

Hyperfine anomaly studies in Au isotopes at CRIS

Osama Ahmad

Supervisor: Prof. dr. Gerda Neyens

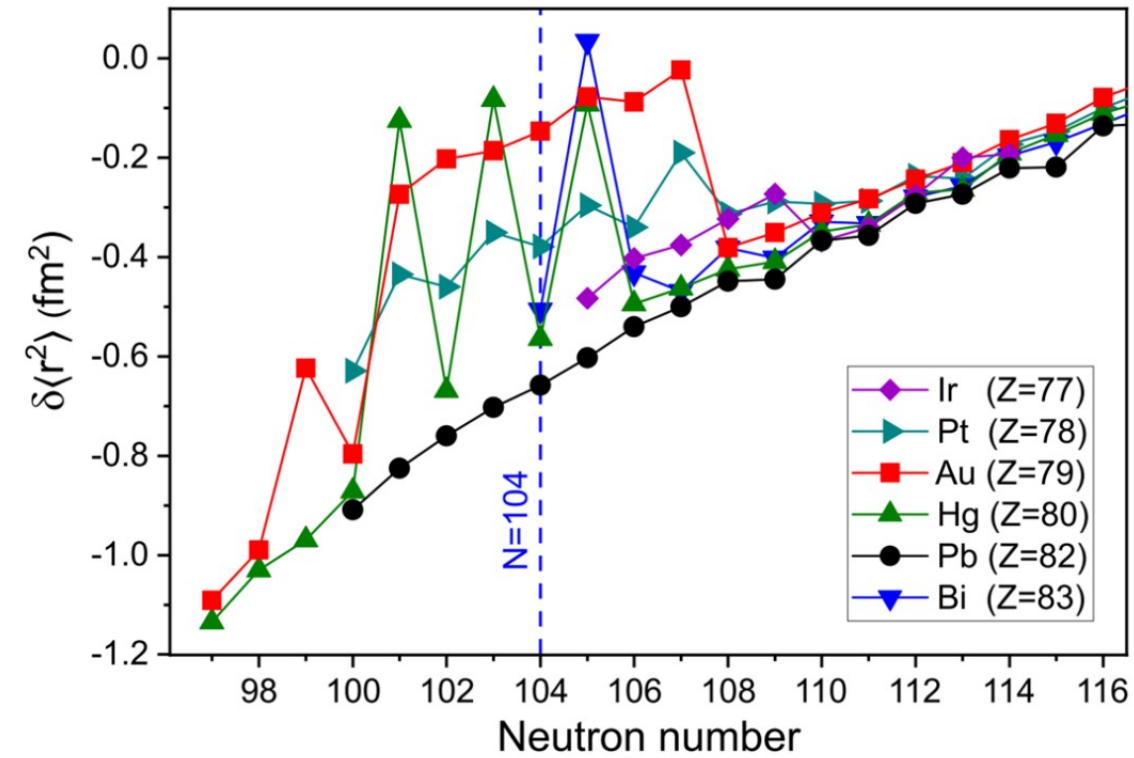
Co-supervisor: Dr. Jessica Warbinek

03/08/2026



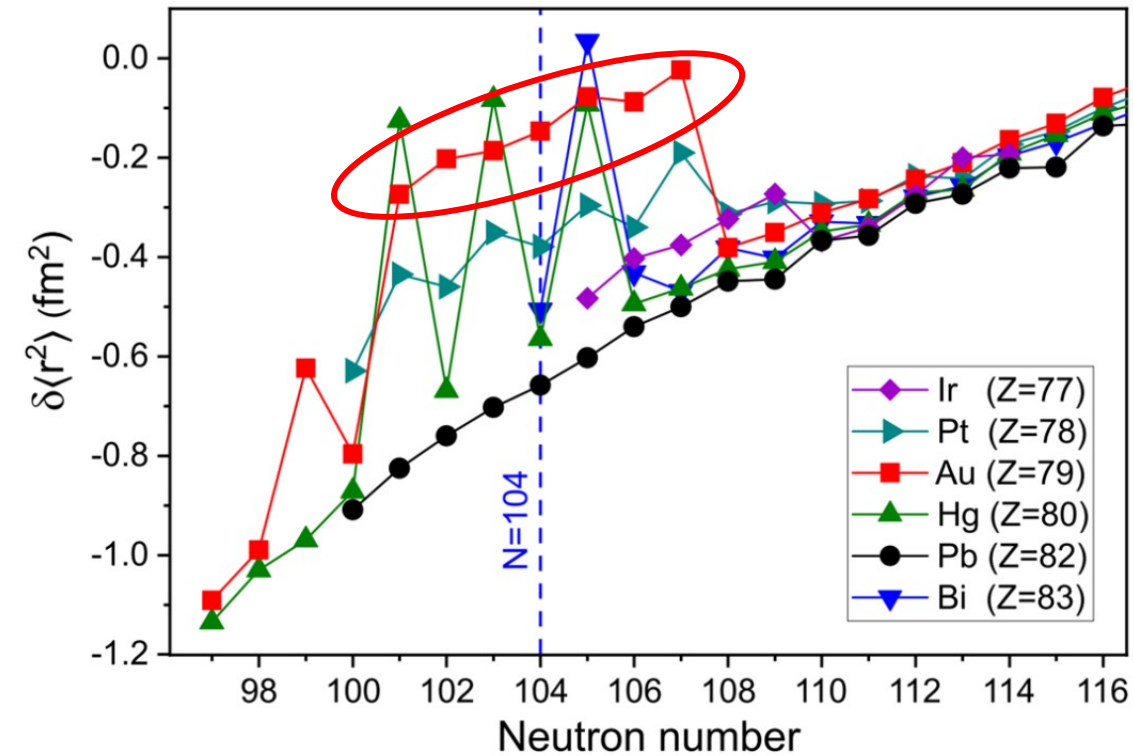
Motivation

79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth
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Motivation

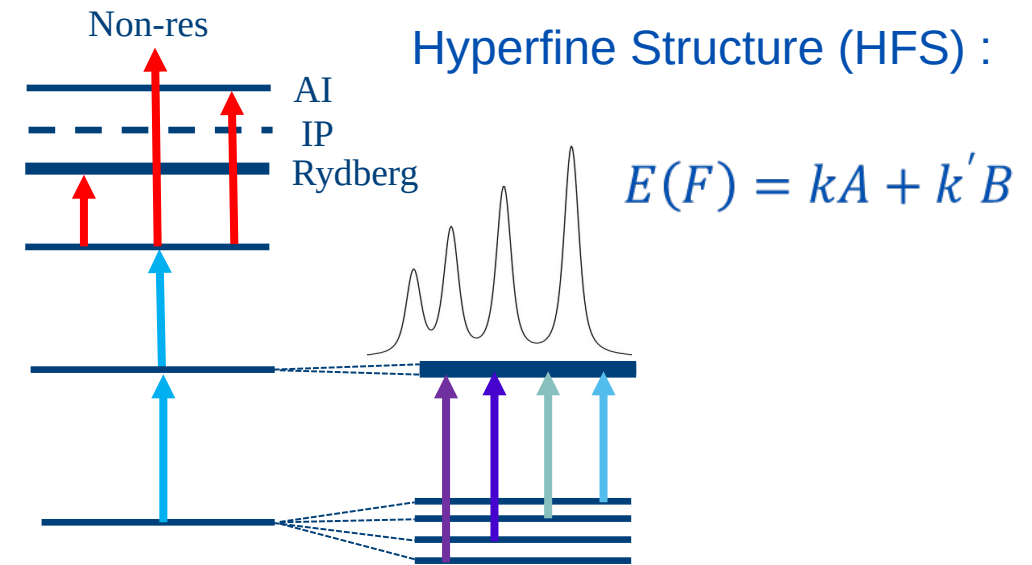
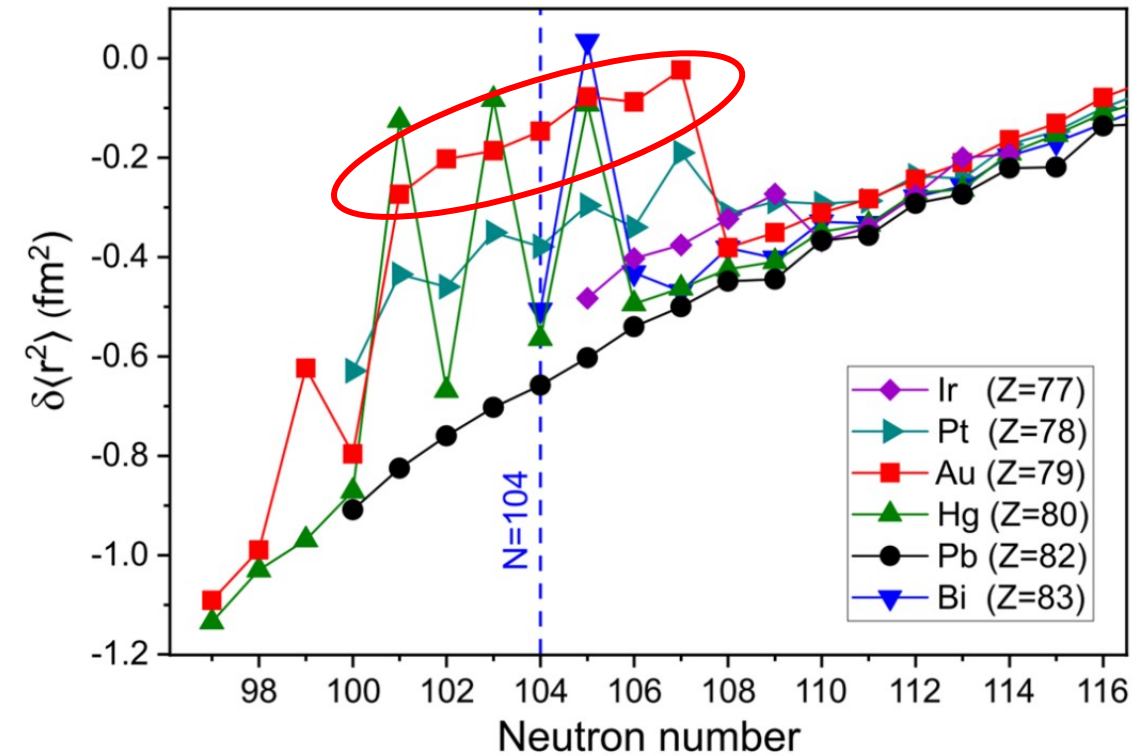
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Au: strong increase in charge radii at $N = 101-107$

→ Proposed “**Island of deformation**”

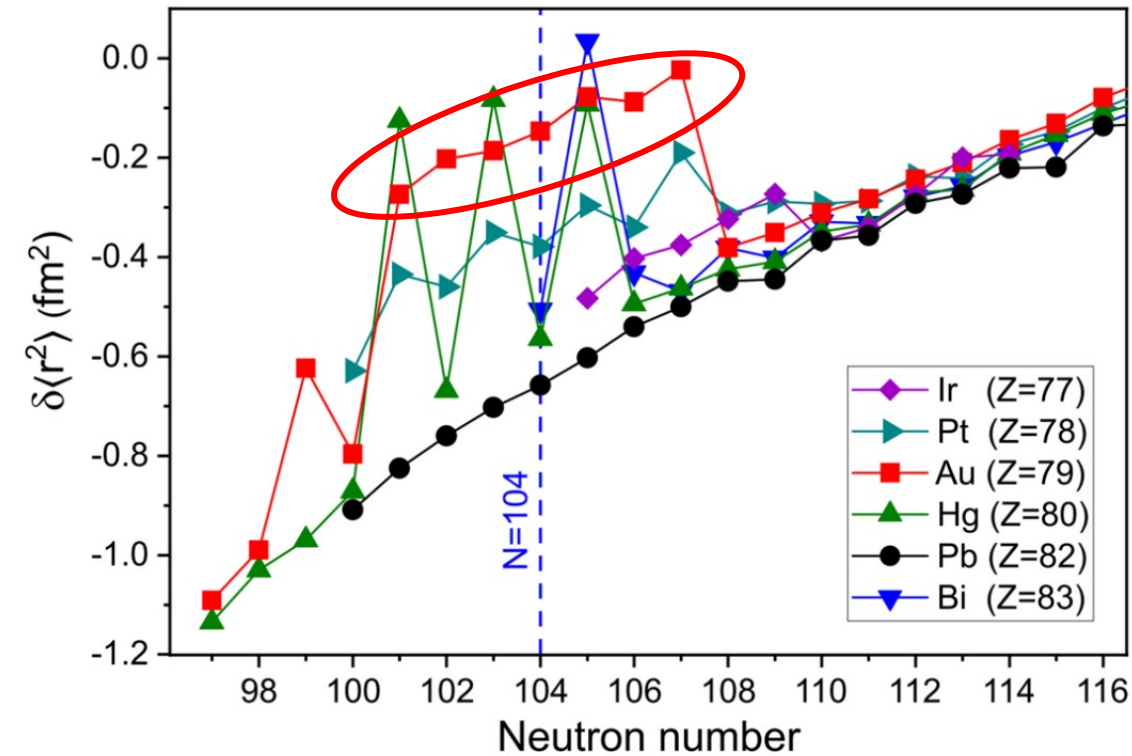
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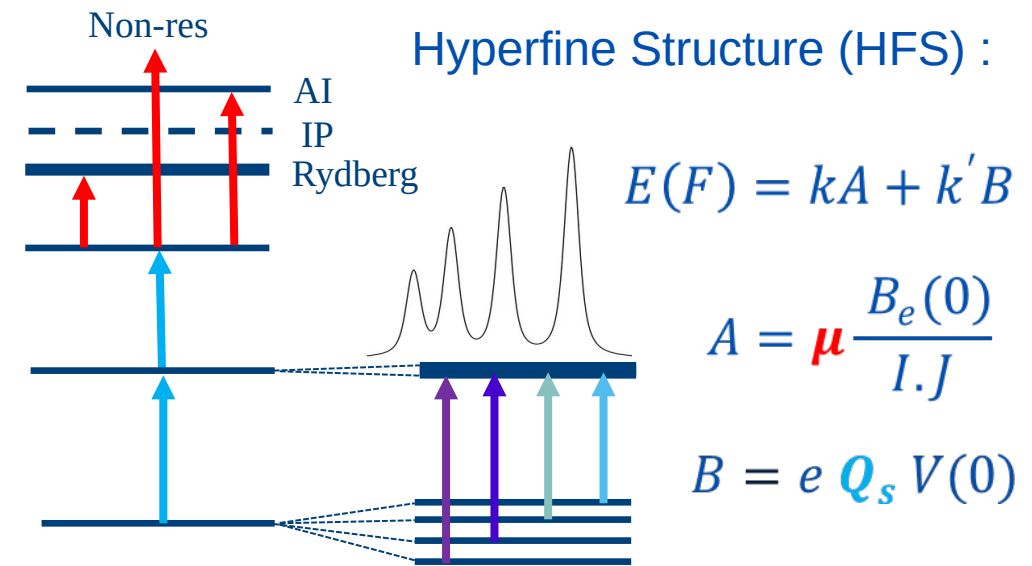
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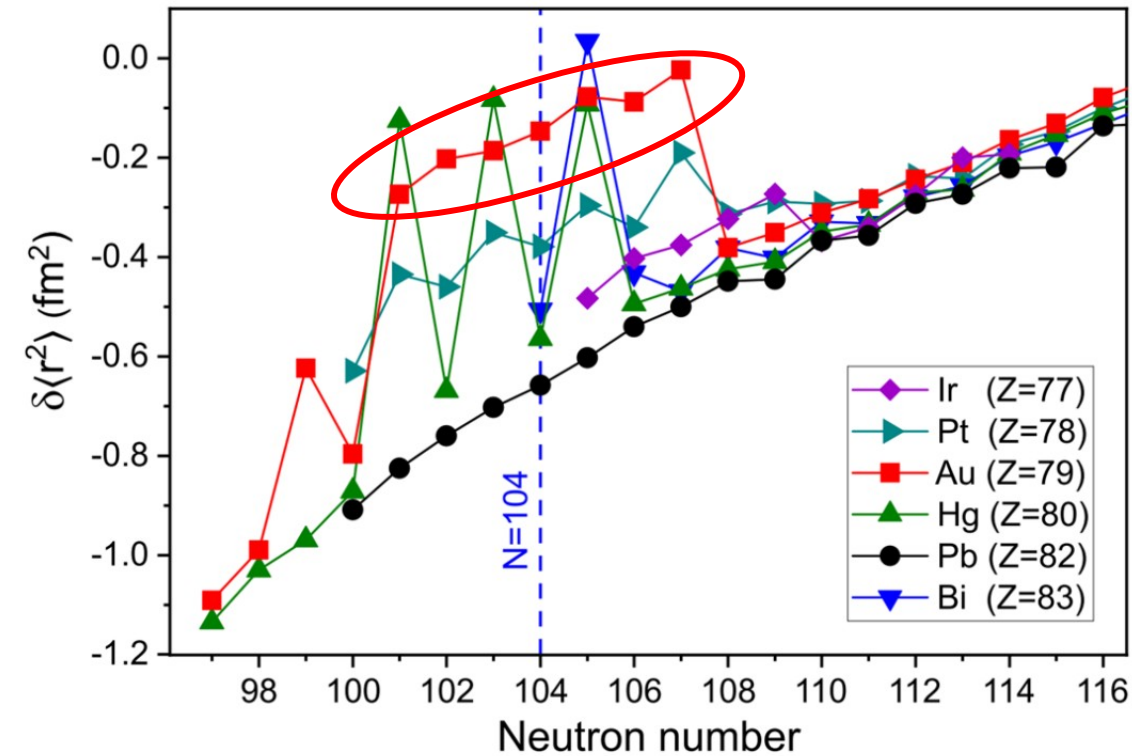


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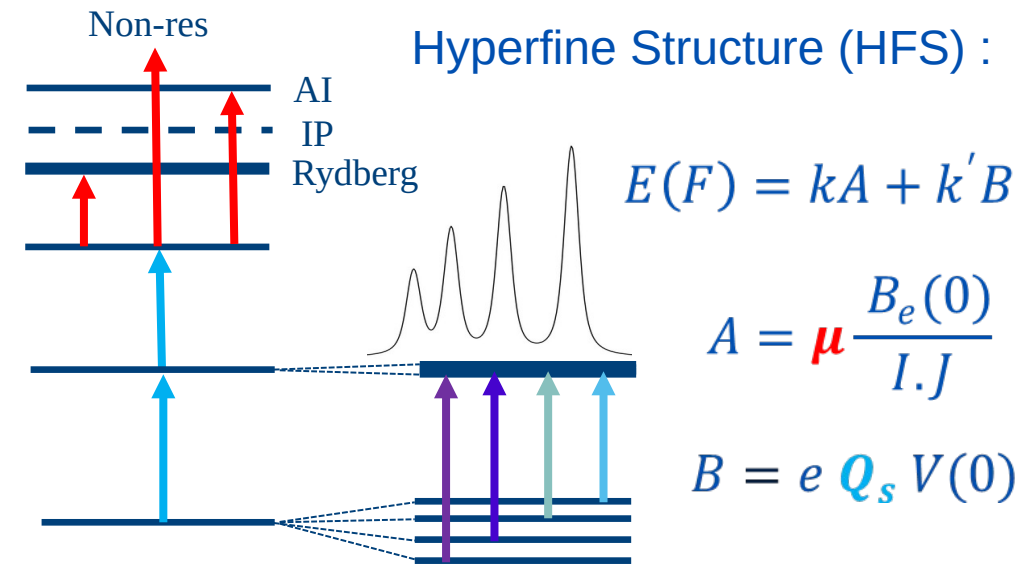


Motivation



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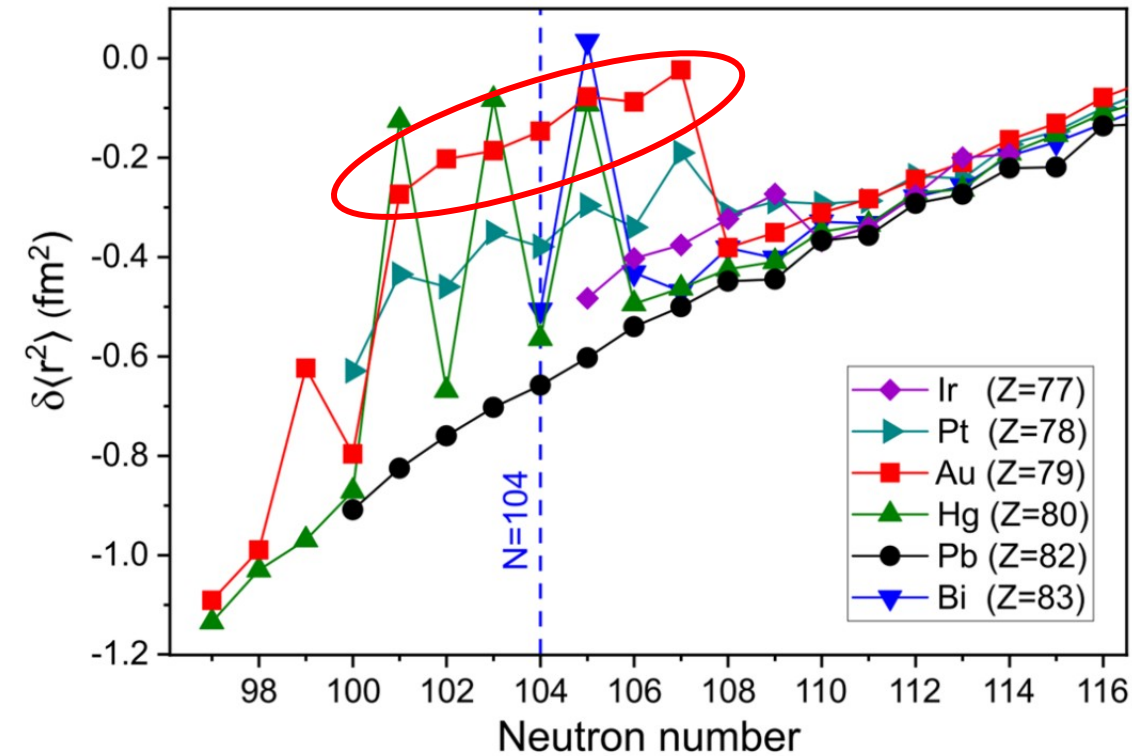
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Isotope shift : shift of HFS between two isotopes A and A'

