New Data on Wobbling Motion for A≈130 Mass Region

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Outline

Nuclear Deformation

Nuclear shapes

Most generally described in terms of the **nuclear radius**:

$$R(\theta,\varphi) = R_0 \left(1 + \sum_{\lambda=0}^{\infty} \sum_{\mu=-\lambda}^{\lambda} \alpha_{\lambda\mu} Y_{\lambda}^{\mu}(\theta,\varphi) \right)$$

Quadrupole deformations $\lambda = 2$

- Most relevant modes are the **quadrupole vibrations** $\lambda = 2 \Longrightarrow$ *Play a crucial role in the rotational spectra of nuclei:*
- $\alpha_{2\mu}$ reduced to only two *deformation parameters*: β_2 (**eccentricity**) and γ (**triaxiality**) (*Bohr and Mottelson, 1969*).

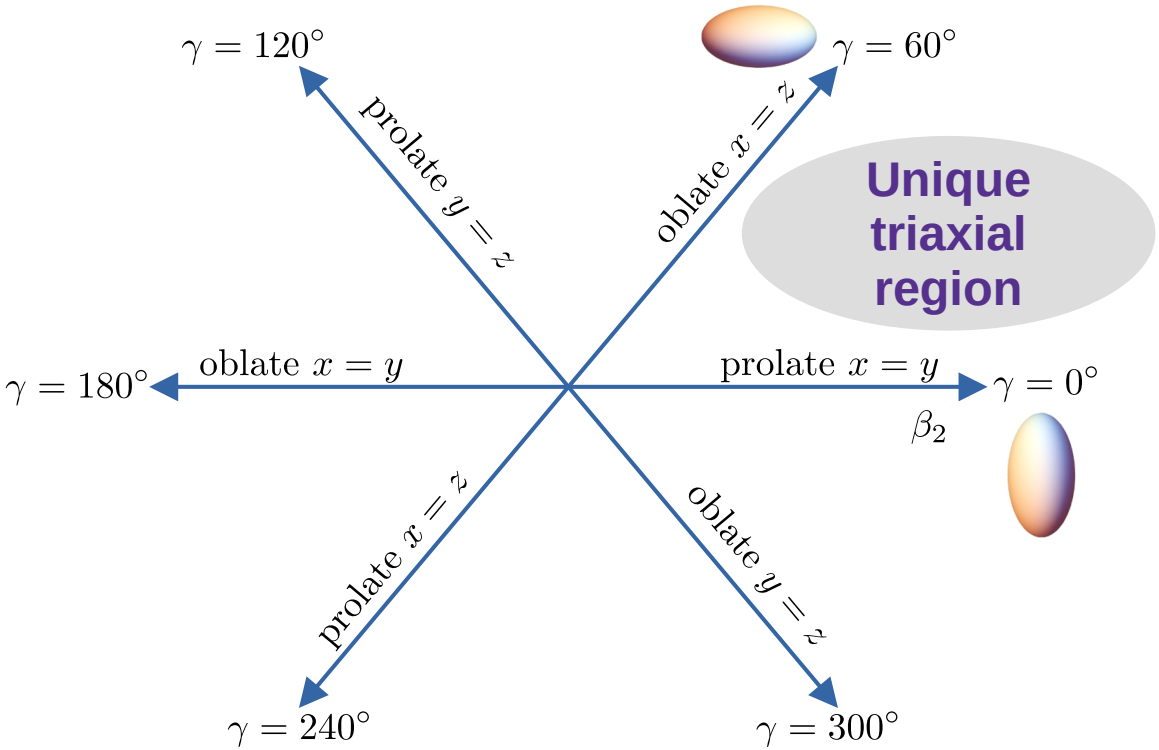
Axial shapes

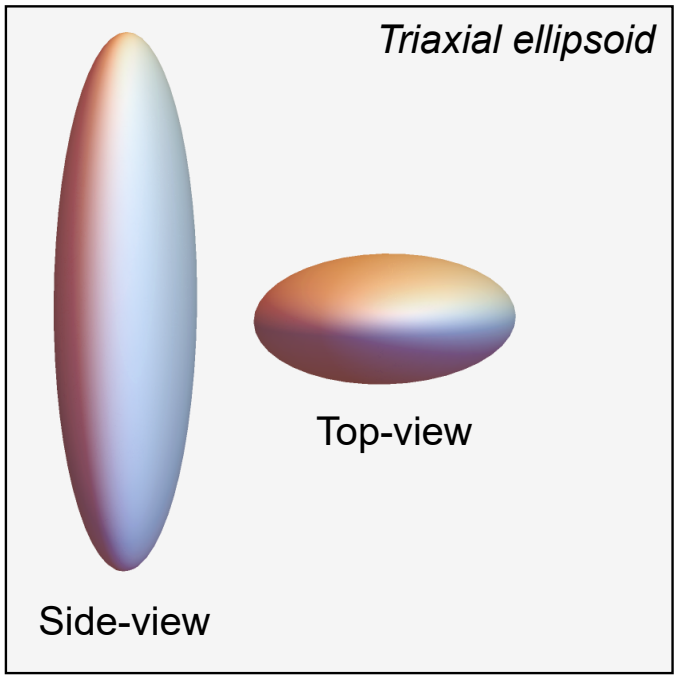
- Most of the nuclei are either **spherical** or **axially symmetric** in their ground-state.
- Nuclear moments of inertia $\mathcal{I}_{1,2,3}$: only two are equal.

Figure: **spherical:** $\beta_2 = 0$ **prolate:** $\beta_2 > 0$ **oblate:** $\beta_2 < 0$. ($\gamma = 0°$).

