Branching ratios from a Triaxial Superdeformed "β-band" in ^{162}Yb

R.A. Bark[1], C. Fransen[2], A.N. Andreyev[3], N. Bernier[4], M.G. Borge[5], D. Bucher[6], J.C. Cubiss[3], F. Dunkel[2], L. Gaffney[7], J. Gerl[8], K. Hadyńska-Klęk[9], H. Hess[2], R. Hirsch[2], E. Ince[9], M. Jafta[4], J. Jolie[2], P. Jones1, T. Kröll[11], C.-D. Lakenbrink[2], E. Lawrie[1], J.J. Lawrie[1], Z. P. Li[12], S. Majola[13], B.O. Mampaso[5], C. Mehl[4], S.M. Mullins[14], C. Müller-Gatermann[15], P.J. Napiorkowski[9], C. Ngwetsheni[4], S. Ntshangase[16], G. O'Neill, N. Orce[4], C. Page[3], J. Pakarinen[17], N. Pietralla[11], L. Pellegri[1], P. Reiter[2], A. Ilana[18] J. Srebrny[9], M. Stryjczyk[17], J.F.Sharpey-Schafer[16], F. von Spee[2], N. Warr[2], K. Wrzosek-Lipska[9], M. Wiedeking[1], Z. Yue[3] and S.Q. Zhang[19]

INTC-P-725

This proposal is for the second of two experiments to test whether the "β-band" in ^{162}Yb is actually a triaxial-superdeformed band.

The first experiment has been approved:

INTC-P-708

Coulomb Excitation and RDDS measurement of a Triaxial Superdeformed "β-band" in ^{162}Yb

Physics Motivation:

Studying the origin of 0_2^+ bands in mass 160 region

β vibrations?
shape coexistence?
"pairing isomers" – "second vacuum"?
X(5)….?

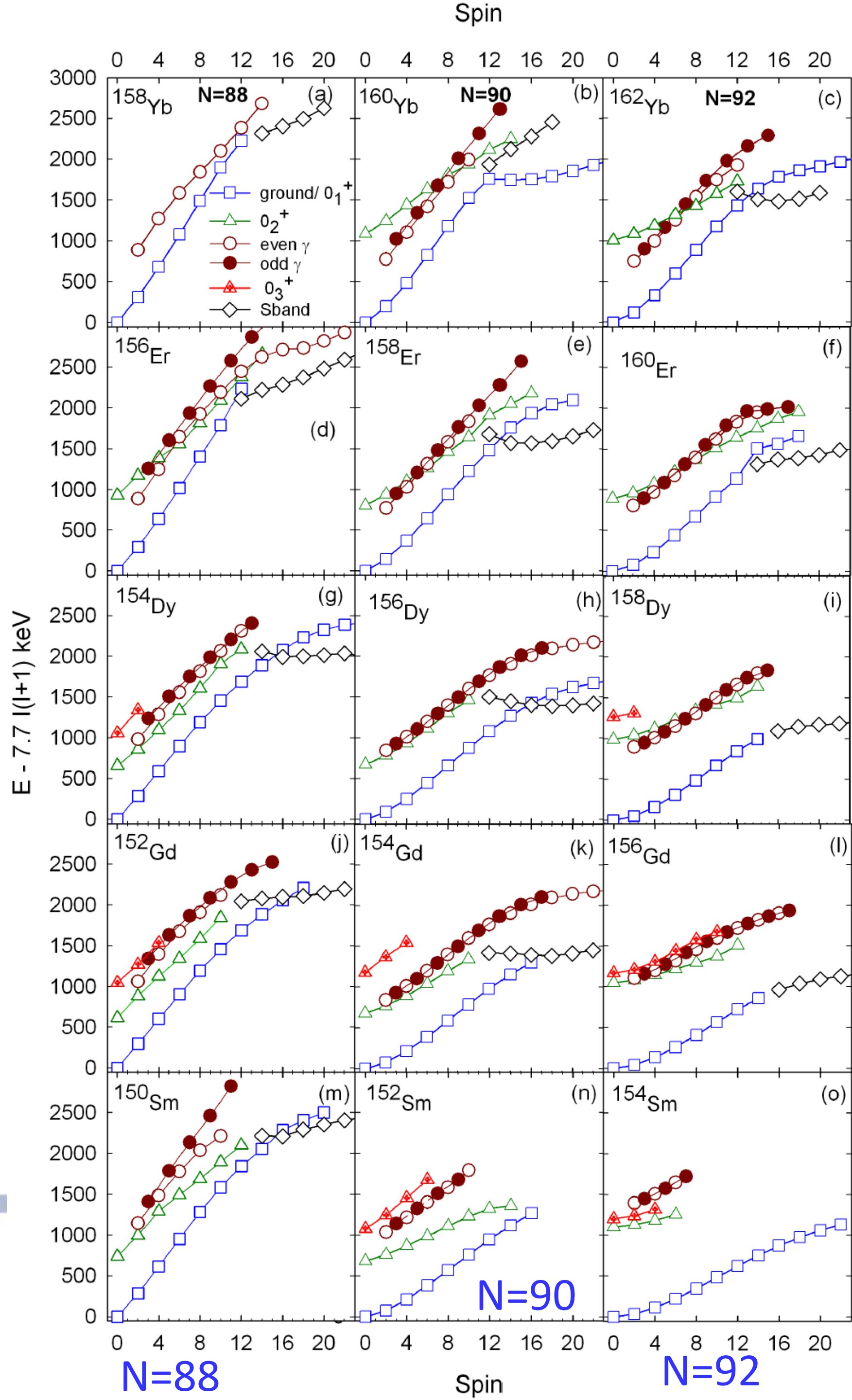
Energy Systematics

PHYSICAL REVIEW C **100**, 044324 (2019)

β and γ bands in $N = 88$, 90, and 92 isotones investigated with a five-dimensional collective Hamiltonian based on covariant density functional theory: Vibrations, shape coexistence, and superdeformation

S. N. T. Majola,[1,2,3,4] Z. Shi,[5] B. Y. Song,[6] Z. P. Li,[6] S. Q. Zhang,[7] R. A. Bark,[2] J. F. Sharpey-Schafer,[8] D. G. Aschman,[4]

- ○ ground band
- △ β band
- ● ○ γ band
- □ 0_3^+ band
- ◇ S-band



- γ-band almost always parallel to ground band
- β-band not always parallel, especially in Er and Yb nuclei

