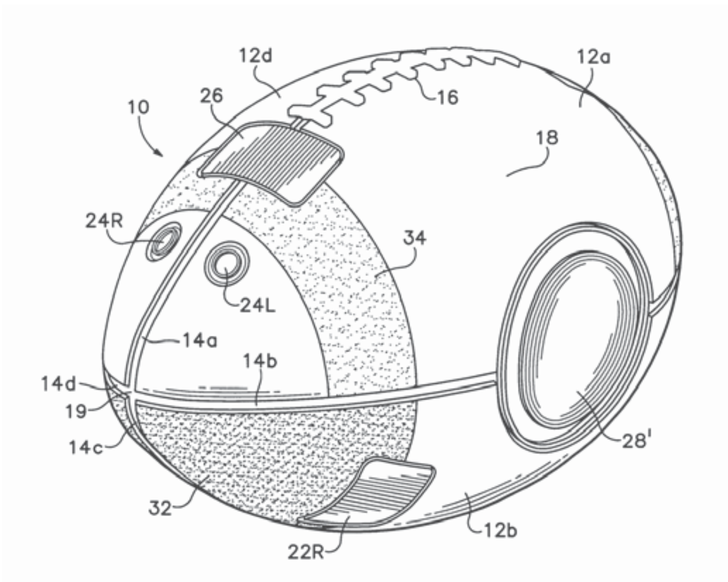
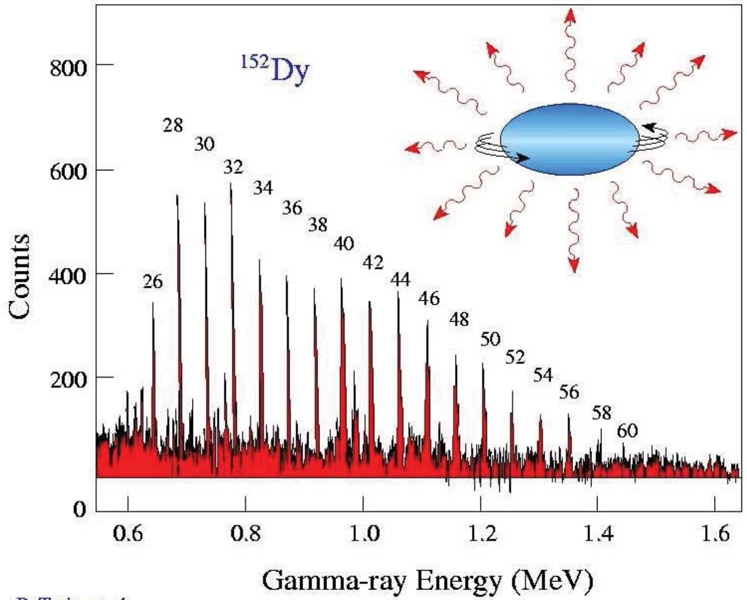
Shape effects from Pn measurements: a possibility to explore in the A=110 region

Alejandro Algora,
IFIC (CSIC-Univ. Valencia), Spain



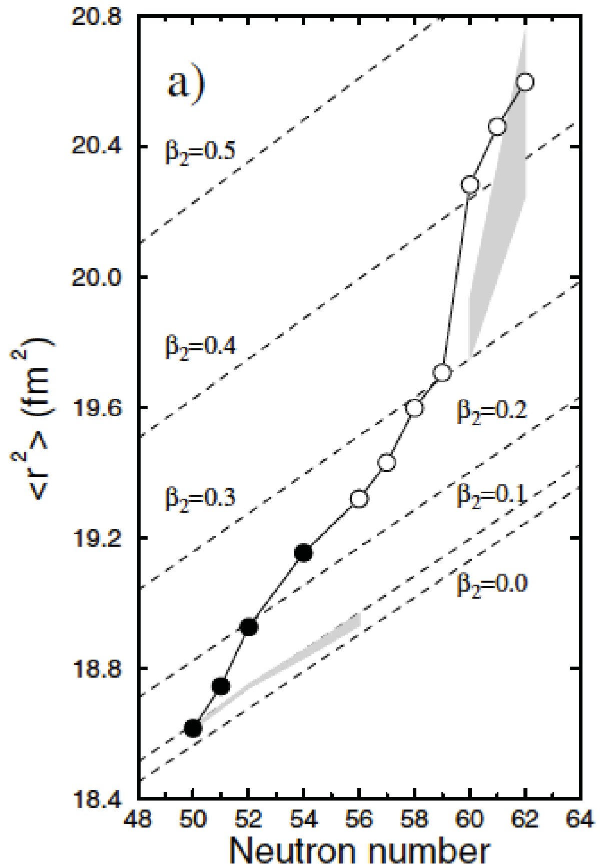
Experimentally how we determine shapes…

- •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)

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

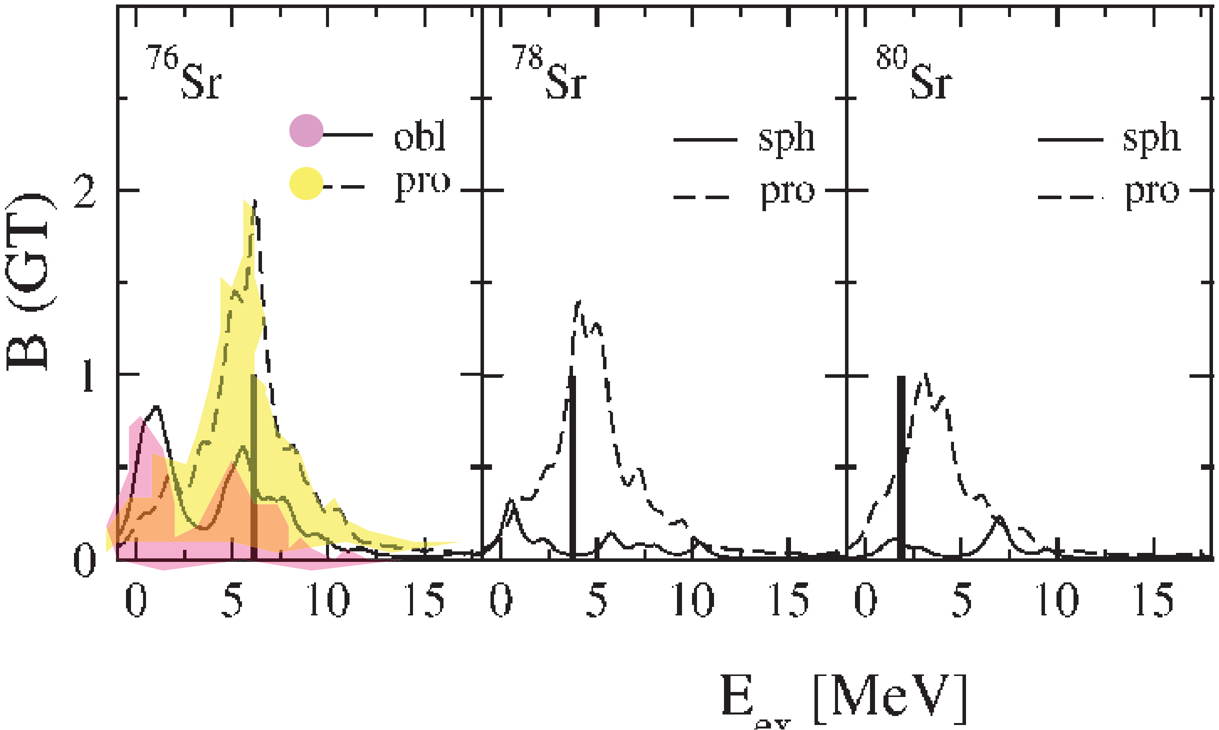


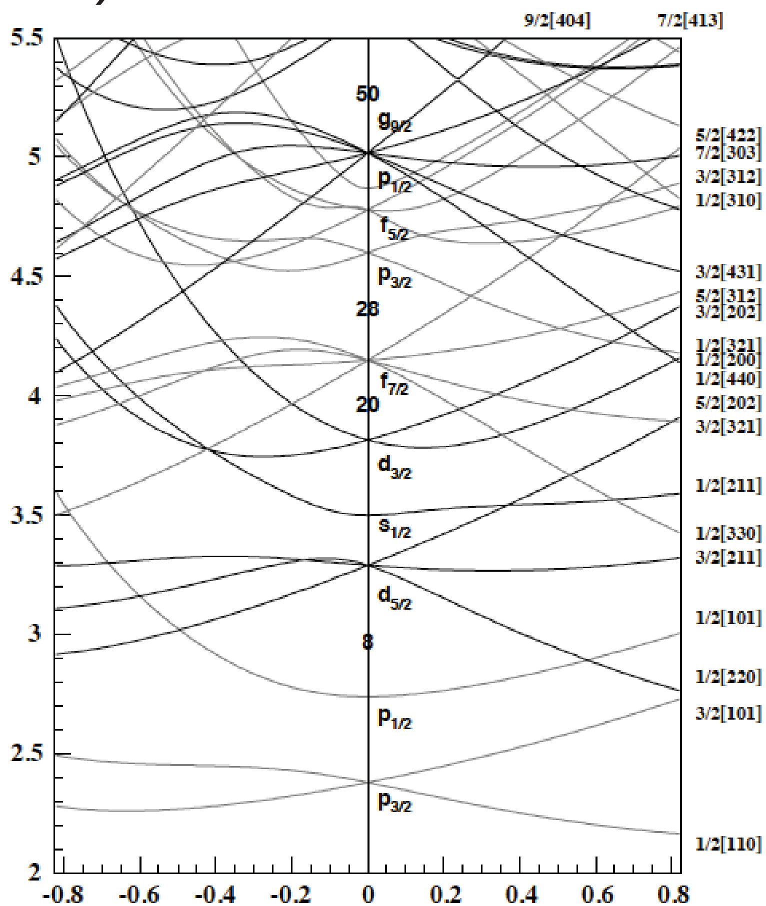
Laser spectroscopy of cooled Zr fission products (Campbell PRL 89, 2002) Mean square charge radii deduced from the measurements compared with droplet model predictions.

