Beta-decay properties of neutron-rich lanthanides and the formation of the rare-earth peak

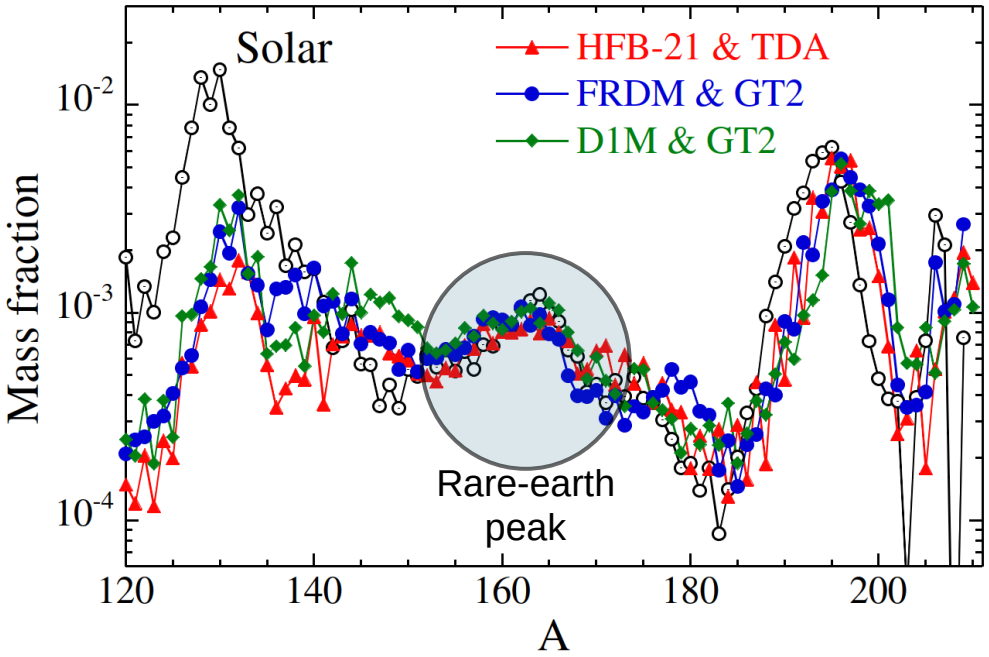
Sándor R. Kovács, G. G. Kiss, A. Vitéz-Sveiczer

and BRIKEN collaboration

Hirschegg 2025 - Nucleosynthesis of Heavy Elements: r-process

Formation of rare-earth peak

S. Goriely et al., PRL **111**, 242502 (2013)



Located far from closed shells

- Freeze-out phase
- Sensitive to nuclear physics input
- Tool to constrain late r-process conditions

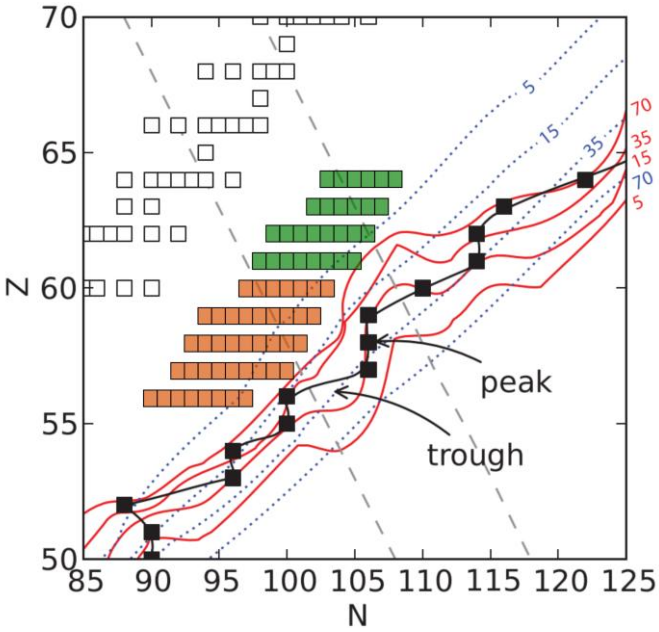
1. Double asymmetric fission fragment distribution

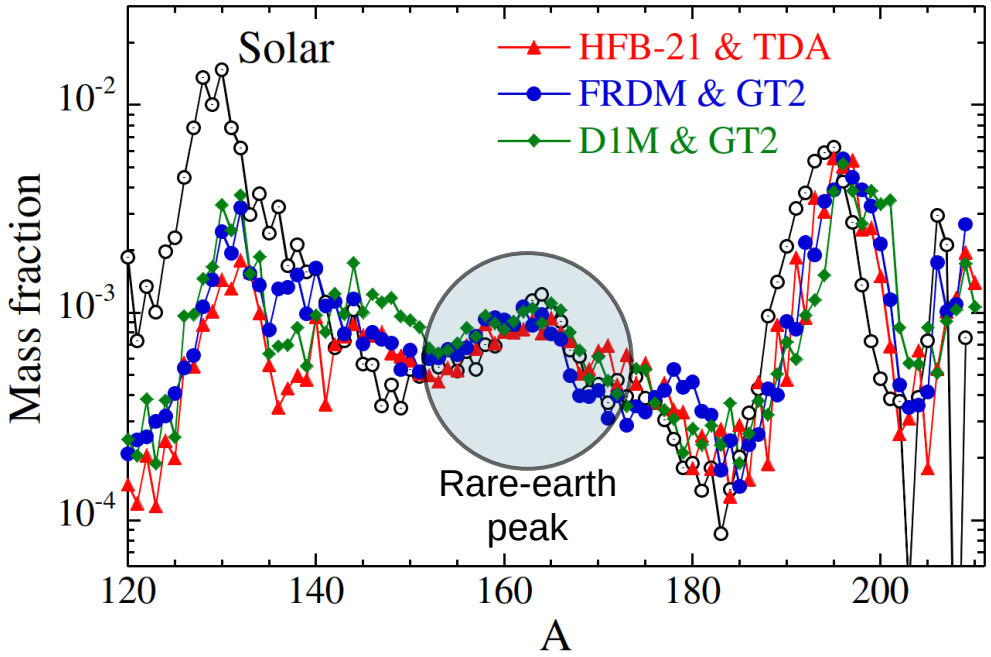
Formation of rare-earth peak

RIBF148 - published
RIBF148 - data analysis ongoing

M. R. Mumpower et al., PRC **85**, 045801 (2012)

S. Goriely et al., PRL **111**, 242502 (2013)





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2. Slower neutron capture rates

Formation of rare-earth peak

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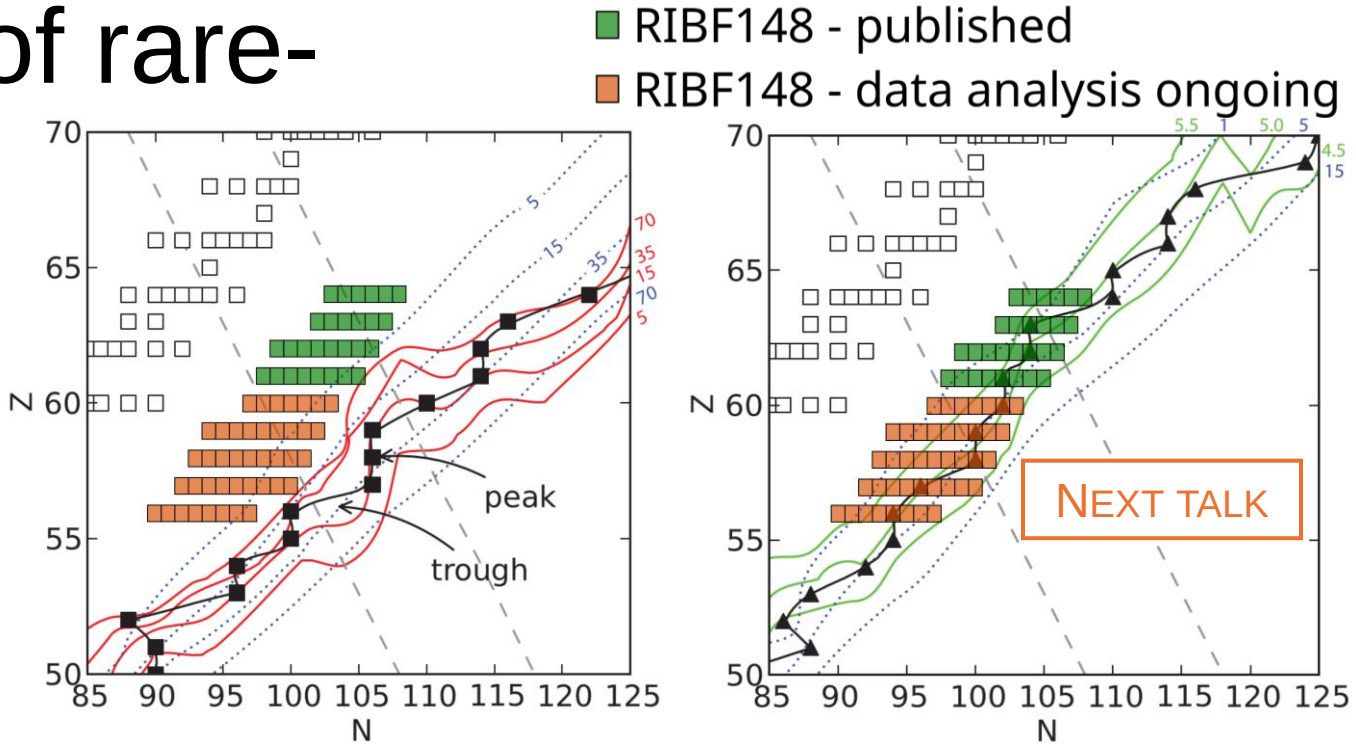

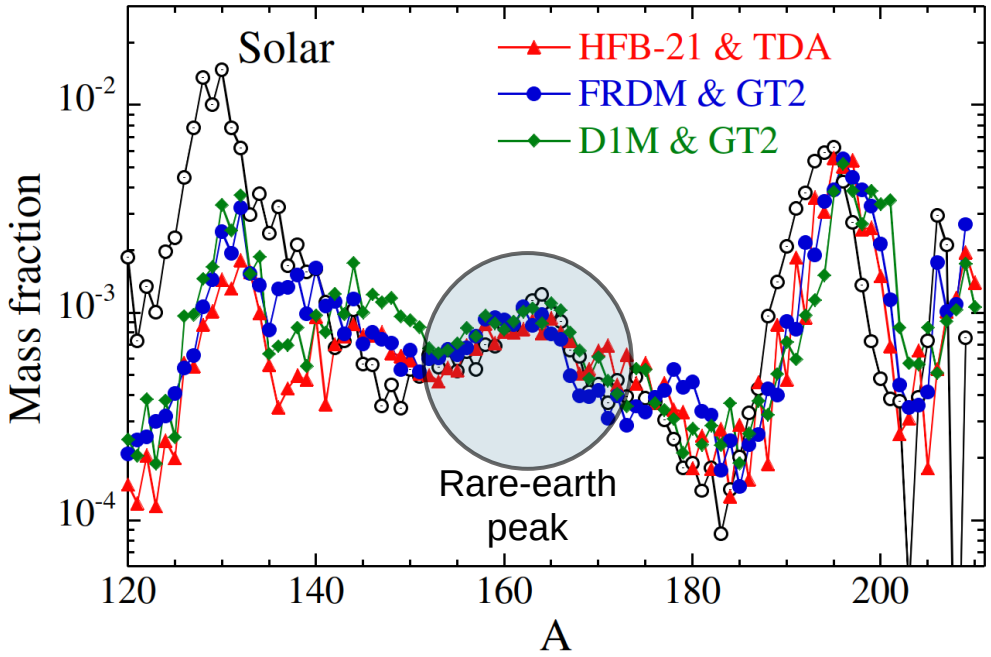

Located far from closed shells

- Freeze-out phase
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1. Double asymmetric fission fragment distribution
2. Slower neutron capture rates
3. Kink in the lines of constant neutron separation energies

