

Measurement of g-factors with ISOL beams

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What are g factors?

→ link magnetic moment to spin

$$\vec{\mu} = g \vec{I} \mu_N$$

→ sensitive to single-particle structure

$$\vec{\mu} = \sum_{k=1}^A g_l^{(k)} \vec{l}^{(k)} + g_s^{(k)} \vec{s}^{(k)}$$

→ Test of shell structure

Tabelle 1.

Klassen-Nr.	Drallquantenzahl	Multiplizität	Summe aller Multiplizitäten bis zur Unterklasse r_j	Zustände im Zentralfeld	oder
r	j	$2j+1$		(n, l, j)	
1	$\frac{1}{2}$	2	2	$1s_{1/2}$	$1s_{1/2}$
2	$\frac{3}{2}$	4	6	$2p_{3/2}$	$2p_{3/2}$
	$\frac{1}{2}$	2	8	$2s_{1/2}$	$2s_{1/2}$
3	$\frac{5}{2}$	6	14	$3d_{5/2}$	$3d_{5/2}$
	$\frac{3}{2}$	4		$3p_{3/2}$	$3p_{3/2}$
	$\frac{1}{2}$	2	20	$3s_{1/2}$	$2p_{1/2}$
4	$\frac{7}{2}$	8	28	$4f_{7/2}$	$4f_{7/2}$
	$\frac{5}{2}$	6		$4d_{5/2}$	$4d_{5/2}$
	$\frac{3}{2}$	4		$4p_{3/2}$	$3d_{3/2}$
	$\frac{1}{2}$	2	40	$4s_{1/2}$	$3s_{1/2}$
5	$\frac{9}{2}$	10	50	$5g_{9/2}$	$5g_{9/2}$
	$\frac{7}{2}$	8		$5f_{7/2}$	$5f_{7/2}$
	$\frac{5}{2}$	6		$5d_{5/2}$	$4f_{5/2}$
	$\frac{3}{2}$	4		$5p_{3/2}$	$4p_{3/2}$
	$\frac{1}{2}$	2	70	$5s_{1/2}$	$3p_{1/2}$
6	$\frac{11}{2}$	12	82	$6h_{11/2}$	$6h_{11/2}$
	$\frac{9}{2}$	10	92	$6g_{9/2}$	$6g_{9/2}$
	$\frac{7}{2}$	8		$6f_{7/2}$	$5g_{7/2}$
	$\frac{5}{2}$	6		$6d_{5/2}$	$5d_{5/2}$
	$\frac{3}{2}$	4		$6p_{3/2}$	$4d_{3/2}$
	$\frac{1}{2}$	2	112	$6s_{1/2}$	$4s_{1/2}$
7	$\frac{13}{2}$	14	126	$7i_{13/2}$	$7i_{13/2}$
	$\frac{11}{2}$	12		$7h_{11/2}$	$7h_{11/2}$
	$\frac{9}{2}$	10		$7g_{9/2}$	$6h_{9/2}$
	$\frac{7}{2}$	8		$7f_{7/2}$	$6f_{7/2}$
	usw.	usw.			

Figure: Jensen et al. Naturwis. 35, 376 (1948),
Nobel prize with Goeppert-Mayer in 1963



Why measure g factors?

Example: Seniority in Te isotopes

- $\pi g_{7/2}^2$ seniority structure
- Level energies: *gradual* change from seniority to collectivity
- $g(2^+)$ values: *abrupt* change from seniority to collectivity
- Persisting seniority in 6^+ states?