What can beta decay offer apart from spectroscopy …

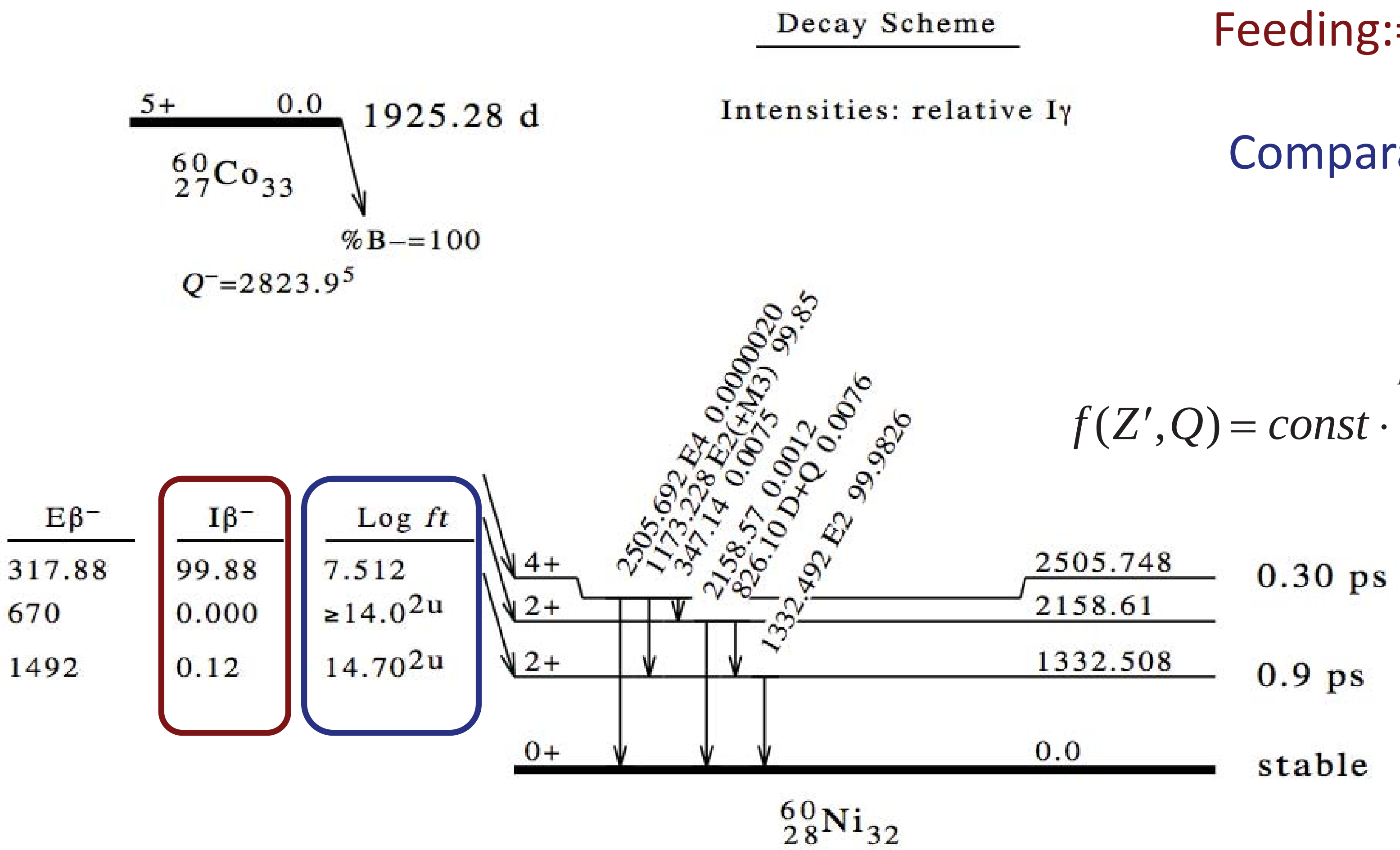
One alternative, based in the pioneering work of I. Hamamoto, (Z. Phys. A353 (1995) 145) later followed by studies of P. Sarriguren *et al*., Petrovici *et al*. is related to the dependency of the strength distribution in the daughter nucleus depending on the shape of the parent. It can be used, when 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/



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

Comparative half-life: ft

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

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

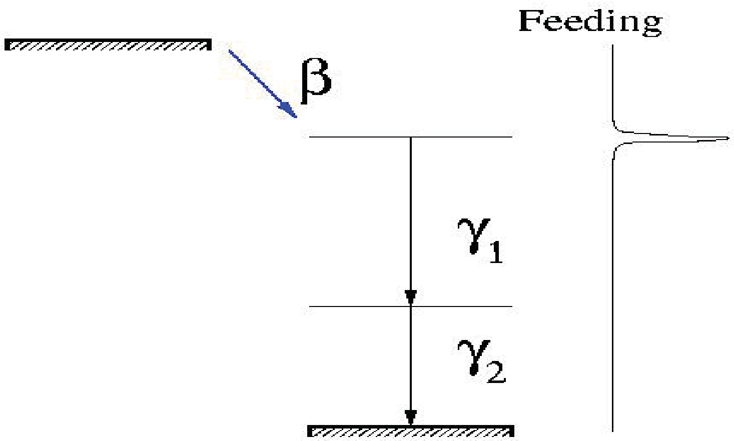
$$ft_f = const'\frac{1}{|M_{if}|^2} = const'\frac{1}{B_{i\to f}}$$

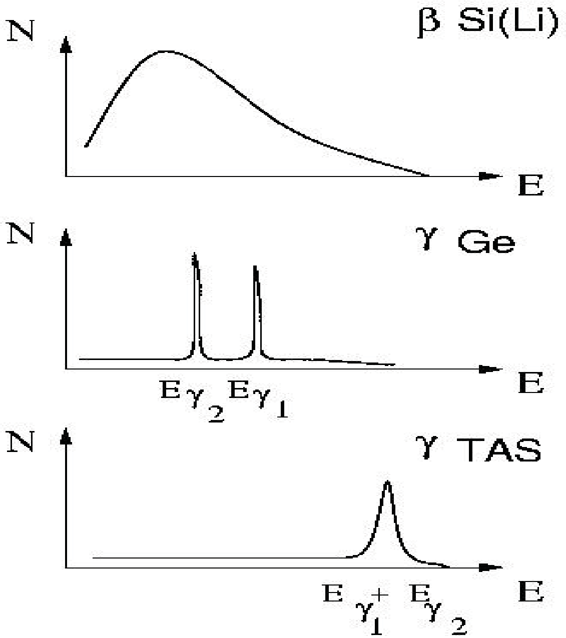
$$S_\beta(E_{ex}) = \frac{P_\beta(E_{ex})}{f(Z',Q_\beta - E_{ex})T_{1/2}} = \frac{1}{ft(E_{ex})}$$

$$B_{i\to f}(GT) = \left|\frac{1}{\sqrt{2}}\left\langle \Psi_f \left| \sum_\mu \sum_k \sigma_k^\mu \tau_k^\pm \right| \Psi_i \right\rangle\right|^2$$

$$B_{i\to f}(F) = \left|\frac{1}{\sqrt{2}}\left\langle \Psi_f \left| \tau^\pm \right| \Psi_i \right\rangle\right|^2$$

TAGS measurements (gamma part)





Strength ➔ feeding ➔ gamma detection

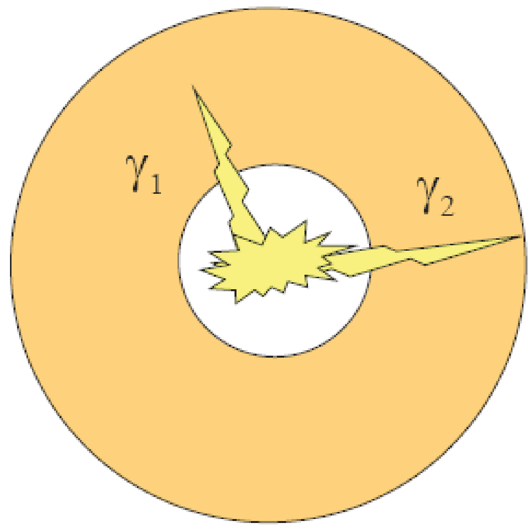
The only reasonable way to solve the problem, without suffering from the so-called Pandemonium effect is to use a highly efficient device:

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.

