Chiral Wobbling in ^{135}Pr

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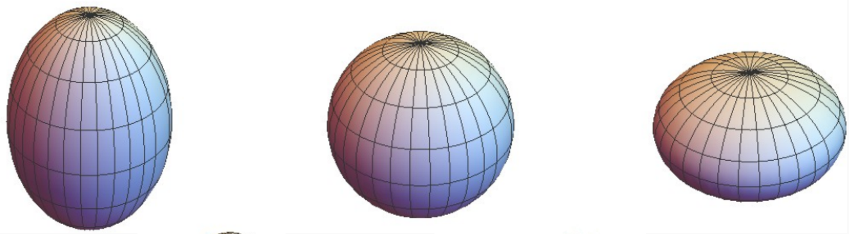
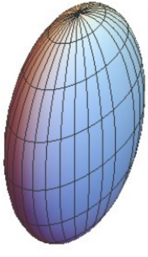
University of Notre Dame

Nuclear Shapes

Prolate   Spherical   Oblate

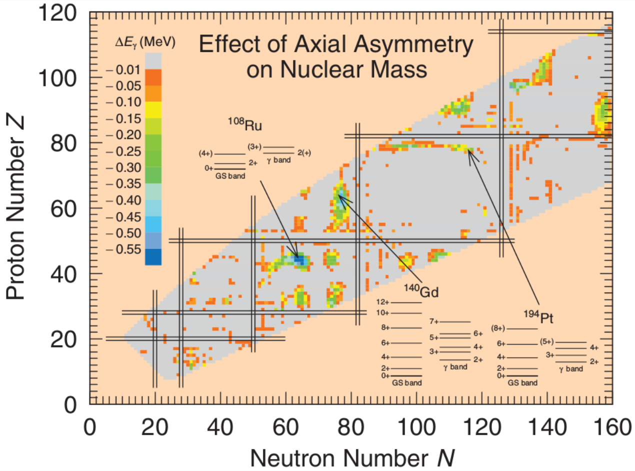




Triaxial

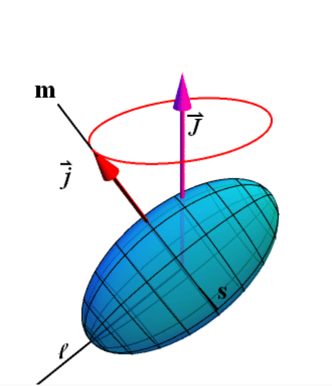
Triaxiality - A rare phenomenon!

P. Möller et. al. PRL 97, 162502 (2006)



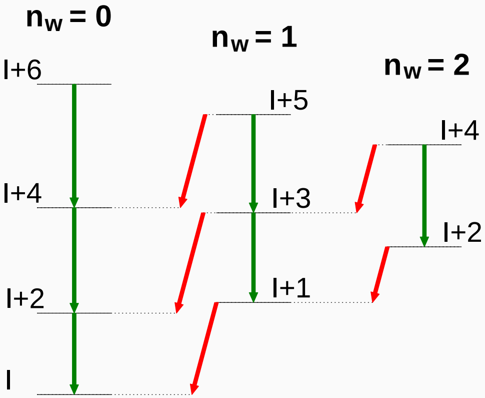
Wobbling - Unique fingerprint of Triaxiality (1/2)

- Harmonic oscillation of one of the principal axes about the space fixed $\vec{J}$.
- Analog of the spinning motion of an asymmetric top.
- For odd-A nuclei:
  - Odd particle aligns with m-axis - Longitudinal wobbling
  - Odd particle aligns $\perp$ to m-axis - Transverse wobbling



Animation courtesy - J. T. Matta

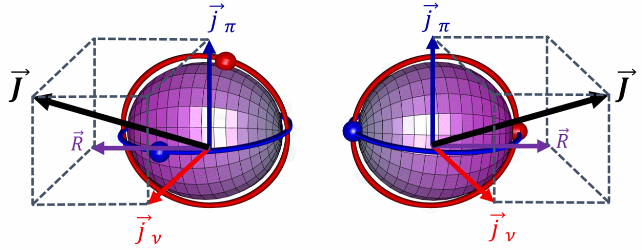
Wobbling - Unique fingerprint of Triaxiality (1/2)



Standard fingerprints for Wobbling bands:

- Rotational bands corresponding to $n_w = 0, 1, 2, ...$
- Transitions from $n_{w+1} \rightarrow n_w$ ($\Delta n_w = +1$)
- Interband Transitions are $\Delta I = 1$, E2

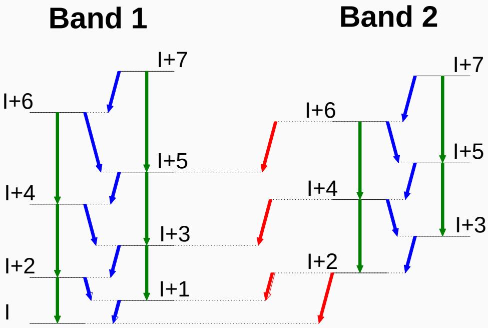
Chirality - Unique fingerprint of Triaxiality (2/2)



Animation courtesy - X. H. Wu

- Axis of rotation lies outside all of the three principal planes of the nucleus.
- High-*j* particles align with the s-axis, high-*j* holes align with the l-axis and the triaxial core rotates about the m-axis.
- This arrangement breaks the time-reversal symmetry.
- The system is R.H. if the s-, m- and l-axes are ordered counterclockwise w.r.t $\vec{J}$ and L.H. otherwise.

