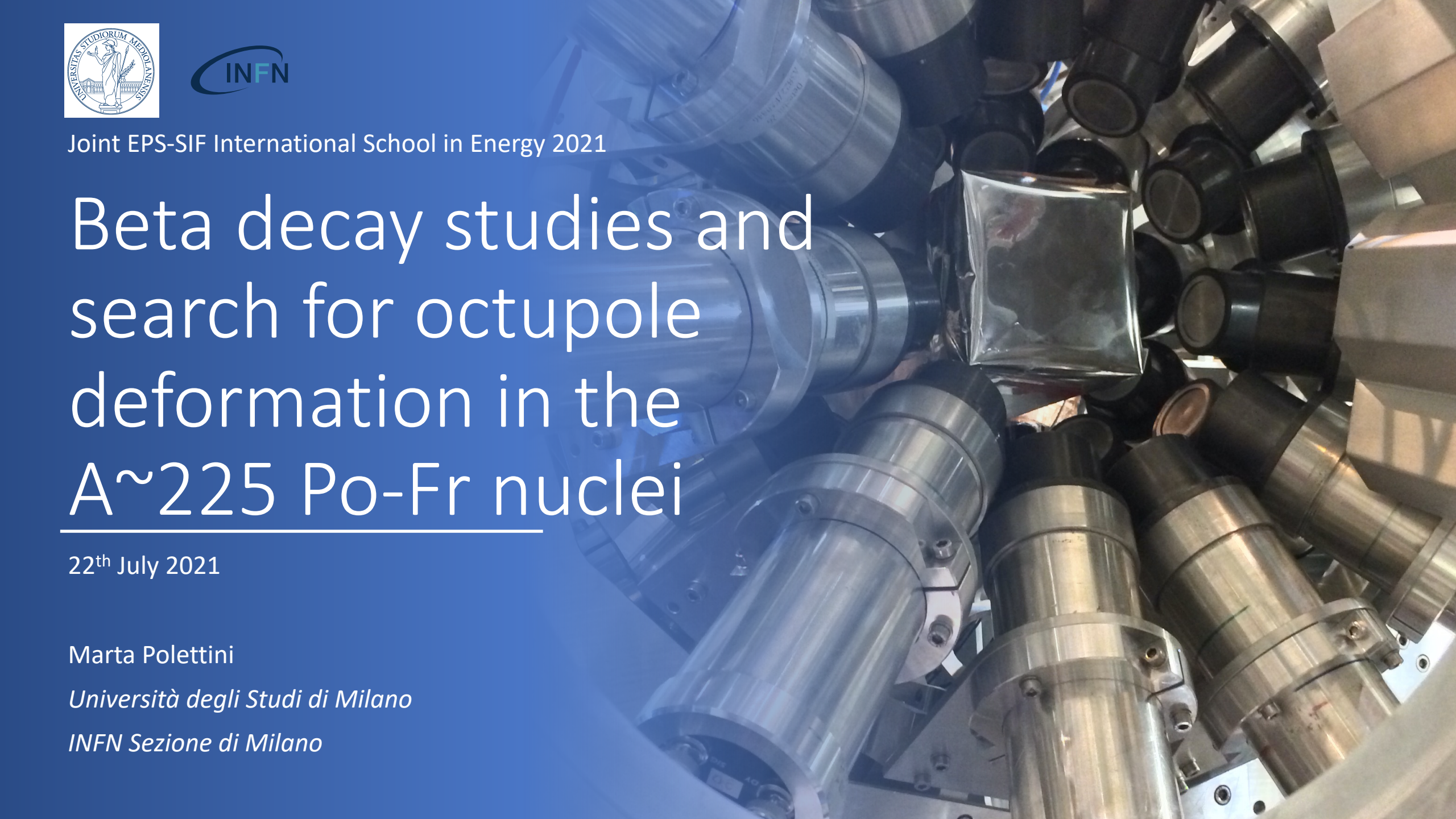


Joint EPS-SIF International School in Energy 2021

Beta decay studies and search for octupole deformation in the A~225 Po-Fr nuclei

22th July 2021

Marta Polettini

Università degli Studi di Milano

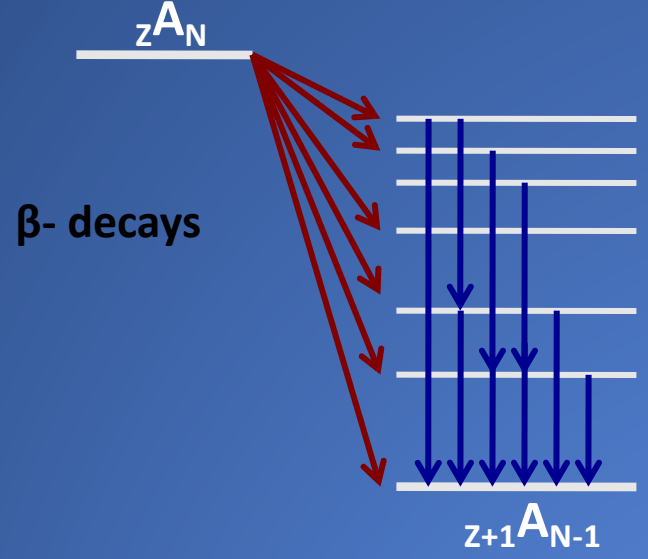
INFN Sezione di Milano

Outline

- Beta decay
- Octupole deformation
- Case study: 220<A<230 Po-Fr nuclei
- GSI facility:
  - In-flight fragmentation reactions
  - The FRS Fragment Separator
  - The DESPEC decay station
- Preliminary results
- Conclusions and outlook

