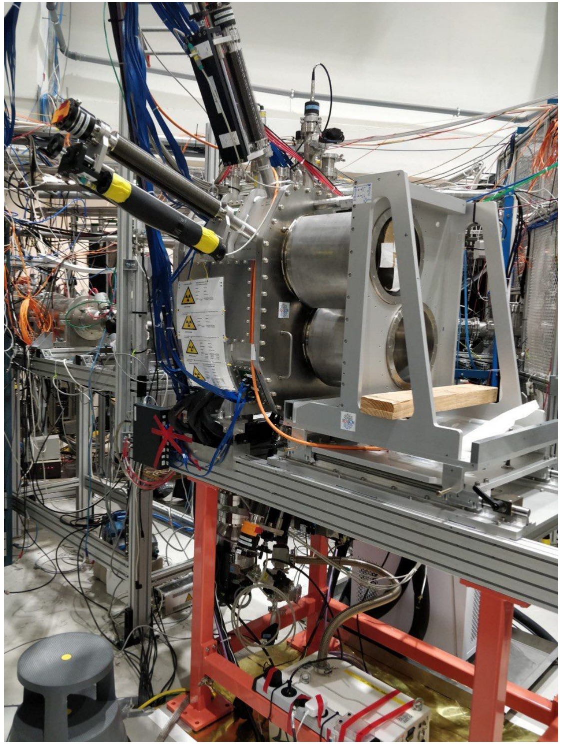
First results of the SEASON detector commissioning and insights on the octupole collectivity in ^{221}Ac

Mathilde Ragot

Supervisors : Damien Thisse
Marine Vandebrouck
Iain Moore

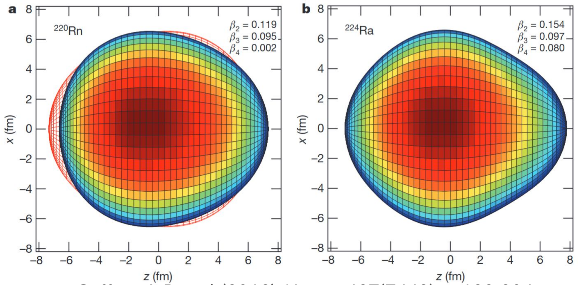


Colloque GANIL 22/09/2026

1. Nuclear shapes

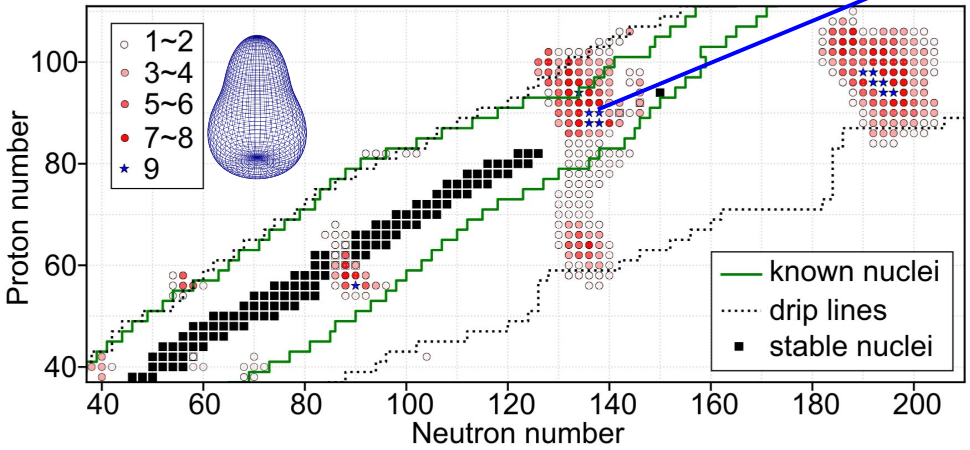
Studying nuclear shapes

- Coulomb excitation experiments:
  → direct measurements of E3 transitions strength



Gaffney, L.P. *et al.* (2013), *Nature*, 497(7448), p. 199-204.

Octupole deformation in the heavy nuclei region:



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

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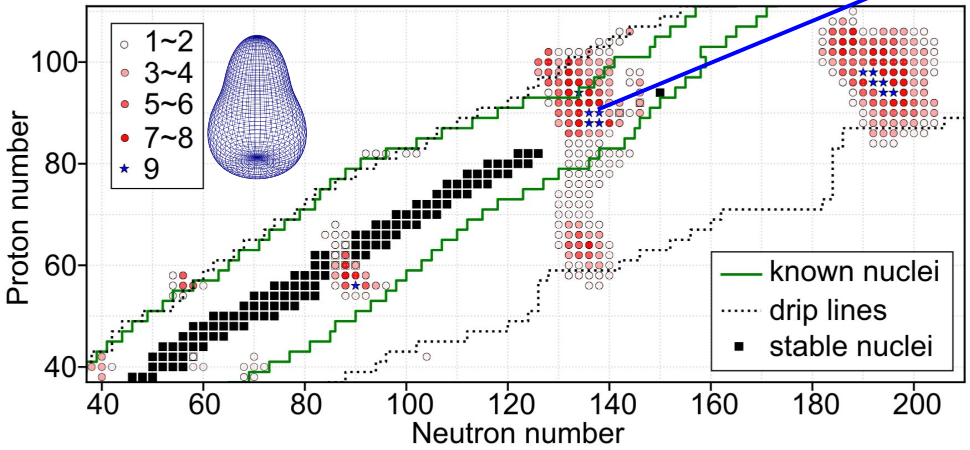

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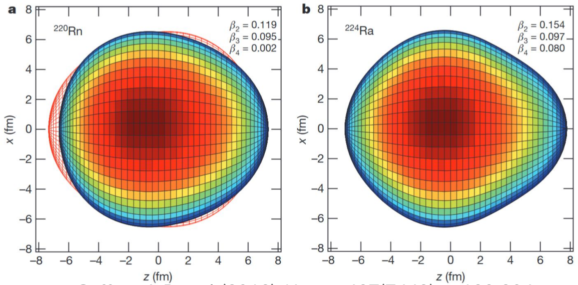

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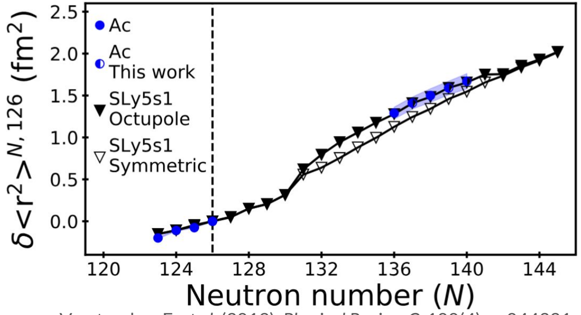
- Other links can be made probing:
  → $\delta\langle r^2\rangle$ with laser spectroscopy



Verstraelen, E. *et al.* (2019), *Physical Review C*, 100(4), p. 044321.

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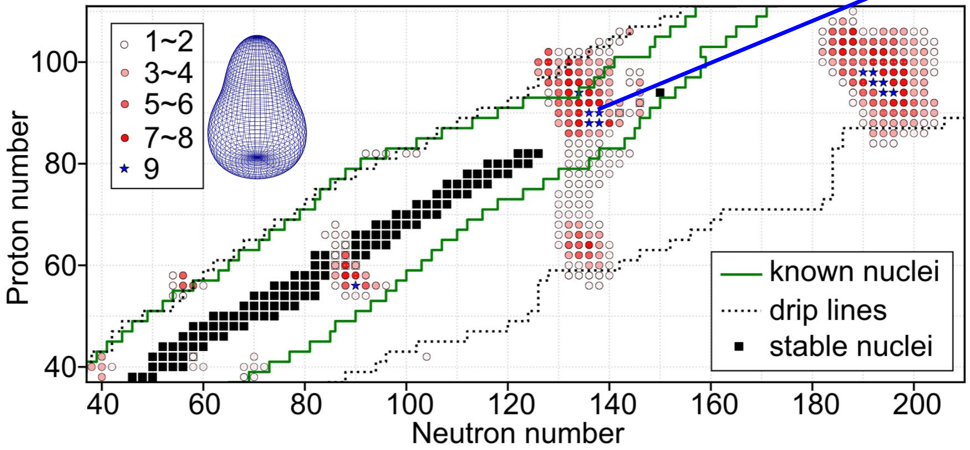

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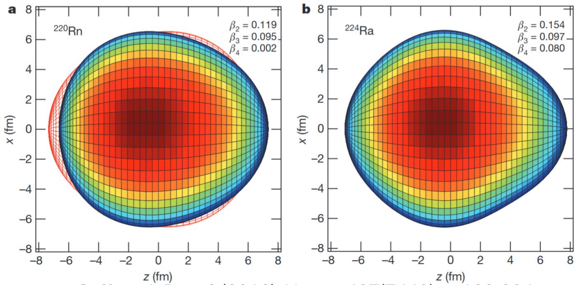

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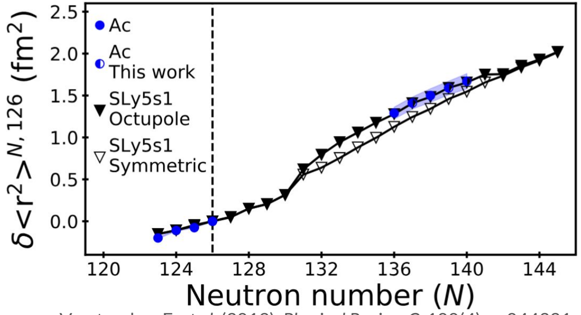

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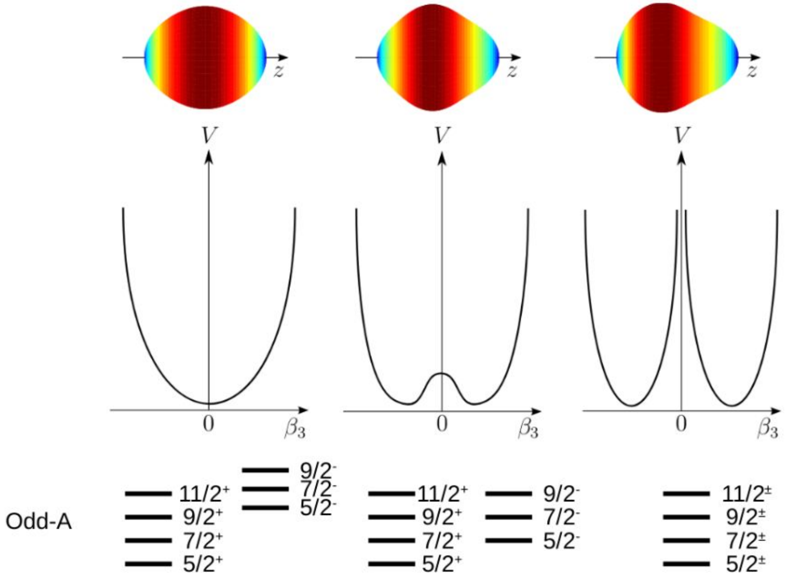
- **Decay spectroscopy**

Microscopic signatures of octupole collectivity ?

