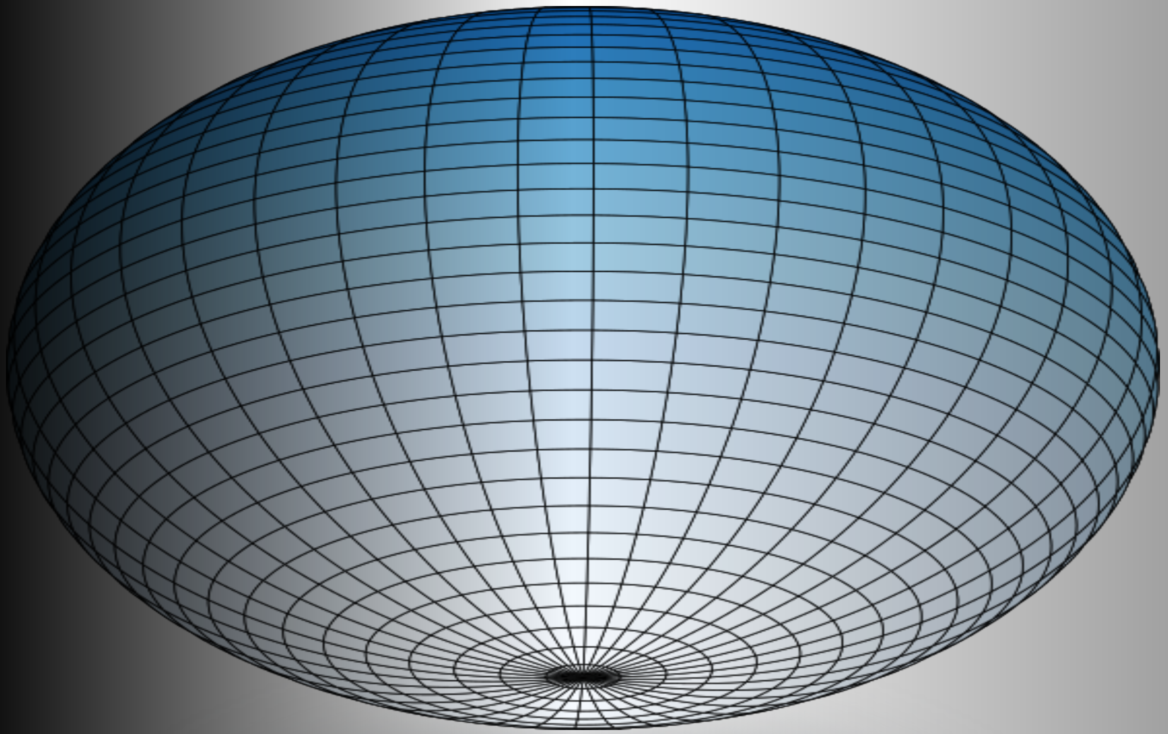
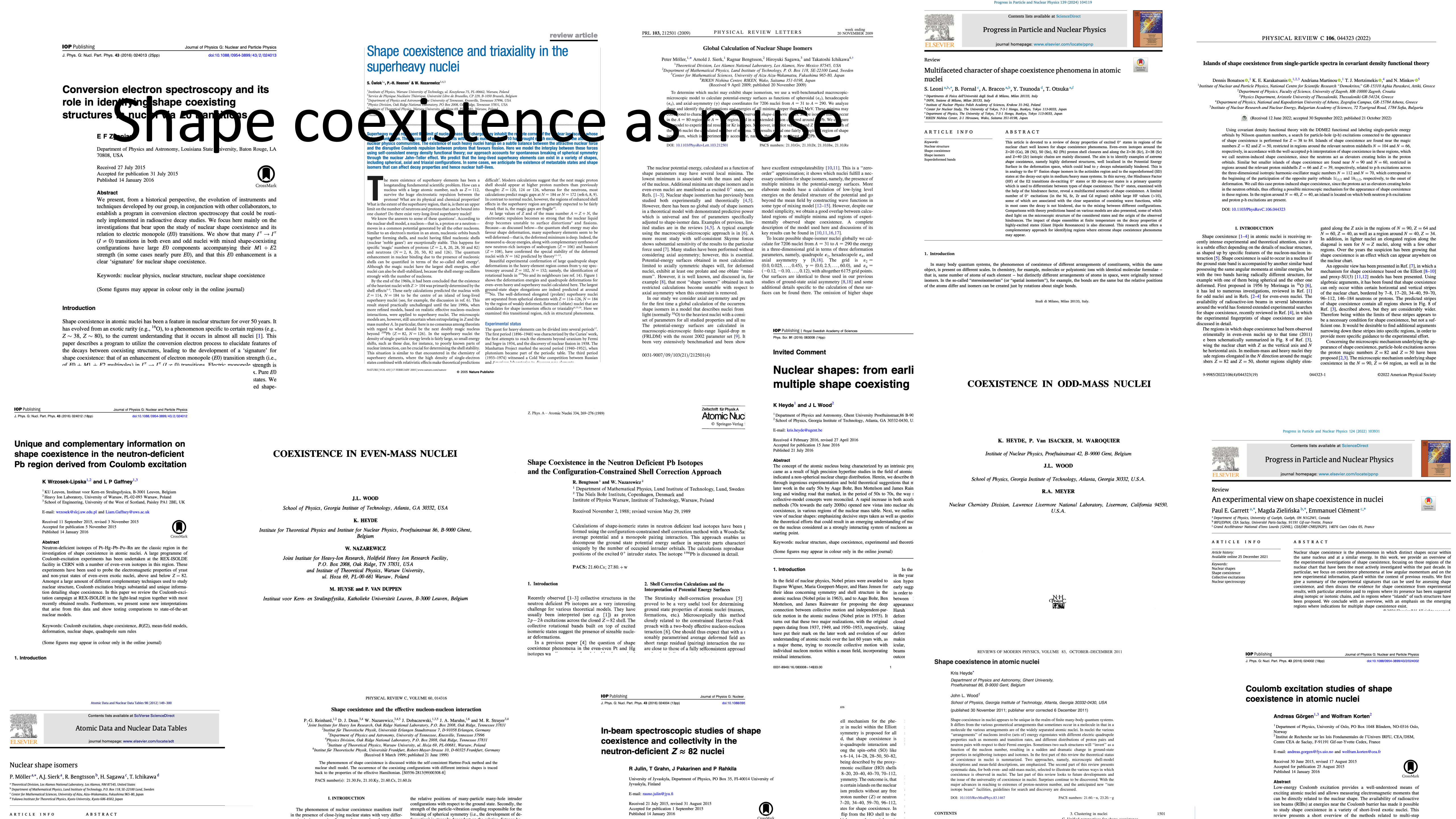


Onset of oblate deformation in Pb isotopes

Janne Pakarinen
University of Jyväskylä
SSNET 2024, Orsay, France

Shape coexistence as muse



Global phenomenon in atomic nuclei

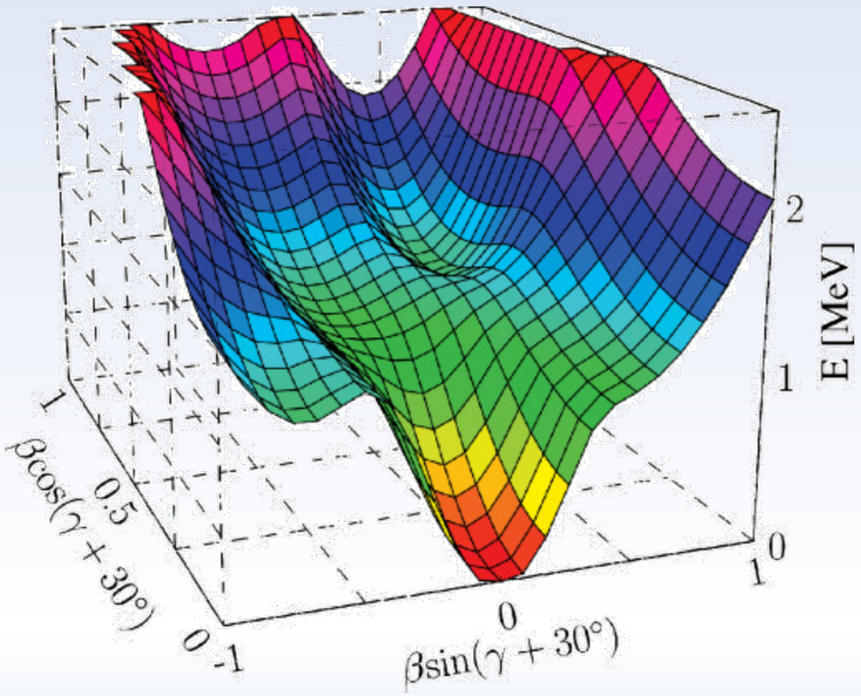
Kris Heyde and John L Wood
Nuclear shapes: from earliest ideas to multiple shape coexisting structures,
Physica Scripta 91, 083008 (2016)