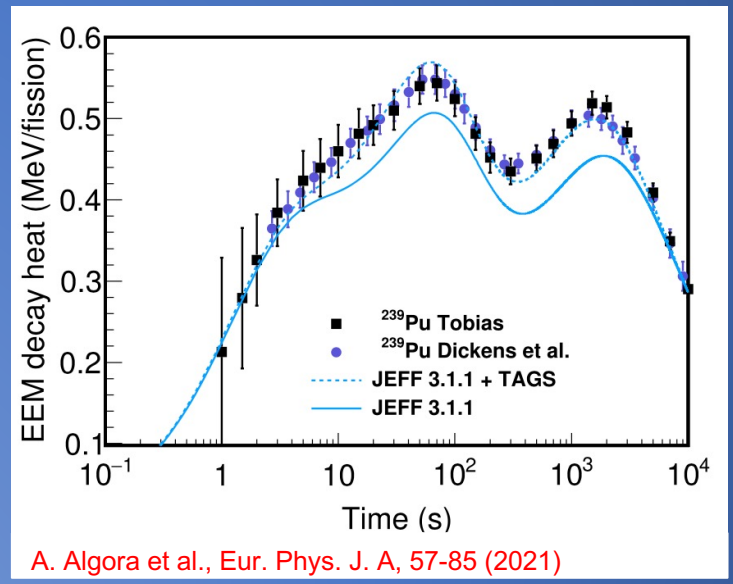
This project is part of the experimental program of the HISPEC/DESPEC collaboration

Quantities that can be extracted in a β decay experiment



- γ transitions
  → Possible existence of many decaying states
- γ–γ coincidences → level schemes
- Relative intensities I_β → log*ft*

- Estimation and control of the heat emitted by the decay of fission products → key role in the safe operation of reactors
- 8% of the total energy generated during the fission process is related to the energy released in the natural decay of fission products (*decay heat*)
- These calculations require extensive libraries of cross sections, fission yields, and decay data
- These simulations are also used to determine the anti-neutrino spectrum associated to the β decay of fission products

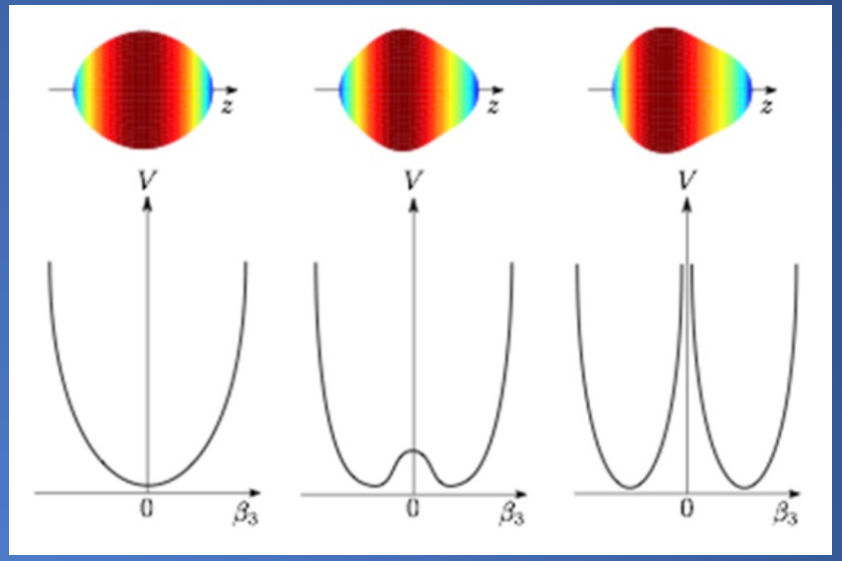


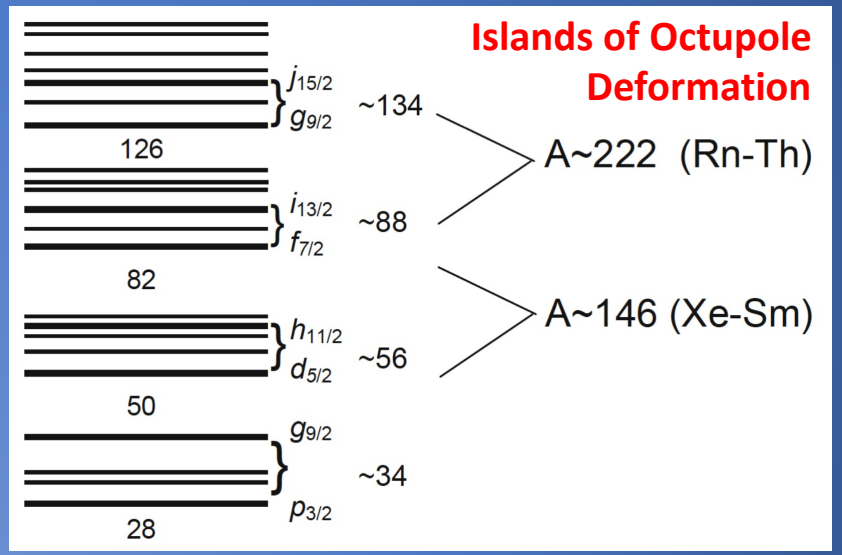
A. Algora et al., Eur. Phys. J. A, 57-85 (2021)

Octupolar deformation

Octupole correlations: $\beta_{30} \neq 0$

- These correlations are the result of the long-range, **octupole-octupole interaction** between nucleons occupying pairs of orbitals which differ by 3 units in both orbital- and total-angular momentum.
- Evidence for static octupole deformation are detected when orbitals which differ by **Δj, Δl =3** approach the Fermi level for both protons and neutrons.





