Precise g factor and transition probability studies at the UniLac

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IJCLab / IN2P3 / CNRS

Summary / Wish list

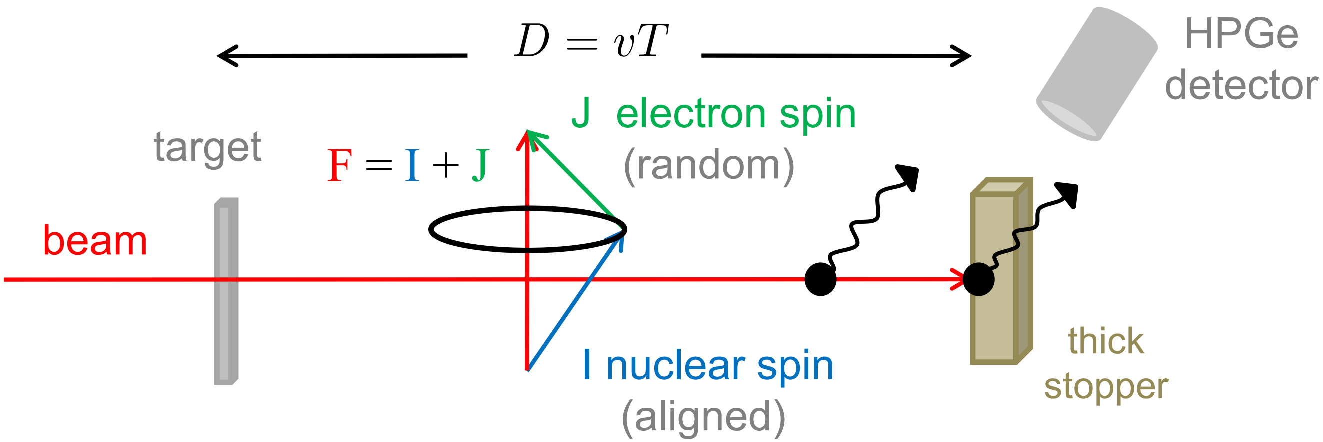
A. Recoil in vacuum: plunger-type g-factor measurements with precision

- H-like ions radioactive beam geometry (^{20,22}Ne, ^{40}Ar, ^{42,44}Ca)
- Na-like ions conventional geometry (^{84}Kr)
- High-Z multielectron ions (Pt and/or W ions)

B. Coulomb excitation of Xe isotopes: B(E2) and Q

- Emerging collectivity, triaxiality?

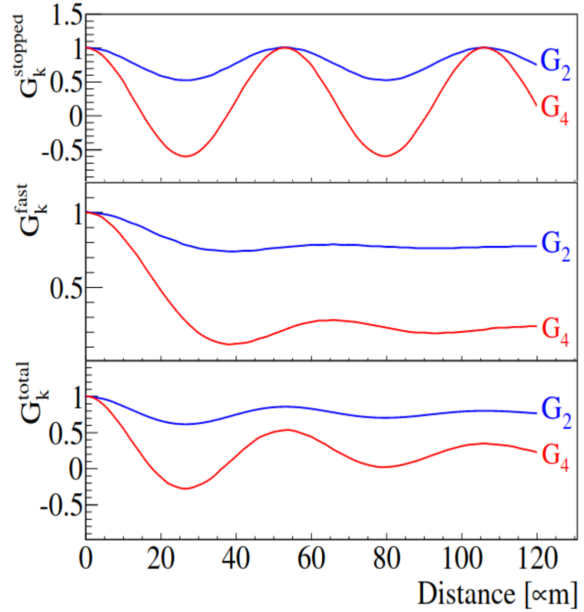
TDRIV g-factor measurements: H-like ions



$$\omega_{FF'} \propto |g|\, B_{HF}$$

$$B_{HF} = B_{1s} = 16.7\, Z^3 \text{ tesla}$$

A. Kusoglu *et al.*, J. Phys.: Conf. Ser. 590 012041 (2015)

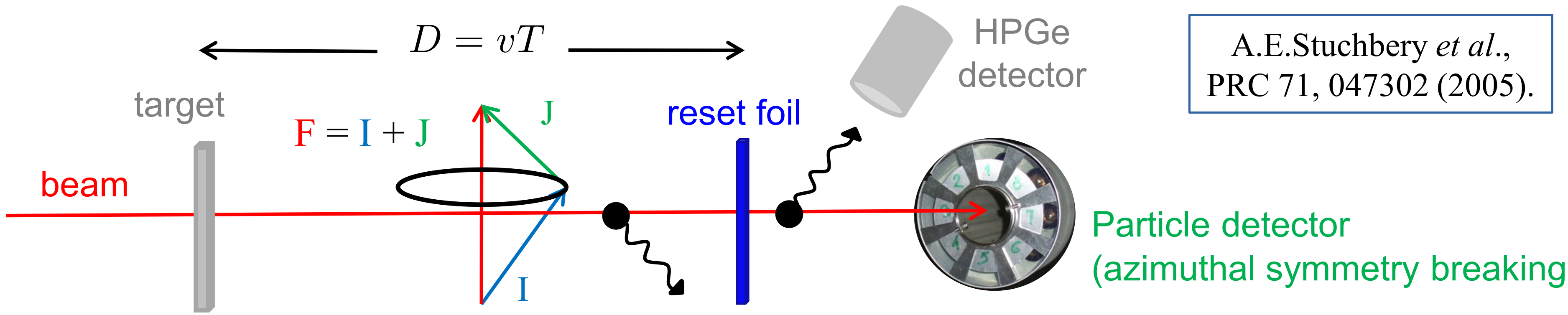


$$W(t,\phi,\theta) = \sum_{k,q} \sqrt{2k+1}\rho_{kq} G_k(t) F_k Q_k D^{k*}_{q0}(\phi,\theta,0) \qquad G_k(t) = \sum_{F,F'} C^{FF'}_{IJ}(k)\cos(\omega_{FF'}t)$$

