Search for Wobbling Bands in Hf Nuclei: Are the TSD Bands Triaxial?

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A Brief History of TSD

- Best evidence for triaxiality is in ^{163}Lu
  - See "wobbling" excitations based on $\pi i_{13/2}$ structure
- Evidence of wobbling seen in ^{165}Lu & ^{167}Lu
- Ultimate Cranker predicts ^{164,166}Hf are good candidates
  - But no TSD bands found!
- We found 4 presumably SD bands in ^{174}Hf
  - And more are on the way…

^{163}Hf	^{164}Hf	^{165}Hf	^{166}Hf	^{167}Hf	^{168}Hf 3	^{169}Hf	^{170}Hf 1	^{171}Hf 1	^{172}Hf 3	^{173}Hf 1	^{174}Hf 8	^{175}Hf 2
^{162}Lu 3	^{163}Lu 4	^{164}Lu 8	^{165}Lu 4	^{166}Lu	^{167}Lu 5	^{168}Lu 2	^{169}Lu	^{170}Lu	^{171}Lu	^{172}Lu	^{173}Lu	
N =	92	93	94								102	

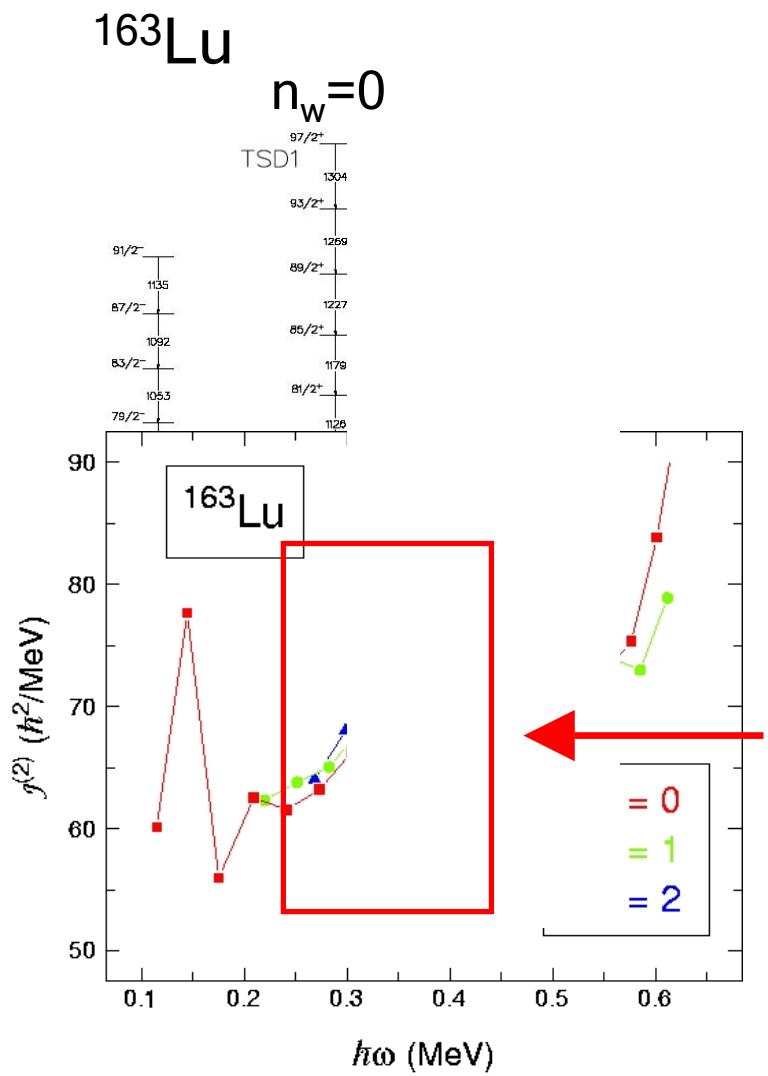
M.K. Djongolov *et al.*, PLB **560**, 24 (03)

G. Schönwaßer *et al.*, PLB **552**, 9 (03)

H. Amro *et al.*, PLB **553**, 197 (03)

S.W. Ødegård *et al.*, PRL **86**, 5866 (01)

