Formation of the Rare Earth Peak: investigating neutron-rich nuclei at RIKEN RIBF

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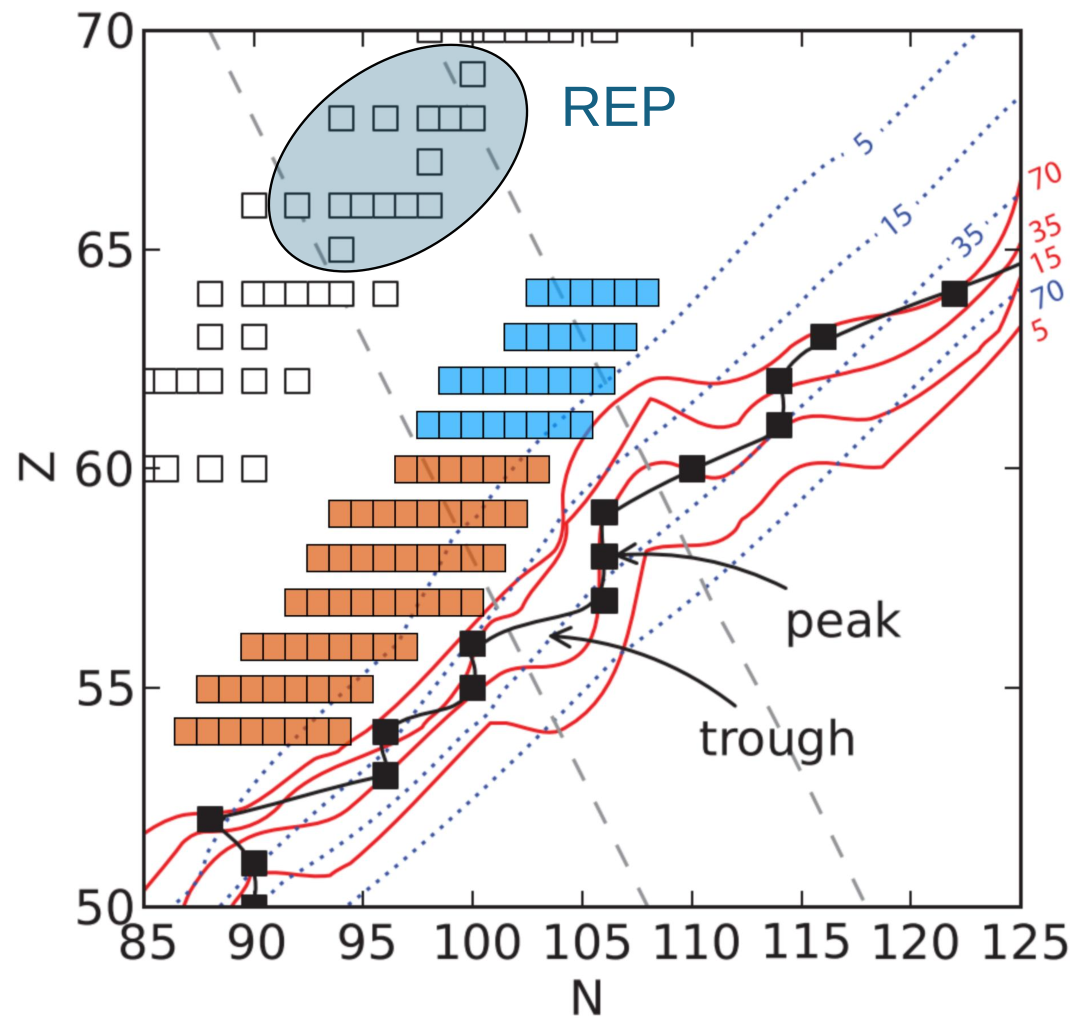
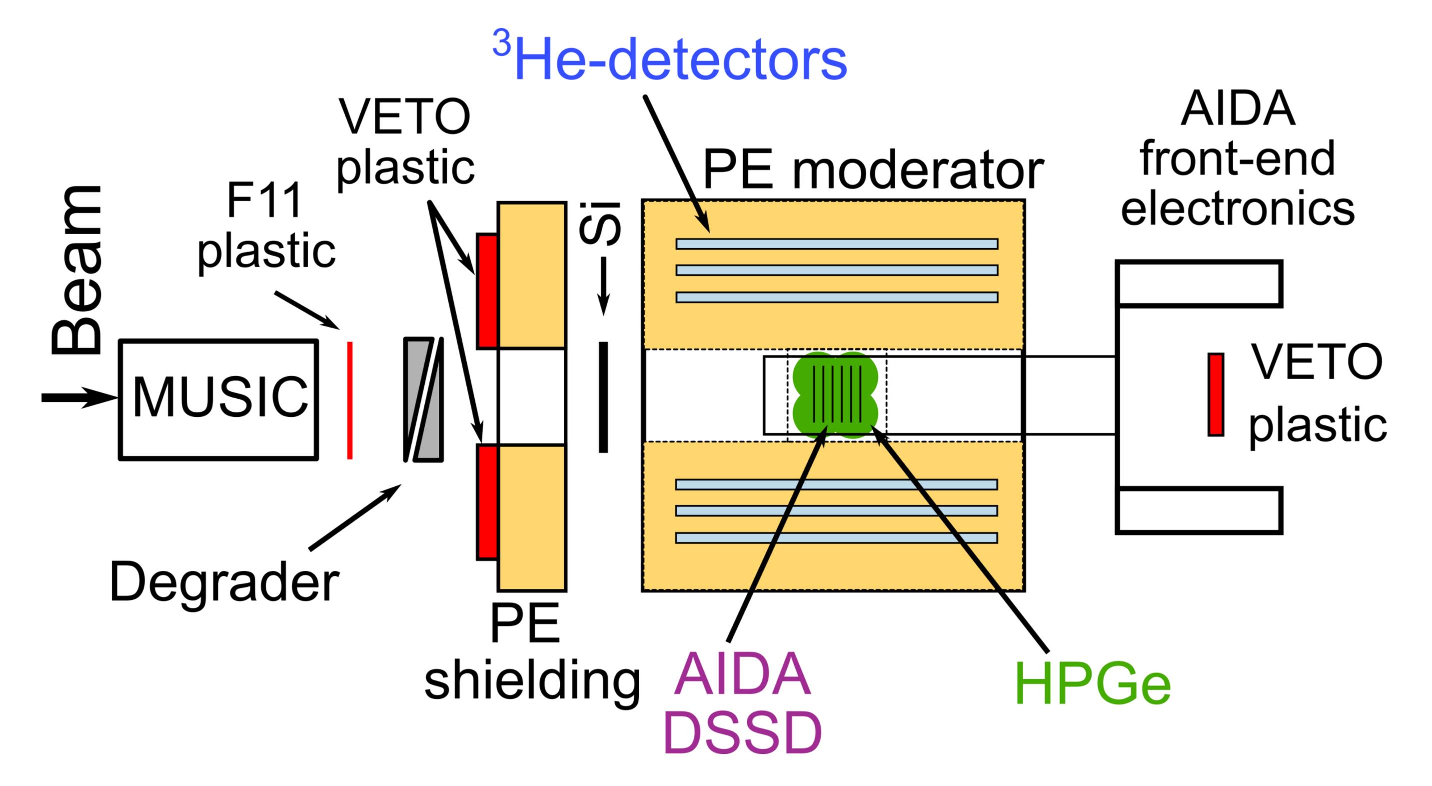
Motivation

