HISPEC/DESPEC Collaboration meeting

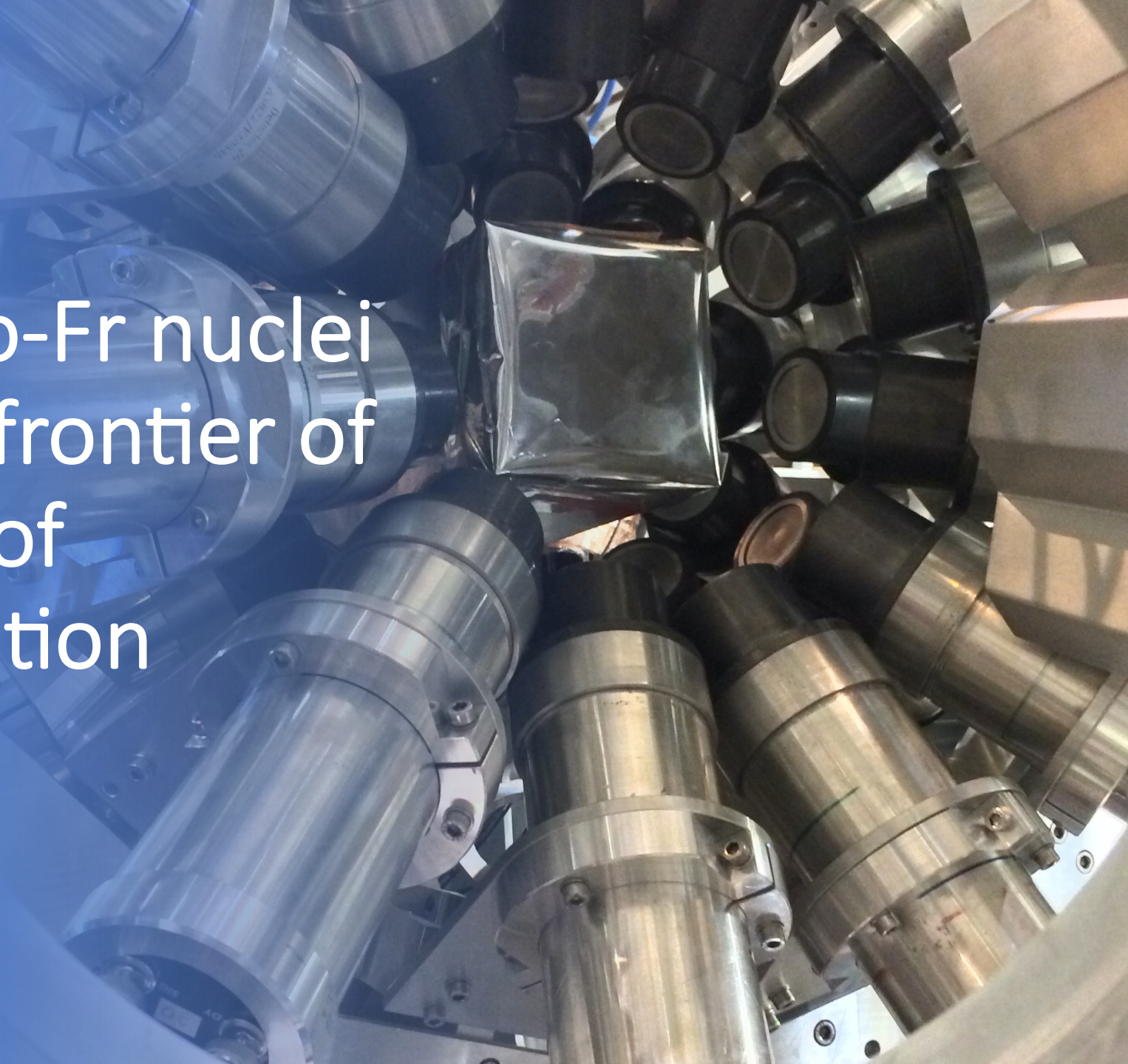
4th-5th October 2021

Investigation of Po-Fr nuclei in the south-east frontier of the A~225 island of octupole deformation

Marta Polettini for the **S460 collaboration**

Università degli Studi di Milano

INFN Sezione di Milano



Outline

- Case study: 220<A<230 Po-Fr nuclei
  - Octupole deformation in the A~222 region
  - Aims of the experiment
- Experiment
  - The DESPEC setup
  - Experiment realization
- On-going analysis:
  - Alpha decay in Rn isotopes
  - Calibration and ion identification optimisation
  - Future steps

