Studies of the shapes of heavy *pear-shaped* nuclei at ISOLDE

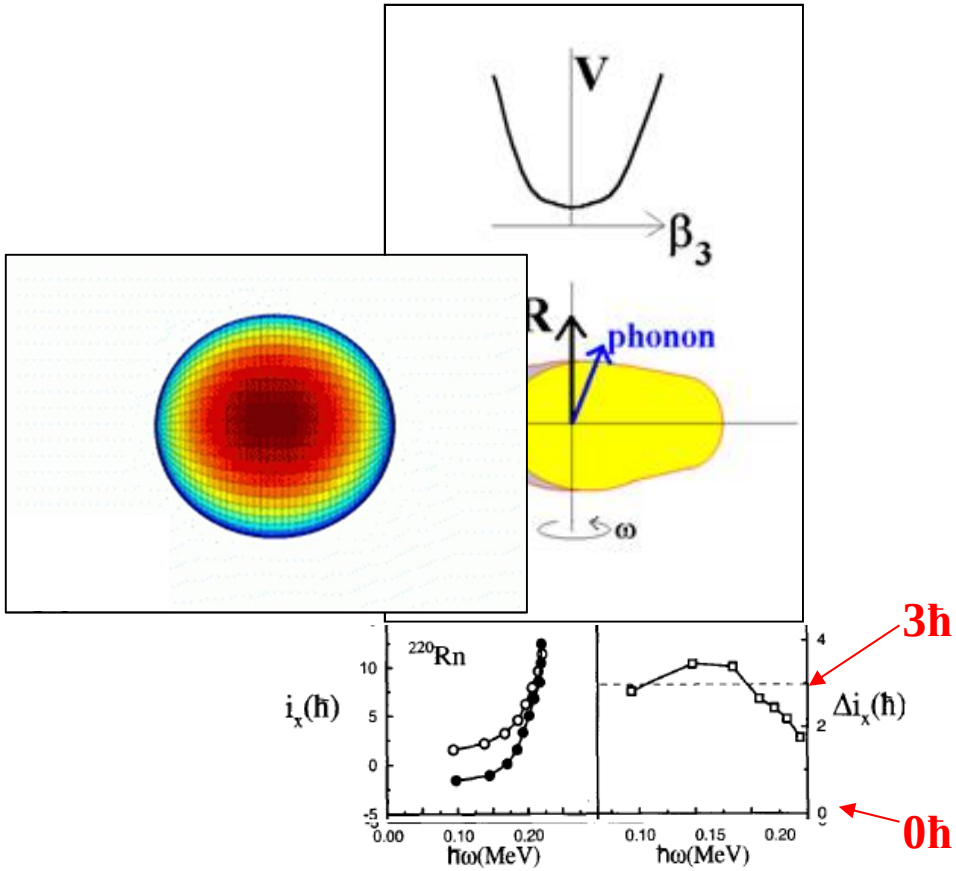
Peter Butler

University of Liverpool

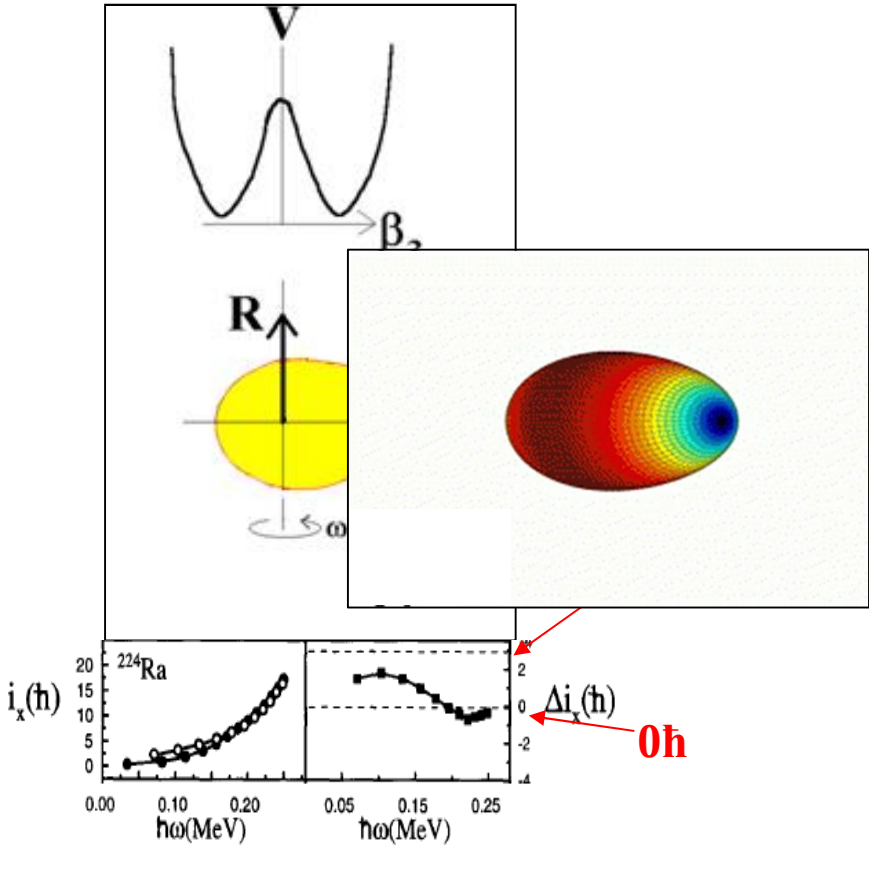
Rotating even-even nuclei
E3 moments ^{220}Rn, ^{224}Ra

