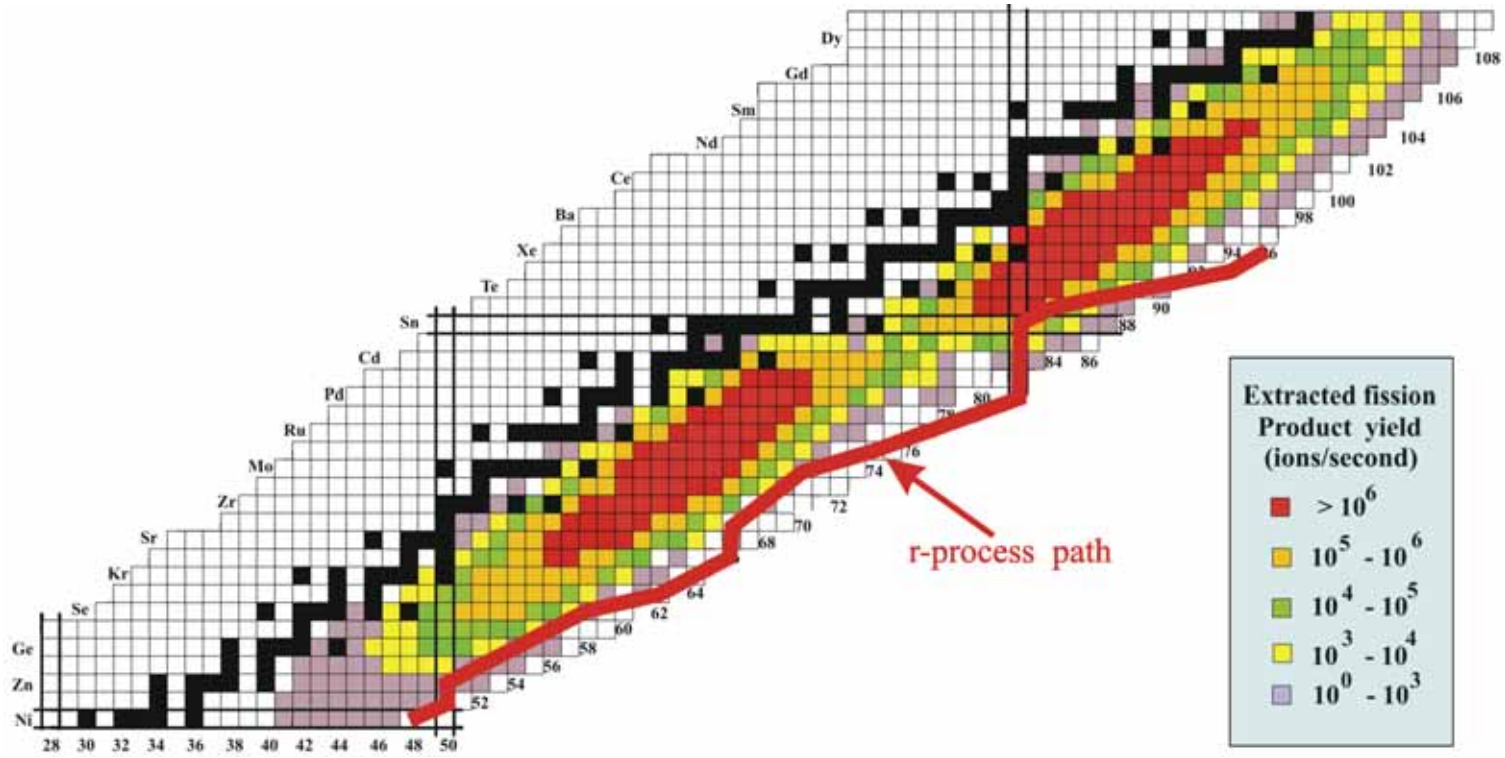
Nuclear Structure Opportunities at CARIBU



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Introduction

Concepts:-

Physics Goals of structure research of neutron rich nuclei.

What do the excess neutrons do?

Single Particle state modification
Correlation modification (pairing)
New Shapes
New Collective modes

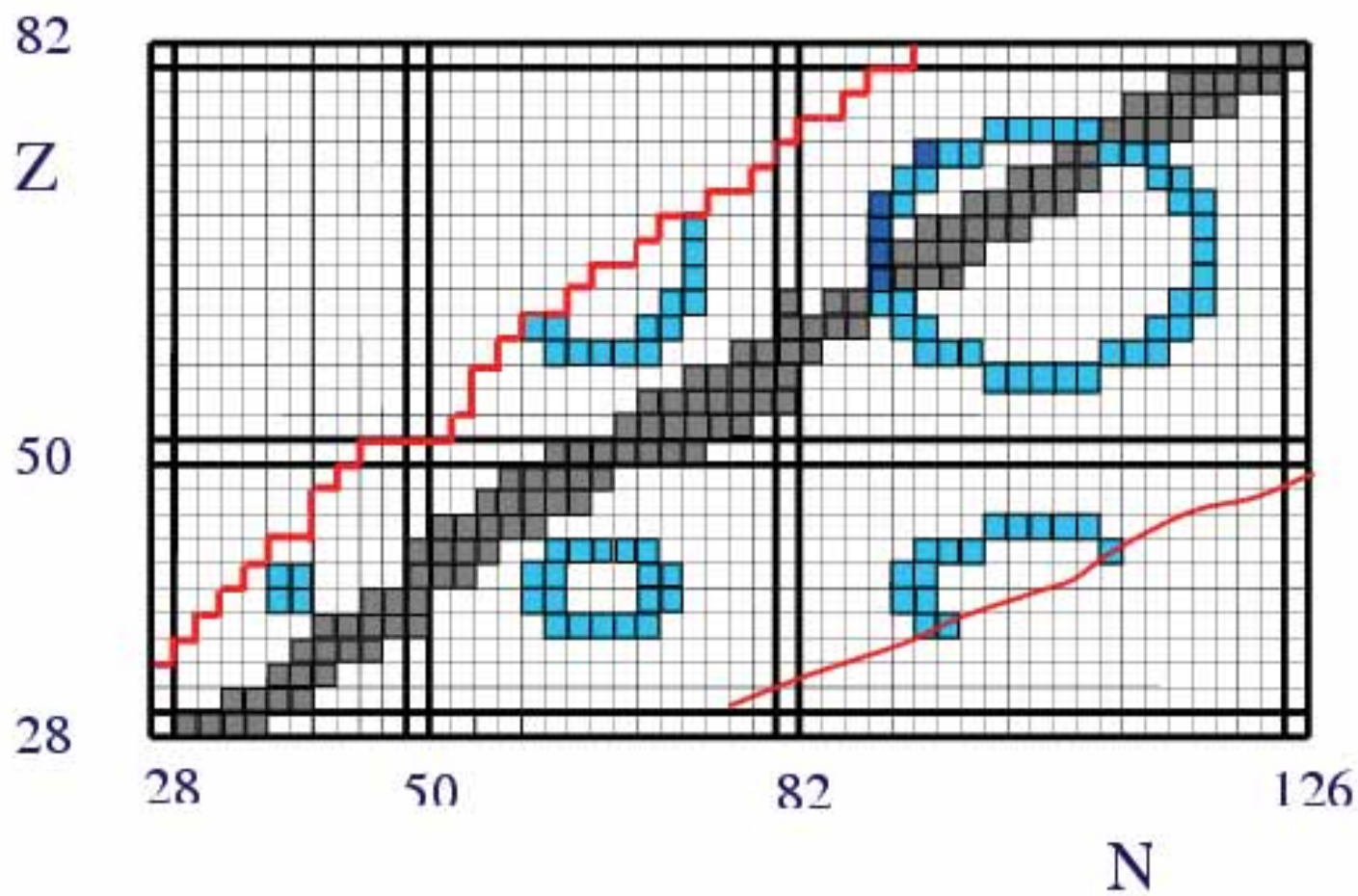
Practicalities:-

What we might actually be able to see with CARIBU beams.

Concepts

We should be looking for deviations from "business as usual"…… that is the key.

Is "normal" in fact a special case?



Concepts

Deformation……..

Does it always develop the same?

Look for deviations from the P-Scheme

Does the relationship between inertia and charge change?

Look for deviations from Grodzin's Rule

Are there new modes of collectivity?