- The r-process: rapid **neutron capture and β-decay**.
- Rare Earth Peak forms during **freeze-out**, mainly influenced by nearby neutron-rich isotopes [1,2].
- Theoretical models provide **high uncertainty predictions** due to the lack of experimental data.
- Improved nuclear decay data can help to **constrain the astrophysical conditions** of the r-process.



RIBF148 – published

RIBF148 – data analysis is ongoing



Experimental Setup

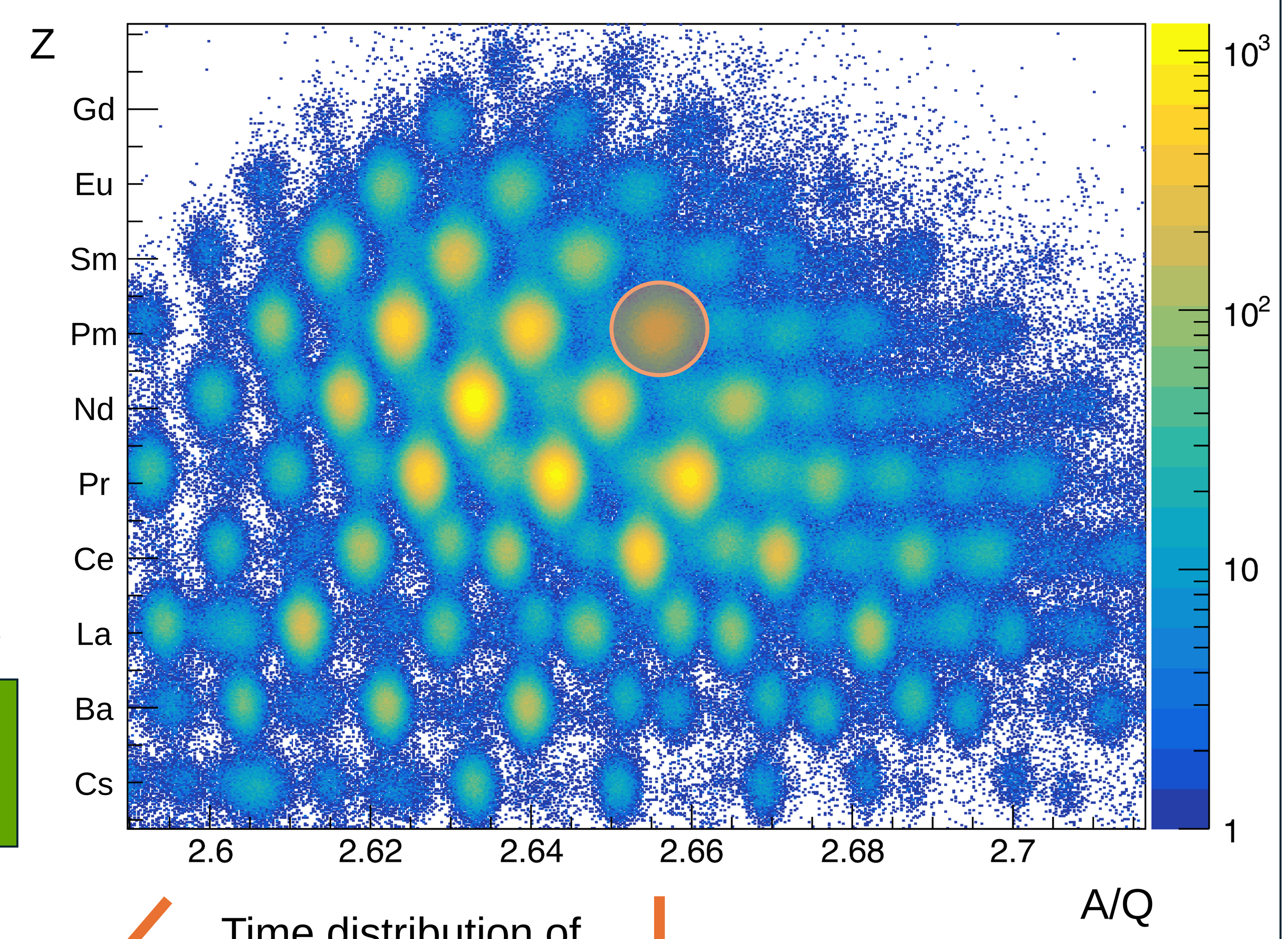
- ^{238}U primary beam ($I = 60$ pnA, $E_{pr} = 345$ MeV/nucleon) hits a 5 mm thick ^{9}Be target, causing **in-flight fission**.
- **Cocktail beam** is in-flight separated by BigRIPS and implanted into AIDA-BRIKEN detector systems [3]:
  - 6 DSSD: implantation, β-events
  - 2 clover HPGe detectors: γ-events
  - 140 ^{3}He filled proportional counters: neutron-events

