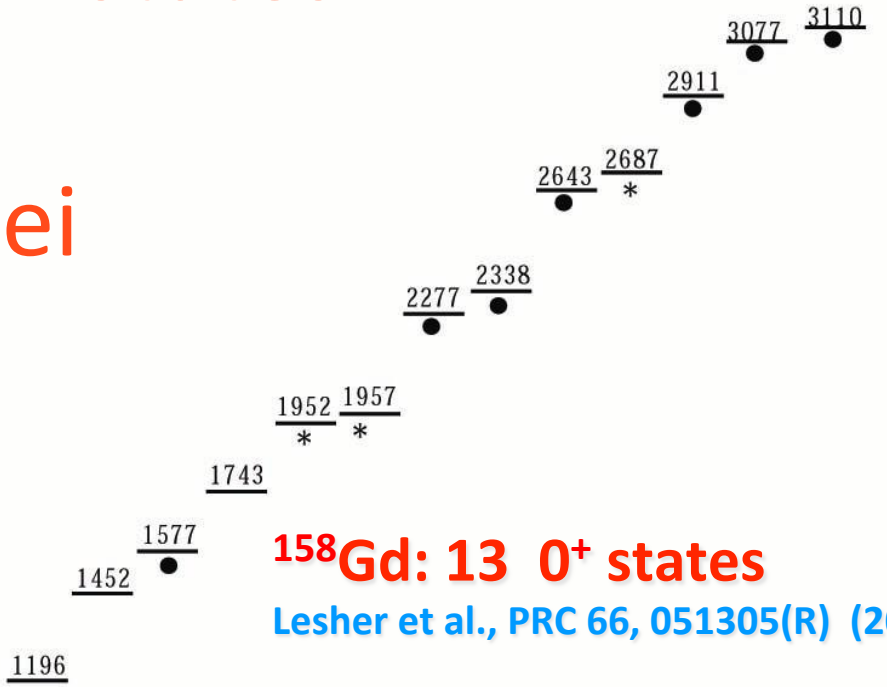
Institute for Structure And Nuclear Astrophysics

The Nature of 0^+ states in Deformed Nuclei



^{158}Gd: 13 0^+ states

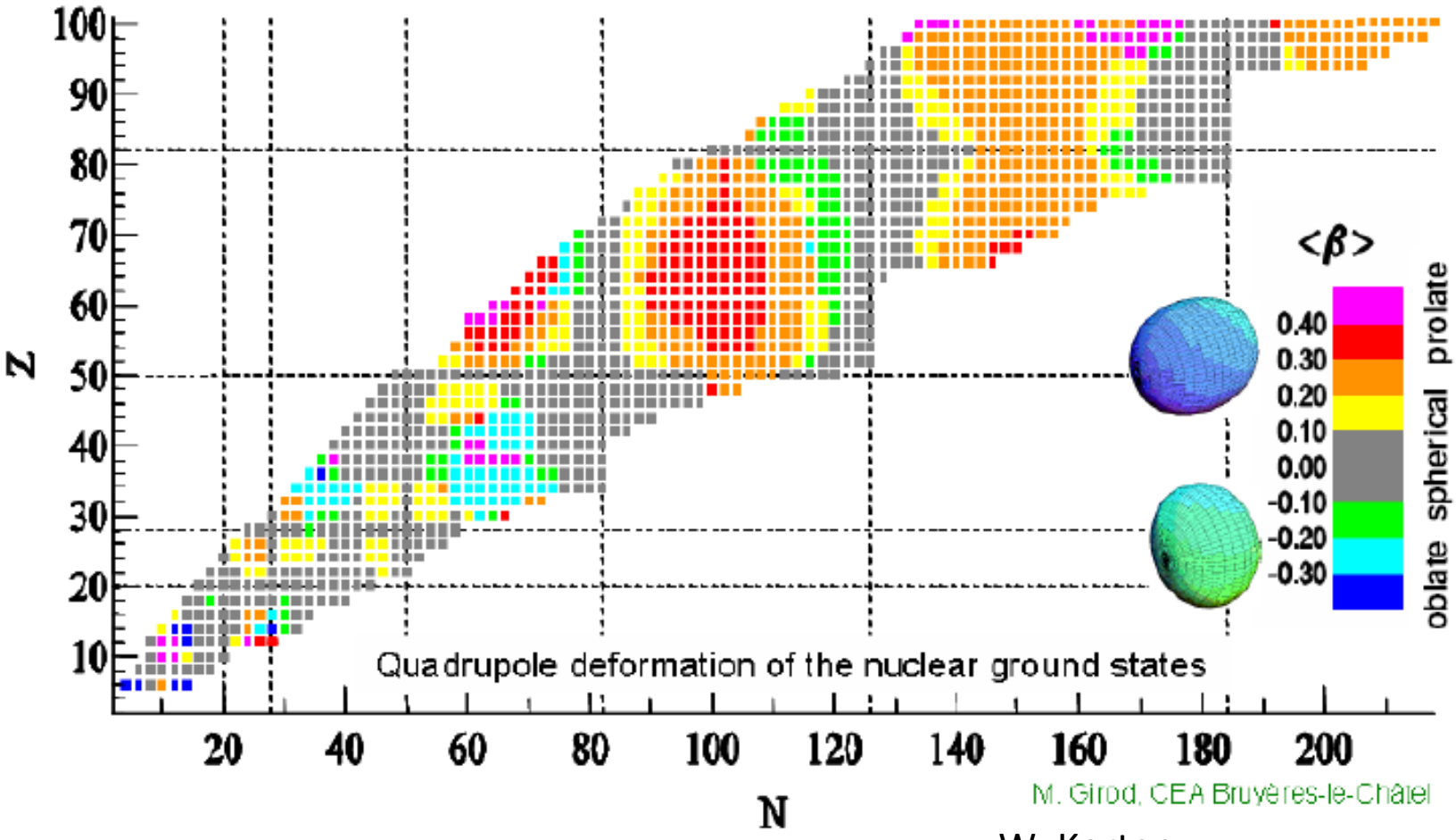
Lesher et al., PRC 66, 051305(R) (2002)

Ani Aprahamian

Sept. 15, 2016 INPC2016

NSF

UNIVERSITY OF NOTRE DAME



W. Korten

Lowest shape oscillations:

Quadrupole oscillations of a deformed nucleus: β and γ

$K=0^+$, $K=2^+$

Transfer rxs, E0s, lifetimes etc..

What can we expect to see?

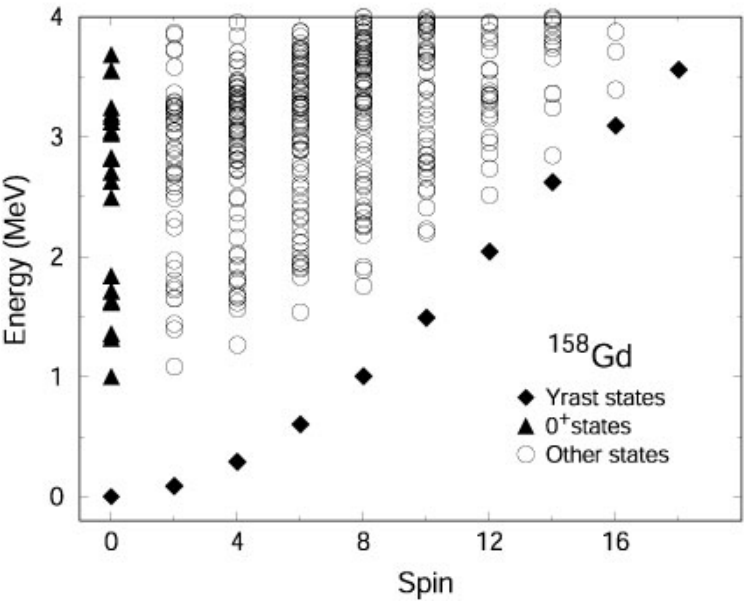
Energy =2

$K=4^+_{\gamma\gamma}$ $K=0^+_{\gamma\gamma}$ $K=0^+_{\beta\beta}$ $K=2^+_{\beta\gamma}$

