European Nuclear Science and Applications Research
ENSAR
Within the Seventh Framework Programme of the European Commission

FUSHE 2012
Erbismühle – Weilrod, Germany MAY 13th-16th 2012
ENSAR-ECOS Workshop on FUture SuperHeavy Element Strategy

Collective properties/ in-beam spectroscopy

- -Motivation
- -Experimental Techniques
- -Results & Issues
- -Conclusion & Perspectives

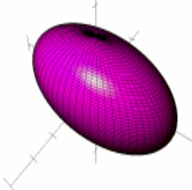
A. Lopez-Martens

cnrs IN2P3
Les deux infinis

CSNSM

UNIVERSITÉ PARIS SUD
Comprendre le monde, construire l'avenir®

Motivation



Atomic beam magnetic resonance:

^{254m}Es: $Q_s(2+) = 3.7(5)$ b ⇨ $Q_0 = 12.9(1.6)$ b

^{253}Es: $Q_s(\mathrm{gs}:7/2+) = 6.7(8)$ b ⇨ $Q_0 = 14.3(1.7)$ b

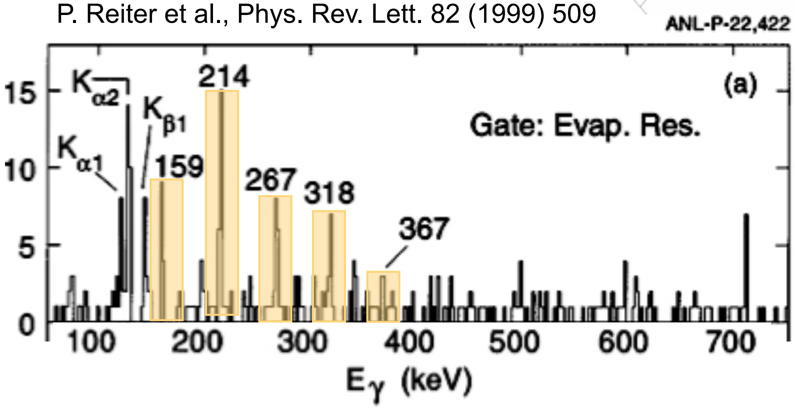
L.S. Goodman et al., Phys. Rev. A 11 (1975) 499

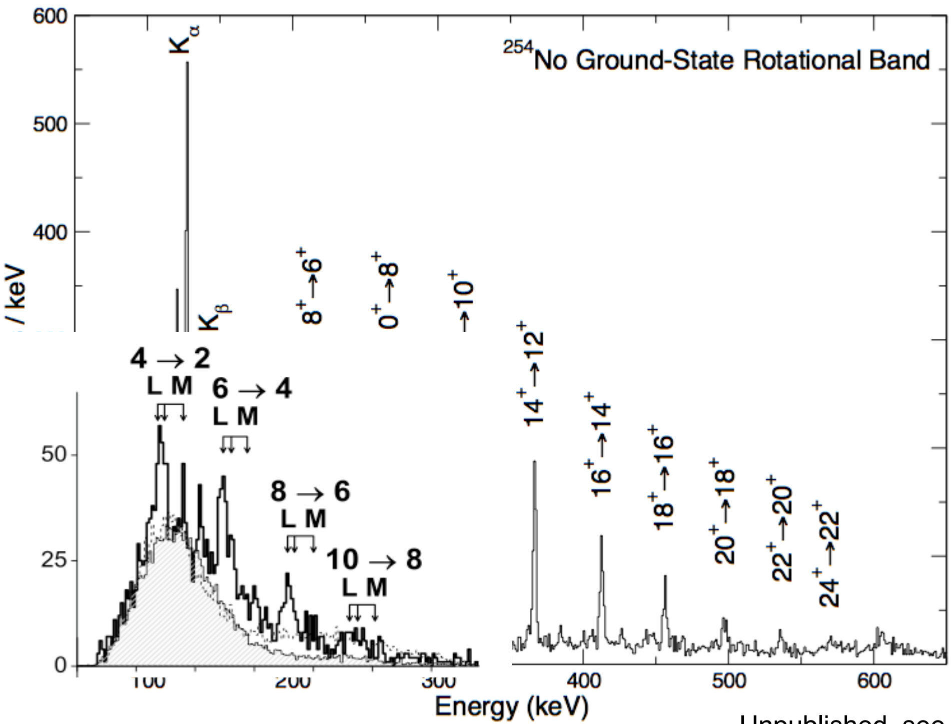
Coulex with α-particles:

^{252}Cf: $B(E2)\uparrow = 16.7(1.1)\ e^2b^2$ ⇨ $Q_0 = 12.9(0.4)$ b

J.L.C. Ford et al., Phys. Rev. Lett. 27 (1971) 1232

P. Reiter et al., Phys. Rev. Lett. 82 (1999) 509





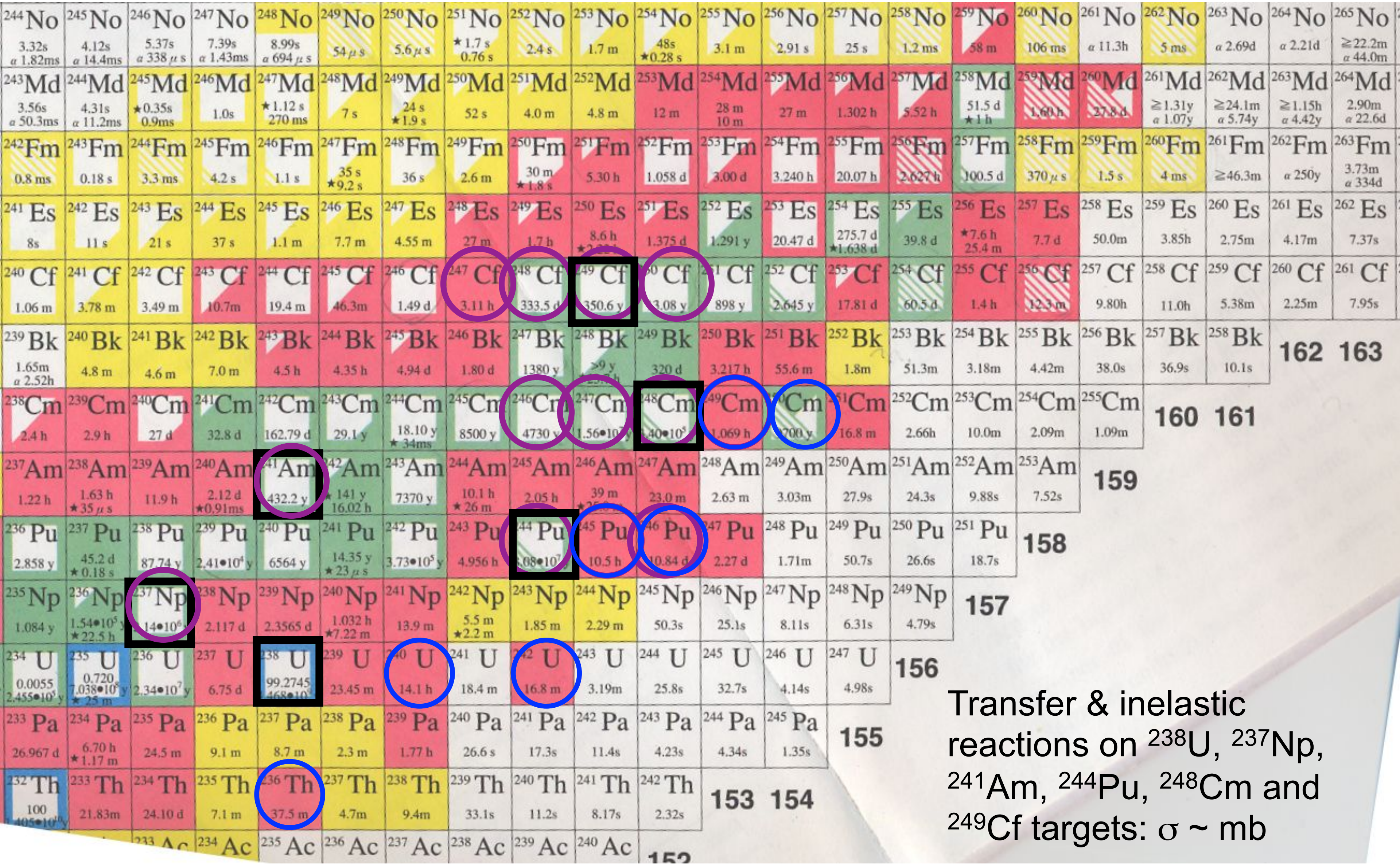
P.A. Butler et al. Phys. Rev. Lett. 89 (2002) 202501

Unpublished, see also:
S.Eeckhaudt,P.T.Greenlees et al.,EPJA 26 (2005) 227

What can we learn from in-beam spectroscopy?

- Dynamic properties: $\Im(\omega)$
- Correlations and shell effects
- Limits of stability
- Electromagnetic properties: single-particle spectra

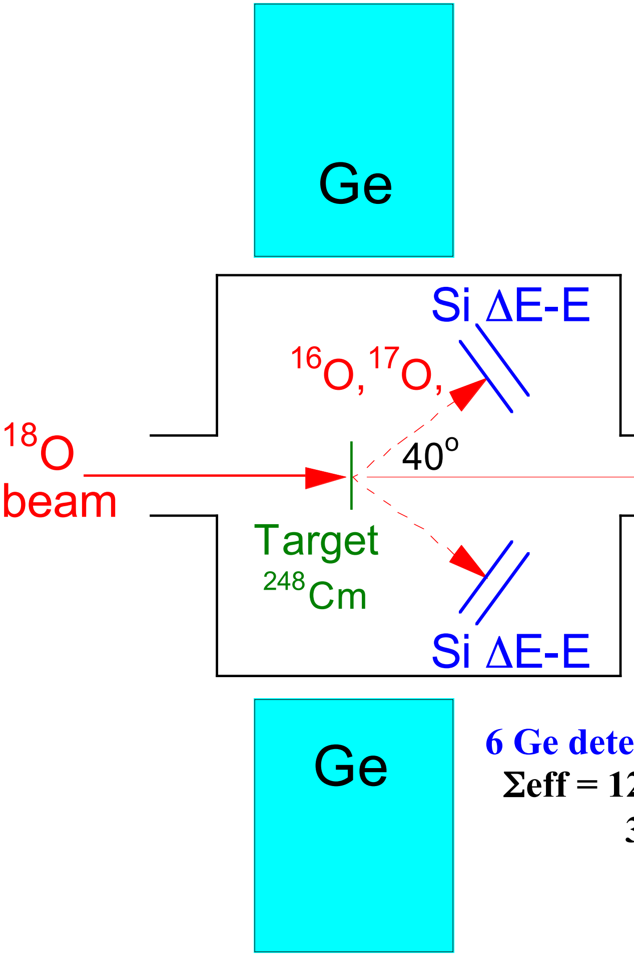
Experimental techniques (1)



^{244}No 3.32s α 1.82ms	^{245}No 4.12s α 14.4ms	^{246}No 5.37s α 338 μs	^{247}No 7.39s α 1.43ms	^{248}No 8.99s α 694 μs	^{249}No 54 μs	^{250}No 5.6 μs	^{251}No ★1.7 s 0.76 s	^{252}No 2.4 s	^{253}No 1.7 m	^{254}No 48s ★0.28 s	^{255}No 3.1 m	^{256}No 2.91 s	^{257}No 25 s	^{258}No 1.2 ms	^{259}No 58 m	^{260}No 106 ms	^{261}No α 11.3h	^{262}No 5 ms	^{263}No α 2.69d	^{264}No α 2.21d	^{265}No ≧22.2m α 44.0m
^{243}Md 3.56s α 50.3ms	^{244}Md 4.31s α 11.2ms	^{245}Md ★0.35s 0.9ms	^{246}Md 1.0s	^{247}Md ★1.12 s 270 ms	^{248}Md 7 s	^{249}Md 24 s ★1.9 s	^{250}Md 52 s	^{251}Md 4.0 m	^{252}Md 4.8 m	^{253}Md 12 m	^{254}Md 28 m 10 m	^{255}Md 27 m	^{256}Md 1.302 h	^{257}Md 5.52 h	^{258}Md 51.5 d ★1 h	^{259}Md 1.60 h	^{260}Md 27.8 d	^{261}Md ≧1.31y α 1.07y	^{262}Md ≧24.1m α 5.74y	^{263}Md ≧1.15h α 4.42y	^{264}Md 2.90m α 22.6d
^{242}Fm 0.8 ms	^{243}Fm 0.18 s	^{244}Fm 3.3 ms	^{245}Fm 4.2 s	^{246}Fm 1.1 s	^{247}Fm 35 s ★9.2 s	^{248}Fm 36 s	^{249}Fm 2.6 m	^{250}Fm 30 m ★1.8 s	^{251}Fm 5.30 h	^{252}Fm 1.058 d	^{253}Fm 3.00 d	^{254}Fm 3.240 h	^{255}Fm 20.07 h	^{256}Fm 2.627 h	^{257}Fm 100.5 d	^{258}Fm 370 μs	^{259}Fm 1.5 s	^{260}Fm 4 ms	^{261}Fm ≧46.3m	^{262}Fm α 250y	^{263}Fm 3.73m α 334d
^{241}Es 8s	^{242}Es 11 s	^{243}Es 21 s	^{244}Es 37 s	^{245}Es 1.1 m	^{246}Es 7.7 m	^{247}Es 4.55 m	^{248}Es 27 m	^{249}Es 1.7 h	^{250}Es 8.6 h ★[illegible]	^{251}Es 1.375 d	^{252}Es 1.291 y	^{253}Es 20.47 d	^{254}Es 275.7 d ★1.638 d	^{255}Es 39.8 d	^{256}Es ★7.6 h 25.4 m	^{257}Es 7.7 d	^{258}Es 50.0m	^{259}Es 3.85h	^{260}Es 2.75m	^{261}Es 4.17m	^{262}Es 7.37s
^{240}Cf 1.06 m	^{241}Cf 3.78 m	^{242}Cf 3.49 m	^{243}Cf 10.7m	^{244}Cf 19.4 m	^{245}Cf 46.3m	^{246}Cf 1.49 d	^{247}Cf 3.11 h	^{248}Cf 333.5 d	^{249}Cf 350.6 y	^{250}Cf 3.08 y	^{251}Cf 898 y	^{252}Cf 2.645 y	^{253}Cf 17.81 d	^{254}Cf 60.5 d	^{255}Cf 1.4 h	^{256}Cf 12.3 m	^{257}Cf 9.80h	^{258}Cf 11.0h	^{259}Cf 5.38m	^{260}Cf 2.25m	^{261}Cf 7.95s
^{239}Bk 1.65m α 2.52h	^{240}Bk 4.8 m	^{241}Bk 4.6 m	^{242}Bk 7.0 m	^{243}Bk 4.5 h	^{244}Bk 4.35 h	^{245}Bk 4.94 d	^{246}Bk 1.80 d	^{247}Bk 1380 y	^{248}Bk >9 y ★[illegible]	^{249}Bk 320 d	^{250}Bk 3.217 h	^{251}Bk 55.6 m	^{252}Bk 1.8m	^{253}Bk 51.3m	^{254}Bk 3.18m	^{255}Bk 4.42m	^{256}Bk 38.0s	^{257}Bk 36.9s	^{258}Bk 10.1s	**162**	**163**
^{238}Cm 2.4 h	^{239}Cm 2.9 h	^{240}Cm 27 d	^{241}Cm 32.8 d	^{242}Cm 162.79 d	^{243}Cm 29.1 y	^{244}Cm 18.10 y ★34ms	^{245}Cm 8500 y	^{246}Cm 4730 y	^{247}Cm $1.56\bullet10^{7}$ y	^{248}Cm $3.40\bullet10^{5}$	^{249}Cm 1.069 h	^{250}Cm 700 y	^{251}Cm 16.8 m	^{252}Cm 2.66h	^{253}Cm 10.0m	^{254}Cm 2.09m	^{255}Cm 1.09m	**160**	**161**		
^{237}Am 1.22 h	^{238}Am 1.63 h ★35 μs	^{239}Am 11.9 h	^{240}Am 2.12 d ★0.91ms	^{241}Am 432.2 y	^{242}Am ★141 y 16.02 h	^{243}Am 7370 y	^{244}Am 10.1 h ★26 m	^{245}Am 2.05 h	^{246}Am 39 m ★[illegible]	^{247}Am 23.0 m	^{248}Am 2.63 m	^{249}Am 3.03m	^{250}Am 27.9s	^{251}Am 24.3s	^{252}Am 9.88s	^{253}Am 7.52s	**159**				
^{236}Pu 2.858 y	^{237}Pu 45.2 d ★0.18 s	^{238}Pu 87.74 y	^{239}Pu $2.41\bullet10^{4}$ y	^{240}Pu 6564 y	^{241}Pu 14.35 y ★23 μs	^{242}Pu $3.73\bullet10^{5}$ y	^{243}Pu 4.956 h	^{244}Pu $8.08\bullet10^{7}$	^{245}Pu 10.5 h	^{246}Pu 10.84 d	^{247}Pu 2.27 d	^{248}Pu 1.71m	^{249}Pu 50.7s	^{250}Pu 26.6s	^{251}Pu 18.7s	**158**					
^{235}Np 1.084 y	^{236}Np $1.54\bullet10^{5}$ y ★22.5 h	^{237}Np $2.14\bullet10^{6}$	^{238}Np 2.117 d	^{239}Np 2.3565 d	^{240}Np 1.032 h ★7.22 m	^{241}Np 13.9 m	^{242}Np 5.5 m ★2.2 m	^{243}Np 1.85 m	^{244}Np 2.29 m	^{245}Np 50.3s	^{246}Np 25.1s	^{247}Np 8.11s	^{248}Np 6.31s	^{249}Np 4.79s	**157**						
^{234}U 0.0055 $2.455\bullet10^{5}$ y	^{235}U 0.720 $7.038\bullet10^{8}$ y ★25 m	^{236}U $2.34\bullet10^{7}$ y	^{237}U 6.75 d	^{238}U 99.2745 $4.468\bullet10^{9}$	^{239}U 23.45 m	^{240}U 14.1 h	^{241}U 18.4 m	^{242}U 16.8 m	^{243}U 3.19m	^{244}U 25.8s	^{245}U 32.7s	^{246}U 4.14s	^{247}U 4.98s	**156**							
^{233}Pa 26.967 d	^{234}Pa 6.70 h ★1.17 m	^{235}Pa 24.5 m	^{236}Pa 9.1 m	^{237}Pa 8.7 m	^{238}Pa 2.3 m	^{239}Pa 1.77 h	^{240}Pa 26.6 s	^{241}Pa 17.3s	^{242}Pa 11.4s	^{243}Pa 4.23s	^{244}Pa 4.34s	^{245}Pa 1.35s	**155**								
^{232}Th 100 $1.405\bullet10^{10}$ y	^{233}Th 21.83m	^{234}Th 24.10 d	^{235}Th 7.1 m	^{236}Th 37.5 m	^{237}Th 4.7m	^{238}Th 9.4m	^{239}Th 33.1s	^{240}Th 11.2s	^{241}Th 8.17s	^{242}Th 2.32s	**153**	**154**									
		^{233}Ac	^{234}Ac	^{235}Ac	^{236}Ac	^{237}Ac	^{238}Ac	^{239}Ac	^{240}Ac	**152**											

