Total Absorption Spectroscopy of ^{76}Br and ^{152}Tb for their medical interest

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… for the IS722 collaboration

Intro: Beta decay and TAS

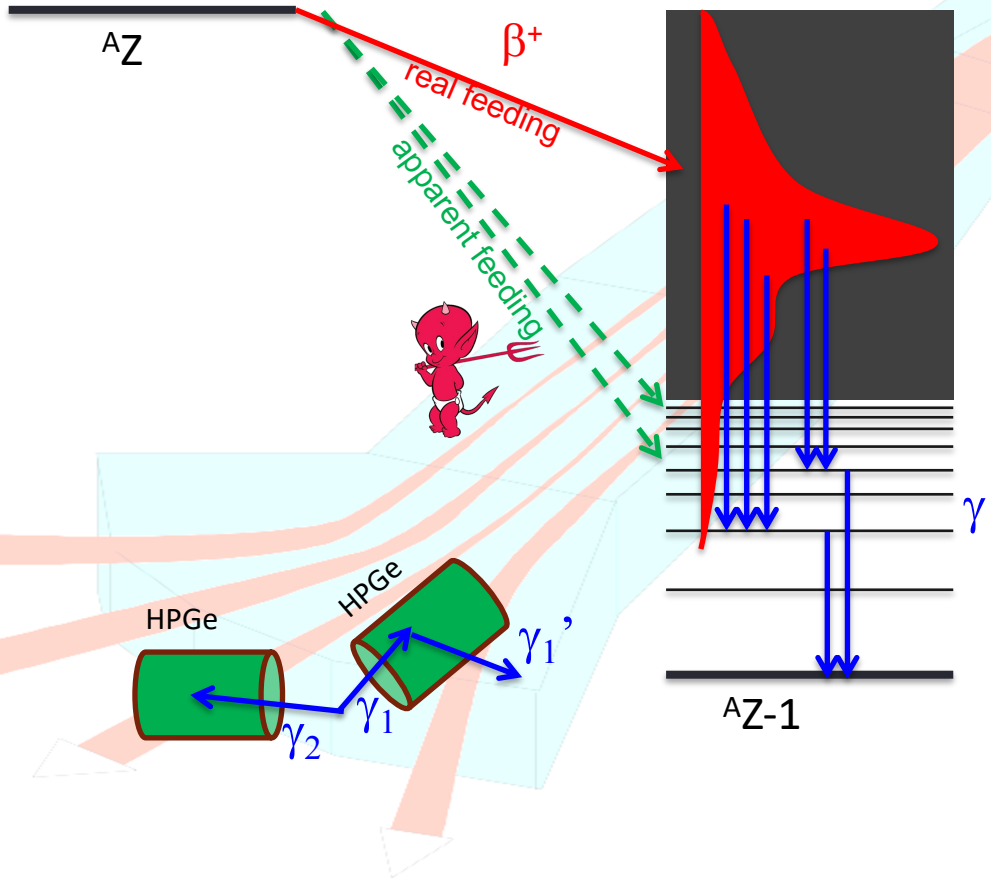
- Beta decay: often the first source of experimental information on nuclear structure far from the drip lines. Info on nuclear structure: decay scheme and beta strength (S_β)

- Measuring the $S_\beta(E)^{(*)}$ means measuring the beta intensity distribution $I_\beta(E)$: very far from trivial (explanation coming next…)

(*) Remember that S_β is the *"experimental"* side of the *"theoretical"* B(GT)

The experimental technique

- Why don't we just measure with a Ge array?