Non-axial shapes

- The triaxiality parameter $\gamma \neq 0°$: departure from axial symmetry.
- Moments of inertia: $\mathcal{I}_1 \neq \mathcal{I}_2 \neq \mathcal{I}_3$.





Wobbling Motion

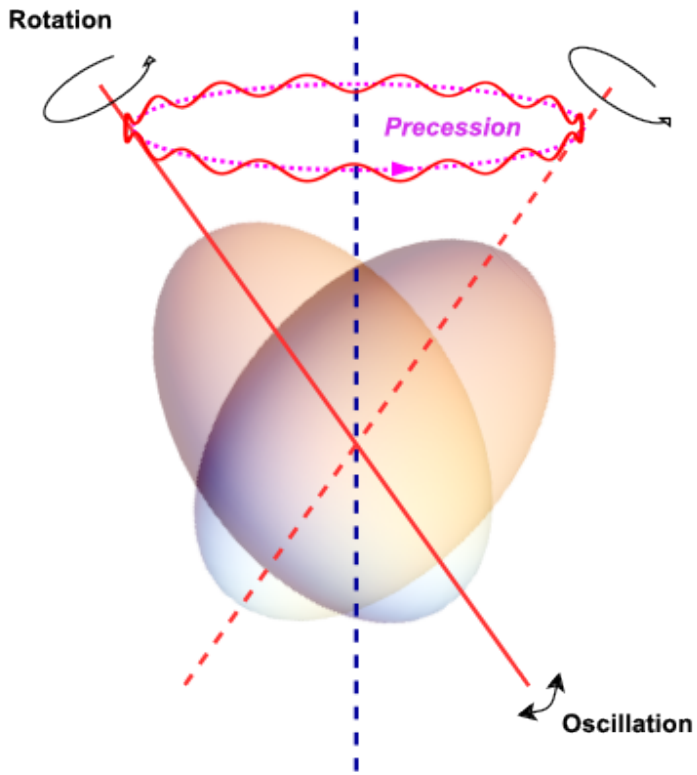
$\gamma \neq 0°$

↓

MOI anisotropy

↓

main rotation around $\mathcal{J}_{\text{max}}$ is disturbed by the other two axes



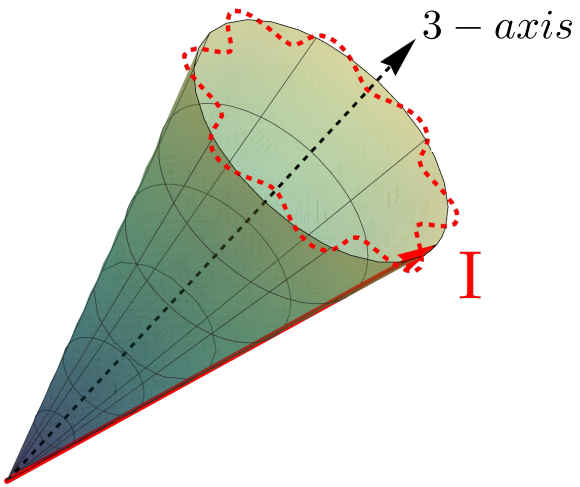
Wobbling Effect

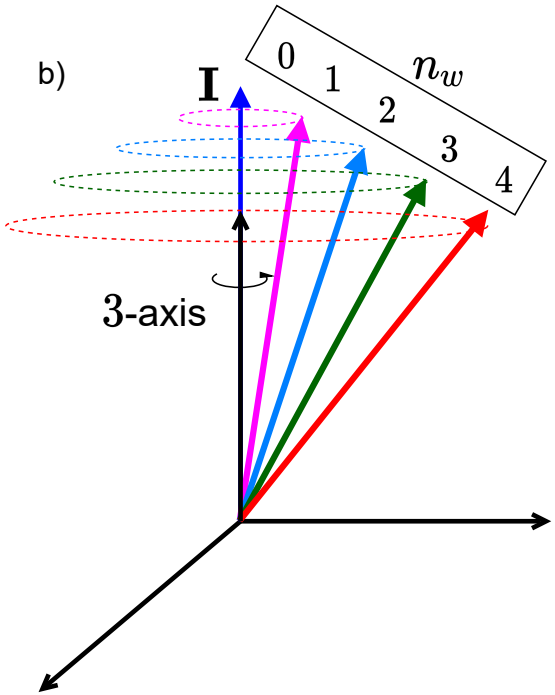
- The **total angular momentum** of the nucleus **precesses** and **oscillates** around $\mathcal{J}_{\text{max}}$.

