



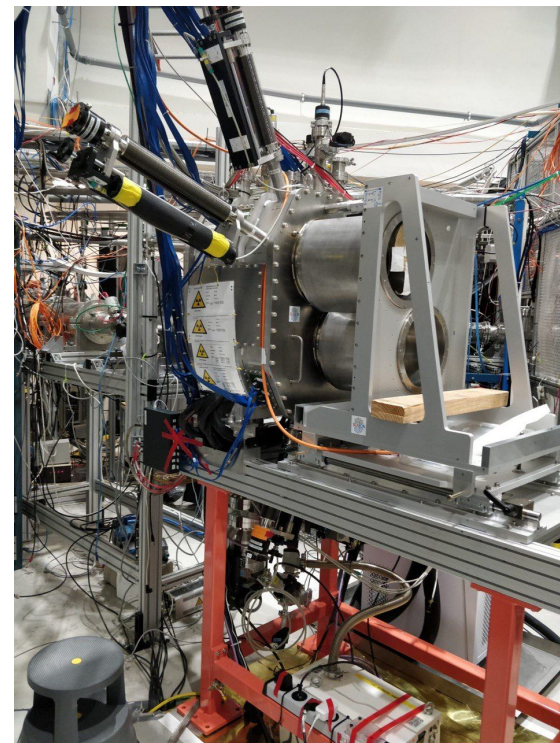
irfu



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



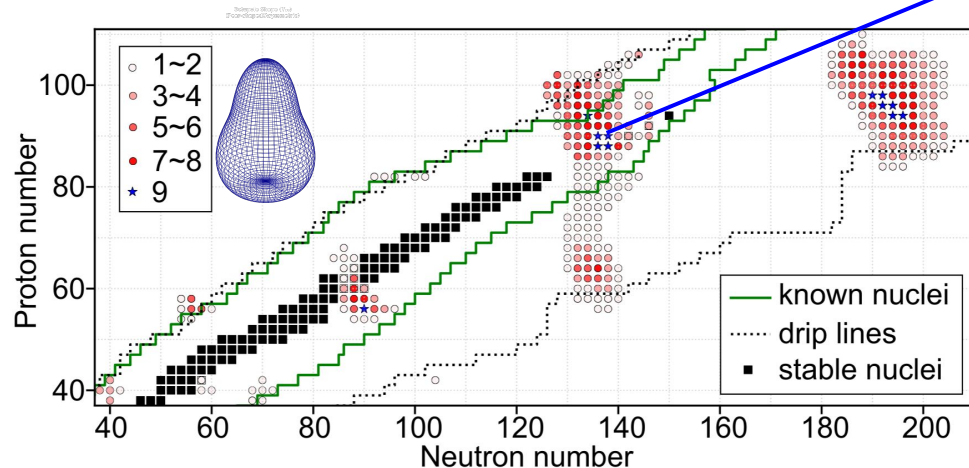
1.

Nuclear shapes

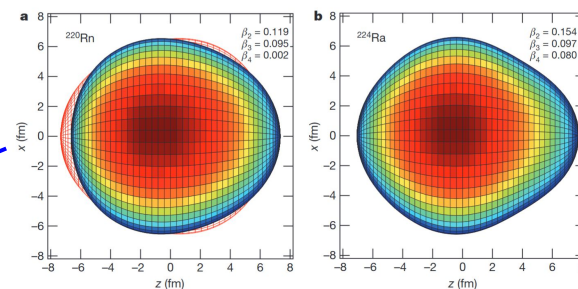
Studying nuclear shapes

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

Octupole deformation in the heavy nuclei region:



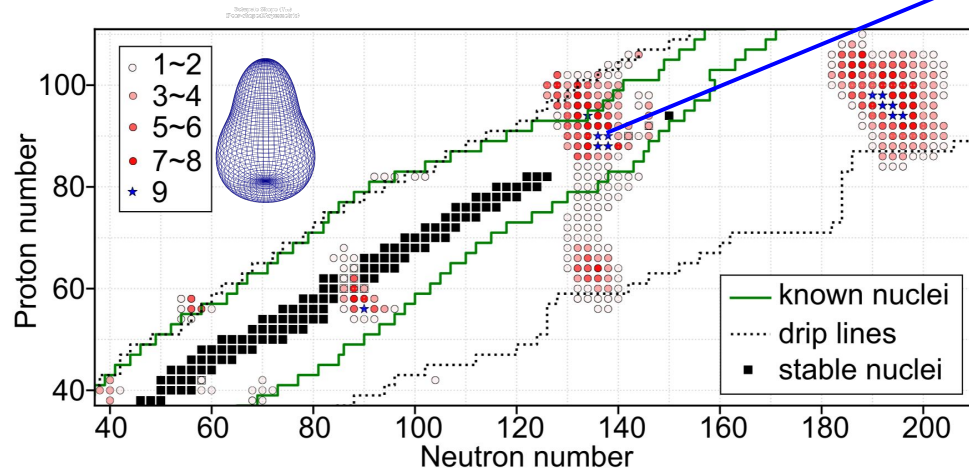
Cao, Y. et al. (2020) *Physical Review C*, 102(2), p. 024311.



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

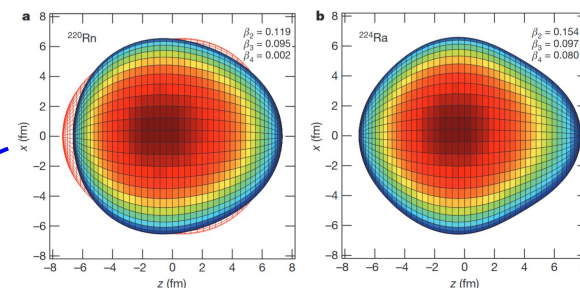
Studying nuclear shapes

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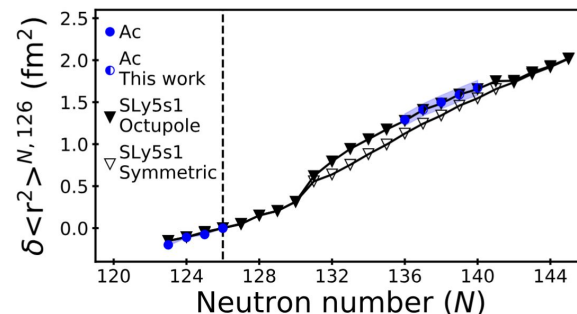
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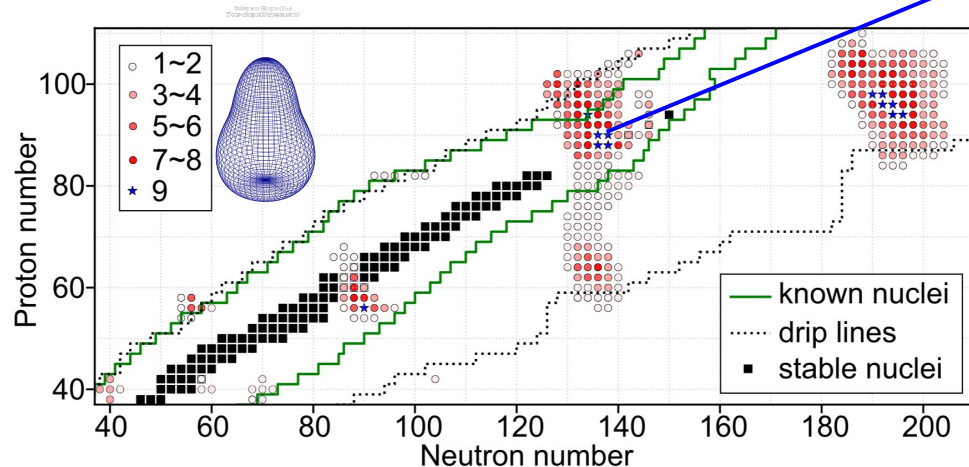
- Other links can be made probing:
→ masses, $\delta\langle r^2 \rangle$ with laser spectroscopy



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

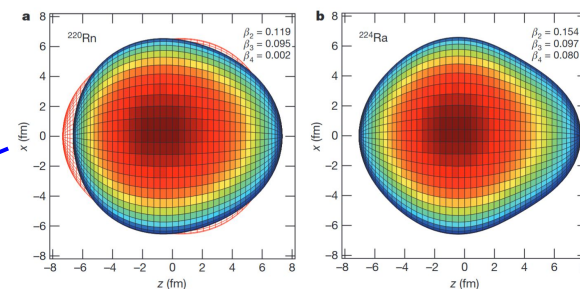
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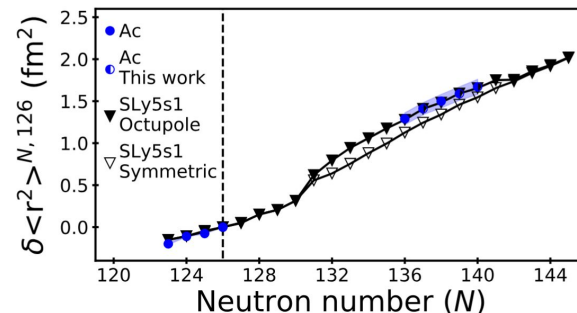
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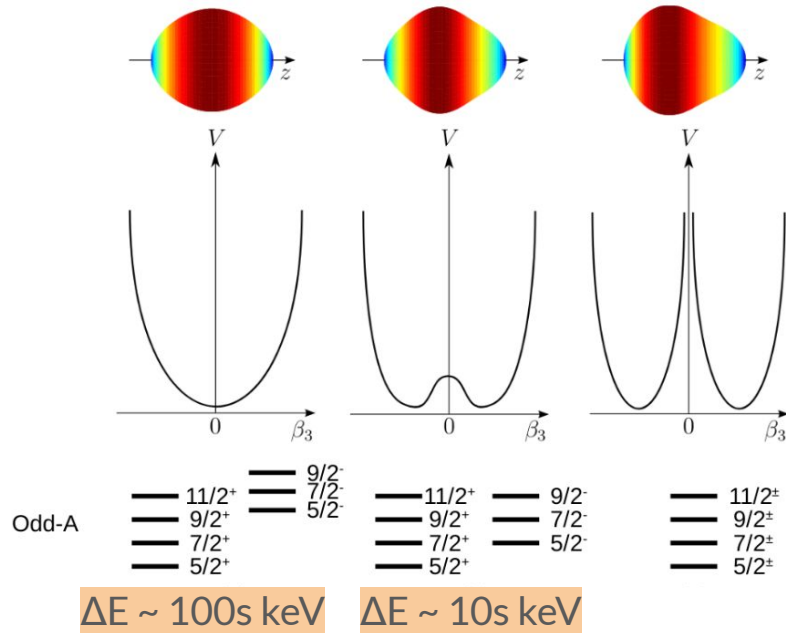


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- **Decay spectroscopy**

Microscopic signatures of octupole collectivity ?