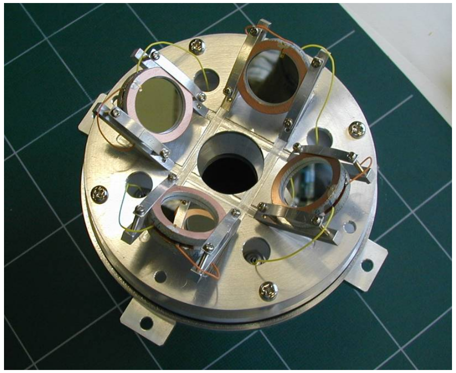
Transfer & inelastic reactions on ^{238}U, ^{237}Np, ^{241}Am, ^{244}Pu, ^{248}Cm and ^{249}Cf targets: σ ~ mb

Complete selection of γ-rays by measuring Z,A, KE of the outgoing particles with the setup @ Tokai tandem, JAEA

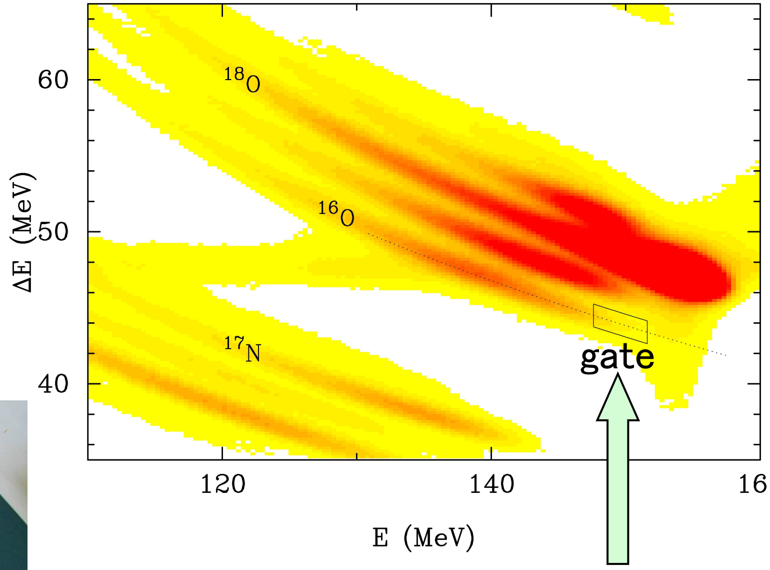


6 Ge detectors
Σeff = 12% @ 0.2 MeV
3% @ 1.3 MeV

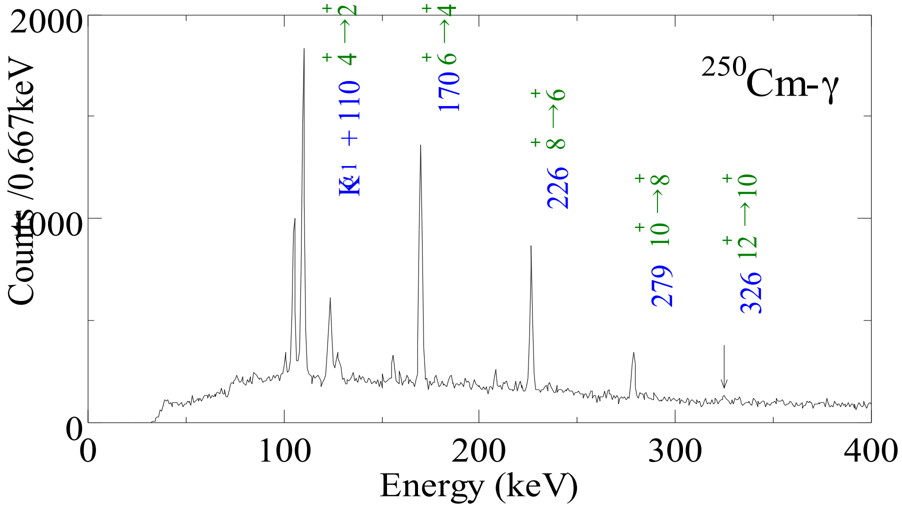
4 Si ΔE-E telescopes
ΔE: 75μm thickness



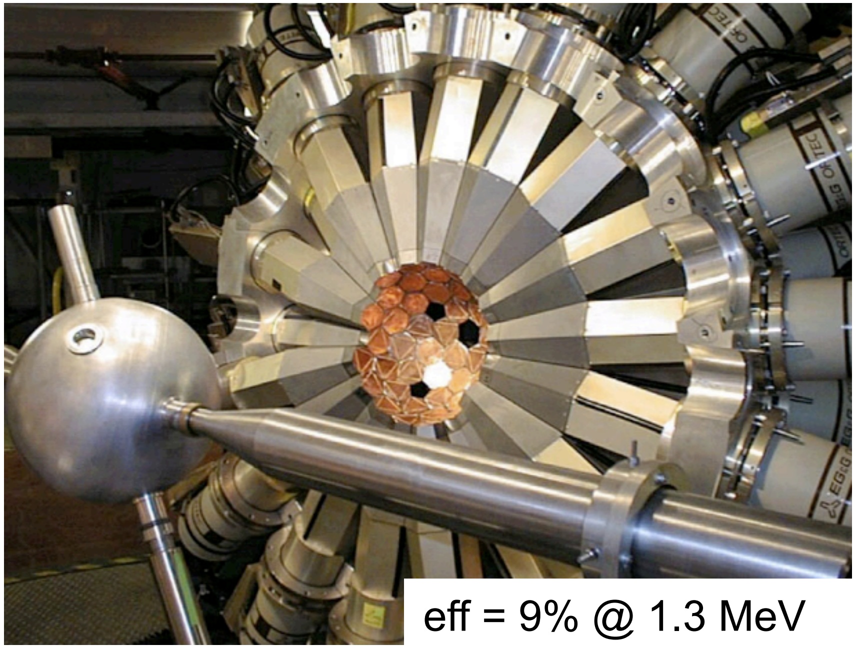
T. Ishii et al., JPSJ 75, 043201 (2006).



E_x of ^{250}Cm < S_n



Using the power of Gammasphere to identify the nucleus and pull out rotational sequences @ ATLAS, ANL

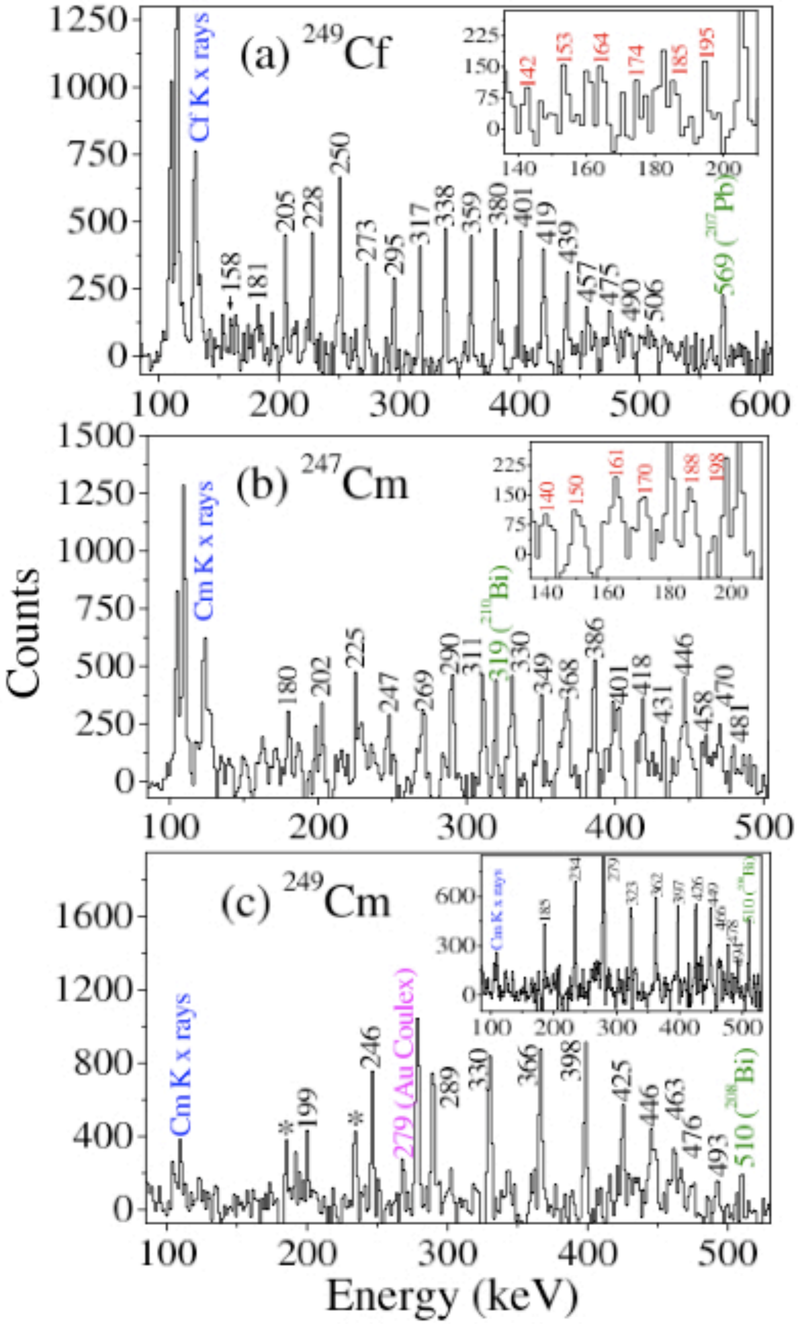


eff = 9% @ 1.3 MeV

inelastic excitation:
^{249}Cf(^{207}Pb,^{207}Pb)^{249}Cf @ 1.43 GeV

neutron transfer:
^{248}Cm(^{209}Bi,^{208}Bi)^{249}Cm @ 1.45 GeV
^{248}Cm(^{209}Bi,^{210}Bi)^{247}Cm

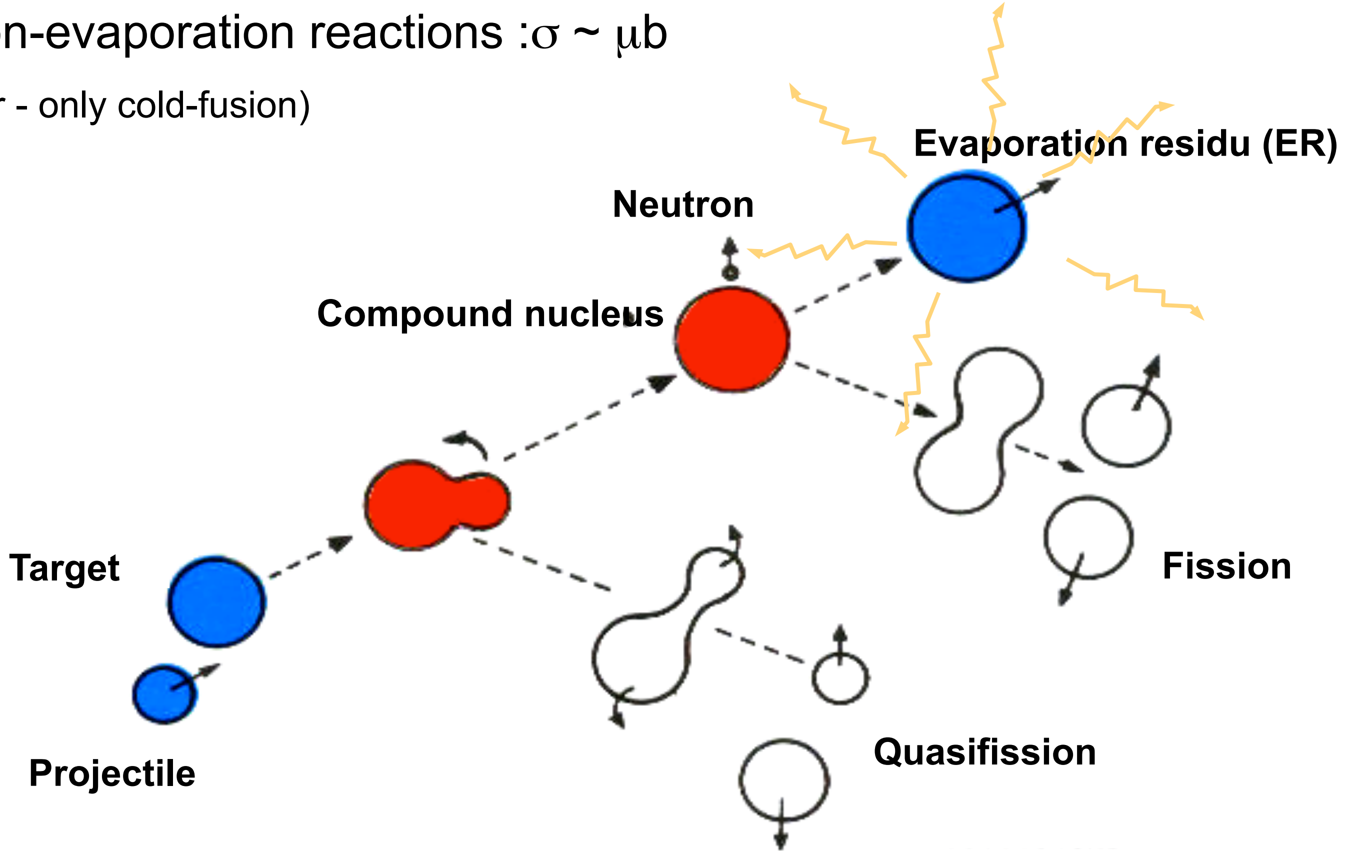
S.U. Tandel et al., Phys. Rev. C **82**, 041301(R)(2010)



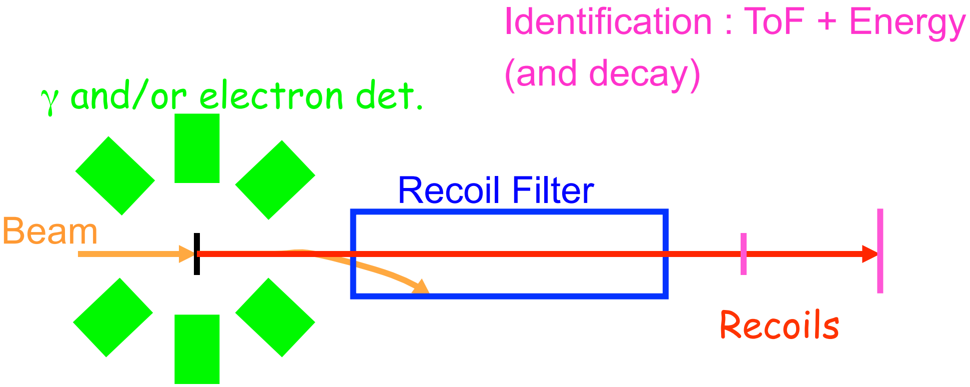
Experimental technique (2)

fusion-evaporation reactions :$\sigma \sim \mu b$

(so far - only cold-fusion)



Finding the needle in the haystack with a recoil filter



Identification : ToF + Energy
(and decay)

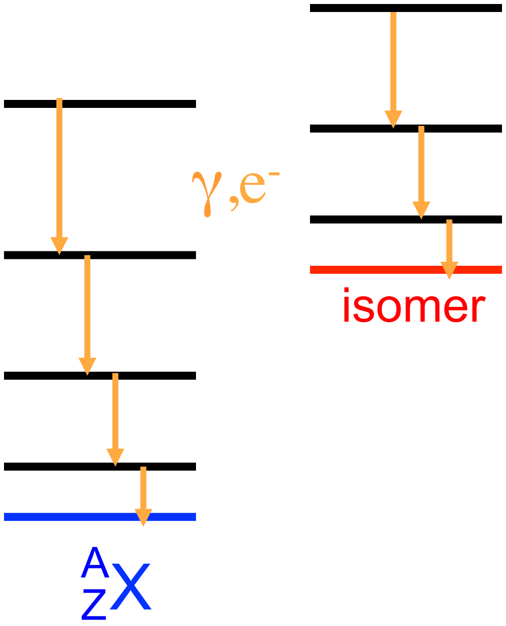
γ and/or electron det.

