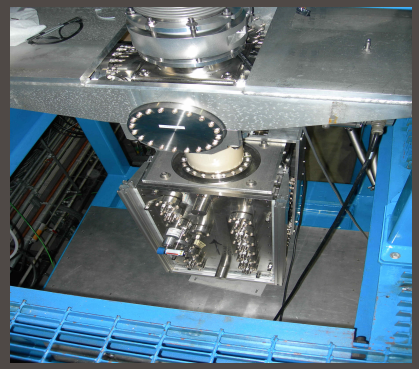
TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

Measuring ground state nuclear properties at TRIUMF



Matthew Pearson

TRIUMF

February 21, 2014

Ground state nuclear properties

Measured via the hyperfine interaction

Measurement of the interaction between a nucleus and its environment can yield

- Nuclear spin, I
- Magnetic dipole moment μ
- Electric quadrupole moment Q_s
- Change in RMS charge radii $\delta\langle r^2\rangle$

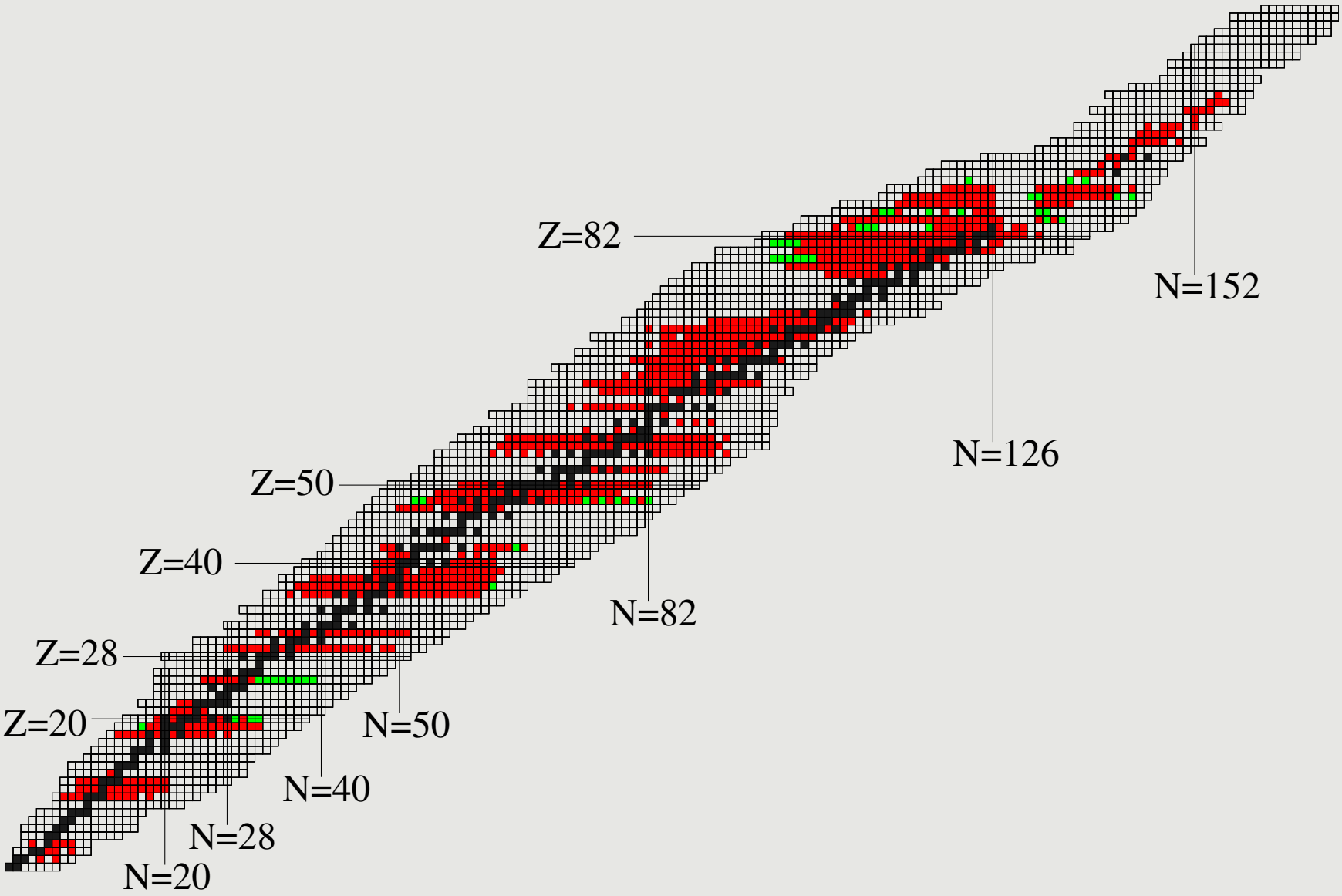
  (calculated from the isotope shift)

Isotope shift	$\Rightarrow$	$\langle\beta_2^2\rangle$	Dynamic deformation
Q_s	$\Rightarrow$	$\langle\beta_2\rangle$	Static deformation

$$\langle\beta_2^2\rangle \neq \langle\beta_2\rangle^2$$

Scope of measurements

as of Jan 2014



Interaction between an implanted nucleus and the crystal around it is given by

$$H = -m\frac{\mu}{I}H_o + \frac{e^2qQ}{4I(2I-1)}\left[\hat{I_z}^2 - \hat{I}^2 + \eta\left(\hat{I_x}^2 - \hat{I_y}^2\right)\right]$$

where $\eta = \frac{V_{xx}-V_{yy}}{V_{zz}}$

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where $\eta = \frac{V_{xx}-V_{yy}}{V_{zz}}$