- Parity doublets in the rotational bands



ΔE ~ 100s keV

ΔE ~ 10s keV

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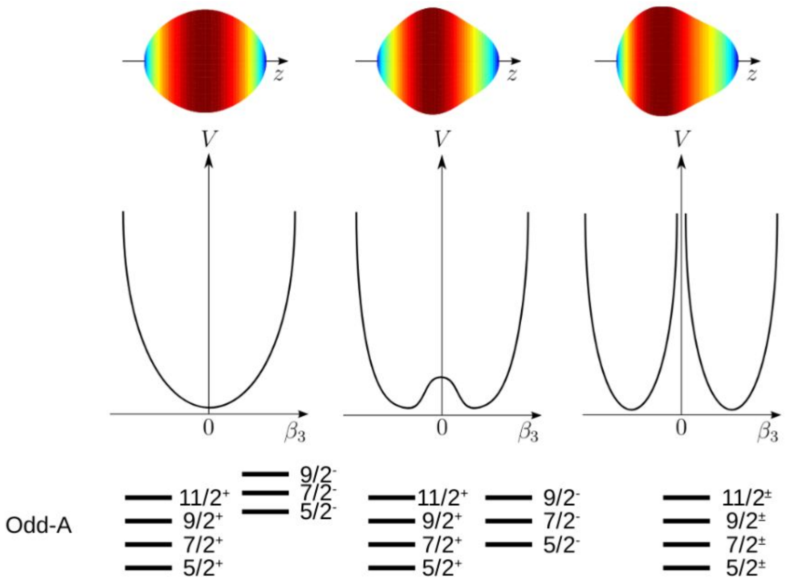
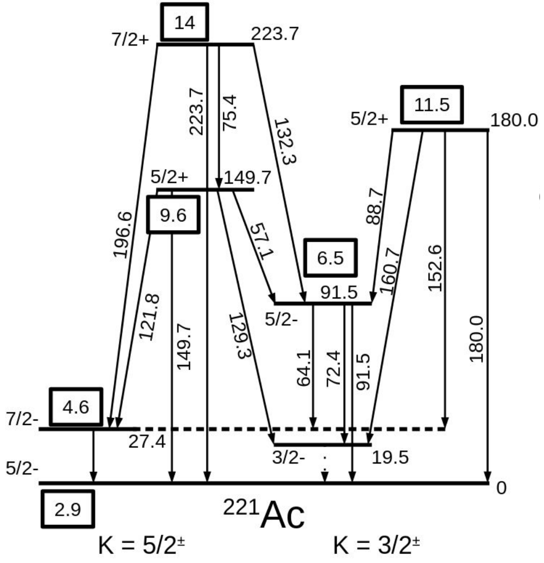


ΔE ~ 100s keV ΔE ~ 10s keV

- Example of ^{221}Ac



Rey-herme *et al.* (2023) *PRC 108, 014304*

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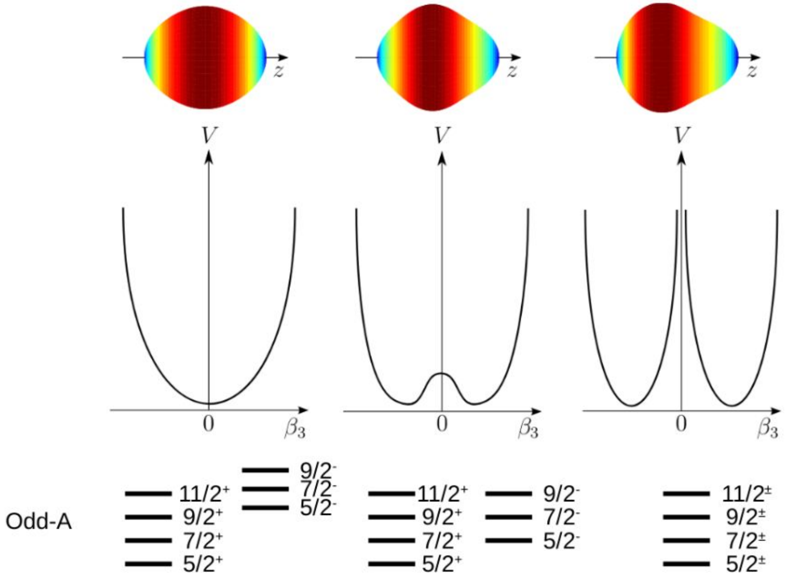


ΔE ~ 100s keV   ΔE ~ 10s keV

- 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

octupole deformation

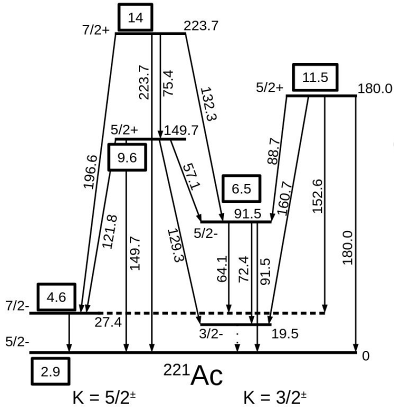
2. SEASON decay station

SEASON project

- Designed for S^3-Low Energy Branch (LEB) at Spiral2

Goals: study heavy nuclei through

- **Detailed α, e^-, ɣ -decay spectroscopy**
- Counter for **laser spectroscopy**



Rey-herme *et al.* (2023) *PRC 108, 014304*

- ➔ nuclear excitation energies
- ➔ alpha hindrance factors
- ➔ conversion electron factors
- ➔ half lives

Needs:

- High efficiency: HN = low production rate
- Good resolution: HN = high density of excited states
- Low energy thresholds

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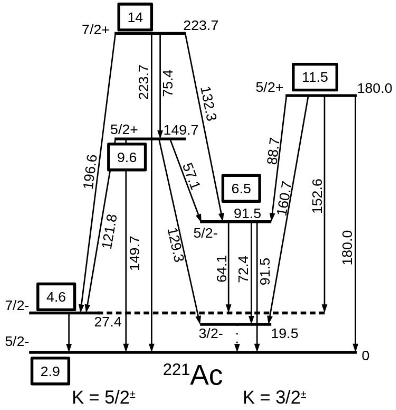

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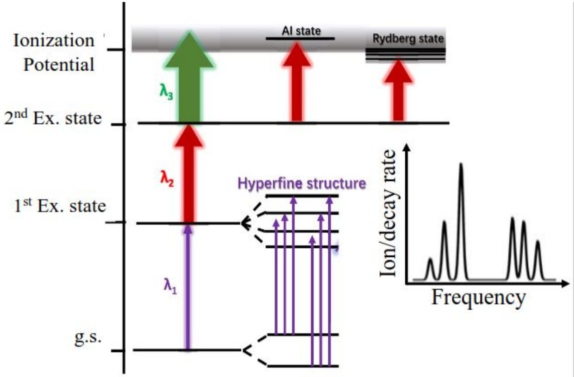
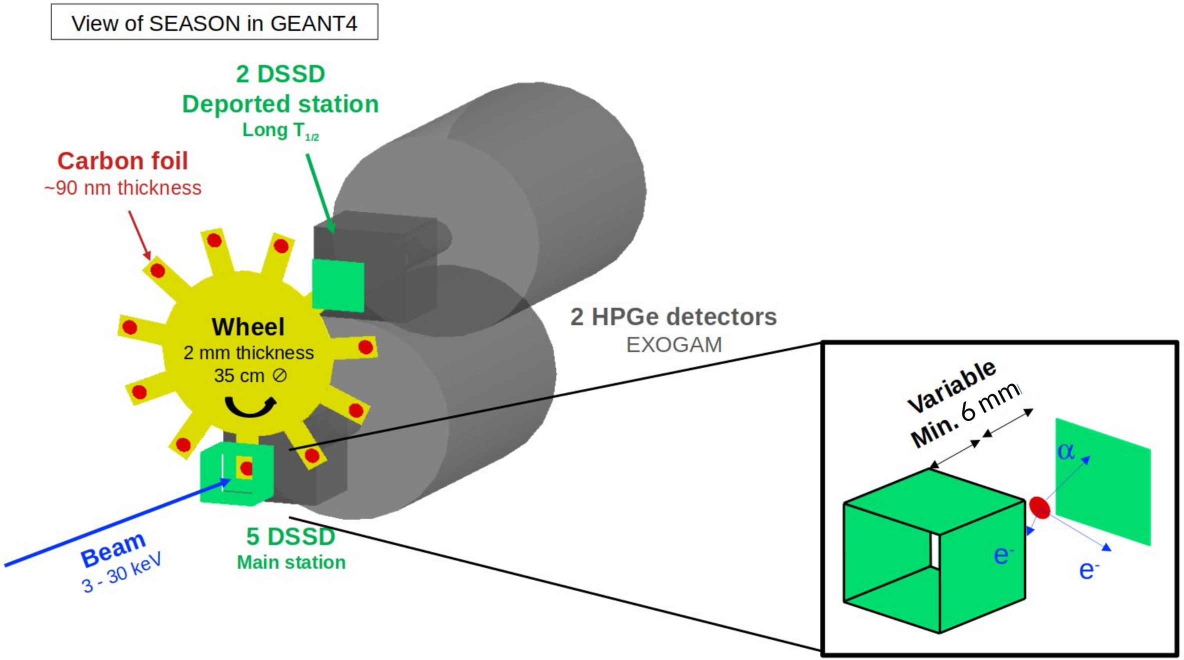


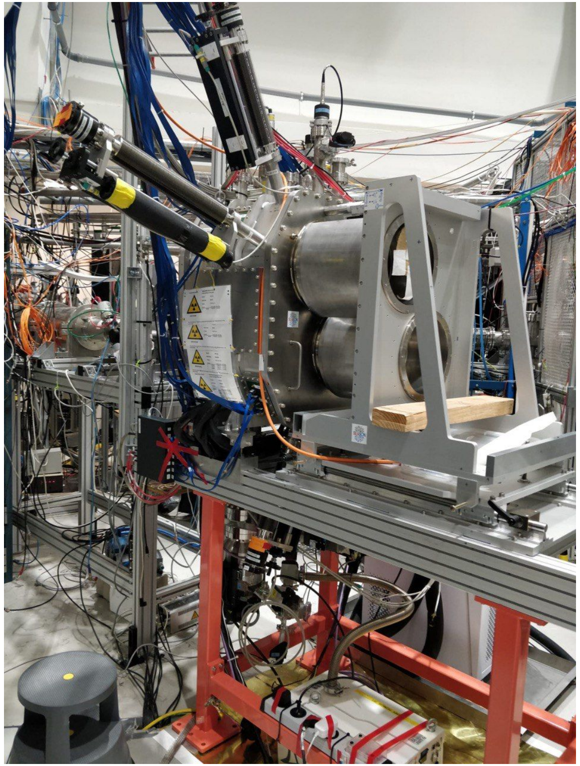
- ➔ mean square charge radii
- ➔ electric quadrupole moments
- ➔ dipole magnetic moments
- ➔ spins

SEASON scheme



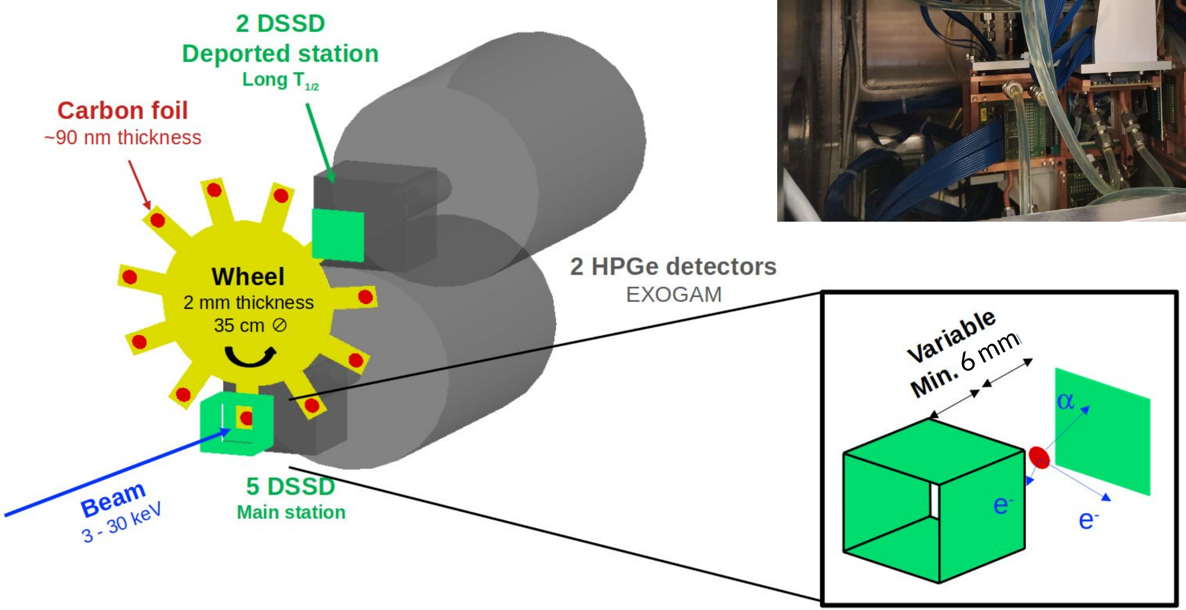
simulation done by Emmanuel Rey-herme

SEASON at Jyväskylä



SEASON scheme

View of SEASON in GEANT4



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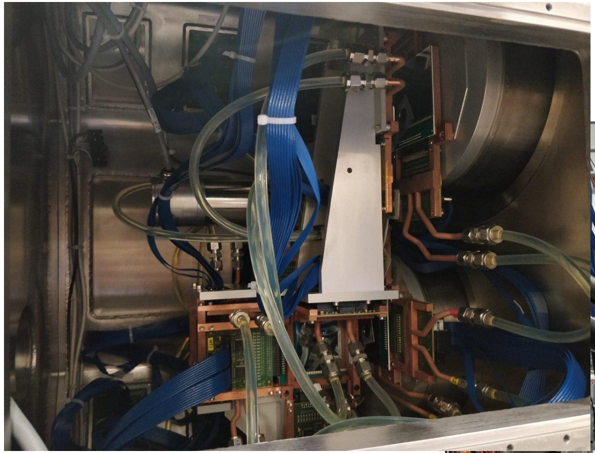