Figure: K. Stoychev

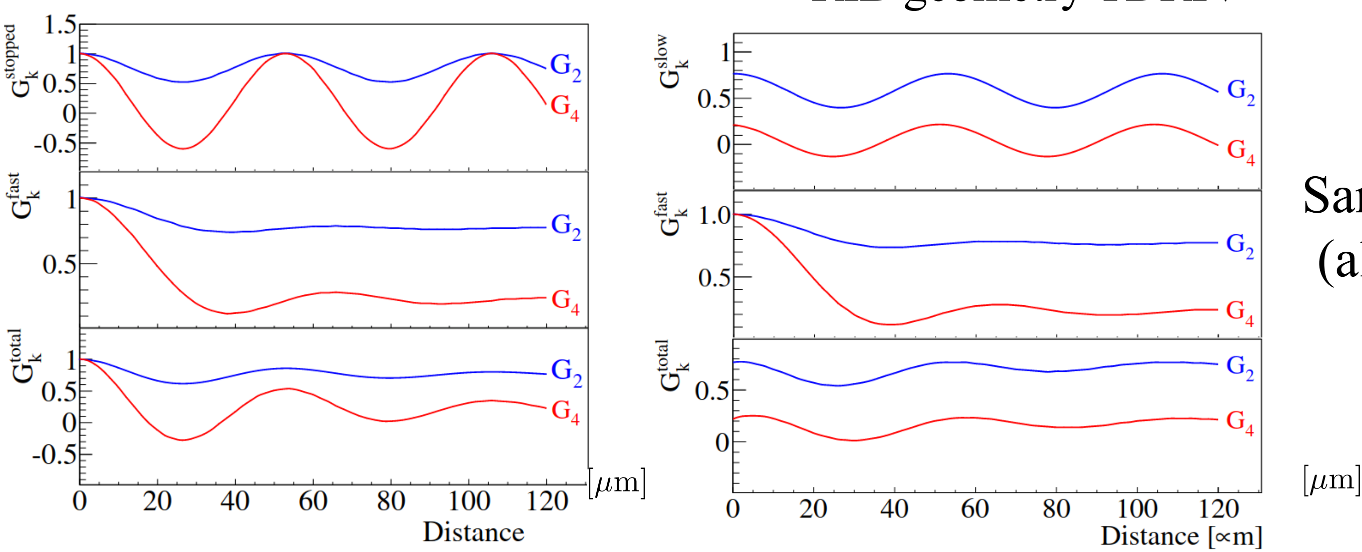
TDRIV radioactive beam geometry

A.E.Stuchbery *et al.*, PRC 71, 047302 (2005).



TDRIV

RIB geometry TDRIV



Same oscillation frequency
(albeit smaller amplitude)

A. Kusoglu *et al.*, J. Phys.: Conf. Ser. 590 012041 (2015)

TDRIV RIB geometry with ^{24}Mg

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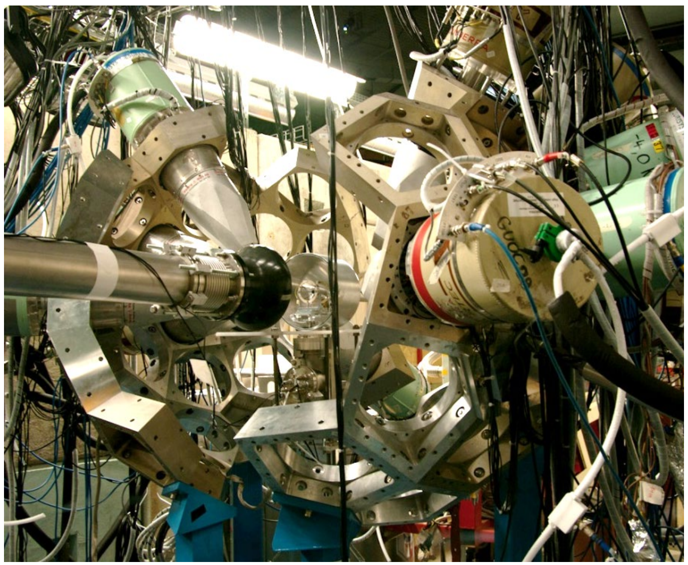
Proof of concept:

PRL **114**, 062501 (2015) PHYSICAL REVIEW LETTERS week ending 13 FEBRUARY 2015

Magnetism of an Excited Self-Conjugate Nucleus: Precise Measurement of the g Factor of the 2_1^+ State in ^{24}Mg

A. Kusoglu,[1,2] A. E. Stuchbery,[3,*] G. Georgiev,[1] B. A. Brown,[4,5] A. Goasduff,[1] L. Atanasova,[6,†] D. L. Balabanski,[7] M. Bostan,[2] M. Danchev,[8] P. Detistov,[6] K. A. Gladnishki,[8] J. Ljungvall,[1] I. Matea,[9] D. Radeck,[10] C. Sotty,[1,‡] I. Stefan,[9] D. Verney,[9] and D. T. Yordanov[9,11,12]

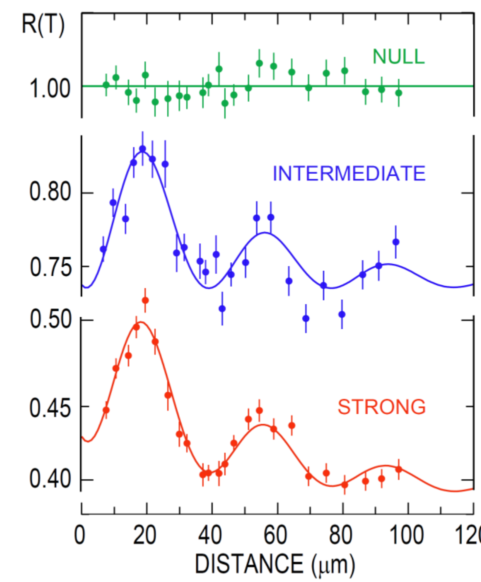
- ORGAM array: 13 HPGe detectors
- 8-fold segmented annular particle detector
- Orsay Universal Plunger System



