Update on the campaign at Legnaro National Laboratory

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Department of Physics and Astronomy - University of Padova

AGATA week – Strasbourg – 10-14 September 2018

Publications since last AGATA week

18 Phys. Rev. C + 3 Phys. Rev. Lett. + 1 Phys. Lett. B ...
+ 4 Phys. Rev. C

- **Quadrupole collectivity in ^{42}Ca from low-energy Coulomb excitation with AGATA**
  K. Hadyńska-Klek, P. J. Napiorkowski, M. Zielińska, et al.
  PHYSICAL REVIEW C **97**, 024326 (2018)
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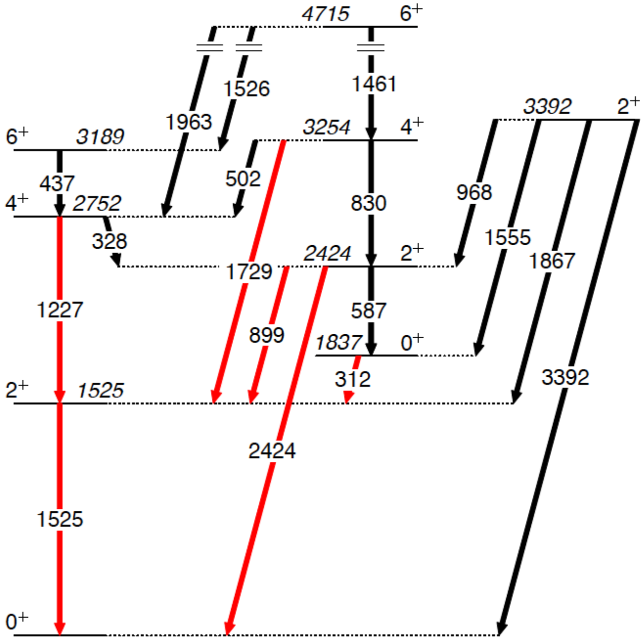
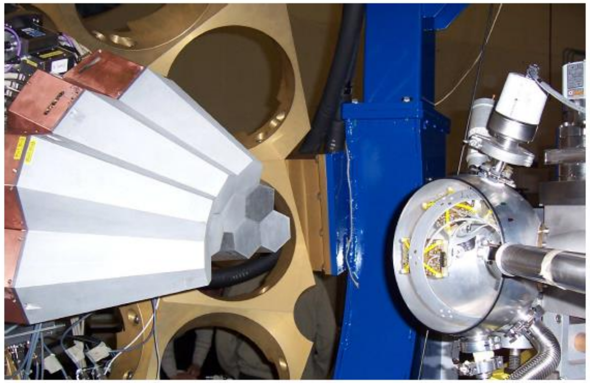
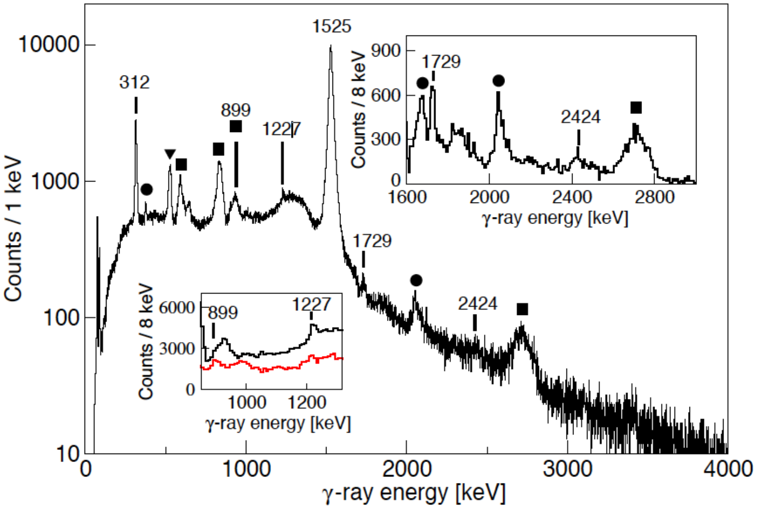
Coulomb excitation of ^{42}Ca – experiment, INFN LNL, Italy

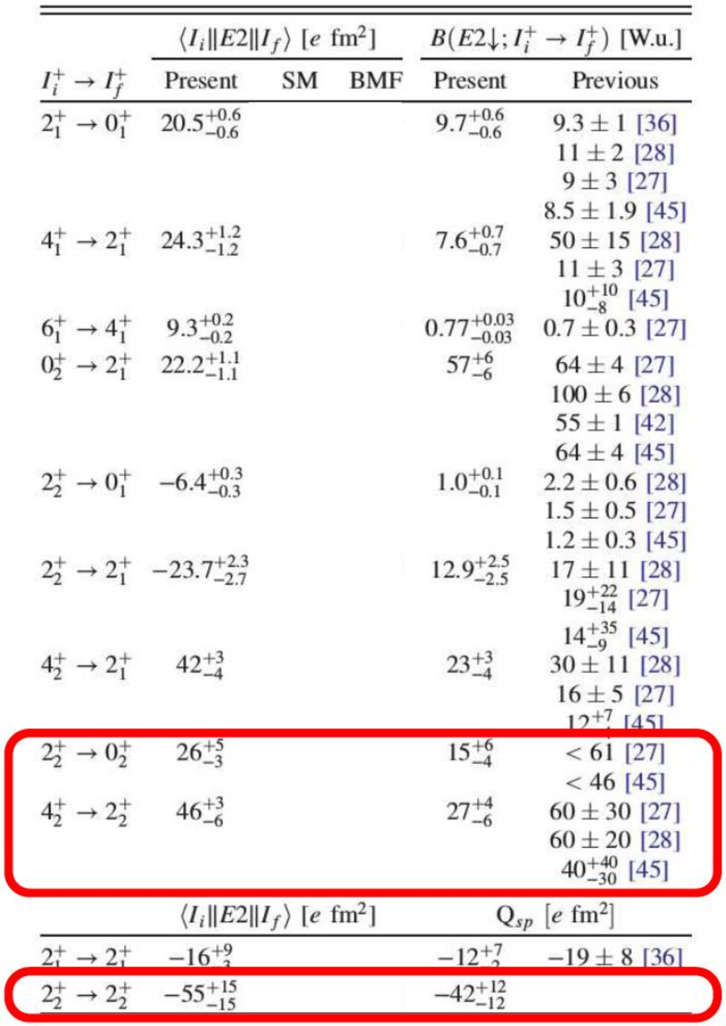
- Beamtime:
  Feb.2010, INFN LNL
- Beam:
  ^{42}Ca, E=170 MeV
- Targets:
  ^{208}Pb, 1 mg/cm^2
  ^{197}Au, 1 mg/cm^2
- AGATA: 3 triple clusters, 143.8 mm from the target
- DANTE: 3 MCP detectors, θ range from 100^o-144^o





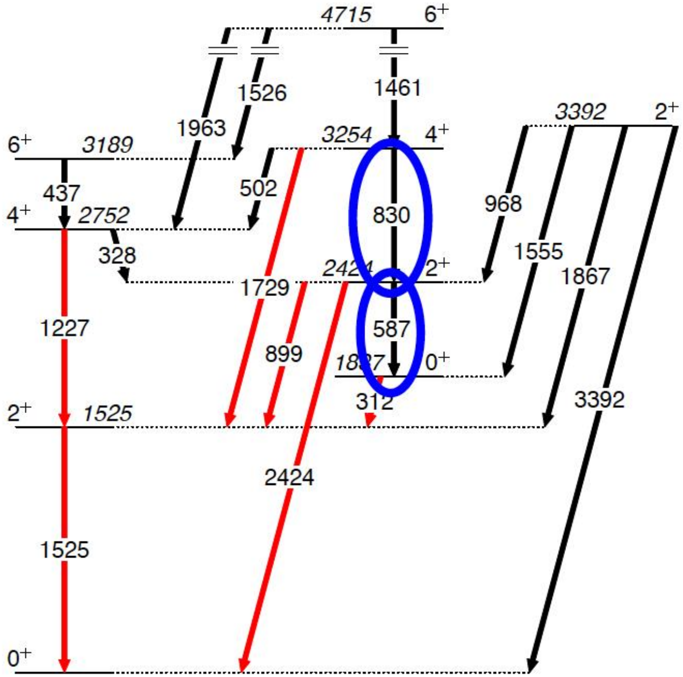


Coulomb excitation of ^{42}Ca – transition probabilities



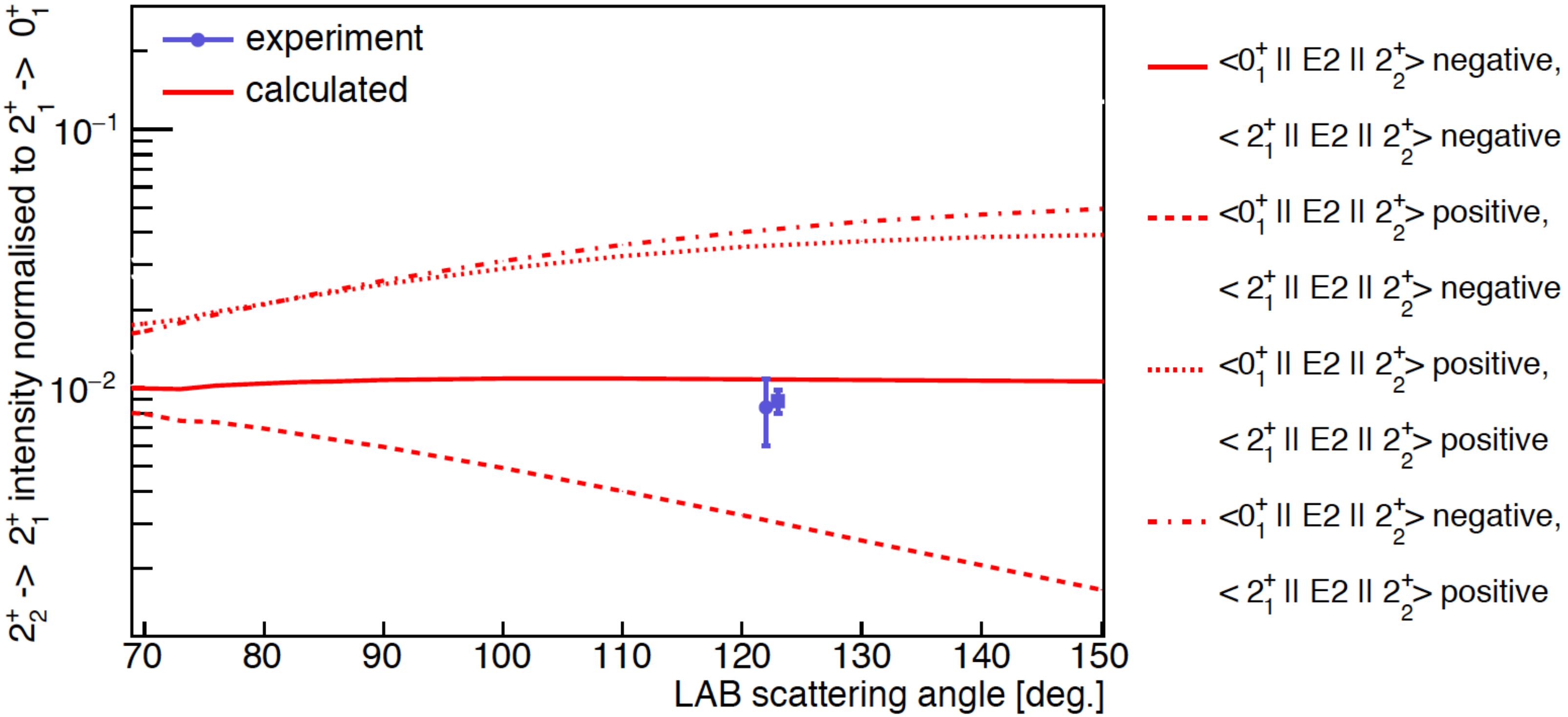
	$\langle I_i \| E2 \| I_f \rangle$ [e fm^2]			$B(E2\downarrow; I_i^+ \rightarrow I_f^+)$ [W.u.]	
$I_i^+ \rightarrow I_f^+$	Present	SM	BMF	Present	Previous
$2_1^+ \rightarrow 0_1^+$	$20.5^{+0.6}_{-0.6}$			$9.7^{+0.6}_{-0.6}$	9.3 ± 1 [36] 11 ± 2 [28] 9 ± 3 [27] 8.5 ± 1.9 [45]
$4_1^+ \rightarrow 2_1^+$	$24.3^{+1.2}_{-1.2}$			$7.6^{+0.7}_{-0.7}$	50 ± 15 [28] 11 ± 3 [27] 10^{+10}_{-8} [45]
$6_1^+ \rightarrow 4_1^+$	$9.3^{+0.2}_{-0.2}$			$0.77^{+0.03}_{-0.03}$	0.7 ± 0.3 [27]
$0_2^+ \rightarrow 2_1^+$	$22.2^{+1.1}_{-1.1}$			57^{+6}_{-6}	64 ± 4 [27] 100 ± 6 [28] 55 ± 1 [42] 64 ± 4 [45]
$2_2^+ \rightarrow 0_1^+$	$-6.4^{+0.3}_{-0.3}$			$1.0^{+0.1}_{-0.1}$	2.2 ± 0.6 [28] 1.5 ± 0.5 [27] 1.2 ± 0.3 [45]
$2_2^+ \rightarrow 2_1^+$	$-23.7^{+2.3}_{-2.7}$			$12.9^{+2.5}_{-2.5}$	17 ± 11 [28] 19^{+22}_{-14} [27] 14^{+35}_{-9} [45]
$4_2^+ \rightarrow 2_1^+$	42^{+3}_{-4}			23^{+3}_{-4}	30 ± 11 [28] 16 ± 5 [27] 12^{+7} [45]
$2_2^+ \rightarrow 0_2^+$	26^{+5}_{-3}			15^{+6}_{-4}	< 61 [27] < 46 [45]
$4_2^+ \rightarrow 2_2^+$	46^{+3}_{-6}			27^{+4}_{-6}	60 ± 30 [27] 60 ± 20 [28] 40^{+40}_{-30} [45]

	$\langle I_i \| E2 \| I_f \rangle$ [e fm^2]	Q$_{sp}$ [e fm^2]	
$2_1^+ \rightarrow 2_1^+$	-16^{+9}	-12^{+7}	-19 ± 8 [36]
$2_2^+ \rightarrow 2_2^+$	-55^{+15}_{-15}	-42^{+12}_{-12}	



KHK et al., PRL 117, 062501 (2016)
KHK et al., PRC 97, 024326 (2018)

Discussion: Unique solution?



