“Signatures of nuclear shape transitions with a microscopic perspective ”

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Some points to keep in mind:

1) A better microscopic understanding of the evolution of the nuclear shapes with the number of nucleons as well as its consequences for low-lying spectroscopy remains a major challenge.

2) Low-lying spectroscopy represents a powerful source of information about structural evolution and/or shape transitions $\longrightarrow$ it allows us to correlate excitation energies with deformation properties.

3) Systematic mean field calculations, based on universal EDFs (like Gogny-EDF), are possible all over the nuclear chart. But to access spectroscopic properties one needs, in general, to go beyond the mean field (GCM is quite hard computationally).

4) The IBM has been quite successful in reproducing experimental spectra and transition probabilities (with parameters adjusted to experiment !!!!)

What could we do?

We have undertaken our first steps in bosonization techniques for many-fermion systems.

Novel Mapping of Gogny-HFB calculations into IBM-2

Mapping Gogny-HFB calculations into IBM-2

In order to obtain the Gogny-HFB (β, γ) PESs we constrain the mass quadrupole operators $\hat{Q}_{20} = \frac{1}{2}\left(2z^2 - x^2 - y^2\right)$ and $\hat{Q}_{22} = \frac{\sqrt{3}}{2}\left(x^2 - y^2\right)$

$$Q_{20} = \langle \Phi_{\mathrm{HFB}} | \hat{Q}_{20} | \Phi_{\mathrm{HFB}} \rangle \tag{1}$$

$$Q_{22} = \langle \Phi_{\mathrm{HFB}} | \hat{Q}_{22} | \Phi_{\mathrm{HFB}} \rangle . \tag{2}$$

to obtain the HFB vacua $|\Phi_{\mathrm{HFB}}(\beta, \gamma)\rangle$ and energies $E_{\mathrm{HFB}}(\beta, \gamma)$ with

$$\beta = \sqrt{\frac{4\pi}{5}} \frac{\sqrt{Q_{20}^2 + Q_{22}^2}}{A\langle r^2 \rangle} \tag{3}$$

and

$$\tan\gamma = \frac{Q_{22}}{Q_{20}} \tag{4}$$

Ref-1 L.M.Robledo et al., J.Phys.G:Nucl.Part.Phys. **36** 115104 (2009).

Ref-2 R.R.Rodríguez-Guzmán et al., PRC **81**, 024310 (2010).

All the HFB calculations presented in this talk are based on the finite range and density dependent Gogny ”interaction” given by

$$\begin{aligned}\hat{V}(1,2) &= \sum_{i=1,2} e^{-\frac{(\vec{r}_1-\vec{r}_2)^2}{\mu_i^2}} \left(W_i + B_i\hat{P}^\sigma - H_i\hat{P}^\tau - M_i\hat{P}^\sigma\hat{P}^\tau\right) \\ &+ iW_{LS}\left[\left(\vec{\sigma}^{(1)} + \vec{\sigma}^{(2)}\right)\vec{k}\times\delta(\vec{r}_1-\vec{r}_2)\vec{k}\right] \\ &+ t_3\left(1 + x_0\hat{P}^\sigma\right)\delta(\vec{r}_1-\vec{r}_2)\rho^\alpha\left(\frac{\vec{r}_1+\vec{r}_2}{2}\right) \qquad (5)\end{aligned}$$

The parametrization D1S of the Gogny-EDF is already considered as global and has shown its power to reproduce low-energy experimental data quite reasonably.

Ref R.R.Rodríguez-Guzmán et al., PRC **81**, 024310 (2010).

For the subsequent mapping procedure we use the IBM-2 Hamiltonian

$$\hat{H}_{\mathrm{IBM}} = \epsilon(\hat{n}_{d\pi} + \hat{n}_{d\nu}) + \kappa \hat{Q}_\pi \cdot \hat{Q}_\nu . \tag{6}$$

where

$$\hat{n}_{d\rho} = d^\dagger_\rho \cdot \tilde{d}_\rho, \quad (\rho = \pi, \nu) \tag{7}$$

and

$$\hat{Q}_\rho = [s^\dagger_\rho \tilde{d}_\rho + d^\dagger_\rho \tilde{s}_\rho]^{(2)} + \chi_\rho [d^\dagger_\rho \tilde{d}_\rho]^{(2)} \tag{8}$$

stand for the d-boson number operator and the quadrupole operator, respectively.

The bosonic PES is represented by the expectation value of $\hat{H}_{\mathrm{IBM}}$, computed in terms of the so-called boson coherent state

$$|\Phi\rangle \propto \prod_{\rho=\pi,\nu} \left[s^\dagger_\rho + \sum_{\mu=0,\pm 2} \alpha_{\rho\mu} d^\dagger_{\rho\mu} \right]^{n_\rho} |0\rangle \tag{9}$$

$$\alpha_{\rho 0} = \beta_\rho \cos\gamma_\rho$$
$$\alpha_{\rho\pm 1} = 0$$
$$\alpha_{\rho\pm 2} = \frac{1}{\sqrt{2}}\beta_\rho \sin\gamma_\rho. \quad (10)$$

For simplicity we assume:

