Time Dependent Recoil In Vacuum measurements on radioactive ions

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Nuclear moments – Why?

- Nuclei with non-zero spin have magnetic dipole moment $\mu = gI\,[\mu_N]$

- Sources of nuclear magnetism:
  - orbital movement of charged particles;
  - intrinsic spin of the nucleons.

- Magnetic moment of a nucleus:

$$\vec{\mu} = \sum_{k=1}^{A} g_\ell^{(k)} \vec{\ell}^{(k)} + \sum_{k=1}^{A} g_s^{(k)} \vec{s}^{(k)}$$ - the contribution of every nucleon

- π/ν *g* factors:

$free - nucleon$

$$g_s^\pi = 5.585 \quad g_\ell^\pi = 1$$
$$g_s^\nu = -3.286 \quad g_\ell^\nu = 0$$

↔

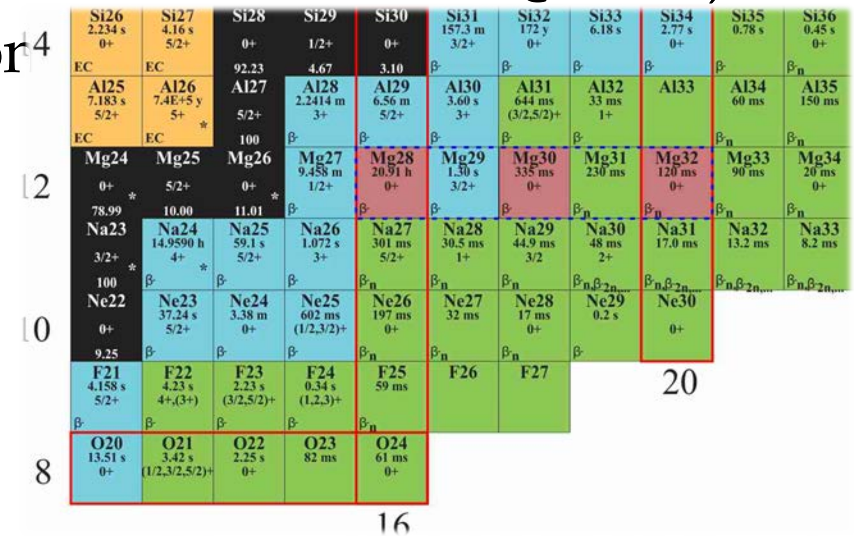
$effective$

$$g_s^\pi = 0.7 * g_s^\pi \quad g_\ell^\pi = 1.x$$
$$g_s^\nu = 0.7 * g_s^\nu \quad g_\ell^\nu = 0.y$$

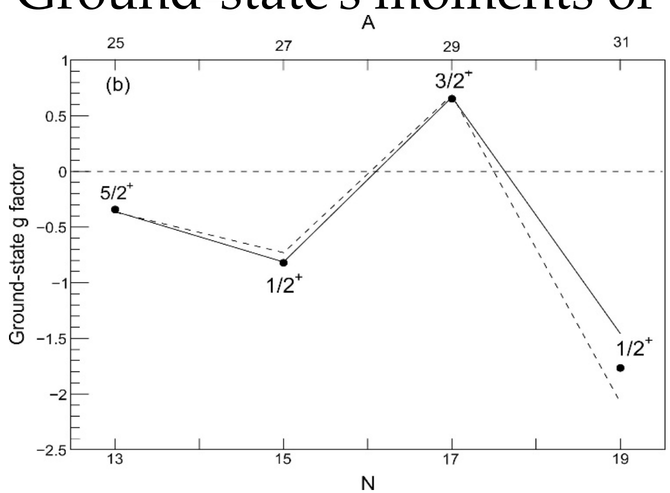
Nuclear moments around the “Island of Inversion”

IS628 @ ISOLDE, CERN

- Mg’s and the “Island of Inversion”
  - ^{32}Mg – first identified with **high B(E2)** and **low E_x (2^+)**



