β-Strength Measurements of Exotic Nuclei with Total Absorption Gamma-Ray Spectroscopy

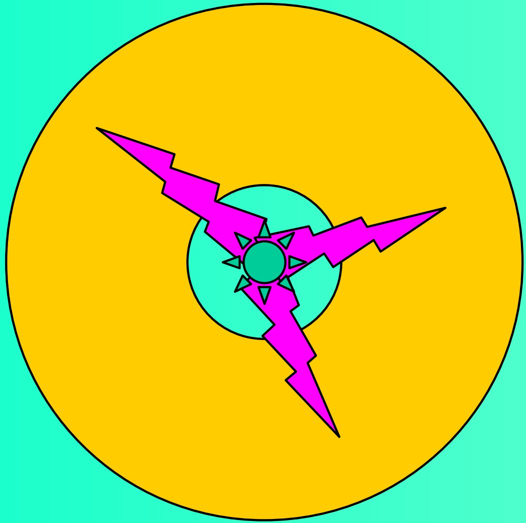
A. Algora, B. Rubio and J.L. Tain

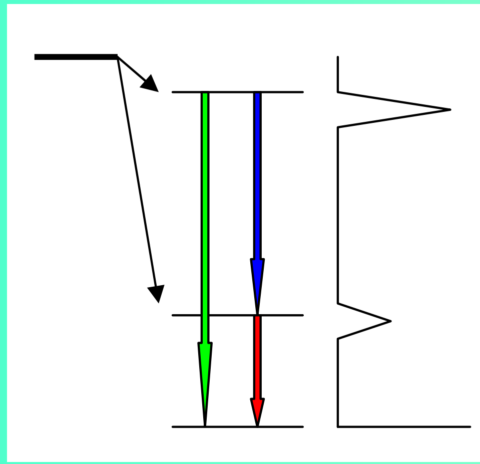
- Reminder of the TAGS technique
- Something about possible spectrometers
- Some physics cases

Jose L. Tain @ IFIC-Valencia

DESIR Meeting, Leuven, 26-28 May, 2010

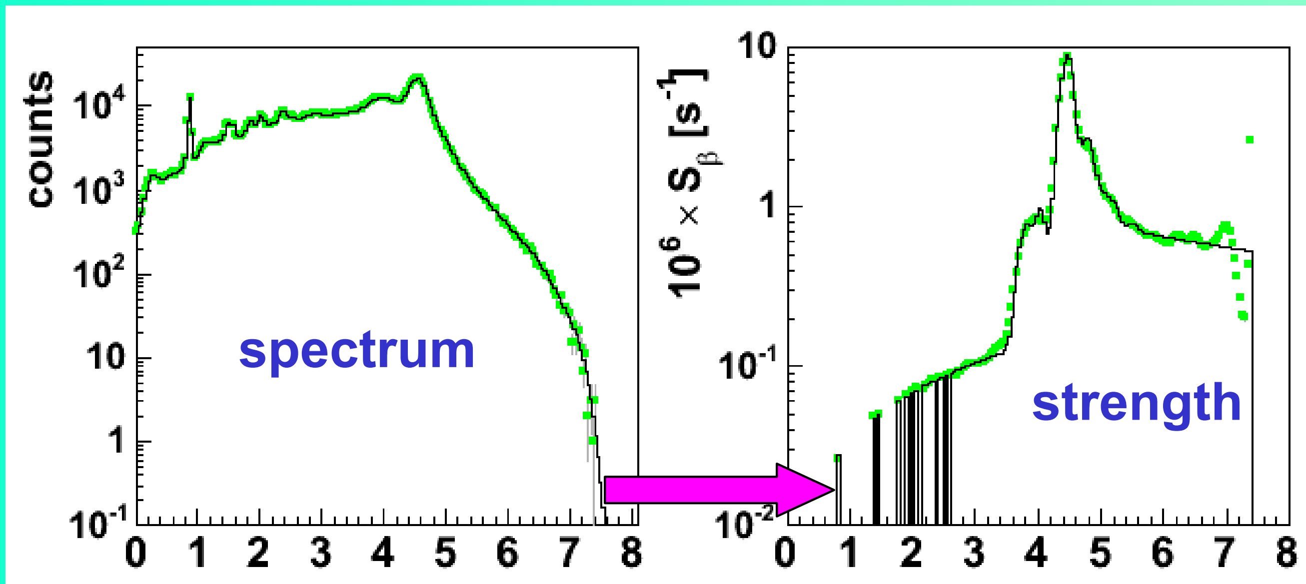
TAGS uses **large 4π scintillation detectors**, aiming **to detect the full γ-ray cascade** rather than individual γ-rays





An ideal TAS would give directly the β-intensity I_β

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



Deconvolution with spectrometer response to decay

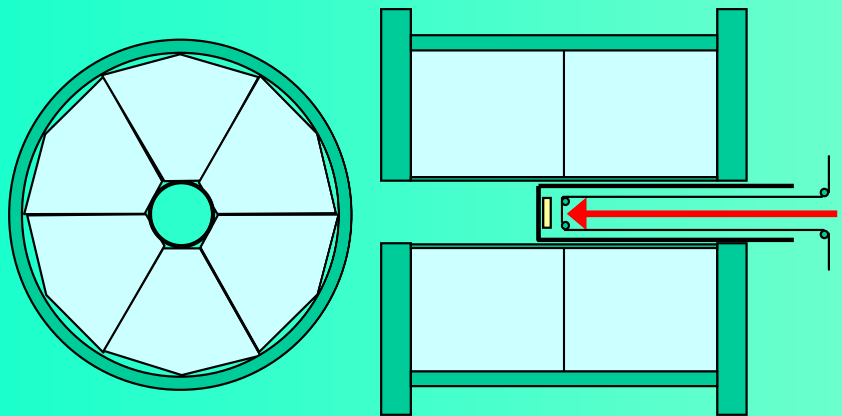
$$\mathbf{f} = "\mathbf{R}^{-1} \cdot \mathbf{d}"$$

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

Response from MC simulations and nuclear statistical model

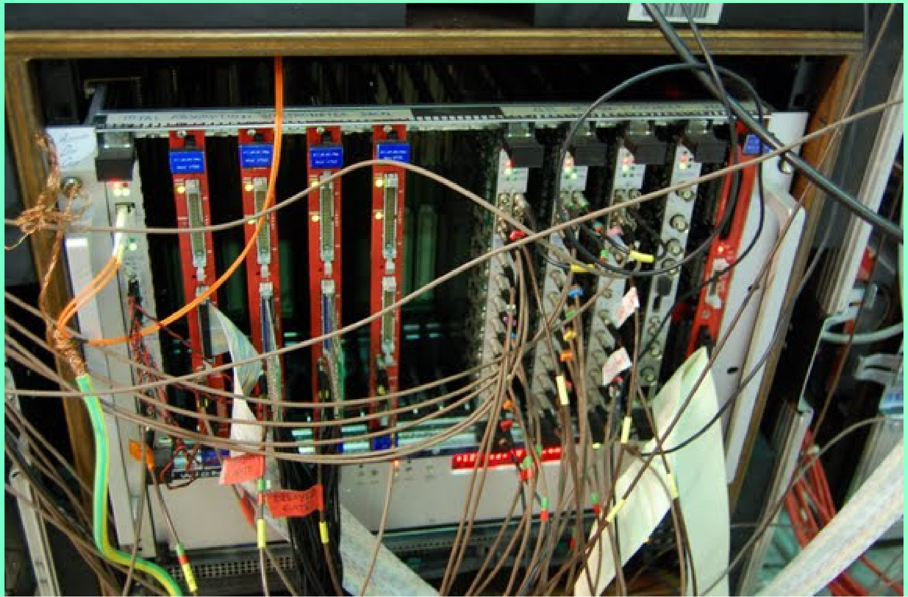
☞ **Clean sources & minimum of statistics**

New segmented 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)

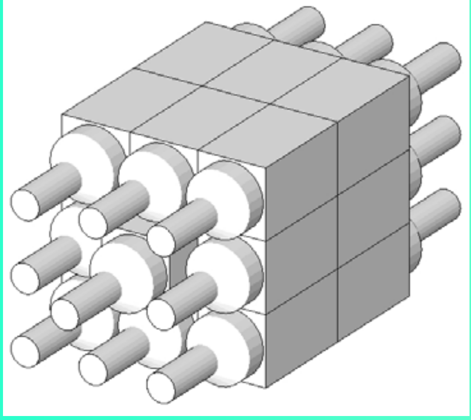


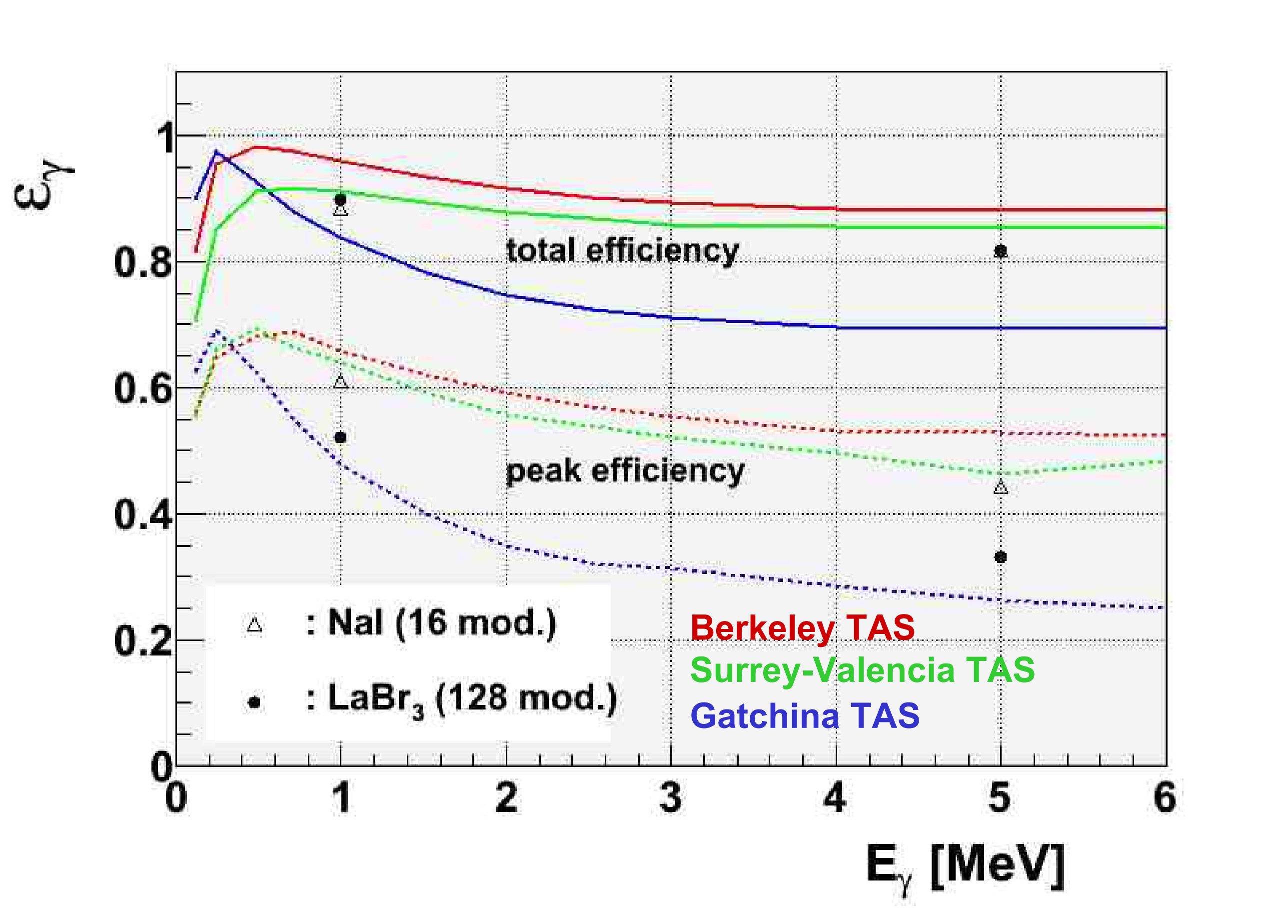
A Total Absorption Spectrometer for DESPEC

Design choices

16 + 1 modules:
15×15×25 cm³ **NaI(Tl)**
+ 5” PMT (50% light col.)
V= 95 L, M= 351 kg

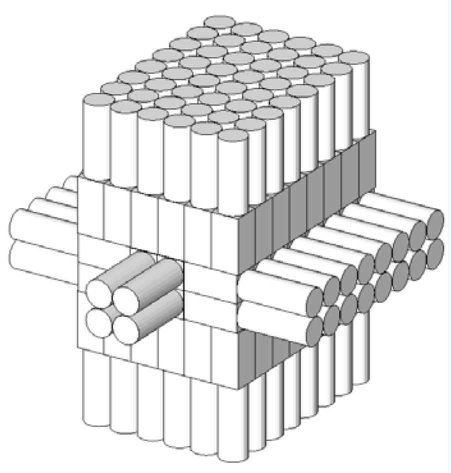
ΔE/E ~ 5%
(@1.3MeV)
Δt ~ 2 ns
τ ~ 230ns





128 + 4 modules:
5.5×5.5×11 cm³ **$LaBr_3$:Ce**
+ 2” PMT (60% light col.)
V= 44 L, M= 223 kg