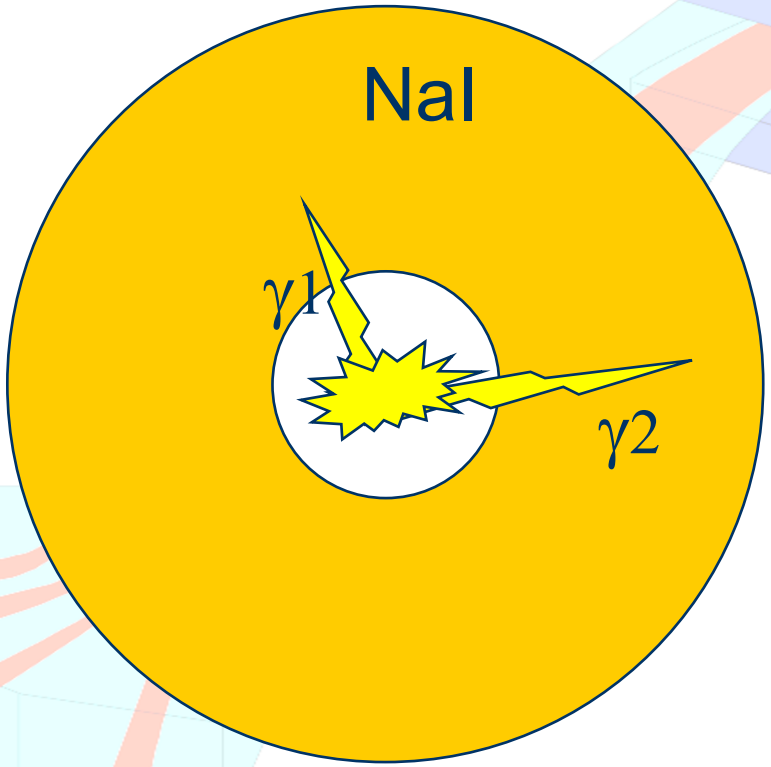


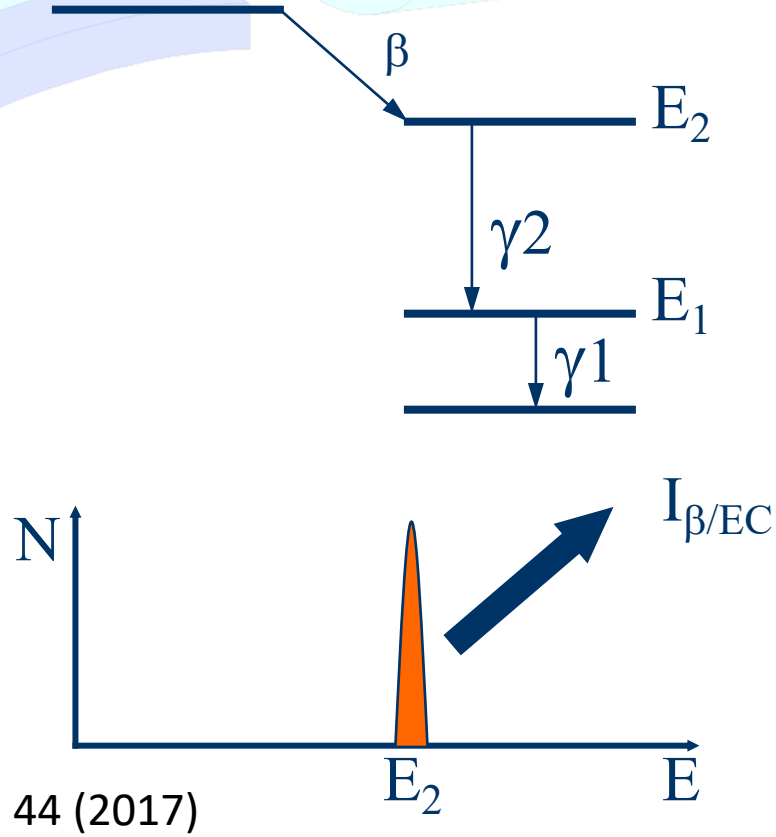
- Medium mass and heavy nuclei: large level density at high energy.
- Very fragmented $I_{\beta/EC}$ distribution and γ de-excitation pattern.
- HPGe arrays do the great job of the level scheme and gamma branching ratios, but not so great at $I_{\beta/EC}(E)$ and $S_{\beta}(E)$

Hardy et al., Physics Letters B 71 (1977)
→ Pandemonium

The experimental technique

- Total Absorption Spectroscopy (Ideal case)