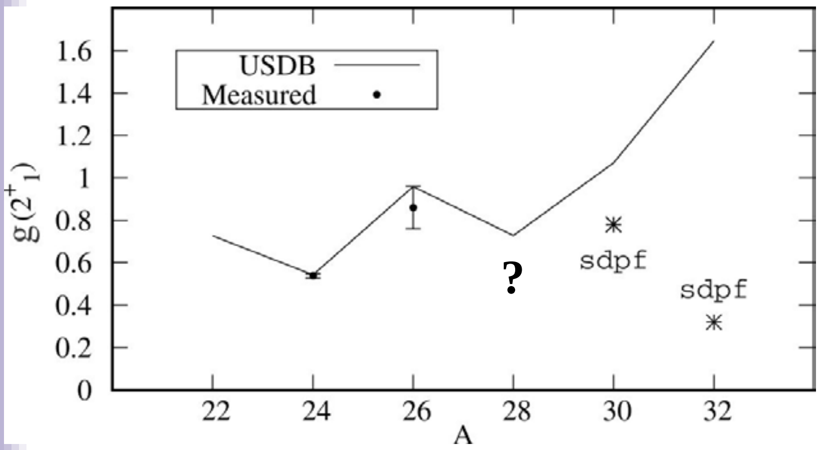
- Ground-state’s moments of the Mg isotopes:



→ s.p. states, not sensitive to configuration mixing but to the odd-nucleon orbit

e.g. ^{31}Mg – magnetic moment of $1/2^+$ state well reproduced even if its energy (*sd* model space) is > 1 MeV off

Even-even Mg isotopes (2^+ states)



- ^{26}Mg – new results from a TF measurement (**B.P. McCormick *et al.*, PLB 779, 445 (2018)**)
- ^{24}Mg (N=Z) and ^{26}Mg ($\nu d_{5/2}$ subshell) – rather "simple" theory cases
- ^{28}Mg – ^{32}Mg – real tests for the interactions

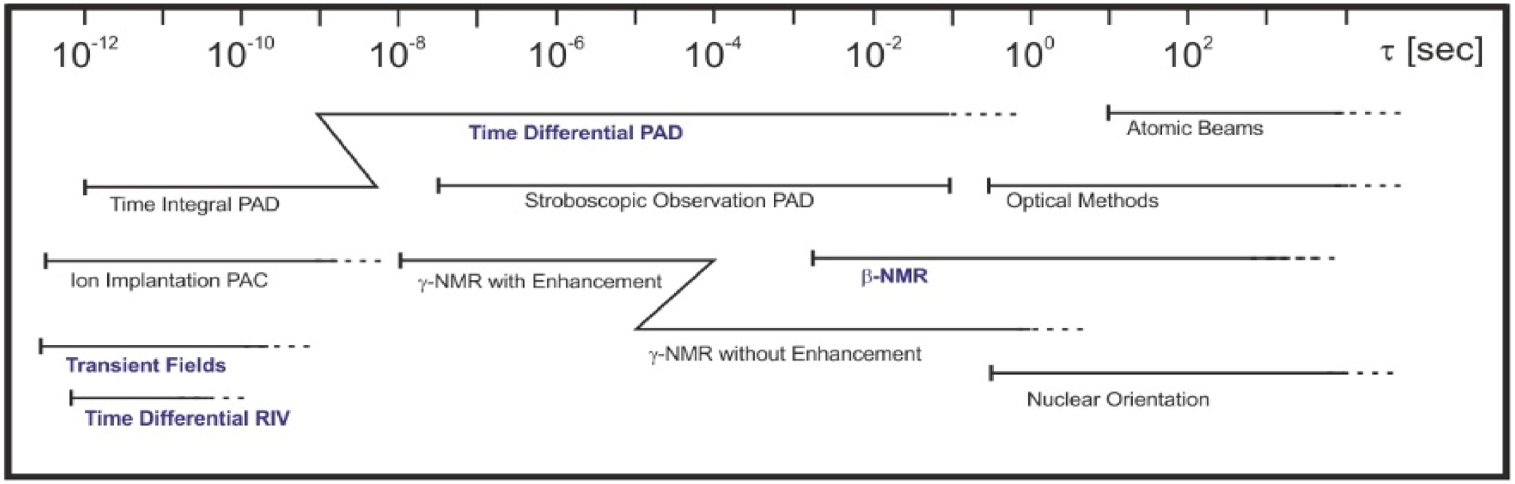
- ^{28}Mg – the important (*or not?*) role of the N=16 sub-shell gap at Z=12?
- New estimations for the borders of the "Island of Inversion"

