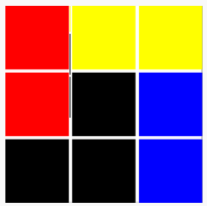
β decay studies of neutron-deficient gallium isotopes with Lucrecia

INTC-P-718

in the framework of

LOI259

Víctor Guadilla



Nuclear Physics Division
University of Warsaw

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Physics motivation

Superallowed transitions crucial for electroweak interaction

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- Test the conservation of weak vector current (CVC)
- Test CKM unitarity: $V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$?

$\hookrightarrow 2\sigma$ tension with the standard model

A. Falkowski et al., EPJA 59, 113 (2023)

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$$\mathcal{F}t = ft(1 + \delta_R')(1 + \delta_{NS} - \delta_C) \propto G_V^{-2}$$

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$$f(Q_\beta, Z) \text{ and } t = \frac{T_{1/2}(1 + P_{EC})}{I_\beta^{super}}$$

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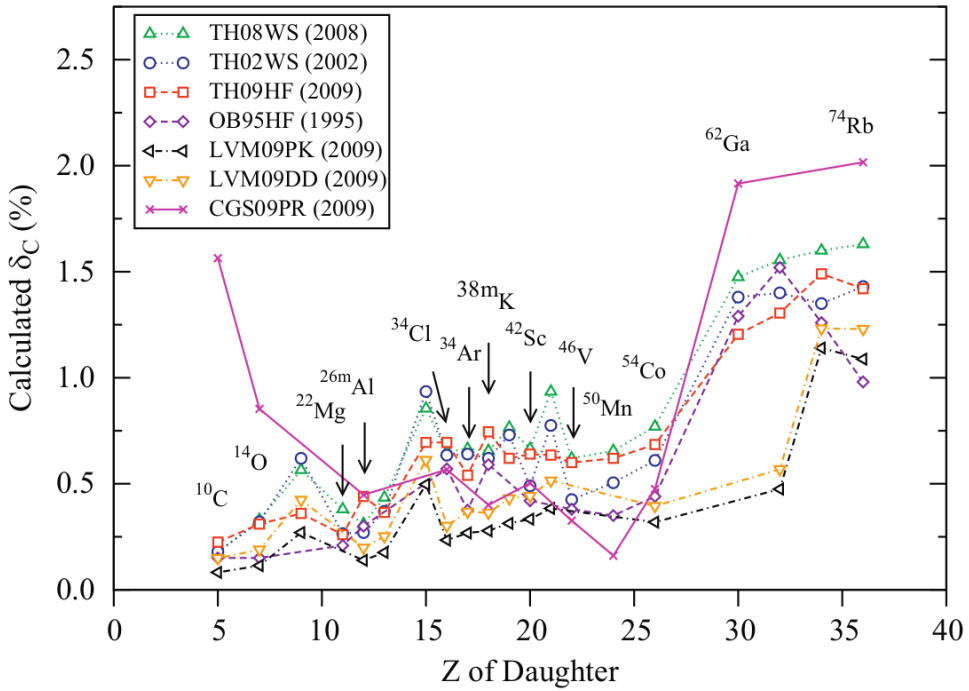
- Theoretical ingredients: δ_C + radiative corrections.

Physics motivation

Conserved Vector Current hypothesis $\rightarrow$ **constrain different models:**

$$\delta_C^{emp.} = 1 + \delta_{NS} - \frac{\overline{\mathcal{F}t}}{ft(1+\delta'_R)}$$



G.F. Grinyer et al., NIMA 622, 236 (2010)

Shell model, Hartree-Fock, density functional theory, random phase approximation, isovector monopole-resonance model, ab initio

Physics cases

61Ga	62Ga	63Ga	64Ga	65Ga	66Ga
166 ms	116.123 ms	32.1 s	2.627 min	15.134 min	9.304 h
ε+β+=100% εp<0.25%	ε+β+=100%	ε+β+=100%	ε+β+=100%	ε+β+=100%	ε+β+=100%

β decay for nuclear astrophysics and nuclear structure

- rp-process path close to the ^{60}Zn waiting point
- Information about low-spin states in the daughter zinc isotopes
- Role of $1g_{9/2}$ orbital
- Recent study of ^{64,66}Ga at ISOLDE with Lucrecia

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^{63}Ga

- Known β feeding up to 1691.62 keV.
- Over 60 levels observed in ^{64}Zn(d,t)^{63}Zn.

K.G. Leach et al., PRC 87, 064306 (2013)

Q_{EC}=5666.3(20) keV

$T_{1/2}$=32.1(5) s

$I_{\beta}^{g.s.}$=<54%

Physics cases

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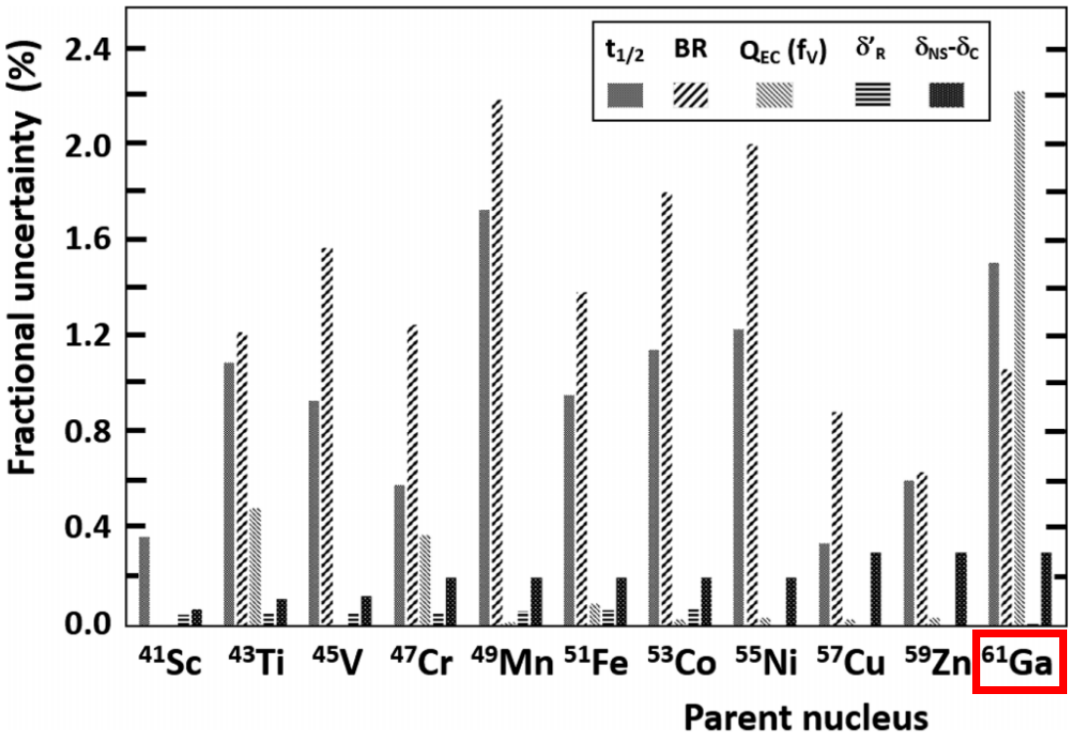