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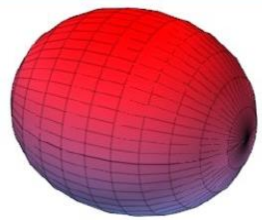
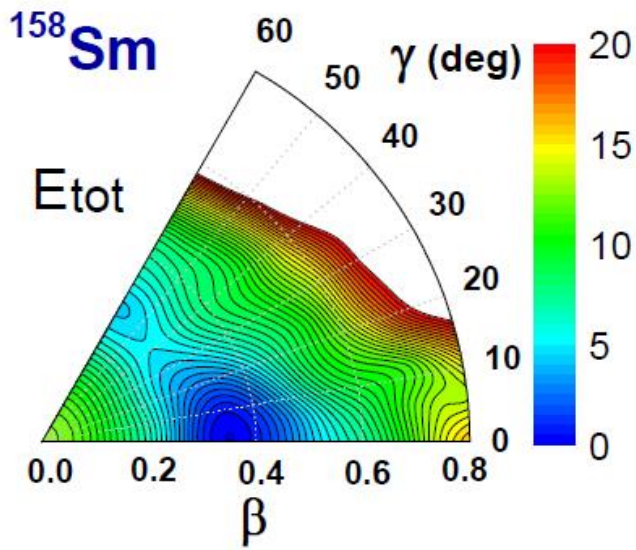
The vibrating nucleus





Vibrating Liquid drop

The Bohr Hamiltonian

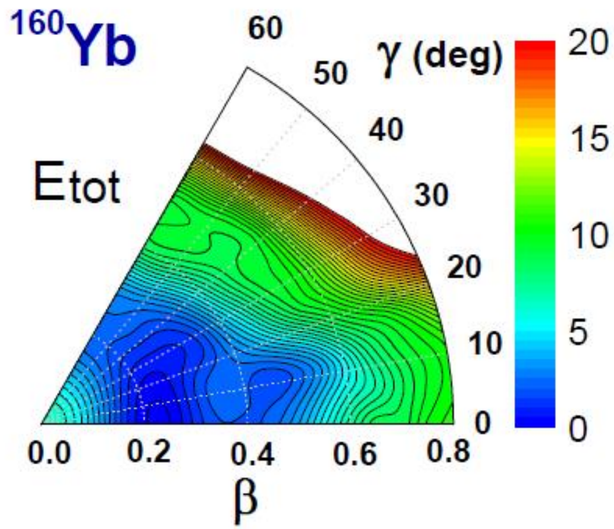
The differential Bohr equation with

$$H = -\frac{\hbar^2}{2\boxed{B}}\left[\underbrace{\frac{1}{\beta^4}\frac{\partial}{\partial\beta}\beta^4\frac{\partial}{\partial\beta} + \frac{1}{\beta^2\sin 3\gamma}\frac{\partial}{\partial\gamma}\sin 3\gamma\frac{\partial}{\partial\gamma}}_{T_{vib}} \underbrace{- \frac{1}{4\beta^2}\sum_{\kappa}\frac{Q_\kappa^2}{\sin^2(\gamma - \frac{2}{3}\pi\kappa)}}_{T_{rot}}\right] + \boxed{V(\beta,\gamma)}$$

T_{vib}

T_{rot}

In reality:
Complicated Potential Energy Surfaces



The Bohr Hamiltonian

The differential Bohr equation with

$$H = -\frac{\hbar^2}{2B}\left[\frac{1}{\beta^4}\frac{\partial}{\partial\beta}\beta^4\frac{\partial}{\partial\beta} + \frac{1}{\beta^2 \sin 3\gamma}\frac{\partial}{\partial\gamma}\sin 3\gamma\frac{\partial}{\partial\gamma} - \frac{1}{4\beta^2}\sum_{\kappa}\frac{Q_\kappa^2}{\sin^2(\gamma - \frac{2}{3}\pi\kappa)}\right] + V(\beta,\gamma)$$

T_{vib}

T_{rot}

Re-cast Bohr Hamiltonian: 5 Dimensional Collective Hamiltonian

$$\hat{H} = \hat{T}_{\text{vib}} + \hat{T}_{\text{rot}} + V_{\text{coll}}$$

$$\hat{T}_{\text{vib}} = -\frac{\hbar^2}{2\sqrt{wr}}\left\{\frac{1}{\beta^4}\left[\frac{\partial}{\partial\beta}\sqrt{\frac{r}{w}}\beta^4 B_{\gamma\gamma}\frac{\partial}{\partial\beta} - \frac{\partial}{\partial\beta}\sqrt{\frac{r}{w}}\beta^3 B_{\beta\gamma}\frac{\partial}{\partial\gamma}\right] + \frac{1}{\beta\sin 3\gamma}\left[-\frac{\partial}{\partial\gamma}\sqrt{\frac{r}{w}}\sin 3\gamma B_{\beta\gamma}\frac{\partial}{\partial\beta} + \frac{1}{\beta}\frac{\partial}{\partial\gamma}\sqrt{\frac{r}{w}}\sin 3\gamma B_{\beta\beta}\frac{\partial}{\partial\gamma}\right]\right\}$$

$$\hat{T}_{\text{rot}} = \frac{1}{2}\sum_{k=1}^{3}\frac{\hat{J}_k^2}{\mathcal{I}_k}$$