T. Otsuka *et al.*, INPC 2016 presentation.

→ it is necessary to include *pf* admixtures in order to reproduce the structure of the excited states already in ^{30}Mg

Experimental approach

- Important ingredients:
  - Obtain nuclear spin-oriented ensemble
  - Apply an external (magnetic) perturbation → $\omega_L = -\frac{g\mu_N B}{\hbar}$
    - Have sufficient time for the interaction
    - Know with a sufficient precision the perturbing field
  - Measure the level of perturbation

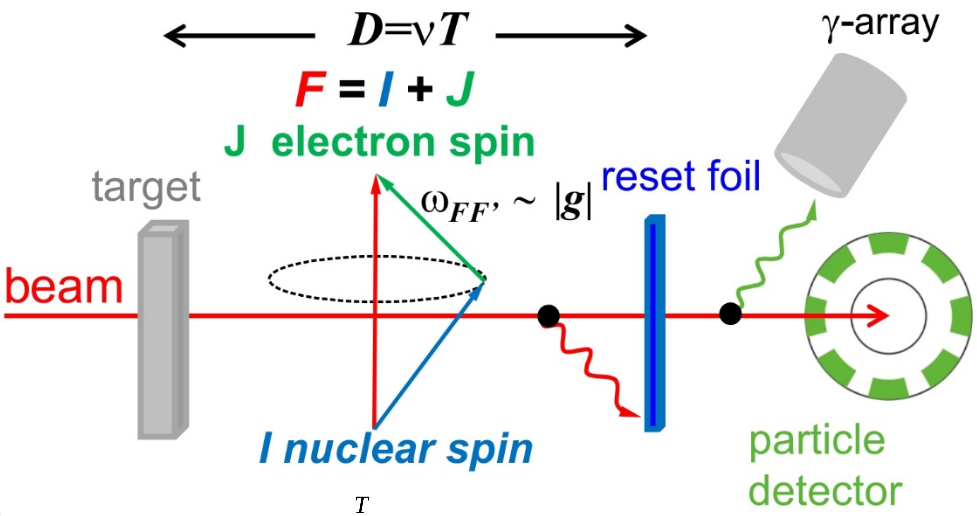


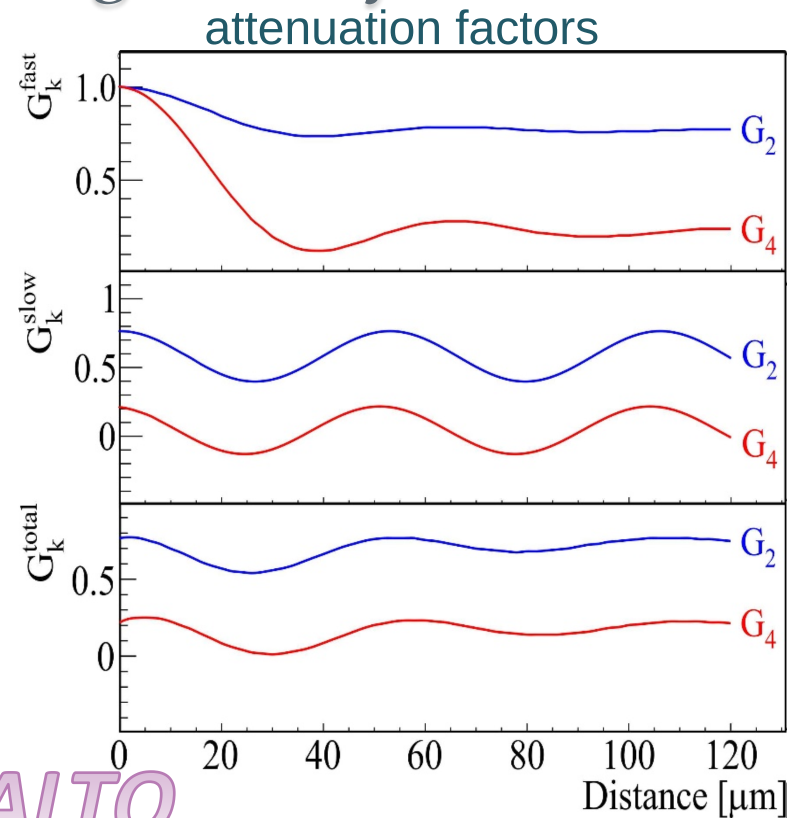
E. Recknagel in Pure and Applied Physics, 40C