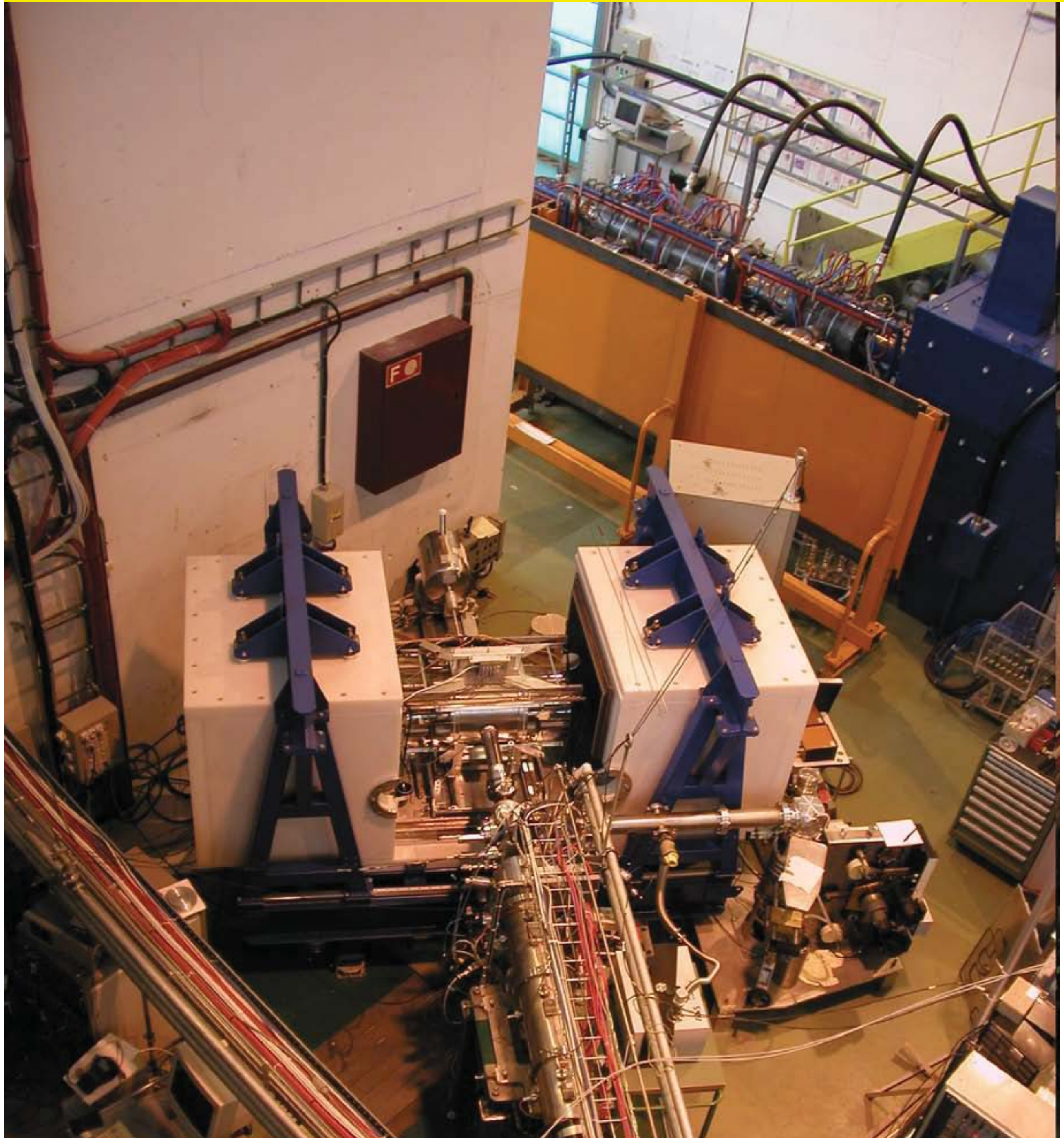
A TAS is like a calorimeter!

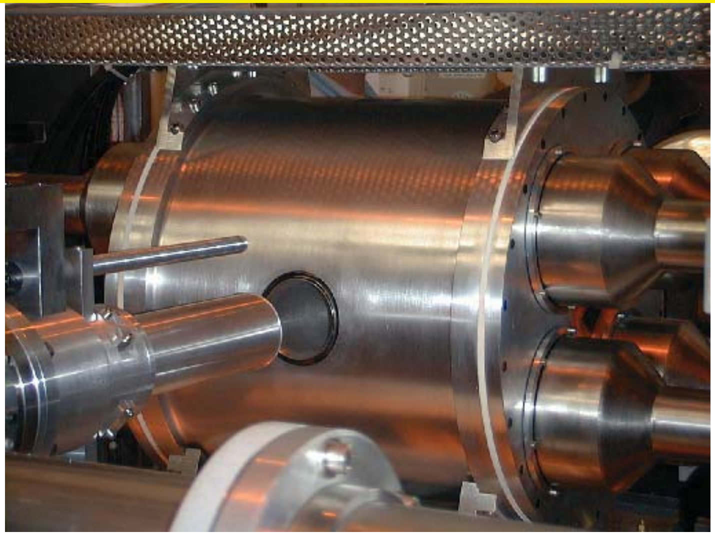
Big crystal, 4 π



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

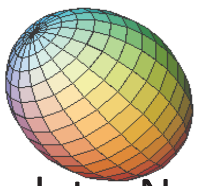
Lucrecia: the TAS at ISOLDE (CERN) (Madrid-Strasbourg-Surrey-Valencia)



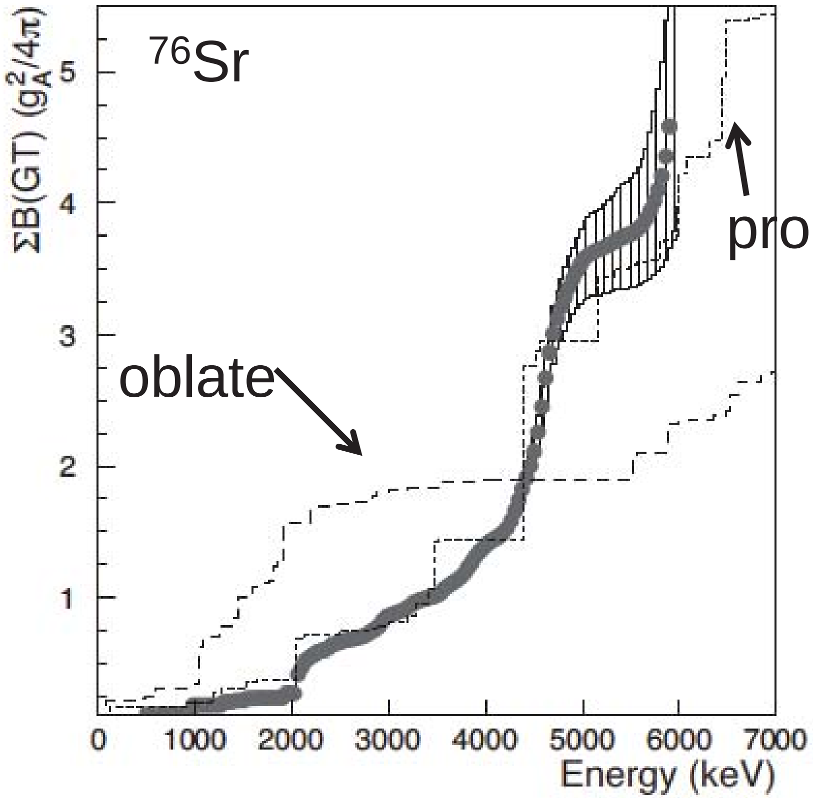


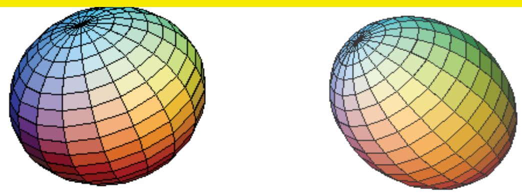
- A large NaI cylindrical crystal 38 cm Ø, 38cm length
- An X-ray detector (Ge)
- A β detector
- Possibility of collection point inside the crystal

Some earlier examples
(proposals of B. Rubio, W. Gelletly, P. Dessagne et al.)