Q_{EC}=9214(38) keV

$T_{1/2}$=166(3) ms

I_{β}^{super}=94(1)%

N. Severijns et al., PRC 107, 015502 (2023)

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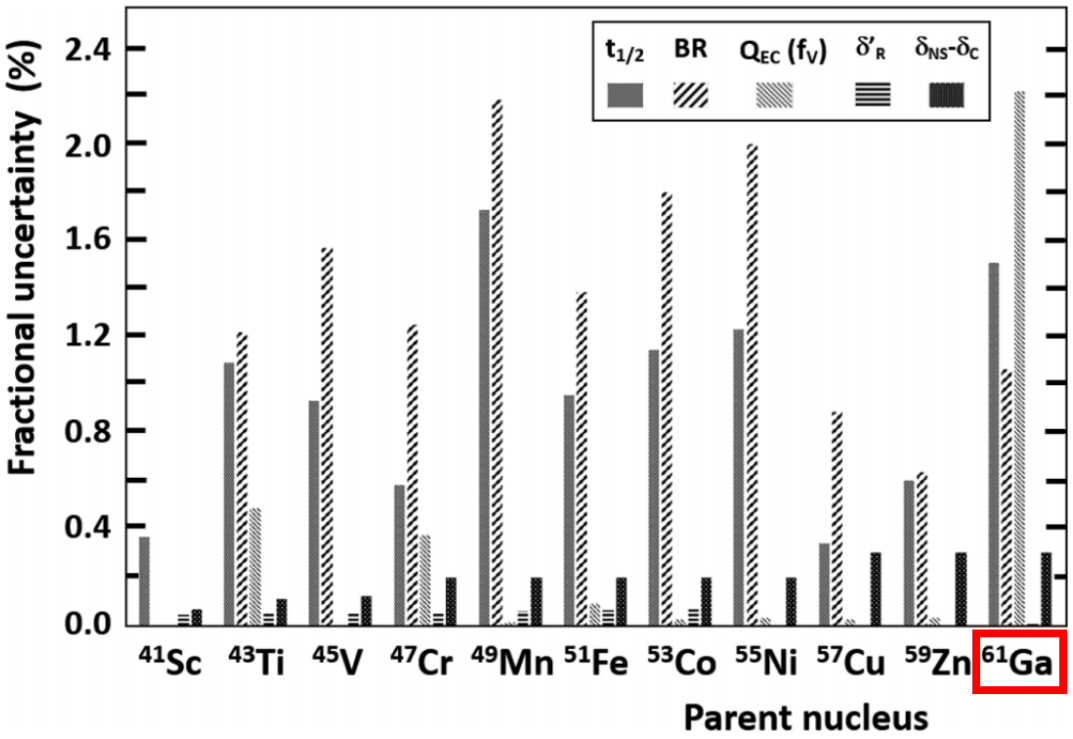

Q_{EC} =9235(20) keV

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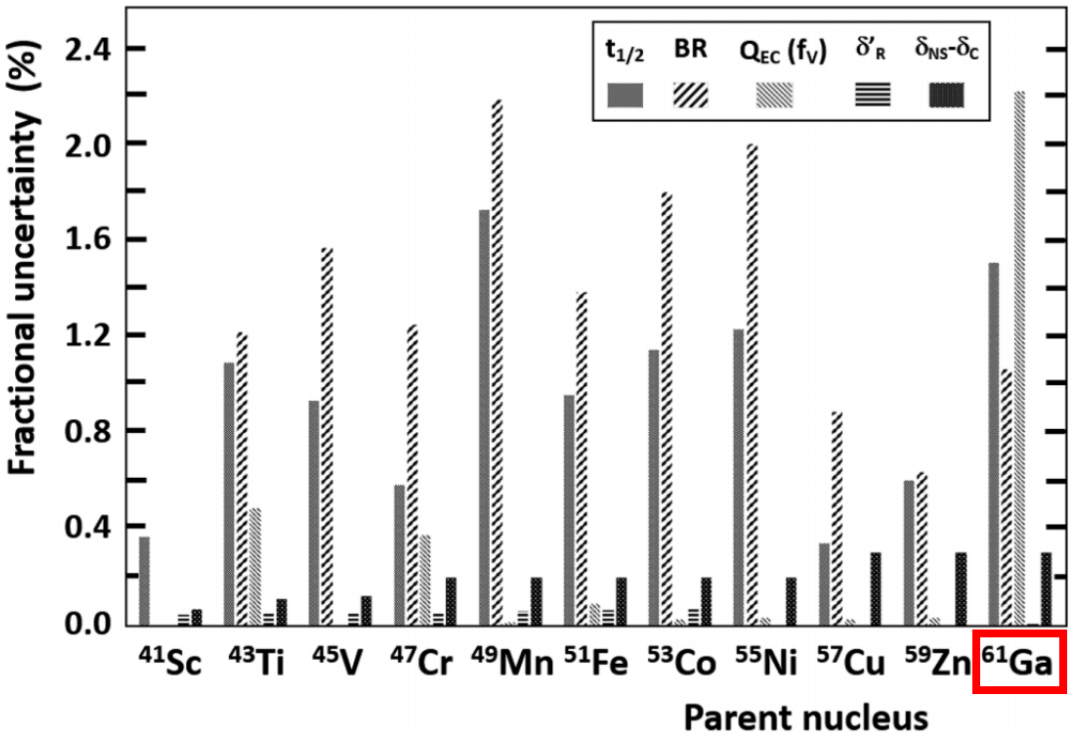

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- ISOLDE: β feeding up to 938 keV excitation energy in ^{61}Zn.

L. Weissman et al., PRC 65, 044321 (2002)

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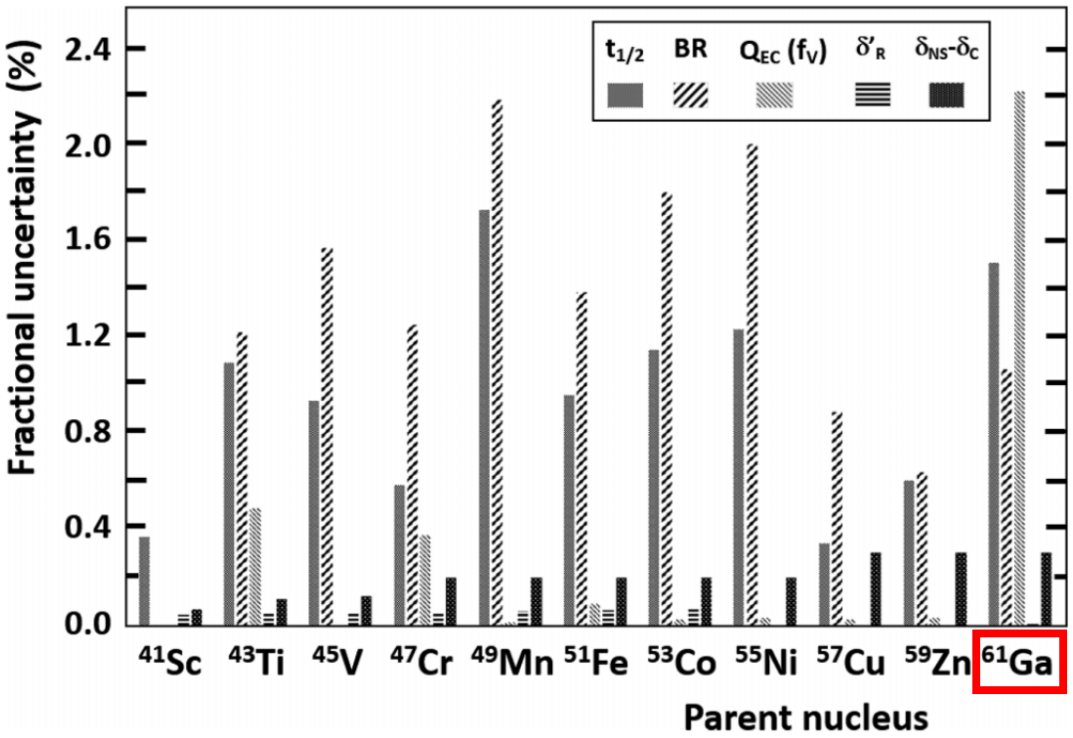

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L. Weissman et al., PRC 65, 044321 (2002)

- 200 states predicted up to S_p (5293(16) keV).

