UNIVERSITY OF LIVERPOOL

Decays of K isomers in the deformed neutron-deficient A = 130 region

Andy Briscoe

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Outline

- Introduction
- Experimental techniques and apparatus
- Results: Highly deformed A =130 Region
- Summary

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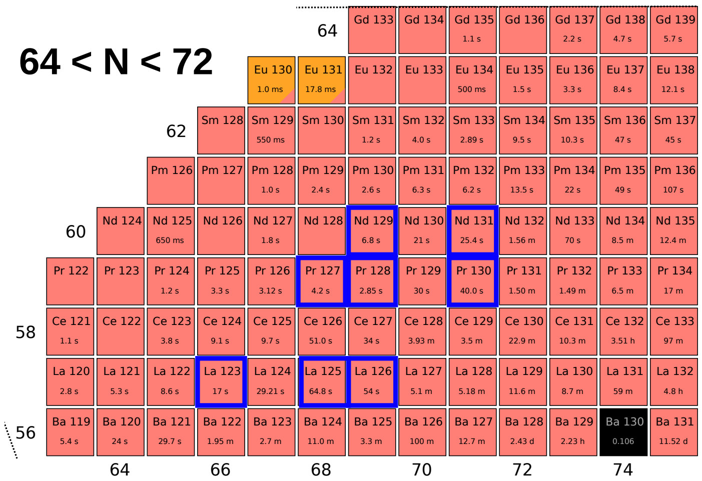
Introduction: Structure deformed A≈130

56 < Z < 61

64 < N < 72

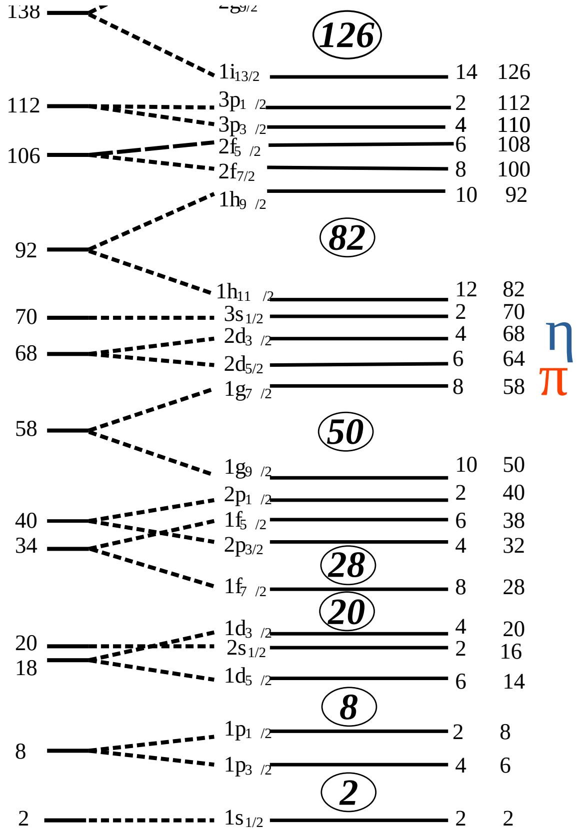
Region of interest

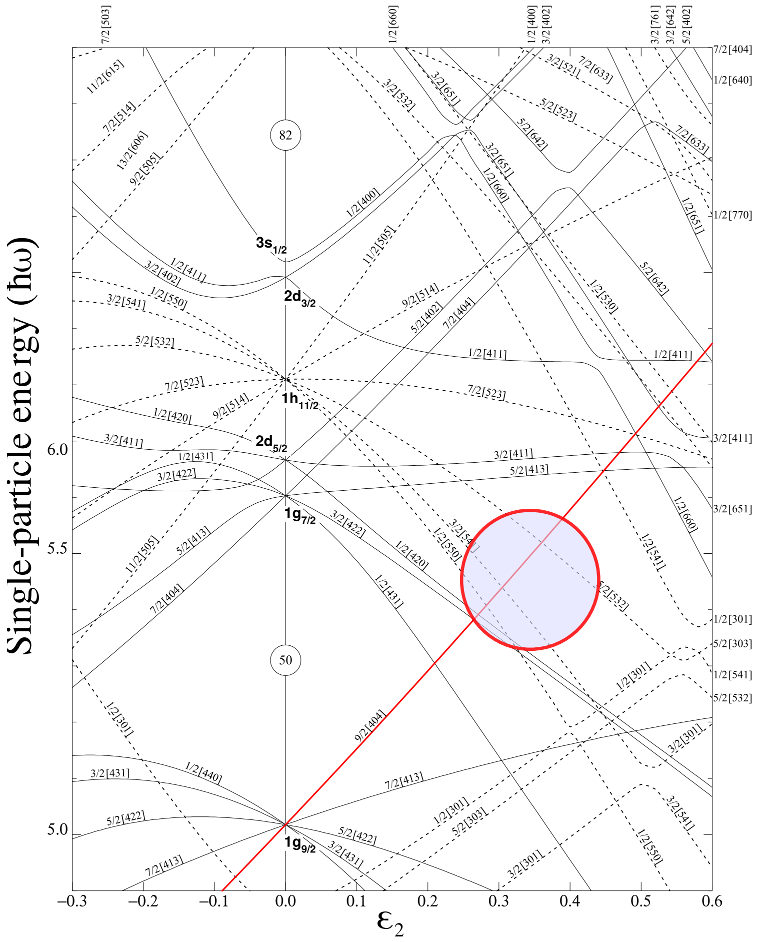


At non-zero deformation 2j+1 degeneracy lifted orbitals split into projection onto symmetry axis, K-quantum number (+\- omega).

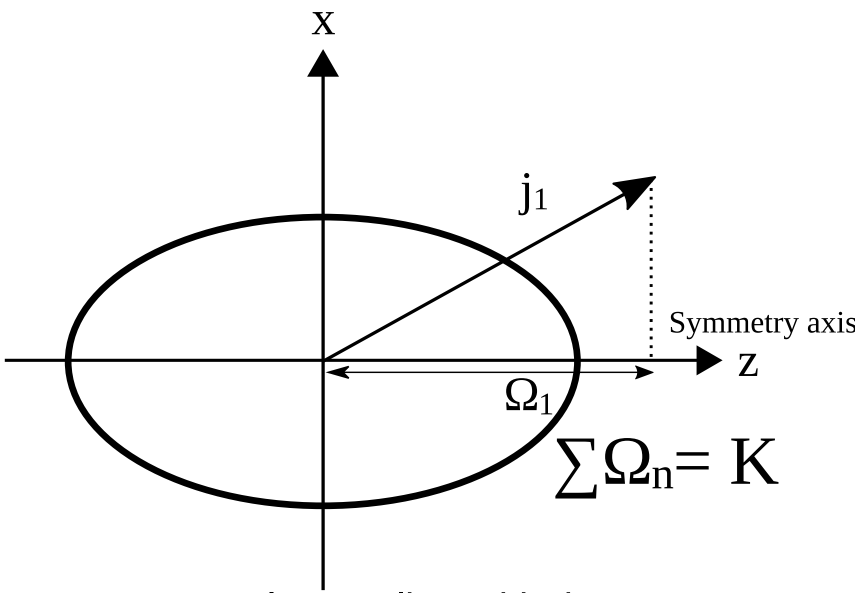
At large deformation the high-K component of the $\pi g_{9/2}$ orbital traverses the Z = 50 shell gap.

Presence of both high-K and low-K band heads at fermi surface can give to isomeric nature of band heads





Introduction: K-isomers



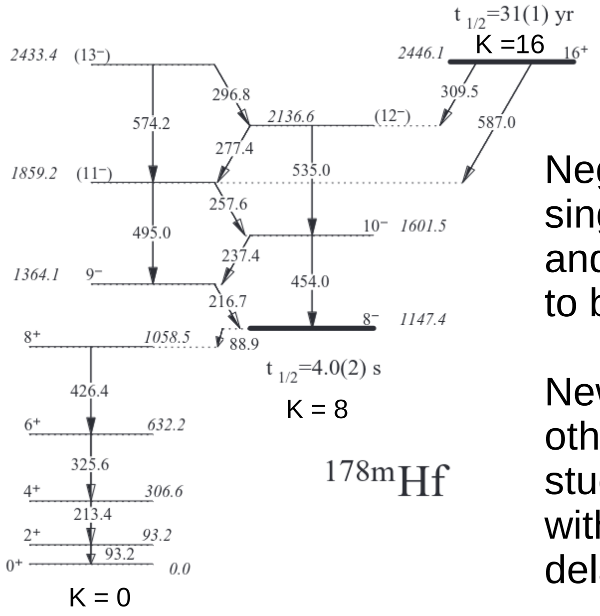
One or many nucleons align with the symmetry (z) axis. K is an approximate quantum number.

It is difficult for rotational bands to decay from high-K to low-K due to the necessary reorientation of the angular momentum vector.

$|K_f - K_i| = |\Delta K| \leq \lambda$ K can only change by units up to multipolarity of the transition

$|\Delta K| - \lambda = \nu$ larger changes in K result in hindered transitions

$F_w = t_{1/2}^{exp} / t_{1/2}^{Weis}$ Hindrance factor increases (approximately) linearly with ΔK



S. ZHU, PRC 102, 044326 (2020)

Neglecting K-hindrances, single particle decays of and 8^- state would be expected to be of the order 10^{-13} s

New K-hindered transitions in other mass regions can be studied with a sensitivity to delayed half-lives.

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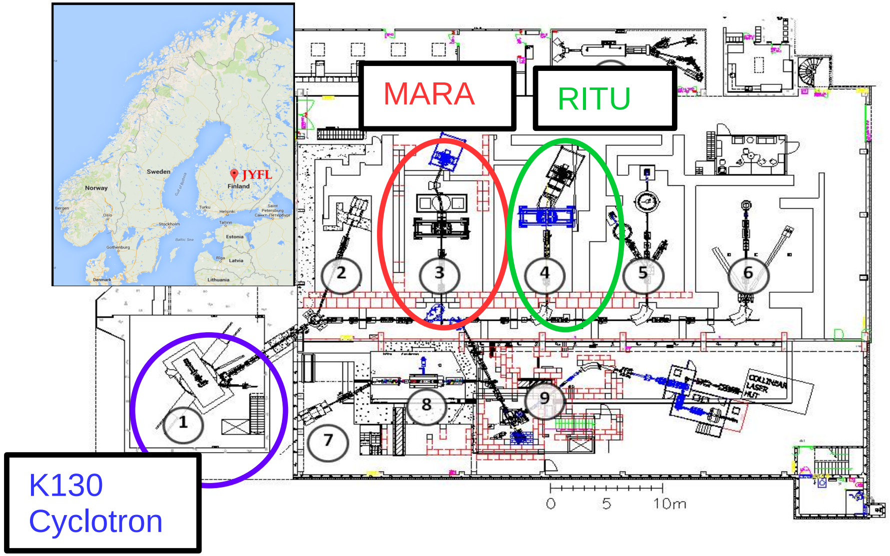
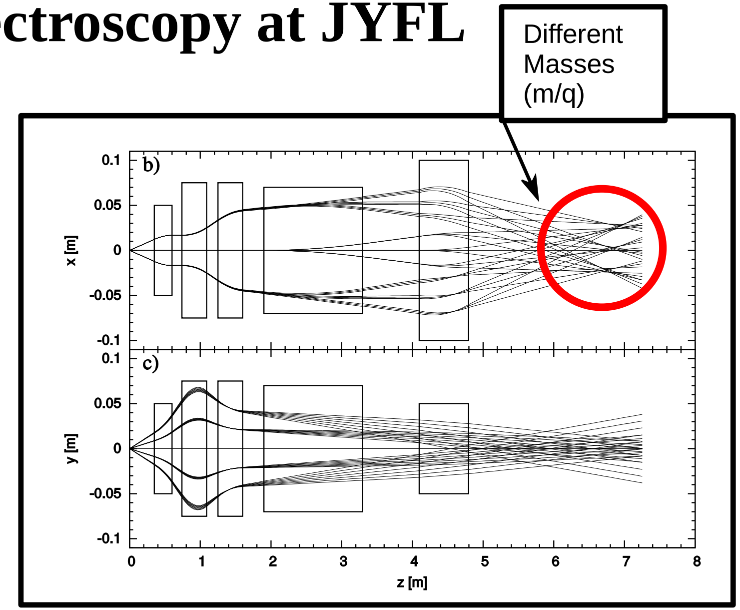
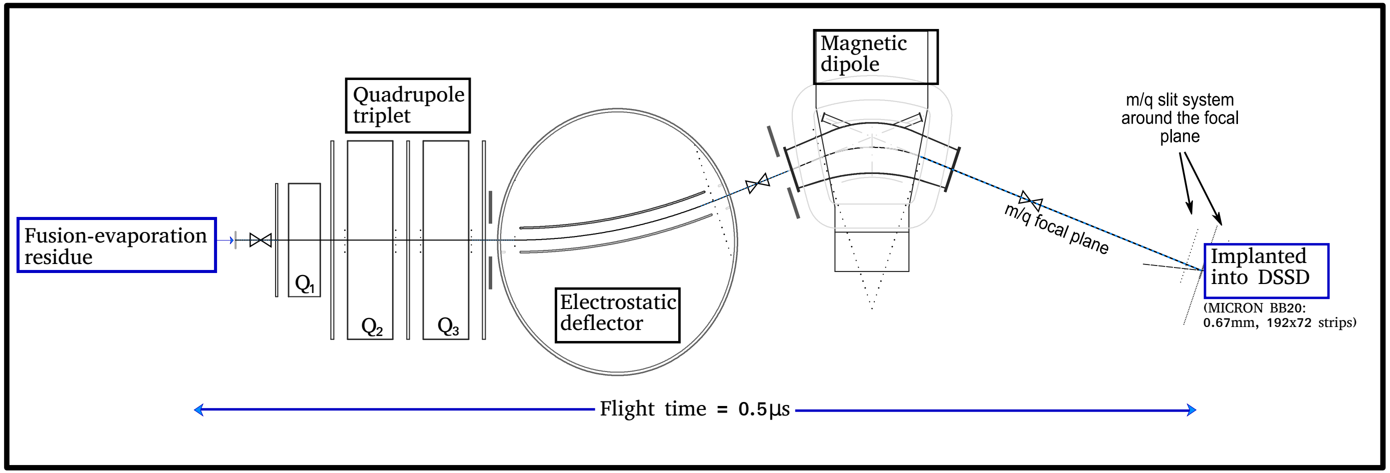
Experimental techniques and apparatus: Nuclear Spectroscopy at JYFL



