What can we learn about the shapes of heavy nuclei from Coulex of radioactive beams?

Peter Butler

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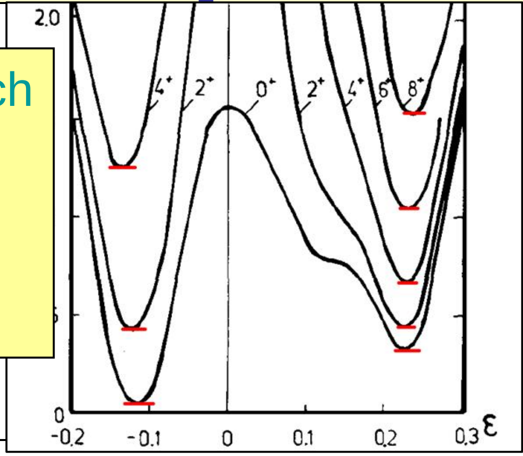
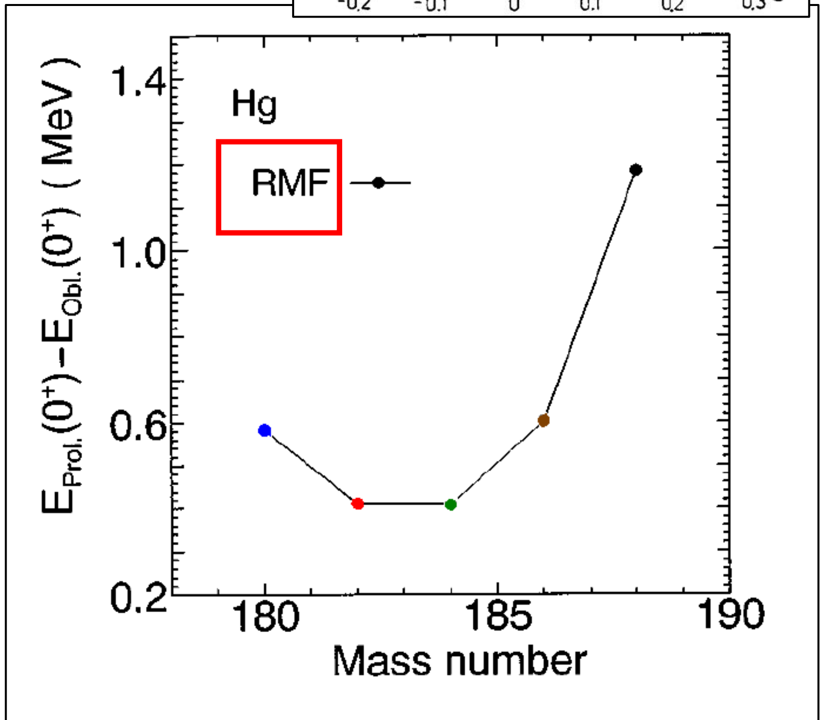
Shape coexistence in $^{182-188}Hg$

Octupole collectivity in ^{220}Rn, ^{224}Ra

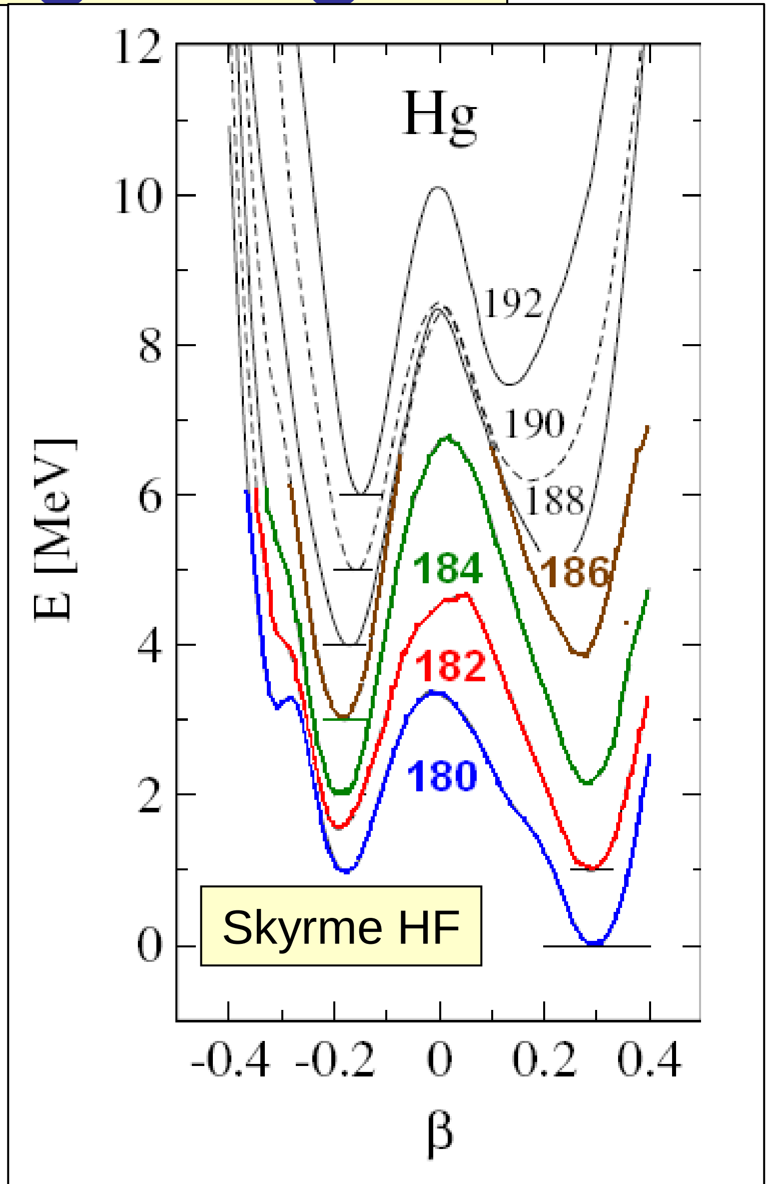
Shapes in light Hg

Frauendorf & Paskevich 1973
Nazarewicz et al.
PLB 305 (1993)195
^{182,184}**Hg oblate**



