

# $\beta$ -Strength Measurements of Exotic Nuclei with Total Absorption Gamma-Ray Spectroscopy

A. Algora, B. Rubio and J.L. Tain

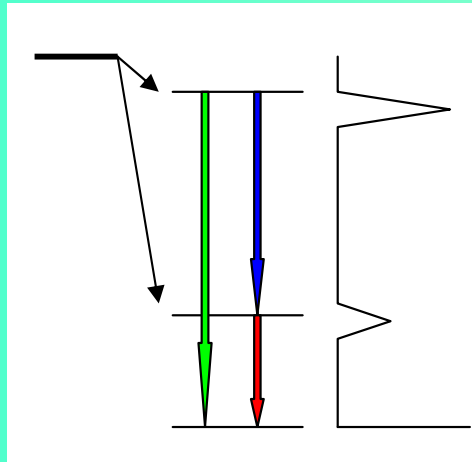
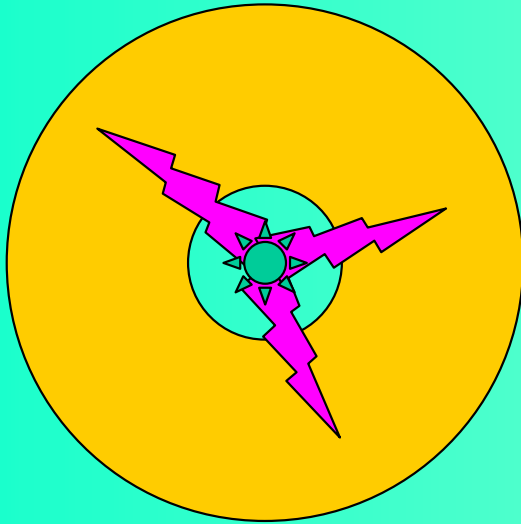
- Reminder of the TAGS technique
- Something about possible spectrometers
- Some physics cases



Jose L. Tain @ IFIC-Valencia

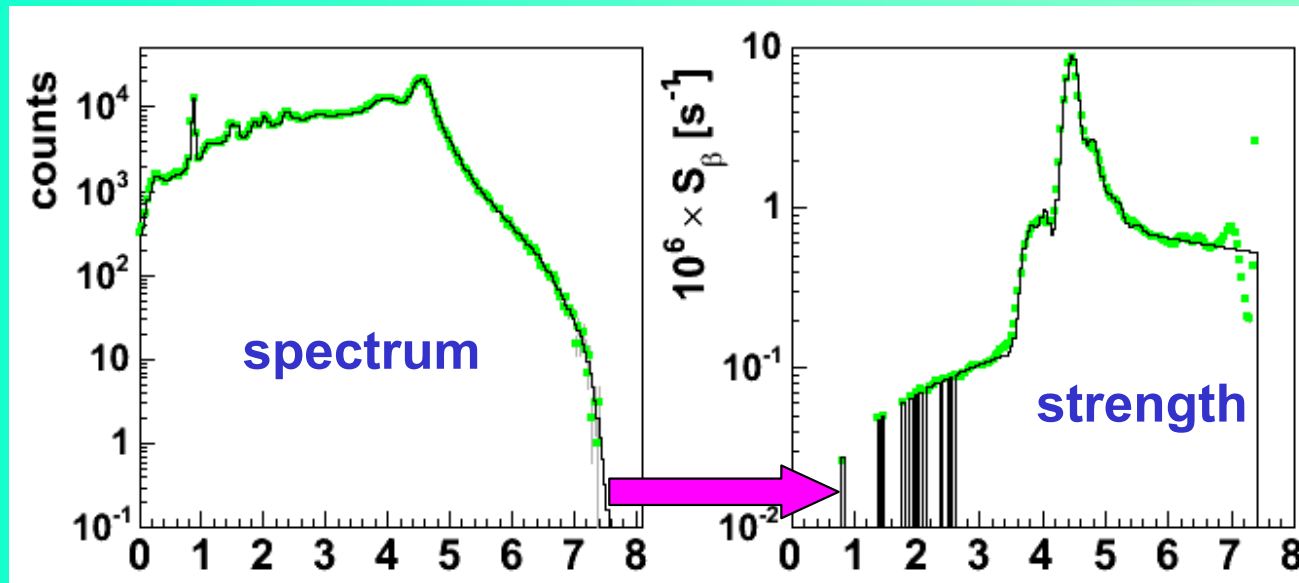
DESIR Meeting, Leuven, 26-28 May, 2010

TAGS uses **large  $4\pi$  scintillation detectors**, aiming **to detect the full  $\gamma$ -ray cascade** rather than individual  $\gamma$ -rays



An ideal TAS would give directly the  $\beta$ -intensity  $I_\beta$

$$S_i = \frac{I_i}{f(Q_\beta - E_i)T_{1/2}} \quad [s^{-1}]$$



Deconvolution with spectrometer response to decay

$$\mathbf{f} = \mathbf{R}^{-1} \cdot \mathbf{d}$$

$$\mathbf{R}_j = \sum_{k=0}^{j-1} b_{jk} \mathbf{g}_{jk} \otimes \mathbf{R}_k$$

Response from MC simulations and nuclear statistical model

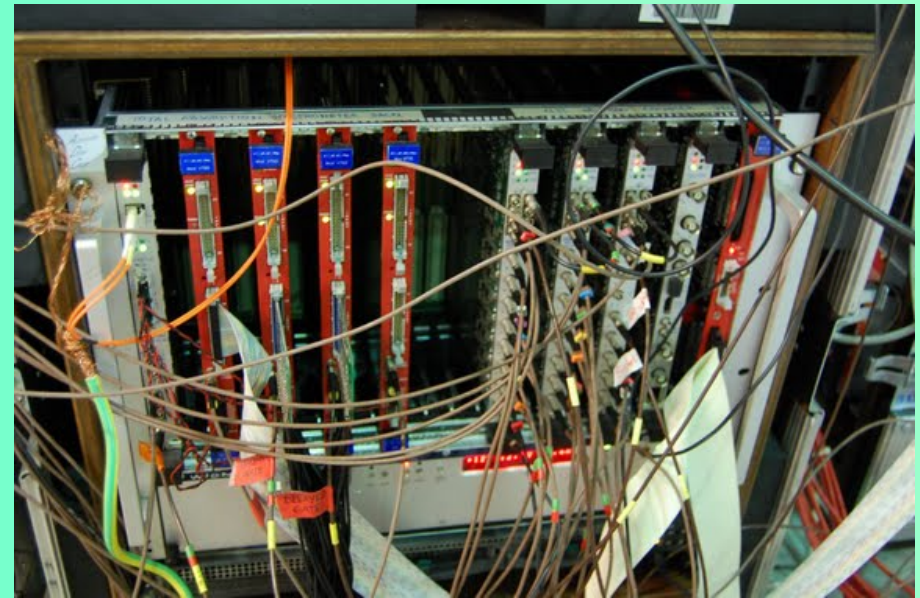
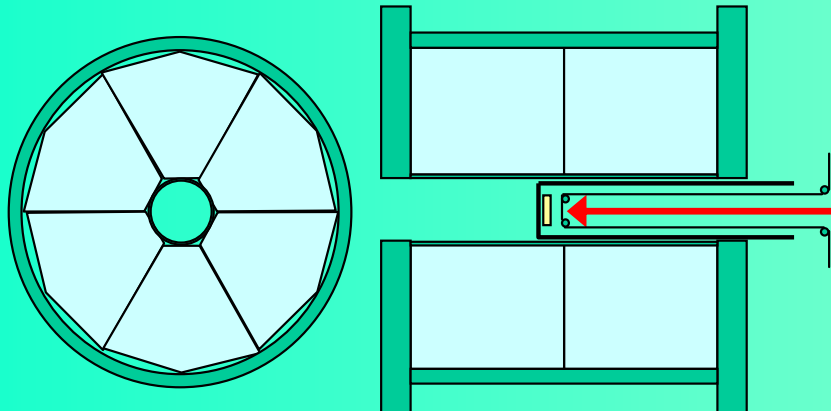
**👉 Clean sources & minimum of statistics**

# New segmented $\text{BaF}_2$ TAS (Surrey-Valencia)



## First measurement at IGISOL-JYFLTRAP (November 2009)

- Isotopically pure beams: 86,87,88Br, 91,92,93,94Rb
- First measurement with a segmented TAS
- Quality of the reconstruction of the software sum
- Use of multiplicity information to reduce analysis systematic errors
- “Conventional” electronics (V785, V775, V792) being substituted by “digital” electronics (SIS3302)

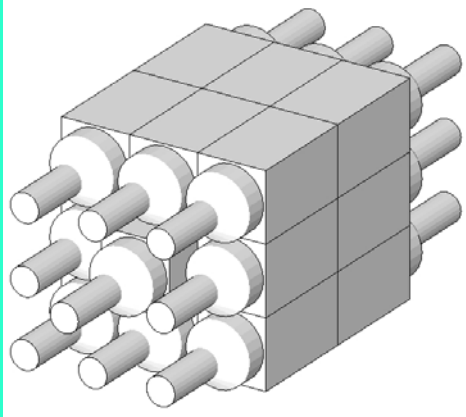


# A Total Absorption Spectrometer for DESPEC

## Design choices

### 16 + 1 modules:

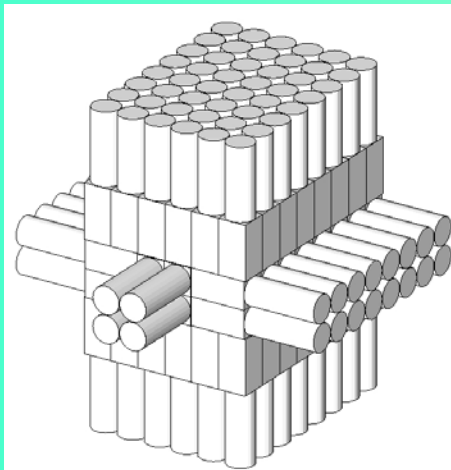
15×15×25 cm<sup>3</sup> **Nal(Tl)**  
+ 5" PMT (50% light col.)  
V= 95 L, M= 351 kg



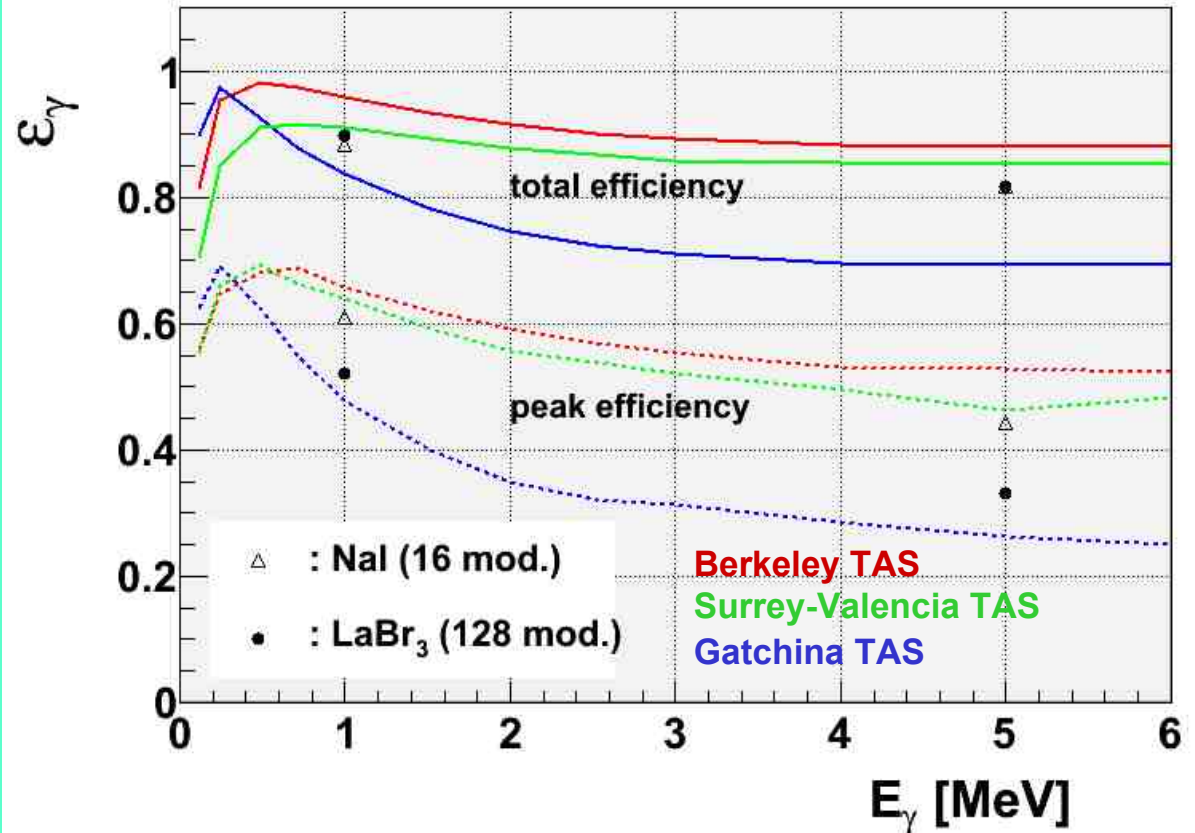
$\Delta E/E \sim 5\%$   
(@1.3MeV)  
 $\Delta t \sim 2$  ns  
 $\tau \sim 230$ ns

### 128 + 4 modules:

5.5×5.5×11 cm<sup>3</sup> **LaBr<sub>3</sub>:Ce**  
+ 2" PMT (60% light col.)  
V= 44 L, M= 223 kg



$\Delta E/E \sim 2\%?$   
(@1.3MeV)  
 $\Delta t \leq 1$  ns  
 $\tau \sim 26/160$ ns