^{3}He + n → ^{1}H + ^{3}H + 764 keV

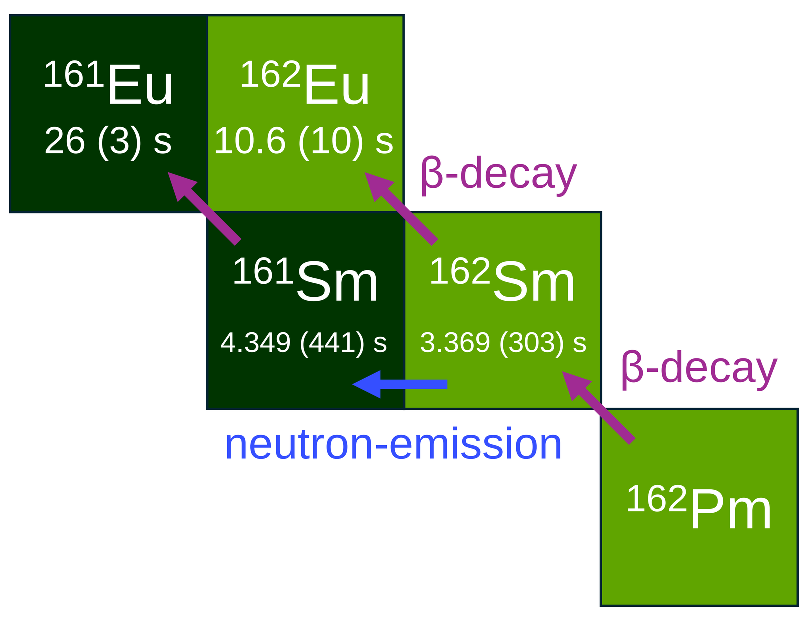
Identification

BigRIPS in-flight separation:

- energy loss → Z
- magnetic rigidity → A/Q
- time-of-flight → velocity

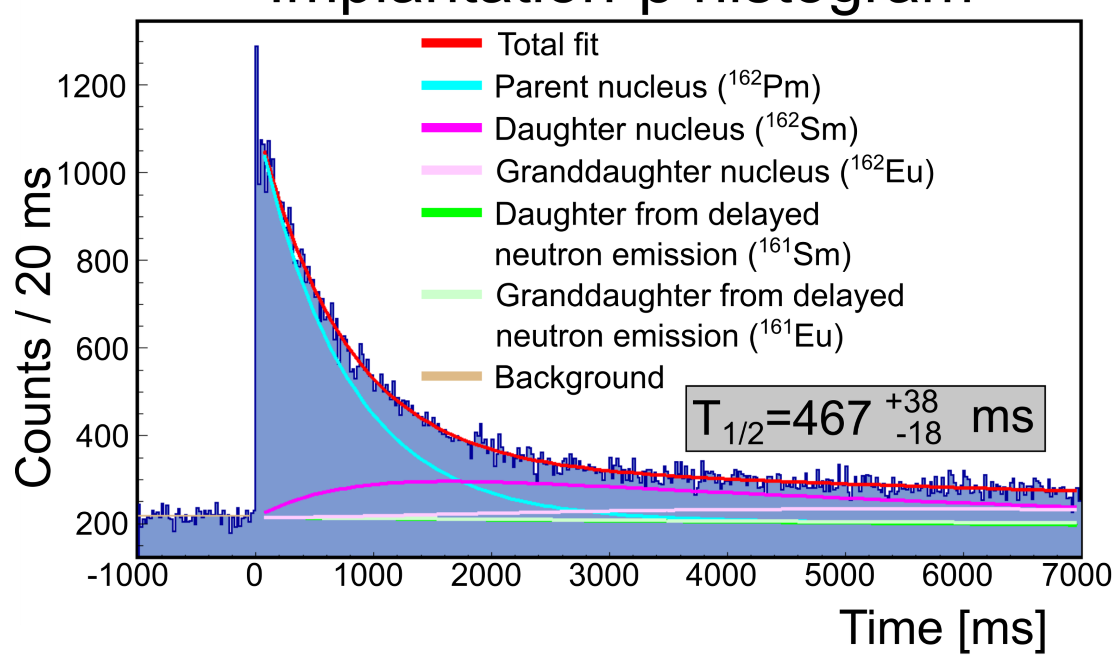


Decay chains:

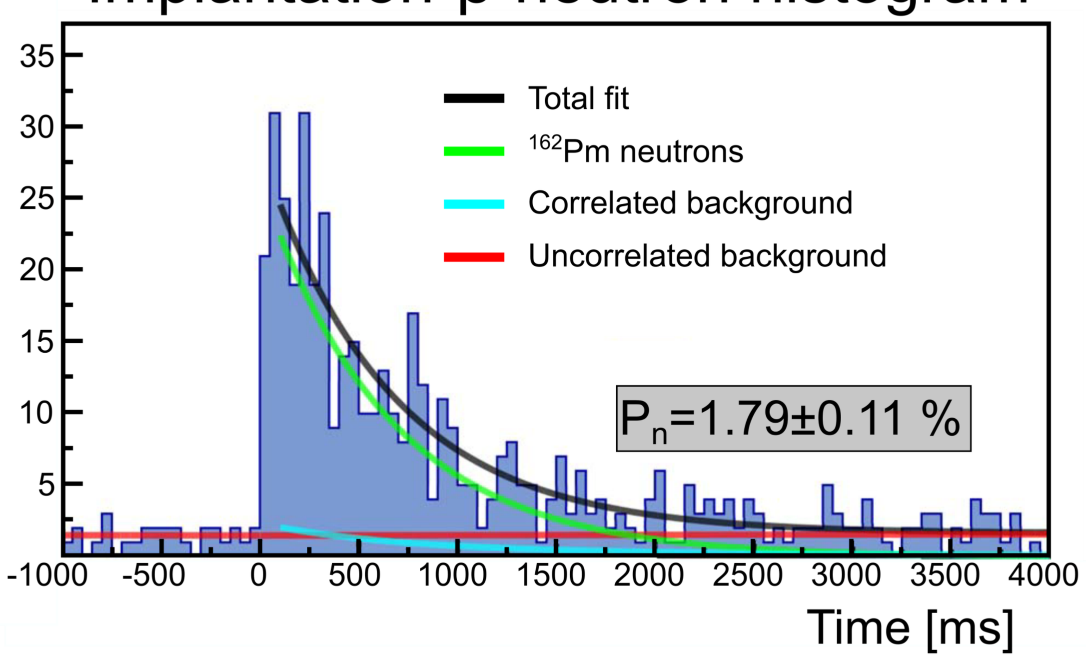


Time distribution of gated events (^{162}Pm)

