Measuring the beta-decay properties for exotic rare-earth isotopes

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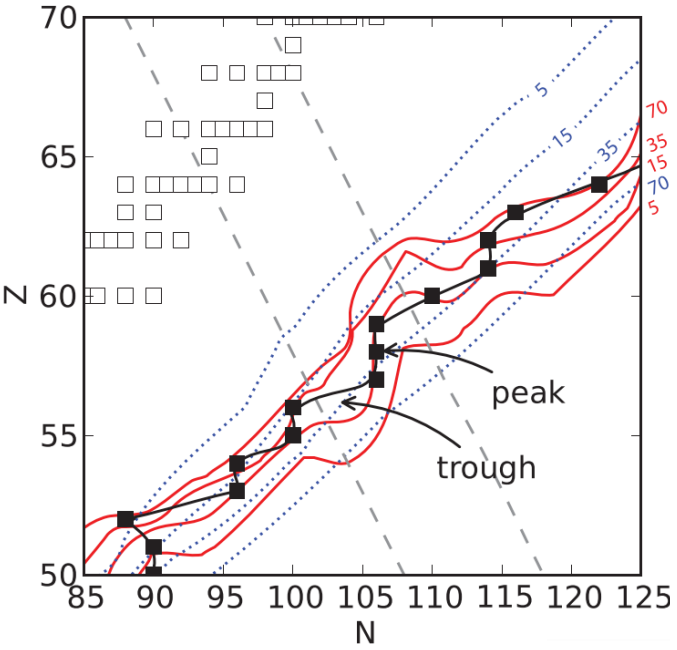
Supervisor:

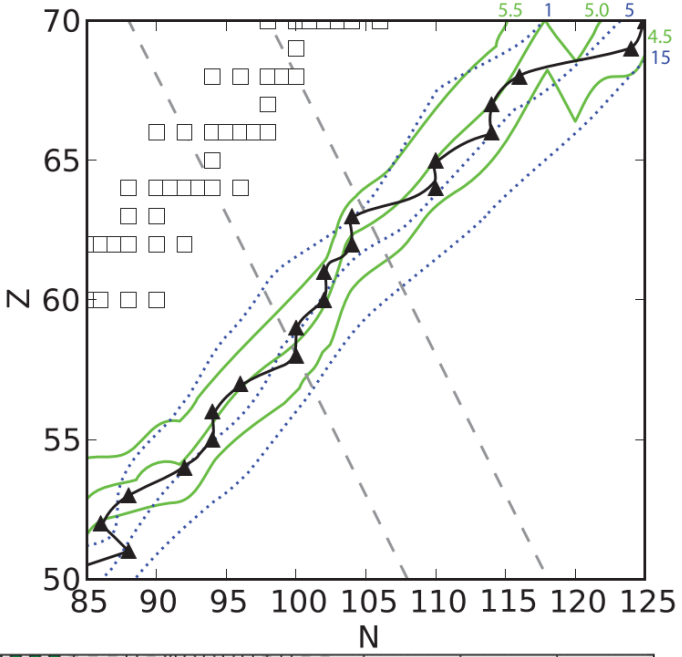
Dr. Gyula Gábor Kiss

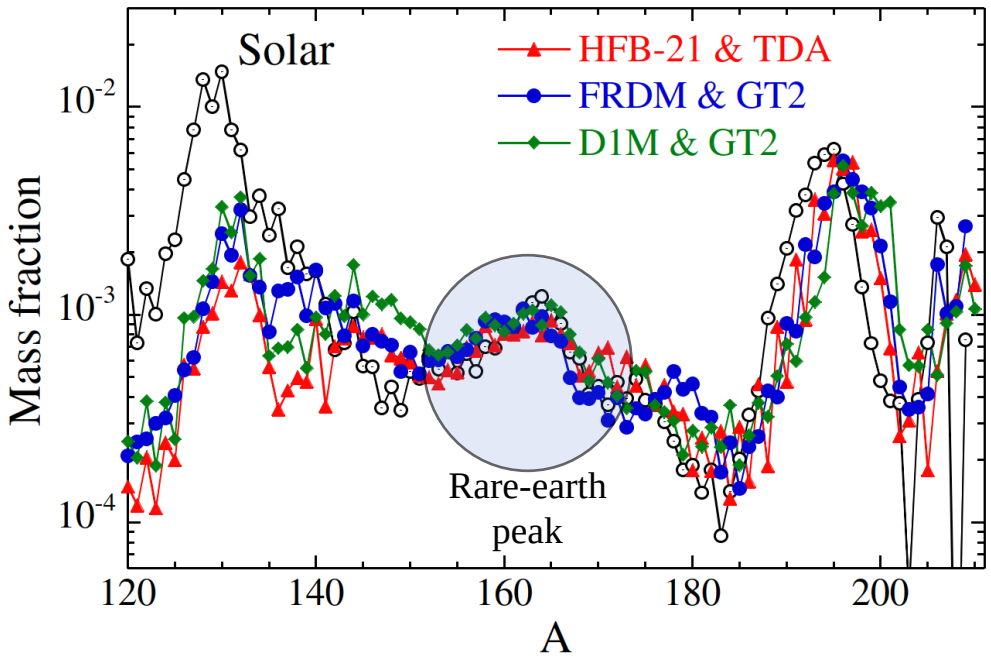
Formation of rare-earth peak

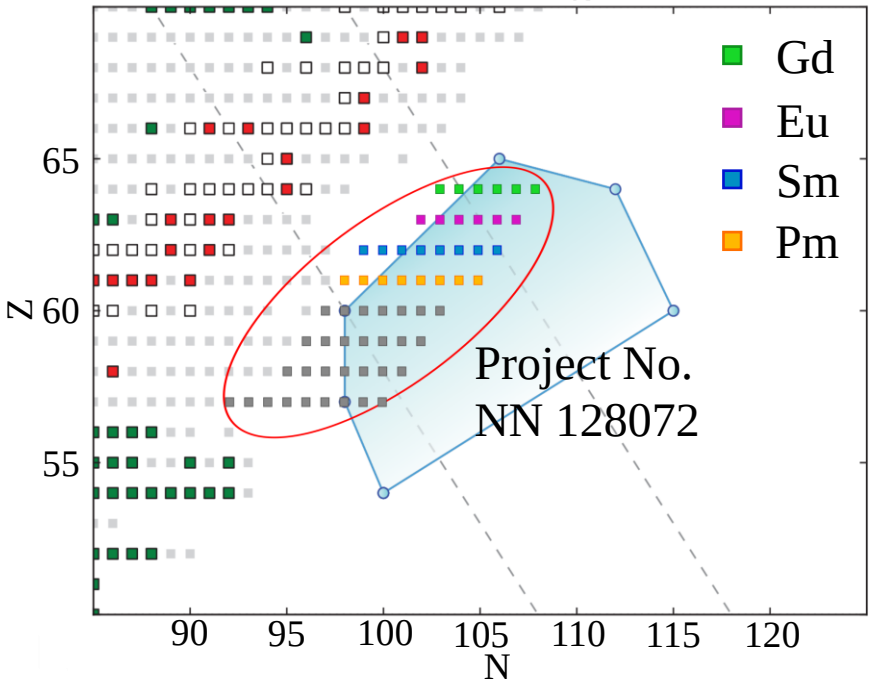
M. R. Mumpower et al., PRC **85**, 045801 (2012) & APJ **752**, 117 (2012)

