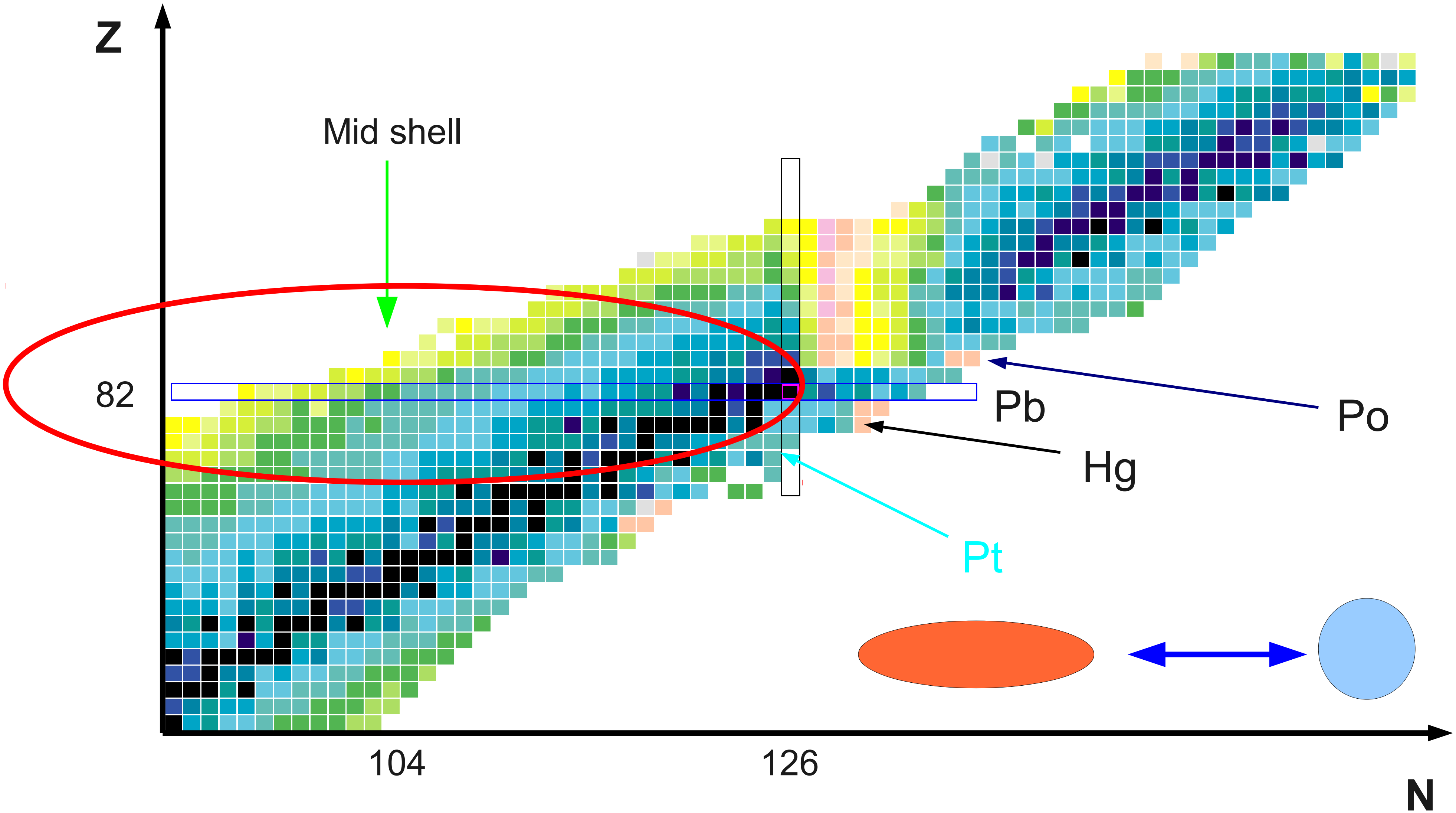
www.uhu.es/gem

How evident is the shape coexistence phenomenon in the lead region?

J.E. García-Ramos[1], K. Heyde[2]

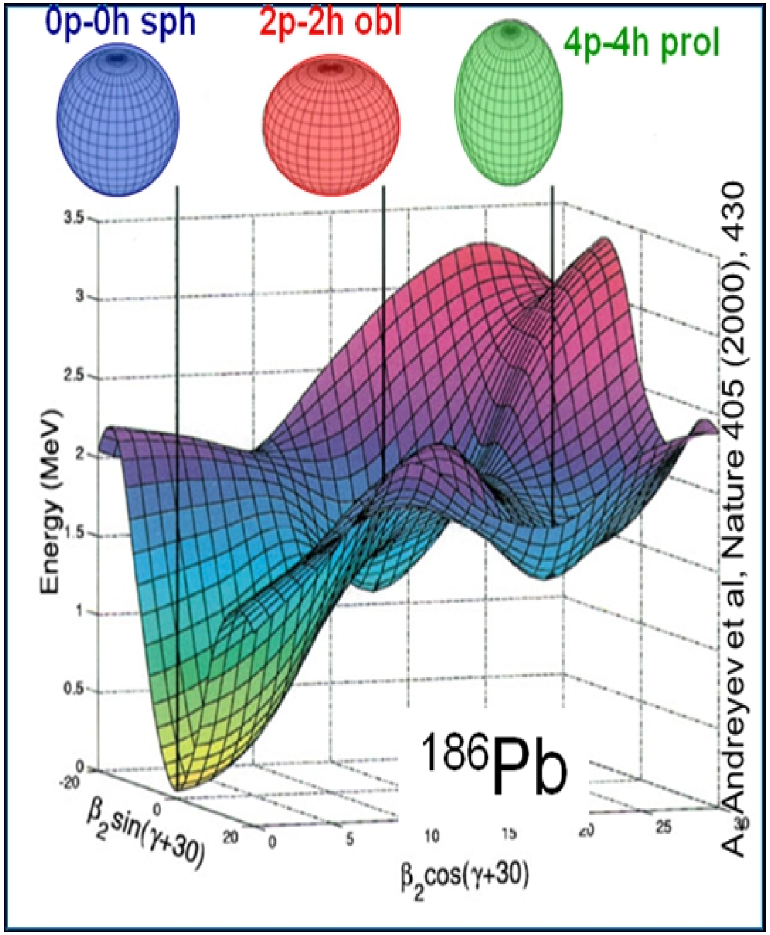
[1]Departamento de Física Aplicada, Universidad de Huelva, Spain
[2]Department of Physics and Astronomy, University of Ghent, Belgium