Energy =1

$K=2^+$ $K=0^+$

$K=0^+$



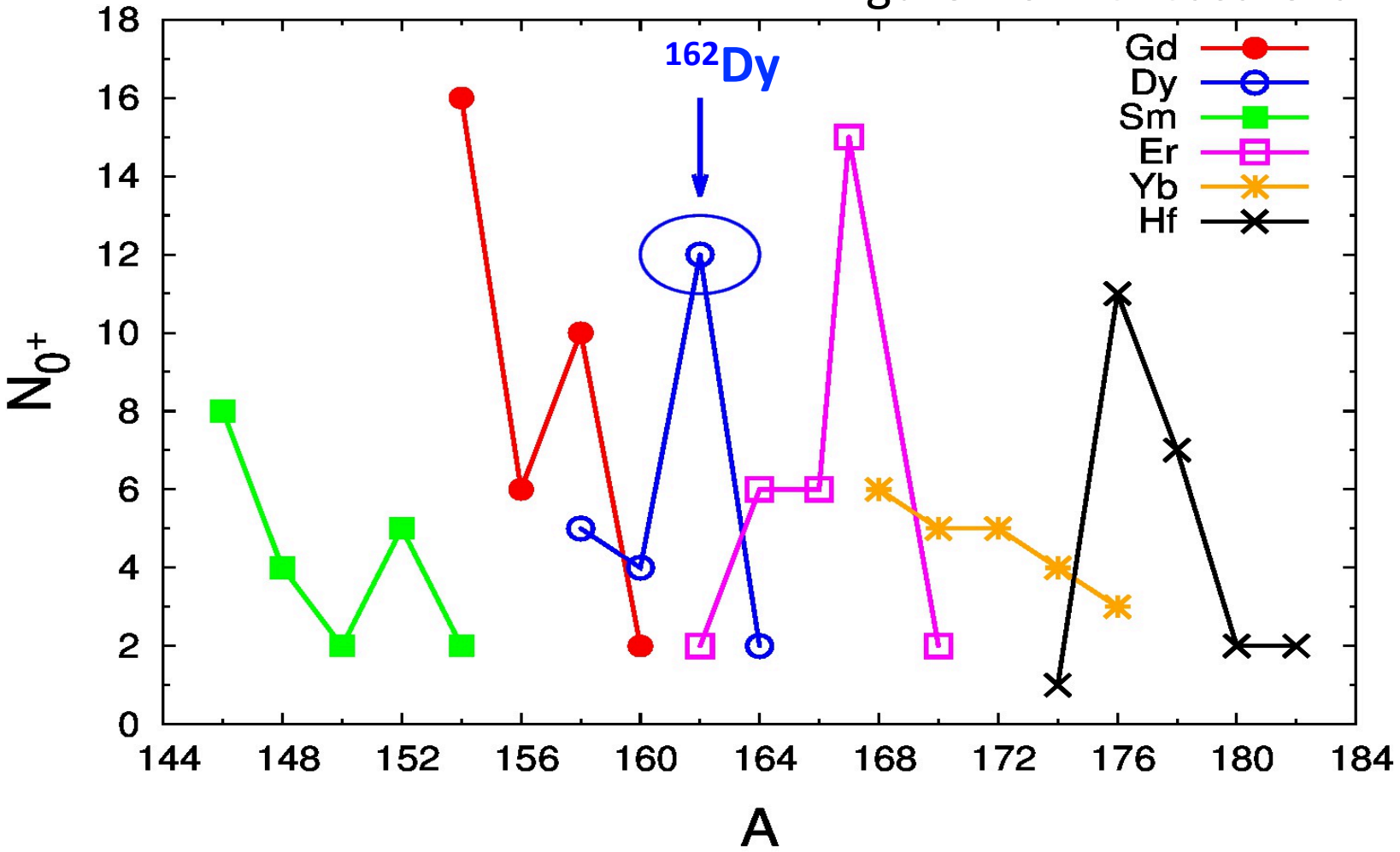
Y.Sun, 2003

$$\frac{B(E2:4^+_{\gamma\gamma} \rightarrow 2^+_{\gamma})}{B(E2:2^+_{\gamma} \rightarrow 0^+_{gs})} = 2.78$$

$$\frac{B(E2:0^+_{\gamma\gamma} \rightarrow 2^+_{\gamma})}{B(E2:2^+_{\gamma} \rightarrow 0^+_{gs})} = 5.0$$

$$\frac{B(E2:2^+_{\beta\beta} \rightarrow 0^+_{gs})}{B(E2:2^+_{\beta} \rightarrow 0^+_{gs})} = 2.0$$

Figure from C. Casarella



Nature of K=0$^+$ excitations in deformed nuclei ?

Quasi-particle excitations

Pairing vibrations

Collective excitations

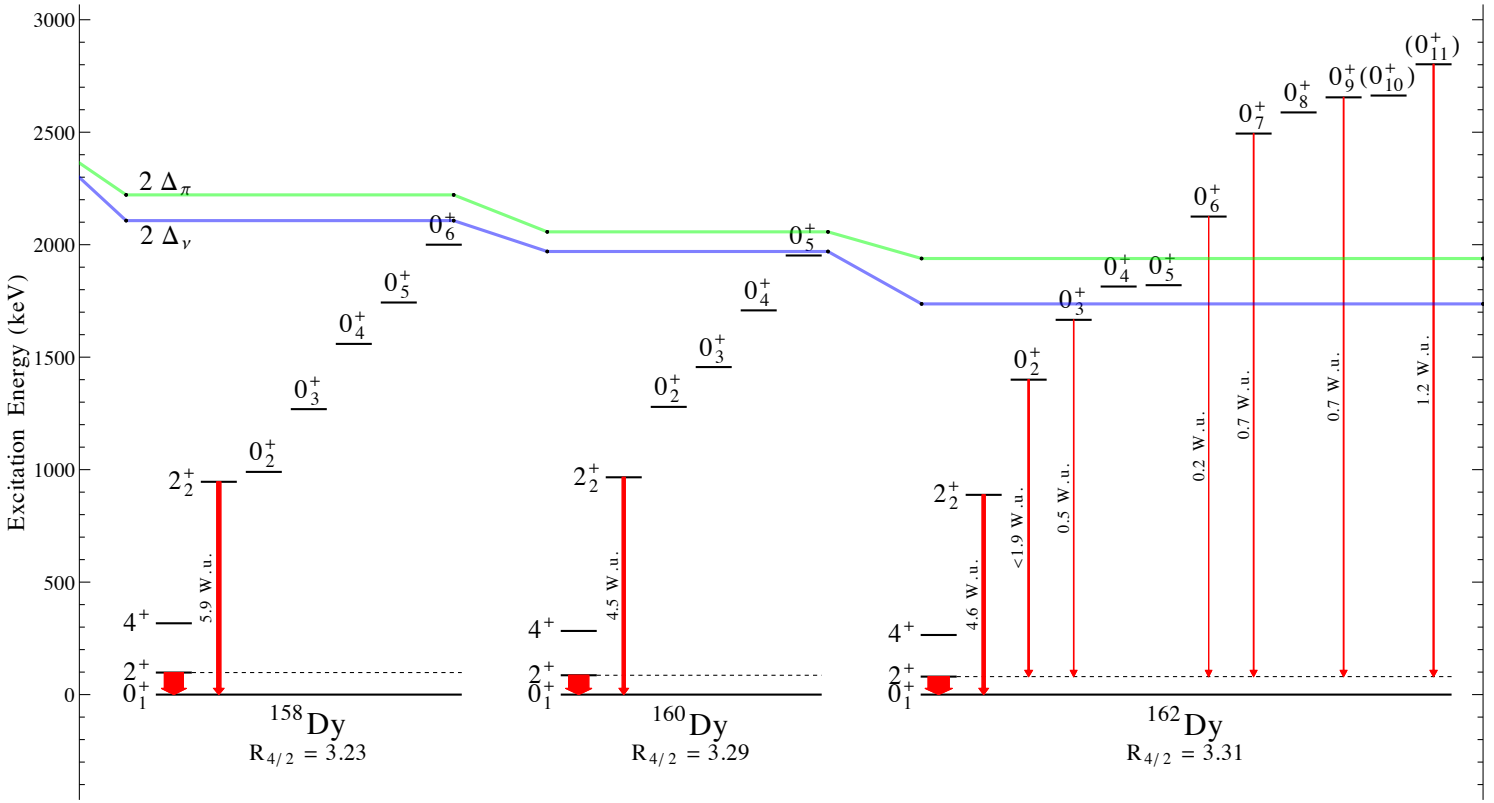
^{162}Dy: D.A. Meyer et al., Phys. Rev. C 74, 044309 (2006)

^{162}Dy

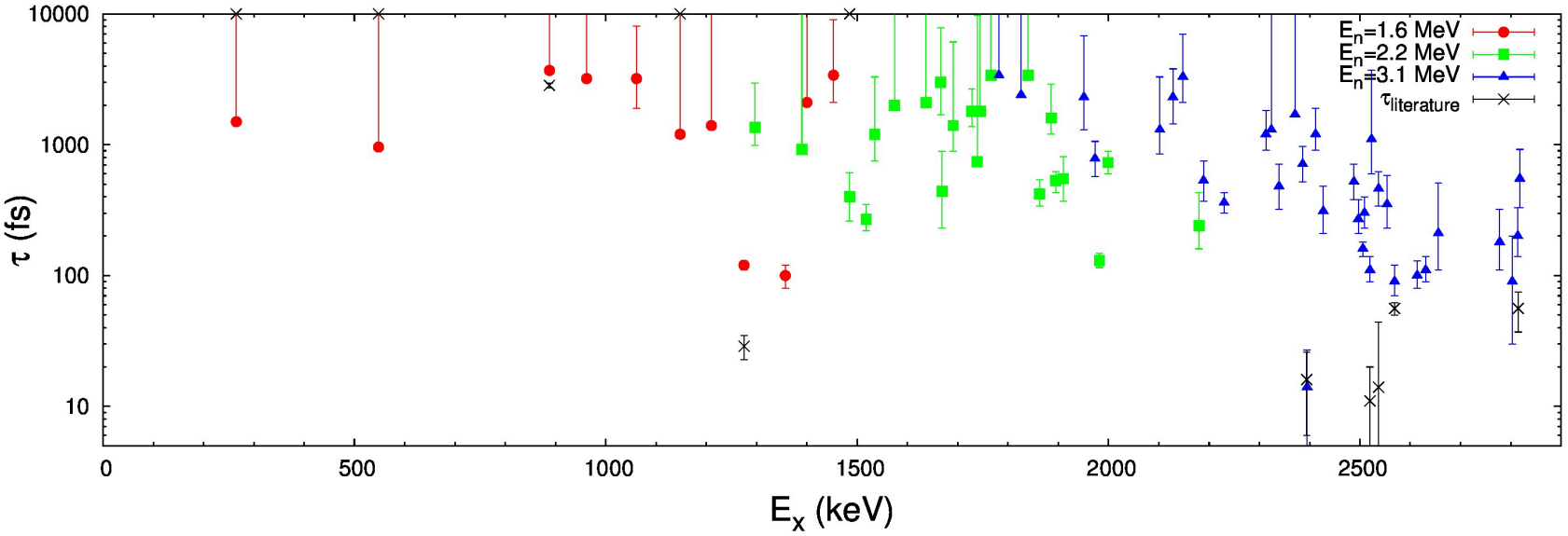
Aprahamian et al., NPA 764, 42 (2006)

