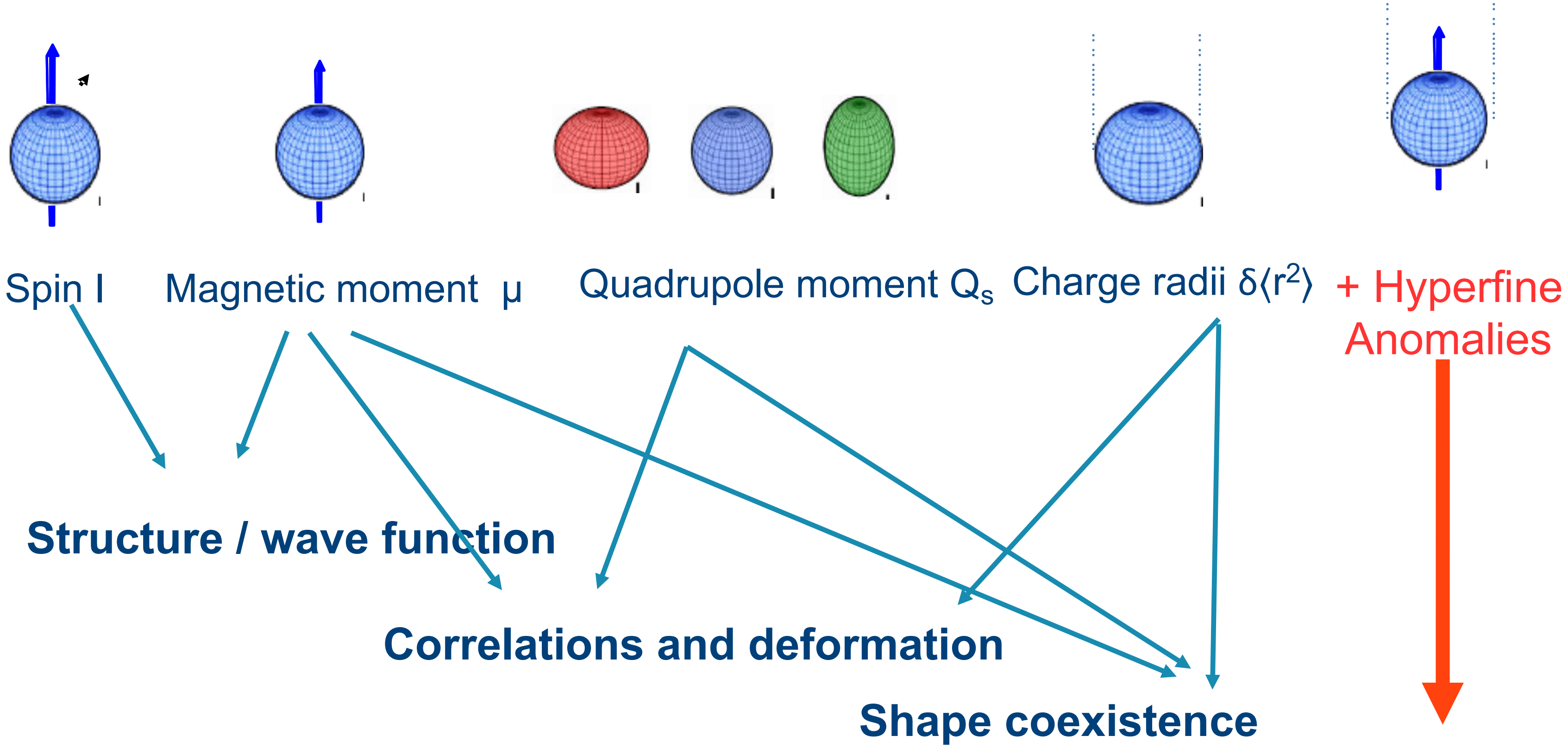
ISOLDE

Nuclear moments of Bismuth

MANCHESTER
1824
The University of Manchester

CERN

Laser Spectroscopy Observables



Spin I

Spin I

Magnetic moment μ

Quadrupole moment Q_s

Charge radii $\delta\langle r^2\rangle$

+ Hyperfine Anomalies

Structure / wave function

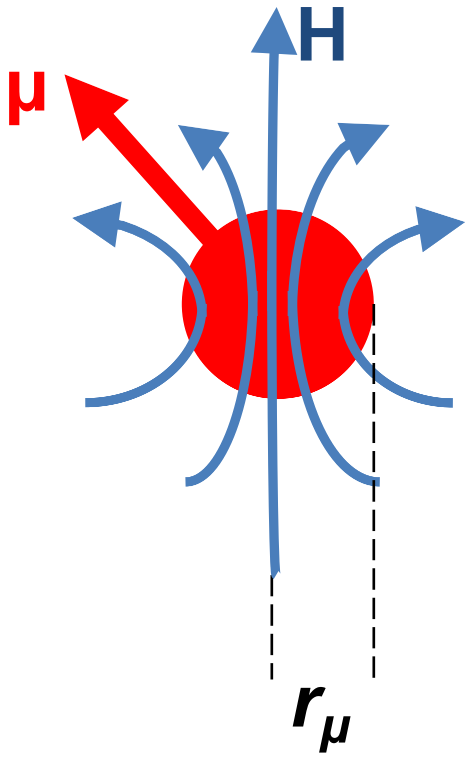
Correlations and deformation

Shape coexistence

Nuclear Magnetization Radius

What is the the Hyperfine Anomaly?

2. The Bohr-Weisskopf effect: Extended nuclear magnetization.



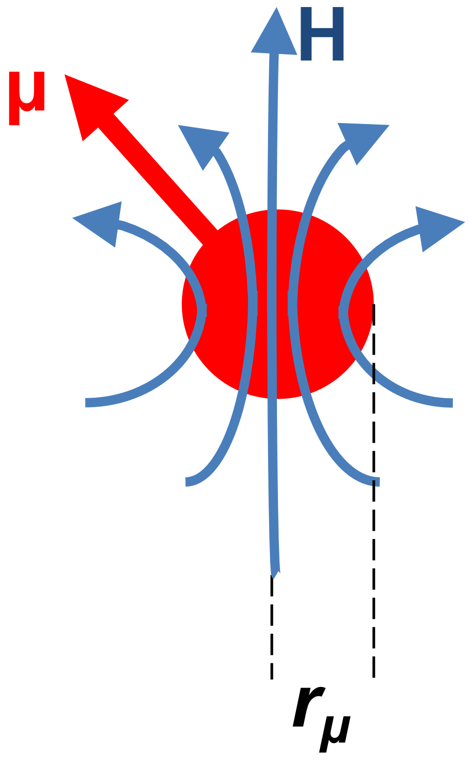
$$\int_0^{r_\mu} \mu(r) \cdot H(r)\, dr$$

r_μ : 1) *Only unpaired nucleons contribute.*

2) *Both protons and neutrons contribute on an equal footing.*

What is the the Hyperfine Anomaly?