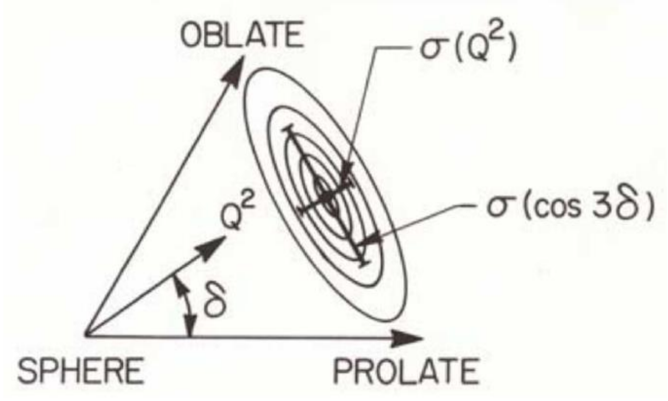
M. Zielińska and KHK,
The 16th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics
EPJ Web of Conferences 178, 02014 (2018)

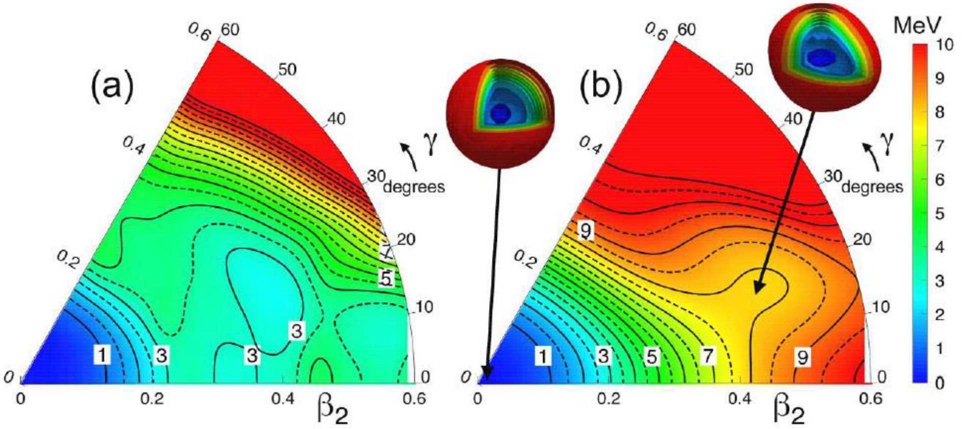
Discussion: Shape parameters

	EXP		SM		BMF	
state	$\langle Q^2 \rangle$	$\sigma(Q^2)$	$\langle Q^2 \rangle$	$\sigma(Q^2)$	$\langle Q^2 \rangle$	$\sigma(Q^2)$
0_1^+	480 (20)	350 (30)	240	470	100	250
2_1^+	890 (100)		250	490	100	310
0_2^+	1310 (250)	350 (30)	1200	500	1910	520
2_2^+	1440 (250)		1130	500	1970	310

state	$\langle \cos(3\delta) \rangle_{exp}$	$\langle \cos(3\delta) \rangle_{SM}$	$\langle \cos(3\delta) \rangle_{BMF}$
0_1^+	0.06 (10)	0.34	0.34
0_2^+	0.79 (13)	0.67	0.49

CONCLUSIONS:
0_1^+ – SPHERICAL with large fluctuations around minimum
0_2^+ – SUPERDEFORMED, SLIGHTLY TRIAXIAL/PROLATE shape





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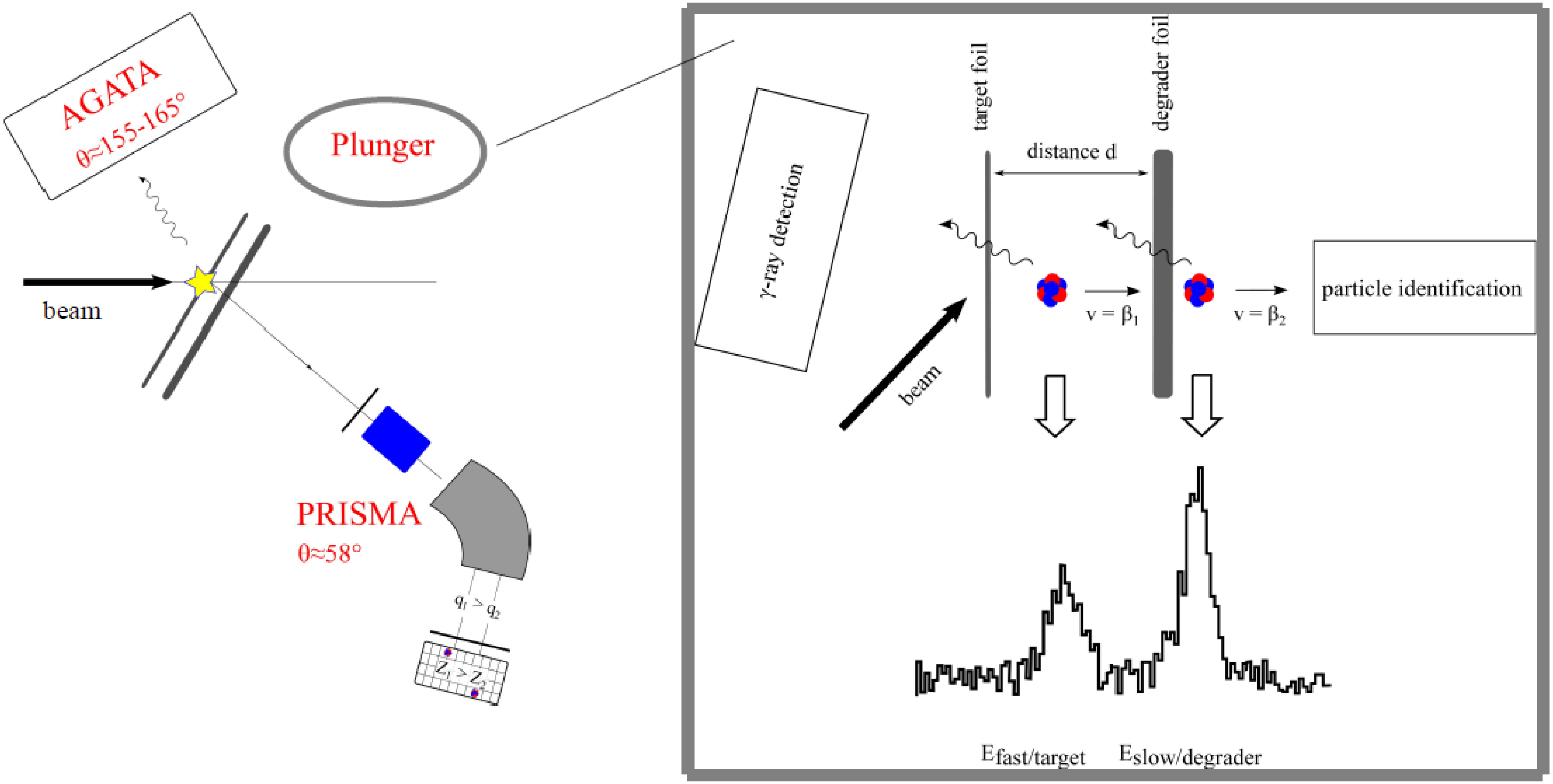
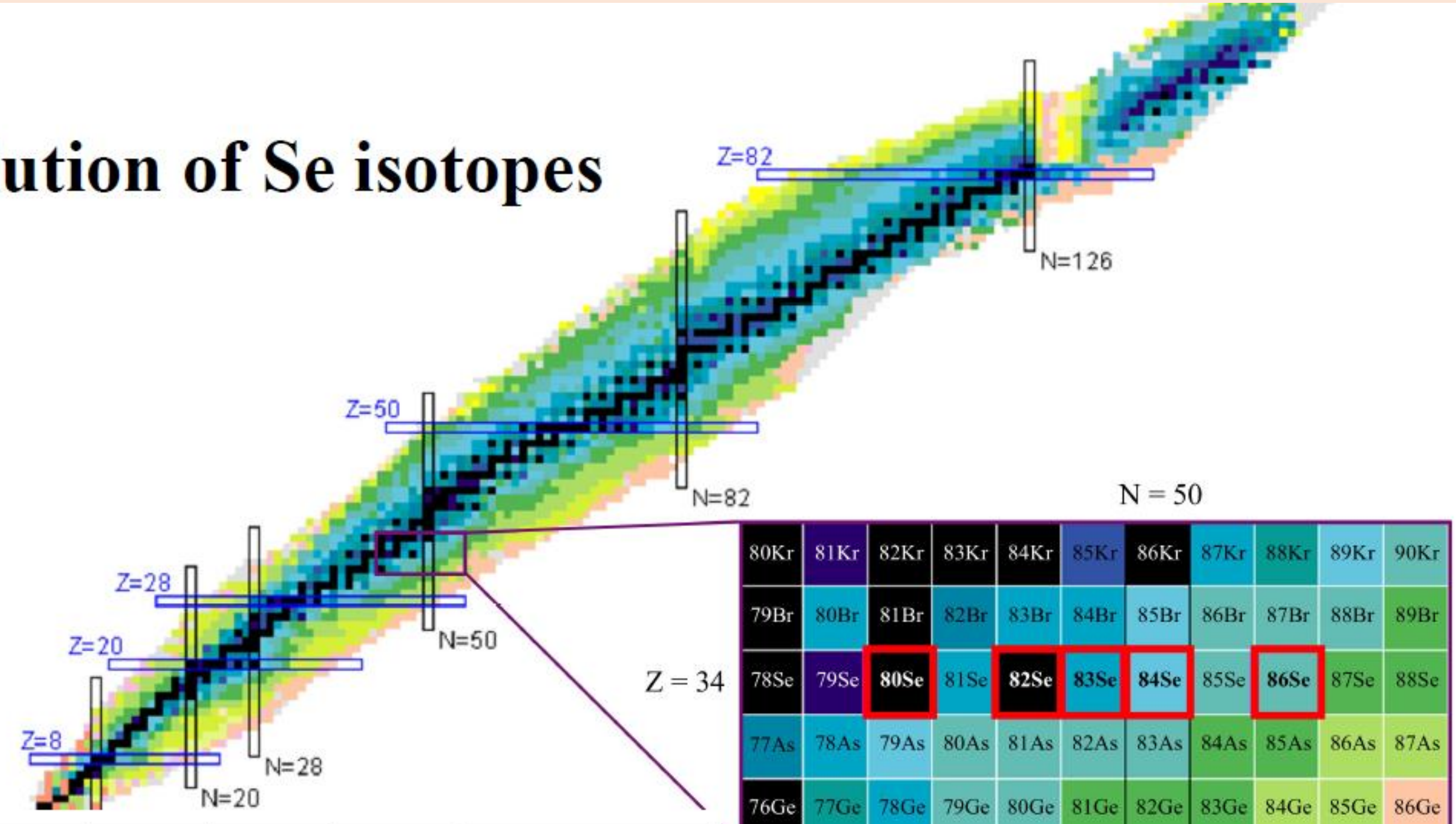
  PHYSICAL REVIEW C **98**, 014309 (2018)

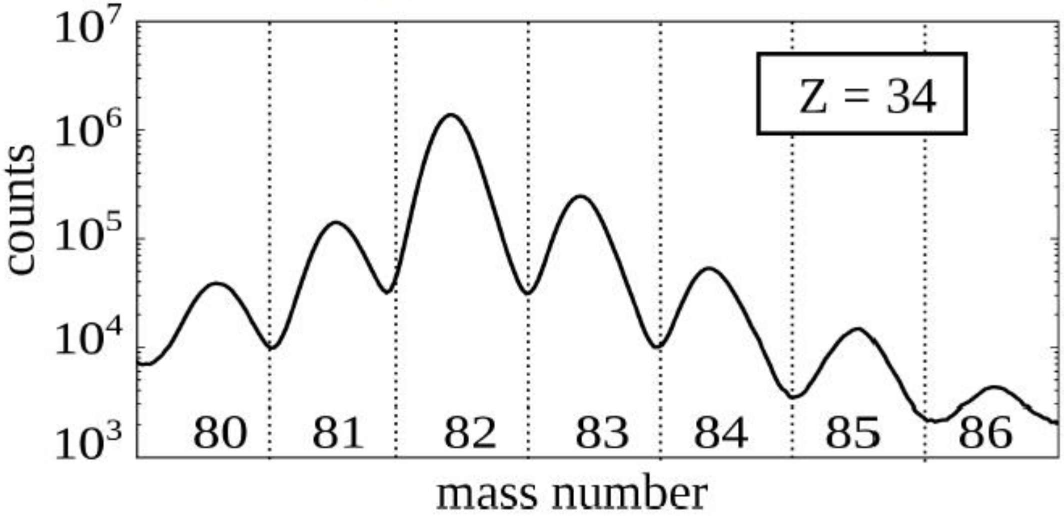
^{82}Se + ^{238}U The recoil distance doppler shift method



Mass resolution of Se isotopes



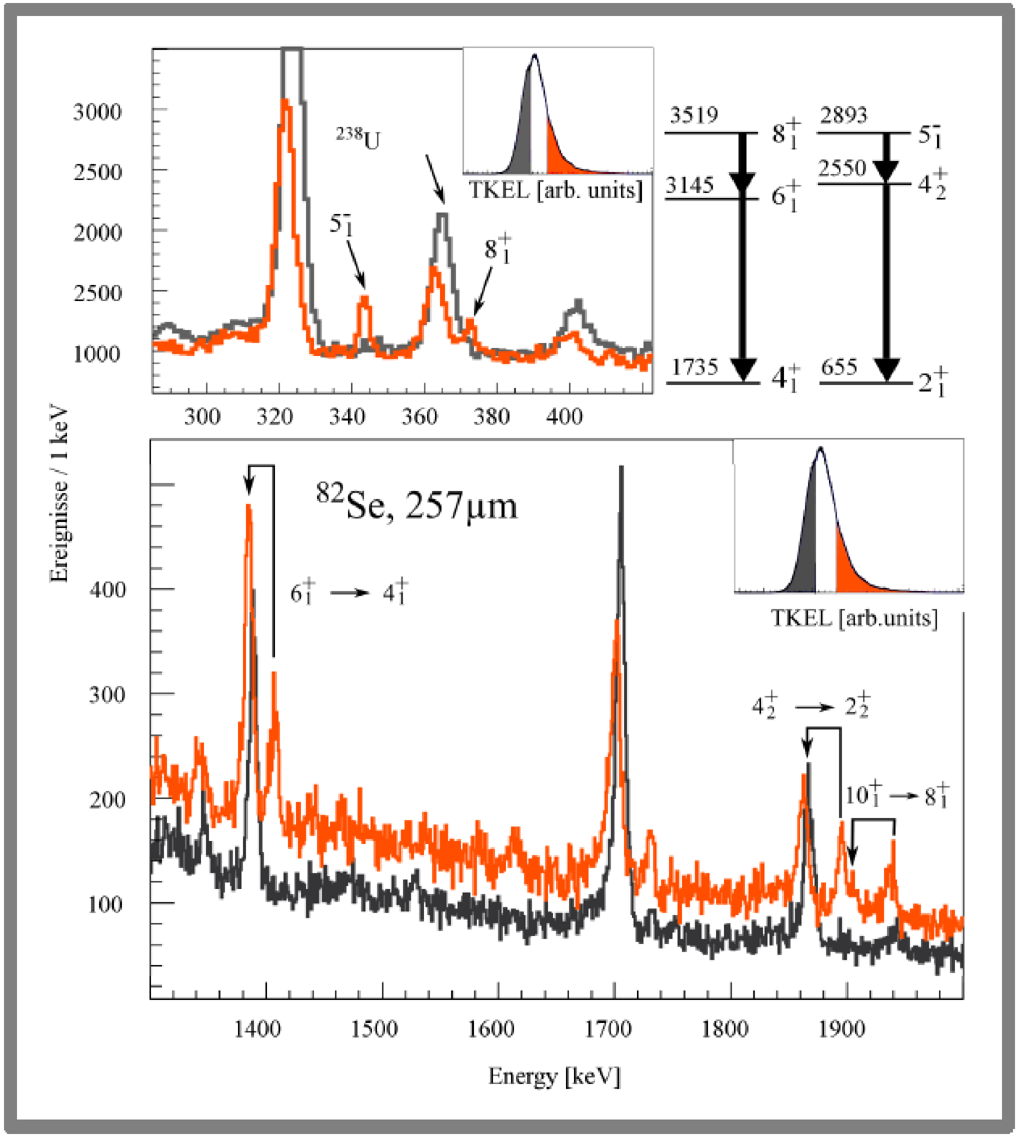
	80Kr	81Kr	82Kr	83Kr	84Kr	85Kr	86Kr	87Kr	88Kr	89Kr	90Kr
	79Br	80Br	81Br	82Br	83Br	84Br	85Br	86Br	87Br	88Br	89Br
Z = 34	78Se	79Se	**80Se**	81Se	**82Se**	**83Se**	**84Se**	85Se	**86Se**	87Se	88Se
	77As	78As	79As	80As	81As	82As	83As	84As	85As	86As	87As
	76Ge	77Ge	78Ge	79Ge	80Ge	81Ge	82Ge	83Ge	84Ge	85Ge	86Ge



Mass resolution m/Δm ≈ 235

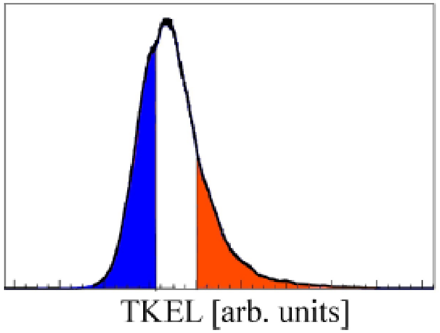
Universität zu Köln

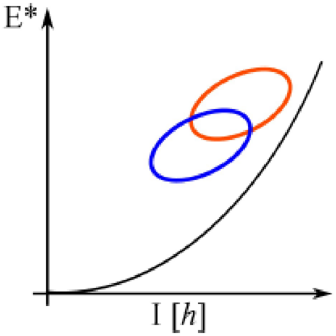
Analysis of the experiment
→ Effect of TKEL gates on level feeding