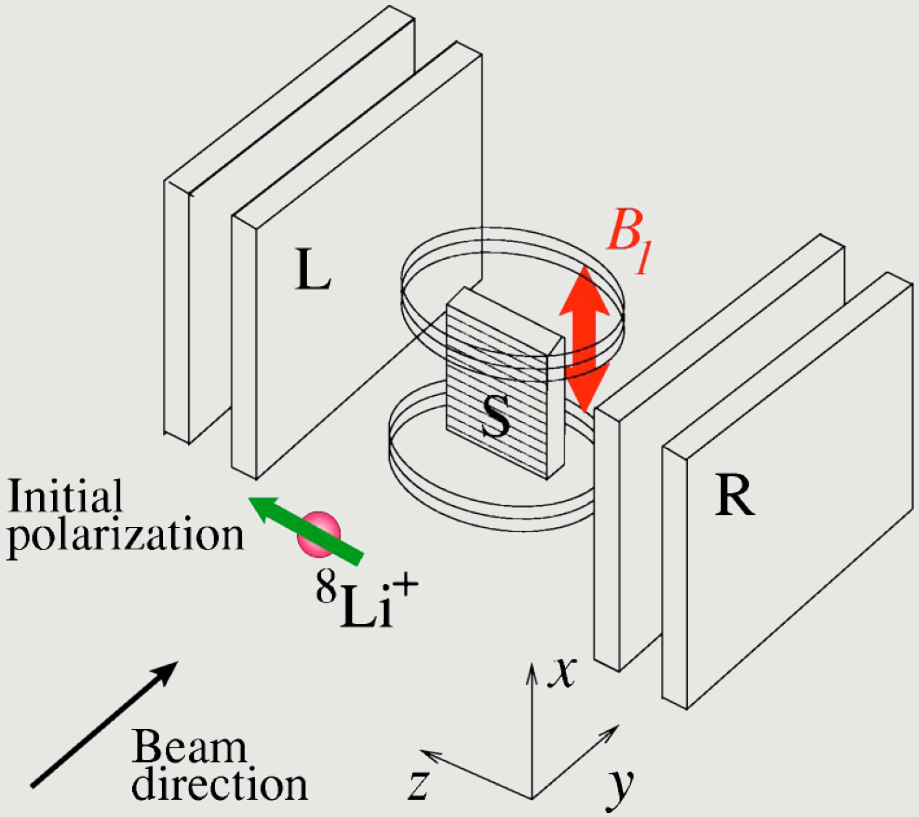
To measure μ arrange for $e^2q = 0$

$$H = -m\frac{\mu}{I}H_o$$

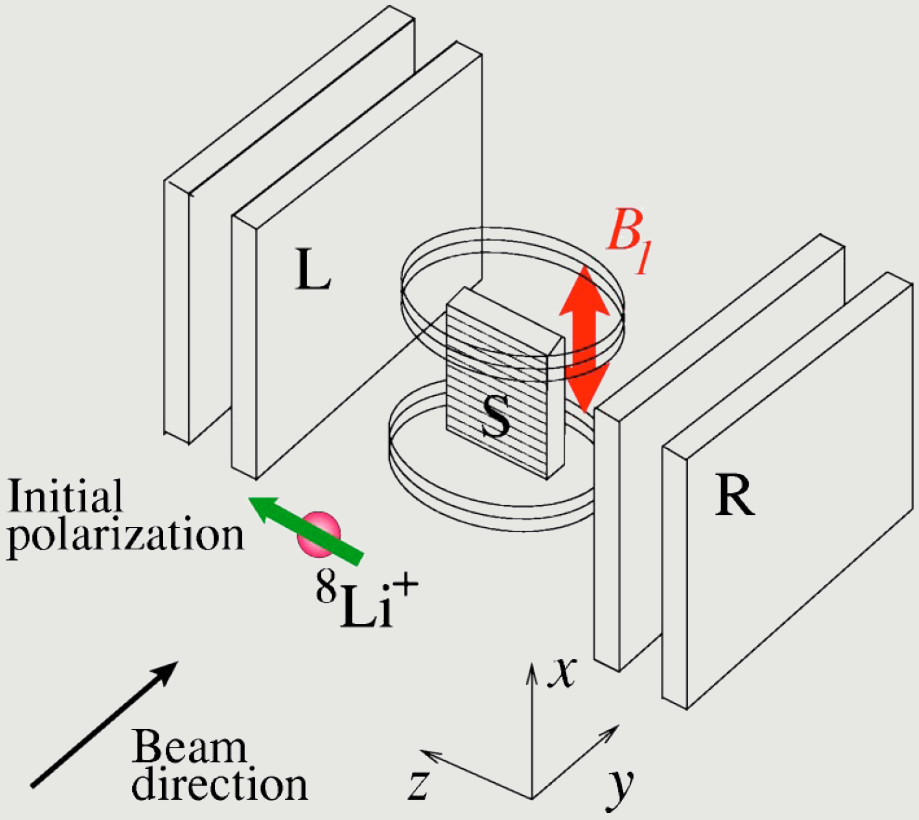
To measure Q reduce H_o to zero

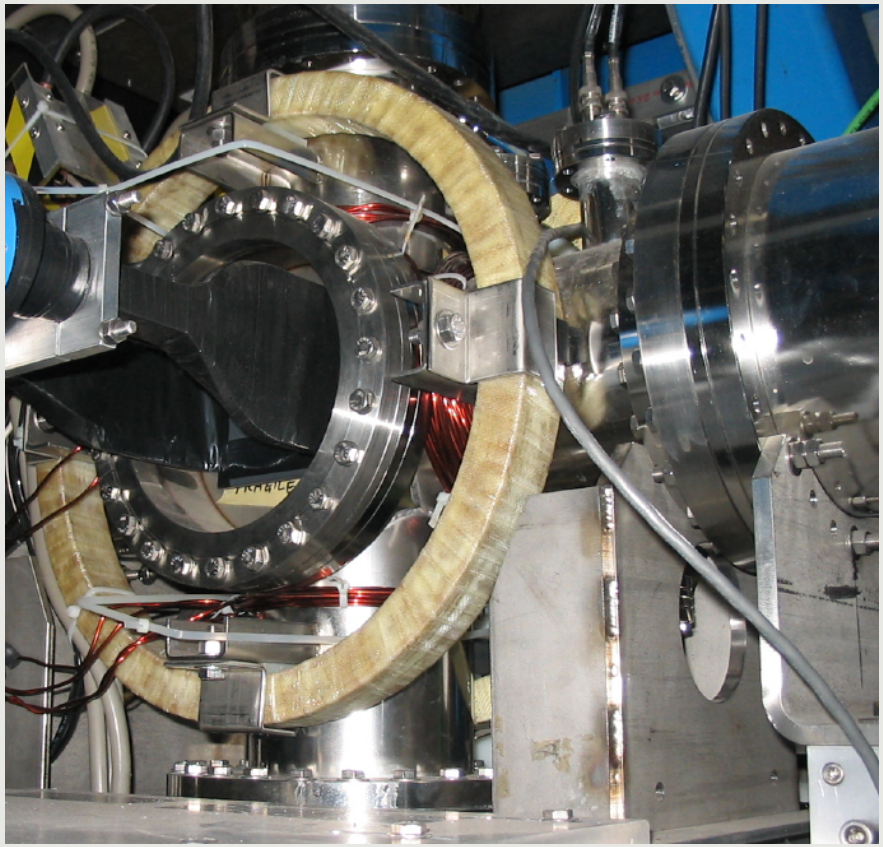
$$H = \frac{e^2qQ}{4I(2I-1)}\left[3m_I^2 - I(I+1)\right]$$

In practice

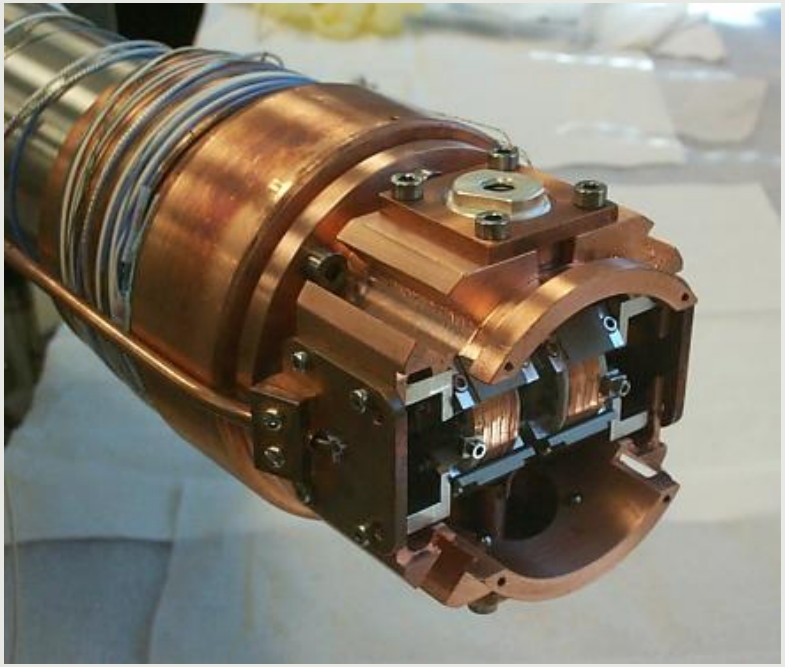


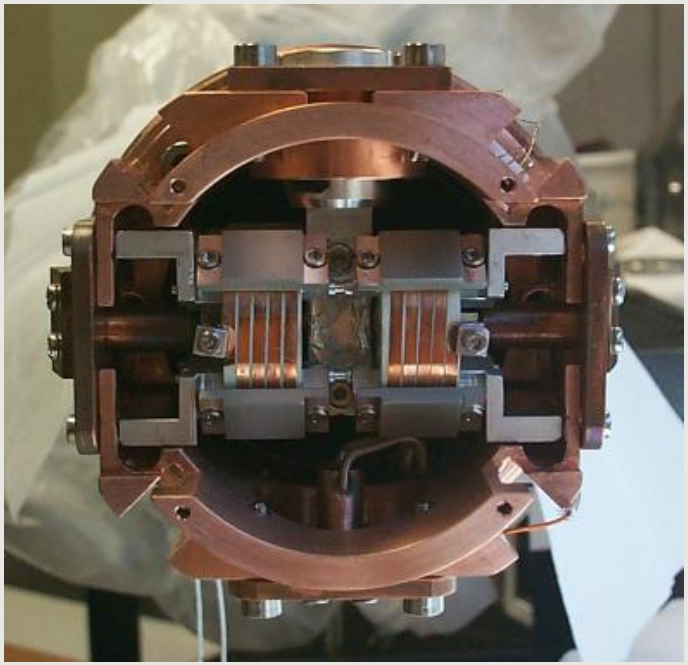
In practice





Inside the vacuum system



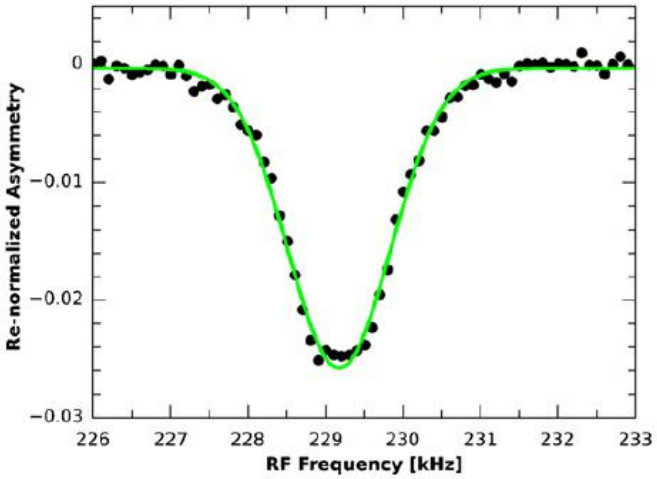


50Ω RF transmission line

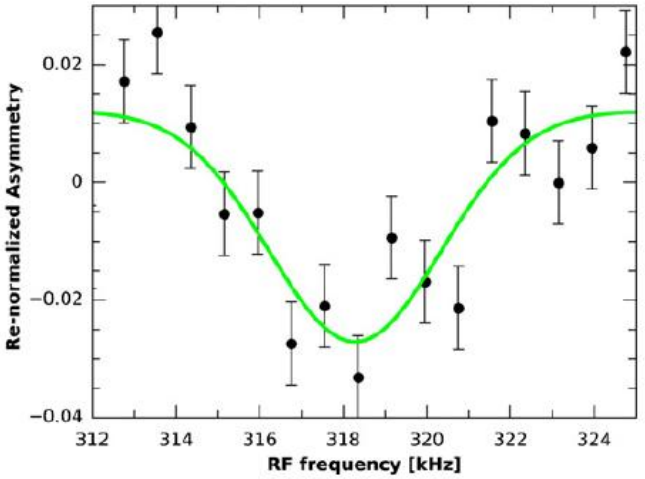
Non resonant ⇒ no tuning !!!