  - **Time Differential measurements:**
    - observe several rotations of the nuclear spin ensemble within its lifetime
      → for a state with $g \sim 0.4 – 0.5$

lifetime	magnetic field
150 ns	1 Tesla
1.5 ps	***100 kTesla***

TDRIV – basic principles and RIB geometry



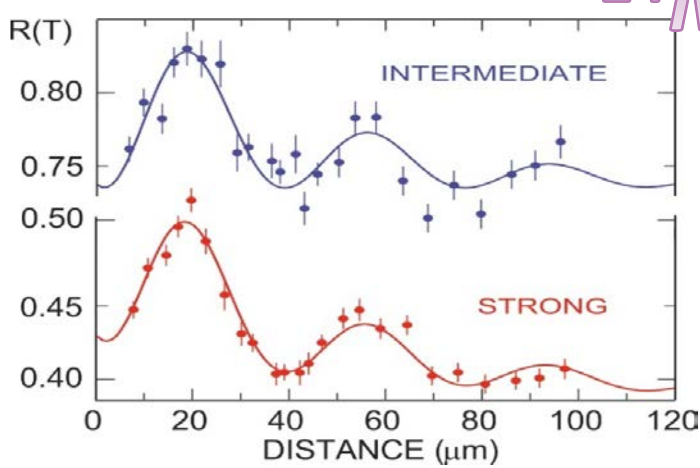


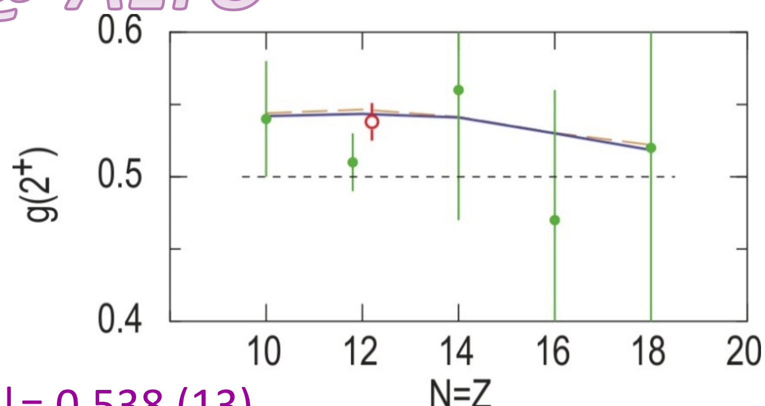
$$\overline{G_k(T)} = \int_0^T G_k(t)\lambda e^{-\lambda t}dt \qquad G_k(T)G_k(\infty)$$

$$G_k(\infty) = \int G_k(t)\lambda e^{-\lambda t}dt$$

A.E. Stuchbery et al., Phys. Rev. C71, 047302 (2005).