Recoil Filter

Beam

Recoils

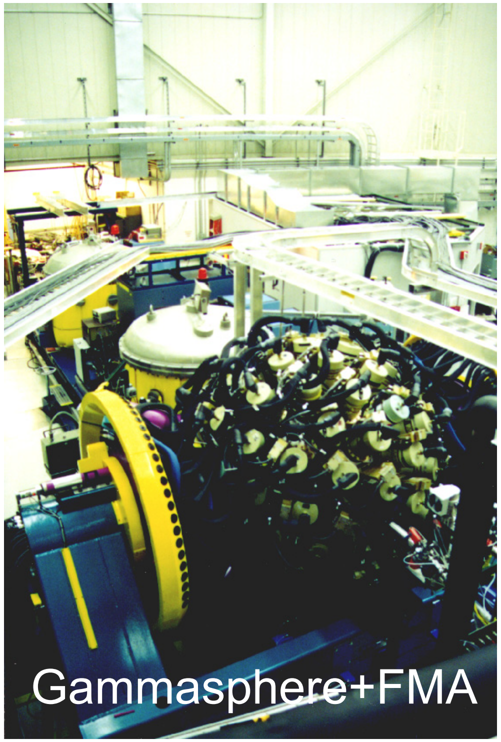
Recoil
(decay)
Tagging



γ,e$^-$

isomer

$^{A}_{Z}X$



Gammasphere+FMA

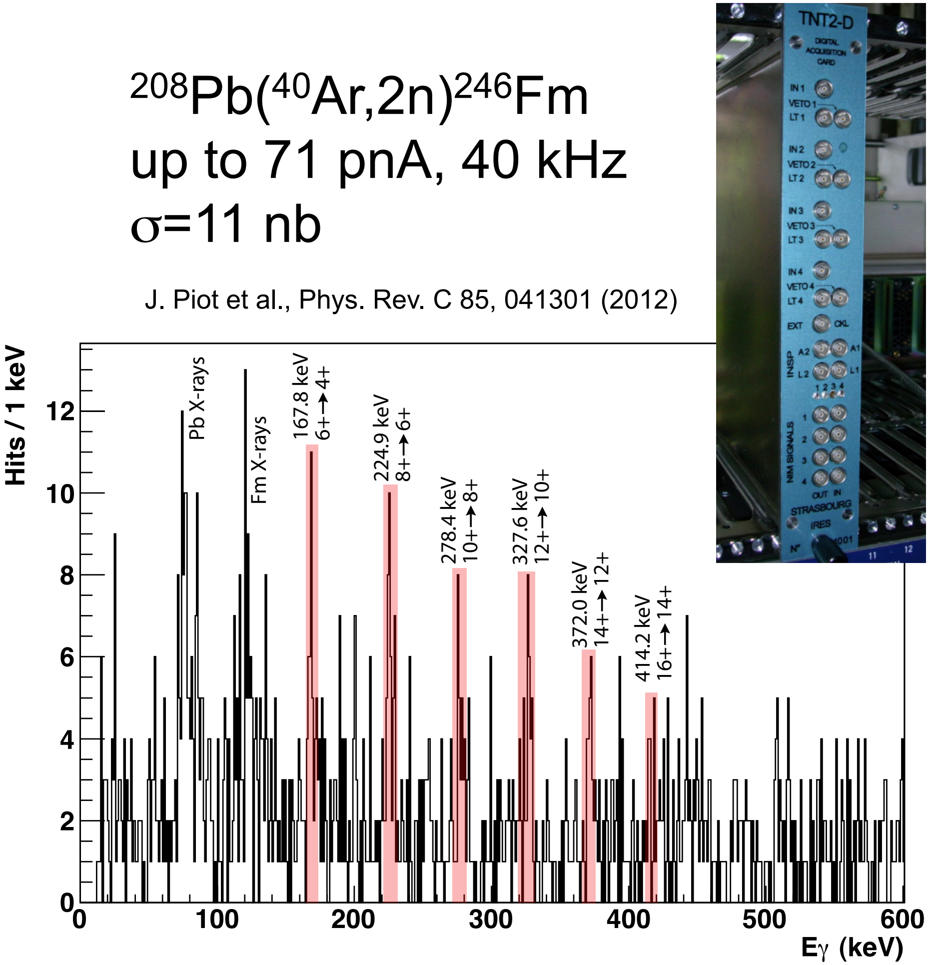
Jurogam + RITU

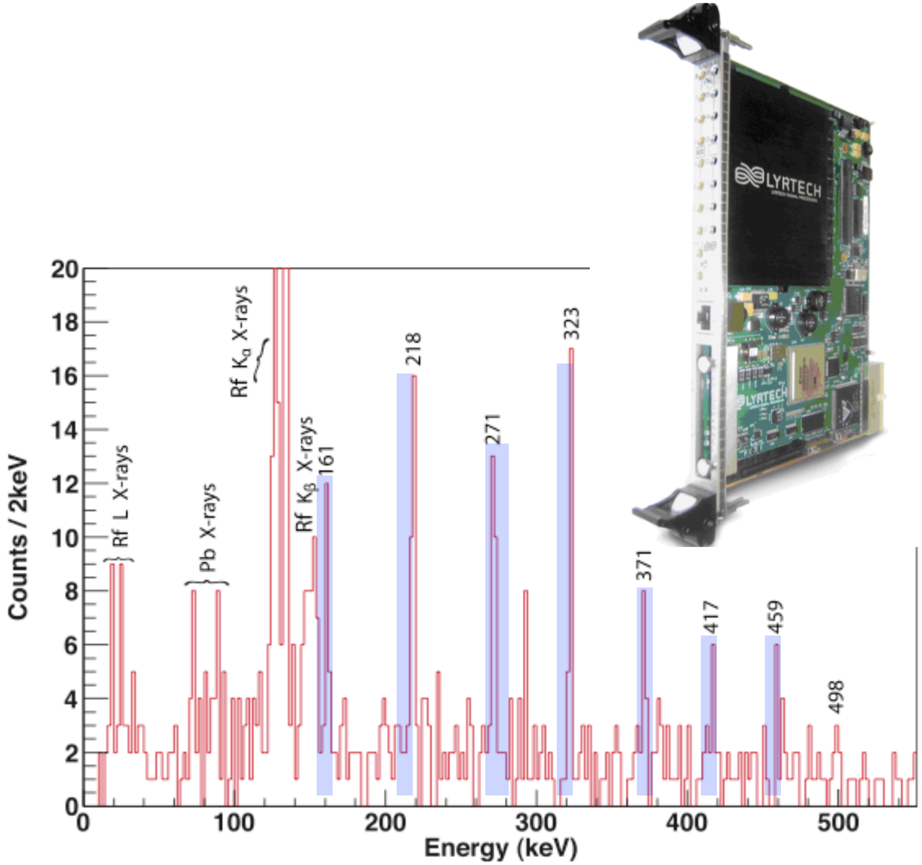
eff = 5% @ 1.3 MeV

Current limit for in-beam spectroscopy

^{208}Pb(^{40}Ar,2n)^{246}Fm
up to 71 pnA, 40 kHz
σ=11 nb

J. Piot et al., Phys. Rev. C 85, 041301 (2012)

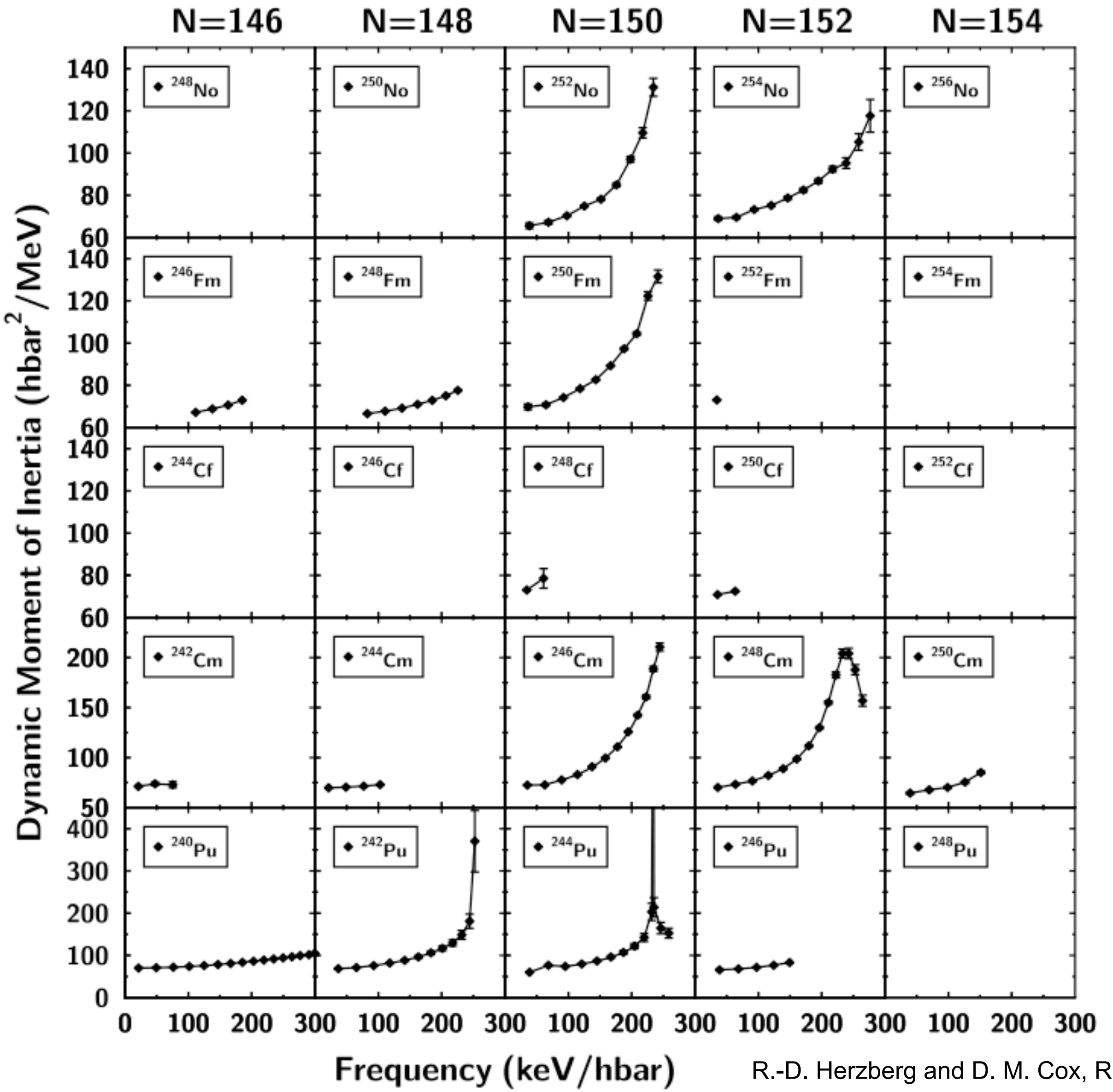




^{208}Pb(^{50}Ti,2n)^{256}Rf
up to 45 pnA, 50 kHz
σ=15 nb

P.T. Greenlees, submitted to Phys. Rev. Lett.

Moments of inertia in gs bands of e-e nuclei



$$\Im^{(1)} = \hbar^2 I_x \left(\frac{dE}{dI_x}\right)^{-1} = \hbar\frac{I_x}{\omega}$$

$$\Im^{(2)} = \hbar\frac{dI_x}{d\omega} \approx \frac{4\hbar^2}{\Delta E_\gamma}$$

$$\hbar\omega = \frac{dE}{dI_x} \approx \frac{E_\gamma}{2}$$

Coriolis anti-pairing force proportional to *I* and *j*

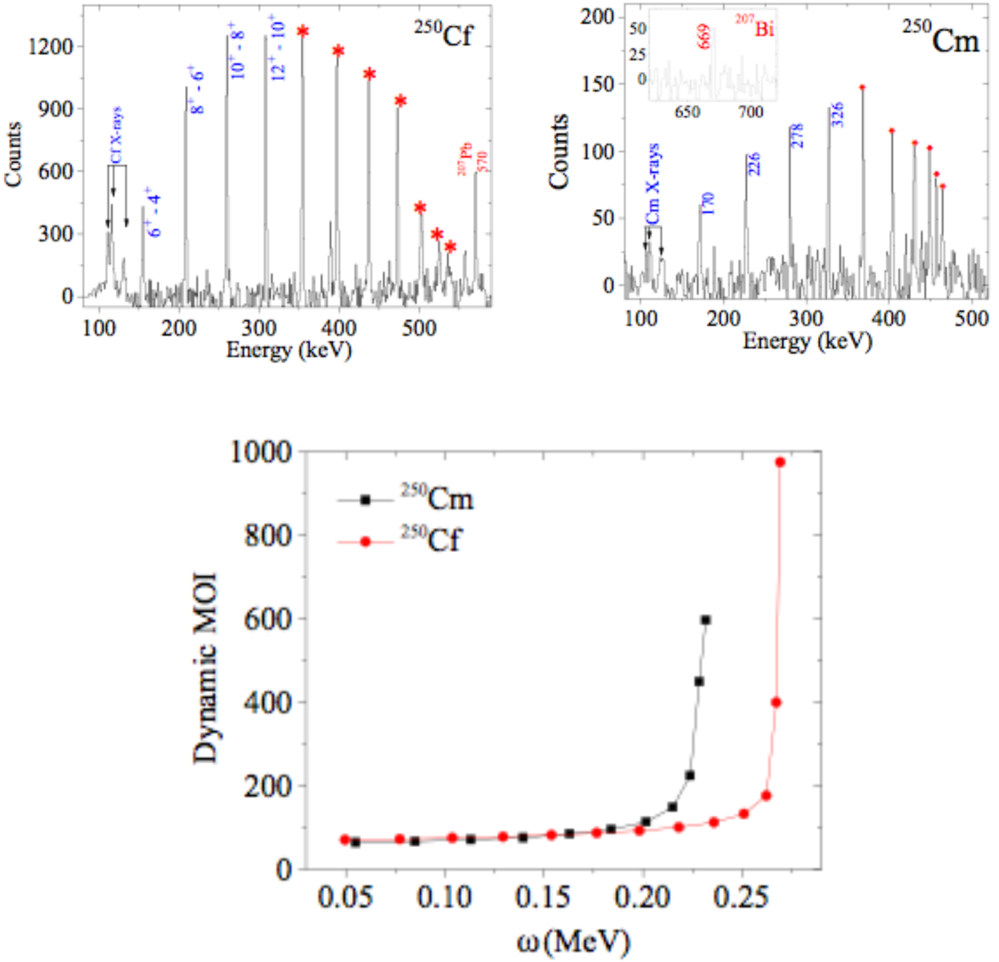
Aligning pairs: $\pi i_{13/2}$, $\nu j_{15/2}$

R.-D. Herzberg and D. M. Cox, Radiochim. Acta **99**, 441 (2011)

New (preliminary) data

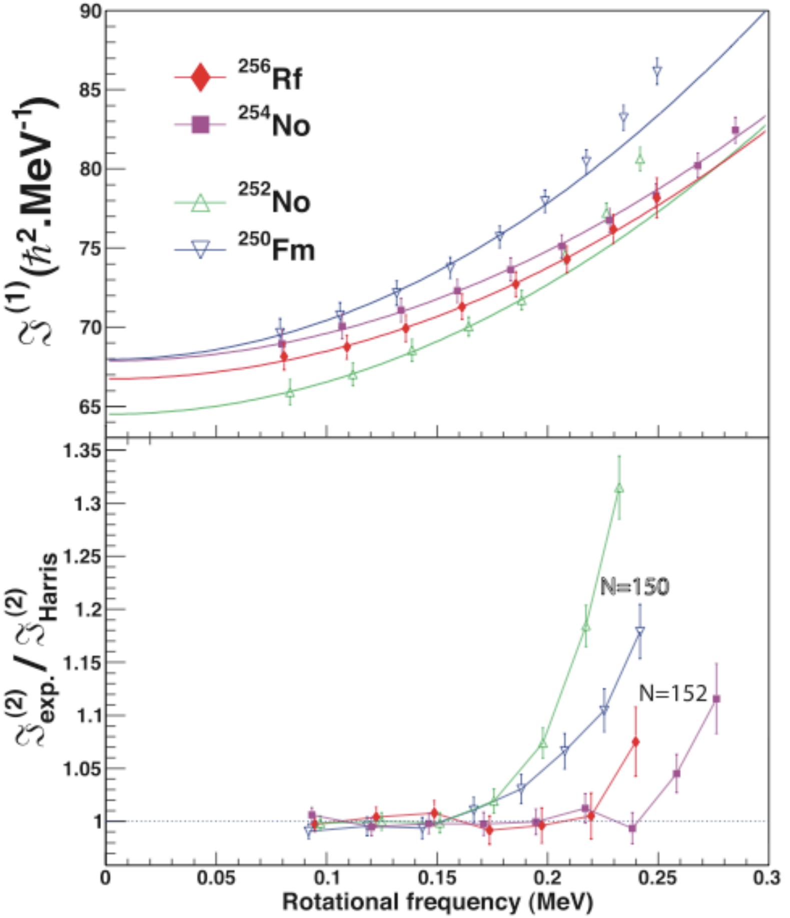
^{250}Cf, ^{250}Cm

S.S Hota, PhD thesis (2012), University of Lowell



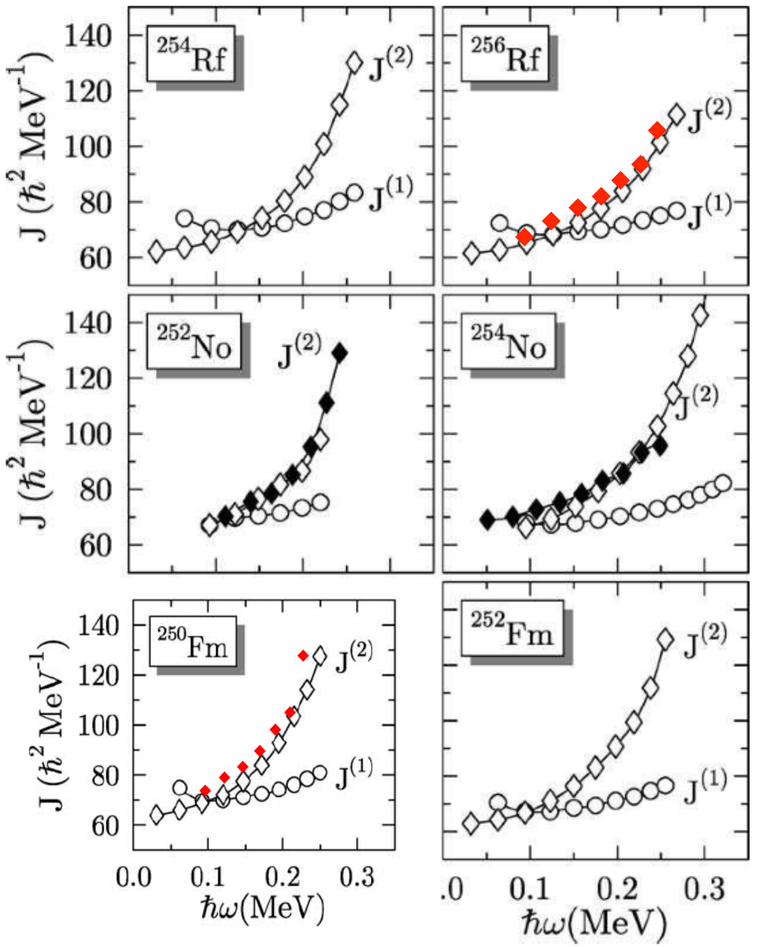
^{256}Rf

P.T. Greenlees et al., submitted to Phys. Rev. Lett.