$$E\rho_E = \frac{pv}{q} \approx \frac{2E_K}{q}$$

$$B\rho_B = \frac{p}{q} \approx \frac{\sqrt{2E_K m}}{q}$$



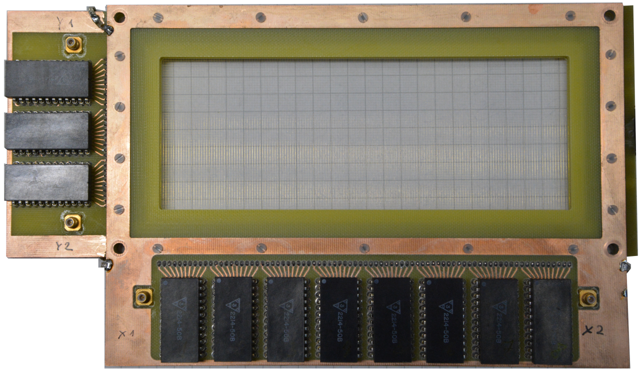


200 MeV Recoil => v/c = 0.05

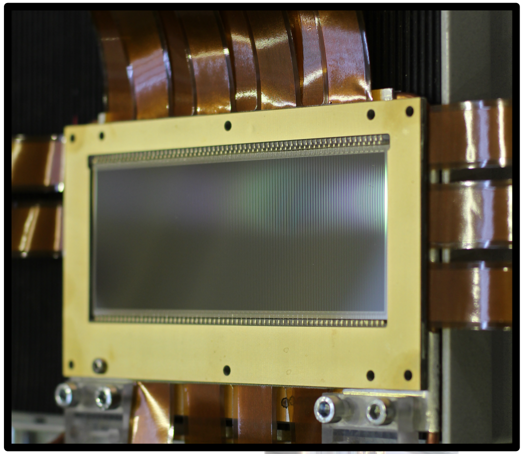
Fusion-evaporation residues transported to focal plane for spectroscopy

Experimental techniques and apparatus: Focal-plane detectors

Multi-wire proportional counter (MWPC)

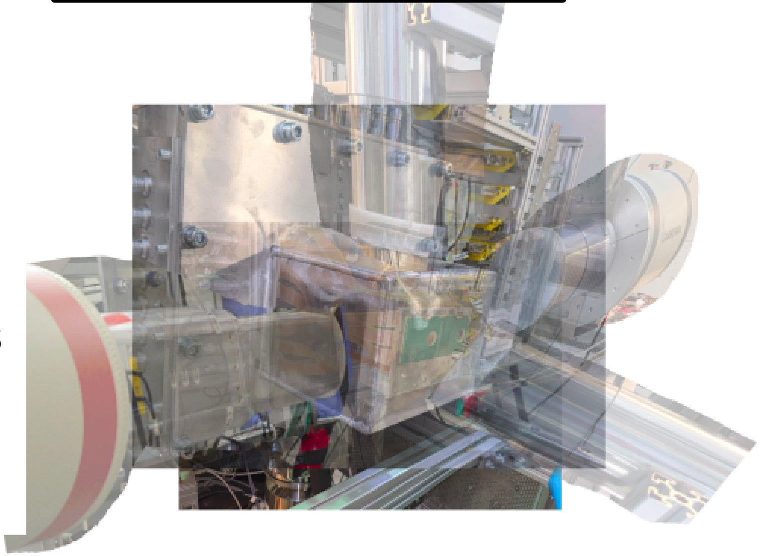


Grid of 20 μm diameter gold-coated tungsten wires, provides (x,y) position of recoils



Micron BB20 DSSD

72 x 192 strips,
13,824 0.45 mm^2 pixels
300 um thick Si



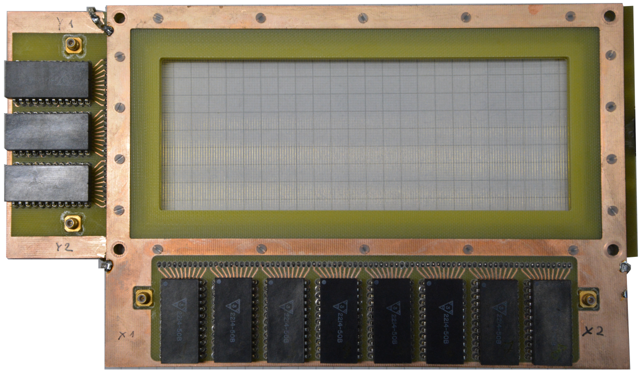
Ge detectors

3 BEGe & 1 Clover detectors outside chamber surrounding DSSD in close geometry.

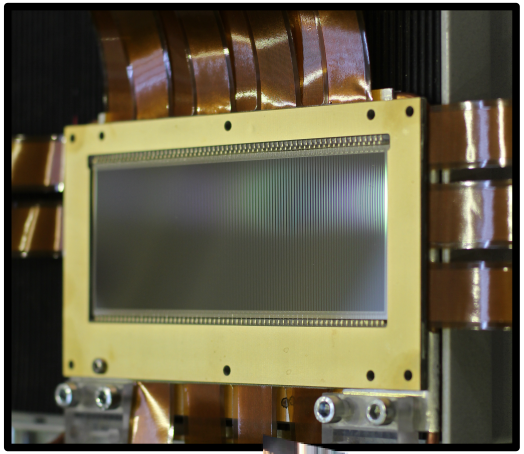
All signals time stamped by a 100 MHz clock,
read out individually and digitized for complex correlation analysis with signals at target.

Experimental techniques and apparatus: Focal-plane detectors

Multi-wire proportional counter (MWPC)



Grid of 20 μm diameter gold-coated tungsten wires, provides (x,y) position of recoils



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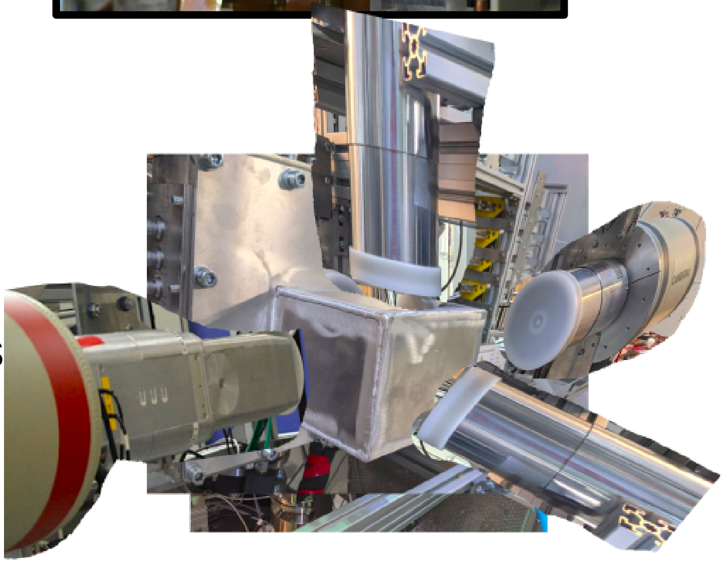
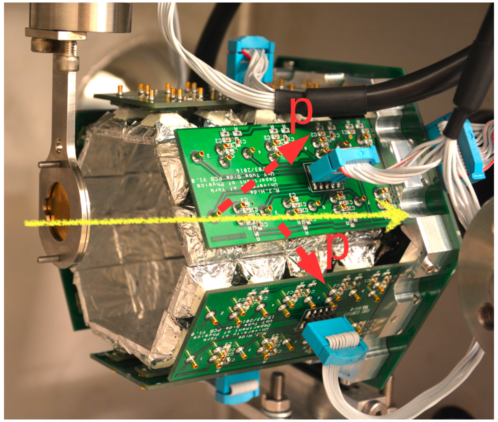
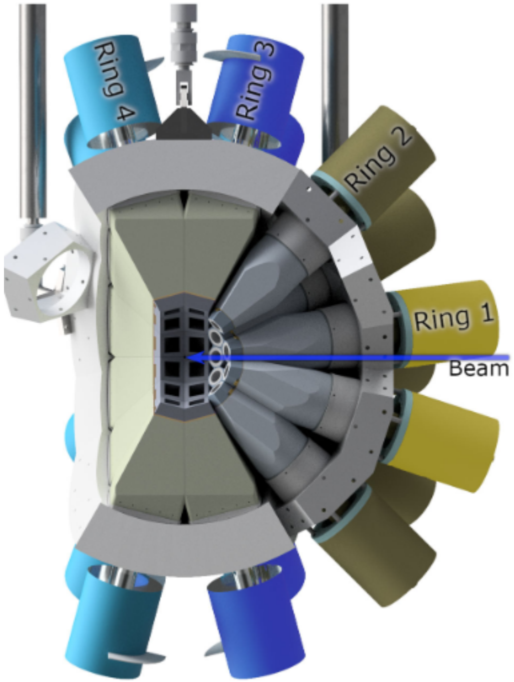


All signals time stamped by a 100 MHz clock, read out individually and digitized for complex correlation analysis with signals at target.

