A look to Rudstam-Tengblad data from the TAGS point of view

Jose L. Tain (*tain@ific.uv.es*)

Instituto de Fisica Corpuscular (Valencia)

- Total Absorption Gamma Ray Spectroscopy
- Comparison with Rudstam spectral technique
- Discrepancy of Greenwood *et al.* with Rudstam *et al.* results

Total Absorption Gamma-Ray Spectroscopy applied to β-decay

Goal:

- Determine the probability of a β-decay process which leads to a state de-exciting through a γ-ray cascade

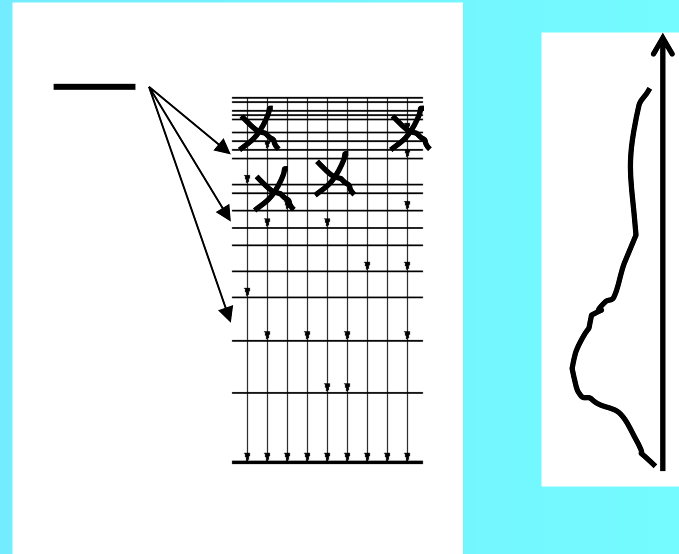
Problem:

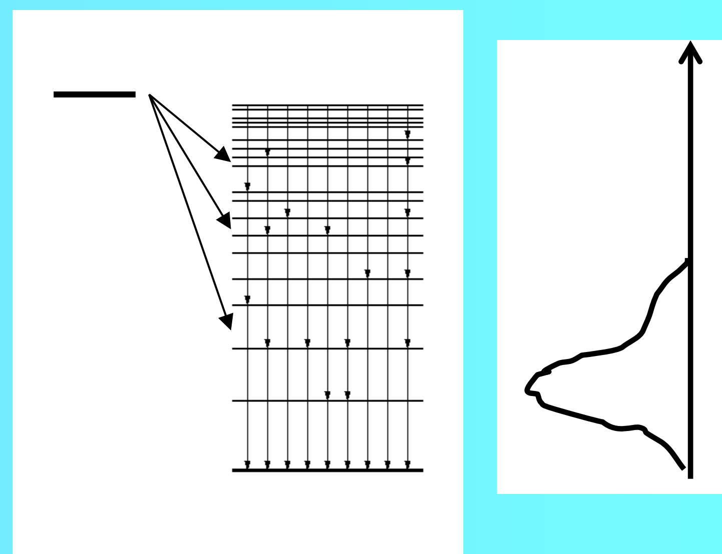
- The limited efficiency of γ-ray detectors together with the complicated de-excitation path leads to systematic errors when trying to measure individual γ-rays: shift of intensity towards low excitation energy or *Pandemonium* effect in β-decay level schemes

Solution:

- Measure the full γ-ray cascade with a calorimeter ➔ TAGS

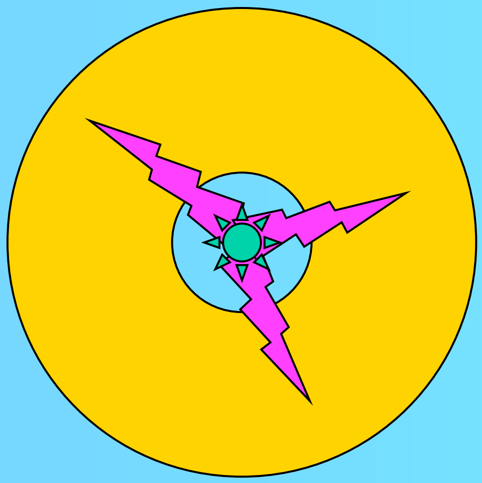
I_β **from level scheme:**

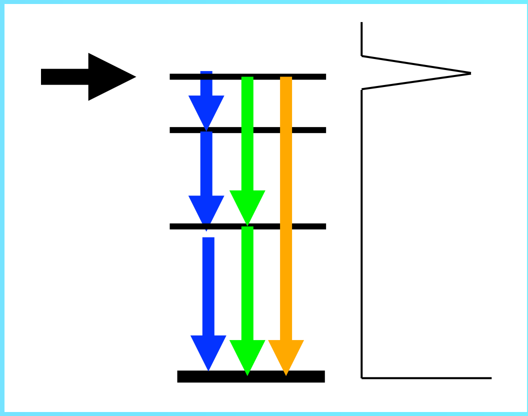




It is a good idea because:

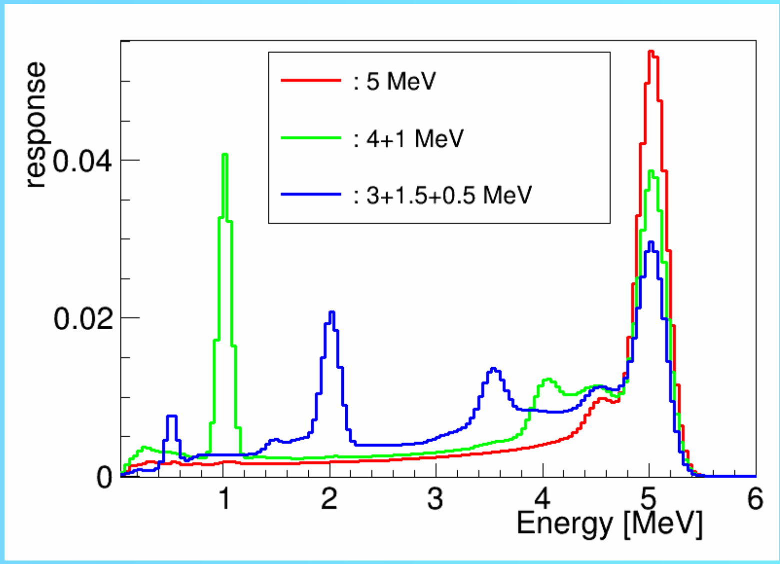
Ideal very thick 4π detector: 100% peak efficiency





Insensitive to decay path (branching ratios)

However for a real spectrometer



Sensitive to decay path (branching ratios)

Is it then such a good idea? Yes …

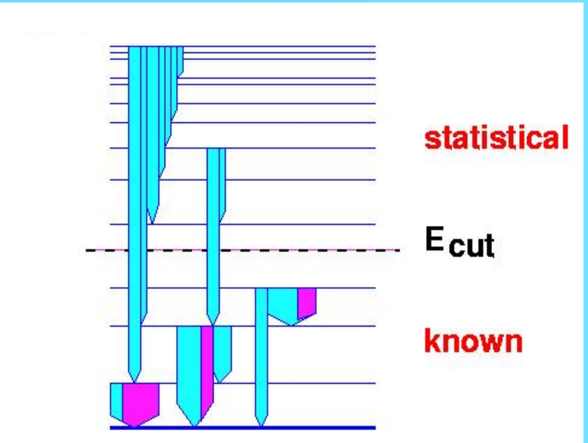
… if you are ready to pay the price of an involved analysis