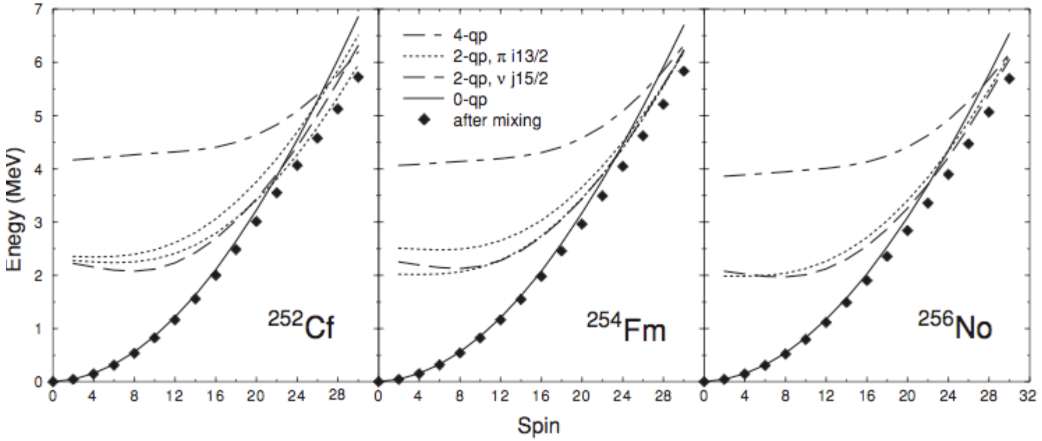
Comparison to theory

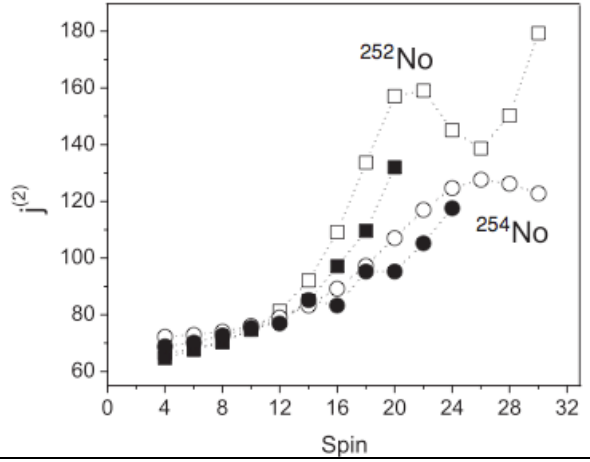
The different behaviours of the moment of inertia are attributed to the competition between neutron $j_{15/2}$ and proton $i_{13/2}$ alignment effects



M.Bender et al., Nucl. Phys. A 723, 354 (2003), Cranked HFB with SLY4 + 0-range density-dependent pairing + Lipkin-Nogami

F. Al-Khudair et al., Phys. Rev. C 79 (2009) 032320
Projected Shell Model using deformed Nilsson single particle states + BCS





Are we at the limit in spin ?

calorimetric technique @ GAMMASPHERE
ε_{GS}(110 Ge)=9% → ε_{GS}(110 (Ge+7 BGO))=78%

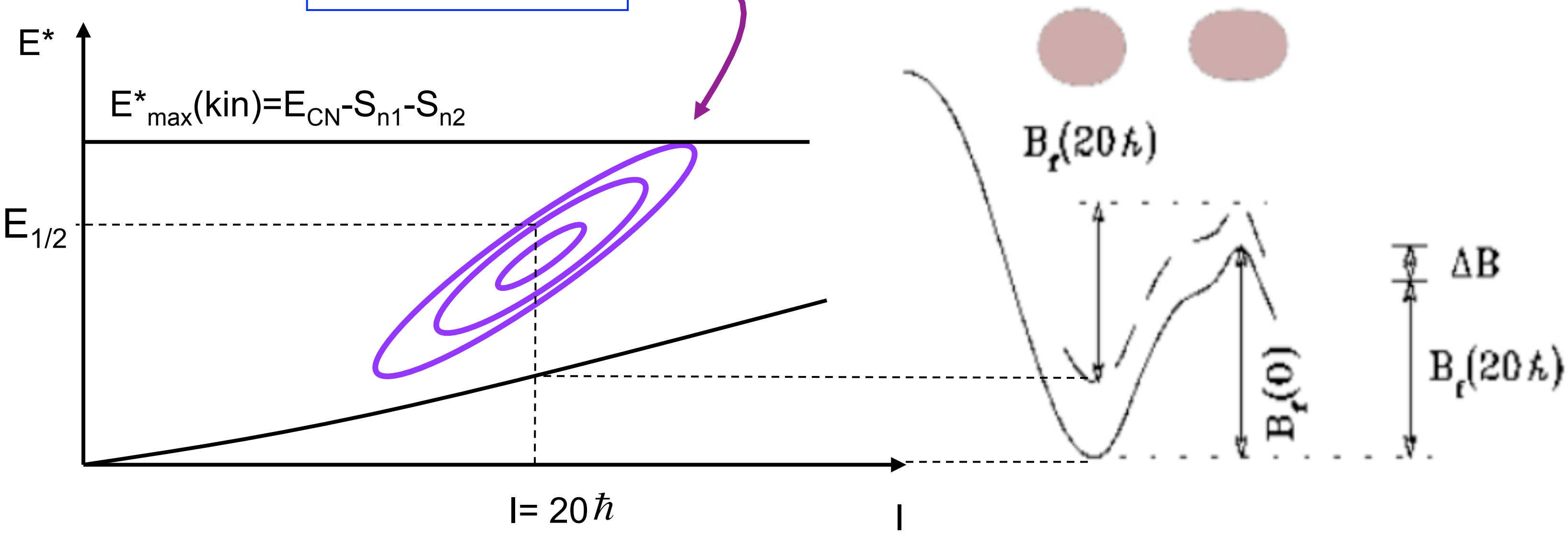
Total pulse height $H=\Sigma h_i$
Number of firing modules K

↓

detector response
function & transformation

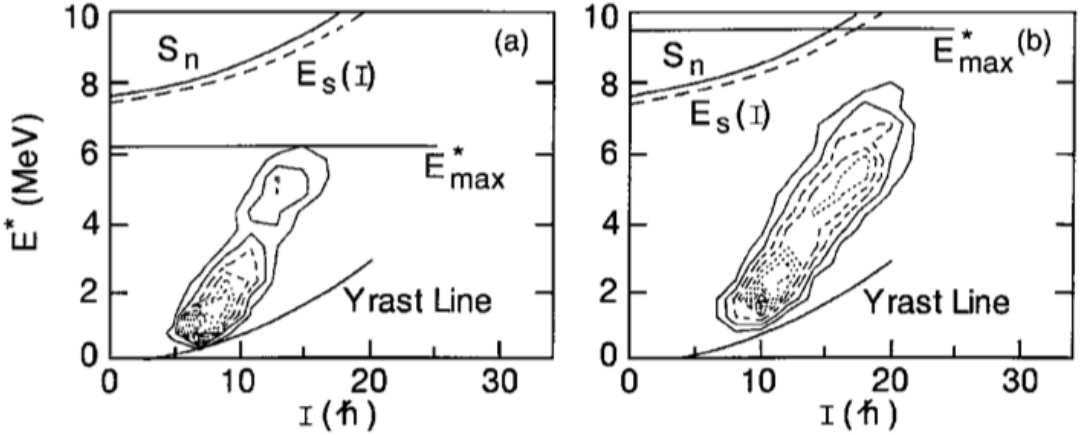
↓

Total energy E^*
Total spin I



Maximum energy & spin in ^{254}No

P. Reiter et al., Phys. Rev. Lett. 84 (2000) 3542



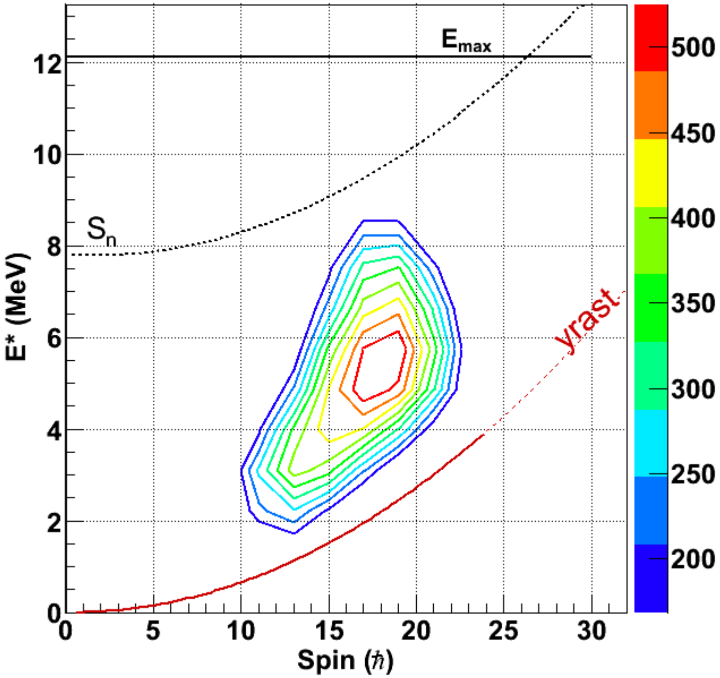
E_{beam}=215 MeV

$E_{CN} \approx$ 19.3 MeV

E_{beam}=219 MeV

$E_{CN} \approx$ 22.7 MeV

G. Henning, T.L. Khoo, A. Lopez-Martens et al.,
PRELIMINARY



E_{beam}=223 MeV

$E_{CN} \approx$ 25.4 MeV

Increase in the maximum spin going from E_b=219 to 223 MeV

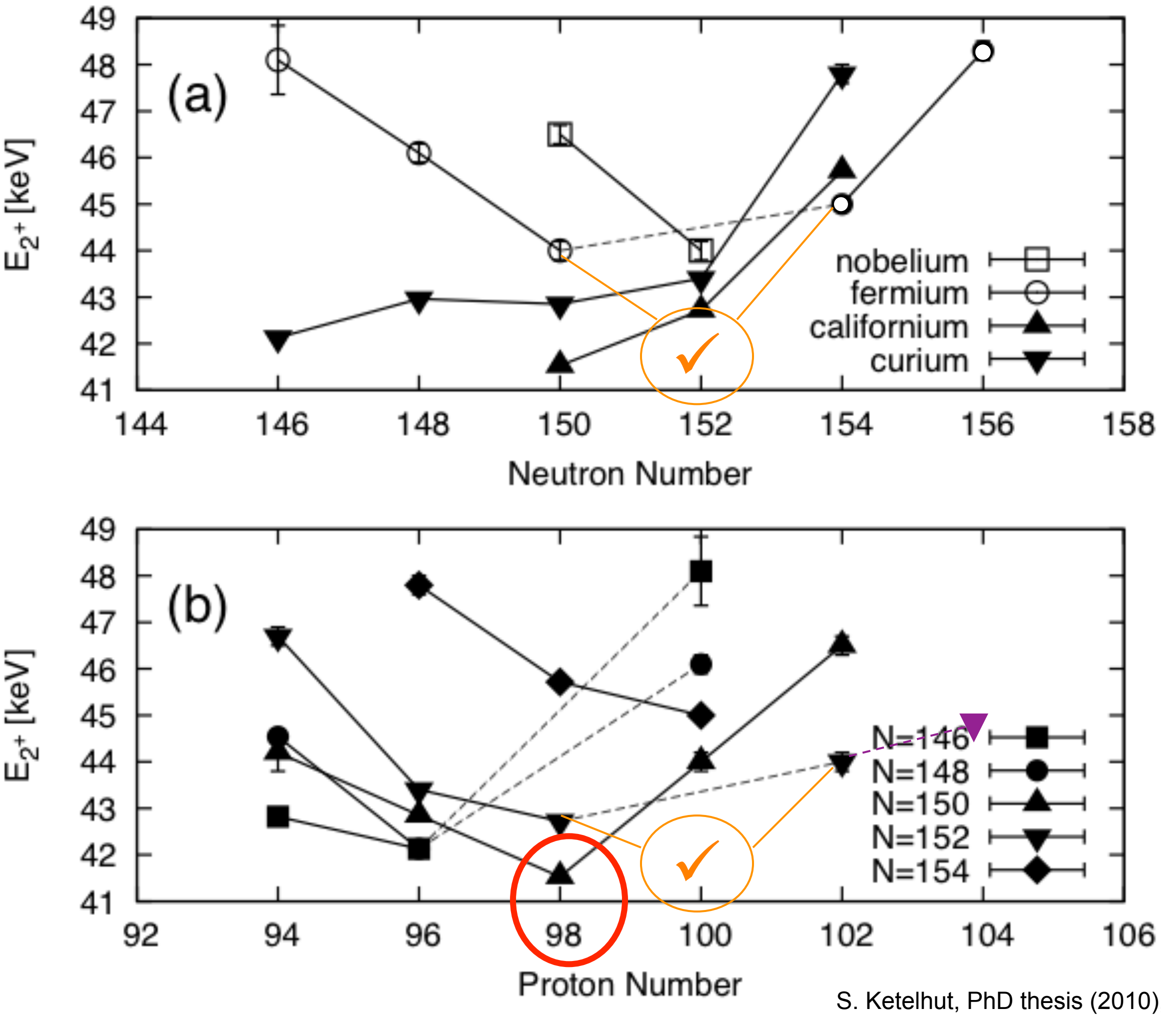
Saturation in E* ⇔ direct barrier effect

E_2^+ energies

Pairing correlations are reduced at a deformed shell gap

⇨ larger $\mathfrak{I}$ ⇨smaller E_2^+

A. Sobiczewski, I. Muntian, and Z. Patyk., Phys. Rev. C. 63 (2001) 034306



New data for ^{252}Fm:
(α-decay of ^{256}No, priv. com. from M. Asai et al.,)

gap @ N=152 & 100

New data for 256Rf:

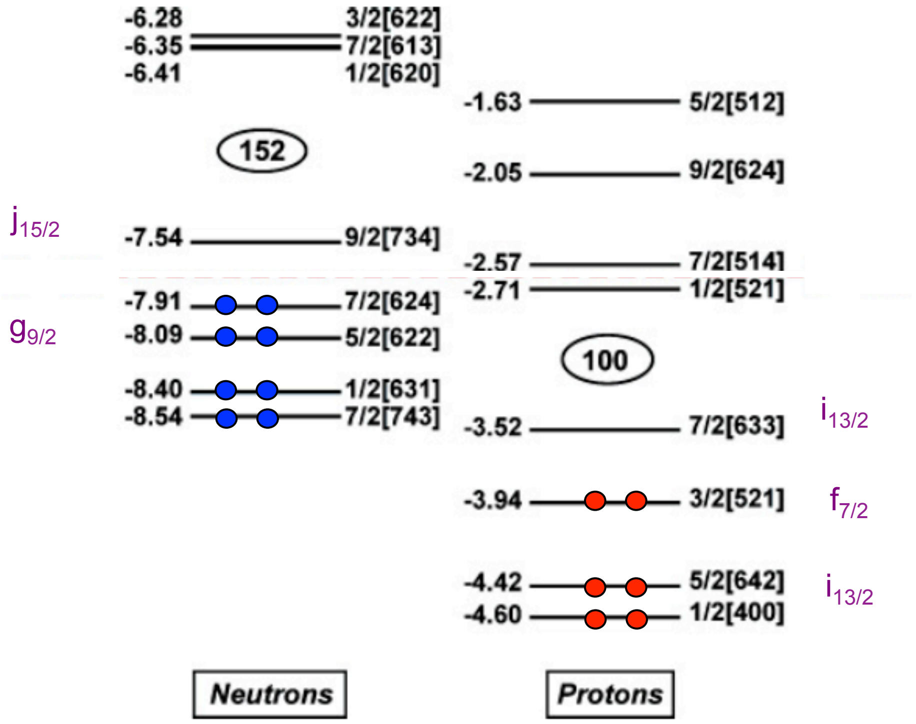
No significant gap @ Z=104

Strong collective effects in Cf

S. Ketelhut, PhD thesis (2010), University of Jyväskylä

Special ^{248}Cf

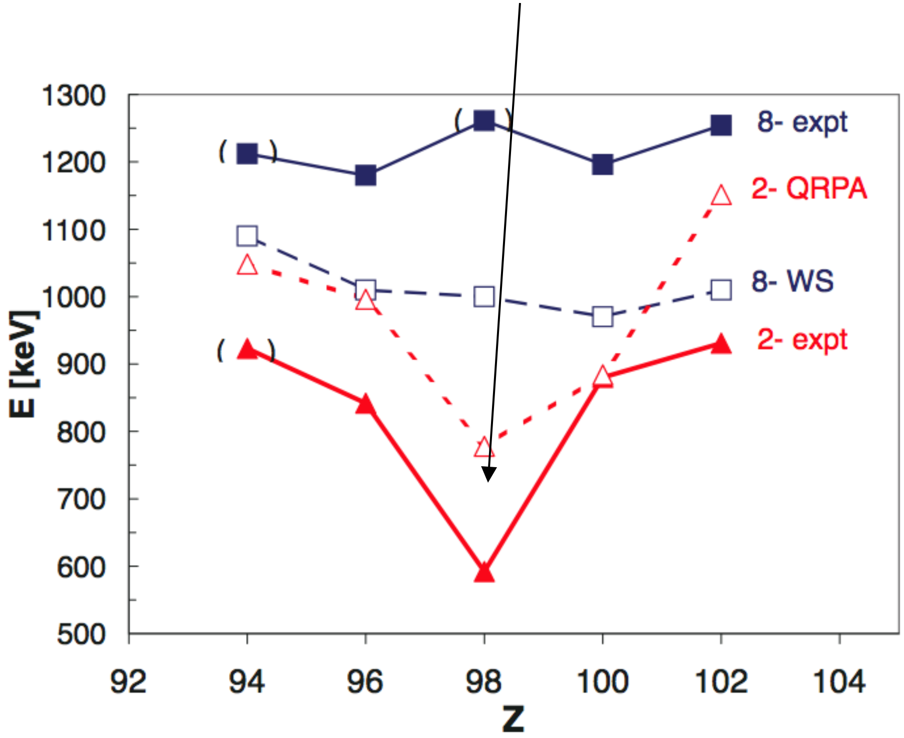
$\Delta j = \Delta l = 3$



s.p. levels for ^{252}No from the Woods-Saxon potential with the universal parameter set

2^{-}: $5/2+[622]\nu \otimes 9/2-[734]\nu$

$+\ 2^{-}\{7/2[633]\pi \otimes 3/2[621]\pi\}$



A.P. Robinson et al., Phys. Rev. C **78**, 034308 (2008)

Low energy of the 2- state in ^{248}Cf ⇨ near degeneracy of the $7/2[633]\pi$ and $3/2[621]\pi$ levels

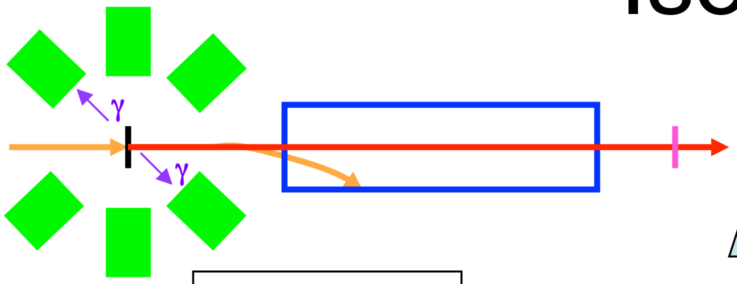
What do the models say ?