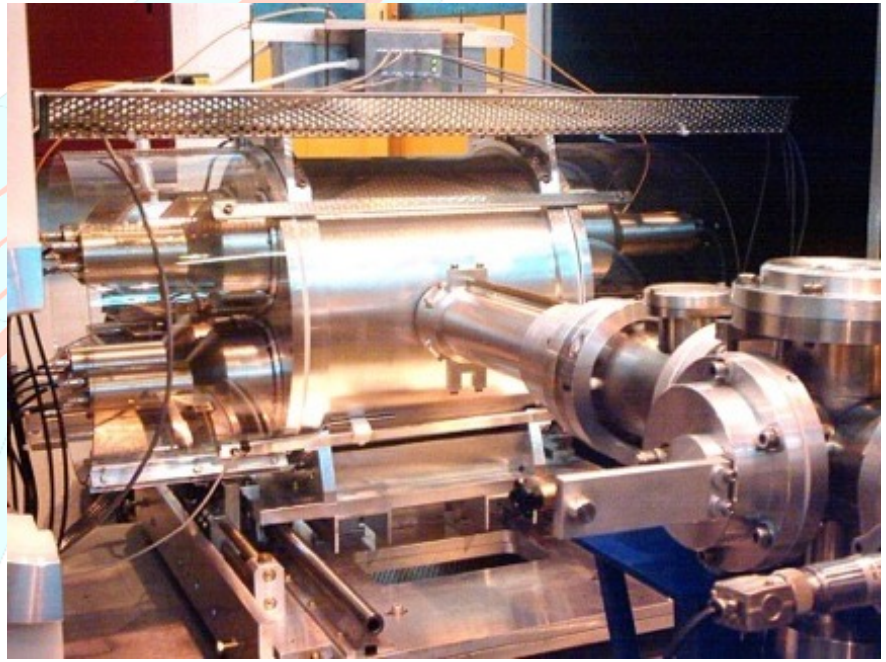


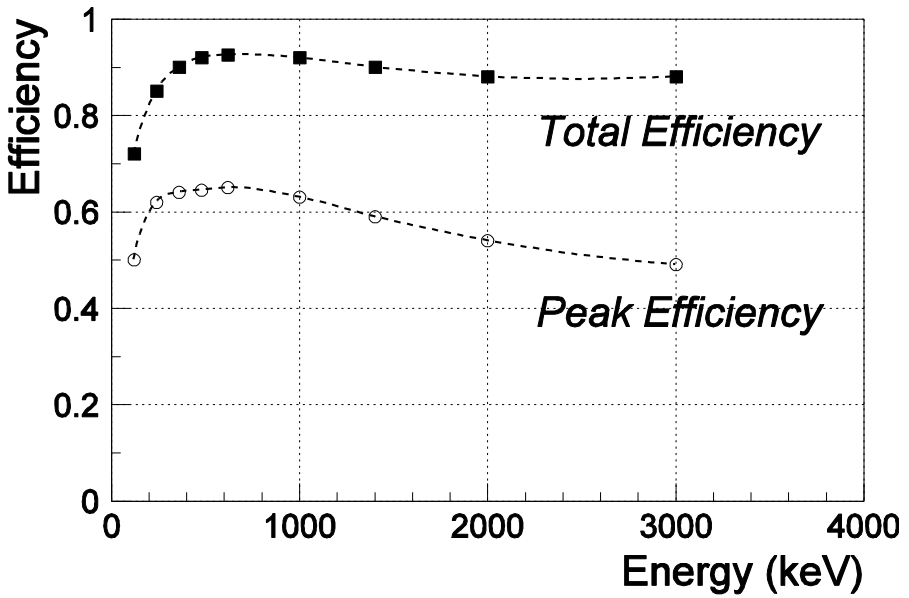


Review of the TAS technique: Rubio et al., J. Phys. G 44 (2017)
Development of TAS analysis techniques: Taín et al., NIM A571 (2007)