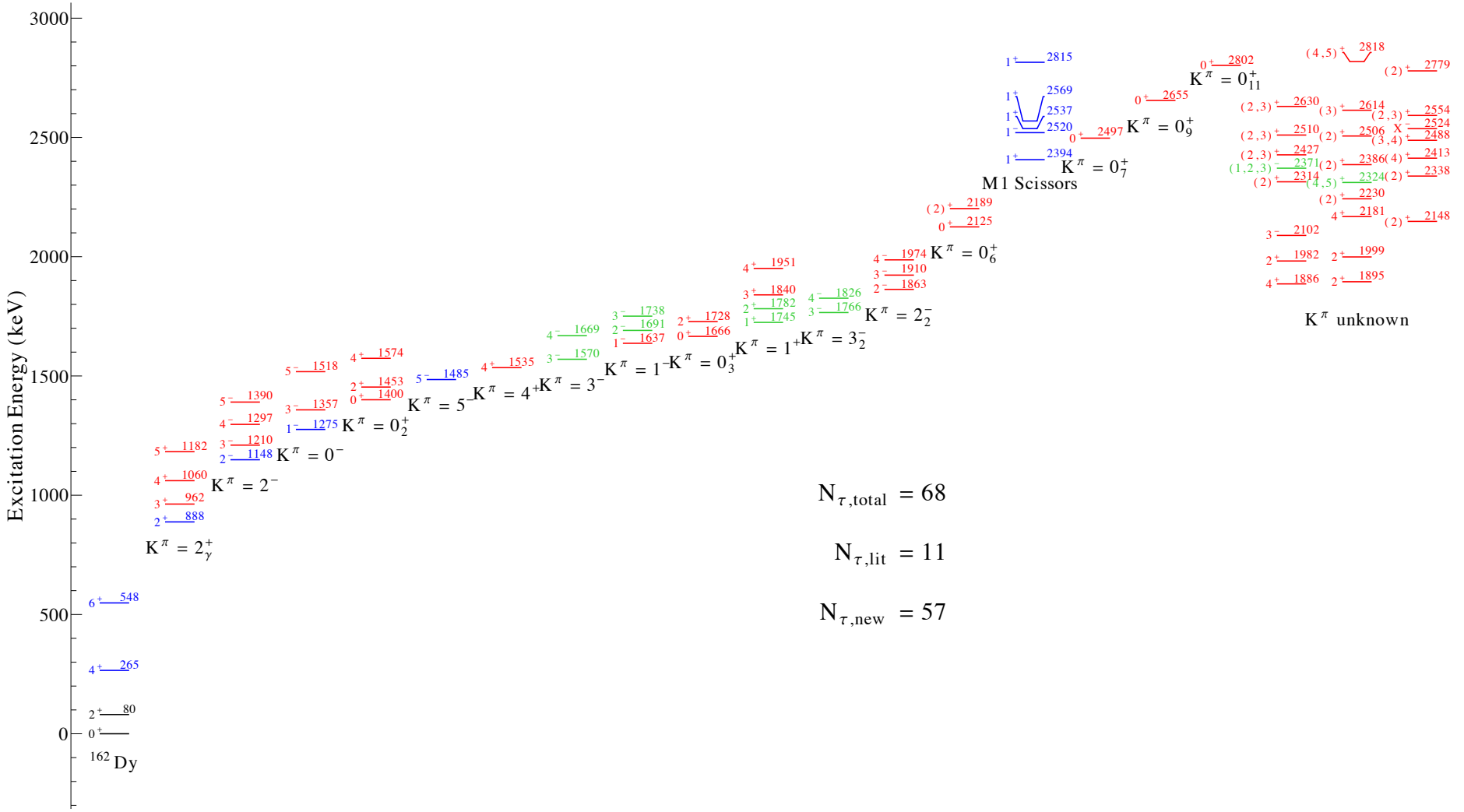
GRID (n,γ) at ILL

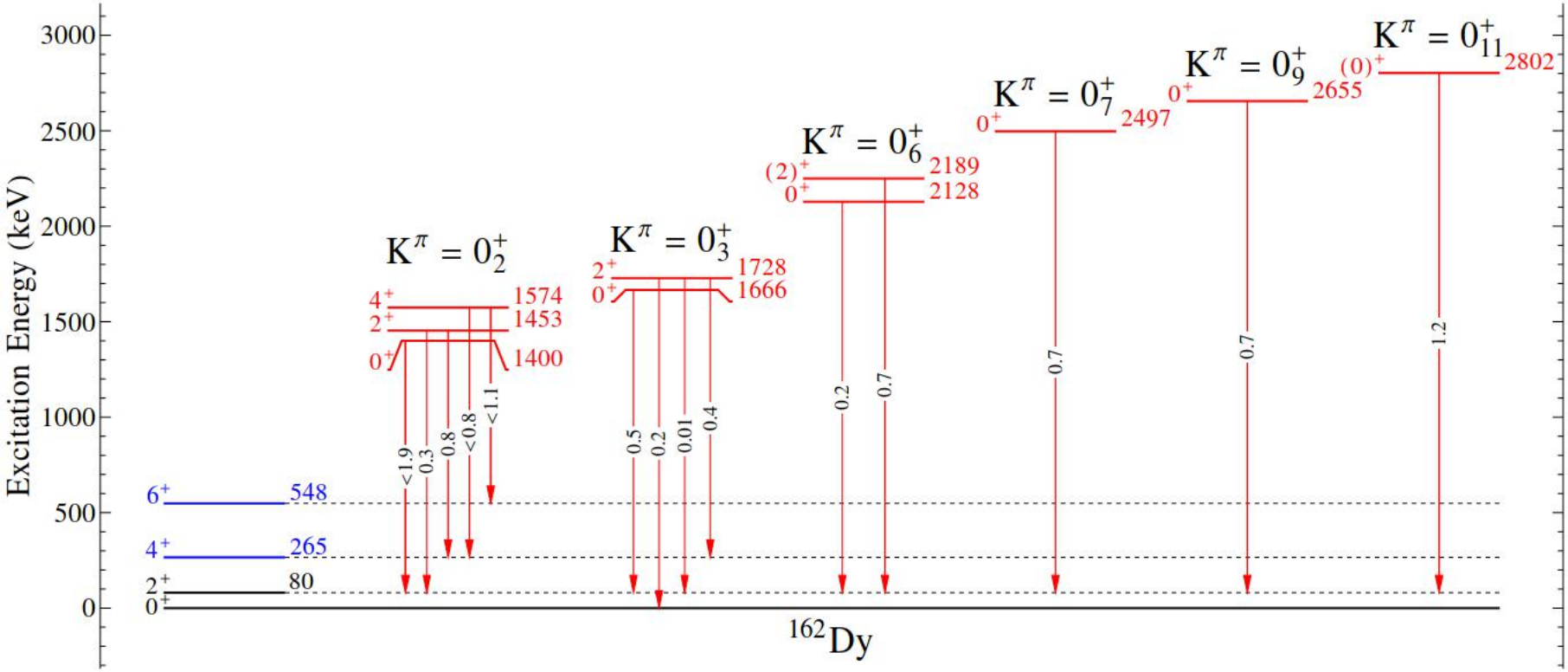
DSAM (n,n'γ) at U Kentucky

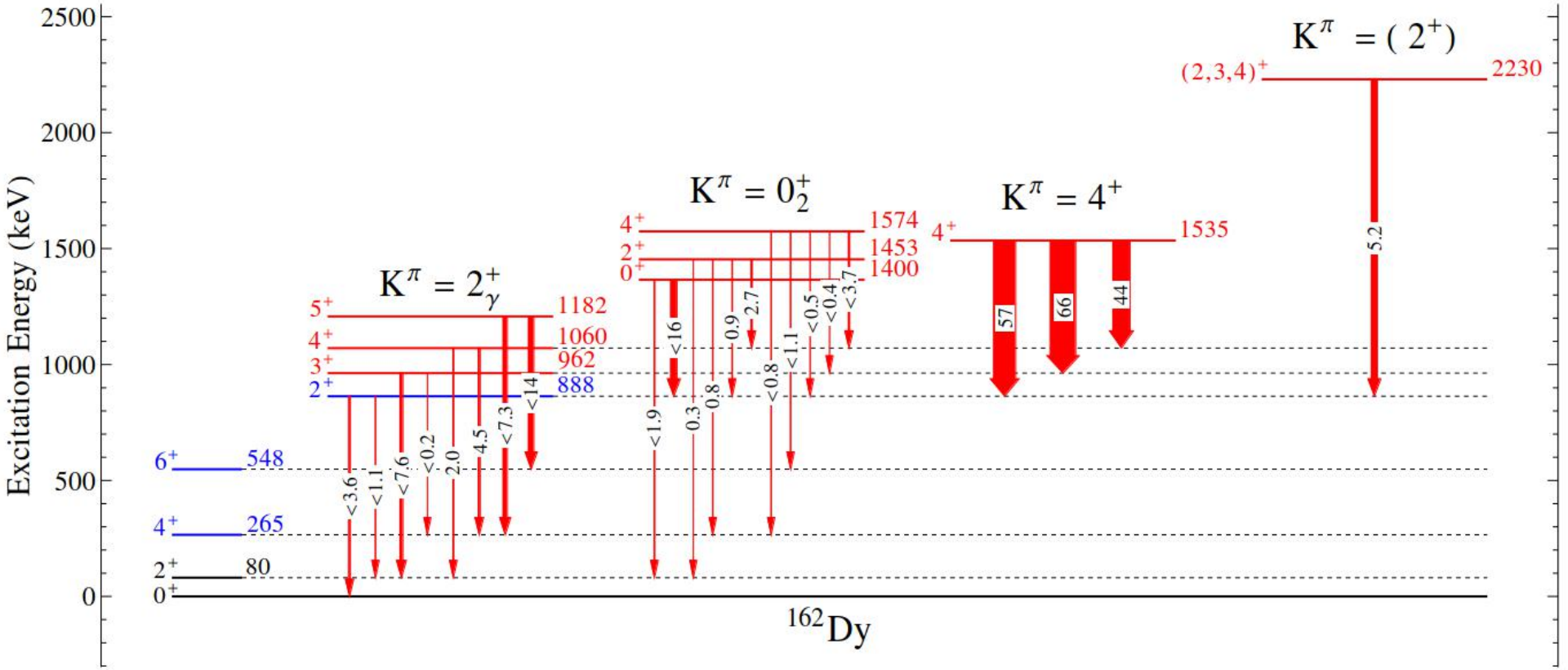


DSAM via (n,n'γ) at UKY



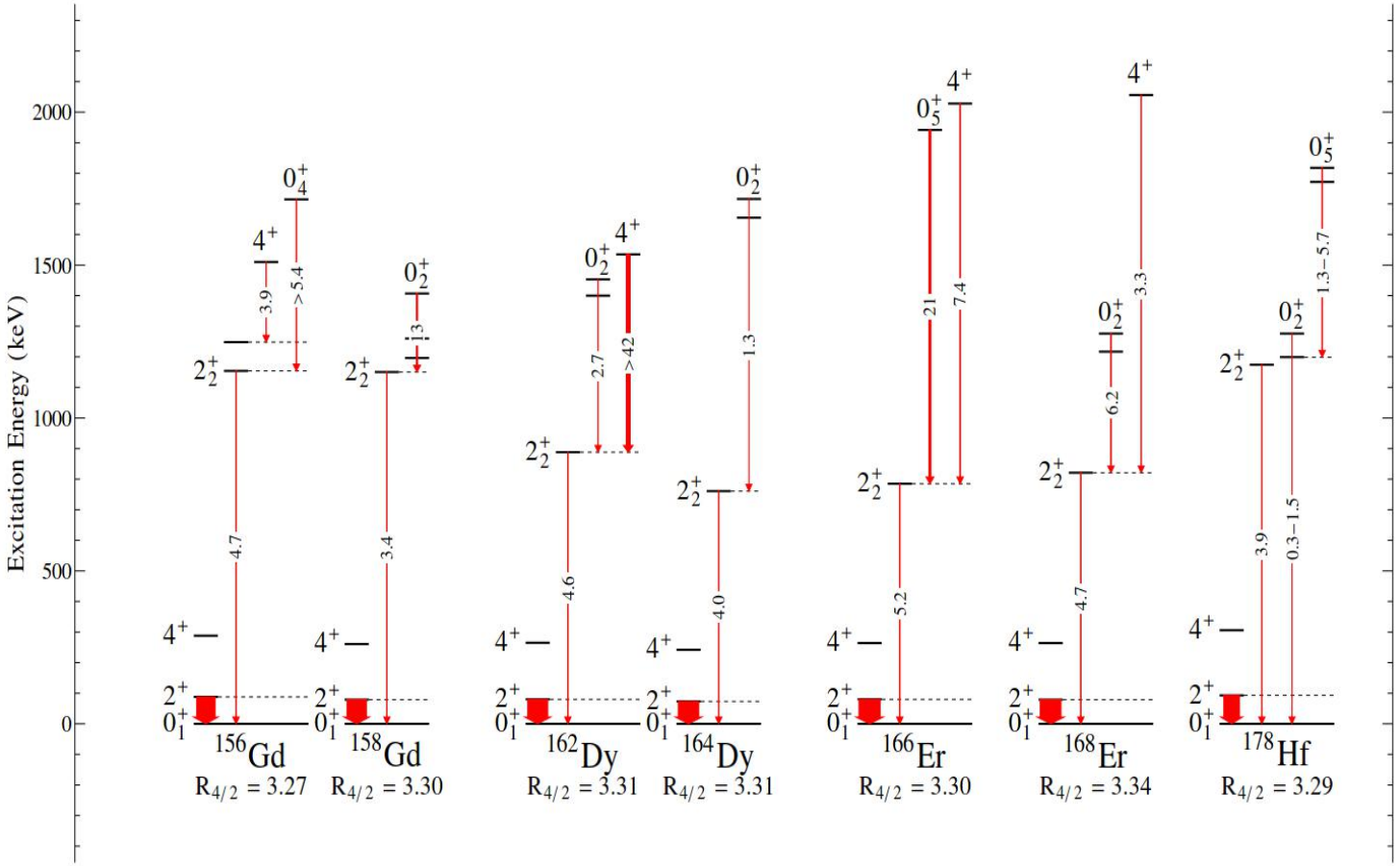

Excitation Energy (keV)
3000
2500
2000
1500
1000
500
0
^{162}Dy
6+ 548
4+ 265
2+ 80
0+
$K^\pi = 2^+_\gamma$
5+ 1182
4+ 1060
3+ 962
2+ 888
$K^\pi = 2^-$
5− 1390
4− 1297
3− 1210
2− 1148
$K^\pi = 0^-$
5− 1518
3− 1357
1− 1275
$K^\pi = 0^+_2$
4+ 1574
2+ 1453
0+ 1400
$K^\pi = 5^-$
5− 1485
4+ 1535
$K^\pi = 4^+$
4− 1669
3− 1570
$K^\pi = 3^-$
3− 1738
2− 1691
1− 1637
$K^\pi = 1^-$
2+ 1728
0+ 1666
$K^\pi = 0^+_3$
4+ 1951
3+ 1840
2+ 1782
1+ 1745
$K^\pi = 1^+$
4− 1826
3− 1766
$K^\pi = 3^-_2$
4− 1974
3− 1910
2− 1863
$K^\pi = 2^-_2$
(2)+ 2189
0+ 2125
$K^\pi = 0^+_6$
1+ 2815
1+ 2569
1+ 2537
1− 2520
1+ 2394
M1 Scissors
$K^\pi = 0^+_7$
