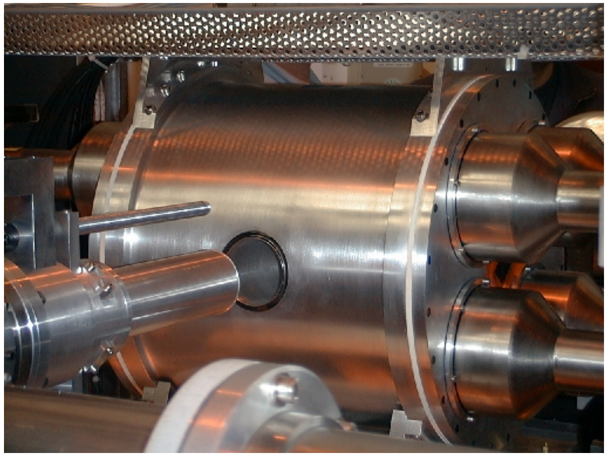
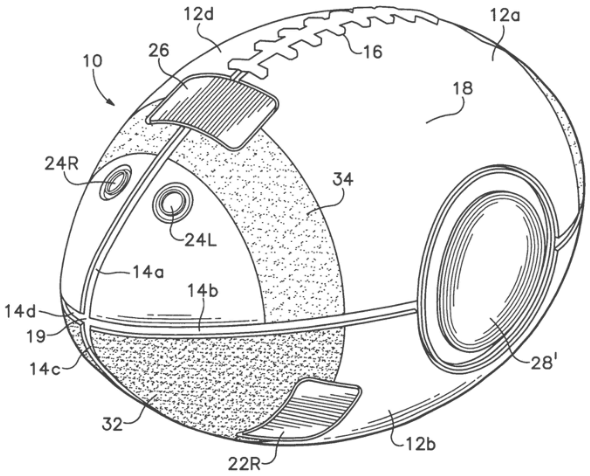
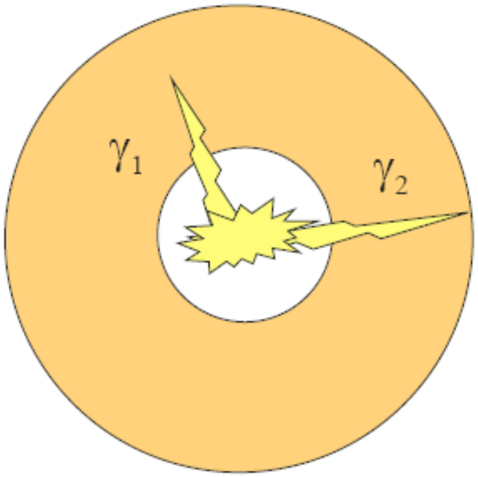
Shape effects from TAS measurements

Alejandro Algora
IFIC (CSIC-Univ. Valencia), Spain
MTA ATOMKI, Debrecen, Hungary

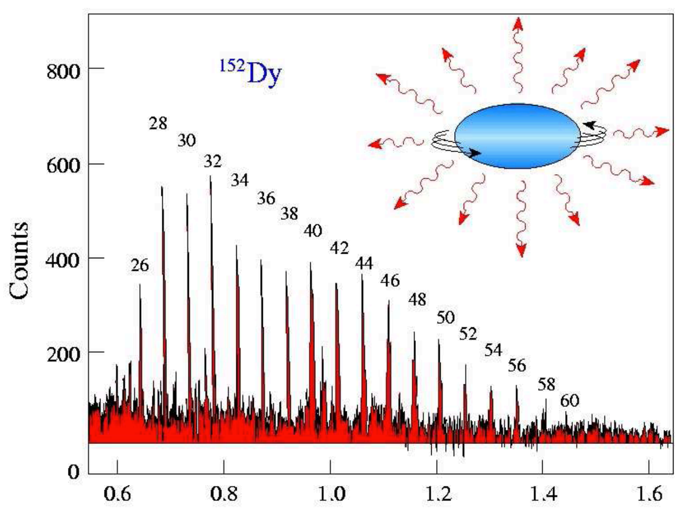






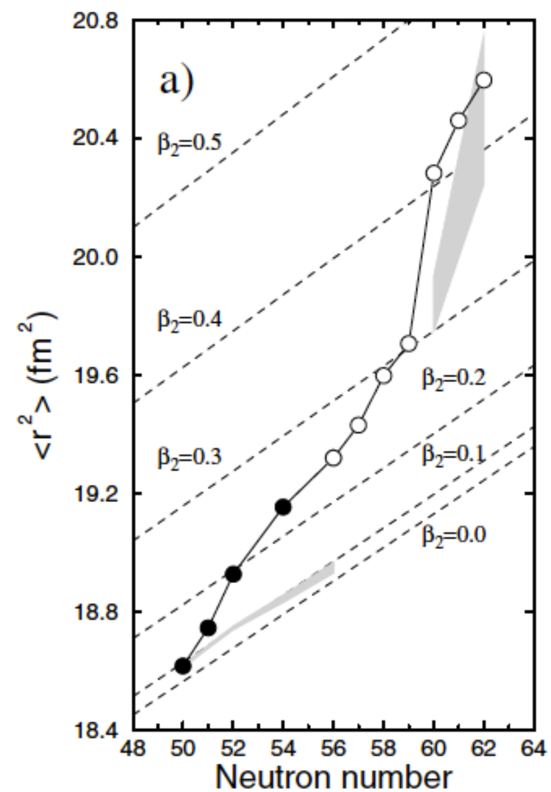
Experimentally how we determine shapes…

- •Nuclear electric quadrupole measurements (not valid for J=0,1/2 gs)
- •Nuclear radii measurements, by means of particle scattering experiments
- •Nuclear radii determinations by means of isotopic shifts (laser spectroscopy, muonic atoms)
- •Nuclear spectroscopic information: level life time measurements, B(E2), transitions in a band, E(0), etc.
- •Coulomb excitation



P. Twin et. al
Phys. Rev. Lett. 57 (1986)

$$|Q| = \sqrt{16\pi B(E2{:}2_1^+ \to 0_1^+)} = \frac{3Ze}{\sqrt{5\pi}} R_0^2(\beta + 0.16\beta^2),$$

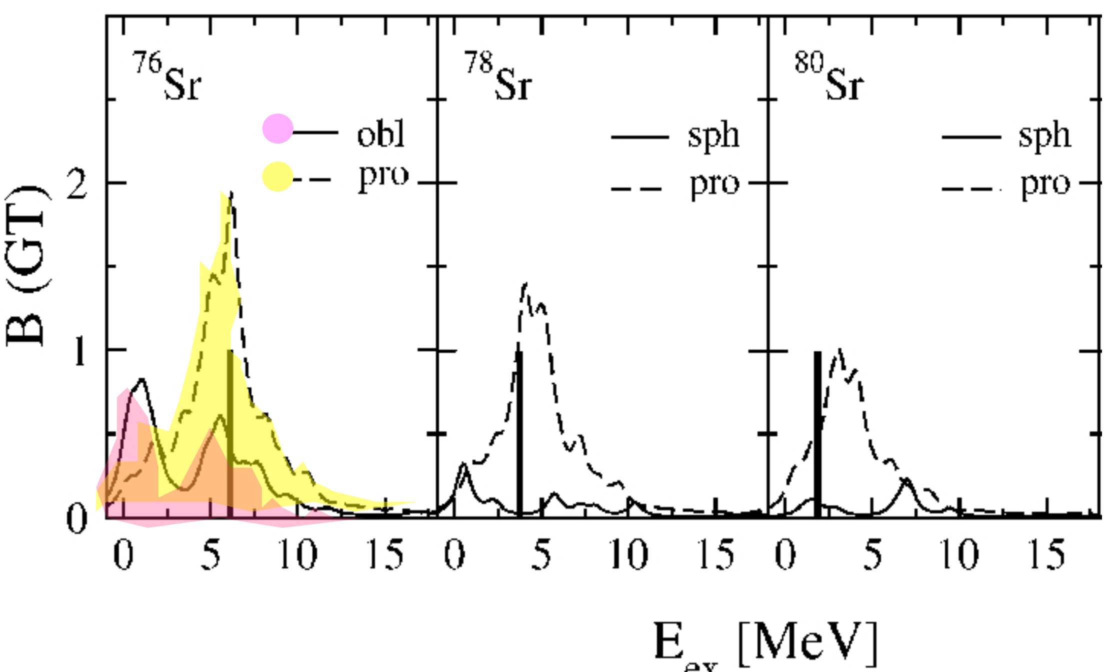


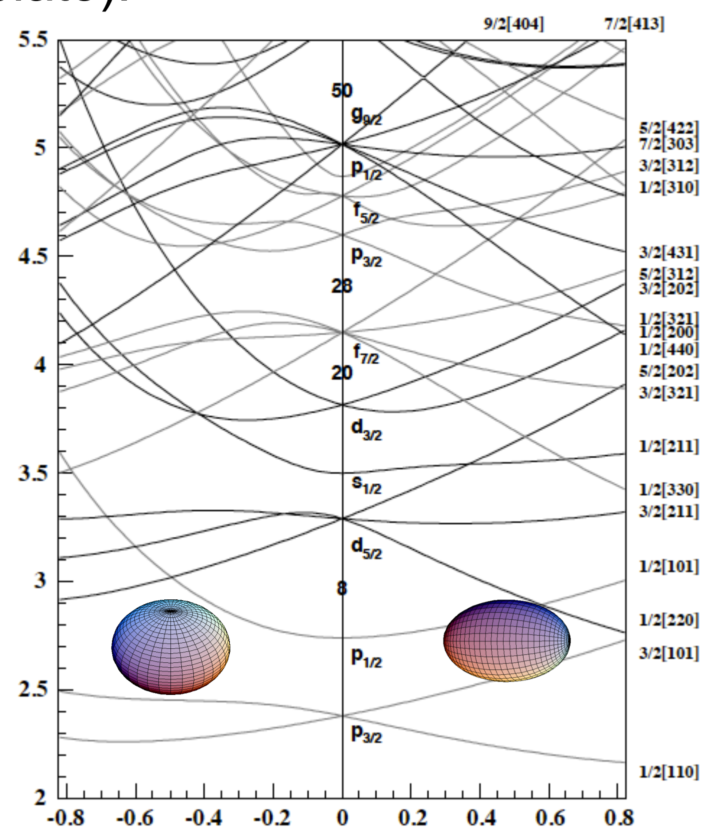
Laser spectroscopy of cooled Zr fission products (Campbell PRL 89, 2002) Mean square charge radii deduced from the measurements compared with droplet model predictions.

What can beta decay offer apart from spectroscopy …

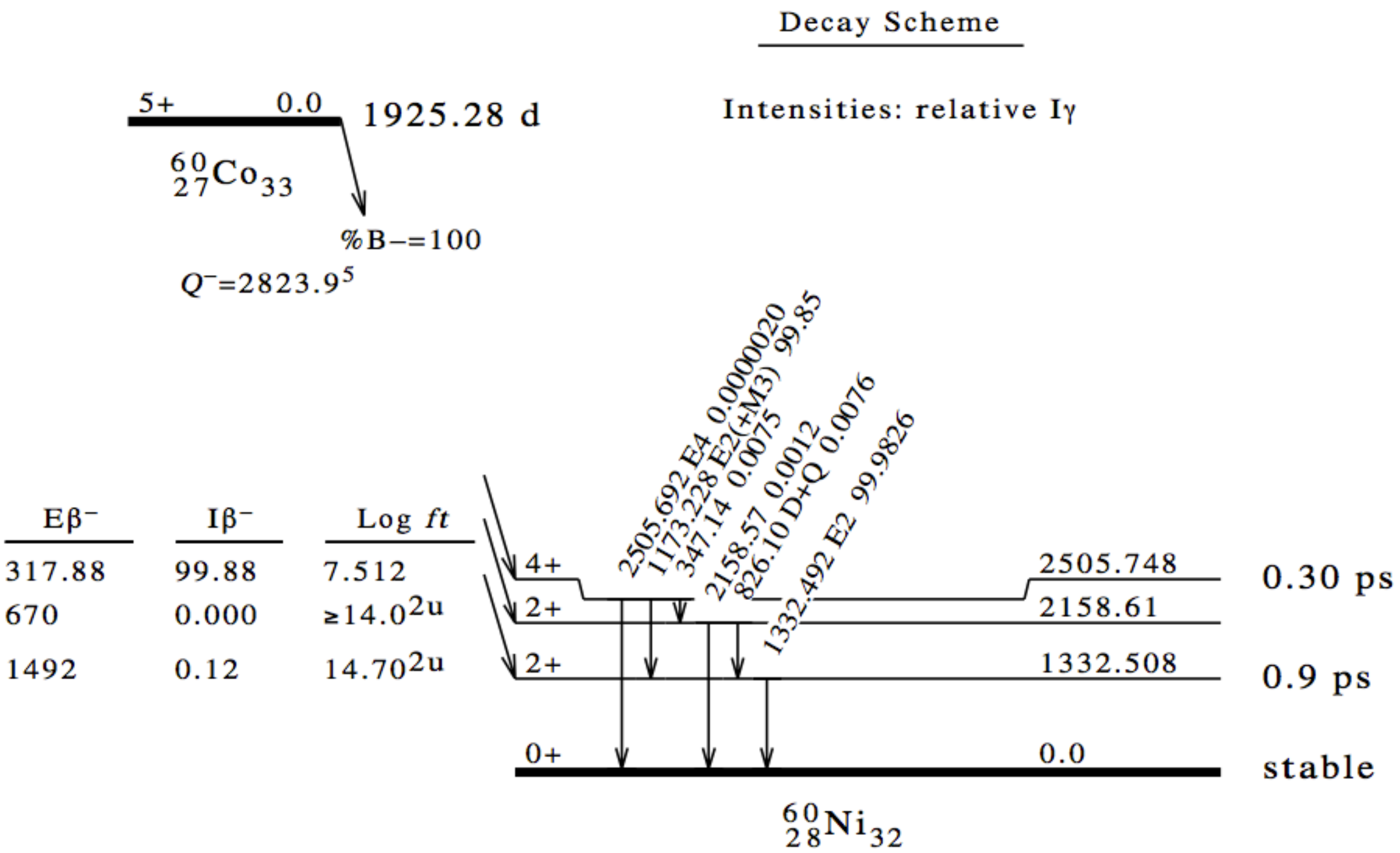
Another alternative, based in the pioneering work of I. Hamamoto, (Z. Phys. A353 (1995) 145) later followed by studies of P. Sarriguren *et al*., Petrovici *et al*. is related to the dependency of the strength distribution in the daugther nucleus depending on the shape of the parent. It can be used when theoretical calculations predict different B(GT) distributions for the possible shapes of the ground state (prolate, spherical, oblate).

P. Sarriguren *et al*., Nuc. Phys. A635 (1999) 13



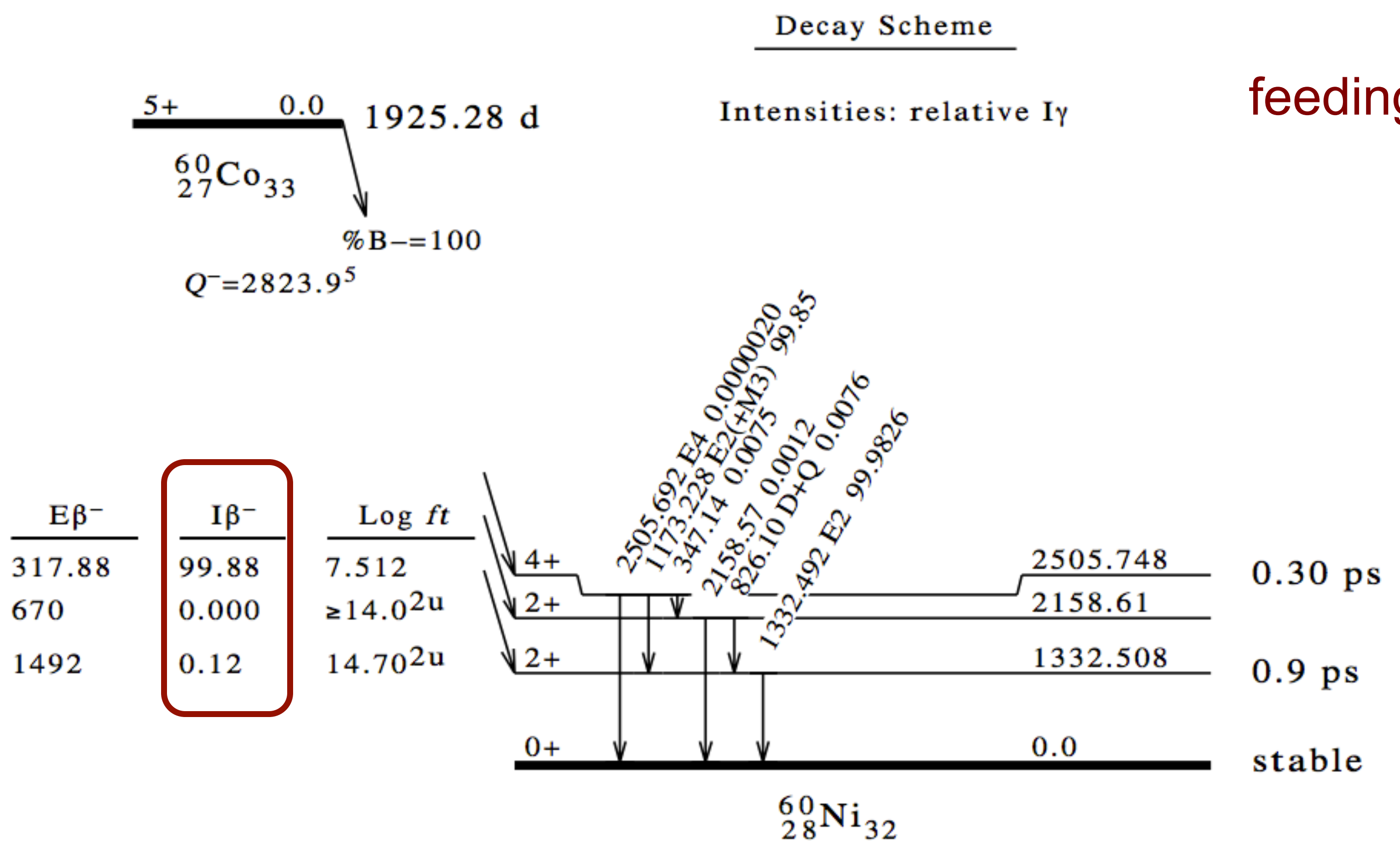


Example: ^{60}Co decay from http://www.nndc.bnl.gov/



Example: ^{60}Co decay from http://www.nndc.bnl.gov/

feeding:=$I_\beta = P_f * 100$



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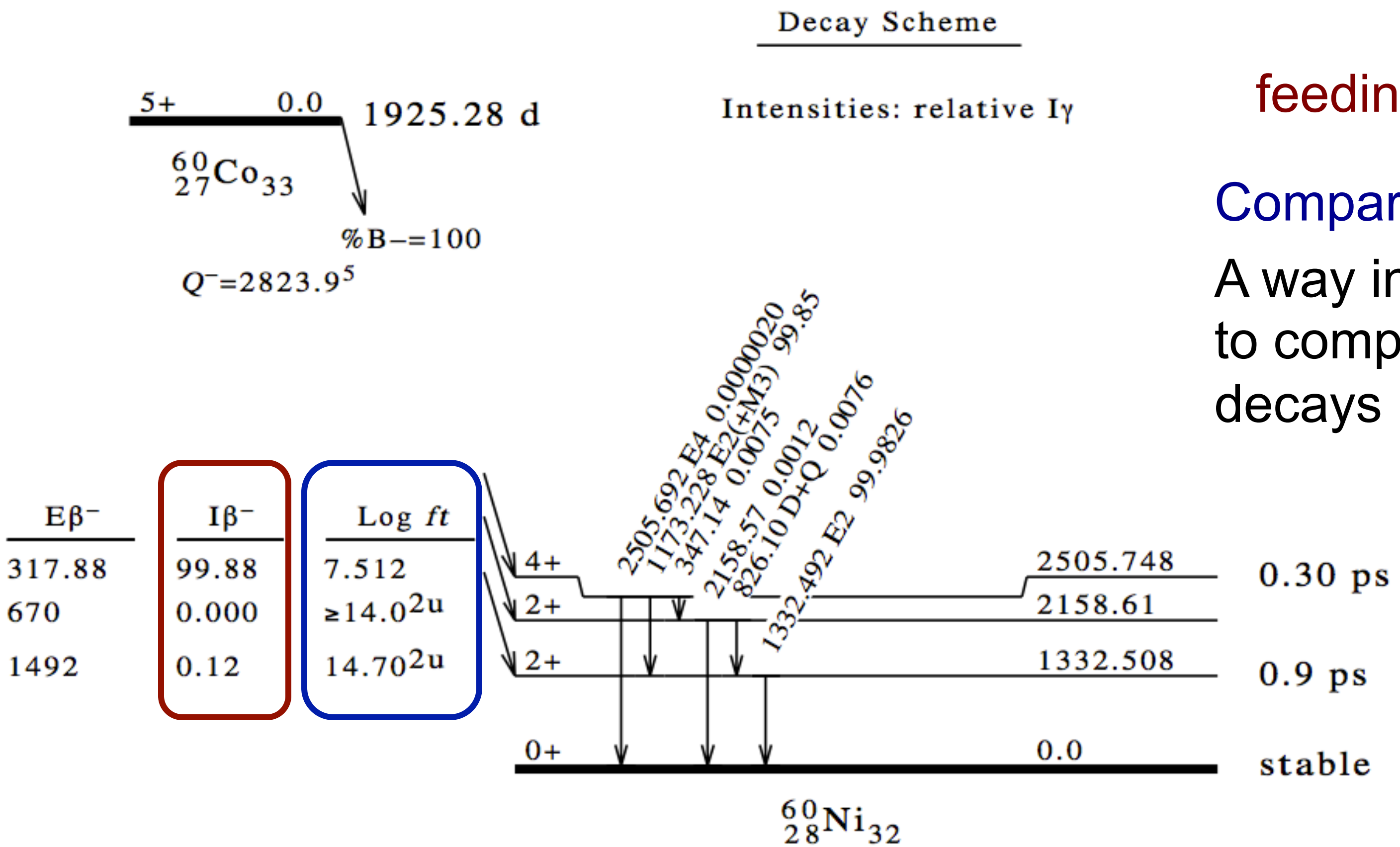
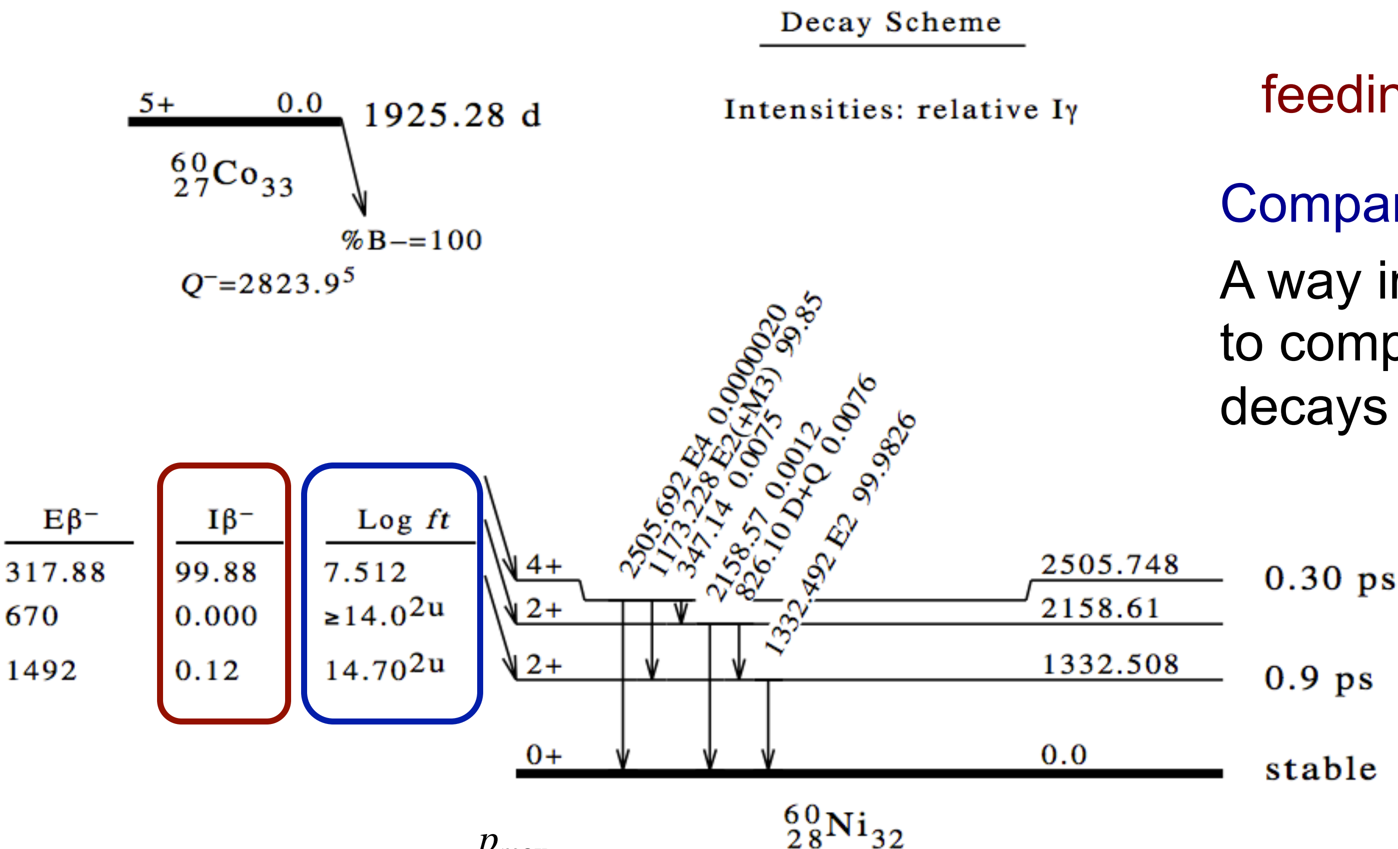


feeding:= $I_\beta = P_f$*100

Comparative half-life: ft

A way introduced by Fermi to compare the different decays (Q, Z’)

Example: ^{60}Co decay from http://www.nndc.bnl.gov/



feeding:=I_β = P_f*100

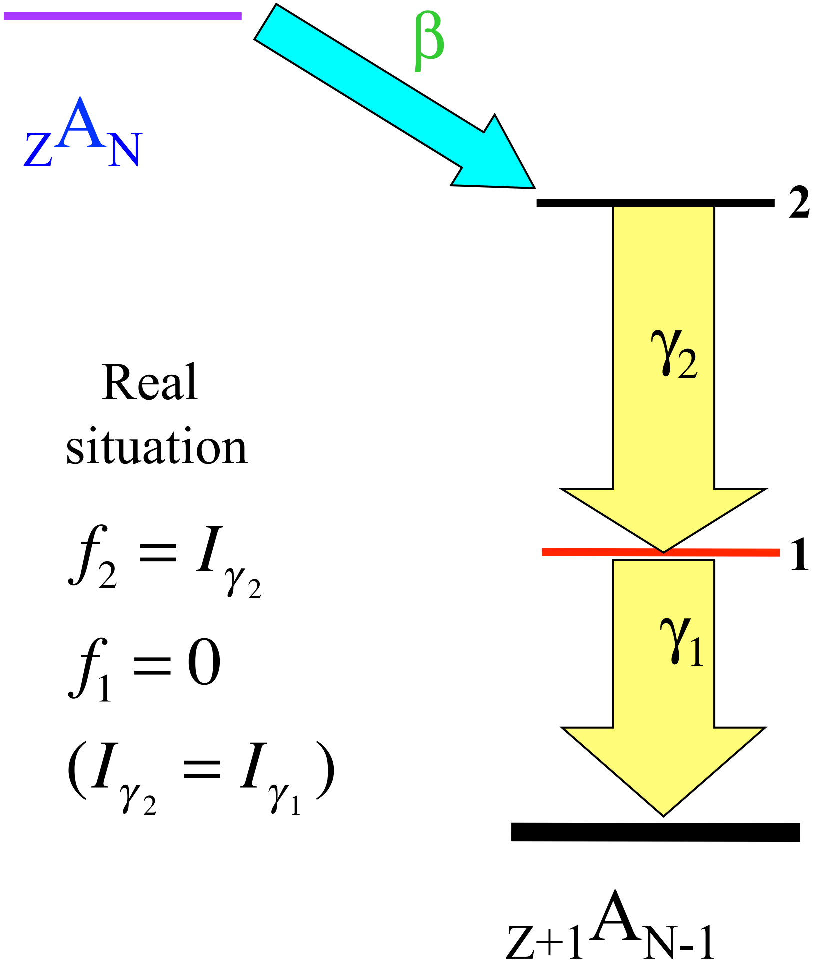
Comparative half-life: ft

A way introduced by Fermi to compare the different decays (Q, Z')

$$f(Z',Q) = const \cdot \int_0^{p_{\max}} F(Z',p)\,p^2 (Q-E_e)^2\,dp, \qquad t_f = \frac{T_{1/2}}{P_f}$$

$$ft_f = const' \frac{1}{\left|M_{if}\right|^2} = const' \frac{1}{B_{i\to f}} \qquad B_{i\to f} = \frac{1}{2J_i+1}\left|\left\langle \Psi_f \middle| \tau^{\pm}\ or\ \sigma\tau^{\pm} \middle| \Psi_i \right\rangle\right|^2$$