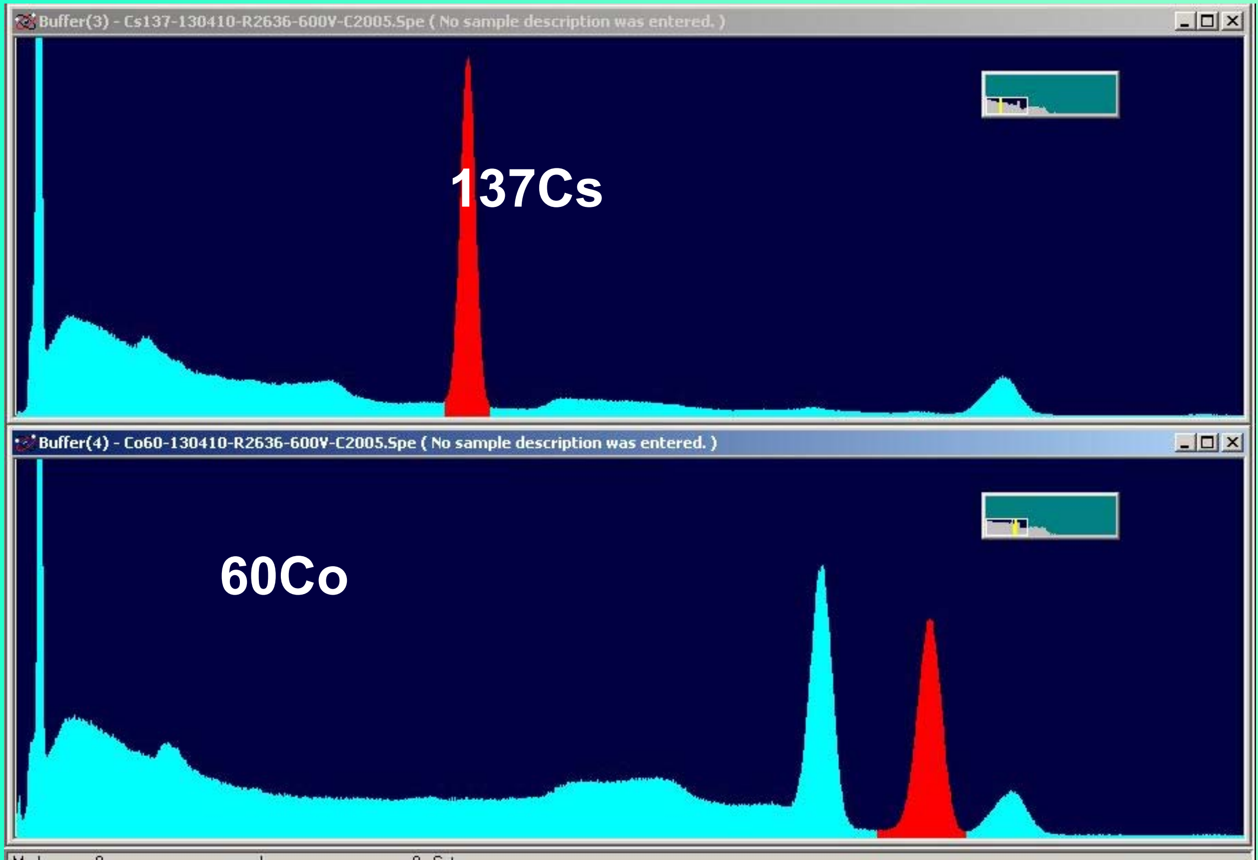
ΔE/E ~ 2%?
(@1.3MeV)
Δt ≤1 ns
τ ~ 26/160ns



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

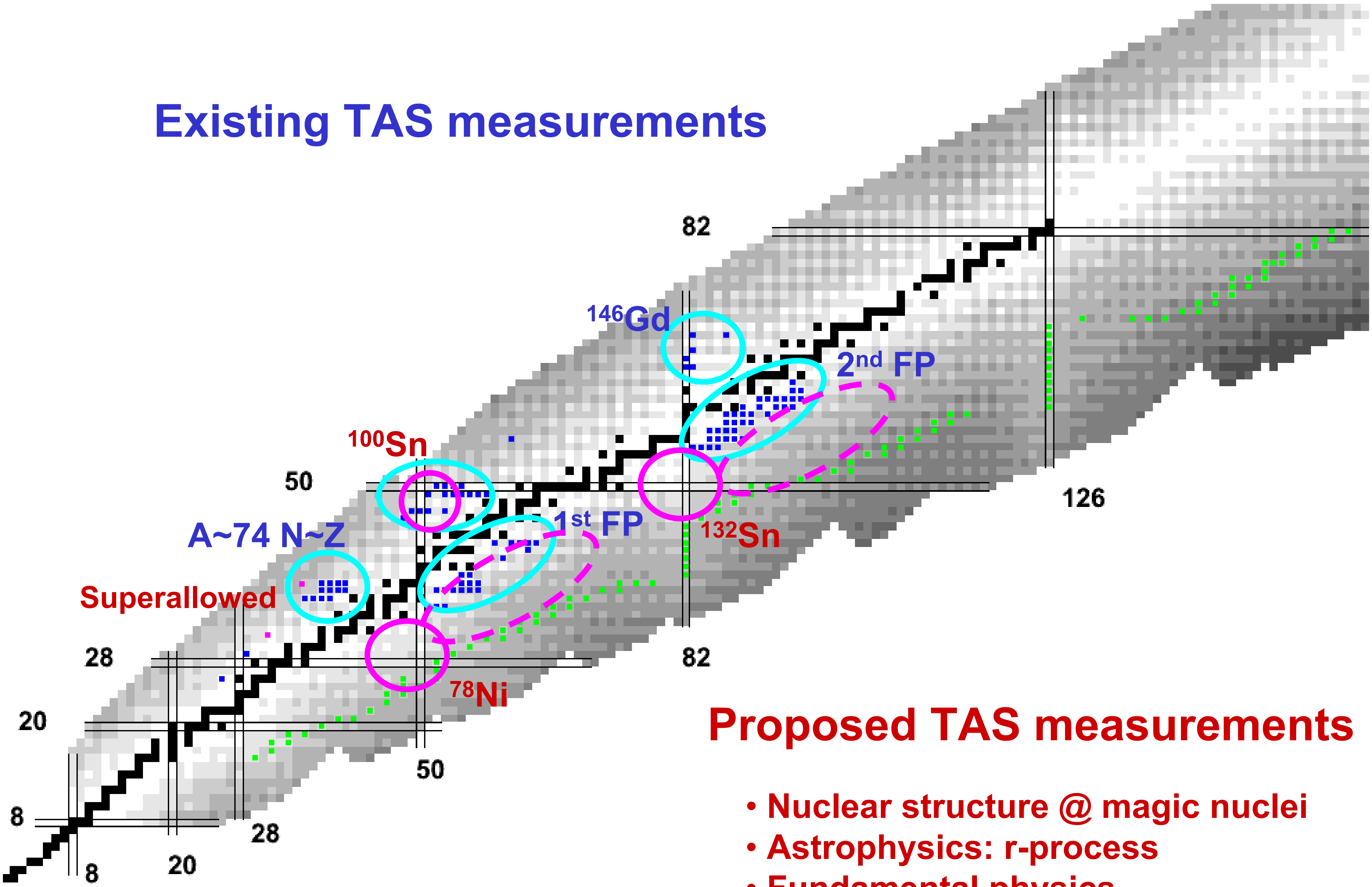


R = 3.6 %

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

TAS Studies in the ^{100}Sn region

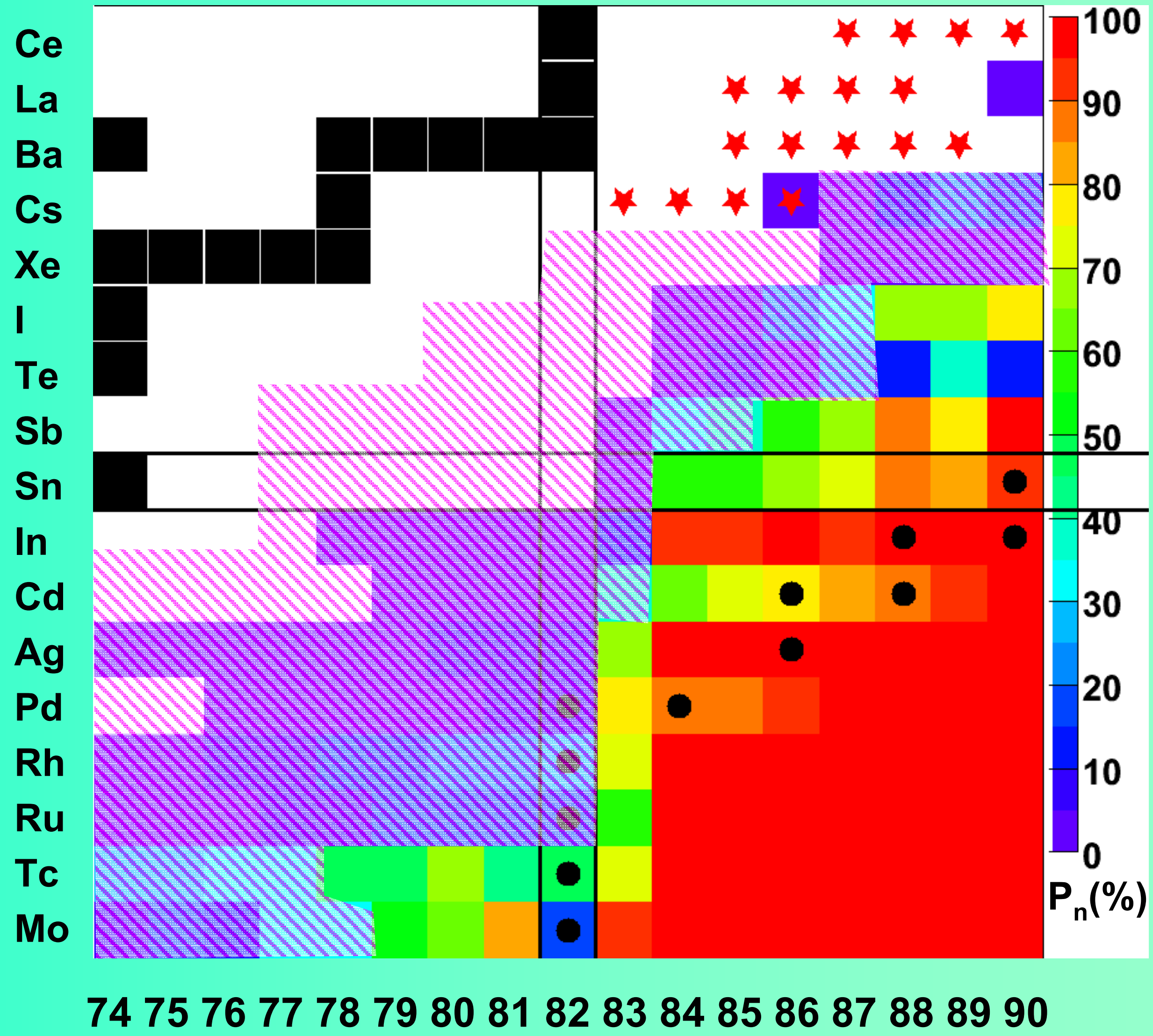
Studies performed earlier at GSI On-line Mass-Separator

Studies still to be done

Motivation:

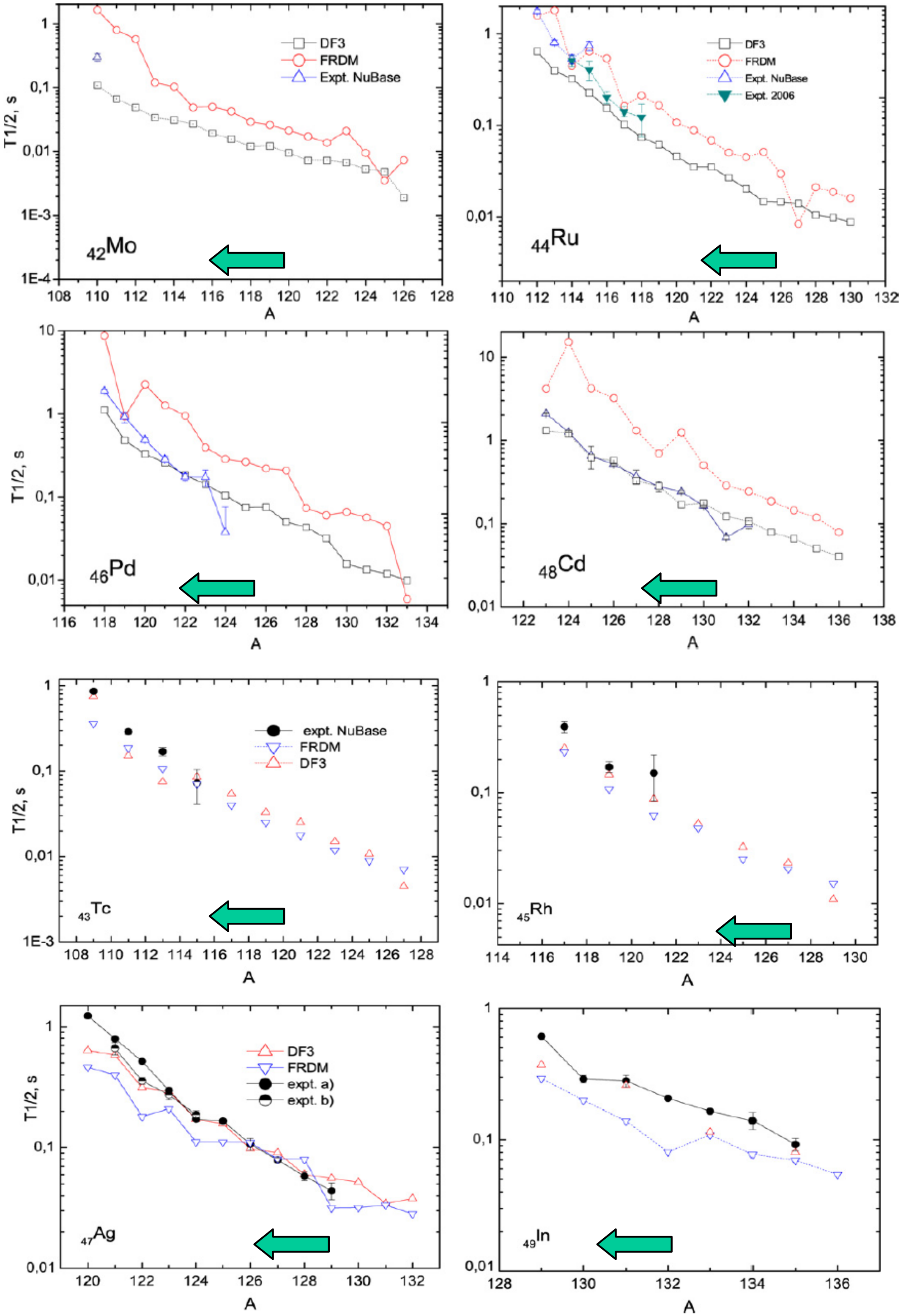
- One of the few regions where the GT+ resonance ($\pi g_{9/2} \rightarrow \nu g_{7/2}$) lies within the Q_{EC} window
- Allows the study of the quenching of the GT strength

~ ^{132}Sn



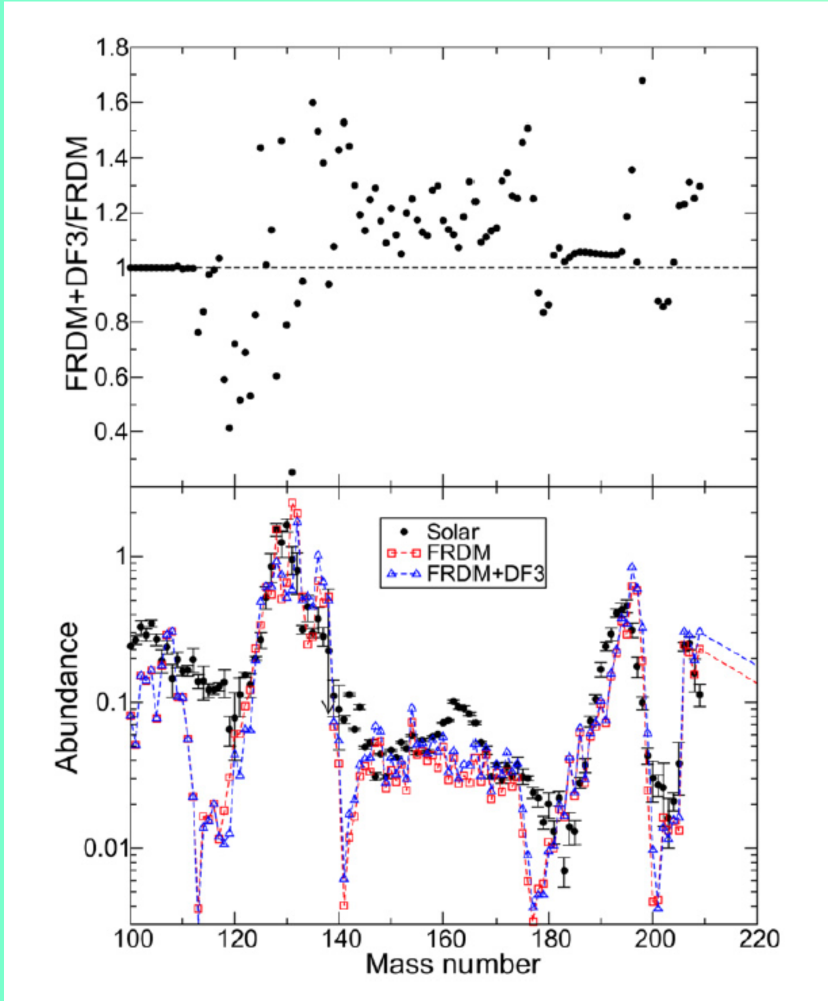
When looking to neutron rich nuclei one must consider the beta-delayed neutron emission:

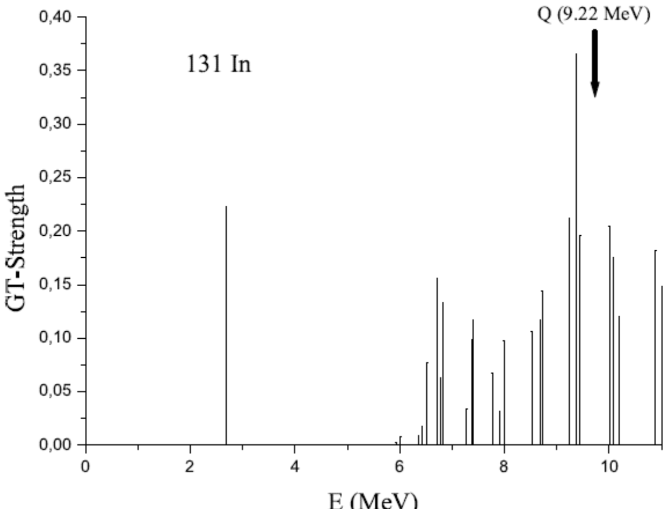
- which “removes” strength from TAS observation
- which introduces contamination from final nucleus γ-rays and from neutron interactions

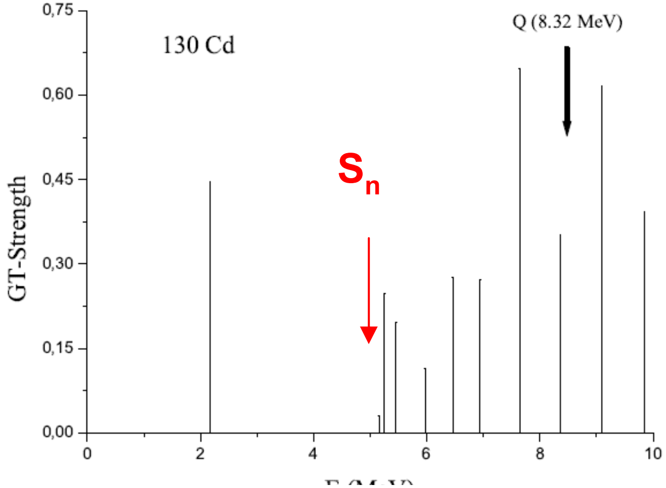


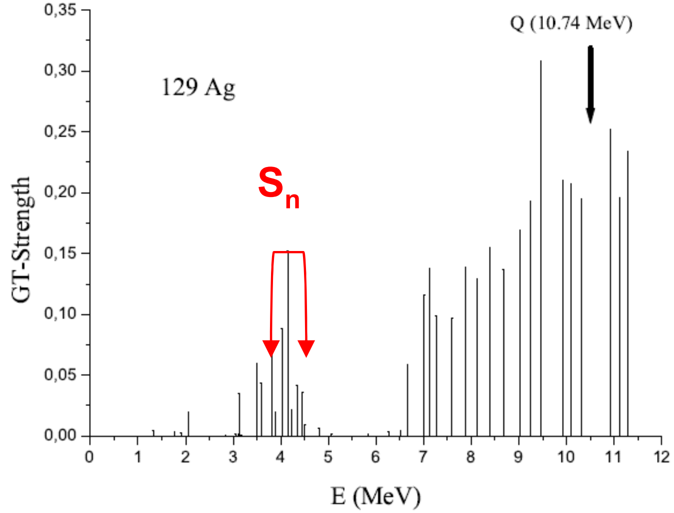
β-strength calculations of Z<50 nuclei close to N=82

