Total Absorption Spectroscopy Studies with the LUCRECIA setup

Status report for IS440 and IS539

IFIC, (CSIC-University of Valencia), Valencia, Spain
University of Surrey, Guildford, UK
IEM, CSIC, Madrid, Spain
Universidad Complutense de Madrid, Madrid, Spain
Institute of Nuclear Research, Debrecen, Hungary
CERN, Switzerland
Petersburg Nuclear Physics Institute, Gatchina, Russia
School of Engineering, University of the West of Scotland, UK
Instituto de Ciencias Nucleares, UNAM, Mexico
Istanbul University, Science Faculty, Istanbul, Turkey

Beta-decay

✓ Level feeding in beta-decay

→ Beta transition probability to daughter nucleus levels

→ Missing strength due to low efficiency of standard Ge setups

Strength function

Beta feeding

$$S_\beta(E) = \frac{I_\beta(E)}{f(Q_\beta - E)T_{1/2}}$$

Half life of parent

Fermi function

Relationship

$$S_\beta = \frac{1}{6147 \pm 7}\left(\frac{g_A}{g_V}\right)^2 \sum_{E_f \in \Delta E} \frac{1}{\Delta E} B(GT)_{i \to f}$$

$$B(GT) = \left| \frac{1}{\sqrt{2}} \langle \psi_f | \sum_\mu \sum_k \sigma_k^\mu \tau_k^\pm | \psi_i \rangle \right|^2$$

Beta-decay

✓ Level feeding in beta-decay

→ Beta transition probability to daughter nucleus levels

→ Missing strength due to low efficiency of standard Ge setups

Strength function

$$S_\beta(E) = \frac{I_\beta(E)}{f(Q_\beta - E)T_{1/2}}$$

Beta feeding

Half life of parent

Fermi function

Relationship

$$S_\beta = \frac{1}{6147 \pm 7}\left(\frac{g_A}{g_V}\right)^2 \sum_{E_f \in \Delta E} \frac{1}{\Delta E} B(GT)_{i \to f}$$

$$B(GT) = \left| \frac{1}{\sqrt{2}} \langle \psi_f | \sum_\mu \sum_k \sigma_k^\mu \tau_k^\pm | \psi_i \rangle \right|^2$$

TOTAL ABSORPTION SPECTROSCOPY

→ detection of the gamma **cascades** with highly efficient detectors

→ nuclear structure studies and practical applications

Lucrecia – the ISOLDE TAgS

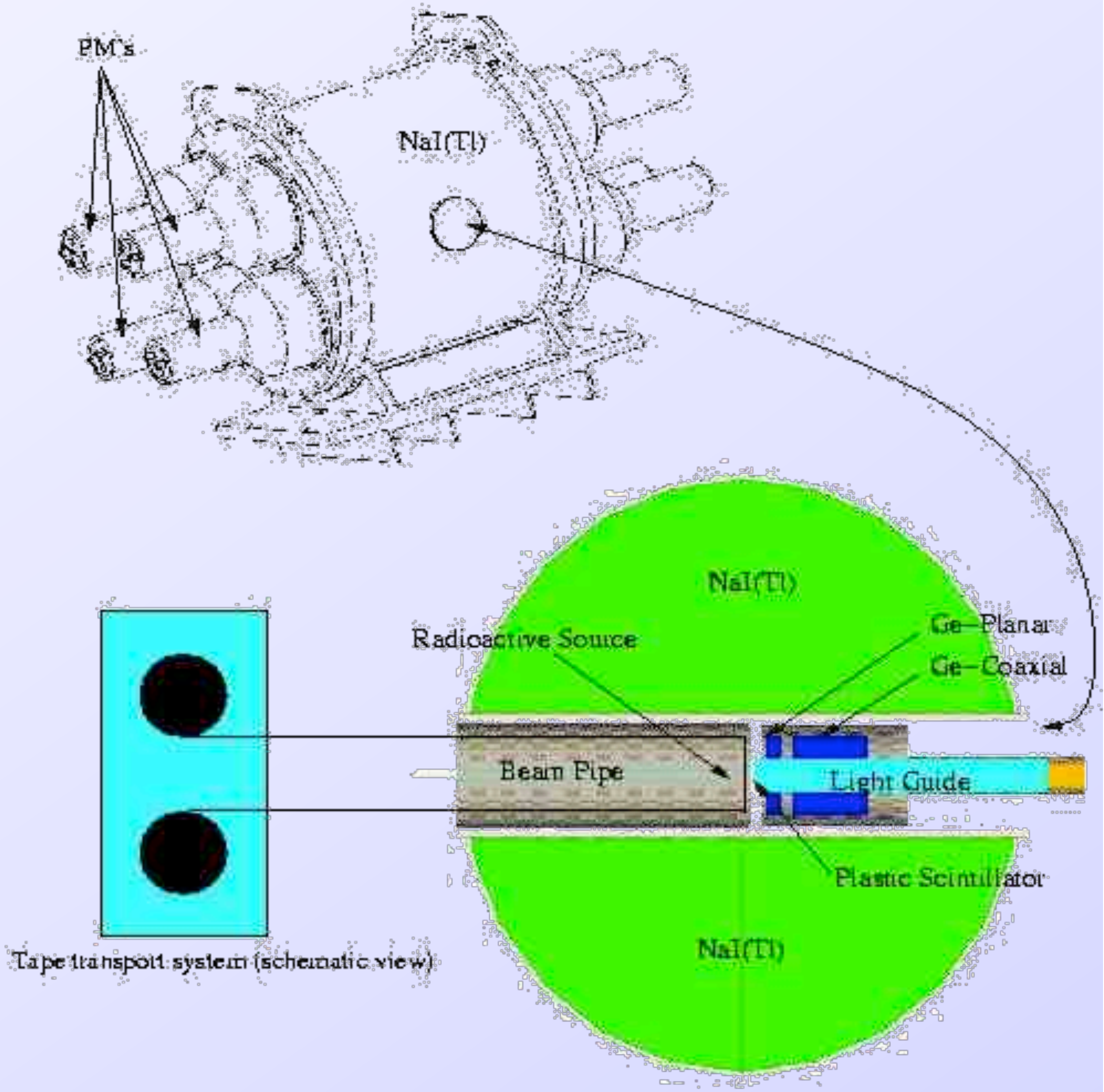
Total absorption gamma spectrometer at CERN