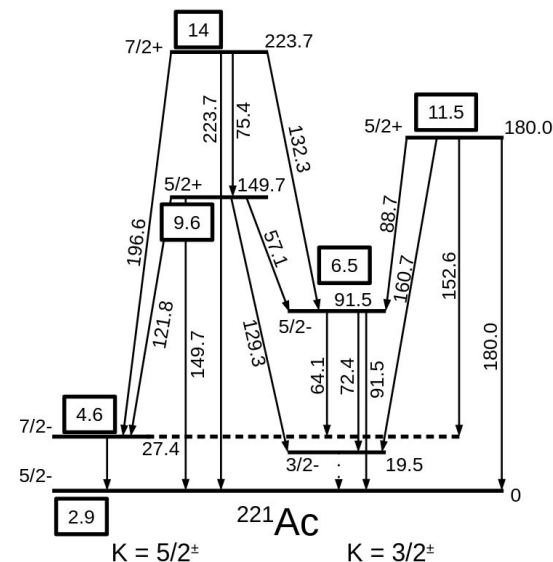
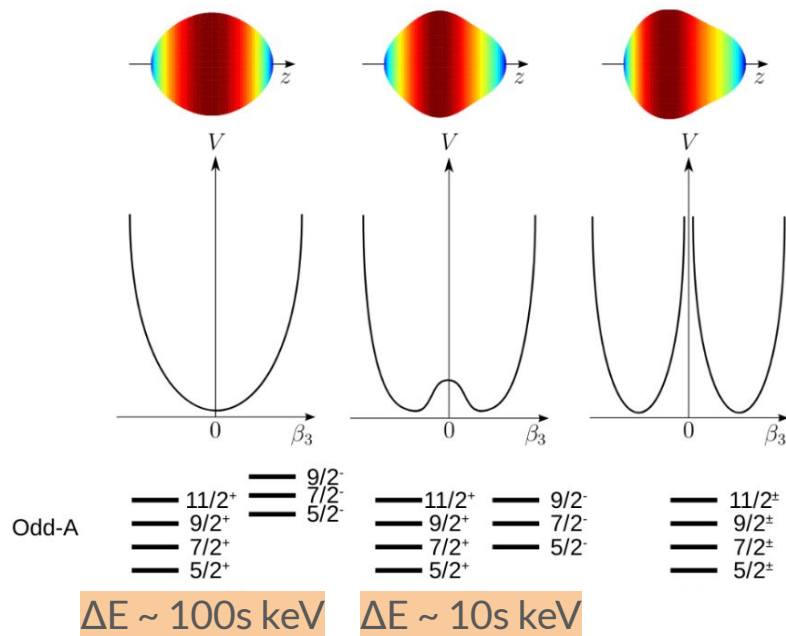
- Parity doublets in the rotational bands



Microscopic signatures of octupole collectivity ?

- Parity doublets in the rotational bands

- Example of ^{221}Ac



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

Microscopic signatures of octupole collectivity ?

- Parity doublets in the rotational bands

- α -decay

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

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

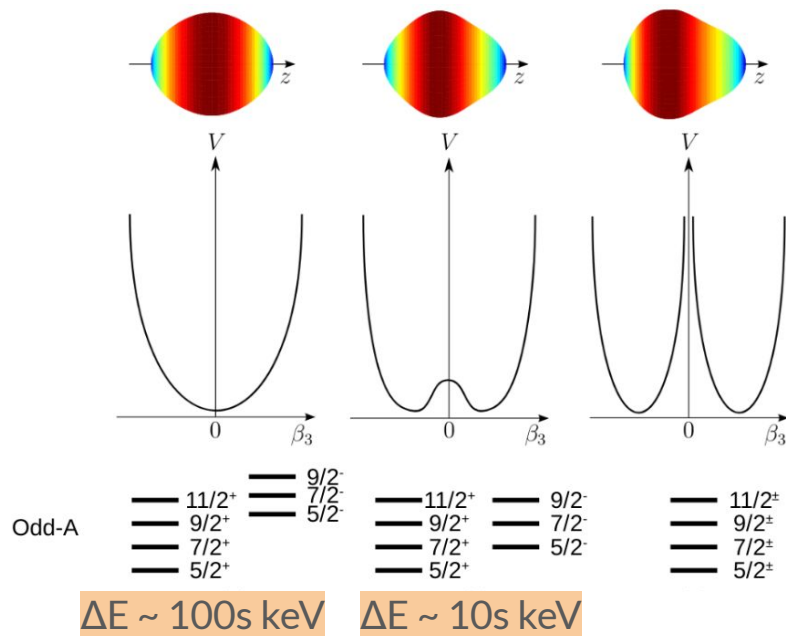
Typical values :

HF ~ 1-4: Favored transitions

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



octupole
deformation



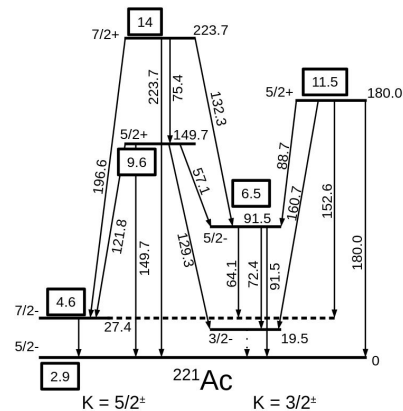
2. SEASON decay station

SEASON project



Goals: study heavy nuclei through

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



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

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

Needs:

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

SEASON project

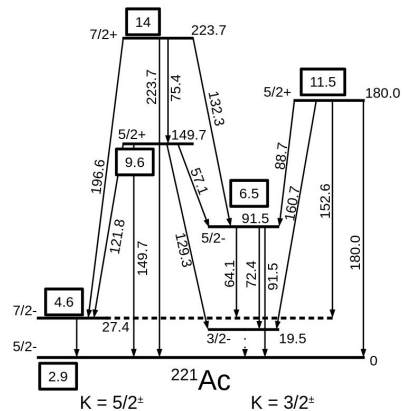


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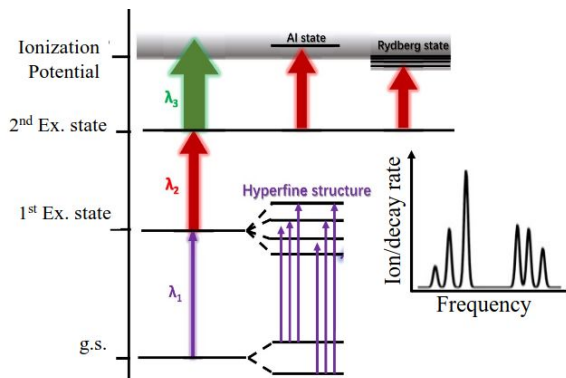
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Rey-herme et al. (2023) PRC 108, 014304

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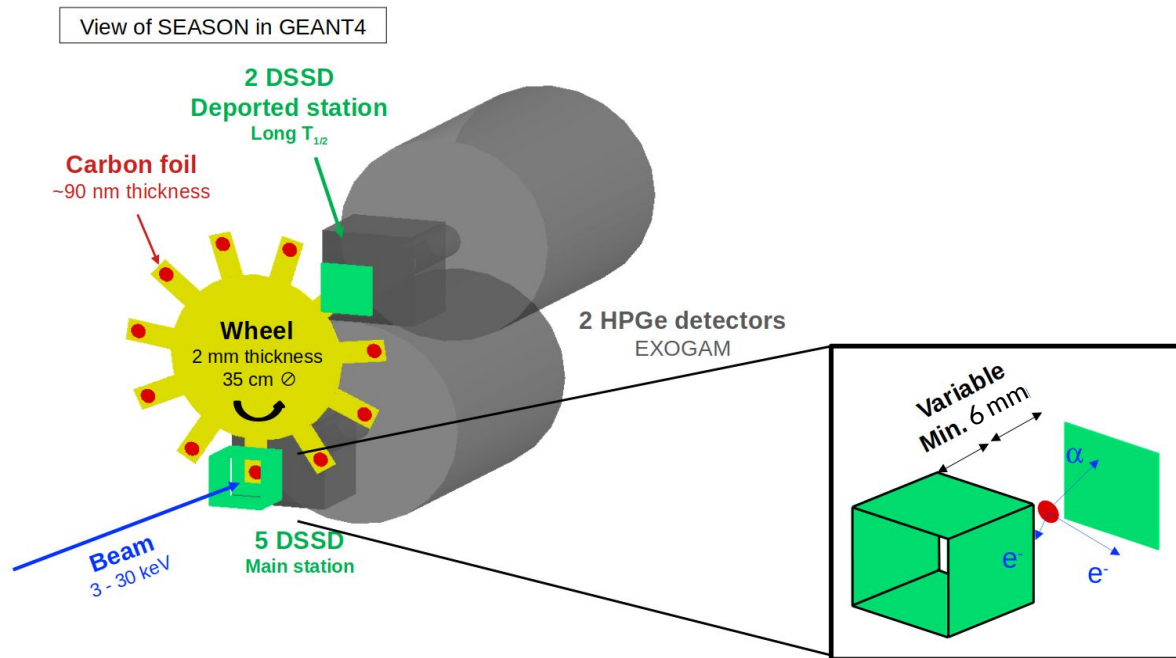


- mean square charge radii
- electric quadrupole moments
- dipole magnetic moments
- spins