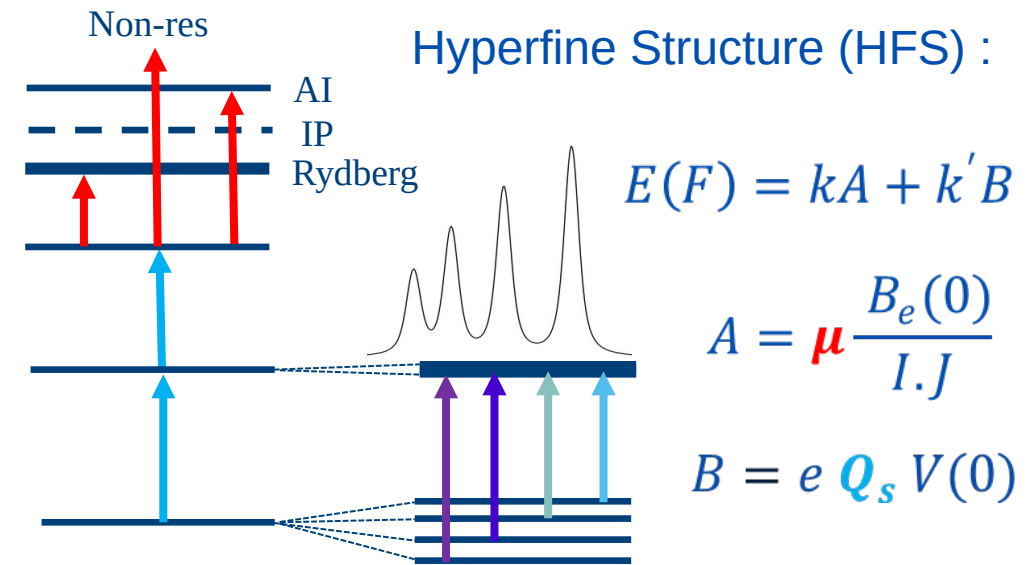
$$\delta \nu_i^{A,A'} = \frac{A - A'}{AA'} M_i + F_i \quad \delta \langle r^2 \rangle$$

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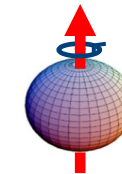


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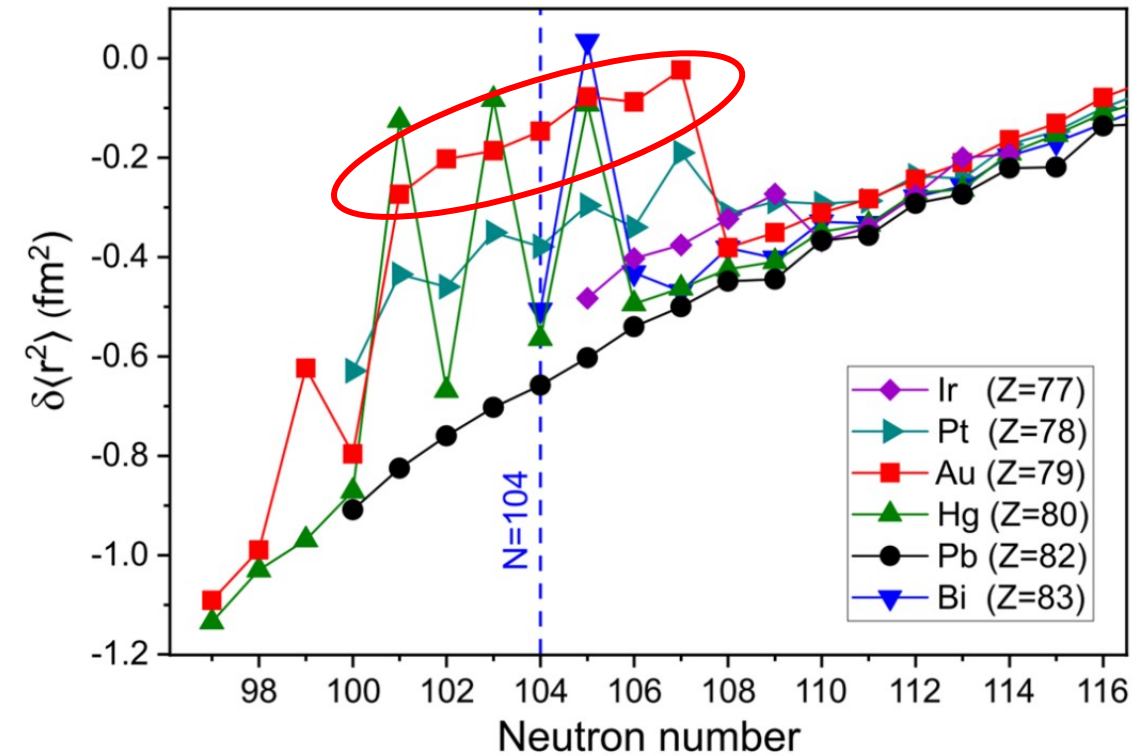
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Measuring the HFS :

Nuclear Spin (I)

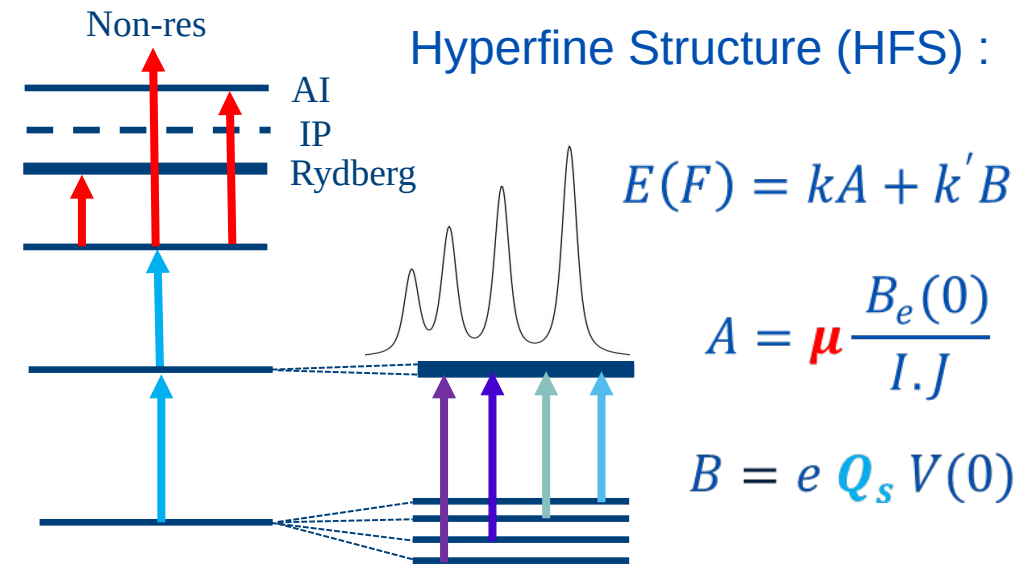


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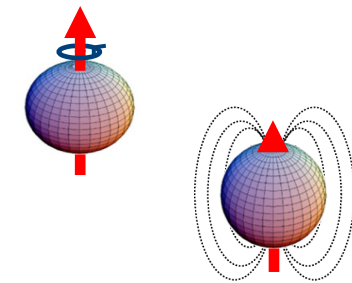
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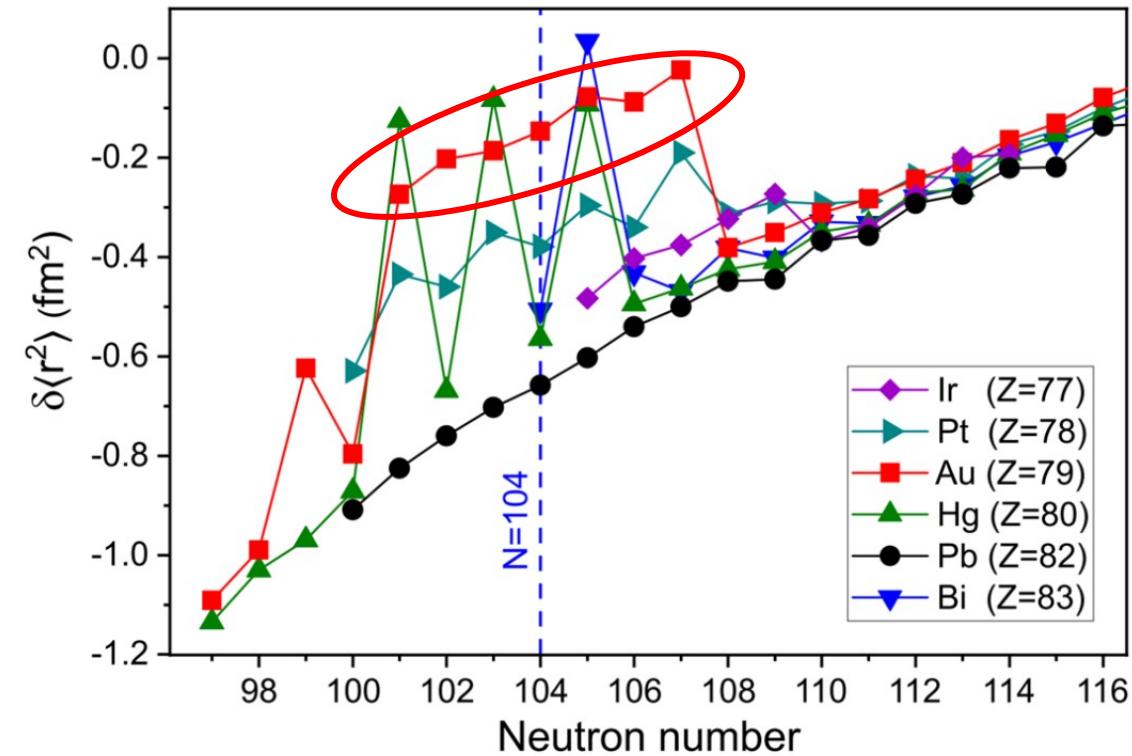
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Magnetic dipole moment (μ)

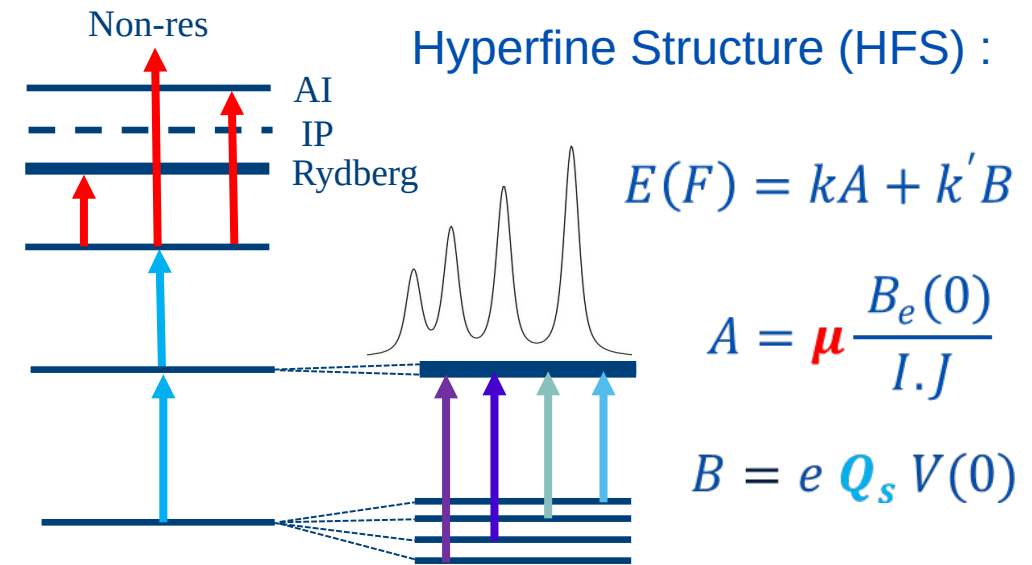


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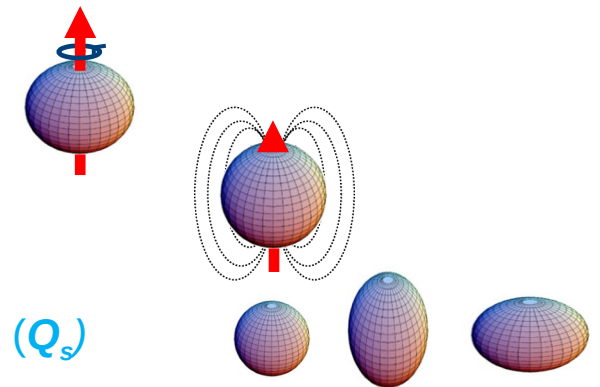
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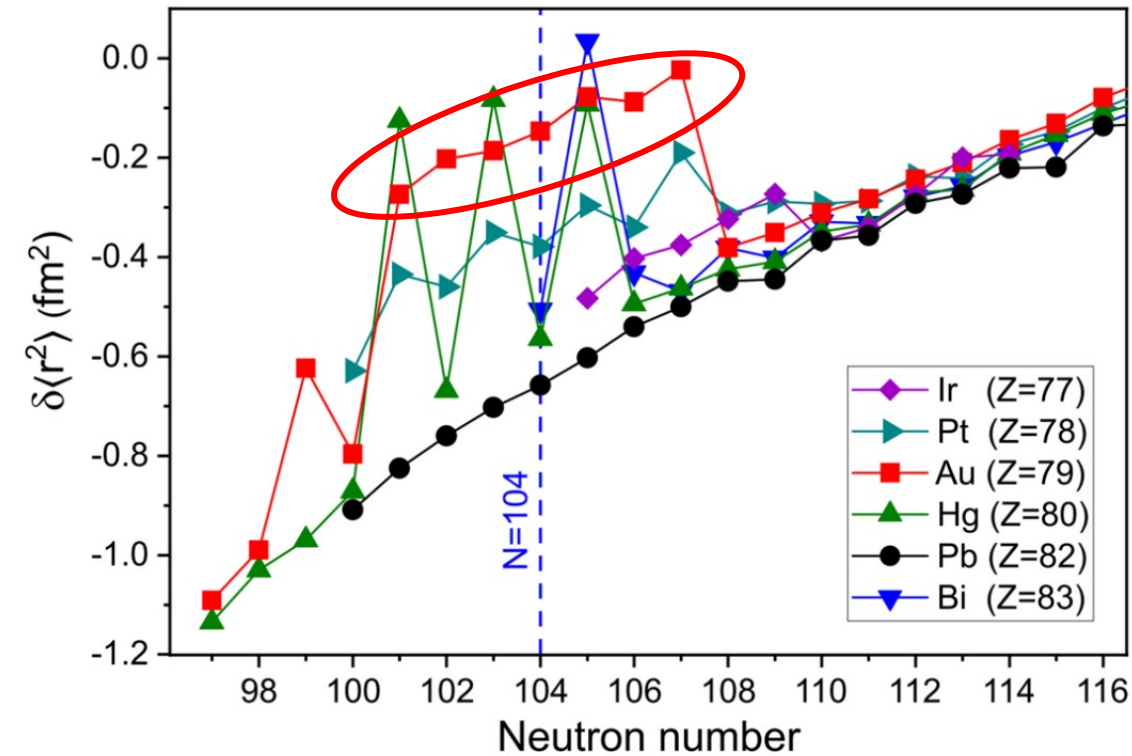
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Magnetic dipole moment (μ)

Electric Quadrupole moment (Q_s)

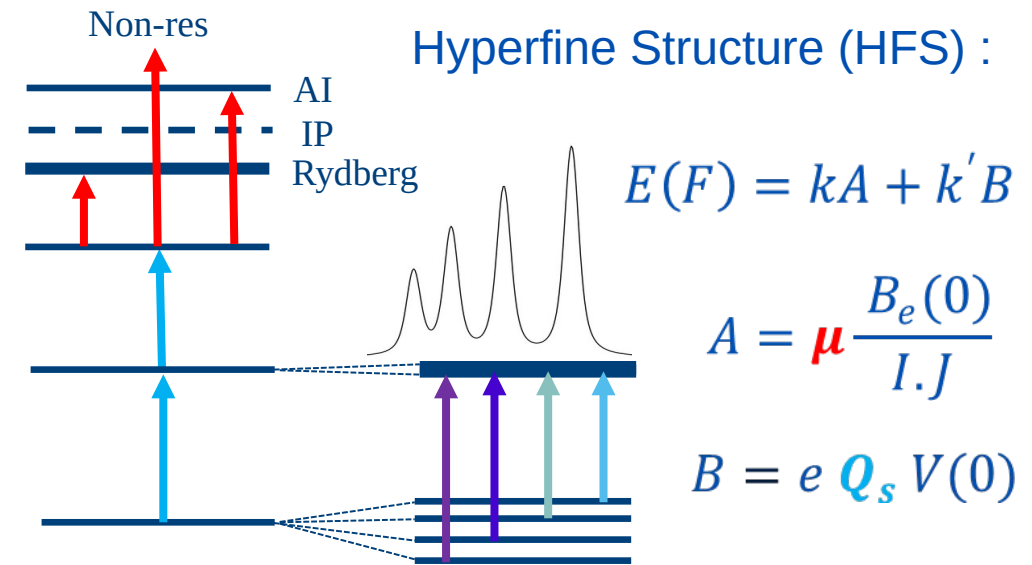


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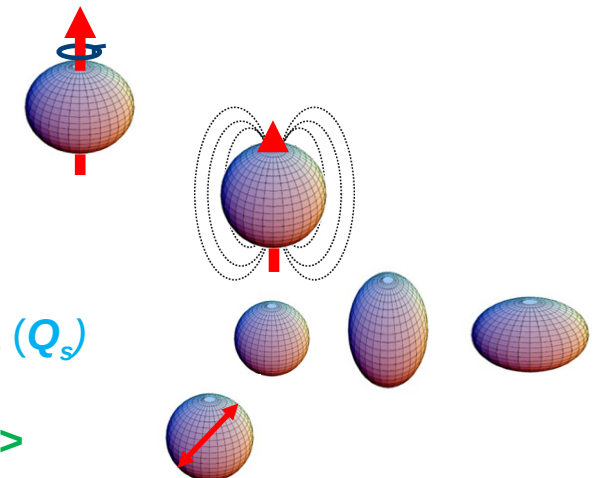
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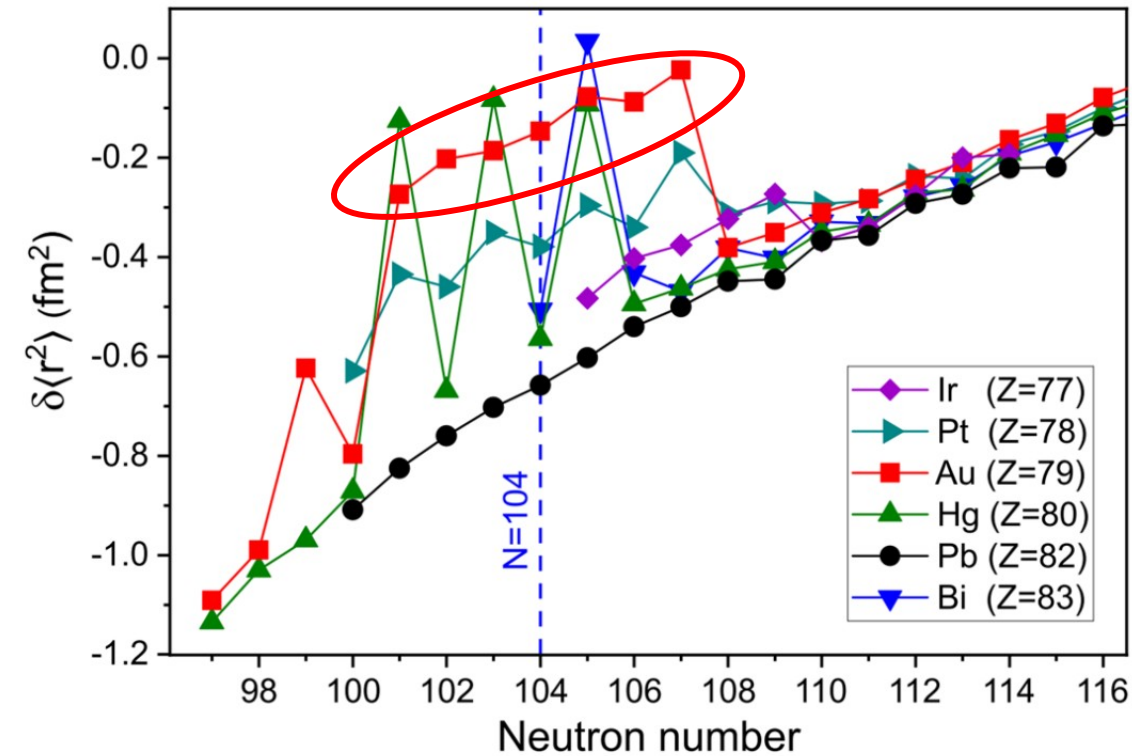
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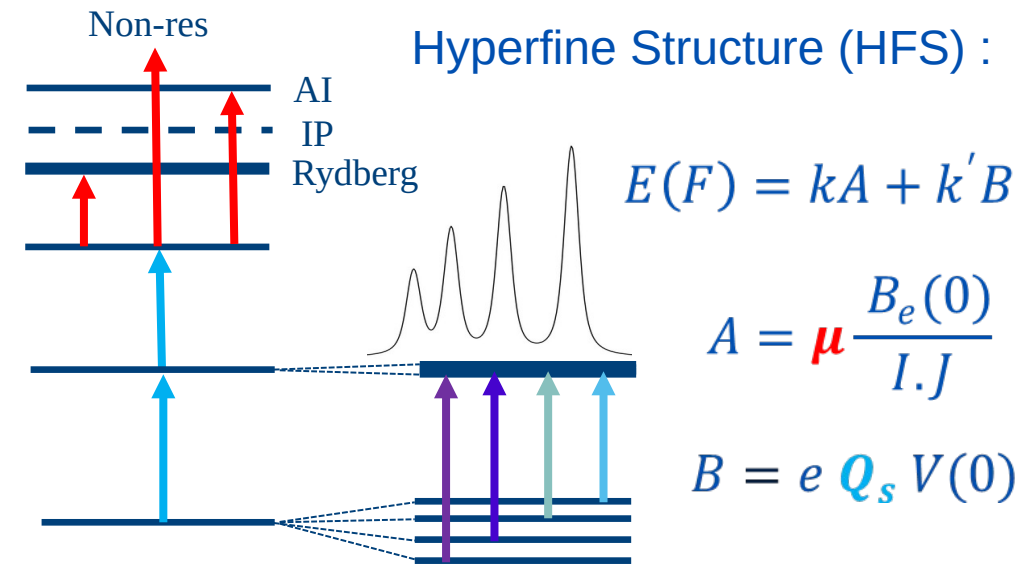


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Isotope shift : shift of HFS between two isotopes A and A'

See talk by A. Karadimas

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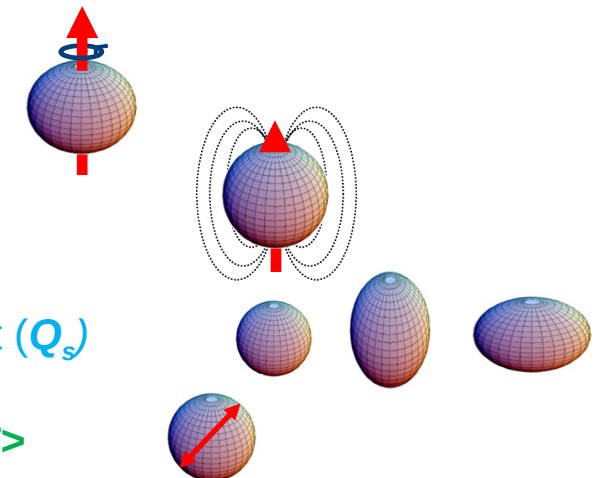
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Spin assignment

For ^{181}Au , ^{182}Au and ^{183}Au : Spin assignment is tentative in the literature.