2. The Bohr-Weisskopf effect: Spin and angular nuclear magnetization.

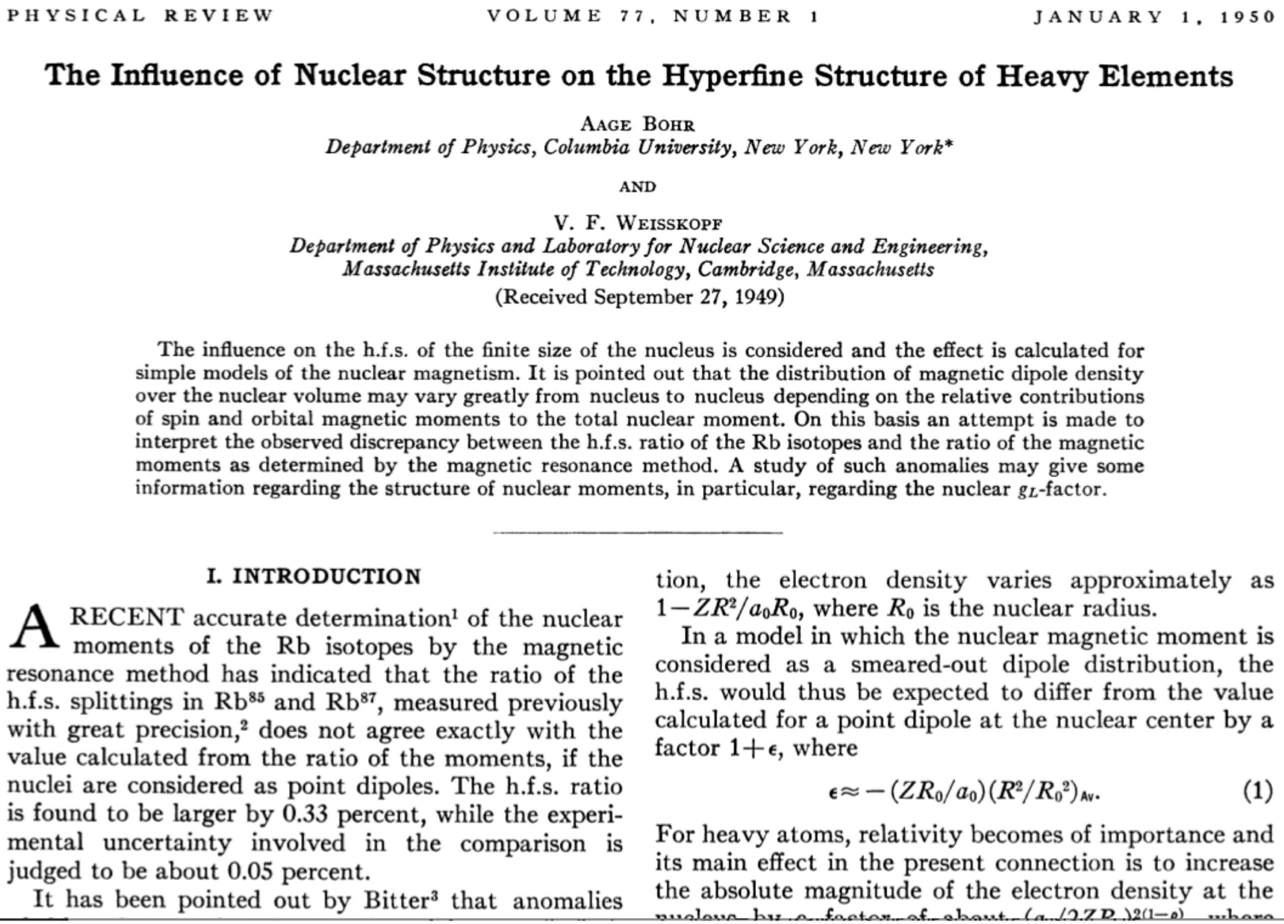


- *Nuclear magnetization from spin results in a larger HFA than that from orbital angular momentum.*
- *In the case of opposing spin and orbital contributions (p1/2 ,d3/2 etc)* $\boldsymbol{\mu} \rightarrow 0$ *and the HFA* → ∞.

  N. Stone, Journal de Physique Colloques **34** 69 (1973)
- μ_s and μ_L are therefore experimental observables!

$$\int_0^{r_\mu} \mu_s(r)\cdot H(r)\,dr + \int_0^{r_\mu} \mu_L(rL)\cdot \overline{H}(r < rL)\,dr$$

The Hyperfine Anomaly



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The Influence of Nuclear Structure on the Hyperfine Structure of Heavy Elements

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(Received September 27, 1949)

The influence on the h.f.s. of the finite size of the nucleus is considered and the effect is calculated for simple models of the nuclear magnetism. It is pointed out that the distribution of magnetic dipole density over the nuclear volume may vary greatly from nucleus to nucleus depending on the relative contributions of spin and orbital magnetic moments to the total nuclear moment. On this basis an attempt is made to interpret the observed discrepancy between the h.f.s. ratio of the Rb isotopes and the ratio of the magnetic moments as determined by the magnetic resonance method. A study of such anomalies may give some information regarding the structure of nuclear moments, in particular, regarding the nuclear g_L-factor.

I. INTRODUCTION

A RECENT accurate determination[1] of the nuclear moments of the Rb isotopes by the magnetic resonance method has indicated that the ratio of the h.f.s. splittings in Rb^{85} and Rb^{87}, measured previously with great precision,[2] does not agree exactly with the value calculated from the ratio of the moments, if the nuclei are considered as point dipoles. The h.f.s. ratio is found to be larger by 0.33 percent, while the experimental uncertainty involved in the comparison is judged to be about 0.05 percent.

It has been pointed out by Bitter[3] that anomalies

tion, the electron density varies approximately as $1-ZR^2/a_0R_0$, where R_0 is the nuclear radius.