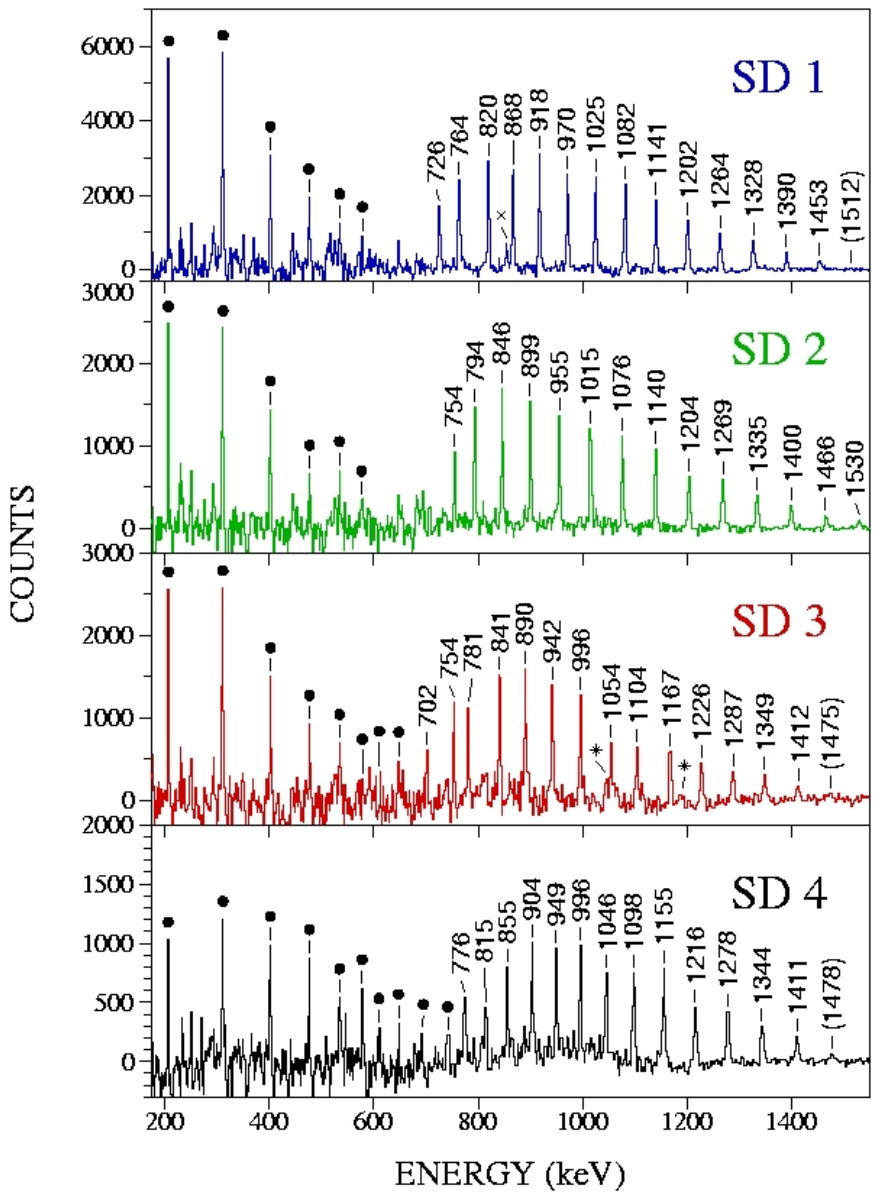
Observing Wobbling Bands Proves Triaxiality



D.R. Jensen *et al.*, PRL **89**, 142503 (02)

- Triaxial nucleus allows rotation about all 3 axes
- Total ang. momentum vector lies off principal axis - precession
- Amount it lies off axis quantized into wobbling phonons (n_w)
- See a family of bands based on same configuration (different n_w)
- Bands are linked together
  - $\Delta I = 1$ have dominant E2 nature
- Bands have similar properties
  - Moments of inertia, quadrupole moment, alignment

