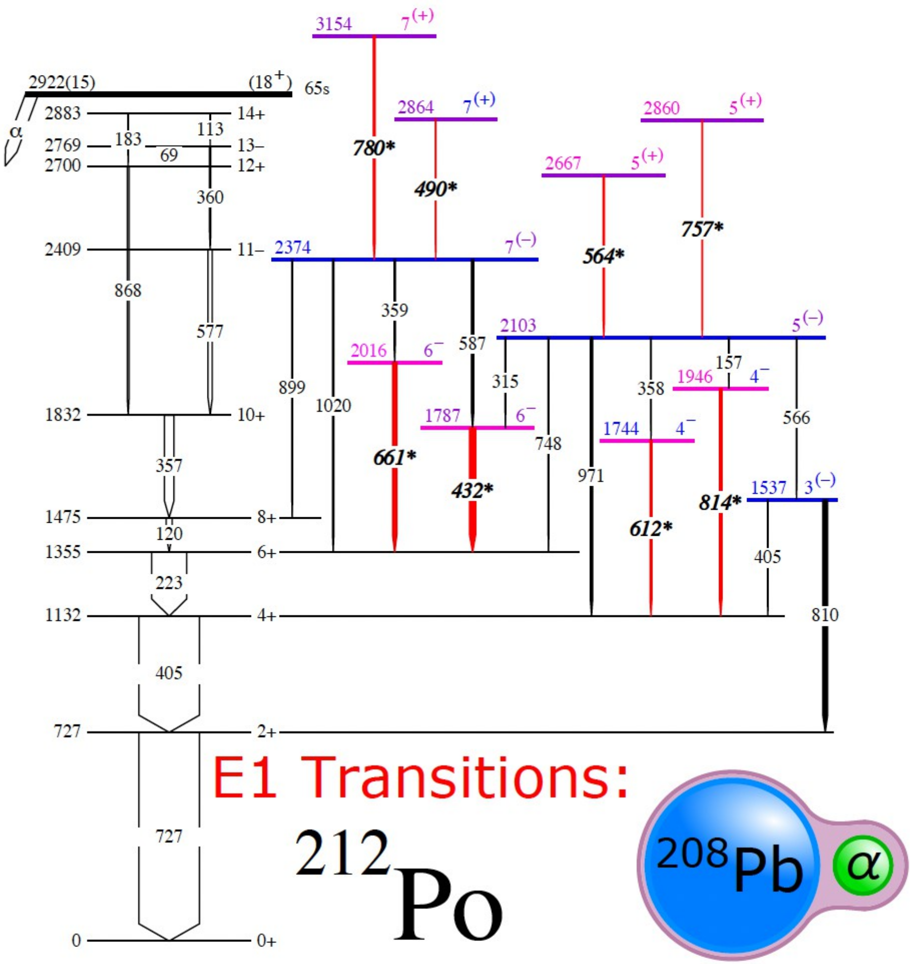


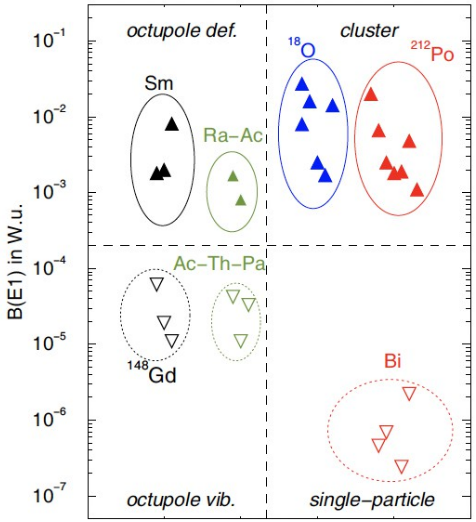
However, several parameters are not known exactly:

- ☞ Beam fully stopped in the target
  - ⇨ Energy: $B_{Coulomb} \leq E(^{18}\mathrm{O}) \leq 85$ MeV
- ☞ γ multiplicity (^{212}Po) << γ multiplicity (FF)
  - ⇨ EB Trigger (fold ≥ 3) not optimized for ^{212}Po

Alpha-clustering in excited heavy nuclei?

EUROBALL





- Enhanced E1 transitions cannot be explained by Shell Model.

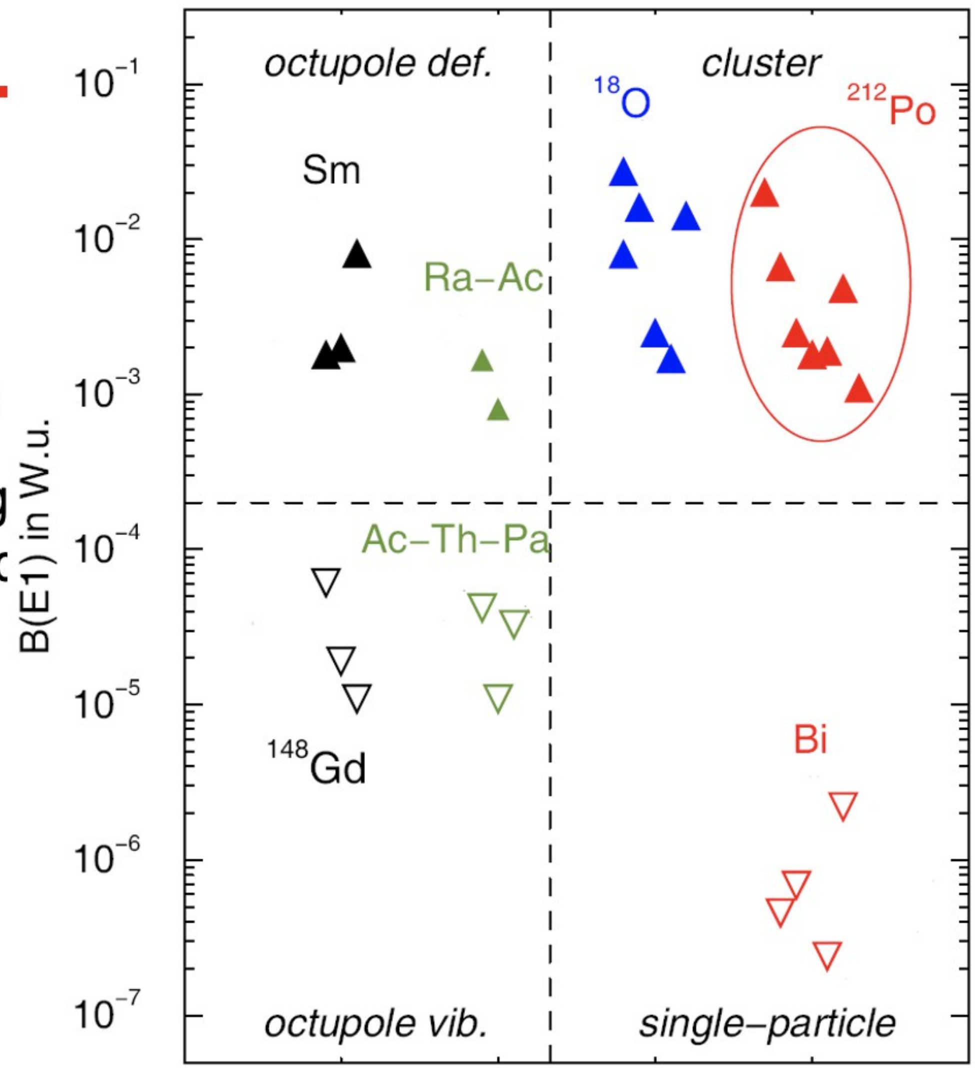
- Limited γ-spectroscopy studies.