TAGS analysis Valencia method in a nutshell

1) Reduce the analysis to a **linear inverse problem** taking the b.r. as parameters:

$$d_i = \sum_j R_{ij}(b) \cdot f_j$$

2) Make a reasonable choice of b.r. matrix: we use the **nuclear statistical model** plus **known level-scheme**



3) Construct the spectrometer response using **MC simulations**: need to make **careful calibrations**

$$\mathbf{r_j} = \sum_{k=0}^{j-1} b_{jk} \gamma_{\mathbf{jk}} \otimes \mathbf{r_k}$$

$$\mathbf{R}_j = \beta_j \otimes \mathbf{r}_j$$

4) Apply any suitable (**deconvolution**) algorithm: we use the EM method

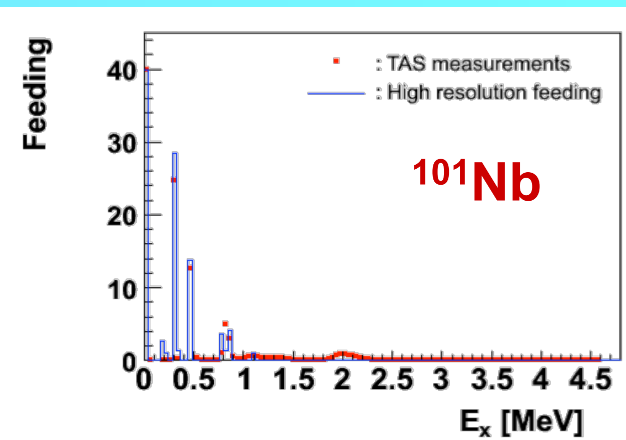
5) Study the effect of different b.r assumptions: **systematic errors**

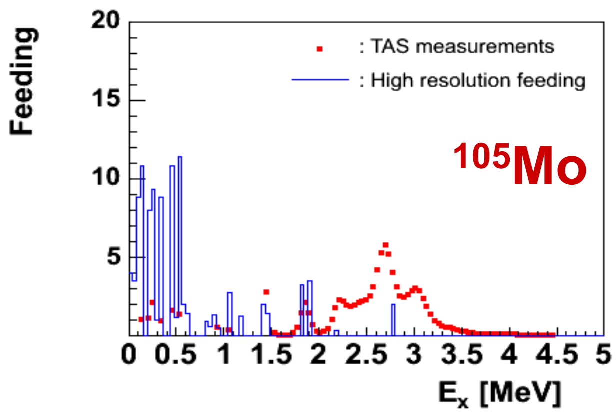
NIM: A430(1999)p333, A571(2007)p728, A571(2007)p719

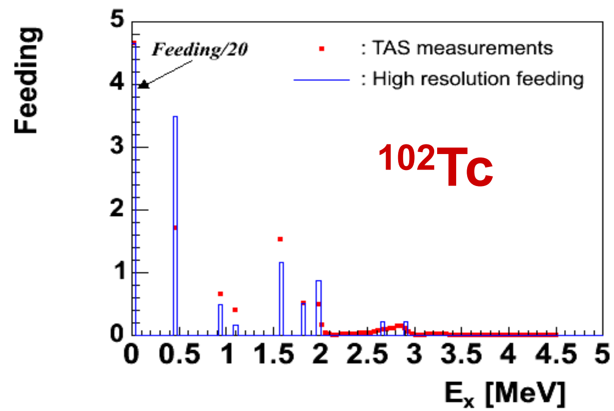
… and Pandemonium error is really important!

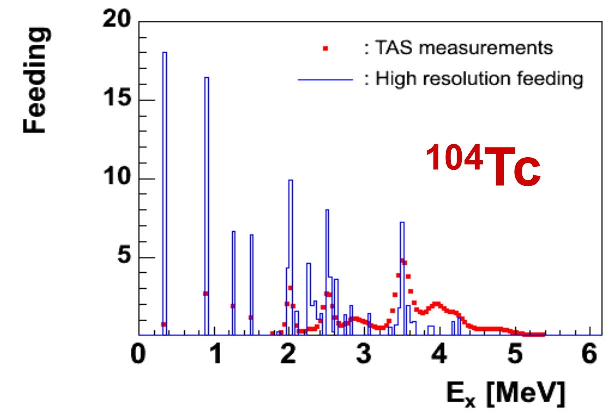
MD. Jordan
PhD Thesis
U. Valencia

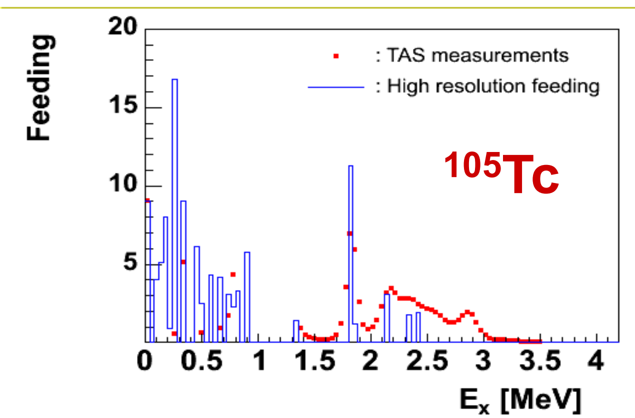
	58	59	60	61	62	63	64	65	66
	102Ru STABLE 31.55%	103Ru 39.26 D β-: 100.00%	104Ru STABLE 18.62%	105Ru 4.44 H β-: 100.00%	106Ru 373.59 D β-: 100.00%	107Ru 3.75 M β-: 100.00%	108Ru 4.55 M β-: 100.00%	109Ru 34.5 S β-: 100.00%	110Ru 11.6 S β-: 100.00%
43	101Tc 14.22 M β-: 100.00%	102Tc 5.28 S β-: 100.00%	103Tc 54.2 S β-: 100.00%	104Tc 18.3 M β-: 100.00%	105Tc 7.6 M β-: 100.00%	106Tc 35.6 S β-: 100.00%	107Tc 21.2 S β-: 100.00%	108Tc 5.17 S β-: 100.00%	109Tc 0.86 S β-: 100.00% β-n: 0.08%
	100Mo 0.78E+19 Y 9.63% 2β-: 100.00%	101Mo 14.61 M β-: 100.00%	102Mo 11.3 M β-: 100.00%	103Mo 67.5 S β-: 100.00%	104Mo 60 S β-: 100.00%	105Mo 35.6 S β-: 100.00%	106Mo 8.4 S β-: 100.00%	107Mo 3.5 S β-: 100.00%	108Mo 1.09 S β-: 100.00%
41	99Nb 15.0 S β-: 100.00%	100Nb 1.5 S β-: 100.00%	101Nb 7.1 S β-: 100.00%	102Nb 4.3 S β-: 100.00%	103Nb 1.5 S β-: 100.00%	104Nb 4.9 S β-: 100.00% β-n: 0.06%	105Nb 2.95 S β-: 100.00% β-n: 1.70%	106Nb 1.02 S β-: 100.00% β-n: 4.50%	107Nb 330 MS β-: 100.00%