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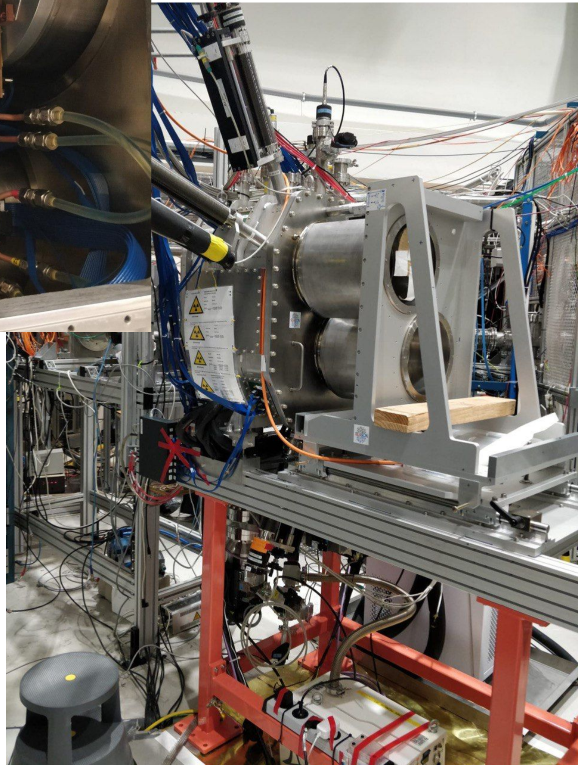


Technical SEASON properties

FEANICS

Front end electronics FEANICS: 2 acquisition modes

- automatic gain switch: gain changes based on signal amplitude
- fixed gain: one gain per detector

In conditions of the online commissioning experiment:

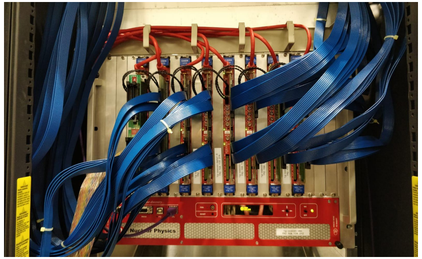
Acquisition mode	Particle	Energy resolution (main DSSD)	Energy resolution (tunnel DSSDs)	Total efficiency	Detection energy thresholds
automatic gain switch	α-particle	~18 keV	~15 keV	44 ± 13 %	~45 keV
	electron	~14 keV	~14 keV	29 ± 4 %	
fixed gain	α-particle	/	~15 keV	24 ± 7 %	~30 keV
	electron	~10 keV	/	20 ± 3 %	

Preliminary

→ from ^{219}Rn energy spectrum
→ from mass 225 energy spectrum
→ from 3 α source measurements
→ from ^{133}Ba source measurements

In Finland : coupling to CAEN VX2745 acquisition modules

- 8 cards of 64 channels
- controlled by locally developed DAQ system *Dakki*
- JABS adaptator SAMTEK to CAEN (IRFU made)



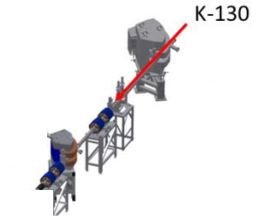
3. Commissioning in Jyväskylä, Finland

→ February 20th – February 27th

SEASON at Jyväskylä

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

^{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

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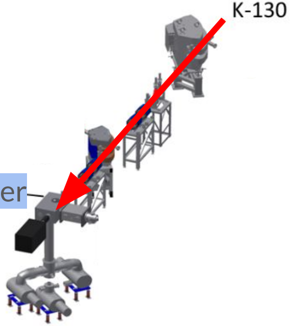
+p

Target chamber



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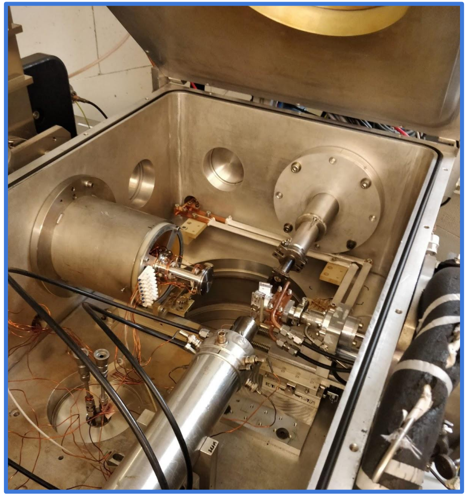

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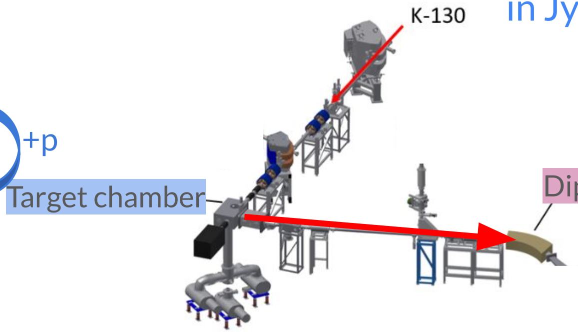

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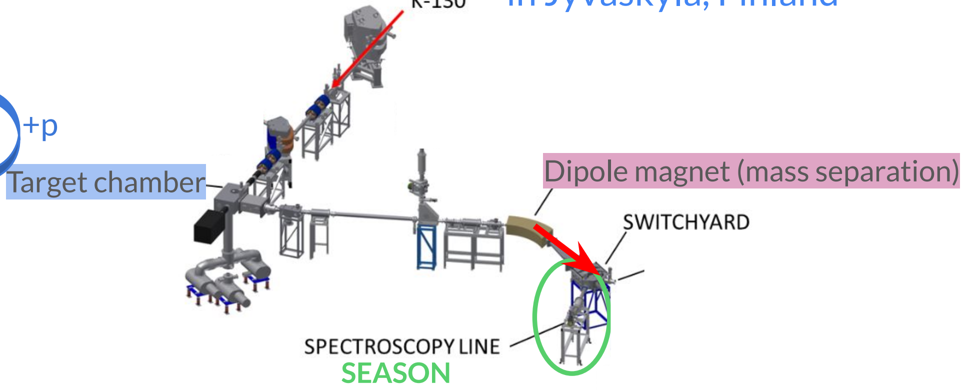


Also measured masses 221, 226, 222, 224 & test of an alpha beam

4. Preliminary results of the commissioning

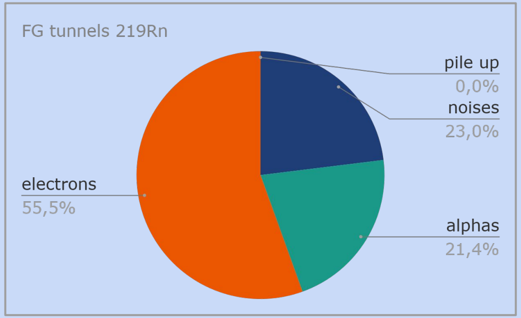
Analysis method

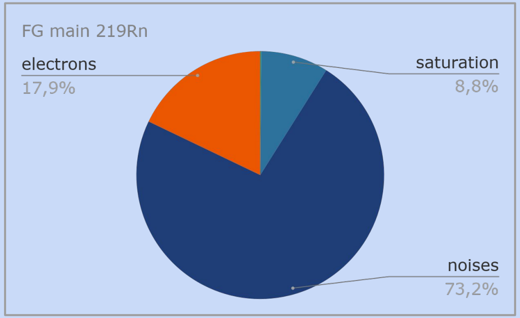
The different steps:

- PSD
- time alignment
- gain matching
- energy calibration
- event reconstruction

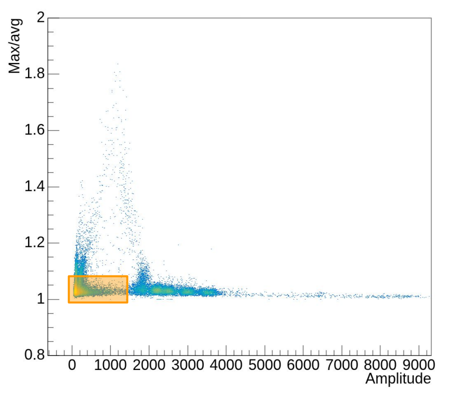
Noise, alpha, electron, interstrips, pile up, cross talk, saturation… → everything (above threshold) is recorded

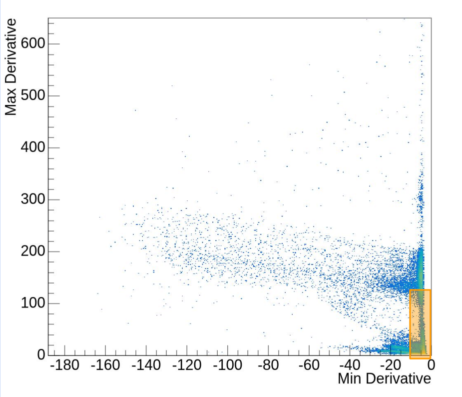
Ratios of real events to noise in fixed gain mode on implanted beam run:





Examples of discrimination plots based on trace features:





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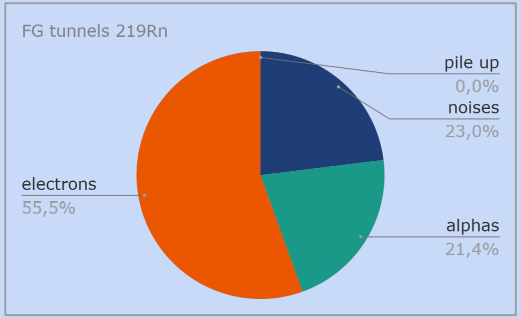
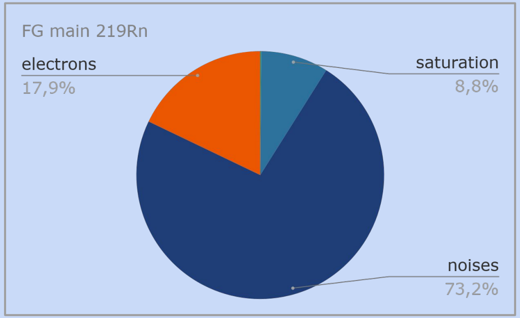
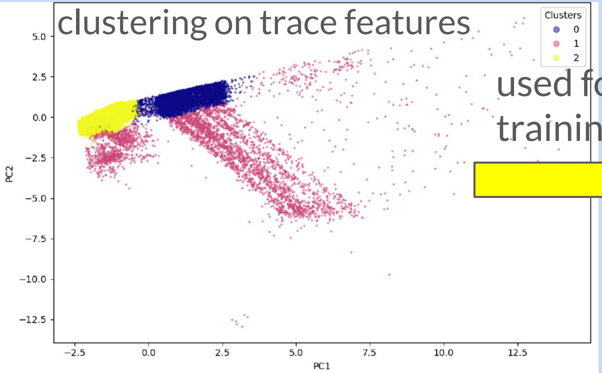




Or use of simple ML models : **work of M1 intern Zineb Bahaj-Filali**



CNN 1D, Binary classification:

Check on pure electron source:

99 % classified e-

Analysis method

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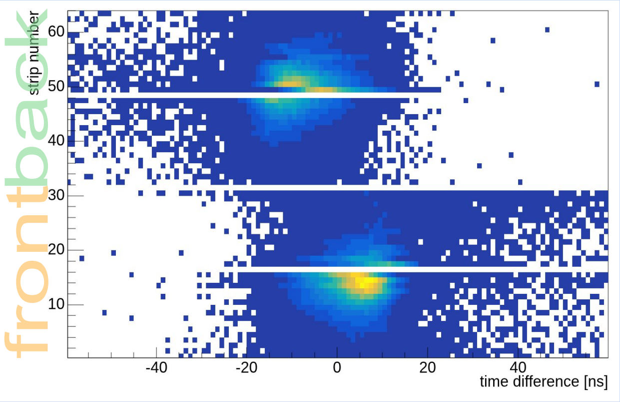
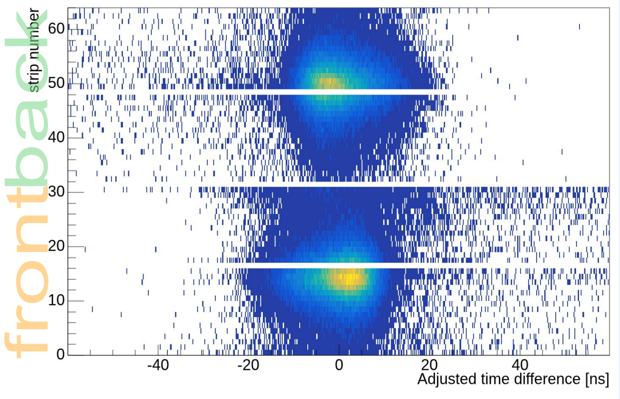
Alignment on the physics event, ie when particle is detected at the same time on front and back sides on the detectors