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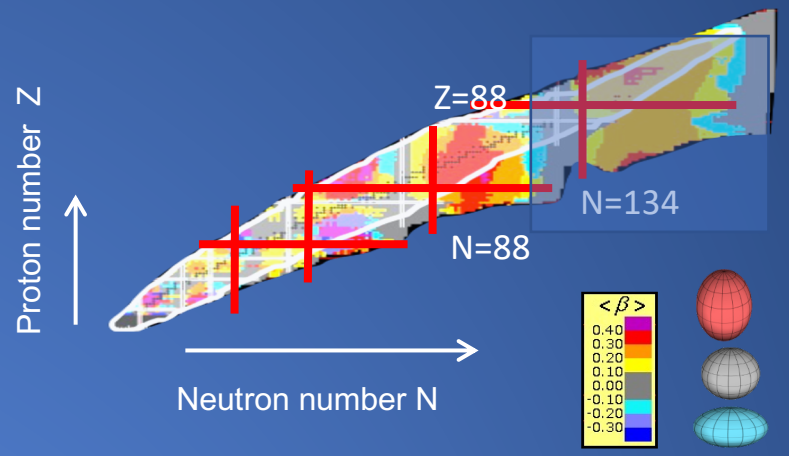
Island of octupole deformation: actinide region

- The Rn-Th (Z=88-90) actinide nuclei around mass number A∼225 delimit the region of the nuclear chart where the strongest octupole correlations are manifested.



- In general, there is a dearth of experimental information on the structure of heavy nuclei in the 220<A<230 transitional region between the Z=82 closed-shell regime and the south-east corner of the A∼222 IOD.

- Direct measurements of octupole correlations were performed recently, finding evidences for typical decay pattern and enhanced transitions

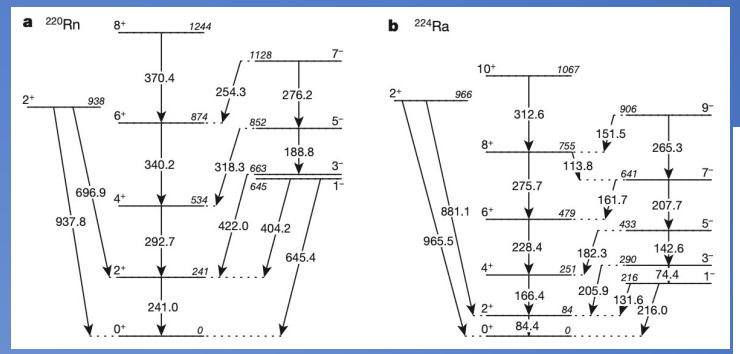
  For example:

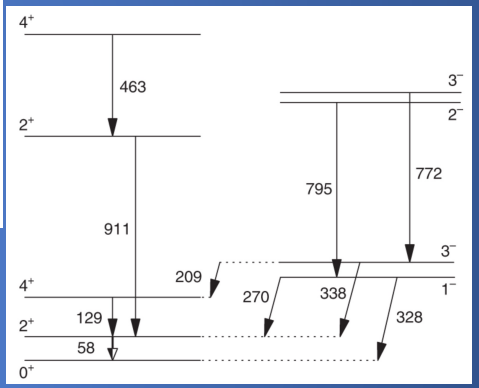
  - **^{220}Rn** and **^{224}Ra** from L.P. Gaffney et al.

    L.P. Gaffney et al., Nature 497,199–204 (2013)

  - **^{228}Th** from M.M.R. Chishti et al.

    M.M.R. Chishti et al., Nature Physics 16, 853–856 (2020)



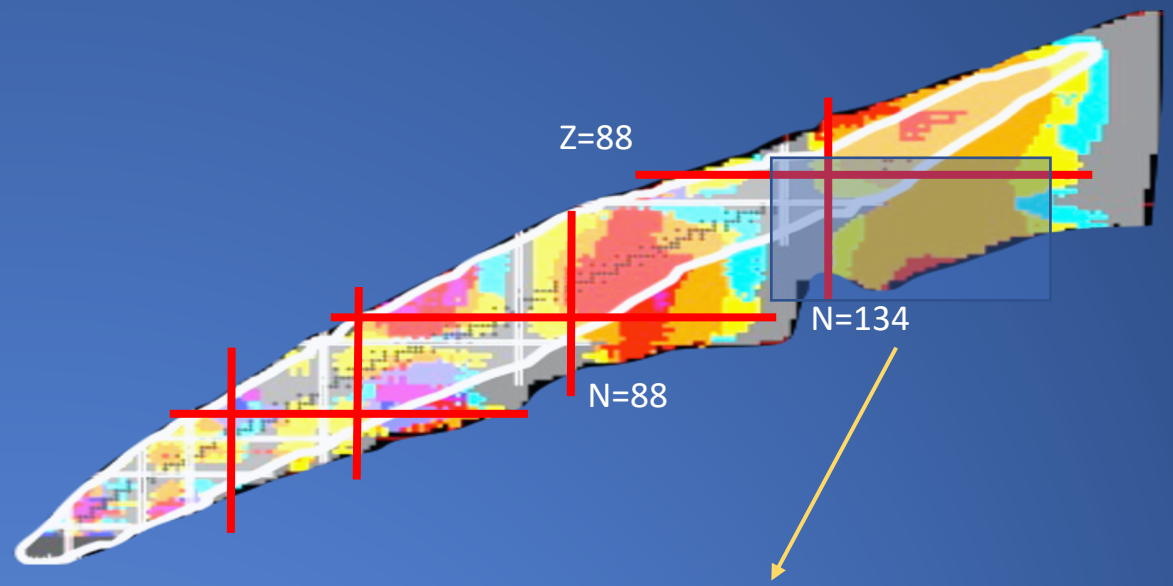


Aims of the experiment

- **Octupole deformation around A~225**
  - Beta delayed and fast-timing spectroscopy:
    - Locate low-lying 1^- and 3^- states
    - Measure reduced transition strengths