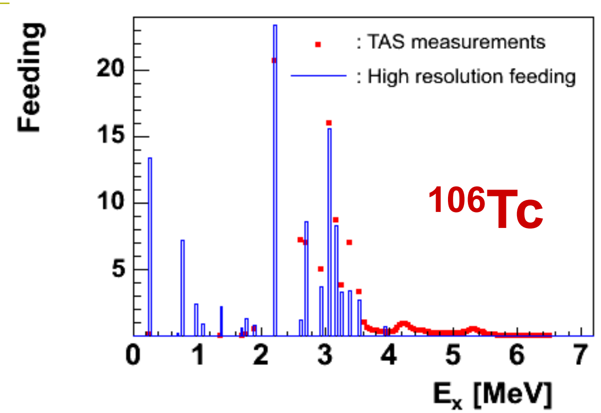


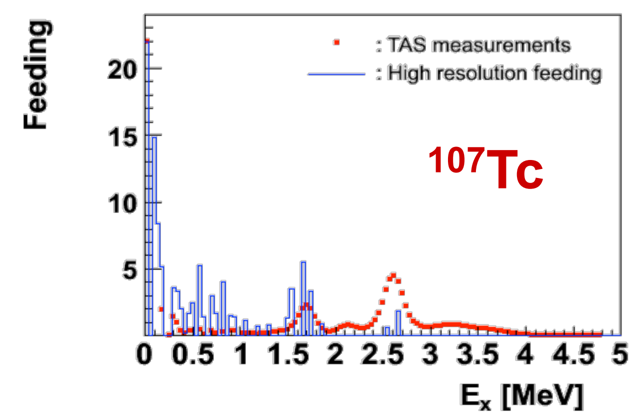












Analysis of the discrepancies between fission product average γ-ray and average β-particle energies obtained by

Rudstam et al.* (ATNDT 45, 239-320)

and

Greenwood et al. (NIM A 390, 95-154)

(First pointed out by O. Bersillon)

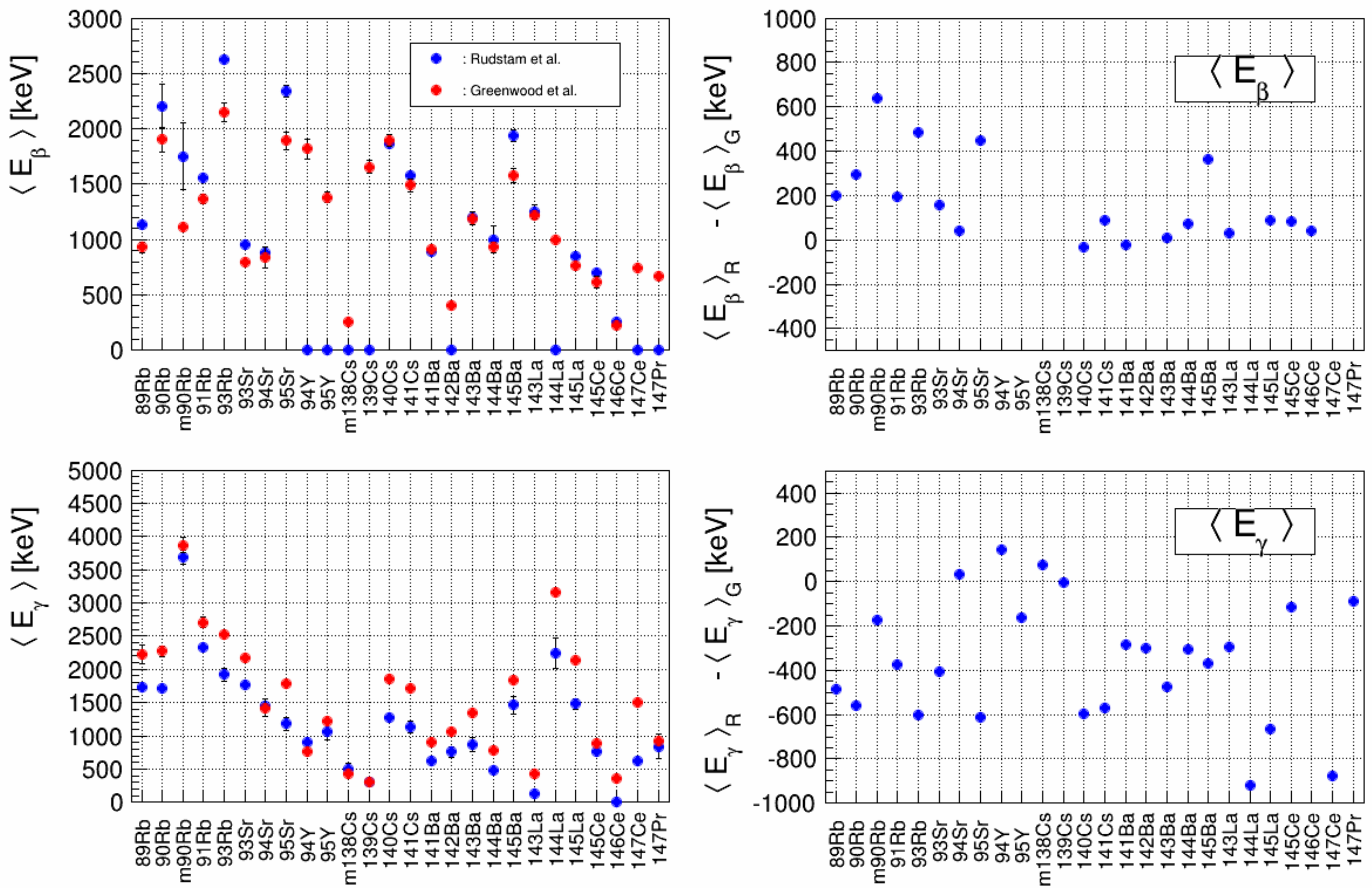
- **From the 48 nuclides measured by *Greenwood et al.* there are 26 which can be compared with *Rudstam et al.:* 25 for $\langle E_\gamma \rangle$ and 18 for $\langle E_\beta \rangle$**
- **From the comparison, the most conspicuous fact is a systematic difference of opposite trend for $\langle E_\gamma \rangle$ and $\langle E_\beta \rangle$:**

$$\langle E_\beta \rangle^R - \langle E_\beta \rangle^G = +177 \text{ keV} \qquad \langle E_\gamma \rangle^R - \langle E_\gamma \rangle^G = -360 \text{ keV}$$

