



irfu

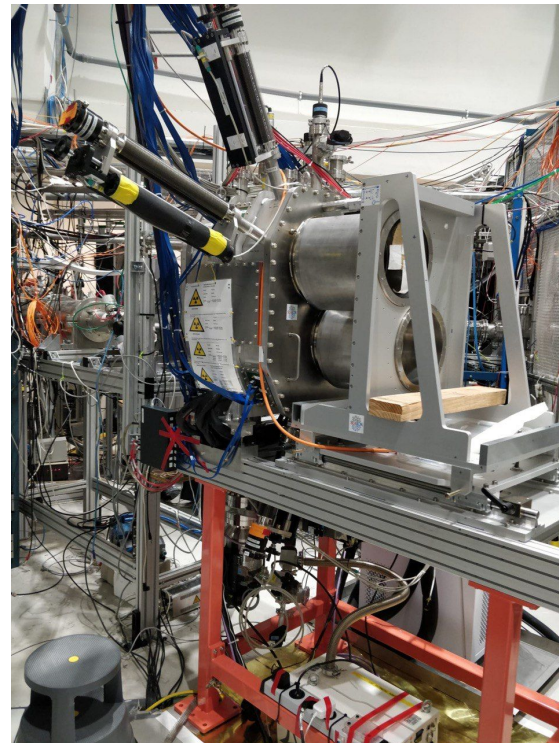


Octupole deformation & SEASON commissioning

Mathilde Ragot

Supervisors : Damien Thisse
Marine Vandebrouck
Iain Moore

PHENIICS Fest - 8/06/26

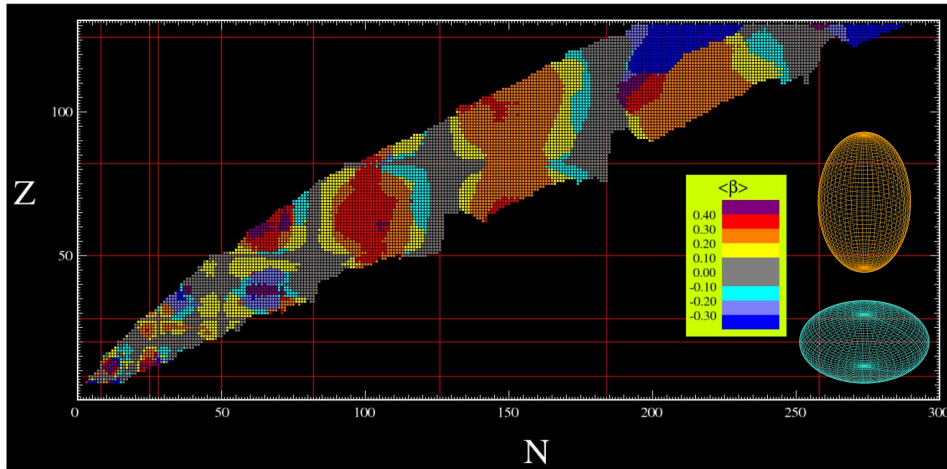


1.

Nuclear shapes

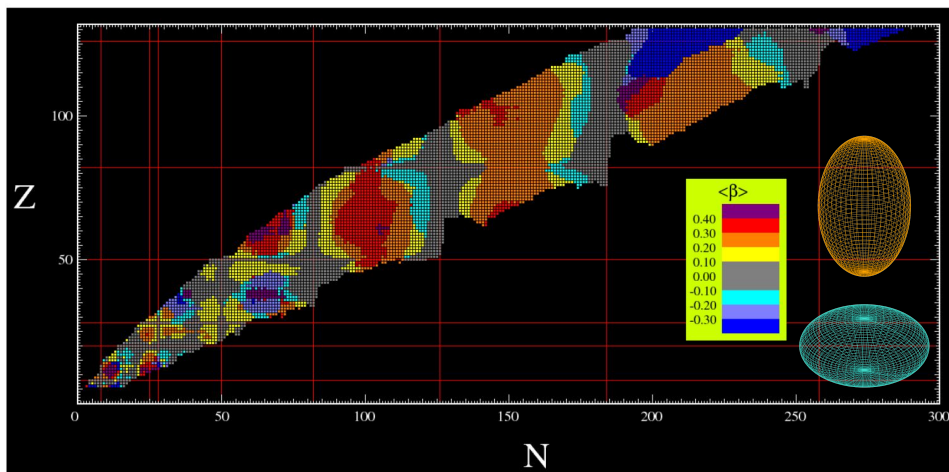
Studying nuclear shapes

Quadrupole deformation across the nuclear chart:

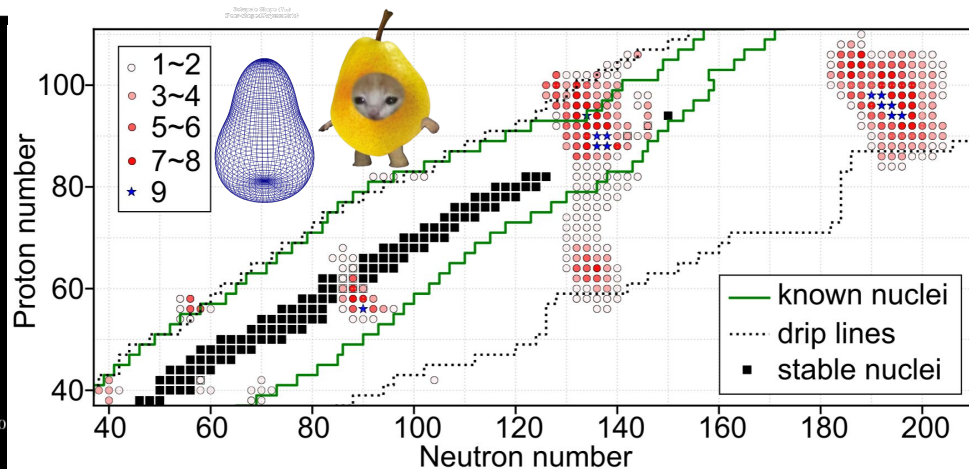


Studying nuclear shapes

Quadrupole deformation across the nuclear chart:



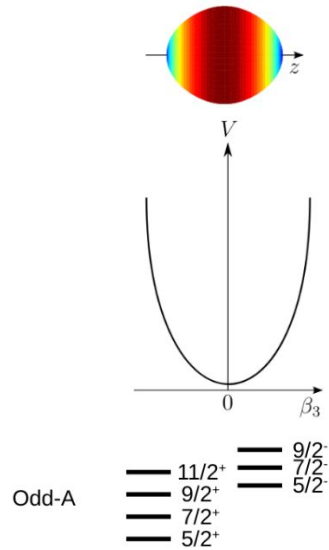
Octupole deformation in the upper part of the nuclear chart :



Cao, Y. et al. (2020) *Physical Review C*, 102(2), p. 024311.

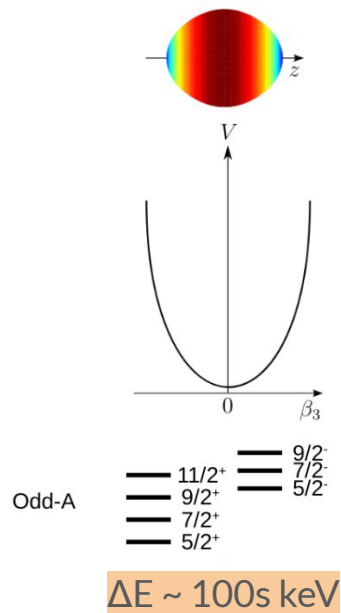
Microscopic evidence of octupole collectivity ?