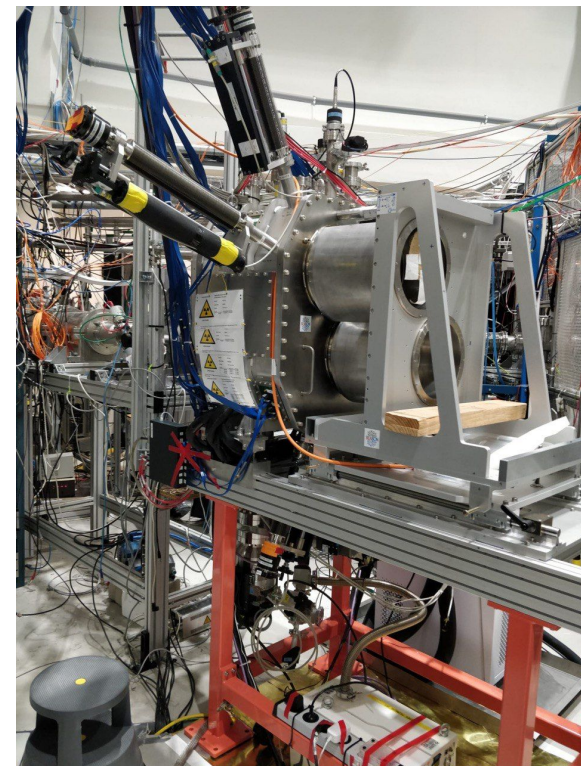
SEASON scheme



SEASON at Jyväskylä



simulation done by Emmanuel Rey-herme

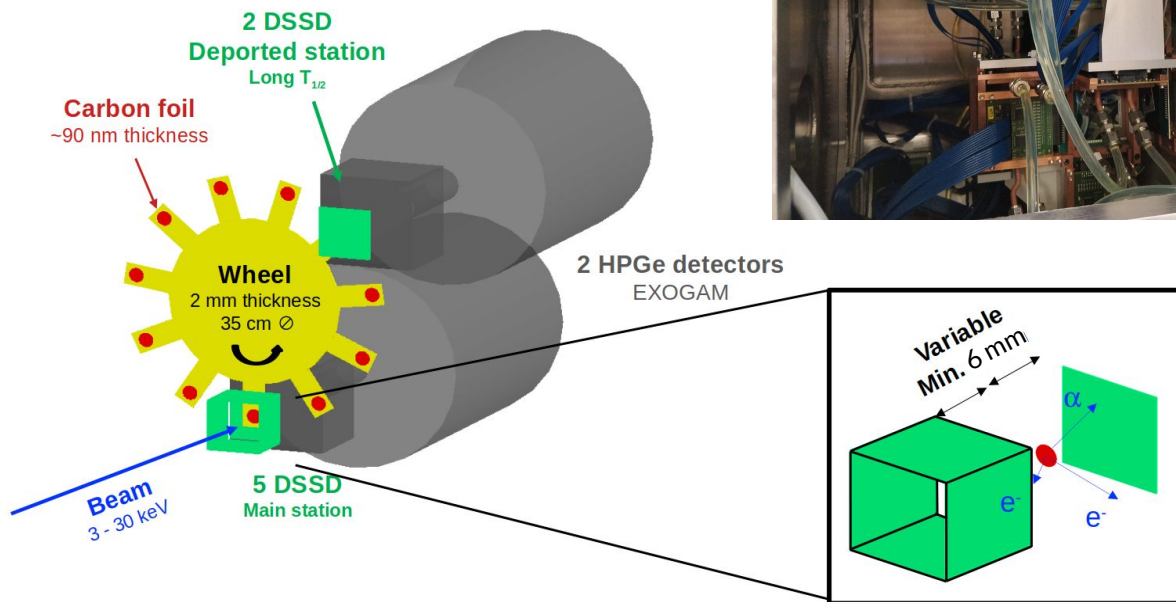


SEASON scheme

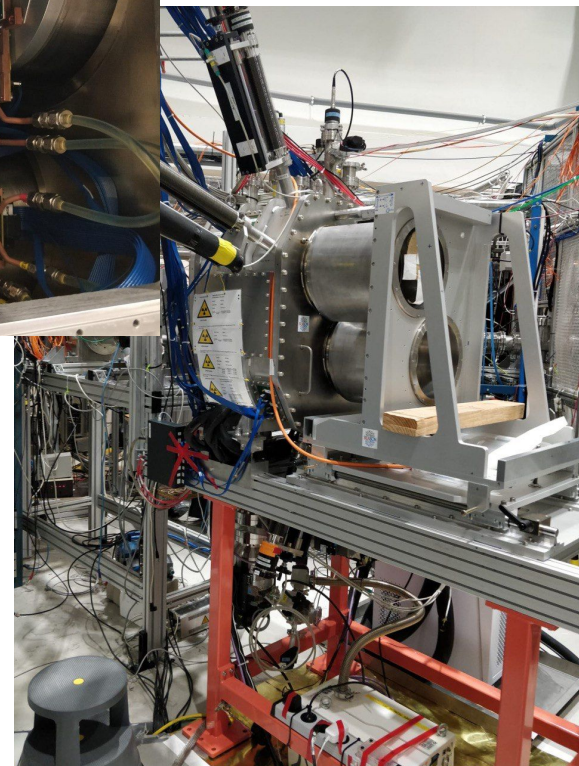


SEASON at Jyväskylä

View of SEASON in GEANT4



simulation done by Emmanuel Rey-herme



Technical SEASON properties



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	$44 \pm 13 \%$	~45 keV
	electron	~14 keV	~14 keV	$29 \pm 4 \%$	
fixed gain	α -particle	/	~15 keV	$23.5 \pm 7 \%$	~30 keV
	electron	~10 keV	/	$19.5 \pm 3 \%$	

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

3.

Commissioning in Jyväskylä, Finland

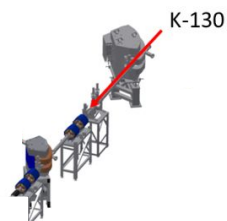
→ February 20th – February 27th



SEASON at Jyväskylä

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

$^{223}\text{Pa}_{\alpha}$	$^{224}\text{Pa}_{\alpha}$	$^{225}\text{Pa}_{\alpha}$	$^{226}\text{Pa}_{\alpha}$	$^{227}\text{Pa}_{\alpha}$	$^{228}\text{Pa}_{\beta+}$	$^{229}\text{Pa}_{e^{-}\text{ capture}}$	$^{230}\text{Pa}_{\beta+}$	$^{231}\text{Pa}_{\alpha}$	$^{232}\text{Pa}_{\beta-}$	$^{233}\text{Pa}_{\beta-}$
$^{222}\text{Th}_{\alpha}$	$^{223}\text{Th}_{\alpha}$	$^{224}\text{Th}_{\alpha}$	$^{225}\text{Th}_{\alpha}$	$^{226}\text{Th}_{\alpha}$	$^{227}\text{Th}_{\alpha}$	$^{228}\text{Th}_{\alpha}$	$^{229}\text{Th}_{\alpha}$	$^{230}\text{Th}_{\alpha}$	$^{231}\text{Th}_{\beta-}$	$^{232}\text{Th}_{\alpha}$
$^{221}\text{Ac}_{\alpha}$	$^{222}\text{Ac}_{\alpha}$	$^{223}\text{Ac}_{\alpha}$	$^{224}\text{Ac}_{\beta+}$	$^{225}\text{Ac}_{\alpha}$	$^{226}\text{Ac}_{\beta-}$	$^{227}\text{Ac}_{\beta-}$	$^{228}\text{Ac}_{\beta-}$	$^{229}\text{Ac}_{\beta-}$	$^{230}\text{Ac}_{\beta-}$	$^{231}\text{Ac}_{\beta-}$
$^{220}\text{Ra}_{\alpha}$	$^{221}\text{Ra}_{\alpha}$	$^{222}\text{Ra}_{\alpha}$	$^{223}\text{Ra}_{\alpha}$	$^{224}\text{Ra}_{\alpha}$	$^{225}\text{Ra}_{\beta-}$	$^{226}\text{Ra}_{\alpha}$	$^{227}\text{Ra}_{\beta-}$	$^{228}\text{Ra}_{\beta-}$	$^{229}\text{Ra}_{\beta-}$	$^{230}\text{Ra}_{\beta-}$
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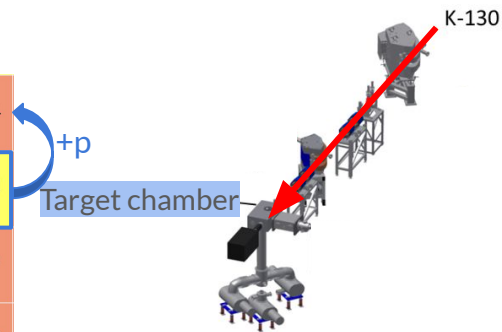


Layout of the IGISOL facility
in Jyväskylä, Finland

SEASON at Jyväskylä

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$^{221}\text{Ac}_{\alpha}$	$^{222}\text{Ac}_{\alpha}$	$^{223}\text{Ac}_{\alpha}$	$^{224}\text{Ac}_{\beta+}$	$^{225}\text{Ac}_{\alpha}$	$^{226}\text{Ac}_{\beta-}$	$^{227}\text{Ac}_{\beta-}$	$^{228}\text{Ac}_{\beta-}$	$^{229}\text{Ac}_{\beta-}$	$^{230}\text{Ac}_{\beta-}$	$^{231}\text{Ac}_{\beta-}$
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Layout of the IGISOL facility in Jyväskylä, Finland



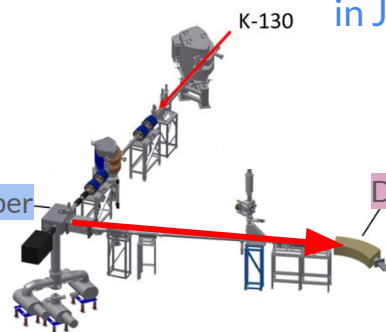
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$^{221}\text{Ac}_{\alpha}$	$^{222}\text{Ac}_{\alpha}$	$^{223}\text{Ac}_{\alpha}$	$^{224}\text{Ac}_{\beta+}$	$^{225}\text{Ac}_{\alpha}$	$^{226}\text{Ac}_{\beta-}$	$^{227}\text{Ac}_{\beta-}$	$^{228}\text{Ac}_{\beta-}$	$^{229}\text{Ac}_{\beta-}$	$^{230}\text{Ac}_{\beta-}$	$^{231}\text{Ac}_{\beta-}$
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+p

Target chamber



Layout of the IGISOL facility
in Jyväskylä, Finland

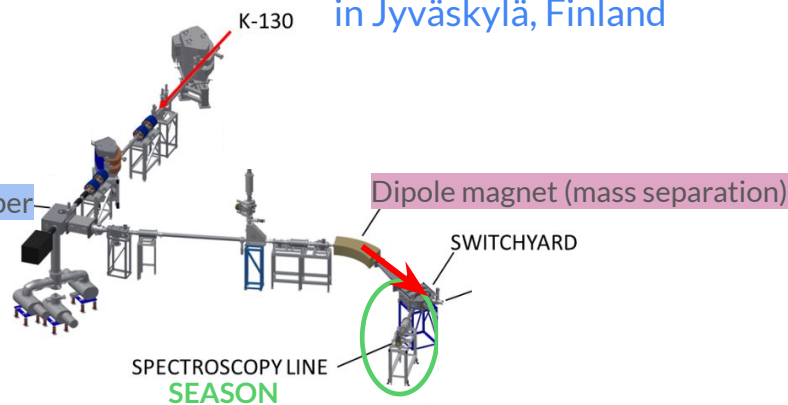
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Diagram showing the reaction path for the SEASON experiment. A blue arrow labeled '+p' points to the $^{232}\text{Th}_{\alpha}$ cell, which is labeled 'Target chamber'. A green arrow points from $^{232}\text{Th}_{\alpha}$ to $^{224}\text{Ac}_{\beta+}$, and another green arrow points from $^{224}\text{Ac}_{\beta+}$ to $^{221}\text{Fr}_{\alpha}$.

