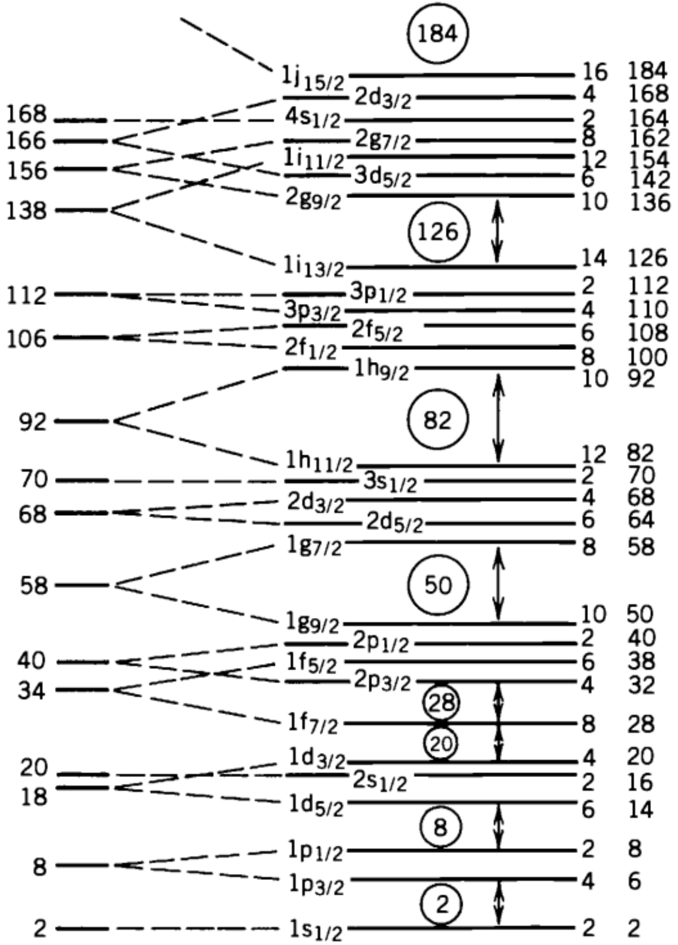
DEFINING AND IDENTIFYING PRE-COLLECTIVE NUCLEI THROUGH ELECTROMAGNETIC TRANSITIONS AND MOMENTS

Spin dependent emergence of collectivity

Australian
National
University

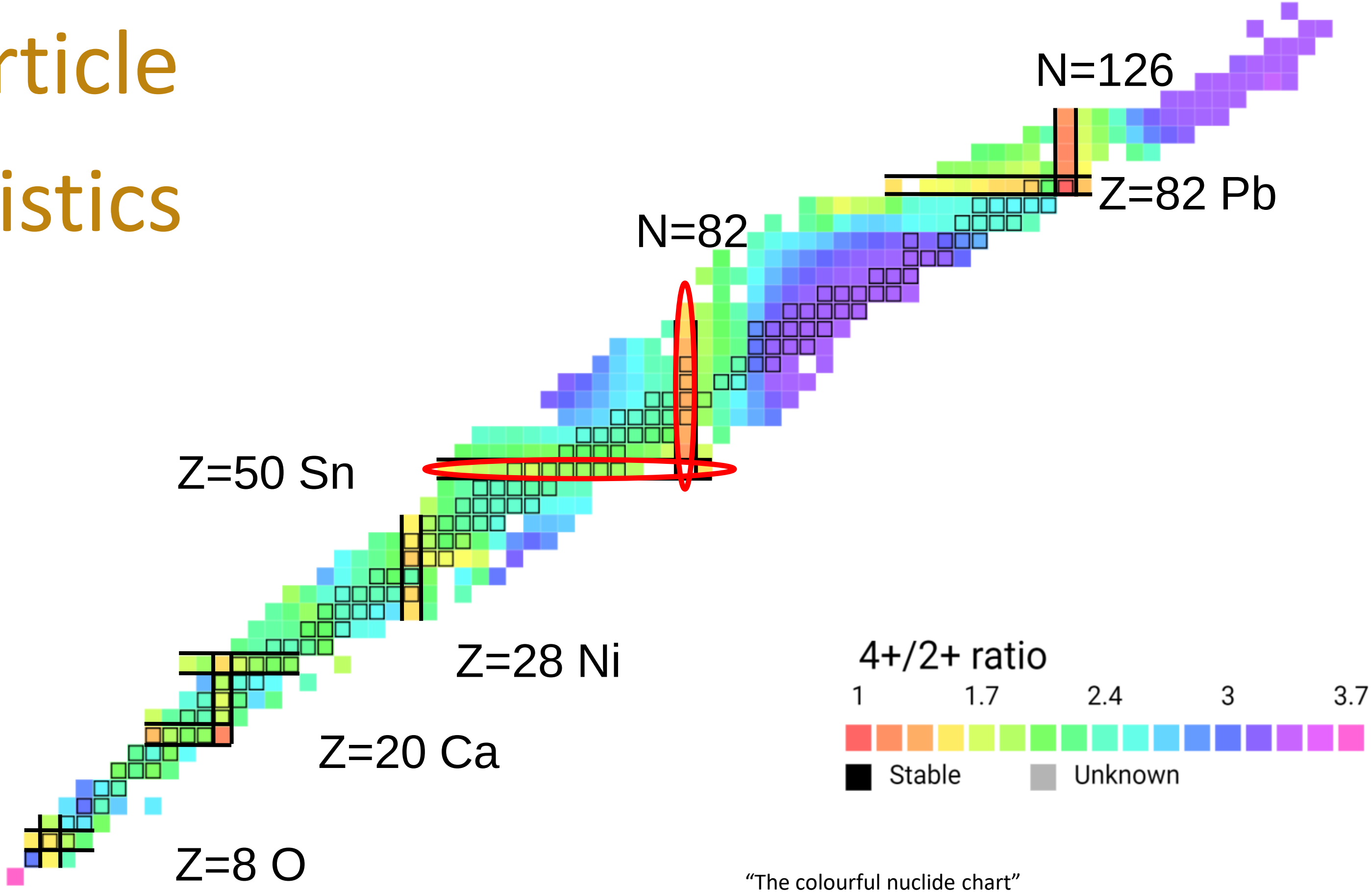
The shell model

Nucleon orbits



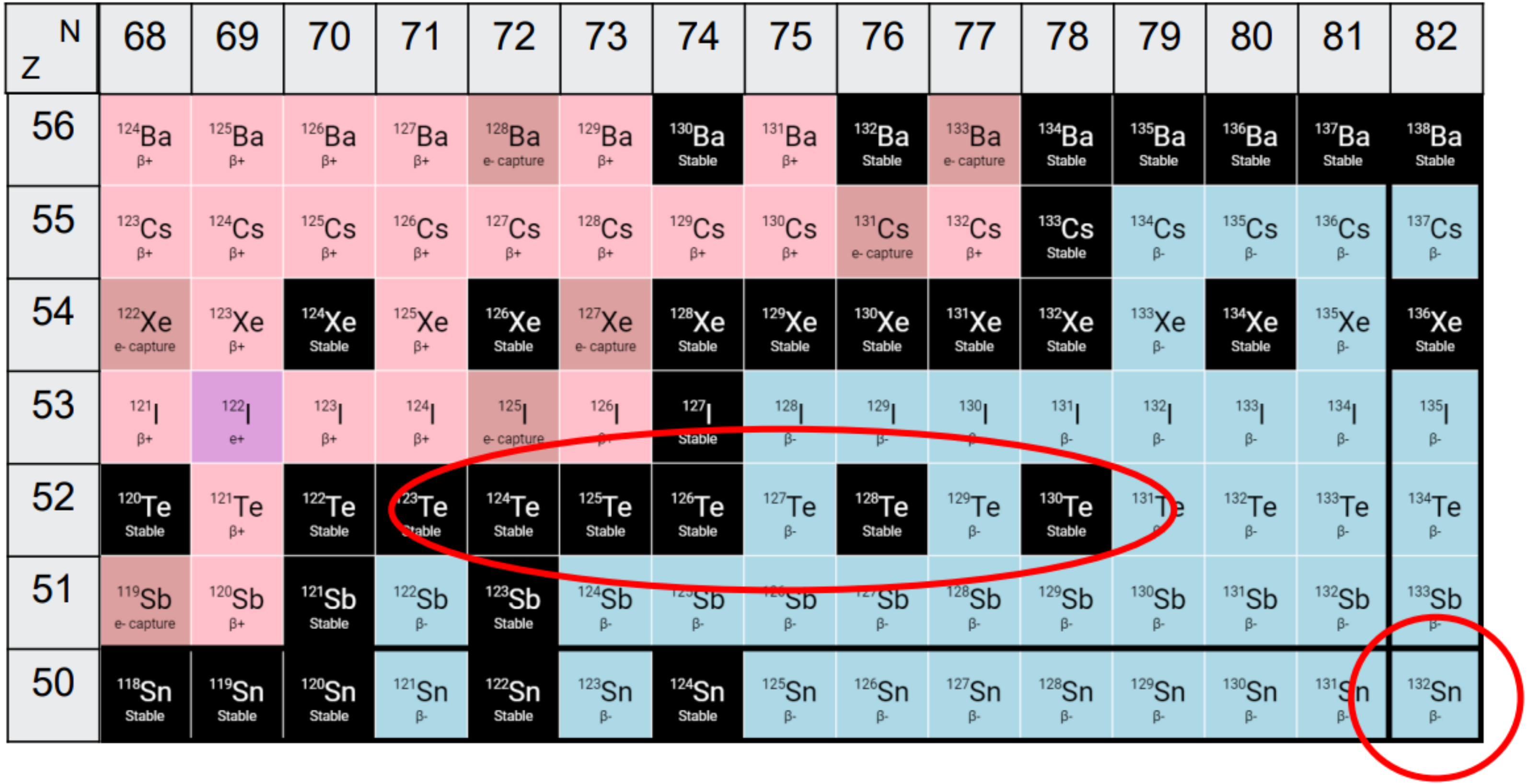
Single-particle characteristics

The ^{132}Sn region



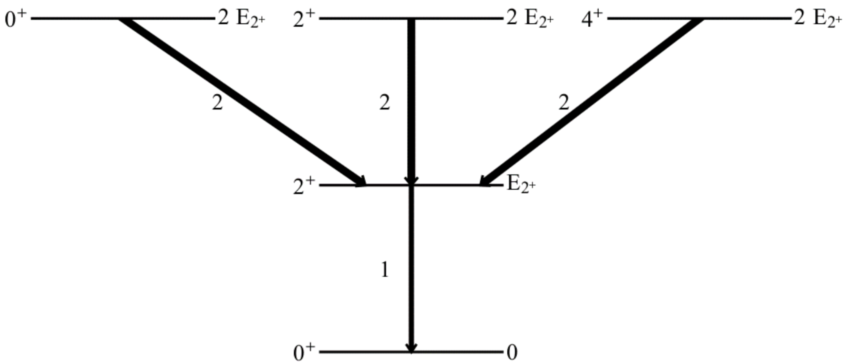
“The colourful nuclide chart”
https://people.physics.anu.edu.au/~ecs103/chart/