Odd-mass nuclei & EDMs
Spectroscopy with TSR

Rotating octupole shapes

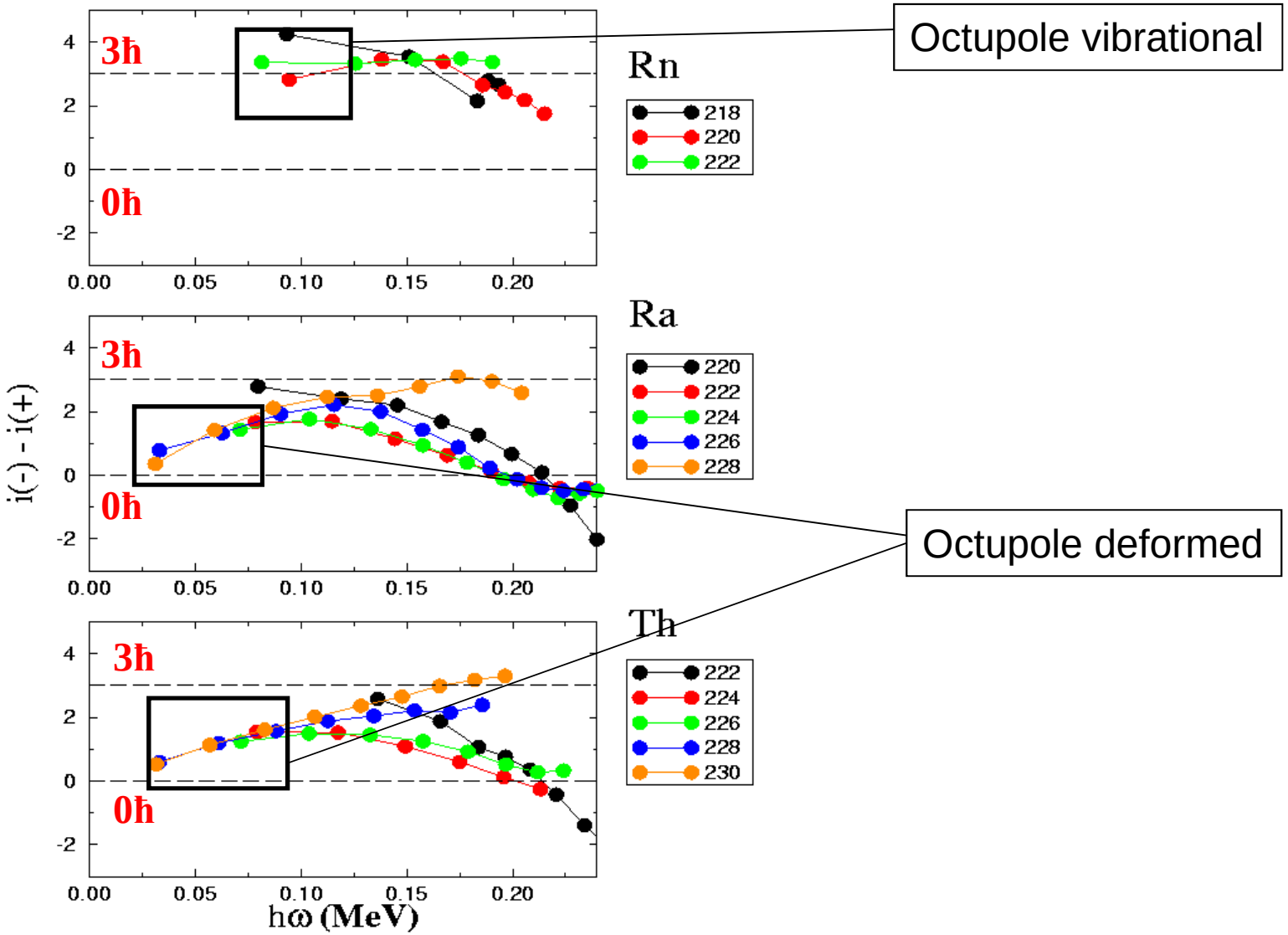


Octupole vibrational



Octupole deformed

Actual Behaviour (near the ground state)

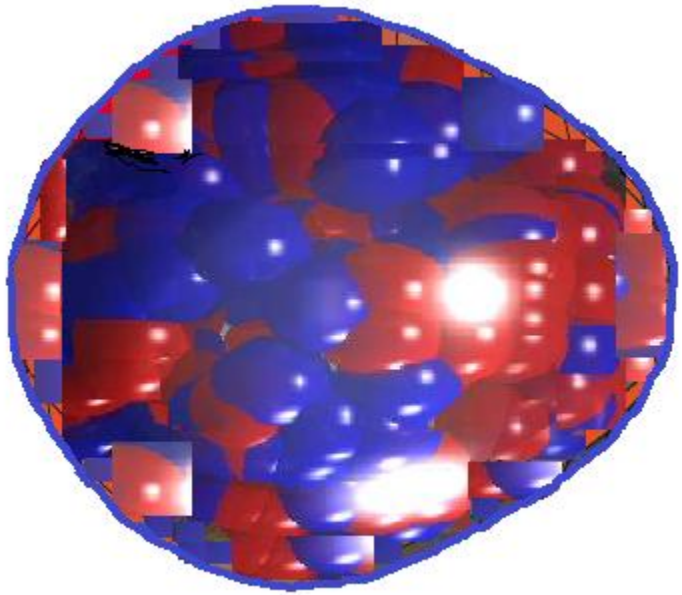


JFC Cocks et al PRL 78 (1997) 2920, Nucl. Phys. A645 (1999) 61

B(E3) transitions

$$Q_3 = \frac{3}{\sqrt{7\pi}} ZeR_0^3 \overline{\beta}_3$$

$$\overline{\beta}_3 = f(\beta_3, ...)$$



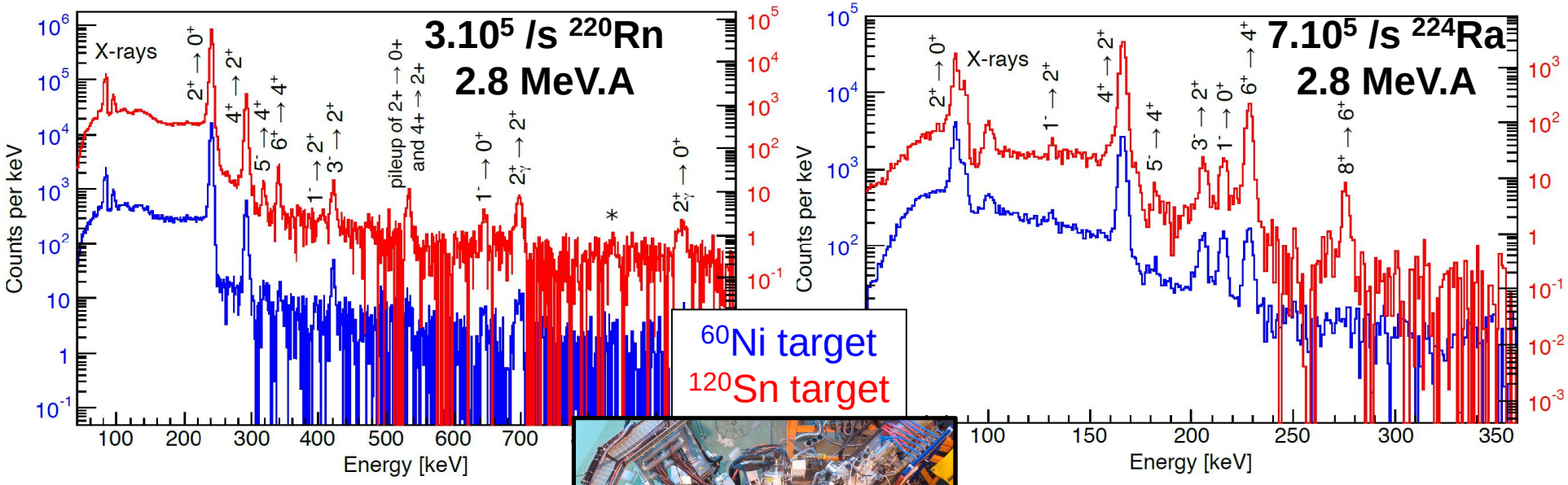
$$B(E3; I_i \rightarrow I_f) = \frac{7}{16\pi} < I_i 030 | I_f 0 >^2 Q_3^2$$