Formation of rare-earth peak

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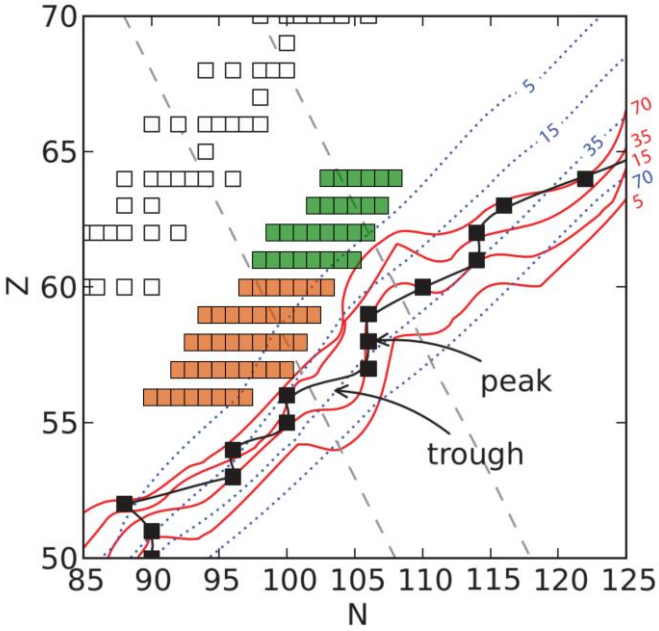
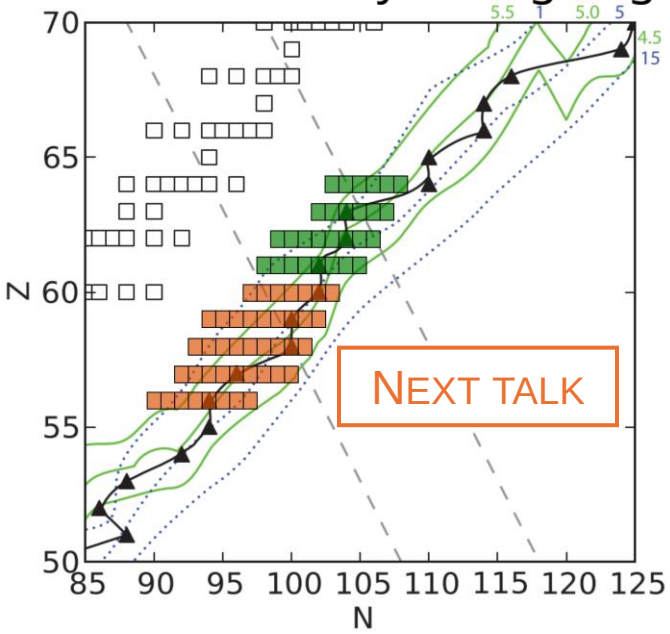
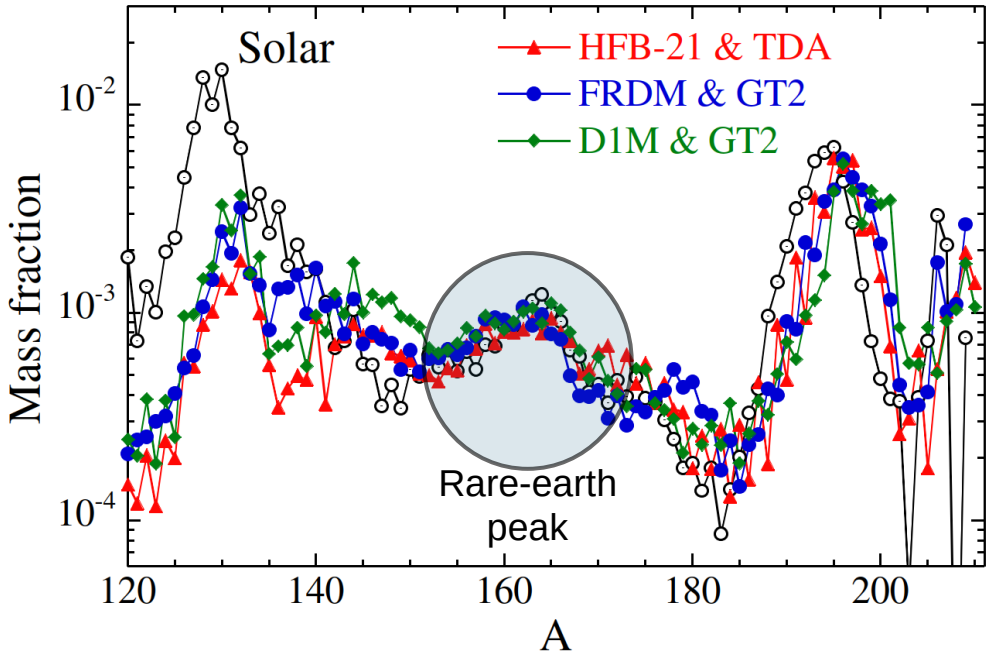
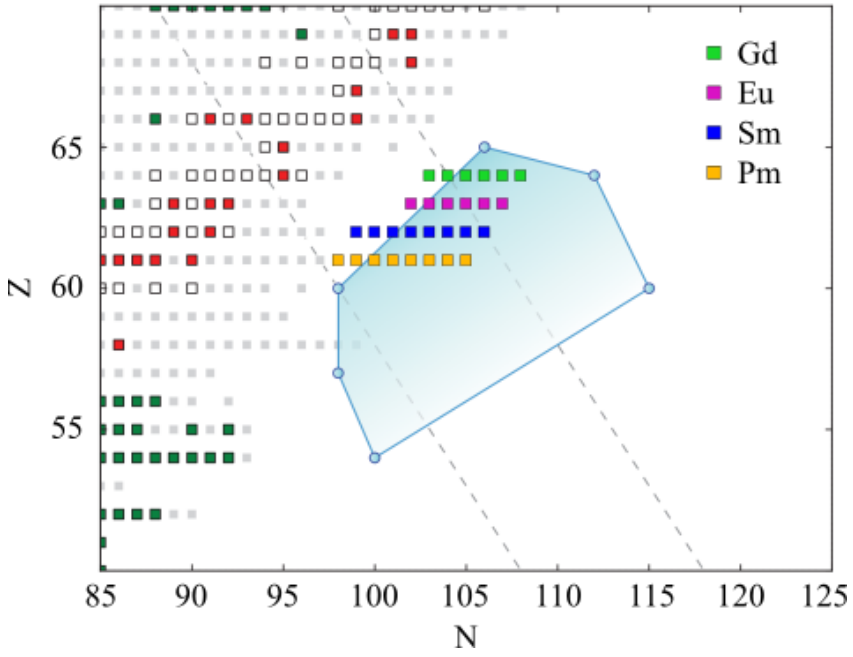


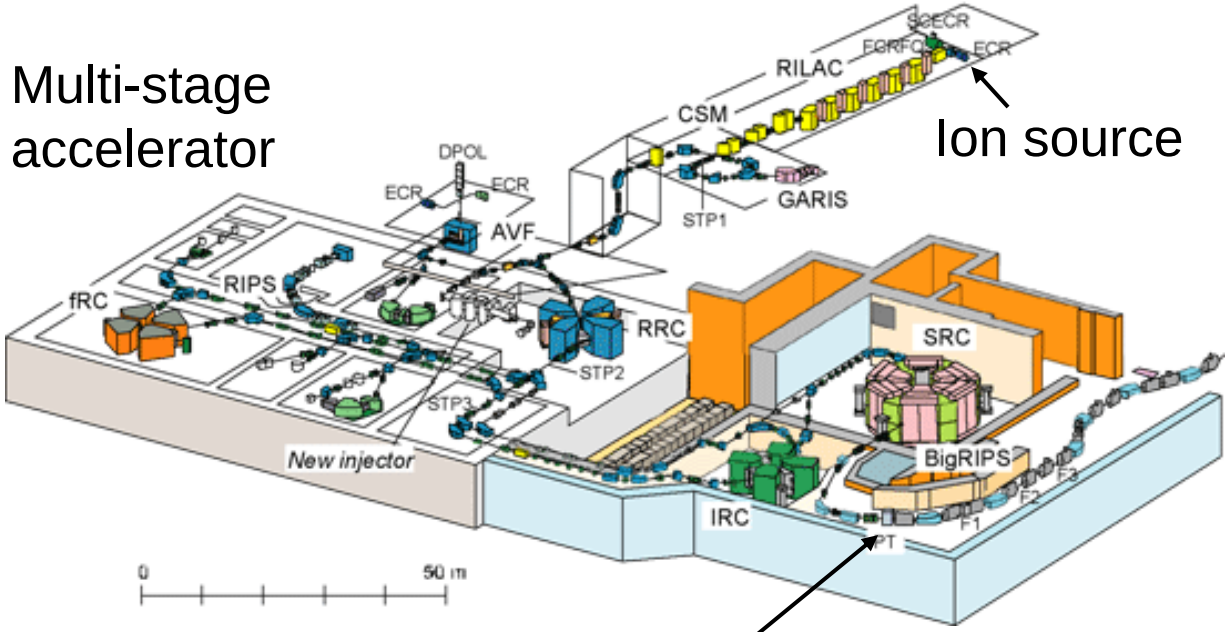






RIKEN Nishina Center-RIBF

Multi-stage accelerator



Ion source

Be-target + ^{238}U

primary beam energy: 345MeV/u

H. Okuno et al., PTEP **2012**, 03C002 (2012)

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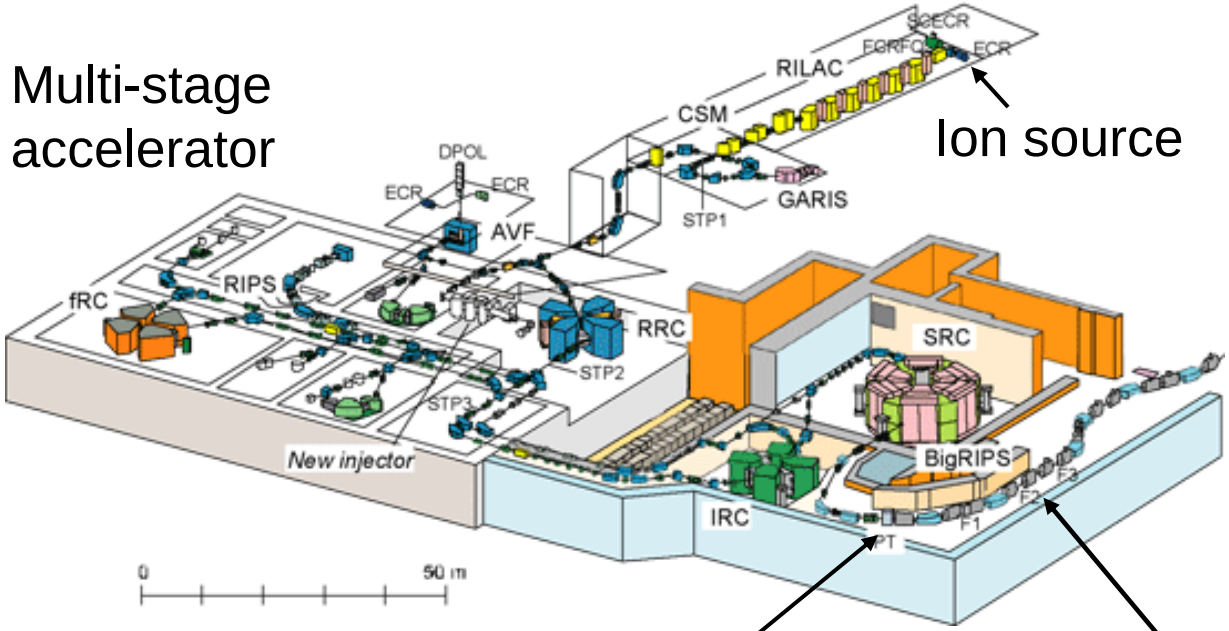
Multi-stage accelerator



