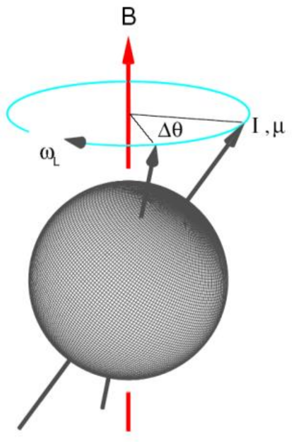
Australian National University

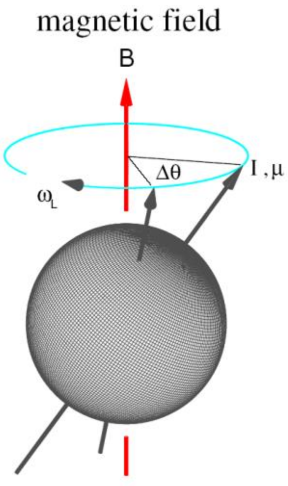
Prospects for nuclear moment measurements with $LaBr_3$ detectors



Andrew Stuchbery

Department of Nuclear Physics, ANU

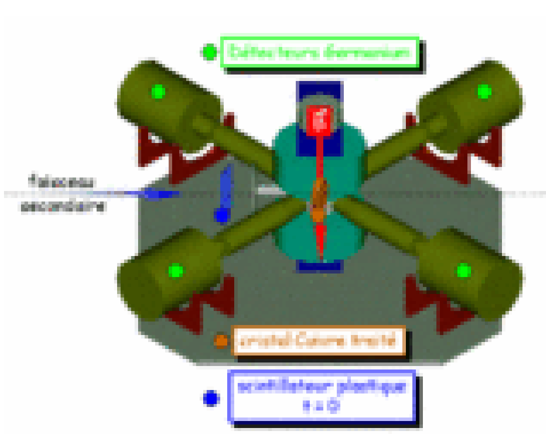
TDPAD method

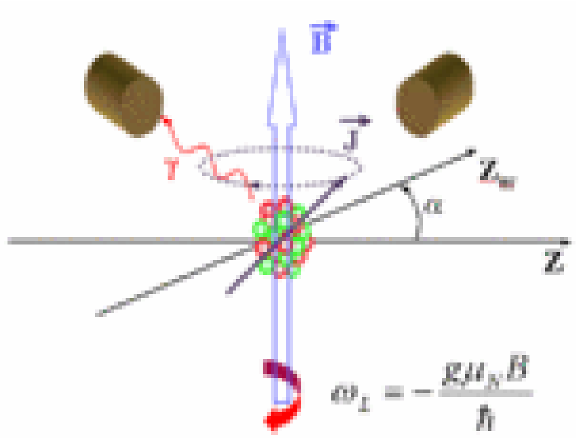


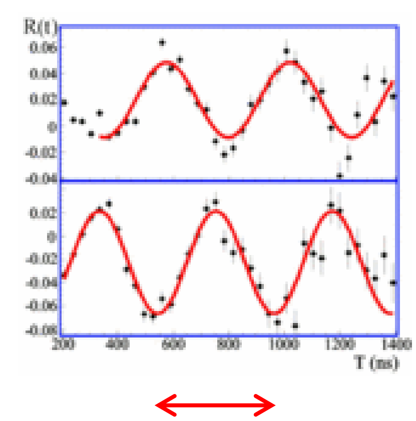
Nuclear spin rotation

$$\omega_L = g\,\frac{\mu_N}{\hbar}B \qquad T = \frac{\pi}{\omega_L}$$

magnetic moments from precession frequency







T

Figures from CEA website

Australian National University

$LaBr_3$ & TDPAD

Ge detectors
- ‘Excellent’ energy resolution
- Poor timing resolution TDPAD period T > 10 ns

$LaBr_3$ detectors
- ‘Good’ energy resolution
- Good timing resolution TDPAD period T > 0.2 ns

BaF_2 detectors
- ‘Poor’ energy resolution
- Good timing resolution TDPAD period T > 0.2 ns

- In-beam
- Hyperfine fields (tens of kTesla)

$LaBr_3$ & TDPAD

Ge detectors

- 'Excellent' energy resolution
- Poor timing resolution TDPAD period T > 10 ns

$LaBr_3$ detectors

- 'Good' energy resolution
- Good timing resolution TDPAD period T > 0.2 ns

BaF_2 detectors

- 'Poor' energy resolution
- Good timing resolution TDPAD period T > 0.2 ns

- In-beam
- Hyperfine fields

Can now tackle some long standing problems

^{110}Cd g(10^+)

ELSEVIER

Nuclear Physics A 591 (1995) 533–547

NUCLEAR PHYSICS A

Measurement of the g-factor of the yrast 10^+ state in ^{110}Cd

P.H. Regan [a,b], A.E. Stuchbery [a], S.S. Anderssen [a]

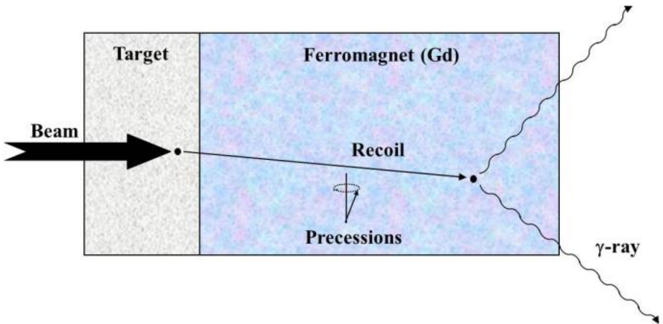
[a] *Department of Nuclear Physics, Research School of Physical Science and Engineering, Australian National University, Canberra, ACT 0200, Australia*

[b] *Department of Physics, University of Surrey, Guildford GU2 5XH, UK*

Received 28 March 1995

^{110}Cd g(10^+)

^{100}Mo(^{13}C,3n)^{110}Cd 45 MeV



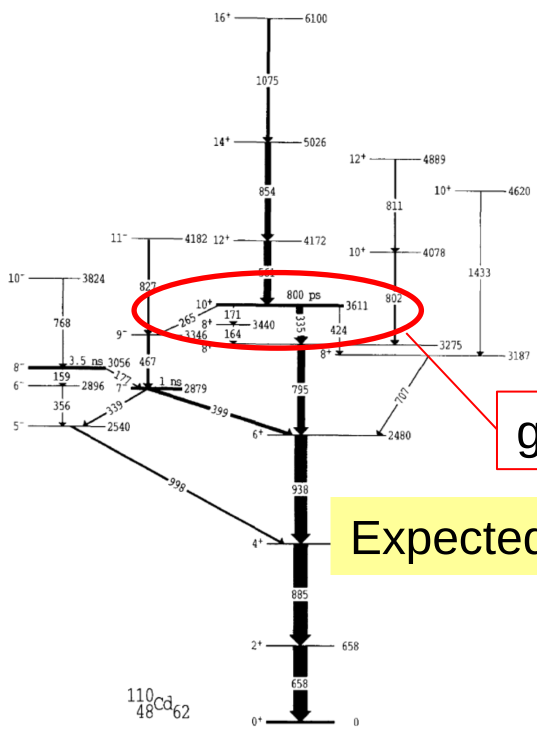
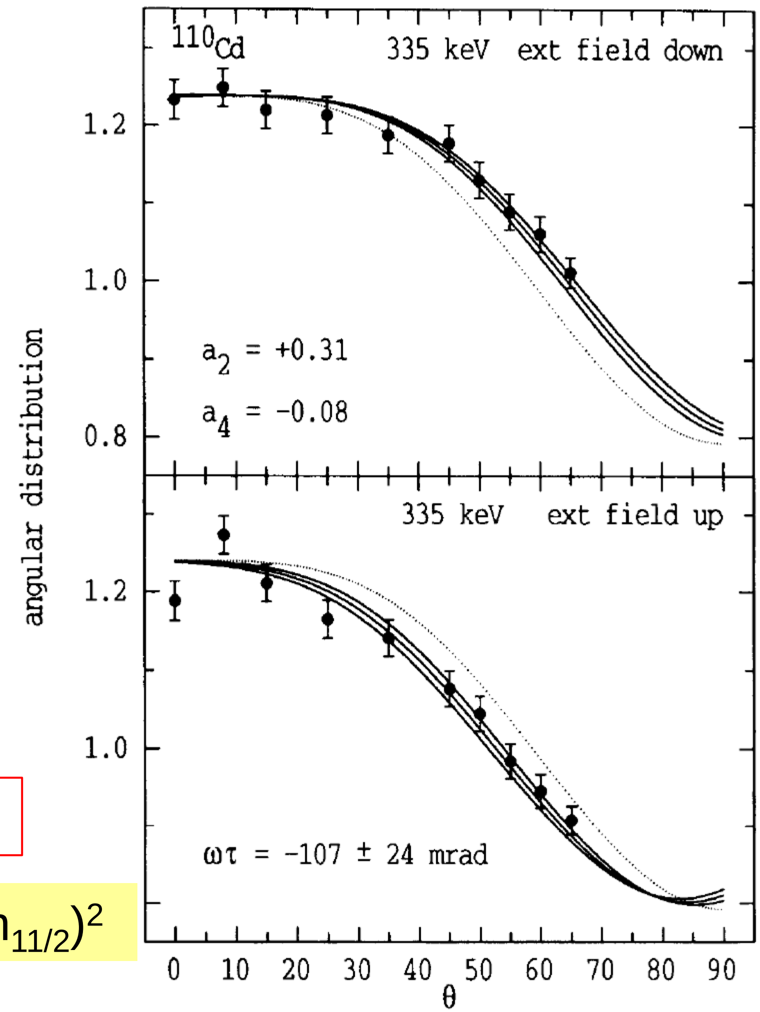


Fig. 1. Partial decay scheme for ^{110}Cd. Mean lives are shown for the longer-lived states of interest.

g(10^+) = -0.09(3)

Expected g ~ -0.2 for $\nu(h_{11/2})^2$



Integral perturbed angular correlations

^{110}Cd g(10^{+})

Do we know the field(s) at the implantation site(s)?

(Electric field gradients & quadrupole interactions?)