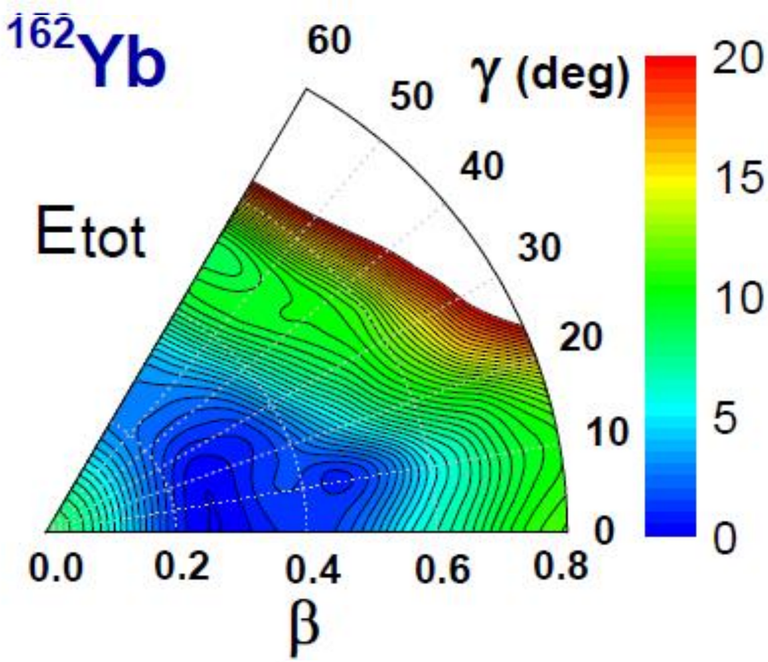
Need to determine *I*'s, *B*'s

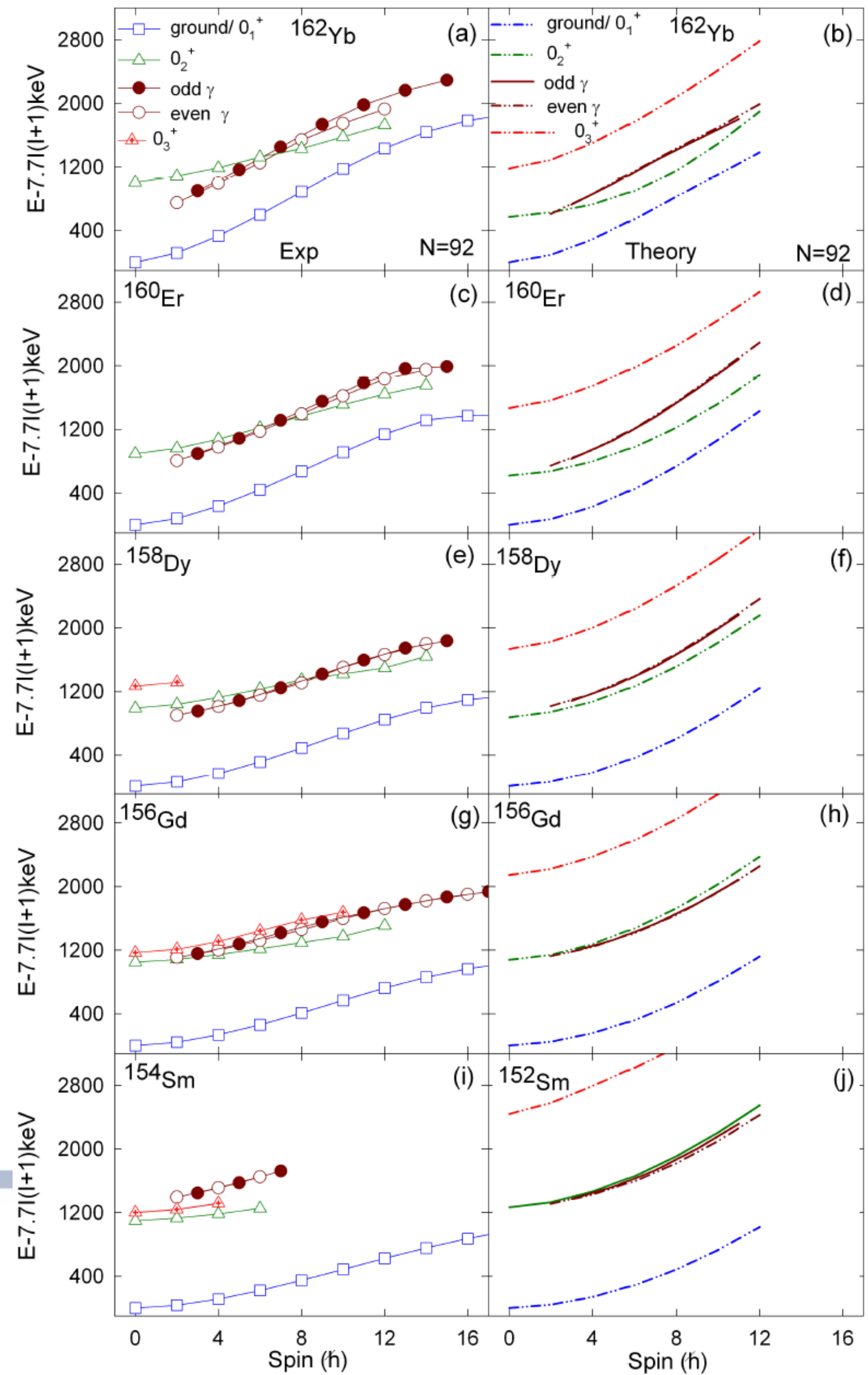
T. Niksic et al PRC 79, 034303 (2009)

Z.P. Li et al., PRC 79, 054301 (2009)

N=92

Calculated Energies (lines) compared to experiment (points)





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Superdeformed triaxial bands in ^{163,165}Lu

H. Schnack-Petersen[a], R. Bengtsson[b], R.A. Bark[a,c], P. Bosetti[a,1], A. Brockstedt[c], H. Carlsson[c], L.P. Ekström[c], G.B. Hagemann[a], B. Herskind[a], F. Ingebretsen[d], H.J. Jensen[a], S. Leoni[a], A. Nordlund[c], H. Ryde[c], P.O. Tjøm[d], C.X. Yang[c,2]

Nuclear Physics A 594 (1995) 175–202

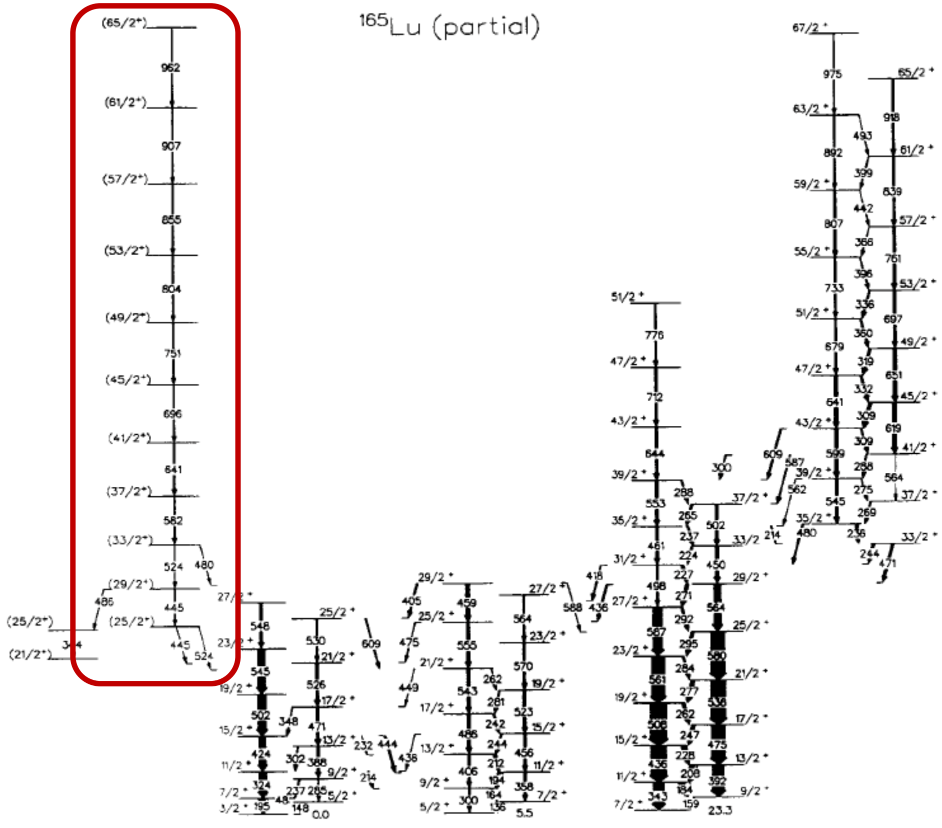
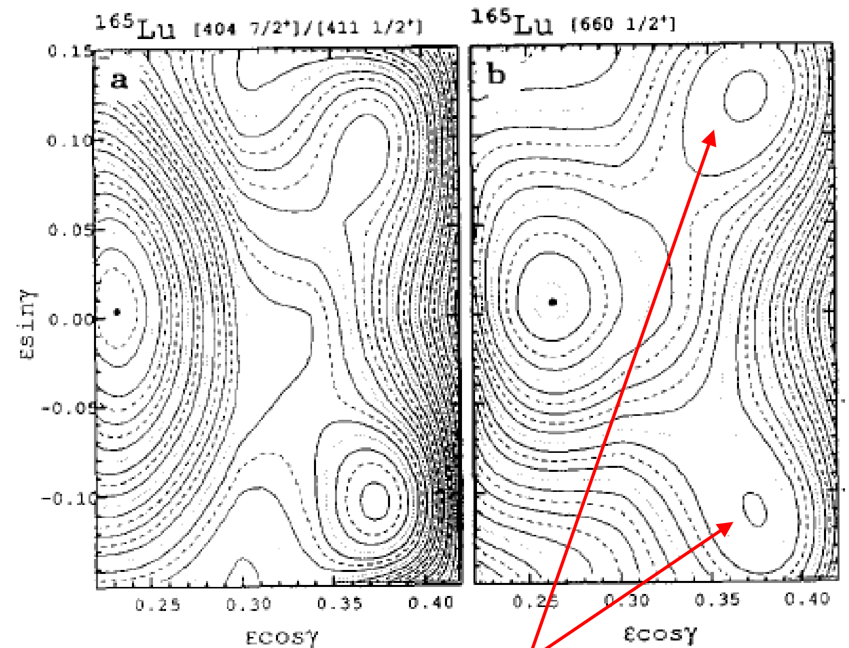