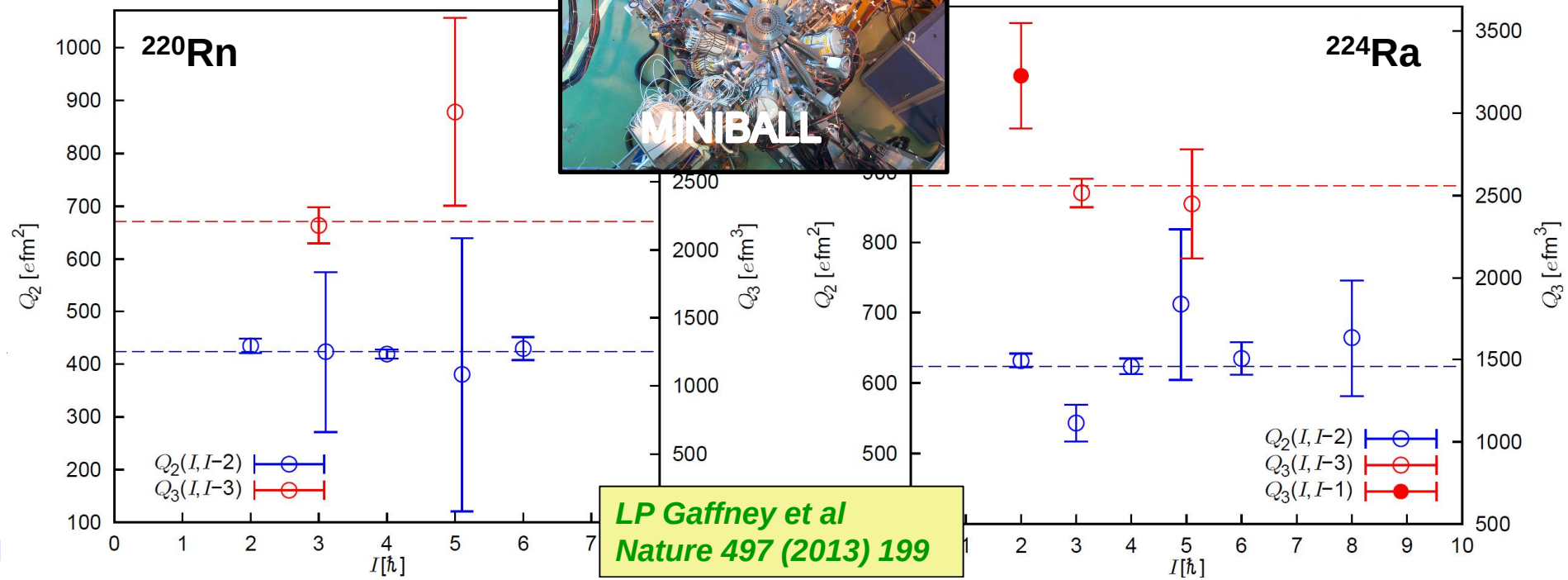
$B(E3; 0^+ \rightarrow 3^-)$ ~ **30 – 50** single particle units for β_3 ~ 0.1

$B(E1)$ ~ **$10^{-(2\text{-}3)}$** single particle units

$B(E2)$ ~ **100** single particle units

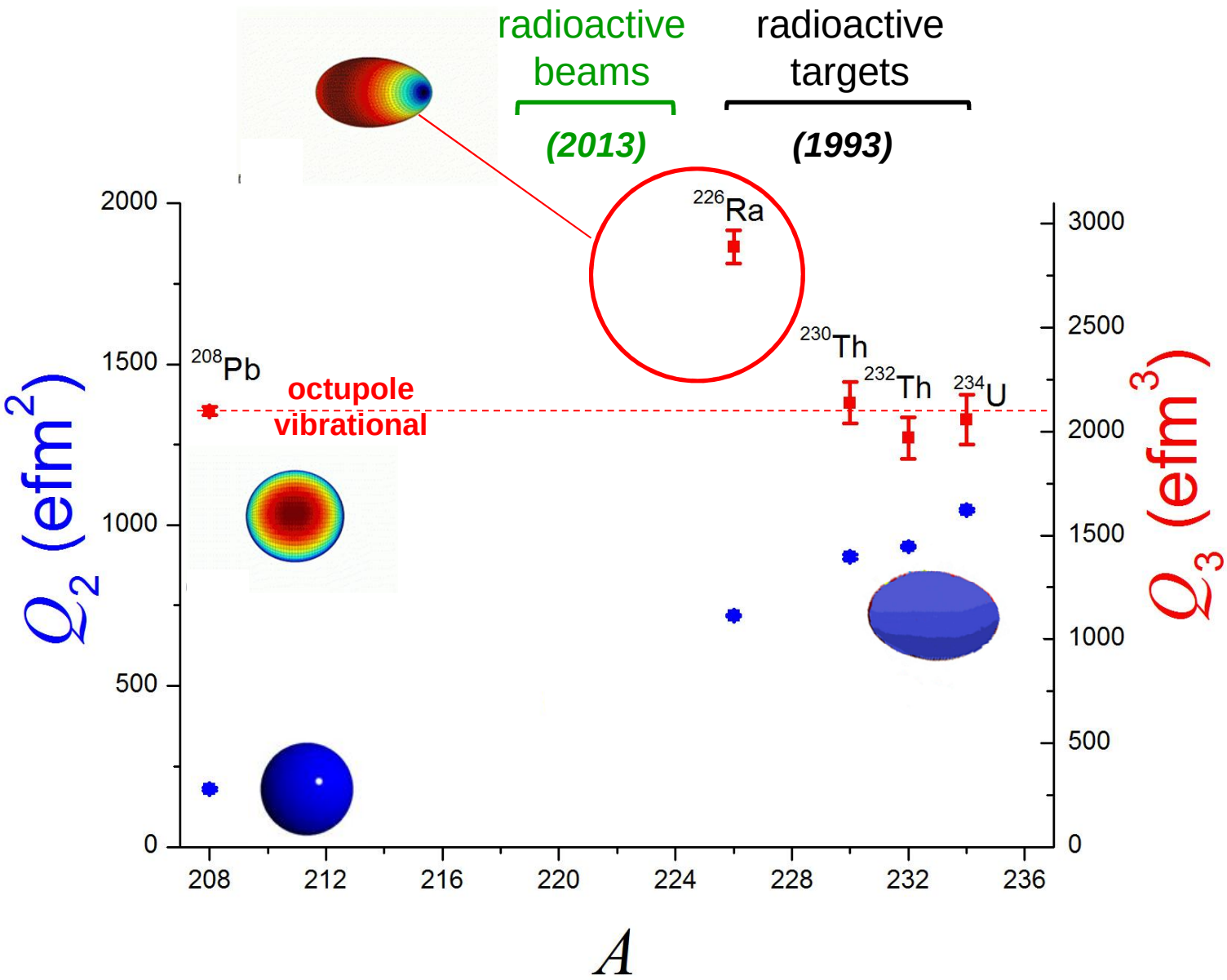
Recent experimental results (REX-ISOLDE)





