Transverse spatial structure of excited states in nuclei?

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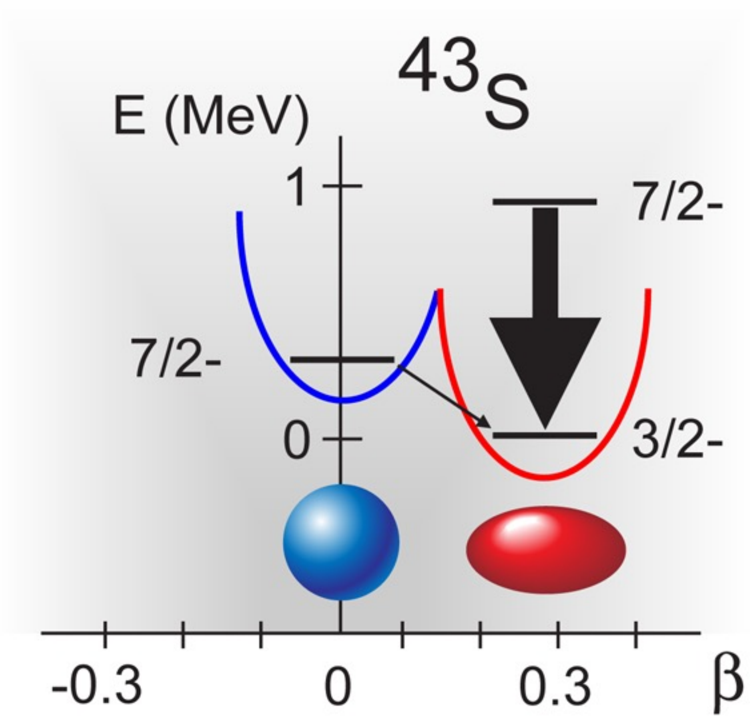
Nuclear shapes

- Nuclear *ground states* close to filled shells (magic numbers) tend do be spherical, while ones far from the magic numbers tend to be deformed.

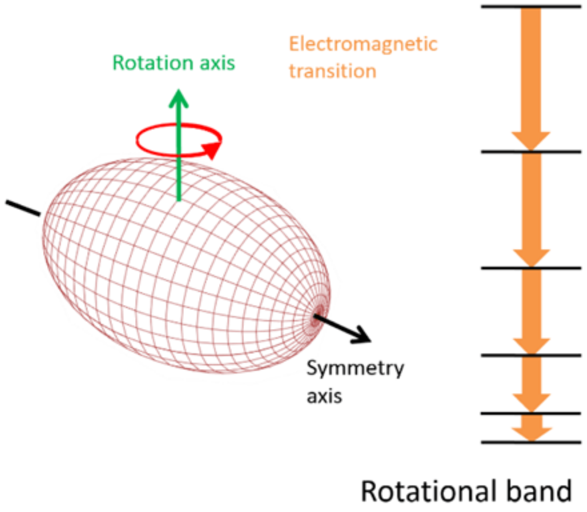
- The shapes of *excited states* can vary.

- In this presentation, we will look at rotational states as a simple example.



Collective excitations and rotational bands

- Nuclear excitations can involve the excitation of one nucleon to a different orbital, or the collective motion of the nucleus as a whole.



- Collective excitations include rotations, vibrations, and giant resonances (in the continuum).

- Rotations are only possible in deformed nuclei.
  - The rotation is quantized, and leads to a "band" of excited states.
  - Measuring the band (γ-spectroscopy) provides a very precise determination of the deformation.