Pictures courtesy of G.D. Morris

NQR Data

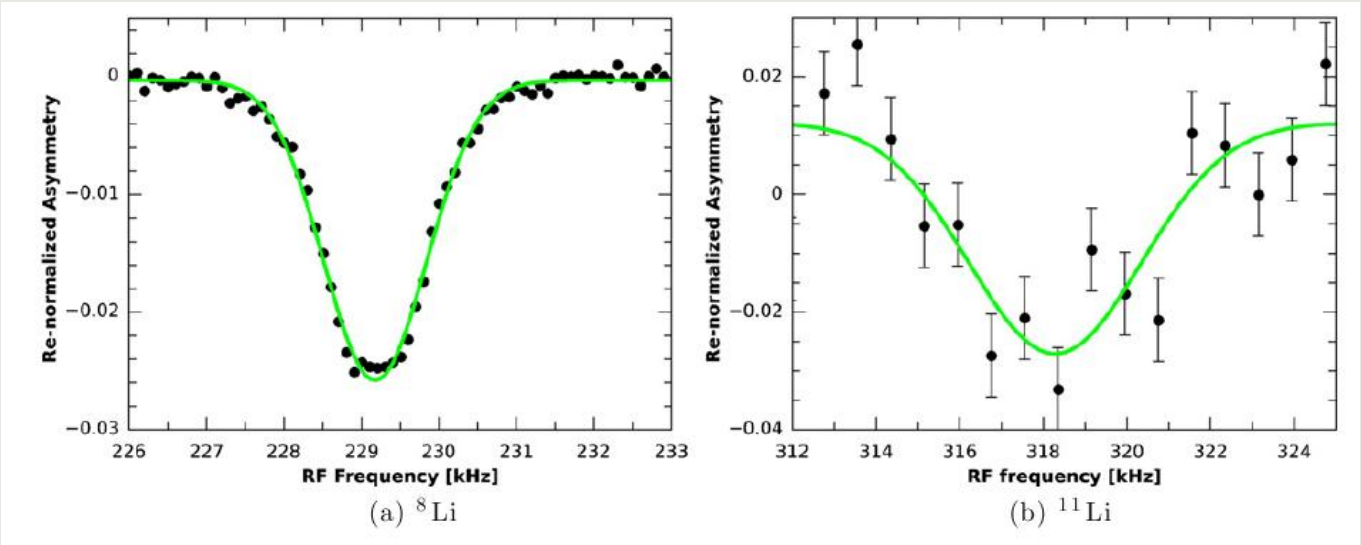


(a) ^{8}Li

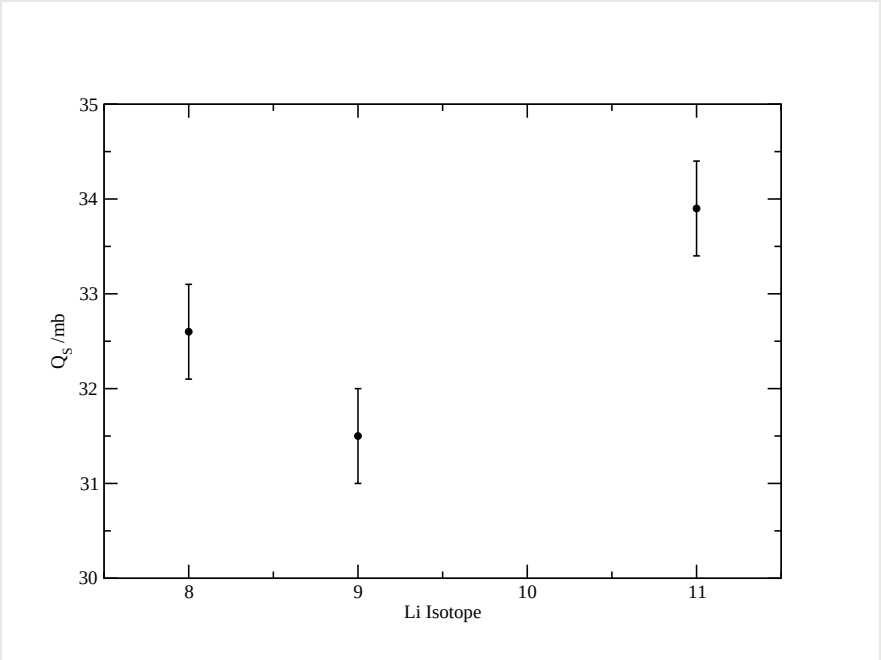


(b) ^{11}Li

NQR Data



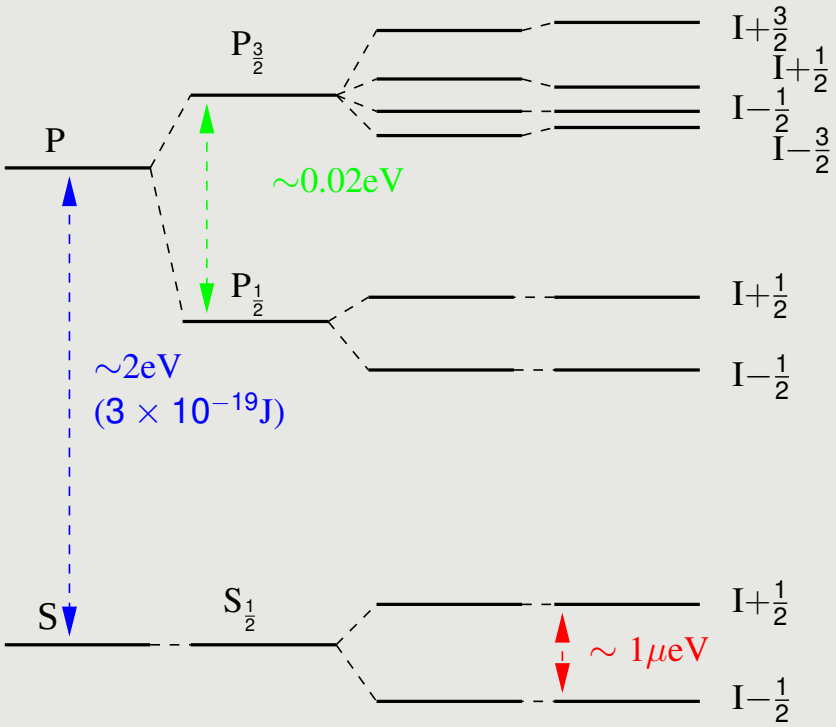
(a) ^{8}Li (b) ^{11}Li



Q_{11}/Q_9	1.0775(12)
Q_9/Q_8	0.96675(9)

Voss et al. J. Phys. G. **41** 015104 (2014)

Atomic Hyperfine structure



Harmonic Oscillator | L+S | Magnetic dipole interaction + electric quadrupole interaction

$$\Delta E_{hfs} = A\frac{K}{2} + B\frac{\frac{3}{2}K(K+1) - 2I(I+1)J(J+1)}{4I(2I-1)J(2J-1)}$$

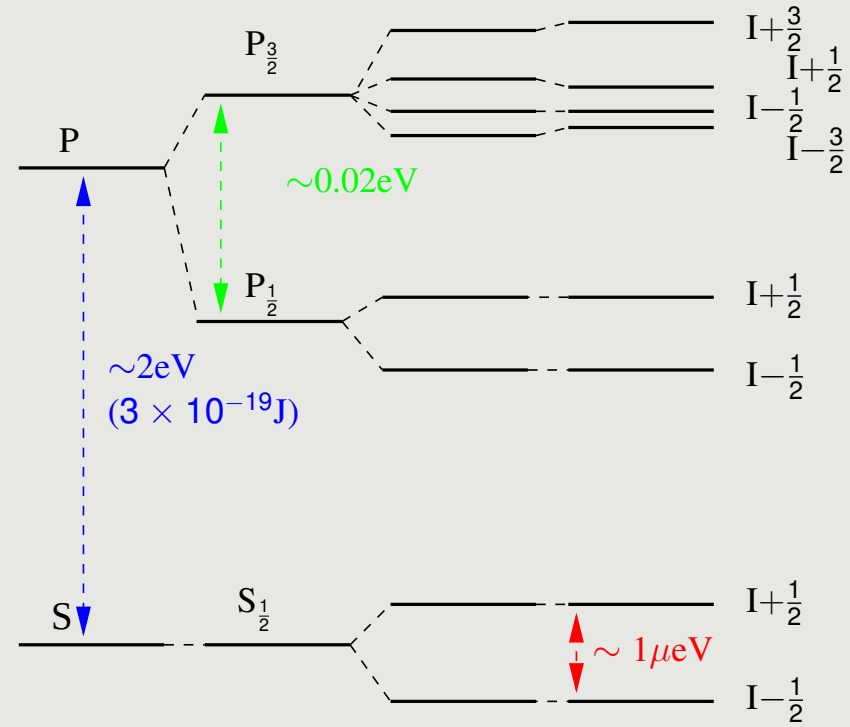
$$K = F(F+1) - J(J+1) - I(I+1)$$

$$A = \mu_N g_I \frac{B_{el}}{J} \qquad B = eQ_s\langle\frac{\delta^2 V}{\delta z^2}\rangle$$

A photon has angular momentum 1 therefore can induce

transitions $\Delta F = 0, \pm 1$ (NOT $0 \rightarrow 0$)

