β-Decay Total Absorption Spectroscopy: A Tool for Applied and Fundamental Research

J.L. Tain

Jose.Luis.Tain@ific.uv.es
http://ific.uv.es/gamma/

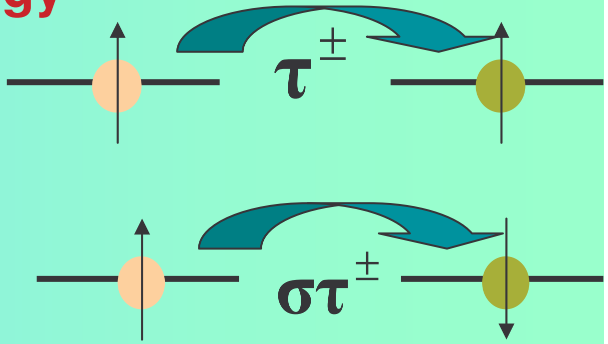
Instituto de Física Corpuscular
C.S.I.C - Univ. Valencia

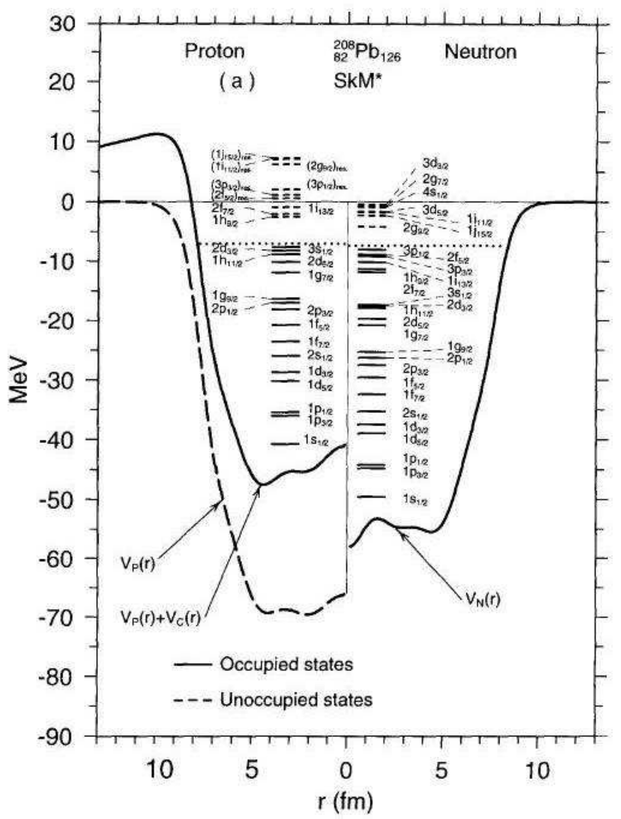
An accurate knowledge of the distribution of the β-decay probability over the daughter-nucleus levels provides information of relevance for the understanding of the structure of nuclei or for other fields as astrophysics or reactor technology

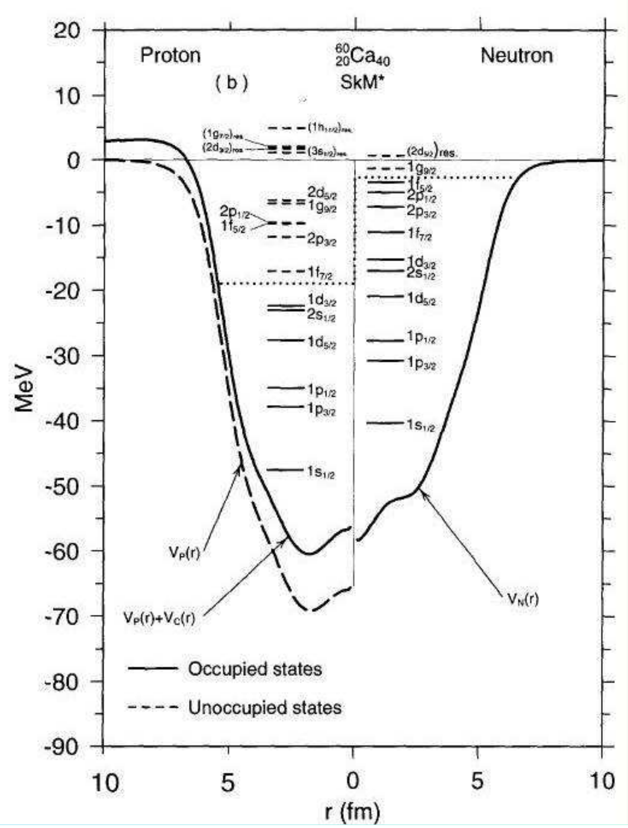
- **Basic process: simple and sensitive to the wave function**

Fermi / Gamow-Teller

$$\left|\left\langle \Psi_f \middle| \tau^{\pm} \ or \ \sigma\tau^{\pm} \middle| \Psi_i \right\rangle\right|^2$$



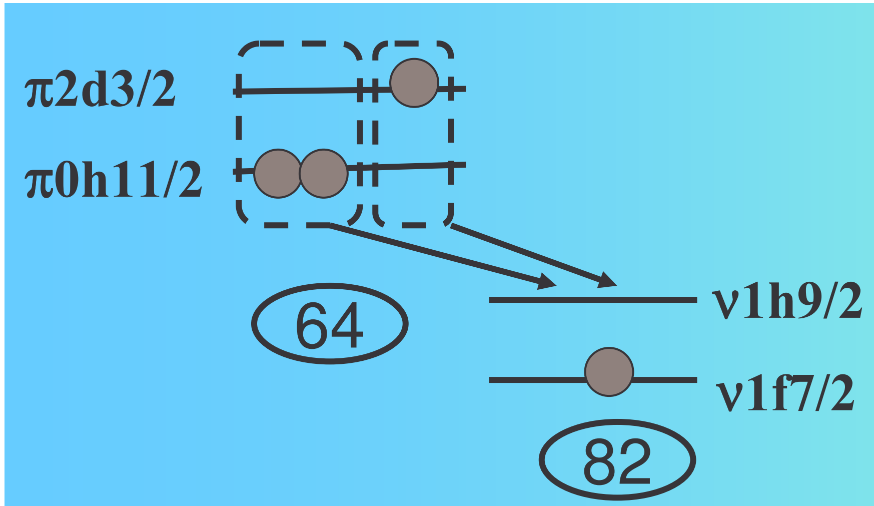




- **In general the bulk of the strength lies outside the Q_{β} window**

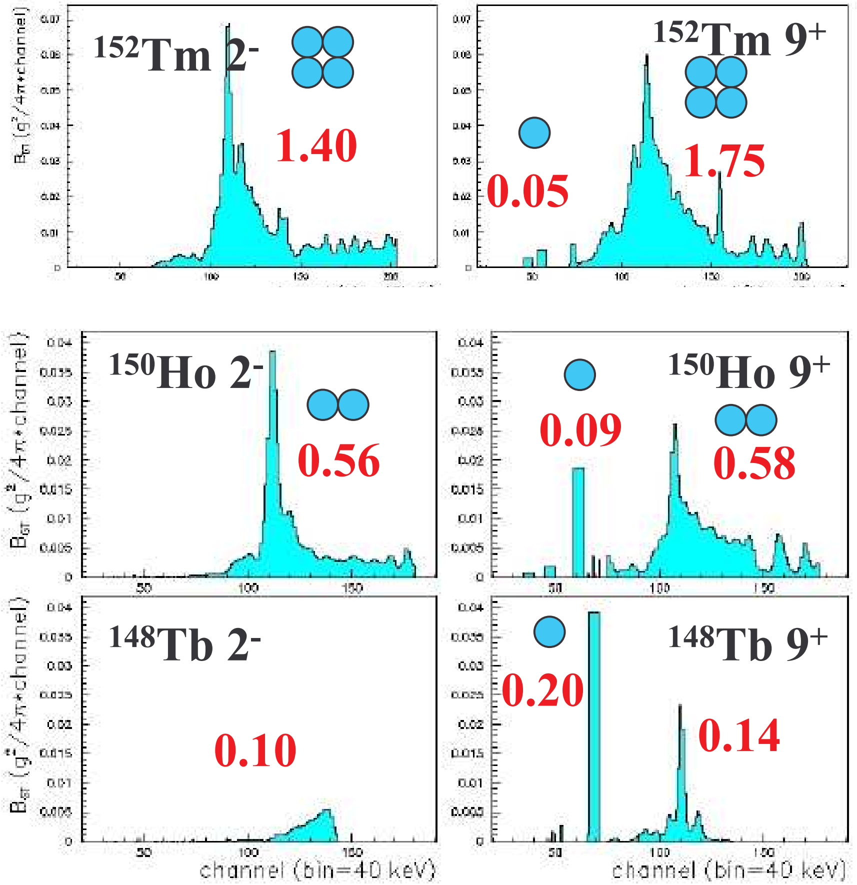
Exception:
- **β+/EC for A~150, A~100, N~Z**