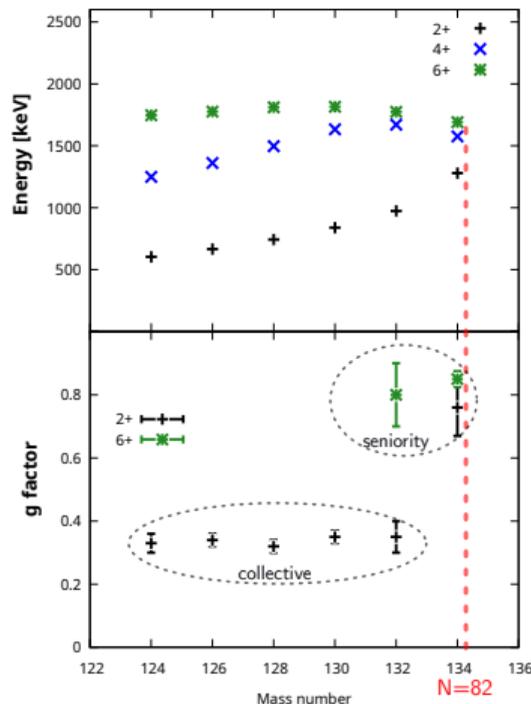
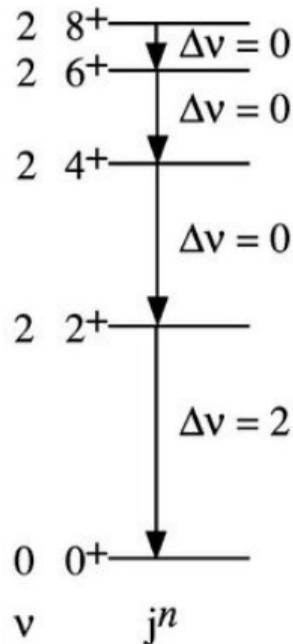


Figure: Seniority in Te





How to measure g factors of excited states?

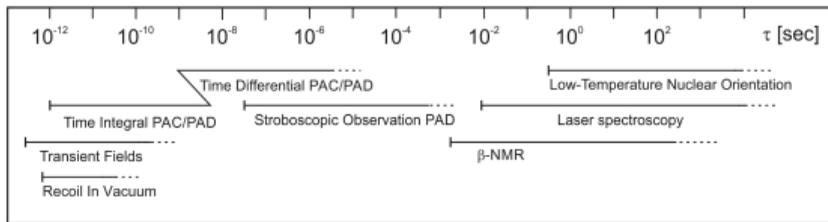


Figure: Different techniques for g factor measurements

Fig. modified from Recknagel, E.: Magnetic Moments of Excited States. vol 40, pp. 93-141, Elsevier, (1974)

Appropriate method depends on:

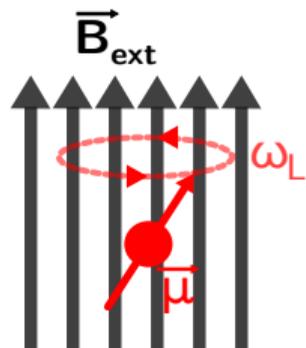
- Lifetime of state of interest
- Population mechanism of the state of interest
- Expected g factor value

Time Dependent Perturbed Angular Distribution (TDPAD) & Time Dependent Perturbed Angular Correlation (TDPAC)

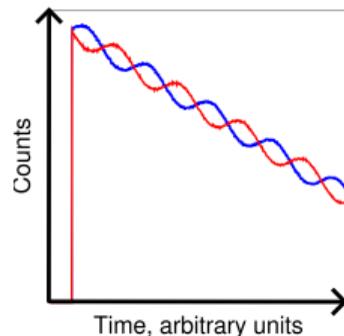
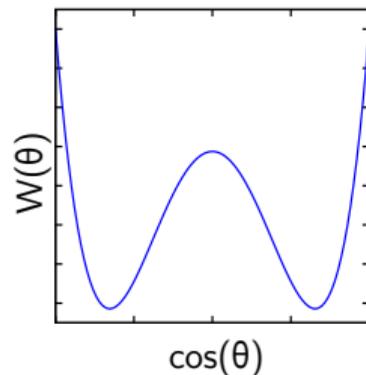
- Suitable for decay spectroscopy
 - Lifetimes in the ns range
- Effect of external magnetic field on angular distribution/correlation of γ rays