The problem of measuring the β-feeding

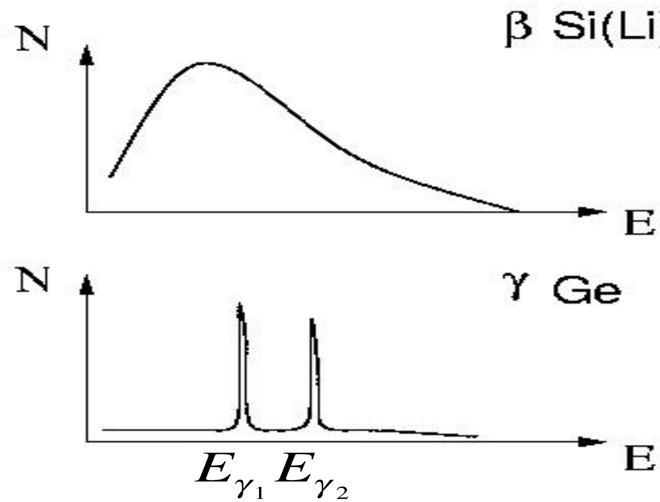


Real situation

$$f_2 = I_{\gamma_2}$$

$$f_1 = 0$$

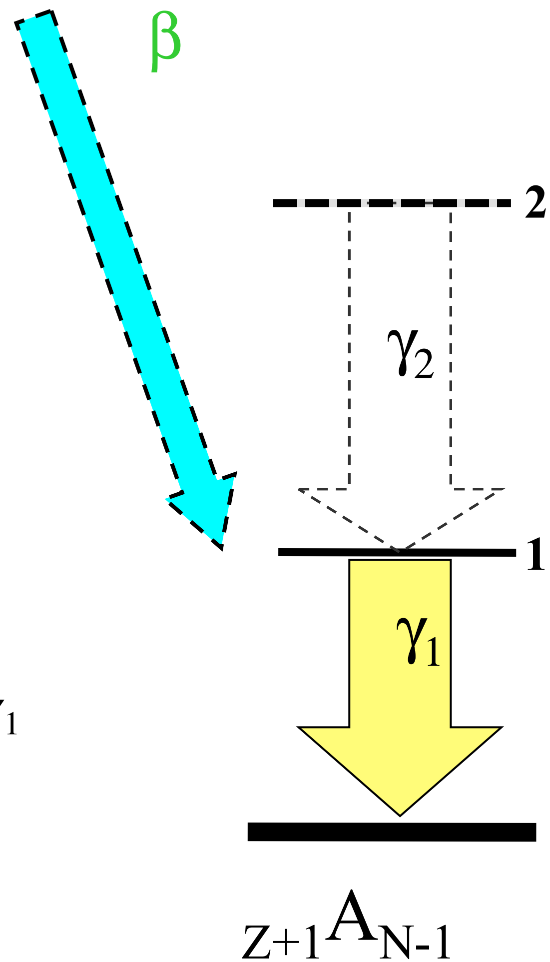
$$(I_{\gamma_2} = I_{\gamma_1})$$



- Ge detectors are conventionally used to construct the level scheme populated in the decay

- From the γ intensity balance we deduce the β-feeding

Experimental perspective: the problem of measuring the β- feeding

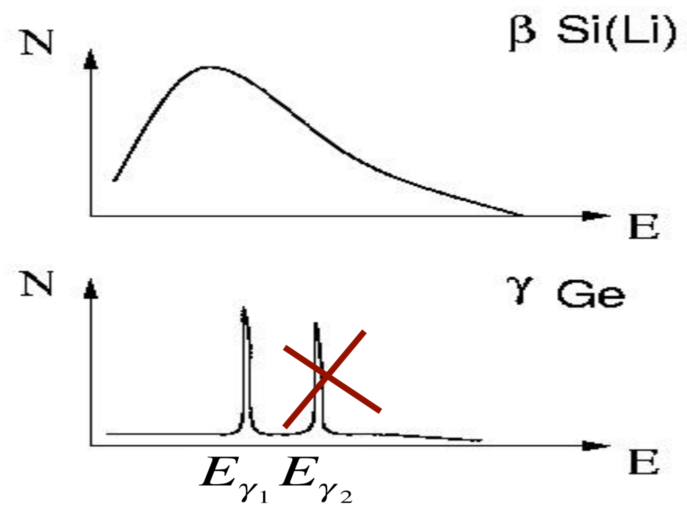


$_{Z}A_{N}$

Apparent situation

$$f_2 = 0$$

$$f_1 = I_{\gamma_1}$$

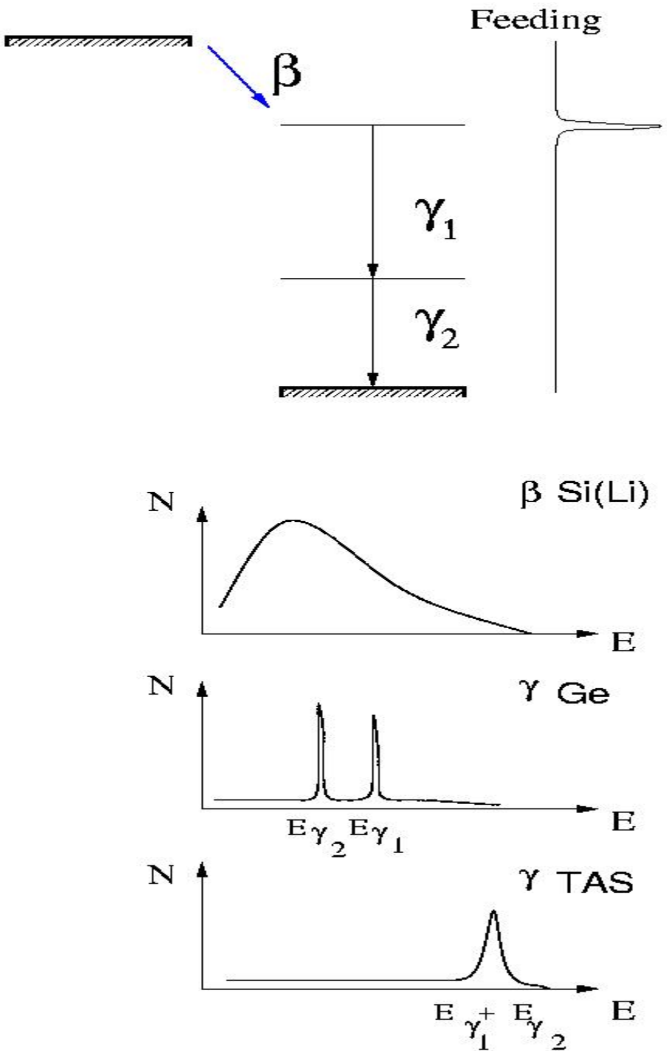


- What happens if we miss some intensity

$$Single\ \gamma \sim \varepsilon$$

$$Coinc\ \gamma_1\gamma_2 \sim \varepsilon_1\varepsilon_2$$

TAGS measurements



$$gamma\ rays \rightarrow feeding \rightarrow Strength$$

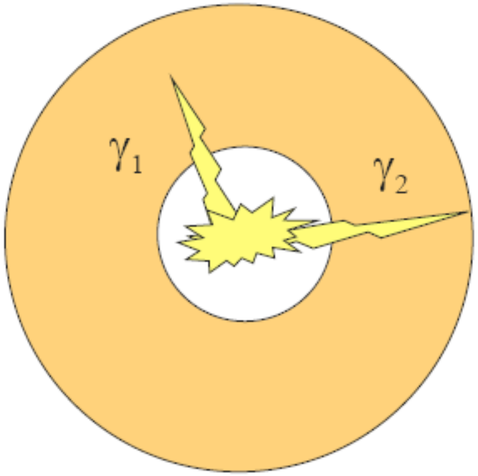
The only reasonable way to solve the problem, without suffering from the so-called Pandemonium effect is to use a highly efficient device:

A TOTAL ABSORTION SPECTROMETER

But there is a change in philosophy. Instead of detecting the individual gamma rays we sum the energy deposited by the gamma cascades in the detector.

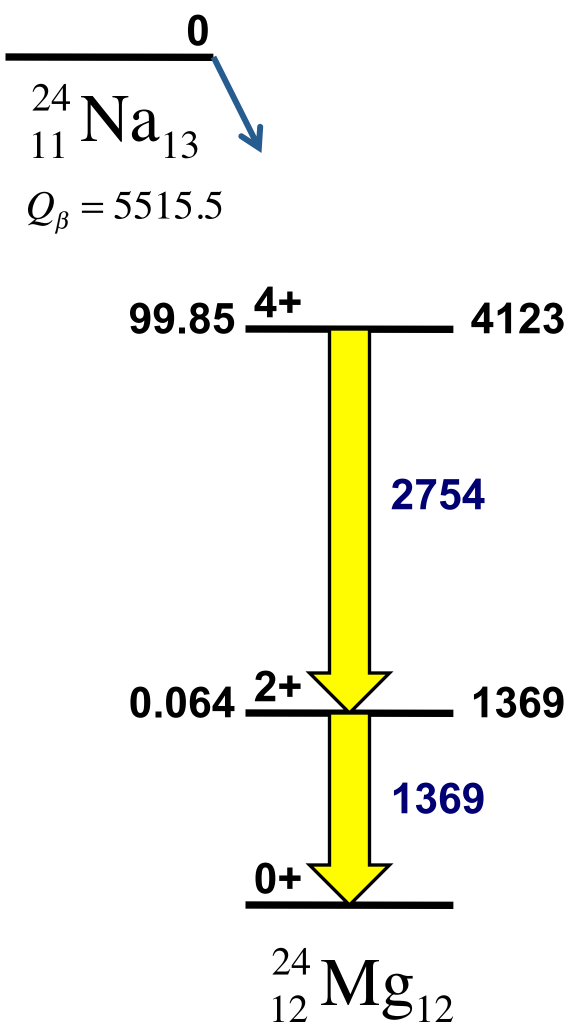
A TAS is like a calorimeter!

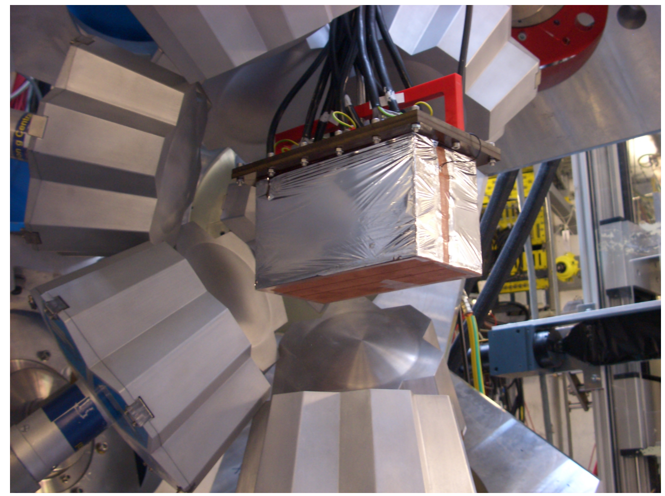
Big crystal, 4π



$$d = R(B) \cdot f$$

Ge detector case: ^{24}Na decay





RISING

Stopped Beam Configuration:

15 clusters, 105 Ge capsules

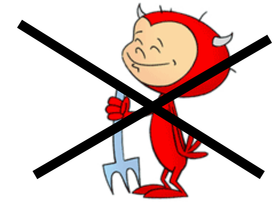
$$\varepsilon_{p1} = 0.10 \qquad \gamma_1 = 1369 \text{ keV}$$

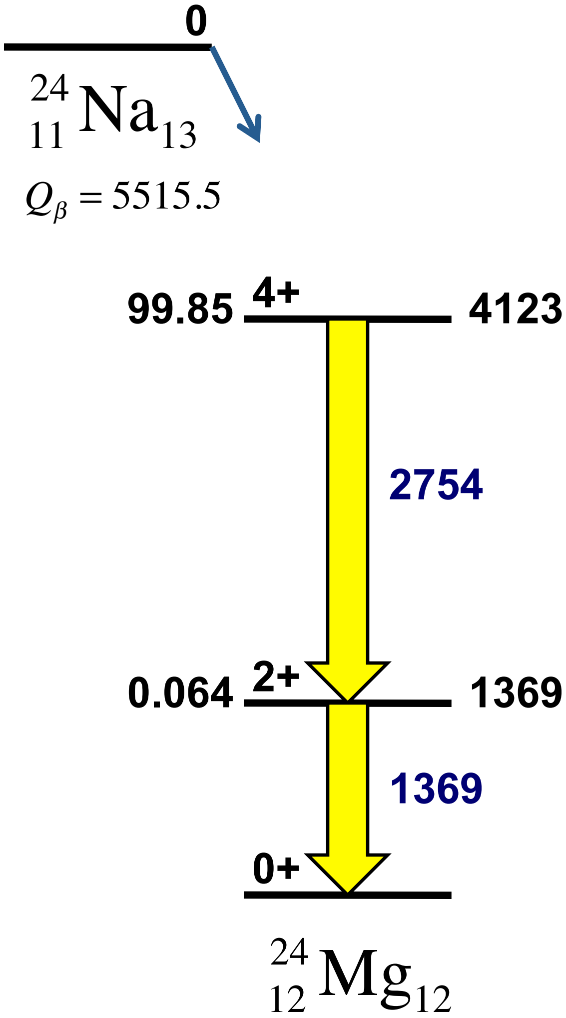
$$\varepsilon_{p2} = 0.06 \qquad \gamma_2 = 2754 \text{ keV}$$

$$\varepsilon_{coinc} = \varepsilon_{p1} \cdot \varepsilon_{p2}$$

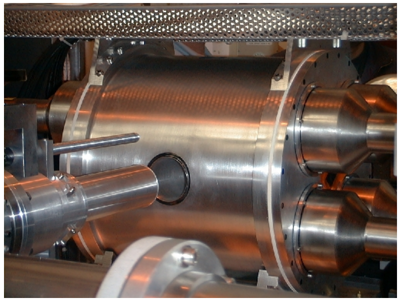
$$\varepsilon_{coinc} = 0.006$$

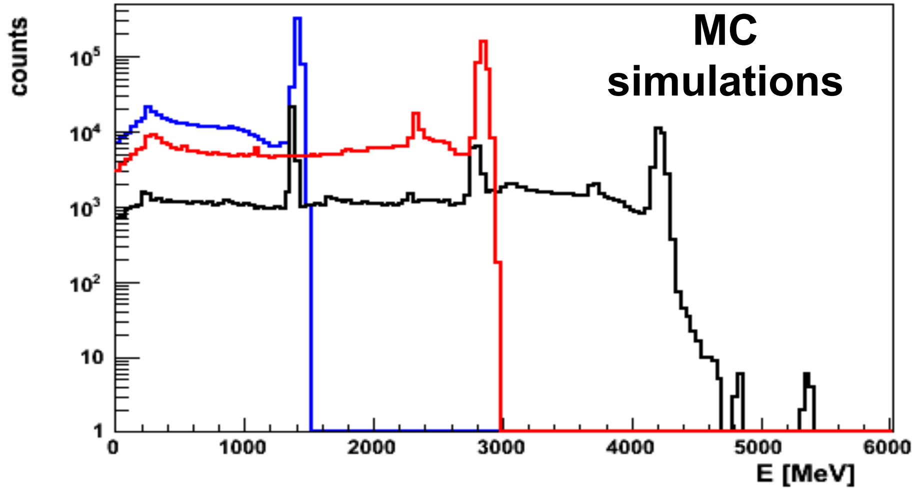
TAS case: ^{24}Na decay





$$d = R(B) \cdot f$$





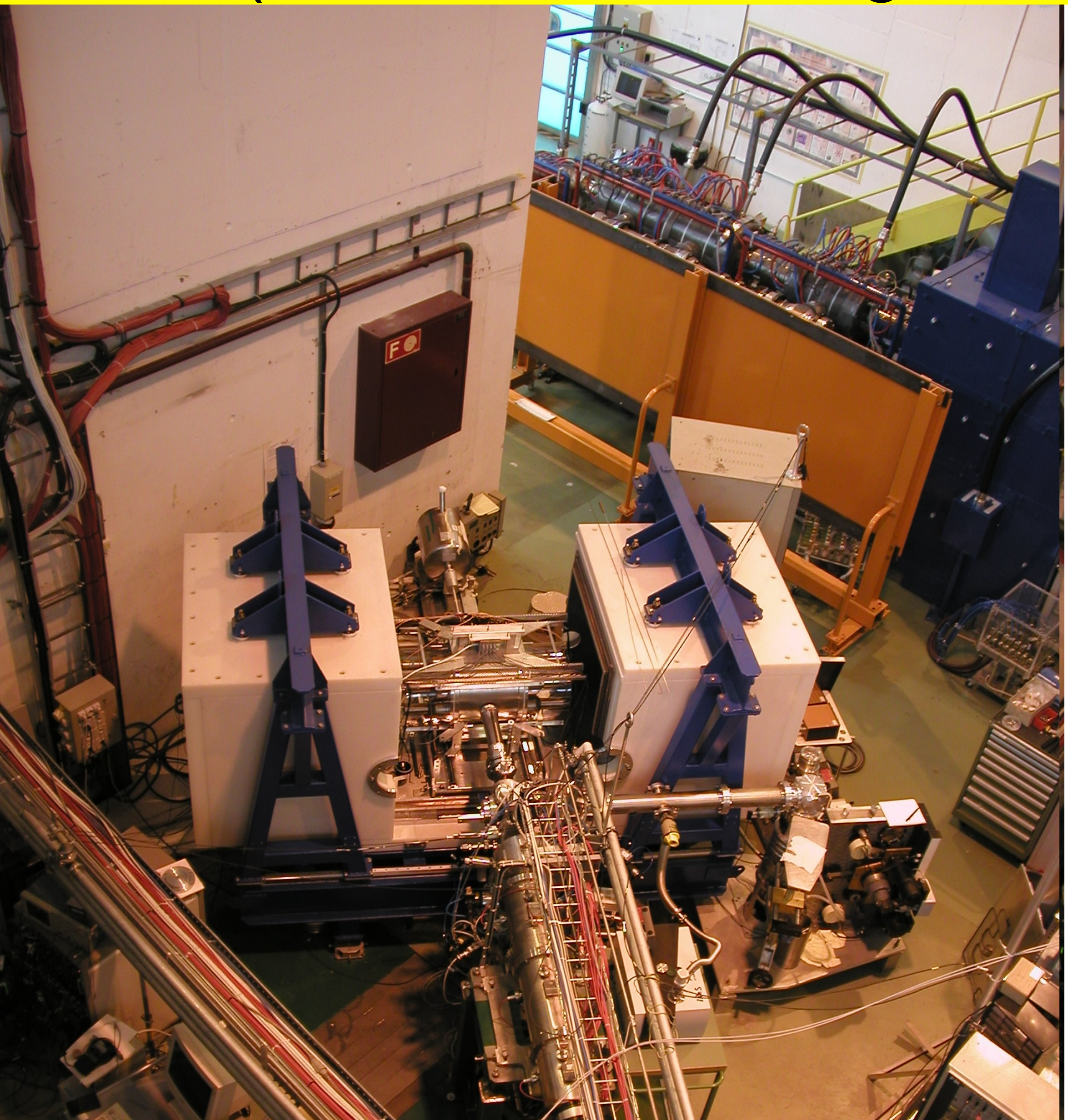
$$\varepsilon_{Total}^{\gamma_1}(1369\ \text{keV}) = 0.81$$

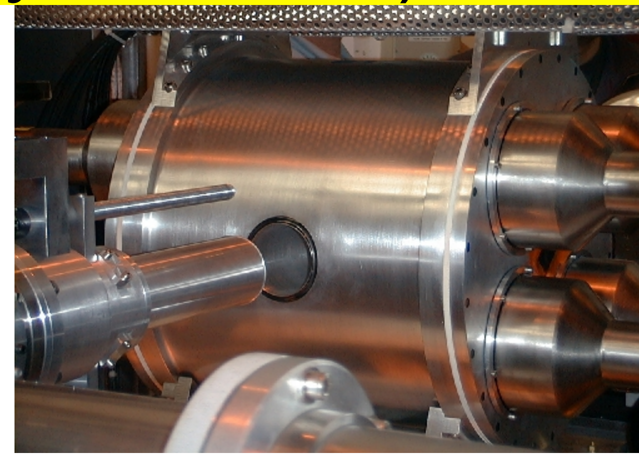
$$\varepsilon_{Total}^{\gamma_2}(2754\ \text{keV}) = 0.72$$

$$\varepsilon_{Total}(cascade) = \varepsilon_{Total}^{\gamma_1} \otimes \varepsilon_{Total}^{\gamma_2} =$$

$$\varepsilon_{Total}^{\gamma_1}(1-\varepsilon_{Total}^{\gamma_2}) + \varepsilon_{Total}^{\gamma_2}(1-\varepsilon_{Total}^{\gamma_1}) + \varepsilon_{Total}^{\gamma_1}\varepsilon_{Total}^{\gamma_2} = 0.95$$

Lucrecia: the TAS at ISOLDE (CERN) (Madrid-Strasbourg-Surrey-Valencia)

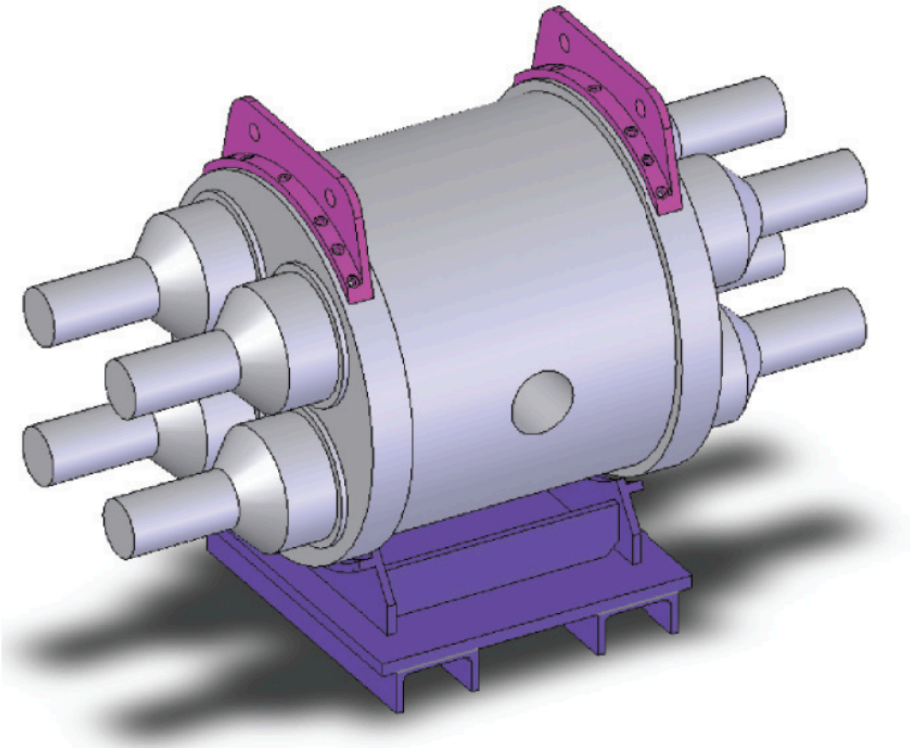


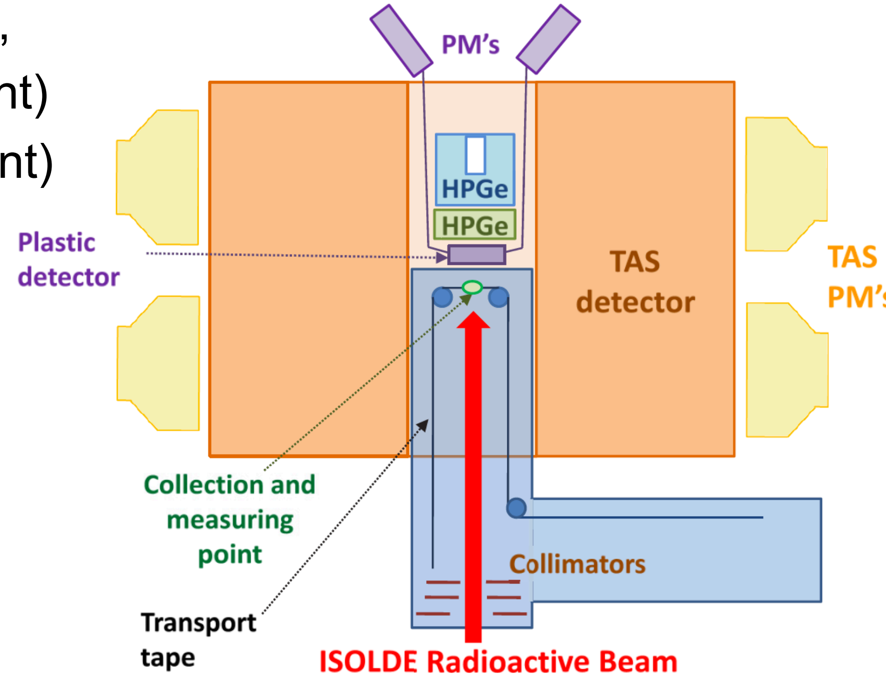


- A large NaI cylindrical crystal 38 cm Ø, 38cm length
- An X-ray detector (Ge)
- A β detector
- Possibility of collection point inside the crystal

Lucrecia: the TAS at ISOLDE (CERN) (Madrid-Strasbourg-Surrey-Valencia)

Analysis can be done (p-rich side)
singles (beta and EC component together),
or in coincidences with betas (beta component)
orr in coincidences with X-rays (EC component)





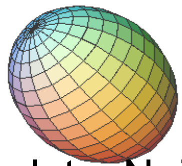
$$_Z A_N \rightarrow {}_{Z+1}A_{N-1} + e^- + \bar{\nu} \qquad \beta^-$$

$$_Z A_N \rightarrow {}_{Z-1}A_{N+1} + e^+ + \nu \qquad \beta^+$$

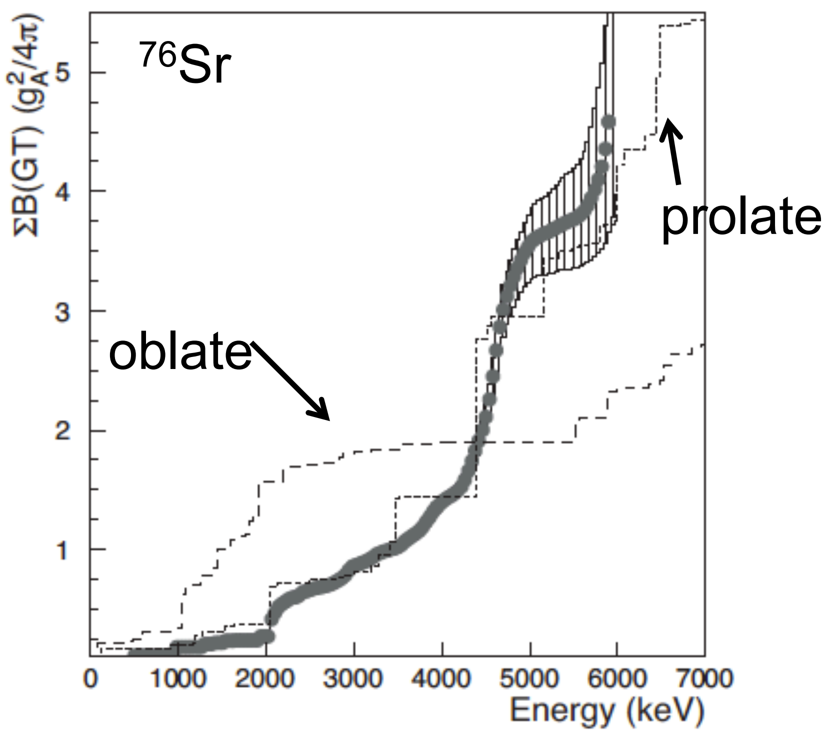
$$_Z A_N + e^- \rightarrow {}_{Z-1}A_{N+1} + \nu + X_{ray} \qquad \mathrm{EC}$$

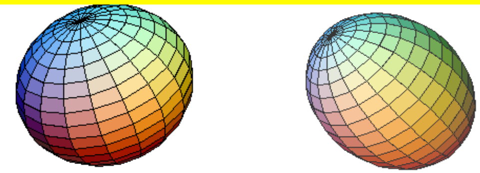
Figures taken from Briz *et al*. PRC92, Perez *et al*. PRC88

Some earlier examples (proposals of Rubio and Dessagne)

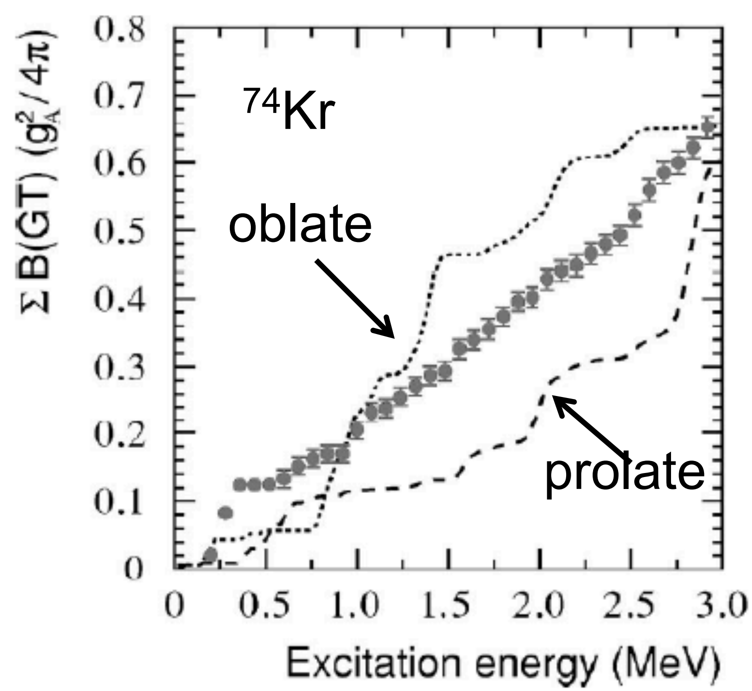


Very prolate N=Z nucleus





Mixture of prolate and oblate



E. Nácher *et al. PRL 92 (2004) 232501 and PhD thesis Valencia*

Ground state of ^{76}Sr prolate (β_2 ~0.4) as indicated in Lister et al., PRC 42 (1990) R1191

E. Poirier *et al., Phys. Rev. C 69, 034307 (2004) and PhD thesis Strasbourg*

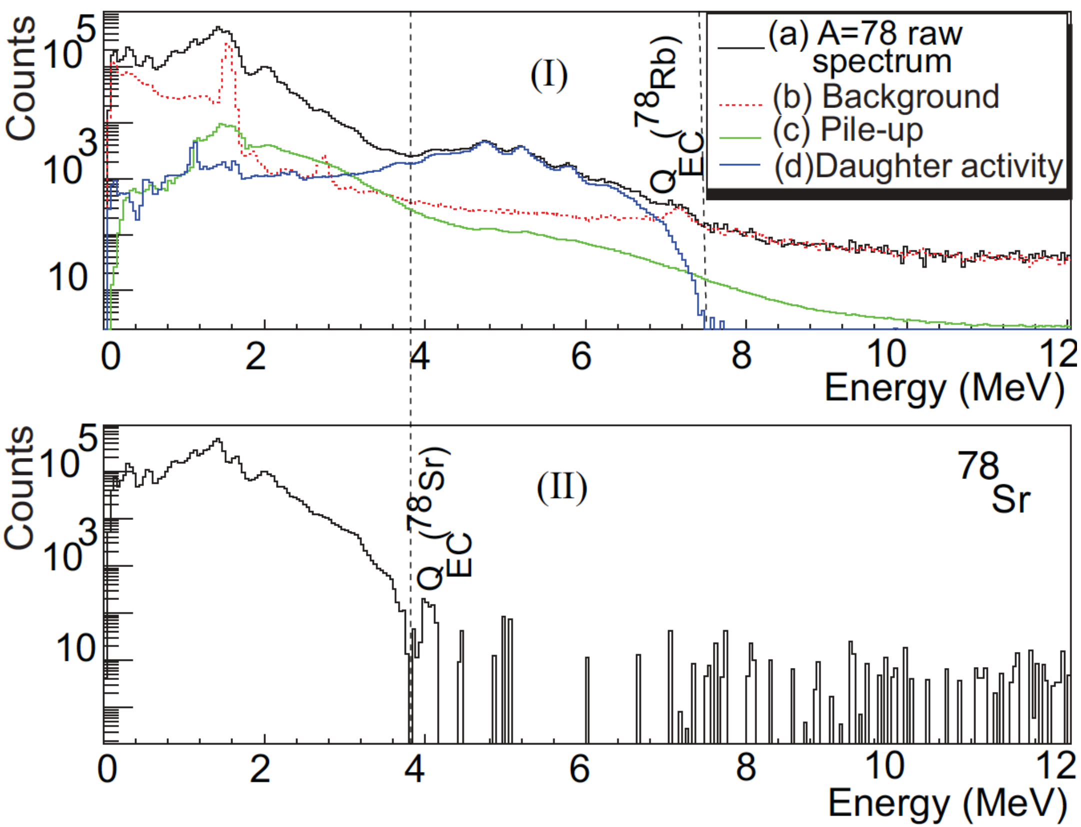
Ground state of ^{74}Kr:(60±8)% oblate, in agreement with other exp results and with theoretical calculations (A. Petrovici et al.)

