Study of ^{12}Be structure in multi-threshold vicinity with ACTAR TPC

Lou DIENIS, GANIL

Plenary meeting of the french low energy nuclear physics community
GDR RESANET
November 3th, 2025

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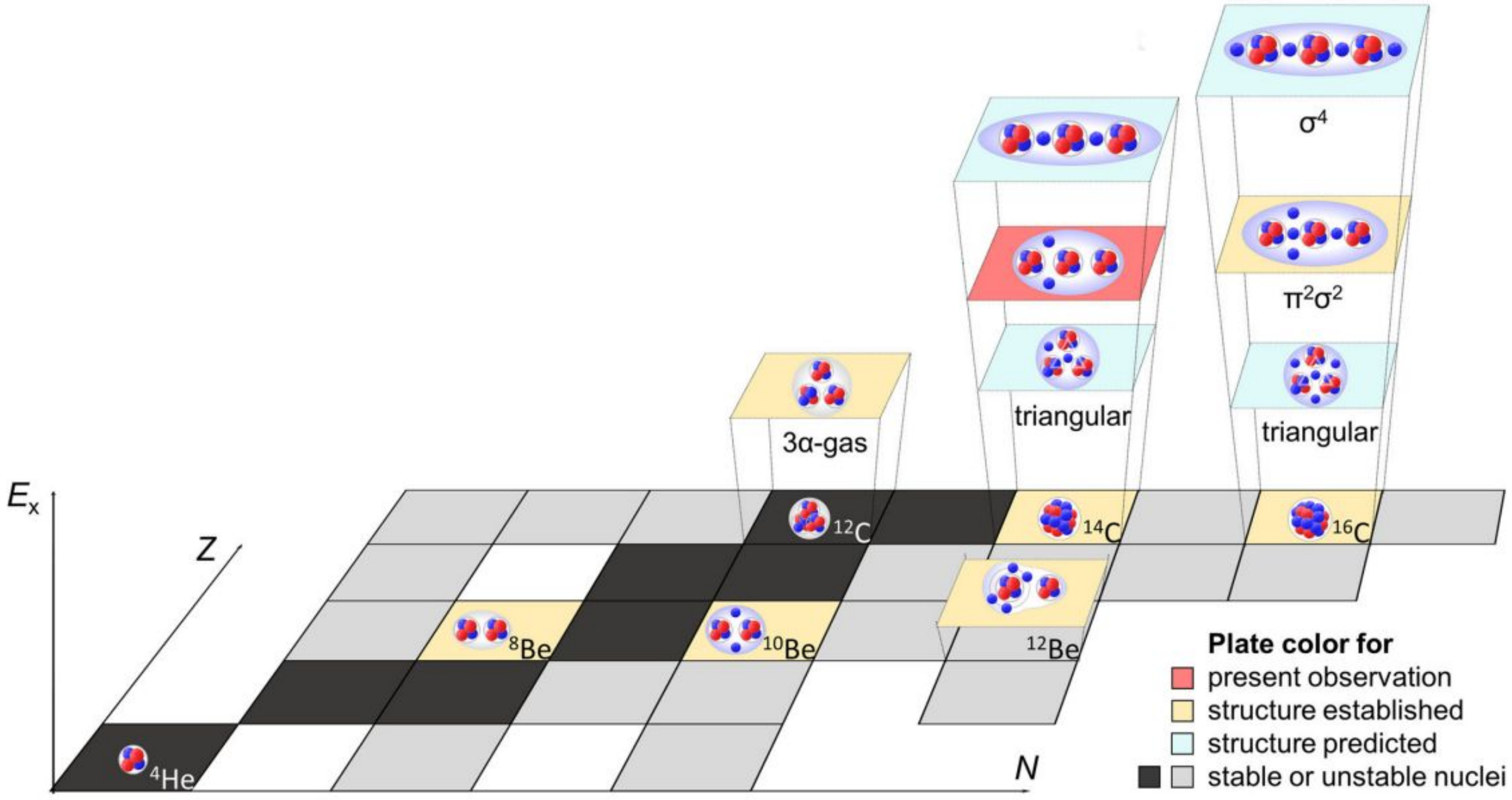
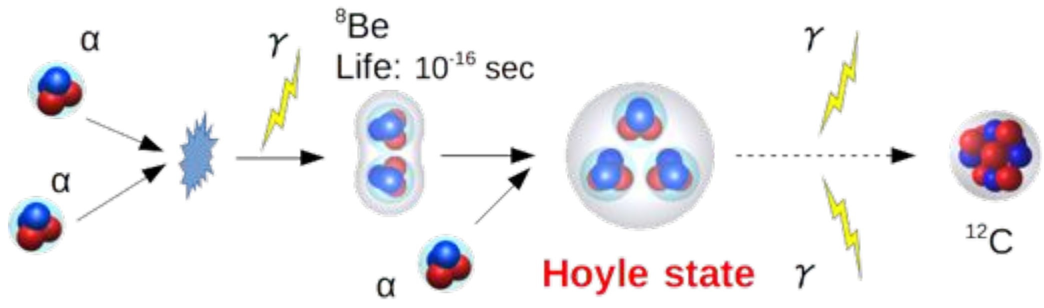
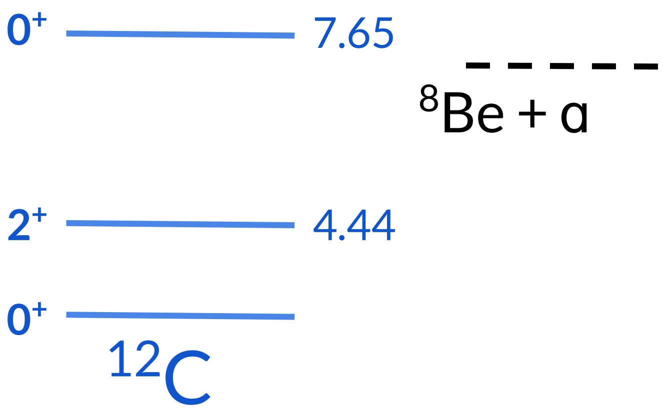
Physics motivation : Clusters

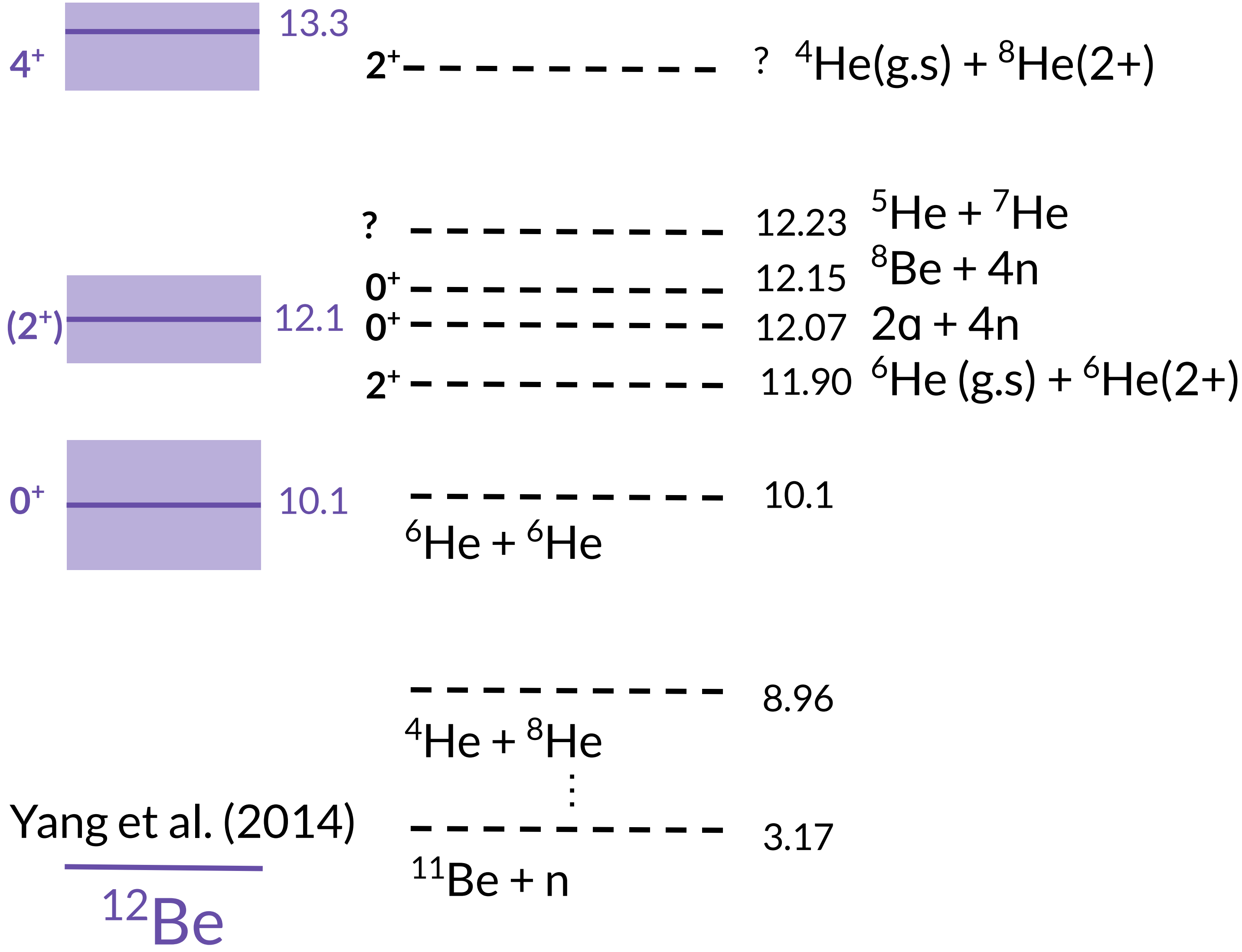
- Light nuclei -> cluster configuration where nucleons are grouped in clusters