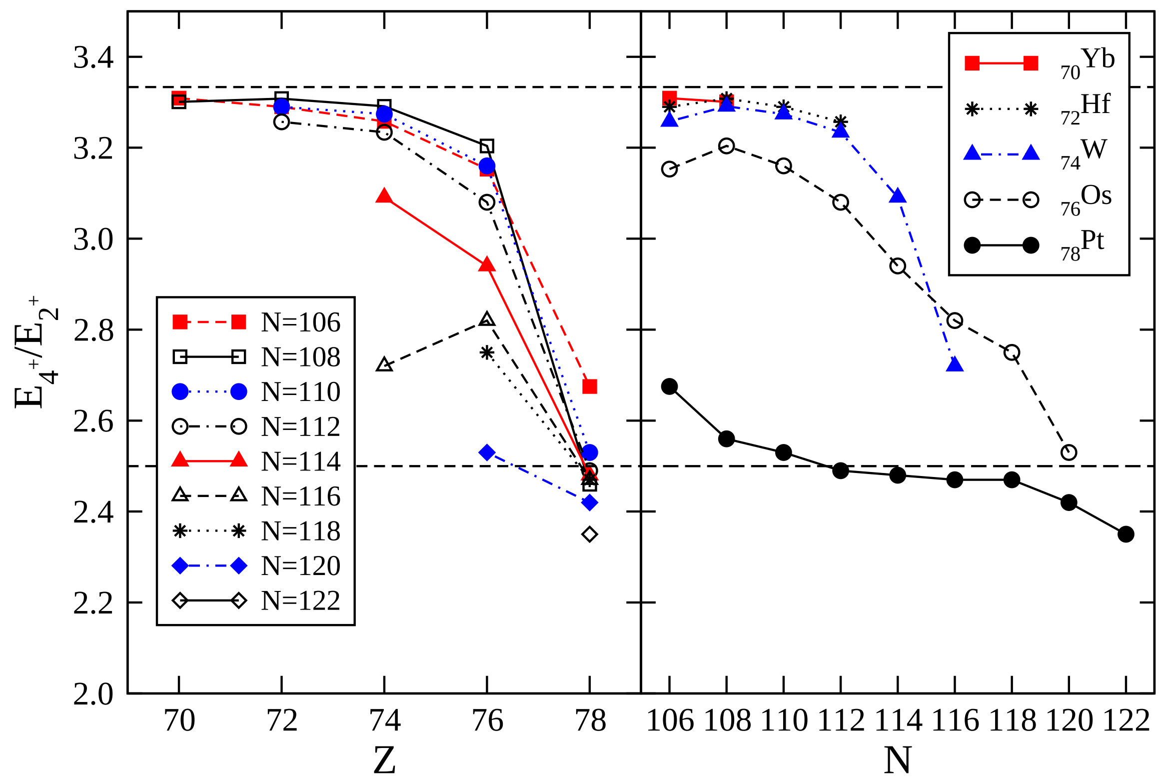
1) $\beta_\pi = \beta_\nu = \beta_B = C_\beta \beta$

2) $\gamma_\pi = \gamma_\nu = \gamma_B = \gamma$

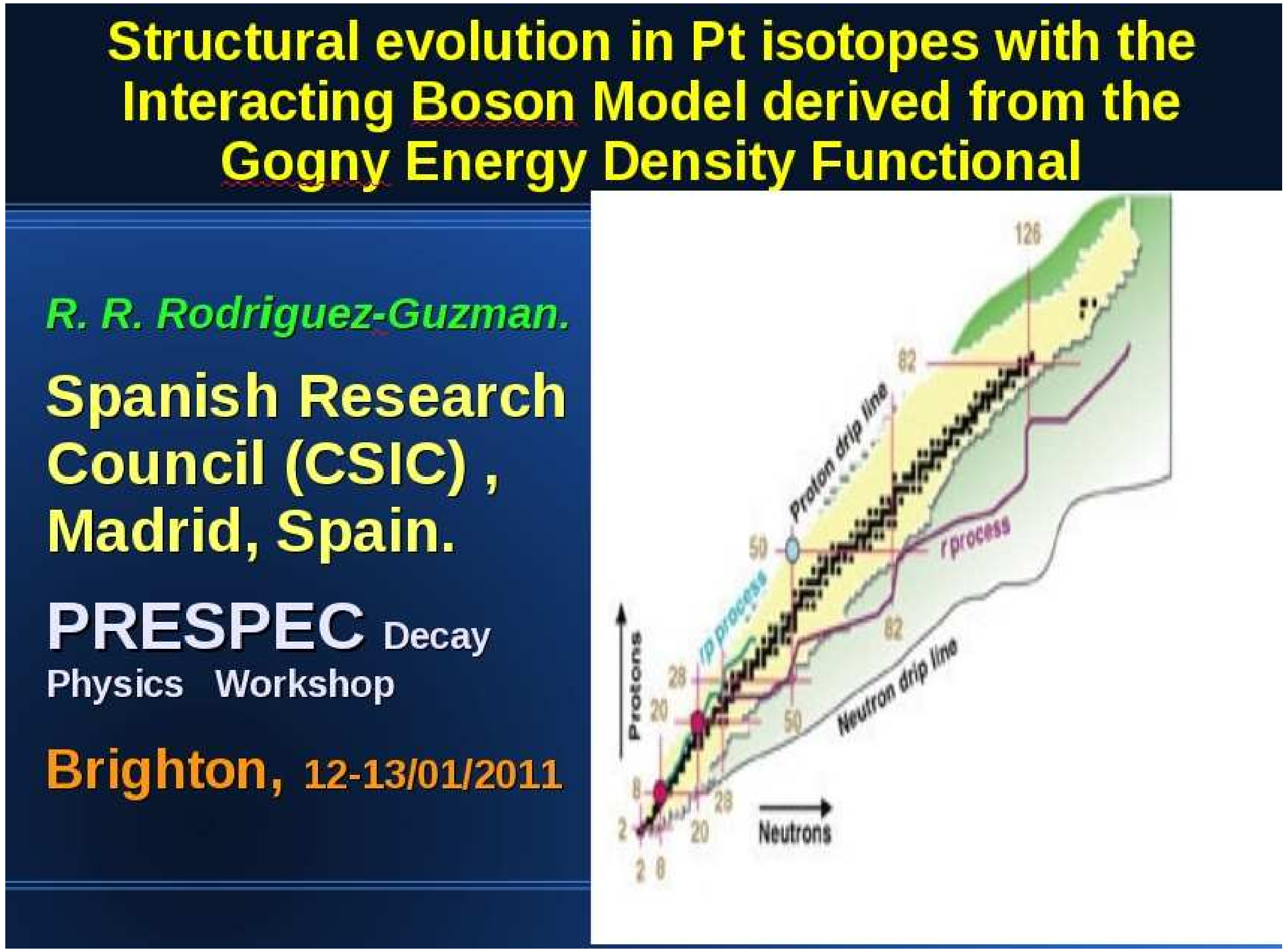
$$E_{\rm IBM}(\beta_{\rm B}, \gamma_{\rm B}) = \frac{\epsilon(n_\pi + n_\nu)\beta_{\rm B}^2}{1+\beta_{\rm B}^2} + n_\pi n_\nu \kappa \frac{\beta_{\rm B}^2}{(1+\beta_{\rm B}^2)^2} \times \left[4 - 2\sqrt{\frac{2}{7}}(\chi_\pi + \chi_\nu)\beta_{\rm B}\cos 3\gamma_{\rm B} + \frac{2}{7}\chi_\pi \chi_\nu \beta_{\rm B}^2\right]. \quad (11)$$

Ref-1 K. Nomura, N. Shimizu and T. Otsuka, PRL **101**, 142501 (2008); PRC **81**, 044307 (2010).