The total kinetic energy loss

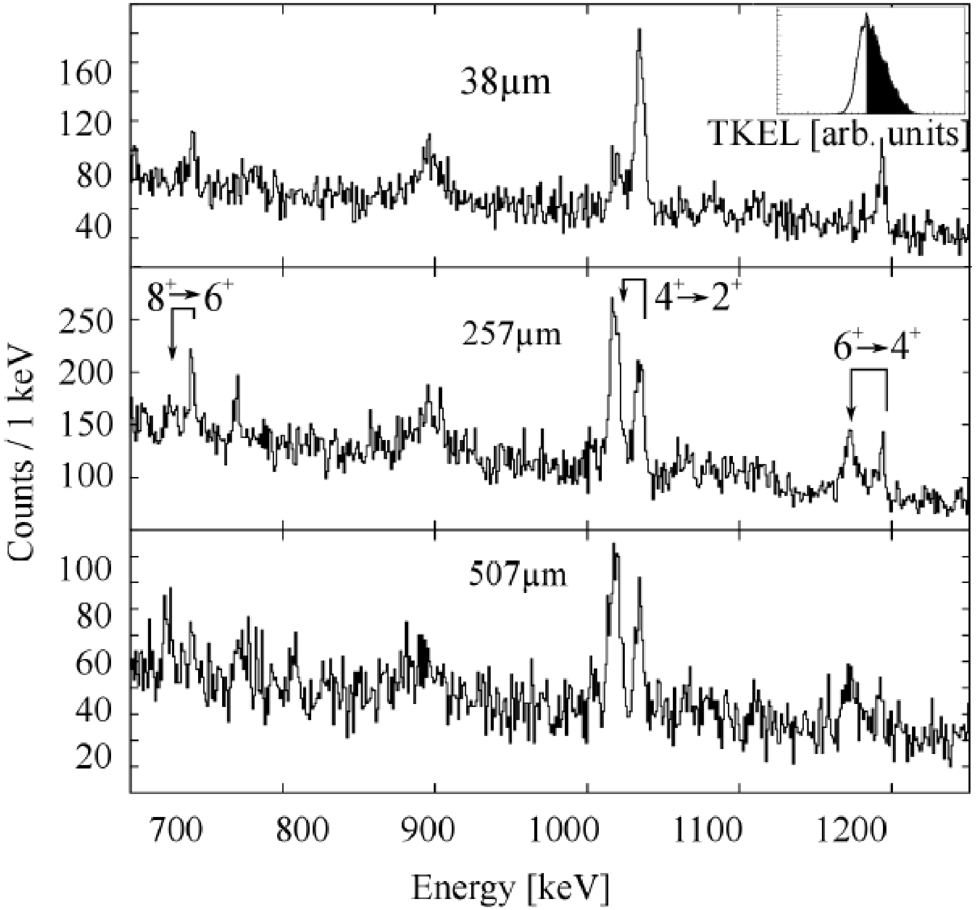
$$TKEL = -Q = E_T + E_B - (E_{TL} + E_{BL} + E^*_{TL} + E^*_{BL})$$

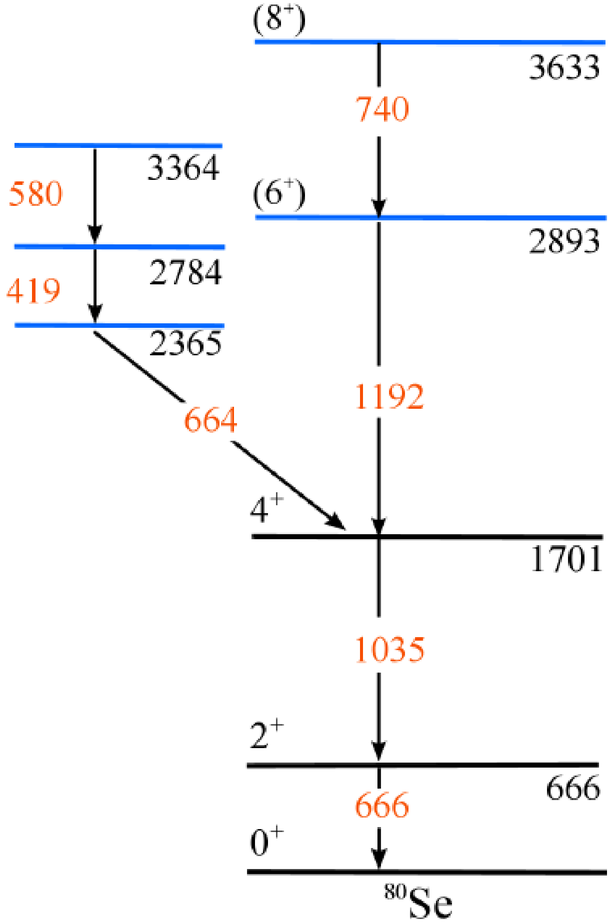




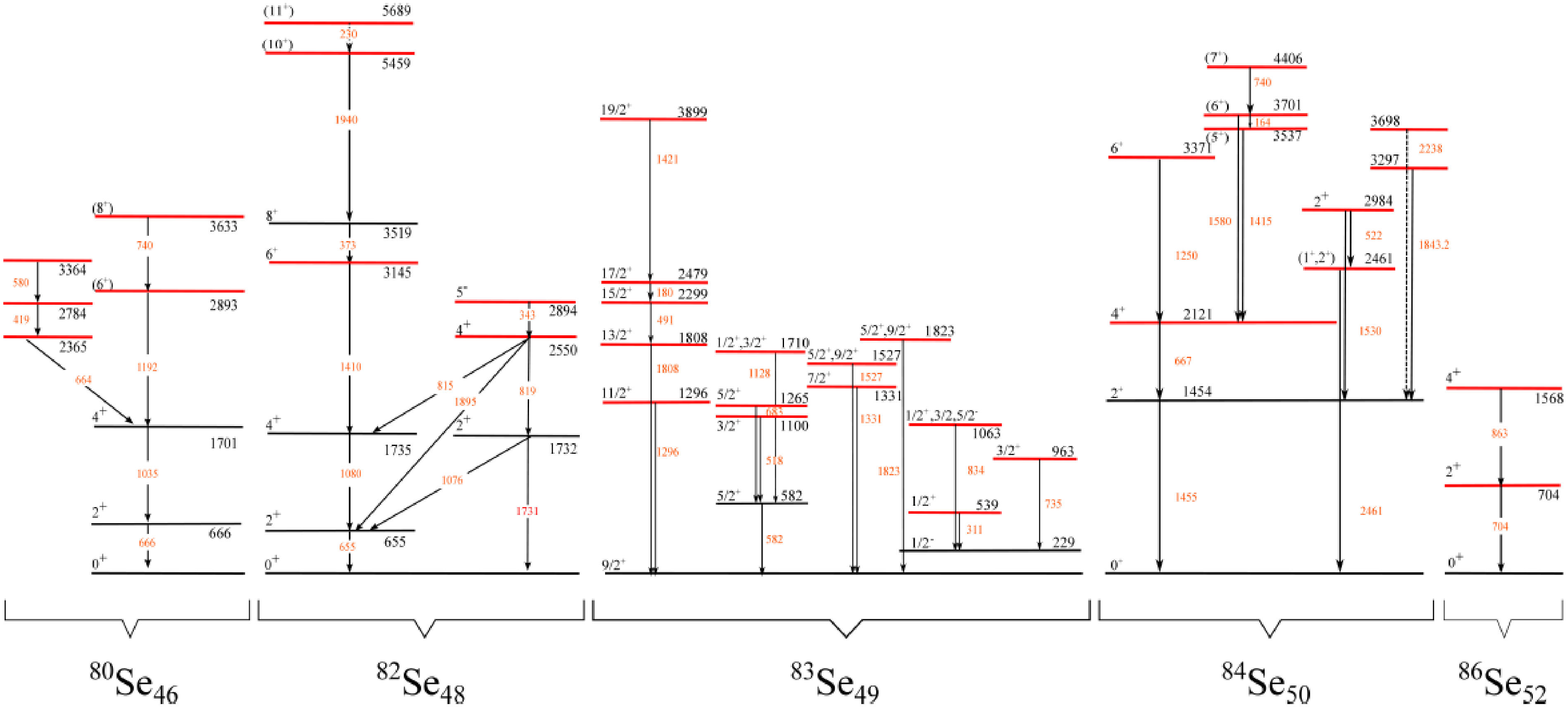
- **Cross check feeding assumptions**
- **Helpful for lifetime analysis**

^{80}Se


38μm
TKEL [arb. units]
257μm
8+→6+
4+→2+
6+→4+
507μm
Counts / 1 keV
160
120
80
40
250
200
150
100
100
80
60
40
20
700
800
900
1000
1100
1200
Energy [keV]


(8+)
3633
740
(6+)
2893
3364
580
2784
419
2365
664
1192
4+
1701
1035
2+
666
666
0+
80Se

Overview of the experimental results on the Se isotopes



Transition probabilities in neutron-rich ^{84,86}Se

J. Litzinger, A. Blazhev, A. Dewald,

PHYSICAL REVIEW C 92, 064322 (2015)

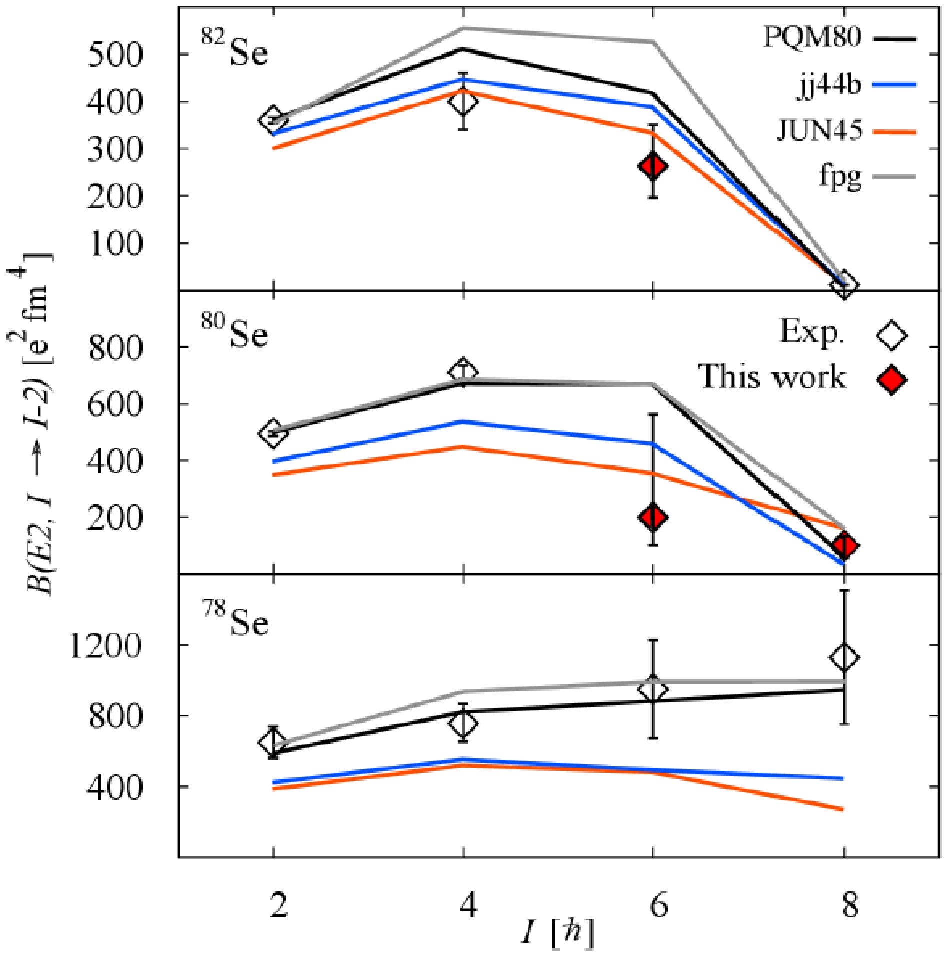
N

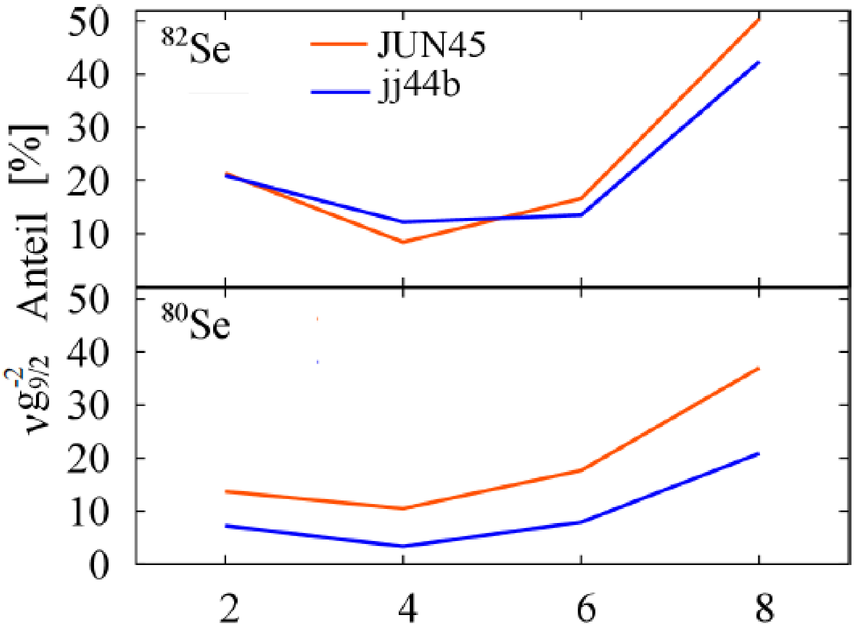
^{80,82}Se: J. Litzinger, A. Blazhev, A. Dewald, F. Didierjean, G. Duc

R. Lozeva, D. Verney et al., Phys. Rev. C 97, 044323 (2018)

Shell model calculations on ^{80,82}Se

→ The role of the $\nu g_{9/2}$ orbital





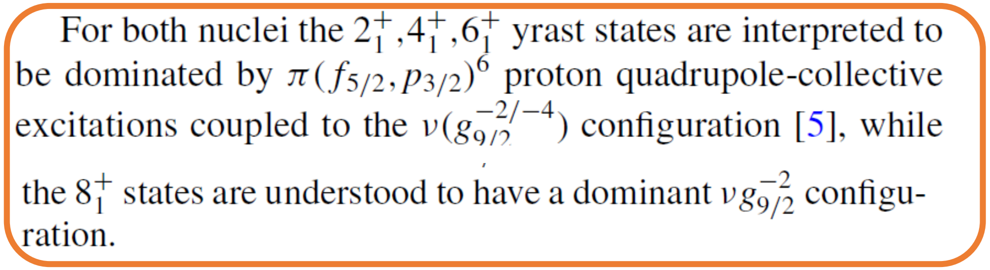
$B(E2)$ trends for the yrast cascades of ^{80,82}Se as calculated by JUN45 and jj44b behave approximately inversely to the $\nu g_{9/2}$ contribution of the corresponding decaying state. This is consistent with the understanding that $\nu g_{9/2}$ configurations in these nuclei are single-particle excitations, whereas the remaining percentage of the wave functions are dominantly of proton character and can be interpreted in terms of collective excitations.

jj44b, JUN45, fpg: Srivastava, Ermamatov, Phys. Scripta

PQM80: Yoshinaga, Higashiyama, Regan, Phys Rev. C 78. 004320 (2008)

Configurations & conclusion

- Different structures:
  - 0^+-6^+ are collective
  - 8+ single particle character ($g_{9/2}$)
- B(E2; $8^+ \rightarrow 6^+$) hindered
  - Correlated w/ $g_{9/2}$ occupancies
  - microscopic mechanism from ν-π components



For both nuclei the $2_1^+, 4_1^+, 6_1^+$ yrast states are interpreted to be dominated by $\pi(f_{5/2}, p_{3/2})^6$ proton quadrupole-collective excitations coupled to the $\nu(g_{9/2}^{-2/-4})$ configuration [5], while the 8_1^+ states are understood to have a dominant $\nu g_{9/2}^{-2}$ configuration.