Fig. 1. Partial level scheme of the selected positive parity bands related to the $i_{13/2}$[660 1/2+] band.

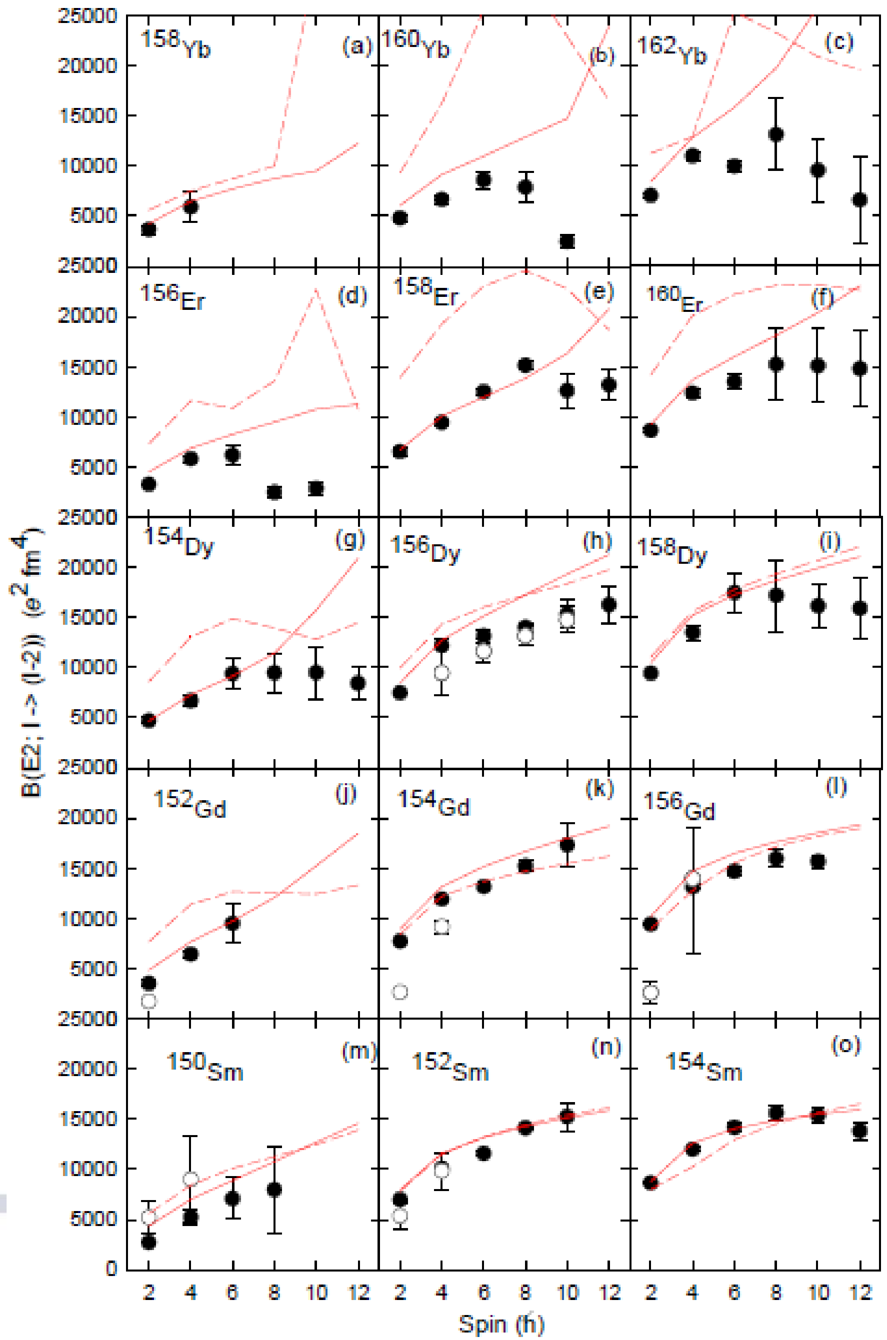


$(\varepsilon_2 = 0.389,\ \gamma = |18°|)$

In-band B(E2)s

—— ground band (theory)

- - - - 0_2^+ band (theory)



● ground band (exp)

○ 0_2^+ band (exp)