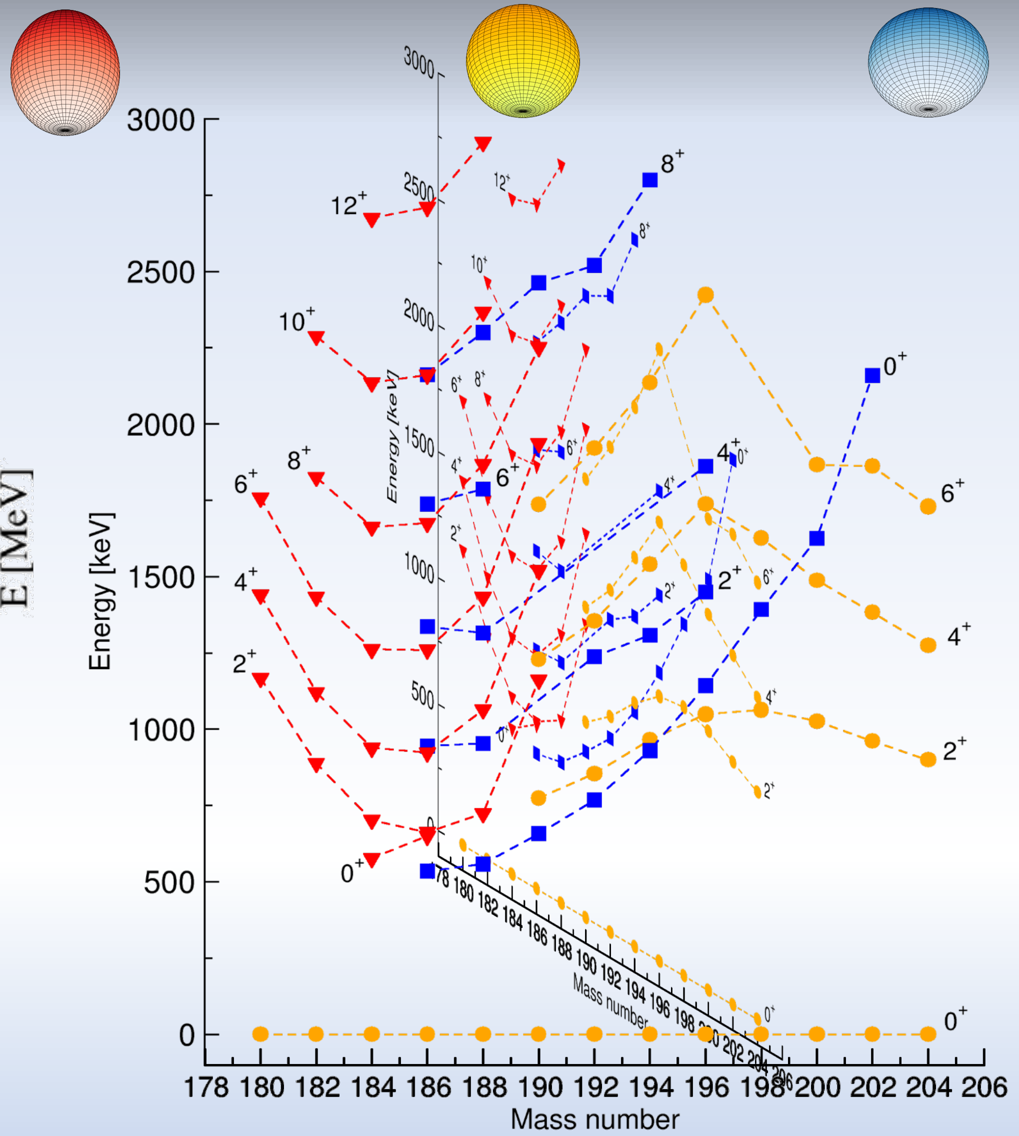
"While shape coexistence has, to date, only been established or inferred in a few hundred nuclei, there are compelling reasons to believe that it is a universal feature of (almost) all nuclei.

It is now understood that it is even the feature of nuclear structure that is 'responsible for us all being here': the Hoyle State is the result of ^{12}C possessing shape coexistence."

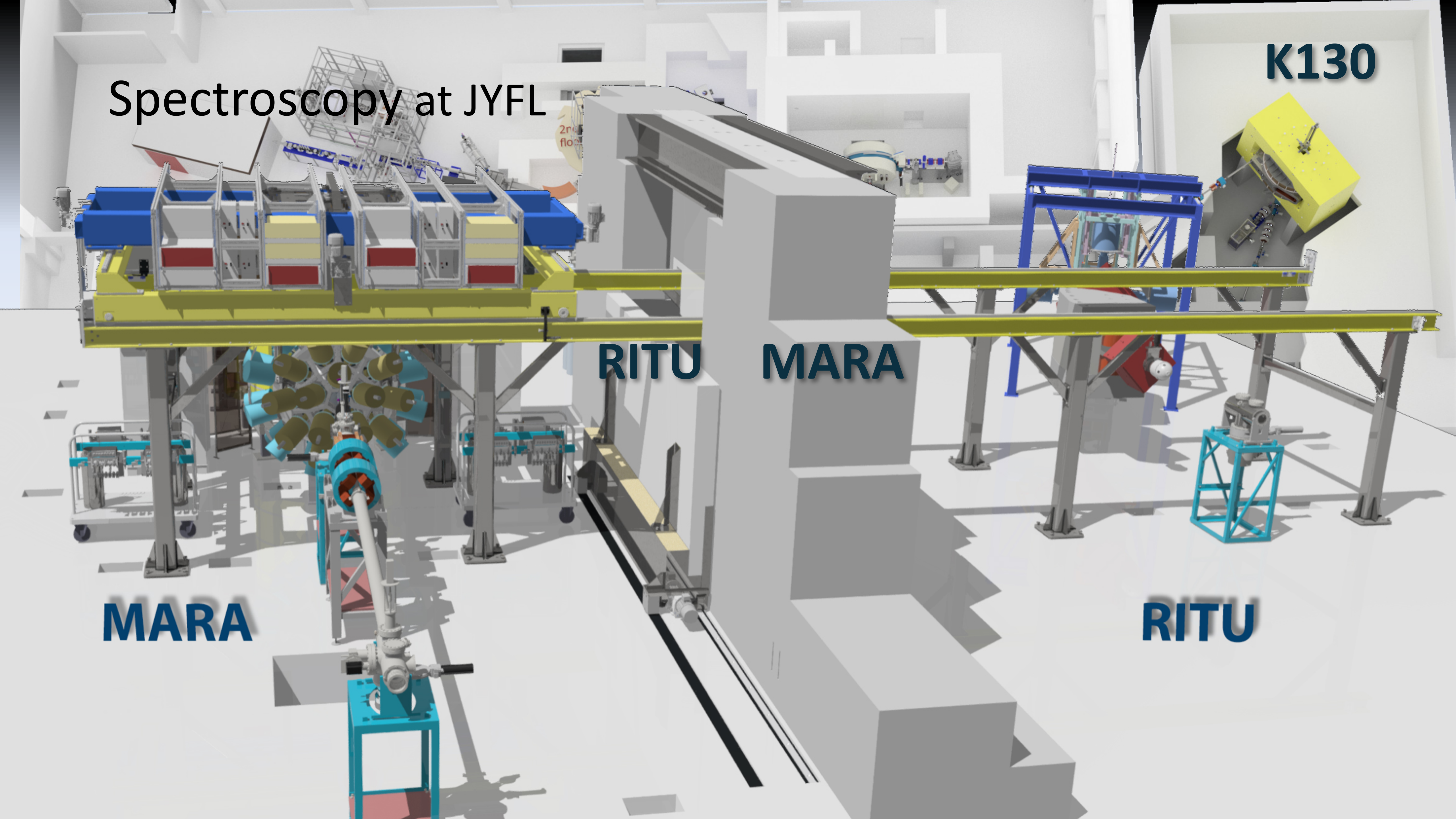
Level energy systematics prior to this work