A large NaI cylindrical crystal
38 cm Ø, 38cm length

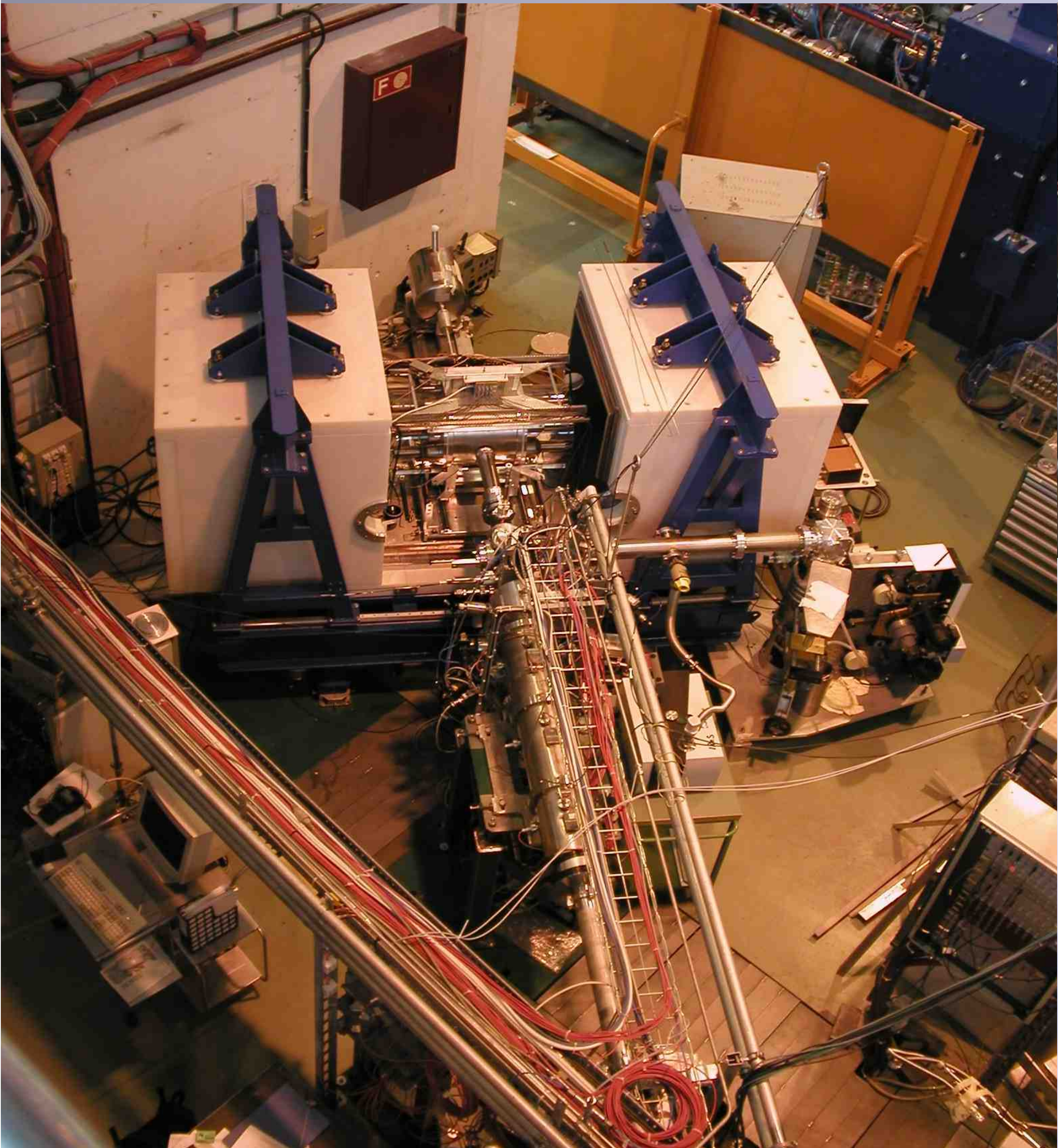
An X-ray detector (Ge)

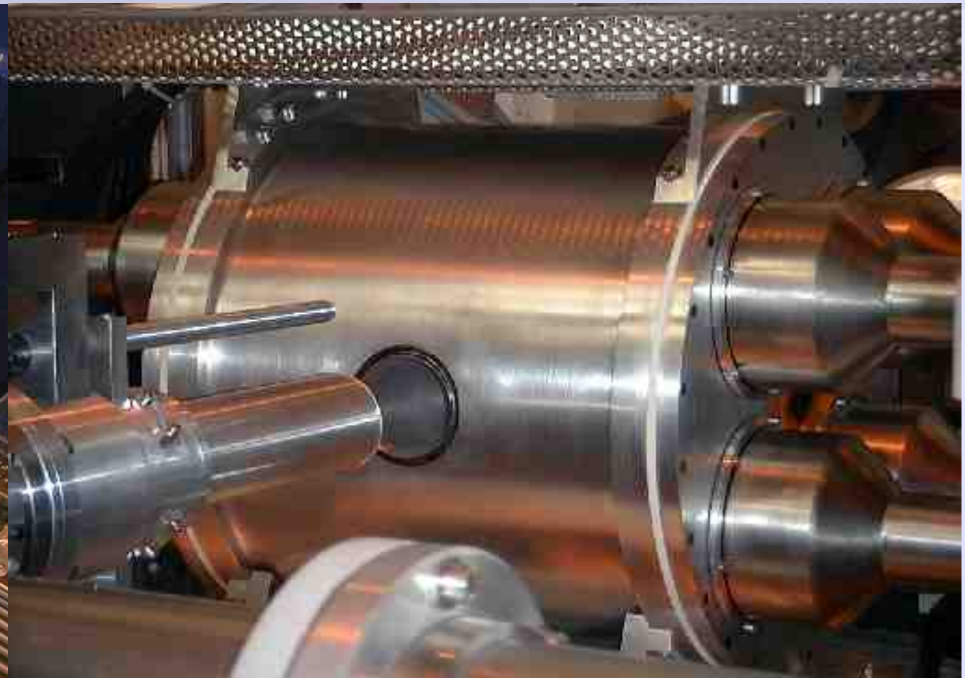
A β detector

Collection point inside the crystal



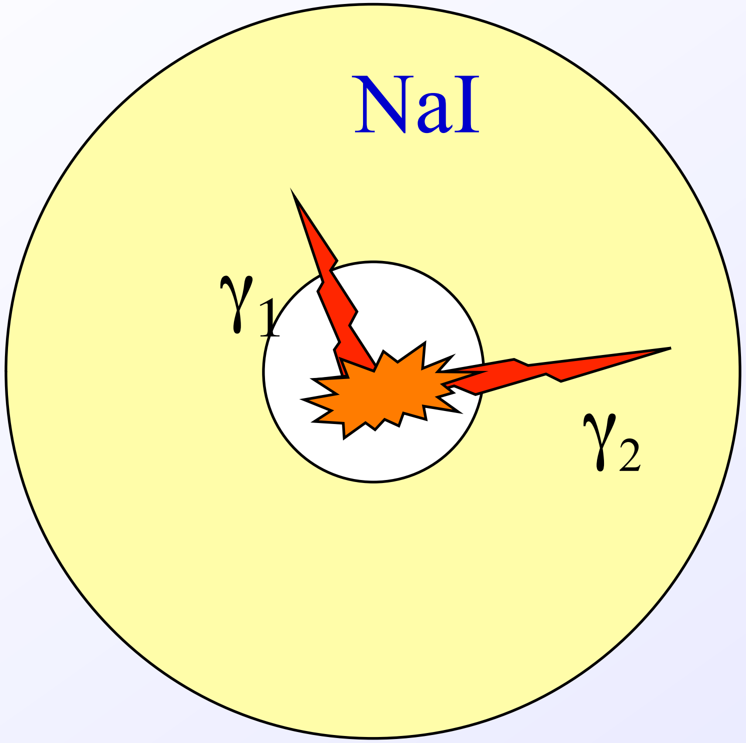
Lucrecia – the ISOLDE TAgS

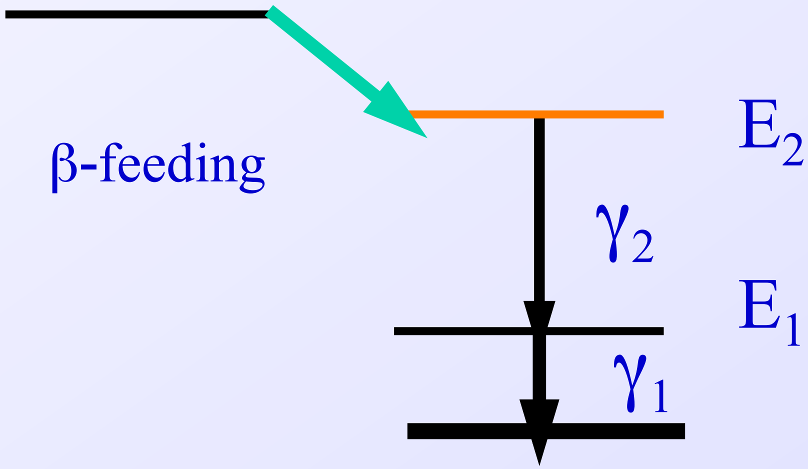


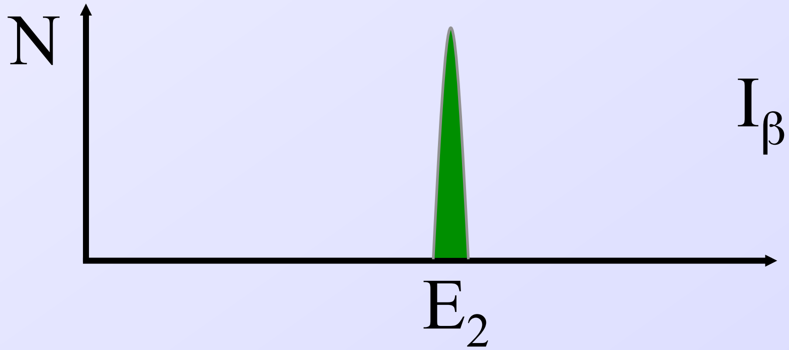


Valencia – Strasbourg – Surrey – Madrid collaboration

Total absorption spectroscopy







Excitation in the daughter

Ideal case: beta minus decay, and no contamination.
There is need for a 100% efficient summing device