Collective structures near closed shells

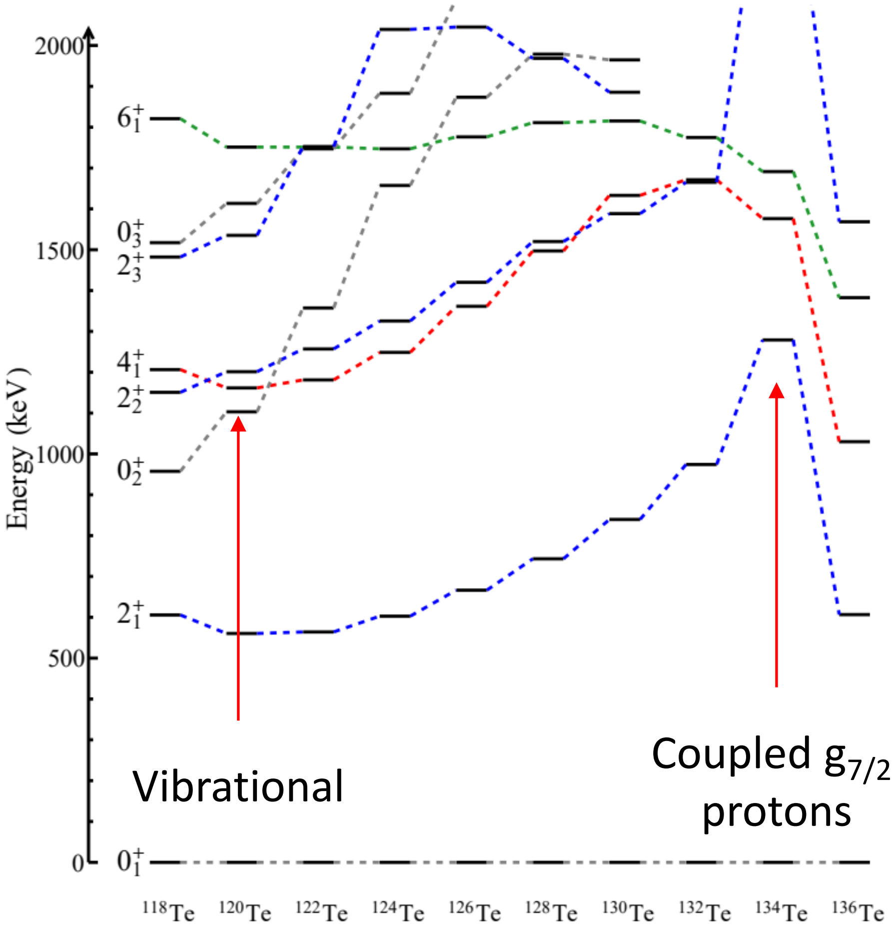


Z \ N	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
56	^{124}Ba β+	^{125}Ba β+	^{126}Ba β+	^{127}Ba β+	^{128}Ba e- capture	^{129}Ba β+	^{130}Ba Stable	^{131}Ba β+	^{132}Ba Stable	^{133}Ba e- capture	^{134}Ba Stable	^{135}Ba Stable	^{136}Ba Stable	^{137}Ba Stable	^{138}Ba Stable
55	^{123}Cs β+	^{124}Cs β+	^{125}Cs β+	^{126}Cs β+	^{127}Cs β+	^{128}Cs β+	^{129}Cs β+	^{130}Cs β+	^{131}Cs e- capture	^{132}Cs β+	^{133}Cs Stable	^{134}Cs β-	^{135}Cs β-	^{136}Cs β-	^{137}Cs β-
54	^{122}Xe e- capture	^{123}Xe β+	^{124}Xe Stable	^{125}Xe β+	^{126}Xe Stable	^{127}Xe e- capture	^{128}Xe Stable	^{129}Xe Stable	^{130}Xe Stable	^{131}Xe Stable	^{132}Xe Stable	^{133}Xe β-	^{134}Xe Stable	^{135}Xe β-	^{136}Xe Stable
53	^{121}I β+	^{122}I e+	^{123}I β+	^{124}I β+	^{125}I e- capture	^{126}I β+	^{127}I Stable	^{128}I β-	^{129}I β-	^{130}I β-	^{131}I β-	^{132}I β-	^{133}I β-	^{134}I β-	^{135}I β-
52	^{120}Te Stable	^{121}Te β+	^{122}Te Stable	^{123}Te Stable	^{124}Te Stable	^{125}Te Stable	^{126}Te Stable	^{127}Te β-	^{128}Te Stable	^{129}Te β-	^{130}Te Stable	^{131}Te β-	^{132}Te β-	^{133}Te β-	^{134}Te β-
51	^{119}Sb e- capture	^{120}Sb β+	^{121}Sb Stable	^{122}Sb β-	^{123}Sb Stable	^{124}Sb β-	^{125}Sb β-	^{126}Sb β-	^{127}Sb β-	^{128}Sb β-	^{129}Sb β-	^{130}Sb β-	^{131}Sb β-	^{132}Sb β-	^{133}Sb β-
50	^{118}Sn Stable	^{119}Sn Stable	^{120}Sn Stable	^{121}Sn β-	^{122}Sn Stable	^{123}Sn β-	^{124}Sn Stable	^{125}Sn β-	^{126}Sn β-	^{127}Sn β-	^{128}Sn β-	^{129}Sn β-	^{130}Sn β-	^{131}Sn β-	^{132}Sn β-

Systematics of the Te isotopes



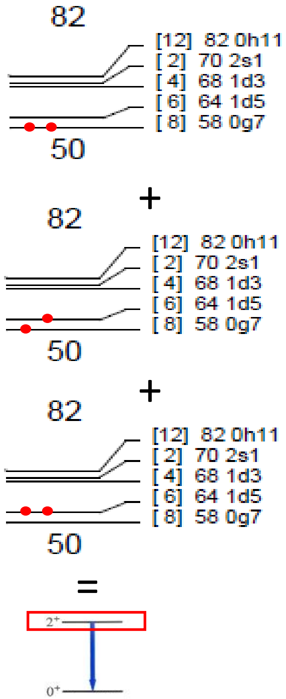
Harmonic Vibrator



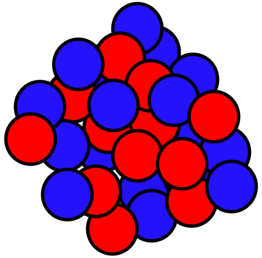
Vibrational

Coupled $g_{7/2}$ protons

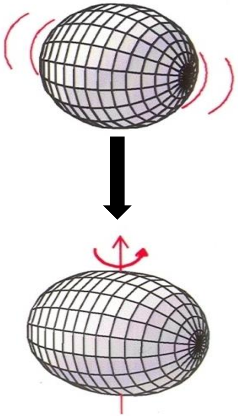
Signatures of emerging collectivity



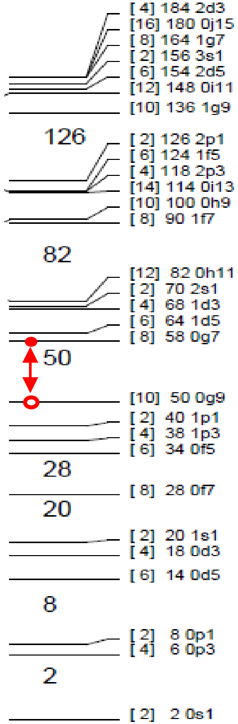
Fragmentation



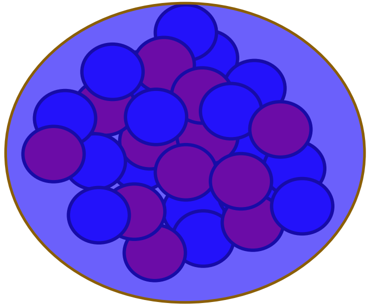
Proton-neutron contributions



Deformation

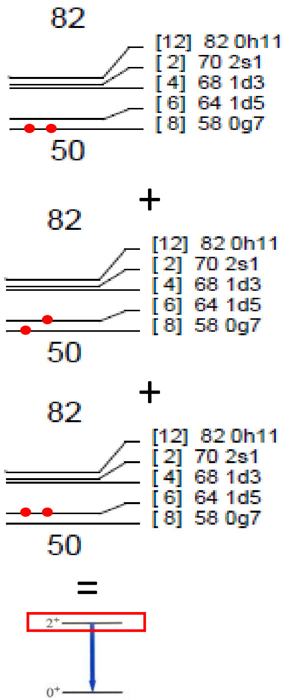


Breakdown of shell structure



Loss of single-particle character

Signatures of emerging collectivity



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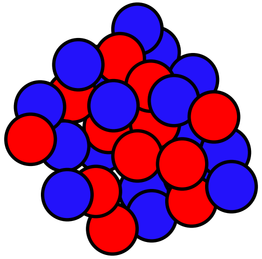

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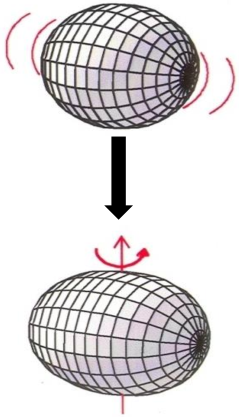

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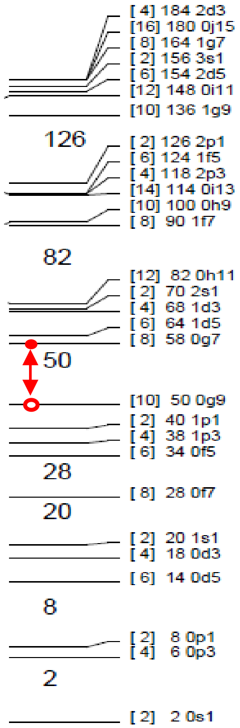

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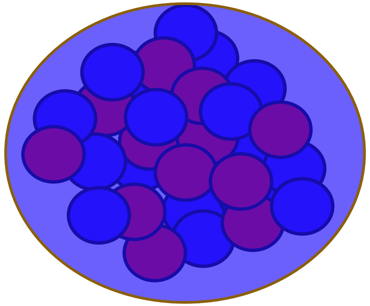

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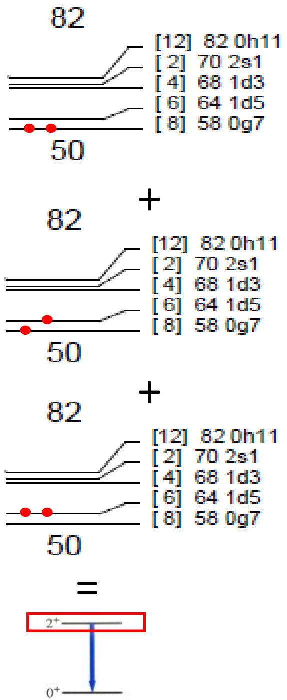

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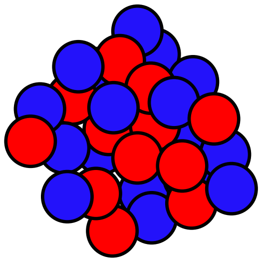

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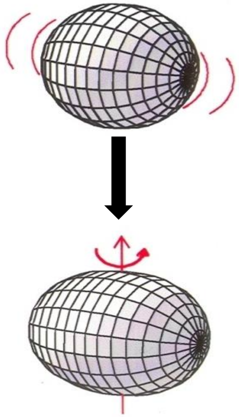
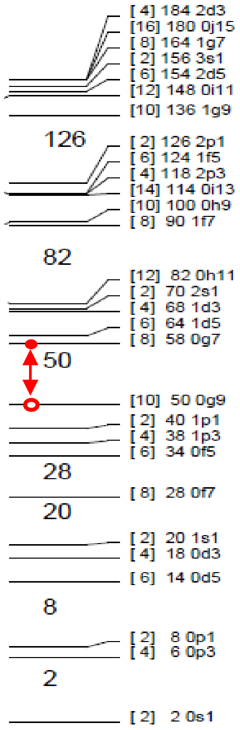


Deformation



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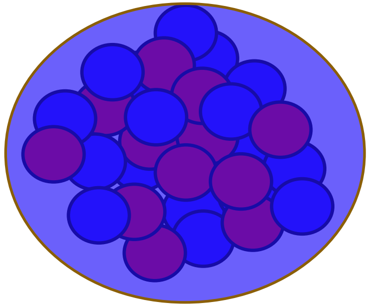


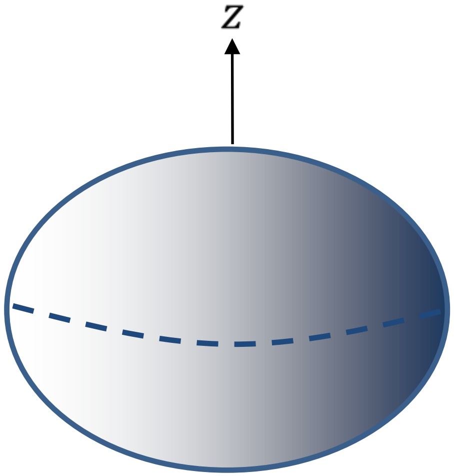
Loss of single-particle character

Measurements of nuclear structure

Quadrupole moment:

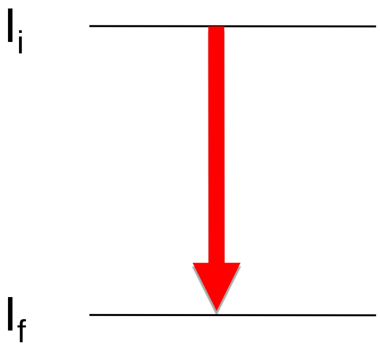
$$Q = \langle I | M(E2) | I \rangle$$

$$Q_0 = \int \rho (3z^2 - r^2) dV$$



Transition strength:

$$B(E2)\downarrow = \frac{1}{2I_i + 1} \langle I_i | M(E2) | I_f \rangle^2$$



g factors:

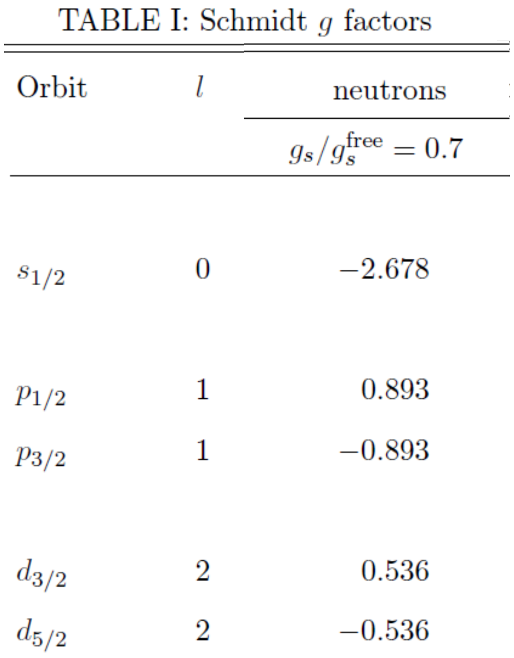


TABLE I: Schmidt g factors

Orbit	l	neutrons
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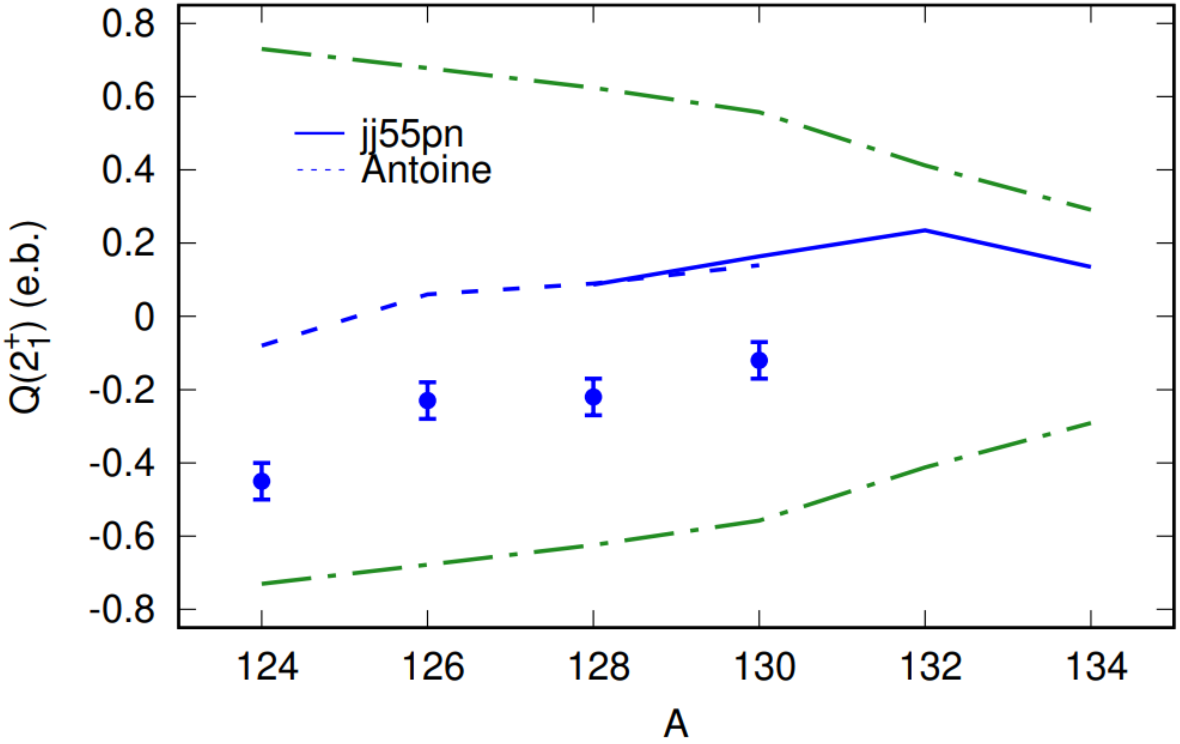
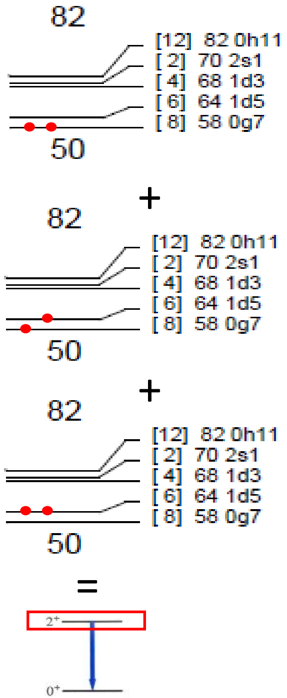
Combined study of the Te isotopes

Quadrupole moments

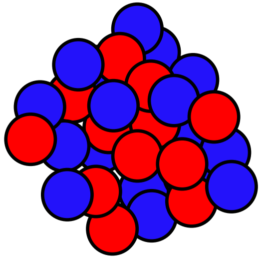


Data from N. Stone, Table of Nuclear Electric Quadrupole Moments, Tech. Rep. INDC(NDS)– 0650 (2013)

Signatures of emerging collectivity



Fragmentation



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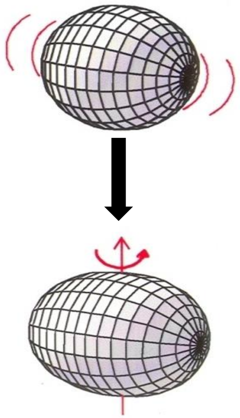

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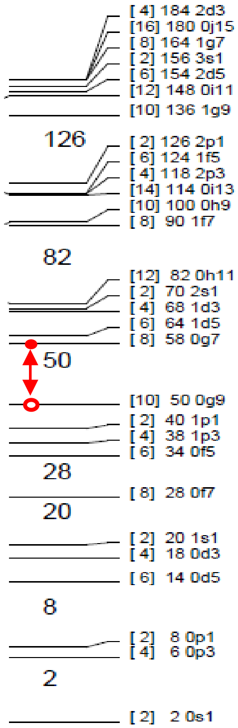

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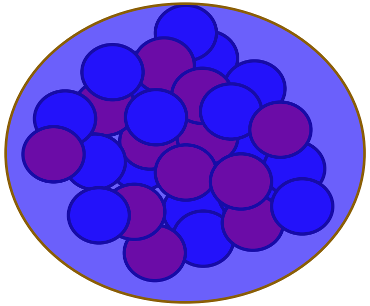

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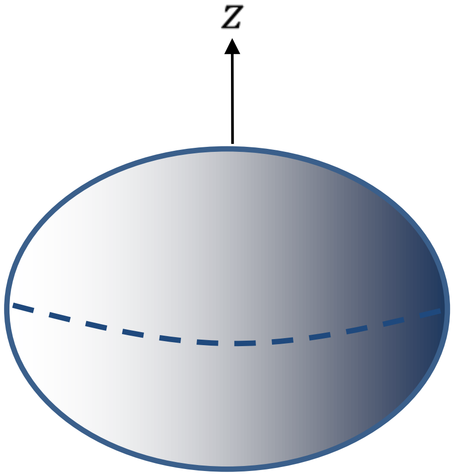

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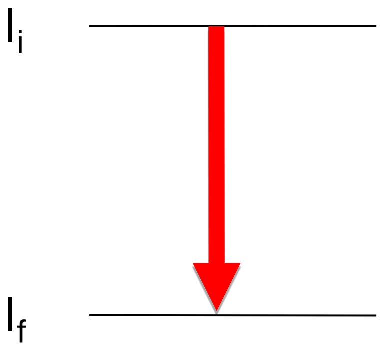
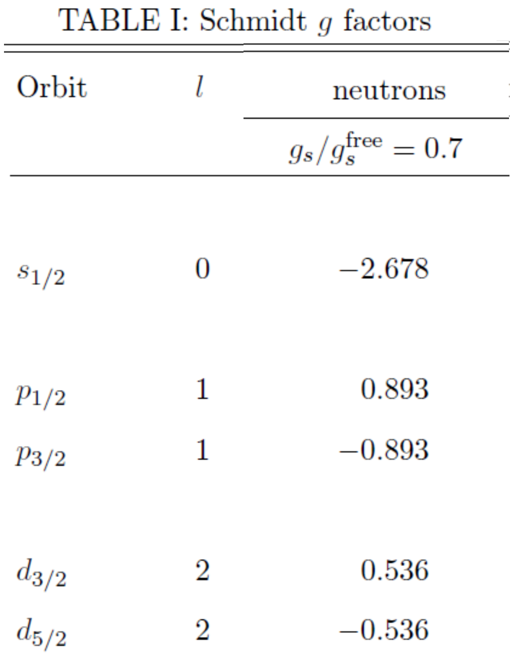


g factors:



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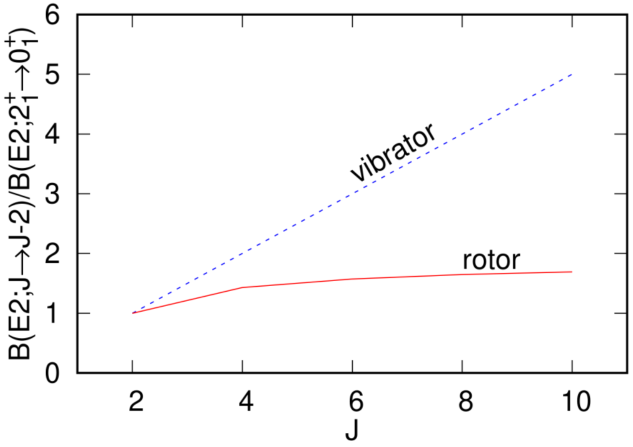
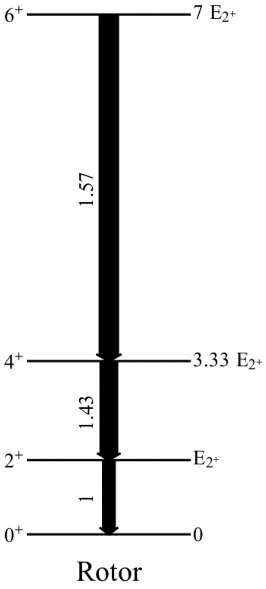
Transition strengths

