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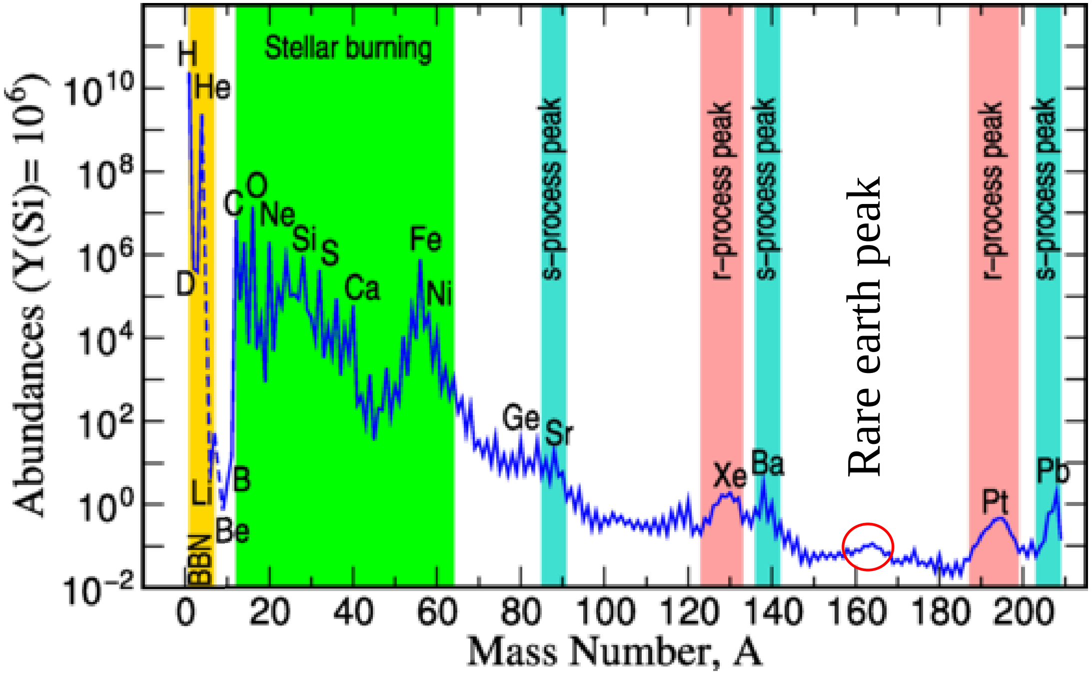
Measuring the half-life values for exotic rare-earth isotopes

Overview

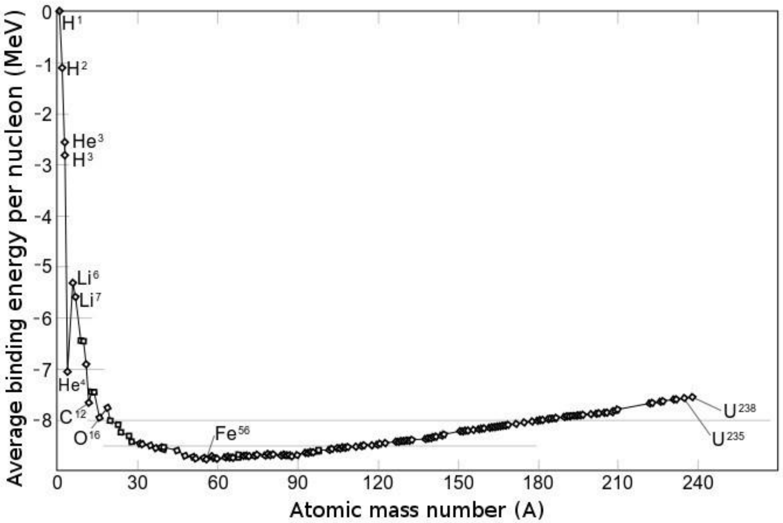
J.J. Cowan, Rev. Mod. Phys. 93, 015002

The formation of the elements is the result of different processes:

- Big Bang Nucleosynthesis
- Stellar burning



Average binding energy per nucleon



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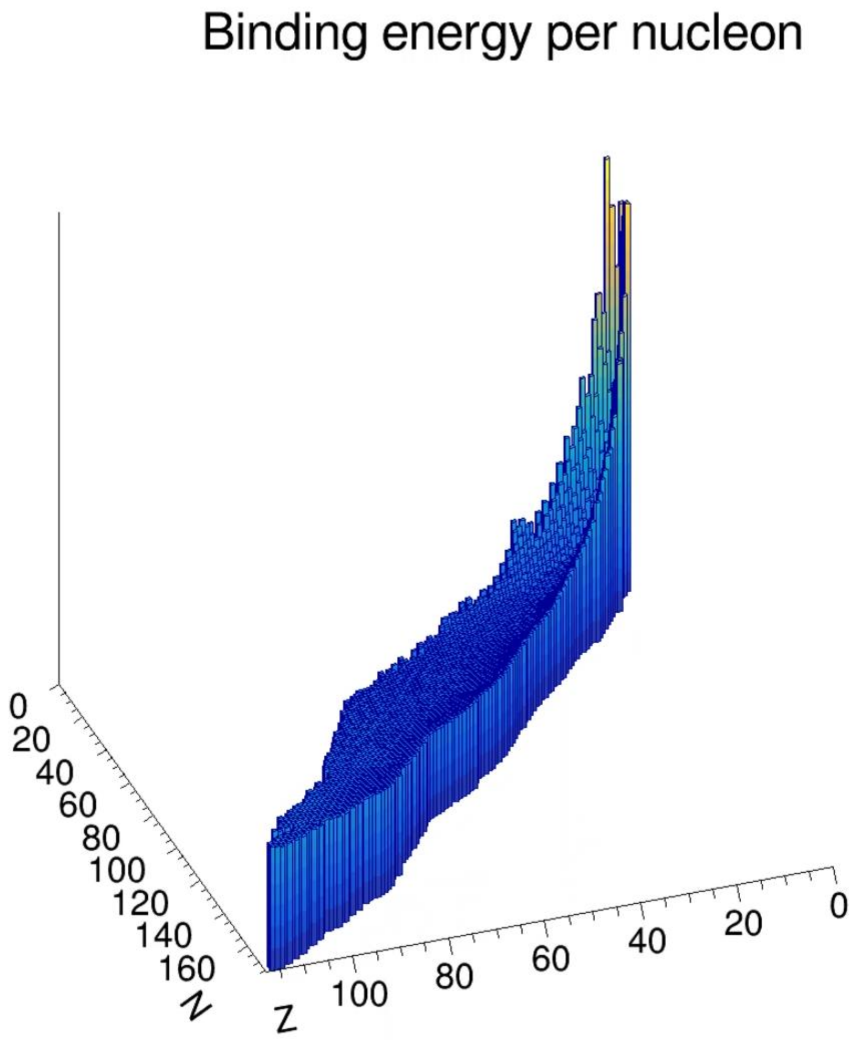
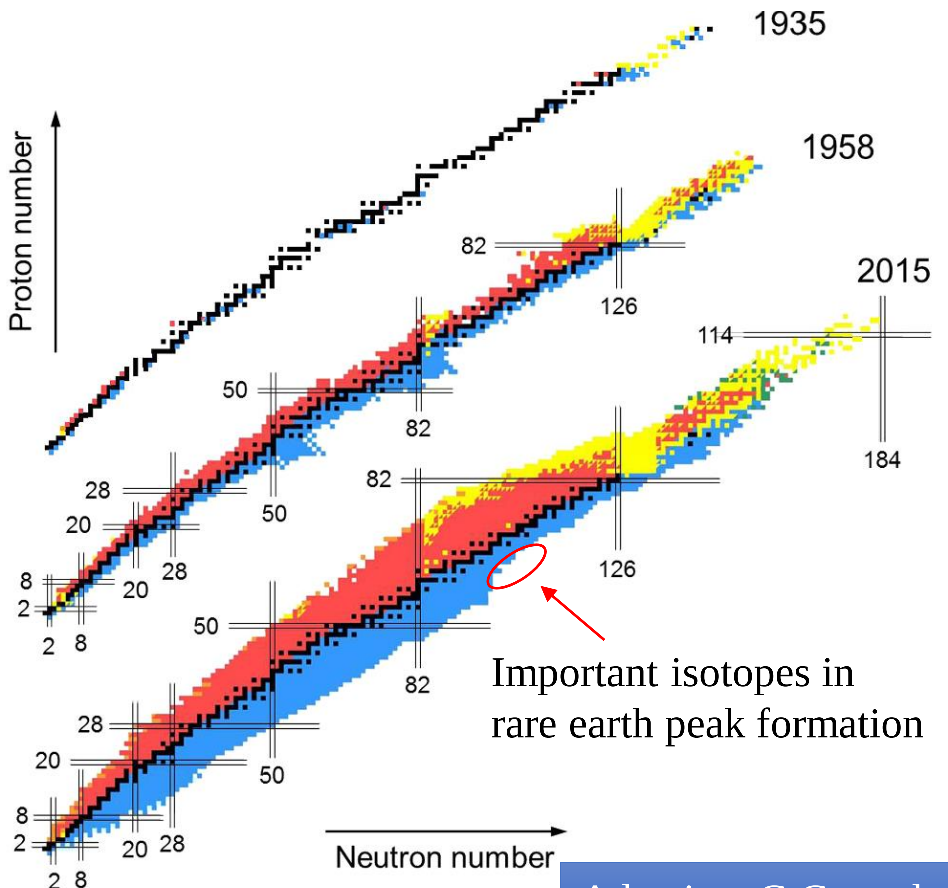
Why is it a little bit suprising that there are heavier isotopes?