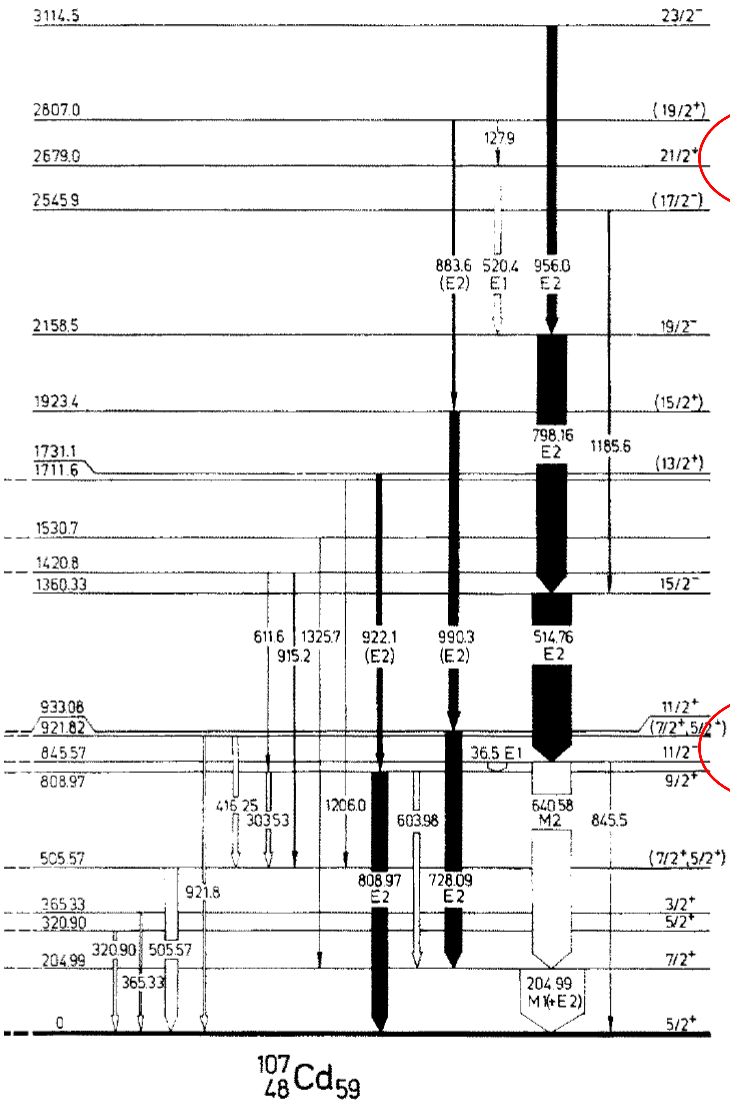
How do we find out?

TDPAD – time dependent angular distributions

$^{100}Mo(^{12}C,5n)^{107}Cd$ 65 MeV

Pulsed beam (~ 1ns FWHM)

^{107}Cd isomers known g

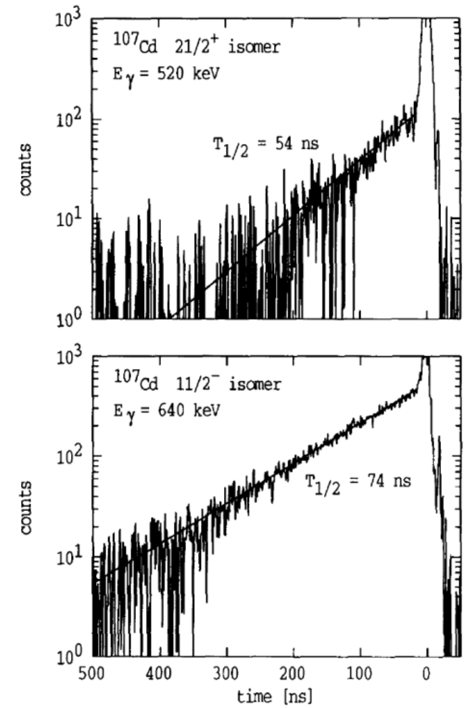


Level scheme from NPA 228, 112

g ~ 0.8

g ~ -0.2

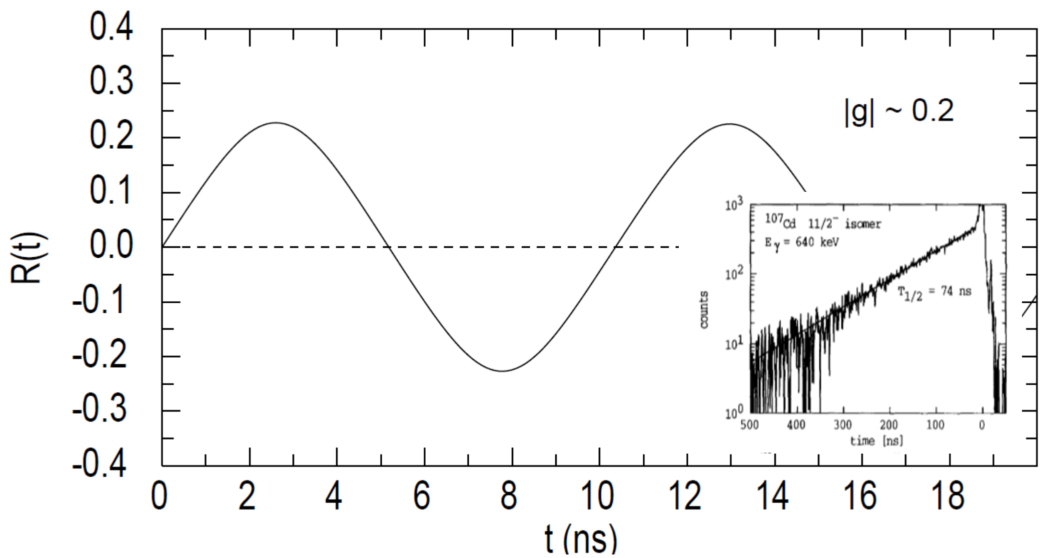
^{100}Mo(^{12}C,5n)^{107}Cd 65 MeV



We observed the $11/2^-$ and $21/2^+$ isomers but could not resolve spin precessions with HPGe detectors

- Can revisit and solve problem with $LaBr_3$

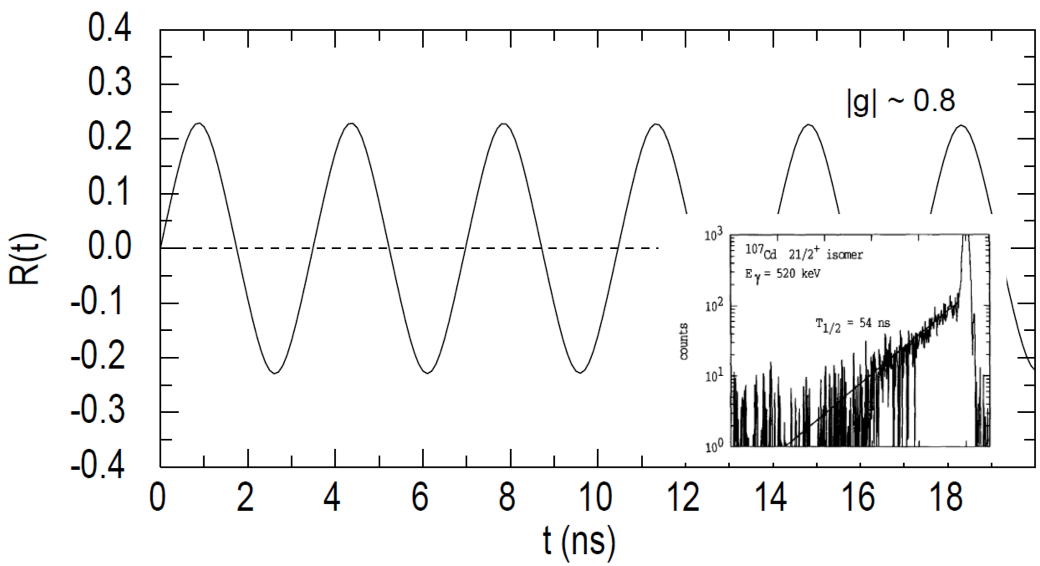
Time resolution in R(t)



30 kTesla hyperfine field

Pure magnetic interaction

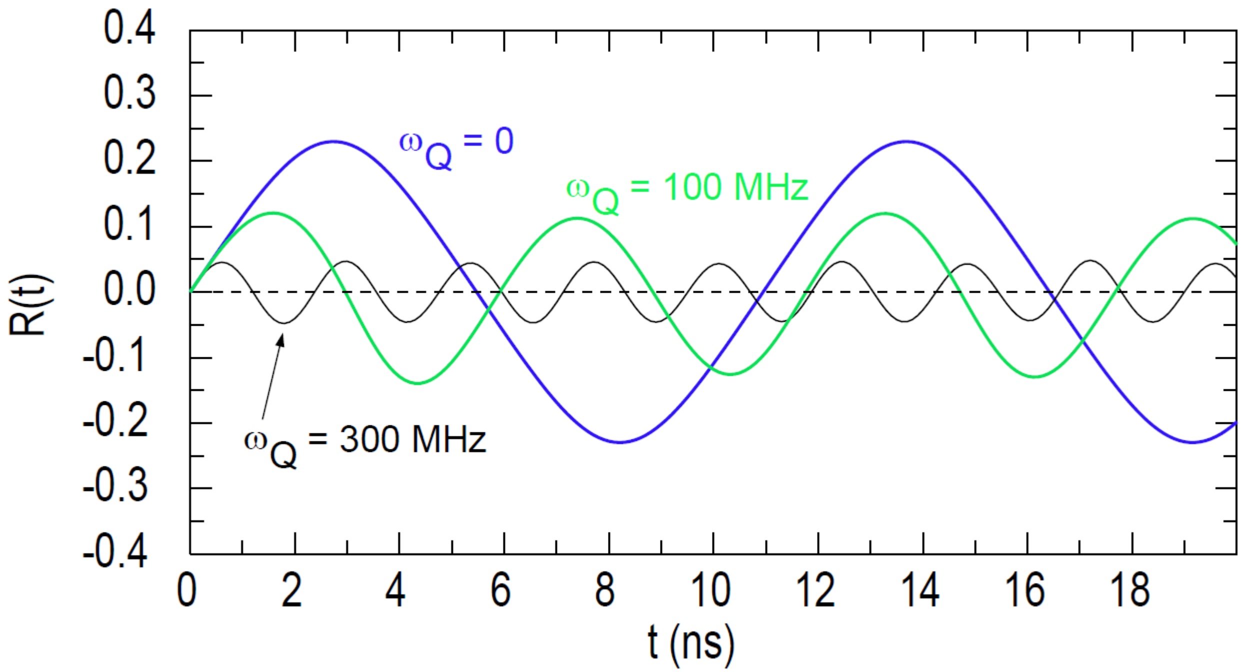
Could not see this oscillation with HPGe



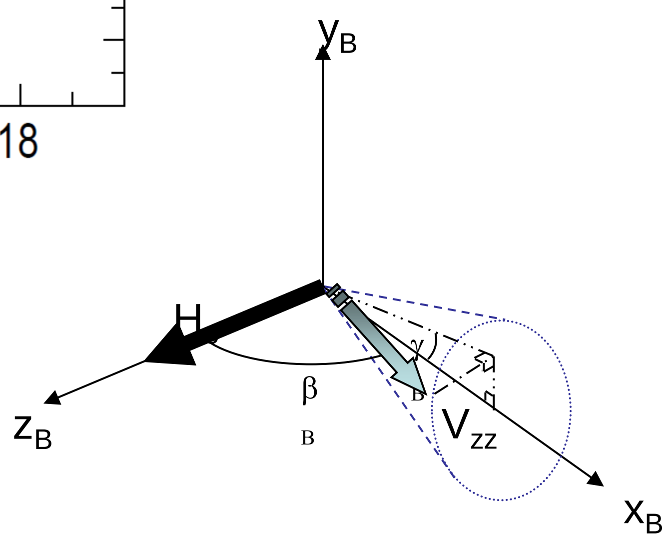
Periods within time resolution of $LaBr_3$