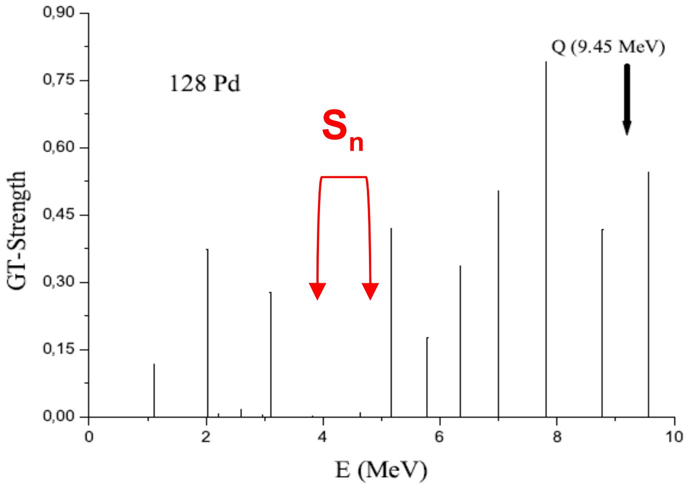
Borzov et al., NP A814 (2008) 159

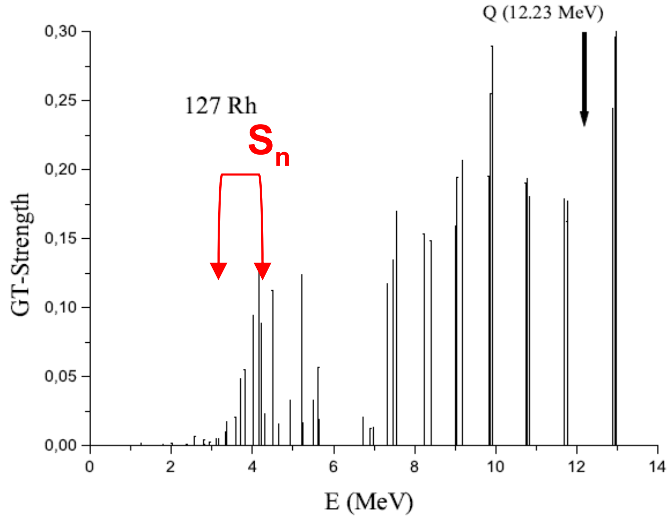


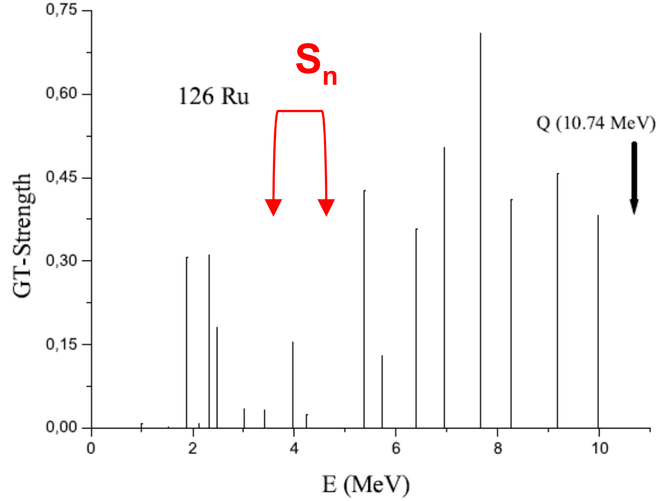


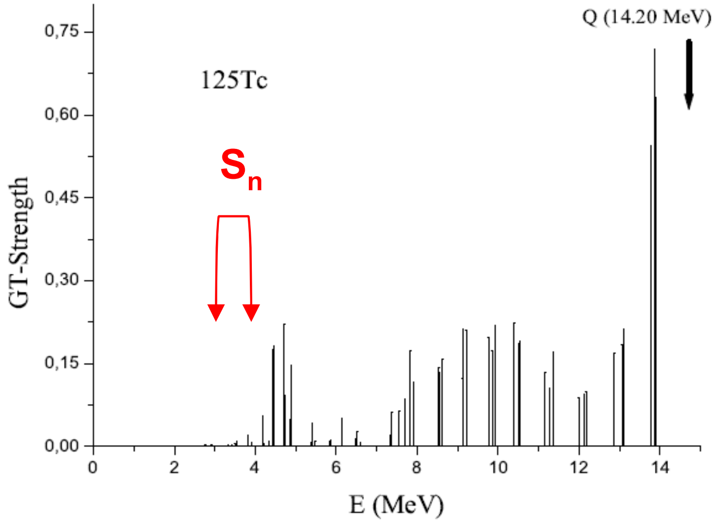


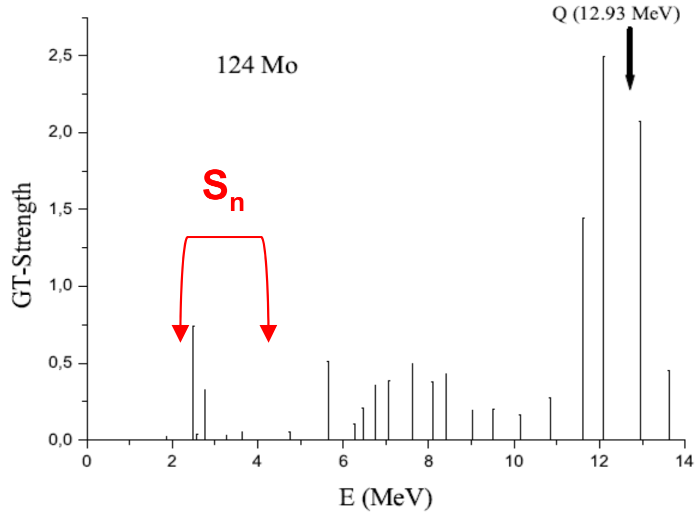






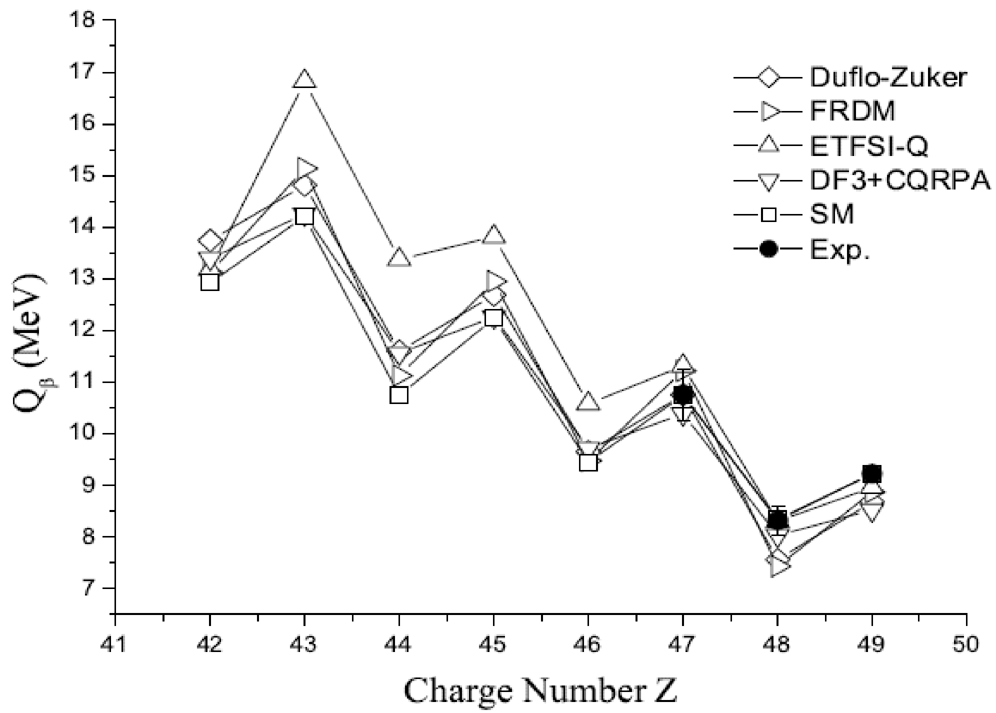


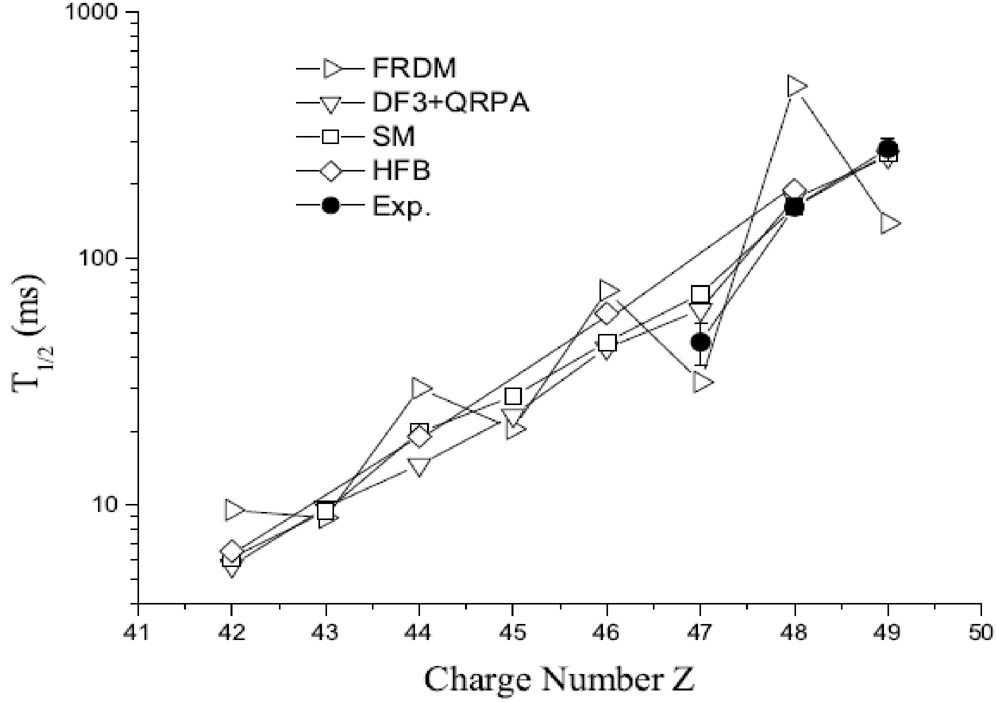


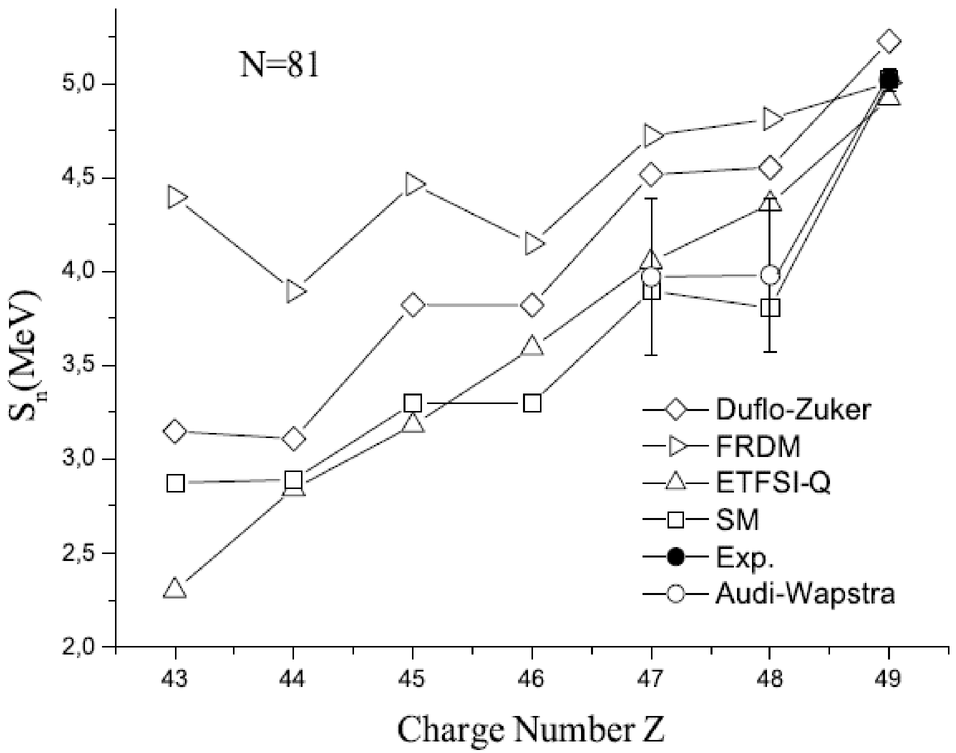


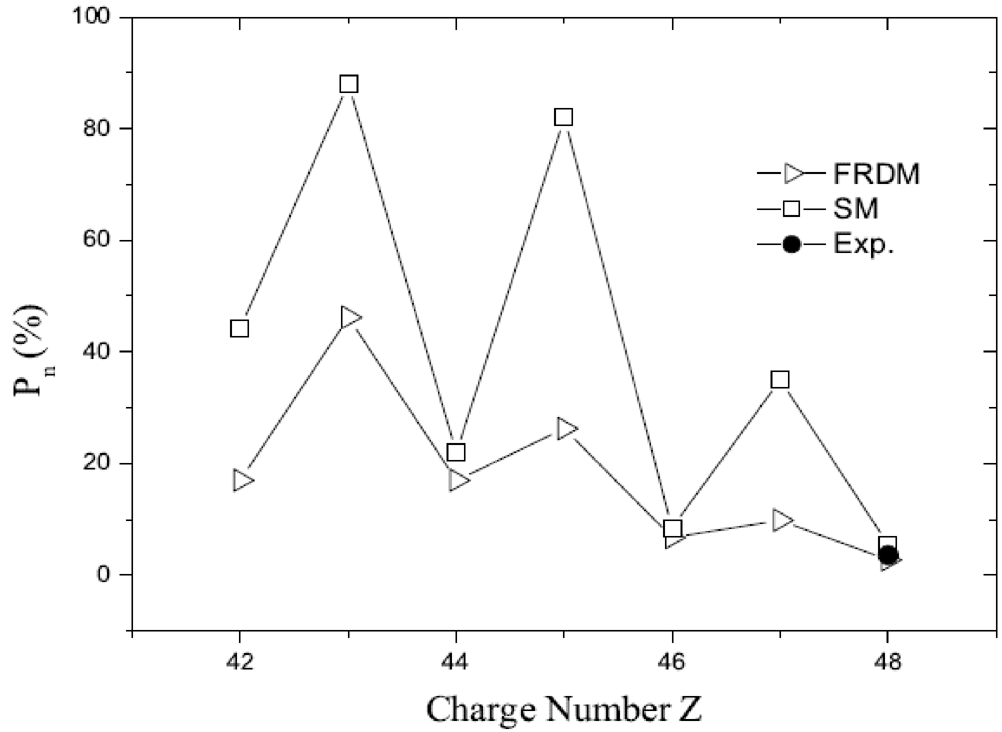
Shell Model Calculations N=82:

Cuenca-Garcia et al. EPJA 34 (2007) 99


Q_β (MeV)
Charge Number Z
Duflo-Zuker
FRDM
ETFSI-Q
DF3+CQRPA
SM
Exp.


$T_{1/2}$ (ms)
Charge Number Z
FRDM
DF3+QRPA
SM
HFB
Exp.


N=81
S_n(MeV)
Charge Number Z
Duflo-Zuker
FRDM
ETFSI-Q
SM
Exp.
Audi-Wapstra

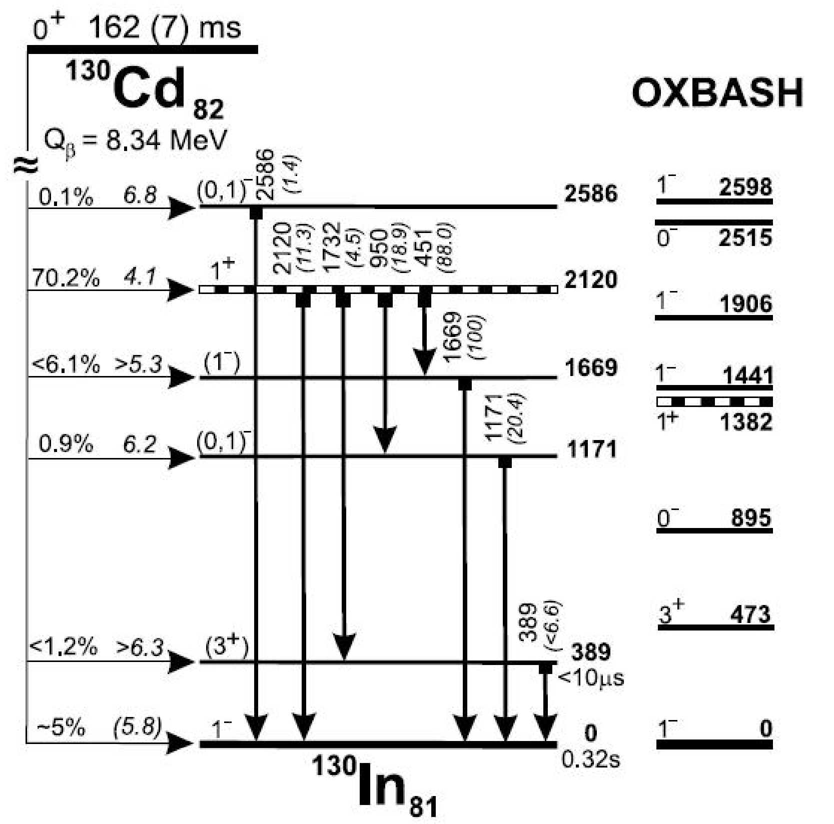

P_n (%)
Charge Number Z
FRDM
SM
Exp.