Isotope	Half-life	I^π
$^{181}\text{Au}_{102}$	13.7 s	$(3/2^-)$
$^{182}\text{Au}_{103}$	15.5 s	(2^+)
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Possible spins for ^{181}Au & ^{183}Au : $3/2$, $5/2$, $7/2$

For ^{182}Au : $2, 3, 4, 5$

Spin assignment

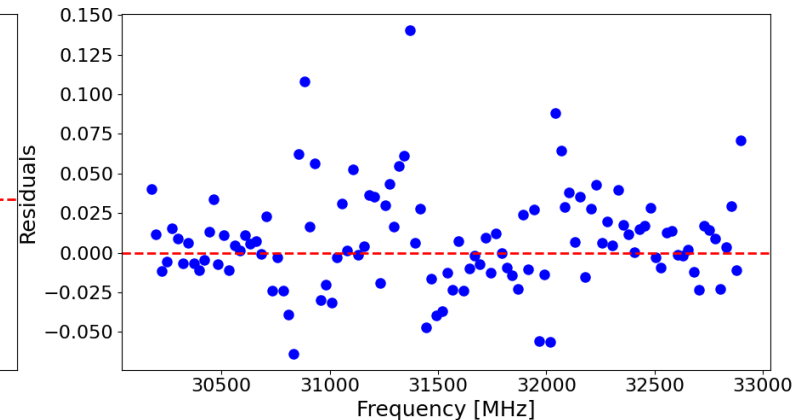
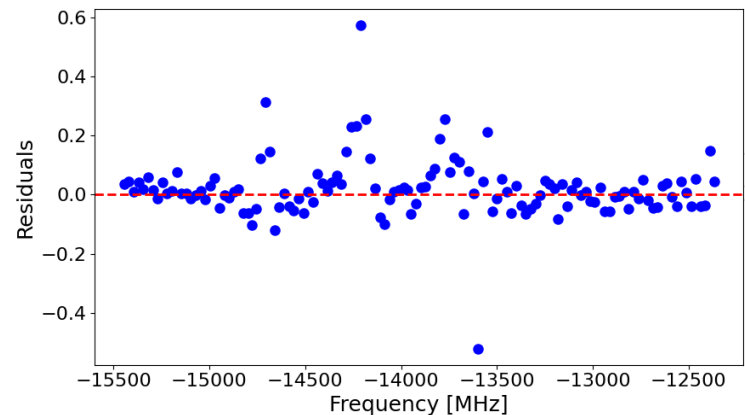
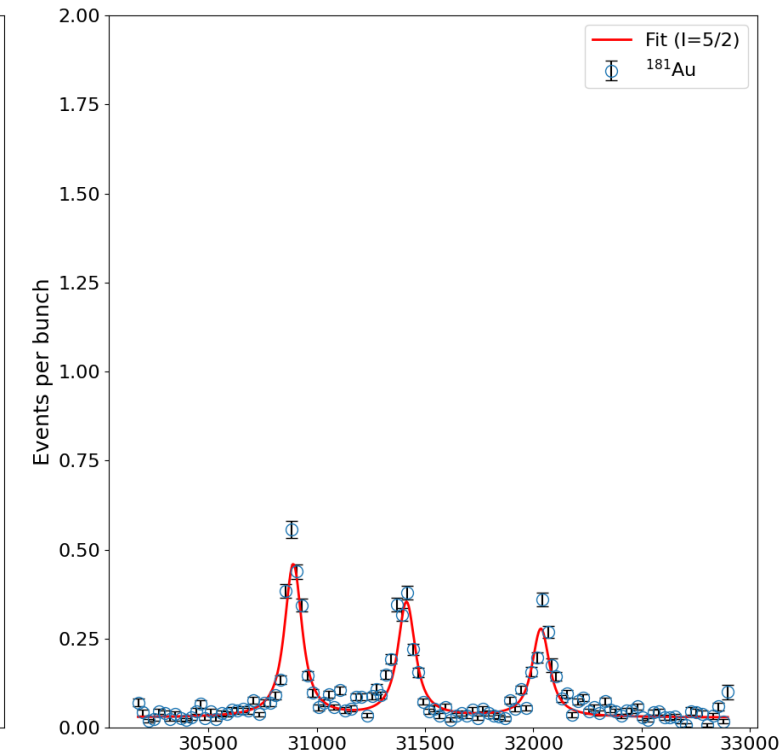
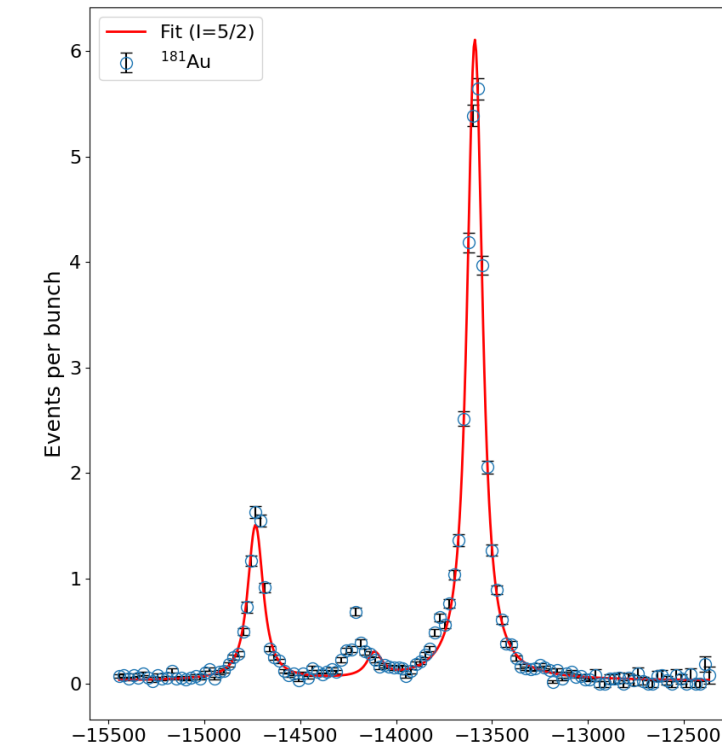
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Fit quality



Spin assignment

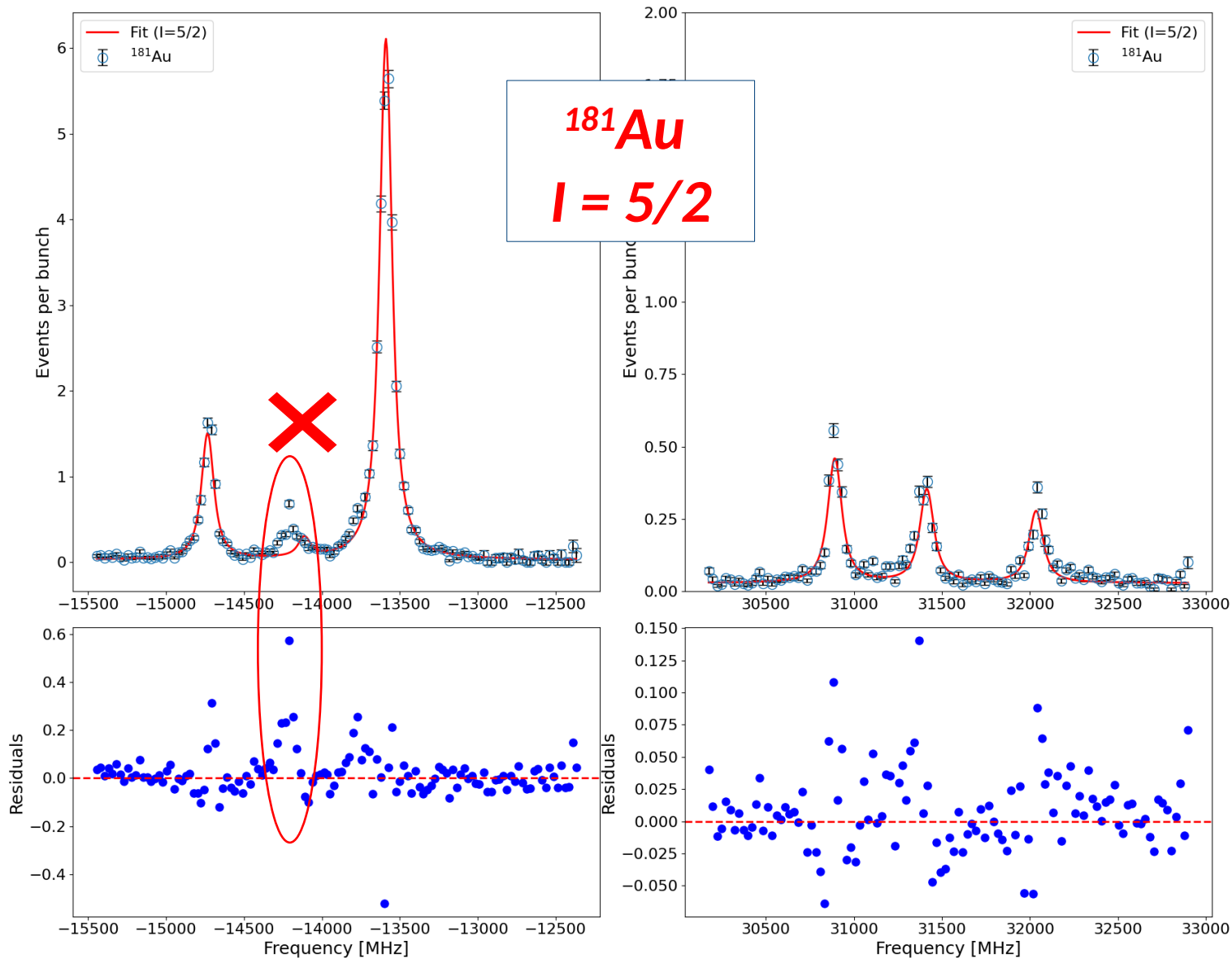
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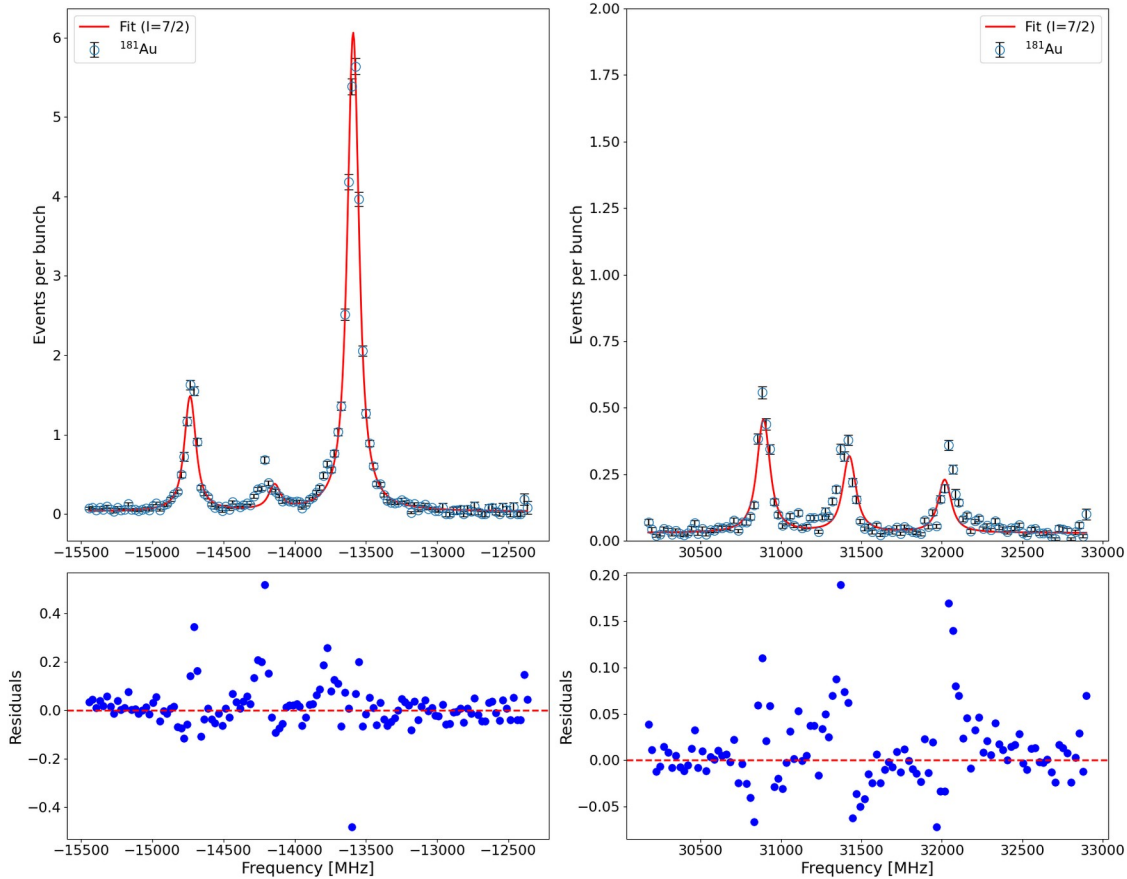
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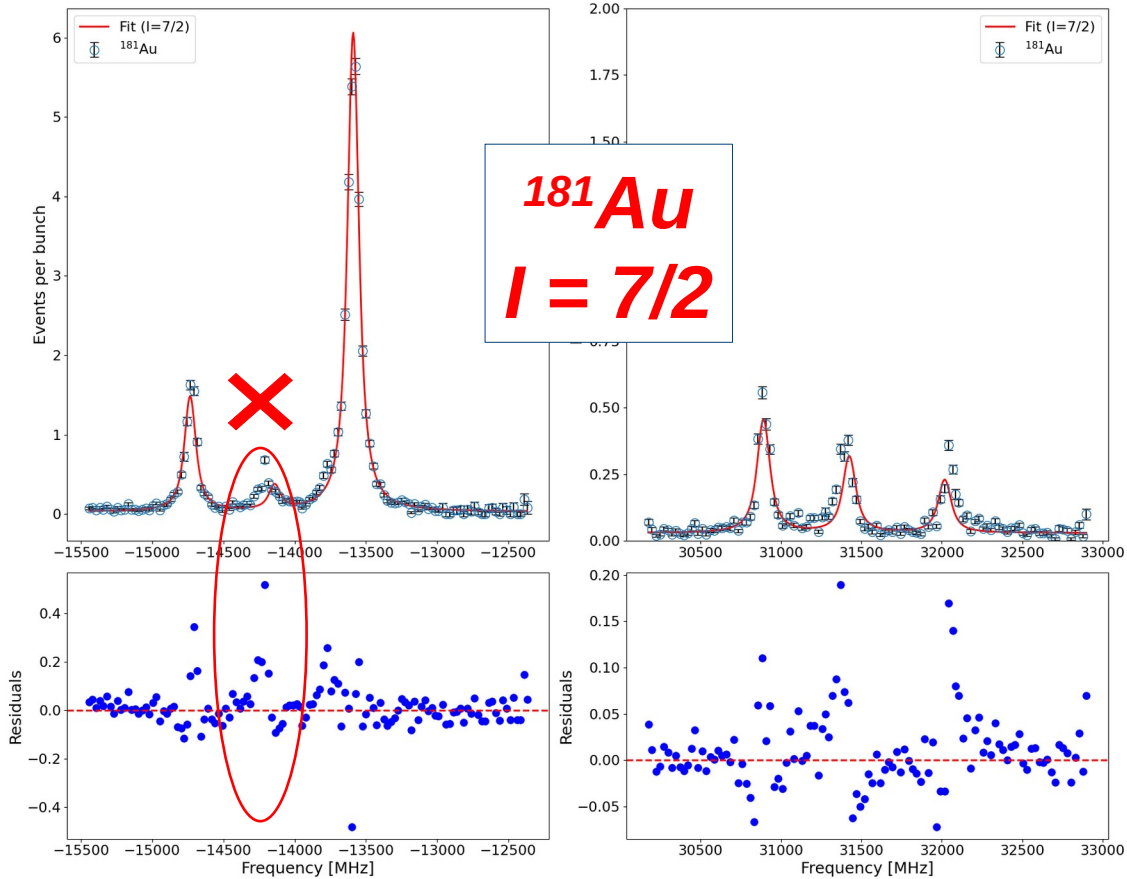
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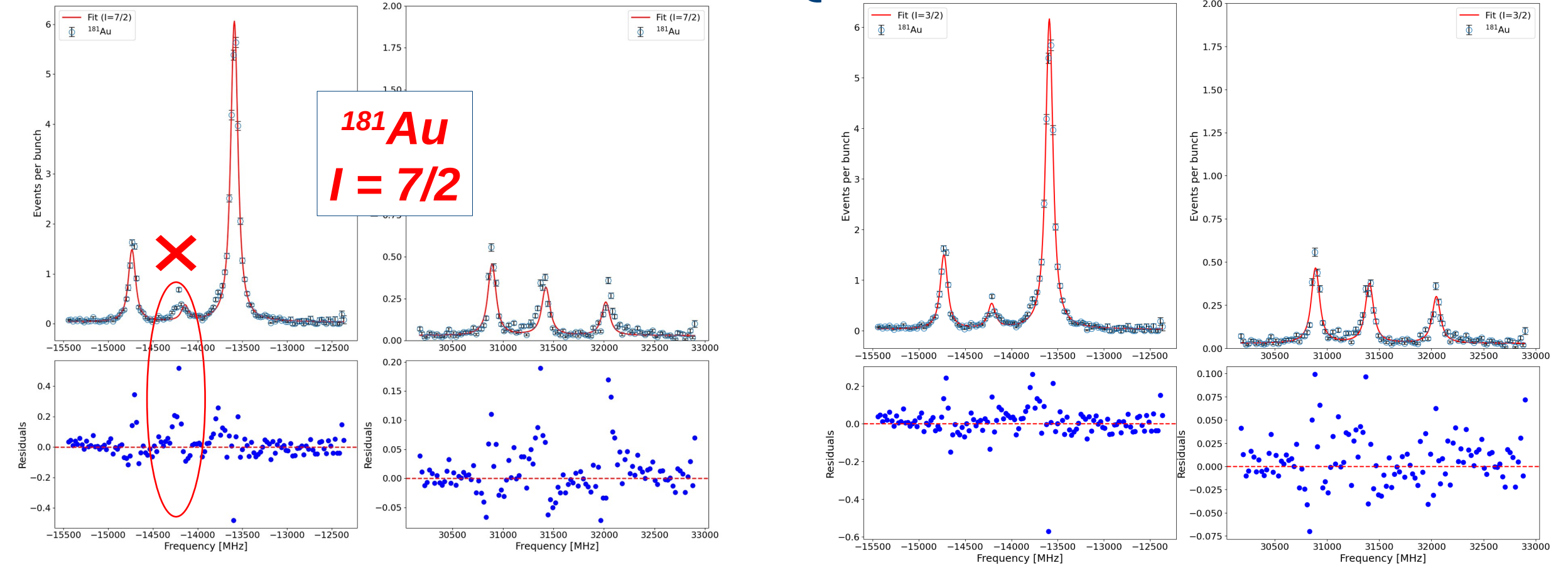
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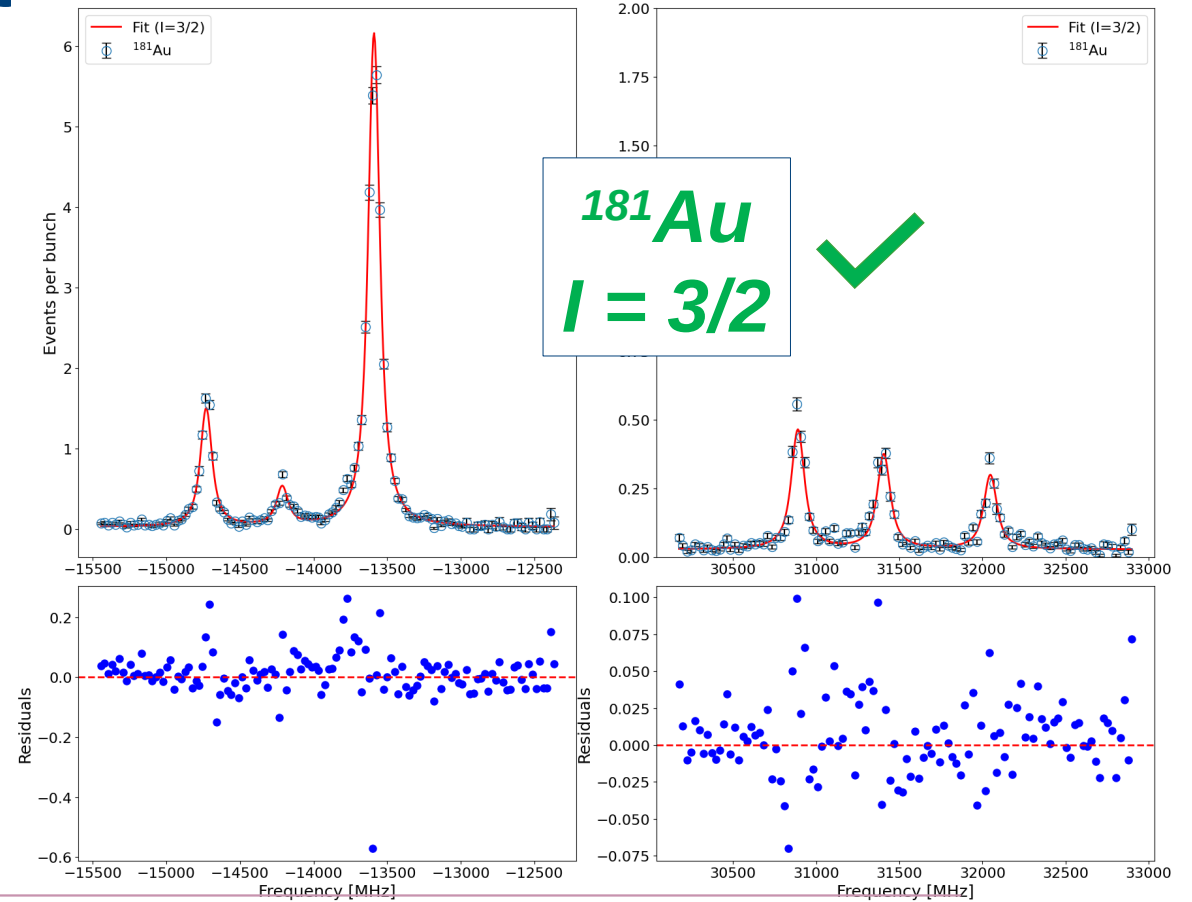
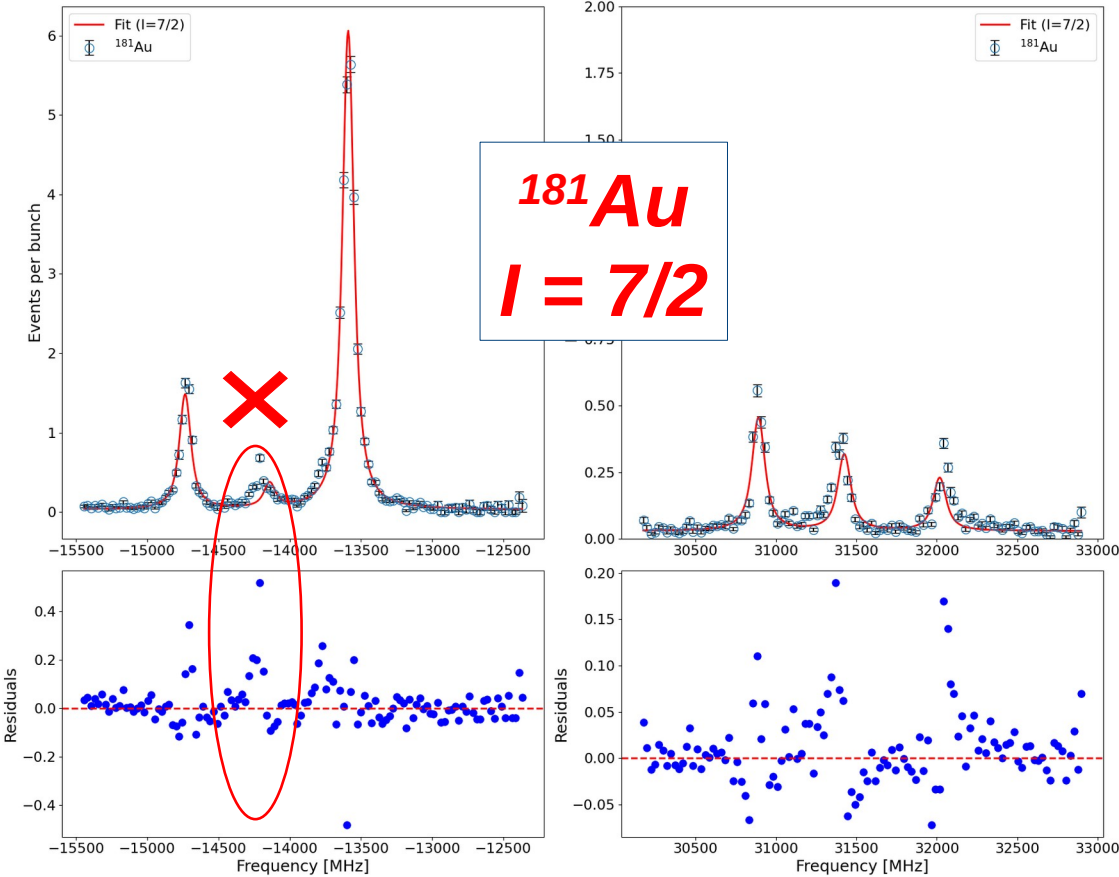
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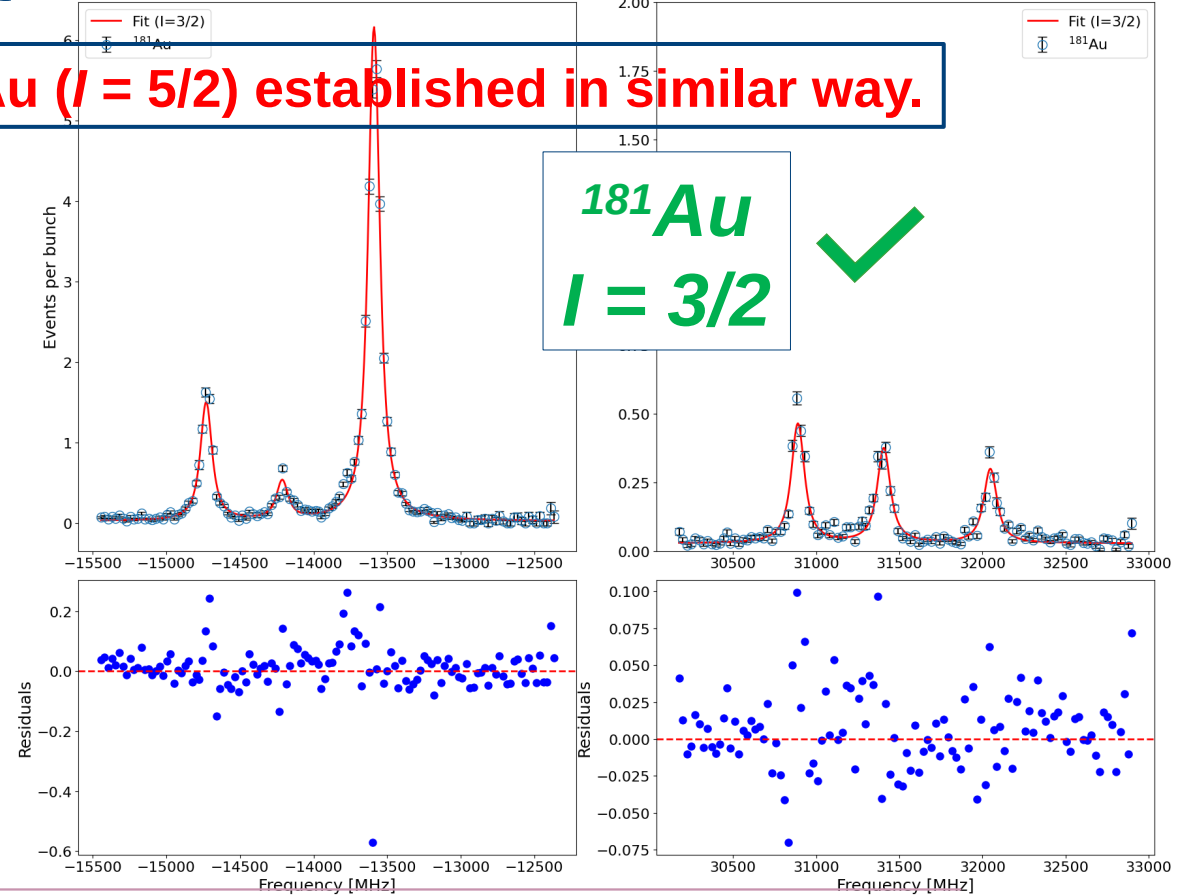
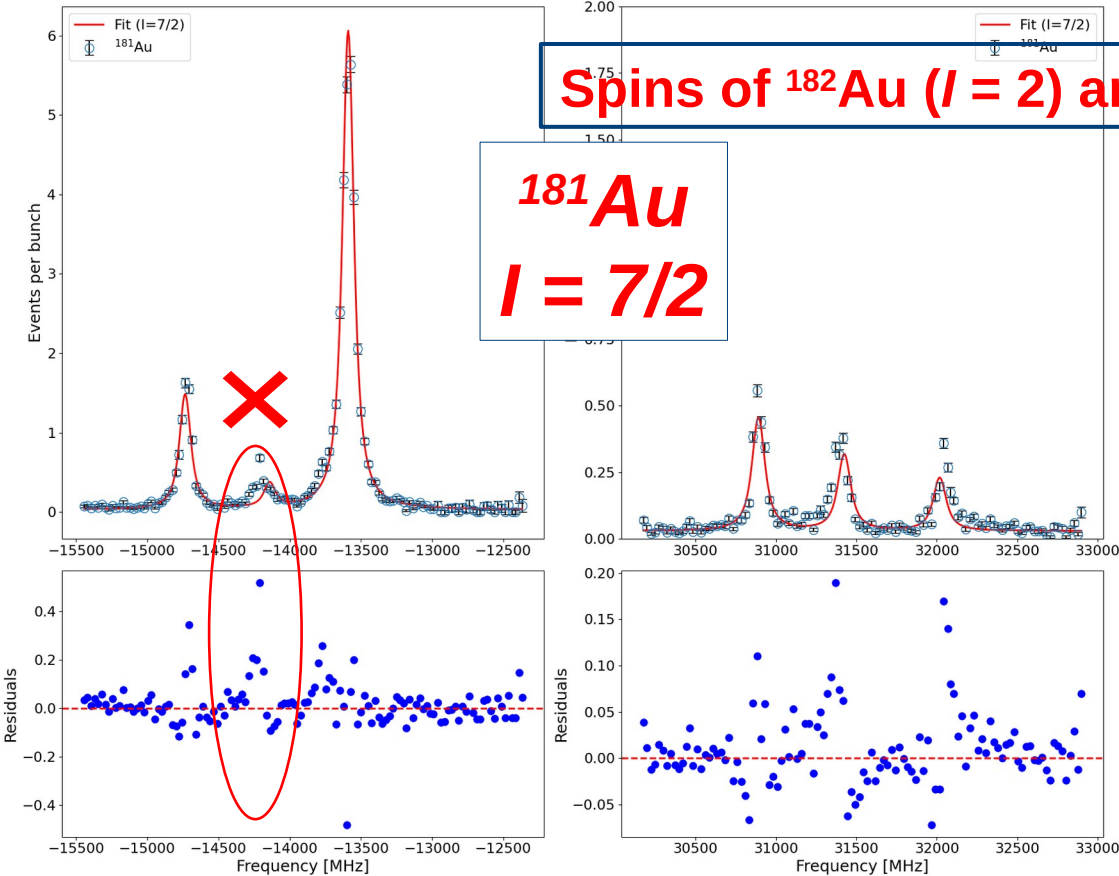
Isotope	Spin	$A(6s\ ^2S_{1/2})$	$A(6p\ ^2P_{3/2})$	$B(6p\ ^2P_{3/2})$	Centroid	A_u/A_l	χ^2_{red}
181	3/2	22809.6(18)	124.6(7)	765.8(21)	3046.09(11)	0.005	6.01
181	5/2	15382.6(14)	174.3(5)	-217.7(48)	5039.9(17)	0.011	8.81
181	7/2	11539.8(13)	135.63(43)	-177(6)	5937.7(19)	0.012	9.64