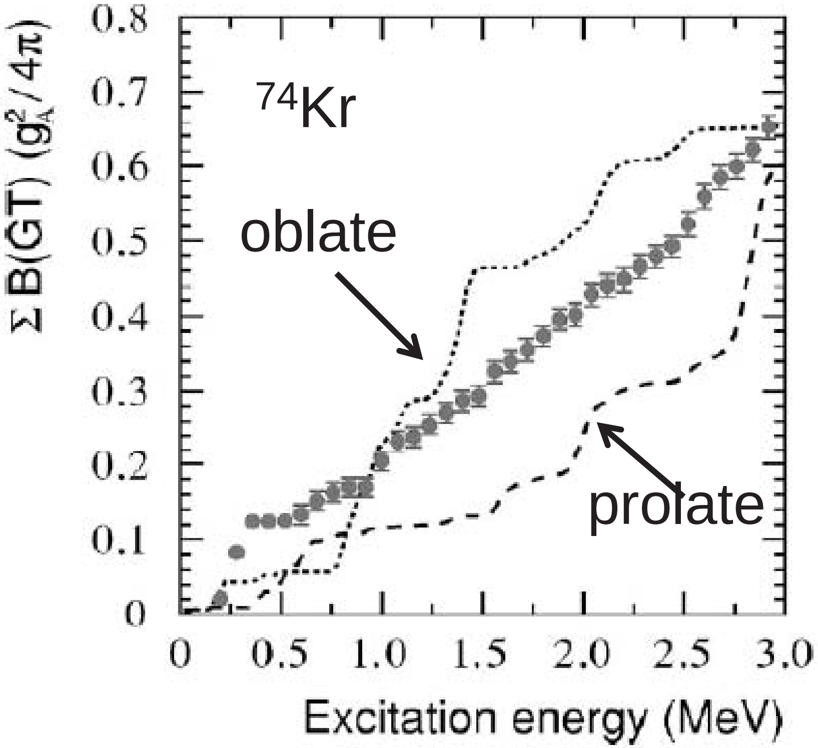


Very prolate N=Z nucleus





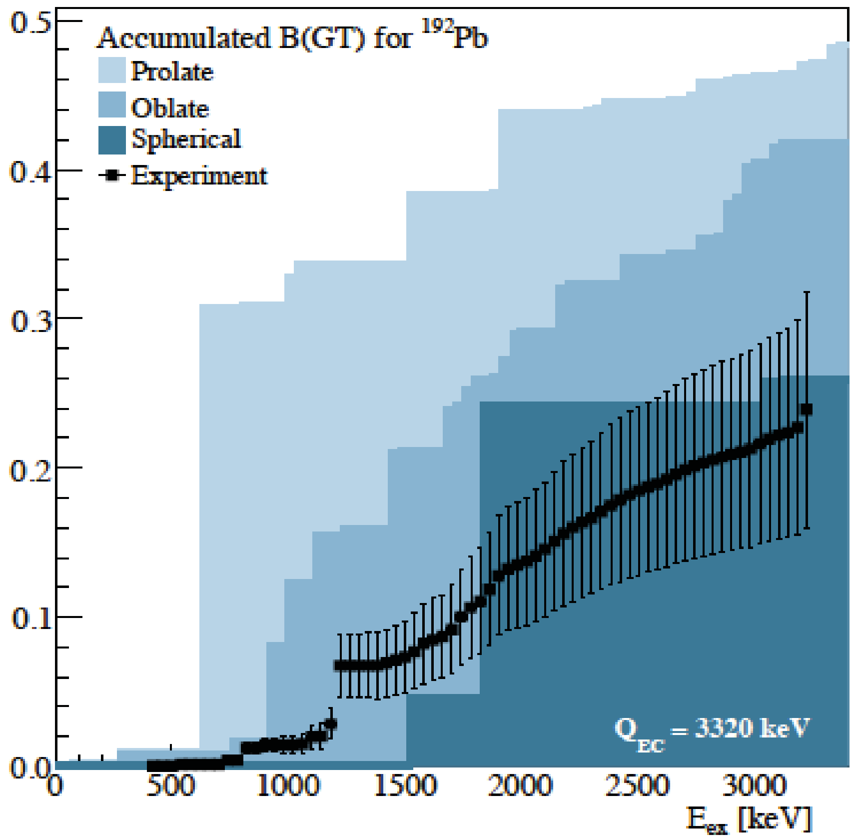
Mixture of prolate and oblate

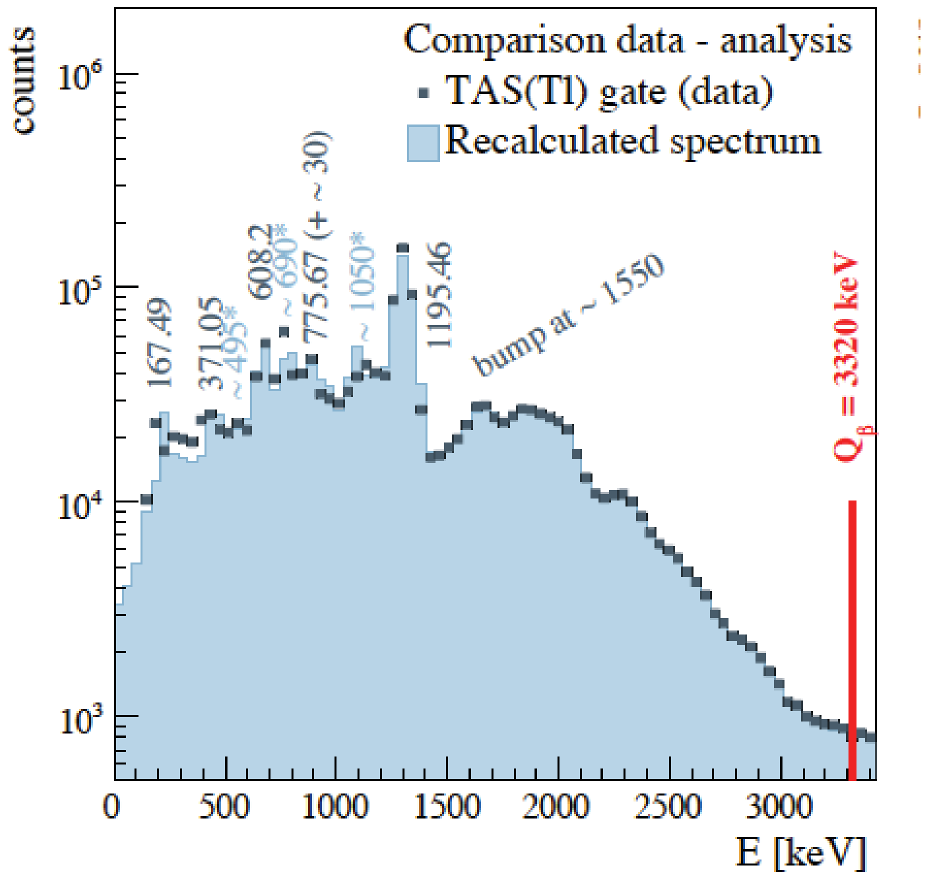


E. Nácher *et al. PRL 92 (2004) 232501 and PhD thesis Valencia*
Ground state of ^{76}Sr prolate (β_2 ~0.4) as indicated in Lister et al., PRC 42 (1990) R1191

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.)

IS440 results: ^{192}Pb, a recent example (proposal by A. Algora et al.)

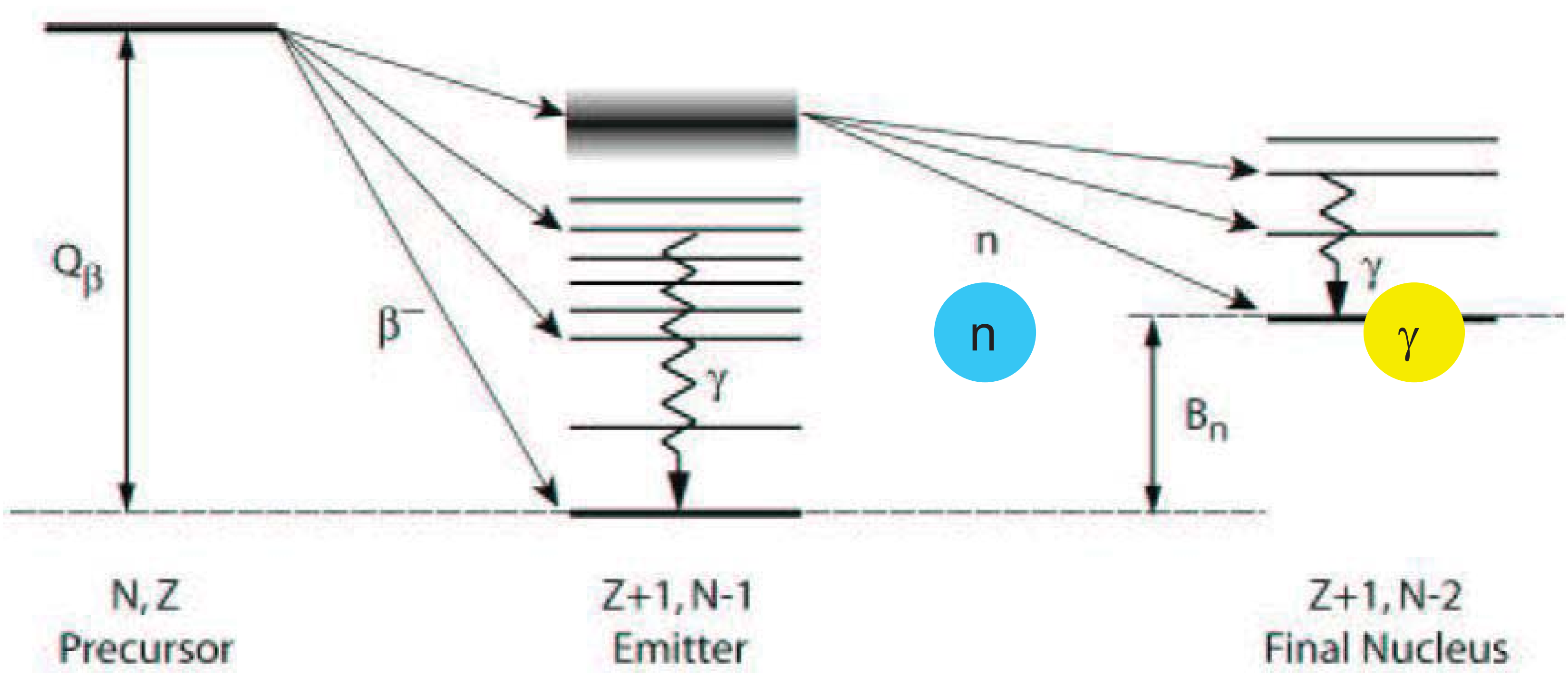




Thesis work of M. E. Estevez 2012, and M. E. Estevez *et al.* in preparation. Theory from PRC 73 (2006) 054317

Results consistent with spherical picture, but less impressive than in the A≈80 region. Similar situation for ^{190}Pb. *Possible explanation, the spherical character of the Pb nuclei, but requires further testing.*

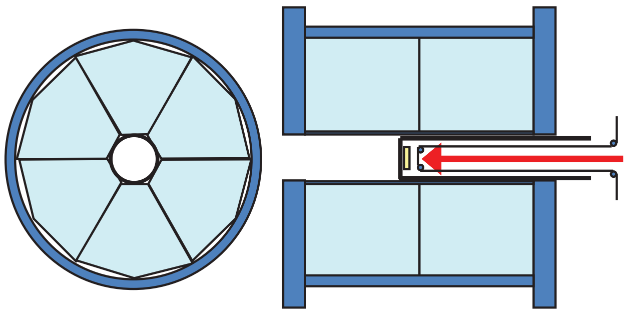
Beta decay in the neutron rich side



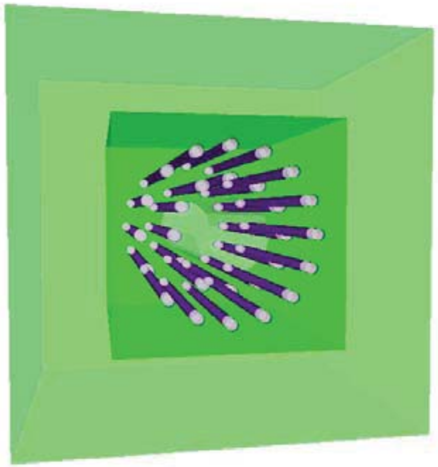
If $S_n < Q_\beta$
and the decay proceeds to states above S_n, neutron emission competes and can dominate over γ-ray de-excitation
The process will dominate far from stability on the n-rich side.
To have a full picture of the strength …