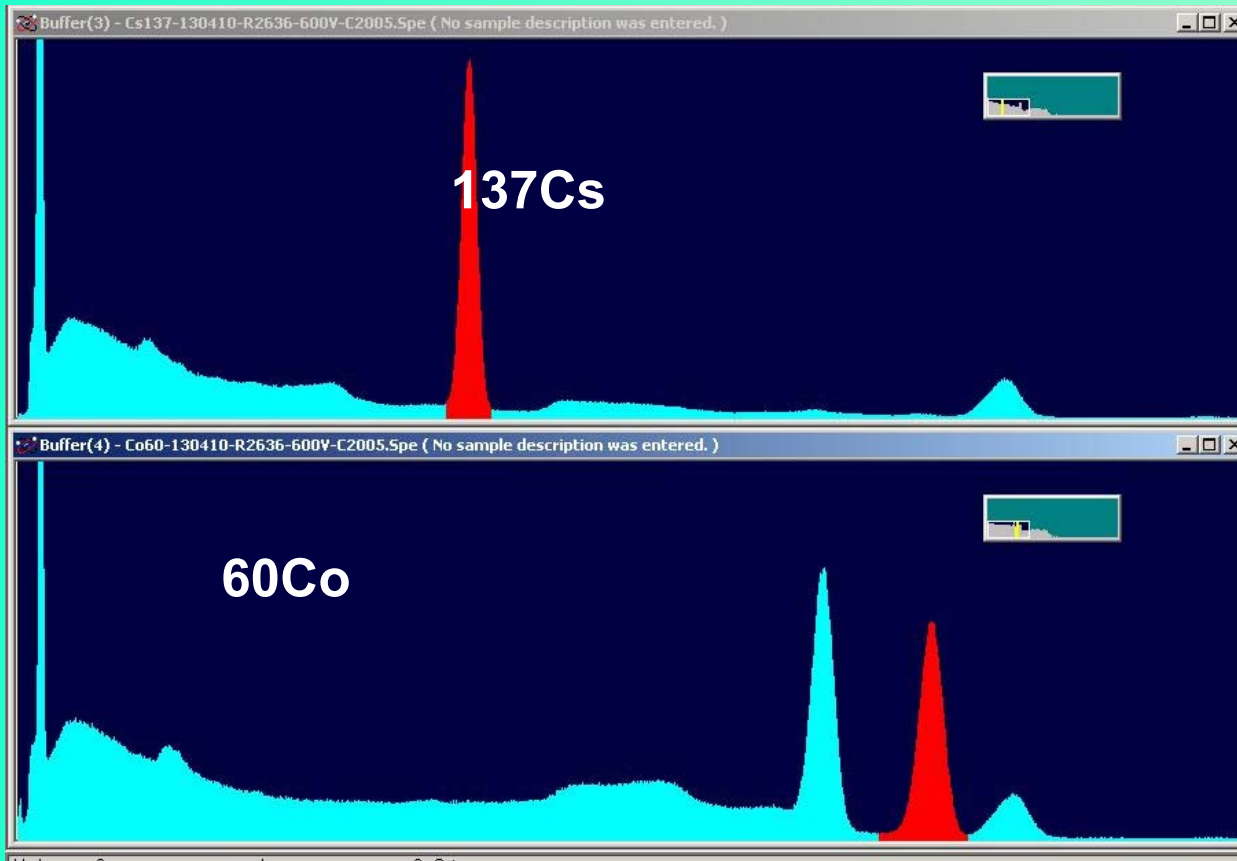


## Status of DESPEC-TAS prototype

A **LaBr3 prototype** with the required characteristics has been purchased:

- lateral wall thicknesses reduced from 2.5 mm to 0.5 mm
- transversal section increased from 50mm×50mm to 55mm×55mm (necessary to accommodate 2" PMT in a compact configuration)
- Resolution-linearity tests with high QE 2" PMT, square 2"×2" PMT and Si Geiger-PD





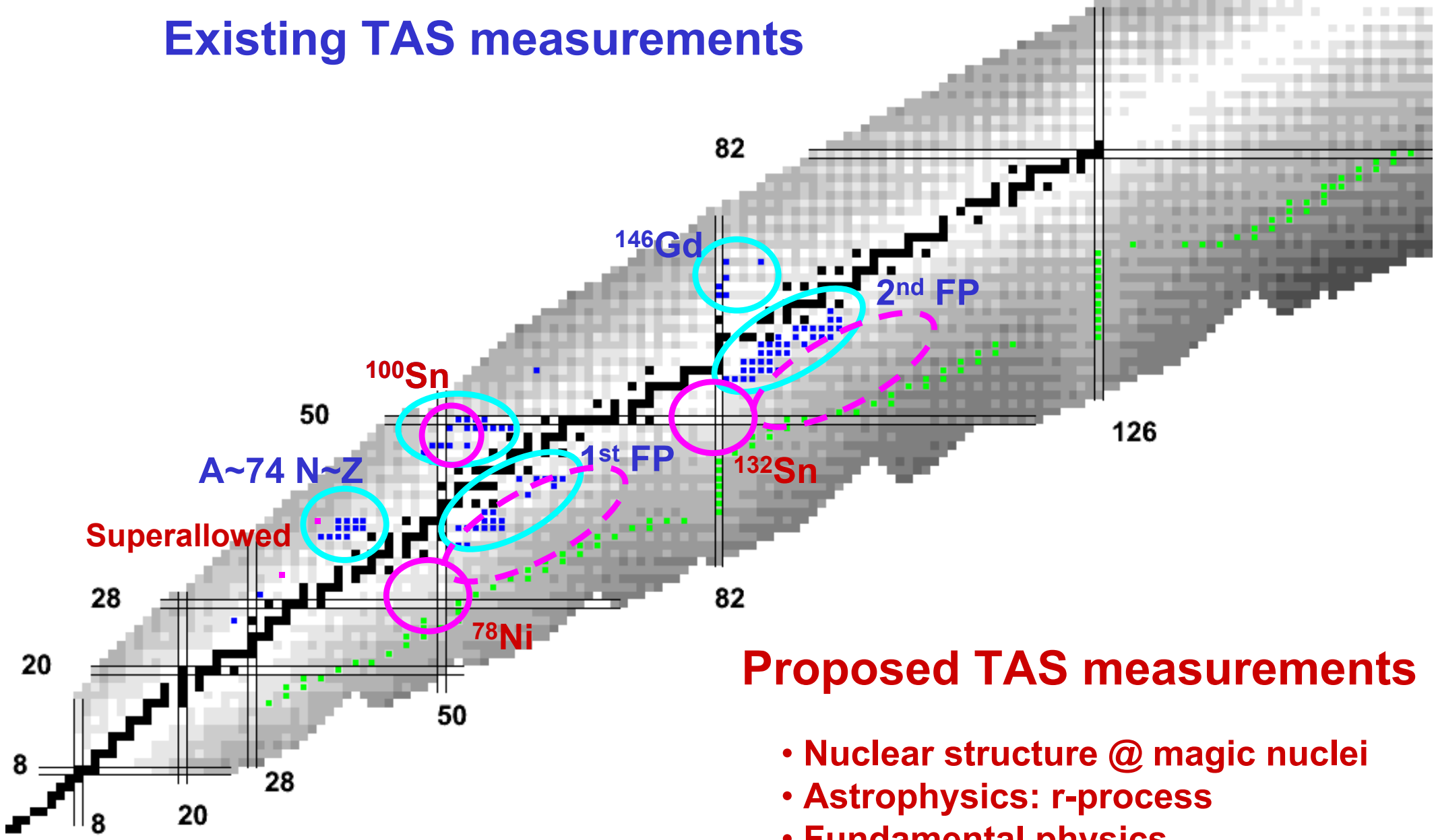
**R = 3.6 %**

**R = 2.9 %**

- NaI prototype module will be ordered
- In-beam tests at the FRS to verify backgrounds and response
- Under discussion:
  - LaBr3 cluster prototype (2×2 or 3×3) with reduced reflector + damper thickness (now 2.25mm)
  - NaI functional prototype to prove TAS experiments with high-energy beams



# Existing TAS measurements

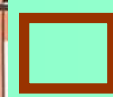


# Proposed TAS measurements

- Nuclear structure @ magic nuclei
- Astrophysics: r-process
- Fundamental physics
- Reactor decay-heat
- Reactor neutrino-spectrum

51	Sb 121.760	Sb 103 >1.5 μs	Sb 104 0.44 s	Sb 105 1.12 s	Sb 106 1.1 s	Sb 107 4.6 s	Sb 108 7.6 s	Sb 109 16.7 s	Sb 110 24.0 s	Sb 111 75 s	Sb 112 53.5 s	
Sn 118.710	Sn 100 0.94 s	Sn 101 3 s	Sn 102 3.8 s	Sn 103 7.0 s	Sn 104 20.8 s	Sn 105 34 s	Sn 106 2.1 m	Sn 107 2.9 m	Sn 108 10.3 m	Sn 109 18.0 m	Sn 110 4.11 h	Sn 111 35.3 m
In 98 1.7 s	In 99 3.1 s	In 100 5.9 s	In 101 16 s	In 102 22.1 s	In 103 34 s	In 104 69 s	In 105 15.7 s	In 106 1.8 m	In 107 43 s	In 108 4.8 m	In 109 5.33 m	In 110 6.26 m
Cd 97 2.8 s	Cd 98 9.2 s	Cd 99 16 s	Cd 100 49.1 s	Cd 101 1.2 m	Cd 102 5.5 m	Cd 103 7.3 m	Cd 104 57.7 m	Cd 105 55.5 m	Cd 106 1.25	Cd 107 6.5 h	Cd 108 0.89	Cd 109 462.6 d
Ag 96 4.40 s	Ag 97 25.3 s	Ag 98 46.7 s	Ag 99 10.5 s	Ag 100 2.3 m	Ag 101 3.1 s	Ag 102 11.1 m	Ag 103 8 m	Ag 104 13 m	Ag 105 5.7 s	Ag 106 1.1 h	Ag 107 33.5 m	Ag 108 69.2 m
Pd 95 14 s	Pd 96 2.0 m	Pd 97 3.1 m	Pd 98 17.7 m	Pd 99 21.4 m	Pd 100 3.7 d	Pd 101 8.47 h	Pd 102 1.02	Pd 103 16.96 d	Pd 104 11.14	Pd 105 22.33	Pd 106 27.33	Pd 107 21.3 s
Rh 94 70.6 s	Rh 95 1.96 m	Rh 96 1.5 m	Rh 97 9.9 m	Rh 98 44 m	Rh 99 31 m	Rh 100 3.5 m	Rh 101 8.7 m	Rh 102 4.7 h	Rh 103 16 d	Rh 104 4.7 m	Rh 105 20.8 h	Rh 106 4.4 d
Ru 93 10.8 s	Ru 94 59.7 s	Ru 95 51.8 m	Ru 96 5.54	Ru 97 2.9 d	Ru 98 1.87	Ru 99 12.76	Ru 100 12.60	Ru 101 17.06	Ru 102 31.55	Ru 103 4.4 m	Ru 104 42 s	Ru 105 45 s

# TAS Studies in the <sup>100</sup>Sn region



Studies performed earlier at GSI On-line Mass-Separator



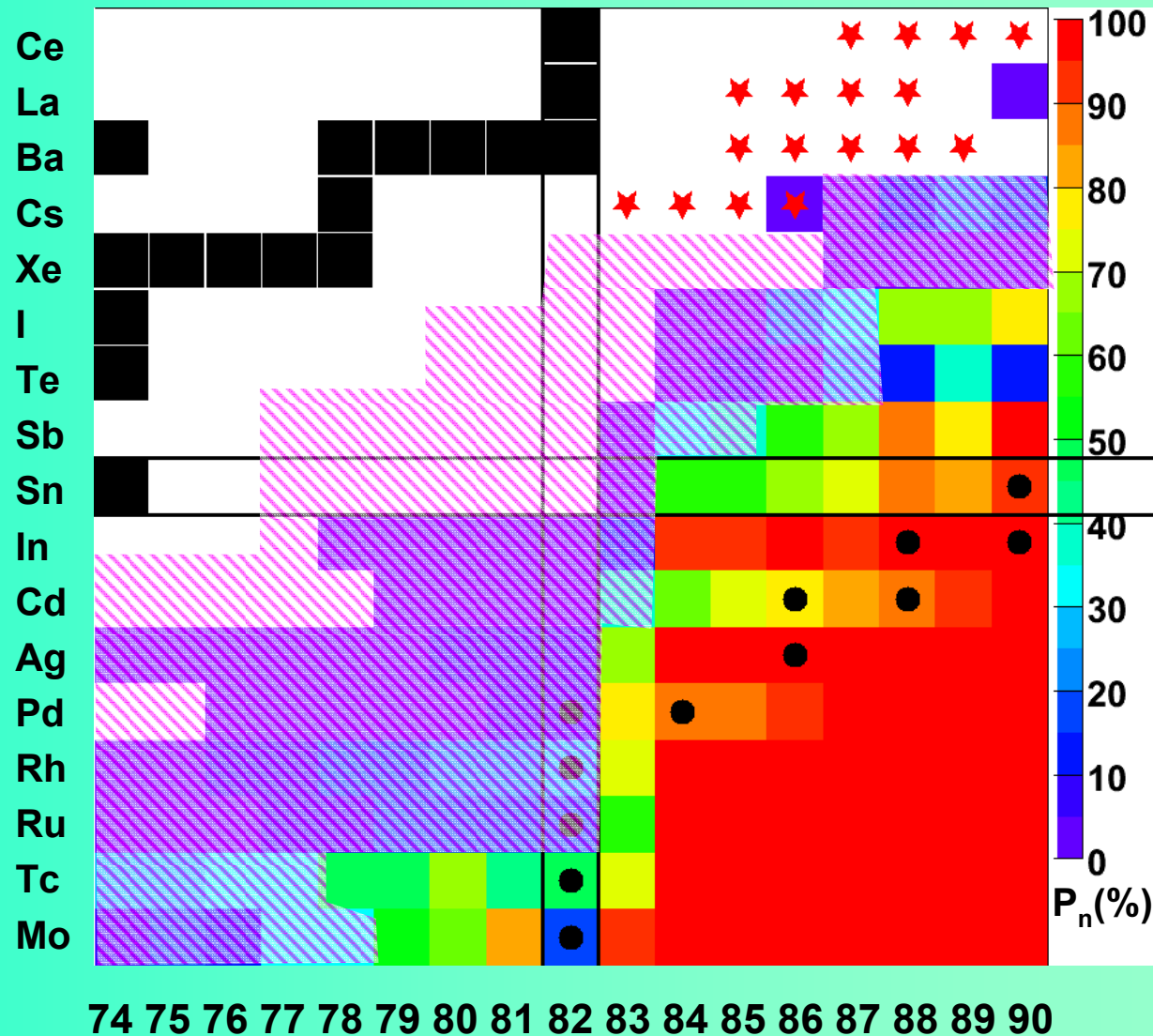
Studies still to be done

## Motivation:

- One of the few regions where the GT+ resonance ( $\pi g_{9/2} \rightarrow \nu g_{7/2}$ ) lies within the  $Q_{EC}$  window
- Allows the study of the quenching of the GT strength