S. Goriely et al., PRC 78, 064307 (2008)

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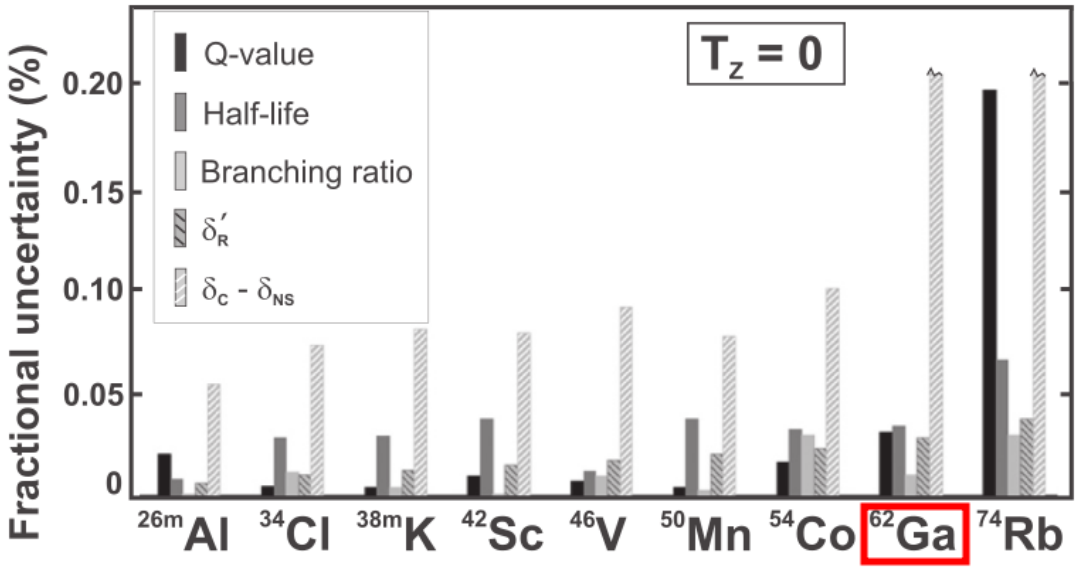

Q_{EC}=9181.07(54) keV

$T_{1/2}$=116.121(40) ms

I_{β}^{super}=99.862(11)%

J.C. Hardy and I.S. Towner PRC 102, 045501 (2020)

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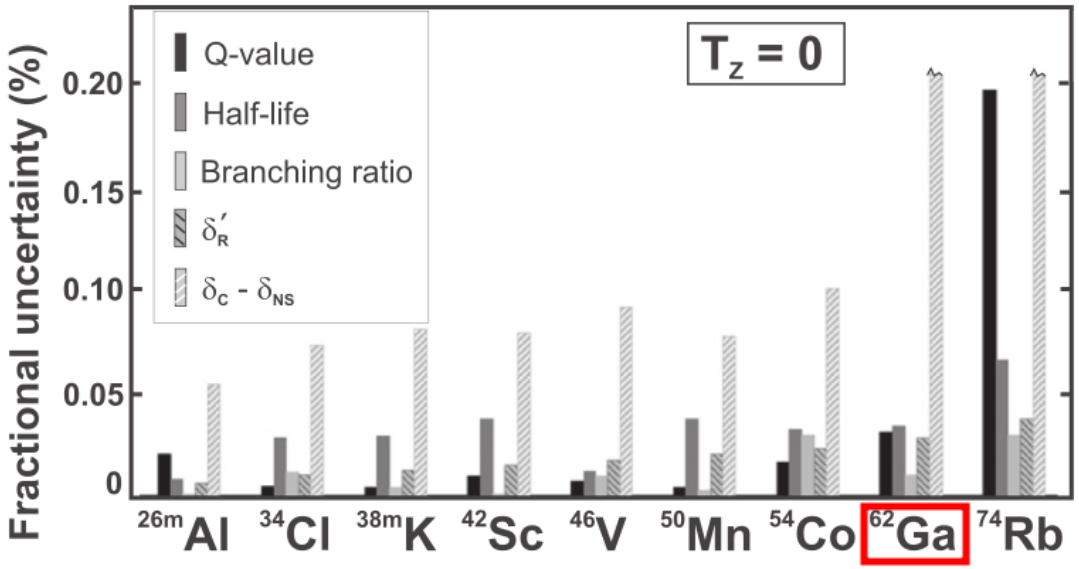

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$I_\beta^{super}=99.8577^{+0.0023}_{-0.0029}\%$

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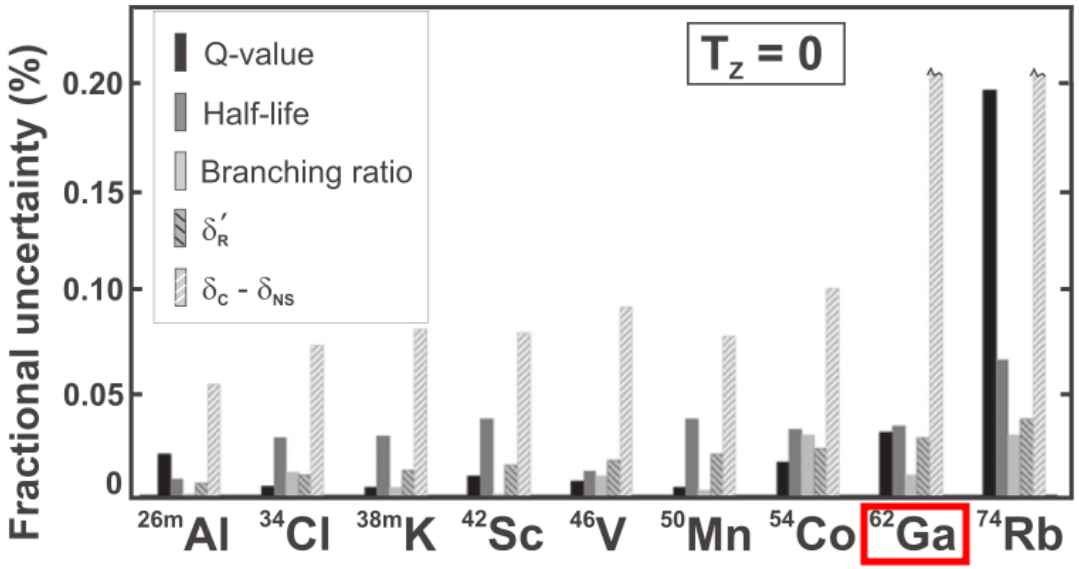

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- Non-analog Fermi decay to 0^+ states: three 0^+ excited states observed in ^{64}Zn(p,t)^{62}Zn but not in β decay

K.G. Leach et al., PRC 88, 031306(R) (2013)