Chirality - Unique fingerprint of Triaxiality (2/2)

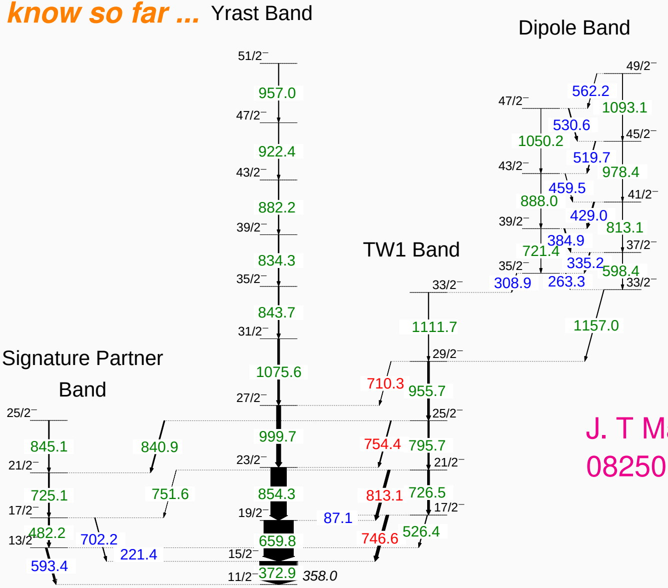


Standard fingerprints for Chiral bands:

- Opposite chirality bands - Two $\Delta I = 1$ bands of same parity
- Close excitation energies
- Constant staggering parameter
- Identical B(M1)/B(E2) ratios

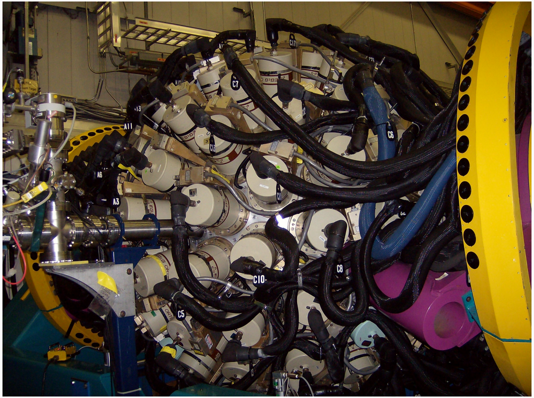
Level Scheme of ^{135}Pr

What we know so far ...



J. T Matta et al., PRL 114, 082501 (2015)

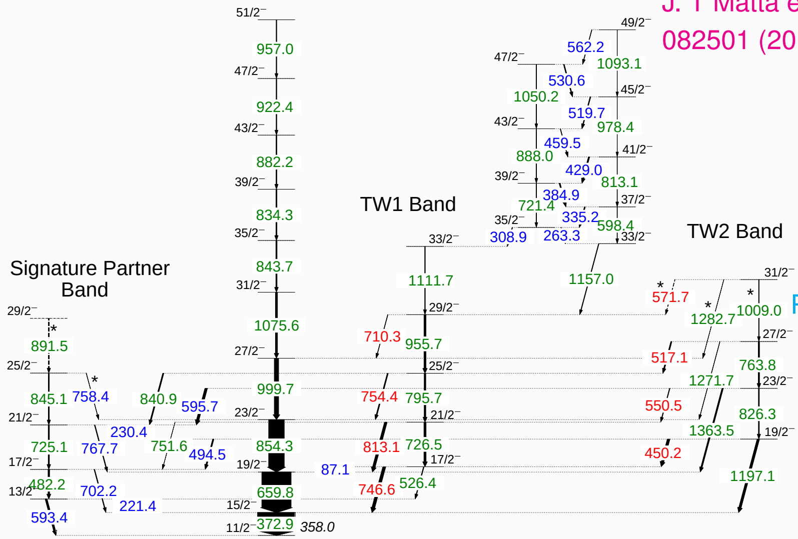
Experimental Details (1/2)



- Experiment performed using the Gammasphere facility at Argonne National Laboratory.
- Reaction used: ^{123}Sb(^{16}O,4n)^{135}Pr at 80 MeV.
- 83 compton suppressed HpGe detectors used.
- No. of three- and higher-fold γ-ray coincidence events $\approx 1.5 \times 10^{10}$.

