In-source laser spectroscopy of Pb, Bi and Po isotopes at ISOLDE

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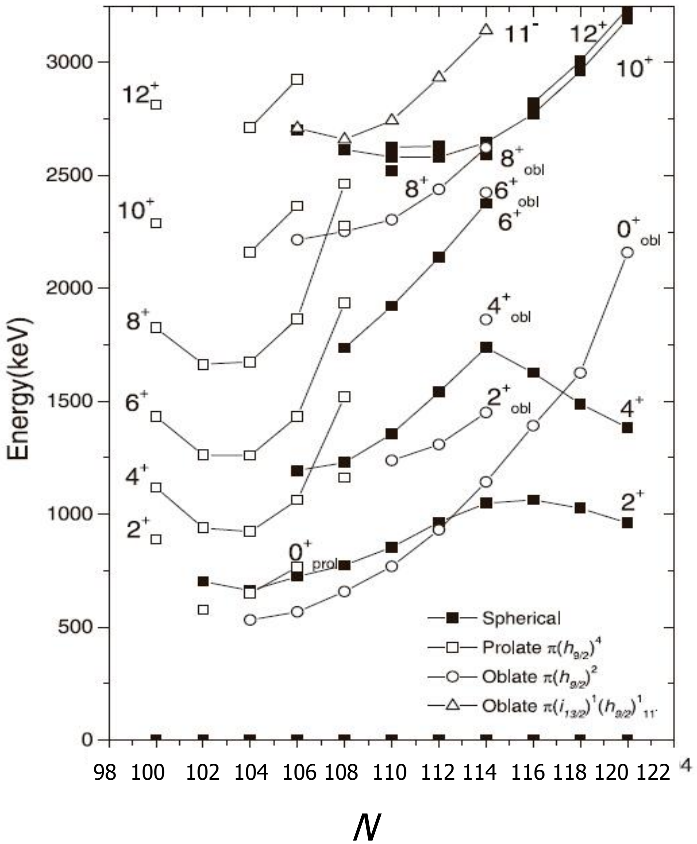
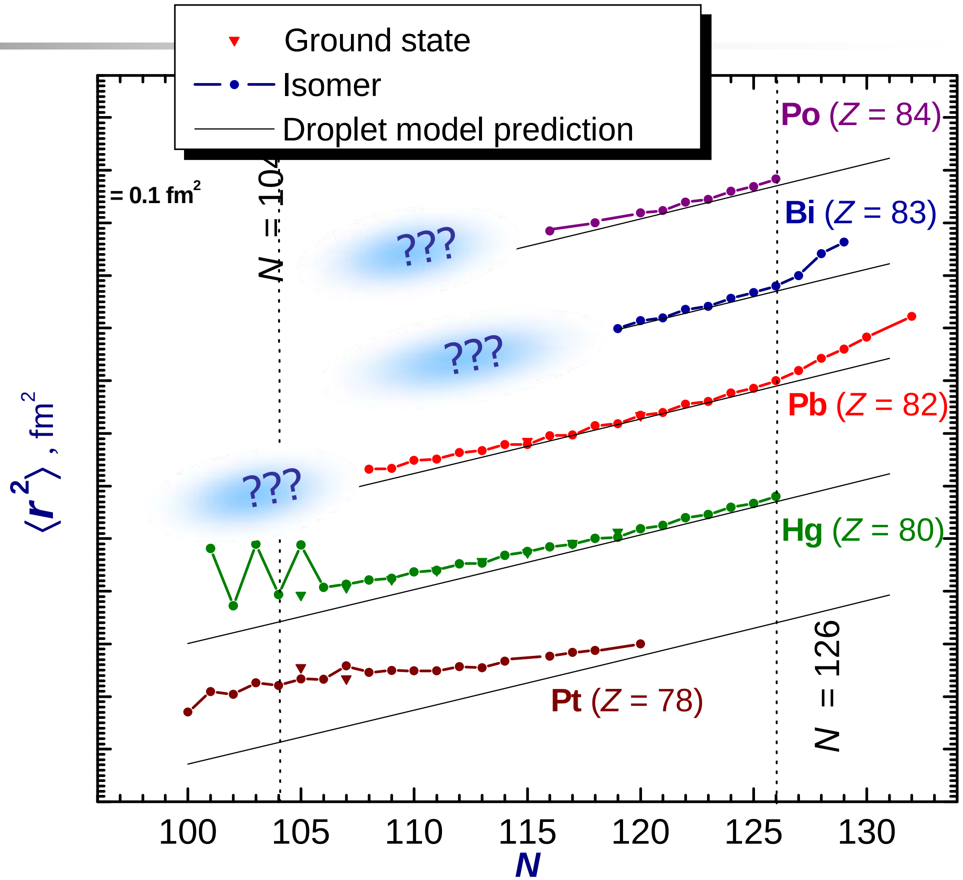
- Charge Radii around $Z = 82$ and $N = 104$
- In-source resonant photoionization spectroscopy at ISOLDE
- $^{182-190}$Pb: charge radii, magnetic moments...
- ^{189,191}Bi: isotope shifts and magnetic moments
- Po: photoionization schemes and yield tests
- Discussion and outlook

Charge radii below and above $Z = 82$

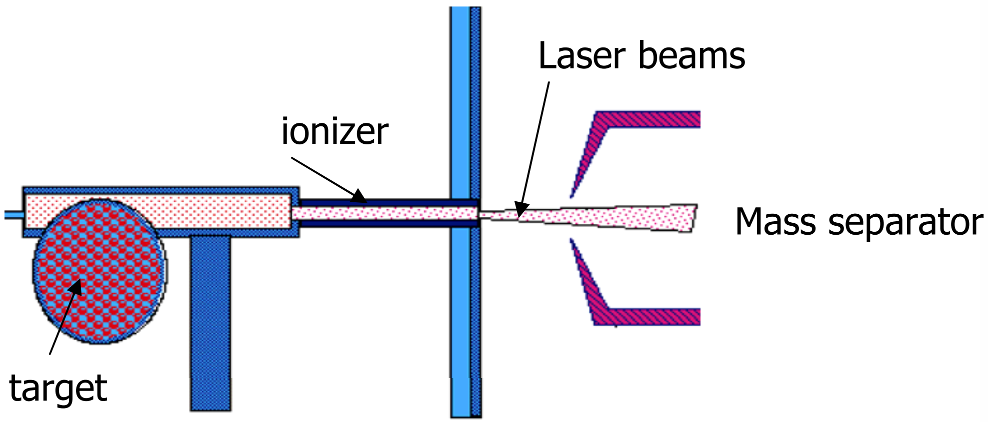


Level systematics for the neutron-deficient lead isotopes.
R. Julin et al., *J. Phys. G: Nucl. Part. Phys.* ***27*** *(2001)*