Before alignement



After alignement

e- : 26 ns FWHM
alpha : 6 ns FWHM



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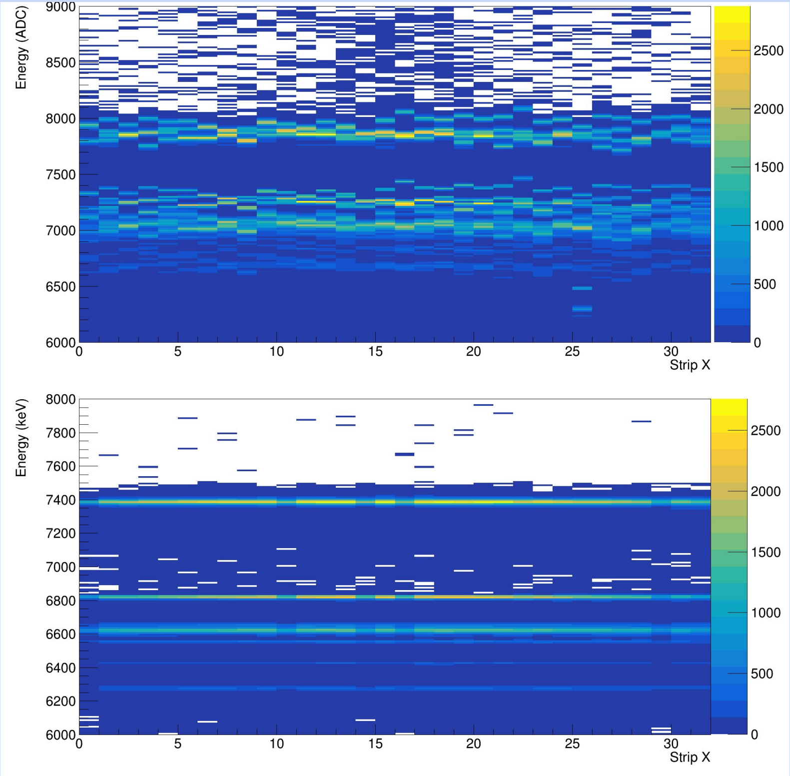
Every strip is matched in gain with the rest using a high statistic run
+ some strip shift between the runs and must be corrected



Analysis method

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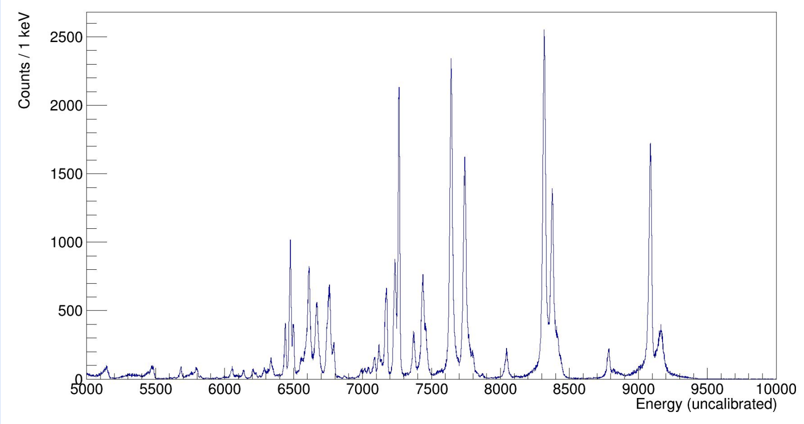
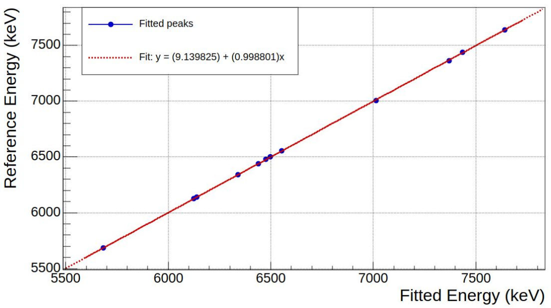
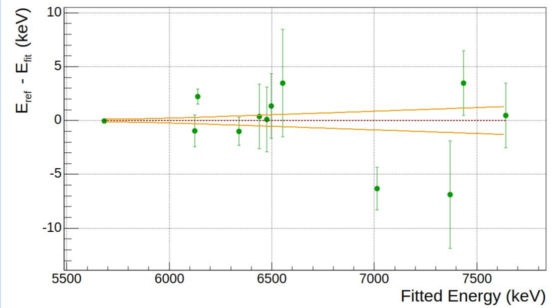
Different calibrations depending on the mode and the particle.

Example with alphas in fixed gain mode:



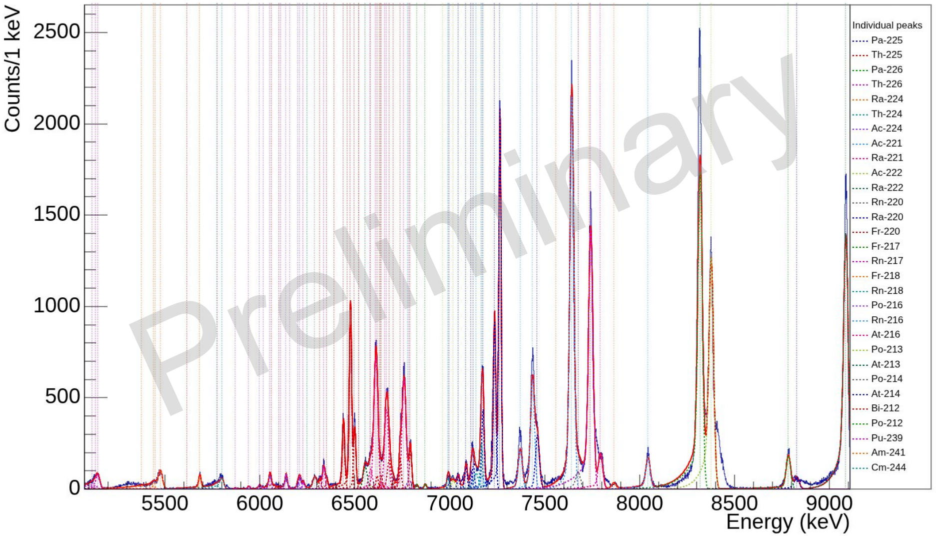
Calibration line and calibration residues:





Mass 225

Alpha energy spectrum (in fixed gain mode)



Mass 225

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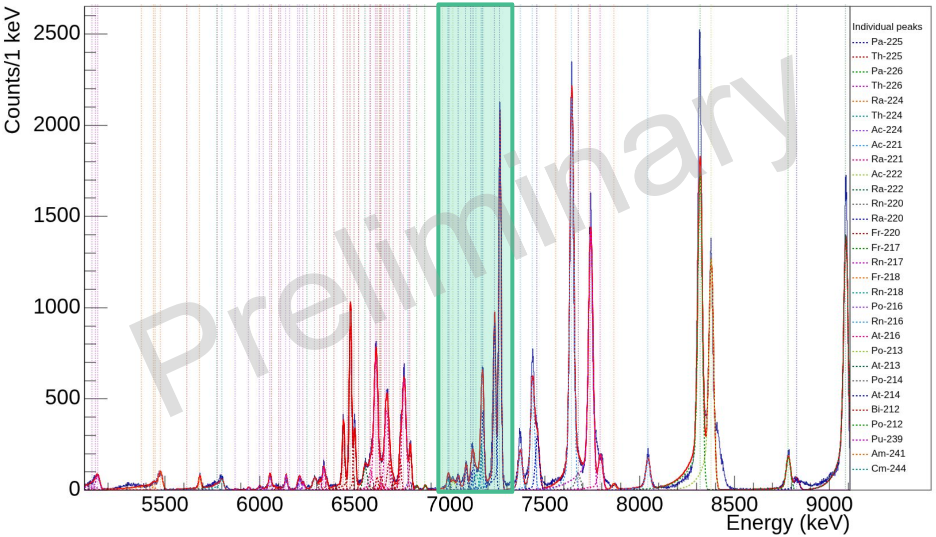
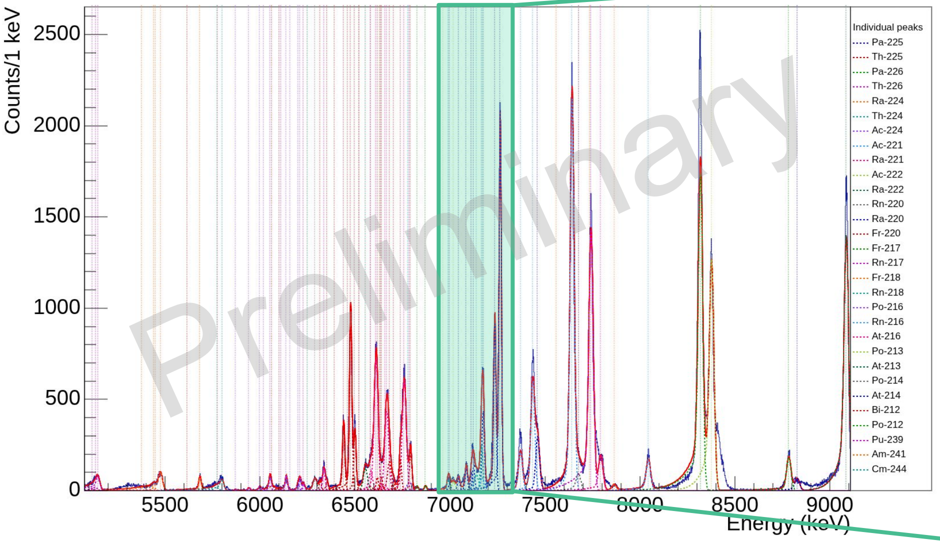
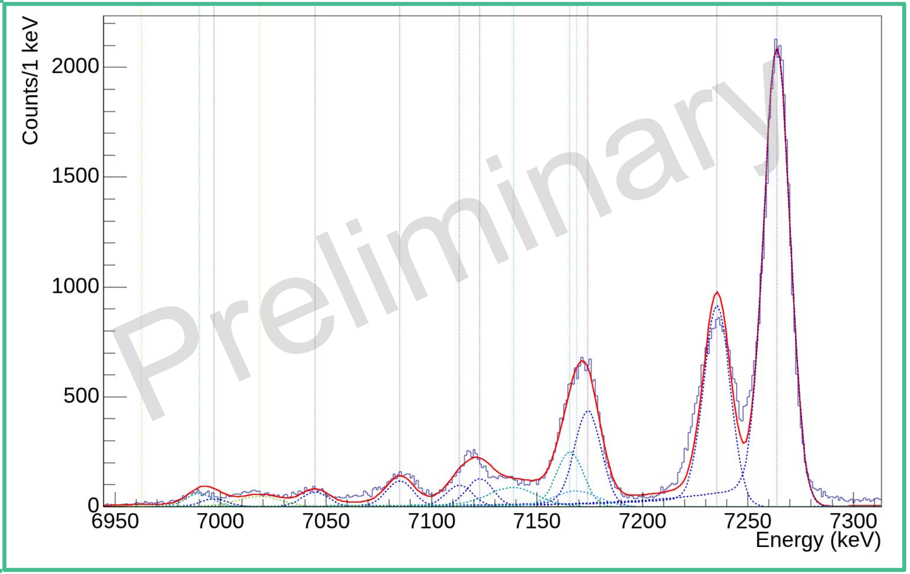


Mass 225

Alpha energy spectrum (in fixed gain mode)