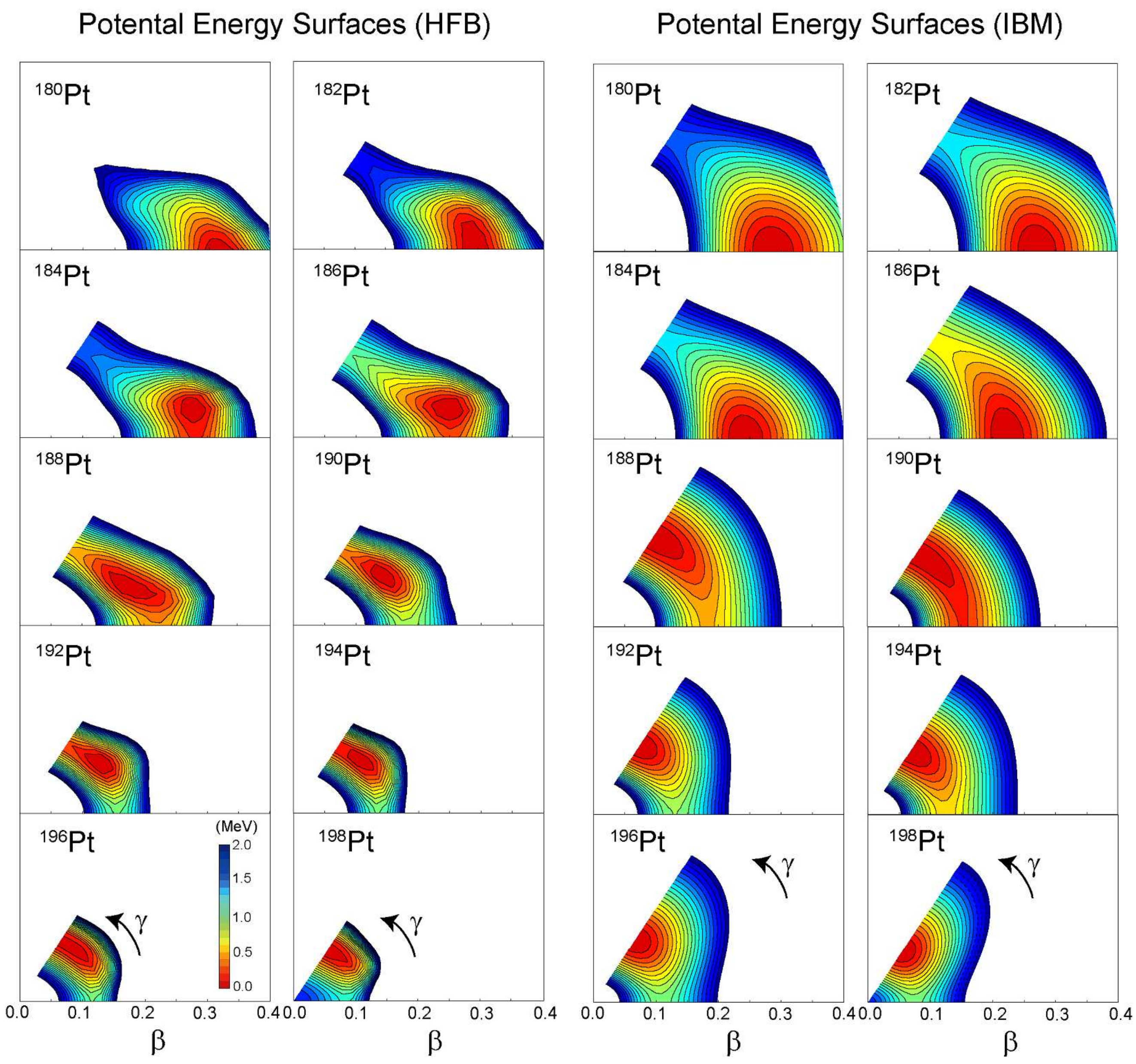
Ref-2 K. Nomura, T. Otsuka, R.R.Rodríguez-Guzmán, L.M.Robledo and P.Sarriguren, arXiv/nucl-th:1010.5078 – in press PRC.



Ref-3 R.R.Rodríguez-Guzmán and P.Sarriguren, PRC **76**, 064303 (2007).