- Parity doublets in the rotational bands



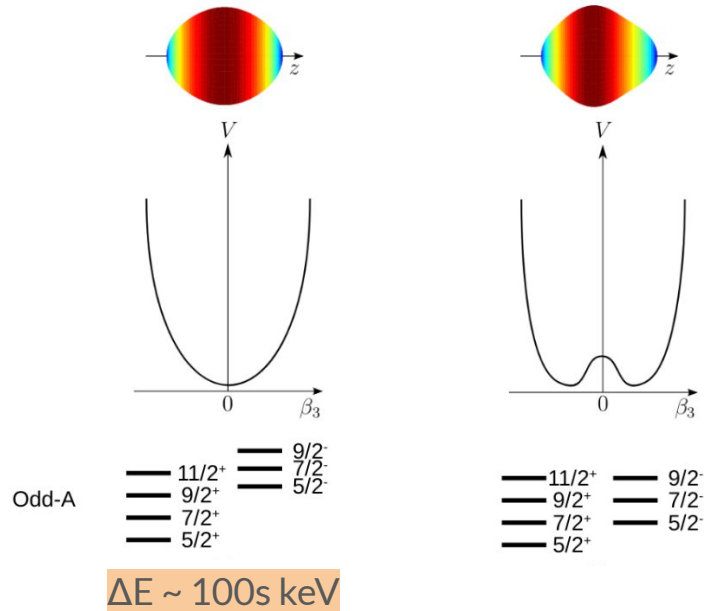
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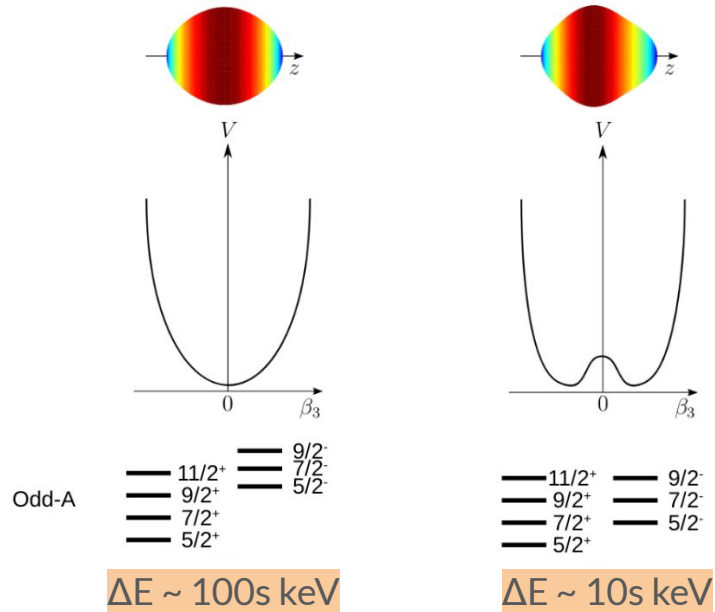
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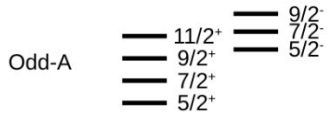
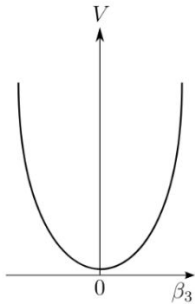
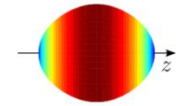
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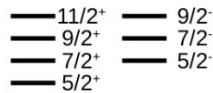
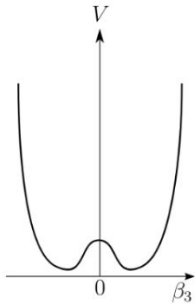
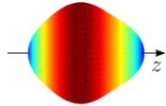


Microscopic evidence of octupole collectivity ?

- Parity doublets in the rotational bands



$\Delta E \sim 100\text{s keV}$



$\Delta E \sim 10\text{s keV}$

- α -decay

gap between simple alpha decay model (Gamow) and experimental results represented with :

$$HF = \frac{T_{1/2,exp}}{T_{1/2,th}}$$

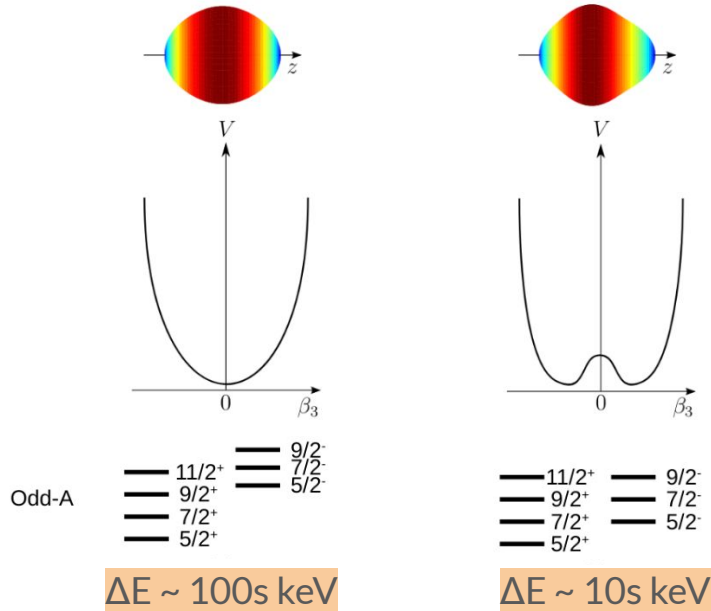
Typical values :

HF ~ 1-4: Favored transitions

HF ~ 10-100: Initial and final particle state do not have favourable overlap

Microscopic evidence of octupole collectivity ?

- Parity doublets in the rotational bands



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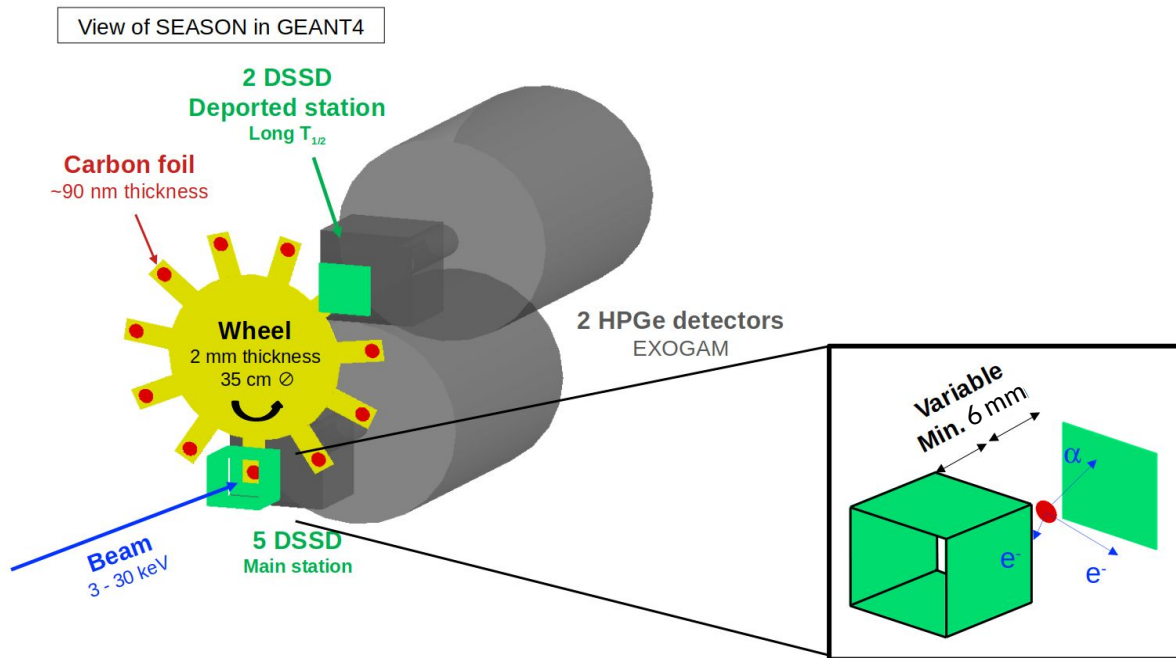
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octupole
deformation