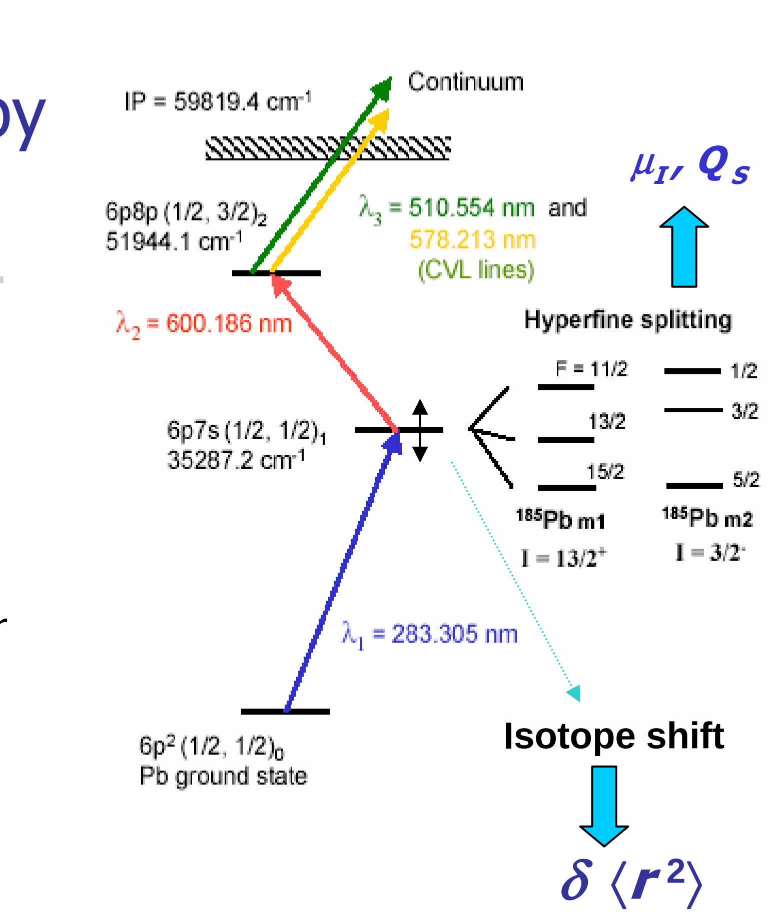


nuclear ground and isomeric state properties : $\boldsymbol{\delta}\langle \boldsymbol{r}^2 \rangle$

In-source resonant photoionization spectroscopy at ISOLDE



Laser Ion Source (LIS)



Procedure:

- measurement of radioactive Pb isotopes
- measurements of stable $^{206,207,208}Pb$
- reference measurements

Advantages:

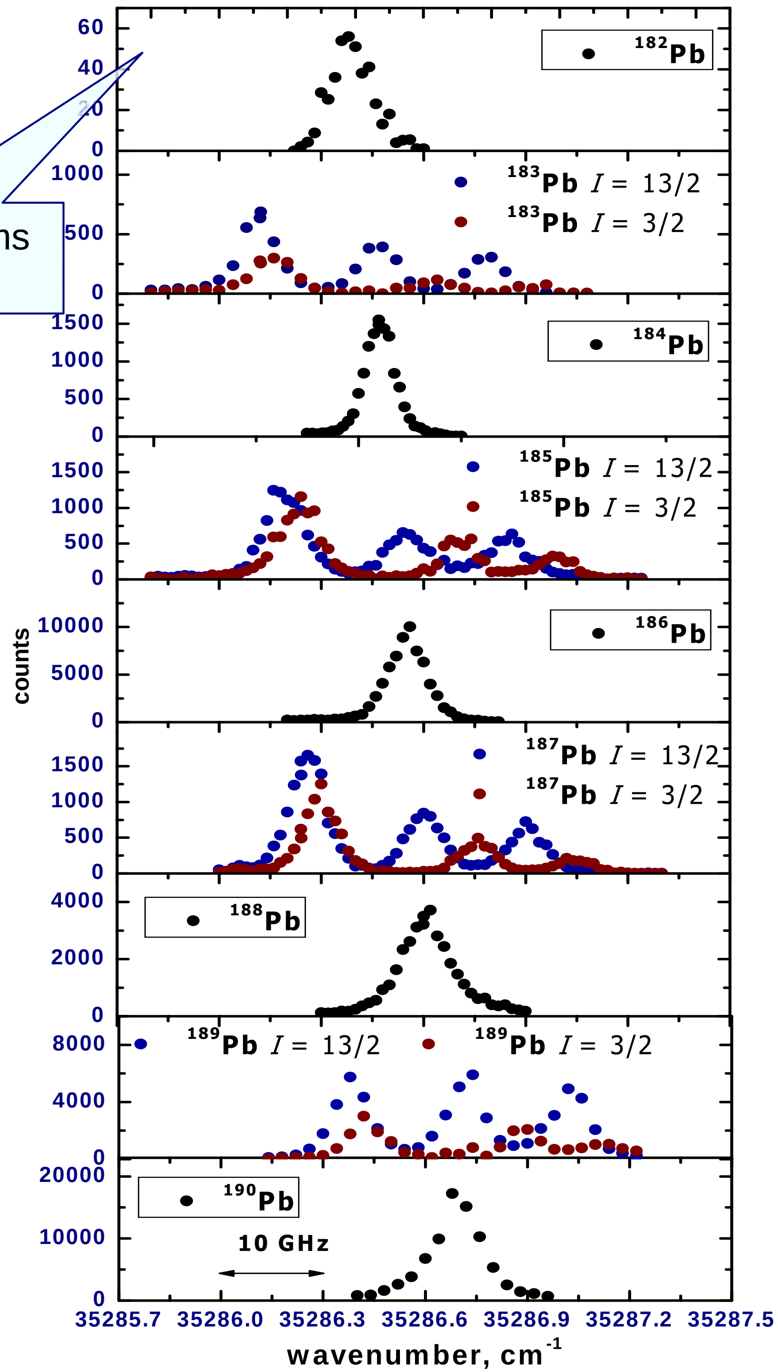
- sensitivity: e.g. ^{183}Pb 10 atoms/s at resonance

Limitation:

- large Doppler broadening

Pb: atomic spectroscopy

^{182}**Pb**: $T_{1/2}$= 55 ms
Yield: **~1 s^{-1}**



Isotope shift $\Delta\nu_{A,A'}$:

$\delta\nu_{A,A'} = F * \lambda_{A,A'} +$ (NMS+SMS)