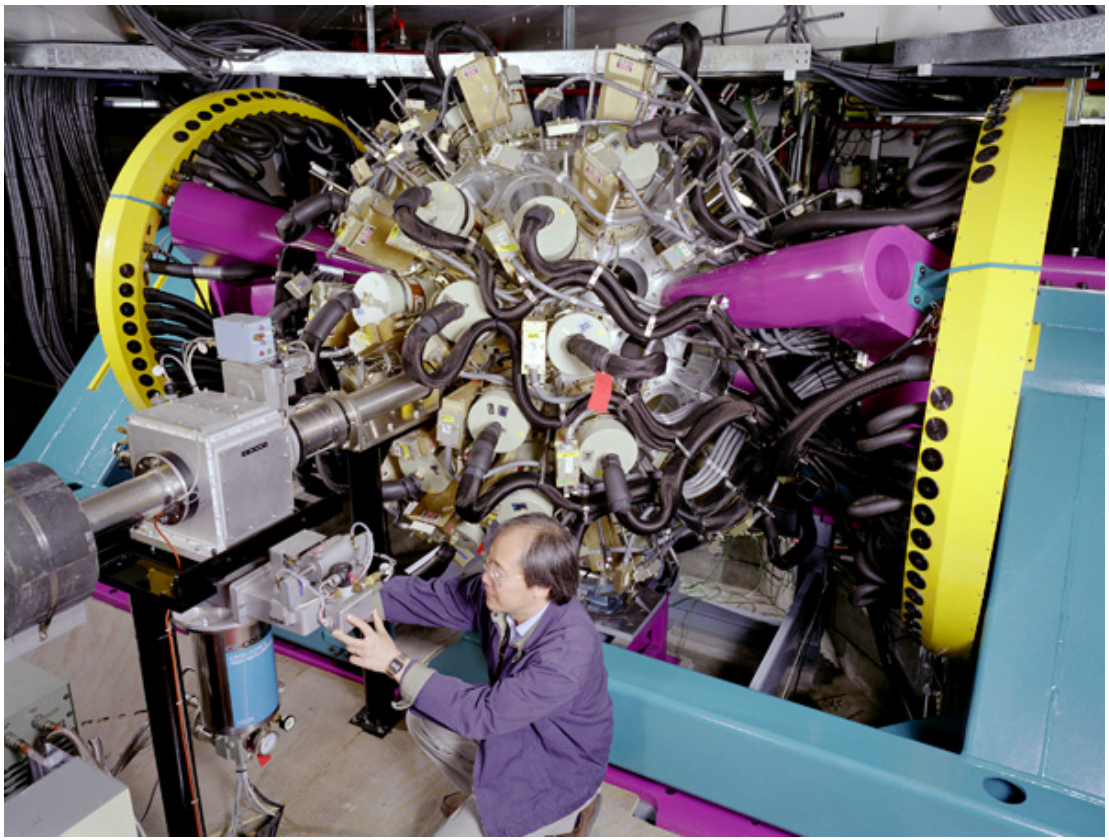
Quest to Prove Triaxiality in ^{174}Hf



- 4 bands known in ^{174}Hf
  - Found in a 24 hour experiment with Gammasphere
- Ultimate Cranker suggests SD bands are triaxial
- Performed 2 experiments at Gammasphere
  - Lifetime measurement to confirm large (and similar) deformation
  - High-statistics, thin-target run to look for linking transitions and other possible wobbling bands

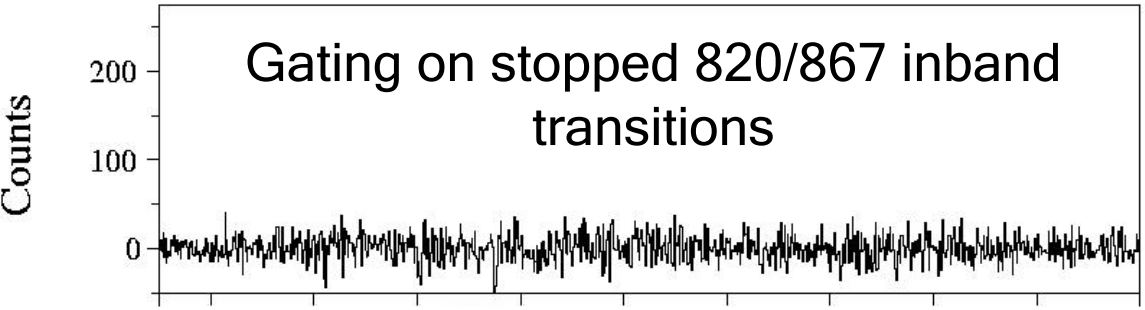
The Lifetime Measurement was Performed with Gammasphere at LBNL

- The reaction was $^{130}Te(^{48}Ca,4n)^{174}Hf$ (E_{beam} = 200 MeV)
- Gold-backed target to stop recoils
- $\approx 3.5 \times 10^9$ 5-fold events were recorded



- Created a Blue database for "easy" extraction of angle dependent double gates - M. Cromaz *et al.*, NIM A **462**, 519 (2001)
- Semi-automatic background subtraction - K. Starosta *et al.*, NIM A **515**, 771 (2003)

