A many-particles plus rotor approach to magnetic rotation

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Structure of this talk

Overview of the model
Hamiltonian, Basis states etc.

Application 1, Magnetic rotation
Tilted axis cranking model decription:
proton and neutron spin vectors align around static tilt angle.
Is the same description obtained when spins are coupled properly ?

Application 2, Wobbling motion
Wobbling bands only observed in odd-even Lu isotopes ?
What can be expected in neighboring nuclei ?

Model I

System divided into
macroscopic rotor + microscopic valence particles

New features

- large particle space
- parameters from mean field models

Model II

Particle-rotor Hamiltonian without pairing:

$$H^{PR} = \sum_i \frac{R_i^2}{2\mathcal{J}_i} + h_{s.p.} = \sum_i \frac{(I_i - j_i)^2}{2\mathcal{J}_i} + h_{s.p.}$$

Nilsson potential:

$$h_{s.p.}(\varepsilon_2, \gamma, \varepsilon_4) = \sum_i e_i a_i^\dagger a_i$$

Strong coupling wave functions chosen as basis states

$$\left|\Psi^I_{MK\alpha}\right\rangle = N_{\alpha K} \frac{1}{\sqrt{2}} \left(1 + e^{-ij_2\pi} e^{iI_2\pi}\right) \sqrt{\frac{2I+1}{8\pi^2}} \left|IMK\right\rangle \left|\alpha\right\rangle$$

$$= N_{\alpha K} \sqrt{\frac{2I+1}{16\pi^2}} \left(\left|IMK\right\rangle \left|\alpha\right\rangle + (-1)^{I-K} \left|IM-K\right\rangle \left|\widetilde{\alpha}\right\rangle\right)$$

A basis of slater determinants is used for the valence particles

$$\left|\alpha\right\rangle = \left(\prod_{i=1}^{Z_1} a^\dagger_{\beta_i}\right) \left(\prod_{i=1}^{N_1} a^\dagger_{\gamma_i}\right) \left|0\right\rangle$$

Model III

PAC calculation for the rotor part

$$H^{PAC} = h_{s.p.}(\varepsilon_2, \gamma, \varepsilon_4) - \omega j_x$$

gives:
energy $E(I_x)$, quadrupole moments Q_{20}, Q_{22} and effective gyromagnetic moment g_R

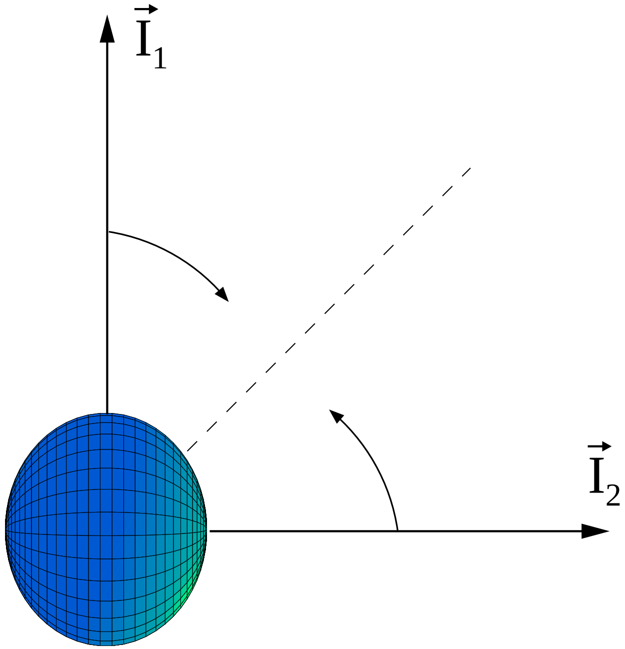
$$g_R(I_x) = [g_{l,\pi} \langle j_{\pi,x} \rangle + (g_{s,\pi} - g_{l,\pi}) \langle S_{\pi,x} \rangle + g_{s,v} \langle S_{v,x} \rangle]/I_x$$

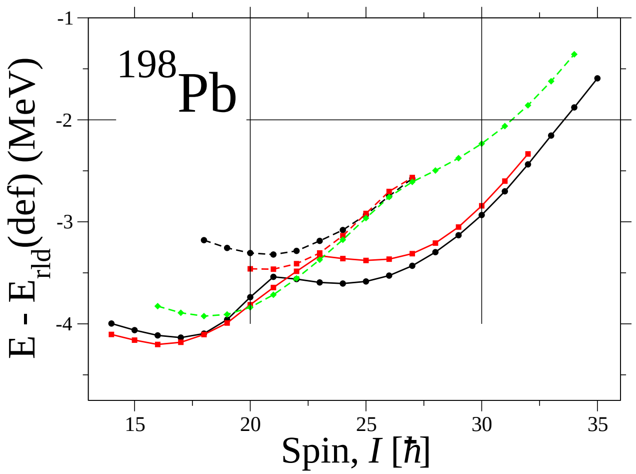
$$Q_{20}(I_x) = \sum_i^Z q_{20,i}$$

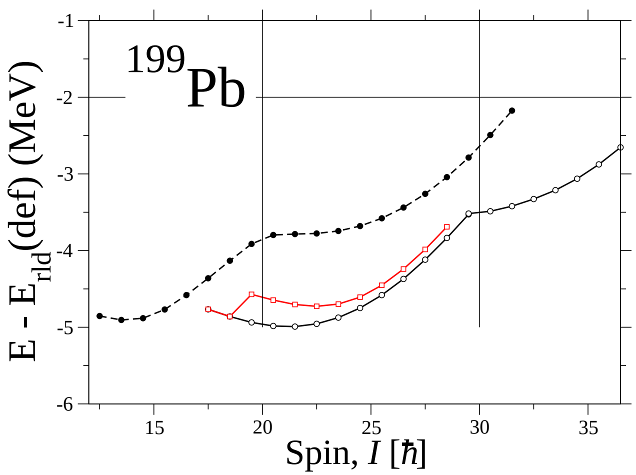
Well-behaved core,

$$g_R(I_x) \simeq g_R, \; Q_{20}(I_x) \simeq Q_{20} \text{ and } E(I_x) \simeq E_0 + \frac{I_x^2}{2\mathcal{J}_x}$$

Magnetic rotation or the Shears mode







- Oblate shapes ($\varepsilon_2 \sim -0.14, \gamma \sim 0$)
- Alignment around non-principal axis
- Large *B(M1)* values
- Several bands found in lead isotopes (see H. Hübel $et.al.$, Prog. Part. Phys. 54 (2005))

