

Structure of low-lying states in ^{140}Sm studied by Coulomb excitation

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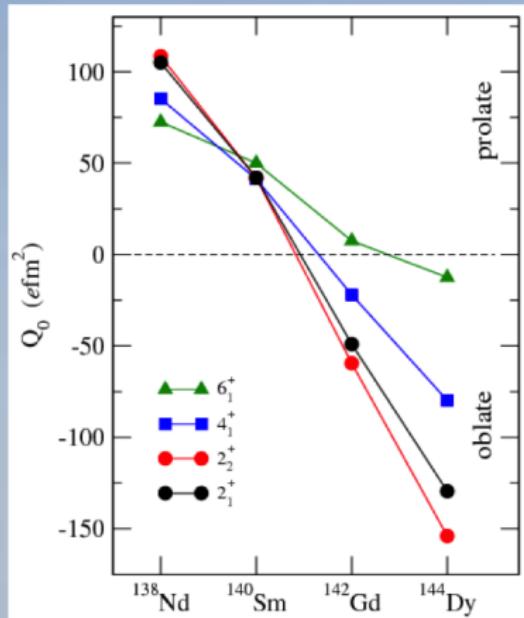
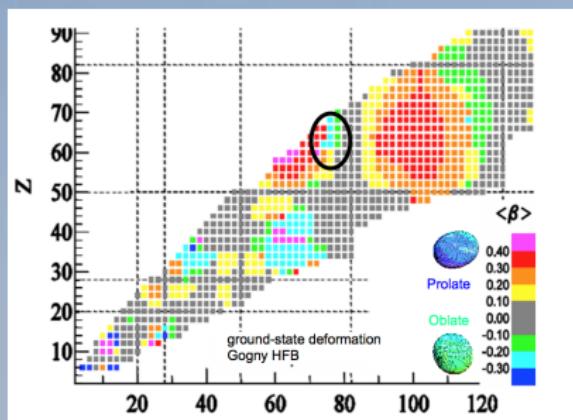


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Outline

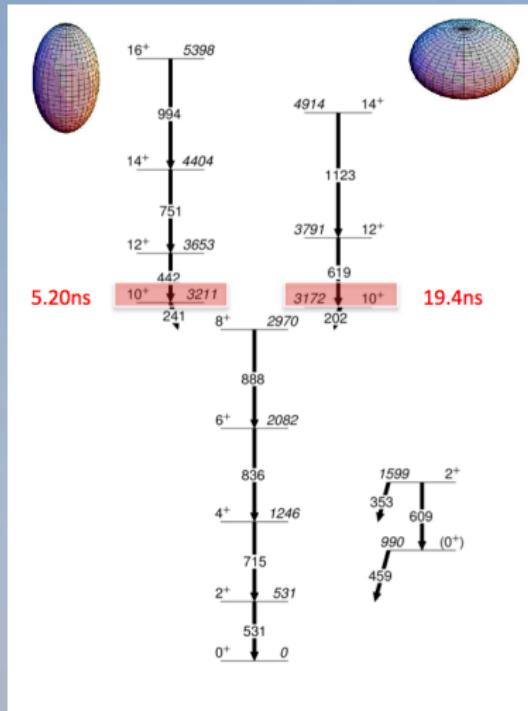
- ▶ ^{140}Sm - Why do we care?
- ▶ The Coloumb excitation experiment
- ▶ Spectra
- ▶ GOSIA2 calculations and results
- ▶ Angular correlations
- ▶ Interpretation
- ▶ Future

$^{140}_{62}\text{Sm}$, How does collectivity evolve?



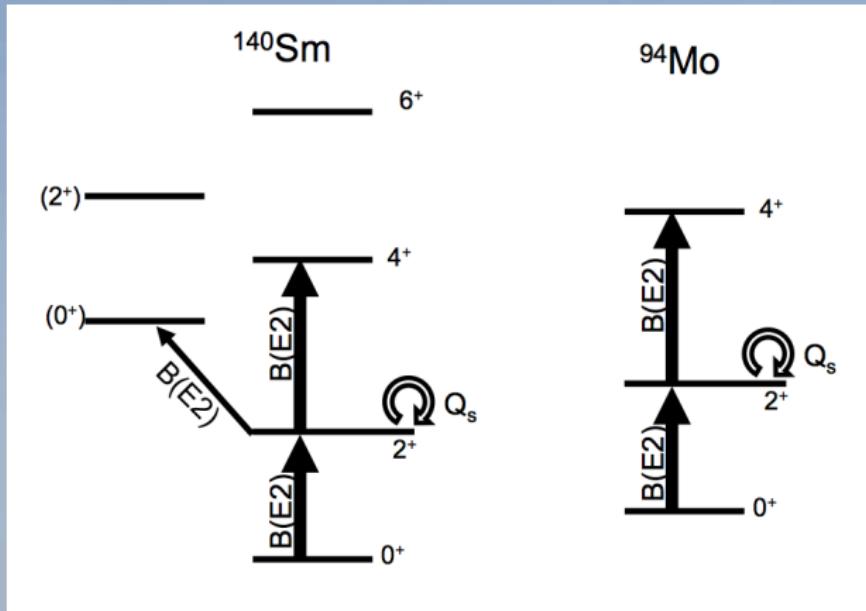
- ▶ Beyond mean field calculations of nuclear shape.