Implantation-β histogram



Implantation-β-neutron histogram

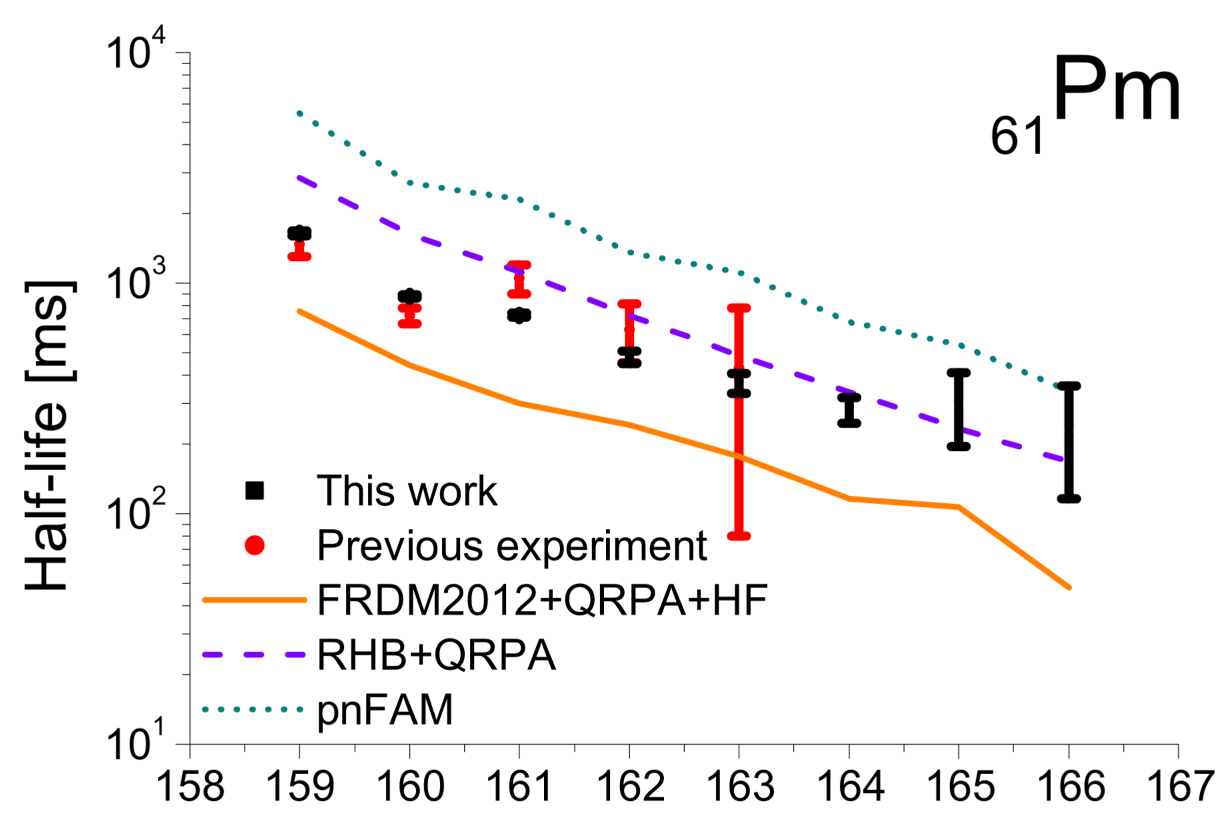


Analysis

- Neutron-rich isotopes decay through **β-decay chains**.
- β-delayed neutron emission causes **branching**.
- Implantation-β-neutron time distributions are fitted with an exponential to determine **β-delayed neutron emission probabilities**.
- Bateman formula with linear background fits the implantation-β time histograms, yielding **half-lives**.