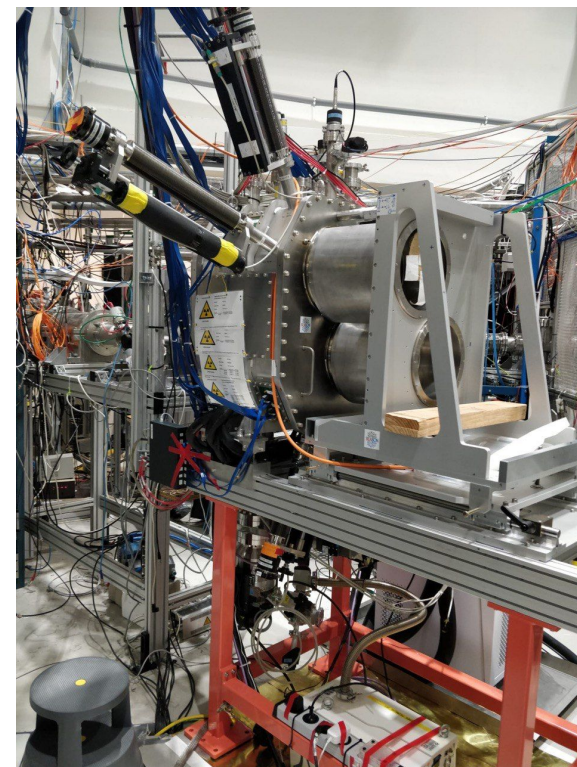
2. SEASON decay station

SEASON scheme



simulation done by Emmanuel Rey-herme

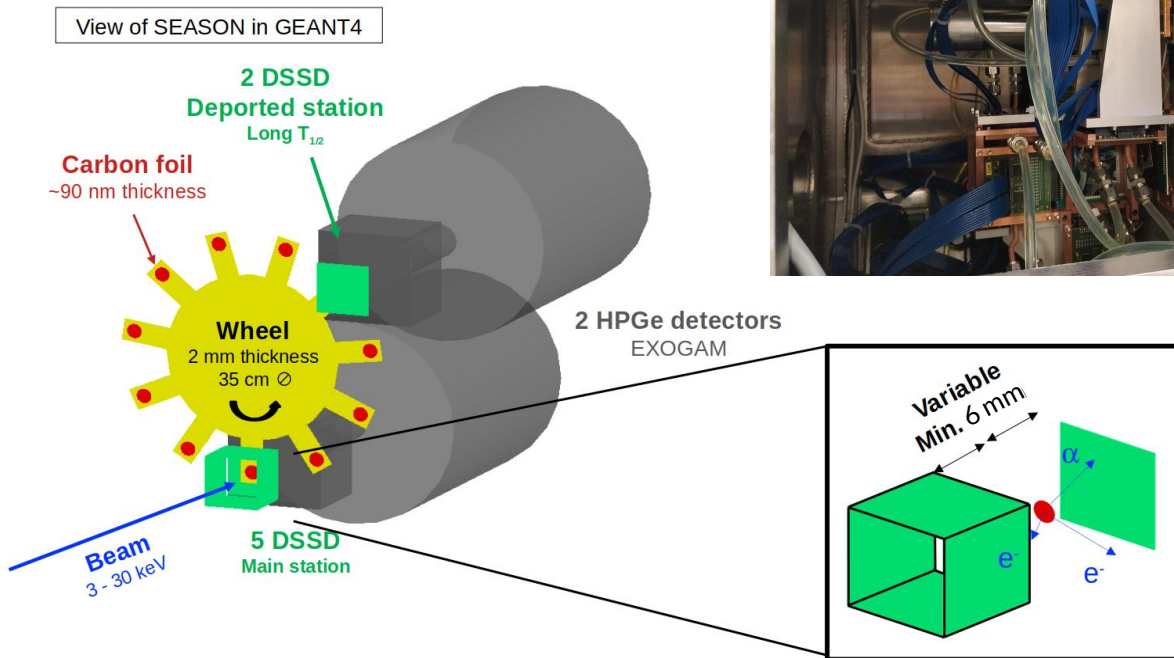
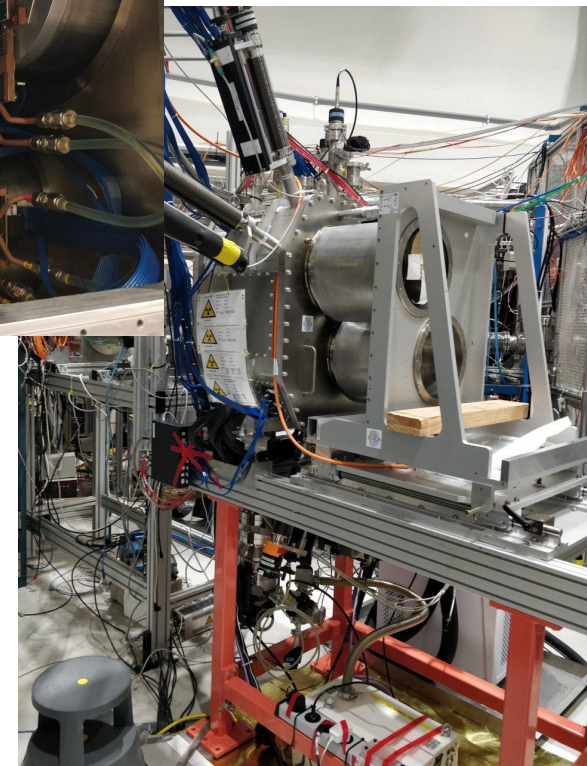
SEASON at Jyväskylä



SEASON scheme



SEASON at Jyväskylä



simulation done by Emmanuel Rey-herme

2.

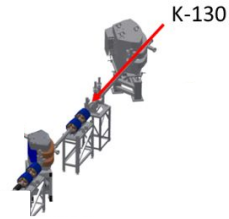
Commissioning in Jyväskylä, Finland

→ february 20th – february 27th

SEASON at Jyväskylä

Reaction used : $^{232}\text{Th}(p,xn)^{233-x}\text{Pa}$

^{223}Pa α	^{224}Pa α	^{225}Pa α	^{226}Pa α	^{227}Pa α	^{228}Pa β^+	^{229}Pa e- capture	^{230}Pa β^+	^{231}Pa α	^{232}Pa β^-	^{233}Pa β^-
^{222}Th α	^{223}Th α	^{224}Th α	^{225}Th α	^{226}Th α	^{227}Th α	^{228}Th α	^{229}Th α	^{230}Th α	^{231}Th β^-	^{232}Th α
^{221}Ac α	^{222}Ac α	^{223}Ac α	^{224}Ac β^+	^{225}Ac α	^{226}Ac β^-	^{227}Ac β^-	^{228}Ac β^-	^{229}Ac β^-	^{230}Ac β^-	^{231}Ac β^-
^{220}Ra α	^{221}Ra α	^{222}Ra α	^{223}Ra α	^{224}Ra α	^{225}Ra β^-	^{226}Ra α	^{227}Ra β^-	^{228}Ra β^-	^{229}Ra β^-	^{230}Ra β^-
^{219}Fr α	^{220}Fr α	^{221}Fr α	^{222}Fr β^-	^{223}Fr β^-	^{224}Fr β^-	^{225}Fr β^-	^{226}Fr β^-	^{227}Fr β^-	^{228}Fr β^-	^{229}Fr β^-

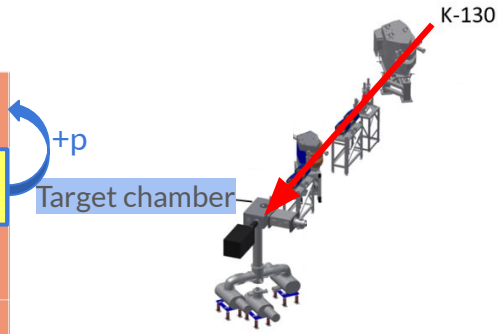


Layout of the IGISOL facility in Jyväskylä, Finland

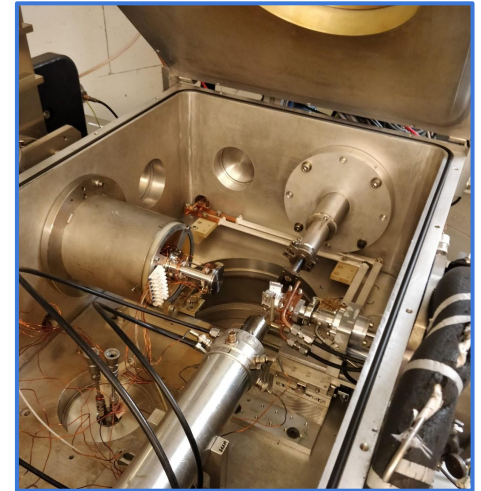
SEASON at Jyväskylä

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^{221}Ac α	^{222}Ac α	^{223}Ac α	^{224}Ac β^+	^{225}Ac α	^{226}Ac β^-	^{227}Ac β^-	^{228}Ac β^-	^{229}Ac β^-	^{230}Ac β^-	^{231}Ac β^-
^{220}Ra α	^{221}Ra α	^{222}Ra α	^{223}Ra α	^{224}Ra α	^{225}Ra β^-	^{226}Ra α	^{227}Ra β^-	^{228}Ra β^-	^{229}Ra β^-	^{230}Ra β^-
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Layout of the IGISOL facility in Jyväskylä, Finland



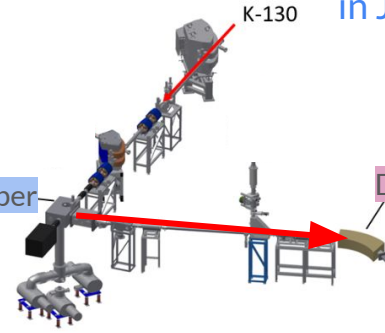
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^{221}Ac α	^{222}Ac α	^{223}Ac α	^{224}Ac β^+	^{225}Ac α	^{226}Ac β^-	^{227}Ac β^-	^{228}Ac β^-	^{229}Ac β^-	^{230}Ac β^-	^{231}Ac β^-
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+p

Target chamber



Layout of the IGISOL facility in Jyväskylä, Finland

Dipole magnet (mass separation)