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

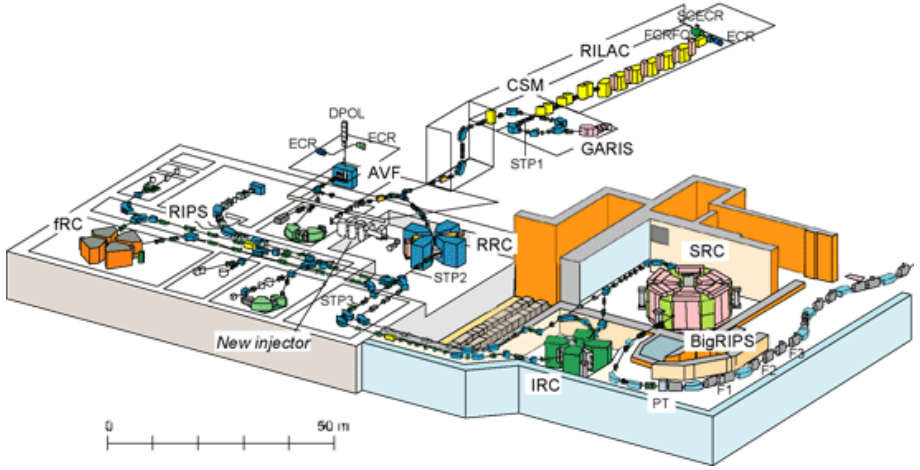


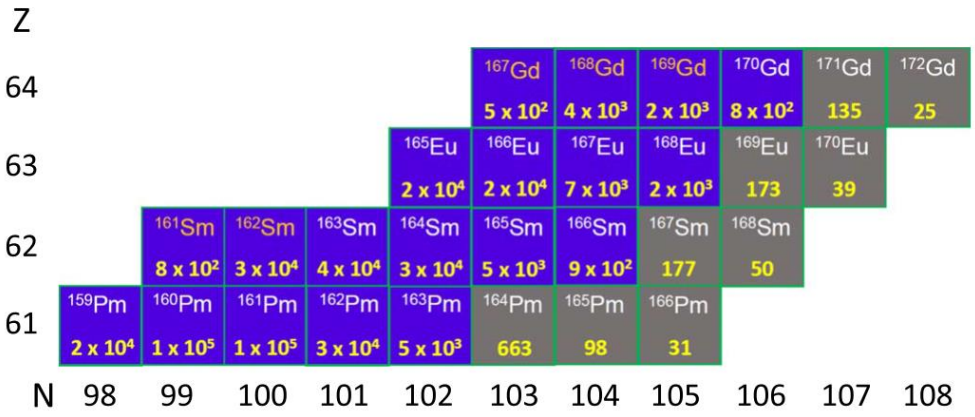




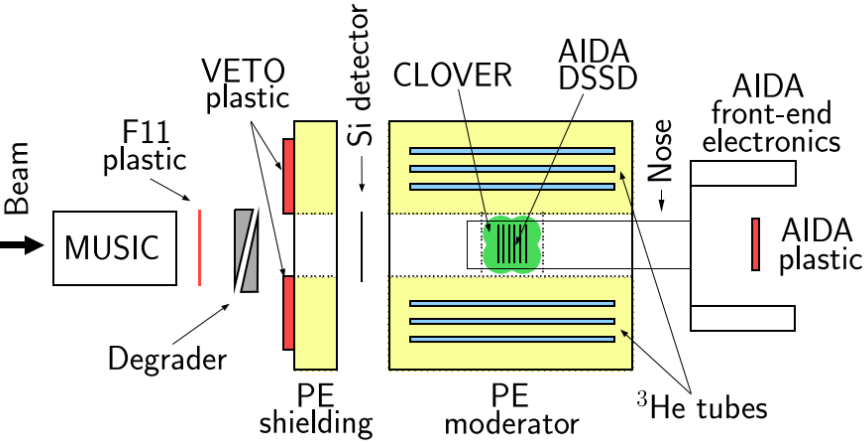


Experimental setup





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



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

Detection of:

AIDA: 6 DSSD → implantation, β-events

140 ^{3}He filled proportional counter → neutrons

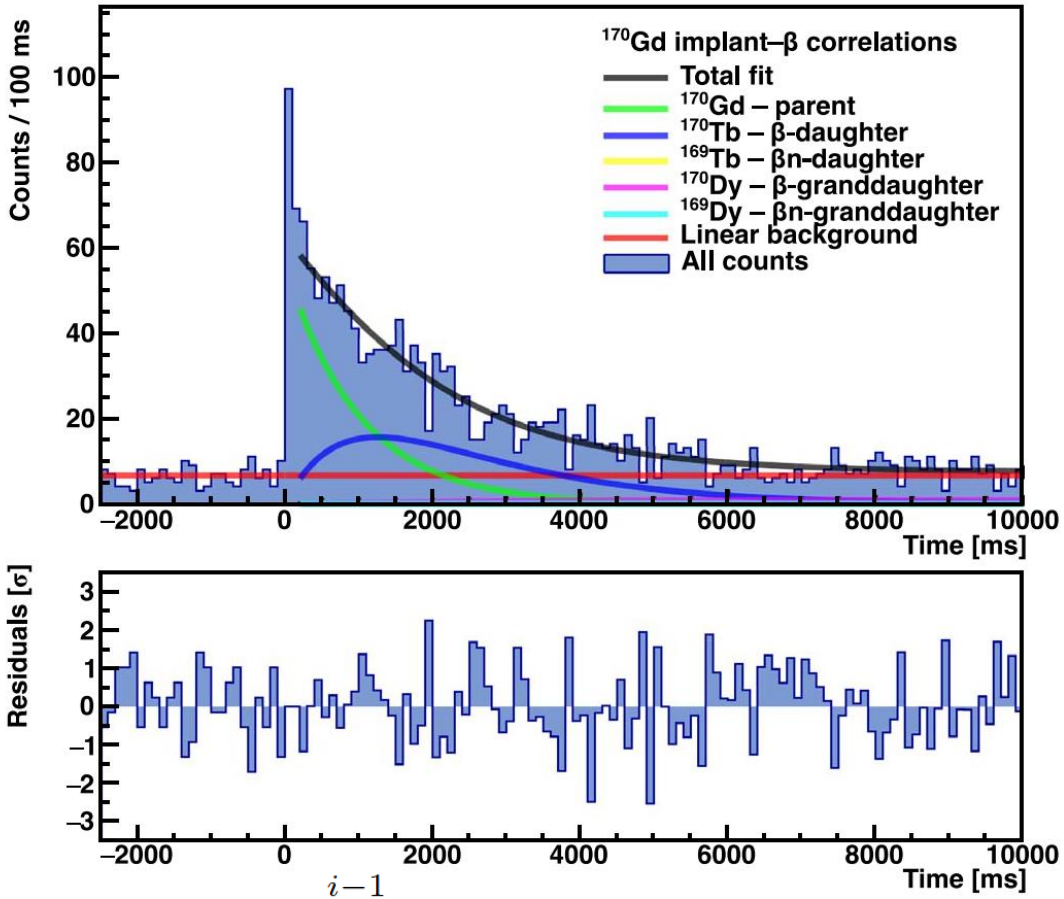
2 clover HPGe detectors → γ-photons

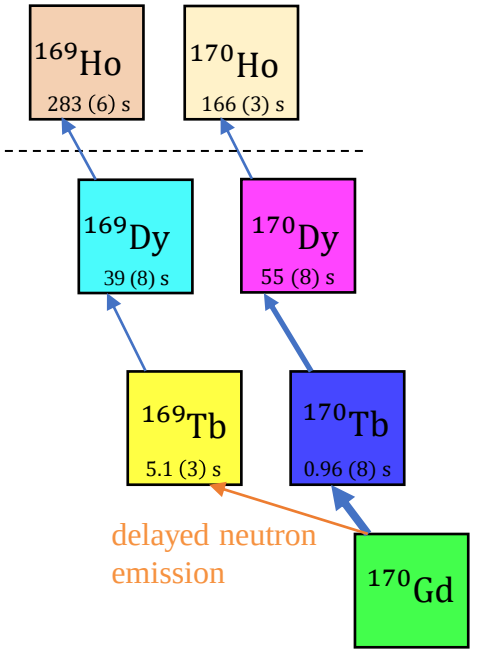
$$^{3}He + n \rightarrow {}^{1}H + {}^{3}H + 764\ keV$$