Level Scheme of ^{135}Pr (cont.)

What we know so far ...

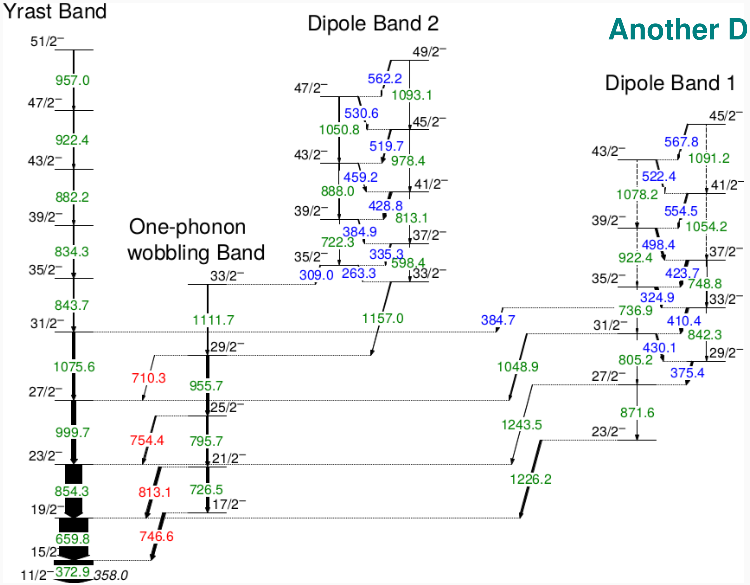


J. T Matta et al., PRL 114, 082501 (2015)

N. Sensharma et al., PLB 792, 170 (2019)

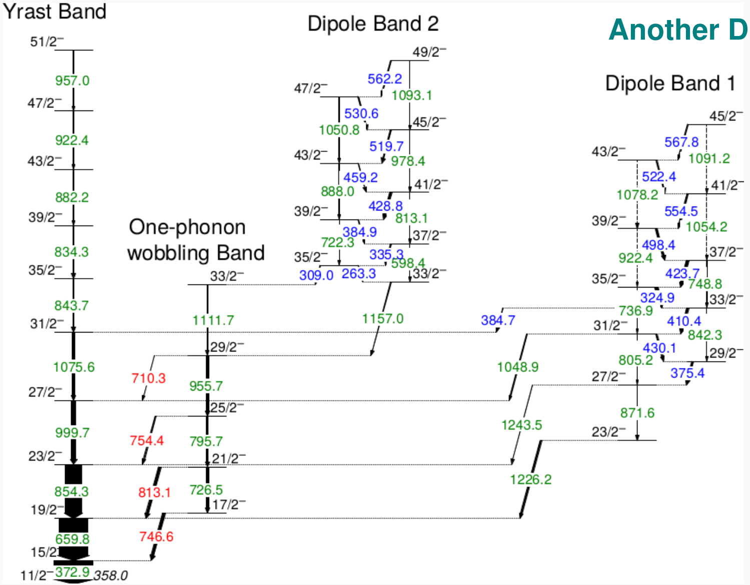
Level Scheme of ^{135}Pr (cont.)

Another Dipole Band



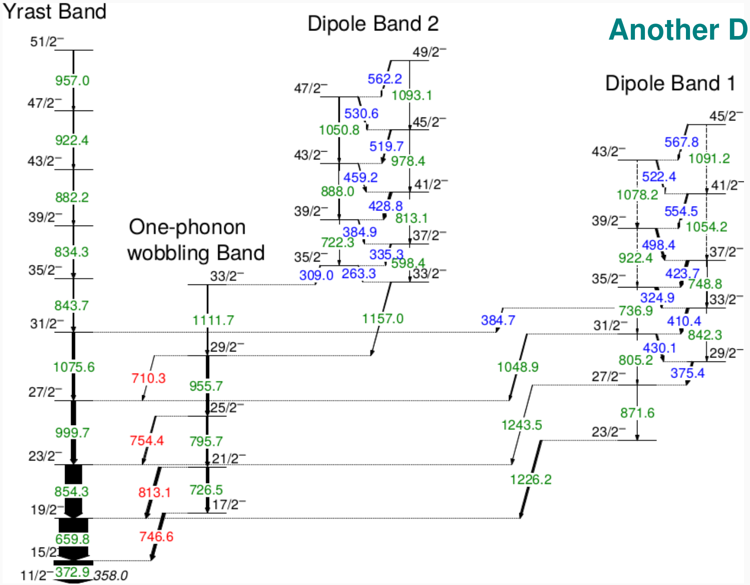
Level Scheme of ^{135}Pr (cont.)

Another Dipole Band



Origin?

Level Scheme of ^{135}Pr (cont.)