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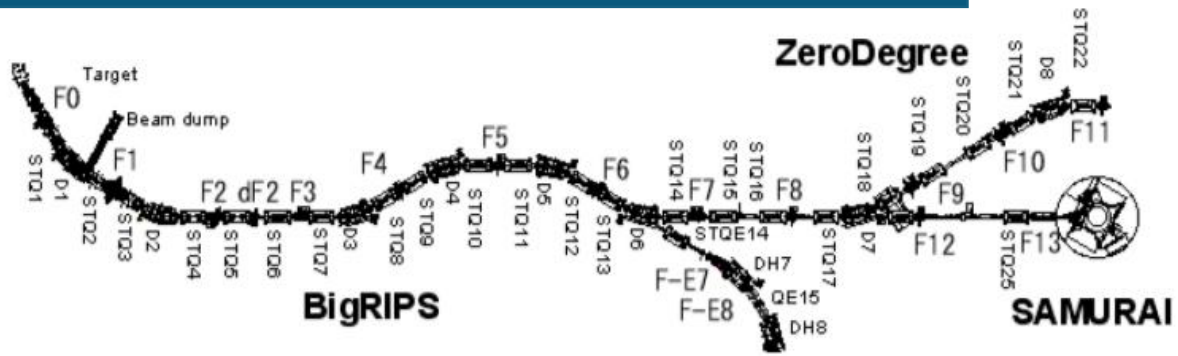

BigRIPS separator

- ToF → v
- $B\rho$ → A/Q
- $\frac{dE}{dx}$ → Z

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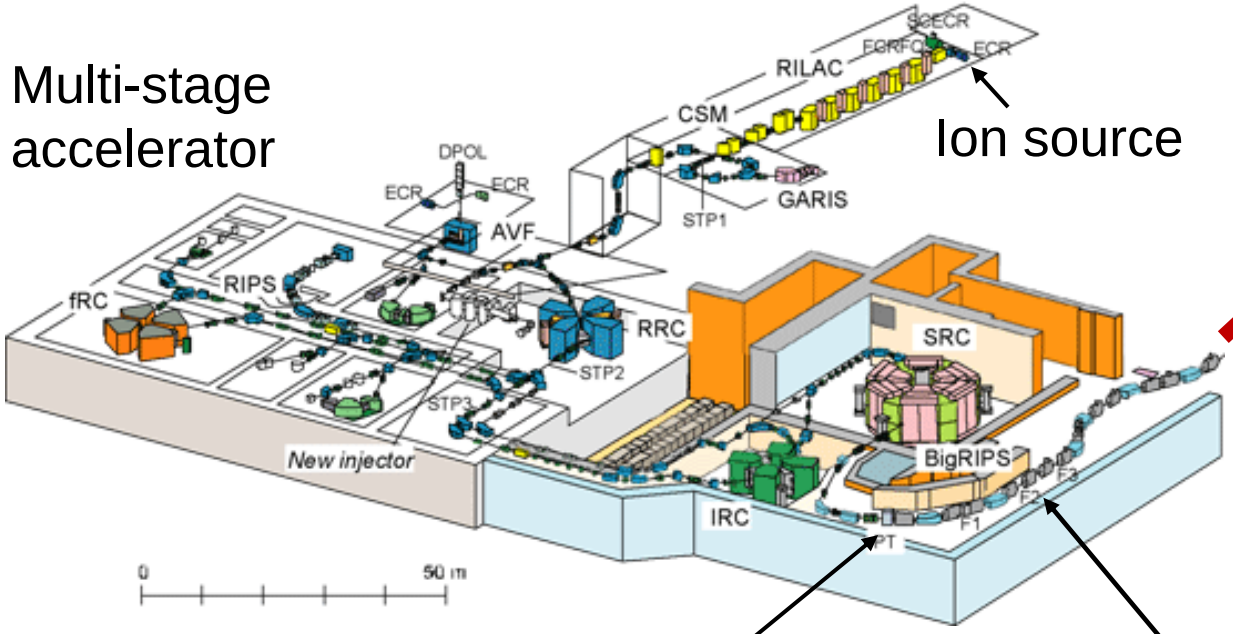


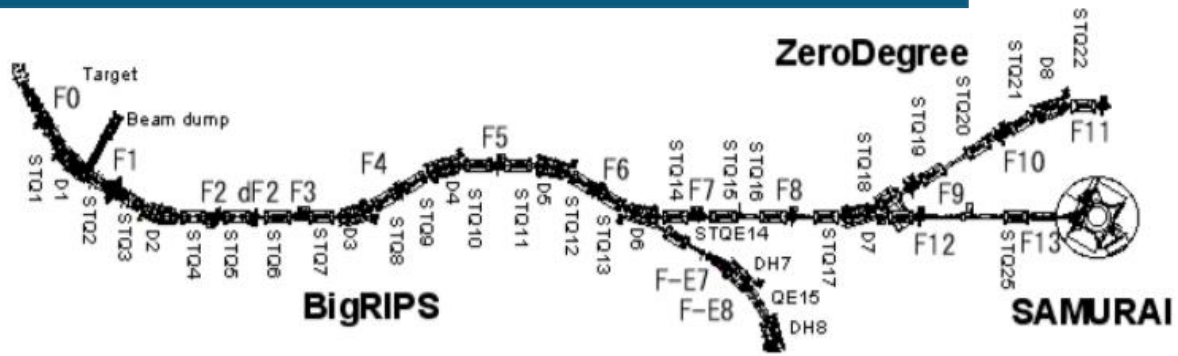
Ion source

AIDA and **BRIKEN**

A. Tolosa-Delgado et al., NIMA **925**, 133 (2019)

Be-target + ^{238}U
primary beam energy: 345MeV/u

H. Okuno et al., PTEP **2012**, 03C002 (2012)



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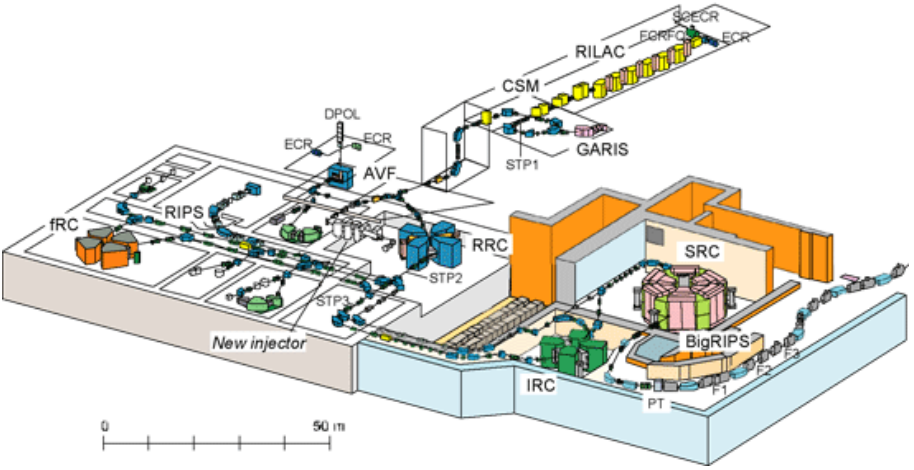
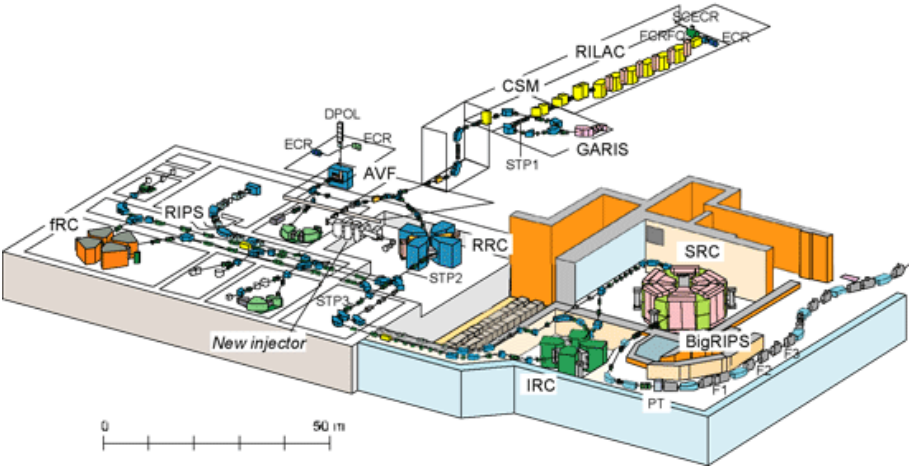
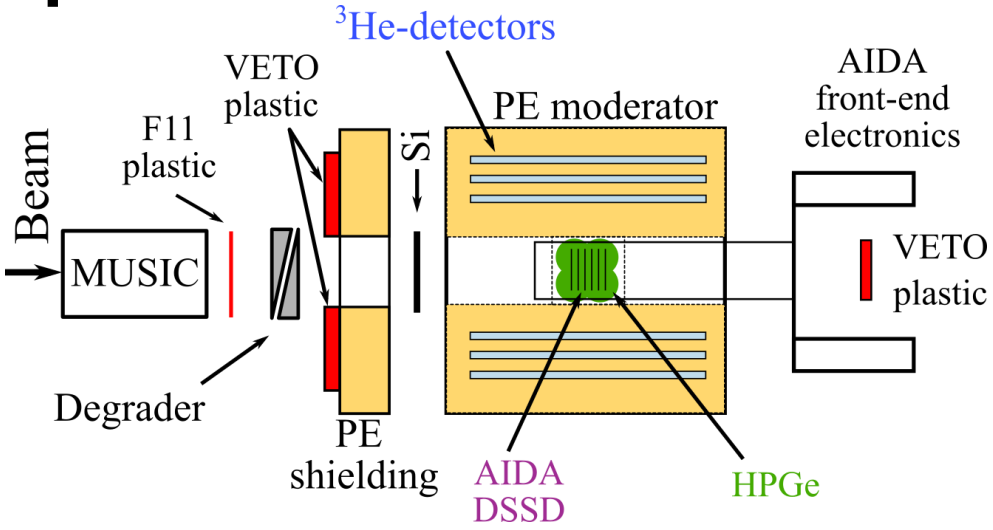
Experimental setup