A. Astier et al. PhysRevLett.104.042701 (2010)

Lifetime measurements

Results

- All **measured lifetimes** are in the range
- The other states, for which the decaying necessarily a lifetime **≤ 1.4 ps**, correspo target.



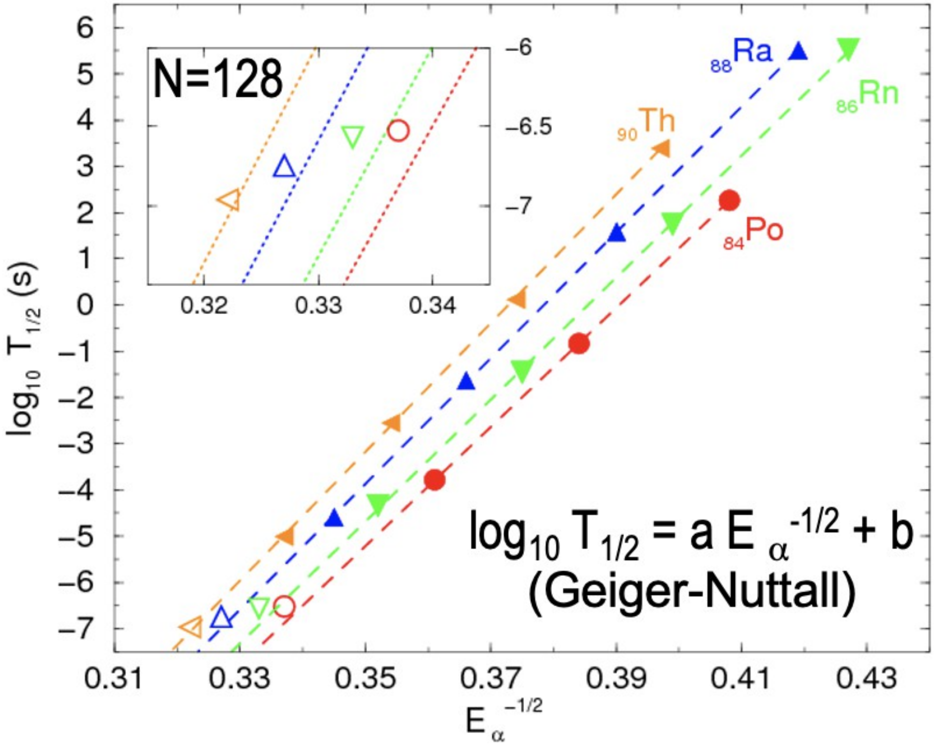
Conclusion

B(E1)’s are **huge**:

Up to **1000 times** the values of typical B(E1)’s generated by only one nucleon!

α decay of the ^{212}Po ground state

☞ The half-life of the ^{212}Po ground state is shorter than expected by the systematics



Hindrance Factor (N=128)

$_{90}$Th	$_{88}$Ra	$_{86}$Rn	$_{84}$Po
1.4	1.8	2.2	**2.3**

- $T_{1/2}$ should be larger (expected: HF(^{212}Po)~2.6)
- Sign of α preformation in ^{212}Po

^{212}Po and the shell model interpretation

The ^{212}Po description by the shell model works *relatively* well :

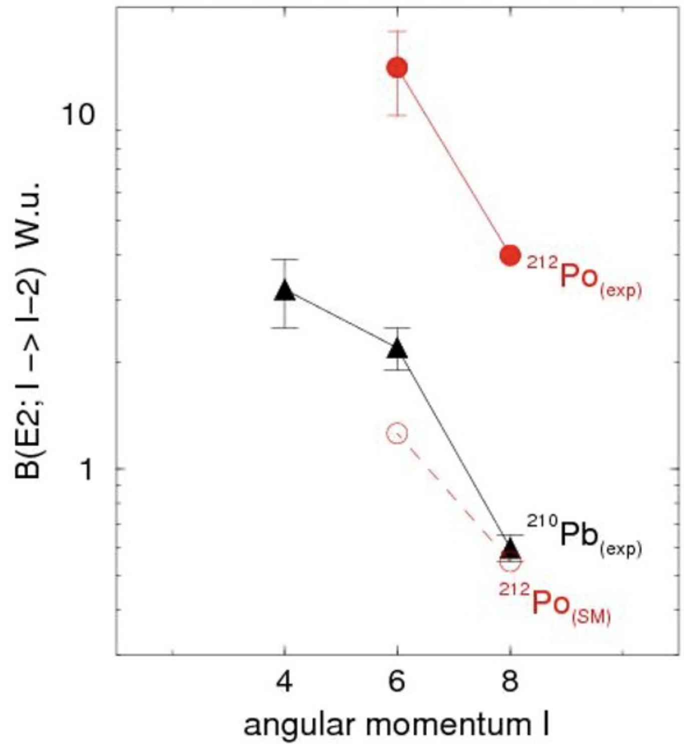
☺ The excitation energies of *yrast* states are reproduced

However it is not completely satisfactory, calculations fail to reproduce by more than an order of magnitude the experimental values:

☹ B(E2)'s (measured for the 6^+ et 8^+ states)

☹ α decay of the ground state

☹ **the new states -with non-natural parity- (4^-, 6^-, 8^-) cannot be explained at such low excitation energies**



Anomalous conversion coefficients

Table 5. Conversion coefficients for the low-energy transitions of ^{212}Po extracted from intensity balances done on gated spectra, the theoretical values come from the *BrIcc* database [28]. The transitions marked with an asterisk are discussed in sects. 3.3 and 3.4.