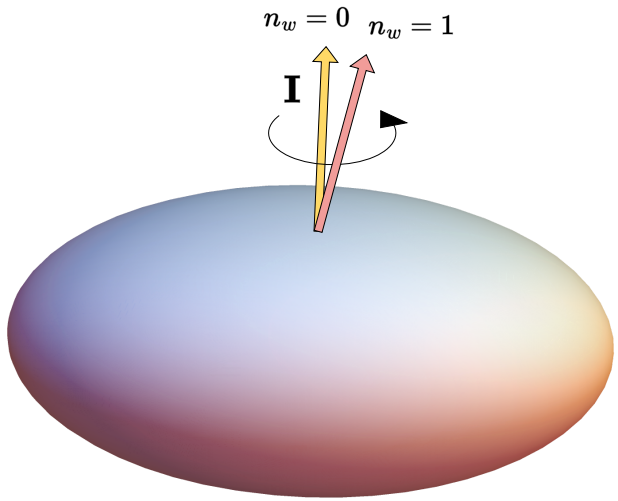
Wobbling Motion

Harmonic oscillation

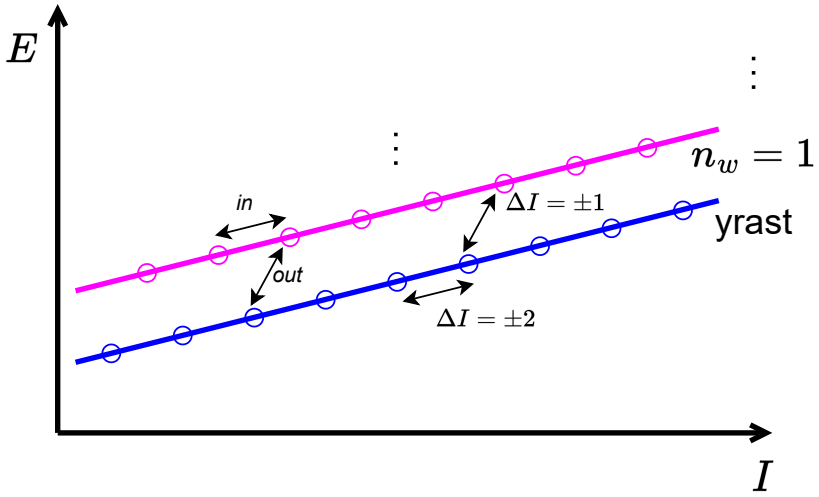
- Precession of **I** is affected by **rotational frequency** and/or **tilting**
- Tilting only by "specific" amount $\rightarrow$ **harmonic character** $\rightarrow$ **wobbling phonon**: $n_w = 0, 1, 2, \ldots$.