Electric field gradients

or “What can go wrong”



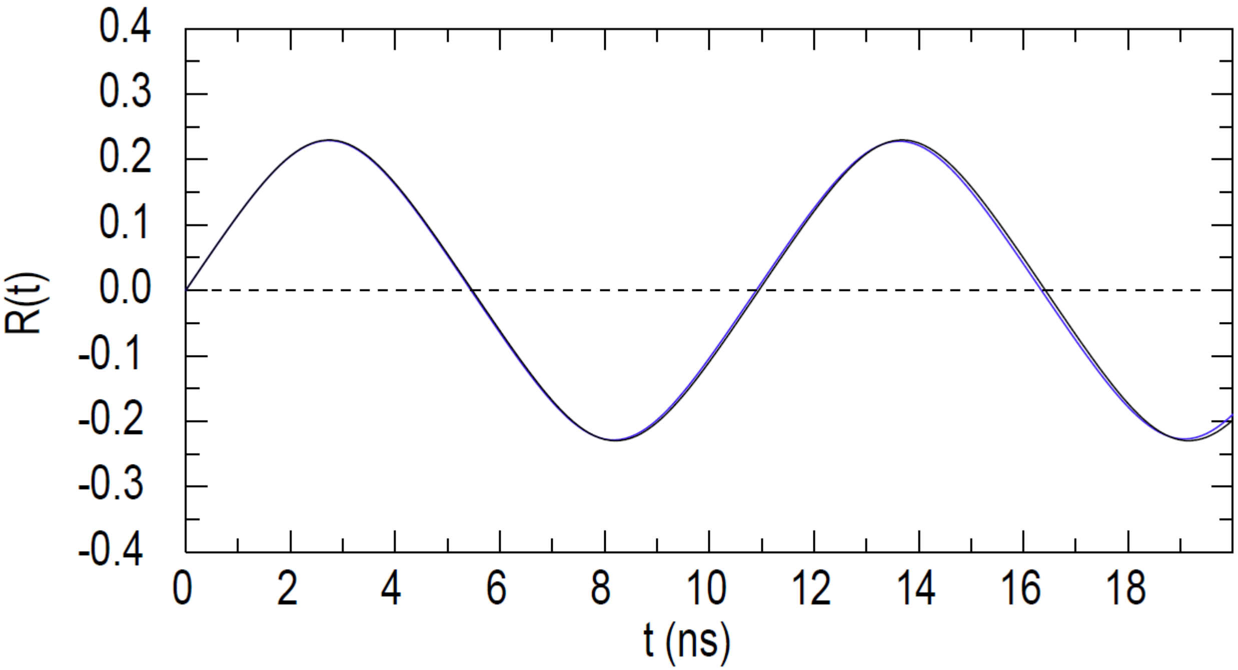
EFG in beam direction

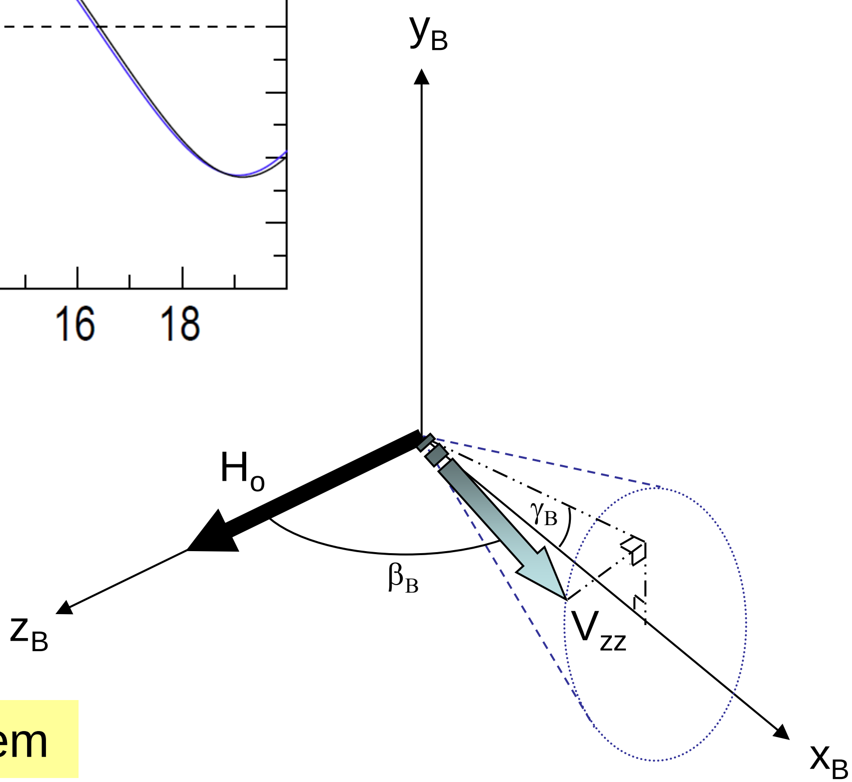


Beam direction

What expect

With realistic EFG little effect on R(t)



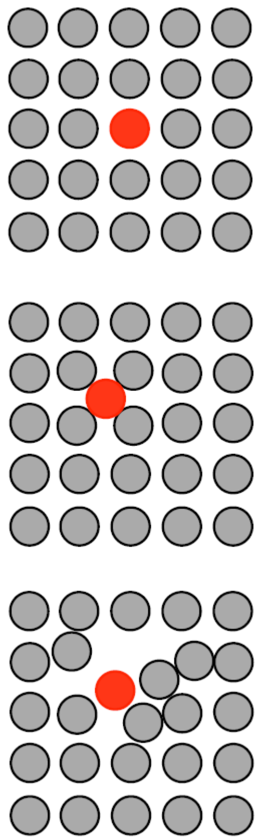


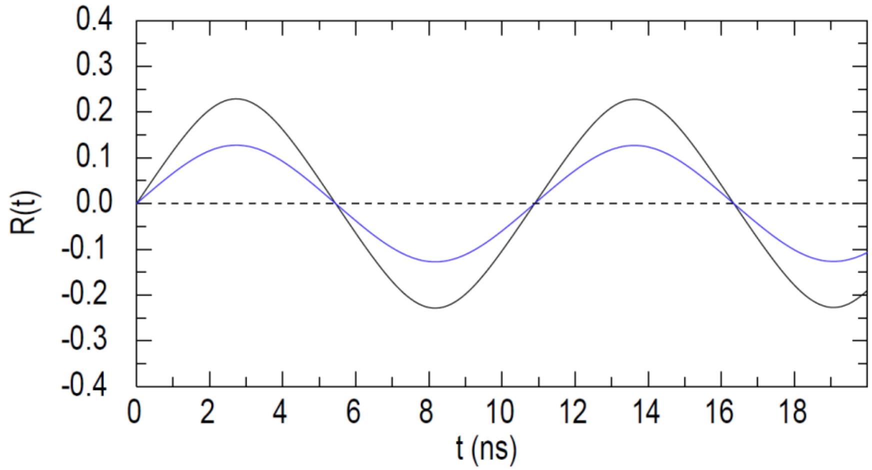
Quadrupole interactions likely not a problem

Australian National University

Nuclei on low-field sites

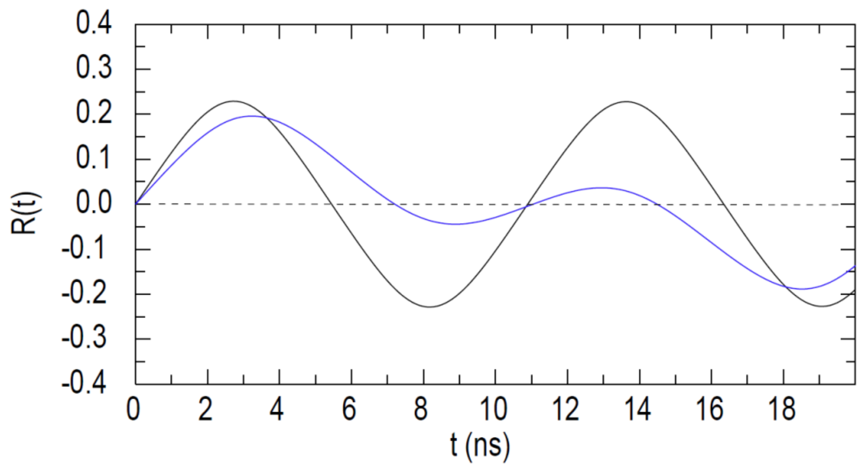
or "What else can go wrong"





50% on zero-field sites

Big impact on R(t).



50% on half-field sites

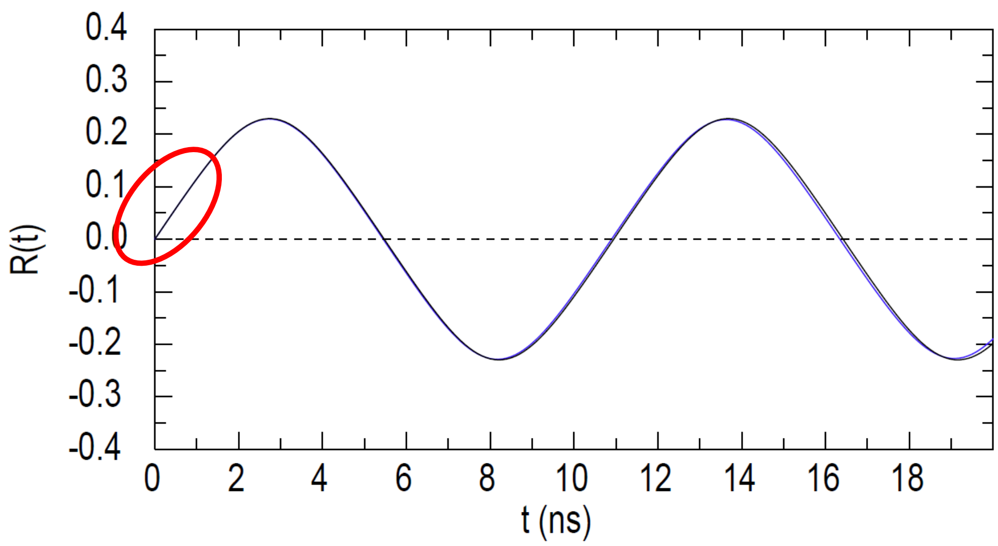
Important application for $LaBr_3$ detectors – in-beam hyperfine interactions

