Study of ^{82}Ga populated from the beta decay of ^{82}Zn

ISS441 Collaboration

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Outline

- IS441 experiment – scientific motivation
- Experimental facility – ISOLDE, CERN
- Experimental setup
- β^- decay chains of ^{82}Zn
  - ^{82}Rb contamination issue
  - Identification of ^{82}Zn
- Halflife of ^{82}Zn
- β / β-n decay ratio of ^{82}Zn
- Tentative level schemes for $^{82,81}Ga$

IS441 experiment

- IS441 experiment:
  - Ultra Fast Timing measurements campaign on neutron rich nuclei in the vicinity of ^{78}Ni.

Z	80Se STABLE 49.61% 2β-	81Se 18.45 M β-: 100.00%	82Se STABLE 8.73%	83Se 22.3 M β-: 100.00%	84Se 3.26 M β-: 100.00%	85Se 32.9 S β-: 100.00%	86Se 14.3 S β-: 100.00%	87Se 5.50 S β-: 100.00% β-n: 0.20%	88Se 1.53 S β-: 100.00% β-n: 0.67%
33	79As 9.01 M β-: 100.00%	80As 15.2 S β-: 100.00%	81As 33.3 S β-: 100.00%	82As 19.1 S β-: 100.00%	83As 13.4 S β-: 100.00%	84As 4.2 S β-: 100.00% β-n: 0.18%	85As 2.021 S β-: 100.00% β-n: 59.40%	86As 0.945 S β-: 100.00% β-n: 26.00%	87As 0.56 S β-: 100.00% β-n: 15.40%
32	78Ge 88.0 M β-: 100.00%	79Ge 18.98 S β-: 100.00%	80Ge 29.5 S β-: 100.00%	81Ge 7.6 S β-: 100.00%	82Ge 4.56 S β-: 100.00%	83Ge 1.85 S β-: 100.00%	84Ge 0.954 S β-: 100.00% β-n: 10.20%	85Ge 0.56 S β-: 100.00% β-n: 14.00%	86Ge >150 NS β-n β-
31	77Ga 13.2 S β-: 100.00%	78Ga 5.09 S β-: 100.00%	79Ga 2.847 S β-: 100.00% β-n: 0.09%	80Ga 1.676 S β-: 100.00% β-n: 0.86%	81Ga 1.217 S β-: 100.00% β-n: 11.90%	82Ga 0.599 S β-: 100.00% β-n: 19.80%	83Ga 308.1 MS β-: 100.00% β-n: 62.80%	84Ga 0.085 S β-: 100.00% β-n: 74.00%	85Ga <100 MS β-n > 35.0% β-
30	76Zn 5.7 S β-: 100.00%	77Zn 2.08 S β-: 100.00%	78Zn 1.47 S β-: 100.00%	79Zn 0.995 S β-: 100.00% β-n: 1.30%	80Zn 0.54 S β-: 100.00% β-n: 1.00%	81Zn 304 MS β-: 100.00% β-n: 7.50%	82Zn >150 NS β-	83Zn >300 NS β-n β-	84Zn >633 NS β-2n β-
	46	47	48	49	50	51	52	53	N

- ^{82}Zn beta decay results:
  - Astrophysical interest:
    - Interesting region for describing the r – process dynamics - the vicinity of the N=50 shell closure
    - Nuclear properties of interest for the study of the r – process:
      - **β decay halflifes**
      - **β delayed neutron emission probabilities P_n**
  - Verify model predictions and put constraints on the model parameters

^{82}Zn and ^{82}Ga data

Constrain shell model interactions.

^{82}Zn

Z = 30

2 p in (1f7/2 2p3/2 1f5/2 2p1/2) orbitals

N = 52

2 n in (1g9/2 1g7/2 2d5/2 2d3/2 3s1/2) orbitals

For beta decay lifetime predictions:

- fp and gds shells valence space for protons
- gds shell valence space for neutrons

^{82}Ga

Z = 31

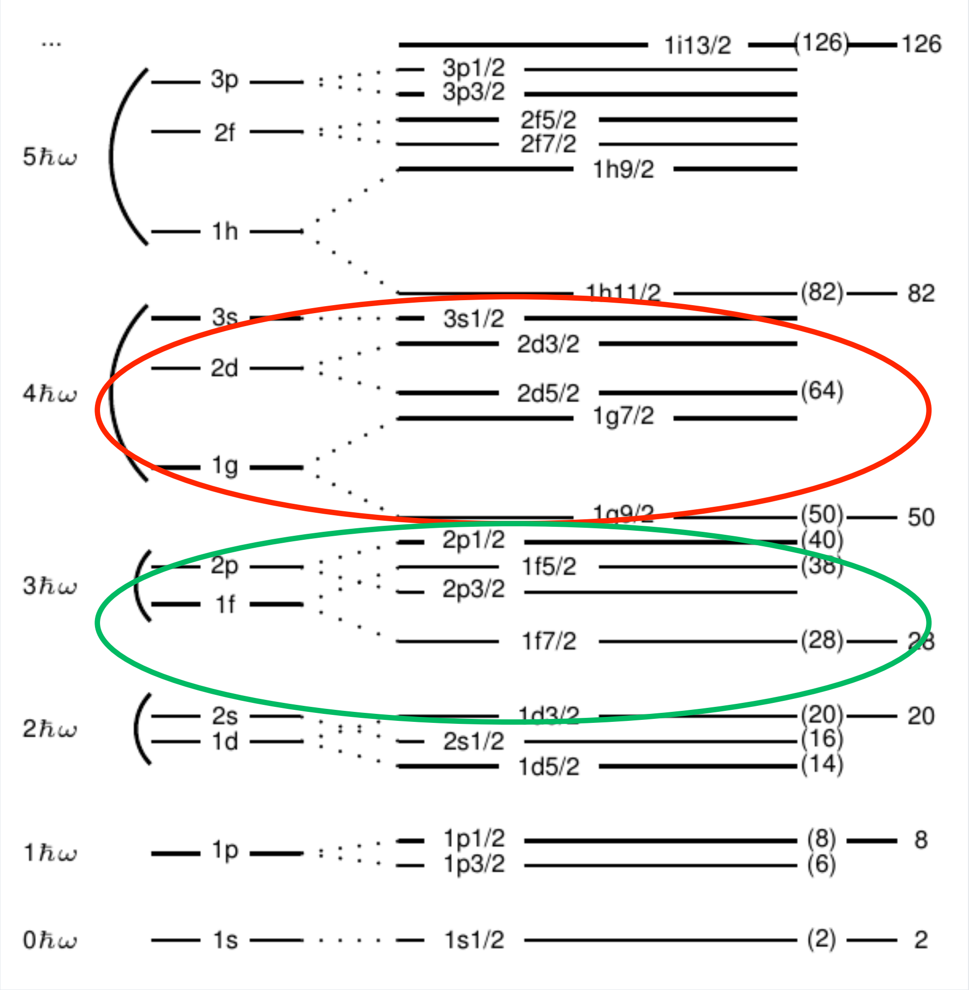
3 protons in (1f7/2 2p3/2 1f5/2 2p1/2) orbitals