^{186}Pb

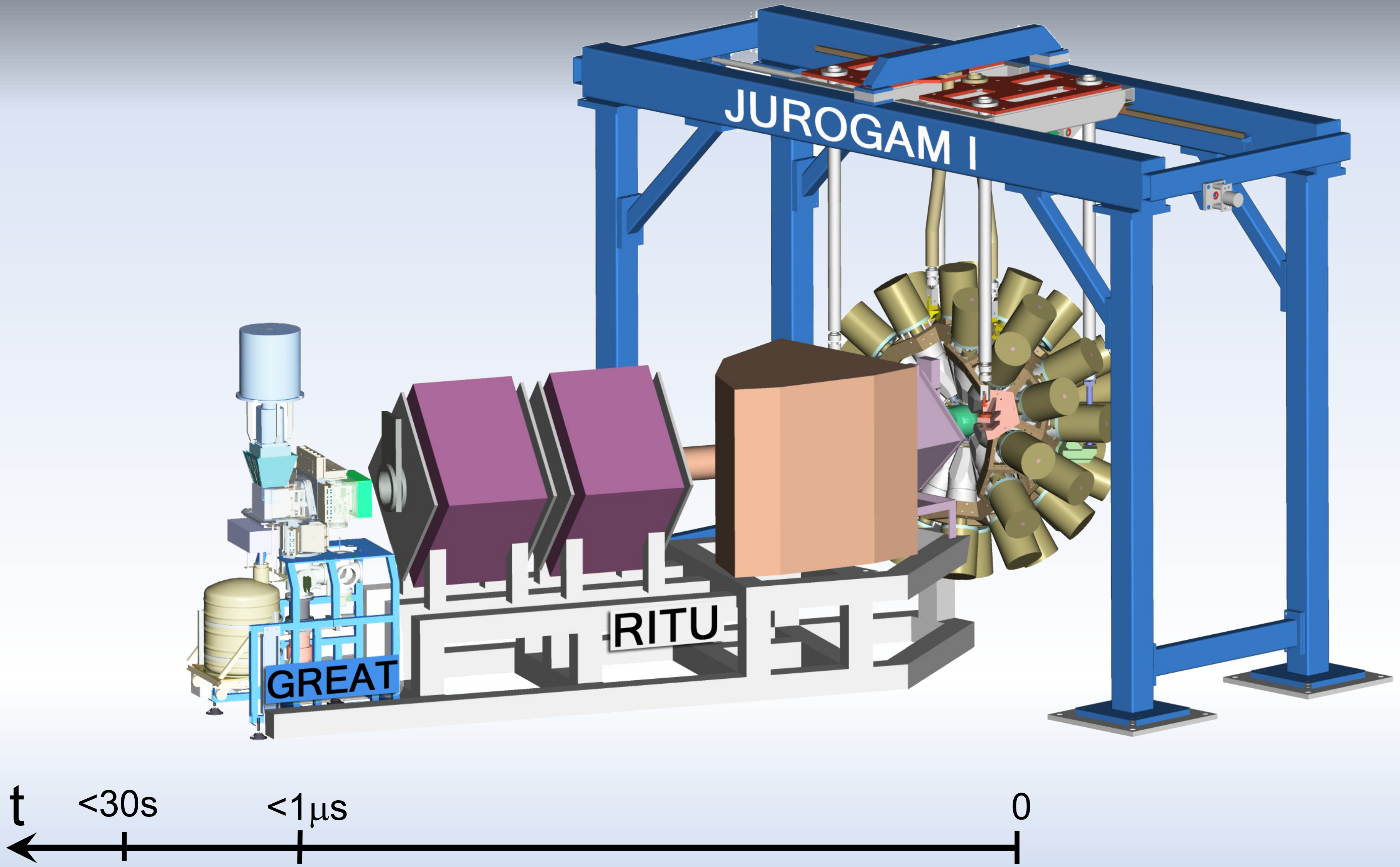




Spectroscopy at JYFL

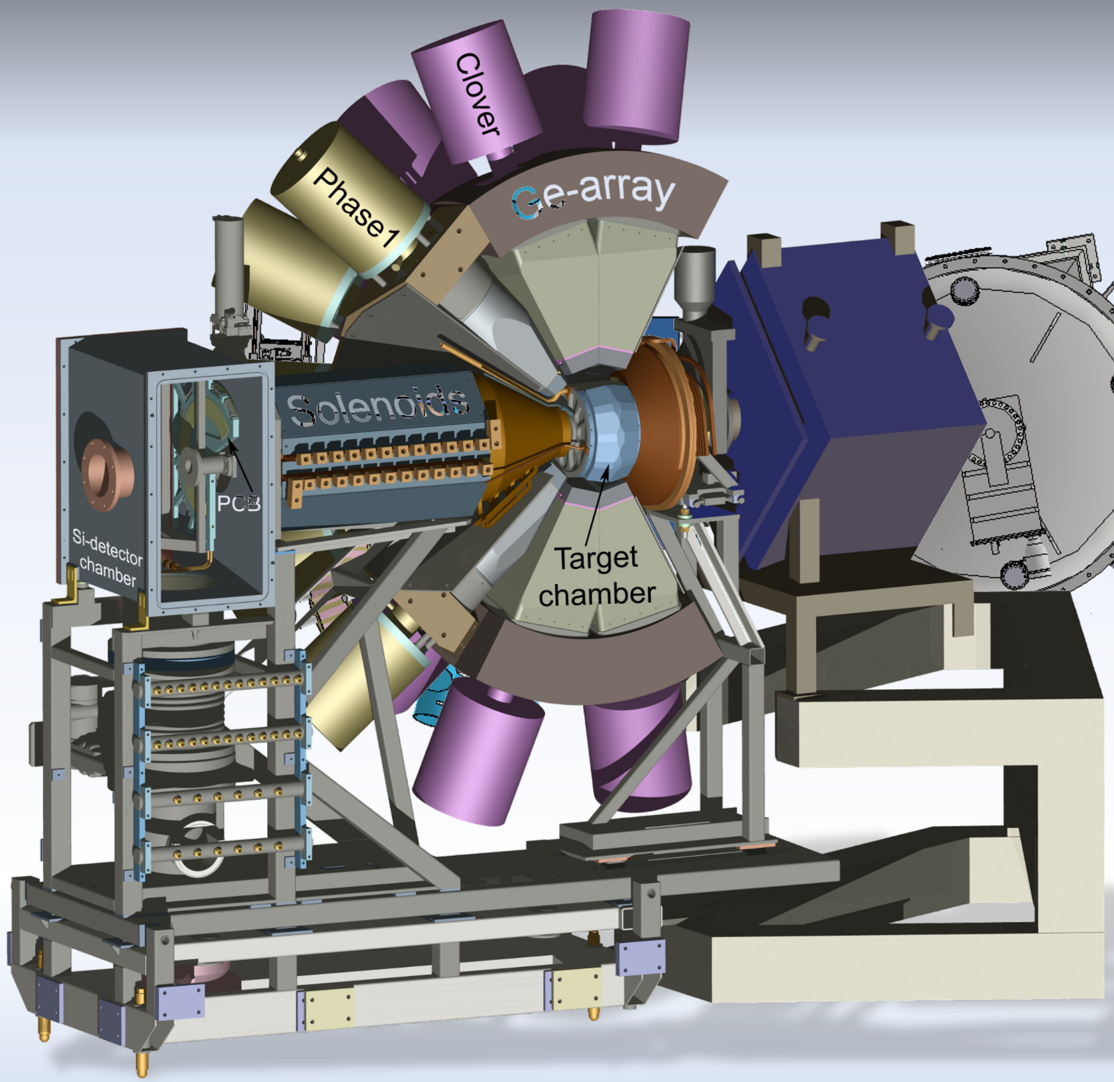


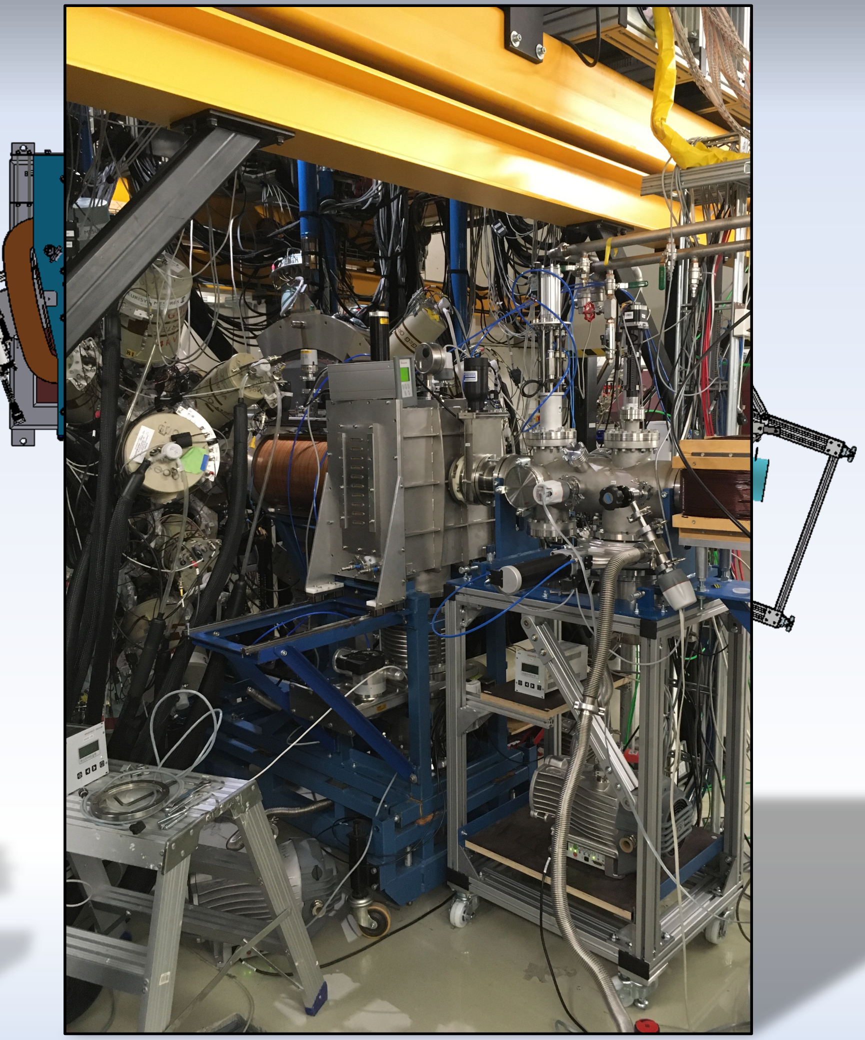
Recoil-decay tagging technique



M. Leino *et al.*, Nucl. Instrum. Methods B99, 653 (1995)

SAGE at JYFL recoil separators





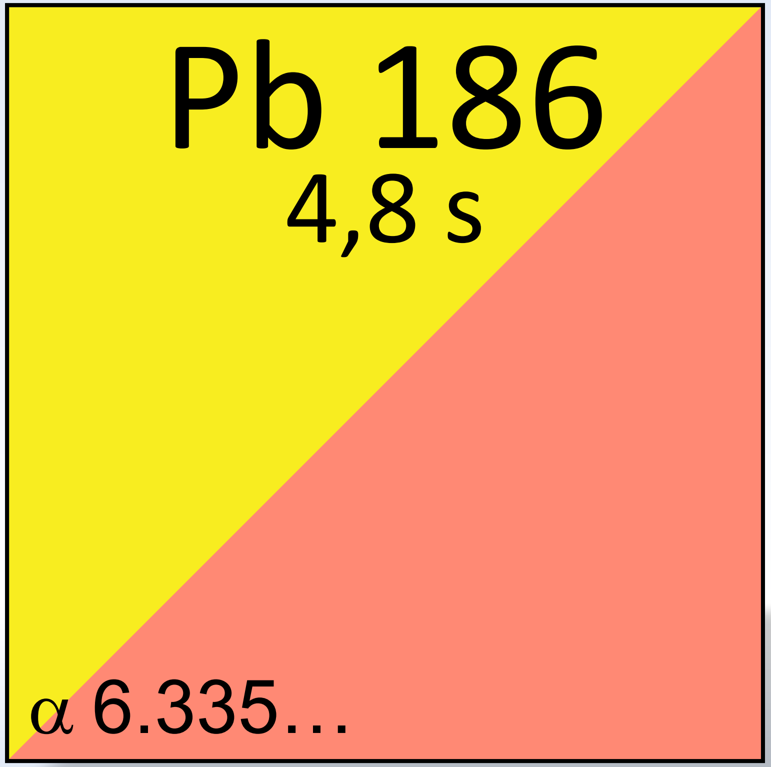
J. Pakarinen *et al.*, Eur. Phys. J. A **50**(3): 53 (2014)
J. Uusitalo *et al.*, Acta Phys. Pol. **B50**, 319 (2019)

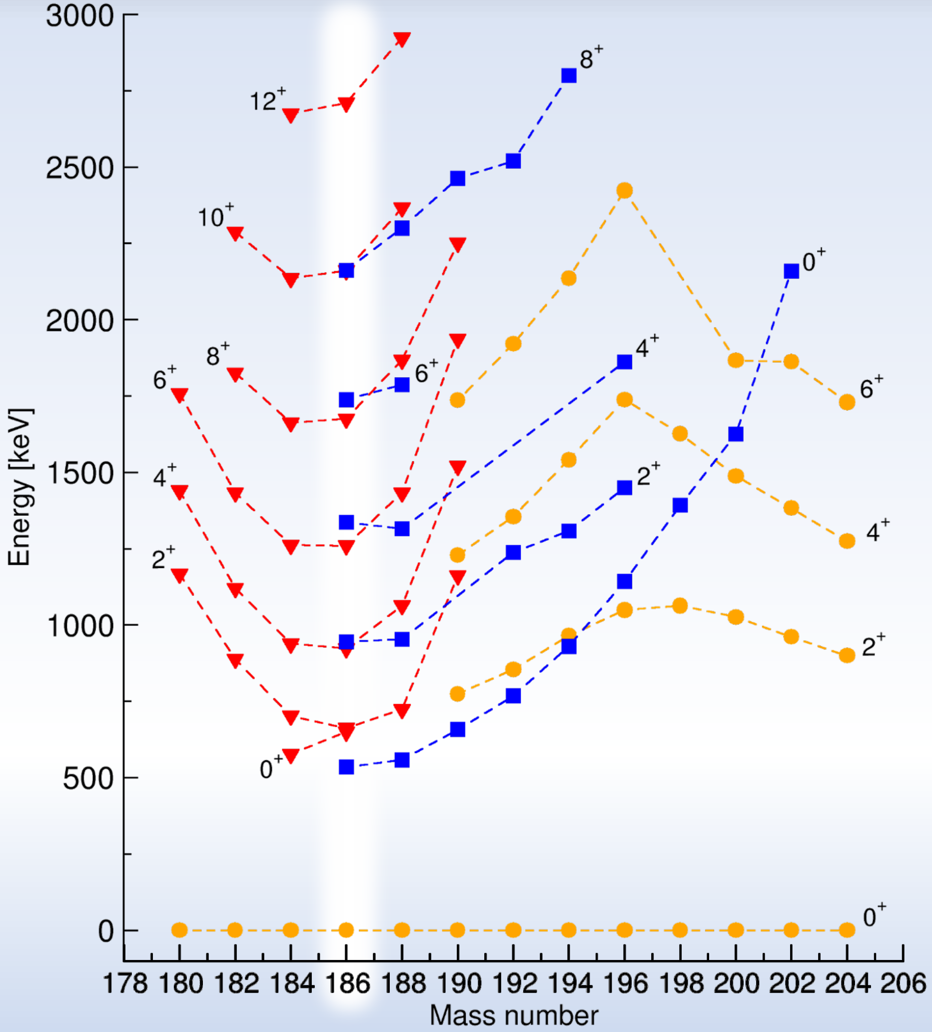
Experiments in a nutshell

	^{186}Pb	^{188}Pb	^{190}Pb	
Instrumentation	SAGE+RITU+GREAT	SAGE+RITU+GREAT	SAGE+MARA+MARA_FP	APPA+RITU+RITU_FP
Channel selection	Recoil-decay tagging	Recoil gating	Recoil gating	Recoil gating
Reaction	^{106}Pd(^{83}Kr,3n)^{186}Pb	^{160}Dy(^{32}S,4n)^{188}Pb	^{159}Tb(^{35}Cl,4n)^{190}Pb	^{108}Pd(^{86}Kr,4n)^{190}Pb
Beam energy	365 MeV	165 MeV	164 MeV	378 MeV
Beam intensity	~5 pnA	~13 pnA	~10 pnA	~2 pnA