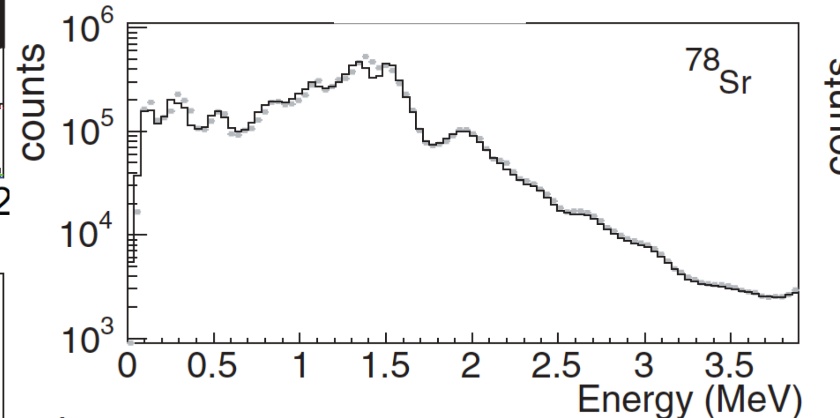
^{78}Sr case

PHYSICAL REVIEW C **88**, 014324 (2013)

Deformation of Sr and Rb isotopes close to the $N = Z$ line via β-decay studies using the total absorption technique

A. B. Pérez-Cerdán,[1] B. Rubio,[1,*] W. Gelletly,[2] A. Algora,[1,3] J. Agramunt,[1] E. Nácher,[1,4] J. L. Taín,[1] P. Sarriguren,[4] L. M. Fraile,[5] M. J. G. Borge,[4] L. Caballero,[1] Ph. Dessagne,[6] A. Jungclaus,[4] G. Heitz,[6] F. Marechal,[6] E. Poirier,[6] M. D. Salsac,[6] and O. Tengblad[4]





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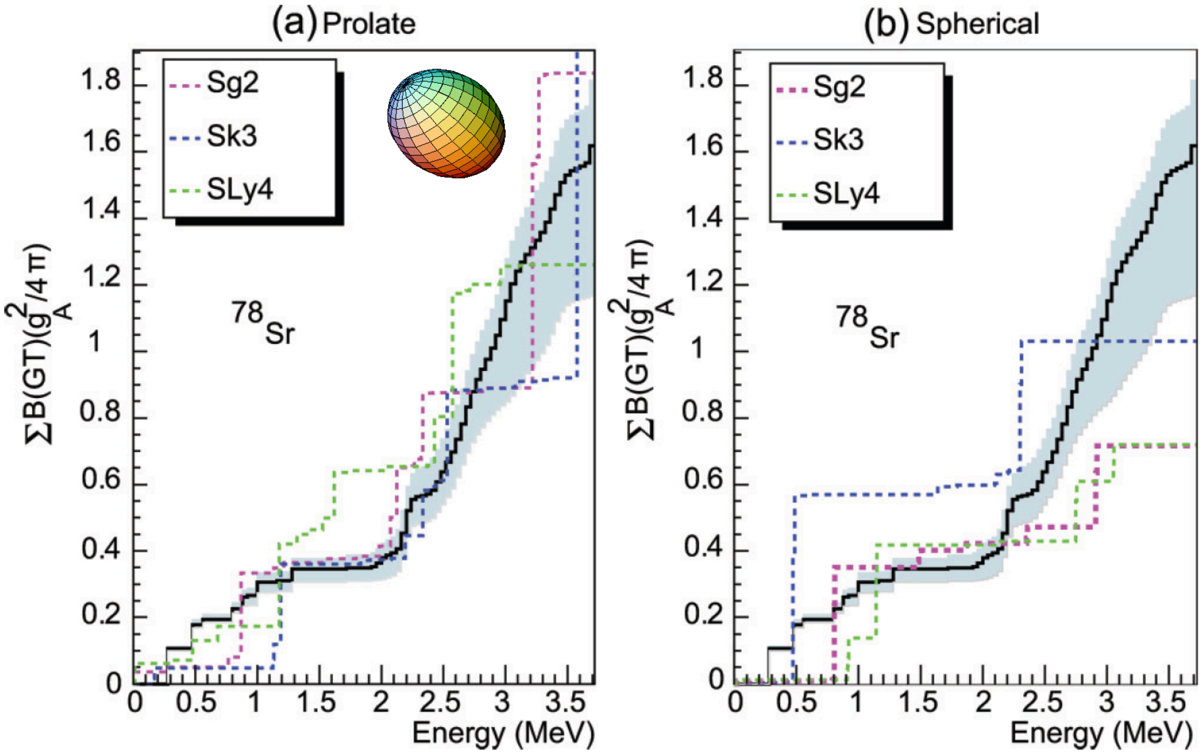
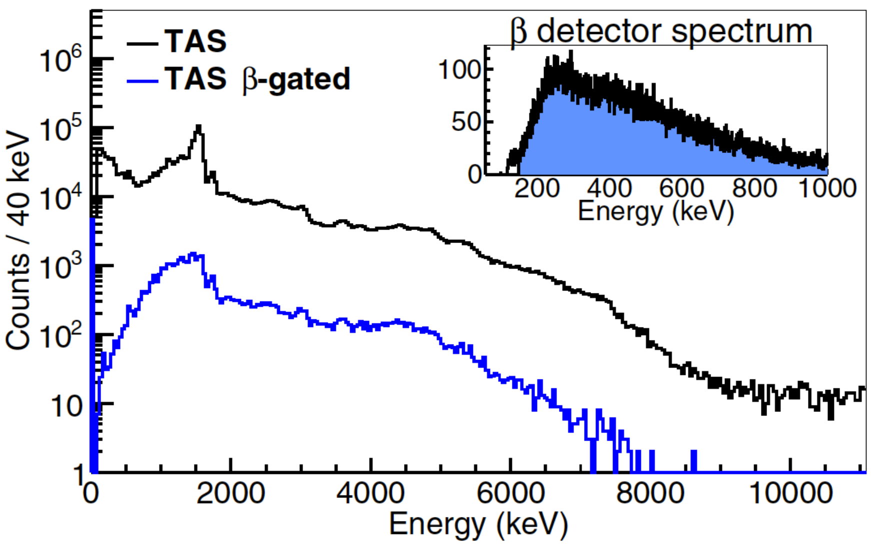


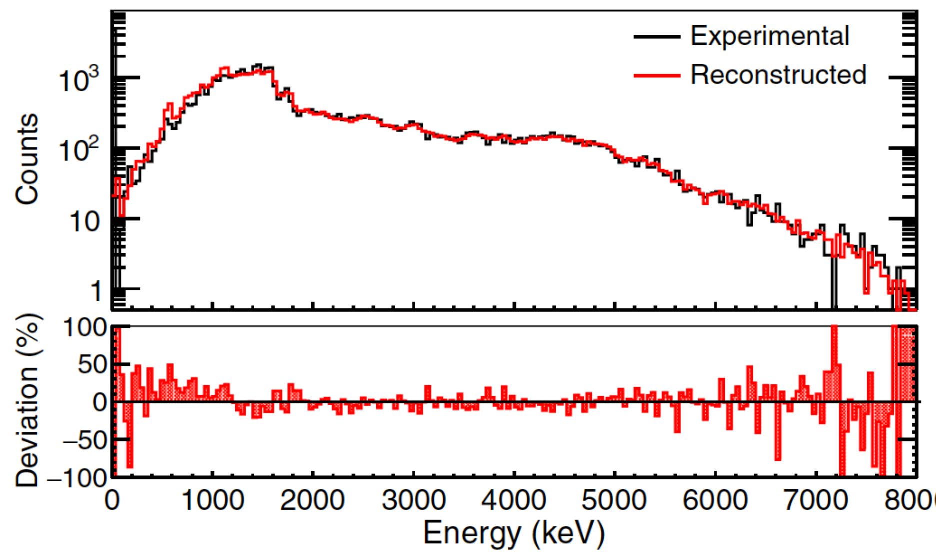
^{72}Kr case

PHYSICAL REVIEW C **92**, 054326 (2015)

Shape study of the $N = Z$ nucleus ^{72}Kr via β decay

J. A. Briz,[1,*] E. Nácher,[1,2] M. J. G. Borge,[1,3] A. Algora,[2,4] B. Rubio,[2] Ph. Dessagne,[5,6] A. Maira,[1] D. Cano-Ott,[2,7] S. Courtin,[5,6] D. Escrig,[1] L. M. Fraile,[8] W. Gelletly,[9] A. Jungclaus,[1] G. Le Scornet,[3] F. Maréchal,[5,6] Ch. Miehé,[5,6] E. Poirier,[5,6] A. Poves,[10] P. Sarriguren,[1] J. L. Taín,[2] and O. Tengblad[1]





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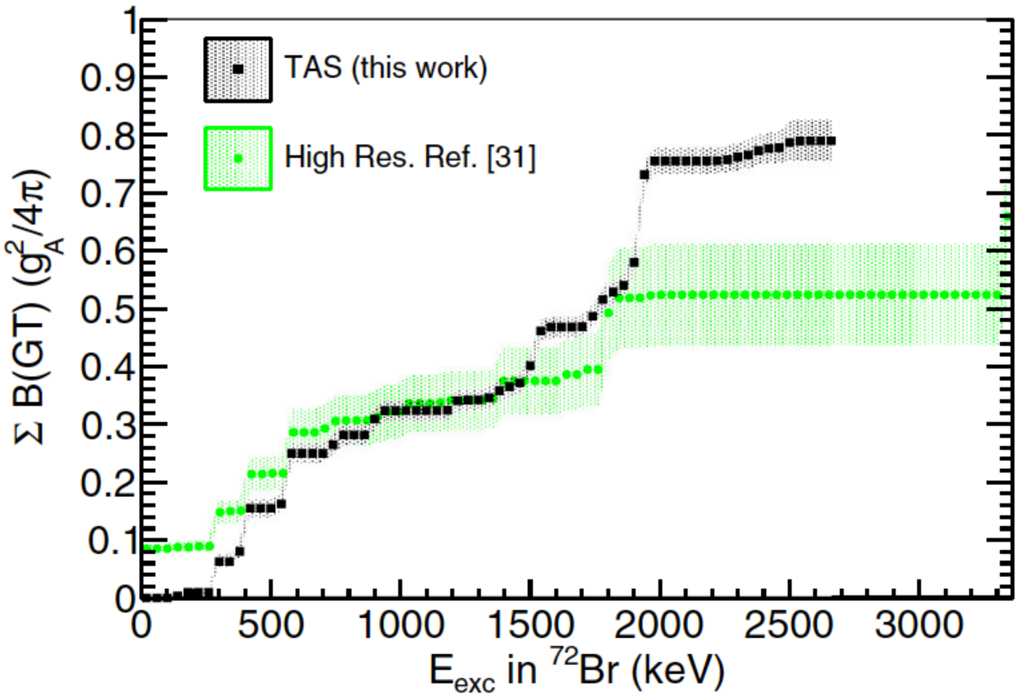

FIG. 9. (Color online) Comparison of the accumulated B(GT) distribution with results from the high-resolution spectroscopy study of Piqueras *et al.* [31]. Evidence of the Pandemonium effect can be seen.

The answer is not always clear

PHYSICAL REVIEW C **92**, 054326 (2015)

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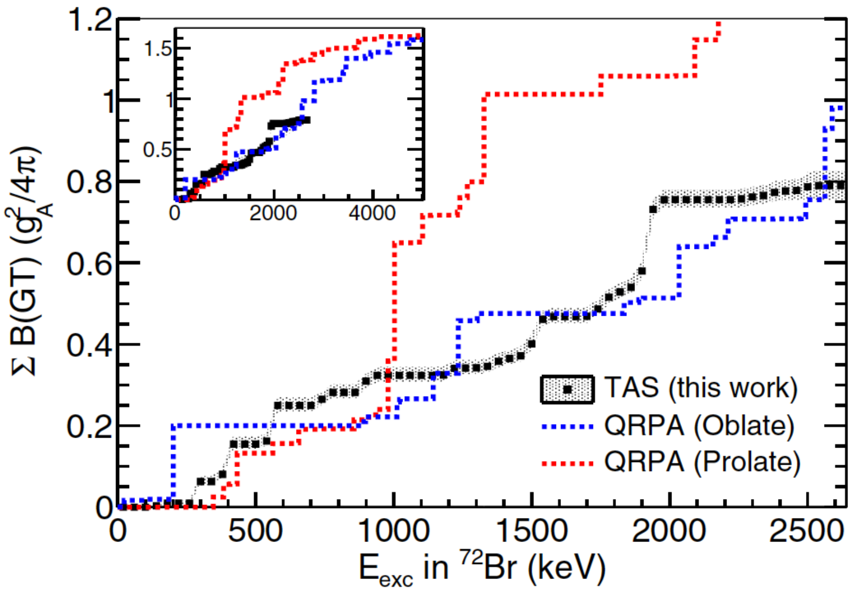
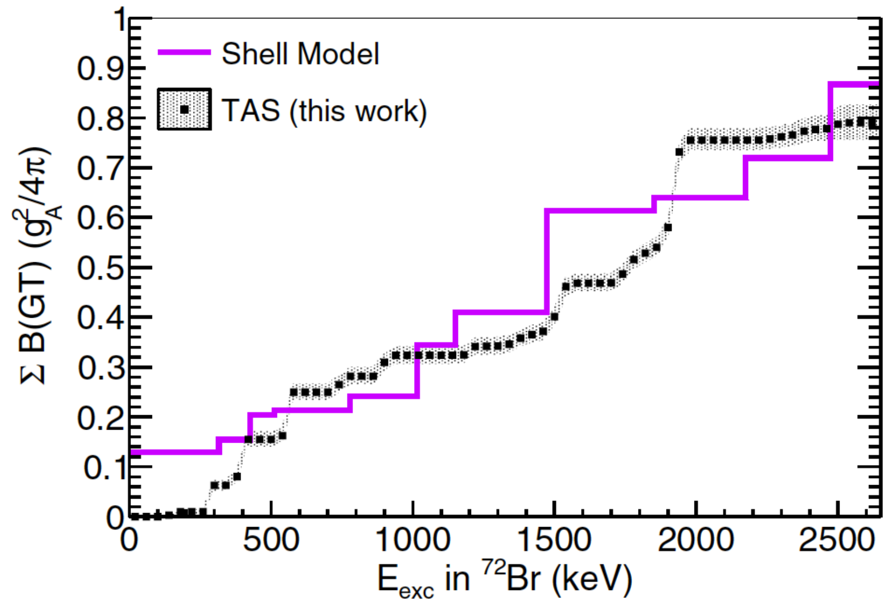
QRPA calculations (Sarriguren)



SM calculations (Poves)



The SM (Poves) and complex Excited VAMPIR calculations (Petrovici) imply a ground state with mixed configuration (oblate-prolate mixing)

SM predicts more gs feeding

Can an answer still be given?

J. A. BRIZ *et al.*

TABLE II. Accumulated $B(\mathrm{GT})$ values (in units of $g_A^2/4\pi$) for the ^{72}Kr decay obtained in this work in comparison with theoretical predictions.

Energy (keV)	Expt. TAS	QRPA [40] Obl.	QRPA [40] Pro.	EXVAM [19] Bonn-A	EXVAM [19] Bonn-CD	Shell model
120	0.0(0)	0.019	0	0.03	0.06	0.13
1000	0.32(2)	0.22	0.36	0.12	0.17	0.24
2000	0.76(2)	0.51	1.10	0.55	0.51	0.64
2680	0.79(4)	0.98	1.40	0.63	0.59	0.87
5000		1.58	1.64	0.82	0.70	1.23

Other experiments were consistent with an oblate shape

A. Gade et al., PRL 96 (2006) 189901; E. Bouchez et al., PRL 90 (2003)082502; H. Iwasaki et al. PRL112 (2014) 142502

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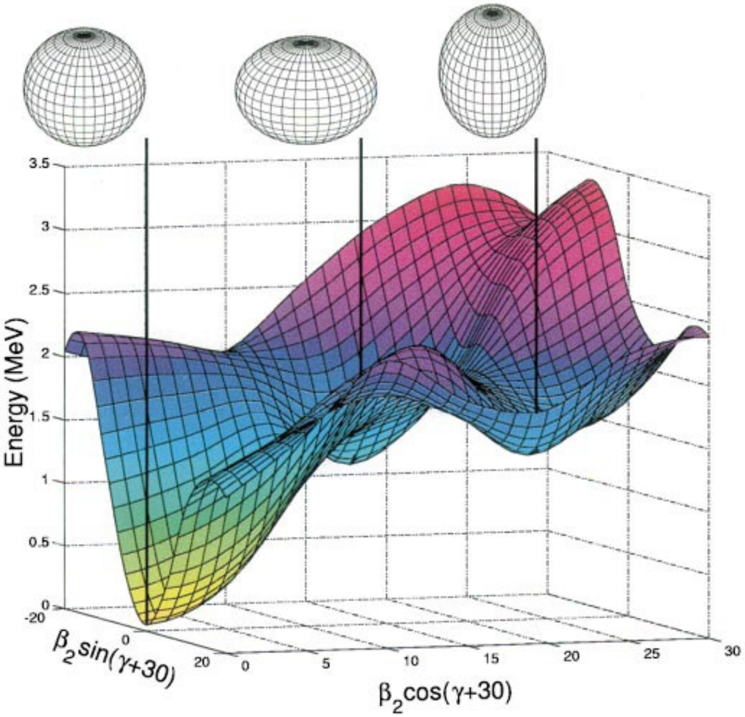
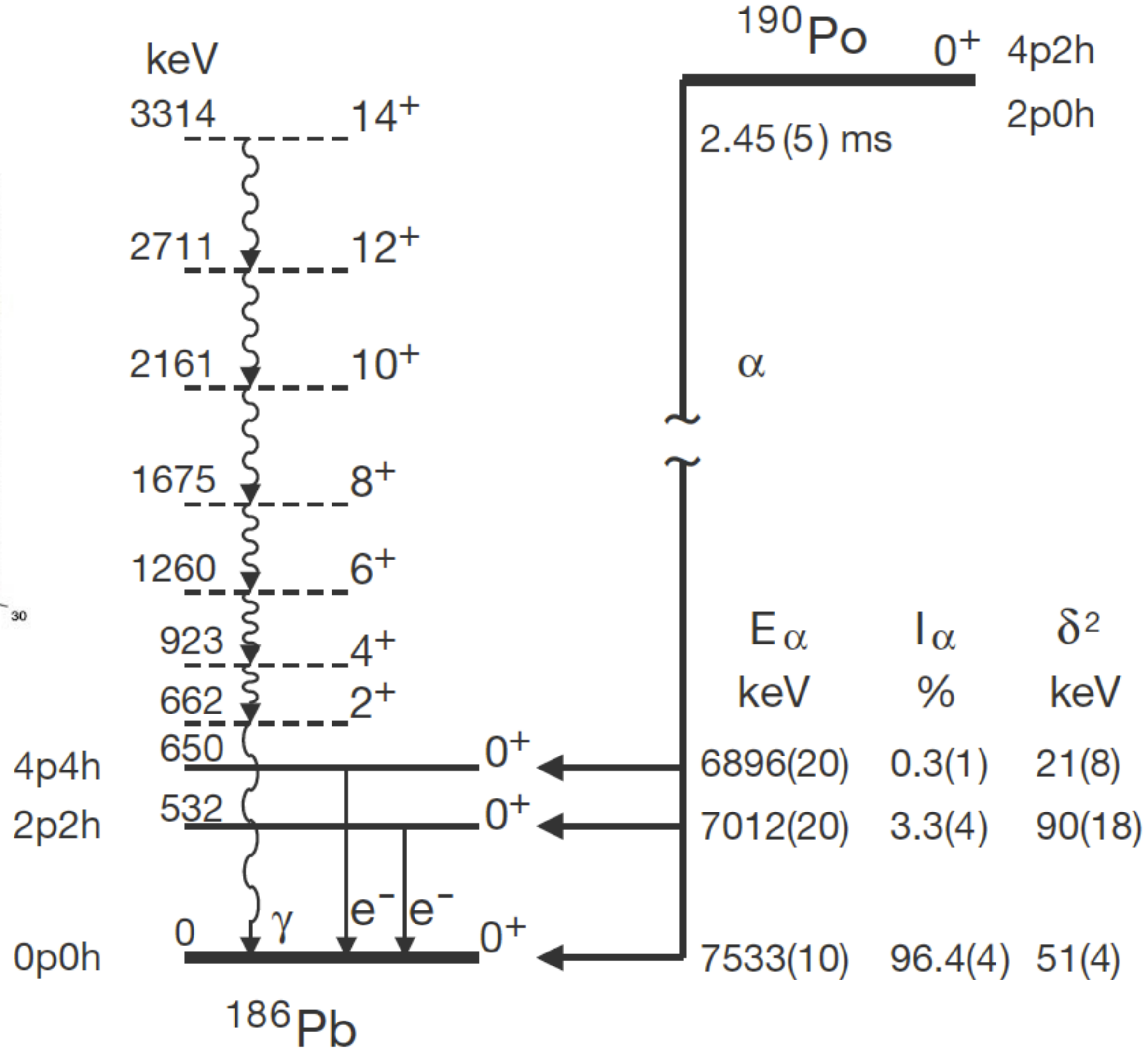
Possible questions

- is the method only valid for A~80 ?
- was the good agreement accidental ?
- because the method can be useful for exotic nuclei
- So it is worth explore heavier domains …

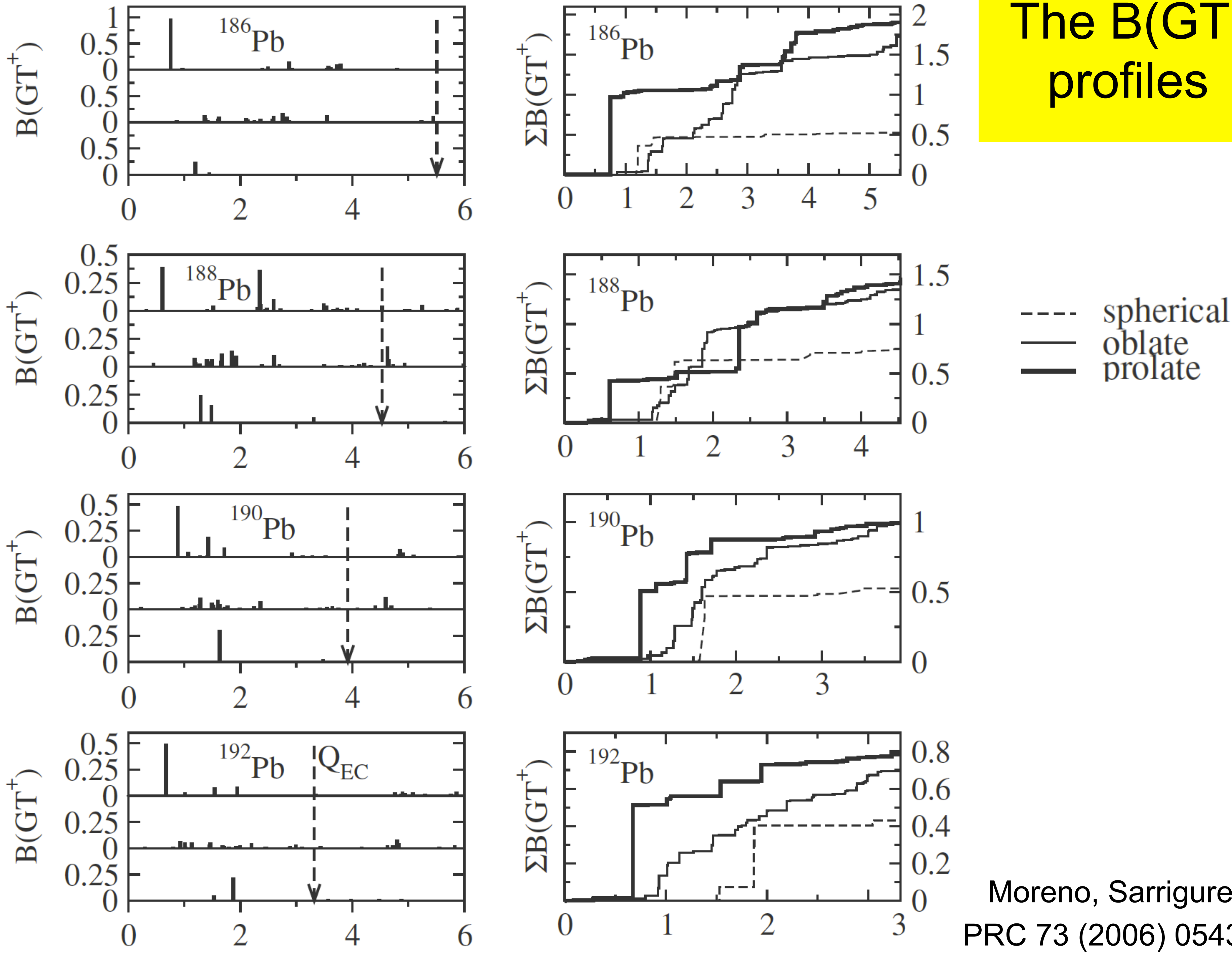
Intruder 0+ states in ^{186}Pb



A. N. Andreyev *et al*.
Nature 405 (2000) 430



The B(GT) profiles

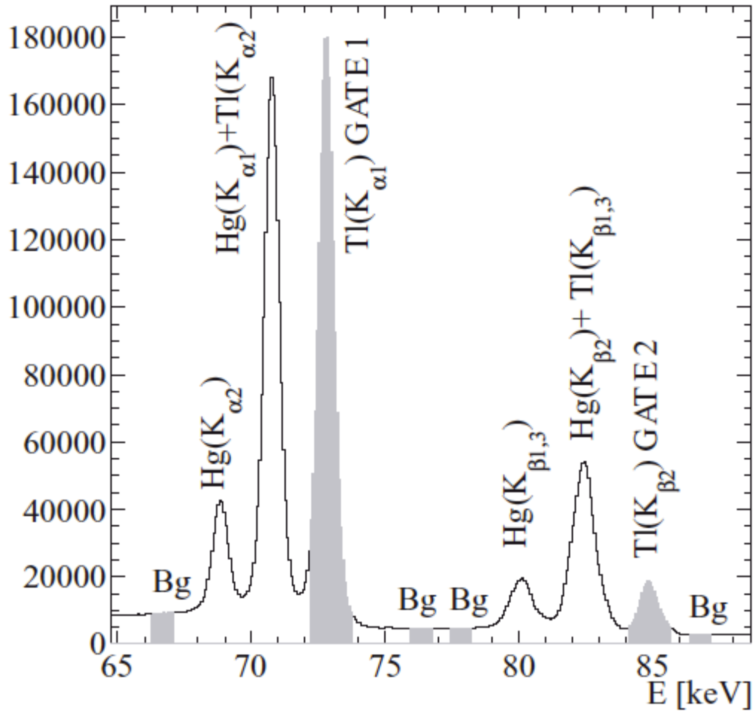


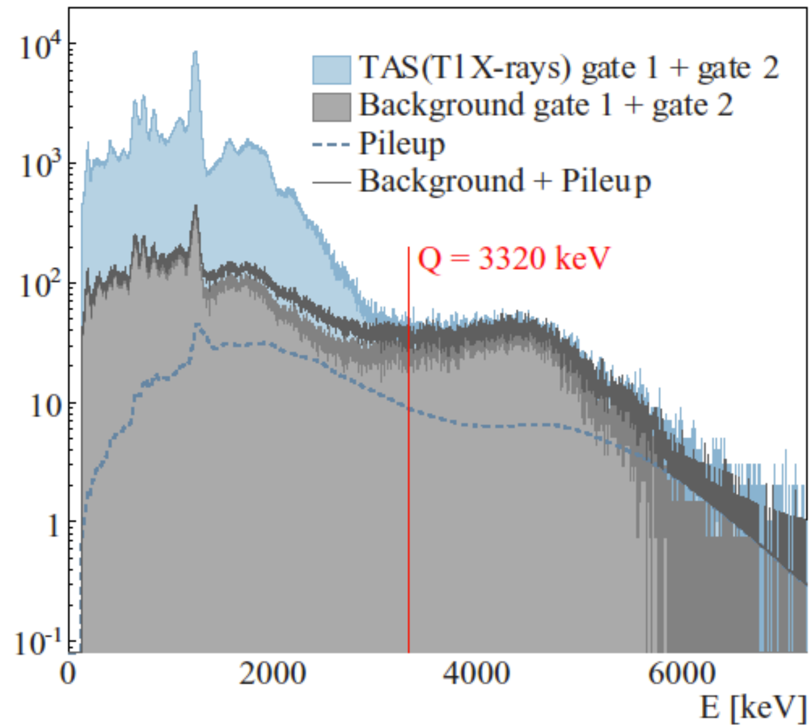
Moreno, Sarriguren
PRC 73 (2006) 054317

IS440 results: $^{192}Pb \to {}^{192}Tl$ example (proposal by Algora, Rubio, Gelletly)

$${}_Z A_N \rightarrow {}_{Z-1}A_{N+1} + e^+ + \nu \qquad \beta^+$$

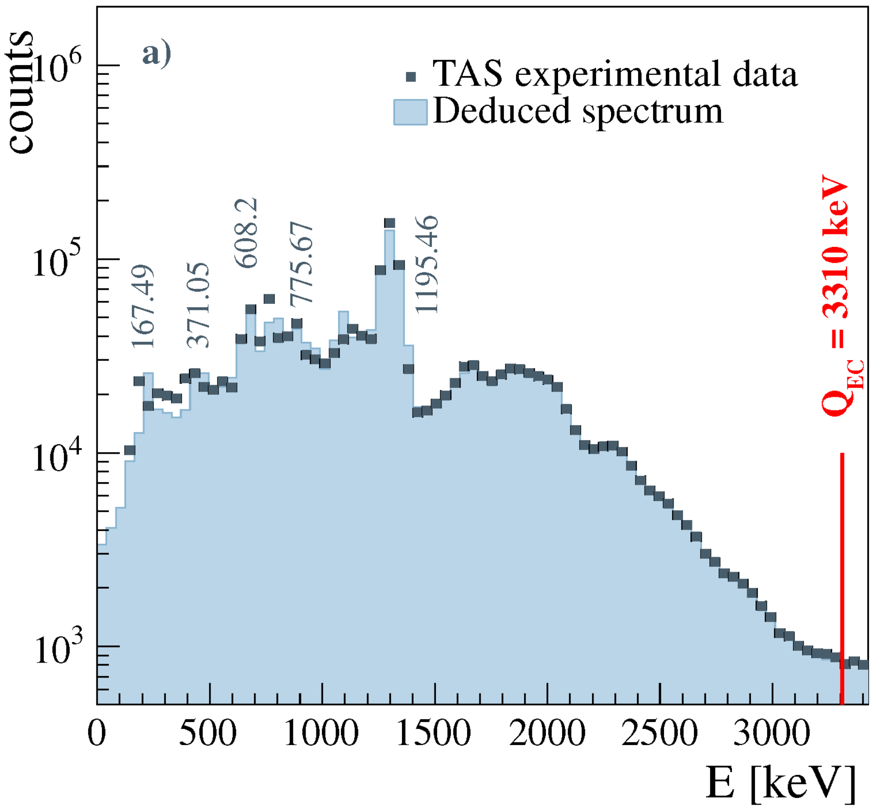
$${}_Z A_N + e^- \rightarrow {}_{Z-1}A_{N+1} + \nu + X_{ray} \qquad \text{EC}$$