N = 51

1 neutron in (1g9/2 1g7/2 2d5/2 2d3/2 3s1/2)

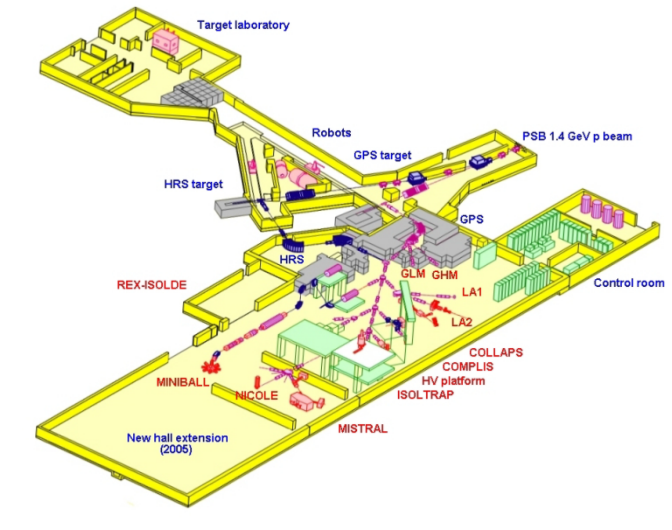
For excited states predictions:

- fp shell valence space for protons
- gds shell valence space for neutrons

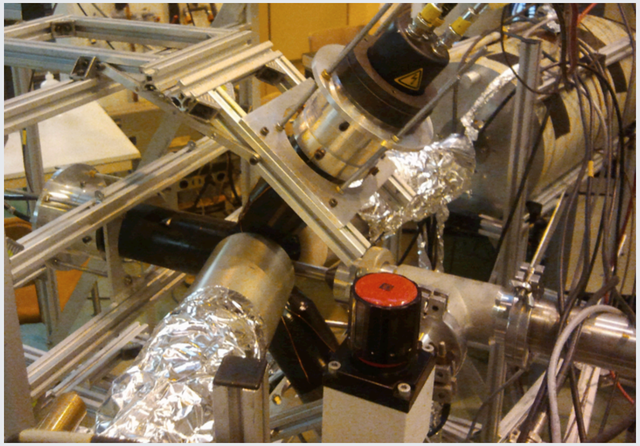


Experimental facility : ISOLDE – CERN

- Radioactive beam – fission products (2000 °C hot **UCx/graphite** target)
- 1.4 GeV PS Booster proton beam directed onto a **neutron converter**
- Chemical species separated by laser ion source (**RILIS**)
- High Resolution Separator (**HRS**) mass selection
- ^{82}Zn separated and **implanted on a Aluminium foil**



Experimental setup



- **$\beta - \gamma - \gamma$ coincidences**
- Three types of detectors:
  - 2 x HPGe – 100% efficiency
  - 2 x LaBr3 scintillator
  - 1 x plastic scintillator NE111A – β detector

- Acquisition system: **Digital Gamma Finder** (DGF) – Pixie standard

- Time information:
  - Pixie time
    - proton impact moment
    - detector signal moment (γ or β detection)
    - 75 MHz clock
  - TAC
    - β – HPGe TAC
    - β – LaBr3 TAC
    - LaBr3 – LaBr3 TAC

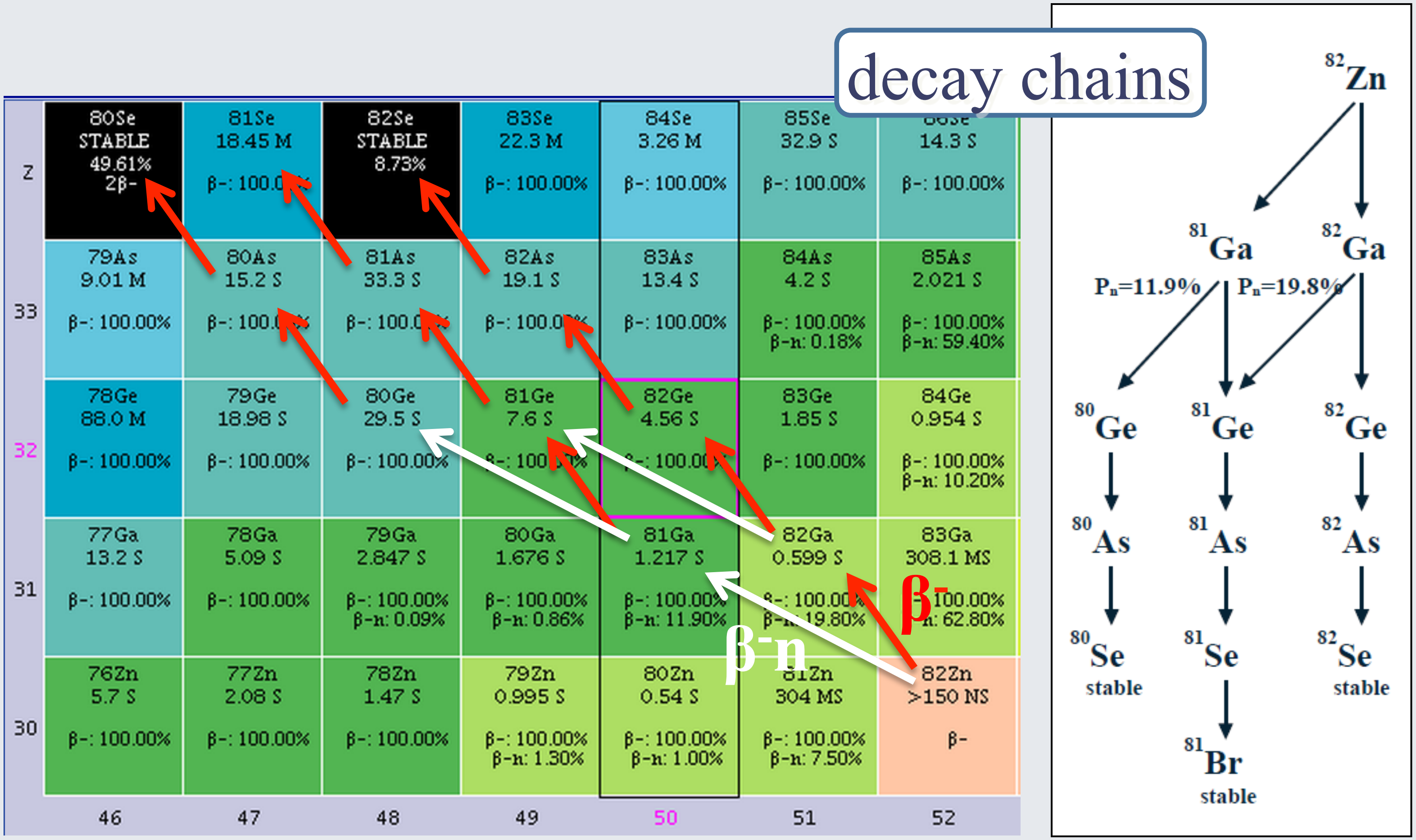
- Energy information:
  - β energy – only in coincidence with any of the γ detectors
  - γ energy – from LaBr3 and HPGe detectors – ungated