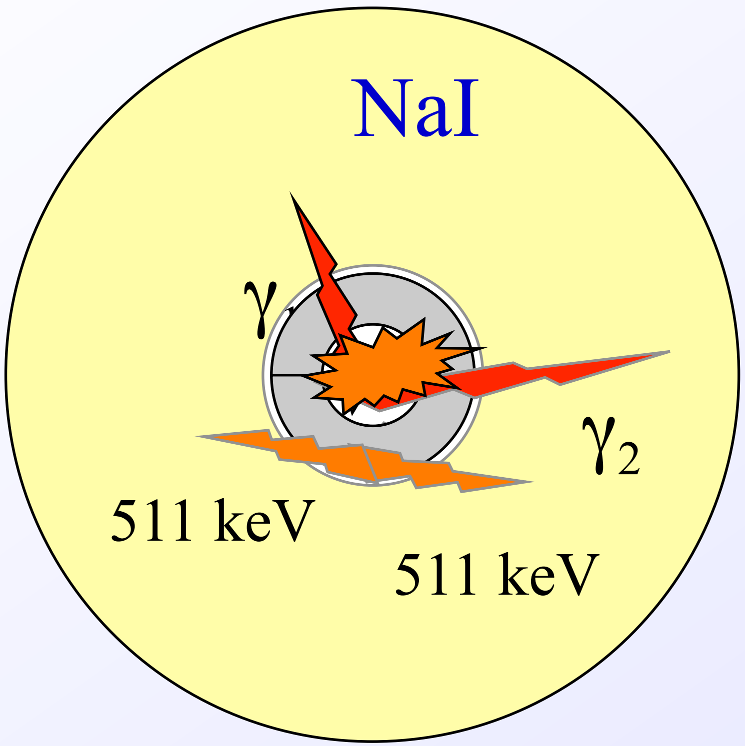
$$d = R(B)\, f$$

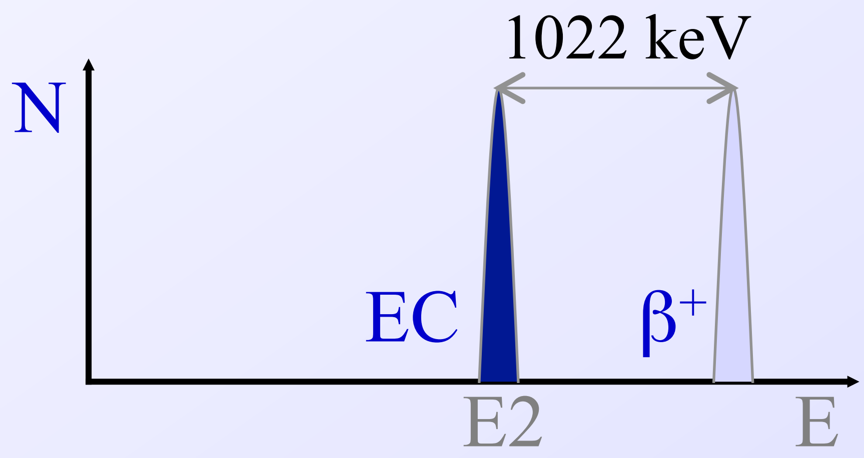
Analysis method (Valencia group)

NIM A 571, 710 (2007)

NIM A 571, 728 (2007)

Total absorption spectroscopy



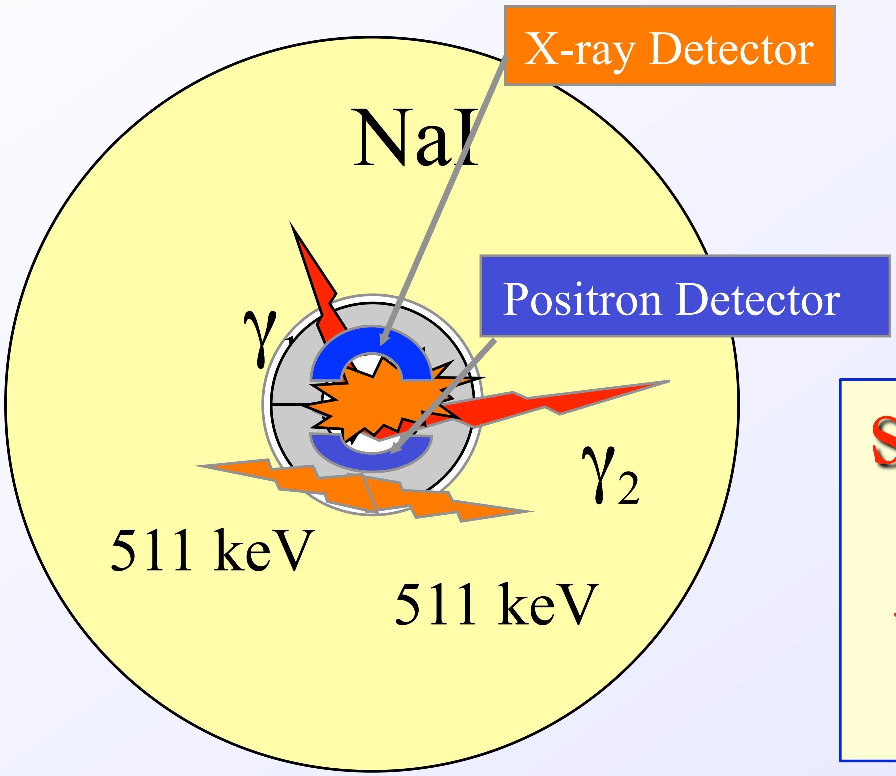


Real case: 2 processes in the beta+/EC
We need to distinguish between them

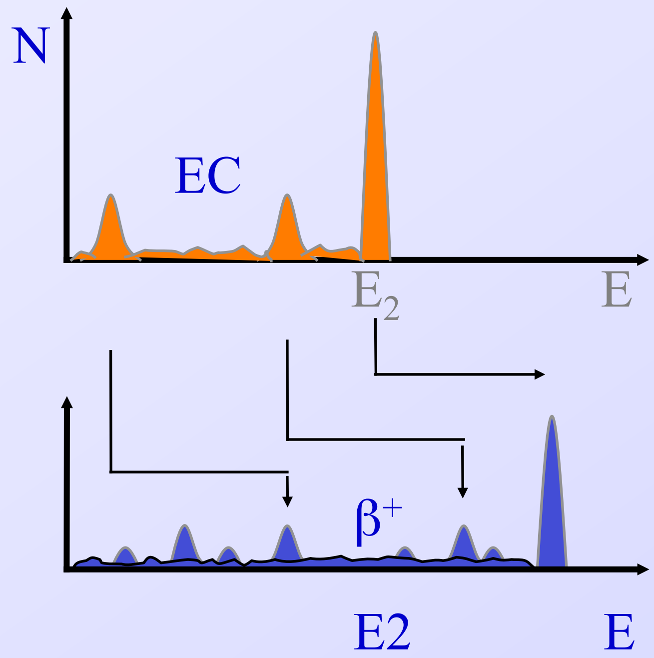
EC: $${}^{A}_{Z}X + e^{-} \longrightarrow {}^{A}_{Z-1}X + \nu_{e}$$

