Structure of exotic nuclei through nuclear moment and transition probability studies

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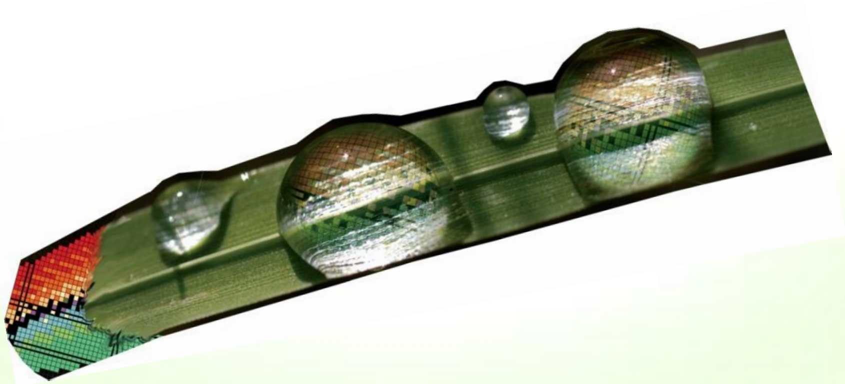
NSP13, Padova, 10 – 12 June, 2013



Ciao Enrico

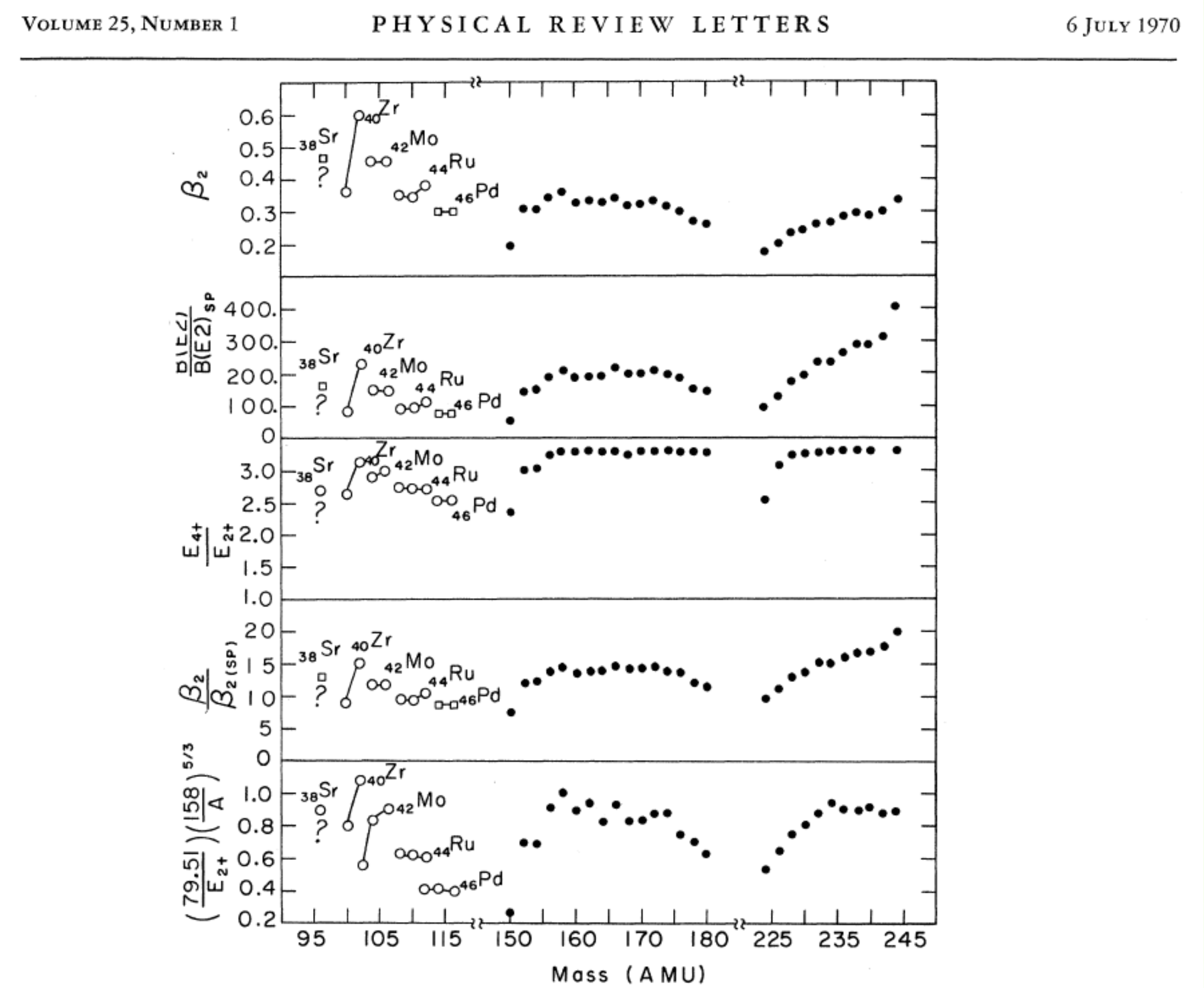
Euroschool on Exotic Beams, Leuven, 1997

Overview

- Neutron-rich A~100 region – a sudden onset of deformation at N=60.
  - Previous results from nuclear moments, charge radii, mass measurements and gamma-ray spectroscopy
  - What the advances in post-accelerated radioactive beams could bring up the scene?
- Coulomb excitation studies of the odd-mass Rb isotopes at REX-ISOLDE using the Miniball array
  - Quasi-spherical ^{93}Rb and ^{95}Rb vs. well deformed ^{97}Rb and ^{99}Rb. ^{97}Rb – the corner stone of the deformation in the region
- Magnetic dipole moments of short-lived excited state – the challenges
- TDRIV on H-like ions – high-precision, model-independent approach. ^{24}Mg measurement at ALTO, Orsay – a step towards the use of the method with radioactive beams
- Conclusions and perspectives

Nuclear structure around A~100

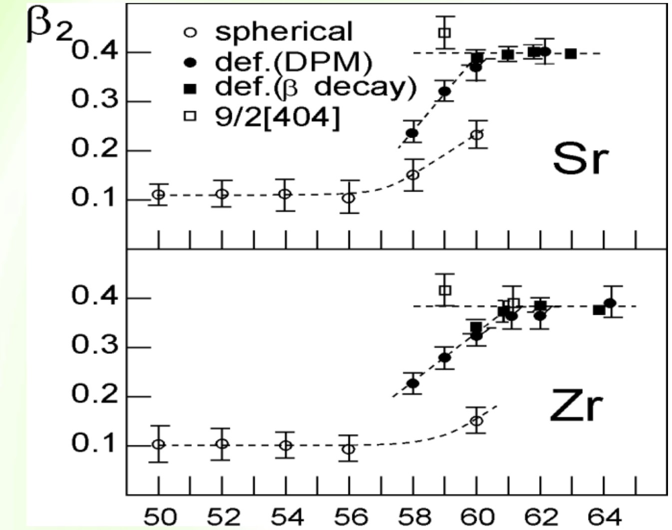
- First announcement of a region of onset of deformation in around A=100 still in the 70's (Cheitfetz et al., PRL 25, 38, 1970)