Spin assignment

Spins of ^{182}Au ($I = 2$) and ^{183}Au ($I = 5/2$) established in similar way.

^{181}Au
 $I = 7/2$

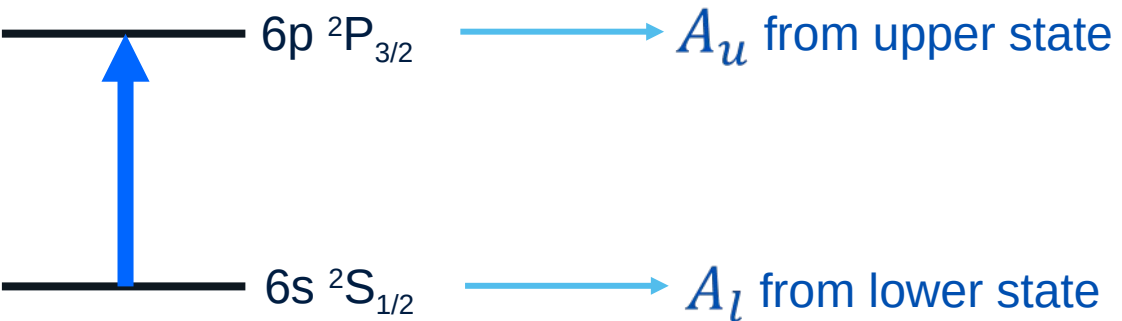
^{181}Au
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Isotope	Spin	$A(6s\ ^2S_{1/2})$	$A(6p\ ^2P_{3/2})$	$B(6p\ ^2P_{3/2})$	Centroid	A_u/A_l	χ^2_{red}
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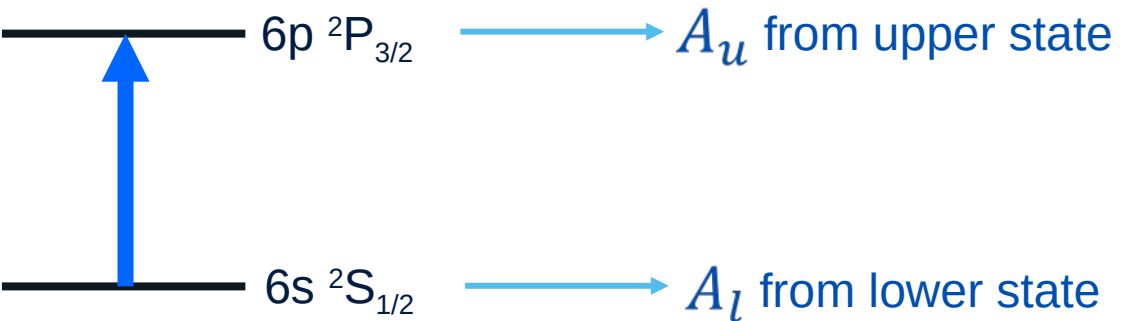
Alternative method: based on $A(P_{3/2})/A(S_{1/2})$

A_u/A_l ratio: The ratio of magnetic dipole HFS parameters of two atomic states $R = A_u/A_l$ remains constant across the isotopic chain.



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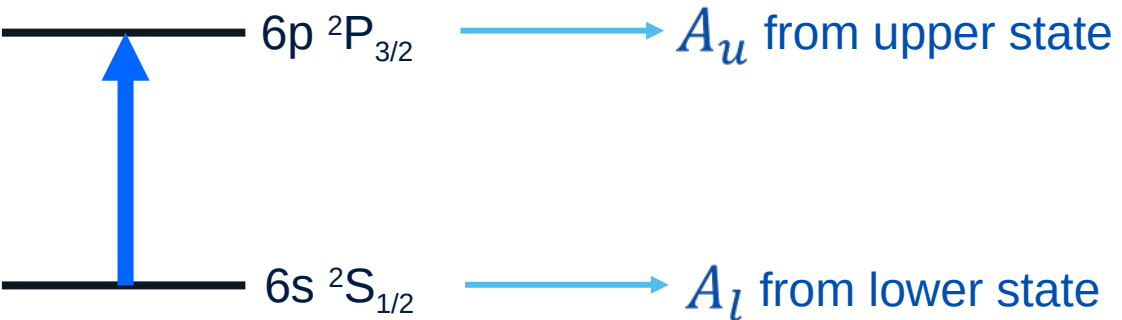
$$\frac{A(P_{3/2})}{A(S_{1/2})} = \frac{B_e(P_{3/2})}{3/2} \frac{1/2}{B_e(S_{1/2})}$$