TDPAD/C: Measurement idea



+



Nuclei precess with Larmor frequency

$$\omega_L = -\frac{g\mu_N B}{\hbar}$$
$$\theta = 2\omega_L t$$

Angular distribution

$$W(\theta) = \sum a_l P_l(\cos(\theta))$$

Decay curve

$$I(\theta, t) \propto e^{-\lambda t} W(\theta, t)$$



TDPAD

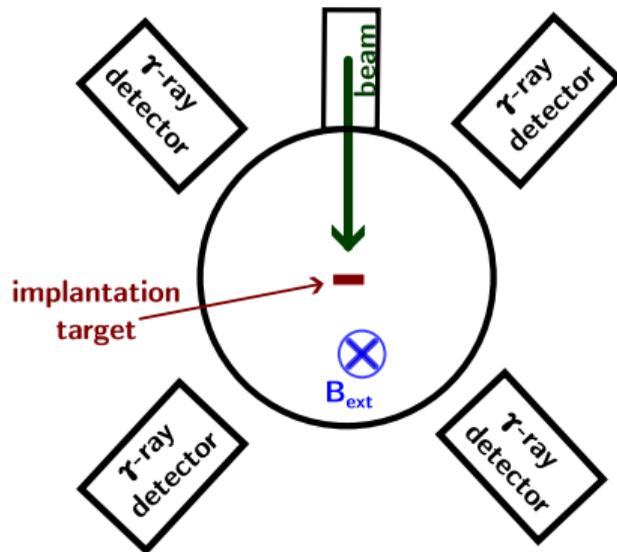
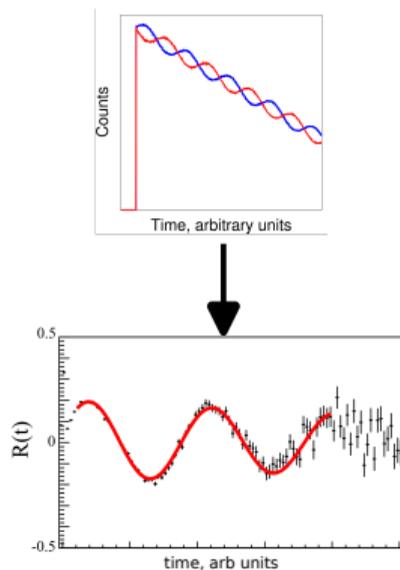
- nuclei need to be oriented
→ anisotropic distribution
- magnetic field orthogonal to detector plane
- start signal?

g factor via $R(t)$

$$\vec{\mu} = g\vec{I} \quad \omega_L = gB\mu_N/\hbar$$

$$R(t) = \frac{I(\theta, t) - \epsilon I(\theta + \pi/2, t)}{I(\theta, t) + \epsilon I(\theta + \pi/2, t)}$$

$$R(t) \propto \cos(2(\omega_L t - \theta))$$





TDPAC

- gate on populating transition
- unoriented nuclei
- magnetic field orthogonal to detector plane

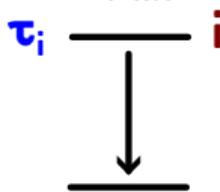
g factor via $R(t)$

$$R(t) = \frac{I(\theta, t) - \epsilon I(\theta + \pi/2, t)}{I(\theta, t) + \epsilon I(\theta + \pi/2, t)}$$