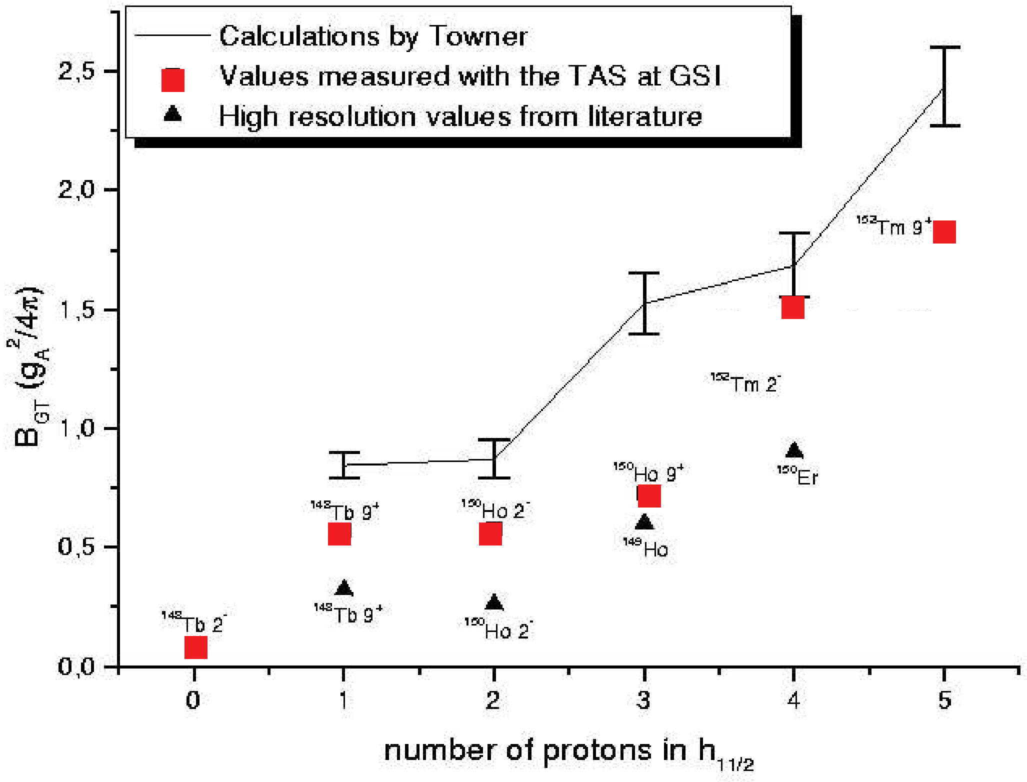
Previous work at the β$^+$ side



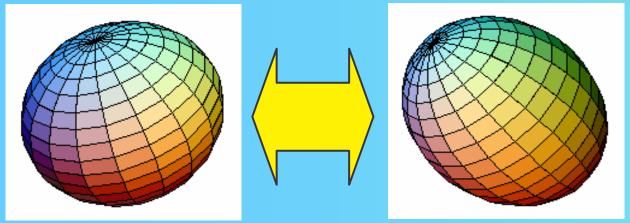
Gamow-Teller στ$^+$ resonance

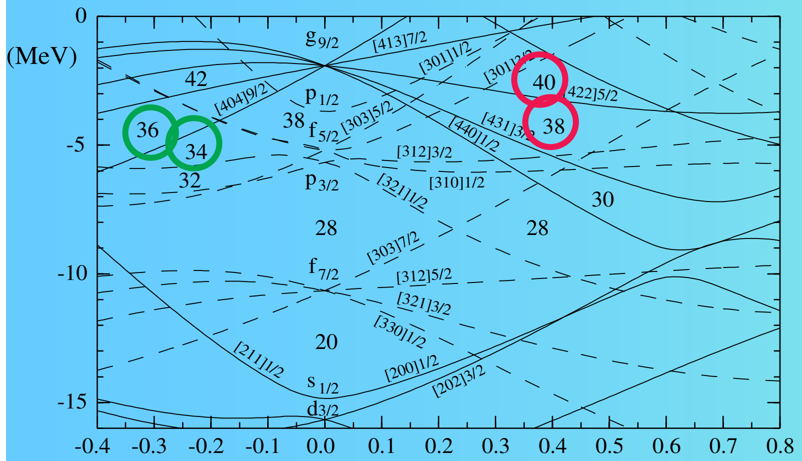
Odd-Odd N=83 nuclei
above 146Gd

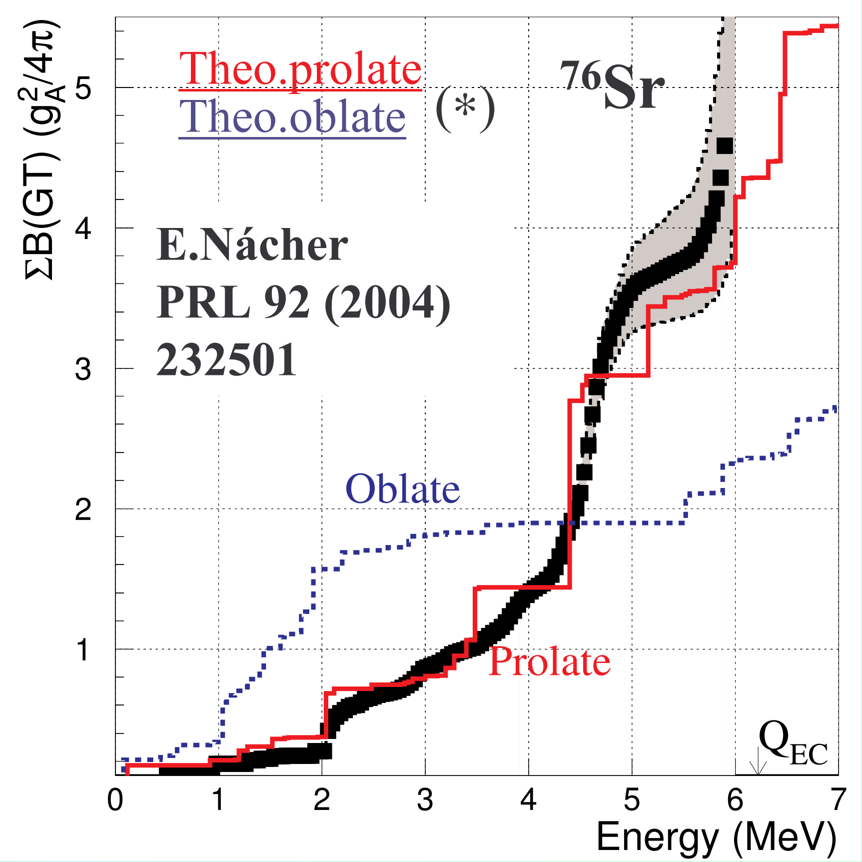




Oblate-prolate competition

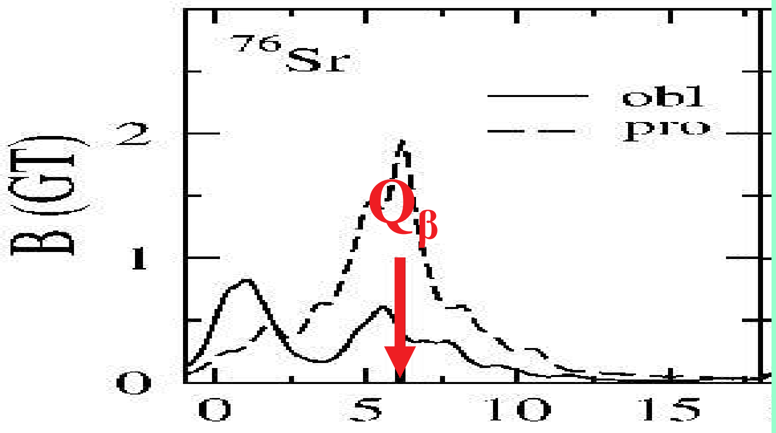






(*) P.Sarriguren et al.NPA 658 (1999)13

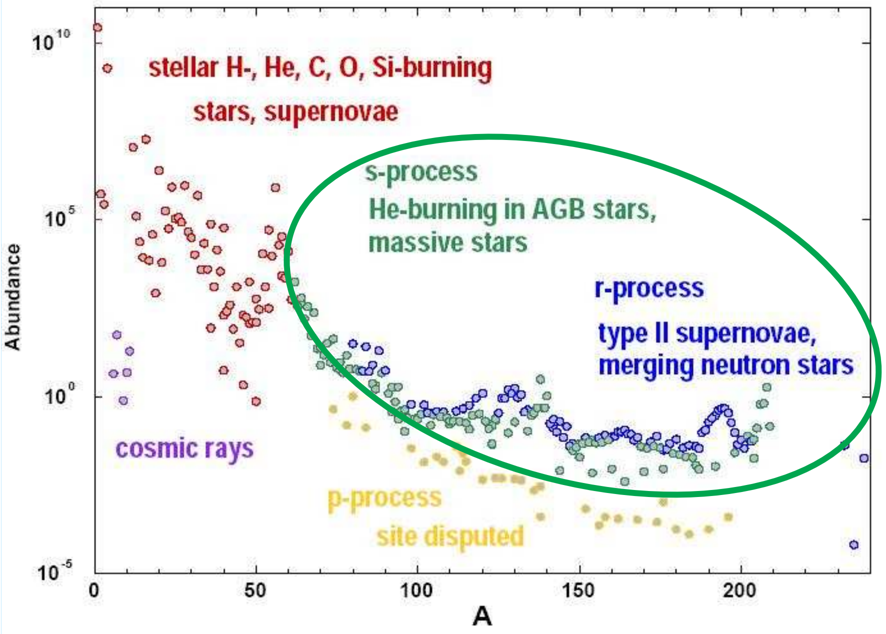
N~Z nuclei with A~70-80

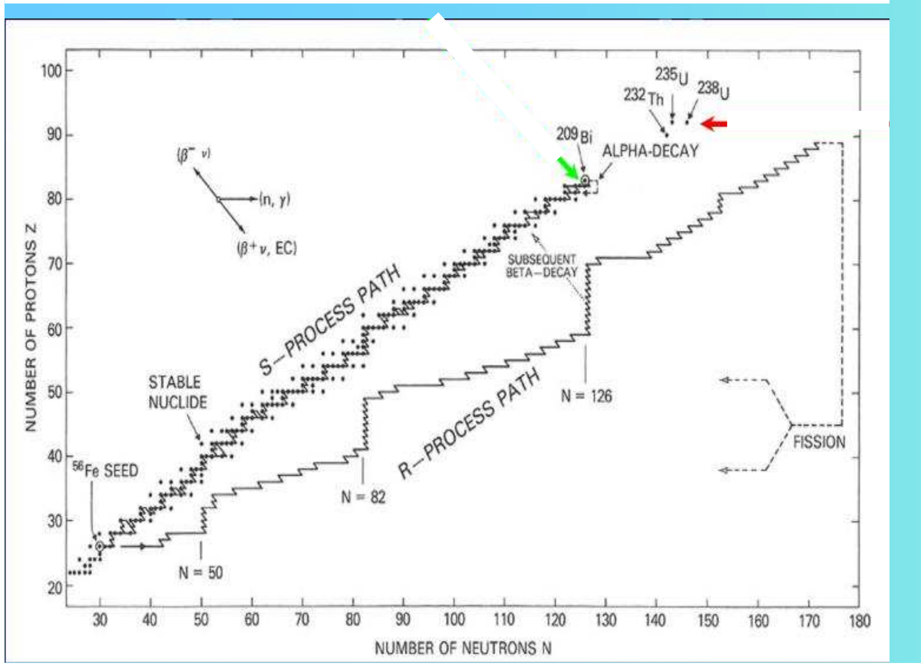


Previous work at the β^+ side

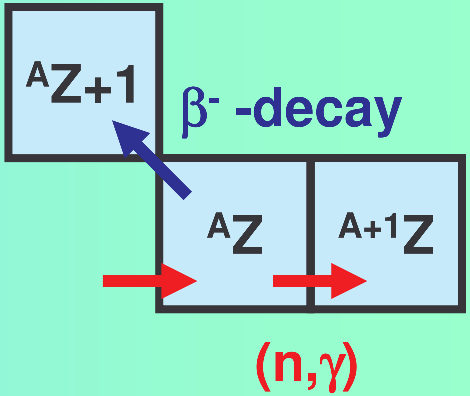
Future work at the β^- side