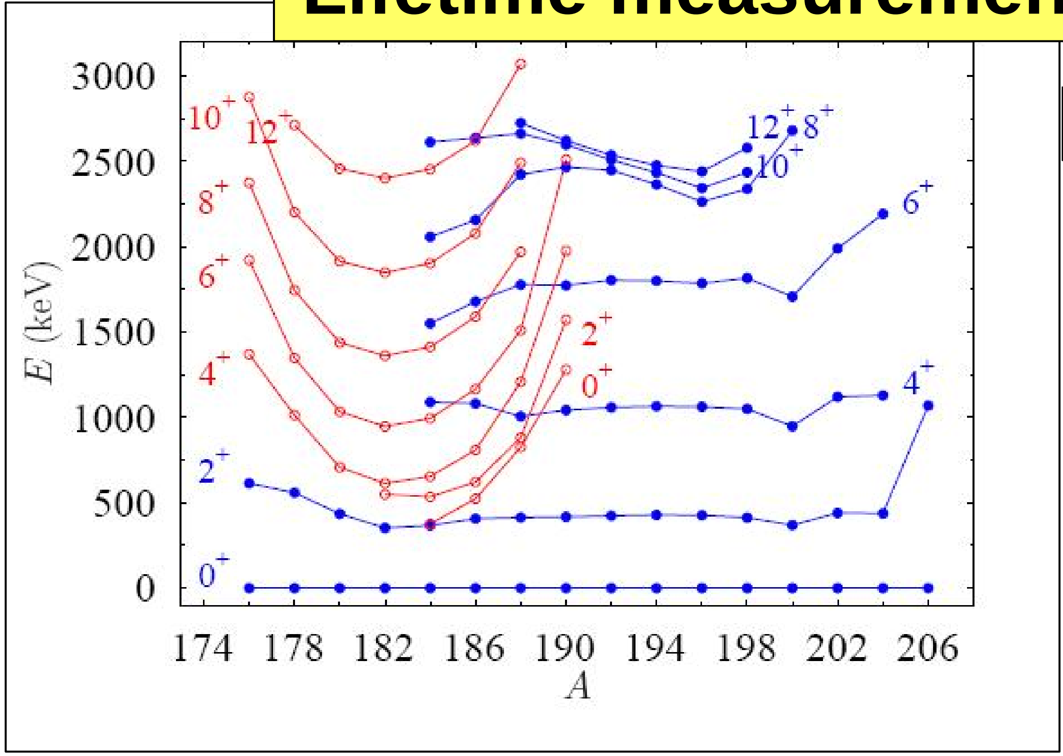


Yoshida and Takigawa
PRC 55 (1997)1255



Moreno et al.
PRC 73 (2006) 054302

Lifetime measurements in $^{180\text{-}186}Hg$

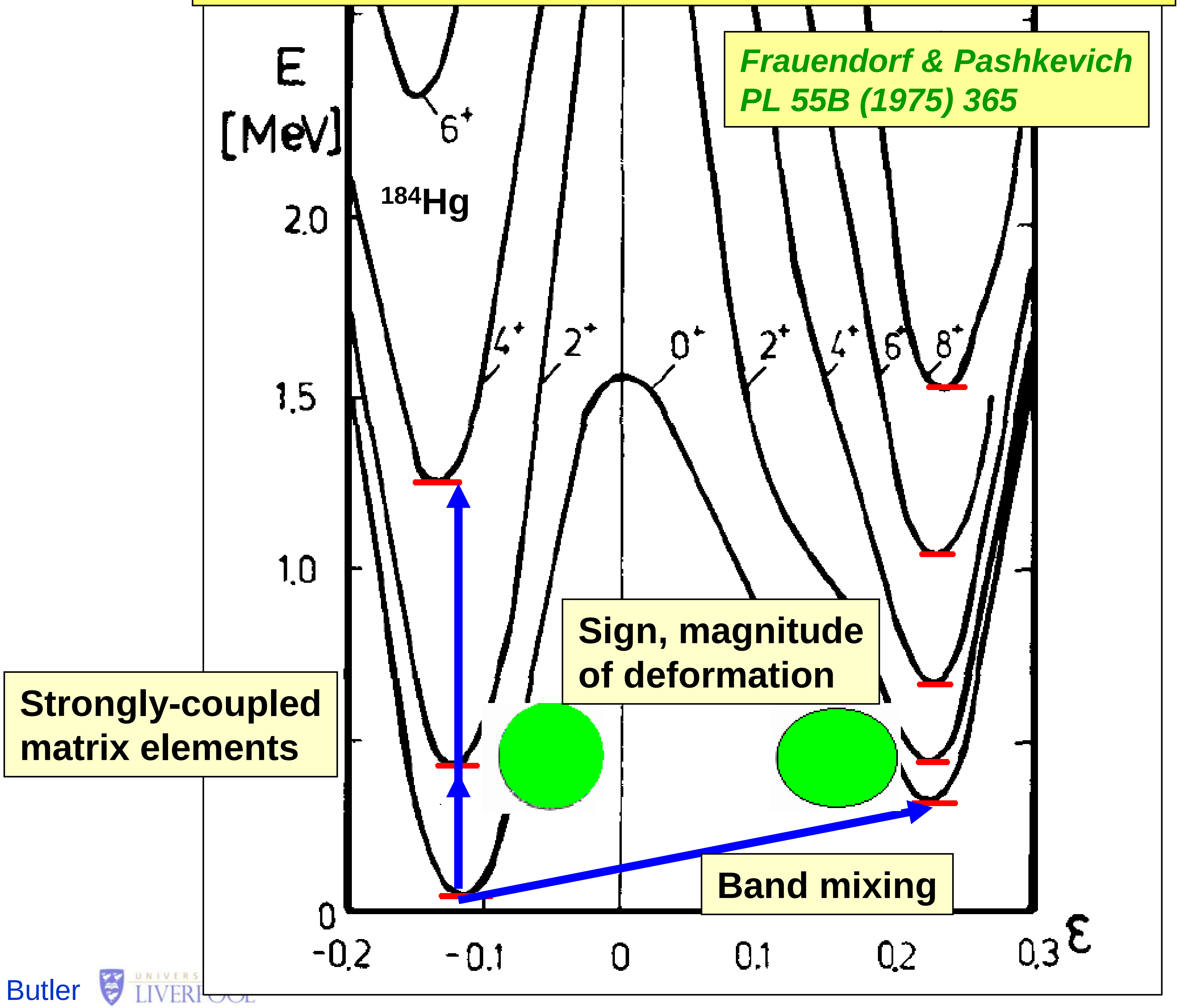


after R Julin

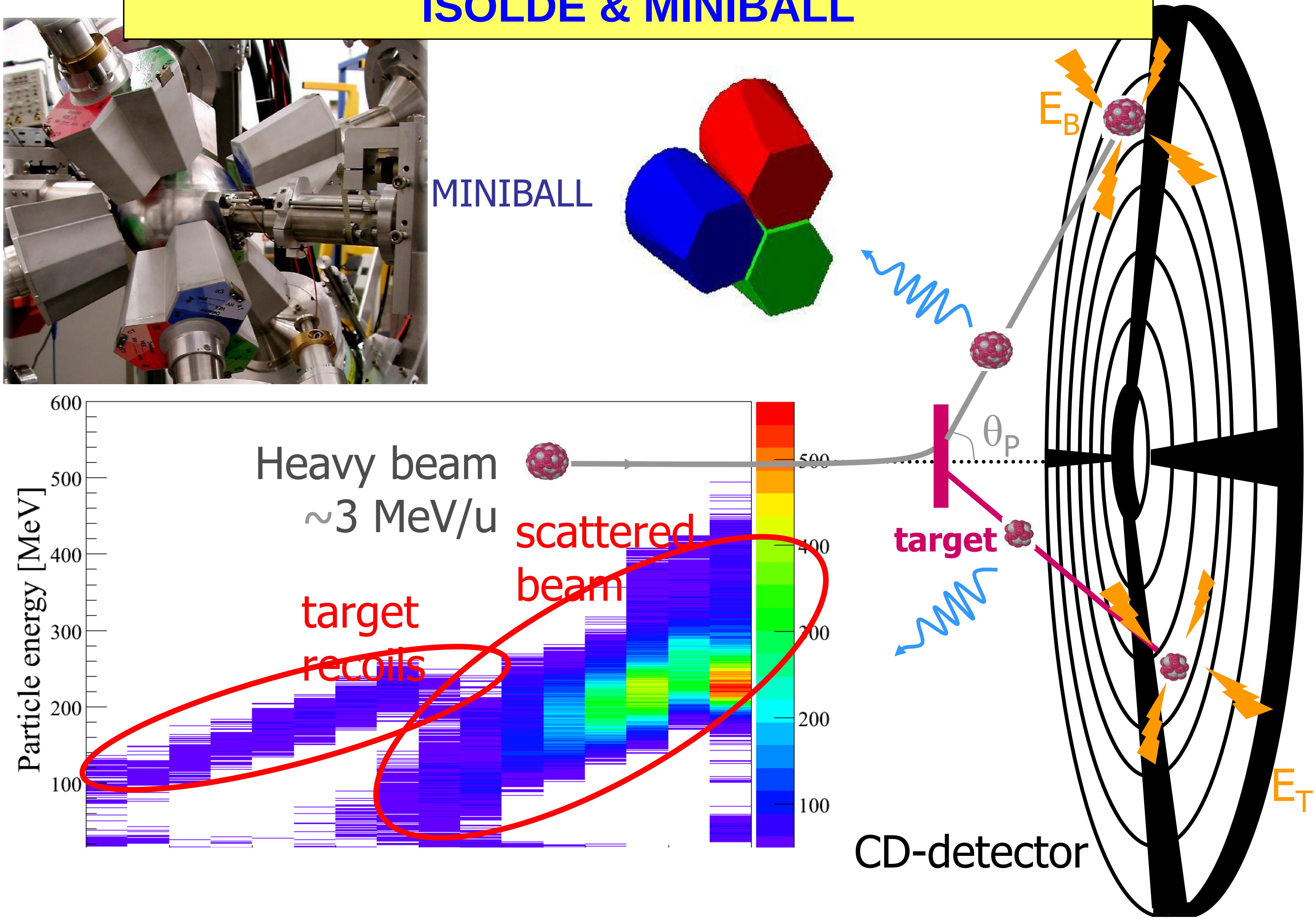
LP Gaffney, M. Hackstein
Cologne plunger @GAMMASPHERE