0+ 2497
0+ 2655
$K^\pi = 0^+_9$
0+ 2802
$K^\pi = 0^+_{11}$
(4,5)+ 2818
(2)+ 2779
(2,3)+ 2630
(3)+ 2614
(2,3)+ 2554
(2,3)+ 2510
(2)+ 2506
X
2524
(3,4)+ 2488
(2,3)+ 2427
(1,2,3)− 2371
(2)+ 2386
(4)+ 2413
(2)+ 2314
(4,5)+ 2324
(2)+ 2338
(2)+ 2230
4+ 2181
(2)+ 2148
3− 2102
2+ 1982
2+ 1999
4+ 1886
2+ 1895
K^π unknown
$N_{\tau,\text{total}} = 68$
$N_{\tau,\text{lit}} = 11$
$N_{\tau,\text{new}} = 57$

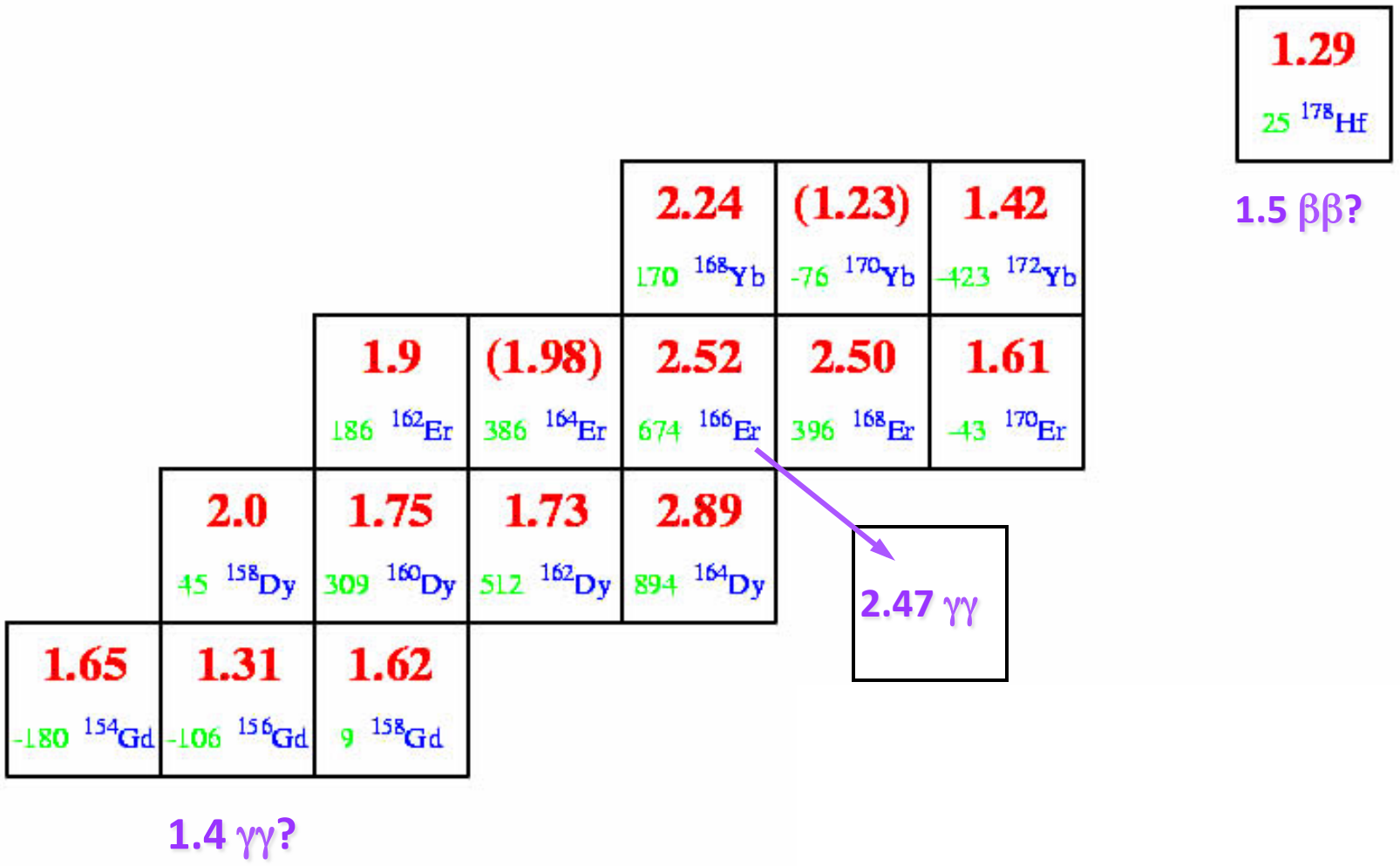

Excitation Energy (keV)
3000
2500
2000
1500
1000
500
0
$K^\pi = 0_2^+$
$K^\pi = 0_3^+$
$K^\pi = 0_6^+$
$K^\pi = 0_7^+$
$K^\pi = 0_9^+$
$K^\pi = 0_{11}^+$
6^+ 548
4^+ 265
2^+ 80
0^+
4^+ 1574
2^+ 1453
0^+ 1400
2^+ 1728
0^+ 1666
$(2)^+$ 2189
0^+ 2128
0^+ 2497
0^+ 2655
$(0)^+$ 2802
<1.9
0.3
0.8
<0.8
<1.1
0.5
0.2
0.01
0.4
0.2
0.7
0.7
0.7
1.2
^{162}Dy



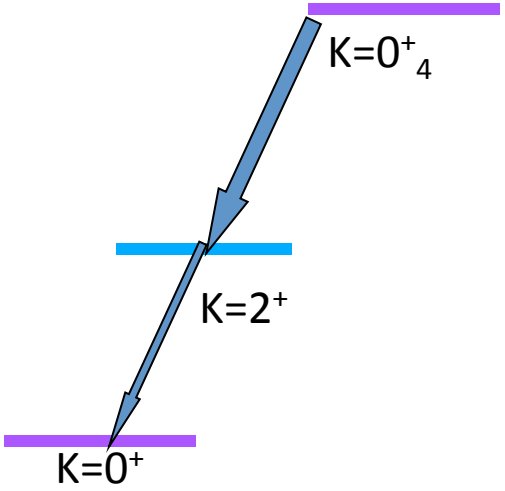
Energy ratios of $K=4^+$ to $K=2^+$: 1.7