Physics motivation : ^{12}Be states

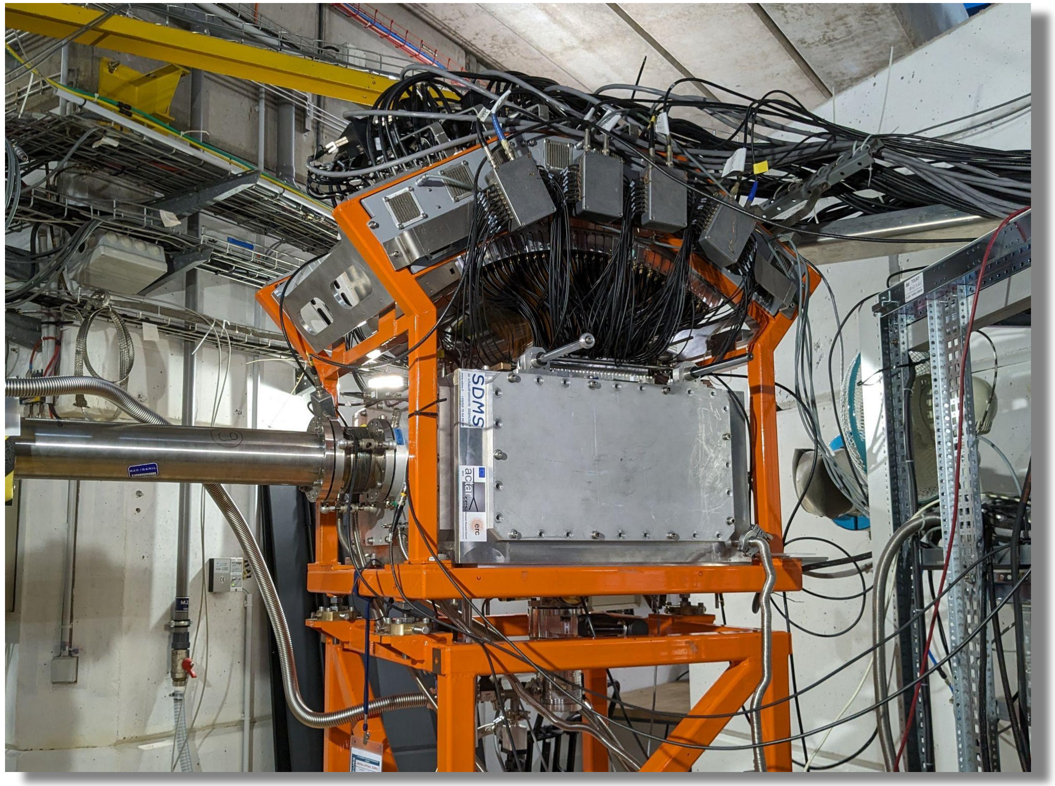


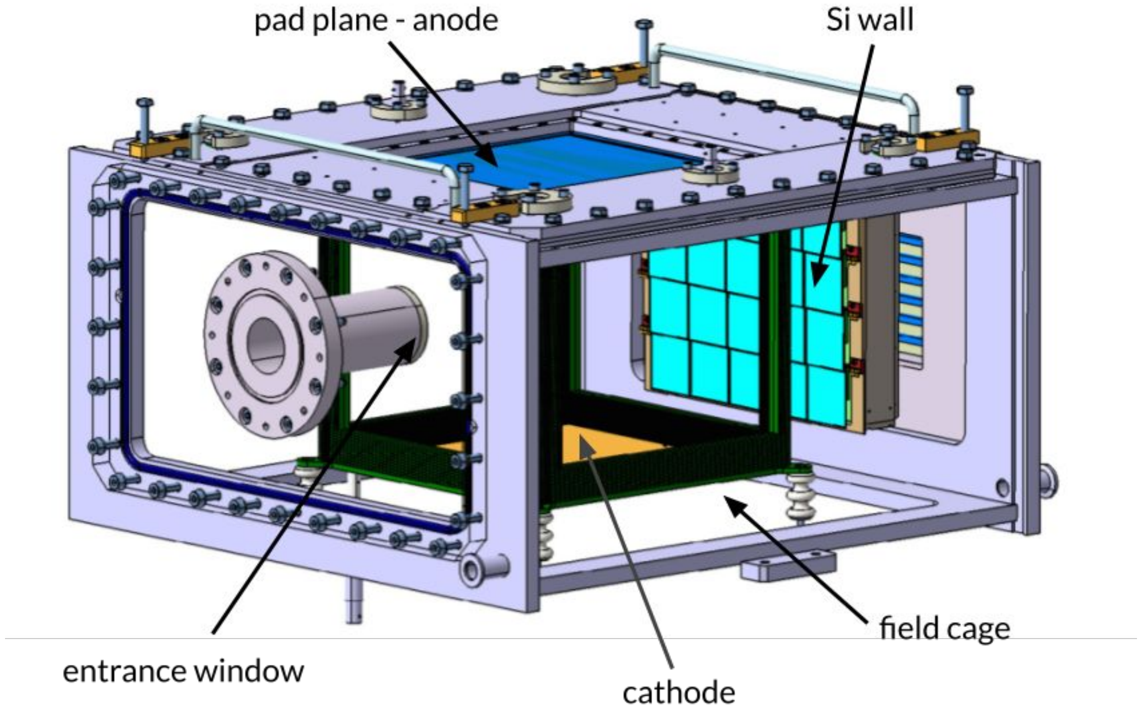




Experiment method : ACTAR TPC

- Resonant elastic scattering reaction α(^{8}He, ^{8}He)α -> population of ^{12}Be states
- ^{8}He beam at 1.8 MeV/u , and ACTAR TPC filled with ^{4}He gas





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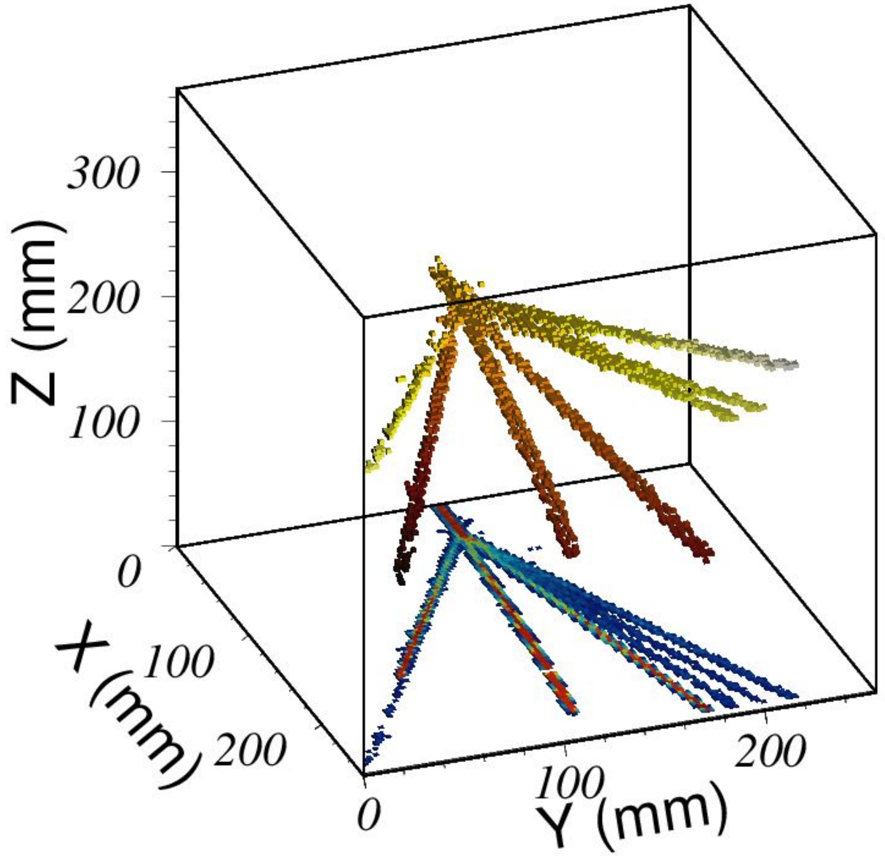