E (keV)		α (exp.)	α ($E1$)	α ($E2$)	α ($M1$)	Adopted
69.2	tot	0.2(1)	0.26	39.2	6.2	$E1$
113.3	tot	< 3.0	0.33	4.26	7.77	$E1$
120.3	tot	3.2(5)	0.29	3.32	6.60	$E2$
	K			0.41		
182.6	tot	0.6(3)	0.10	0.65	2.00	$E2$
222.6	tot	0.33(5)	0.063	0.33	1.15	$E2$
	K			0.13		
276.1*	tot	0.37(7)	0.038	0.162	0.635	$E1^{(a)}$
	K	~ 0.4	0.031	0.081	0.516	
432.3*	tot	0.13(3)	0.014	0.046	0.188	$E1^{(a)}$
	K	~ 0.1	0.011	0.030	0.153	

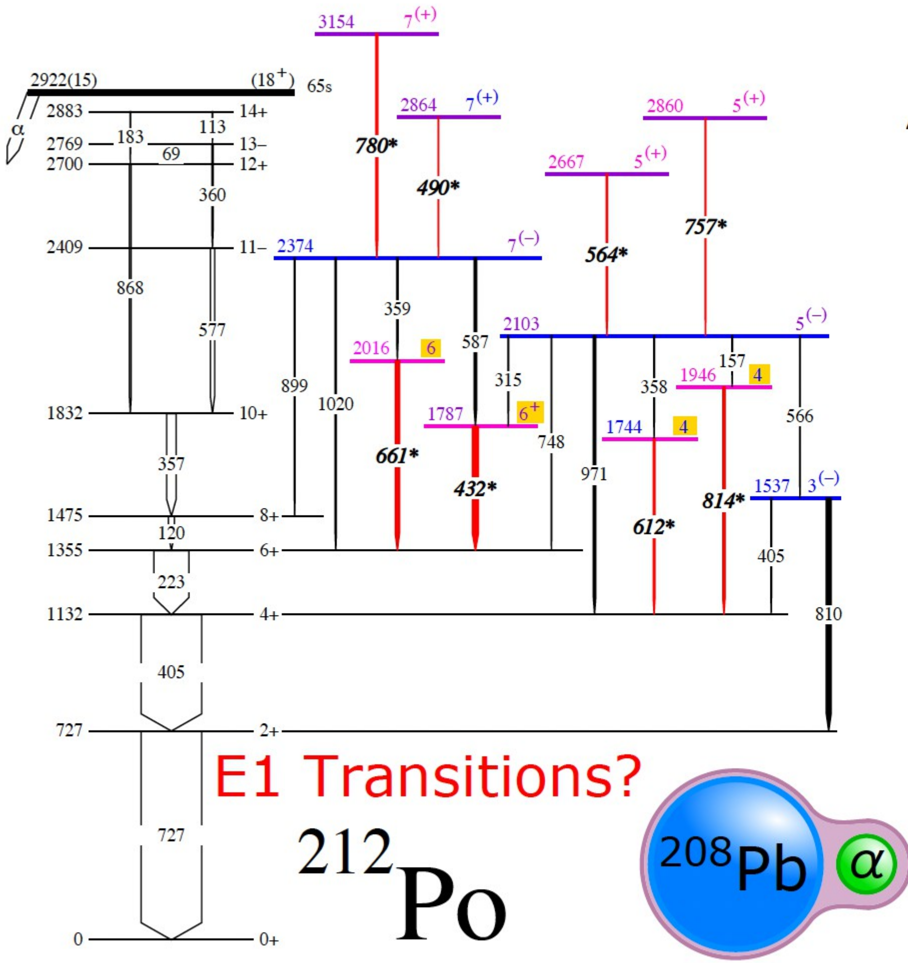
$^{(a)}$ See sect. 3.3.

- The a_2 angular coefficient computed for such mixed multipolarities is no longer in agreement with the measured values, as the quadrupole component leads to a large decrease of the a_2 coefficient (for $\delta = +1$) and even to a quasi-isotropic emission (for $\delta = -1$).
- The $B(E2)$ reduced transition probability computed from the lifetime of the 1751 keV state (given in the next section) largely exceeds the recommended upper limit (RUL) for γ-ray strengths: $B(E2, 276\,\mathrm{keV}) \sim 5 \times 10^3$ W.u., that is larger than what is obtained for $E2$ transitions *inside* the superdeformed bands in the Hg-Pb region, $B(E2, \mathrm{SD}) \sim 2 \times 10^3$ W.u.

It is noteworthy that the $E2$ component of the 432 keV transition would lead to $B(E2) \sim 6 \times 10^2$ W.u. Such a large value would be the sign of a quadrupole deformation, implying a rotational behaviour, contrary to what is observed (the 120 keV transition populating the same yrast state as the 432 keV transition has $B(E2) \sim 10$ W.u., see fig. 13).

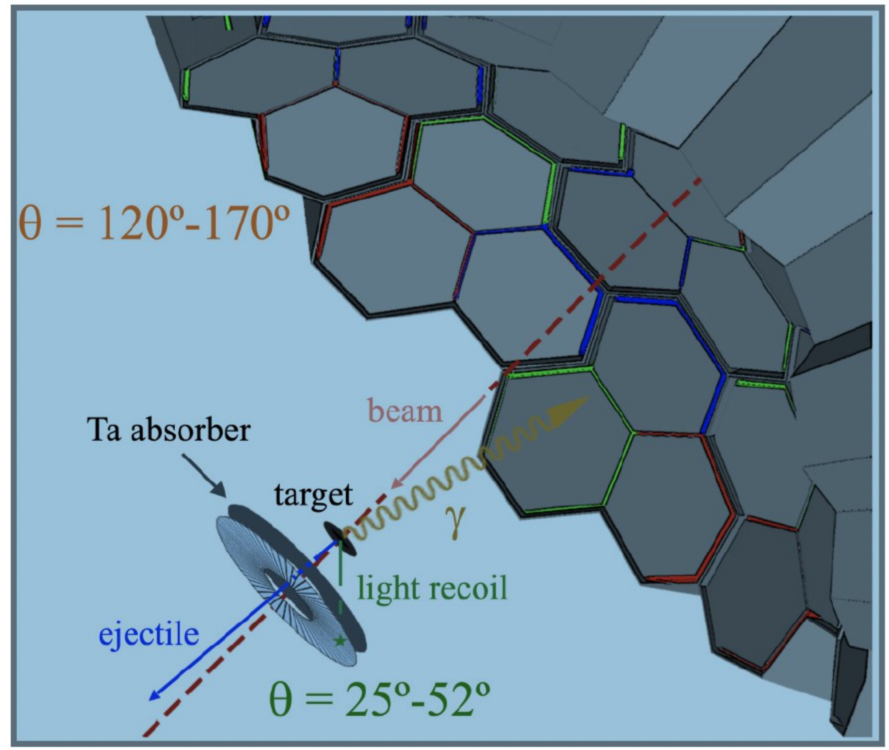
Cluster states in ^{212}Po questioned from an AGATA experiment

Alpha-clustering in excited heavy nuclei?



E1 Transitions?

AGATA: Compton polarimetry



- Reassigned to M1 transitions, explained by Shell Model.