Experimental techniques and apparatus: In beam detectors surrounding target



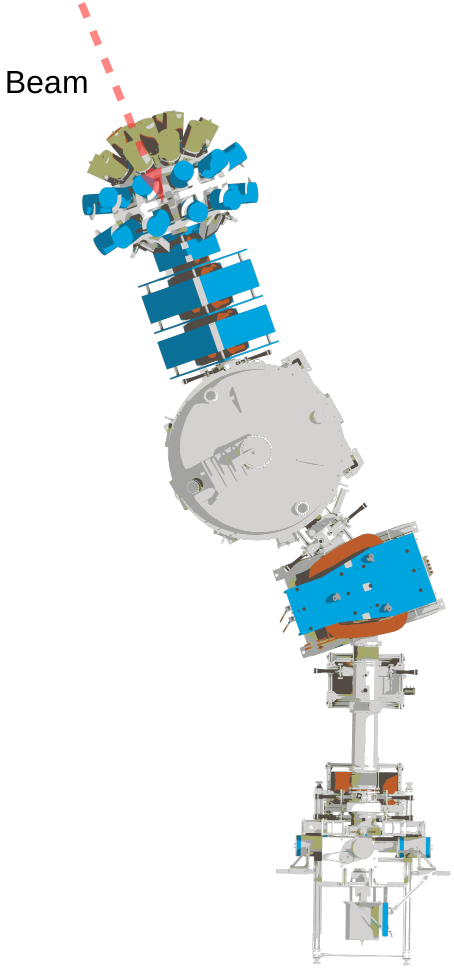
JYTube charged- particle detector:120 2mm-thick plastic scintillators read out by SiPMs
Hexagonal cylinder geometry



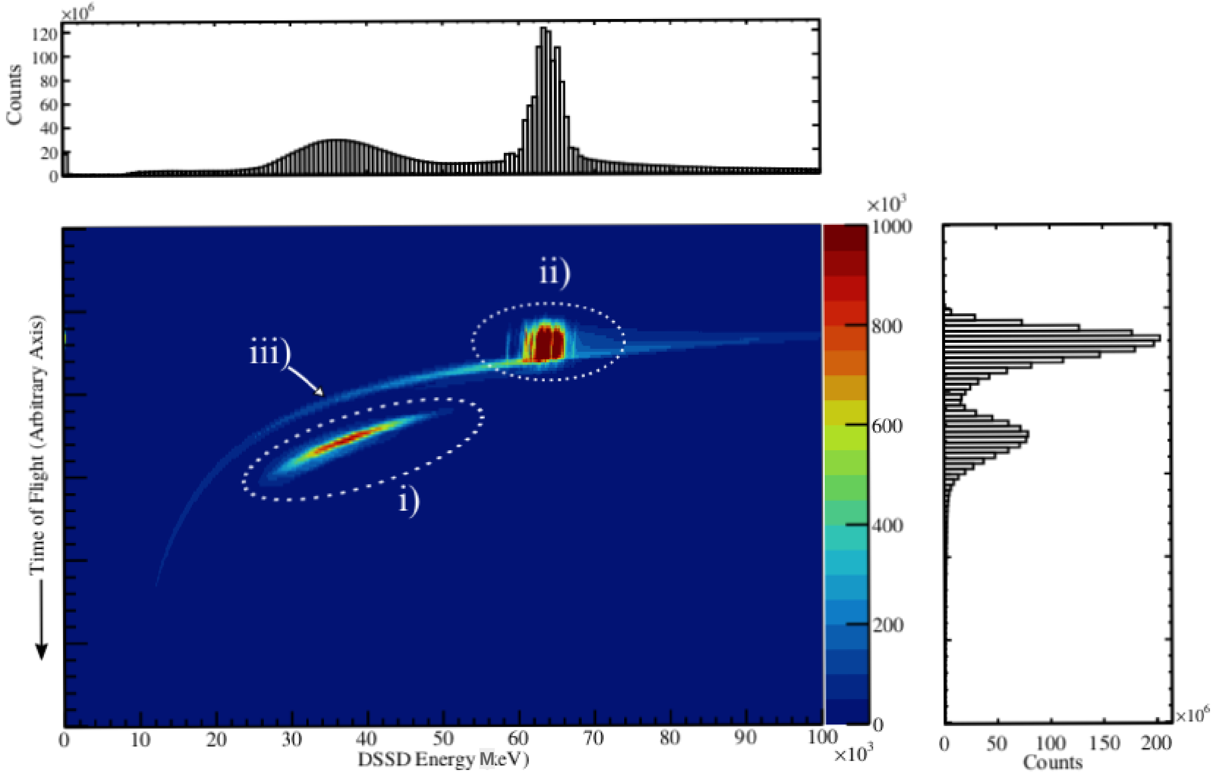
JUROGAM3 Array: 24 Clover and 16 Phase 1 Ge detectors, 4 angles

The JUROGAM 3 spectrometer

J. Pakarinen[1,a], J. Ojala[1], P. Ruotsalainen[1], H. Tann[1,2], H. Badran[1,4], T. Calverley[1,2], J. Hilton[1,2], T. Grahn[1], P. T. Greenlees[1], M. Hytönen[1], A. Illana[1], A. Kauppinen[1], M. Luoma[1,3], P. Papadakis[1,5], J. Partanen[1], K. Porras[1], M. Puskala[1], P. Rahkila[1], K. Ranttila[1], J. Sarén[1], M. Sandzelius[1], S. Szwec[1], J. Tuunanen[1], J. Uusitalo[1], G. Zimba[1]



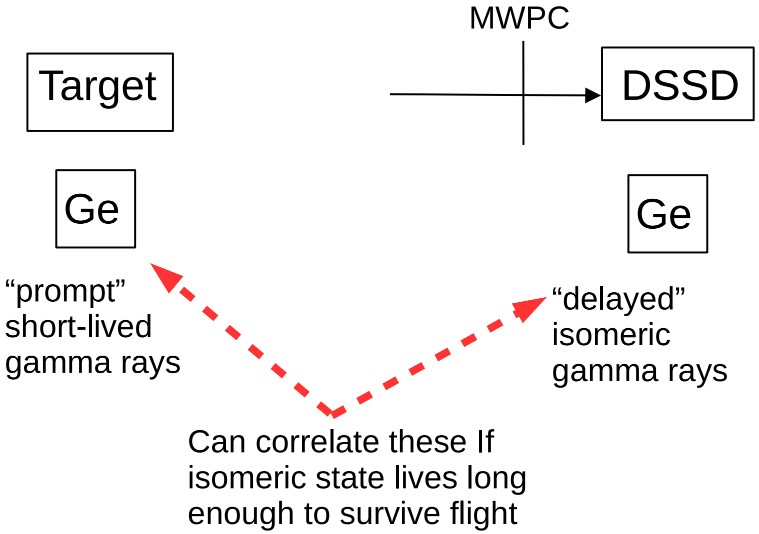
Experimental techniques and apparatus: Evaporation residue discrimination



Recoils are discriminated by:

- ToF between MWPC and DSSD
- Characterstic implantation energy in Si

Simplified isomer correlation logic:
if implantation signal at DSSD



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Results: Experimental Details

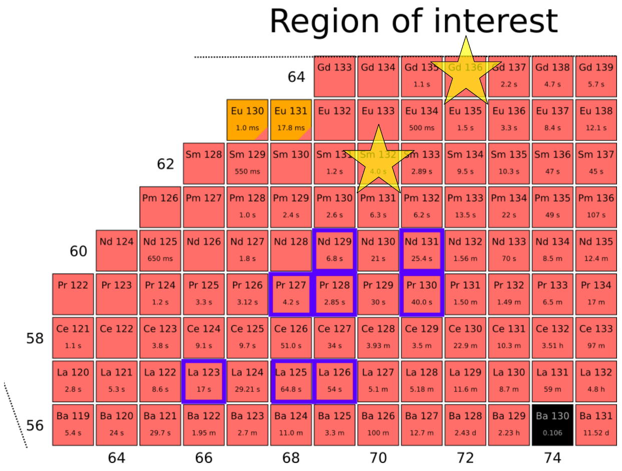
Primary goals of experiments concerned with proton decay studies with at high energies (p4n-6n channels)

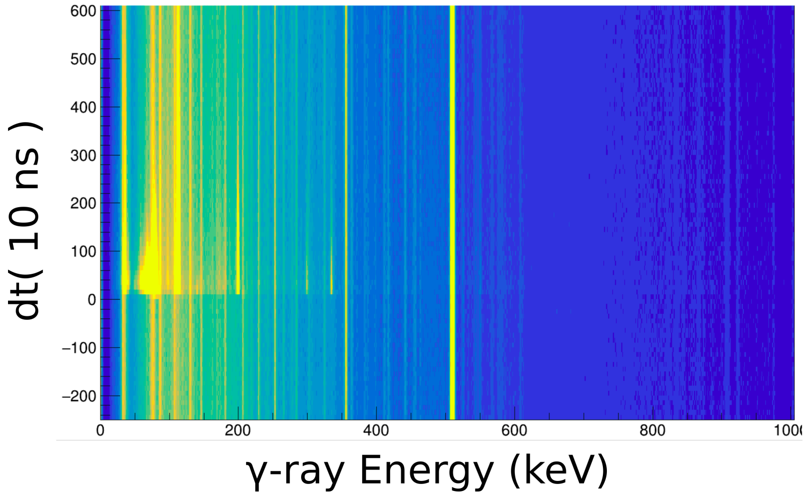
$^{78}Kr + {}^{58}Ni \rightarrow {}^{136}Gd^*$
$^{78}Kr + {}^{54}Fe \rightarrow {}^{132}Sm^*$

Inverse reactions, high transmission with MARA

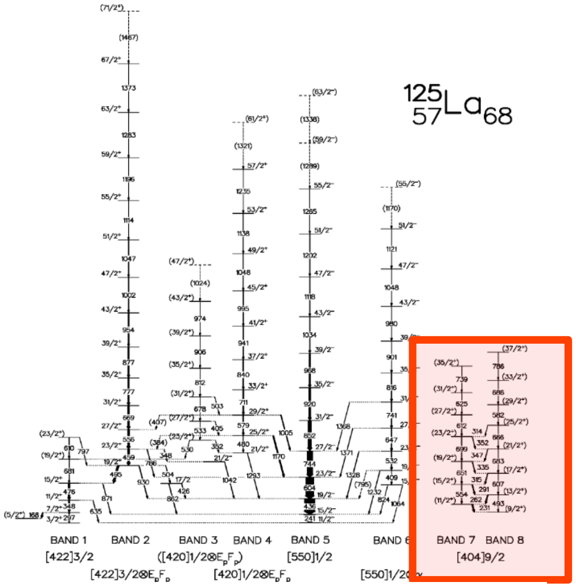
Used full FPGe array and Jurogam detectors "just in case" – free data from stronger production channels.

Identification based on in-beam ɣ rays (JYTube, & mass).