In a model in which the nuclear magnetic moment is considered as a smeared-out dipole distribution, the h.f.s. would thus be expected to differ from the value calculated for a point dipole at the nuclear center by a factor $1+\epsilon$, where

$$\epsilon \approx -(ZR_0/a_0)(R^2/R_0^2)_{\mathrm{Av}}. \qquad (1)$$

For heavy atoms, relativity becomes of importance and its main effect in the present connection is to increase the absolute magnitude of the electron density at the

$$\epsilon = -[(1+0.38\zeta)\alpha_s + 0.62\alpha_L]b(Z,R_0)(R/R_0)^2$$

The Hyperfine Anomaly

$$\epsilon = -[(1 + 0.38\zeta)\alpha_s + 0.62\alpha_L] b(Z, R_0)(R/R_0)^2$$

The extreme single particle model:

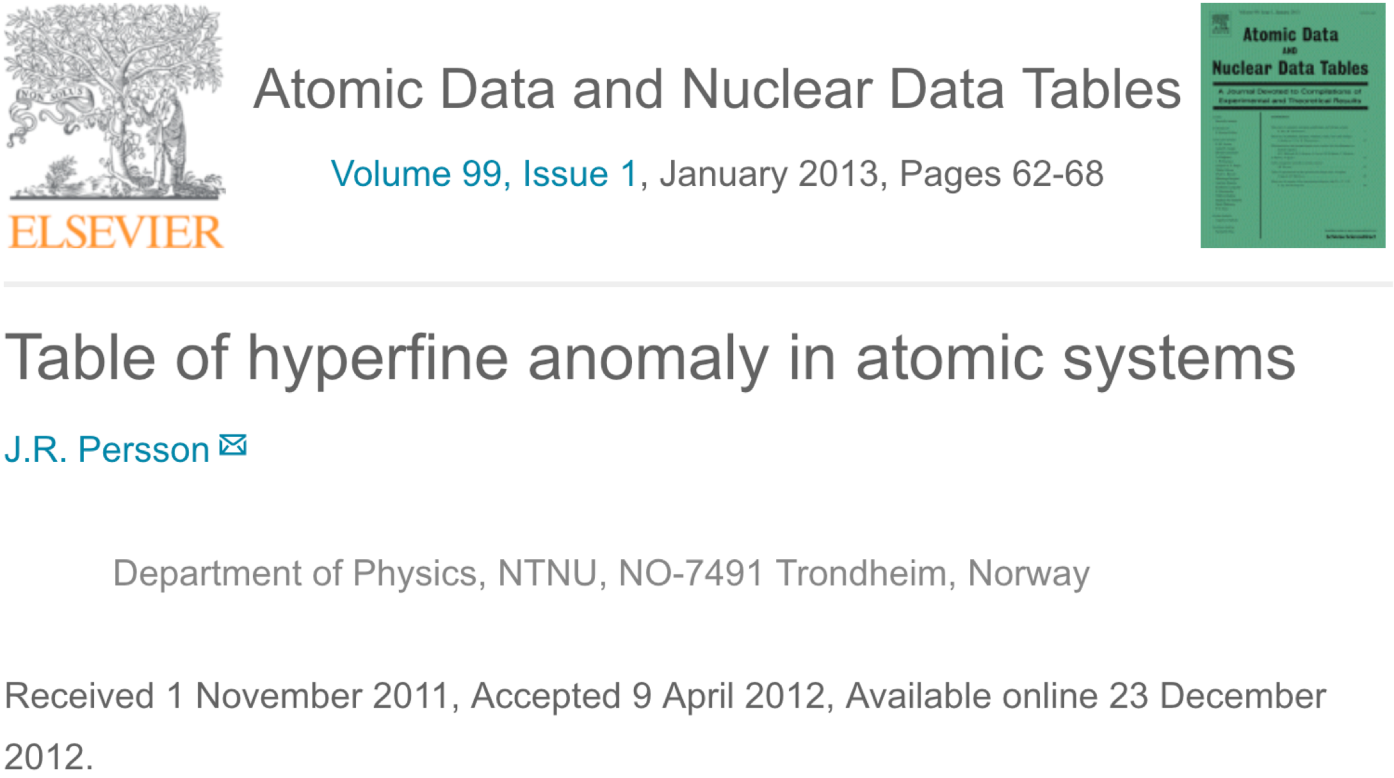
$\alpha_s = (g_s/g_I)(g_I - g_L)/(g_s - g_l)$ $\alpha_L = 1 - \alpha_s$

$\zeta = (2I-1)/4(I+1)$: $I = L + 1/2$
$\zeta = (2I+1)/4(I+2)$: $I = L - 1/2$

$\epsilon_{BW} = \epsilon_\pi \beta_\pi + \epsilon_\nu \beta_\nu$ odd-odd

A simple model, but illustrates the different dependence on gl and gs.

Previous Work



Atomic Data and Nuclear Data Tables

Volume 99, Issue 1, January 2013, Pages 62-68

Table of hyperfine anomaly in atomic systems

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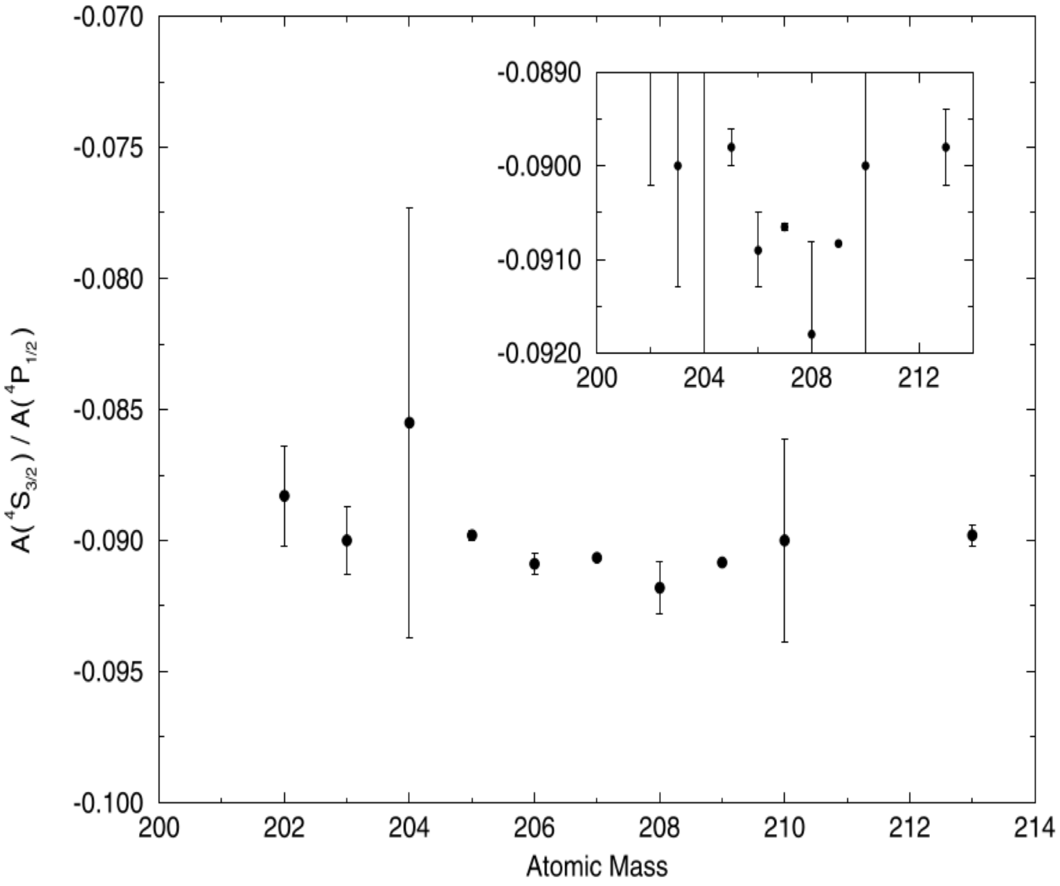
Received 1 November 2011, Accepted 9 April 2012, Available online 23 December 2012.