Beam on target	108 h	129 h	320 h	~250 h
Target thickness	1 mg/cm^2	500 μg/cm^2	350 μg/cm^2	0.95 mg/cm2
Production cross section	75μb	1100μb	~10mb	~10mb

Additional complementary in-beam experiments:
JR4: A recoil-gated plunger lifetime measurement of ^{188}Pb with JUROGAM and the RITU separator
JR33: A recoil-decay tagged plunger lifetime measurement for the yrast levels of ^{186}Pb

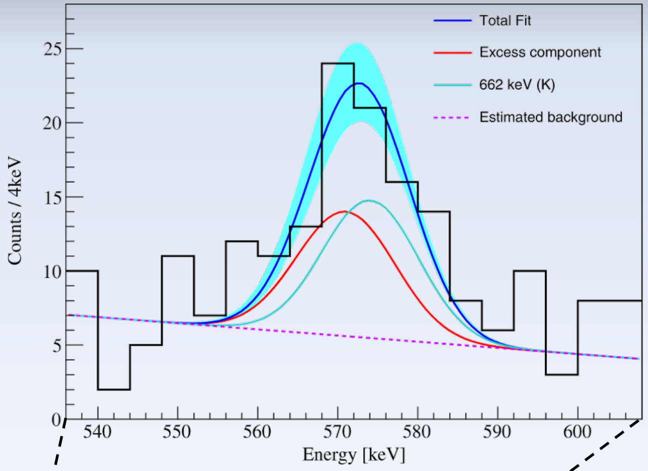
Unique case - ^{186}Pb nucleus



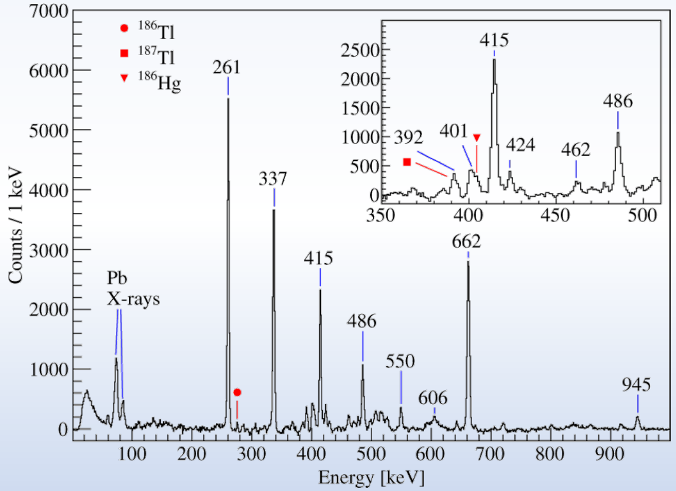


^{186}Pb – direct measurement of conversion electrons

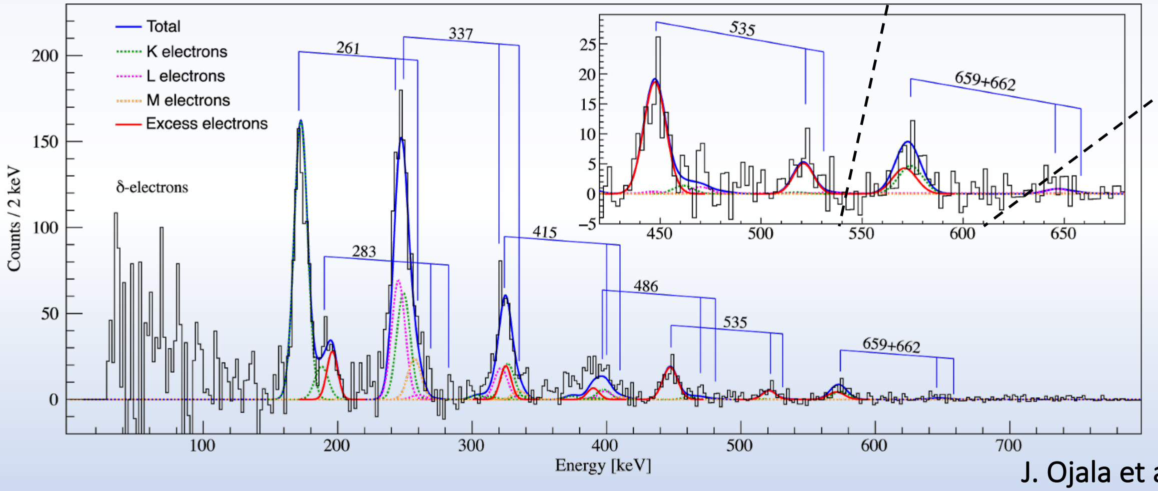
- Very clean γ-ray and electron energy spectra (thanks to recoil-decay tagging)
- Calculated electron energy spectra show excess counts => associated with E0 transitions
- The first direct measurement of the $0_2^+ \rightarrow 0_1^+$ and $0_3^+ \rightarrow 0_1^+$ transitions in ^{186}Pb