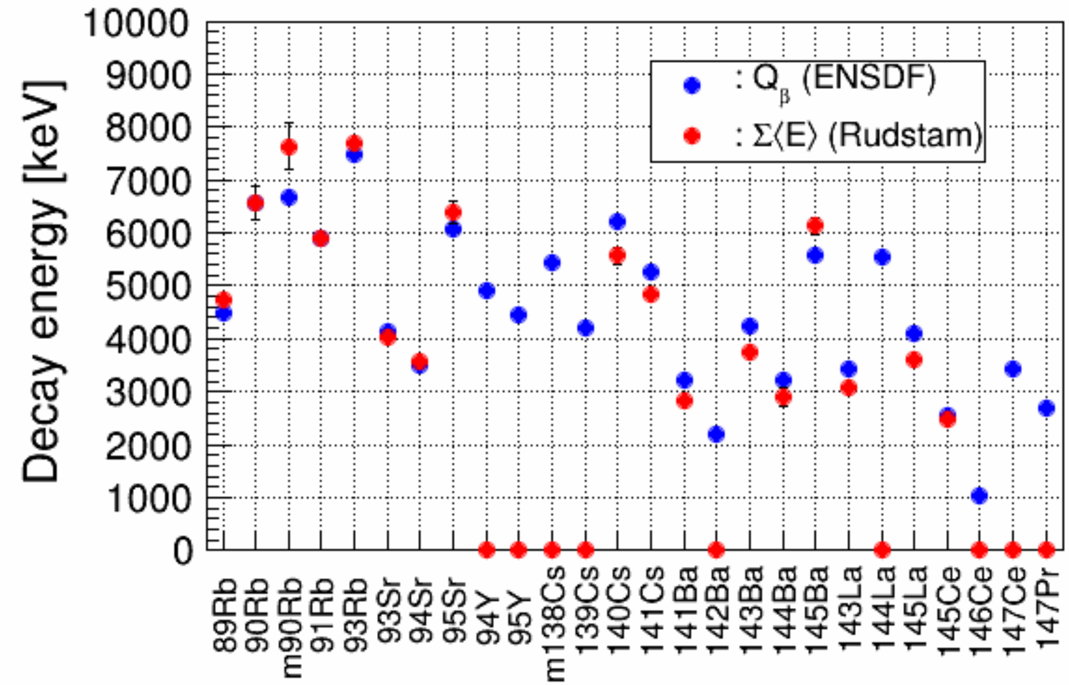
(*) β spectra from Tengblad et al., NPA503 (1989) 136

… and the wilder fluctuations on $\langle E_\gamma \rangle$ differences

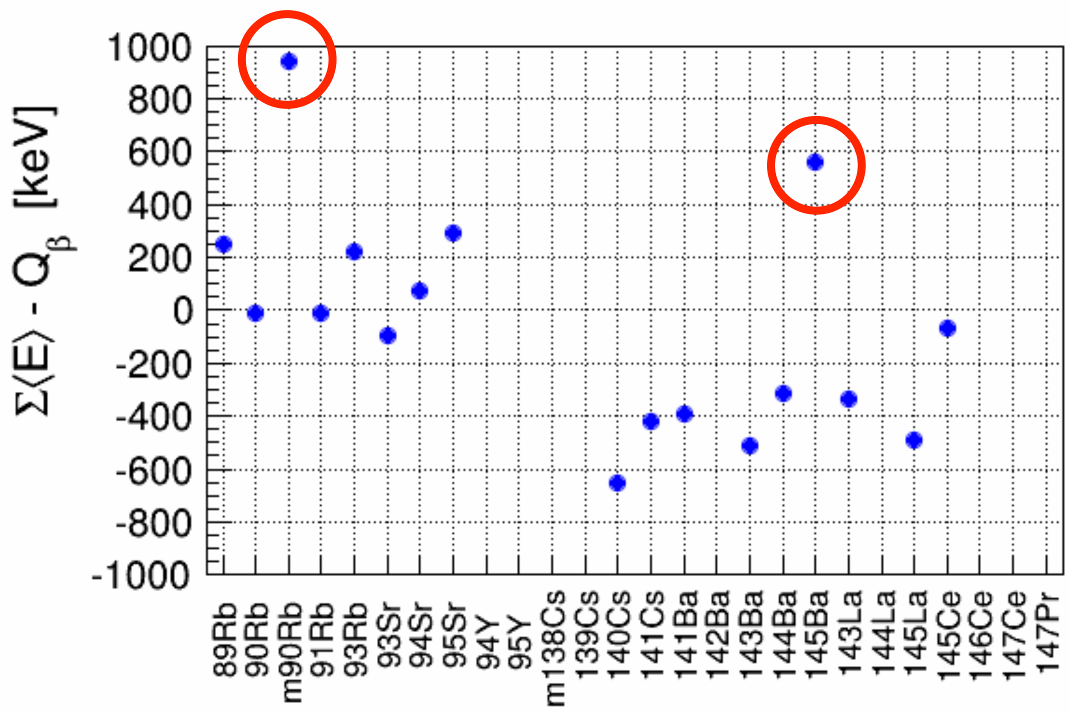
(Numbers from A. Sonzogni)