SEASON at Jyväskylä

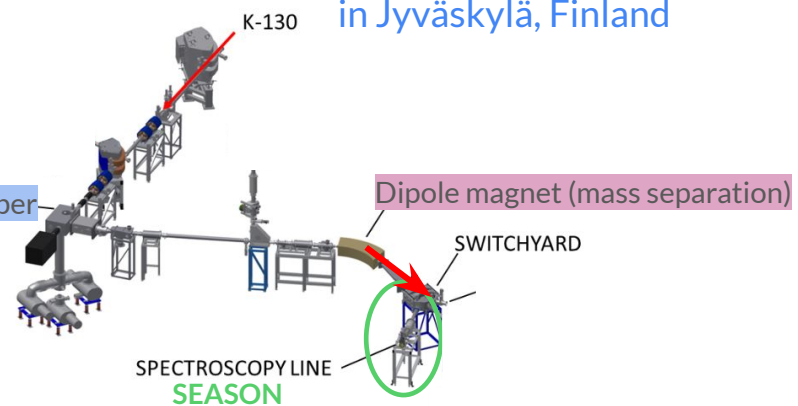
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Layout of the IGISOL facility in Jyväskylä, Finland

^{223}Pa α	^{224}Pa α	^{225}Pa α	^{226}Pa α	^{227}Pa α	^{228}Pa β^+	^{229}Pa e- capture	^{230}Pa β^+	^{231}Pa α	^{232}Pa β^-	^{233}Pa β^-
^{222}Th α	^{223}Th α	^{224}Th α	^{225}Th α	^{226}Th α	^{227}Th α	^{228}Th α	^{229}Th α	^{230}Th α	^{231}Th β^-	^{232}Th α
^{221}Ac α	^{222}Ac α	^{223}Ac α	^{224}Ac β^+	^{225}Ac α	^{226}Ac β^-	^{227}Ac β^-	^{228}Ac β^-	^{229}Ac β^-	^{230}Ac β^-	^{231}Ac β^-
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Target chamber



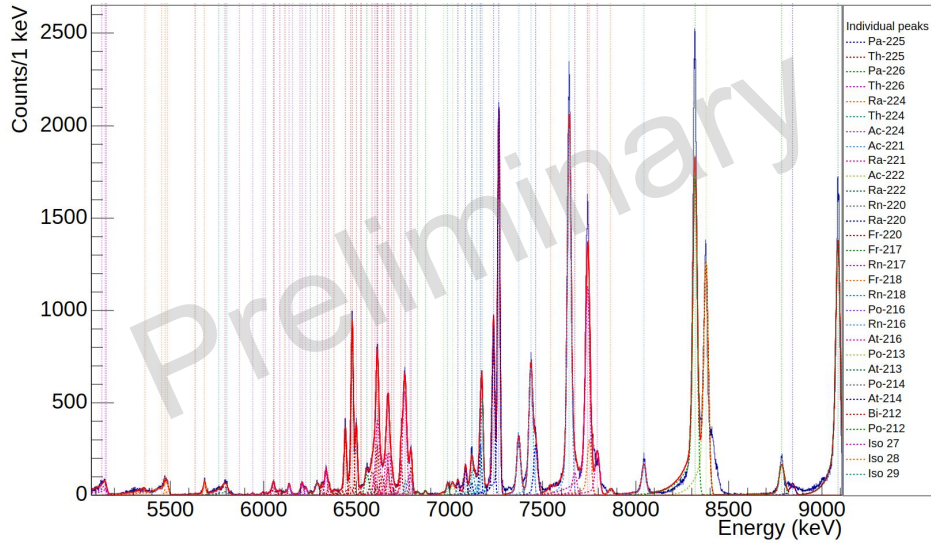
Measurement: ~ 40 hours on mass 225 using two different acquisition modes

