Decay spectroscopy of neutron-rich Zn isotopes by total absorption

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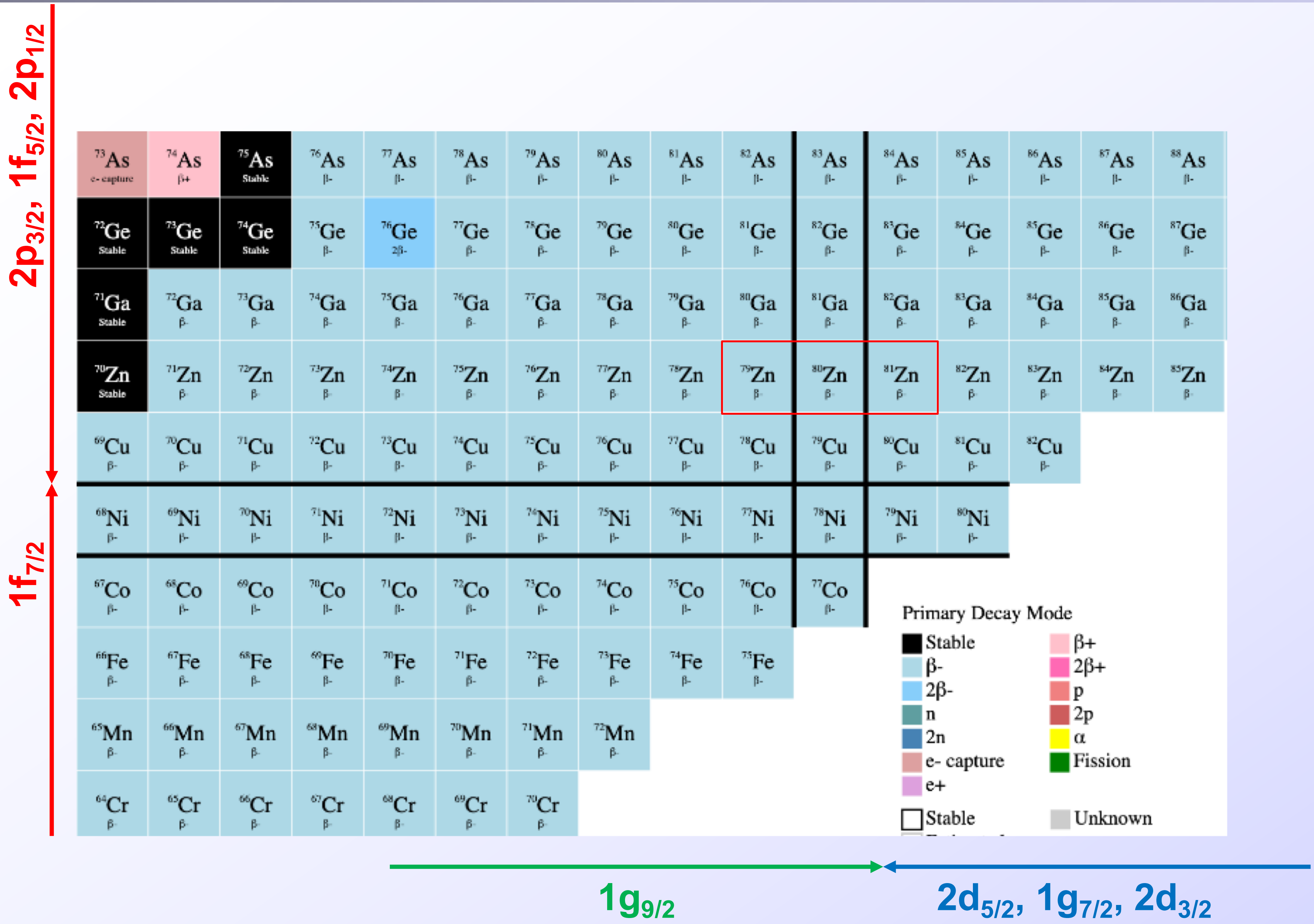
Region under study



Aims of the proposal

Investigate the β decay of $^{80-82}Zn$ by total absorption spectroscopy using the Lucrecia setup at ISOLDE

Competition of Gamow-Teller and first-forbidden transitions beyond ^{78}Ni

Includes accurate measurement of g.s. feeding

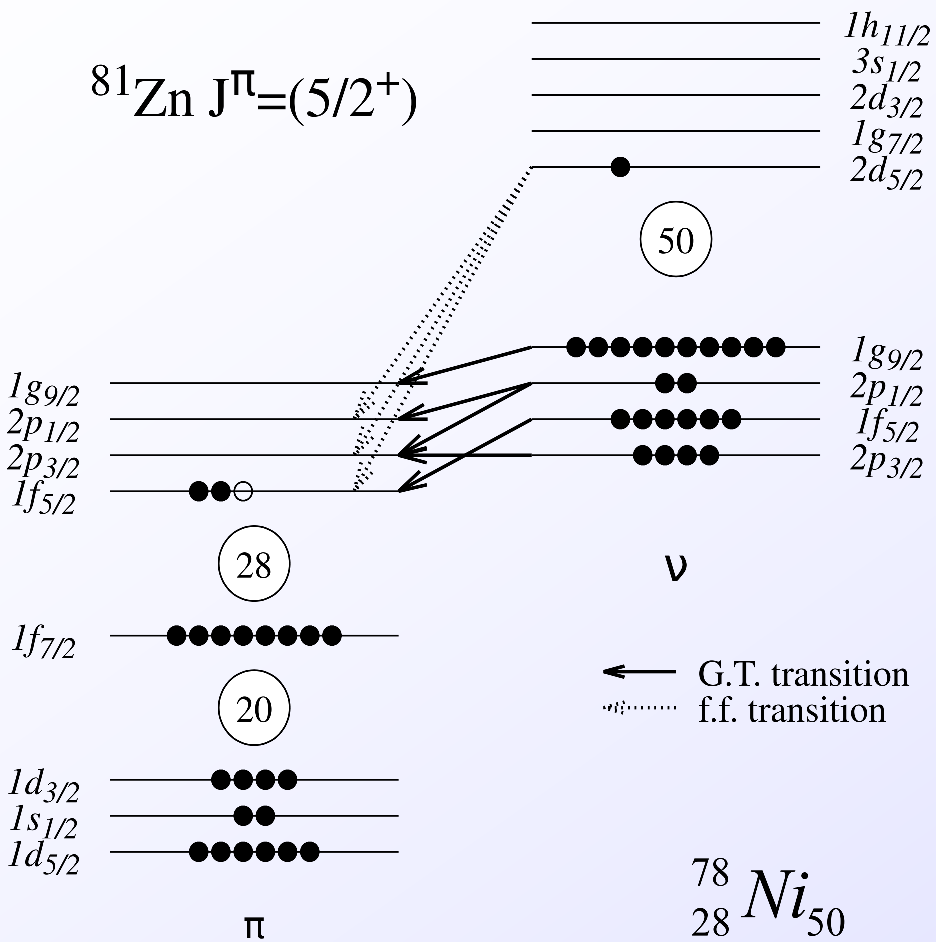
Gamma-ray emission from neutron unbound states