Shape coexistence above Isomeric states



- ▶ Lifetimes of low excited states unknown, due to isomeric 10^+ states of $\pi(h_{11/2})^2$ and $\nu(h_{11/2})^{-2}$.
- ▶ Low lying 0_2^+ ..

Goal



- ▶ Obtain $B(E2)$ and Q , using normalization to target excitation.

The experiment

- ▶ Coulomb excitation experiment

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- ▶ $^{140}\text{Sm} + ^{94}\text{Mo}$

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- ▶ $^{140}\text{Sm} + ^{94}\text{Mo}$
- ▶ ^{140}Sm obtained at ISOLDE with Resonant Laser Ionization

The experiment

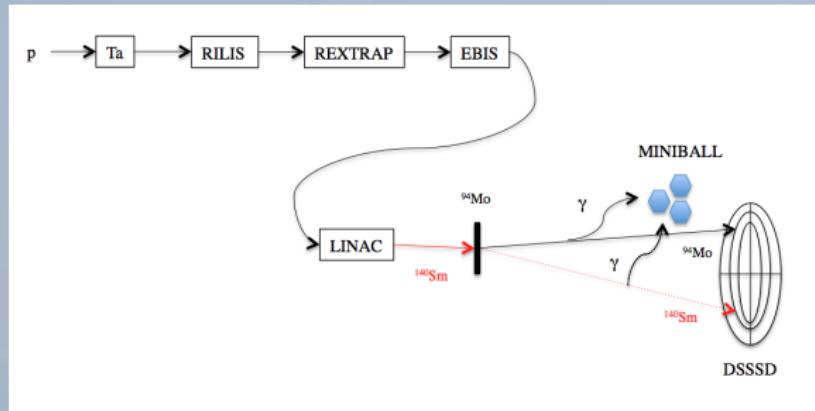
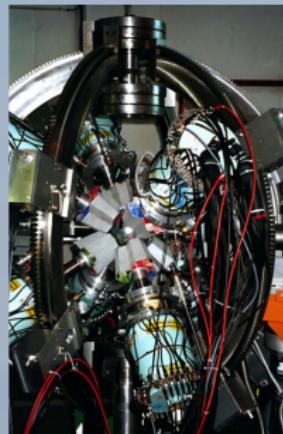
- ▶ Coulomb excitation experiment
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- ▶ Beam energy: 2.85 MeV/nucleon and Intensity: $2 \cdot 10^5$ particles/s

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- ▶ γ -photons detected in MINIBALL

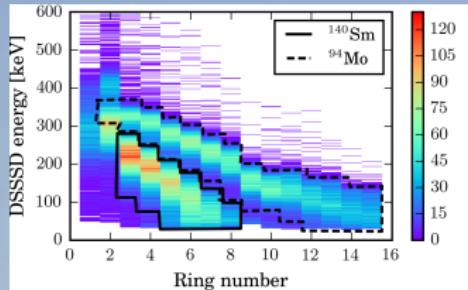
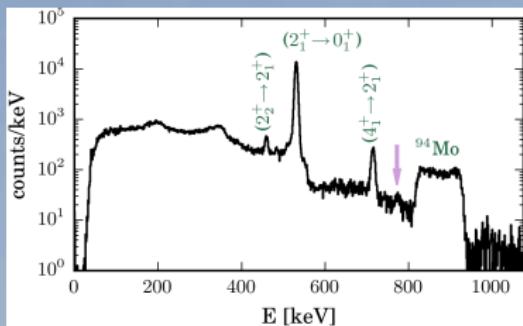
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- ▶ Beam energy: 2.85 MeV/nucleon and Intensity: $2 \cdot 10^5$ particles/s
- ▶ γ -photons detected in MINIBALL
- ▶ Particles detected in circular DSSSD. Angular range: [20 58] deg