Atomic Hyperfine structure



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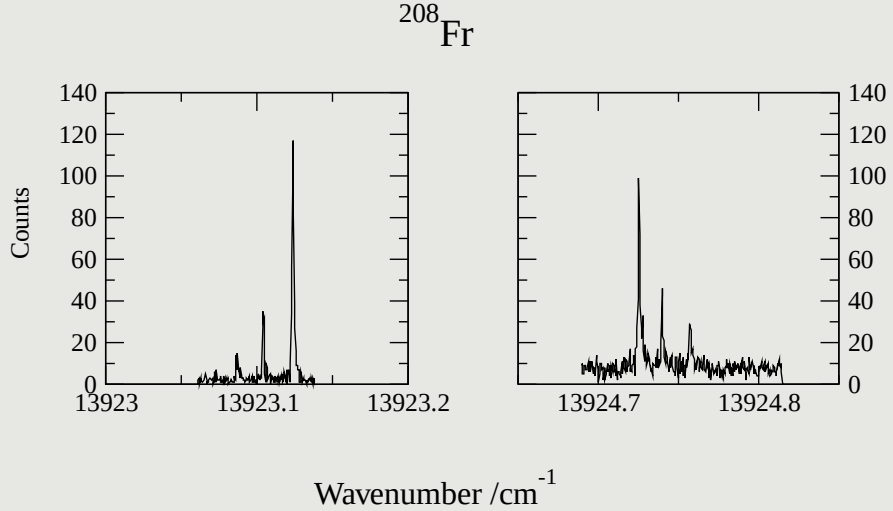
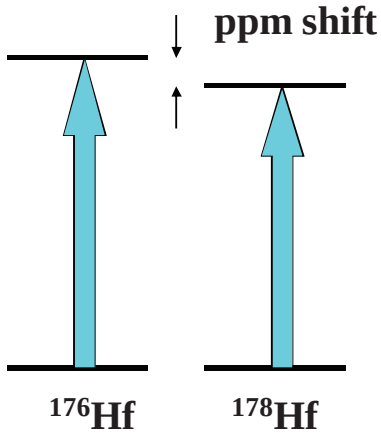


Isotope shift of an atomic transition



Two components: mass shift (nuclear recoil) and *volume shift*

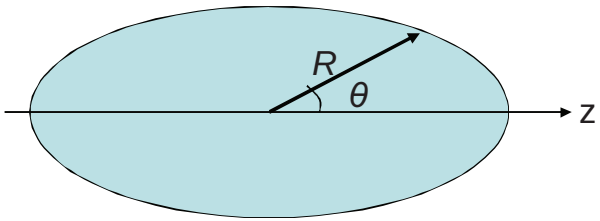
Analysis of *volume shift* yields the change in nuclear mean square charge radius, $\delta\langle r^2\rangle$

Nuclear size, deformation

$$\delta\langle r^2\rangle = \delta\langle r^2\rangle_{\mathrm{sph}} + \langle r^2\rangle_{\mathrm{sph}} \frac{5}{4\pi} \delta\langle \beta_2^2\rangle$$

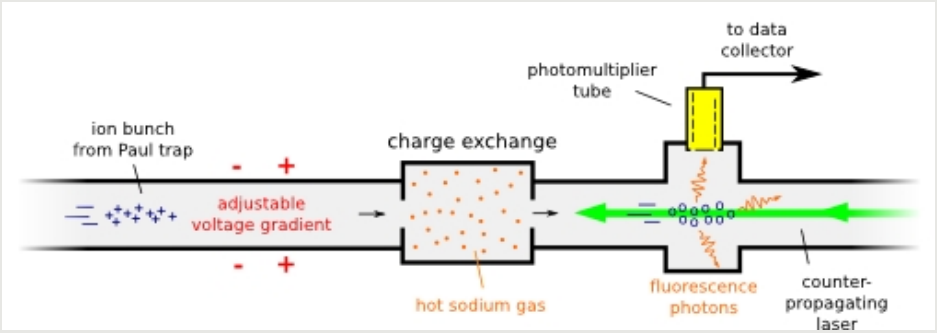
volume

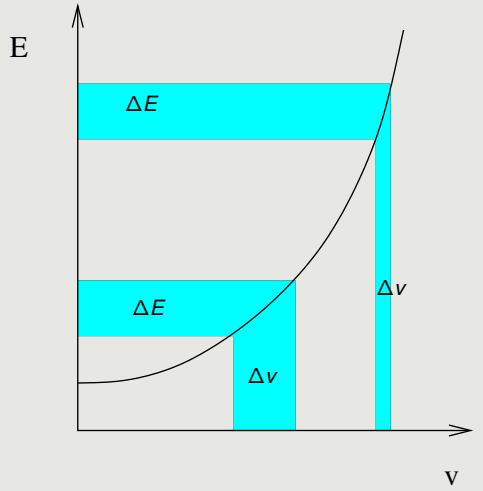
dynamic deformation



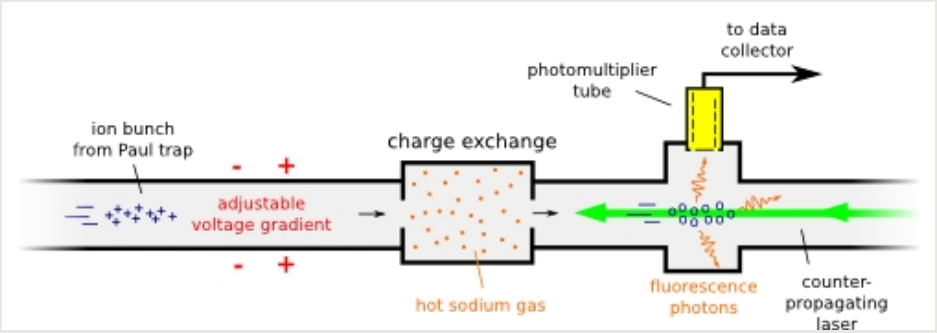
$R = R_0 (1 + \beta_2 Y_{2,0} (\theta,\varphi))$