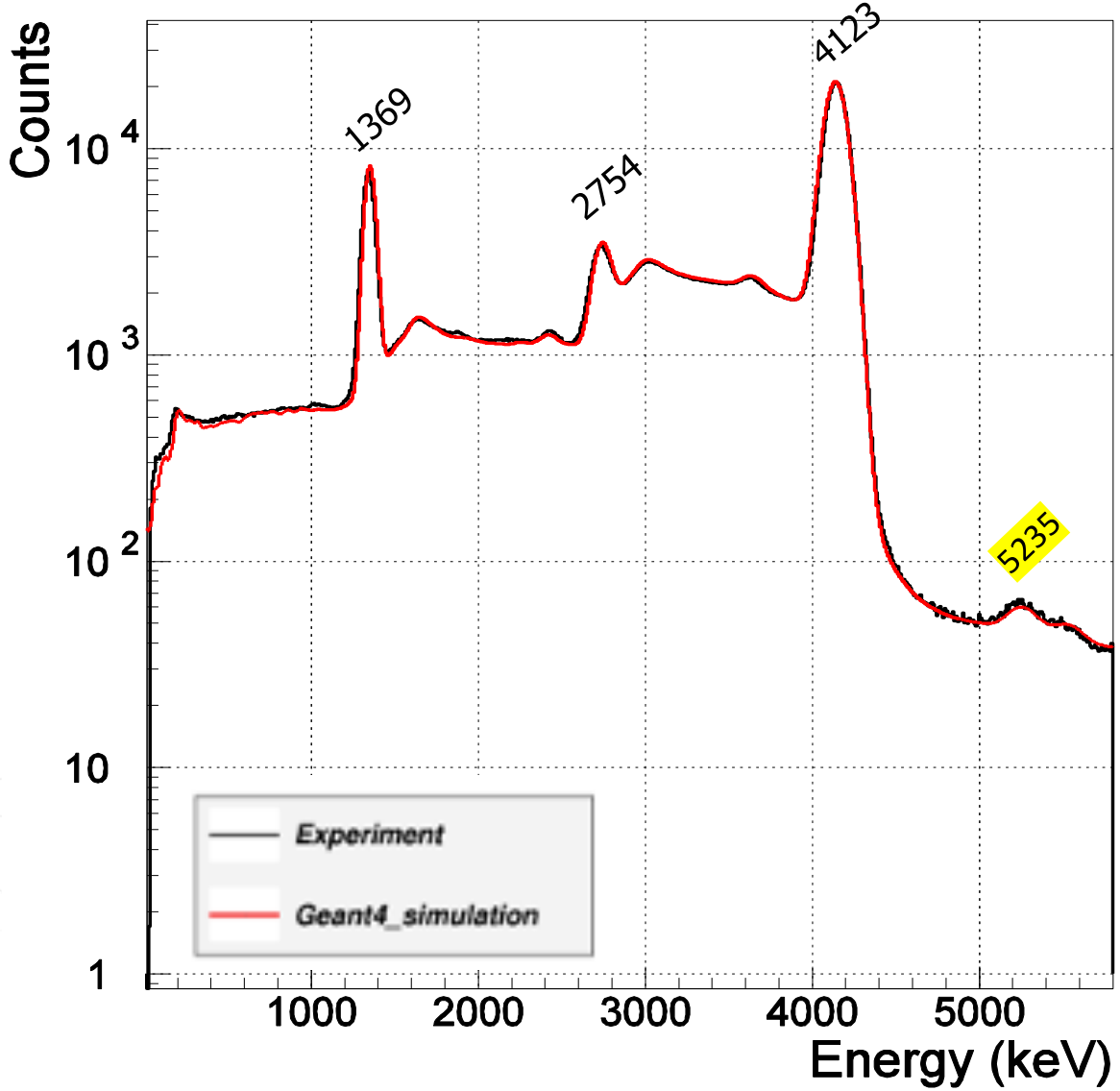
The experimental technique

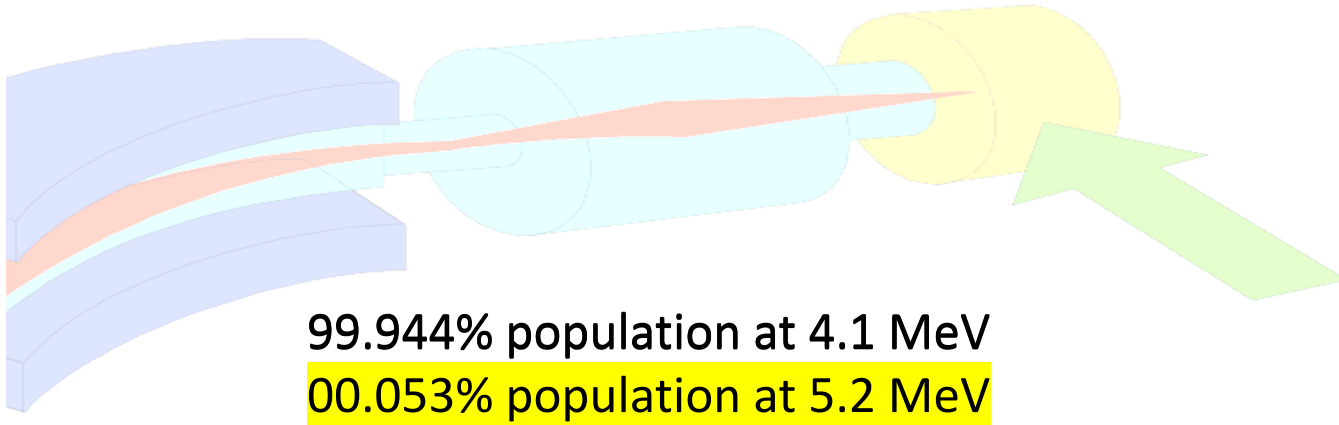
- Lucrecia, the TAS at ISOLDE
  - Main NaI(Tl) cylinder: Ø38 cm x 38 cm
  - Ancillary detectors: Ge telescope + plastic scintillator