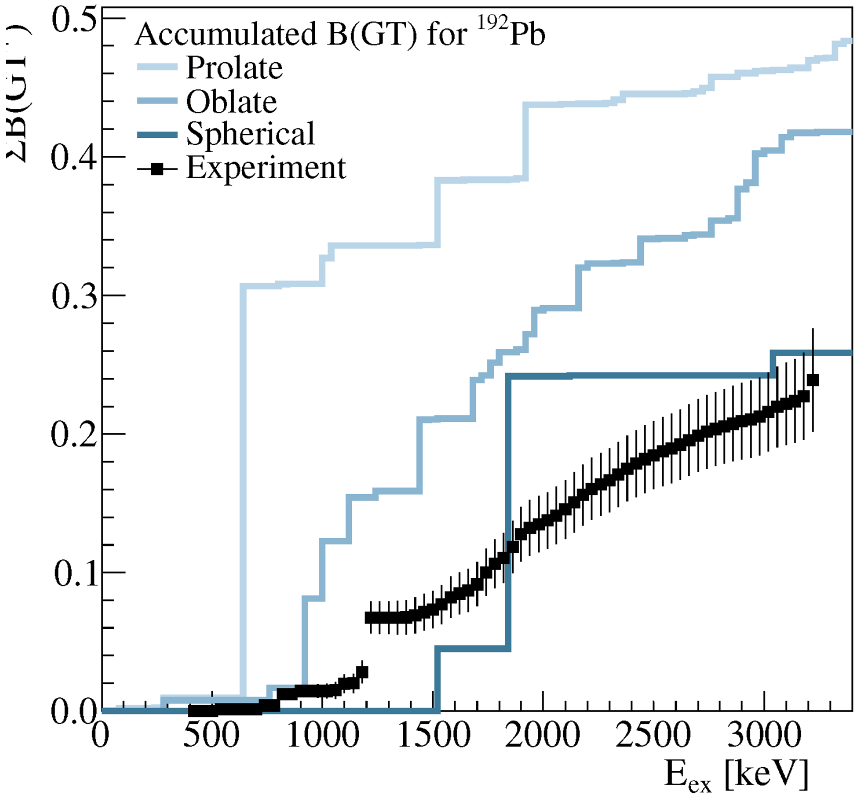




Thesis work of M. E. Estevez 2011, and M. E. Estevez *et al. PRC 92, 044321 (2015)*.

IS440 results: ^{192}Pb example





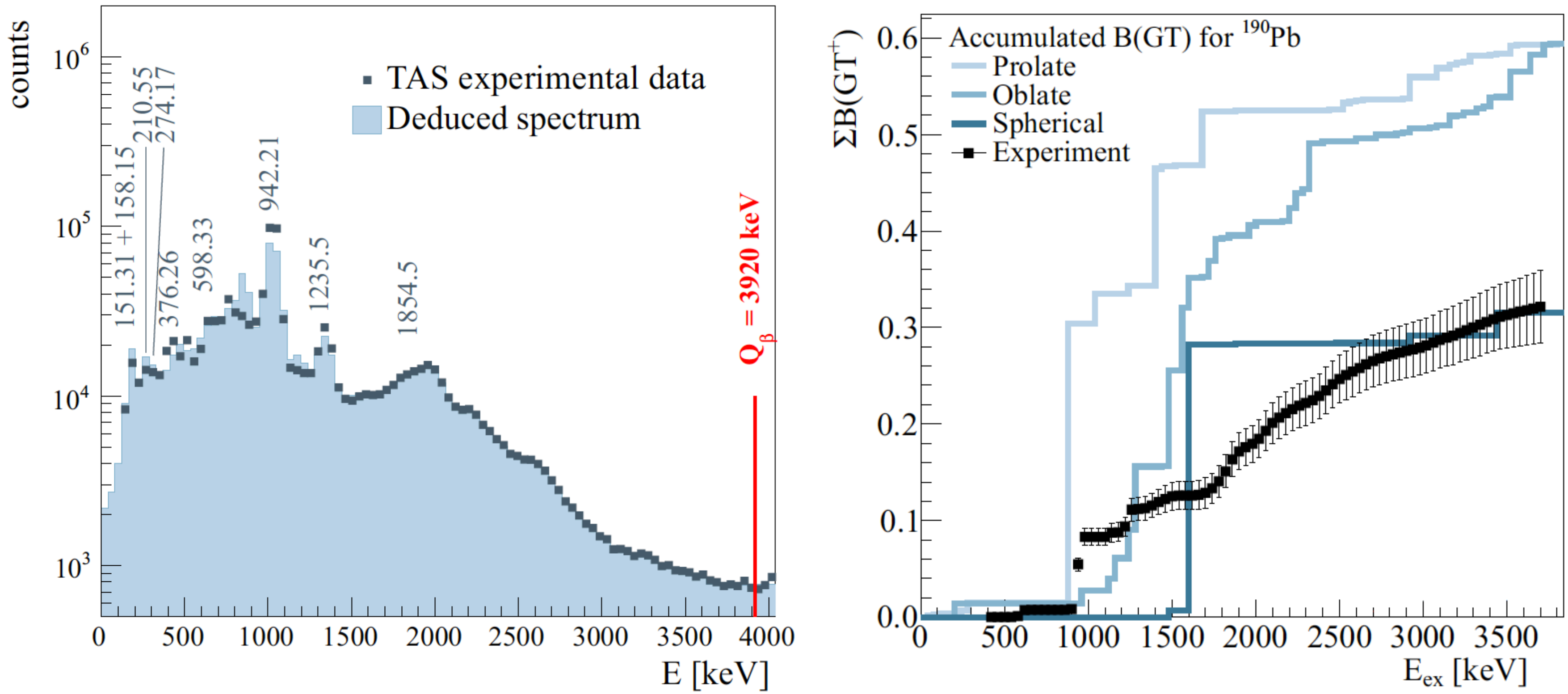
Thesis work of M. E. Estevez 2011, and M. E. Estevez *et al. PRC 92, 044321 (2015)*.

Theory from PRC 73 (2006) 054317)

Results consistent with spherical picture, but less impressive than in the A≈80 region.

Experiment has more "spreading" than theory. Similar situation for ^{190}Pb. *Possible explanation, the spherical character of the Pb nuclei, but requires further testing.*

IS440 results: ^{190}Pb



Thesis work of M. E. Estevez 2011, and M. E. Estevez *et al. PRC 92, 044321 (2015)*.

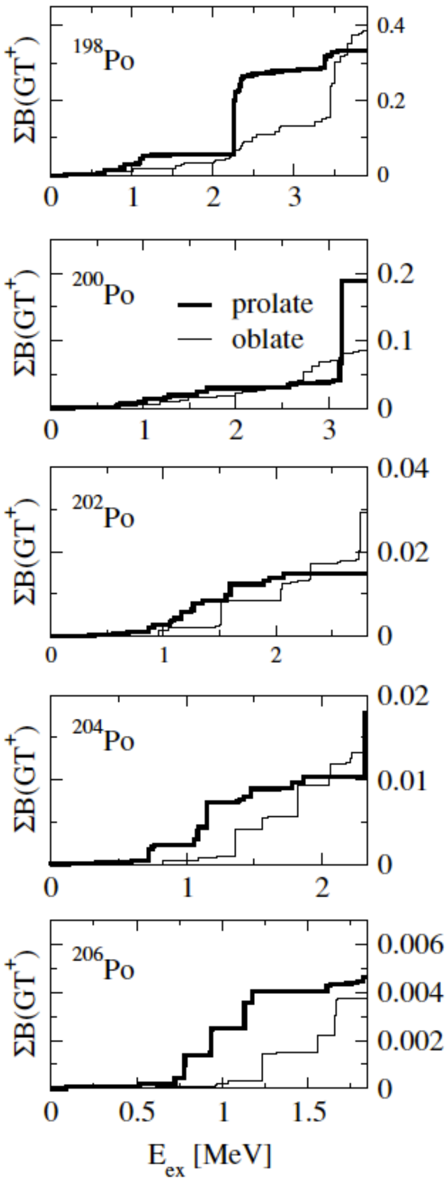
Theory from PRC 73 (2006) 054317)

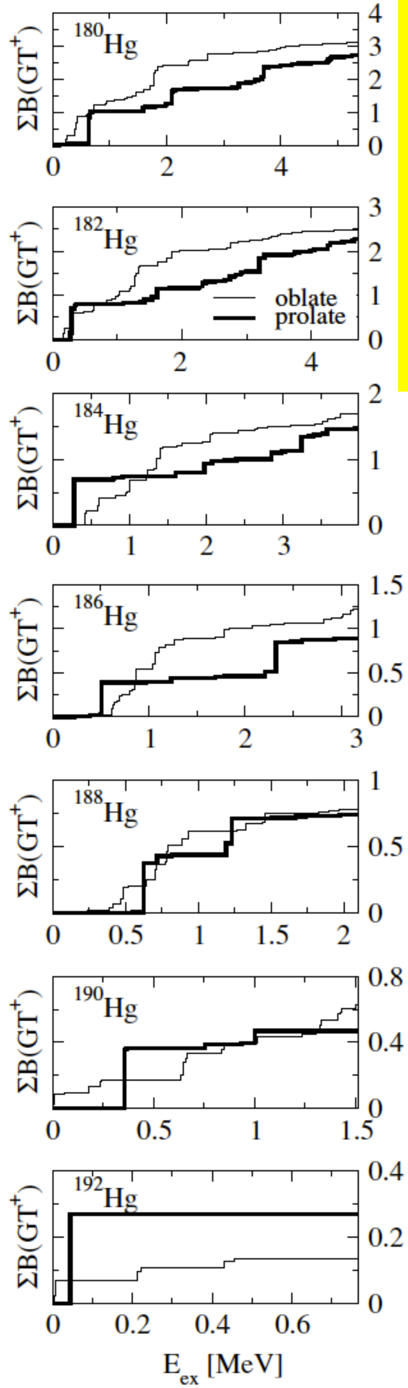
Results consistent with spherical picture, but less impressive than in the A≈80 region. *Possible explanation, the spherical character of the Pb nuclei, but requires further testing.*

On-going and future studies in the region

(even Hg experiment already performed)

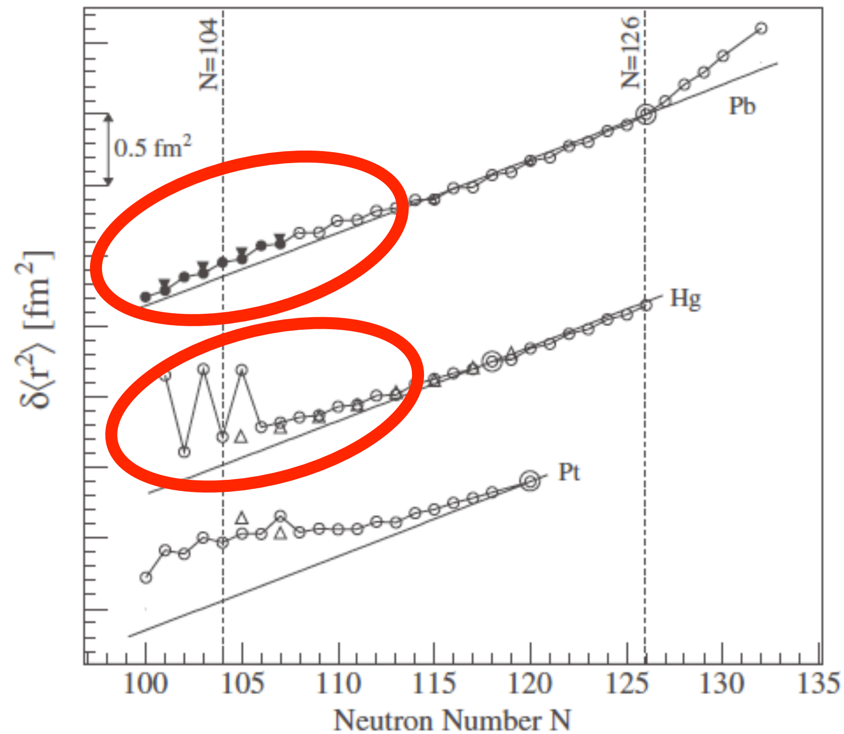
Prop by: Algora, Fraile, Nácher





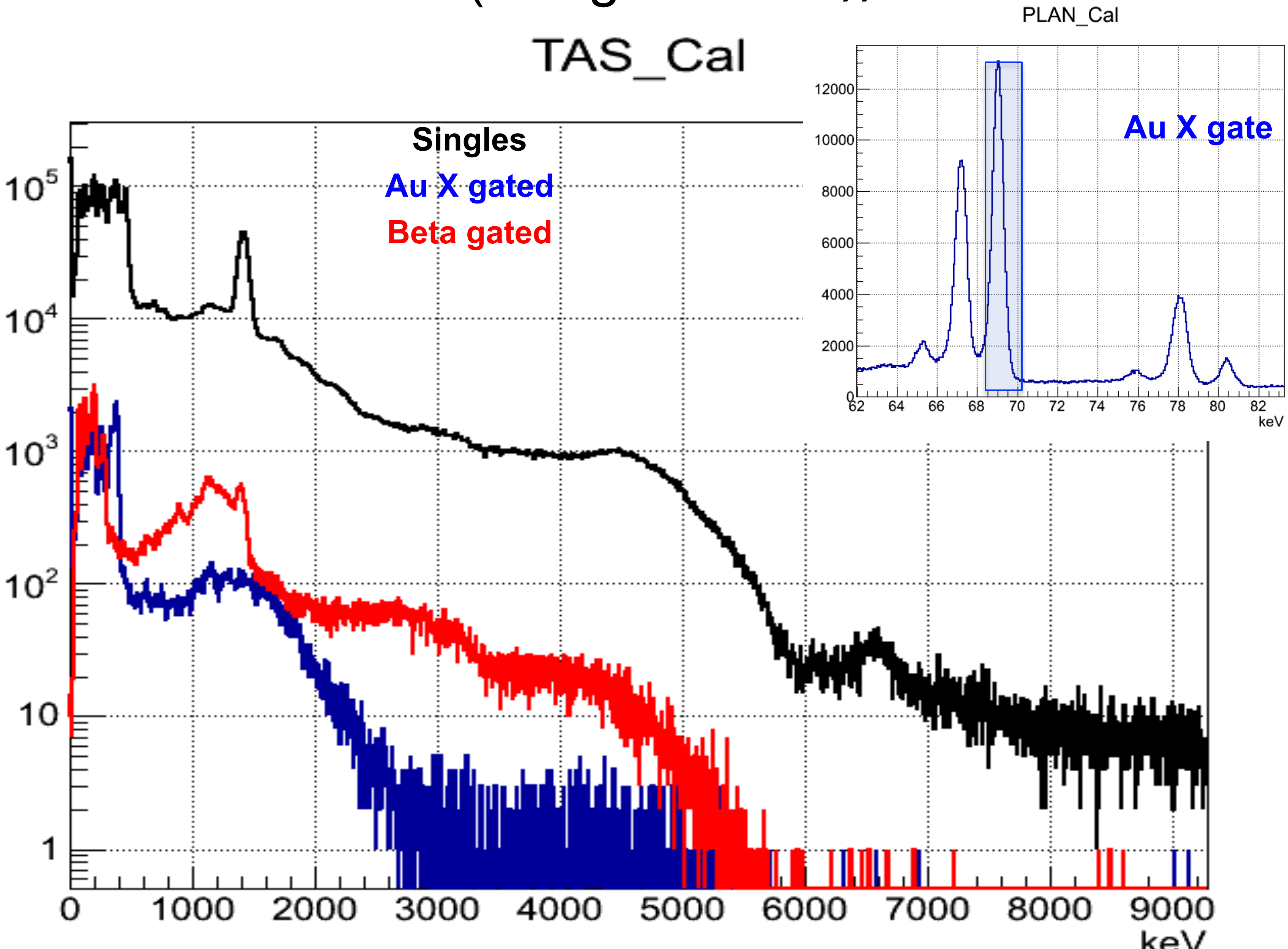
O. Moreno *et al.*
PRC 73, 054302

H. De Witte *et al. PRL 98, 0112502*

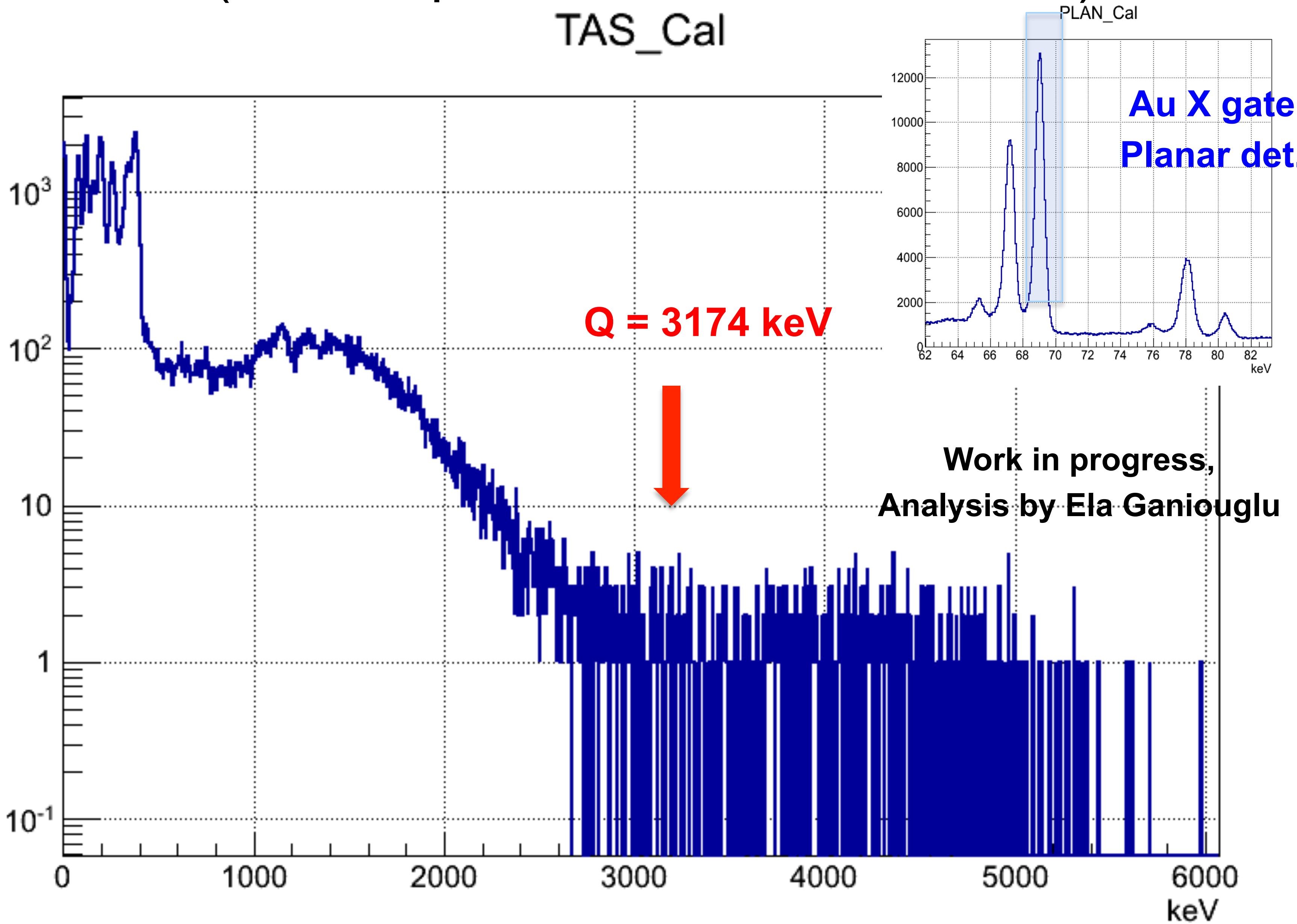


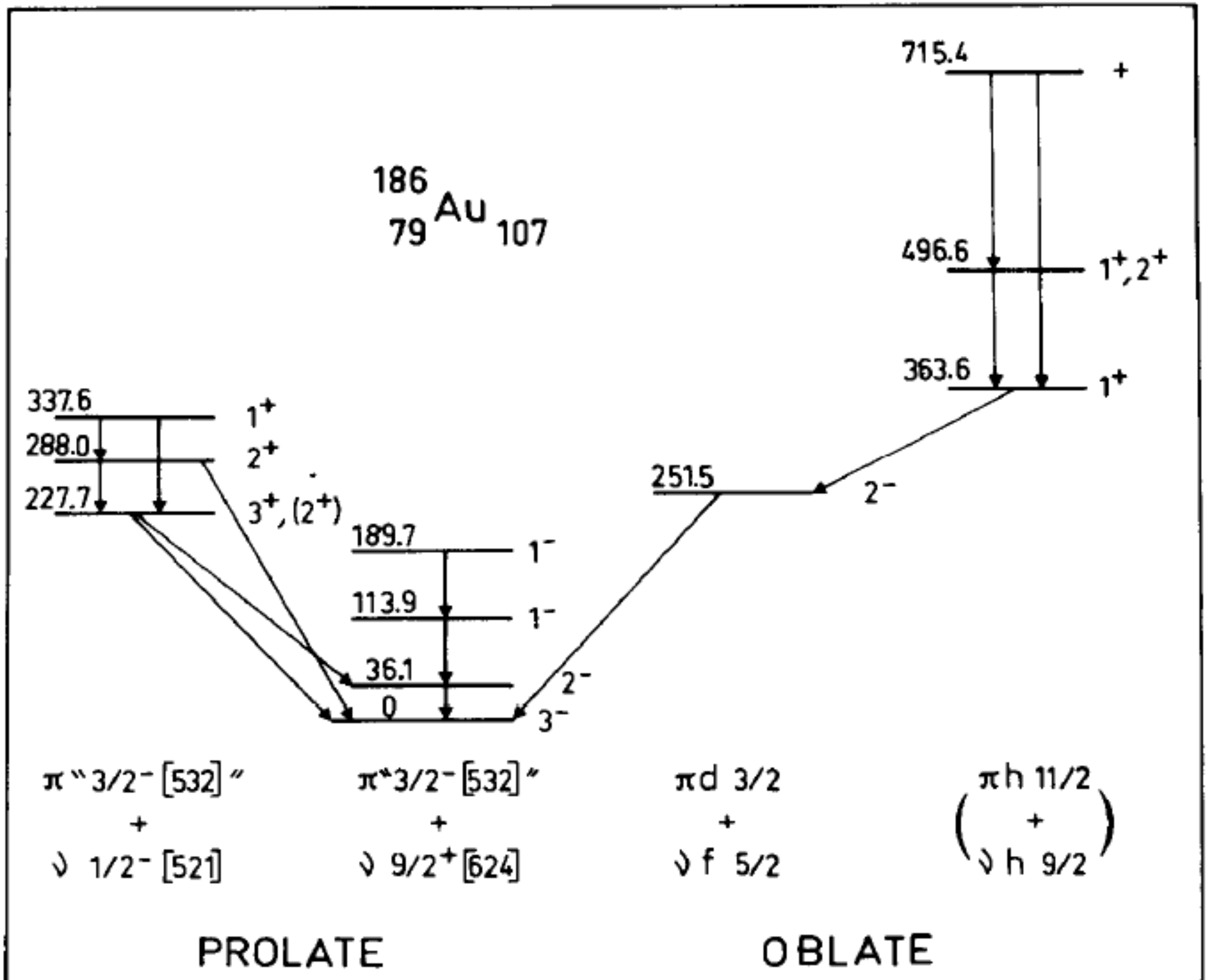
Also T. Cocolios *et al*. *PRL 106, 052503*

On-line spectra from mass 186, the alchemist dream (^{186}Hg -> ^{186}Au))



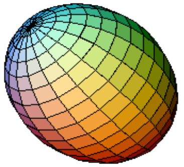
On-line spectra TAS spectrum from mass 186 (EC component, two list mode files)





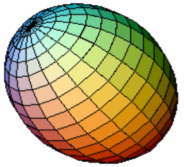
715.4
+
496.6
1+, 2+
363.6
1+
186
79 Au 107
337.6
1+
288.0
2+
227.7
3+, (2+)
189.7
1−
113.9
1−
36.1
2−
0
3−
251.5
2−
π "3/2− [532]"
+
ν 1/2− [521]
π "3/2− [532]"
+
ν 9/2+ [624]
πd 3/2
+
ν f 5/2
πh 11/2
+
ν h 9/2
PROLATE
OBLATE

Is the TAS answer meaningful ?



Decaying ISOTOPE	TAS Def. (Sarriguren)	Moller Def.	ETFSI Def.
72Kr	-0.3 (+10% +0.4 ?) or mixed config	-0.35	-0.40
74Kr	Mixed config	+0.40	-0.30
76Sr	~+0.4	+0.42	+0.44
78Sr	~+0.4	+0.42	+0.43
190Pb	~0.0	0.00	-0.02
192Pb	~0.0	0.00	-0.02

Is the TAS answer meaningful ?