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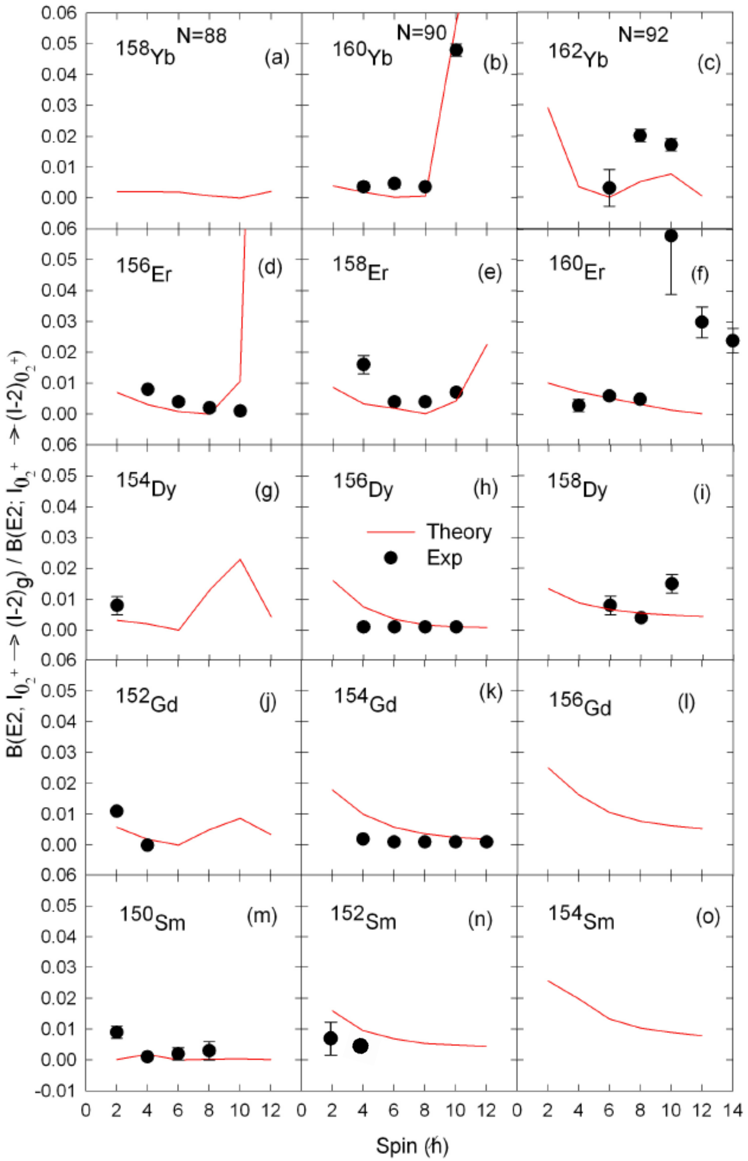
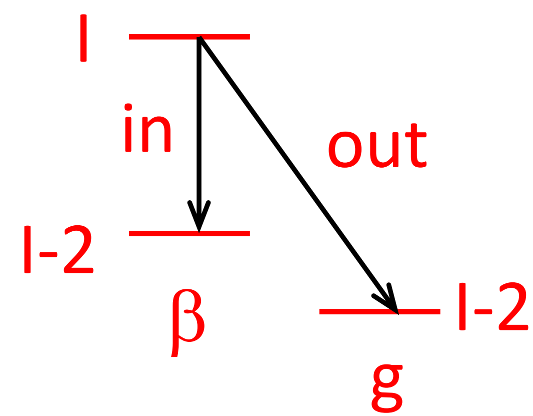
Branching Ratios β-band



β-band B(E2)
branching
ratios: out/in



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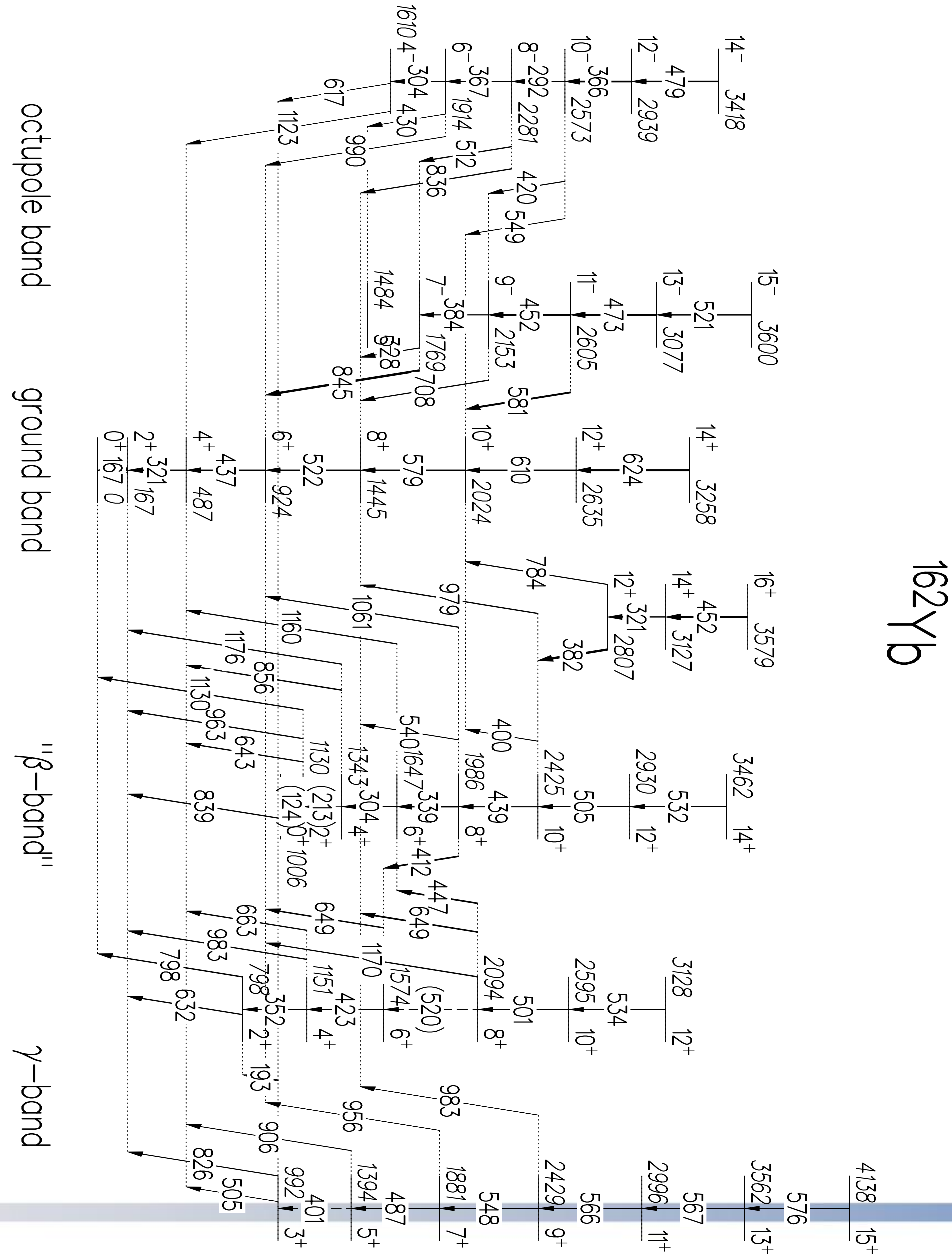