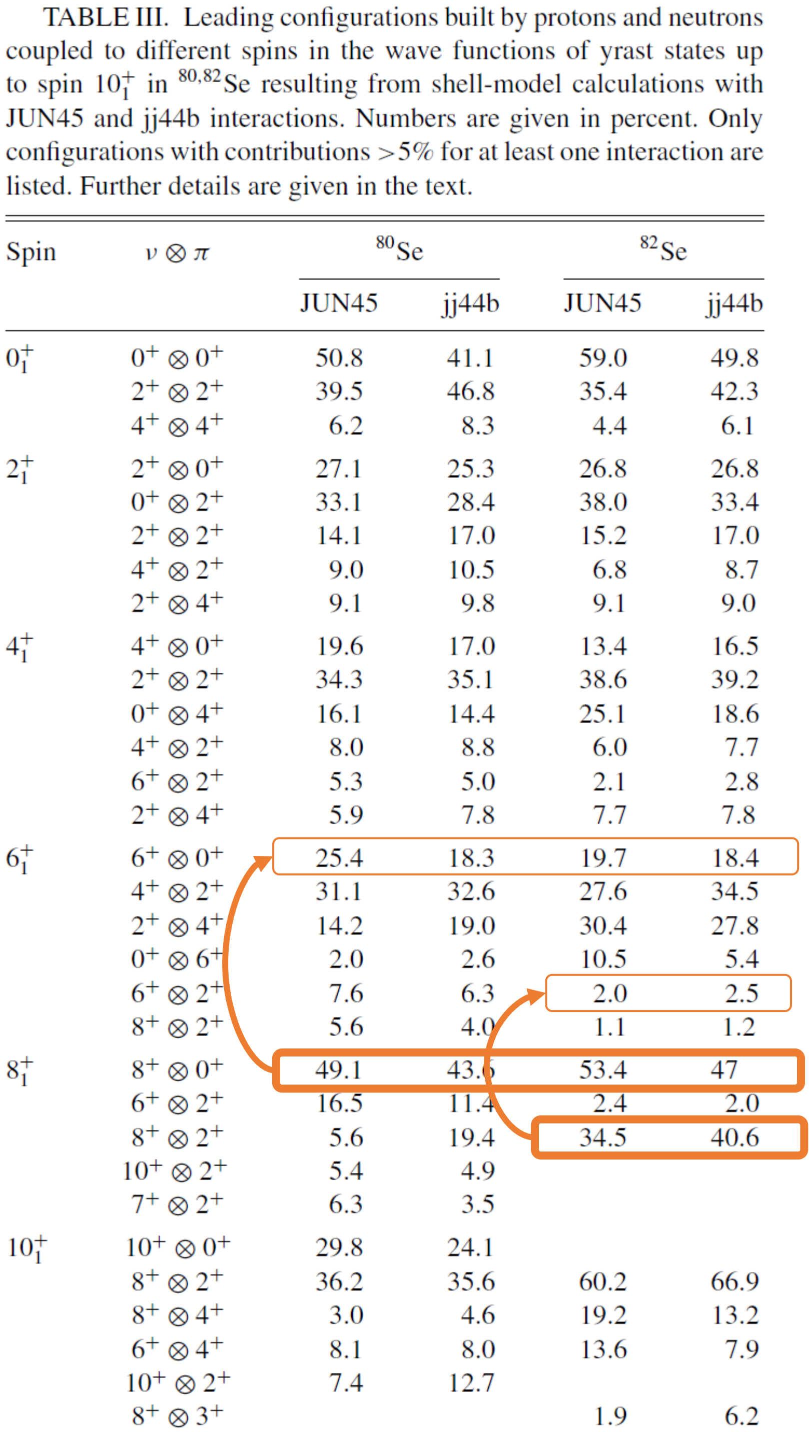


TABLE III. Leading configurations built by protons and neutrons coupled to different spins in the wave functions of yrast states up to spin 10_1^+ in ^{80,82}Se resulting from shell-model calculations with JUN45 and jj44b interactions. Numbers are given in percent. Only configurations with contributions >5% for at least one interaction are listed. Further details are given in the text.

Spin	$\nu \otimes \pi$	^{80}Se		^{82}Se	
		JUN45	jj44b	JUN45	jj44b
0_1^+	$0^+ \otimes 0^+$	50.8	41.1	59.0	49.8
	$2^+ \otimes 2^+$	39.5	46.8	35.4	42.3
	$4^+ \otimes 4^+$	6.2	8.3	4.4	6.1
2_1^+	$2^+ \otimes 0^+$	27.1	25.3	26.8	26.8
	$0^+ \otimes 2^+$	33.1	28.4	38.0	33.4
	$2^+ \otimes 2^+$	14.1	17.0	15.2	17.0
	$4^+ \otimes 2^+$	9.0	10.5	6.8	8.7
	$2^+ \otimes 4^+$	9.1	9.8	9.1	9.0
4_1^+	$4^+ \otimes 0^+$	19.6	17.0	13.4	16.5
	$2^+ \otimes 2^+$	34.3	35.1	38.6	39.2
	$0^+ \otimes 4^+$	16.1	14.4	25.1	18.6
	$4^+ \otimes 2^+$	8.0	8.8	6.0	7.7
	$6^+ \otimes 2^+$	5.3	5.0	2.1	2.8
	$2^+ \otimes 4^+$	5.9	7.8	7.7	7.8
6_1^+	$6^+ \otimes 0^+$	25.4	18.3	19.7	18.4
	$4^+ \otimes 2^+$	31.1	32.6	27.6	34.5
	$2^+ \otimes 4^+$	14.2	19.0	30.4	27.8
	$0^+ \otimes 6^+$	2.0	2.6	10.5	5.4
	$6^+ \otimes 2^+$	7.6	6.3	2.0	2.5
	$8^+ \otimes 2^+$	5.6	4.0	1.1	1.2
8_1^+	$8^+ \otimes 0^+$	49.1	43.6	53.4	47
	$6^+ \otimes 2^+$	16.5	11.4	2.4	2.0
	$8^+ \otimes 2^+$	5.6	19.4	34.5	40.6
	$10^+ \otimes 2^+$	5.4	4.9		
	$7^+ \otimes 2^+$	6.3	3.5		
10_1^+	$10^+ \otimes 0^+$	29.8	24.1		
	$8^+ \otimes 2^+$	36.2	35.6	60.2	66.9
	$8^+ \otimes 4^+$	3.0	4.6	19.2	13.2
	$6^+ \otimes 4^+$	8.1	8.0	13.6	7.9
	$10^+ \otimes 2^+$	7.4	12.7		
	$8^+ \otimes 3^+$			1.9	6.2

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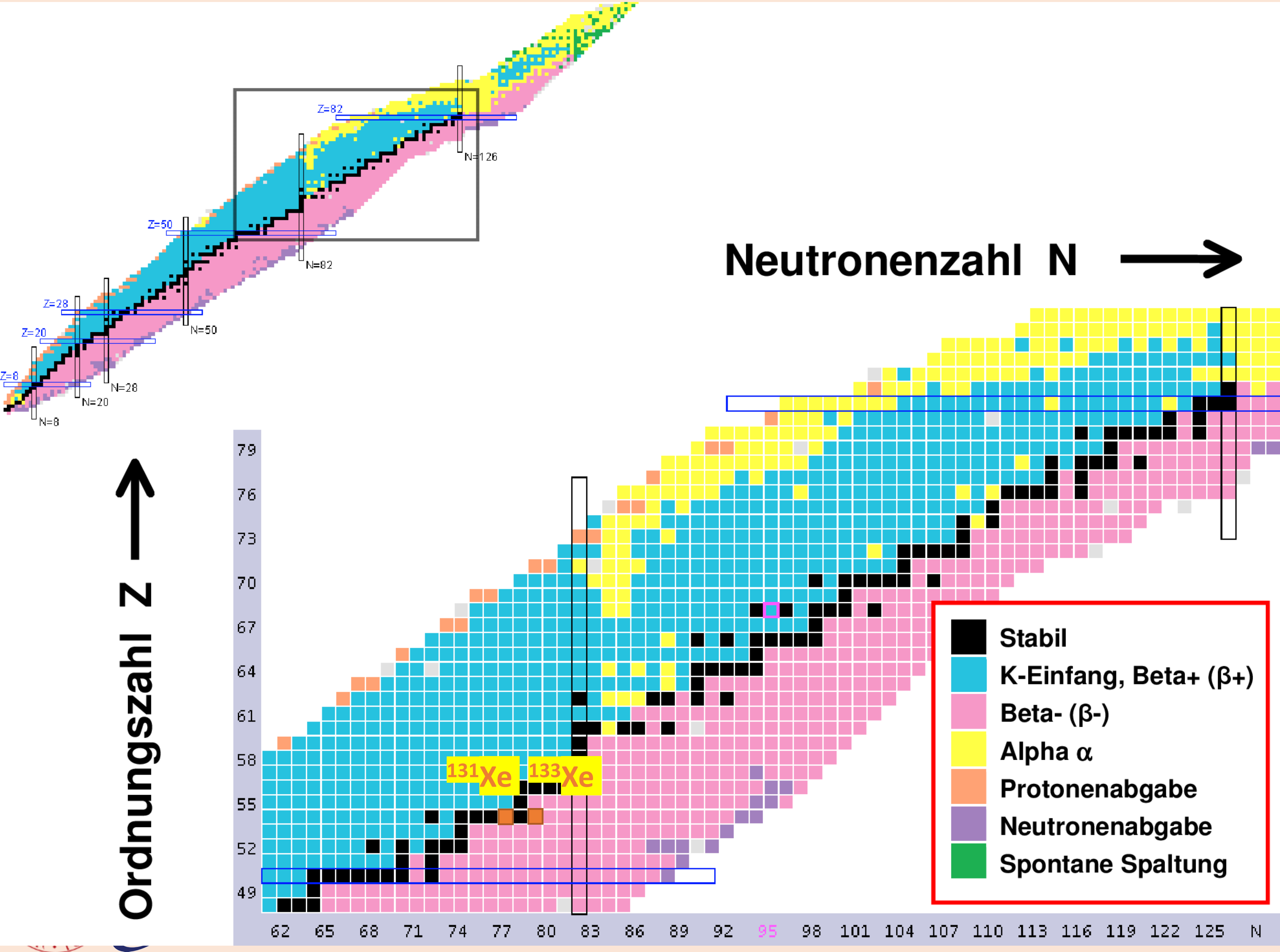
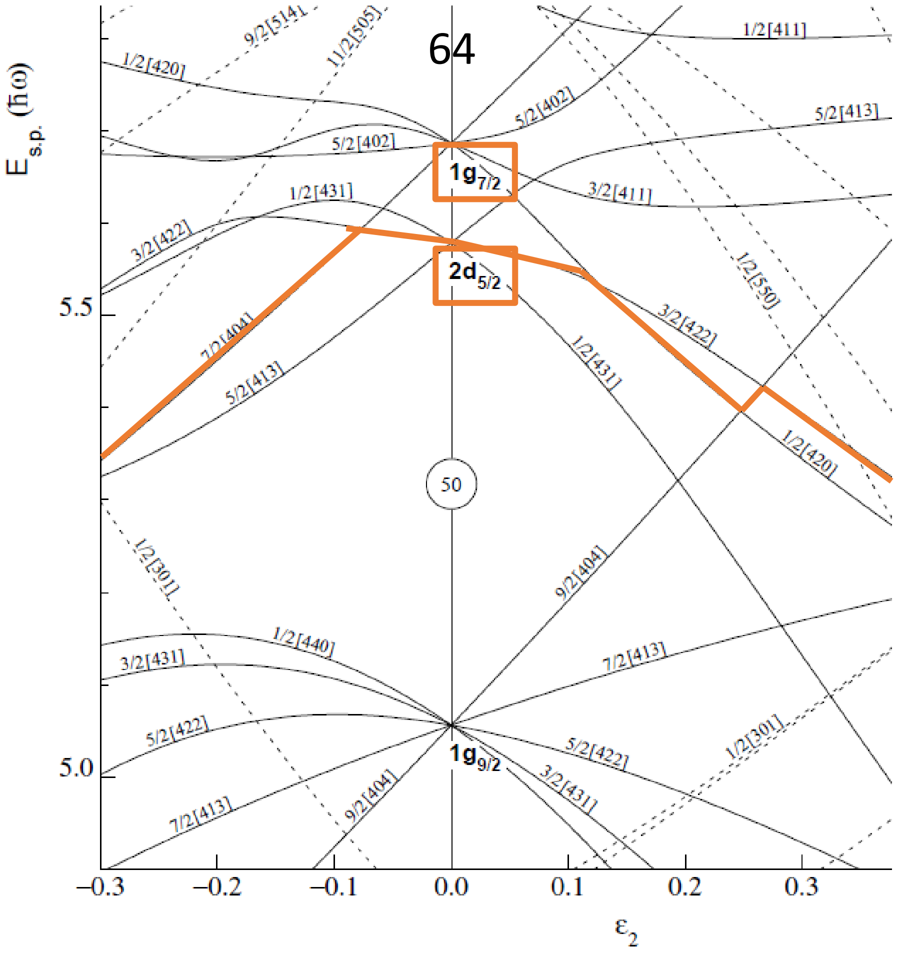
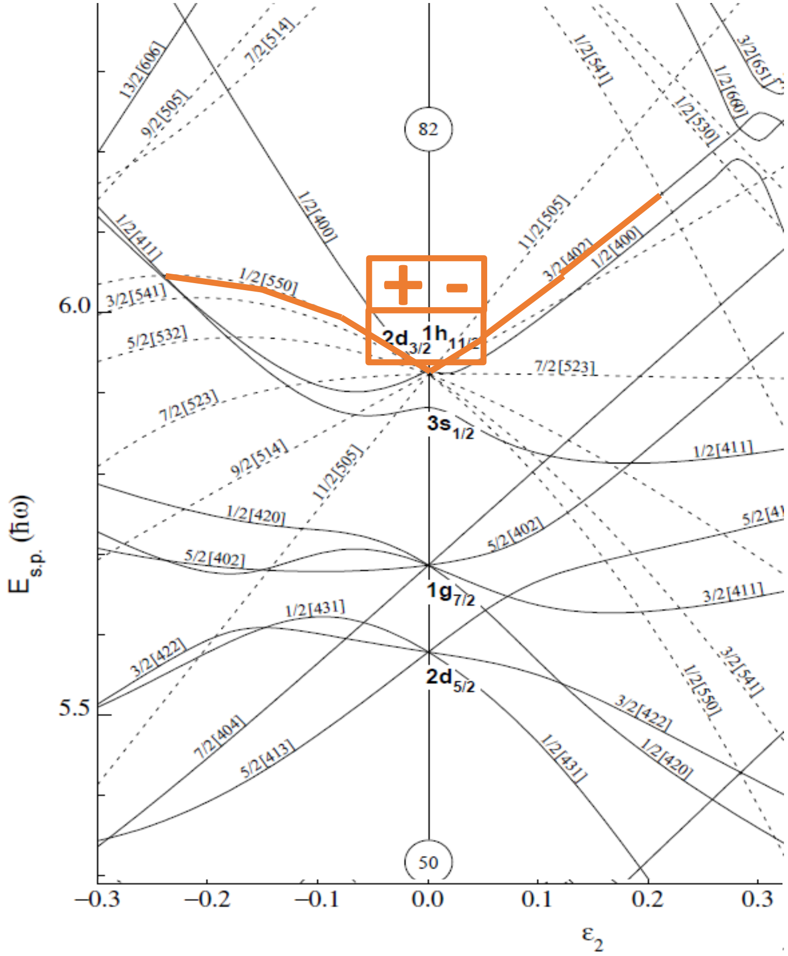

Z=82
Z=50
Z=28
Z=20
Z=8
N=126
N=82
N=50
N=28
N=20
N=8
Neutronenzahl N
Ordnungszahl Z
79
76
73
70
67
64
61
58
55
52
49
62
65
68
71
74
77
80
83
86
89
92
95
98
101
104
107
110
113
116
119
122
125
N
^{131}Xe
^{133}Xe
Stabil
K-Einfang, Beta+ (β+)
Beta- (β-)
Alpha α
Protonenabgabe
Neutronenabgabe
Spontane Spaltung