Neutron capture is the source of elements heavier than iron





The **interplay** between **β-decay** and **(n,γ)** determine the isotopic abundances

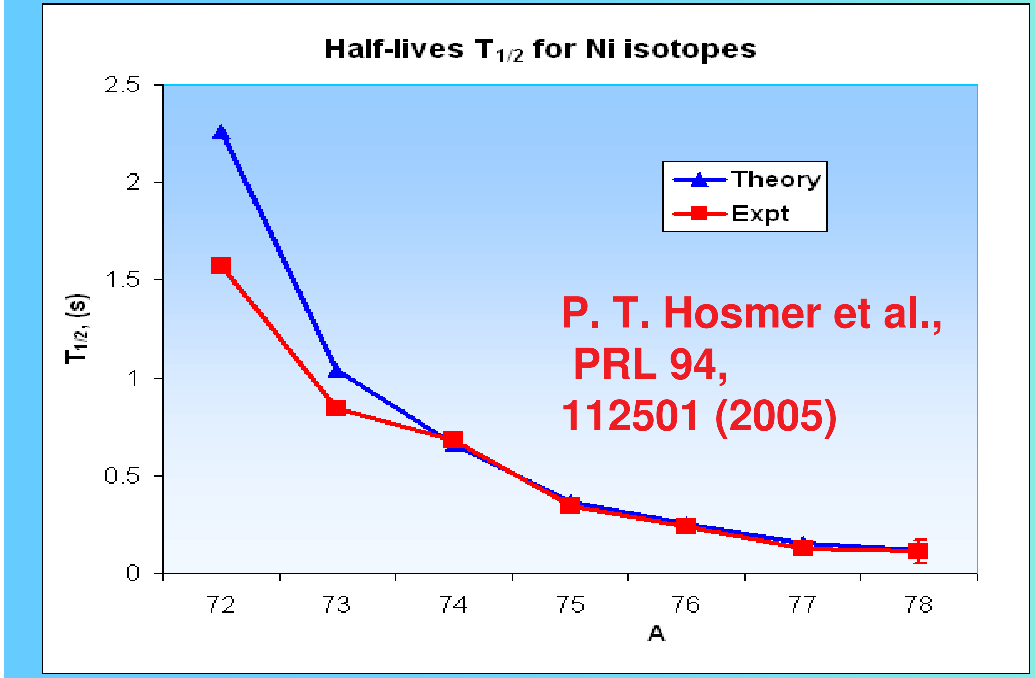


- For the s-process (close to stability) the relevant quantity (except at branching points) is $\sigma_{(n,\gamma)}$ (experimental)

- For the **r-process** (very far from stability) the relevant quantity is $T_{1/2}$ (theoretical)
✦ **trimming of the codes to reproduce S_β may help to improve their predictive power**

Example: Ni isotopes
(taken from A. Lisetskiy)

Quenching for GT operator:
up to q=0.37!
(Standard value is 0.70-0.75)