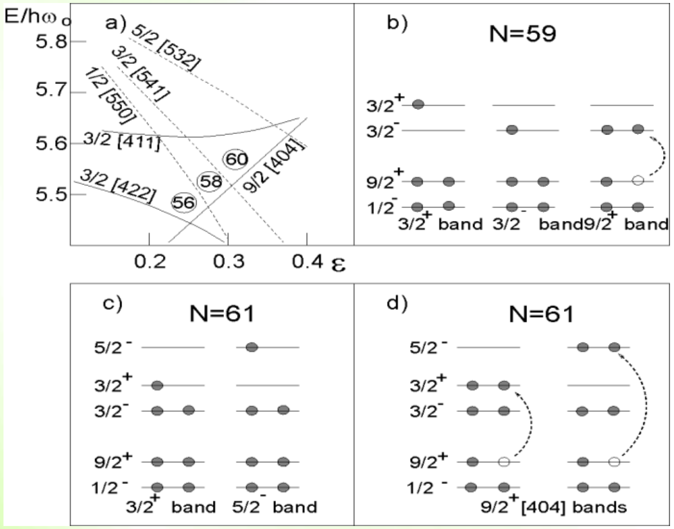


VOLUME 25, NUMBER 1 PHYSICAL REVIEW LETTERS 6 JULY 1970

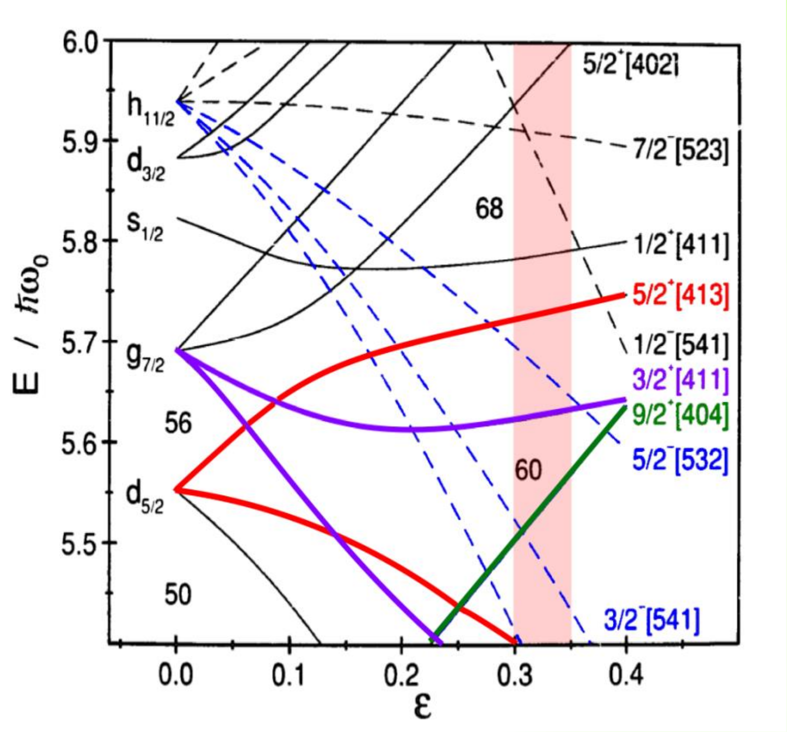
The role of the neutrons

W. Urban *et al.*, Eur. Phys. J. A22, 241 (2004)





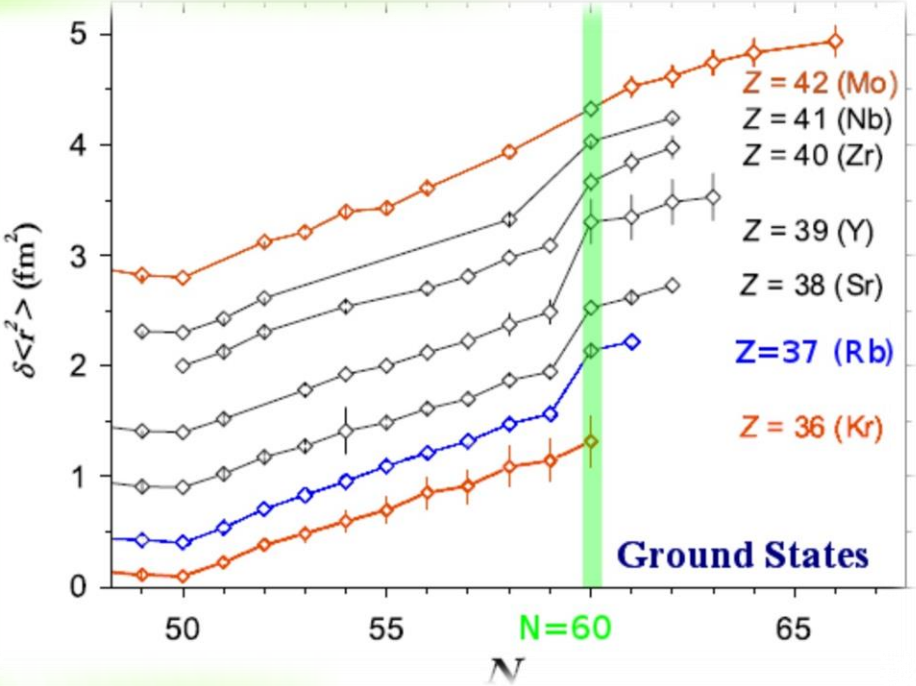
$\nu 9/2^+[404]$, $\nu 1/2^-[550]$, $\nu 3/2^-[541]$, $\nu 3/2^+[411]$

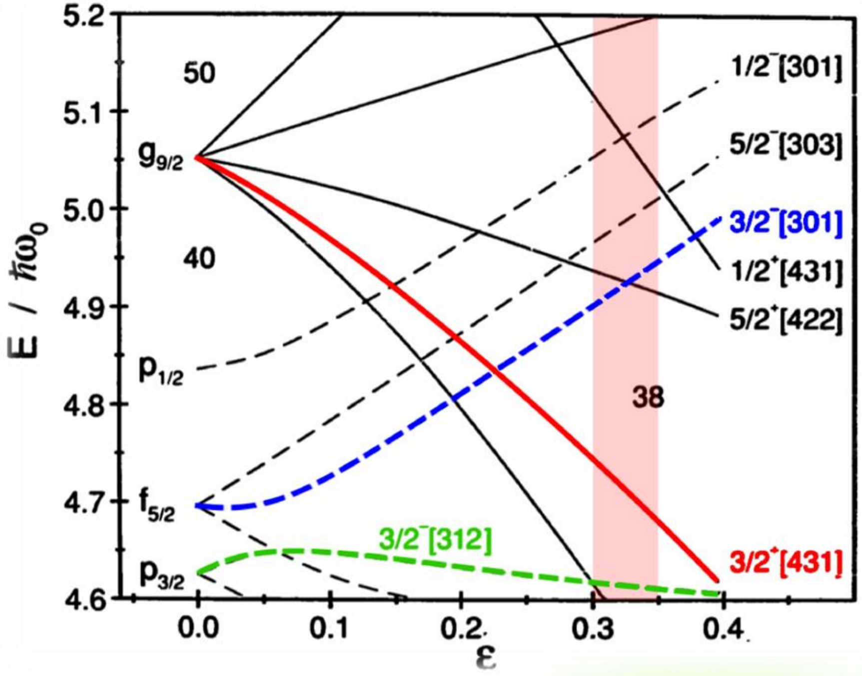


M.A.C Hotchkis *et al.*, Nucl. Phys. A530, (1991)

- Zr (Z=40) and Sr (Z=38)
  → clear shape change across N=60
- Balance between down-sloping - (deformation driving) and up-sloping (deformation reduction) orbitals
  → blocking of the deformation below N = 60

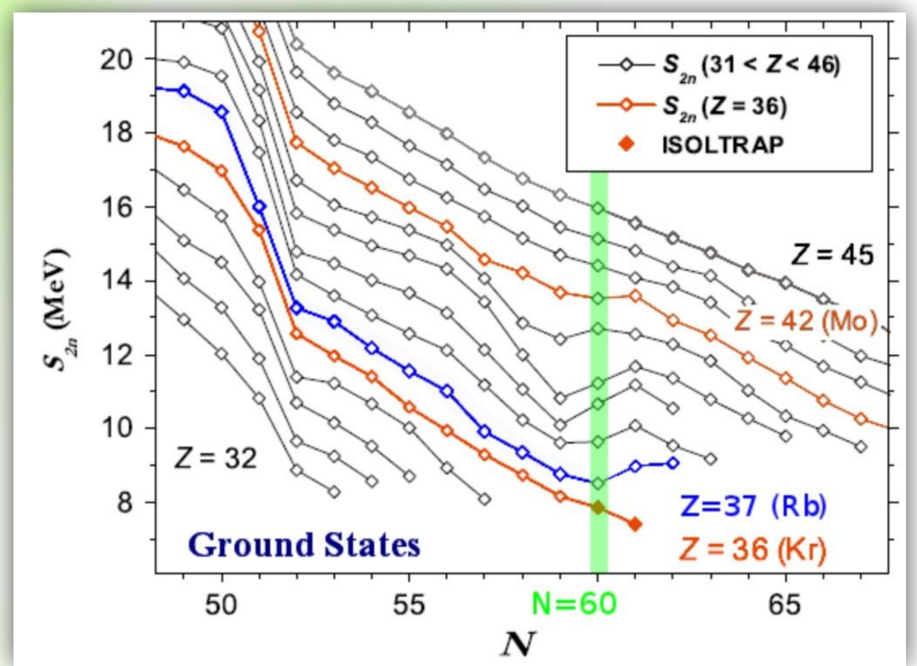
What is the role played by the protons for the onset of deformation?



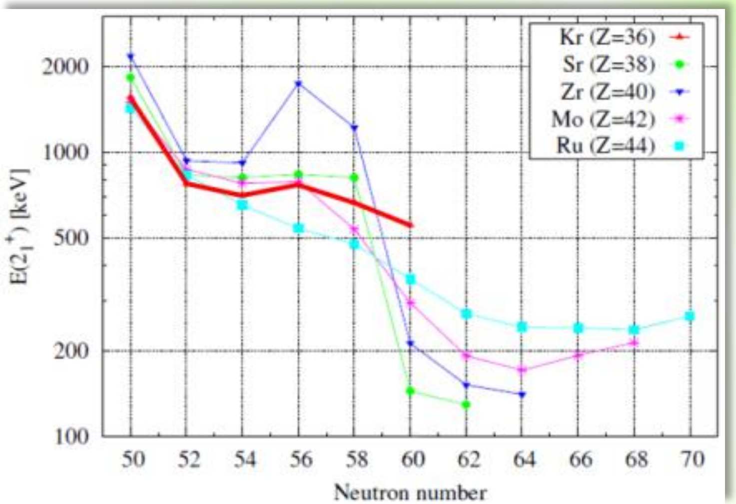


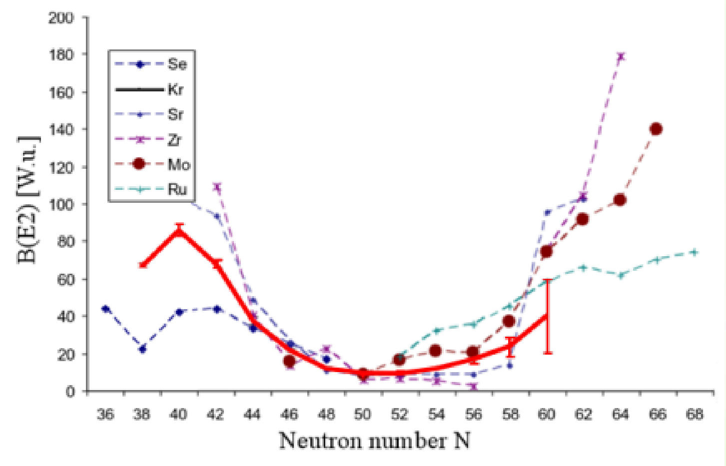
- Charge radii - localizing it for the Rb, Sr, Y, Zr and Nb isotopes
- Where is the border of the deformed region?
- What is the origin for the deformation in this region?