γ-ray singles energy spectrum



Electron singles energy spectrum



J. Ojala et al., Commun. Phys. 5, 213 (2022)

^{186}Pb – reassigning the shapes of the 0$^+$ states

Based on the $B(E2; 2_1^+ \rightarrow 0_1^+)$ = 6(2) W.u.

and the measured branching ratio $I_\gamma(2_1^+ \rightarrow 0_2^+)/I_\gamma(2_1^+ \rightarrow 0_1^+)$

$\Rightarrow$ Reduced transition probability: $B(E2; 2_1^+ \rightarrow 0_2^+)$ = 190(80) W.u.

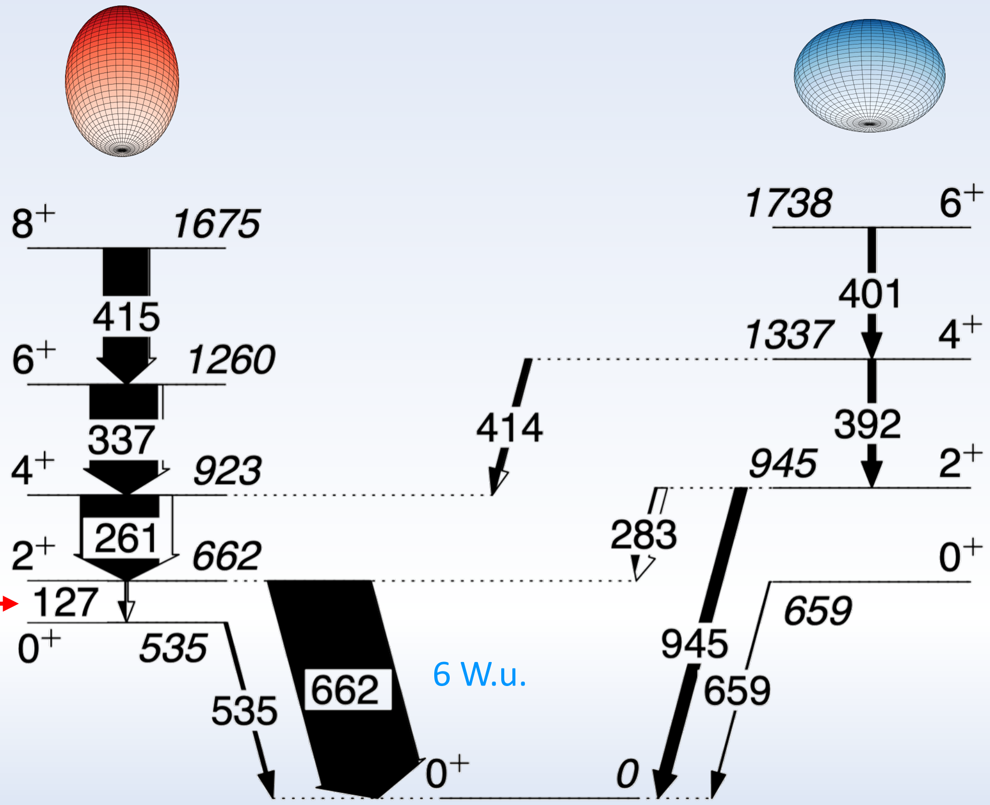
Typically in this region: *B(E2;prolate in-band)* = 390(40) W.u.

$\Rightarrow$ Transitional quadrupole moment: $|Q_t(2_1^+ \rightarrow 0_2^+)|$ = 7.7(33) eb

Typically in this region: *Q_t(E2;prolate in-band)* = 9.0(5) eb

B(E2) =190(80) W.u.

Q_t = 7.7(33) eb



The 0_2^+ state a prolate band member

J. Ojala et al., Commun. Phys. 5, 213 (2022)

^{186}Pb – feeding of the excited 0$^+$ states from the 2_2^+ state

Assuming $I(2_2^+ \rightarrow 0_3^+) = I(0_3^+ \rightarrow 0_1^+) = 26(6)$

and $B(E2; 2_2^+ \rightarrow 0_1^+) =$ 5 W.u.

$\Rightarrow$ $B(E2; 2_2^+ \rightarrow 0_3^+) <$ 200(120) W.u.

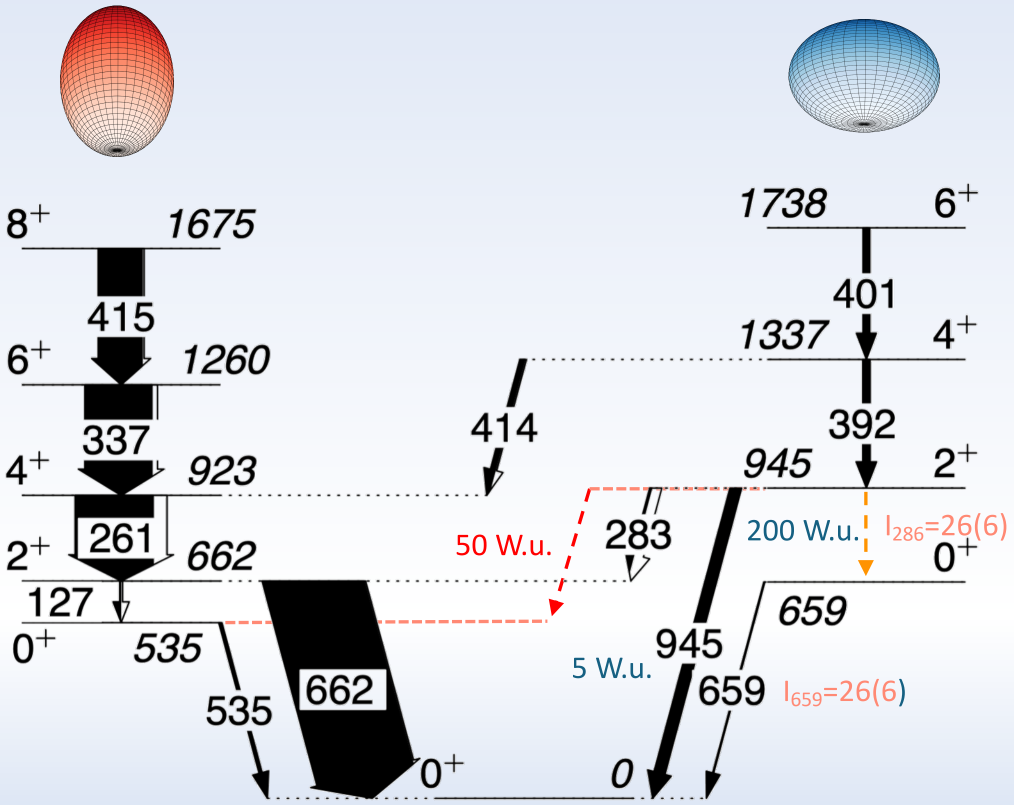
Consequently, the non-observation of the $2_2^+ \rightarrow 0_3^+$ transition does not exclude the existence of a collective (oblate) in-band transition.

If we further assume $\mathrm{B(E2}; 2_2^+ \rightarrow 0_2^+) =$ 50 W.u.

$\Rightarrow$ $\mathrm{I}(2_2^+ \rightarrow 0_2^+) = 19(2)$

does not fit within margins.

$\Rightarrow$ The 0_2^+ state does not have a notable oblate component.