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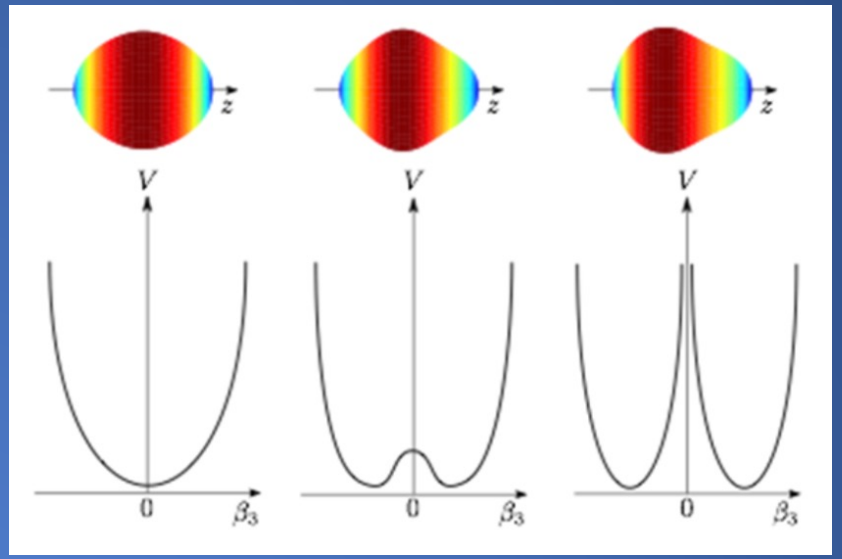
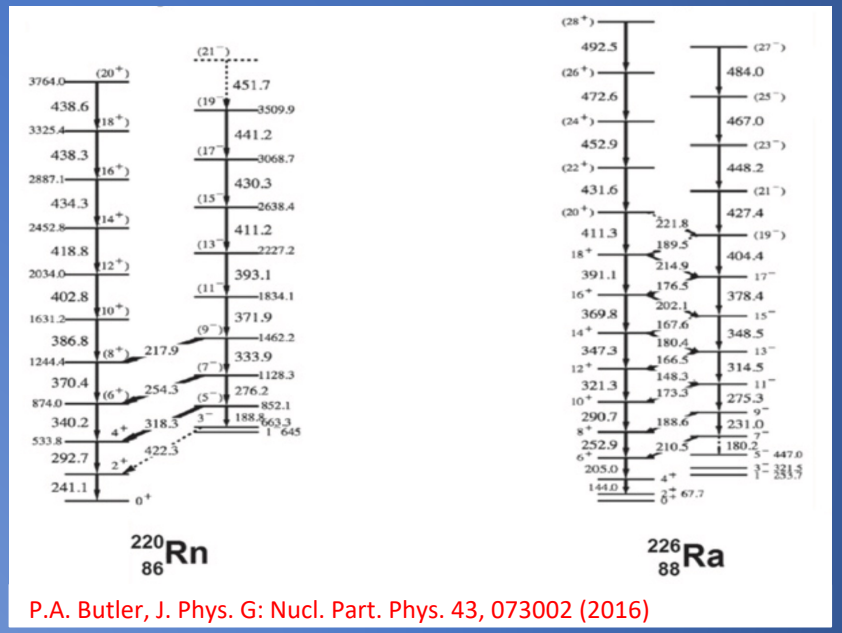
Experimental evidences:

- The **excitation energy spectrum**:
  - Alternating negative and positive parity states
  - Energies of the lowest-lying negative-parity states are higher than those of the positive-parity ones
- Large **E3** transition probabilities
- Enhanced **E1** transition



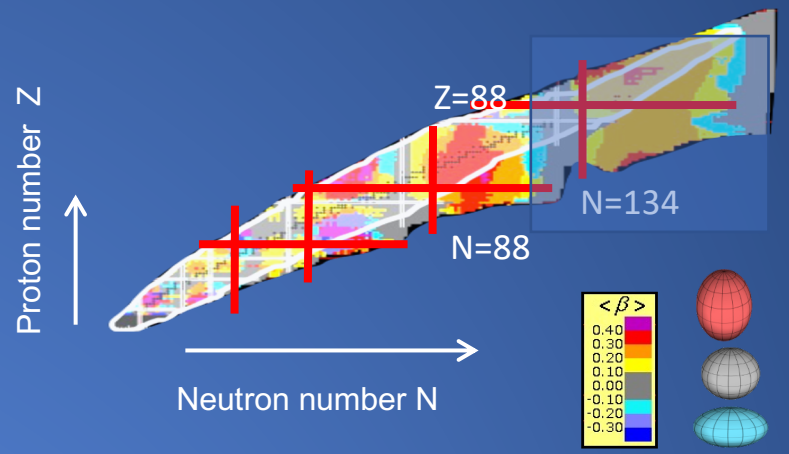


P.A. Butler, J. Phys. G: Nucl. Part. Phys. 43, 073002 (2016)

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.

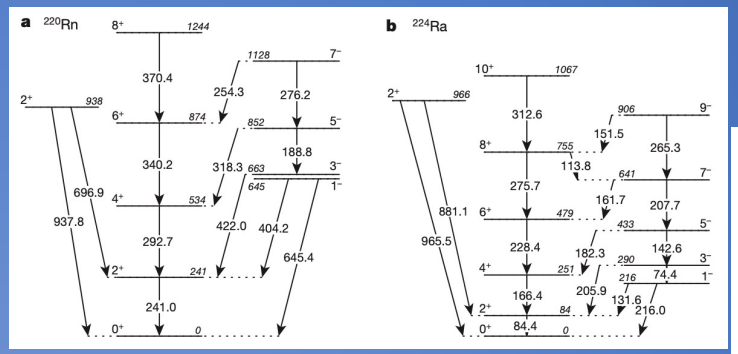
- In general, there is a dearth of experimental information on the structure of heavy nuclei in the 220<A<230 transitional region between the Z=82 closed-shell regime and the south-east corner of the A∼222 IOD.

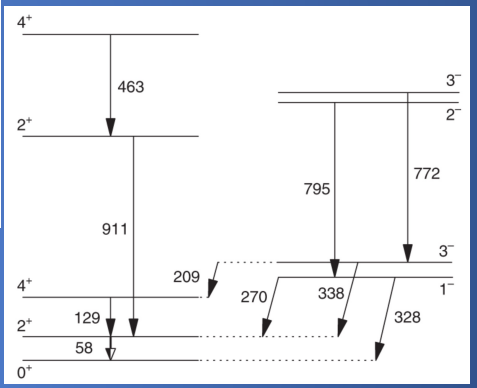


- Direct measurements of octupole correlations were performed recently. For example:

  - **^{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**

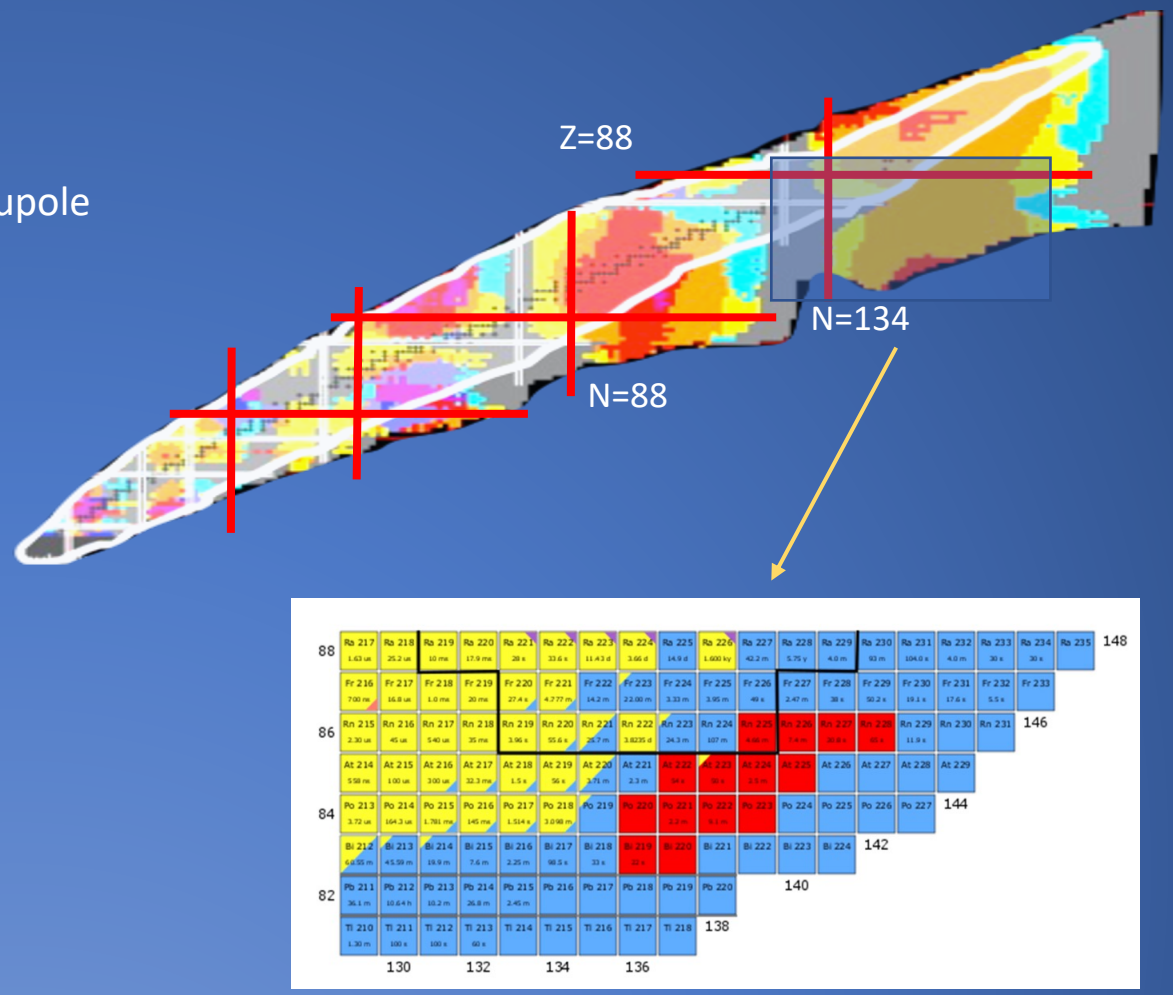
  Study the octupole degree of freedom and quadrupole-octupole correlations at the far end of the IOD

- **Test of nuclear models for r process**

  Obtain new beta-decay information beyond N=126

- **Shape isomers in ^{220,222}Po**

  Prove the existence of super-deformed bands at low excitation energies



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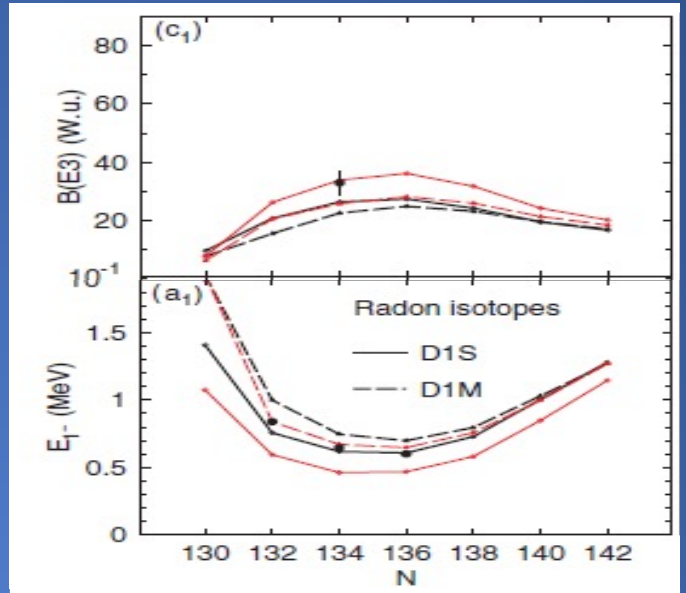
238U @ 1AGeV + Be (1624 mg/cm²) Setting 225At				
Parent Nucleus	**$t_{1/2}$**	**energy 1st excited state in daughter**	**half-life 1st exc state in daughter**	**ppd @ AIDA**
228Rn	65 s	unknown	unknown	2,80E+04
227Rn	20.8 s	2.74 keV	unknown	1,29E+05
226Rn	7.4 m	unknown	unknown	8,85E+04
225Rn	4.66 m	28.55 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