^{133}Xe – Fermi surface

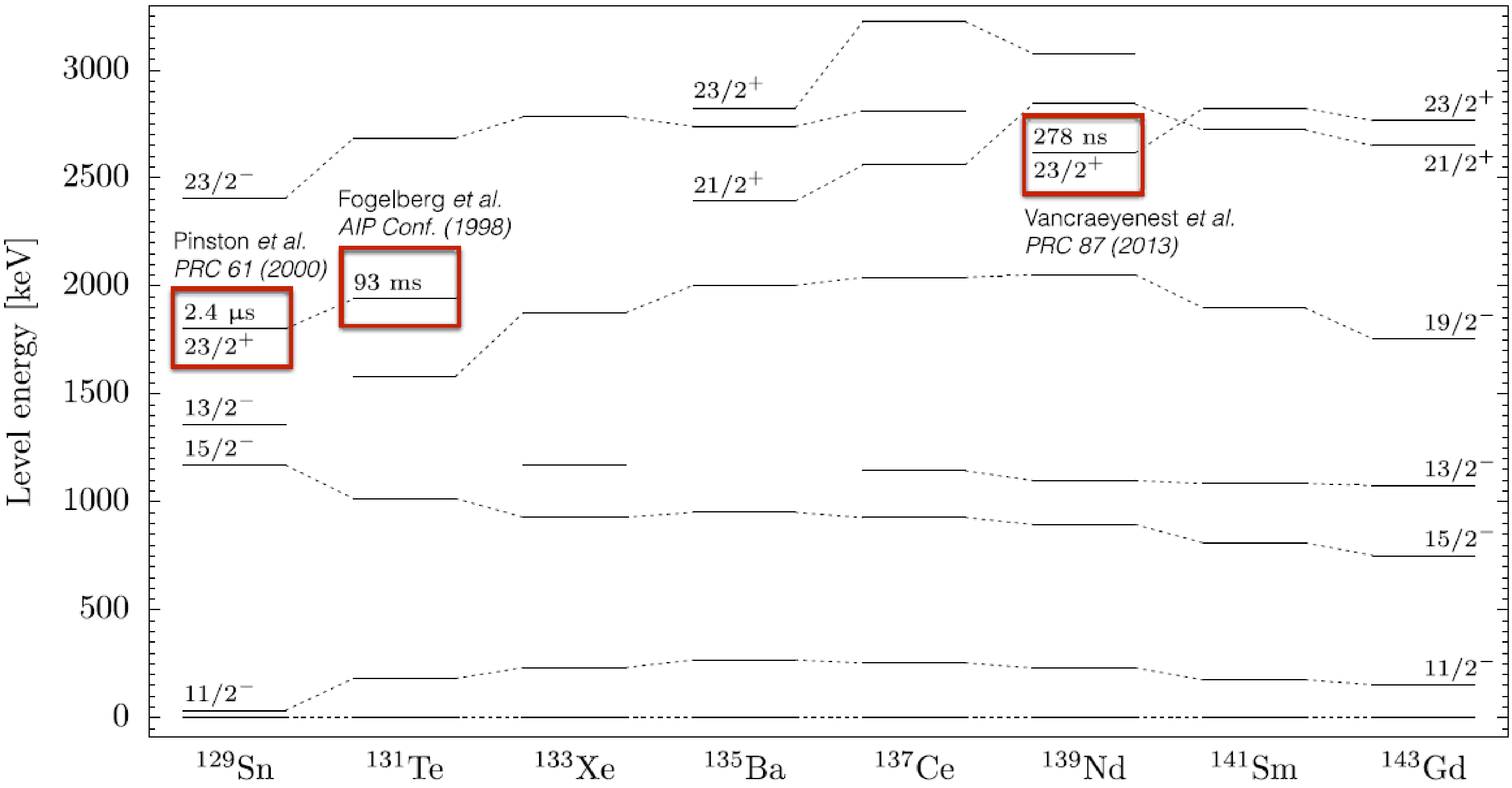


54 protons



77 neutrons

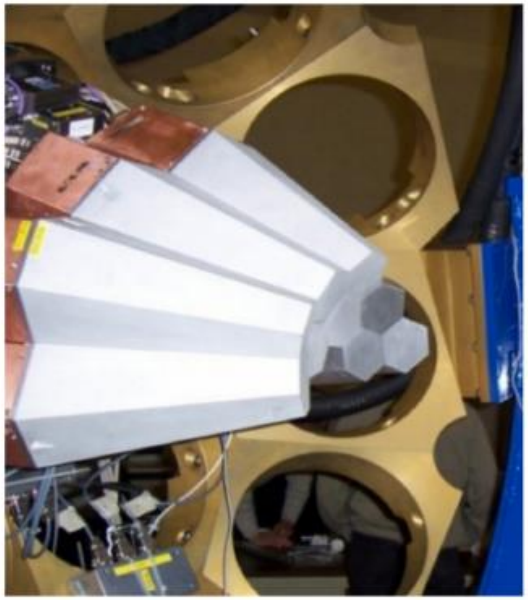
Isomeric gap along *N* = 79



$23/2^+$ corresponding to $\nu(g9/2)^{-2} \times \nu(d3/2)^{-1} = 10^+ \times 3/2^+$

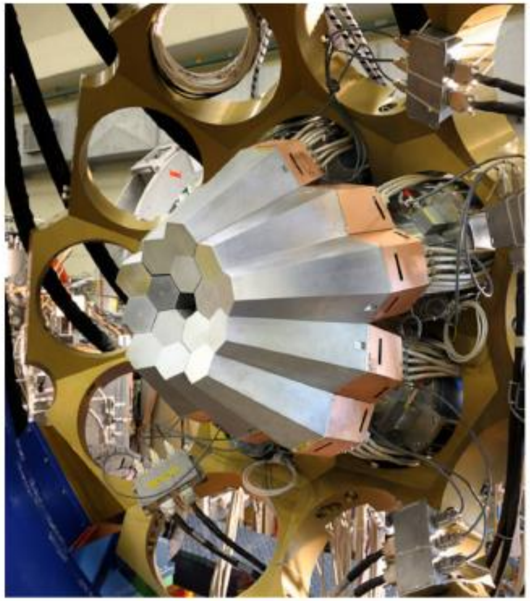
Where is this configuration in the other isotopes?

Exploiting data from three experiments



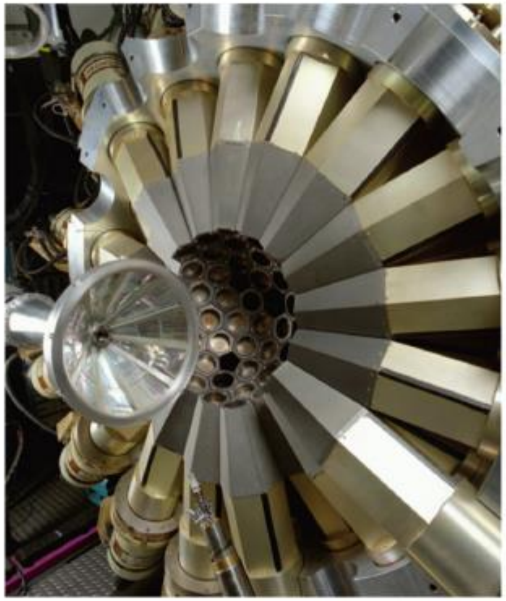
^{136}Xe + ^{208}Pb @ 930 MeV
three triple clusters
+ PRISMA

M. Siciliano *et al.*
INFN-LNL Rep. **241** 63 (2015)



^{136}Xe + ^{238}U @ 1 GeV
AGATA demonstrator
+ PRISMA

A. Vogt *et al.*
PRC 92, 024619 (2015)



^{136}Xe + ^{198}Pt @ 850 MeV
GAMMASPHERE
+ CHICO

J.J. Valiente-Dobón *et al.*
PRC 69, 024316 (2004)

Access to these isotopes in the proper spin regime

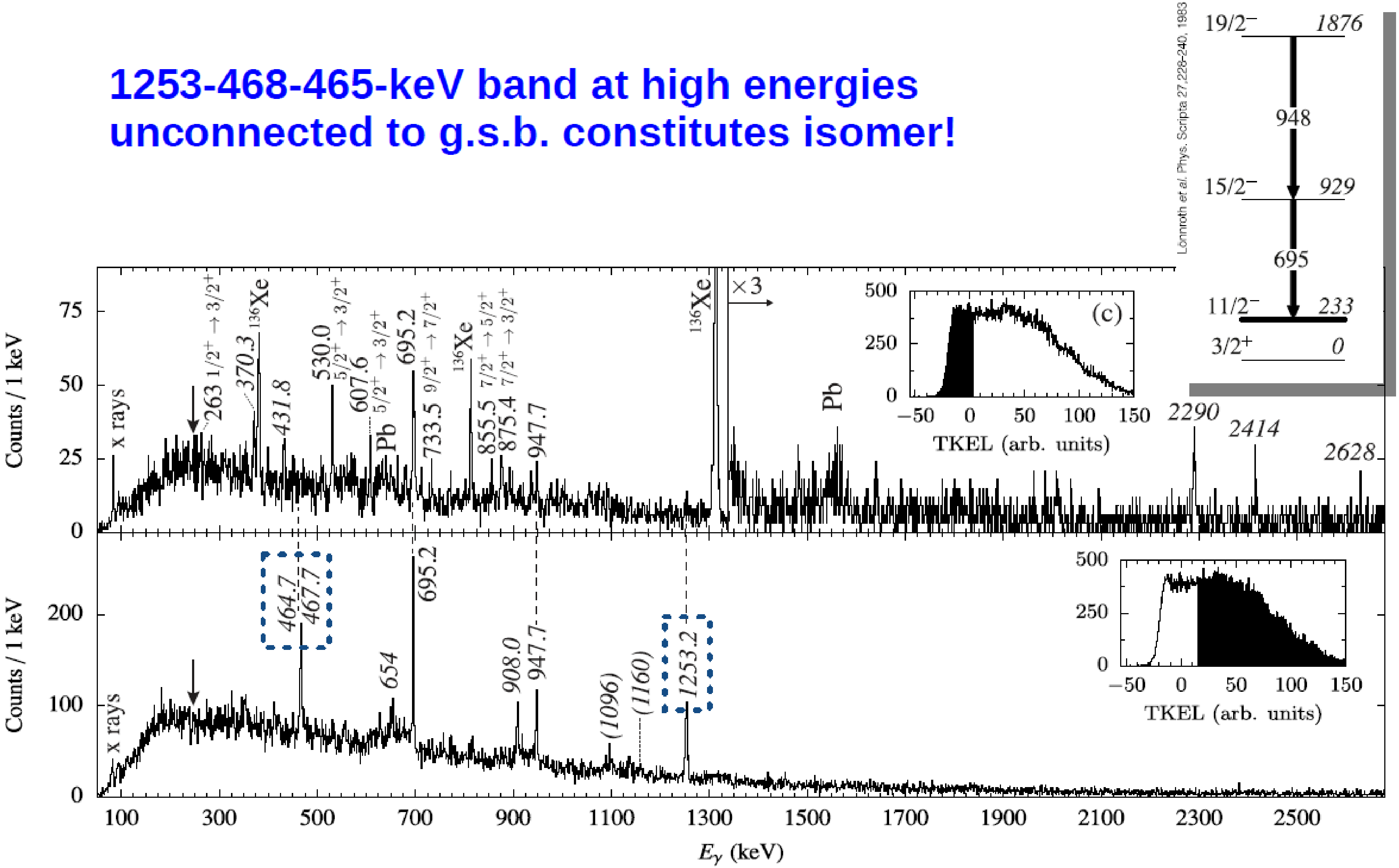
→

^{132}Xe ^{133}Xe ^{134}Xe ^{135}Xe

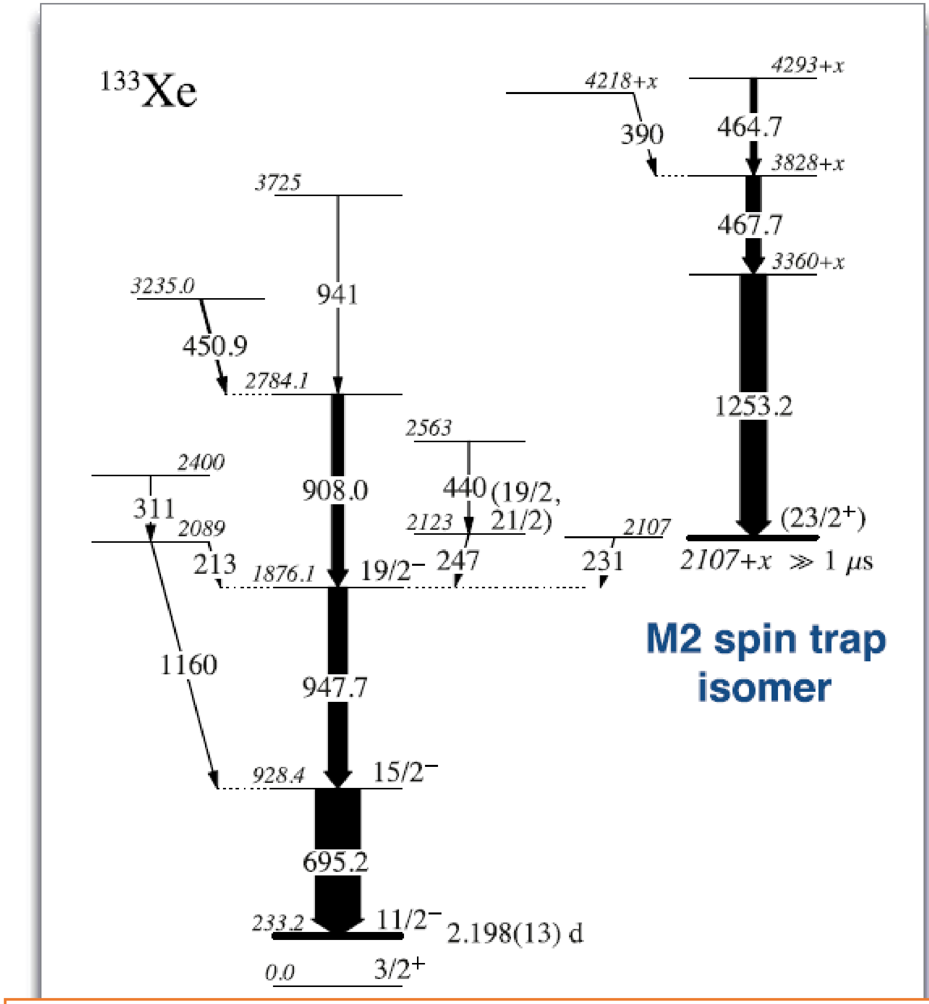
Discrimination of low- and high-spin regimes

^{133}Xe

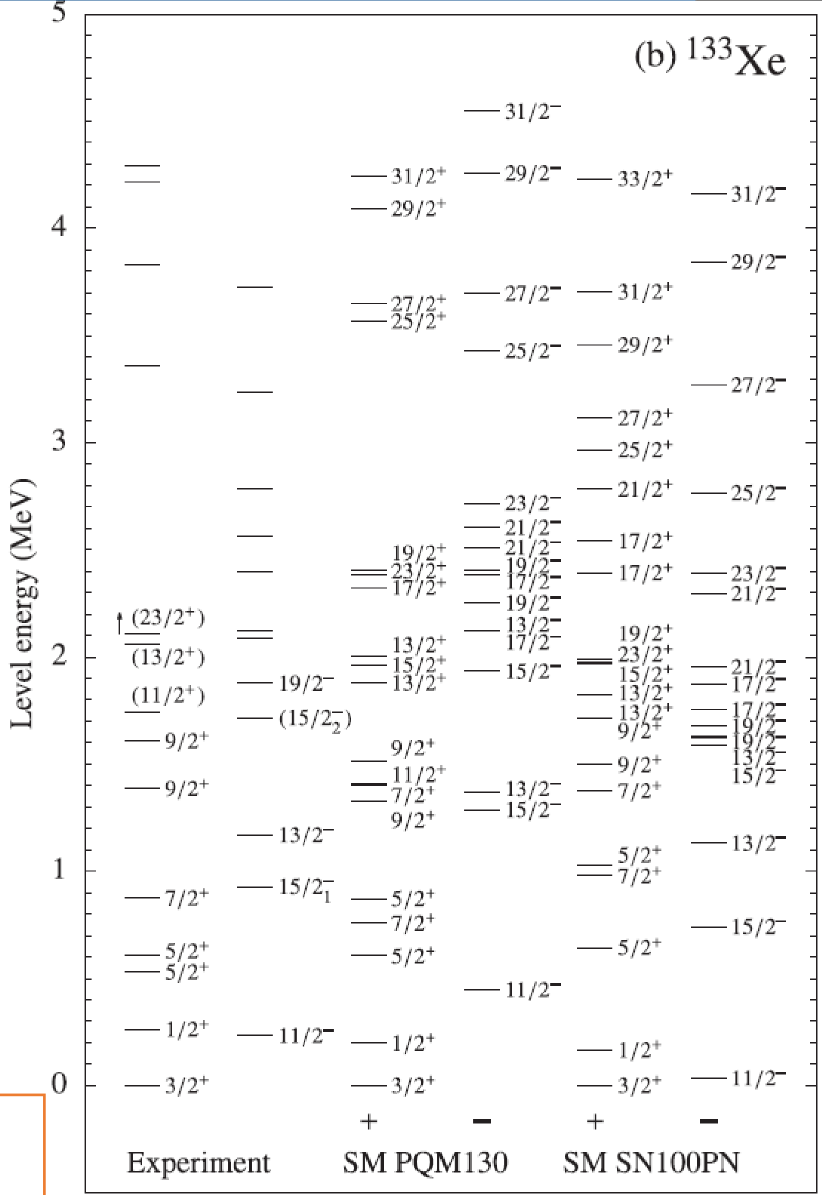
1253-468-465-keV band at high energies unconnected to g.s.b. constitutes isomer!