With only a couple of notable exceptions only the stable isotopes are known….

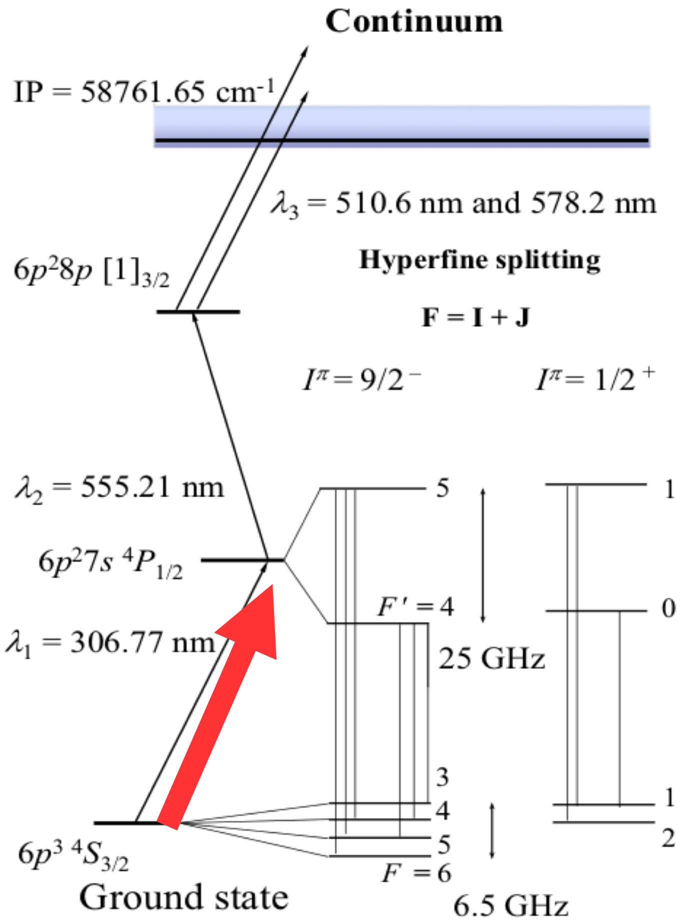
Hyperfine Anomalies in Bi?



J. Phys. G: Nucl. Part. Phys. **26** (2000) 1829–1848. Printed in the UK PII: S0954-3899(00)16812-4

Large HF anomaly between ^{205}Bi and ^{209}Bi.

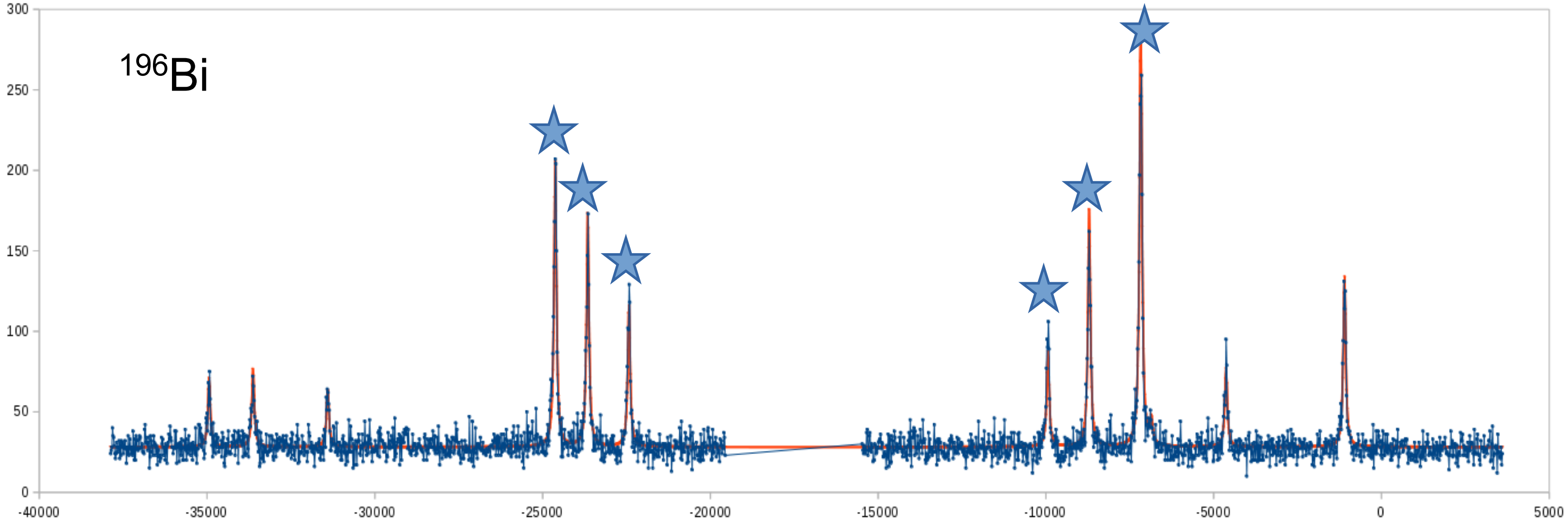
The Laser Scheme



PHYSICAL REVIEW C **94**, 024334 (2016)