Competition of decay modes for (n,γ) rates

GT vs. ff transitions around ^{78}Ni

β decay is relevant for r-process nucleosynthesis

Gamow-Teller are normally considered, but
First-forbidden transitions play a role in medium and heavy nuclei



Region above ^{78}Ni:

- ^{81}Zn → ^{81}Ga (N=50)
- Decay to odd-odd Ga

Total absorption γ spectroscopy ideal to measure beta feeding to high-lying states

Competition between γ and neutron decay

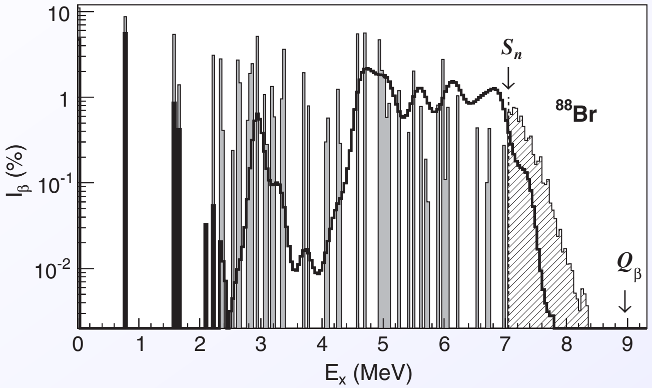
Important process for radiative capture rates in nucleosynthesis

· Gamma-decay of neutron-unbound states by γ rays may have a sizeable impact in astrophysical scenarios

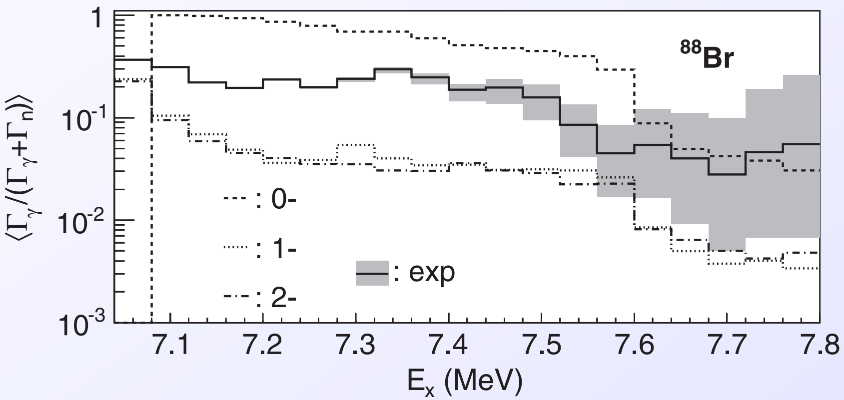
Usually assumed that n decay dominates for β-fed nuclear states above S_n

· Process has been documented for a few cases

· Photon strength function increase leads to a similar increase in the (n,γ) cross section: r process abundance calculations!



Emission of n above S_n hindered by the *l* barrier.
Nuclear structure and β selection rules play a role



Total absorption γ spectroscopy is the better suited tool to efficiently detect γ cascades from neutron unbound states.

J. L. Tain et al., PRL115, 062502 (2015)

A. Spyrou et al., PRL117, 142701 (2016)

r-process sensitivity studies of (n,γ) rates

TABLE II. Nuclei with maximum neutron capture rate sensitivity measures $F > 10$ from the combined results of fifty-five neutron capture rate sensitivity studies run under a range of distinct astrophysical conditions, from Fig. 7.

Z	A	F
26	67	15.8
26	71	11.2
27	68	11.6
27	75	17.3
28	76	17.2
28	81	34.1
29	72	10.4
29	74	15.1
29	76	25.0
29	77	12.5
29	79	10.2
30	76	13.1
30	78	23.5
30	79	15.2
30	81	13.6
31	78	12.8
31	79	12.1
31	80	26.0
31	81	18.8
31	84	10.5
31	86	11.0
32	81	17.5
32	85	13.1
32	87	19.1
33	85	10.5
33	86	22.5
33	87	17.8
33	88	22.6
34	87	18.0
34	88	11.2
34	89	10.3
34	91	15.3

R. Surman et al., WSPC Proceedings (2013)

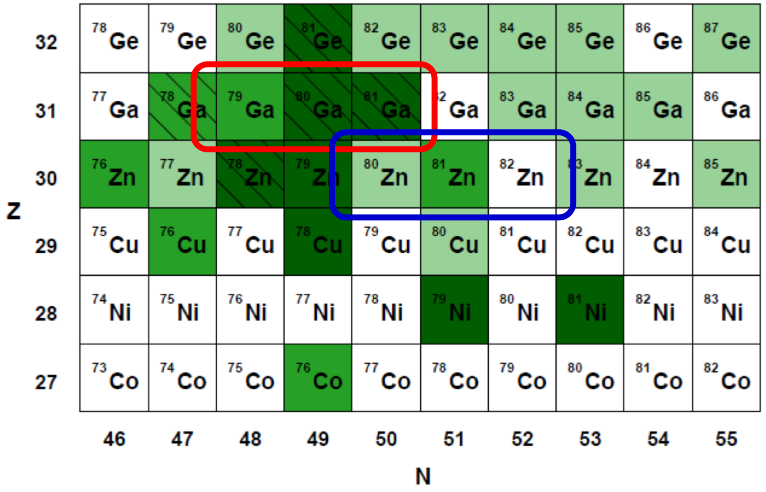


Fig. 1. Shows the nuclei whose capture rates affect at least a 5 – 10% (lightest shading), 10 – 15%, or > 15% (darkest shading) change to the overall *r*-process abundance pattern when increased by a factor of 100 over a baseline simulation. Hatchmarks indicate the nuclei whose capture rates affect at least a 5% change in ten or more simulations.

r-process sensitivity studies of (n,γ) rates point toward the key role of the nuclei of interest