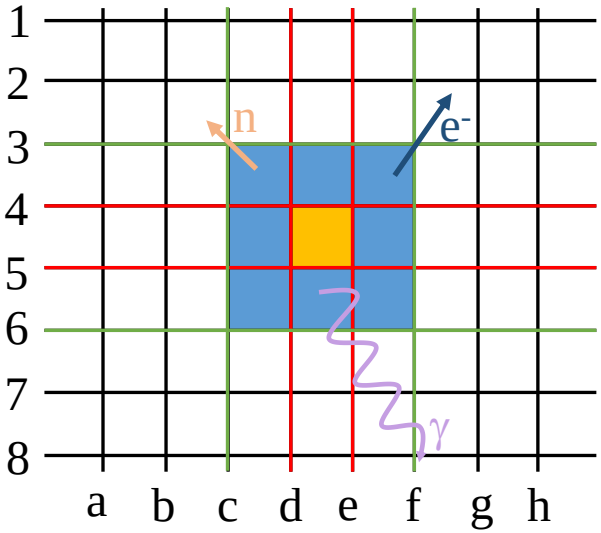
+ Veto detector
+ Shared time stamps

Determination of half life

+ Validation with implant-β-γ correlations



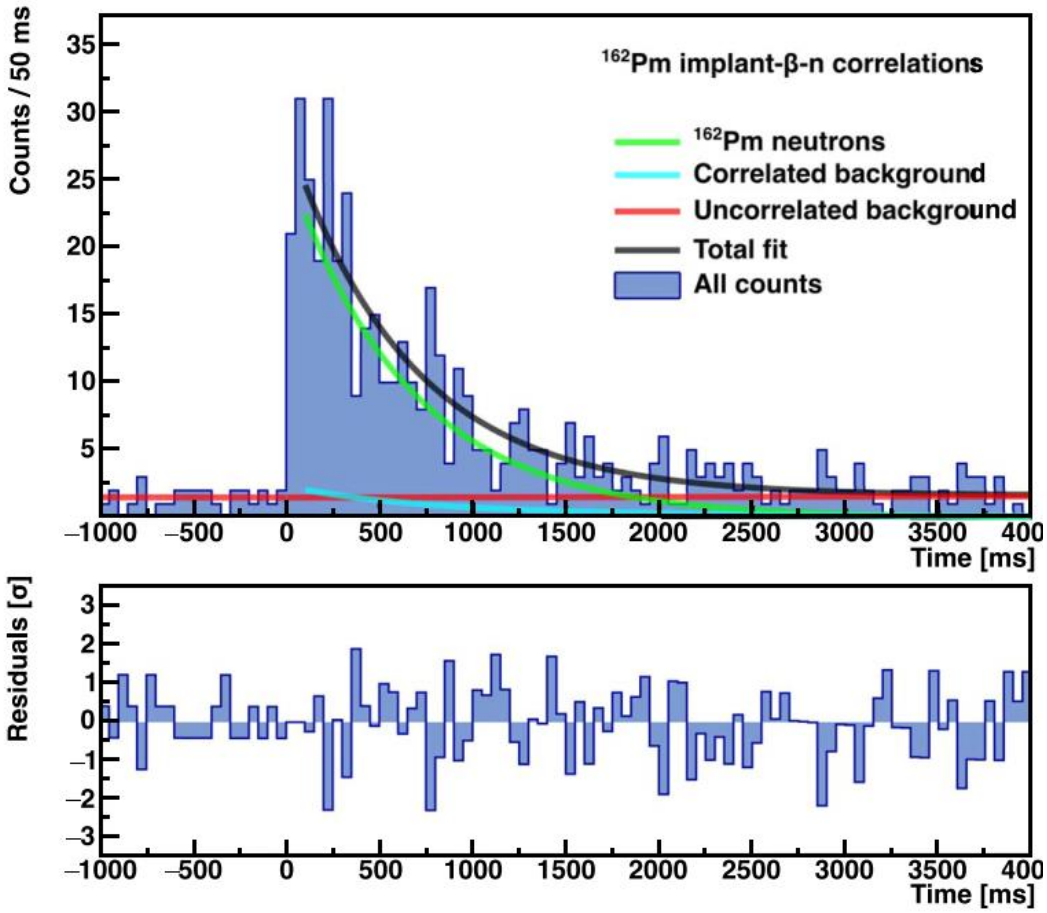


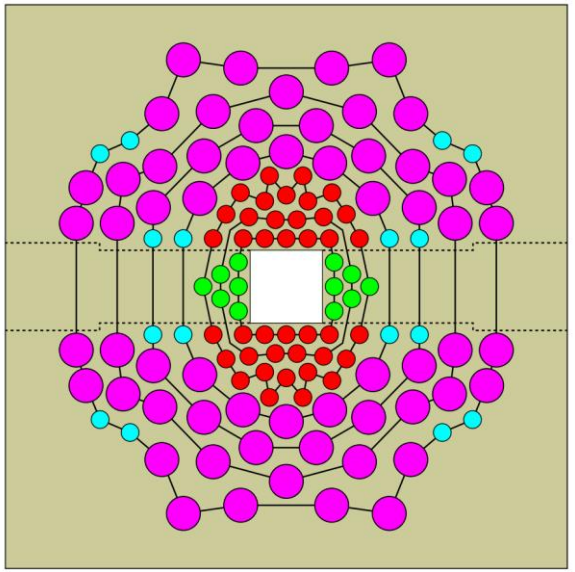


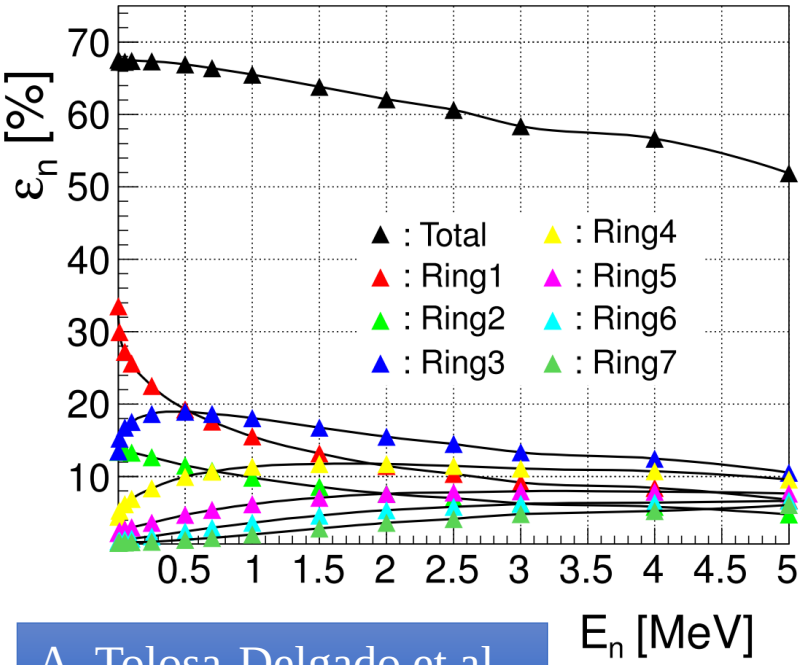
$$N_i(t) = \sum_{j=1}^{i} \frac{N_{10} \prod_{k=1}^{i-1} \lambda_k}{\prod_{\substack{k=1 \\ k \neq j}}^{i} (\lambda_k - \lambda_j)} e^{-\lambda_j t} \rightarrow A_{tot}(t) = \sum_{i=1}^{n} \lambda_i N_i(t)$$

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

Determination of P_n value