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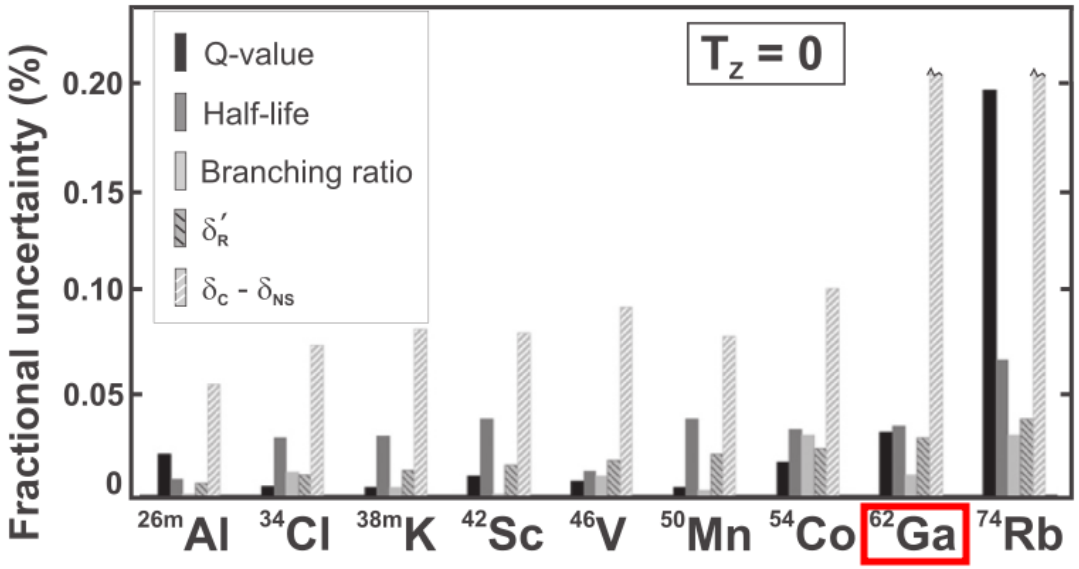

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- Non-analog Fermi decay to 0^+ states: three 0^+ excited states observed in ^{64}Zn(p,t)^{62}Zn but not in β decay

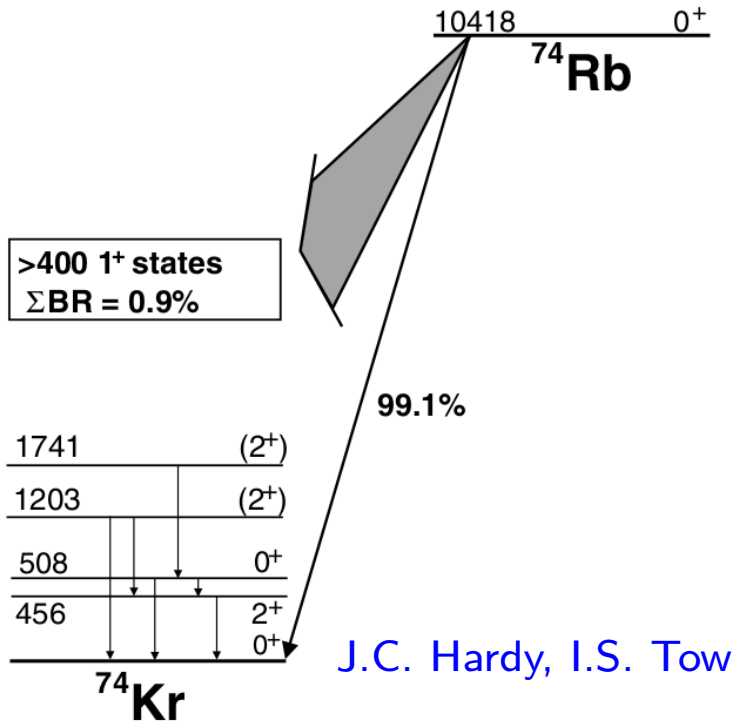
K.G. Leach et al., PRC 88, 031306(R) (2013)

- Shell model calculations predict more than 100 1^+ states in ^{62}Zn within Q_{EC}, only 17 found experimentally.

A.D. MacLean et al., PRC 102, 054325 (2020)

Physics cases

• Increasing A: large amount states fed by numerous Gamow-Teller transitions $\Rightarrow$ possible **Pandemonium**



J.C. Hardy, I.S. Towner, PRL 88, 252501 (2002)

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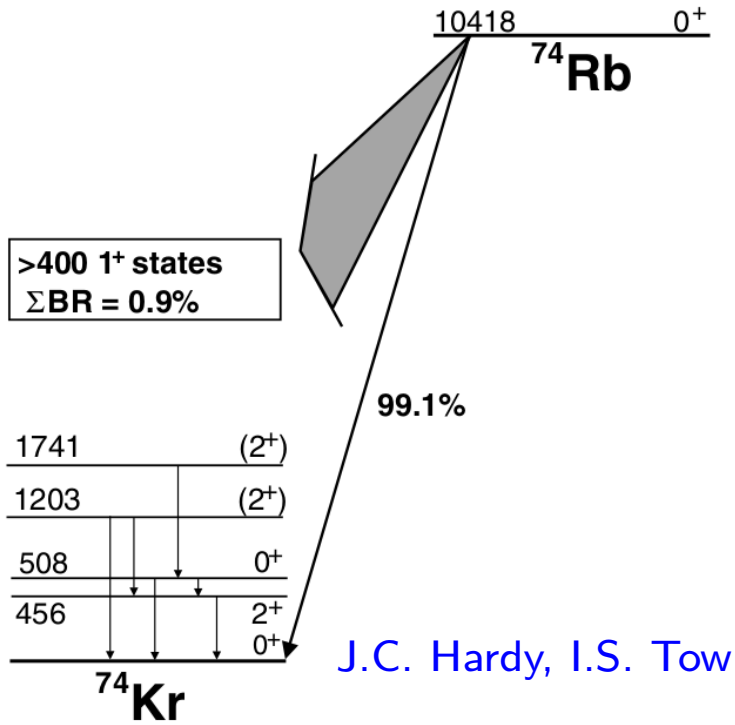
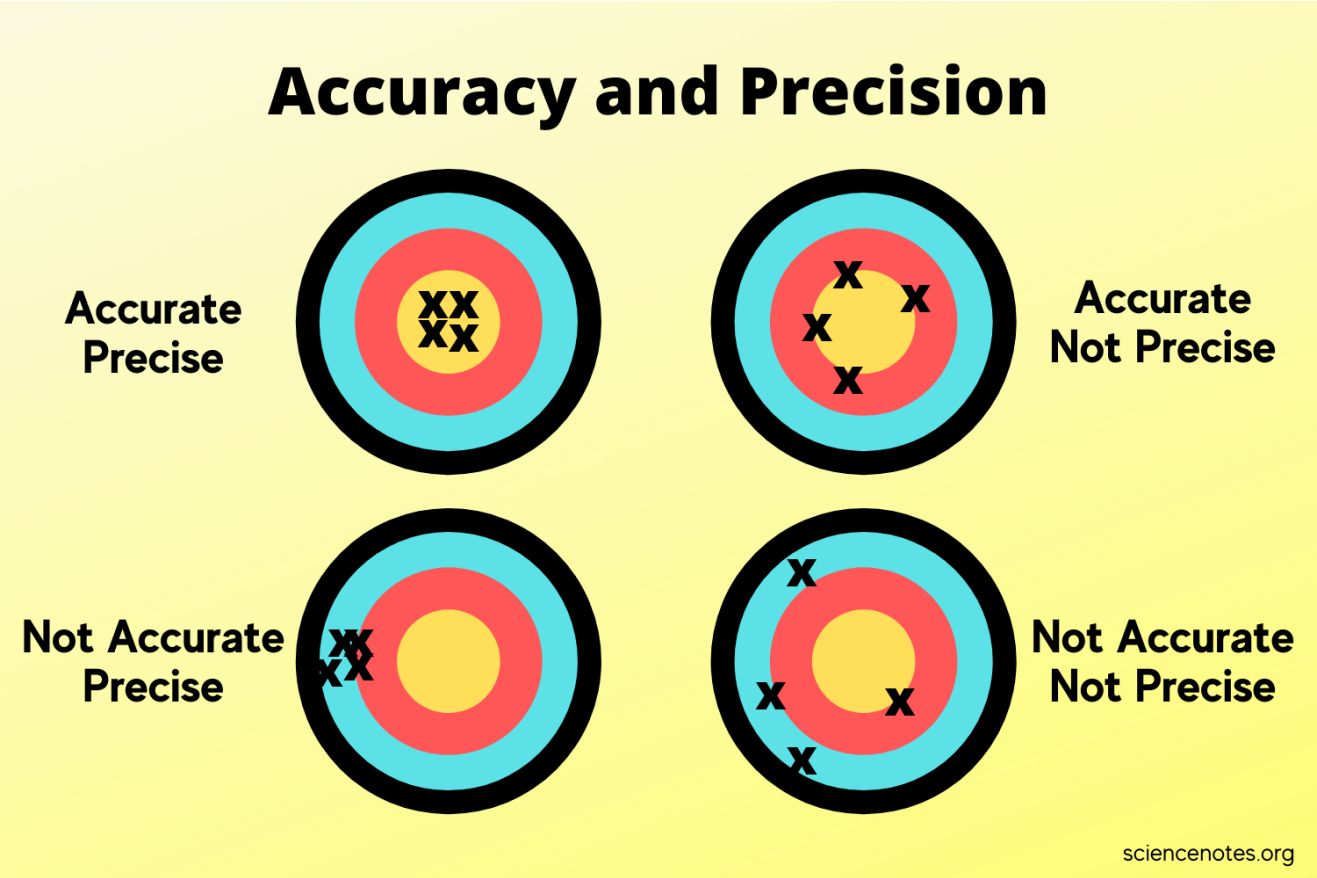