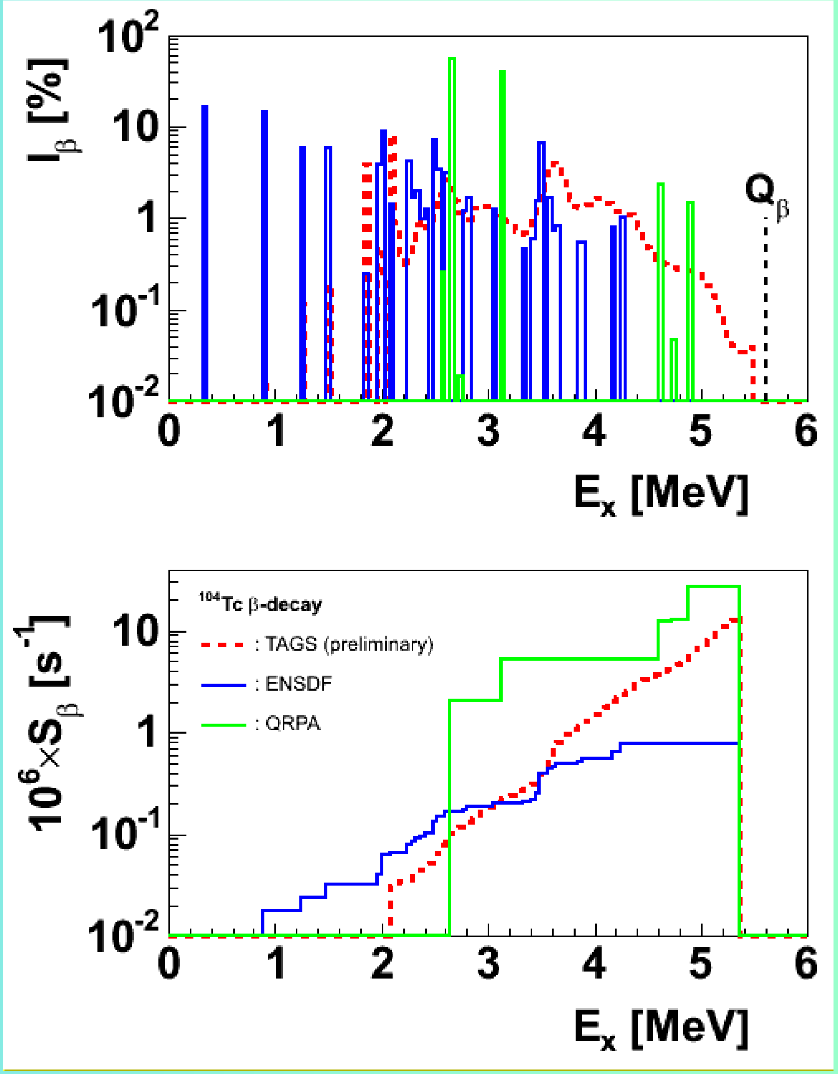


P. T. Hosmer et al., PRL 94, 112501 (2005)

Anomalous quenching or wrong S_β distribution?

Example: ^{104}Tc
QRPA: P. Möller & K.L. Kratz

T1/2=2.7 min (Exp: 18.3 min)

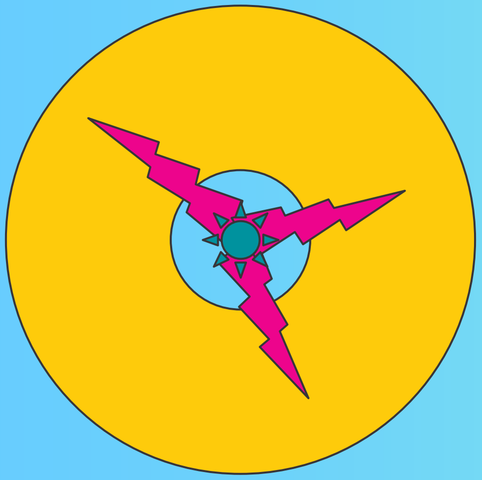


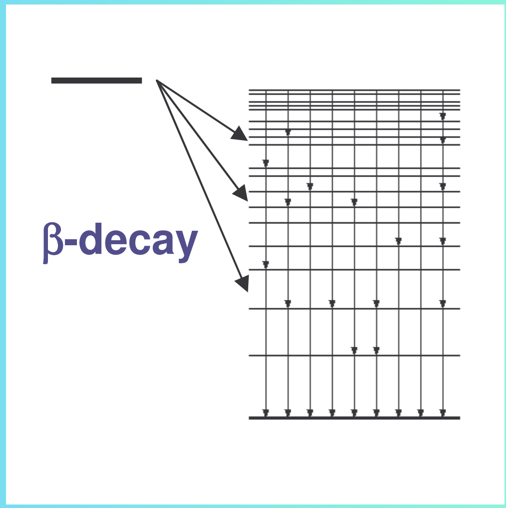
The TAS technique

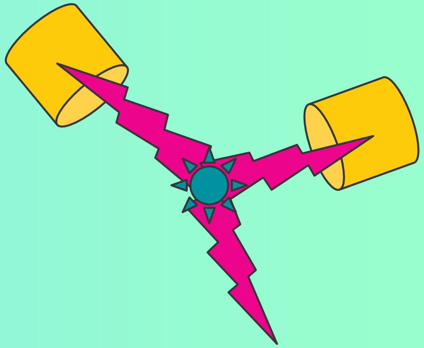
- Total absorption gamma-ray spectroscopy is **the best technique to measure the β-decay strength** distribution over the entire energy window in particular for nuclei far from the stability.

- Total absorption spectroscopy, using **large 4π scintillation detectors**, aims **to detect the full γ-ray cascade** rather than individual γ-rays as in high resolution spectroscopy, using Ge detectors.

- Total absorption spectroscopy **avoids the “Pandemonium effect”** (misplacement of β-strength) when constructing level schemes in high resolution spectroscopy.



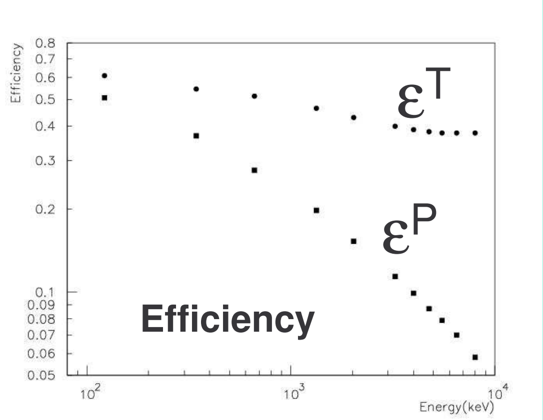


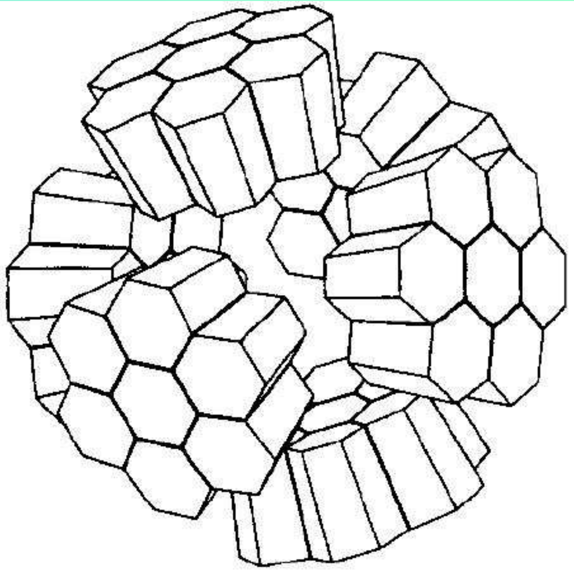


The Pandemonium effect in ^{150}Ho decay:

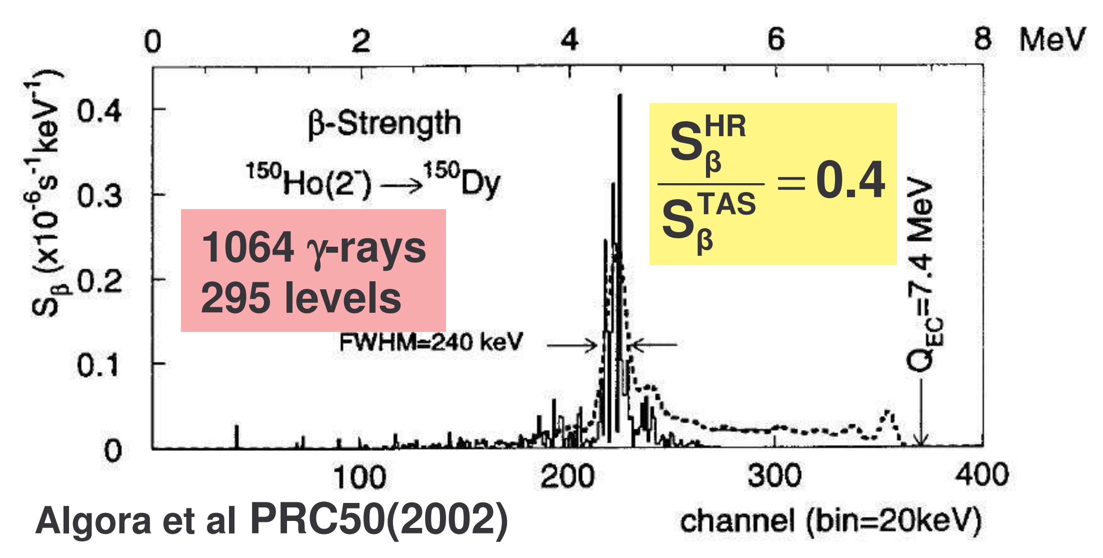
CLUSTER-CUBE:
6 EUROBALL Clusters in cubic geometry

CLUSTER:
7 Ge detectors, 60% each



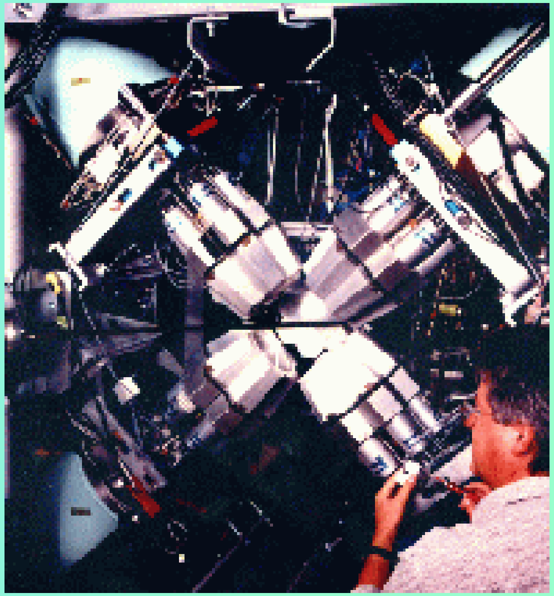


CLUSTER-CUBE at GSI



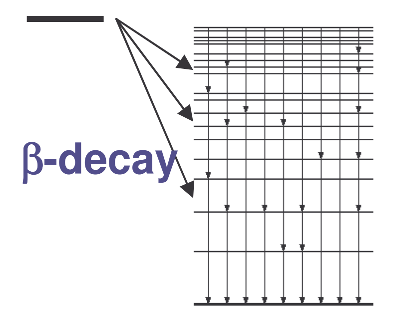
$$\frac{S_\beta^{HR}}{S_\beta^{TAS}} = 0.4$$

Algora et al PRC50(2002)



An ideal TAS (100% peak efficiency) provides directly S_β but

- **How do we extract the β-strength from real TAS spectra?**



Statement of the problem:

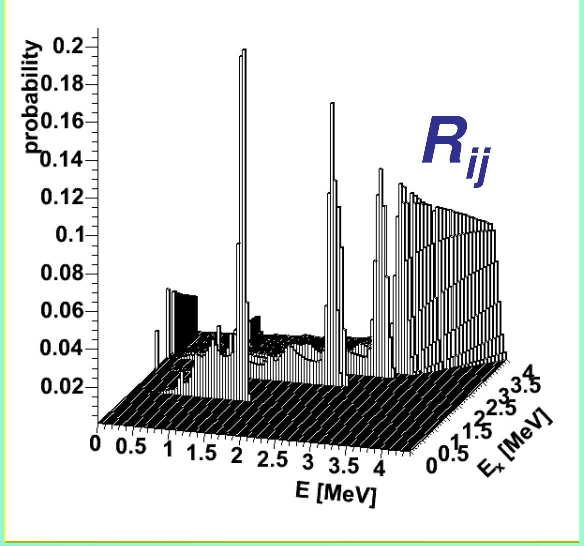
Relation between β-strength S_β and β-intensity I_β:

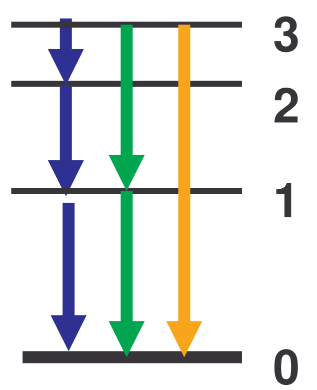
$$S_i = \frac{I_i}{f(Q_\beta - E_i)T_{1/2}}$$

Relation between TAS data and the β-intensity distribution:

$$I_i = f_i \Big/ \sum_k f_k$$

$$\boldsymbol{d_i = \sum_j R_{ij} f_j}$$





Response R_{ij}: probability that for decay to level j we register a count in channel i

$$\mathbf{R_j} = \sum_{k=0}^{j-1} b_{jk} \mathbf{g_{jk}} \otimes \mathbf{R_k}$$

Solution: “de-convolute” TAS spectrum using the spectrometer “decay” response (**inverse problem**)

Requirements:

- **Spectrum must be clean**:
  → eliminate background and contaminations

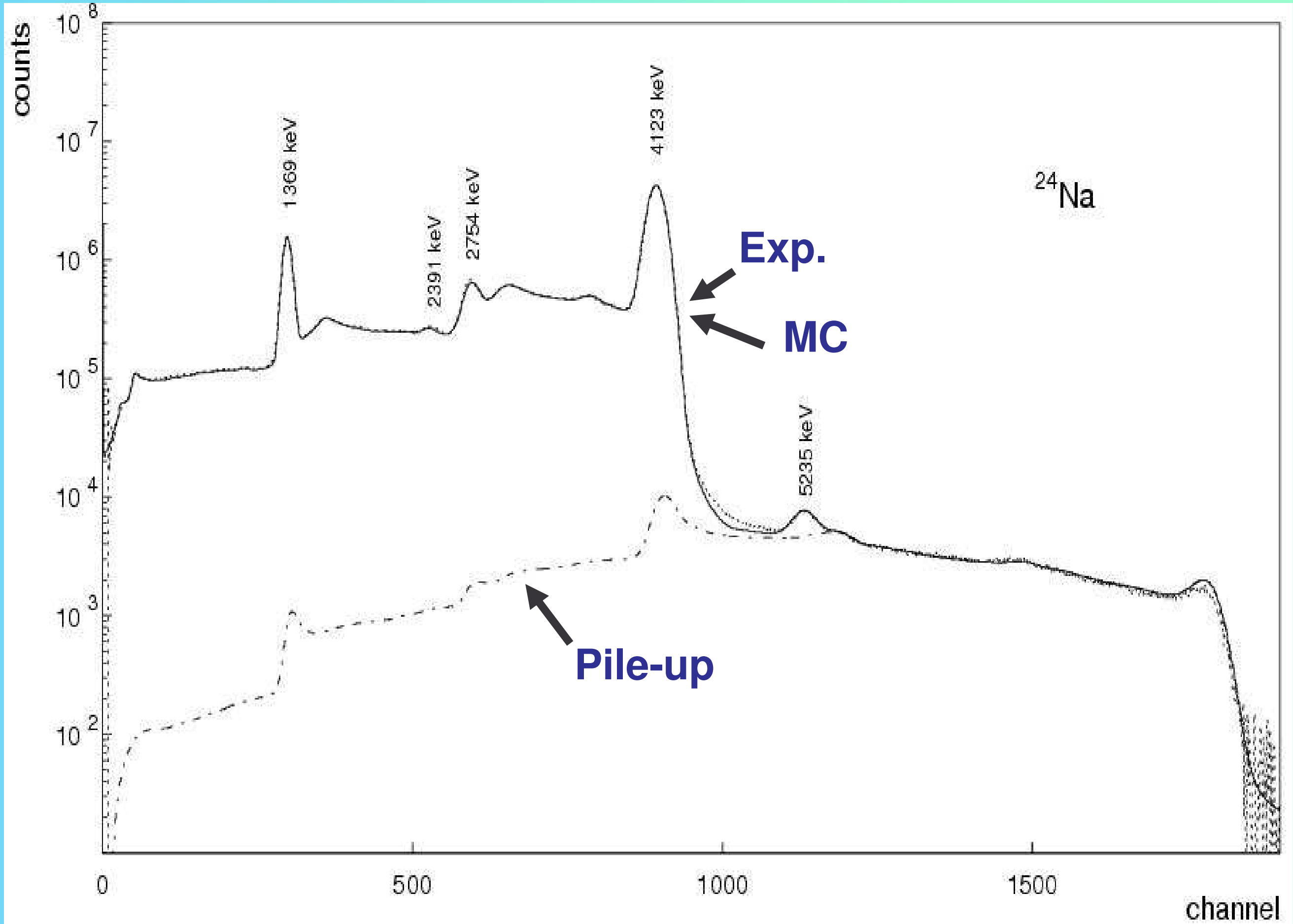
- **Response must be accurately known**:
  → response should depend “weakly” on de-excitation branching ratios
    → high efficiency