Layout of the IGISOL facility in Jyväskylä, Finland



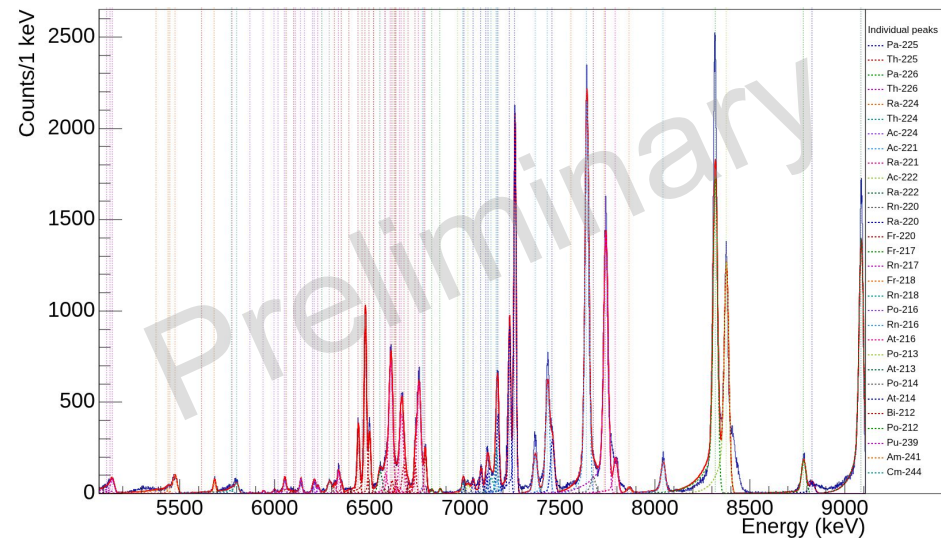
Also measured masses 221, 226, 222, 224 & test of an alpha beam

4.

Preliminary results of the commissioning

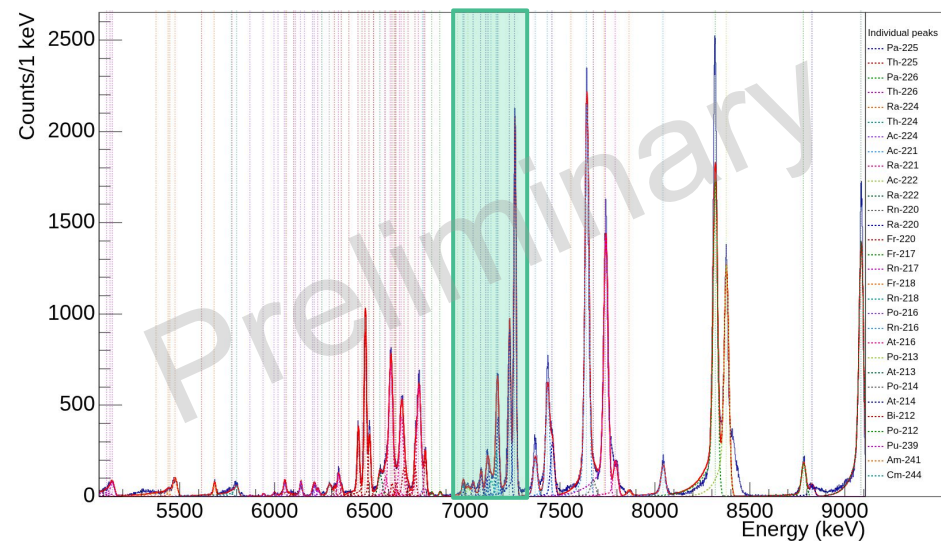
Mass 225

Alpha energy spectrum (in fixed gain mode)



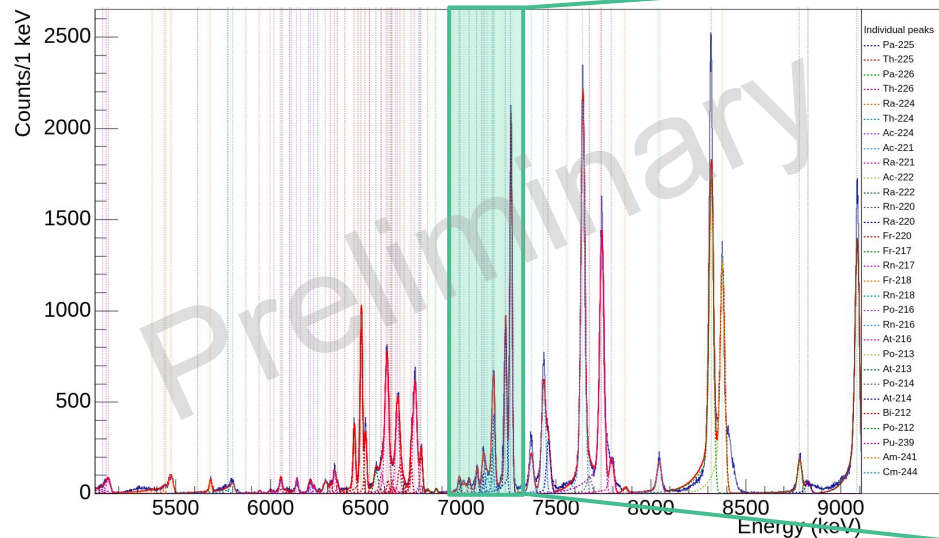
Mass 225

Alpha energy spectrum (in fixed gain mode)

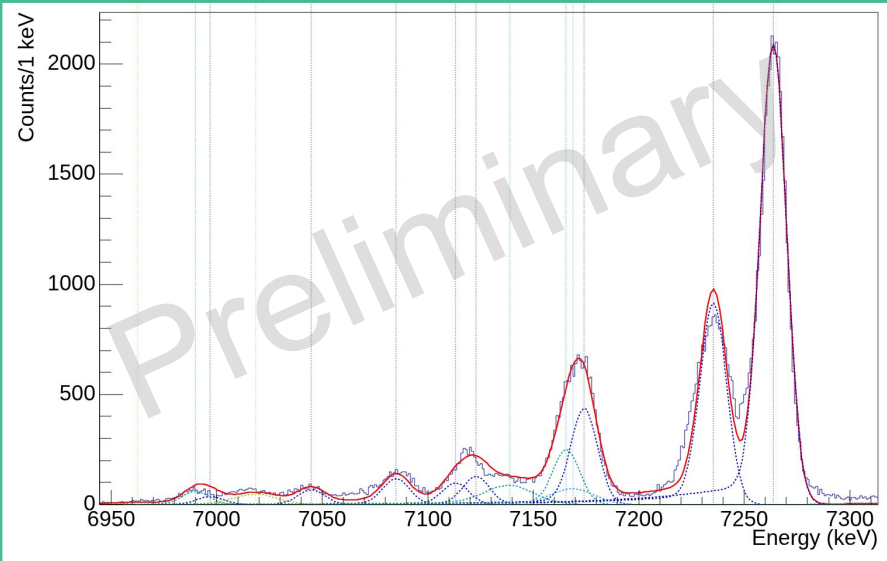


Mass 225

Alpha energy spectrum (in fixed gain mode)