J.C. Hardy, I.S. Towner, PRL 88, 252501 (2002)

- Ground state feeding determination in high-resolution γ-spectroscopy:

$$I_{\beta}^{g.s.} = 1 - I_{\beta\gamma}$$

Physics cases



^{62}Ga

$99.8577^{+0.0023}_{-0.0029}\%$

A.D. MacLean et al., PRC 102, 054325 (2020)

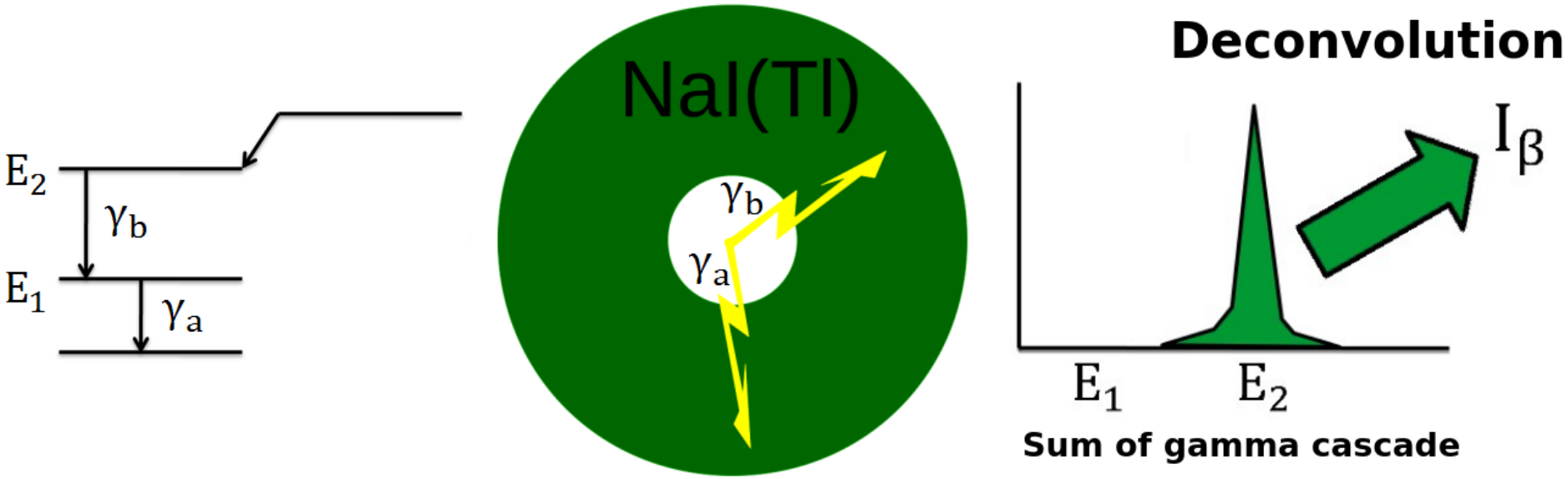
^{74}Rb

99.545(31)%

R. Dunlop et al., PRC 88, 045501 (2013)

Proposed technique

Total Absorption γ-Ray Spectroscopy (TAGS)



J. L. Tain and D. Cano-Ott, NIMA (2007)

Pandemonium free technique: **complete** I_β distributions

Proposed technique

Ground state feeding determination with a TAS detector

V. Guadilla, Front. Phys. 12, 1452988 (2024)

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Ground state feeding determination with a TAS detector

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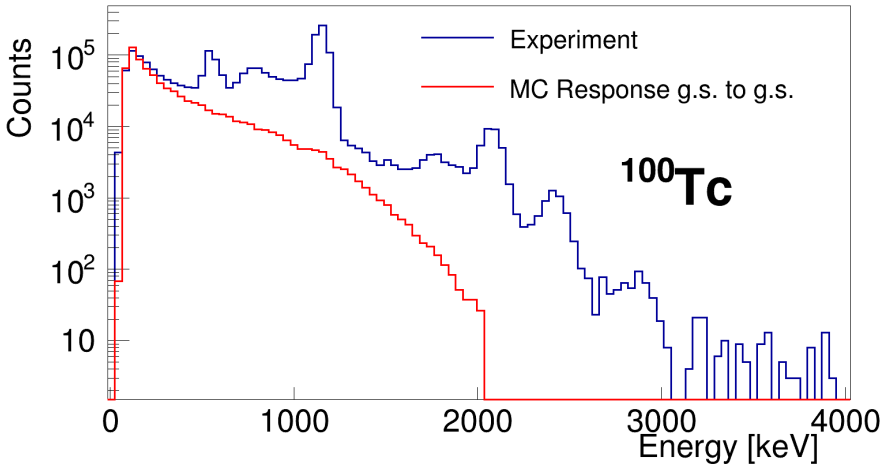
- TAGS technique naturally gives a value due to the β penetration!