- **Solution of inverse problem must be stable**

- Historically there has been some lack of confidence on the reliability of TAS results
- During the past few years we have undertaken a **systematic investigation of** systematic uncertainties associated with the **analysis of TAS data**:

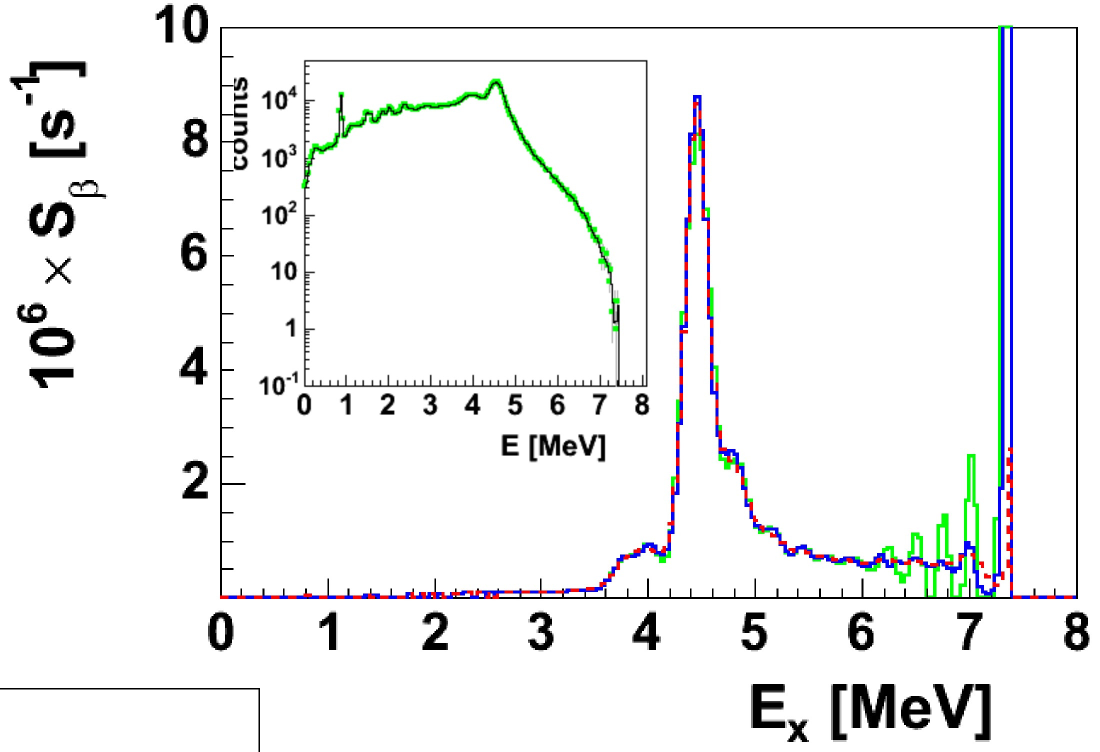
1. Accurate calculation of pulse pile-up which constitutes an intrinsic background close to the end point **(Cano et al. NIMA430, p.488)**

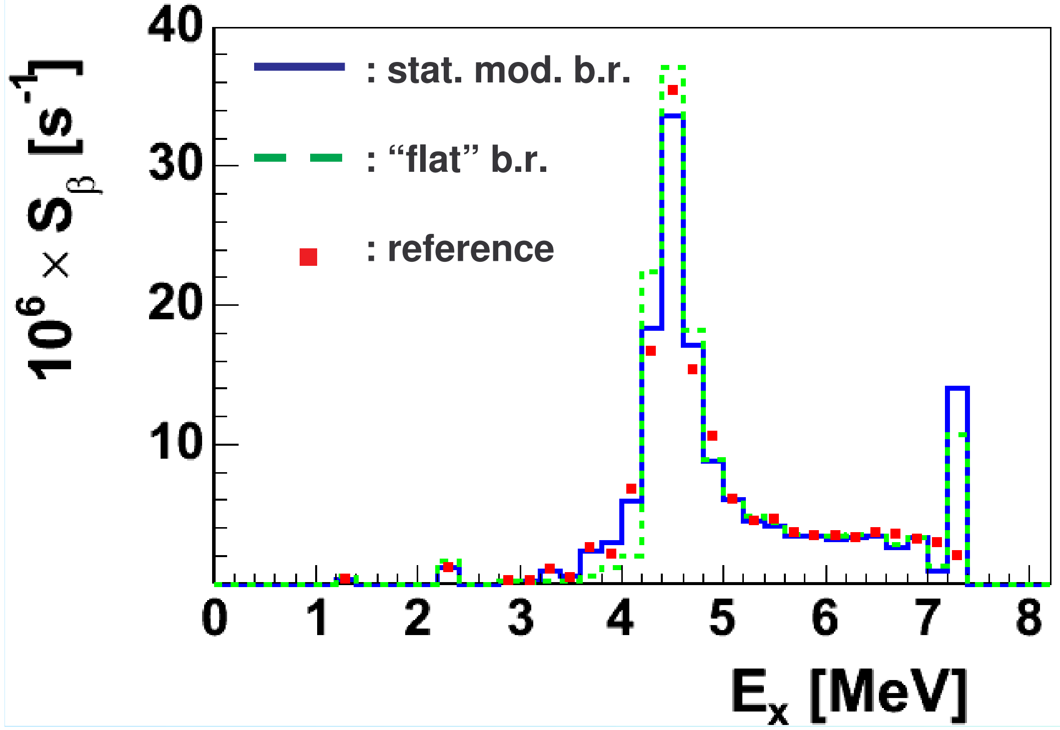
2. Demonstration of the accuracy of Monte Carlo simulations to obtain the spectrometer response (**Cano et al. NIMA430, p.333)**



3. Investigation of the adequacy of several algorithms for the solution of the TAS inverse problem **(Tain et al., NIMA submitted)**

LINEAR REGULARIZATION ✯
MAXIMUM ENTROPY ✪
EXPECTATION-MAXIMIZATION ✪



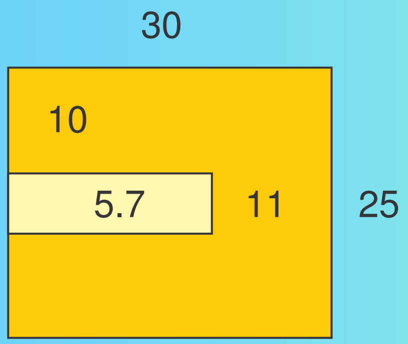


4. Investigation of the dependency of the result on the assumption about the cascade branching ratios **(Tain et al., NIMA accepted)**