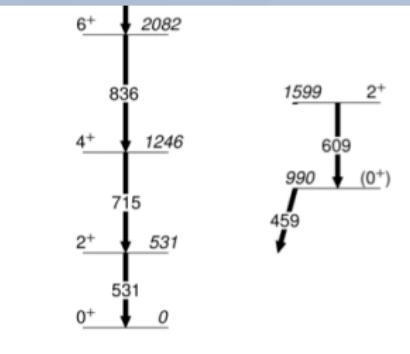
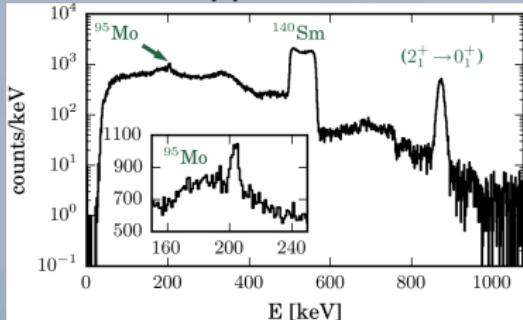


Spectra

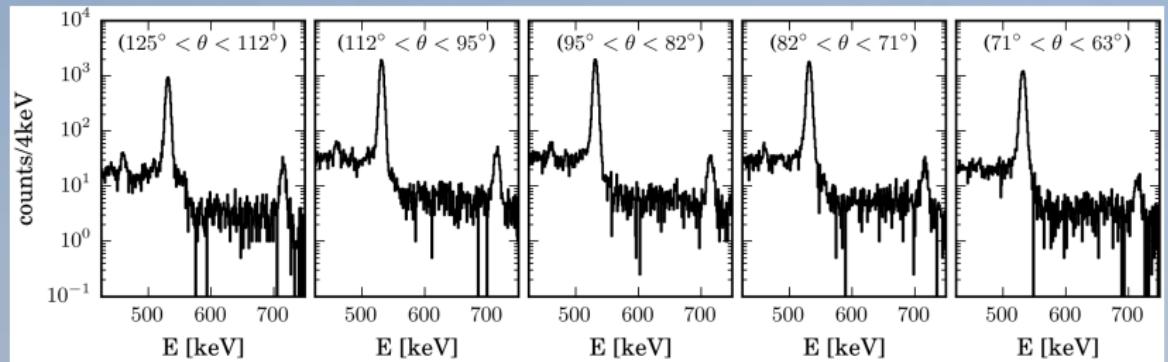
^{140}Sm Doppler correction



^{94}Mo Doppler correction



Angular binning

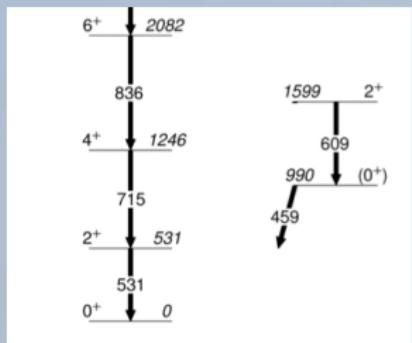
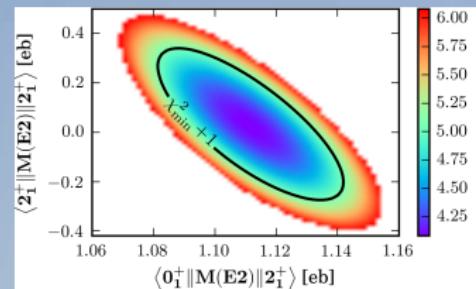


GOSIA results

GOSIA2 scan over χ^2

Table: Matrix elements in ^{140}Sm with correlated errors obtained with target normalization approach.

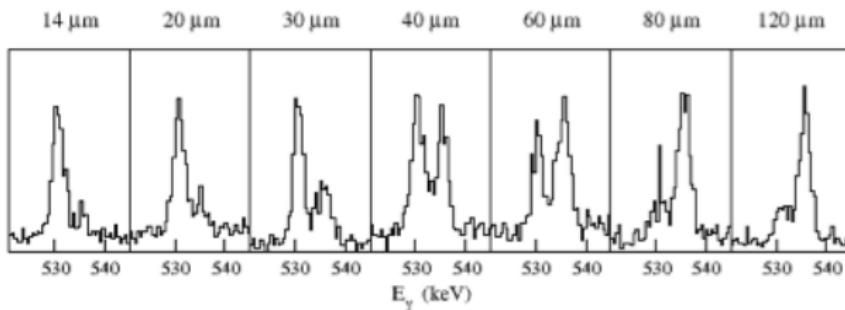
I_i	I_f	$\langle I_f M(E2) I_i \rangle$ eb	$B(E2; I_i \rightarrow I_f)$ $e^2 b^2$	W.U.
2_1^+	0_1^+	$1.12_{-0.05}^{+0.05}$	$0.25_{-0.02}^{+0.02}$	58_{-5}^{+5}
2_1^+	2_1^+	$-0.18_{-0.29}^{+0.43}$	-	-
4_1^+	2_1^+	$1.64_{-0.05}^{+0.05}$	$0.30_{-0.02}^{+0.02}$	70_{-5}^{+5}
$(0_2^+) 2_1^+$		$1.01_{-0.07}^{+0.07}$	$1.02_{-0.15}^{+0.15}$	236_{-35}^{+35}