^{110}Cd g(10^+) conclusions

$T_{1/2}$ = 800 ps

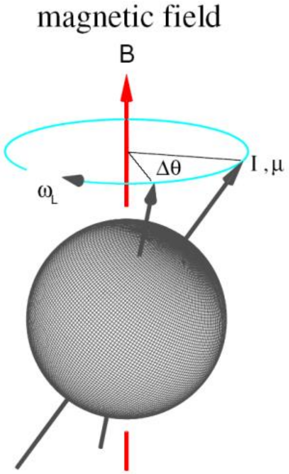
Too short to measure R(t) for g-factor measurement on this 10^+ state

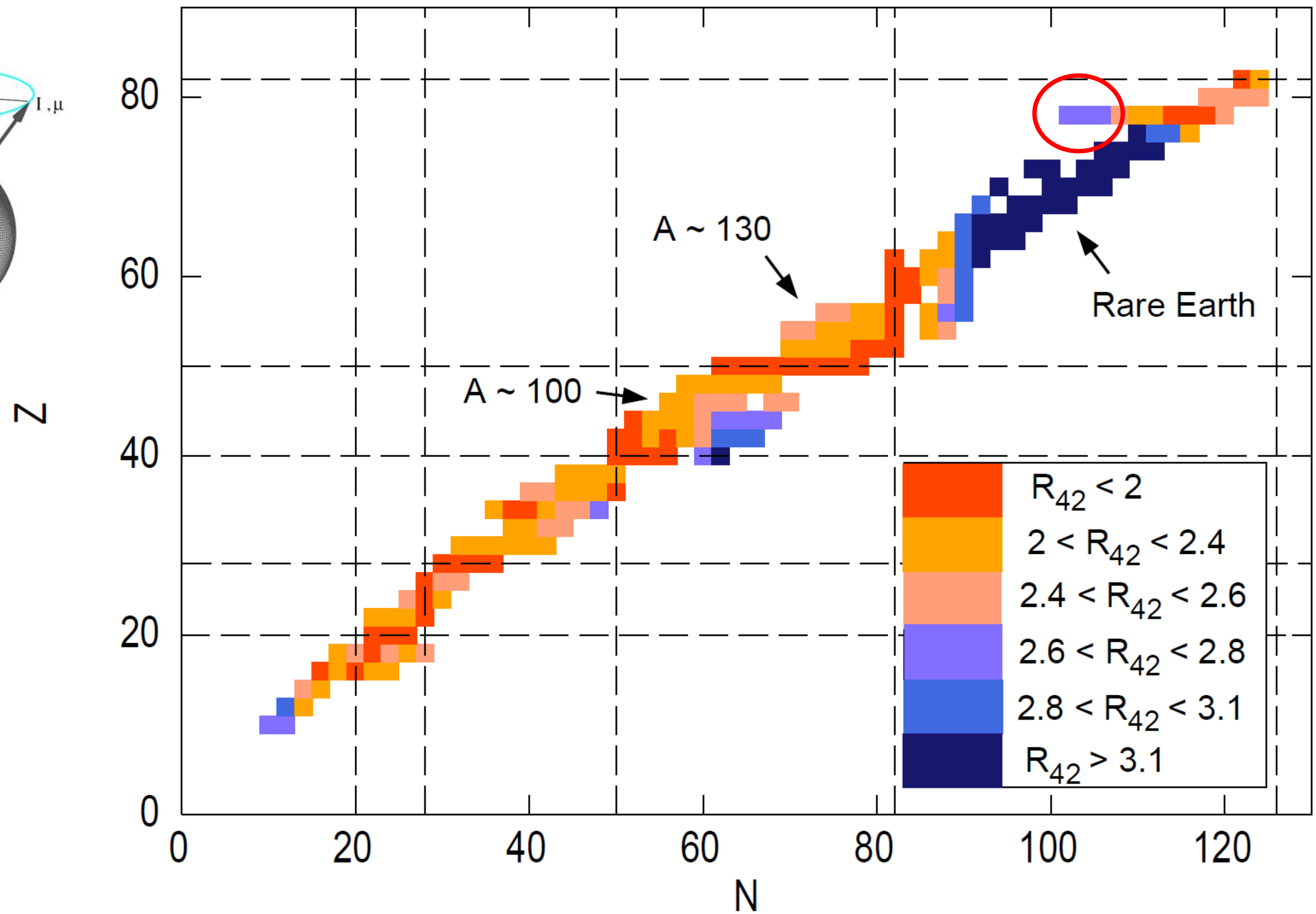
Can use R(t) on longer-lived states to determine the effective field in the integral g-factor measurement



Q(2^+) in ^{182,184}Pt

Nuclei with known g(2+)





Australian National University

Perturbed DCO

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 485 (2002) 753–767

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

Perturbed γ–γ correlations from oriented nuclei and static moment measurements I: formalism and principles

Andrew E. Stuchbery*, Martyn P. Robinson

Department of Nuclear Physics, Research School of Physical Sciences and Engineering, The Australian National University, Canberra, ACT 0200, Australia

Received 9 August 2001; accepted 21 August 2001

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 489 (2002) 469–495

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

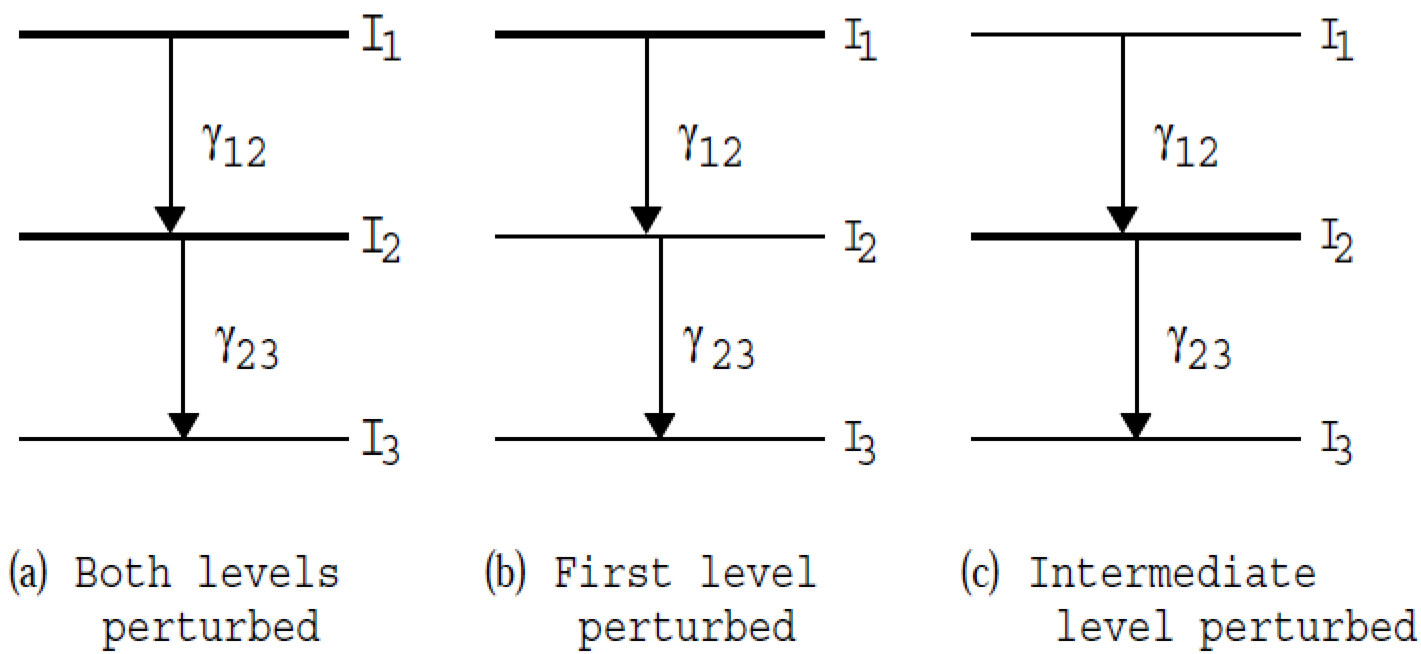
www.elsevier.com/locate/nima

Perturbed γ–γ correlations from oriented nuclei and static moment measurements. II: *g* factors at low spin and high spin

Martyn P. Robinson, Andrew E. Stuchbery*

Department of Nuclear Physics, Research School of Physical Sciences and Engineering, The Australian National University, Canberra, ACT 0200, Australia

Perturbed DCO



Time-dependent perturbed angular correlations:

- Triple correlations. Ge-$LaBr_3$-$LaBr_3$
- Pulsed picosecond beams + $\gamma\gamma$ correlations (Ge-$LaBr_3$)

Perturbed DCO

(ii) If only the intermediate level I_2 is perturbed, Fig. 2(c), Eq. (18) becomes

$$
\begin{aligned}
W(t) = \sum_{kk_1k_2k_2'qq_2q_2'} & B_{k_1}(I_1)A_k^{k_2k_1}(\delta_{\gamma_{12}}LL'I_2I_1) \\
& \times G_{k_2k_2'}^{q_2q_2'*}(t)A_{k_2'}(\delta_{\gamma_{23}}LL'I_3I_2) \\
& \times Q_k(E_{\gamma_{12}})Q_{k_2'}(E_{\gamma_{23}}) \\
& \times (-1)^{k_1}\sqrt{(2k+1)}\begin{pmatrix} k_1 & k & k_2 \\ 0 & q & q_2 \end{pmatrix} \\
& \times D_{q0}^{k*}(\phi_1,\theta_1,0)D_{q_2'0}^{k_2'*}(\phi_2,\theta_2,0). \qquad (23)
\end{aligned}
$$

Q(2$^+$) in ^{182,184}Pt

Spectroscopic quadrupole moments in ^{182}Pt and ^{184}Pt

Andrew Stuchbery

Martyn Robinson, Robert Bark, Aidan Byrne, George Dracoulis,

Simon Mullins and Allan Baxter

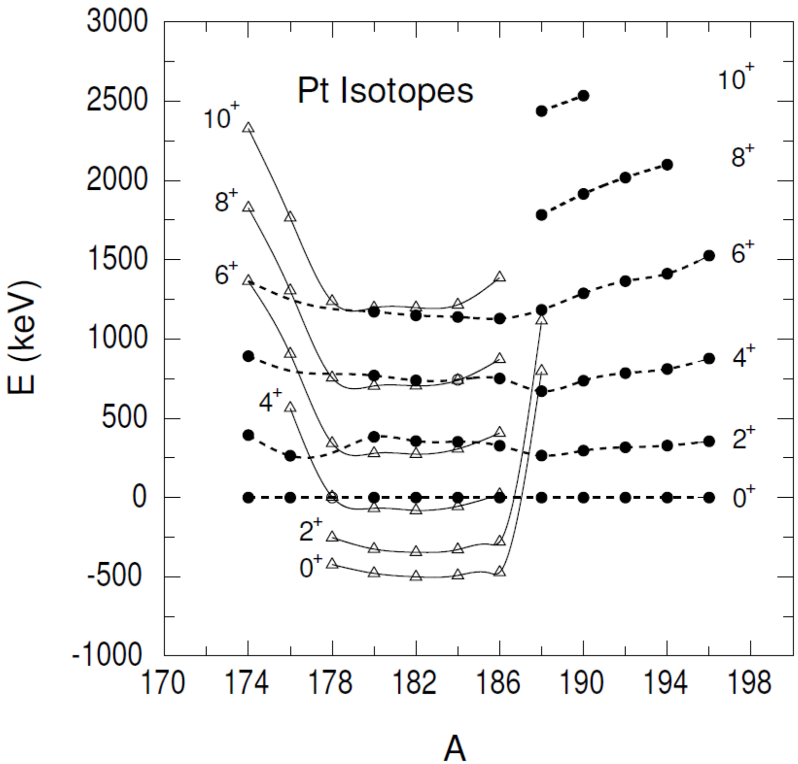
Department of Nuclear Physics, The Australian National University,