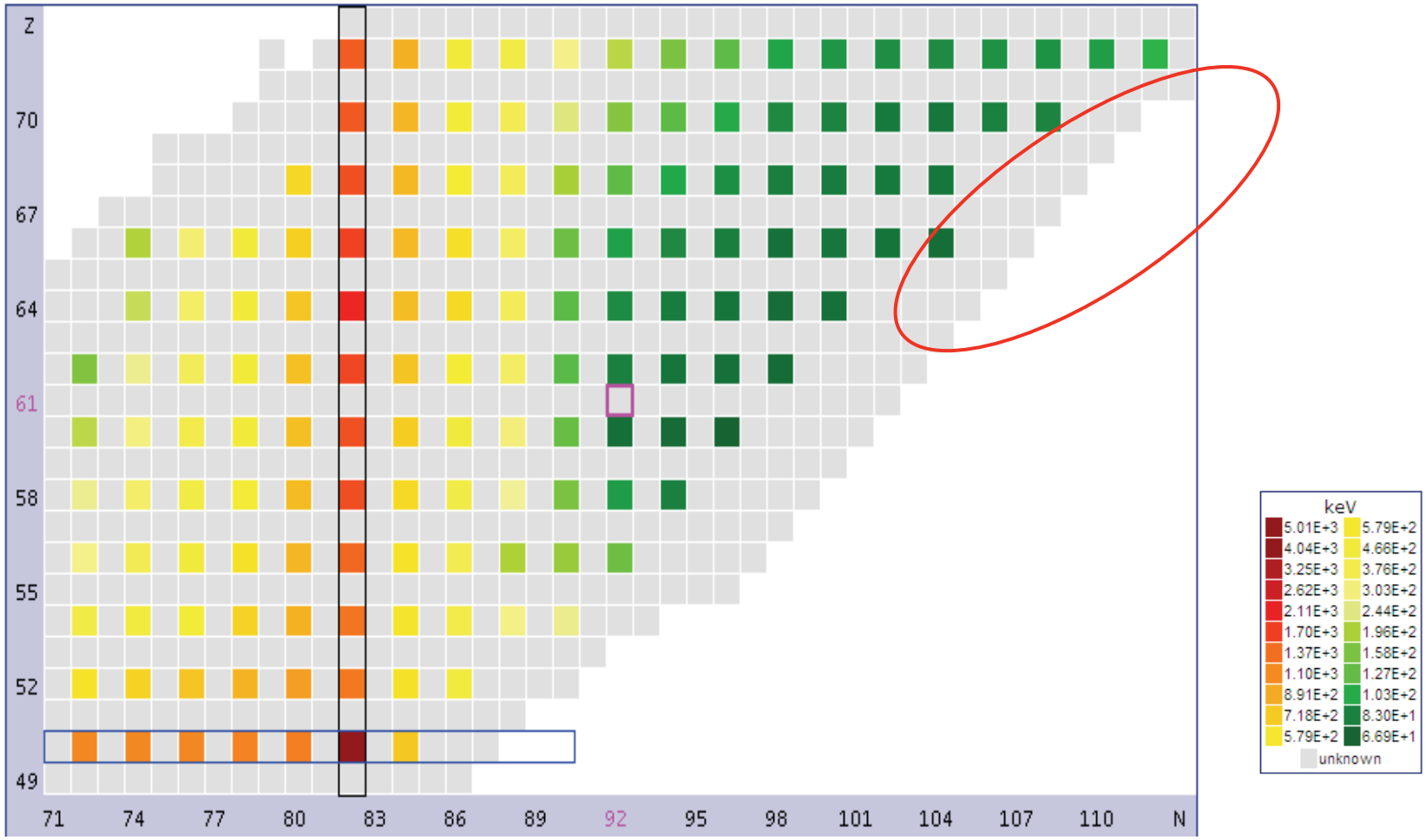
Look for Mixed Symmetry States, etc.

Look for new shapes….and shape transitions?????

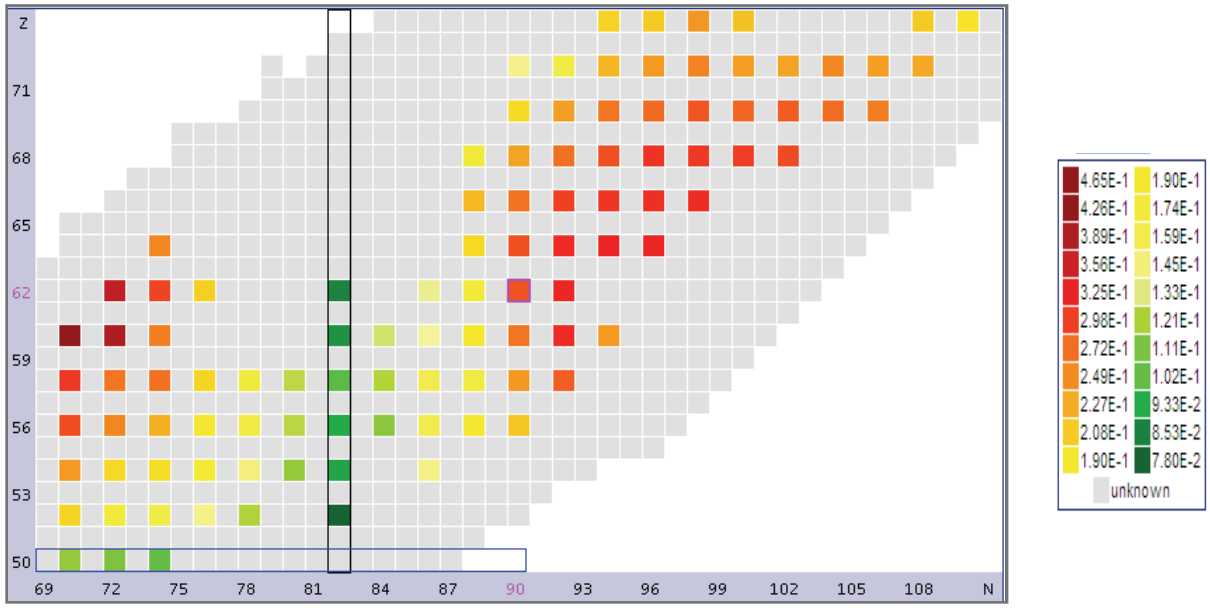
X(5), Octupoles, Tetrahedrons etc……

Practicalities: Collectivity in e-e Nuclei

Where can CARIBU beams take us?..... Can we find new even-even nuclei?