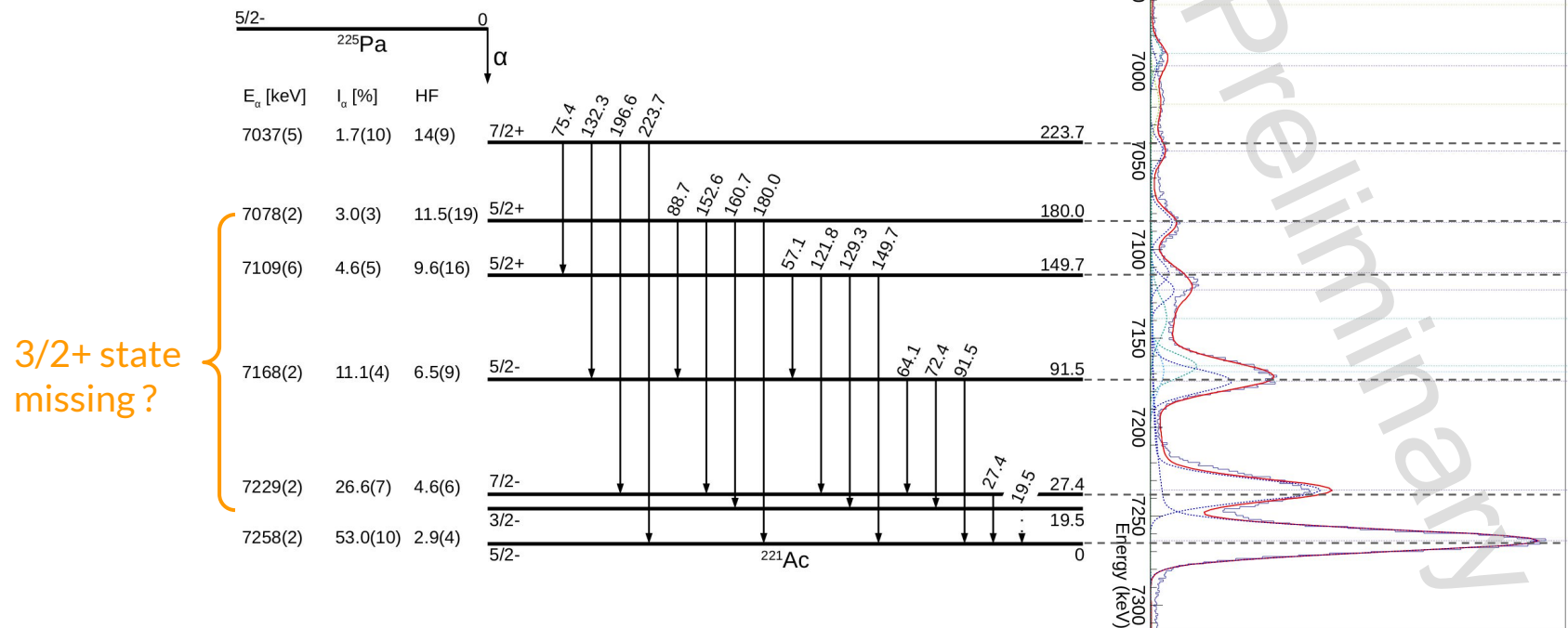


zoomed in on the energies of ^{225}Pa decay



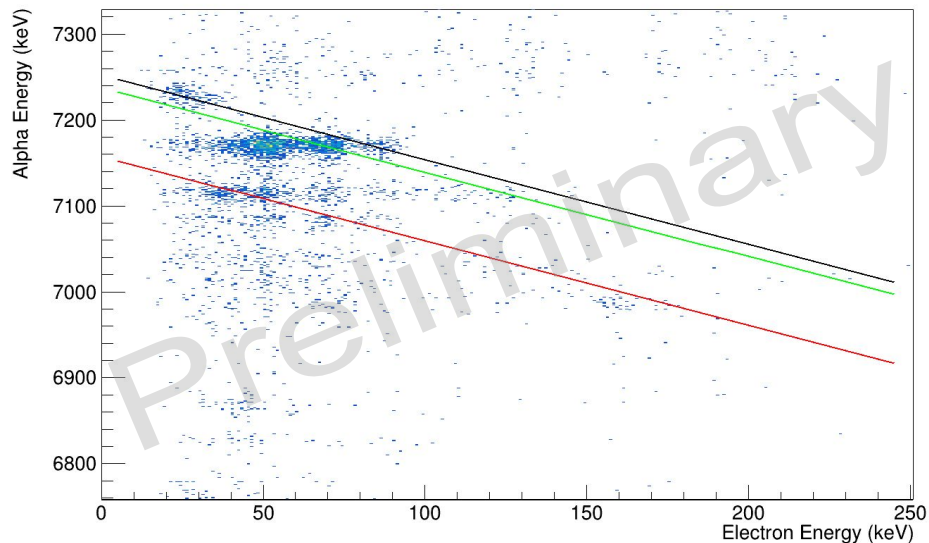
Mass 225 : study of ^{225}Pa decay

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



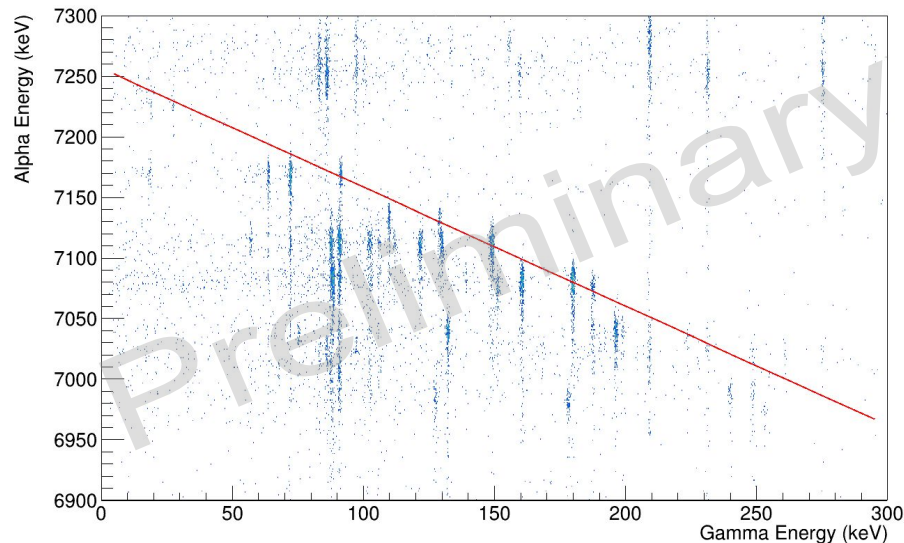
Mass 225 : study of ^{225}Pa decay

α – electron matrix (in fixed gain mode)



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

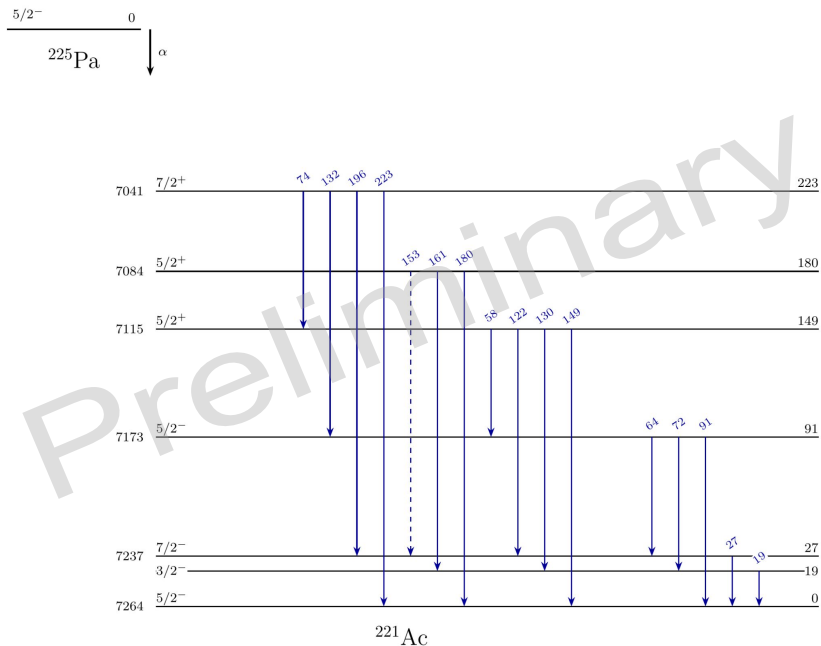
α – γ matrix (in automatic gain switch mode)



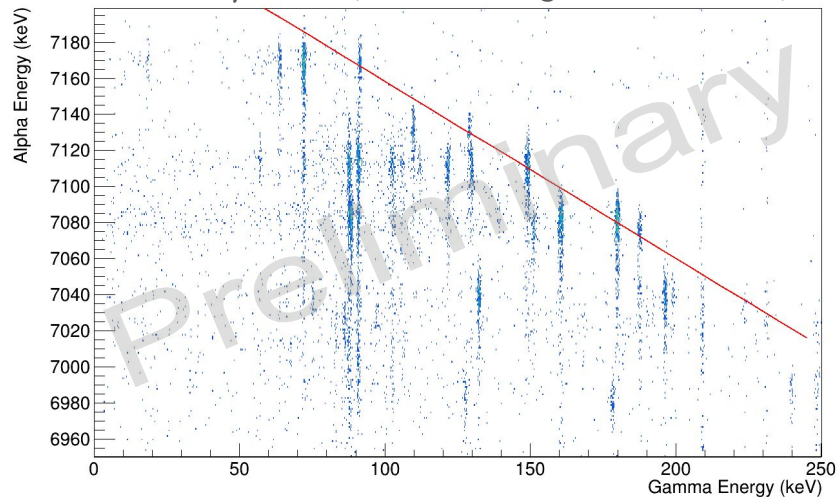
$$\text{---} E_{\alpha} + E_{\gamma} = Q_{\alpha}(gs \text{ to } gs)$$

First indications of the missing state

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

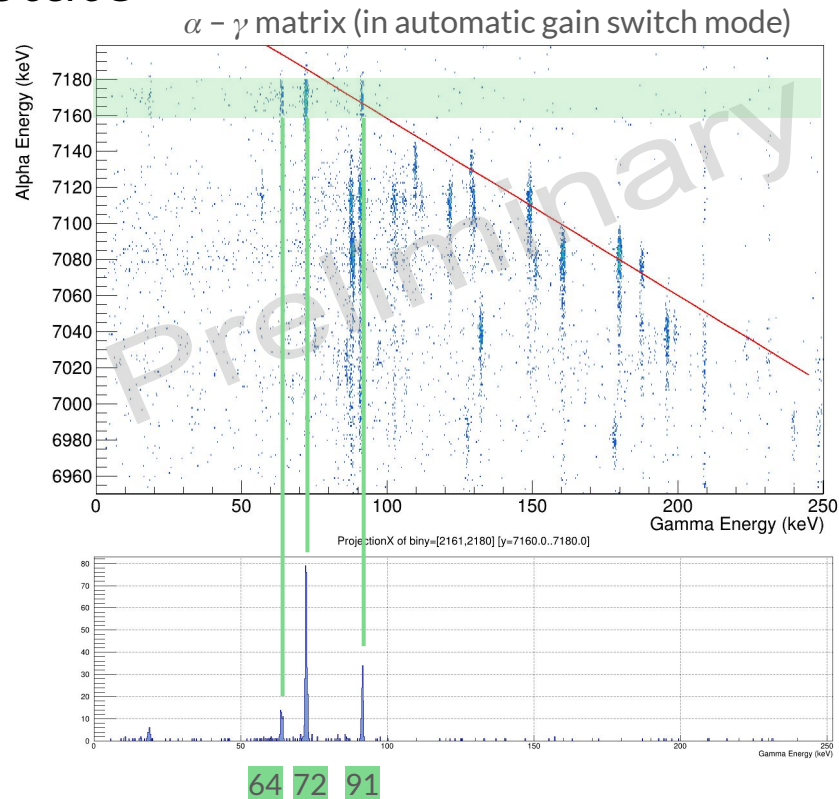
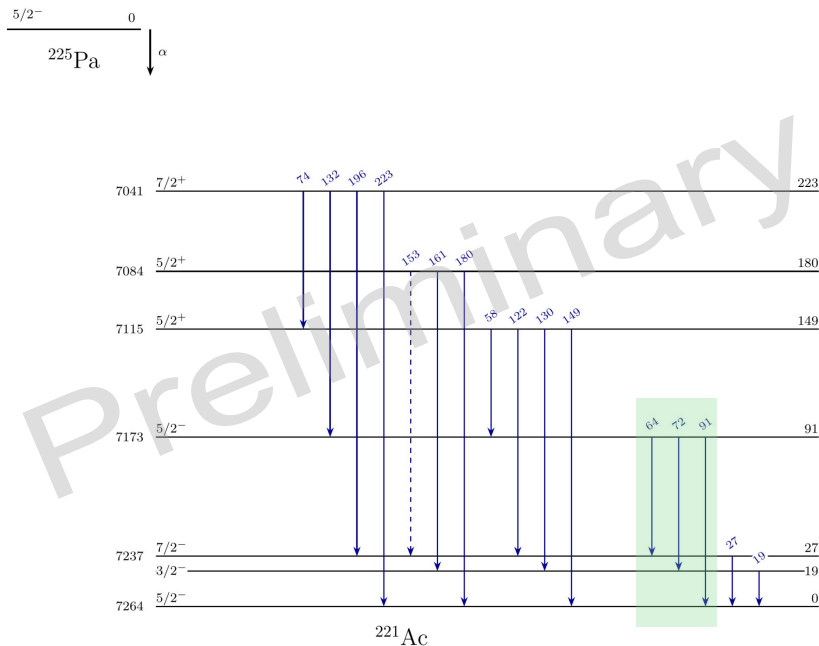


$\alpha - \gamma$ matrix (in automatic gain switch mode)