Canberra ACT 0200 Australia

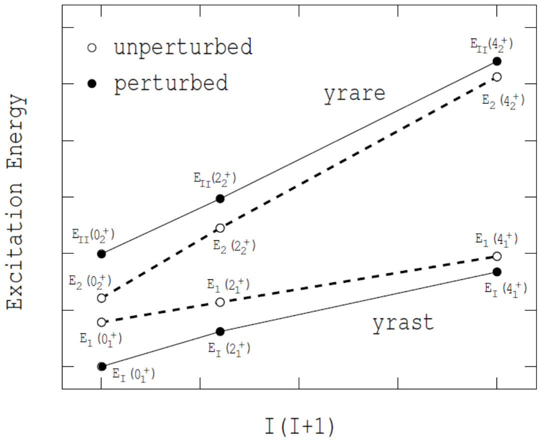
Outline

- shape coexistence in the Pt isotopes:
  is the excited configuration prolate or oblate?
- quadrupole moment measurement
  perturbed DCO technique
- results and discussion:
  shape coexistence and triaxiality

Shape coexistence



Empirical model (simplified)

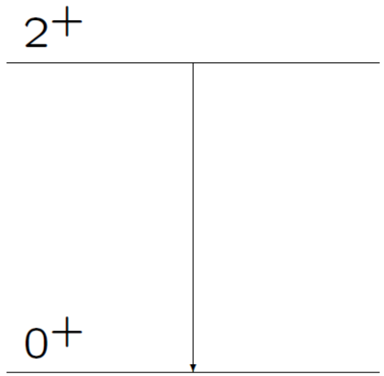


$$|\psi(0^+)\rangle = 0.73|\psi_d(0^+)\rangle + 0.68|\psi_s(0^+)\rangle$$

$$|\psi(2^+)\rangle = 0.85|\psi_d(2^+)\rangle + 0.53|\psi_s(2^+)\rangle$$

$$|\psi(4^+)\rangle = 0.94|\psi_d(4^+)\rangle + 0.33|\psi_s(4^+)\rangle$$

B(E2) and Q(2$^+$)



$$A|\psi_d(2^+)\rangle + \sqrt{1-A^2}|\psi_s(2^+)\rangle$$

$$B|\psi_d(0^+)\rangle + \sqrt{1-B^2}|\psi_s(0^+)\rangle$$

Cross terms are usually ignored

$$\begin{aligned}\langle 0||T(E2)||2\rangle &= AB\langle\psi_d(0^+)||T(E2)||\psi_d(2^+)\rangle \\ &+ \sqrt{(1-A^2)(1-B^2)}\langle\psi_s(0^+)||T(E2)||\psi_s(2^+)\rangle \\ &+ A\sqrt{(1-B^2)}\langle\psi_s(0^+)||T(E2)||\psi_d(2^+)\rangle \\ &+ B\sqrt{(1-A^2)}\langle\psi_d(0^+)||T(E2)||\psi_s(2^+)\rangle\end{aligned}$$

$$B(E2;2\rightarrow 0) = \frac{e^2}{32\pi}\left(ABQ_0(d) + \sqrt{(1-A^2)(1-B^2)}Q_0(s)\right)^2$$

$$Q(2) = -\frac{2}{7}\left(A^2Q_0(d) + (1-A^2)Q_0(s)\right)$$

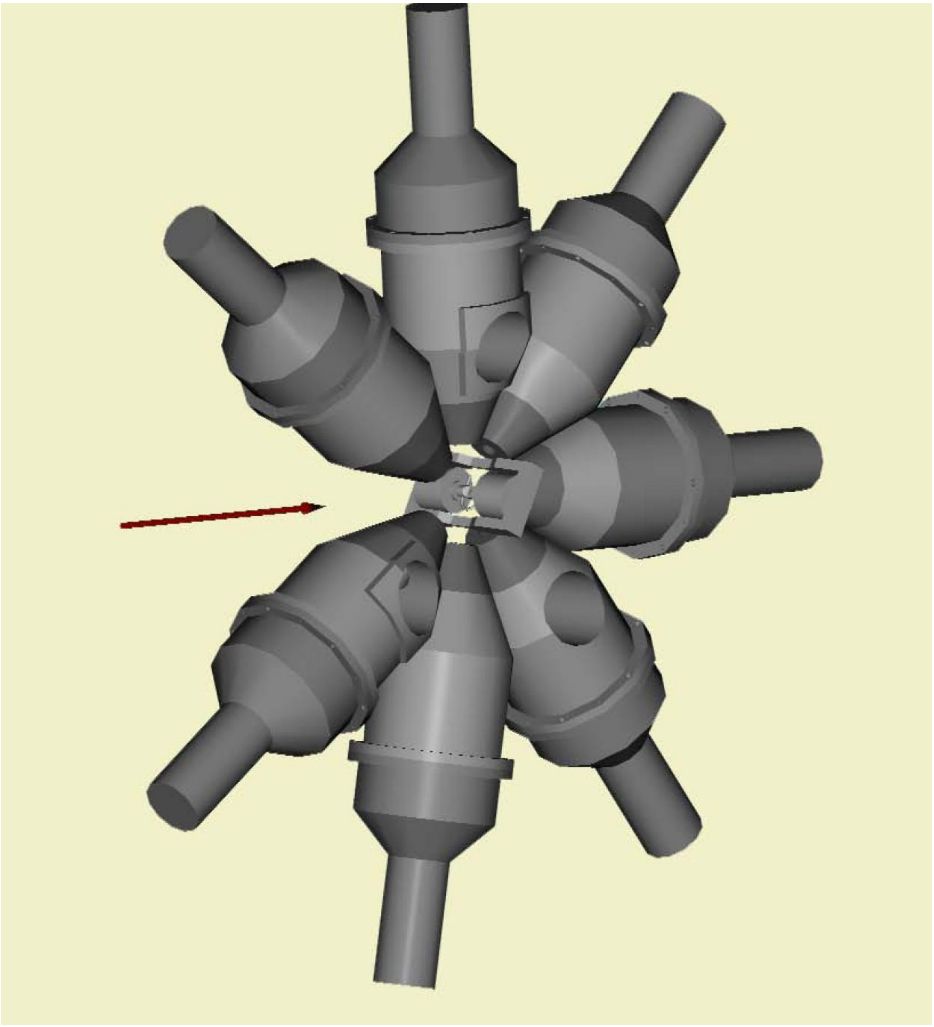
Australian National University

$Q(2^+)$ in ^{182,184}Pt

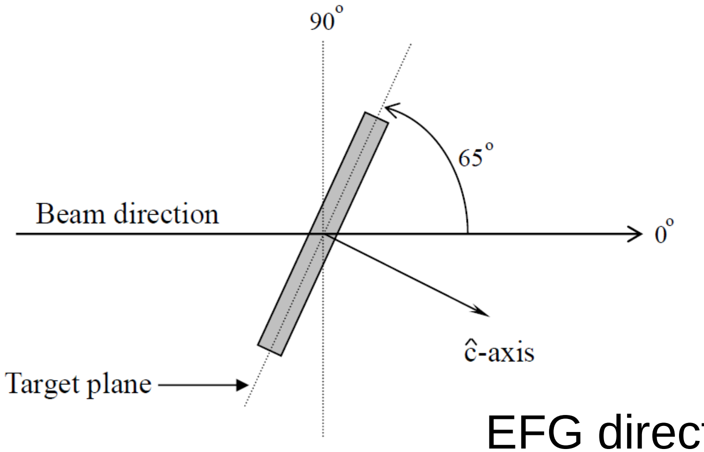
PDCO $Q(2^+)$ in ^{182,184}Pt

- 145 MeV ^{29}Si + ^{nat}Gd $\rightarrow$ $^{180-184}$Pt
  - target:
    5.96 mg cm^{-2} ^{nat}Gd (rolled and annealed)
    17.5 mg cm^{-2} ^{nat}Pb
    In flashing + 12 μm Cu
- Gd is both target and host
  - magnetic hyperfine fields known (or small)
    - g factor: PRL 76 (1996) 2246
    - static field: PRC 51 (1995) 1017
  - hcp $\Rightarrow$ electric field gradients
    - oriented microcrystals
    - texture $\approx$ single crystal
  - Curie temperature 293 K
    - 'warm'/'cold' $\Rightarrow$ magnetic interactions off/on