LP Gaffney et al
Nature 497 (2013) 199

E2 and E3 moments in “octupole” mass region

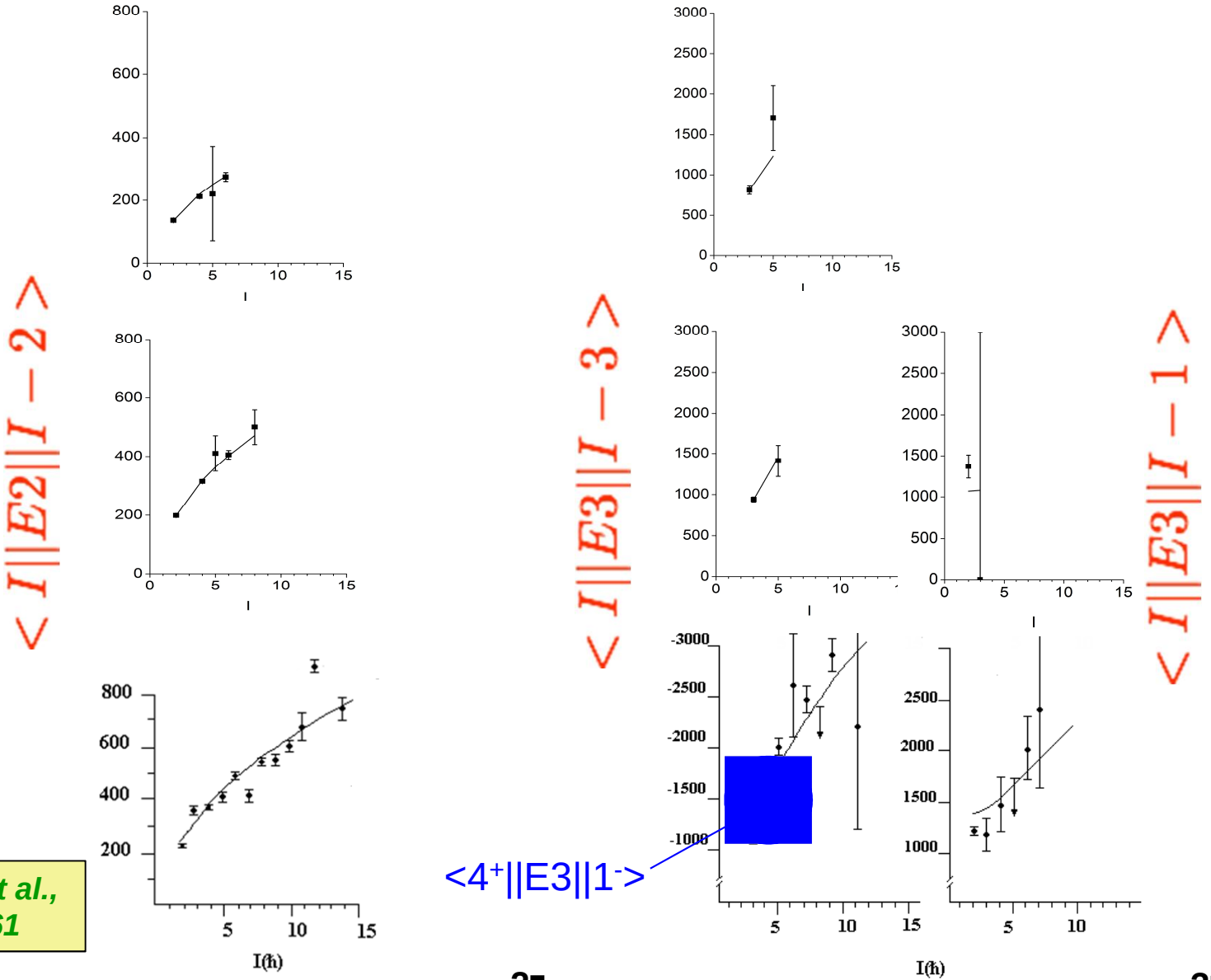


Rotating charged pear-shape

^{220}Rn

^{224}Ra

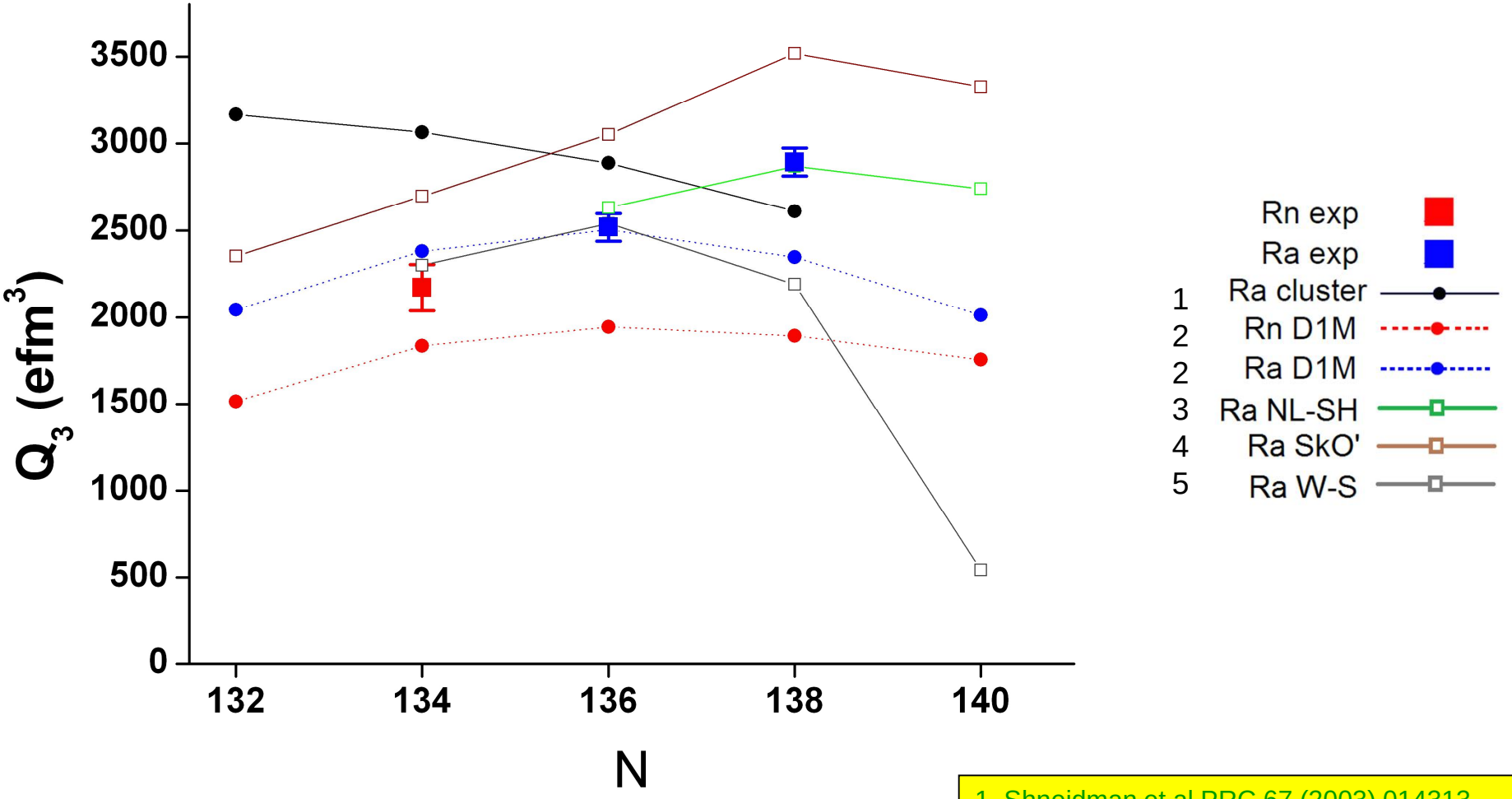
^{226}Ra



HJ Wollersheim et al., NP A556 (1993) 261

E2 matrix elements [e·fm^2] **E3 matrix elements [e·fm^3]**

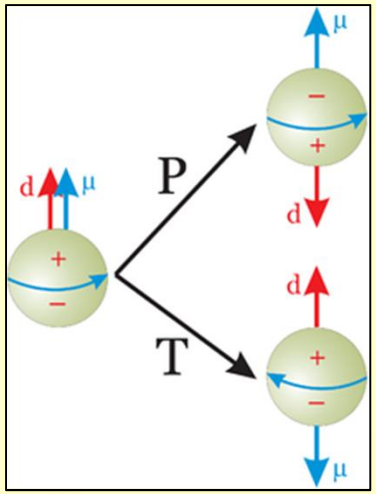
Comparison with theory

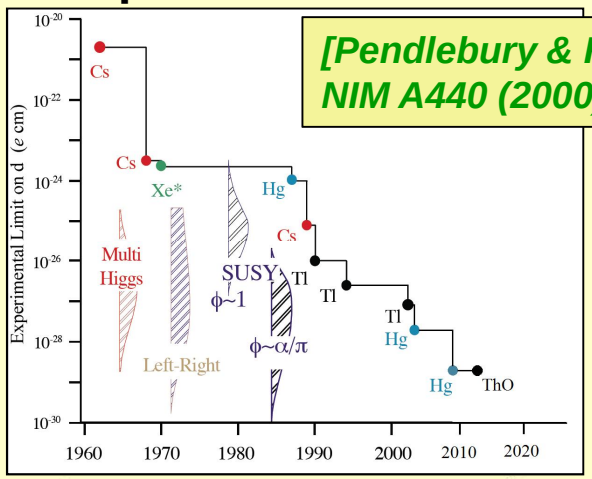


1. Shneidman et al PRC 67 (2003) 014313
2. Robledo & Butler PRC 88 (2013) 051302(R)
3. Rutz et al. NP A590 (1995) 680
4. Engel et al. PRC 68 (2003) 025501
5. Nazarewicz et al NP A429 (1984) 269

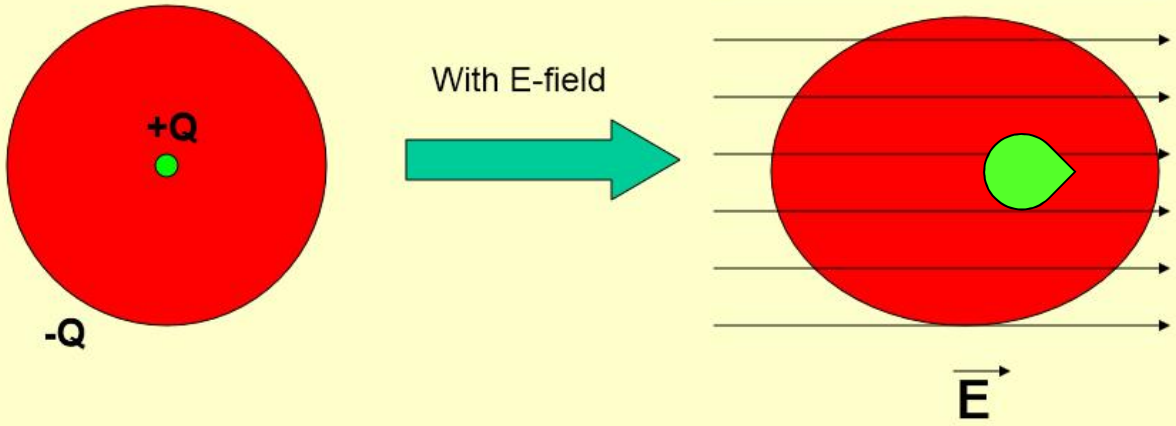
Neutron and Atomic EDM moment

Static Electric Dipole Moment implies CP-violation