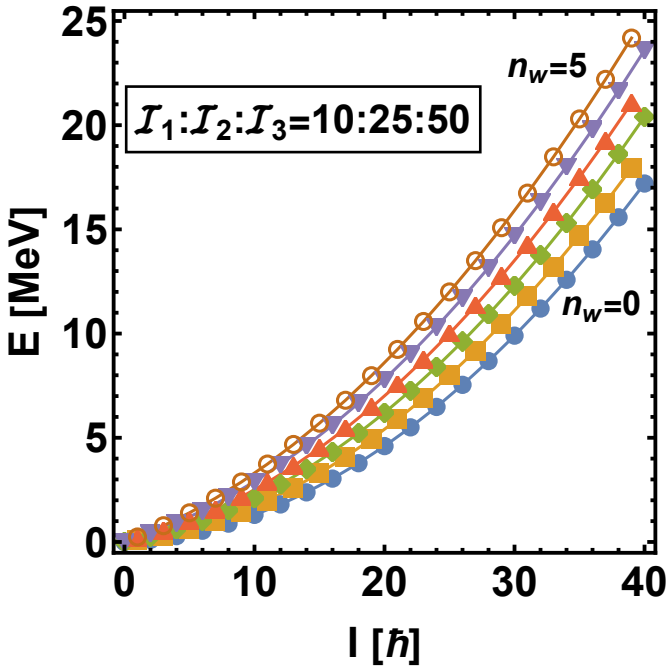


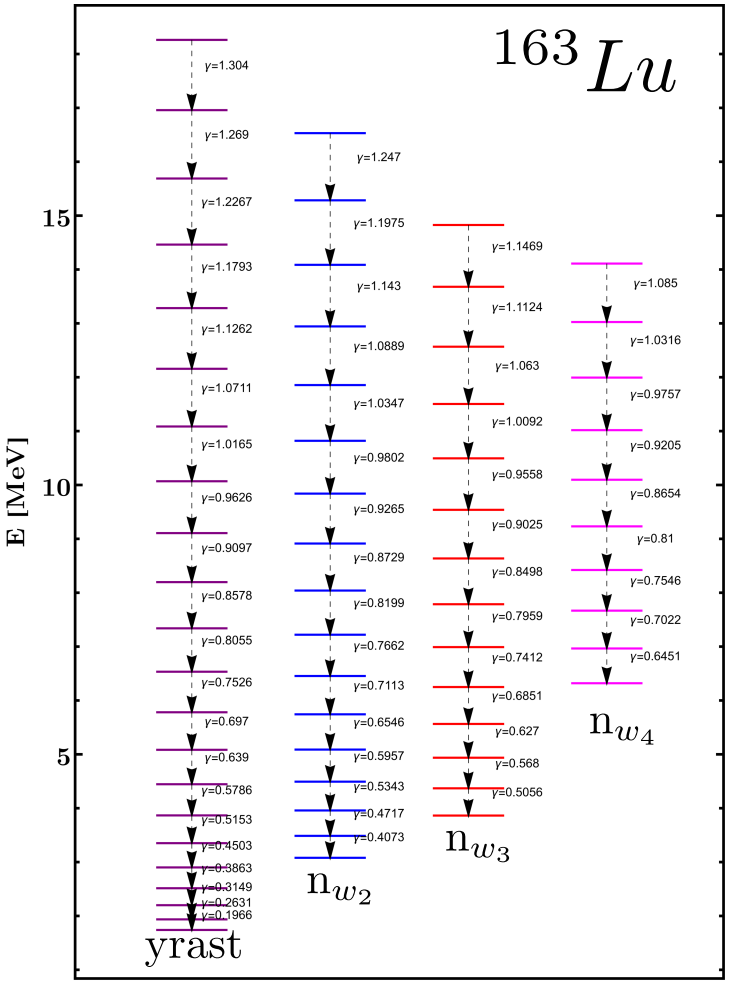




Wobbling Motion II



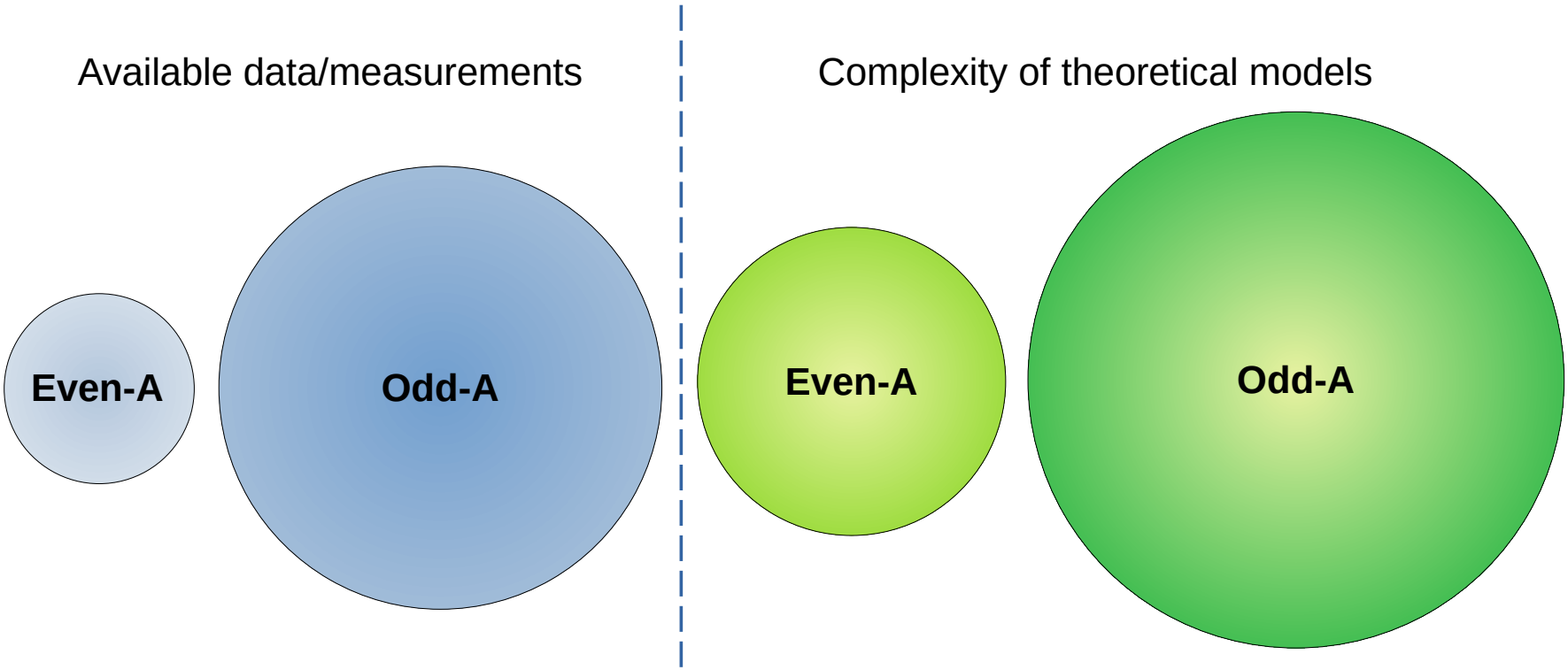




R. Poenaru, 2023.

Even-A vs. Odd-A Picture

- Predicted for even-A nuclei more than 50 years ago.
- First experimental evidence: ^{163}Lu (*Ødegård, 2001*).
- Current mass-regions for wobblers: $A \approx [130, 160, 180]$.



$A \approx 100$

Excitation energies vs. **Wobbling Energies**:

$$E_{\mathrm{wob}}(I_{\mathrm{even}}) = E_{I,n} - E_{I,0} \ ,$$
$$E_{\mathrm{wob}}(I_{\mathrm{odd}}) = E_{I,n} - \frac{1}{2}\left(E_{I-1,0} + E_{I+1,0}\right)$$