Where the border line is – Kr?



S. Naimi *et al.*, PRL 105, 032502 (2010)



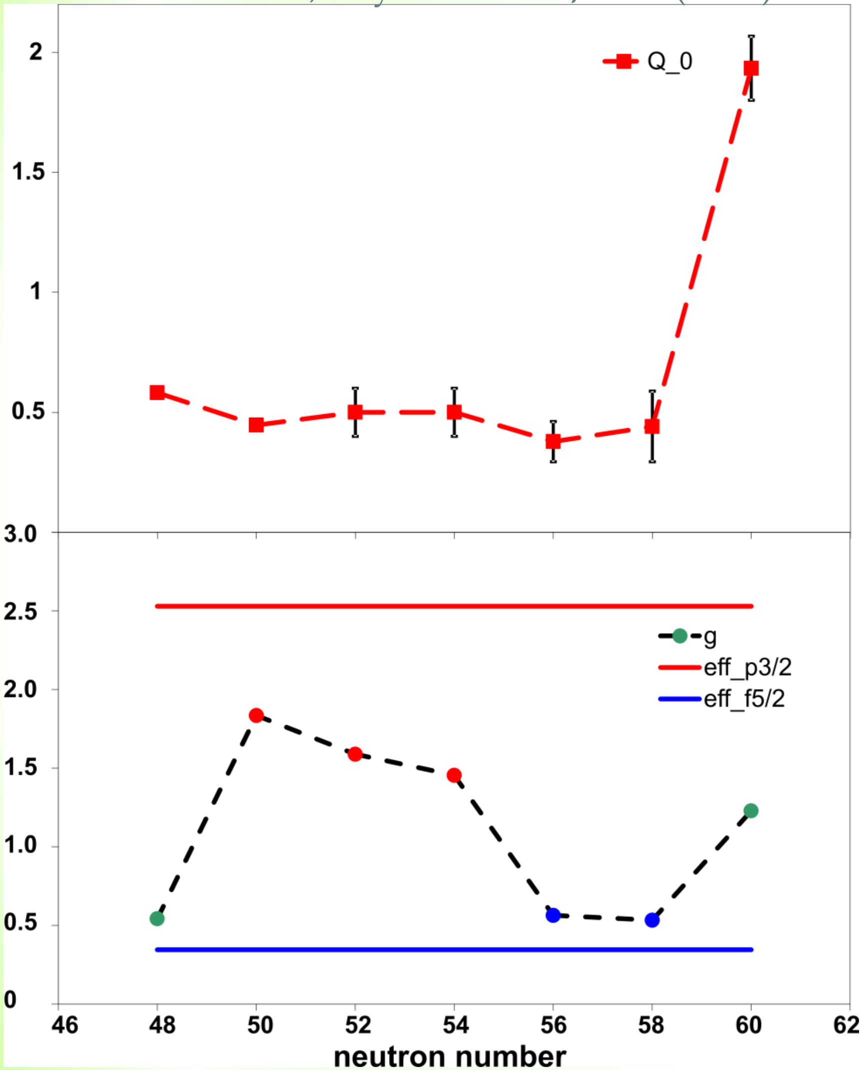


M. Albers et al., PRL 108, 062701 (2012)

- ✓ Gradual development of deformation in the Kr isotopes

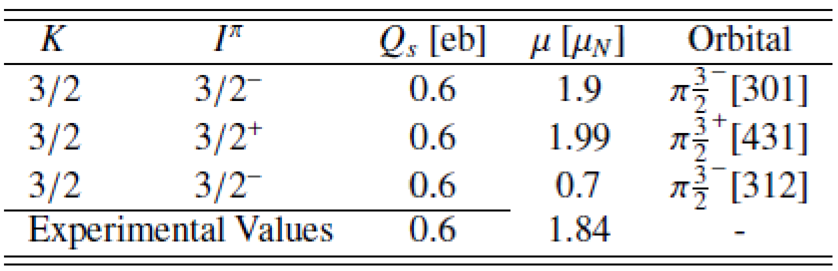
What about Rb's?

C. Thibault *et al.*, Phys. Rev. **C23,** 2720 (1981)



$\pi3/2^-[312]$, $\pi3/2^-[301]$, $\boldsymbol{\pi3/2^+[431]}$

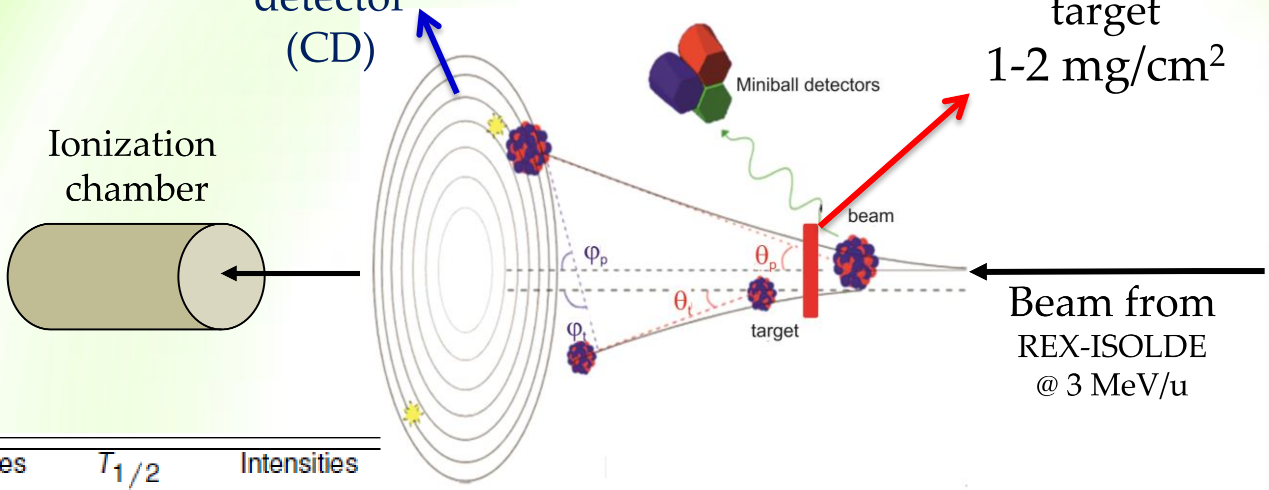
Ground-state nuclear moment measurements of ^{97}Rb



K	I^π	Q_s [eb]	μ [μ_N]	Orbital
3/2	$3/2^-$	0.6	1.9	$\pi\frac{3}{2}^-[301]$
3/2	$3/2^+$	0.6	1.99	$\pi\frac{3}{2}^+[431]$
3/2	$3/2^-$	0.6	0.7	$\pi\frac{3}{2}^-[312]$
Experimental Values		0.6	1.84	-

- ✓ Sudden onset of deformation at ^{97}Rb
- ✓ Ground-state magnetic moment measurement – favors $\pi3/2^+[431]$ but does not exclude $\pi3/2^-[301]$

Coulomb excitation with Miniball

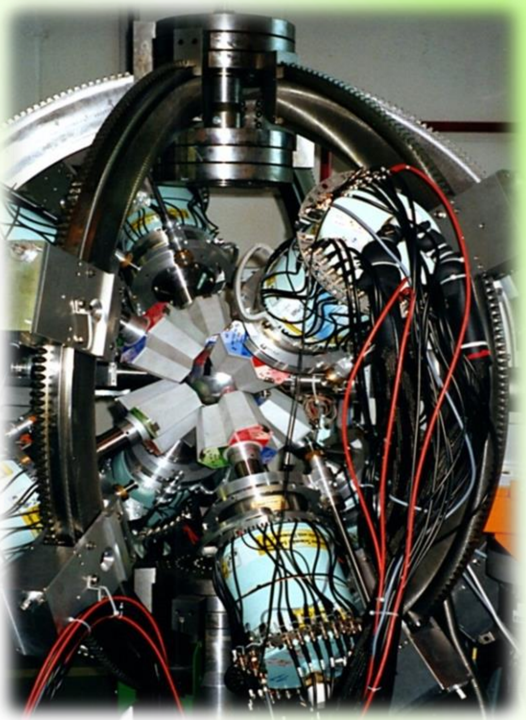


Particle detector (CD)