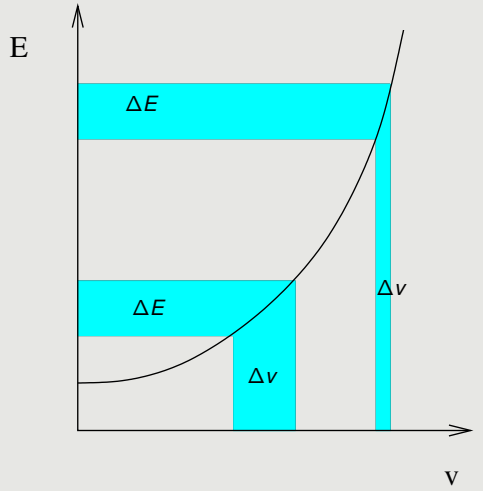
Collinear fast beam spectroscopy

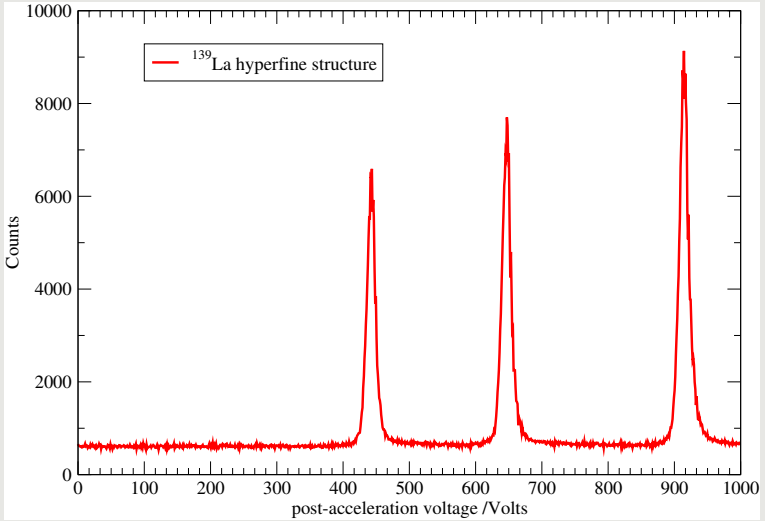




Collinear fast beam spectroscopy

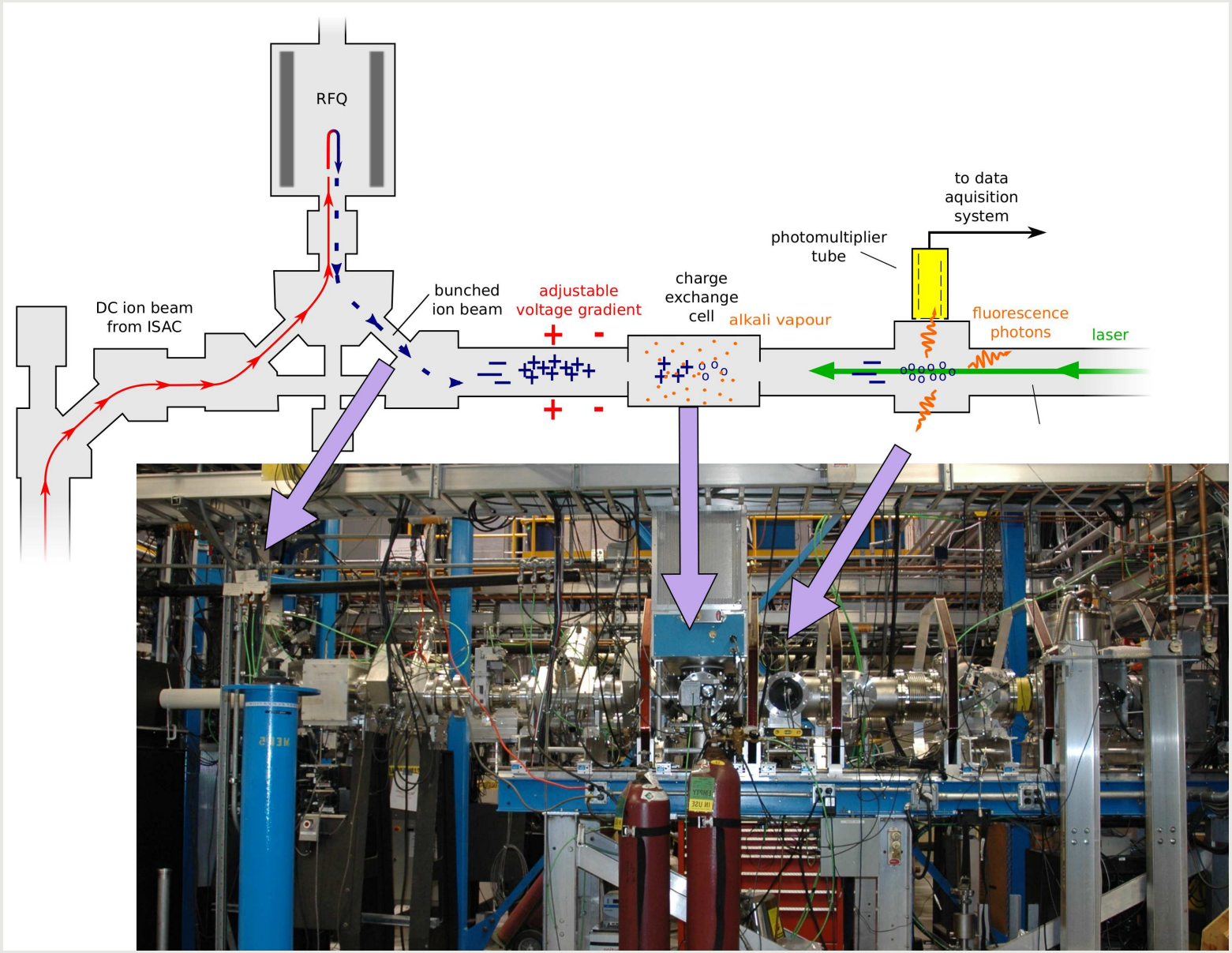




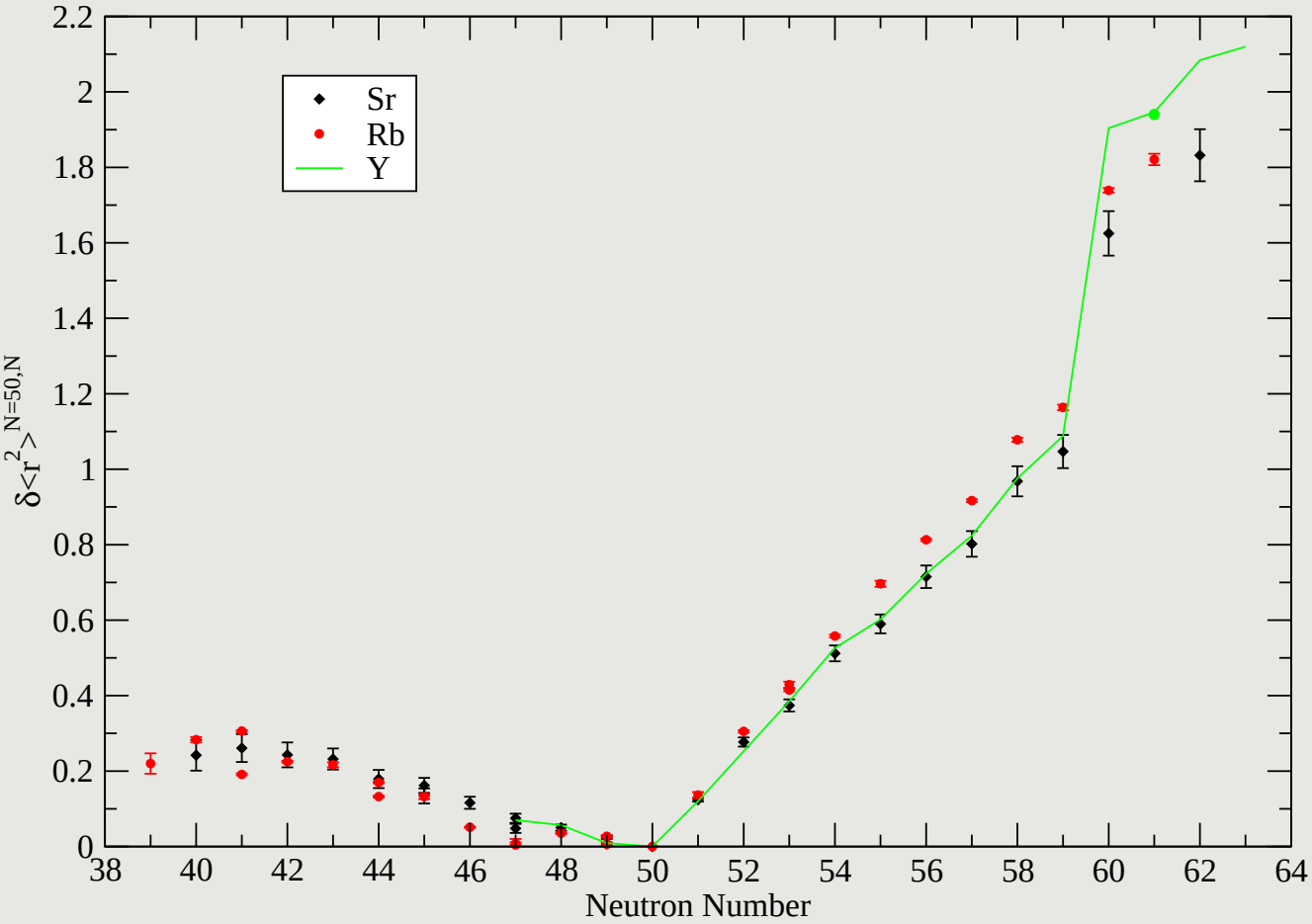