A signal triggered by the beam impingement on the UCx target was also collected. This pulse marks the starting point on ^{82}Zn beta accumulation and decay curve and was used for timing purposes.

β – decay chains of ^{82}Zn

$^{82}\mathrm{Zn} \rightarrow {}^{82}\mathbf{Ga} + e^- + \tilde{\nu}_e$ β⁻ branch

$^{82}\mathrm{Zn} \rightarrow {}^{81}\mathbf{Ga} + e^- + \tilde{\nu}_e + n$ βn branch

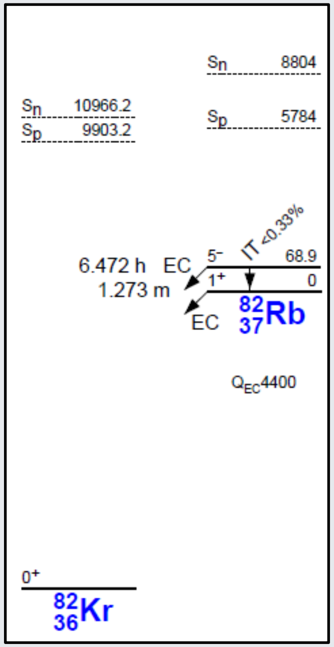


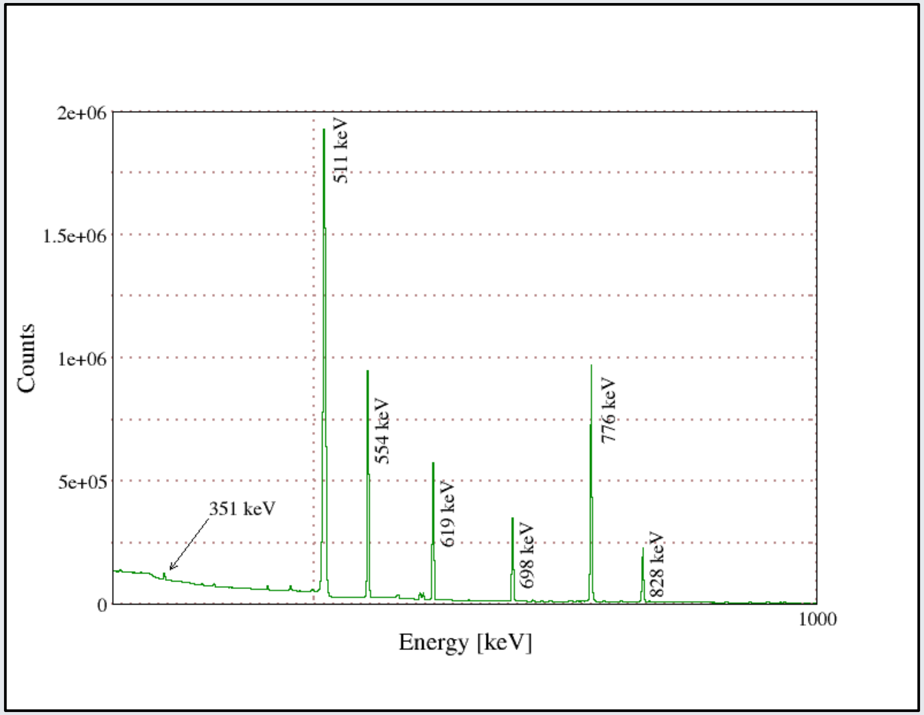
^{82}Rb contamination

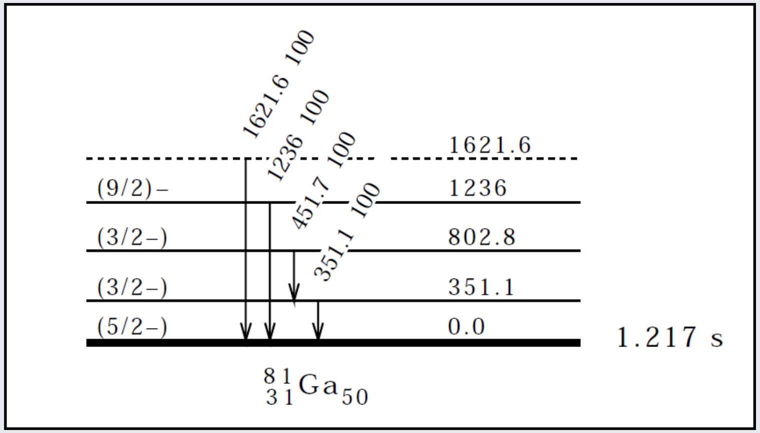
^{82}Rb also ionised – the beam was heavily contaminated