Example for ^{198}Pb

Configuration rel. ^{208}Pb

Case A

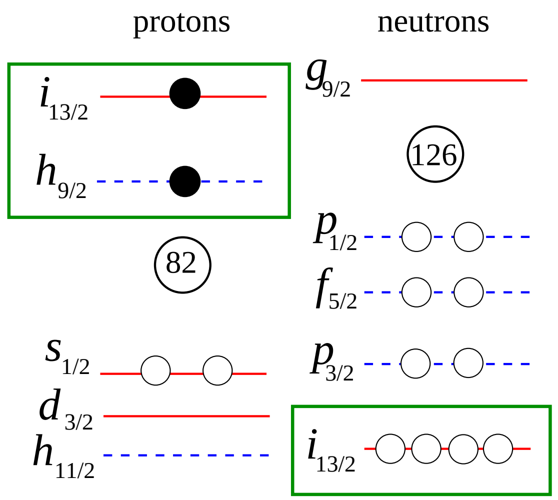
4 neutron holes in a $i_{13/2}$ shell

1 proton in a $i_{13/2}$ shell

1 proton in a $h_{9/2}$ shell.

=> 84084 basis states of each signature

$I^{core}_{max} = 8\hbar$

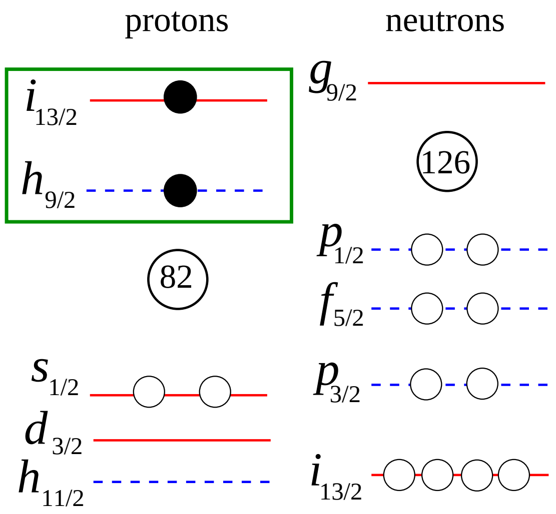


Case B

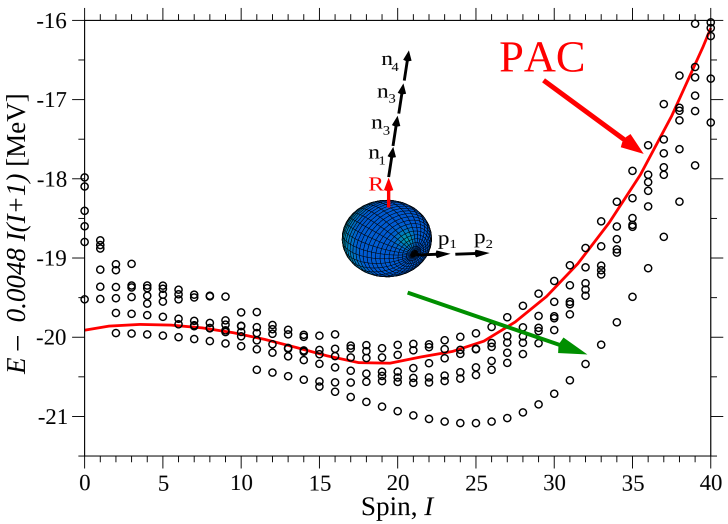
Neutrons holes treated as core

=> 84 basis states of each signature

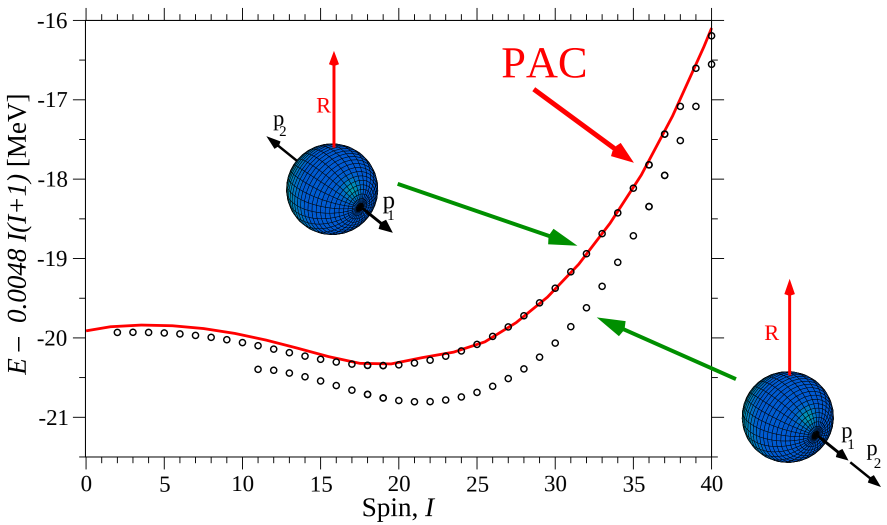
$I^{core}_{max} = 8 + 20 = 28\hbar$



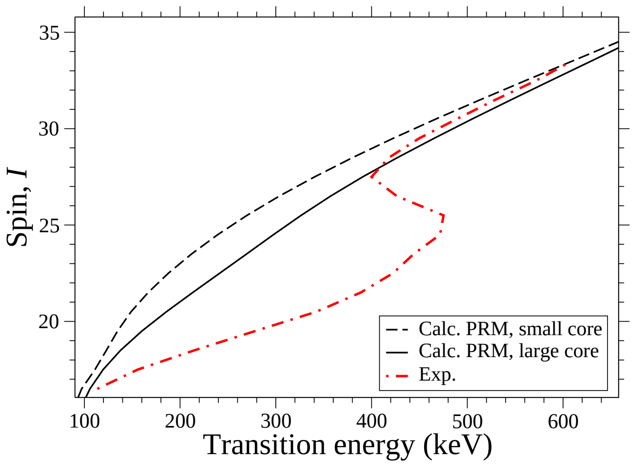
^{198}Pb: Numerical Computation, energies