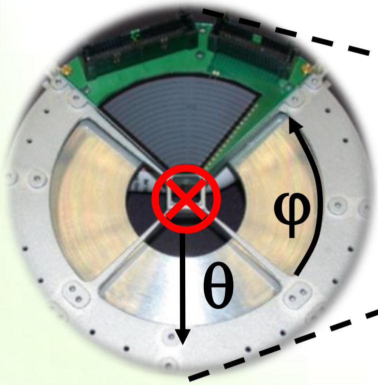
Ionization chamber

Secondary target
1-2 mg/cm²

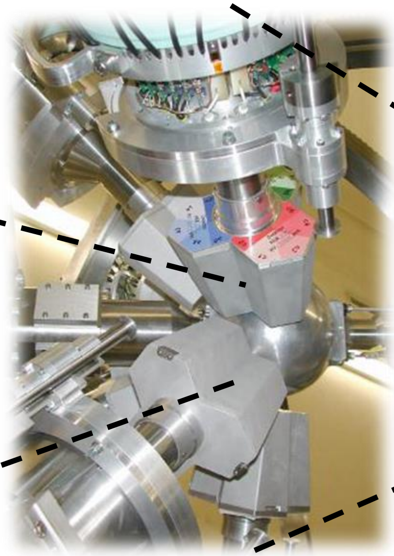
Beam from
REX-ISOLDE
@ 3 MeV/u



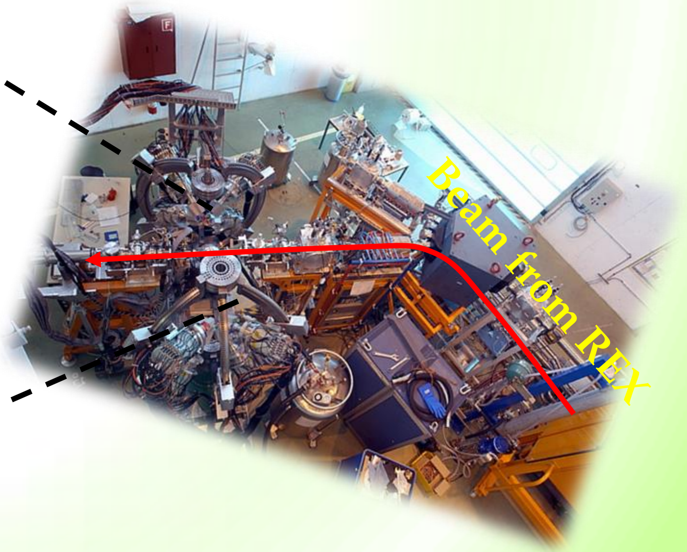
Isotopes	$T_{1/2}$	Intensities
^{93}Rb	5.8s	6 10^6pps
^{95}Rb	377ms	1 10^6pps
^{97}Rb	170ms	4 10^5pps
^{99}Rb	50ms	few 10^3pps



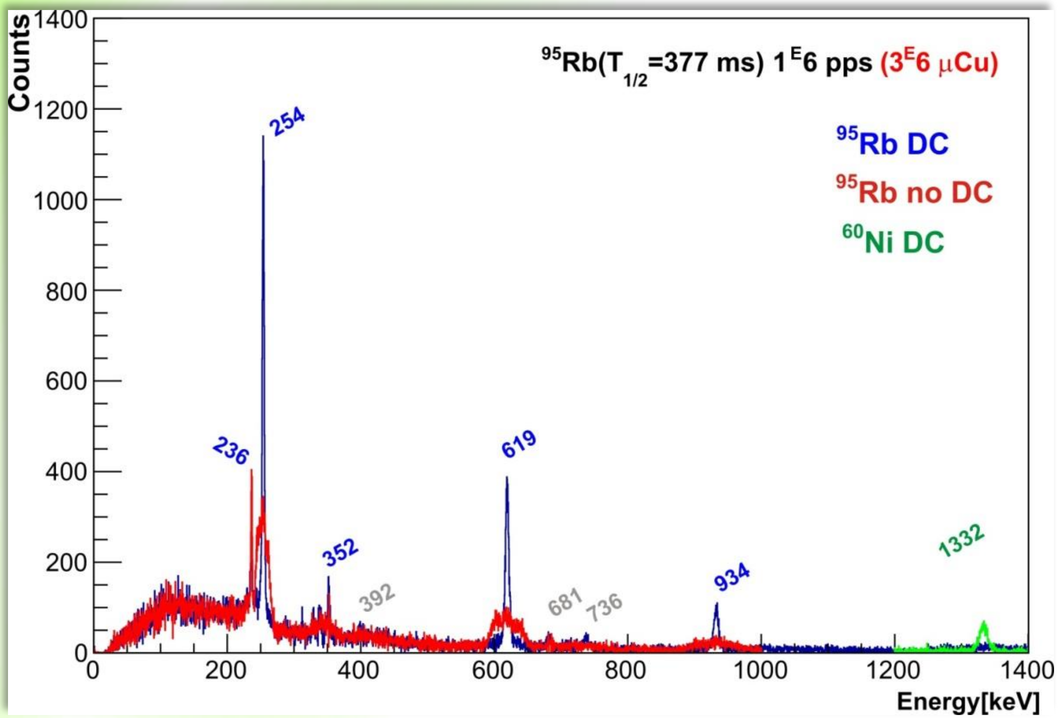
CD detector
(16° – 53°)