Peak width $\sim$ 50MHz, Doppler width $\sim$1,000MHz

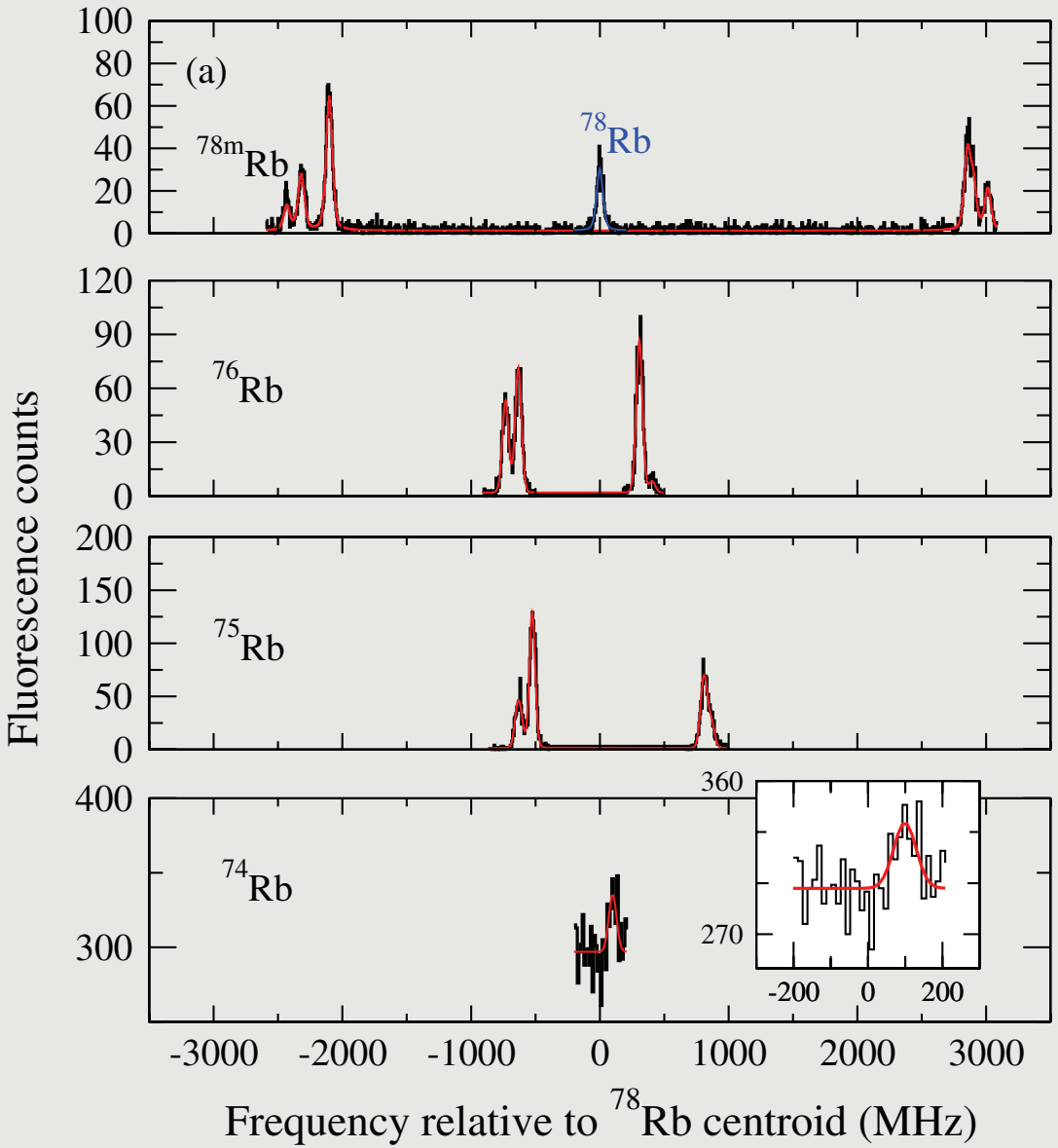
What it looks like



Rb isotopic chain

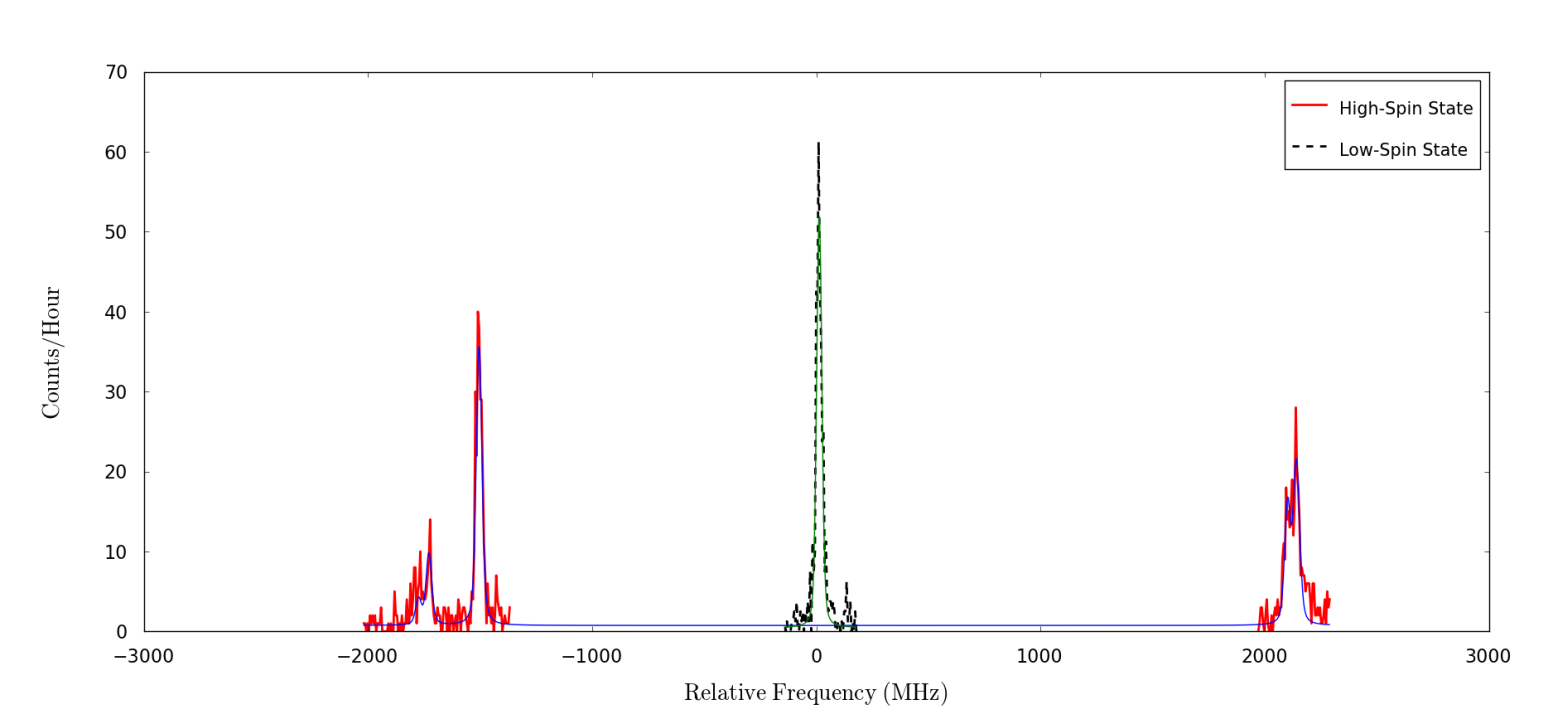


light Rb Data

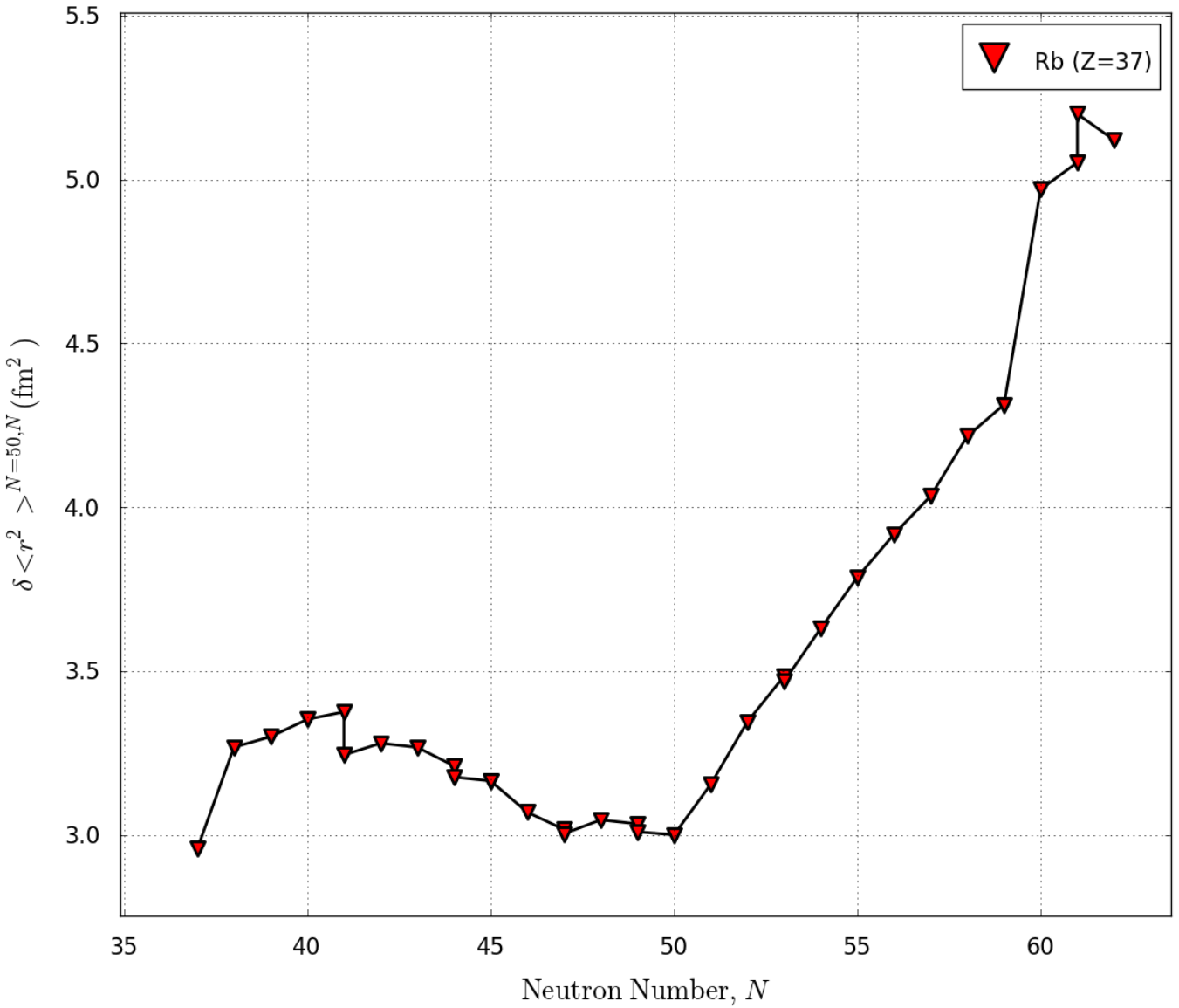


PRL **107** 212502 (2011)