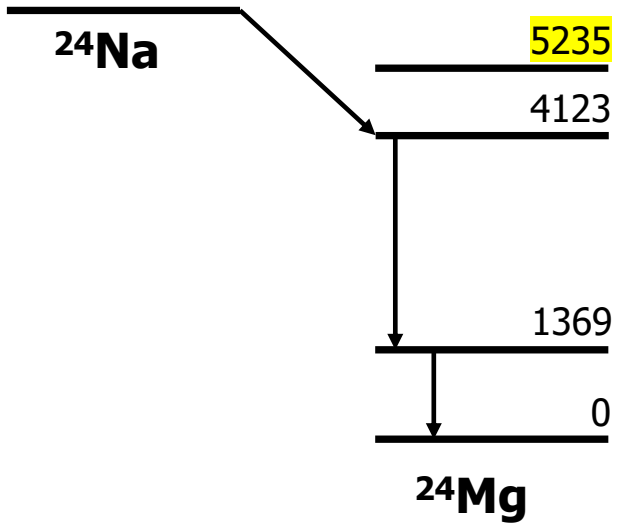
Benchmarking the Response Function





99.944% population at 4.1 MeV

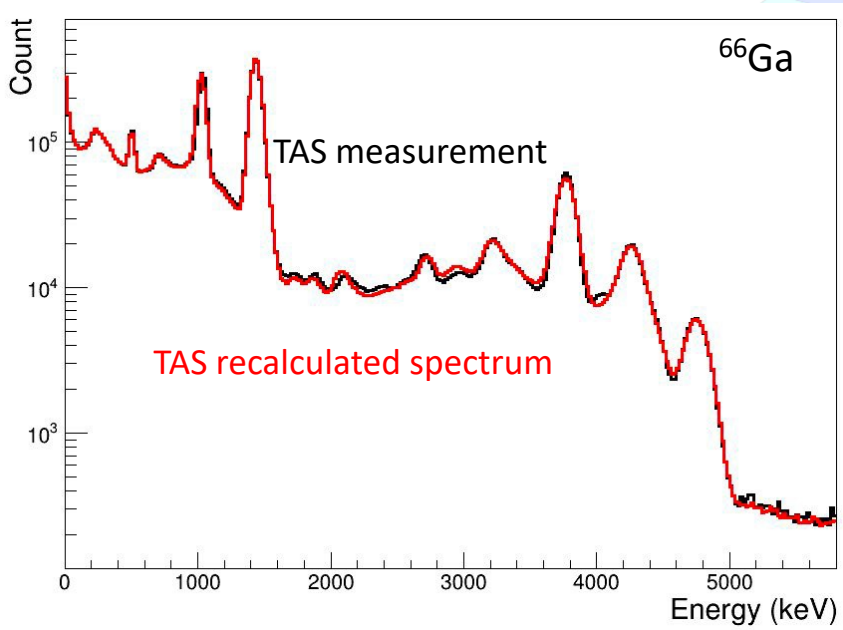
00.053% population at 5.2 MeV

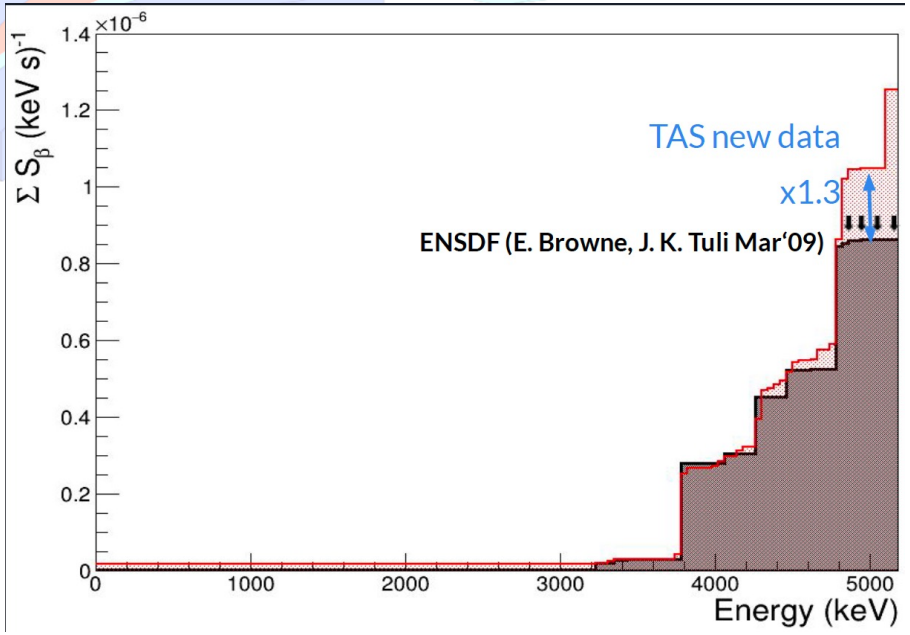


β-decay of ^{24}Na: benchmark for our simulations

TAS of close-to-stability nuclei

- One example to illustrate what we can do close to stability: ^{66}Ga decay, for its medical interest and nucl structure (isospin mixing)

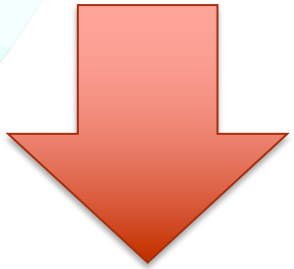




- From the medical point of view: nothing new. As for the isospin mixing, along with ^{64}Ga… TAS confirms what was known.^{66}Ga is not a pandemonium guy

The isotopes of interest

- Radio-isotopes used in medicine: important to know accurately the beta intensity distribution $I_\beta(E)$. This tells us:
  - The **total EC/β^+ ratio** (specially relevant for PET isotopes)
  - The **ratio** between energy per decay **in the form of γ-rays** and the energy per decay **in the form of β particles** (relevant for all isotopes used in medicine)



- Essential to calculate **the dose** administered to the patient **and its spatial distribution** both in diagnosis using PET or SPECT cameras and in treatment (brachytherapy and theranostics). Used by simulation codes and therapy planners.

- The beta decay of radio-isotopes of use or potential use in medicine must be well studied and the **$I_\beta(E)$ must be accurate and reliable**

The isotopes of interest

- ^{76}Br and ^{152}Tb are used in medicine within radiolabelled molecules for PET and SPECT imaging or as theranostic pairs for treatment.

- These two isotopes, among others, have been identified by Nichols [NIC22] as needing for a TAGS measurement

DE GRUYTER Radiochim. Acta 2022; aop

Contribution to "Diamond Jubilee of RCA"

Alan L. Nichols*

Status of the decay data for medical radionuclides: existing and potential diagnostic γ emitters, diagnostic β^+ emitters and therapeutic radioisotopes

https://doi.org/10.1515/ract-2022-0004
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adequate quantification of the required decay data (i.e., dose calculations include half-lives, energies and emission probabilities of α, β^+, various electron particles, γ and X-rays,

[NIC22] Nichols A. L., *"Status of the decay data for medical radionuclides"*. Radiochim. Acta 110, 609 (2022)

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- ^{76}Br and ^{152}Tb are used in medicine within radiolabelled molecules for PET and SPECT imaging or as theranostic pairs for treatment.