$K=0^+$ to $K=2^+$: 1.6

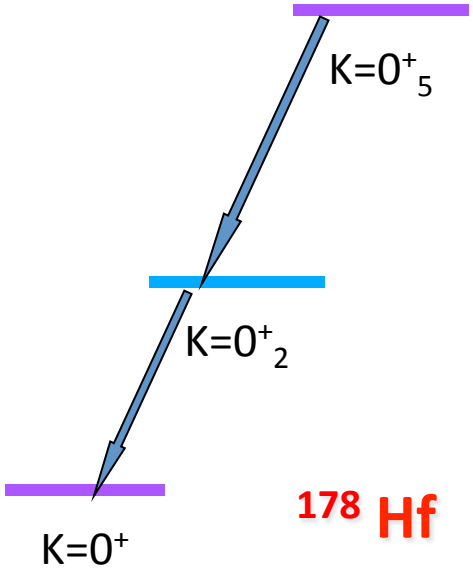

Excitation Energy (keV)
2000
1500
1000
500
0
0_4^+
4^+
2_2^+
0_2^+
4^+
0_1^+
3.9
>5.4
4.7
13
3.4
2.7
>42
4.6
1.3
4.0
21
7.4
5.2
6.2
3.3
1.3–5.7
3.9
0.3–1.5
0_5^+
^{156}Gd
$R_{4/2}$ = 3.27
^{158}Gd
$R_{4/2}$ = 3.30
^{162}Dy
$R_{4/2}$ = 3.31
^{164}Dy
$R_{4/2}$ = 3.31
^{166}Er
$R_{4/2}$ = 3.30
^{168}Er
$R_{4/2}$ = 3.34
^{178}Hf
$R_{4/2}$ = 3.29


1.29
25 178Hf
1.5 ββ?
2.24
170 168Yb
(1.23)
-76 170Yb
1.42
-423 172Yb
1.9
186 162Er
(1.98)
386 164Er
2.52
674 166Er
2.50
396 168Er
1.61
-43 170Er
2.0
45 158Dy
1.75
309 160Dy
1.73
512 162Dy
2.89
894 164Dy
2.47 γγ
1.65
-180 154Gd
1.31
-106 156Gd
1.62
9 158Gd
1.4 γγ?

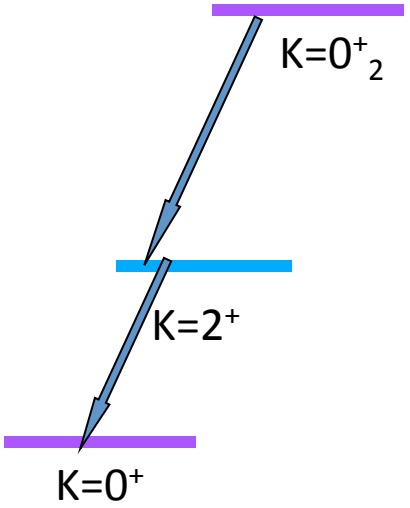
Conclusions: What is the nature of $K=0^+$ bands?



^{156}Gd



^{178} Hf



^{162,164}Dy, ^{168}Er

More to come……

Collaborators:

GRID

ILL Grenoble — H. Boerner, M. Jentschel

Univ. of Brighton — A.M. Bruce

(n,n'γ)

Univ of Kentucky — B.P. Crider, M. Lowe, E. E. Peters, F.M. Prados-Estevez, T. J. Ross, Z. Tully, S.W. Yates

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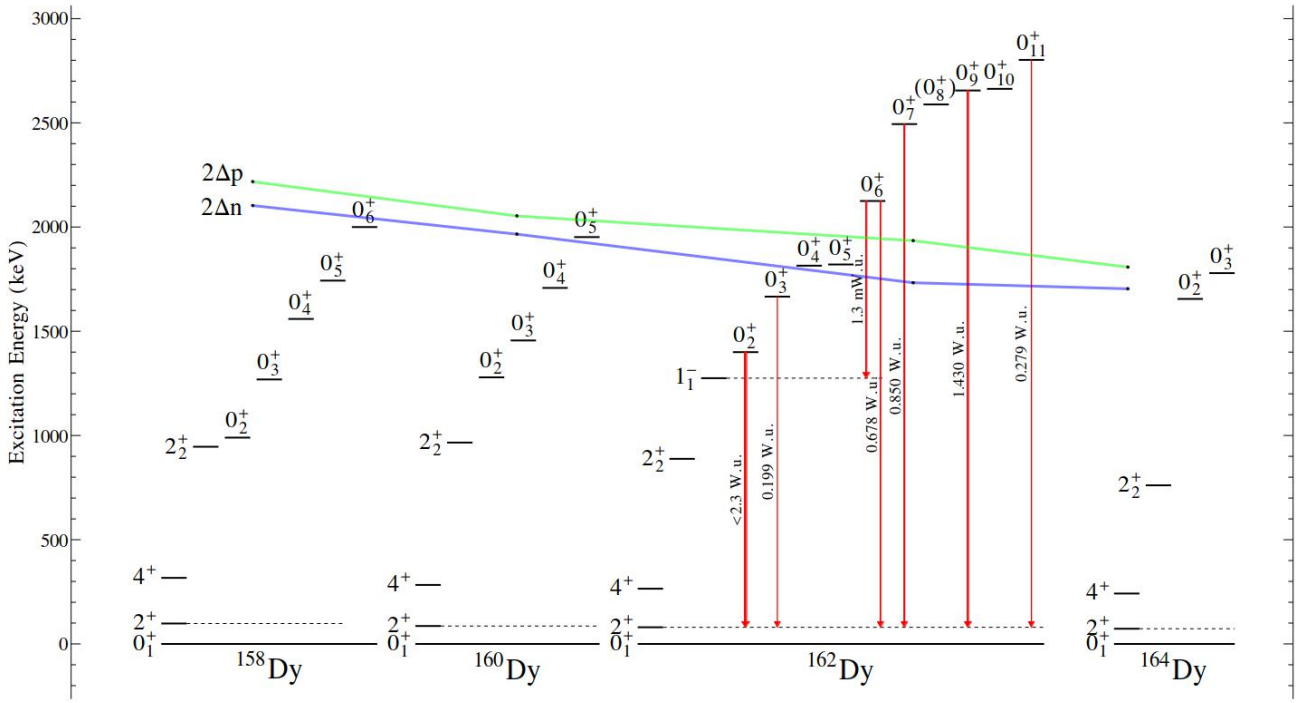
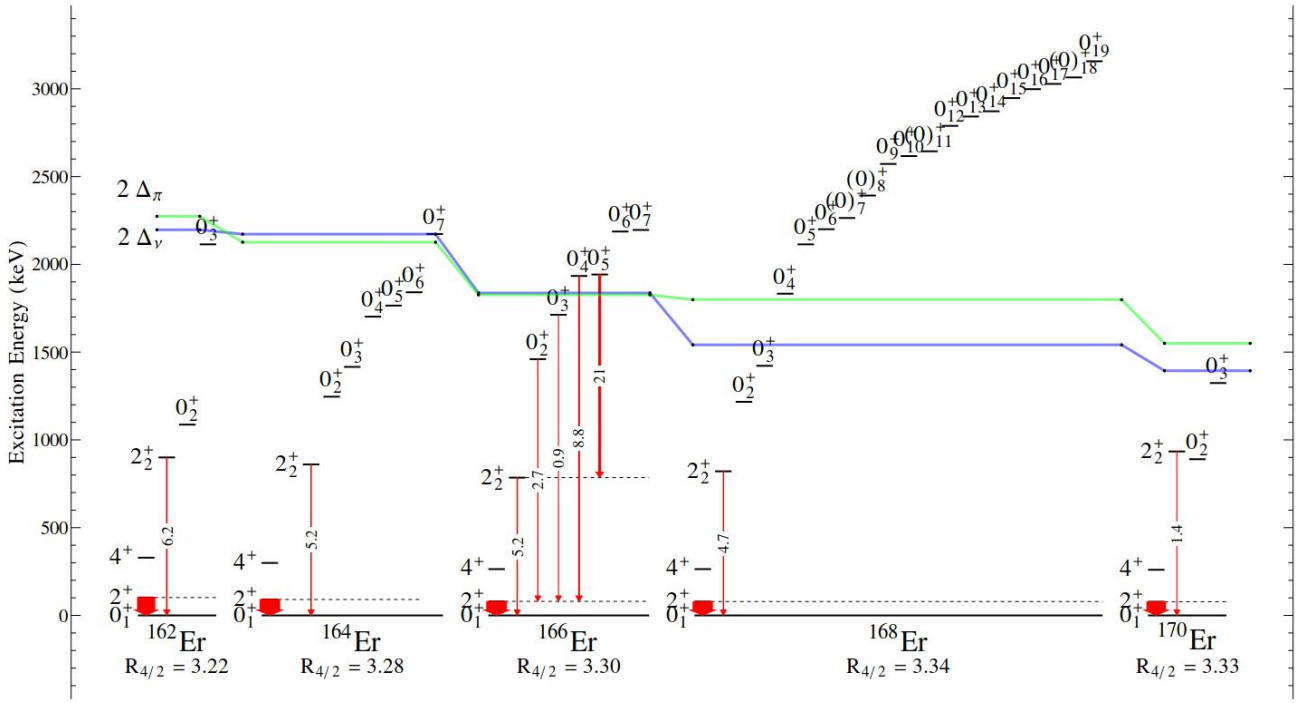
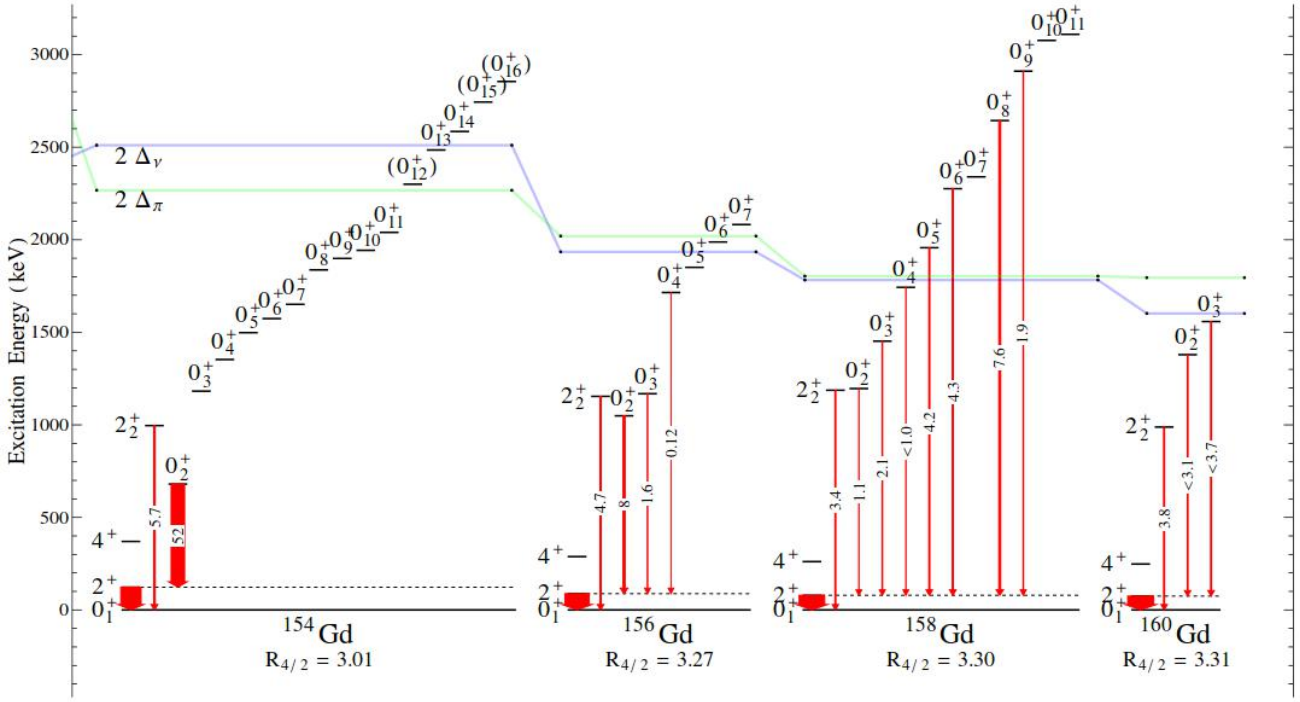
Univ. of Wisconsin-LaCrosse S.R. Lesher