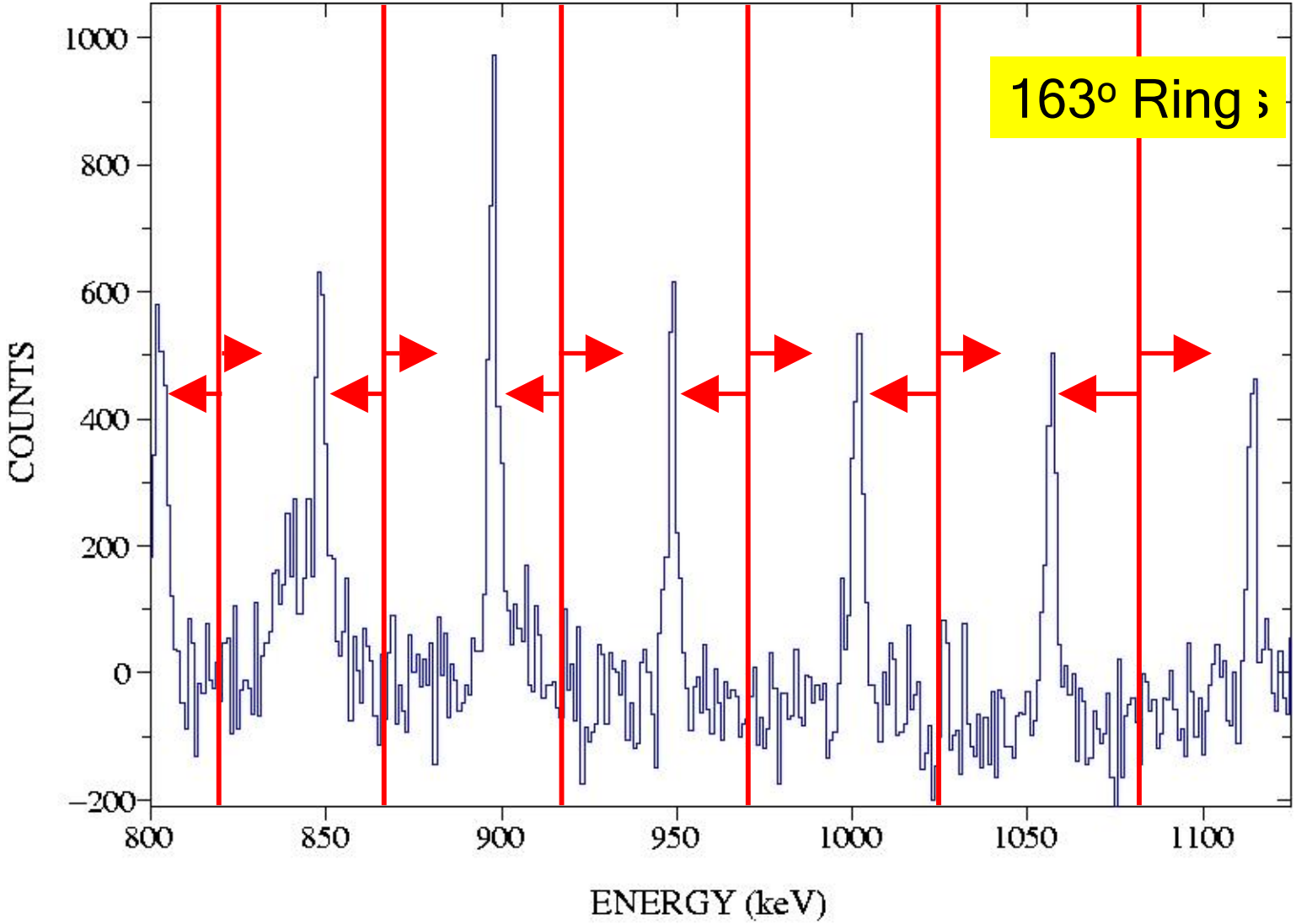
Applying “moving” double gates was a necessity to observe bands



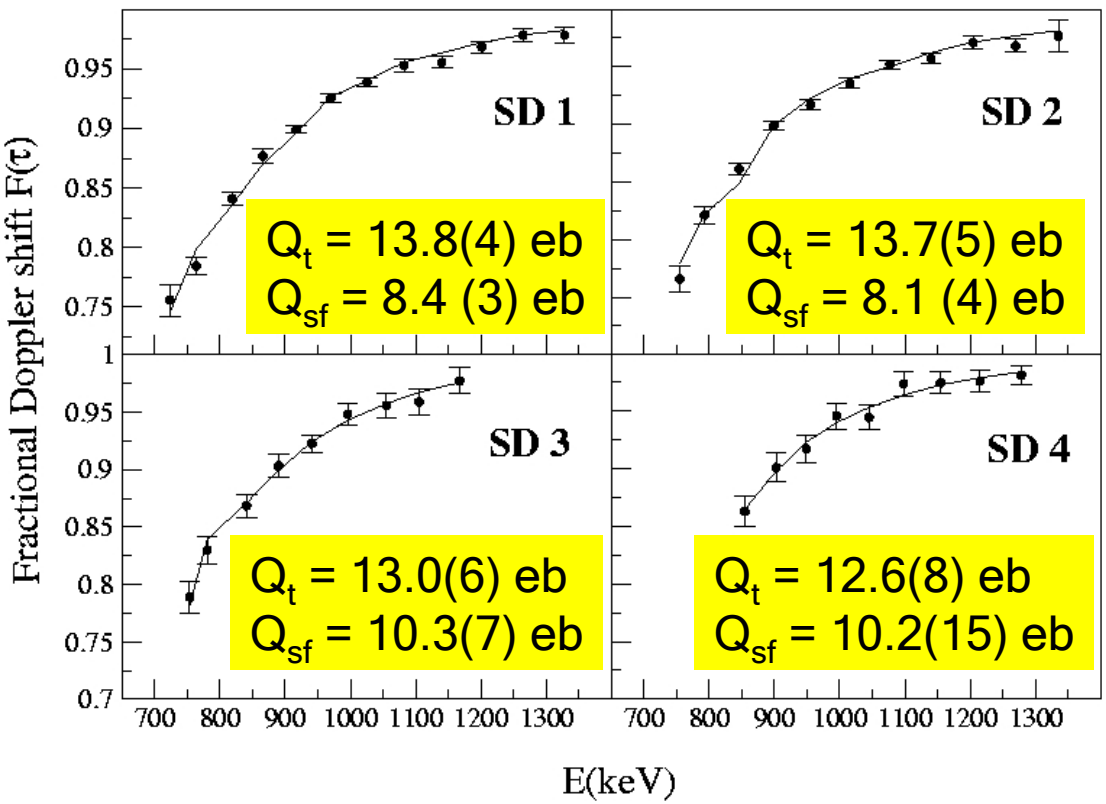
- Double gates must be used to see band
- Gating with stopped energies brings back only background
- We assumed Q_t would be similar to ^{168}Hf
- Angle-dependent energy shifts were calculated for ^{174}Hf
- Gating with shifted energies brings back the band