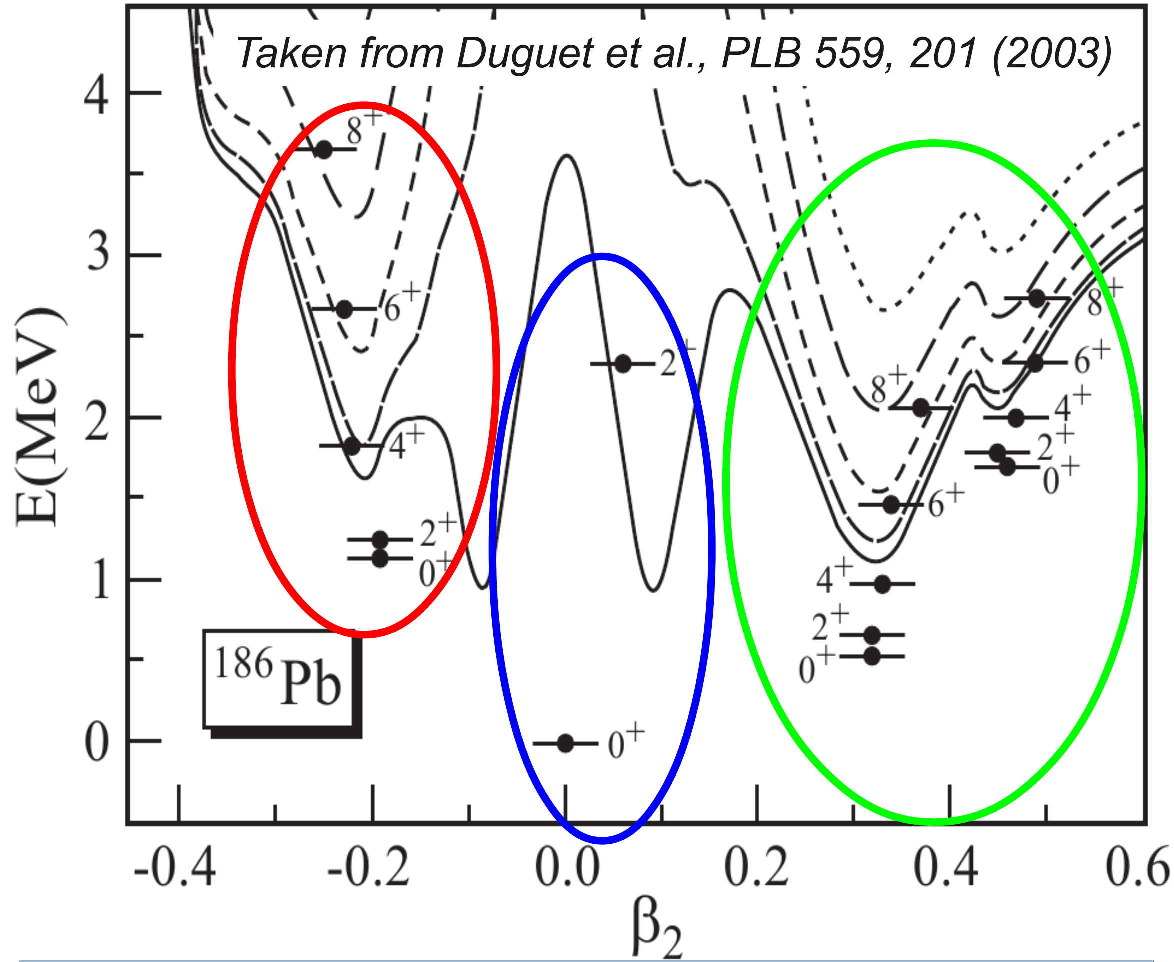
Region of interest



Universidad de Huelva
www.uhu.es/gem

Mean Field

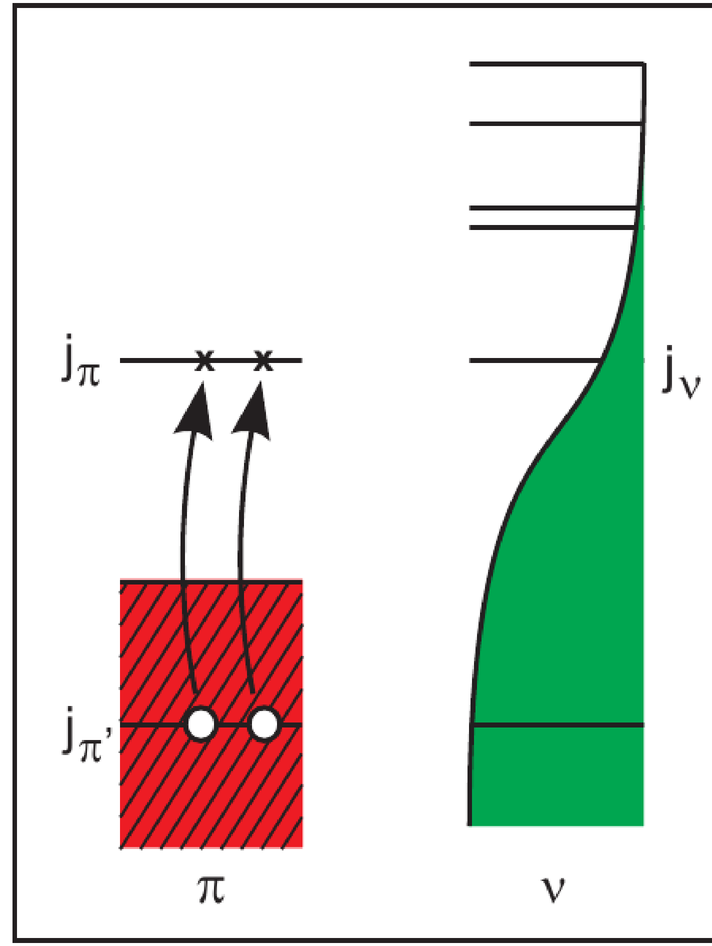


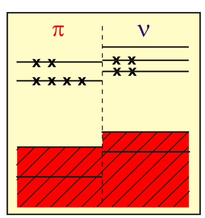


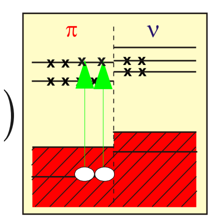
The angular momentum projected mean field plus the Generator Coordinate Method generates different bands with very different deformation.

Shell Model/Interacting Boson Model

- For nuclei near to closed shells, either for neutrons or for protons, it can be energetically favorable to have excitations of 2p-2h, 4p-4h … crossing the energy gap.
- The np-nh excitations have a lower excitation energy than expected due to the correlation energy: pairing and deformed correlations.
- Restricted to light and medium-heavy nuclei, at present.



$\phi(J,M) = a(J,M)$ 

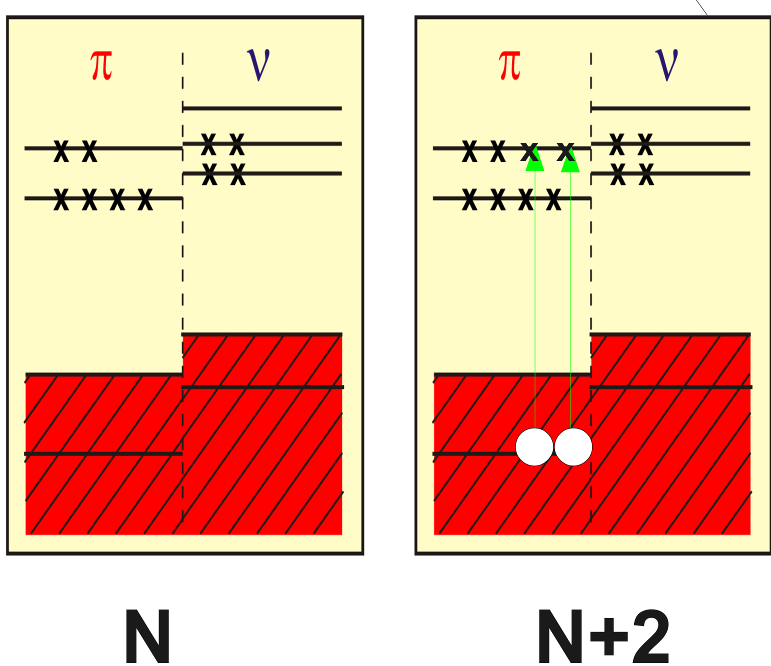
$+ \; b(J,M)$ 

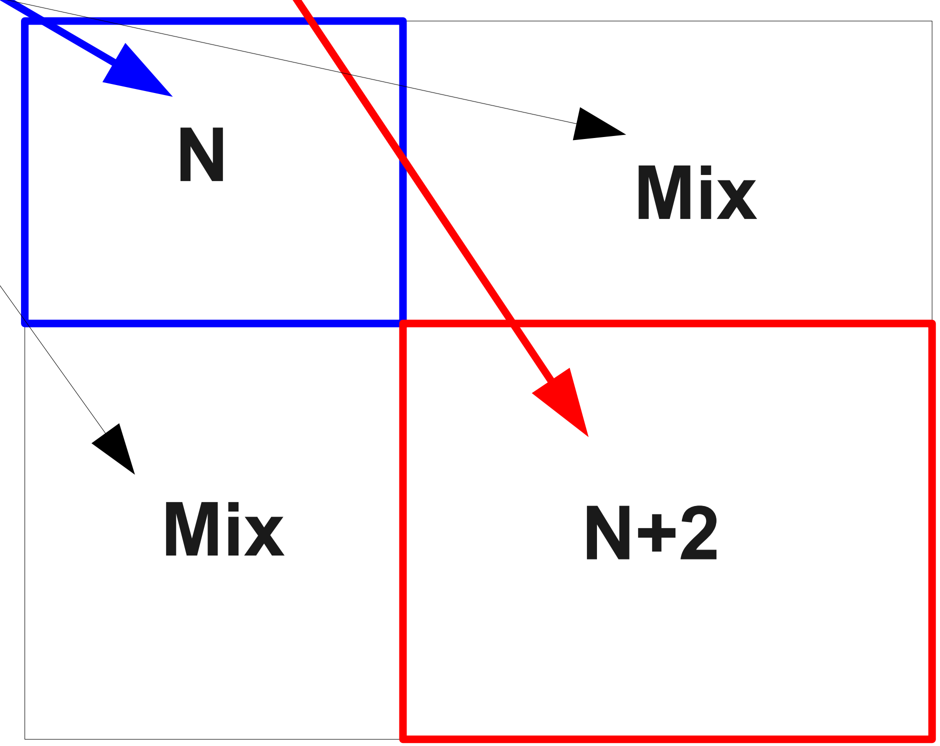
In heavy nuclei the huge model space imposes some kind of truncation: symmetry dictated truncation.