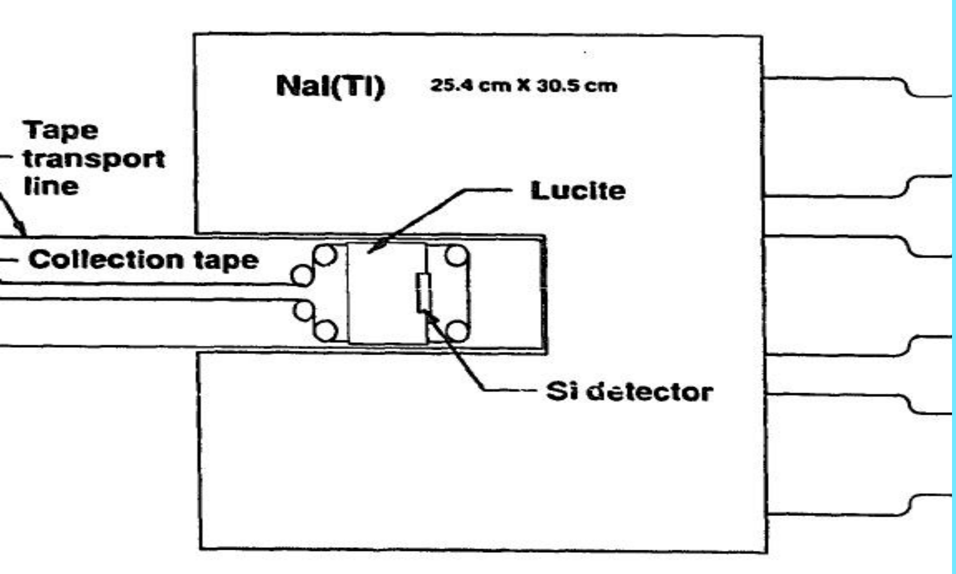


Sum rule:
The sum of all average energies should add up to the Q-value

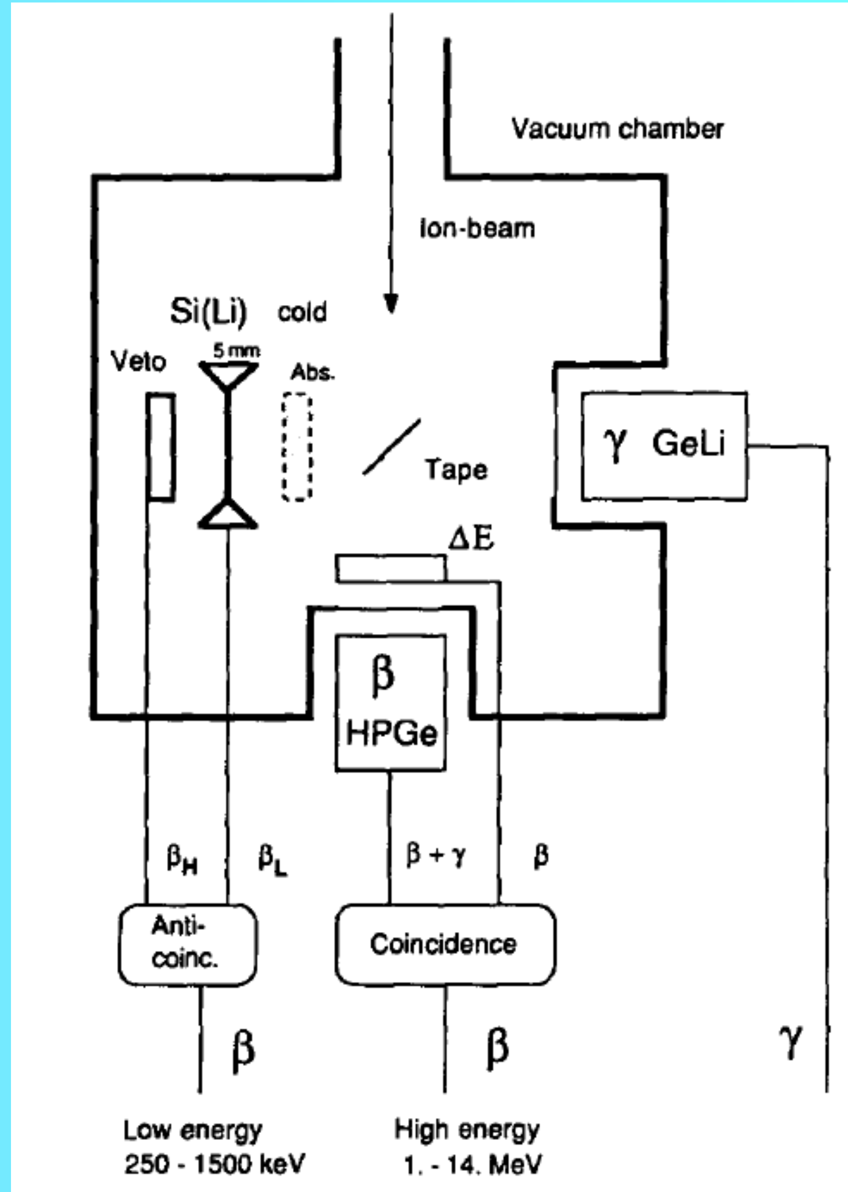


Difference between the light mass and heavy mass fission products ➔

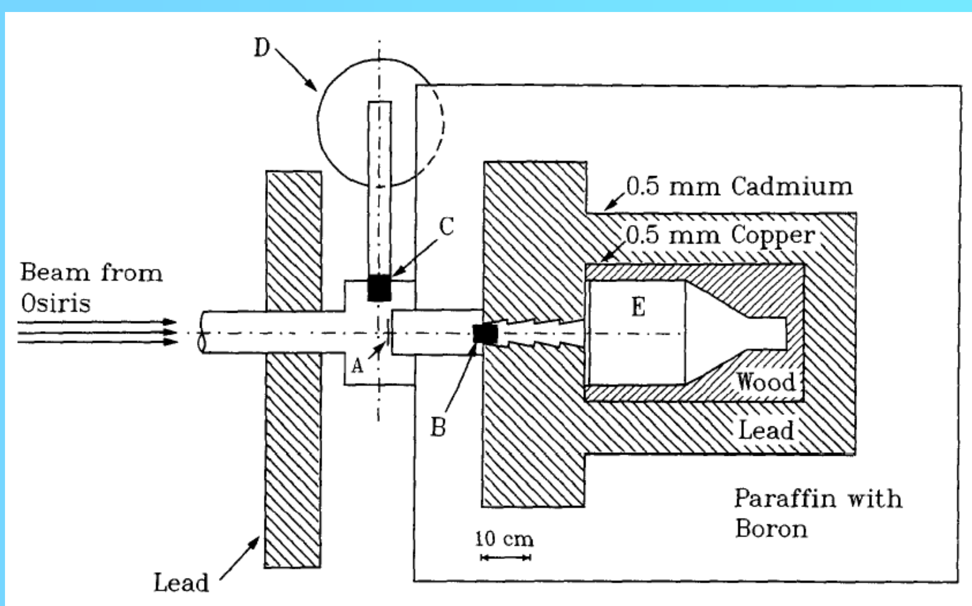




← Greenwood et al.



Rudstam et al.↓→



Greenwood et al. :

Measurement:

- Experiment at INEL (Idaho): ^{252}Cf + ISOL
- Total Absorption Gamma-ray Spectrometer: 25cm×30cm NaI(Tl) well + 1mm Si (β tagging) + 3.8cm Lucite (β absorber)
- $\varepsilon_\gamma^{TOT} \sim 90\%$ $\varepsilon_\gamma^{PEAK} \sim 68\%$ @ 1 MeV ; $\varepsilon_\gamma^{TOT} \sim 80\%$ $\varepsilon_\gamma^{PEAK} \sim 40\%$ @ 5 MeV
  $\varepsilon_{CASCADE} \sim 100\%$ (absolute)
- E^{thr}(NaI) ~ 70-120 keV ; E^{thr}(Si) > 80 keV
- Isotopic separation: measurements with different collection-measuring times
- Background subtraction
- Pileup subtraction

Analysis:

- Monte Carlo simulation (CYLTRAN) of γ-response and β-response
- Forward solution (not deconvolution): Decay scheme modified by hand until satisfactory agreement with singles and β-gated spectrum
- Ground state β-feeding determined separately (TAGS as 4πγ-β)
- From the deduced $I_\beta(E_x)$ one calculates directly $\langle E_\gamma \rangle$. From Q_β and assumption on the character (allowed,…) of decay one calculates $\langle E_\beta \rangle$

Rudstam et al. :

Measurements of $\langle E_\gamma \rangle$:

- Experiments at OSIRIS (Studsvik): 235U(n_{th},f) + ISOL
- 5”×5” NaI(Tl), collimated + 5cm plastic (β absorber)
- $\varepsilon_\gamma^{TOT} \sim 67\%$ $\varepsilon_\gamma^{PEAK} \sim 42\%$ @ 1 MeV ; $\varepsilon_\gamma^{TOT} \sim 72\%$ $\varepsilon_\gamma^{PEAK} \sim 26\%$ @ 5 MeV (intrinsic)
- E^{thr}(NaI) ~ 100-800 keV
- Isotopic separation: measurements with different collection-measuring times normalized with transitions (absolute intensity) seen in a Ge detector
- Background subtraction

Analysis:

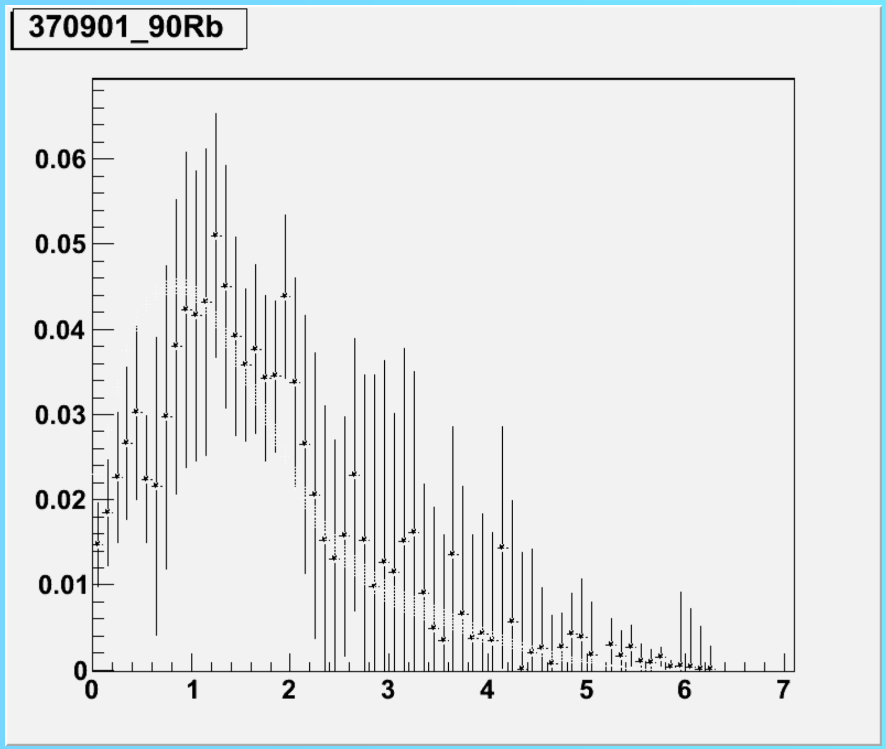
- Response obtained from sources and inter/extrapolated (?)
- Deconvolution using COOLC (W.R. Burrus)
- Absolute normalization: ^{91}Rb, assumed know decay scheme
- Ground state β-feeding correction implicit in absolute intensity of transitions used in Ge
- Correction for γ-rays below threshold from somewhere else (?)
- From normalized γ-ray spectrum one calculates directly $\langle E_\gamma \rangle$