$$R(t) \propto \cos(2(\omega_L t - \theta))$$

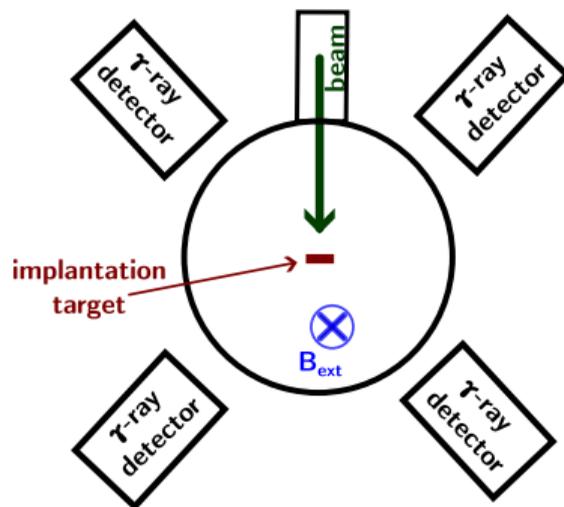
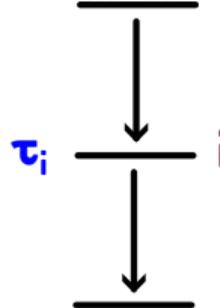
TDPAD

no feeder



TDPAC

feeder needed





Timing

- Lifetime \gtrsim oscill. period
→ choice of mag. field strength
- Oscill. period \gg time resolution
→ choice of detectors

Magnet

- Electromagnet
- Permanent Magnet
- Implantation in Co, Fe, Ni, Gd

Population mechanism

- TDPAD
 - ▶ fus. evap
 - ▶ proj. fragmentation
 - ▶ CoulEx
- TDPAC
 - ▶ β decay

ISOL beams needed to access
g factors far from stability!

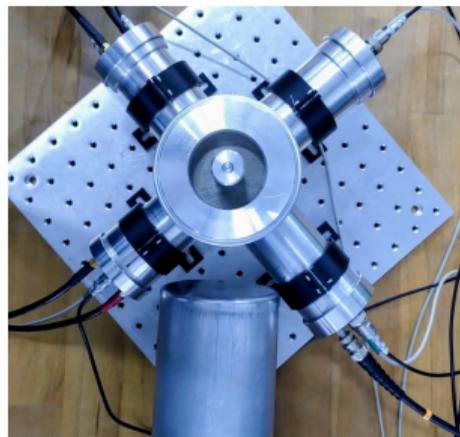


Figure: Setup for TDPAC after β decay using 4 LaBr's



- Dedicated setup for ISOLDE

G. Georgiev, C. Costache, A. Turturica, R. Lica *et. al*

- Chamber with integrated small permanent magnet
- Target ladder allows change of implantation target
→ fast change of magnetic field
- Can be equipped with HPGe or LaBr detectors
- Commissioned in April 2025