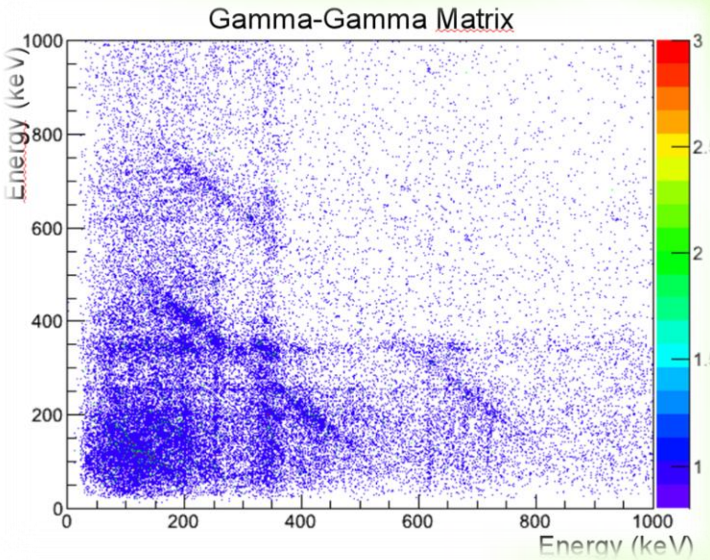


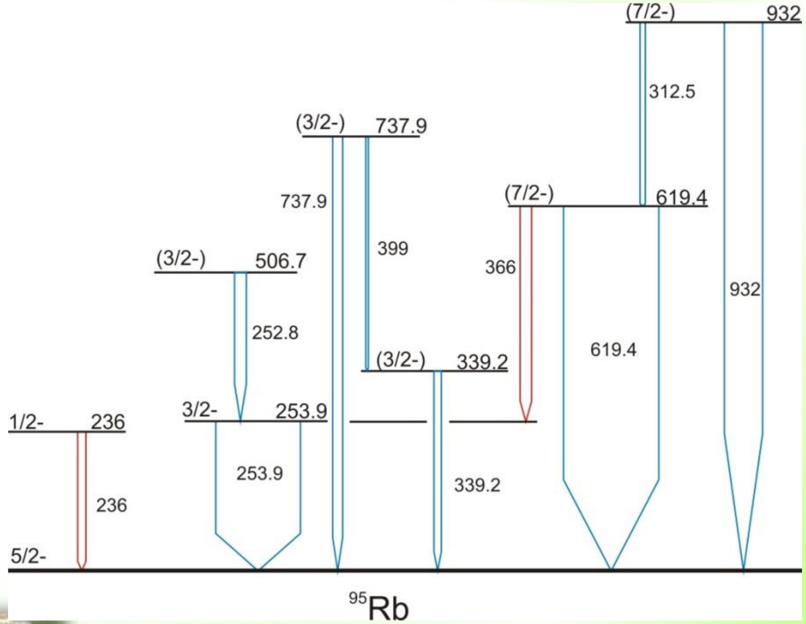
Vacuum chamber &
Miniball detectors



“Spherical results” – example of ^{95}Rb



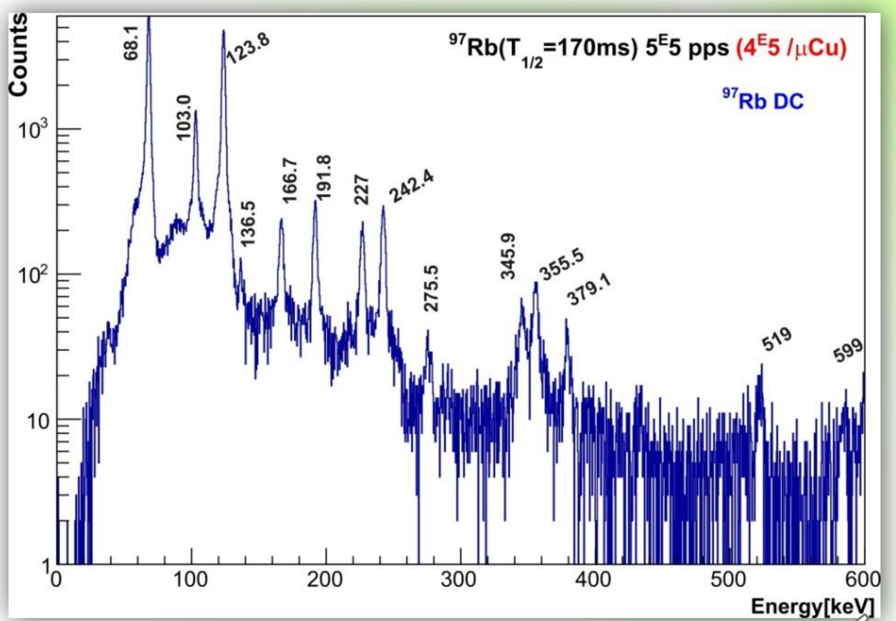


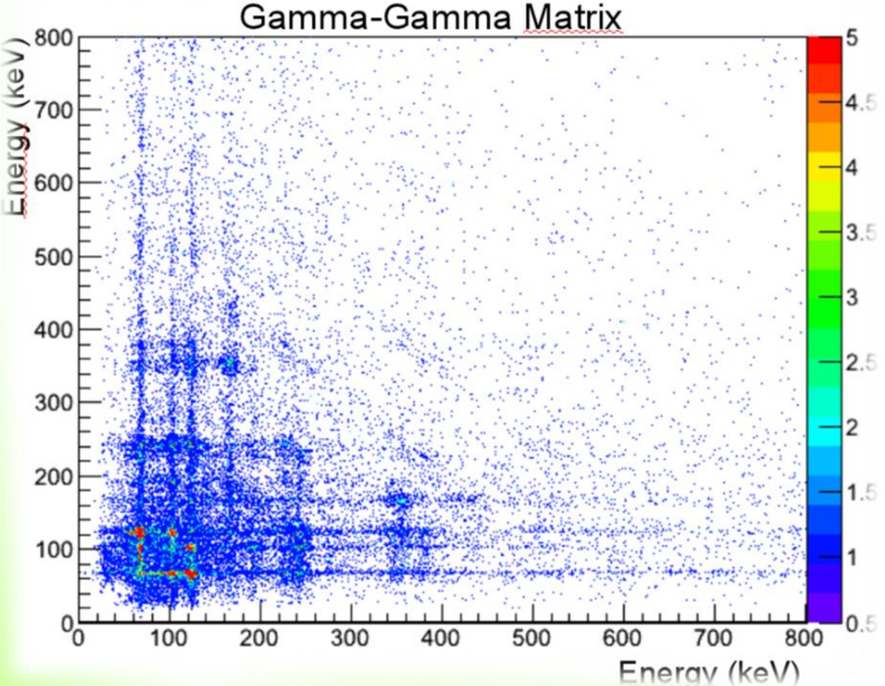


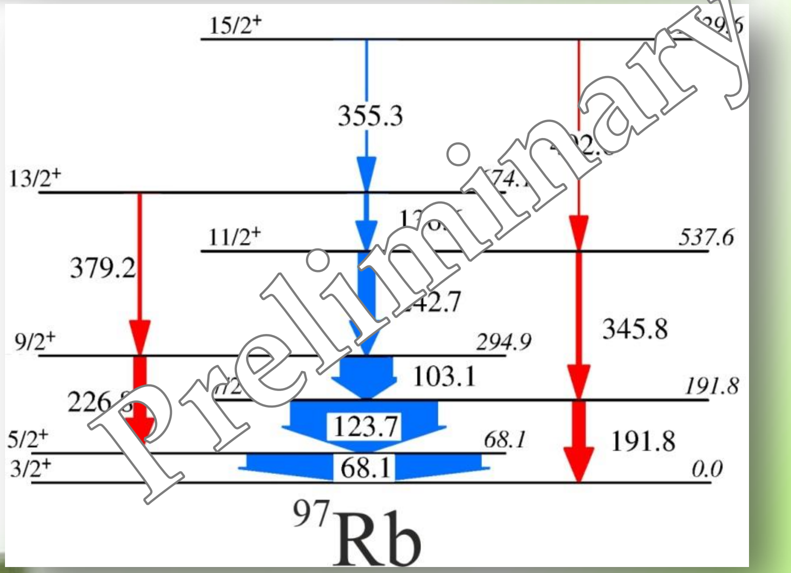
- Single-particle like spectra
- Typical **B(E2)** (^{93}Rb, ^{95}Rb) **~20 W.u.**

Deformed example – ^{97}Rb

- Multi-step Coulomb excitation giving access to rotational bands in ^{97}Rb and ^{99}Rb
- Obtained transition probabilities in ^{97,99}Rb → B(E2) ~120 W.u.







G. Georgiev

NSP13, Padova, 10 – 12 June 2013

What could we extract?

K,J	Branching ratio	B(M1)/B(E2)	$\vert g_K - g_R \vert$	[illegible]
3/2, 7/2	0.070(24)	1.50(4)	[illegible]	[illegible]
3/2, 9/2	0.255(10)	[illegible]	[illegible]	[illegible]
3/2, 11/2	[illegible]	[illegible]	[illegible]	0.153(6)
[illegible]	[illegible]	2.12(38)	1.45(23)	0.051(5)
[illegible]	0.35(11)	1.59(52)	1.28(30)	0.11(2)

Wood-Saxon potential with universal parameterization from *P. Moller, ADNDT 59 (1995) 185* (F.G. Kondev *priv. comm.*)

$3/2^-$ [301]
K = 3/2, Q_0= 2.90, g_R = 0.30
$\vert g_K - g_R \vert$**=1.610**

$3/2^+$[431]
K = 3/2, Q_0= 2.90, g_R = 0.30
$\vert g_K - g_R \vert$**=1.410**

Ground-state band in ^{97}Rb unambiguously identified as built on the **$3/2^+$ [431]** Nilsson orbital

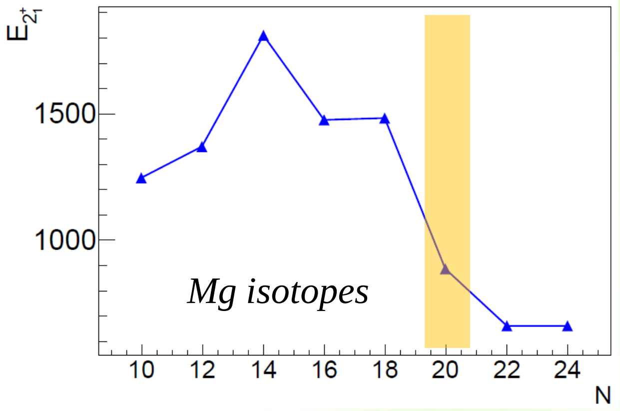
Nuclear moments at ALTO

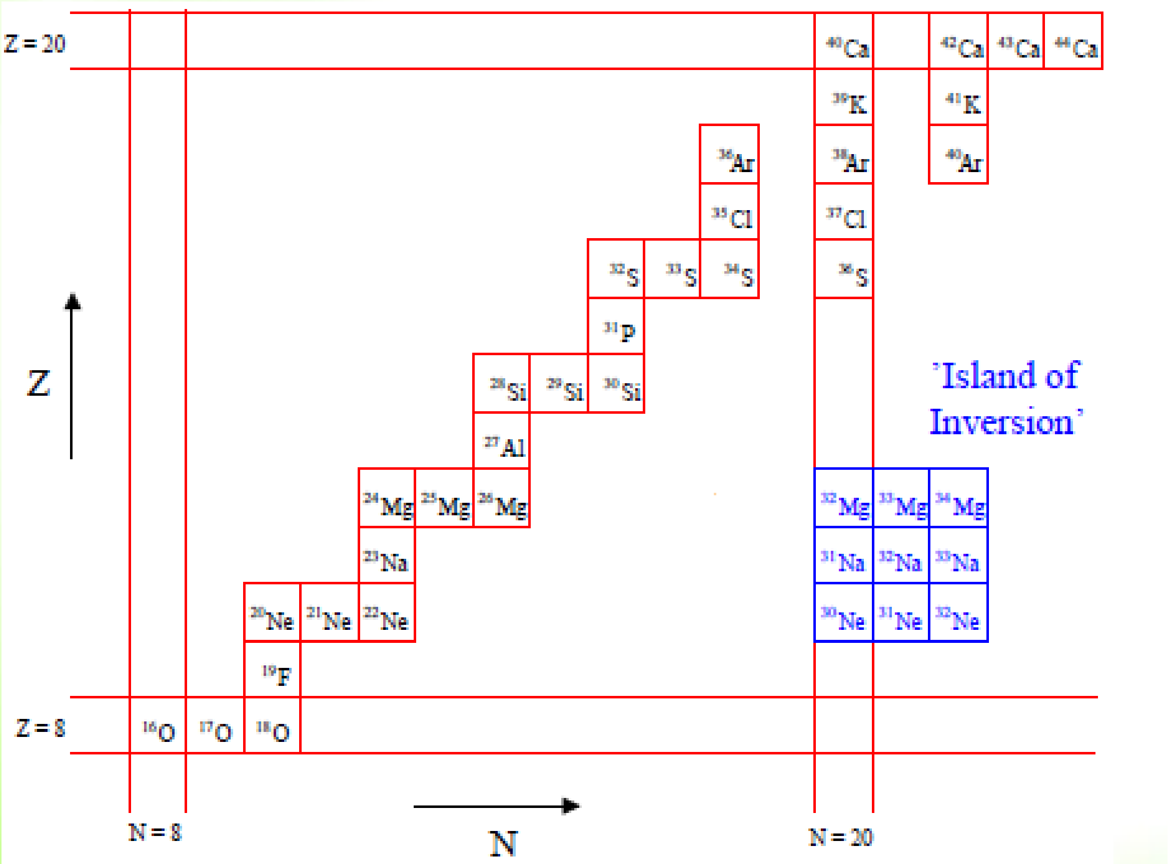
Nov. 2012

Magnetic moments – what can we learn?