Binding energy per nucleon





Important isotopes in rare earth peak formation

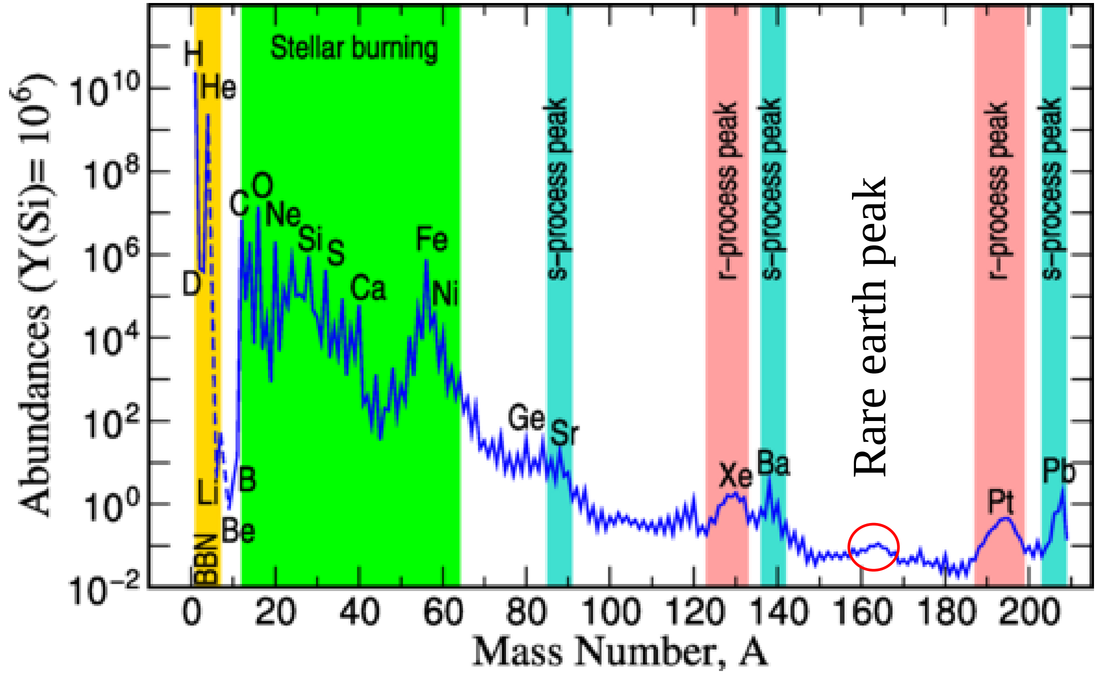
Adamian, G.G. et al.
Eur. Phys. J. A **56,** 47

Nucleosynthesys beyond the iron peak

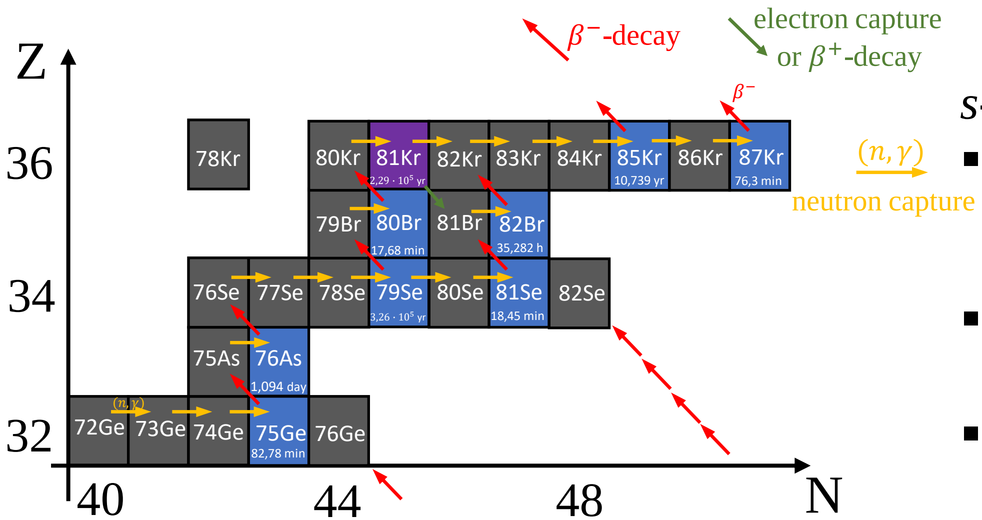
Neutron capture

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

p-process, *i*-process etc.