- **Test of nuclear models for r process**
  - Measurement of ground state half-lives
  - Determination of possible competing α branches
  - Beta-delayed gamma spectroscopy to:
    - Investigate low-lying structure in daughters
    - Determine apparent I_β and logft

- **Shape isomers in ^{220,222}Po**
  - Delayed isomer spectroscopy
    - Measure lifetimes of super-deformed 2^+ states



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238U @ 1AGeV + Be (1624 mg/cm²) Setting 225At				
Parent Nucleus	**$t_{1/2}$**	**energy 1st excited state in daughter**	**half-life 1st exc state in daughter**	**ppd @ AIDA**
228Rn	65 s	unknown	unknown	2,80E+04
227Rn	20.8 s	2.74 keV	unknown	1,29E+05
226Rn	7.4 m	unknown	unknown	8,85E+04
225Rn	4.66 m	28.55 keV	unknown	1,01E+05
226At	unknown	unknown	unknown	1,79E+04
225At	unknown	unknown	unknown	7,19E+04
224At	76 s	unknown	unknown	1,98E+05
223At	50 s	unknown	unknown	1,86E+05
222At	54 s	186.2	0.32 ns	2,53E+05
221At	2.3 m	30 keV	unknown	2,57E+04
223Po	unknown	unknown	unknown	6,90E+03
222Po	550 s	unknown	unknown	2,03E+04
221Po	112 s	unknown	unknown	2,97E+04
220Po	unknown	unknown	unknown	5,26E+04

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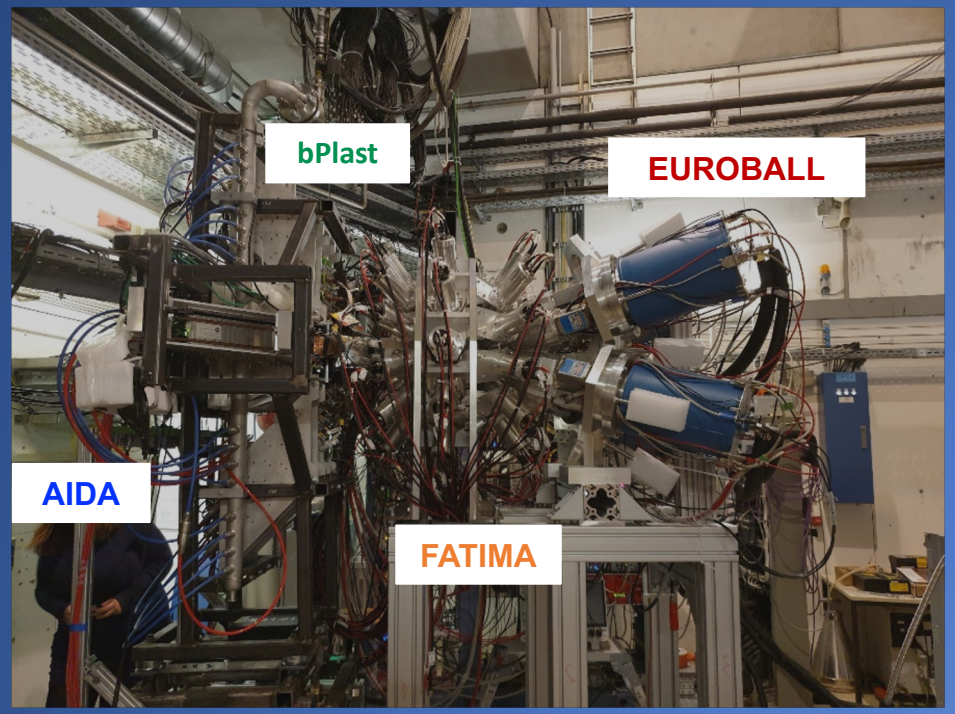
FRS+DESPEC at GSI-FAIR: the β decay station



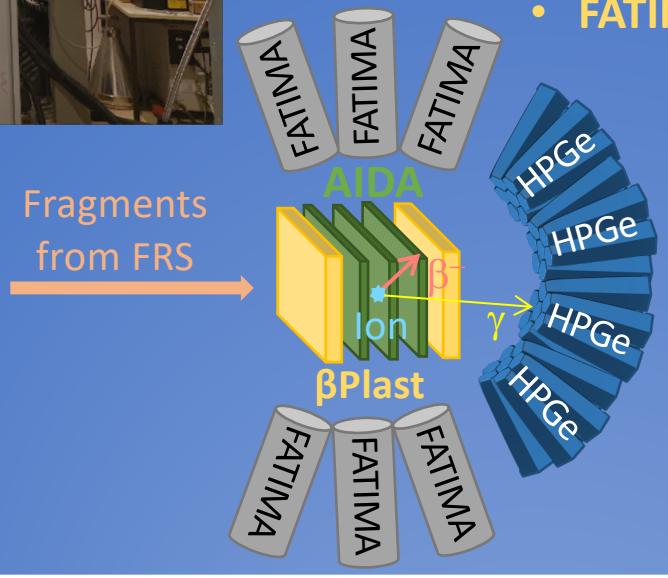
The setup is composed of:

- **AIDA**: a stack of 3 DSSSD detectors
- **bPlast**: fast plastic detector
- **Euroball**: HPGe array for gamma detection – four 7-fold clusters

  (efficiency 2% at 1 MeV)
- **FATIMA**: array of 36 $LaBr_3(Ce)$ detectors

  (efficiency 2.9% at 1 MeV)

The nuclei of interest were produced using the fragmentation of a **^{238}U beam** at an energy of **1GeV/nucleon**.



Ion → Isomers

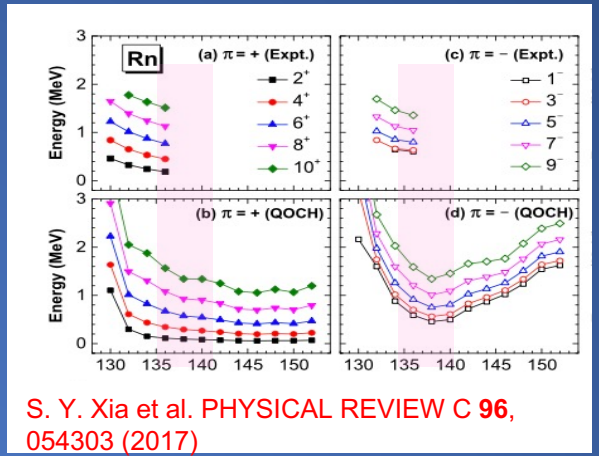
Ion → β decay → γ rays

Challenges of S460 experiment

Critical aspects:

- Proximity to primary beam
- Strong production of fission fragments

No known isomers in the region ⟶ **Test settings on alpha emitters**



S. Y. Xia et al. PHYSICAL REVIEW C **96**, 054303 (2017)

Color code	Half-life	Decay Mode	Q_{β^-}	Q_{EC}	Q_{β^+}	S_n	S_p	Q_α	ΔQ_α	S_{2n}	S_{2p}	$Q_{2\beta^-}$	Q_{2EC}
Q_{β^-2n}	BE/A	(BE-LDM Fit)/A	Pair. gap	$E_{1st\ ex.\ st.}$	E_{2+}	E_{3-}	E_{4+}	E_{4+}/E_{2+}	β_2	$B(E2)_{42}/B(E2)_{20}$	$\sigma(n,\gamma)$	$\sigma(n,F)$ 235U	

Z	136	137	138	139	140	141	142	143	N
	223Fr 22.00 M β-: 99.99% α: 6.0E-3%	224Fr 3.33 M β-: 100.00%	225Fr 3.95 M β-: 100.00%	226Fr 49 S β-: 100.00%	227Fr 2.47 M β-: 100.00%	228Fr 38 S β-: < 100.00%	229Fr 50.2 S β-: 100.00%	230Fr 19.1 S β-: 100.00%	231Fr 17.6 S β-: 100.00%
86	222Rn 3.8235 D α: 100.00%	223Rn 24.3 M β-: 100.00%	224Rn 107 M β-: 100.00%	225Rn 4.66 M β-: 100.00%	226Rn 7.4 M β-: 100.00%	227Rn 20.2 S β-: 100.00%	228Rn 65 S β-: 100.00%	229Rn 12.0 S β-: 100.00%	230Rn >300 NS β-: 100.00%
85	221At 2.3 M β-: 100.00%	222At 54 S β-: 100.00%	223At 50 S β-: 100.00%	224At 1.3 M β-: 100.00%	225At >300 NS β-: 100.00%	226At >300 NS β-: 100.00%	227At >300 NS β-: 100.00% β-n	228At >300 NS β-: 100.00%	229At >300 NS β-: 100.00% β-n
84	220Po >300 NS β-: 100.00%	221Po 112 S β-: 100.00%	222Po 550 S β-: 100.00%	223Po >300 NS β-: 100.00%	224Po >300 NS β-: 100.00%	225Po >300 NS β-: 100.00%	226Po >300 NS β-: 100.00%	227Po >300 NS β-: 100.00%	
83	219Bi 22 S β-: 100.00%	220Bi >300 NS β-: 100.00%	221Bi >300 NS β-: 100.00% β-n	222Bi >300 NS β-: 100.00%	223Bi >300 NS β-: 100.00% β-n	224Bi >300 NS β-: 100.00% β-n			

Choosing the FRS settings proved to be very challenging:

- **Challenging ion–β–γ correlations**
  - ⟶ first experiment with β decay measurement as the primary goal!
- **Long half-lives (~min)**
  - ⟶ challenging ion–β correlations in the DSSSDs
- **Little known**
  - ⟶ difficulty in providing a test of the correlation method