I. Ahmad et al., Phys. Rev. C 71 (2005) 054305

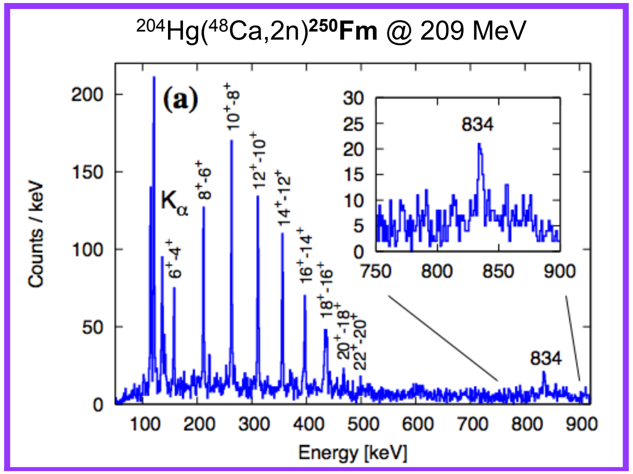
D. Seweryniak et al., Nucl. Phys. A 834 (2010) 357c

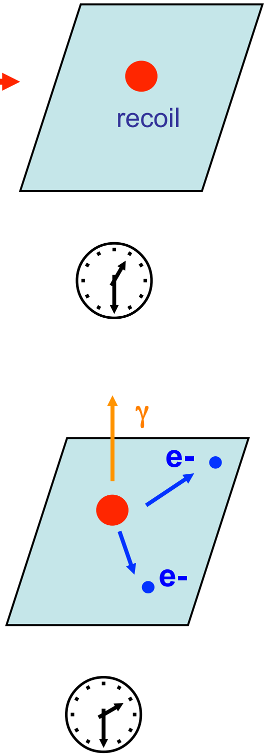
The position and nature of 2qp also reflects the energy and sequence of sp levels

Isomer-tagging



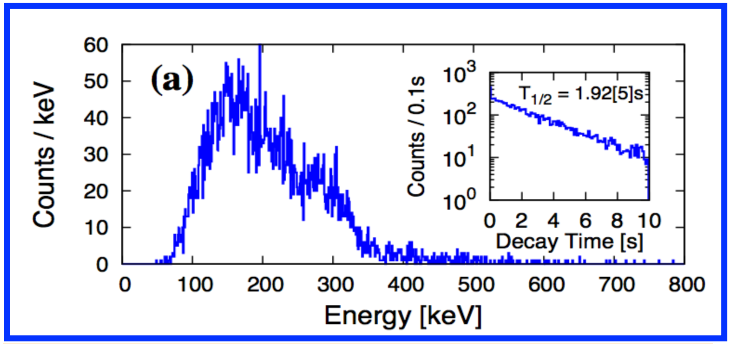
at the target

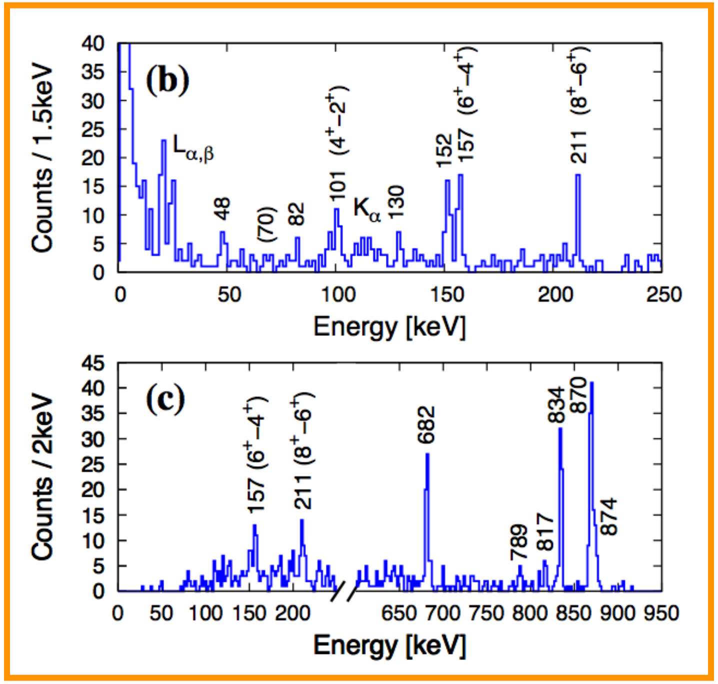

^{204}Hg(^{48}Ca,2n)^{250}**Fm** @ 209 MeV



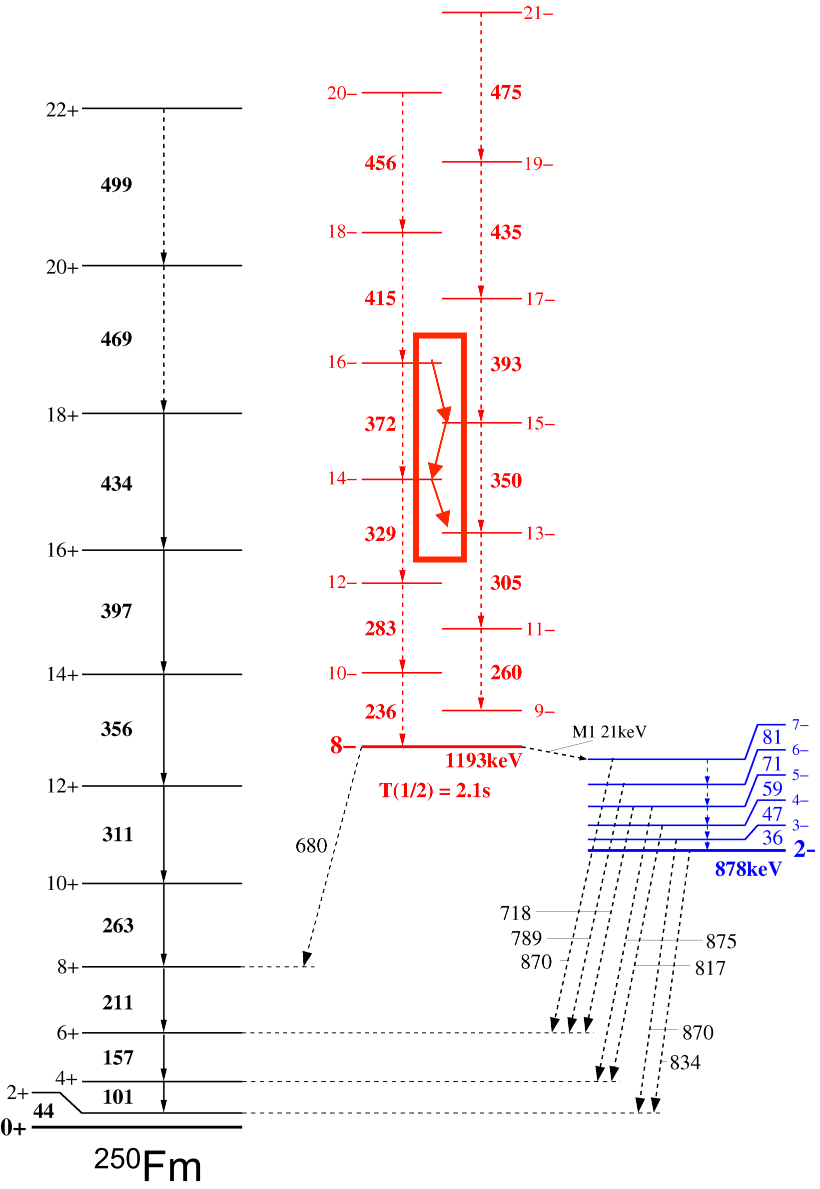
G.D. Jones calorimetric method : Nucl. Instr. Meth. A488 (2002) 471

at the focal plane





K=8$^-$ band in N=150 isotones



P. Greenlees et al., Phys. Rev. C 78 (2008) 021303(R)

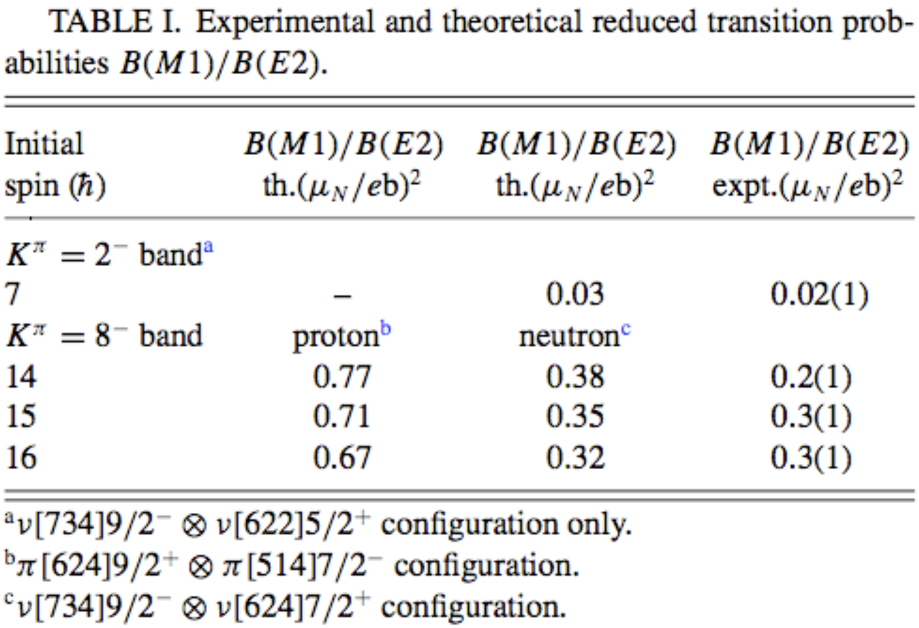


TABLE I. Experimental and theoretical reduced transition probabilities $B(M1)/B(E2)$.

Initial spin ($\hbar$)	$B(M1)/B(E2)$ th.$(\mu_N/eb)^2$	$B(M1)/B(E2)$ th.$(\mu_N/eb)^2$	$B(M1)/B(E2)$ expt.$(\mu_N/eb)^2$
$K^\pi = 2^-$ band[a]			
7	–	0.03	0.02(1)
$K^\pi = 8^-$ band	proton[b]	neutron[c]	
14	0.77	0.38	0.2(1)
15	0.71	0.35	0.3(1)
16	0.67	0.32	0.3(1)

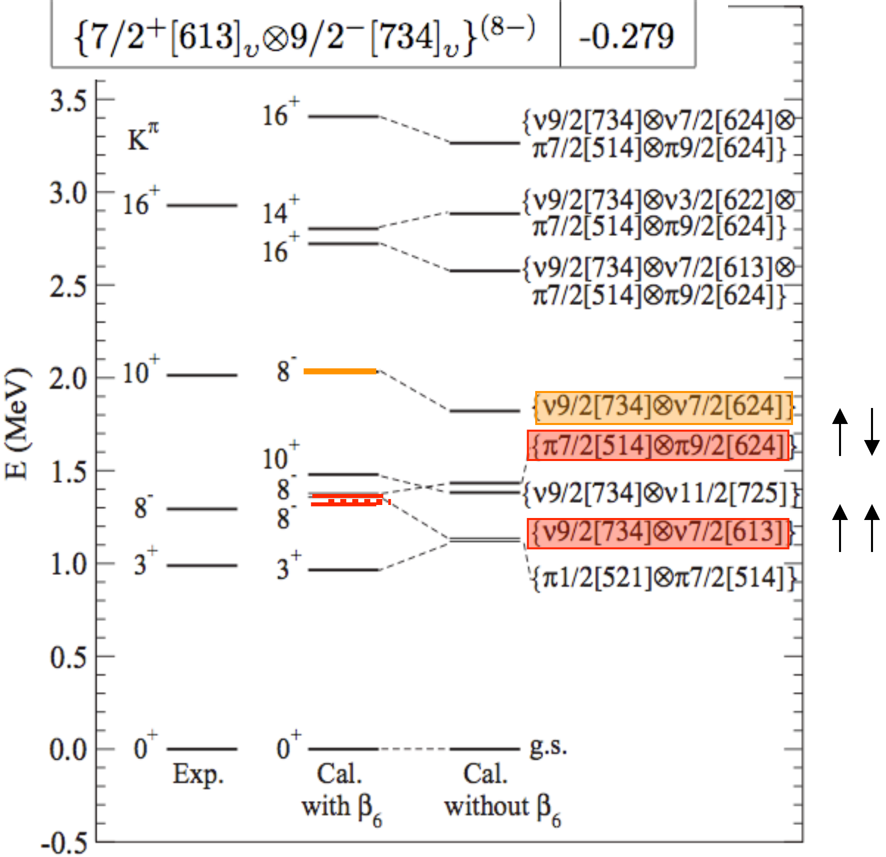
[a] $\nu[734]9/2^- \otimes \nu[622]5/2^+$ configuration only.
[b] $\pi[624]9/2^+ \otimes \pi[514]7/2^-$ configuration.
[c] $\nu[734]9/2^- \otimes \nu[624]7/2^+$ configuration.

^{252}No: 0.109 s K=8$^-$ state also unambiguously assigned as a 7/2$^+$[624]ν ⊗ 9/2$^-$[734] ν configuration

B. Sulignano et al., to be published

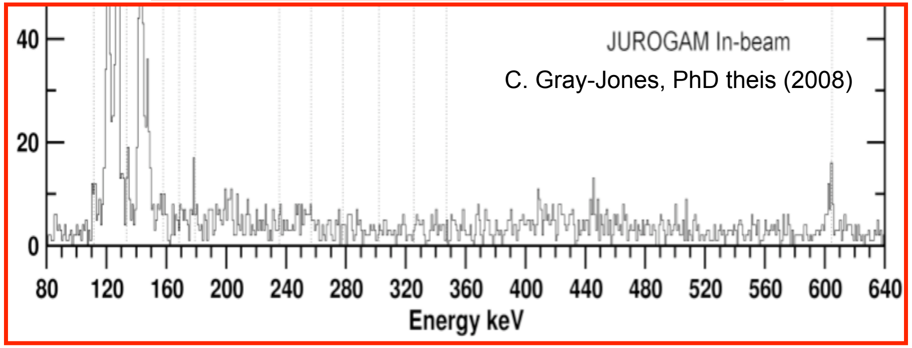
What about the K=8- band in ^{254}No ?

Configuration	g_K
$\{7/2^-[514]_\pi \otimes 9/2^+[624]_\pi\}^{(8-)}$	1.006
$\{7/2^+[624]_\nu \otimes 9/2^-[734]_\nu\}^{(8-)}$	-0.021
$\{7/2^+[613]_\nu \otimes 9/2^-[734]_\nu\}^{(8-)}$	-0.279

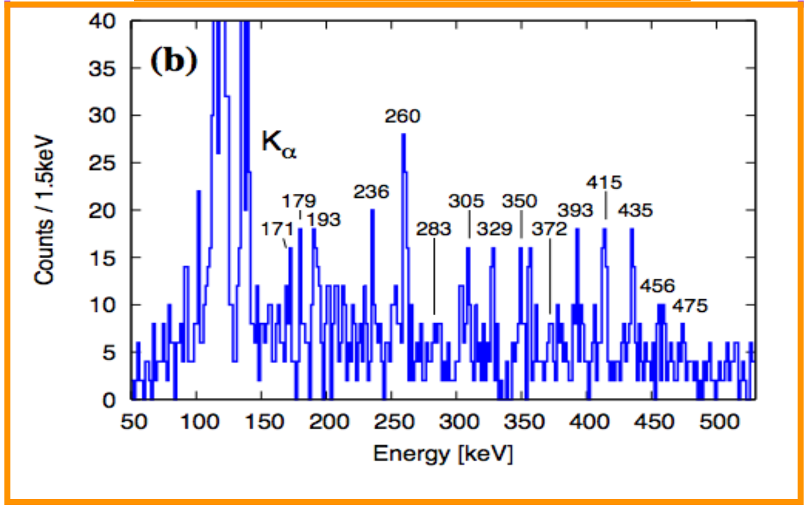


H.L. Liu, F. R. Xu, P.M. Walker and C.A. Bertulani, Phys. Rev. C 823(2011) 011303(R)
Woods-Saxon potential with the set of universal parameters