Part of the nuclide chart



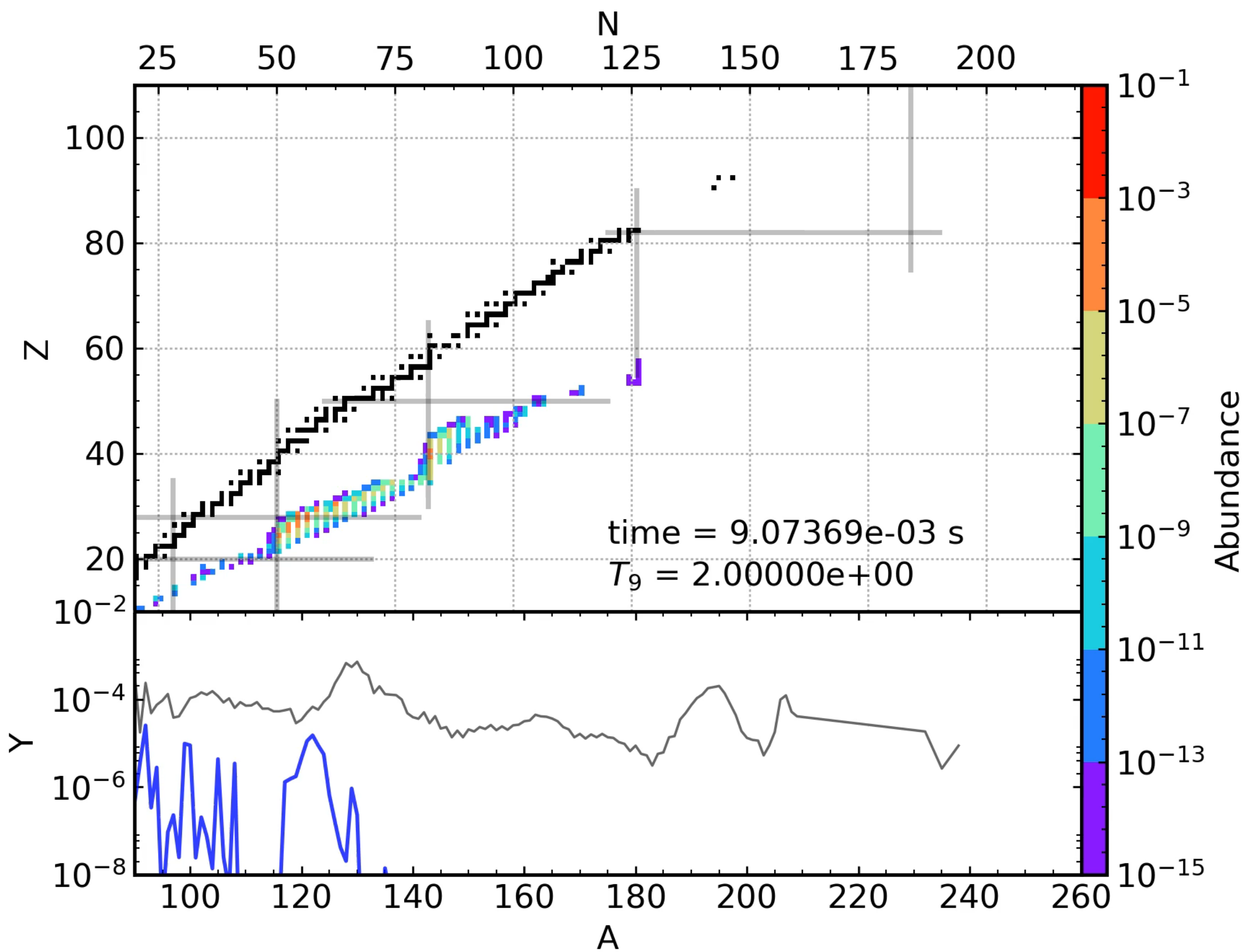
s-process

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

r-process

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

The *r*-process path



Erika M. Holmback

Possible astophysical sites

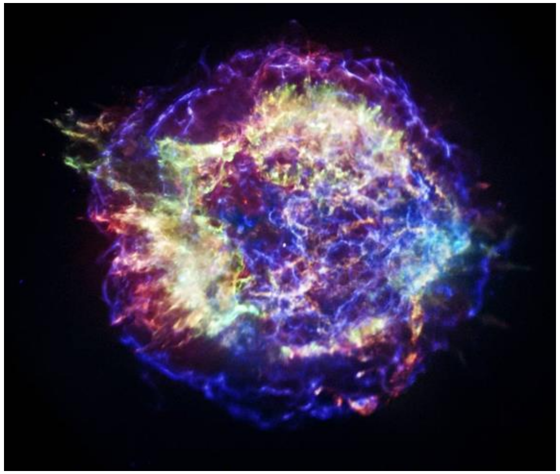
Fingerprints of the *r*-process nucleosynthesis:

- 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

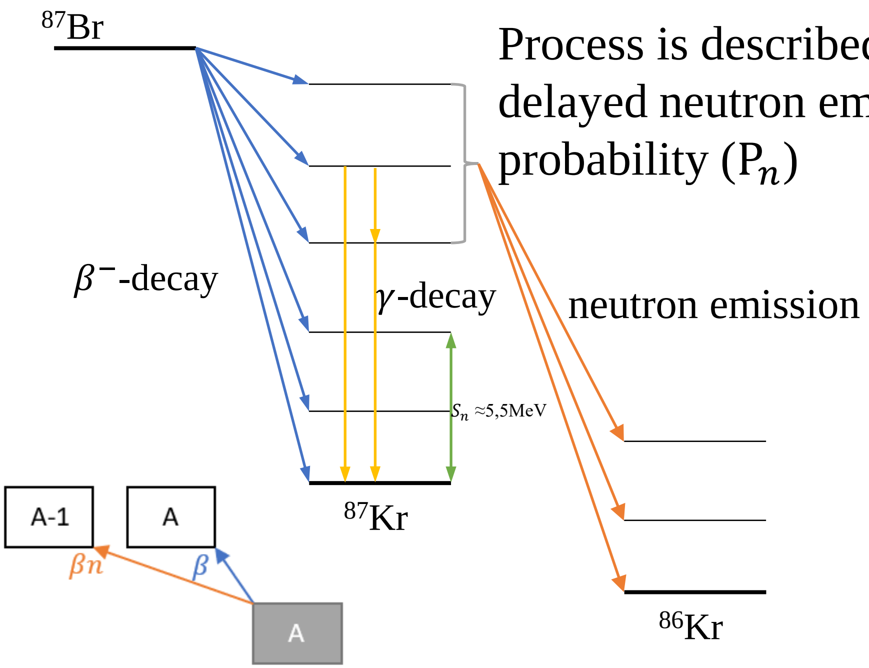
<u>**GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral**</u>

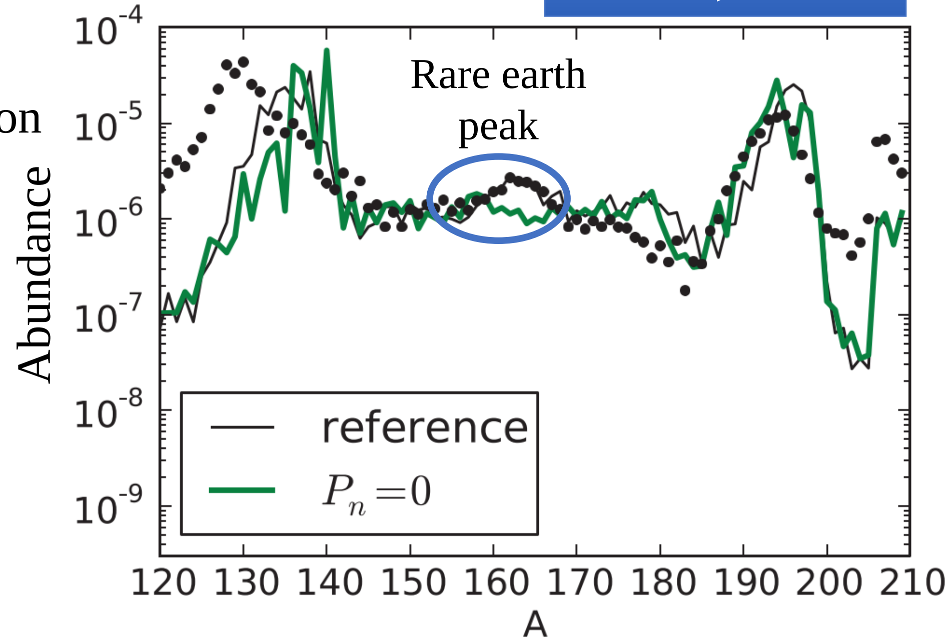
Cowan, J., Sneden, C., Nature **440,** 1151
Ji, A. et al., Nature **531,** 610
Siegel, D.M.et al., Nature **569,** 241
D.Watson et al., Nature **577,** 497
B. P. Abott et al., Phys Rev. Lett. **119**, 161101