Experimental techniques

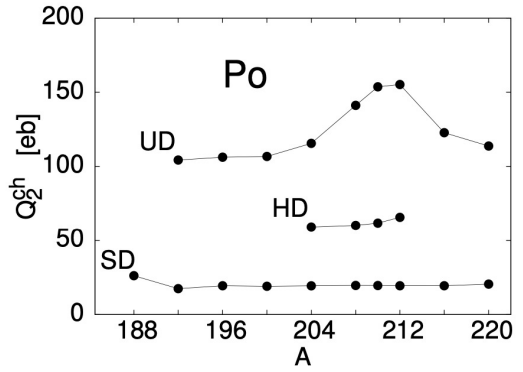
- **Octupole deformation around A~225**
  - Beta delayed and fast-timing spectroscopy:
    - Measure reduced transition strengths
    - Locate low-lying 1^- and 3^- states
    - Determine excitation energy and B(E2) of first 2^+ states in even-even nuclei

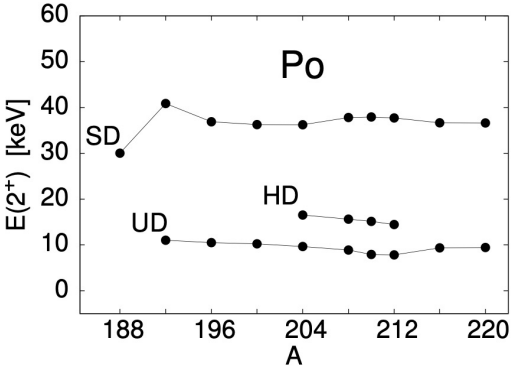
- **Test of nuclear models for r process**
  - Measurement of ground state half-lives
  - Determination of possible competing α branches
  - Beta-delayed gamma spectroscopy to:
    - Investigate low-lying structure in daughters
    - Determine apparent I_β and logft

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



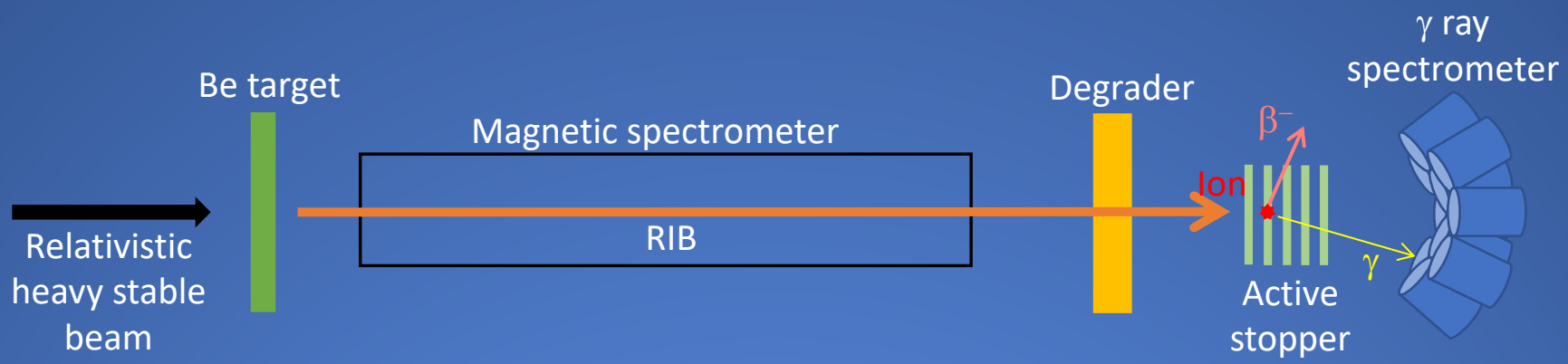
L. M. Robledo and P. A. Butler, Phys. Rev. C **88**, 051302(R) (2013)





B. Nerlo-Pomorska et al., A. Phys. Pol. B **47**, 943 (2016)

In flight fragmentation



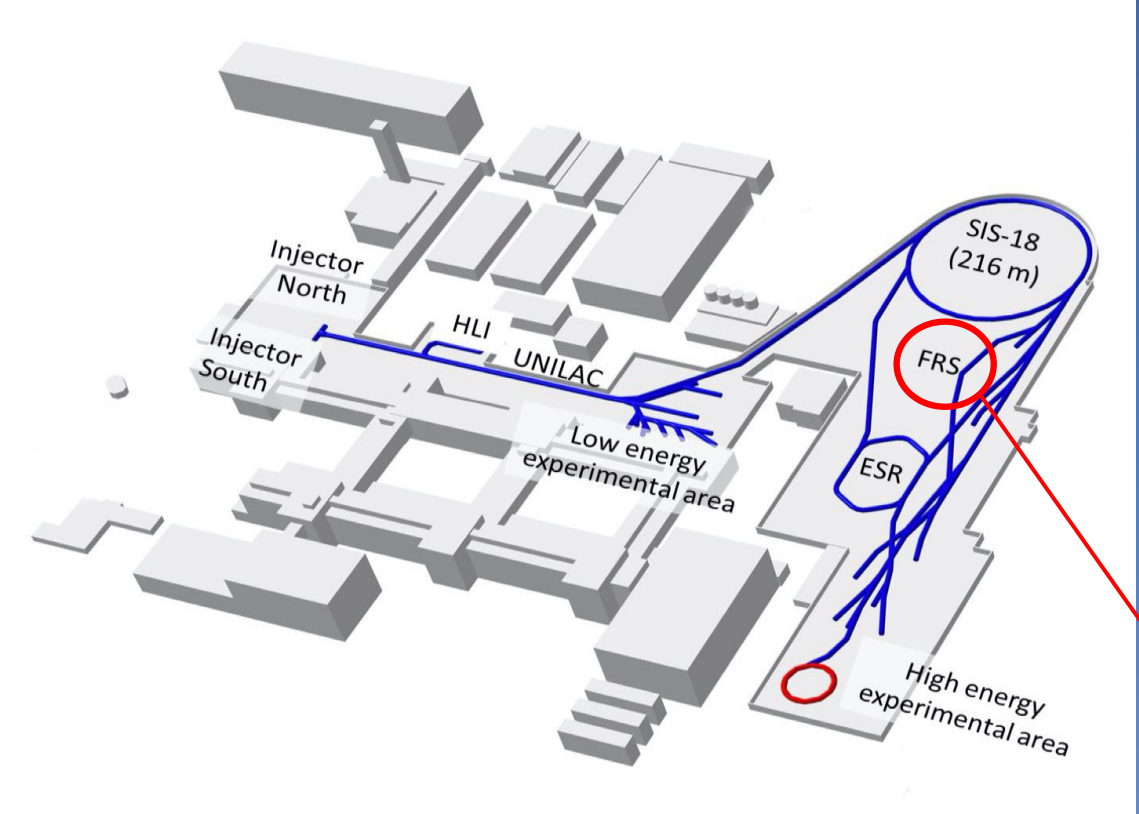
Relativistic fragmentation/fission of heavy nuclei on thin targets:

- > 50 MeV/u ⟶ production of cocktail beams of many nuclei
- Use of spectrometers to transport/separate nuclei of interest ⟶ Relatively long decay paths Δt > 150-300 ns
- Nuclei are brought to rest in final focal plane and let decay

✓ cocktail beam: many nuclei at once
✓ both short and long-living species
✓ get information already with few ions

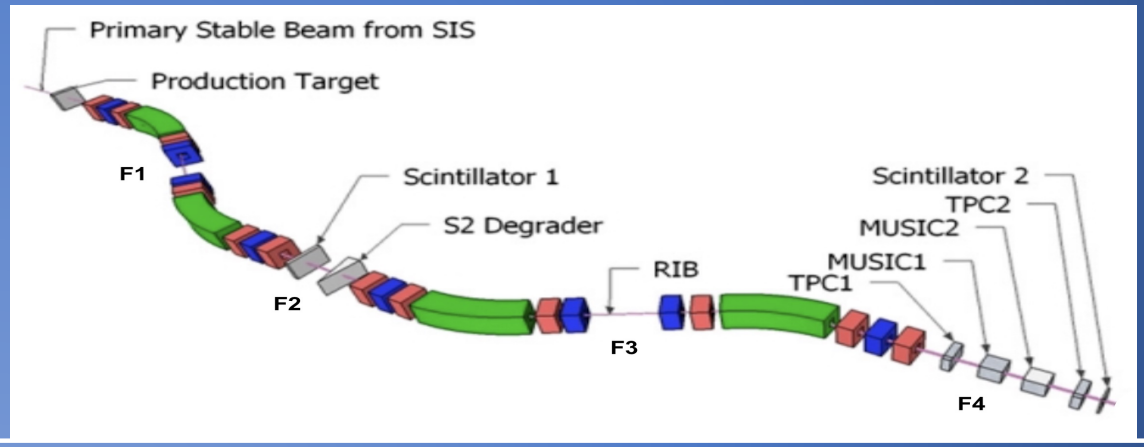
X Low cross sections
X Limitation on rate to distinguish contribution from each species

GSI facility and FRS



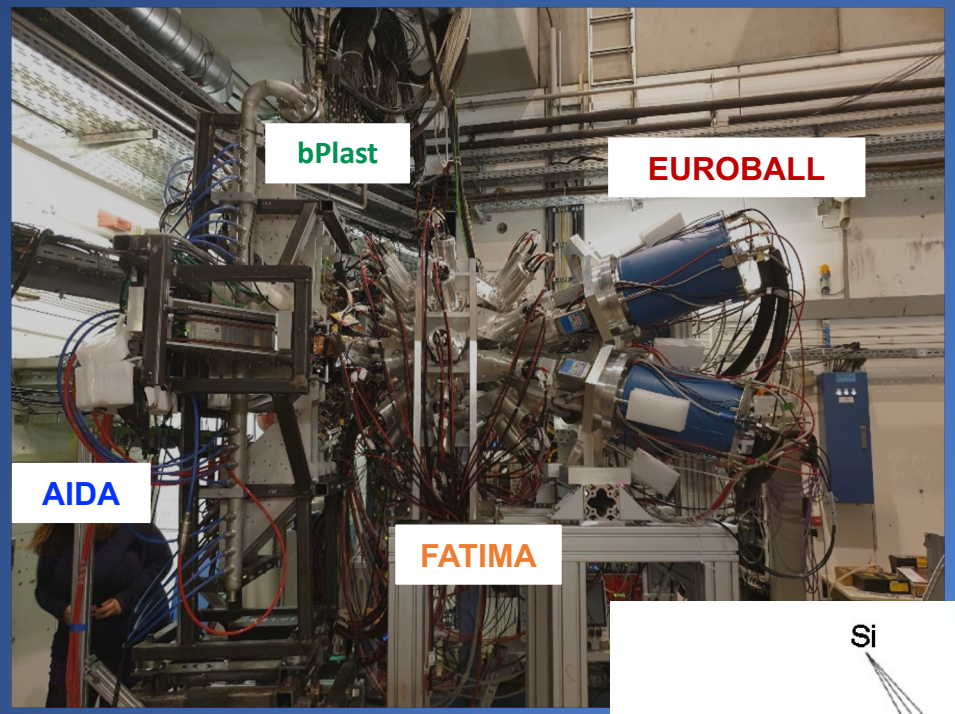
- Acceleration of heavy ion beams with:
  - **UNILAC** (linear accelerator)
  - **SIS18** (synchrotron)
- Selection and transport using: $\mathbf{B\rho - \Delta E - B\rho}$ method

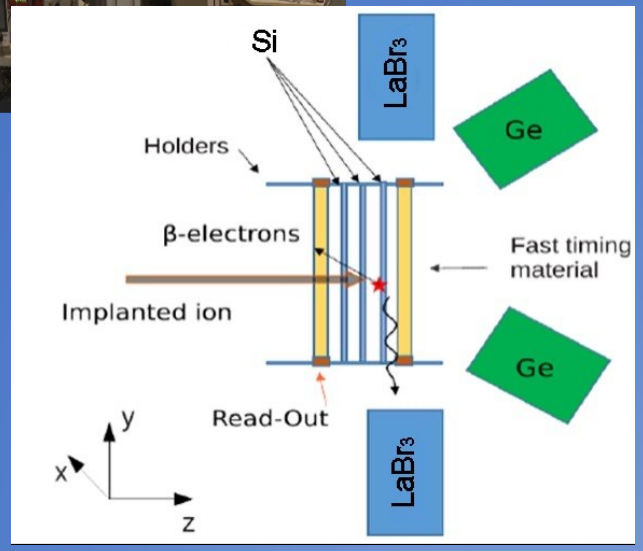
  $\boldsymbol{ToF - B\rho - \Delta E}$ method
- Identification via the measurement of:
  - The ratio of **mass number over ionic charge** A/Q
  - The **atomic number Z** or the **X position** in the focal planes