Final gating energies were determined from observed peaks

Tracking SD1 Transitions in ^{174}Hf



Quadrupole Moments Determined with FITFTAU

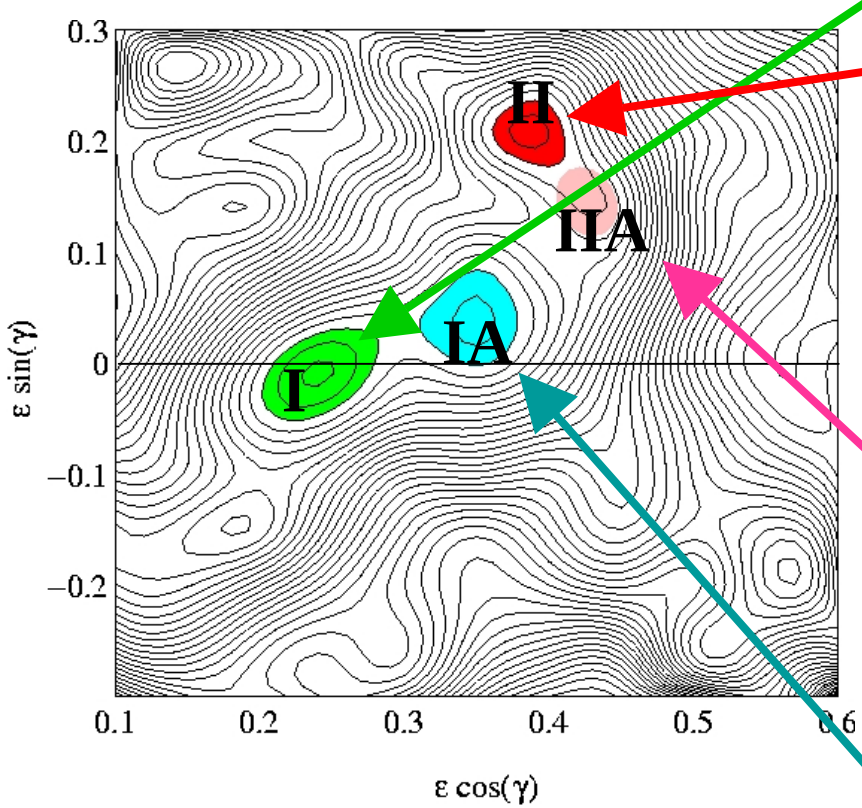


Errors based only on centroid uncertainty – additional 15-20% error due to stopping powers (SRIM2003)

- $F(\tau)$ determined from centroid shifts
- Values fit with FITFTAU
  - Assumes Q_t & Q_{sf} are constant
- Q_t & Q_{sf} varied until minimum χ^2 found
- Large deformation confirmed & bands have similar Q_t's
- But are they triaxial…