J. Ojala et al., Commun. Phys. 5, 213 (2022)

Mixing of configurations in ^{188}Pb

Pb 188

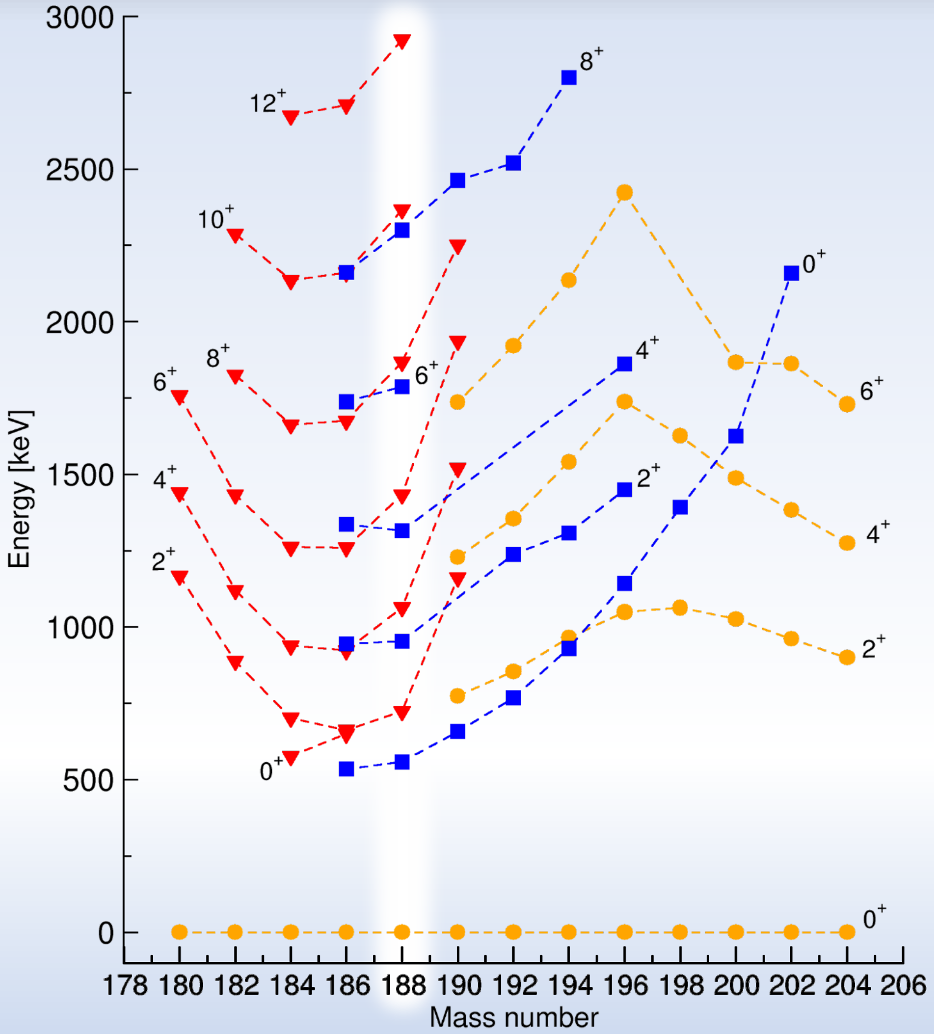
25.5 s

ε, β^+

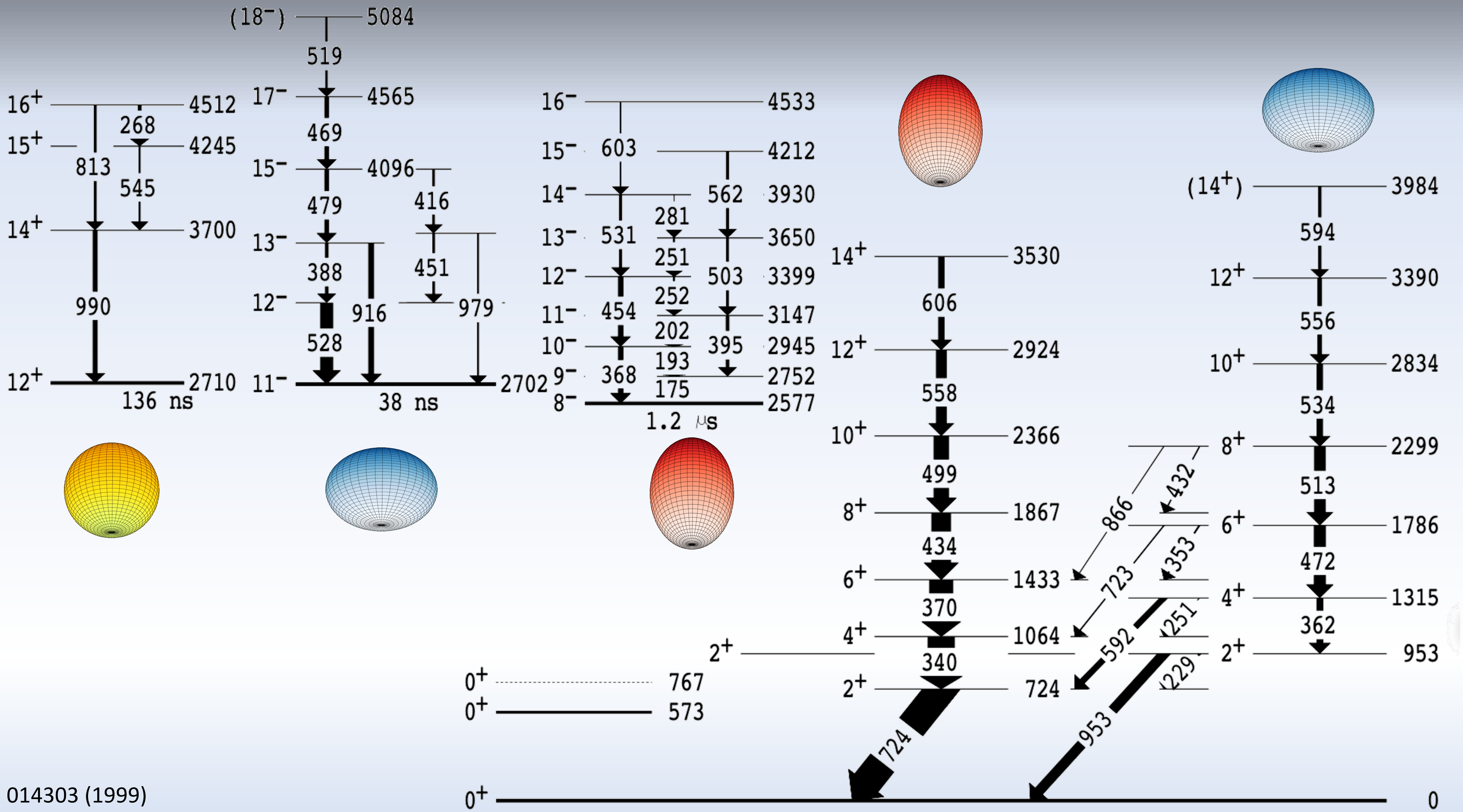
γ 185,758

g

α 5.983



In-beam γ-ray spectroscopy on ^{188}Pb



G.D. Dracoulis *et al.*, Phys. Rev C **60**, 014303 (1999)
G.D. Dracoulis *et al.*, Phys. Rev C **67**, 051301(R) (2003)
G.D. Dracoulis *et al.*, Phys. Rev C **69,** 054318 (2004)

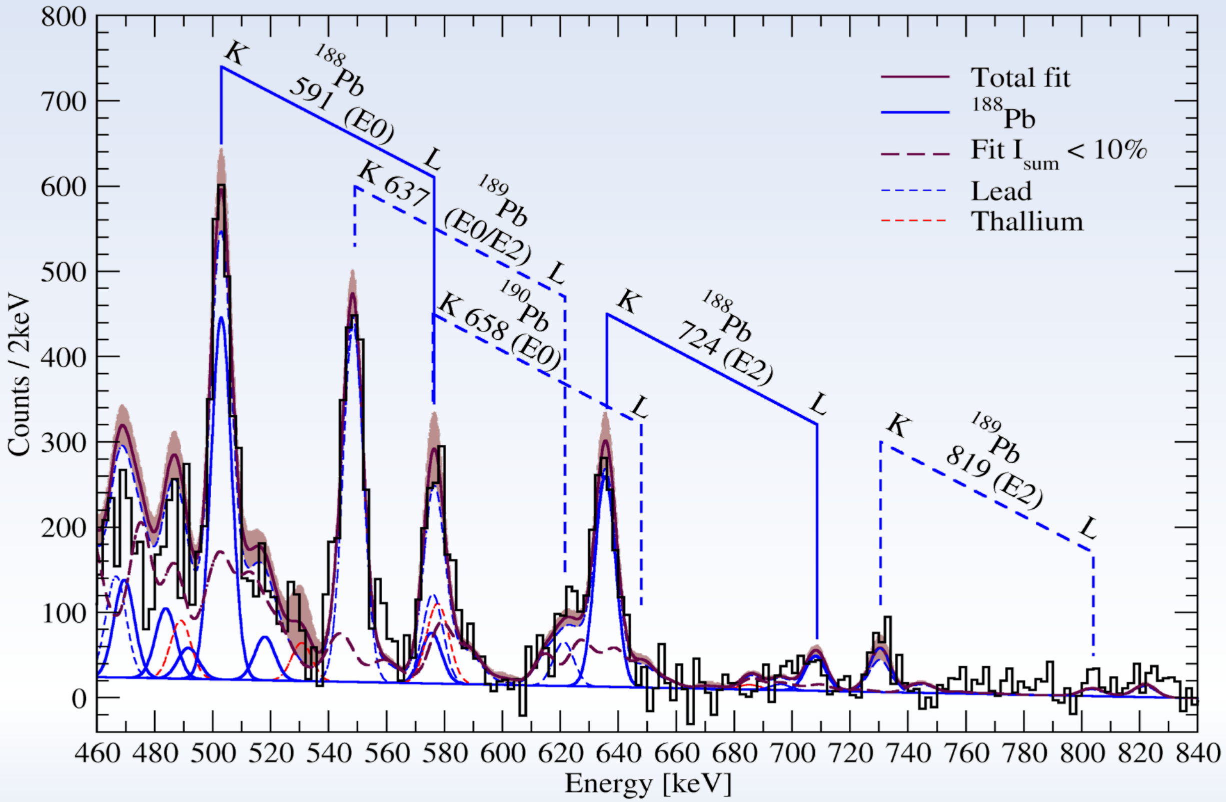
^{188}Pb – recoil-gated singles electrons