$^{82}Rb + e^{-} \rightarrow {}^{82}Kr + \nu_e$

Strongest lines in the spectra – gammas from ^{82}Kr







Identification and lifetime of ^{82}Zn

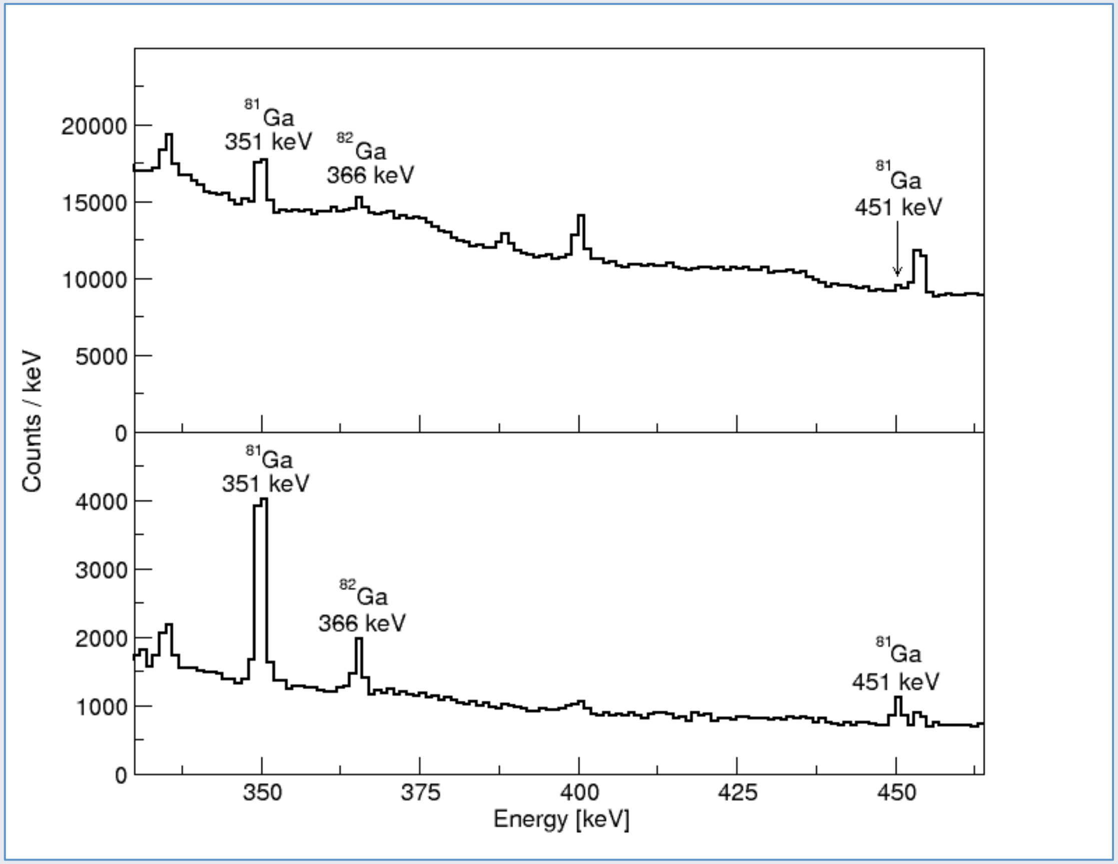
Q: Did we separate ^{82}Zn? Do we detect any ^{82}Zn activity?

Enhance fast components in the spectra:

- Beta gate
- Time to proton gate

Result:

- Identification of peaks corresponding to known ^{81}Ga γ transitions



Identification and lifetime of ^{82}Zn

Q: Is ^{81}Ga populated by the β^-n decay of ^{82}Zn?

Possibilities:

- Populated by the β^- decay of ^{81}Zn
- Populated by the β^-n decay of ^{82}Zn

Confirmation:

- Compare the halflife obtained by fitting the background subtracted decay curve of the 351 keV transition with the known halflife of ^{81}Zn.

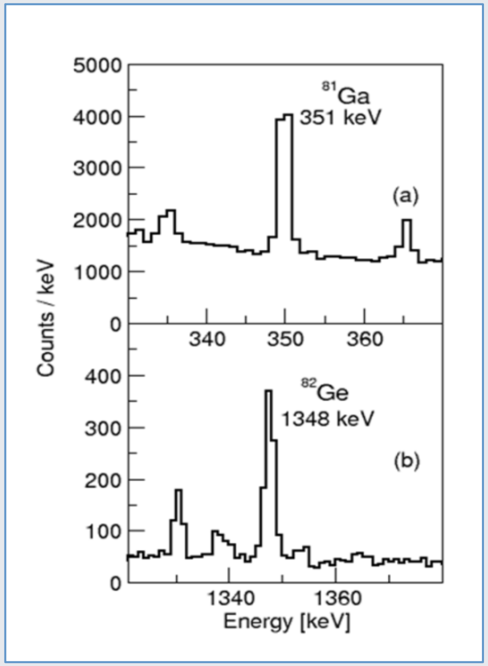
Identification and lifetime of ^{82}Zn

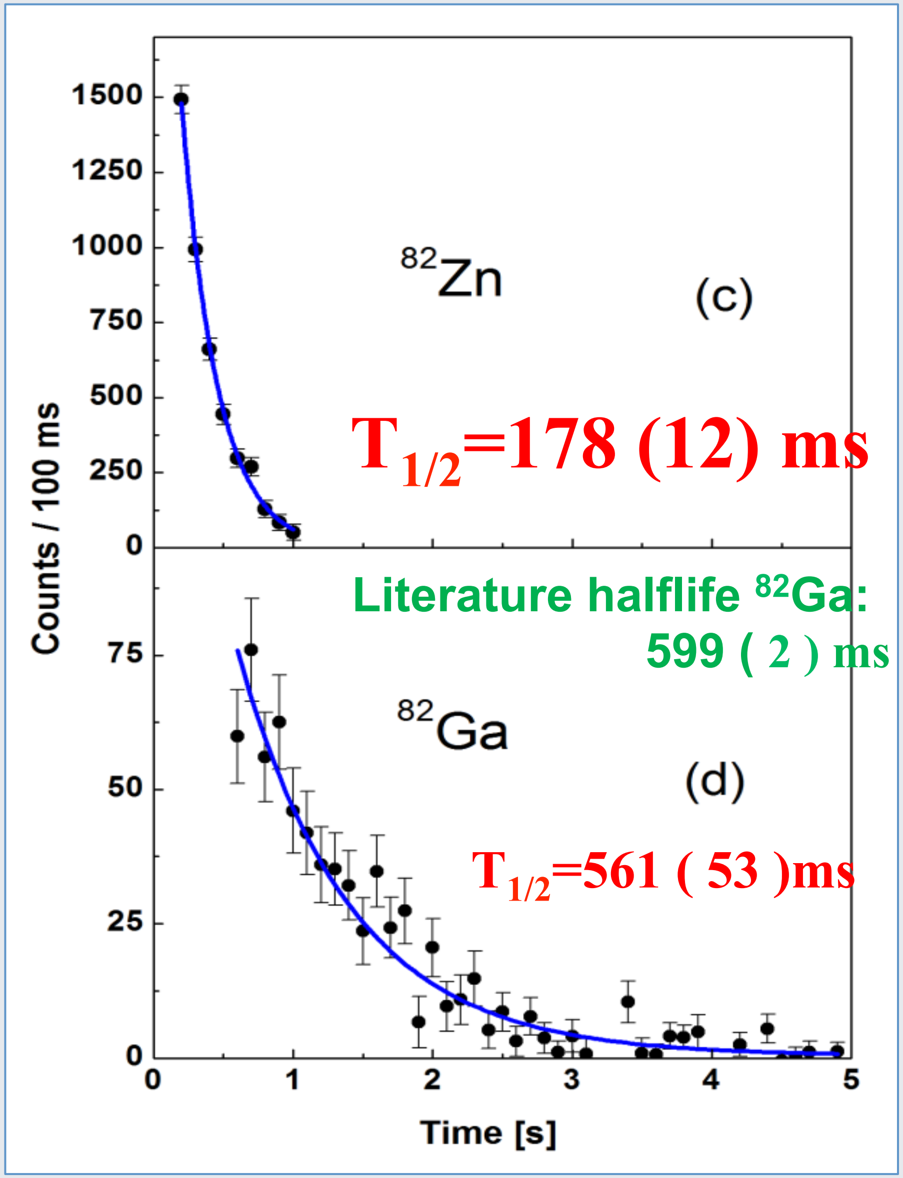
Left image:

- γ transitions used to determine the halflifes of ^{82}Zn (351 keV) and ^{82}Ga (1348 keV).
- β gated and time gated spectra
- gate on 700 ms in respect to the proton pulse.

Right image:

- decay curves for ^{82}Zn and ^{82}Ga.
- data fit to an exponential decay plus constant.





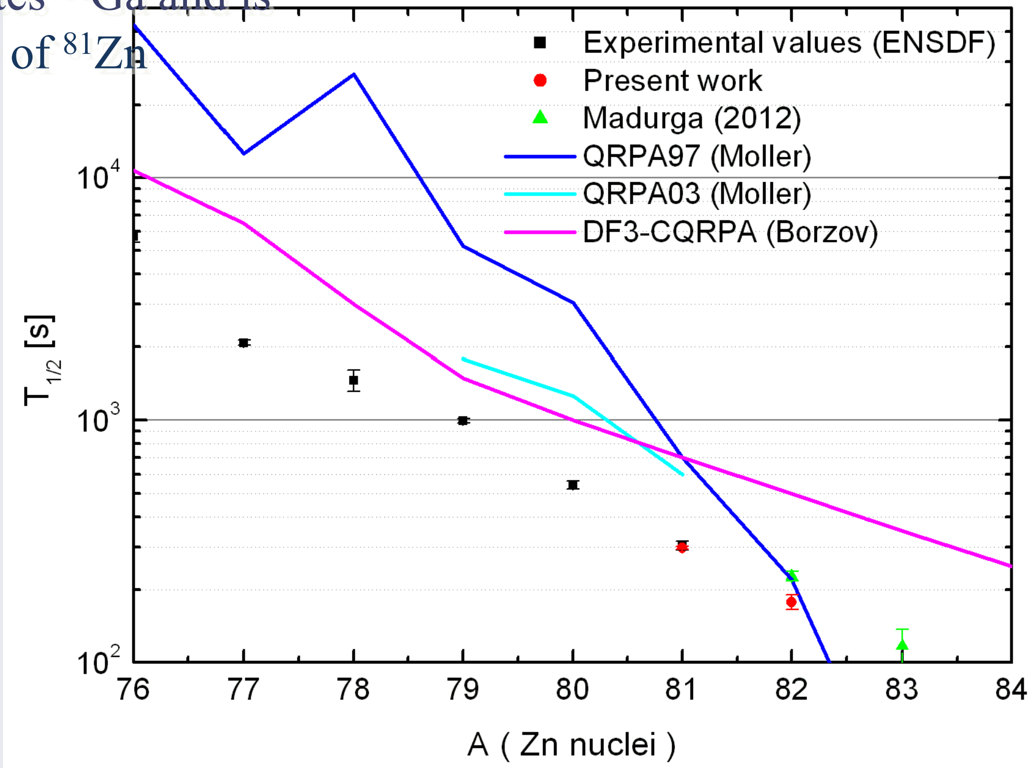
Identification and lifetime of ^{82}Zn

- $T_{1/2}$ of ^{82}Zn (Madurga 2012) : 228 (10) ms
- Remeasured $T_{1/2}$ of ^{81}Zn (this experiment):

$$T_{1/2} = 297 \pm 4 \text{ ms}$$

- Measured halflife: $T_{1/2} = 178 \pm 12$ ms
- We identified a decay which populates ^{81}Ga and is significantly faster than the β^- decay of ^{81}Zn

⇒ **We isolated ^{82}Zn**



PRL 109, 112501 (2012)
M. Madurga et al, "New Half-lives of r-process Zn and Ga Isotopes Measured with Electromagnetic Separation"

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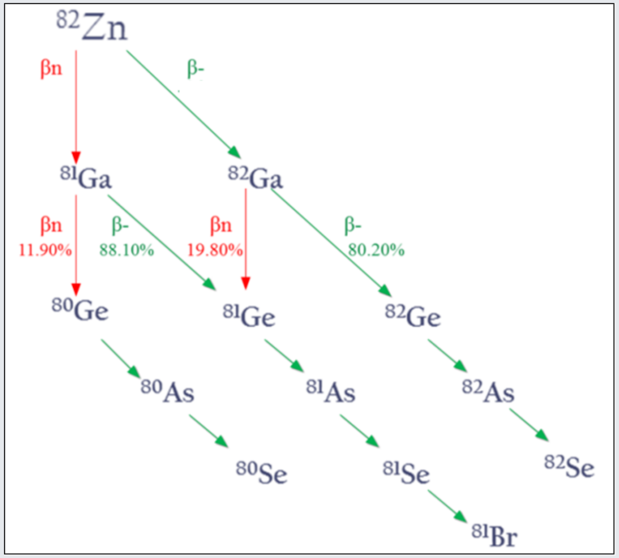
P. Moller et al, "Nuclear Proprieties for Astrophysical and Radioactive-Ion-Beam Applications"

PRC 82, 025806 (2012)
P. Hosmer et al, "Half-lives and branchings for β-delayed neutron emission for neutron-rich Co-Cu isotopes in the r-process"

PRC 71, 065801 (2005)
I.N. Borzov, "β-delayed neutron emission in the ^{78}Ni region"