T. Grahn et al.
PRC 80 (2009) 014324
Cologne plunger
@JUROGAM+RITU

Coulomb excitation



Coulomb excitation of heavy beams at REX-ISOLDE & MINIBALL

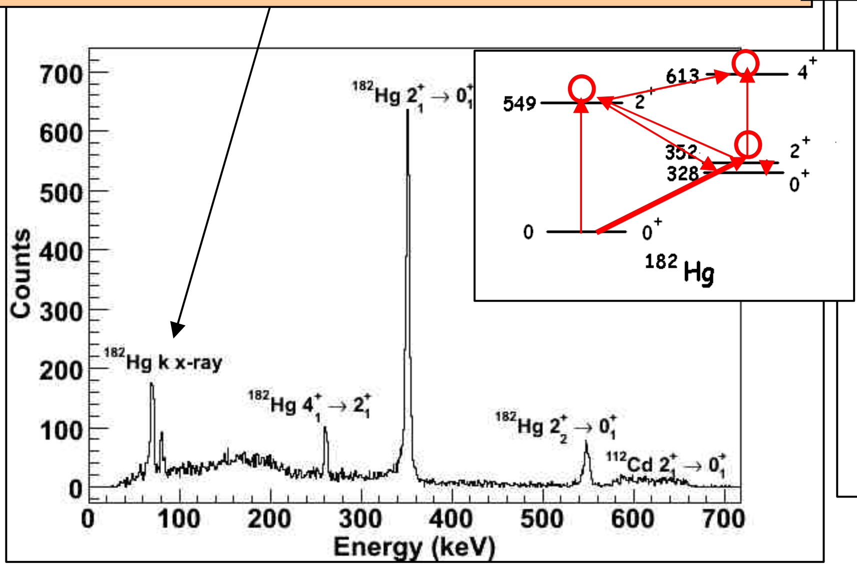


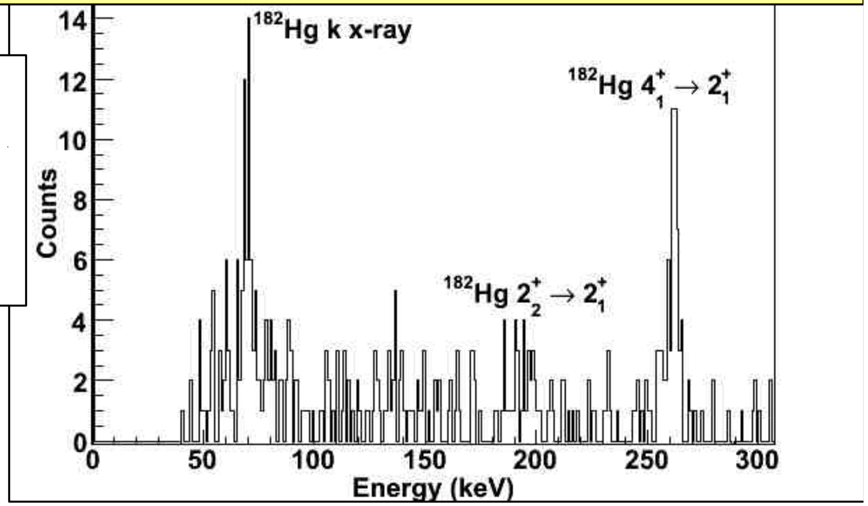
Coulomb Excitation of $^{182,184,186,188}Hg$

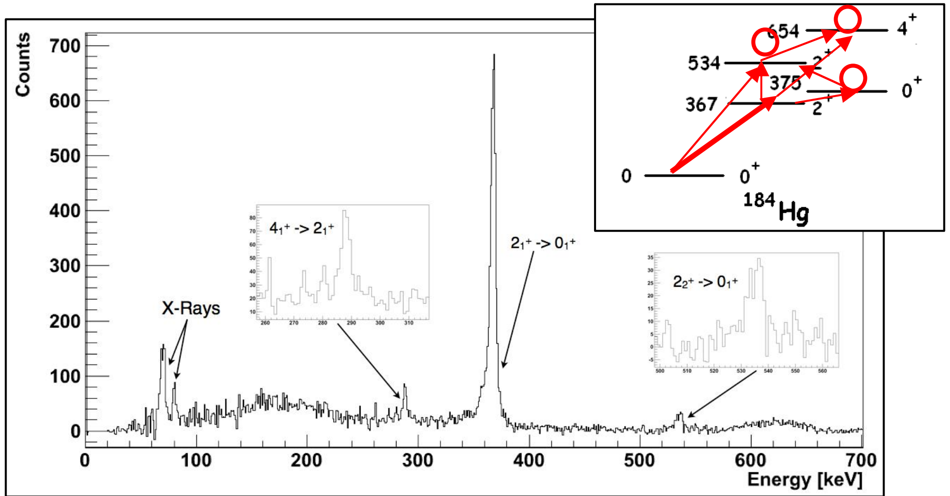
mostly contributions from $2^+_2 \rightarrow 2^+_1$ (E0/M1/E2) and $0^+_2 \rightarrow 0^+_1$ (E0)

E0 component of $2^+_2 \rightarrow 2^+_1$ from β-decay (*E Rapisarda et al, Tuesday*)

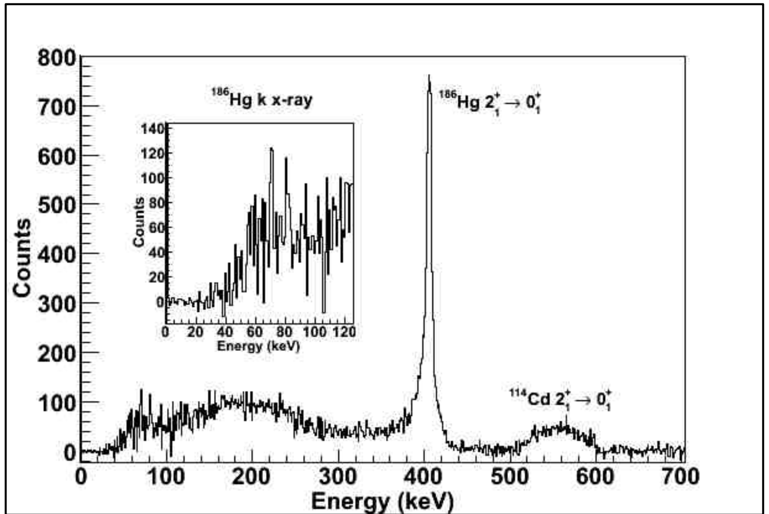
^{182}Hg







^{184}Hg



^{186}Hg

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Experimental Data

τ from RDM:

$2^+_1, 4^+_1, 6^+_1, 8^+_1$ — ^{180}**Hg**

$2^+_1, 4^+_1, 6^+_1, 8^+_1, 10^+_1$ — ^{182}**Hg**

T Grahn, A Petts et al. PRC 80 (2009) 014324

$2^+_1, 4^+_1, 6^+_1, 8^+_1$ — ^{184}**Hg**

$2^+_1, 4^+_1, 6^+_1, 8^+_1, 10^+_1$ — ^{186}**Hg**

M Hackstein, L Gaffney et al. Poster 4

Coulex yields, e.g. ^{182}**Hg** (also ^{184,186,188}**Hg**)

sensitivity to

$\langle 0^+_1||E2||2^+_1\rangle$, $\langle 2^+_1||E2||4^+_1\rangle$, $\langle 0^+_1||E2||2^+_2\rangle$,
$\langle 0^+_2||E2||2^+_1\rangle$, $\langle 0^+_2||E2||2^+_2\rangle$, $\langle 2^+_1||E2||2^+_2\rangle$,
$\langle 2^+_2||E2||4^+_1\rangle$, $\langle 4^+_1||E2||6^+_1\rangle$,
($\langle 2^+_1||M1||2^+_2\rangle$, $\langle 2^+_1||E0||2^+_2\rangle$ from Γ_e/Γ_γ)