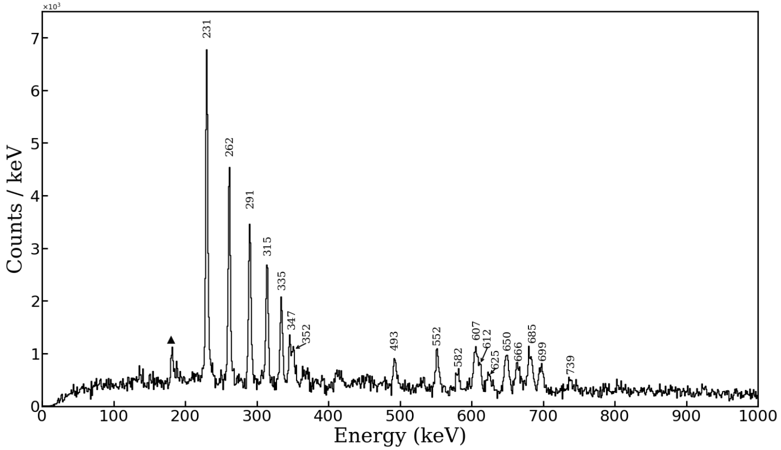
Results: ^{125}La

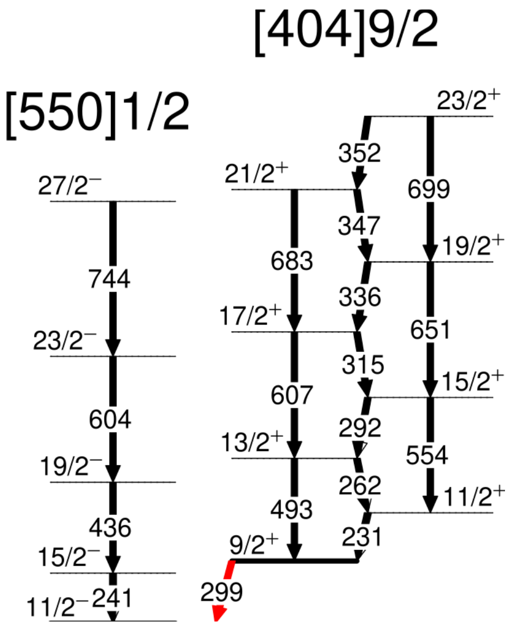


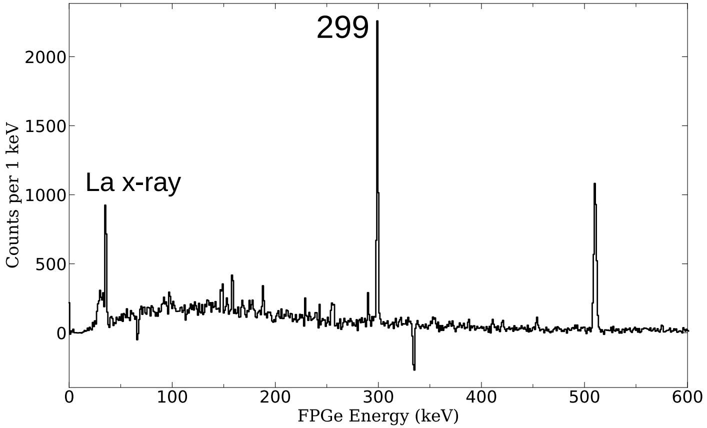
PHYSICAL REVIEW C, VOLUME 60, 014308

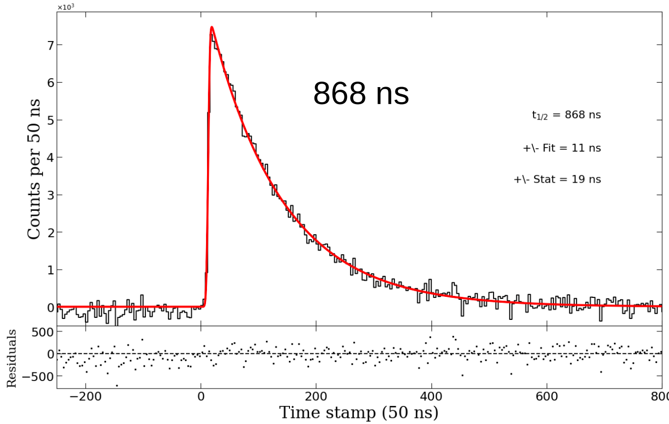
Rotational structures in ^{125}La and alignments in $A \approx 130$ nuclei

D. J. Hartley, L. L. Riedinger, H. Q. Jin,* W. Reviol, and B. H. Smith
Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996





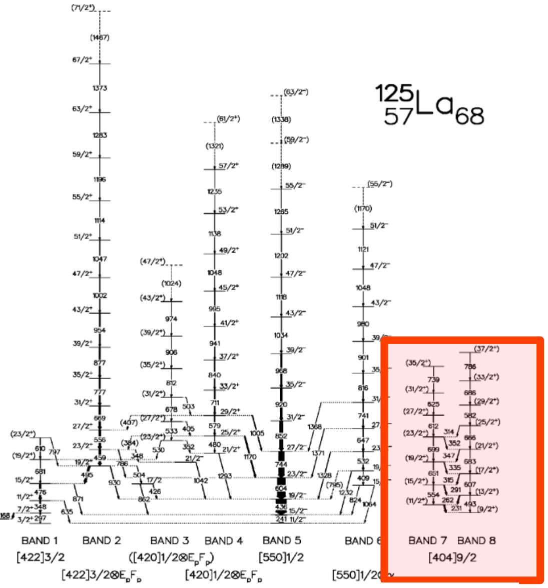




Fantastic prompt ɣ-ray spectroscopy by Hartley et al, at Lawrence Berkeley with Gammasphere.

Many bands built upon different orbitals. High-k band attributed to high-k $g_{9/2}$ floating

Results: ^{125}La



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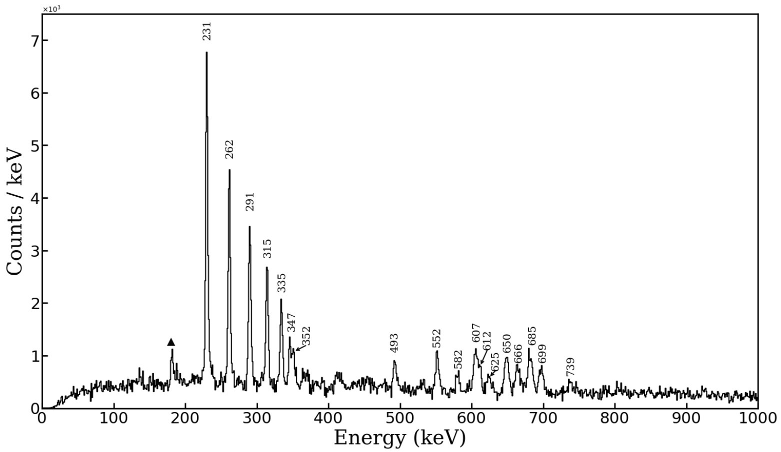


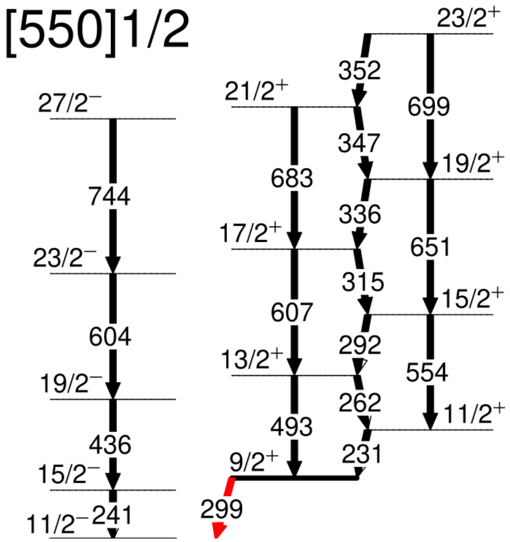
299 keV transition from $9/2^+$ to $11/2^-$