M. Mumpower et al., AIP Advances 4, 041008 (2014)

Beta-decay of ^{81}Zn

Allowed Gamow-Teller decays to positive parity states

→ **core excited** states

→ may appear close to S_n = 6.5 MeV

First-forbidden decays to negative parity states

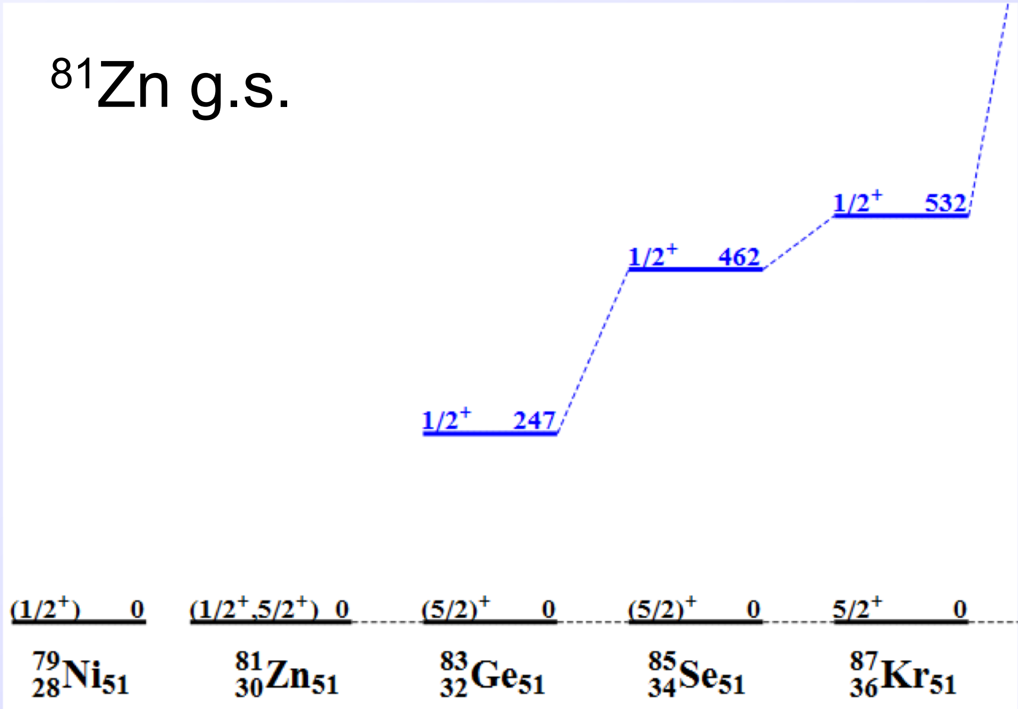
→ lower energies

→ sizeable (apparent) feeding in the region

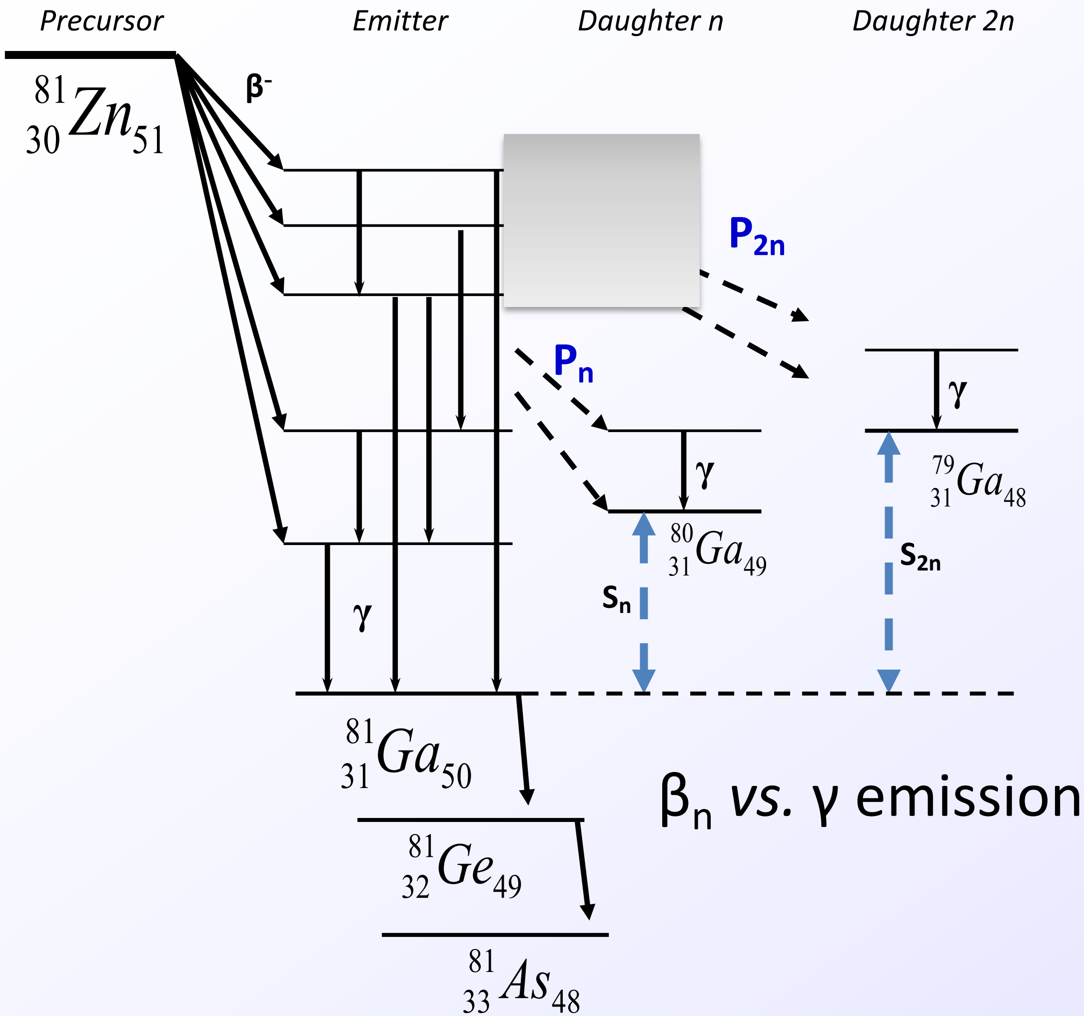
Spin-parity ^{81}Ga g.s is 5/2$^-$

Cheal et al., PRL 104, 252502 (2010)