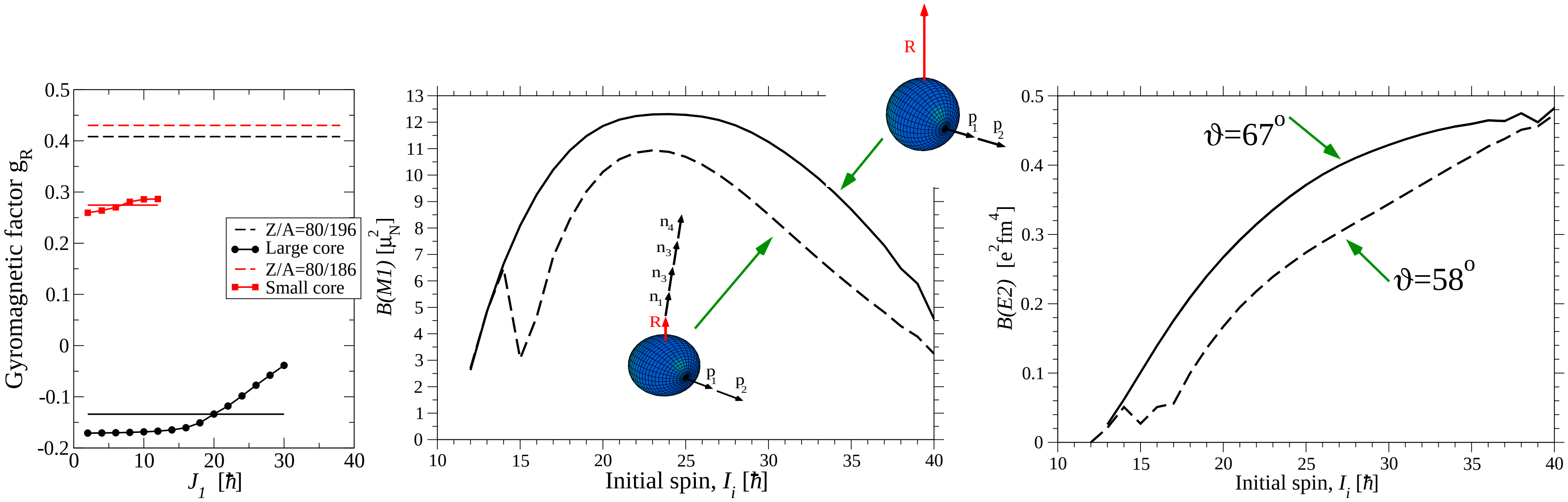
Case A



Case B



^{198}Pb: Numerical Computation, transitions

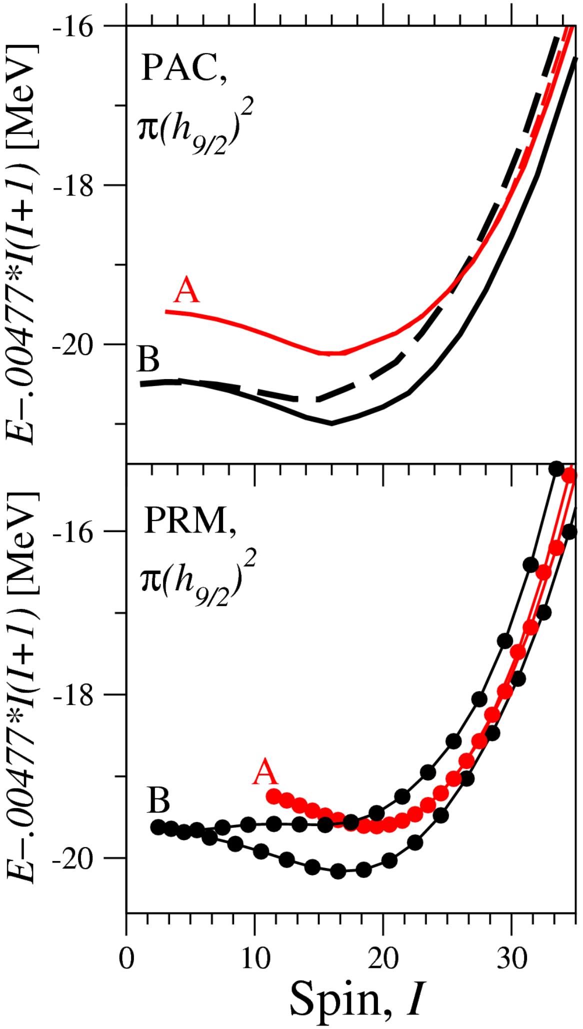


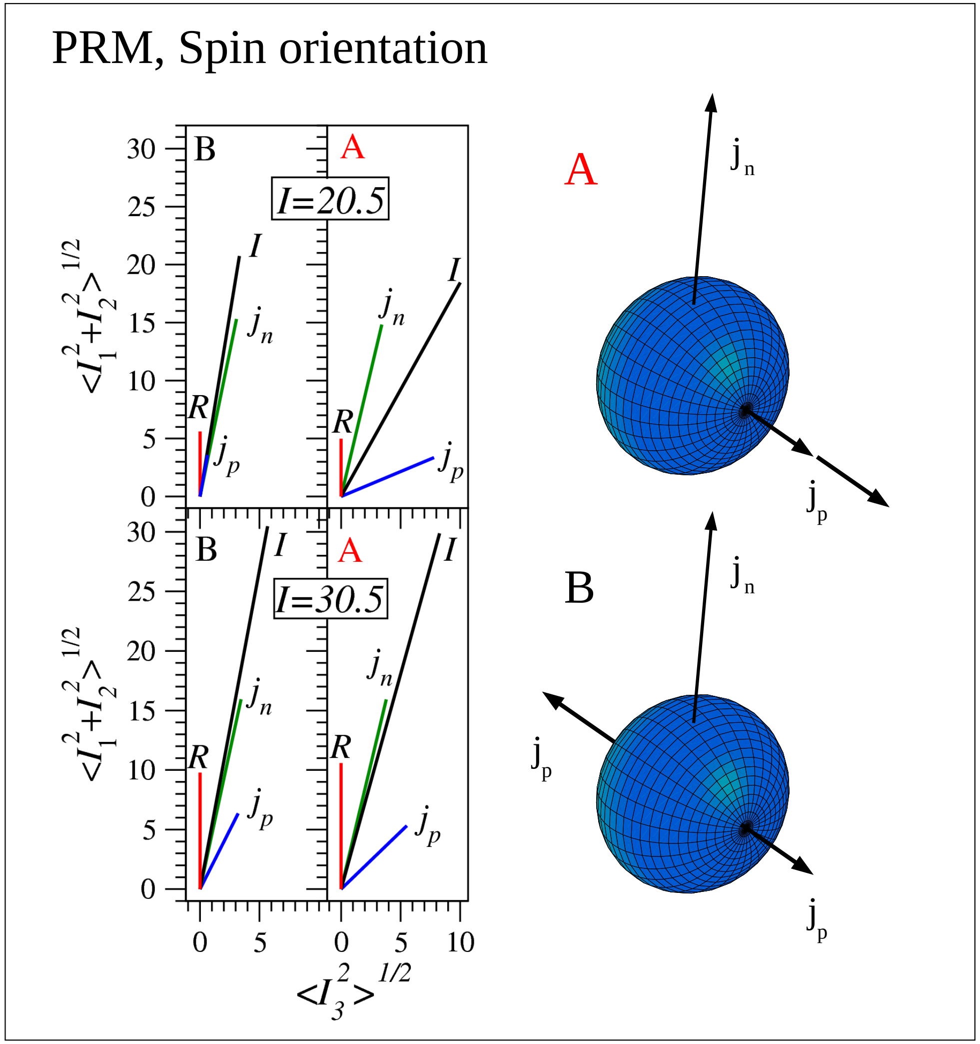
Dashed line = Case A $\quad \pi(i_{13/2})^1(h_{9/2})^1 \otimes \nu(i_{13/2})^{-4}$