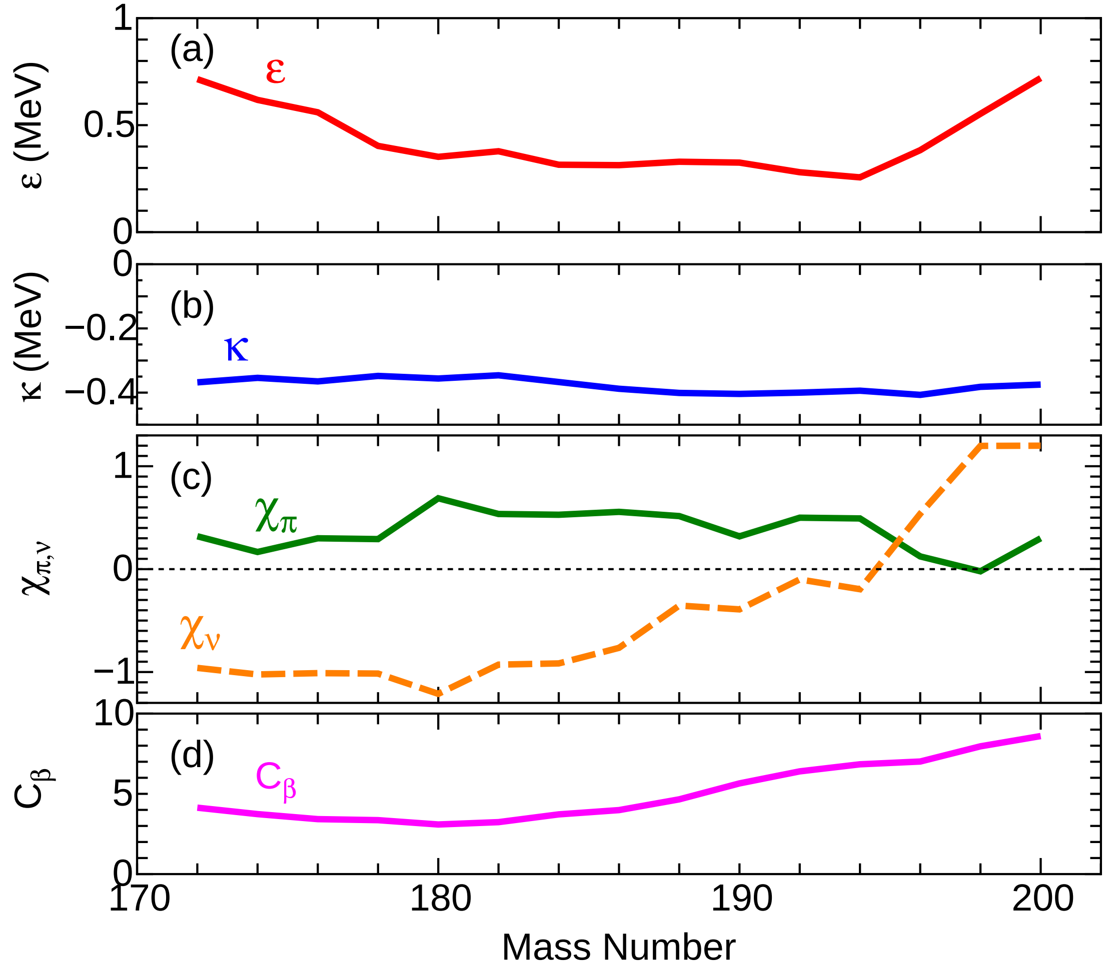


Ref K. Nomura, T. Otsuka, R.R.Rodríguez-Guzmán, L.M.Robledo and P.Sarriguren, arXiv/nucl-th:1010.5078 – in press PRC.



Potental Energy Surfaces (HFB)
Potental Energy Surfaces (IBM)
180Pt
182Pt
184Pt
186Pt
188Pt
190Pt
192Pt
194Pt
196Pt
198Pt
(MeV)
2.0
1.5
1.0
0.5
0.0
γ
0.0
0.1
0.2
0.3
0.4
β

Derived IBM parameters for $^{172-200}Pt$



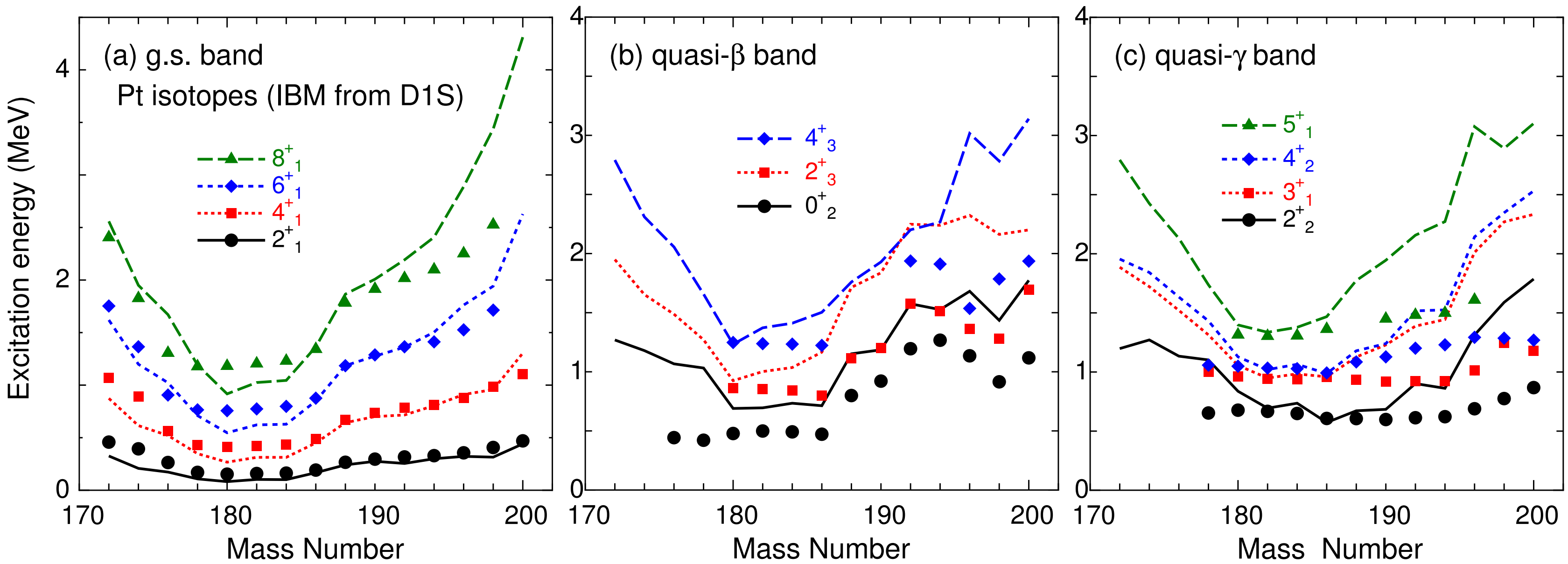
→ κ is somewhat smaller than the phenomenological value.

→ Now we have , κ, C_β, χ_π, χ_ν

→ Therefore we have $\hat{H}_{\mathrm{IBM}}$

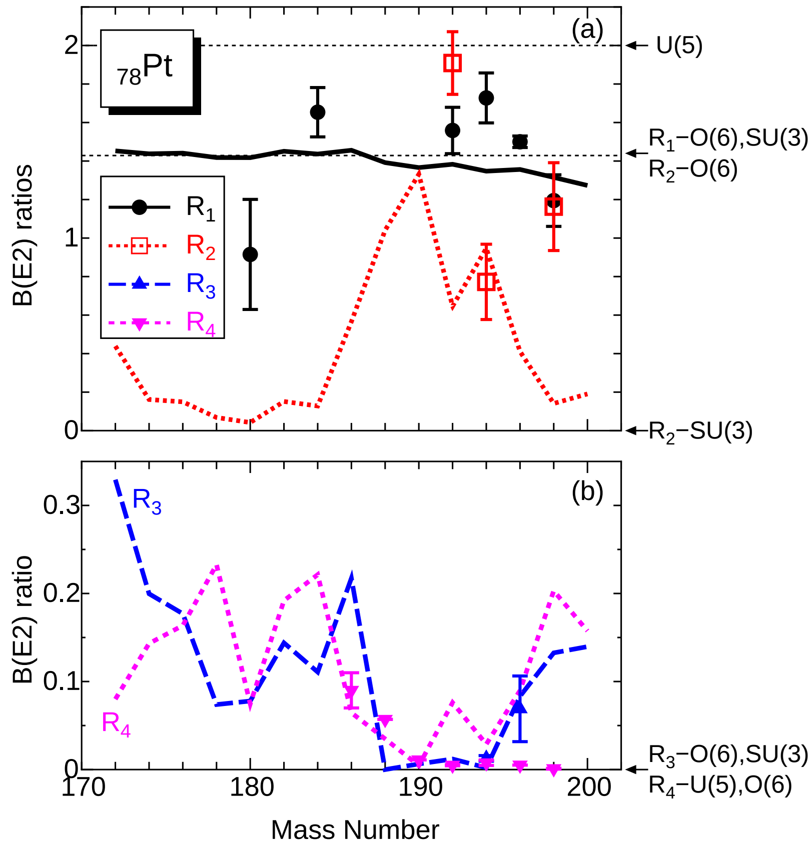
→ We then perform the numerical diagonalization of $\hat{H}_{\mathrm{IBM}}$ using the **NPBOS** code (K. Nomura, T. Otsuka, R.R.Rodríguez-Guzmán, L.M.Robledo and P.Sarriguren, arXiv/nucl-th:1010.5078 – in press PRC).