Experimental setup





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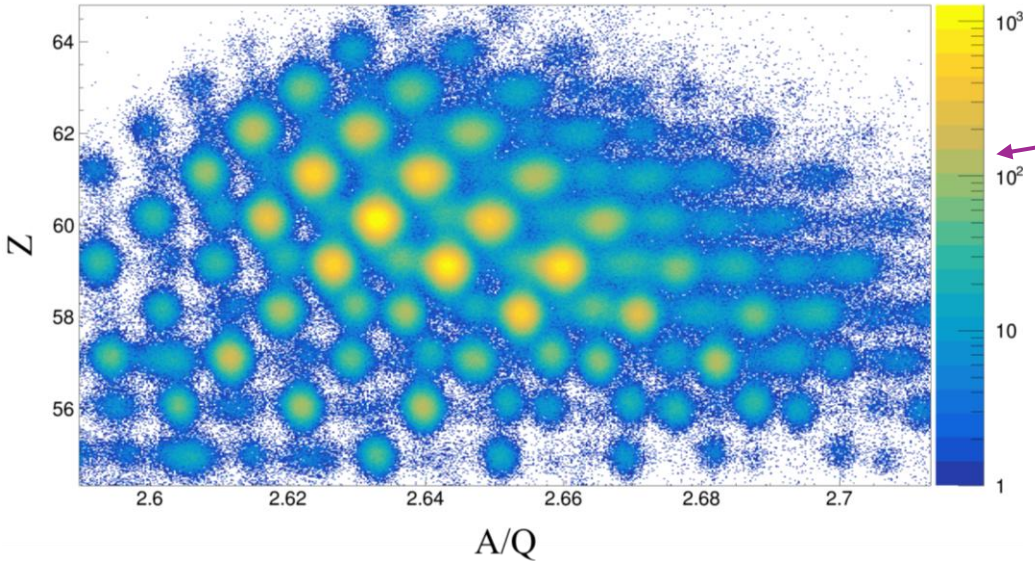
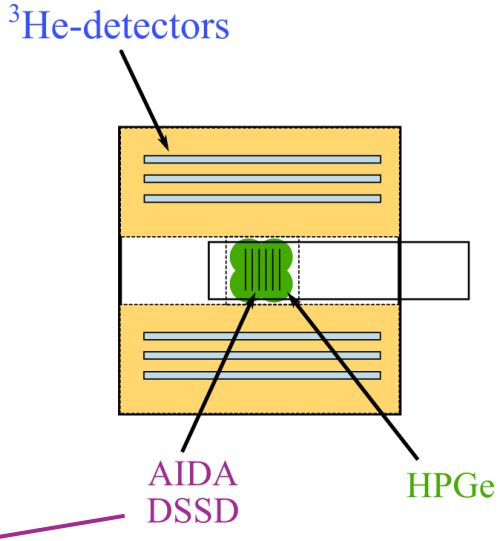
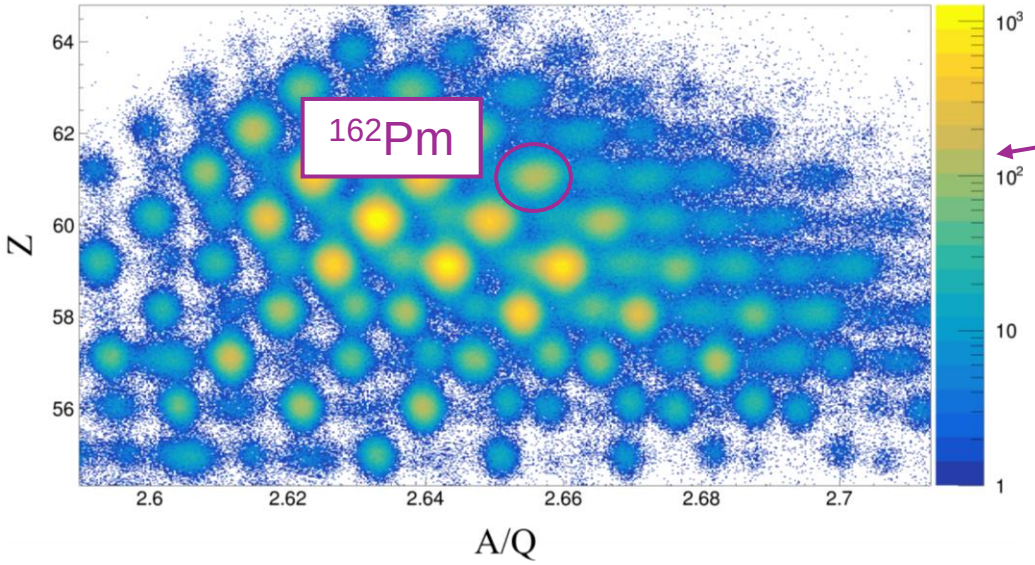
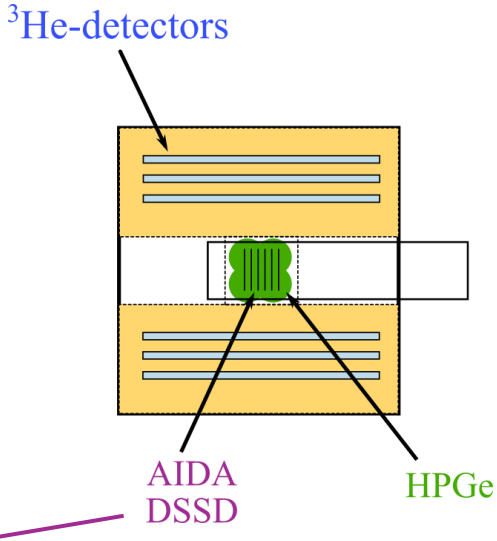




Implantation
and β-events

Experimental setup





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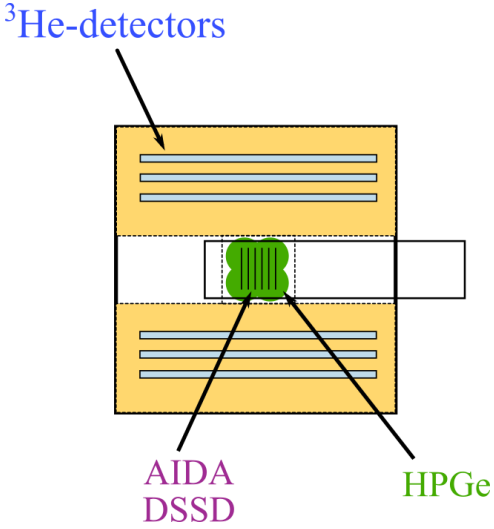

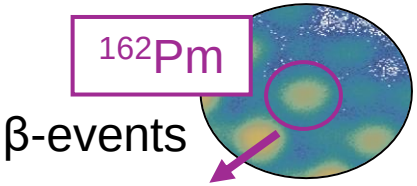

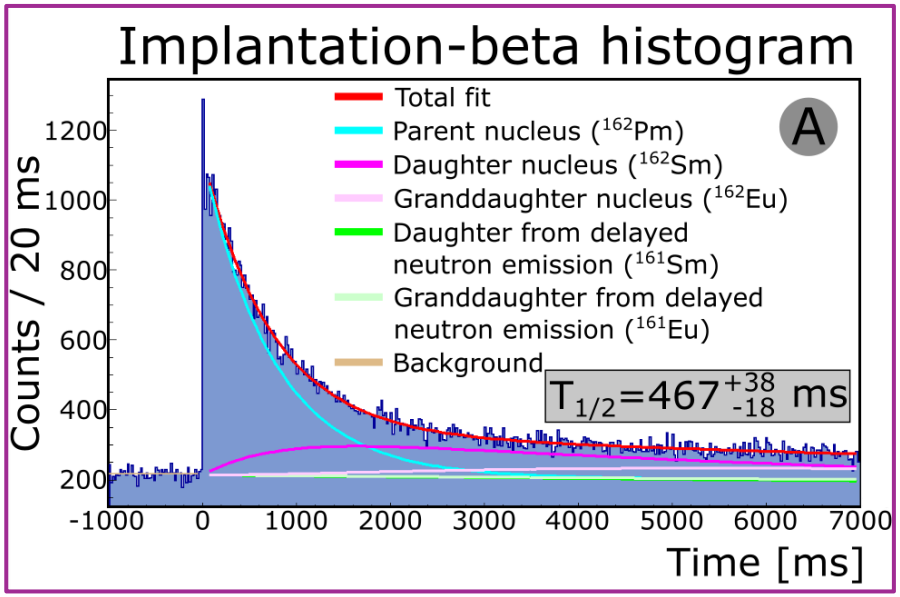

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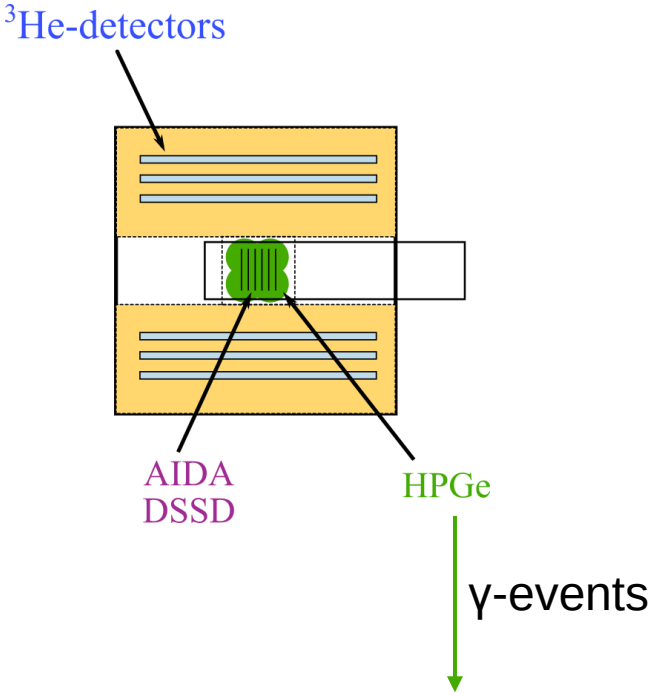

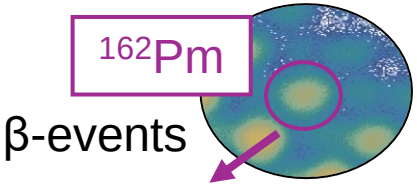

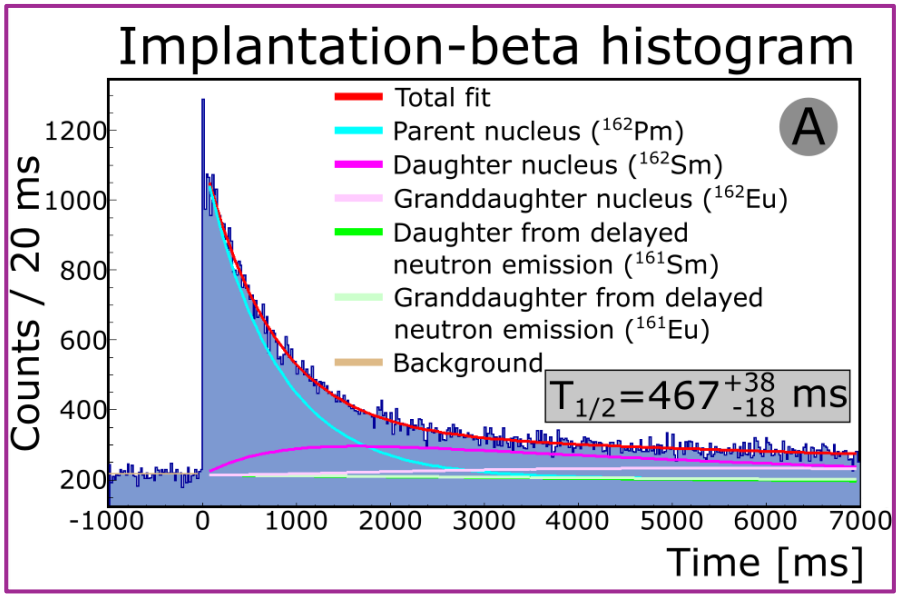

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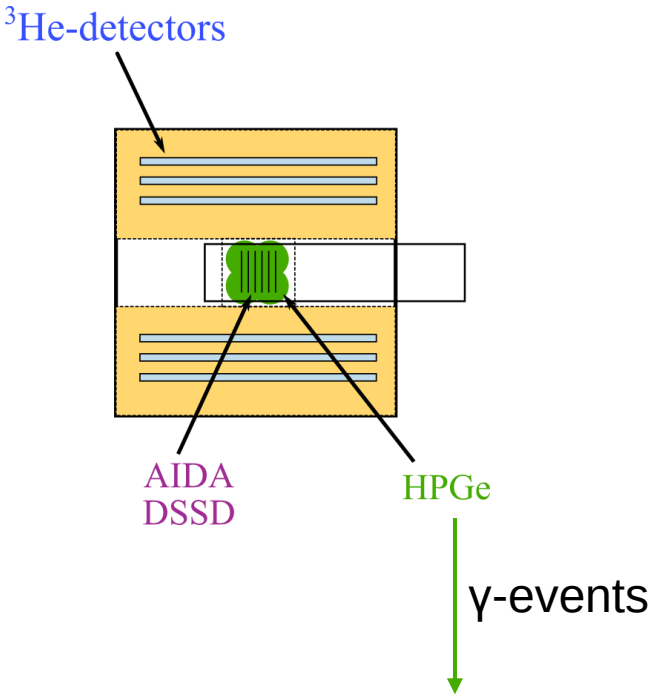