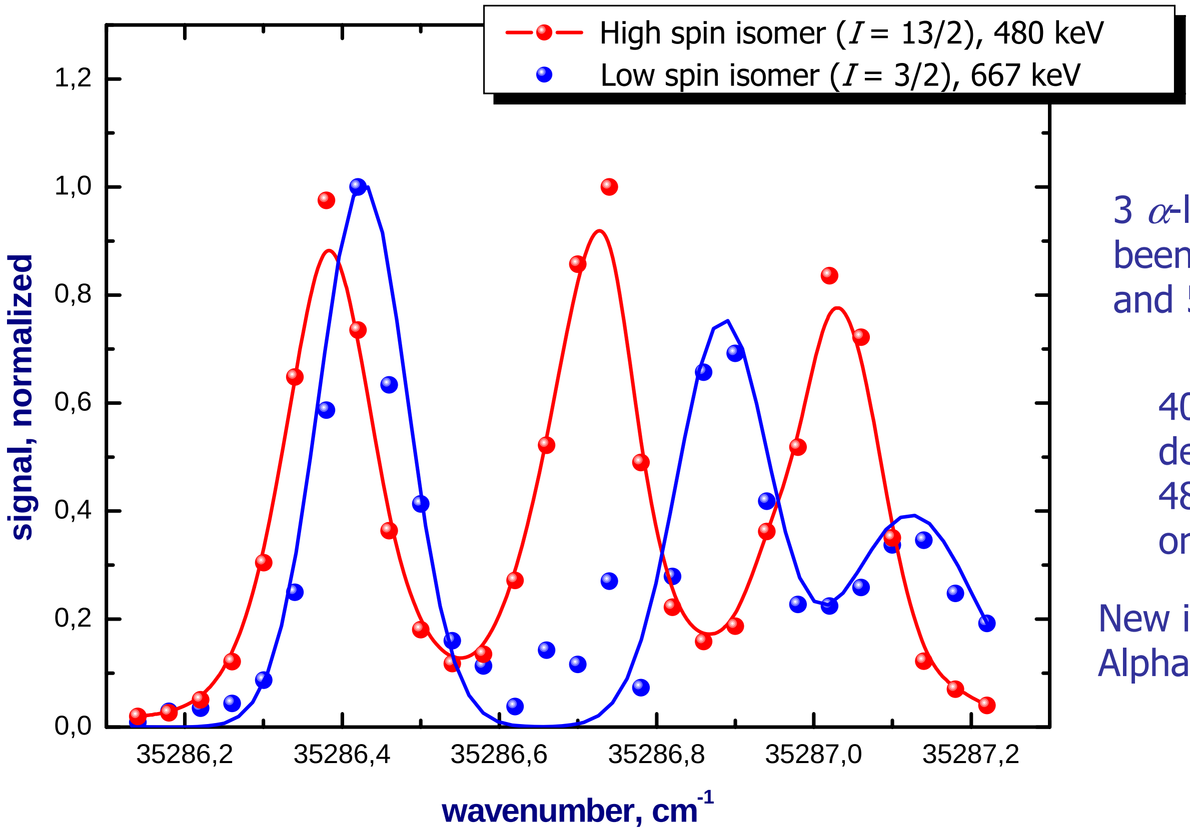
F = 20.26(18) GHz.fm^{-2}
MS =0 .19(25)*NMS
(Anselment et al, NPA451 (1986) 471)

Rms charge radius :

$\lambda_{A,A'} = \langle r^2\rangle + C_2\delta\langle r^4\rangle + \ldots = 0.93\ \delta\langle r^2\rangle$

Relative line position (Hyperfine splitting) $\rightarrow$ hyperfine constants $\boldsymbol{A}$ & $\boldsymbol{B} \rightarrow \boldsymbol{\mu_I}$ & $(\boldsymbol{Q_S})$:
$\boldsymbol{A} = \boldsymbol{A}(\boldsymbol{\mu_I}, \boldsymbol{I})$, $\boldsymbol{B} = \boldsymbol{B}(\boldsymbol{Q_S}, \boldsymbol{I})$

^{189}Pb: combination of nuclear and laser spectroscopy



3 α-lines belonging to the ^{189}Pb decay have been observed with energies: 5727, 5764 and 5619 keV

40 gamma lines belonging to the β/EC decay of ^{189}Pb have been identified: 386, 480, 700, 399....and 667keV are the main ones.

New isomer identified (I = 3/2)
Alpha decay scheme has been established

Ground state characteristics of $^{183-190}$Pb

Isotope	I^{π}	$*\delta\nu_{A,208}$(GHz)	$**A$ (GHz)	$*\delta\langle r^2\rangle_{A,208}$ (fm^2)***	$**\mu$ (n.m.)
^{182}Pb	0^+	-24.56(25)	—	-1.299(12)	—
^{183m1}Pb	$3/2^-$	-22.95(15)	-5.742(25)	-1.2145(75)	-1.158(5)
^{183m2}Pb	$13/2^+$	-23.54(15)	-1.423(6)	-1.2455(75)	-1.245(5)
^{184}Pb	0^+	-21.74(10)	—	-1.150(5)	—
^{185m1}Pb	$3/2^-$	-20.66(15)	-5.652(25)	-1.0930(75)	-1.141(5)
^{185m2}Pb	$13/2^+$	-21.26(15)	-1.405(12)	-1.1245(75)	-1.229(10)
^{186}Pb	0^+	-19.81(10)	—	-1.048(5)	—
^{187m1}Pb	$3/2^-$	-18.78(12)	-5.584(25)	-0.993(6)	-1.127(5)
^{187m2}Pb	$13/2^+$	-19.37(12)	-1.383(6)	-1.025(6)	-1.210(5)
^{188}Pb	0^+	-17.57(12)	—	-0.930(6)	—
^{189m1}Pb	$3/2^-$	-16.82(15)	-5.36(4)	-0.8904(75)	-1.081(8)
^{189m2}Pb	$13/2^+$	-17.36(20)	-1.374(7)	-0.9184(75)	-1.202(7)
^{190}Pb	0^+	-15.86(10)	—	-0.839(5)	—