$I_{\beta}^{g.s.}$ value:
93.3(1)% ENSDF
93.9(5)% TAGS

V. Guadilla et al., PRC 96, 014319 (2017)

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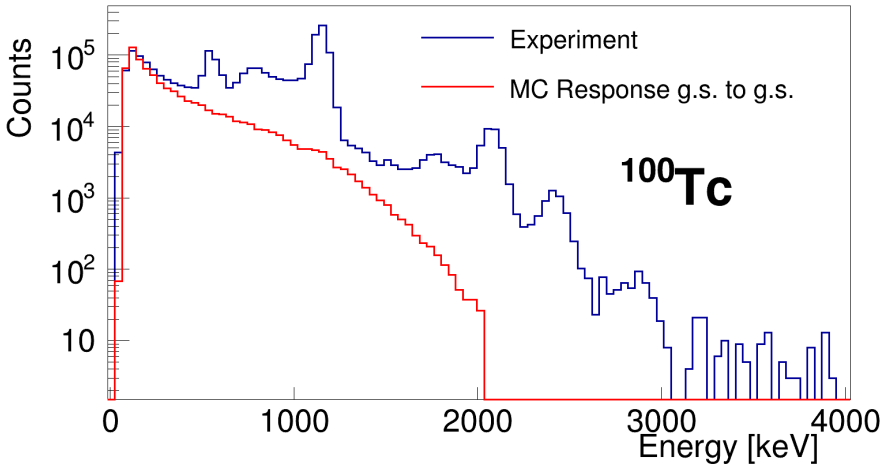

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V. Guadilla et al., PRC 96, 014319 (2017)

- Counting method: R.C. Greenwood et al., NIMA 317, 175 (1992)

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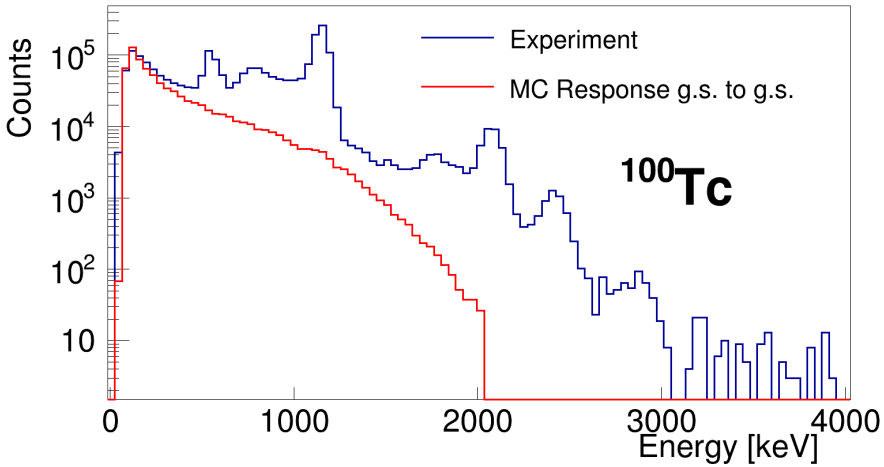


$I_\beta^{g.s.}$ value:
93.3(1)% ENSDF
93.9(5)% TAGS
92.8(5)% $4\pi\gamma - \beta$

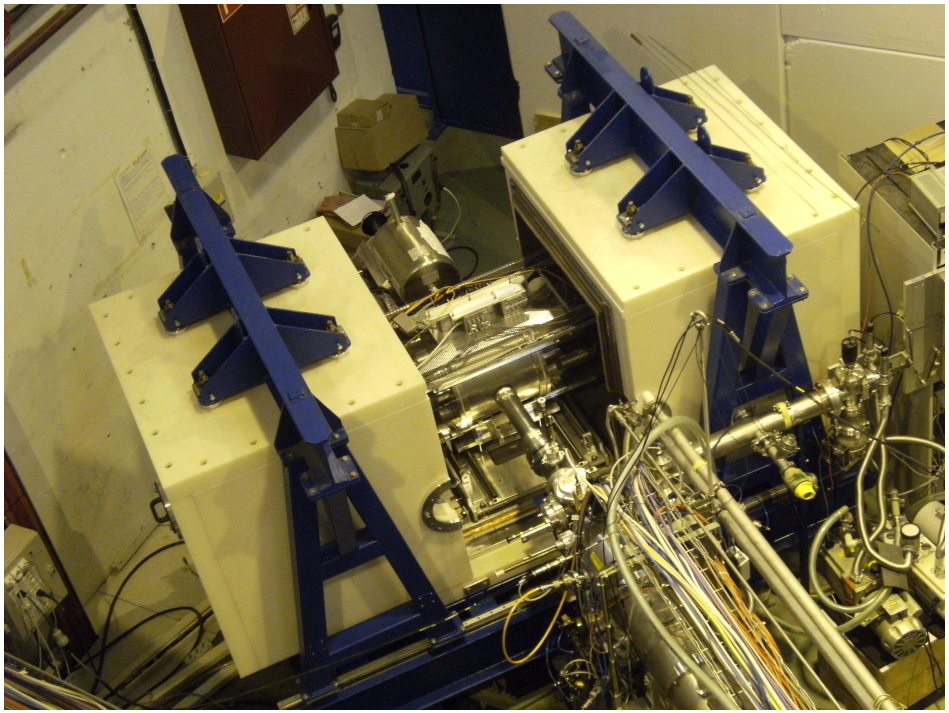
V. Guadilla et al., PRC 96, 014319 (2017)

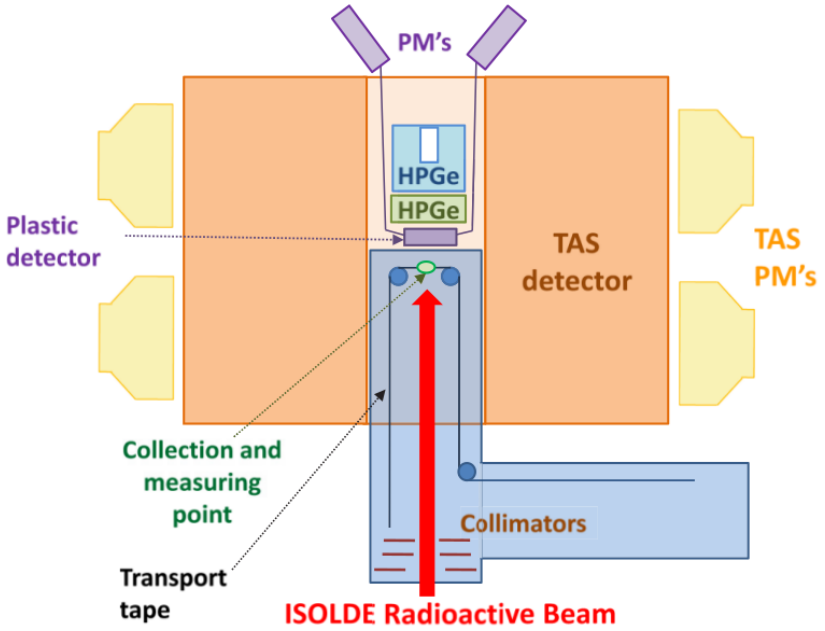
- Counting method: R.C. Greenwood et al., NIMA 317, 175 (1992)
- Recently revised: $4\pi\gamma - \beta$

  ratio $N_{\beta\gamma}/N_\beta$ (exp.) + ratios of β efficiencies (MC)