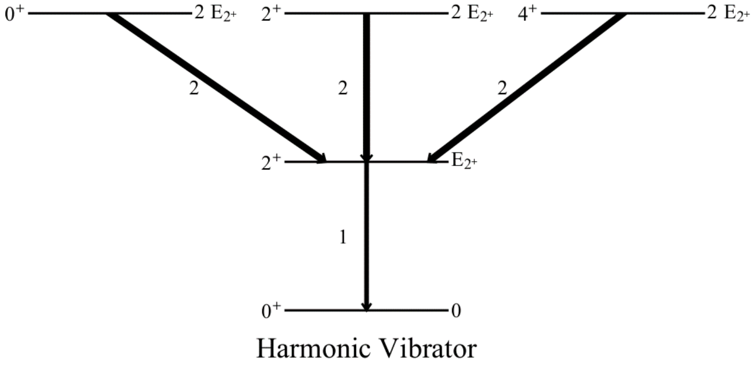
Vibrations and rotations

Weisskopf units:

$$B(E2)(W.u.) = \frac{B(E2)}{B(E2)_{sp}}$$





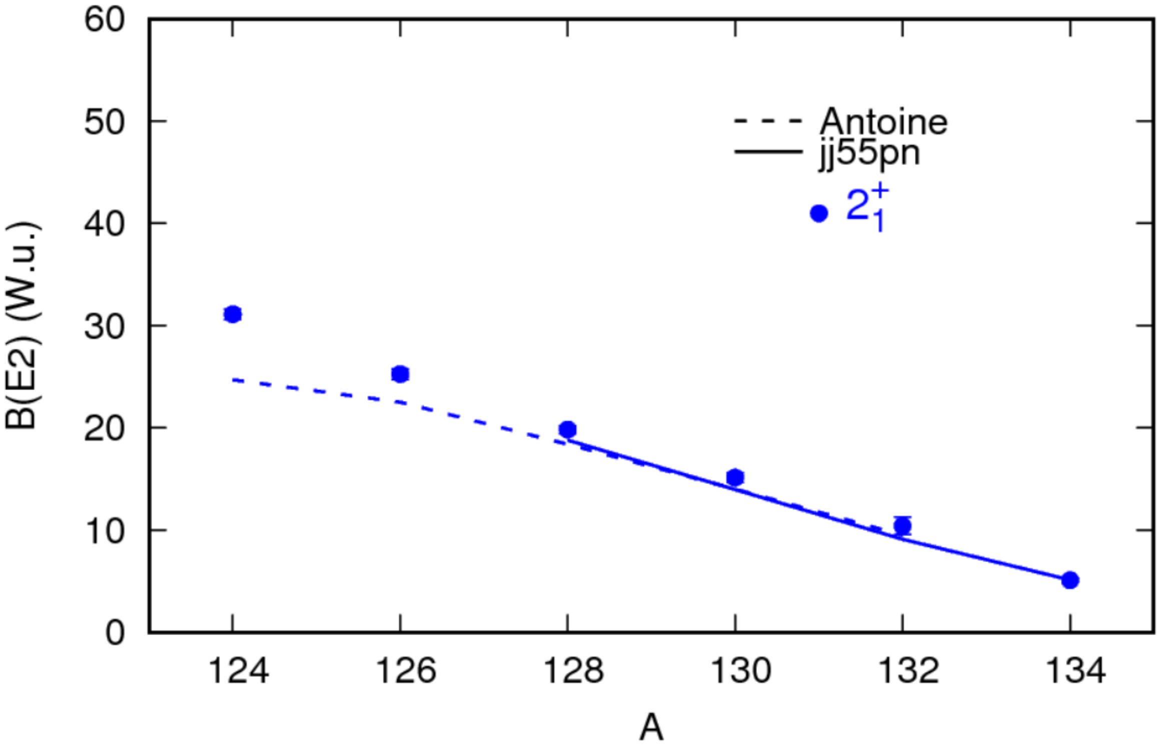


B(E2; 2+→0+) > 50 W.u.

B(E2; 2+→0+) ~ 30 W.u.

Increasing collectivity

B(E2) measurements



Data from this work and B. Pritychenko **et al.** (2016), Atomic Data and Nuclear Data Tables **107**, 1, and *Nuclear Data Sheets*

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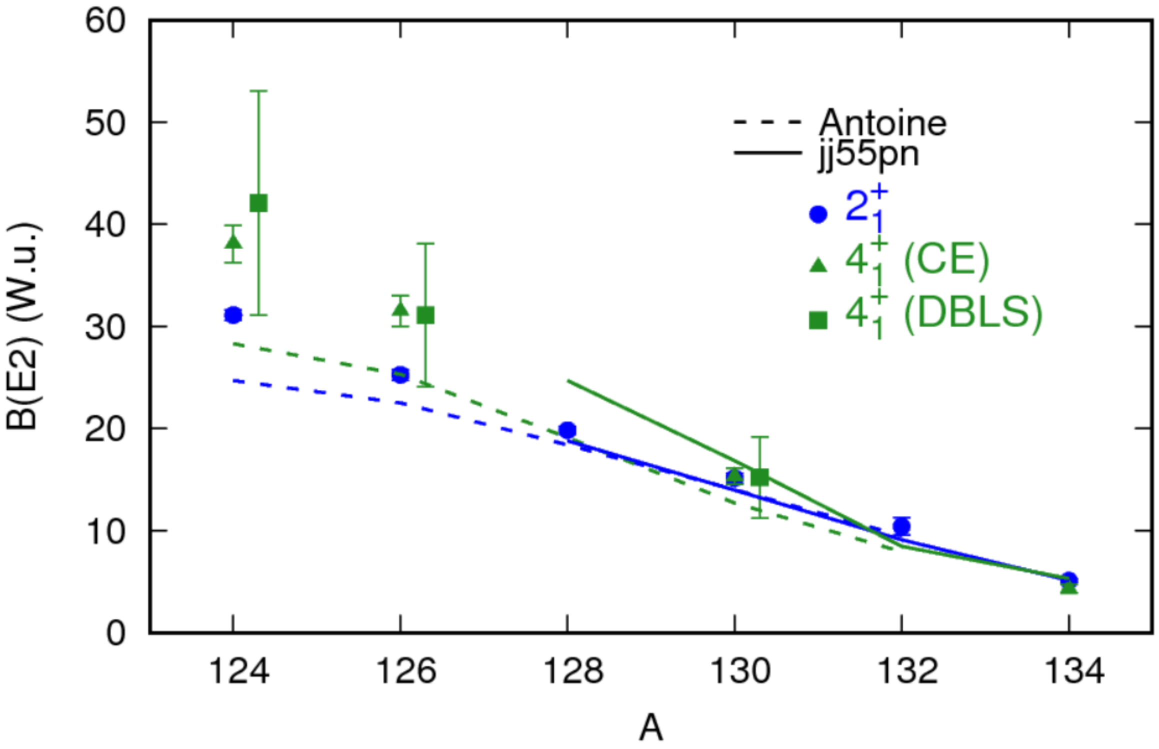

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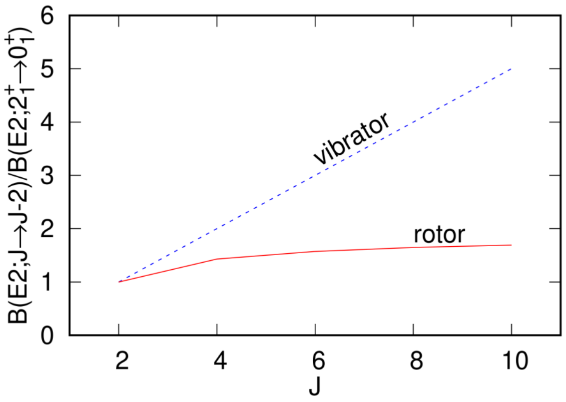
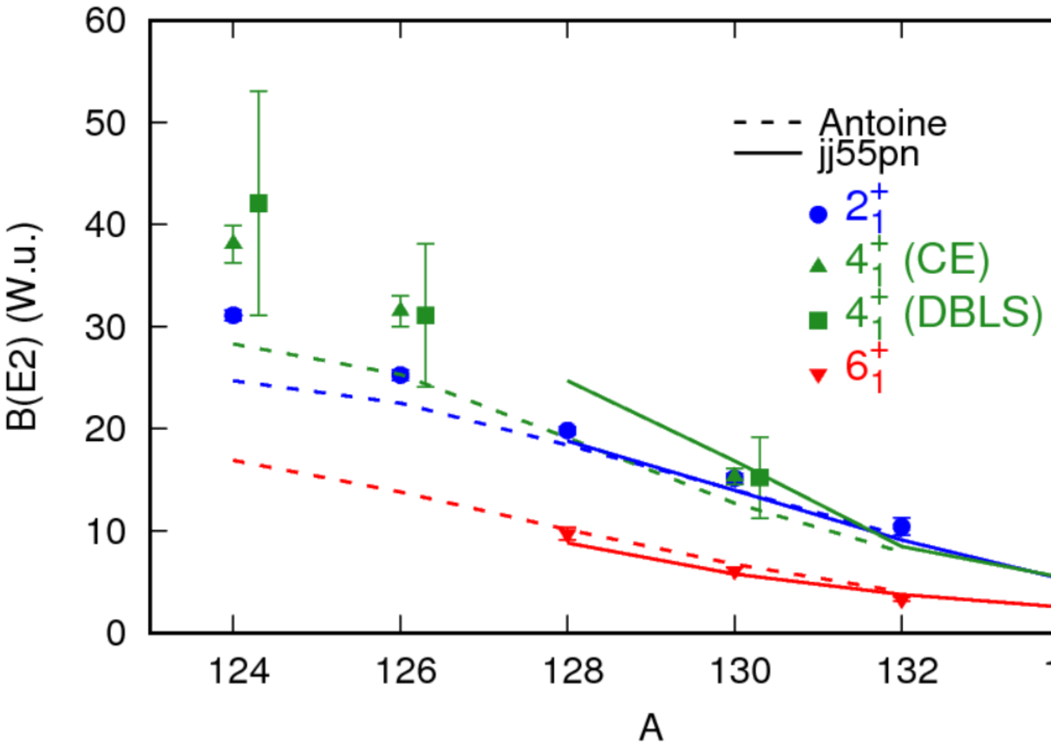
Lower *B(E2)* from the 6^+ state

B(E2) measurements





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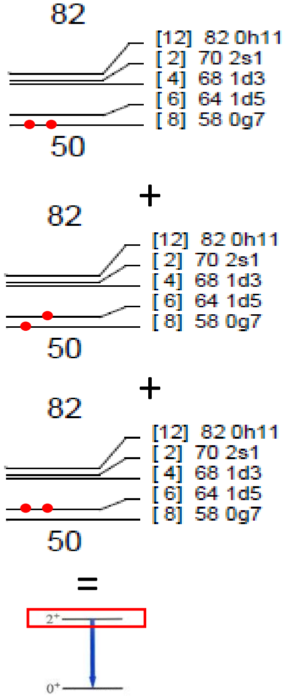
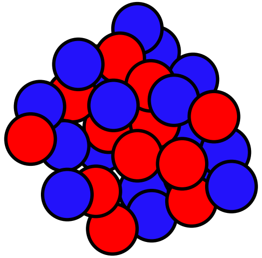
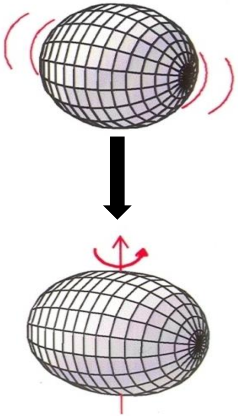
Signatures of emerging collectivity



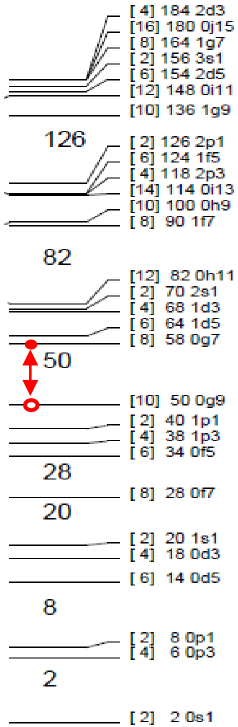
Fragmentation



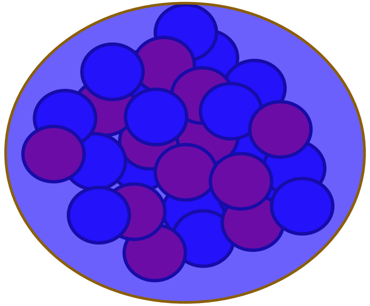
Proton-neutron contributions



Deformation



Breakdown of shell structure



Loss of single-particle character

Measurements of nuclear structure

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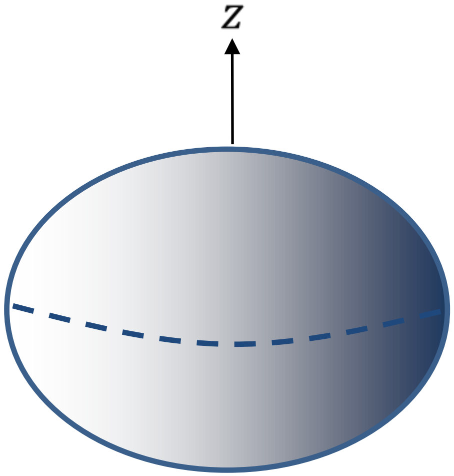