The ^{130}Cd decay case:

Present experimental information:

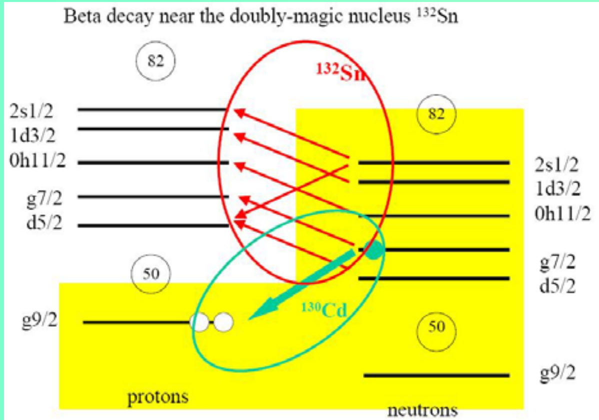
Dillmann et al. PRL 91 (2003) 162503

Q_β= 8.34 MeV, S_n=5.02 MeV, $T_{1/2}$=162 ms



+ 7 additional high lying levels with 3.5% intensity

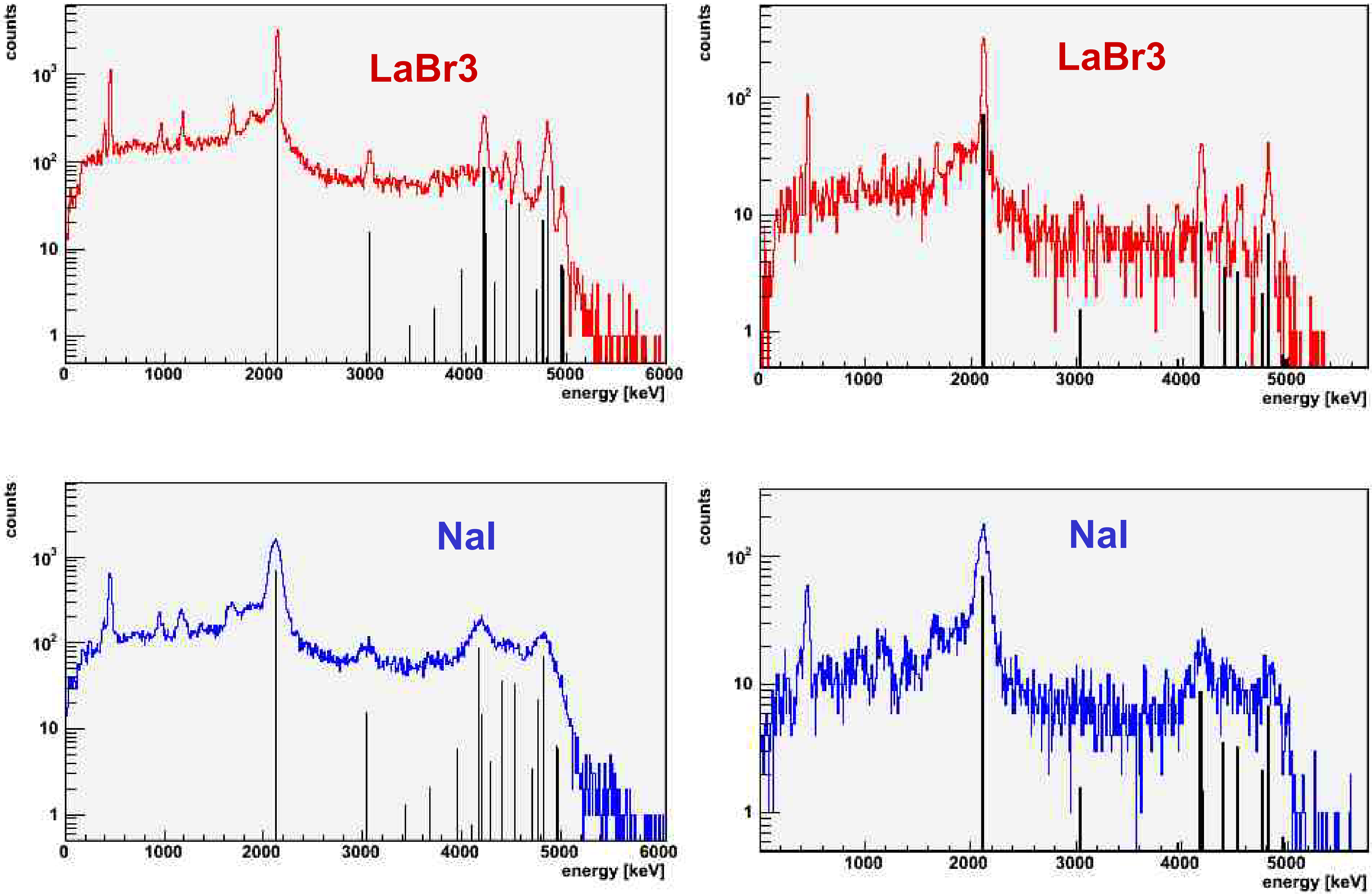
Total I_β = 90 % (including high lying 3.5%, P_n=3.6% and I_{gs}=5% from theory)



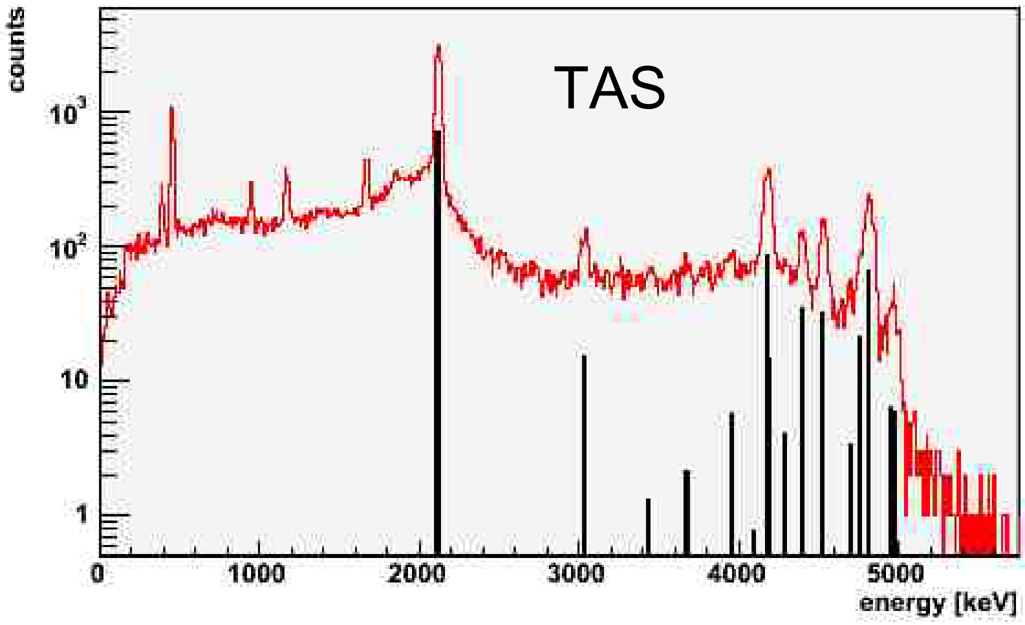
Statistical model has been used to simulate realistic cascades:

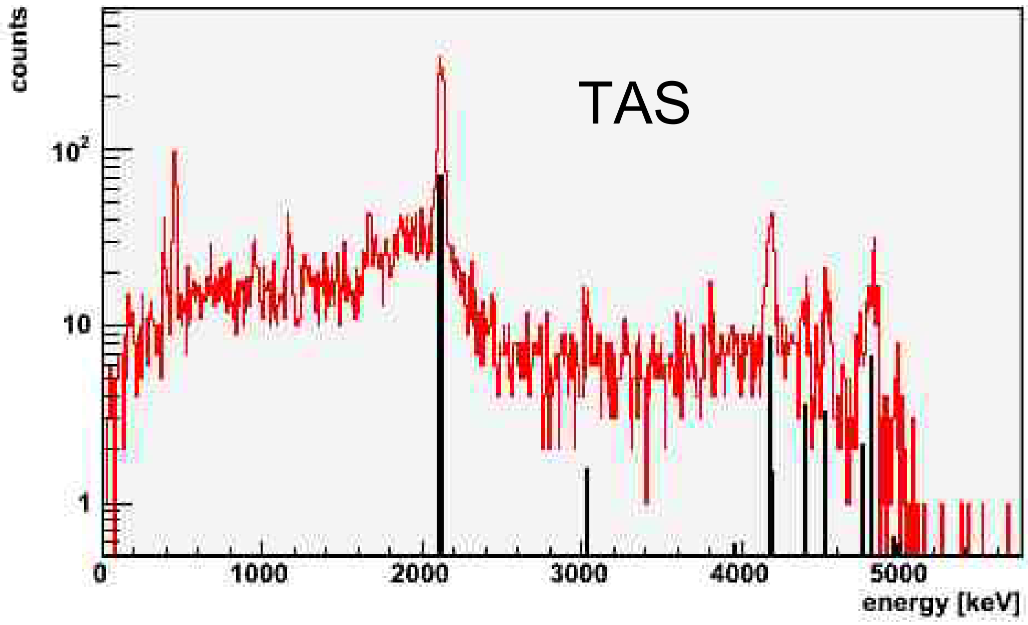
- Known levels: up to 2.12 MeV (ignore other Jπ)
- MC levels 2.12-5.03 MeV:
  1+: 15 lev. , Total (J<10) 425 lev.
- 70% intensity to the 2.12 MeV 1+
- 30% intensity to the 15 higher 1+ levels (intensity decrease with Fermi function, Porter-Thomas fluctuations)
- E1, M1 and E2 strength from RIPL-2 global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