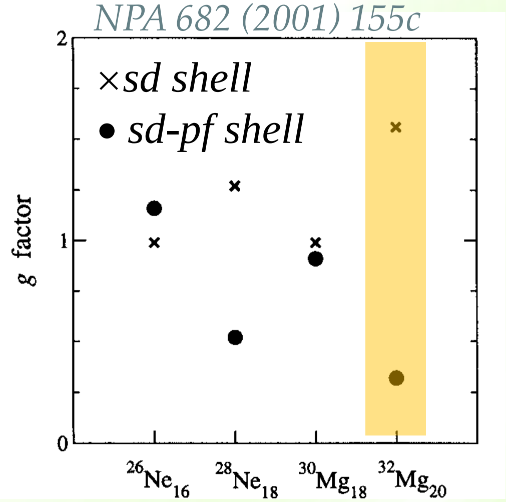
- Magnetic dipole moments – high sensitivity towards:
  - the single-particle structure of the state of interest;
  - the purity of the wave function;
  - proton/neutron contributions

*D. Guillemaud-Mueller et al., NPA **426**, 37 (1984)*





T.Otsuka et. al., NPA 682 (2001) 155c



MCSM calculations

Magnetic moments of short-lived states – the challenge

- interaction between the nuclear spin and a magnetic field

  → Larmor precession

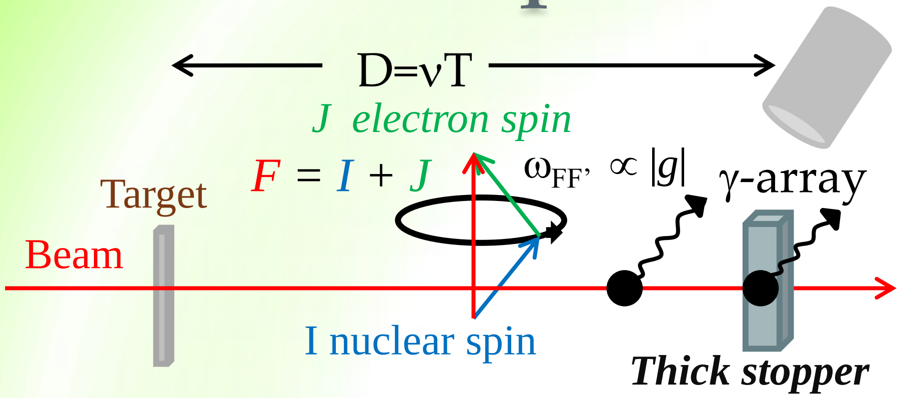
$$\boxed{\omega_L = -g\frac{\mu_N}{\hbar}B}$$

- "sufficient" interaction within the nuclear lifetime – observable modification of the γ-ray angular distribution

$$\Delta\theta \sim \omega_L \Delta t$$

- **kT fields** necessary for few degrees of rotation for picosecond states
- In the "standard techniques" e.g. Transient Field (TF) or Recoil In Vacuum (RIV) require calibration measurements with well-known states for determination of the obtained magnetic fields
- use of **H-like ions** – field strength calculated from first principles

Time Dependent Recoil In Vacuum



D=νT

J electron spin

$F = I + J$

$\omega_{FF'} \propto |g|$

Target

γ-array

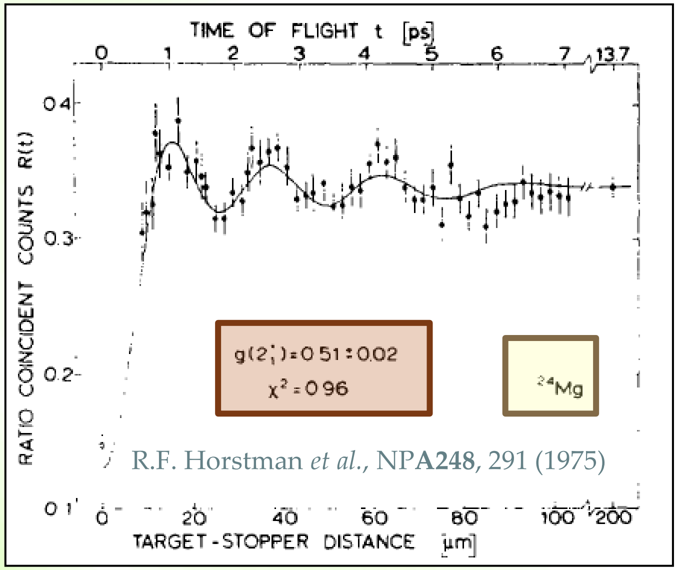
Beam

I nuclear spin

Thick stopper

$$\boxed{0 \le |G_k| \le 1}$$

$$W(\theta_p,\theta_\gamma) \approx \sum_{k,q} \rho_{kq}(\theta_p) G_k F_k Q_k D^{k*}_{q0}$$

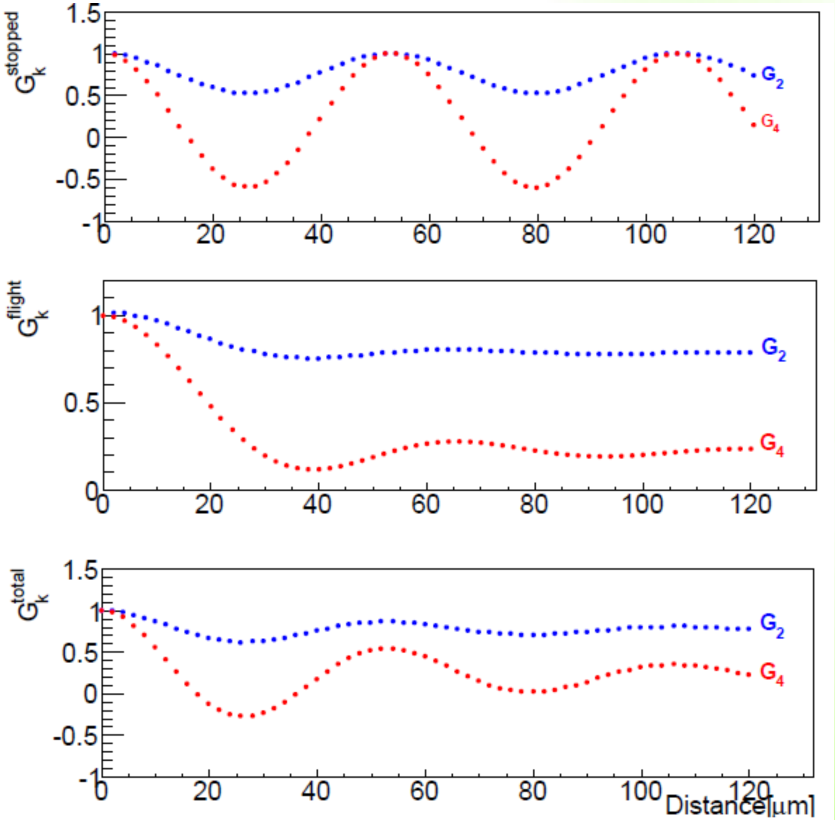


$g(2_1^+) = 0.51 \pm 0.02$

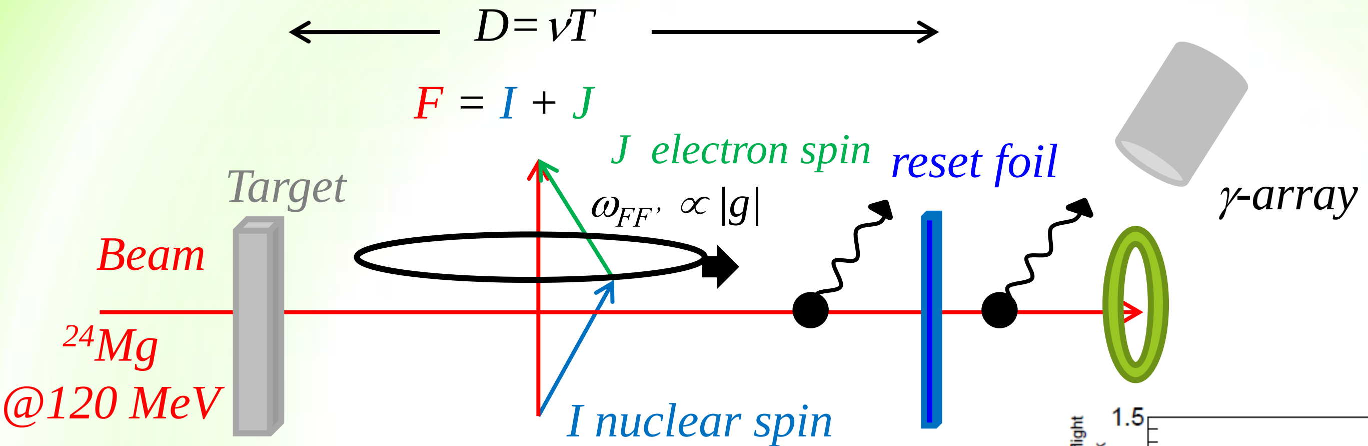
$\chi^2 = 0.96$

^{24}Mg

R.F. Horstman *et al.*, NP**A248**, 291 (1975)