weak sensitivity to

$\langle 2^+_1||E2||2^+_1\rangle$, $\langle 2^+_2||E2||2^+_2\rangle$

N Bree, A Petts, K Wrzosek-Lipska, L Gaffney

Γ_e/Γ_γ from β-decay for $2^+_2 \rightarrow 2^+_1$ — ^{180,182,184}**Hg**

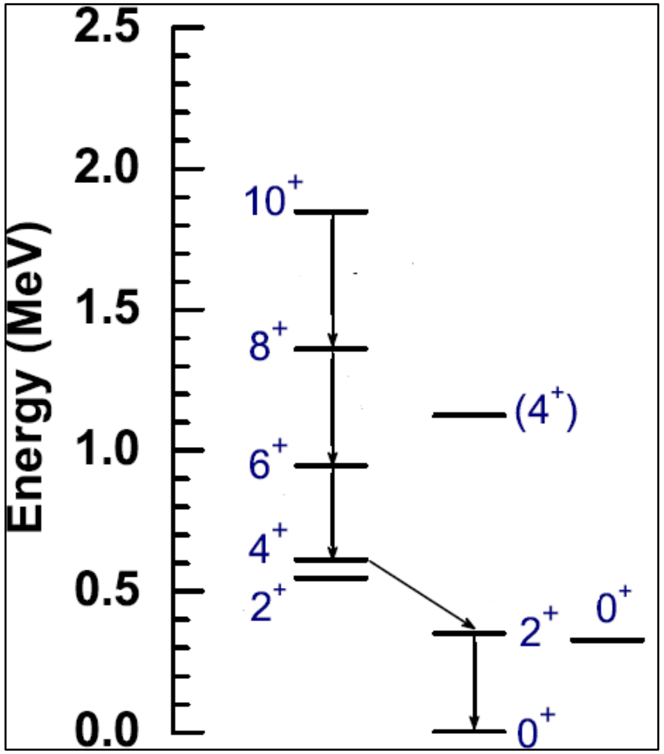
E Rapisarda - Tuesday

Γ_e/Γ_γ from in-beam SAGE for $2^+_2 \rightarrow 2^+_1$ — ^{186}**Hg**

M Scheck et al. PRC 83 (2011)037303

Population of 0^+_2 from **X-ray analysis**

N Bree



See also N Kesteloot's talk on Friday – ^{200}Po

Rotational Invariants

see D Cline, Ann Rev Nucl Part Sci 36(1986)683

$$E(2,0) = Q\cos\delta$$

$$E(2,1) = E(2,-1) = 0$$

$$E(2,2) = E(2,-2) = (1/\sqrt{2}) \bullet Q\sin\delta$$

$$[E2xE2]^0 = \frac{1}{\sqrt{5}}Q^2$$

$$\left\{[E2xE2]^2\, xE2\right\}^0 = \frac{\sqrt{2}}{\sqrt{35}}Q^3\cos 3\delta$$

Hg Summary

In this case cannot determine diagonal 2^+ matrix elements precisely.

However, can we show that:

Ground state has weak oblate deformation;

Second 0^+ state has increasing deformation with A and for $^{182,184}Hg$ probably not prolate (triaxial)

Studies of shape-coexistence in Hg

A. Andreyev[2], B. Bastin[2], P.Butler[1], A. Blazhev[12], **N. Bree**[2], B. Bruyneel[12], M. Carpenter[6], J. Cederkäll[11], E. Clement[3], T.E. Cocolios[2], T. Davinson[7], P. Delahaye[3], J. Diriken[2], J. Eberth[12], A. Ekstrom[11], L. Fraile[3], C. Fransen[12], T. Grahn[1], **L. Gaffney**[1], M. Guttormsen[4], K. Hadynska[5], R.-D. Herzberg[1], M. Huyse[2], O. Ivanov[2], D.G. Jenkins[8], R. Julin[9], S. Knapen[2], Th. Kroell[10], R. Krücken[10], A.C. Larsen[4], P. Marley[8], P.J. Napiorkowski[5], J. Pakarinen[1], N. Patronis[2], **A. Petts**[1], P.J. Peura[9], E. Piselli[3], P. Reiter[12], M. Scheck[1], S. Siem[4], I. Stefanescu[2], J. Van de Walle[3], P. Van Duppen[2], D. Voulot[3], N. Warr[12], F. Wenander[3] **K. Wrzosek-Lipska**[2] and M. Zielinska[5]

$^{182-184}$Hg Coulex@ISOLDE

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[9]University of **Jyvaskyla**, Finland
[2]University of **Leuven**, Belgium
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[11]University of **Lund**, Sweden
[10]Technical University **Munich**, Germany
[4]University of **Oslo**, Norway
[5]University of **Warsaw**, Poland
[8]University of **York**, UK

^{184,186}Hg lifetimes@ANL

P. A. Butler[1], P. F. Bertone[6], N. Bree[4], R. J. Carroll[1], M. Carpenter[6], C. J. Chiara[6], A. Dewald[2], F. E. E. Filmer[1], C. Fransen[2], **L. P. Gaffney**[1], T. Grahn[3], **M. Hackstein**[2], M. Huyse[4], D. T. Joss[1], R. Julin[3], F. Kondev[6], P. Nieminen[3], R. D. Page[1], J. Pakarinen[5], S. V. Rigby[1], M. Scheck[1], P. Van Duppen[4], H. Watkins[1], and S. Zhu[6]

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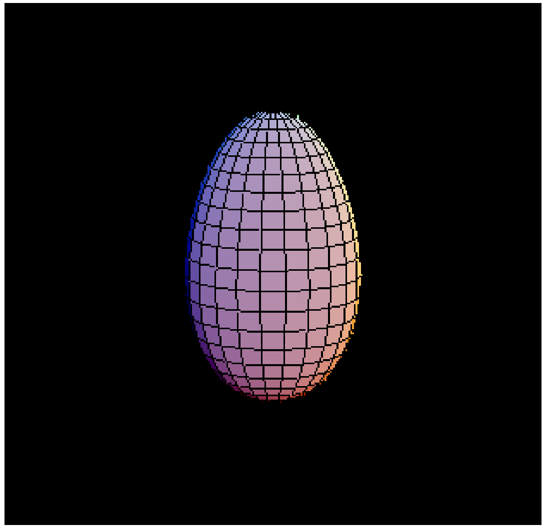
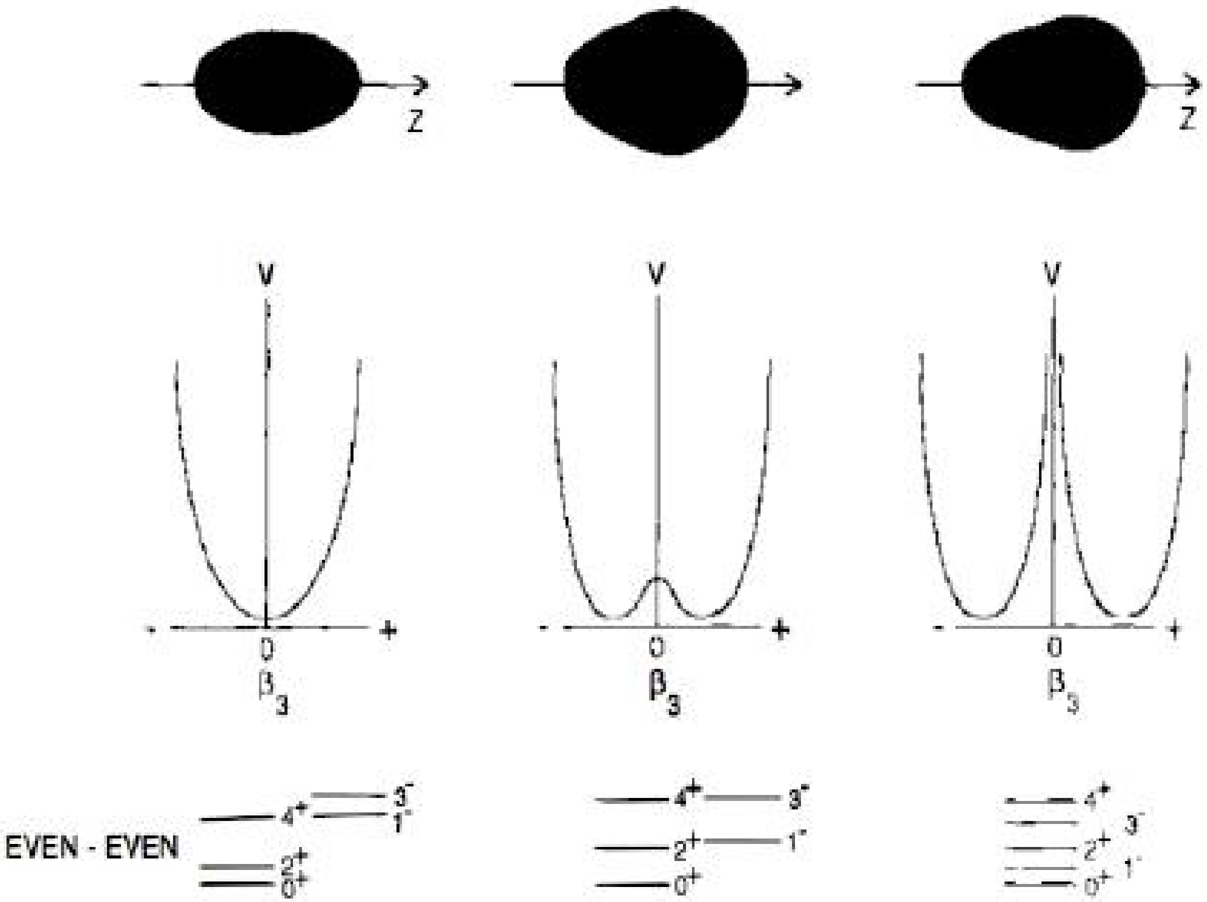
[3]University of **Jyvaskyla**, Finland
[4]University of **Leuven**, Belgium
[1]University of **Liverpool**, UK