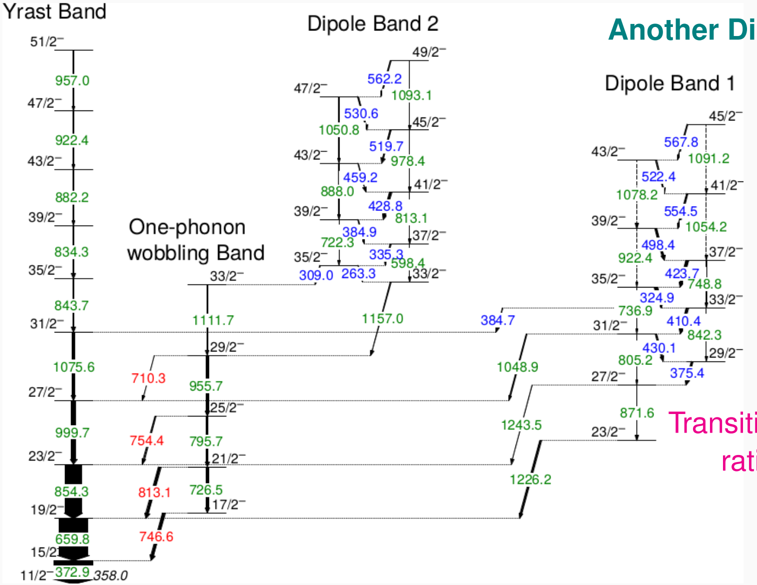


Another Dipole Band

Origin?

Any linking transitions?

Level Scheme of ^{135}Pr (cont.)



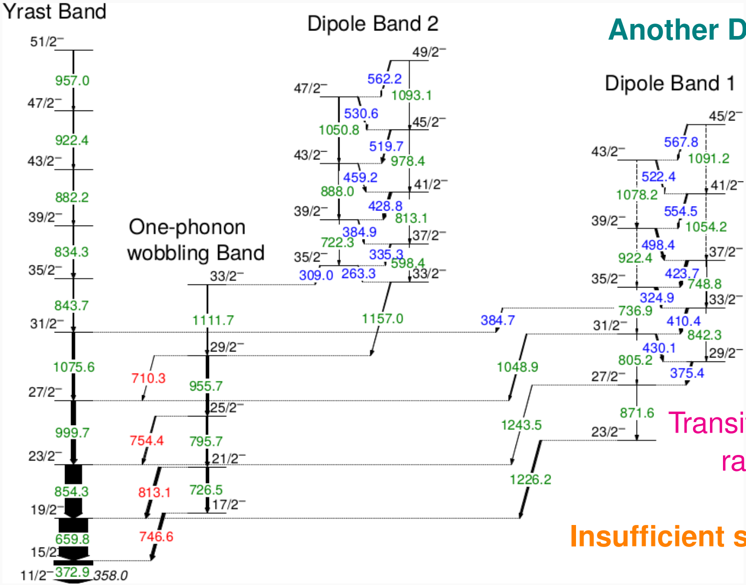
Another Dipole Band

Origin?

Any linking transitions?

Transition probability ratios?

Level Scheme of ^{135}Pr (cont.)



Another Dipole Band

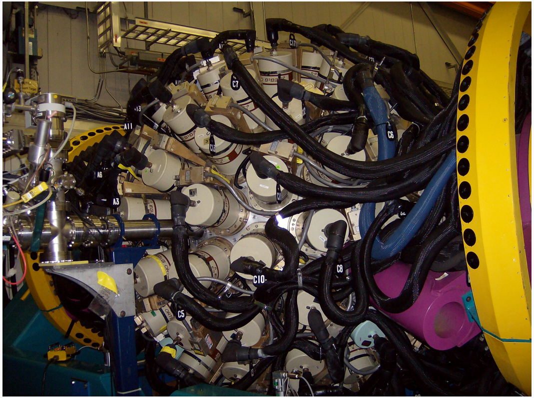
Origin?

Any linking transitions?

Transition probability ratios?

Insufficient statistics

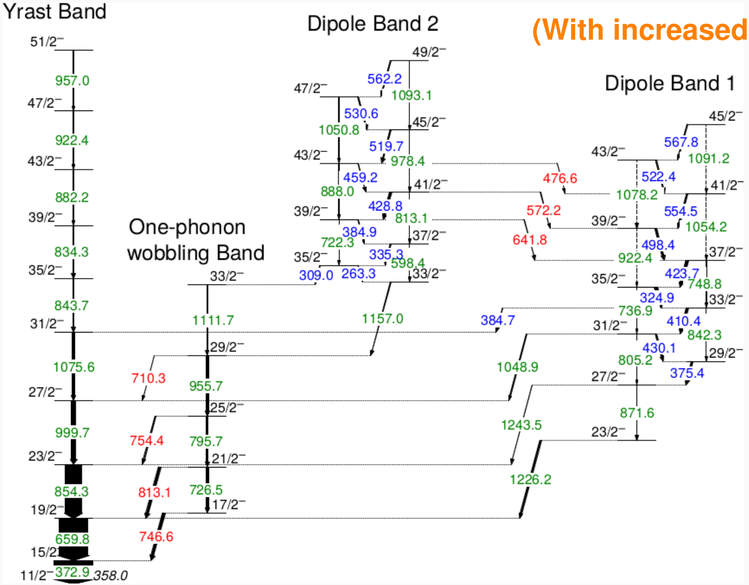
Experimental Details (2/2)