Beta strength measurements: combination of techniques

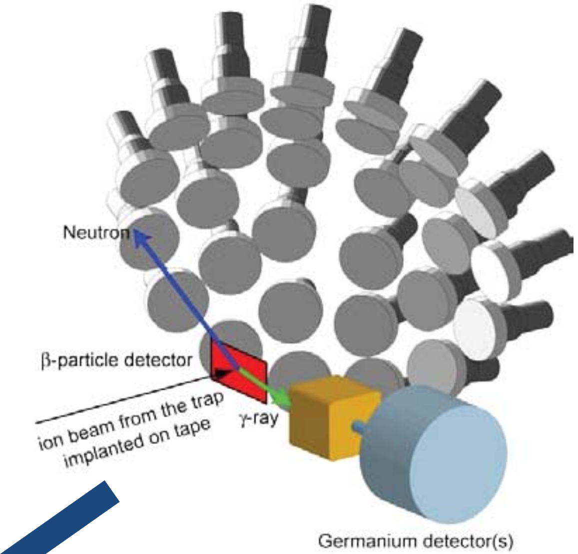
Total Absorption γ-Ray Spectrometer



4π Neutron Counter

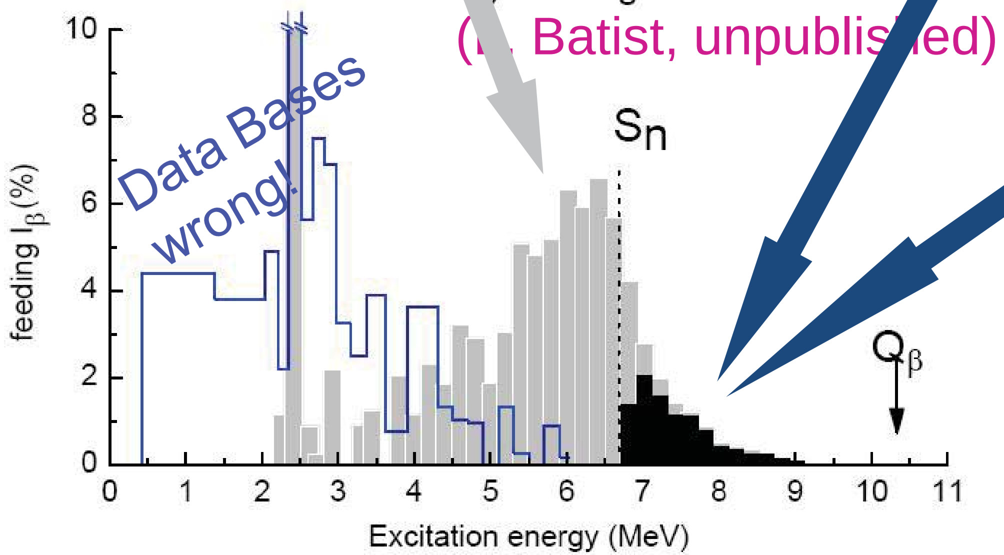


Neutron Time of Flight Spectrometer



Beta decay of ^{94}Rb

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



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

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

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

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

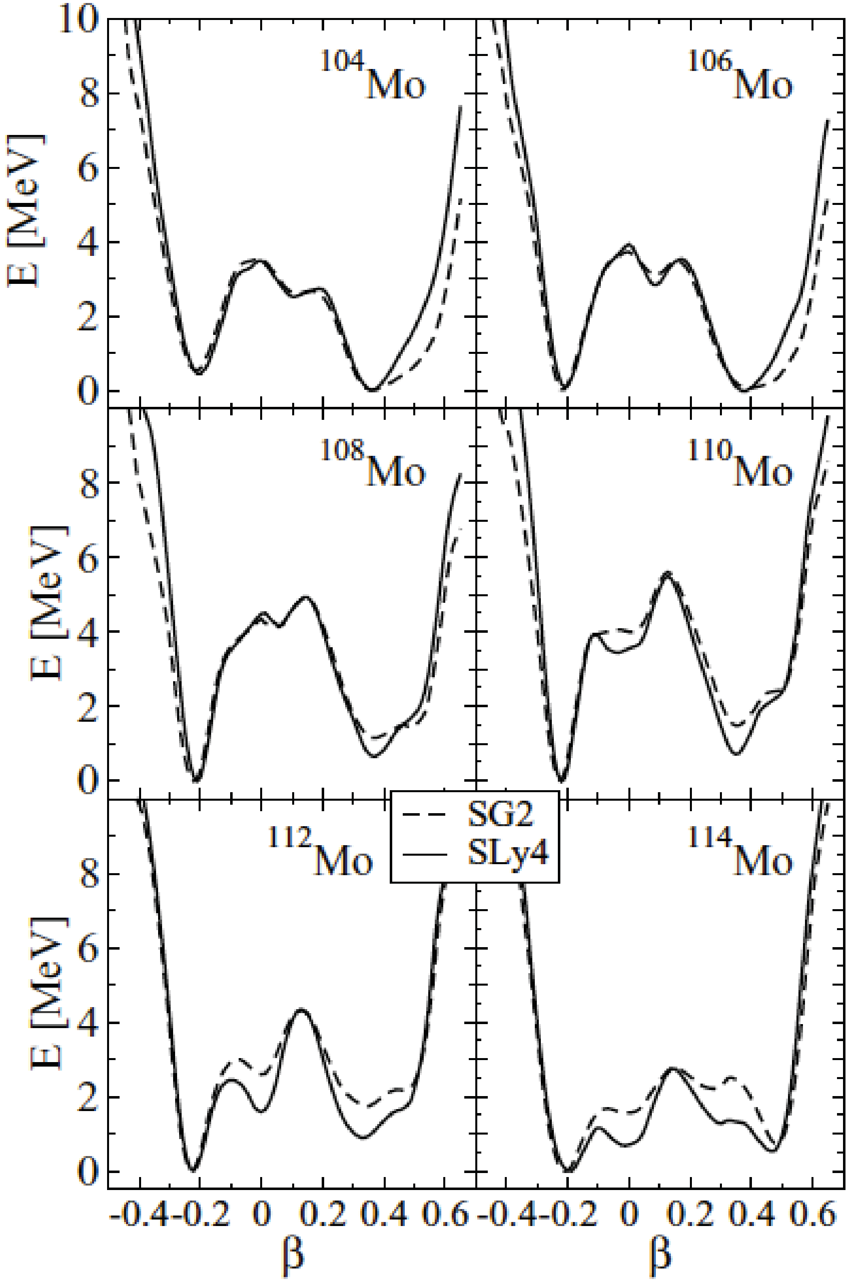
$$P_n = \frac{\sum_{S_n<E_{ex}<Q_\beta} f(Z, Q_\beta - E_{ex}) B(GT, E_{ex})}{\sum_{0<E_{ex}<Q_\beta} f(Z, Q_\beta - E_{ex}) B(GT, E_{ex})}$$

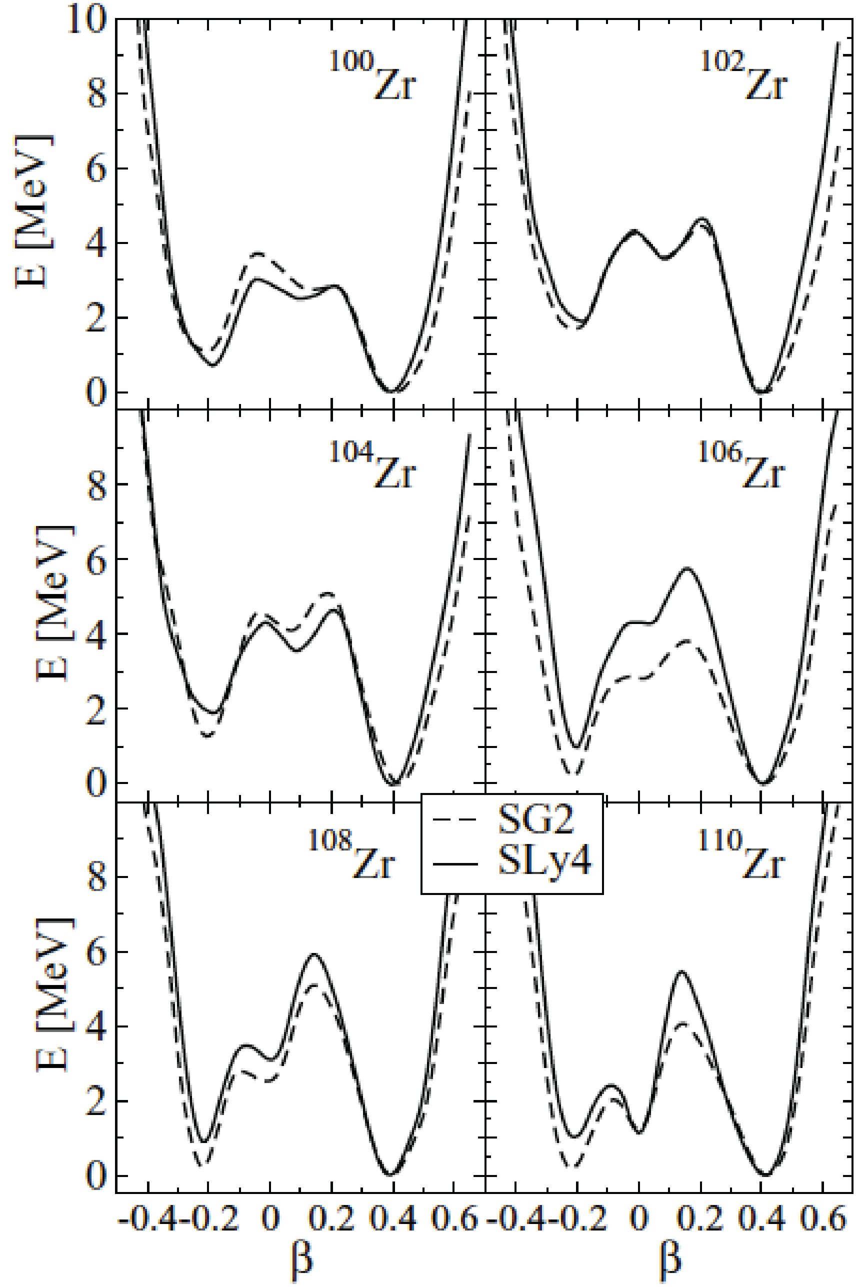
Hartree-Fock calculations: A=100

(P. Sarriguren, J. Pereira PRC 81 (2010) 064314)

- 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.