Beam: **^{24}Mg** @ 120 MeV (5 MeV/u)
Target: 2.4 mg/cm^2 ^{93}Nb
Reset foil: 1.7 mg/cm^2 ^{197}Au

$$\left|g(2_1^+)\right| = 0.538(13)$$

(2.5% relative uncertainty for a state with τ = 1.9 ps)



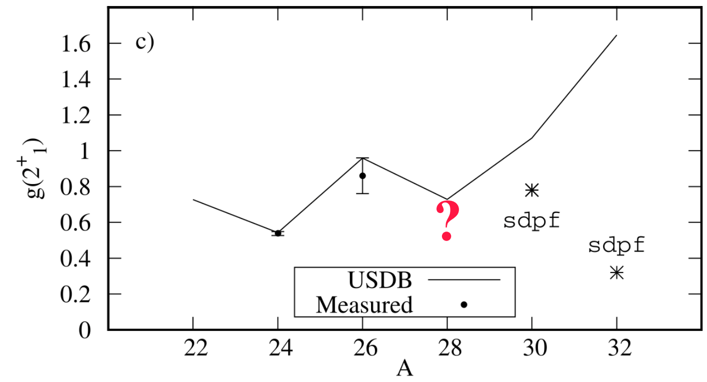
$$\left|g(2_1^+)\right| = 0.51(2)$$

R.F. Horstman *et al.*, NPA 248, 291 (1975)

TDRIV 28Mg @ ISOLDE

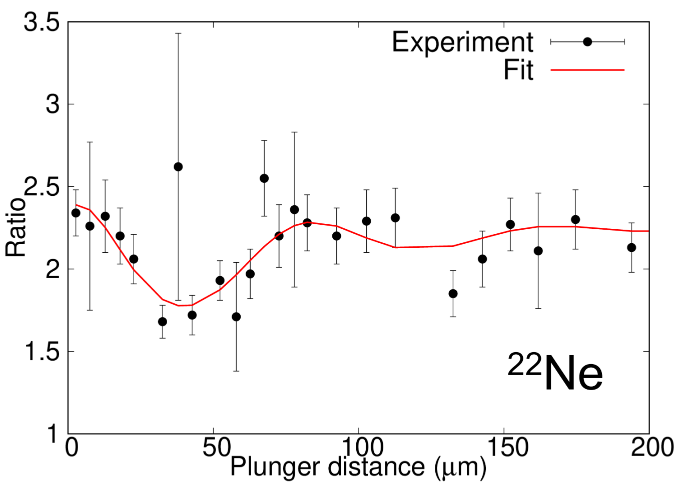
- Miniball array: 8 triple-clusters HPGe detectors
- CD DSSSD particle detector
- First use of the Miniball plunger device

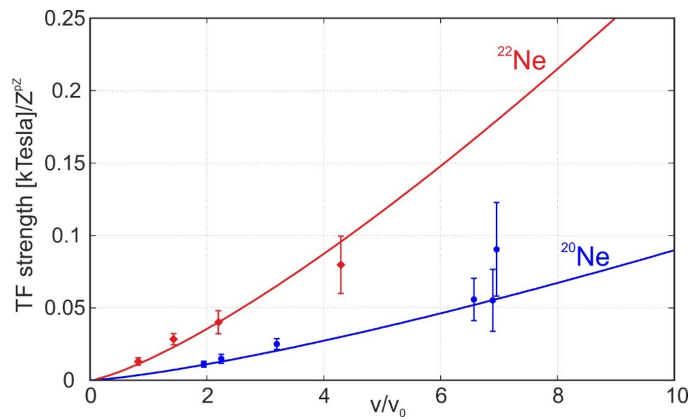
Beam: ^{28}**Mg** @ 154 MeV (5.5 MeV/u)
Target: 3.9 mg/cm^2 ^{93}Nb
Reset foil: 1.1 mg/cm^2 ^{171}Ta



B.P. McCormick *et al.*, Phys. Lett. B 779 (2018) 445–451

Calibration measurement: ^{22}**Ne** @ 121 MeV (5.5 MeV/u)





Discrepancy in ^{20,22}Ne transient-field data long known.

Now clear the problem is the ^{22}Ne g factor

$$|g(2_1^+, {}^{22}Ne)| \approx 0.46$$

PRELIMINARY

$$\left|g(2_1^+, {}^{22}\mathrm{Ne})\right| = 0.326(12)$$

R.E. Horstman *et al.*, NP A 275 (1977), 237

Priorities & needs for H-like TDRIV@UniLac

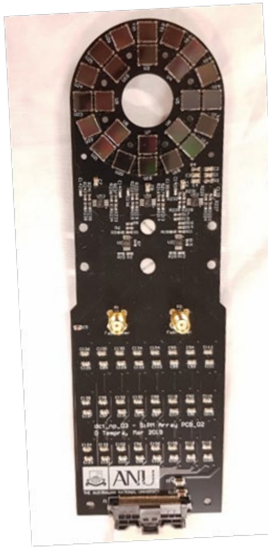
Priorities

- ^{22}Ne g(2^+) high precision – cf. ^{24}Mg, E_{beam} ~ 5 MeV/u
- Other possibilities:
  - ^{20}Ne: g ~ 0.5
  - ^{40}Ar: g ~ -0.04(6)
  - ^{42}Ca: g ~ +0.04(6)
  - ^{44}Ca: g ~ 0.17(3)

	g	tau (ps)	period (ps)
22Ne	0.4	5.29	3.91
20Ne	0.5	1.04	3.13
24Mg	0.5	1.97	1.80
28Si	0.5	0.703	1.13
34S	0.5	0.443	0.76
40Ar	0.04	1.89	6.60
42Ca	0.04	1.19	4.78
44Ca	0.17	4.19	1.12

Requirements

- Plunger (e.g. Orsay Universal Plunger System, OUPS)
- Segmented particle detector to take high rates (e.g. Orsay Particle Scintillator Array, OPSA)
- Gamma-ray detector array – high efficiency at 90° to beam; good symmetry preferred.