Comparison with Ultimate Cranker Preditions

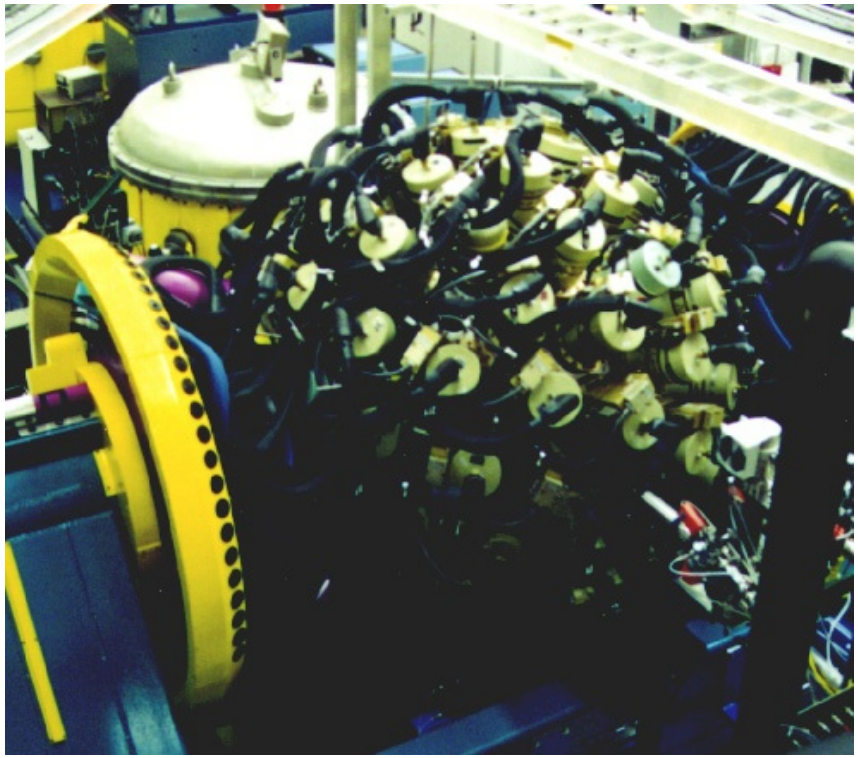
Spin = 50 ħ, $(\pi,\alpha) = (+,0)$



- Min. I is ND ($\varepsilon_2 \approx 0.25$, $\gamma \approx 0^o$)
- Min. II is lowest TSD ($\varepsilon_2 \approx 0.45$, $\gamma \approx 27^o$)
  - Seen for all (π,α)
- Predicted $Q_t \approx 9.9$ *e*b is much smaller than 13.5 *e*b
- Min. IIA has $\varepsilon_2 \approx 0.47$, $\gamma \approx 18^o$ leading to $Q_t \approx 12.2$ *e*b
  - Seen only for $(\pi,\alpha)=(+,0)$
  - Seen only for I = 50-56ħ
- Min. IA has $\varepsilon_2 \approx 0.35$, $\gamma \approx 8^o$ leading to $Q_t \approx 9.9$ *e*b

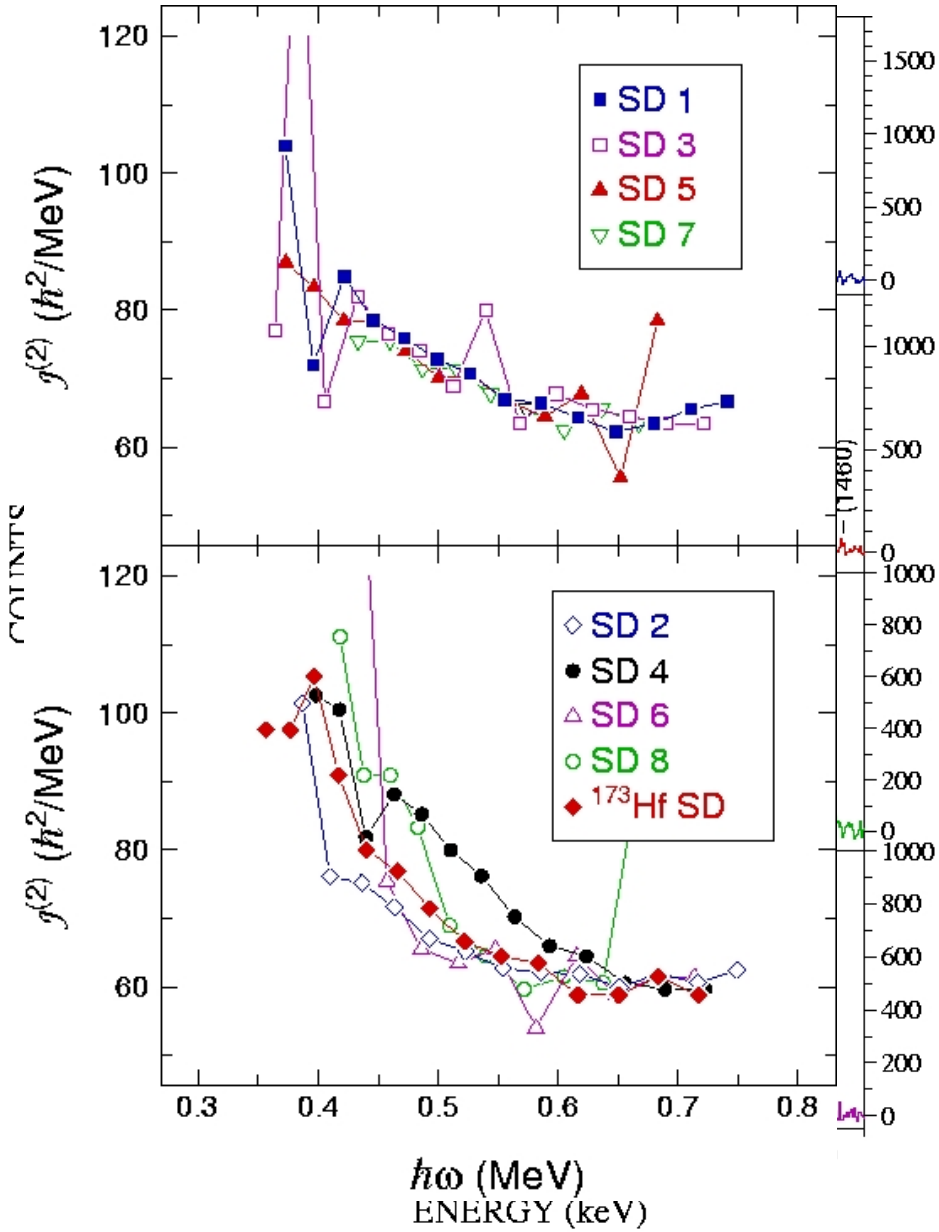
Discrepancy between UC and expt. is of concern since UC is main basis for TSD