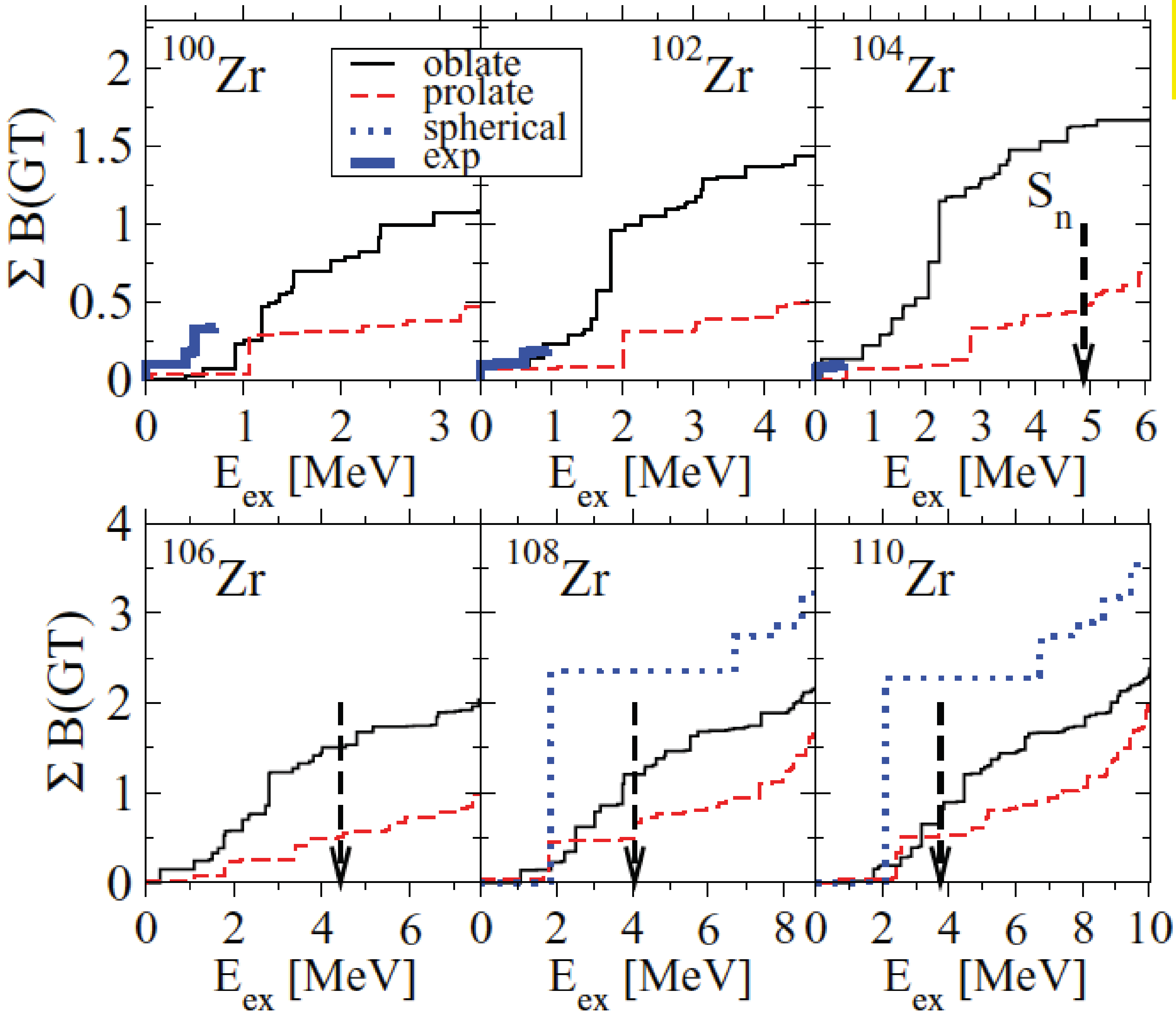
A=100 region, equilibrium shapes

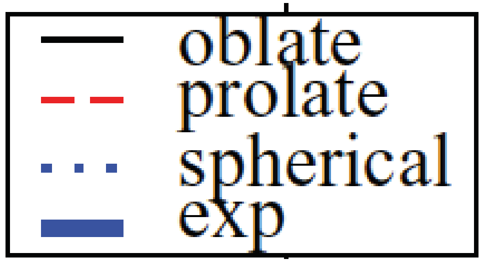




Sarriguren, Pereira PRC 81(2010) 064314

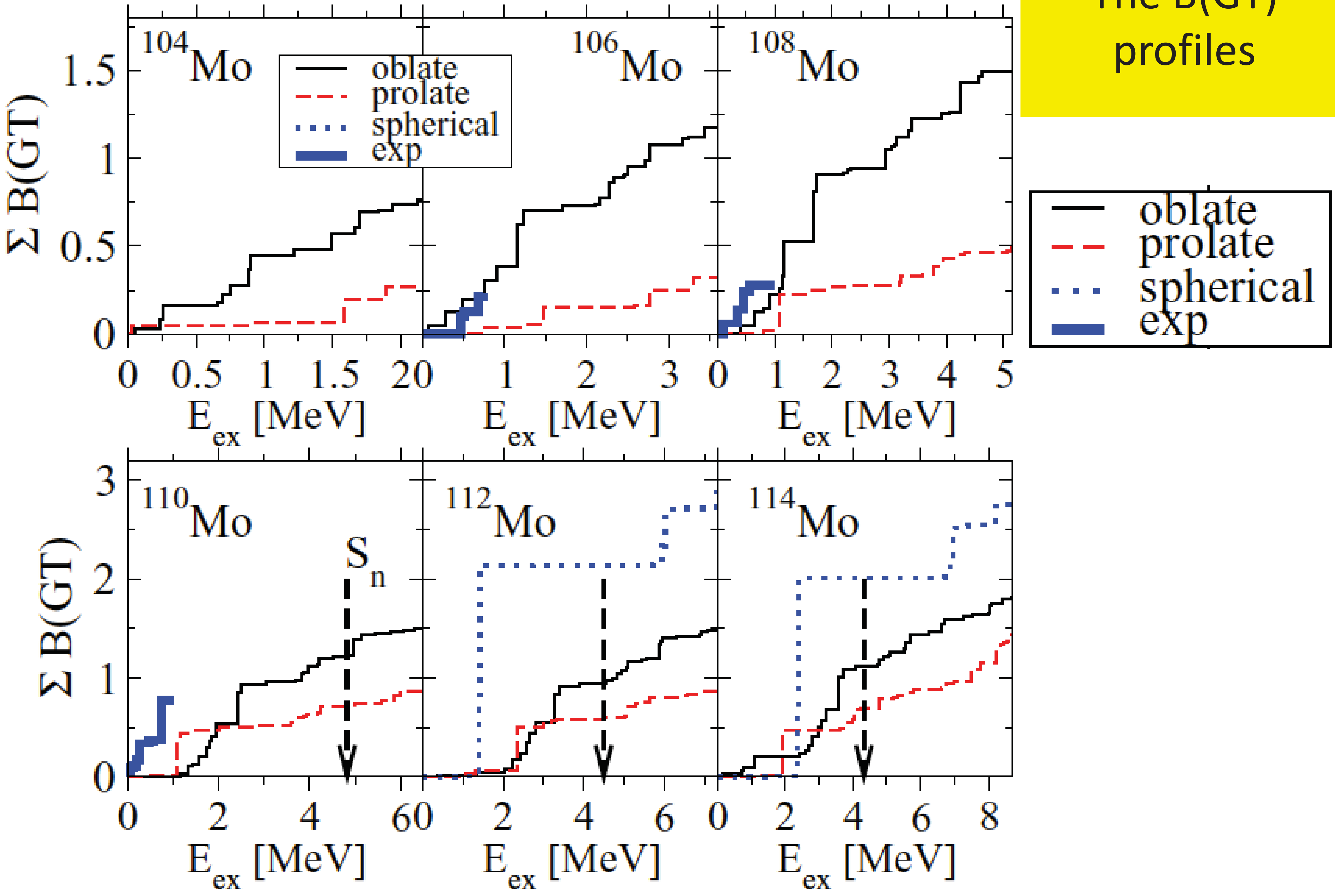
The B(GT) profiles





Sarriguren, Pereira
PRC 81(2010) 064314