4. ■

Preliminary results of the
online commissioning

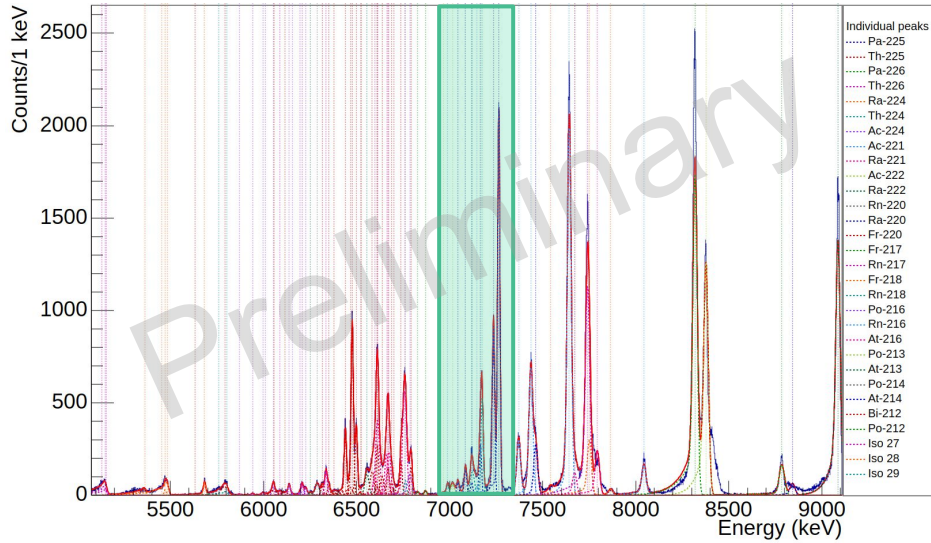
Mass 225

Alpha energy spectrum



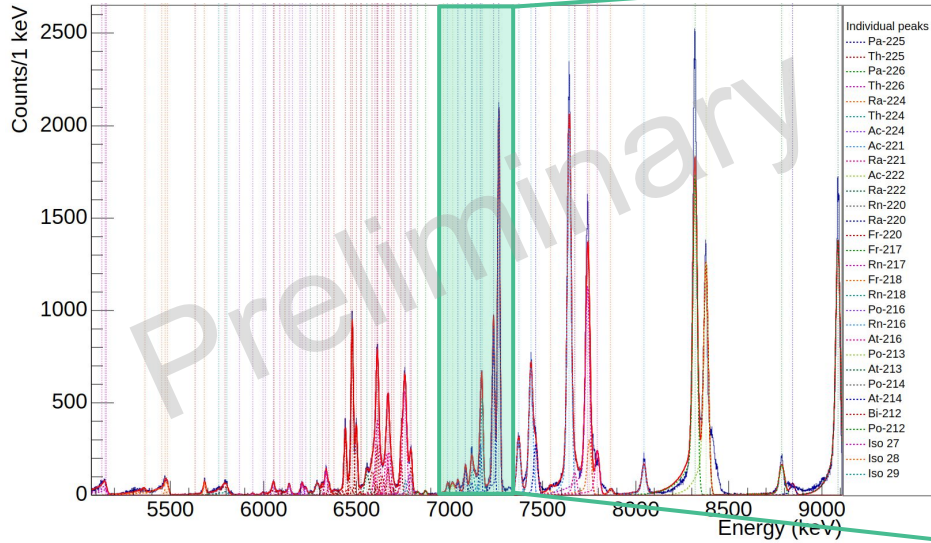
Mass 225

Alpha energy spectrum

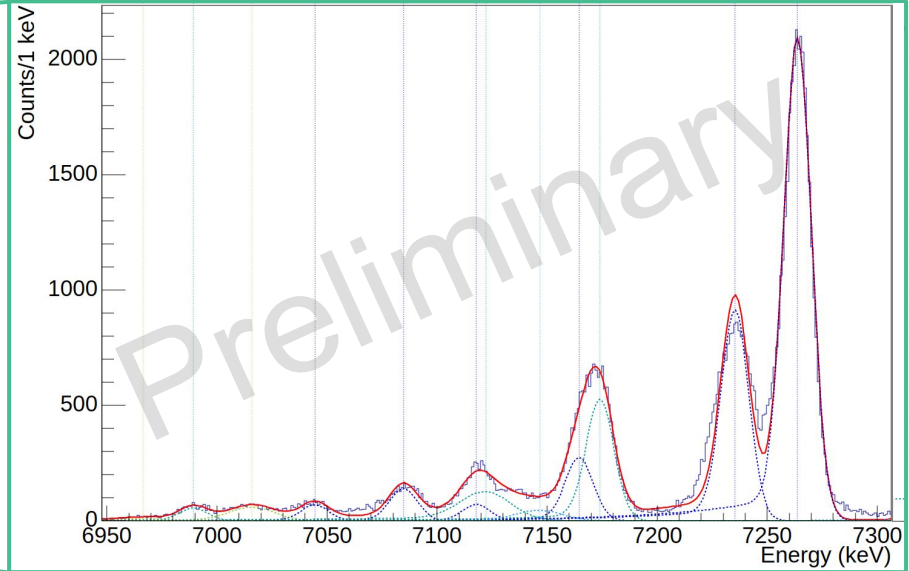


Mass 225

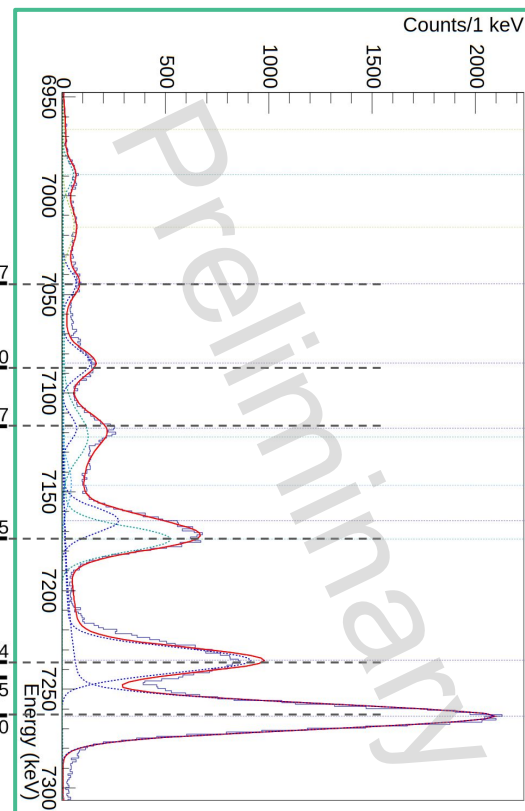
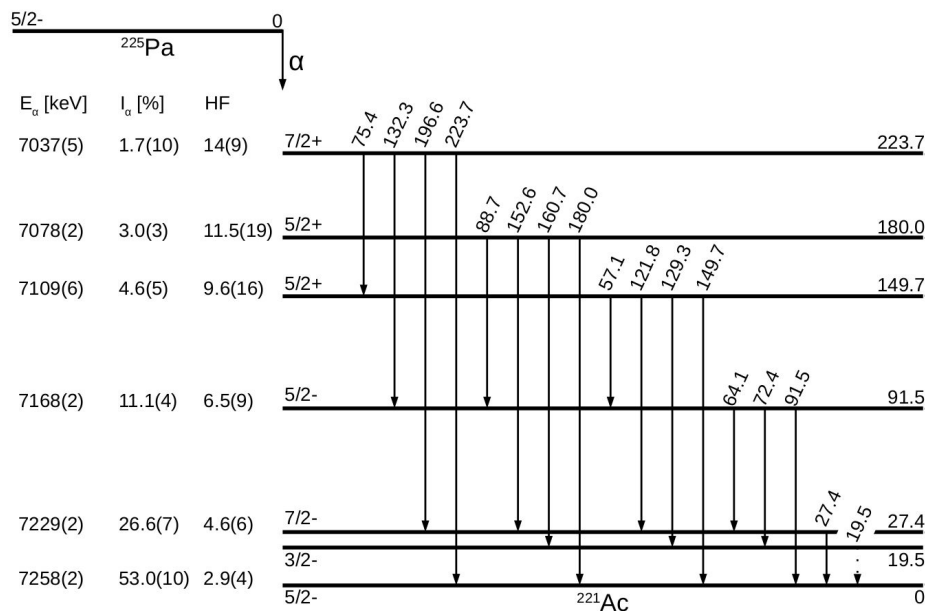
Alpha energy spectrum



Alpha energy spectrum zoomed in on the the energies of 225Pa decay



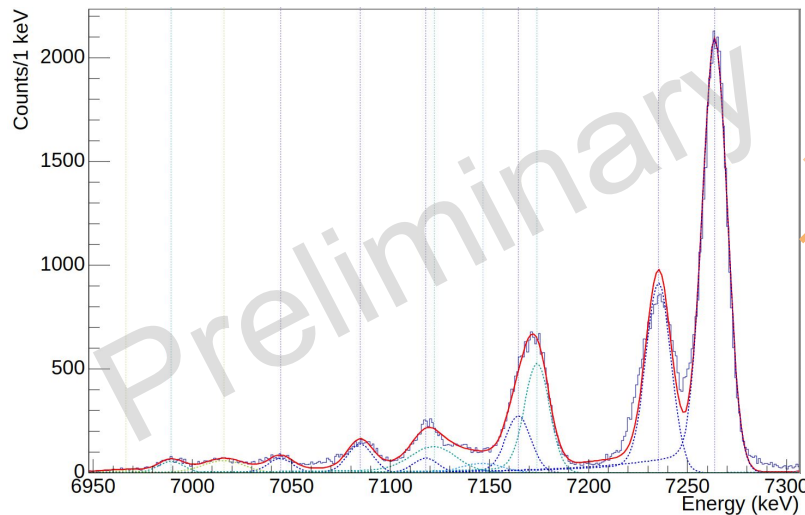
Mass 225 : study of ^{225}Pa



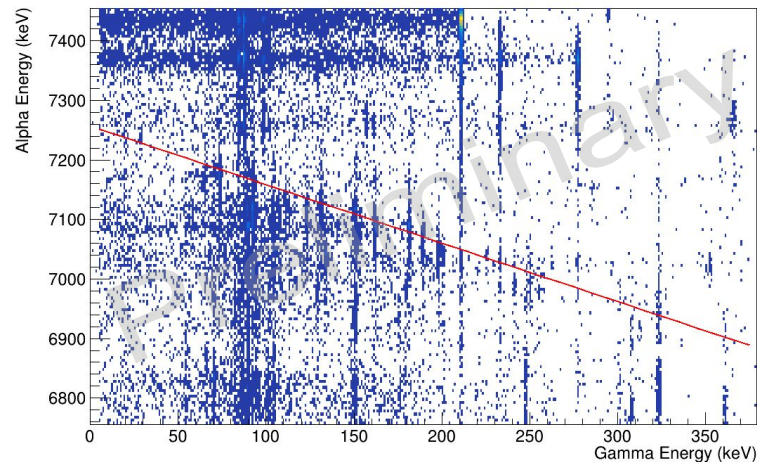
E. Rey-herme PhD thesis (2023)

Mass 225 : study of ^{225}Pa

Alpha energy spectrum:



γ -coincidences

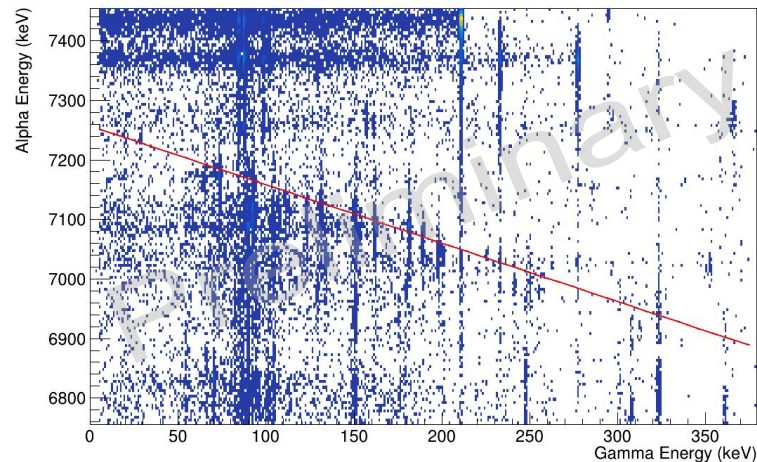
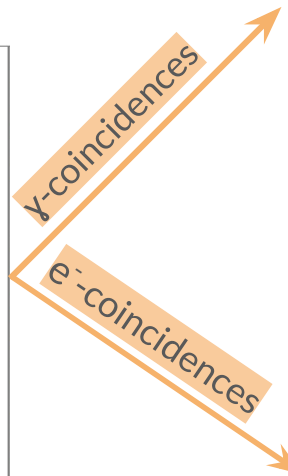
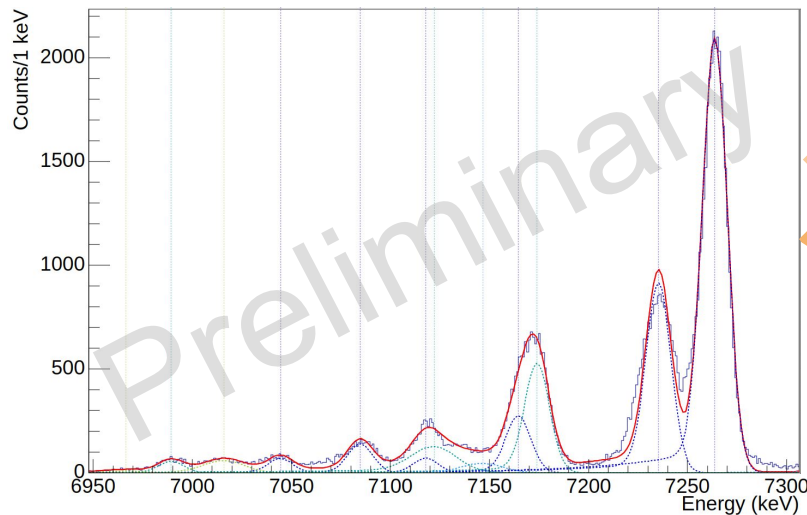


$$Q_{\alpha} + E_{\gamma} = Q_{\alpha}(gs \text{ to } gs)$$

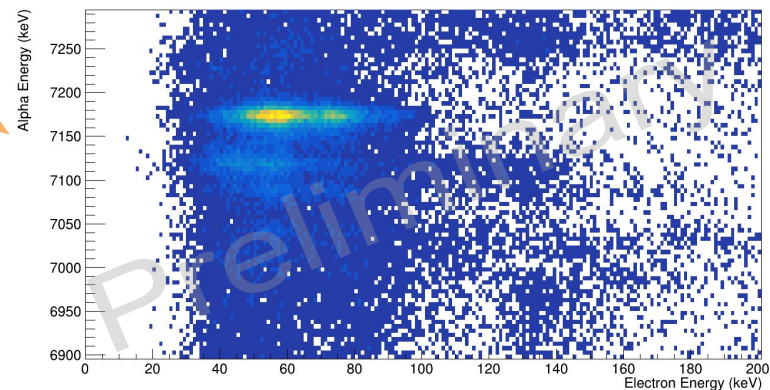
-> few issues of time alignment and energy resolution to be solved

Mass 225 : study of ^{225}Pa

Alpha energy spectrum:



$$Q_\alpha + E_\gamma = Q_\alpha(gs \text{ to } gs)$$



-> few issues of time alignment and energy resolution to be solved



JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

Thank you !