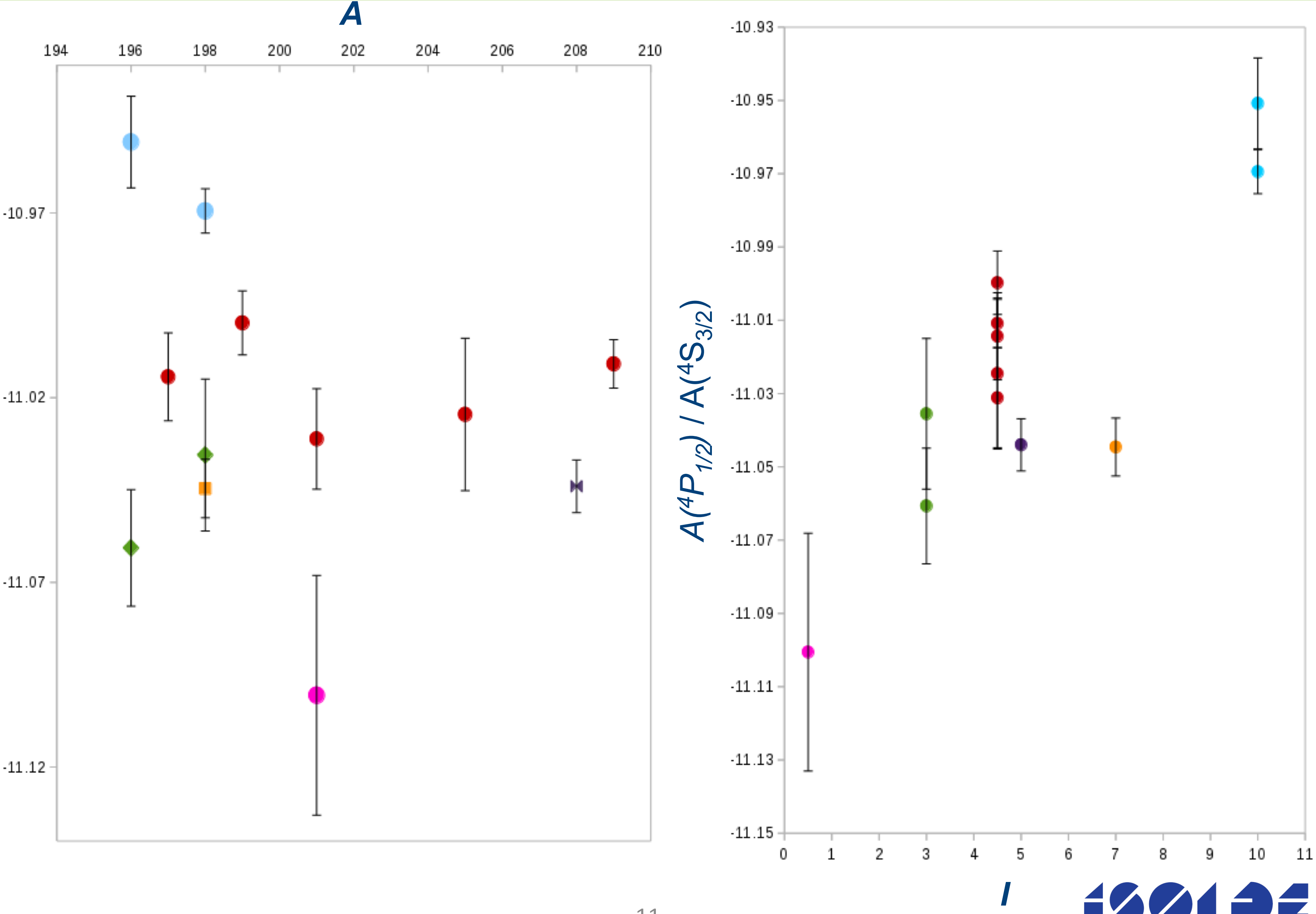
- GS transition selected to provide maximum information for in-source spectroscopy.
- Very poorly populated in the charge exchange process.

Results

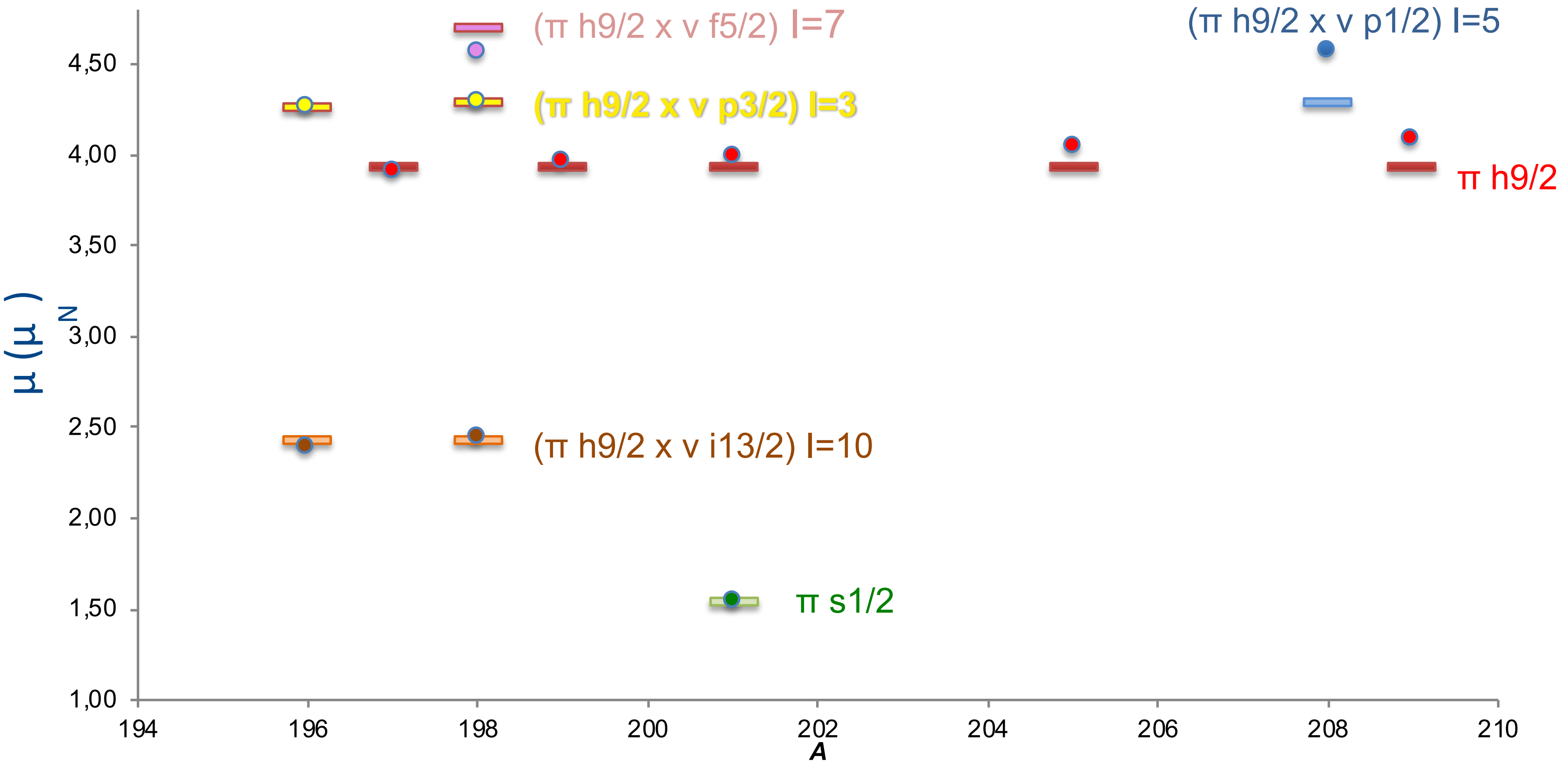


Measurements of a similar quality obtained for- 209,208,205,201,199,198,197Bi.