Full line = Case B $\quad \pi(i_{13/2})^1(h_{9/2})^1$

$$\upsilon = \arccos\left(\frac{\sqrt{\langle I_z^2\rangle}}{\sqrt{I(I+1)}}\right) \qquad B(E2) = \frac{15}{128\pi}(eQ_{20})^2 \sin^4 \upsilon$$

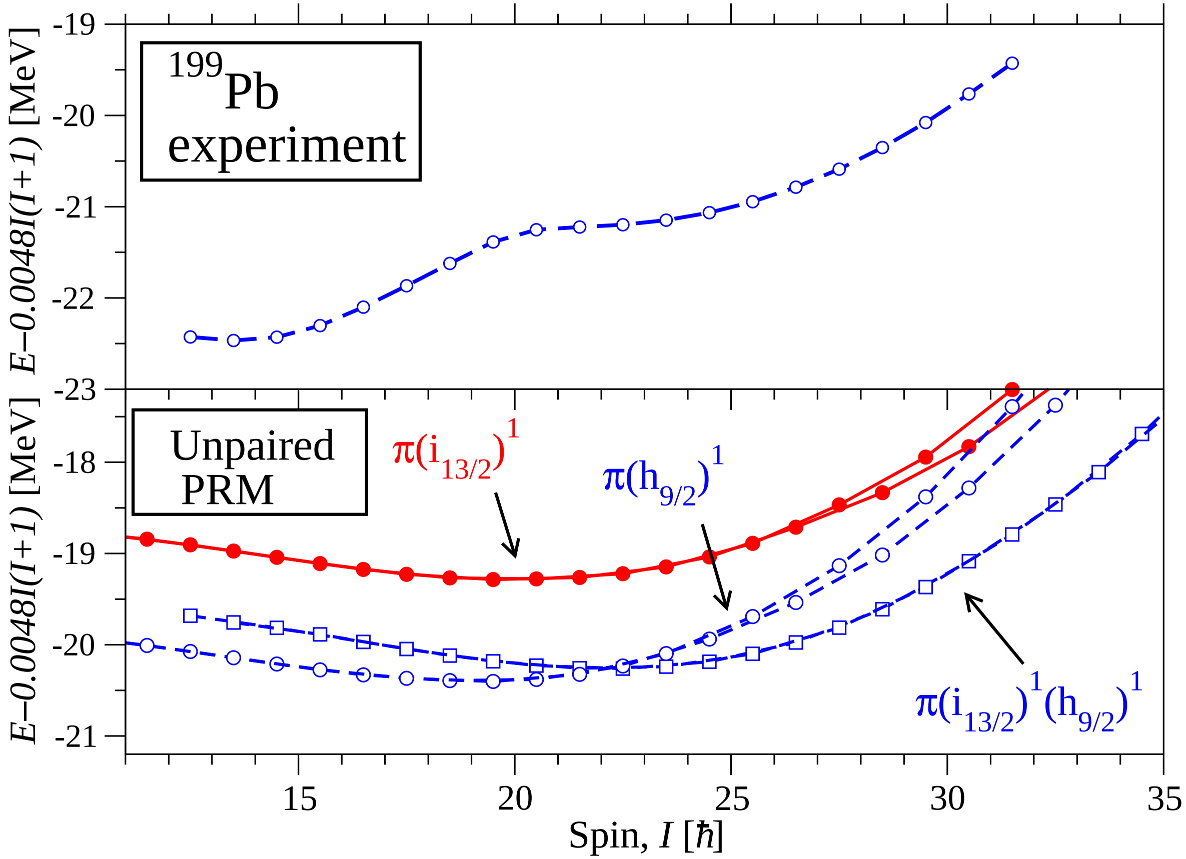
^{199}Pb $\pi(h_{9/2})^2 \otimes \nu(i_{13/2})^{-3}$