V. Guadilla et al., PRC 102, 064304 (2020)

Proposed experimental setup





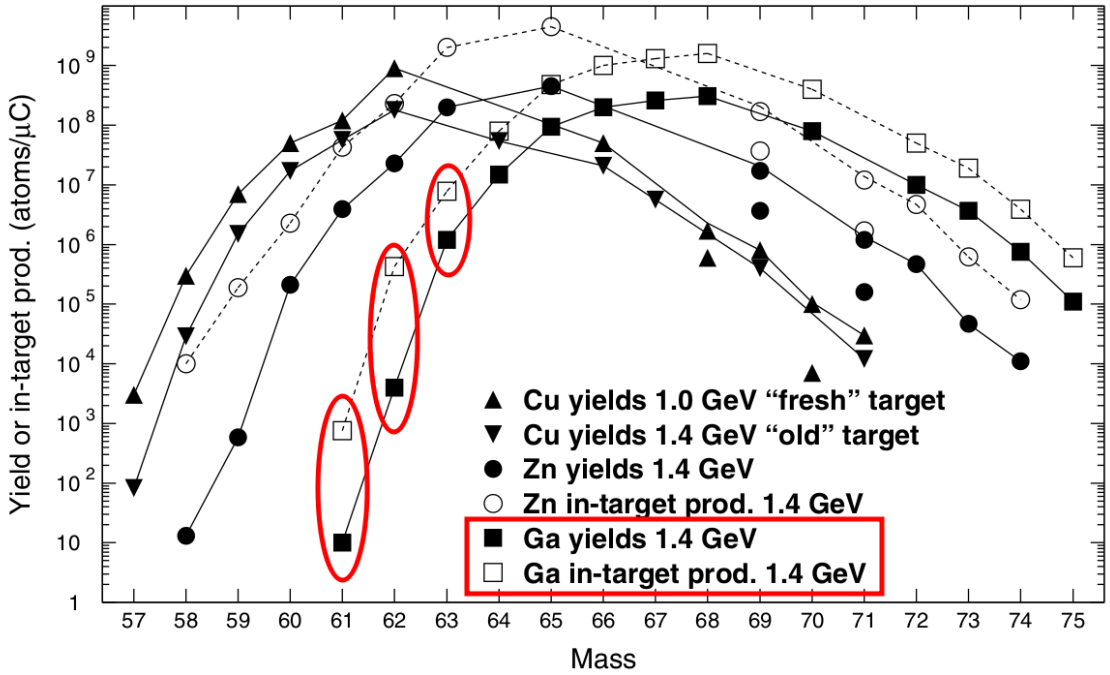
J. A. Briz et al. PRC 92, 054326 (2015)

- LUCRECIA: NaI(Tl) spectrometer

  B. Rubio et al., J. Phys. G: Nucl. Part. Phys. 44, 084004 (2017)
- Total efficiency ∼90%
- Coincidences β-γ
- Movable tape for implantation and removal of the activity

Beam time request (+ TAC's comments)

ZrO_2 felt target + RILIS



U. Köster et al., NIMB 204, 303 (2003)

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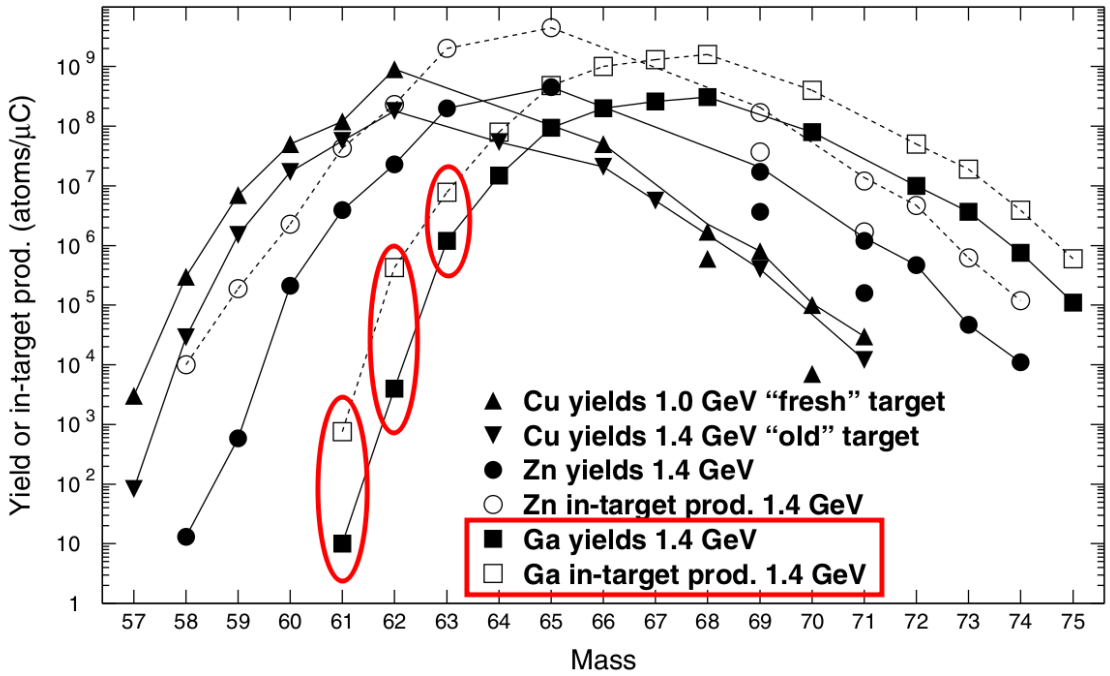

U. Köster et al., NIMB 204, 303 (2003)

TAC recommendation

"The TAC notes that while the yields were achievable in the past, there is no guarantee they can be reproduced. What are the minimum required yields for the experiment to remain feasible?"

Beam time request (+ TAC's comments)

Nucleus	Yield/μC	Shifts	Statistics (TAS)	Minimum yield/μC
^{61}Ga	10	14	1×10^6	
^{62}Ga	4000	2.5	70×10^6	
^{63}Ga	1.2×10^6	0.5	70×10^6	

Assumptions:

- ⋆ Average intensity 1.6 μA
- ⋆ 70% transmission to Lucrecia.
- ⋆ Total γ and β detection efficiencies 80% and 40%, respectively.
- ⋆ Negligible contribution of descendants.

Beam time request (+ TAC's comments)

Nucleus	Yield/μC	Shifts	Statistics (TAS)	Minimum yield/μC
^{61}Ga	10	14	1×10^6	10
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↑ shifts

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Collaboration

V. Guadilla[1], J. Agramunt[2], A. Algora[2], M. Araszkiewicz[1], M. Au[3], C. Bernerd[3], J.A. Briz[4], K. Chrysalidis[3], A. Fijałkowska[1], L.M. Fraile[4], E. Ganioğlu[5], W. Gelletly[6], R. Heinke[3], M. Karny[1], A. Korgul[1], K. Miernik[1], M. Młynarczyk[1], F. Molina[7], E. Nácher[2], S.E.A. Orrigo[2], B.M. Rebeiro[8], S. Rothe[3], B. Rubio[2], W. Satuła[1], K. Solak[1], S. Stegemann[3], J.L. Tain[2], J.C. Thomas[8], P. Wakuluk[1], S. Zajda[1]

[1] *Faculty of Physics, University of Warsaw, 02-093 Warsaw, Poland*

[2] *Instituto de Física Corpuscular, CSIC-Universidad de Valencia, E-46071 Valencia, Spain*

[3] *ISOLDE, CERN, CH-1211 Geneva 23, Switzerland*

[4] *Grupo de Física Nuclear & IPARCOS, Universidad Complutense de Madrid, E-28040, Spain*