TDRIV for radioactive ion beams



$D = vT$

$F = I + J$

J electron spin

reset foil

Target

$\omega_{FF'} \propto |g|$

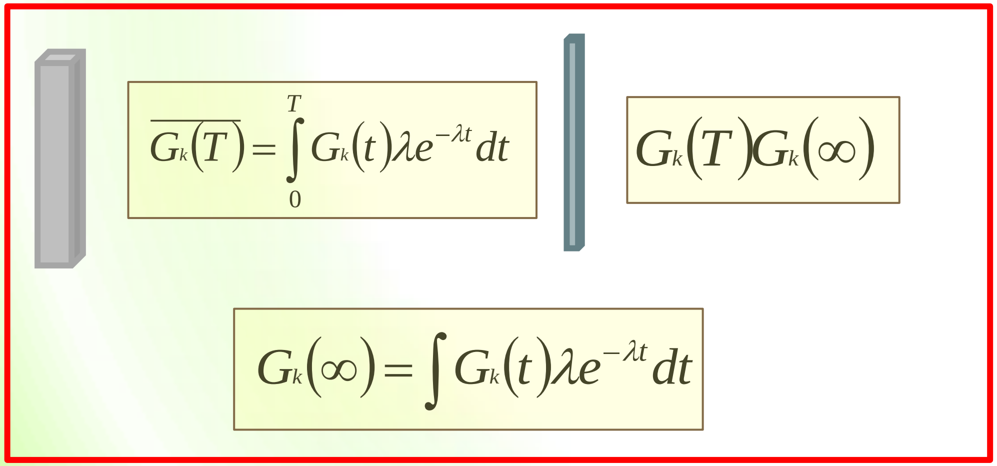
γ-array

Beam

^{24}Mg

@120 MeV

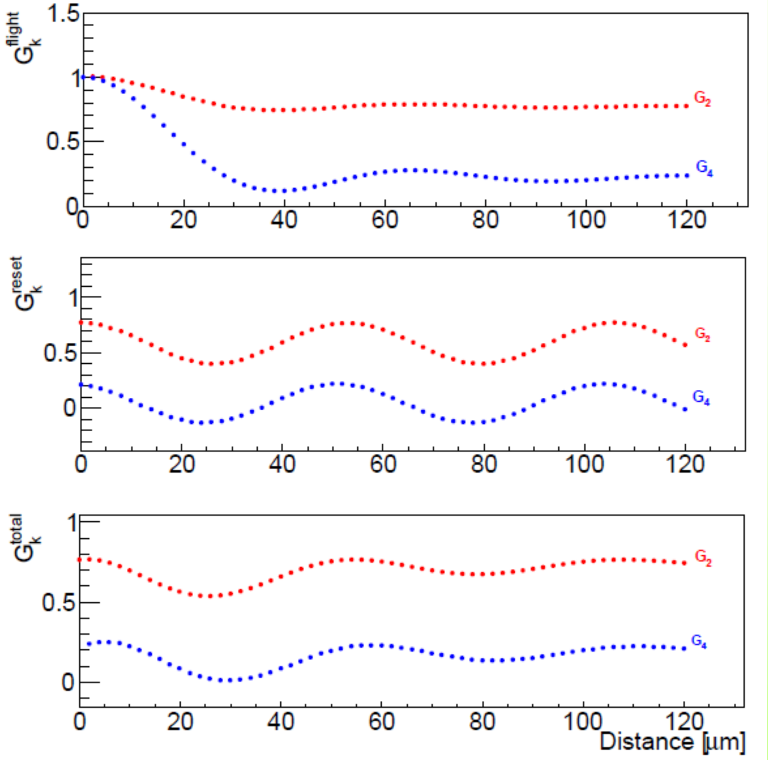
I nuclear spin



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

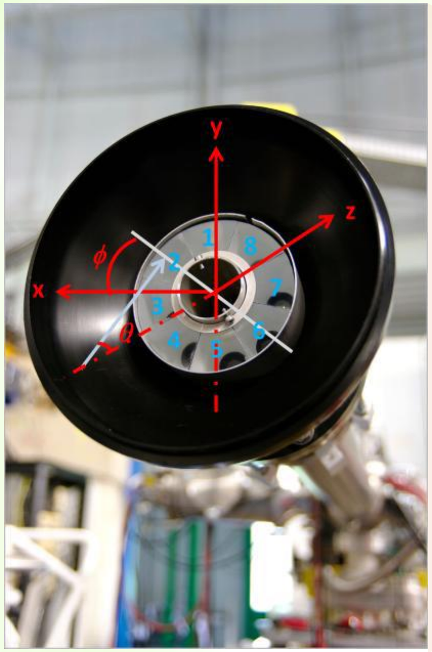
$$G_k(T)G_k(\infty)$$

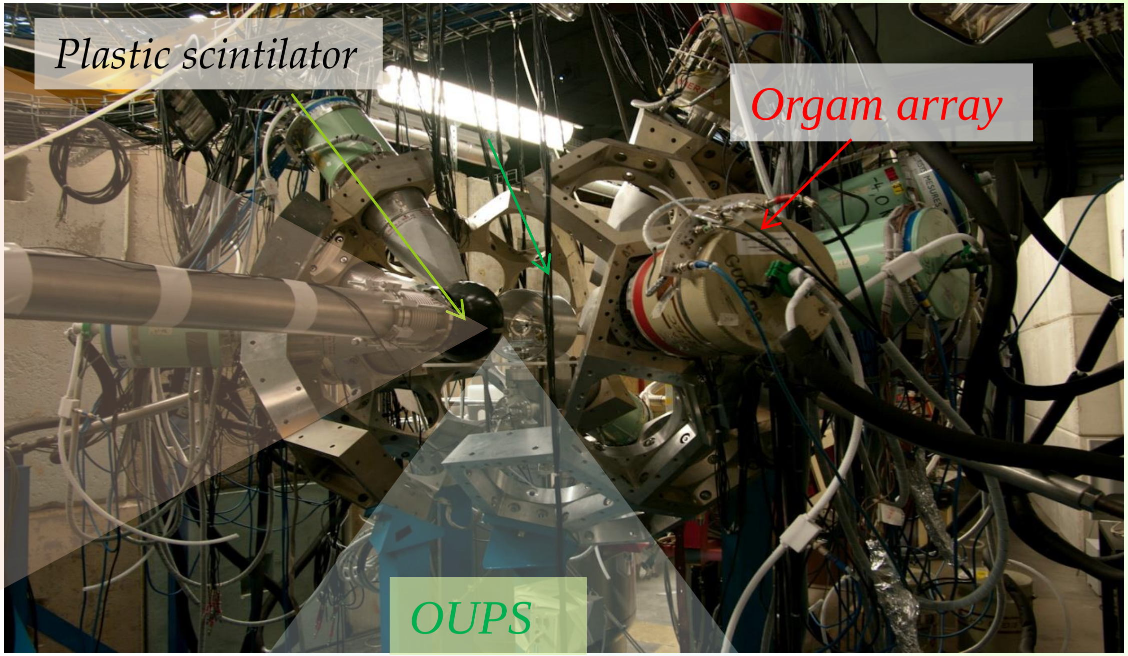
$$G_k(\infty) = \int G_k(t)\lambda e^{-\lambda t}\,dt$$