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

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





The setup is composed of:

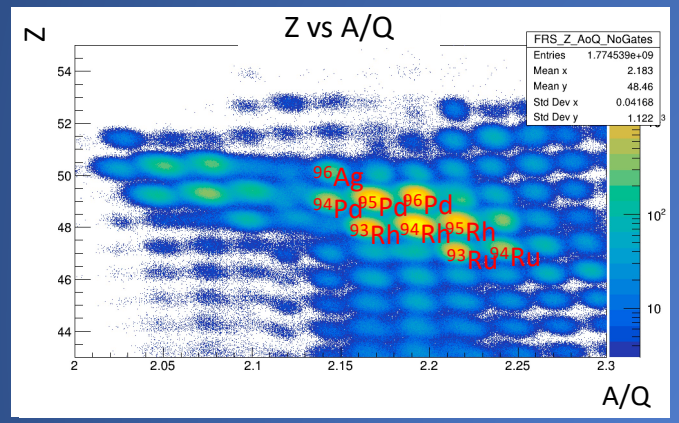
- **AIDA**: a stack of 3 DSSSD detectors
- **bPlast**: fast plastic detector
- **Euroball**: HPGe array for gamma detection – 4 7-fold clusters (efficiency 2% at 1 MeV)
- **FATIMA**: array of 36 $LaBr_3$(Ce) detectors (efficiency 2.9% at 1 MeV)

Ion → Isomers

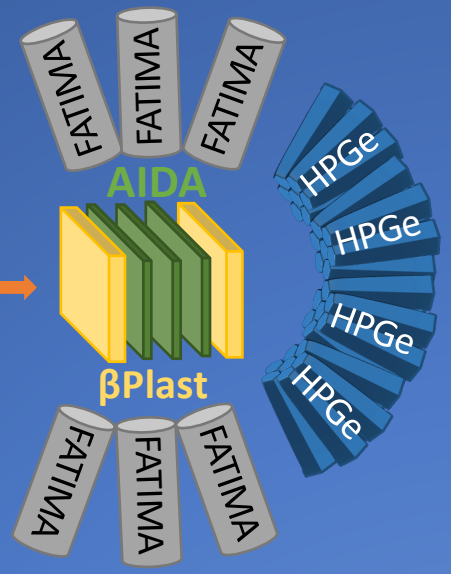
Ion → β decay → γ rays

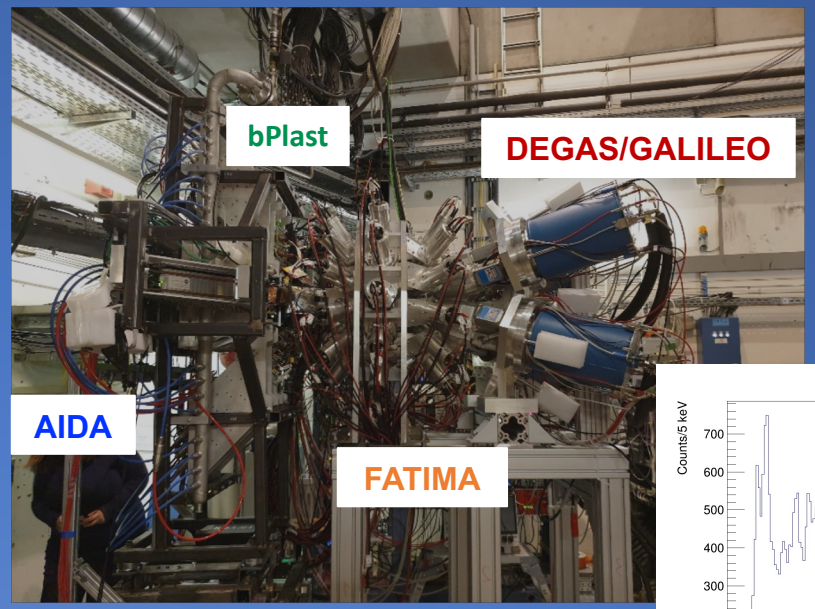
FRS+DESPEC at GSI-FAIR: the β decay station