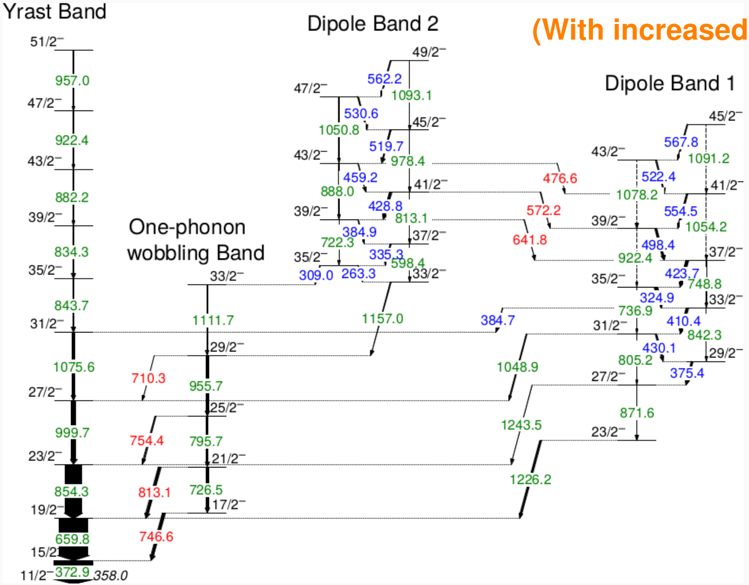
- Experiment repeated using the Gammasphere facility at Argonne National Laboratory.
- Same reaction, energy and similar targets as previous experiment.
- 63 compton suppressed HpGe detectors used.
- Both datasets added together.
- Total no. of three- and higher-fold γ-ray coincidence events $\approx 2.5 \times 10^{10}$.

Level Scheme of ^{135}Pr (cont.)

(With increased statistics)



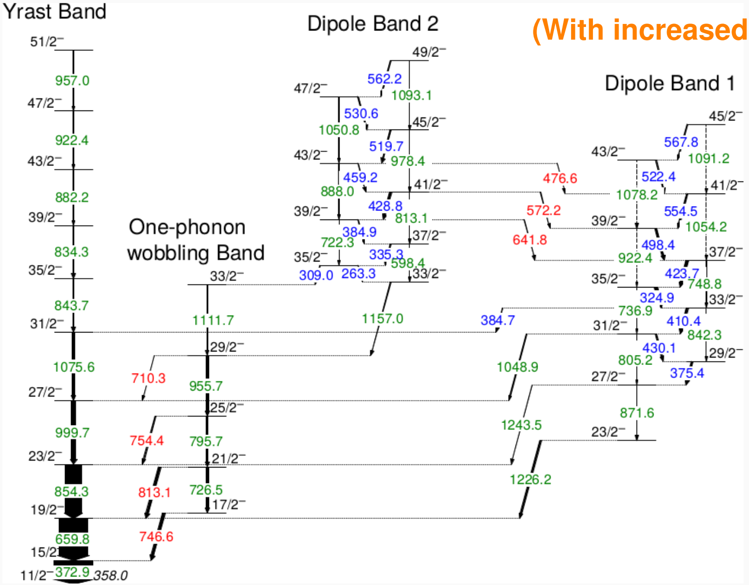
Level Scheme of ^{135}Pr (cont.)



(With increased statistics)

Three linking transitions

Level Scheme of ^{135}Pr (cont.)

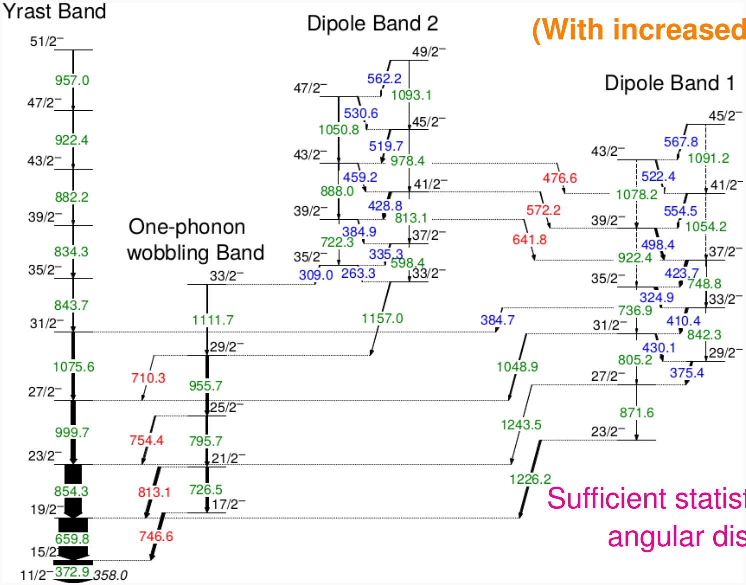


(With increased statistics)

Three linking transitions

Could these be Chiral Partners??