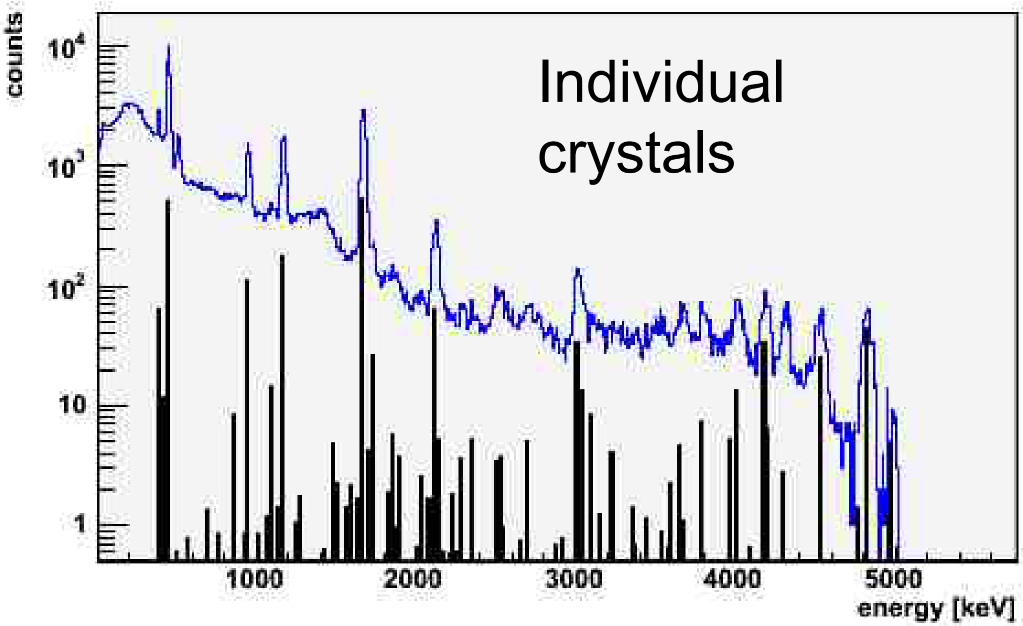
10^5 decays 10^4 decays

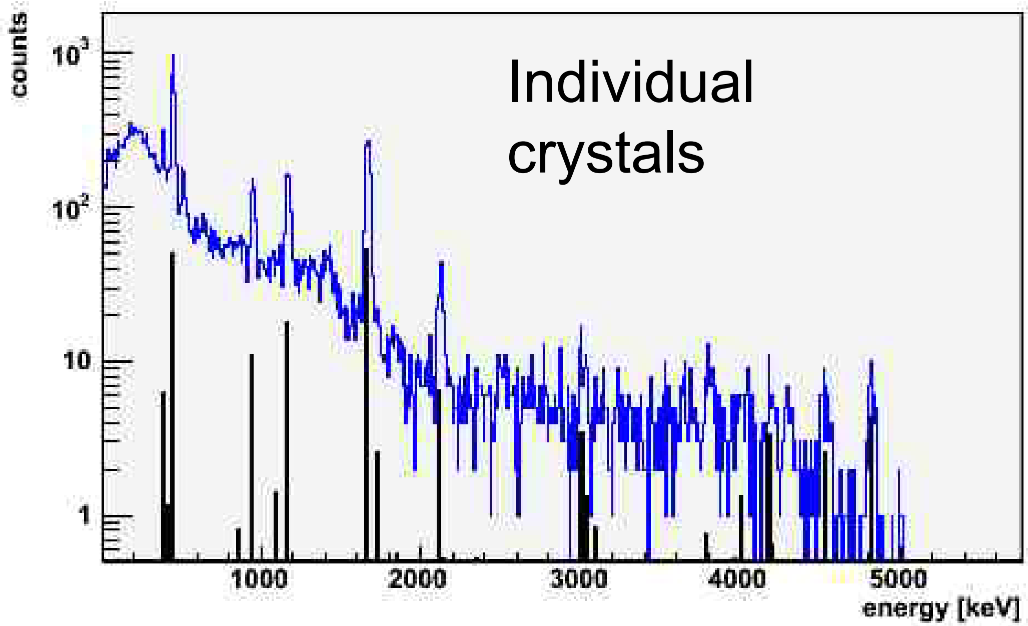


10^5 decays **LaBr3** 10^4 decays

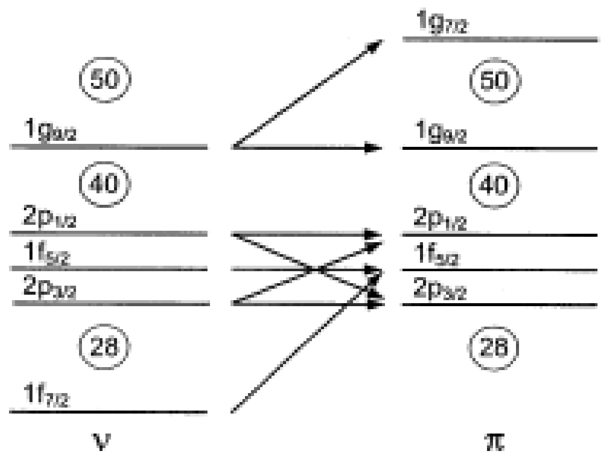






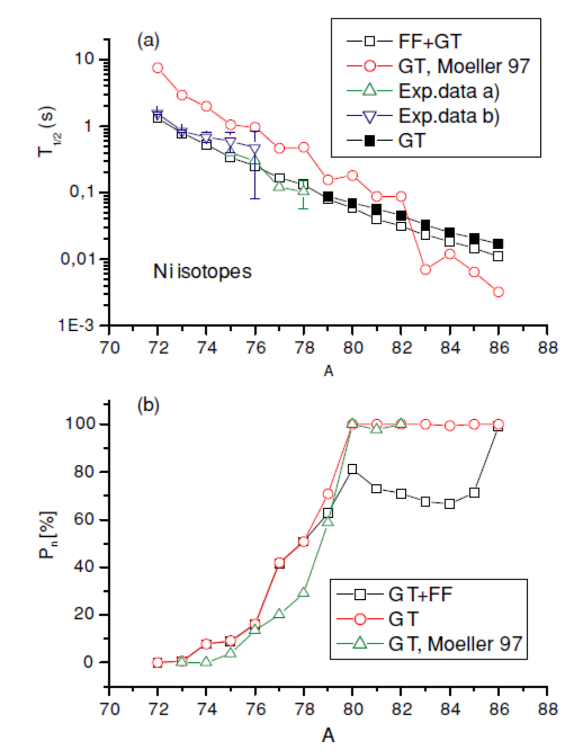


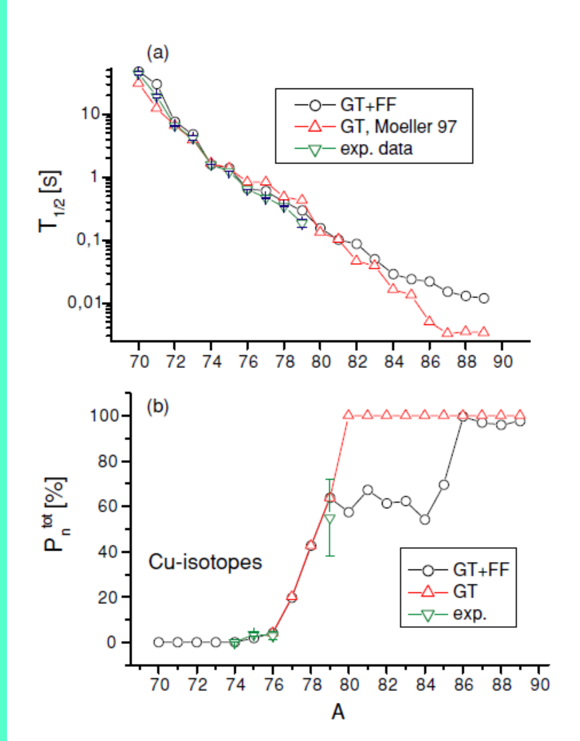
~ ^{78}Ni

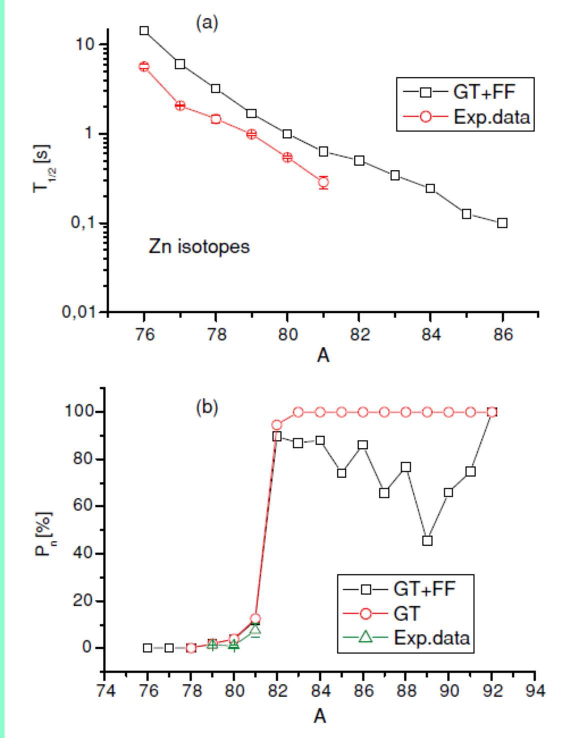


Motivation

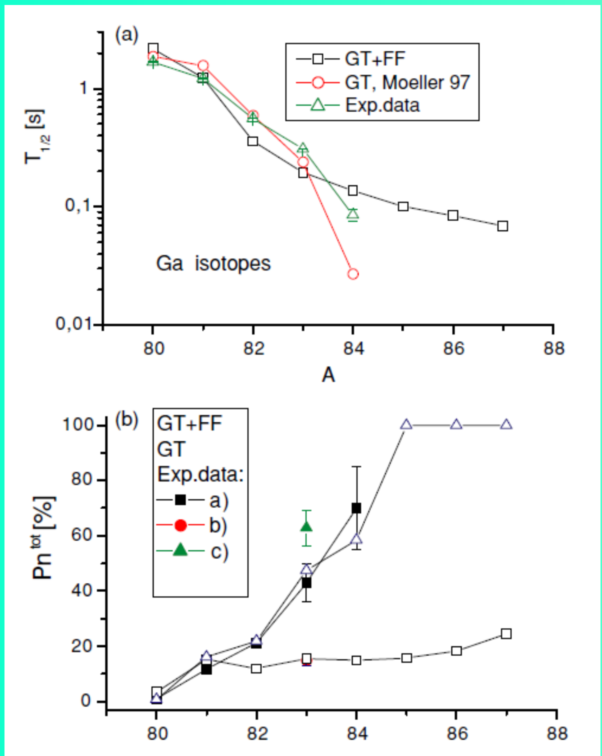
- GT- resonance is close to Q_β window
- Complementary to earlier studies using high resolution (Leuven group)