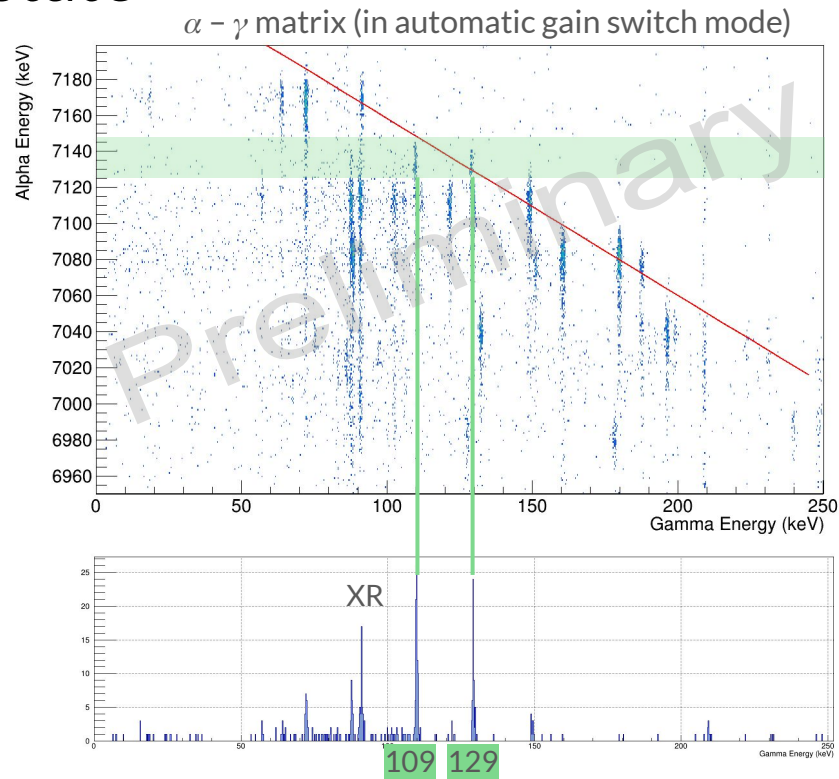
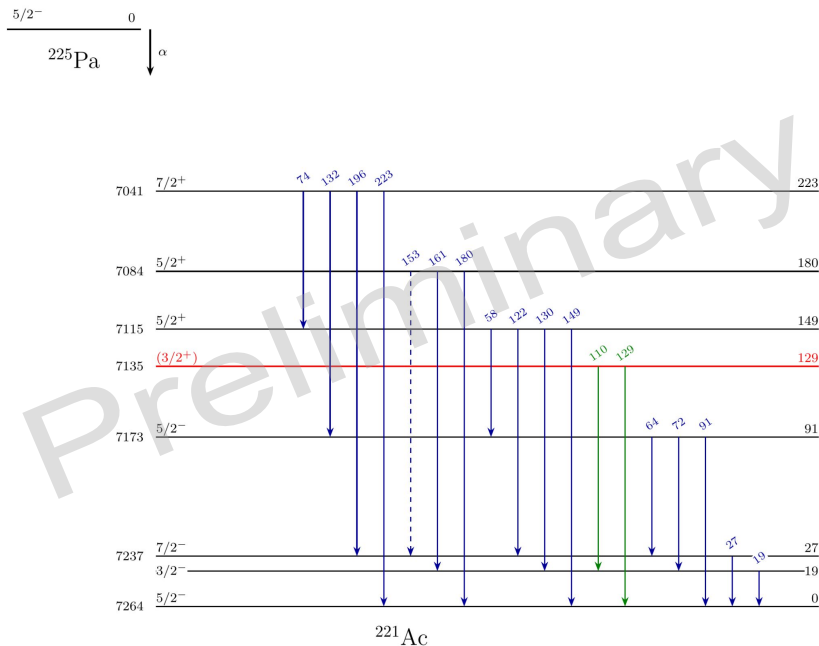
First indications of the missing state

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



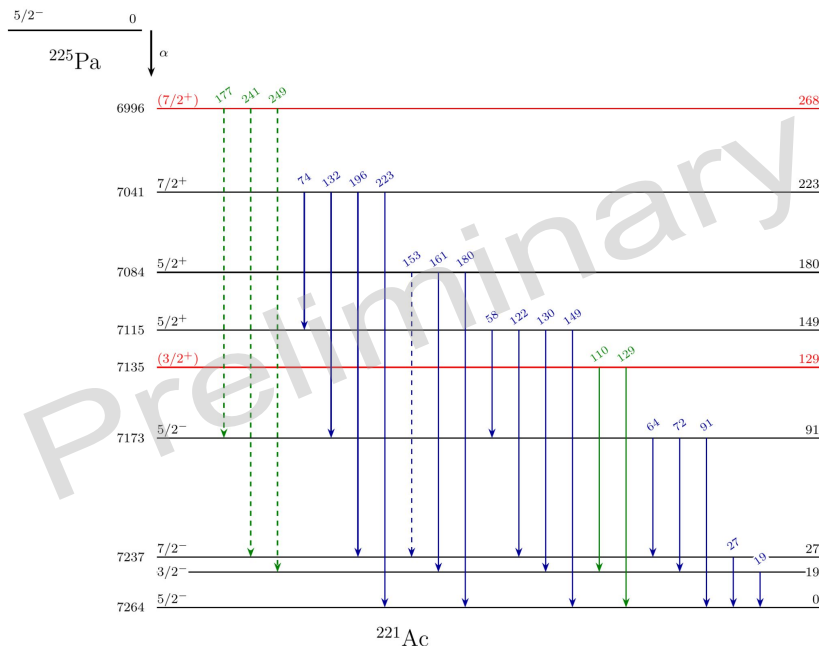
First indications of the missing state

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

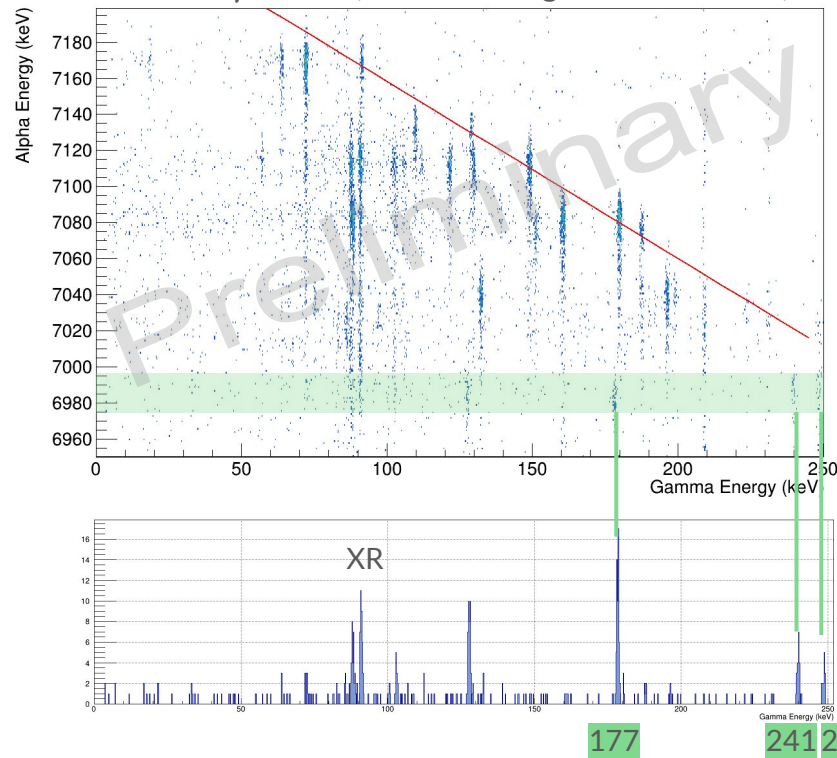


Indications of a higher excited state

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

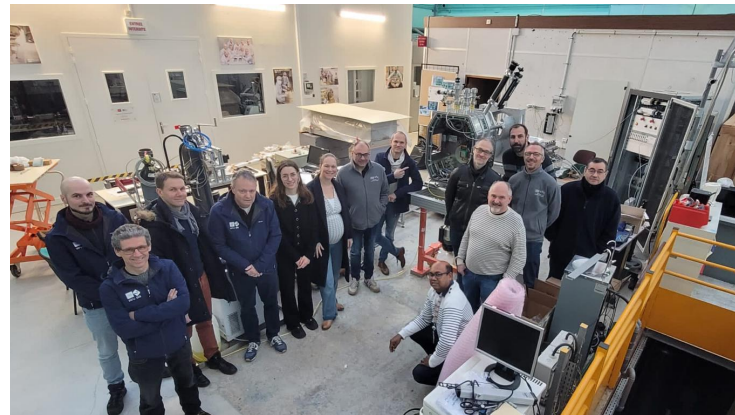


$\alpha - \gamma$ matrix (in automatic gain switch mode)

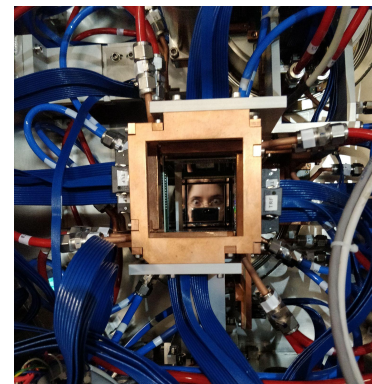


Conclusions

- 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 will be submitted to the PAC in september to pursue the study of the **limits and the magnitude of the octupole region**.



SEASON's development team at Saclay DIS in 2024





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

CEA

Damien Thisse, Nino Abrassart Martin, Zineb Bahaj-Filali, 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)
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

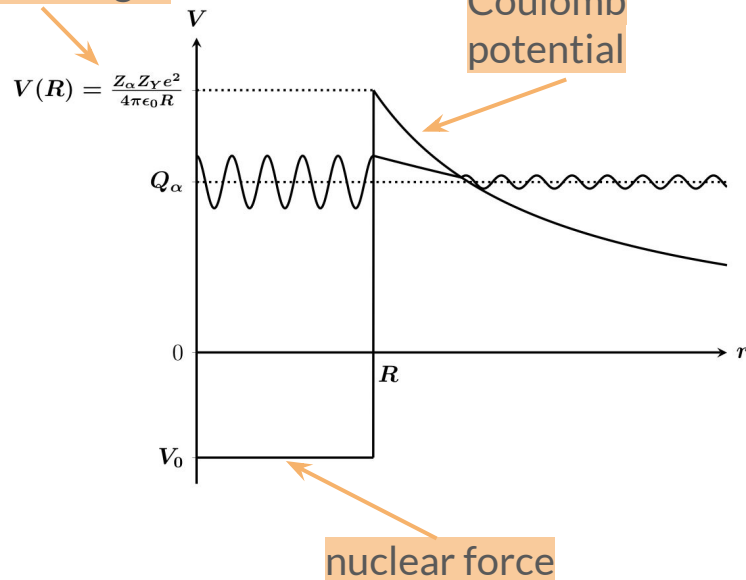
Electrical engineering :

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

■ Back-up

Alpha hindrance factors

Coulomb
barrier height



- 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

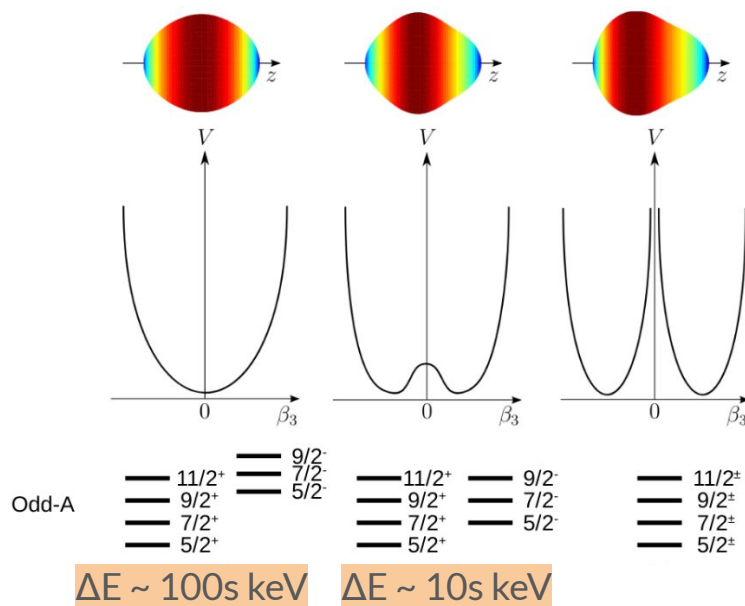


octupole
deformation

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 ?