^{24}Mg @ ALTO





|g(2$^+$)|= 0.538 (13)

A. Kusoglu *et al.*, PRL 114, 062501 (2015)

TDRIV @ HIE-ISOLDE – the setup

- 8 Miniball triple cluster detectors @ (close to) 90°angles

DSSD for particle detection

- *3.9 mg/cm² Nb target*
- *1.1 mg/cm² Ta degrader*

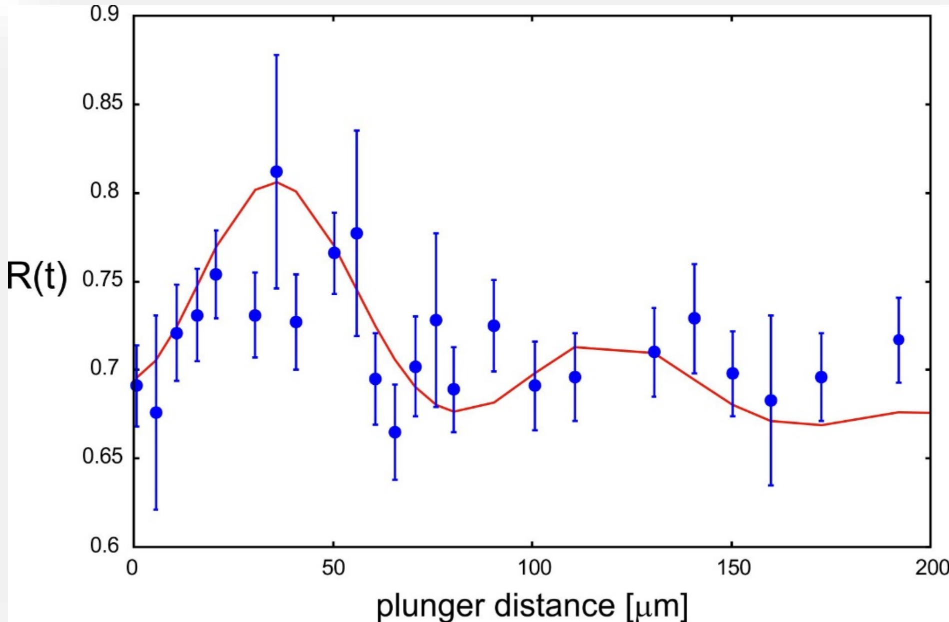
- angular coverage
  $\theta = 21° - 50°$
  14 sectors
  $\varphi = 0° - 360°$
  4 quadrants, 12 sectors each

- *first use of the Miniball plunger*
- ~ 20 distances

- ~7% efficiency at 1.4 MeV

^{22}Ne – a "test" measurement

- ^{22}Ne (5.5 Mev/u, 1.5 ppA) – from EBIS rest gas
- Beam intensity (10^7 pps) - limited by the scattering rate in the CD detector
- 5 days stable beam run



our preliminary value:
|g| = 0.445(25)

vs.

previous measurements:

R.E. Horstman *et al.*, NP A 275 (1977), 237 — **|g| = 0.326(12)**

and

R. Böhm *et al.*, Z. Phys. A 278 (1976) 133 — **|g| = 0.36(3)**

How reliable is the previous value of g(2^+) of ^{22}Ne?

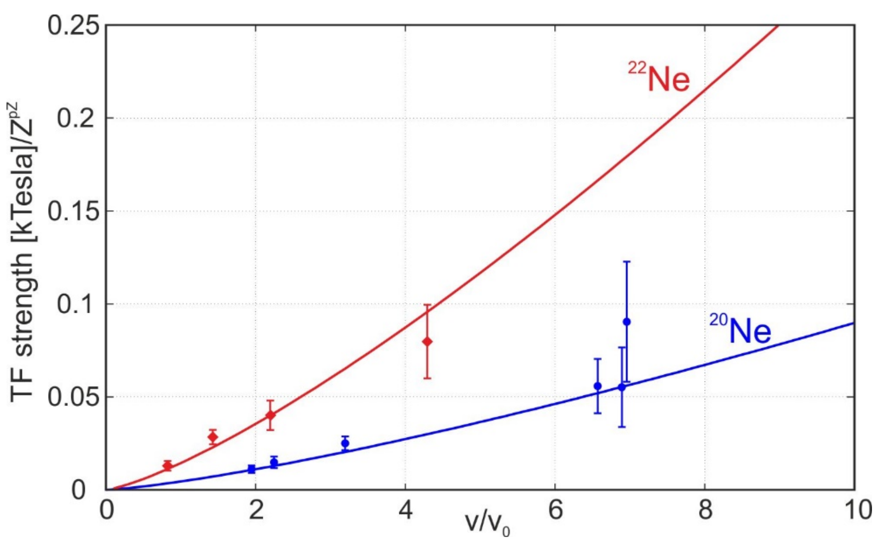
- Could there be something *not quite correct* with the ***previous most accurate g(2^+) value*** of R.E. Horstman *et al.* (adopted by N.J. Stone in "Table of nuclear moments" INDC(NDS)-0658)???
- Comparison of previously known g(2^+) in