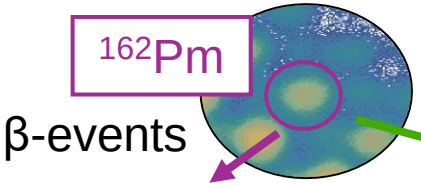

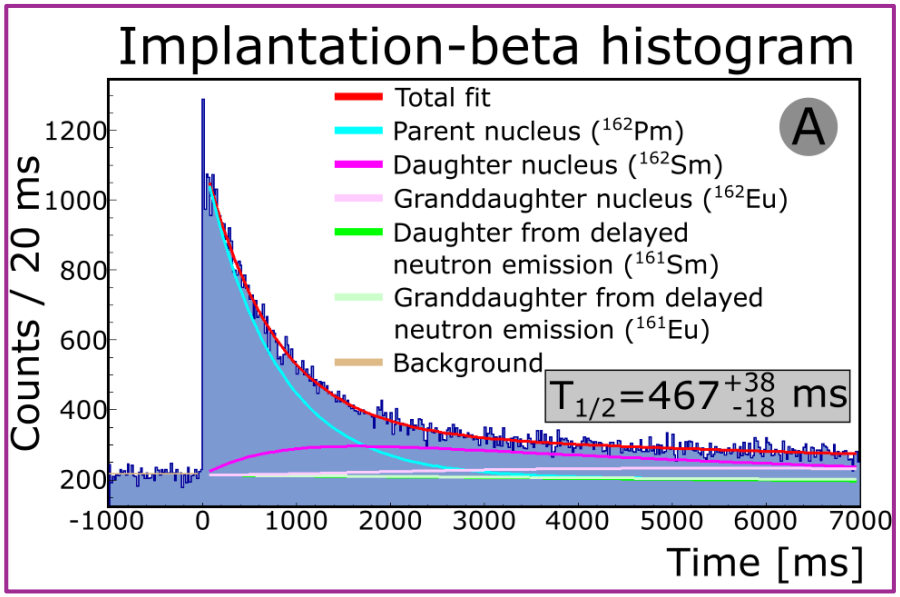

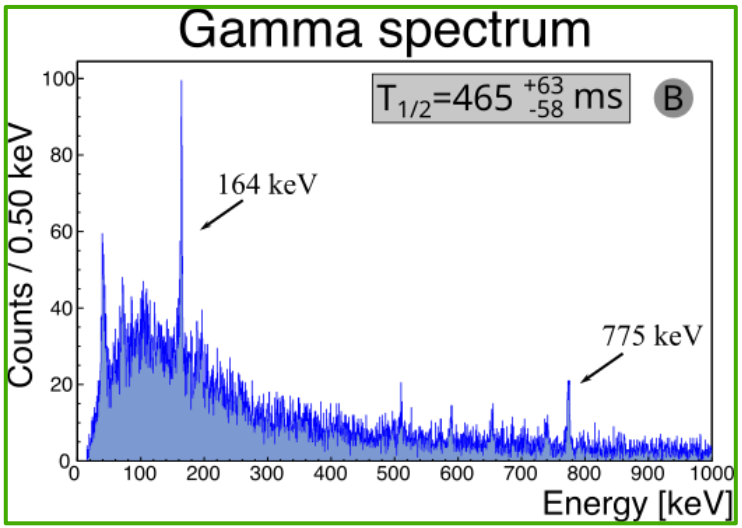

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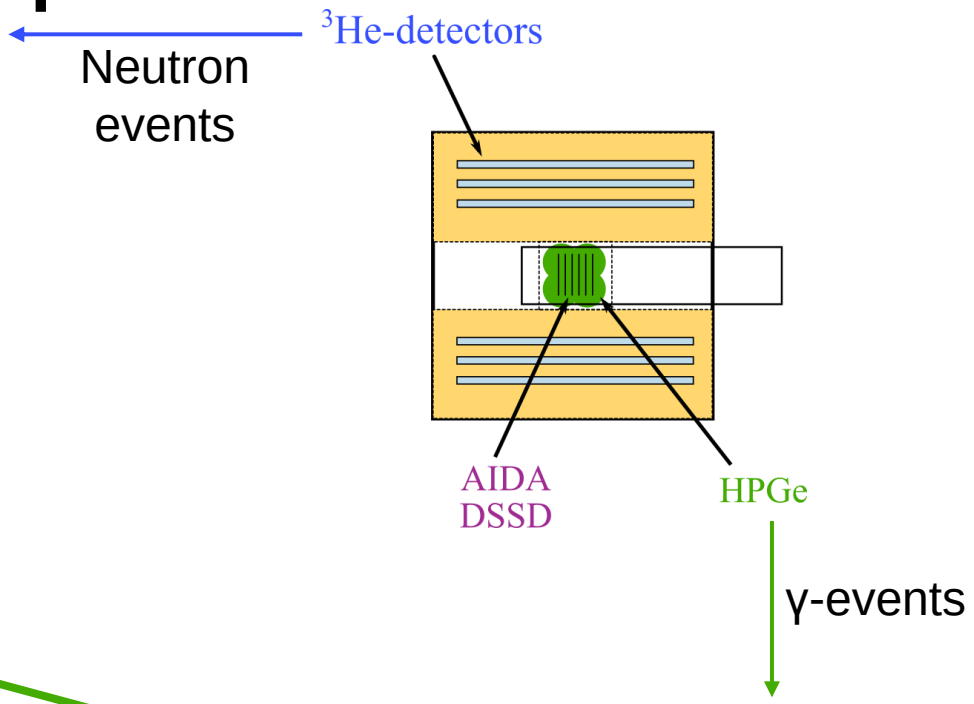

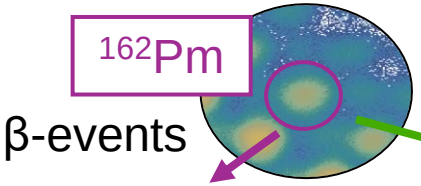

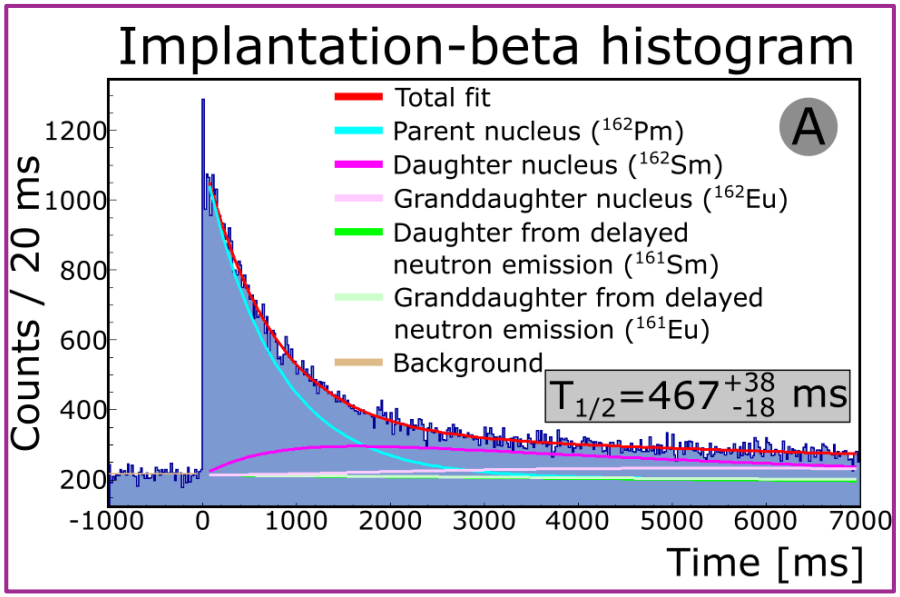

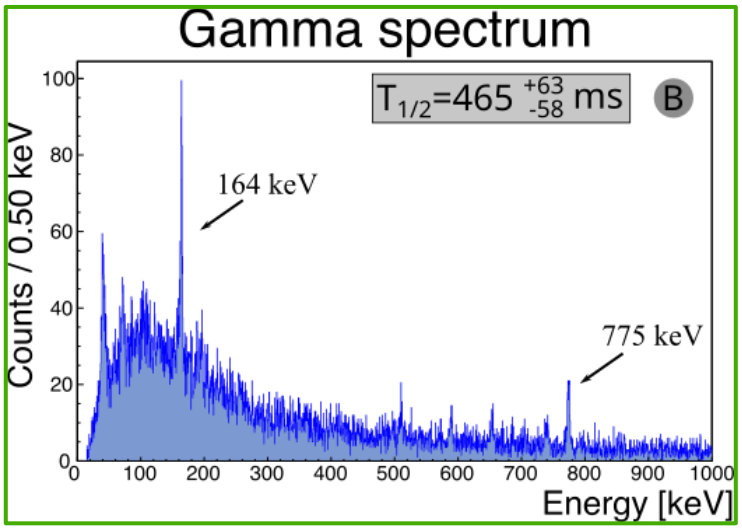

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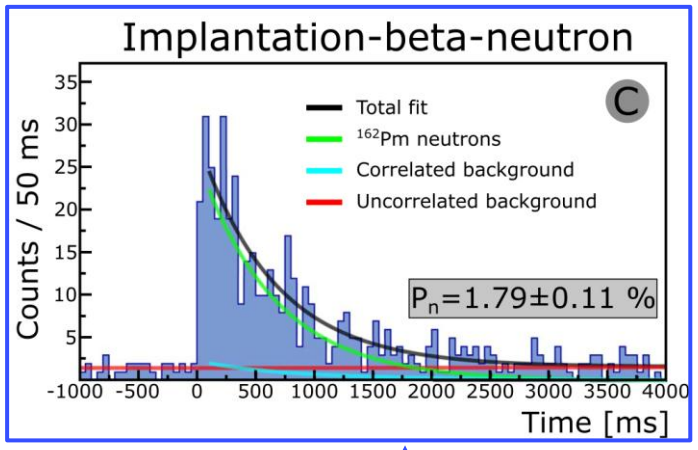
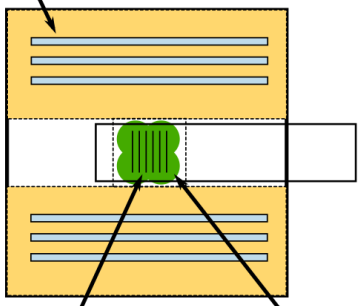