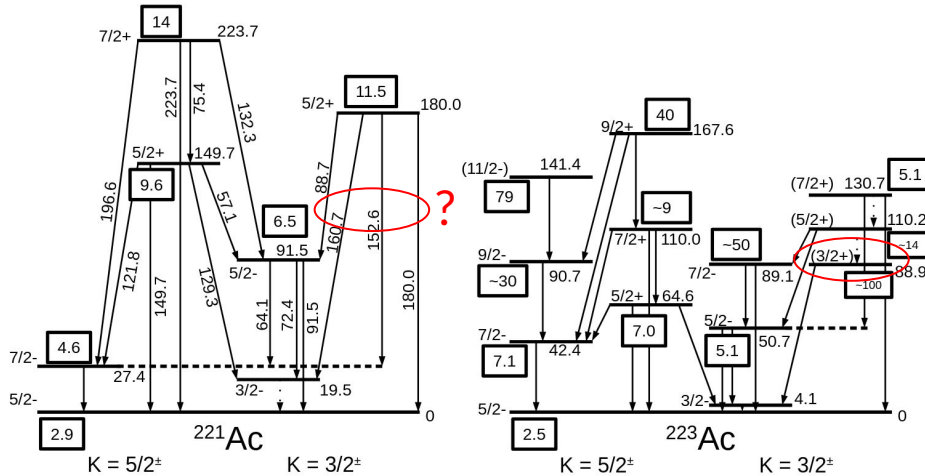
Reflection asymmetry -> Parity is broken at the intrinsic level: the intrinsic state is not an eigenstate of parity.

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.

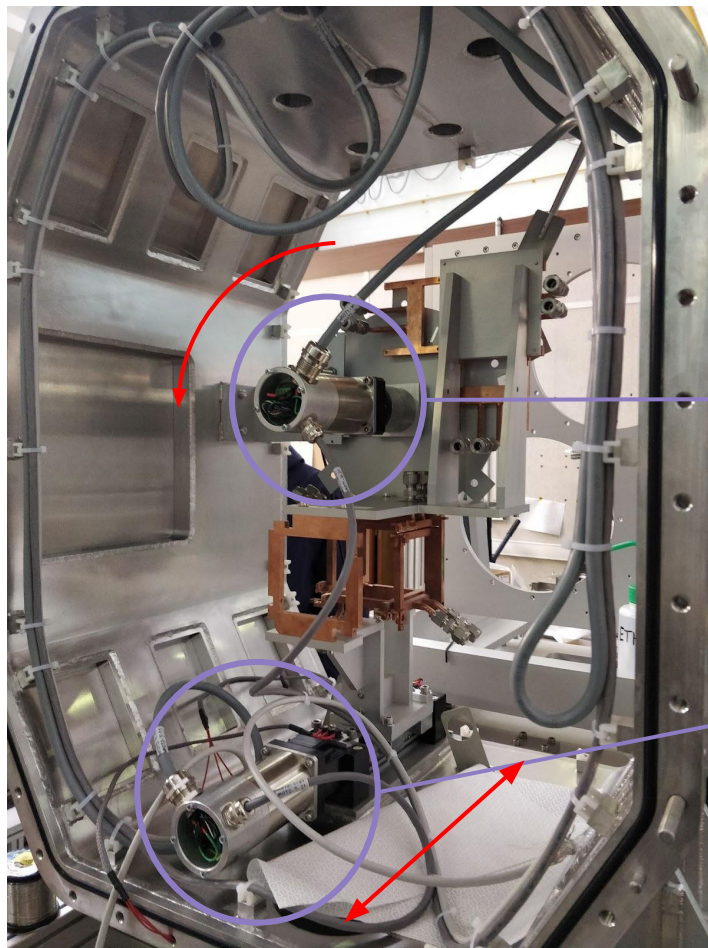
Where is the $3/2^+$ state expected ?



- 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)



- 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:

Gain switch +
fixed gain

Measurement:

● mass 225: 40 hours

● mass 221: 32 hours

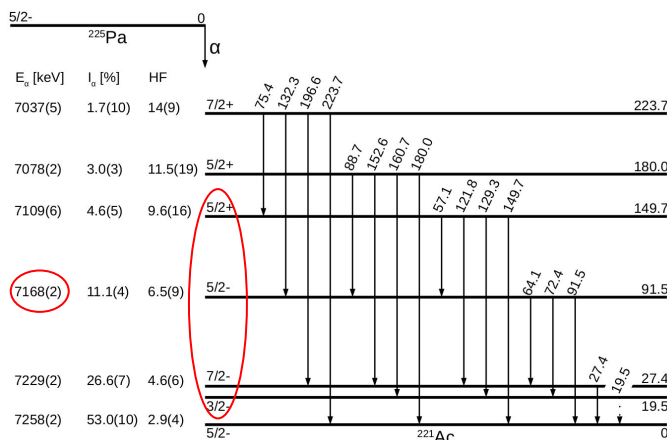
Gain switch

● mass 226: 29 hours

● mass 222: 12 hours

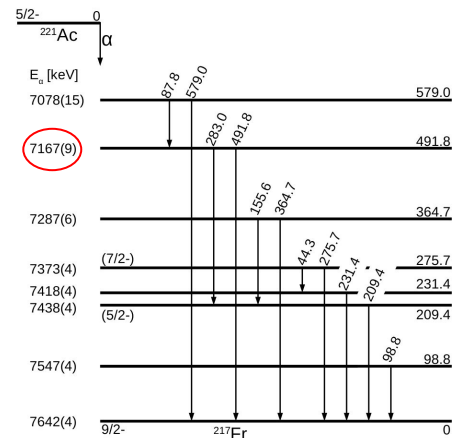
● mass 224: 4.5 hours

+ test of an alpha beam



-> characterization of SEASON properties
+ search of more excited states of ^{221}Ac not accessible before

E. Rey-herme PhD thesis (2023)



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

SEASON at Jyväskylä

Acquisition modes:

Gain switch +
fixed gain

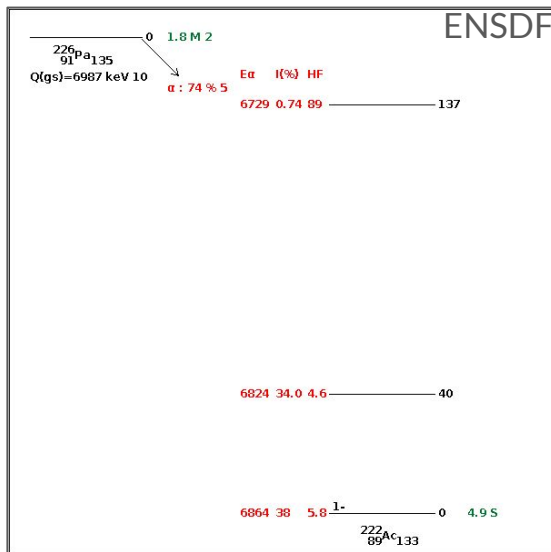
Measurement:

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

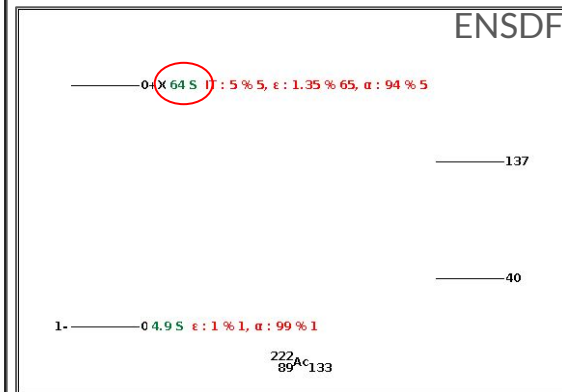
Gain switch

- 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

Acquisition modes:

Gain switch + fixed gain

Measurement:

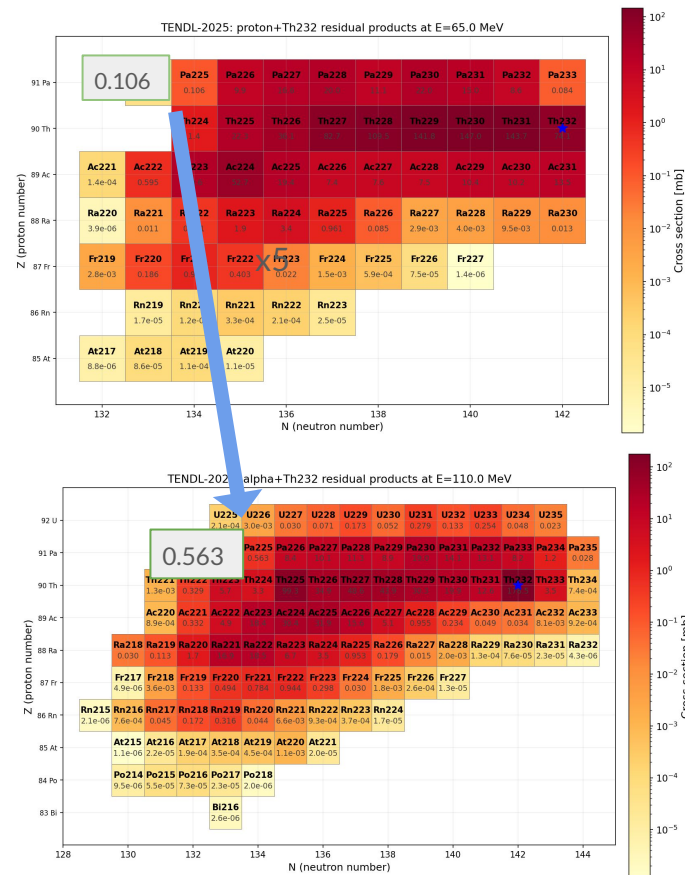
- mass 225: 40 hours
- mass 221: 32 hours