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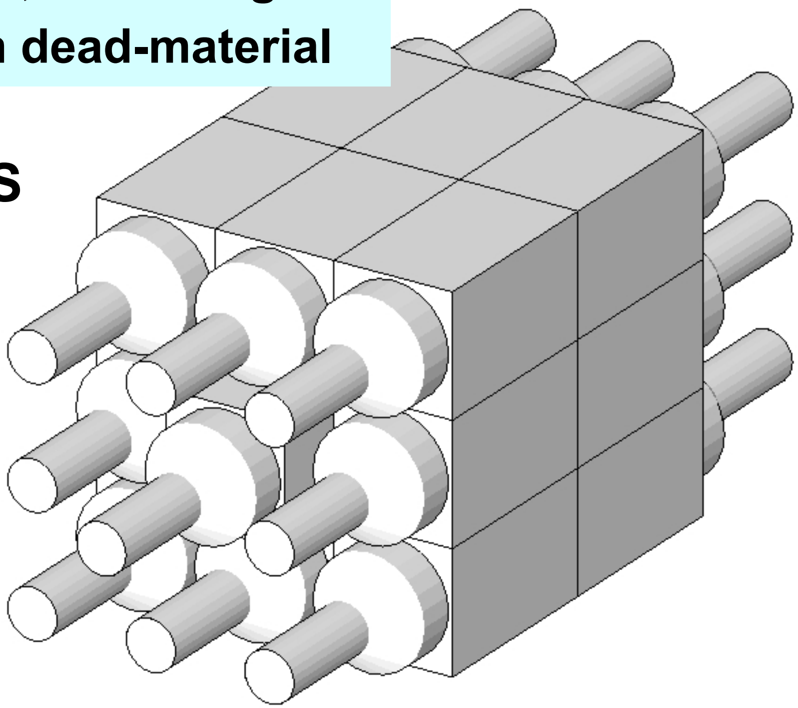
78Sr	~+0.4	+0.42	+0.43	✔
190Pb	~0.0	0.00	-0.02	✔
192Pb	~0.0	0.00	-0.02	✔

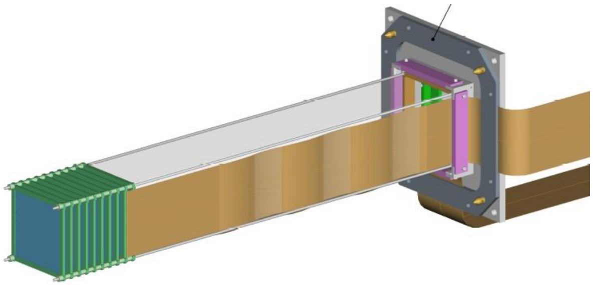
DTAS detector for DESPEC(FAIR)

16 + (2) modules:
15 x15 x 25 cm^3 NaI(Tl)
+ 5" PMT (50% light col.)
V= 95 L, M= 351 kg
Minimum dead-material

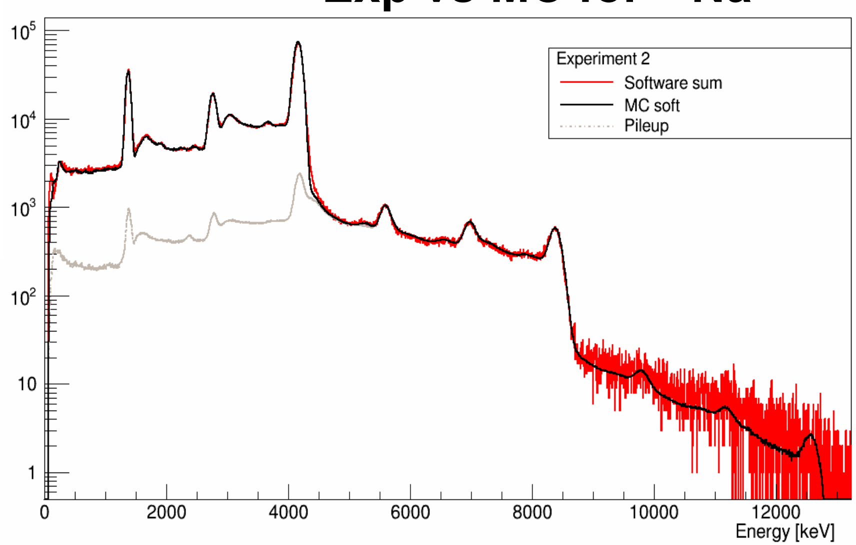
DTAS



Fast ions active stopper: AIDA (Stack of DSSSD)



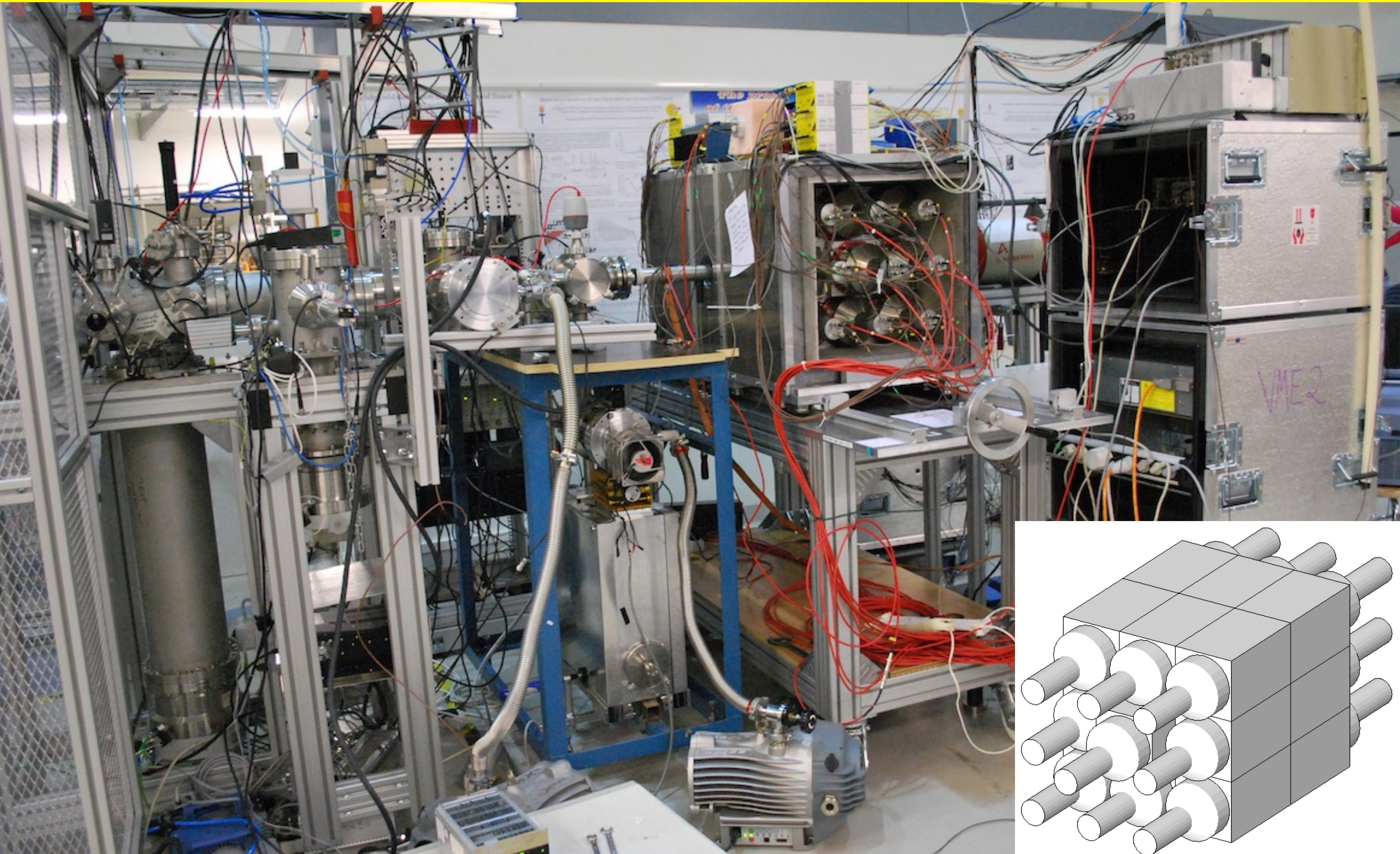
Exp vs MC for ^{24}Na



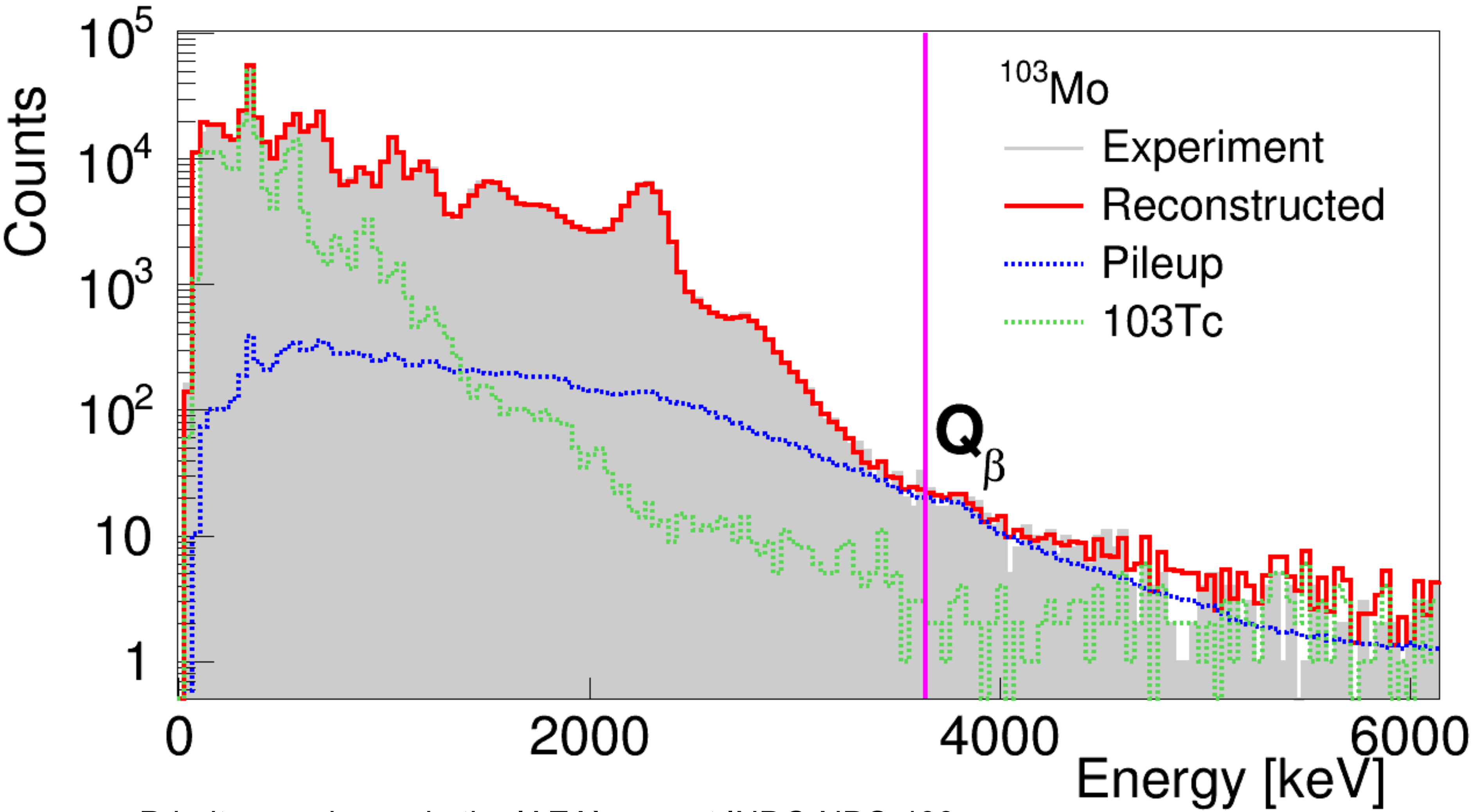
Designed for a fragmentation facility
TDR approved (01/2013)
Commissioning at IFIC (01/2014)
First experiments at JYFL (02-03/2014)

DTAS at Jyväskylä (Feb. 2014)

(collaboration with Subatech, spokespersons: Fallot, Tain, Algora)

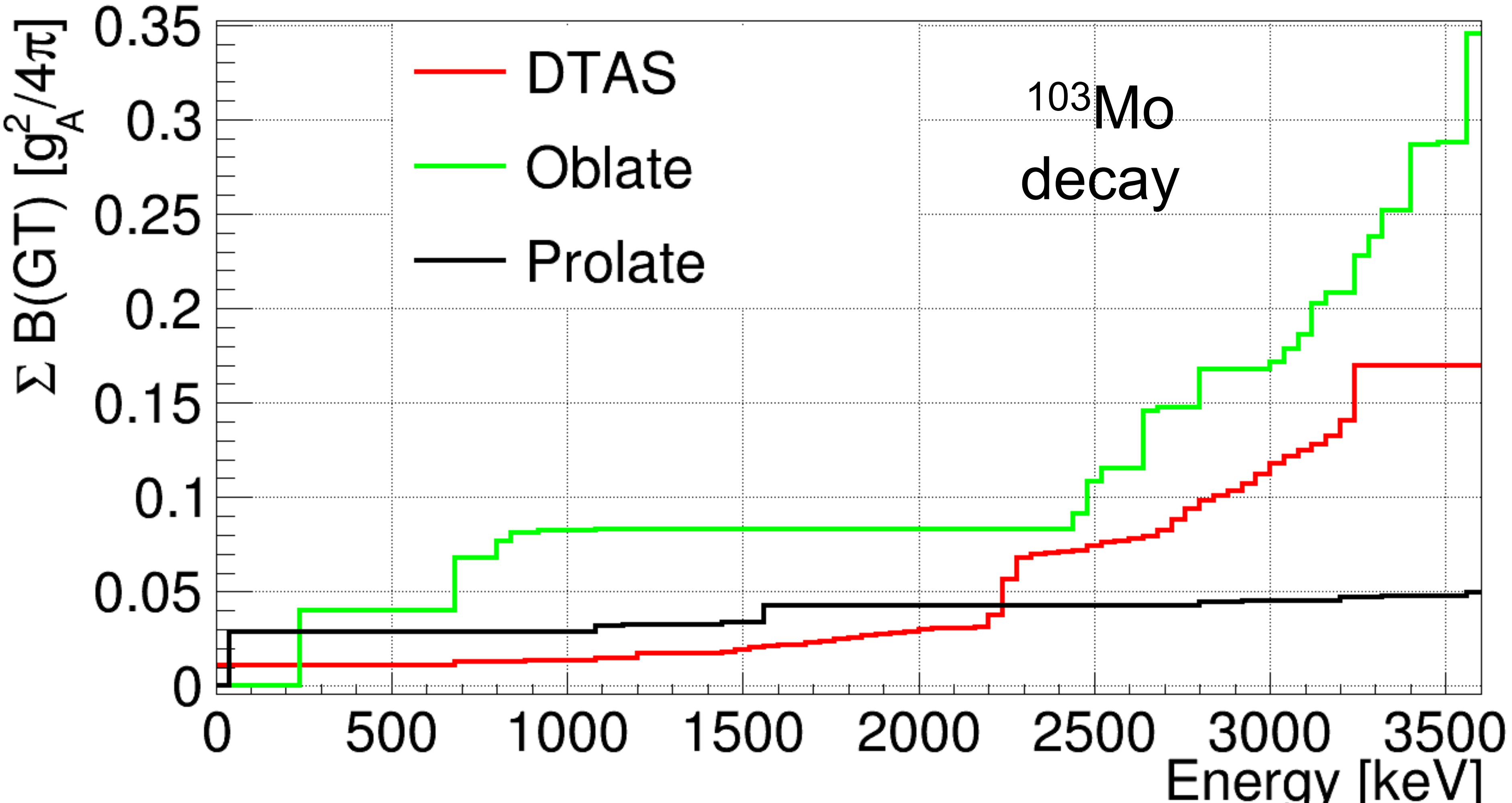


Collateral effect of research for applications



Priority one decay in the IAEA`s report INDC-NDS-499
for decay heat in reactors, measured at IGISOL Jyväskylä
V. Guadilla, thesis work, Valencia

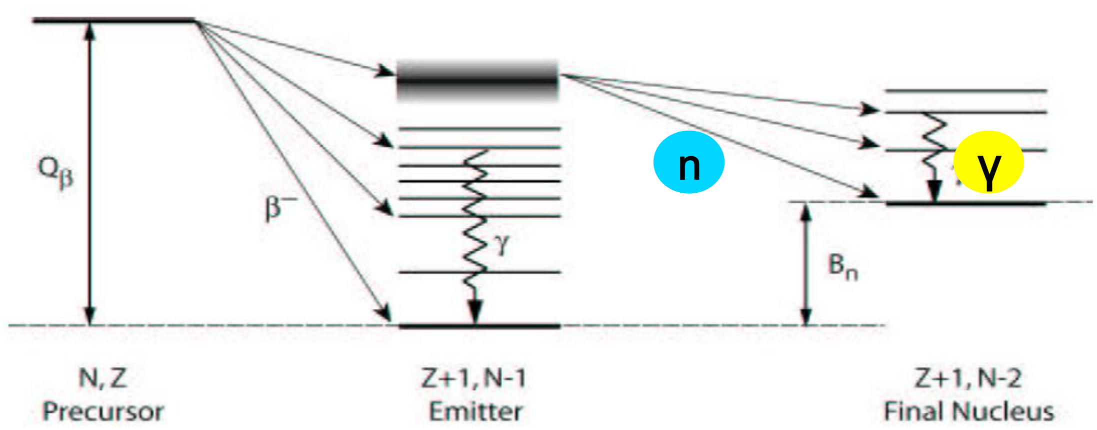
Collateral effect of research for applications



Priority one decay in the IAEAs report indc-nds-499
for decay heat in reactors, measured at IGISOL Jyv.
V. Guadilla, thesis work, Valencia
Theory might be still improved ?, calc. By P. Sarriguren

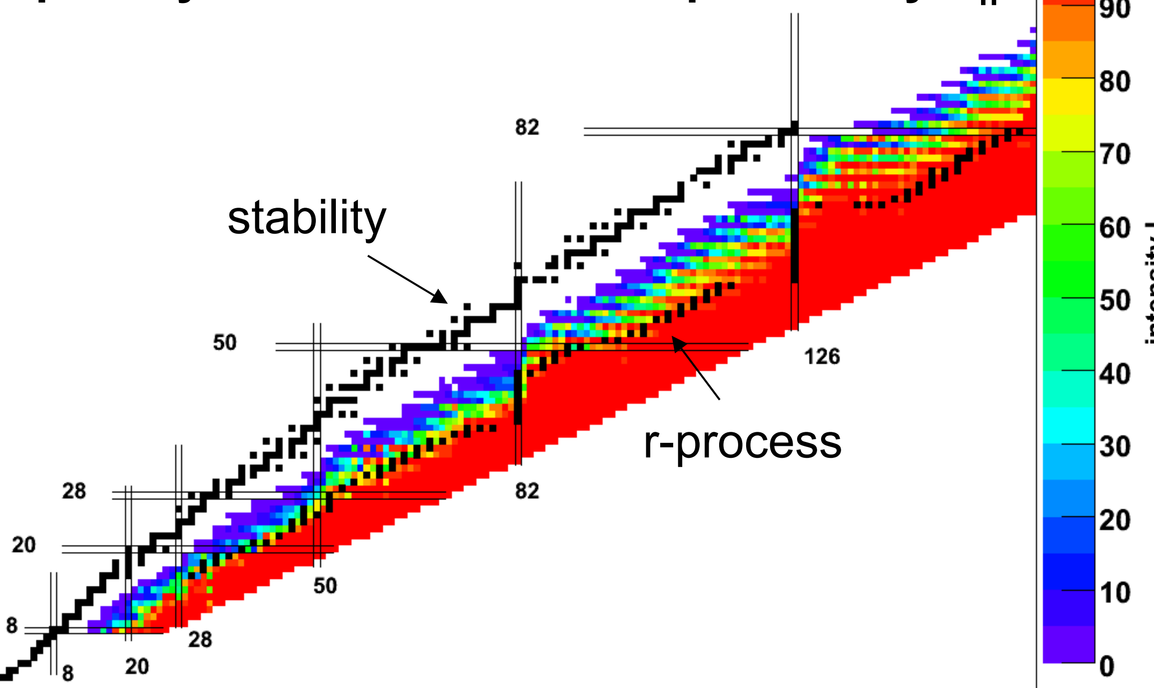
Möller def: + 0.36
ETFSI def*: + 0.35
*transitional region

Beta decay in the ("exotic") neutron rich side

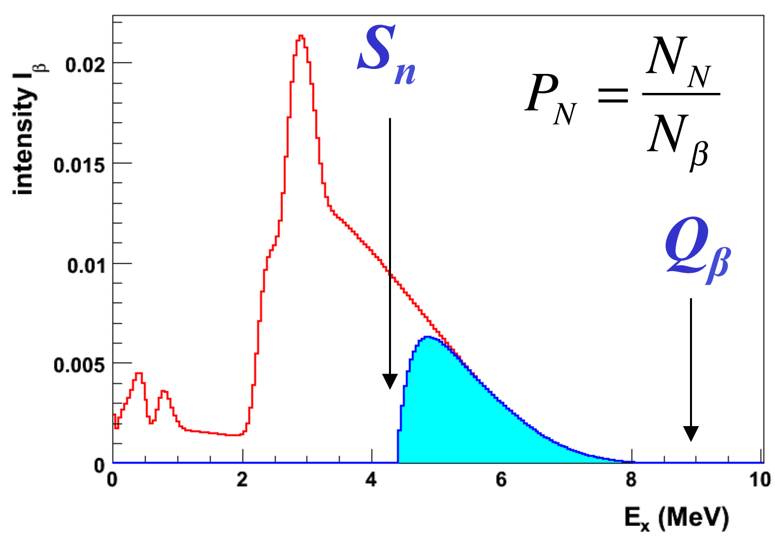


If $S_n < Q_\beta$ and the decay proceeds to states above S_n, neutron emission competes and can dominate over γ-ray de-excitation

β-delayed neutron emission probability P_n

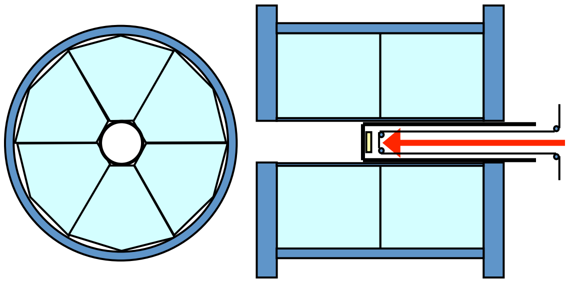


The process will dominate far from stability on the n-rich side. To have a full picture of the strength …

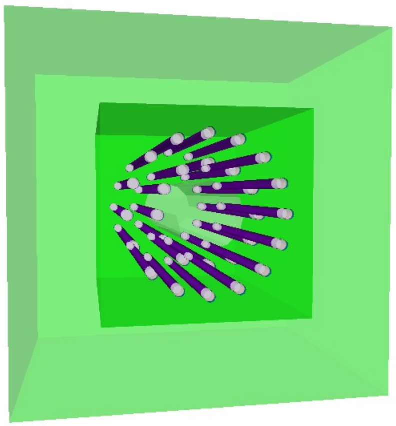


Beta strength measurements: combination of techniques

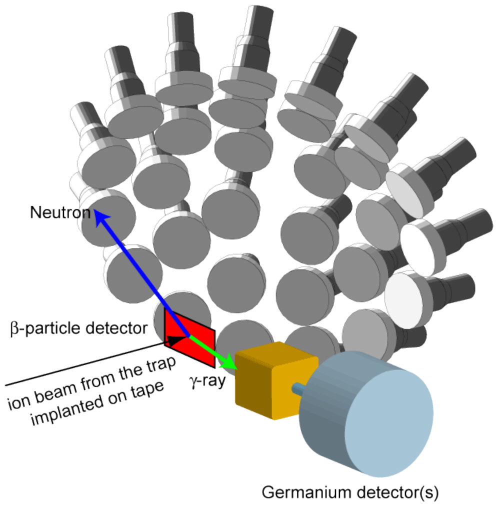
Total Absorption γ-Ray Spectrometer



4π Neutron Counter



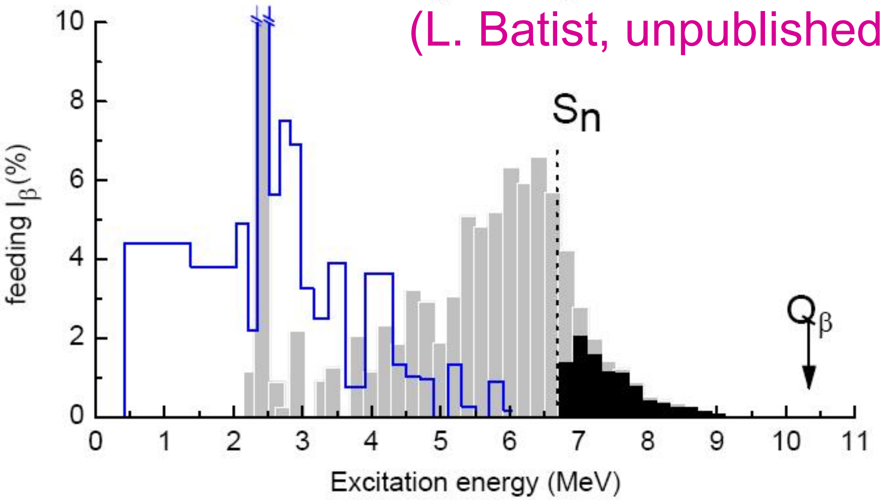
Neutron Time of Flight Spectrometer



Beta decay of ^{94}Rb

Distribution of the beta-decay feeding to the ^{94}Sr states.

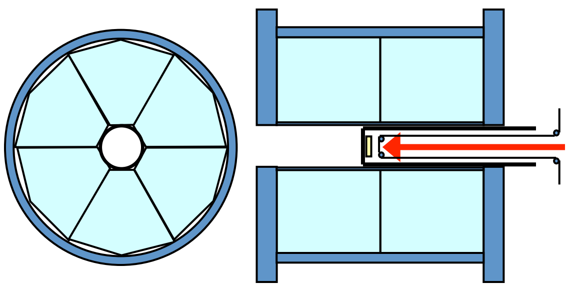
(L. Batist, unpublished)



- TAGS provides data free of "Pandemonium" systematic error
- 4π n-Counter provides P_n
- n-ToF Array provides the E_n distribution

Beta strength measurements: combination of techniques

Total Absorption γ-Ray Spectrometer



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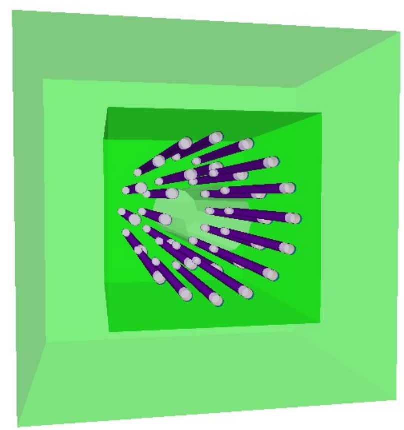

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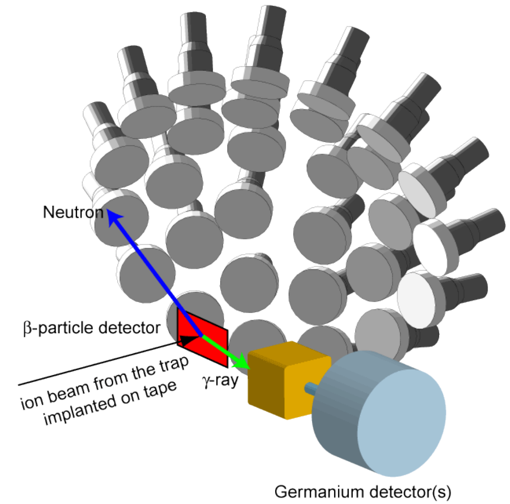

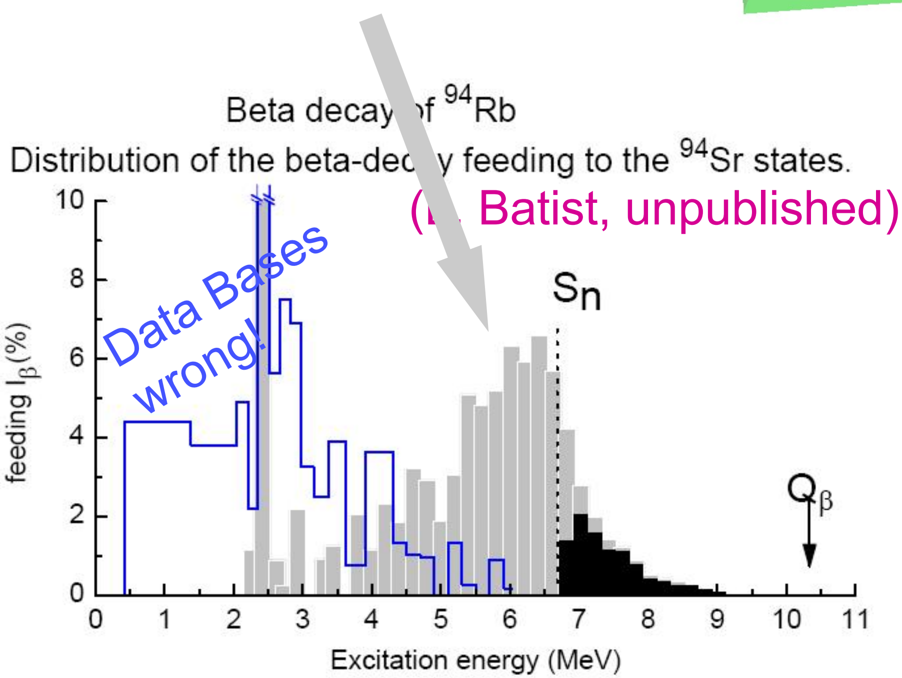

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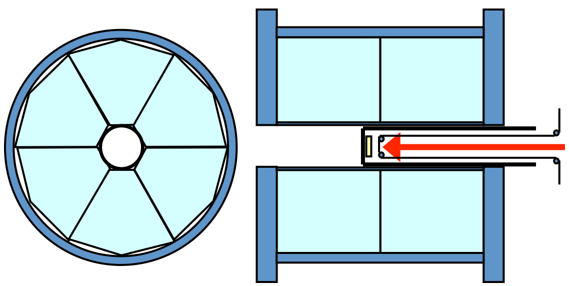

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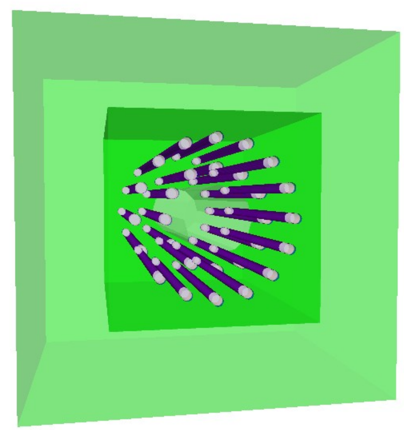
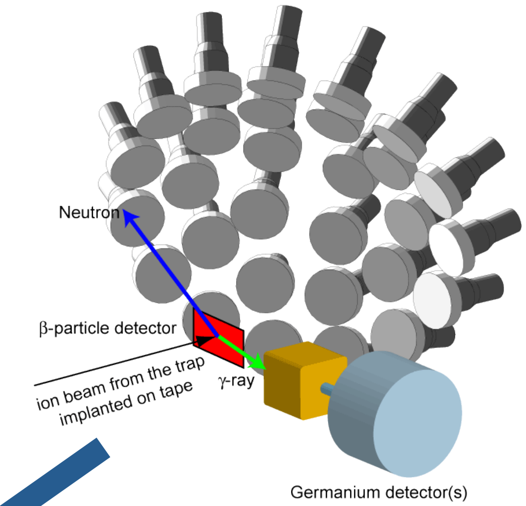
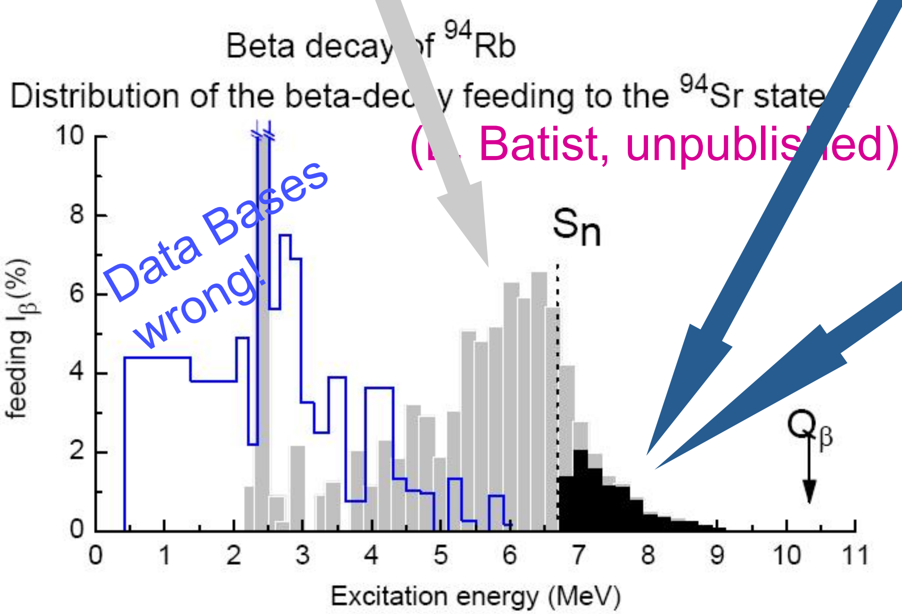