$\sim {}^{132}\text{Sn}$

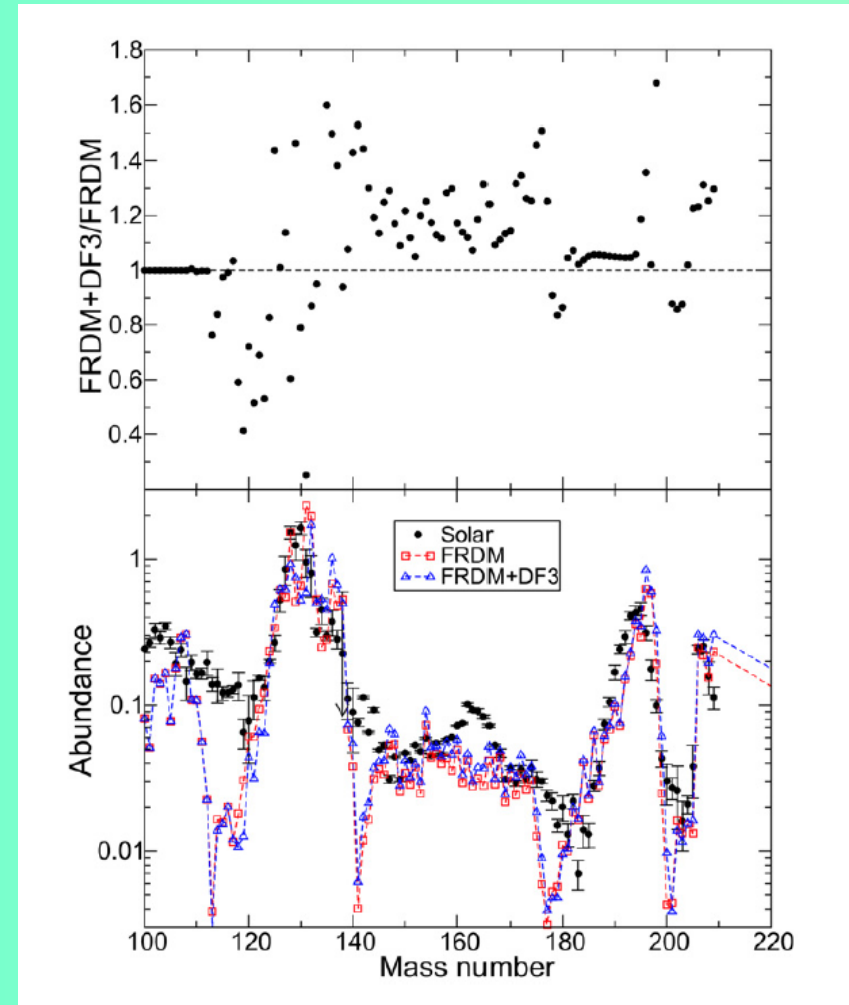
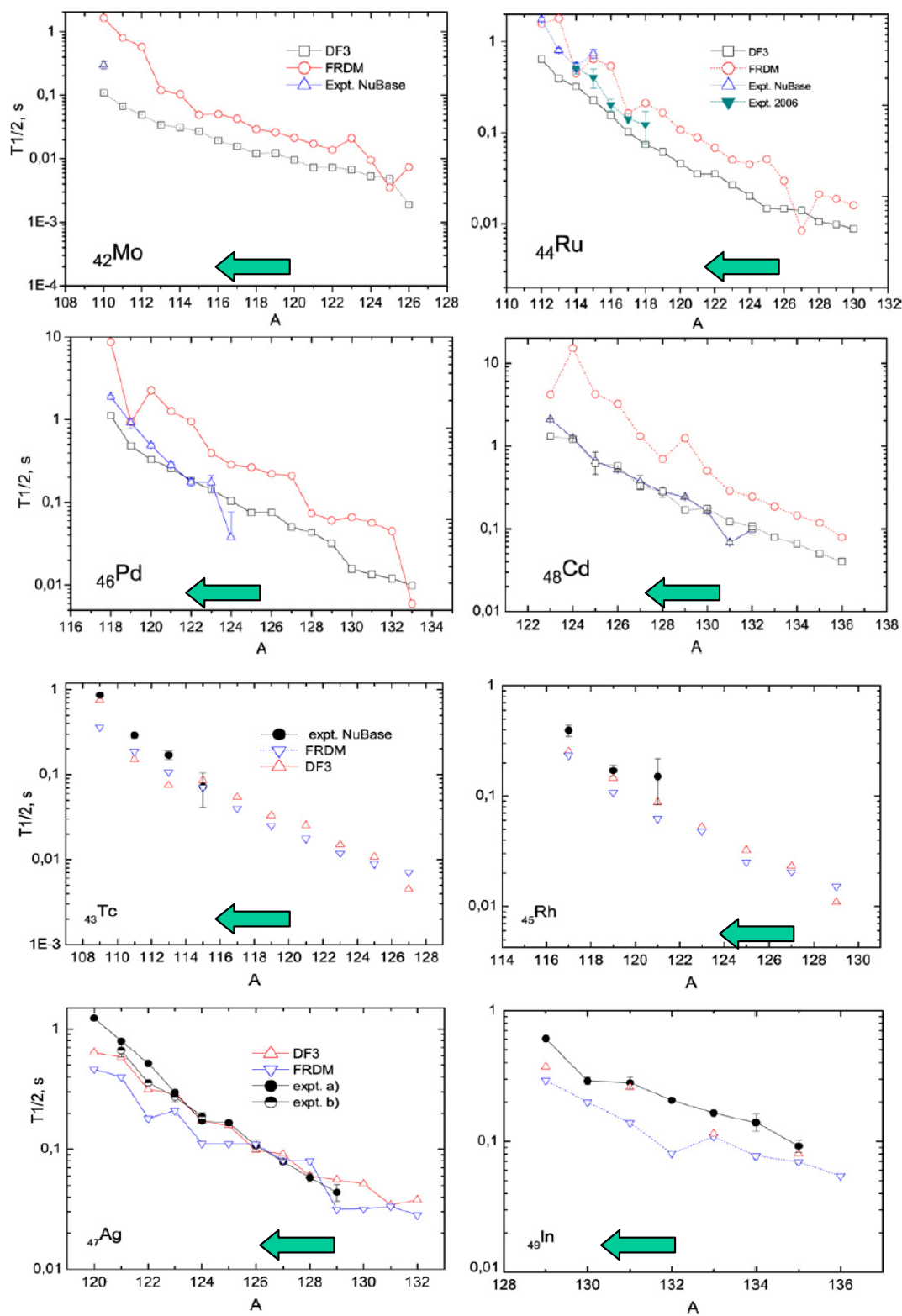


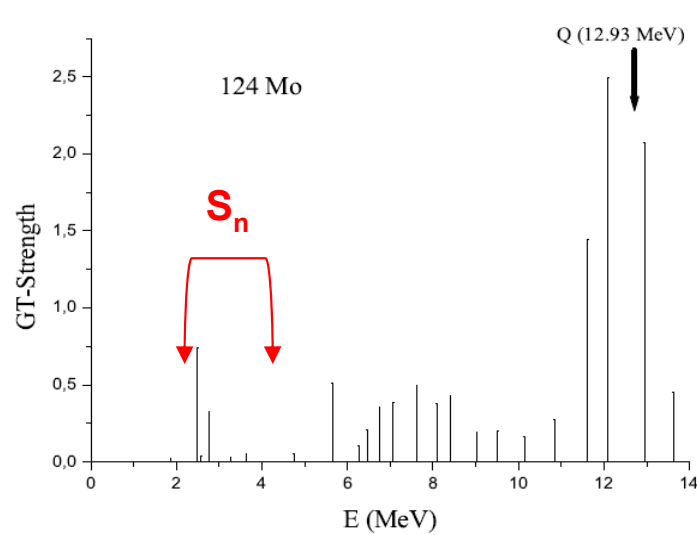
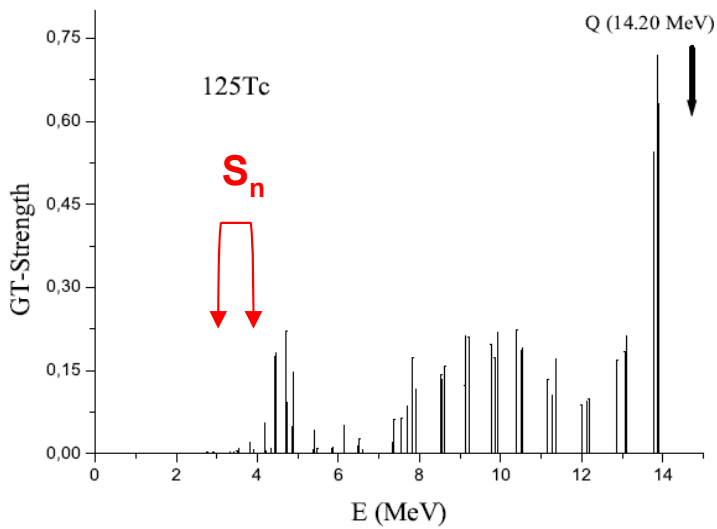
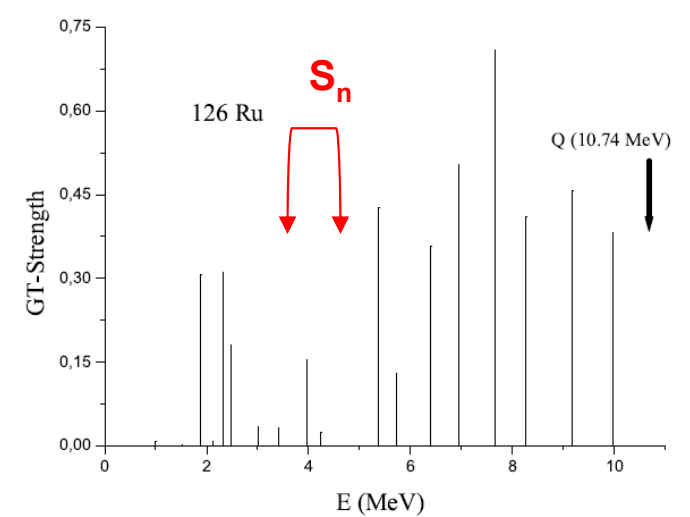
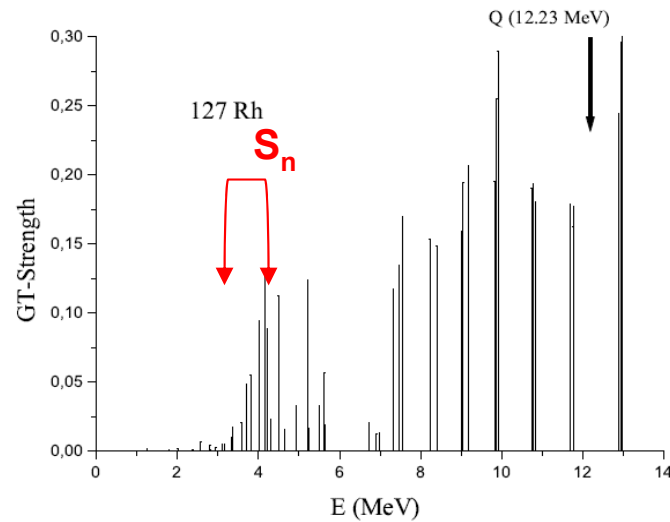
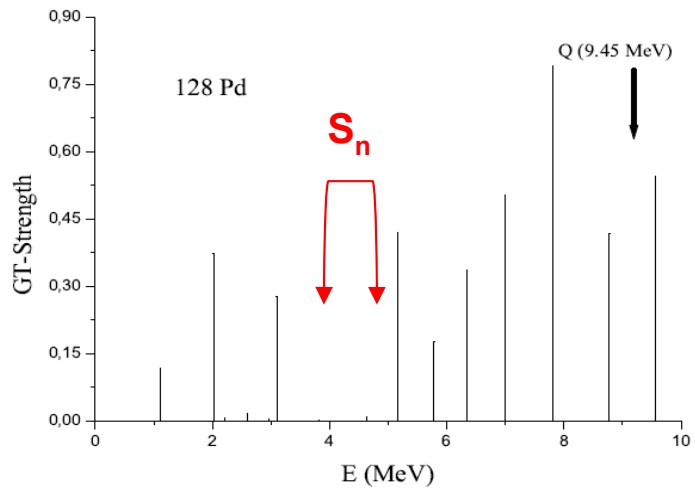
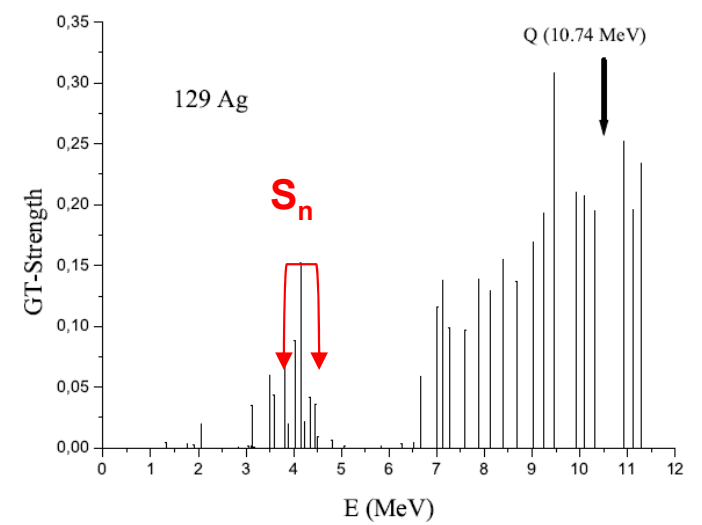
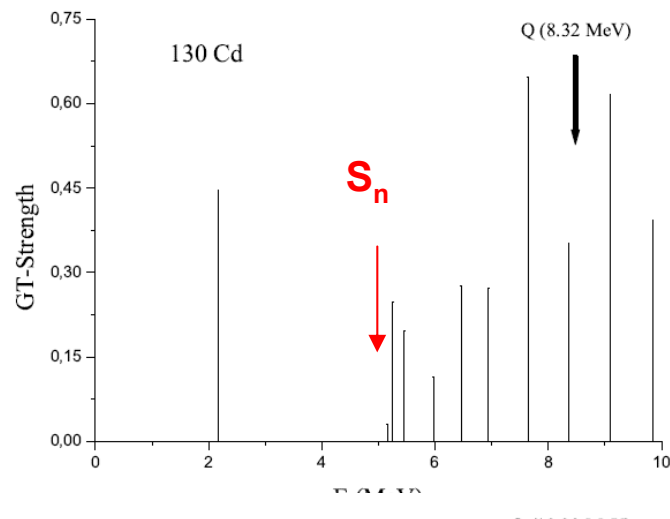
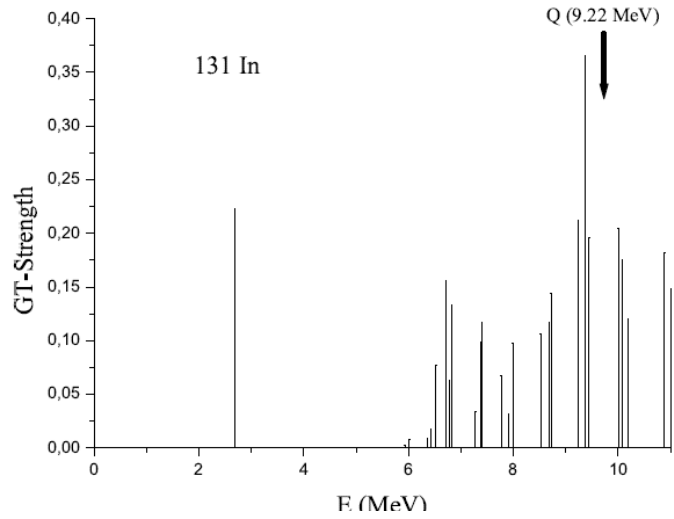
When looking to neutron rich nuclei one must consider the beta-delayed neutron emission:

- which “removes” strength from TAS observation
- which introduces contamination from final nucleus  $\gamma$ -rays and from neutron interactions