Gain switch

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

+ test of an alpha beam

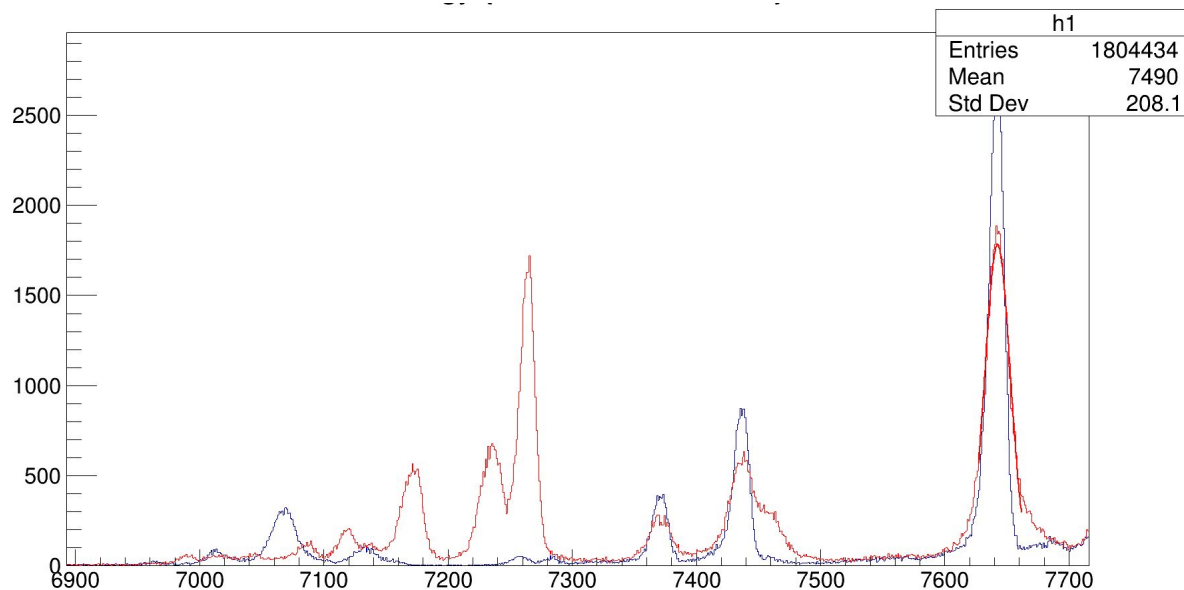
In principle :



Figures by Emmanuel Rey-herme

Mass A221 : Study of ^{221}Ac decay

What can we learn from studying the decay of the daughter nuclei ?

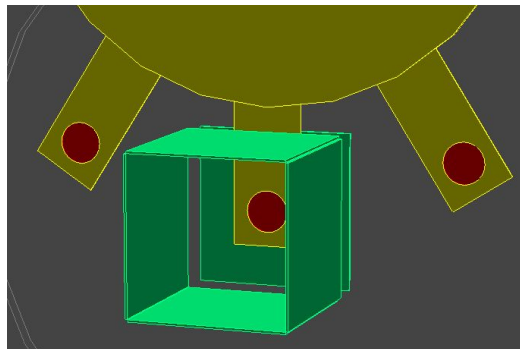


- Disentangle the alpha energies
- Find out branching ratios and HF
- Build the decay spectrum of ^{221}Ac

SEASON's commissioning experiment

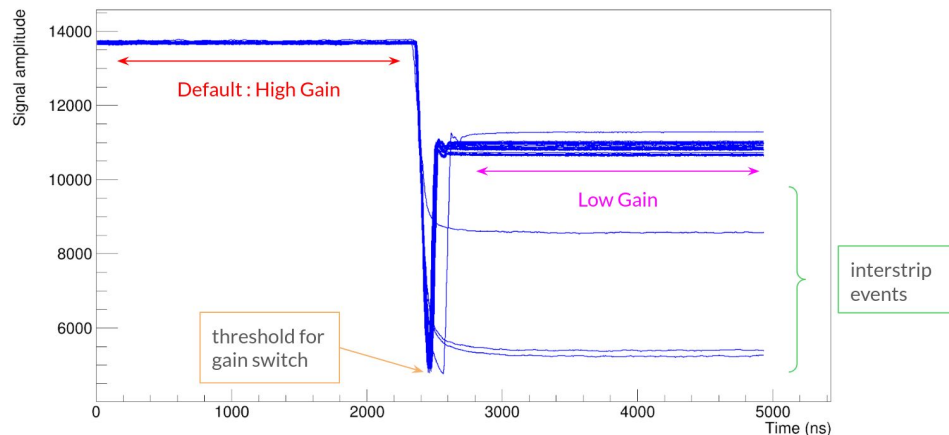
Test of two FEANICS modes :

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



+ high efficiency

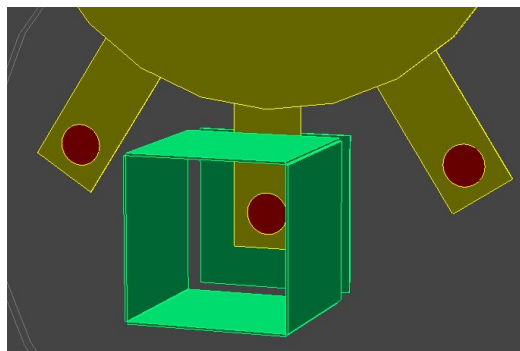
— noise level higher
→ resolution
slightly degraded
→ higher energy
threshold



SEASON's commissioning experiment

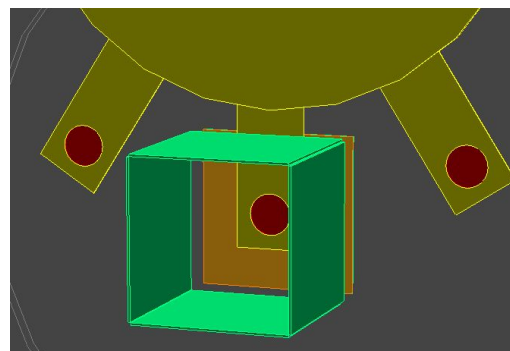
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- + high efficiency
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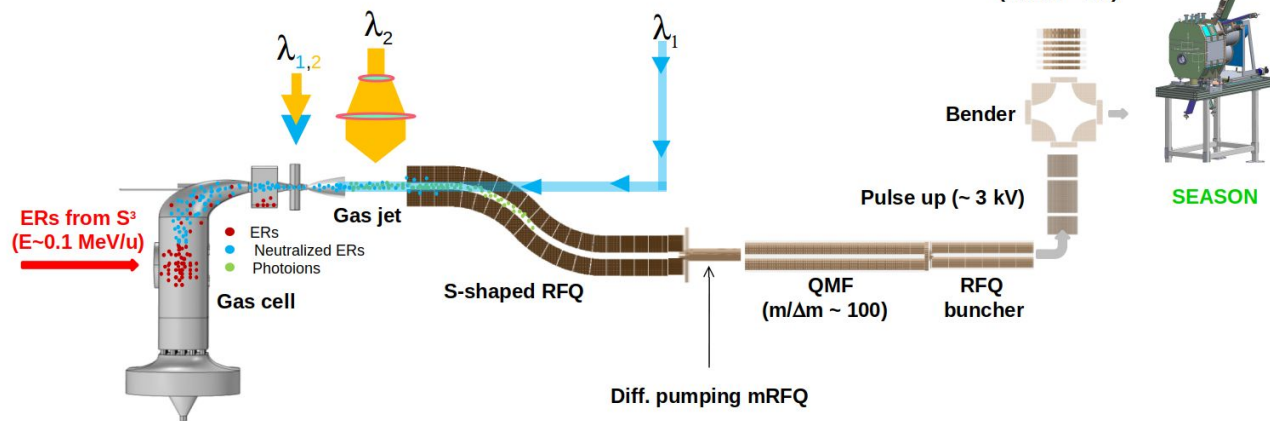
Fixed gain :
Main detector in a high gain mode,
Tunnel detectors in a low gain mode



- + 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

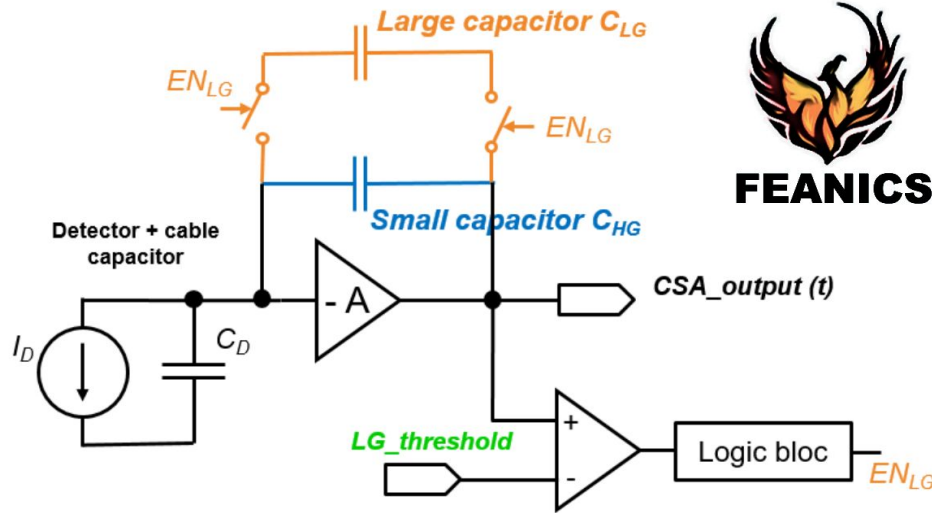


GANIL

- 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 $^{230}\text{Th}(p, xn)^{231-x}\text{Pa}$ with SEASON

E. Rey-herme¹, D. Thisse¹, M. Vandebrouck¹, M. Ragot¹, N. Abrassart¹, I. Moore², Ch. E. Düllmann^{3,4,5}, T. Eronen², A. Kankainen², S. Lecanuet⁶, S. Pineda⁷, A. Raggio⁸, D. Renisch^{3,4}, J. Sarén², B. Sulignano¹, et al.⁰, the IGISOL group², and the SEASON collaboration¹



→ 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 $^{233}\text{U}(p, xn)^{234-x}\text{Np}$ with SEASON

D. Thisse¹, E. Rey-herme¹, M. Vandebrouck¹, M. Ragot¹, N. Abrassart¹, B. Sulignano¹, I. Moore², J. Sarén², T. Eronen², A. Kankainen², A. Raggio³, S. Pineda⁴, D. Renisch^{5,6}, C. Düllmann^{5,6,7}, S. Lecanuet⁸, the IGISOL group², and the SEASON collaboration¹



→ ^{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