independent of the nuclear properties

***if the HFS spectrum is fitted with the correct nuclear spin**

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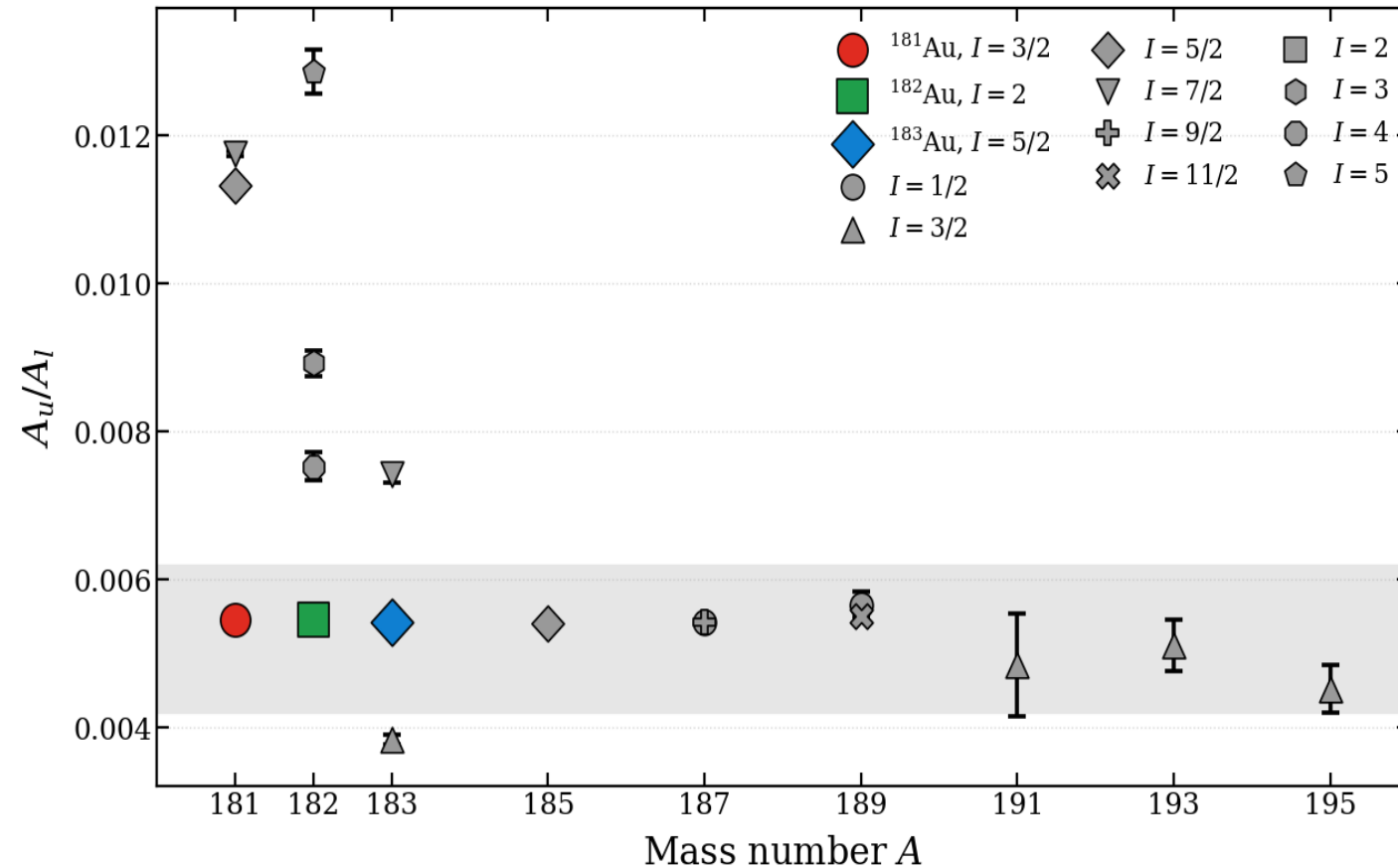
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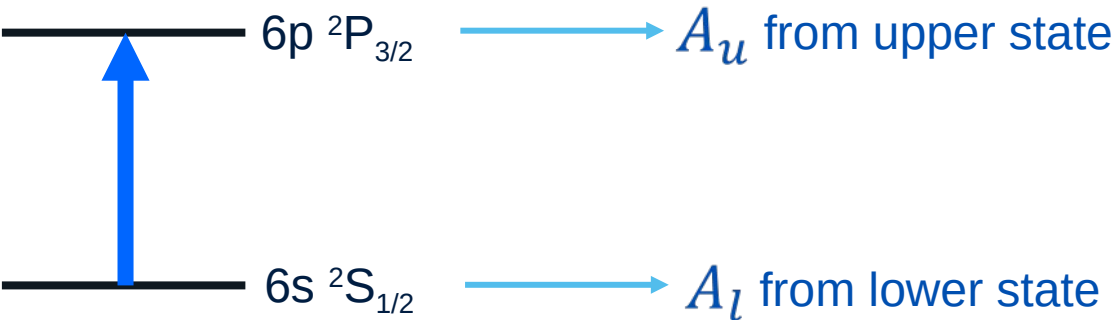
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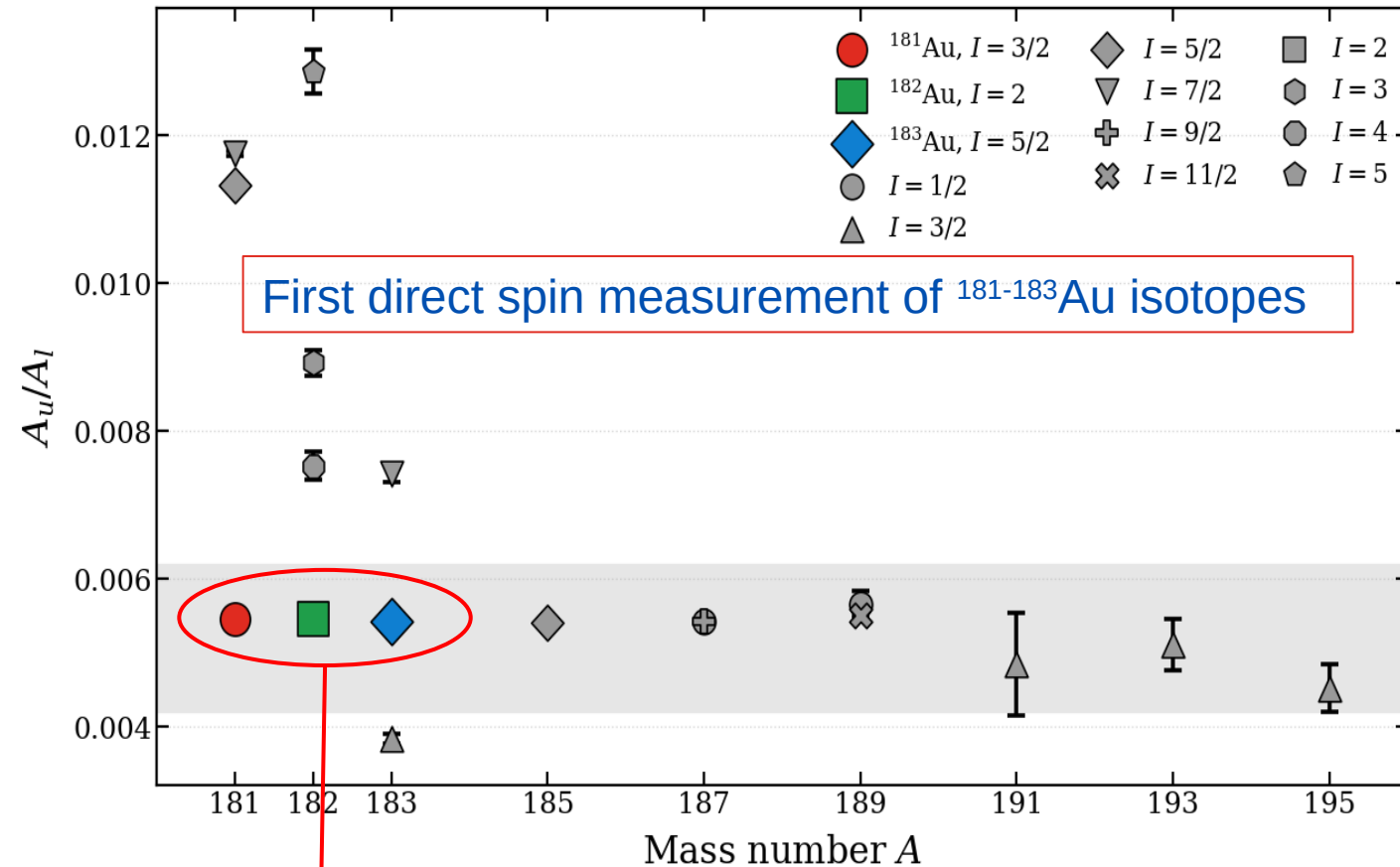
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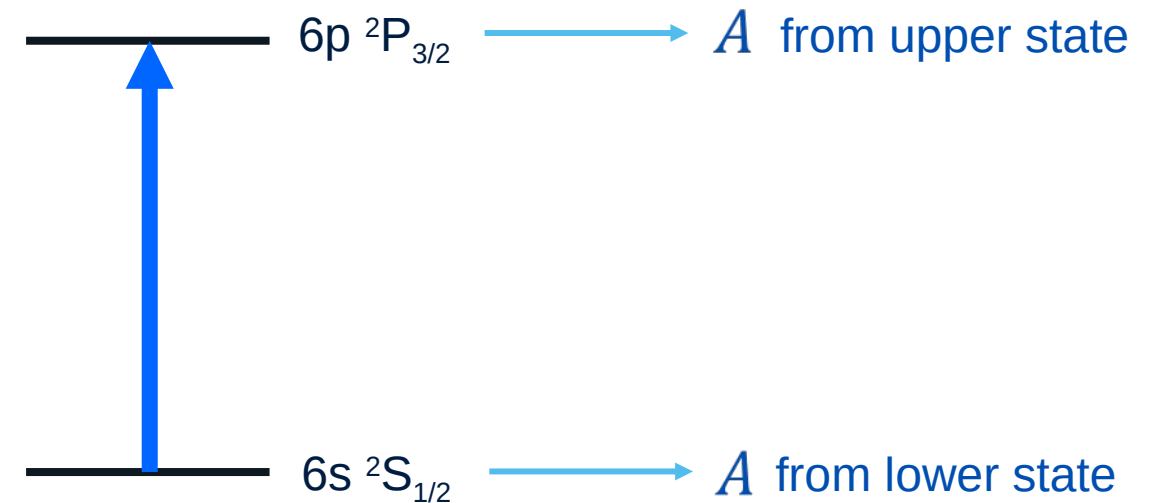
New spin assignments

^{181}Au : $I = 3/2$

^{182}Au : $I = 2$

^{183}Au : $I = 5/2$

Magnetic dipole moment and Hyperfine Anomaly

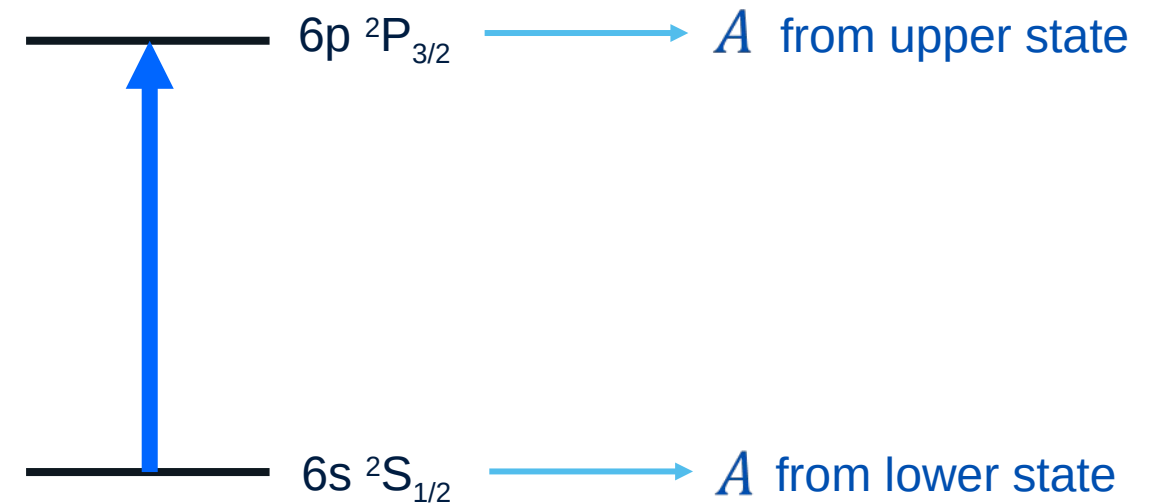


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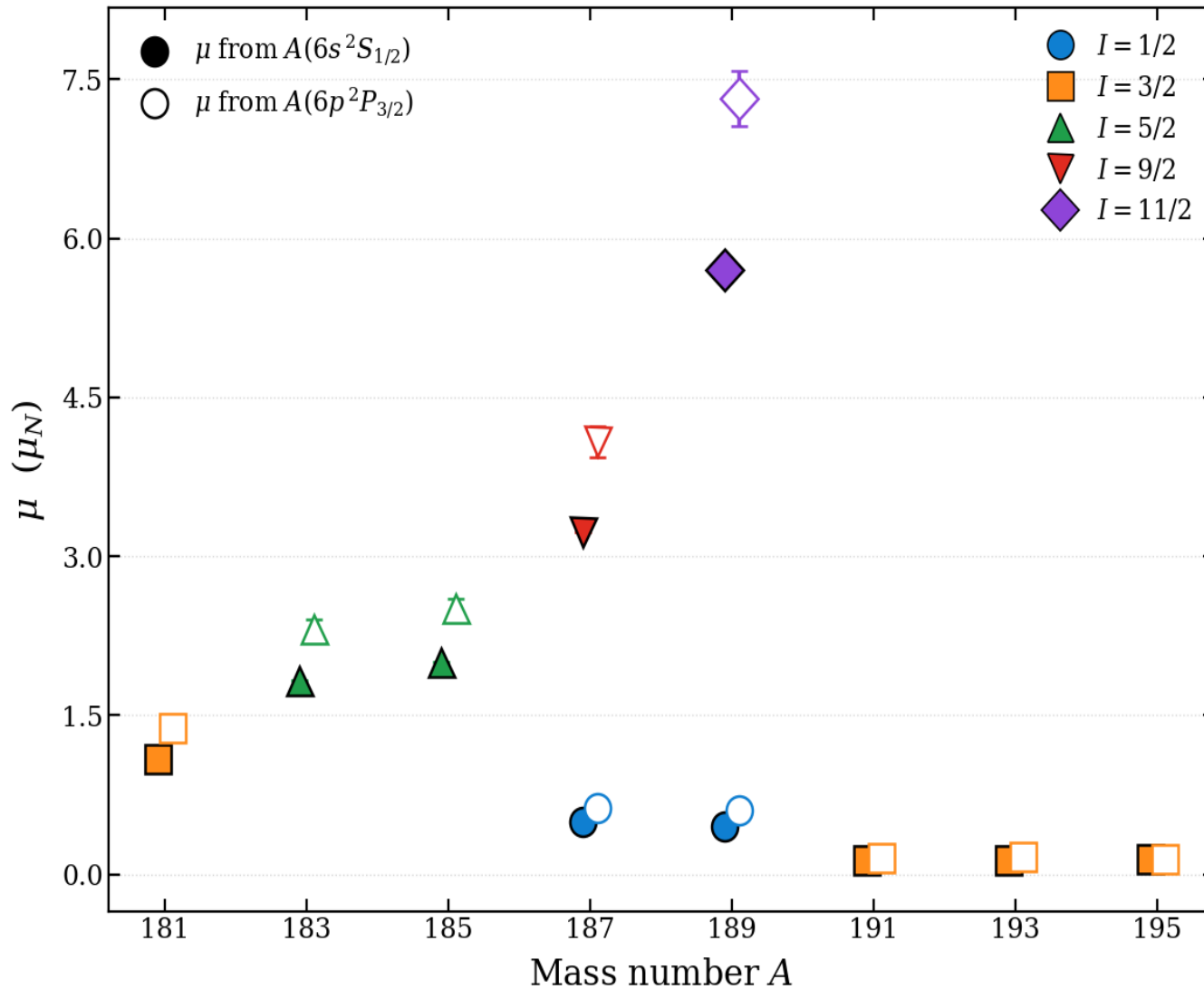
$$A = \mu \frac{B_e(0)}{IJ} \quad \text{from } A \text{ to } \mu$$

$$\mu_A = \mu_{197\text{Au}} \frac{I_A}{I_{197\text{Au}}} \frac{A_A}{A_{197\text{Au}}}$$