Low-lying spectra of $^{172-200}Pt$



→ Note that we do not have intruders !!!!

B(E2) ratios for $^{172-200}Pt$



$$R_1 = \frac{B(E2, 4_1^+ \to 2_1^+)}{B(E2, 2_1^+ \to 0_1^+)}$$

$$R_2 = \frac{B(E2, 2_2^+ \to 2_1^+)}{B(E2, 2_1^+ \to 0_1^+)}$$

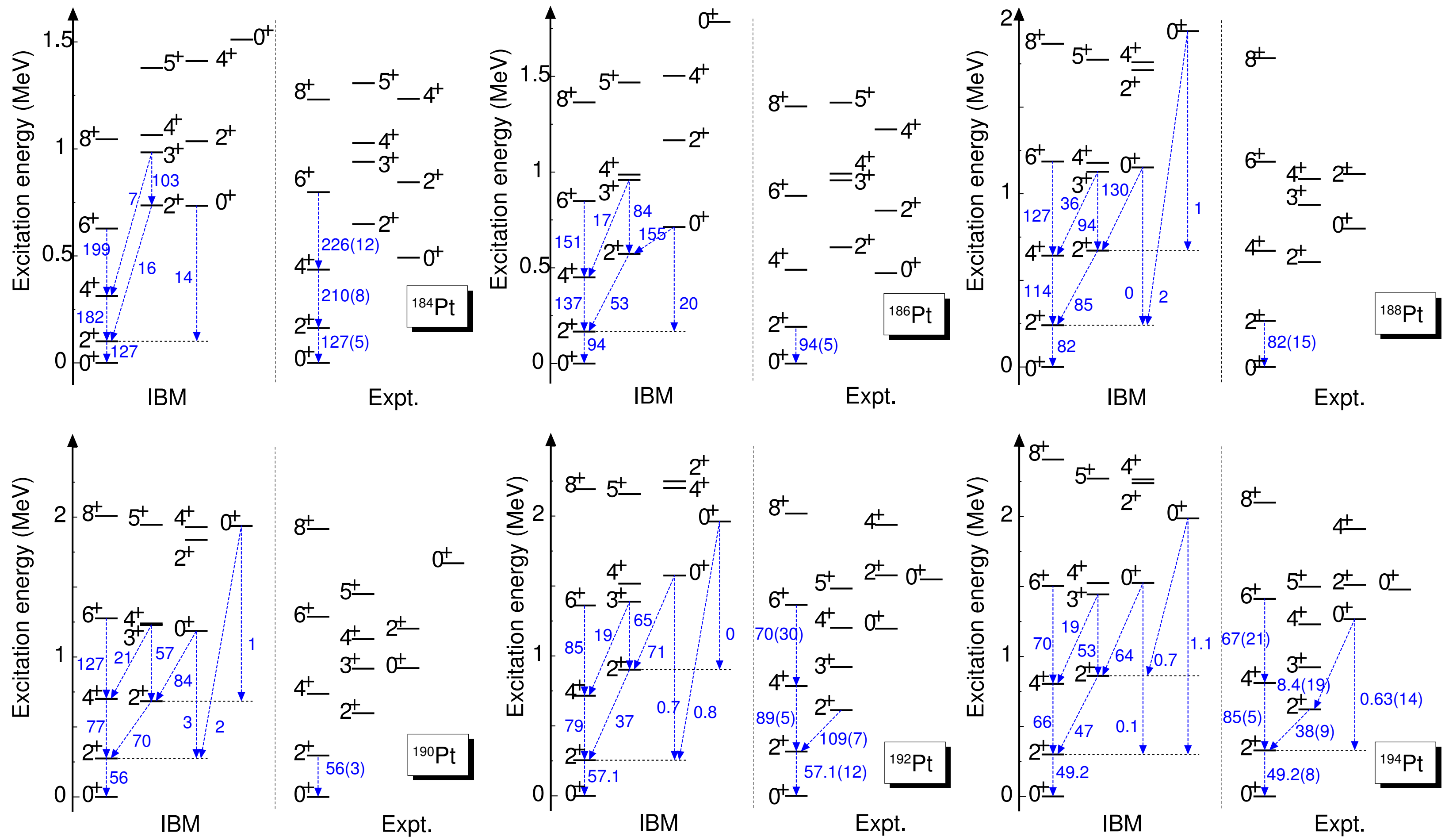
$$R_3 = \frac{B(E2, 0_2^+ \to 2_1^+)}{B(E2, 2_1^+ \to 0_1^+)}$$

