Clustering in nuclei: experimental approaches and perspectives

Caterina Ciampi

GANIL

24th Colloque GANIL

Bussang, France
September 21st - 25th, 2026

Clustering in nuclei

A phenomenon across the nuclear chart

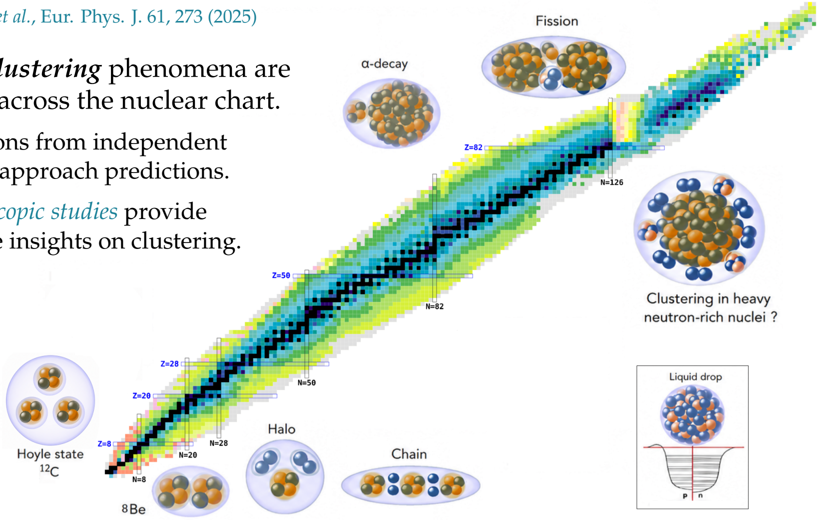
Clustering: tendency of many-body systems to form correlated structures, ubiquitous phenomenon in nature across a large range of scales.

T. Nakamura *et al.*, Eur. Phys. J. 61, 273 (2025)

Nuclear clustering phenomena are observed across the nuclear chart.

→ Deviations from independent particle approach predictions.

→ *Spectroscopic studies* provide valuable insights on clustering.



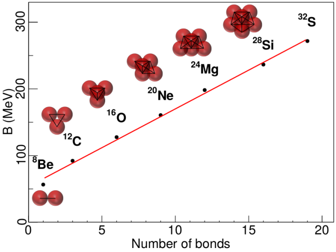
Clustering in α-conjugate nuclei

First descriptions in the nuclear landscape

Alpha-conjugate nuclei show the strongest evidences of clustering:

- Early description: binding energy in terms of number of interactions between the alpha constituents $N_{\alpha-\text{interactions}}$.

  L. Hafstad and E. Teller, Phys. Rev. 54, 681 (1938).



Clustering in α-conjugate nuclei

First descriptions in the nuclear landscape

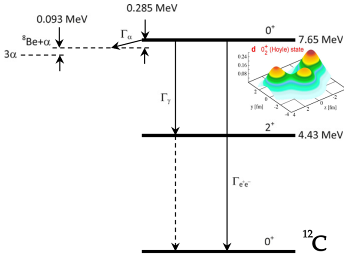
Alpha-conjugate nuclei show the strongest evidences of clustering:

- Early description: binding energy in terms of number of interactions between the alpha constituents $N_{\alpha-\text{interactions}}$.

  L. Hafstad and E. Teller, Phys. Rev. 54, 681 (1938).

- ^{12}**C Hoyle state**: second excited 0^+ state at 7.65 MeV, crucial for 3α process in stellar nucleosynthesis and key to organic life, strong α-cluster character.

  F. Hoyle, Astrophys. J. Suppl. Ser. 1, 121 (1954).

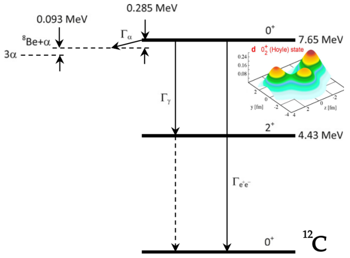


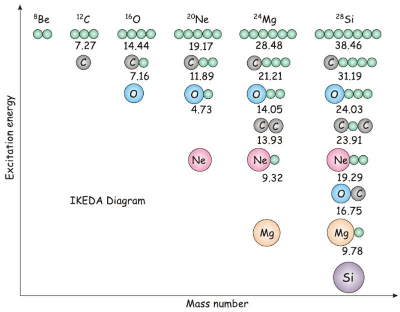
Clustering in α-conjugate nuclei

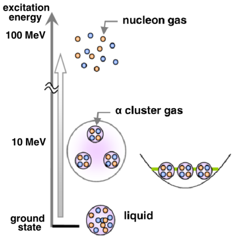
First descriptions in the nuclear landscape

Alpha-conjugate nuclei show the strongest evidences of clustering:

- Early description: binding energy in terms of number of interactions between the alpha constituents $N_{\alpha-\text{interactions}}$.
  L. Hafstad and E. Teller, Phys. Rev. 54, 681 (1938).
- ^{12}**C Hoyle state**: second excited 0^+ state at 7.65 MeV, crucial for 3α process in stellar nucleosynthesis and key to organic life, strong α-cluster character.
  F. Hoyle, Astrophys. J. Suppl. Ser. 1, 121 (1954).
- **Ikeda conjecture**:
  cluster nature ↔ cluster decay threshold
  K. Ikeda *et al.*, Prog. Theor. Phys. Suppl. E 68, 464 (1968).







Bose-Einstein-condensate-like states in $N\alpha$ nuclei

Interpretation of Hoyle-like states, associated with their large radius and low density $\rightarrow$ THSR wave function

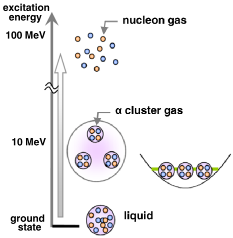
A. Tohsaki *et al.*, Phys. Rev. Lett. 87, 192501 (2001)

Good description of ^{8}Be and ^{12}C, while indications but no conclusive evidence for ^{16}O, ^{20}Ne, ^{24}Mg.

J. Chen *et al.*, Sci. Bull. 68, 1119 (2023), S. Adachi *et al.*, Phys. Lett. B 819, 136411 (2021)

Clustering in α-conjugate nuclei

Alpha-condensate-like states



Bose-Einstein-condensate-like states in $N\alpha$ nuclei
Interpretation of Hoyle-like states, associated with their large radius and low density → THSR wave function

A. Tohsaki *et al.*, Phys. Rev. Lett. 87, 192501 (2001)

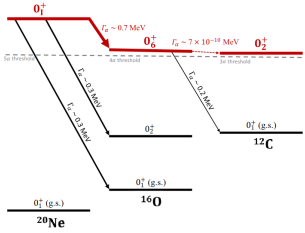
Good description of ^{8}Be and ^{12}C, while indications but no conclusive evidence for ^{16}O, ^{20}Ne, ^{24}Mg.