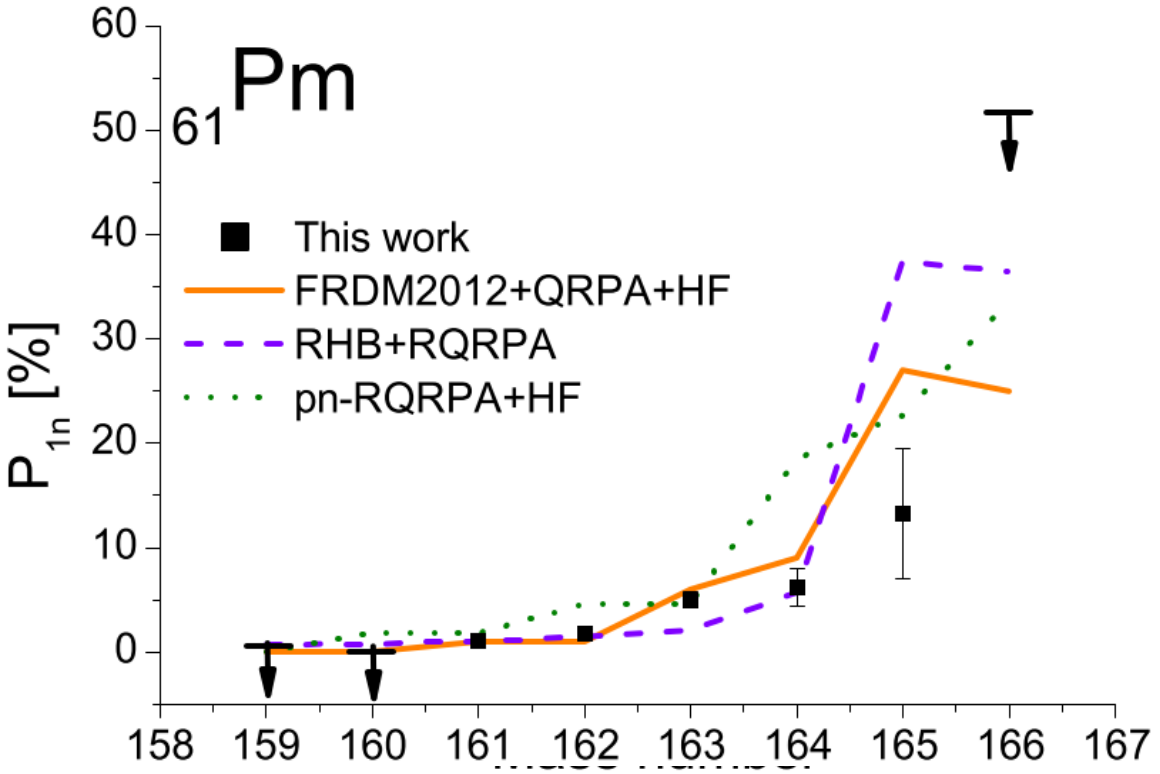


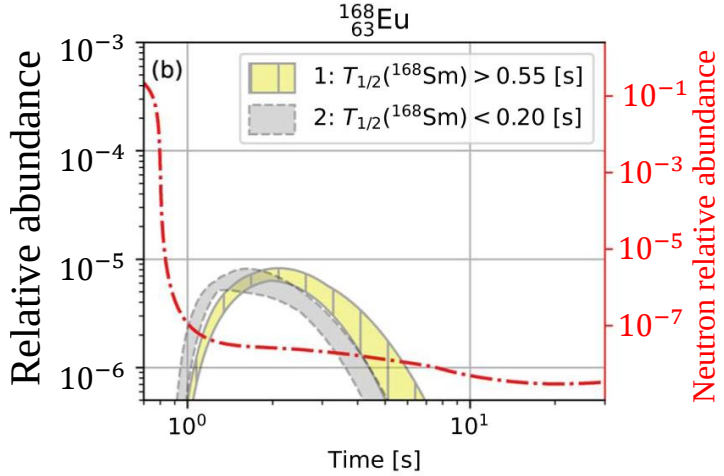
$$^{3}\mathrm{He} + \mathrm{n} \rightarrow {}^{1}\mathrm{H} + {}^{3}\mathrm{H} + 764\ \mathrm{keV}$$

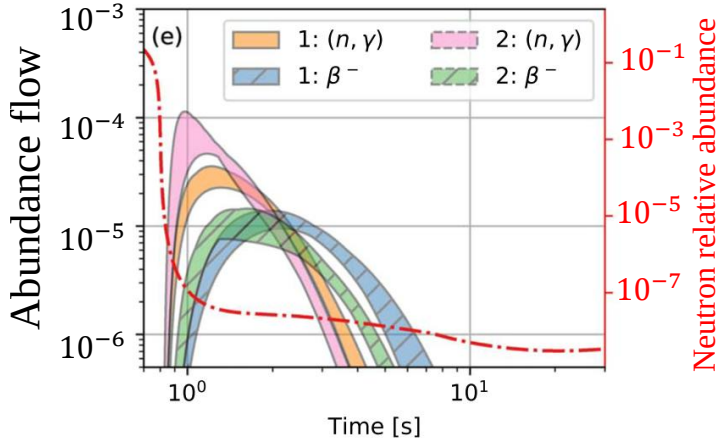
$$P_n \cong \frac{1}{\text{n det. efficiency}} \cdot \frac{\text{i}-\beta-\text{n events}}{\beta-\text{events}}$$

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

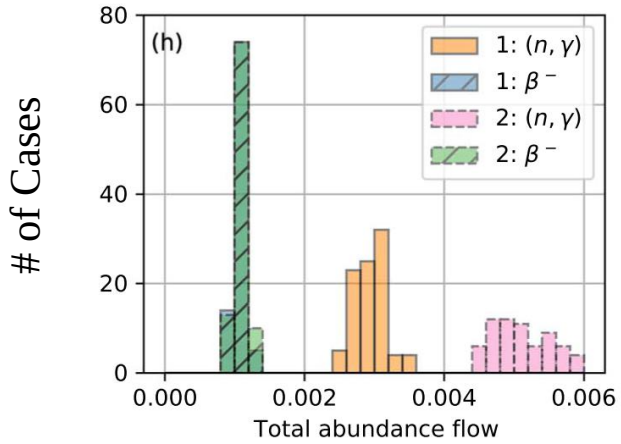
Results







- 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
- **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



Thank you for your attention!