Neutron Time of Flight Spectrometer





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- 4π n-Counter provides P_n
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What can $T_{1/2}$ and P_n measurements provide ?

$$B_{i\to f} \sim \left|\left\langle \Psi_f \right| \tau^{\pm} \; or \; \sigma\tau^{\pm} \left| \Psi_i \right\rangle\right|^2$$

$$\frac{1}{T_{1/2}} = \frac{(g_A / g_V)^2_{eff}}{D} \sum_{0<E_{ex}<Q_\beta} f(Z, Q_\beta - E_{ex}) B(GT, E_{ex})$$

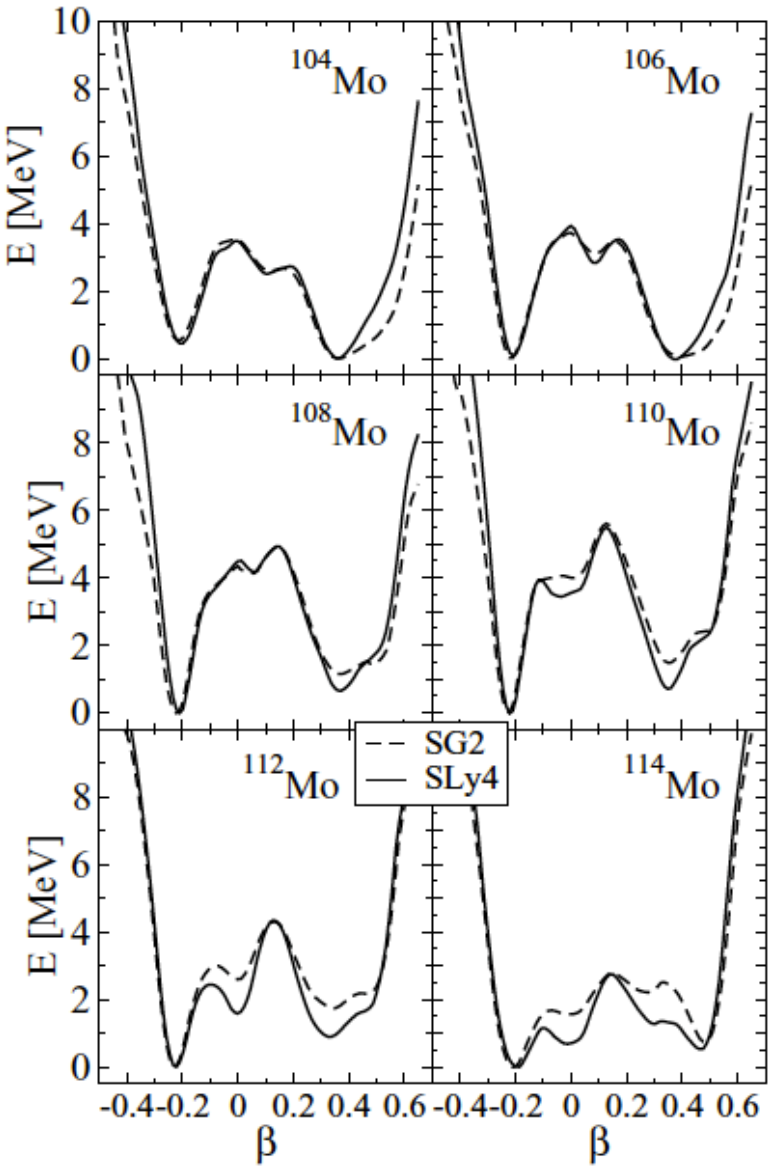
$$P_n = \frac{\sum_{S_n<E_{ex}<Q_\beta} f(Z, Q_\beta - E_{ex}) B(GT, E_{ex})}{\sum_{0<E_{ex}<Q_\beta} f(Z, Q_\beta - E_{ex}) B(GT, E_{ex})}$$

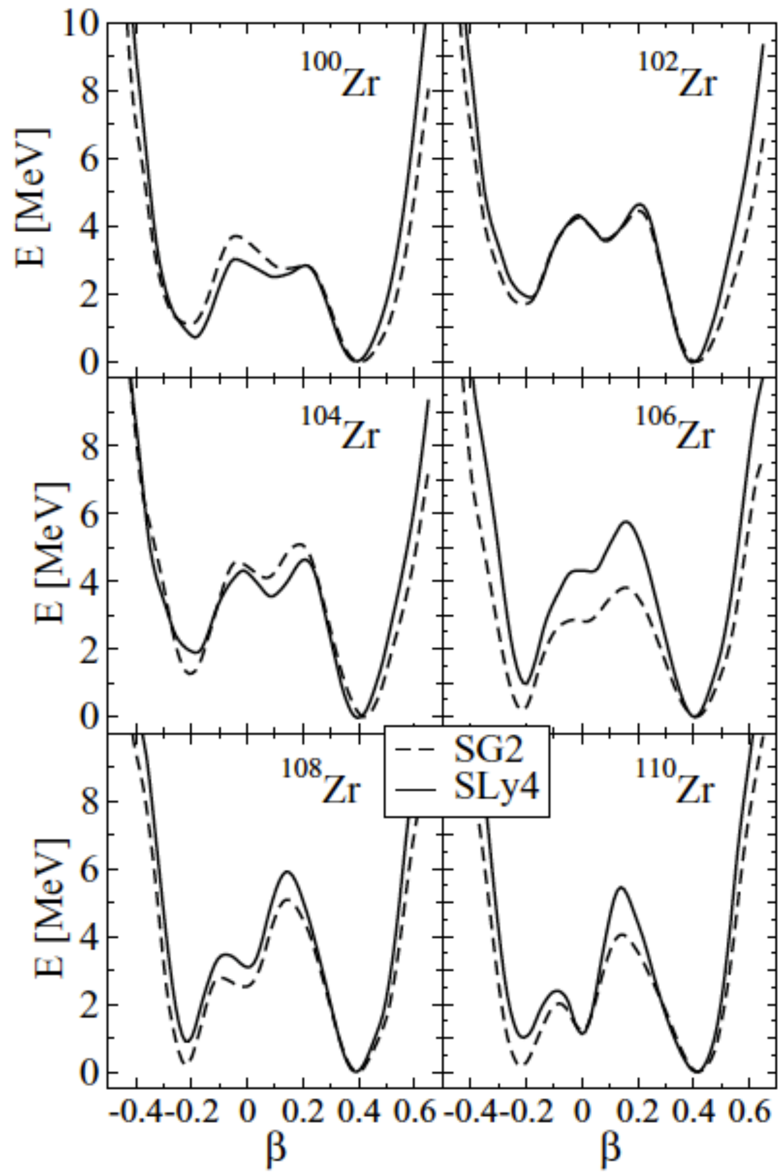
Hartree-Fock calculations: A=100

(Sarriguren, Pereira PRC 81 (2010) 064314 and
Sarriguren, Algora, Pereira PRC 89 (2014) 034311)

- Hartree-Fock mean field calculations using an effective two-body Skyrme interaction and including pairing correlations in the BCS approximation. In this framework single part. energies, wave functions and occupation probabilities are generated from the mean field
- Force used: Skyrme SLy4, considered representative of Skyrme forces, and includes some selected properties of unstable nuclei in the adjusting procedure of the parameters
- Result: different B(GT) profiles depending on the shape of the parent nucleus. According to the calculations the deformation of the ground state of parent and daughter is practically the same.

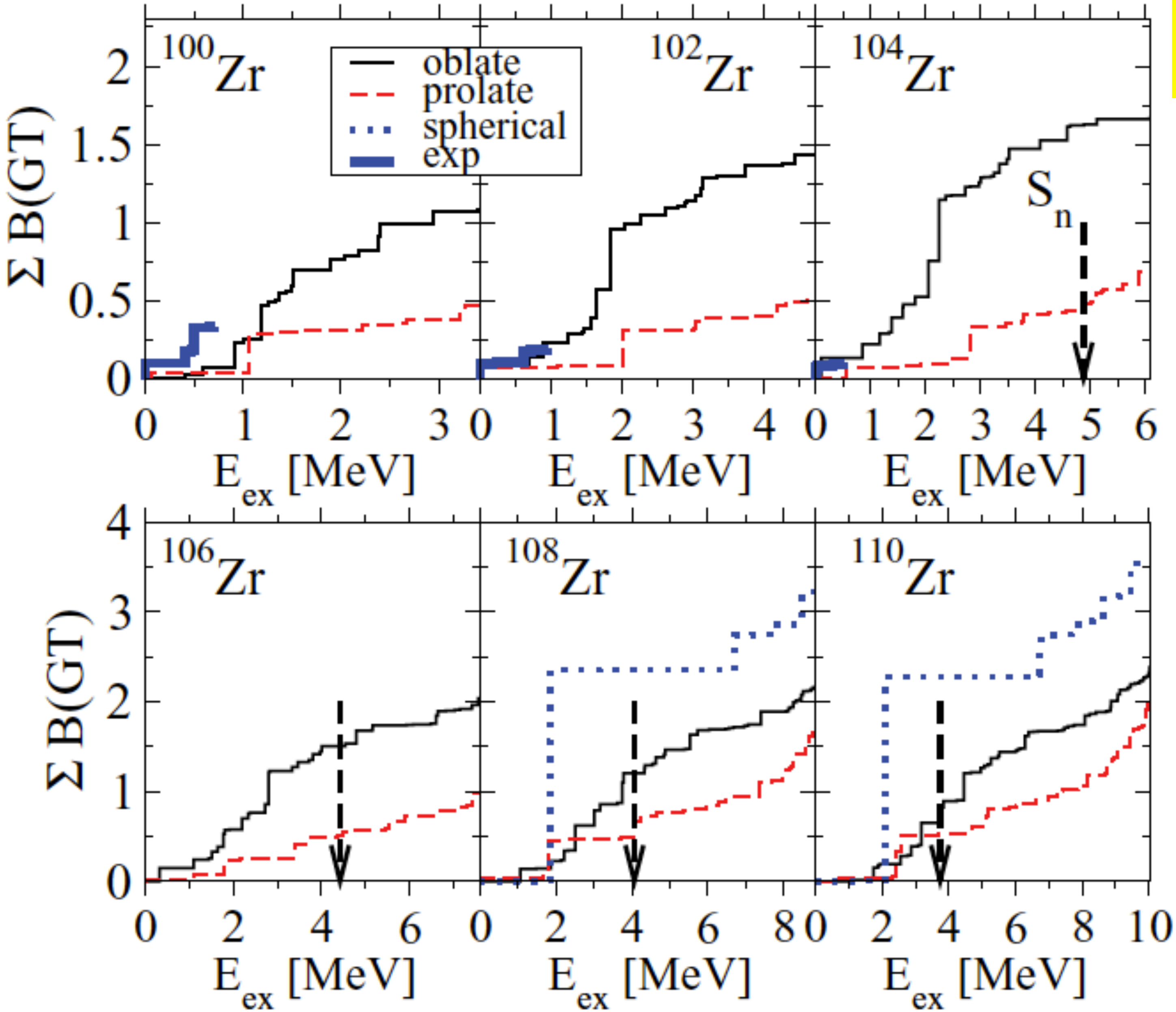
A=100 region, equilibrium shapes

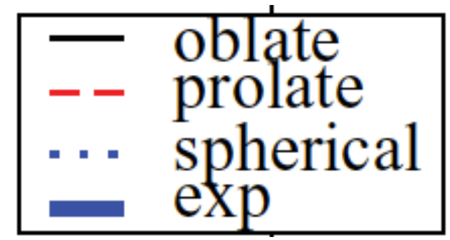




Sarriguren, Pereira PRC 81(2010) 064314

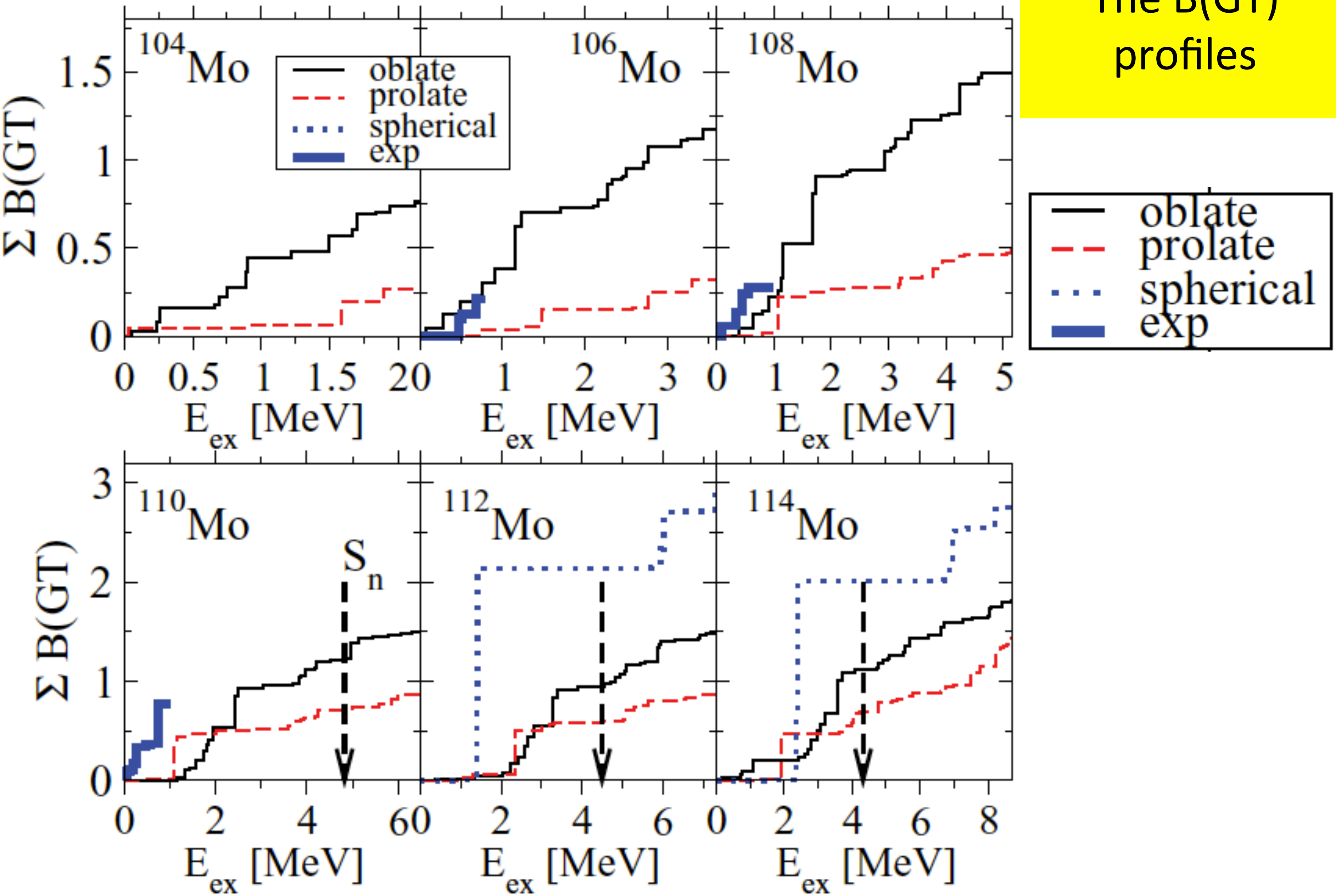
The B(GT) profiles





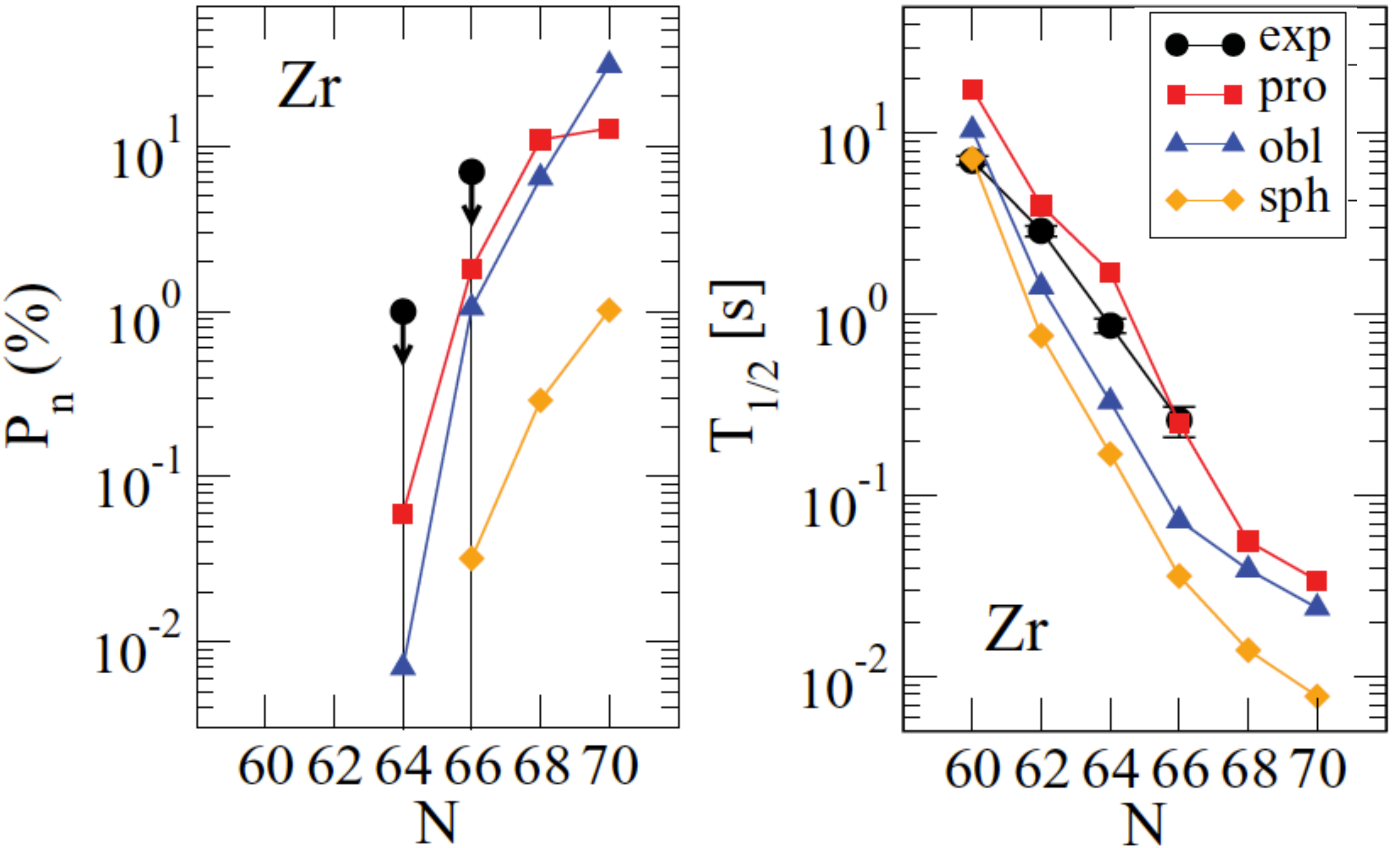
Sarriguren, Pereira
PRC 81(2010) 064314

The B(GT) profiles

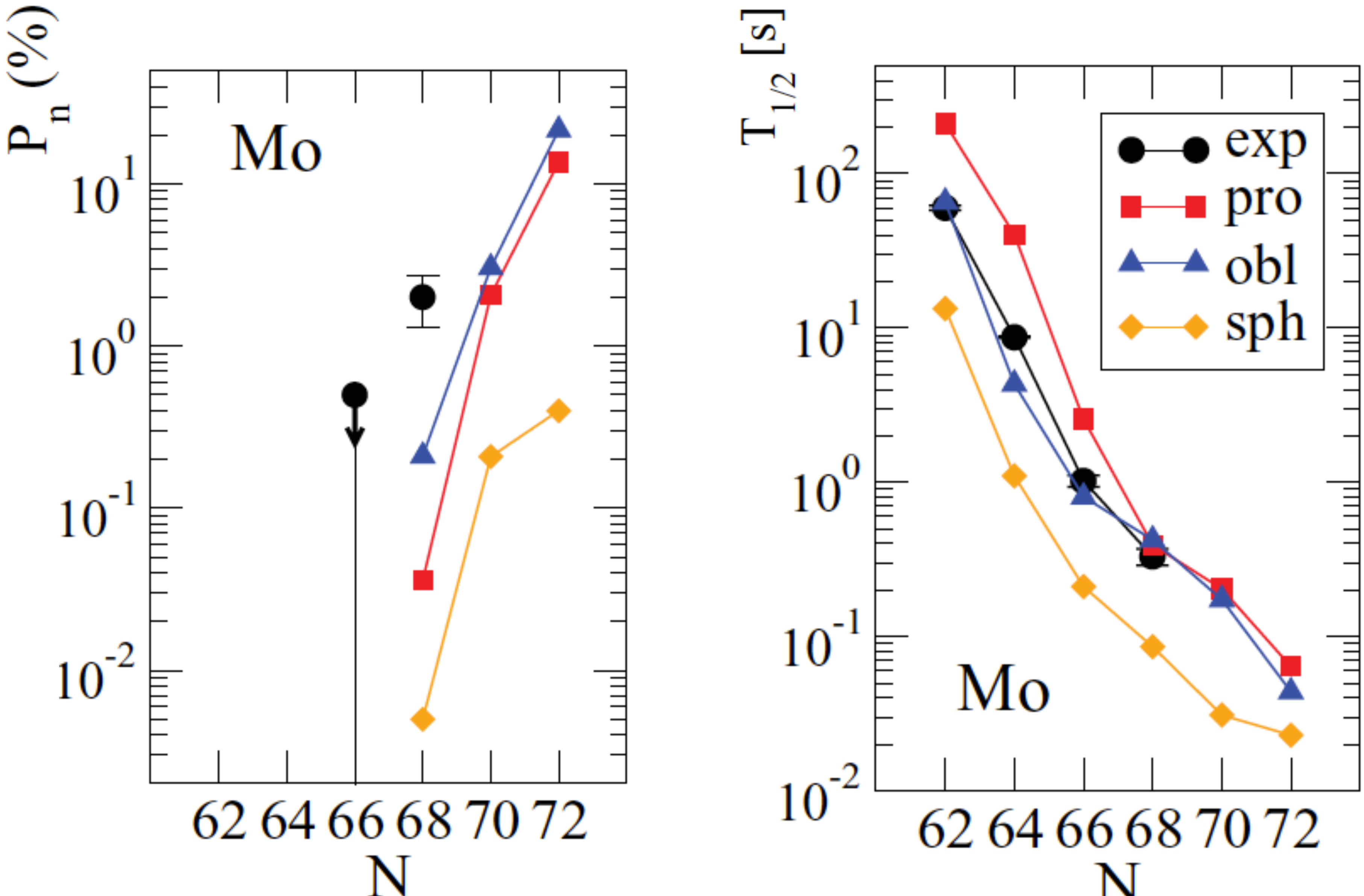


Sarriguren, Pereira
PRC 81(2010) 064314

What can $T_{1/2}$ and P_n measurements provide (SLy4) ?

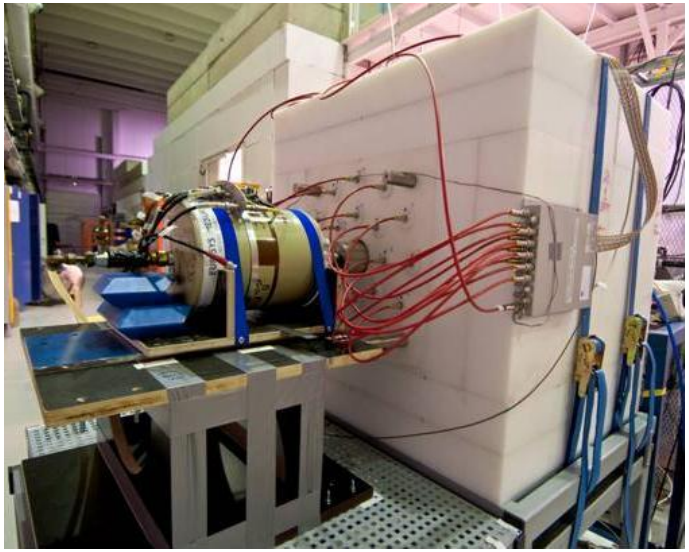


Mo isotopes (SLy4)



P_n and $T_{1/2}$ values (SLy4)

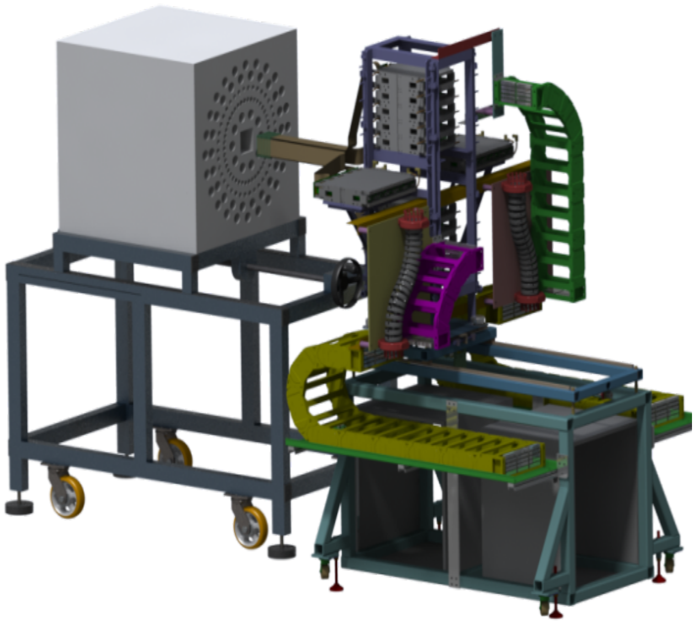
Isotope	Oblate shape	Spherical shape	Prolate shape	Experiment (Pereira)
106Zr	1.05	0.032	1.81	≤ 7
108Zr	6.44	0.29	10.94	
110Zr	30.93	1.02	12.82	
110Mo	0.21	0.005	0.036	2.0(7)
112Mo	3.05	0.208	2.03	
114Mo	21.54	0.4	13.66	

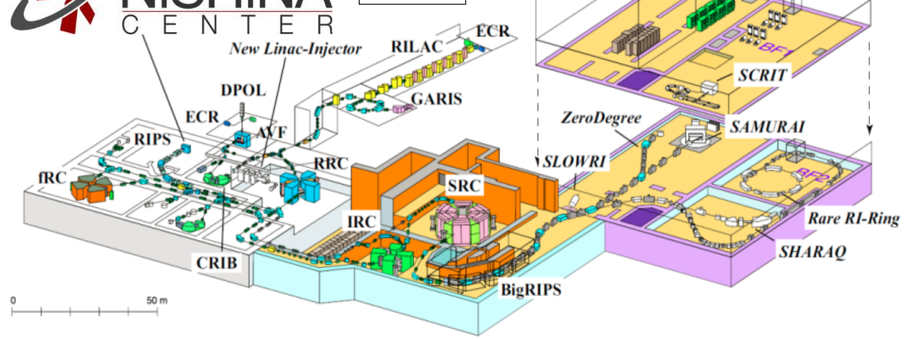


Isotope	Oblate shape	Spherical shape	Prolate shape	Experiment (Nishimura)
106Zr	0.073	0.036	0.252	0.186(11)
108Zr	0.039	0.014	0.056	0.073(4)
110Zr	0.024	0.0078	0.034	0.037(17)
110Mo	0.424	0.086	0.393	
112Mo	0.174	0.031	0.204	0.120(13)
114Mo	0.044	0.023	0.064	0.060(13)

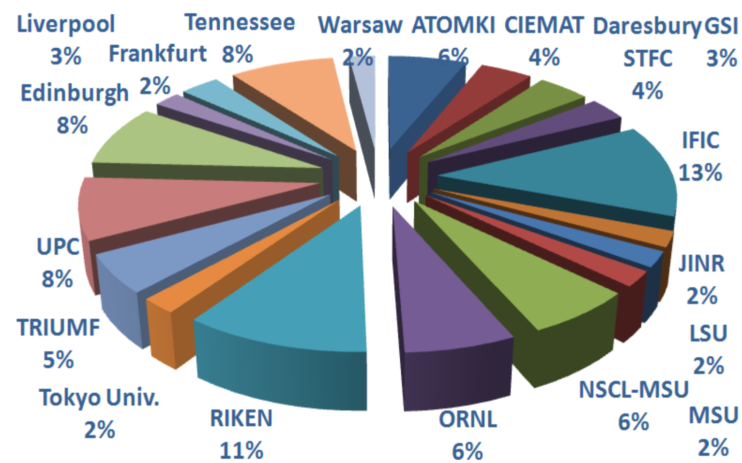
BRIKEN Project: Beta delayed neutron measurements at RIKEN

Largest ^{3}He array ever built (182 ^{3}He tubes)