β+: $${}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}X + \beta^{+} + \nu_{e}$$

Total absorption spectroscopy



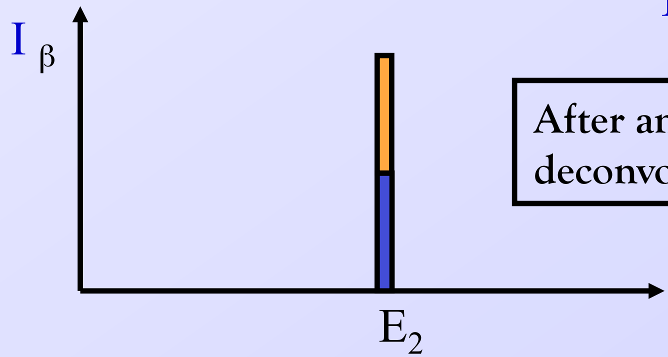
Solution: use of coincidences with ancillary detectors



Real case: 2 processes in the beta+/EC
We need to distinguish between them

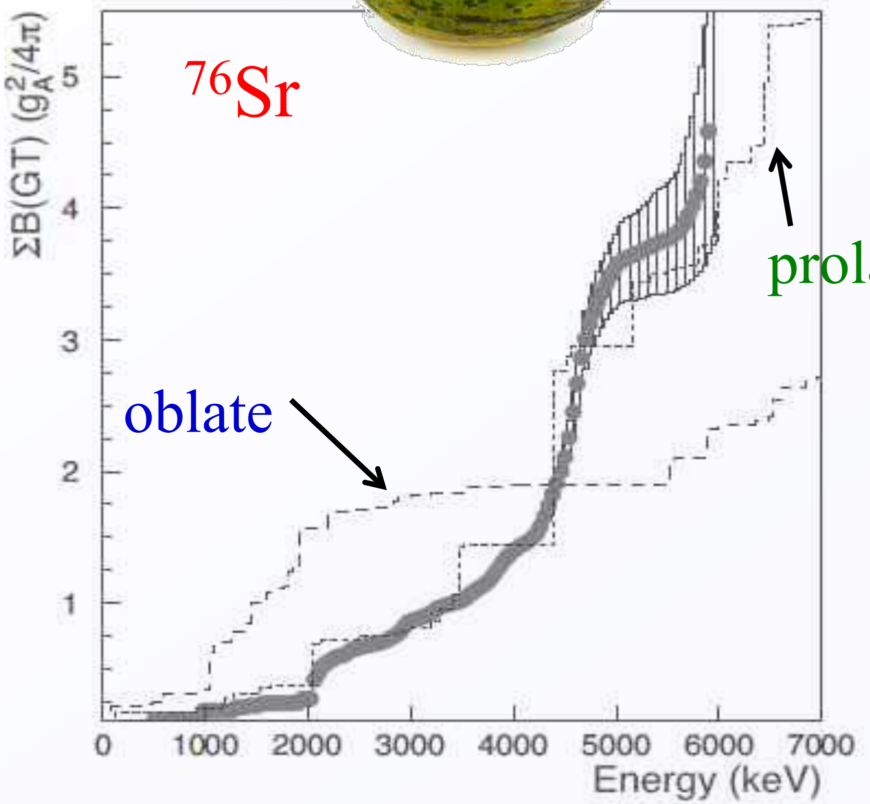
EC: $${}^{A}_{Z}X + e^{-} \longrightarrow {}^{A}_{Z-1}X + \nu_e$$

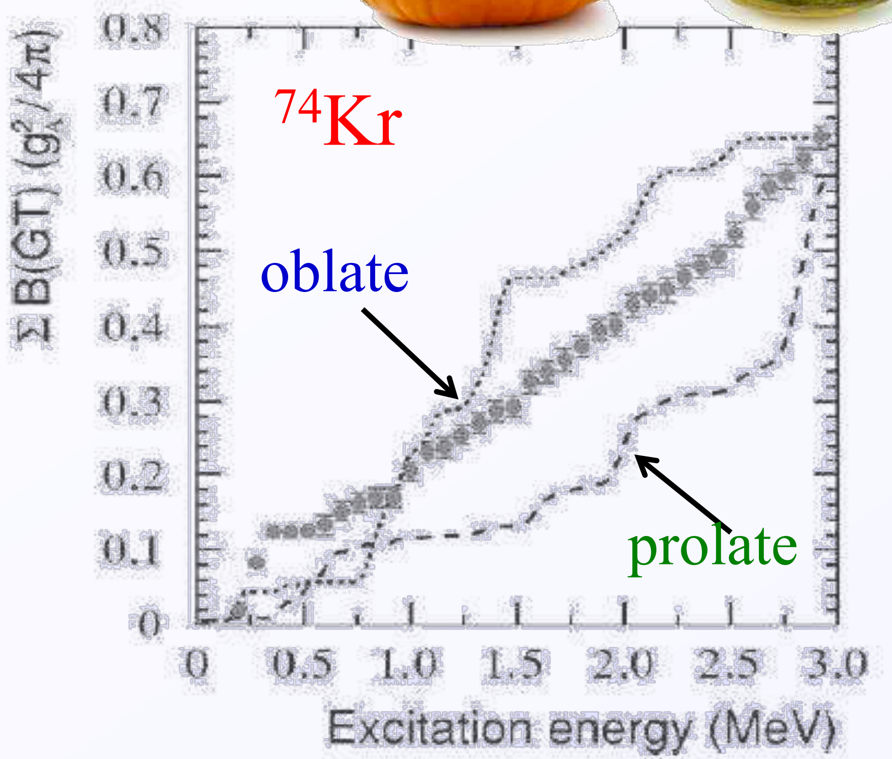
β+: $${}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}X + \beta^{+} + \nu_e$$



After an ideal deconvolution and sum

Earlier work





Very prolate N=Z nucleus

Admixture 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 by 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.)*

Shape effects along the Z=82 line: study of the beta decay of ^{188,190,192}Pb using total absorption