Octupole Collectivity

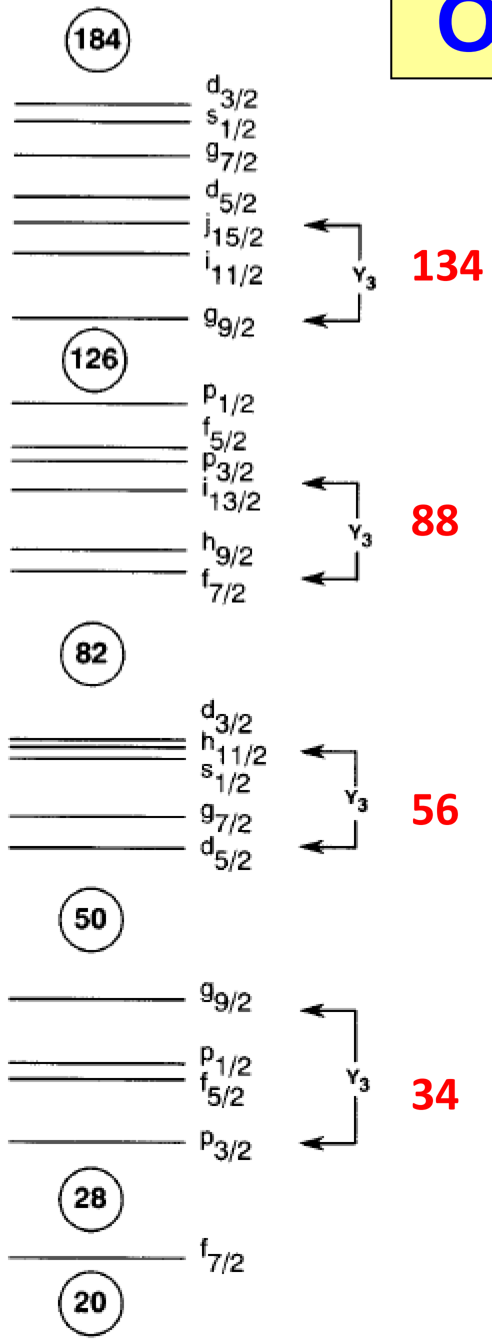


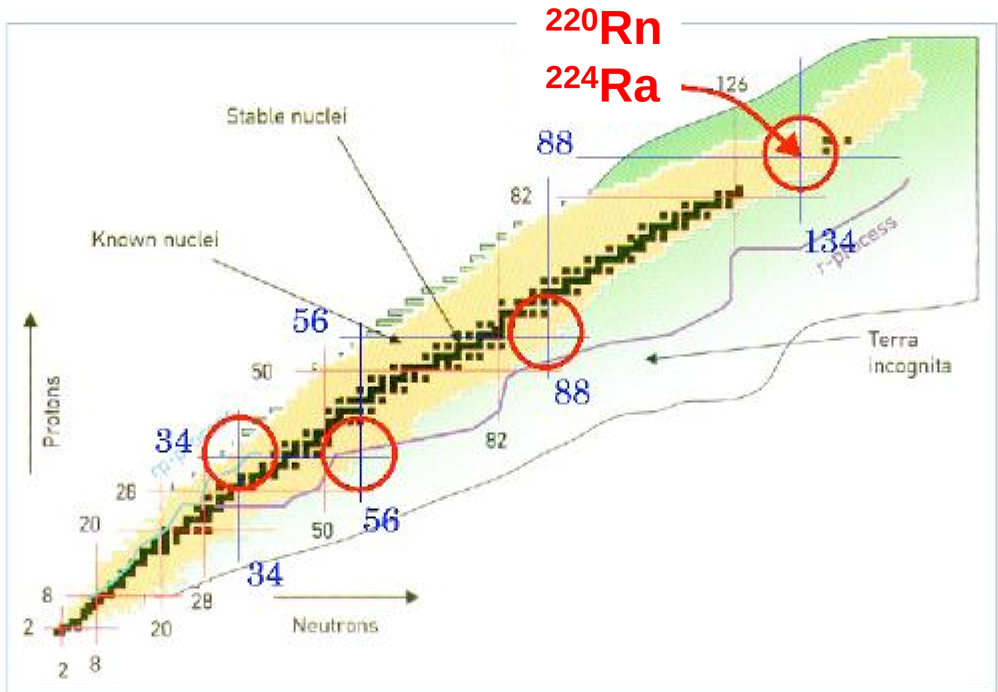
Octupole (Y_{30}) Vibration

Soft Octupole	Static Deformation	Rigid Deformation



Octupole 'Magic' Numbers





- Octupole correlations occur between orbitals which differ in both orbital (ℓ) and total (j) angular momenta by 3

- Octupole 'Magic' numbers occur at 34, 56, 88 and 134

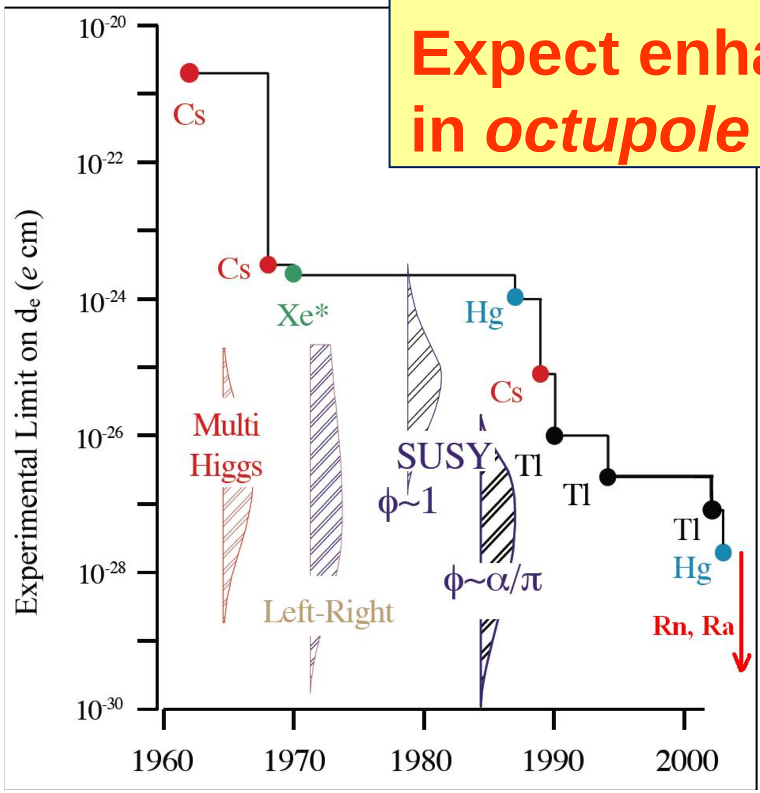
- Nuclei with both proton and neutron numbers close to these are the best candidates to show **octupole** effects

Testing theories of CP violation

Tests of ***CP*** invariance in hadronic sector from static Electric Dipole Moment (EDM) of atom (best limits so far from ^{199}Hg on

$\bar{\theta}_{QCD}$ $\tilde{d}_d$ C_T C_S ε_q^{SUSY} ε^{Higgs} χ^{LR})