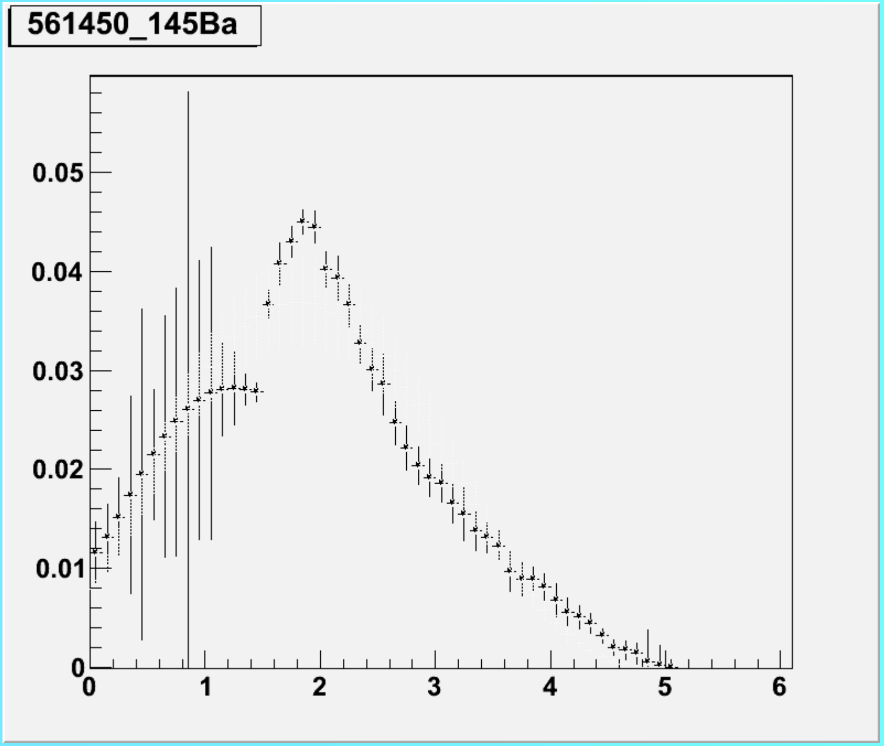
Rudstam et al. :

Measurements of $\langle E_\beta \rangle$:
- Experiments at OSIRIS (Studsvik) and ISOLDE (Geneva): U/Th(600MeV-p,spallation)
- 0.25-1.5 MeV: 5mm Si(Li) + plastic scintillator (veto) + 1cm Al absorber (γ-ray component)
- 0.5-15 MeV: 15mm Ge + plastic scintillator (tagging)
- E^{thr}(Si) ~ 250 keV
- Isotopic separation: measurements with different collection-measuring times normalized with transitions (absolute intensity) seen in a Ge detector
- Background subtraction

Analysis:
- Response obtained from sources and inter/extrapolated
- Deconvolution method?
- Both detector spectra matched
- Correction for β-particles below threshold and at high energies from extrapolation calculated for I_β from deconvolution (peel-off)
- From β-particle spectrum one calculates directly $\langle E_\beta \rangle$

Problematic data: Beta spectra in Rudstam et al.





Sources of systematic deviations:

Common to both:

- **Background correction**
- **Isotopic separation/contamination**
- **Response to individual quanta (γ-ray and β-particles)**
- **(deconvolution procedure)**

Greenwood et al. :

- **Response to the decay (branching ratios)**
- **Ground state feeding**

Rudstam et al. :

- **Absolute normalization for $\langle E_\gamma \rangle$ based on ^{91}Rb**
- **Corrections below threshold for $\langle E_\gamma \rangle$**
- **Corrections below threshold and at high energy for $\langle E_\beta \rangle$**

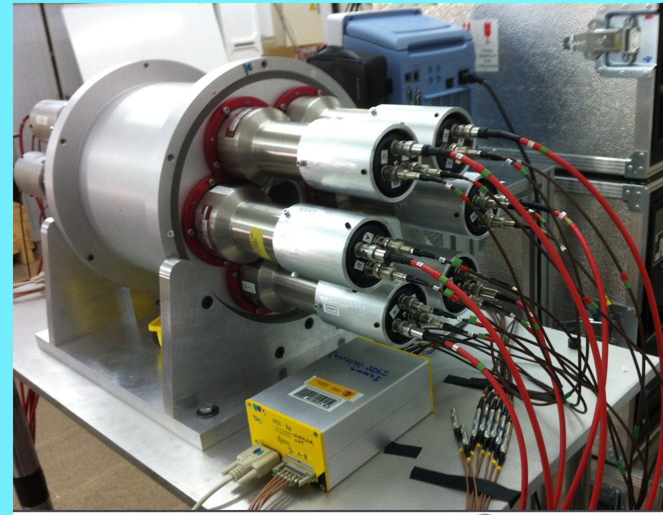
… but Greenwood finds Pandemonium ➔ we checked it