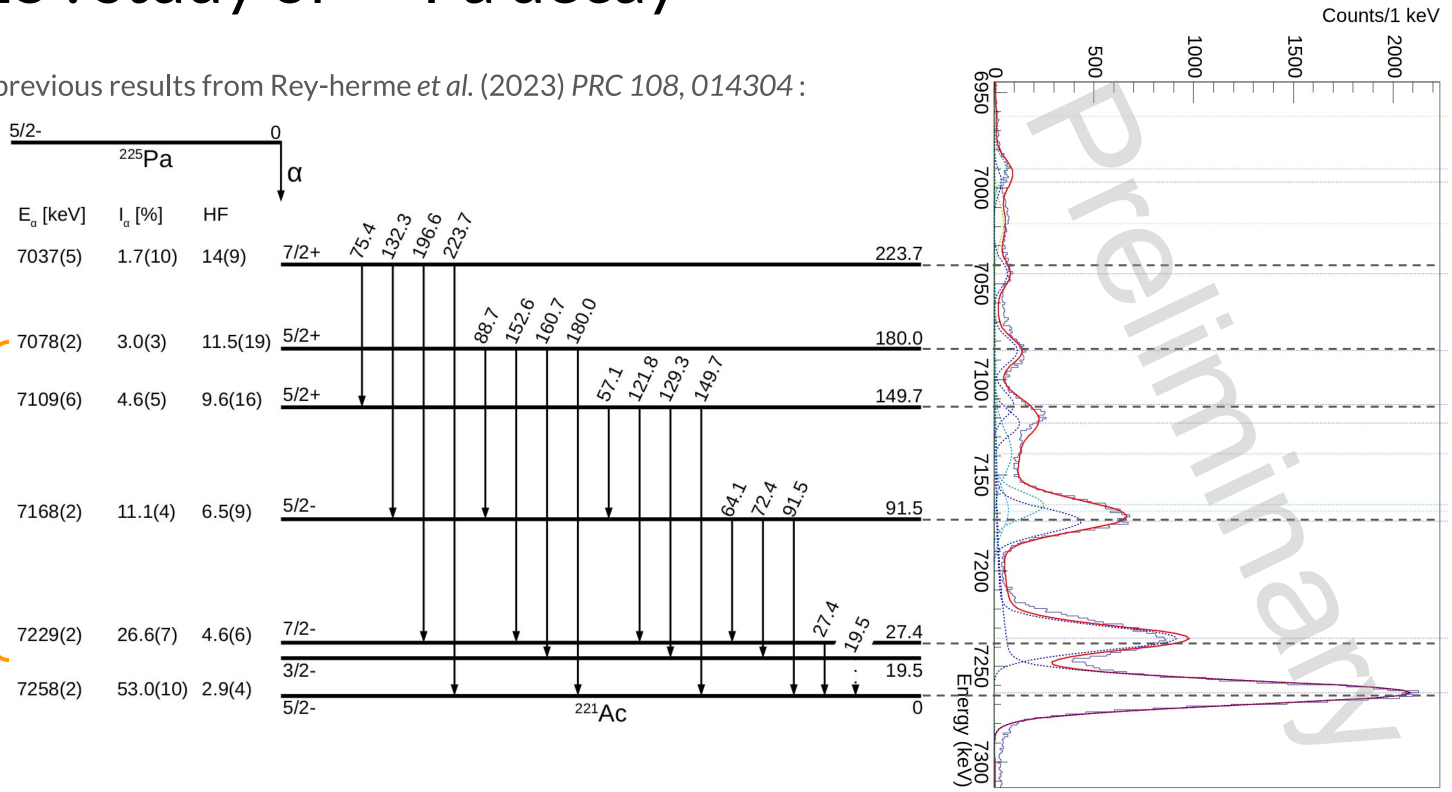
zoomed in on the energies of ^{225}Pa decay



Mass 225 : study of ^{225}Pa decay

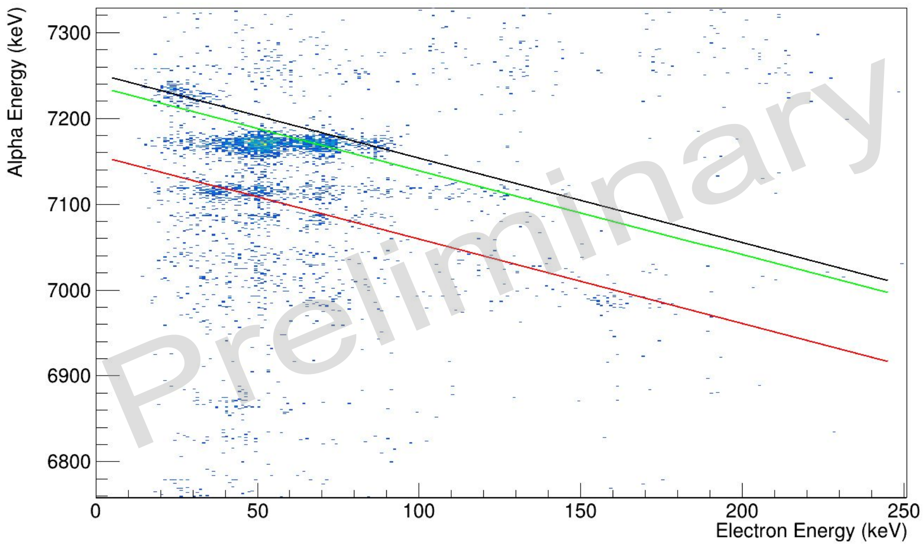
Comparison with previous results from Rey-herme *et al.* (2023) *PRC 108, 014304* :

3/2+ state missing ?



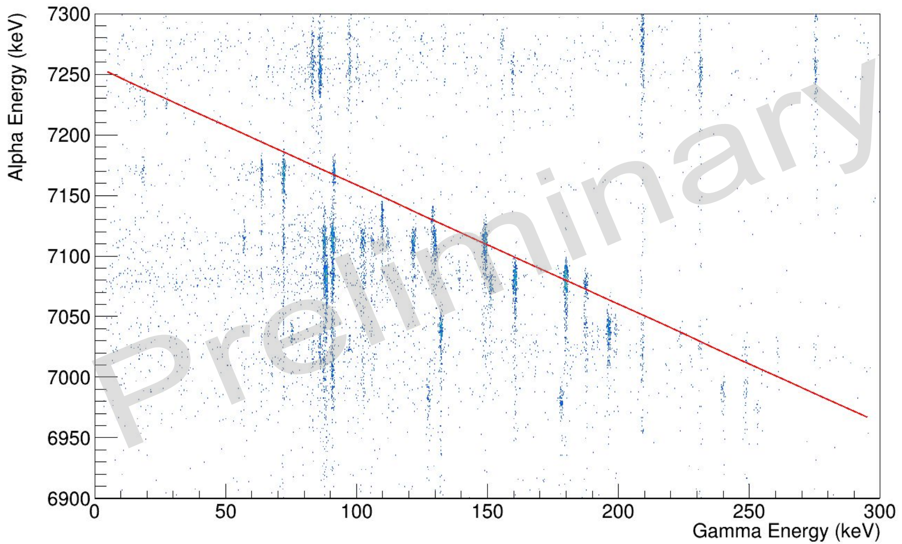
Mass 225 : study of ^{225}Pa decay

α – electron matrix (in fixed gain mode)



$$E_\alpha + E_\gamma - B_{K,L,M} = Q_\alpha(gs\ to\ gs)$$

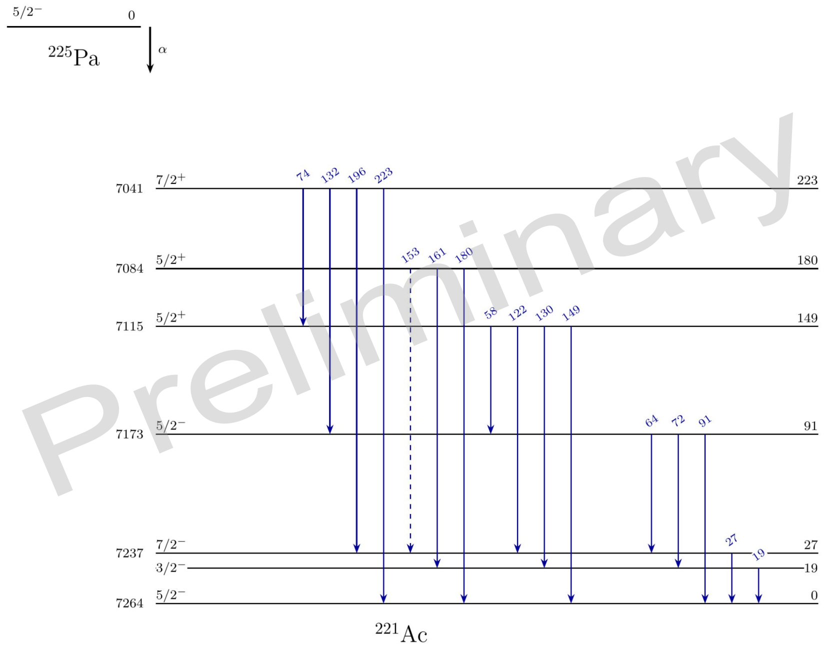
α – γ matrix (in automatic gain switch mode)



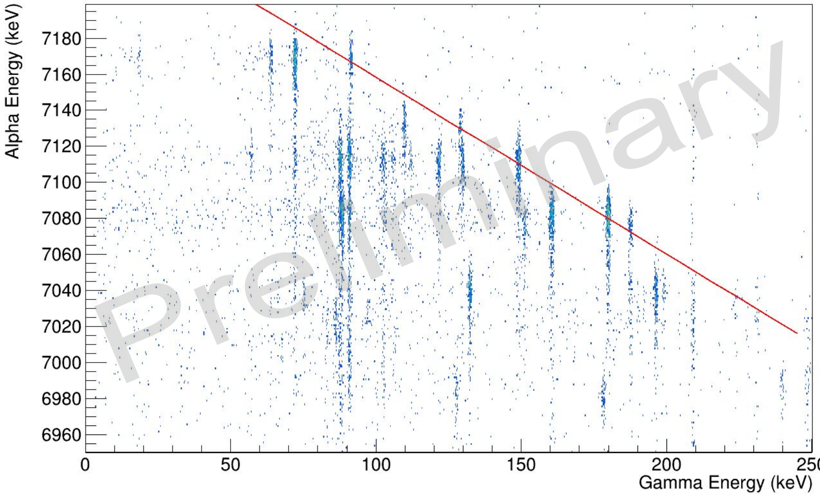
$$E_\alpha + E_\gamma = Q_\alpha(gs\ to\ gs)$$

First indications of the missing state

Reconstructed excited level scheme : one example of consistency with previous results

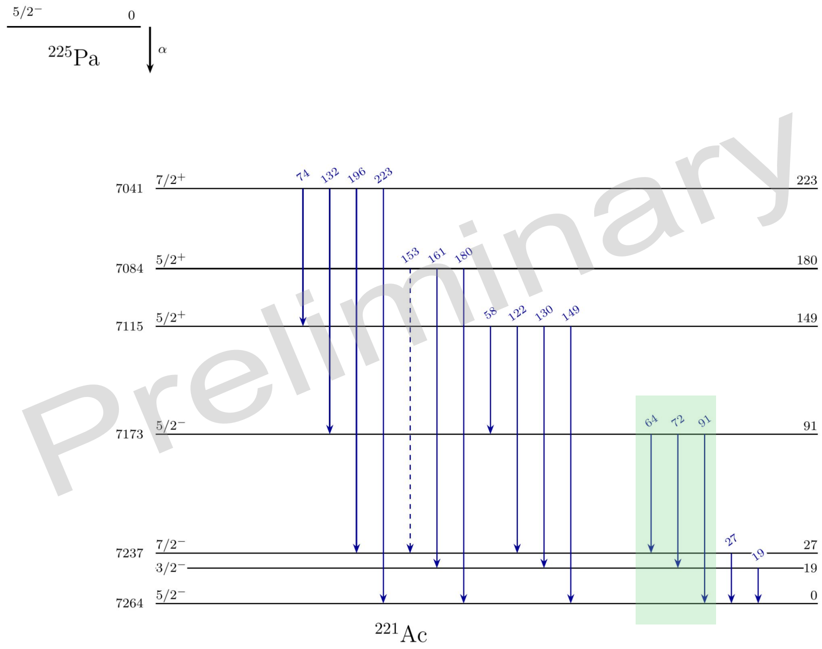


$\alpha - \gamma$ matrix (in automatic gain switch mode)

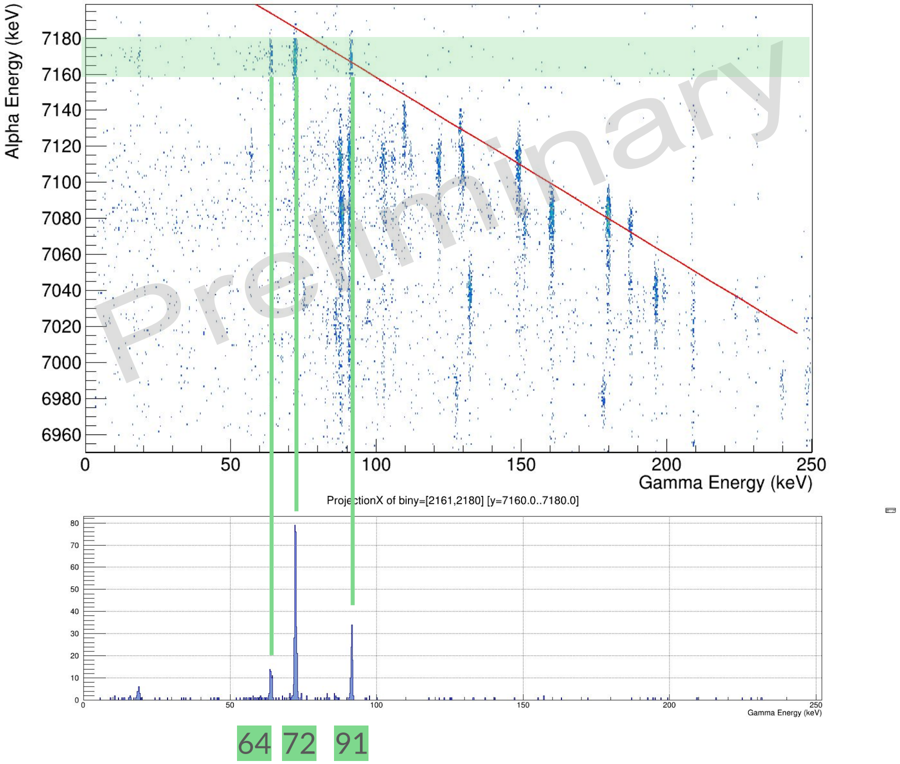


First indications of the missing state

Reconstructed excited level scheme : one example of consistency with previous results