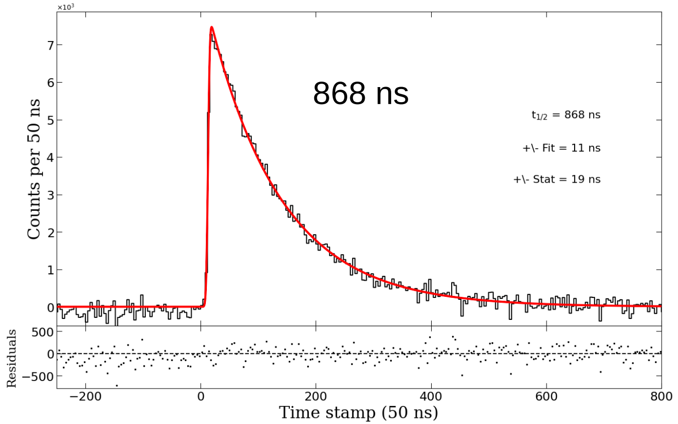
K-hindered E1

$|\Delta K| = 9/2 – 1/2 = 4$

Log(Fw) = 8.94

[404]9/2





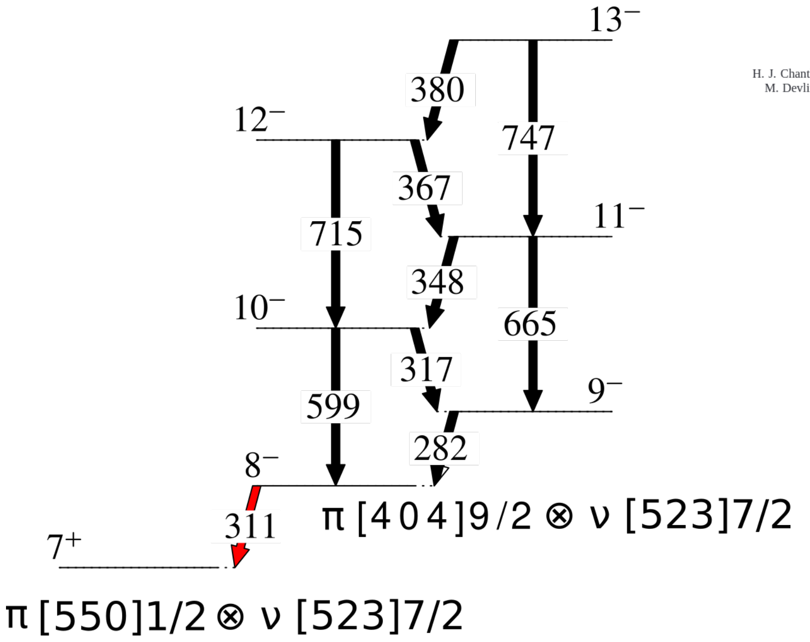
Results: ^{122}La

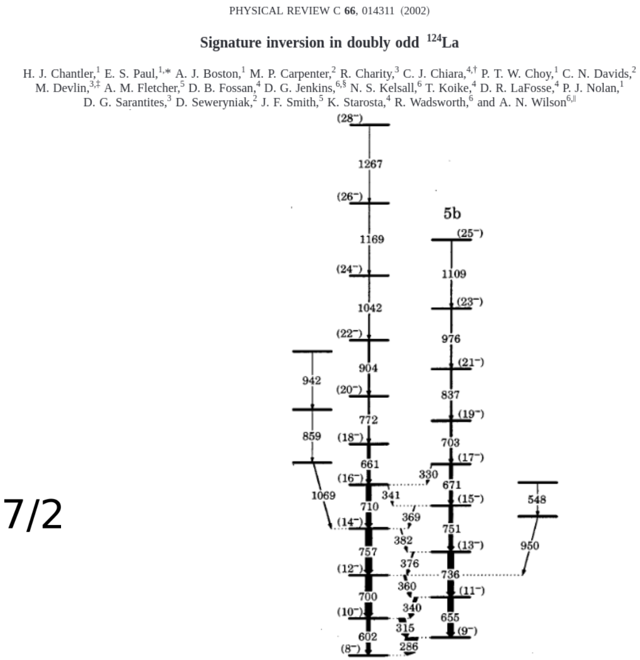
311 keV transition from 8- to 7+

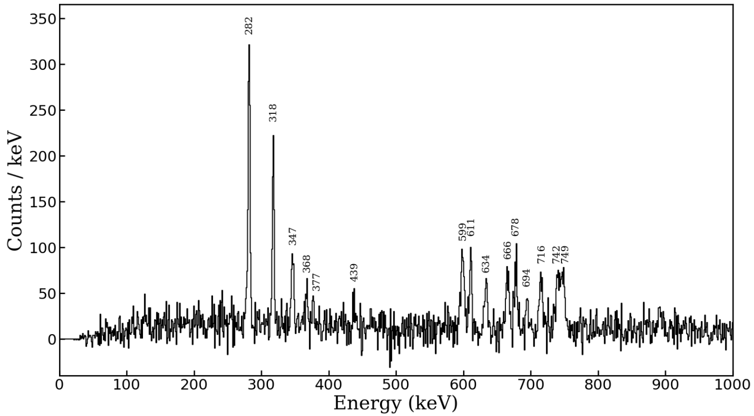
K-hindered E1

$|\Delta K| = 16/2 - 8/2 = 4$

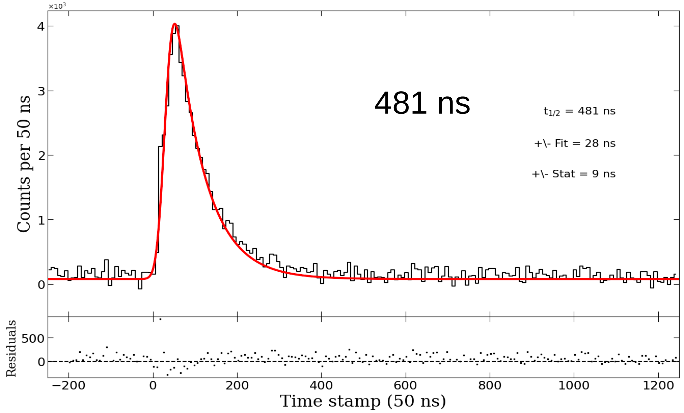
Log(Fw) = 7.73



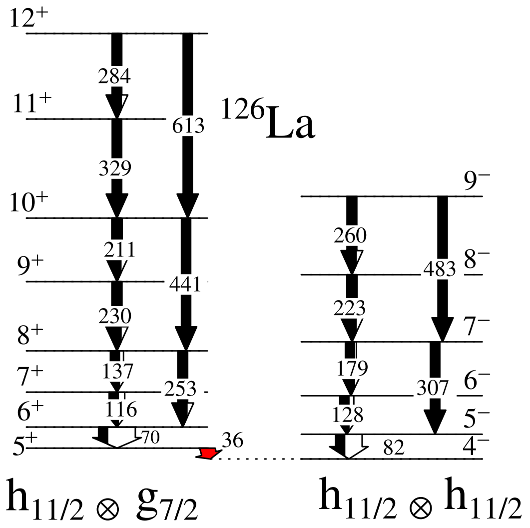


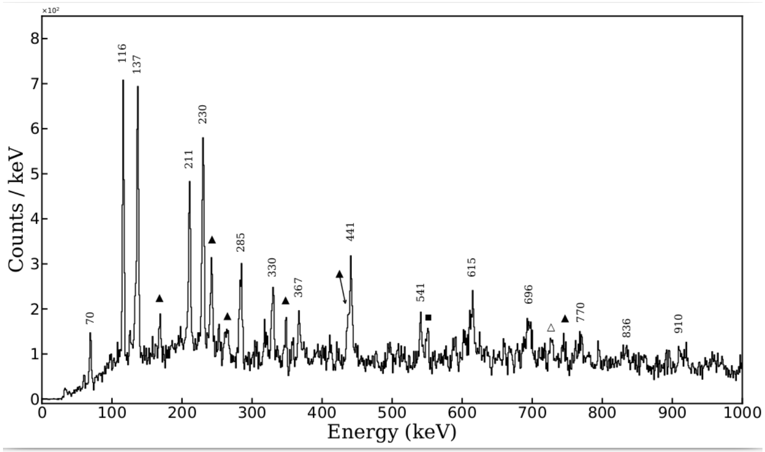


Band in ^{122}La in is new, analogous band in ^{124}La shown for reference



Results: ^{126}La



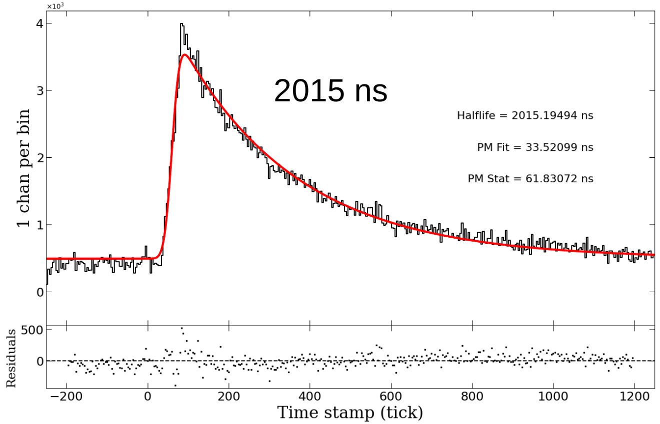


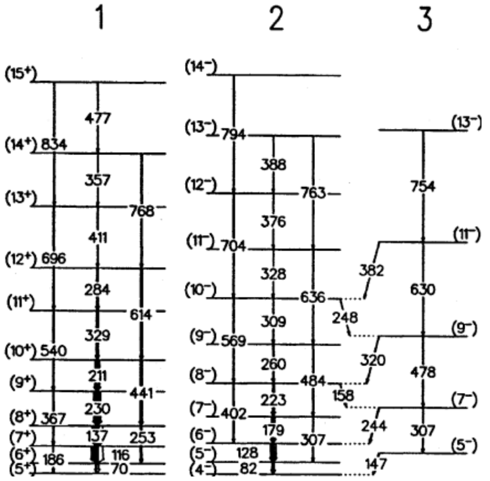
36 keV transition from 5^+ to 4^-

K-hindered E1

$|\Delta K| = 7/2 - 3/2 = 2$

Log(Fw) = 5.78



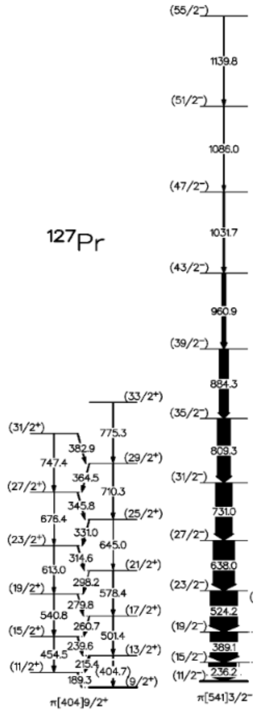


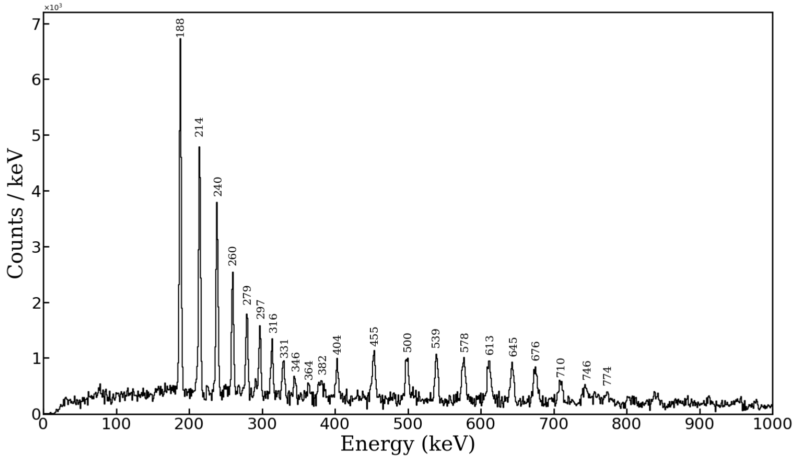
Short note

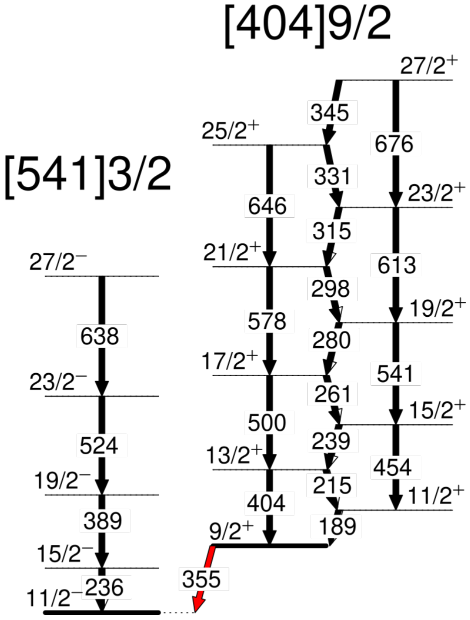
Configuration assignments and decay of ^{126}La high-spin bands

J. Timár[1,2], A. Gizon[1], P. Paris[3], J. Genevey[1], J. Gizon[1], F. Hannachi[3], C.F. Liang[3], A. Lopez-Martens[4], J.C. Merdinger[4], B.M. Nyakó[2], B. Weiss[5], L. Zolnai[2]

Results: ^{127}Pr





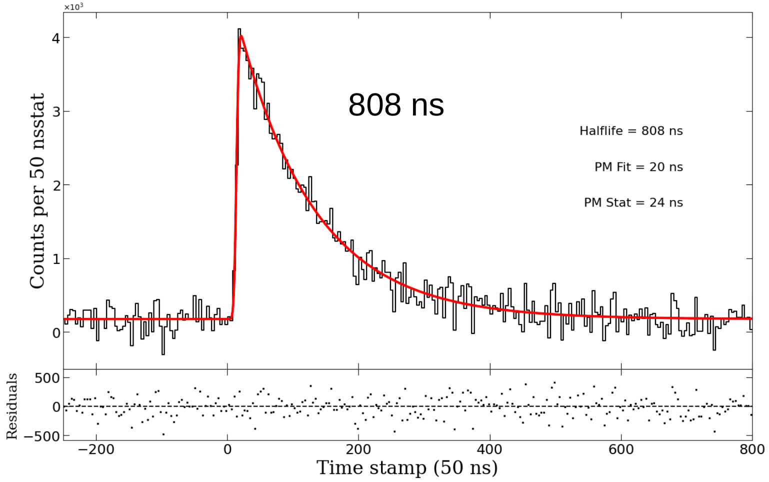


355 keV transition from 9/2$^+$ to 11/2$^-$

K-hindered E1

|ΔK| = 9/2 – 3/2 = 3

Log(Fw) = 8.06



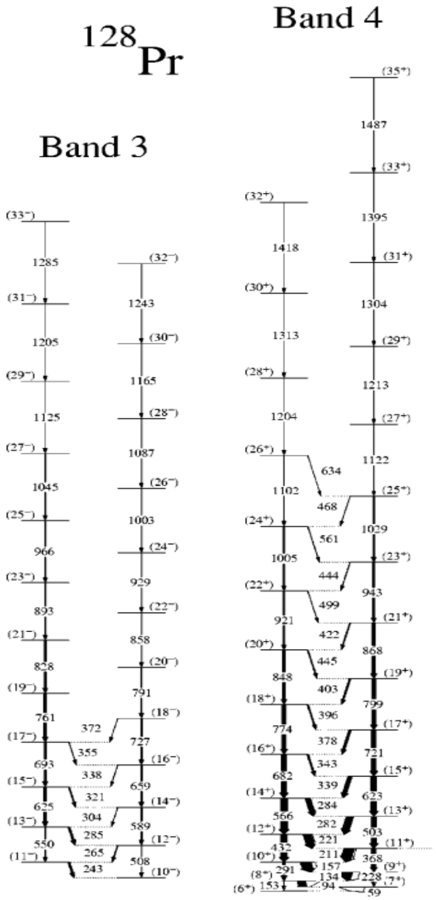
PHYSICAL REVIEW C VOLUME 58, NUMBER 5 NOVEMBER 1998

Extruder proton-hole band in the near-drip-line nucleus ^{127}Pr

S. M. Mullins,[1] A. Galindo-Uribarri,[2,*] C. E. Svensson,[3] R. A. E. Austin,[3,†] G. C. Ball,[2,‡] M. Cromaz,[4,§] V. P. Janzen,[2] D. C. Radford,[2,*] I. Ragnarsson,[5] J. C. Waddington,[3] and D. Ward[2,§]

Similar story. High-k band attributed to high-k $g_{9/2}$ floating

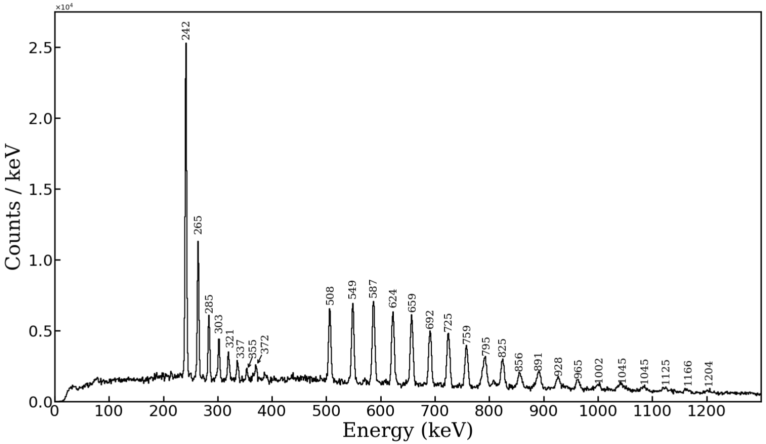
Results: ^{128}Pr

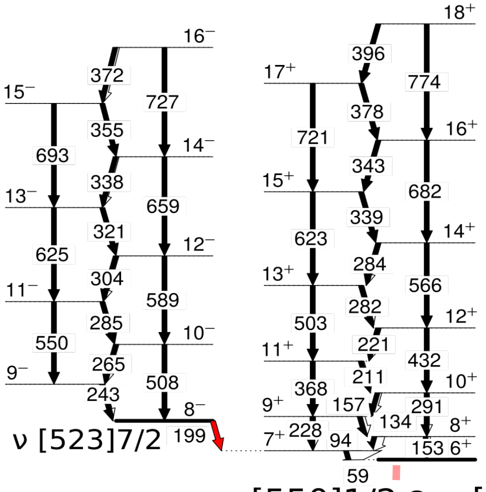


PHYSICAL REVIEW C, VOLUME 65, 054324

Observation of a doublet band in the nucleus ^{128}Pr

C. M. Petrache,[1] G. Lo Bianco,[1] D. Bazzacco,[2] S. Lunardi,[2] R. Menegazzo,[2] M. Nespolo,[2] G. de Angelis,[3] N. Blasi,[4] V. I. Dimitrov,[5] S. Frauendorf,[5] P. Semmes,[6] and Jing-ye Zhang[7]