Expect enhancement (by 10^2) of EDM in *octupole* radioactive nuclei



Schiff moment

$$S \approx -\frac{2}{3}\langle \hat{S}_z \rangle \frac{\langle \hat{V}_{PT} \rangle}{E_0 - E_i}$$

parity doublet

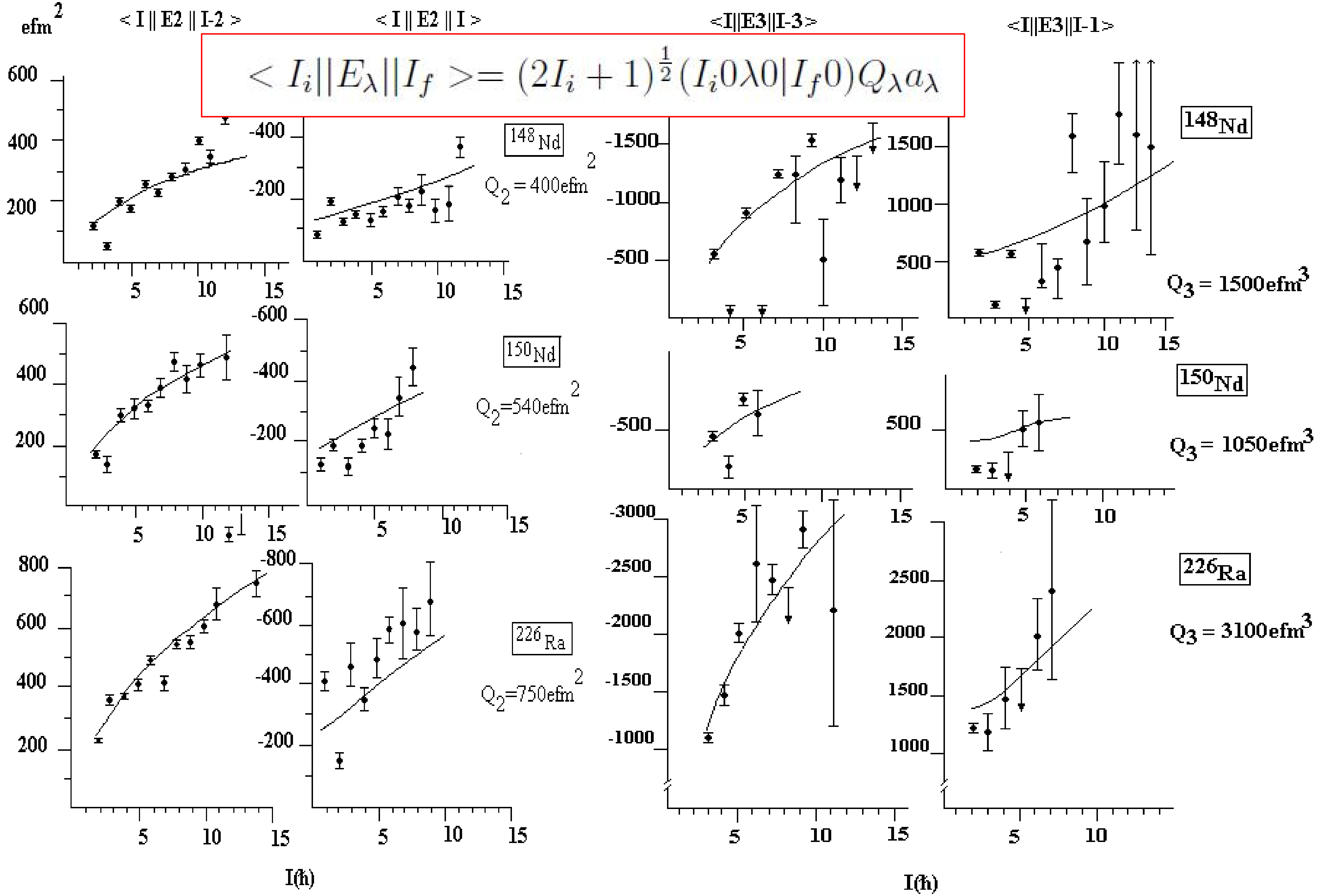
$$\hat{S}_z = \frac{e}{10}\sum_p \left(r_p^2 - \frac{5}{3}\bar{r}_{ch}^2 \right) z_p$$

octupole deformation

Odd Rn or odd Ra?

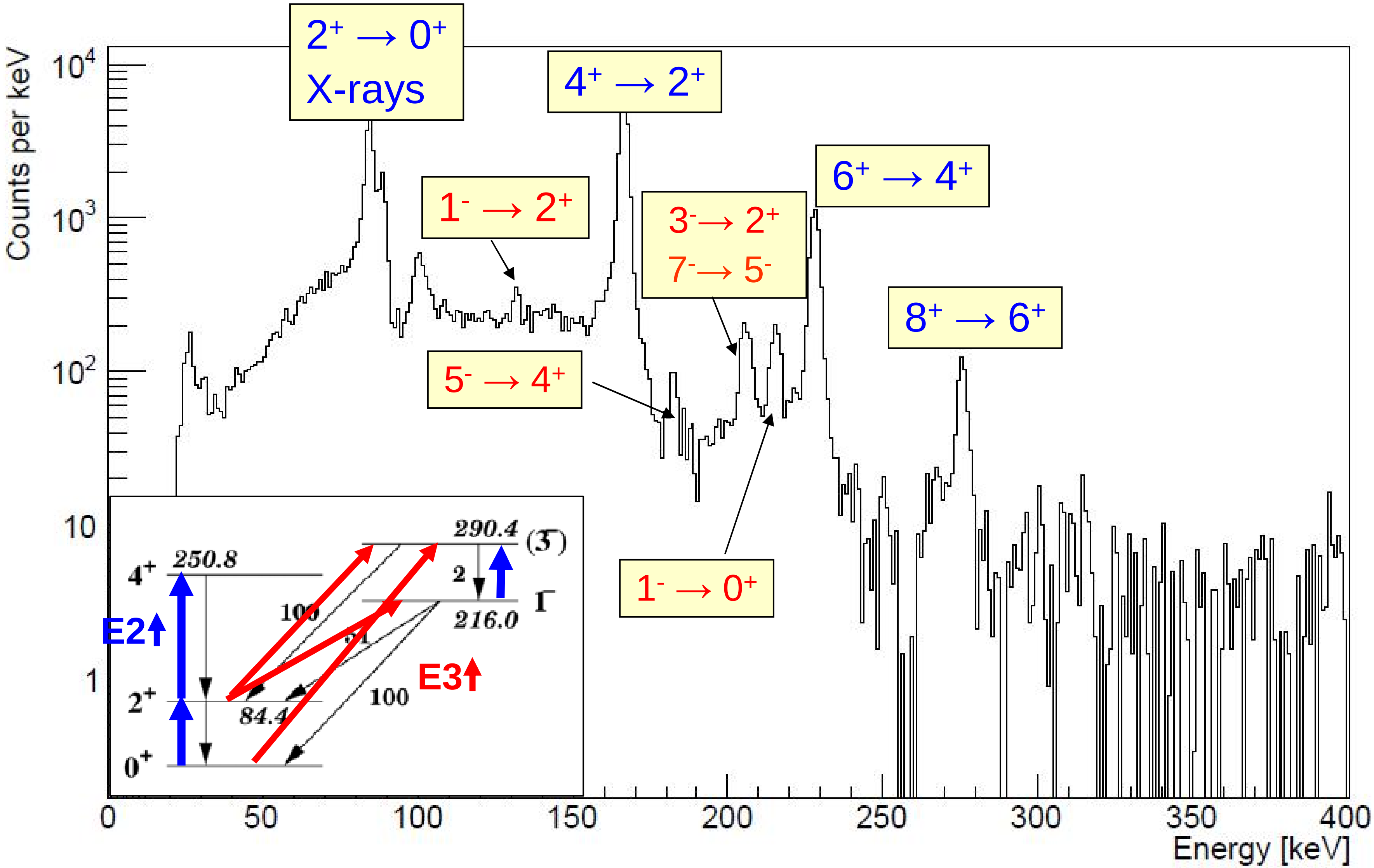
Eλ matrix elements from Coulomb excitation

$$< I_i||E_\lambda||I_f >= (2I_i+1)^{\frac{1}{2}}(I_i 0 \lambda 0|I_f 0)Q_\lambda a_\lambda$$