$Q(2^+)$ in $^{182,184}Pt$



Magnetic field out of page



EFG direction

Quadrupole frequency

$$\omega_Q = eQV_{zz}\frac{1}{4\hbar I(2I-1)}$$

Lamor frequency

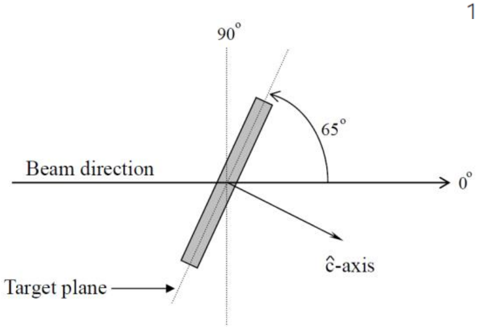
$$\omega_L = -g\frac{\mu_N}{\hbar}B$$

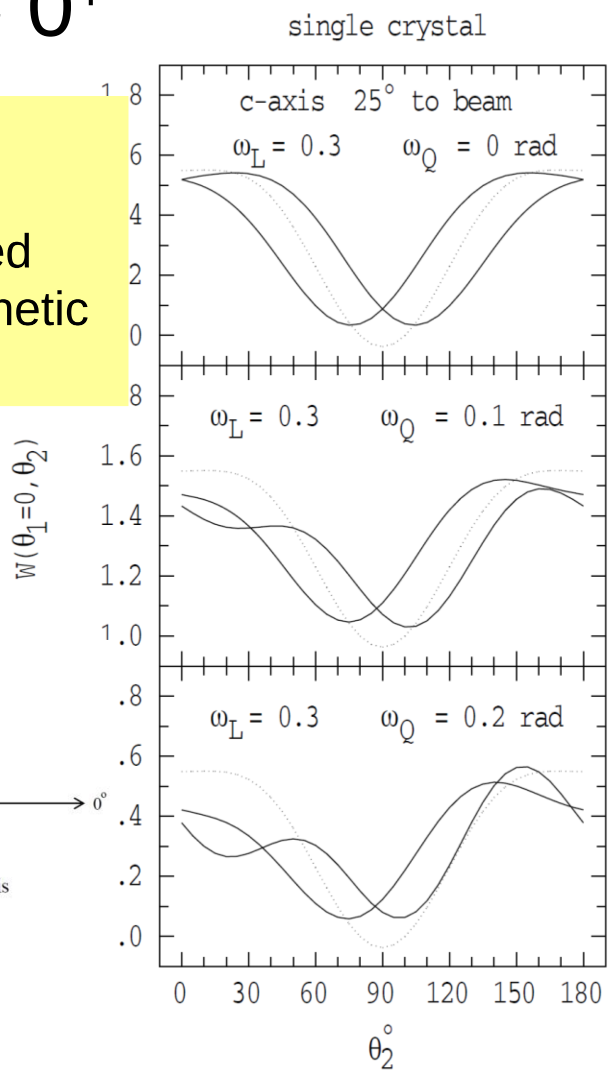
Perturbed DCO simulation

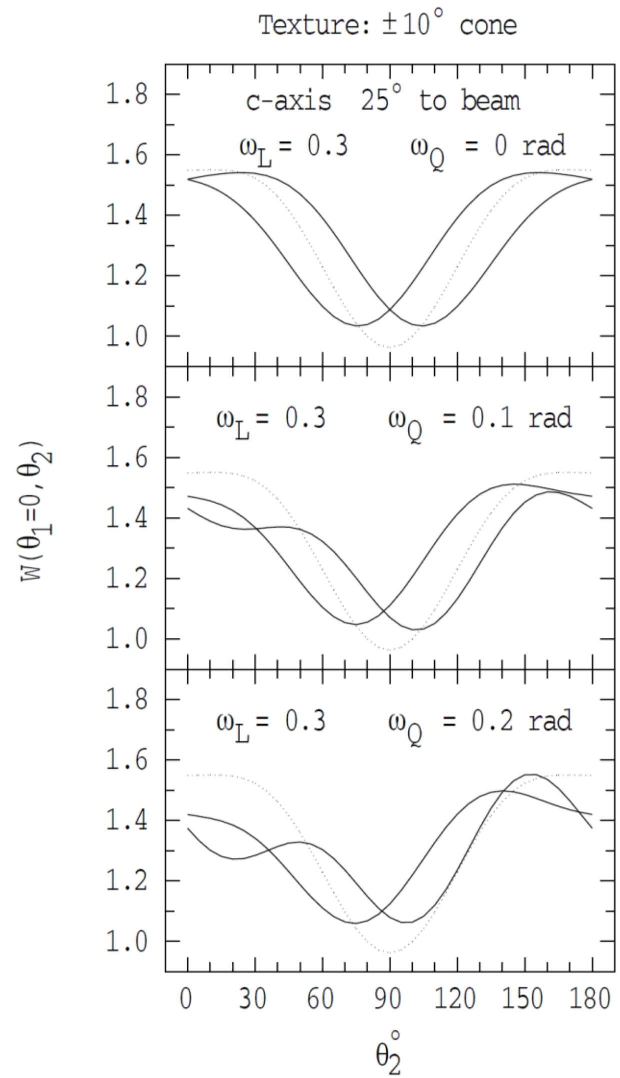
$4^+ \rightarrow 2^+ \rightarrow 0^+$

SIMULATION:

Effect of combined electric and magnetic interactions

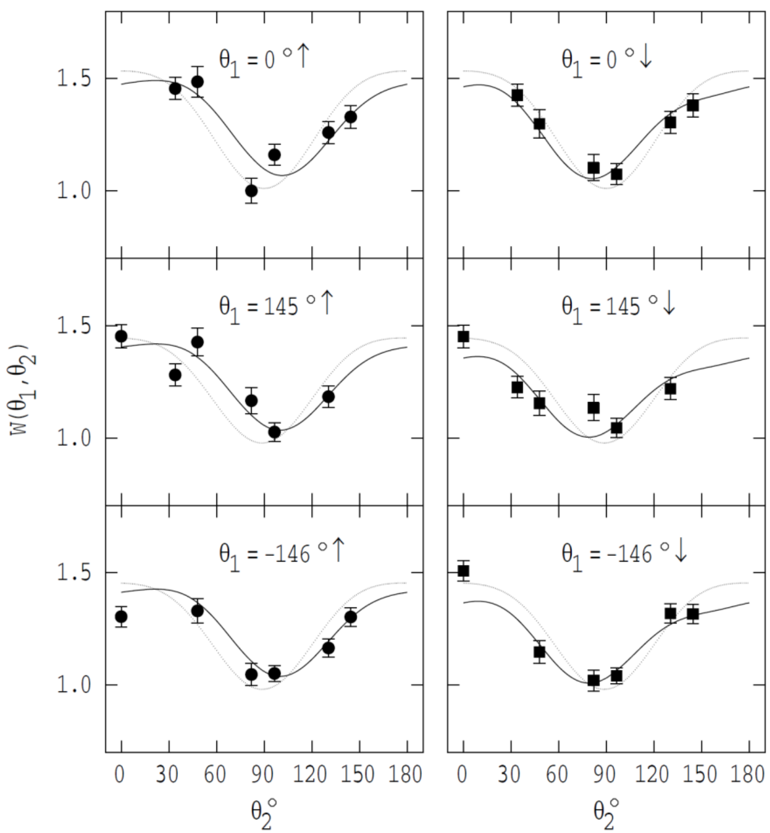


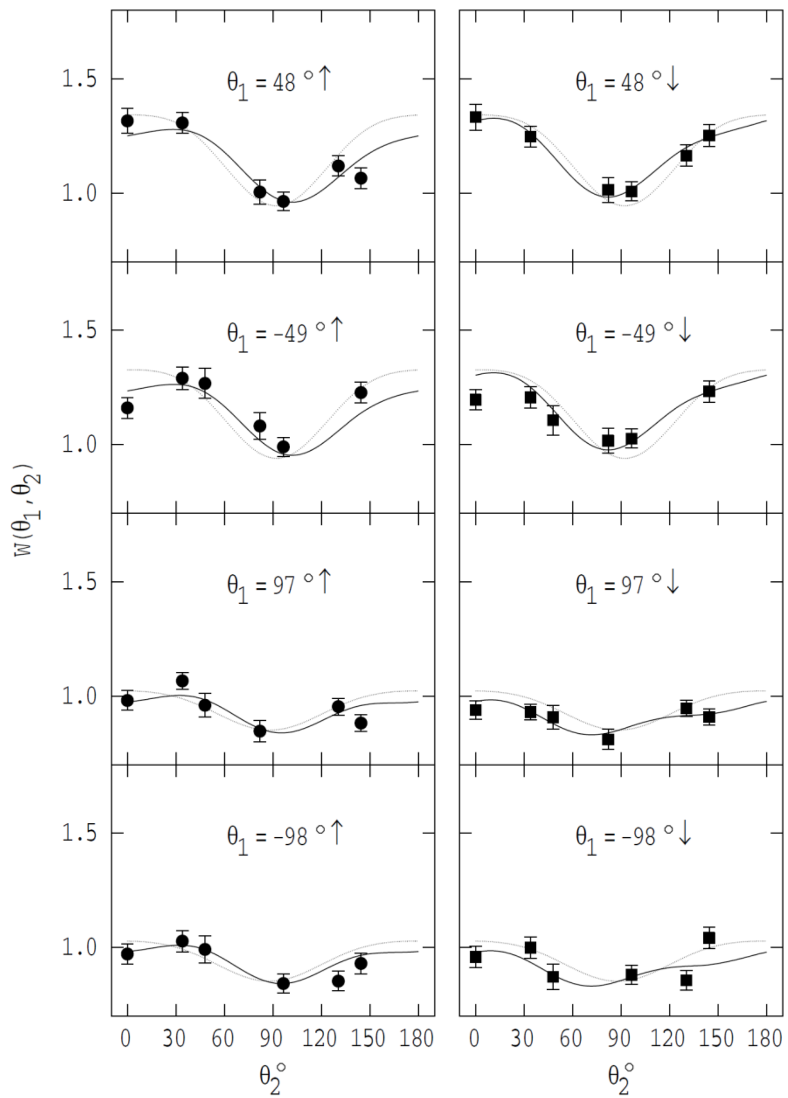




Perturbed DCO data

$4^+ \rightarrow 2^+ \rightarrow 0^+$





$Q(2^+)$ in ^{182,184}Pt

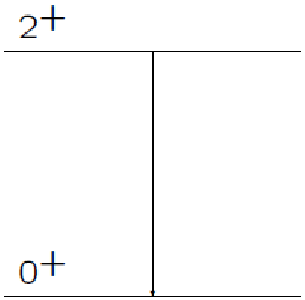
- $B(E2)$ and Q are inconsistent with simple shape-coexistence model
  - $B(E2) \Rightarrow$ $Q_0(s)$ and $Q_0(d)$ have the same sign:

    $Q_0(d) \sim +7.5$ b $\quad Q_0(s) \sim +3.5$ b
  - $Q(2) \Rightarrow$ $Q_0(s)$ and $Q_0(d)$ have opposite signs:

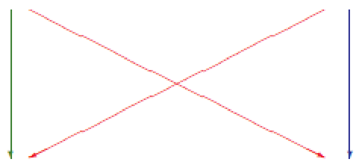
    $Q_0(d) \sim +7.5$ b $\quad Q_0(s) \sim -4.6 \pm 2.0$ b

- For consistency must re-instate cross terms
  - how?
  - strong interaction between prolate and oblate configurations
  - compare with triaxial rotor model