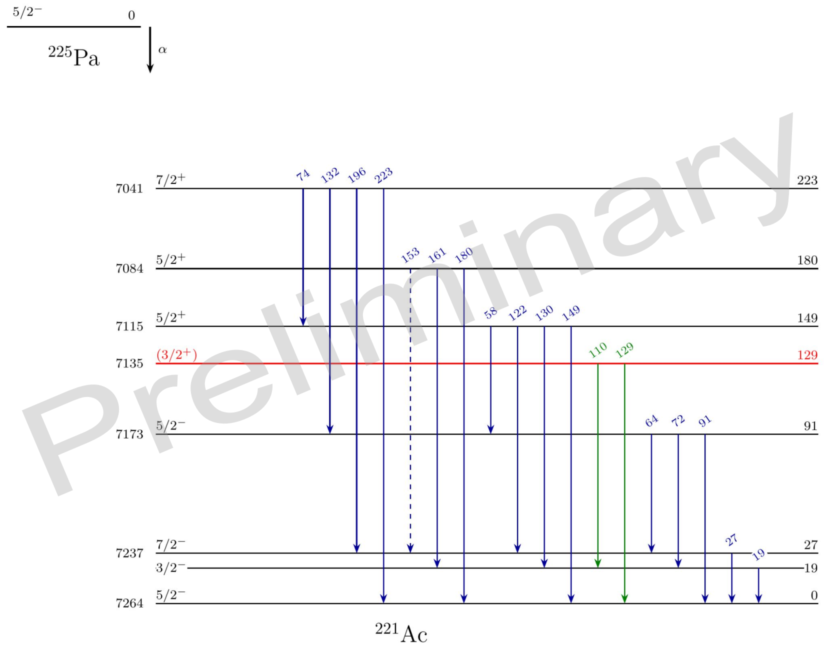


$\alpha - \gamma$ matrix (in automatic gain switch mode)

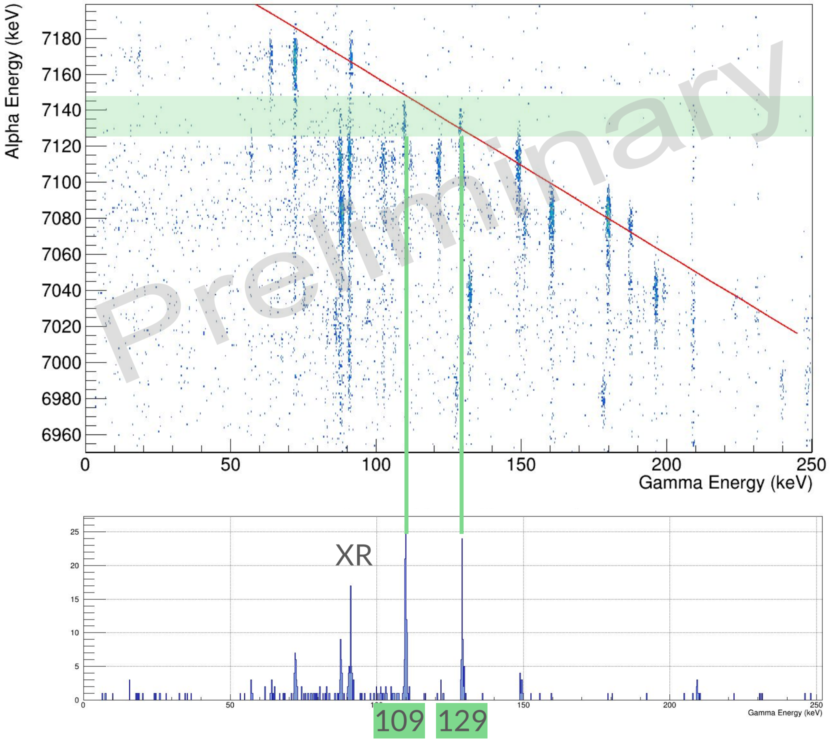


First indications of the missing state

Reconstructed excited level scheme : new state observed in the energy range where the 3/2+ is expected

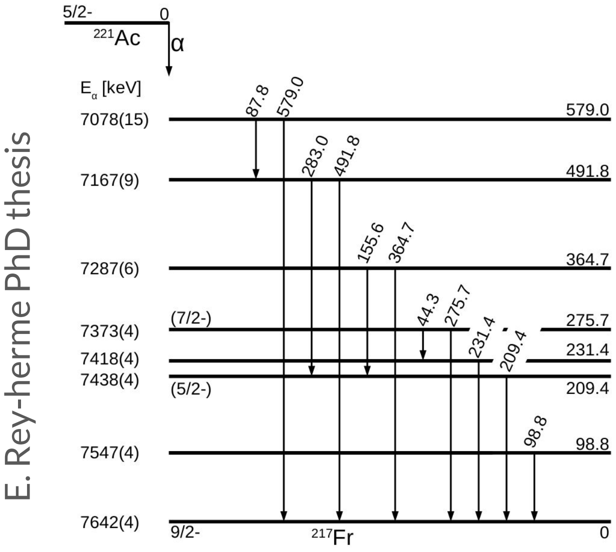


$\alpha - \gamma$ matrix (in automatic gain switch mode)



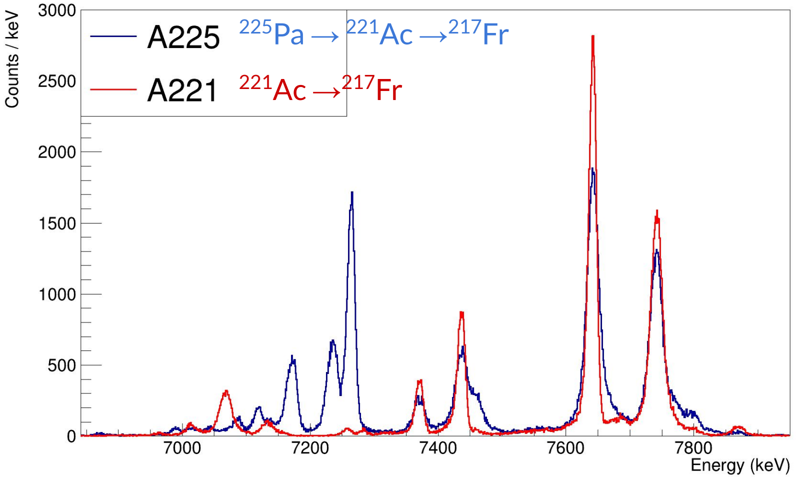
Study of ^{221}Ac

Mass 221 was not directly implanted before
→ no intensities & HF



previous decay scheme obtained for 221Ac

Alpha spectra obtained in I308 experiment

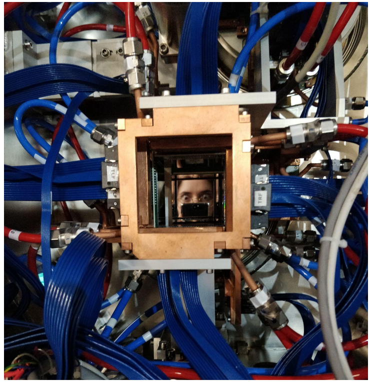


- Disentangle the alpha energies
- Find out branching ratios and HF
- Build the decay spectrum of 221Ac

Conclusions

- Nuclear shapes and in particular octupole deformation in ^{221}**Ac is studied through decay spectroscopy.**
- **SEASON was successfully commissioned at the IGISOL facility** in Jyväskylä.
- Several masses (225, 221, 226, 222 & 224) were measured in **two different acquisition modes.**
- Beginning of the analysis is promising:
  - resolutions are satisfactory
  - issues regarding global noise on the detector and distances to the foil will be worked on.
  - **indications of new states in the excited level scheme of ^{221}Ac, will be confirmed with the measurement of the conversion electron factors.**
- The next experiments also in Jyväskylä have been submitted to the PAC of september to pursue the study of the **limits and the magnitude of the octupole region.**

SEASON's development team at Saclay DIS in 2024



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

GSI
Sebastian Raeder

IJCLab
Matthieu Lebois

LP2iB
Samuel Lecanuet

LPC Caen
Skyy Pineda

GANIL
Margarida Paulino

KU Leuven
Andrea Raggio

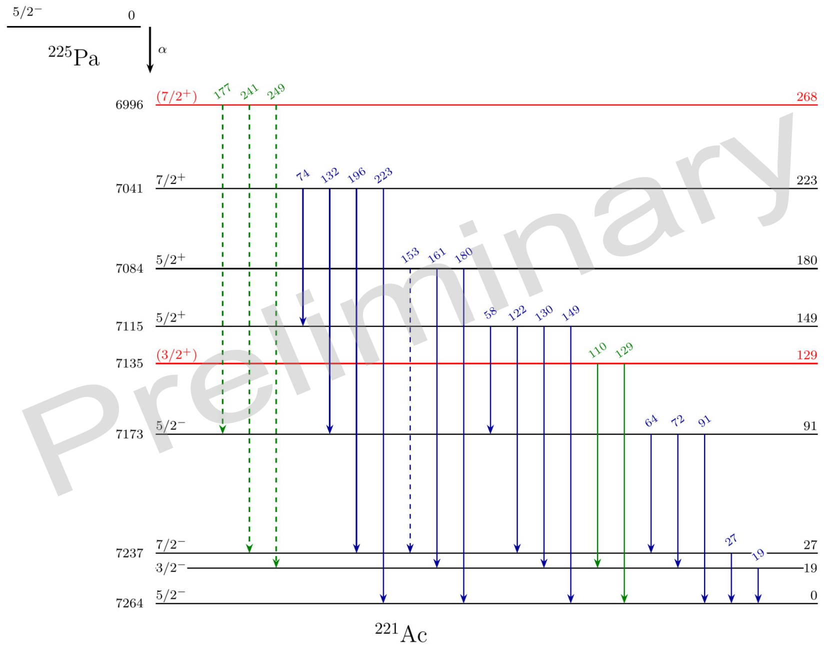
CEA
Damien Thisse, **Nino Abrassart Martin**, Zineb Bahaj-Filali, Léonard Jost, **Emmanuel Rey-herme**, Killian Ronxin, Barbara Sulignano, **Marine Vandebrouck**

SEASON development team :
Project Managers :
O. Cloué (technic)
D. Thisse (scientific)
M. Vandebrouck
Mechanical conception :
S. Cazaux, P. Daniel-Thomas
Detection/Acquisition :
F. Bouyjou, T. Chaminade, J. Dartois
Control & Command :
A. Gaget, J. Relland, A. Roger, S. Tzvetkov, T. Joannem
Electrical engineering :
J. Noury, Y. Reinert, J. Mendes Ribeiro