[5] *Department of Physics, Istanbul University, 34134, Istanbul, Turkey*

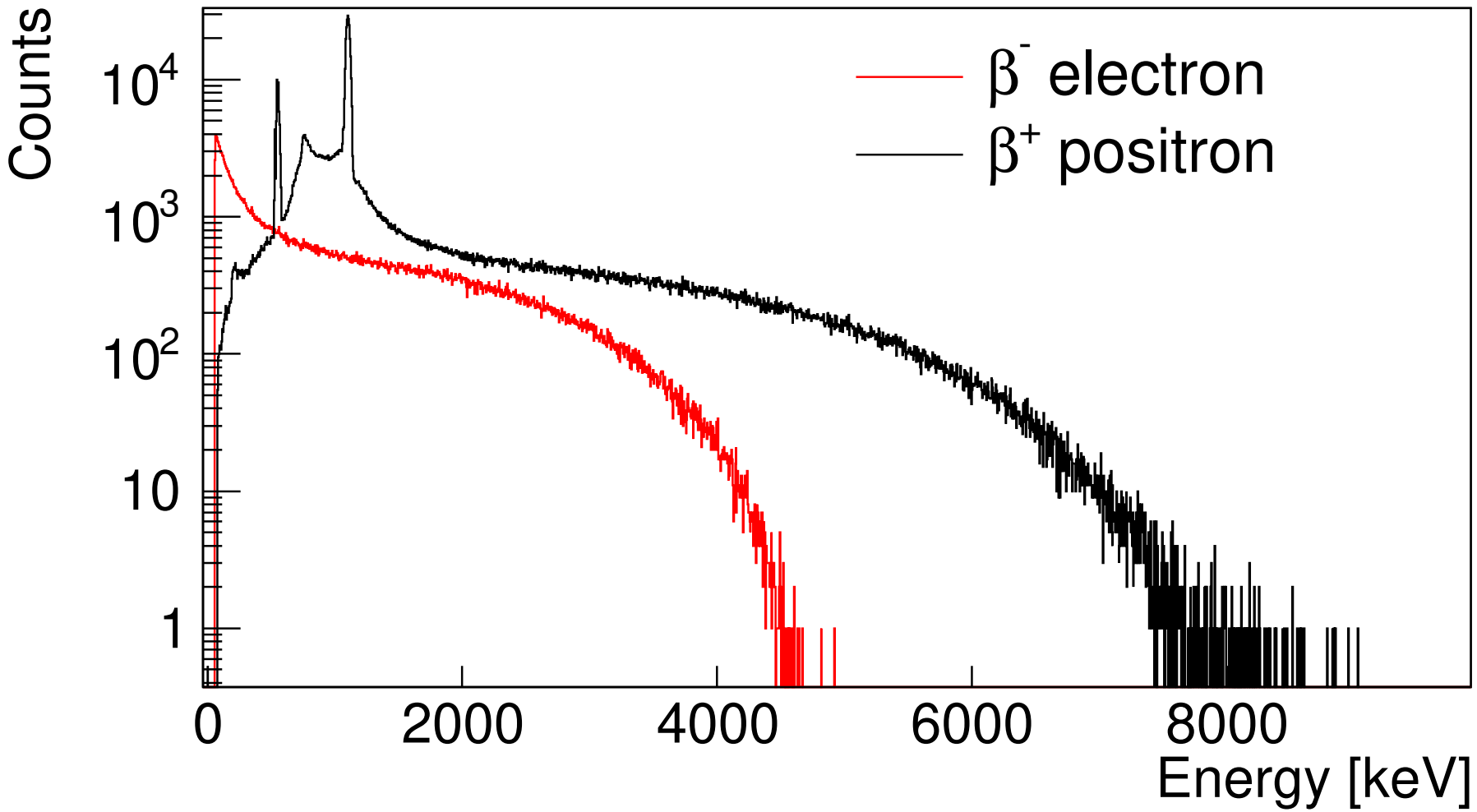
[6] *Department of Physics, University of Surrey, GU2 7XH, Guildford, UK*

[7] *Comisión Chilena de Energía Nuclear, Casilla 188-D, Santiago, Chile*

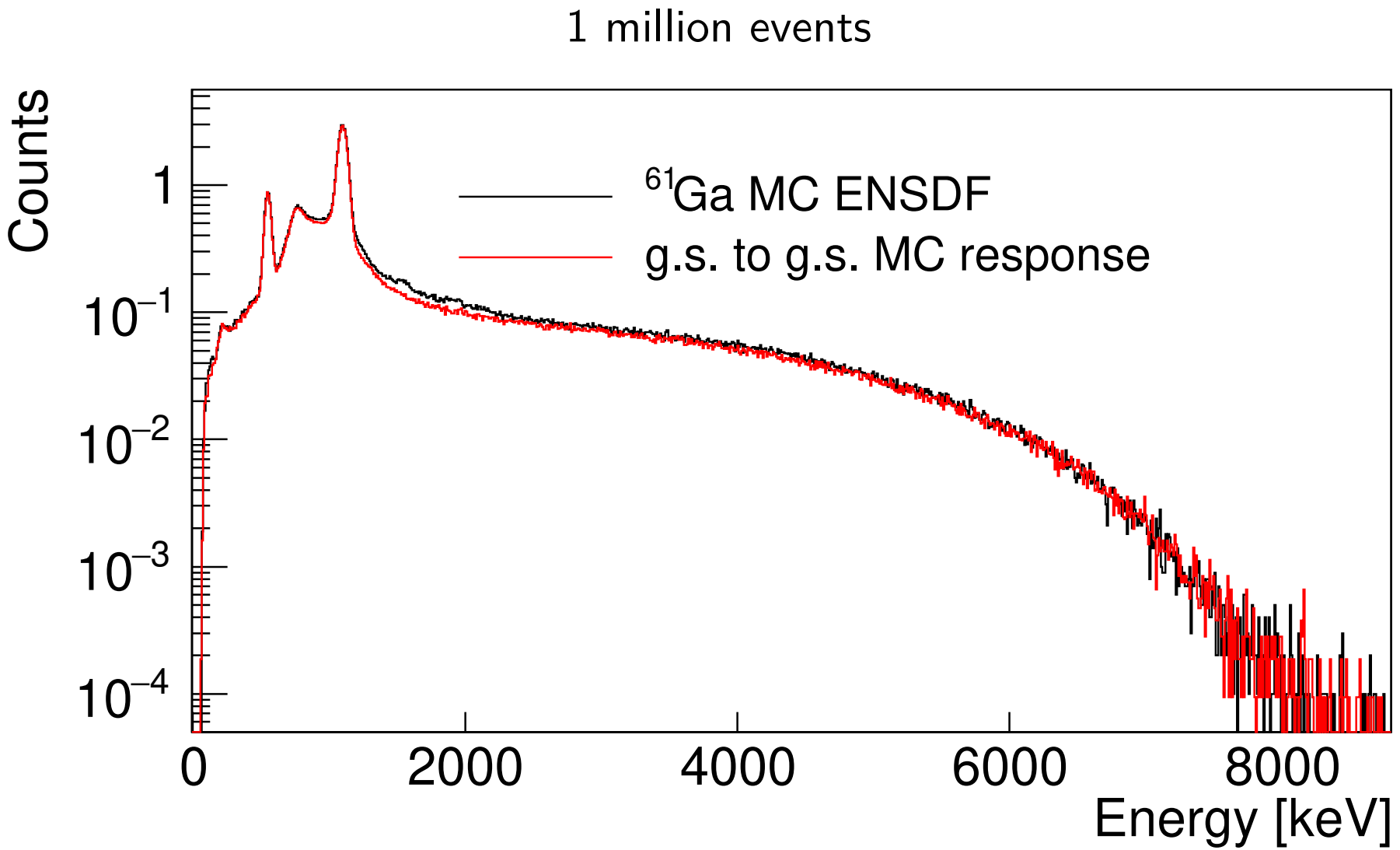
[8] *GANIL, CEA/DRF-CNRS/IN2P3, Boulevard Henri Becquerel, Caen, France*

Thank you very much for your attention!

MC response


Counts
10^4
10^3
10^2
10
1
0
2000
4000
6000
8000
Energy [keV]
β^- electron
β^+ positron

Beam time request



Beam time request