Spokespersons: A. Algora, B. Rubio, W. Gelletly

→ Region of shape co-existence

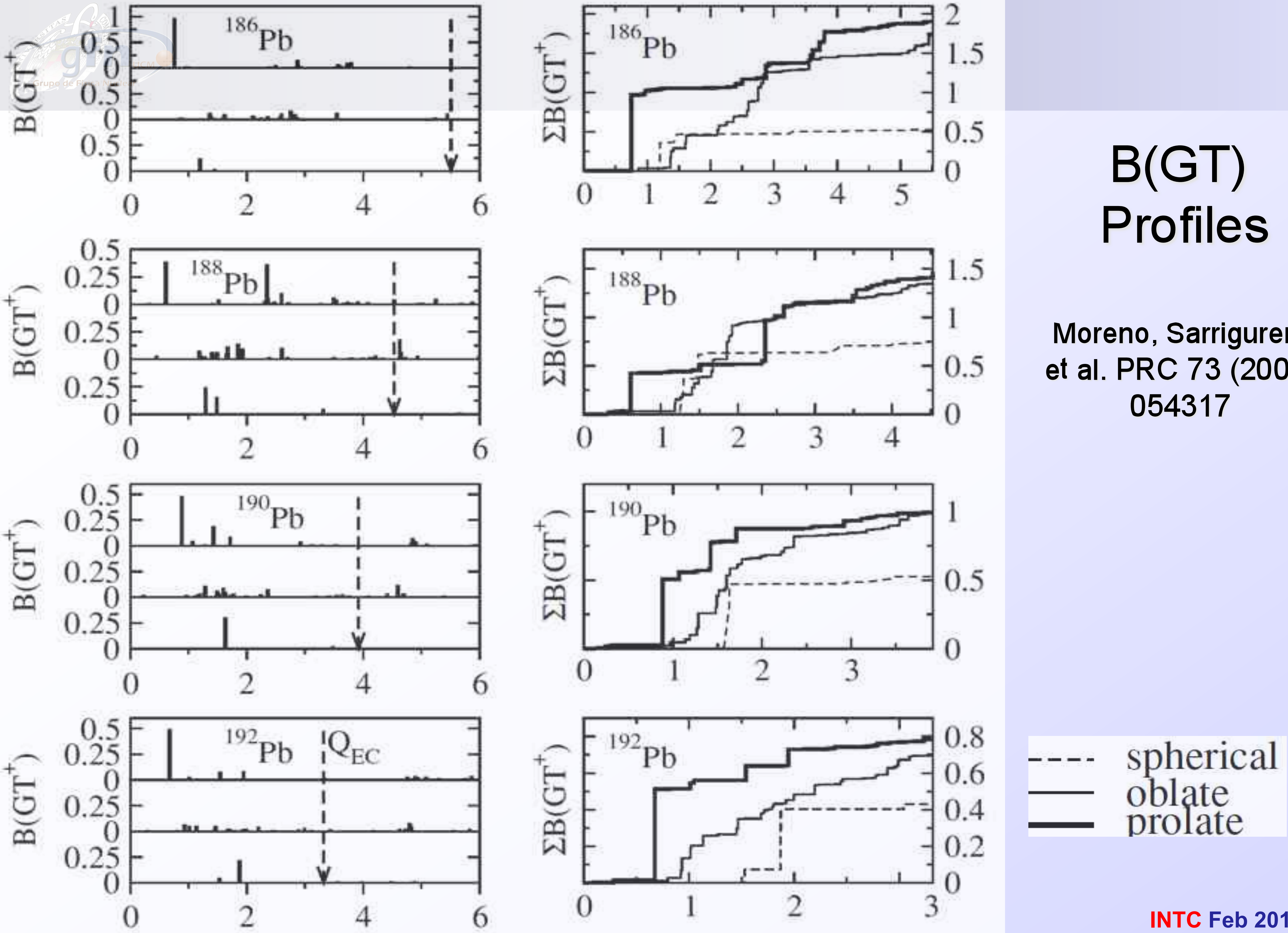
→ Theoretical calculations by P. Sarriguren et al. show that the GT strength distributions show clearly different patterns depending on the deformation of the parent nucleus (PRC 72 (2005) 054317, PRC 73 (2006) 054317

→ DEFORMATION from the measurement of the Beta Strength

Neutron-deficient Pb isotopes

- ✓ Subject of intensive experimental and theoretical work (shape coexistence, see for example ^{186,188}Pb)
- ✓ Hartree-Fock mean field calculations using an effective two-body Skyrme interaction and including pairing correlations in the BCS approximation
  - → s.p. energies, wave functions and occupation probabilities are generated from the mean field
  - → Results independent on force (Sk3 and SG2) and pairing
  - → Different profiles depending on the deformation: characteristic B(GT) profile
- ✓ Complementary studies on deformation, i.e. isotope shifts
- ✓ Test of nuclear models

B(GT) Profiles

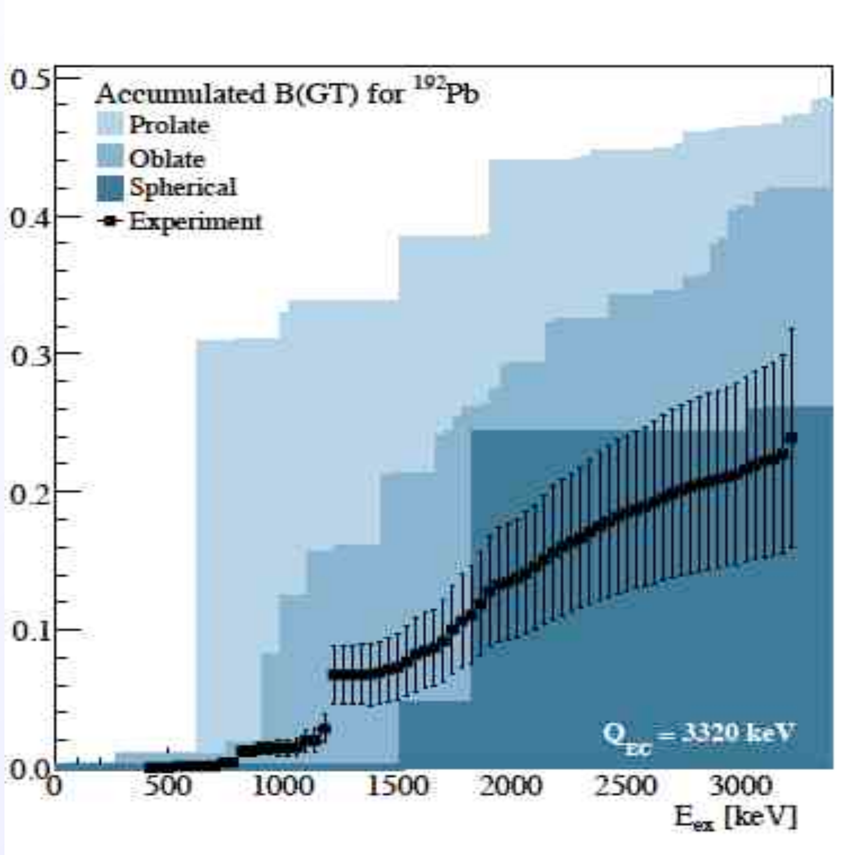


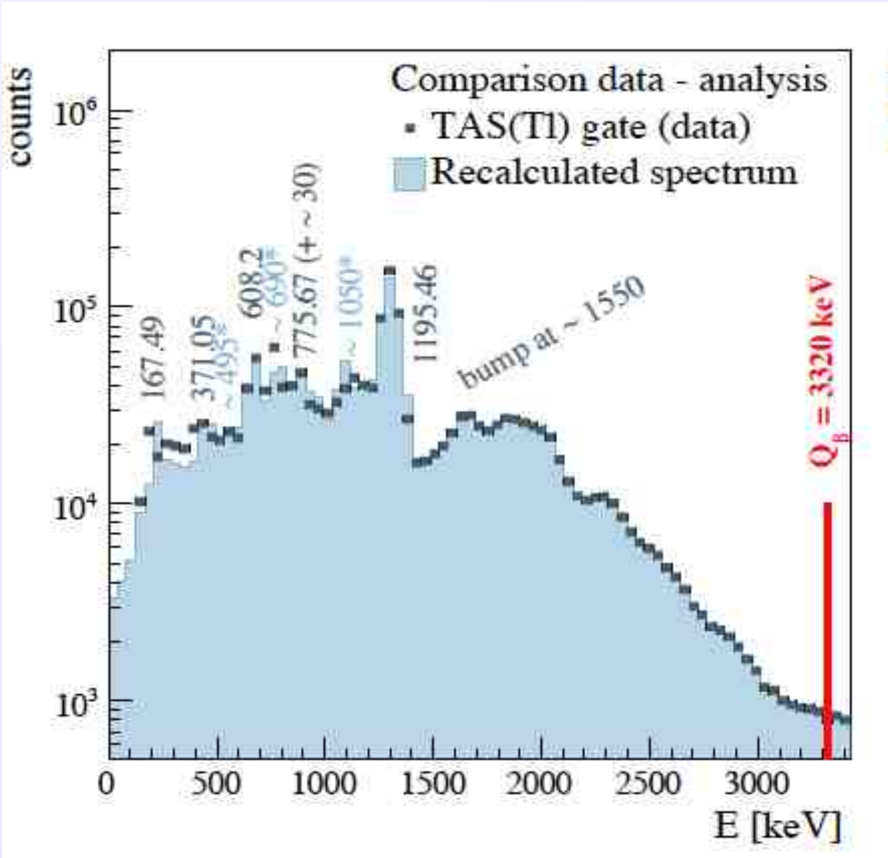
Moreno, Sarriguren et al. PRC 73 (2006) 054317

IS440 – experimental details

Isotope	Half life	EC branch (%)	Sp (keV)	Q_{EC}(keV)	Status
^{186}Pb	4.82(3) s	60(8)	1303(185)	5205(25)	proposed
^{188}Pb	25.1(1) s	90.7(8)	1520(40)	4530(30)	to be completed
^{190}Pb	71(1) s	99.6(4)	1990(60)	3920(50)	done
^{192}Pb	3.5(1) min	99.9941(7)	2570(40)	3320(30)	done

IS440: example ^{192}Pb





PhD Thesis by M.E. Estévez (2012), and M.E. Estévez, A. Algora *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.*

We realized that the decay information of the studied nuclei is incomplete!