Lifetime measurement

The Lifetime of the 2_1^+ was measured independently, using Recoil Distance Doppler shifted method, at HIL, Warsaw.

$^{124}\text{Te}(^{20}\text{Ne},4\text{n})^{140}\text{Sm}$. 9.0(7) ps



Analysis by Frank Bello, University of Oslo.

Result

Table: Matrix elements in ^{140}Sm with correlated errors obtained with lifetime normalization approach.

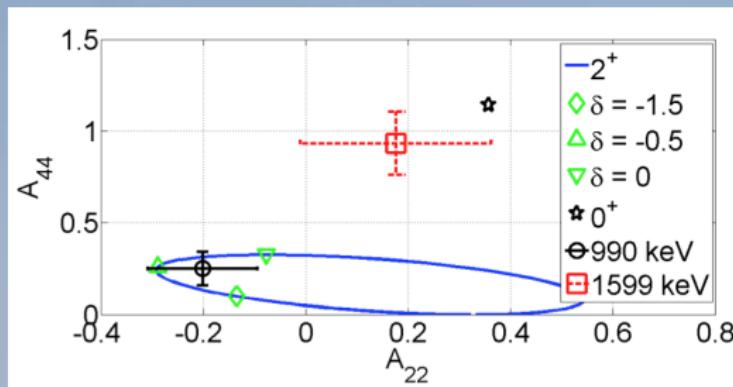
I_i	I_f	$\langle I_f M(E2) I_i \rangle$	$B(E2; I_i \rightarrow I_f)$	
		eb	$e^2 b^2$	W.U.
2_1^+	0_1^+	$1.03_{-0.03}^{+0.04}$	$0.21_{-0.01}^{+0.02}$	49_{-3}^{+4}
2_1^+	2_1^+	$-0.36_{-0.23}^{+0.29}$	-	-
4_1^+	2_1^+	$1.63_{-0.05}^{+0.05}$	$0.30_{-0.02}^{+0.02}$	69_{-5}^{+5}
$(0_2^+) 2_1^+$		$1.00_{-0.07}^{+0.07}$	$0.99_{-0.14}^{+0.15}$	229_{-32}^{+35}

Investigate tentatively assigned 0^+

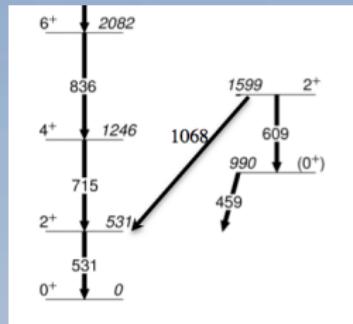
β -decay experiment performed at HIL,

Warsaw. $^{112}\text{Cd}(\text{³²S},\text{p3n})\text{¹⁴⁰Eu}$.

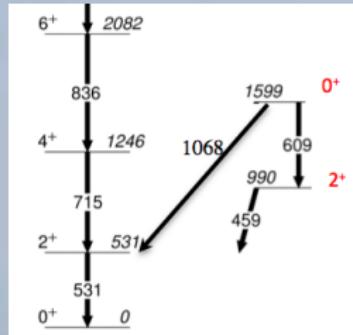
Result from angular correlation.



Before



After



Analysis by Malin Klintefjord, University of Oslo
and Justyna Samorajczyk, University of Lodz.