[Pendlebury & Hinds NIM A440 (2000) 471]



Schiff Theorem: neutral atomic system of point particles in electric field readjusts itself to give zero E field at all charges.

BUT: finite size and shape of nucleus breaks the symmetry

Octupole enhanced atomic EDM moment

EDM programme at Groningen, ANL (^{225}Ra) and TRIUMF (^{223}Rn)

PS1-071

Schiff moment:

$$S = -2\frac{J}{J+1}\frac{\langle \hat{S}_z \rangle \langle \hat{V}_{PT} \rangle}{\Delta E}$$

related to Q_3

P,T-violating n-n interaction

energy splitting of parity doublet *in odd-A* nuclei

V Spevak, N Auerbach, and VV Flambaum
PR C **56** (1997) 1357

J Dobaczewski and J Engel
PRL **94** (2005) 232502

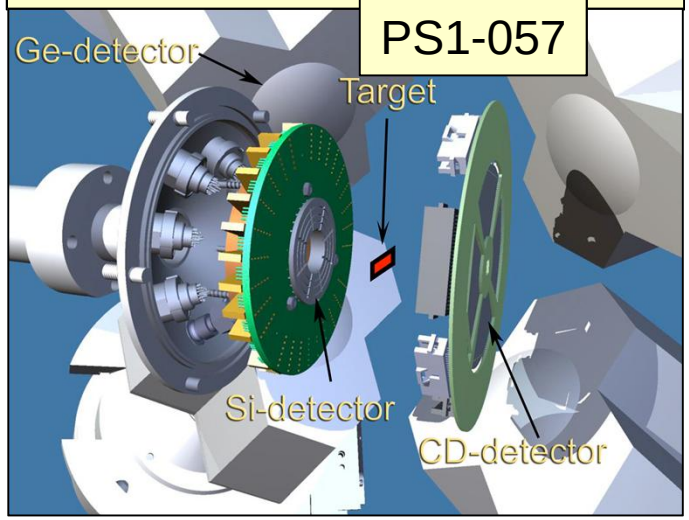
J Ellis, JS Lee and A Pilaftsis
JHEP **02** (2011) 045