J. Chen *et al.*, Sci. Bull. 68, 1119 (2023), S. Adachi *et al.*, Phys. Lett. B 819, 136411 (2021)

Experimental search for BEC-like states in $N\alpha$ nuclei:

- Enhanced yield α cluster emission
- Low kinetic energy of the decay products
- Decay path through α-condensate subsystems

Precision break-up measurements with complete detection of multi-α decay products
→ clean reconstruction of the decay path



B. Zhou *et al.*, Nat. Comm. 14, 8206 (2023)

Clustering in non-α conjugate nuclei

Beyond the Ikeda diagram: more exotic manifestations of clustering

Clustering phenomena also appear in **non-α-conjugate nuclei**:
the description extends to **nuclear molecules** and **generalized clusters**.

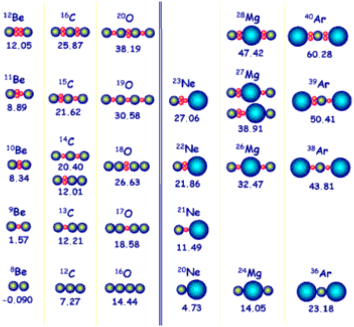
Clustering in non-α conjugate nuclei

Beyond the Ikeda diagram: more exotic manifestations of clustering

Clustering phenomena also appear in **non-α-conjugate nuclei**:
the description extends to **nuclear molecules** and **generalized clusters**.

Nuclear molecules: Nuclear structures based on α-cores + extra nucleons acting as covalent bonds.
$\rightarrow$ *extended Ikeda diagram*

W. von Oertzen *et al.*, Phys. Rep. 432, 43-113 (2006)



Clustering in non-α conjugate nuclei

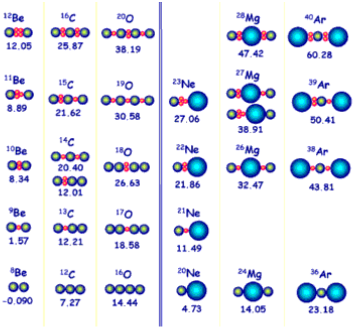
Beyond the Ikeda diagram: more exotic manifestations of clustering

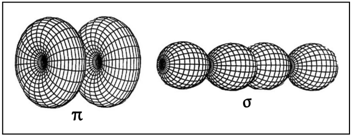
Clustering phenomena also appear in **non-α-conjugate nuclei**:
the description extends to **nuclear molecules** and **generalized clusters**.

Nuclear molecules: Nuclear structures based on α-cores + extra nucleons acting as covalent bonds.
$\longrightarrow$ *extended Ikeda diagram*

W. von Oertzen *et al.*, Phys. Rep. 432, 43-113 (2006)

- Be isotopes: *dimeric* configuration.
  Valence neutrons $\rightarrow$ σ or π molecular orbitals
  ^{10}Be in AMD: Y. Kanada En'yo *et al.*, Phys. Rev. C 60, 064304 (1999)
  $\longrightarrow$ *see talk by* *L. Dienis*





Clustering in non-α conjugate nuclei

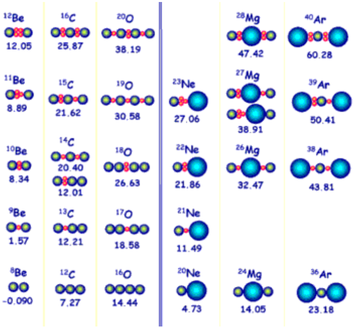
Beyond the Ikeda diagram: more exotic manifestations of clustering

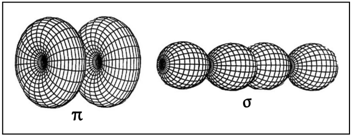
Clustering phenomena also appear in **non-α-conjugate nuclei**:
the description extends to **nuclear molecules** and **generalized clusters**.

Nuclear molecules: Nuclear structures based on α-cores + extra nucleons acting as covalent bonds.
$\rightarrow$ *extended Ikeda diagram*

W. von Oertzen *et al.*, Phys. Rep. 432, 43-113 (2006)

- Be isotopes: *dimeric* configuration.
  Valence neutrons $\rightarrow$ σ or π molecular orbitals
  ^{10}Be in AMD: Y. Kanada En'yo *et al.*, Phys. Rev. C 60, 064304 (1999)
  $\rightarrow$ *see talk by L. Dienis*
- C isotopes: *trimeric* configuration.
  3α in triangular/linear configurations
  ^{16}C in AMD: T. Baba *et al.*, Phys. Rev. C 97, 054315 (2018)





Clustering in non-α conjugate nuclei

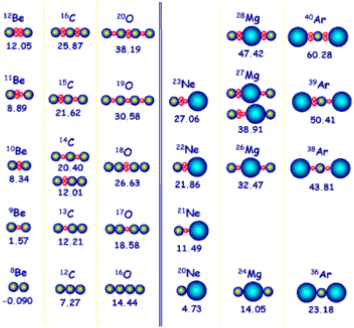
Beyond the Ikeda diagram: more exotic manifestations of clustering

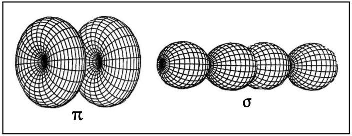
Clustering phenomena also appear in **non-α-conjugate nuclei**:
the description extends to **nuclear molecules** and **generalized clusters**.

Nuclear molecules: Nuclear structures based on α-cores + extra nucleons acting as covalent bonds.
$\rightarrow$ *extended Ikeda diagram*

W. von Oertzen *et al.*, Phys. Rep. 432, 43-113 (2006)

- Be isotopes: *dimeric* configuration.
  Valence neutrons $\rightarrow$ σ or π molecular orbitals
  ^{10}Be in AMD: Y. Kanada En'yo *et al.*, Phys. Rev. C 60, 064304 (1999)
  $\rightarrow$ *see talk by L. Dienis*
- C isotopes: *trimeric* configuration.
  3α in triangular/linear configurations
  ^{16}C in AMD: T. Baba *et al.*, Phys. Rev. C 97, 054315 (2018)
- Nuclear *polymers* for heavier species
  $\rightarrow$ more exotic configurations





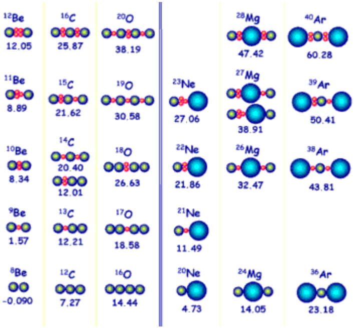
Clustering in non-α conjugate nuclei

Beyond the Ikeda diagram: more exotic manifestations of clustering

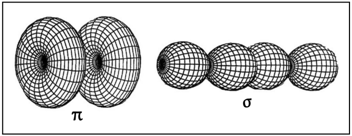
Clustering phenomena also appear in **non-α-conjugate nuclei**:
the description extends to **nuclear molecules** and **generalized clusters**.