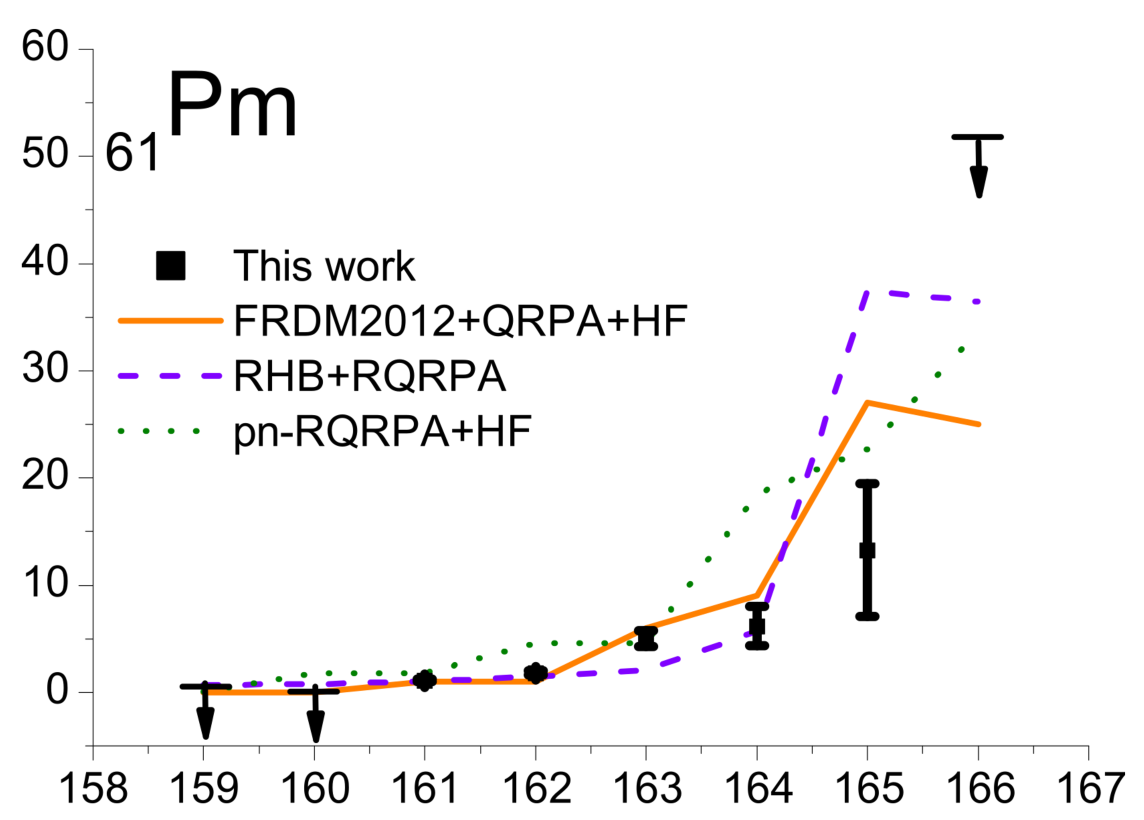
$$N_i(t) = \sum_{j=1}^{i} \frac{N_{10}\prod_{k=1}^{i-1}\lambda_k}{\prod_{k=1,\,k\neq j}^{i}(\lambda_k-\lambda_j)}\, e^{-\lambda_j t}\ ;\ A_{tot}(t) = \sum_{i=1}^{n}\lambda_i N_i(t)$$

- For some isotopes, half-lives are verified with implantation-β-γ correlation fits.



Summary

- The **β-decay properties** of 28 neutron rich ($^{159-166}$Pm, $^{161-168}$Sm, $^{165-170}$Eu, $^{167-172}$Gd) isotopes were measured [4].
- Nuclear reaction network calculations analyzed the importance of nuclear physics input.
- **Key isotopes** in peak formation were identified.
- A new measurement (NP2212-RIBF217) will determine the **beta-strength function** of the isotopes in this region.



Key references

[1] J.J. Cowan et al., Rev. of Mod. Phys. **93**, 015002 (2021)
[2] M.R. Mumpower, G.C. McLaughlin, PRC **85**, 045801 (2012)
[3] A. Tolosa-Delgado et al., NIM **925**, 133 (2019)
[4] G.G. Kiss et al., ApJ **936**, 107 (2022)

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