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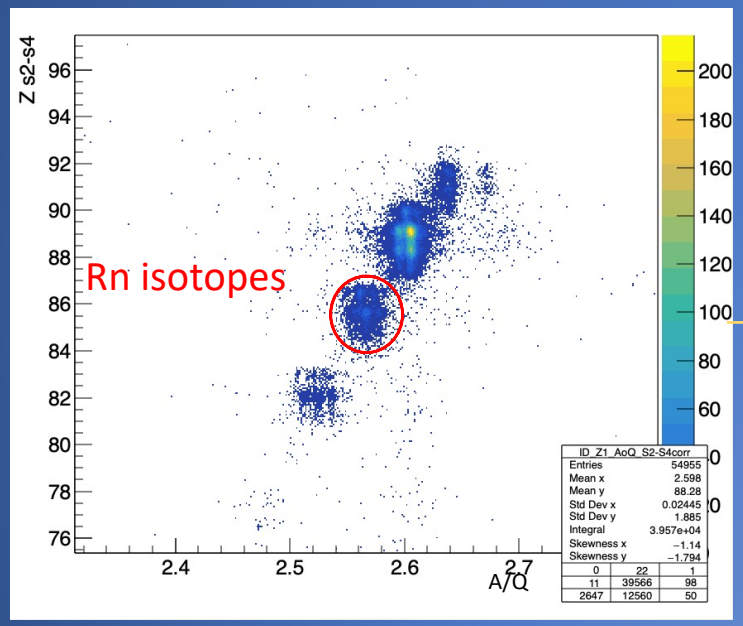
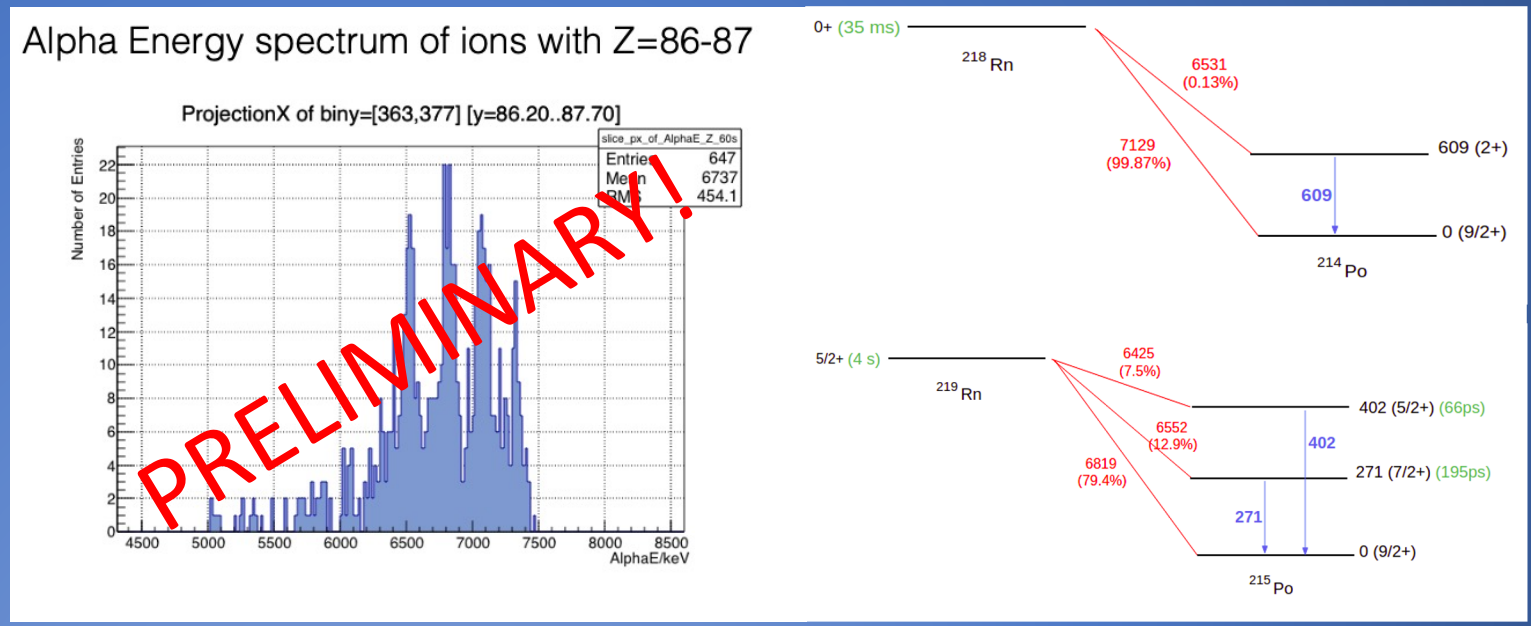
Preliminary results: alpha decay of ^{218,219}Rn