β delayed neutron emission probabilities (P_n) for ^{82}Zn



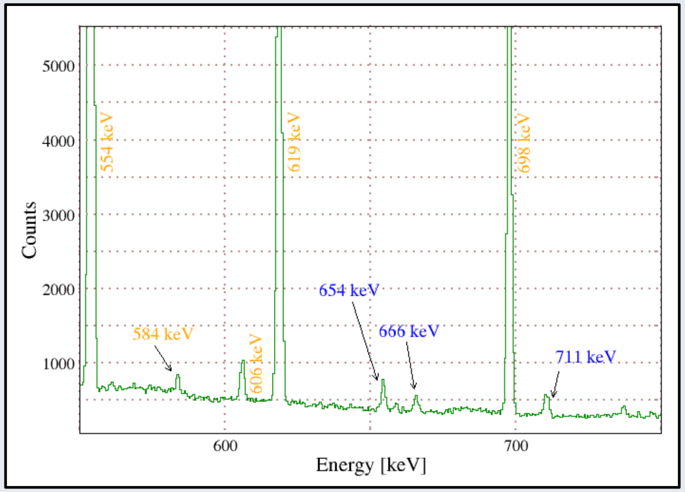
^{82}Zn ?% β → ^{82}Ga 80.2% β → ^{82}Ge → ^{82}As → ^{82}Se

^{82}Zn ?% β*n* → ^{81}Ga 12% β*n* → ^{80}Ge → ^{80}As → ^{80}Se

Nucleus	γ [keV]	I_γ
^{82}Se	654	14 ± 3 %
^{80}Se	666	42 ± 5 %

No neutron detectors => estimation of the P_n branching ration using the total production of stable nuclei from different decay chains of ^{82}Zn.

- A=80 chain
  - P_n for ^{81}Ga = 11.9 ± 0.7 %
  - 666 keV γ transition in ^{80}Se
- A=82 chain
  - P_n for ^{82}Ga = 19.8 ± 0.7 %
  - 654 keV γ transition in ^{82}Se



β delayed neutron emission probabilities (P_n) for ^{82}Zn

$$\frac{\beta n}{\beta+\beta n} = \frac{\beta n\ Decays\ of\ 82Zn}{\beta\ Decays\ of\ ^{82}Zn + \beta n Decays\ of\ ^{82}Zn}$$

$$= \frac{\beta n\ Decays\ of\ 82As\ /\beta n\ br.\ of\ 82Ga}{\beta\ Decays\ of\ 82As\ /\beta\ br.of\ 82Ga + \beta decays\ of\ 80As\ /\beta n\ br.of\ 81Ga}$$

$$branching\ ratio = br$$

P_n for ^{82}Zn = 57.57 ± 12.34 %

PRC 71, 065801 (2005)
I.N. Borzov, "β-delayed neutron emission in the ^{78}Ni region"

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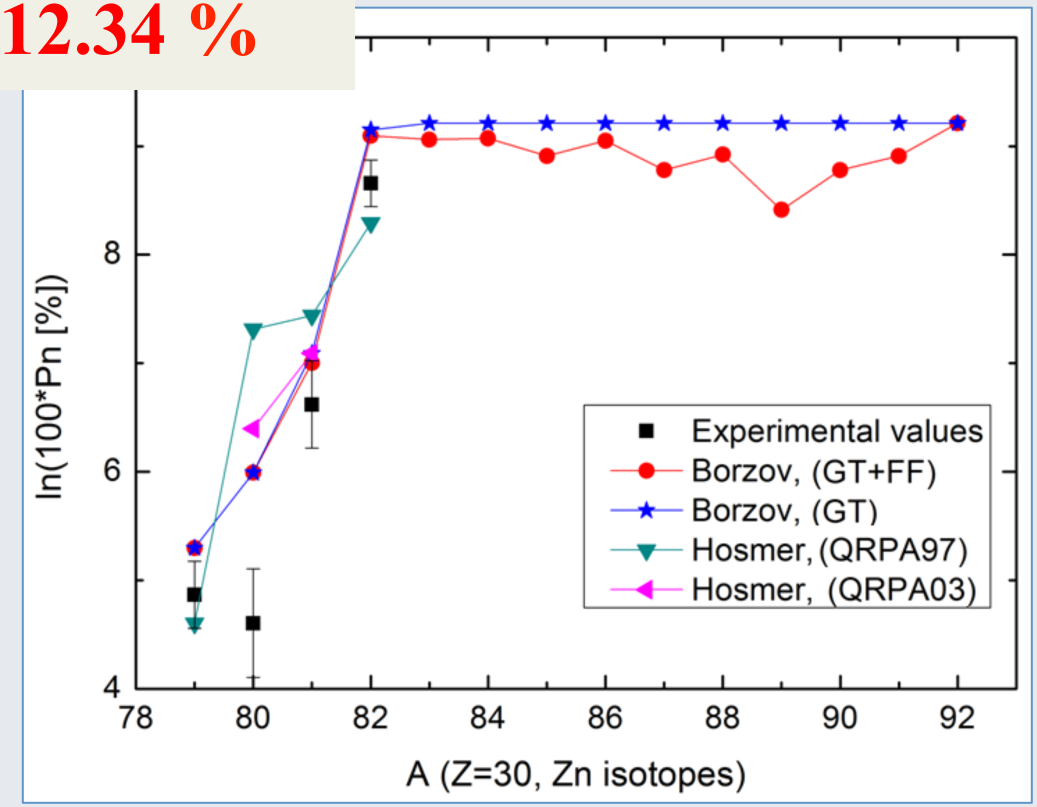
P. Hosmer et al, "Half-lives and branchings for β-delayed neutron emission for neutron-rich Co-Cu isotopes in the r-process"