Interacting Boson Model

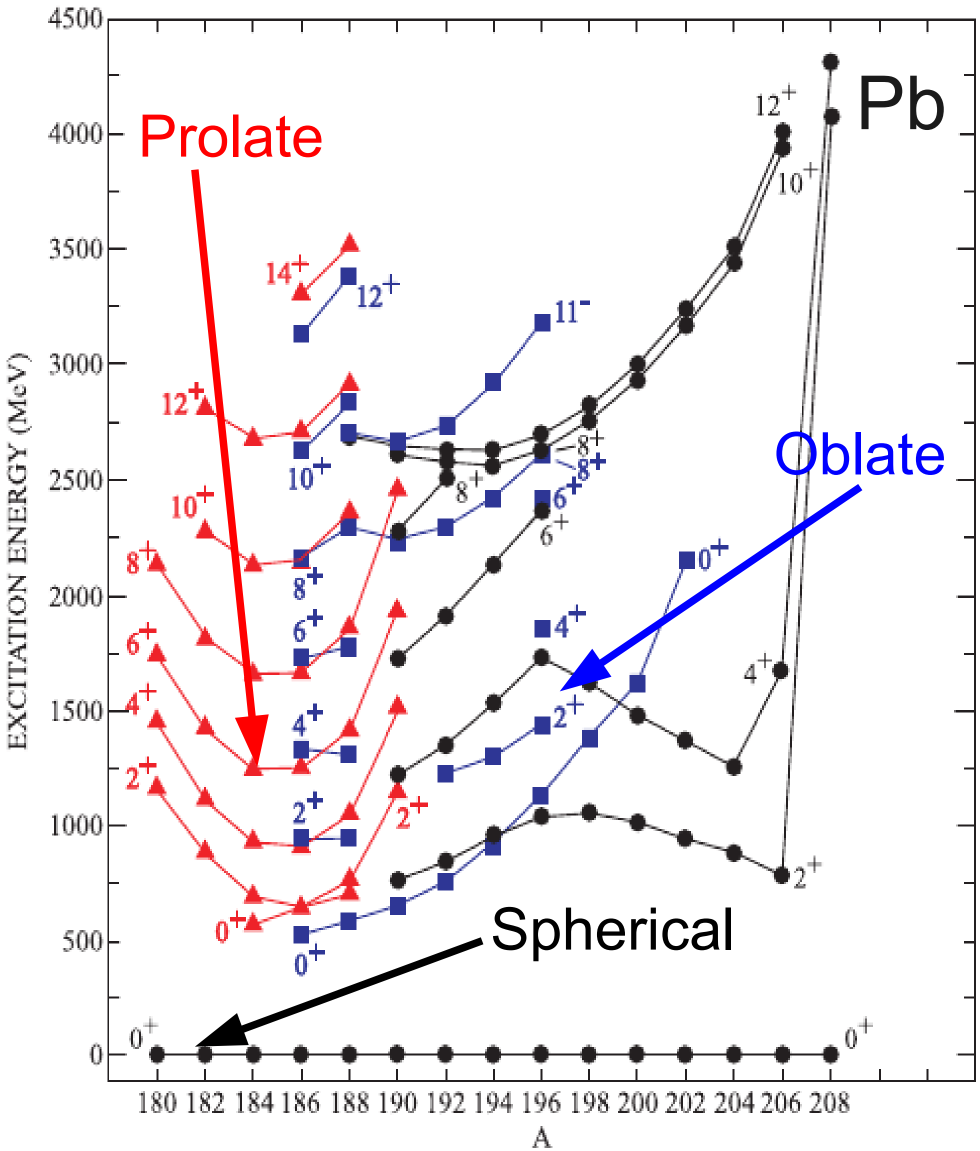
(configuration mixing)

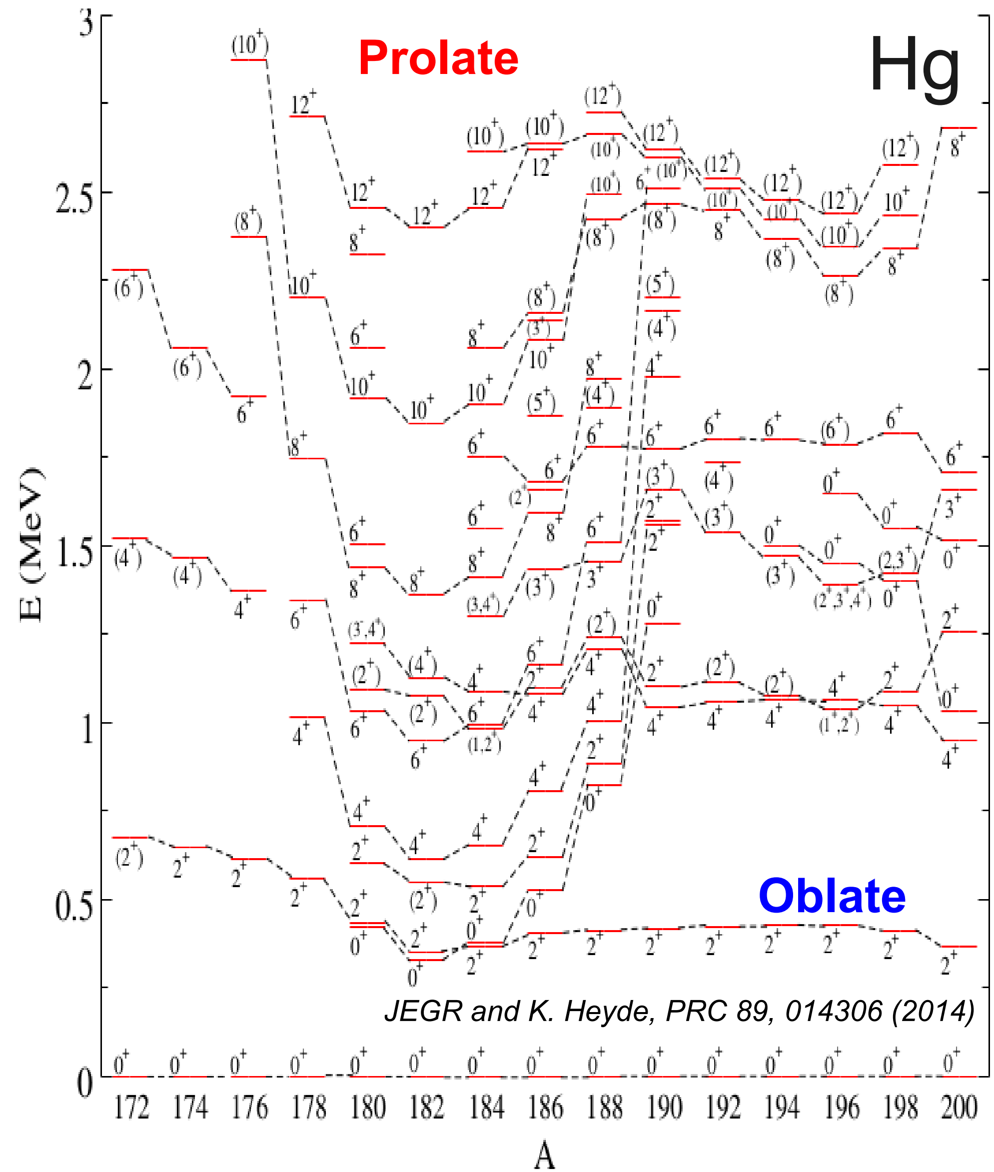
$$\hat{H} = \hat{P}_N^\dagger \hat{H}_{\mathrm{ECQF}}^{N} \hat{P}_N + \hat{P}_{N+2}^\dagger \left(\hat{H}_{\mathrm{ECQF}}^{N+2} + \Delta^{N+2}\right) \hat{P}_{N+2} + \hat{V}_{\mathrm{mix}}^{N,N+2},$$