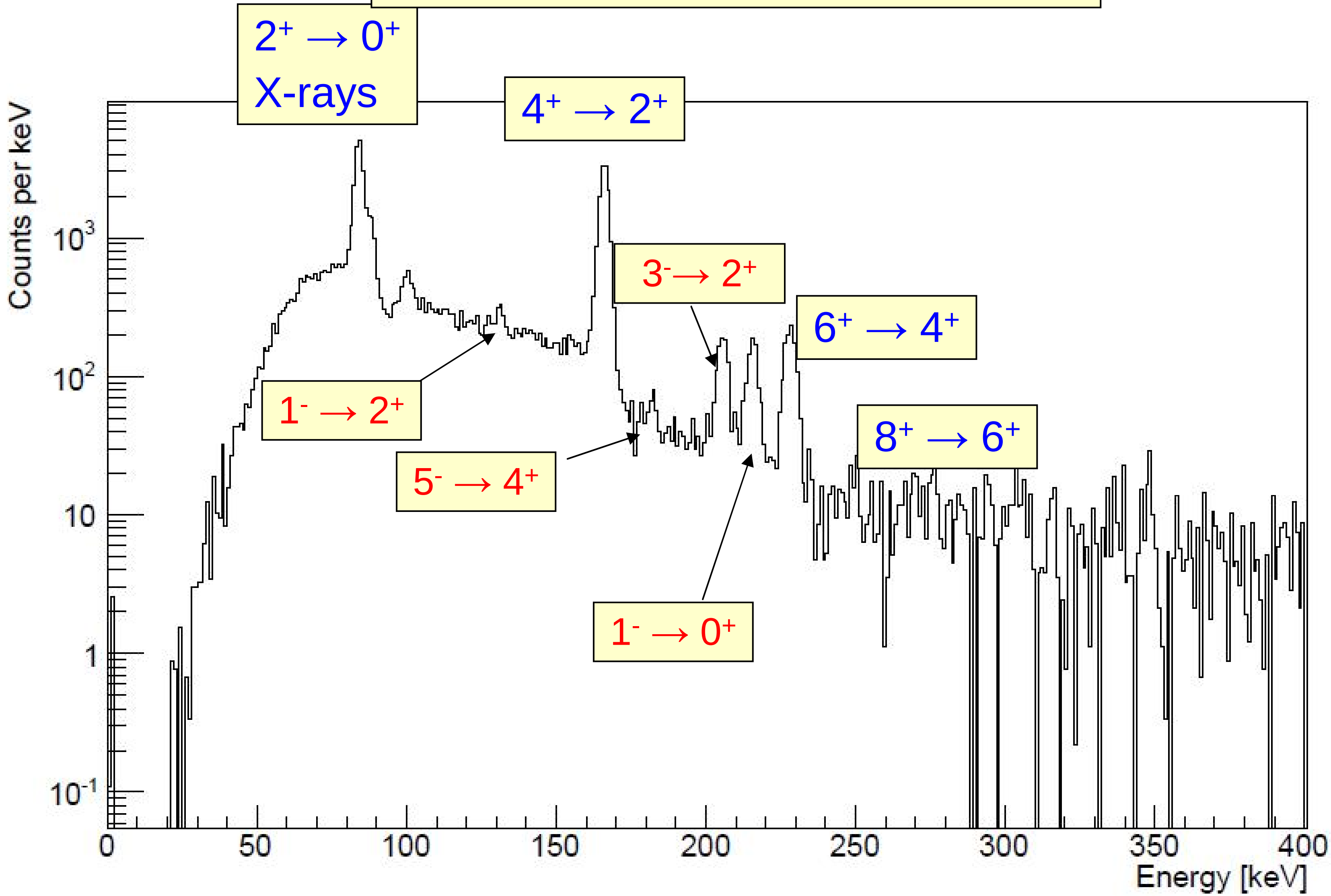


HJ Wollersheim et al., NP A556 (1993) 261 R Ibbotson et al PRL 71 (1993) 1990

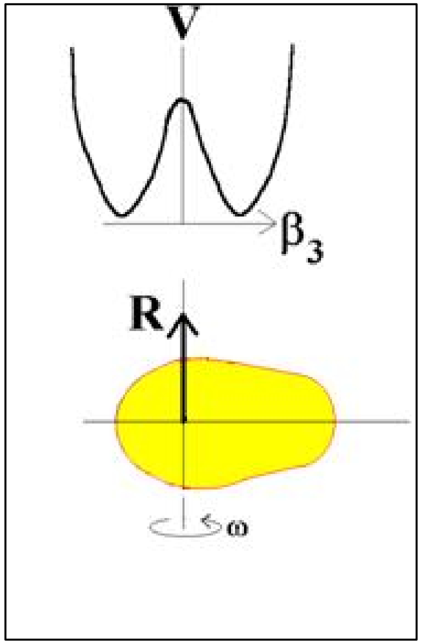
^{224}Ra (+ ^{120}Sn) Coulomb excitation