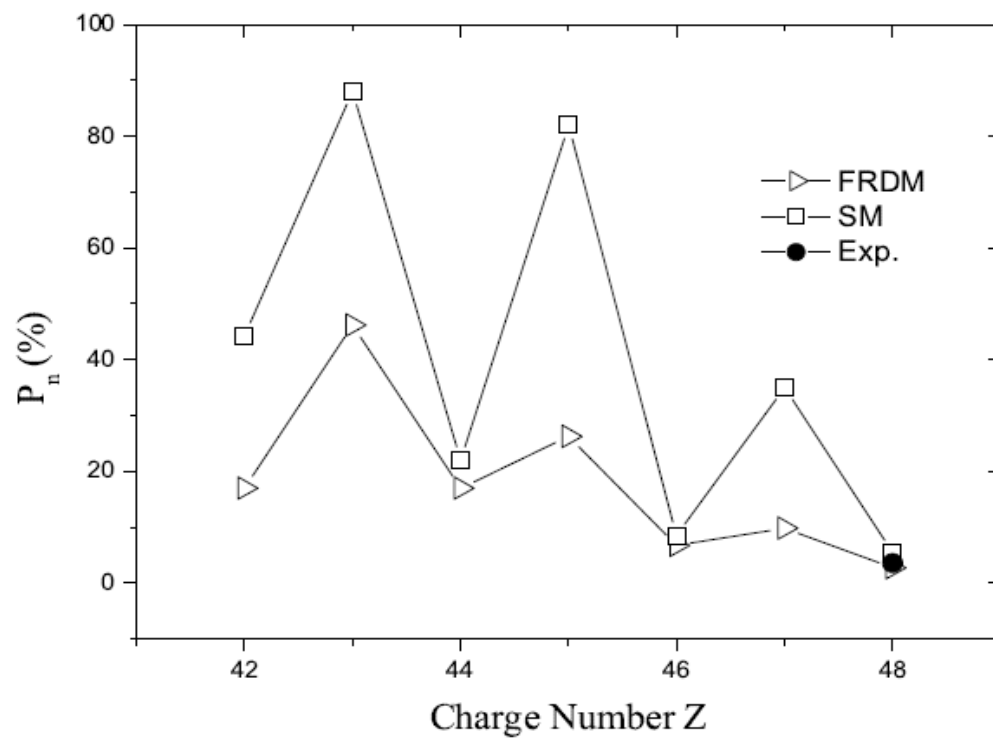
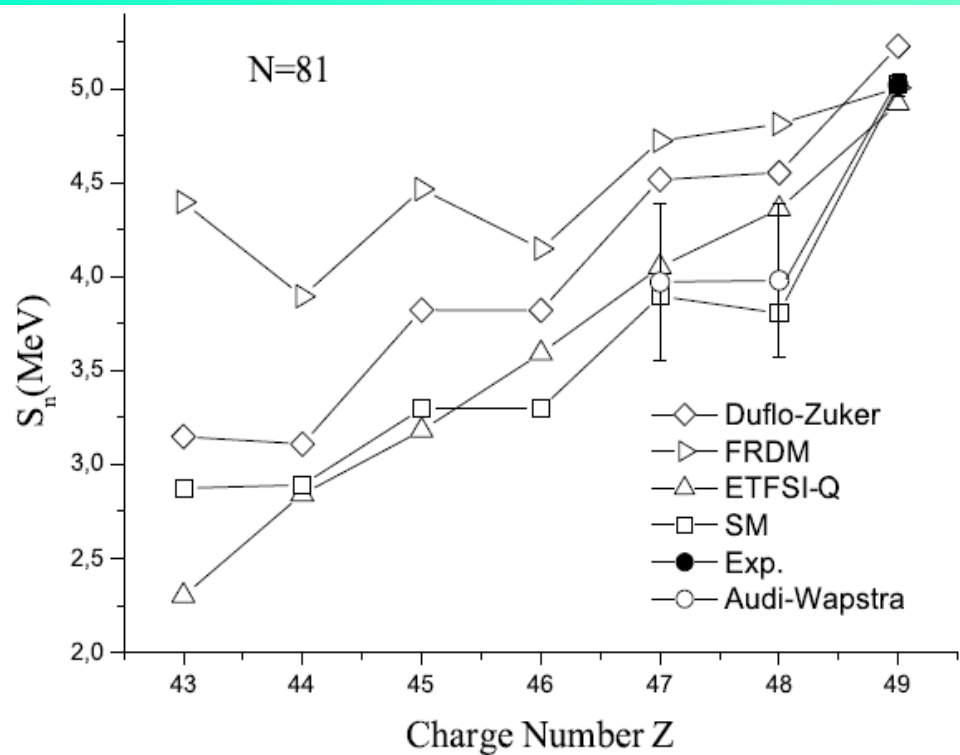
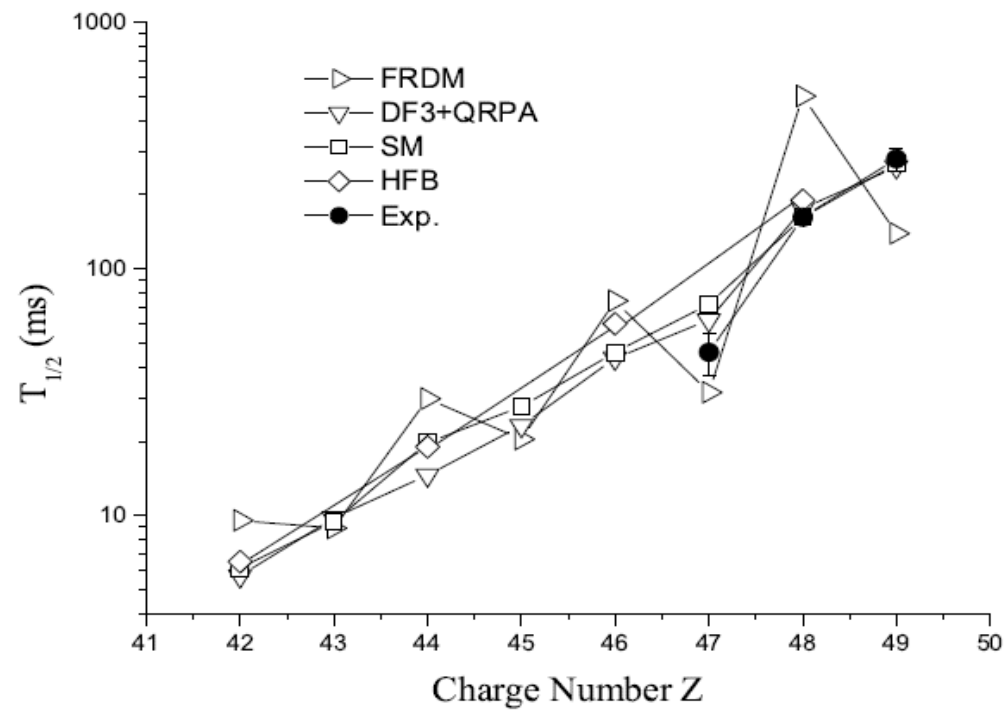
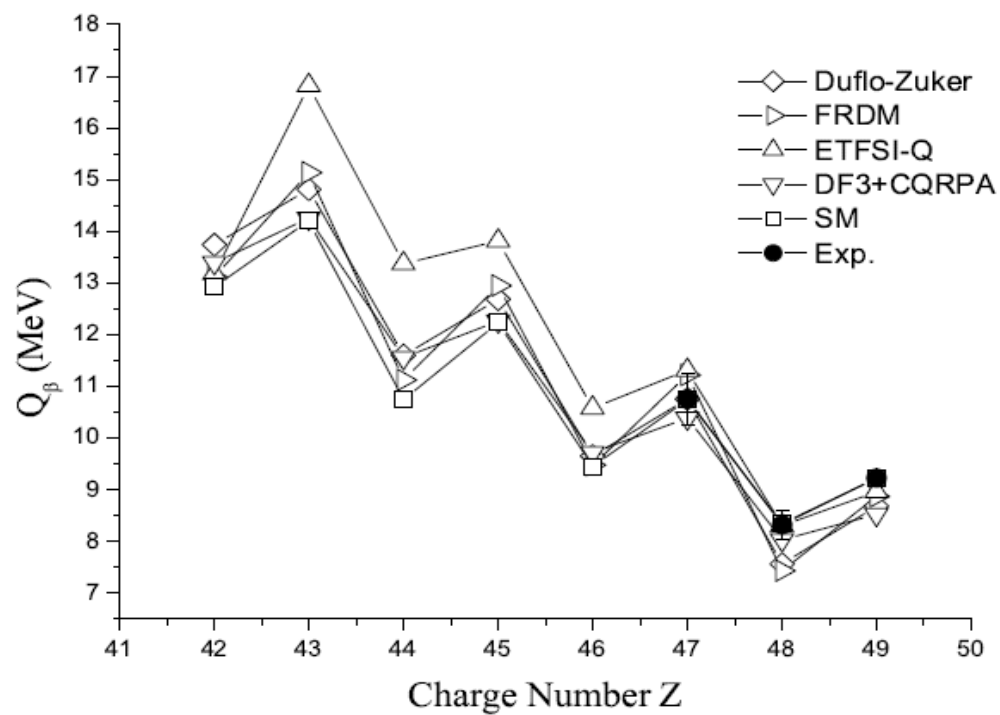
# $\beta$ -strength calculations of $Z < 50$ nuclei close to $N = 82$

Borzov et al., NP A814 (2008) 159





**Shell Model  
Calculations  
N=82:  
Cuenca-Garcia et al.  
EPJA 34 (2007) 99**



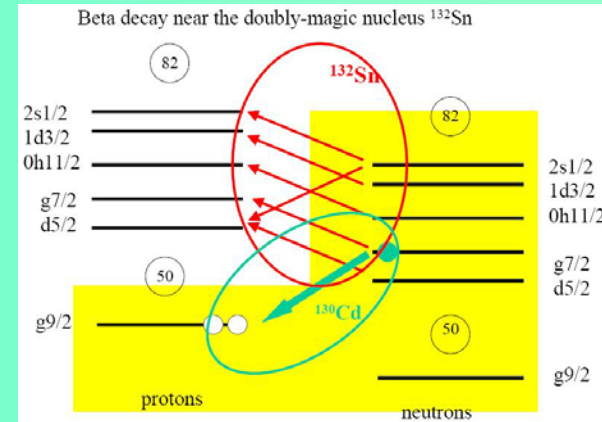


# The $^{130}\text{Cd}$ decay case:

$$Q_\beta = 8.34 \text{ MeV}, S_n = 5.02 \text{ MeV}, T_{1/2} = 162 \text{ ms}$$

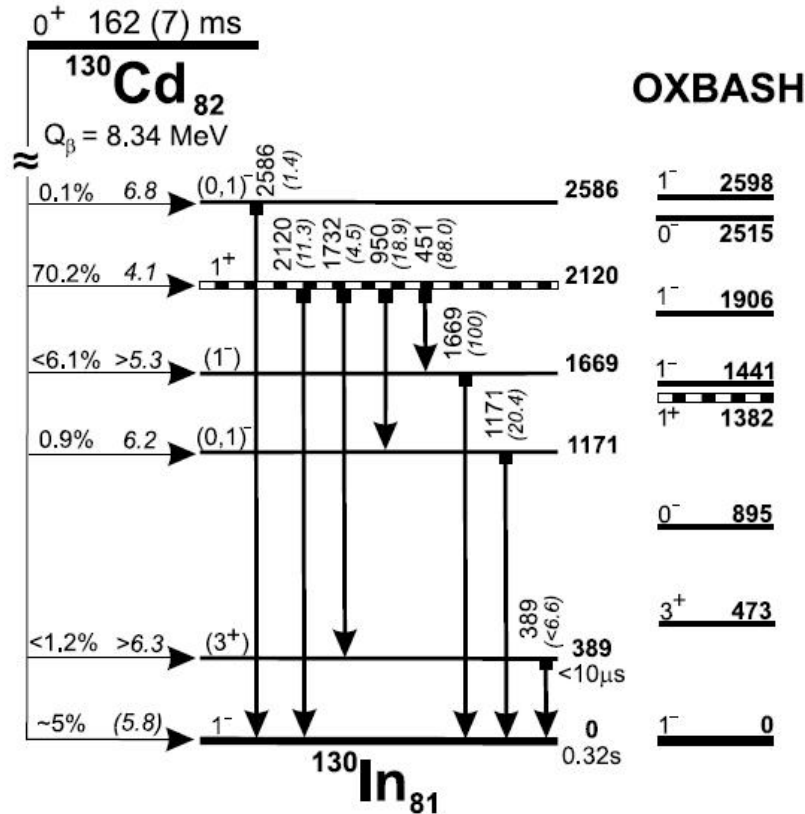
Present experimental information:

Dillmann et al. PRL 91 (2003) 162503



Statistical model has been used to simulate realistic cascades:

- Known levels: up to 2.12 MeV (ignore other  $J\pi$ )
- MC levels 2.12-5.03 MeV:  
1+: 15 lev. , Total ( $J < 10$ ) 425 lev.
- 70% intensity to the 2.12 MeV 1+
- 30% intensity to the 15 higher 1+ levels (intensity decrease with Fermi function, Porter-Thomas fluctuations)
- E1, M1 and E2 strength from RIPL-2 global parameterization