Lonnroth *et al.* Phys. Scripta 27, 228-240, 1983

A new spintrap isomer in ^{133}Xe



M2 spin trap isomer

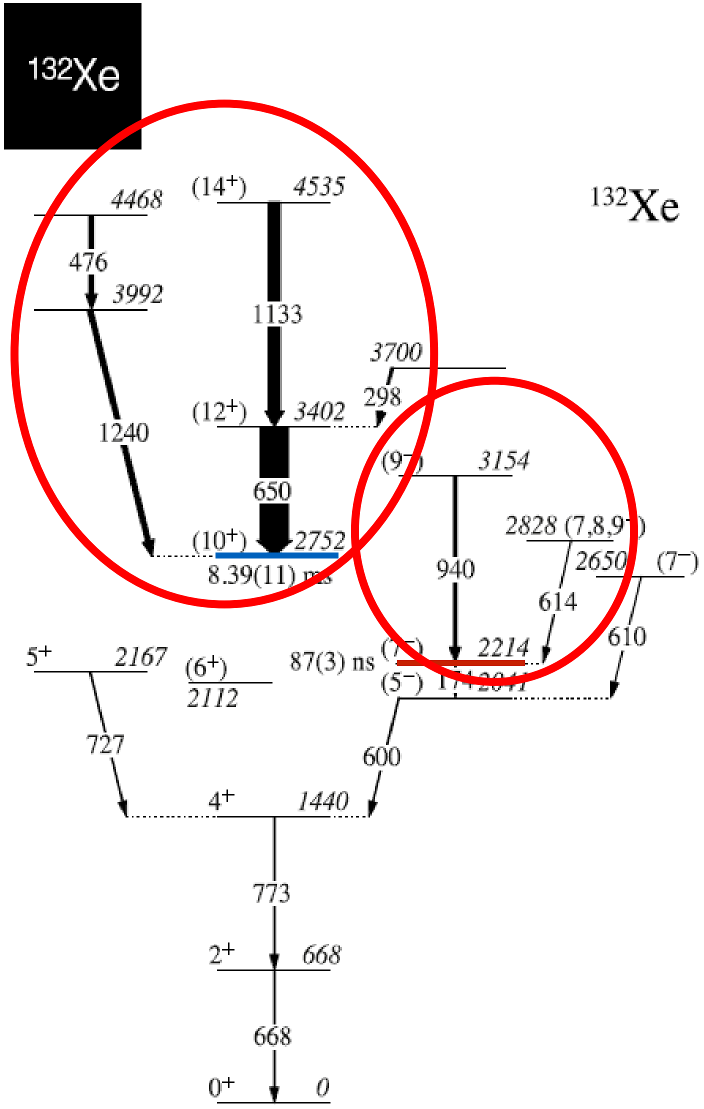


50 < *gdsh* < 82 valence space, ^{100}Sn core

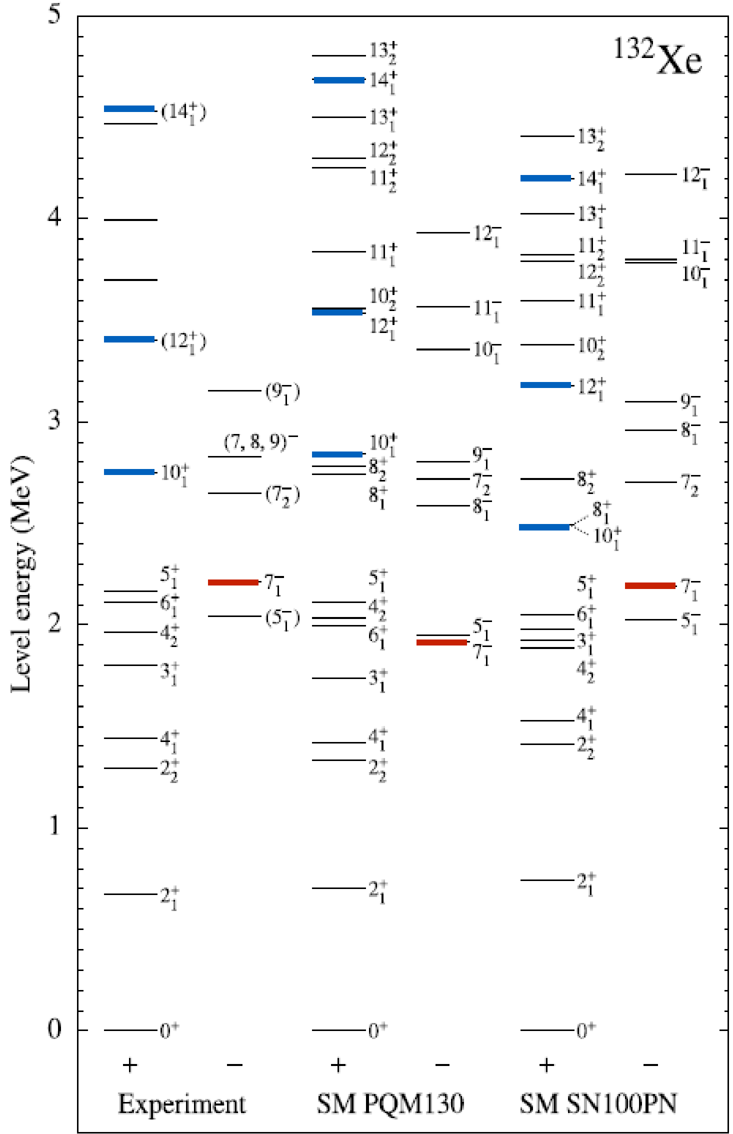
- PQM130: Pairing+QQ+Multipole for mass region 130 (Higashiyama and Yoshinaga)
- SN100PN: jj55pna renormalized from CD-Bonn – fitted @ 130

Calculations can reproduce the experiment

Extended level scheme of ^{132}Xe



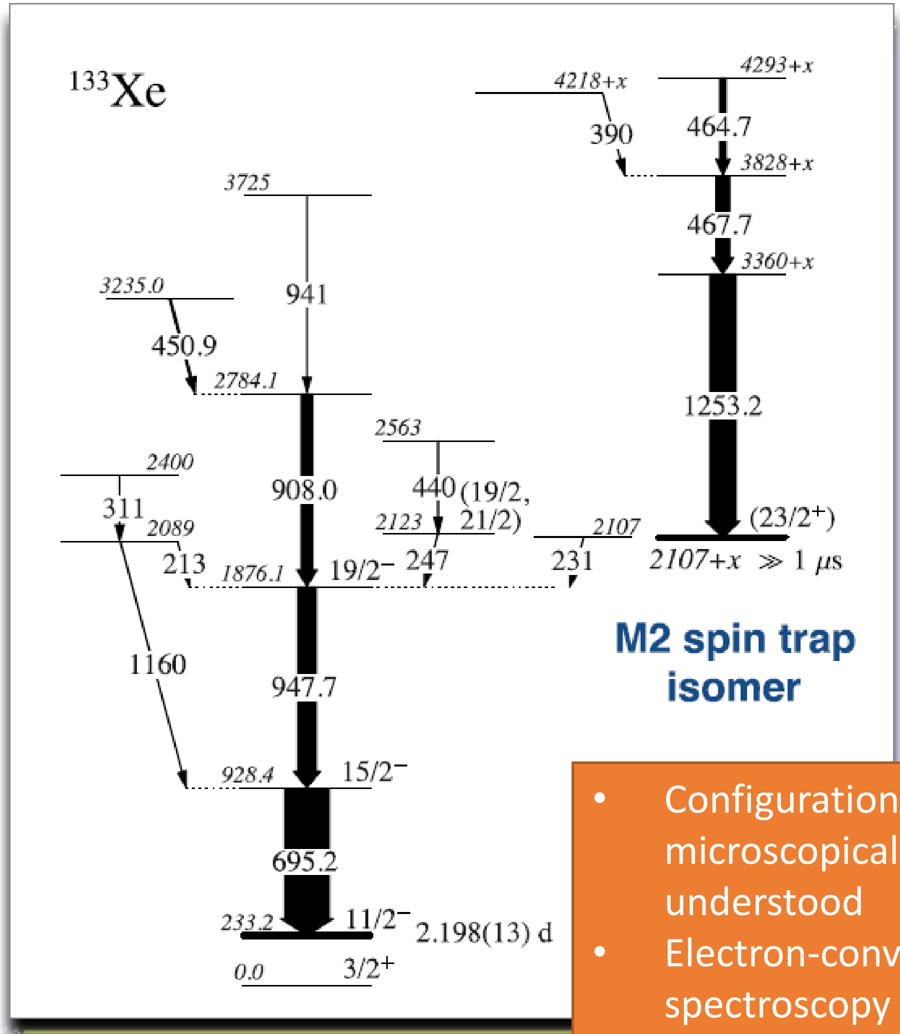
A. Vogt *et al.* PRC 96, 024321 (2017)



Calculations can reproduce the experiment

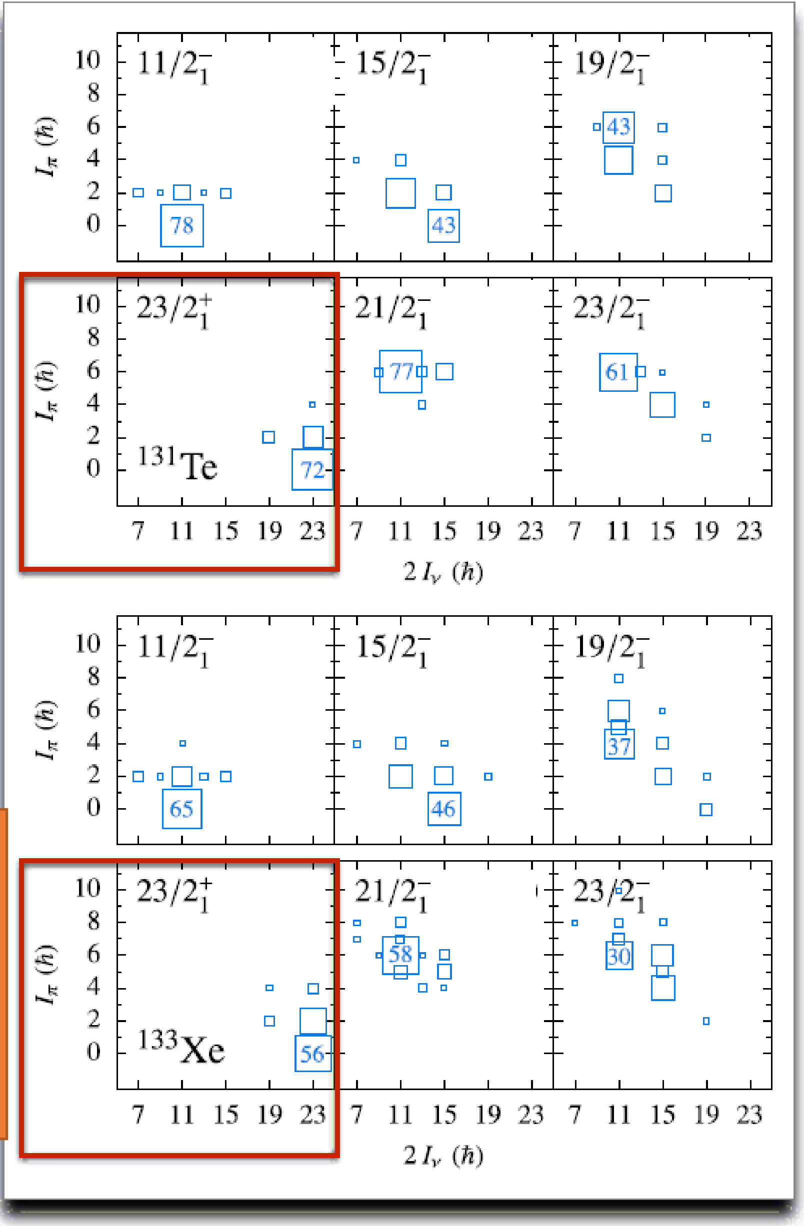
A new spintrap isomer in ^{133}Xe

^{133}Xe



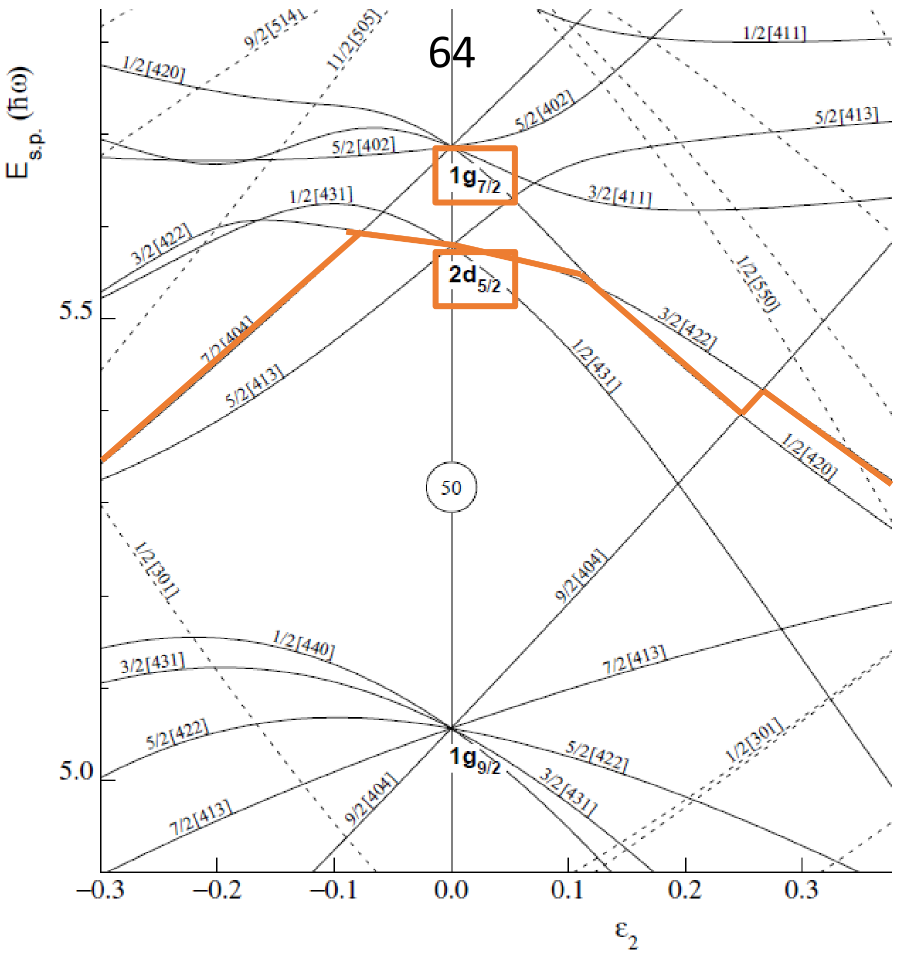
M2 spin trap isomer

- Configurations microscopically understood
- Electron-conversion spectroscopy needed