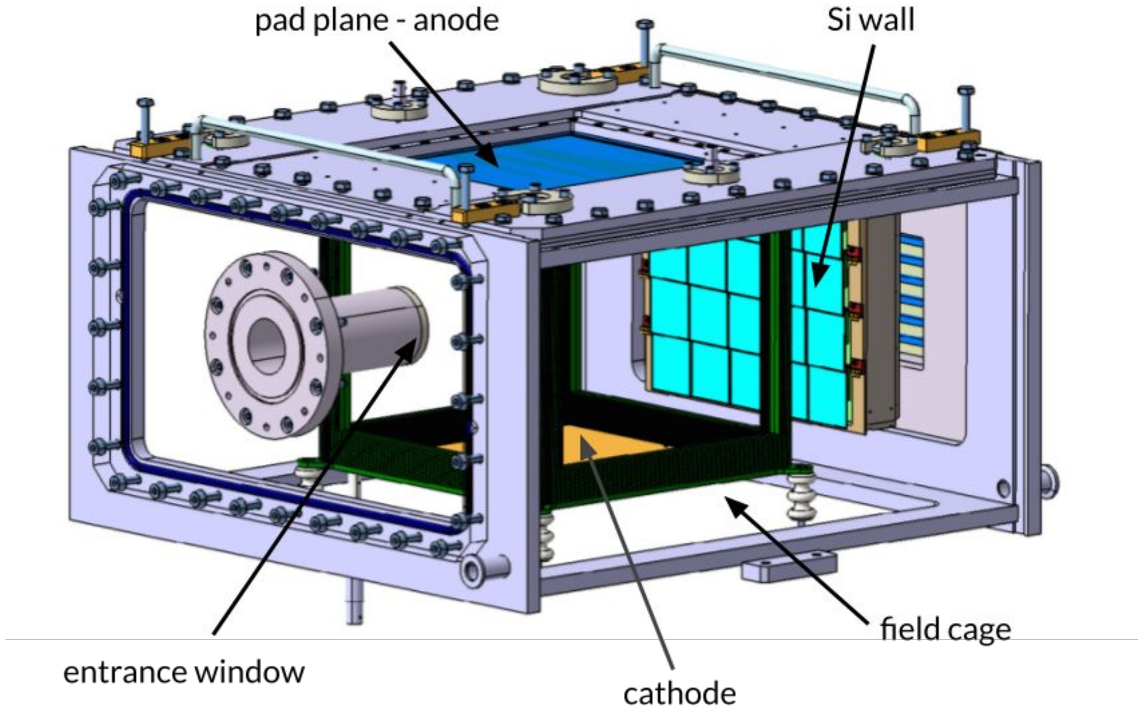

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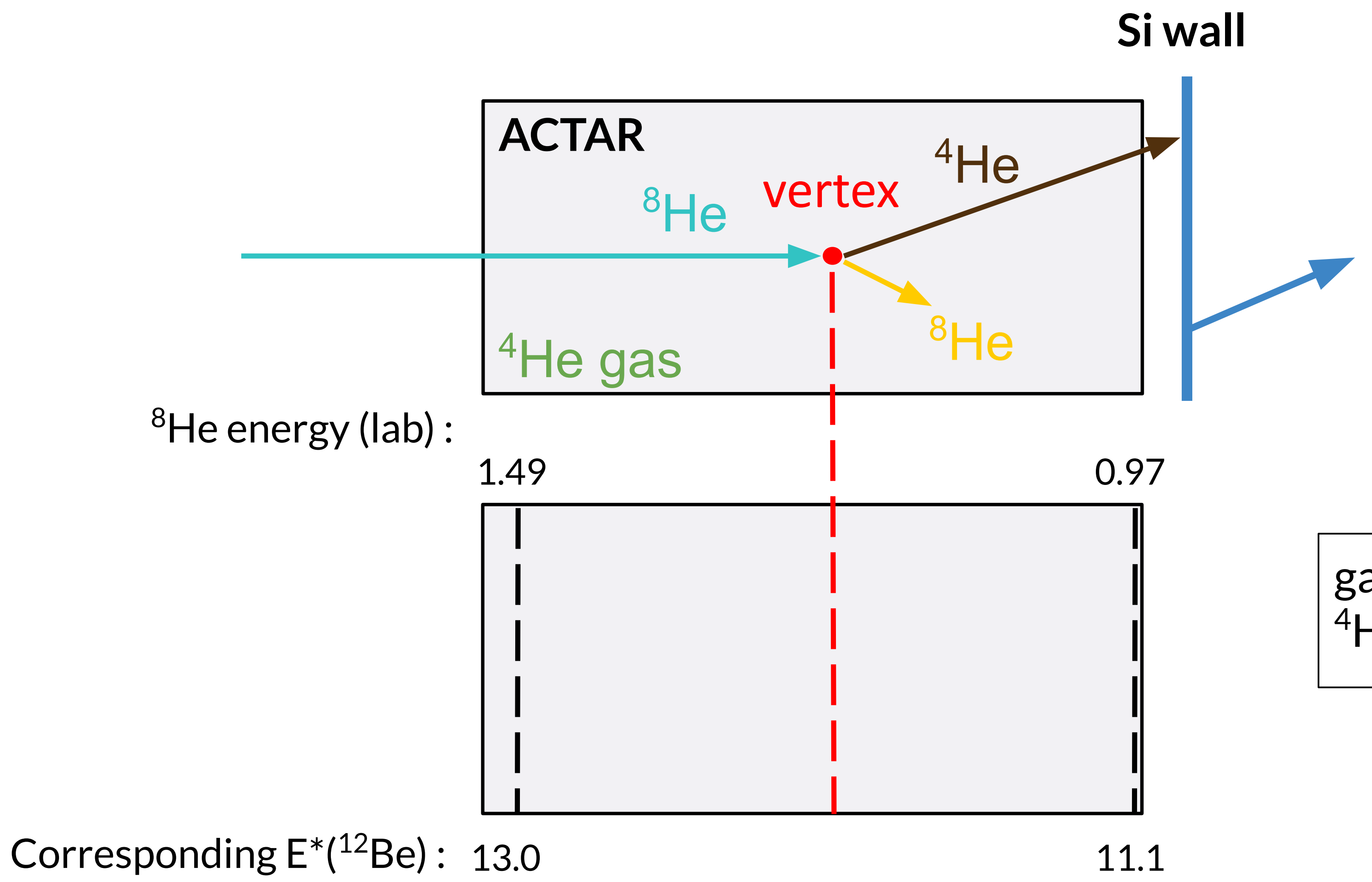
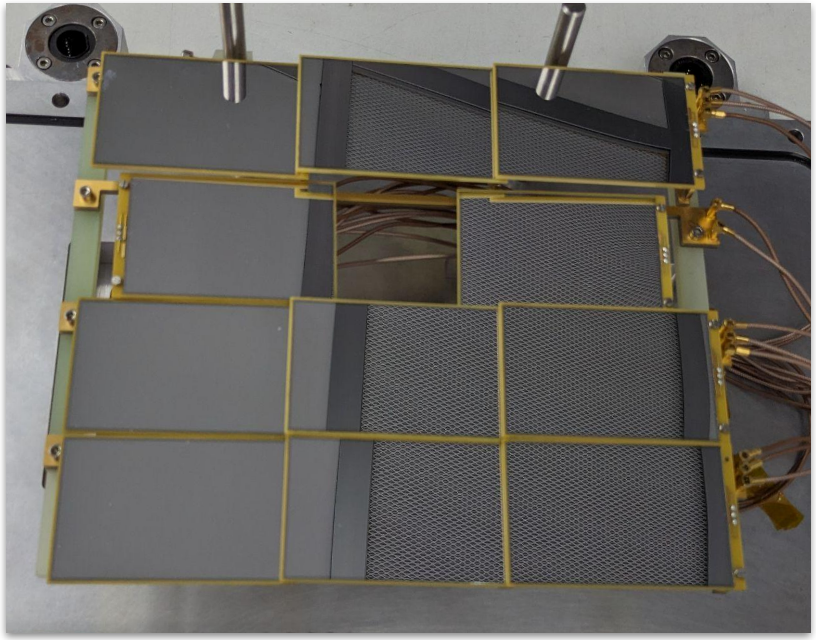
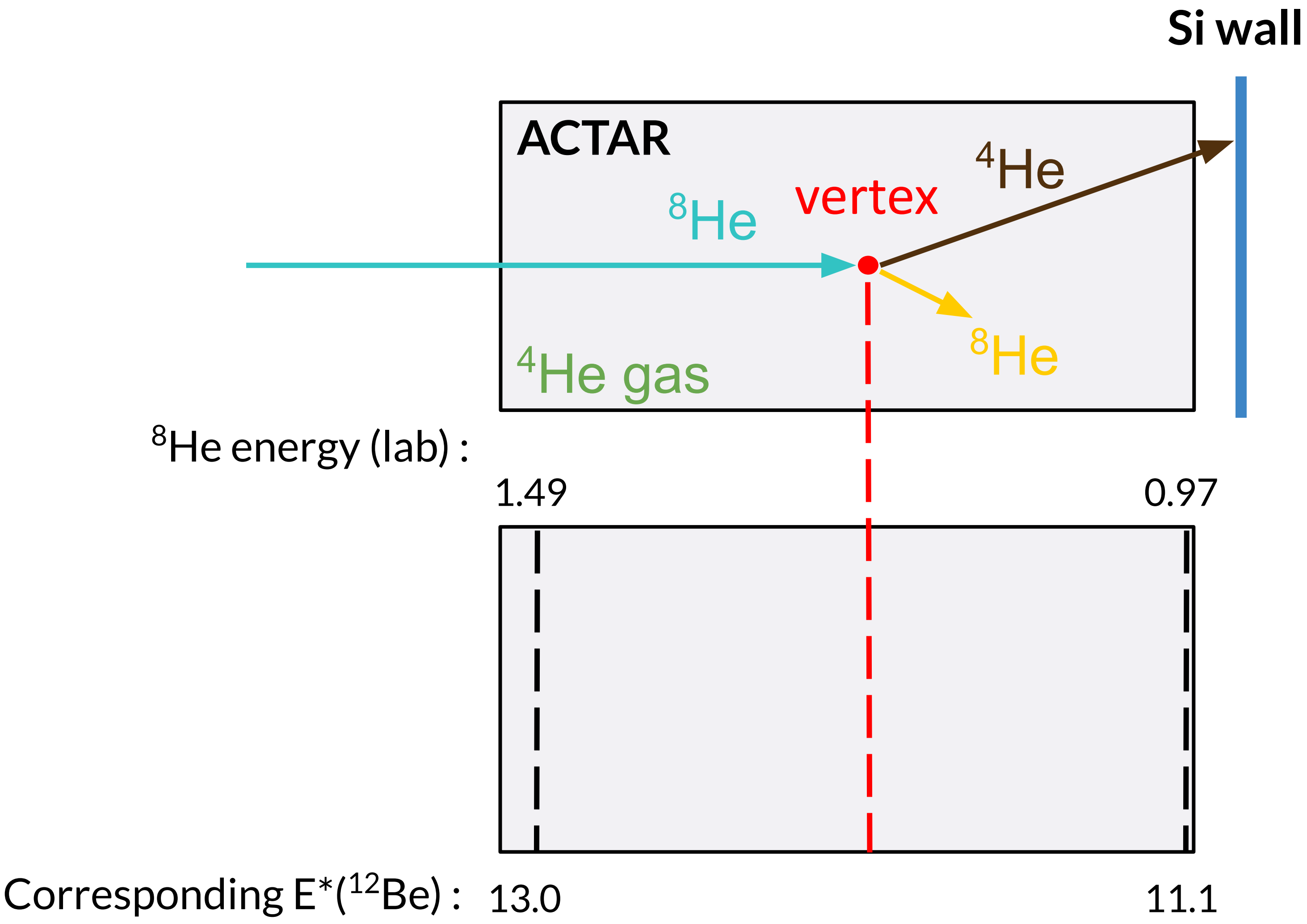
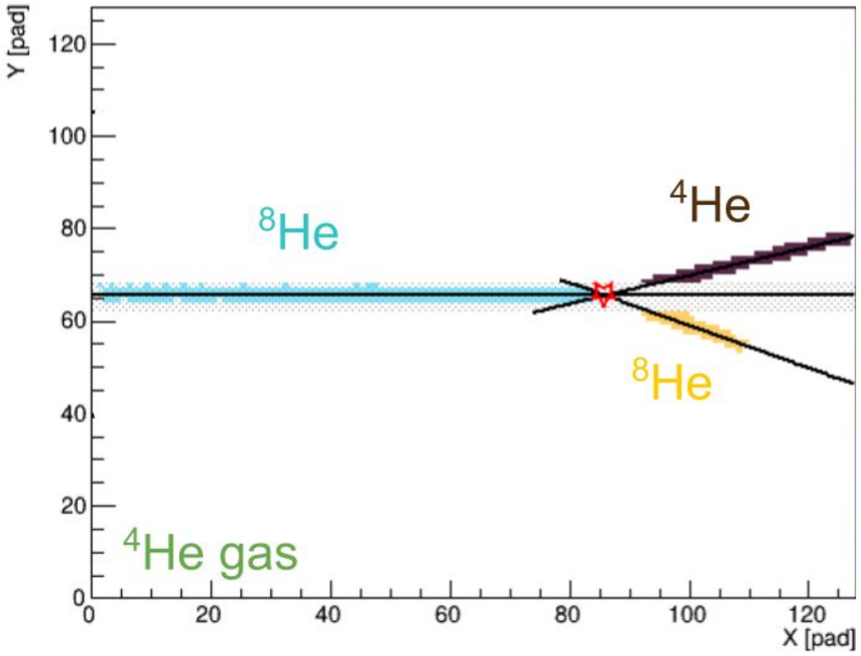




gas :
^{4}He (97%) + iC_4H_{10} (3%) @ 700 mbar

Experiment method : α(^{8}He,^{8}He)α

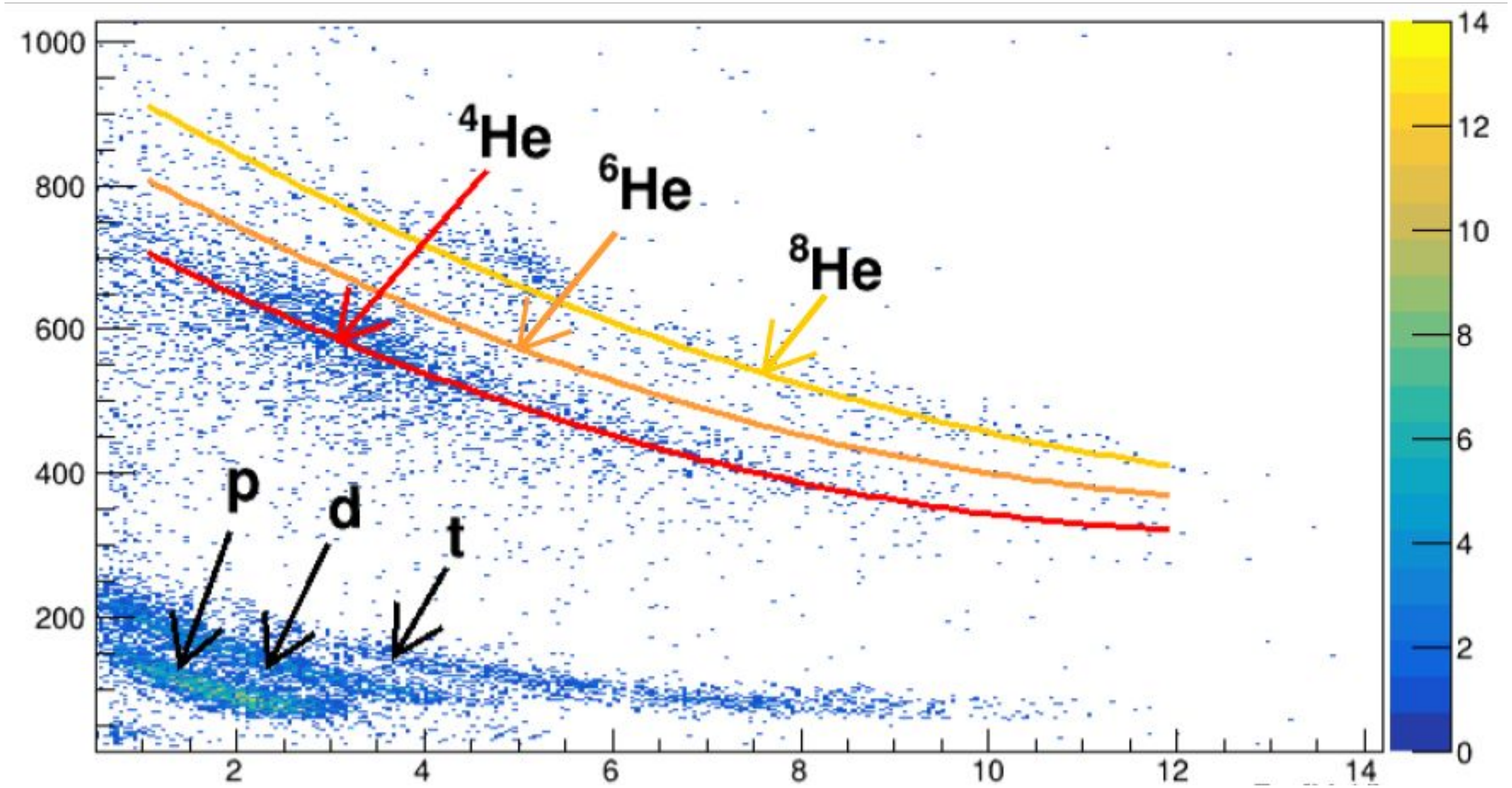




gas :
^{4}He (97%) + iC_4H_{10} (3%) @ 700 mbar

Analysis : Particle identification

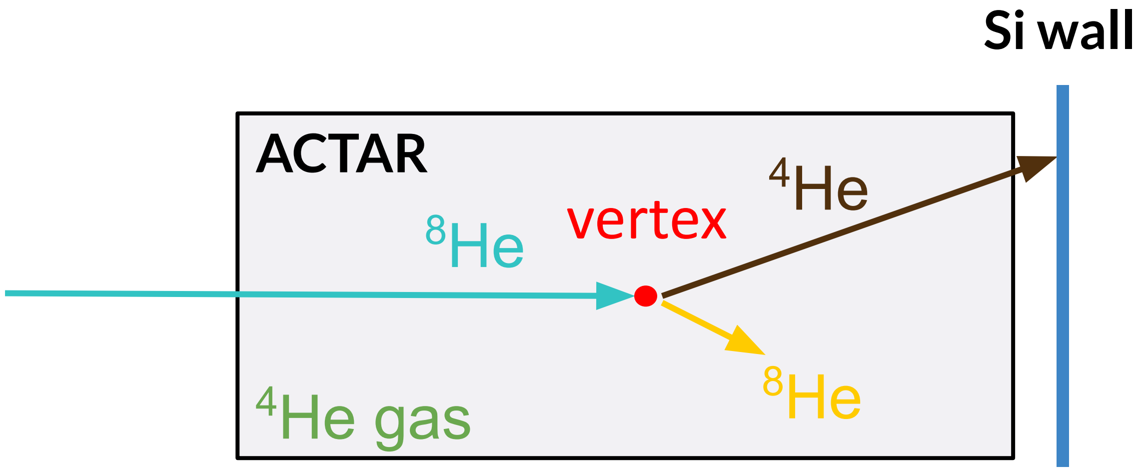
ΔE (u.a)