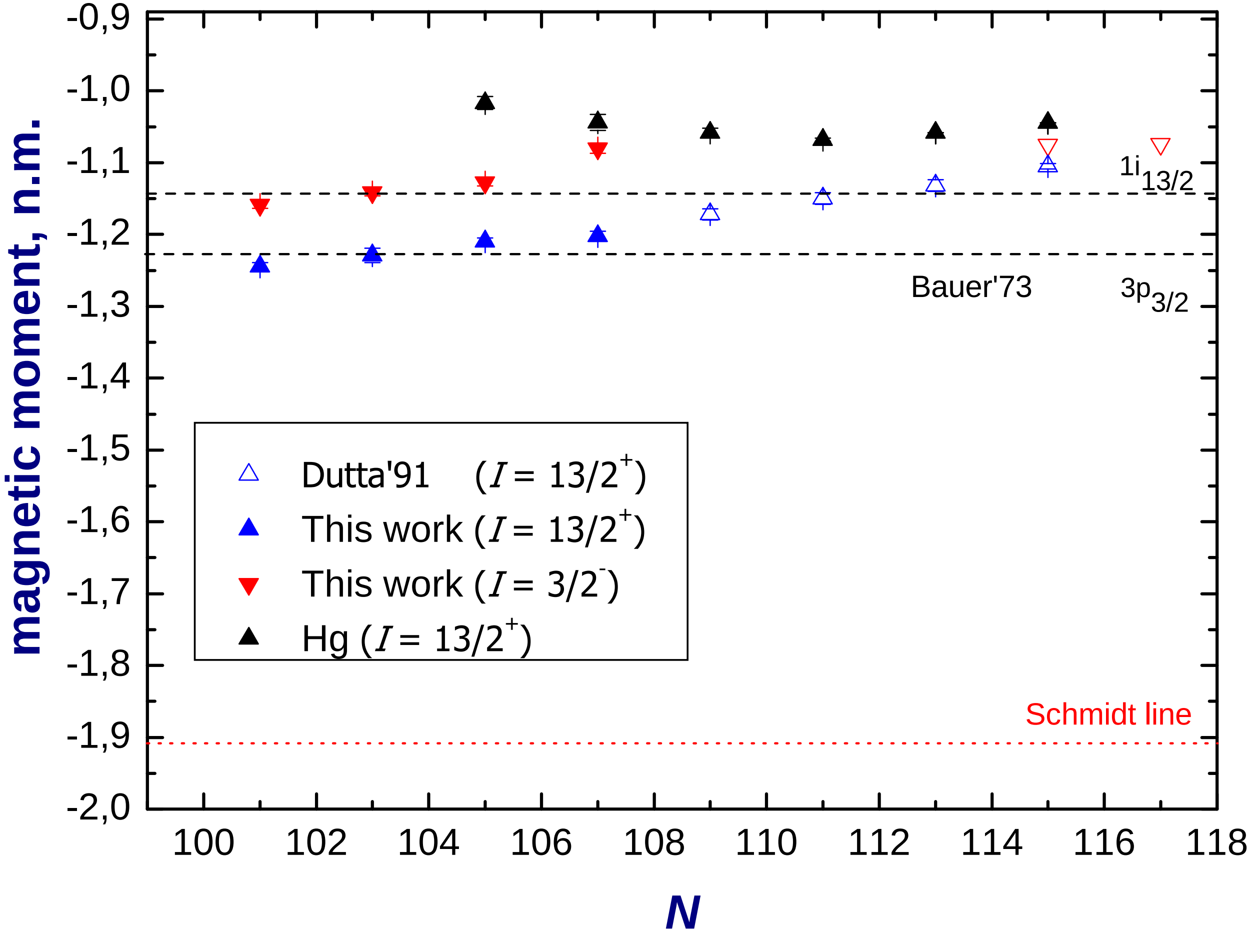
** H. de Witte et al., „Nuclear charge radii of neutron deficient lead isotopes beyond N=104 mid shell investigated by in-source laser spectroscopy", to be published in PRL, 2007*

*** Preliminary*

**** Errors due to the isotope shifts measurements' uncertainties are given only. The total errors are 0,013 fm^2 for $^{183-185}$Pb and 0.010 fm^2 for heavier isotopes.*

Reference value $\delta\langle r^2\rangle_{190,208}$ = -0.840(10) fm^2
S.B. Dutta *et al.*, Z. Phys. A **341**, 39 (1991)

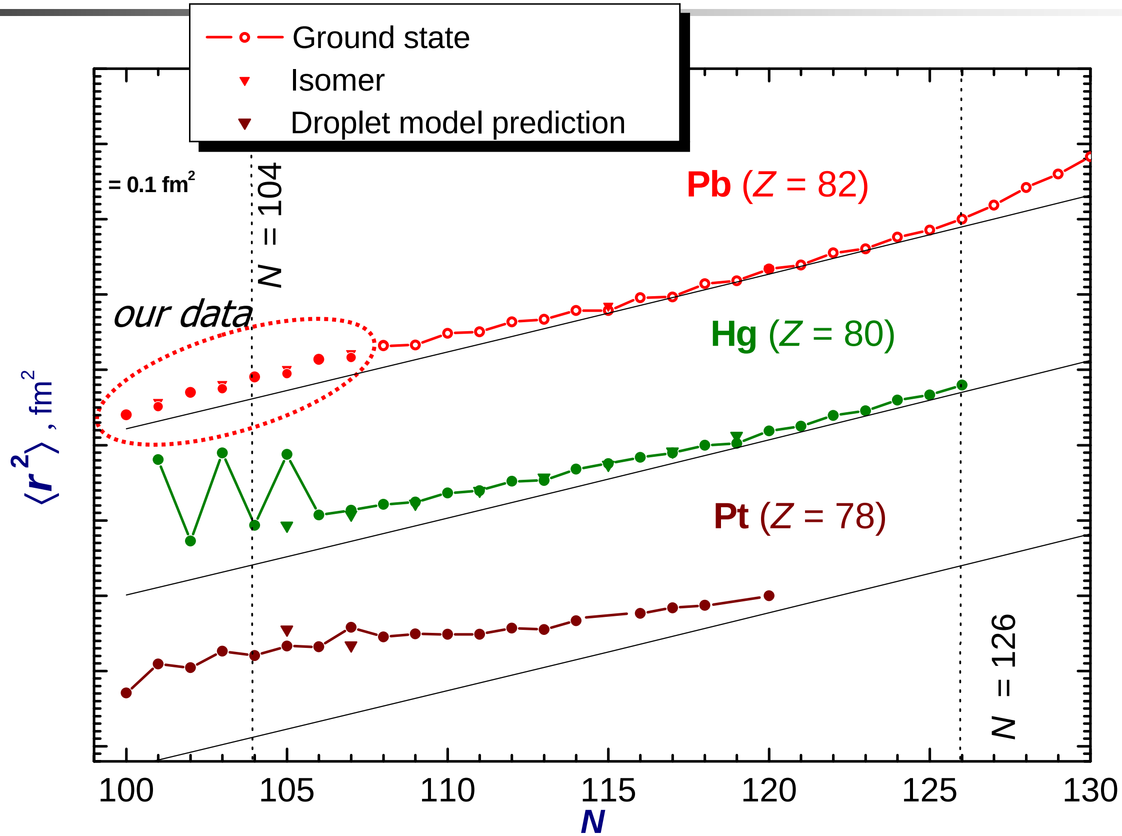
Nuclear magnetic moments



Magnetic moments for the neutron deficient odd-*A* lead isotopes.

The theoretical curve, labelled "Bauer '73", is taken from *Bauer R. et al., Nucl. Phys. A 209 (1973), 535*.