The B(GT) profiles



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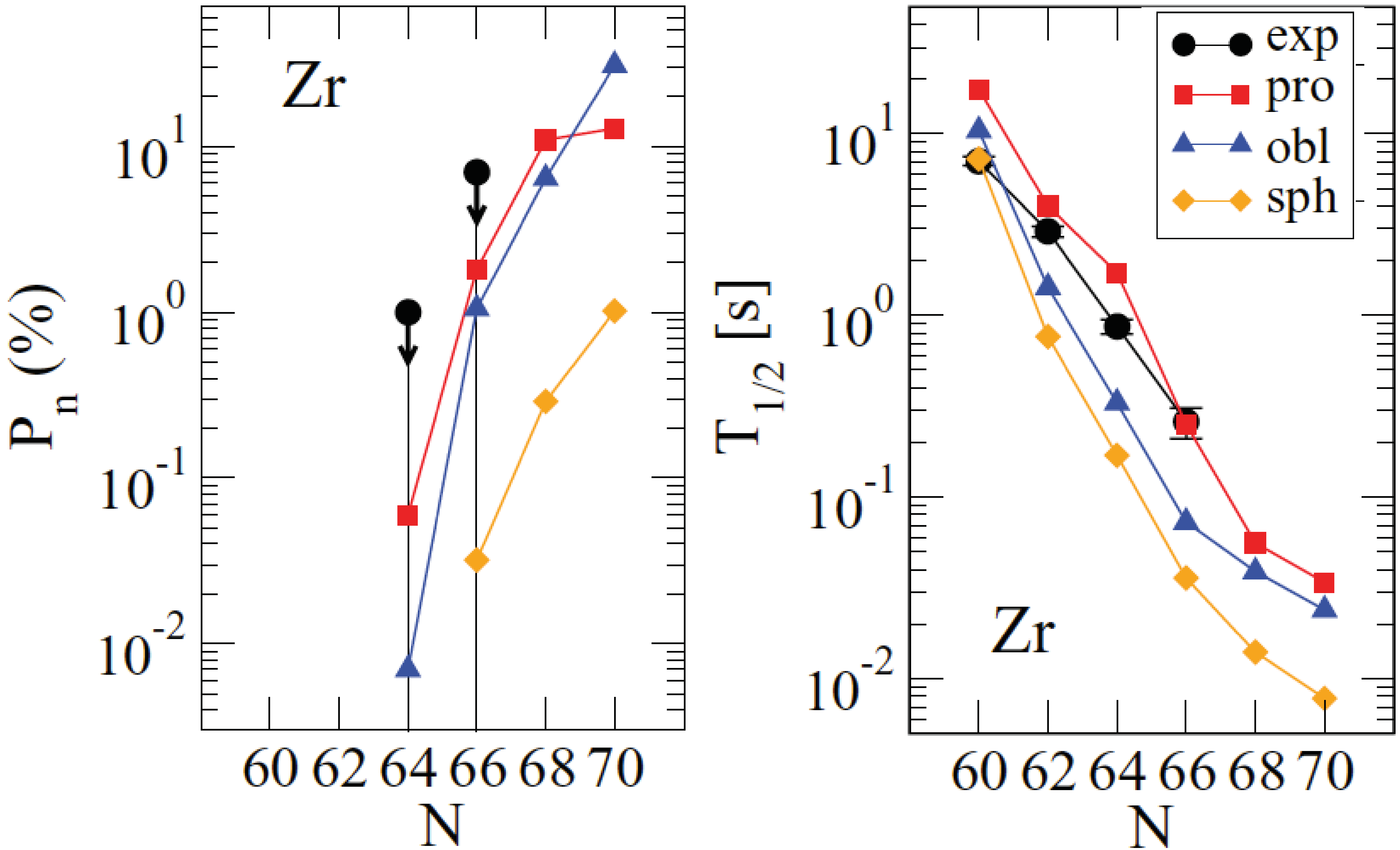
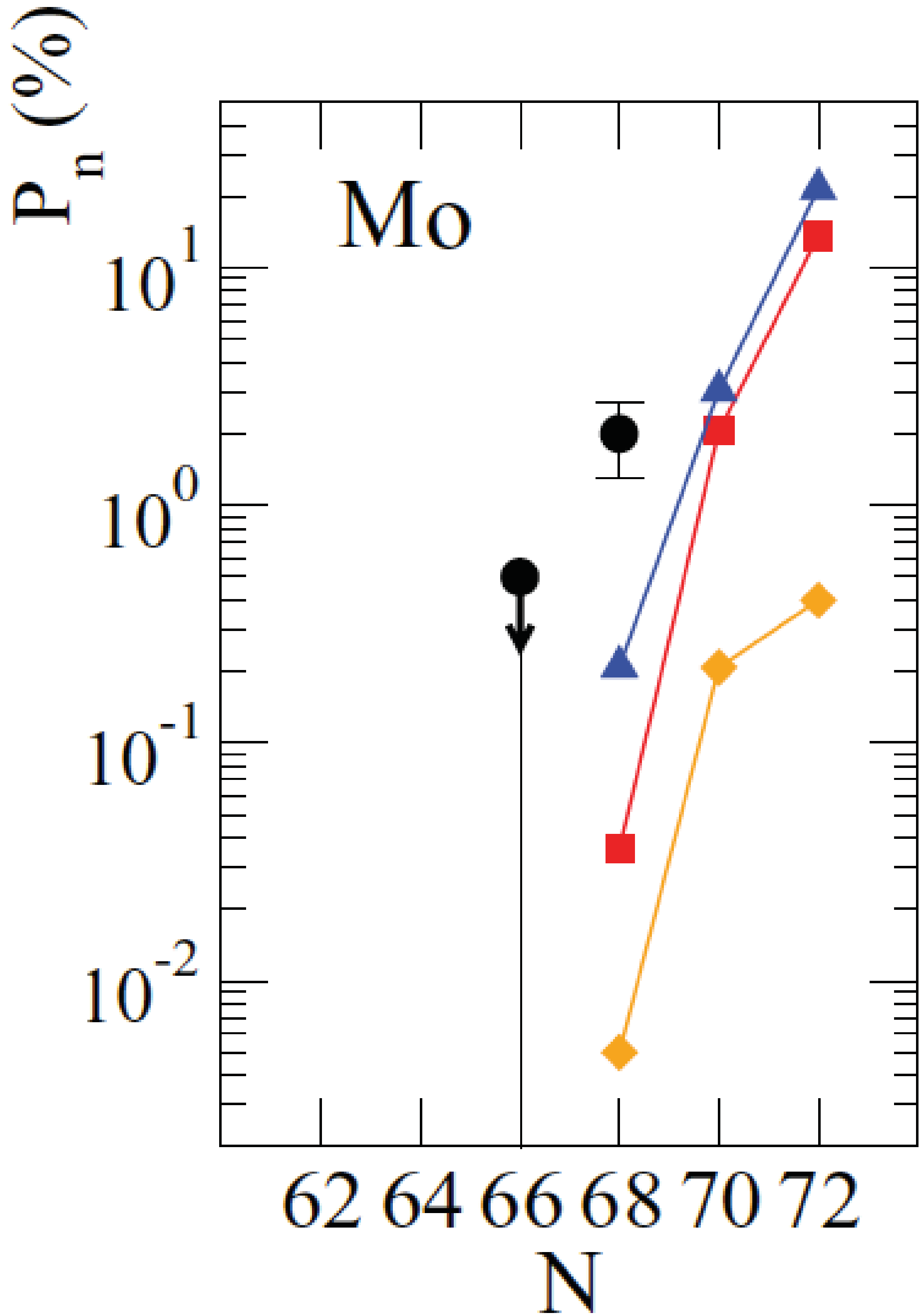
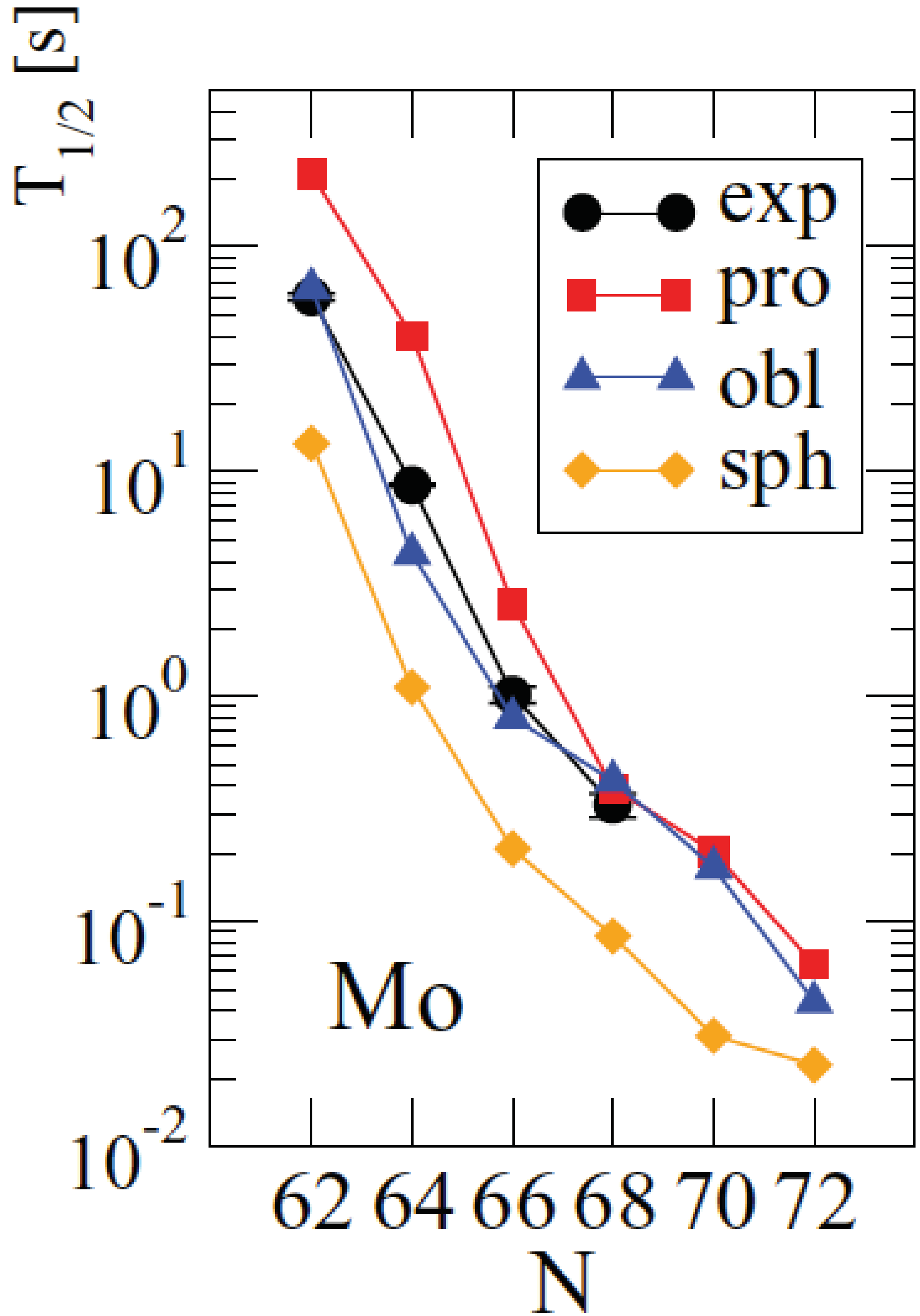
What can $T_{1/2}$ and P_n measurements provide (SLy4) ?