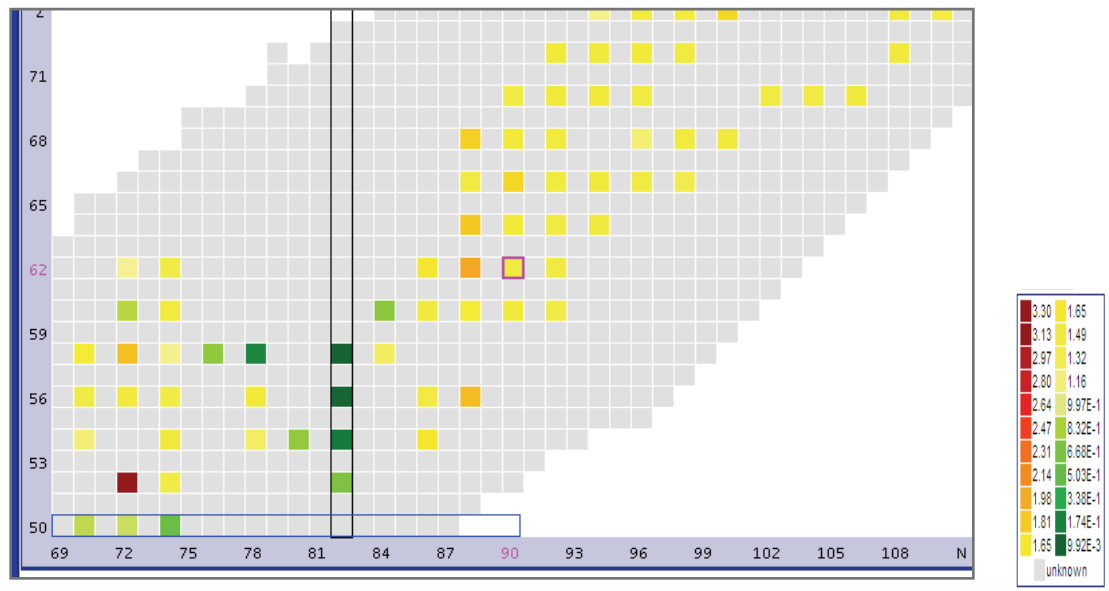


Practicalities: B(E2)s in e-e nuclei



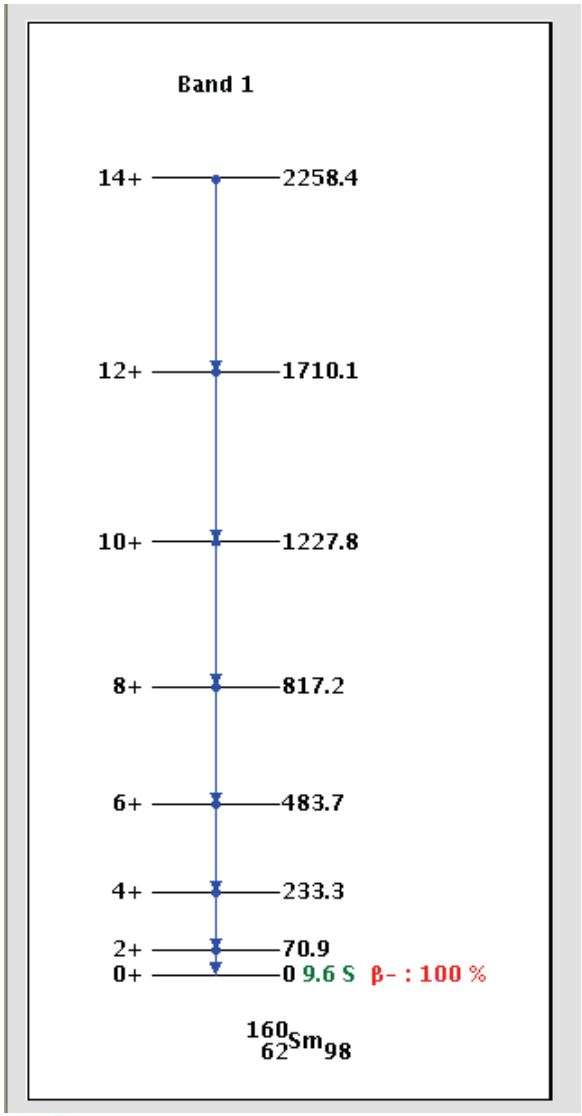
Measured deformation inferred from B(E2: 2-0)

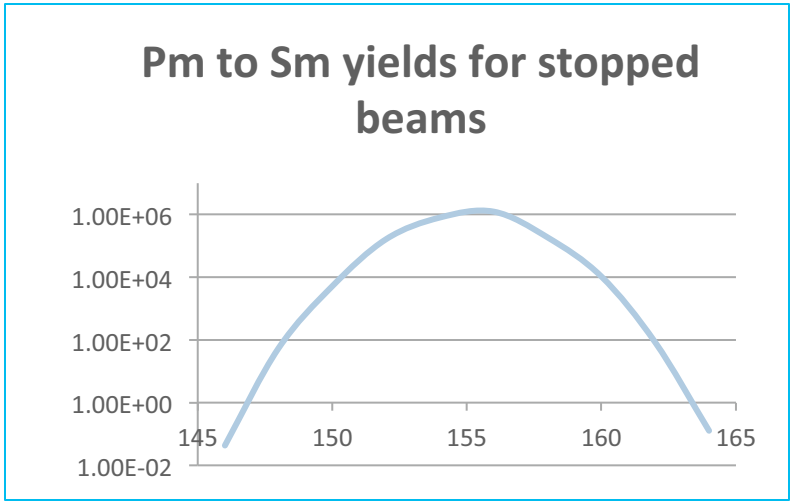
Measured B(E2: 4-2) / B(E2: 2-0)



An Example

What can we aspire to in measuring B(E2)s in decay work?





By extrapolation:-

$$T_{1/2}(2 \rightarrow 0) = 5.5ns$$

$$T_{1/2}(4 \rightarrow 2) = 86\,ps$$

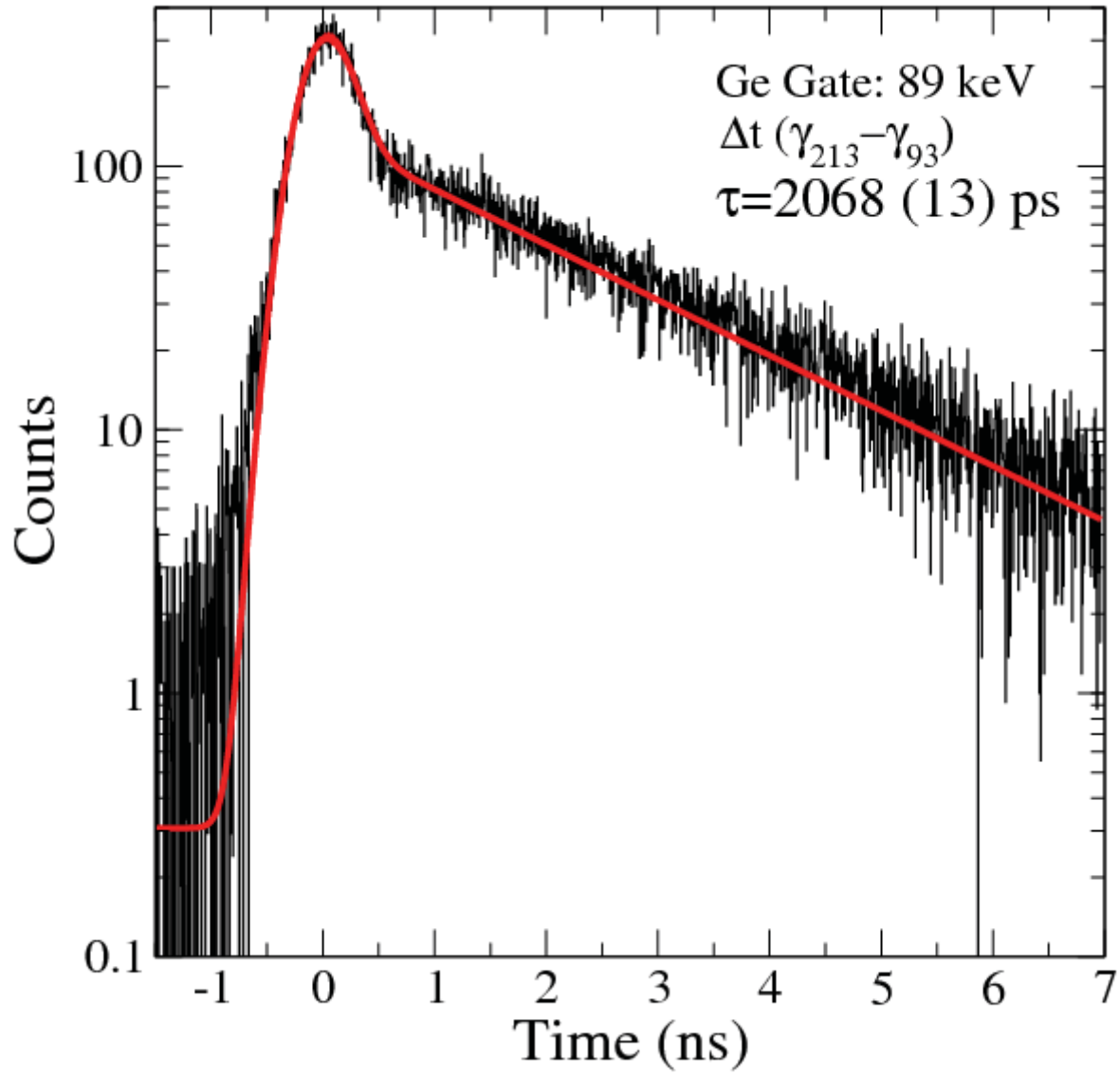
Electronic Timing

Direct electronic timing techniques for measuring the decay of sub-nanosecond states have been established for a long time:

HOWEVER

New bright scintillators, like $LaBr_3$ and $CeBr_3$, SrI_2 have both good energy resolution AND good timing .

Combined HpGe-Scintillator spectroscopy seems essential for decay studies.



S. Zhu and F. Kondev (ANL)

Collective Vibrations …..β and γ

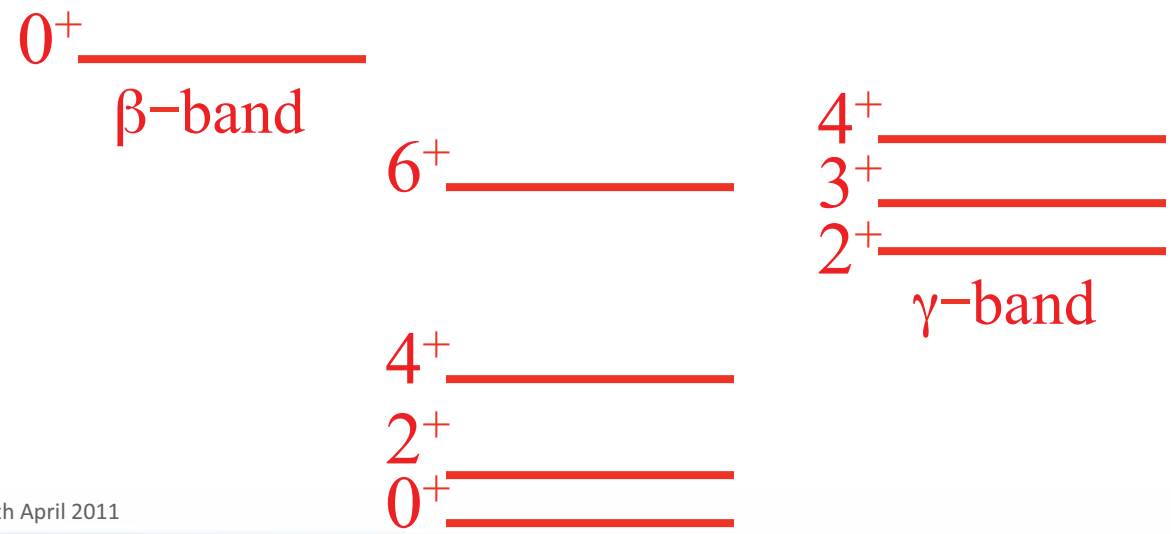
Vibrational bands are the keys to quantifying deformation: for perfect rigid rotors they should be high and low-collectivity. Are they different in very neutron-rich nuclei?