Why UniLac: Noble-gas beam

OPSA prototype @ ANU

Summary / Wish list

A. Recoil in vacuum: plunger-type g-factor measurements with precision

- H-like ions radioactive beam geometry (^{20,22}Ne, ^{40}Ar, ^{42,44}Ca)
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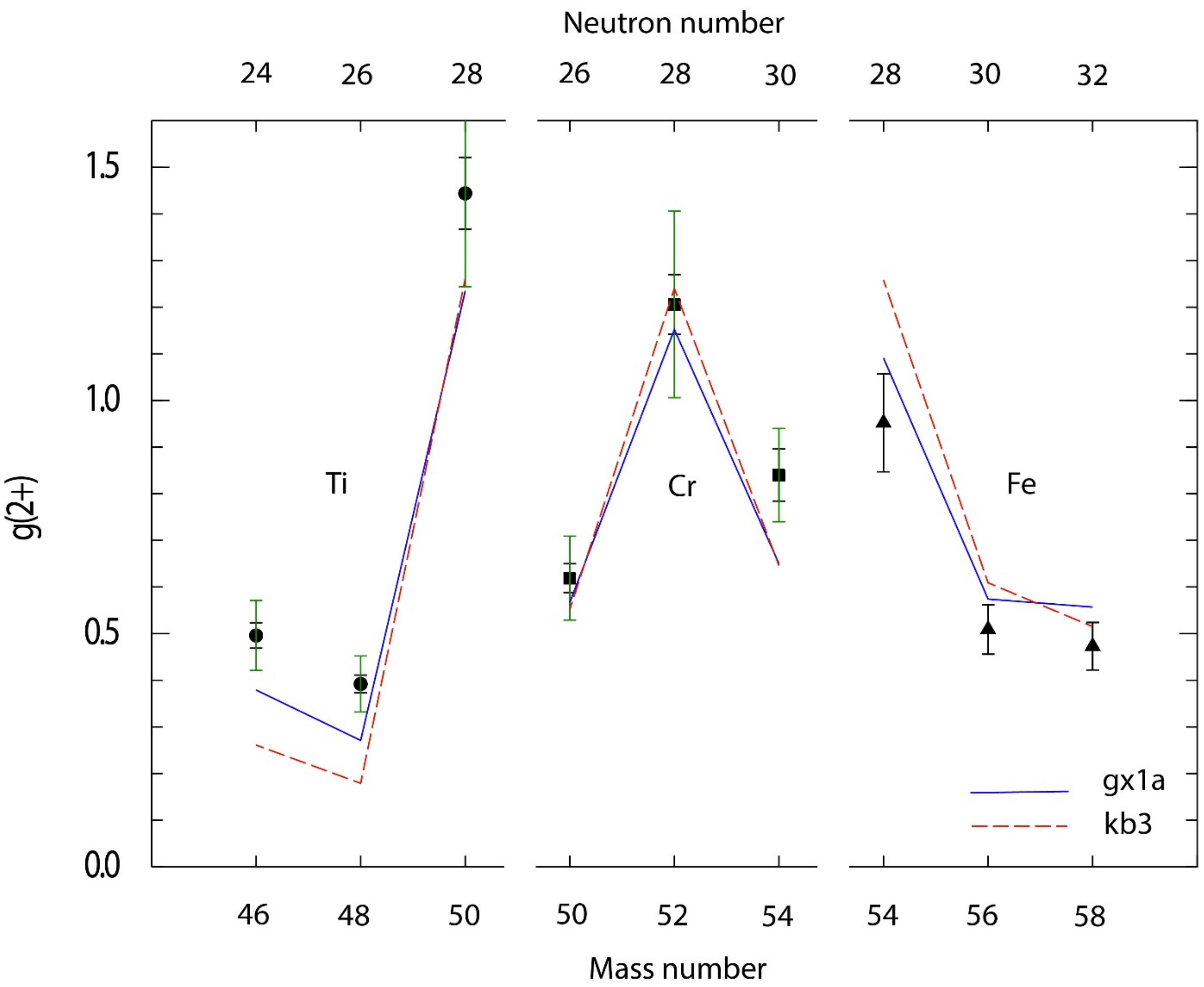
B. Coulomb excitation of Xe isotopes: B(E2) and Q

- Emerging collectivity, triaxiality?