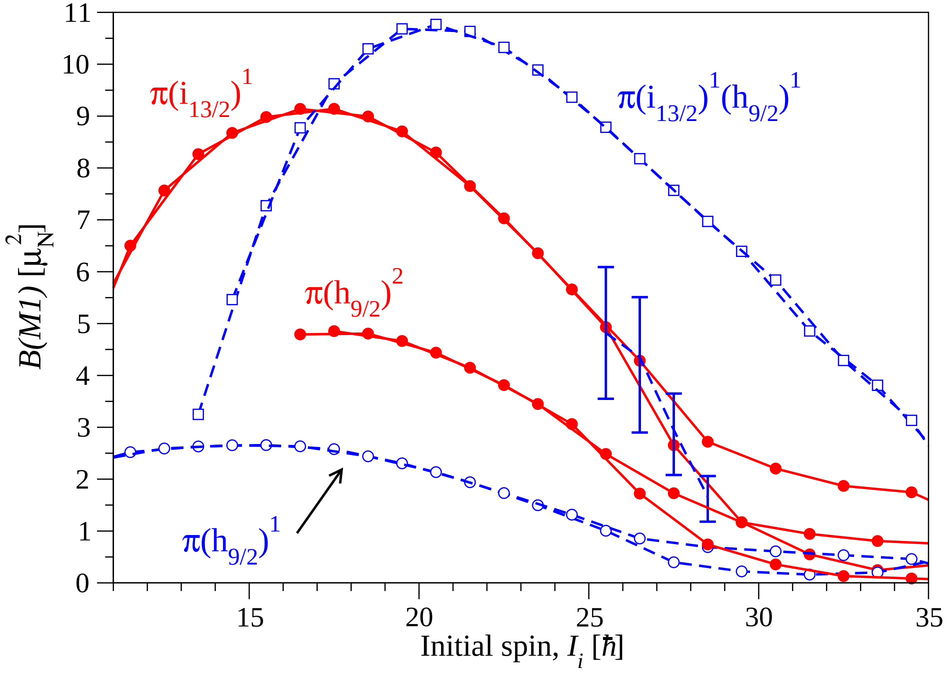


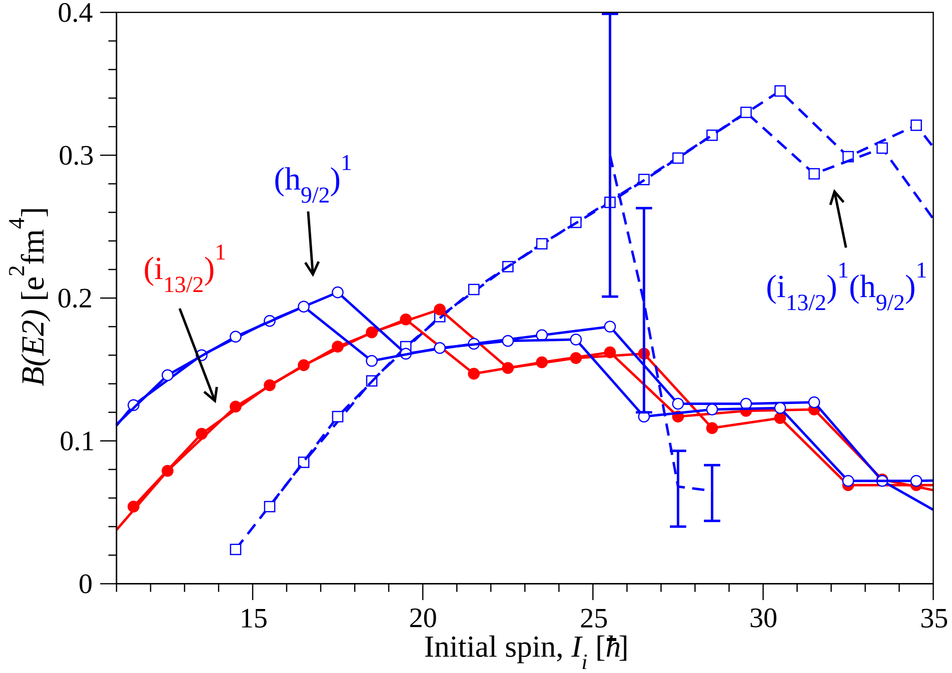
Comparison with experiments, ^{199}Pb

$v(i_{13/2})^{-3}$ coupled with different proton configurations.
Energy minimized with respect to ε_2



Comparison with experiments, ^{199}Pb

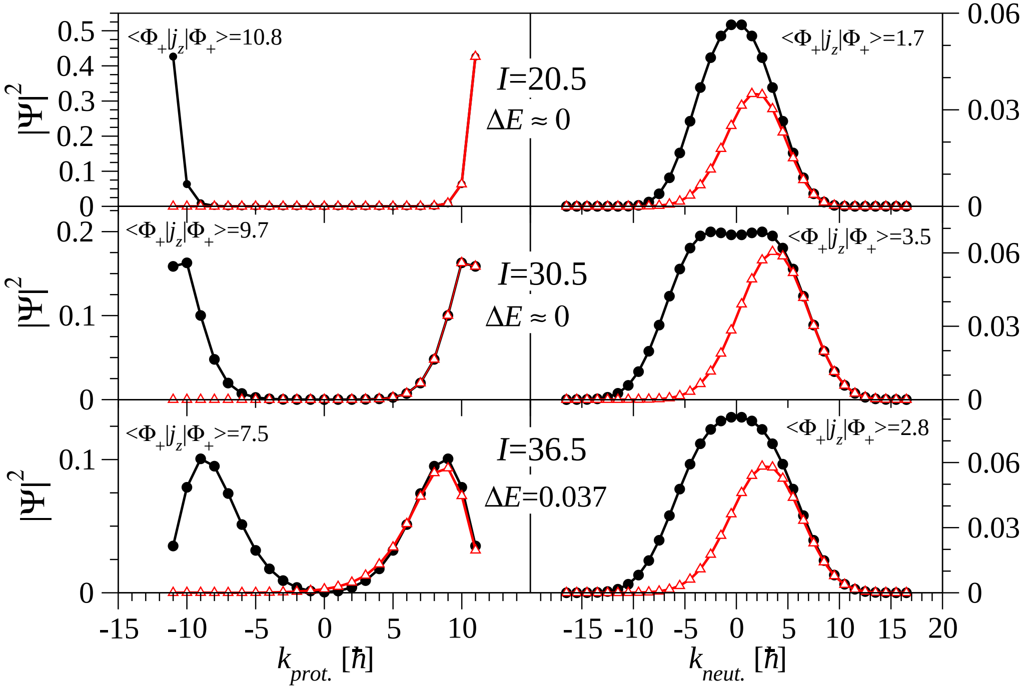




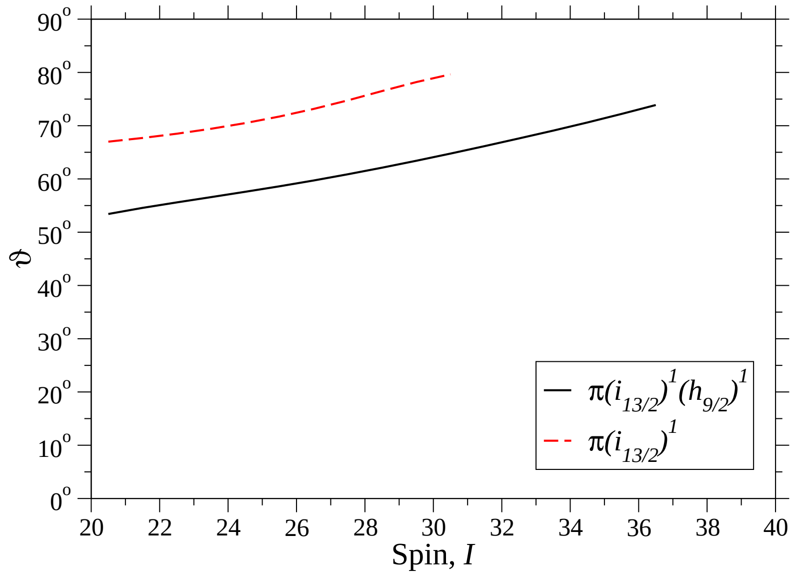
B(E2) values indicate low collectivity already around $I = 30\hbar$