The Astrophysical Journal, 936:107 (18pp), 2022 September 10 https://doi.org/10.3847/1538-4357/ac80fc

Measuring the β-decay Properties of Neutron-rich Exotic Pm, Sm, Eu, and Gd Isotopes to Constrain the Nucleosynthesis Yields in the Rare-earth Region

G. G. Kiss[1], A. Vitéz-Sveiczer[1,2], Y. Saito[3,4], A. Tarifeño-Saldivia[5,6], M. Pallas[5], J. L. Tain[6], I. Dillmann[3,7], J. Agramunt[6], A. Algora[1,6], C. Domingo-Pardo[6], A. Estrade[8], C. Appleton[9], J. M. Allmond[10], P. Aguilera[11,12], H. Baba[13], N. T. Brewer[10,14], C. Bruno[9], R. Caballero-Folch[3], F. Calvino[5], P. J. Coleman-Smith[15], G. Cortes[5], T. Davinson[9], N. Fukuda[13], Z. Ge[13], S. Go[13,16], C. J. Griffin[3], R. K. Grzywacz[10,14], O. Hall[9], A. Horváth[17], J. Ha[13,18], L. J. Harkness-Brennan[19], T. Isobe[13], D. Kahl[9], T. T. King[14], A. Korgul[20], S. Kovács[2], R. Krücken[3,4], S. Kubono[13], M. Labiche[15], J. Liu[21], J. Liang[3], M. Madurga[14], K. Miernik[20], F. Molina[11], A. I. Morales[6], M. R. Mumpower[22,23], E. Nacher[6], A. Navarro[5], N. Nepal[8], S. Nishimura[13], M. Piersa-Siłkowska[20], V. Phong[13], B. C. Rasco[10,14], B. Rubio[6], K. P. Rykaczewski[10], J. Romero-Barrientos[11], H. Sakurai[13], L. Sexton[3,9], Y. Shimizu[13], M. Singh[14], T. Sprouse[22,23], T. Sumikama[13], R. Surman[24], H. Suzuki[13], T. N. Szegedi[1], H. Takeda[13], A. Tolosa[6], K. Wang[8], M. Wolinska-Cichocka[25], P. Woods[9], R. Yokoyama[26], and Z. Xu[14]

Half-life measurement using implant$-(\beta-\gamma)$ time correlations in the region of neutron-rich lanthanides*

A. Vitéz-Sveiczer[a,b], S. Kovács[b], G. G. Kiss[a] on behalf of NP1112-RIBF93 collaboration.

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[b] University of Debrecen, 4001 Debrecen, Egyetem tér 1, Hungary

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Új Nemzeti Kiválóság Program

Innovációs és Technológiai Minisztérium

Possible astophysical sites

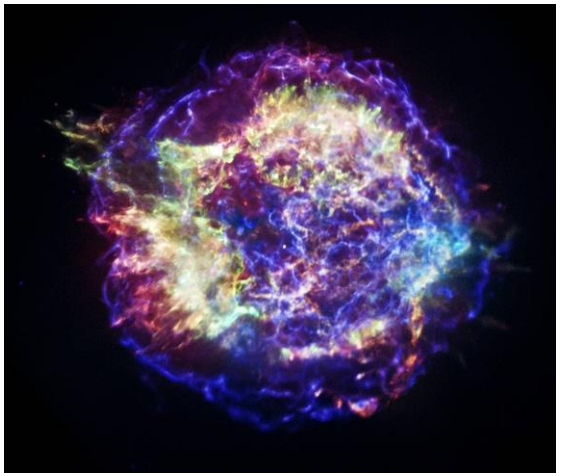
Fingerprints of the *r*-process nucleosynthesis:

- Metal poor stars
- Gravitational wave and optical signals

Successful r-process site characteristics:

- very large neutron densities $\left(> 10^{22} \frac{1}{\mathrm{cm}^3}\right)$
- sufficiently high temperatures, but not too high (~ GK)
- rapid expansion time scales (~1s)

Cassiopeia A



Artist's impression of two neutron stars

GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

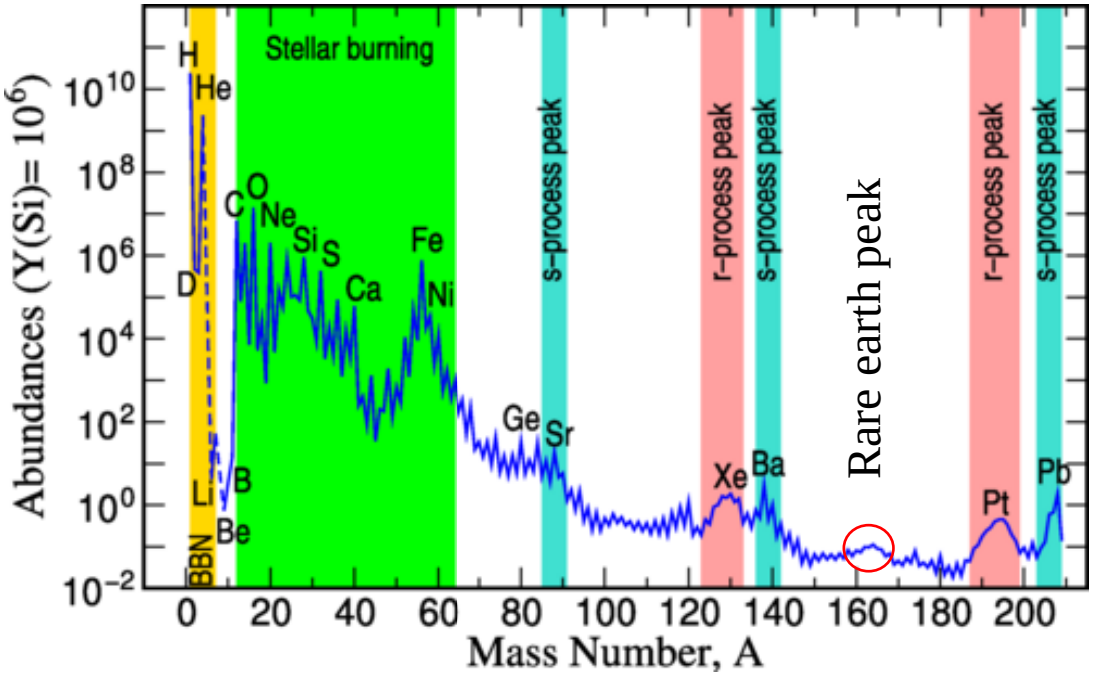
Cowan, J., Sneden, C., Nature **440,** 1151
Ji, A. et al., Nature **531,** 610
Siegel, D.M.et al., Nature **569,** 241
D.Watson et al., Nature **577,** 497
B. P. Abott et al., Phys Rev. Lett. **119**, 161101