Charge radii for Pb chain



The experimental error bar is smaller than the symbol size. The distance between the different chains is chosen arbitrarily for better display. One minor division on the vertical scale corresponds to 0.1 fm^2

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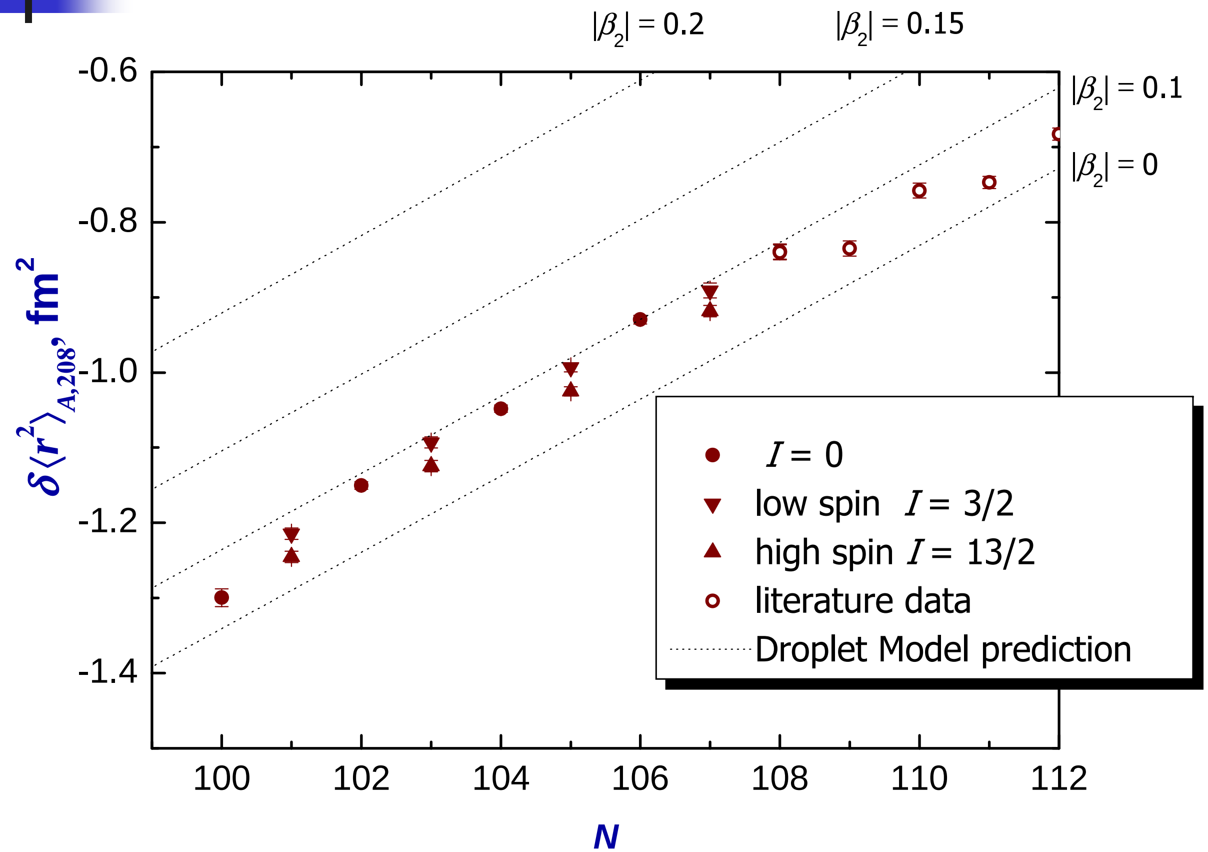
$^{182-190}$Pb charge radii: experiment



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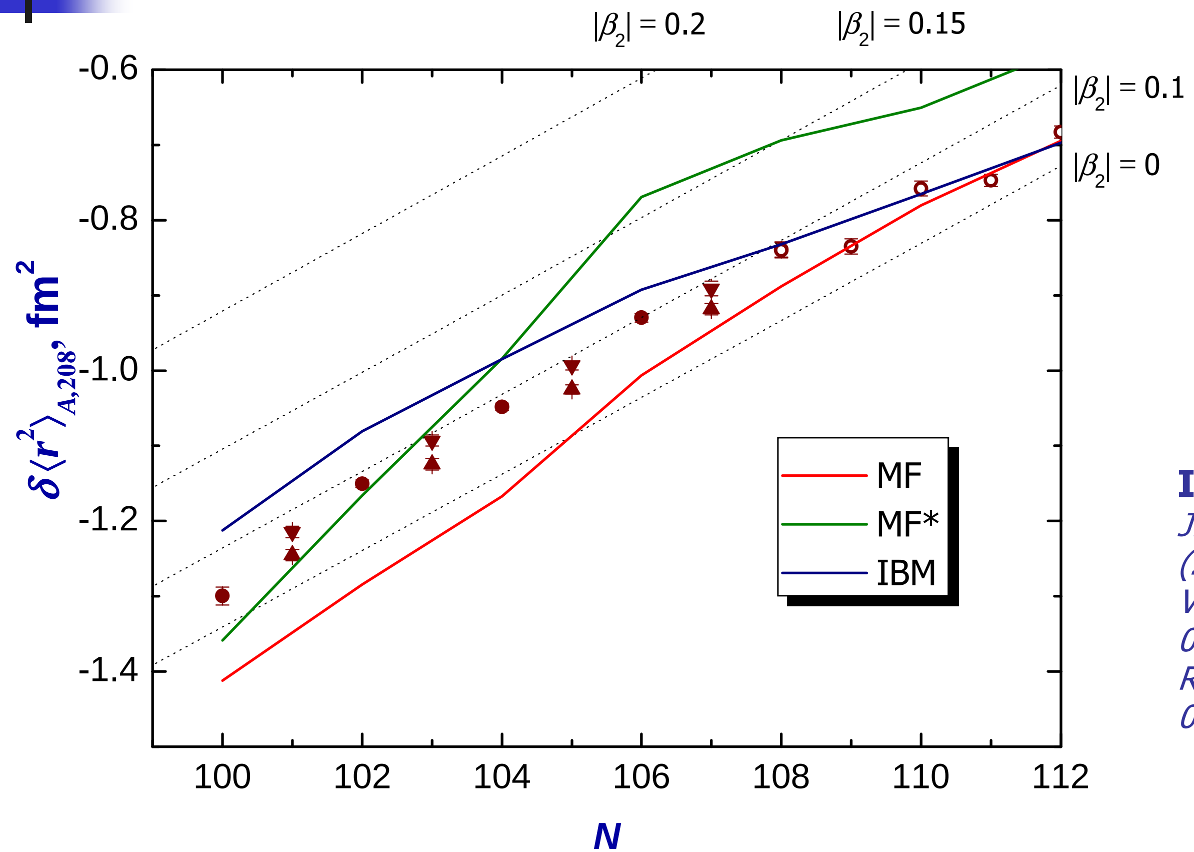
$^{182-190}$Pb charge radii: theoretical models