60 scientists from 24 institutions

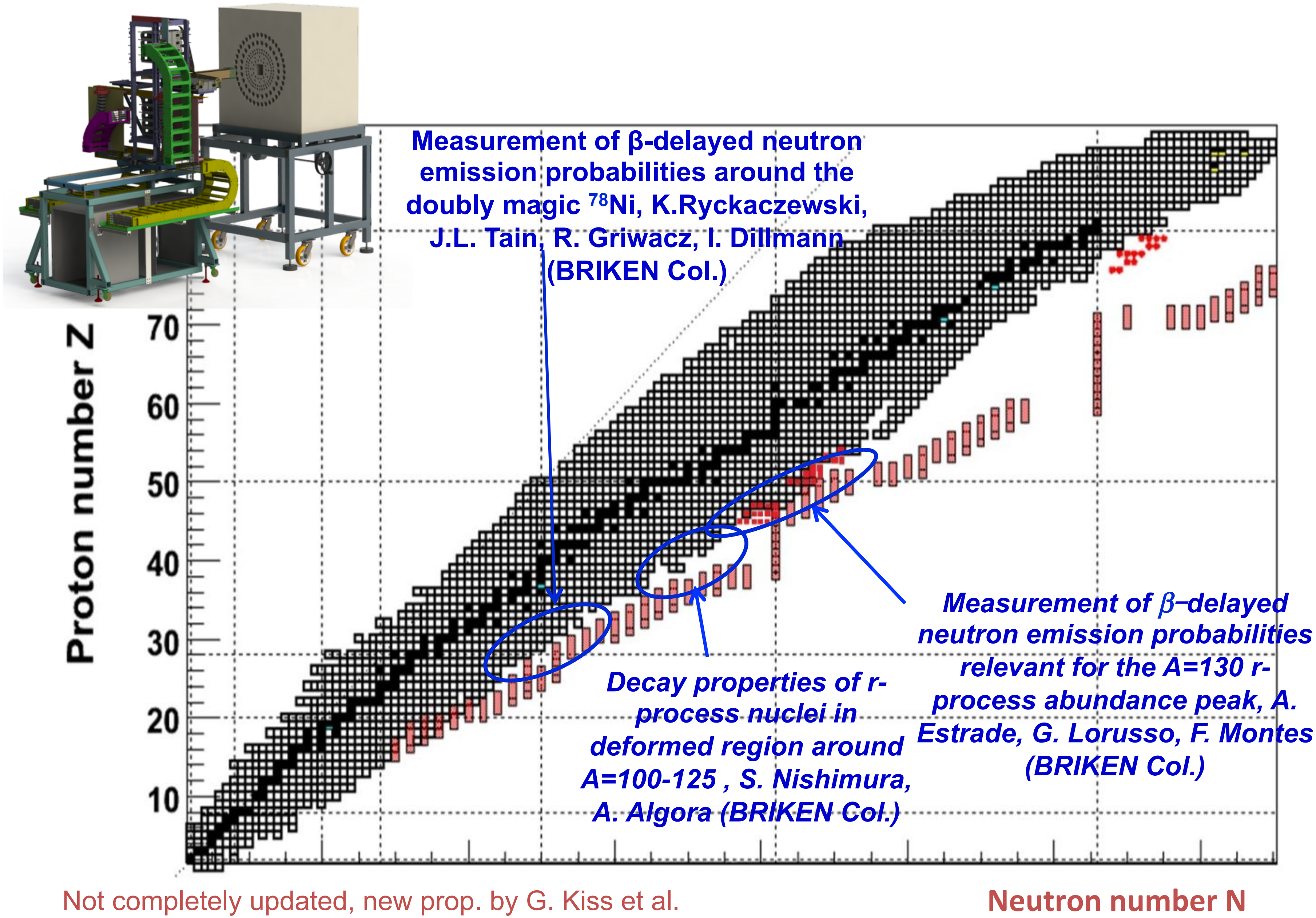


Astrophysics, nuclear structure, reactor technology

3 Exp. Proposals approved 2014-2015

✓ **23 days of beam-time approved at RIKEN / BigRIPS!**

BRIKEN Project: Beta delayed neutron approved proposals

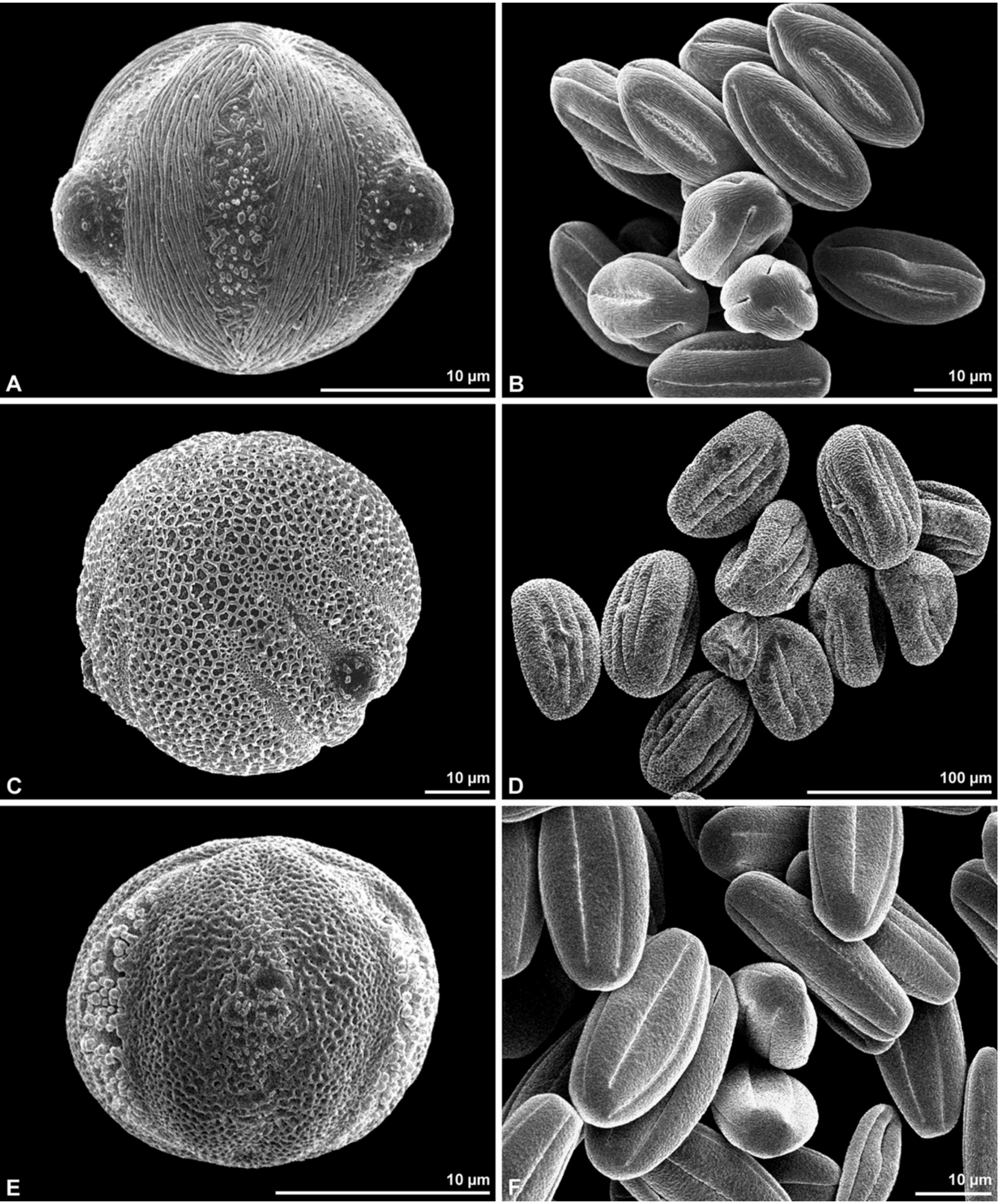


Not completely updated, new prop. by G. Kiss et al.

Summary

- Even though there are other techniques to determine the shape of the ground state of the nucleus, I hope I have shown you that strength measurements using the TAS technique can be useful for particular cases.
- In the neutron rich side Pn and $T_{1/2}$ measurements can provide an alternative source of information for exotic nuclei (depends heavily on theory and on the case)

THANK YOU

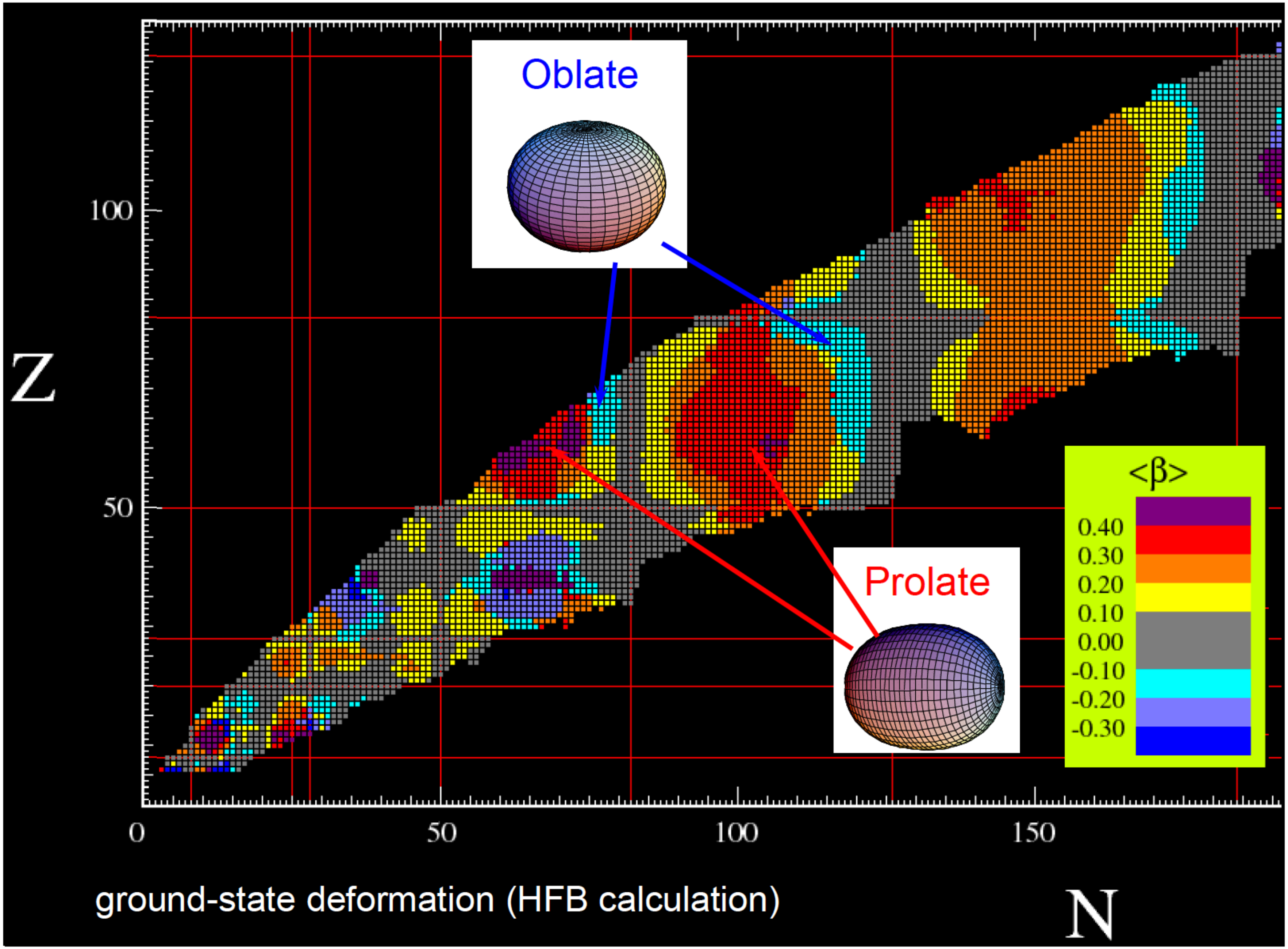


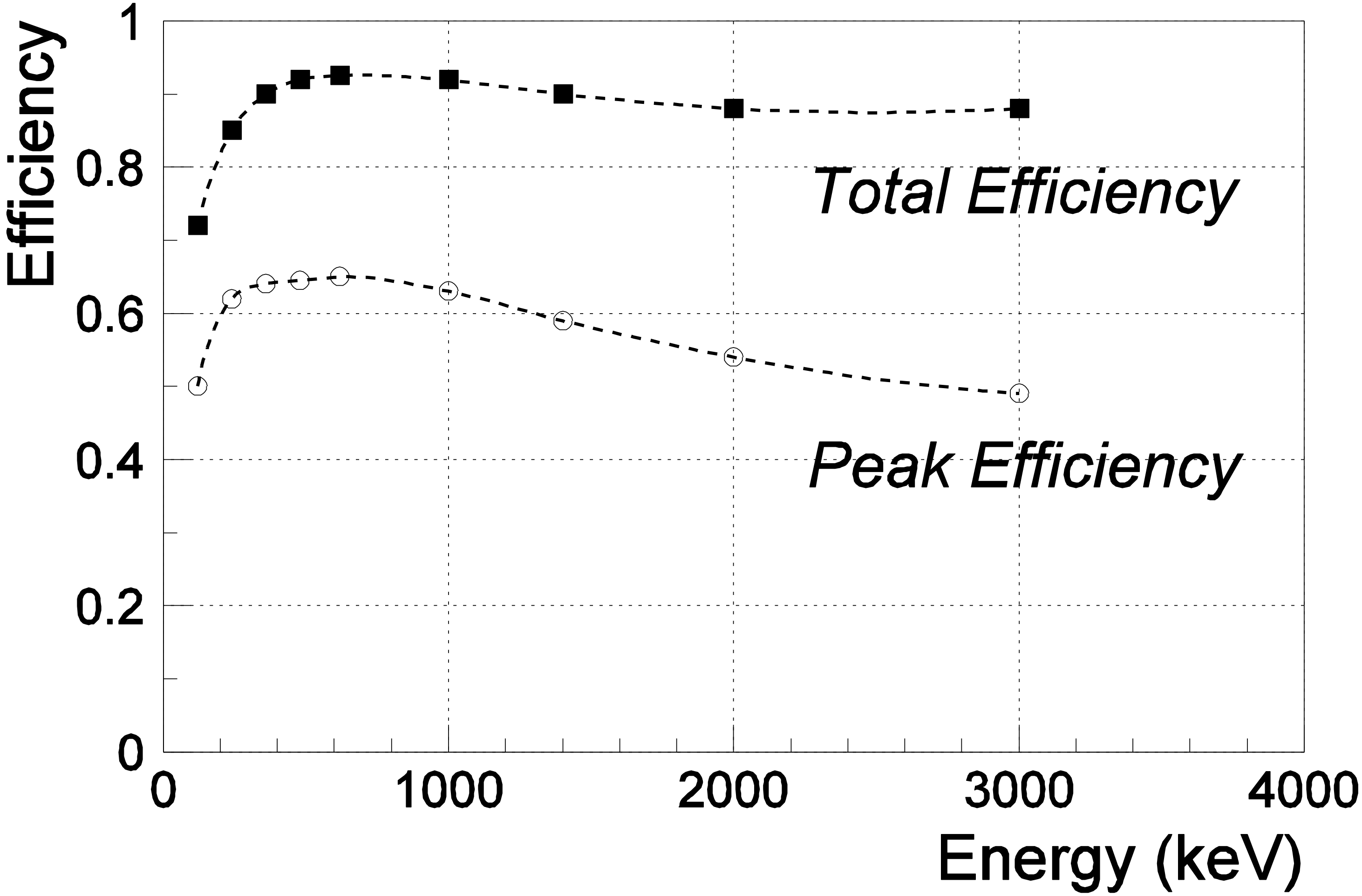
E. Estevez, J .L. Tain, B. Rubio, E.Nácher, J. Agramunt, A. B. Perez, L. Caballero, F. Molina, D. Jordan, A. Krasznahorkay, M. Hunyadi, Zs. Dombrádi, W. Gelletly, P. Sarriguren, O. Moreno, M. J. G. Borge, O. Tengblad, A. Jungclaus, L. M. Fraile, D. Fedosseev, B. A. Marsh, D. Fedorov, A. Frank, A. Algora

J.L. Tain, B. Rubio, E. Nácher, L. Caballero, J. Agramunt, A. B. Perez, D. Jordan, F. Molina, W. Gelletly, L. Batist, A. Garcia, J. Äystö, H. Penttilä, I. Moore, P. Karvonen, A. Jokinen, S. Rinta-Antila, A. Kankainen, T. Eronen, U. Hager, T. Sonoda, J. Hakala, A. Nieminen, A. Saastamoinen, J. Rissanen, T. Kessler, C. Weber, J. Ronkainen, S. Rahaman, V. Elomaa, T. Yoshida, F. Storrer, A. L. Nichols, G. Lhersonneau, K. Burkard, W. Huller, A. Krasznahorkay, A. Vitéz, J. Gulyás, M. Csatlos, M. D. Hunyadi, L. Csige, A. Sonzogni, K. Perajarvi, K. L. Kratz, A. Petrovici,, E. Valencia, S. Rice, M. Fallot, A. Porta, Z. A. Aziz, A. Algora

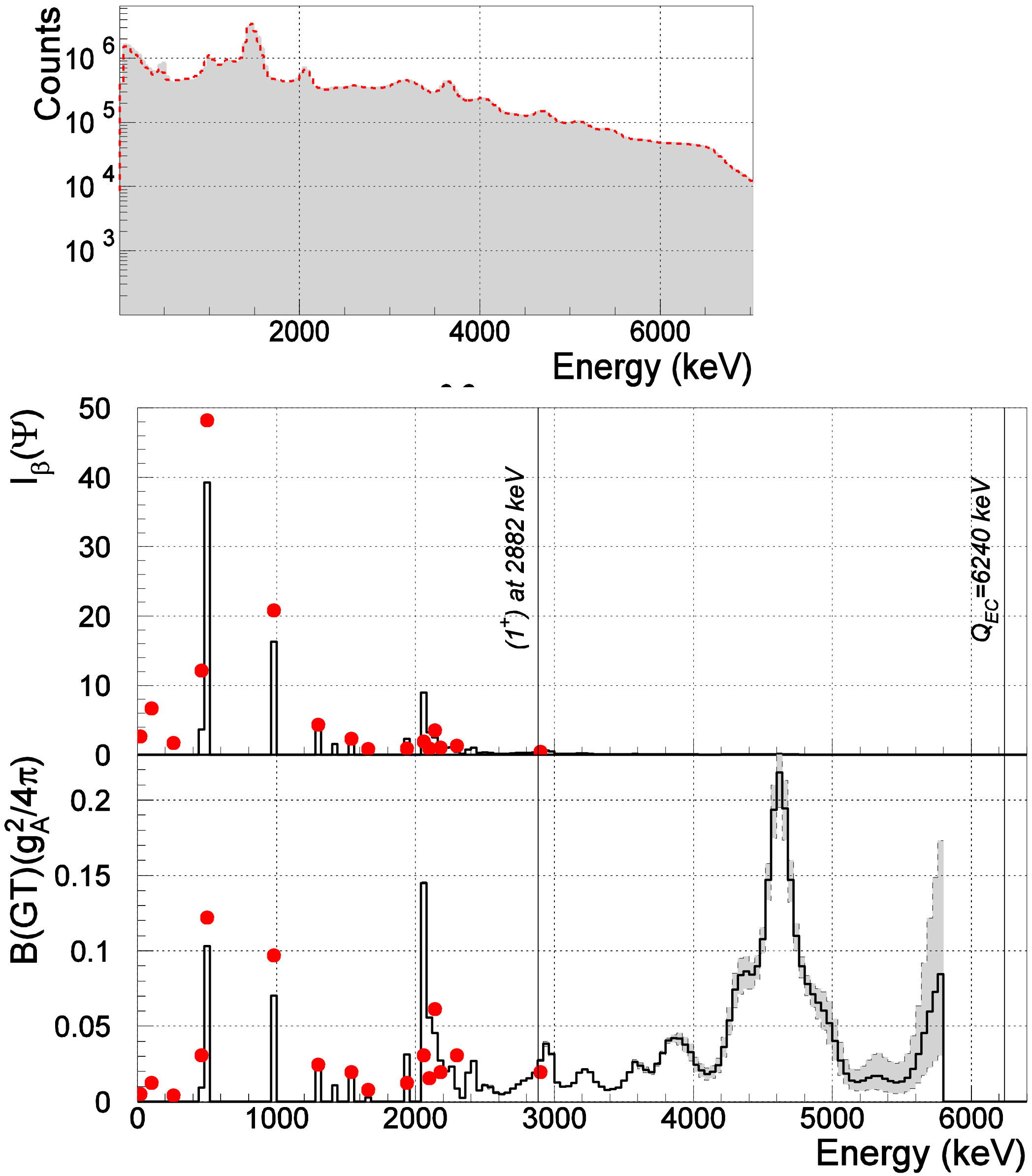
THANK YOU

Mean-field prediction for ground-state shapes




Efficiency
1
0.8
0.6
0.4
0.2
0
0
1000
2000
3000
4000
Energy (keV)
Total Efficiency
Peak Efficiency

76Sr beta decay



E. Nácher, PhD
Thesis, Valencia

The nuclear shape concept evolution …

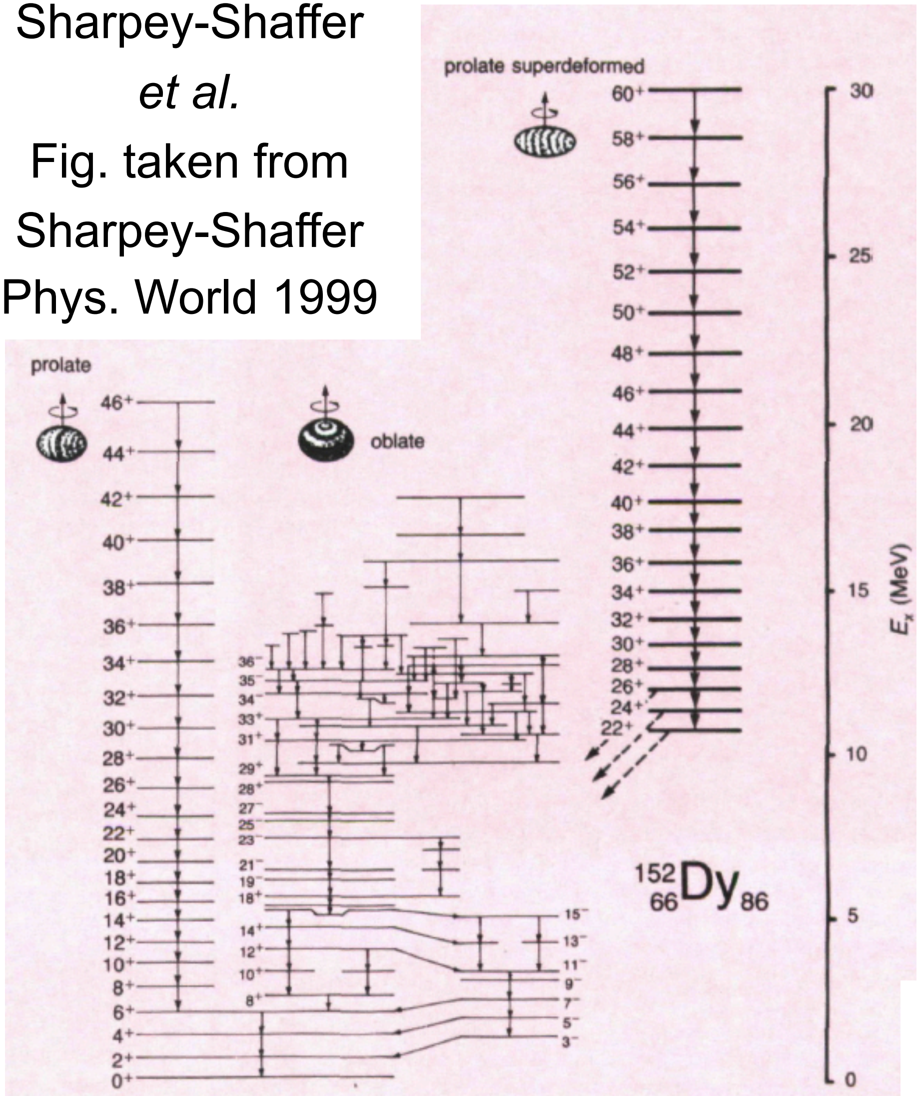
- Rutherford model: point like shape (approx. 100 years ago)
- To interpret the binding energies the liquid drop model is created (spherical shapes), later it evolves into the droplet model with diffuse surface
- Revolution in the 50´s: collectivity and static deformed shapes are born. Shape becomes a concept and a tool for testing nuclear models. It is a necessity to interpret data on nuclear multipoles, Coulomb excitation data, etc.
- The interpretation of fission requires the assumption of elongated shapes, or a very drastic shape change.
- Strutinsky shell correction it combination with the liquid drop model predicts deformed minima
- Direct measurements by means of scattering experiments …
- Nilsson model, and shell model relation (Elliot Model), mean field
- Shape coexistence
- SD bands, HD states, etc, etc, etc.

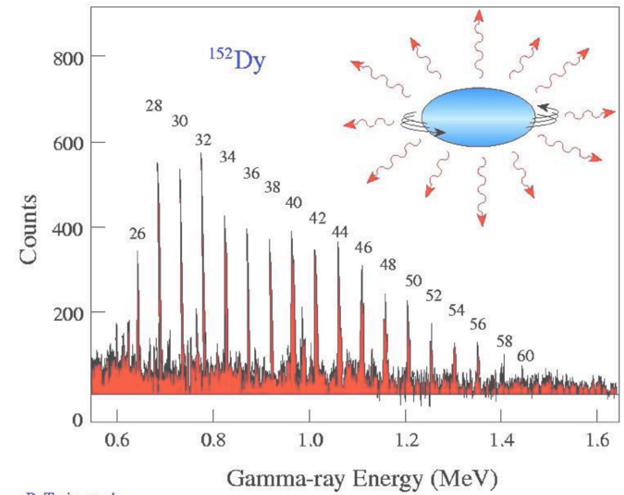
(more than 1144 publications in APS journals 1940-2010)

Shapes from nuclear spectroscopic information (mainly gamma spectroscopy)

Twin, Nyako, Sharpey-Shaffer *et al.*

Fig. taken from Sharpey-Shaffer Phys. World 1999



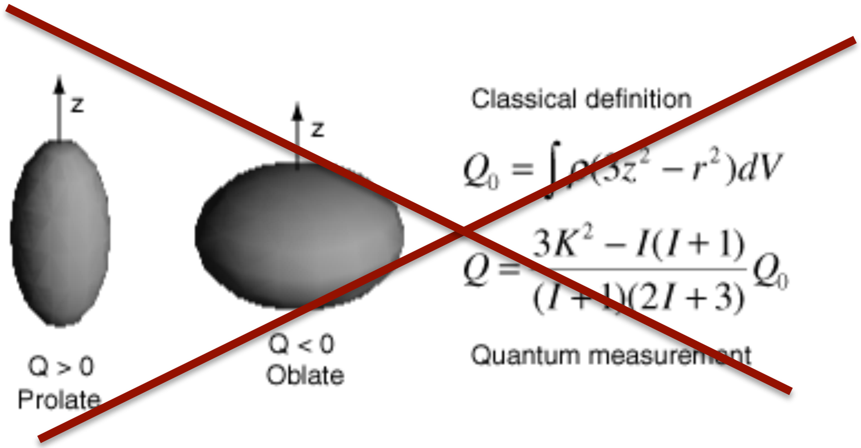


P. Twin et. al
Phys. Rev. Lett. 57 (1986)

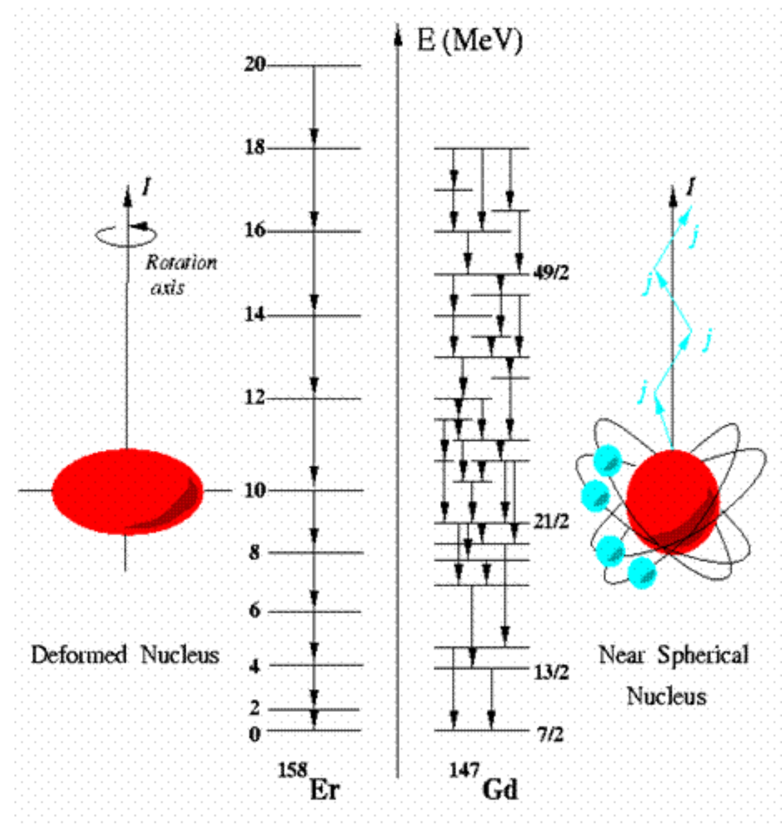
- From level lifetimes, B(E2)-s, deformation can be deduced
- From in-band multipole mixing ratios (angular distributions) the sign of the Q can be deduced
- E0 (electric monopole transitions) are associated with shape changes

$$|Q| = \sqrt{16\pi B(E2{:}2_1^+ \to 0_1^+)} = \frac{3Ze}{\sqrt{5\pi}} R_0^2(\beta + 0.16\beta^2),$$

How do we deduce the nuclear shape of the ground state when it is a 0+ state …



- Nuclear radii determination (isotope shifts)
- Analysis of spectroscopic information (B(E2)-s, $T_{1/2}$ and assuming that we have a band with the same deformation
- ???



Pandemonium (The Capital of Hell)

introduced by John Milton (XVII) in his epic poem Paradise Lost

John Martin (~ 1825)

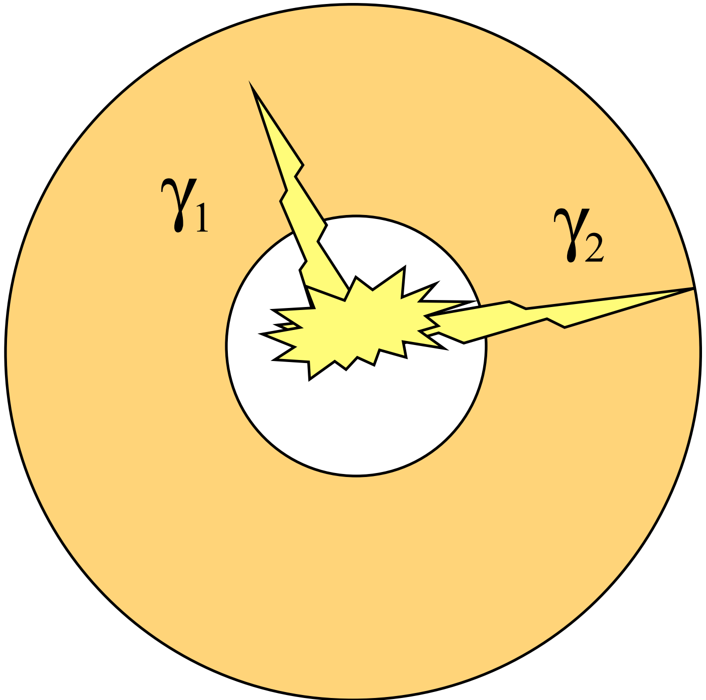
Hardy et al., Phys. Lett. 71B (1977) 307

Problems associated with TAS (TAZ ?)