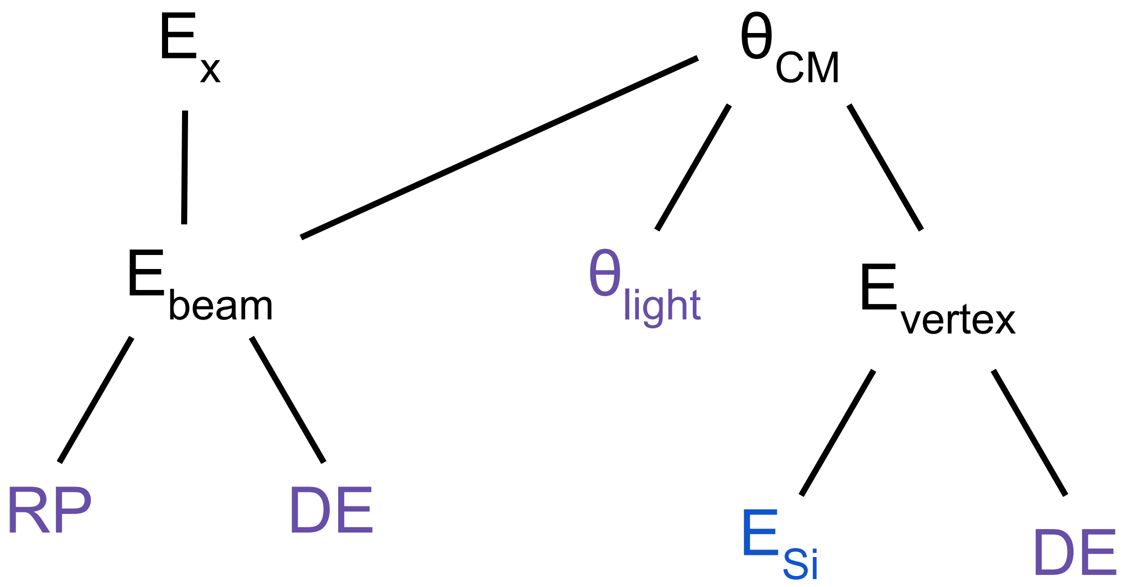


E (MeV)

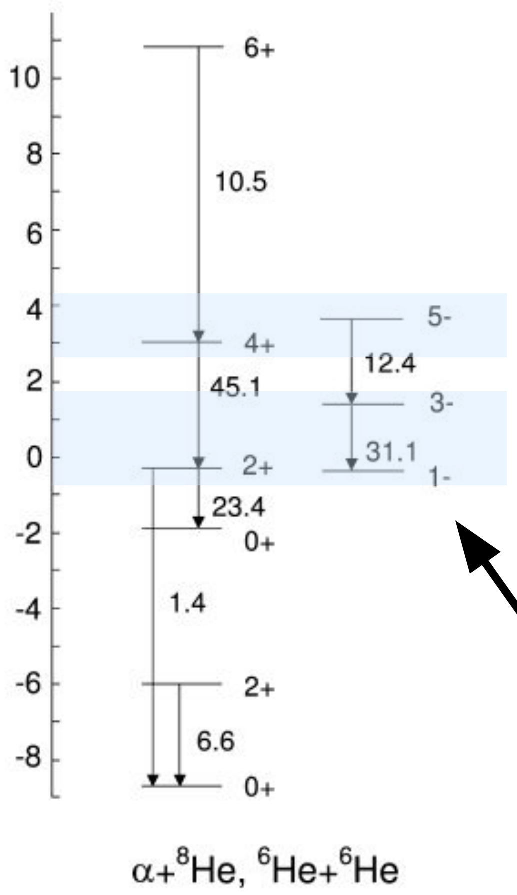
Analysis : Building excitation energy

$$E^{*}_{^{12}Be} = e_{beam} \times \frac{m_{^4He}}{m_{^4He} + m_{^8He}} + e_{thr}$$

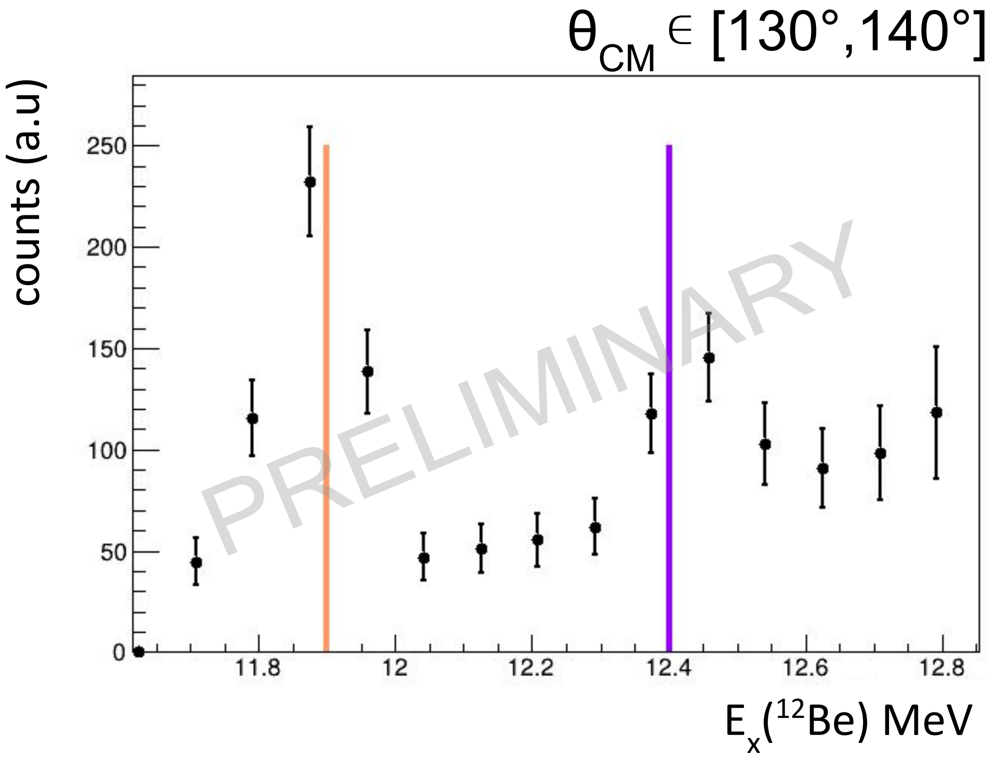




Hypothesis on states measured



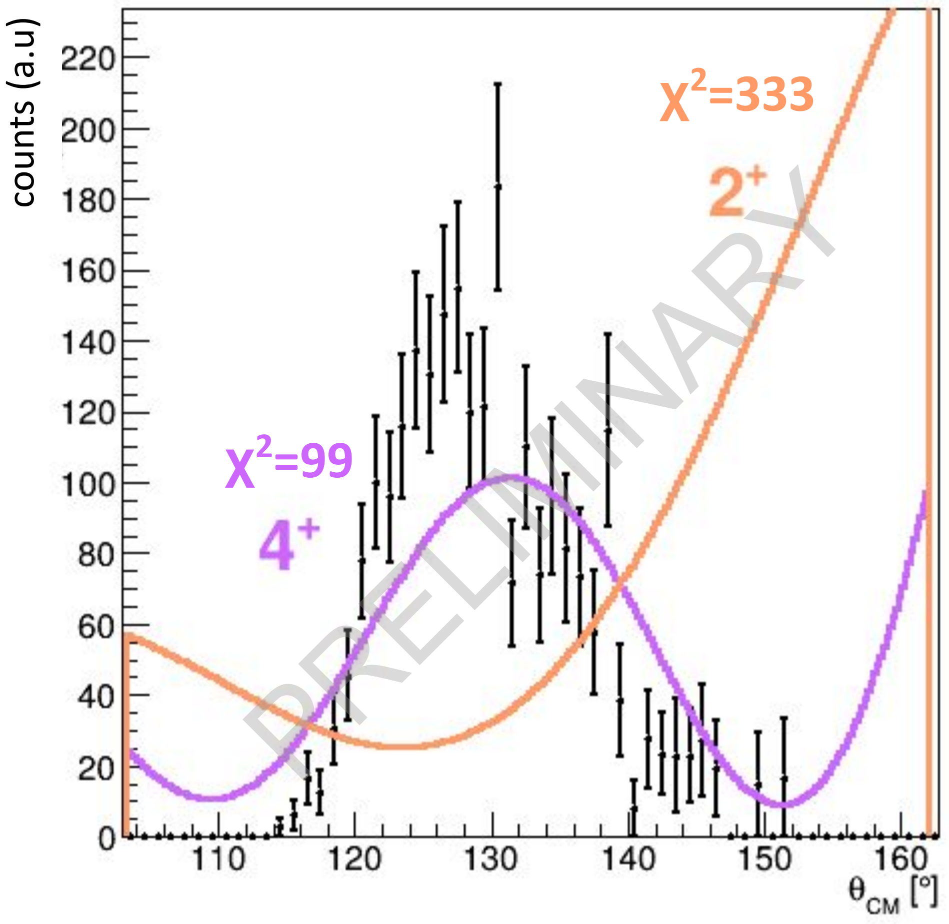
P. Decouvemont, D.Baye / Physics Letters B (2001)