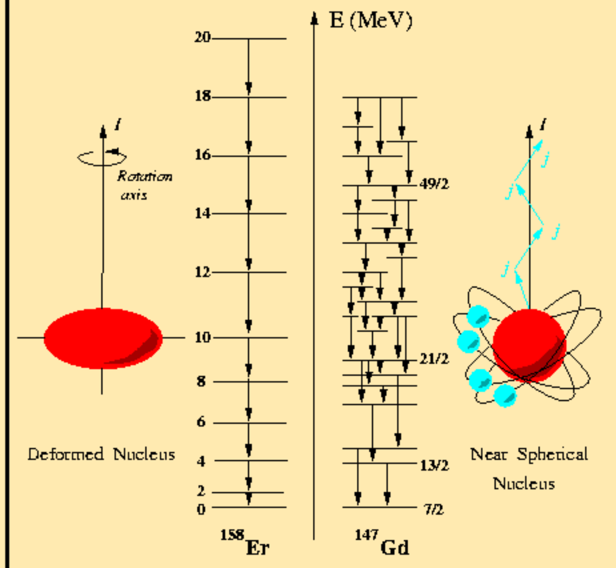
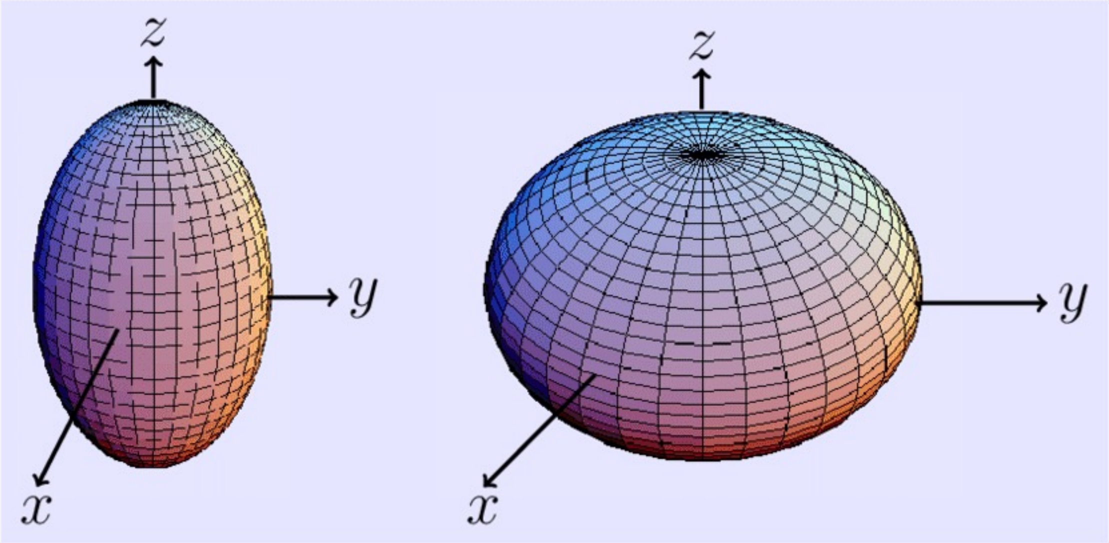


Figure : The two ways that a nucleus can generate angular momentum (spin). "Collective", or classical, behaviour is shown to the left and "noncollective", or quantal, behaviour to the right.

Rotational states in real nuclei



- When rotating around its short axis, a nucleus with a prolate deformation looks oblate.
- The shape is similar for all states in a rotation band
- Real nuclei have both rotational bands and single particles states, but the rotations are fairly distinct.

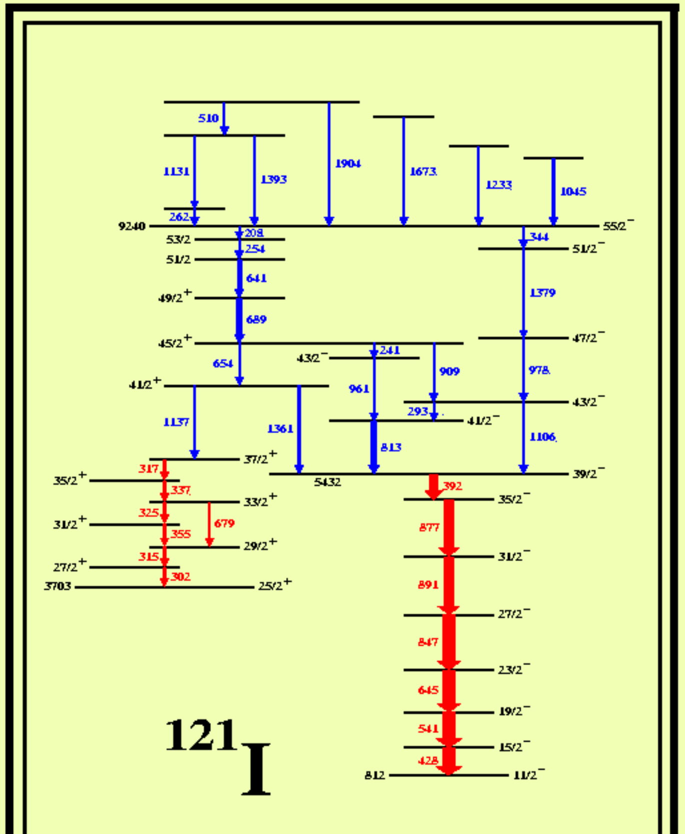
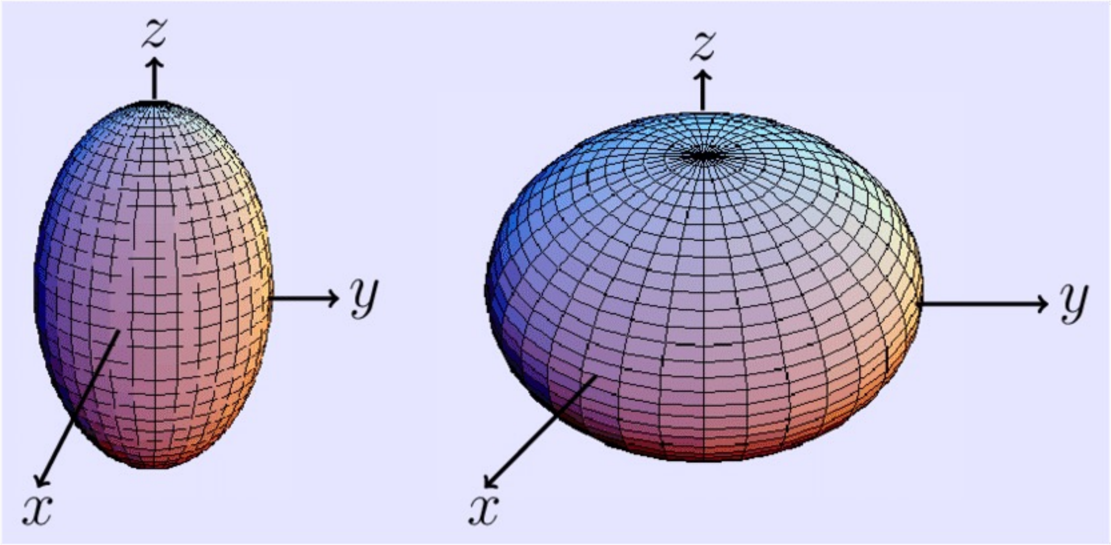