$$\mu \text{ from } A(^2S_{1/2}) = \mu \text{ from } A(^2P_{3/2})$$



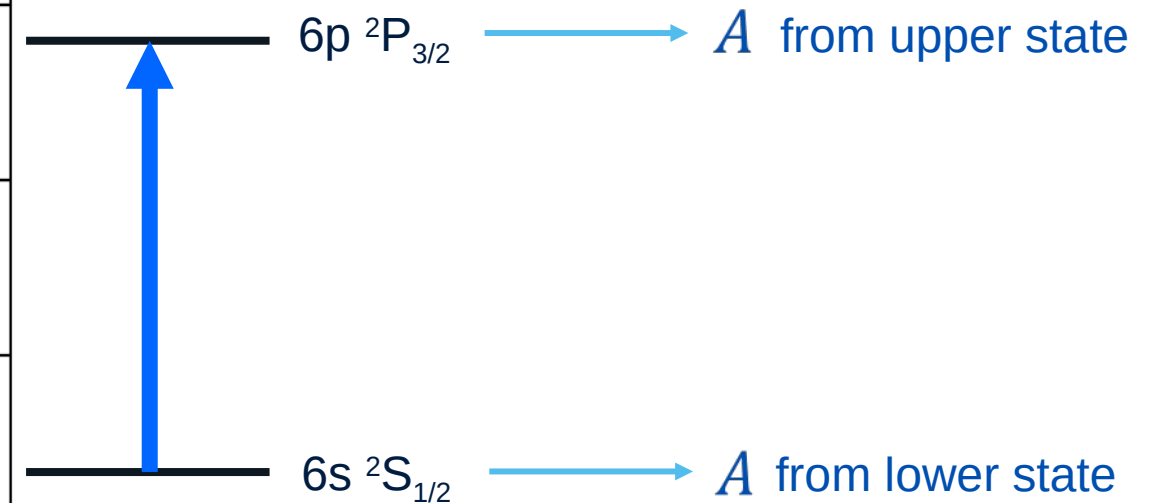
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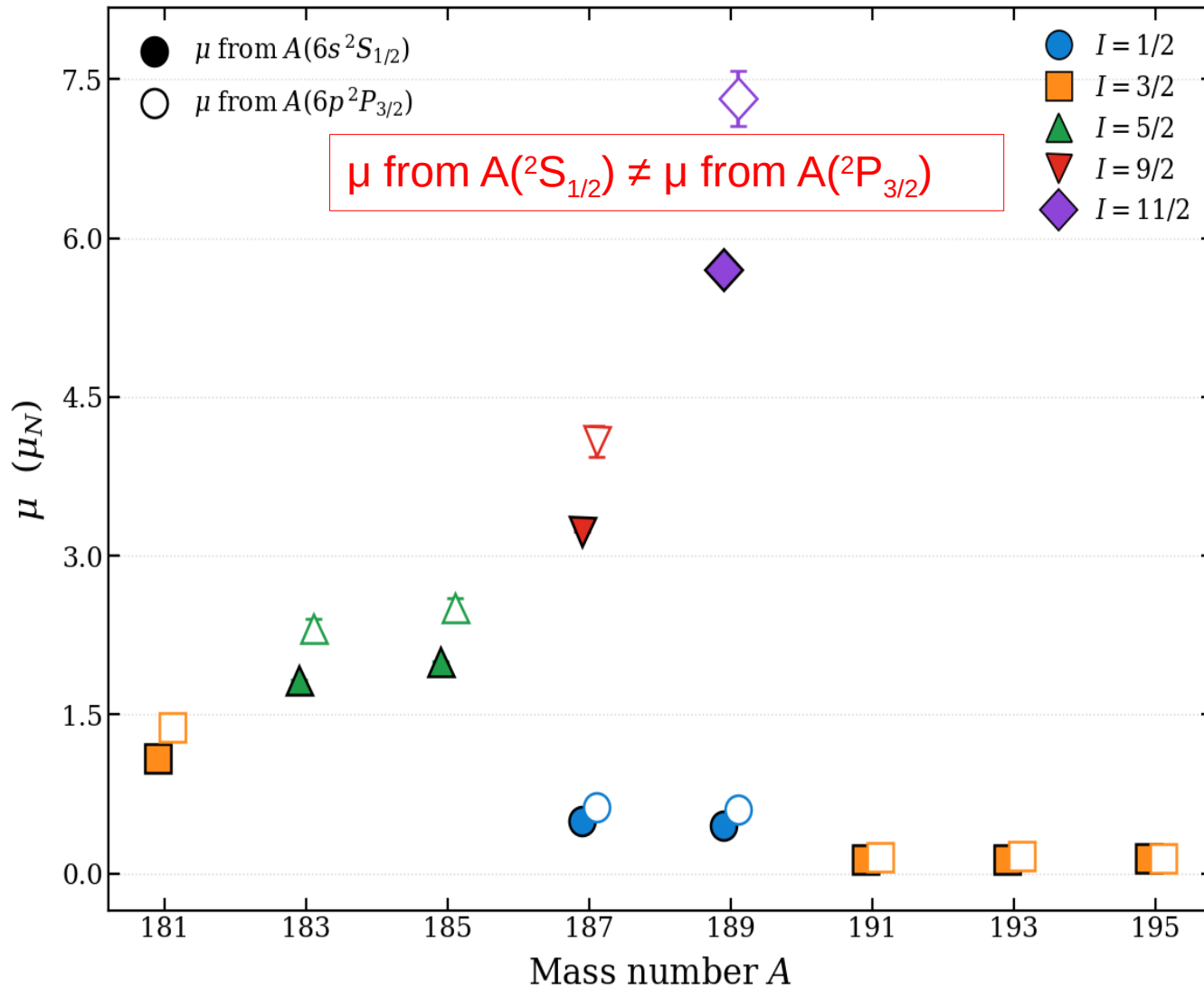
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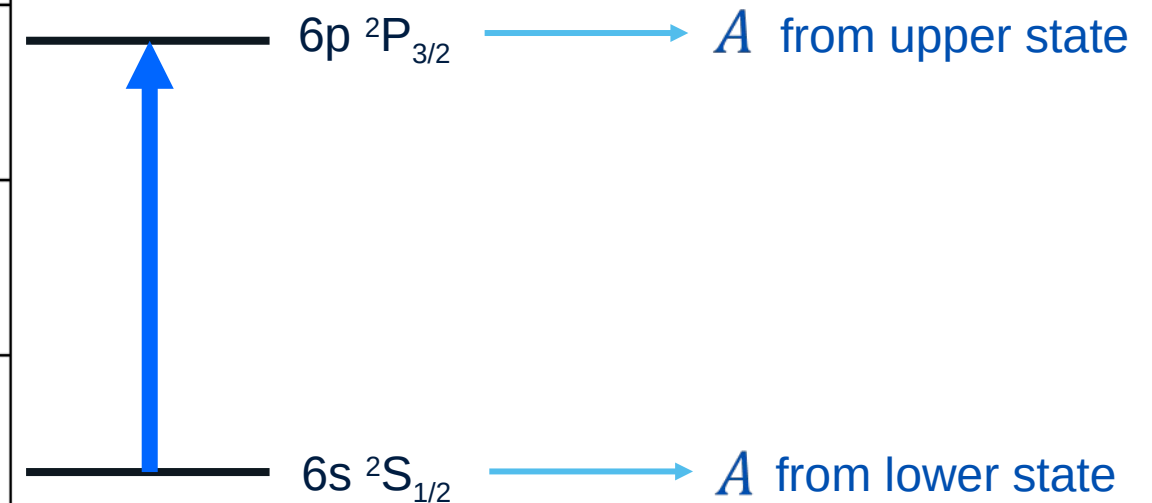
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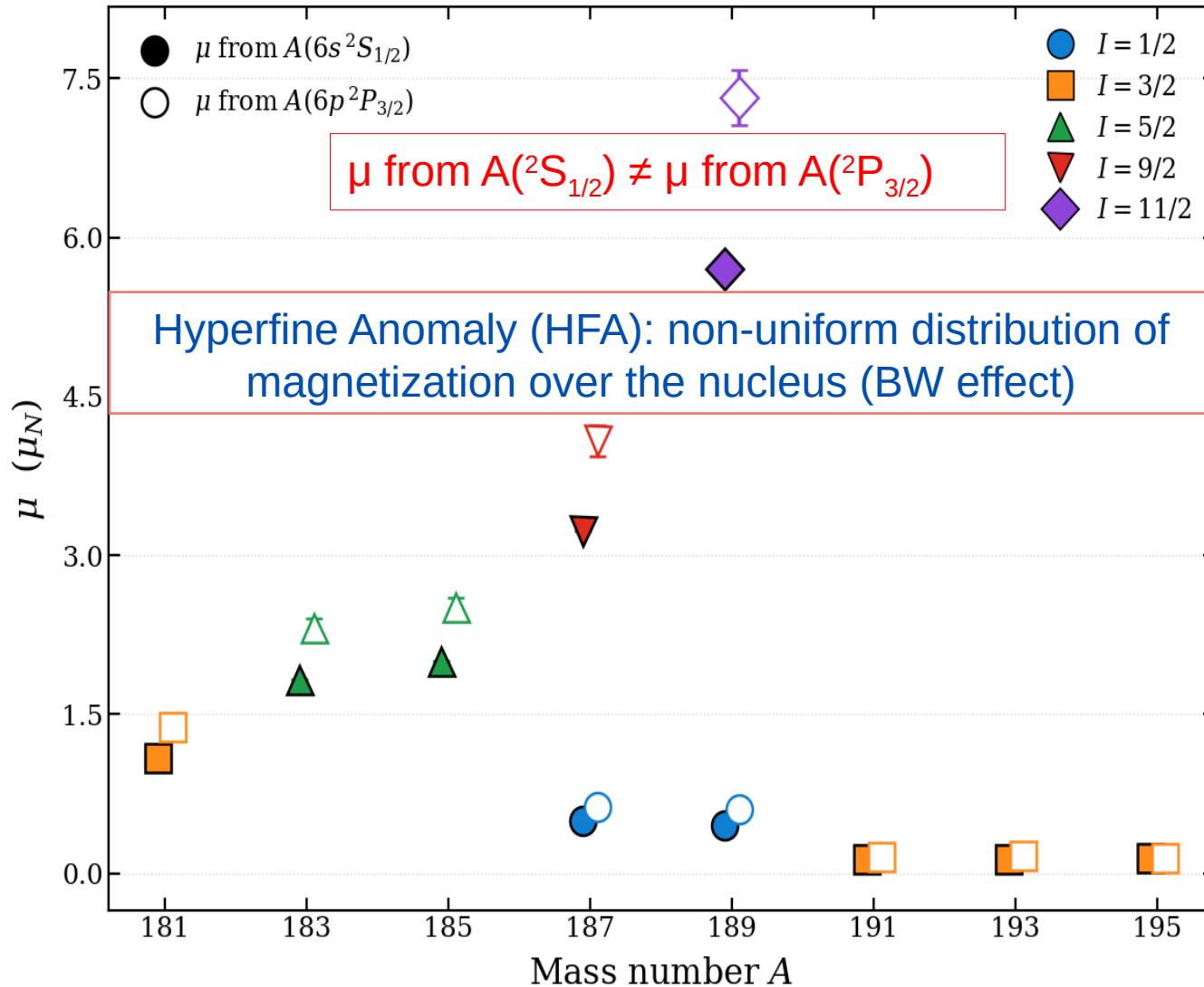
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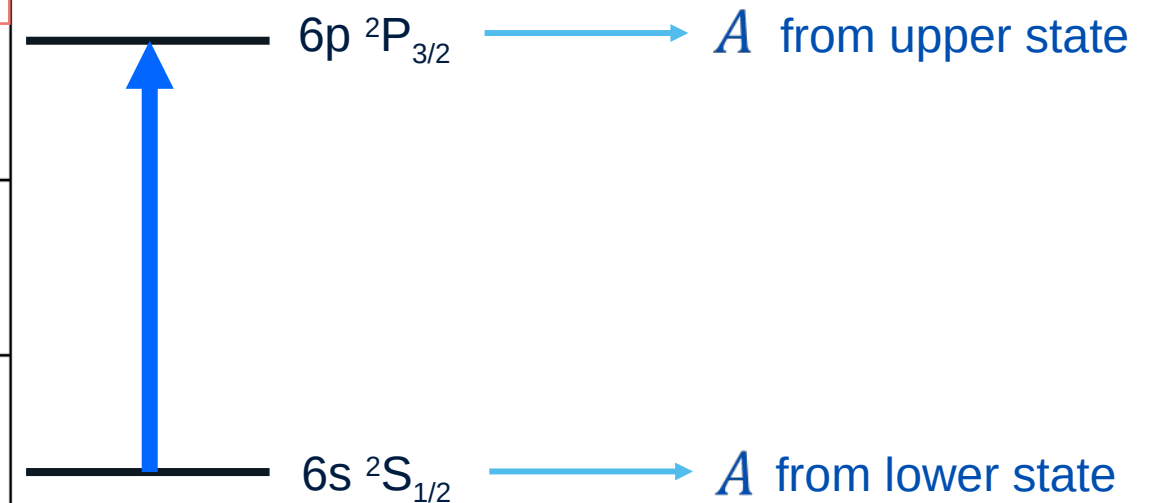
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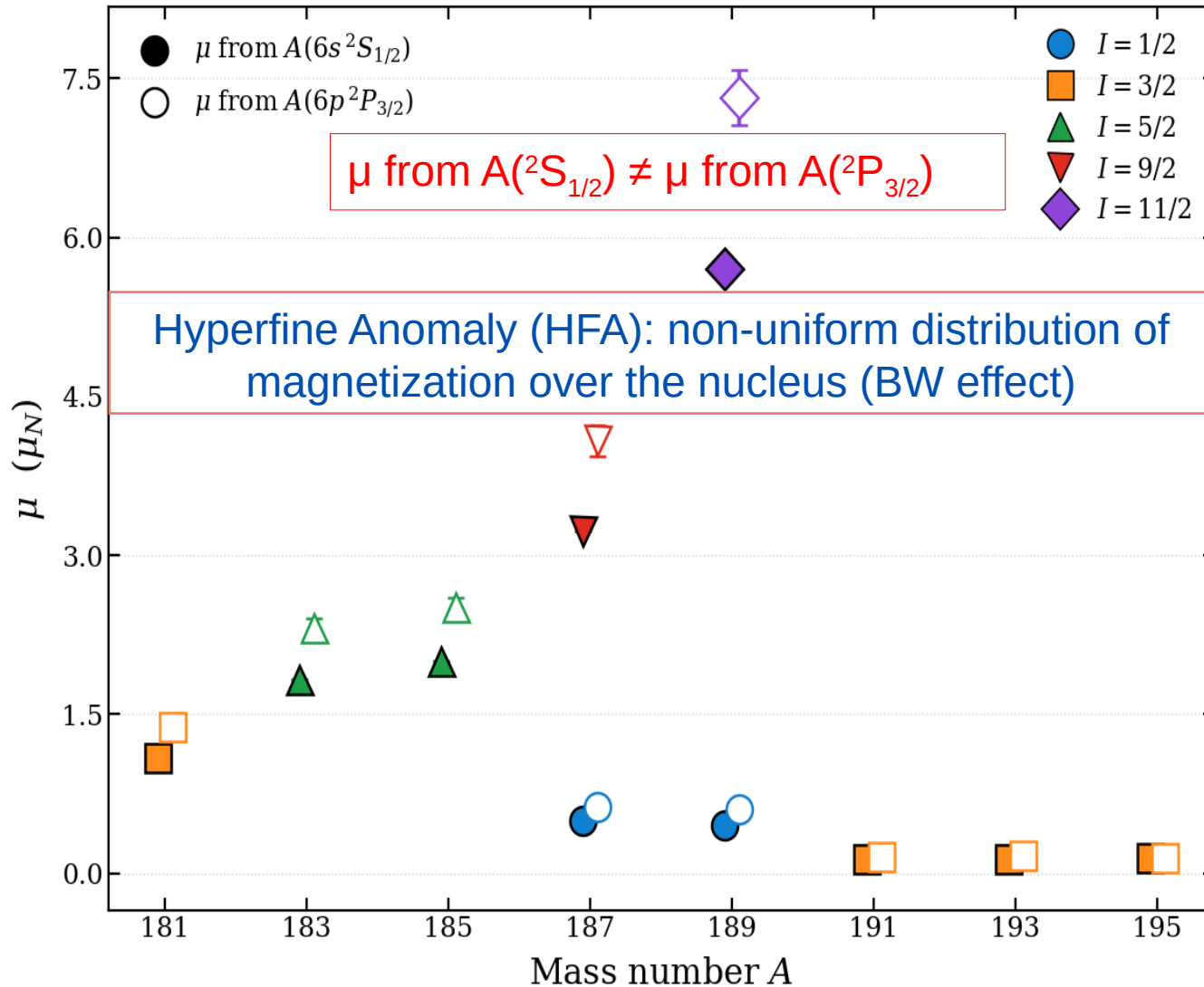
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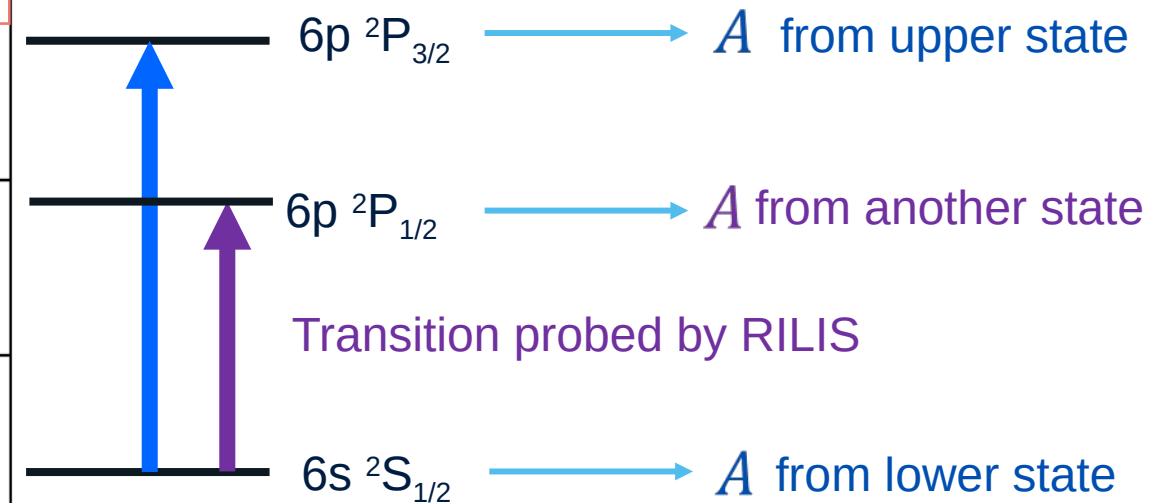
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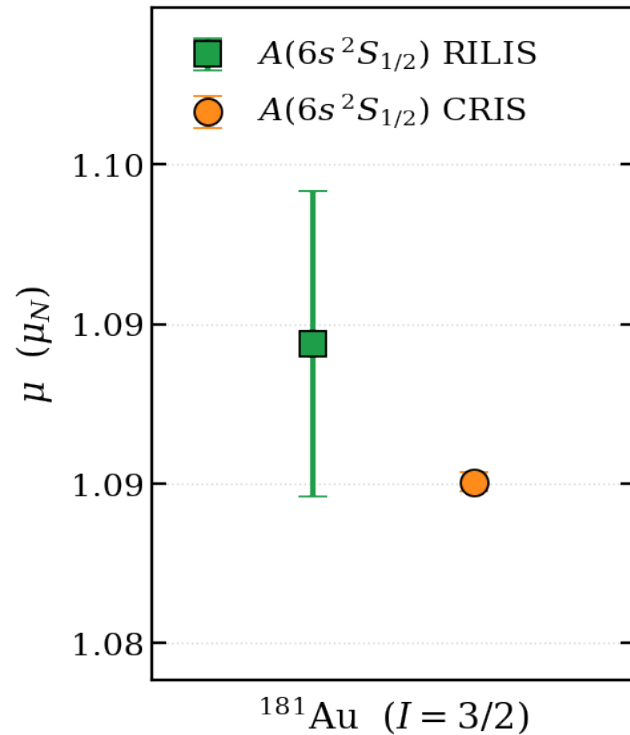
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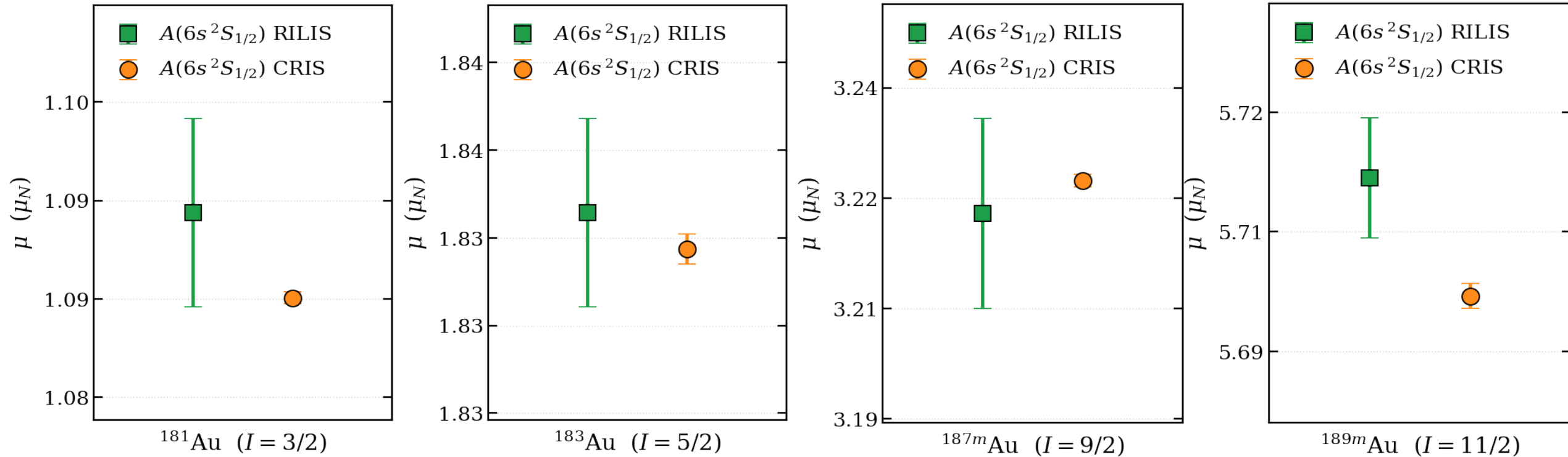


Magnetic dipole moment



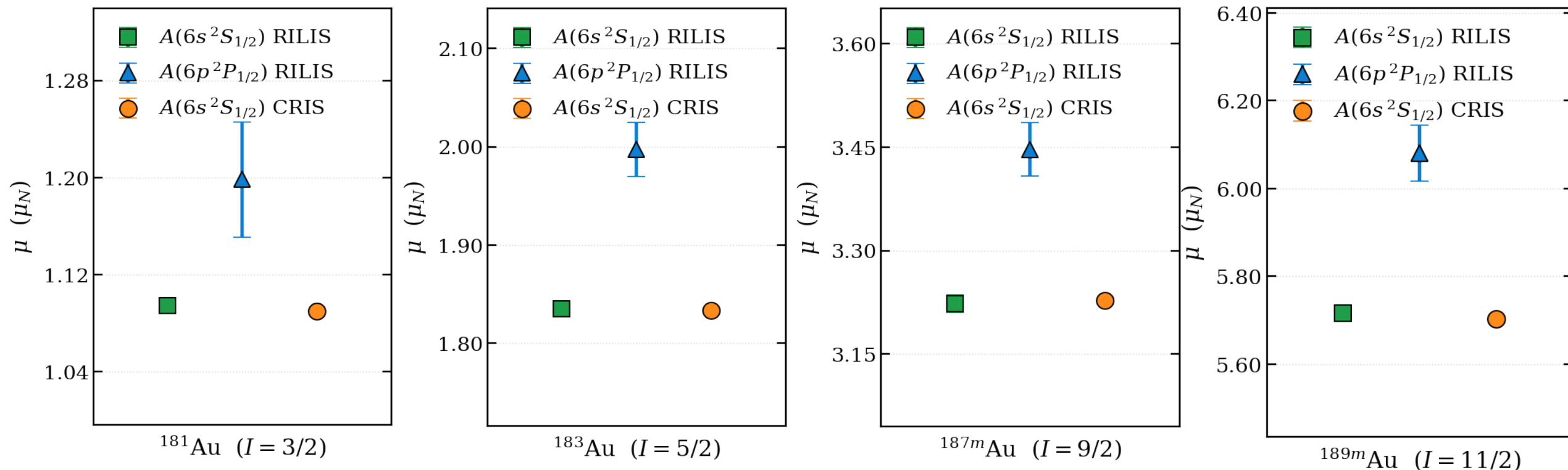
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Magnetic dipole moment



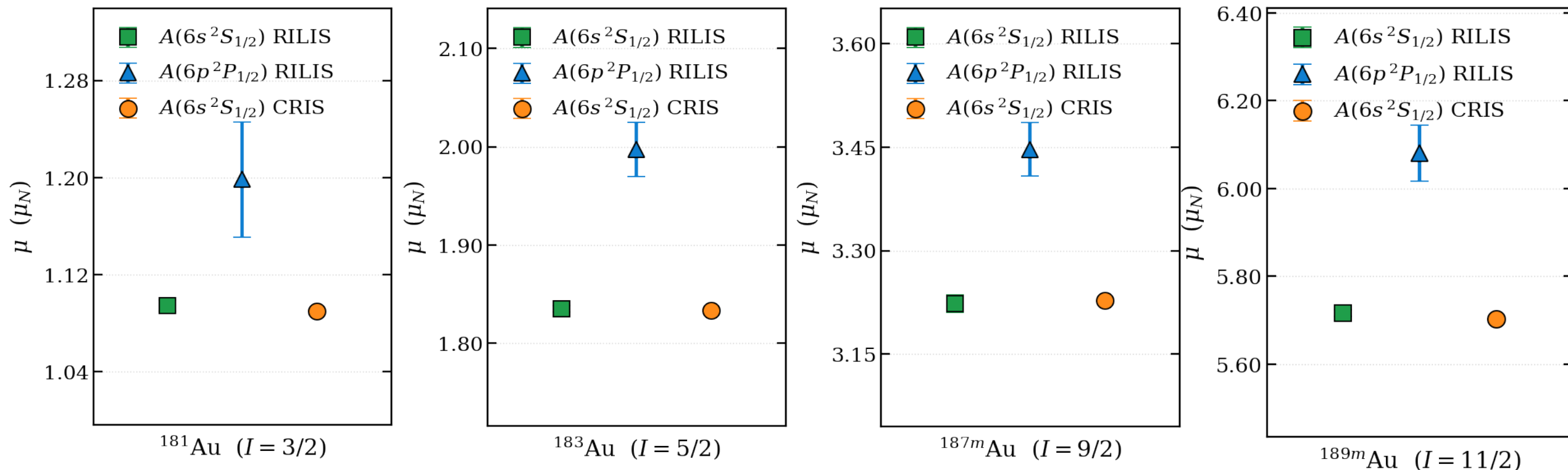
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- $A(6s^2S_{1/2})$ value for ^{189m}Au is debated in literature [1-2].

μ from different electronic levels



- $A(6p^2P_{1/2})$ values from RILIS have precision of 1-4% [1-3]
- $\mu(6s^2S_{1/2})$ RILIS don't agree with $\mu(6p^2P_{1/2})$ RILIS
- μ from $6s^2S_{1/2}$ is different ($2\sigma - 6\sigma$) from μ from $6p^2P_{1/2}$

μ from different electronic levels



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- μ from $6s^2S_{1/2}$ is different (2σ - 6σ) from μ from $6p^2P_{1/2}$

HFA calculations from theory needed!

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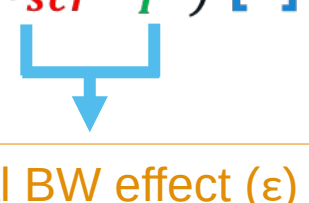
↓
Total BW effect (ϵ)

The parameters highlighted in red are defined only by the electronic wavefunction – calculated.
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Systems of 2 equations and 2 unknowns using $A(6s \ ^2S_{1/2})$ (CRIS, most precise) and $A(6p \ ^2P_{1/2})$ (RILIS)

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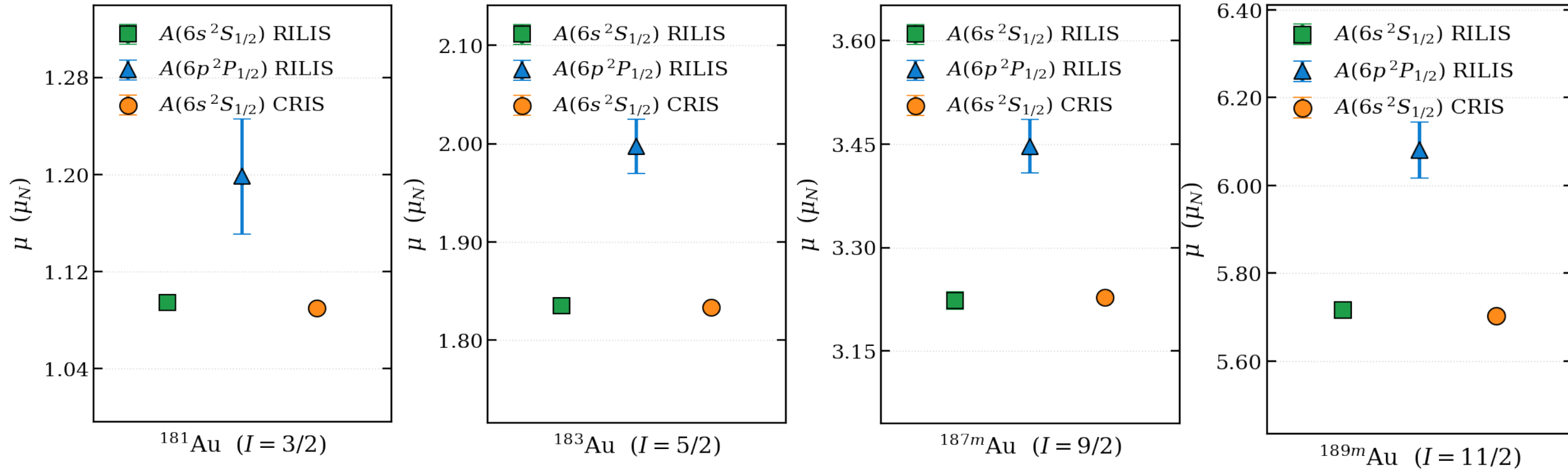
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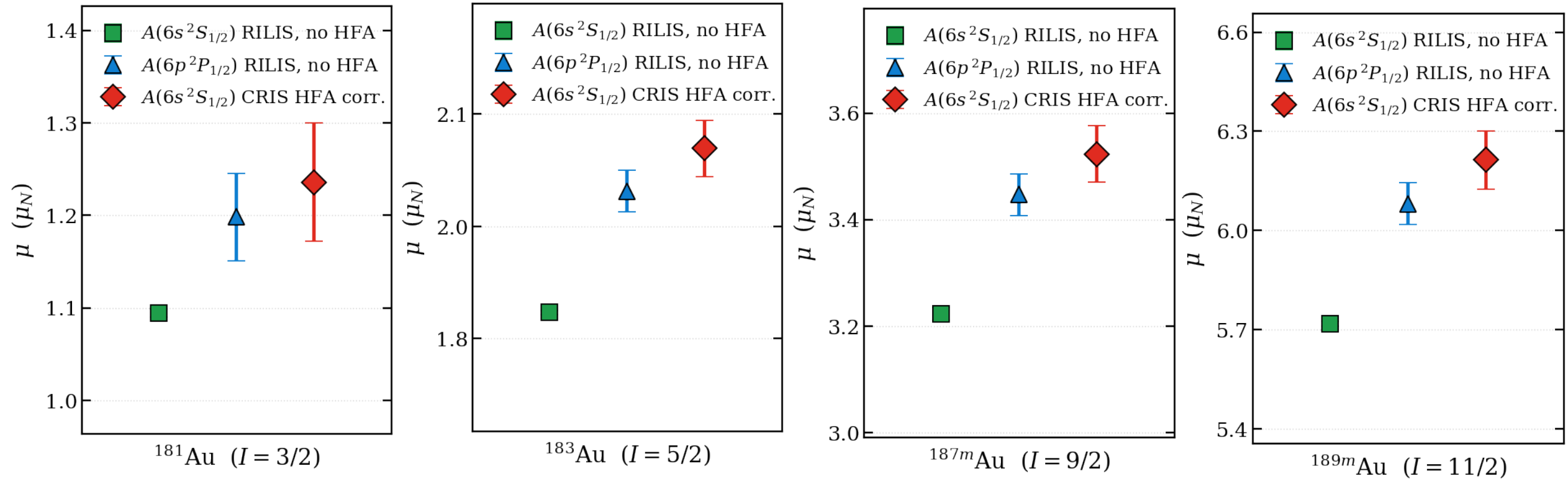
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Calculations by **J.S.M Ginges** and **C.J West**.
 University of Queensland, Australia