Nuclear molecules: Nuclear structures based on α-cores + extra nucleons acting as covalent bonds.
$\rightarrow$ *extended Ikeda diagram*

W. von Oertzen *et al.*, Phys. Rep. 432, 43-113 (2006)



- Be isotopes: *dimeric* configuration.
  Valence neutrons $\rightarrow$ σ or π molecular orbitals
  ^{10}Be in AMD: Y. Kanada En'yo *et al.*, Phys. Rev. C 60, 064304 (1999)
  $\rightarrow$ *see talk by L. Dienis*
- C isotopes: *trimeric* configuration.
  3α in triangular/linear configurations
  ^{16}C in AMD: T. Baba *et al.*, Phys. Rev. C 97, 054315 (2018)
- Nuclear *polymers* for heavier species
  $\rightarrow$ more exotic configurations



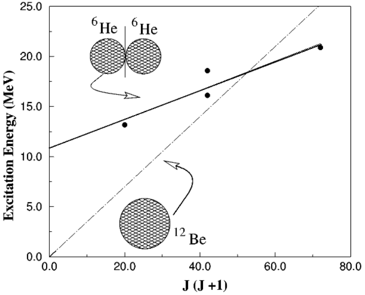
Generalized clusters: Description introducing clusters more weakly bound than α in the proposed molecular structure, such as d, t, ^{3}He.

Molecular-like structures $\leftrightarrow$ Pronounced deformations $\rightarrow$ *Rotational bands*.

Molecular-like structures $\leftrightarrow$ Pronounced deformations $\rightarrow$ *Rotational bands*.

Be isotopes (dimers):

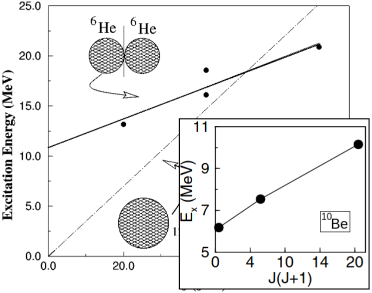
- ^{12}Be: M. Freer *et al.*, Phys. Rev. Lett. 82, 1383 (1999)
  α:4n:α probed via ^{6}He+^{6}He breakup following inelastic scattering of ^{12}Be on CH_2 in LISE.
  Slope $\hbar^2/2\mathcal{I}$ compatible with two touching ^{6}He.
  Band intercept close to decay threshold.



Molecular-like structures $\leftrightarrow$ Pronounced deformations $\rightarrow$ *Rotational bands*.

Be isotopes (dimers):

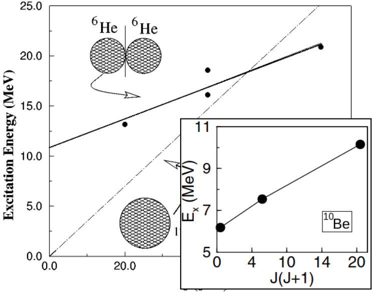
- ^{12}Be: M. Freer *et al.*, Phys. Rev. Lett. 82, 1383 (1999)
  α:4n:α probed via ^{6}He+^{6}He breakup following inelastic scattering of ^{12}Be on CH_2 in LISE.
  Slope $\hbar^2/2\mathcal{I}$ compatible with two touching ^{6}He.
  Band intercept close to decay threshold.
- ^{10}Be: M. Freer *et al.*, Phys. Rev. Lett. 96, 042501 (2006)
  α:2n:α probed via resonant ^{6}He+^{4}He elastic scatt.
  $J^\pi = 4^+$ member of rotational band built on the 0_2^+, predicted by AMD as associated with σ-orbital.



Molecular-like structures $\leftrightarrow$ Pronounced deformations $\rightarrow$ *Rotational bands*.

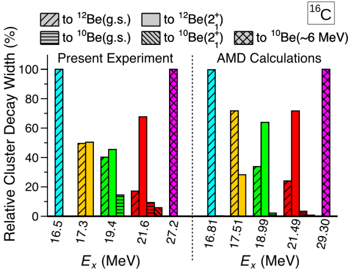
Be isotopes (dimers):

- ^{12}Be: M. Freer *et al.*, Phys. Rev. Lett. 82, 1383 (1999)
  α:4n:α probed via ^{6}He+^{6}He breakup following inelastic scattering of ^{12}Be on CH_2 in LISE.
  Slope $\hbar^2/2\mathcal{I}$ compatible with two touching ^{6}He.
  Band intercept close to decay threshold.
- ^{10}Be: M. Freer *et al.*, Phys. Rev. Lett. 96, 042501 (2006)
  α:2n:α probed via resonant ^{6}He+^{4}He elastic scatt.
  $J^\pi = 4^+$ member of rotational band built on the 0_2^+, predicted by AMD as associated with σ-orbital.



C isotopes (trimers):

- ^{16}C: Y. Liu *et al.*, Phys. Rev. Lett. 124, 192501 (2020)
  Cluster Be-He decays following inelastic scattering.
  0^+ band head found, matching AMD $\pi^2\sigma^2$ predict.
  Selective decay pattern analysis on higher members.



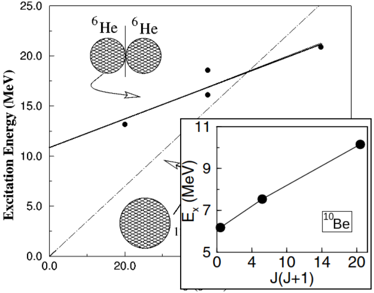
Clustering in non-α conjugate nuclei

Nuclear molecules and deformation

Molecular-like structures $\leftrightarrow$ Pronounced deformations $\rightarrow$ *Rotational bands*.