Nucleosynthesys beyond the iron peak

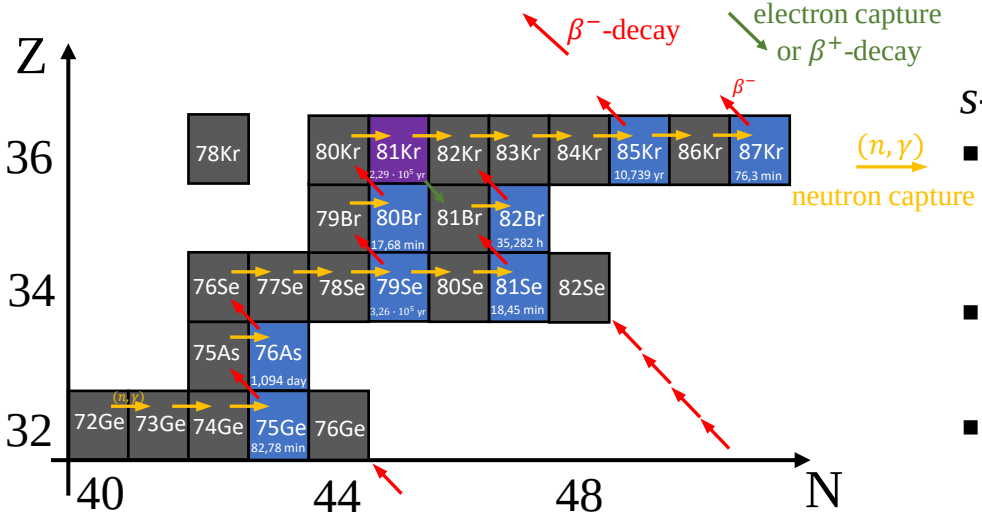
Neutron capture

- *s*-process
- ***r*-process**

p-process, *i*-process etc.



Part of the nuclide chart



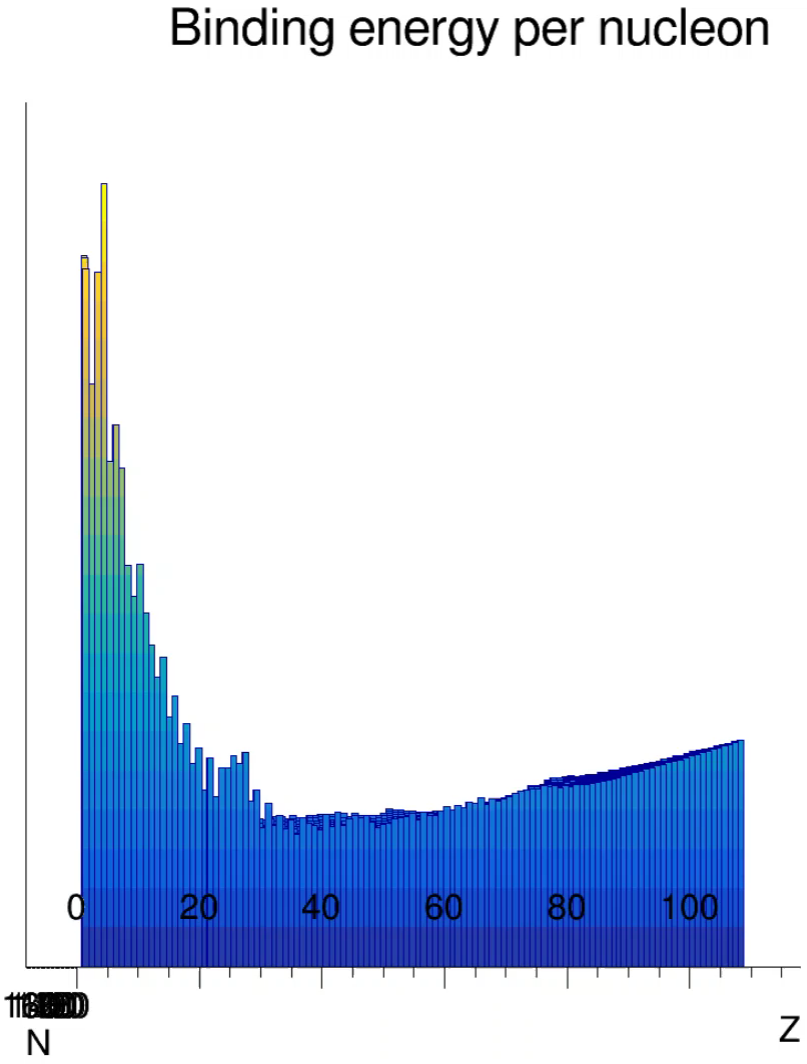
s-process

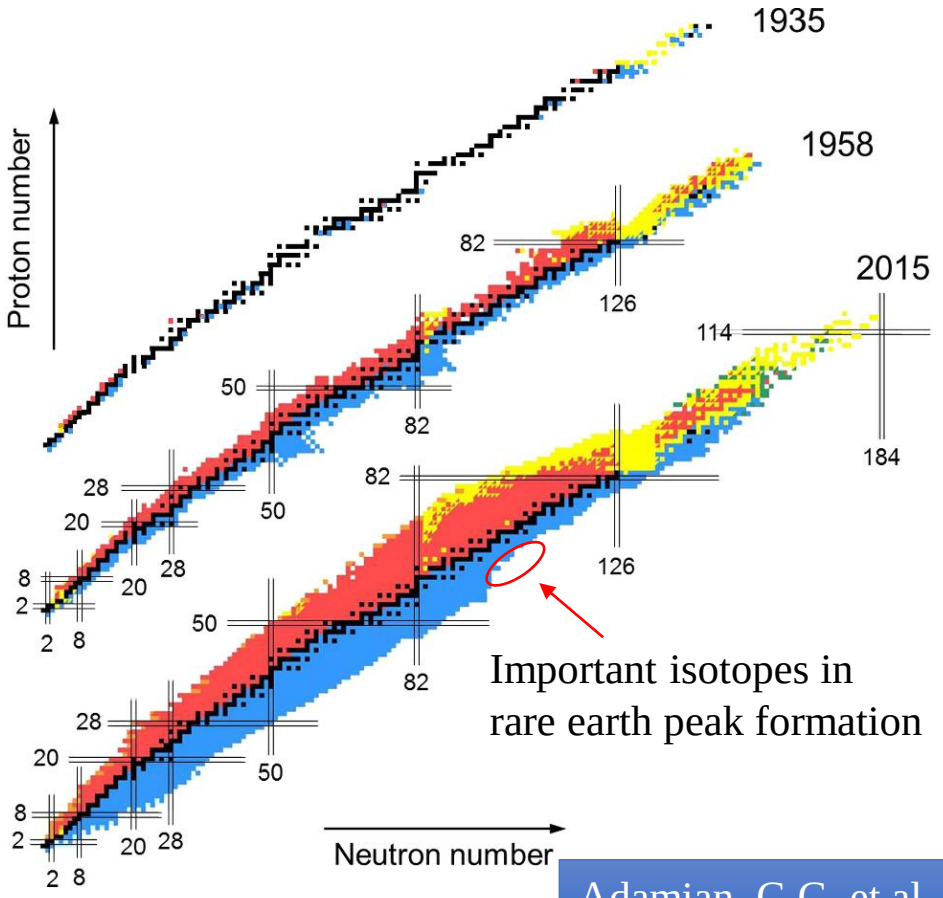
- Low neutron density $\left(10^6 - 10^{12}\,\frac{1}{\mathrm{cm}^3}\right)$
- Along the valley of stability
- Slow (~10000 years)

r-process

- High neutron density $\left(> 10^{22}\,\frac{1}{\mathrm{cm}^3}\right)$
- Away from the stability valley, near the neutron drip line
- Rapid (< 1 s)