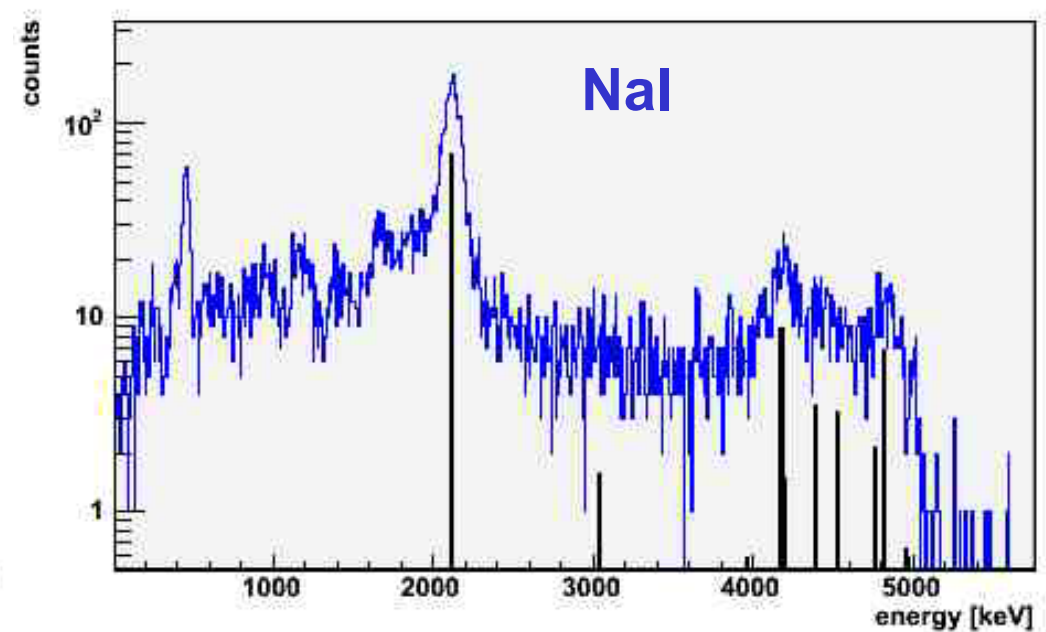
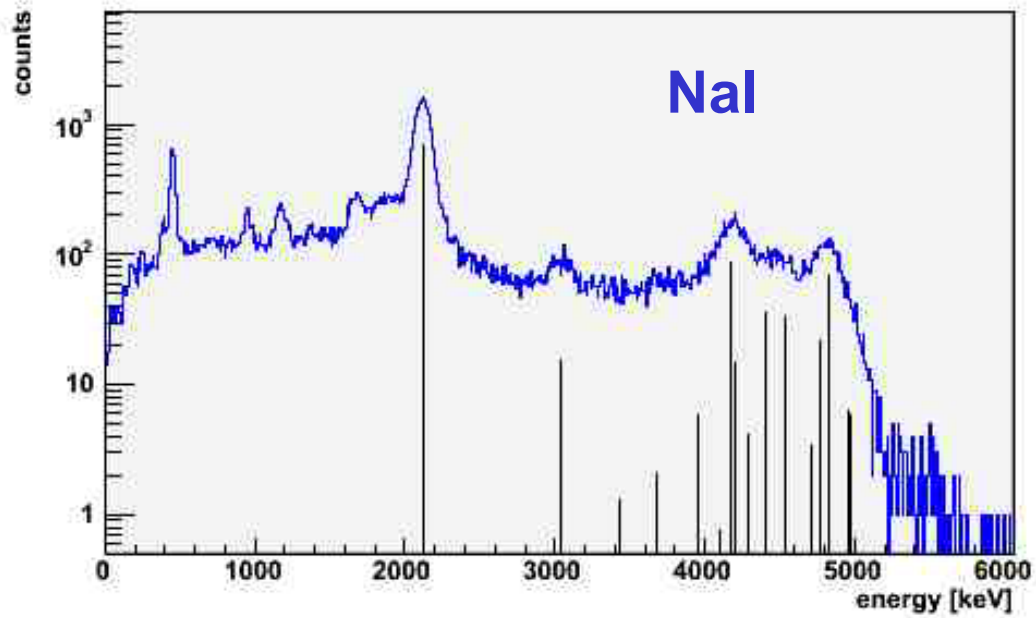
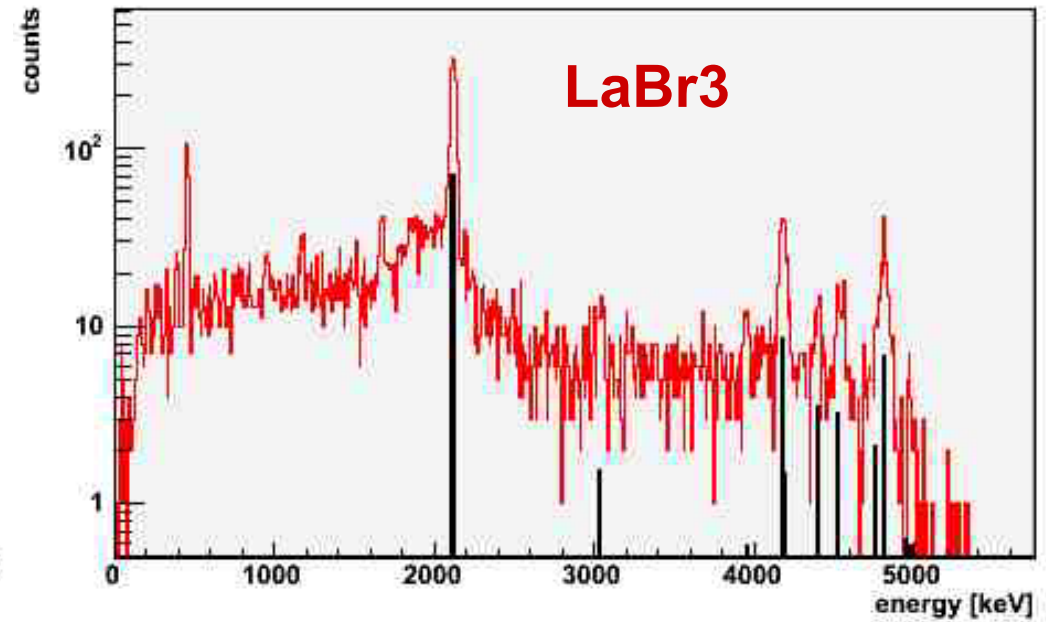
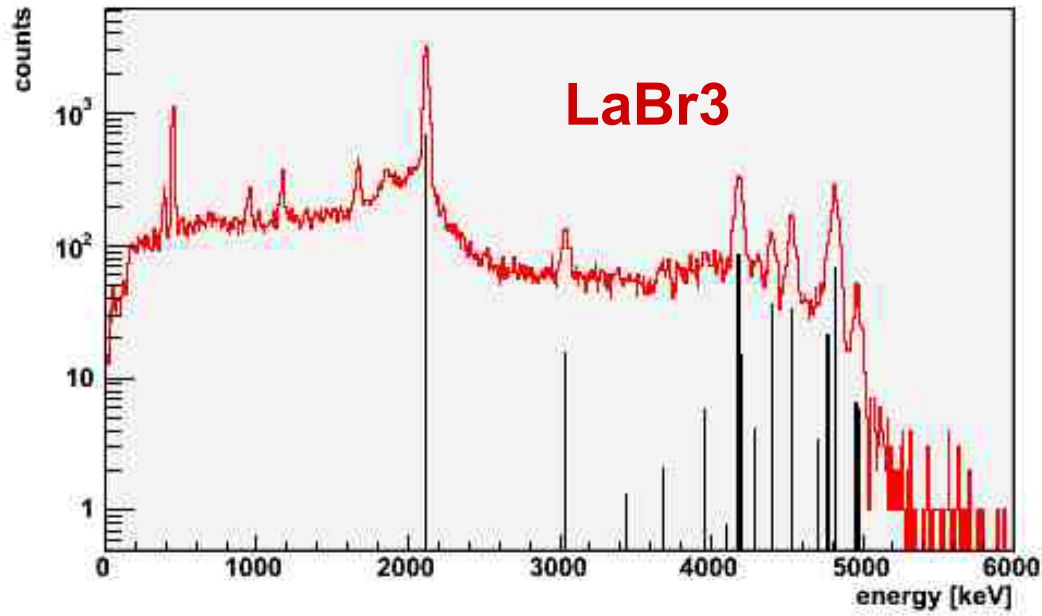


+ 7 additional high lying levels with 3.5% intensity

Total  $I_\beta = 90\%$  (including high lying 3.5%,  $P_n = 3.6\%$  and  $I_{gs} = 5\%$  from theory)

$10^5$  decays

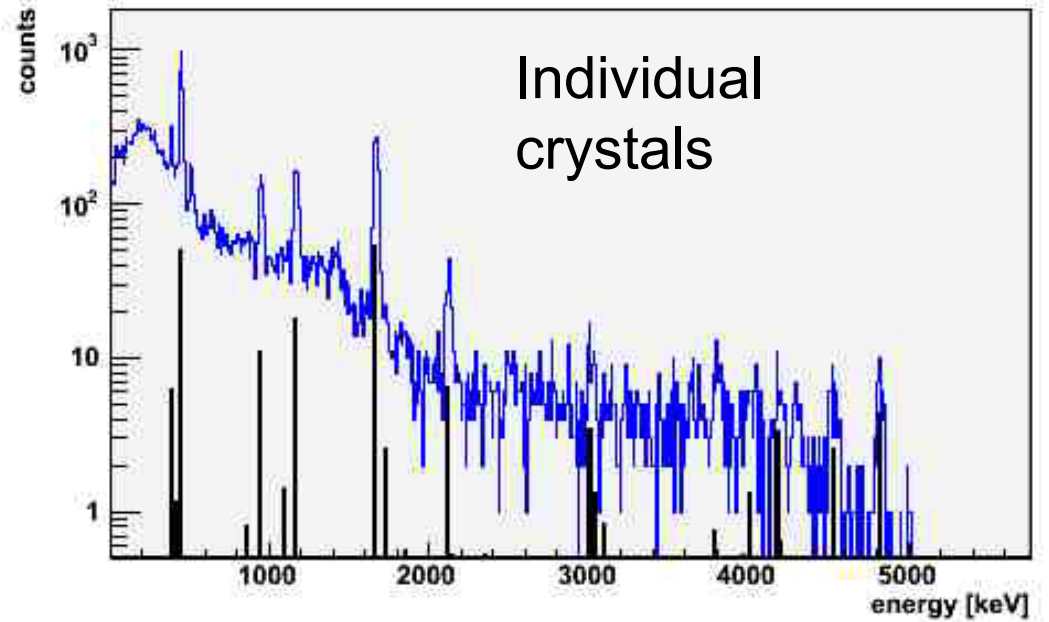
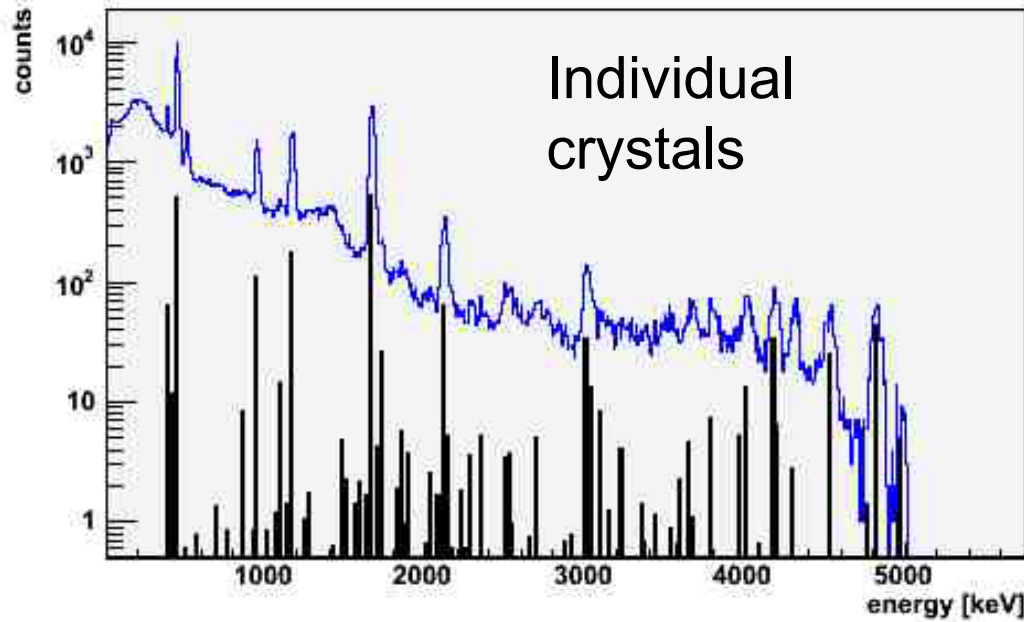
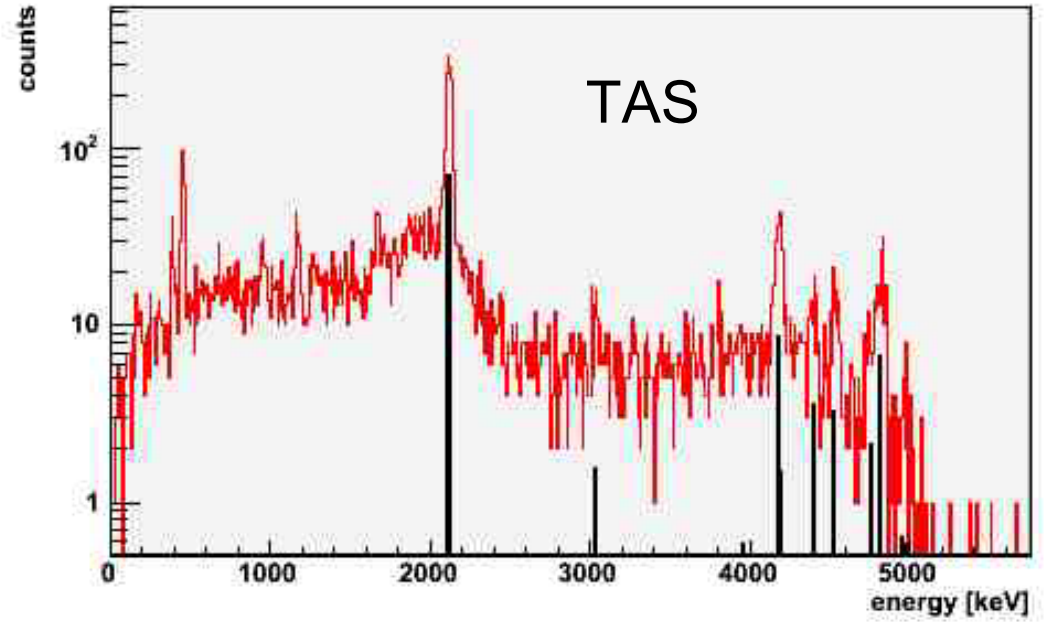
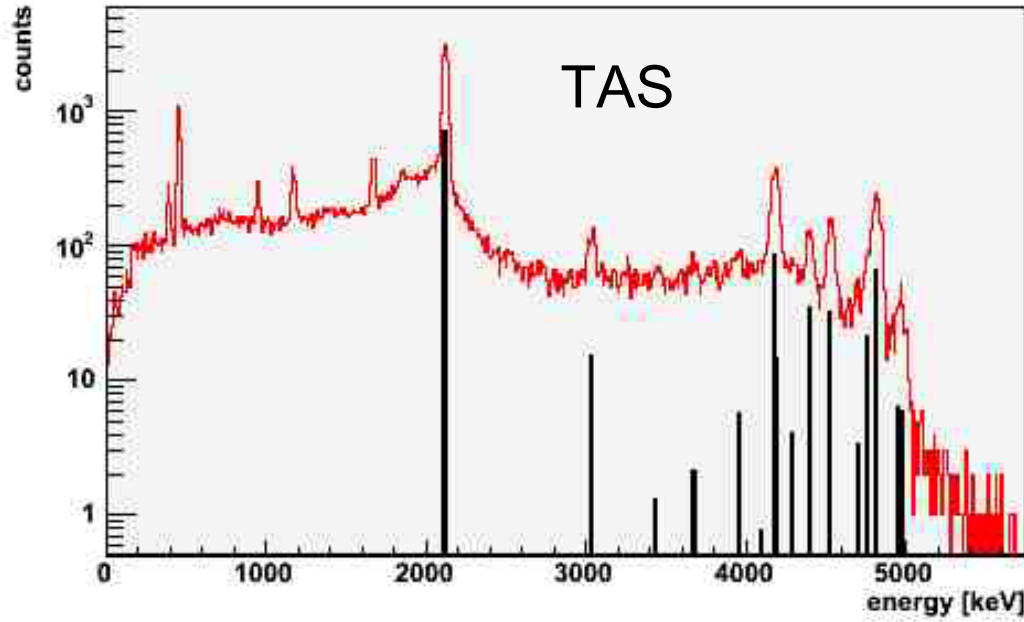
$10^4$  decays