Measured in ^{223,225}Ra *(but not odd-A Rn)*

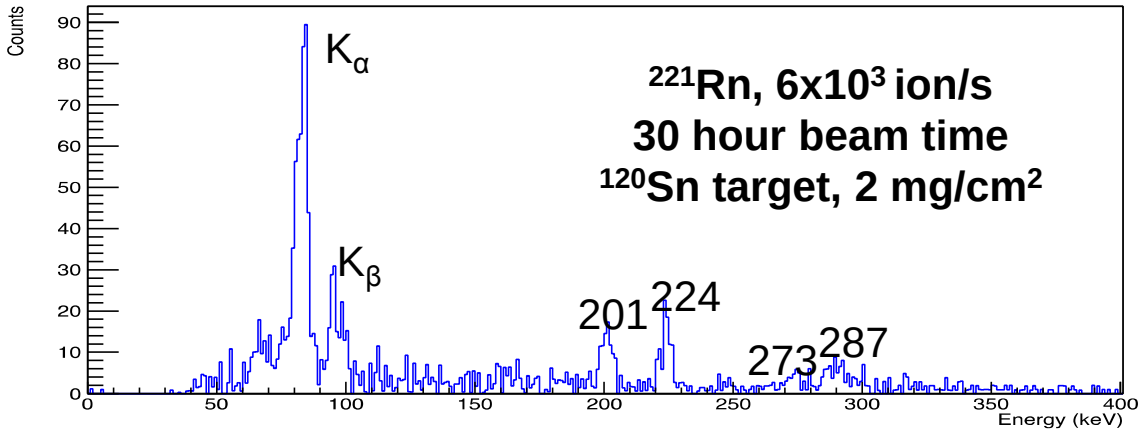
Measured in ^{220}Rn, ^{224,226}Ra *(but not odd-A nuclei)*

Future at HIE-ISOLDE (1) :
^{221,222,224,226}Rn, $^{222,\ 228}$Ra
MINIBALL + SPEDE