A. FERNÁNDEZ et al. PHYSICAL REVIEW C 104, 054316 (2021)

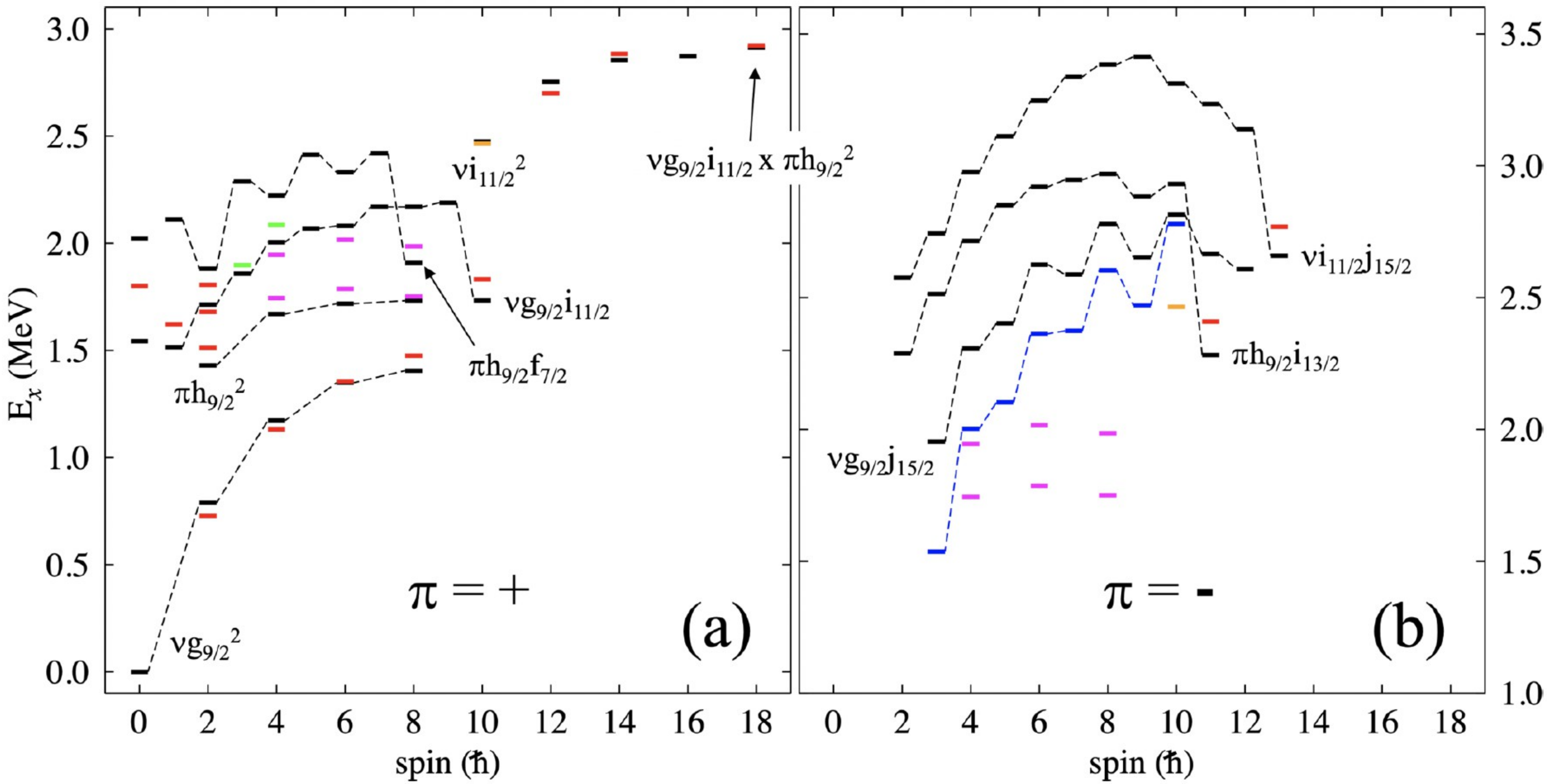


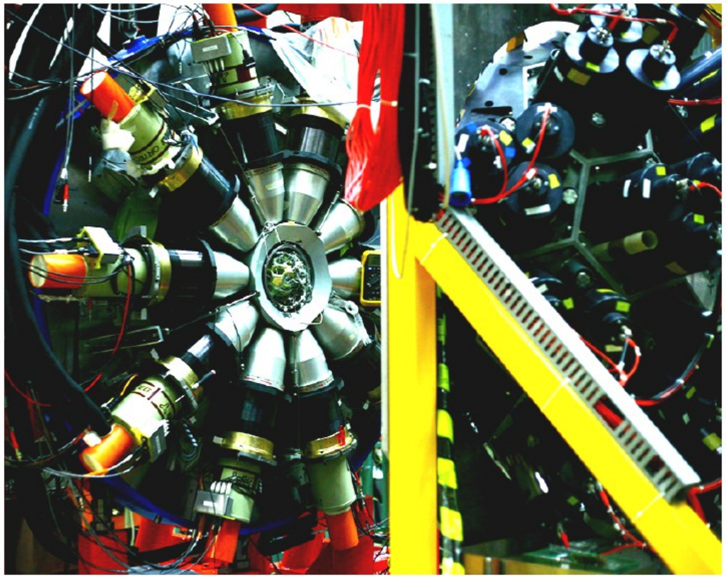
FIG. 13. Comparison between calculated (black) and experimental (colored) excited states of (a) positive and (b) negative parity in ^{212}Po. The results of the calculations performed with the KHPE interaction are presented. Calculated states sharing a >50% main component of the wave function, as well as the experimentally established levels shown in blue in Fig. 10, are connected by dashed lines.

Cluster states in ^{126}Te?

Results of a previous experiment ^{13}C + ^{122}Sn

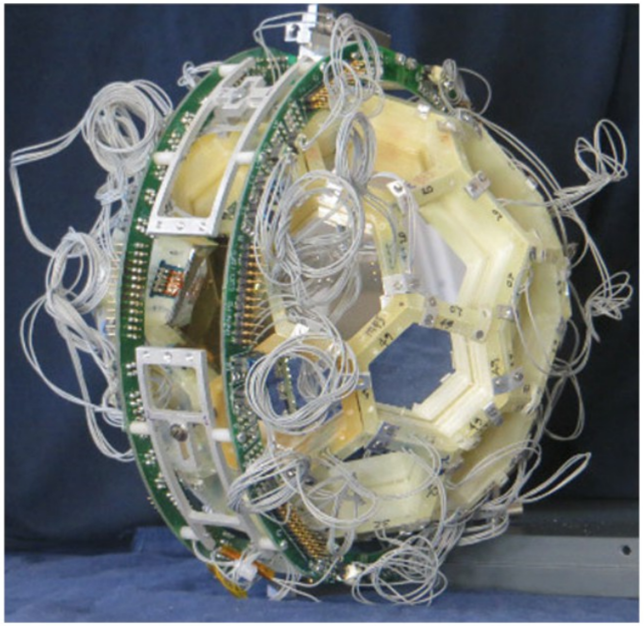
Gamma ray detection: Gamma Array of Legnaro INFN Laboratories for nuclEar spectroscopy (GALILEO):

- Array of High-Purity Ge (HPGe) crystals with high energy resolution.
- 25 detectors for $\sim 2\pi$ coverage.