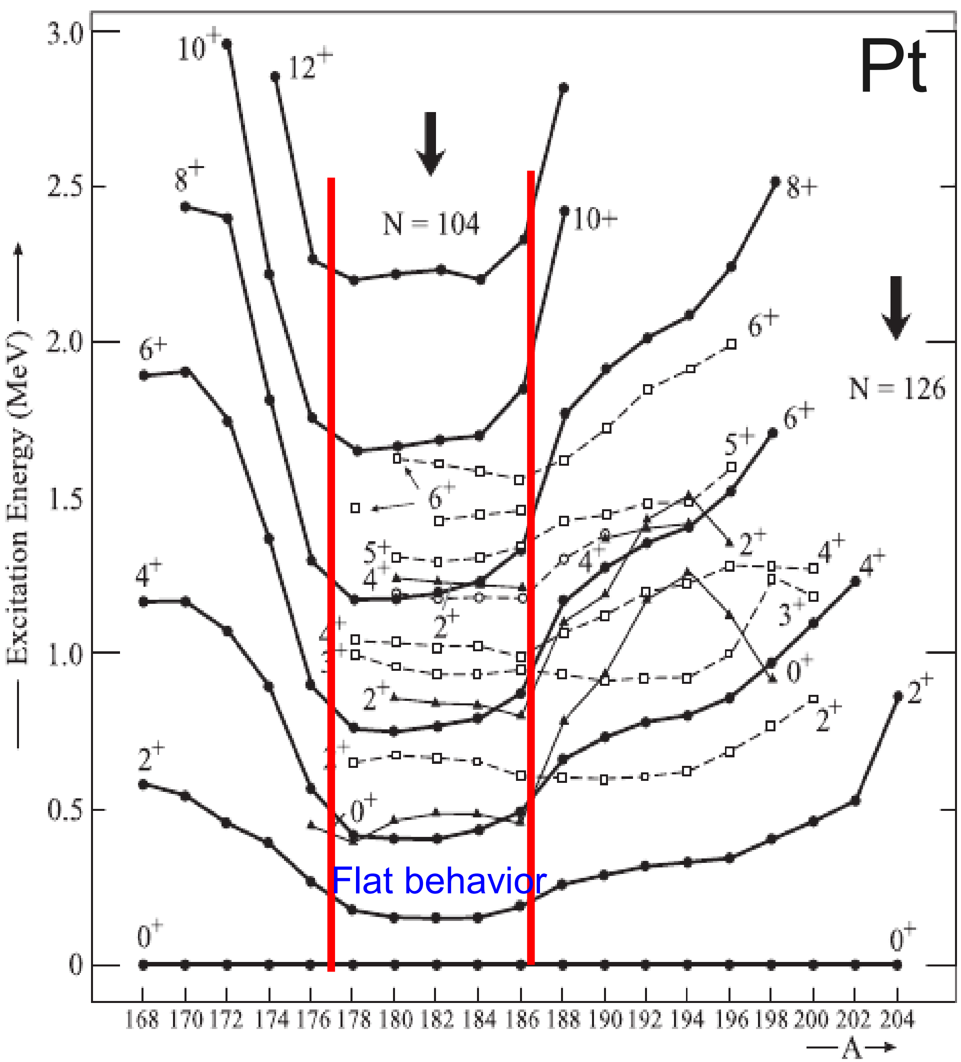


Pb and Hg isotopes

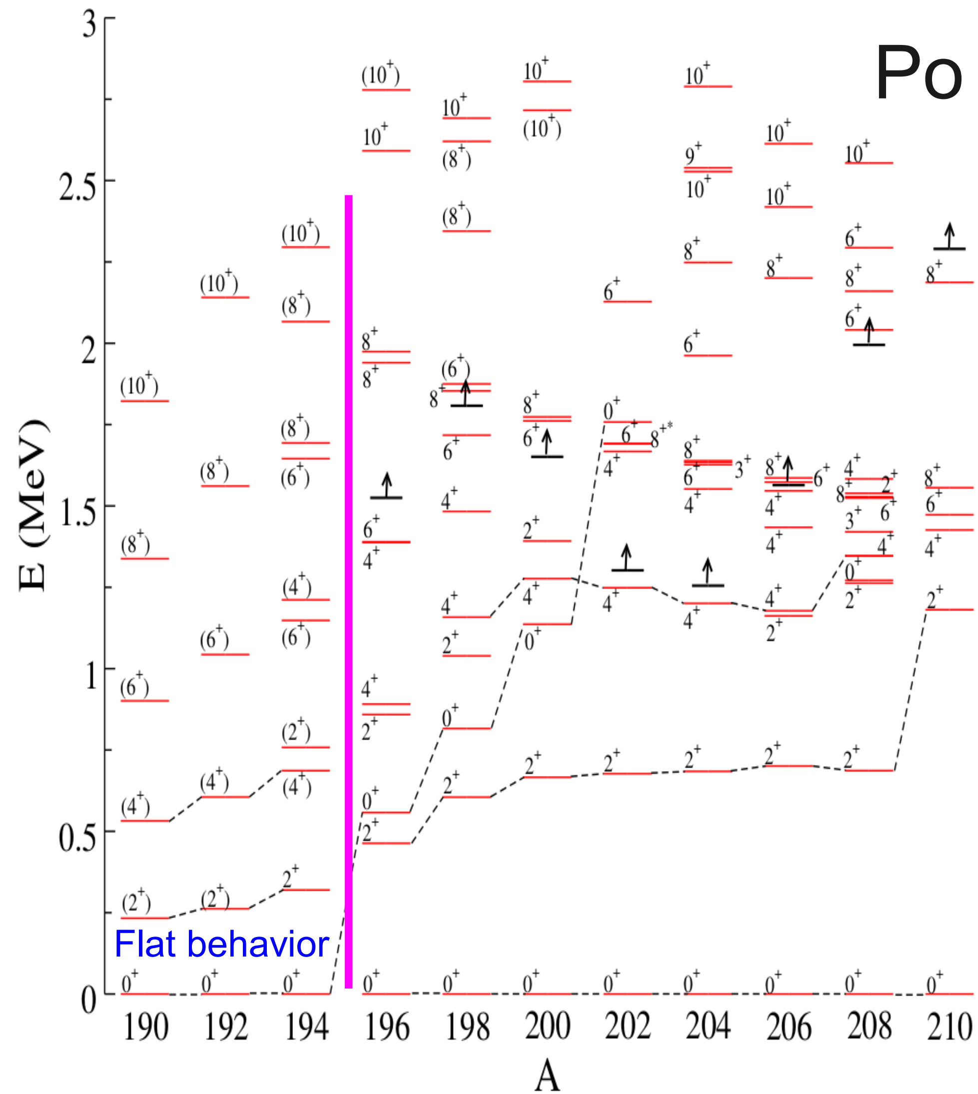




Pt and Po isotopes

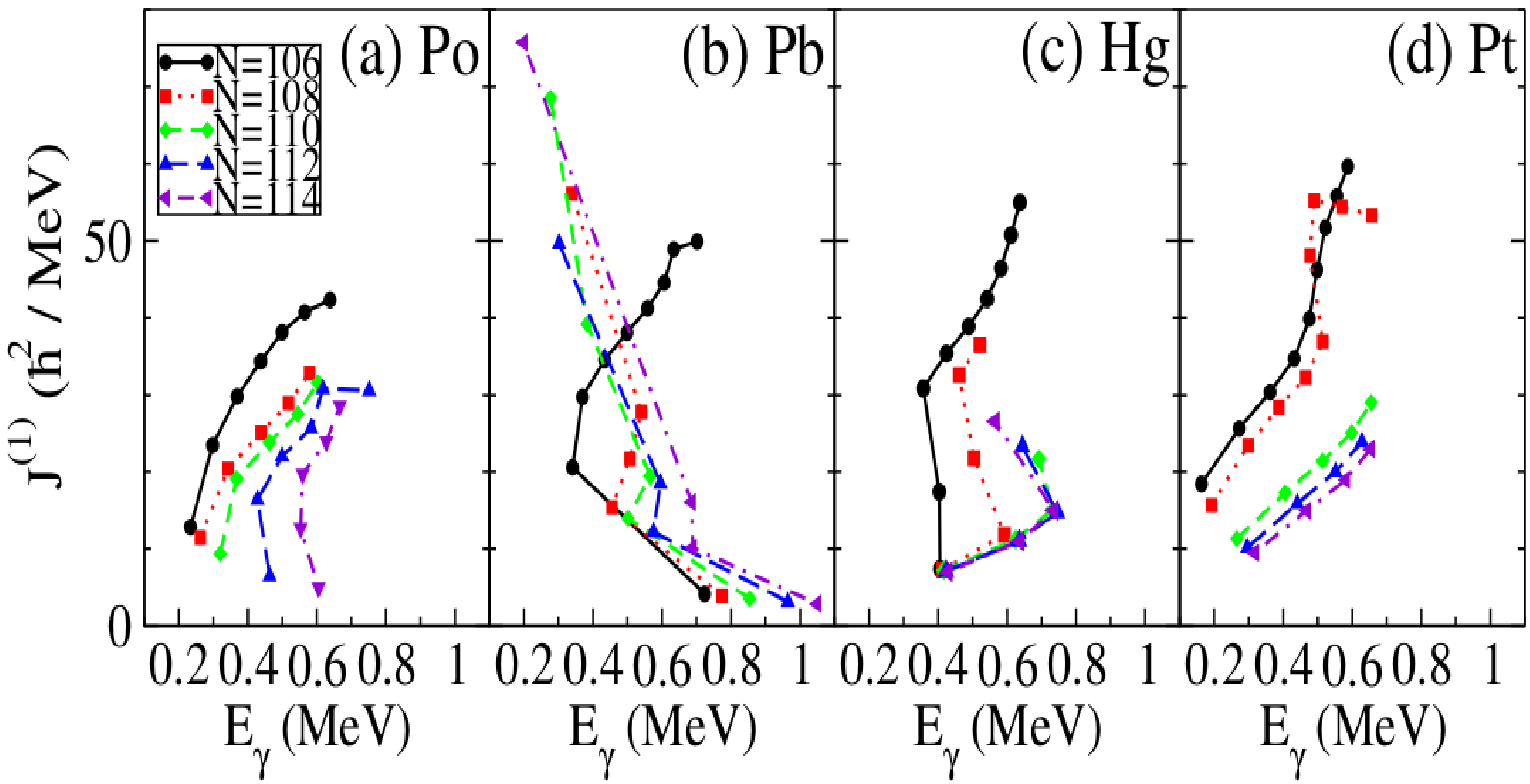


JEGR and K. Heyde, NPA 825, 39 (2009),
JEGR, V. Hellemans, and K. Heyde, PRC 84, 014331 (2011).



JEGR and K. Heyde, PRC to appear.

Dynamic moment of inertia



$$J^{(1)} = \frac{\hbar^2}{2}\left(\frac{dE}{d\left(J(J+1)\right)}\right)^{-1} \approx \frac{\hbar^2(2J-1)}{2E_\gamma(J \to (J-2))}$$

How to fix the parameters (IBM)

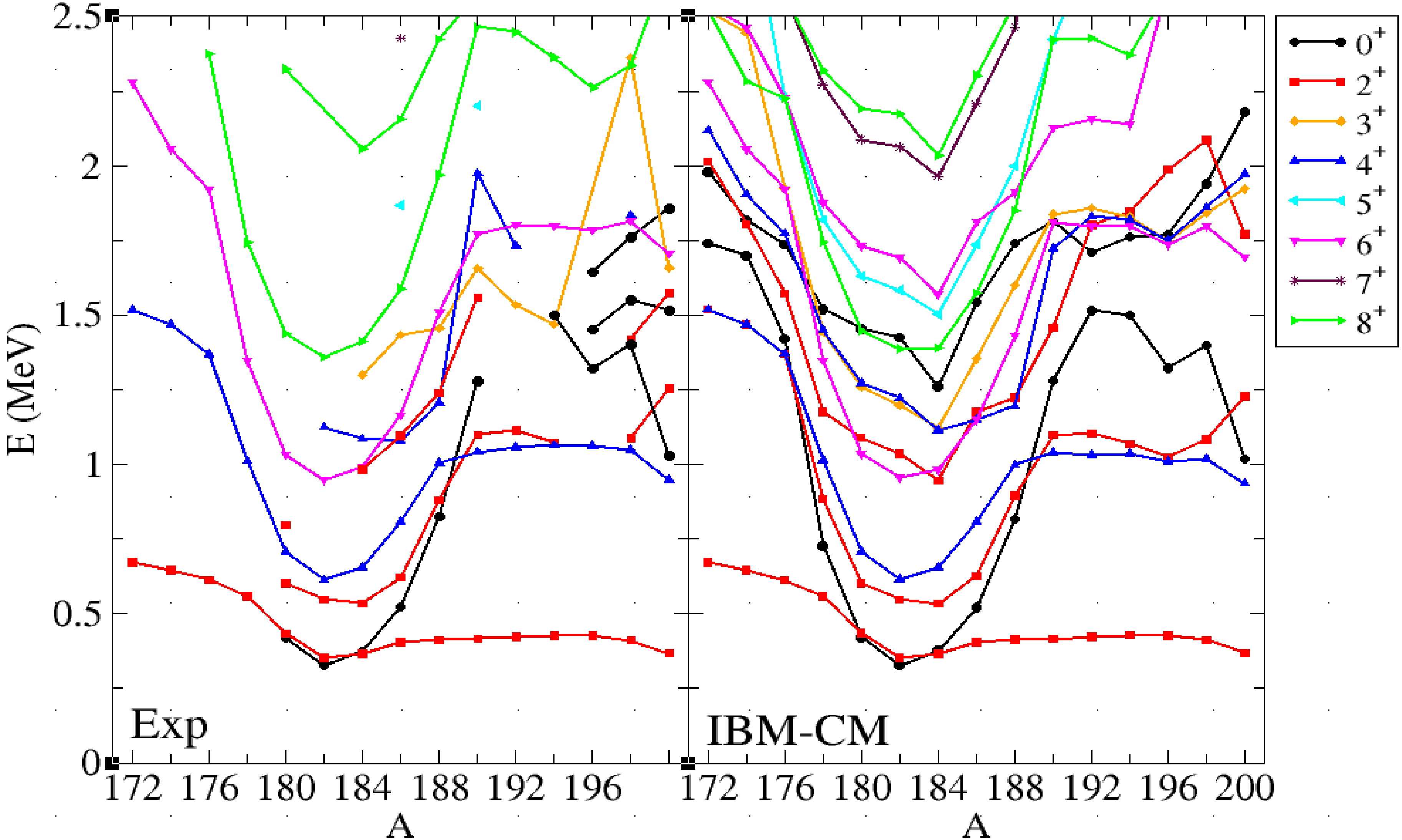
Least squares fit to the experimental data, including excitation energies and absolute B(E2) transitions.