Magnetic dipole moment

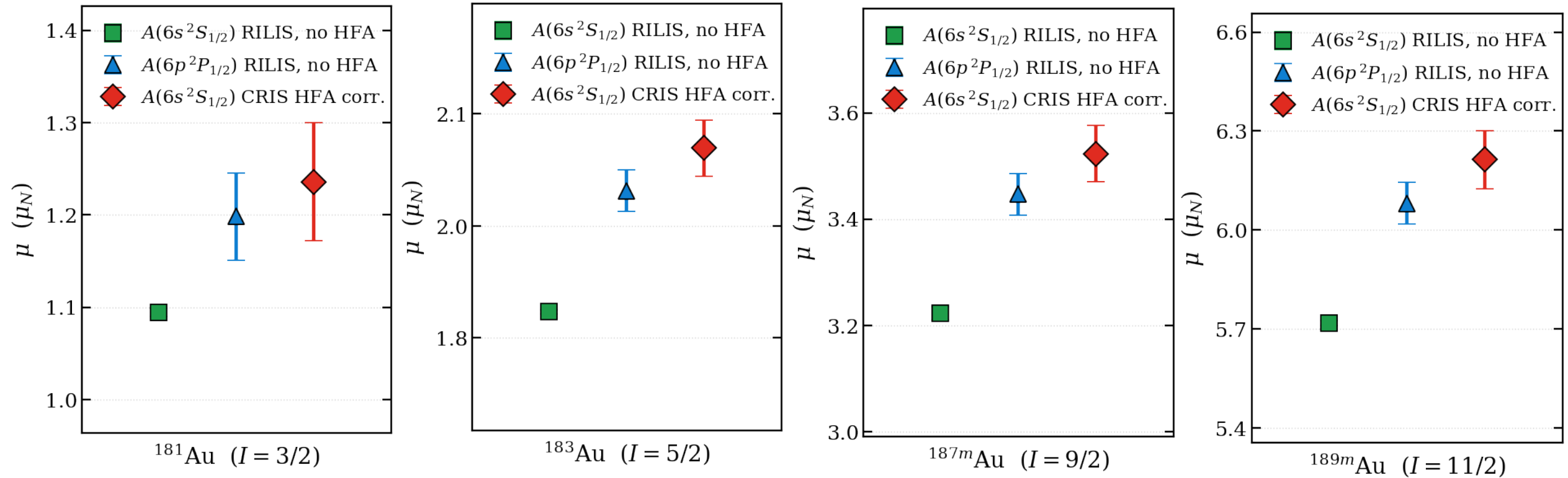


HFA correction (CRIS)



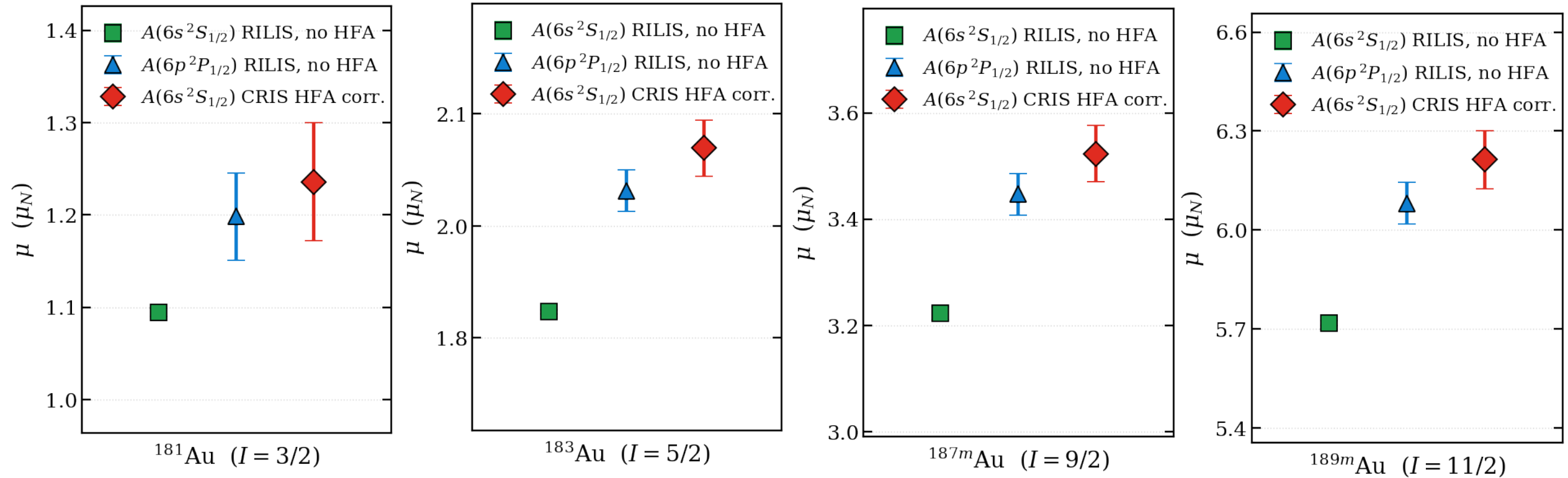
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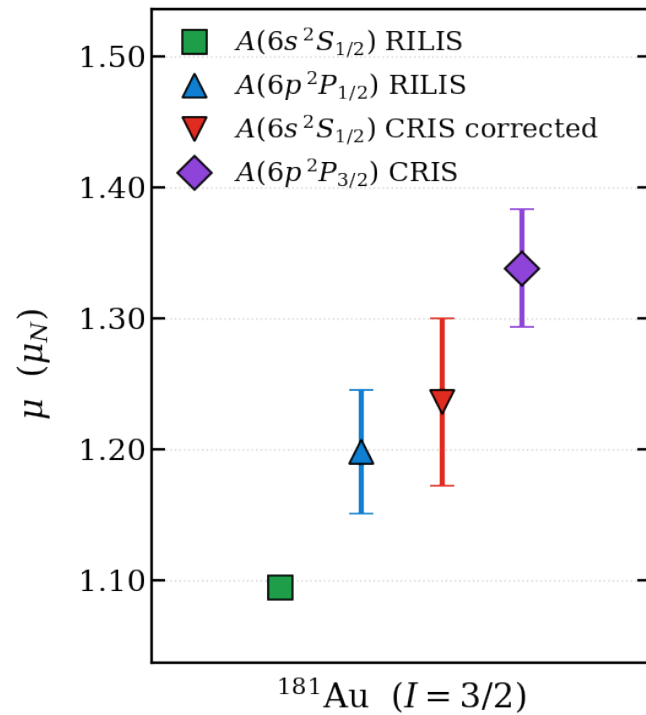
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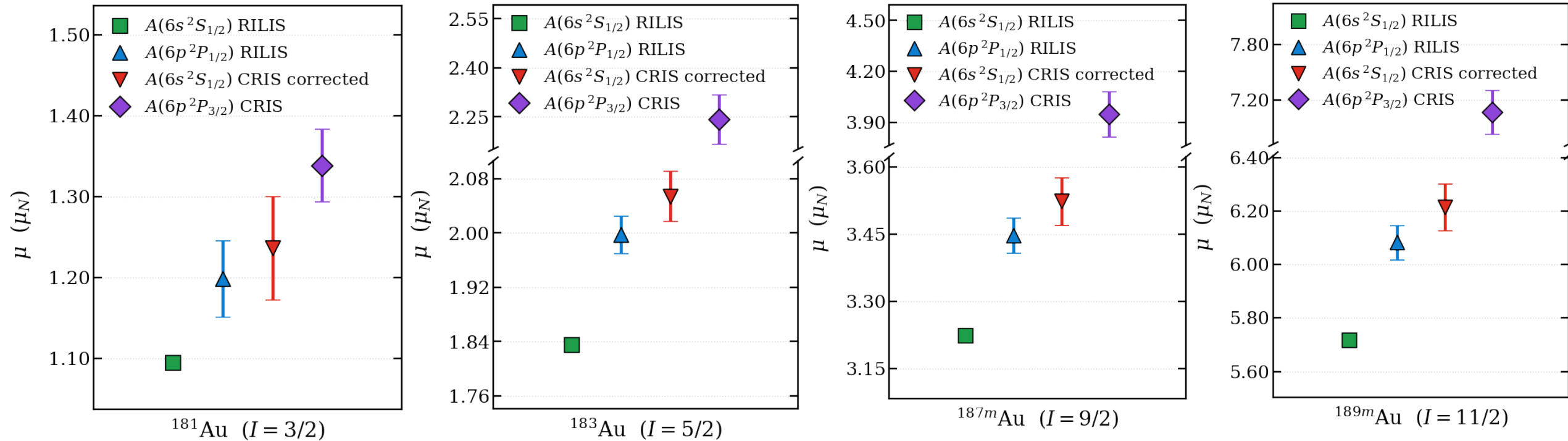
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μ from $A(6p \ ^2P_{3/2})$ CRIS ?

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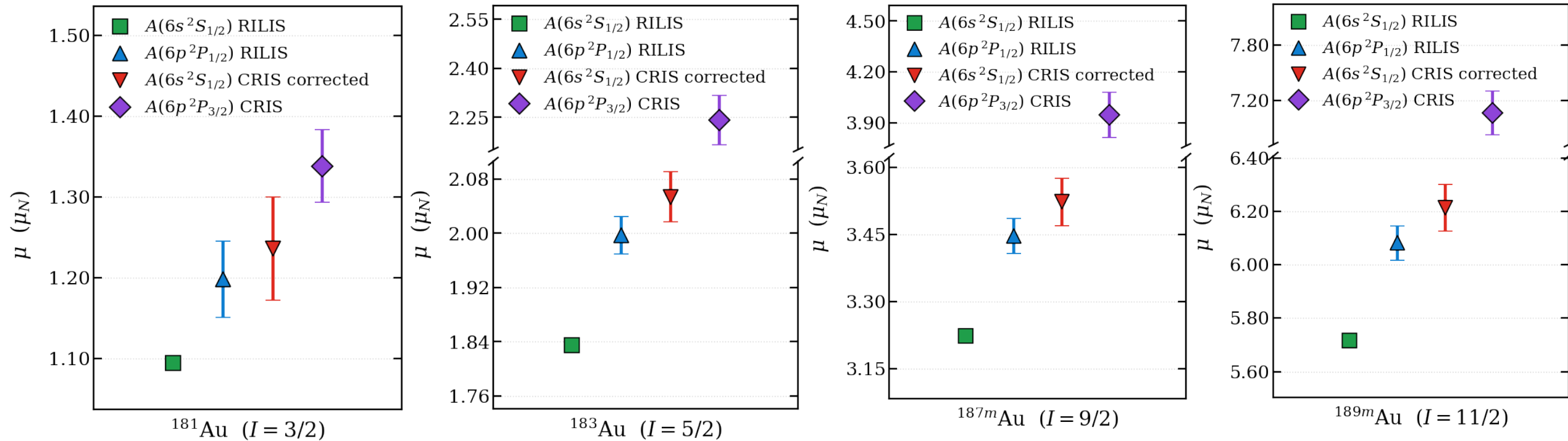


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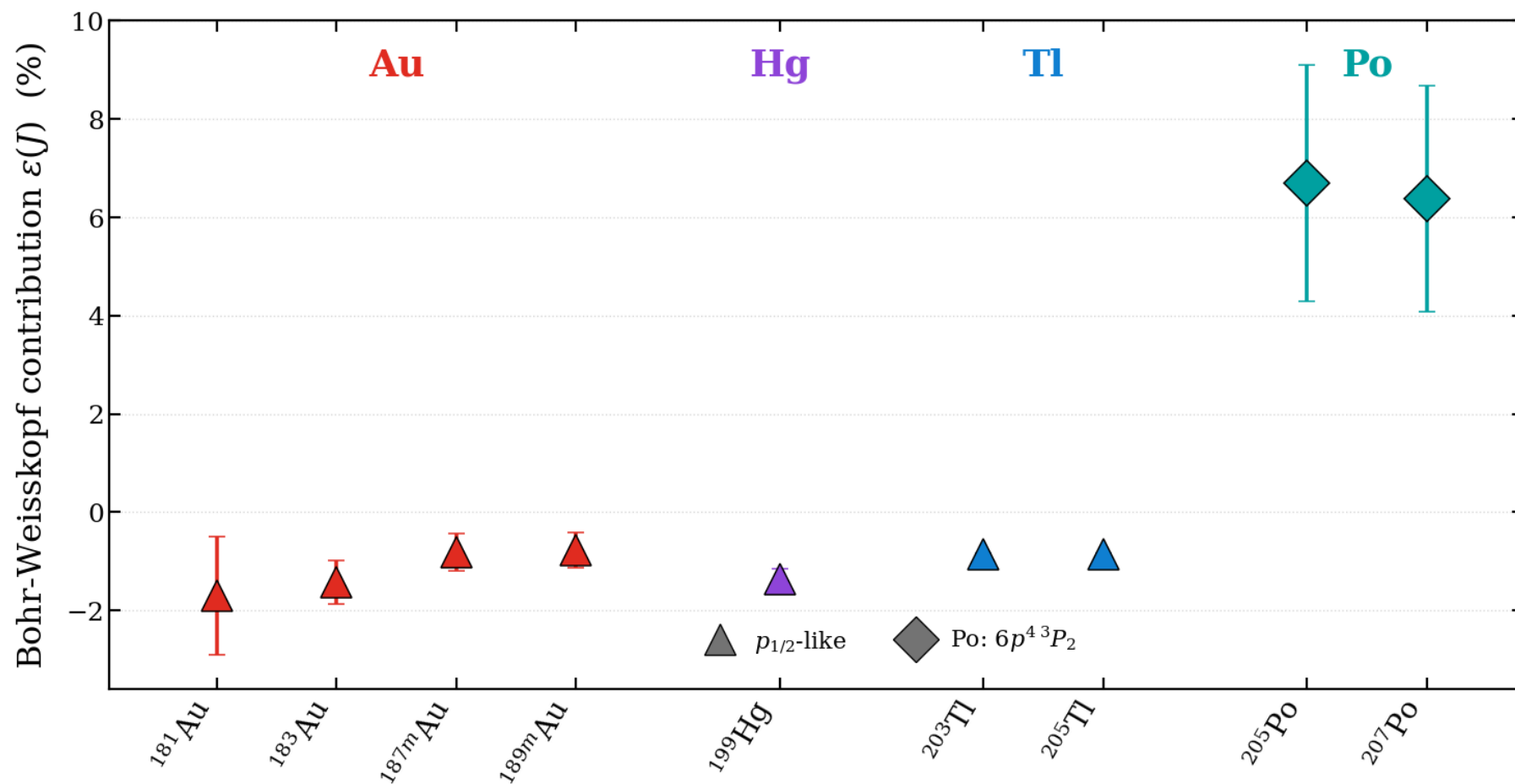
What about atomic calculations for $P_{3/2}$?

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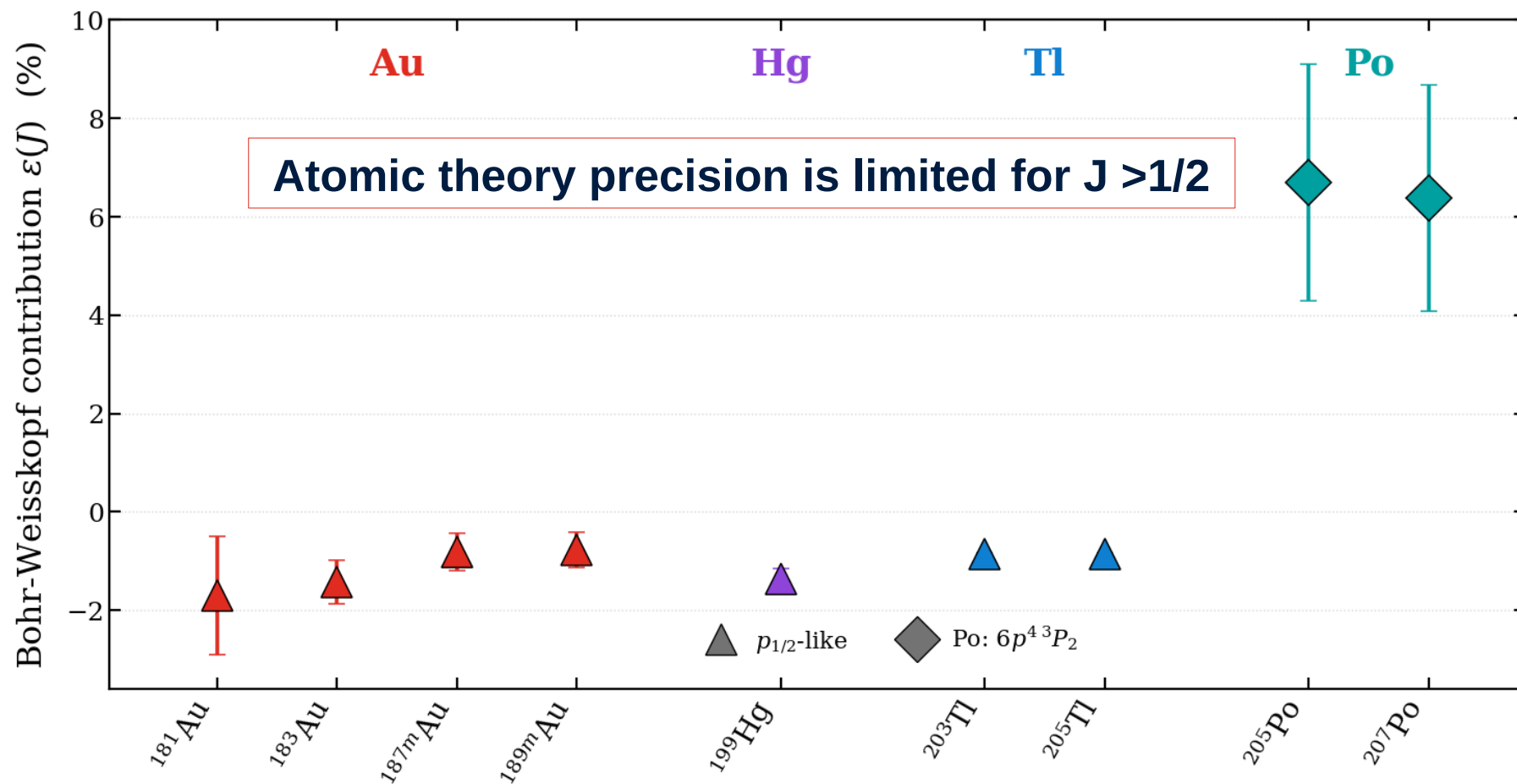
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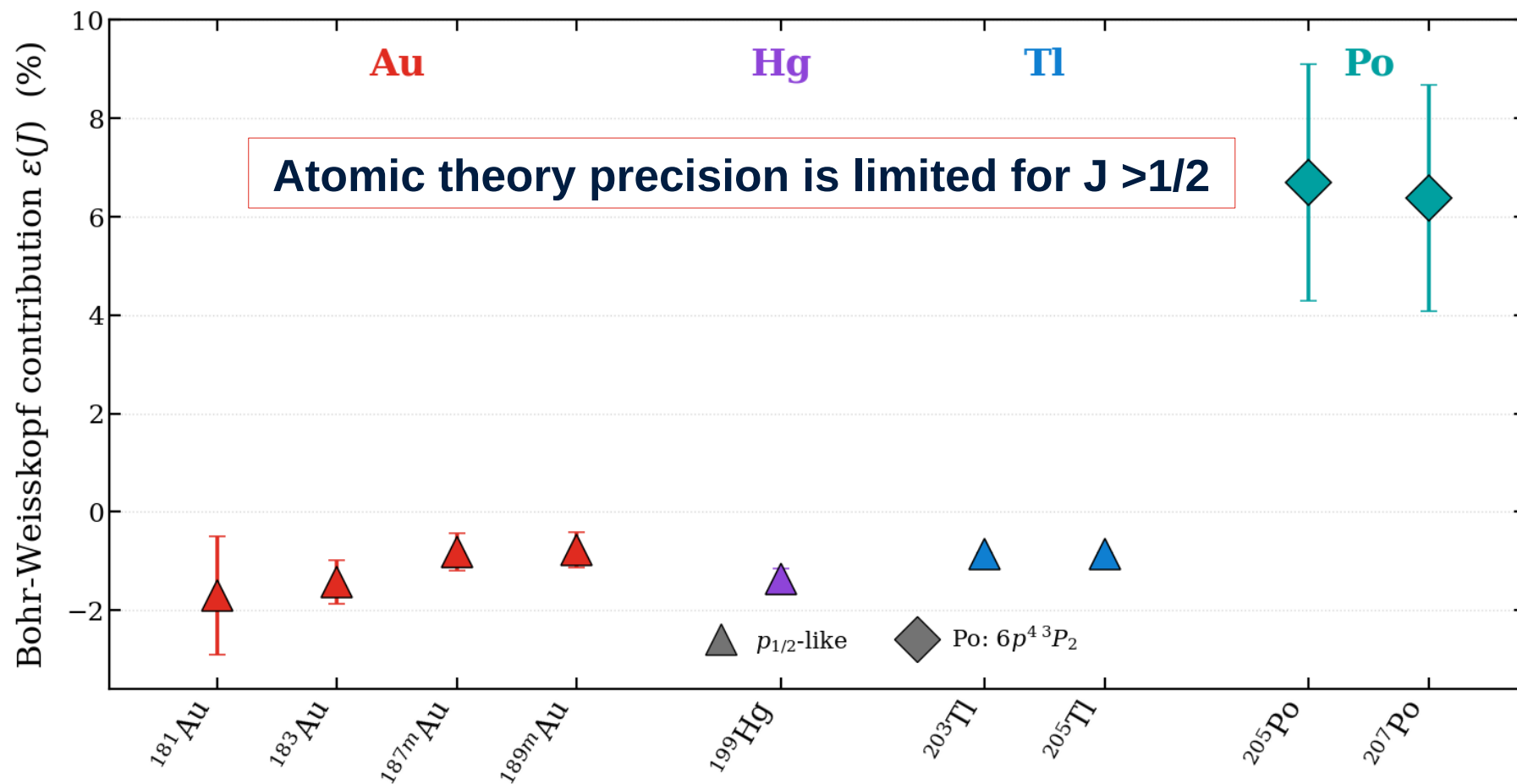
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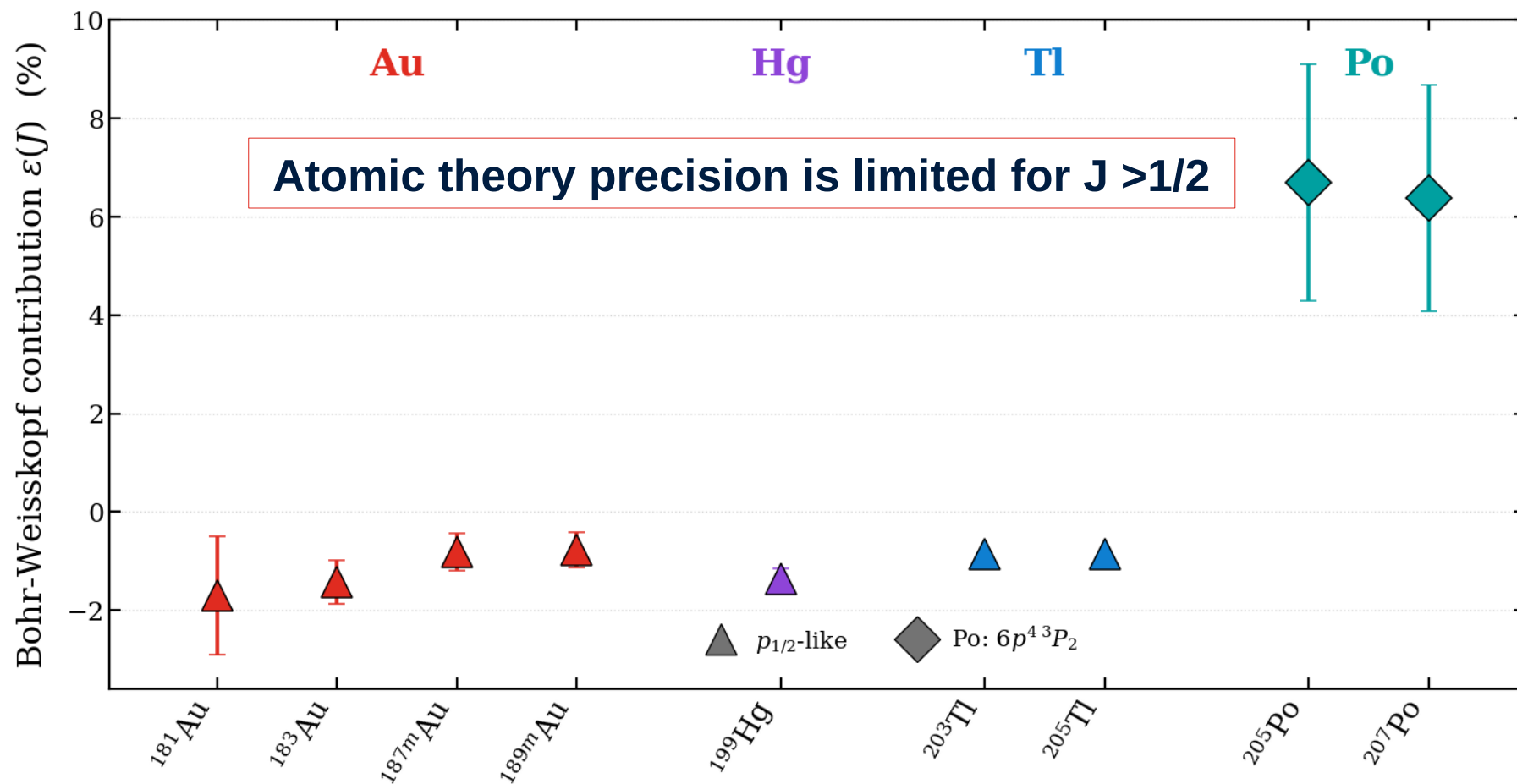