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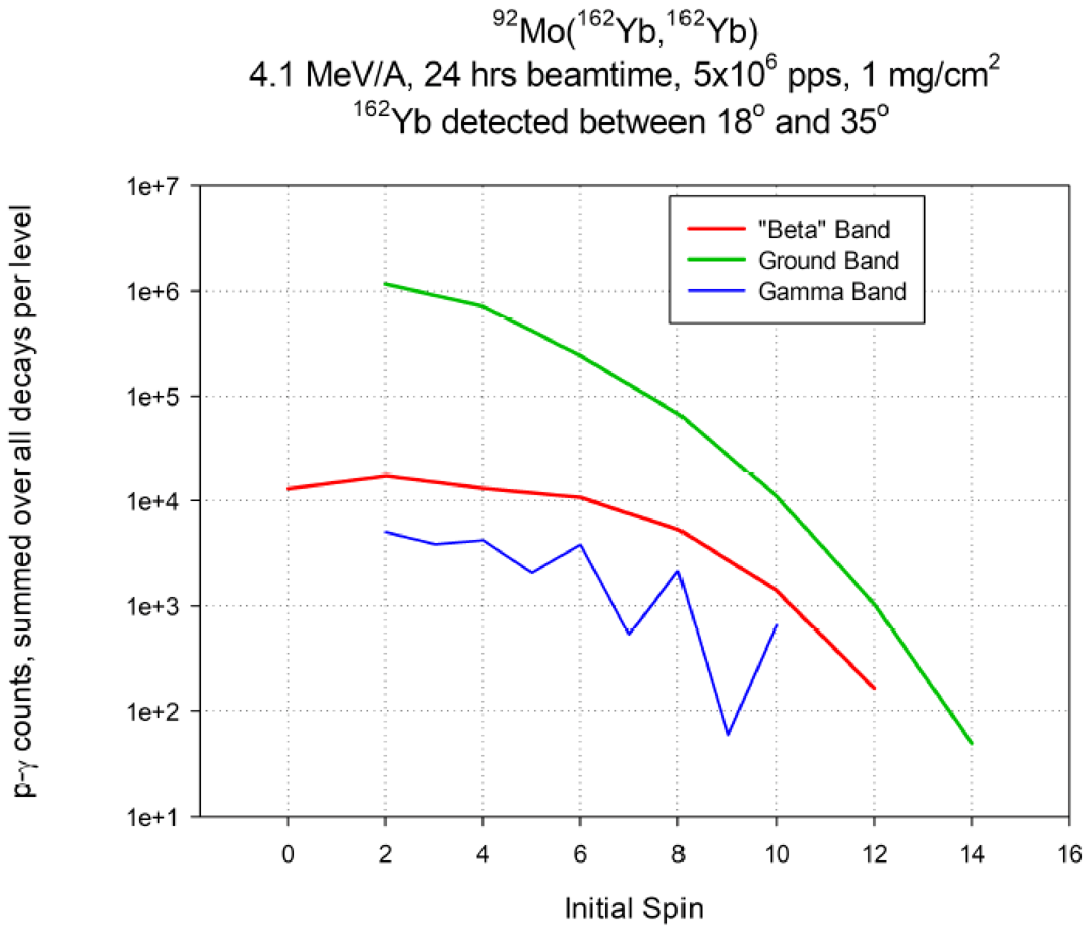
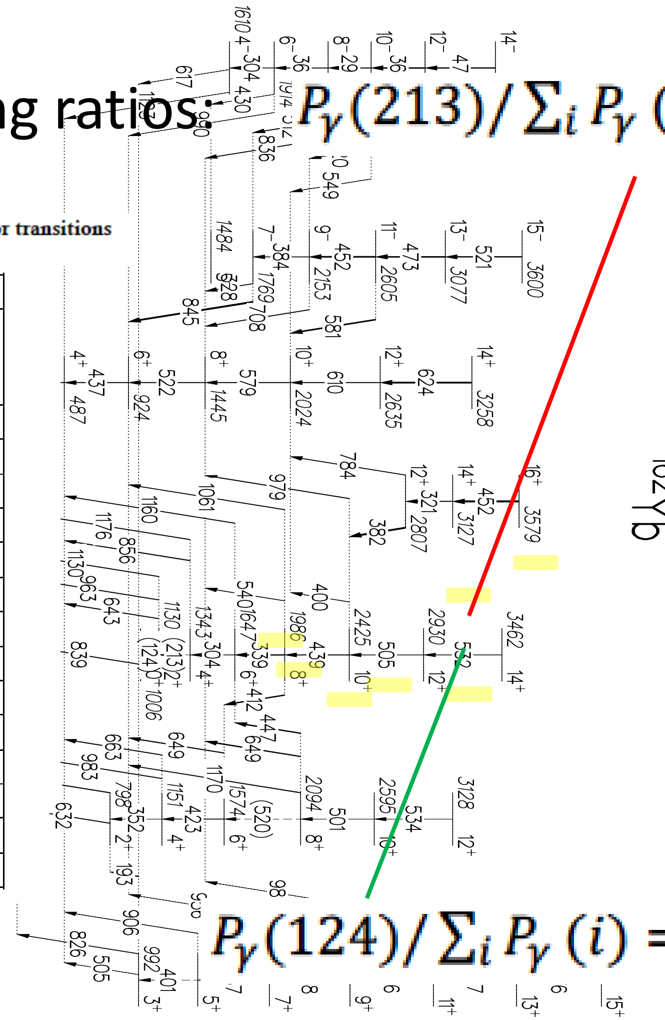
GOSIA Calculation: Coulomb Excitation of ^{162}Yb



Statistics: Coulomb Excitation of ^{162}Yb "β -band"

Calculated branching ratios: $P_\gamma(213)/\sum_i P_\gamma(i) = 10^{-2}$



$P_\gamma(124)/\sum_i P_\gamma(i) = 5.3 \times 10^{-4}$

Table 1. Estimated γ-ray yields, assuming constant efficiency (7%) and 1 day of beam time, for transitions depopulating the β-band of ^{162}Yb. "Clean" transitions are highlighted.