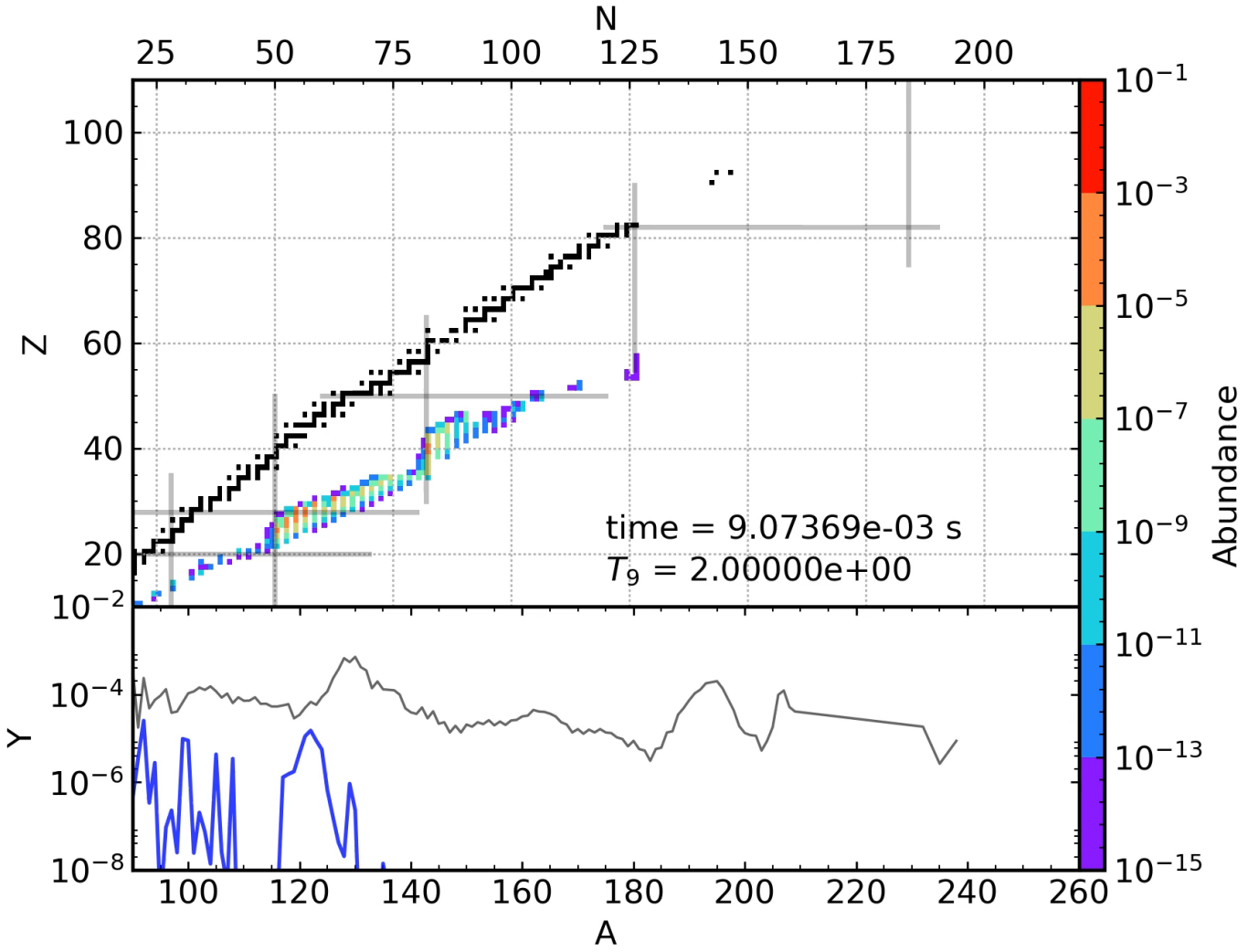
Binding energy per nucleon





Adamian, G.G. et al.
Eur. Phys. J. A **56,** 47

The *r*-process path

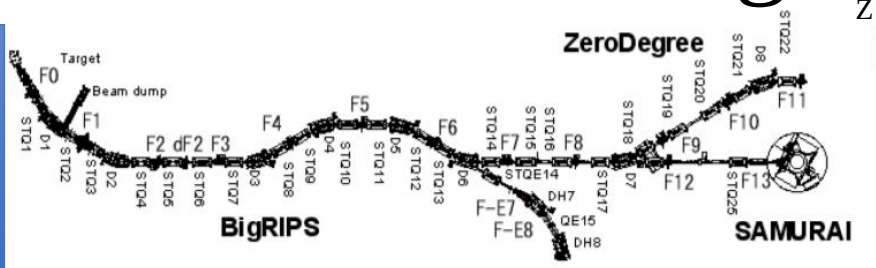


Erika M. Holmback

Particle Identification Diagram (PID)

BigRIPS separator

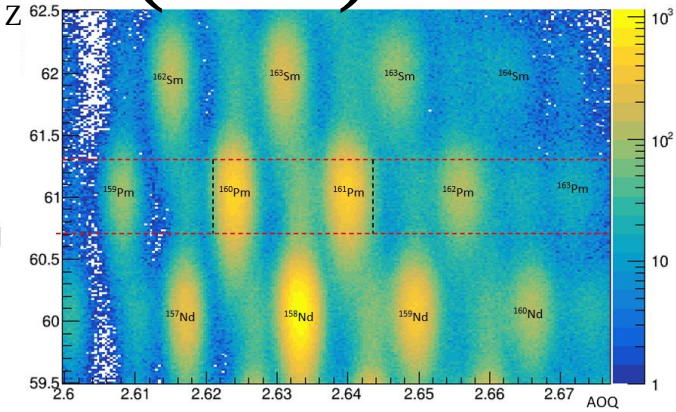
- ToF → v
- $B\rho$ → A/Q
- $\frac{dE}{dx}$ → Z