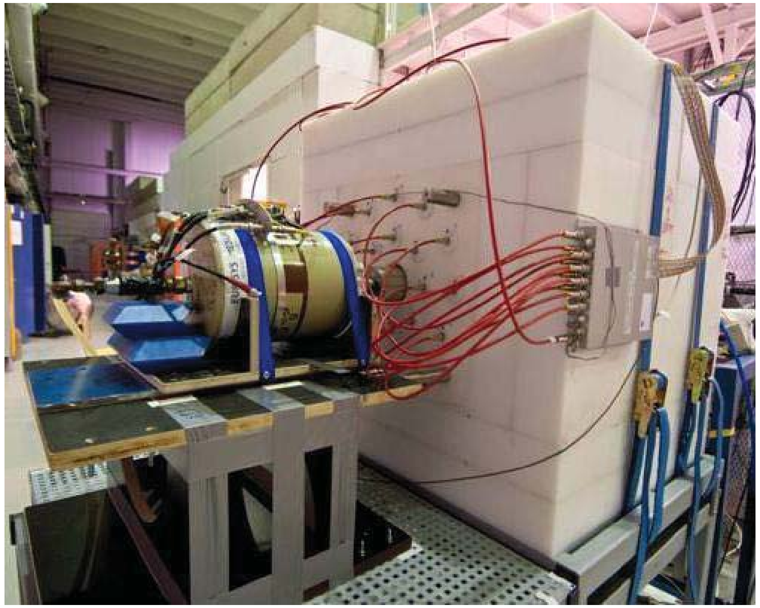
Mo isotopes (SLy4)





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

Isotope	Oblate shape	Spherical shape	Prolat e 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)

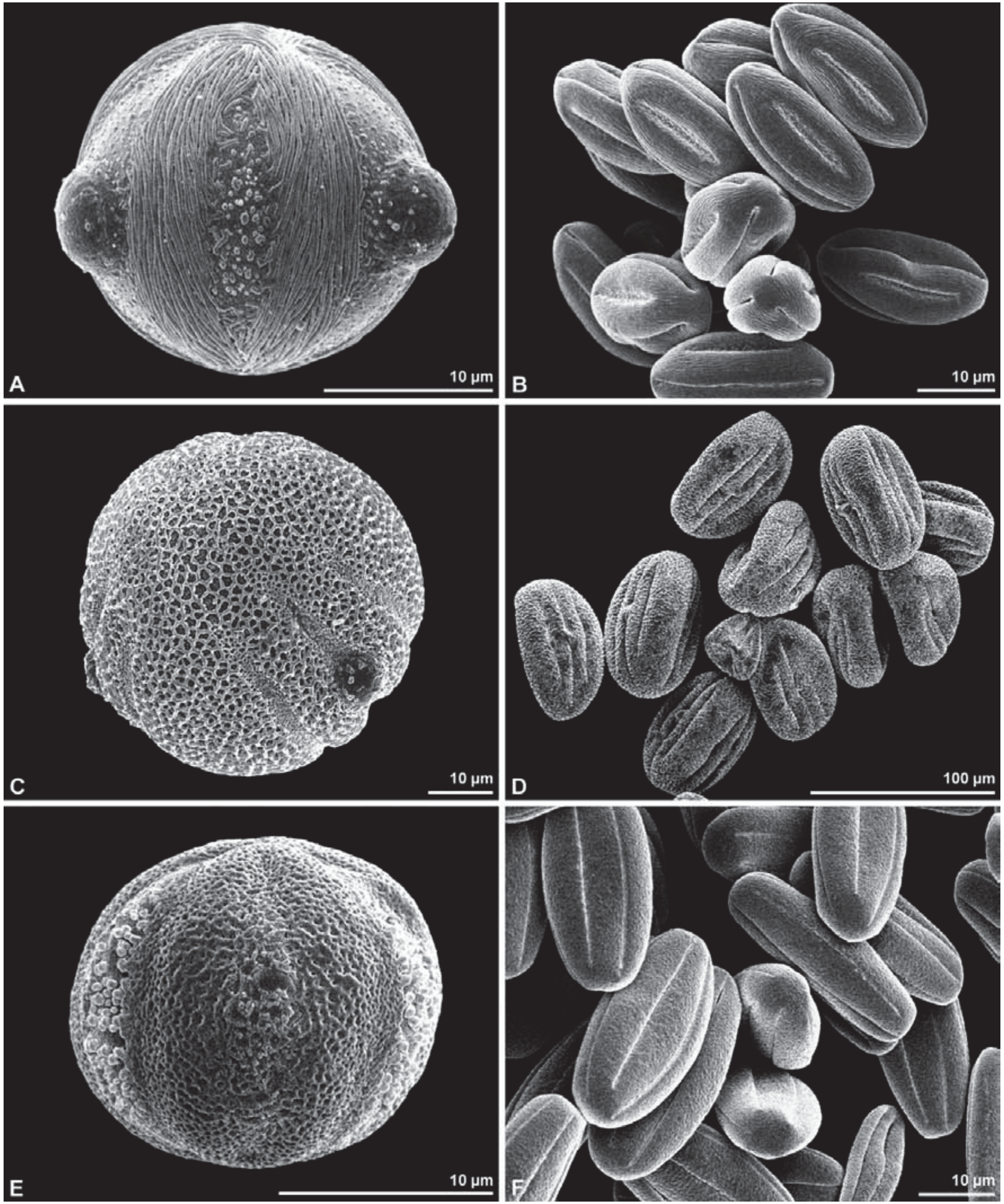
Expected yields (from Riken homepage)

Isotope	238U/Pb (fission) 238U/Be(fission)	136Xe/Be (fragm.)
106Zr	1.4x10E+02 9.1x10E+02	6.5x10E+00
108Zr	- 1.0x10E+01	5.2x10E-01
110Zr	- 4.0x10E-02	1.4x10E-01
110Mo	1.5x10E+03 -	7.4x10E+01
112Mo	1.5x10E+01 -	8.2x10E+00
114Mo	- 2.4x10E+00	9.5x10E-01

Measurements already performed in the region at RIKEN and published by Nishimura et al. PRL 106, Watanabe et al. PLB 704, Sumikama et al. PRL 106

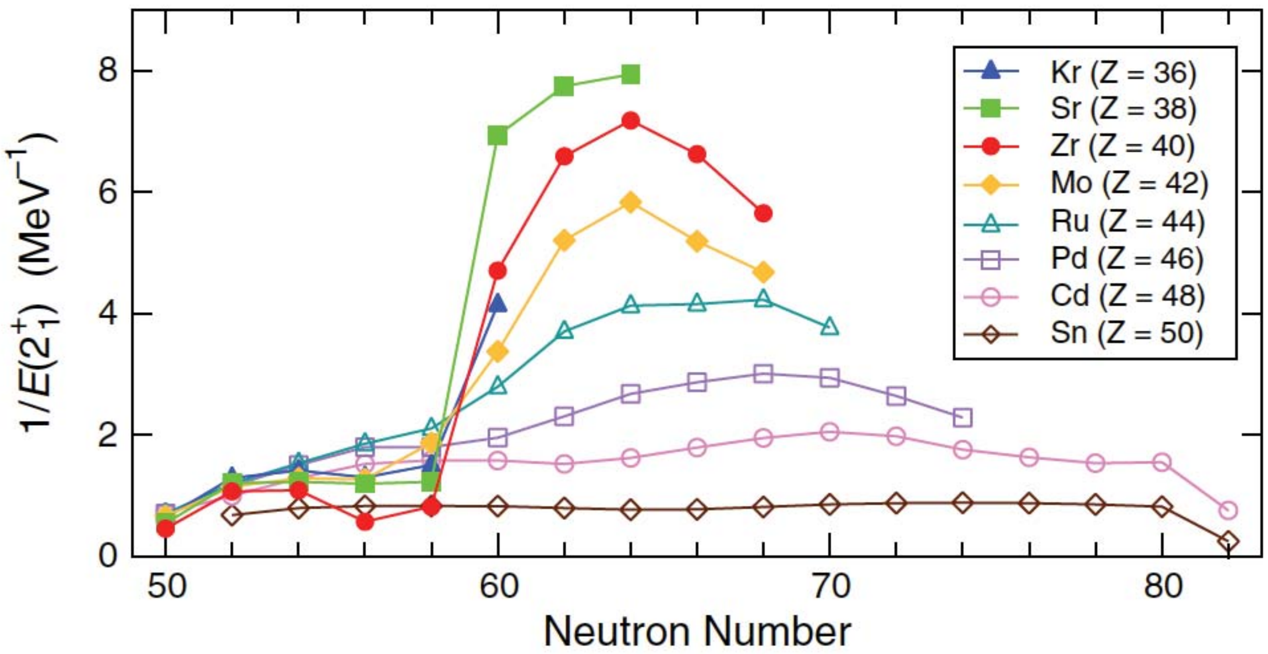
Summary

- 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 and in particular Pn and $T_{1/2}$ measurement can provide an alternative source of information for exotic nuclei (depends heavily on theory and on the case)
- The region of A=100 is interesting and feasible from that point of view
- In any case apart from the clear implications in astrophysics these measurements can provide experimental data useful for testing nuclear models



THANK YOU

Summary of what is known



Taken from Sumikama et al. PRL.106.202501

A few questions/conclusions that have been drawn

- Several questions: is there a transition to oblate shapes (Skalsky et al, for Z~40)
- Is there a N=70 spherical shell, it has important astrophysical implications
- ^{110}Mo looks axially asymetric, (see Watanabe et al.)
- ^{108}Zr seems deformed (see Sumikama et al.)