Rare earth peak formation

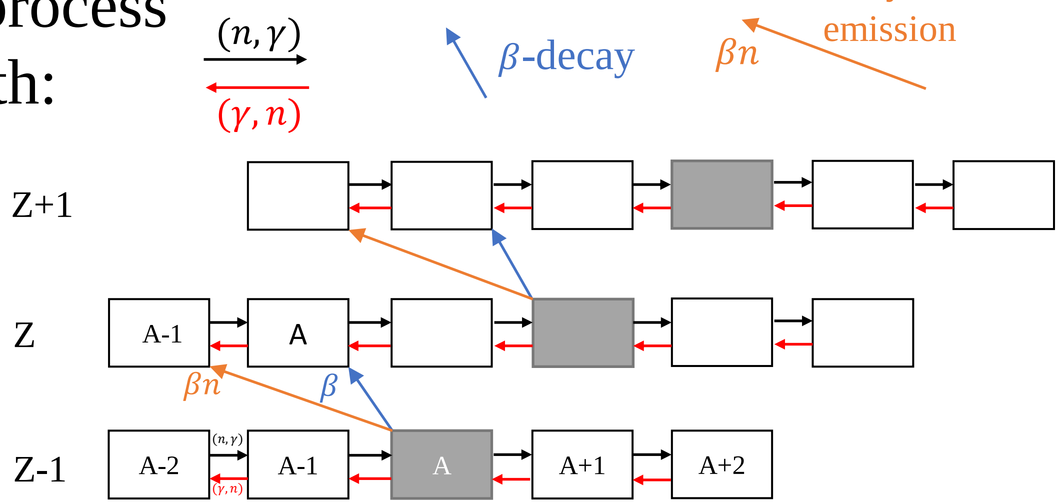
A. Arcones, PRC 83, 045809

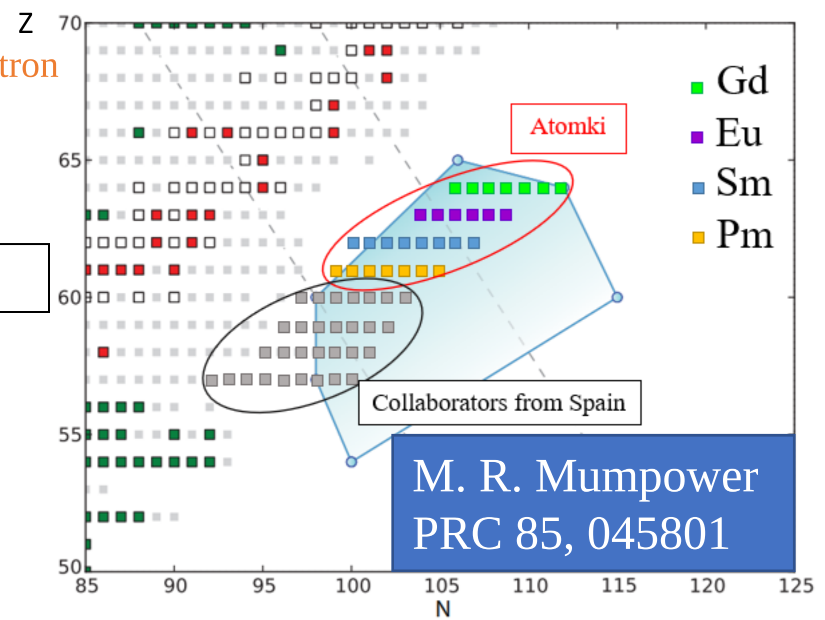
Process is described by delayed neutron emission probability (P_n)





r-process path:

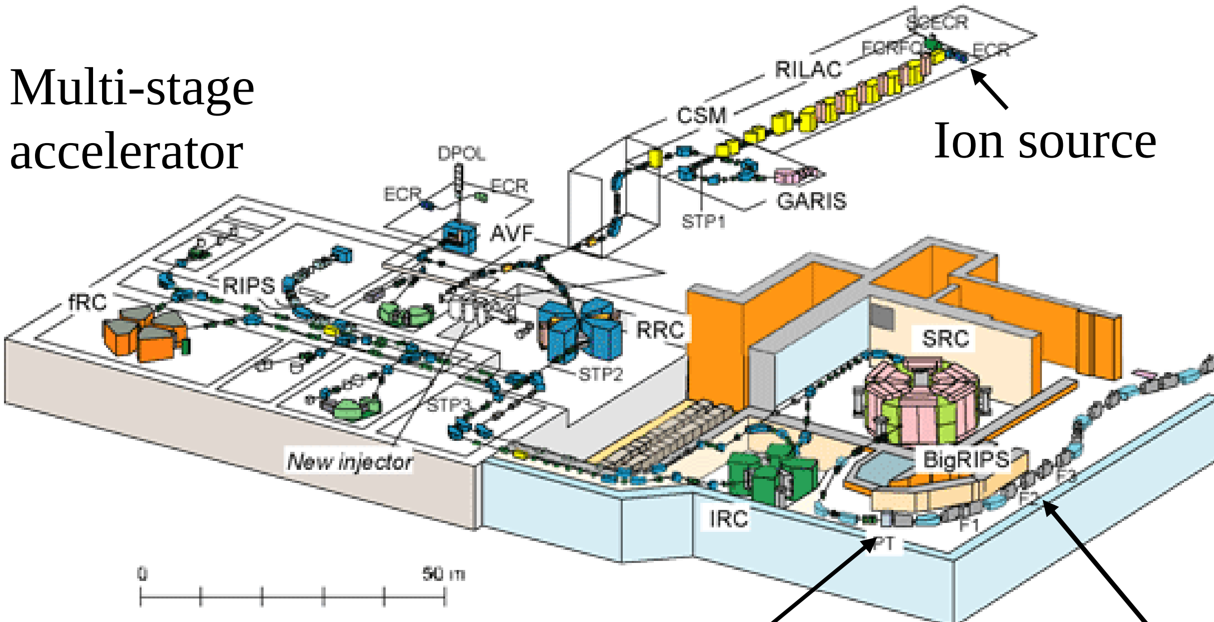




M. R. Mumpower PRC 85, 045801

RIKEN Nishina Center-RIBF

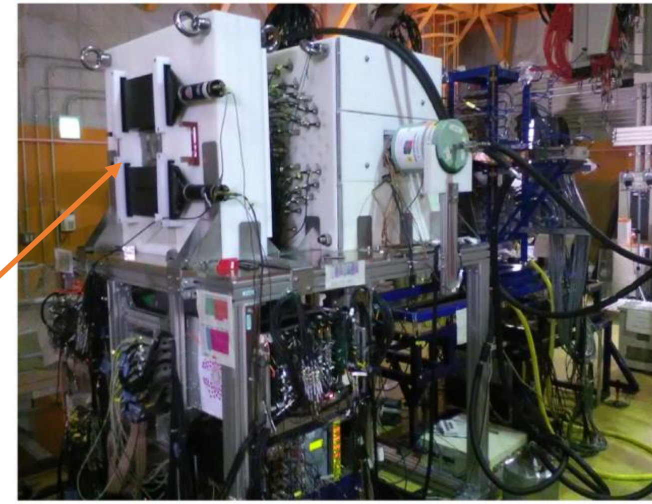
Multi-stage accelerator



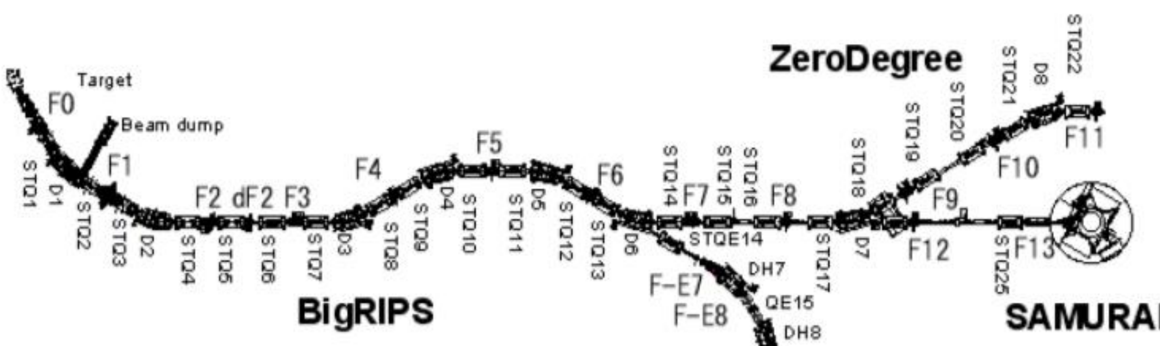
Ion source

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

AIDA and **BRIKEN** detectors



A. Tolosa-Delgado,
Physics Research, A 925



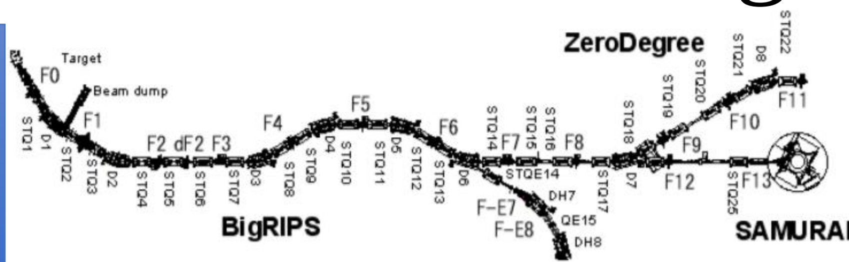
BigRIPS separator

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

Particle Identification Diagram (PID)

BigRIPS separator

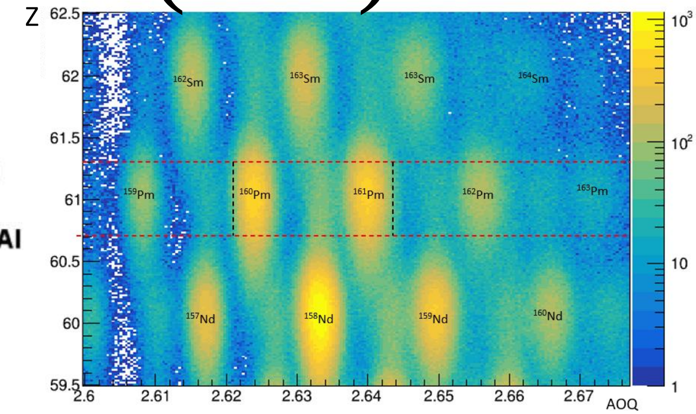
- ToF $\longrightarrow$ v
- $B\rho \longrightarrow$ A/Q
- $\frac{dE}{dx} \longrightarrow$ Z