^{254}No: 266ms-8$^-$-isomer-tagged



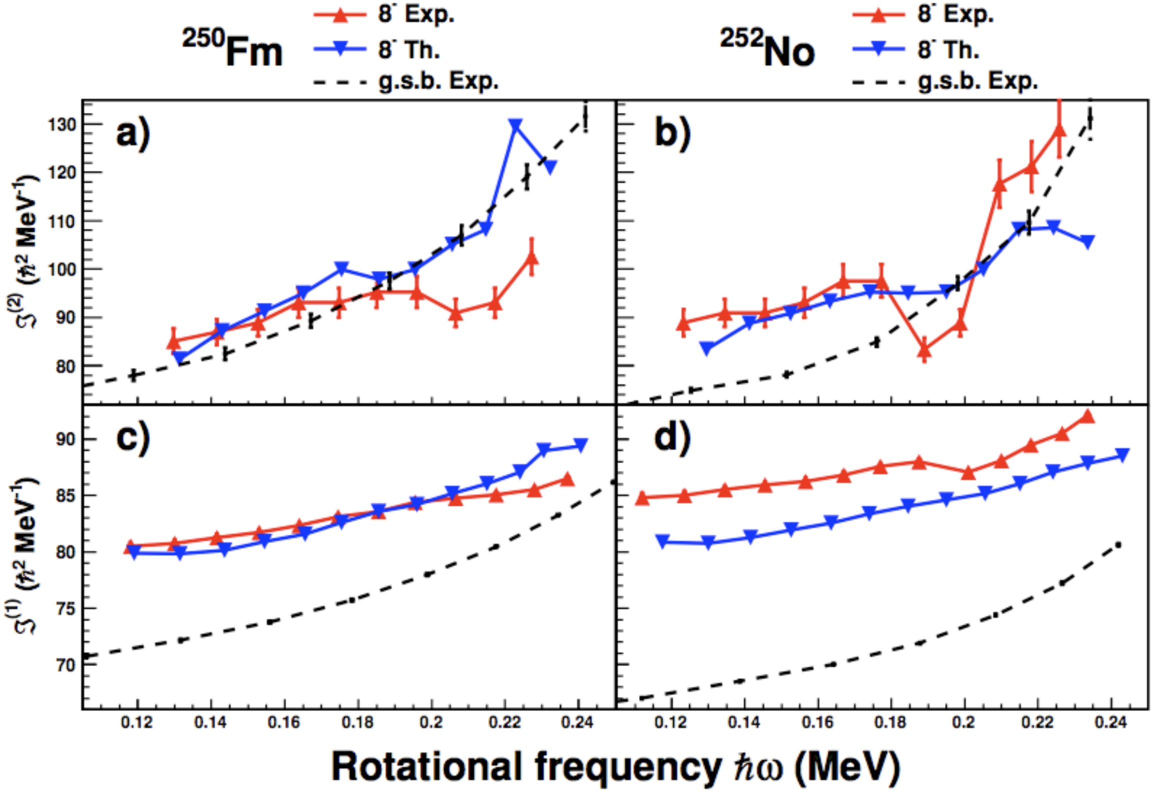
^{250}Fm: 2s-8$^-$-isomer-tagged

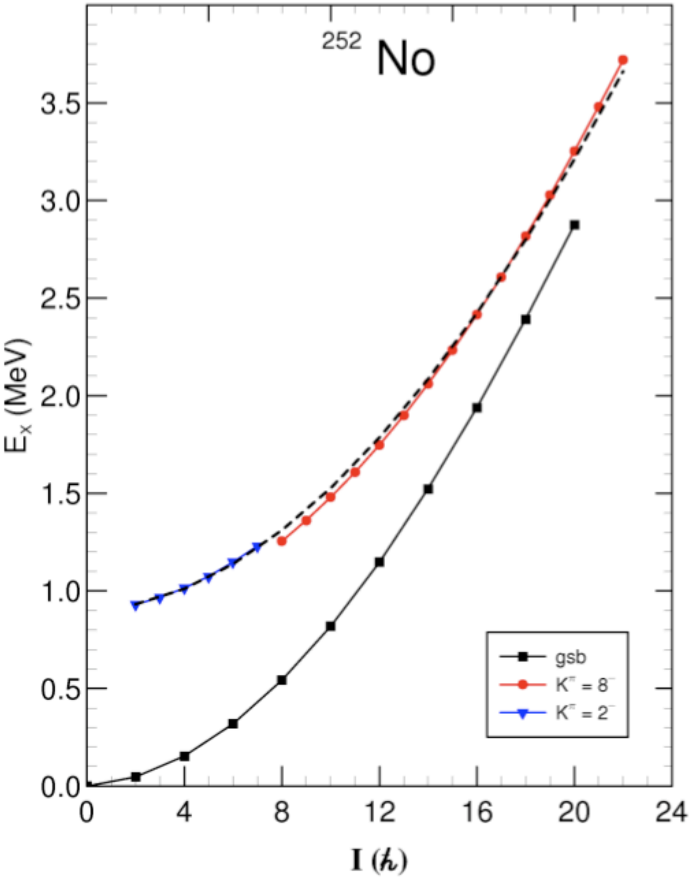


Experiment accepted @ JYFL to study the structure of the high-K state in ^{254}No (P. Papadakis et al.,)

Kinks in the moments of inertia

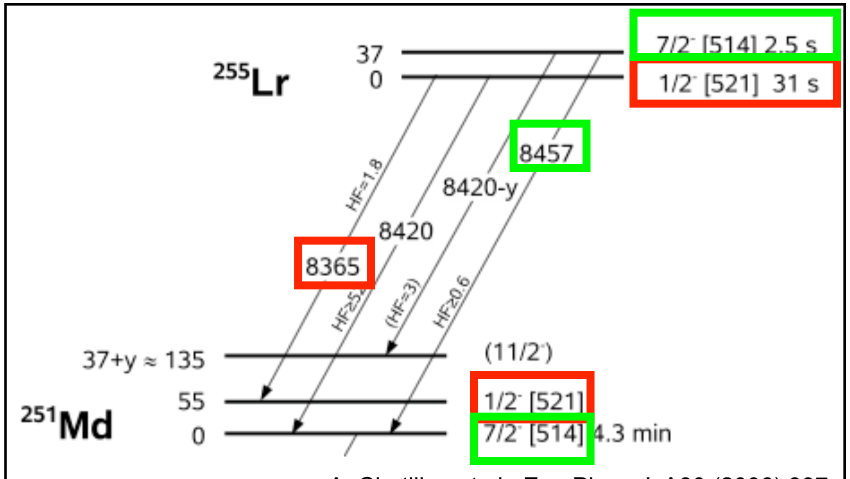
B. Sulignano et al., to be published





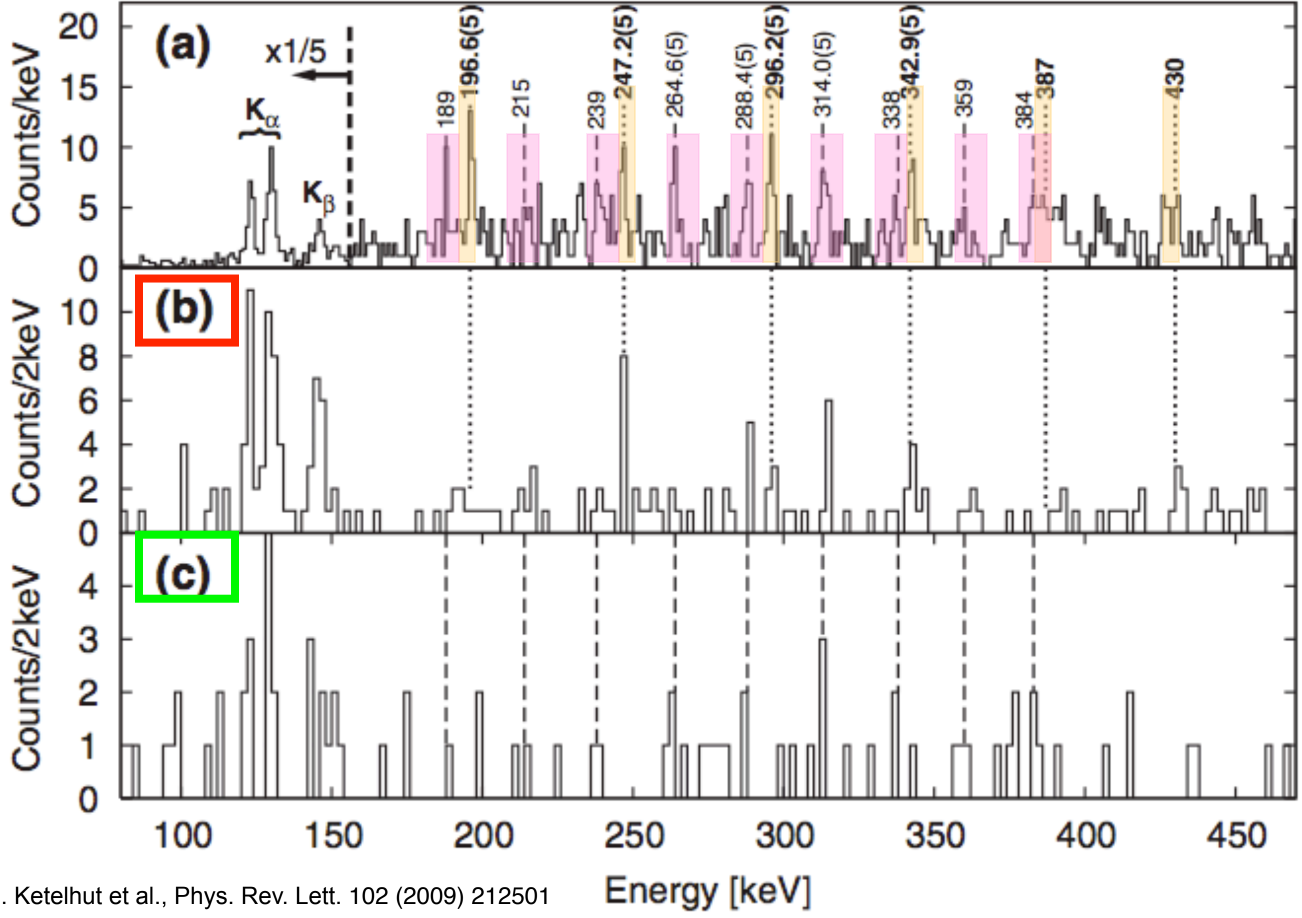
theory: triaxial HBF calculations using D1S force and breaking time-reversal and z-signature symmetries
J. -P. Delaroche et al., Nucl. Phys. A 771, 103 (2006)

Electromagnetic properties in o-e nuclei

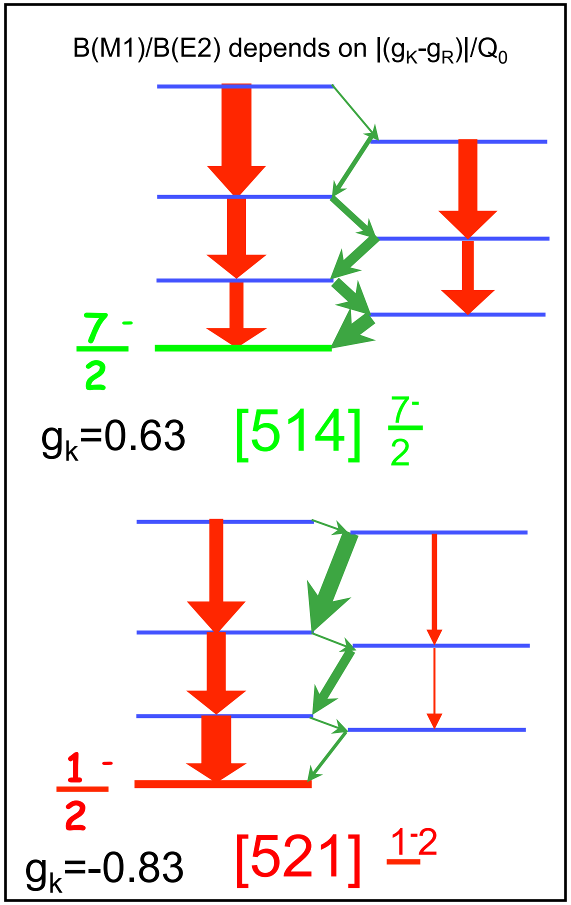


A. Chatillon et al., Eur. Phys. J. A30 (2006) 397

^{209}Bi(^{48}Ca,2n)^{255}Lr



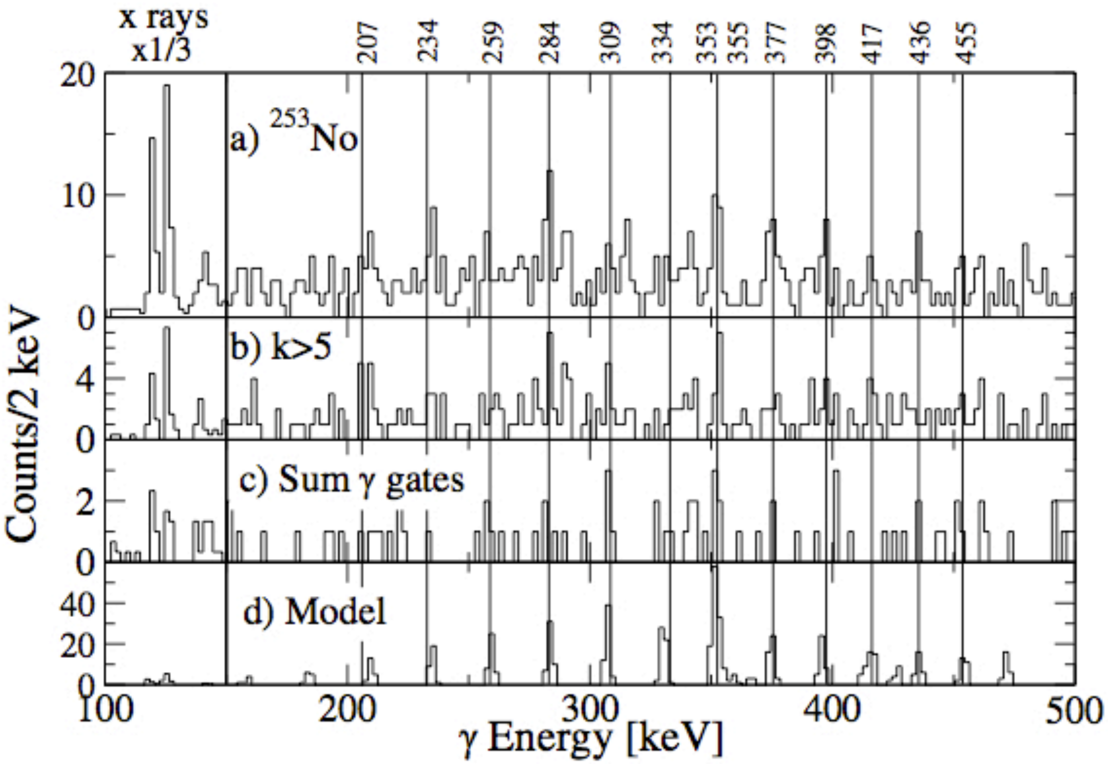
S. Ketelhut et al., Phys. Rev. Lett. 102 (2009) 212501



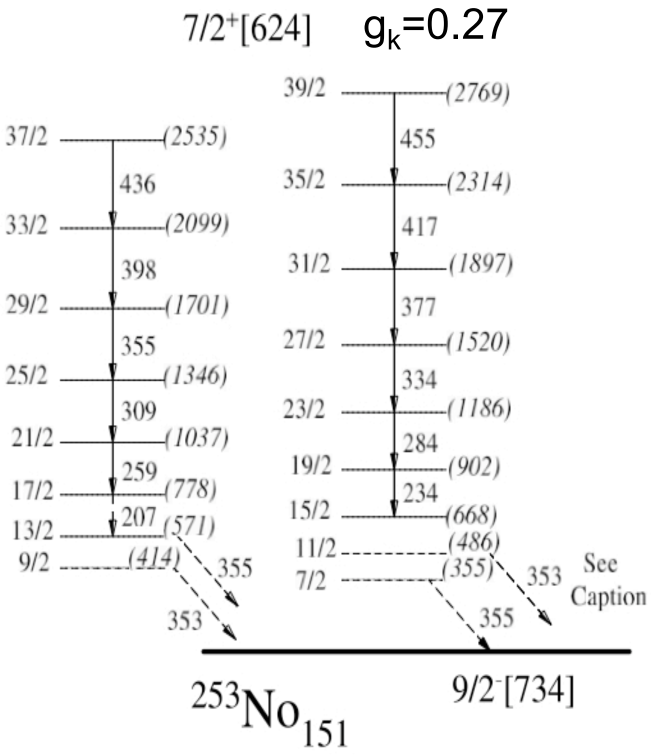
B(M1)/B(E2) depends on $|(g_K-g_R)|/Q_0$

Case of ^{253}No

^{207}Pb(^{48}Ca,2n)^{253}No,
α-decay: gs based on ν9/2$^-$[734] state g$_k$= -0.24

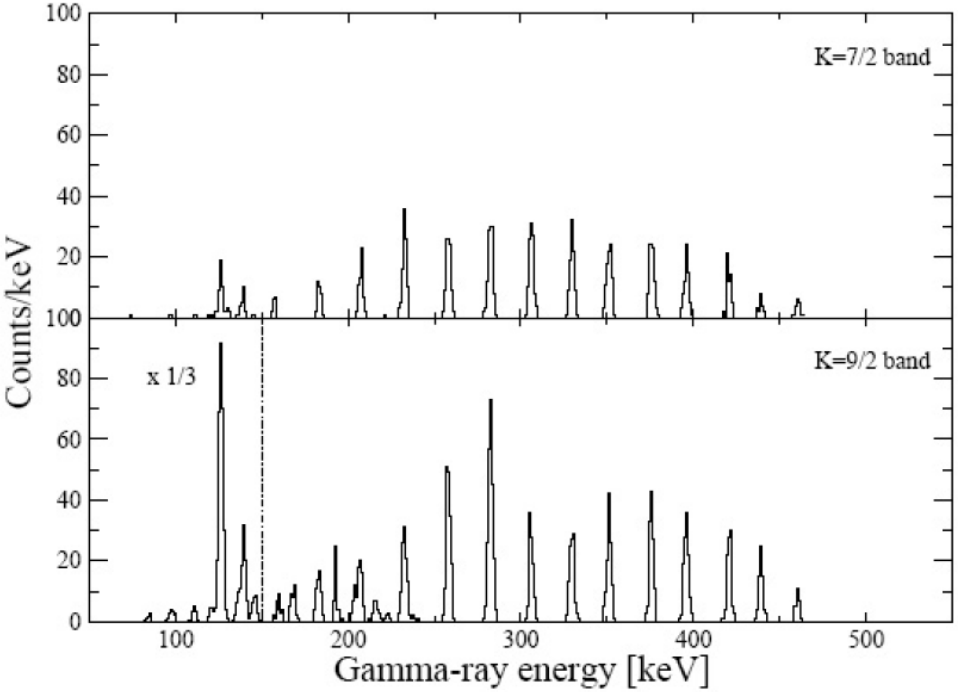


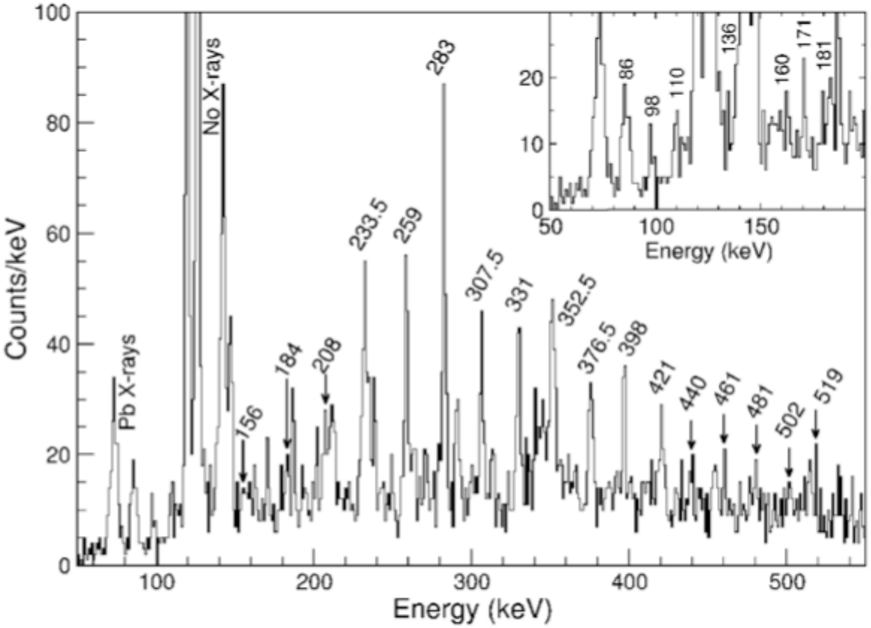
P. Reiter et al. Phys. Rev. Lett. 95 (2005) 032501



^{253}No: gs or excited band ?