π [4 0 4]9/2 ⊗ ν [523]7/2

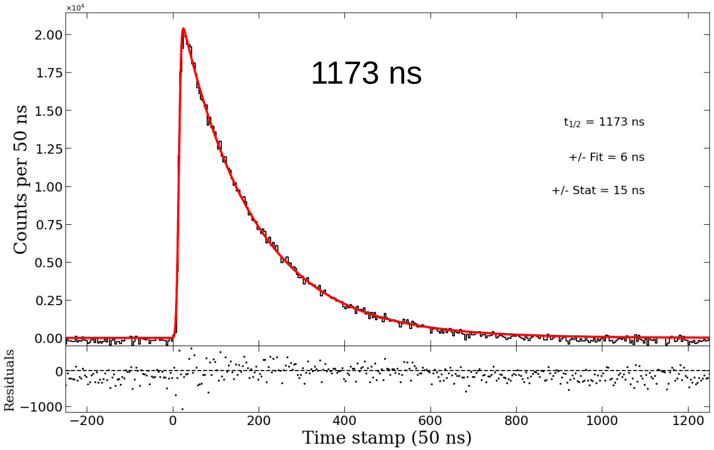
π [550]1/2 ⊗ ν [523]7/2

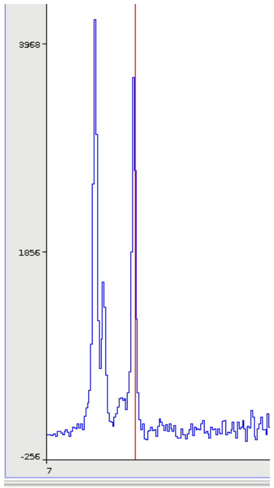
119 keV transition from 8- to 7+

K-hindered E1

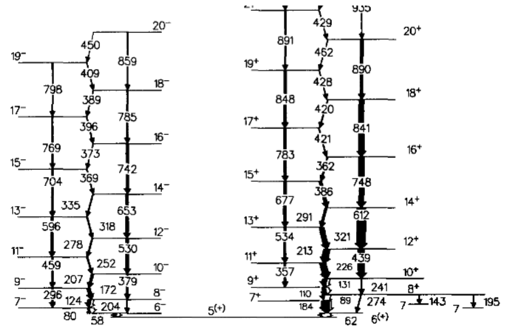
|ΔK| = 16/2 – 8/2 = 4

Log(Fw) = 7.56

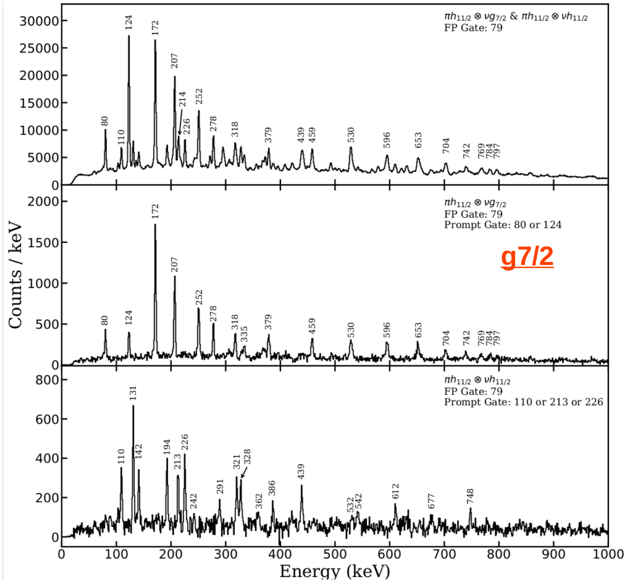




Results: ^{130}Pr


Detailed spectroscopy and IBFFM interpretation of the odd–odd nuclei ^{132}Pr and ^{130}Pr

C.M. Petrache [a,1], S. Brant [b], D. Bazzacco [a], G. Falconi [a], E. Farnea [c], S. Lunardi [a], V. Paar [b], Zs. Podolyák [c,2], R. Venturelli [a], D. Vretenar [b]



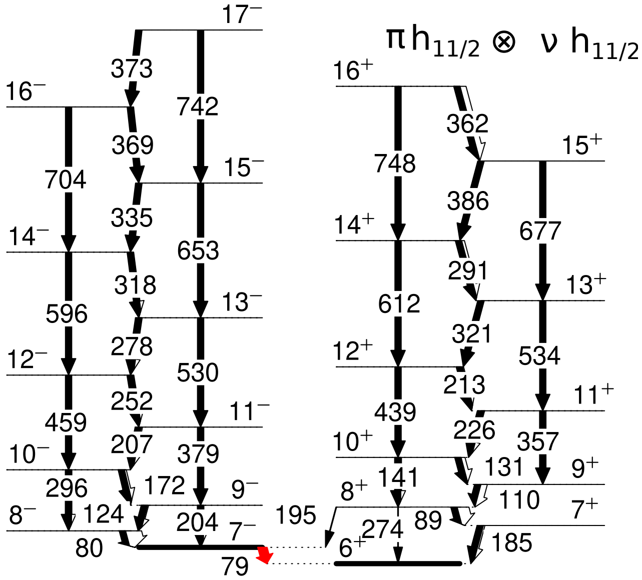
^{130}Pr

$\pi\ h_{11/2} \otimes \nu\ g_{7/2}$

Band 1

Band 2

$\pi h_{11/2} \otimes\ \nu\ h_{11/2}$

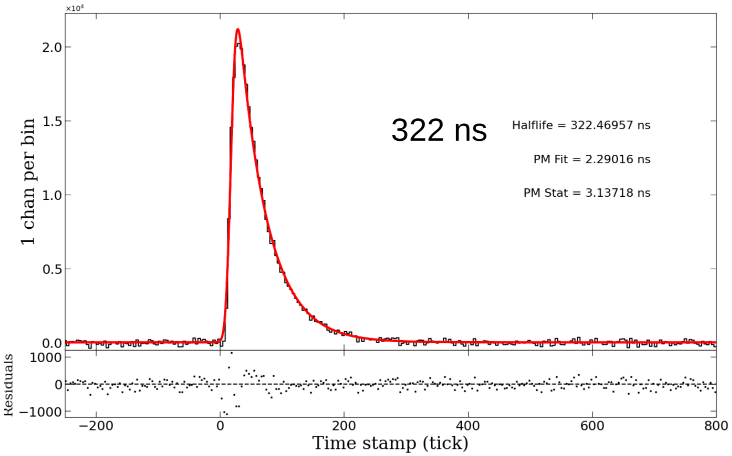


79 keV transition from 7⁻ to 6+

K-hindered E1

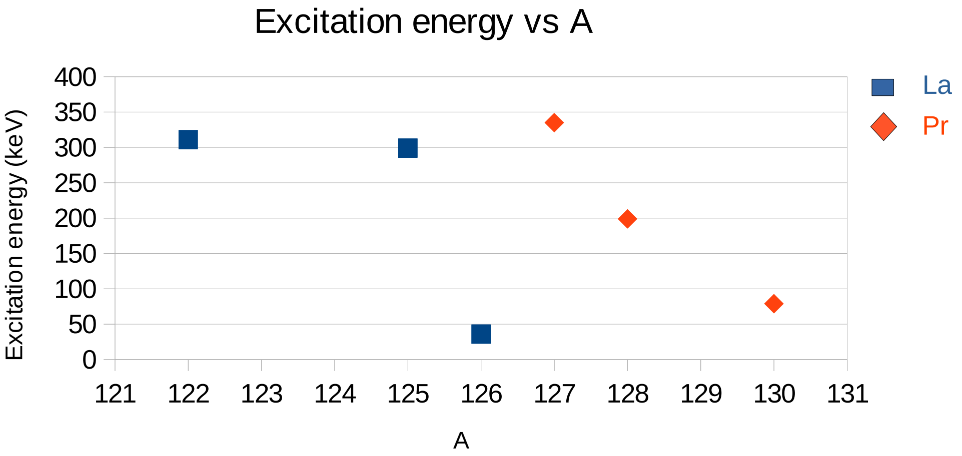
$|\Delta K| = 7/2 – 3/2 = 2$

Log(Fw) = 5.95

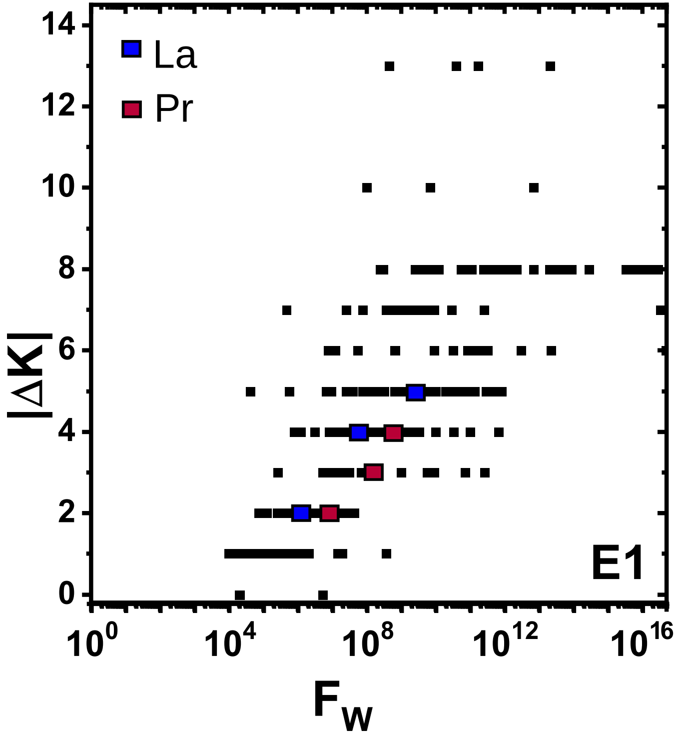


Results: Hindrance Values for SQP K Isomers

Isotope	E(gamma) [keV]	T1/2 [ns]	W.E. (E1)	Tot conv.	LogFw	ΔK
122La	311	481	9.05E-15	0.011	7.73	4
125La	299	868	1.01E-15	0.012	8.94	5
126La	37	2015	5.31E-12	0.59	5.78	2
127Pr	335	808	7.09E-15	0.01	8.06	4
128Pr	199	1173	3.36E-14	0.038	7.56	3
130Pr	79	323	5.32E-13	0.48	5.95	2



Data spans broad mass region,
(A > 100)