		^{162}Yb		
Level	Transition	Eγ (keV)	Experimental γ-branching	p-γ yield 1 mg/cm^2 ^{92}Mo 5×10^6 pps
0_β	$0_\beta \rightarrow 2_1$	839	100	13000
2_β	$2_\beta \rightarrow 0_1$	1130	100	7600
	$2_\beta \rightarrow 2_1$	963	74	5800
	$2_\beta \rightarrow 4_1$	643	50	4000
4_β	$4_\beta \rightarrow 2_1$	1176	100	12000
	$4_\beta \rightarrow 2_\beta$			
	$4_\beta \rightarrow 4_1$	856	8	960
6_β	$6_\beta \rightarrow 4_1$	1160	100	6360
	$6_\beta \rightarrow 4_\beta$	304	68	4320
	$6_\beta \rightarrow 6_1$			
8_β	$8_\beta \rightarrow 6_1$	1061	31	740
	$8_\beta \rightarrow 6_\beta$	339	44	1060
	$8_\beta \rightarrow 8_1$	540	44	1060
	$8_\beta \rightarrow 6_\gamma$	412	100	2400

$$P_\gamma \propto E_\gamma^5 B(E2)$$

β - decay of ^{162}Lu into ^{162}Yb

Determine branching ratios at 4_2^+ and 2_2^+ levels

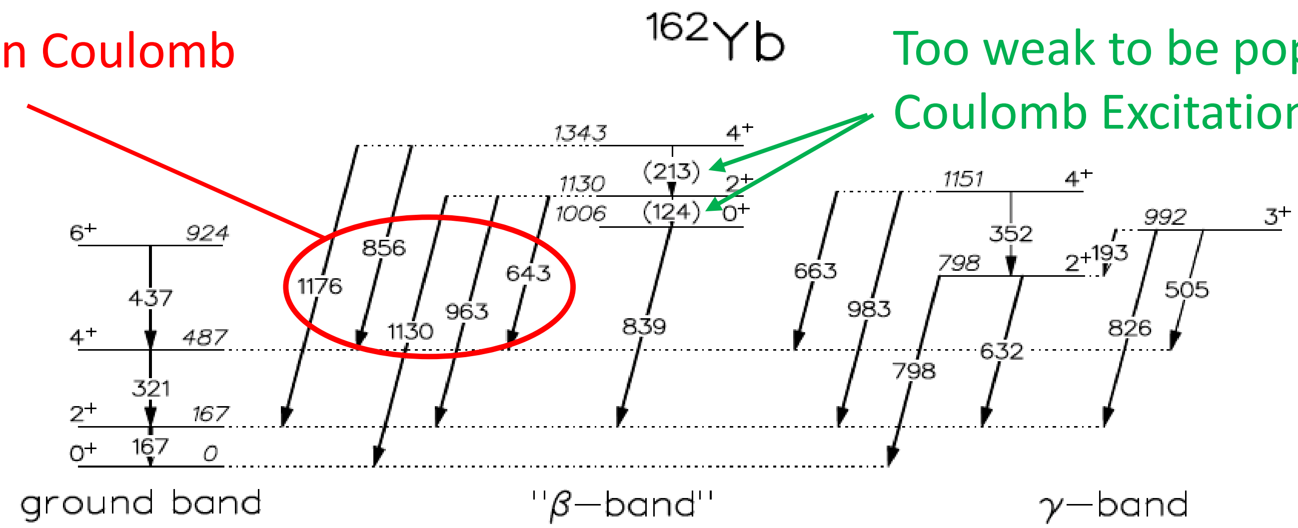
To get in-band B(E2)'s of 213 and 124 keV transitions

$$P_\gamma \propto E_\gamma^5 B(E2) \qquad B(E2) \propto Q_t^2 \qquad Q_t \propto \beta + 0.36\beta^2$$

$$P_t = \sum P_{\gamma_i} + P_{e_i}$$

Easily seen in Coulomb Excitation

Too weak to be populated in Coulomb Excitation



McCutchan 2004

Success of experiment depends on ^{162}Lu beam intensity.
LoI 268 was approved to determine yields of ^{162}Lu

Ran together with LoI 278 in which Tm yields were measured
Unfortunately, target "failed" before Lu yields were measured

By then Tm yields had dropped a factor of 10. The measured yield of ^{162}Lu was ~ 5e3 pps/μC