Do real β-bands exist anywhere?? (Paul Garrett would say "no")

Where are the lowest $J^{\pi}=0^{+}$ states? {shape coexistence, pairing isomers}

Do γ-bands suggest nuclei are vibrational-like, or rigid??

β-decay is perfect for finding these band heads



How Octupole collective are neutron rich barium nuclei?

This has been an open question for 20 years.

Fission fragment spectroscopy and β-decay have found parity-doublet bands of states.

But there is almost NO data on real matrix elements, either quadrupole or octupole.

A NEW REGION OF INTRINSIC REFLECTION ASYMMETRY IN NUCLEI AROUND ^{145}Ba?

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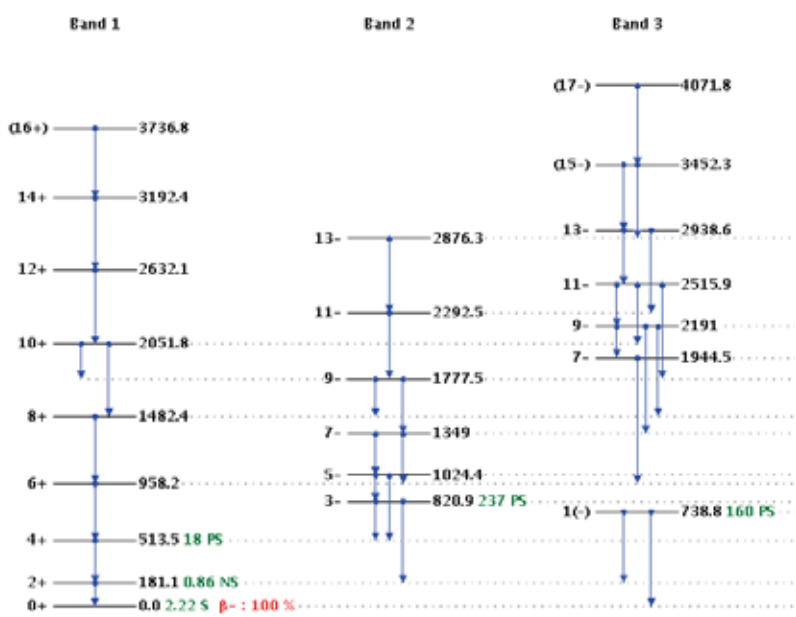
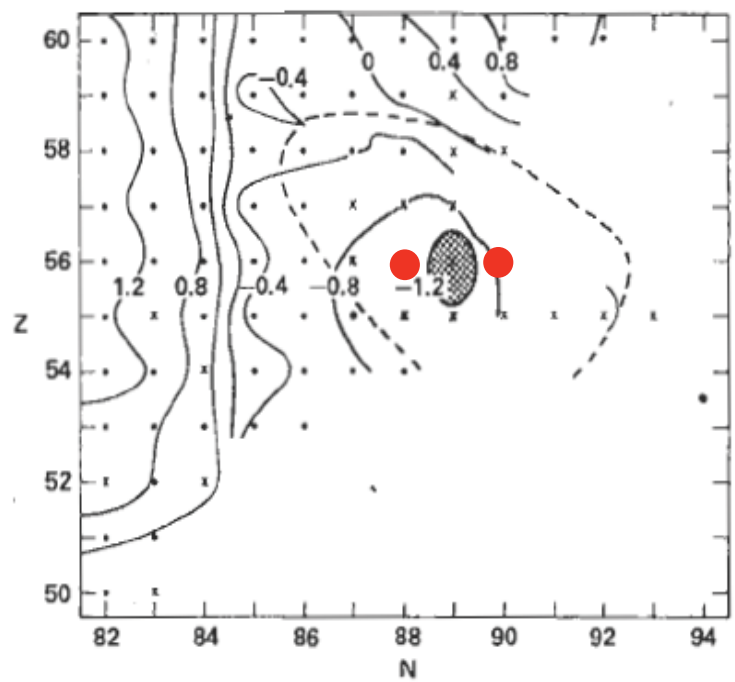
Received 9 December 1984

Leander at al PL 152B (1985)



^{146}Ba



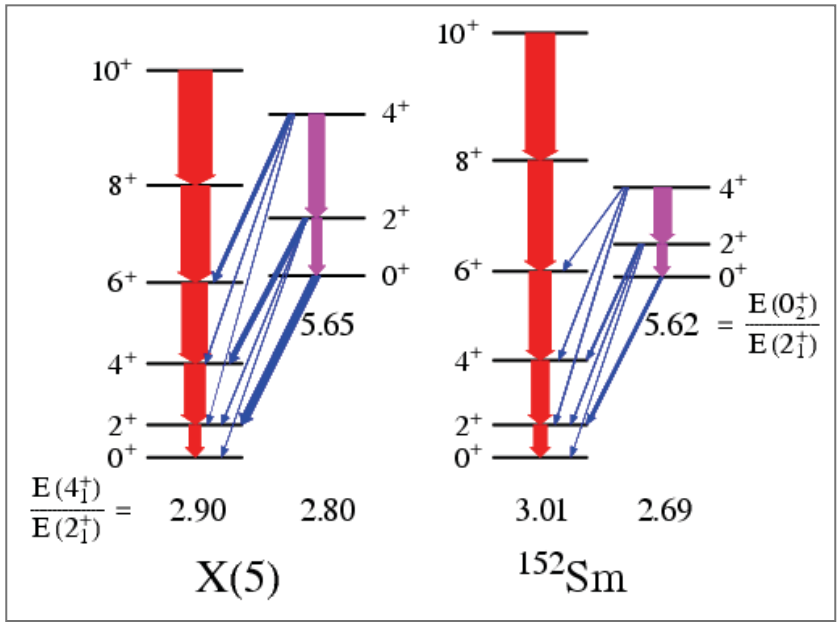
Do neutron rich barium nuclei show X(5) symmetry?

Analytic model for nuclei at critical point of transition from spherical to deformed shapes

Provides good description of N = 90 isotones of Nd, Sm, and Gd

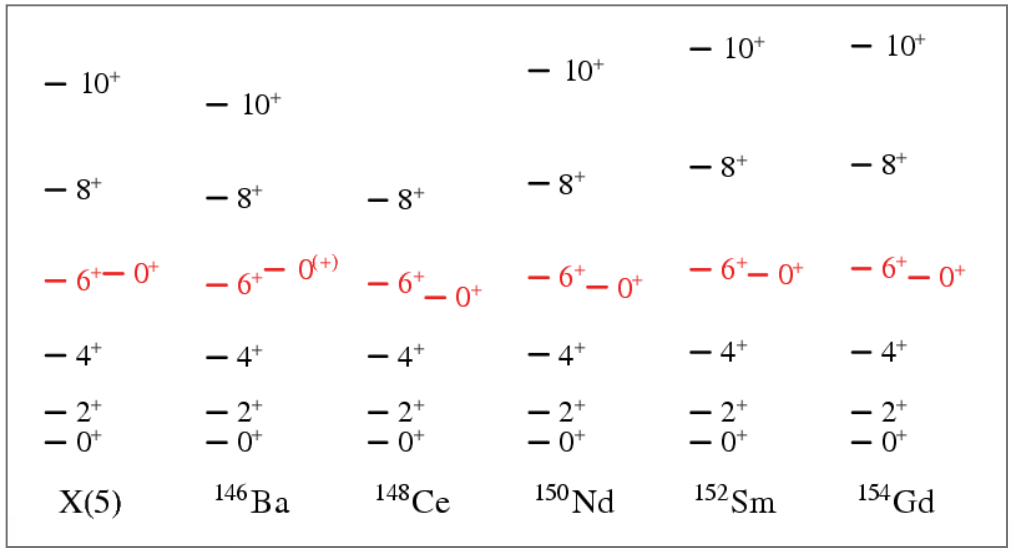
Key signatures involve low-spin, non-yrast states

Lighter Z, N=90 nuclei seem to have similar structure BUT essential states are not known



A Key Study:

Beta decay into ^{146,148}Ce

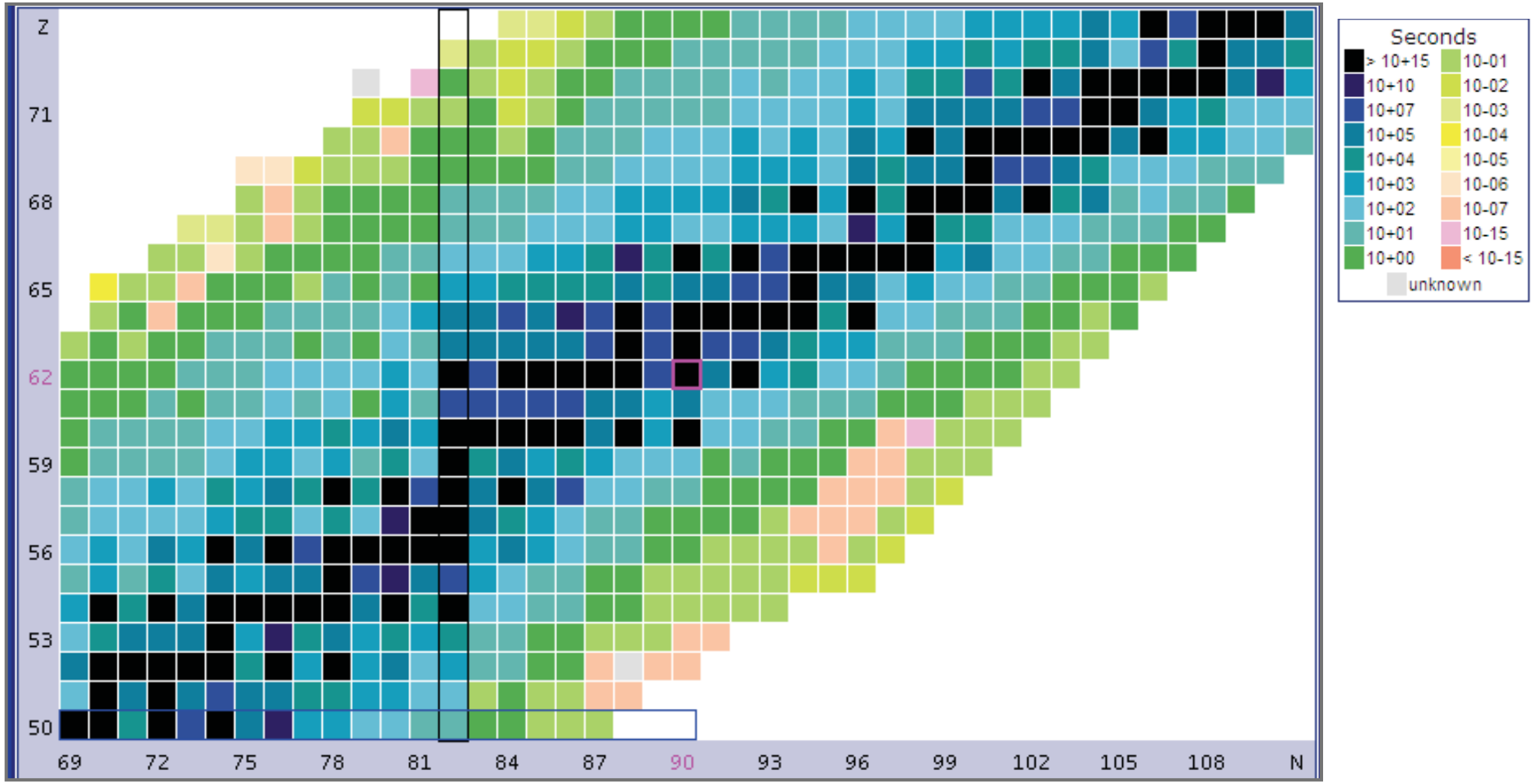


Measure:-

Non-yrast state energies, mixing ratios, and branching ratios

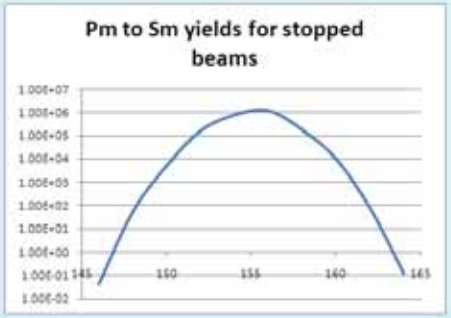
Practicalities: Ground state half-lives

Where can CARIBU beams take us?. Can we find new even-even nuclei..New Physics?



Heavy Fragment Yields from 1Ci ^{252}Cf source

Mass	Cs Fraction 55 Bariums			Lanthanum 57 Ceriums			Praseodymium 59 Neodymiums			Promethium 61 Samariums			Europium 63 Gadoliniums			Terbium 65 Dysprosioums			Holmium 67 Erbiums		
130																					
132																					
134																					
136																					
138	0.573	32.2m	1547270.2																		
140	2.77	1.06m	7479822.7	0.00503	1.678d	13582.48															
142	2.53	1.8s	6831751.4	0.414	1.54h	1117922															
144	0.549	1.01s	1482463.1	1.86	40.7s	5022549	3.80E-05	17.28m	1.03E+02												
146	0.0258	0.322s	69667.663	2.39	6.3s	6453705	0.0307	24.2m	8.29E+04	1.59E-08	5.53y	4.29E-02									
148	1.54E-04	0.15s	415.84574	0.986	1.1s	2662491	0.541	2.27m	1.46E+06	2.00E-05		5.40E+01									
150	1.17E-07	0.124s	0.3159347	0.0551	0.608s	148786.3	1.3	6.2s	3.51E+06	1.92E-03	2.68h	5.18E+03									
152				5.59E-04	0.285s	1509.465	0.696	3.2s	1.88E+06	0.0606	4.1m*	1.64E+05	4.35E-07	9.3h*	1.17E+00						
154				6.18E-07	0.149s	1.668782	0.0533	2.3s	1.44E+05	0.298	1.7m	8.05E+05	2.58E-04	8.8y	6.97E+02						
156							1.82E-03	0.397s	4.91E+03	0.458	26.7s	1.24E+06	9.93E-03	15.2d	2.68E+04	1.17E-08	5.1d*	3.16E-02			
158							4.82E-06	0.169s	1.30E+01	0.0691	4.8s	1.87E+05	0.148	45.9m	4.00E+05	1.20E-05	10.9s*	3.24E+01			
160							4.55E-09	????	1.23E-02	3.90E-03	0.729s	1.05E+04	0.157	38s	4.24E+05	6.73E-04	72.3d	1.82E+03			
162										3.10E-05	0.324s	8.37E+01	0.047	11s	1.27E+05	3.43E-03	7.6m	9.26E+03	4.22E-08	66m*	1.14E-01
164										4.70E-08	????	1.27E-01	3.52E-03	1.58s	9.51E+03	1.65E-02	3.0m	4.46E+04	7.00E-06	24m*	1.89E+01
166													6.30E-05	????	1.70E+02	1.40E-02	?????	3.78E+04	1.40E-04	1.117d*	3.78E+02
168													1.75E-07	?????	4.73E-01	1.24E-03	?????	3.35E+03	7.33E-04	3.0m	1.98E+03
170													9.78E-11	????	2.64E-04	3.62E-05	????	9.78E+01	3.48E-04	43s*	9.40E+02
172																2.35E-07	?????	6.35E-01	1.63E-04	????	4.40E+02



Many new even-even isotopes to be identified, especially deep into the rare-earth domain.

Many Odd-odd to even-even decays have both low and high spin β-decays, enriching scope.

Can we expect anything new in "Nilsson" bandheads, or pairing correlations?????

Concepts

Spherical nuclei……..These should be the "simplest" cases of nuclear structure.

Where are the unperturbed "Single Particle: states?

Definitively fix Energies, Spins, Spectroscopic Factors.

What are the Residual Interactions?

Definitively identify multiplets.

What are the effective charges?

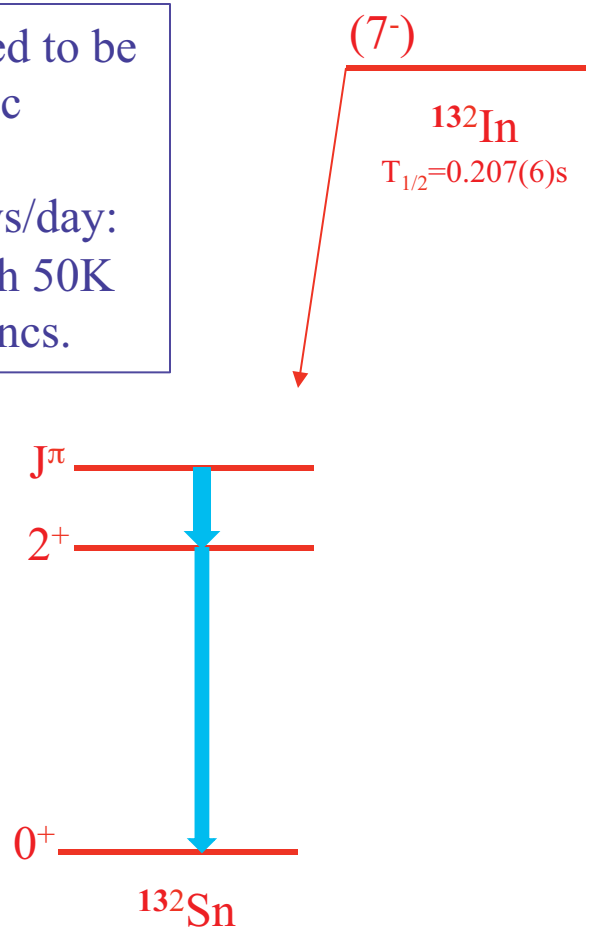
Precisely measure electromagnetic matrix elements.