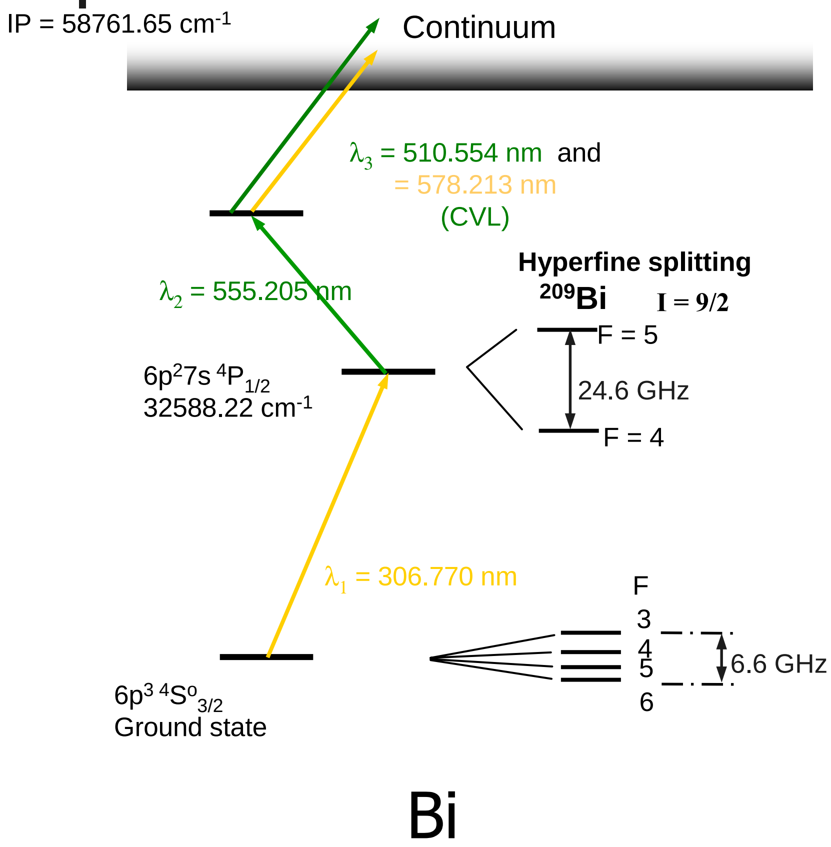
Beyond Mean Field (MF)
*M. Bender et al., Phys. Rev. C **69**, 064303 (2004).*

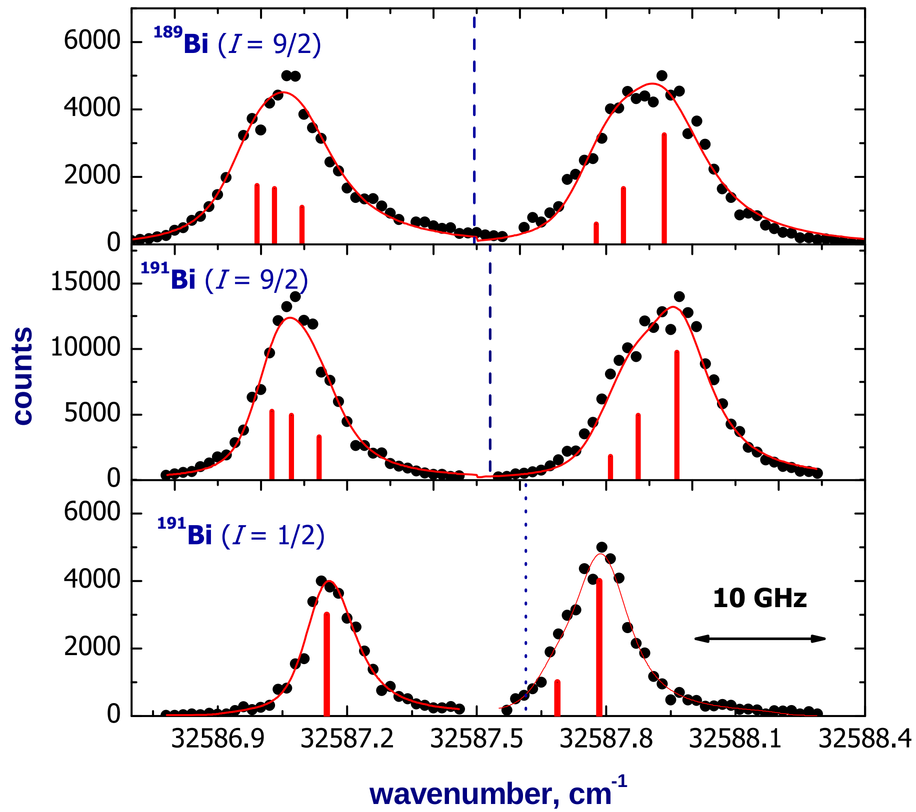
Beyond Mean Field (MF*)
Reduced pairing
*M. Bender et al., Phys. Rev. C **73**, 034322 (2006).*

Interacting Boson Model (IBM)
J. Pakarinen et al., to be published (2006).
V. Hellemans et al., Phys. Rev. C 71, 034308 (2005).
R. Fossion et al., Phys. Rev. C 67, 024306 (2003).

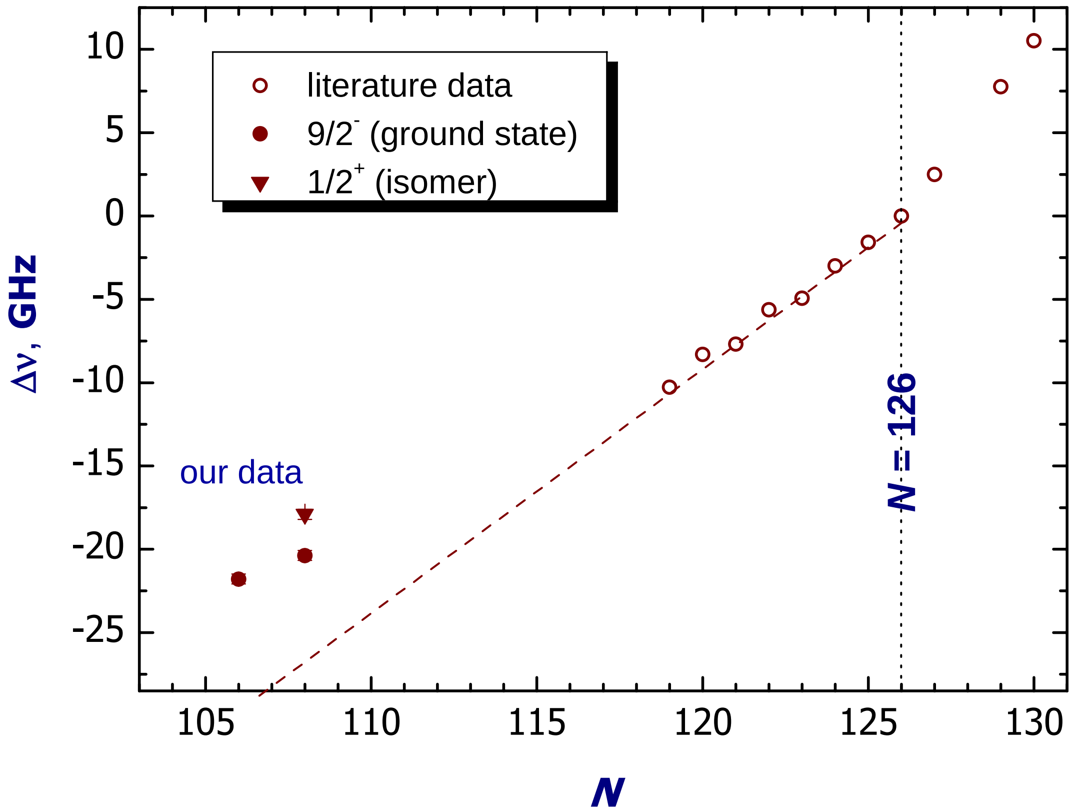
H. de Witte et al., „Nuclear charge radii of neutron deficient lead isotopes beyond N=104 mid shell investigated by in-source laser spectroscopy", to be published in PRL, 2007