Neutron events

^{3}He-detectors



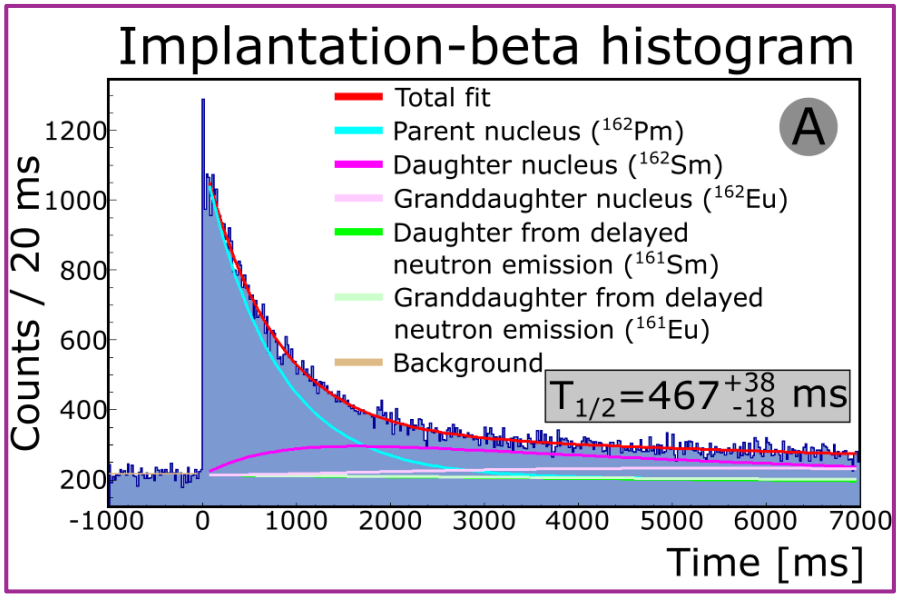
AIDA DSSD

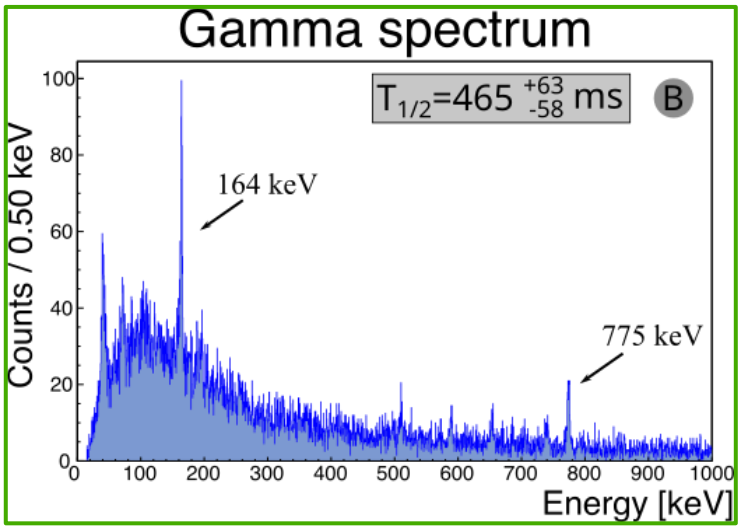
HPGe

γ-events

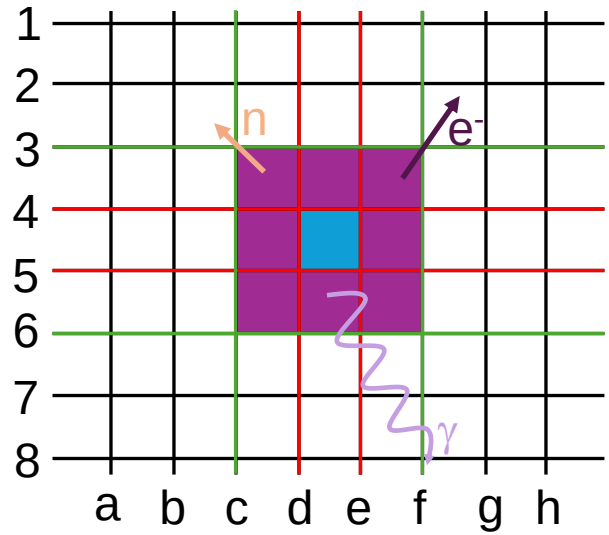
^{162}Pm

β-events





Determination of half life



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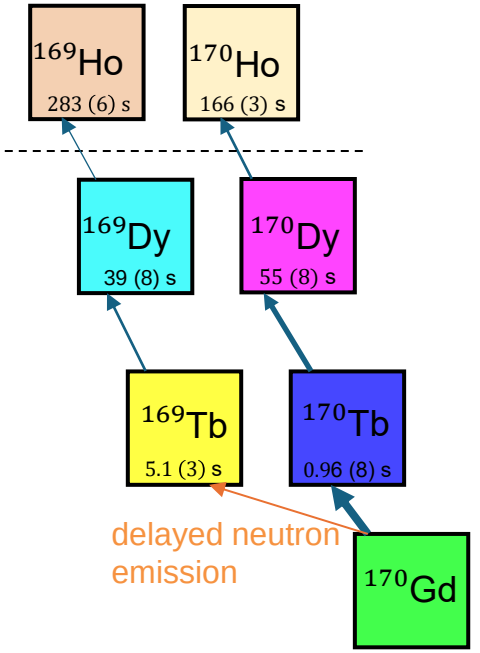
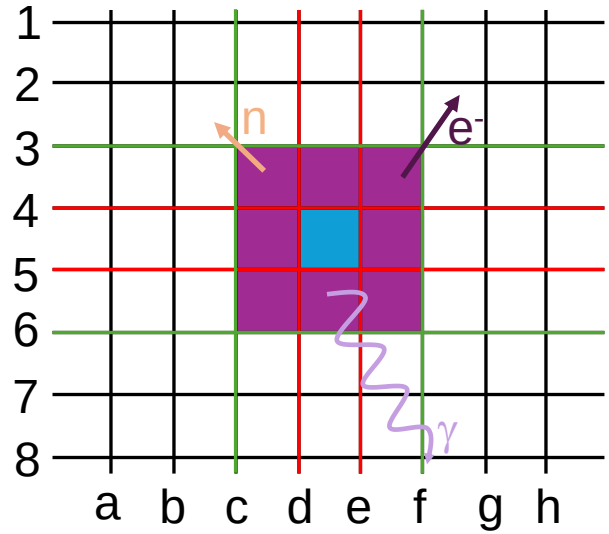
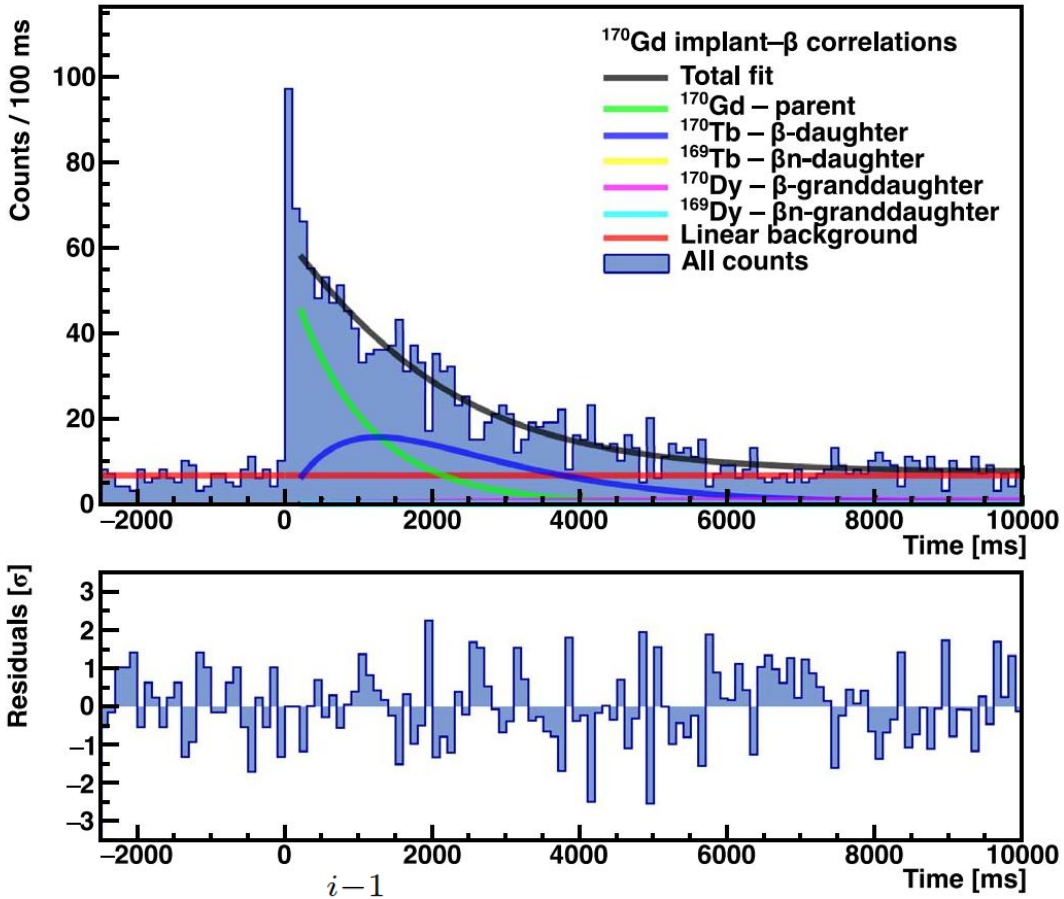


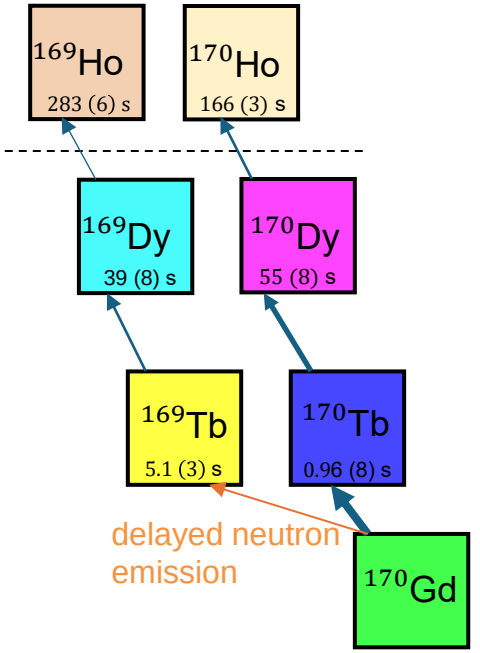


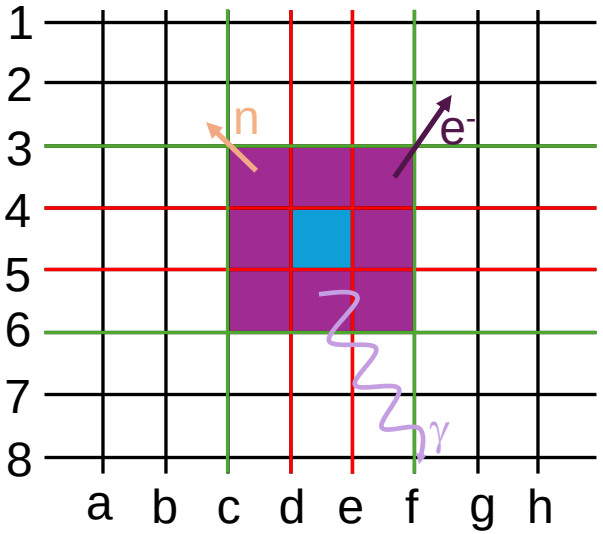
$$N_i(t) = \sum_{j=1}^{i} \frac{N_{10} \prod_{k=1}^{i-1} \lambda_k}{\prod_{\substack{k=1 \\ k \neq j}}^{i} (\lambda_k - \lambda_j)} e^{-\lambda_j t} \rightarrow A_{tot}(t) = \sum_{i=1}^{n} \lambda_i N_i(t)$$

Determination of half life

+ Validation with implant-β-γ correlations







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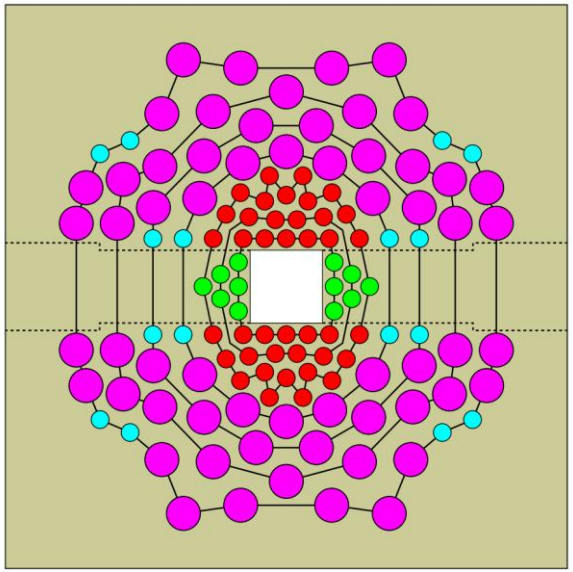
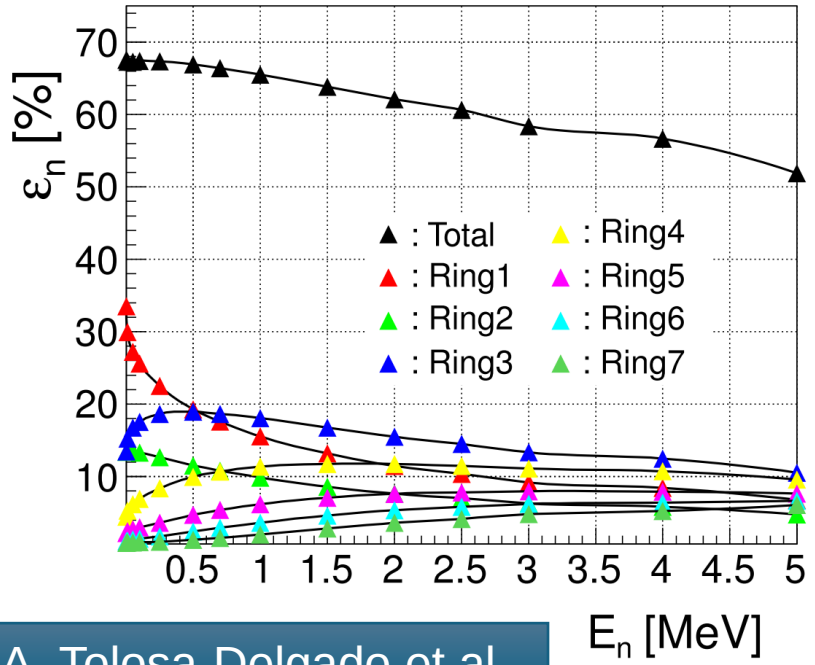
H. Bateman, PCPS **15**, 423 (1910)