Spin orientation ^{199}Pb

Spin projection for $\pi(i_{13/2})^1(h_{9/2})^1 \otimes \nu(i_{13/2})^{-3}$ cfg.



Spin angle



Wavefunction separates into two degenerate parts:

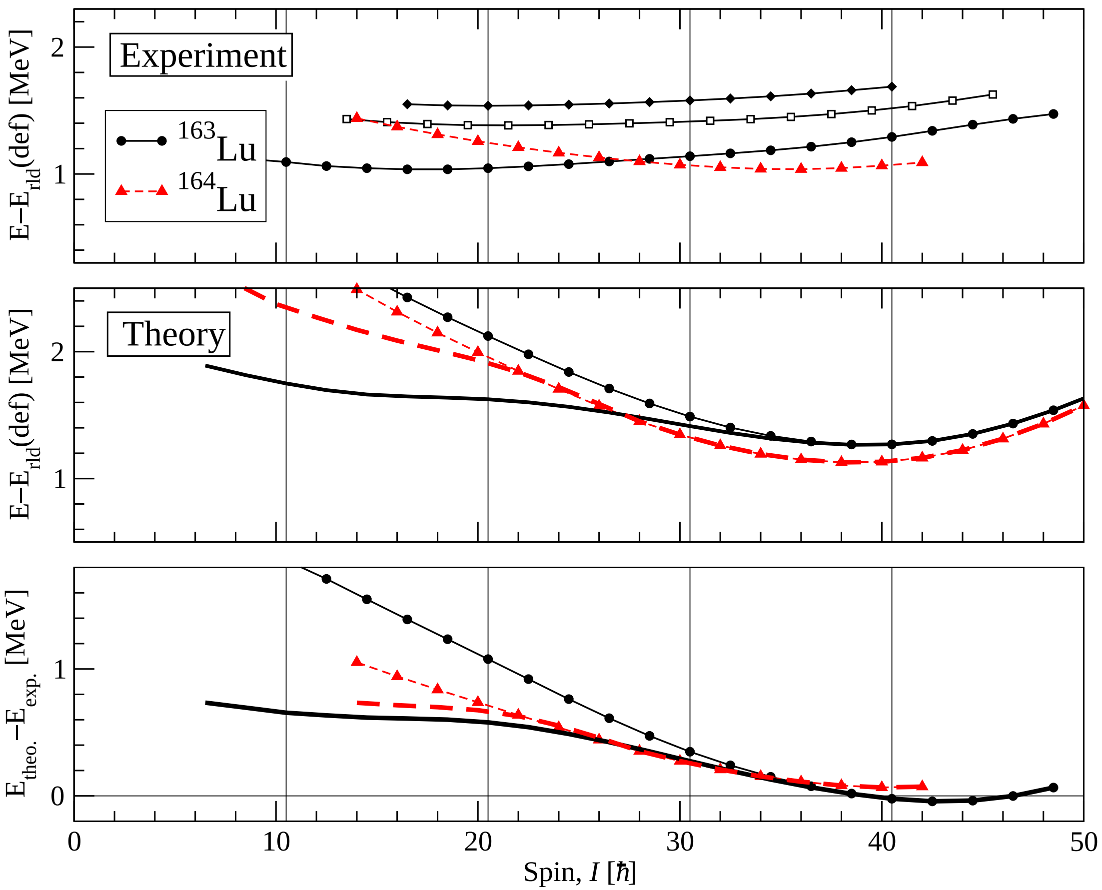
$$\left|\Psi^I\right\rangle = \frac{1}{\sqrt{2}}\left(\left|\Phi_{k_p>0}\right\rangle + \left|\Phi_{k_p<0}\right\rangle\right)$$

Summary

- In several cases the many particles + rotor calculations with parameters from cranking give similar results as the PAC calculations
- Calculations for ^{199}Pb revealed different types of bands:
  - ▷ with 2 high-j protons, shears effect + collective spin
  - ▷ with 1 high-j proton, less shears effect, some signature splitting at high spins
  - ▷ 2 protons in same shell => antiparallel coupling is favored
- Core spin constrained to point in one direction, effect on result ?

(to be published G.B Carlsson and Ingemar Ragnarsson, Phys. Rev. C)

Triaxial superdeformed bands (TSD)