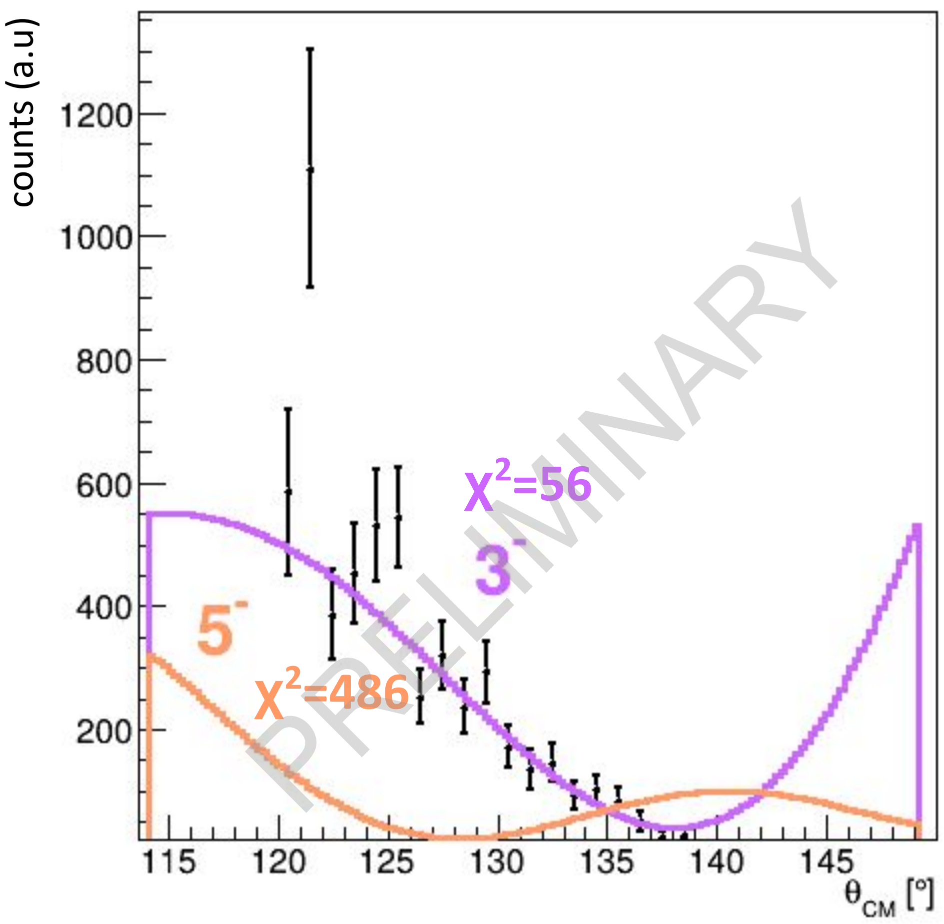
- Two states measured at 11.9 and 12.4 MeV
- Compatible with 12.1 MeV (2^+) by *Yang et al.*
- Two pairs ($2^+/3^-$) and ($4^+/5^-$) predicted by *Descouvemont et al.*
- Hypothesis : 11.9 (2^+ or 4^+), 12.4 (3^- or 5^-)

Analysis : angular distribution

11.9 MeV resonance

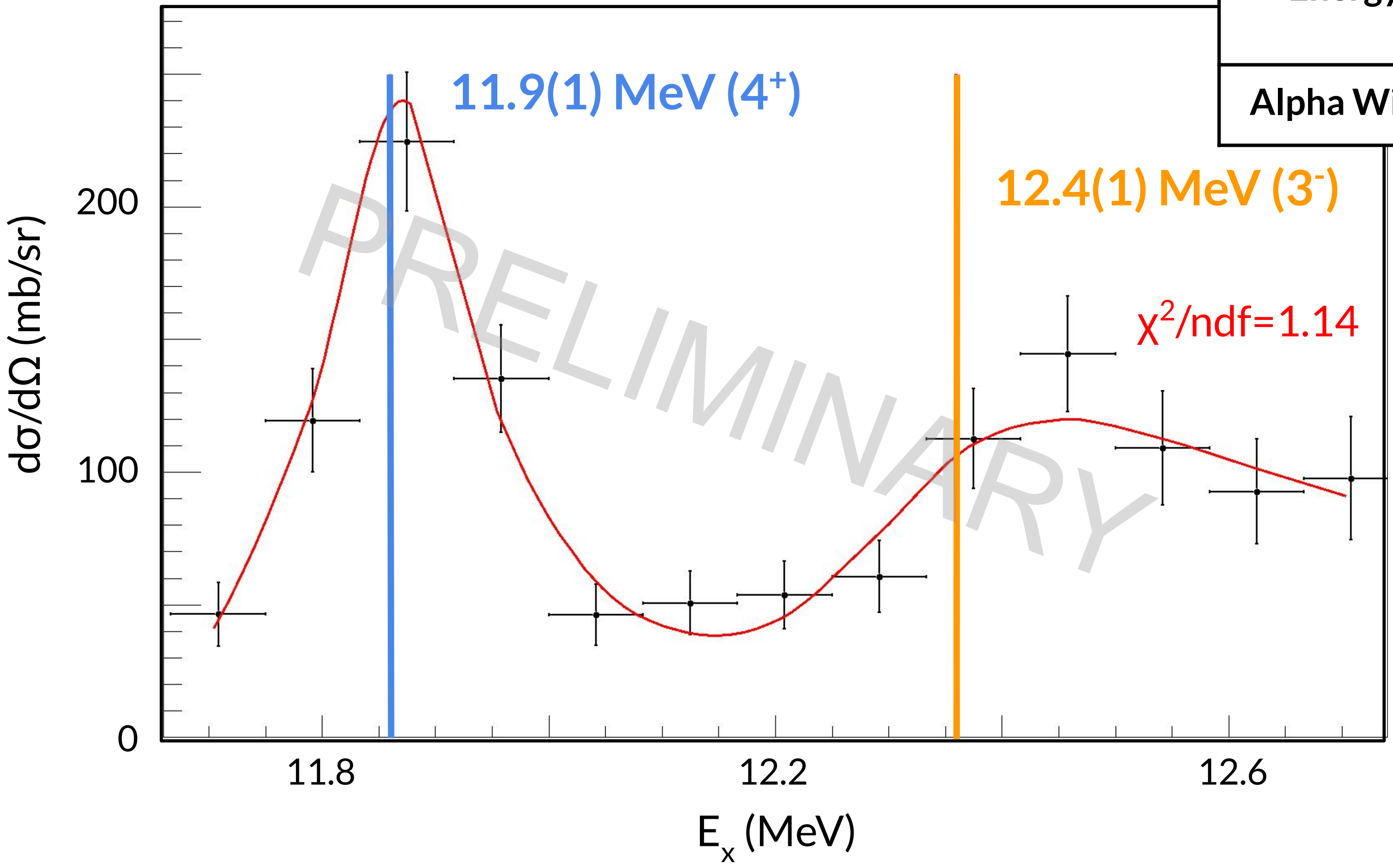


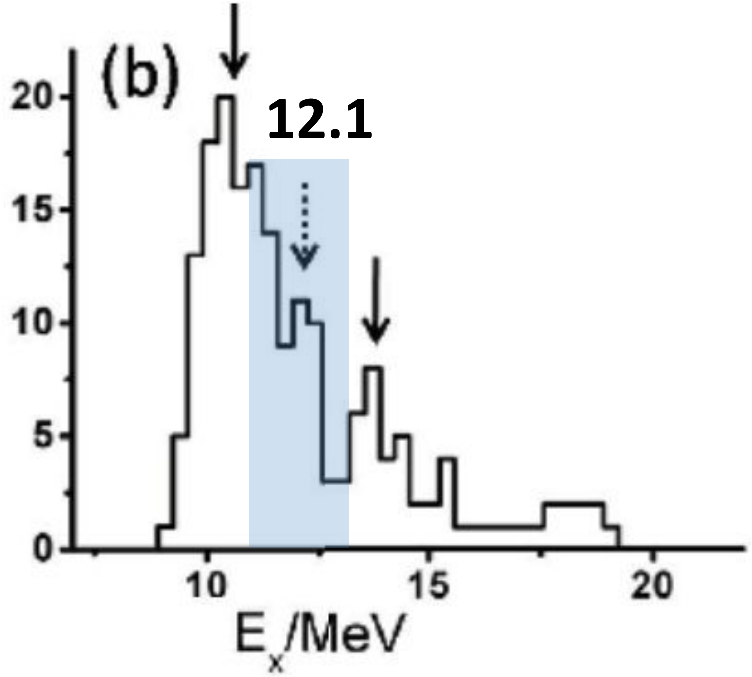
12.4 MeV resonance



Analysis : R-Matrix fit

Spin	4^+	3^-
Energy (MeV)	11.9(1)	12.4(1)
Alpha Width (keV)	205(29)	295(53)





Yang et al. (2014)

Reduced Widths (θ^2) of Cluster Configurations in ^{12}Be

- 11.9 MeV - 4^+ :

channel	θ^2
$^4He+^8He$	0.86(12)
$^6He+^6He$	0.24(20)
$^{11}Be+n$	0.001(1)

-> strong clustering in ^4He + ^8He channel

- 12.4 MeV - 3^- :

channel	θ^2
$^4He+^8He$	0.21(2)
$^6He+^6He$	0.02(3)
$^{11}Be+n$	0.01(1)
$^5He+^7He$	0.88(30)
$^8Be+^4n$	0.49(40)

PRELIMINARY

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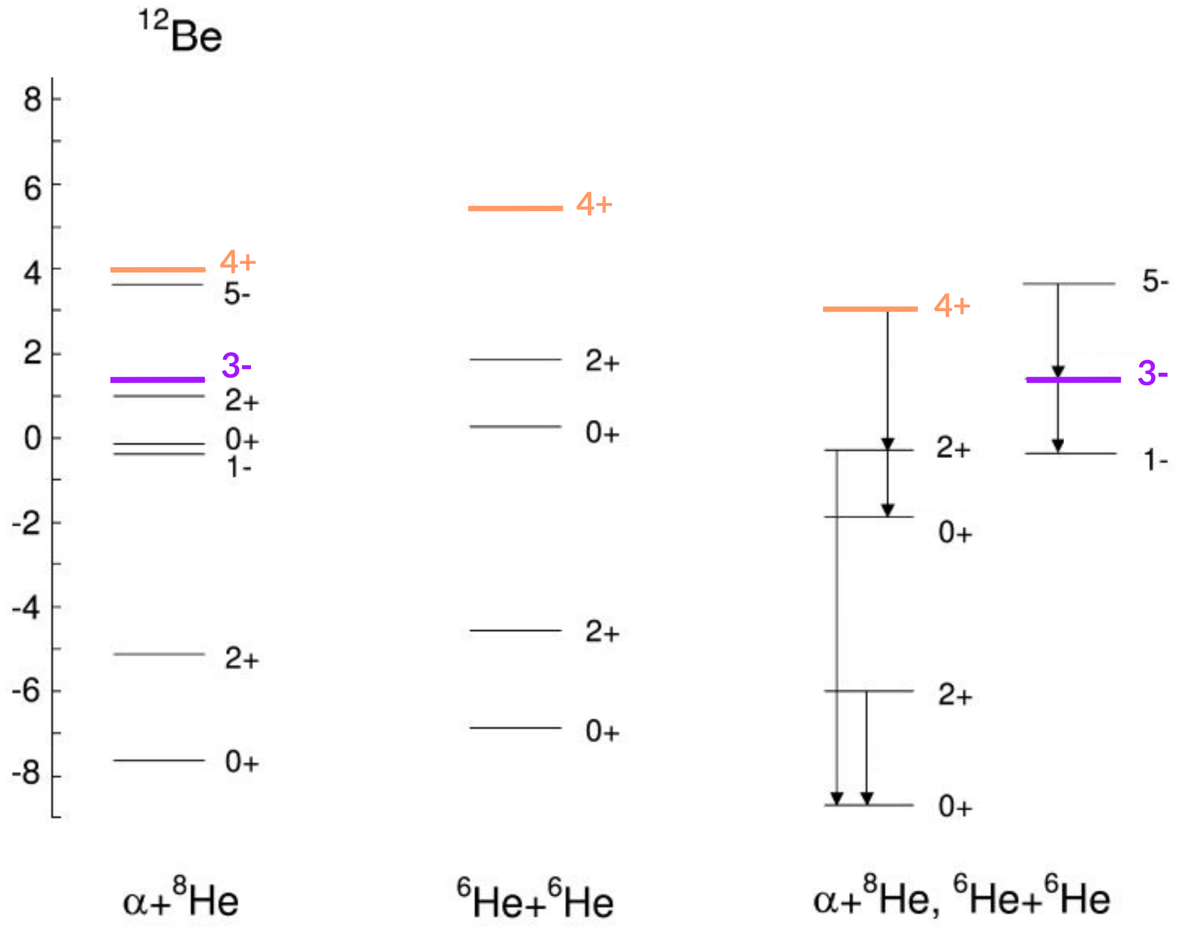
PRELIMINARY