^{132}Sn in Decay

Has been suggested to be the "best" doubly closed shell model (DCSM) nucleus. BUT only one spin has really been firmly established.…and the parent is not rigorous. This should be better.

^{132}In yield predicted to be 1400 ions/sec

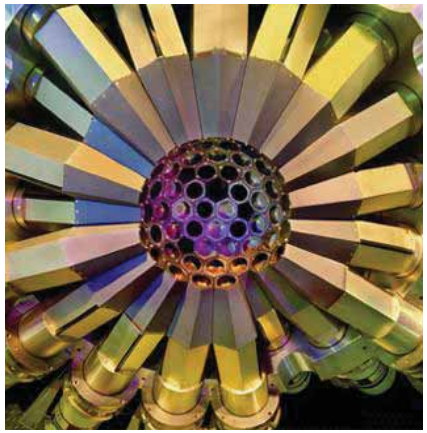
(i.e.) 200M decays/day: 10 angle bins with 50K photo-peak coincs.

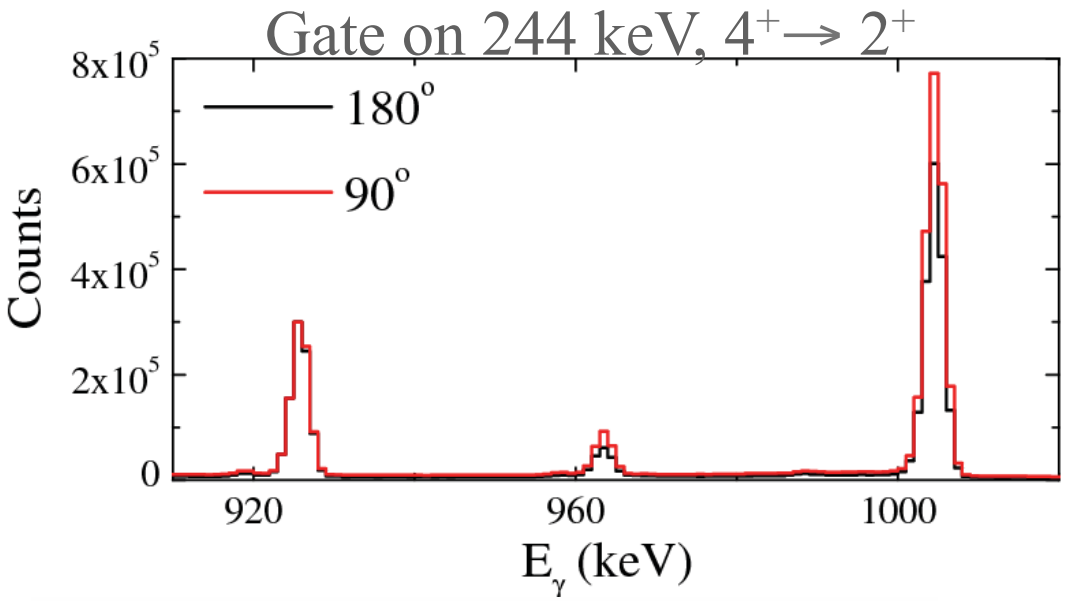


E(level)[‡]	Jπ[§]	XREF	$T_{1/2}$[†]
0.0	0+	ABCDE	39.7 s *8*
4041.20[@] *15*	2+	AB DE	1.9 fs *+14-6*
4351.94 *14*	(3-)	A D	<5.0 ps
4416.29[@] *14*	(4+)	AB D	3.95 ns *13*
4715.91[@] *17*	(6+)	AB D	20.1 ns *5*
4830.97[&] *17*	(4-)	A D	26.0 ps *5*
4848.52[@] *20*	(8+)	AB D	2.03 μs *4*
4885.21[@] *19*	(5+)	A D	<40.0 ps
4919.00[@] *20*	(7+)	A D	62.0 ps *7*
4942.53[&] *16*	(5-)	A D	17.0 ps *5*
5279.5[@] *11*	(9+)	D	
5387.89 *20*	(4-)	A	
5399.22[#] *21*	(6+)	A	
5478.98[#] *23*	(8+)	A	
5629.26[#] *19*	(7+)	A	13.0 ps *5*
6173.20 *20*	(5,6,7)	A	
6235.9 *3*	(6,7,8+)	A	
6598.5 *3*	(6,7-)	A	
6630.3 *3*	(6,7,8+)	A	
6709.04 *21*	(6,7-)	A	
6896.0 *3*	(6,7,8)	A	
7211.14 *17*	(6-)	A	
7244.06 *20*	(7-)	A	
≈7550?		A	

Precision Angular Correlations

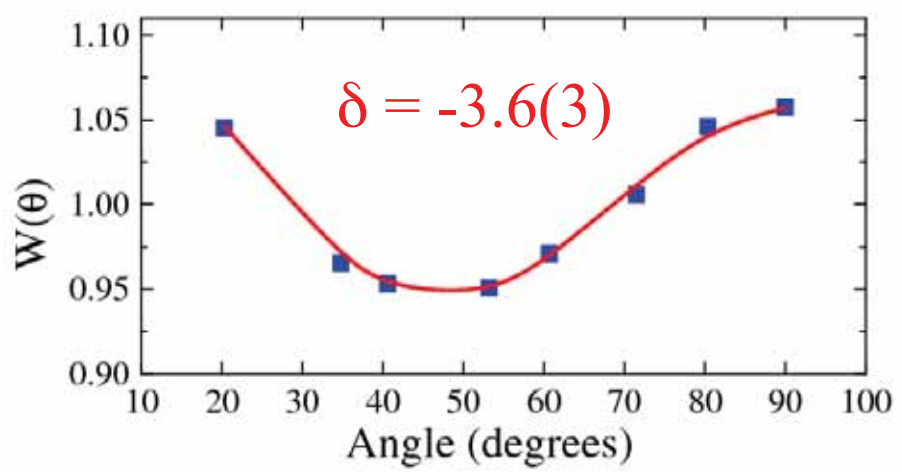
Example ^{152}Eu decay to ^{152}Sm
(McCutchan et al. 2010)