Transient-field g-factors in Ti, Cr, Fe



Problem: inflated errors (green) in Stone recommended values

https://www-nds.iaea.org/publications/indc/indc-nds-0816/

Transient field calibration challenge

Lack of suitable calibration g factors for 12 < Z < 46

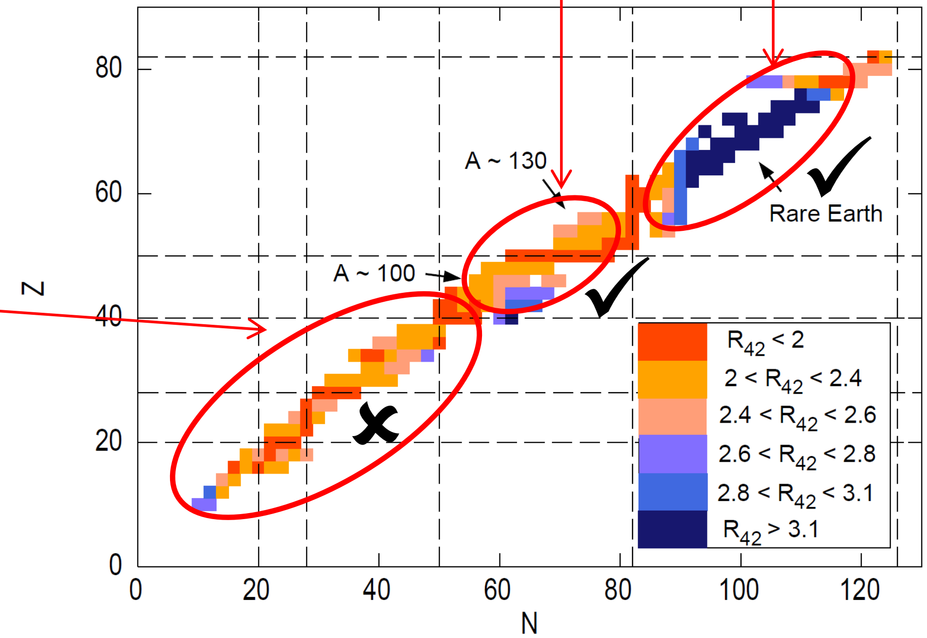
RE region 60 < Z < 82 – no problem!
Many independent measurements

40 < Z < 60 OK? but sparse independent data
^{106}Pd, ^{122,124}Te

12 < Z < 46 Big problem:
Essentially no good calibration data between ^{24}Mg and ^{106}Pd.

^{56}Fe data used are problematic!
See PRC 79, 024303 (2009)

Can we use TDRIV to get accurate absolute g factors?



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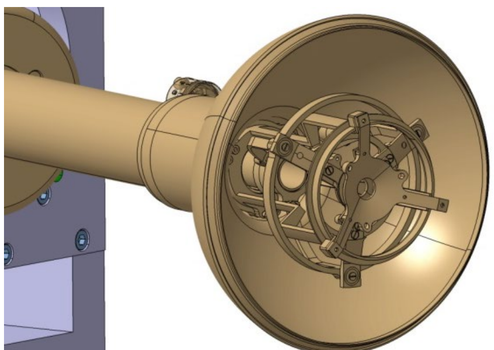
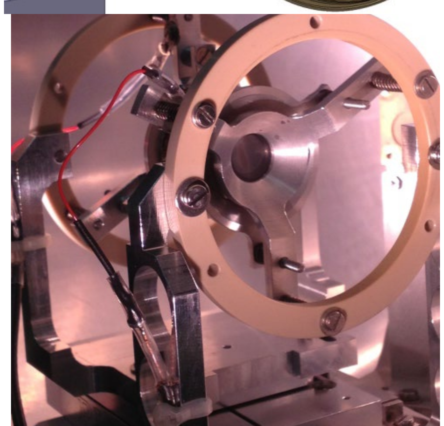
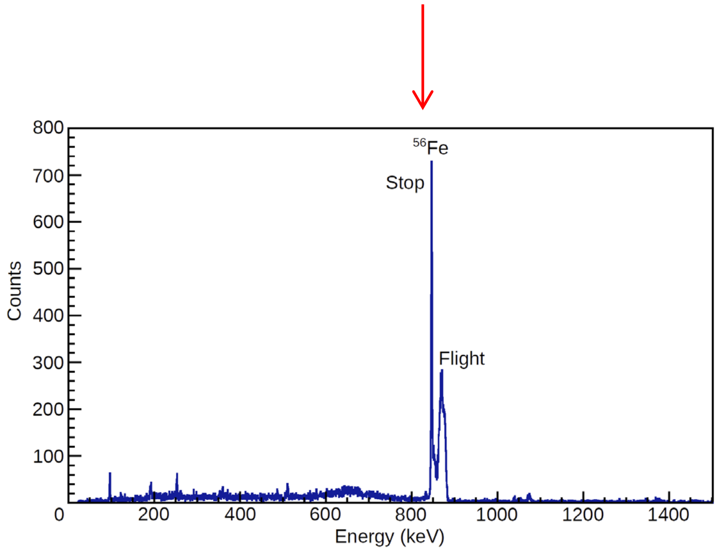
^{56}Fe TDRIV with Na-like ions

$B(0) \propto Z^3$ H-like ions oscillate too fast for Z > ~16. Try Na-like ions for ^{56}Fe.

- 130 MeV ^{56}Fe beam on 0.2 mg/cm^2 C + 0.5μm Ni; 5.8 mg/cm^2 Ni stopper
- Orsay Plunger 'OUPS' and ORGAM+Miniball @ ALTO
- Reaction kinematics to optimize Na-like ions - based on detailed charge-state distributions from ANU; v/c=0.0446 (52 MeV ^{56}Fe)