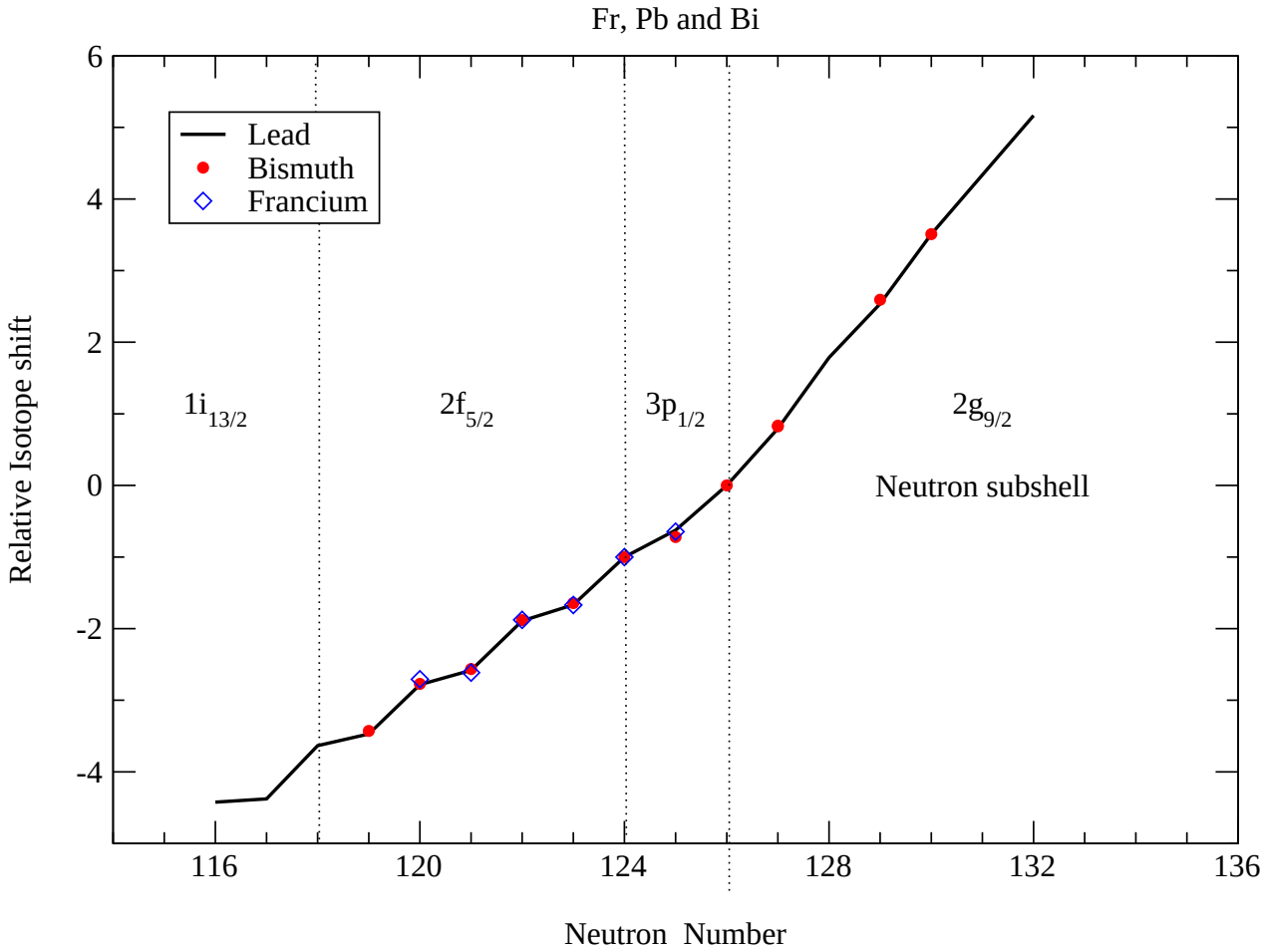
^{98}Rb Data

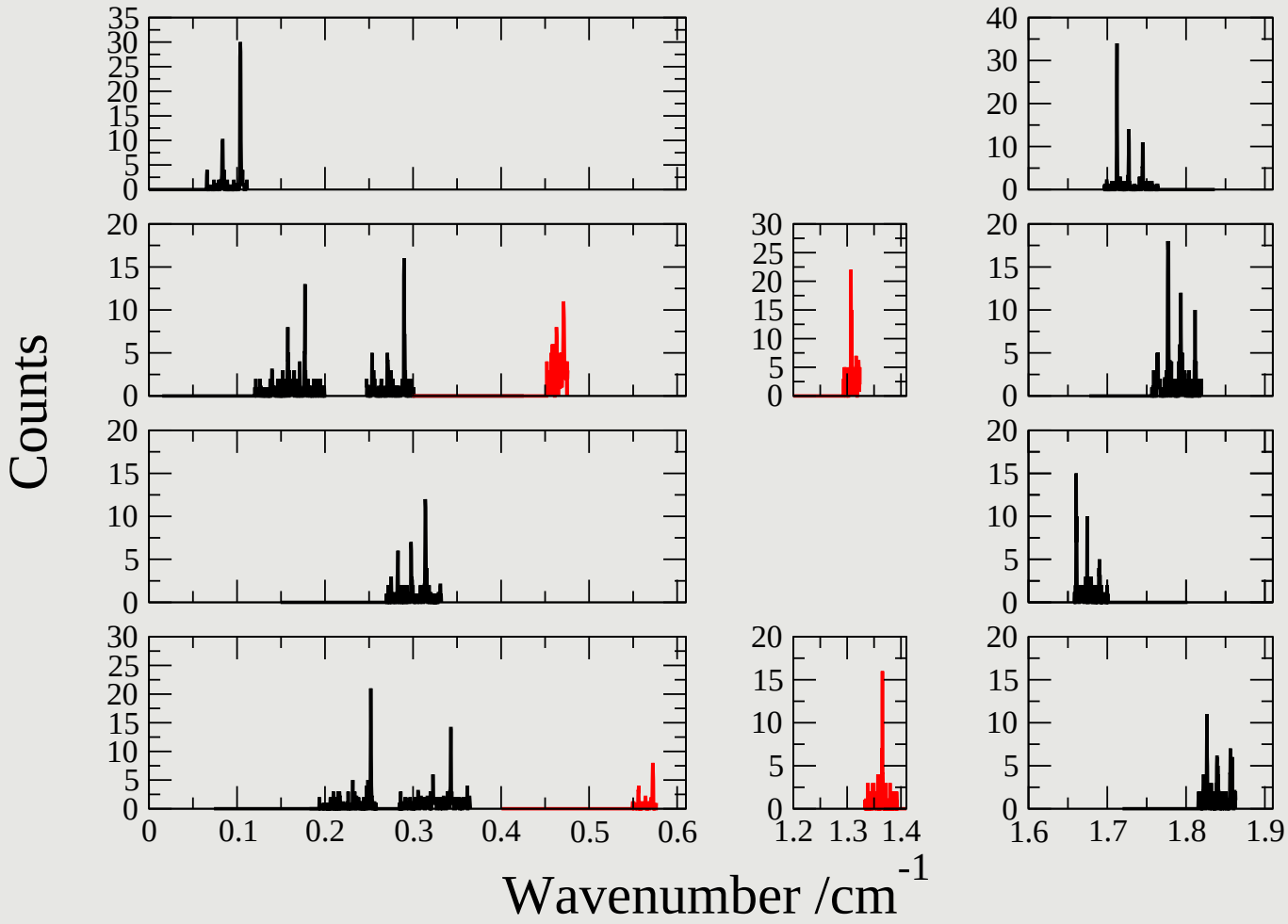

High-Spin State
Low-Spin State
Counts/Hour
Relative Frequency (MHz)
70
60
50
40
30
20
10
0
−3000
−2000
−1000
0
1000
2000
3000

What does it mean?