Search for Linking Transitions Between SD Bands using Gammasphere at ANL



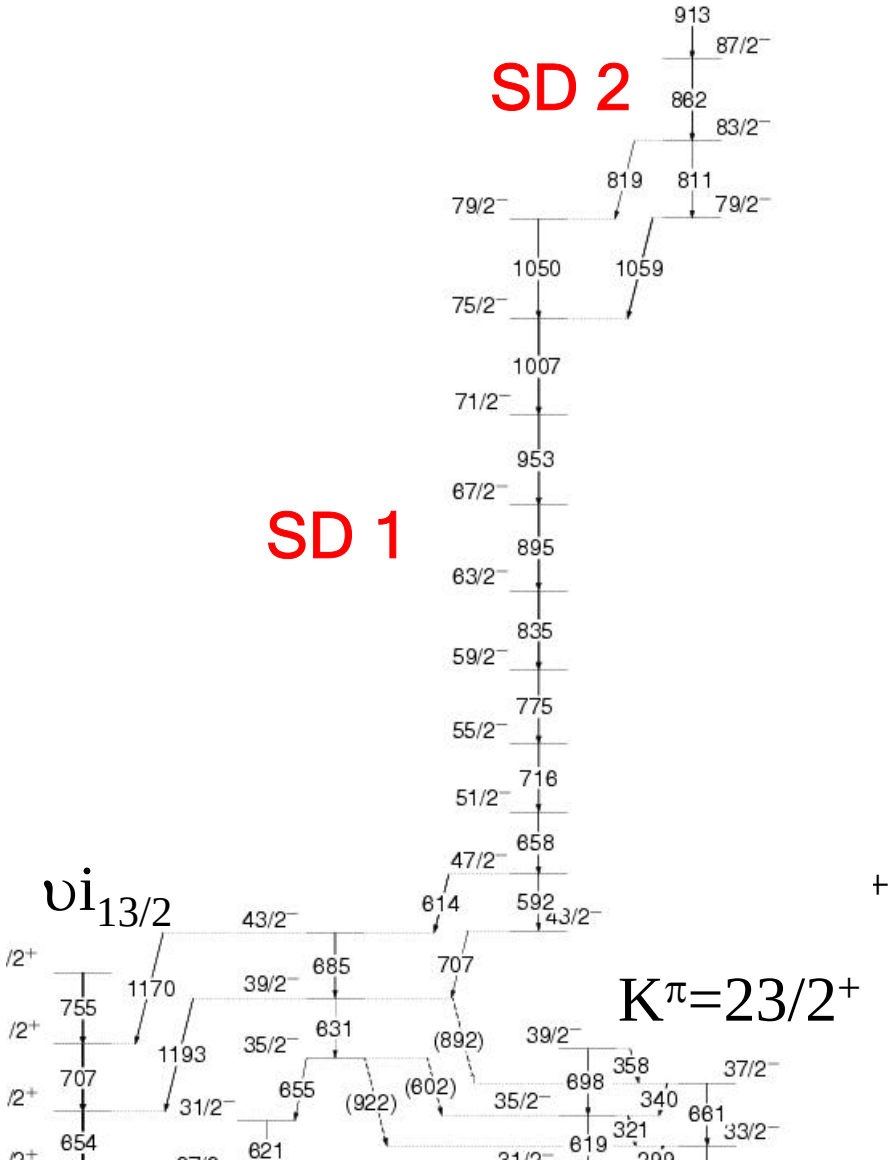
- Reaction: $^{130}Te(^{48}Ca,4n)$ at E_{beam} = 205 MeV
- Used thin target - Doppler corrected γ rays
- Ran for 6 days, collected $\approx 2.6 \times 10^9$ 4-fold and greater events
- Sorted data into coincidence cubes and hypercubes