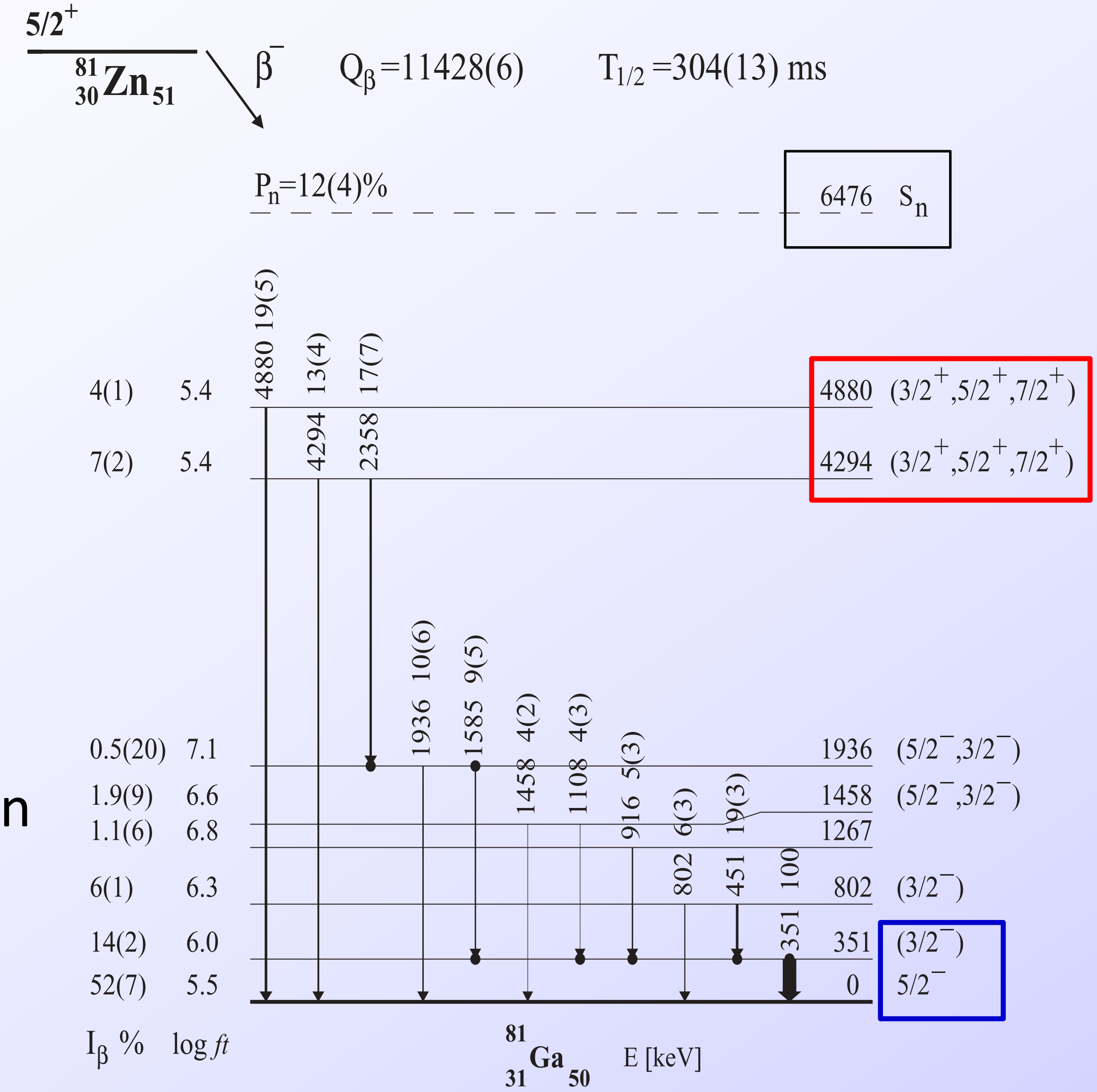
$$B(\mathrm{GT}) = |\langle\Psi_f| \sum_{\mu}\sum_{k} \sigma_k^{\mu}\ t_k^{\pm}|\Psi_i\rangle|^2$$