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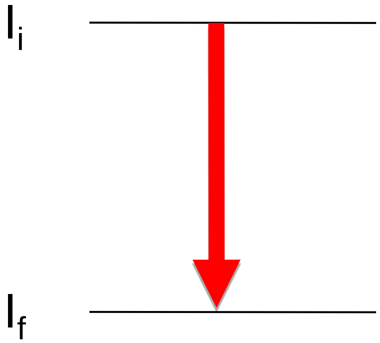
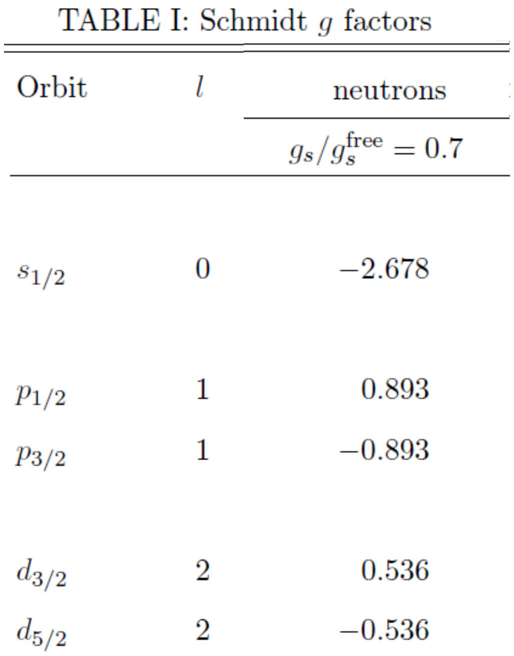


g factors:



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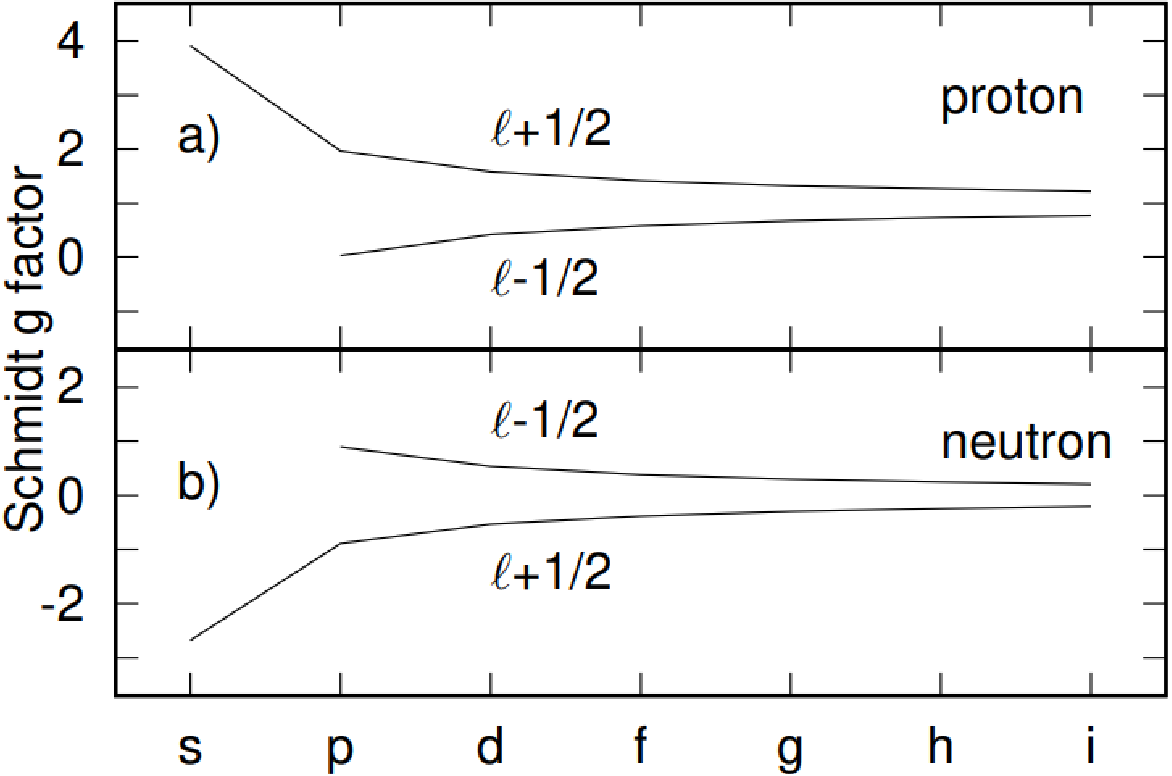


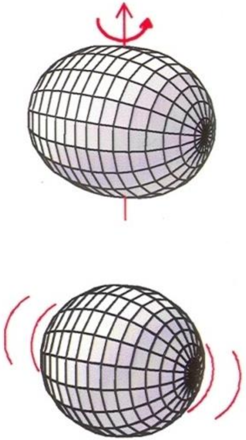
Collective *g* factors:

$$g \approx \frac{I_p}{I_p + I_n}$$

$$g \approx \frac{Z}{A}$$

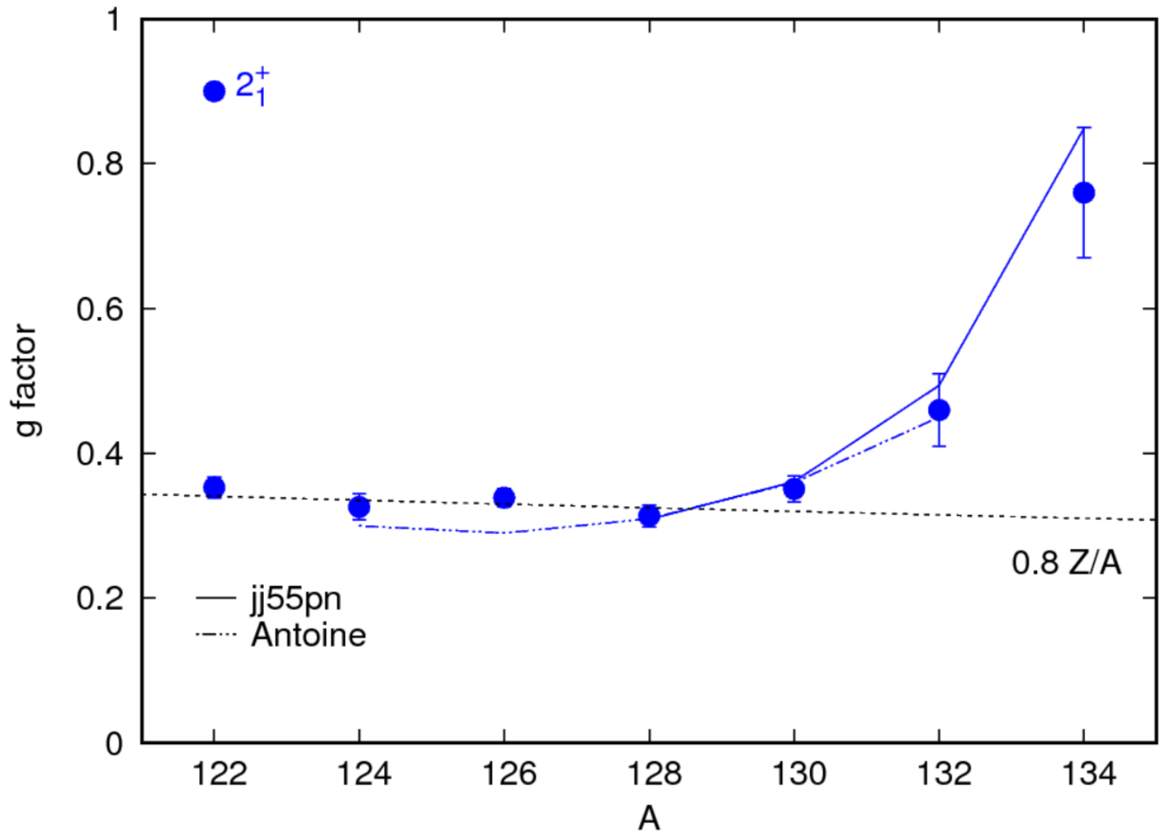
Experimentally:

$$g \approx 0.8\frac{Z}{A}$$



Forgetting single-particle structure

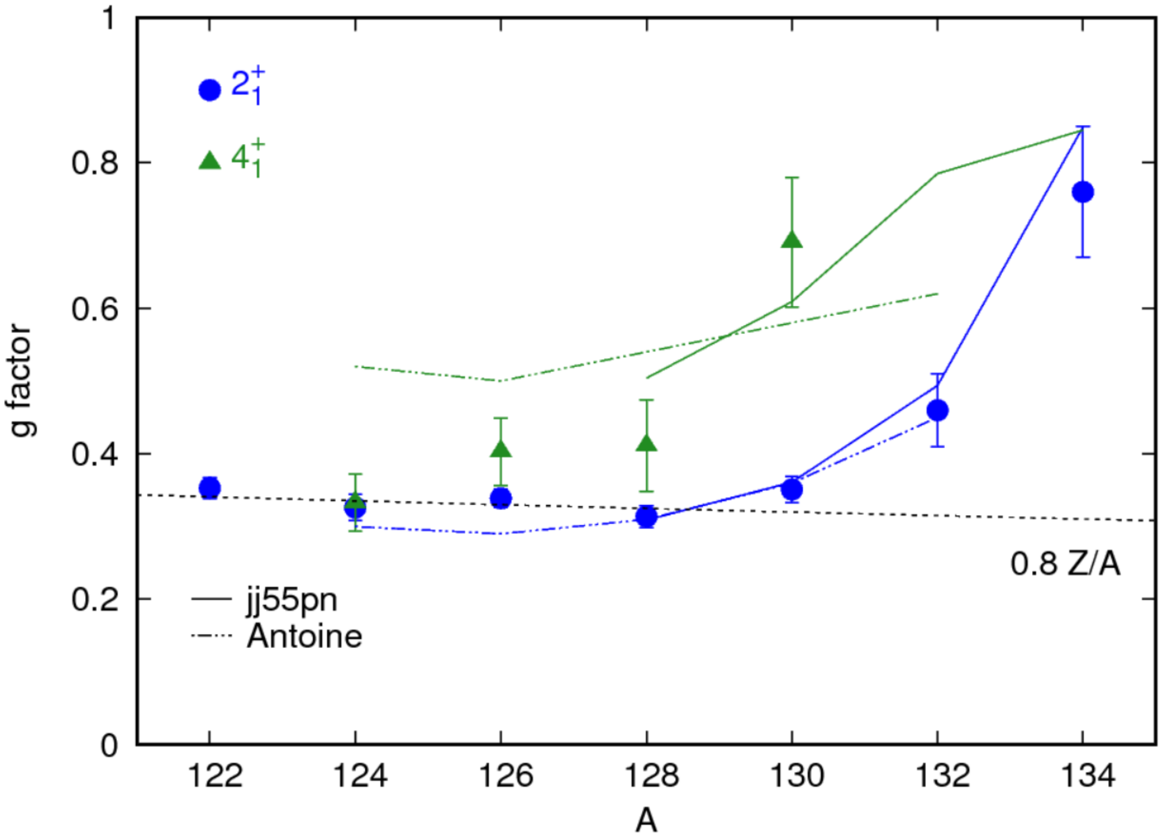
g factor measurements



Data from this work and Stuchbery *et al.* (2007) Phys. Rev. C **76**, 034306, Stone *et al.* (2005) Phys. Rev. Lett. **94**, 192501, Fogelberg *et al.* (1986) Nucl. Phys. A **451** 101-104, Stuchbery *et al.* (2013) Phys. Rev. C **88**, 051304, Wolf *et al.* (1976) Phys.Rev.Lett. 36, 1072