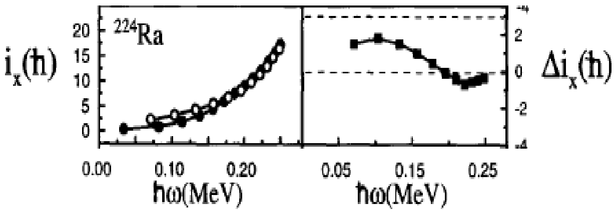


^{224}Ra (+ ^{60}Ni) Coulomb excitation

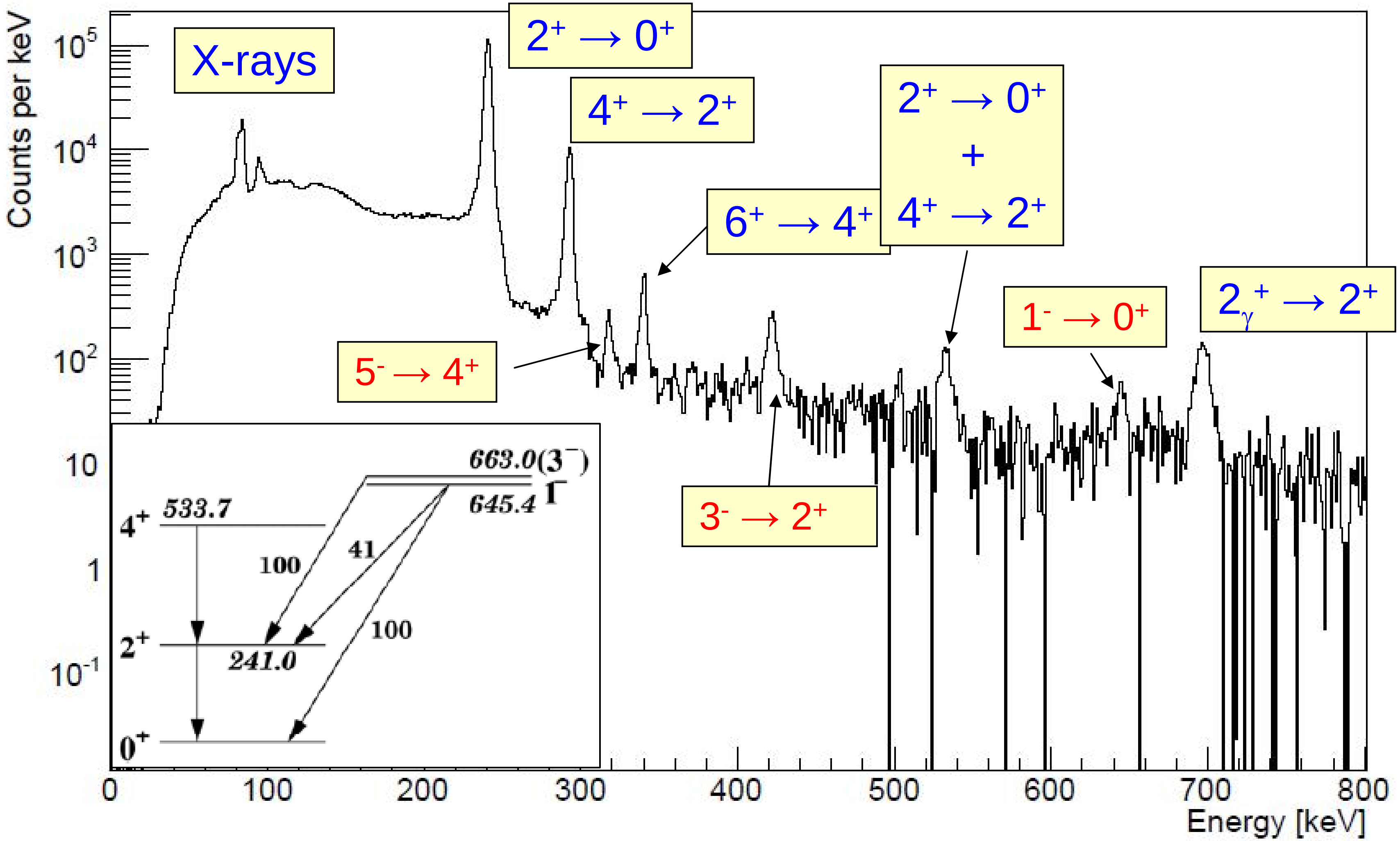


^{224}Ra matrix elements





^{220}Rn (+ ^{120}Sn) Coulomb excitation



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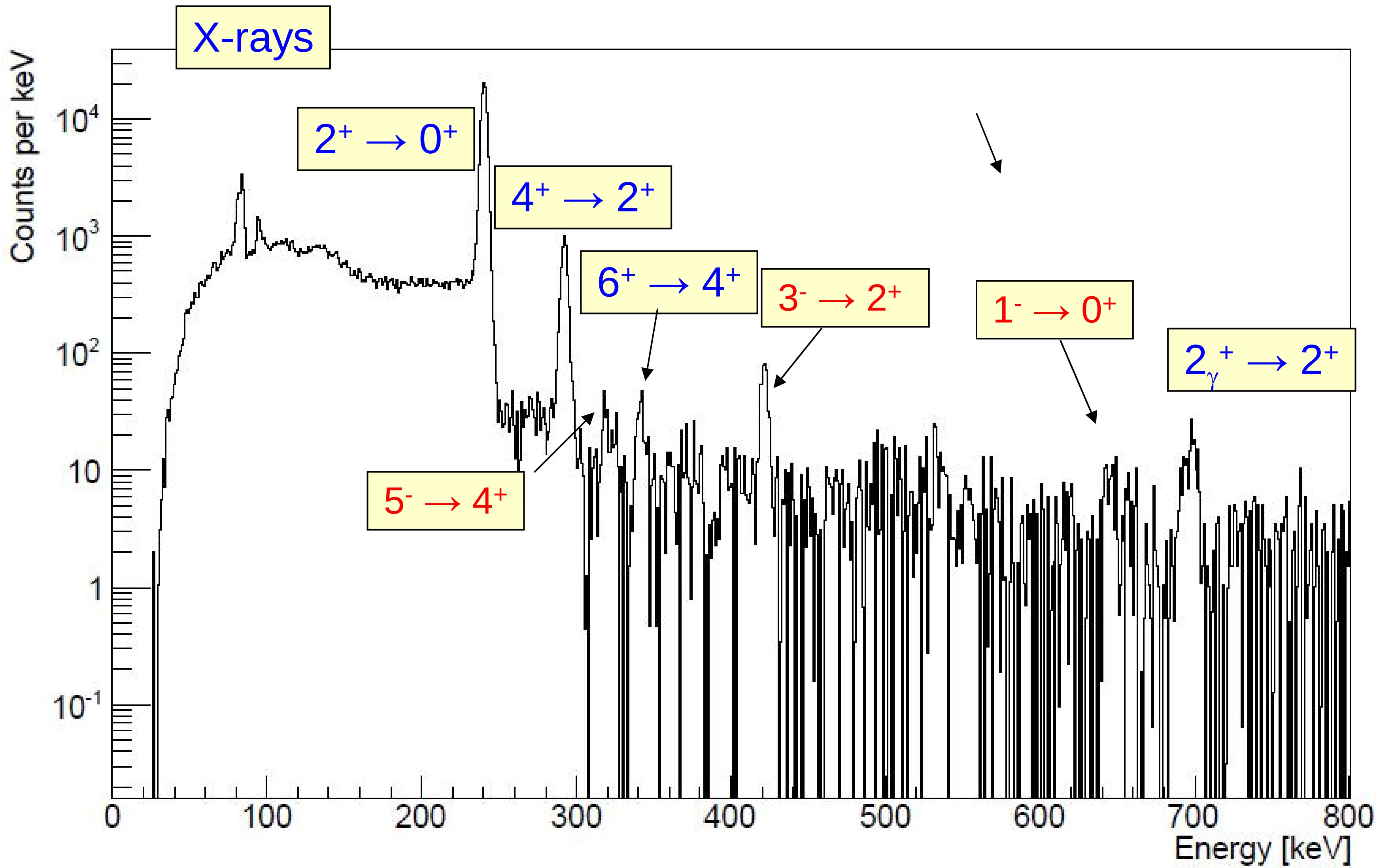
^{220}Rn (+ ^{60}Ni)
Coulomb excitation



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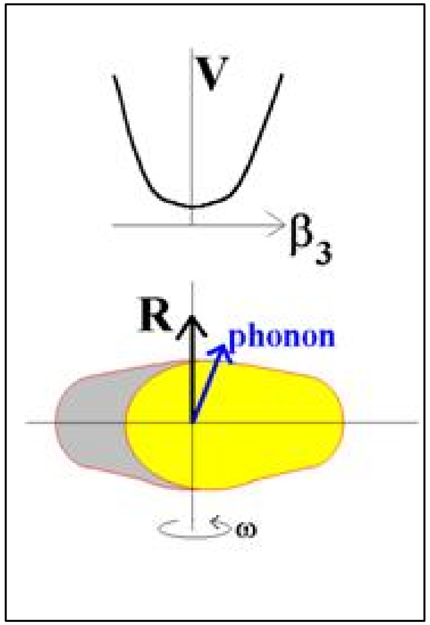
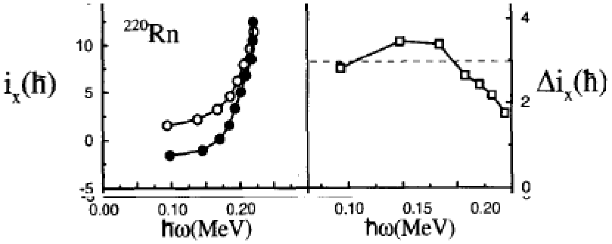
^{220}Rn matrix elements





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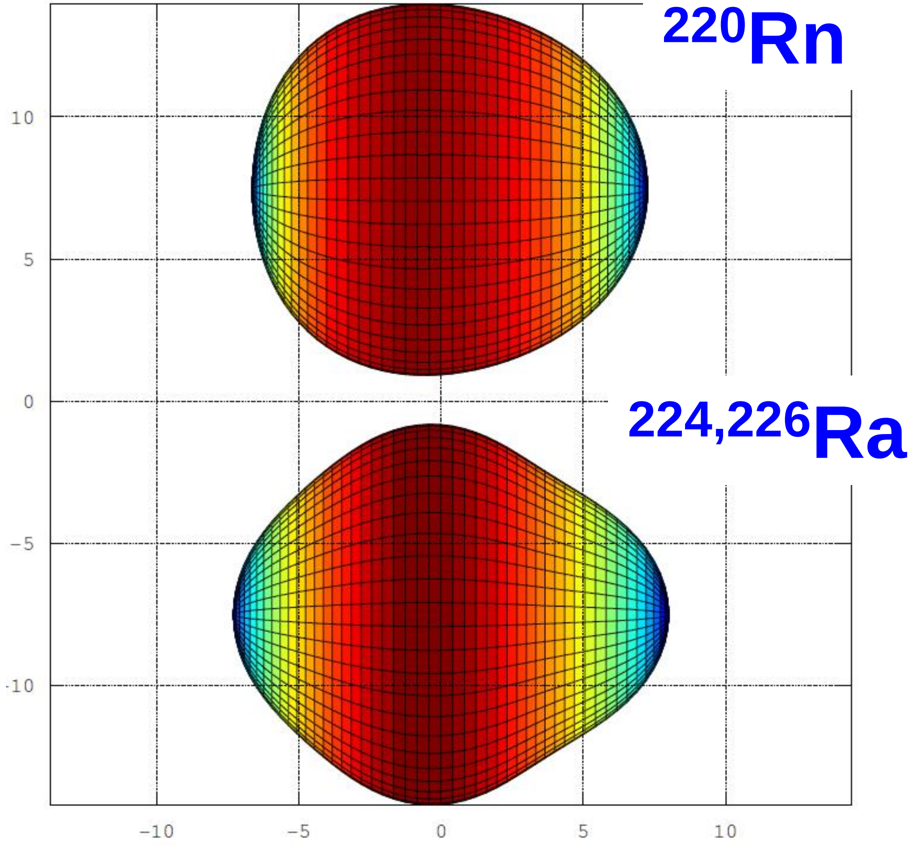
Summary: shape of octupole nuclei



Artist:
Liam Gaffney

Studies of octupole nuclei

M. Albers[2], B. Bastin[12], C. Bauer[6], A. Blazhev[2], P.A. Butler[1], A. Blazhev[2], S. Bönig[6], N. Bree[4], J. Cederkall[13], T. Chupp[10], D. Cline[7], T.E. Cocolios[9], J. Diriken[4], **L.P. Gaffney[1]**, T. Grahn[5], A. Hayes[7], A. Herzan[5], M. Huyse[4], D. Jenkins[11], D.T. Joss[1], N. Kesteloot[4], M. Kowalczyk[3], Th. Kröll[6], E. Kwan[8], K. Moschner[2], P. Napiorkowski[3], M. Pfeiffer[2], D. Radeck[2], K. Reynders[4], S. Rigby[1], M. Rudigier[2], S. Sambi[4], M. Scheck[1,2], M. Seidlitz[2], P. Thoele[2], P. Van Duppen[4], M. von Schmid[6], D. Voulot[9], N. Warr[2], **F. Wenander[9]**, K. Wrzosek-Lipska[4], C.Y. Wu[8], M. Zielinska[3]

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