$10^5$  decays

LaBr<sub>3</sub>

$10^4$  decays



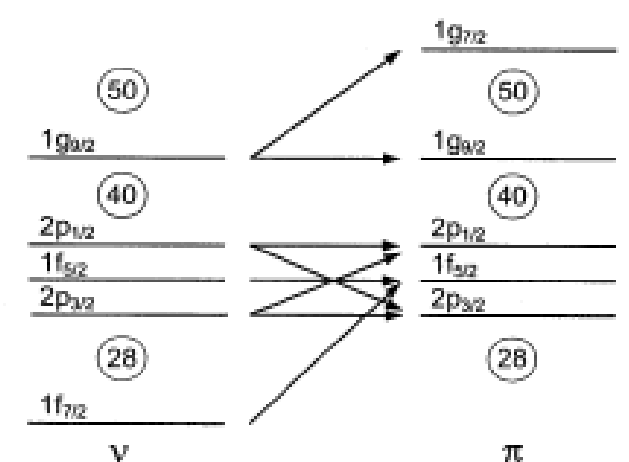


Se 74 0.89	Se 75 119.64 d	Se 76 9.37	Se 77 17.5 s	Se 78 23.77	Se 79 3.9 m	Se 80 49.61	Se 81 57.3 m	Se 82 8.73	Se 83 69 s	Se 84 3.1 m	Se 85 33 s	Se 86 17.1 s	Se 87 5.8 s
As 73 80.3 d	As 74 17.77 d	As 75 100	As 76 26.4 h	As 77 38.8 h	As 78 1.5 h	As 79 8.2 m	As 80 15.2 s	As 81 34 s	As 82 13.6 s	As 83 13.3 s	As 84 4.5 s	As 85 2.03 s	As 86 0.9 s
Ge 72 27.31	Ge 73 7.76	Ge 74 36.72	Ge 75 47 s	Ge 76 7.83	Ge 77 53 s	Ge 78 88 m	Ge 79 39 s	Ge 80 29.5 s	Ge 81 7.6 s	Ge 82 4.60 s	Ge 83 1.85 s	Ge 84 984 ms	Ge 85 535 ms
Ga 71 39.892	Ga 72 14.1 h	Ga 73 4.86 h	Ga 74 9.5 s	Ga 75 2.1 m	Ga 76 32.6 s	Ga 77 13 s	Ga 78 5.49 s	Ga 79 2.85 s	Ga 80 1.70 s	Ga 81 1.22 s	Ga 82 0.60 s	Ga 83 0.31 s	Ga 84 85 ms
Zn 70 0.631	Zn 71 3.9 h	Zn 72 46.5 h	Zn 73 5.8 s	Zn 74 96 s	Zn 75 10.2 s	Zn 76 5.6 s	Zn 77 1.06 s	Zn 78 1.47 s	Zn 79 995 ms	Zn 80 517 ms	Zn 81 0.29 s	Zn 82 >300 ns	Zn 83 >300 ns
Cu 69 3.0 m	Cu 70 5.5 s	Cu 71 19.5 s	Cu 72 6.6 s	Cu 73 3.9 s	Cu 74 1.59 s	Cu 75 1.22 s	Cu 76 1.27 s	Cu 77 469 ms	Cu 78 342 ms	Cu 79 188 ns	Cu 80 >300 ns	Cu 81 0.1981 s	Cu 82 0.328 s
Ni 68 29 s	Ni 69 11.4 s	Ni 70 6.0 s	Ni 71 2.56 s	Ni 72 1.57 s	Ni 73 0.84 s	Ni 74 0.9 s	Ni 75 344 ms	Ni 76 238 ms	Ni 77 128 ms	Ni 78 110 ms	Ni 79 0.04871 s	Ni 80 0.1276 s	Ni 81 0.05504 s
Co 67 425 ms	Co 68 1.6 s	Co 69 227 ms	Co 70 0.50 s	Co 71 79 ms	Co 72 59 ms	Co 73 41 ms	Co 74 30 ms	Co 75 >300 ns	Co 76 4.78E-3 s	Co 77 8.49E-3 s	Co 78 0.02045 s	Co 79 0.02912 s	Co 80 0.02912 s
Fe 66 0.44 s	Fe 67 0.47 s	Fe 68 0.1 s	Fe 69 0.17 s	Fe 70 94 ms	Fe 71 >300 ns	Fe 72 >300 ns	Fe 73 1.00E-4 s	Fe 74 3.40E-4 s	Fe 75 8.30E-4 s	Fe 76 2.89E-4 s	Fe 77 7.01E-4 s	Fe 78 1.62E-3 s	Fe 79 1.62E-3 s

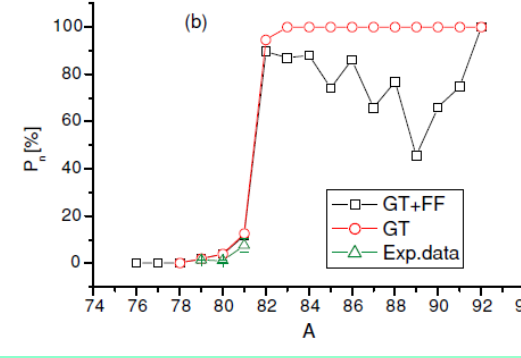
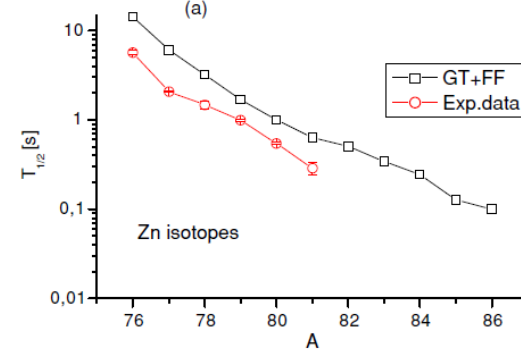
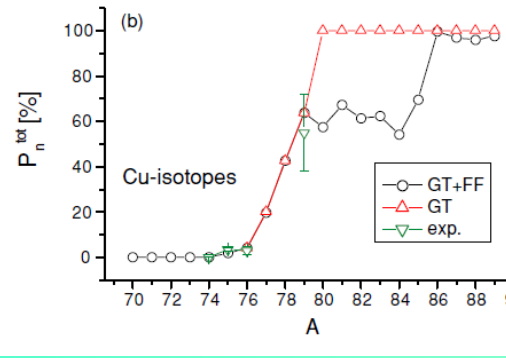
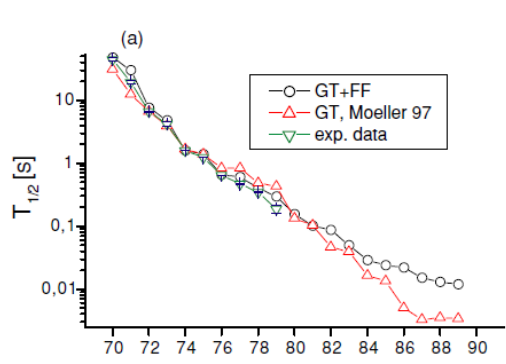
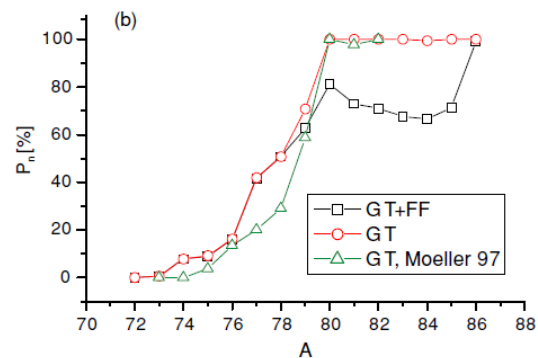
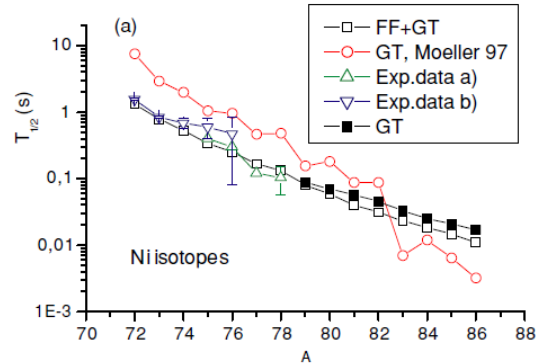
~ <sup>78</sup>Ni

## Motivation

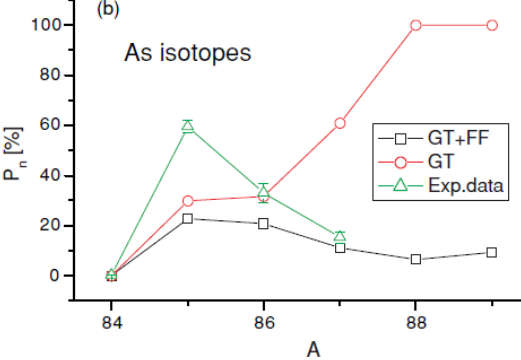
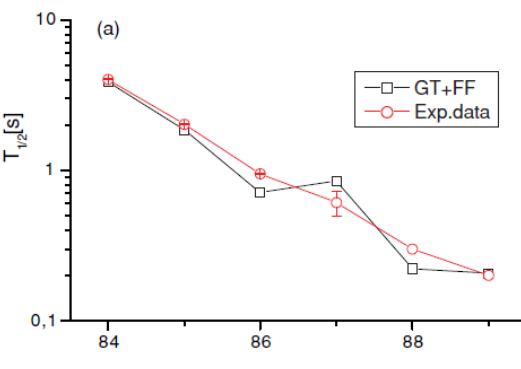
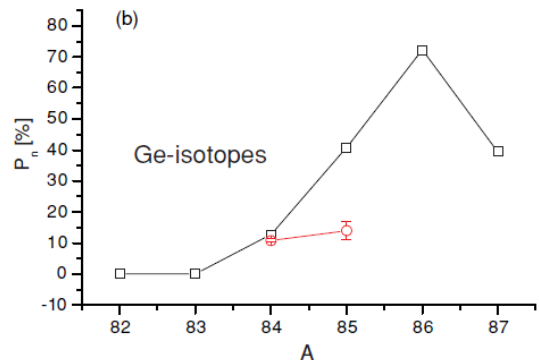
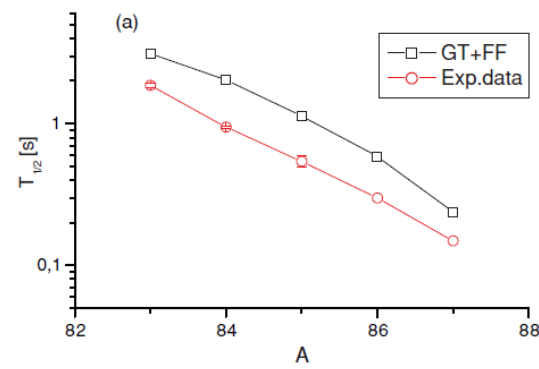
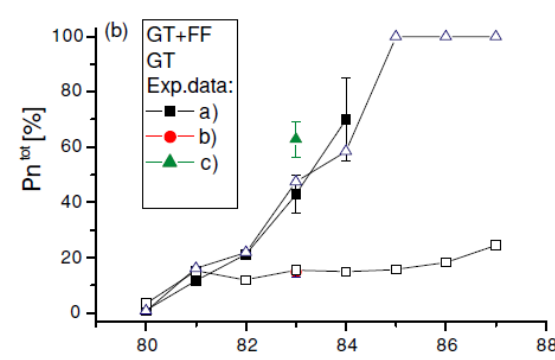
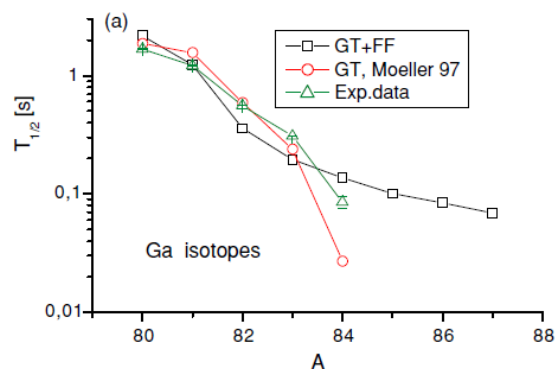
- GT-resonance is close to  $Q_{\beta}$  window
- Complementary to earlier studies using high resolution (Leuven group)