Charged particle detection and ID: EUCLIDES:

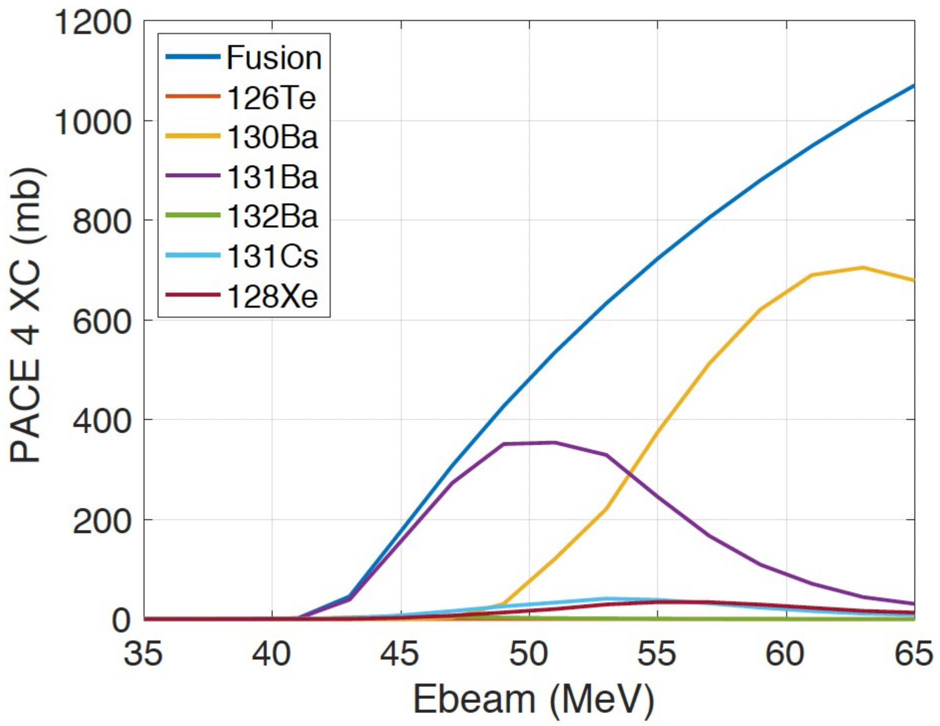
- Array of E-ΔE Si housed in the reaction chamber.
- 55-segment for $\sim 4\pi$ coverage.

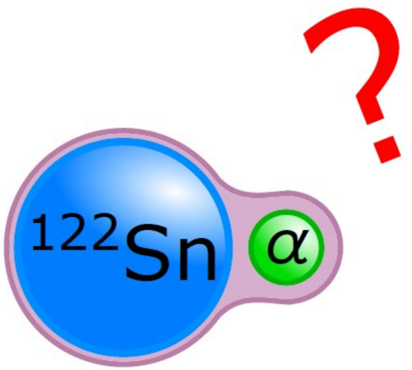


Beam: 65 MeV ^{13}C onto ^{122}Sn.

Eur. Phys. J. A (2019) 55: 47

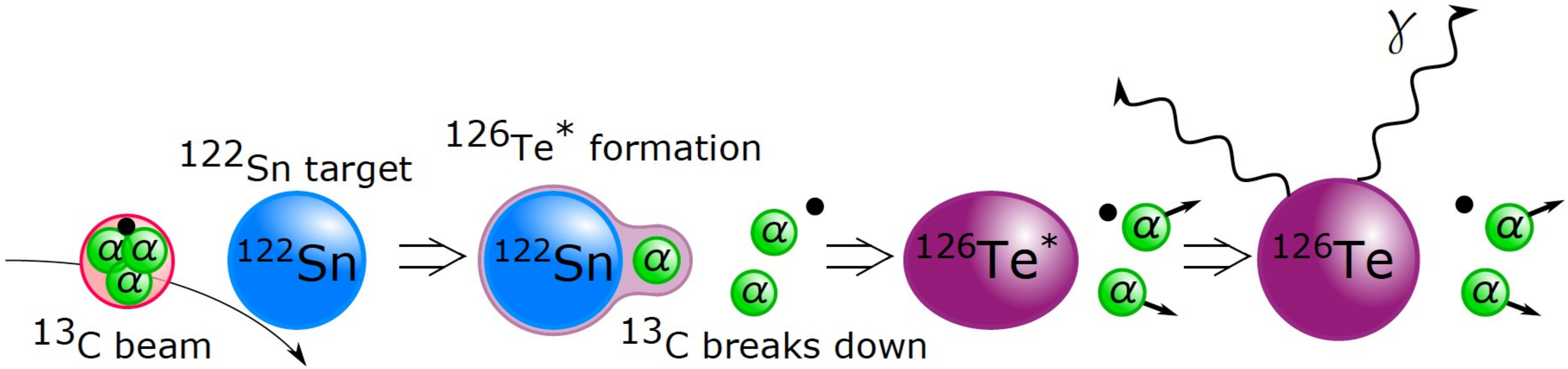
High production rate of ^{126}Te observed at LNL in 2017





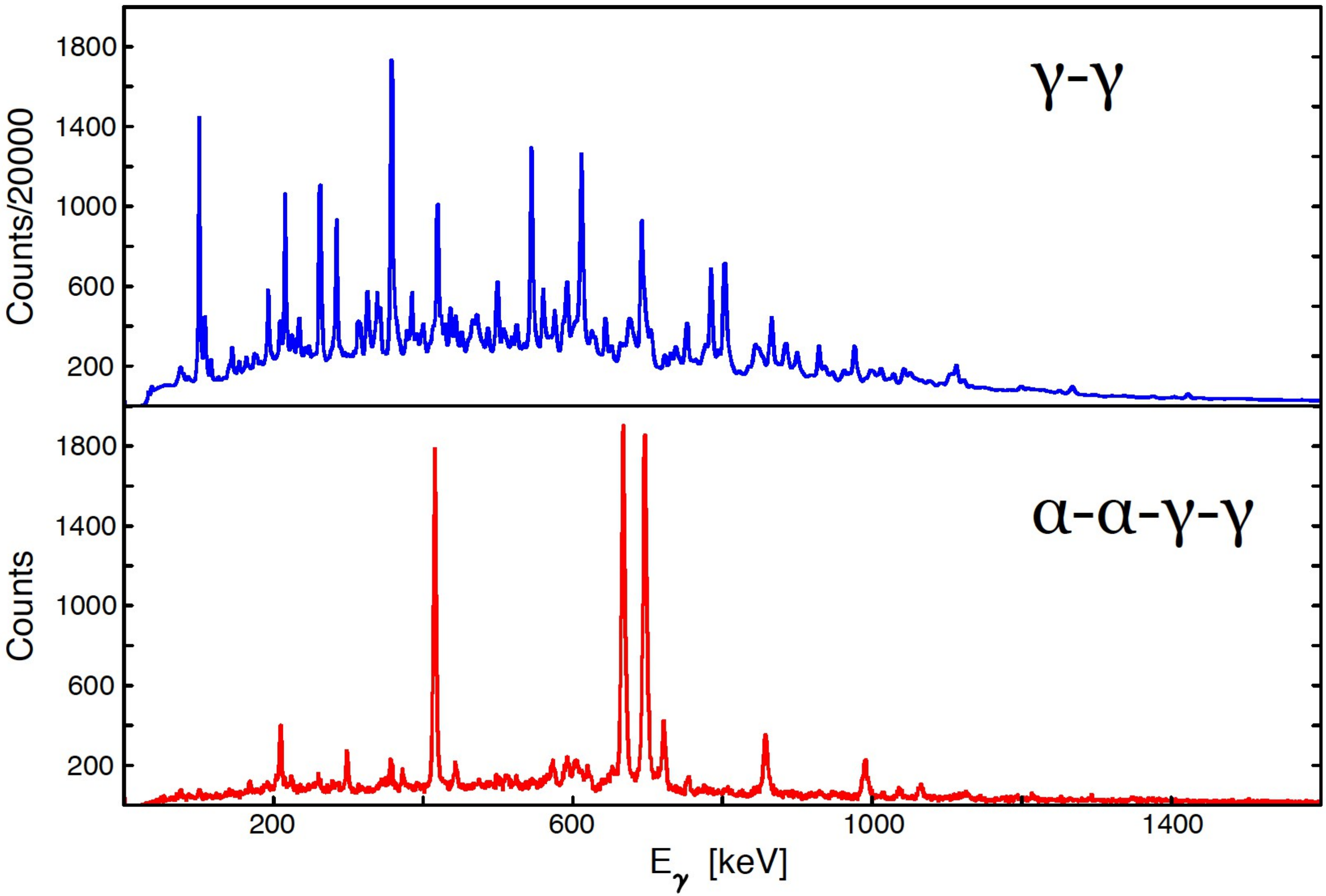
- Predicted ^{126}Te fusion-evaporation cross-section is 0.02 mb.
- Observed at least 4 mb, $\sim$ 200X higher.
- Alpha-transfer or incomplete fusion to suggest clustering?