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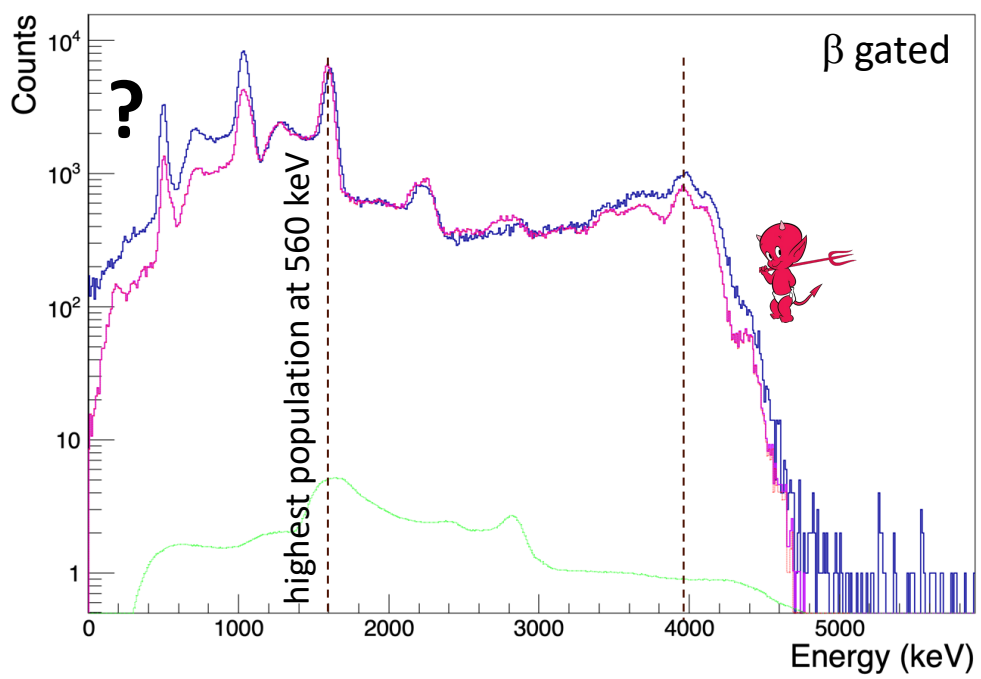
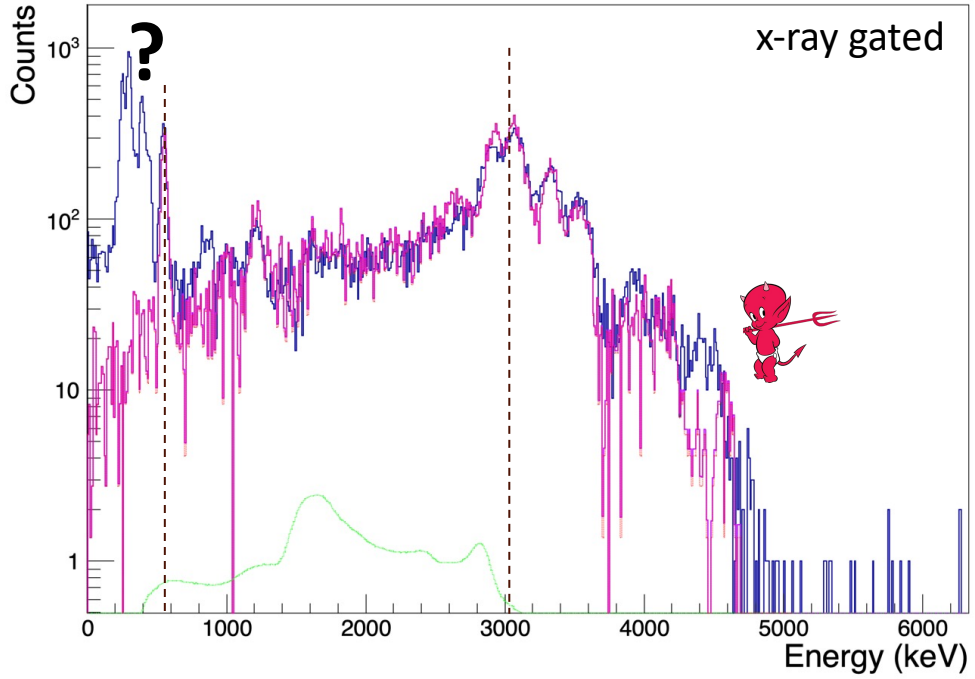
^{152}Tb use with ^{161}Tb as theranostic pair	17.5(1) h	< (7.0×10^{-7})% α 100% EC/β^+: 20.3(15)% β^+ 79.7(15)% EC	95 to 100EC/β^+, 387γ + 248γ unplaced $E_{\beta+}^{\text{end point}}$: 2037, 2353, 2624, 2968 keV E_γ: 271.09, 344.279, 586.27 keV	Most significant EC/β^+ decay directly to the ground (25% (8.0% β^+)), first (12.7% (5.9% β^+)), second (6.85% (1.20% β^+)) and fourth (8.06% (2.30% β^+)) excited states of ^{152}Gd, along with significant depopulation by 271.09, 344.279- and 586.27-keV γ rays and over 380 lower-intensity γ emissions from 117.25 to 3140.20 keV – *extremely extensive and complex decay scheme that includes as many as 387 γ rays of which the placement of only seven are in doubt, while a further 248 γ rays remain unplaced (113.5 to 3621.7 keV); suitable candidate for TAGS*

[NIC22] Nichols A. L., *"Status of the decay data for medical radionuclides"*. Radiochim. Acta 110, 609 (2022)

Pre-analysis

- ^{76}Br is the ideal PET isotope for brominated radiopharmaceuticals, e.g. it's been used to label proteins, antibodies… brain studies with labeled dopamine…
- From the spectra we infer a low Q-value contaminant and some (little) pandemonium, but not very consistent EC to β^+ spectra.