Jyväskylä

Natalia Ambrosio, Theodore Davids, Tommi Eronen, Zhuang Ge, Anu Kankainen, Brian Koote, Iain Moore, Prince Parvez, Simon Rausch, Mikael Reponen, Alexandre Roger, Jan Saren

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Damien Thisse, Léonard Jost, Emmanuel Rey-herme, Killian Ronxin, Barbara Sulignano, Marine Vandebrouck

GSI

Sebastian Raeder

IJCLab

Matthieu Lebois

LP2iB

Samuel Lecanuet

LPC Caen

Skyy Pineda

GANIL

Margarida Paulino

KU Leuven

Andrea Raggio

SEASON development team :

Project Managers :

O. Cloué (technic)

D. Thisse (scientific)

Mechanical conception :

S. Cazaux, P. Daniel-Thomas

Detection/Acquisition :

F. Bouyjou, T. Chaminade, Jules Dartois

Control & Command :

A. Gaget, J. Relland, A. Roger, S.

Tzvetkov, T. Joannem

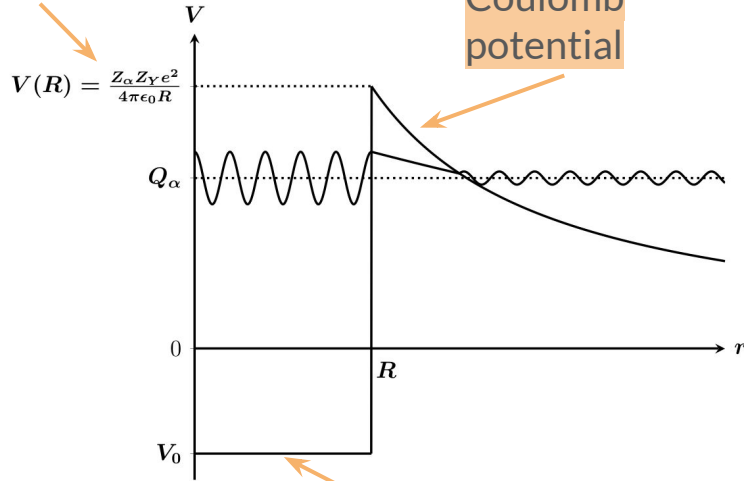
Electrical engineering :

J. Noury, Y. Reinert, J. Mendes Ribeiro

■ Back-up

Microscopic evidence of octupole collectivity ?

Coulomb barrier height



Coulomb potential

nuclear force

- α -decay

gap between Gamow alpha decay model and experimental results represented with :

$$HF = \frac{T_{1/2,exp}}{T_{1/2,th}}$$

Assumes alpha and daughter nuclei preformation inside the parent nucleus. Disregards the structure effect -> Underestimates the half life of nuclei.

Typical values :

HF ~ 1-4: Favored transitions

HF ~ 10-100: Initial and final particle state do not have favourable overlap

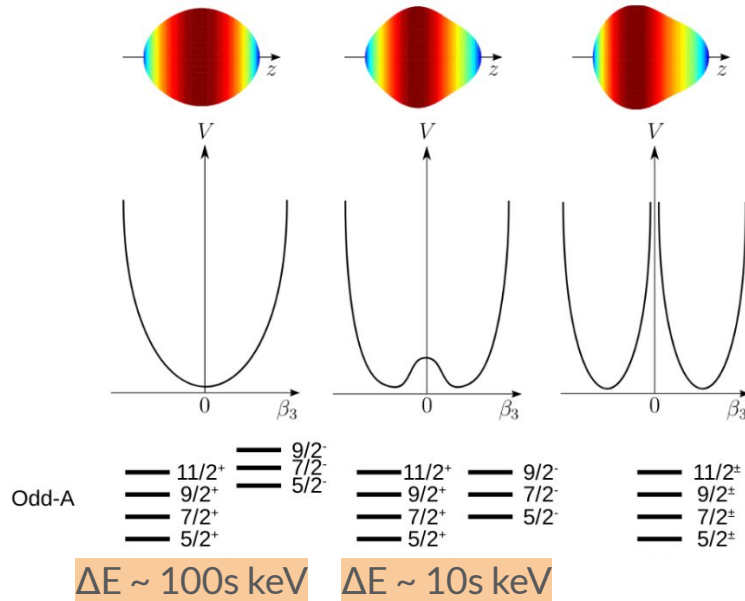


octupole deformation

HF is computed from experimentally measured branching ratios of the transition and total half-life of the parent nucleus using Preston's spin-independent equations.

Microscopic evidence of octupole collectivity ?

- Parity doublets in the rotational bands



- Why do we expect parity doublets ?

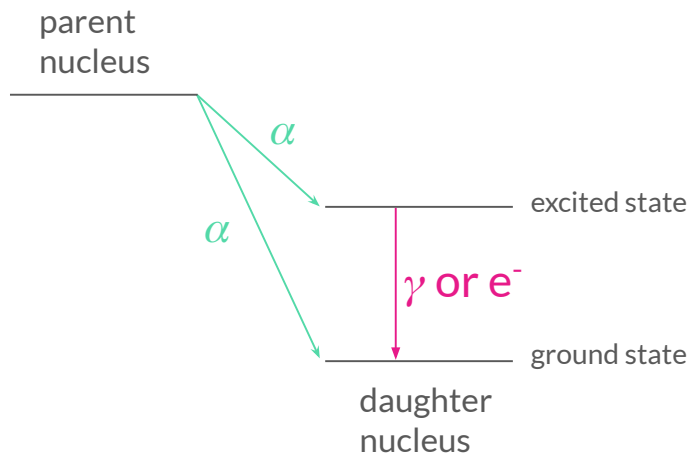
Reflection asymmetry -> Parity is broken at the intrinsic level: the intrinsic state is not an eigenstate of parity.

However, going to the lab frame involves restoring the broken symmetry of the intrinsic state by projecting onto good parity. The intrinsic state therefore projects onto positive and negative parity components.

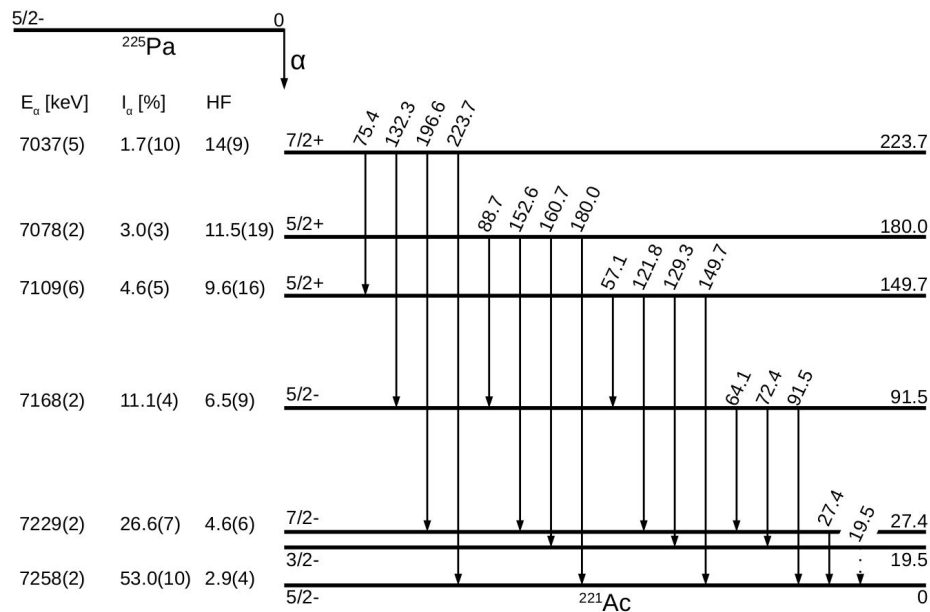
Because the intrinsic state and its mirror image still have similar configurations:

when the octupole deformation is soft, tunneling is more probable between the two configurations. The tunneling strength will increase the energy splitting. => The lower the potential barrier between the two configurations, the larger the splitting between the parity doublets.