Analyze the stop peak to get $G_k(t)$
- t is the plunger flight time

^{56}Fe g(2^+) by TDRIV on Na-like ions

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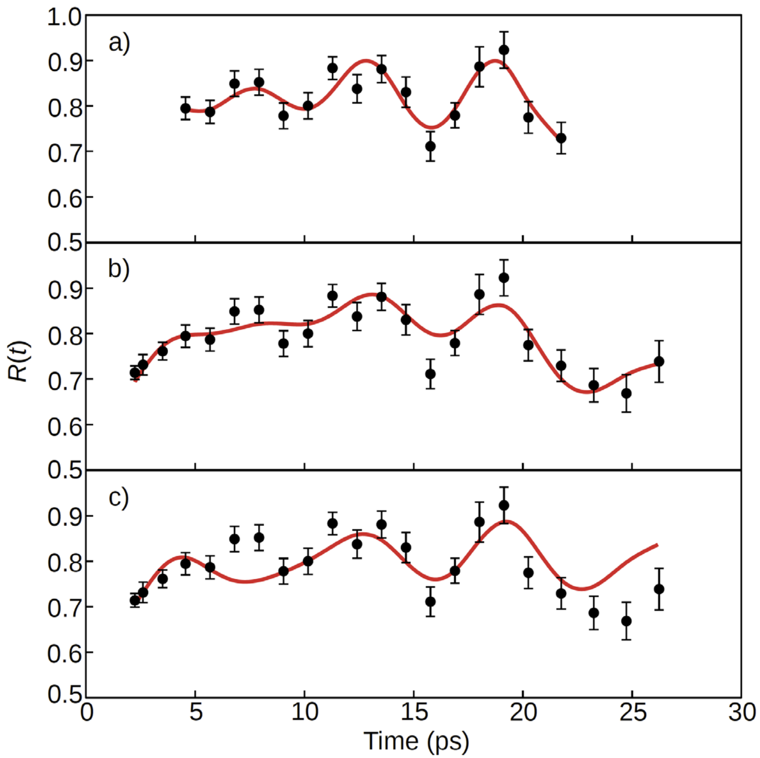
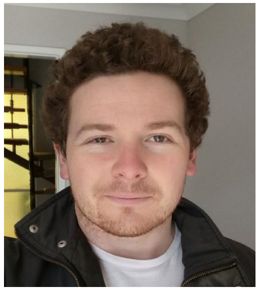
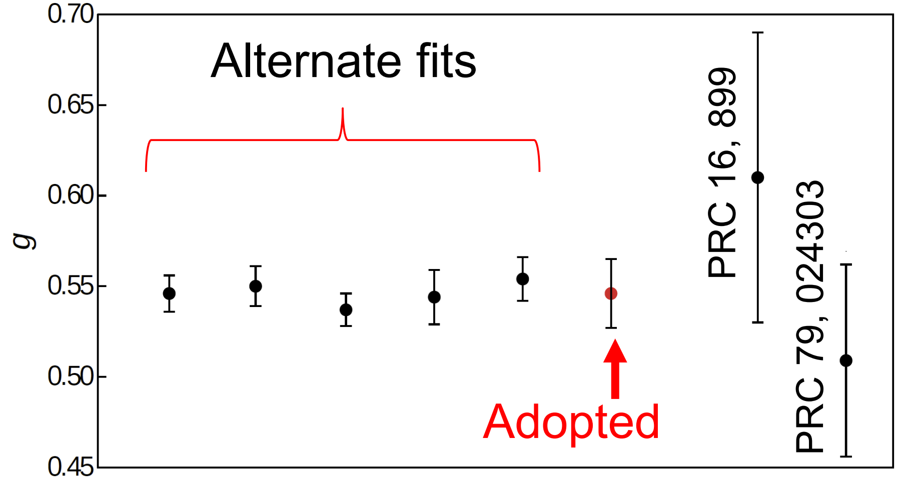
Examples of fits to R(t)



Results

Brendan McCormick
PhD thesis





Fits include $3s_{1/2}$, $3p_{1/2}$, $2p_{3/2}$, $2p_{1/2}$, & null components

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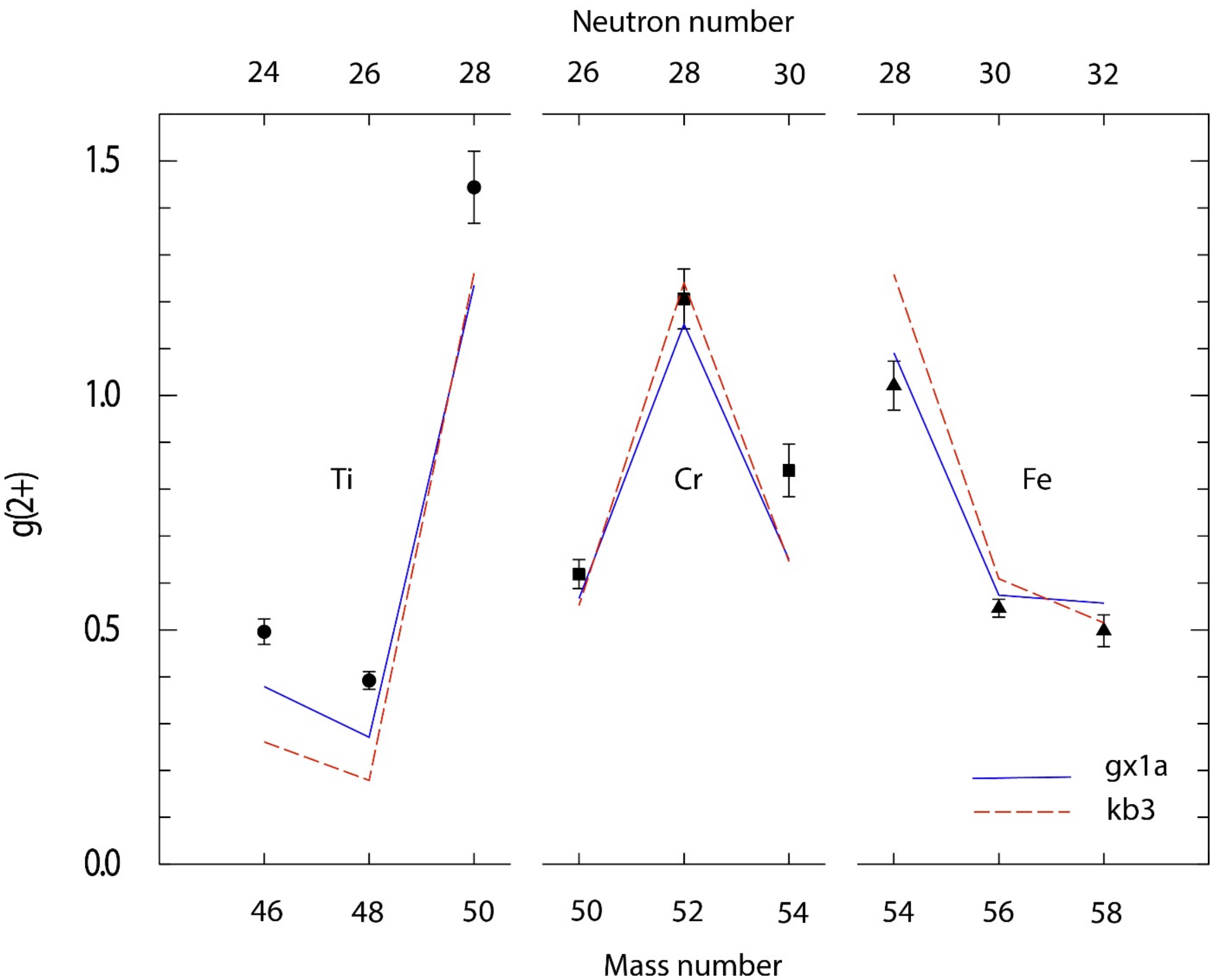
Implications – where we are now:



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Priorities & needs for Na-like TDRIV@UniLac

Priorities

- ^{84}Kr g(2^{+}) high precision – cf. ^{56}Fe, E_{beam} ~ 5 MeV/u

Requirements

- Plunger (e.g. Orsay Universal Plunger System, OUPS)
- Segmented particle detector ~~to take high rates~~ (e.g. Orsay Particle Scintillator Array, OPSA)
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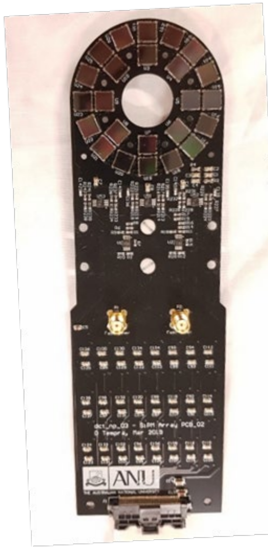
Why UniLac: Noble-gas beam



OPSA prototype @ ANU

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B. Coulomb excitation of Xe isotopes: B(E2) and Q

- Emerging collectivity, triaxiality?

TDRIV with multielectron high-Z ions

Motivation: simultaneous B(E2), Q(2$^+$), and g(2$^+$) on radioactive beams near ^{208}Pb

PRL **118,** 092503 (2017) PHYSICAL REVIEW LETTERS week ending 3 MARCH 2017

Electromagnetic Moments of Radioactive ^{136}Te and the Emergence of Collectivity 2p $\oplus$ 2n Outside of Double-Magic ^{132}Sn

J. M. Allmond,[1] A. E. Stuchbery,[2] C. Baktash,[1] A. Gargano,[3] A. Galindo-Uribarri,[1,4] D. C. Radford,[1] C. R. Bingham,[1,4] B. A. Brown,[5,6] L. Coraggio,[3] A. Covello,[7] M. Danchev,[4,8] C. J. Gross,[1] P. A. Hausladen,[9] N. Itaco,[3,10] K. Lagergren,[9] E. Padilla-Rodal,[11] J. Pavan,[9] M. A. Riley,[12] N. J. Stone,[4,13] D. W. Stracener,[1] R. L. Varner,[1] and C.-H. Yu[1]

PHYSICAL REVIEW C **96**, 014321 (2017)

First-excited state *g* factor of ^{136}Te by the recoil in vacuum method

A. E. Stuchbery,[1,*] J. M. Allmond,[2] M. Danchev,[3,4] C. Baktash,[2] C. R. Bingham,[2,4] A. Galindo-Uribarri,[2,4] D. C. Radford,[2] N. J. Stone,[4,5] and C.-H. Yu[2]

Beam Coulomb-excitation experiments with attention to particle-γ angular correlations

Priorities & needs for high-Z RIV@UniLac

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Priorities

- RIV characterization after Coulex of Pt and/or W isotope(s) (with known g factors) as beams @ ~10 MeV/u

Requirements

- Plunger (e.g. Orsay Universal Plunger System, OUPS)
- Segmented particle detector ~~to take high rates~~ (e.g. Orsay Particle Scintillator Array, OPSA)
- Gamma-ray detector array – high efficiency at 45° and 90° to beam; good symmetry preferred.

Why UniLac: (Only) stable beam accelerator to match HIE-ISOLDE

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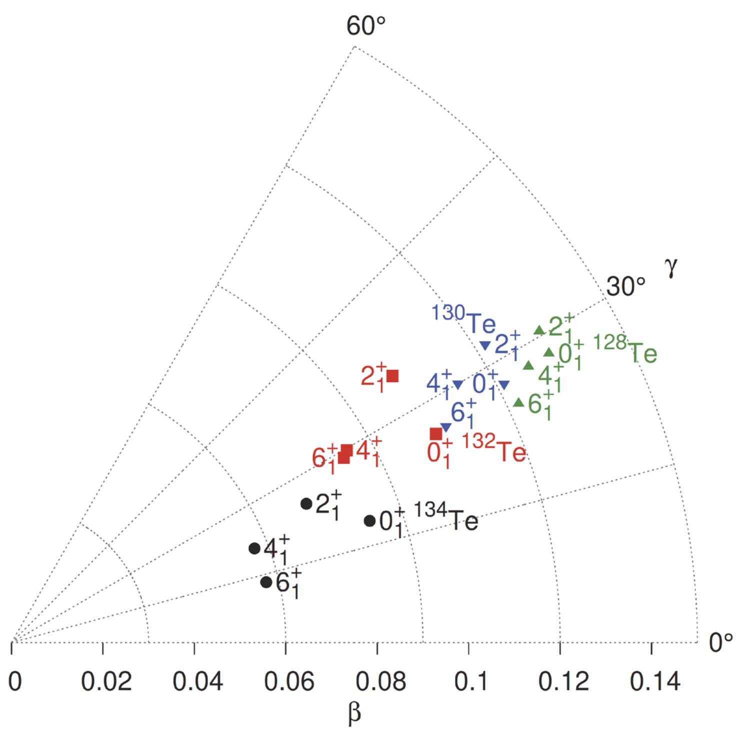
Triaxiality in Xe isotopes?