Reinstate cross terms



$$A|\psi_d(2^+)\rangle + \sqrt{1-A^2}|\psi_s(2^+)\rangle$$

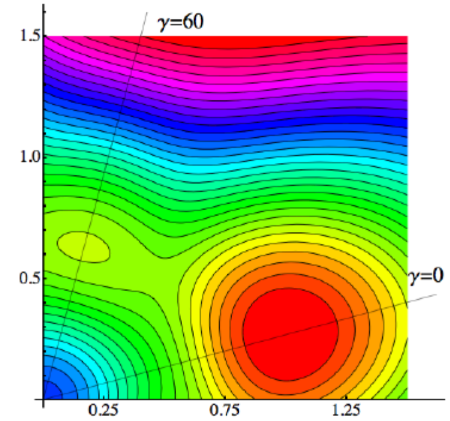


$$B|\psi_d(0^+)\rangle + \sqrt{1-B^2}|\psi_s(0^+)\rangle$$

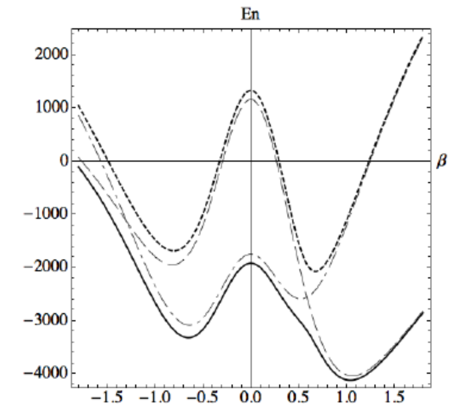
$$\begin{aligned}\langle 0||T(E2)||2\rangle &= AB\langle\psi_d(0^+)||T(E2)||\psi_d(2^+)\rangle \\ &+ \sqrt{(1-A^2)(1-B^2)}\langle\psi_s(0^+)||T(E2)||\psi_s(2^+)\rangle \\ &+ A\sqrt{(1-B^2)}\langle\psi_s(0^+)||T(E2)||\psi_d(2^+)\rangle \\ &+ B\sqrt{(1-A^2)}\langle\psi_d(0^+)||T(E2)||\psi_s(2^+)\rangle\end{aligned}$$

$$\begin{aligned}\langle 2||T(E2)||2\rangle &= A^2\langle\psi_d(2^+)||T(E2)||\psi_d(2^+)\rangle \\ &+ (1-A^2)\langle\psi_s(2^+)||T(E2)||\psi_s(2^+)\rangle \\ &+ A\sqrt{(1-A^2)}\langle\psi_s(2^+)||T(E2)||\psi_d(2^+)\rangle \\ &+ A\sqrt{(1-A^2)}\langle\psi_d(2^+)||T(E2)||\psi_s(2^+)\rangle\end{aligned}$$

But how to calculate?



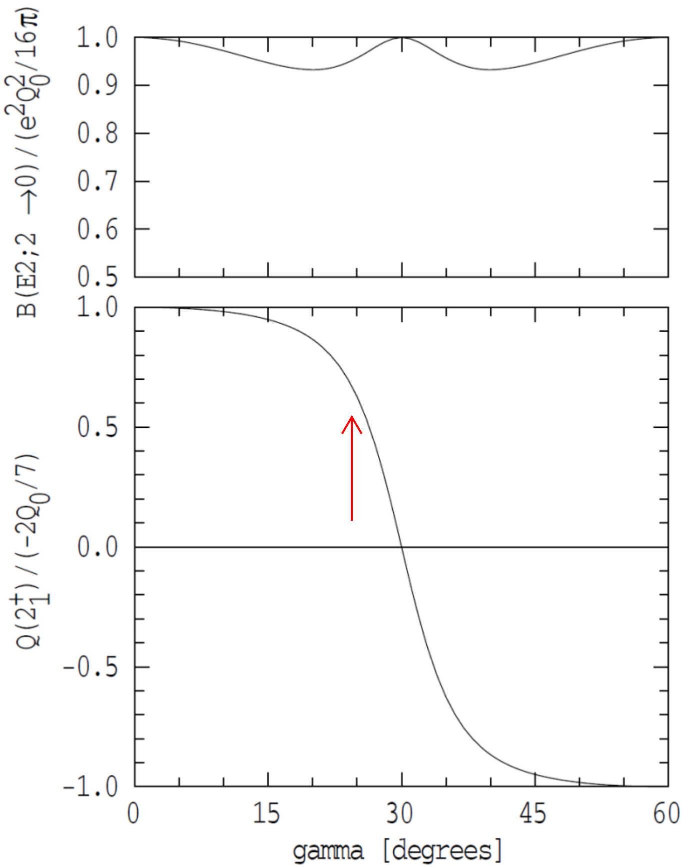
(a)

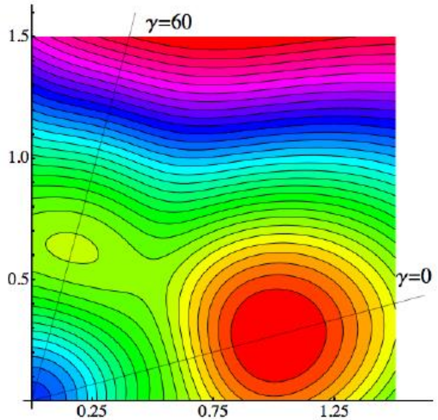


(b)

^{182}Pt Potential energy plots
IO Morales et al.
Physical Review C 78, 024303

Try triaxial rotor





(a)

$$Q(2_1^+)/(-2Q_t/7) \sim 0.7 \Rightarrow \gamma \sim 24^\circ$$

Australian National University

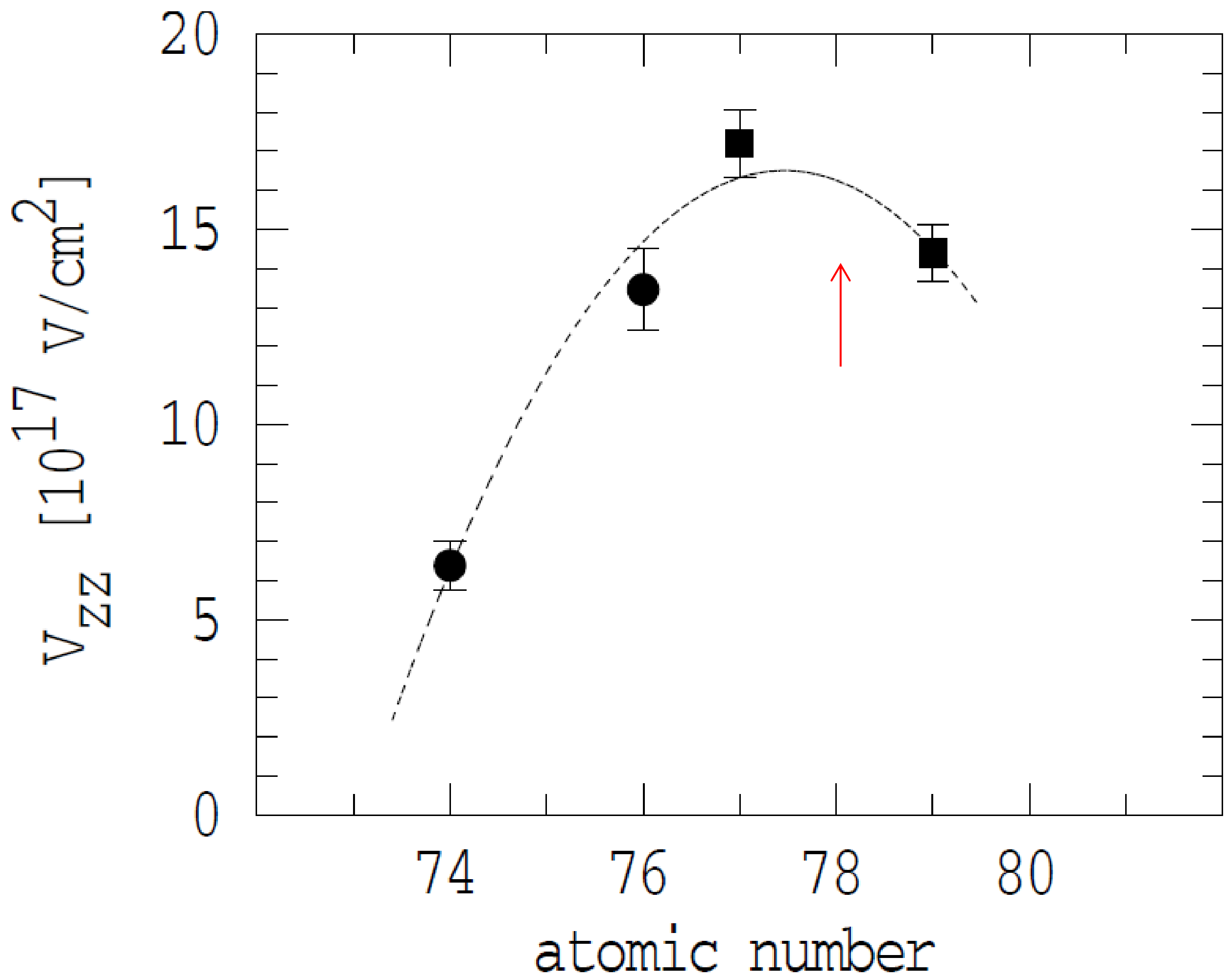
Conclusions, but…

- $Q(2_1^+)$ measured in ^{182,184}Pt
  - Q of sub-ns states in unstable isotopes
- Inconsistent with empirical shape-coexistence model
  - must retain cross terms in E2 matrix elements
- Excited configuration can be oblate
  - consistent with PES calculations
- $Q(2)$ and $B(E2)$ resemble triaxial rotor
  - $\gamma \sim 24°$

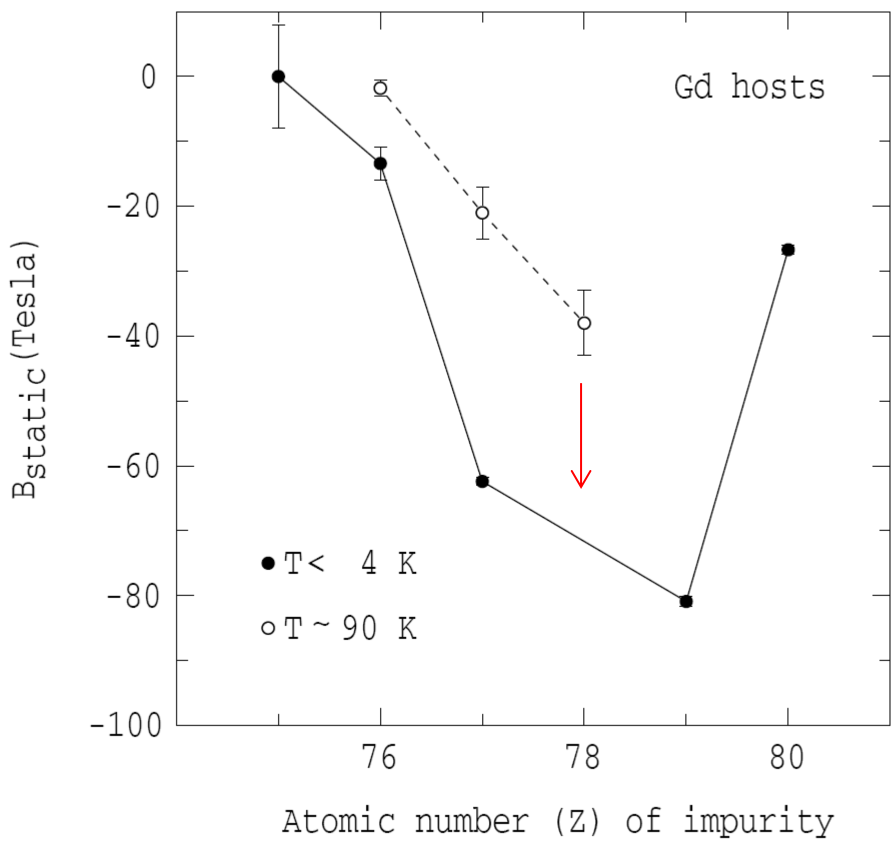
So why the hesitation to publish … ?