P. Decouvemont, D.Baye / Physics Letters B (2001)

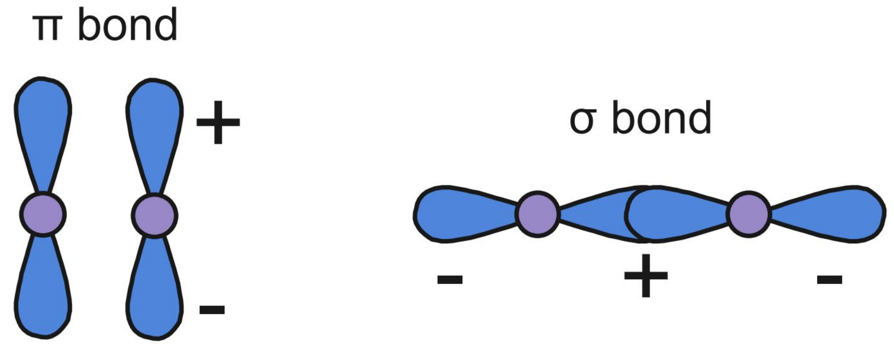
Rotational bands & Nuclear clustering

- Collective excitations in **deformed nuclei**

$$E_J = E_0 + \frac{\hbar^2}{2I} J(J+1)$$

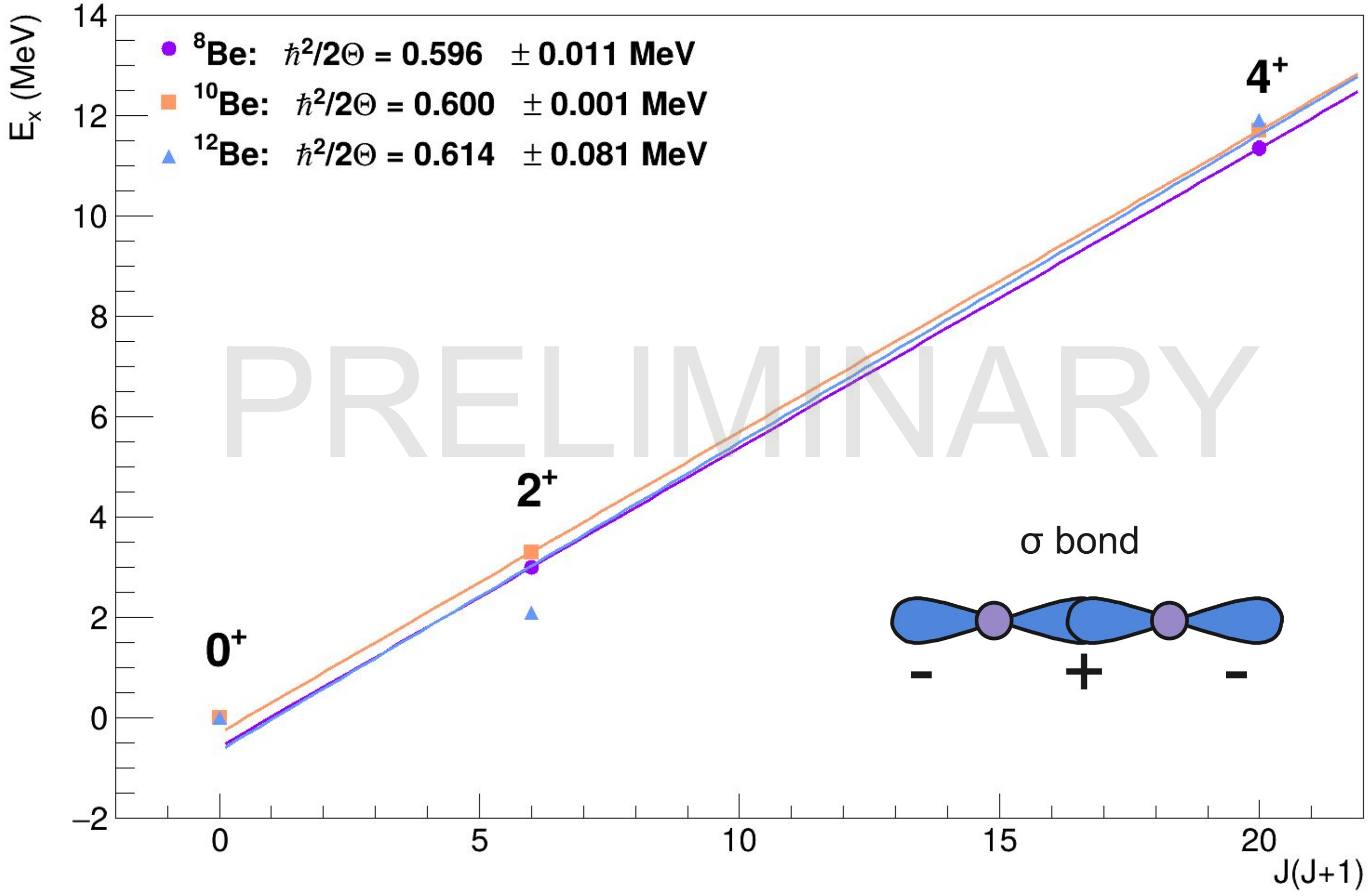
with I: moment of inertia → measure of **deformation**

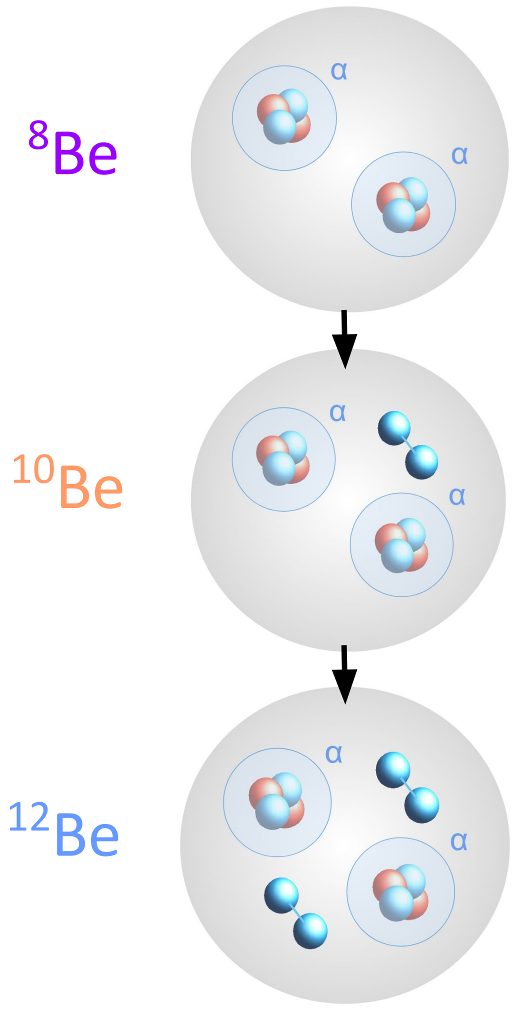
- **Clustered** nuclei → deformed → rotational motion
- **Neutron-rich systems:**
  - **π orbitals:** compact/triaxial
  - **σ orbitals:** elongated/prolate



-> Rotational bands reveal **shape**, **deformation**, and **cluster structure** in nuclei

Rotational band in Be isotopes

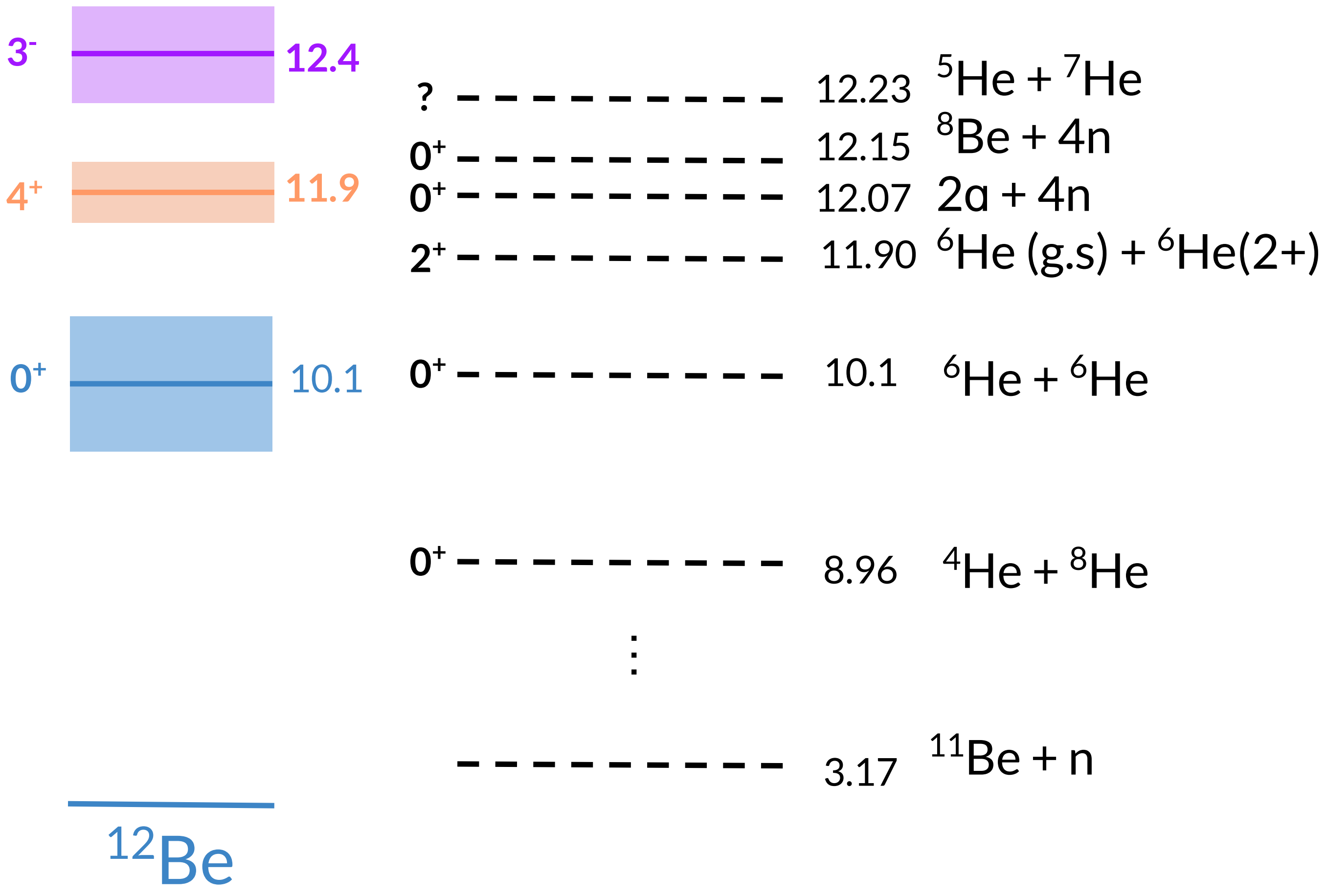




-> Confirms that **α-cluster cores coupled with valence neutrons** generate **collective rotational excitations** in **neutron-rich Be isotopes (^{10}Be, ^{12}Be)**, extending the rotational behavior observed in the **pure α–α system of ^{8}Be**.

Conclusion

- 11.9 MeV - 4^+ :
  - Compatible with 12.1 MeV (2^+) by *Yang et al.* but ≠ spin assignment
  - Compatible with states predicted by *Descouvemont et al.* and *Kanada-En'yo et al.*
  - σ-type alpha-cluster configuration
- 12.4 MeV - 3^- :
  - Not yet measured, predicted at lower energy
  - ^{5}He+^{7}He or ^{8}Be+^{4}n could be dominant, though large uncertainty and possible unaccounted channels prevent firm conclusions.
  - Might be key to study negative-parity band in ^{12}Be



Collaboration

Thank you for your attention !