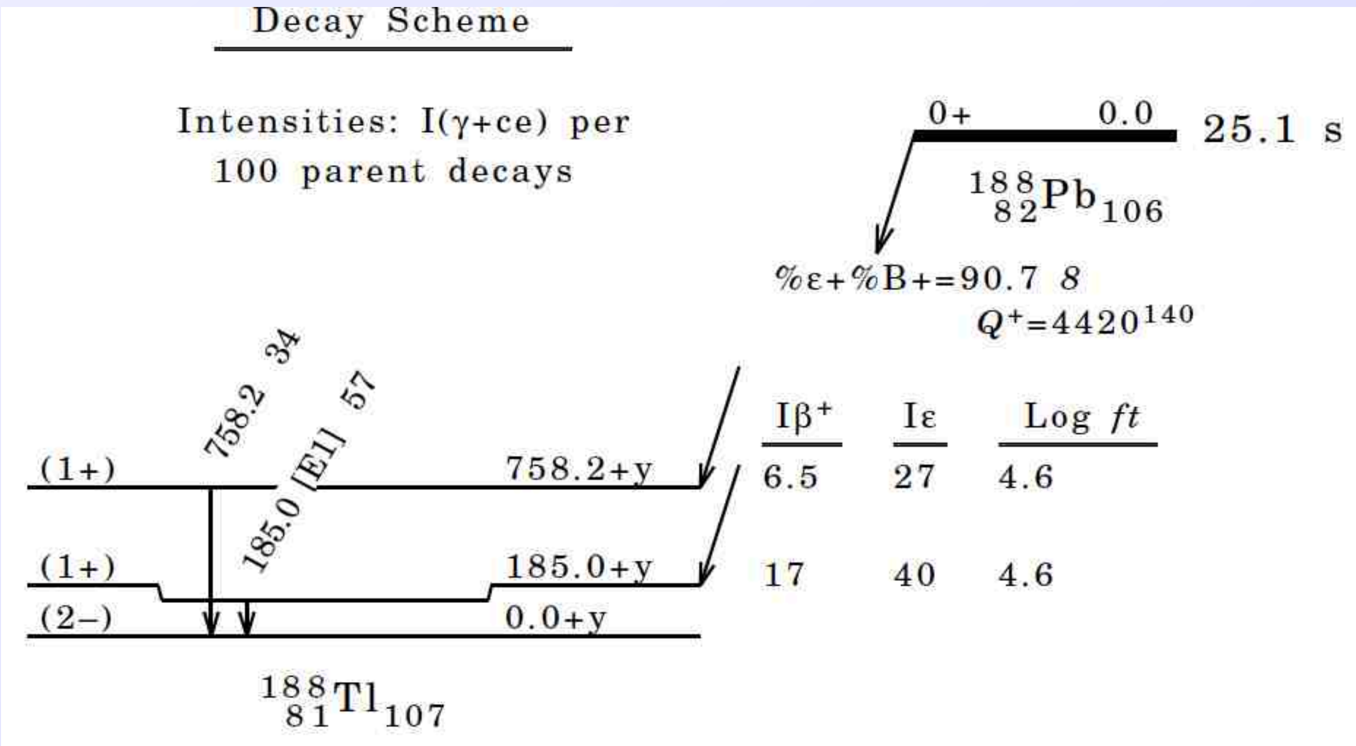
IS440 – request for available shifts

- ✓ The analysis of TAgS data requires the knowledge of the low-lying level scheme of the decay.
  - → The analysis of ^{188}**Pb** (PhD Thesis by E. Estevez) requires a better knowledge of the level scheme from high resolution.
  - → Nothing is known about populated levels by the decay of ^{186}**Pb** (shape co-existence)
    - future TAS study and interesting per se
- ✓ We propose to perform a high-resolution measurement of the decays of ^{186,188}Pb using a Ge setup, preferably using the planned ISOLDE Decay Station (**IDS**) setup in combination with a particle detection setup.

^{186}Pb	**4.6E+04 /μC**	**UC_x - RILIS (Pb)**	**4 shifts**
^{188}Pb	**1.7E+06 /μC**	**UC_x - RILIS (Pb)**	**2 shifts**

IS440 future plans

- ✓ TAS measurements of ^{186}Pb
  - → Study of the ^{186}Pb isotope
  - → Measurement of the daughter activity
- ✓ TAS measurements of ^{188}Pb
  - → βp-branch in combination with the TAS



Shape effects in the vicinity of the Z=82 line: study of the beta decay of $^{182,184,186}Hg$

Spokespersons: A. Algora, L.M. Fraile, E. Nácher

→ Expand measurements to Z = 80

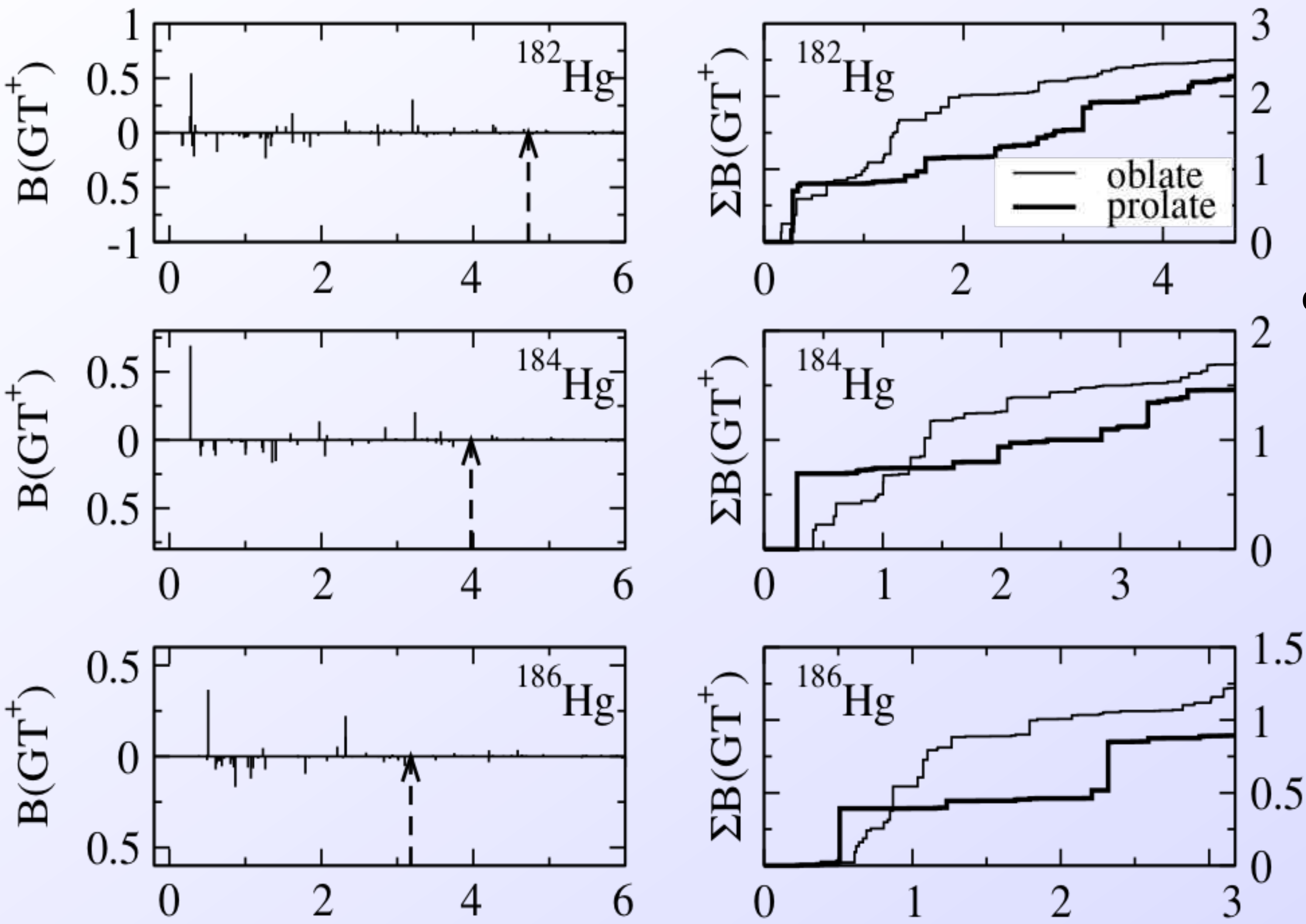
→ Expected to be **oblate** in their ground states