$$\chi^2 = \frac{1}{N_{data} - N_{par}} \sum_{i=1}^{N_{data}} \frac{(X_i(data) - X_i(IBM))^2}{\sigma_i^2}$$

Error (keV)	States
$\sigma = 0.1$	2_1^+
$\sigma = 1$	$4_1^+, 0_2^+, 2_2^+$
$\sigma = 10$	$2_3^+, 3_1^+, 4_2^+, 6_1^+, 8_1^+$
$\sigma = 100$	$2_4^+, 3_1^+, 4_3^+, 6_2^+$

+ all the known B(E2) transitions

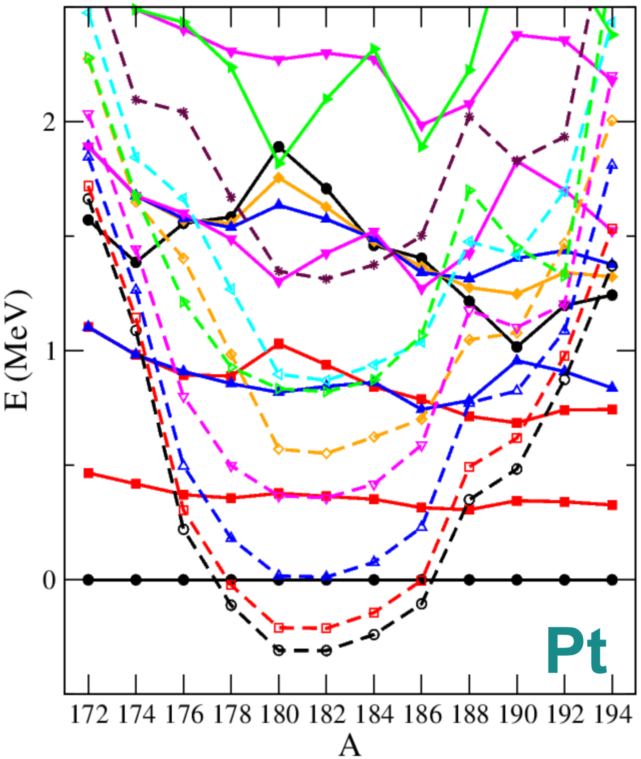
How the IBM results look like?

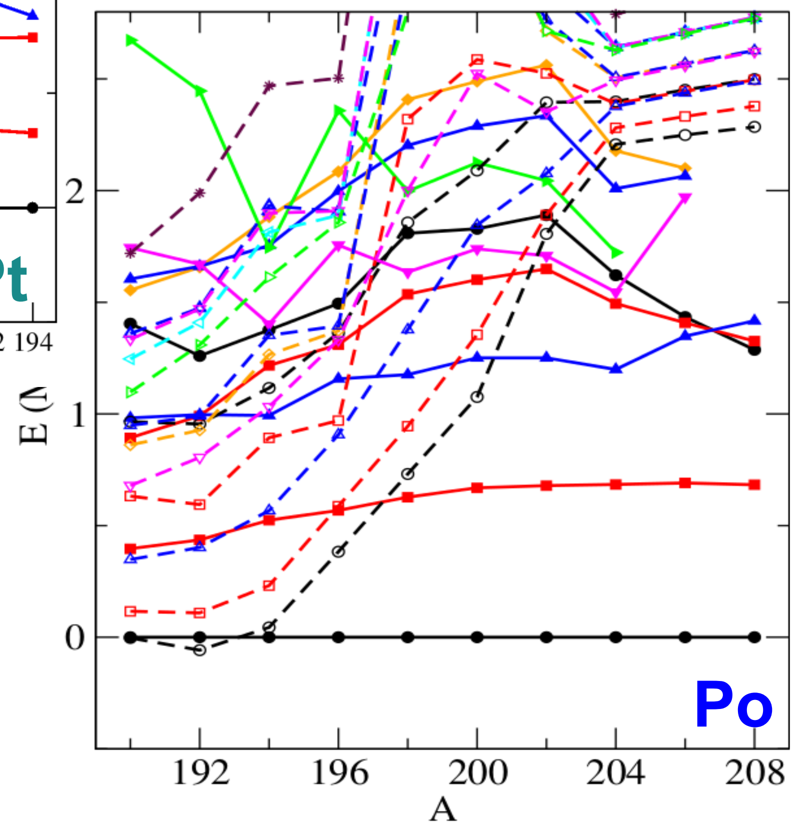


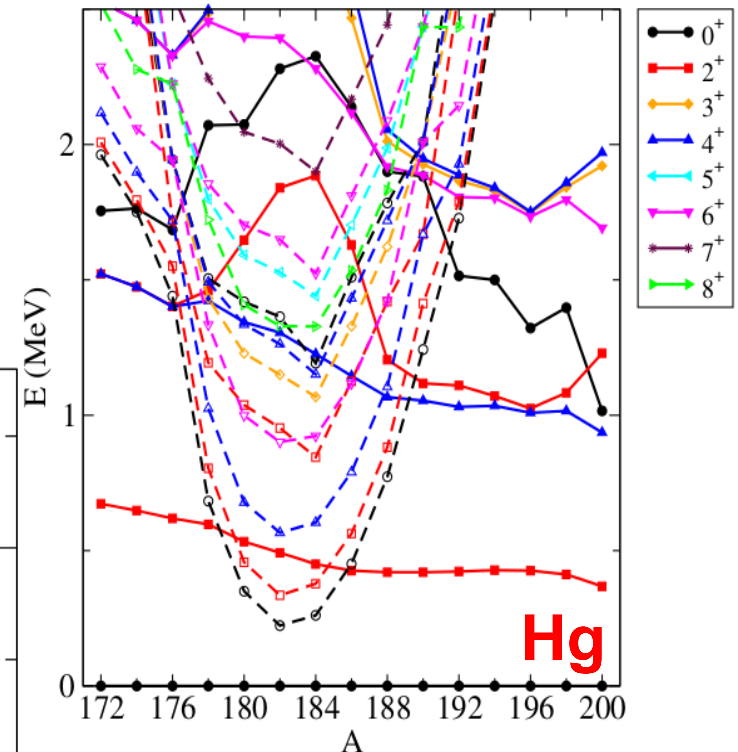
Hg isotopes

JEGR and K. Heyde, PRC 89, 014306 (2014).

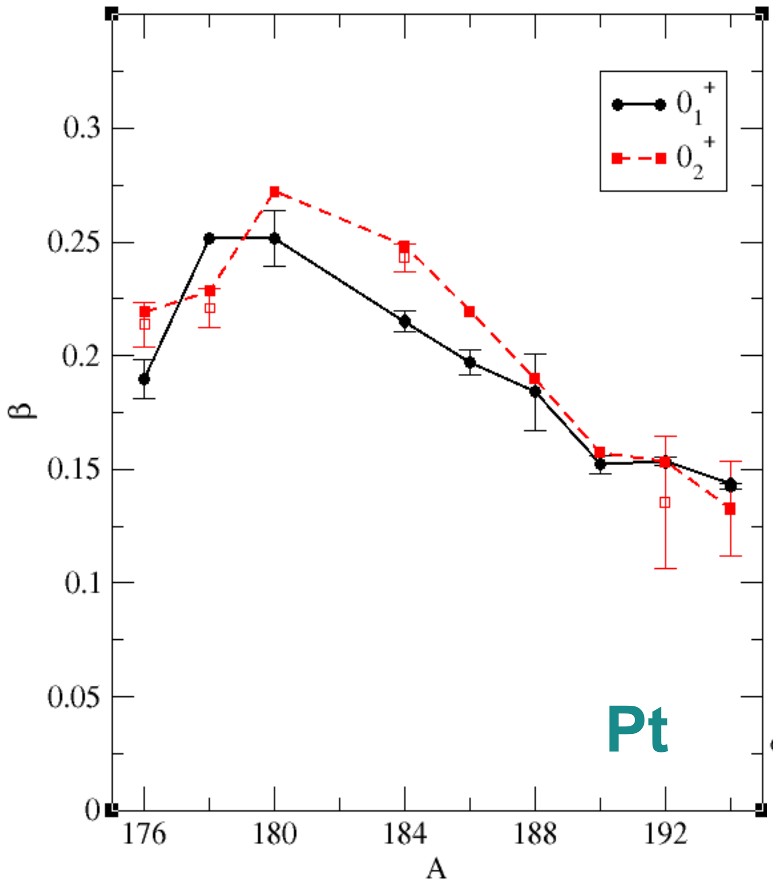
Unperturbed energies (IBM-CM)