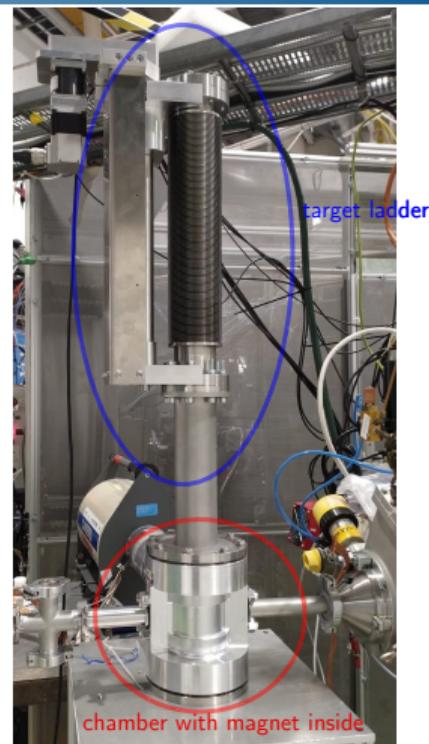


Figure: Chamber of ISOLDE



ISOL beam implications

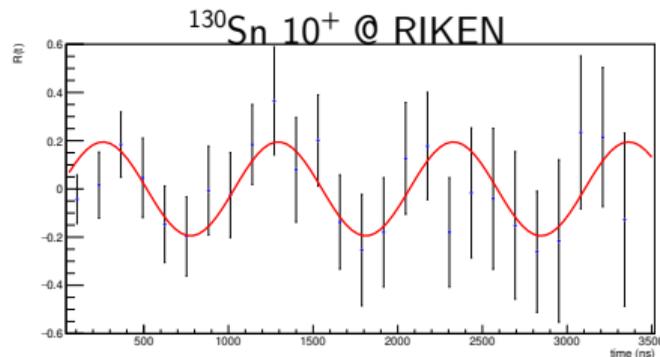
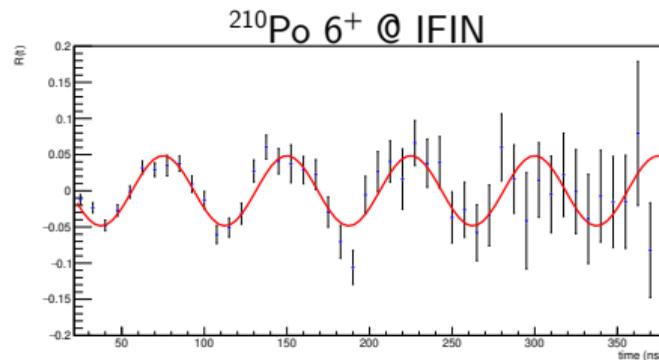
- rare, low intensity beams
- limited beam time

Before the experiment:

- What level of statistics is needed?

During analysis

- How good is my parameter estimation?
- How sure am I that the data do not show random fluctuations?





$$\text{posterior } p(g, A_2 | \mathcal{D}, M) = \frac{\text{likelihood } p(\mathcal{D} | g, A_2, M) \text{ prior } p(g, A_2 | M)}{\text{evidence } p(\mathcal{D} | M)}$$

Allows elimination of nuisance parameters in the likelihood:

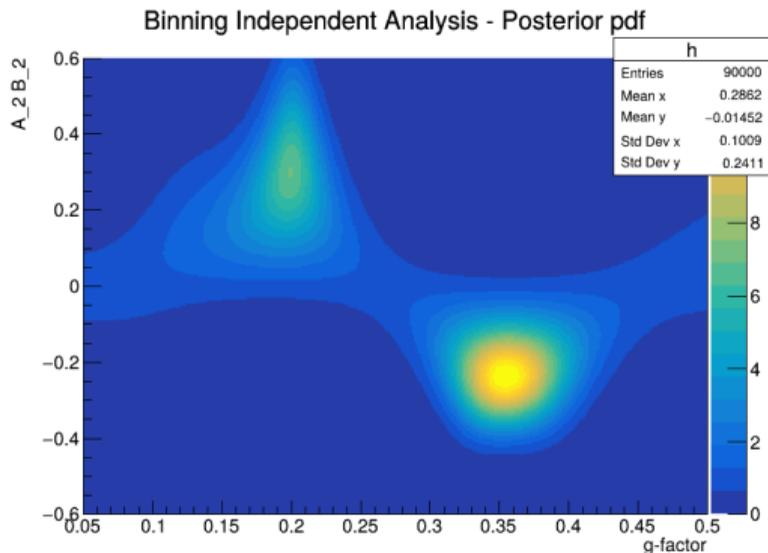
- Detector efficiencies
- Time offset
- Binning

Comparison with χ^2 methods:

- gives full posterior probability density function
- may depend on prior
- allows consecutive analysis



Parameter estimation:



Approximate by Gauss (if possible) to give common uncertainty

Calculation of Bayes factor:

Compares our model M to a model M_0 that assumes random fluctuations

$$B = \frac{p(M|\mathcal{D})}{p(M_0|\mathcal{D})}$$

$B \gg 1 \Rightarrow$ Data are statistically significant

$B \ll 1 \Rightarrow$ Data are dominated by noise



- Measured g factors provide a unique insight to the nuclear shell structure
- ISOL facilities enable g factor measurements far from stability
- Suitable setups exist
- Analysis methods able to "deal" with low statistics



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Thank you for the attention!