- small mixing of the 0^+ prolate intruder states
- competing oblate / prolate minima

→ Complementary to α-decay of Pb isotopes (i.e J. Wauters *et al.*, PRL72 (1994) 1329) and from in-beam measurements of high-spin states (i.e T. Grahn *et al.*, PRC 80 (2009) 014324)

→ Theoretical calculations, same reference: O.Moreno, P. Sarriguren et al., PRC 73 (2006) 054317

HF calculations with Skyrme + BCS pairing



B(GT) Profiles

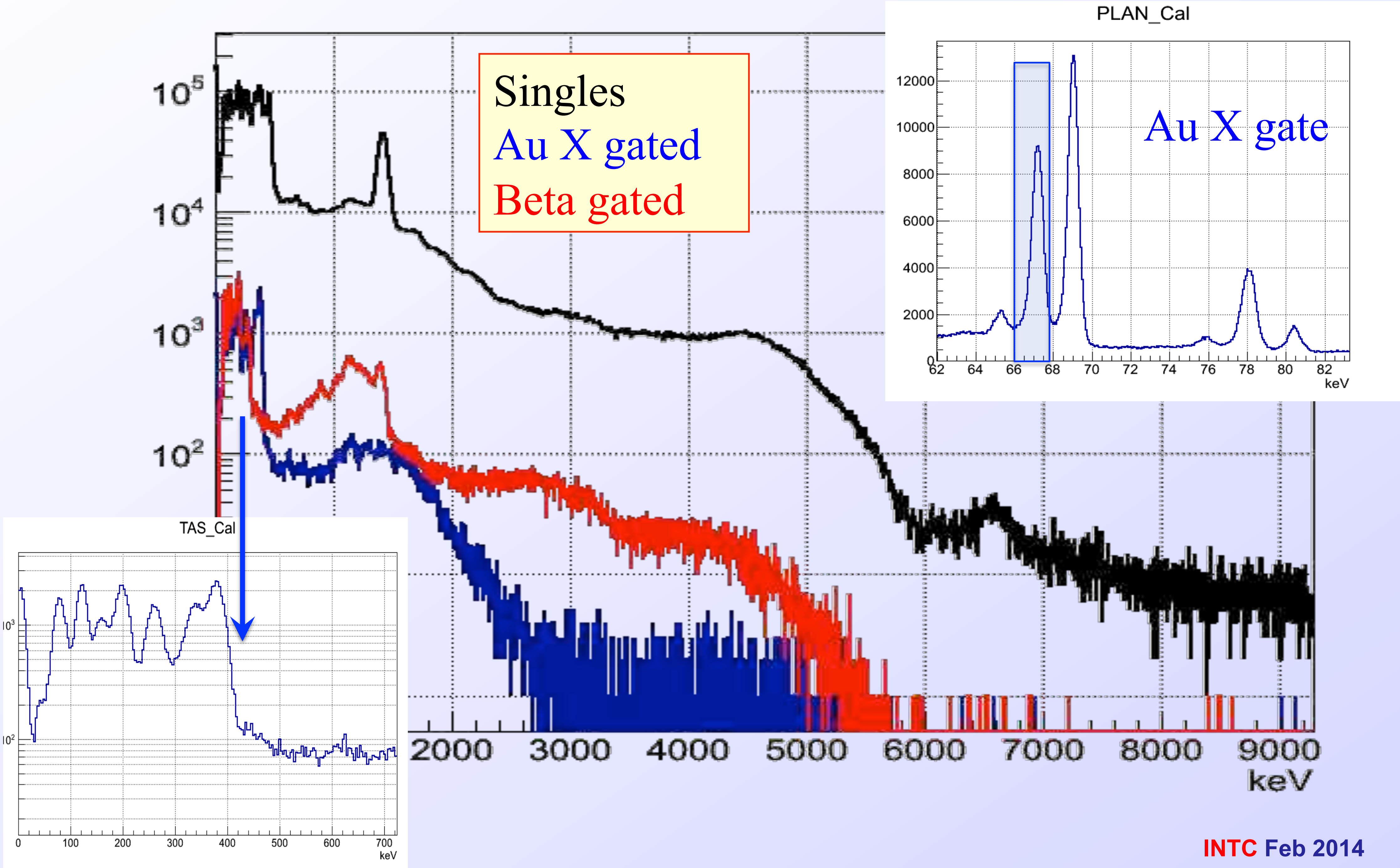
Moreno, Sarriguren et al. PRC 73 (2006) 054317

IS539 – experimental details

Isotope	Half life	β^+/EC branch (%)	α branch (%)	Q_{EC}(keV)	Status
^{182}Hg	10.83 s *6*	84.8 *8*	15.2 *8*	4724 *22*	Data taken
^{184}Hg	30.87 s *26*	98.89 *6*	1.11 *6*	3970 *24*	Test done
^{186}Hg	1.38 min *6*	99.984 *5*	0.02	3176 *24*	Data taken

Alpha branch sizable
Tiny alpha branch in ^{186}Hg to be measured
Beta-delayed particle branches

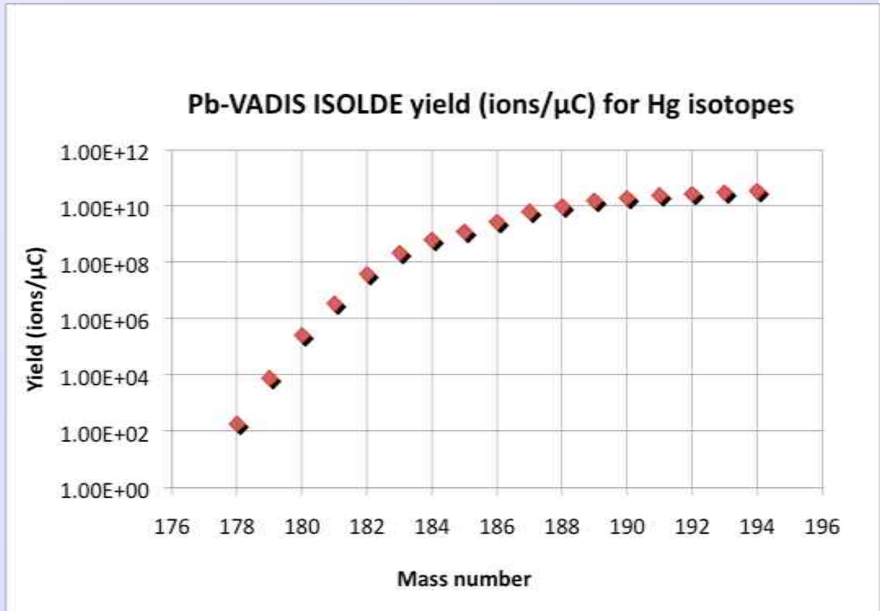
On-line spectra from A=186 ($^{186}Hg \rightarrow ^{186}Au$)