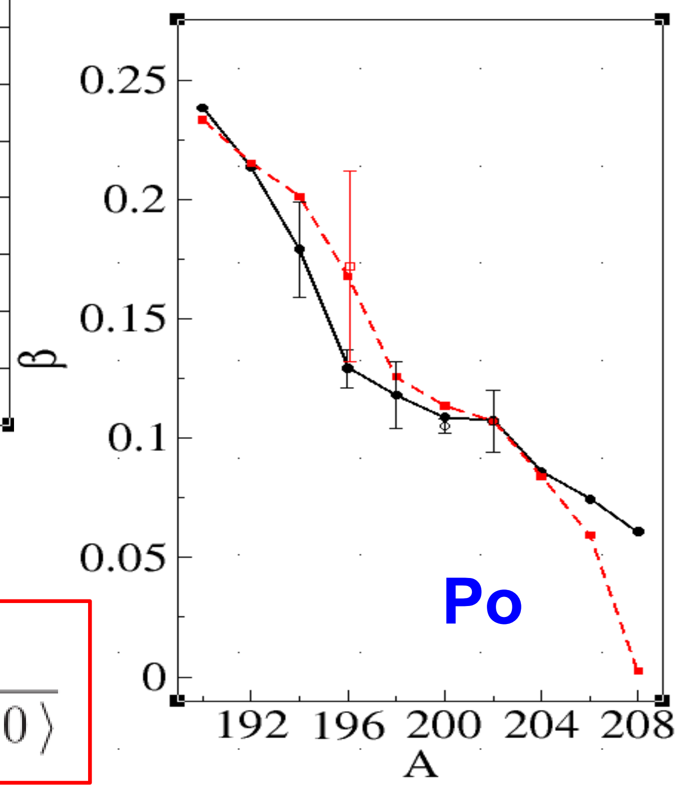


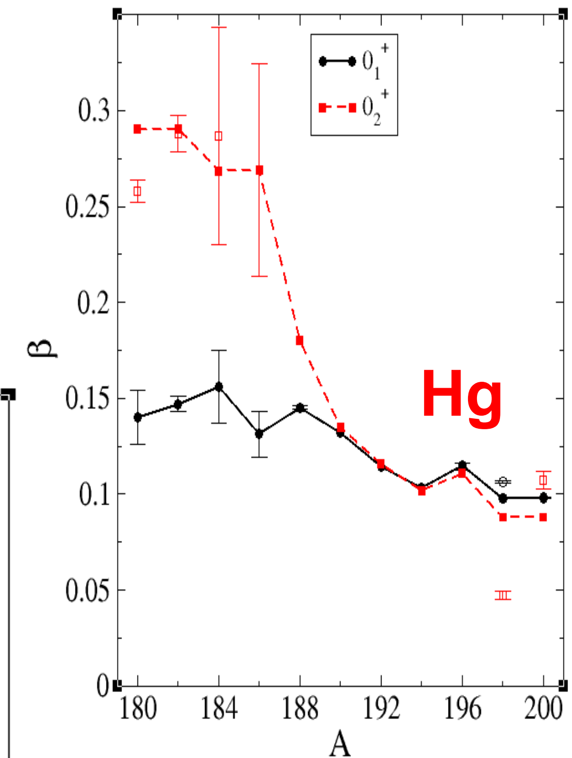




Deformation



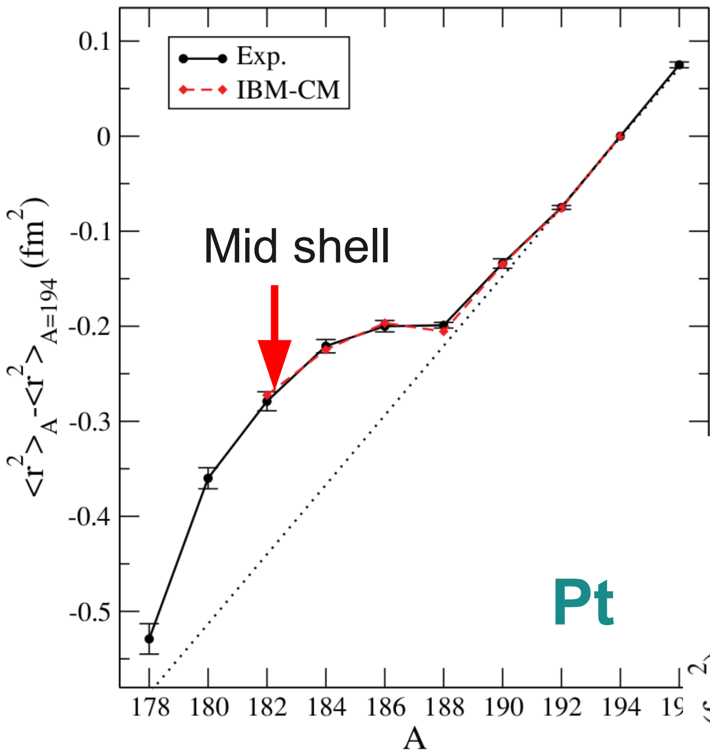


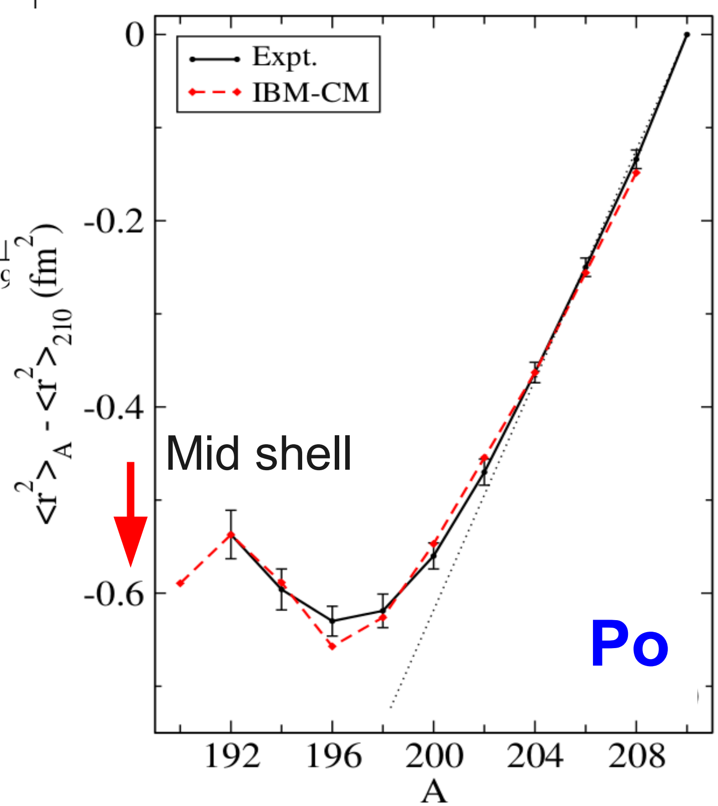


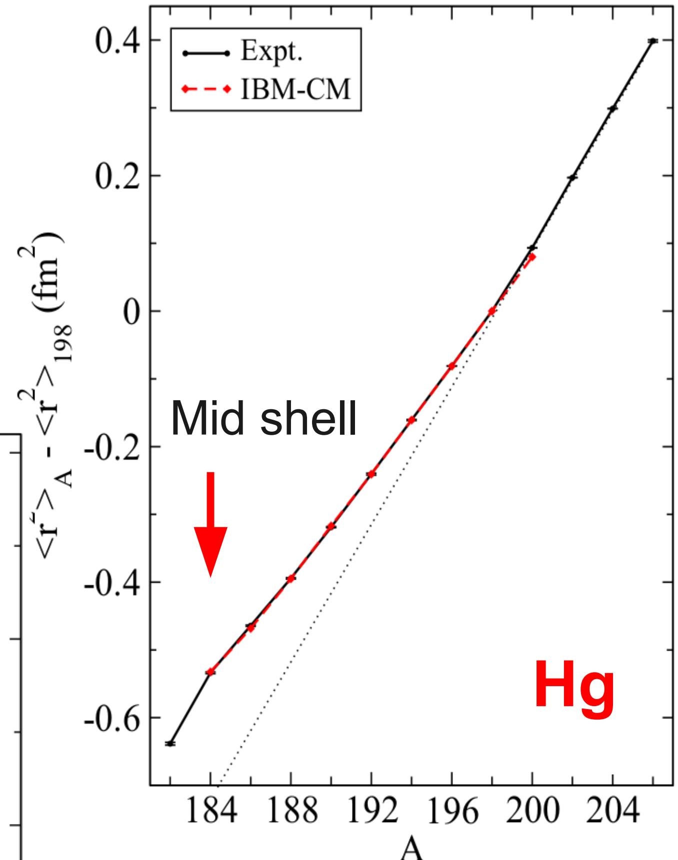
Beta's from B(E2) values

$$\beta = \frac{4\pi\sqrt{B(E2; J \rightarrow J-2)}}{3 Z e r_0^2 A^{2/3} \langle J\, 0\, 2\, 0 | J-2\, 0 \rangle}$$

Radii


Exp.
IBM-CM
Mid shell
Pt
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
178 180 182 184 186 188 190 192 194
A
$<r^2>_A - <r^2>_{A=194}$ (fm^2)


Expt.
IBM-CM
Mid shell
Po
0
-0.2
-0.4
-0.6
192 196 200 204 208
A
$<r^2>_A - <r^2>_{210}$ (fm^2)


Expt.
IBM-CM
Mid shell
Hg
0.4
0.2
0
-0.2
-0.4
-0.6
184 188 192 196 200 204
A
$<r^2>_A - <r^2>_{198}$ (fm^2)

Summary and conclusions

•We have presented a detailed description of even-even Pt-Hg-Po isotopes using the interacting boson model including configuration mixing: excitation energies, BE2's, deformation, radii, ...