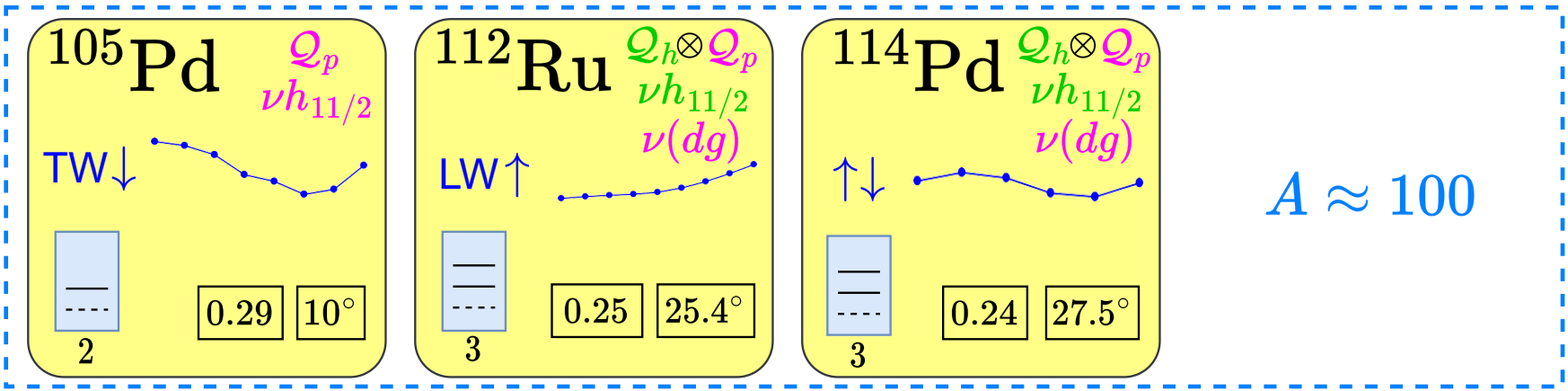


Figure: *Experimentally confirmed wobblers, R Poenaru, 2023.*

$A \approx 130$

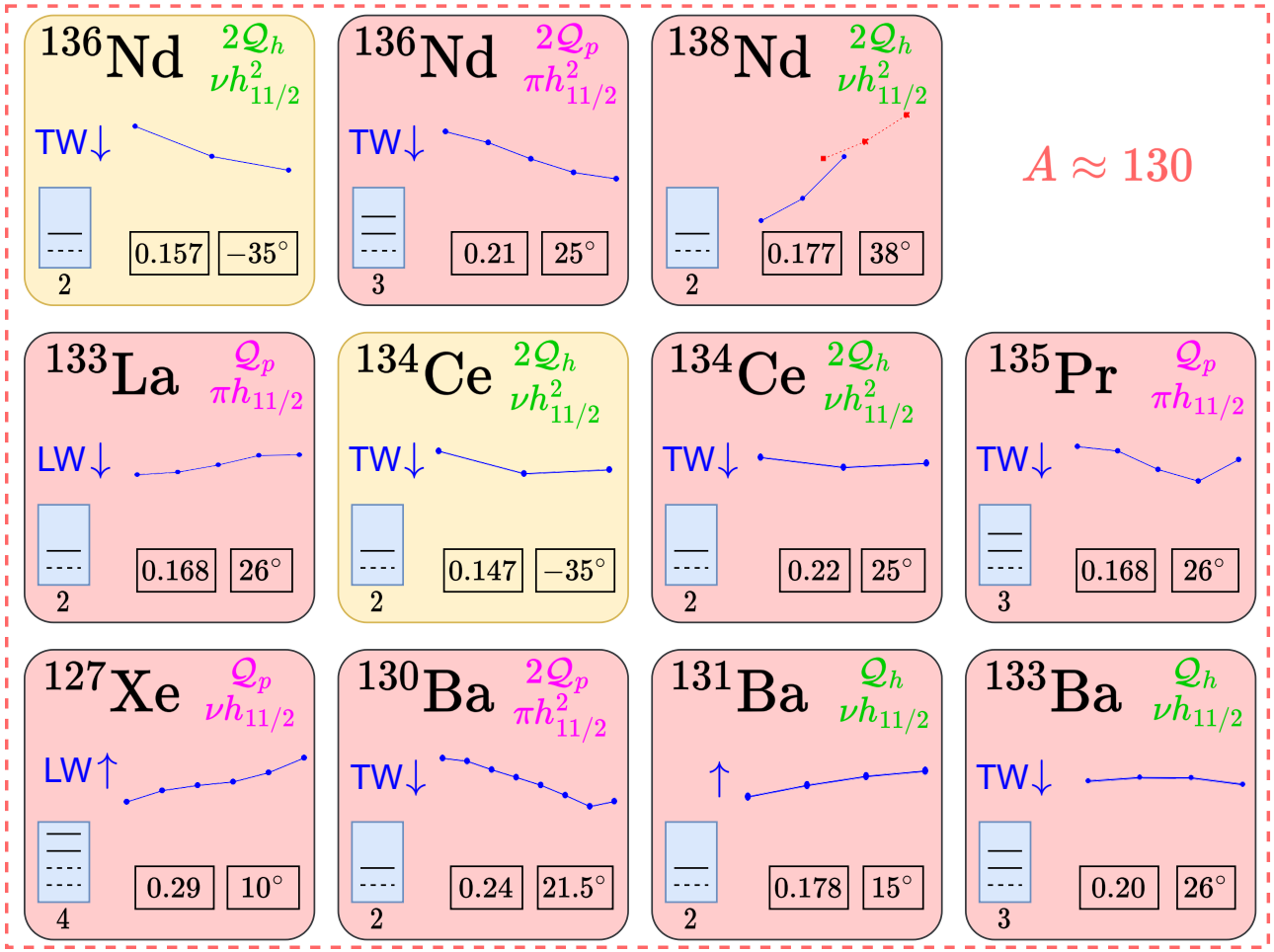