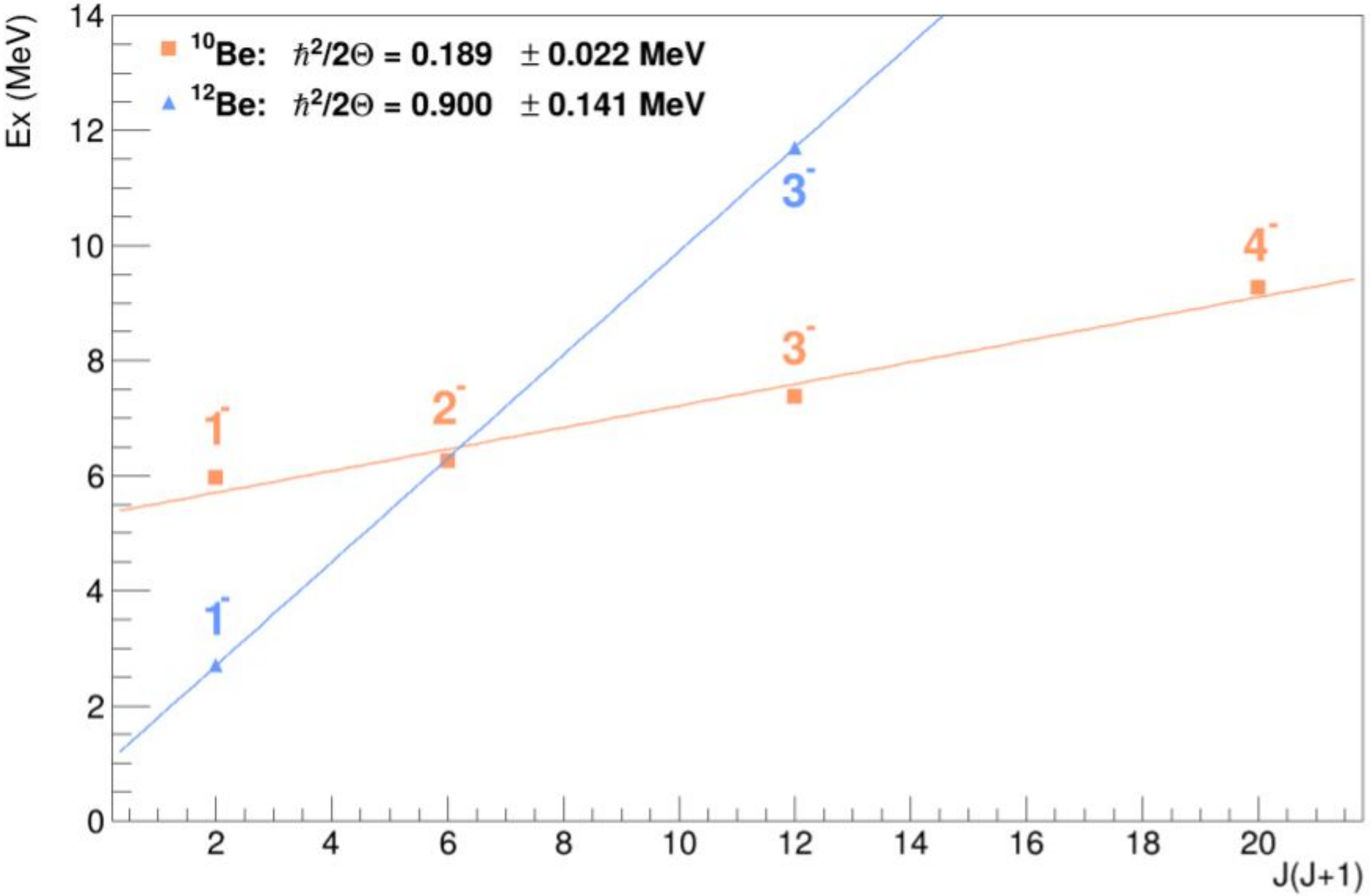
Spokespersons:

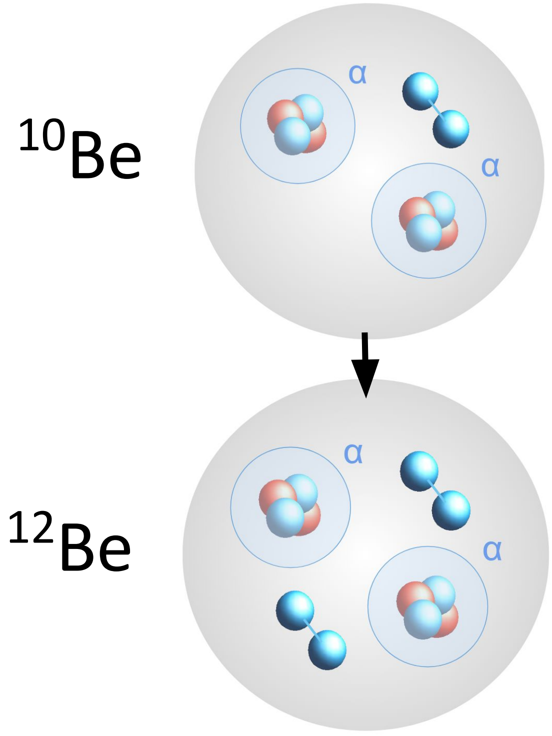
- Valdir Guimarães - University of São Paulo - Brazil
- Thomas Roger - GANIL - France

GANIL, France : F. de Oliveira, T. Roger, J. Pancin, C. Nicolle, M. Fisichella, L. Dienis, A. Cassisa, I. Wakudyanaye, M. Le Joubioux, J. C. Thomas, B. Jacquot, A. Navin
USC, Spain : B. Fernandez-Dominguez, M. Lozano González, B. Errandonea Félix
CEA, France : C. Fougères, M. Vandebrouck
INFN-Sezione di Catania, Italy : M. Grazia Pellegriti
University of Huelva, Spain : A. Miguel Sánchez Benitez
VINCA, Yugoslavia : T. Milanovic, I. Celikovic
IFIN-HH, Bucharest, Romania : M. Stanoiu
NPI ASCR Rez, Czech Republic : J. Mrazek
Michigan State University, USA : J. C. Zamora
NSCL-MSU, USA : Y. Ayyad
IBS (CENS), South Korea : X. Pereira Lopes

Backup slides

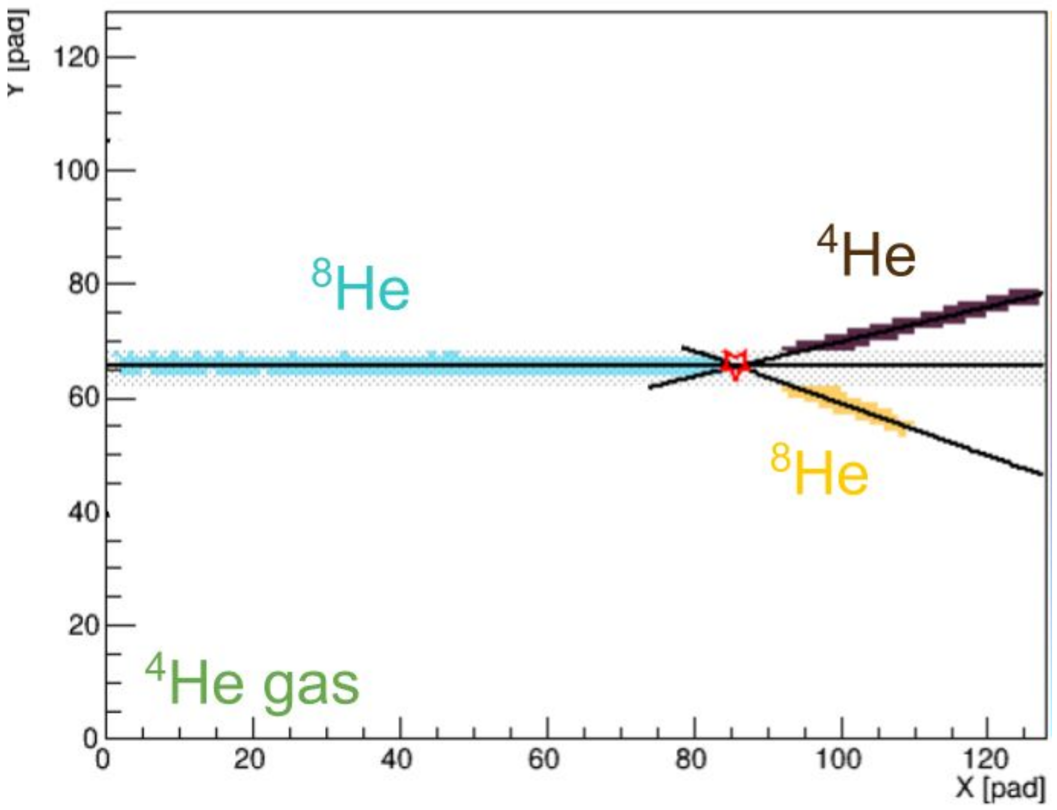
Rotational band in Be isotopes



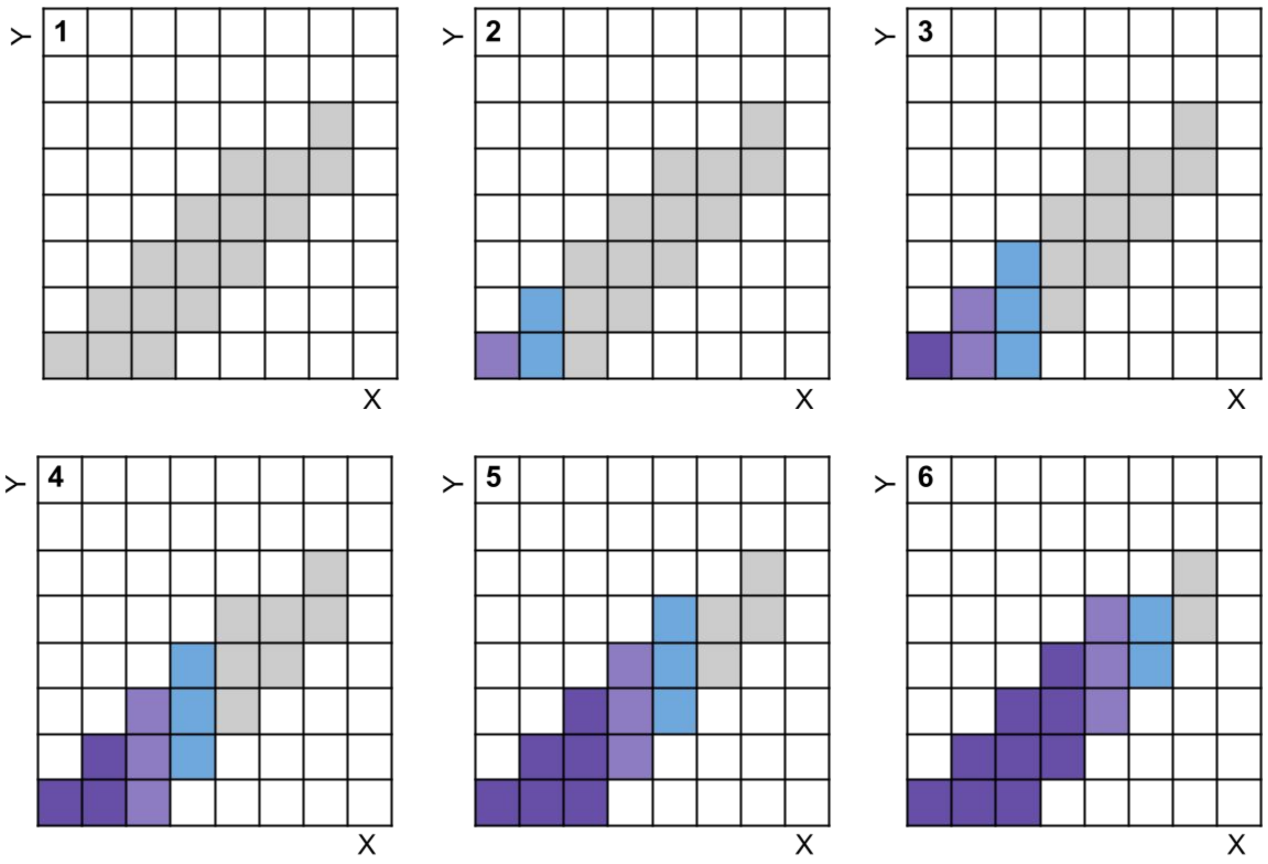


-> **Difference in rotational parameters** highlights the strong **influence of valence neutrons** on **nuclear deformation** and **rotational dynamics**.