Maintains characteristics longer

g factor measurements



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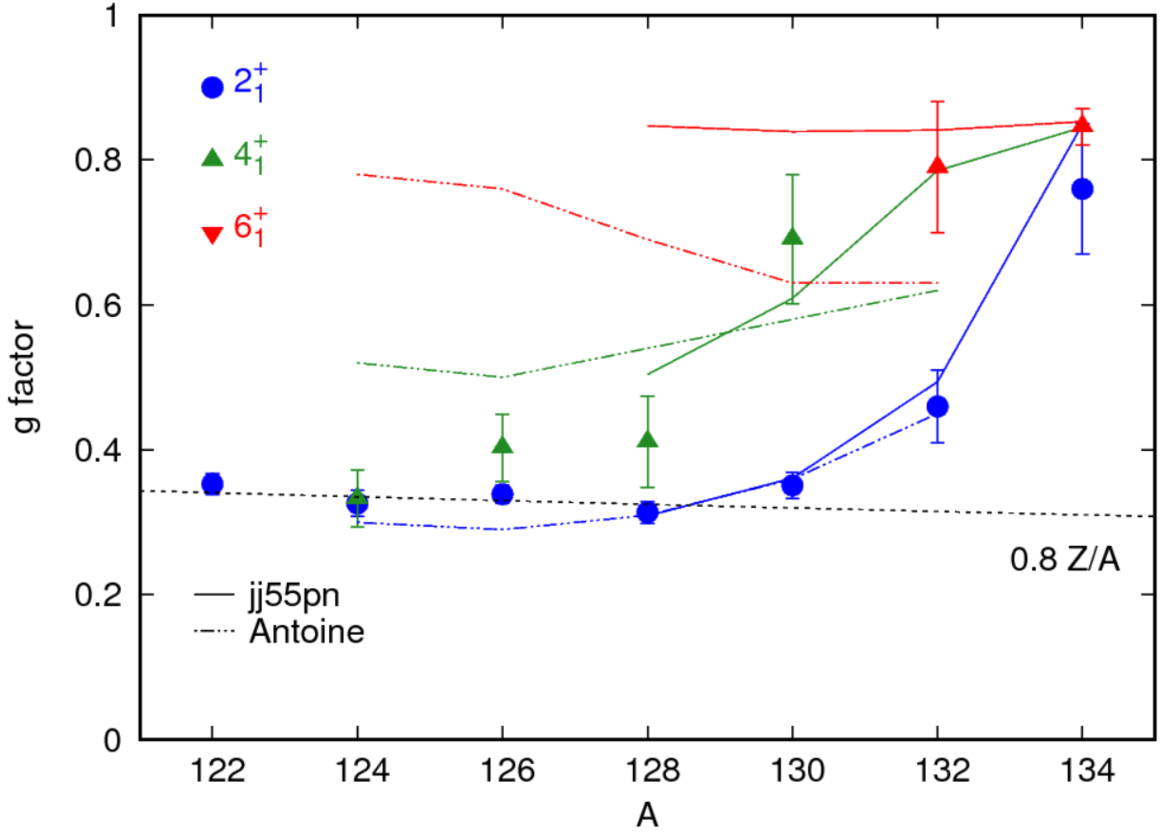
No predicted decrease

g factor measurements



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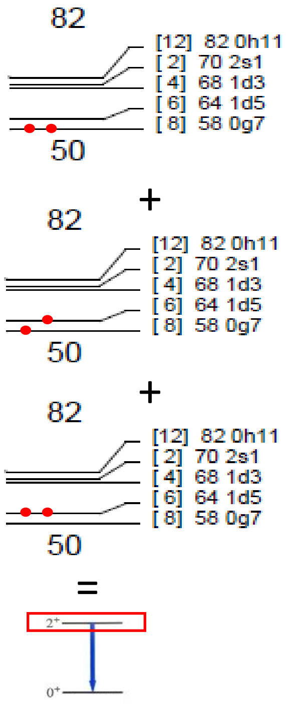
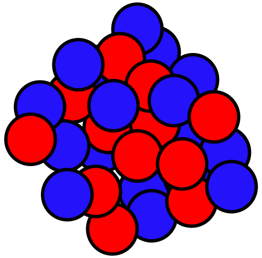
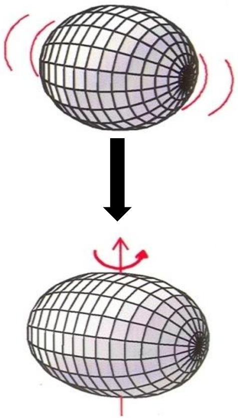
Conclusions



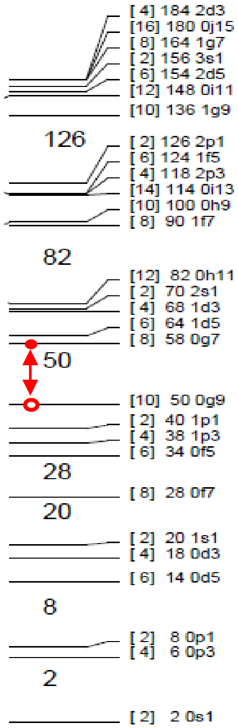
Fragmentation



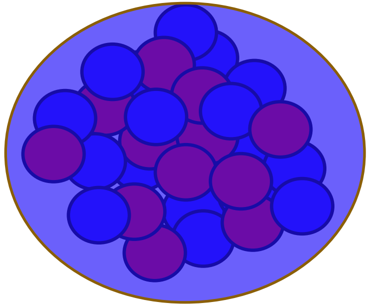
Proton-neutron contributions



Deformation



Breakdown of shell structure



Loss of single-particle character

Questions

What does it mean to be collective?

Are weakly collective nuclei becoming collective as a whole?

Can weakly collective nuclei really be called collective?

How can we model pre-collective nuclei with differing levels of collectivity?

How can we characterise the breakdown of shell structure?

THANK YOU

Contact Us

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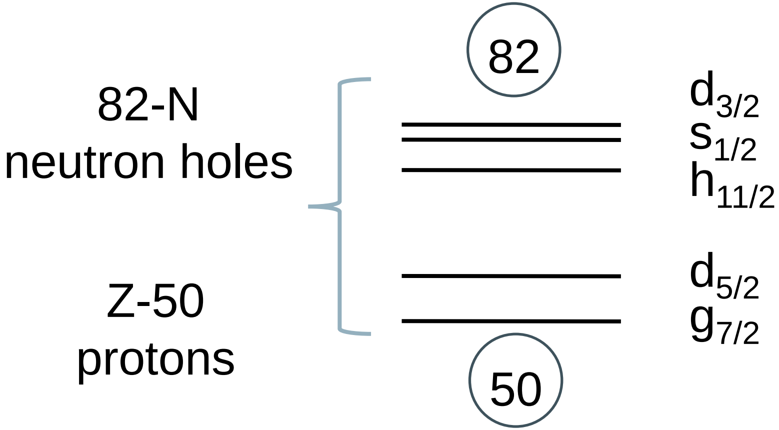
Ben.Coombes@anu.edu.au