Figure: *Experimentally confirmed wobblers, R Poenaru, 2023.*

$A \approx 160$

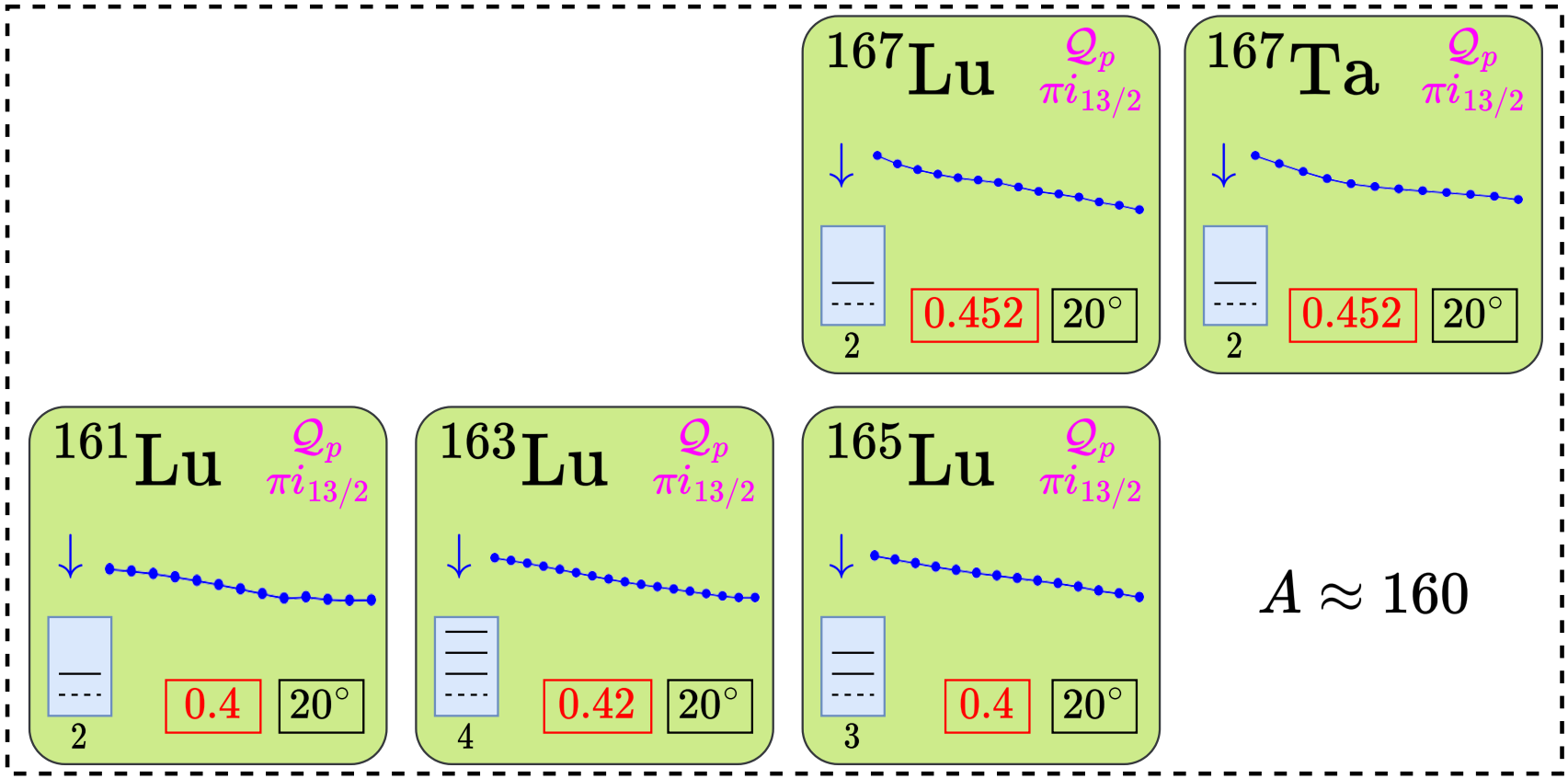