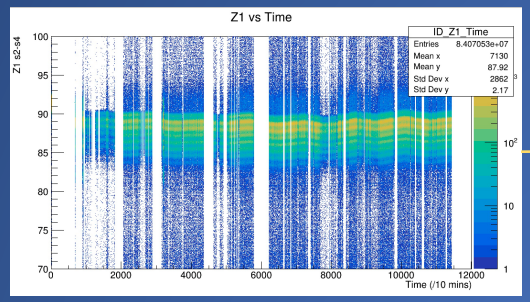
- ^{218,219}Rn to prove correct implantation and correlations
- First time the DESPEC setup was used to measure alpha decay!
- We can provide a validation of pre-existing measurements

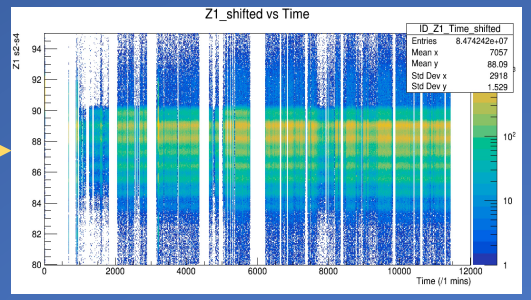




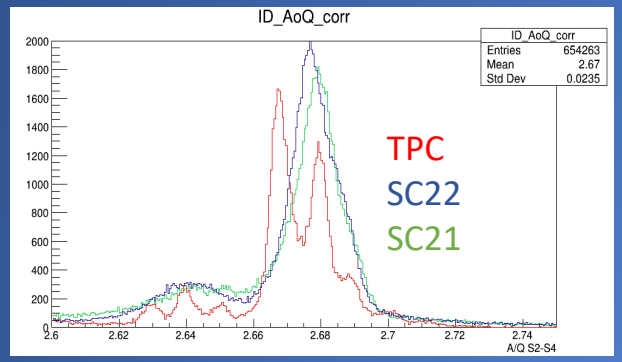
Courtesy of N. Hubbard, H.M. Albers

FRS analysis: ion identification improvement

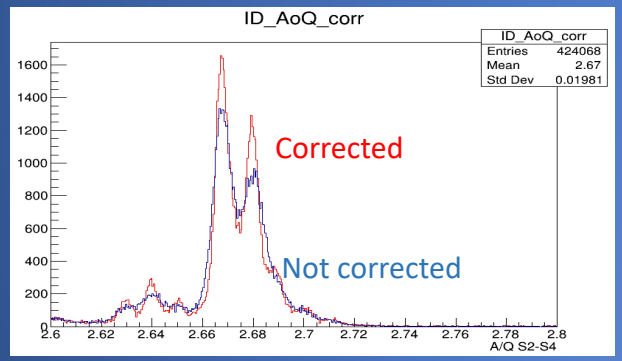




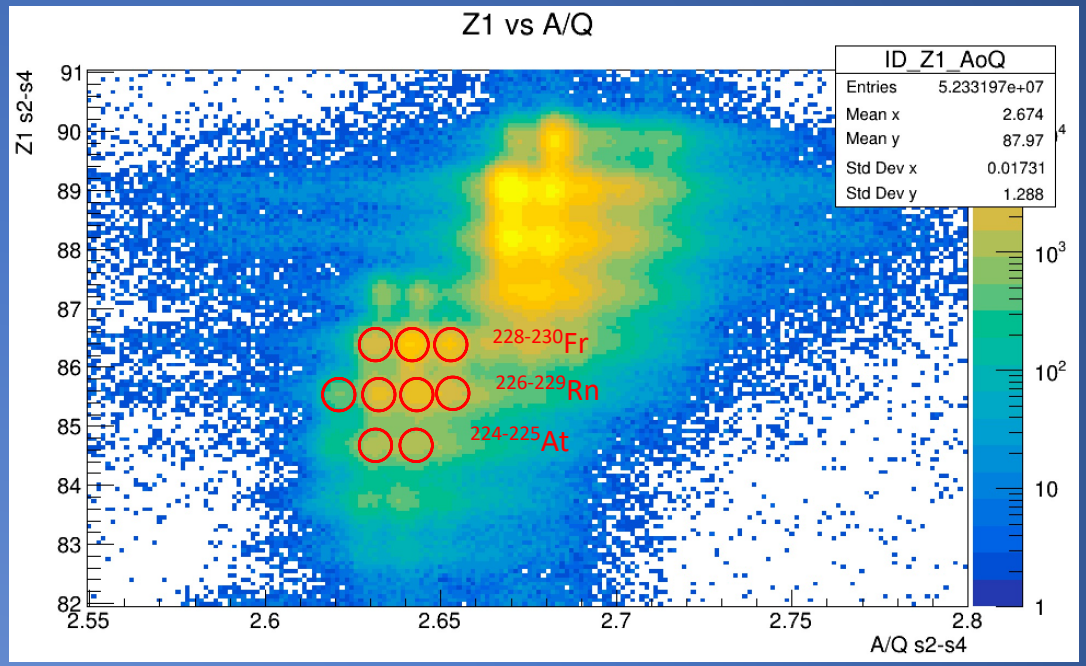
Z drift correction



Resolution comparison for A/Q