Level Scheme of ^{135}Pr (cont.)



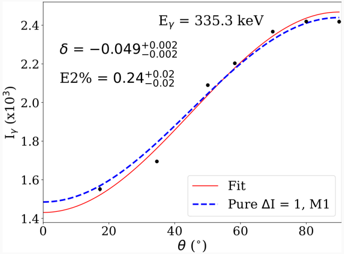
(With increased statistics)

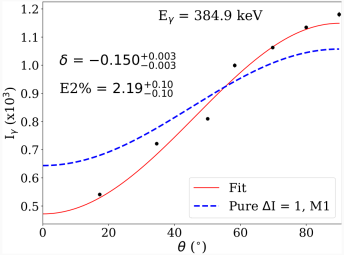
Three linking transitions

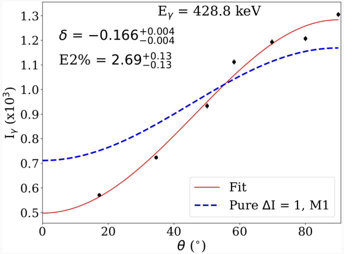
Could these be Chiral Partners??

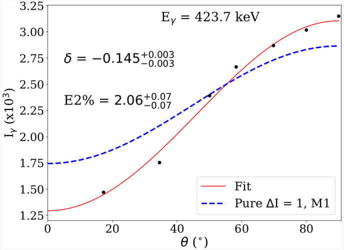
Sufficient statistics to perform angular distributions

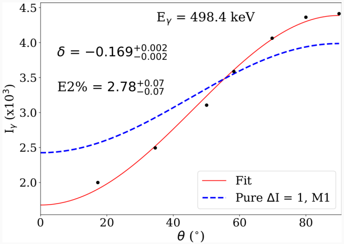
Angular Distributions (1/4)

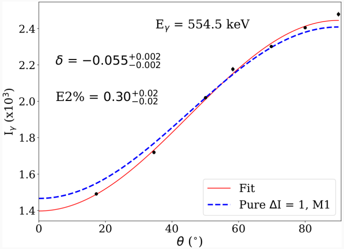




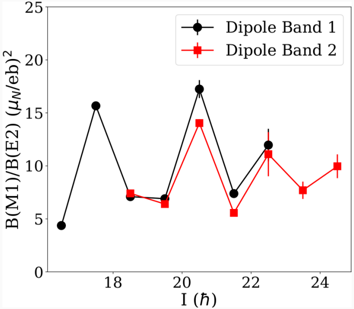


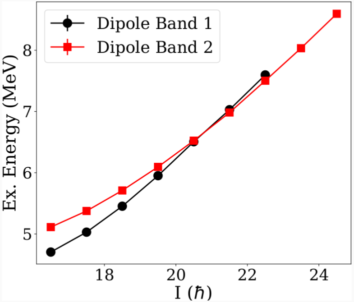


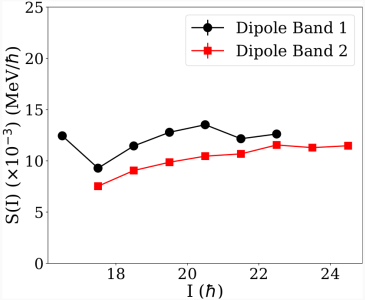




Other parameters







Reduced transition Probability ratios

Excitation Energy

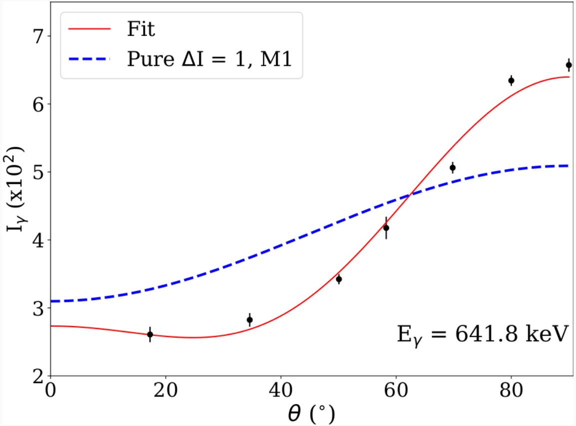
Staggering Parameter

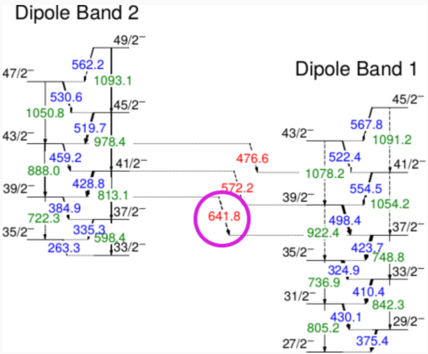
Angular Distributions (2/4)