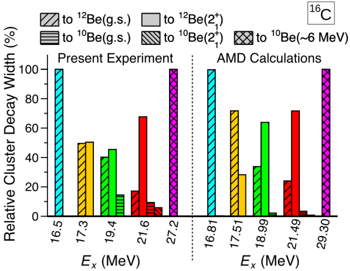
Be isotopes (dimers):

- ^{12}Be: M. Freer *et al.*, Phys. Rev. Lett. 82, 1383 (1999)
  α:4n:α probed via ^{6}He+^{6}He breakup following inelastic scattering of ^{12}Be on CH_2 in LISE.
  Slope $\hbar^2/2\mathcal{I}$ compatible with two touching ^{6}He.
  Band intercept close to decay threshold.
- ^{10}Be: M. Freer *et al.*, Phys. Rev. Lett. 96, 042501 (2006)
  α:2n:α probed via resonant ^{6}He+^{4}He elastic scatt.
  $J^\pi = 4^+$ member of rotational band built on the 0^+_2, predicted by AMD as associated with σ-orbital.



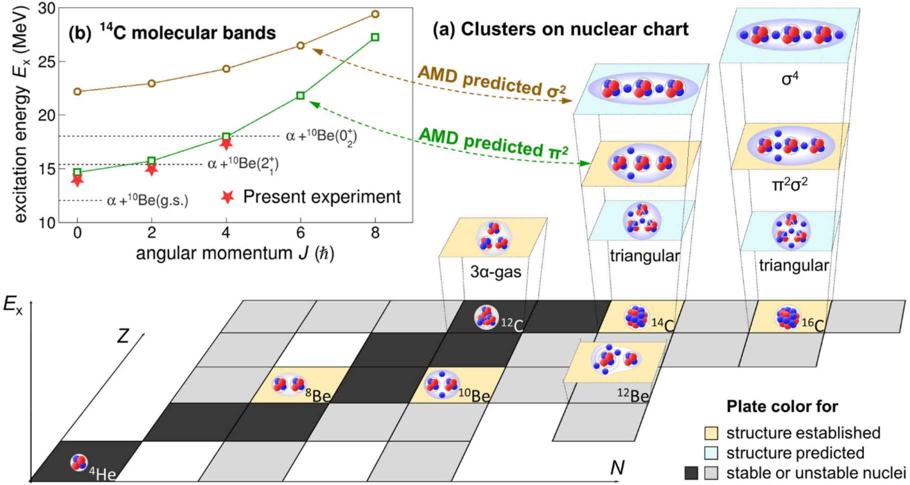
C isotopes (trimers):

- ^{16}C: Y. Liu *et al.*, Phys. Rev. Lett. 124, 192501 (2020)
  Cluster Be-He decays following inelastic scattering.
  0^+ band head found, matching AMD $\pi^2\sigma^2$ predict.
  Selective decay pattern analysis on higher members.
- ^{14}C: J. Han *et al.*, Comm. Phys. 6, 220 (2023)
  Same technique, first 3 members of π-bond linear-chain molecular rotational band "confirmed".



Clustering in non-α conjugate nuclei

Nuclear molecules and deformation



adapted from J. Han *et al.*, Comm. Phys. 6, 220 (2023)

Clustering in non-α conjugate nuclei

Generalized clusters

Light clusters (d, t, ^{3}He) $\leftrightarrow$ *reaction* channel or *decay* channel signature.

Clustering in non-α conjugate nuclei

Generalized clusters

Light clusters (d, t, ^{3}He) $\leftrightarrow$ *reaction* channel or *decay* channel signature.

Reaction channel:
e.g. cluster (t or α) pickup experiment along Be isotopic chain with MUGAST at LISE.
^{10,12}Be(p,α) and ^{10}Be(d,^{6}Li) measurements, complementing RIKEN (p,pα)/(p,pt) knockout experiment, pointing towards strong t clustering in ^{14}Be.

$\rightarrow$ *see talk by* ***V. Girard-Alcindor***

Light clusters (d, t, ^{3}He) ↔ *reaction* channel or *decay* channel signature.

Reaction channel:
e.g. cluster (t or α) pickup experiment along Be isotopic chain with MUGAST at LISE. ^{10,12}Be(p,α) and ^{10}Be(d,^{6}Li) measurements, complementing RIKEN (p,pα)/(p,pt) knockout experiment, pointing towards strong t clustering in ^{14}Be.

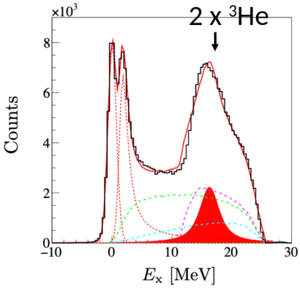
→ *see talk by* ***V. Girard-Alcindor***

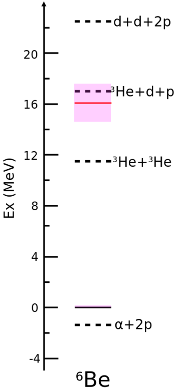
Decay channel:
e.g. (p,d) reactions on N = 3 isotones studied with MUST2 at LISE.

Resonances around 17 MeV in N = 2 isotones, above ^{3}He+x threshold.

e.g. in ^{6}Be, it tends to decay by ^{3}He+^{3}He despite being unbound by about 16MeV with respect to α+2p threshold.

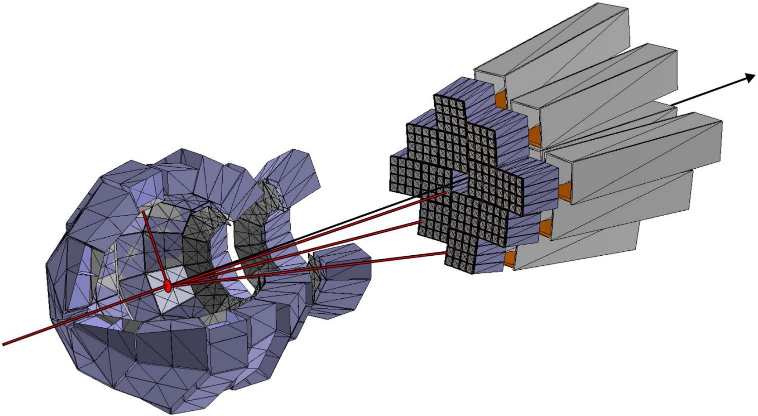
→ *see talk by* ***O. Sorlin***





⇒ Improve detection performance for cluster decay identification.

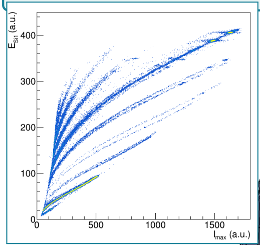
INDRA-FAZIA: state-of-the-art ion identification at Fermi energies.
Provides high granularity (especially fwd, FAZIA) + large coverage (INDRA).