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

Experimental setup



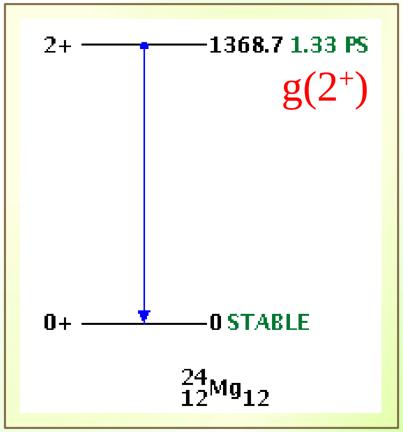


Beam: ^{24}*Mg* *@120 MeV, 1.8 pnA intensity*

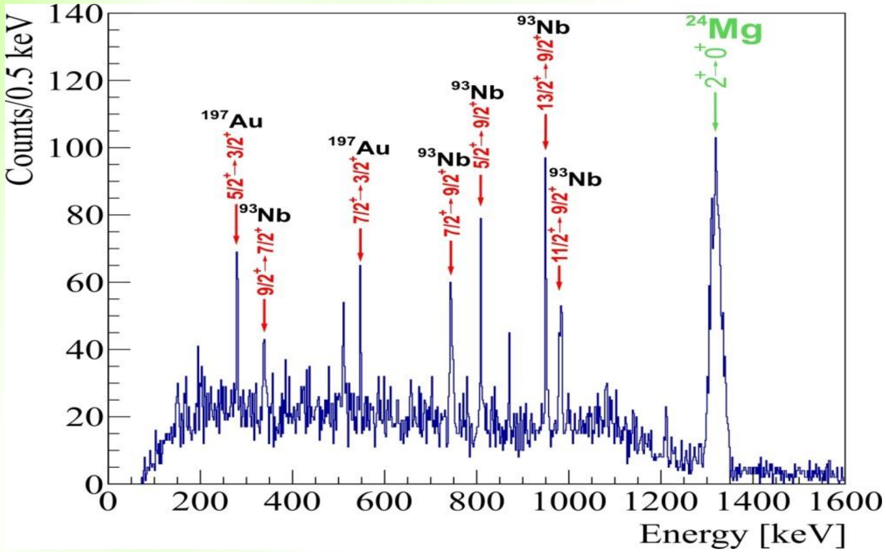
Target: *2.4 mg/cm*^{2} ^{93}*Nb*

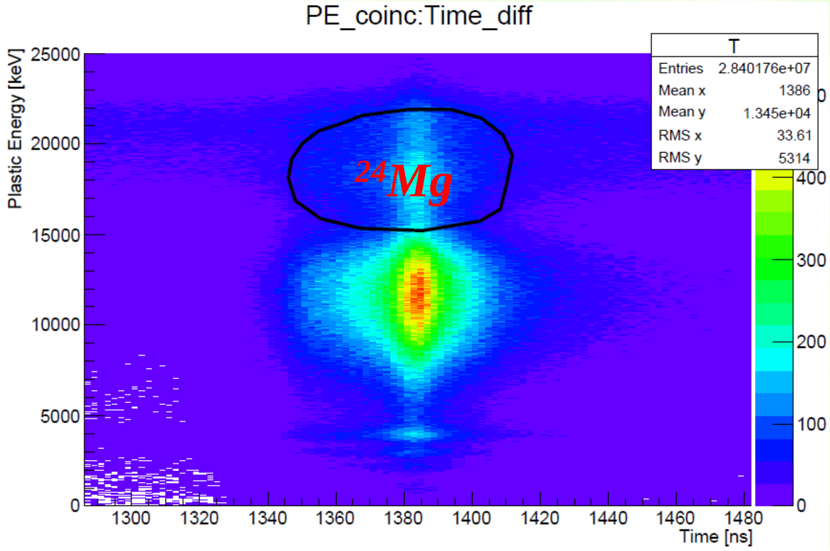
Reset Foil: *1.7 mg/cm*^{2} ^{197}*Au*

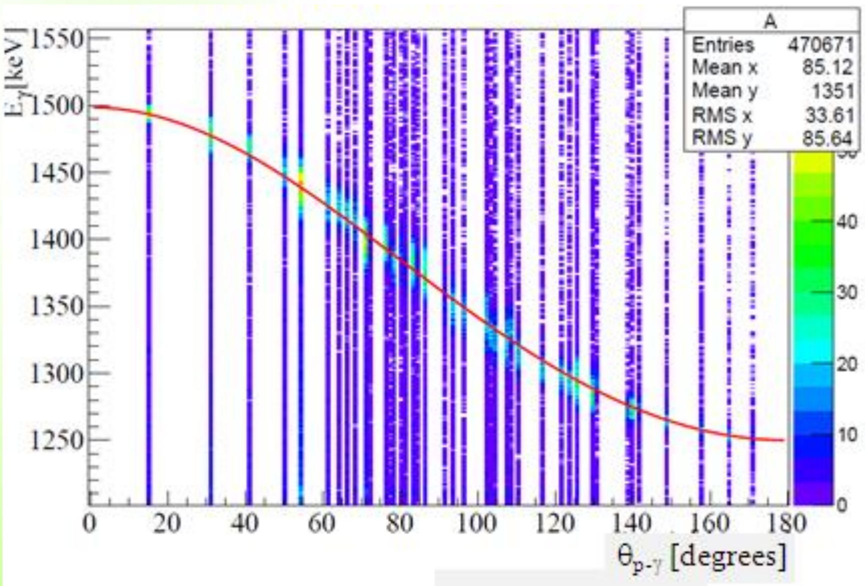
- ✓*13 HPGe*
  θ= 46.5°, 72.1°, 85.8°, 94.2°, 108.0°,133.6°, 157.6°
- ✓*8-fold segmented annular detector*

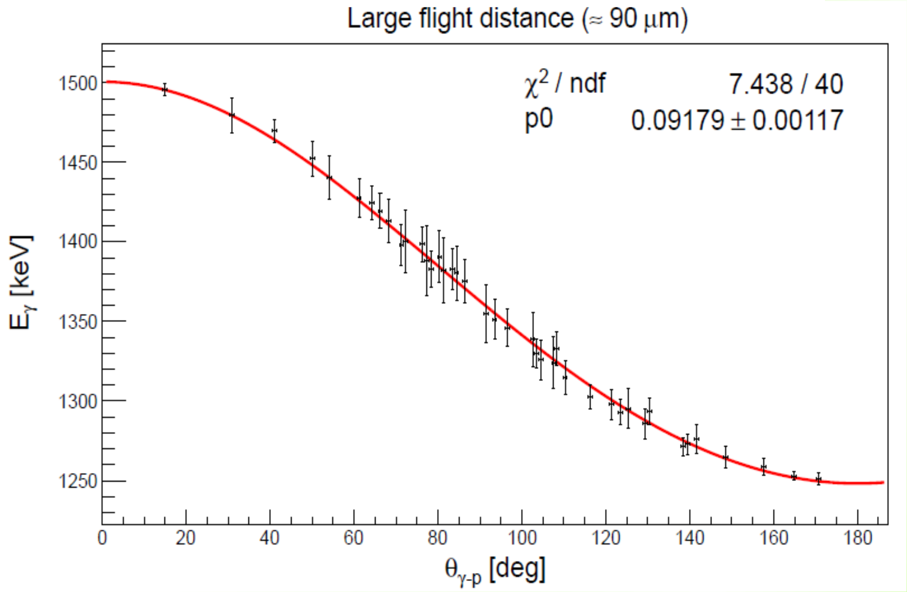


Experimental spectra

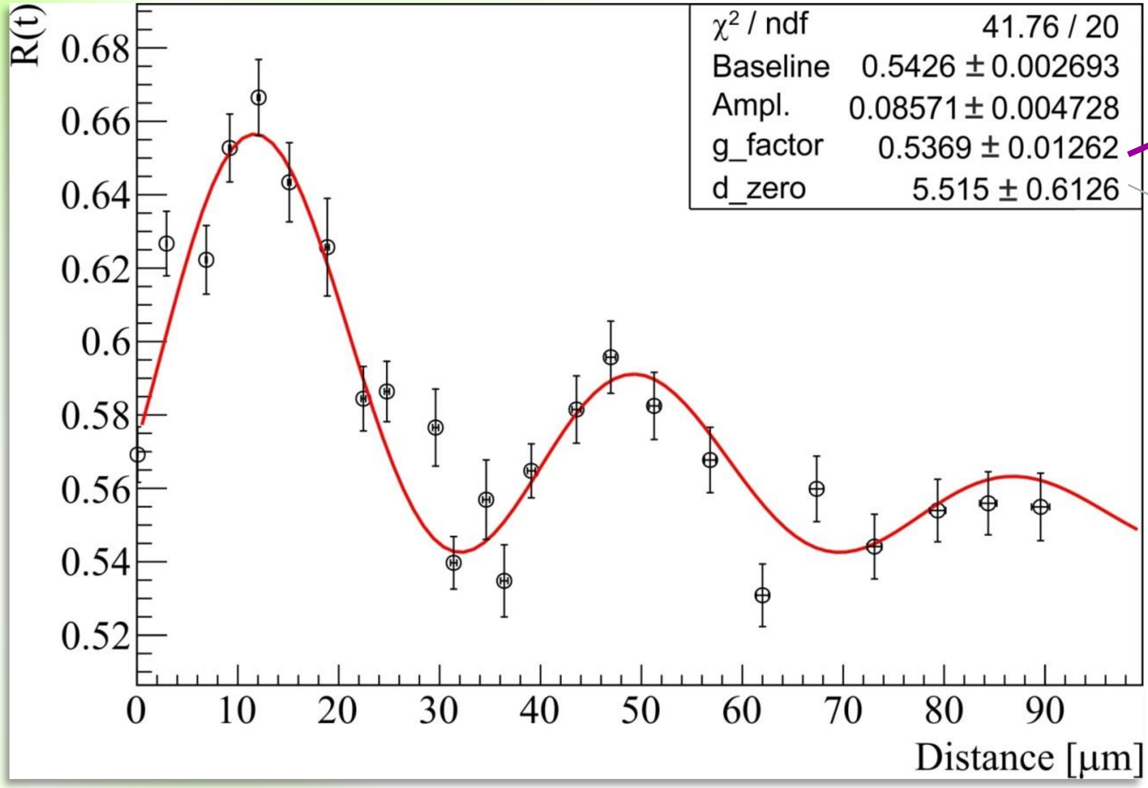








R(t) function



<5% statistical uncertainty

precise absolute distance definition

Result consistent with previous g-factor measurement of g(2^+) ^{24}Mg

→ TDRIV on H-like ions possible with radioactive beams

Conclusions and perspectives

- Transition probability measurements can provide important structure information especially for (odd-mass) nuclei far from stability
- The structure of the Rb isotopes is one of the key ingredients for the understanding of the sudden onset of deformation at N=60
- TDRIV on H-like ions – a method that could provide high-precision model independent results. Getting ready for the soon available radioactive ion beams.

Collaborations

REX-ISOLDE Coulex

- **C. Sotty** - *CSNSM, Orsay, France*
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- S. Das Gupsta - *Dipartimento di Fisica, Universita di Camerino, Italy*
- L. Gafney - *Oliver Lodge Laboratory, University of Liverpool, UK*
- K. Hadynska-Klek, P. Napiorkowski - *Heavy Ion Laboratory, Warsaw University, Warsaw, Poland*
- T. Kroell, M. Scheck - *Technische Universitat Darmstadt, Darmstadt, Germany*
- J. Pakarinen, H. Törnqvist, F. Wenander - *ISOLDE, CERN, Geneva, Switzerland*
- A. Stuchbery - *Department of Nuclear Physics, ANU, Canberra, Australia*
- M. Zielinska – *CEA, Saclay, France*

and REX-ISOLDE and Miniball's collaborators

ALTO TDRIV

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Thank you!