The Ratio of A factors

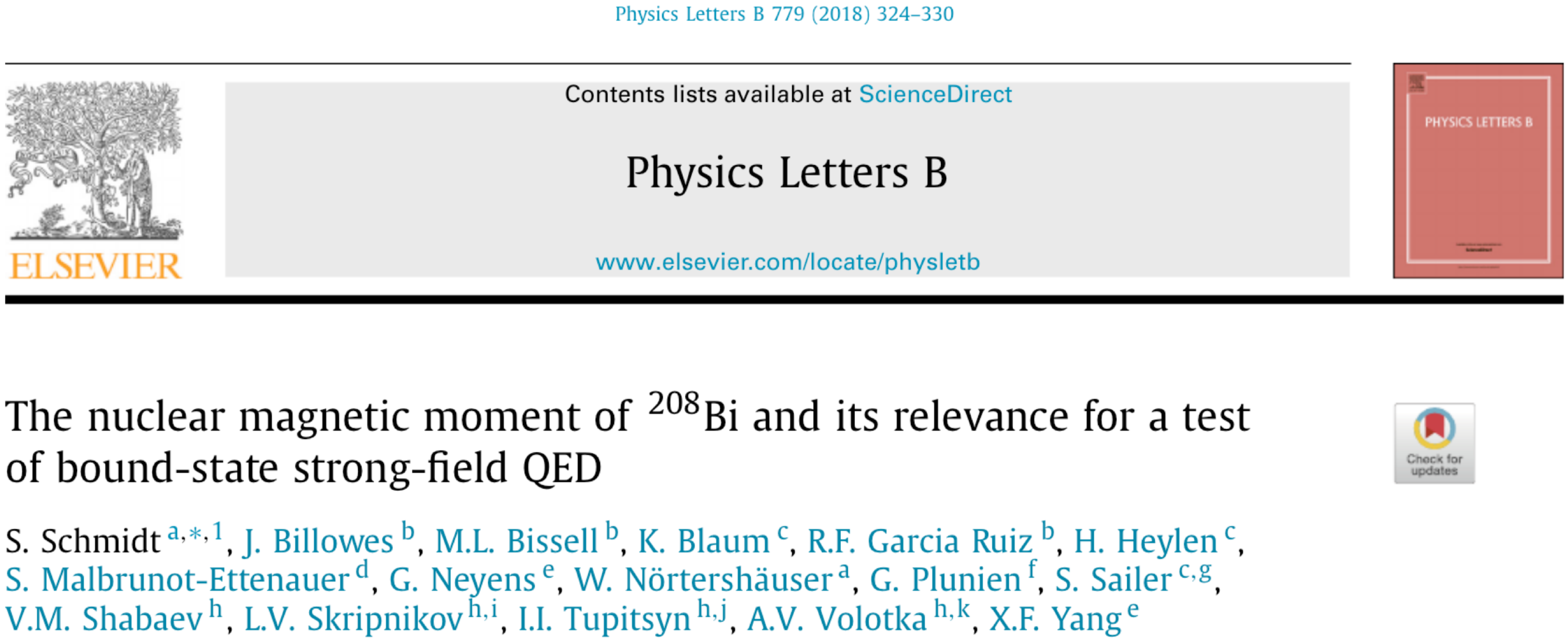


Defining the effective g factors



Proton gs =3,089, Neutron gs= -2,116
Proton gl = 1.06

^{208}Bi



Physics Letters B 779 (2018) 324–330

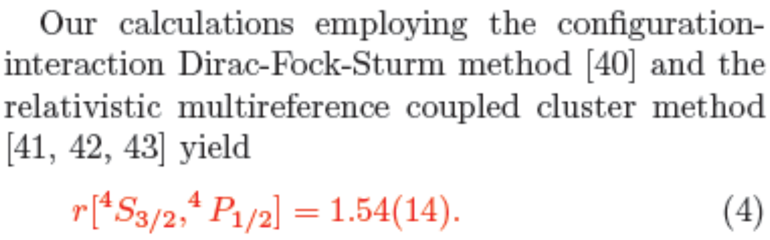
Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

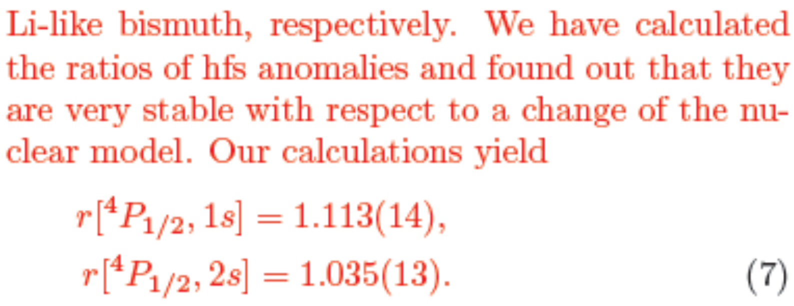
The nuclear magnetic moment of ^{208}Bi and its relevance for a test of bound-state strong-field QED

S. Schmidt [a,*,1], J. Billowes [b], M.L. Bissell [b], K. Blaum [c], R.F. Garcia Ruiz [b], H. Heylen [c], S. Malbrunot-Ettenauer [d], G. Neyens [e], W. Nörtershäuser [a], G. Plunien [f], S. Sailer [c,g], V.M. Shabaev [h], L.V. Skripnikov [h,i], I.I. Tupitsyn [h,j], A.V. Volotka [h,k], X.F. Yang [e]



Our calculations employing the configuration-interaction Dirac-Fock-Sturm method [40] and the relativistic multireference coupled cluster method [41, 42, 43] yield