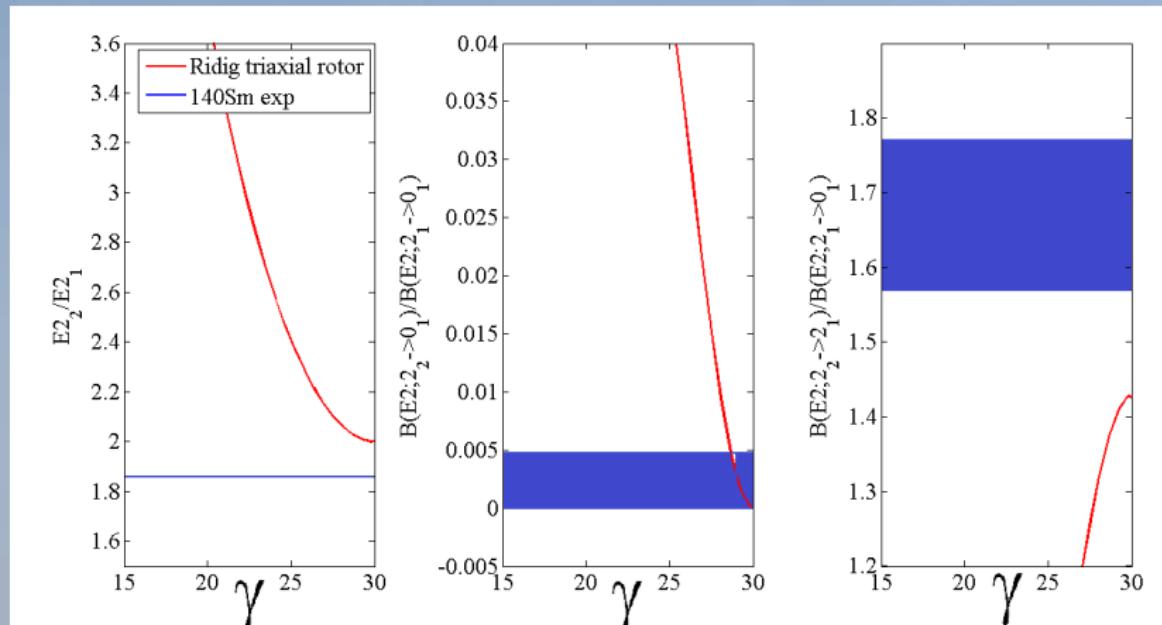
Result

Table: Matrix elements and $B(E2; I_i \rightarrow I_f)$ in ^{140}Sm with correlated errors obtained assuming (2_2^+) state at 990keV.

I_i	I_f	Without lifetime			With lifetime		
		$M(E2)$ eb	$B(E2)$ $e^2 b^2$	W.U.	$M(E2)$ eb	$B(E2)$ $e^2 b^2$	W.U.
$2_1^+ 0_1^+$		$1.12^{+0.03}_{-0.02}$	$0.25^{+0.01}_{-0.01}$	58^{+7}_{-5}	$1.03^{+0.04}_{-0.03}$	$0.21^{+0.02}_{-0.01}$	49^{+4}_{-3}
$2_1^+ 2_1^+$		$+0.06^{+0.54}_{-0.20}$	-	-	$-0.19^{+0.48}_{-0.19}$	-	-
$4_1^+ 2_1^+$		$1.64^{+0.05}_{-0.05}$	$0.30^{+0.03}_{-0.02}$	70^{+5}_{-5}	$1.61^{+0.05}_{-0.05}$	$0.29^{+0.02}_{-0.02}$	67^{+5}_{-5}
$2_2^+ 2_1^+$		$1.32^{+0.08}_{-0.09}$	$0.36^{+0.05}_{-0.05}$	83^{+12}_{-12}	$1.34^{+0.08}_{-0.09}$	$0.36^{+0.05}_{-0.05}$	81^{+12}_{-12}
$2_2^+ 0_1^+$		< 0.1	< 0.002		< 0.07	< 0.001	