$$R_4 = \frac{B(E2, 2_2^+ \to 0_1^+)}{B(E2, 2_1^+ \to 2_1^+)}$$

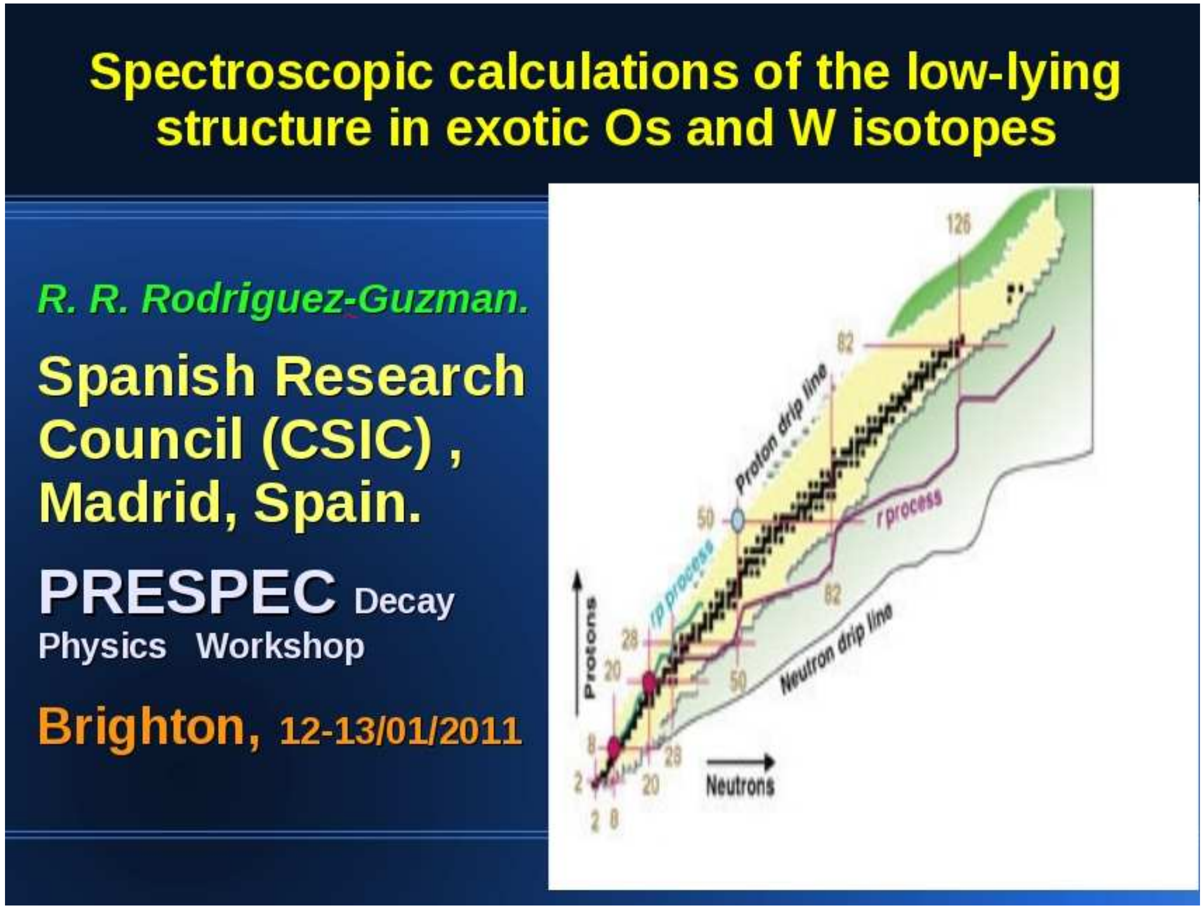
$\longrightarrow$ For the boson effective charges we assume for simplicity $e_\pi = e_\nu$

Ref K. Nomura, T. Otsuka, R.R.Rodríguez-Guzmán, L.M.Robledo and P.Sarriguren, arXiv/nucl-th:1010.5078 – in press PRC.

Level schemes for $^{184-194}Pt$

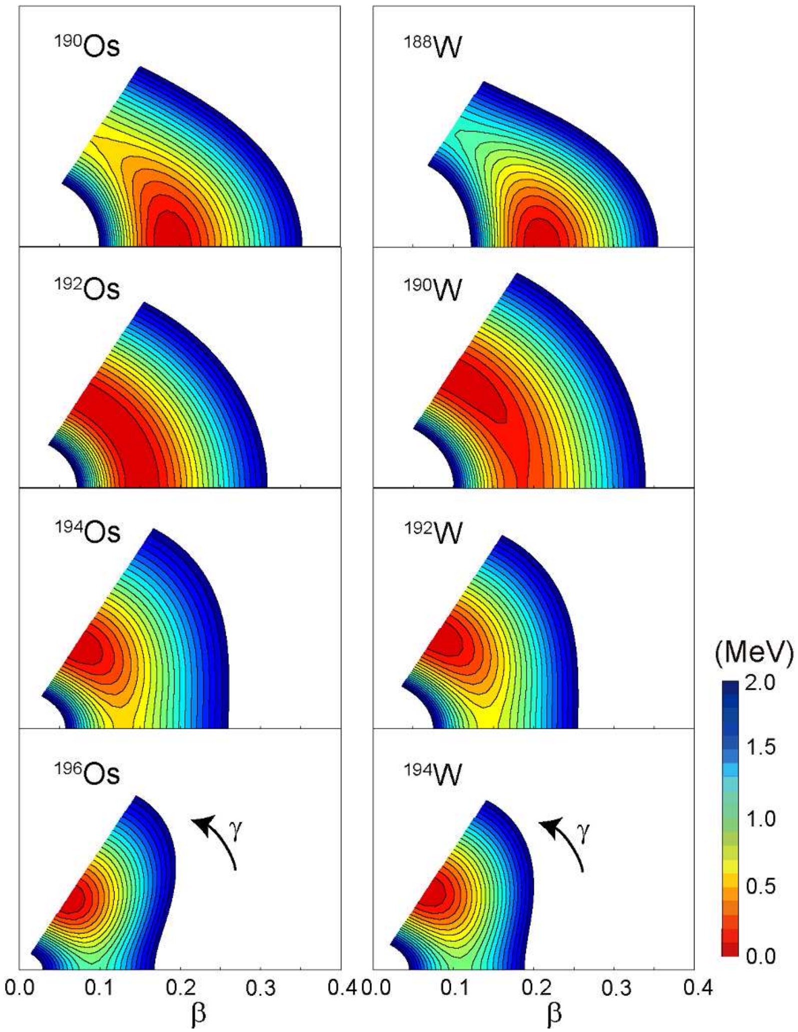


Ref K. Nomura, T. Otsuka, R.R.Rodríguez-Guzmán, L.M.Robledo and P.Sarriguren, arXiv/nucl-th:1010.5078 – in press PRC.