Beta decay of ^{81}Zn

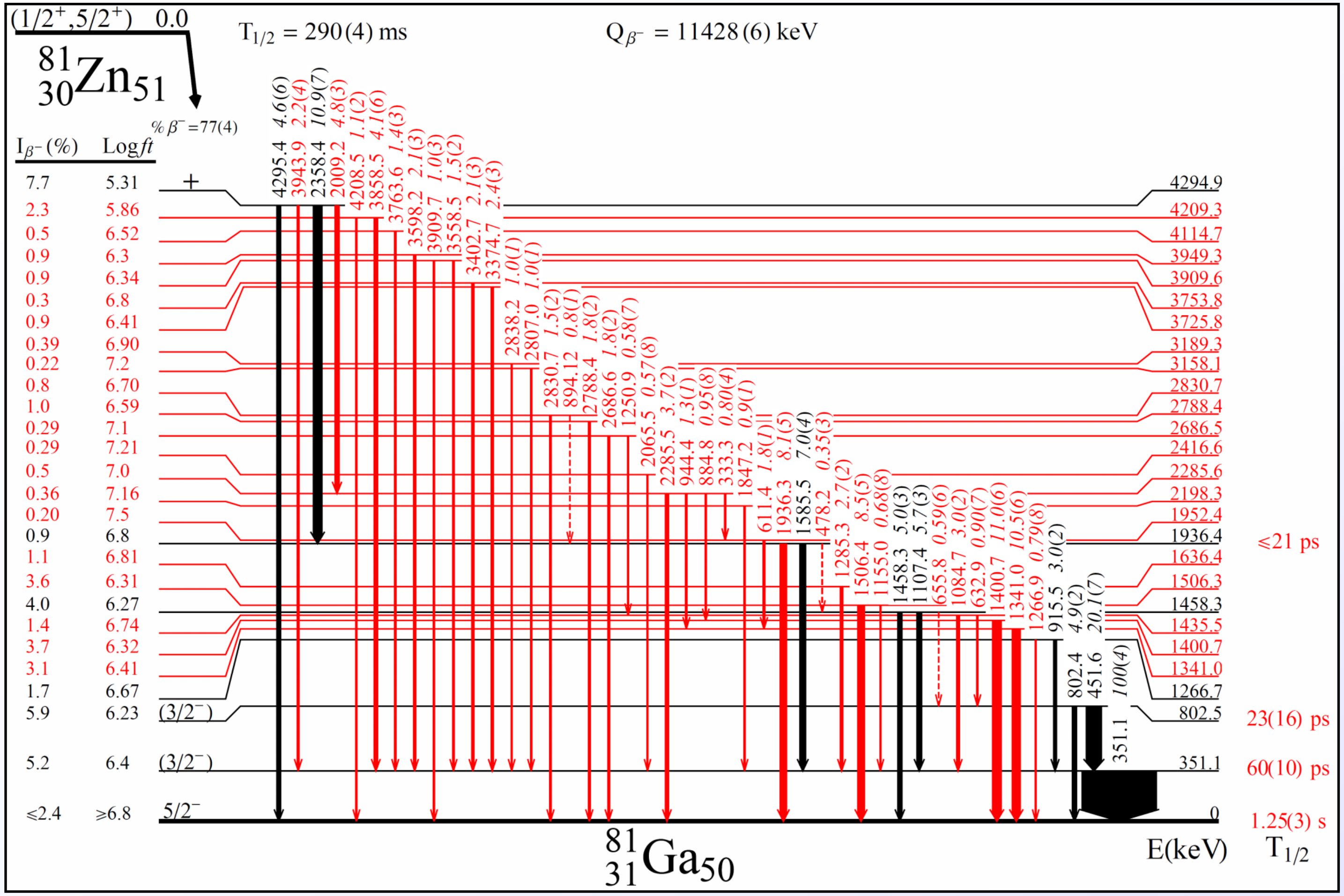


β_n *vs.* γ emission



S. Padgett et al., PRC 82, 064314 (2010) @ORNL

Results from ISOLDE: decay of ^{81}Zn



FF transitions to low-lying (negative) states

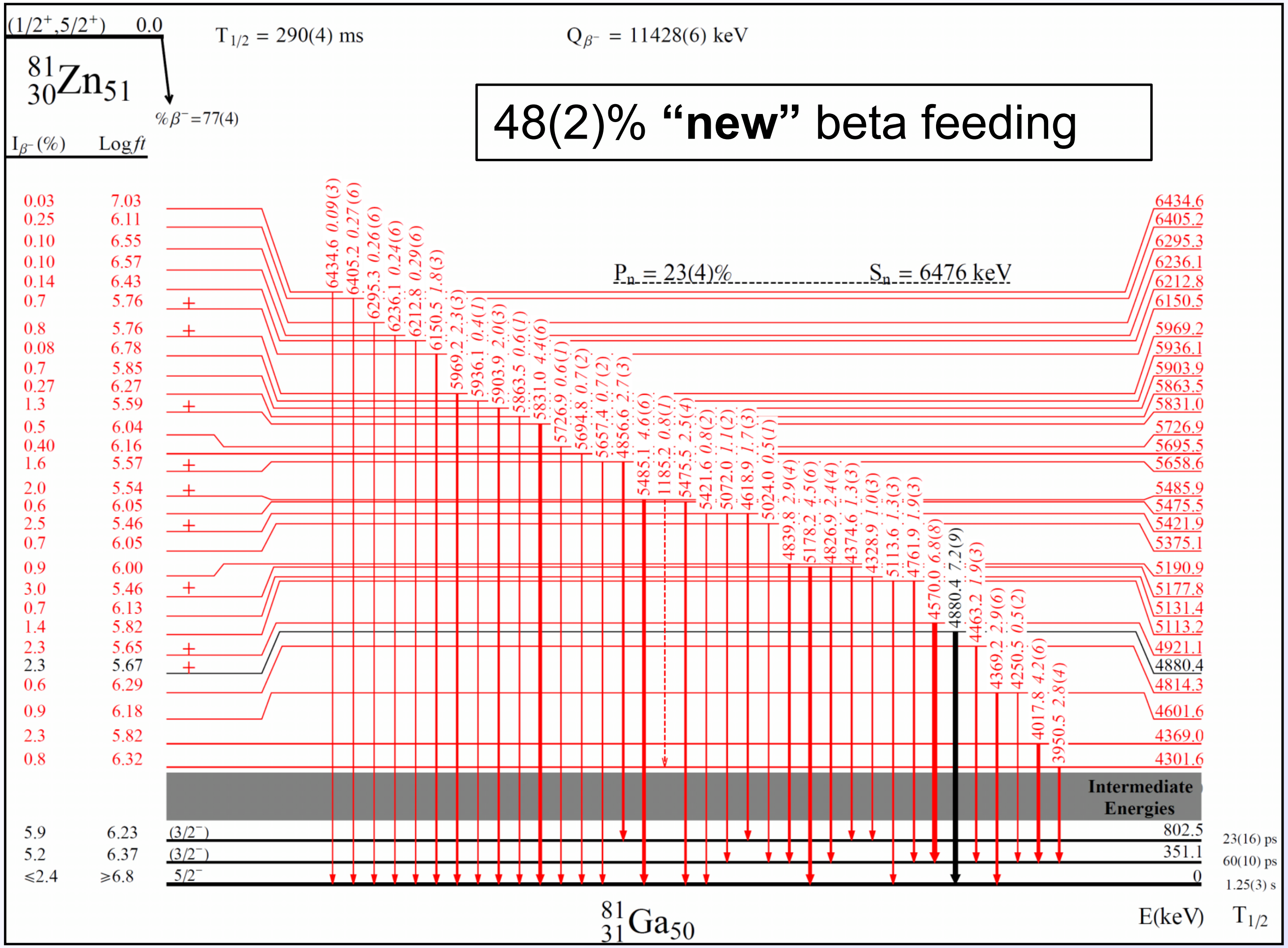
Revised compared to previous high-resolution paper