Determination of P_n value

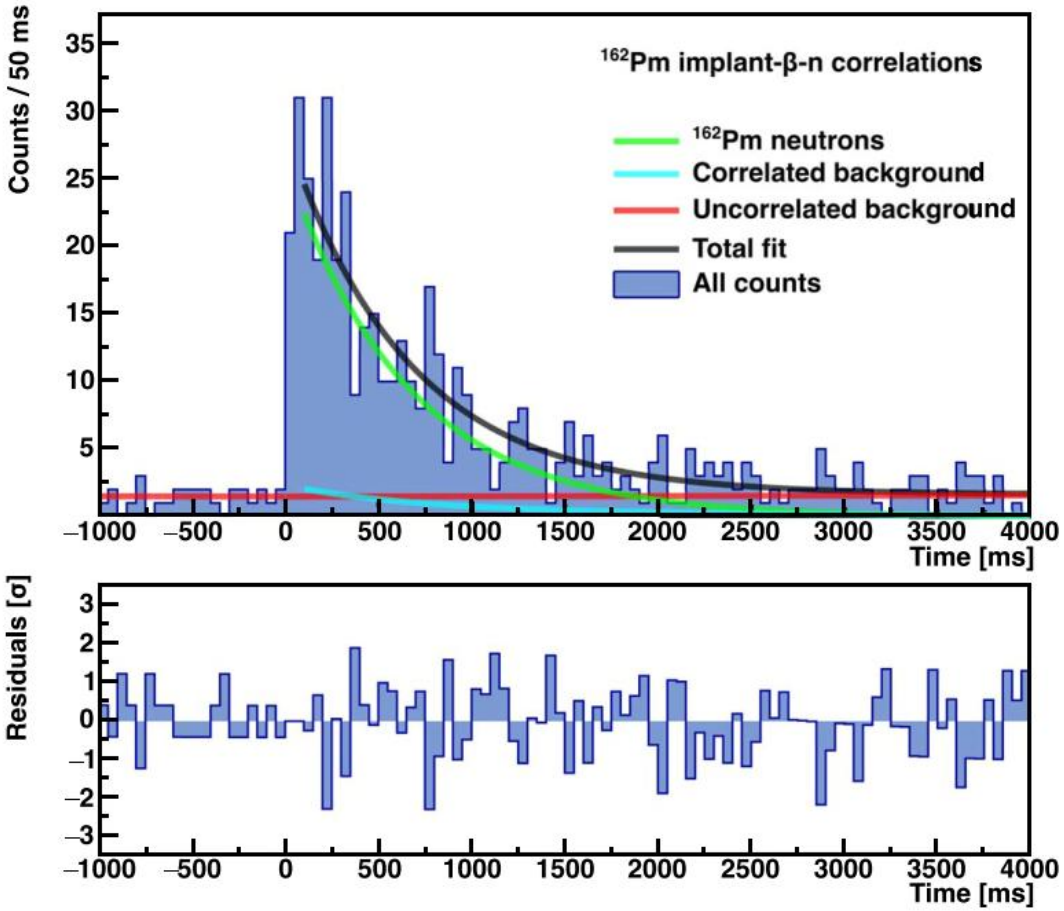


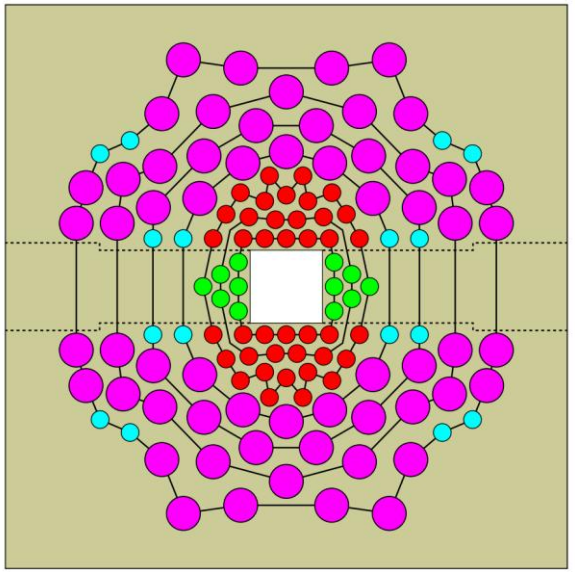
$^{3}He + n \rightarrow {}^{1}H + {}^{3}H + 764\ keV$

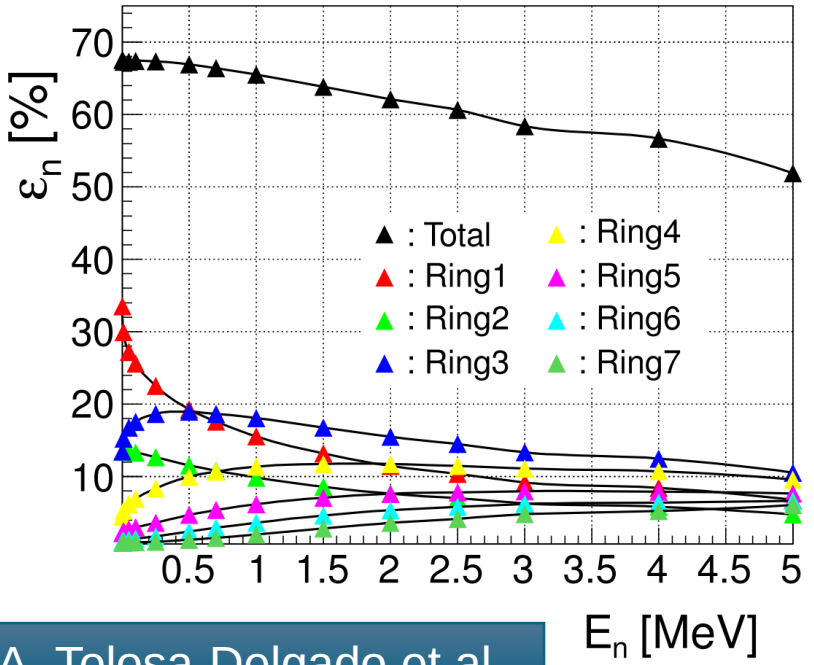


A. Tolosa-Delgado et al., NIMA **925**, 133 (2019)

Determination of P_n value







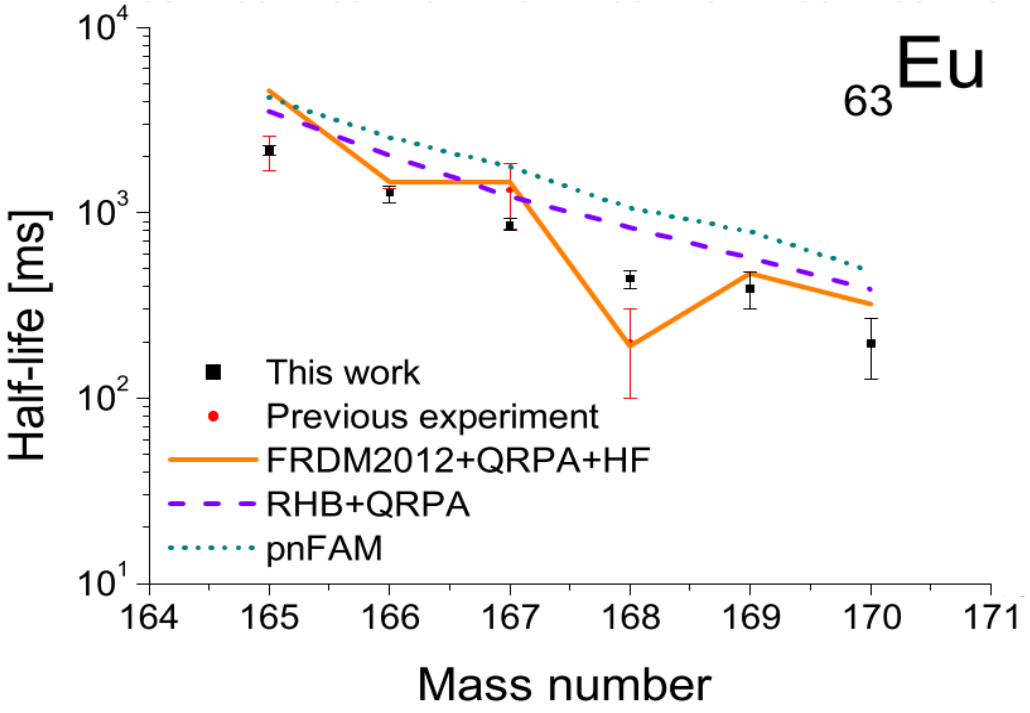
$$^{3}\mathrm{He} + \mathrm{n} \rightarrow {}^{1}\mathrm{H} + {}^{3}\mathrm{H} + 764\ \mathrm{keV}$$

$$P_n \cong \frac{1}{\text{n det. efficiency}} \cdot \frac{\text{i}-\beta-\text{n events}}{\beta-\text{events}}$$

A. Tolosa-Delgado et al., NIMA **925**, 133 (2019)

Results I.

Measured the β-decay properties of **28 neutron-rich Pm, Sm, Eu and Gd isotopes.**



G. G. Kiss et al., APJ **936**, 107 (2022)

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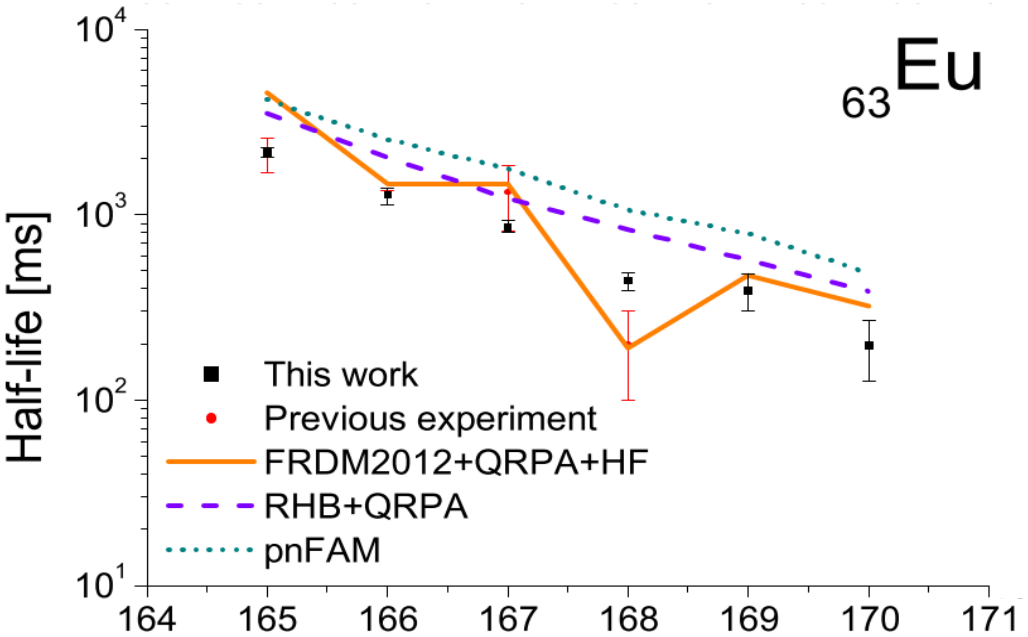
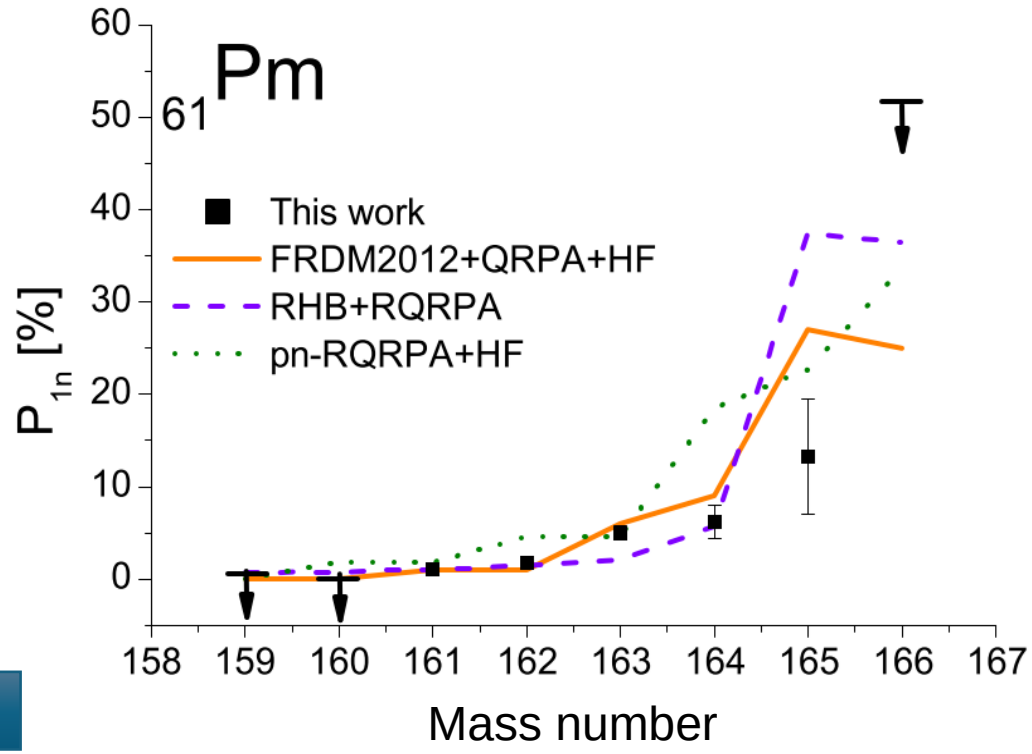
Measured the β-decay properties of **28 neutron-rich Pm, Sm, Eu and Gd isotopes.**