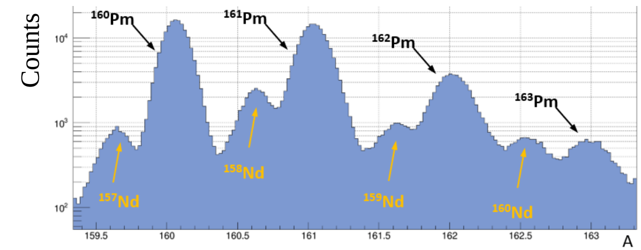


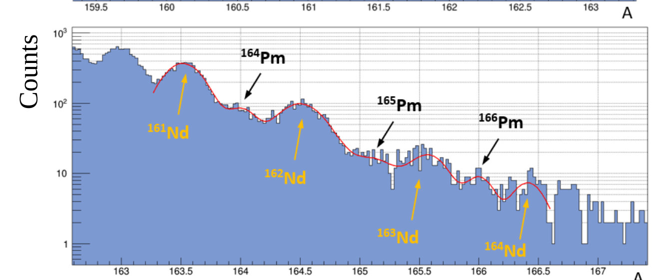
Cocktail beam

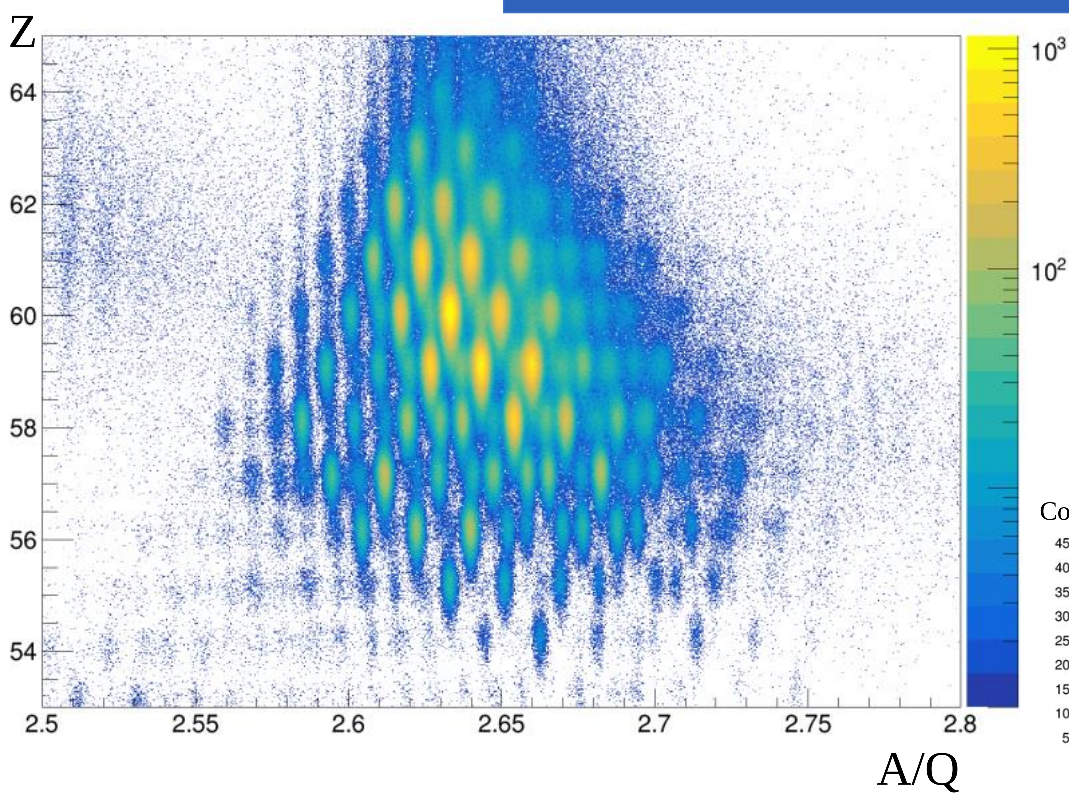
↓

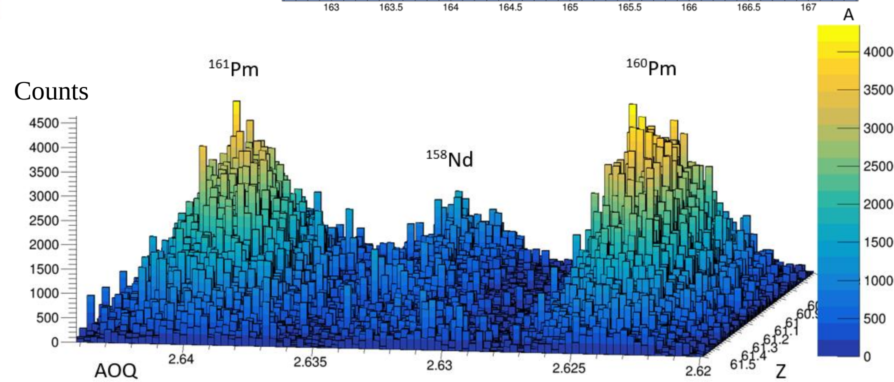
Simultaneous measurement



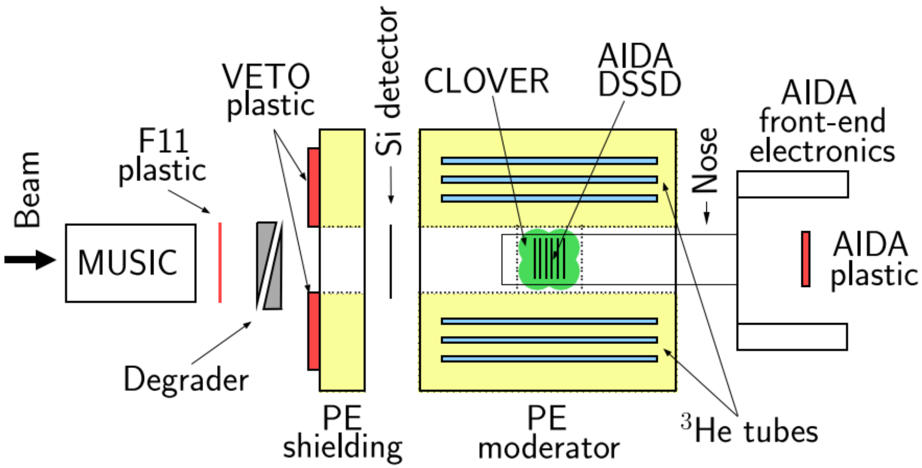


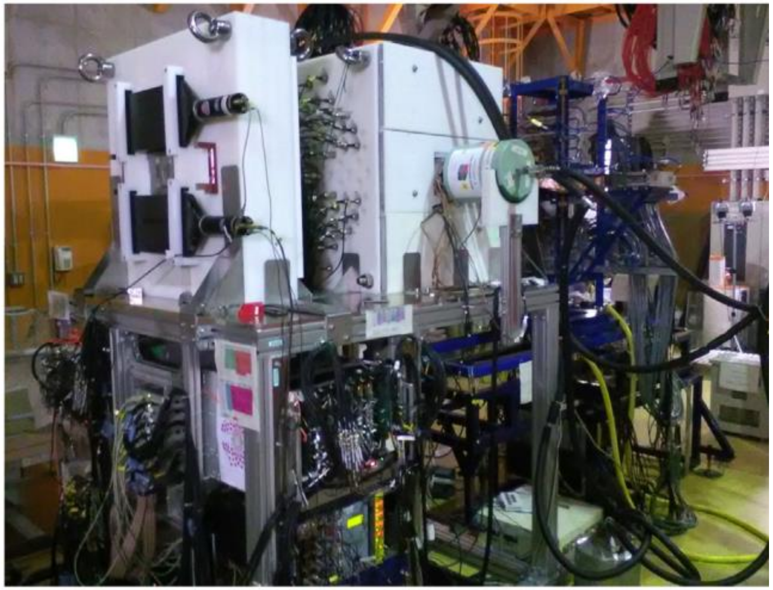




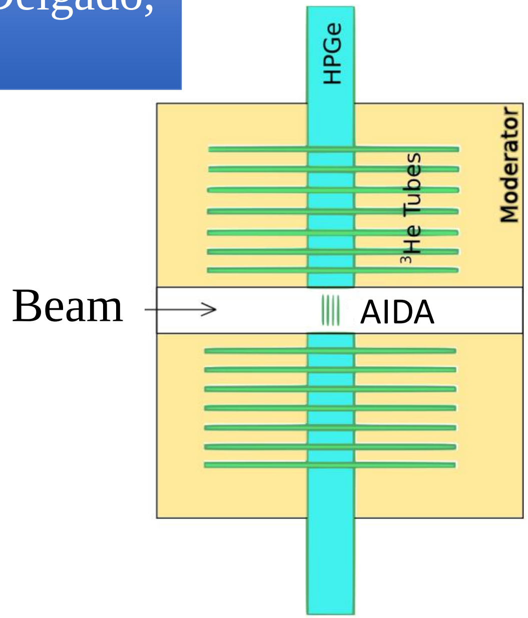


AIDA and BRIKEN





A. Tolosa-Delgado, NIM A 925



Detection of:

AIDA: 6 DSSD → implantation, β-events

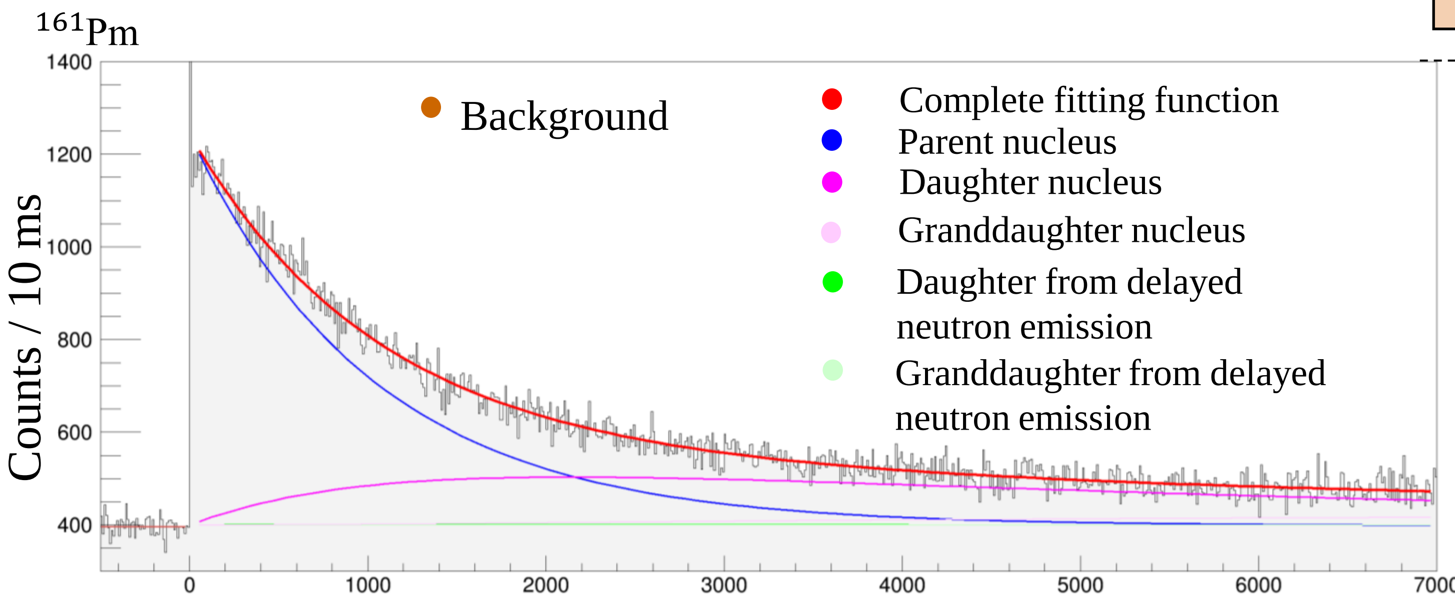
2 clover HPGe detectors → γ-photons

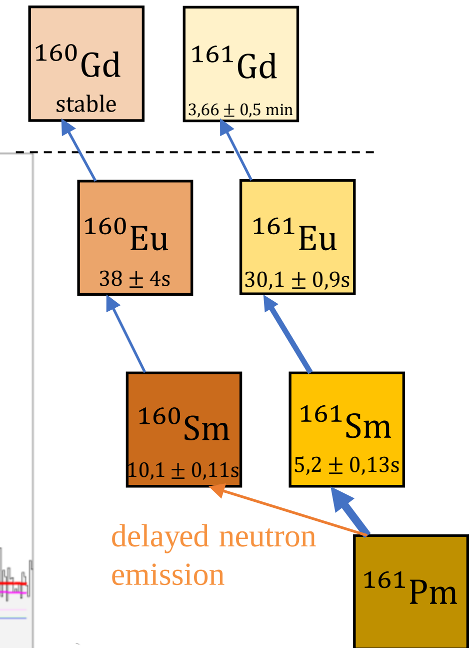
140 ^{3}He filled proportional counters → neutrons

+ Veto detectors
+ Shared time stamps

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

Determination of half life

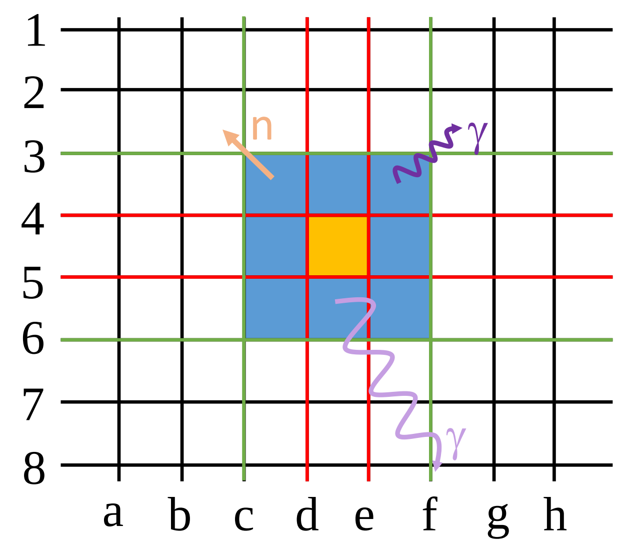




By detecting the electron emissions following β-decay, the implantation-beta histogram can be constructed.

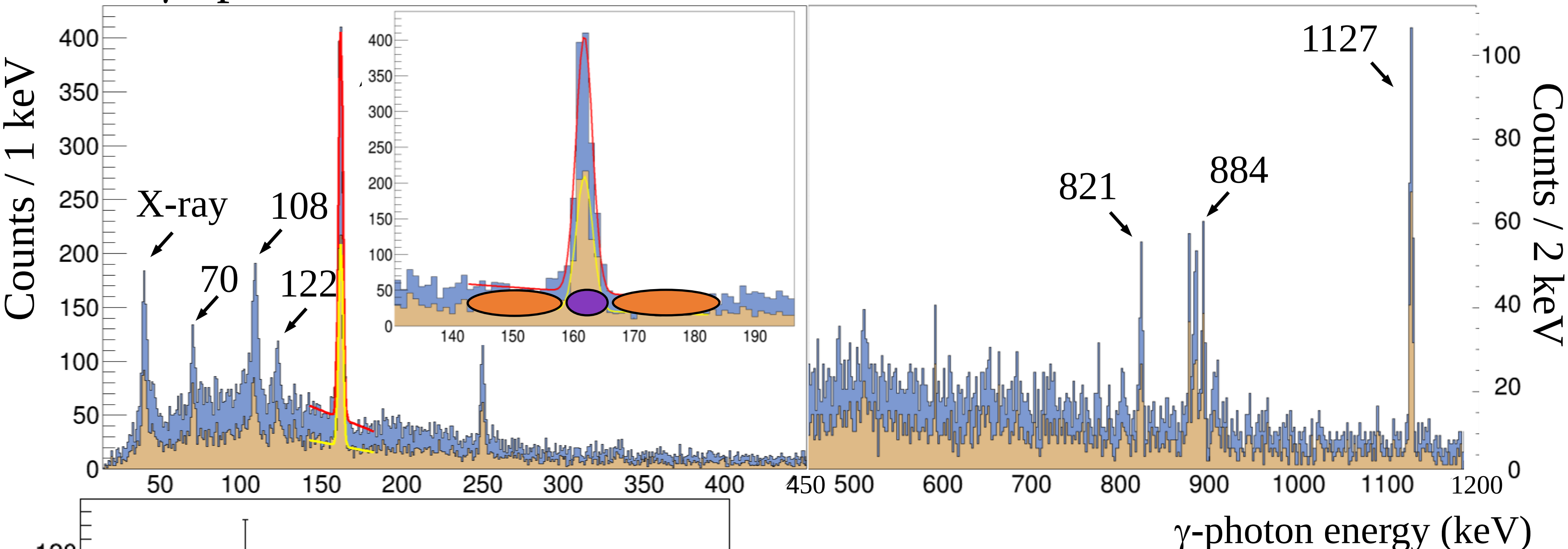
Decay series members appear together, the activity of each nucleus is determined by solving a system of differential equations: the Bateman formula (1910)