Motivation

- Recent studies of Te and Xe isotopes and emerging collectivity near ^{132}Sn
  - Coulex and transfer measurements @ HRIBF, ORNL
  - (n,n′γ) @ UKentucky (e.g. Peters et al. PRC **98**, 034302; **99**, 064321)
  - g-factor measurement on Te isotopes at ANU (Ben Coombes, thesis 2021)
  - Shell model calculations + Kumar-Cline evaluation of shape parameters



Everything looks triaxial!

BUT – g factors etc. show these nuclei are **not** triaxial rotors.

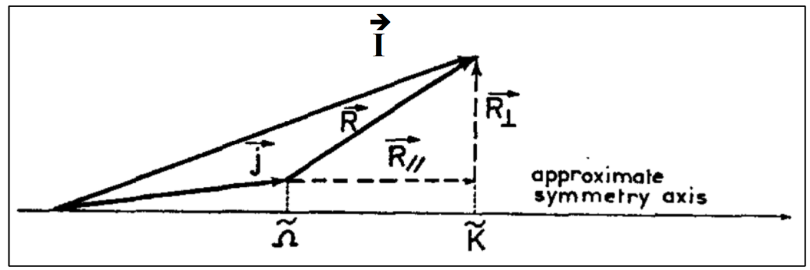
Triaxiality in Xe isotopes?

Motivation

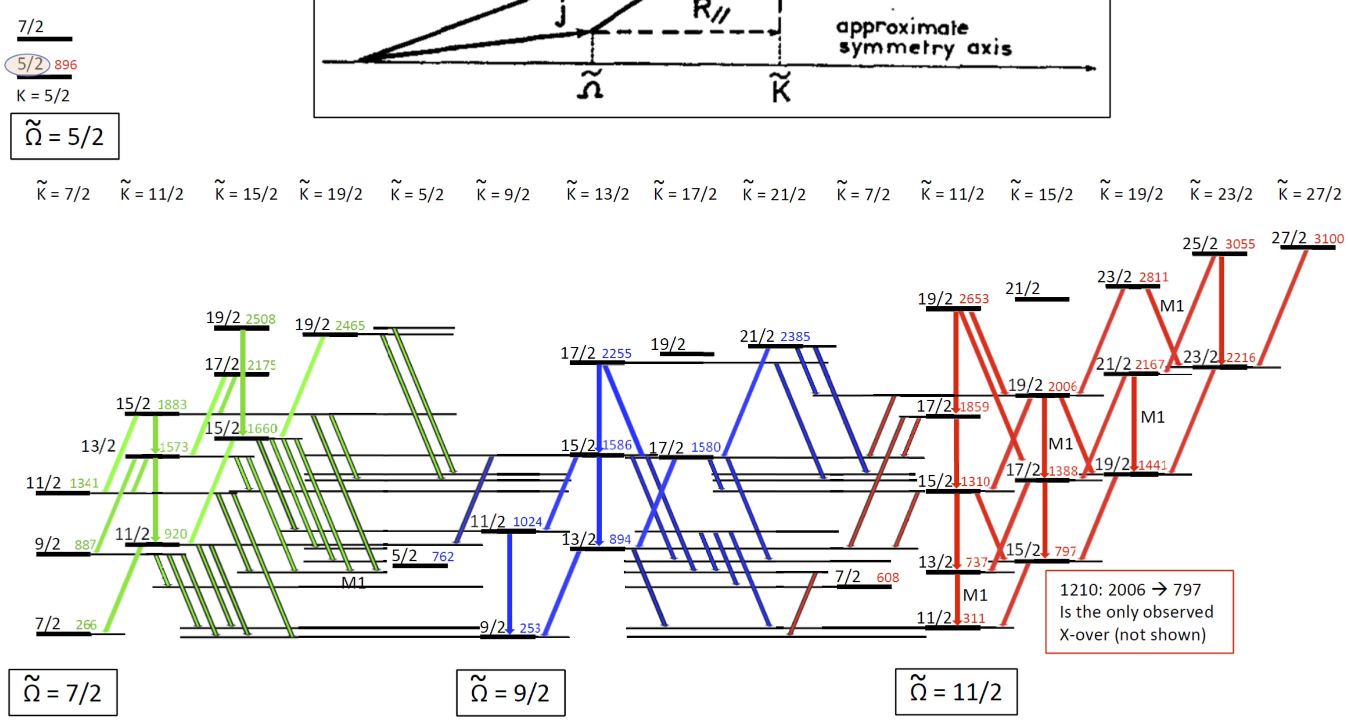
- Courtesy of John Wood: Unique parity states (j=11/2) in ^{125}Xe organized into a “hyperband” pattern due to Meyer-ter-Vehn.

^{125}Xe

$h_{11/2}$



This pattern associated with triaxiality has not previously been recognized.



Triaxiality in Xe isotopes?

Proposed experiments

- Coulomb excitation of all stable even Xe isotopes with targets and scattering conditions optimized to measure quadrupole moments and evidence of triaxiality as collectivity emerges.

- Several measurements have been performed at Argonne using carbon targets (PRC: 83, 044318; 82, 024317; 80, 061304; PLB 683, 11; see also PRC 102, 054304 - ISOLDE); data on higher-Z targets are needed.

- Compare experimental shape parameters (Kumar-Cline sum rules) with theory.

- odd-A? ^{129,131}Xe could be interesting too, but the unique parity states would not be excited…

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Needs for Xe Coulex @UniLac

Priorities

- Coulex of Xe beams on moderate and high-Z targets to measure diagonal and off-diagonal E2 matrix elements
- (RIV information may come for free)
- (Complementary plunger measurements?)

Requirements

- Segmented position-sensitive particle detectors for Coulex
- Gamma-ray detector array – high efficiency.

Why UniLac: Stable Xe beams

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Thanks to many colleagues and students

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