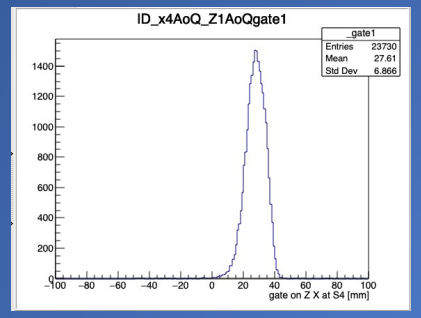
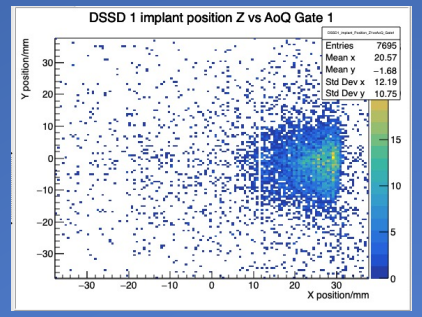
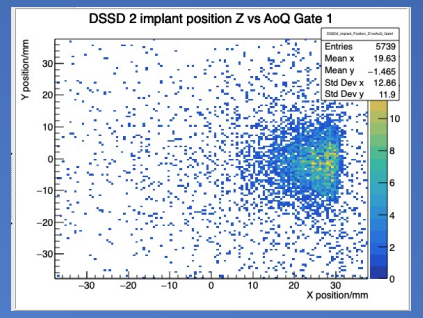
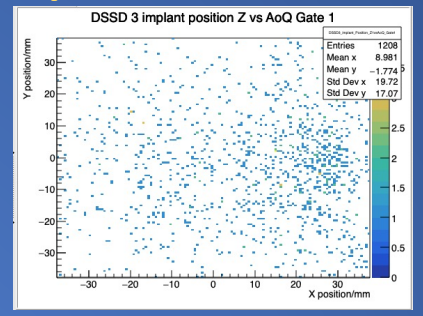
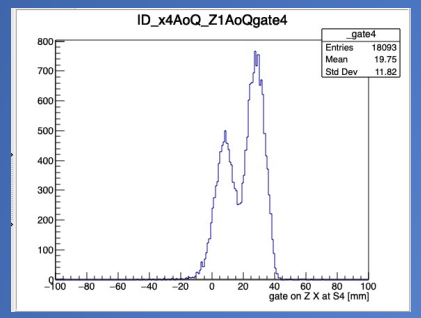
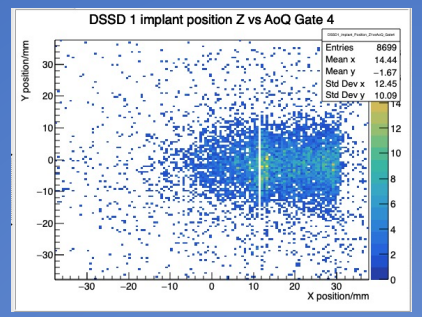
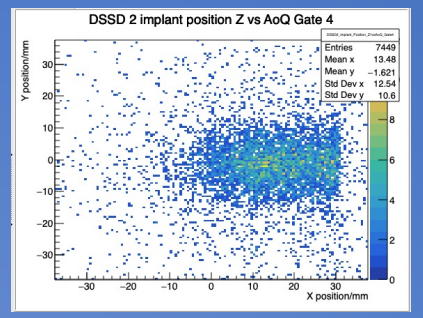
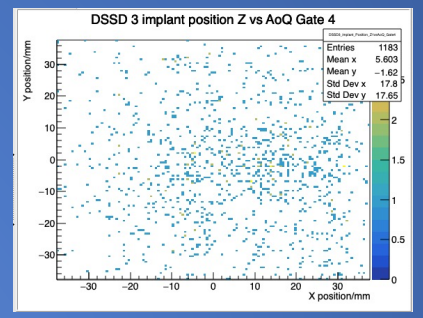
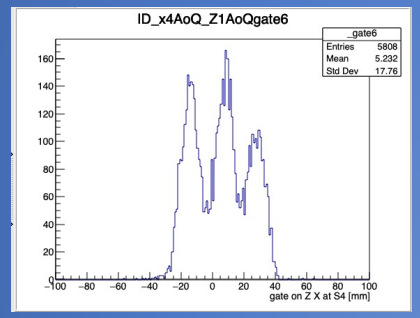
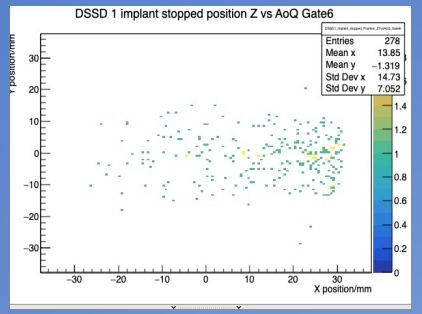
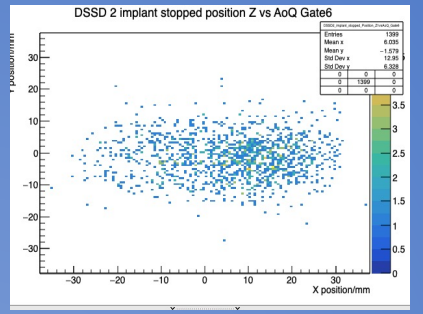
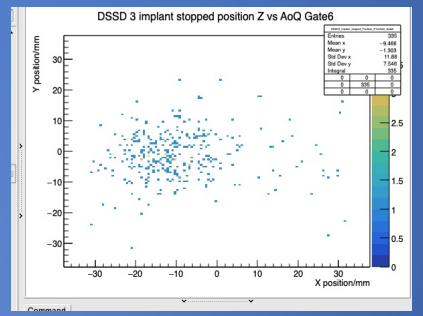
Angle correction for position at the final focal plane