PS1-057



Nuclear spectroscopy programme



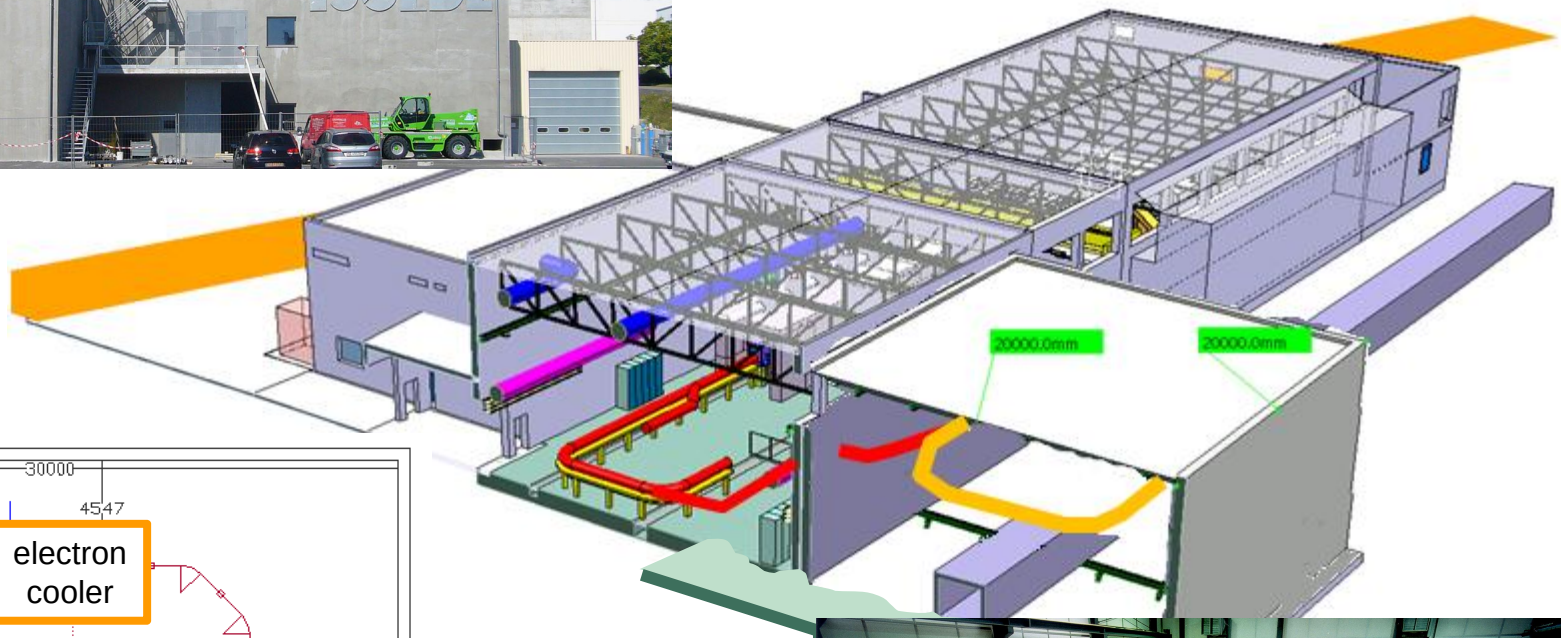
Peter Butler

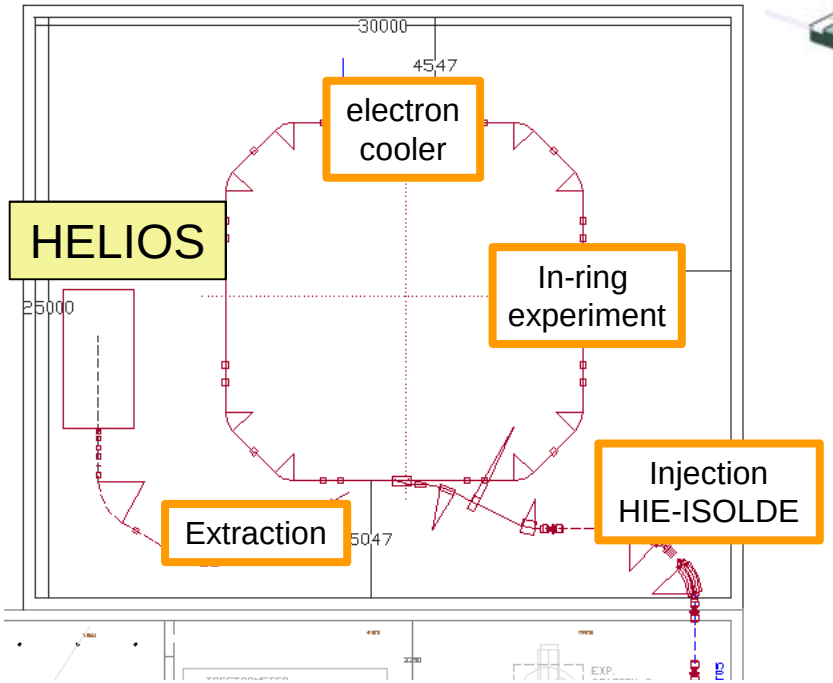
George O'Neill

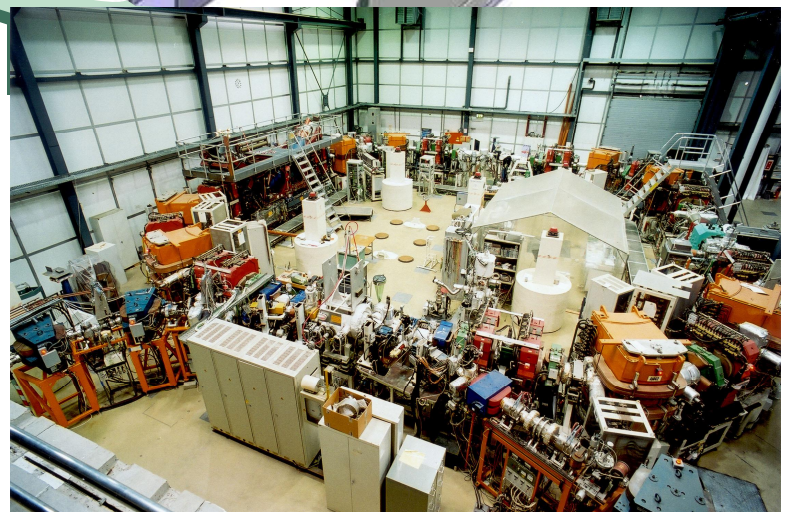
UNIVERSITY OF LIVERPOOL

Future at HIE-ISOLDE (2) : Storage Ring TSR

PS1-126

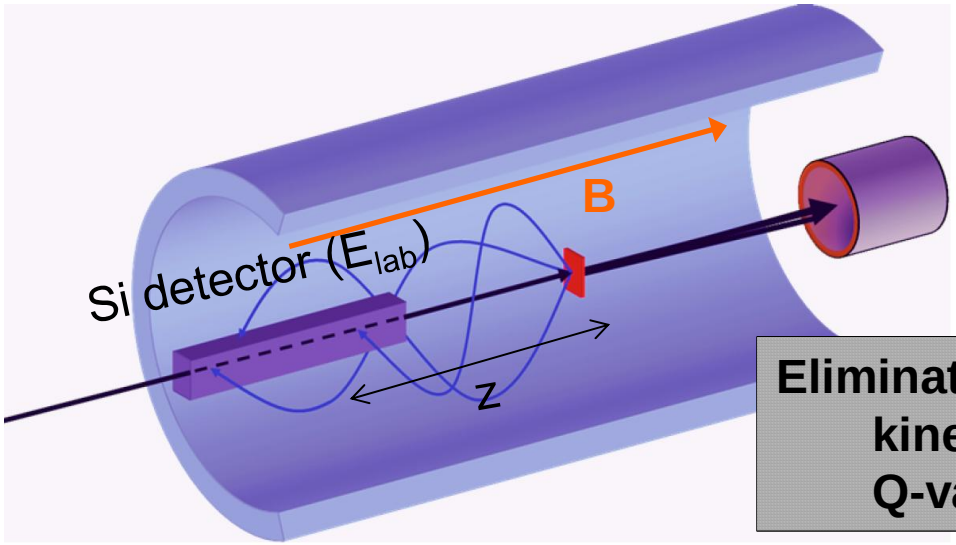






Helical Orbit Spectrometer

AH Wuosmaa et al
NIM A580 (2007) 1290



Eliminates:
kinematic broadening
Q-value compression

10 MeV/u d(^{132}Sn,p)^{133}Sn*
Q-value = 1.01 E_{lab} - 9.92 - 0.21 z

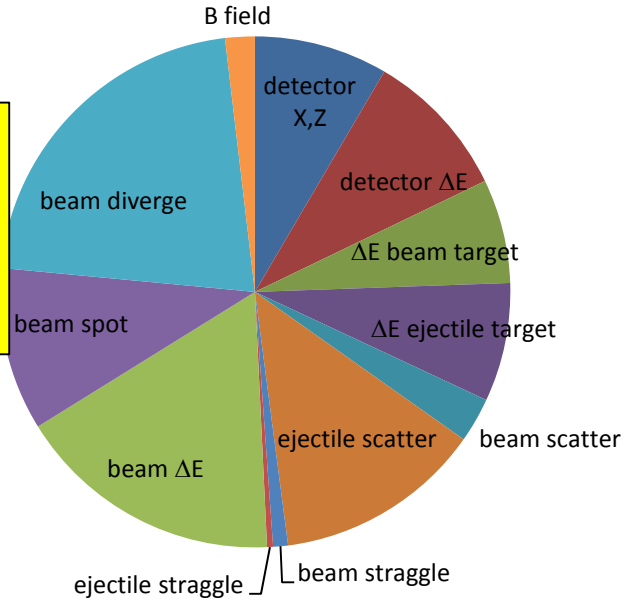
4 MeV/u ^{12}C(^{224}Ra,^{12}C')^{224}Ra*
Q-value = 1.05 E_{lab} - 0.80 z

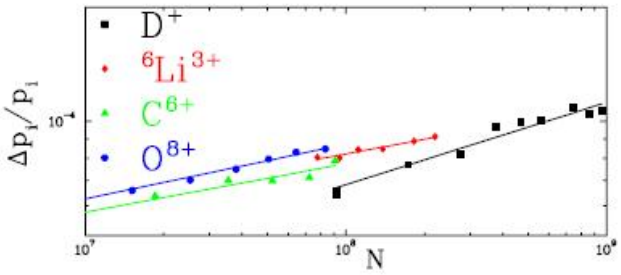
10 MeV/u d(^{223}Ra,d')^{223}Ra*
Q-value = 1.01 E_{lab} - 0.17 z