IS539 – request for available shifts

- ✓ The analysis of TAgS data requires the knowledge of the low-lying level scheme of the decay.
- ✓ Disentangle particle branches.
- ✓ High-resolution measurement of the decays of $^{182,184,186}Hg$ using a ISOLDE Decay Station (**IDS**) setup in combination with a particle detection setup (*see IS577 setup*)
  - → limited by counting rate in HPGe detectors
  - → beta-delayed alpha branch of 10^{-5} – 10^{-4} assumed

^{182}Hg	**4.0E+07/μC**	**Pb - VADIS**	**1.5 shifts**
^{184}Hg	**6.5E+08 /μC**	**Pb - VADIS**	**2.5 shifts**
^{186}Hg	**2.8E+09 /μC**	**Pb - VADIS**	**1.5 shifts**



IS539 future plans

✓ TAS measurements of **odd Hg isotopes** such as ^{185}Hg

→ Selective selection of beta-decaying isomer via RILIS

→ Test of oblate/prolate decay patterns

→ Theoretical calculations ongoing (J.M. Boillos, P. Sarriguren, IEM, Madrid)

ADDENDUM once analysis of even isotopes is more advanced and calculations available

List of collaborators

IS440 and IS539 ISOLDE Collaborations

A. Algora, **B. Rubio**, J.L. Taín, M.E. Estevez, J. Agramunt, E. Valencia, C. Domingo, S. Origo

A. Krasznahorkay, M. Csatlos, Zs. Dombrádi, D. Sohler, J. Timár

W. Gelletly, P. Walker, P. Regan, Z. Podolyák, S. Rice

E. Nácher, P. Sarriguren, M.J.G. Borge, O. Tengblad, A. Jungclaus, J.A. Briz, A. Perea, V. Pesudo

L.M. Fraile, O. Moreno, B. Olaizola, V. Paziy, V. Vedia, J.M. Udías, J. Cal

V. Fedosseev, B.A. Marsh, C. Guerrero, M. Kowalska, D. Fedorov

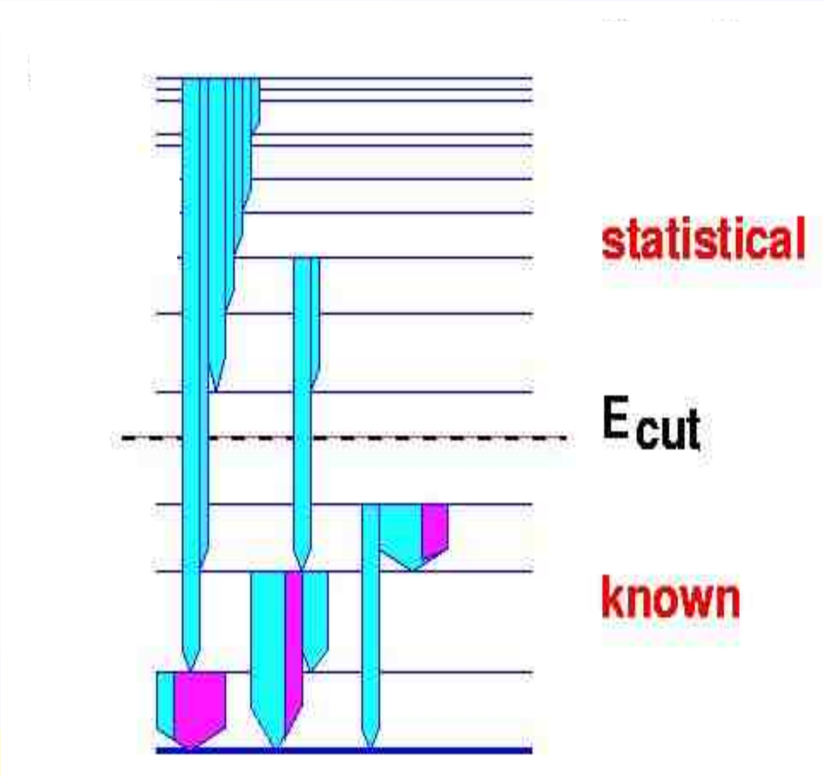
B. Akkus, Y. Oktem, E. Ganioglu, L. Susam, L. Kucuk, R. Burcu Cakirli

A.N. Andreyev

A. Frank

Fin

TAS analysis – knowledge of level scheme



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

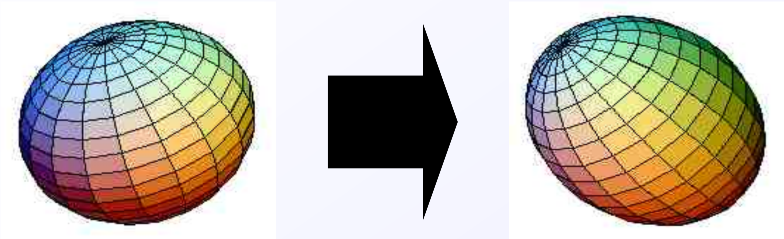
Expectation Maximization (EM) method:
modify knowledge on causes from effects

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

Algorithm:

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

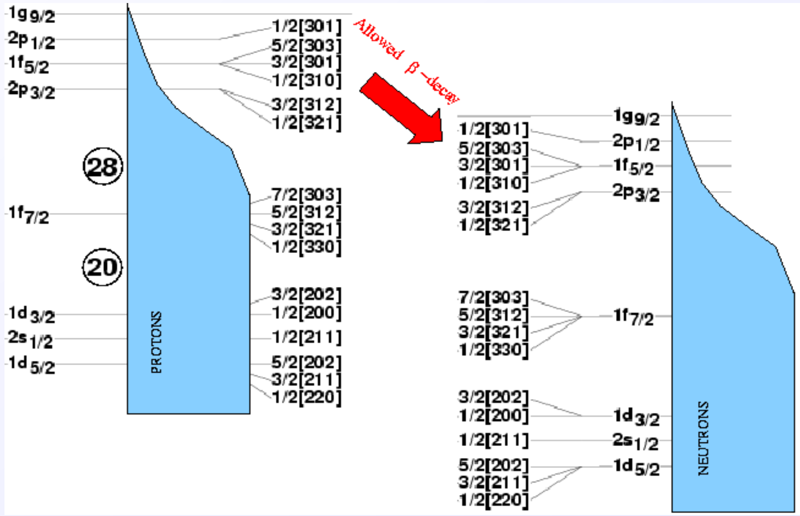
The N≈Z region around A=70-80



⇒ ground state strongly deformed.

⇒ oblate to prolate transition and shape coexistence and mixing are predicted.

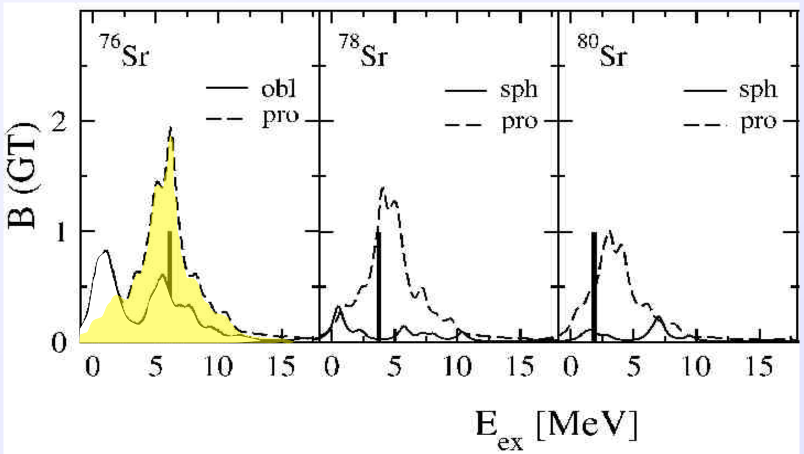
[A. Petrovici et al. Nuc. Phys. A708 (2002) 190 and ref. therein].



Free neutron orbitals with same quantum numbers than the valence protons:

⇒ Gamow-Teller decay allowed.

⇒ large part of the GT strength inside the Q_{EC} window



Theoretical calculations predict different B(GT) distribution for oblate, prolate and spherical shape of the ground state.

[I. Hamamoto *et al.*, Z. Phys. A353 (1995) 145]

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