Figure: *Experimentally confirmed wobblers, R Poenaru, 2023.*

$A \approx 180$

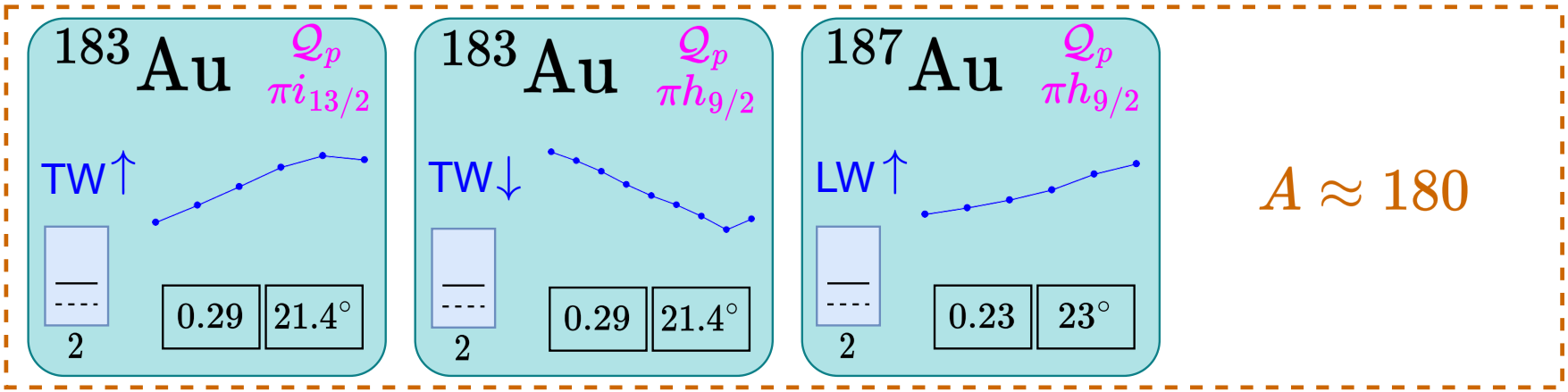
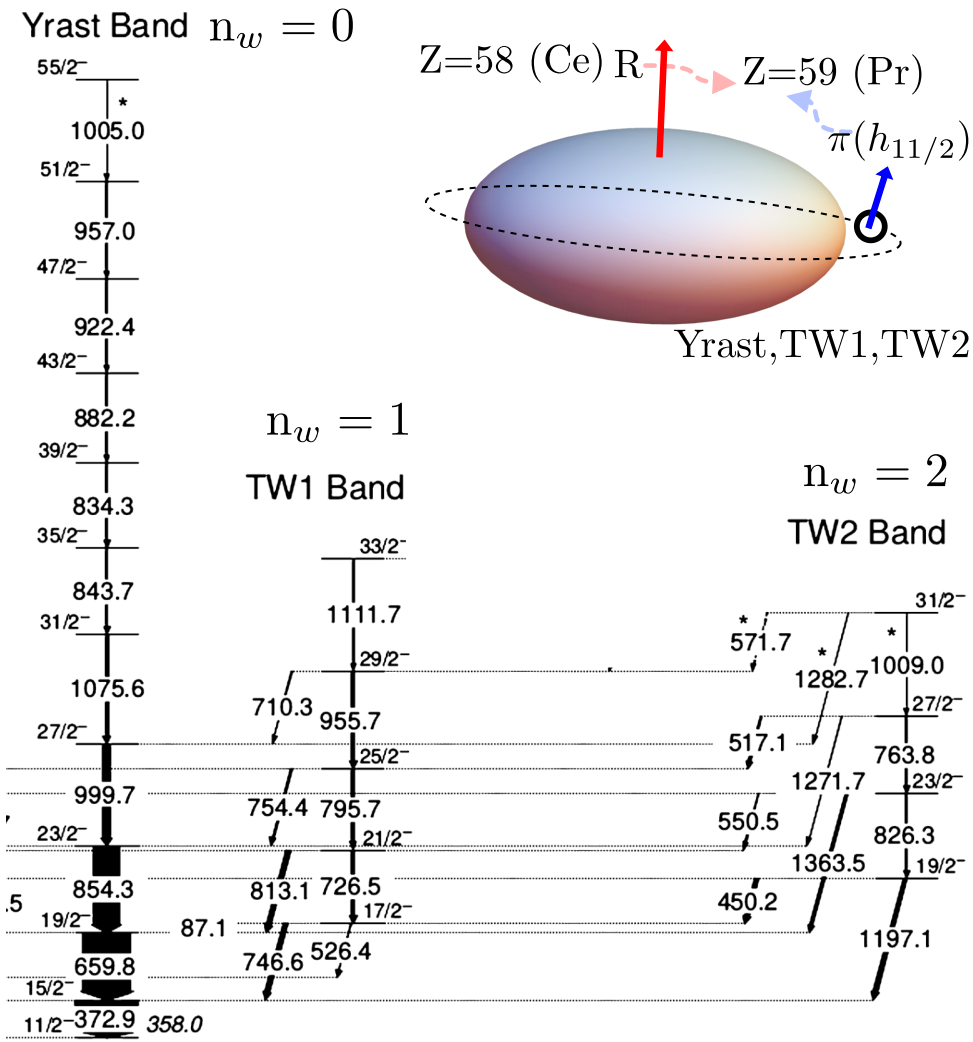