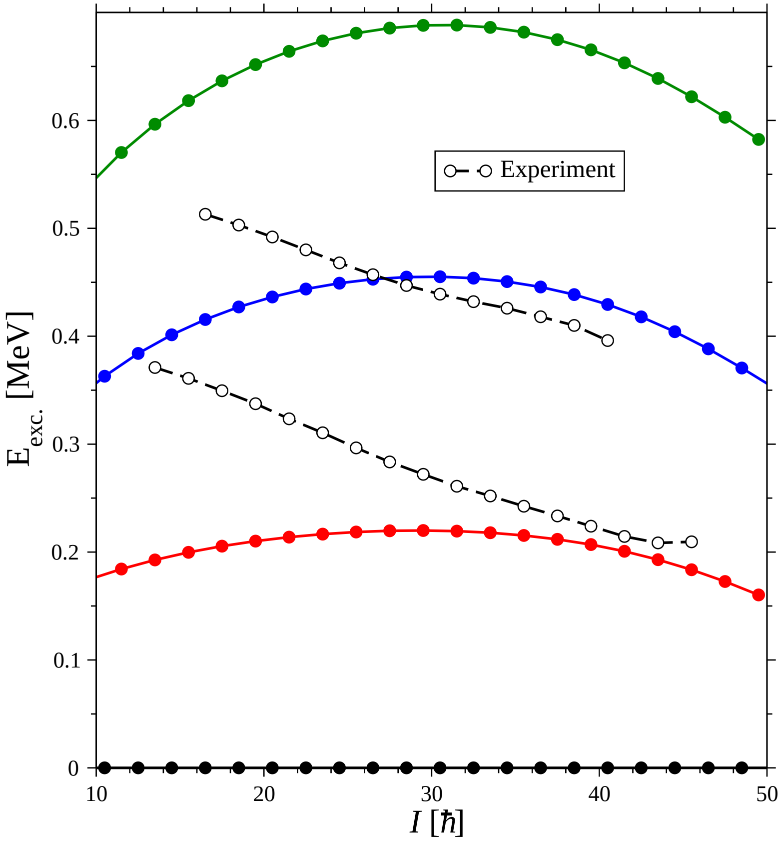


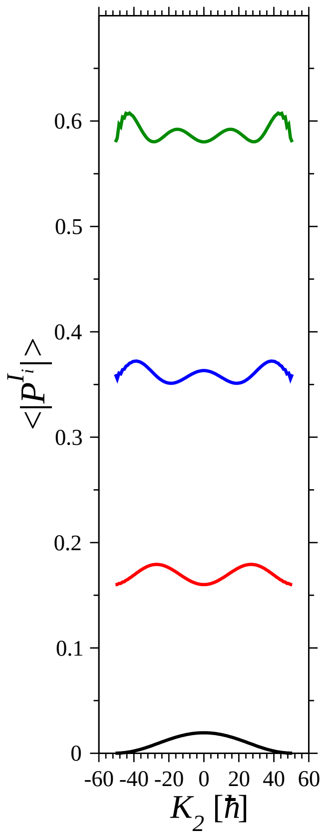
TSD bands in ^{163,164}Lu ($\varepsilon_2 \sim 0.20, \gamma \sim 40°$)

Two wobbling bands in ^{163}Lu

6 unconnected bands in ^{164}Lu

Wobbling excitation energy in ^{163}Lu





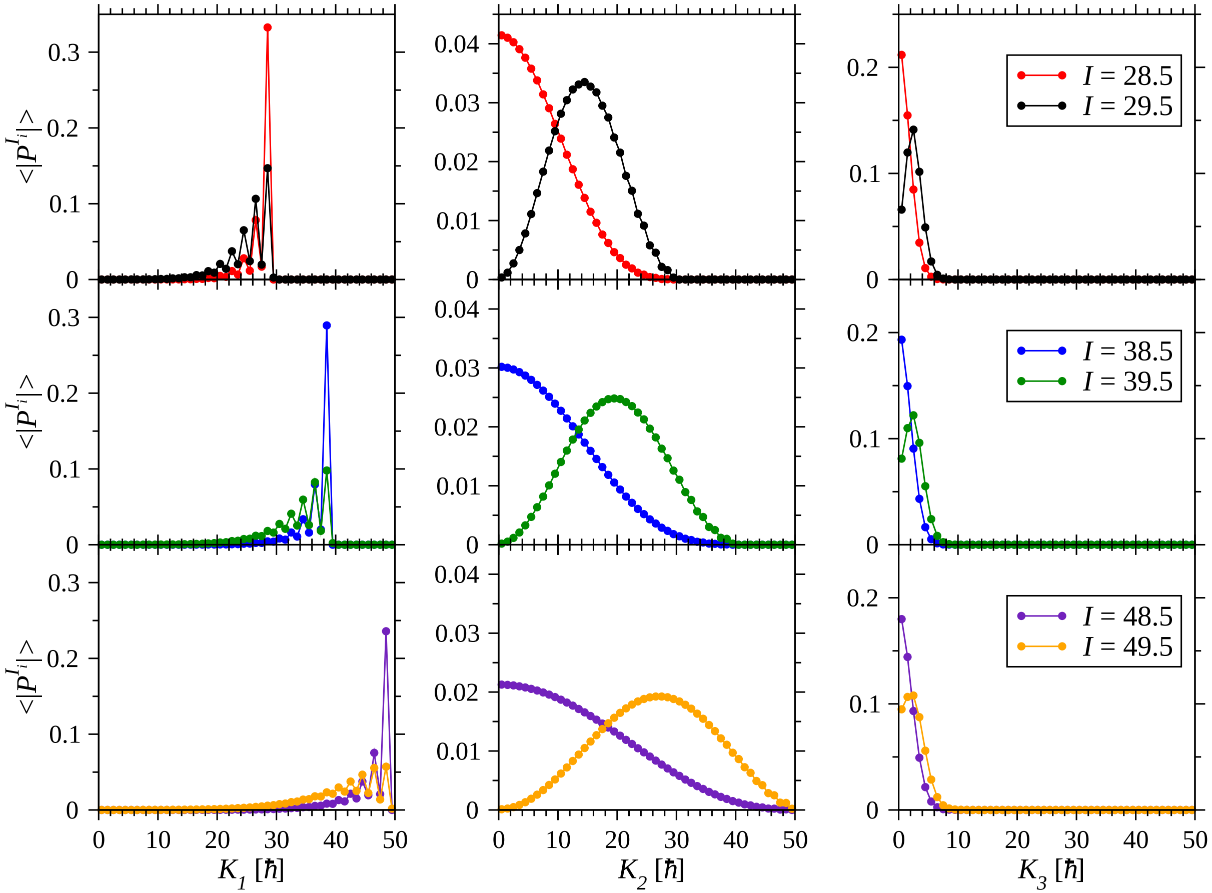
Configuration with respect to the rotor core $\pi(i_{13/2})^1 \upsilon(i_{13/2})^6$