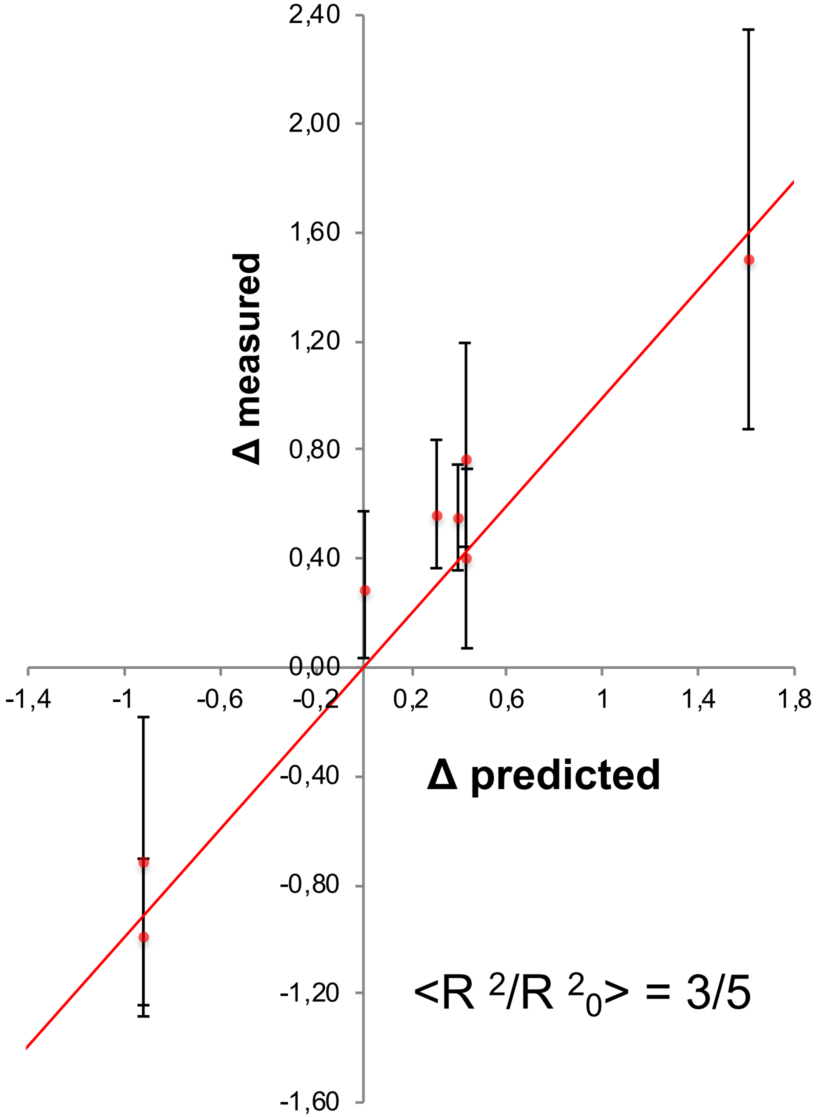
$$r[{}^4S_{3/2},{}^4P_{1/2}] = 1.54(14). \qquad (4)$$



Li-like bismuth, respectively. We have calculated the ratios of hfs anomalies and found out that they are very stable with respect to a change of the nuclear model. Our calculations yield

$$\begin{aligned} r[{}^4P_{1/2}, 1s] &= 1.113(14), \\ r[{}^4P_{1/2}, 2s] &= 1.035(13). \end{aligned} \qquad (7)$$

The Hyperfine Anomaly

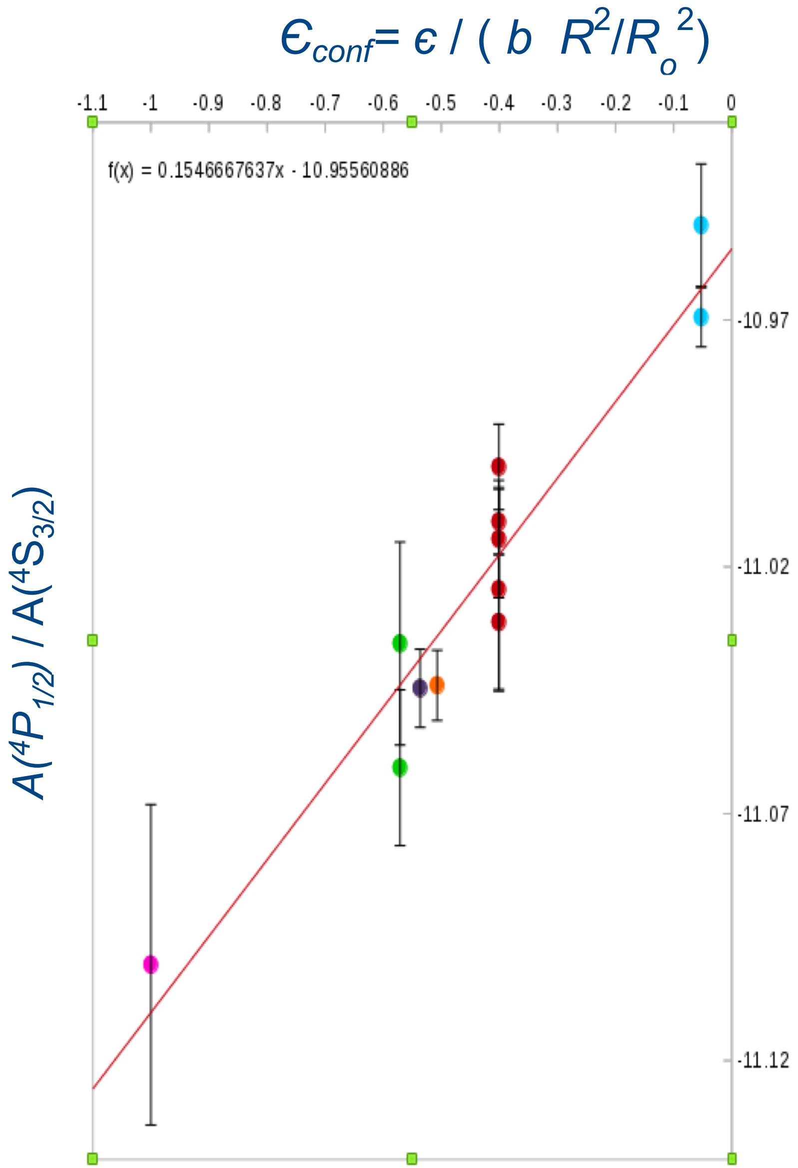


$\langle R^2/R^2_0 \rangle = 3/5$

Observed Hyperfine anomalies are reproduced perfectly when using the quenched g factors in the extreme single particle model.

Results completely consistent with a magnetization radius equal to the charge radius and further a uniform distribution of magnetization across the nucleus.