Conversion electrons : a tool to understand transitions

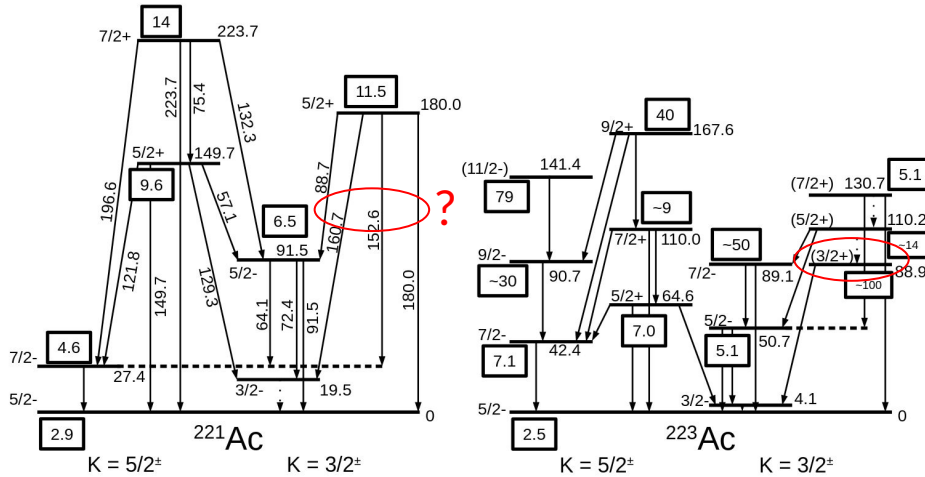


$$\text{conversion coefficient: } \alpha = \frac{N_e}{N_\gamma}$$



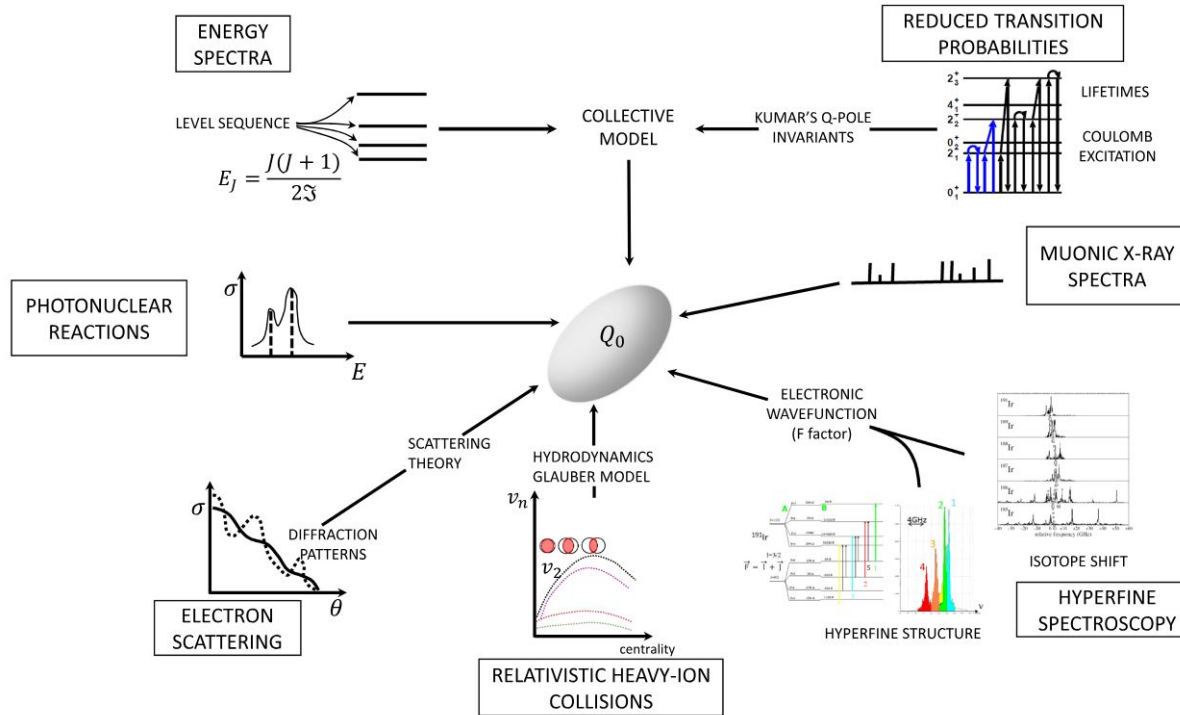
Rey-herme, E. et al. (2023), *Physical Review C*, 108(1)

Where is the 3/2+ state expected ?



- Similarity with ^{223}Ac
- In ^{223}Ac : $3/2^+$ state is at 88.9 keV and the $3/2^-$ is at 4.1 keV
- In ^{221}Ac , $3/2^-$ state is at 19.5 keV, so the $3/2^+$ state would be in between $5/2^-$ (91.5 keV) and $5/2^+$ (149.7 keV)
- This would be an M1 transition, highly converted with very low energy (few 10s keV)

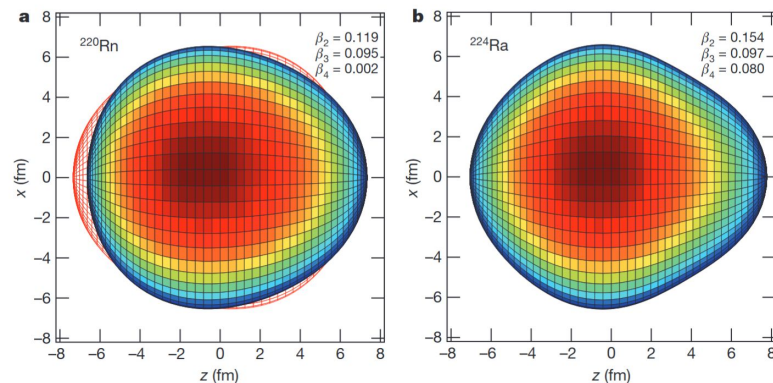
What are the ways to study nuclear shape ?



Verney, D. History of the concept of nuclear shape. *Eur. Phys. J. A* **61**, 82 (2025).

Coulomb excitation : a different approach

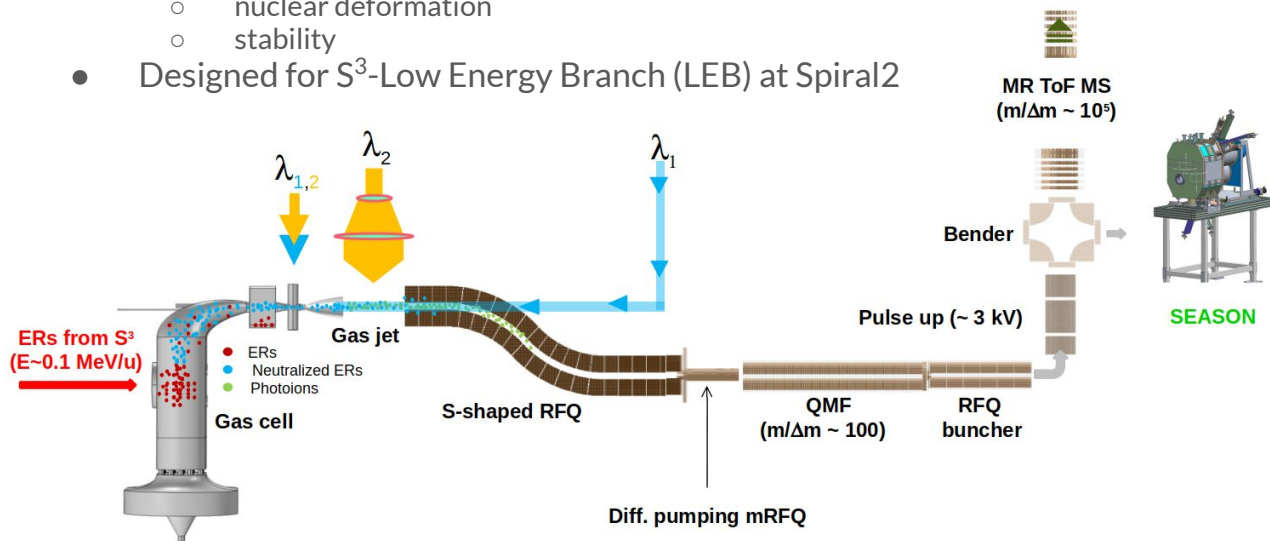
- Ions produced by spallation and sent onto secondary targets at specific energies (few MeV/A) so that the ions and the target interact only via Coulomb. The targets are chosen to give different electromagnetic excitation.
- The gammas emitted after the excitation are detected with germanium detectors. The obtained gamma spectrum allows to measure the cross-sections of the states and deduce the transition moments E1, E2, E3.
- The intrinsic moments Q_λ can be derived from the matrix element $\langle I' || E\lambda || I \rangle$ assuming the validity of the rotational model.