Notre Dame — C. Casarella, R. C. de Haan, A. Aprahamian

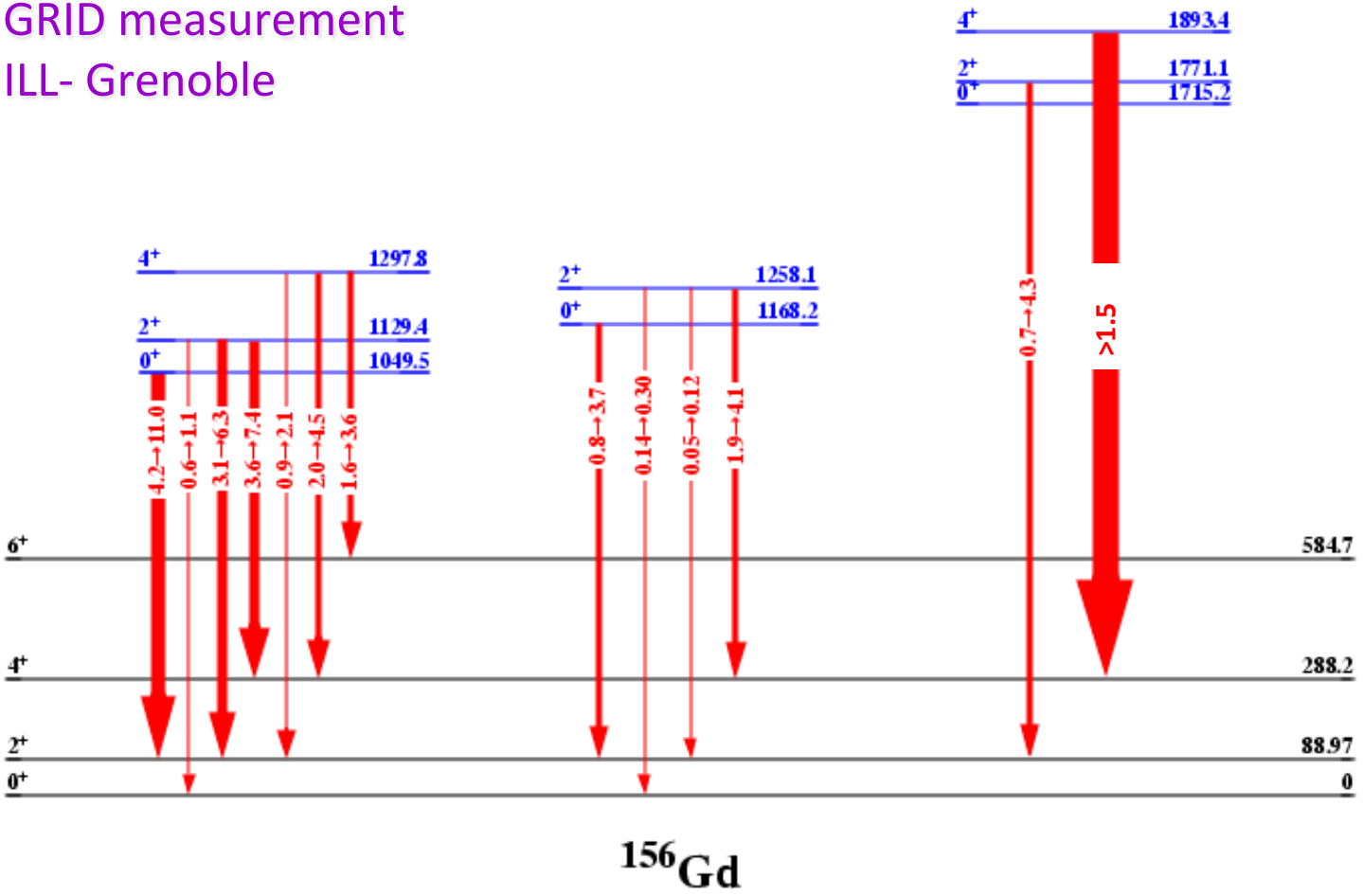
Backup Slides


Excitation Energy (keV)
3000
2500
2000
1500
1000
500
0
2Δp
2Δn
0_6^+
0_5^+
0_4^+
0_3^+
0_2^+
2_2^+
4^+
2^+
0_1^+
^{158}Dy
^{160}Dy
^{162}Dy
^{164}Dy
1_1^-
0_7^+
(0_8^+)
0_9^+
0_{10}^+
0_{11}^+
<2.3 W.u.
0.199 W.u.
0.678 W.u.
1.3 mW.u.
0.850 W.u.
1.430 W.u.
0.279 W.u.

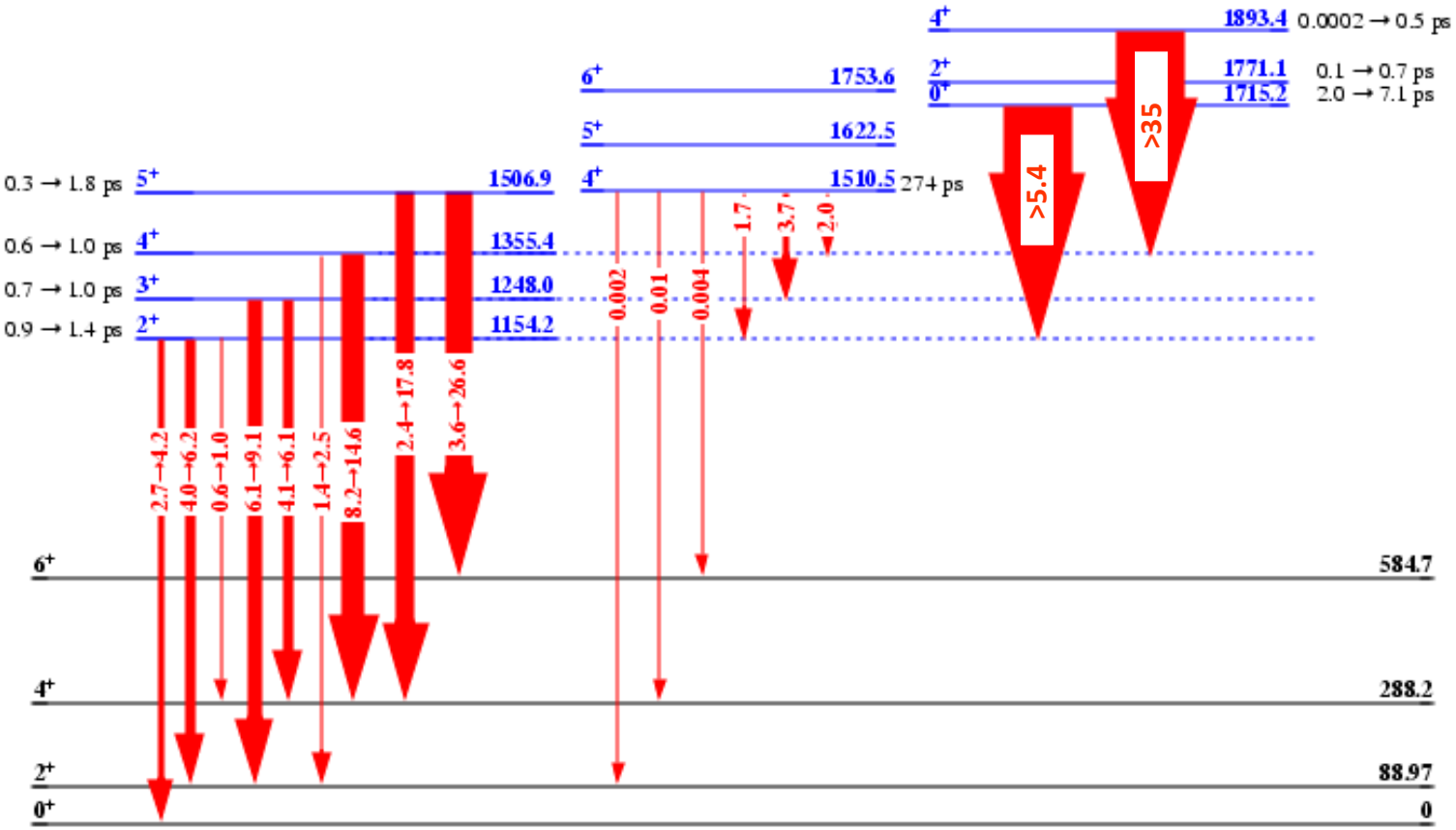

Excitation Energy (keV)
3000
2500
2000
1500
1000
500
0
2 Δπ
2 Δν
0+3
0+7
0+4 0+5 0+6
0+2 0+3
0+6 0+7
0+4 0+5
0+3
0+2
0+5 0+6 (0+)7
(0+)8
0+9 (0+)10 (0+)11
0+12 0+13 0+14
0+15 0+16 (0+)17 (0+)18
0+19
0+4
0+3
0+2
0+3
0+2
2+2
4+
2+1
0+1
6.2
5.2
5.2
2.7
0.9
8.8
21
4.7
1.4
162Er
R4/2 = 3.22
164Er
R4/2 = 3.28
166Er
R4/2 = 3.30
168Er
R4/2 = 3.34
170Er
R4/2 = 3.33