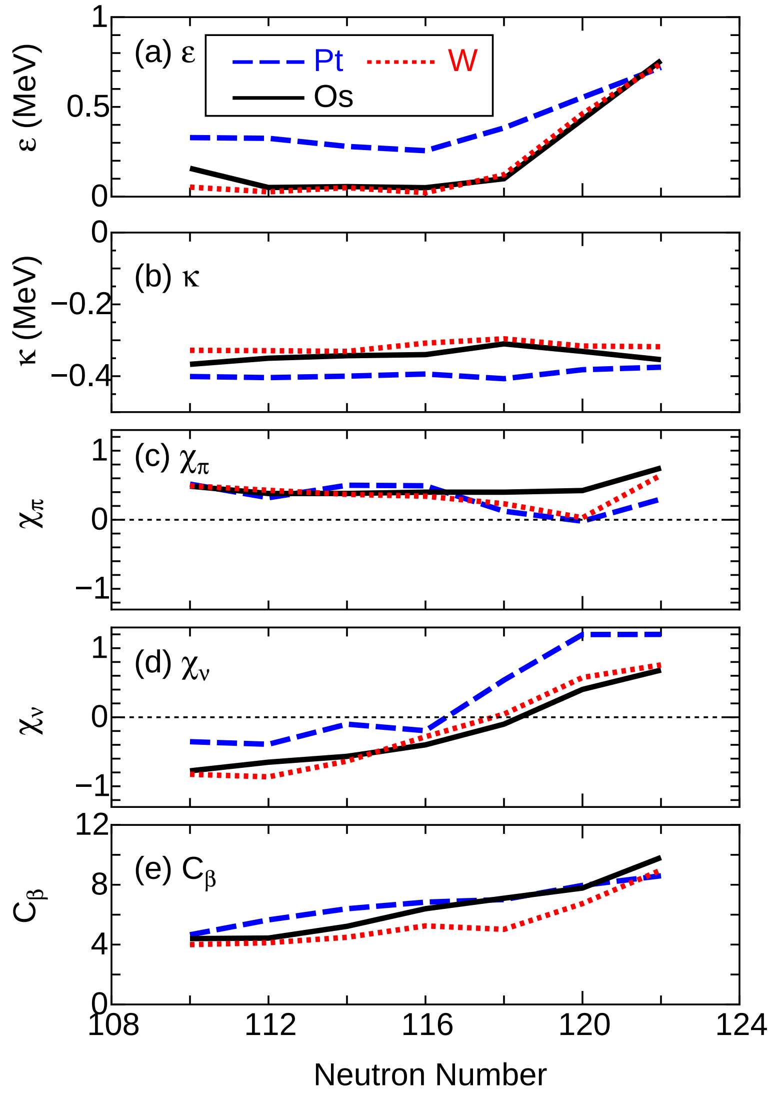


K. Nomura, T. Otsuka, R. Rodríguez-Guzmán,L. M. Robledo, P. Sarriguren, P. H. Regan, P. D. Stevenson and Zs. Podolyák $\longrightarrow$ **Sub. for Pub.**

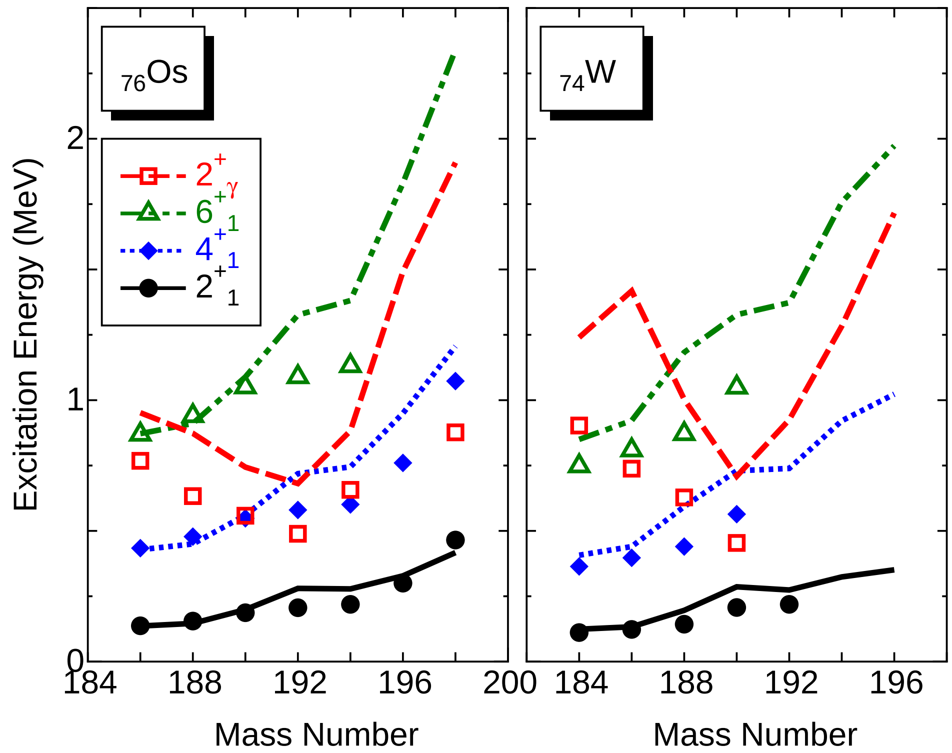
Mapped (IBM) Potential Energy Surfaces for $^{190-196}Os$ and $^{188-194}W$



Derived IBM parameters for $^{186-198}Os$ and $^{184-196}W$

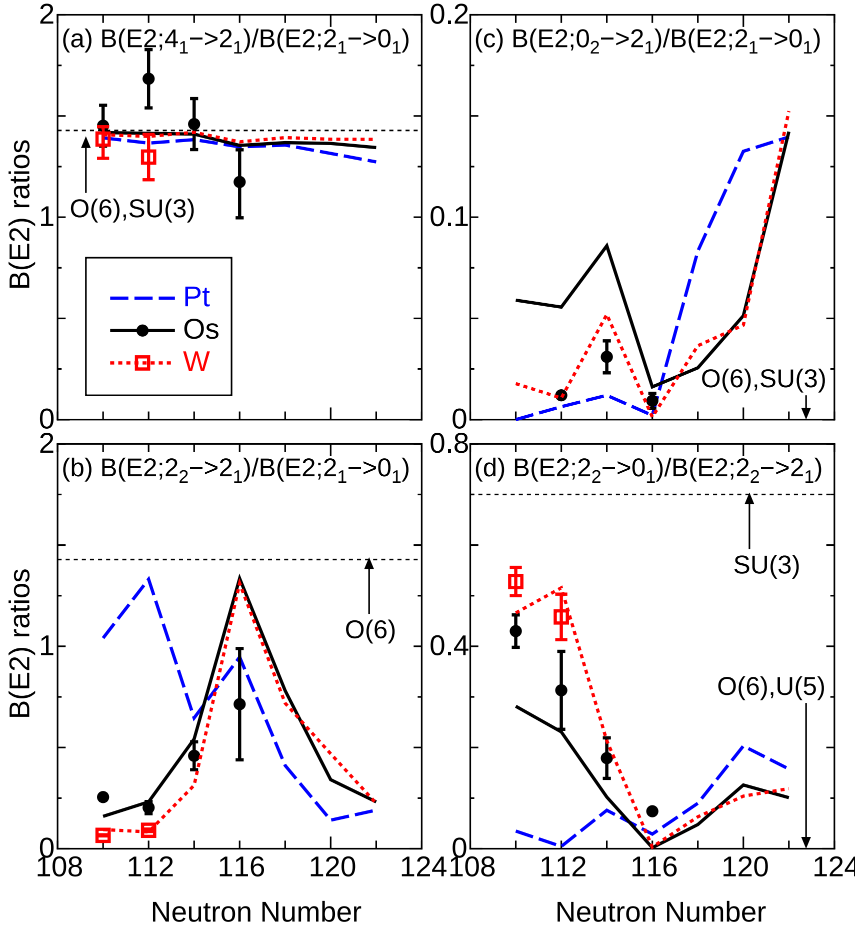


Low-lying g.s band and quasi-γ-bandhead (2^+_γ) for $^{186-198}Os$ and $^{184-196}W$