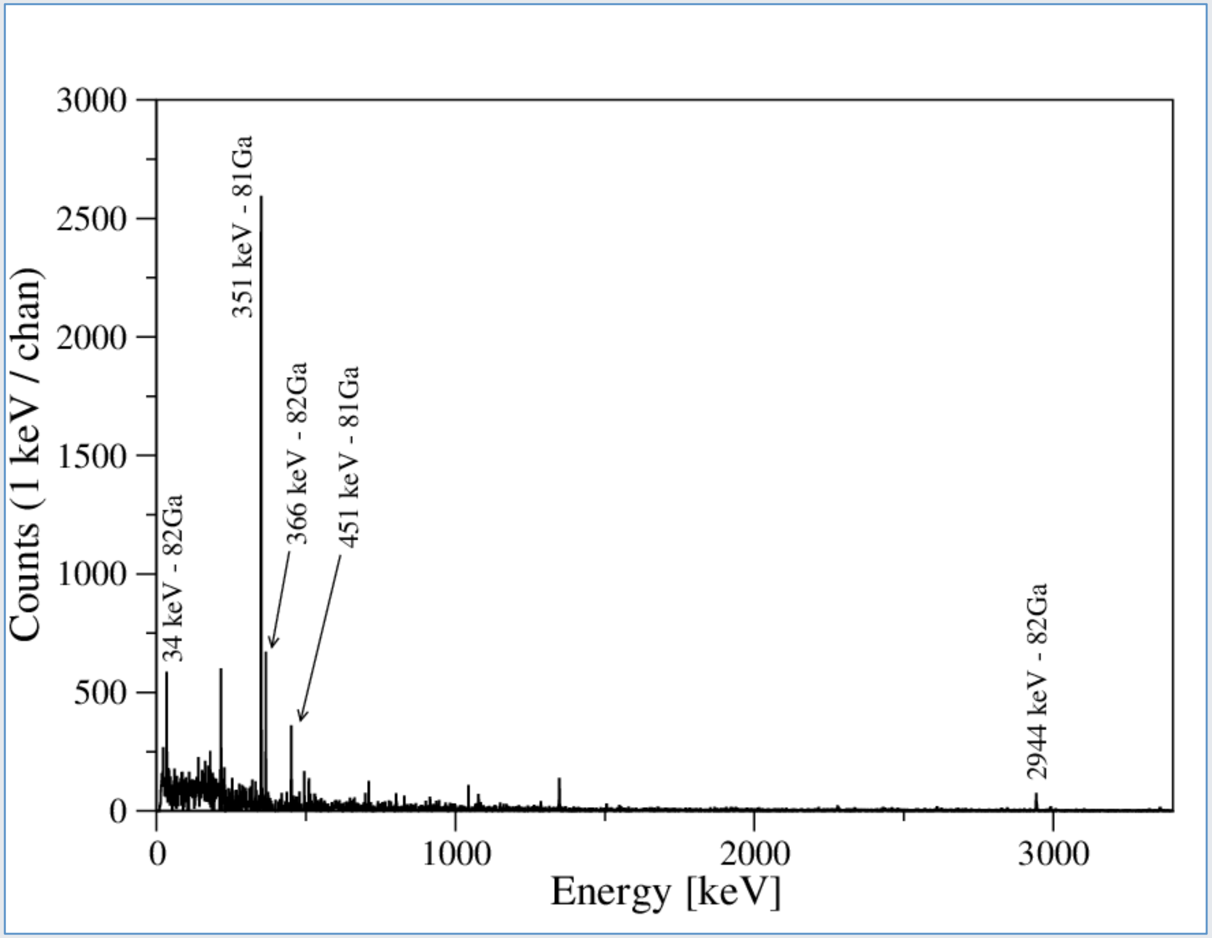


Identification of γ transitions in ^{82}Ga

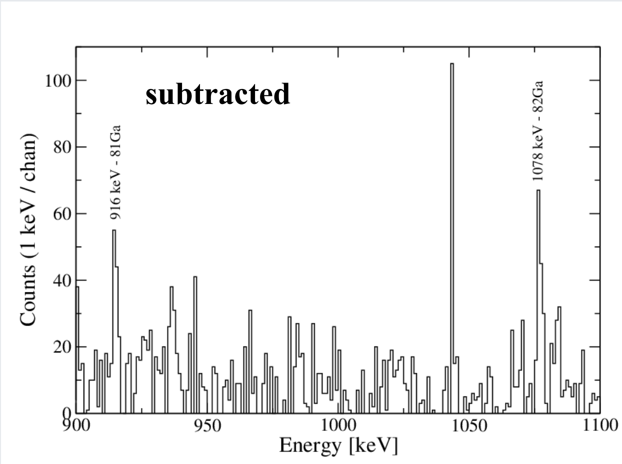
Based on:

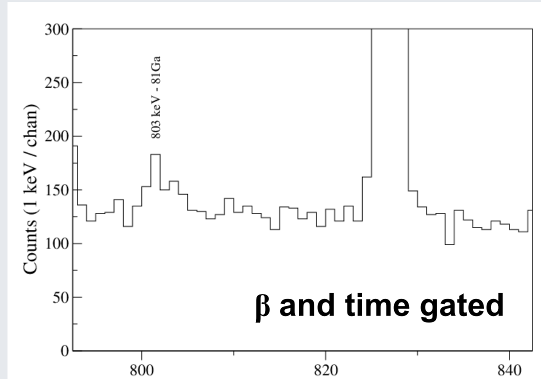
- time to proton impact
- known gammas in ^{81}Ga

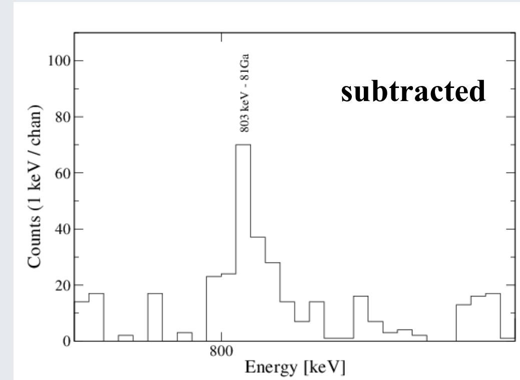
- β-γ(t) coincidences
- long lived component (1-5 sec to proton pulse) renormalized and subtracted from the short lived one (first 700 ms to proton pulse)
- Renormalization done using an intense transition (776 keV) in ^{82}Kr