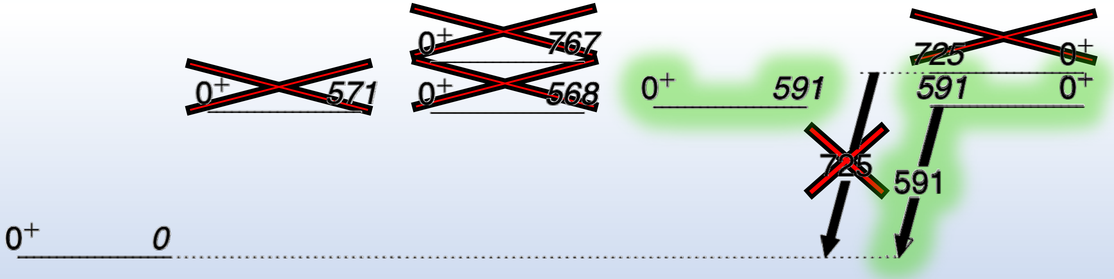
Assessing the conundrum of the 0^+ level energies

- Deconvolution based on observed γ-rays
- Includes 200+ individual components
- Excess electrons assigned to E0 transitions

- Direct observation of the $0_2^+ \rightarrow 0_1^+$ transition at 591(2)keV
- No sign of the 0^+ state at 767keV
- All intensity around 724keV assigned to the $2_1^+ \rightarrow 0_1^+$ transition

- Confirm observations by Van de Vel *et al.,* PRC **68**, 054311 (2003)





P. Papadakis et al., Phys. Lett. B 858,139048 (2024)

^{188}Pb – feeding of the 0^+ state

Relative intensities:

$I_{tot}(2_1^+ \to 0_1^+) = 1000 \quad I_{tot}(0_2^+ \to 0_1^+) = 12(2)$

$I_\gamma(2_2^+ \to 0_2^+) = 3.4(12) \quad I_\gamma(2_2^+ \to 0_1^+) = 117(7)$

Measured B(E2)
Relative B(E2)
IBM B(E2)

Feeding from the prolate band via the 133 keV transition:

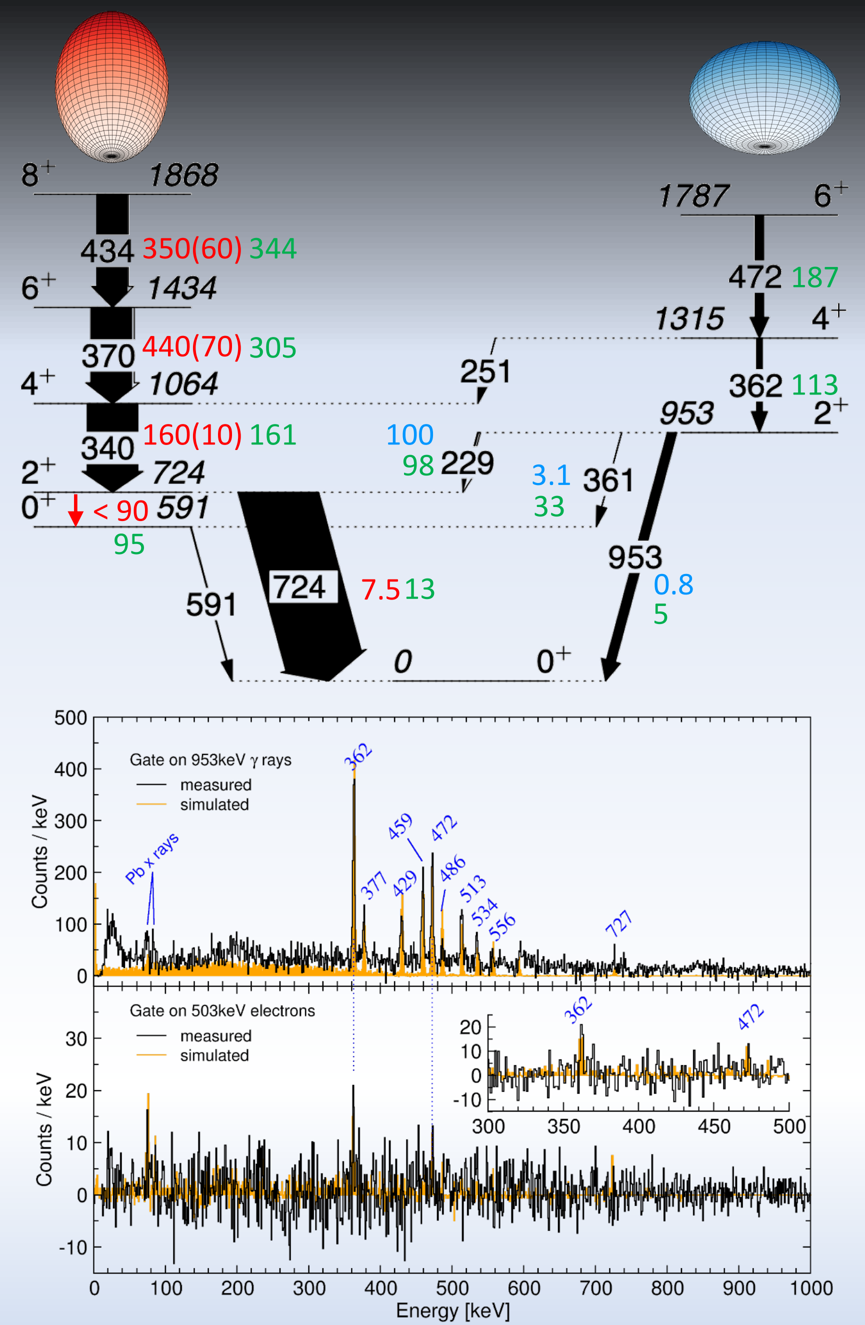
$$I_\gamma(E2; 2_1^+ \to 0_2^+) < \frac{I_{tot}(E0; 0_2^+ \to 0_1^+) - I_{tot}(E2; 2_2^+ \to 0_2^+)}{1 + \alpha_{tot}(2_1^+ \to 0_2^+)} = 1.5$$

Taking $B(E2; 2_1^+ \to 0_1^+) = 7.5(30)$ W.u. ⇒ $\boldsymbol{B(E2; 2_1^+ \to 0_2^+) < 90}$ **W.u.**

Feeding from the oblate band via the 362 keV transition:

$I_\gamma(2_2^+ \to 0_2^+) = 3.4(12)$ and $I_\gamma(2_2^+ \to 0_1^+) = 117(7)$

Assuming: $B(E2; 2_2^+ \to 0_1^+) = 0.8$ W.u. ⇒ $\boldsymbol{B(E2; 2_1^+ \to 0_2^+) = 3.1}$ **W.u.**



Hindered transition from the oblate band ⇒ the $2_2^+ \to 0_2^+$ transition is not a band member, while the $B(E2; 2_1^+ \to 0_2^+) < 90$ W.u. allows transition within a band.