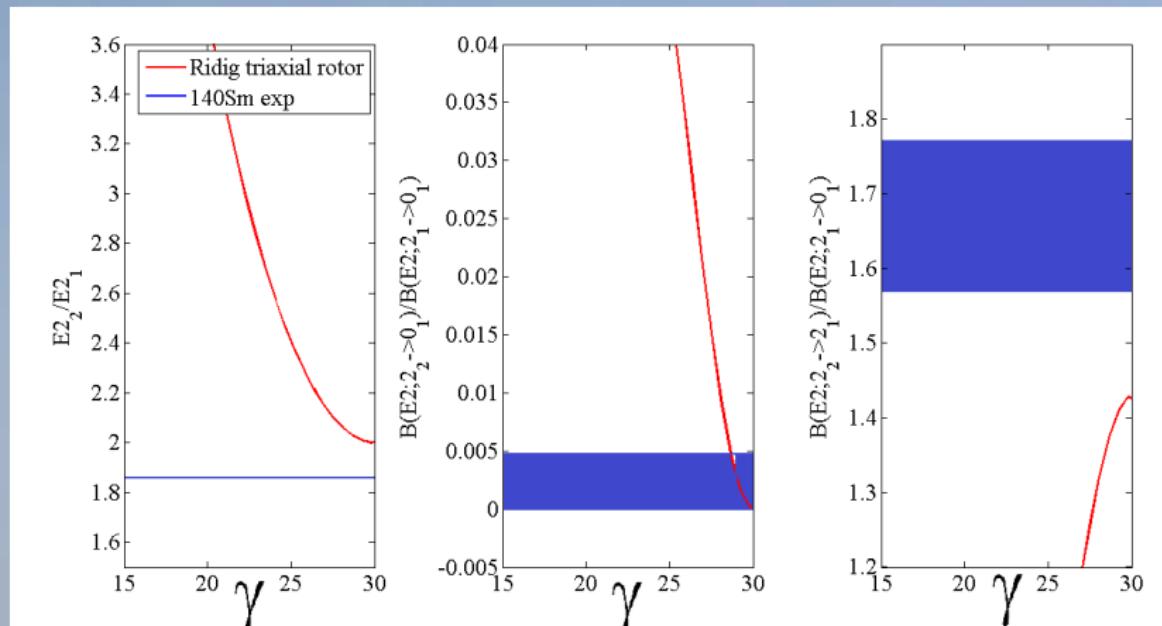
Interpretation

Davydov-Filippov model with $\gamma = 30^\circ$



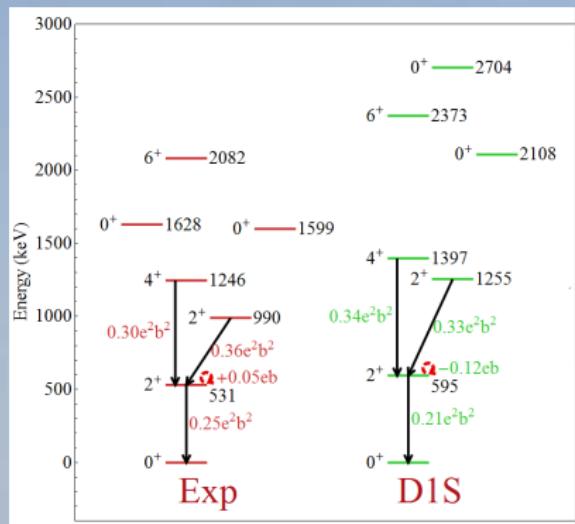
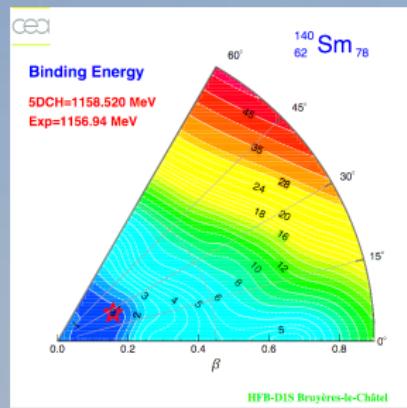
Interpretation

Davydov-Filippov model with $\gamma = 30^\circ$



Experimentally hard to distinguish from γ -soft.

Constrained Hartree-Fock Bogolibov with Gogny D1S interaction



Soft in β and γ .