$\boxed{E_\gamma = 641.8 \text{ keV}}$

$\delta = -2.92^{+0.12}_{-0.13}$

$E2\% = 89.5^{+0.8}_{-0.8}$



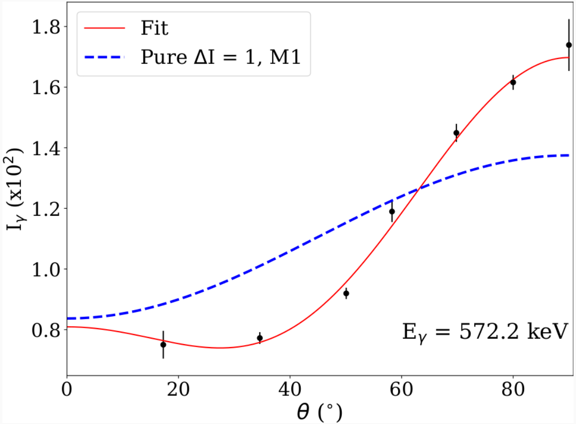


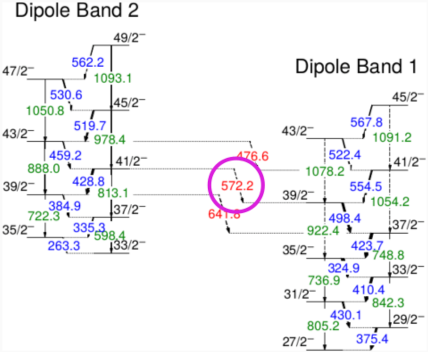
Angular Distributions (3/4)

$\boxed{E_\gamma = 572.2\ \text{keV}}$

$\delta = -3.31^{+0.16}_{-0.18}$

$E2\% = 91.6^{+0.8}_{-0.8}$



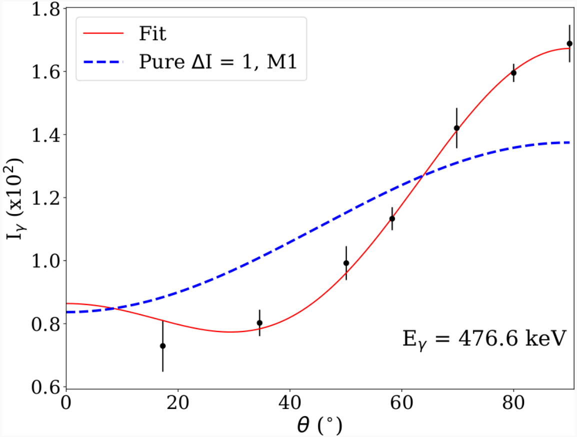


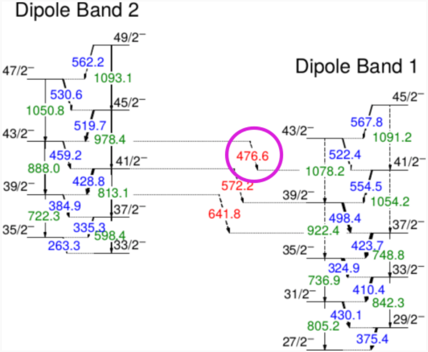
Angular Distributions (4/4)

E_γ = 476.6 keV

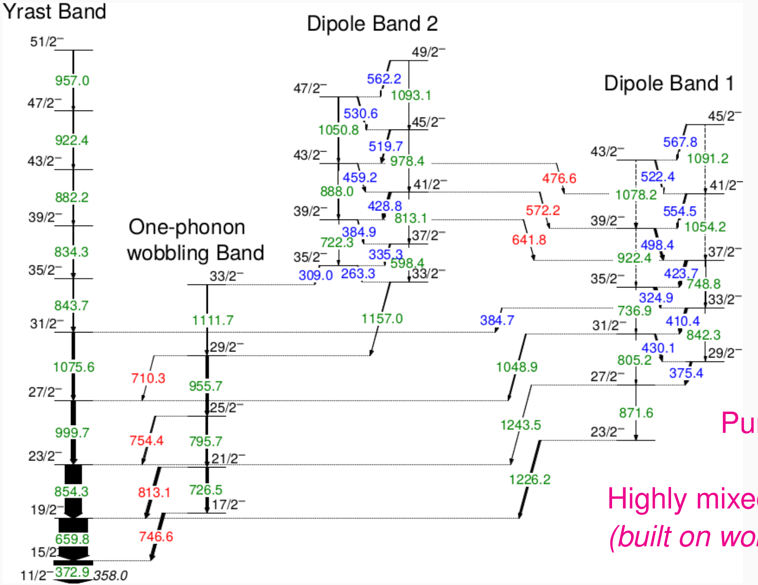
δ = $-3.68^{+0.34}_{-0.39}$

E2% = $93.1^{+1.2}_{-1.3}$





Level Scheme of ^{135}Pr (cont.)