- Experimentally the 2^+_2 lower than the 4^+_1 state in ^{190}W.
- Experimentally the 2^+_1 states in ^{190}W, ^{192}Os have almost identical excitation energies ($\approx 218KeV$) as in ^{192}W, ^{194}Os.

B(E2) ratios for $^{186-198}Os$ and $^{184-196}W$



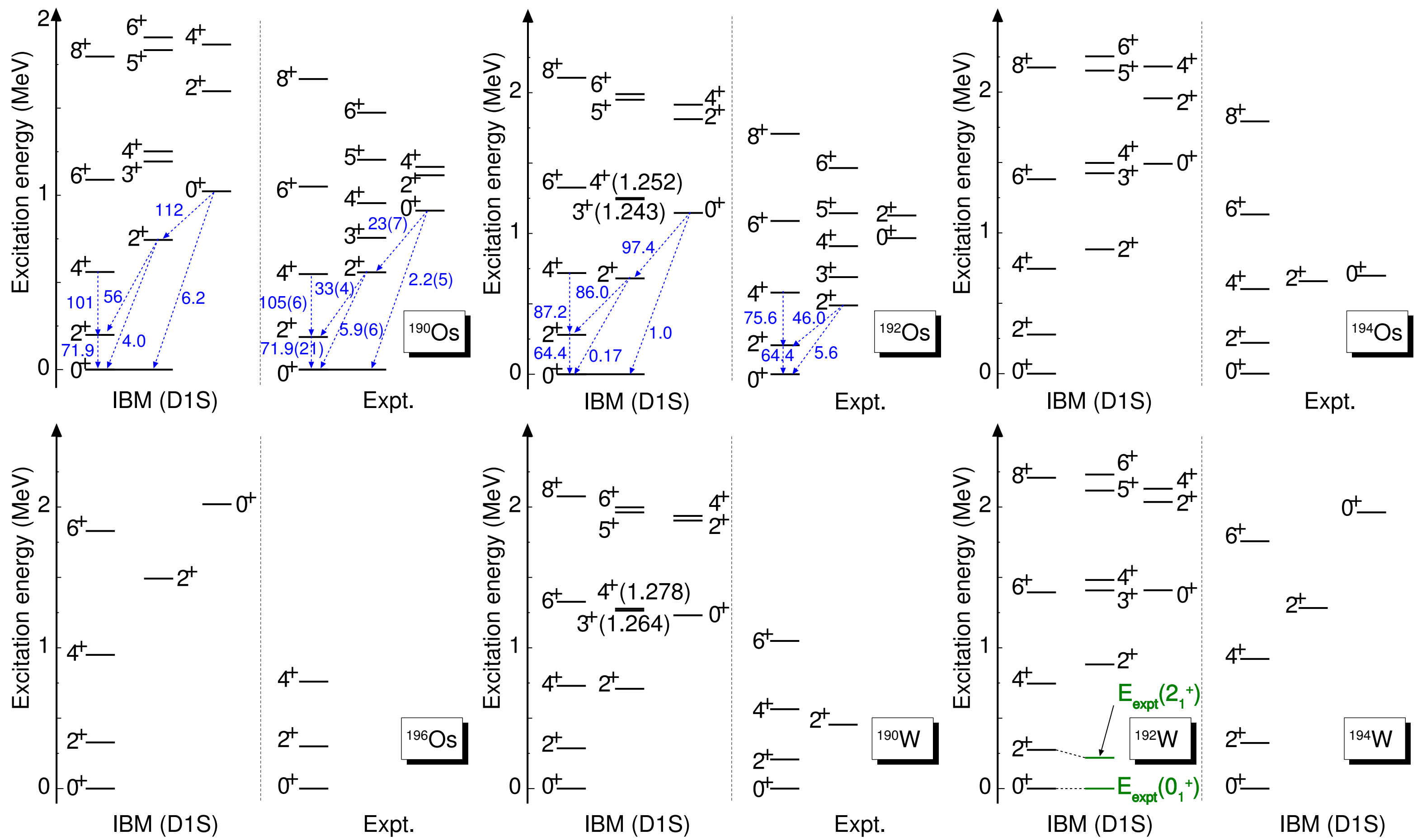
$$R_1 = \frac{B(E2, 4_1^+ \to 2_1^+)}{B(E2, 2_1^+ \to 0_1^+)}$$

$$R_2 = \frac{B(E2, 2_2^+ \to 2_1^+)}{B(E2, 2_1^+ \to 0_1^+)}$$

$$R_3 = \frac{B(E2, 0_2^+ \to 2_1^+)}{B(E2, 2_1^+ \to 0_1^+)}$$

$$R_4 = \frac{B(E2, 2_2^+ \to 0_1^+)}{B(E2, 2_1^+ \to 2_1^+)}$$

Level schemes for $^{190-196}Os$ and $^{190-194}W$



K. Nomura, T. Otsuka, R. Rodríguez-Guzmán, L. M. Robledo, P. Sarriguren, P. H. Regan, P. D. Stevenson and Zs. Podolyák → **Sub. for Pub.**

Conclusions

1) We have undertaken first steps in bosonization techniques based on the Gogny-EDF.

2) We have considered the structural evolution in Pt, Os and W nuclei and performed the corresponding spectroscopic calculations (reasonable agreement with available experimental data + new predictions).

A lot remains to be done, GOOD !!!!!!!

1) L.L-terms in the IBM-2 Hamiltonian considered (in progress).

2) More sophisticated IBM-2 Hamiltonian (in progress).

3) Role of the intruder configurations ?

4) New degrees of freedom relevant for the nuclear many-body problem ... (octupole-quadrupole couplings with a mapped IBM Hamiltonian ?).