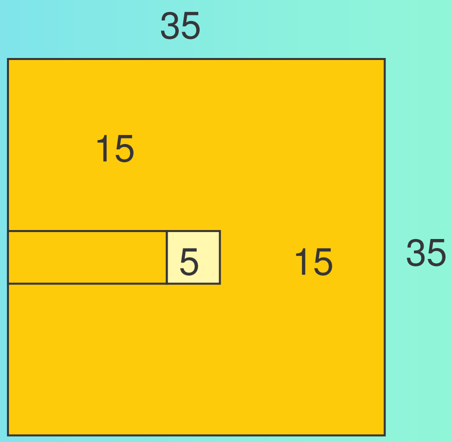
Existing β-decay TAS:

St. Petersburg TAS @ JYFL

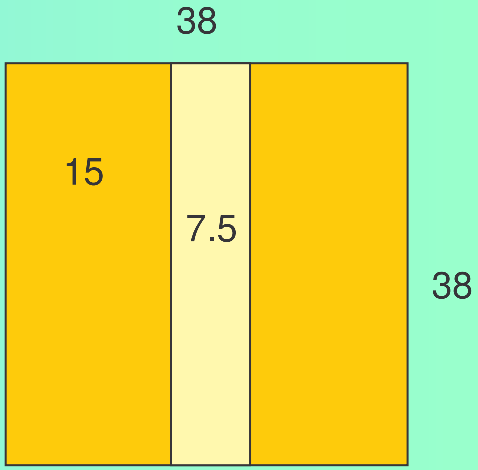
INEL TAS



LBL TAS @ GSI

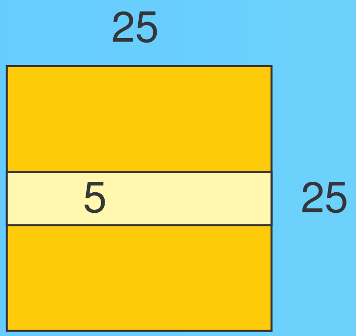


Lucrecia @ ISOLDE



TAS	Material	Size (cm)	1 MeV		5 MeV	
			ε^P	ε^T	ε^P	ε^T
St. Pt.	NaI(Tl)	20×30	0.47	0.87	0.25	0.71
INEL	NaI(Tl)	25×30	0.65	0.90	0.45	0.76
LBL	NaI(Tl)	35×35	0.65	0.97	0.52	0.89
Lucrecia	NaI(Tl)	38×38	0.62	0.89	0.44	0.79

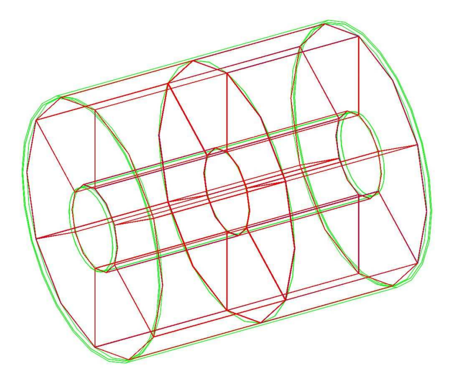
TAS for ALTO ?



BaF_2:

12 Crystals

	ε^P	ε^T
1 MeV	**0.70**	**0.89**
5 MeV	**0.43**	**0.79**



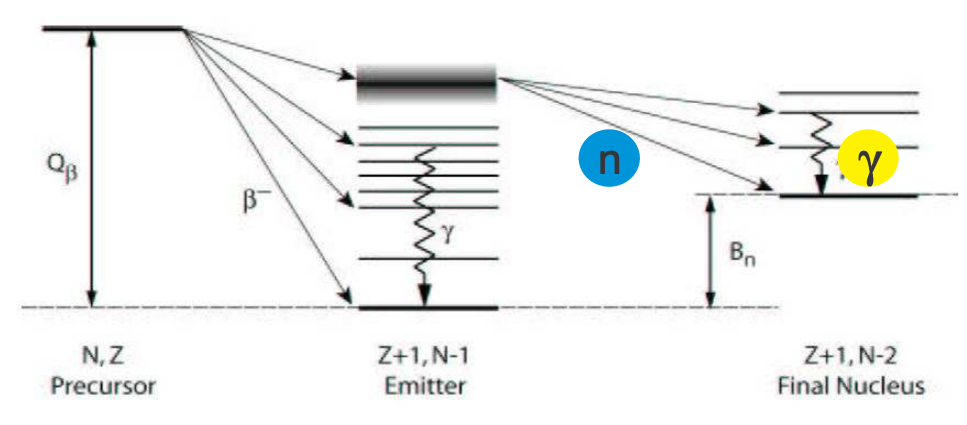

Surrey-Valencia TAS (Rocinante)

- Efficiency compares favorably with *Lucrecia*
- Small sensitivity to very low energy neutrons
- Very good timing resolution

Ancillary detectors:
- X-ray/γ-ray detectors
- β-detectors
- n-detectors?

TAS measurements at the neutron rich side

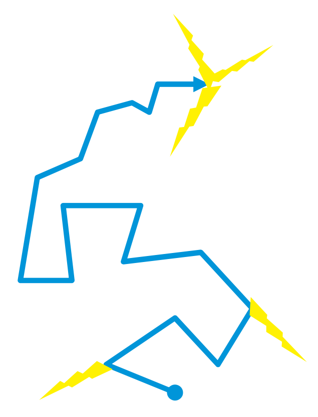
Challenge: β-delayed neutrons and the subsequently emitted γ-rays may become a source of contamination



End-nucleus γ-rays are prompt with the β-decay: they must be measured with Ge + n-detectors and subtracted (anyhow needed to obtain the complete S_β)

Neutrons interact through:

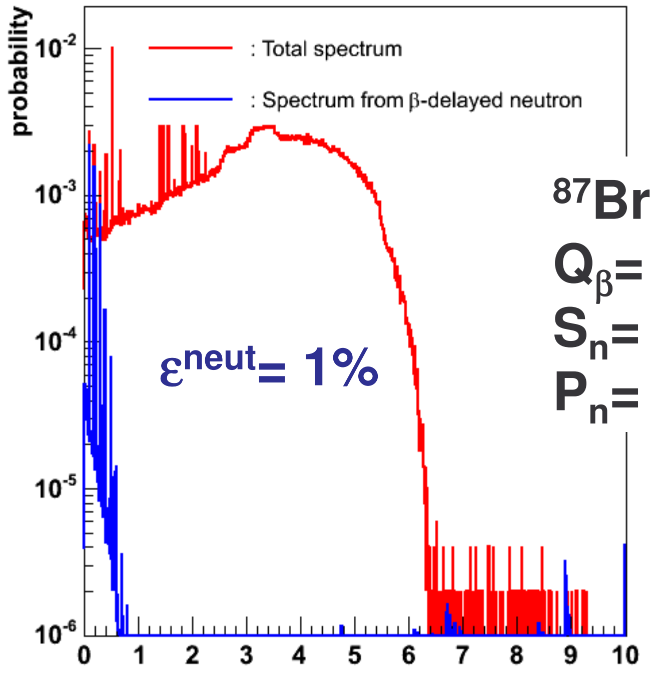
- **elastic scattering**
- **inelastic scattering → γ-rays**
- **capture → γ-rays**
- **other: (n,p), (n,α)… → γ-rays**



n cross-sections are strongly dependent on energy and isotopic composition → MC simulation

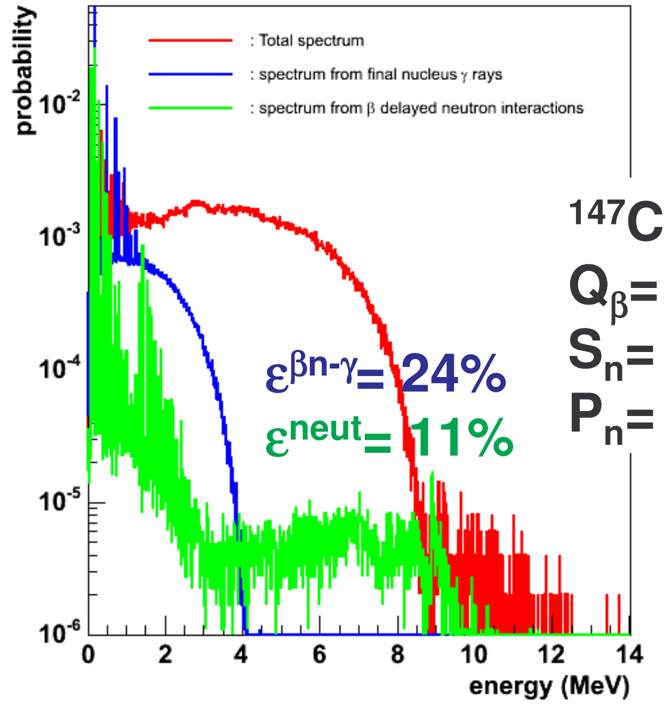
Geant4 MC simulation

(Using nuclear statistical model)