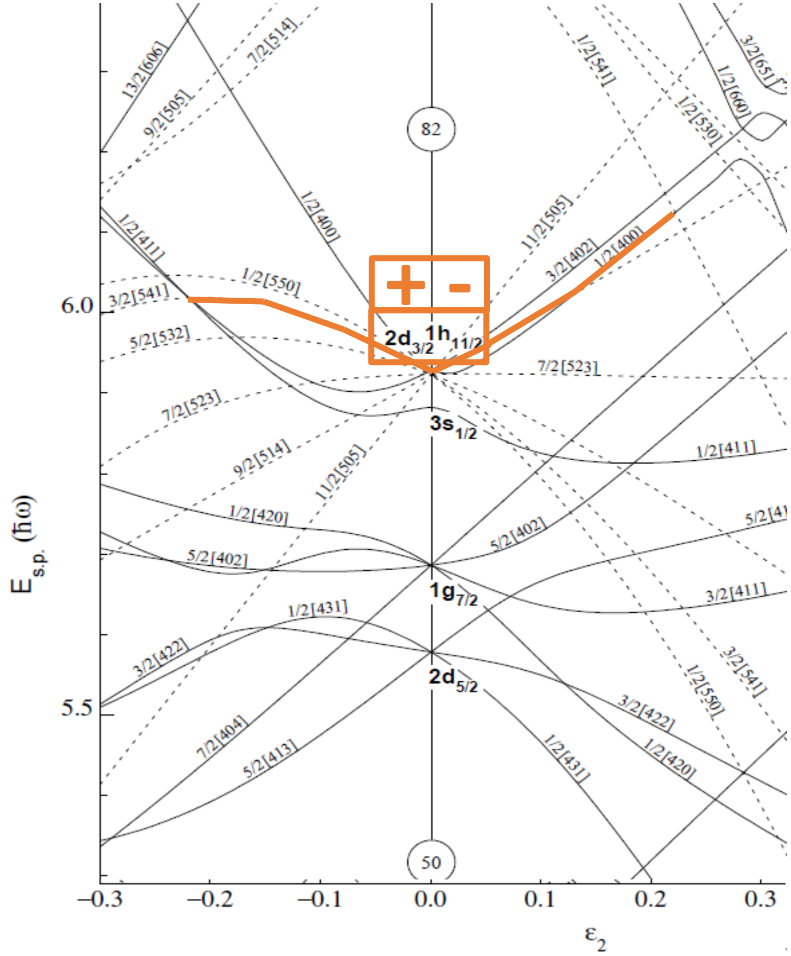


A. Vogt *et al.* PRC 96, 024321 (2017)

^{131}Xe – Fermi surface



54 protons



77 neutrons

L. Kaya, A. Vogt, P. Reiter, et al.
PHYSICAL REVIEW C **98**, 014309 (2018)

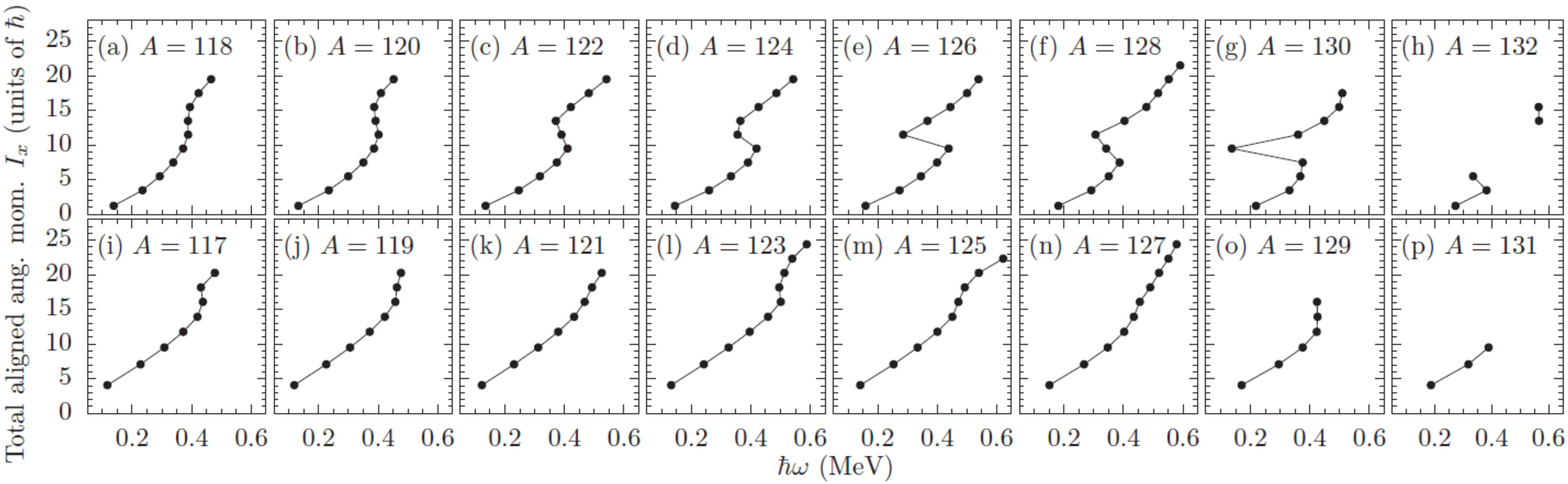
Lighter Xe

Total aligned angular momentum

$$I_x^{i,f} = \sqrt{I^{i,f}(I^{i,f}+1) - K^2}$$

Rotational frequency

$$\hbar\omega = (E_i - E_f)/(I_x^i - I_x^f)$$



^{123}Xe – ^{127}Xe **Neutron alignment** at spin $31/2^-\hbar$ **$\nu(h_{11/2})^3$**

C.-B. Moon *et al.* PRC 76, 067301 (2007)

A. Granderath *et al.* NPA 597, 427-471 (1996)

^{129}Xe Upbend with the alignment of **two $\pi h_{11/2}$ protons [$\nu h_{11/2} \otimes \pi(h_{11/2})^2$]**

Y. Hang *et al.* PRC 93, 064315 (2016)

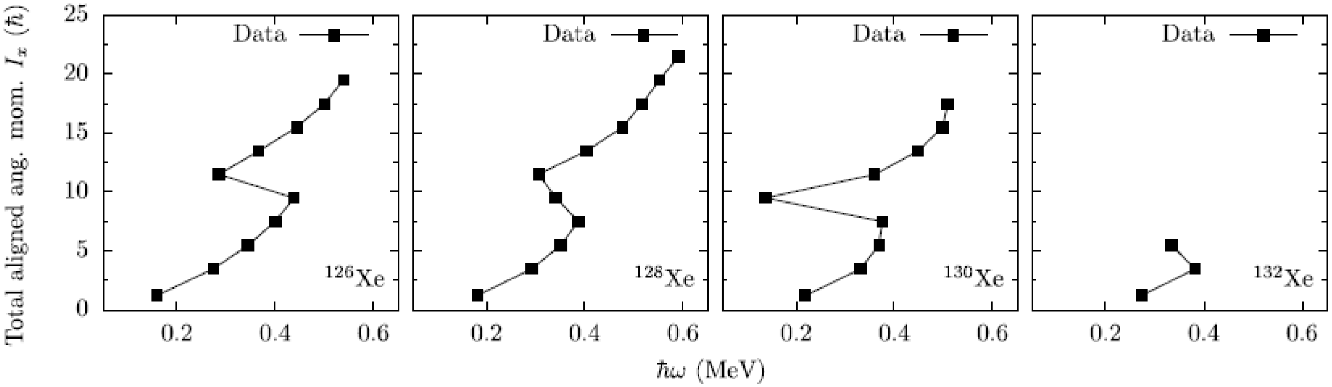
➡ Proton alignment favoured over neutron alignment at *N=73?*

^{131}Xe Origin of the backbending?

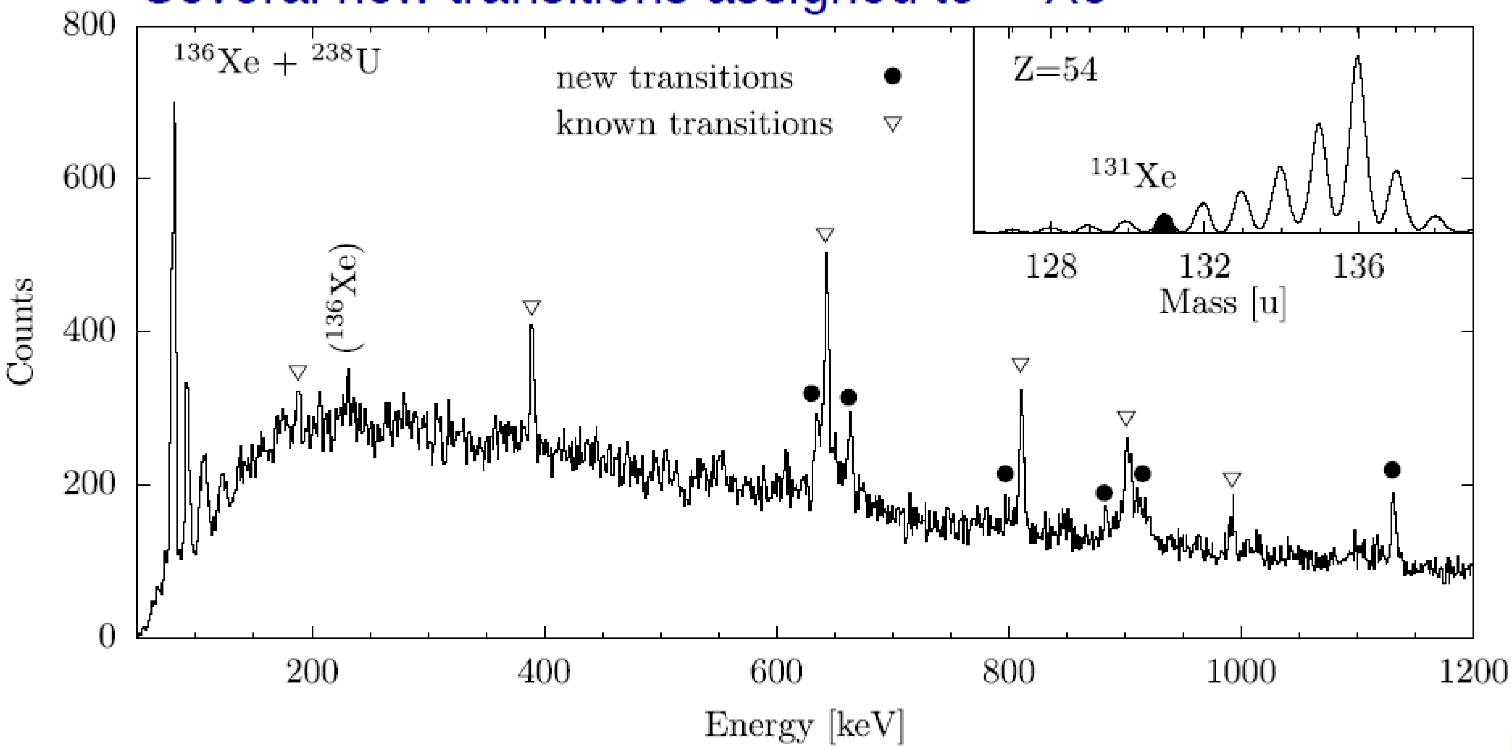
→ What happens at larger mass? ^{131}Xe??

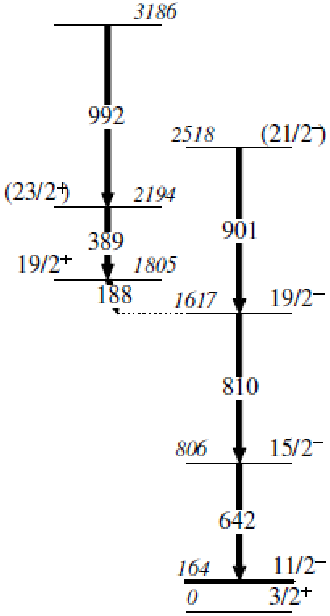
Alignment and backbending in the Xe isotopes: Extended level scheme of ^{131}Xe

Backbending phenomenon between 10^+ and 12^+ in $^{122\text{-}126}$Xe and between 8^+ and 10^+ in $^{128\text{-}130}$Xe



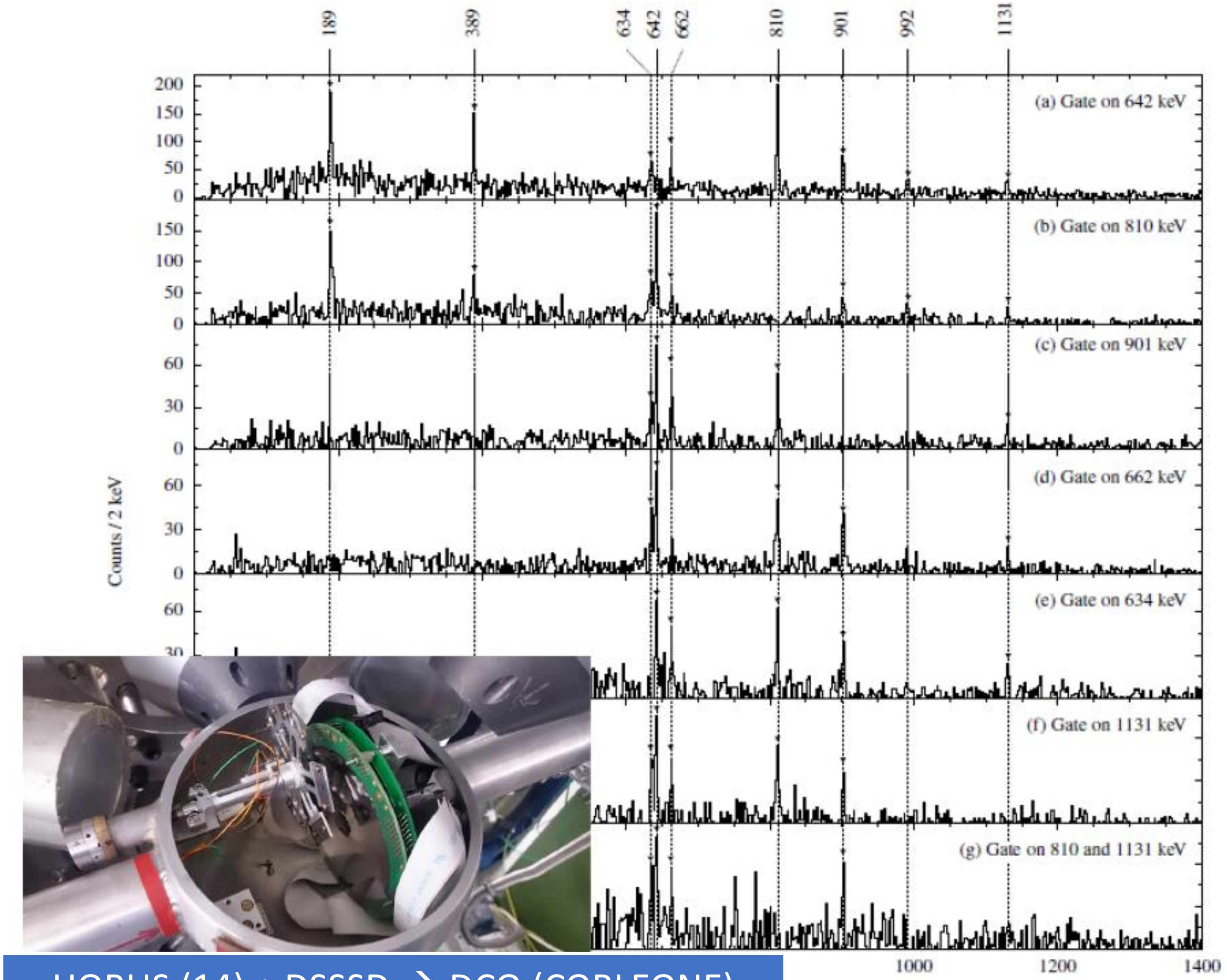
Several new transitions assigned to ^{131}Xe

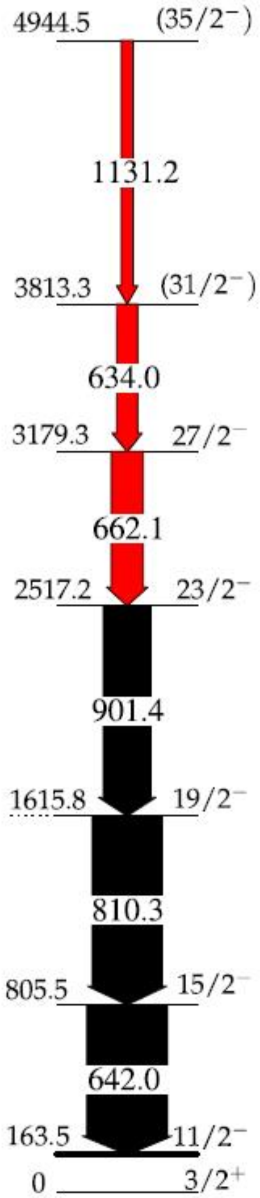




Nucl. Phys. A 172.3 (1971)

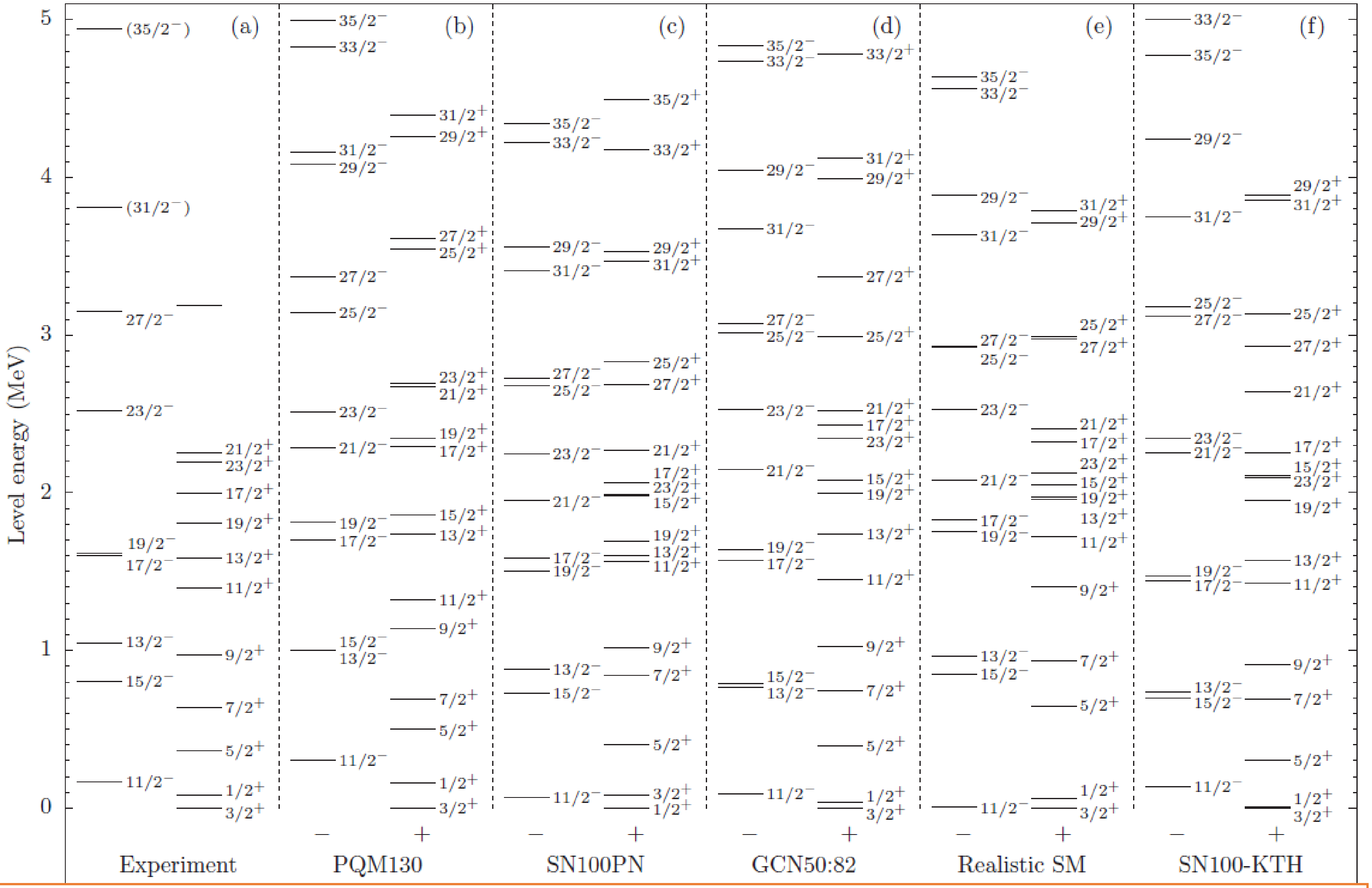
Fusion-evaporation reaction
^{124}Sn(^{11}B,p3n)^{131}Xe @ 54 MeV (8mb)