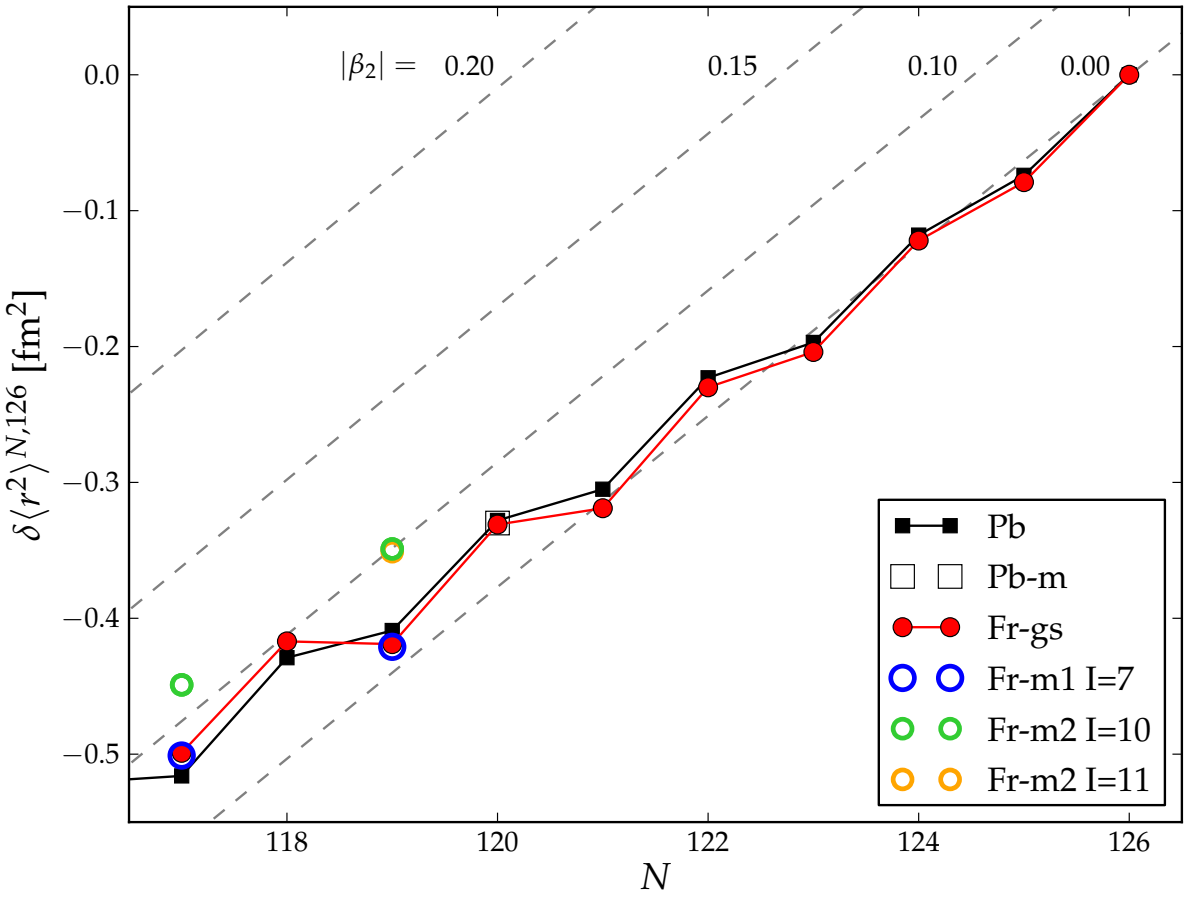


LIGHT Francium isotopes

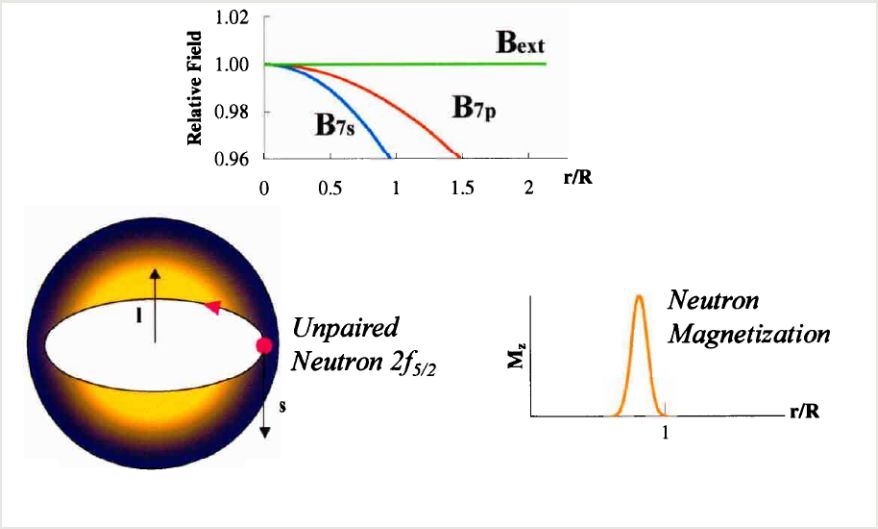


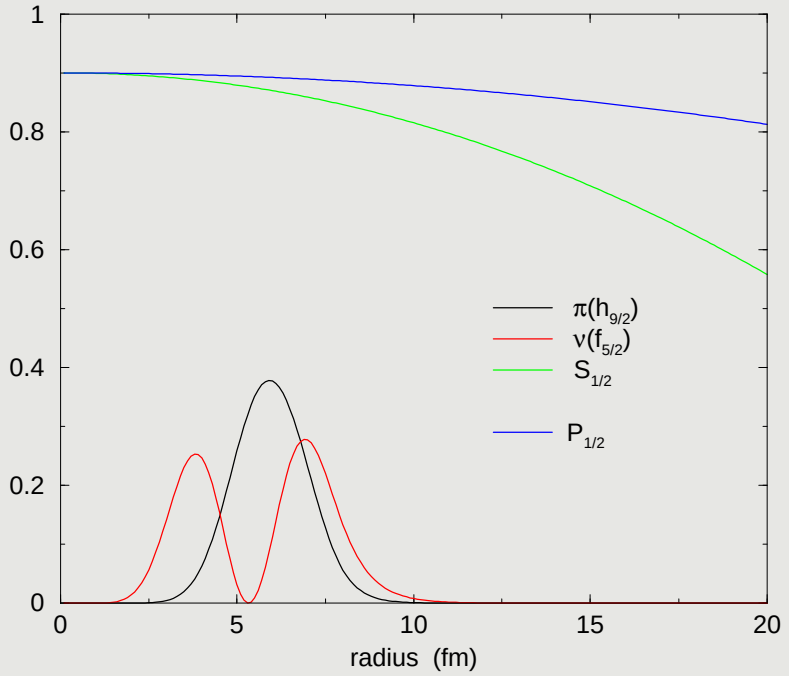

Counts
Wavenumber /cm-1

PRELIMINARY deformations



Bohr Weißkopf effect





$$A = A_{pt}(1+\epsilon)$$

$$\frac{A}{A'} = \frac{A_{pt}(1+\epsilon)}{A'_{pt}(1+\epsilon')} \approx \frac{A_{pt}}{A'_{pt}}(1+\epsilon-\epsilon') = \frac{A_{pt}}{A'_{pt}}(1+\Delta)$$

Bohr Weißkopf effect

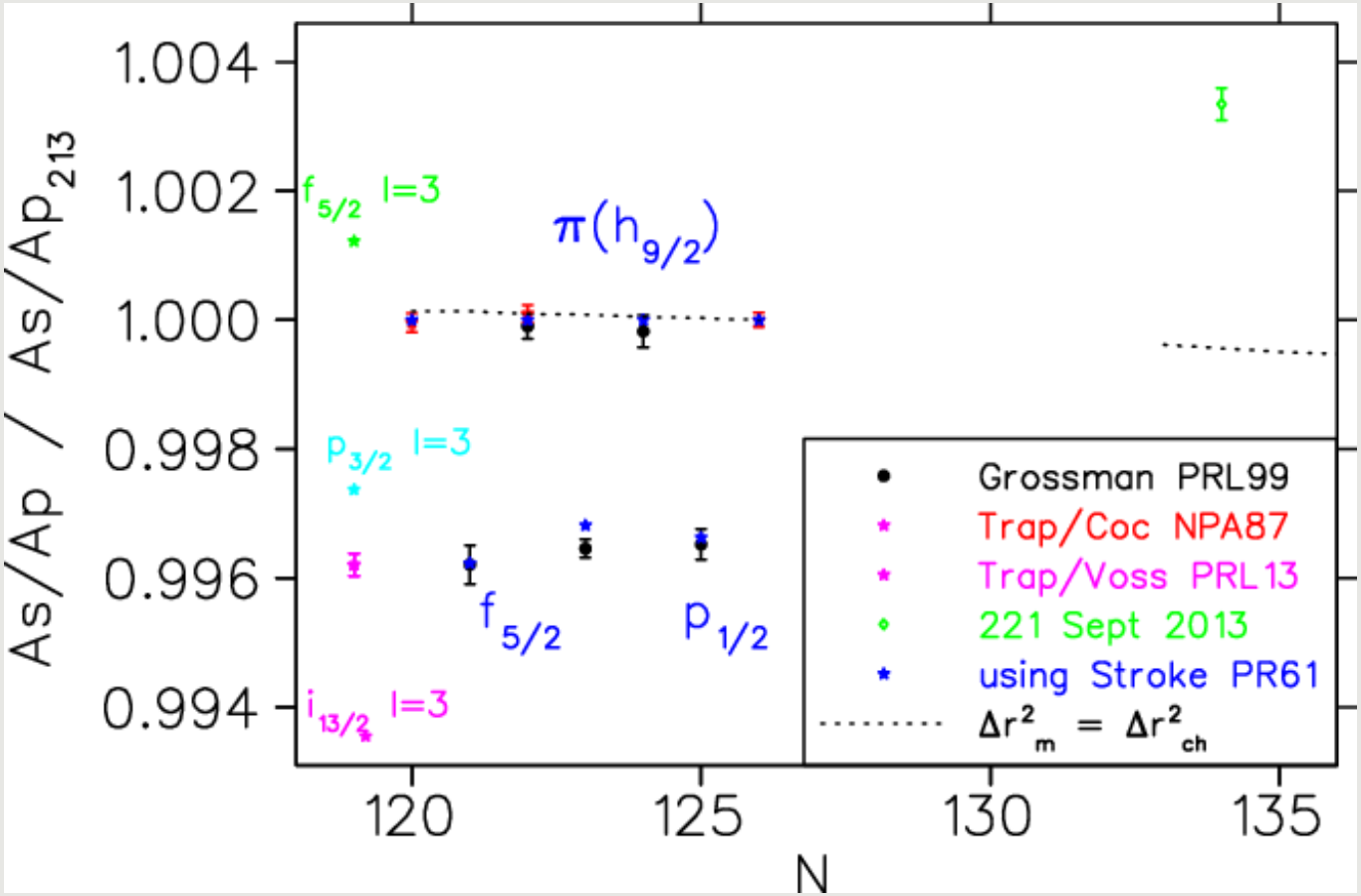


Figure courtesy of J.A. Behr

Future plans

- β-NQR on heavy Mg isotopes out to at least ^{33}Mg
- Laser spectroscopy on neutron rich AL isotopes to investigate deformation and possible isomers in the island of inversion
- RMS charge radius of ^{62}Ga for TRIUMF's super allowed β-decay programme
- Investigation of highly deformed states in neutron deficient Y and Sr isotopes
- Evolution of the shell structure in neutron rich Ca isotopes

Collaborating institutions

Canada

- TRIUMF
- University of British Columbia
- McGill University
- University of Manitoba

Rest of America

- University of Maryland
- William and Mary
- Stony Brook University
- San Luis Potosi

Europe

- University of Jyväskylä
- University of Liverpool
- The University of Manchester