Apparent beta-feeding to ground state revised

V. Paziy et al., Phys. Rev. C102, 014329 (2020)

Need for TAS
Direct measurement of g.s. feeding

Results from ISOLDE: decay of ^{81}Zn



Allowed GT populates high-energy states

Breaking of odd proton orbitals

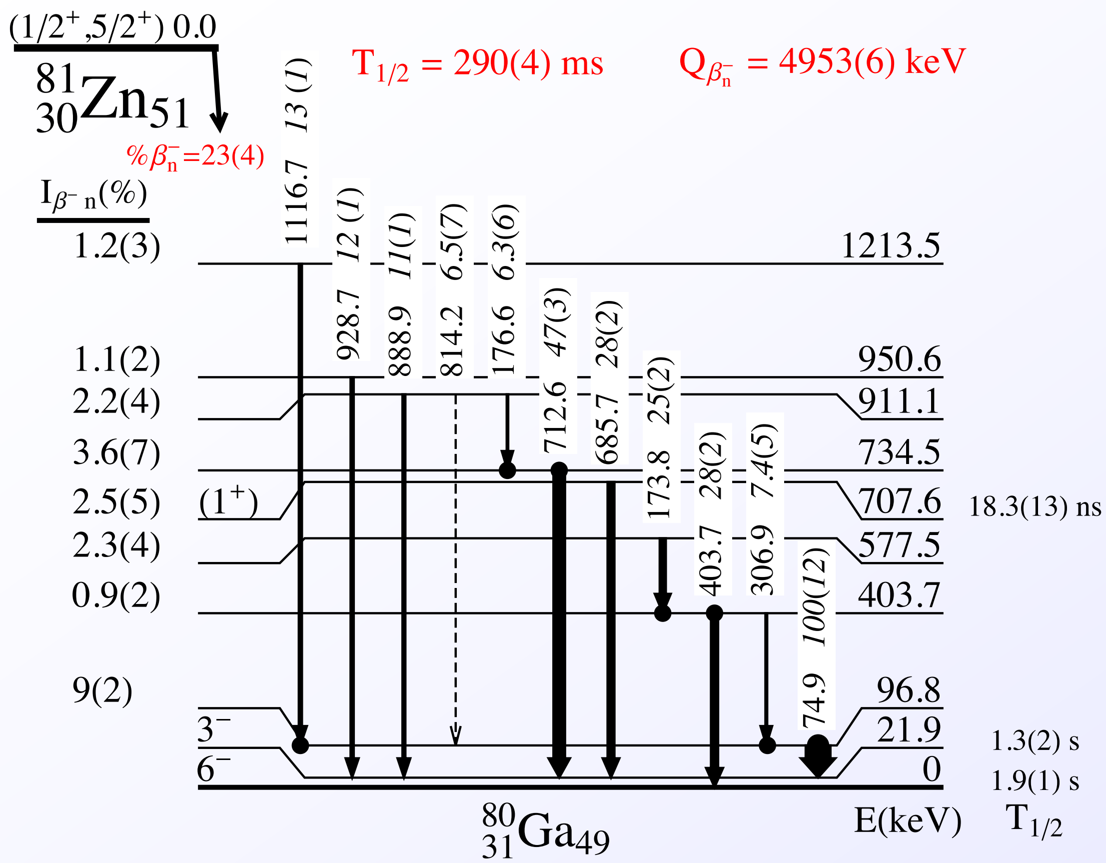
Large P_n value suggests a relevant role of those

Levels known up to S_n

V. Paziy et al., Phys. Rev. C102, 014329 (2020)

TAS measurement required

Beta-n decay of ^{81}Zn to ^{80}Ga



Large P_n value: feeding to states in ^{80}Ga

Information available to take care of TAS response to beta-delayed neutrons

V. Paziy et al., Phys. Rev. C102, 014329 (2020)

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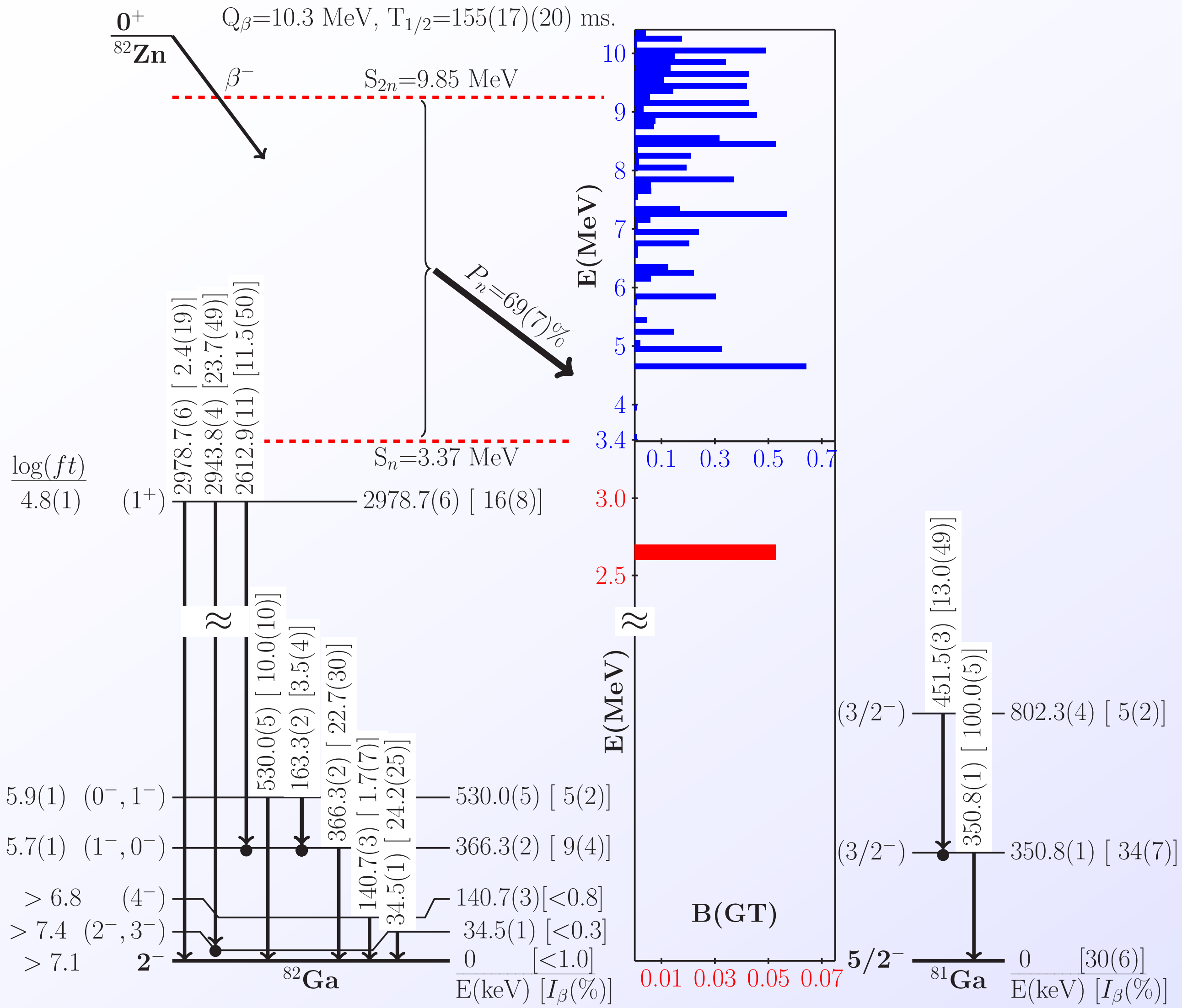
Beta and beta-n decay of ^{82}Zn



Allowed GT populates 1$^+$ states, only one identified

FF highly suppresed but negative states exist: apparent feeding to 4$^-$!