^{126}Te production



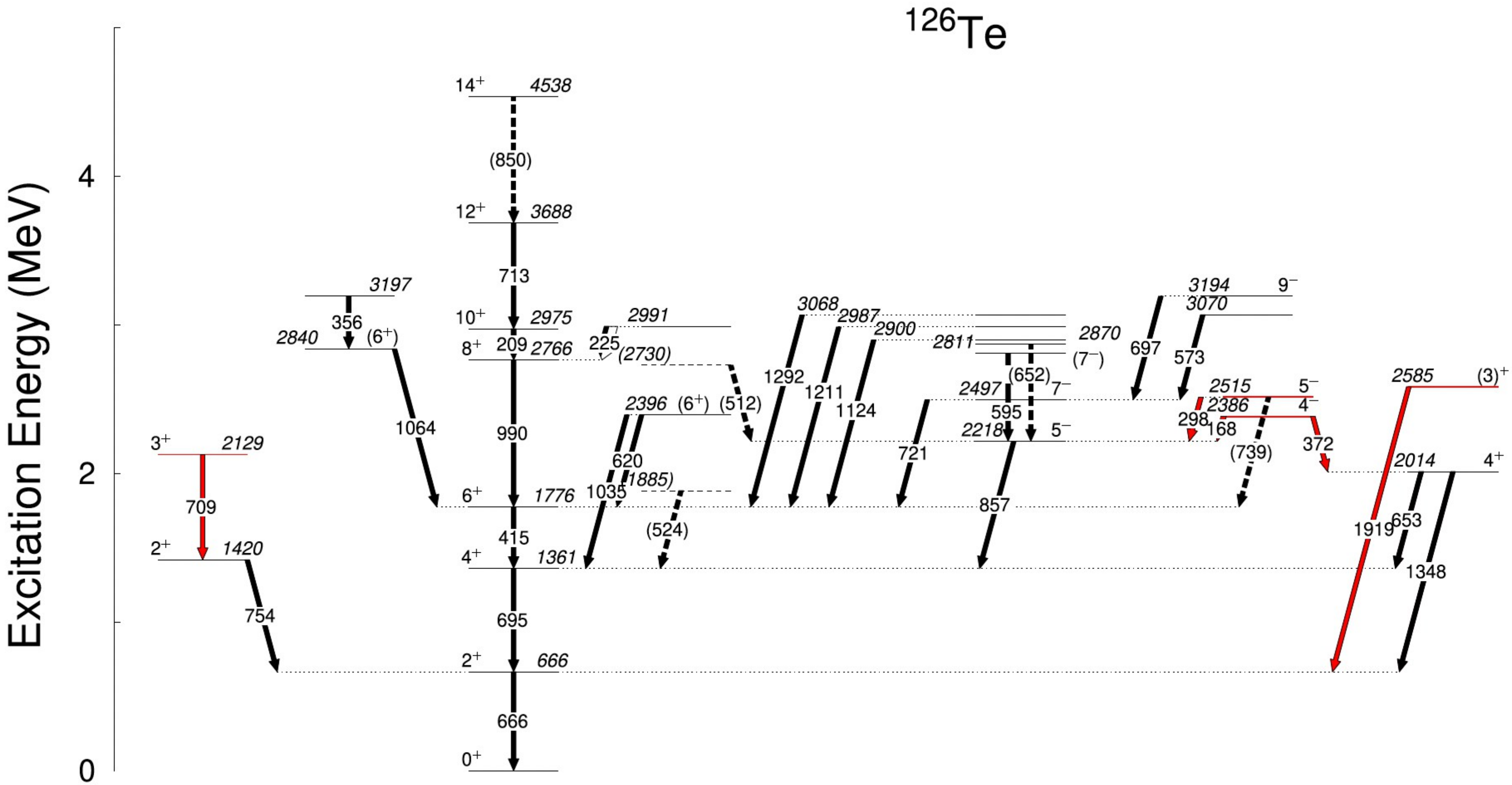
- Particle-gamma coincidence.
- Emits α's: PID to select reaction channel.

Preliminary gamma-ray spectra



- The α-tagging with PID selects one event in 20000.

Preliminary Level Scheme from GALILEO



- Transitions in red not seen in higher-statistics fusion-evaporation.

Two questions:

1. Should we continue to search for cluster states by measuring γ rays?

2. Which nuclei are the best candidates?

PHYSICAL REVIEW C **89**, 064321 2014)

Neutron skin thickness of heavy nuclei with particle correlations and the slope of the nuclear symmetry energy

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Received 12 March 2014; revised manuscript received 23 May 2014; published 30 June 2014)

PHYSICAL REVIEW C **89**, 064321 2014)

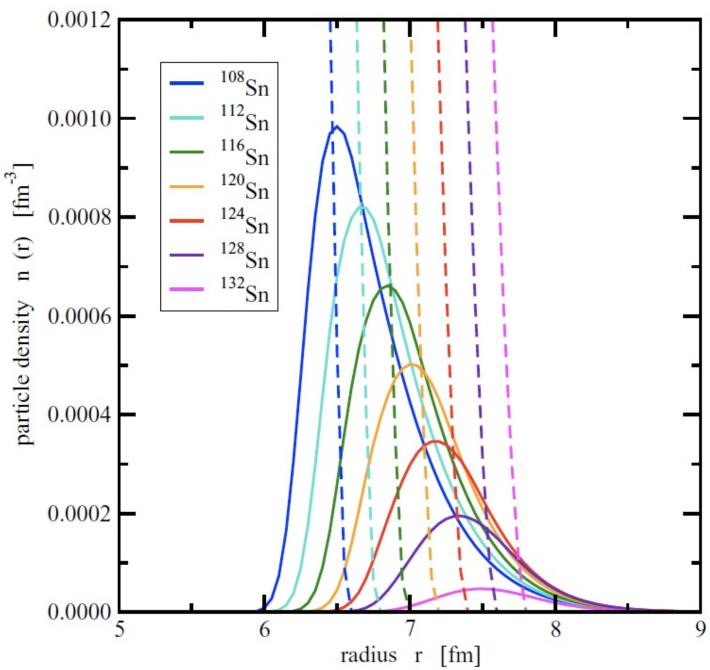

FIG. 1. Color online) Radial density distribution of α particles full lines) and neutrons dashed lines) for a selected set of isotopes of the Sn chain from ^{108}Sn leftmost curve) to ^{132}Sn rightmost curve).