• The analysis is difficult and lengthy since it requires a careful calculation of the response function of the detector to the decay (but nowadays we have the tools to attack the problem)

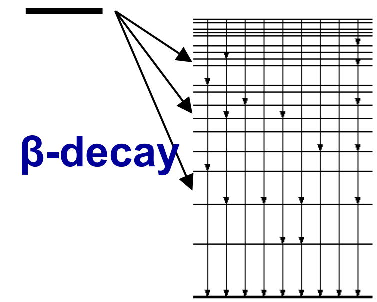
• Special care have to be taken with the contaminants

TAZ (hungry beast)



Analysis

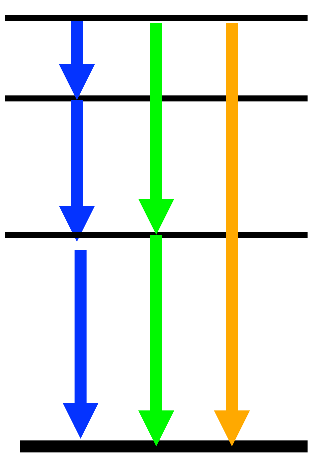
$$d_i = \sum_j R_{ij} f_j \quad or \quad \mathbf{d} = \mathbf{R} \cdot \mathbf{f}$$



R is the response function of the spectrometer, $\boldsymbol{R_{ij}}$ means the probability that feeding at a level ***j*** gives counts in data channel ***i*** *of the spectrum*

The response matrix **R** can be constructed by recursive convolution:

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

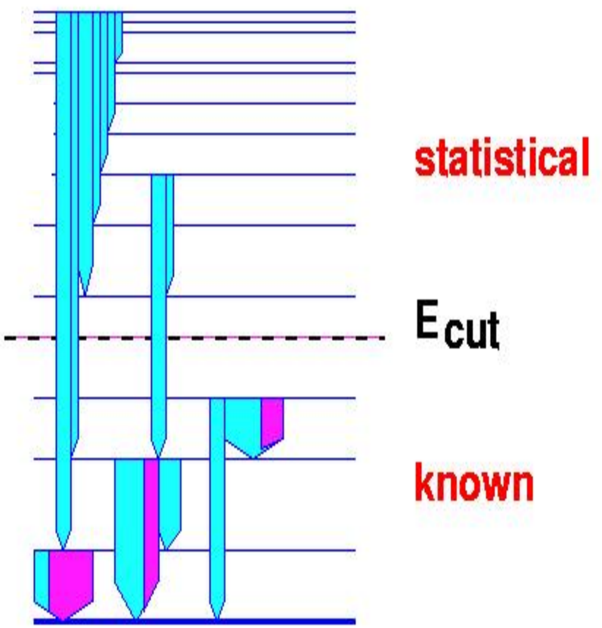


$\mathbf{g_{jk}}$: γ-response for *j* ➔ *k* transition
$\mathbf{R_k}$: response for level *k*
b_{jk}: branching ratio for *j* ➔ *k* transition

Mathematical formalization by Tain, Cano, et al.

The complexity of the TAGS analysis: an ill posed problem

$$d = R(B) \cdot f$$



Steps:

1. **Define B (branching ratio matrix)**
2. **Calculate R(B)**
3. **Solve the equation d=R(B)f using an appropriate algorithm**

Expectation Maximization (EM) method:
modify knowledge on causes from effects

$$P(f_j | d_i) = \frac{P(d_i | f_j) P(f_j)}{\sum_j P(d_i | f_j) P(f_j)}$$

Algorithm: $$f_j^{(s+1)} = \frac{1}{\sum_i R_{ij}} \sum_i \frac{R_{ij} f_j^{(s)} d_i}{\sum_k R_{ik} f_k^{(s)}}$$

The complexity of the TAGS analysis: an ill posed problem

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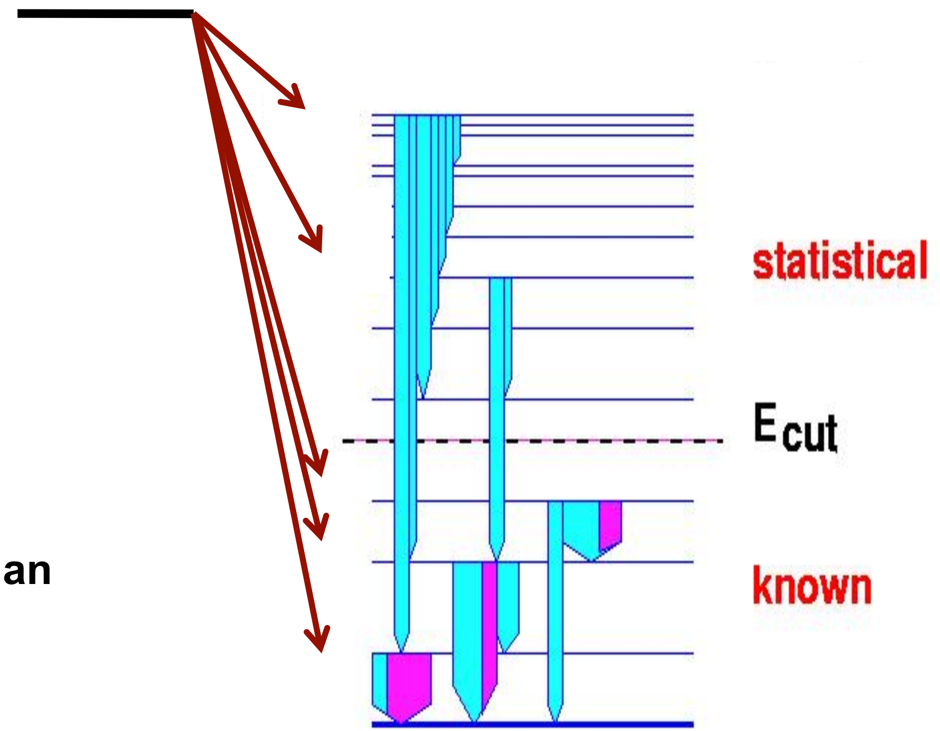

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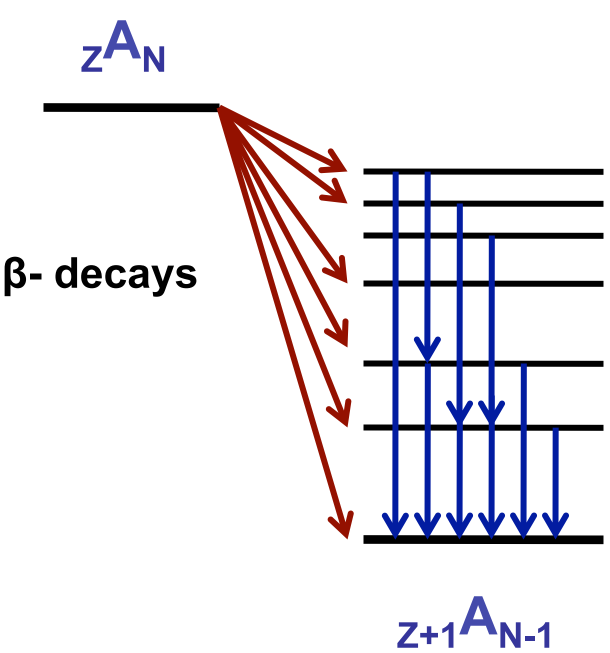
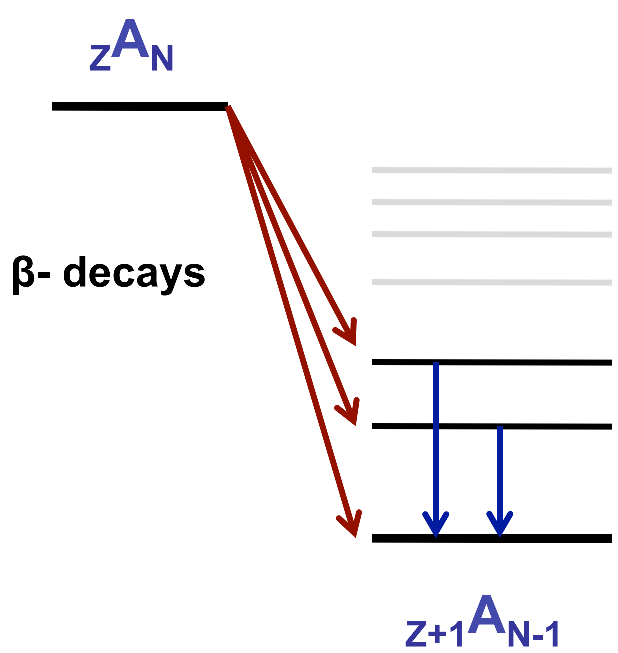
Pandemonium and summation calculations

Real situation



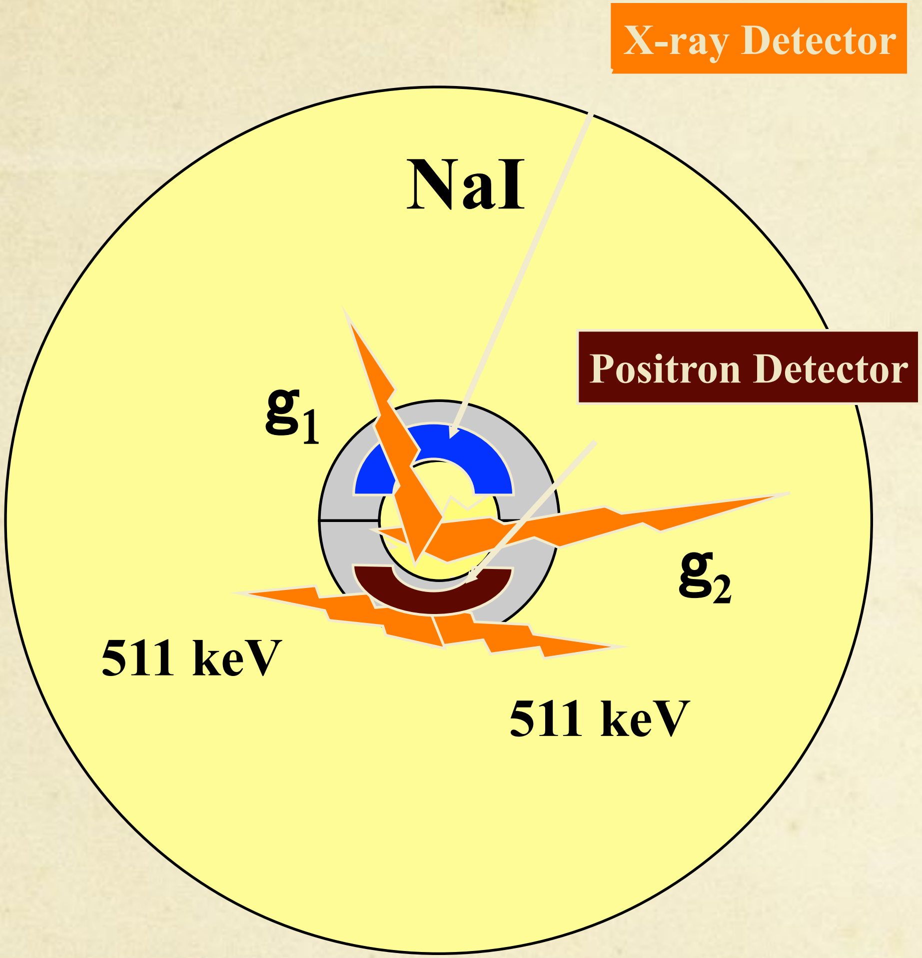
Pandemonium situation

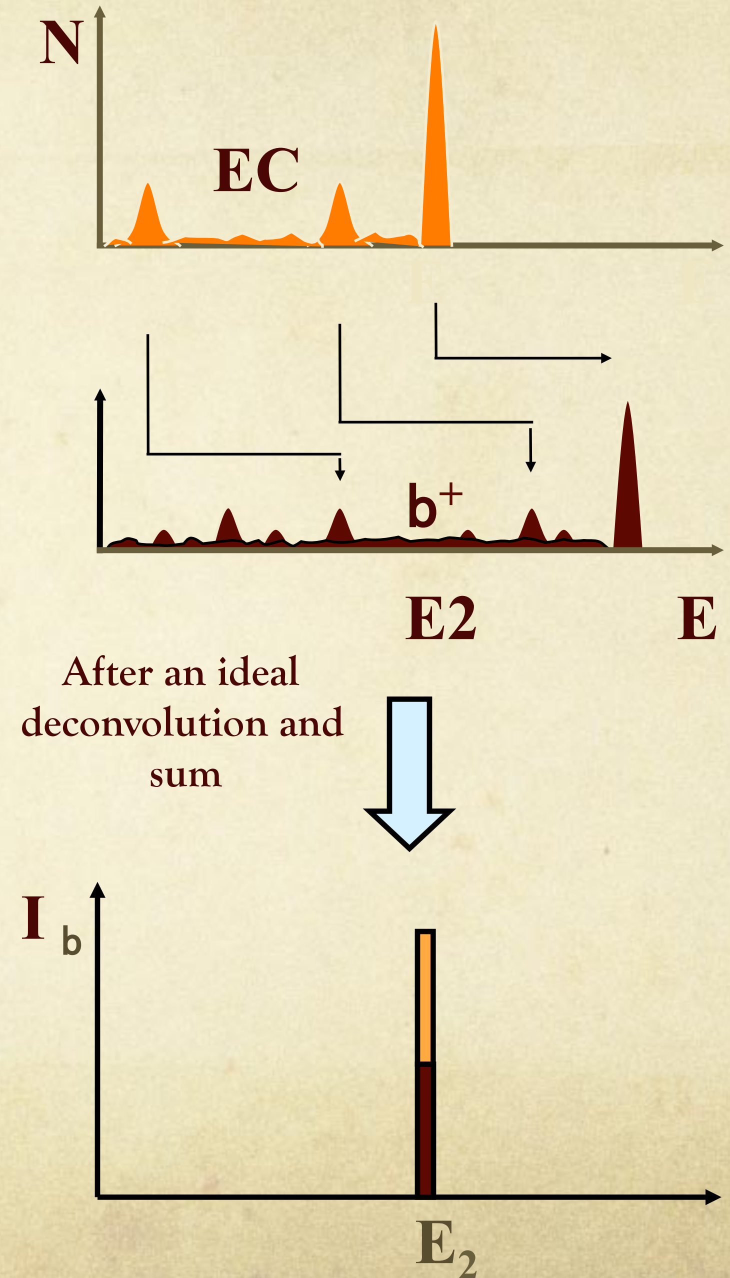


As a result of the Pandemonium, betas and neutrinos are estimated with higher energies from databases. Their spectra is harder.

This is why TAS measurements are very important

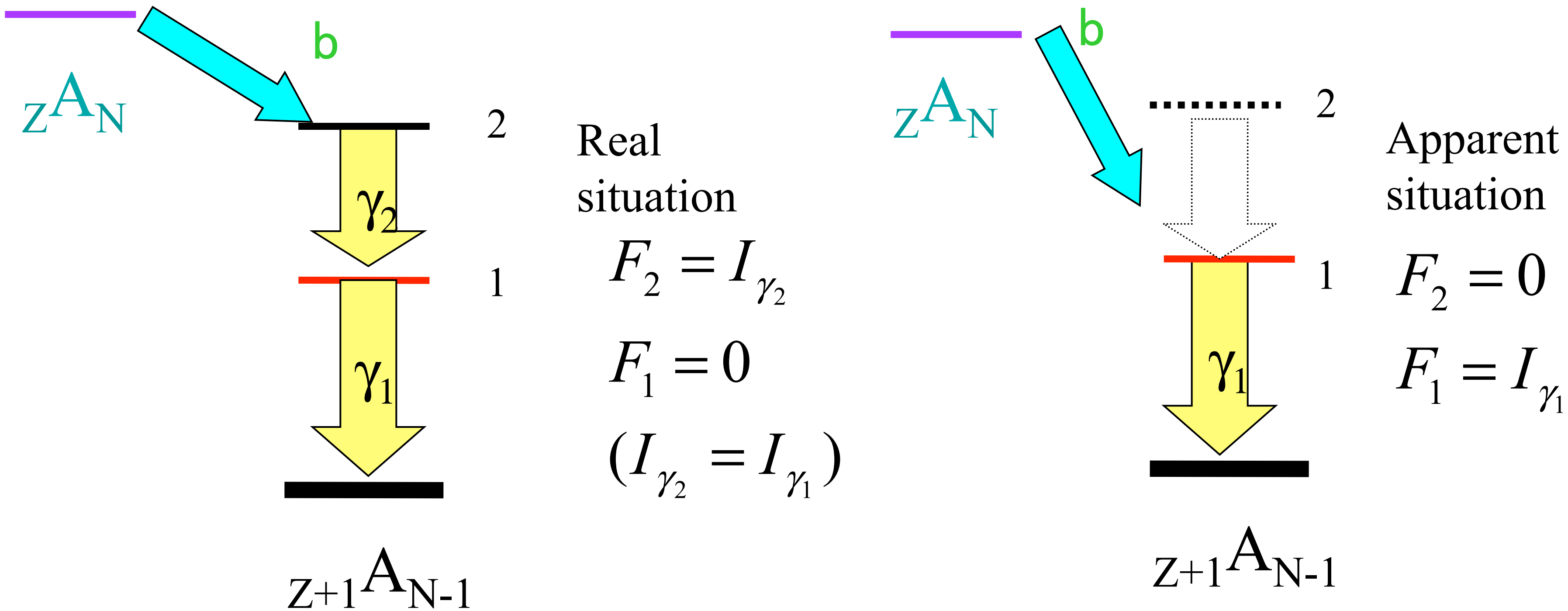
Total absorption spectroscopy





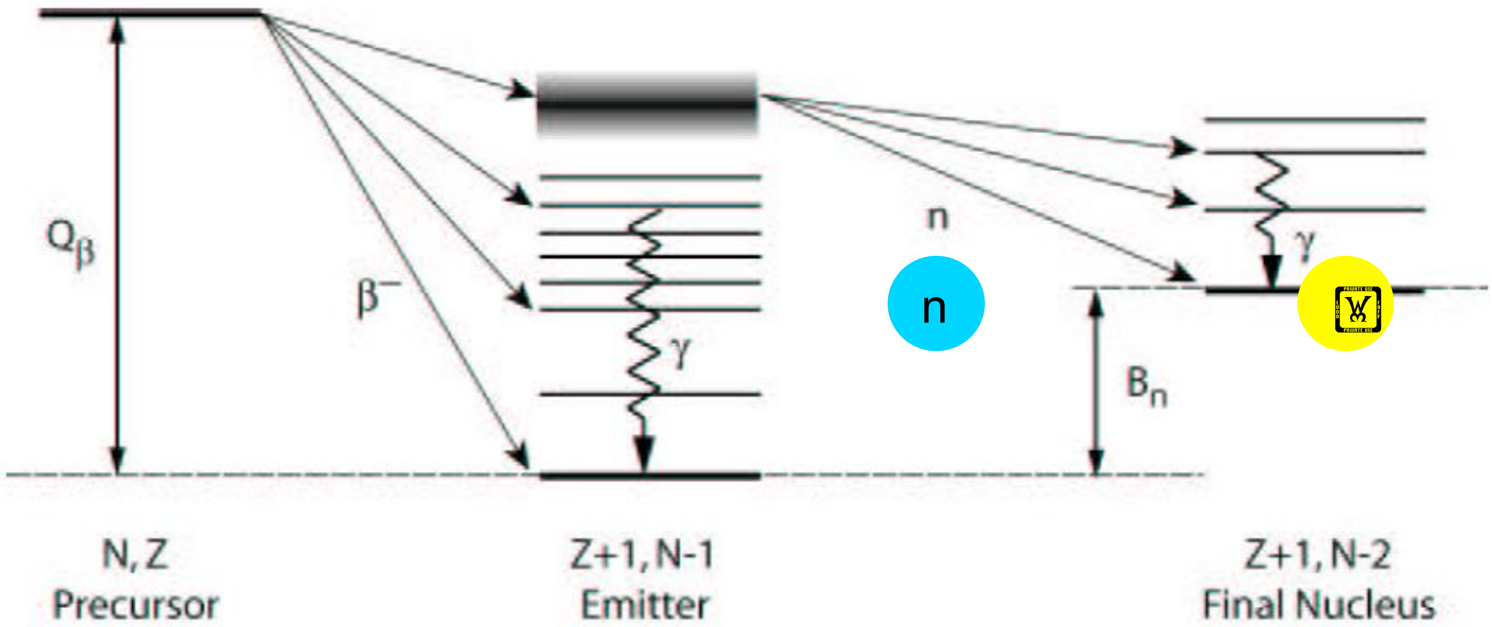
Solution: use of coincidences with ancillary detectors

The problem of measuring the β- feeding (no delayed part.emission)



- We use Ge detectors to construct the level scheme populated in the decay
- From the g intensity balance we deduce the b-feeding
- What happens if we miss some gamma intensity???

Beta decay in the neutron rich side



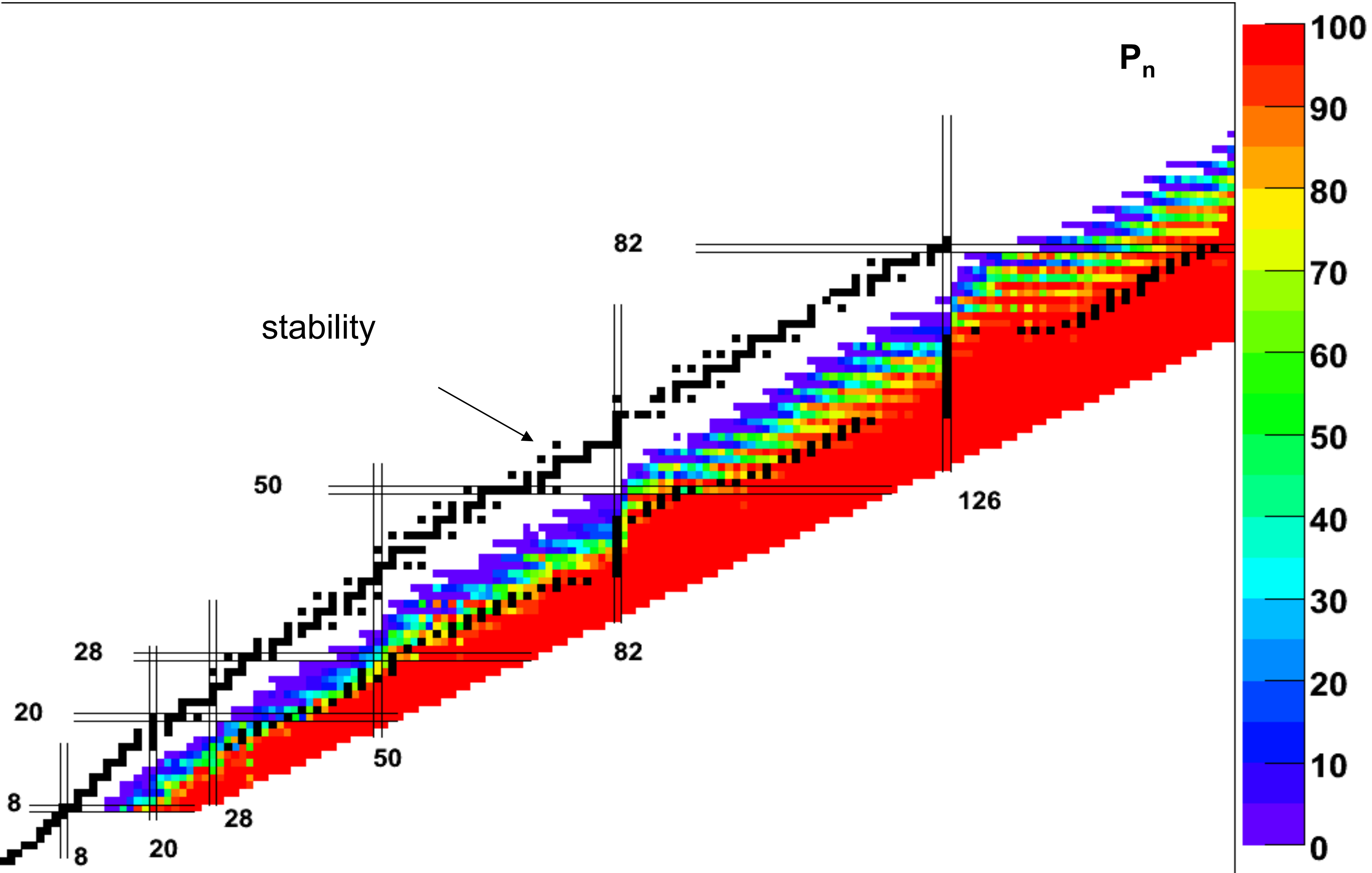
If $S_n < Q_\beta$

and the decay proceeds to states above S_n, neutron emission competes and can dominate over γ-ray de-excitation

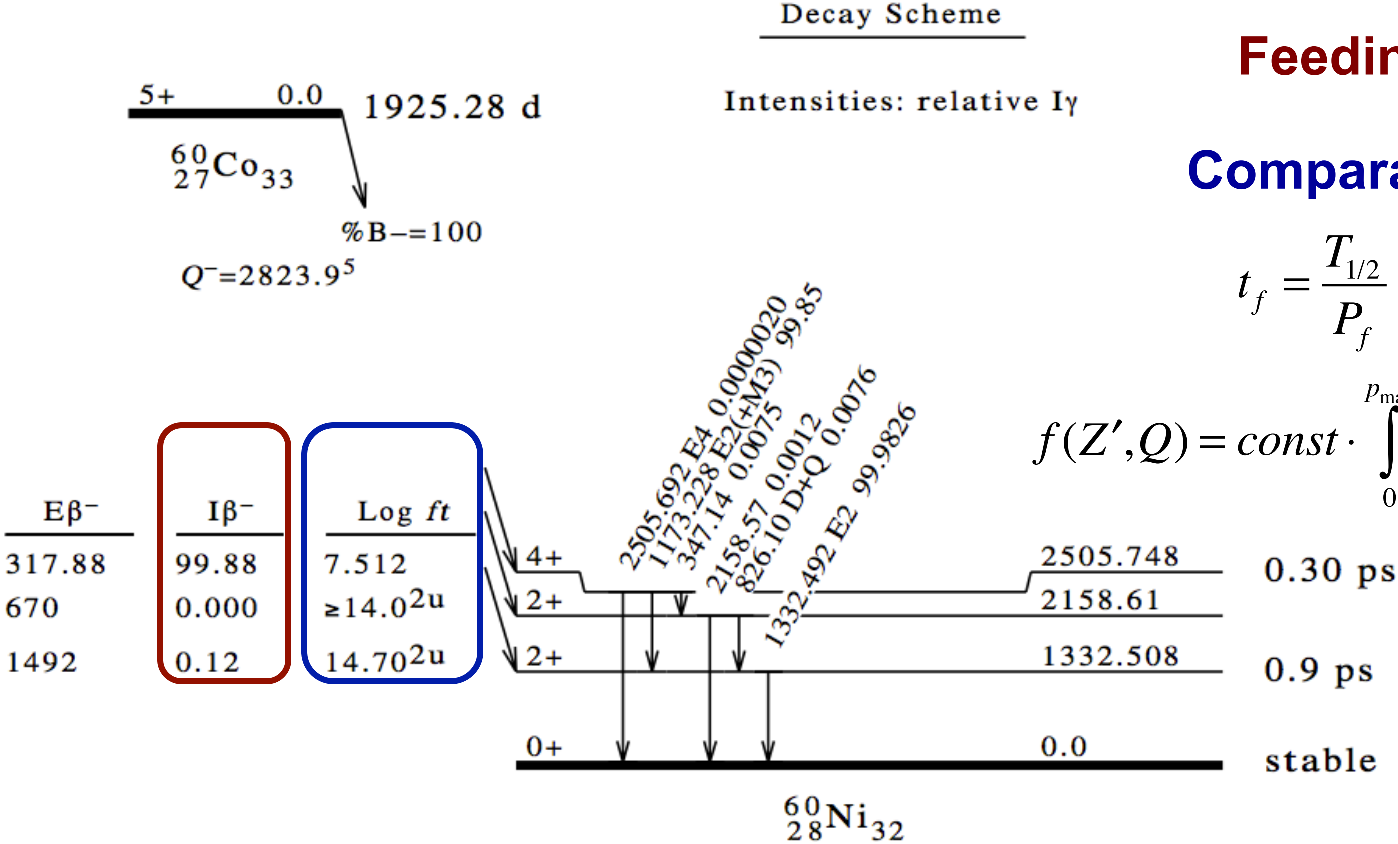
The process will dominate far from stability on the n-rich side.

To have a full picture of the strength …

β-delayed neutron emission probability



Example: ^{60}Co decay from http://www.nndc.bnl.gov/



Feeding:=I_β = P_f*100

Comparative half-life: ft_f

$$t_f = \frac{T_{1/2}}{P_f}$$

$$f(Z',Q) = const \cdot \int_0^{p_{max}} F(Z',p)\,p^2 (Q - E_{ex})^2 \, dp$$

$$ft_f = const' \frac{1}{\left|M_{if}\right|^2} = const' \frac{1}{B_{i\to f}}$$

$$S_\beta(E) = \frac{P_\beta(E)}{f(Z',Q_\beta - E)T_{1/2}} = \frac{1}{ft(E)}$$

$$B_{i\to f} = \frac{1}{2J_i + 1} \left| \left\langle \Psi_f \right| \tau^\pm \text{ or } \sigma\tau^\pm \left| \Psi_i \right\rangle \right|^2$$

$$t_f = \frac{T_{1/2}}{P_f} \qquad T_{1/2} = \frac{\ln(2)}{\lambda} = \tau \ln(2)$$