Most of the feeding above S_n, large P_n value

Gamma-decay above S_n?

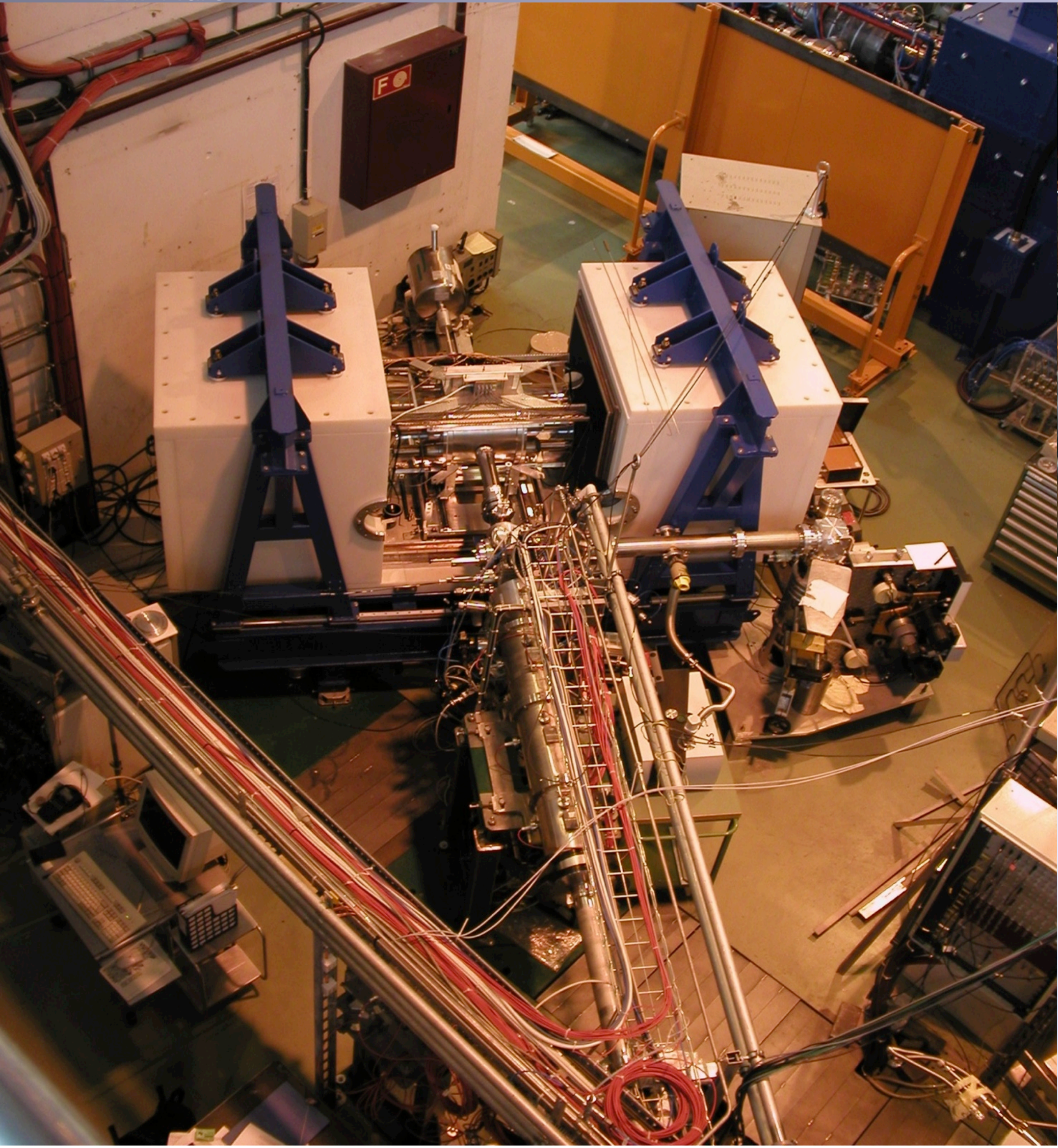
Information on $I_{\beta n}$ exists

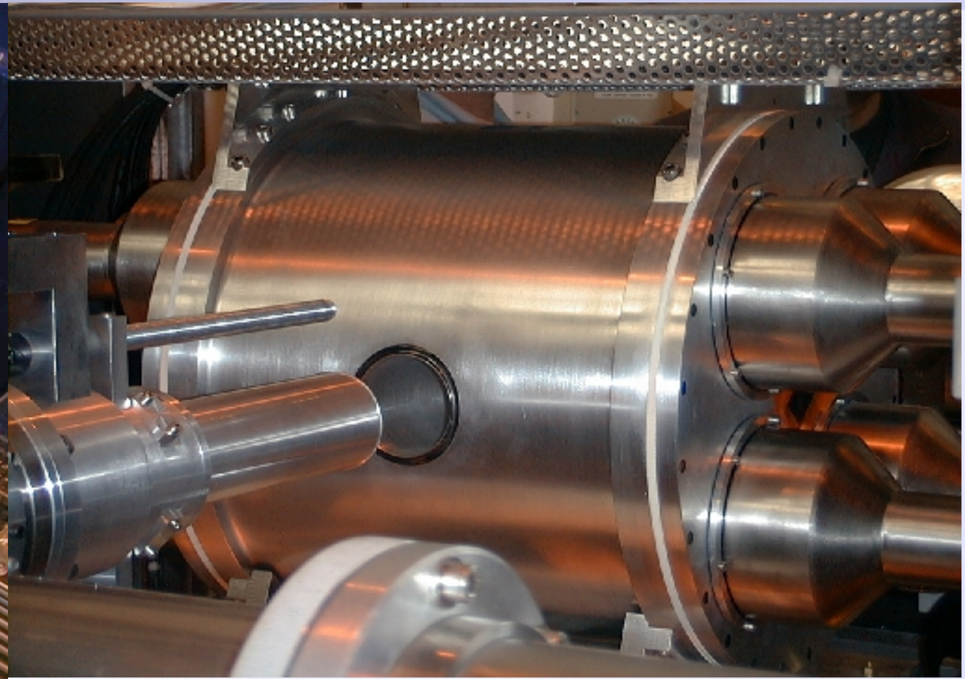
TAS measurement required

M.F. Alshudifat et al., Phys. Rev. C 93, 044325 (2016)

L.M. Fraile

Total absorption spectroscopy





Lucrecia – the ISOLDE TAS

- A large NaI cylindrical crystal 38 cm Ø, 38 cm length
- An X-ray detector (Ge)
- A β detector
- Possibility of collection point inside the crystal