And how can $LaBr_3$ detectors help?

Interpolated EFG



Magnetic hyperfine field



Low fields after implantation - why? Does it impact on the Q(2$^+$) measurement?

Australian National University

Temperature dependence?

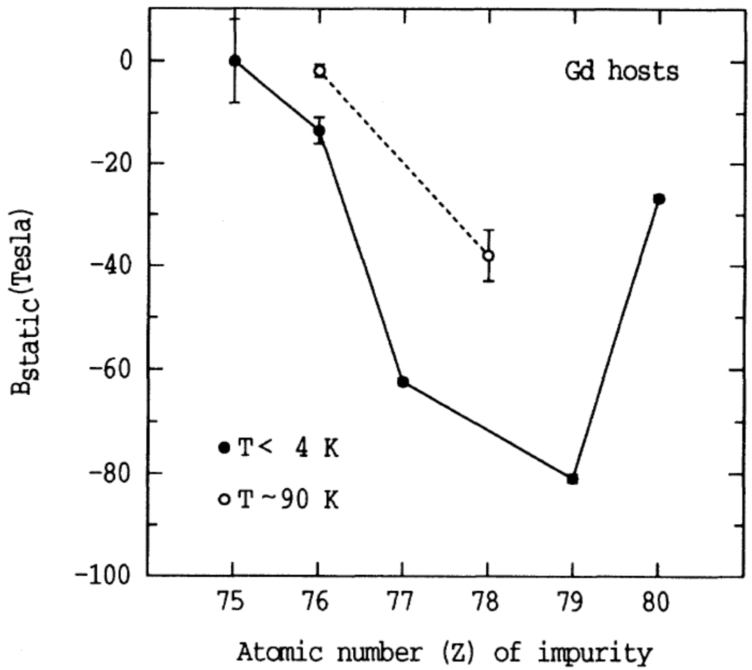


FIG. 3. Hyperfine magnetic fields for impurities with $75 \geq Z \geq 80$ in Gd hosts. The data for temperatures below 4 K are from the compilation of Krane [10]. The data near 90 K are from Forker *et al.* [11] and the present work, for Os ($Z = 76$) and Pt ($Z = 78$), respectively.

- The fields we observe at 90 K (LiN_2 cooling) after in-beam implantation are always smaller than those observed at ≤ 4 K by off-line techniques
- Is the difference due to the temperature?
- Is it due to in-beam implantation?

PHYSICAL REVIEW C VOLUME 51, NUMBER 2 FEBRUARY 1995

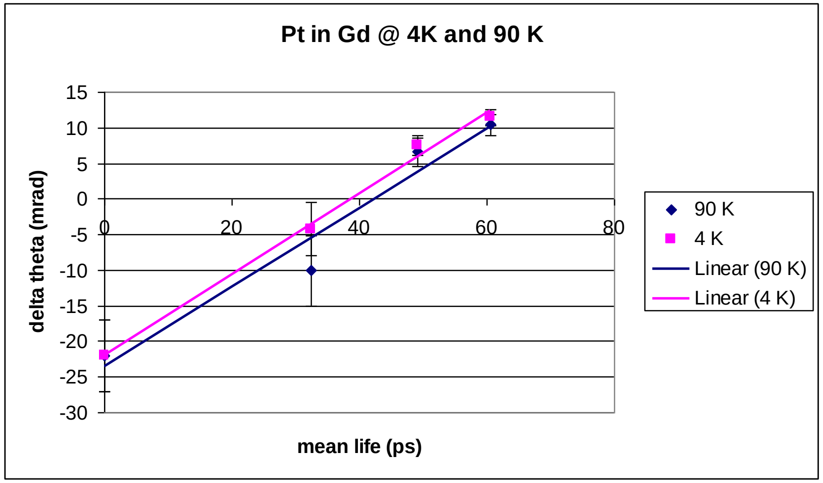
Measured static hyperfine magnetic field for Pt in Gd

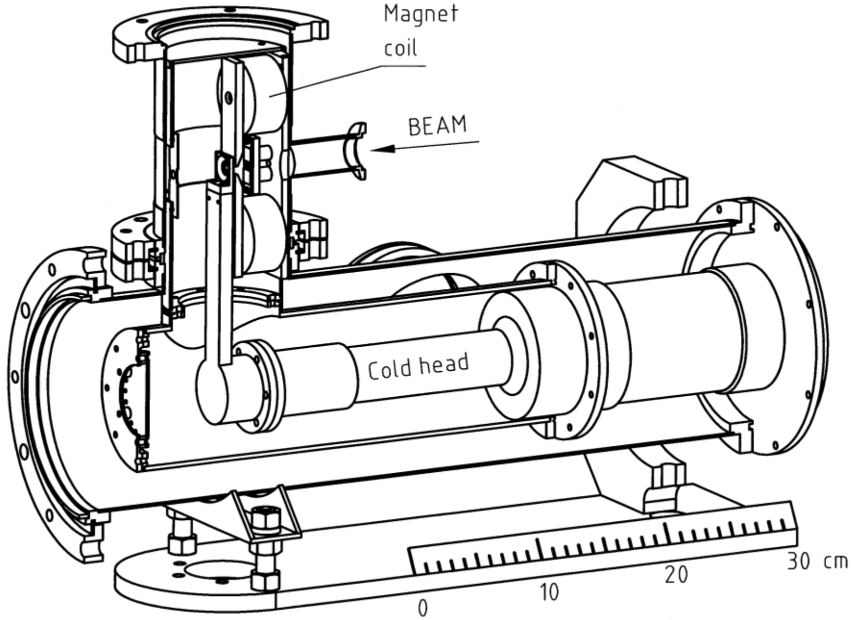
A. E. Stuchbery and S. S. Anderssen
Department of Nuclear Physics, Research School of Physical Sciences and Engineering, Australian National University, Canberra, ACT 0200, Australia
(Received 16 August 1994)

The hyperfine magnetic fields present at ^{194}Pt, ^{196}Pt, and ^{198}Pt nuclei implanted into polarized, ferromagnetic Gd at 92 K were measured using the ion-implantation perturbed angular correlation (IMPAC) technique following Coulomb excitation. The present measured precession for ^{194}Pt agrees with earlier work, but that for ^{196}Pt does not. Our data imply a static field strength for Pt in Gd at 92 K of -38 ± 5 T, which is ~ 50% of the magnitude obtained in the only previous measurement. It is likely that the hyperfine field for Pt in Gd has an anomalous dependence on temperature, similar to that observed for Os in Gd.

Temperature dependence? – No!

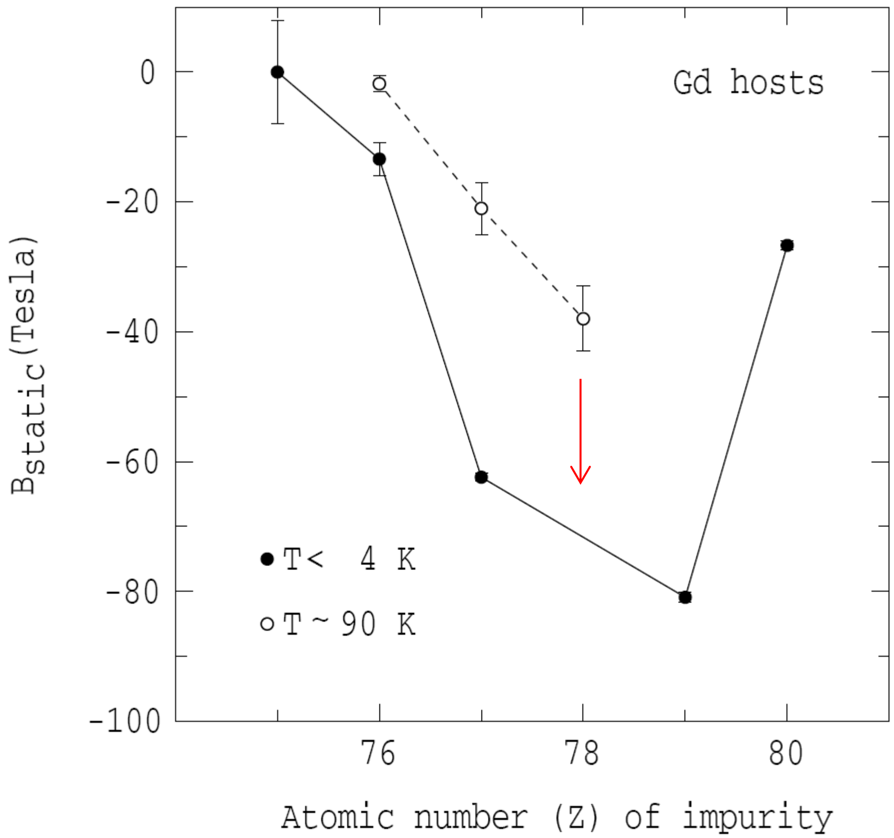
$^{194,196,198}Pt$





- There is no significant difference between the static fields for Pt in *Gd* at 90 K and 4 K (both ≈ –38 Tesla)

Magnetic hyperfine field



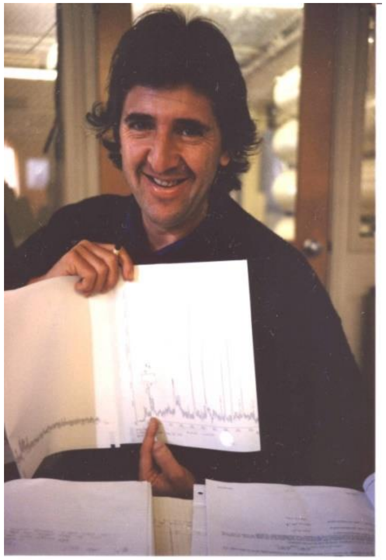
Small field could be due to implantation to damaged sites

TDPAD with $LaBr_3$ detectors, on an appropriate state could clarify the origin of the effective field.

Low fields after implantation - why? Does it impact on the $Q(2^+)$ measurement?

Summary

- $LaBr_3$ detectors enable in-beam hyperfine interactions studies and nuclear moment measurements by the TDPAD method on states with $T_{1/2}$ ~ few ns.
- These measurements can help resolve some long-standing problems
  - New g-factor measurements
  - New quadrupole measurements



"Discovery is easy;

characterization is hard".

George Dracoulis
(19 December 1944 – 19 June 2014)

Thoughts and advice from George's NS2012 closing talk

Discovery/Spectroscopy/Characterization

- Discovery is (relatively) easy - and gets all the glory
- Spectroscopy is hard
- Characterization is even harder
- Spins and parities are the real end game

ELECTROMAGNETIC MOMENTS – lifetimes, g factors, quadrupole moments