Preliminary Particle IDentification plot: starting point for ion-beta correlations

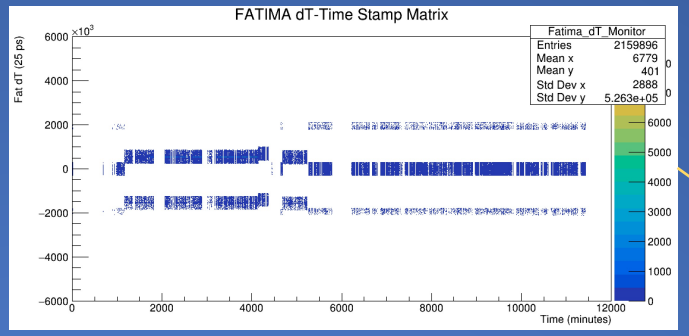
Implantation position in AIDA

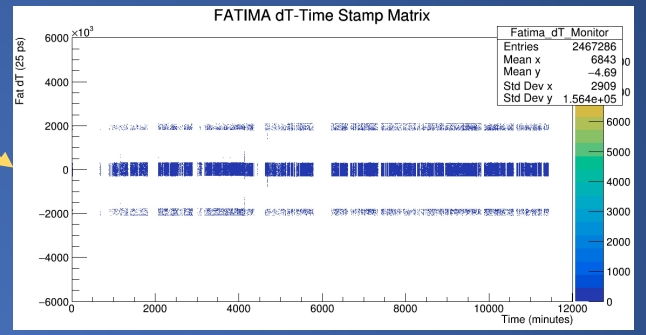
Implantation profile for ions of interest and correlation with position @ S4

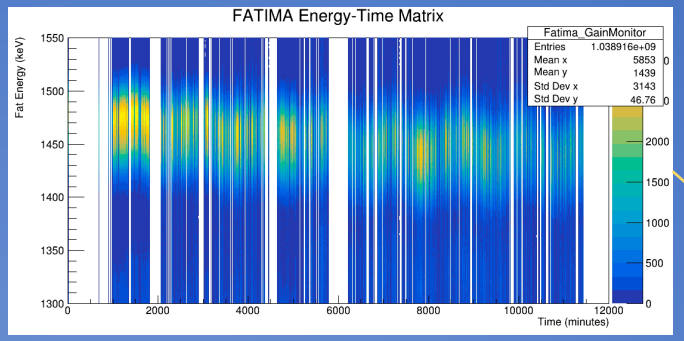
	X position in S4	X position in AIDA1	X position in AIDA2	X position in AIDA3
Rn				
Fr				
At				

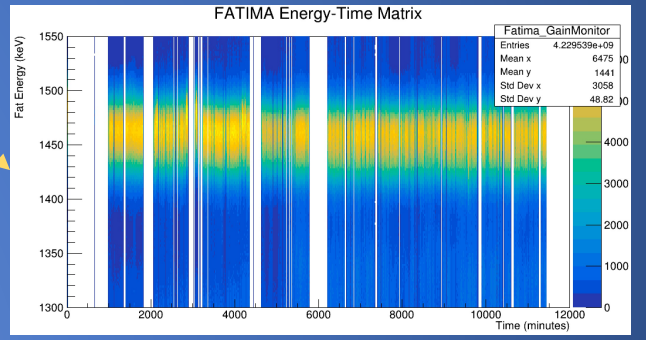
On-going analysis

- Fragment Separator:
  - TOF calibration
  - Position calibration
- DSSSDs:
  - Energy calibration
  - Implementation of ion-beta correlation codes
- Plastic scintillator:
  - Disentanglement of beta and ion signal
  - Position sensitivity
- Gamma-ray detectors (HPGe and $LaBr_3(Ce)$):
  - Time alignment
  - Gain matching
  - Absolute efficiency calculations









Next step: ion–β–γ–γ correlations!

Conclusions

The project aims at performing an experimental study of octupole shapes in heavy actinide nuclei, in the A~225 Po-Fr region.

The experiment was performed at GSI in spring 2021. This talk was focused on:

- Aims of the experiment
- Experimental techniques
- Production of the ions of interest
- The GSI facility: FRS and the DESPEC decay station
- Ion-β-γ-γ correlation method
- Initial stages of analysis

Thank you for your attention!

And thanks to the COLLABORATORS!

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