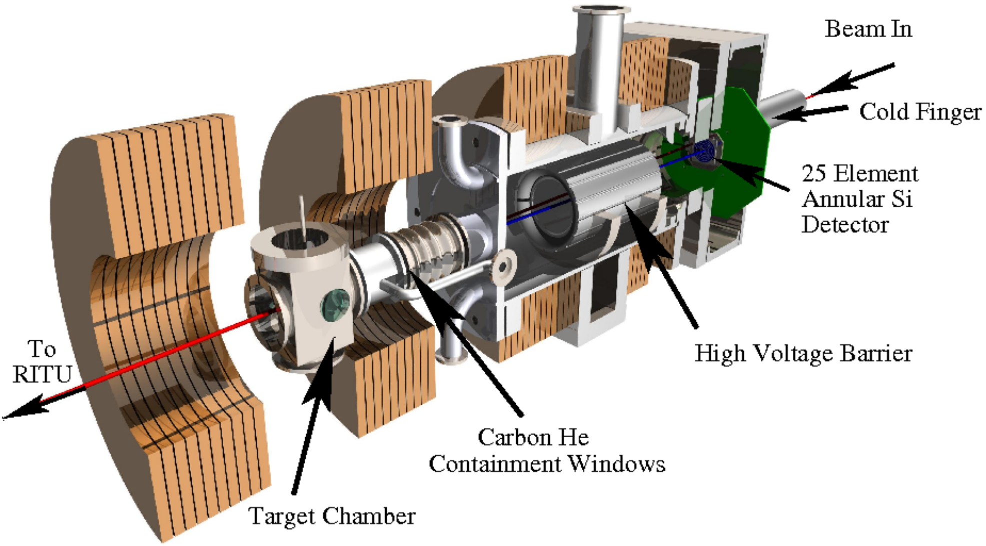
Sarah Eeckhaudt, PhD thesis,University of Jyväskylä, 2006
R.D.Herzberg, et al.,Eur. Phys. J. A42 (2009) 333.



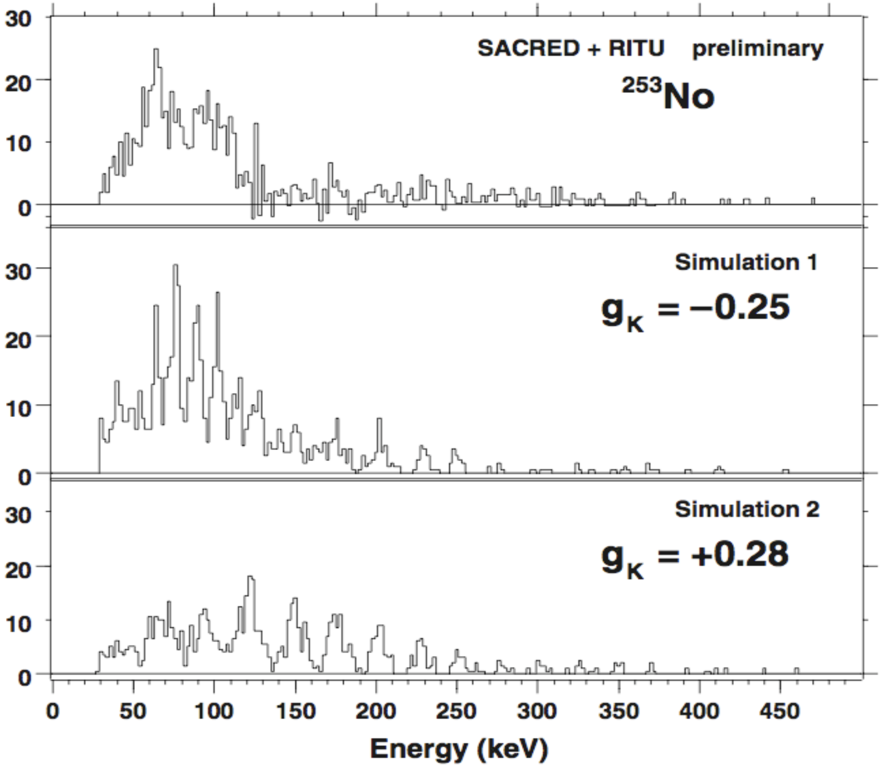


Prompt electron spectroscopy

SACRED (Silicon Array for ConveRsion Electron Detection)



H. Kankaanpää et al., Nucl. Instr. Meth. A 534 (2004) 503
P. Butler et al., Nucl. Instr. Meth. A 381 (1996) 433

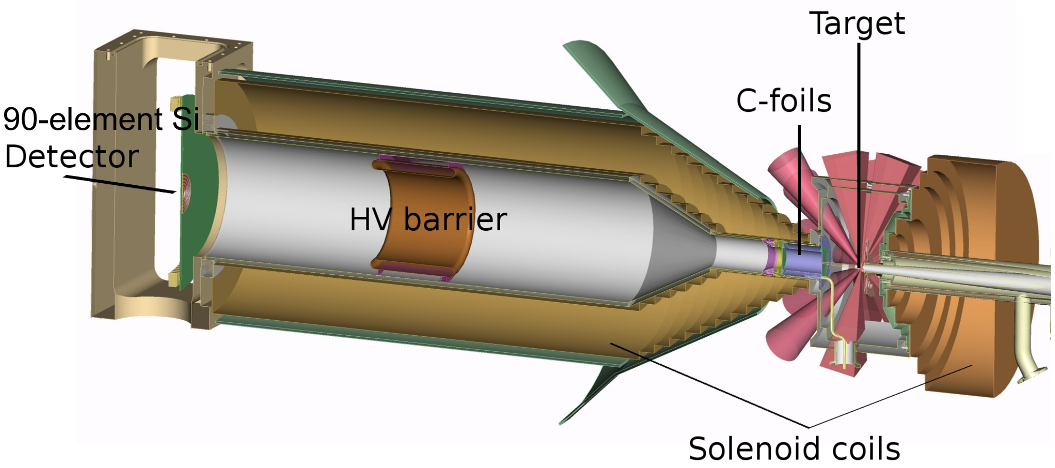


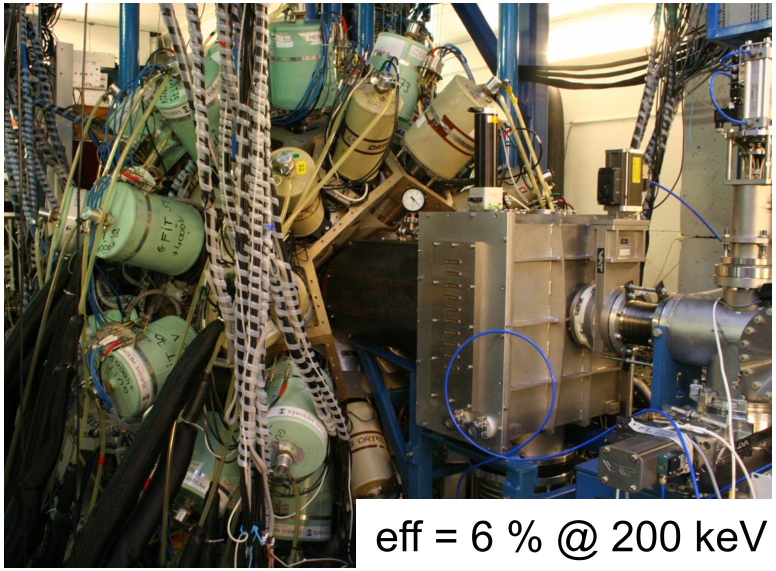
R. Herzberg et al., J. Phys. G: Nucl. Part. Phys. **30** (2004) R123

Observed spectrum is consistent with a band built on the ν7/2$^-$[734] state

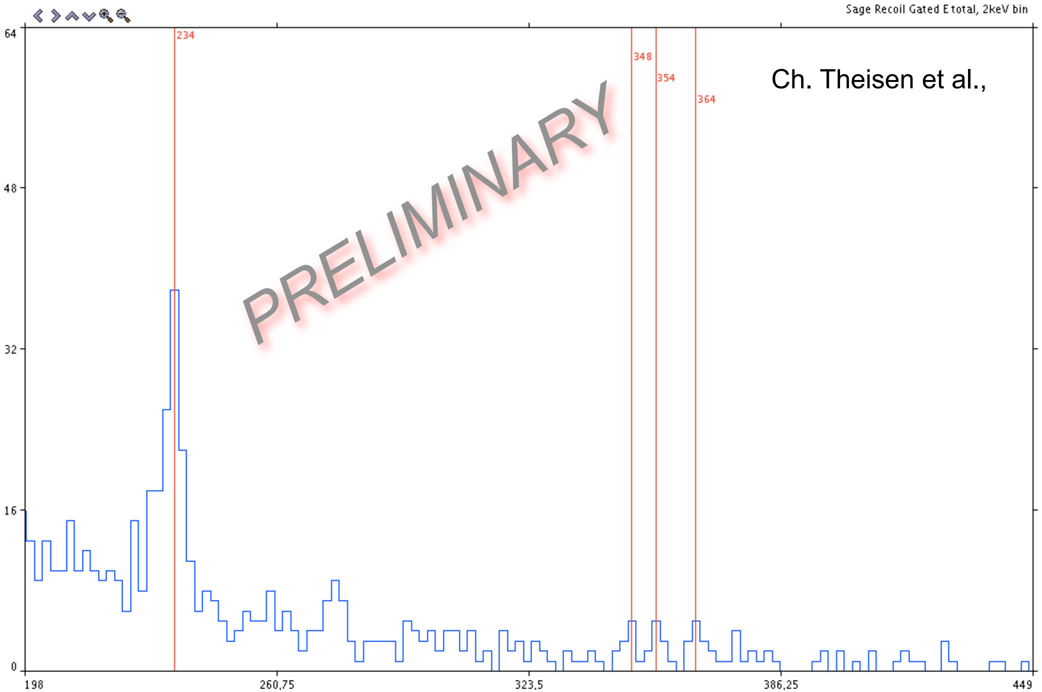
^{253}No & ^{255}Lr revisited recently with SAGE

Silicon And GErmanium array





eff = 6 % @ 200 keV



Ch. Theisen et al.,

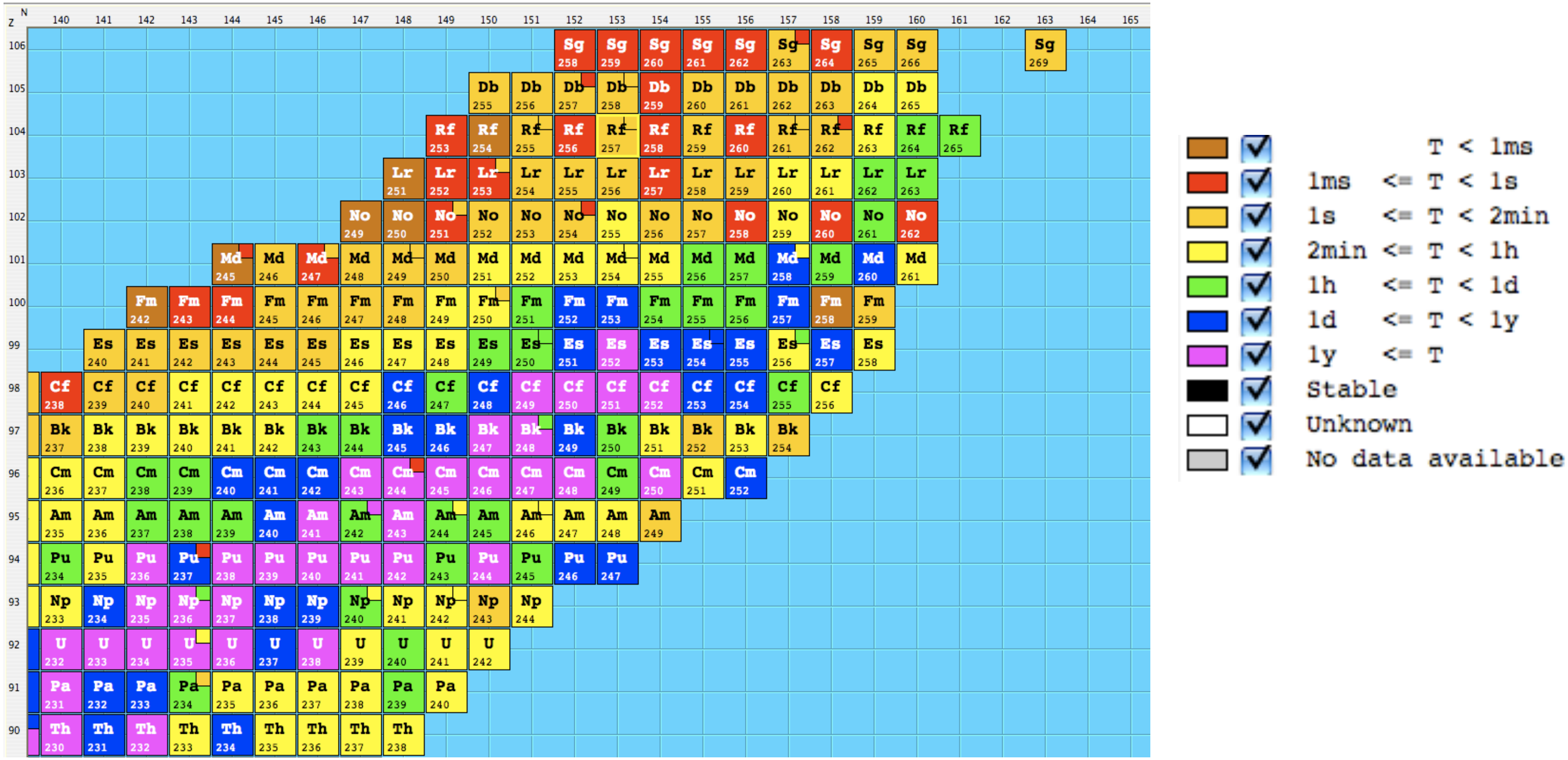
^{205}Tl(^{48}Ca,2n)^{251}Md

recoil-gated e$^-$ spectrum:

clear signal of the conversion of a 390 keV M1 transition

Issues (1)

- availability of long-lived (trans)actinide targets
- maximum allowed activity at various facilities and other security issues
- count rates in the arrays due to the activity of the target



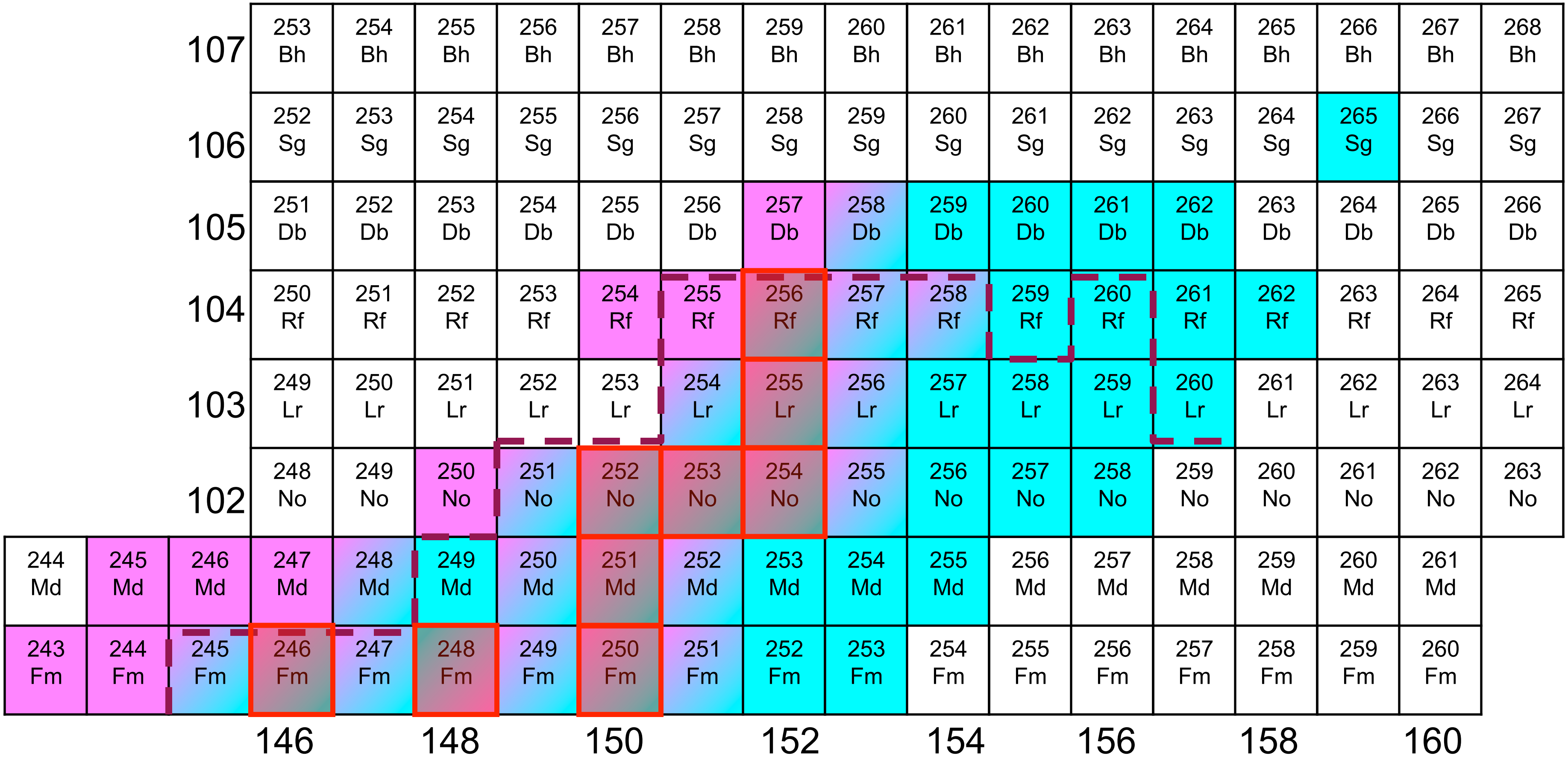
🟫	☑	T < 1ms
🟥	☑	1ms <= T < 1s
🟧	☑	1s <= T < 2min
🟨	☑	2min <= T < 1h
🟩	☑	1h <= T < 1d
🟦	☑	1d <= T < 1y
🟪	☑	1y <= T
⬛	☑	Stable
⬜	☑	Unknown
▨	☑	No data available

Issues (2)

What statistics is required to perform “meaningful” & unambiguous spectroscopy ?