What We Found…



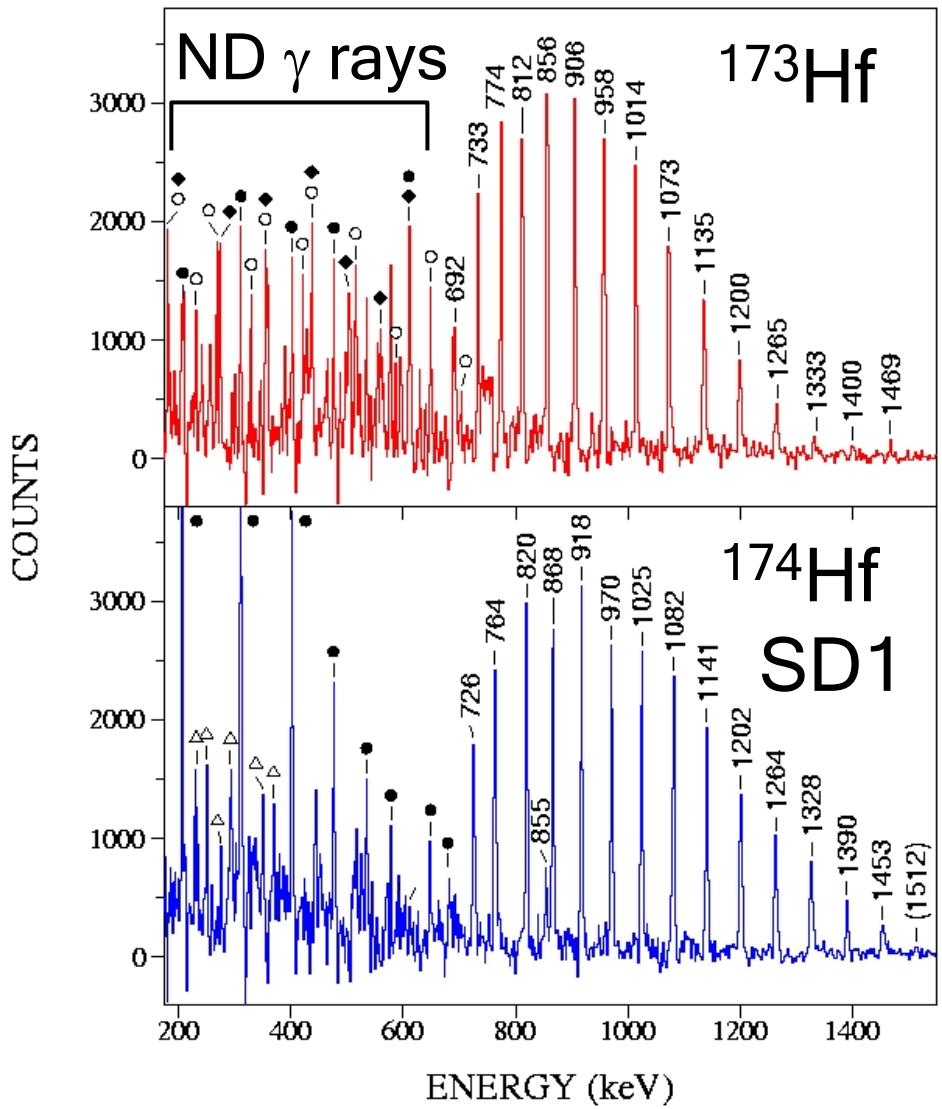
- Found 4 new likely SD bands – now have 8!
  - Too weak to get Q_t
- Also found one SD band in ^{173}Hf (show you later)
- But no linking transitions between any of the bands
- Arrange bands into two families
  - But this is not unique to wobbling
- Cannot prove triaxiality at this time

What Can We Learn From Neighboring Nuclei?
^{175}Hf - From 24-hour GS Experiment



- See poster by D. Scholes *et al.*
- SD 2 in ^{175}Hf is linked and is identical to SD 1 in ^{174}Hf
- SD 2 in ^{175}Hf likely 7-qp band, so SD's in ^{174}Hf are at least 6-qp
- More complex config's than Lu TSD ($\pi i_{13/2}$)
- No family of bands seen

What Can We Learn From Neighboring Nuclei?
^{173}Hf - From 6-day GS Experiment



- Populated with nearly same strength as SD 1 in ^{174}Hf
- Could not be linked
- Only SD band found in ^{173}Hf
- If it is based in a TSD minimum, where is the family of wobbling bands?
- Higher energy for wobbling quanta?
- Not triaxial?

Let's Sum Up…

- Evidence consistent (but not unique) for TSD
  - Large deformation confirmed (≈13.5 *e*b)
  - Bands have similar deformation
  - Can group bands into two families in ^{174}Hf
- Evidence not consistent with theoretical predictions of TSD
  - No evidence of linking transitions between SD bands
  - Q_t's do not compare favorably with UC predictions
  - Family of bands not seen in ^{173,175}Hf
  - Hf bands are a different "class" compared with Lu
- Triaxiality of Hf SD bands is an open question

The Collaboration

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