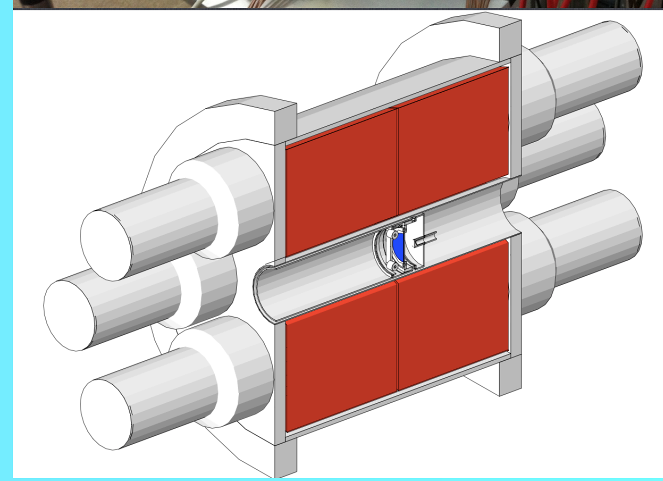
Experiment: November 2009

JYFL Accelerator Laboratory

IGISOL separator **+**
ion guide source:
refractory elements

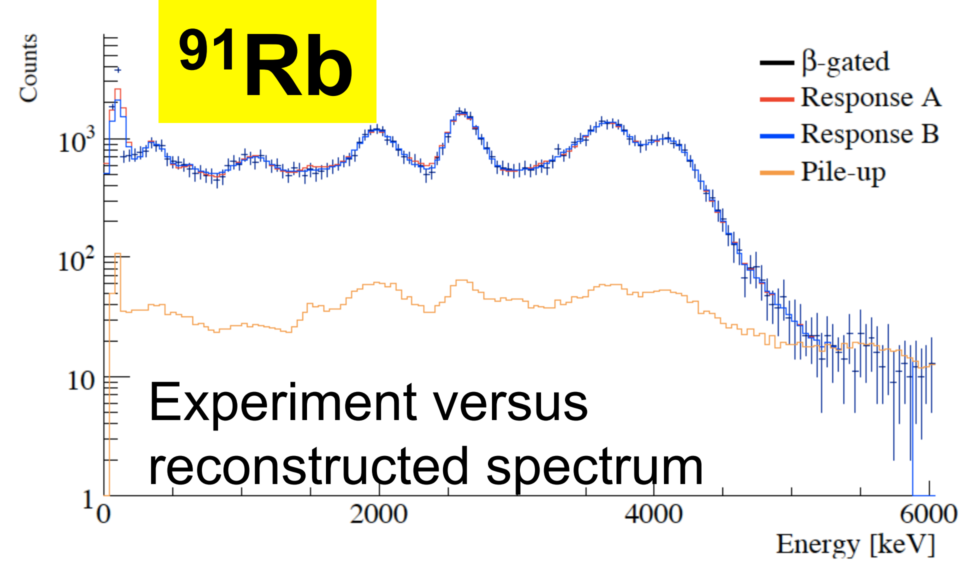
JYFLTRAP
Penning trap:
isotopic purification

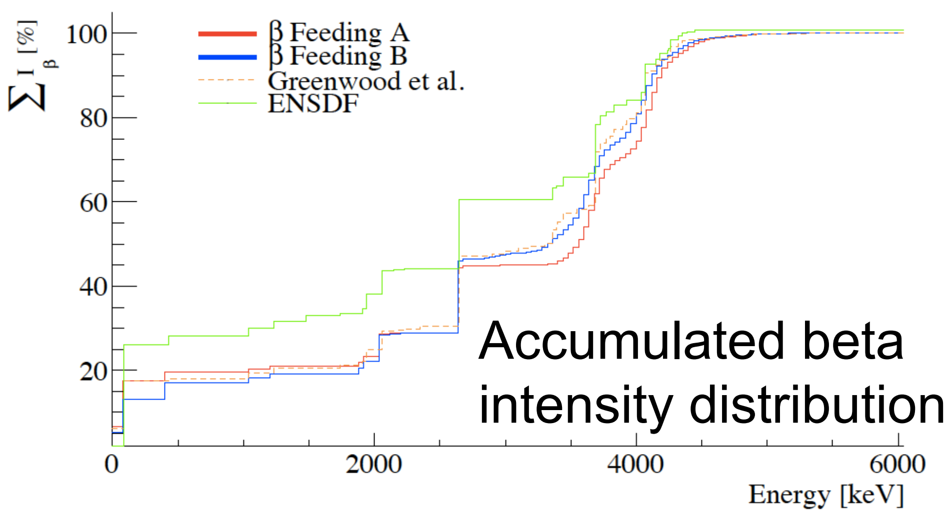




"Rocinante" TAS

- **Compact 12-fold segmented BaF_2 spectrometer**
- **Low neutron sensitivity**
- **Cascade multiplicity information**





S. Rice, PhD Thesis (U. Surrey)

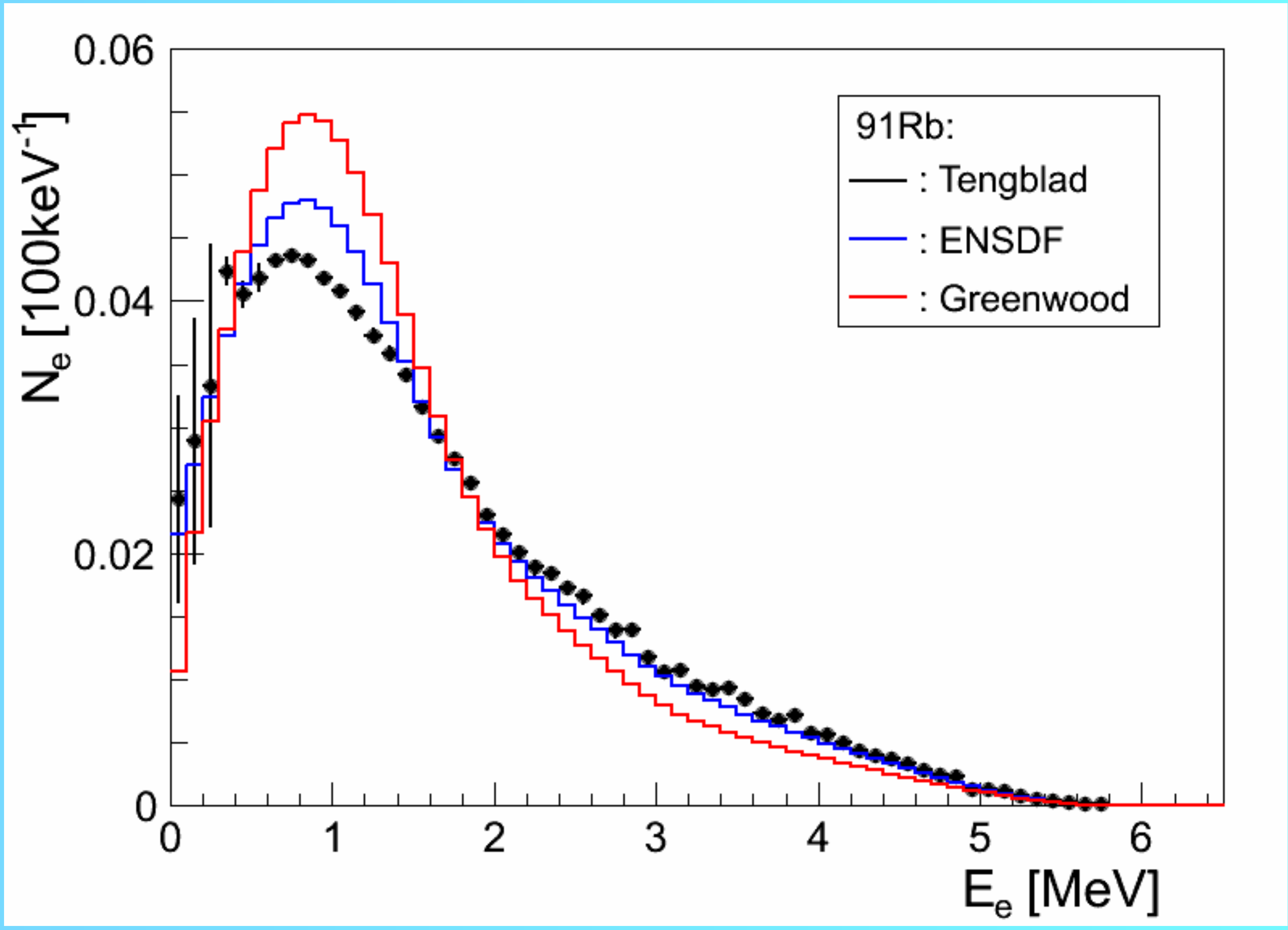
[keV]	Rudstam	Greenwood	This work
$\langle E_\gamma \rangle$	2335 (33)	2708 (75)	2778 (30)
$\langle E_\beta \rangle$	1560 (30)	1370 (44)	1330 (22)