Figure: *Experimentally confirmed wobblers, R Poenaru, 2023.*

Wobbling Motion in ^{135}Pr

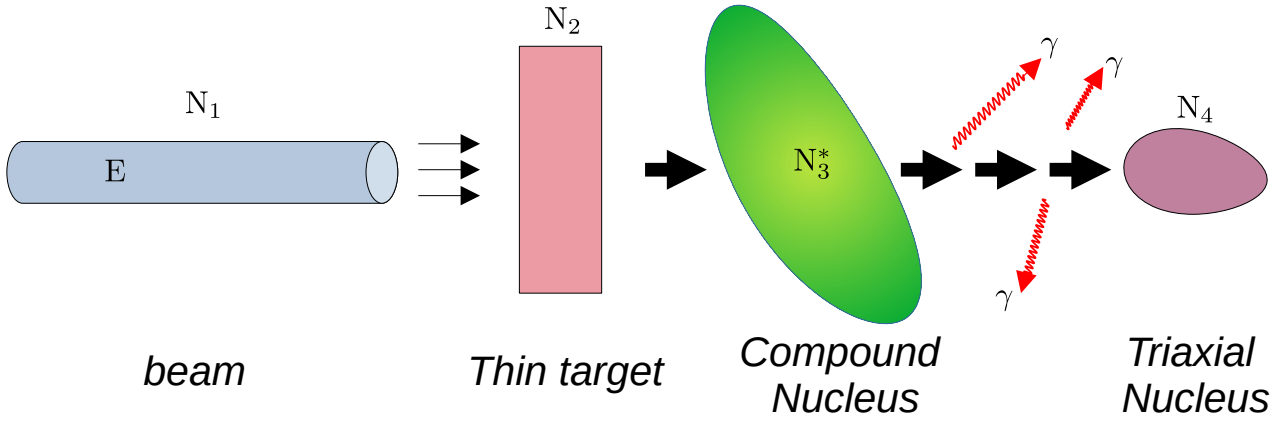
What we know so far

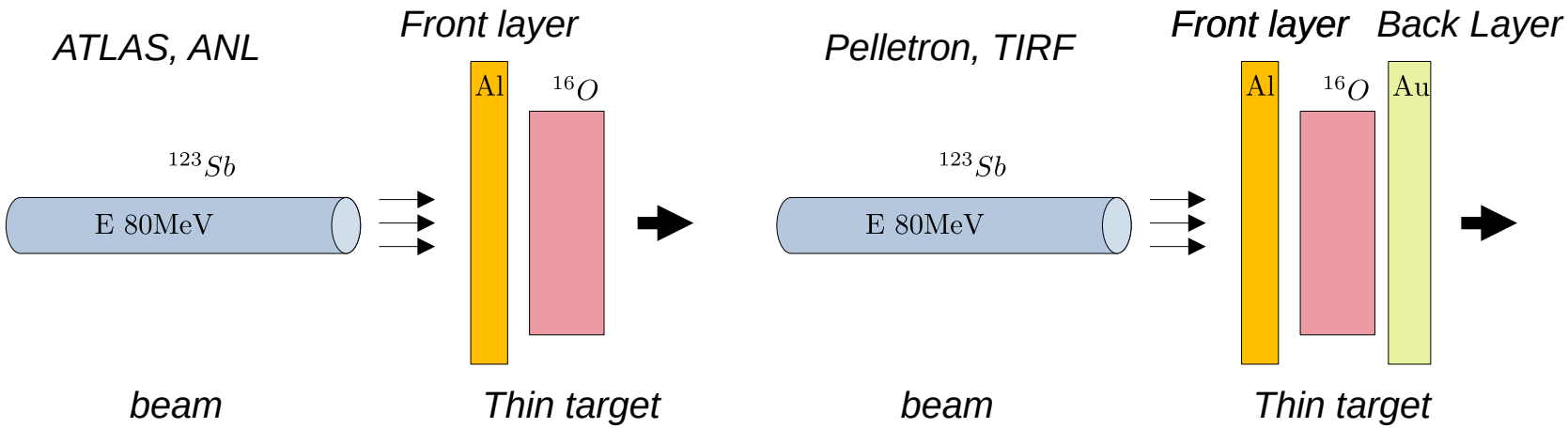
- Two-wobbling phonon bands were measured (*Matta et. al. 2015 + Sensharma et. al. 2019*)
- Exp. measurements: Fusion-Evaporation reactions: $^{123}\mathrm{Sb}\left(^{16}\mathrm{O}, 4n\right)^{135}\mathrm{Pr}$
- **1st round:** ATLAS, ANL (USA), **2nd round:** Pelletron-TIFR, Mumbai.



Fusion Evaporation Reactions

Fusion-evaporation reactions: Long-lived + enhanced deformation





Theoretical Frameowork

New Boson Method

- A rotor Hamiltonian was used to describe the wobbling spectrum of ^{135}Pr
- $\hat{H}_{\text{rot}} = \sum_{k=1,2,3} A_k \left(\hat{I}_k - \hat{j}_k\right)^2$
- The eigenvalues were obtained via a special algebra of the angular momentum operators $\hat{I}_{\pm,0}$.

Results for ^{135}Pr

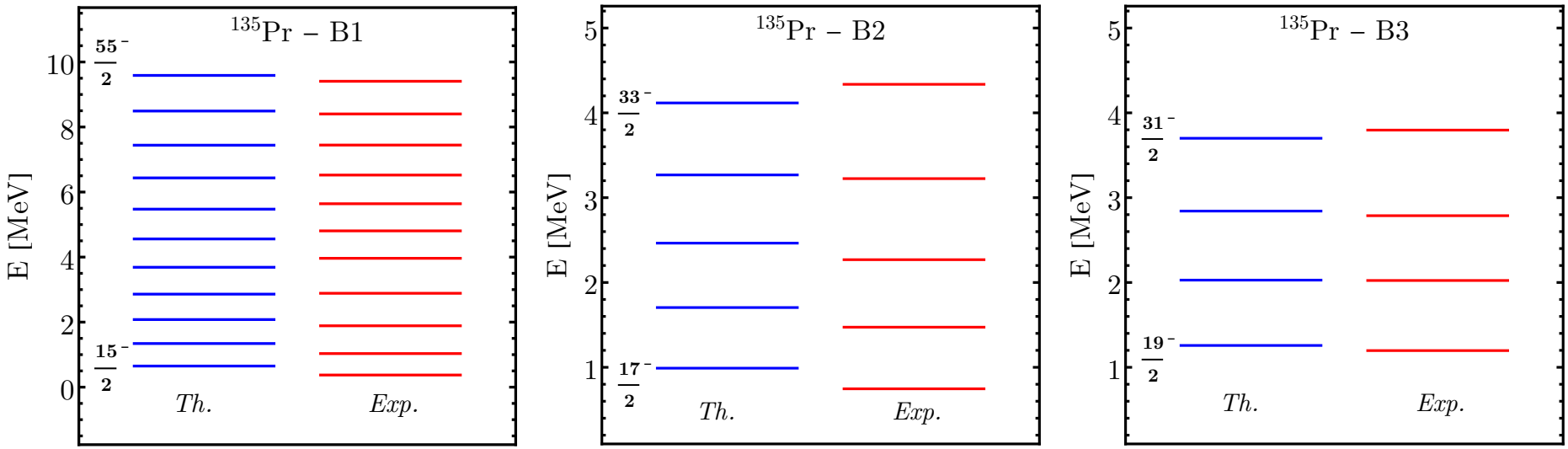


Figure: The excitation energies in ^{135}Pr. Exp data: *Sensharma, 2019*.

$\mathcal{I}_1$	$\mathcal{I}_2$	$\mathcal{I}_3$	θ [degrees]	N.o. states	RMS [MeV]
91	9	51	-119	20	0.174

A.A. Raduta, C.M. Raduta, **R Poenaru**, Journal of Physics G 48, 2020.

New experiments

Article

Wobbling Motion in Nuclei

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Figure: 26th of April, 2023

- Performed new measurements on the γ rays emitted during the fusion-evaporation reactions. $^{100}\mathrm{Mo}\,(40\mathrm{Ar}, 1p4n)^{135}\,\mathrm{Pr}$ ($E_{\mathrm{beam}} = 152$ MeV)
- University of Jyväskylä, Finland, JUROGAM II spectrometer.

Thank you for your attention!