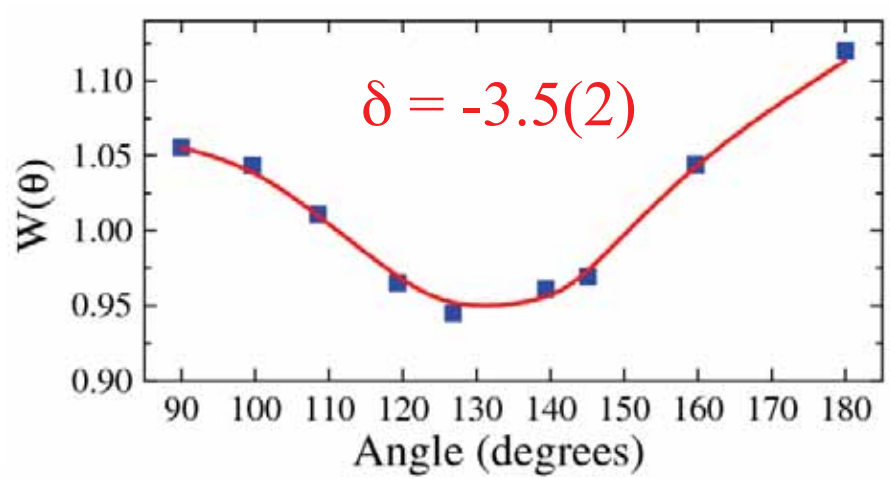




4→4→2
1005-244 keV

Delta gives measure of E2/M1 mixing



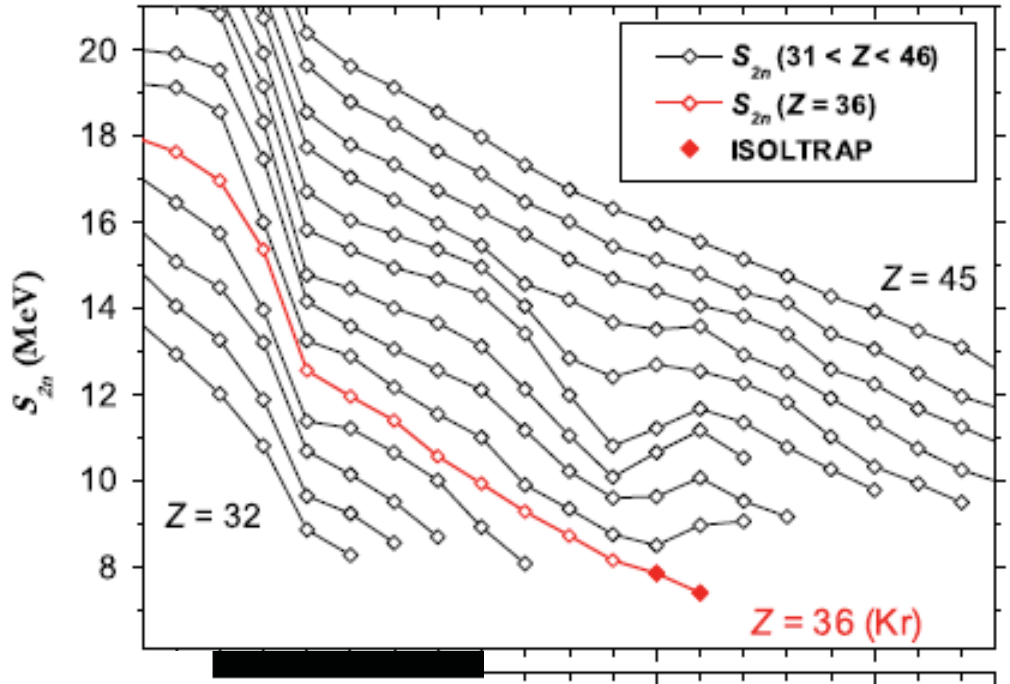


Spectroscopy in the lig

PRL **105,** 032502 (2010) PHYSICAL REVIE

Critical-Point Boundary for the Nuclear Qua from Mass Measuren

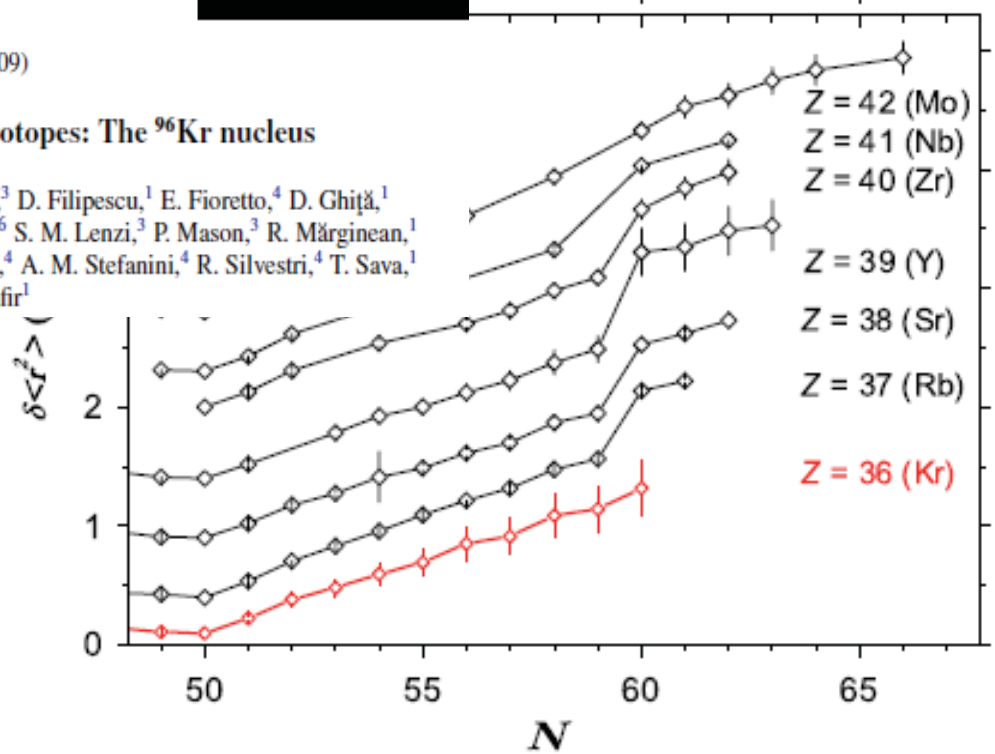
S. Naimi,[1] G. Audi,[1] D. Beck,[2] K. Blaum,[3] Ch. Böhm,[3] Ch. Bo
A. Herlert,[5] M. Kowalska,[3] S. Kreim,[3] D. Lunney,[1,‡]
L. Schweikhard,[4] an



PHYSICAL REVIEW C **80**, 021301(R) (2009)

Evolution of deformation in the neutron-rich krypton isotopes: The ^{96}Kr nucleus

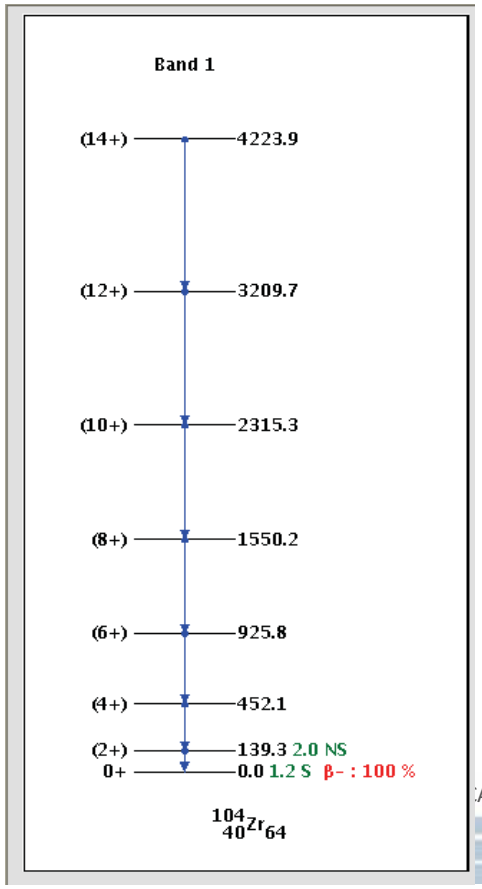
N. Mărginean,[1] D. Bucurescu,[1,2] C. A. Ur,[1,3] C. Mihai,[1] L. Corradi,[4] E. Farnea,[3] D. Filipescu,[1] E. Fioretto,[4] D. Ghiță,[1]
B. Guiot,[4] M. Górska,[5] M. Ionescu-Bujor,[1] A. Iordăchescu,[1] D. Jelavić-Malenica,[6] S. M. Lenzi,[3] P. Mason,[3] R. Mărginean,[1]
D. Mengoni,[4] G. Montagnoli,[3] D. R. Napoli,[4] S. Pascu,[1] G. Pollarolo,[7] F. Recchia,[4] A. M. Stefanini,[4] R. Silvestri,[4] T. Sava,[1]
F. Scarlassara,[3] S. Szilner,[6] and N. V. Zamfir[1]



CARIBU will produce ^{96}Br at a rate of ~5 ions/sec, so resolving this issue should be quite straightforward.

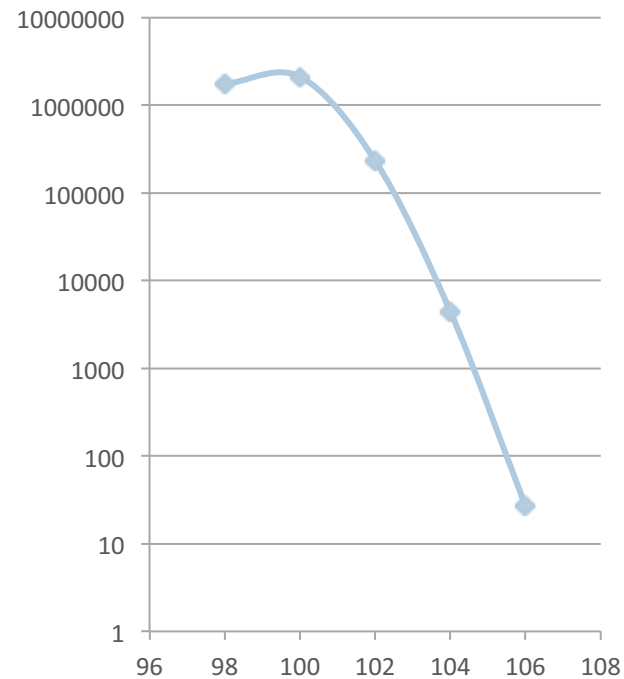
The very deformed regime:-

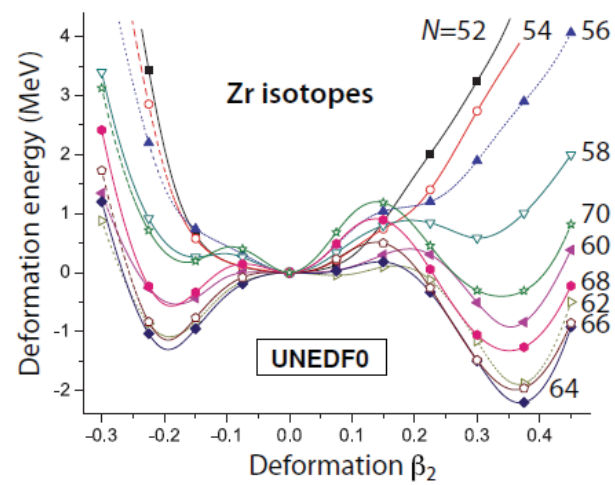
CARIBU yields are high enough to reach beyond what is known in the highly deformed regime, where nuclei are thought to have $\beta_2 > 0.4$, well in excess of any nuclei beyond the p-shell.