Ion identification

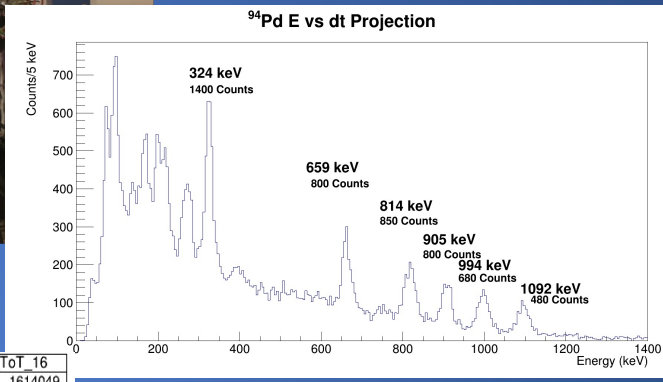


Fragments from FRS

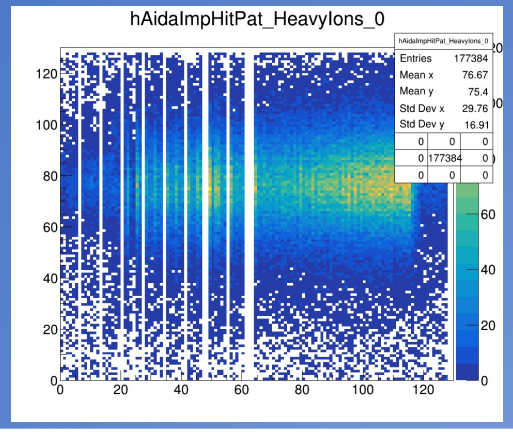


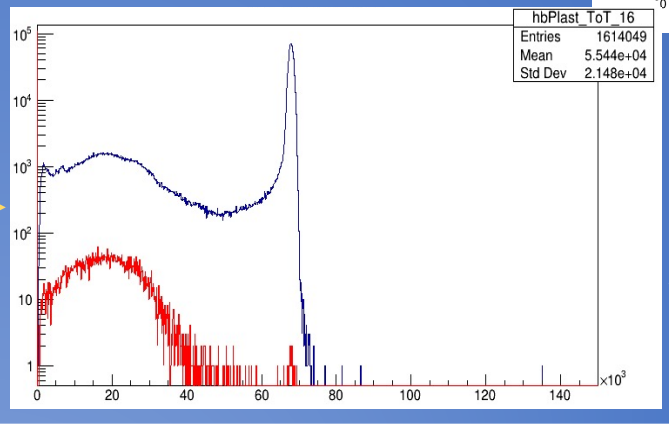


Level scheme and levels' lifetime



Ion implantation

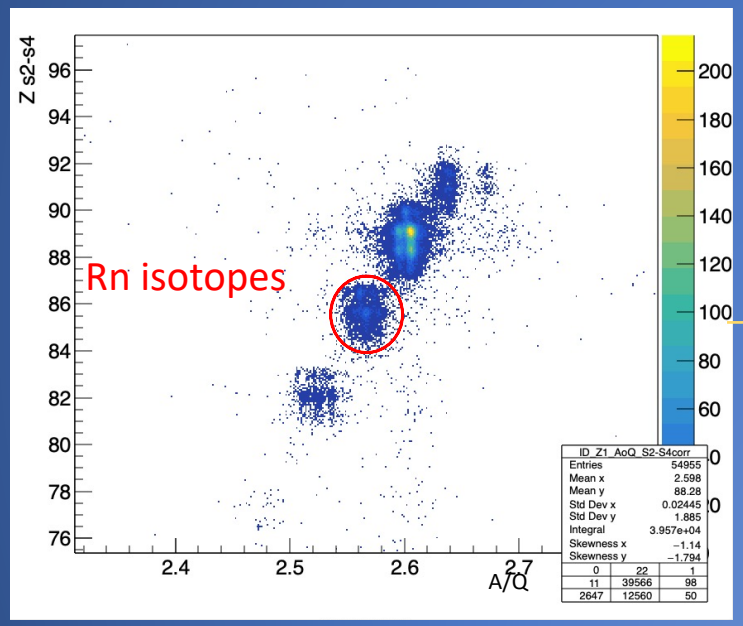


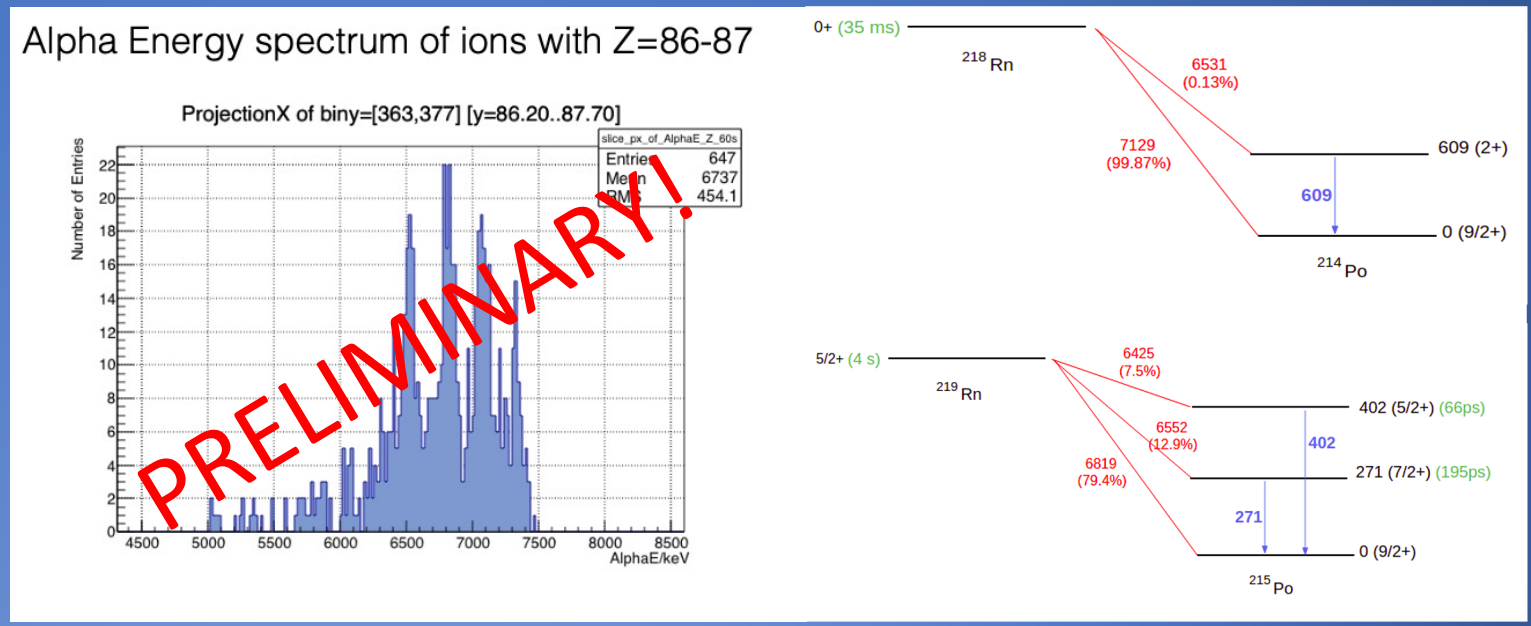


β decay

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

- ^{218,219}Rn to prove correct implantation and correlations
- First time our setup was used to measure alpha decay
- First time this alpha decay is studied with this method!





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

Thank you for your attention!