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NUCLEAR PHYSICS

From nuclear clusters to neutron stars

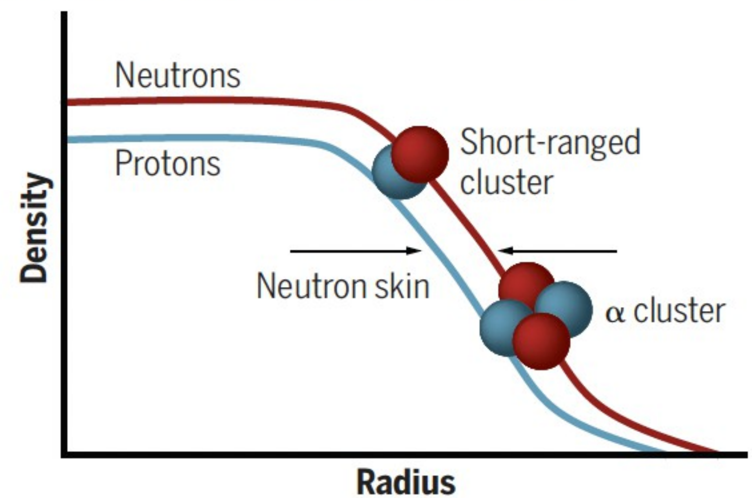
Measurements of α cluster formation in nuclear "skins" can improve neutron star models

By **Or Hen**

Probing neutron skins

The neutron skin, the region where neutron density exceeds proton densities in nuclei, is affected by a cluster formation in the outer low-density regions (as measured by Tanaka *et al.*) and short-ranged clusters at higher-density regions.

Nucleon density in neutron-rich nuclei



REPORT

Tanaka *et al.*, *Science* **371**, 260–264 (2021)

NUCLEAR PHYSICS

Formation of α clusters in dilute neutron-rich matter

Junki Tanaka[1,2,3]*, Zaihong Yang[3,4]*, Stefan Typel[1,2], Satoshi Adachi[4], Shiwei Bai[5], Patrik van Beek[1], Didier Beaumel[6], Yuki Fujikawa[7], Jiaxing Han[5], Sebastian Heil[1], Siwei Huang[5], Azusa Inoue[4], Ying Jiang[5], Marco Knösel[1], Nobuyuki Kobayashi[4], Yuki Kubota[3], Wei Liu[5], Jianling Lou[5], Yukie Maeda[8], Yohei Matsuda[9], Kenjiro Miki[10], Shoken Nakamura[4], Kazuyuki Ogata[4,11], Valerii Panin[3], Heiko Scheit[1], Fabia Schindler[1], Philipp Schrock[12], Dmytro Symochko[1], Atsushi Tamii[4], Tomohiro Uesaka[3], Vadim Wagner[1], Kazuki Yoshida[13], Juzo Zenihiro[3,7], Thomas Aumann[1,2,14]