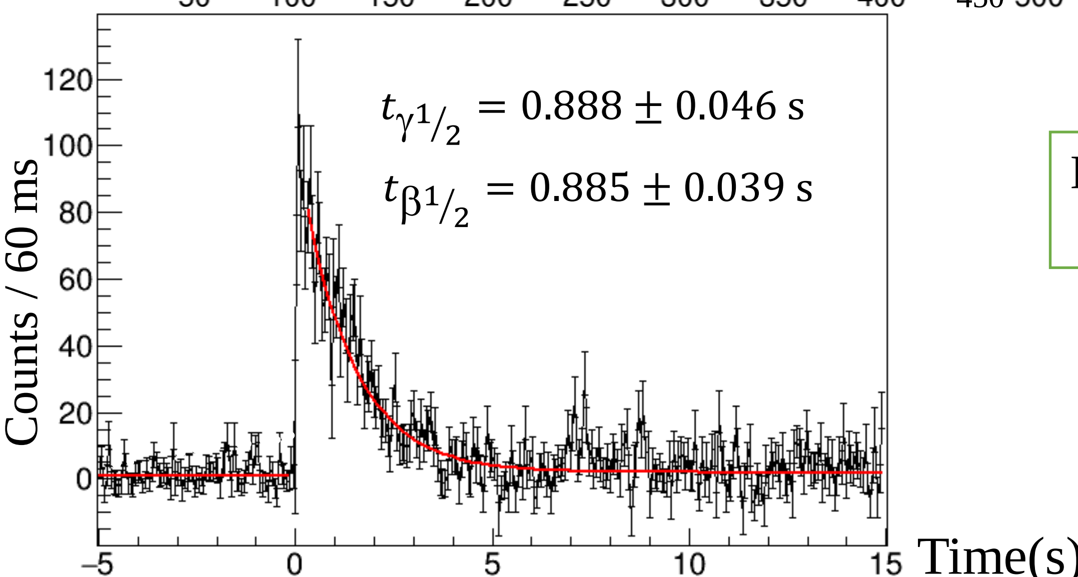
$$N_i(t) = \sum_{j=1}^{i} \frac{N_{10} \prod_{k=1}^{i-1} \lambda_k}{\prod_{\substack{k=1 \\ k \neq j}}^{i} (\lambda_k - \lambda_j)} e^{-\lambda_j t} \rightarrow A_{tot}(t) = \sum_{i=1}^{n} \lambda_i N_i(t)$$



Implantation-β-γ fitting

^{160}Pm γ-spectrum:



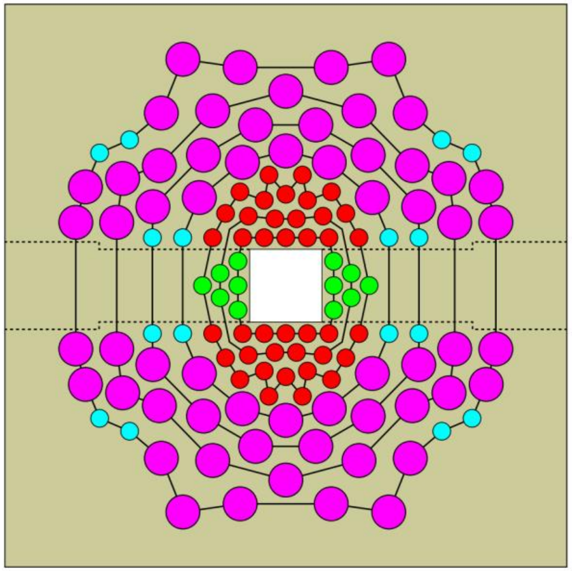


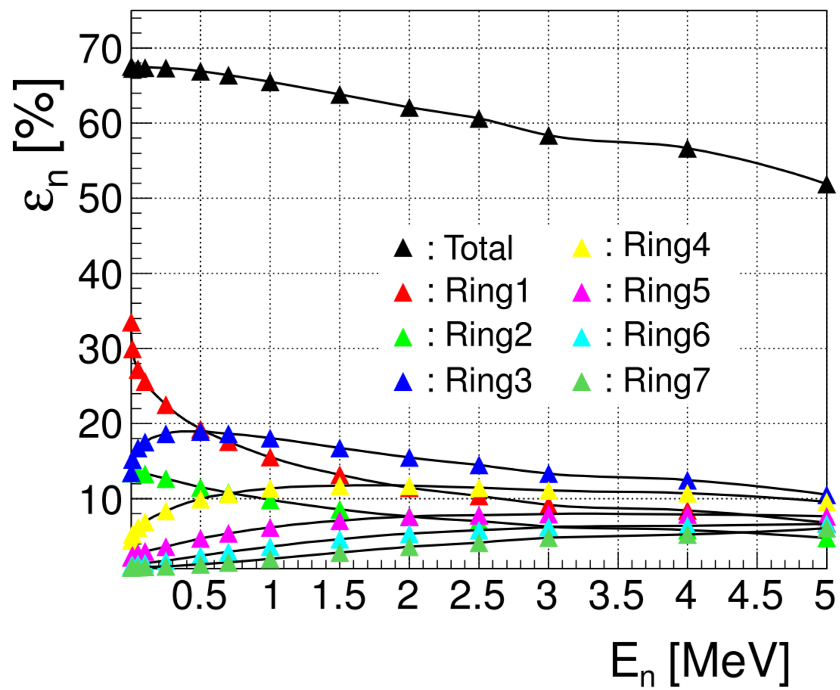
Independent from the half-live values of the later decay series members

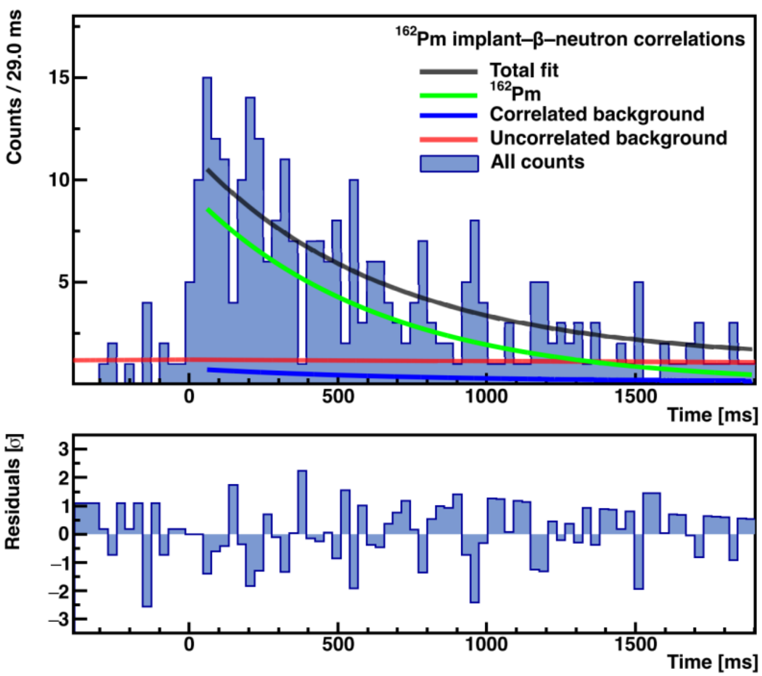
↕

Requires higher statistics

Determination of P_n value







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

Determination of P_n value from i-β-n coincidence events

$$P_n = \frac{1}{\text{n det. efficiency}} \cdot \frac{\text{i−β−n events}}{\beta\text{−events}}$$

Thank you for your attention!

This work was granted by **ÚNKP-21-2-II-DE-245**.