Australian
National
University

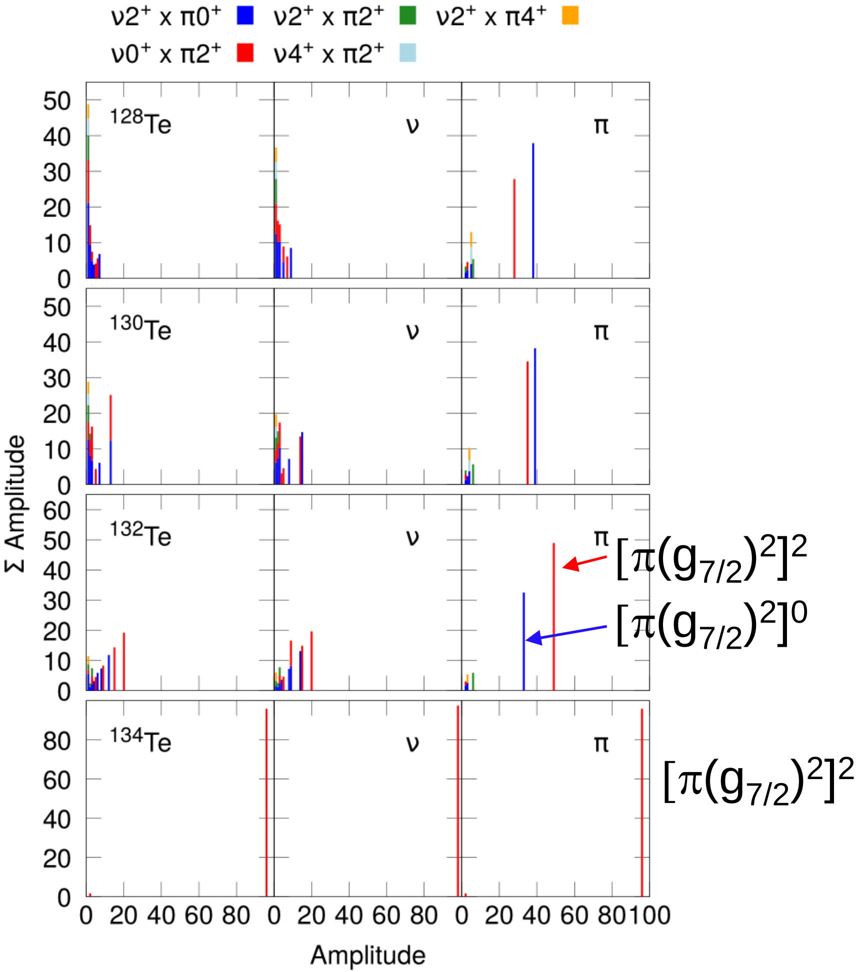
Pre-collective nuclei

Rapidly developing fragmentation



82-N
neutron holes

Z-50
protons



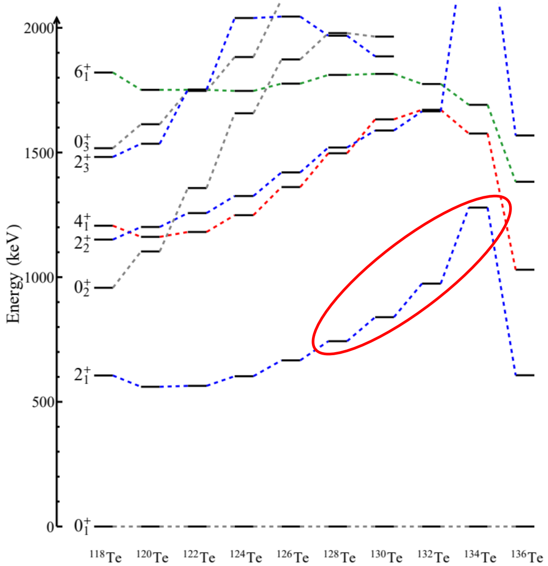
$[\pi(g_{7/2})^2]^2$

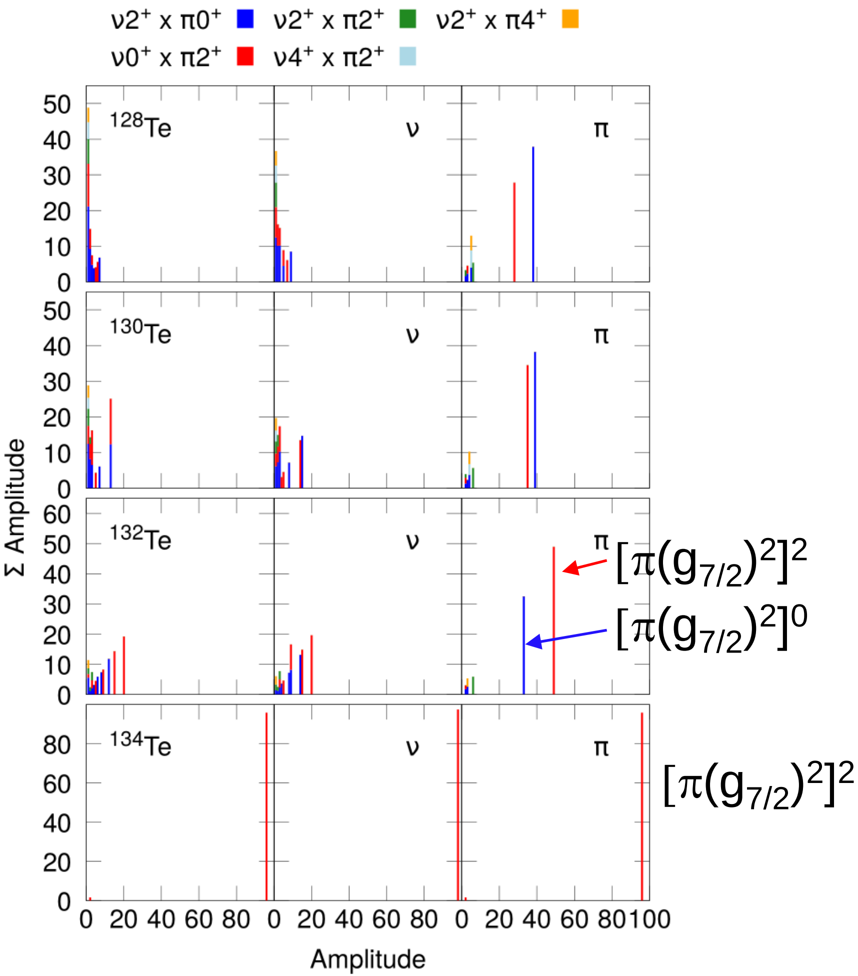
$[\pi(g_{7/2})^2]^0$

$[\pi(g_{7/2})^2]^2$

Pre-collective nuclei

Rapidly developing fragmentation





$[\pi(g_{7/2})^2]^2$

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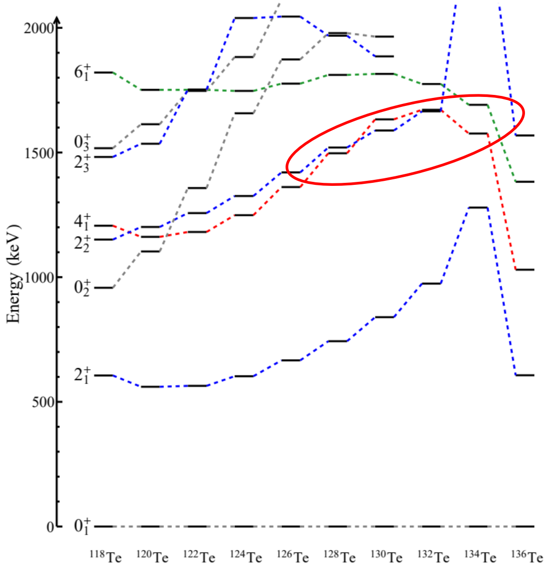
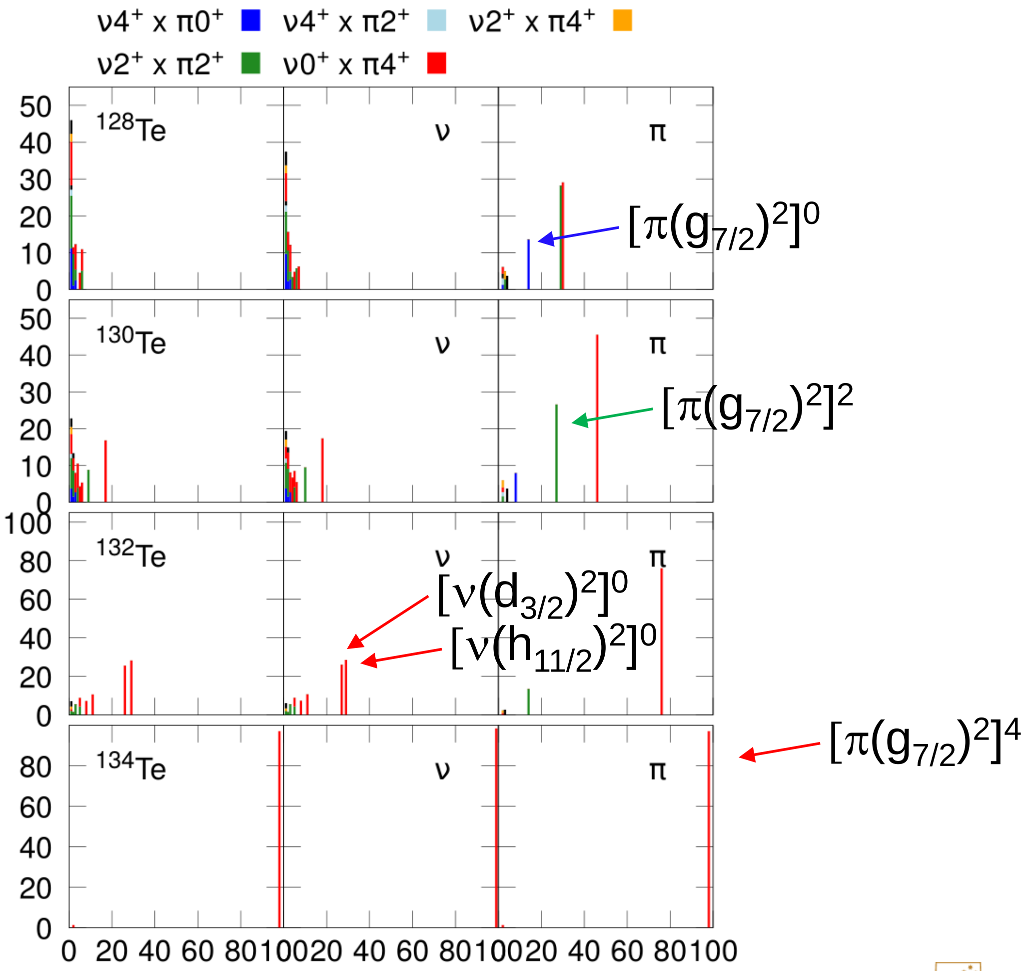
Pre-collective nuclei