Excitation Energy (keV)
3000
2500
2000
1500
1000
500
0
2 Δν
2 Δπ
154 Gd
R4/2 = 3.01
156 Gd
R4/2 = 3.27
158 Gd
R4/2 = 3.30
160 Gd
R4/2 = 3.31

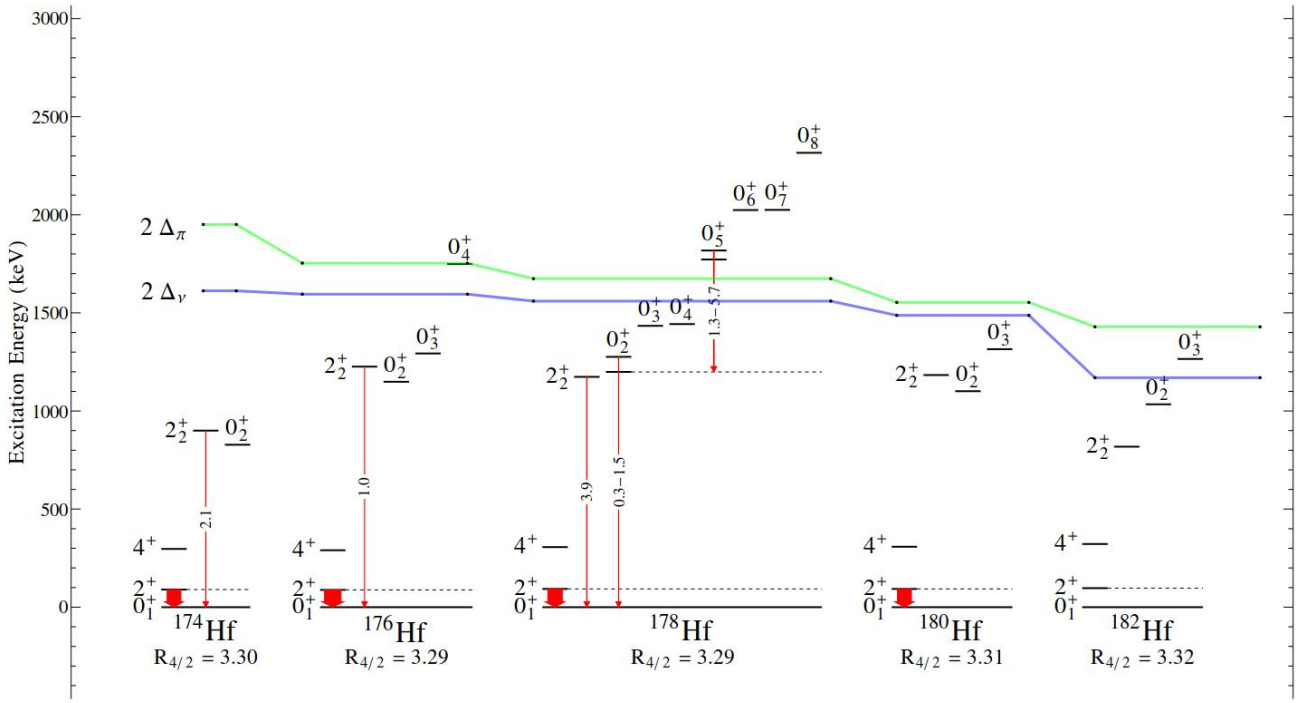
GRID measurement
ILL- Grenoble

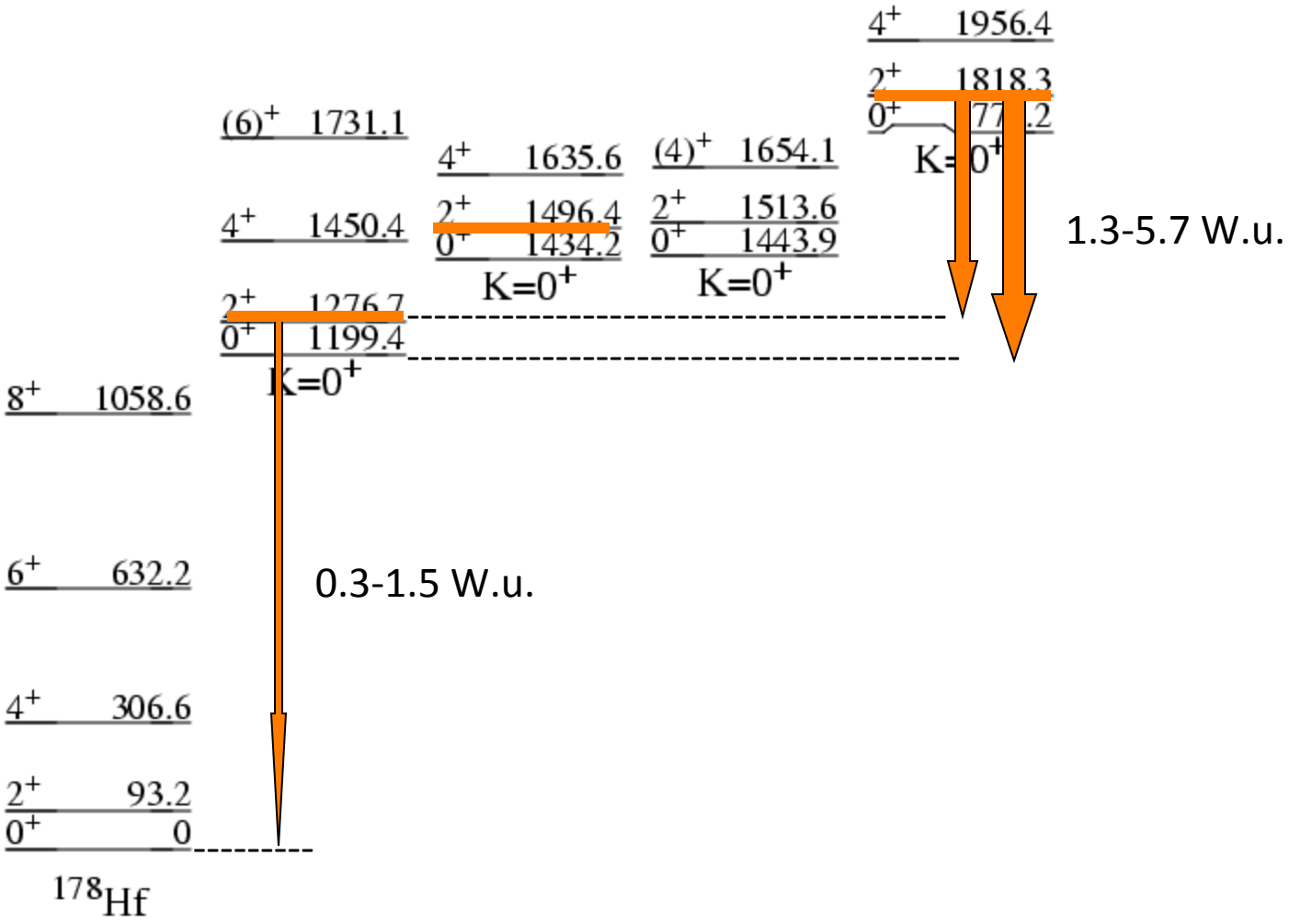


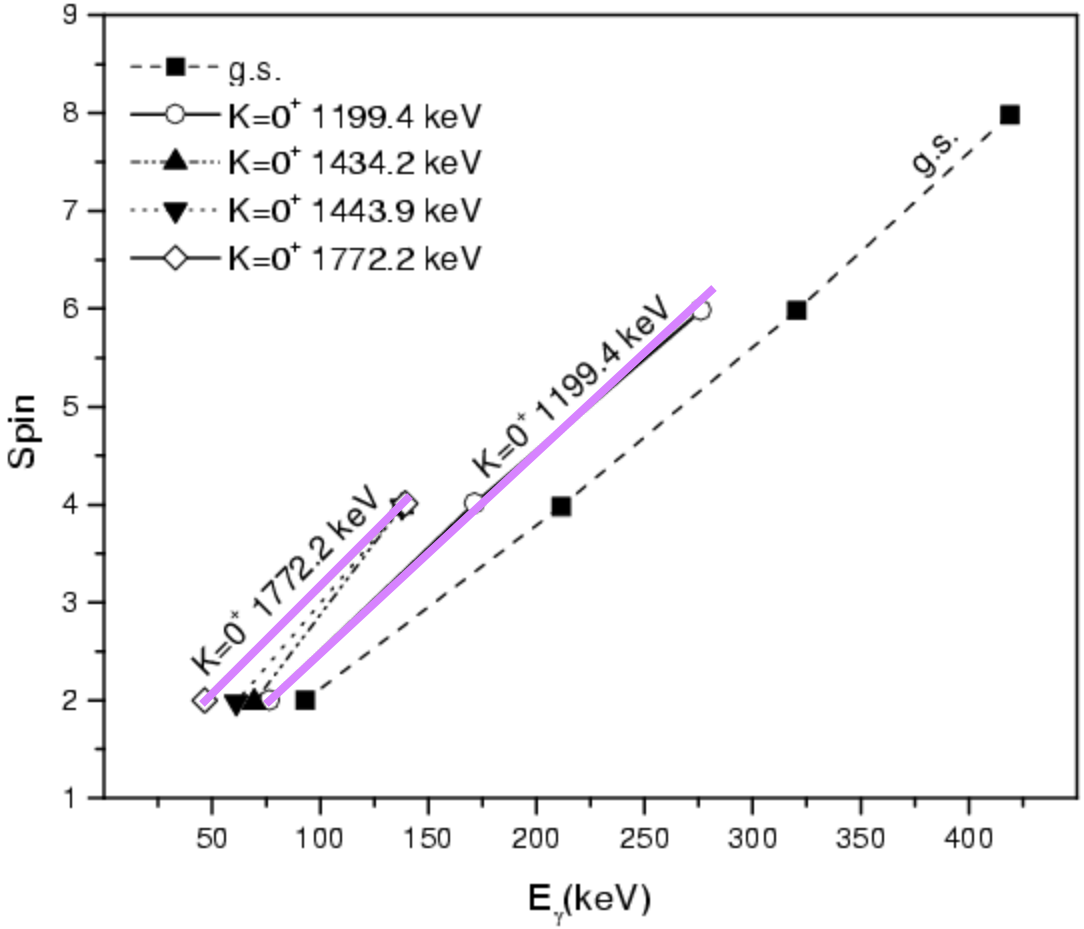
^{156}Gd


4+ 1893.4 0.0002 → 0.5 ps
2+ 1771.1 0.1 → 0.7 ps
0+ 1715.2 2.0 → 7.1 ps
6+ 1753.6
5+ 1622.5
4+ 1510.5 274 ps
0.3 → 1.8 ps 5+ 1506.9
0.6 → 1.0 ps 4+ 1355.4
0.7 → 1.0 ps 3+ 1248.0
0.9 → 1.4 ps 2+ 1154.2
>35
>5.4
1.7
3.7
2.0
0.002
0.01
0.004
2.7→4.2
4.0→6.2
0.6→1.0
6.1→9.1
4.1→6.1
1.4→2.5
8.2→14.6
2.4→17.8
3.6→26.6
6+ 584.7
4+ 288.2
2+ 88.97
0+ 0

^{156}Gd


Excitation Energy (keV)
3000
2500
2000
1500
1000
500
0
2 Δπ
2 Δν
0_8^+
0_6^+ 0_7^+
0_5^+
0_4^+
0_3^+ 0_4^+
1.3–5.7
0_2^+
2_2^+
0_3^+
2.1
1.0
3.9
0.3–1.5
4^+
2_1^+
0_1^+
^{174}Hf
$R_{4/2}$ = 3.30
^{176}Hf
$R_{4/2}$ = 3.29
^{178}Hf
$R_{4/2}$ = 3.29
^{180}Hf
$R_{4/2}$ = 3.31
^{182}Hf
$R_{4/2}$ = 3.32

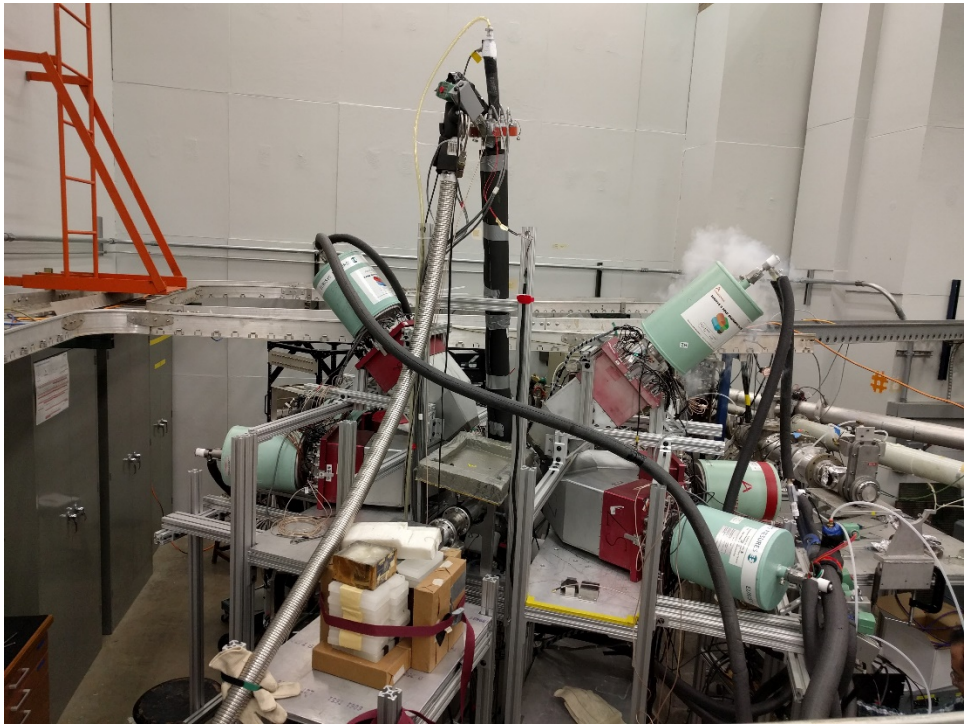

4+ 1956.4
2+ 1818.3
0+ 77 .2
K= 0+
(6)+ 1731.1
4+ 1635.6
(4)+ 1654.1
4+ 1450.4
2+ 1496.4
2+ 1513.6
0+ 1434.2
0+ 1443.9
K=0+
K=0+
2+ 1276.7
0+ 1199.4