The Extreme Single Particle Model



$$R_\epsilon = \frac{\epsilon(S_{3/2})}{\epsilon(P_{1/2})} = 1.54(14)$$

$$R_A = \left(\frac{A(P_{1/2})}{A(S_{3/2})}\right) = R_{A_0} \frac{1 + \epsilon(P_{1/2})}{1 + R_\epsilon \varepsilon(P_{1/2})}$$

Neglecting terms $\sim\epsilon^2$

$$R_A \approx R_{A_0}(1 + \; (1 - R_\epsilon)\epsilon(P_{1/2}))$$

$$Intercept = R_{A_0}$$

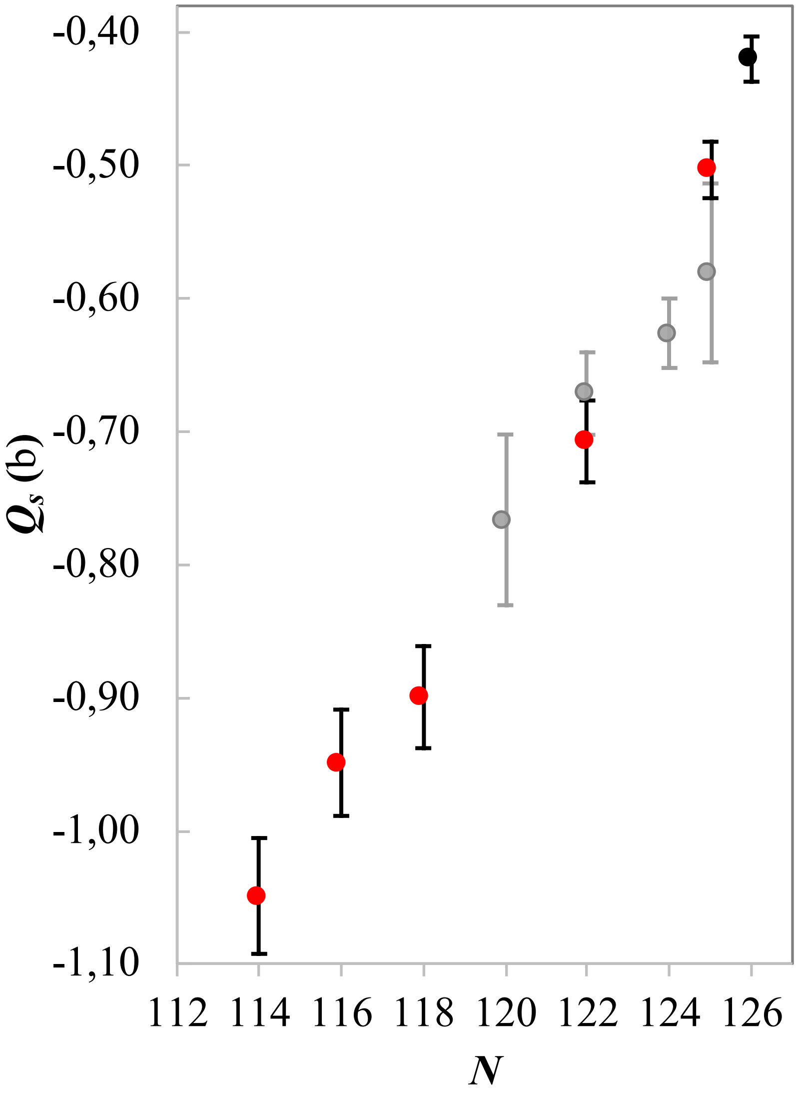
$$Gradient \;\approx R_{A_0} \; (1 - R_\epsilon) \, b(P_{1/2}) \left\langle \frac{R^2}{{R_0}^2} \right\rangle$$

With $\left\langle \frac{R^2}{{R_0}^2} \right\rangle = \frac{3}{5}$ (uniform distribution)

$$b(P_{1/2}) = 4.3\% \; giving \; b(\,^1s) = 3.89\%$$

cf. Bohr-Weisskopf (1950) b= 3.75%

Quadrupole moments of $\pi h_{9/2}$ states



Significant differences observed + few isotopes measured for the first time.

Interpretation of odd-odd Quadrupole moments ongoing.

Numbers

209Bi Au/Al = -11.012(7) → -11.012(8)
208Bi Au/Al = -11.045(8) → -11.045(9)
208Bi Al = -445.9(3) → -445.9(4)
208Bi B = -360.1(32) → -360.1(37)

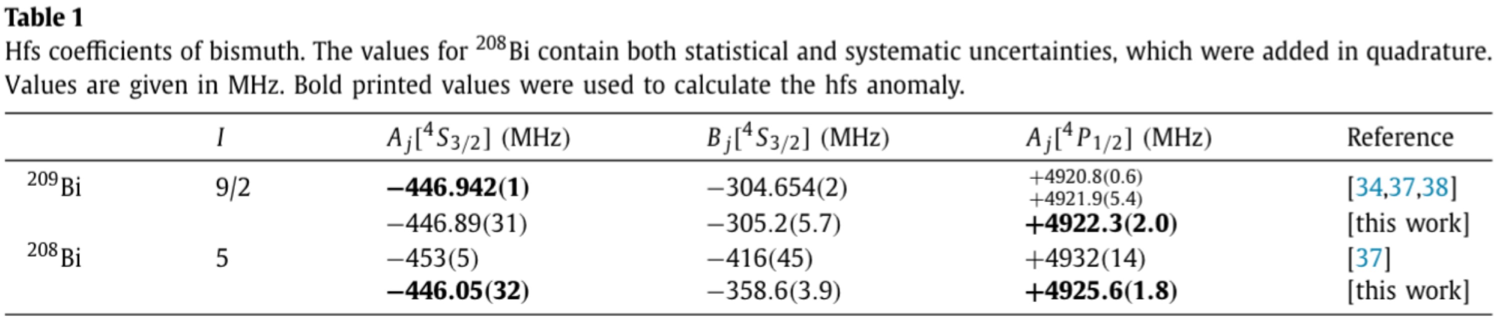


Table 1

Hfs coefficients of bismuth. The values for ^{208}Bi contain both statistical and systematic uncertainties, which were added in quadrature. Values are given in MHz. Bold printed values were used to calculate the hfs anomaly.

	I	$A_j[^4S_{3/2}]$ (MHz)	$B_j[^4S_{3/2}]$ (MHz)	$A_j[^4P_{1/2}]$ (MHz)	Reference
^{209}Bi	9/2	**−446.942(1)**	−304.654(2)	+4920.8(0.6) +4921.9(5.4)	[34,37,38]
		−446.89(31)	−305.2(5.7)	**+4922.3(2.0)**	[this work]
^{208}Bi	5	−453(5)	−416(45)	+4932(14)	[37]
		−446.05(32)	−358.6(3.9)	**+4925.6(1.8)**	[this work]

Conclusions and outlook

No major breakthrough observed, but some interesting effects.
PRC in preparation.

How to treat remaining discrepancies with previous publication?

\We have the immediate possibility to measure these effects with ~2 times resolution and 10 times sensitivity. Is this interesting enough?

Laser Spectroscopy of Bi

HFS scan using MR-TOF MS