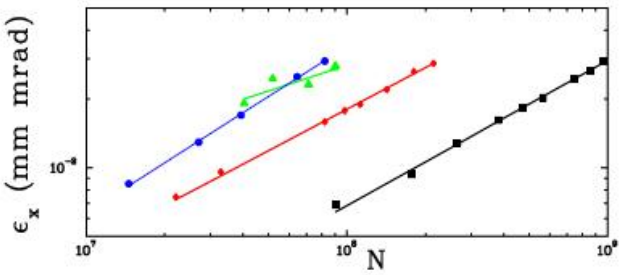
Contributions to Q-value resolution

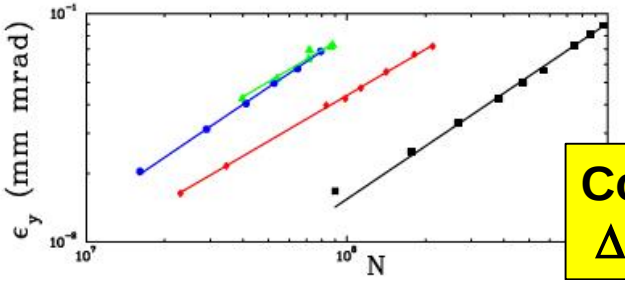
Direct beam from HIE-ISOLDE

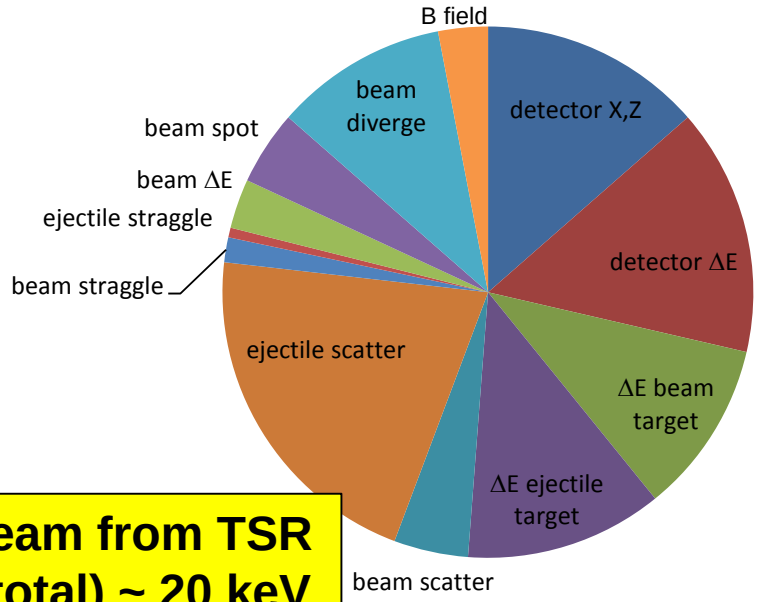
ΔE_{FWHM} (total) ~ 40 keV for (d,d') or (d,p)











Cooled beam from TSR
ΔE_{FWHM} (total) ~ 20 keV

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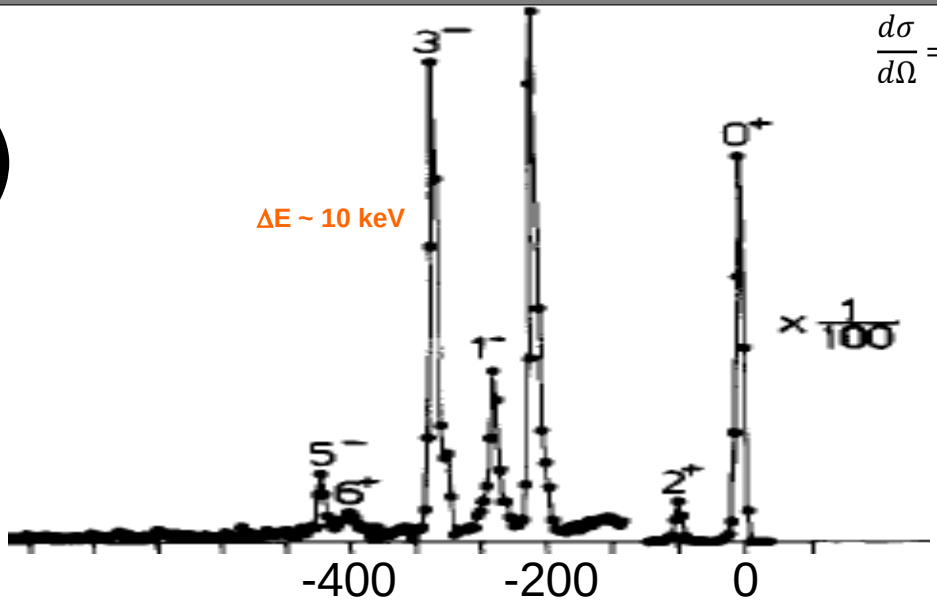
Measuring B(E3)s in ^{225}Ra parity doublet

$$\frac{d\sigma}{d\Omega} = \beta_\ell^2 |< I_A \ell K 0 | I_B >|^2 \, \sigma_{\mathrm{DWUCK}}$$

^{226}Ra(d,d')

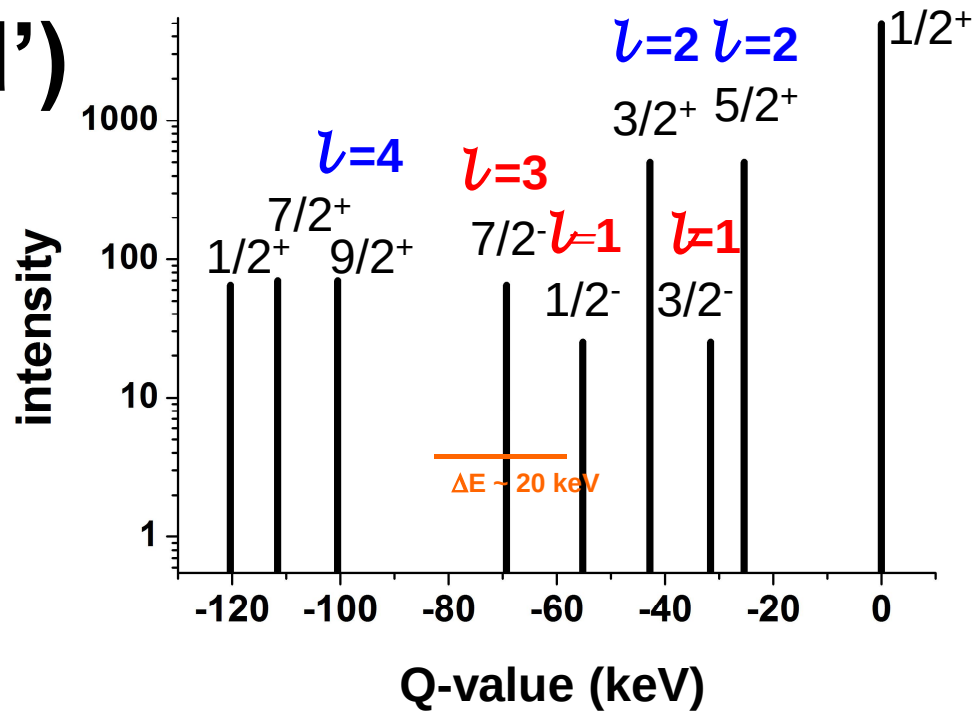
actual data

Thorsteinsen et al.
Phys. Scr. 42 (1990) 141



^{225}Ra(d,d')

2022 ?



Summary

Strong circumstantial evidence that some nuclei are pear-shaped. Evidence comes from behaviour of energy levels and B(E3)s.

Odd mass octupole-deformed nuclei offer greatly increased sensitivity for EDM searches.

Measurement of B(E3) in odd-A nuclei will benefit from beam cooling.

CERN-ISOLDE (T STORA, F WENANDER)
Technische Universität Darmstadt
University of Edinburgh
GANIL
University of Jyväskylä
Universität zu Köln
KU Leuven
Lawrence Livermore National Lab
University of Liverpool (L GAFFNEY)
University of Lund
Universidad Autónoma de Madrid
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Technische Universität München
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