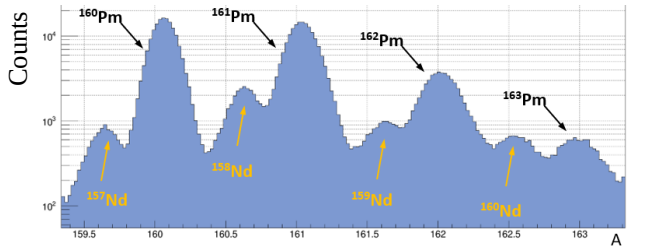


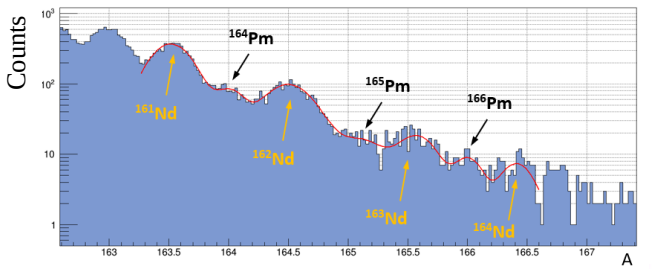
Cocktail beam

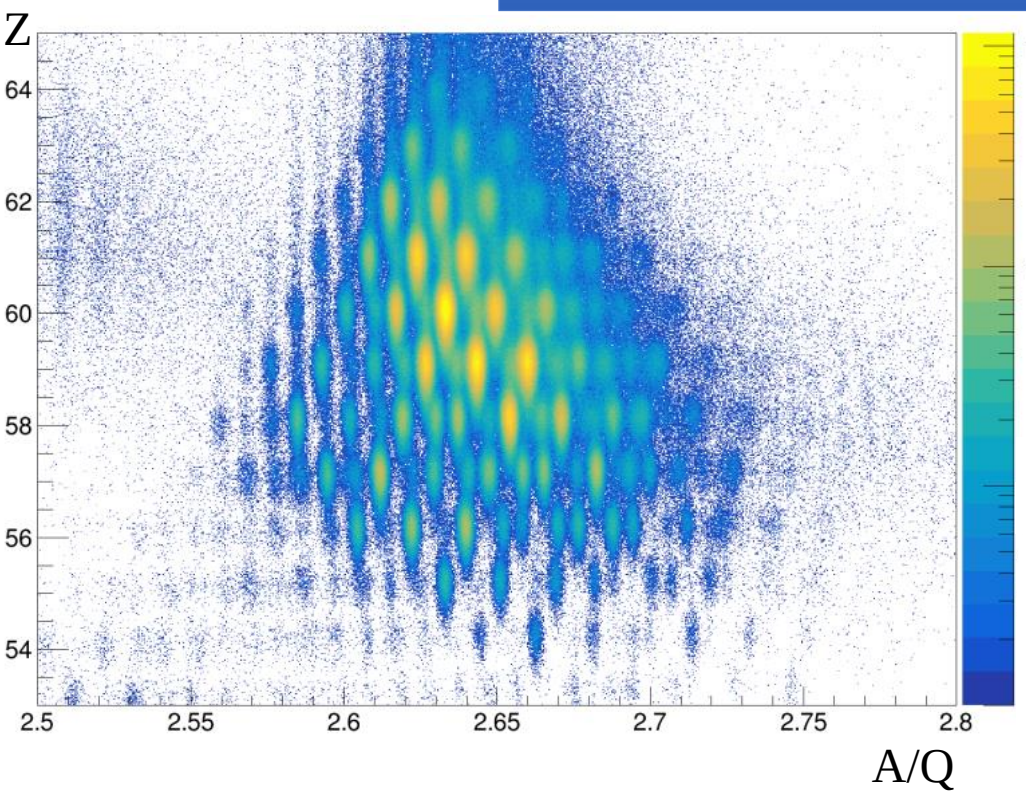
↓

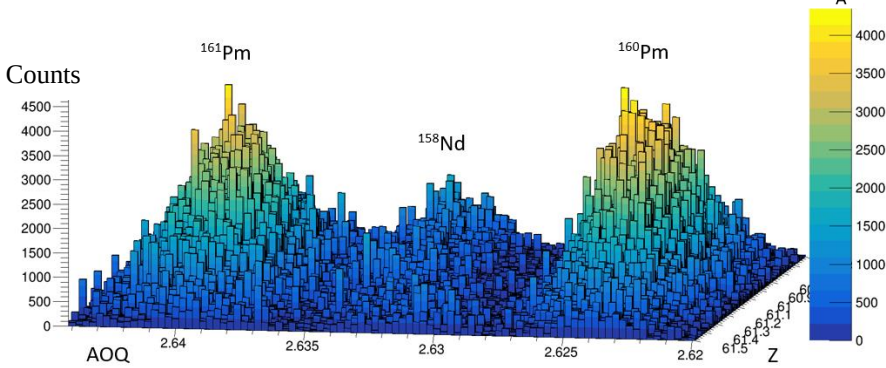
Simultaneous measurement





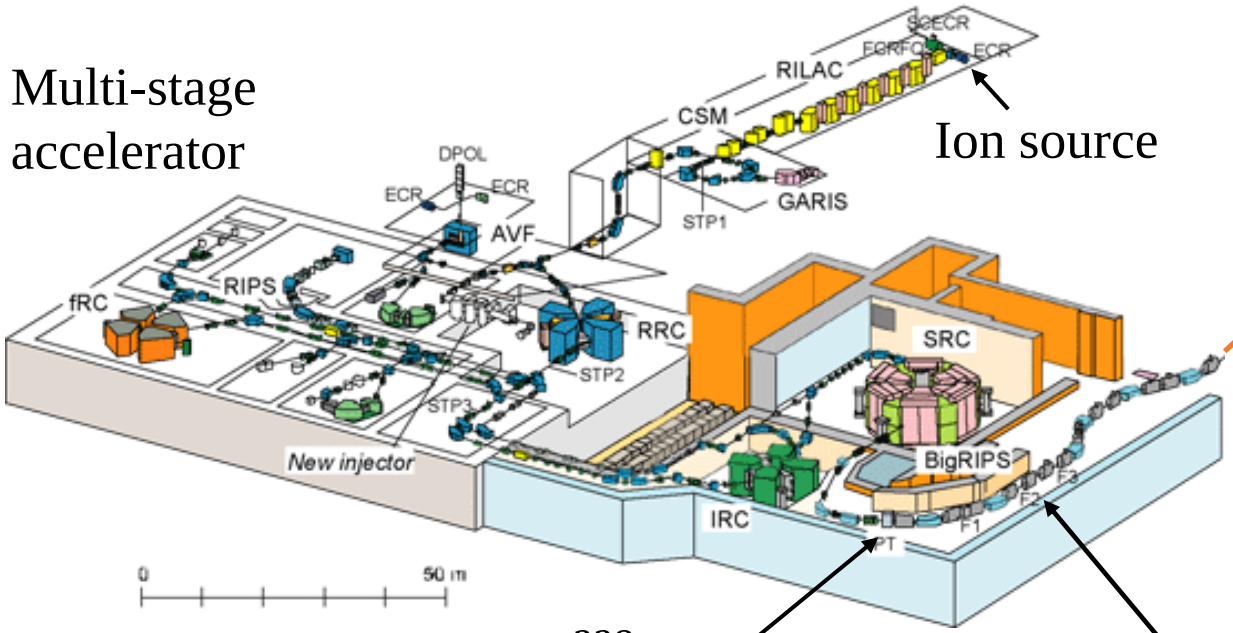






RIKEN Nishina Center-RIBF

Multi-stage accelerator

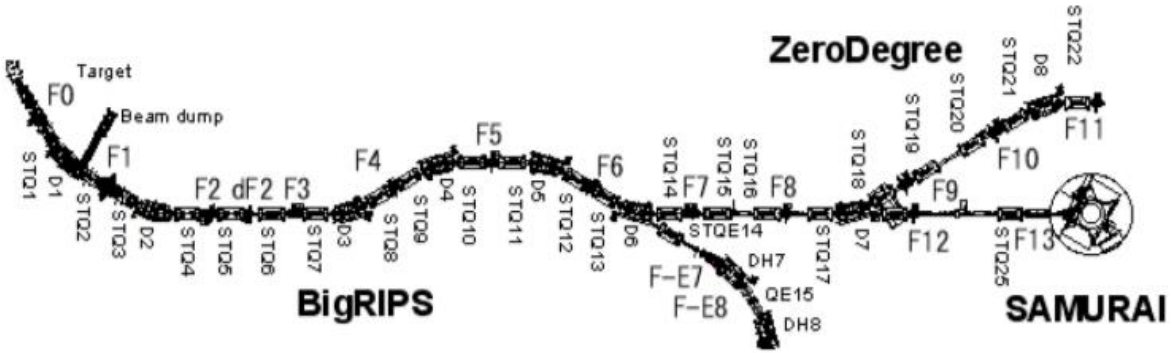


Ion source

AIDA and **BRIKEN** detectors

A. Tolosa-Delgado, Physics Research, A 925

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



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