Two $\Delta I = 1$ bands

Same parity

Similar energies

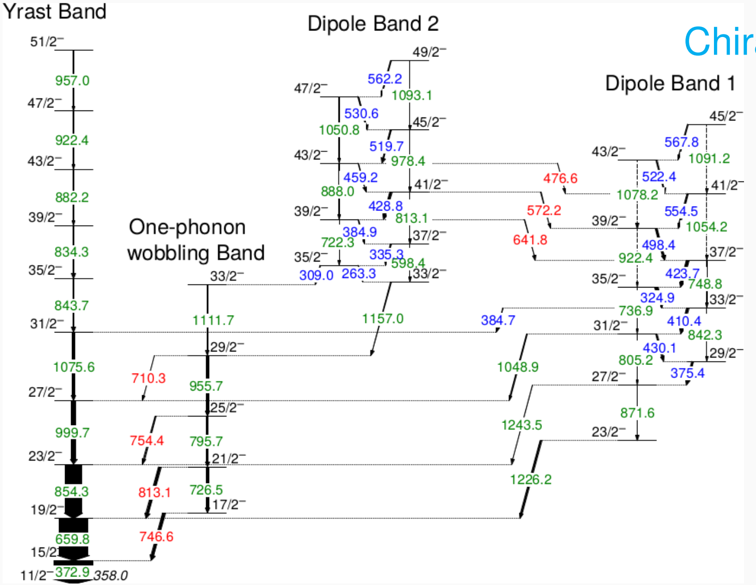
Nearly constant staggering

Identical B(M1)/B(E2) ratios

Pure M1 in-band transitions

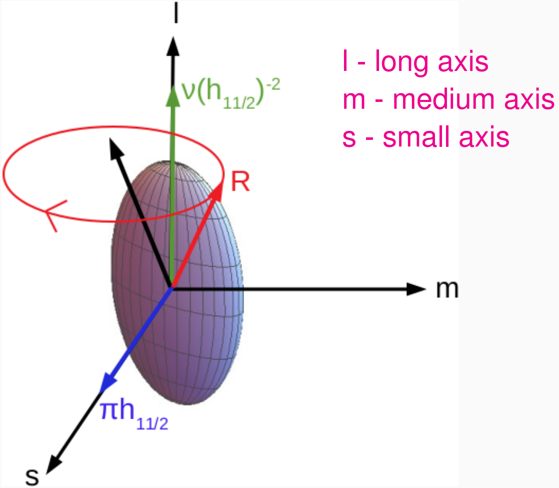
Highly mixed M1+E2 linking transitions
(built on wobbling excitations)

Level Scheme of ^{135}Pr (cont.)



Chiral Partners!

Chiral Wobbling in ^{135}Pr

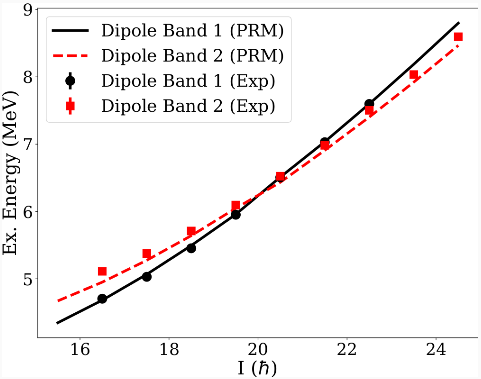


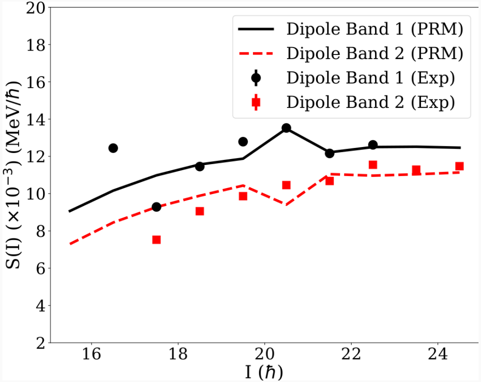
- Two additional $h_{11/2}$ neutron holes align along the l-axis.
- Net angular momentum generated in the s-l plane.
- Collective $\vec{R}$ precesses along this axis.
- Collective excitation of the wobbling type.

Signatures of Chirality

Preliminary theoretical results

- Close excitation energies
- Constant staggering parameter





Conclusion and Future Work

- The phenomenon of chiral wobbling motion has been investigated in ^{135}Pr.
- ^{135}Pr - first possible case of *Chiral wobbling*.
- High statistics angular distribution measurements performed.
- Ongoing analysis to extend the two dipole bands and find more connecting transitions.
- Calculations in the framework of the Particle Rotor Model (PRM) being done to affirm experimental observations.

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