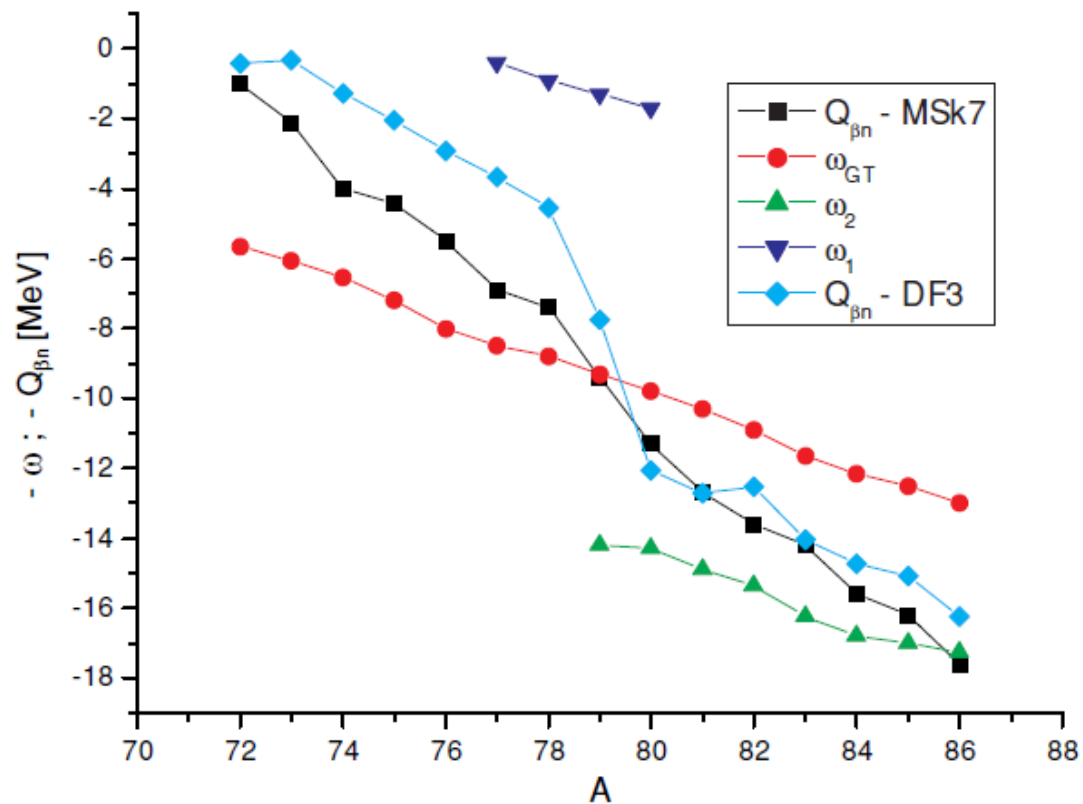






# I. Borzov, PR C71 (2005) 065801



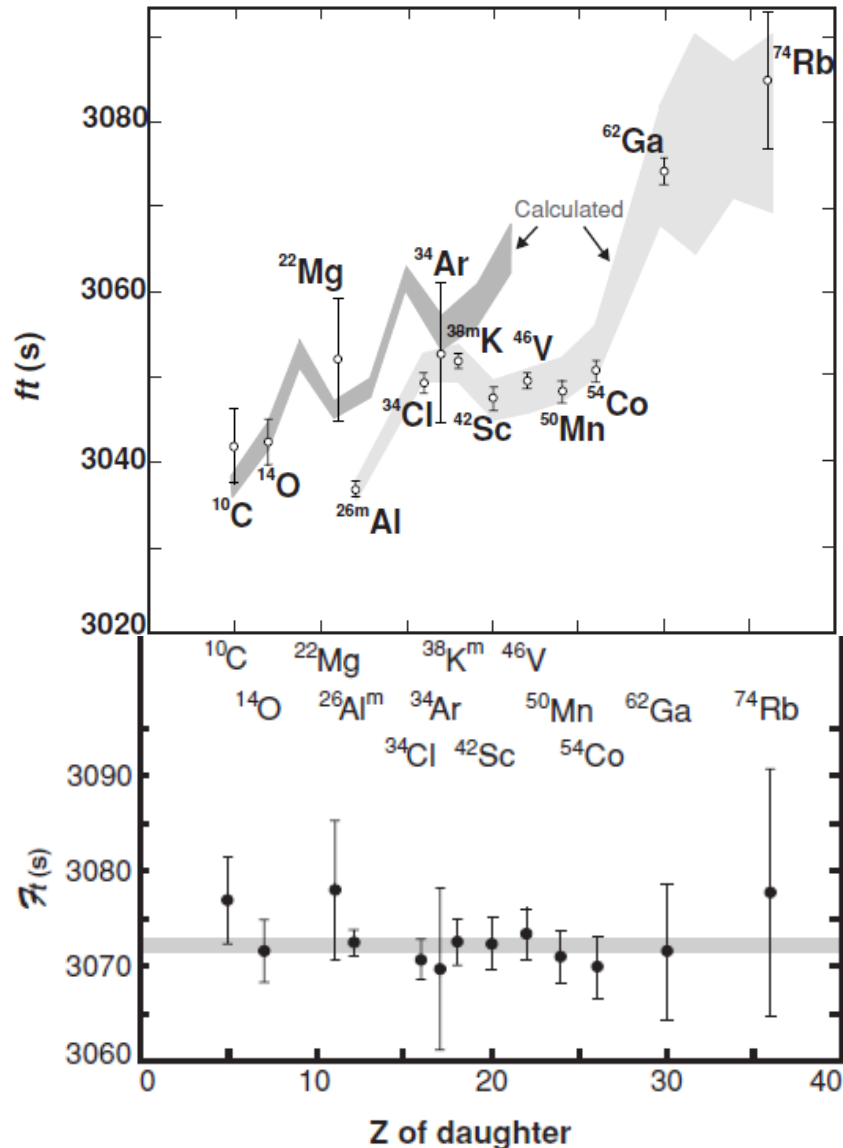


The reason for the behavior of  $P_n$  as a function of  $N$  is the appearance of low lying FF transition

- Direct check with  $4\pi$  neutron counter
- Measurement of  $\beta$ -strength below  $S_n$

# Test of the CVC hypothesis and unitarity of CKM matrix

Super-allowed  $0^+$  (g.s)  $\rightarrow$   $0^+$  (g.s)  $\beta$ -decay



$$ft = \frac{T_{1/2} \cdot f(Q_{EC})}{I_{\beta}}$$

$$Ft = ft(1 + \delta'_R)(1 - \delta_C + \delta_{NS})$$

$$= \frac{K}{g_V^2(1 + \Delta_R)\langle M_F \rangle^2}$$

Determine as accurately as possible  $I_{\beta}$  to the ground state.

## Hardy & Towner PRL88 (2001) 252501

Parent nucleus	$Q_{EC}$ (MeV)	Shell model	First $1^+$ state		No. of $1^+$ states <sup>c</sup>	Total GT branching (%) <sup>c</sup>
			Expt. (MeV)	Theo. (MeV)		
$^{46}\text{V}$	7.051	FPMI3	3.73	4.18	7	0.027
		KB3		2.34	10	0.020
$^{50}\text{Mn}$	7.632	FPMI3	3.63	3.91	16	0.013
		KB3		3.54	35	0.019
$^{54}\text{Co}$	8.243	FPMI3	(3.84) <sup>a</sup>	4.20	23	0.006
		KB3		4.17	75	0.024
$^{62}\text{Ga}$	9.171	MSDI	(3.16) <sup>a</sup>	2.48	110	0.28
$^{66}\text{As}$	9.57 <sup>b</sup>	MSDI	(3.24) <sup>a</sup>	2.27	255	0.67
$^{70}\text{Br}$	9.97 <sup>b</sup>	MSDI	(3.14) <sup>a</sup>	2.71	325	1.59
$^{74}\text{Rb}$	10.418	MSDI	(3.2) <sup>b</sup>	2.69	180	0.72
		MSDI'		2.76	>400	0.92

Problem for the heavier  
N=Z odd-odd nuclei:  
 $^{62}\text{Ga}$ ,  $^{66}\text{As}$ ,  $^{70}\text{Br}$ , ...,  $^{94}\text{Ag}$

**Weak high-lying  
strength**  
☞ **Pandemonium  
effect**

**Use of TAS to detect high  
lying weak GT branches**

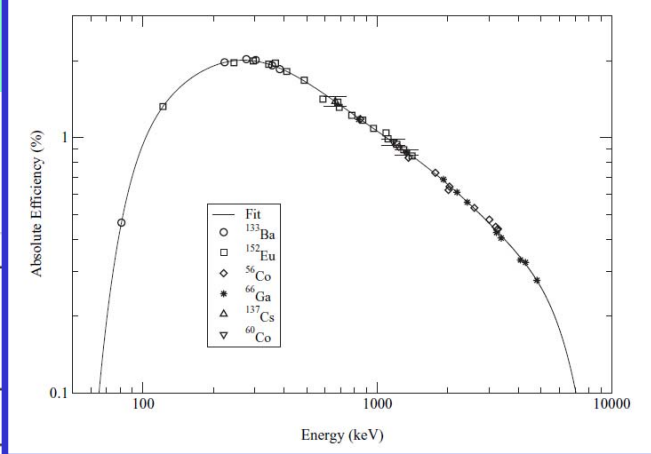
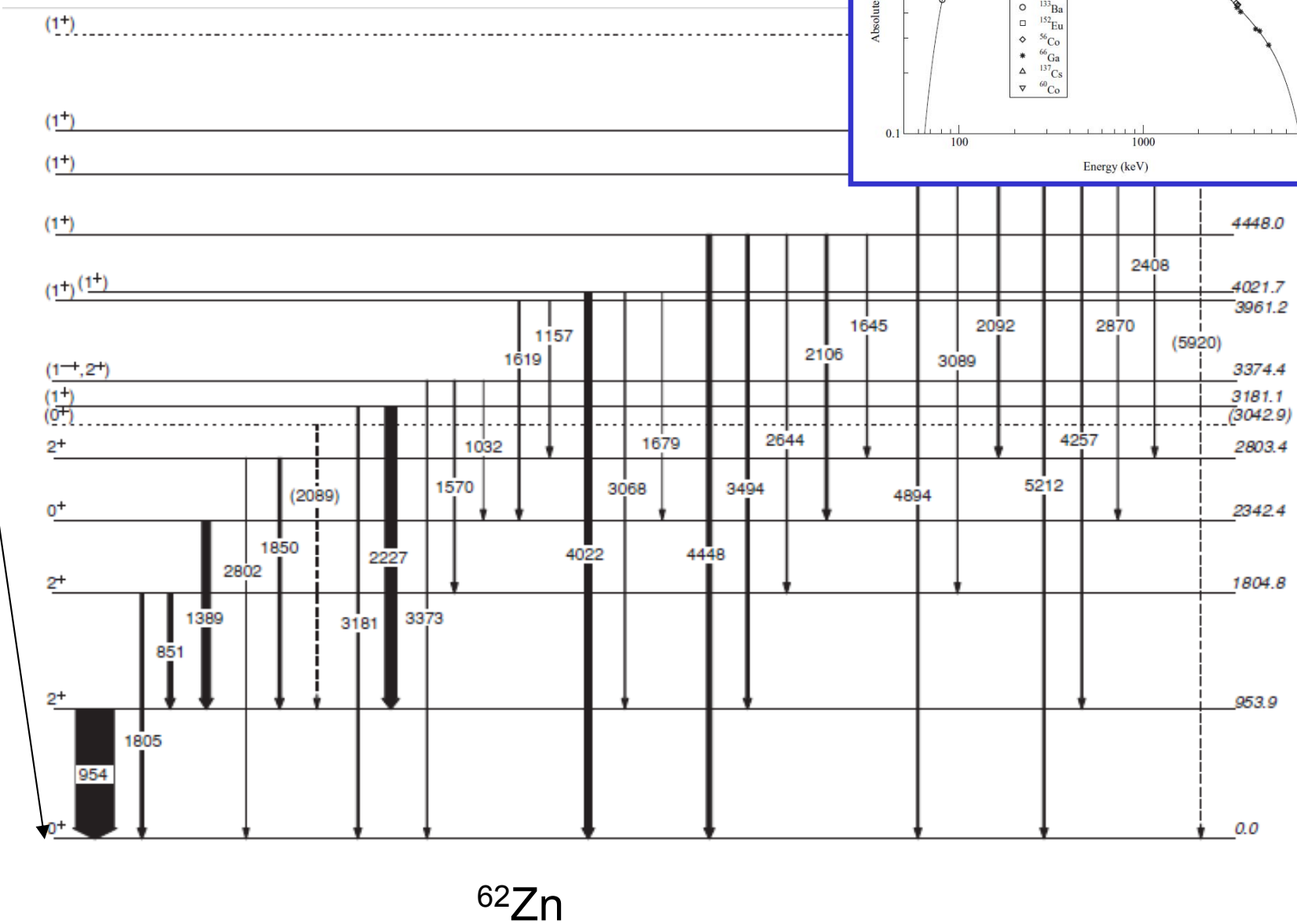
**Precision <  $10^{-3}$  !**



# The $^{62}\text{Ga}$ case: $Q_{\text{EC}} = 9.181 \text{ MeV}$ , $T_{1/2} = 116.12 \text{ ms}$

$0^+ \text{ } ^{62}\text{Ga}$

99.858%



Finlay et al, PR C78 (2008) 025502  
 Bey et al., EPJ A36 (2008) 121

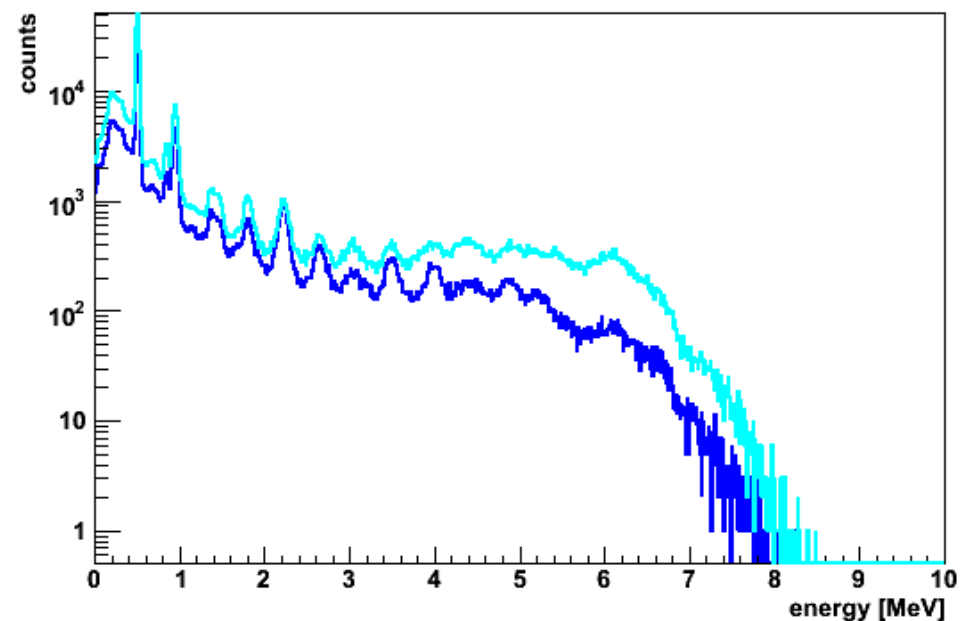
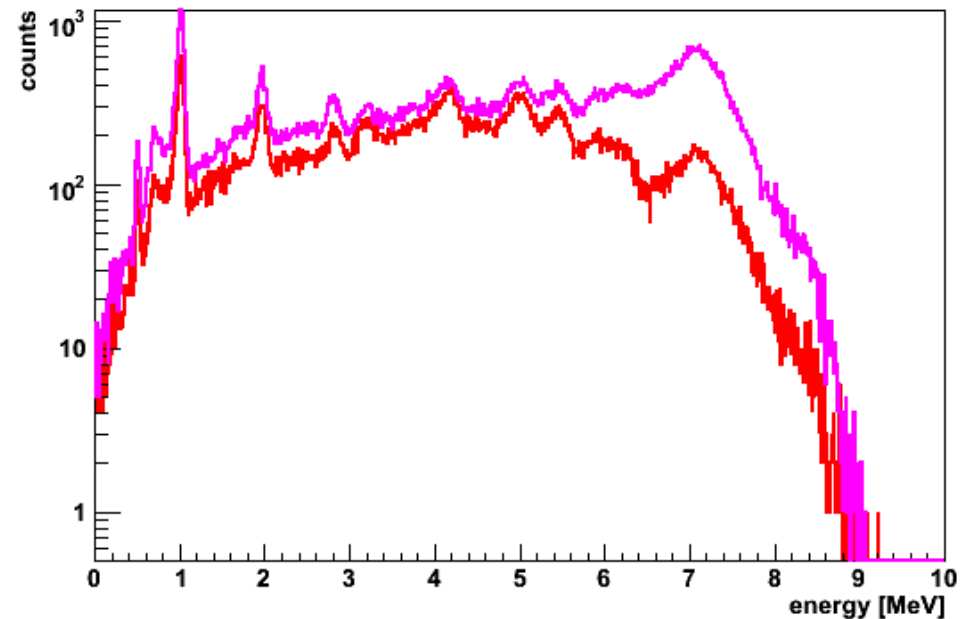
$I_{\beta}^{\text{seen}} = 0.1338\%$  ,  $I_{\beta}^{\text{unseen}} = 0.0082\%$