ε^{neut}= 1%

^{87}Br β-decay:
Q_β= 6.85 MeV
S_n= 5.52 MeV
P_n= 2.6 %

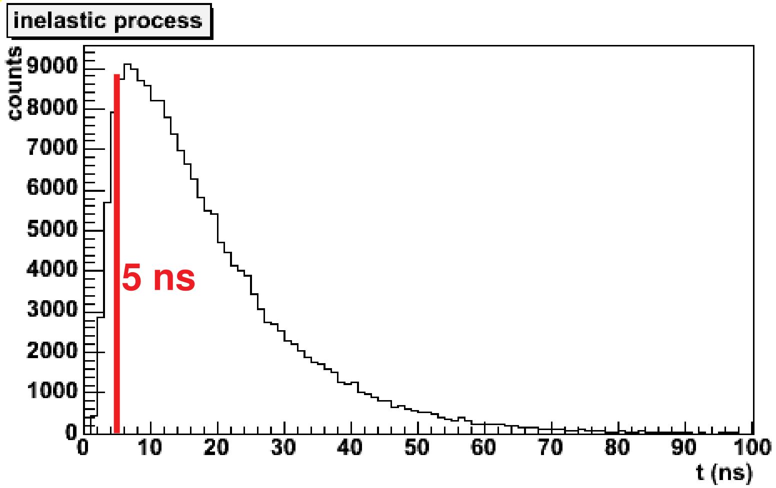


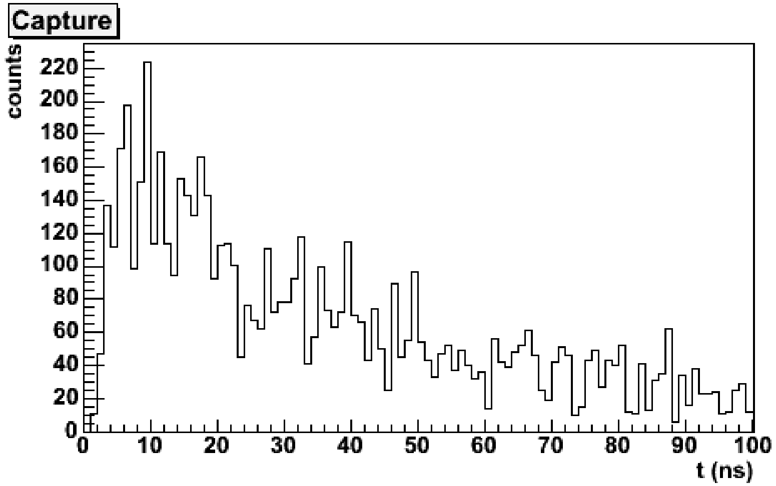
$\varepsilon^{\beta n\text{-}\gamma}$= 24%

ε^{neut}= 11%

^{147}Cs β-decay:
Q_β= 9.2 MeV
S_n= 4.45 MeV
P_n= 27.5 %

Rejection of n-induced signals by timing



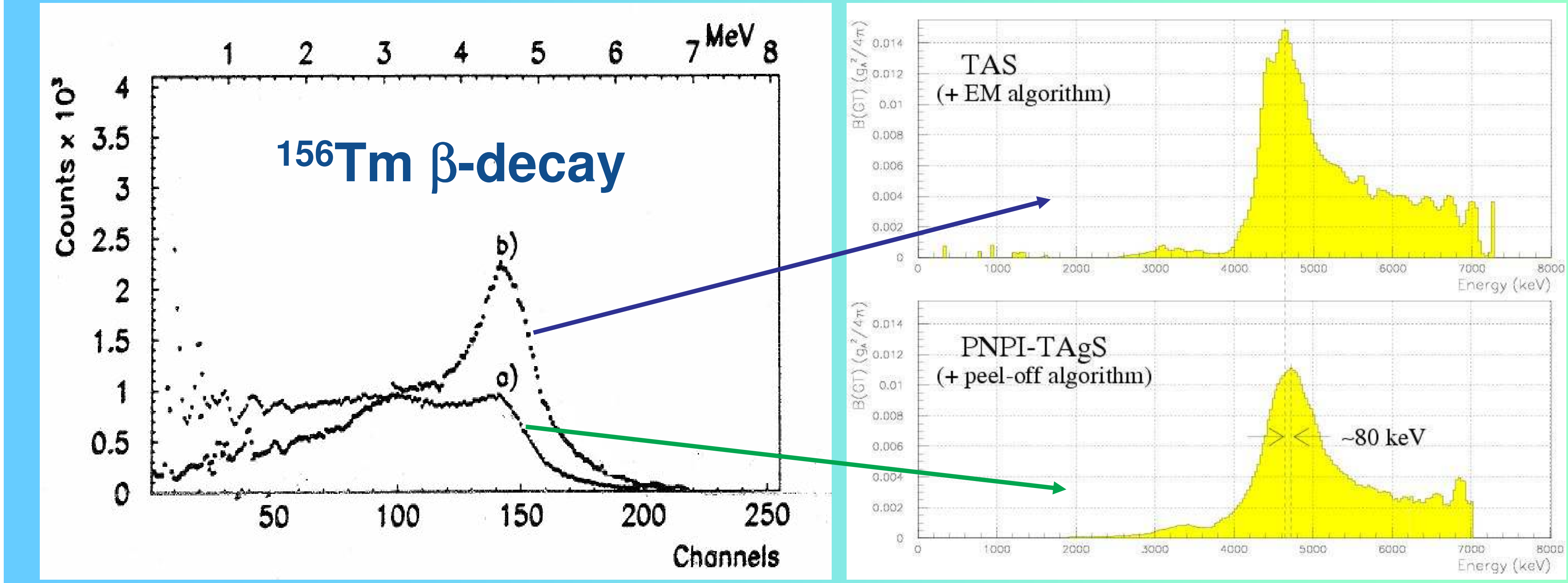


Conclusions:

- The TAS technique is the most powerful technique to investigate the β-strength distribution far from stability, supplemented when necessary by delayed particle spectroscopy
- Many experimental studies are still possible. ALTO seems an ideal place to carry out new measurements at the neutron rich side, not extremely far from stability
- Any means to produce clean sources and eliminate backgrounds will be essential to obtain reliable results

The End

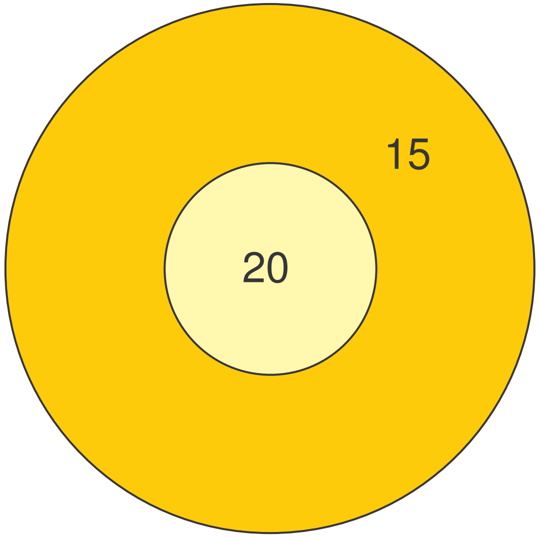
St. Petersburg TAS vs. LBL TAS @GSI



^{156}Tm β-decay

TAC @ FZK and n_TOF

for (n,γ) !



	ε^P	ε^T
1 MeV	0.90	0.98
5 MeV	0.80	0.91

spherical

BaF_2, 42 Crystals