HORUS (14) + DSSSD → DCO (CORLEONE)

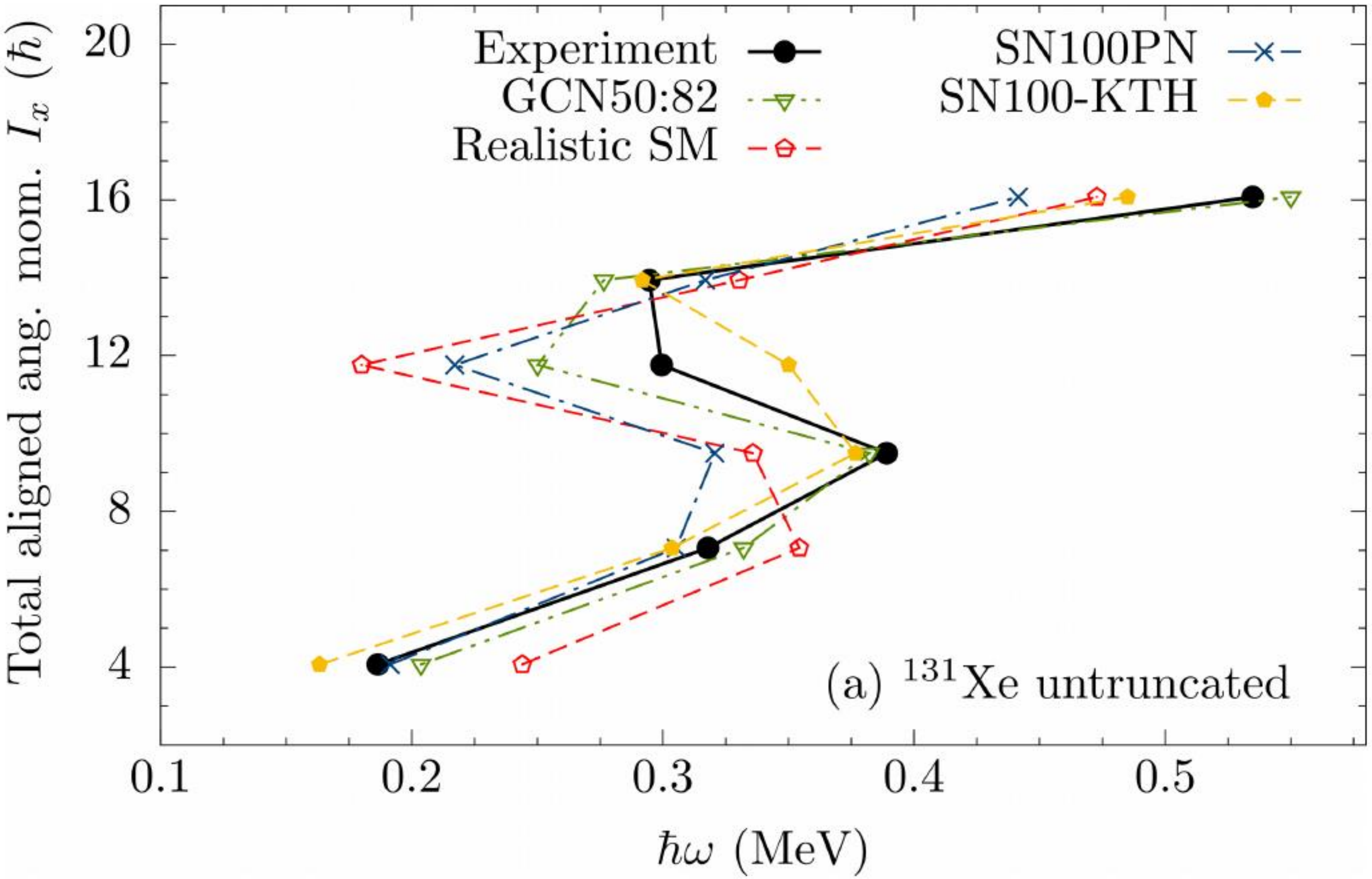
Theory



50 < *gdsh* < 82 valence space, ^{100}Sn core

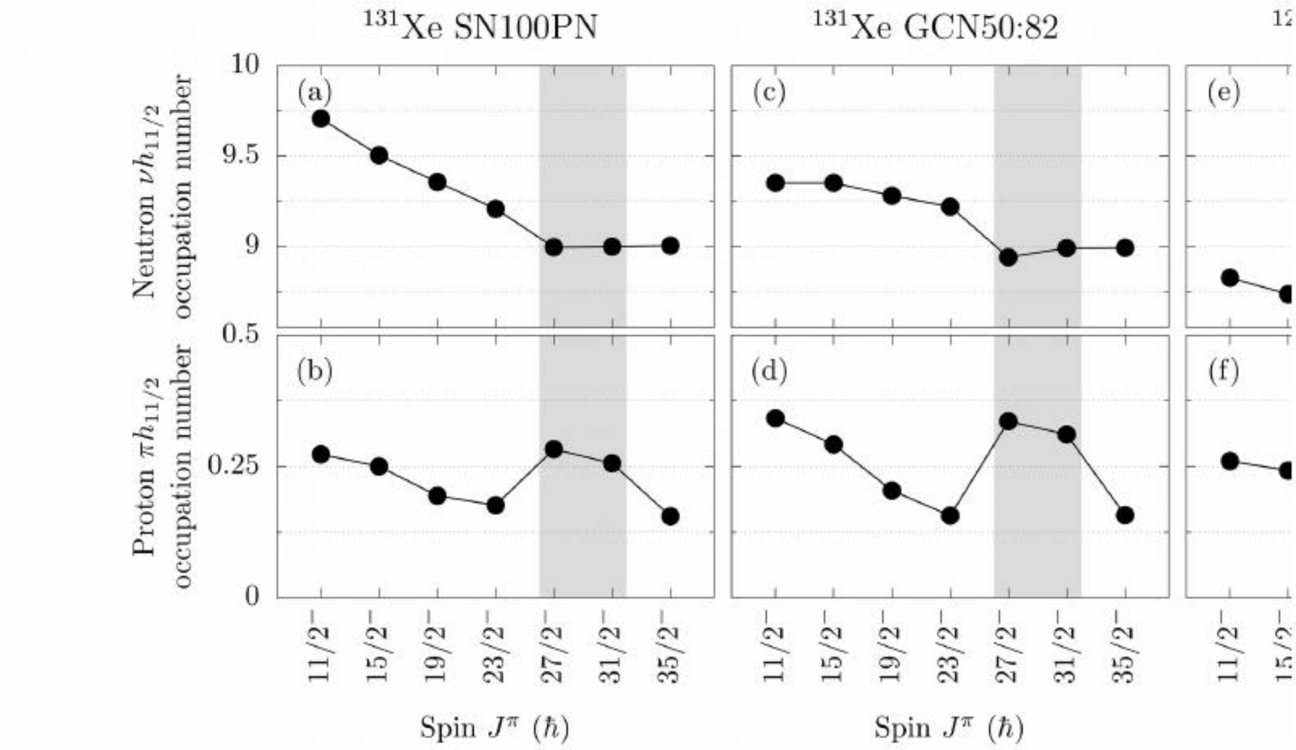
- PQM130: Pairing+QQ+Multipole for mass region 130 (Higashiyama and Yoshinaga)
- SN100PN: jj55pna renormalized from CD-Bonn – fitted @ 130
- GCN50: jj55pna renormalized from CD-Bonn – different fit @ 130
- Realistic SM: $V_{\text{low-k}}$ from CD-Bonn
- SN100 –KTH: CD Bonn renormalized to fit Sn isotopes

Description of backbending with shell model



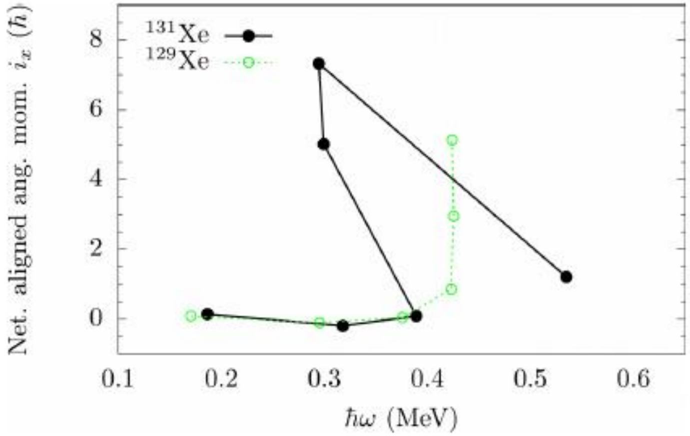
Same interactions work also for ^{129}Xe, ^{130}Xe and ^{132}Xe

Occupancy of alignment states in ^{129}Xe/^{131}Xe



^{129}Xe

Upbend with the alignment of **two $\pi h_{11/2}$ protons** for $J^\pi \geq 27/2^-$ states



Y. Hang *et al.* PRC 93, 064315 (2016)

Summary and Outlook

- High-spin states in ^{137}Ba and ^{135}Xe
- p-n correlations near the N = 82 shell closure

PHYSICAL REVIEW C™

Isomers and high-spin structures in the N=81 isotones ^{135}Xe and ^{137}Ba

A. Vogt *et al.* **PRC 96, 024316 (2017)**

- High-spin states and a new spin-trap isomer in ^{133}Xe
- High-spin spectroscopy of ^{132}Xe

PHYSICAL REVIEW C™

High-spin structures in ^{132}Xe and ^{133}Xe and evidence for isomers along the N=79 isotones

A. Vogt *et al.* **PRC 96, 024321 (2017)**

- Backbending in ^{131}Xe in the favoured neg.-parity band
- Description within the shell-model

PHYSICAL REVIEW C™

High-spin structure in the transitional nucleus ^{131}Xe: Competitive neutron and proton alignment in the vicinity of the N = 82 shell closure

L. Kaya *et al.* **submitted**

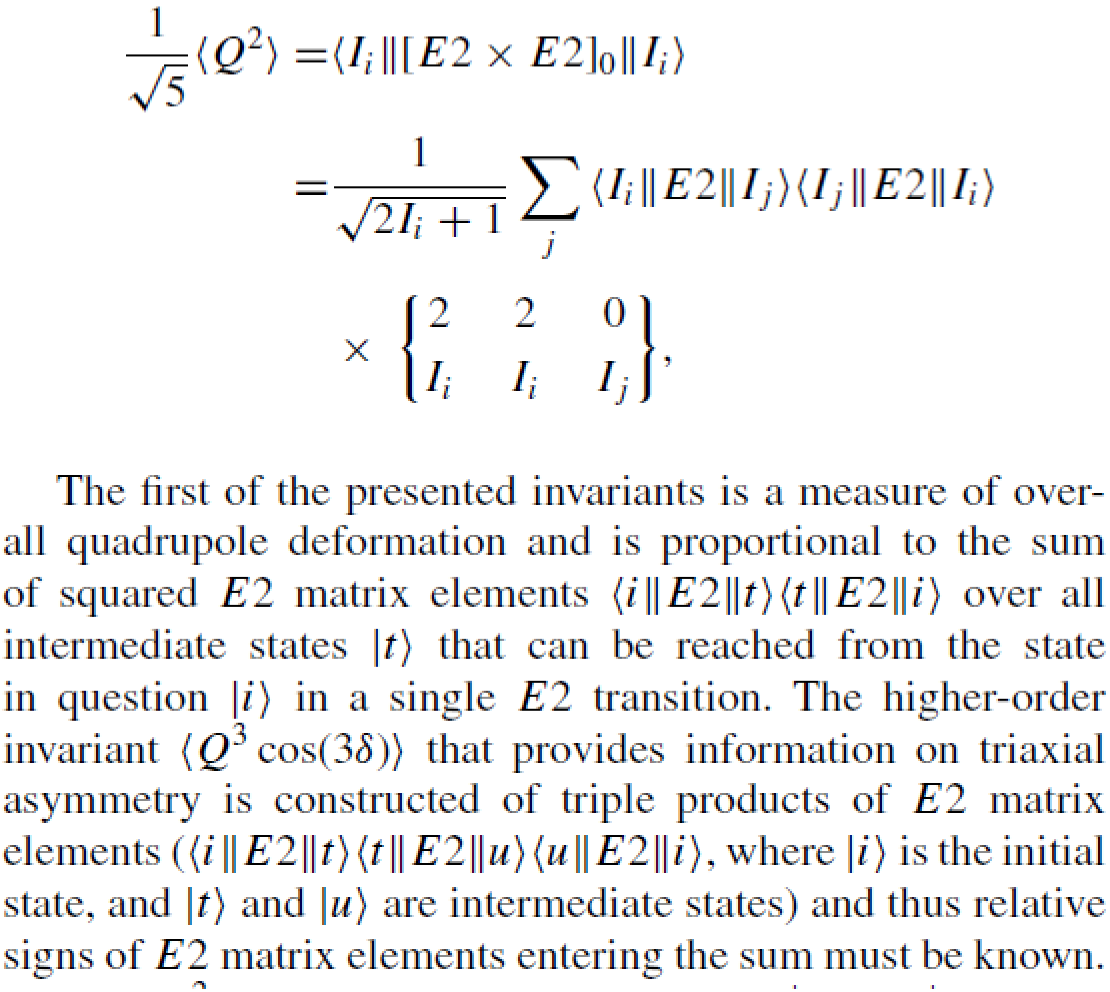
- High-spin states and new 23/2$^+$ spin-trap isomers in ^{133}Xe and ^{135}Ba

PHYSICAL REVIEW C™

High-spin isomers along the N = 79 isotones: 23/2$^+$ isomers in ^{133}Xe and ^{135}Ba

L. Kaya *et al.* **in preparation**

Quadrupole sum rules



$$\frac{1}{\sqrt{5}}\langle Q^2\rangle = \langle I_i \| [E2 \times E2]_0 \| I_i \rangle$$

$$= \frac{1}{\sqrt{2I_i+1}} \sum_j \langle I_i \| E2 \| I_j \rangle \langle I_j \| E2 \| I_i \rangle$$

$$\times \begin{Bmatrix} 2 & 2 & 0 \\ I_i & I_i & I_j \end{Bmatrix},$$

The first of the presented invariants is a measure of overall quadrupole deformation and is proportional to the sum of squared $E2$ matrix elements $\langle i \| E2 \| t \rangle \langle t \| E2 \| i \rangle$ over all intermediate states $|t\rangle$ that can be reached from the state in question $|i\rangle$ in a single $E2$ transition. The higher-order invariant $\langle Q^3 \cos(3\delta)\rangle$ that provides information on triaxial asymmetry is constructed of triple products of $E2$ matrix elements ($\langle i \| E2 \| t \rangle \langle t \| E2 \| u \rangle \langle u \| E2 \| i \rangle$, where $|i\rangle$ is the initial state, and $|t\rangle$ and $|u\rangle$ are intermediate states) and thus relative signs of $E2$ matrix elements entering the sum must be known.