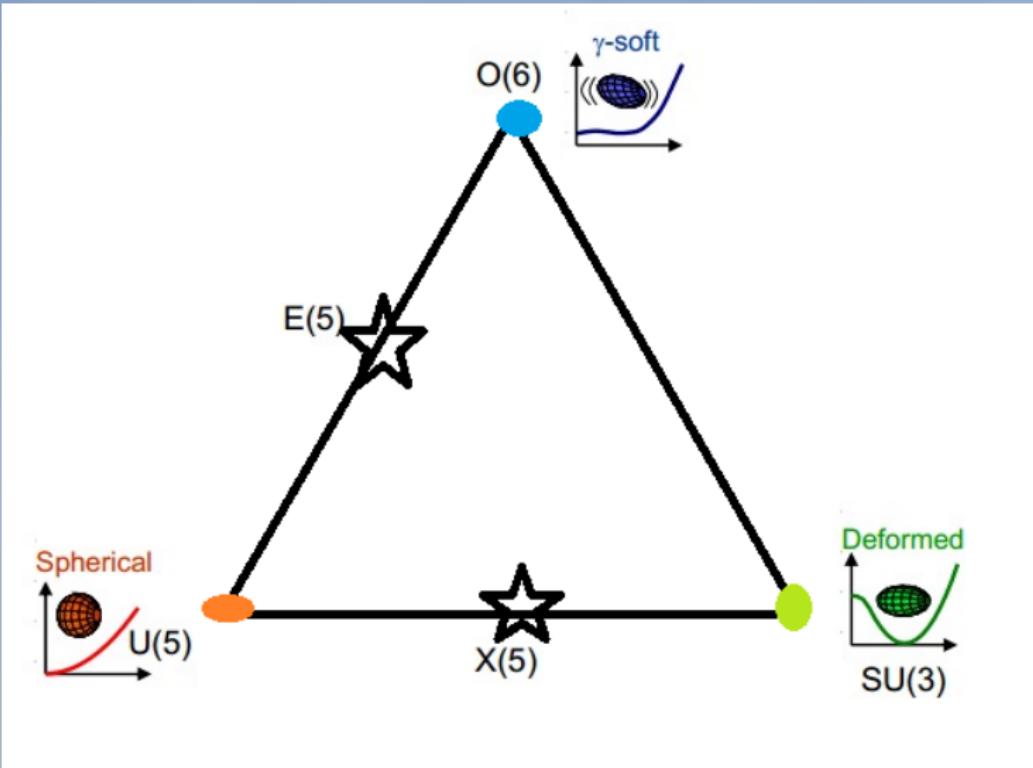
Results from M.Girod and J.-P.Delaroche, CEA Bruyeres-le-Chatel (priv. comm.)

Mapped on 5-dimensional collective Hamiltonian

No free parameters

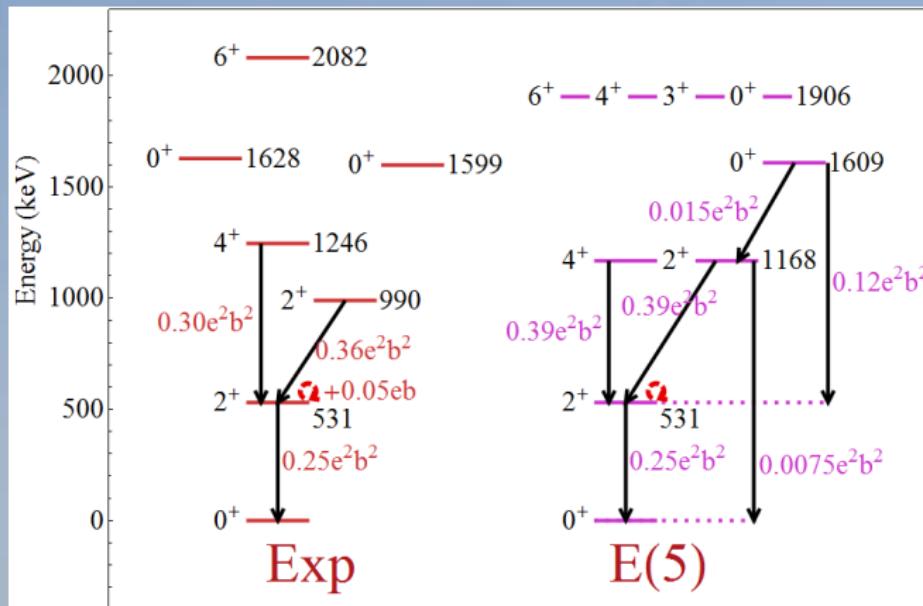
J.-P. Delaroche et al. PRC 81, 014303 (2010)