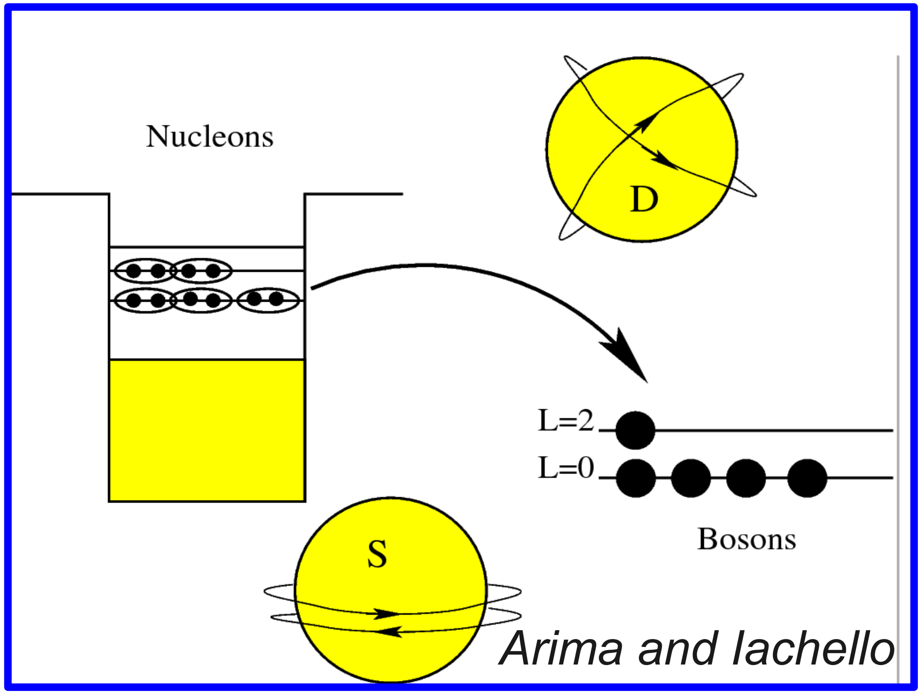
•Two different behaviors are showed up: in Hg and Pb the presence of intruders is self evident while in the case of Pt and Po configuration mixing is somehow *concealed.*

•In Pt-Pb-Po-Hg two (or even three) configurations coexist, one slighlty deformed (or spherical) and of gamma unstable character, corresponding to the regular states and a more deformed one of oblate (prolate) character corresponding to the intruder states.

•Shape coexistence all through the nuclear mass region, is a very general phenomenon, except in few cases where the spherical shell gaps indeed block the development of deformed states.

Thank you

Interacting Boson Model (IBM)



Nucleons couple preferably in pairs with angular momentum either equal to 0 (S) or equal to 2 (D). Those pairs are then described by means of bosons: s and d.

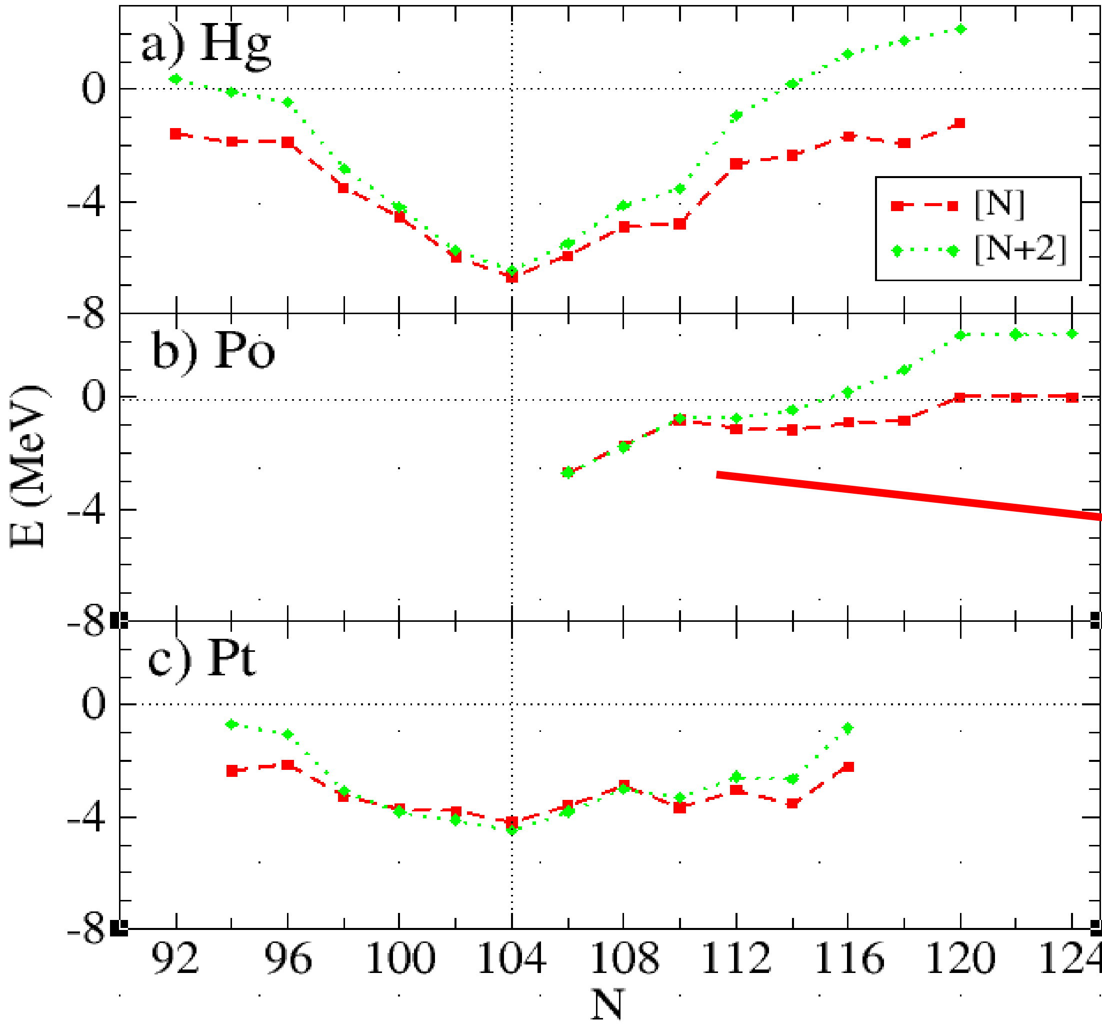
$$s^\dagger, d_m^\dagger (m = 0, \pm 1, \pm 2)$$

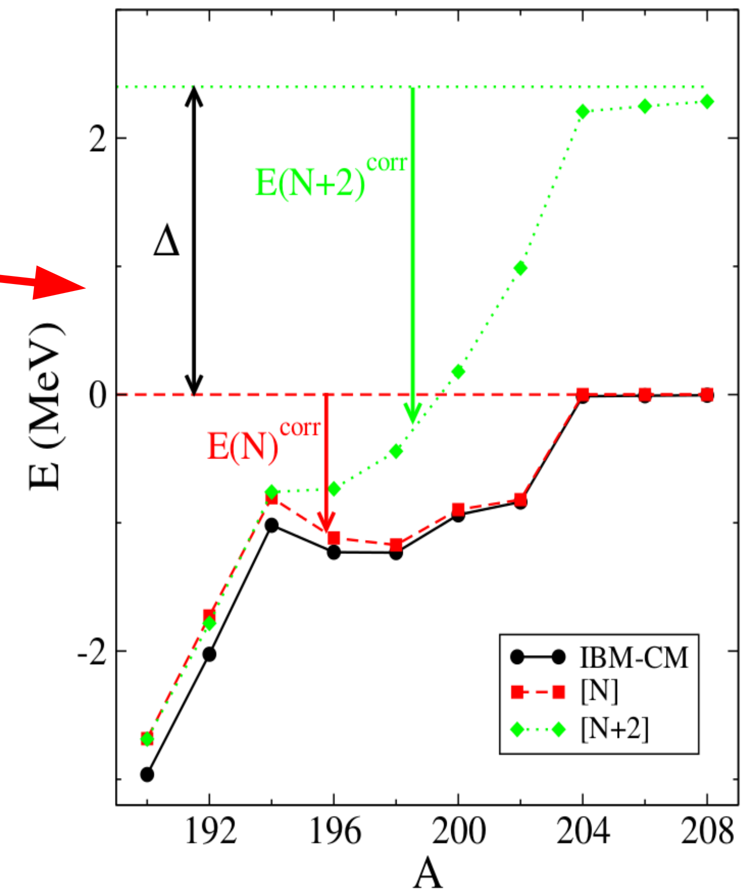
$$s, d_m (m = 0, \pm 1, \pm 2)$$

$$\hat{H}_{ECQF} = \epsilon \hat{n}_d + \kappa \hat{Q} \cdot \hat{Q} + \kappa' \hat{L} \cdot \hat{L}$$

www.uhu.es/gem

Correlation energy (IBM-CM)



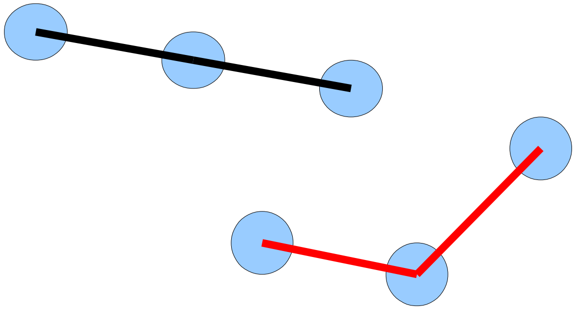


What is shape coexistence?