K Isomers in Transuranium Nuclei

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[1]GSI - Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany
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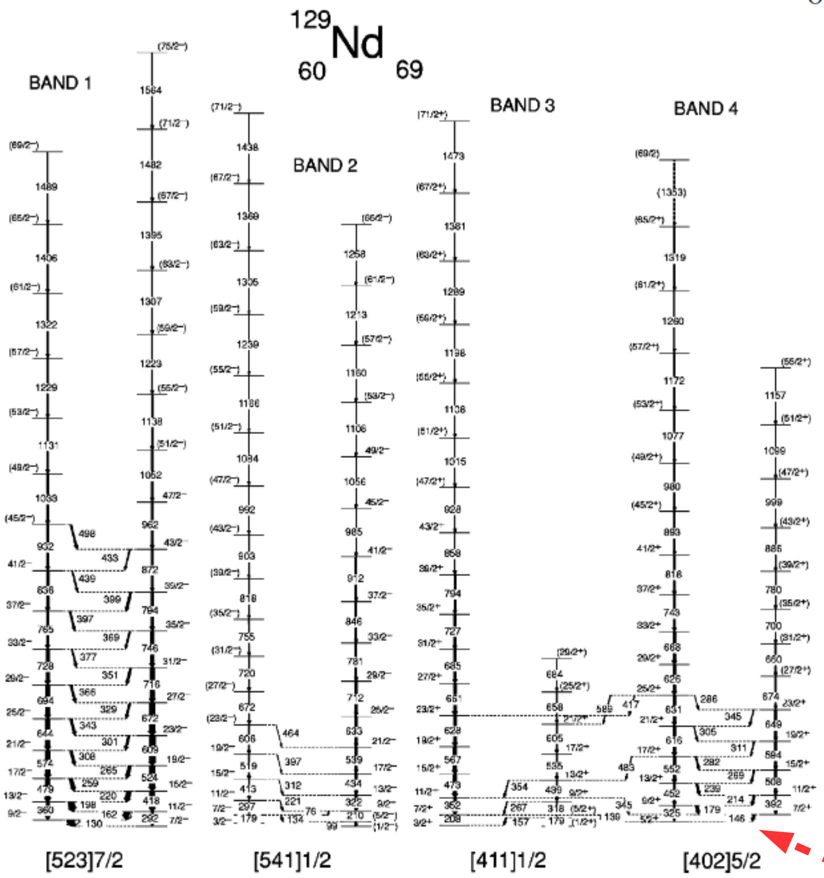
Version: September, 19, 2023

Results: ^{129}Nd previous study

PHYSICAL REVIEW C, VOLUME 65, 024303

Rotational structures in ^{129}Nd and signature splitting systematics of the $\nu h_{11/2}$ bands in $A\sim130$ nuclei

O. Zeidan, D. J. Hartley, L. L. Riedinger, M. Danchev,* W. Reviol,† W. D. Weintraub,‡ and Jing-ye Zhang
Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996



^{94}Mo(^{40}Ca,2pn)^{129}Nd
Gammasphere, Microball

Beautiful example of rotational structure built on high- and low-K orbitals

Positive and negative parity structures remain separate

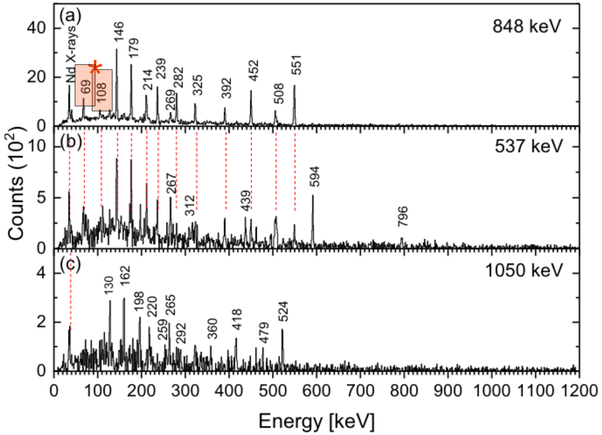
[402]5/2+ band head adopted as beta-decaying ground state

Results: ^{129}Nd multi-quasiparticle isomer

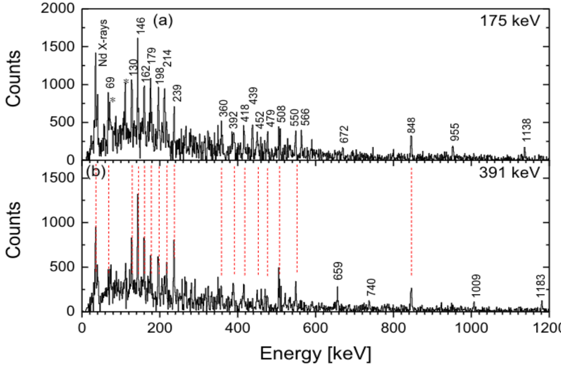
PHYSICAL REVIEW C **108**, 014317 (2023)

High-*K* three-quasiparticle isomers in the proton-rich nucleus ^{129}Nd

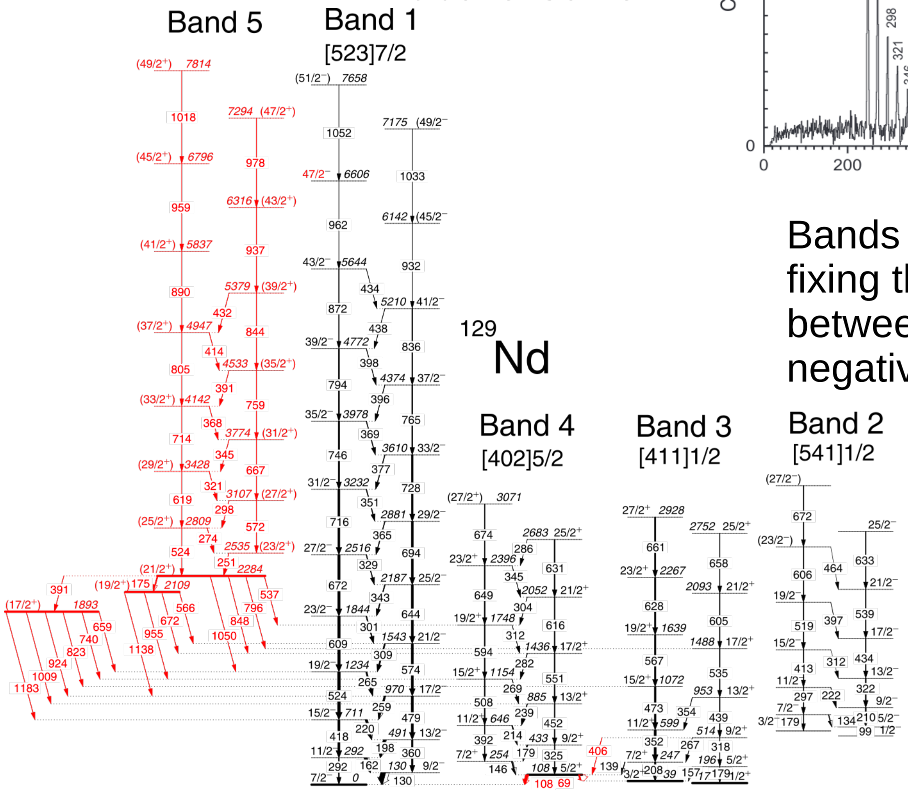
C. M. Petrache, J. Uusitalo, A. D. Briscoe, C. M. Sullivan, D. T. Joss, H. Tann, Ö. Aktas, B. Alayed, M. A. M. Al-Aqeel, A. Astier, H. Badran, B. Cederwall, C. Delafosse, A. Ertoprak, Z. Favier, U. Forsberg, W. Gins, T. Grahn, P. T. Greenlees, X. T. He, J. Heery, J. Hilton, S. Kalantan, R. Li, P. M. Jodidar, R. Julin, S. Juutinen, M. Leino, M. C. Lewis, J. G. Li, Z. P. Li, M. Luoma, B. F. Lv, A. McCarter, S. Nathaniel, J. Ojala, R. D. Page, J. Pakarinen, P. Papadakis, E. Parr, J. Partanen, E. S. Paul, P. Rahkila, P. Ruotsalainen, M. Sandzelius, J. Sarén, J. Smallcombe, J. Sorri, S. Szwec, L. J. Wang, Y. Wang, L. Waring, F. R. Xu, J. Zhang, Z. H. Zhang, K. K. Zheng, and G. Zimba

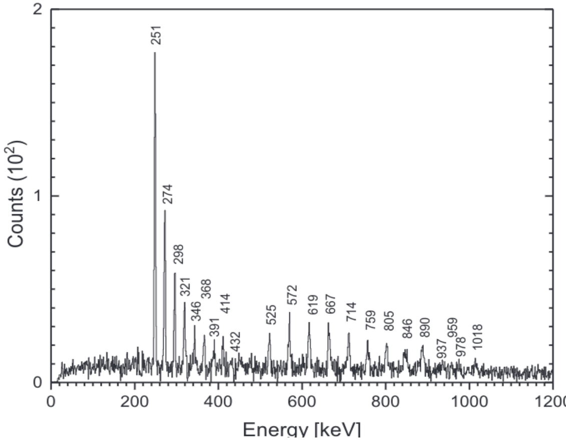


γ-γ coincidence analysis of transitions depopulating the isomer



High-K strongly coupled band above isomer

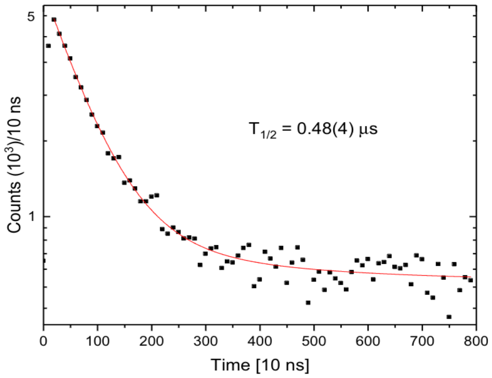


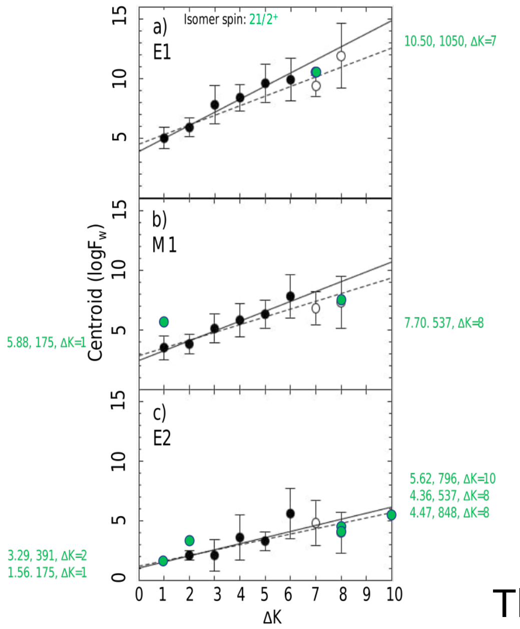


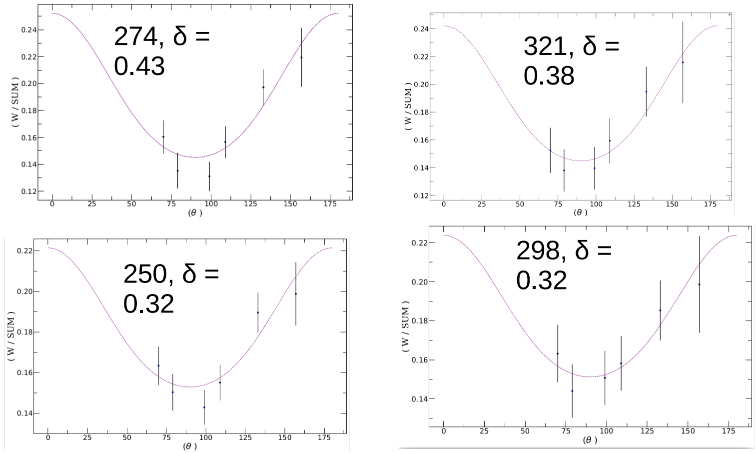
Bands 1, 4 and 3 are fed, fixing the relative energies between positive and negative parity structures

* FP Ge coincidences reassign β-decaying ground state as 7/2$^-$ (band 1)

Results: ^{129}Nd interpreting the isomer(s)







Extracted hindrance factors:

$F_W = t_{1/2}^{exp} / t_{1/2}^{Weis}$

are consistent with systematics

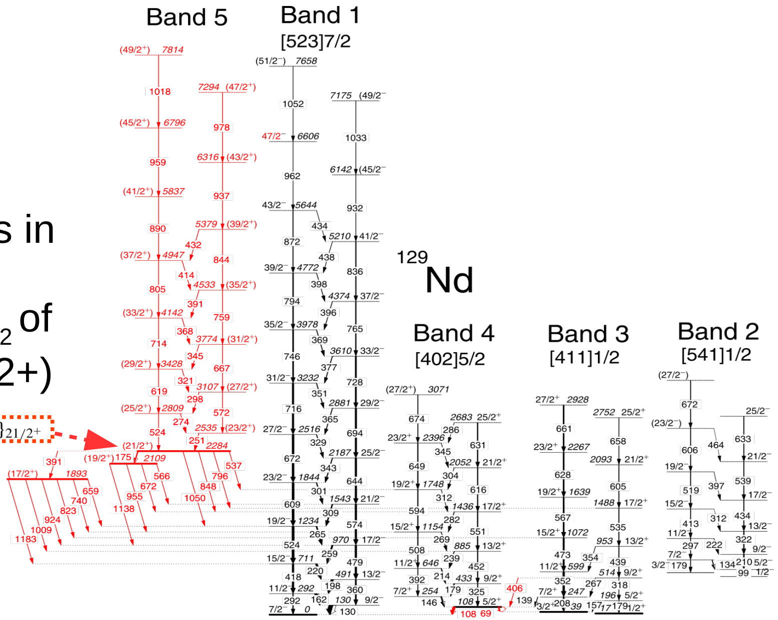
E_γ (keV)[a]	$I_i^\pi \rightarrow I_f^\pi$	T_γ[b]	log F_W
Decay out from the 21/2$^+$ isomer			
175.3	$(21/2^+) \rightarrow (19/2^+)$	15(2)	1.56(7)
391.0	$(21/2^+) \rightarrow (17/2^+)$	20(2)	3.29(8)
536.7	$(21/2^+) \rightarrow 19/2^+$	3(1)	7.70(2)
796.0	$(21/2^+) \rightarrow 17/2^+$	6(1)	5.62(18)
847.8	$(21/2^+) \rightarrow 17/2^+$	49(3)	4.47(5)
1049.8	$(21/2^+) \rightarrow 19/2^-$	7(1)	10.50(9)

Three isomers in cascade (not sensitive to $t_{1/2}$ of 19/2$^+$ and 17/2+)

21/2$^+$ $\{\nu 7/2^-[523] \otimes \pi(9/2^+[404]5/2^-[532])\}_{21/2^+}$

19/2$^+$ $\nu 5/2^+[402] \otimes \pi(9/2^+[404]5/2^+[413])$

17/2$^+$ $\nu 7/2^-[523] \otimes \pi(5/2^+[413]5/2^-[532])$



Summary

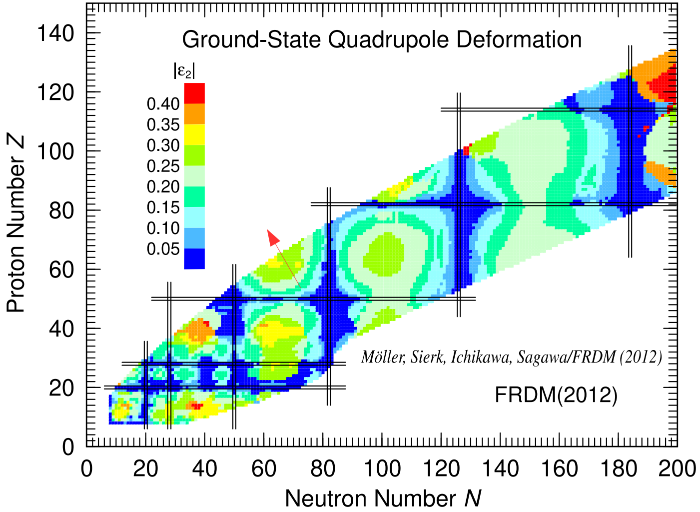
Many single QP K-isomers observed in highly deformed A=130 region, in most cases extruding high K components of $\pi g_{9/2}$ orbital driving the properties of these decays.
Publication in progress for the near future.

This emphasises the superb quality of in-beam studies that previously assigned these bands, confirms high-K nature of these structures.

Extracted F_w values of 10^6-10^9 for K-hindered E1 transitions agree well with systematics of K-isomers in other mass region(s).

Multi-particle $21/2^-$ K-isomer observed in ^{129}Nd, first example of this kind built on high-K $g_{9/2}$ orbital

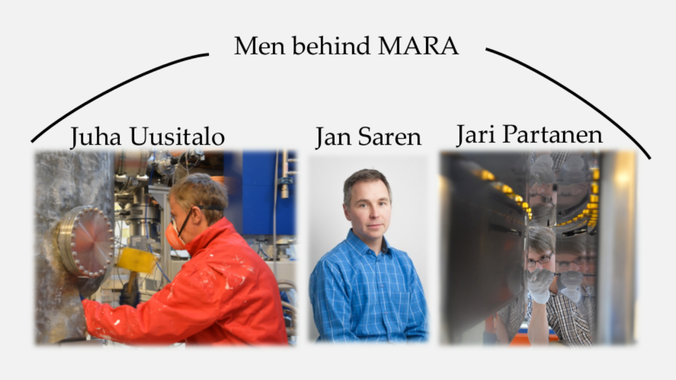
Moving further from stability larger deformations are expected in the region, new ground for future discovery.



thanks for listening

Thanks to my many valued collaborators!

<u>A. D. Briscoe, J. Uusitalo,</u> C. M. Sullivan, D. T. Joss, H. Tann, C. Petrache, Ö. Aktas, B. Alayed, M. A. M. Al-Aqeel, K. Auranen, A. Astier, H. Badran, V. Bogdanoff, B. Cederwall, C. Delafosse, A. Ertoprak, Z. Favier, U. Forsberg, W. Gins, T. Grahn, P. T. Greenlees, J. Heery, J. Hilton, A. Illana, S. Kalantan, R. Li, P. M. Jodidar, H, Joukainen, H, Jutila, R. Julin, S. Juutinen, J. Louko, M. Leino, M. C. Lewis, M. Luoma, B. F. Lv, A. McCarter, S. Nathaniel, J. Ojala, R. D. Page, J. Pakarinen, P. Papadakis, E. Parr, J. Partanen, E. S. Paul, P. Rahkila, P. Ruotsalainen, M. Sandzelius, J. Sarén, J. Smallcombe, J. Sorri, S. Szwec, A. Tolosa, L. J. Waring, K. K. Zheng, E. Uuikyla, and G. Zimba



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Back up slides next

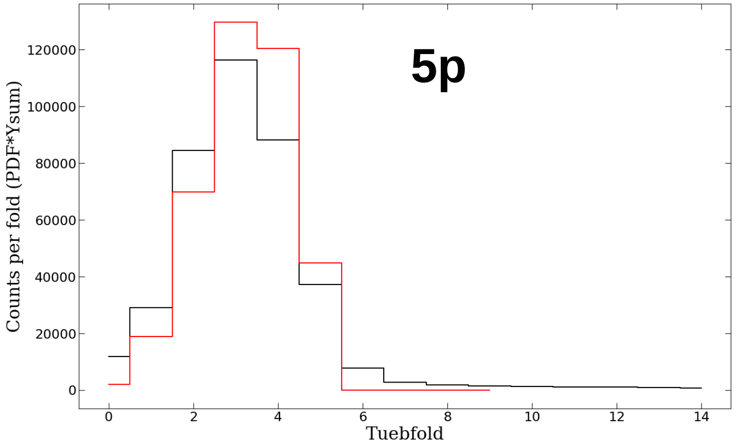
^{125}La, example ID

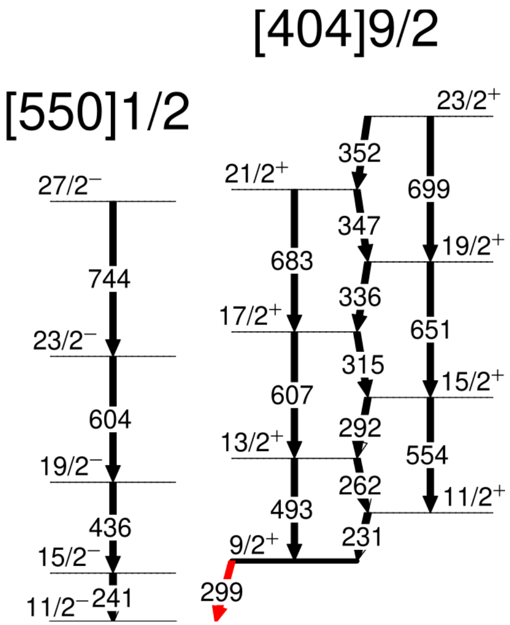
Measure JYTube efficiency for single proton (≈65 %).

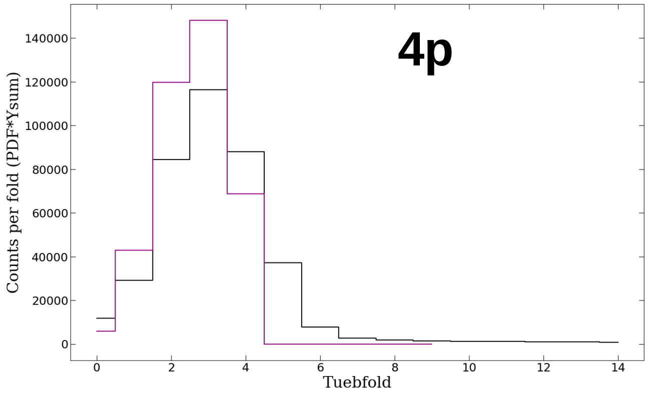
Calculated binomial reference distribution for numbers to compare with experiment

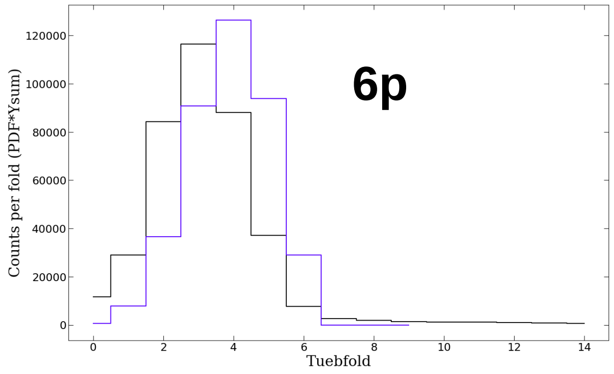
Gives evaporated number of protons → Z of species

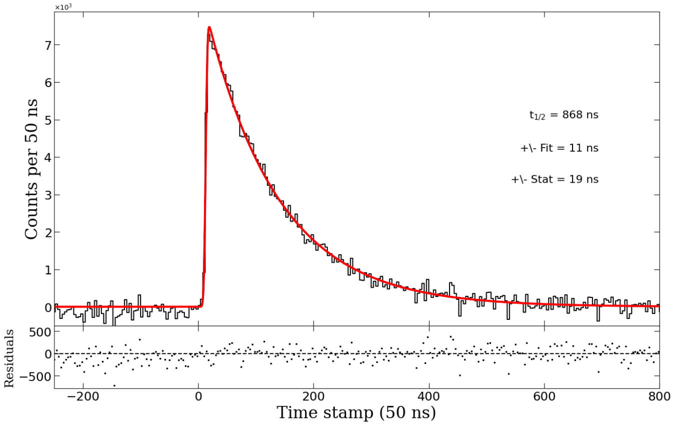
Consistent with La (from Gd compound)











Mixing ratio equations

$$A_k^{max}(J_i L_1 L_2 J_f) = \frac{1}{1+\delta^2}\{f_k(J_f L_1 L_1 J_i) + 2\delta f_k(J_f L_1 L_2 J_i) + \delta^2 f_k(J_f L_2 L_2 J_i)\},$$

```python
def W_theta_oneparam( theta,  delta):
        theta = theta*np.pi / 180
        c1 = -0.2826
        c2 = 1.0032
        c3 = -0.1050
        c4 = 0
        c5 = 0
        c6 = 0.5186
        A2 = (1 / (1 + delta**2) )*(c1  +2*delta*c2   + (delta**2)*c3     )
        A4 = (1 / (1 + delta**2) )*( c4+2*delta*c5  + (delta**2)*c6     )

        return 0.17197802*(( 1 + ((A2)*0.5*(3*((np.cos(theta))**2) - 1))   + (A4)*0.125*(35*(np.cos(theta))**4 - 30*np.cos(theta)**2 + 3 )))
```

TABLES OF COEFFICIENTS FOR ANGULAR DISTRIBUTION OF GAMMA RAYS FROM ALIGNED NUCLEI

$$\frac{\delta^2}{1+\delta^2} = \frac{2K^2(2I-1)}{(I+1)(I-1+K)(I-1-K)}\frac{E_1^5}{E_2^5}\frac{T_2}{T_1}, \quad (1)$$