Interpretation



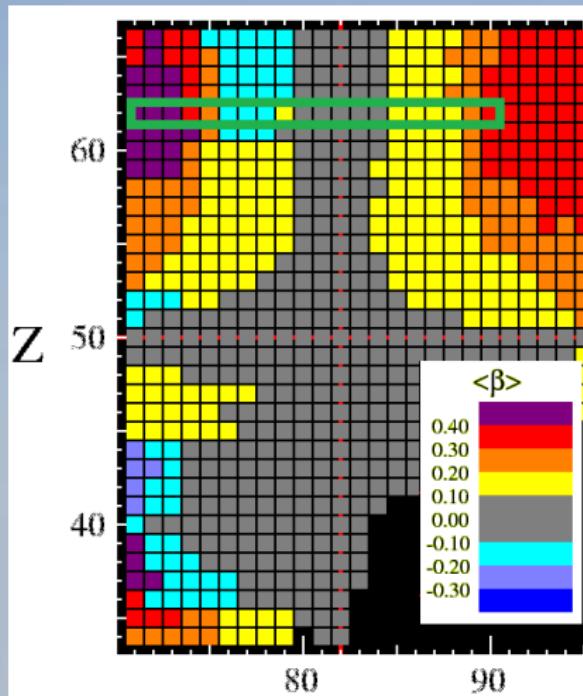
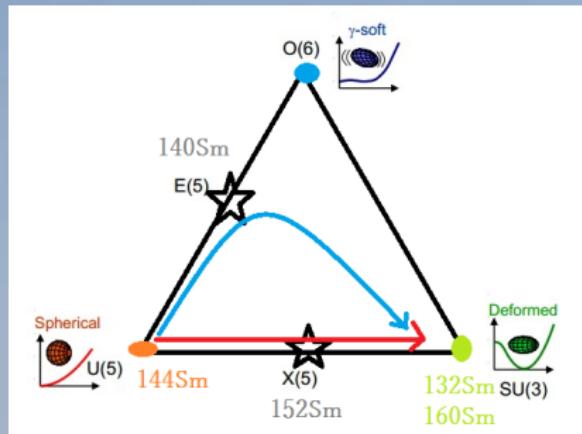
Solving Schrödinger eq for square well gives an analytic solution for the E(5) critical point.

Interpretation



^{140}Sm is as good example for E(5) as any other nucleus. It has been missed so far because of wrong assignment for 990 keV excited state.

Sm isotopes



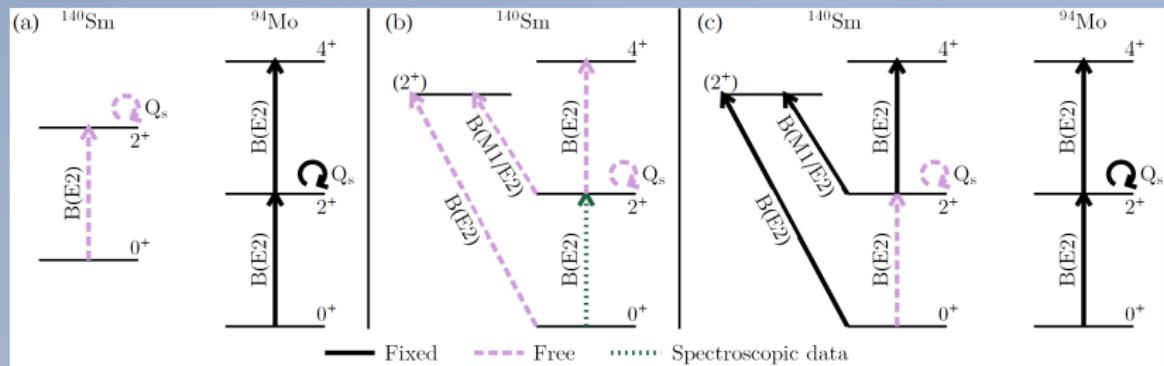
Conclusions

- ▶ Coulomb excitation $^{140}\text{Sm} + ^{94}\text{Mo}$ at CERN, ISOLDE
- ▶ Lifetime investigation at HIL, Warsaw
- ▶ Spin-state assignment from angular correlation at HIL, Warsaw
- ▶ Behavior of typical transitional nucleus
- ▶ Well described by constrained HFB calculations, Gogny D1S interaction
- ▶ Good example for E(5) symmetry
- ▶ Future: accepted proposal at HIE ISOLDE

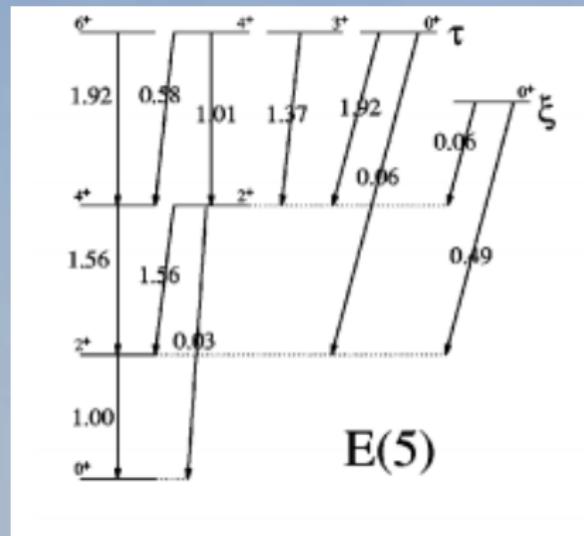
Thank you for your attention!



Backup



Backup



Arias, J. M. Physical Review C, vol. 63, Issue 3, id. 034308