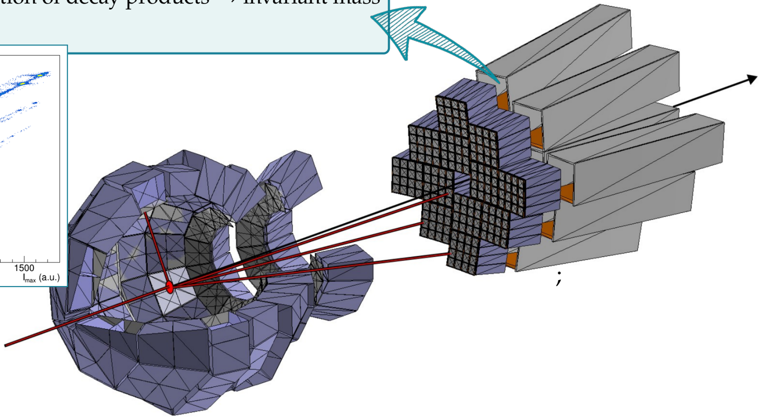


INDRA-FAZIA: state-of-the-art ion identification at Fermi energies.
Provides high granularity (especially fwd, FAZIA) + large coverage (INDRA).

FAZIA: isotopic identification, also for high-multiplicity.

- full identification of decay products → invariant mass





;

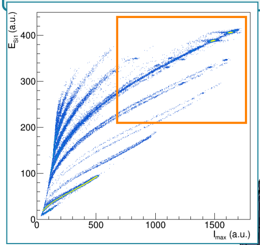
INDRA-FAZIA for direct reactions

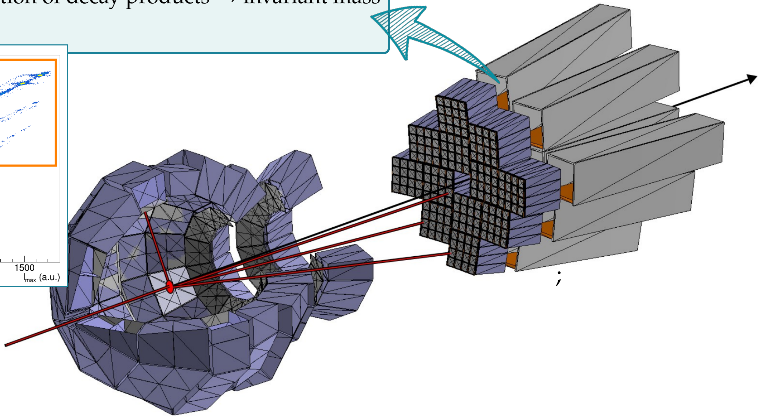
Beyond nuclear-EoS studies

INDRA-FAZIA: state-of-the-art ion identification at Fermi energies.
Provides high granularity (especially fwd, FAZIA) + large coverage (INDRA).

FAZIA: isotopic identification, also for high-multiplicity.

- full identification of decay products → invariant mass

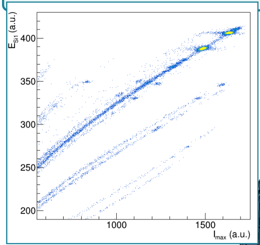


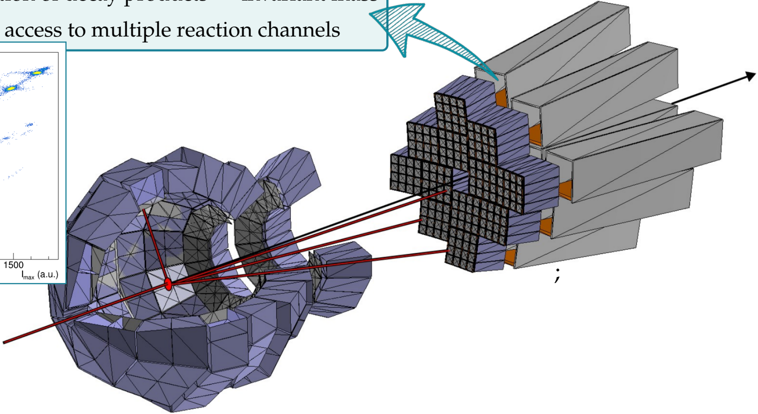


INDRA-FAZIA: state-of-the-art ion identification at Fermi energies.
Provides high granularity (especially fwd, FAZIA) + large coverage (INDRA).

FAZIA: isotopic identification, also for high-multiplicity.

- full identification of decay products → invariant mass
- simultaneous access to multiple reaction channels

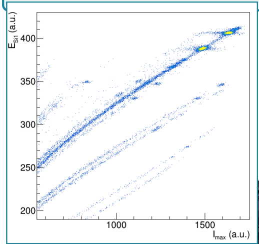


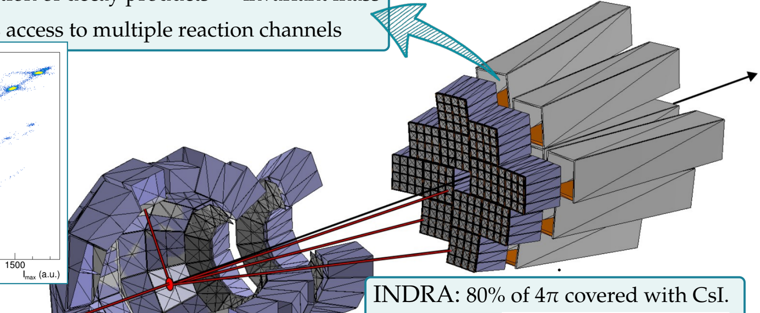


INDRA-FAZIA: state-of-the-art ion identification at Fermi energies.
Provides high granularity (especially fwd, FAZIA) + large coverage (INDRA).

FAZIA: isotopic identification, also for high-multiplicity.

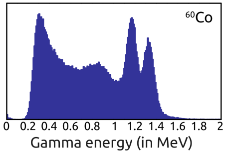
- full identification of decay products → invariant mass
- simultaneous access to multiple reaction channels





INDRA: 80% of 4π covered with CsI.