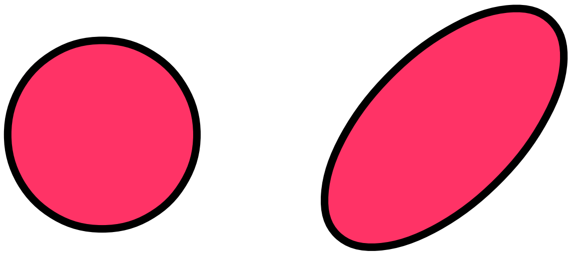
It appears in quantum systems where eigenstates with very different shapes coexist.

Therefore, it is implicit the existence of a geometric interpretation.

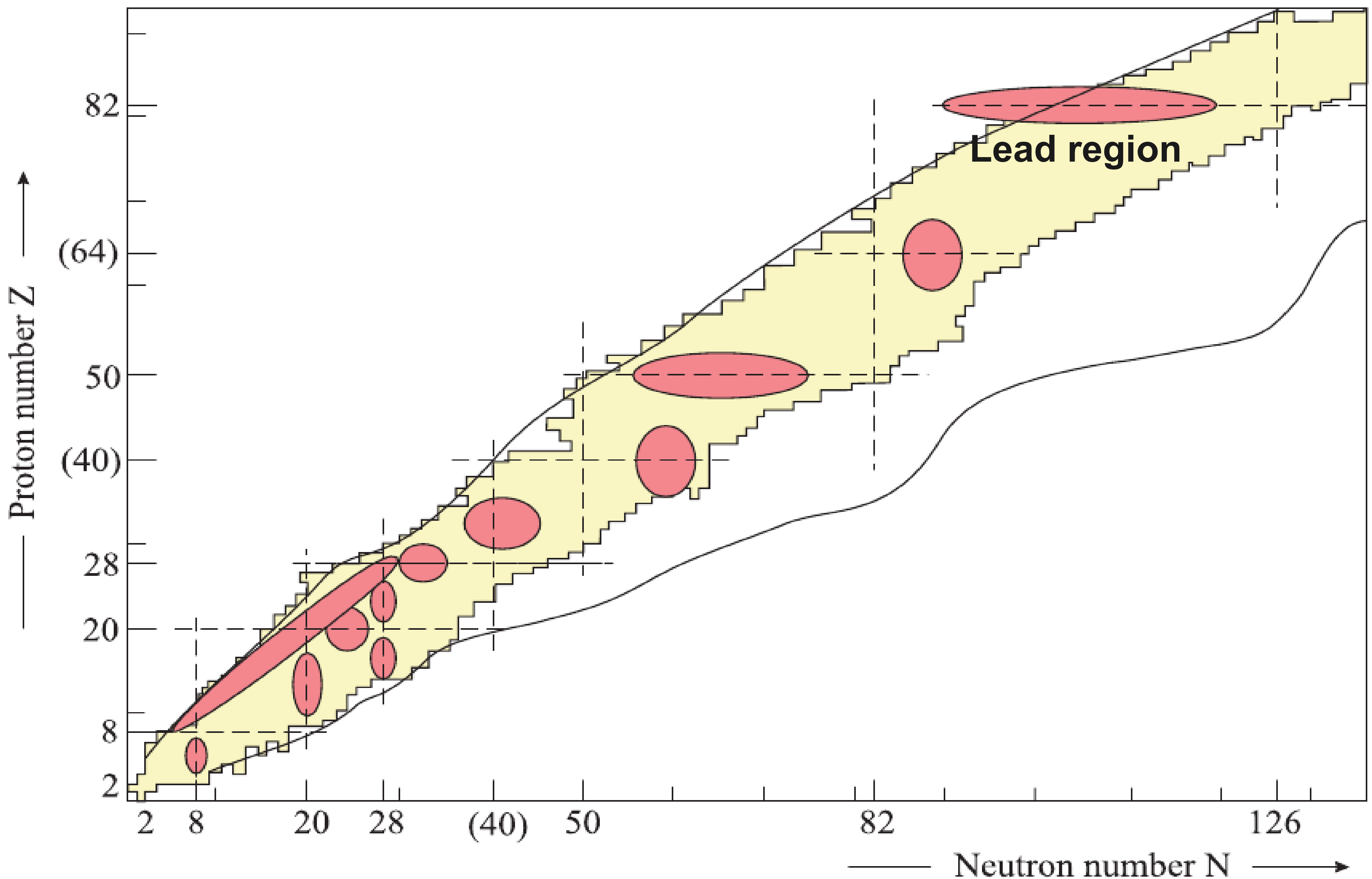
Molecules



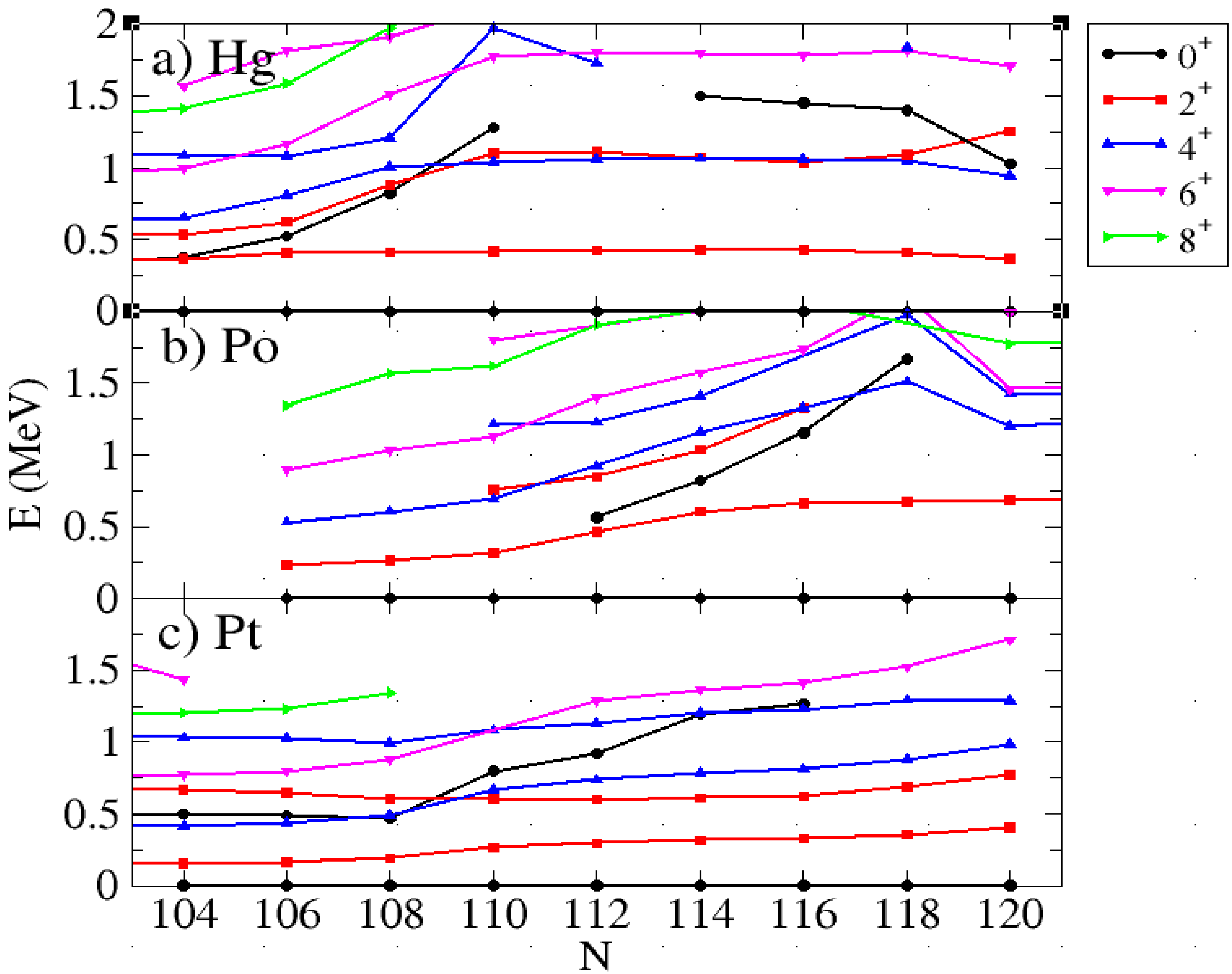
Nuclei



Many regions to understand



Excitation energies (exp)



Wave functions (IBM-CM)