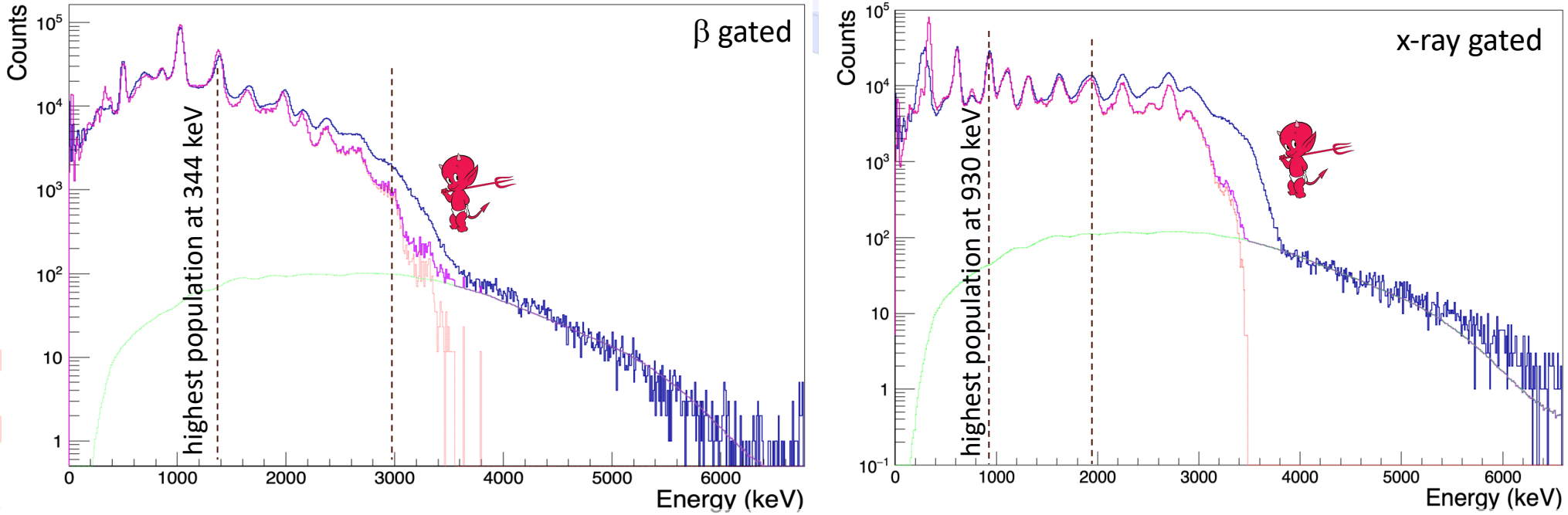




Pre-analysis

- ^{152}Tb a good isotope for PET imaging, theranostic pair of ^{149}Tb, ^{161}Tb and ^{177}Lu, used for therapy, e.g. labeled PSMA-617 (prostate) or DOTATOC (neuroendocrine)

- Very nice TAS spectra with considerably large pandemonium



- Parallel high-resolution study with the FIPPS array at ILL: *"Complete decay spectroscopy of medically relevant ^{152}Tb"*, S. Collins et al., DOI: 10.5291/ILL-DATA.3-01-727

Veeeeery quick set of *"messages" ("conclusions"?)*

- Medium mass and heavy nuclei: one never knows whether there is Pandemonium… need to measure!! Especially cases with particular sensitivity for structure/astro, reactor, medicine
- Parallel high-resolution and TAS studies always complementary and desirable, e.g. ISOLDE TAS and IDS or FIPPS

- ^{64}Ga and ^{66}Ga studied with the ISOLDE TAS: almost no Pandemonium, isospin mixing parameter just confirmed

- ^{76}Br shows possible contamination and little Pandemonium. Still deconvolution pending.

- ^{152}Tb clear TAS spectrum showing large Pandemonium. Still deconvolution pending.

IS722 at ISOLDE: Off-line TAS measurements of the long-lived nuclei ^{152,155}Tb and ^{76,77}Br for their relevance in medicine and neutrino physics

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