$_{78}$Pt,$_{79}$Au,$_{80}$Hg,$_{81}$Tl,$_{82}$Pb,$_{83}$Bi targets

$_{90}$Th, $_{92}$U, $_{94}$Pu, $_{95}$Am, $_{96}$Cm targets



107				253 Bh	254 Bh	255 Bh	256 Bh	257 Bh	258 Bh	259 Bh	260 Bh	261 Bh	262 Bh	263 Bh	264 Bh	265 Bh	266 Bh	267 Bh	268 Bh
106				252 Sg	253 Sg	254 Sg	255 Sg	256 Sg	257 Sg	258 Sg	259 Sg	260 Sg	261 Sg	262 Sg	263 Sg	264 Sg	265 Sg	266 Sg	267 Sg
105				251 Db	252 Db	253 Db	254 Db	255 Db	256 Db	257 Db	258 Db	259 Db	260 Db	261 Db	262 Db	263 Db	264 Db	265 Db	266 Db
104				250 Rf	251 Rf	252 Rf	253 Rf	254 Rf	255 Rf	256 Rf	257 Rf	258 Rf	259 Rf	260 Rf	261 Rf	262 Rf	263 Rf	264 Rf	265 Rf
103				249 Lr	250 Lr	251 Lr	252 Lr	253 Lr	254 Lr	255 Lr	256 Lr	257 Lr	258 Lr	259 Lr	260 Lr	261 Lr	262 Lr	263 Lr	264 Lr
102				248 No	249 No	250 No	251 No	252 No	253 No	254 No	255 No	256 No	257 No	258 No	259 No	260 No	261 No	262 No	263 No
	244 Md	245 Md	246 Md	247 Md	248 Md	249 Md	250 Md	251 Md	252 Md	253 Md	254 Md	255 Md	256 Md	257 Md	258 Md	259 Md	260 Md	261 Md	
	243 Fm	244 Fm	245 Fm	246 Fm	247 Fm	248 Fm	249 Fm	250 Fm	251 Fm	252 Fm	253 Fm	254 Fm	255 Fm	256 Fm	257 Fm	258 Fm	259 Fm	260 Fm	
				146		148		150		152		154		156		158		160	

σ = current 10 nb limit

Issues (3)

- How can we go further ?

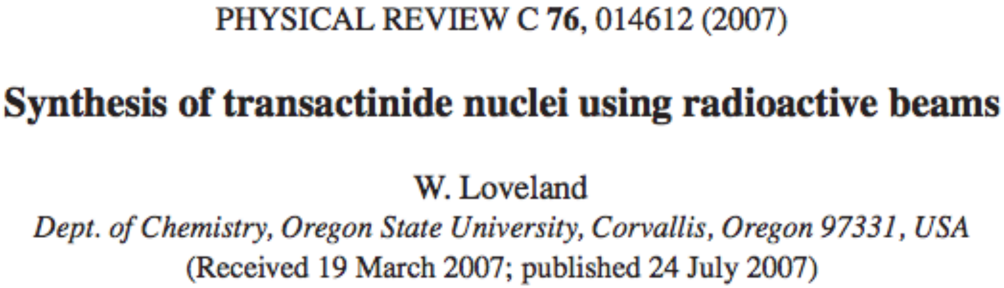
new arrays/focal plane setups: x 2-4
more beam: x 2-5
better transmission (reaction-dependent): x 1.5-2

⇒

~1-2 places to the right
~2-3 places up

-Should we concentrate on getting more detailed data (other observables ?) on lighter species ?

- What production rates do we expect for fusion with RIBS ?



PHYSICAL REVIEW C **76**, 014612 (2007)

Synthesis of transactinide nuclei using radioactive beams

W. Loveland
Dept. of Chemistry, Oregon State University, Corvallis, Oregon 97331, USA
(Received 19 March 2007; published 24 July 2007)

- What cross-sections do we expect in multi-nucleon transfer: ^{238}U+^{232}Th, ^{248}Cm...?

-Problem of clean recoil tag in the case of very low production cross sections and transmission in the case of hot fusion reactions with light projectiles (separator-dependent)

Conclusion & Perspectives

- a lot of new & interesting data
- complementarity with decay data

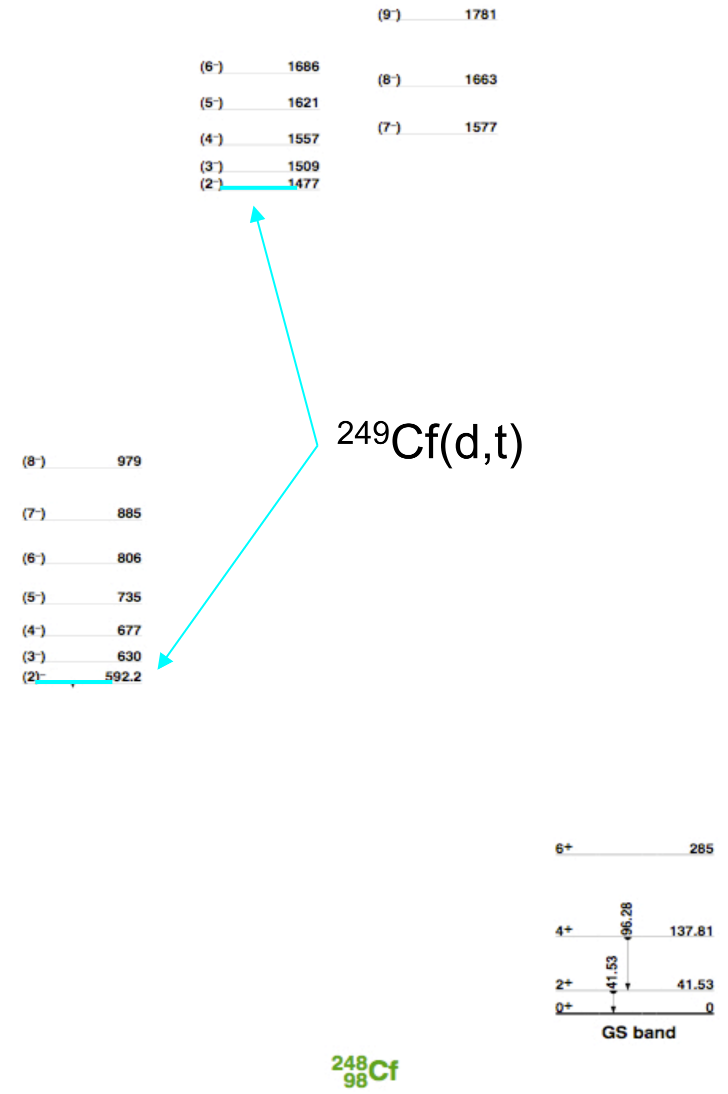
Exciting times ahead !

- prompt conversion-electron with SAGE
- prompt spectroscopy with GRETINA & AGATA's enhanced efficiency
- upgrades/improvements to existing setups and facilities
- new modes of production: fusion with RIBS and multi-nucleon transfer

(cross sections x beam intensities ?)

Evidence for phonon states (1)

S.W. Yates et al., Phys. Rev. C12 (1975) 442



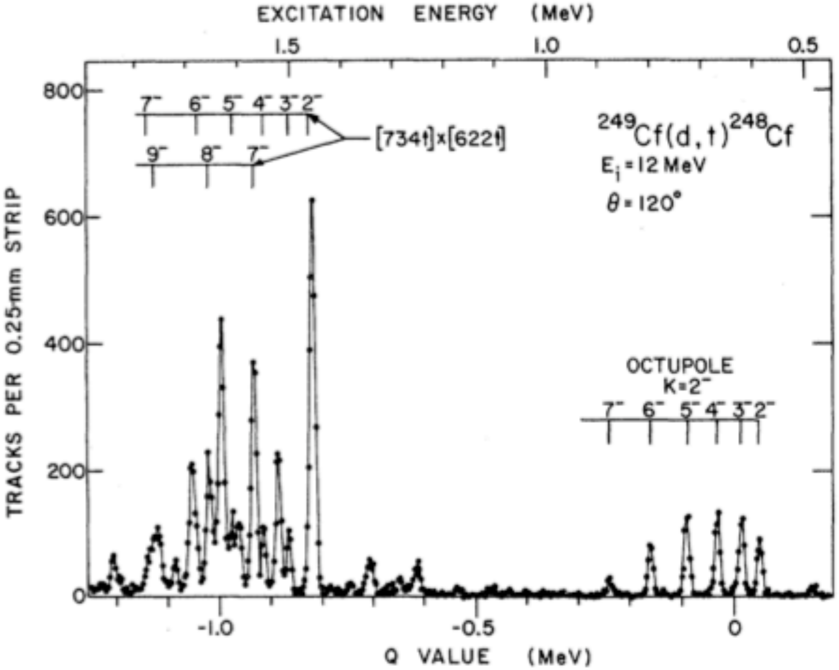


FIG. 2. Triton spectrum from the ^{249}Cf(*d*,*t*)^{248}Cf reaction observed at 120°. The spectrum was measured with a split-pole magnetic spectrograph.

Population of two 2^- states at 592 and 1477 keV in ^{248}Cf

Only 1 $K^\pi=2^-$ neutron 2qp state expected < 2 MeV: $\{9/2^-[734];5/2^+[622]\}\nu$

⇨ Other 2^- state must be predominantly a phonon state

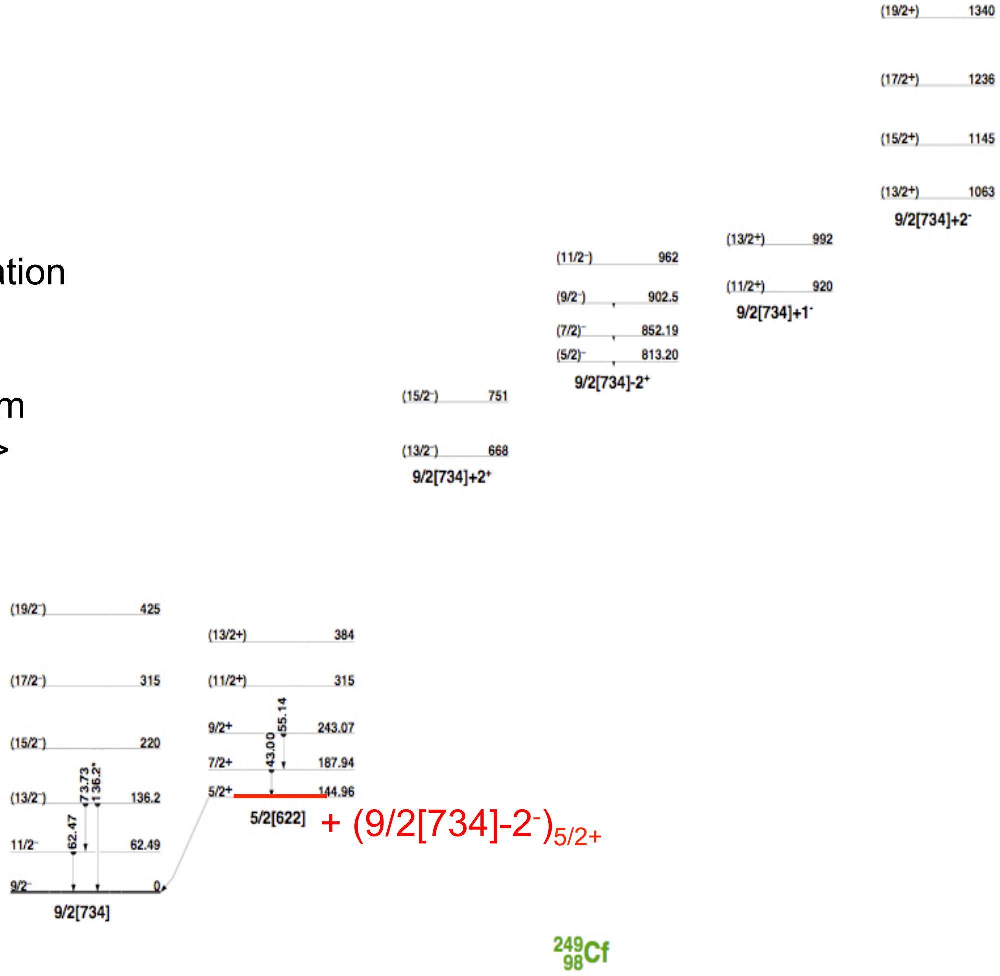
Evidence for phonon states (2)

^{249}Cf(d,d’):

sizeable population of 5/2^{+} state at 145 keV
=> mixing with the {9/2-[734]⊗2^{-} phonon} configuration

Phonon admixture into the 5/2+ state measured to be ~30% in ^{249}Cf (a similar value is obtained from the M2-E3 mixing ratio of the 145 keV transition => B(E3)=10 Wu)

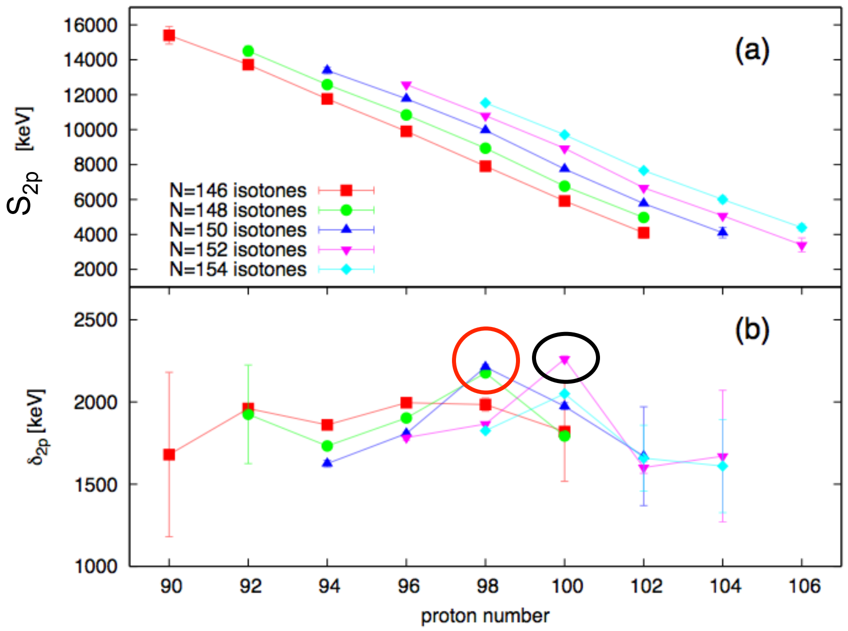
Phonon admixture deduced to be ~15% in ^{247}Cm from M2-E3 mixing ratio => B(E3)= 5 Wu

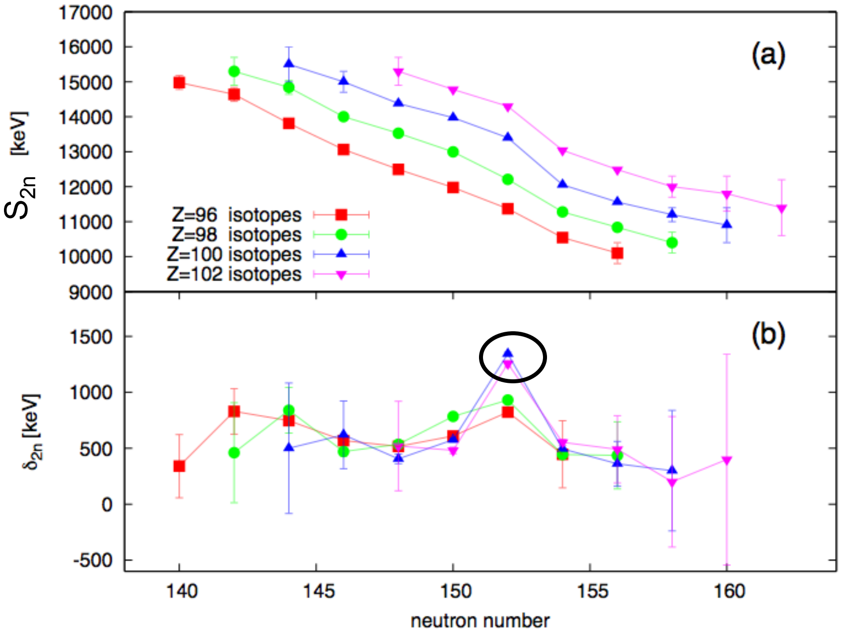


What do the masses say ?

$$
\begin{aligned}
\delta_{2n}(Z,N) &= S_{2n}(Z,N) - S_{2n}(Z,N+2)\,, \\
\delta_{2p}(Z,N) &= S_{2n}(Z,N) - S_{2n}(Z+2,N)\,.
\end{aligned}
$$

masses from AME2033





Gap @ Z=100 & N=152

Strong collective effects in Cf isotopes with peak effect @ N=150