∴ the 0_2^+ state fits better with predominantly prolate band

P. Papadakis et al., Phys. Lett. B 858,139048 (2024)

Oblate minimum in ^{190}Pb

Pb 190

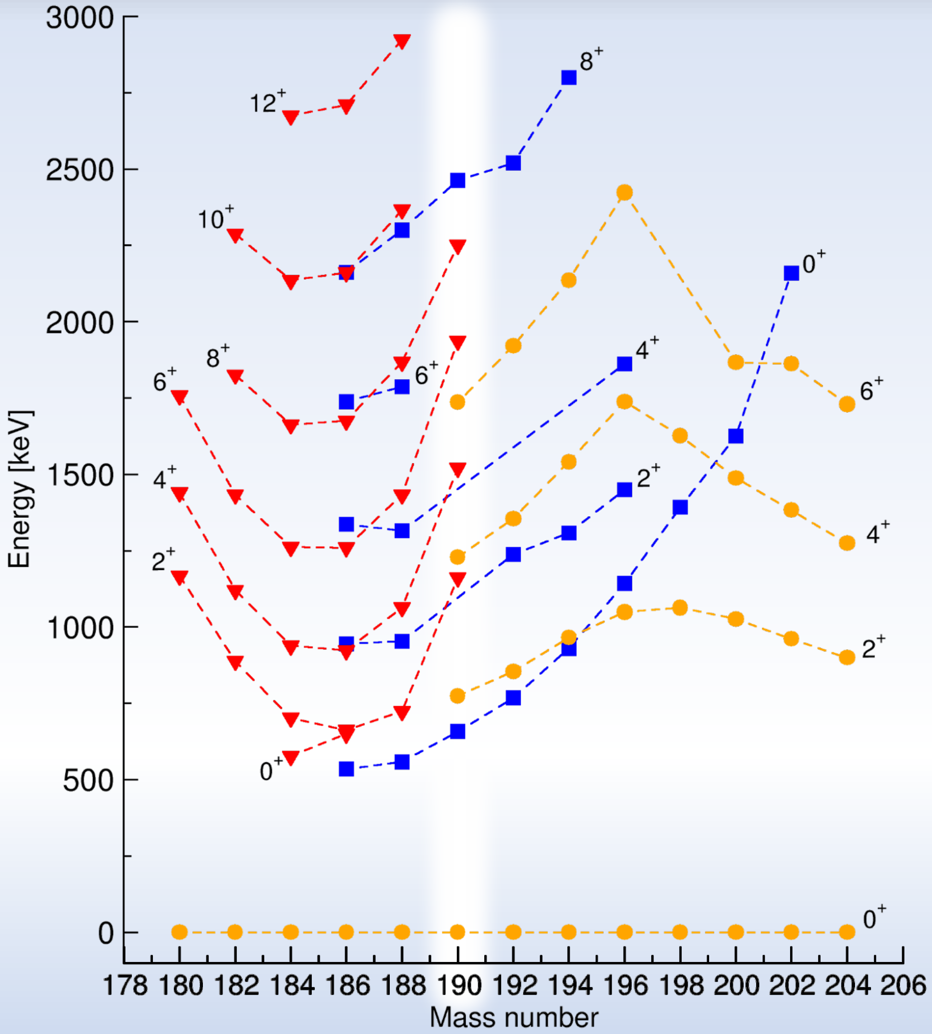
71 s

ε

β^+ 2.0, 2.9…

γ 942, 151, 598…, g

α 5.581…



Summary

Measured B(E2) values

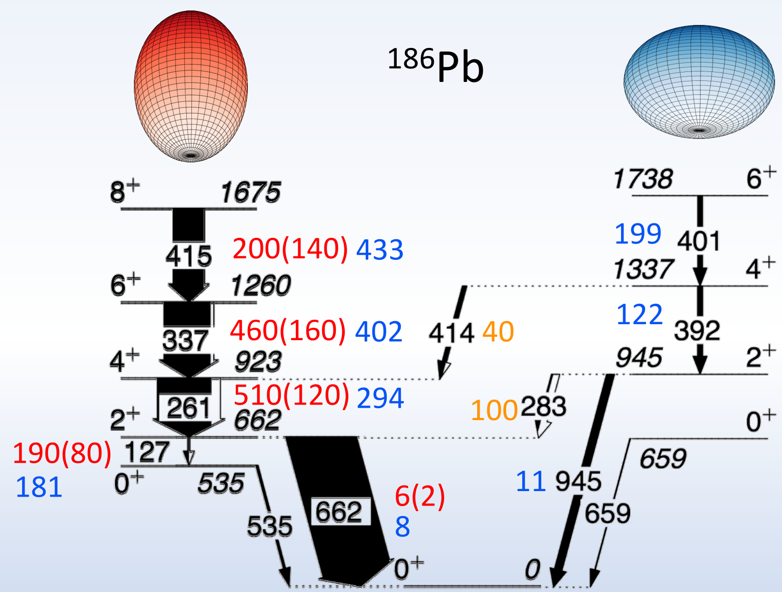
- T. Grahn, et al., Phys. Rev. Lett. 97, 062501 (2006)
- Present work

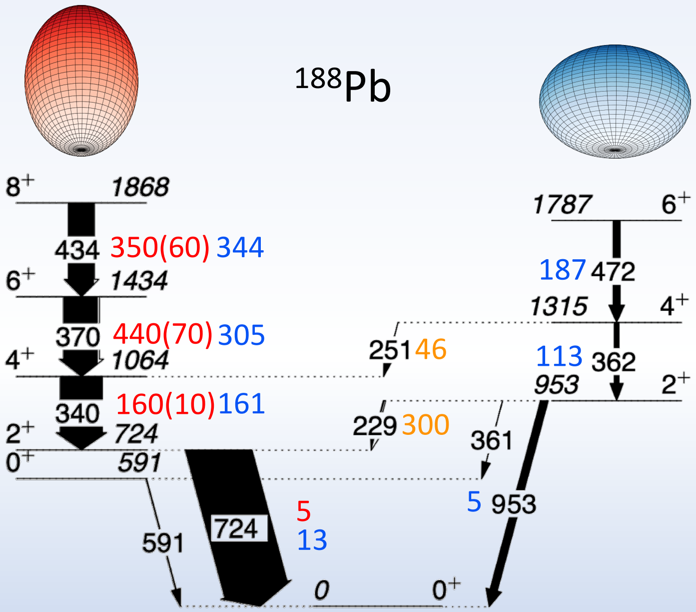
IBM B(E2) values

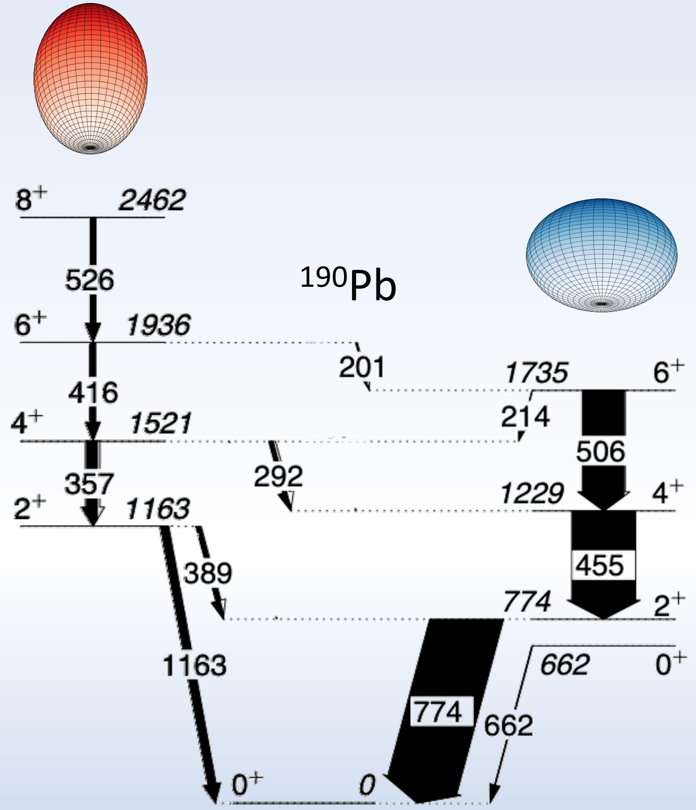
- V. Hellemans *et al.*, Phys. Rev C. 77, 064324 (2008)

Extracted ρ^2

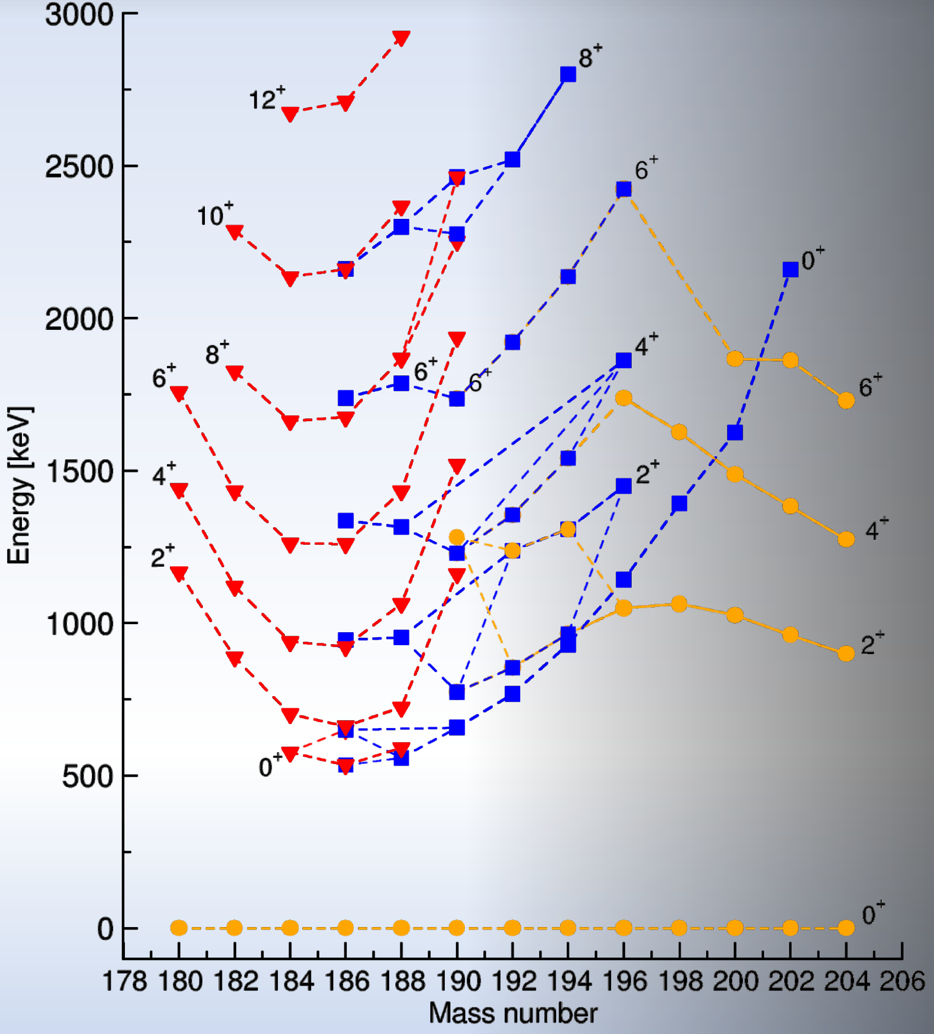
- Based on measured branching ratios and
- Measured or questimated B(E2) values







New assignments and prospects



- ^{186}Pb: prolate and oblate 0^+ states swapped
- ^{188}Pb: 0^+_1 state reassigned as prolate
- ^{190}Pb: yrast band reassigned as oblate
  spherical 2^+ state discovered
  prolate and oblate 8^+ states swapped

Results obtained have changed the picture.

Thank you!

We must question whether the shape assignments of heavier Pb isotopes are correct.

Maybe the onset of oblate deformation starts already at ^{194}Pb.