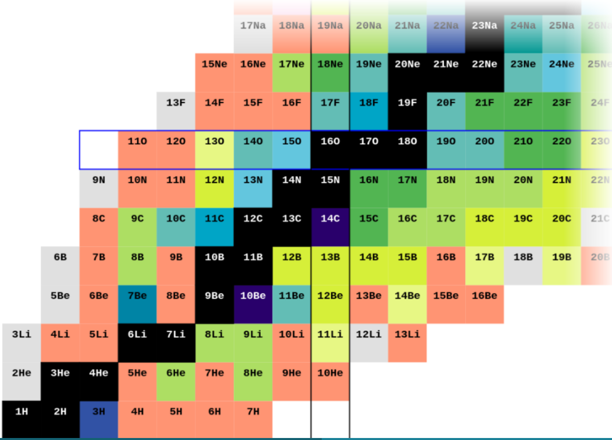
Efficiency for γ detection
↓
study BR of radiative decays



INDRA-FAZIA for direct reactions

Performance of missing mass and invariant mass methods

Some examples from $^{12}C+^{12}C/CH_2$ datasets at 8.75-11 MeV/nucl. (2025-2026):

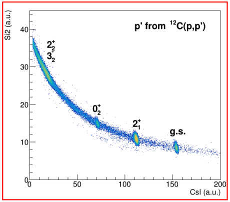


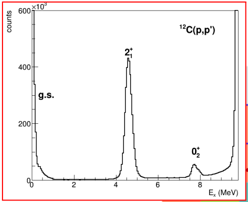
INDRA-FAZIA for direct reactions

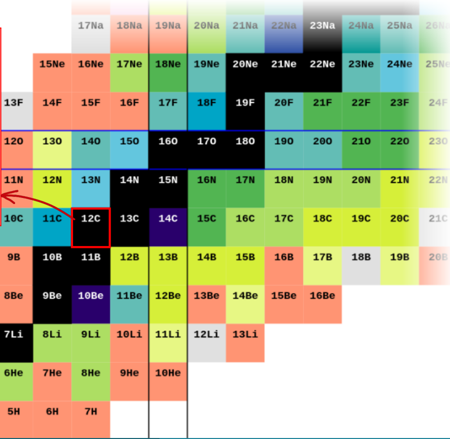
Performance of missing mass and invariant mass methods

Some examples from ^{12}C+^{12}C/CH$_2$ datasets at 8.75-11 MeV/nucl. (2025-2026):

- **Missing mass**: e.g. ^{12}C(p,p′), resolution ∼ 200 − 300 keV FWHM; similar behaviour for ^{12}C(^{12}C,^{12}C′), with double excitations.





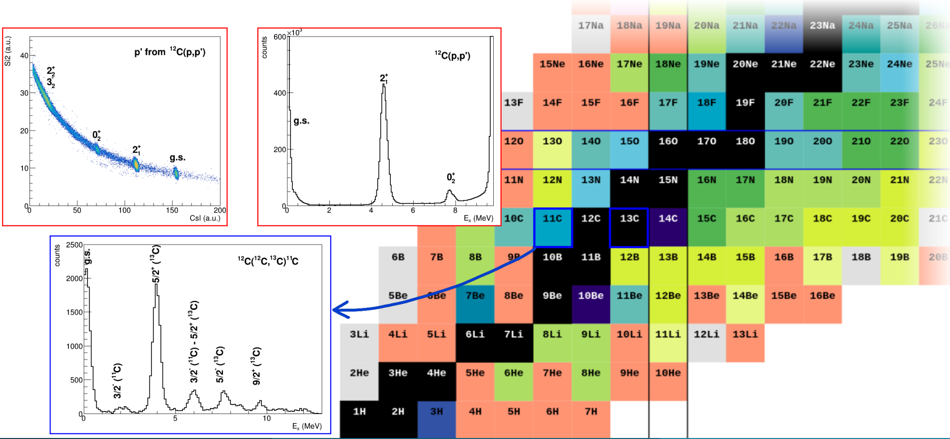


INDRA-FAZIA for direct reactions

Performance of missing mass and invariant mass methods

Some examples from ^{12}C+^{12}C/CH$_2$ datasets at 8.75-11 MeV/nucl. (2025-2026):

- **Missing mass**: e.g. ^{12}C(p,p′), resolution ~ 200 – 300 keV FWHM; similar behaviour for ^{12}C(^{12}C,^{12}C′), with double excitations.
- **Missing mass** on transfer channels ^{12}C(^{12}C,^{A}X), e.g. n-transfer.

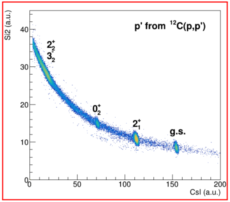


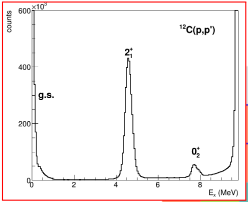
INDRA-FAZIA for direct reactions

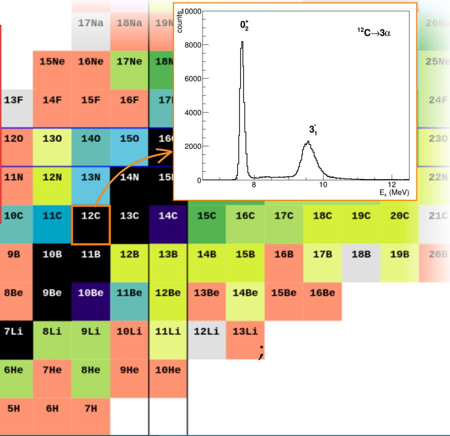
Performance of missing mass and invariant mass methods

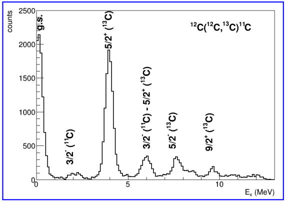
Some examples from ^{12}C+^{12}C/CH$_2$ datasets at 8.75-11 MeV/nucl. (2025-2026):

- **Missing mass**: e.g. ^{12}C(p,p′), resolution ∼ 200 – 300 keV FWHM; similar behaviour for ^{12}C(^{12}C,^{12}C′), with double excitations.
- **Missing mass** on transfer channels ^{12}C(^{12}C,^{A}X), e.g. n-transfer.
- **Invariant mass** on decay products: e.g. ^{12}C→ 3α, resolution ∼ 100 – 200 keV FWHM;







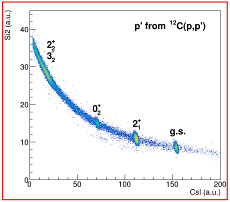


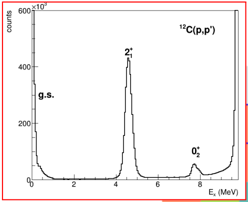
INDRA-FAZIA for direct reactions

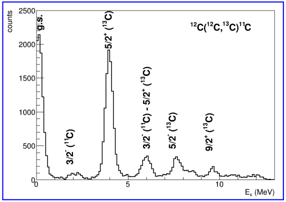
Performance of missing mass and invariant mass methods