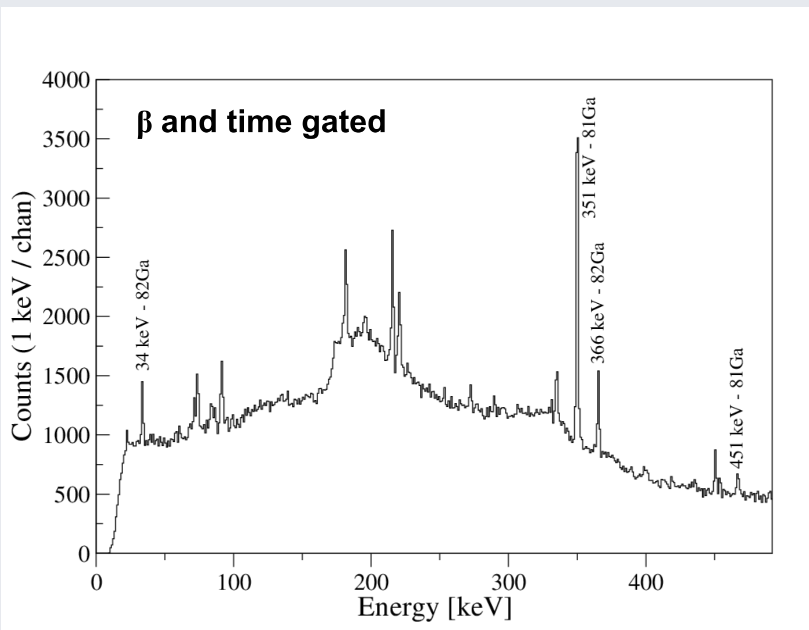


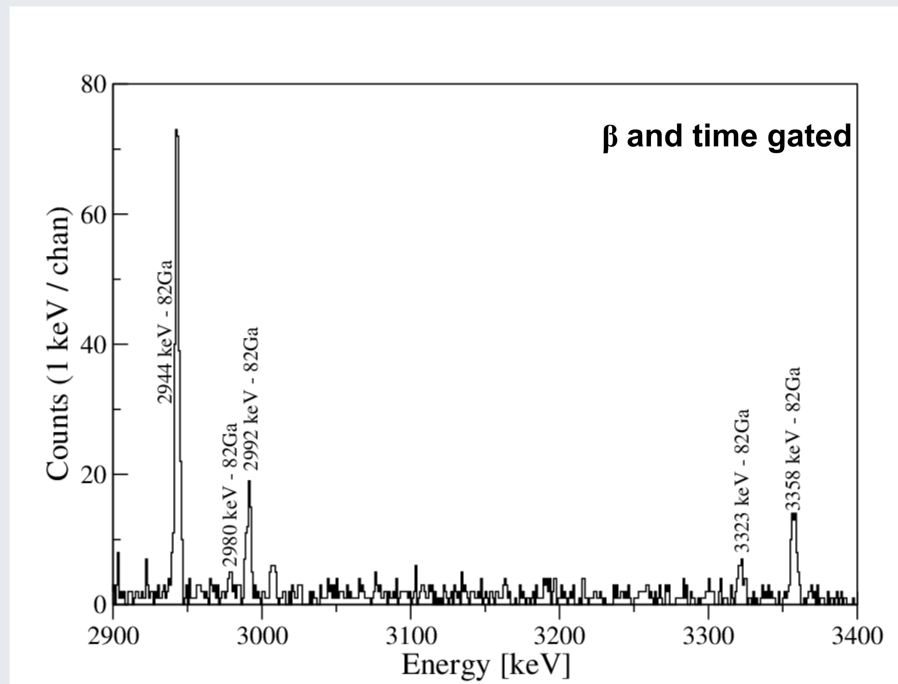
Identification of γ transitions in ^{82}Ga



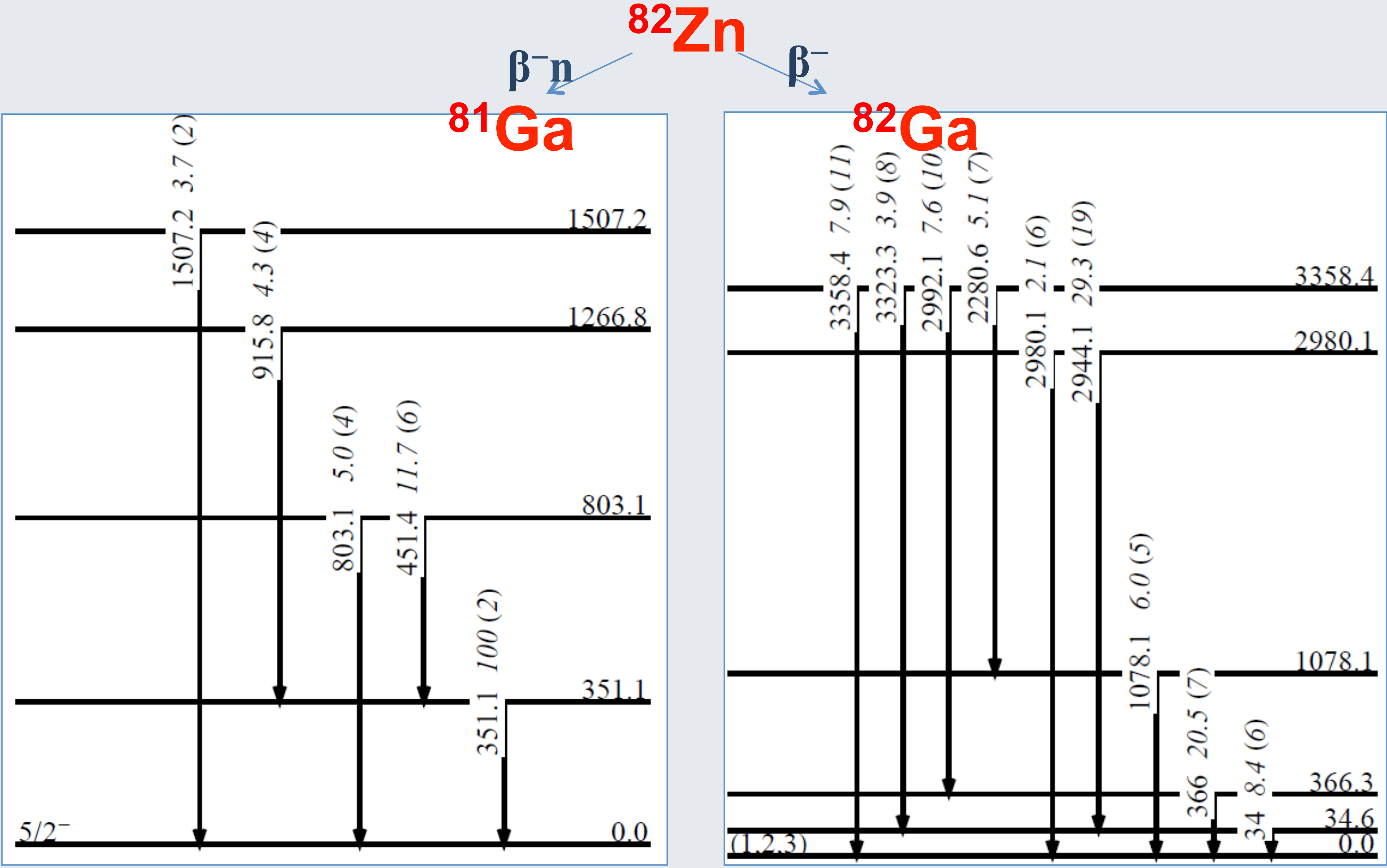








Tentative level scheme for ^{81,82}Ga



The transition intensities are normalized to that of the 351 keV transition in ^{81}Ga, taken as 100.

Summary

- ^{82}Zn was produced and separated at the ISOLDE facility.
- We precisely remeasured the halflife of ^{82}Zn.
- We obtained the β delayed neutron emission probabilities of ^{82}Zn.
- Constructed tentative level schemes for ^{82}Ga (populated by the β^- decay of ^{82}Zn) and for ^{81}Ga (populated by the β^-n decay of ^{82}Zn).

IS441 Collaboration:

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