K=0+
1.3-5.7 W.u.
8+ 1058.6
6+ 632.2
0.3-1.5 W.u.
4+ 306.6
2+ 93.2
0+ 0
178Hf


g.s.
K=0+ 1199.4 keV
K=0+ 1434.2 keV
K=0+ 1443.9 keV
K=0+ 1772.2 keV
K=0+ 1772.2 keV
K=0+ 1199.4 keV
g.s.
Spin
Eγ(keV)
1
2
3
4
5
6
7
8
9
50
100
150
200
250
300
350
400

Search for E0 Transitions in ^{154}Gd

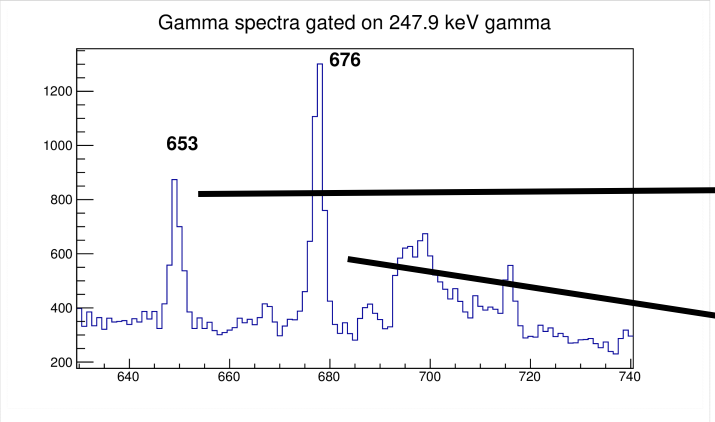
Clovershare was paired with ICEBall (Internal Conversion Electron Ball)

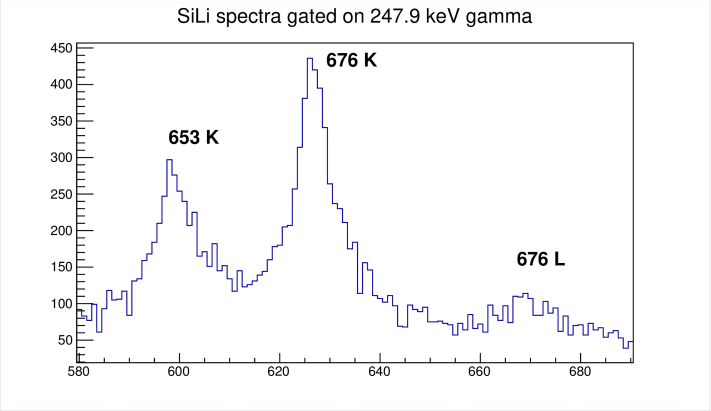
- ICEBall consists of 6 Mini-Orange Spectrometers for detecting conversion electrons
- ^{152}Sm(α,2n) reaction was used
- ^{154}Gd has 16 known 0^+ states. 10 of these were only found in 2006 by Meyer et al.
- The nature of excited 0^+ states is not well understood, E0 transitions are critical for understanding.

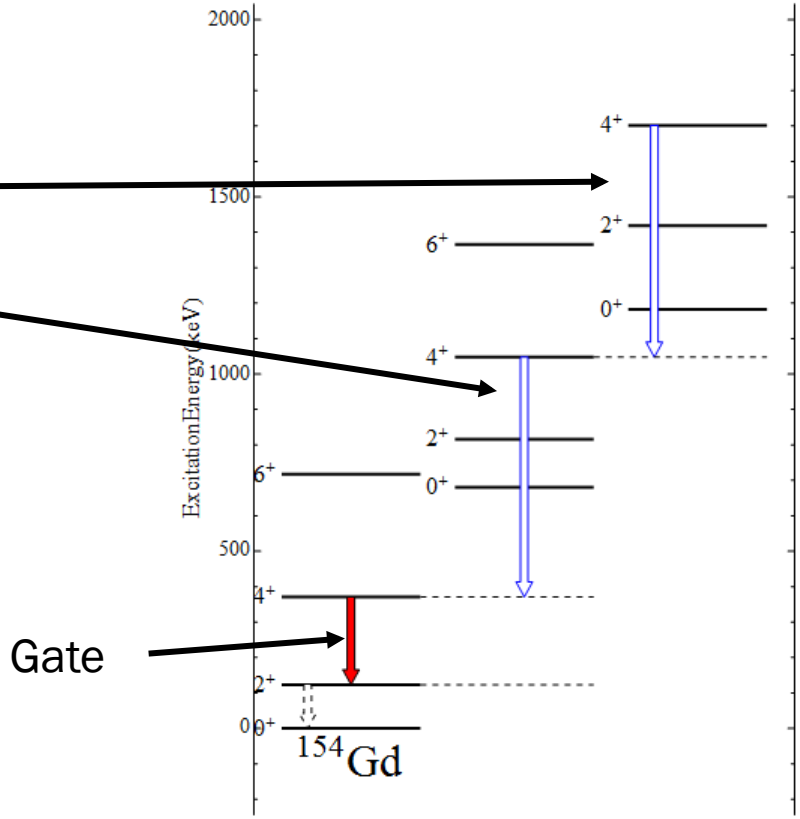


Search for E0 Transitions in ^{154}Gd

Proof of populating the first two excited 0^+ bands using 247.9 keV gate







Plots show γ-spectrum with corresponding SiLi spectrum beneath, shifted for the K-electrons to align with the corresponding γ-lines

Search for E0 Transitions in ^{154}Gd

Proof of populating the excited 0^+ bands using 123.1 keV gate