  - ^{20}Ne: |g| = 0.54(4) (R.E. Horstman *et al.*, NP A 248, (1975), 291)

  and

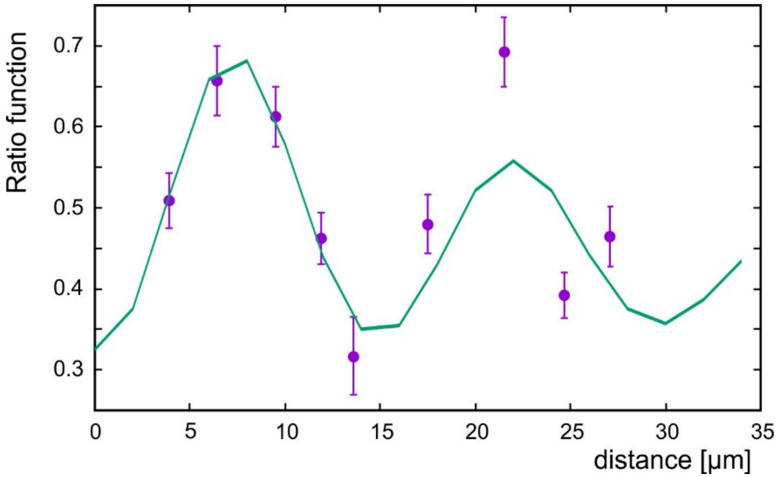
  - ^{22}Ne: |g| = 0.326(12) (R.E. Horstman *et al.*, NP A 275 (1977), 237)

gives a discrepancy (a factor of ~ 2!) for the transient field strength of the two isotopes of the same element – unphysical!!!



The "real RIB" experiment

- ^{28}Mg ($t_{1/2}$ = 20.9 h) – the bright side
  - expected beam intensity: 1x10^{6} – 5x10^{5} pps
  - **available: + 5x10^{6} pps!!**
  - **well pronounced particle – γ angular correlations observed**
  - **10 plunger distances measured**
- **and the difficulties …**
  - count rates in the Ge detectors - + 5k /Ge core (and increasing!) with half of the available proton beam intensity. Running for 7 days @ 10k/det.
  - scattered beam deposited in the vacuum chamber – beta-decay ^{28}Mg → ^{28}Al → ^{28}Si (stable): 100% 1779 keV + more then 60 % of higher then 1342 keV – impossible to be shielded …
- Present status
  - data under analysis in progress



Conclusions and outlook

- Magnetic moments of ***single particle*** (*odd-mass ground or isomeric states*) vs. ***collective*** (*short-lived excited states*) – probing different components and admixtures in the nuclear wave function

- Studies with high intensities post-accelerated RIB are very promising but require some special attention. The radioactive ion beam are … ***radioactive***. ***RIB of 10^6 pps is high intensity!*** Where is the compromise between high-efficiency vs. large opening for RIB's?

- Relying on ***old, "well established" results*** one may run into ***surprises***. Revisiting experimental results from few decades ago (pushing the limits at their time) might be a necessary step before reaching for new exciting ***radioactive beam challenges***.

- Stay tuned for exciting results to follow

The collaboration

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