Analysis : tracks reconstruction



CLIMB Algorithm



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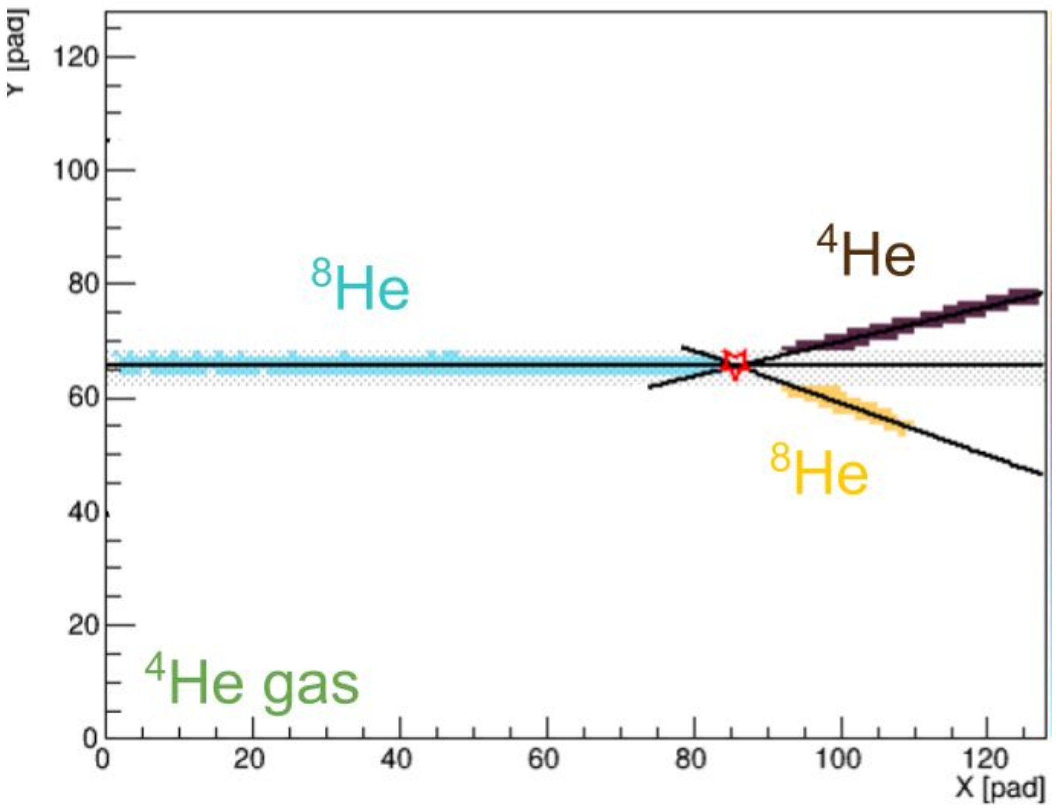

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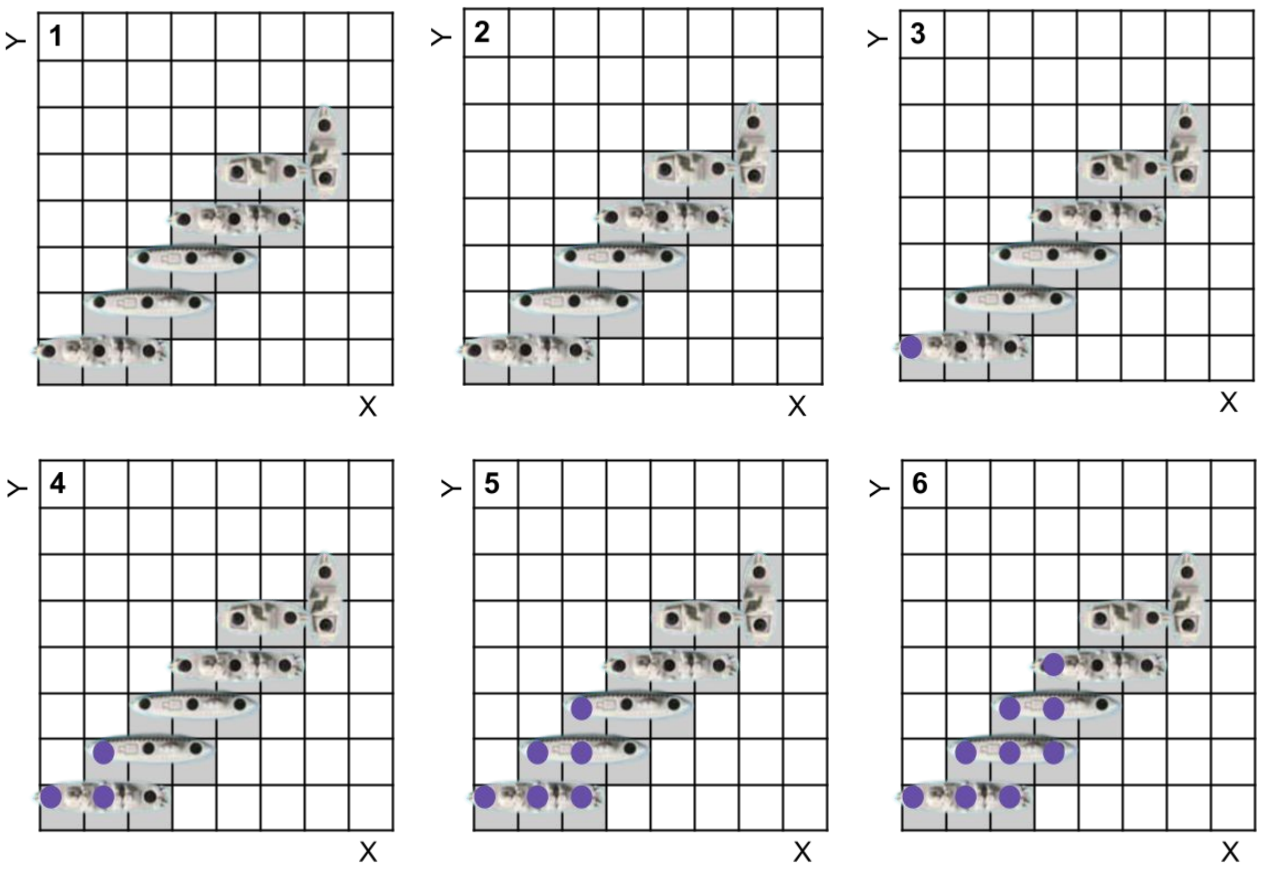
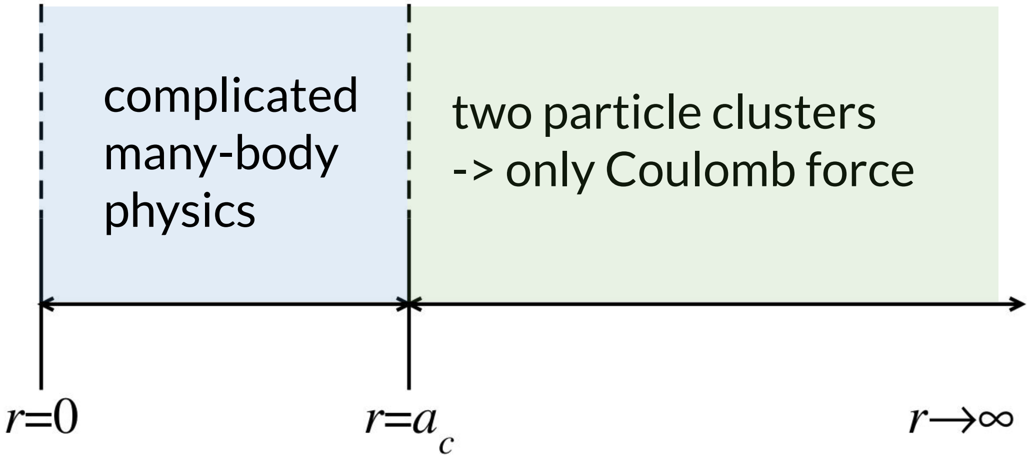


About R-Matrix formalism (1)

Separation of Regions:

- **Internal Region**: Complex nuclear interactions dominate
- **External Region**: Simpler potential



Core Formula:

$$R(E) = \sum_{\lambda} \frac{\gamma_\lambda^2}{E_\lambda - E}$$

E_λ: resonance energies, γ_λ: reduced width amplitudes

About R-Matrix formalism (2)

Difference with Breit Wigner :

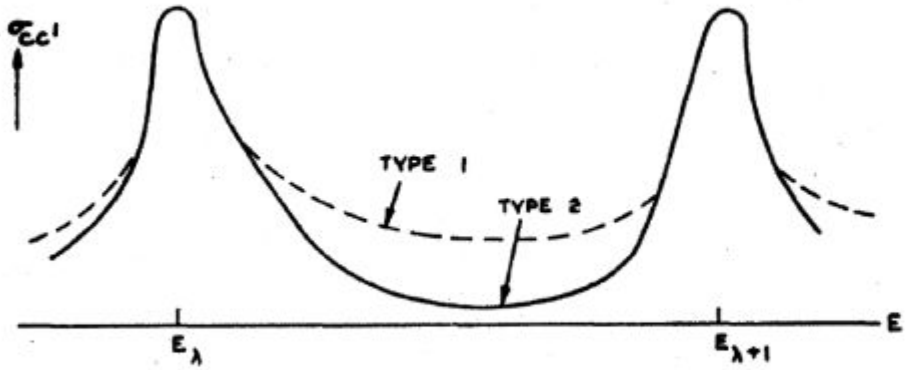
- **Breit-Wigner**

$$\sigma(E) = \pi\lambda^2\omega\frac{\Gamma_1\Gamma_2}{(E-E_0)^2+(\frac{\Gamma_{total}}{2})^2}$$

- **R-Matrix formalism**

-> Takes into account the interference between resonances

$$\begin{aligned}(2s+1)\frac{k_\alpha^2}{}\frac{d\sigma_{\alpha s,\alpha' s'}}{d\Omega_{\alpha'}} &= (2s+1)\left|C_{\alpha'}(\theta_{\alpha'})\right|^2\delta_{\alpha' s',\alpha s}\\ &+ \sum_{J_1 J_2 M_1 M_2}(2l_1+1)^{\frac{1}{2}}(2l_2+1)^{\frac{1}{2}}(sl_1\nu 0|J_1M_1)(sl_2\nu 0|J_2M_2)\\ &\times(sl_2\nu 0|J_2M_2)(s'l_1'\nu' m_1'|JM_1)(s'l_2'\nu' m_2'|J_2M_2)\\ &\times(T^{J1}_{\alpha s'l_1',\alpha s1}Y^{(l_1')}_{m_1}(\Omega_\alpha))\times(T^{J_2}_{\alpha' s' l_2',\alpha s l_2}Y^{(l_2')}_{m_2}(\Omega_\alpha))^*\\ &+\sum_{JMM'}(2l+1)^{\frac{1}{2}}(sl\nu 0|JM)(s'l'\nu' m'|JM)\\ &\times\delta_{\alpha' s'\nu',\alpha s\nu}2\,\mathrm{Re}\left[iT^J_{\alpha' s' l',\alpha s l}Y^{(l')}_m(\Omega_\alpha)C_{\alpha'}(\theta_{\alpha'})\right].\end{aligned}$$



Lane and Thomas, XII.5

Analysis : R-Matrix fit

Bayesian R-matrix Inference Code Kit (BRICK) published in 2021