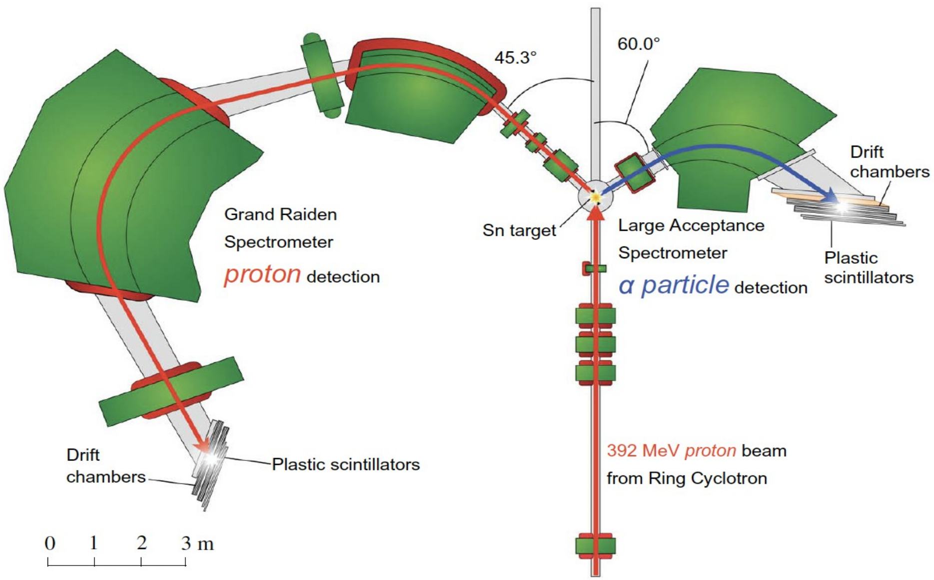
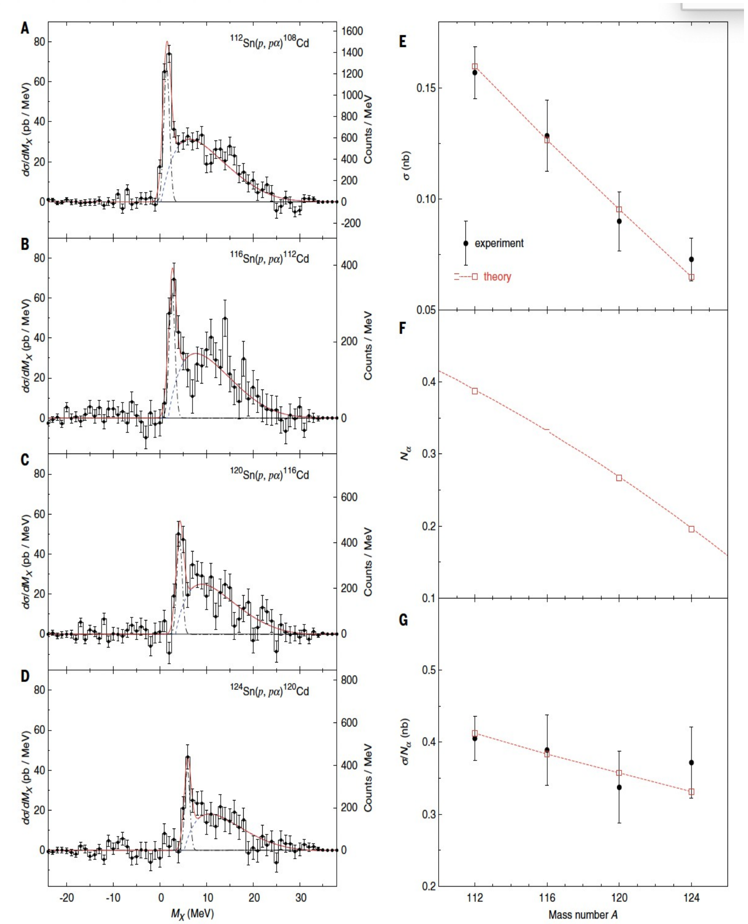
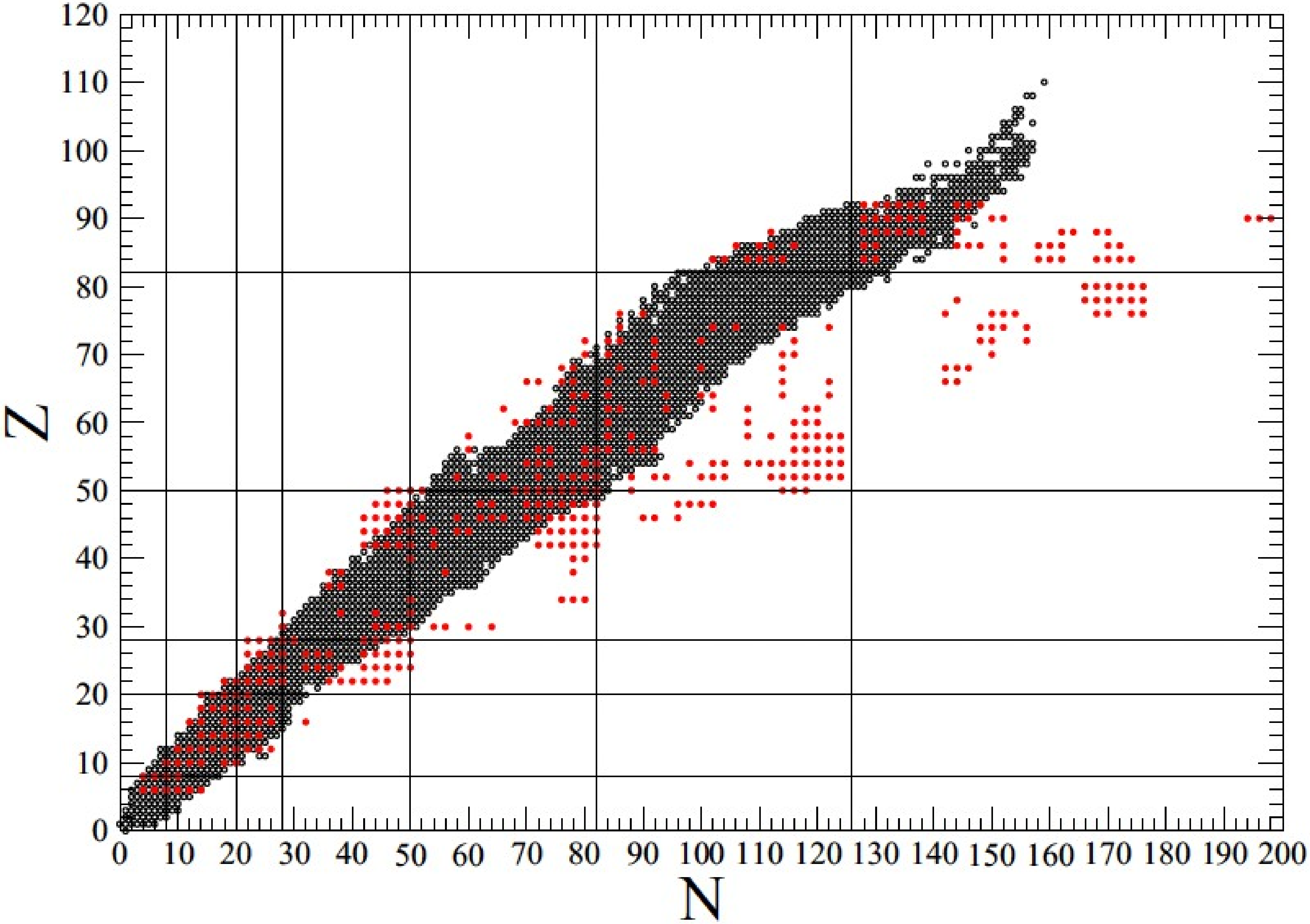


Fig. 1. Schematic illustration of the experimental setup. A 392-MeV proton beam from the ring cyclotron accelerator impinges on a tin target. After a $^{A}\mathrm{Sn}(p, p\alpha)^{A-4}\mathrm{Cd}$ reaction, a scattered proton is detected by the focal-plane detectors, drift chambers, and plastic scintillators after traversing the Grand Raiden spectrometer at an angle of 45.3° with respect to the proton beam. A knocked-out α particle is detected by the focal-plane detectors behind the LAS spectrometer at an angle of 60.0° with respect to the proton beam.



Single-particle spatial dispersion and clusters in nuclei

J.-P. Ebran,[1] E. Khan,[2] R.-D. Lasseri,[2] and D. Vretenar[3]



PHYSICAL REVIEW C **106**, 064330 (2022)

α-particle formation and clustering in nuclei

E. Khan,[1] L. Heitz,[1] F. Mercier,[1] and J.-P. Ebran[2,3]
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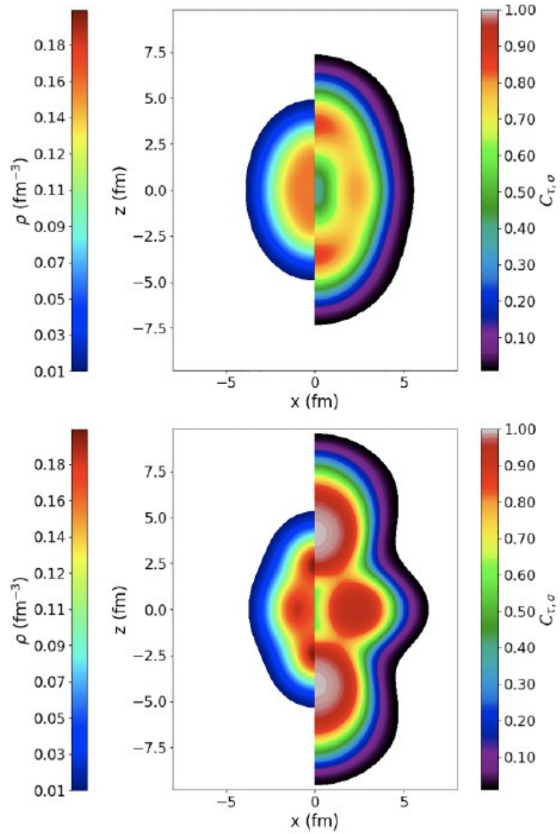

FIG. 4. Microscopic calculations of the density (left part of the figures) and NLF (right part of the figures) in the ground state of ^{20}Ne, using the SLy5 (top) and DD-ME2 (bottom) EDF.

Thank you