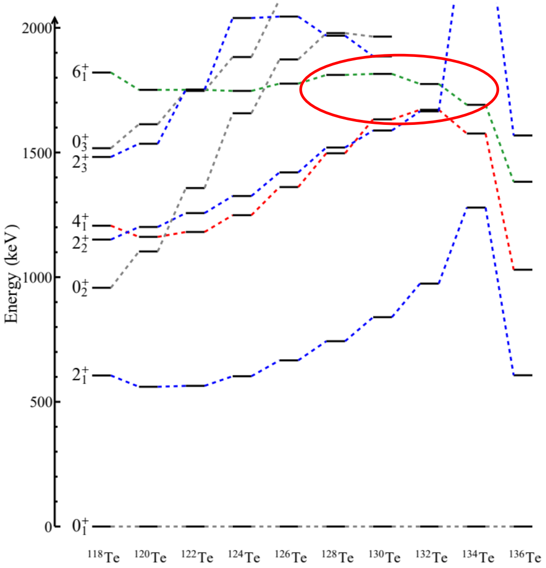
Fragmentation

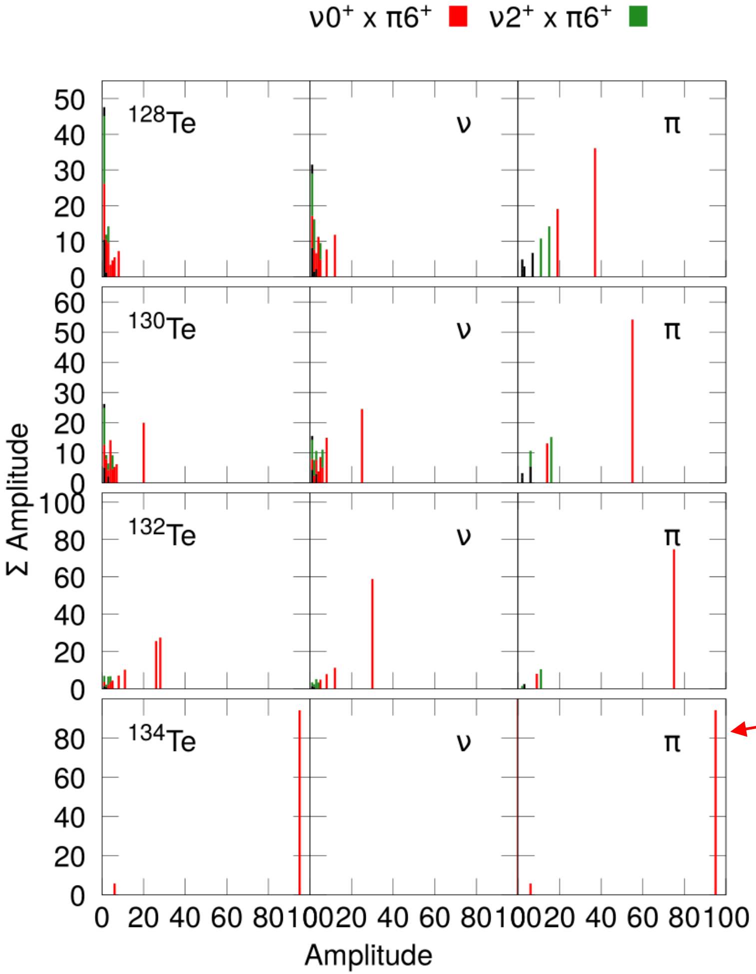




Pre-collective nuclei

Fragmentation less in the 6^+ state

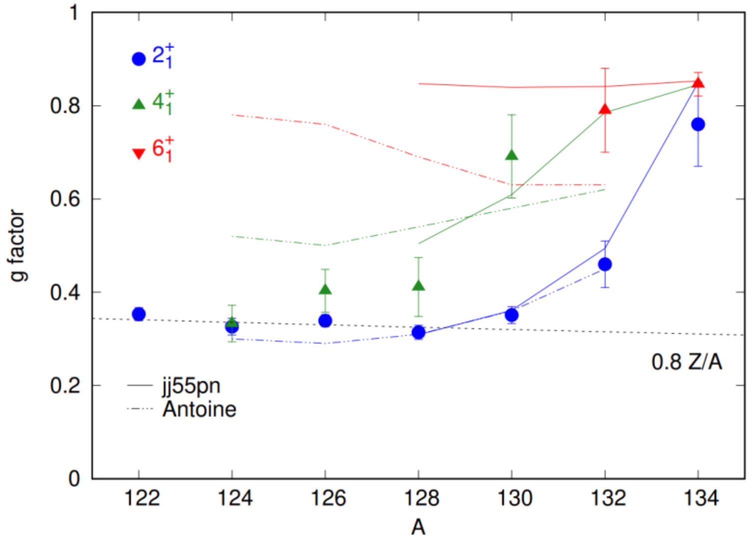


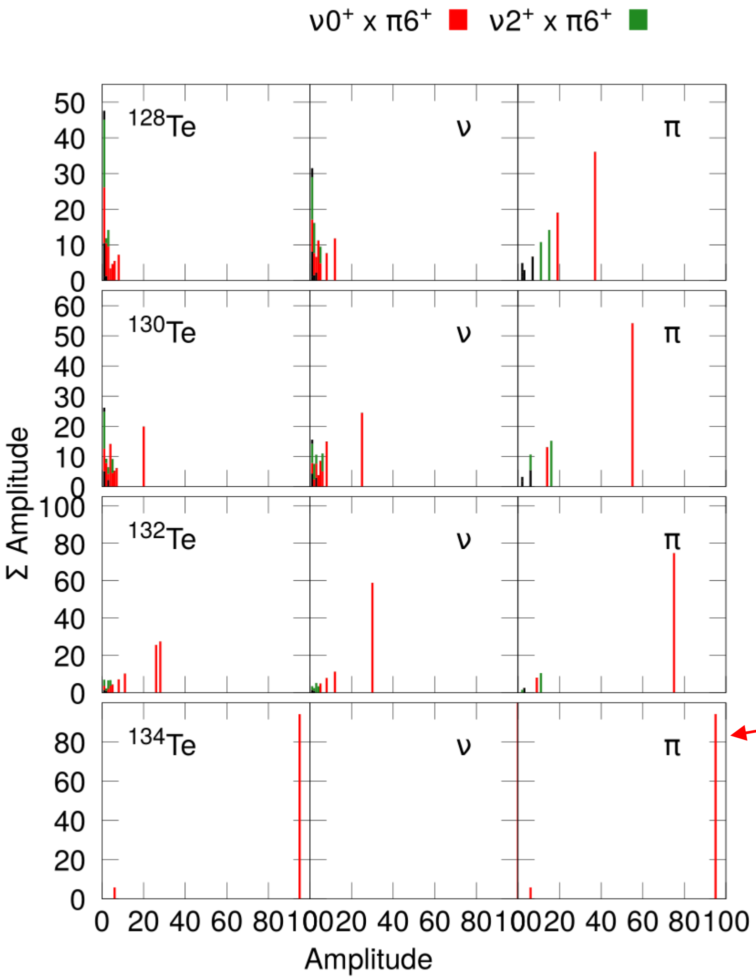


$[\pi(g_{7/2})^2]^4$

Pre-collective nuclei

Fragmentation less in the 6^+ state





$[\pi(g_{7/2})^2]^4$

Pre-collective nuclei

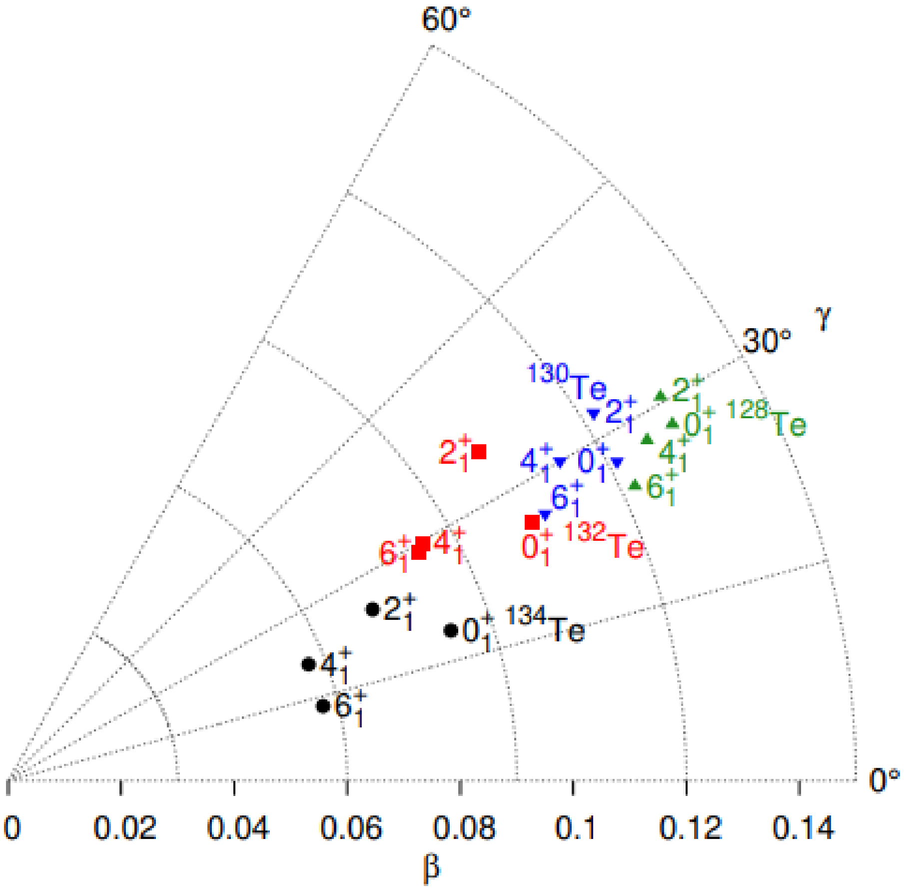
Deformation and triaxiality

$$\{E2 \times E2\}^0 = \frac{1}{\sqrt{5}} Q^2$$

$$\langle s|[E2 \times E2]^0|s\rangle = \frac{(-1)^{2s}}{\sqrt{2s+1}} \sum_r \langle s||E2||r\rangle \langle r||E2||s\rangle \begin{pmatrix} 2 & 2 & 0 \\ s & s & r \end{pmatrix}$$

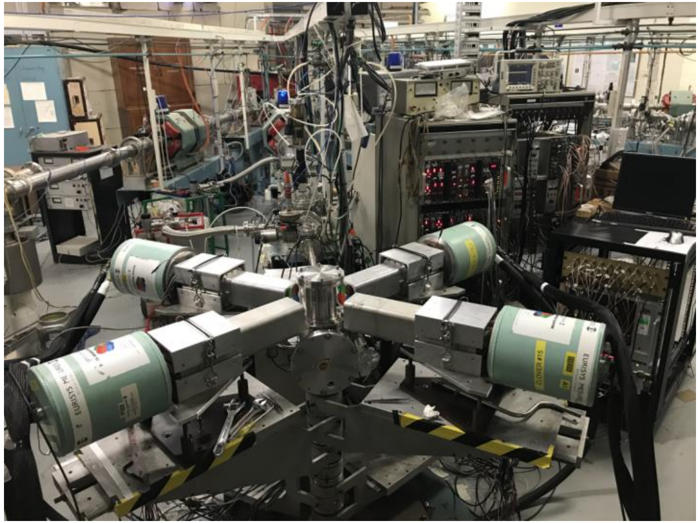
$$\{[E2 \times E2]^2 \times E2\}^0 = -\frac{\sqrt{2}}{35} Q^3 \cos 3\delta$$

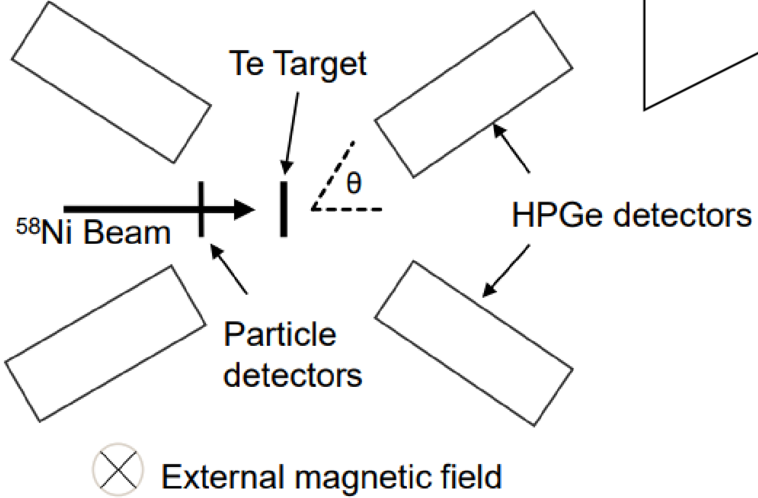
$$\langle s|[(E2 \times E2)^2 \times E2]^0|s\rangle = (-1)^{3s+t} \sqrt{\frac{5}{2s+1}} \sum_{rt} \langle s||E2||r\rangle \langle r||E2||t\rangle \langle t||E2||s\rangle \begin{Bmatrix} 2 & 2 & 0 \\ s & s & r \end{Bmatrix} \begin{Bmatrix} 2 & 2 & 2 \\ t & s & r \end{Bmatrix}$$

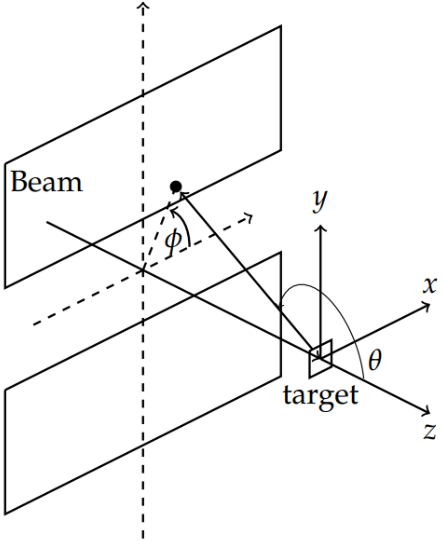


Combined study of the Te isotopes

g factor measurements

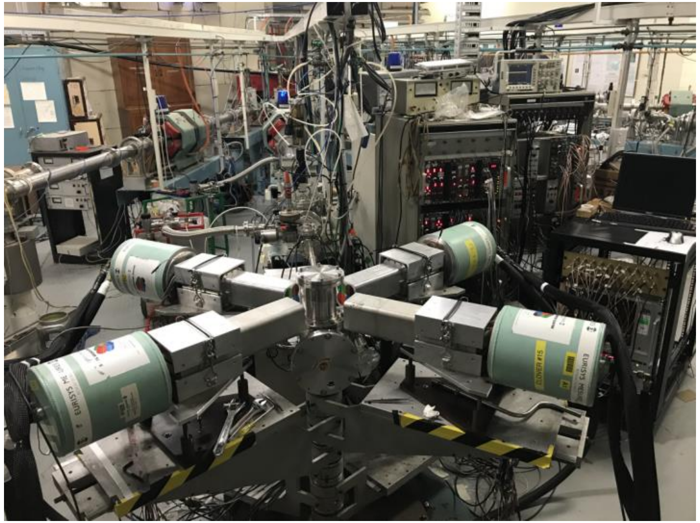


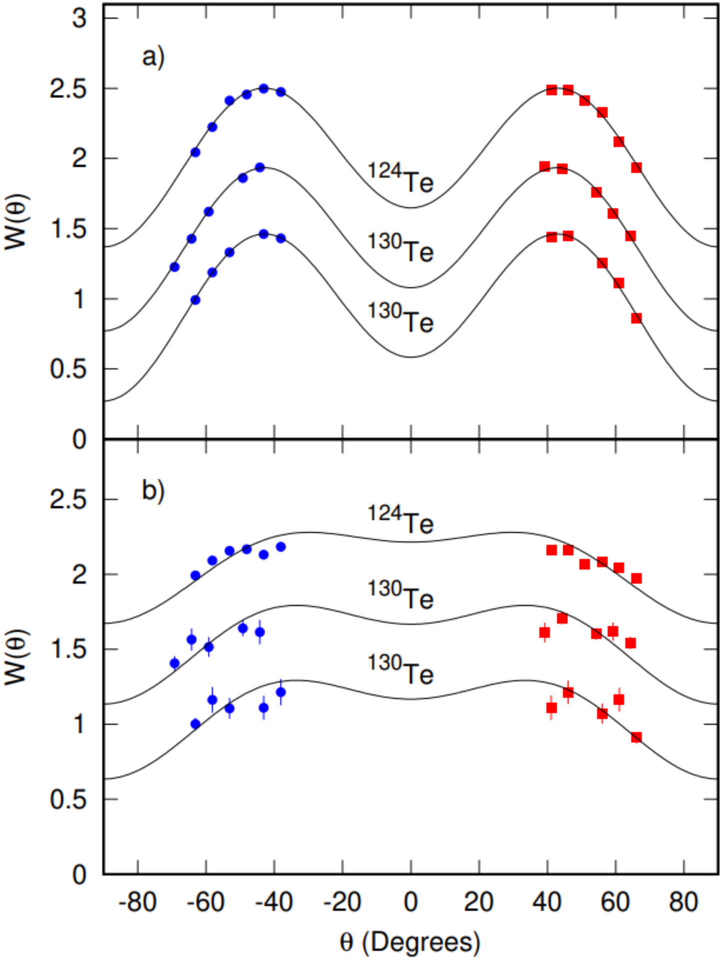




Combined study of the Te isotopes

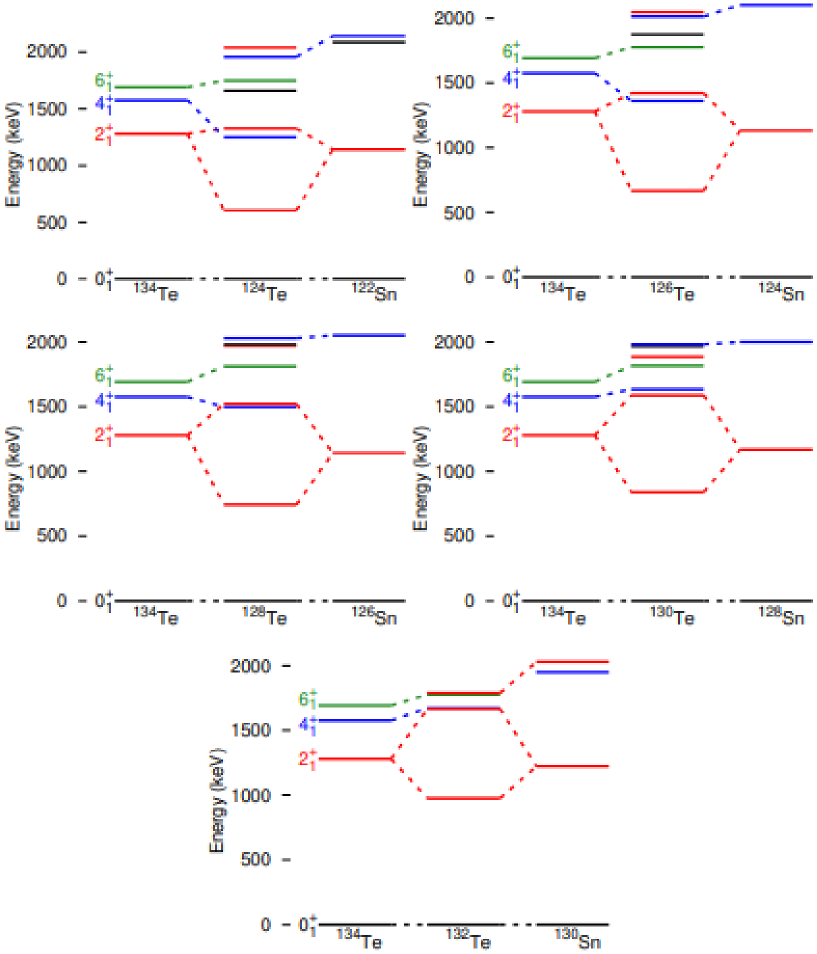
g factor measurements





Combined study of the Te isotopes

Singly-magic isotope and isotones



Combined study of the Te isotopes

Increased sensitivity