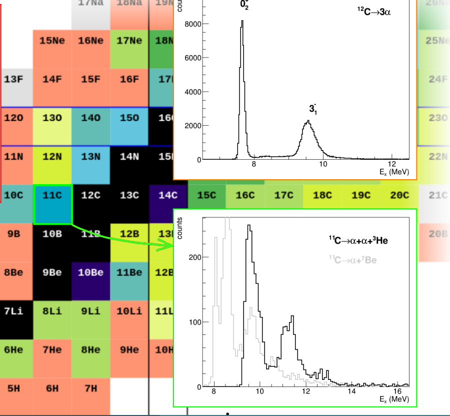
Some examples from ^{12}C+^{12}C/CH$_2$ datasets at 8.75-11 MeV/nucl. (2025-2026):

- **Missing mass**: e.g. ^{12}C(p,p′), resolution ~ 200 – 300 keV FWHM; similar behaviour for ^{12}C(^{12}C,^{12}C′), with double excitations.
- **Missing mass** on transfer channels ^{12}C(^{12}C,^{A}X), e.g. n-transfer.
- **Invariant mass** on decay products: e.g. ^{12}C→ 3α, resolution ~ 100 – 200 keV FWHM;









INDRA-FAZIA for direct reactions

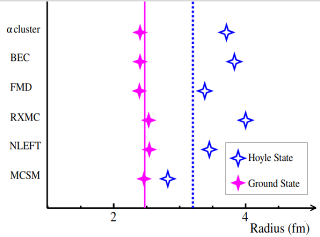
Experiment E881: Measuring the Hoyle state radius via ^{12}C+^{12}C inelastic scattering

"Measurement of the Hoyle state radius via inelastic scattering of ^{12}C+^{12}C at 8.75 MeV/nucleon"

D. Gruyer, D. Dell'Aquila *et al.*, E881 proposal, GANIL PAC 2023

- ^{12}**C Hoyle state**: strong α-cluster character, but with different predictions on the spatial configuration and on the radius.

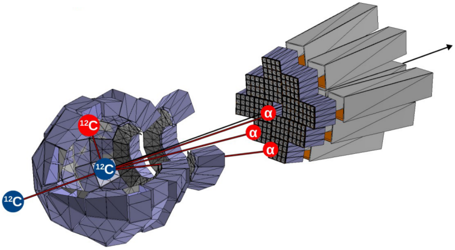
→ *see talk by* ***Ilham Dekhissi***



courtesy of Ilham Dekhissi

Charged particle spectroscopy on multi-α coincidence measurements.

- Invariant mass method on 3α
  → E^* of ^{12}C(proj)
- Missing mass method on recon. proj.
  → E^* of ^{12}C(targ)
  ⇒ selection of E^* combinations
- Single- and double-excitation $d\sigma/d\Omega$ show sensitivity to Hoyle state radius



I. Dekhissi, PhD thesis, *Université de Caen* (2027); A. De Rosa, Master's thesis, *Università di Napoli Federico II* (2025)

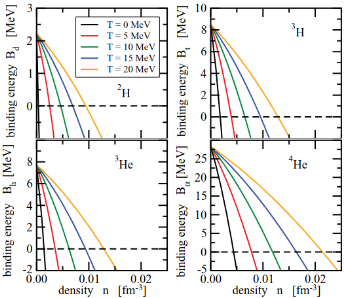
Clustering phenomena in nuclear matter

A necessary ingredient for describing low-density nuclear matter

Description of **infinite nuclear matter** at low density and finite temperature:

- Need to account for **light cluster** formation and the in-medium effects on their properties
- Clusters are bound only below a density threshold (Mott density)

S. Typel *et al.*, Phys. Rev. C 81, 015803 (2010)



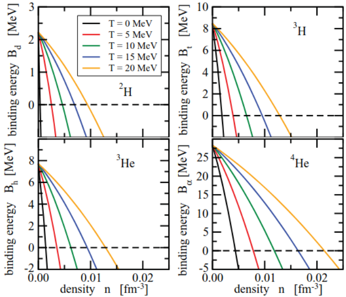
Clustering phenomena in nuclear matter

A necessary ingredient for describing low-density nuclear matter

Description of **infinite nuclear matter** at low density and finite temperature:

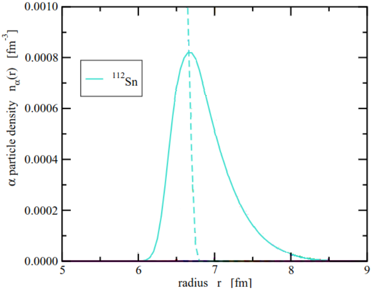
- Need to account for **light cluster** formation and the in-medium effects on their properties
- Clusters are bound only below a density threshold (Mott density)

S. Typel *et al.*, Phys. Rev. C 81, 015803 (2010)



Moving to **finite nuclei**: similar low-density condition are found at the nuclear surface:

- Prediction for the formation of α-particle correlations at the nuclear surface



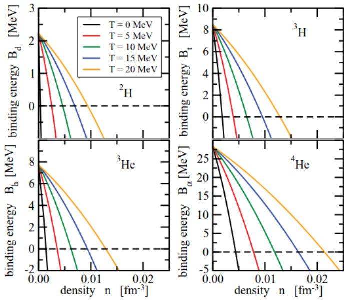
Clustering phenomena in nuclear matter

A necessary ingredient for describing low-density nuclear matter

Description of **infinite nuclear matter** at low density and finite temperature:

- Need to account for **light cluster** formation and the in-medium effects on their properties
- Clusters are bound only below a density threshold (Mott density)

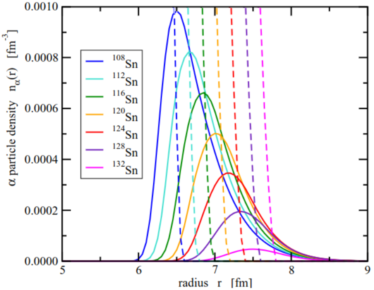
S. Typel *et al.*, Phys. Rev. C 81, 015803 (2010)



Moving to **finite nuclei**: similar low-density condition are found at the nuclear surface:

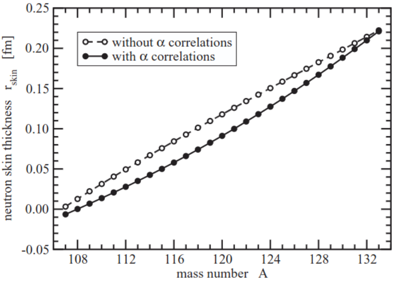
- Prediction for the formation of α-particle correlations at the nuclear surface
- The effect evolves with the isospin content → theoretical study along the Sn isotopic chain