rotor moments of inertia obtained by cranking in 3 directions

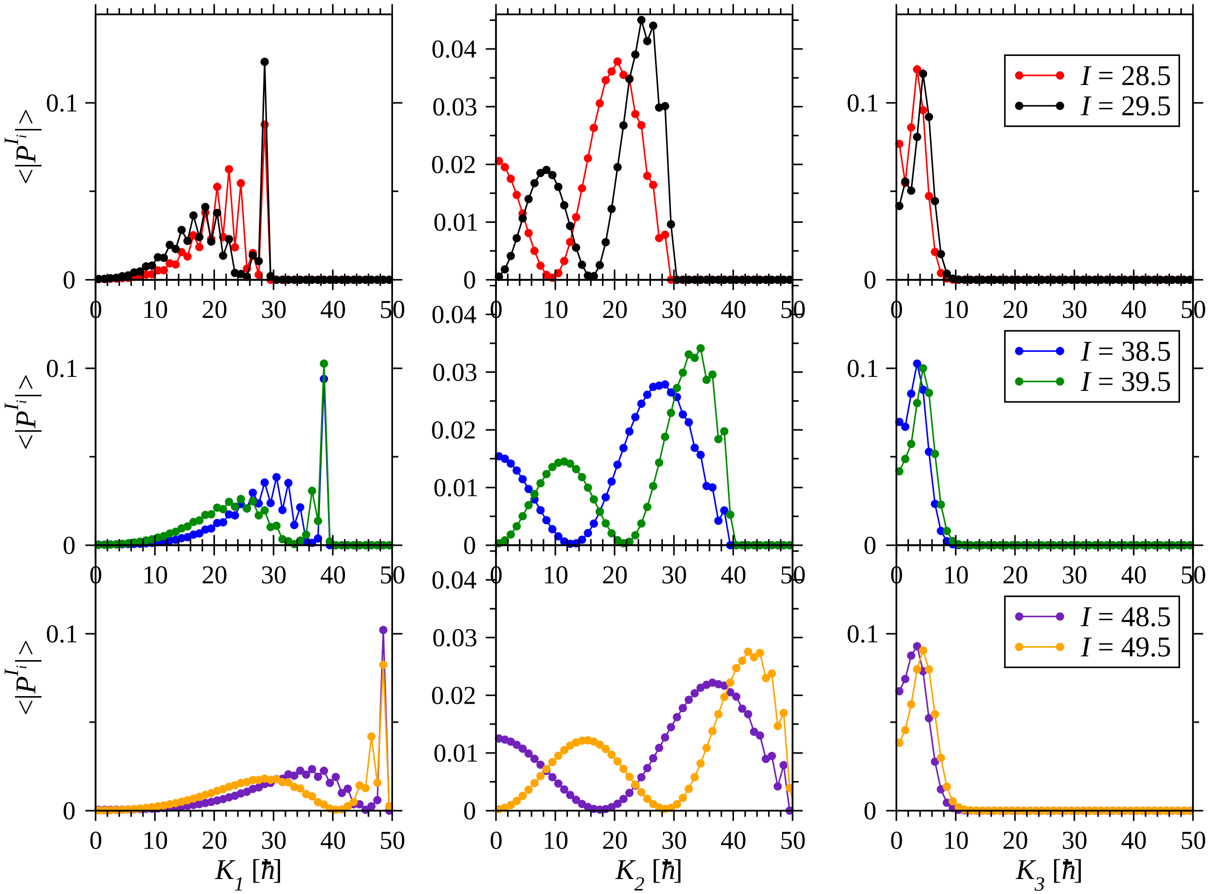
Summary

- Wobbling excitation energies in high-spin limit reasonable
- More work needed to obtain transition probabilities and to go to neighboring nuclei

Spin projection

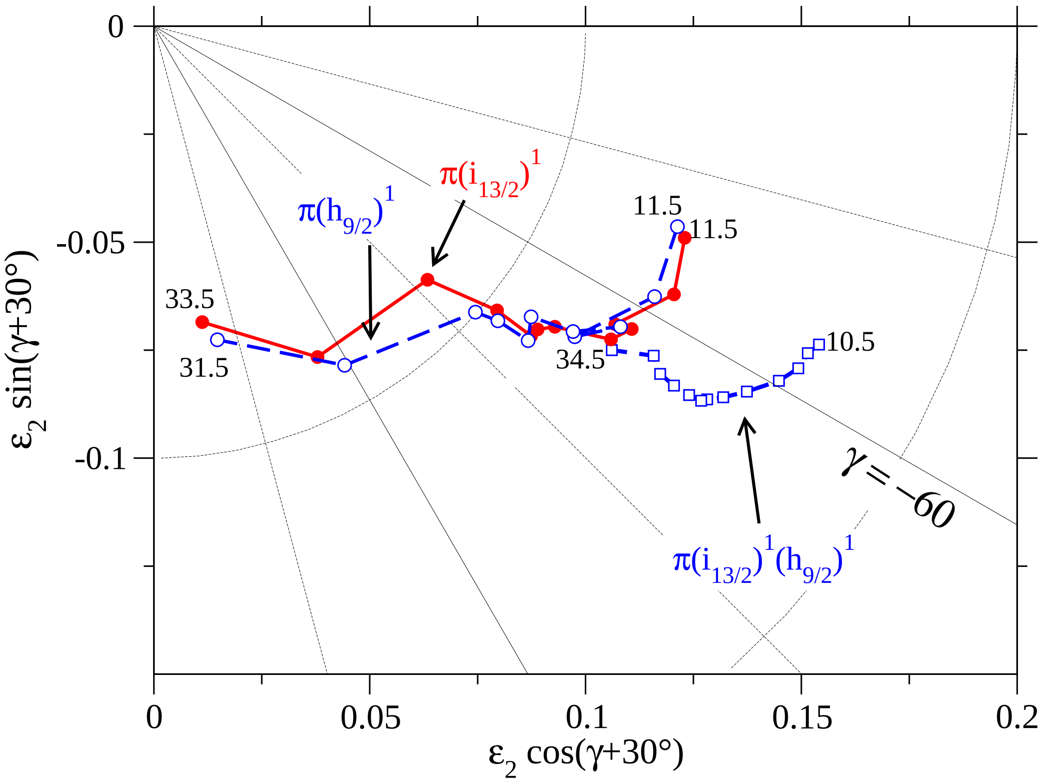


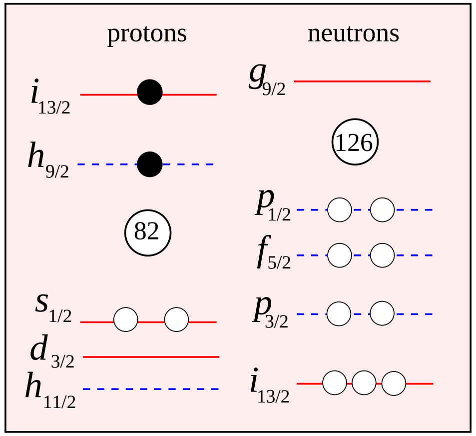
Spin projection



Comparison with experiments, ^{199}Pb

Deformations calculated using principal axis cranking





So far we have assumed axial symmetry in the rotor calculation