- Used by Rudstam et al. to normalize $\langle E_\gamma \rangle$
- Assumed Pandemonium free and value $\langle E_\gamma \rangle$=2335 keV taken from Tol-1986
- Further assumes I_γ (345keV)=8.3(4)%
- Greenwood finds Pandemonium $\langle E_\gamma \rangle$=2708 keV
- We confirm his result
- **All Rudstam $\langle E_\gamma \rangle$ should be increased by 17.5%**
- It reduces the γ-discrepancy

$\langle E_\gamma \rangle^R - \langle E_\gamma \rangle^G$ = -141 keV

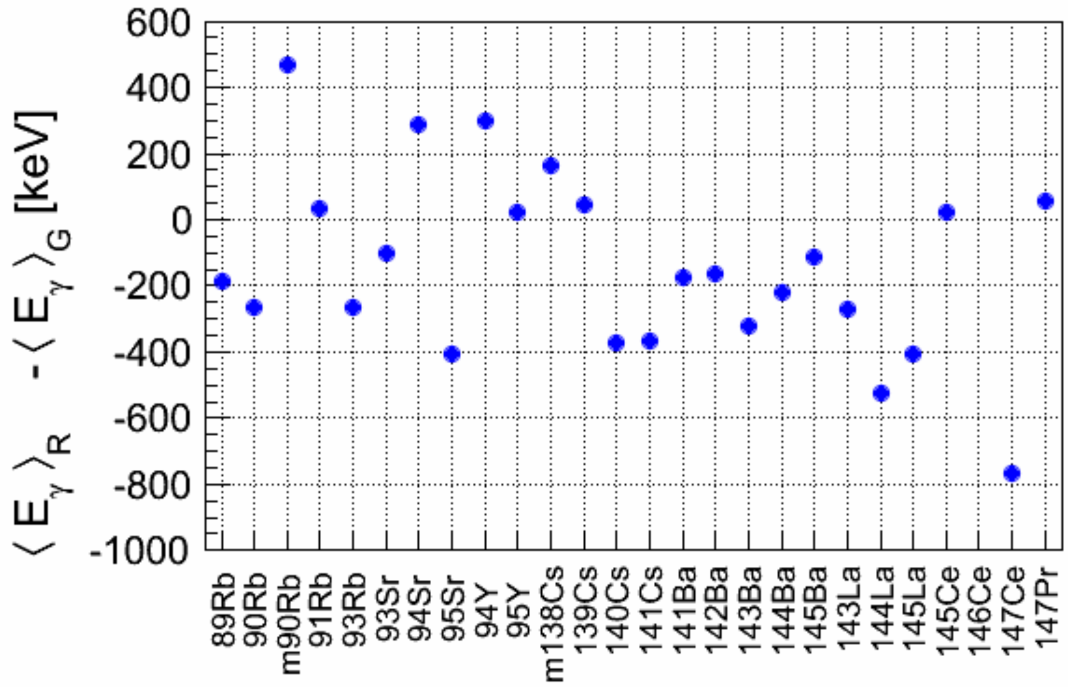
- However in this case the sum-check holds: $\langle E_\gamma \rangle+\langle E_\beta \rangle+\langle E_\nu \rangle$=5890(110) versus Qb=5907(9)
- It means $\langle E_\beta \rangle$, $\langle E_\nu \rangle$ are wrong

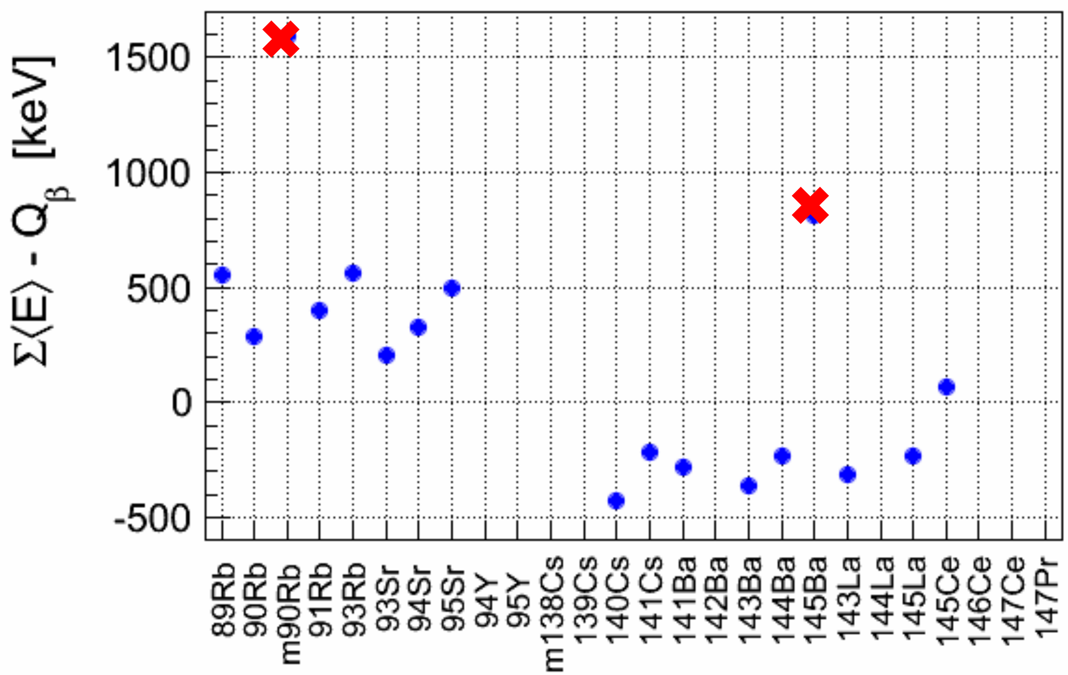
Comparison of β spectra:



(**Tengblad and ENSDF spectra from D. Lhuillier**)

With the modified Rudstam <E_γ>





Conclusions:

- Both types of measurement suffer from different sources of systematic error.
- It is not easy to find a single explanation for the observed systematic differences between both measurements.
- With one exception: the absolute normalization needed by Rudstam et al for $\langle E_\gamma \rangle$. They assume that the decay scheme of ^{91}Rb is perfectly known (no Pandemonium effect, correct g.s. feeding) so they adjusted the efficiency to obtain $\langle E_\gamma \rangle^{91Rb}$=2335 keV. But Greenwood et al find $\langle E_\gamma \rangle^{91Rb}$=2708 keV.
- We have made a new TAGS measurent of 91Rb (S. Rice, PhD Thesis, U. Surrey) and confirm Greenwood result: **all Rudstam et al $\langle E_\gamma \rangle$ should be increased by 17.5%**
- Even so, Rudstam et al. $\langle E_\gamma \rangle$ data seems less reliable than Greenwood et al data (for the nuclides that we have compared): decay heat calculations!
- I_β for excited states from Greenwood et al. are probably more reliable than Rudstam et al.
- The reliability of I_β for the g.s. obtained by Greenwood et al. method should be verified