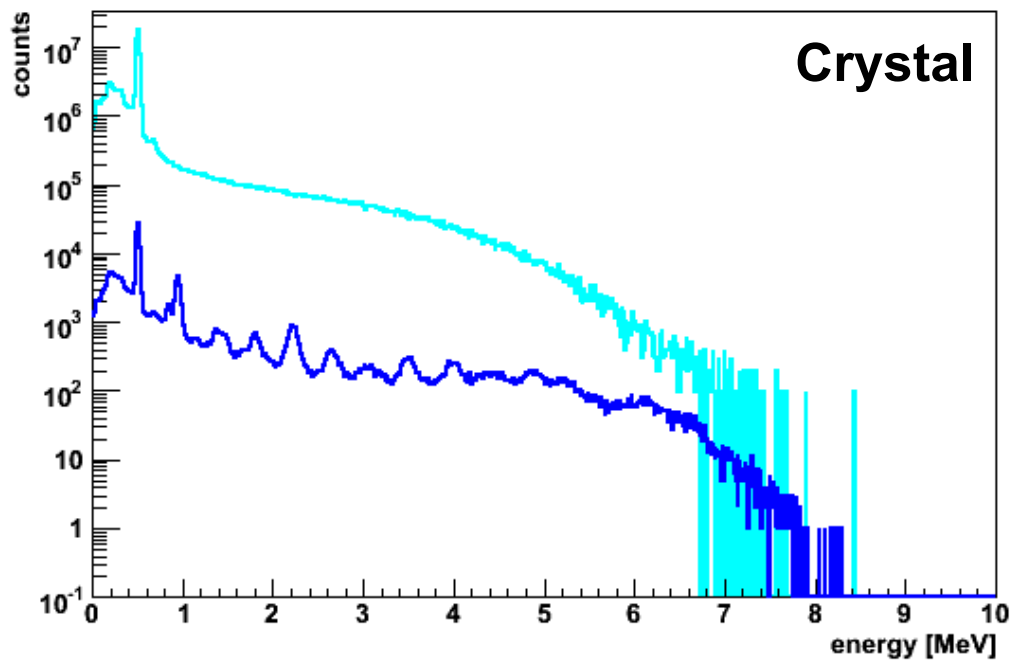
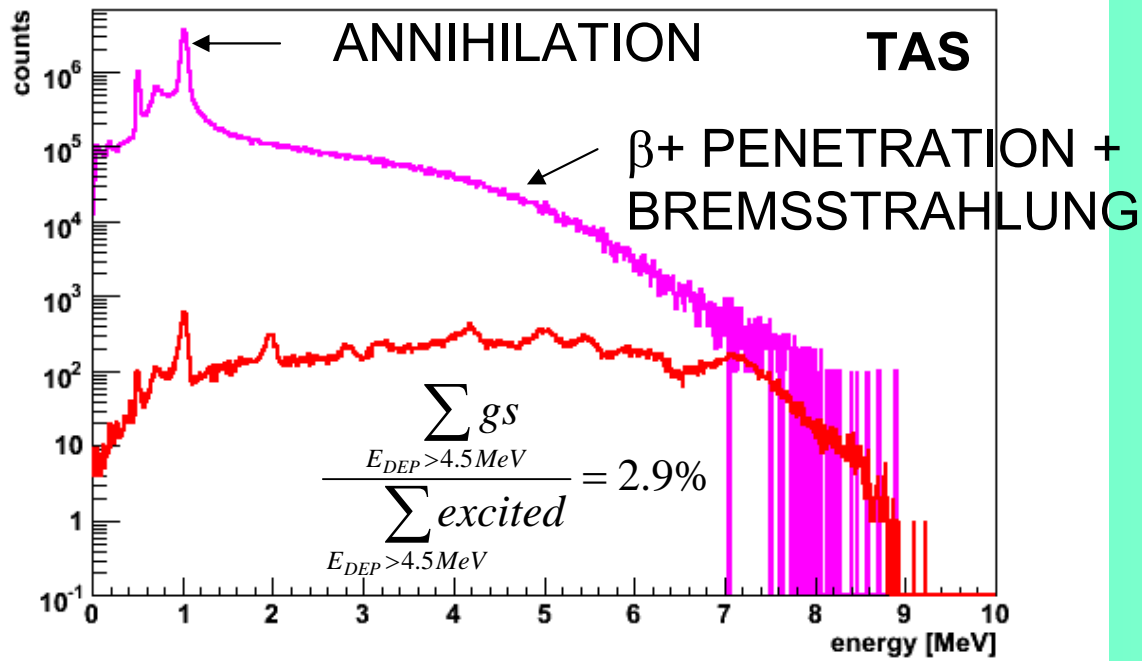
Statistical model has been used to simulate realistic cascades:

- All known levels up to 2.803 MeV
- MC levels 2.9-9.18 MeV
- 1+ levels below 5.25 MeV from Finlay et al included
- 117 1+ levels, total (J<10) 1777 levels.
- Intensity to the 6 1+ levels below 5.25 MeV according to Finlay
- the rest (404 ppm) to the higher lying levels (intensity decrease with Fermi function, Porter-Thomas fluctuations)
- E1, M1 and E2 strength from RIPL-2 global parameterization

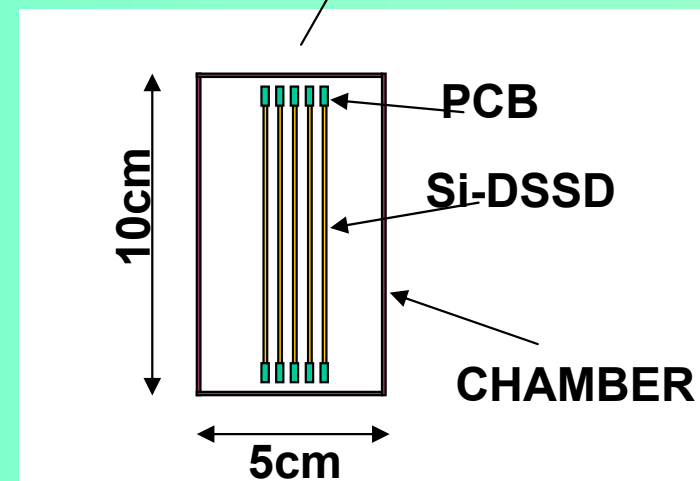
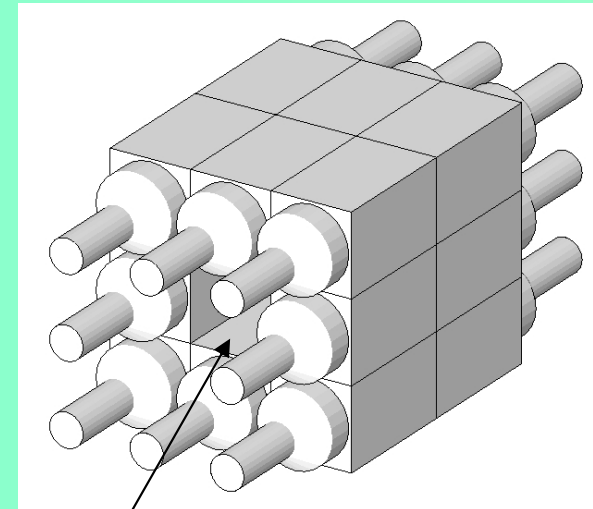
**Sensitivity to high lying strength:**

- 1784 ppm to the high lying states

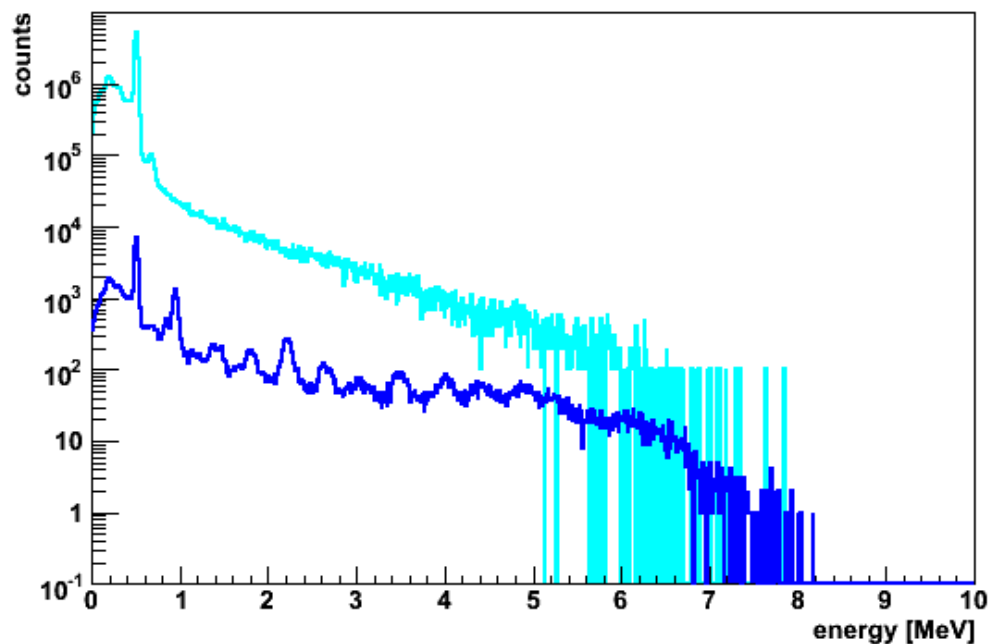
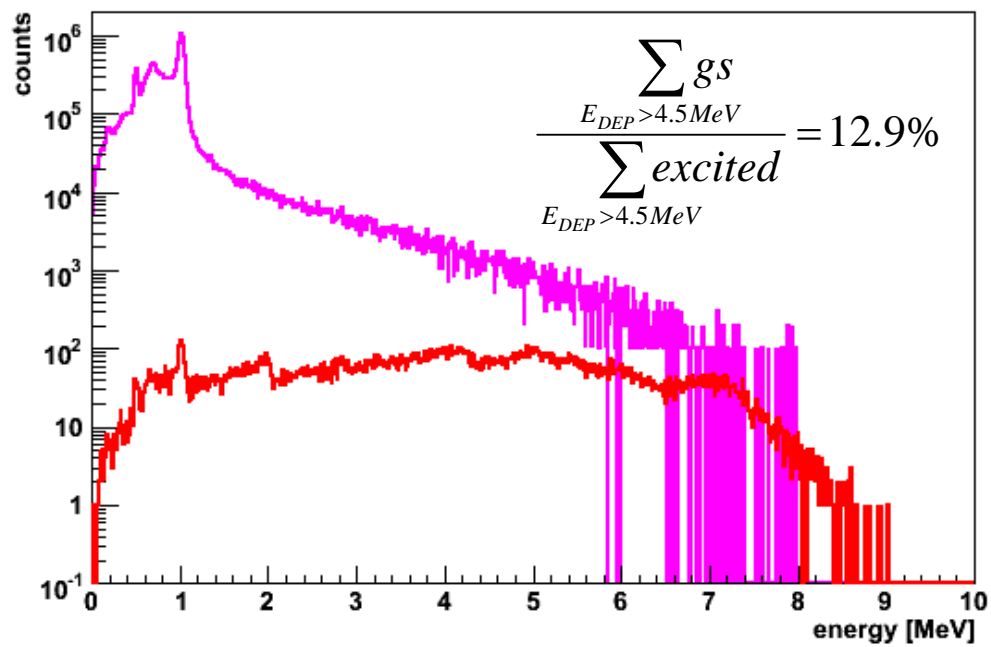




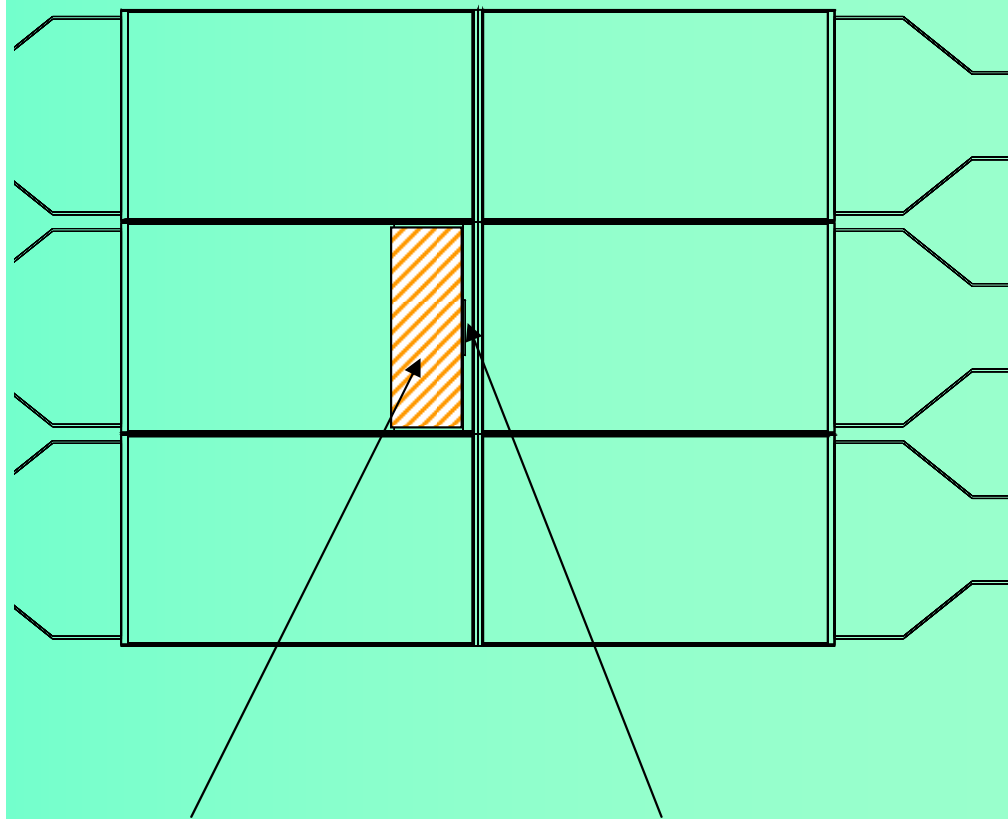
**Penetration + Bremsstrahlung must be reduced !**



**IMPLANTATION DETECTOR**



**Simple solution: beta detector backed by a low-Z absorber**



**PE absorber       $\beta$ -detector ( $\epsilon \sim 30\%$ )**

**Try: segmented  $\beta$ -detector to veto corresponding crystal signal**



## **Conclusions:**

- 1. Measurements on the regions of  $^{78}\text{Ni}$ ,  $^{100}\text{Sn}$ ,  $^{132}\text{Sn}$ , heavy super-allowed (?) and neutron-rich mid shells (Z: 28-50, 50-82) are amenable to TAS measurements**
- 2. Purest beams (Penning-trap, laser-ionization, HRS,...) would guarantee the accuracy of the results**
- 3. Intensities of  $\sim 10$  pps (1 pps?) are sufficient for accurate results (not higher than  $\sim 10^4$ )**

THE END