Implies ~ 10^5 pps is possible

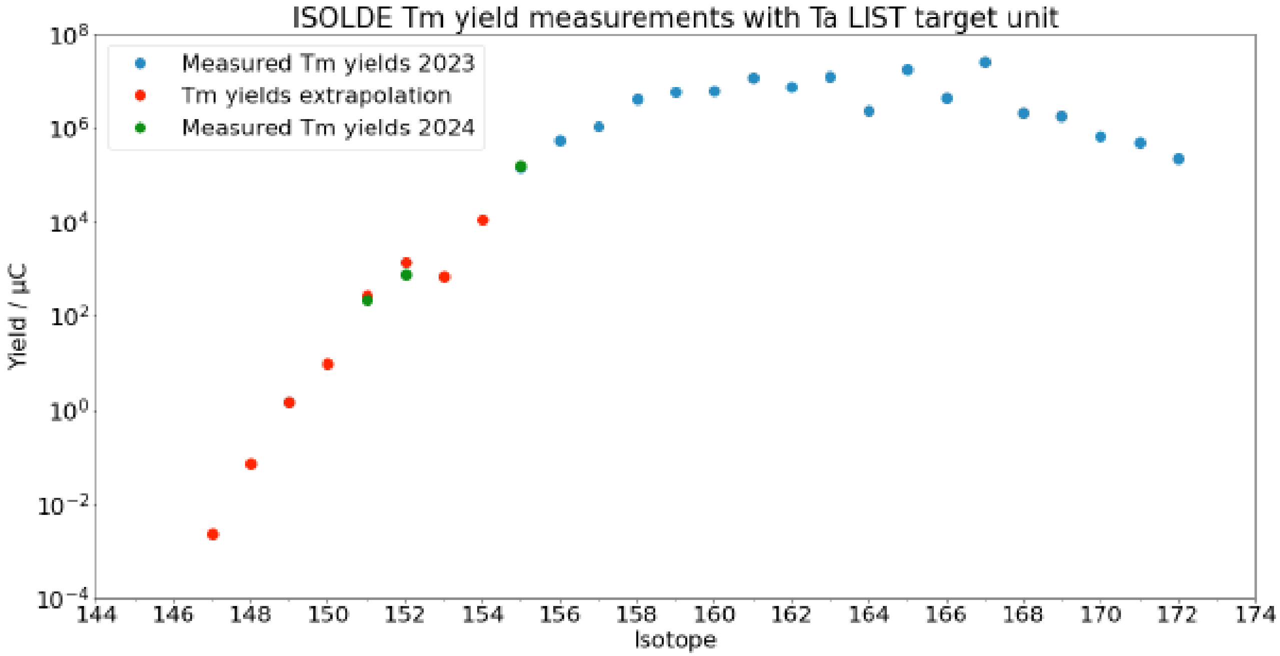
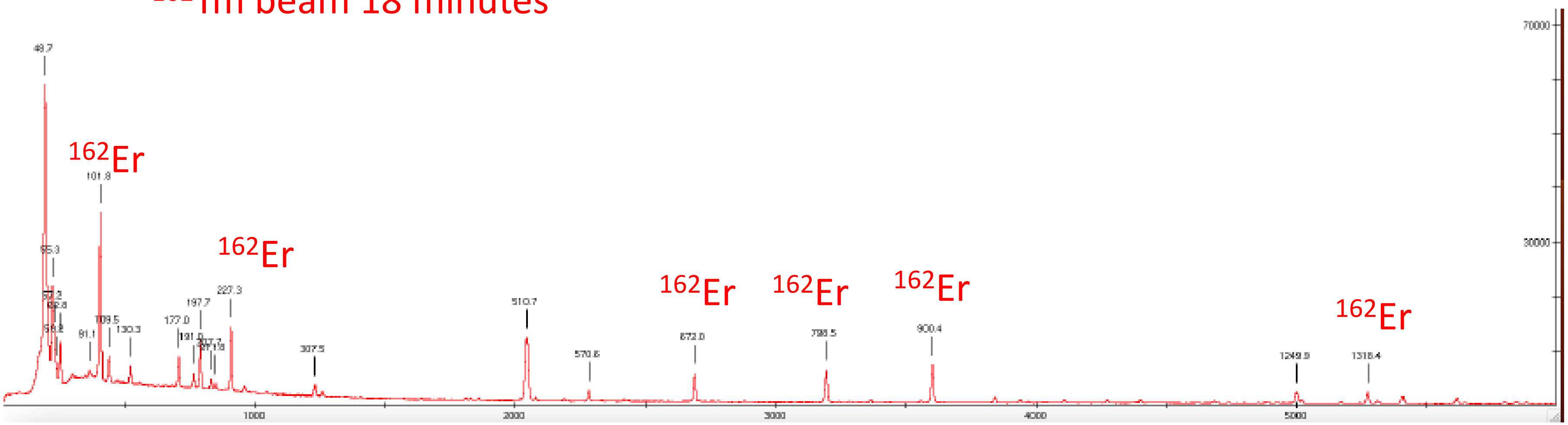
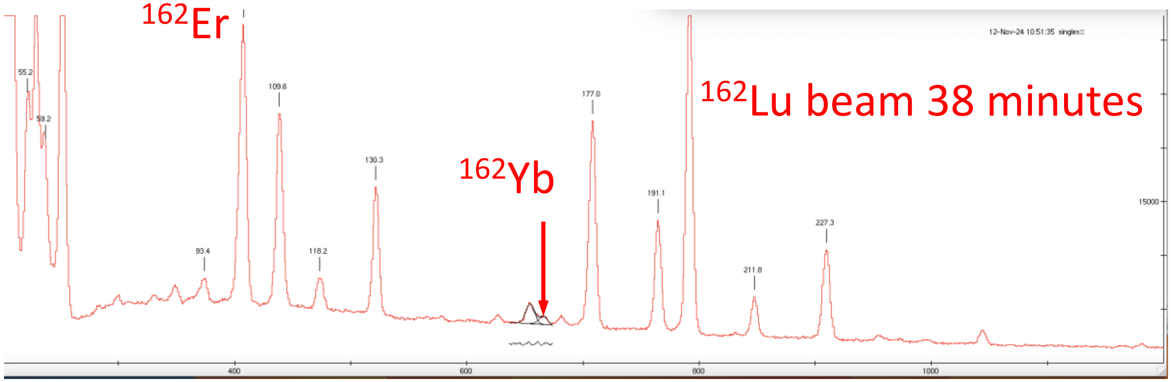


Figure. 4. ISOLDE Tm yield measurements with Ta LIST target unit.

Analysis of β-decay spectra from IDS (LoI268)

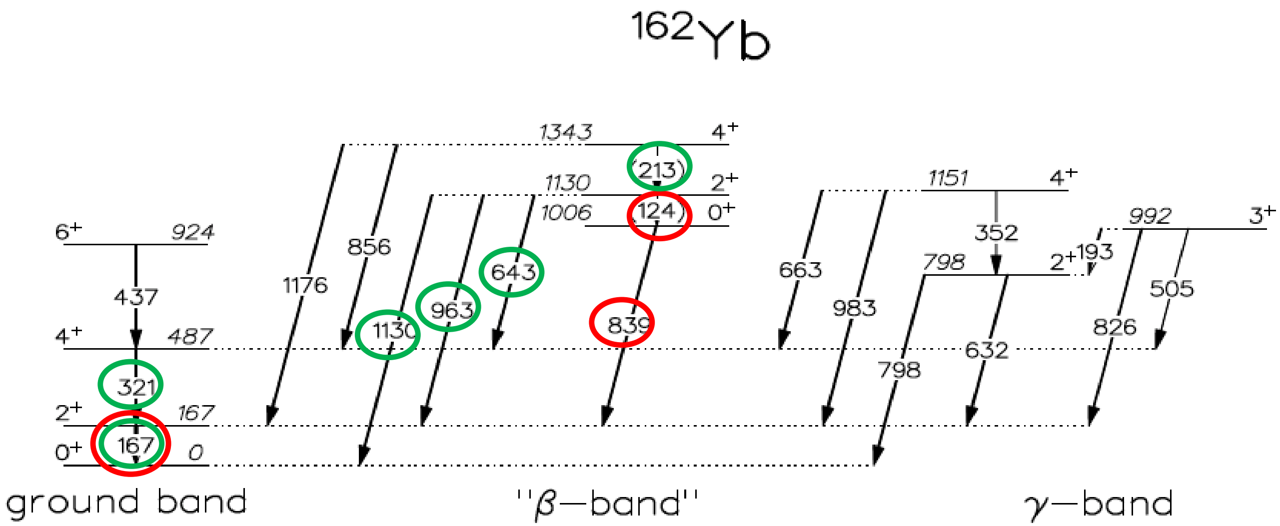
^{162}Tm beam 18 minutes





Again conclude ^{162}Lu beam is 2 orders of magnitude weaker than ^{162}Tm beam

Look for 124 and 213 in coincidence mode



Assuming 10^5 pps and using intensities of McCutchan 2004 & calculated branching ratios, Majola (2019), 12 clovers :

Estimated number of coincidence counts in 9 shifts

- 213 11000 +/-400
- 125 2300 +/-400

TAC question: What if beam is only 10^4 pps?

(Sintering of the target happened after 2-3 days of operation)

Reduce counts by a factor of 10:

	Peak	Bkgd.	$(Bkgd)^{1/2}$	%uncert.
• 213	1100	7500	+/- 90	10%
• 125	230	7500	+/- 90	40%

Conclude only 213 intensity will be obtained.

But remember 9 shifts = 3 days of operation

Summary of beamtime request ^{162}Lu decay

- 9 shifts
- 12 clovers
- SPEDE

Thank You