Bi: atomic spectroscopy





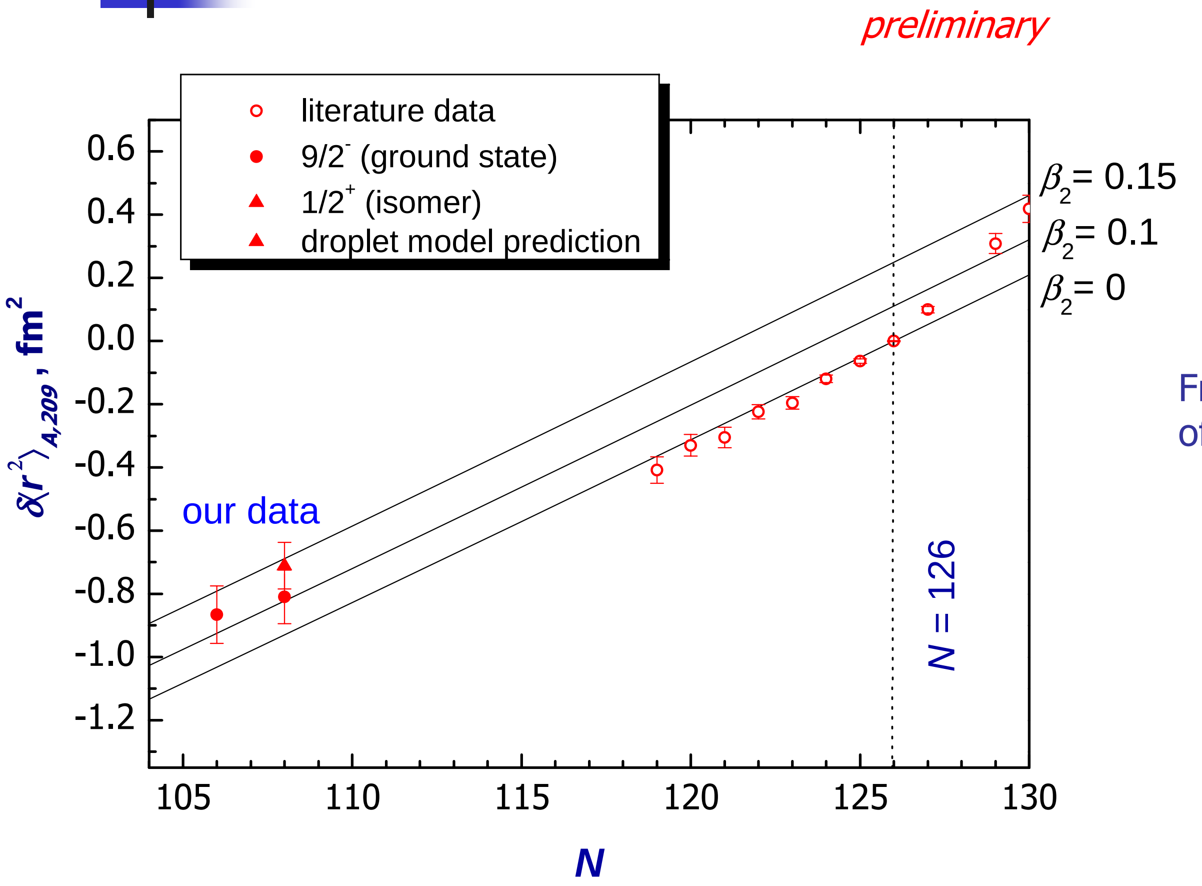
^{189,191}Bi: isotope shifts



preliminary

Isotope	$\Delta\nu_{209,A'}$, GHz
^{189}Bi (I^{π} =9/2$^-$)	-21.8(3)
^{191}Bi (I^{π} =9/2$^-$)	-20.4(3)
^{191}Bi (I^{π} =1/2$^+$)	-17.9(3)

^{189,191}Bi: charge radii



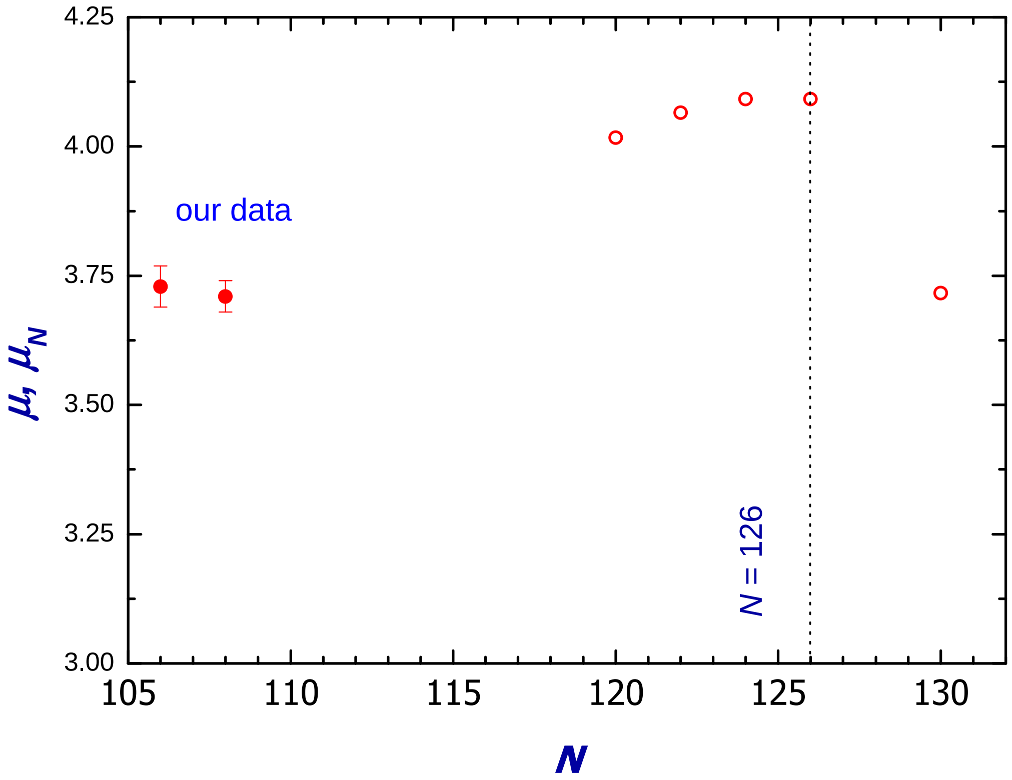
No reliable values for electronic factor and specific mass shift constant