Figure : Partial level scheme for ^{121}I.

Transverse imaging of nuclei

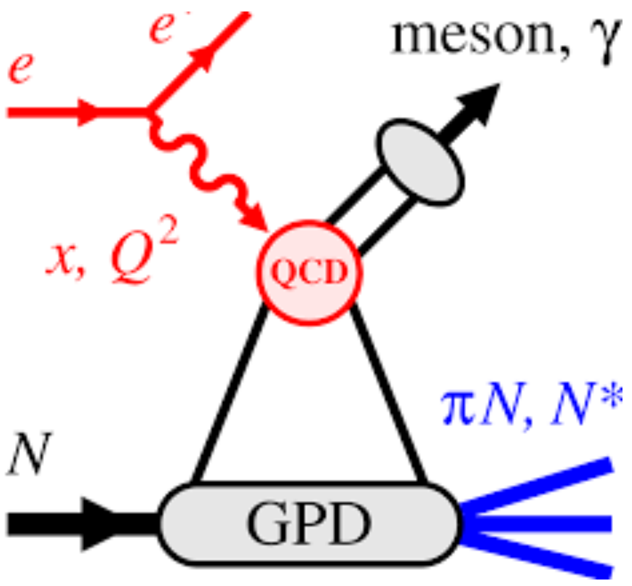


- Exclusive coherent scattering allows measurements of transverse spatial distributions.
  - GPDs, diffraction
  - Quarkonia (*e.g.*, J/psi): gluons / mass
  - DVCS: quarks / charge.
  - Light mesons: flavor

- For unpolarized nuclei, the deformation axis is uncorrelated with the momentum
  - We will see an average, with a tail given by the long axis.

- For “regular” GPDs, both the initial and final states are the ground state

Excited final states and transition GPDs



- On the nucleon, *transition GPDs* describe the process where the initial state is the ground state and the final one is an excited state (N*).
  - Transition GPDs are measured at JLab and could be measured at the EIC – in particular with a 2nd detector if it would have a better B0 layout
  - In the nucleon, the time scale for producing a photon or meson is comparable to N* formation

- Similar measurements can be carried out in nuclei, with an excited nuclear final state.
  - If final state is a rotational excitation, its transverse spatial distribution should be quite different
  - The final state can be determined by measuring the associated γ-photons

Measuring transitions in nuclei

- Measuring structure functions for nuclear transitions could provide new insights on the structure of nuclei, but it is not obvious if the excited state would be fully formed on the time scale on which the production of a photon or meson occurs.
  - One can formally calculate a transition between an initial and final state, but the final state may not be physically relevant if it takes a “long” time to form.

- A simple first test that could be done at the EIC would be to see if one could see any difference in the structure functions measured with a tagged final state that had a significantly different spatial distribution than the ground state (*e.g.*, a rotational state).
  - If there would be no difference, then the time scales would likely be different

- However, even if the conclusion was that there is little sensitivity to the final state, this would still be interesting both from the point of understanding how quickly excited states form, as well as how sensitive coherent exclusive / diffractive measurements are to an admixture of excited states in the final sample (requirement on photon veto efficiency).