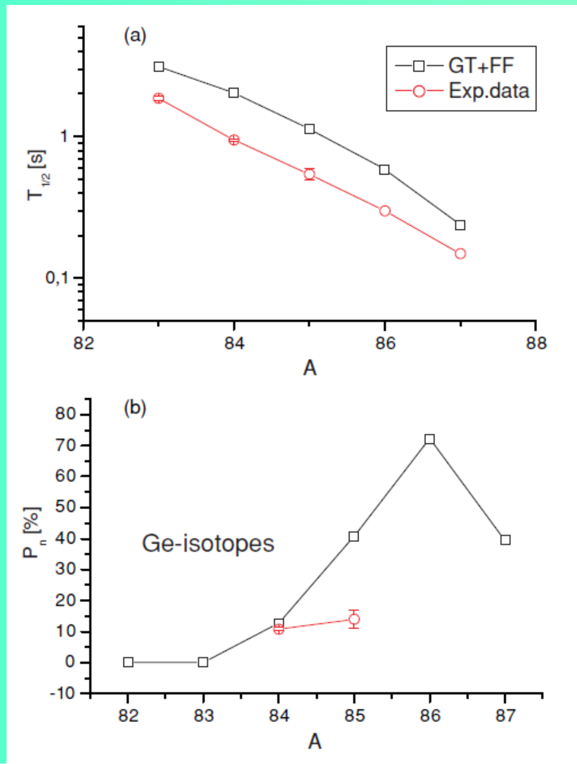


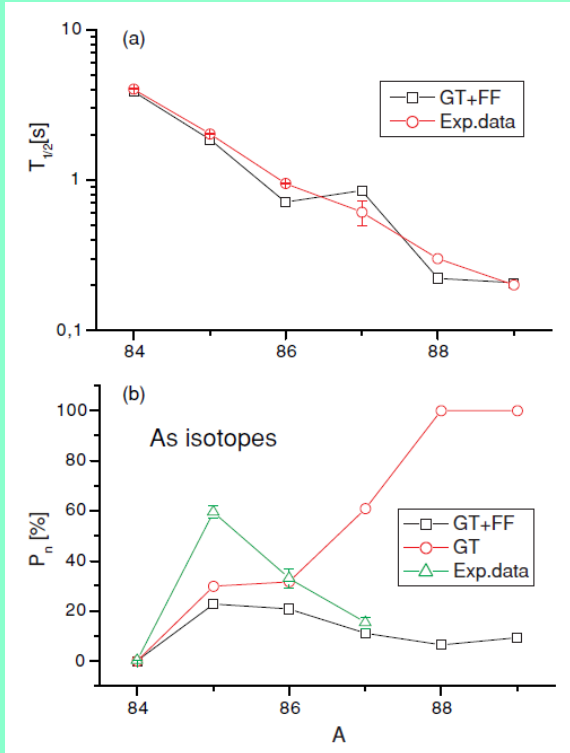


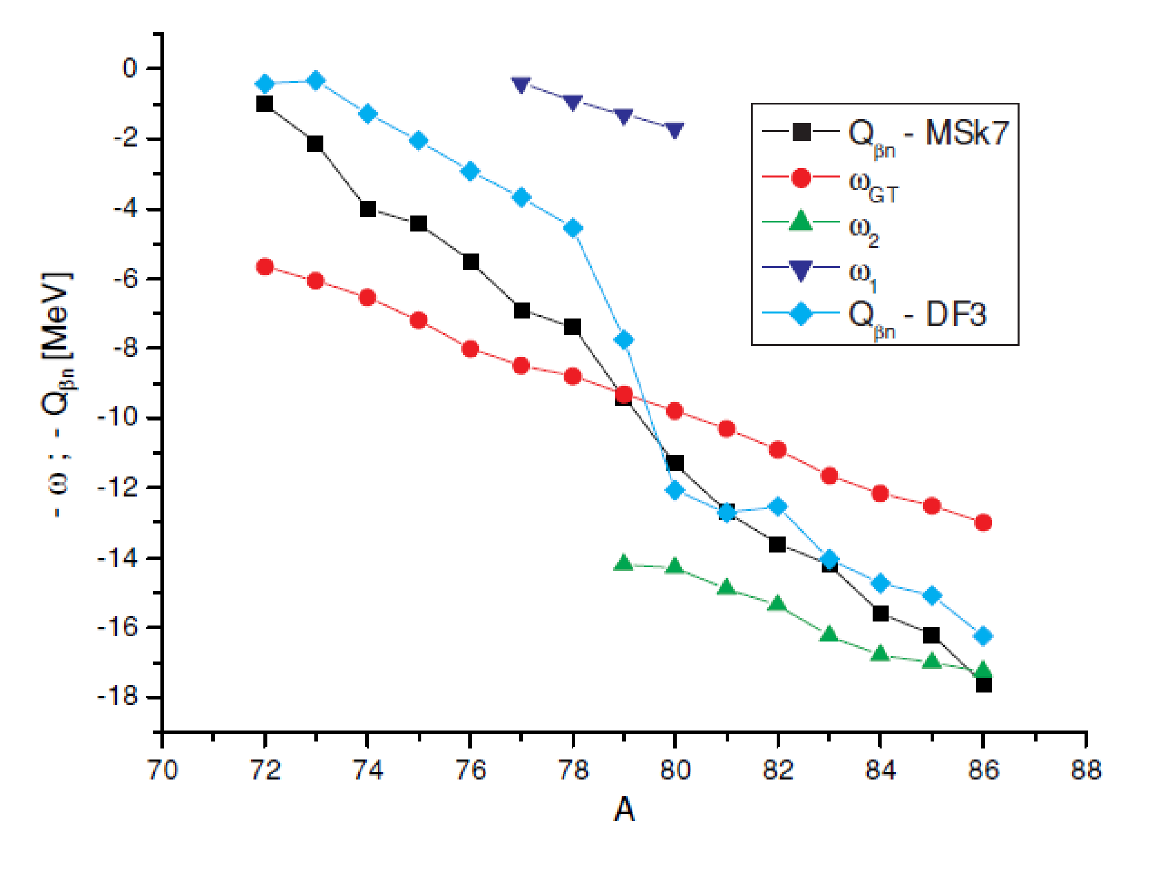


I. Borzov, PR C71 (2005) 065801







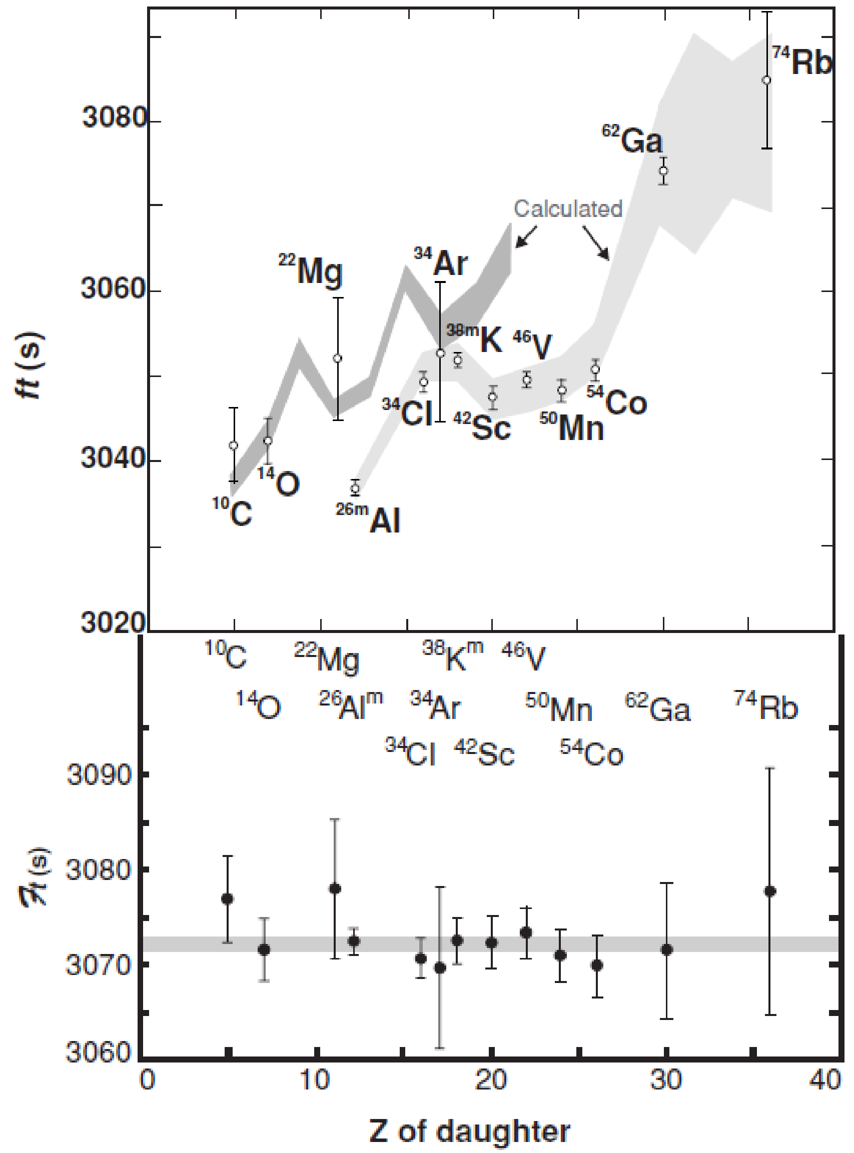


The reason for the behavior of P_n as a function of N is the appearance of low lying FF transition

- Direct check with 4π neutron counter
- Measurement of β-strength bellow S_n

Test of the CVC hypothesis and unitarity of CKM matrix

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



Hardy et al., PRC79 (2009) 055502

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

$$Ft = ft(1+\delta_R')(1-\delta_C+\delta_{NS})$$
$$= \frac{K}{g_V^2(1+\Delta_R)\langle M_F\rangle^2}$$

Determine as accurately as possible I_β to the ground state.

Hardy & Towner PRL88 (2001) 252501

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

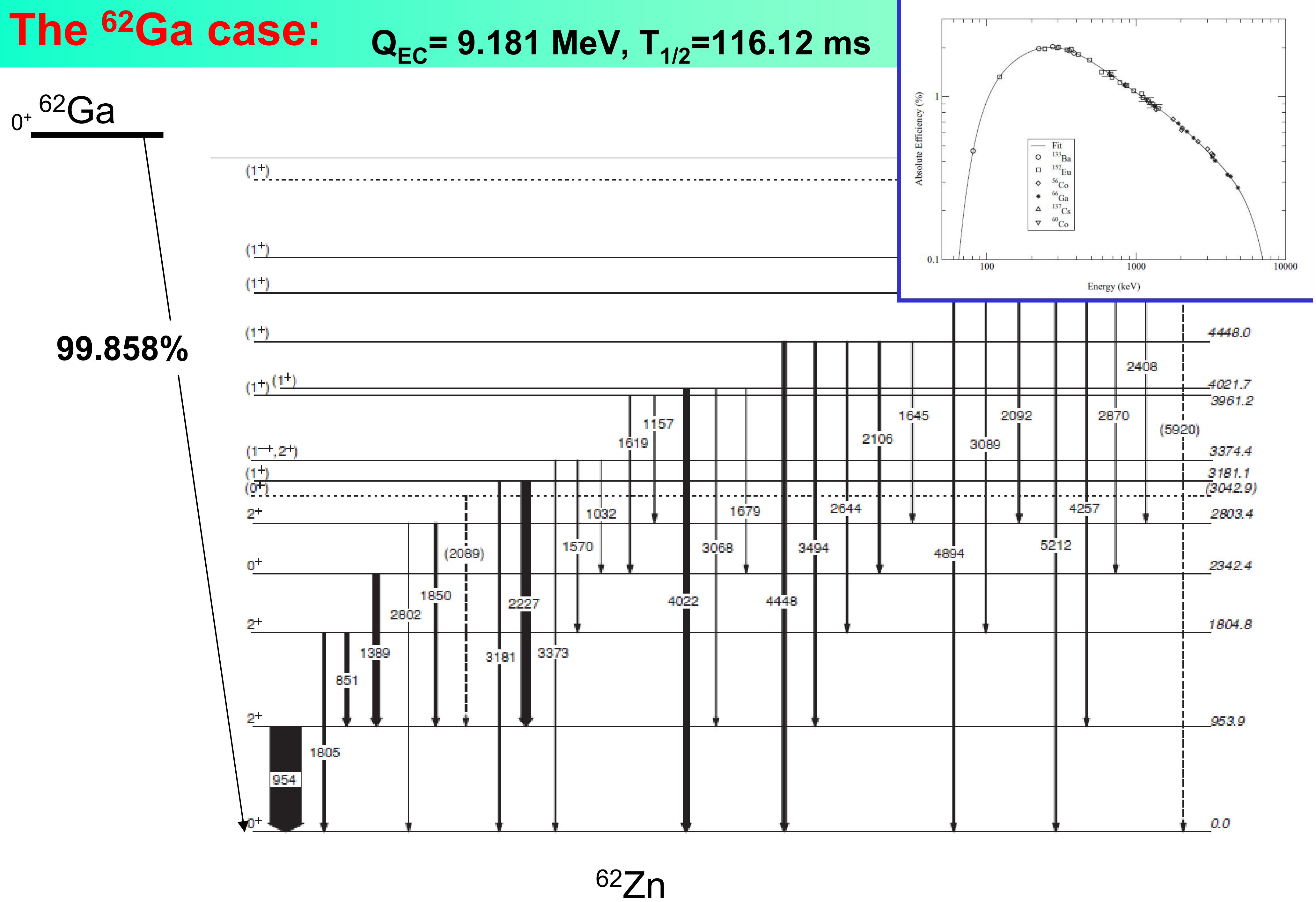
Problem for the heavier N=Z odd-odd nuclei: ^{62}Ga, ^{66}As, ^{70}Br, …, ^{94}Ag

Weak high-lying strength
☞ Pandemonium effect

Use of TAS to detect high lying weak GT branches

Precision < 10^{-3} !

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



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

I_β^{seen} = 0.1338% , I_β^{unseen} = 0.0082%

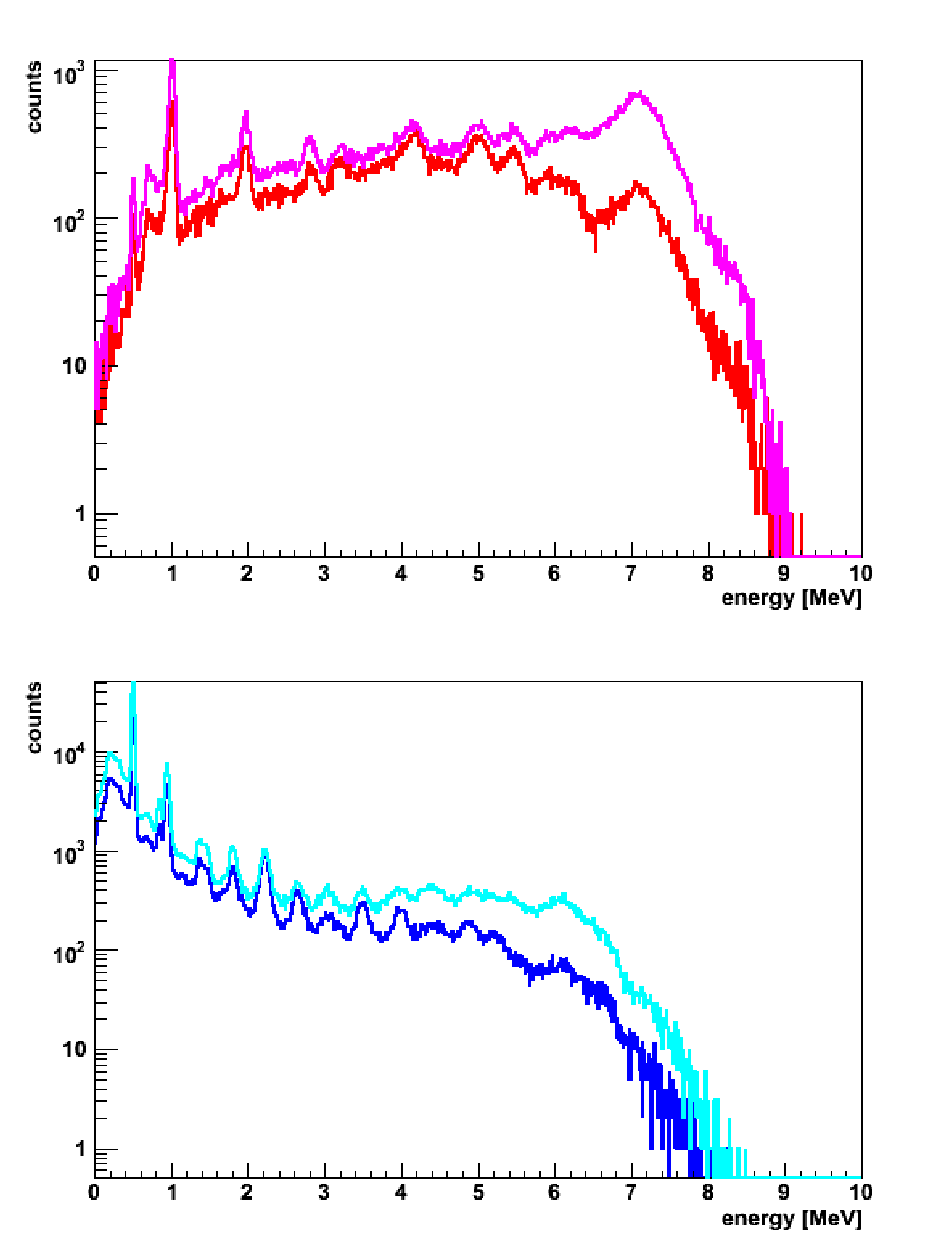
10^8 decays

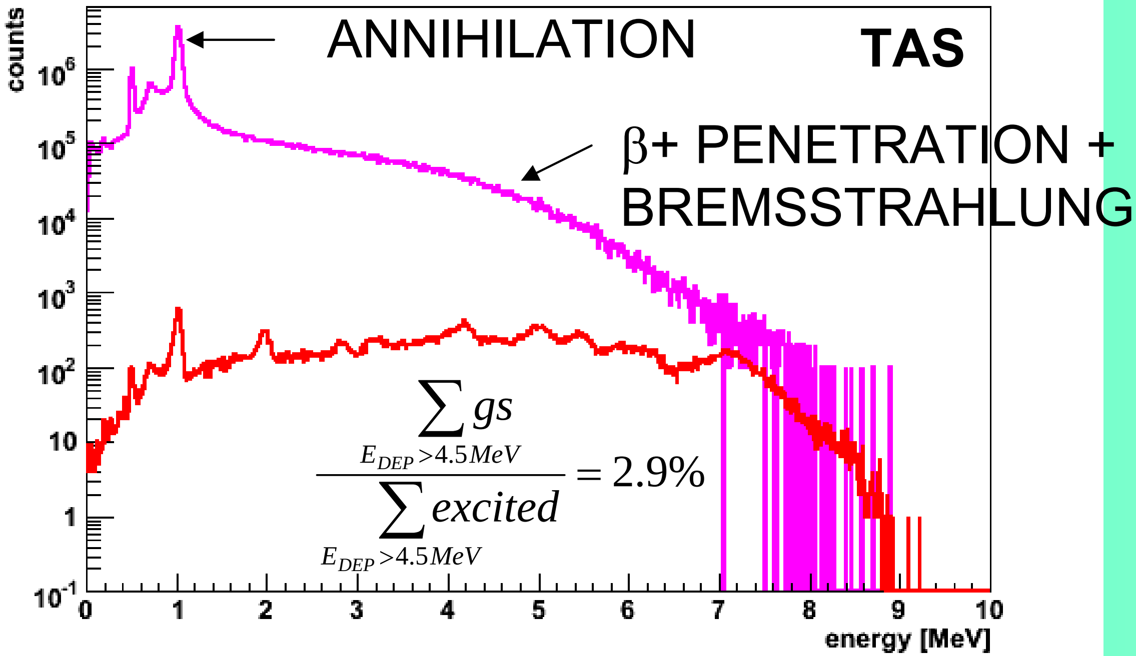
Statistical model has been used to simulate realistic cascades:

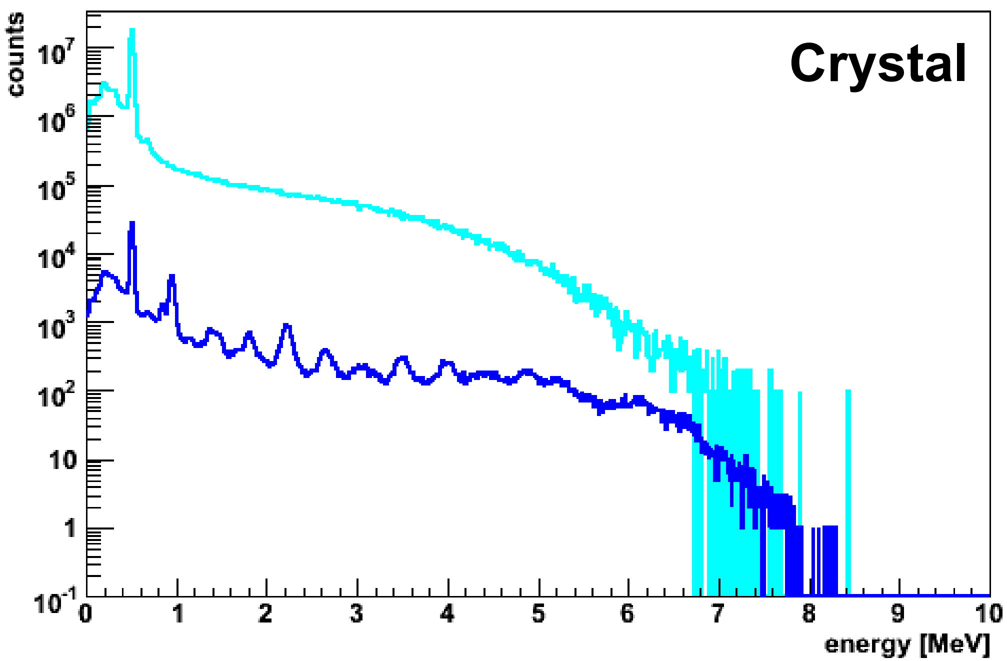
- All known levels up to 2.803 MeV
- MC levels 2.9-9.18 MeV
- 1+ levels below 5.25 MeV from Finlay et al included
- 117 1+ levels, total (J<10) 1777 levels.
- Intensity to the 6 1+ levels below 5.25 MeV according to Finlay
- the rest (404 ppm) to the higher lying levels (intensity decrease with Fermi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

Sensitivity to high lying strength:

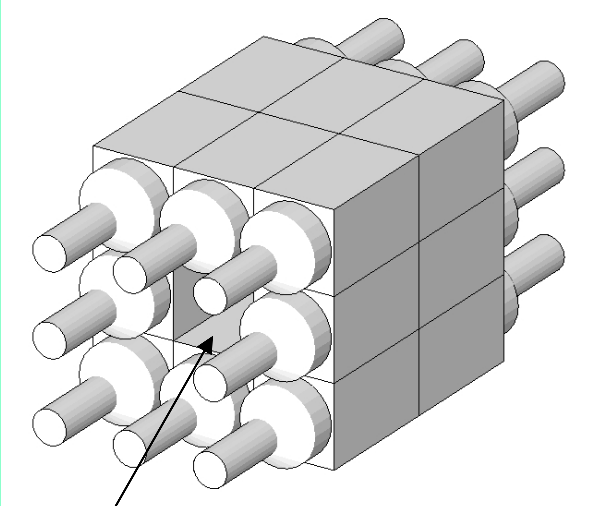
- 1784 ppm to the high lying states

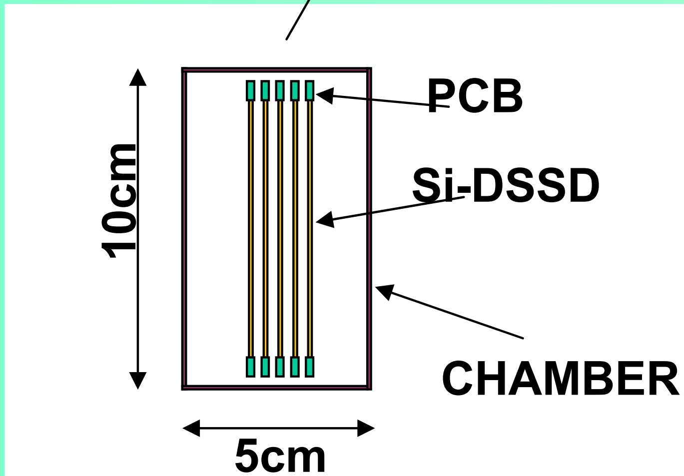




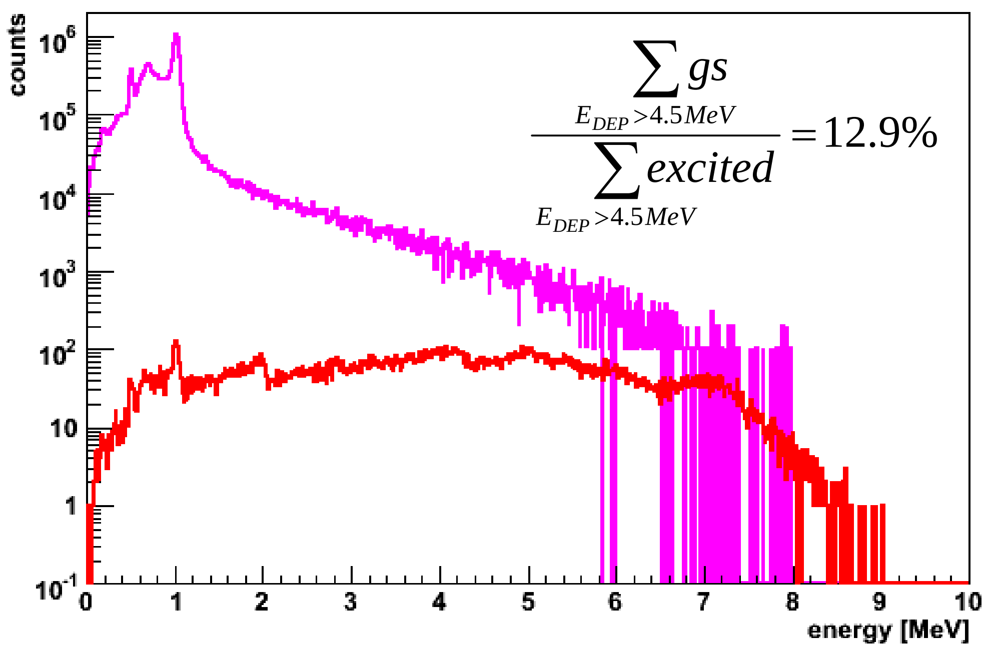


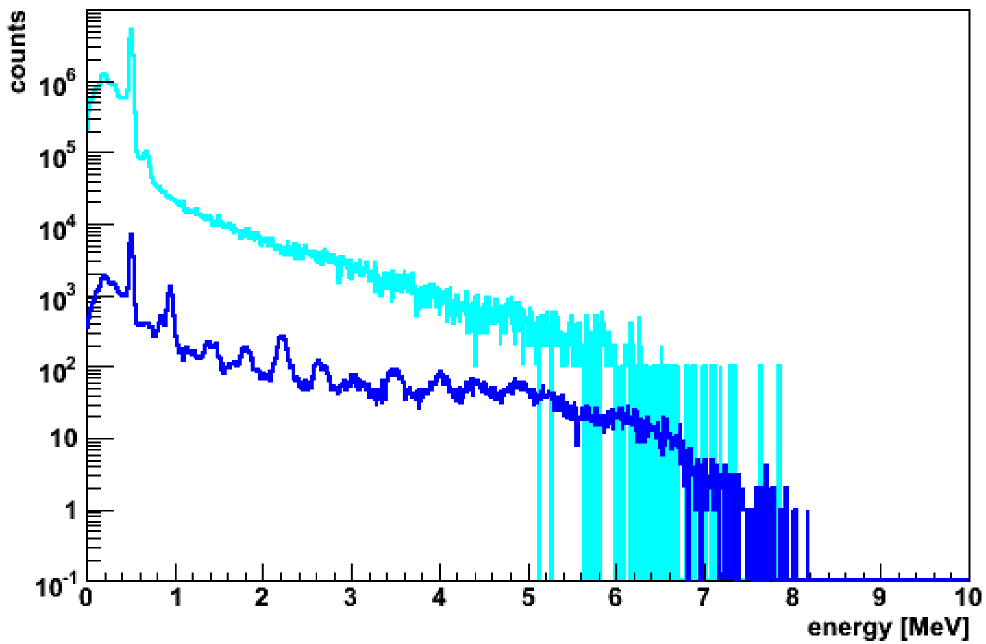
Penetration + Bremsstrahlung must be reduced !



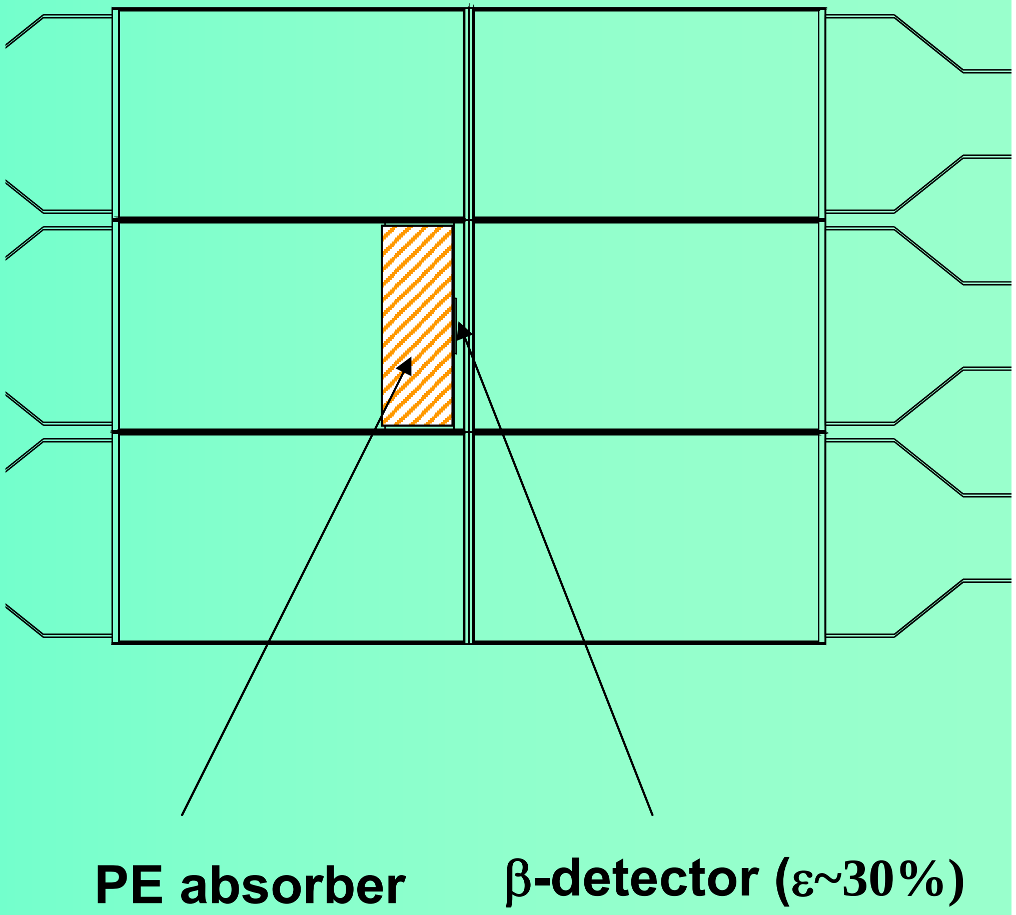


IMPLANTATION DETECTOR





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



Try: segmented β-detector to veto corresponding crystal signal

Conclusions:

1. **Measurements on the regions of 78Ni, 100Sn, 132Sn, 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 ~10 pps (1 pps?) are sufficient for accurate results (not higher than ~10^4)**

THE END