Well-known technique

Measurement

Beta transition probability to daughter nucleus levels

Gamow-Teller beta strength:

$$B(\mathrm{GT})^{\beta} = \frac{K}{\lambda^2} \frac{I_\beta(E)}{f(Q_\beta - E, Z) T_{1/2}}$$

Beta feeding ($I_\beta(E)$)

Half life of parent ($T_{1/2}$)

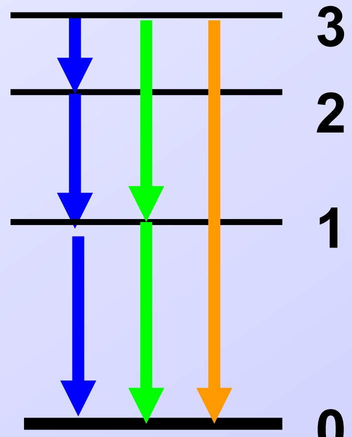
Fermi function (f)

Use of a high-efficiency device to detect gamma rays

→ Sum energy in the detector (calorimeter)

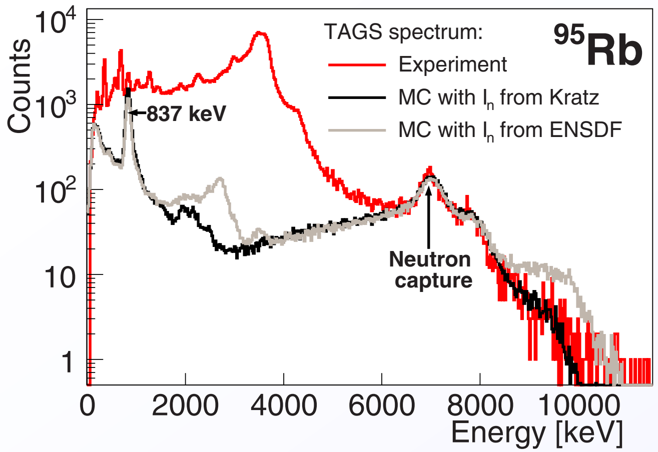
→ Detect gamma-ray cascades

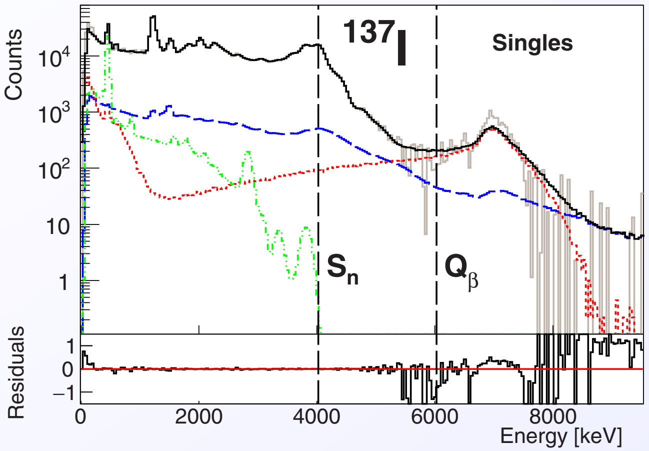
$$d_i = \sum_j R_{ij} f_j \quad or \quad \mathbf{d} = \mathbf{R}(b) \cdot \mathbf{f}$$



Taín, Cano et al., NIM A 571, 710 (2007), NIM A 571, 728 (2007)
Rubio et al., Phys. G: Nucl. Part. Phys. 44 (2017) 084004

Dealing with neutrons in the TAS





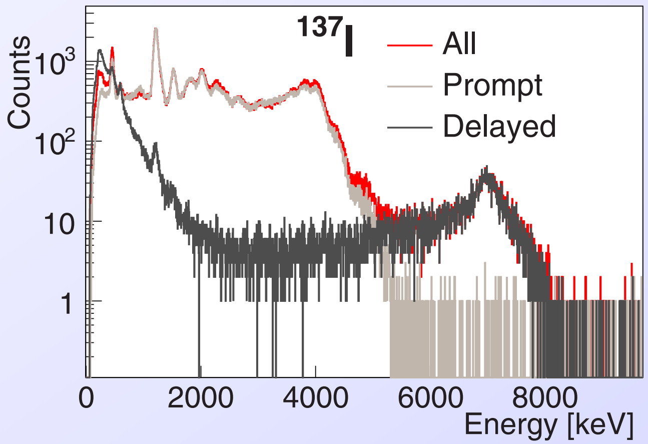
V. Guadilla, J.L. Taín et al., PRC 100, 044305 (2019)

"Contamination" from the interaction of neutrons with the spectrometer

- → NaI(Tl): n capture or inelastic
- → Taken care by **simulations**
- → $I_{\beta n}$ needed, but known to excited states!
- → Simulations **validated** using segmentation for **DTAS** @ JFYL

Alternative: time discrimination

- → Beta-TAS timing



Beam time request

- UC_2/graphite target + neutron converter
- Temperature-controlled quartz glass transfer line
- RILIS

Nuclide	$T_{1/2}$ (ms)	ABRABLA	Exp. yield/μC	Q_β (keV)	$Q_{\beta n}$ (keV)	P_n (%)
^{80}Zn	562(3)	1.40E+05	1.0E+04	7575(4)	2828(3)	~1
^{81}Zn	290(4)	2.50E+03	6.0E+02	11428(6)	4953(6)	23(4)
^{82}Zn	155(26)	—	~1.5E+01	10617(4)	7243(4)	69(7)
Nuclide	$T_{1/2}$ (ms)	ABRABLA	DB yield / μC	Q_β (keV)	$Q_{\beta n}$ (keV)	P_n (%)
^{80}Ga	1900(100)	1.80E+07	6.7E+04	10312(4)	2230(40)	0.9
^{81}Ga	1217(5)	5.80E+06	7.9E+03	8664(4)	3836(4)	12
^{82}Ga	599(2)	3.30E+05	1.8E+03	12484(3)	5290(3)	20
Nuclide	$T_{1/2}$ (min)	ABRABLA	DB yield / μC	Q_{EC} (keV)		
^{80}Rb	0.557(12)	1.60E+08	1.1E+05	5718(2)		
^{81}Rb	30.5(3) / 274.3(2)	5.70E+08	1.7E+05	2240(5)		
^{82}Rb	1.2575(2) / 388.3(4)	1.1E+09	4.50E+06	4404(3)		

Optimization of transfer line: 1 shift

^{80}Zn and ^{81}Zn: 4 shifts (including background and daughter activities)

^{82}Zn: 10 shifts (including RILIS off)

Collaboration

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