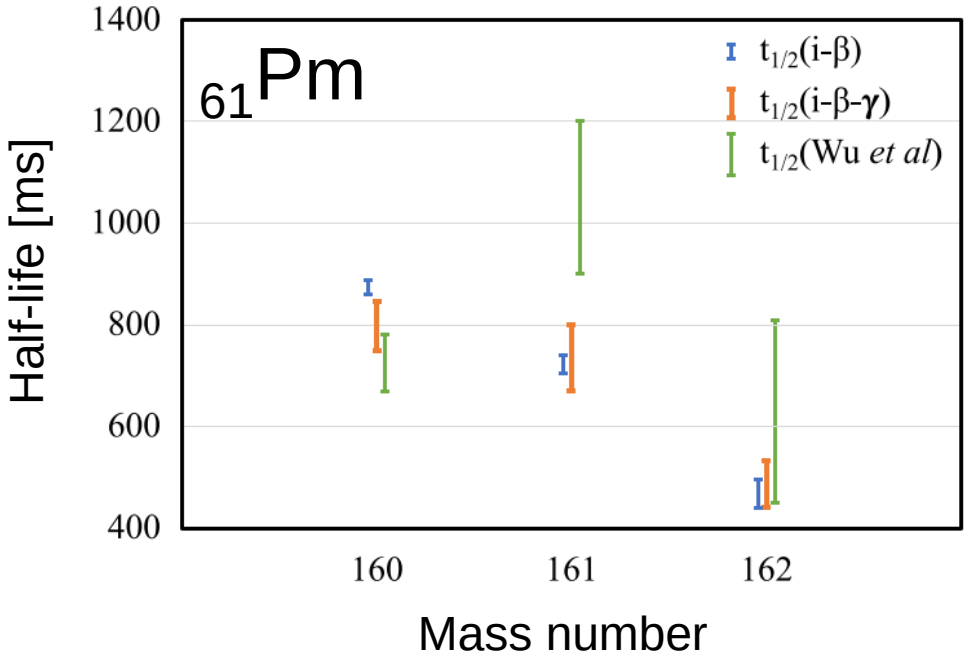
β-delayed neutron-emission probabilities (P_n) were derived for the first time in this mass region.





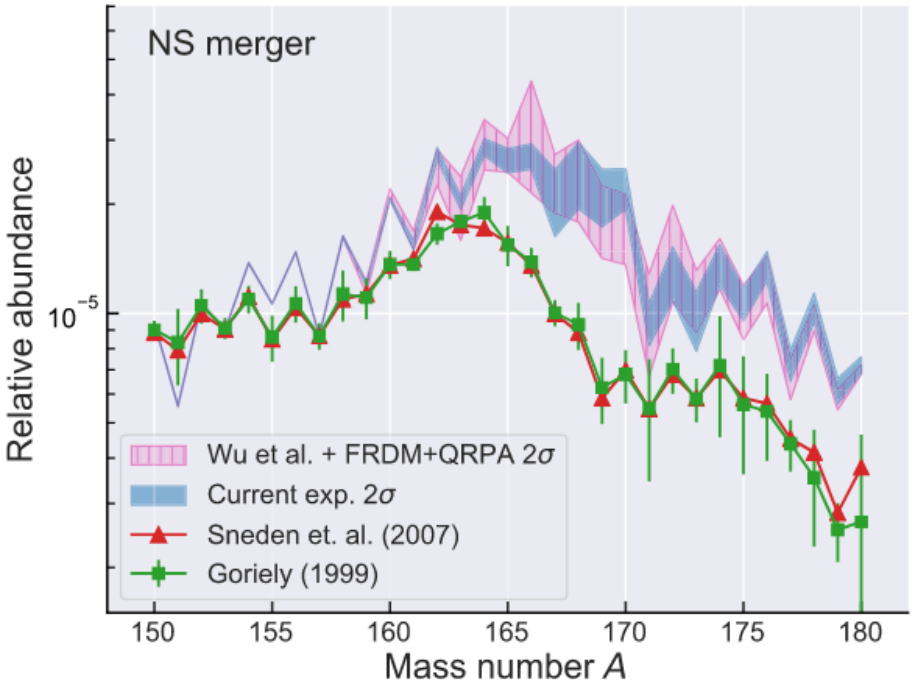
G. G. Kiss et al., APJ **936**, 107 (2022)

Results II.



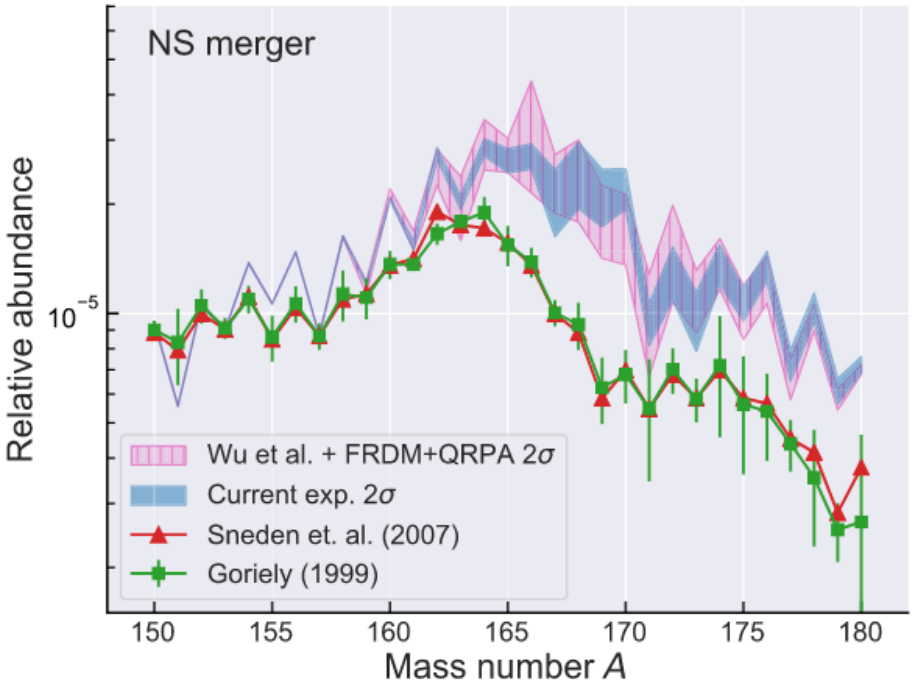
- By studying **beta-delayed gamma** photons the **half-lives** of three isotopes were measured

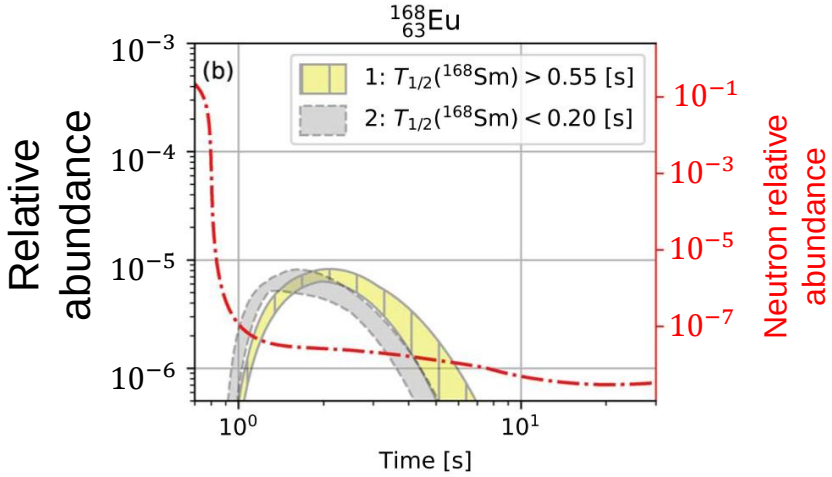
Results II.

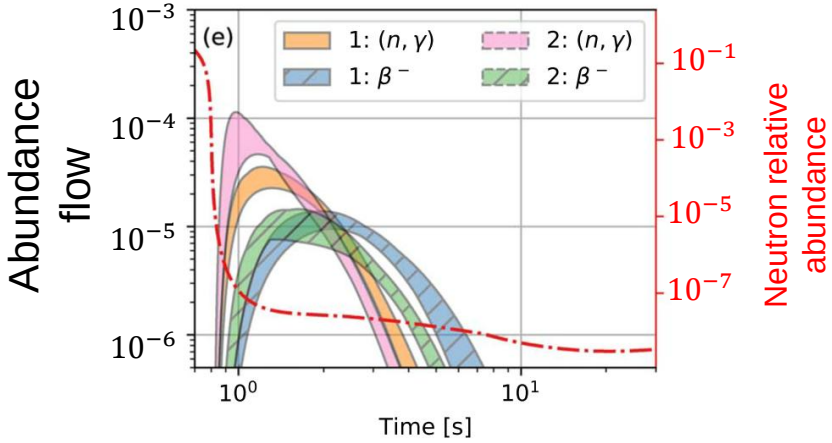


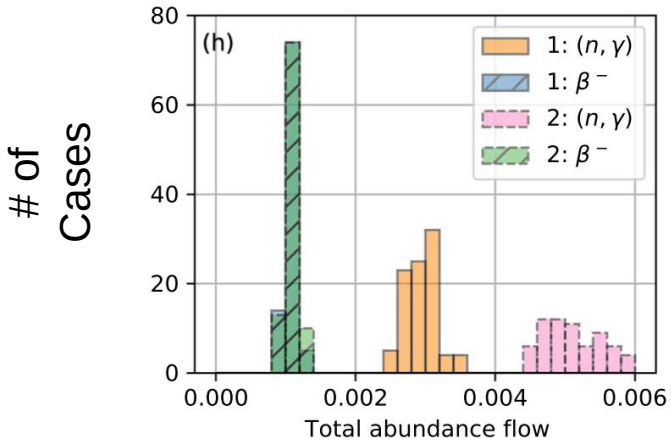
- By studying **beta-delayed gamma** photons the **half-lives** of three isotopes were measured
- **Nuclear reaction network calculations** for the r-process employing a neutron-star merger and a hot wind scenario

Results II.









- By studying **beta-delayed gamma** photons the **half-lives** of three isotopes were measured
- **Nuclear reaction network calculations** for the r-process employing a neutron-star merger and a hot wind scenario
- **Identification of critical isotopes** (e.g. ^{168}Sm) for abundance pattern uncertainty

Summary

- REP provides unique opportunity to test freeze-out models.
- Determination of 28 half-life values for Pm, Sm, Eu, Gd isotopes
- P_n values were derived for the first time in the mass region
- Identification of critical isotopes relevant for REP formation

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Thank you for your attention!