Data is from prompt fission fragment spectroscopy. β-decay can add sidebands and matrix elements and reach MUCH further from stability

Yttrium to Zr Yields from ^{252}Cf Fission



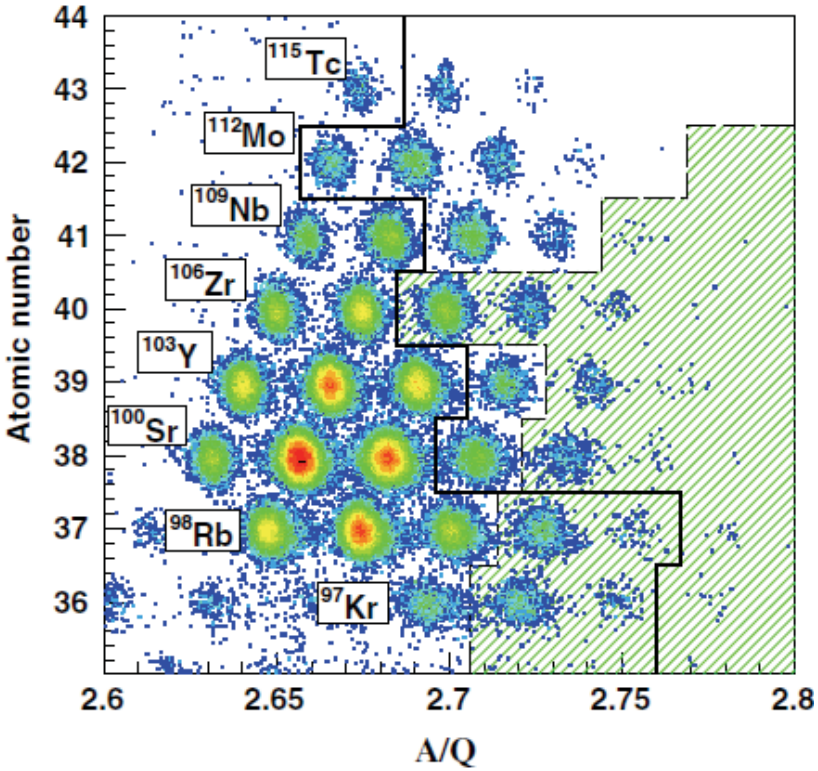


Competitive Business

PRL **106,** 052502 (2011) PHYSICAL REVIEW LETTERS week ending 4 FEBRUARY 2011

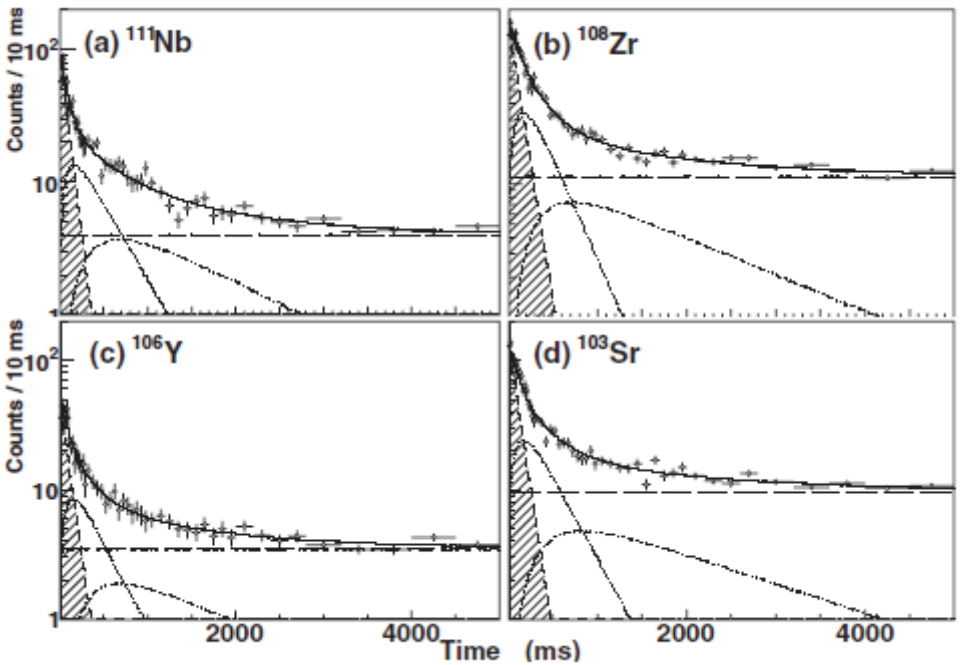
β-Decay Half-Lives of Very Neutron-Rich Kr to Tc Isotopes on the Boundary of the r-Process Path: An Indication of Fast r-Matter Flow

S. Nishimura,[1] Z. Li,[1] H. Watanabe,[1] K. Yoshinaga,[2,1] T. Sumikama,[2] T. Tachibana,[3] K. Yamaguchi,[4]



38 Lifetime measurements……..

Mostly ~2 times faster than expected.



Conclusion

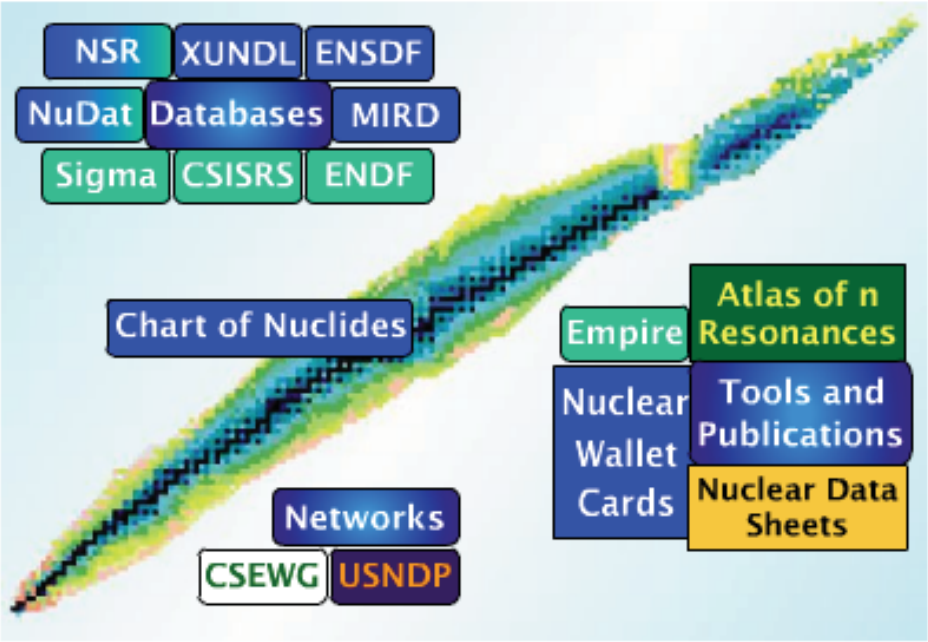
We will be entering "Terra Incognita" in the heaviest fragments from ^{252}Cf fission … and with good yields.

It may be a desert …. It is right in the middle of the rare-earth rotors. But it a desert that we THINK we understand very well.

We CAN and MUST do better in precision spectroscopy near ^{132}Sn

Neutron-rich Sr,Y, Zr nuclei have some of the largest ground state deformations known. Can we find new physics associted with large neutron excesses there? {My best bet for structure surprises}

Acknowledgement



NNDC National Nuclear Data Center
BROOKHAVEN NATIONAL LABORATORY

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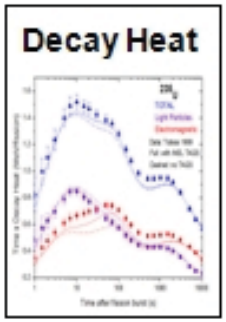

NEW Summer Nuclear Data Week, Montauk, NY, June 20-24

Good Data Bases are essential for this fast-moving field