From the comparison of isotopes shifts of Bi and Pb: ***F* = 27(3) GHz/fm²**

P. Campbell et al., Phys. Lett. B ***346*** *(1995) 21*

MCDF calulations are under way
S. Fritsche (Univ. of Kassel)

Bi: magnetic moments



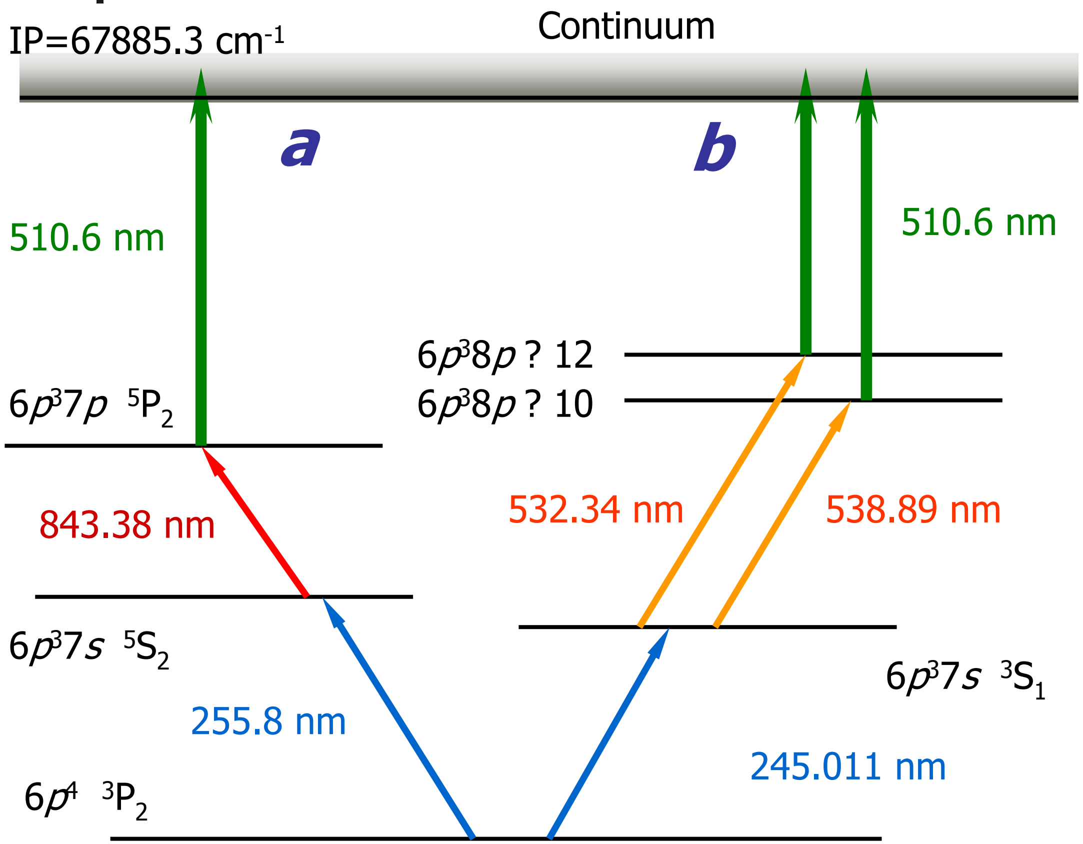
preliminary

Isotope	*A*, GHz	μ , μ_N
^{189}Bi (I = 9/2$^-$)	-0.405(4)	3.73(4)
^{191}Bi (I = 9/2$^-$)	-0.403(3)	3.71(3)
^{191}Bi (I = 1/2$^+$)	-1.45(2)	1.49(2)

Reference:

^{189}Bi (I^{π} =9/2$^-$)	-0.44697(4)	4.1106(2)

Po: photoionization schemes and yield test



Po yields (scheme „a")

Isotope	Half life, s	Yield, Atoms/μC
^{193g}Po	0.42	7×10^{1}
^{193m}Po	0.24	1×10^{2}
^{194}Po	0.392	2.5×10^{3}
^{195g}Po	4.64	2×10^{4}
^{195m}Po	1.92	5×10^{4}
^{196}Po	5.8	4.7×10^{5}
^{197g}Po	53.6	2.5×10^{5}
^{197m}Po	25.8	1.75×10^{6}
^{198}Po	106.2	7×10^{6}

Conclusions & future perspectives

- Laser spectroscopy and nuclear structure:
  - Extention of laser spectroscopy studies to the very neutron deficient isotopes (and isomers) of Pb and Bi
  - Extention of Pb charge radii systematics beyond mid-shell (e.g. ^{182}Pb, $T_{1/2}$= 55 ms)
  - Comparison with calculations: Ground states of Pb remains spherical
  - ^{189}Pb decay scheme has been established
  - ^{189}Pb low spin isomer identified
  - Photoionization scheme for Po was developed

- Method:
  - Improved precision & reproducibility of in-source laser spectroscopy technique
  - Ultra high sensitivity
- Future:
  - Extension to other elements e.g. Po isotopes

CERN-ISOLDE project IS407: Study of the neutron deficient Pb and Bi isotopes by simultaneous atomic- and nuclear-spectroscopy

A. Andreyev, N. Barré, M. Bender, J. Billowes, T.E. Cocolios, S. Dean, D. Fedorov, V.N. Fedoseyev, L.M. Fraile, S. Franchoo, J. Genevey, V. Hellemans, P.H. Heenen, K. Heyde, G. Huber, M. Huyse, A. Ionan, H. Jeppesen, K. Johnston, U. Köster, Yu. Kudryavtsev, P. Kunz, S.R. Lesher, B.A. Marsh, I. Mukha, B. Roussière, J. Sauvage, I. Stefanescu, E. Tengborn, K. Van de Vel, J. Van de Walle, P. Van Duppen, Yu.M. Volkov, H. De Witte

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