Gaffney, L.P. *et al.* (2013) « Studies of pear-shaped nuclei using accelerated radioactive beams », *Nature*, 497(7448), p. 199-204.

SEASON's at GANIL

- Study of heavy and super heavy nuclei
 - single particle structure
 - nuclear deformation
 - stability
- Designed for S³-Low Energy Branch (LEB) at Spiral2



GANIL

- Counter for laser spectroscopy
- Detailed α , e⁻, γ decay spectroscopy

Coupling of atomic and nuclear approaches



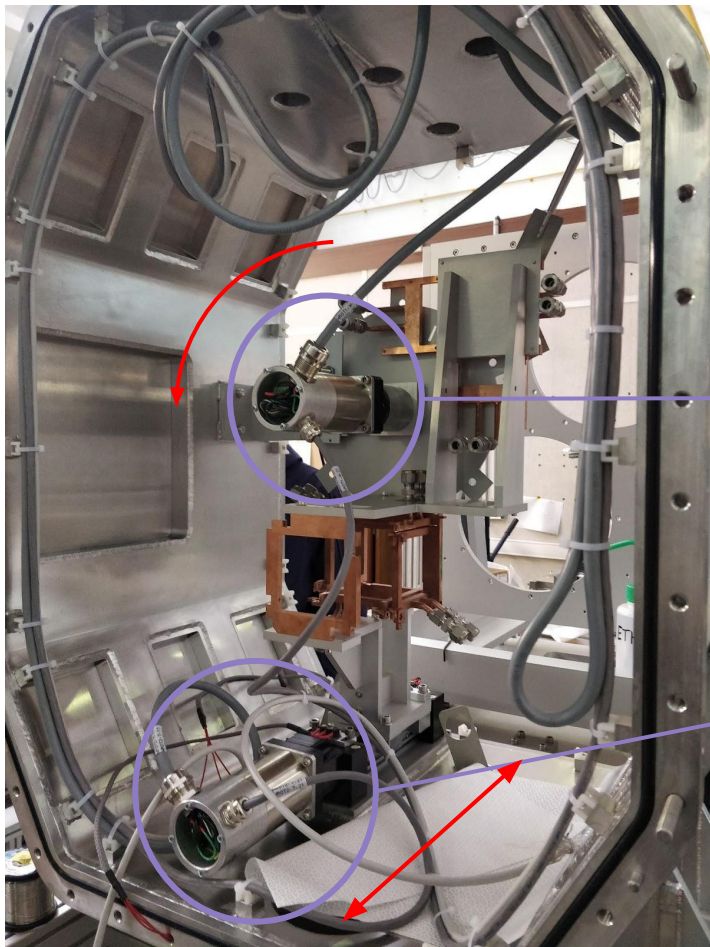
→ beam direction

deported station

wheel

main station

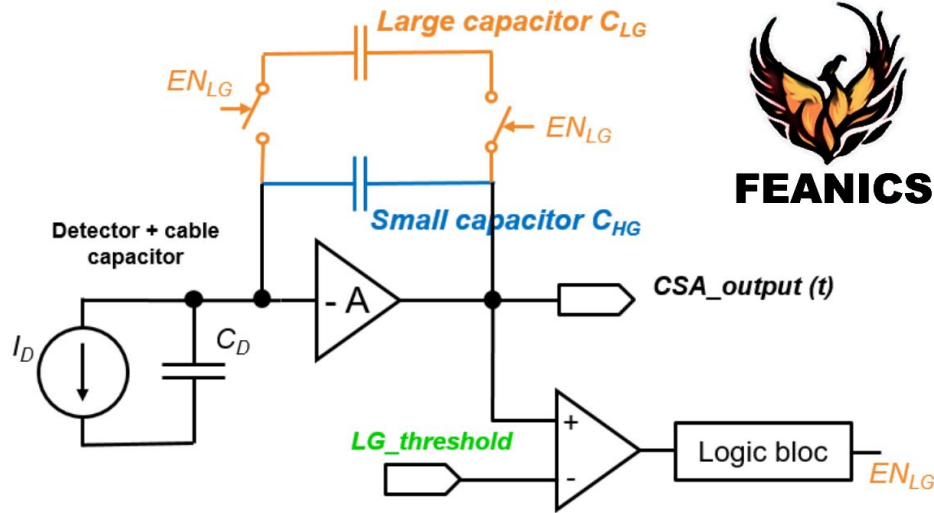
calibration arms and its HMI that manages:
- the control of the sources storage
- the different calibration step
& provides safety features to avoid detector damage.



motor to rotate the wheel

Upstream system: motorised to slide the tunnel part of the main station and one of the two detectors in the deported station

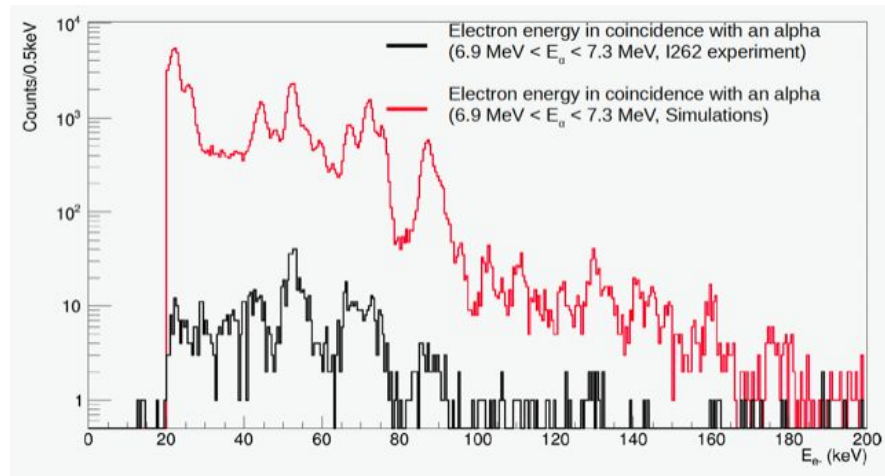
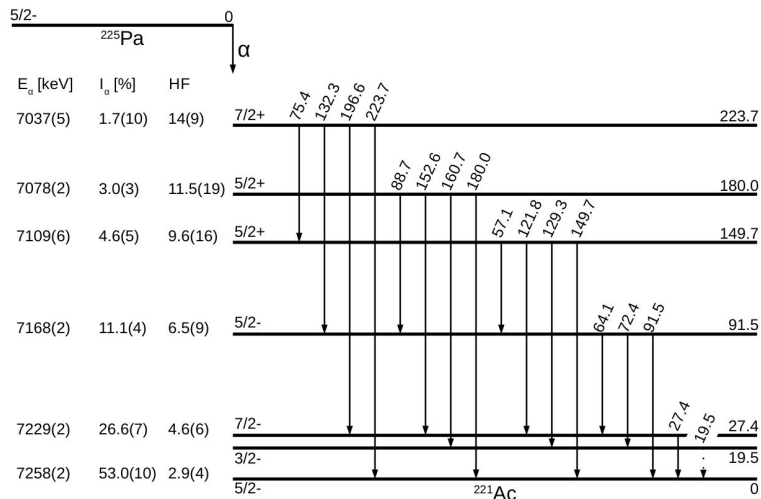
FEANICS



Front End Adaptive gain Integrated CircuitS:

- double gain preamplifier with automatic gain switch
 - CSA floor noise (no detector): ~ 2.3 keV
 - variable threshold for gain switch
 - can also be set to fixed gain
- Directly connected to the detector to limit the noise
- Outputs a differential signal to be sent to the digitizer

Why this reaction ? $^{232}\text{Th}(p,xn)^{233-x}\text{Pa}$



E. Rey-herme, PhD thesis (2023)

- Use previous experimental results as a benchmark to characterize SEASON
- Improved efficiency => look for new transitions that were not visible before

Technical SEASON properties

In automatic gain switch mode :

In conditions of the online commissioning experiment

	Energy resolution in main	Energy resolution in tunnels	Efficiency on Main	Efficiency in tunnels	Total efficiency
α -particle	~20 keV	~18 keV	~36%	~20%	~56%
electron	~14 keV	~14 keV	~23%	~18%	~41%

→ from mass 225 energy spectrum

→ from 3 α source measurements

→ from 133 Ba source measurements