S. Typel *et al.*, Phys. Rev. C 89, 064321 (2014)



Effect of surface α-clustering on finite nuclei:

- Including α-clustering reduces the predicted n-skin thickness along the Sn isotopic chain
- Largest effect at mid-chain, vanishes at both ends (low $A \rightarrow$ no n-skin, high $A \rightarrow$ no efficient α formation)

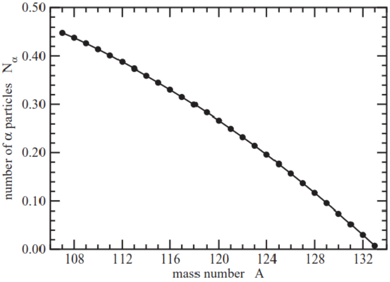


Effect of surface α-clustering on finite nuclei:

- Including α-clustering reduces the predicted n-skin thickness along the Sn isotopic chain
- Largest effect at mid-chain, vanishes at both ends (low $A \rightarrow$ no n-skin, high $A \rightarrow$ no efficient α formation)
- This correlates with the amount of α-clustering: effective number of α N_α decreases monotonically with A

More n-rich $\rightarrow$ harder to correlate p and n into α.

S. Typel *et al.*, Phys. Rev. C 89, 064321 (2014)



Clustering phenomena in nuclear matter

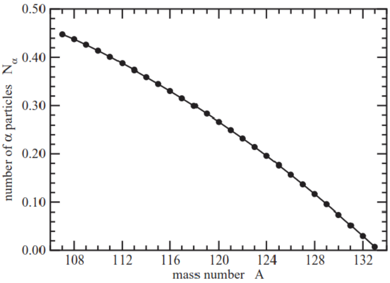
Interplay between clustering and neutron skin formation

Effect of surface α-clustering on finite nuclei:

- Including α-clustering reduces the predicted n-skin thickness along the Sn isotopic chain
- Largest effect at mid-chain, vanishes at both ends (low $A \to$ no n-skin, high $A \to$ no efficient α formation)
- This correlates with the amount of α-clustering: effective number of α N_α decreases monotonically with A

More n-rich $\to$ harder to correlate p and n into α.

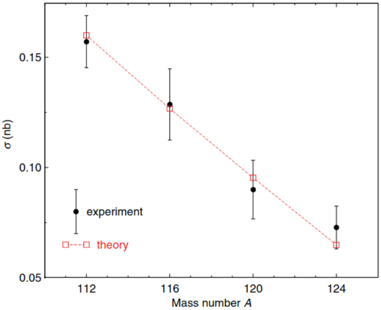
S. Typel *et al.*, Phys. Rev. C 89, 064321 (2014)



Experimental test at RNCP (Osaka):
quasi-free α-knockout reactions ^{A}Sn $(p, p\alpha)$

- $(p, p\alpha)$ cross-section decreases smoothly with A $\to$ direct evidence of decreasing N_α
- Excellent agreement with gRDF prediction

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



"α-clustering in neutron-rich oxygen isotopes"

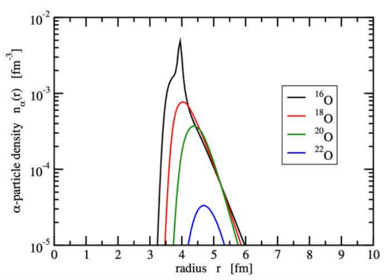
J. Benlliure, A. Chbihi *et al.*, E894 proposal, GANIL PAC 2024

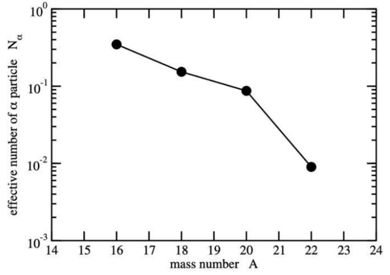
Study of α-transfer reaction cross section along the oxygen isotopic chain:

- (d,^{6}Li) reactions induced by ^{16,18,20}O beams at 7.5 MeV/nucl.
- Unambiguous determination of reaction channel thanks to multi-hit identification capability → study of cluster configurations of unbound states of O isotopes populated by inelastic reactions

Aimed at understanding the interplay between α-cluster formation and n-skin:

- Role of clustering in the relationship between the neutron-skin thickness and the L_{sym} parameter of the symmetry energy.

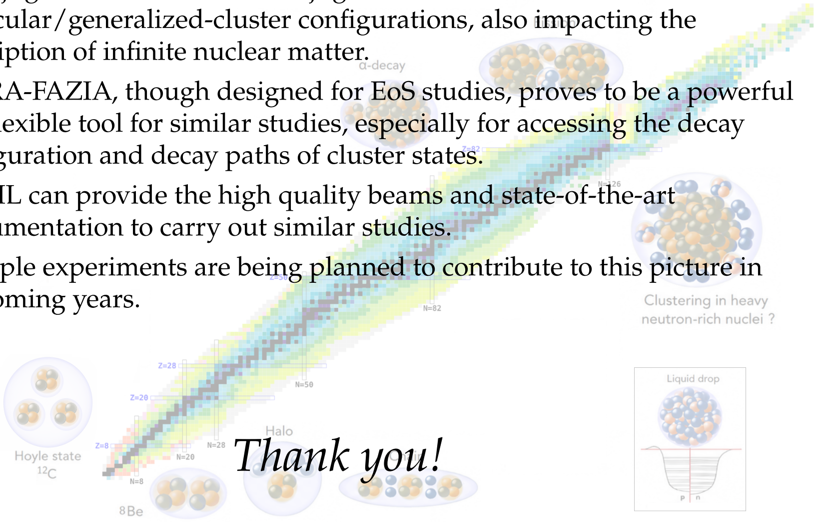




S. Typel, *private communication*

Conclusions and perspectives

- Clustering is a *transversal phenomenon*: from the structure of light α-conjugate nuclei to non-α-conjugate exotic molecular/generalized-cluster configurations, also impacting the description of infinite nuclear matter.
- INDRA-FAZIA, though designed for EoS studies, proves to be a powerful and flexible tool for similar studies, especially for accessing the decay configuration and decay paths of cluster states.
- GANIL can provide the high quality beams and state-of-the-art instrumentation to carry out similar studies.
- Multiple experiments are being planned to contribute to this picture in the coming years.



Thank you!