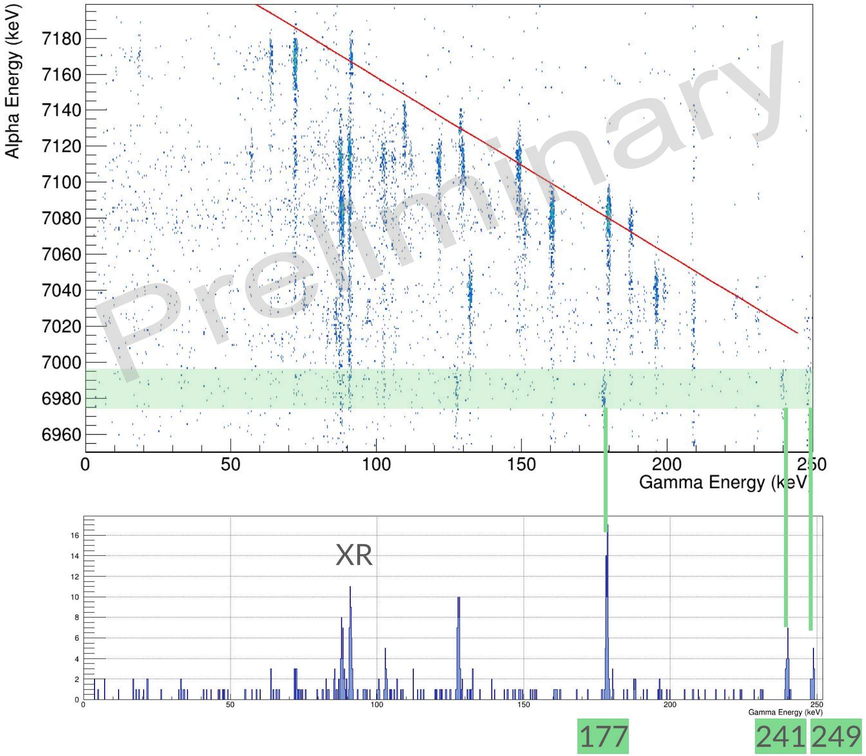
Back-up

Indications of a higher excited state

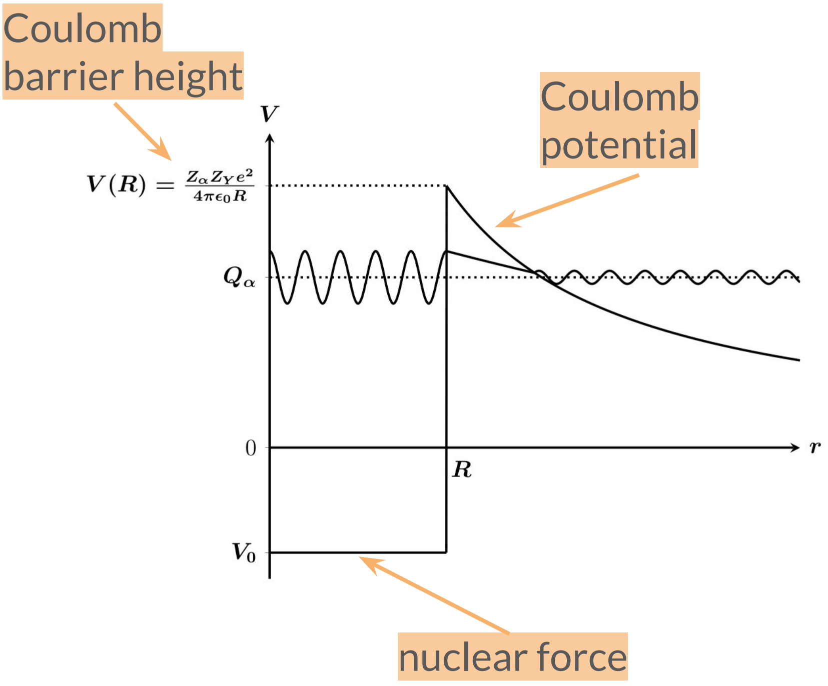
Reconstructed excited level scheme : new state observed in the energy range where the 7/2+ is expected



$\alpha-\gamma$ matrix (in automatic gain switch mode)



Alpha hindrance factors



- 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.

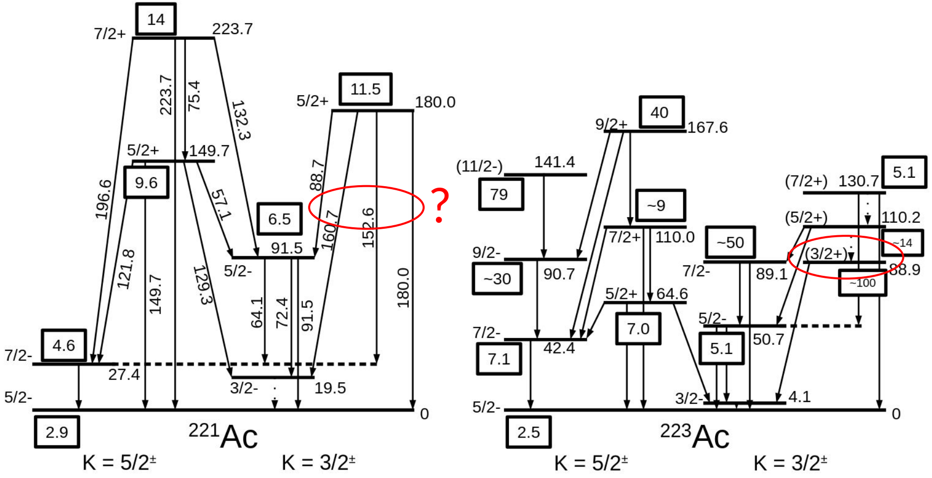
Typical values :

HF ~ 1-4: Favored transitions
HF ~ 10-100: Initial and final particle state do not have favourable overlap

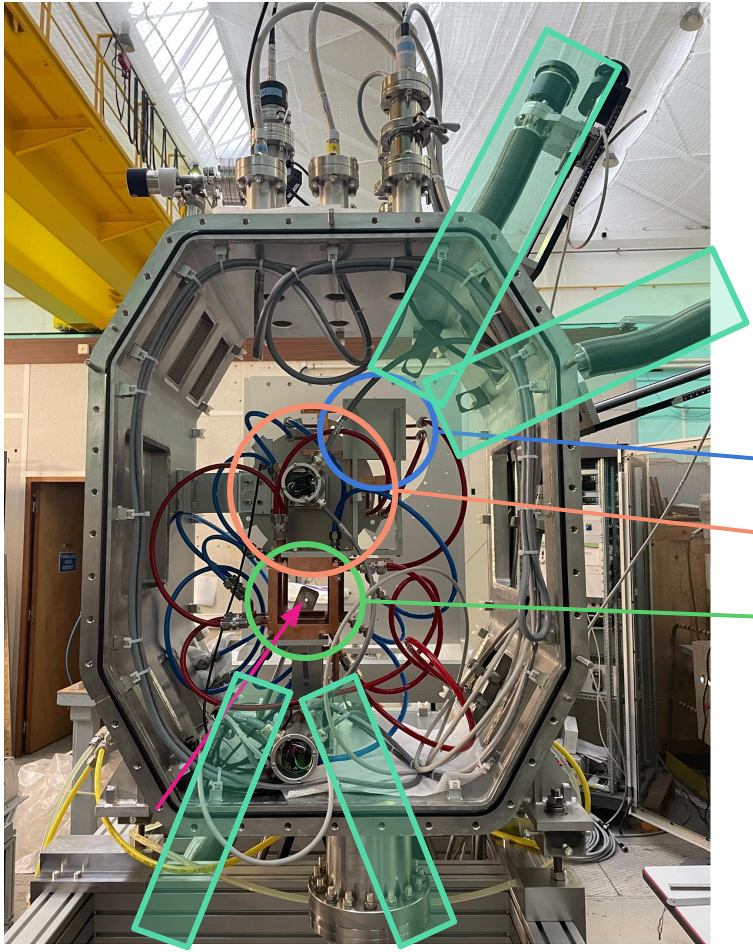
octupole deformation

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.

Where is the 3/2+ state expected ?



- Similarity with 223Ac
- In 223Ac : 3/2+ state is at 88.9 keV and the 3/2- is at 4.1 keV
- In 221Ac, 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)



beam direction

deported station

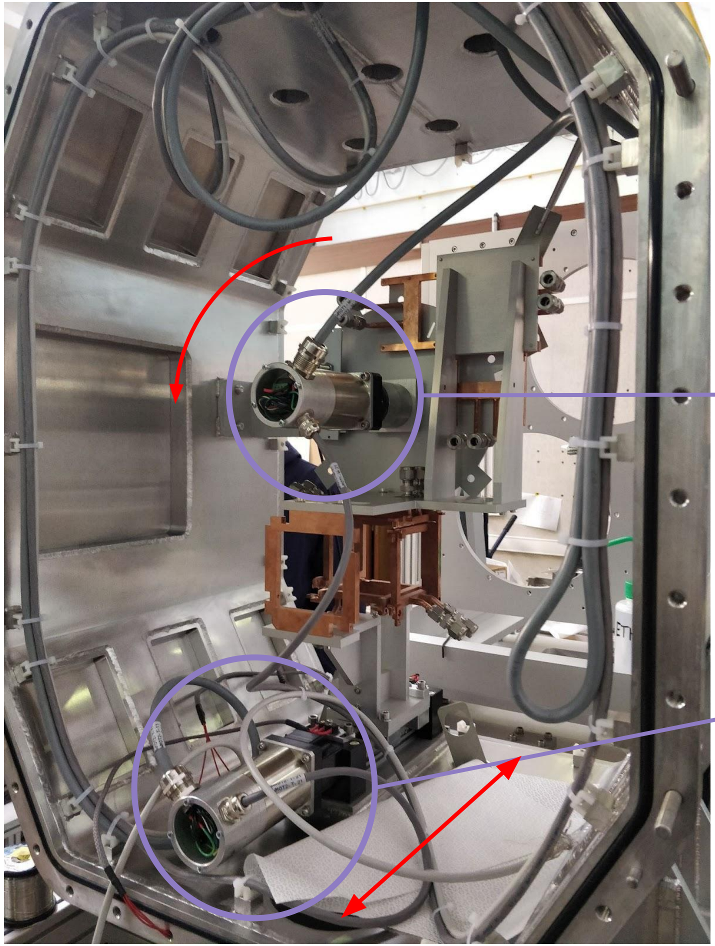
wheel

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

SEASON at Jyväskylä

Acquisition modes:

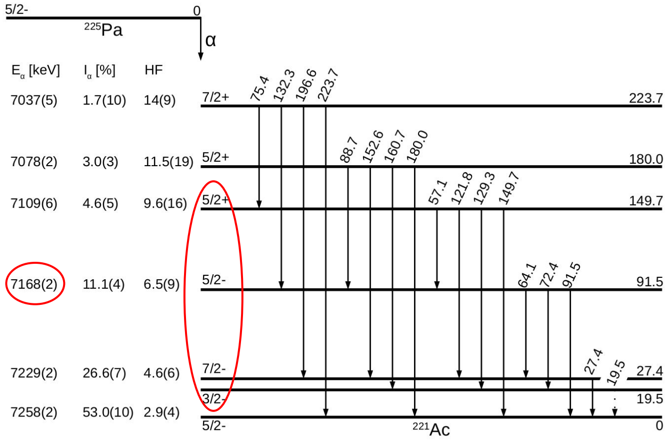
Measurement:

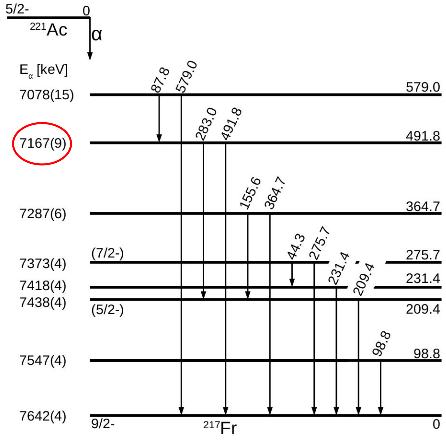
Gain switch + fixed gain
- mass 225: 40 hours
- mass 221: 32 hours

Gain switch
- mass 226: 29 hours
- mass 222: 12 hours
- mass 224: 4.5 hours

\+ test of an alpha beam

E. Rey-herme PhD thesis (2023)





-> characterization of SEASON properties

\+ search of more excited states of ^{221}Ac not accessible before

-> daughter of ^{225}Pa -> ambiguity on states

SEASON at Jyväskylä

Acquisition modes:

Measurement:

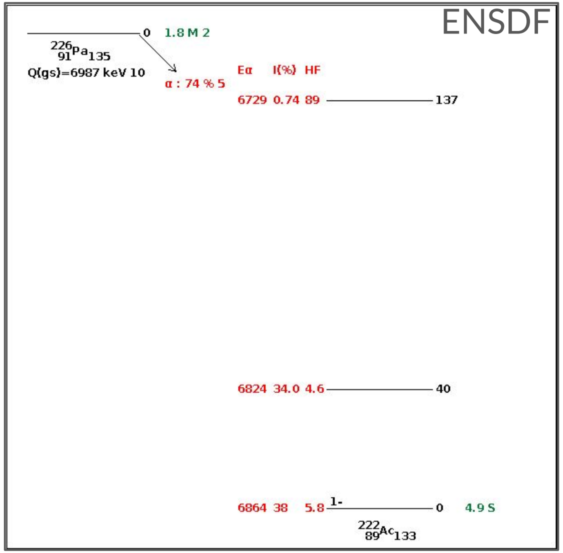
Gain switch + fixed gain

- mass 225: 40 hours
- mass 221: 32 hours

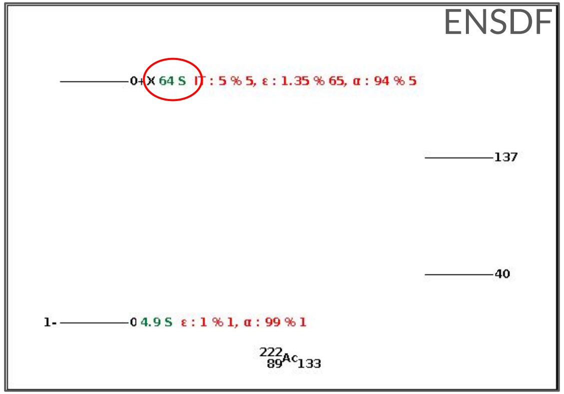
Gain switch

- **mass 226: 29 hours**
- **mass 222: 12 hours**
- mass 224: 4.5 hours

\+ test of an alpha beam



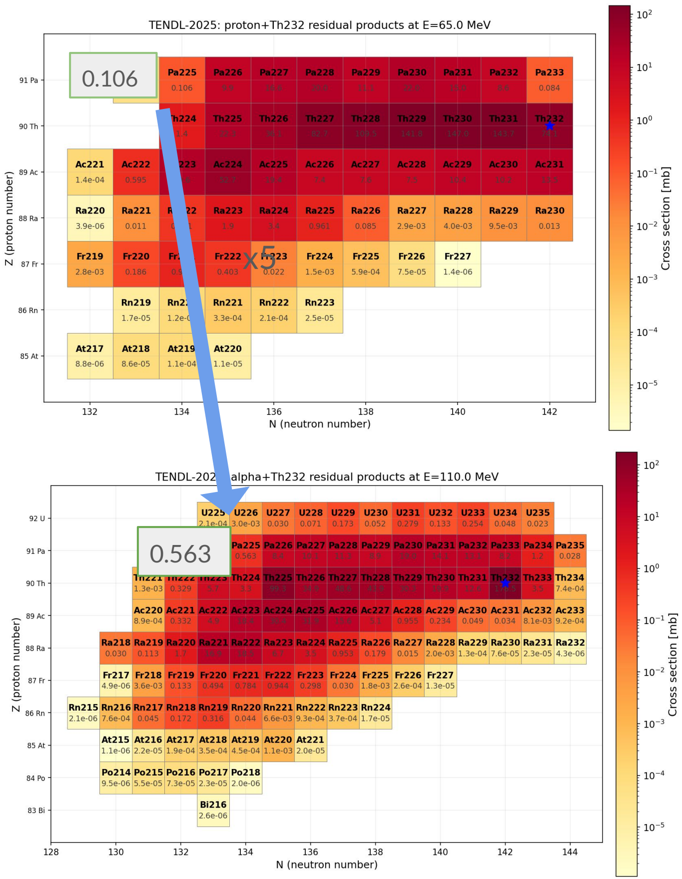
-> poorly known decay scheme



-> isomer : test of $t_{1/2}$ measurement

SEASON at Jyväskylä

In principle :



Figures by Emmanuel Rey-herme

Acquisition modes:

Measurement:

Gain switch + fixed gain
- mass 225: 40 hours
- mass 221: 32 hours

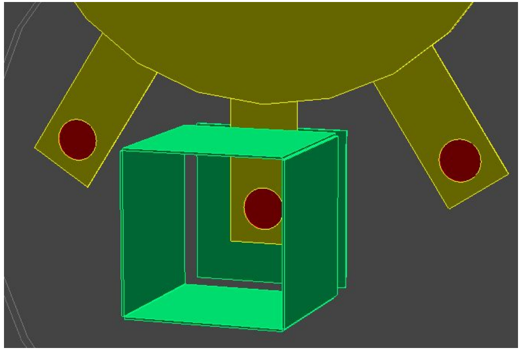
Gain switch
- mass 226: 29 hours
- mass 222: 12 hours
- mass 224: 4.5 hours

\+ test of an alpha beam

SEASON's commissioning experiment

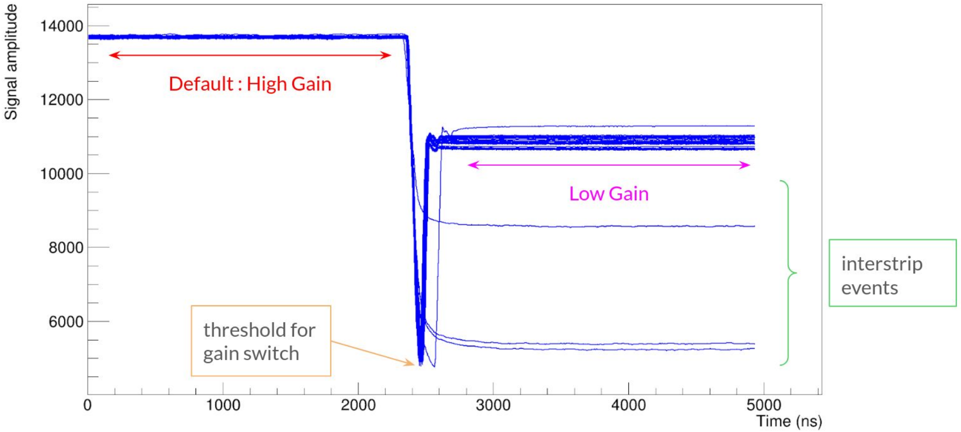
Test of two FEANICS modes :

All detectors : automatic gain switch between α and e$^-$



+ high efficiency

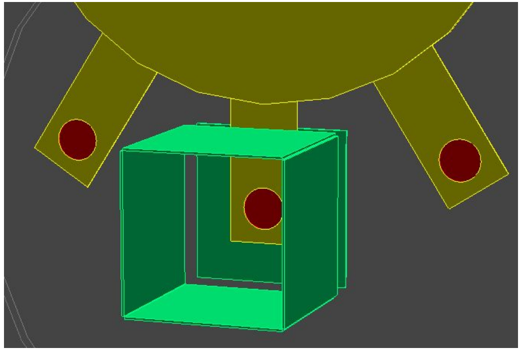
− noise level higher → resolution slightly degraded → higher energy threshold



SEASON's commissioning experiment

Test of two FEANICS modes :

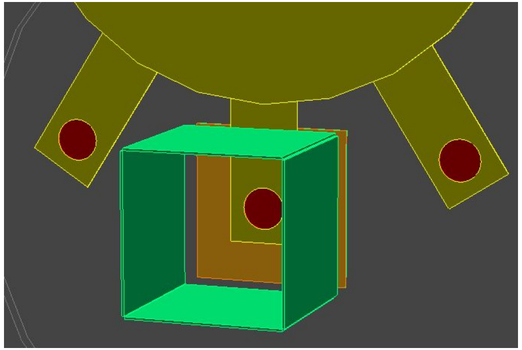
All detectors : automatic gain switch between α and e^-



\+ high efficiency

\- noise level higher
→ resolution slightly degraded
→ higher energy threshold

Fixed gain :
Main detector in a high gain mode,
Tunnel detectors in a low gain mode

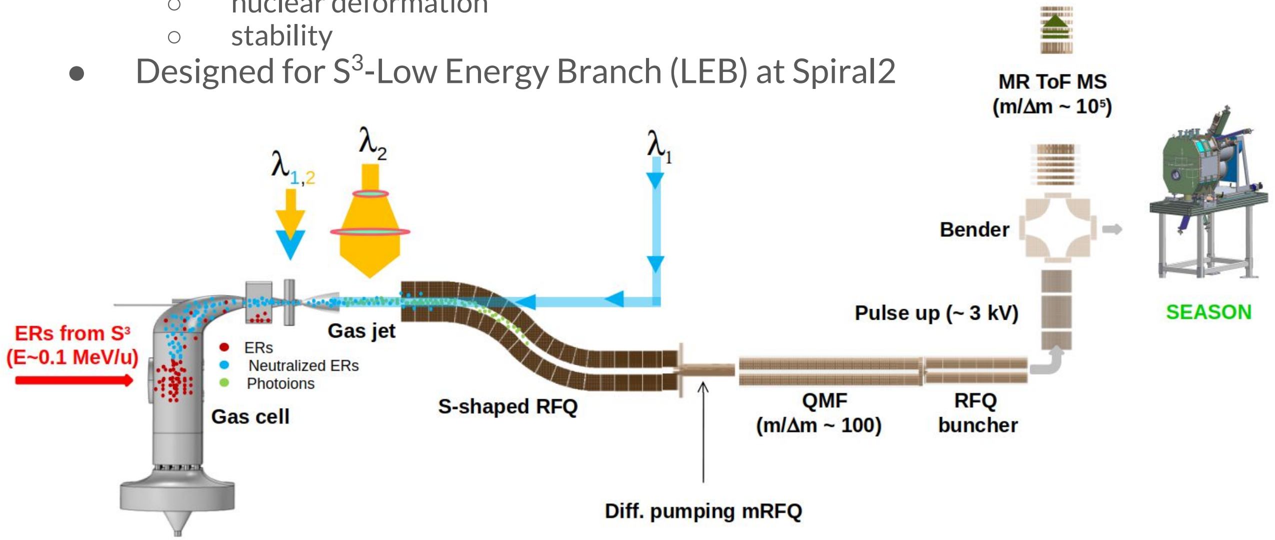


\+ less noisy
→ better resolution
→ lower energy threshold

\- lower efficiency

SEASON's at GANIL

- Study of heavy and super heavy nuclei
    - single particle structure
    - nuclear deformation
    - stability
- Designed for S^3-Low Energy Branch (LEB) at Spiral2

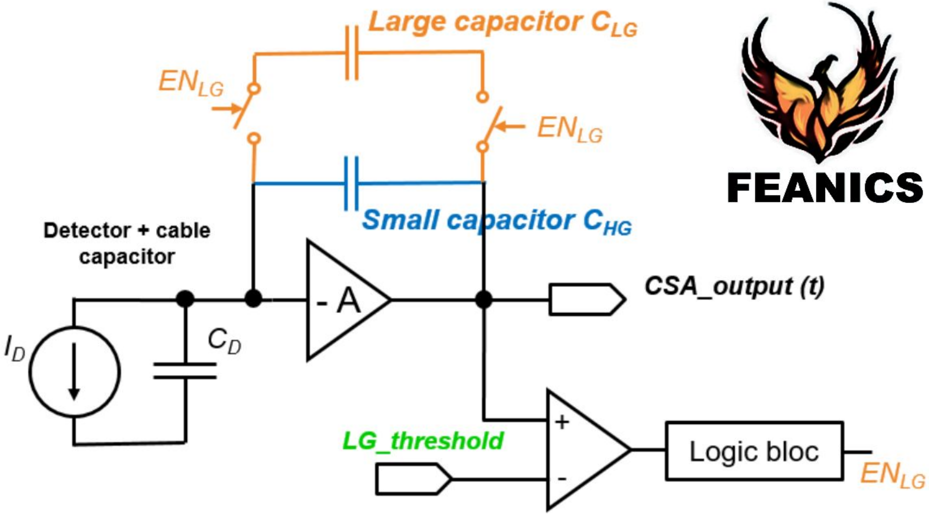


- ❑ Counter for laser spectroscopy
- ❑ Detailed α, e-, γ decay spectroscopy

⇩

Coupling of atomic and nuclear approaches

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

What's next ?

- 2 proposals will be submitted to the PAC of September at IGISOL, Jyväskylä :

Decay spectroscopy of ^{223}Pa produced through the fusion-evaporation reaction ^{230}Th(p, xn)$^{231-x}$Pa with SEASON

E. Rey-herme[1], D. Thisse[1], M. Vandebrouck[1], M. Ragot[1], N. Abrassart[1], I. Moore[2], Ch. E. Düllmann[3,4,5], T. Eronen[2], A. Kankainen[2], S. Lecanuet[6], S. Pineda[7], A. Raggio[8], D. Renisch[3,4], J. Sarén[2], B. Sulignano[1], et al.[0], the IGISOL group[2], and the SEASON collaboration[1]

→ Investigate the limits of the static octupole deformation region in the neutron deficient actinides.
→ ^{219}Ac is expected to have vibrational behaviour

Decay spectroscopy of Neptunium isotopes produced through the fusion-evaporation reaction ^{233}U(p, xn)$^{234-x}$Np with SEASON

D. Thisse[1], E. Rey-herme[1], M. Vandebrouck[1], M. Ragot[1], N. Abrassart[1], B. Sulignano[1], I. Moore[2], J. Sarèn[2], T. Eronen[2], A. Kankainen[2], A. Raggio[3], S. Pineda[4], D. Renisch[5,6], C. Düllmann[5,6,7], S. Lecanuet[8], the IGISOL group[2], and the SEASON collaboration[1]

→ ^{229}Np and ^{230}Np have poorly known decay properties (at most 1 excited state known)
→ Explore further the octupole region

→ SEASON is expected to be sent back to GANIL at S3LEB in 2028