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Reliable μ extraction using two different transitions in systems with known BW effect



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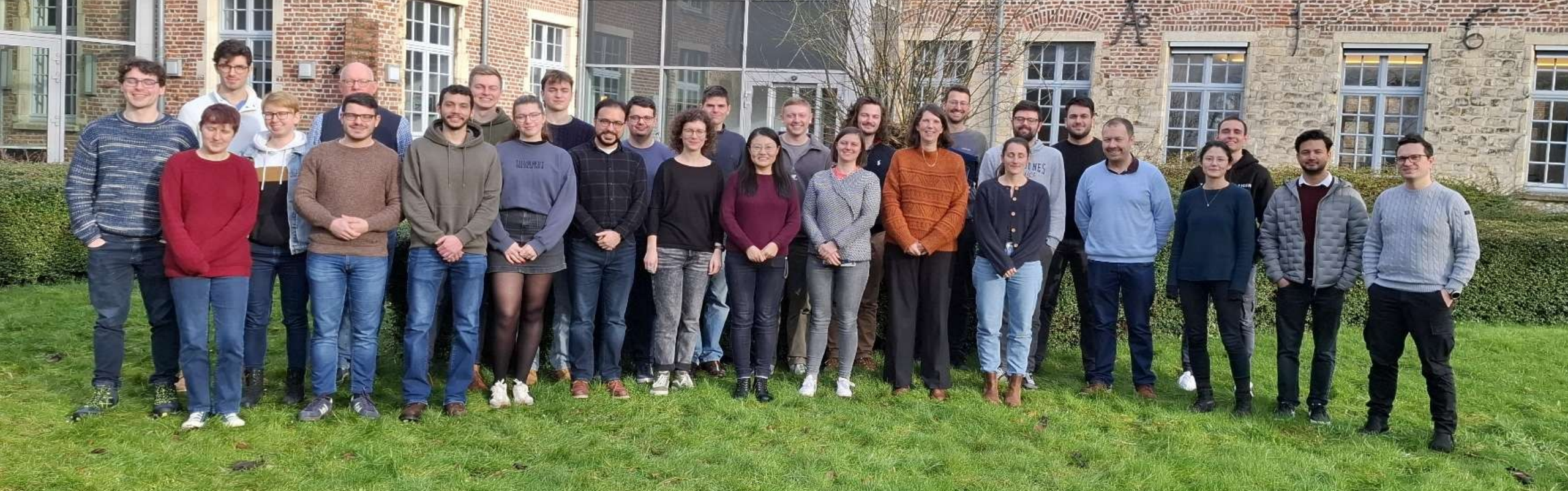
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- The Quadrupole moments, Q_s for the isotopes in the “island of deformation” ($^{181-186}\text{Au}$) have also been (re)measured (Interpretation in progress, interesting nuclear structure phenomena!!)



KU LEUVEN

sck cen

MANCHESTER
1824

The University of Manchester

CRIS Collaboration



UNIVERSITY OF
GOTHENBURG



**Massachusetts
Institute of
Technology**



北京大学
PEKING UNIVERSITY

UC lab
Irène Joliot-Curie
Laboratoire de Physique
des 2 Infinis

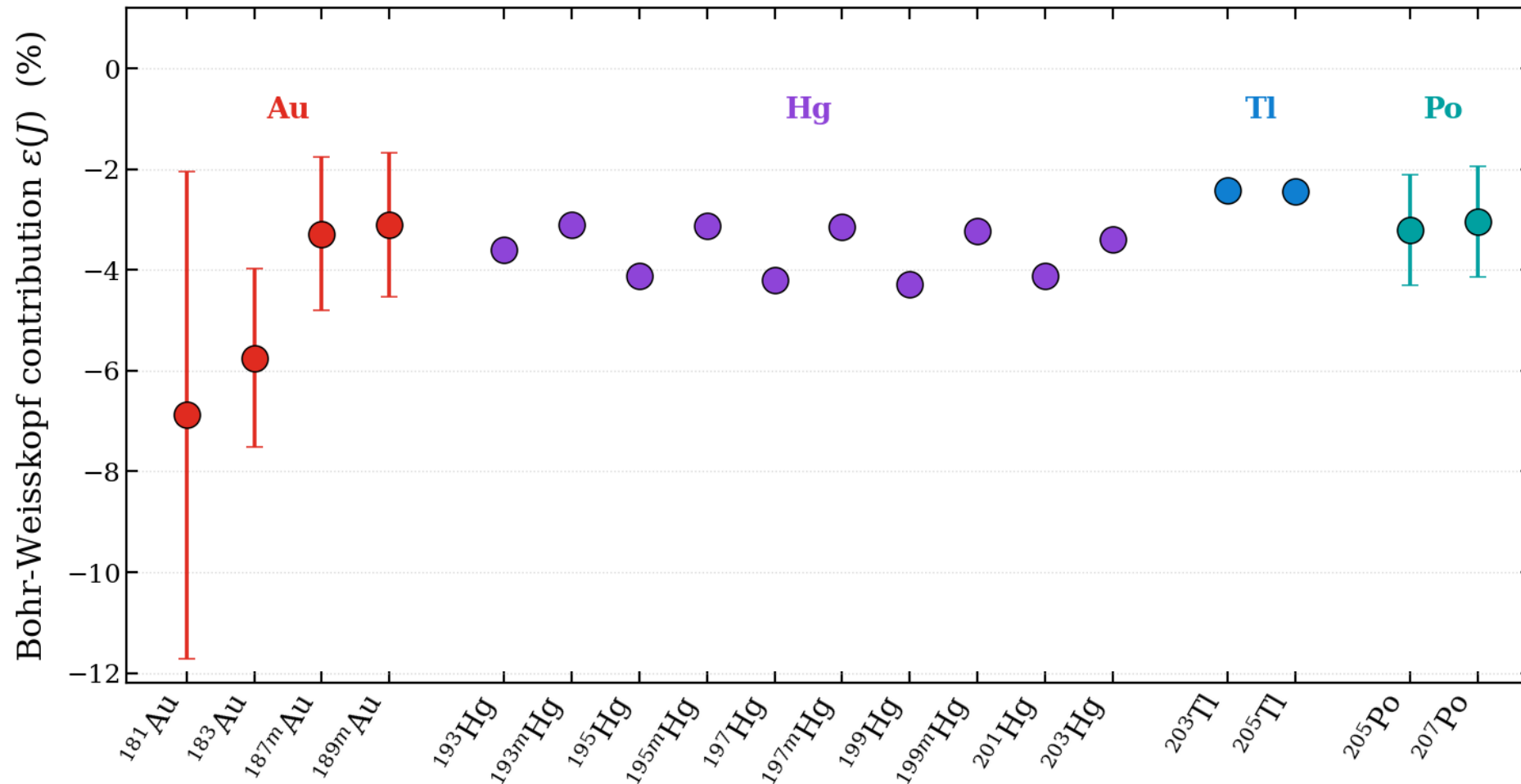
KU LEUVEN

Thank you for your attention



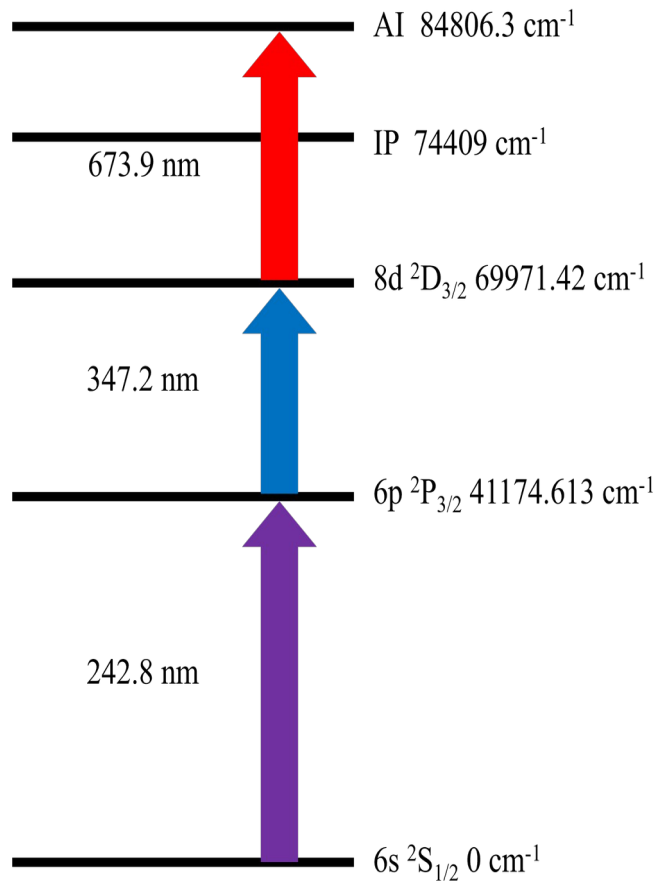
Backup slides

BW contribution in Pb region for $S_{1/2}$

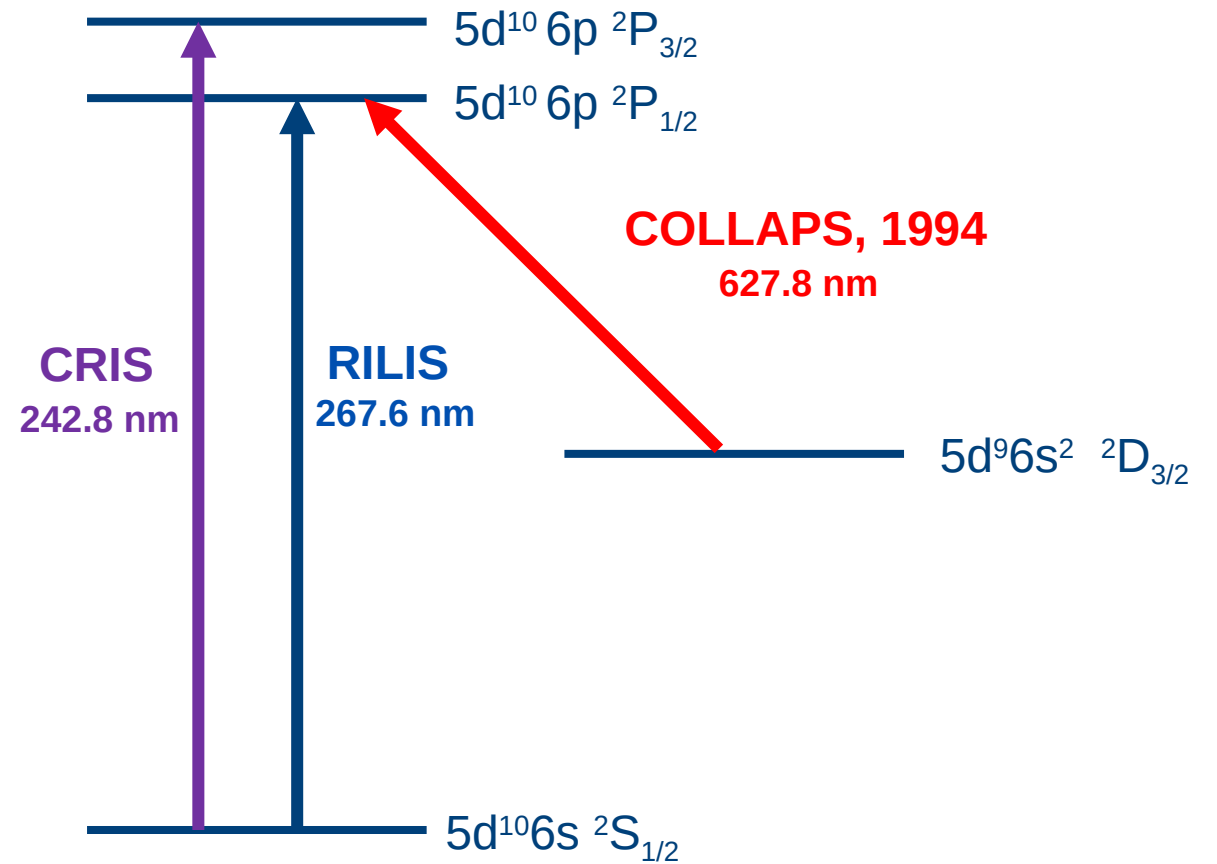


- [1] R. J. Reimann and M. N. McDermott, *Phys. Rev. C* **7**, 2065 (1973)
- [2] Prosyak, Maison & Skripnikov, *J. Chem. Phys.* **152**, 044301 (2020)
- [3] L. V. Skripnikov and A. E. Barzakh, *Phys. Rev. C* **109**, 024315 (2024)

Laser schemes for Au



RIS scheme for Au (CRIS)



Spectroscopy steps used for Au in literature

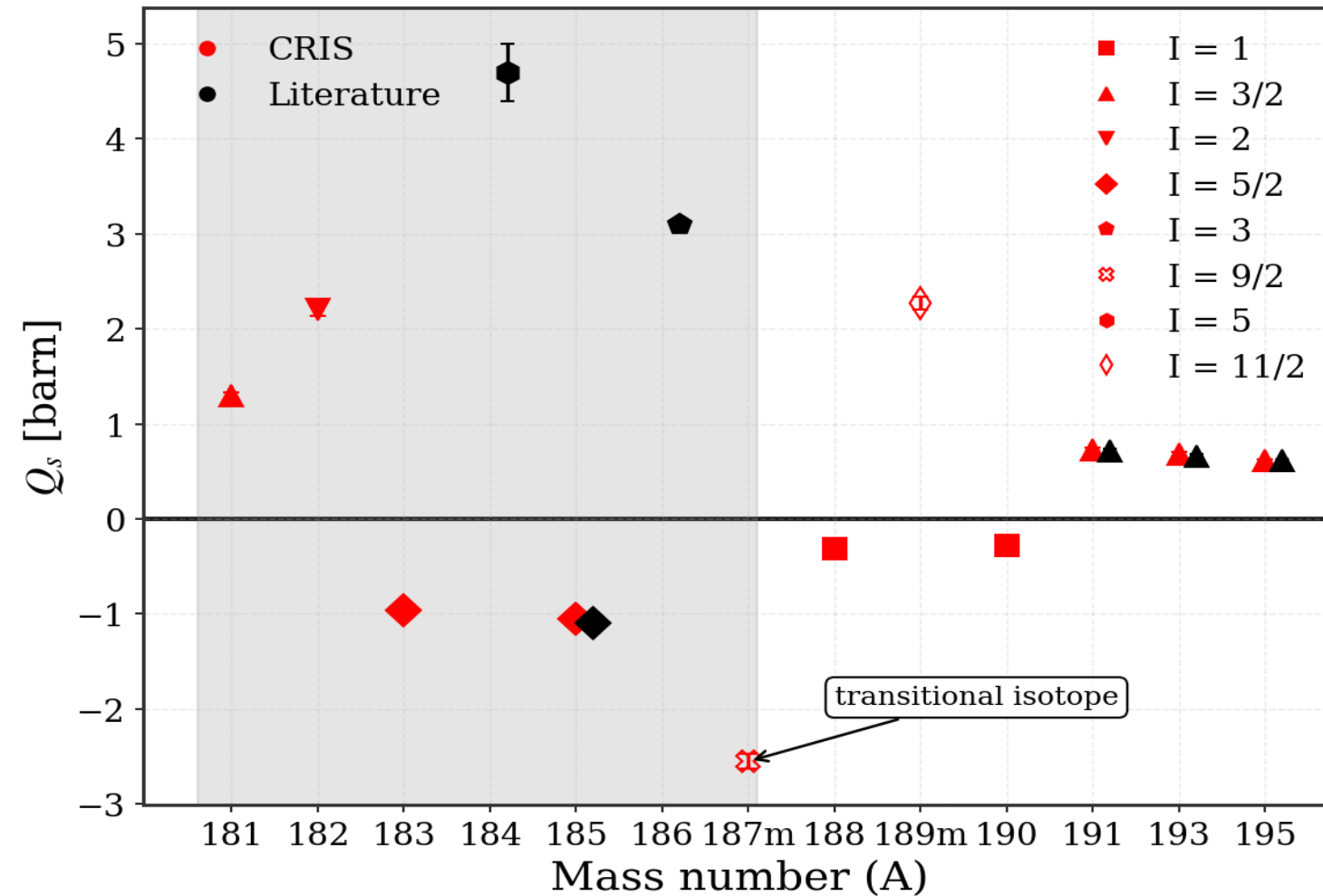
Electric quadrupole moments (Q_s)

$$Q_A = Q_{197} \frac{Bu_A}{Bu_{197}}$$

$$Q_{ref} = 0.547(16) \text{ barn [1]}$$

$$B(6p \ ^2P_{3/2,ref}) = 322(2) \text{ MHz}$$

Table Q_s **red ones** from CRIS measurements, and the **black ones** are the literature values.



Isotope	Spin	$B(6p \ ^2P_{3/2})$	Q_s [b] (this work)	Q_s [b] (literature)
181	3/2	764(5)	1.274(39)	
182	2	1301(6)	2.17(7)	
183	5/2	-566(3)	-0.94(3)	
184	5		-	4.7(3)
185	5/2	-622(2)	-1.04(3)	-1.1(1)
186	3		-	3.10(6)
187m	9/2	-1508(10)	-2.52(8)	
188	1	-186(3)	-0.31(1)	
189m	11/2	1339(9)	2.23(7)	
190	1	-167(2)	-0.280(9)	
191	3/2	428(5)	0.71(2)	0.72(2)
192	1	-130(1)	-0.220(7)	-0.228(8)
193	3/2	402(3)	0.67(2)	0.66(2)
195	3/2	361(2)	0.60(2)	0.61(2)

Q_s & Island of deformation

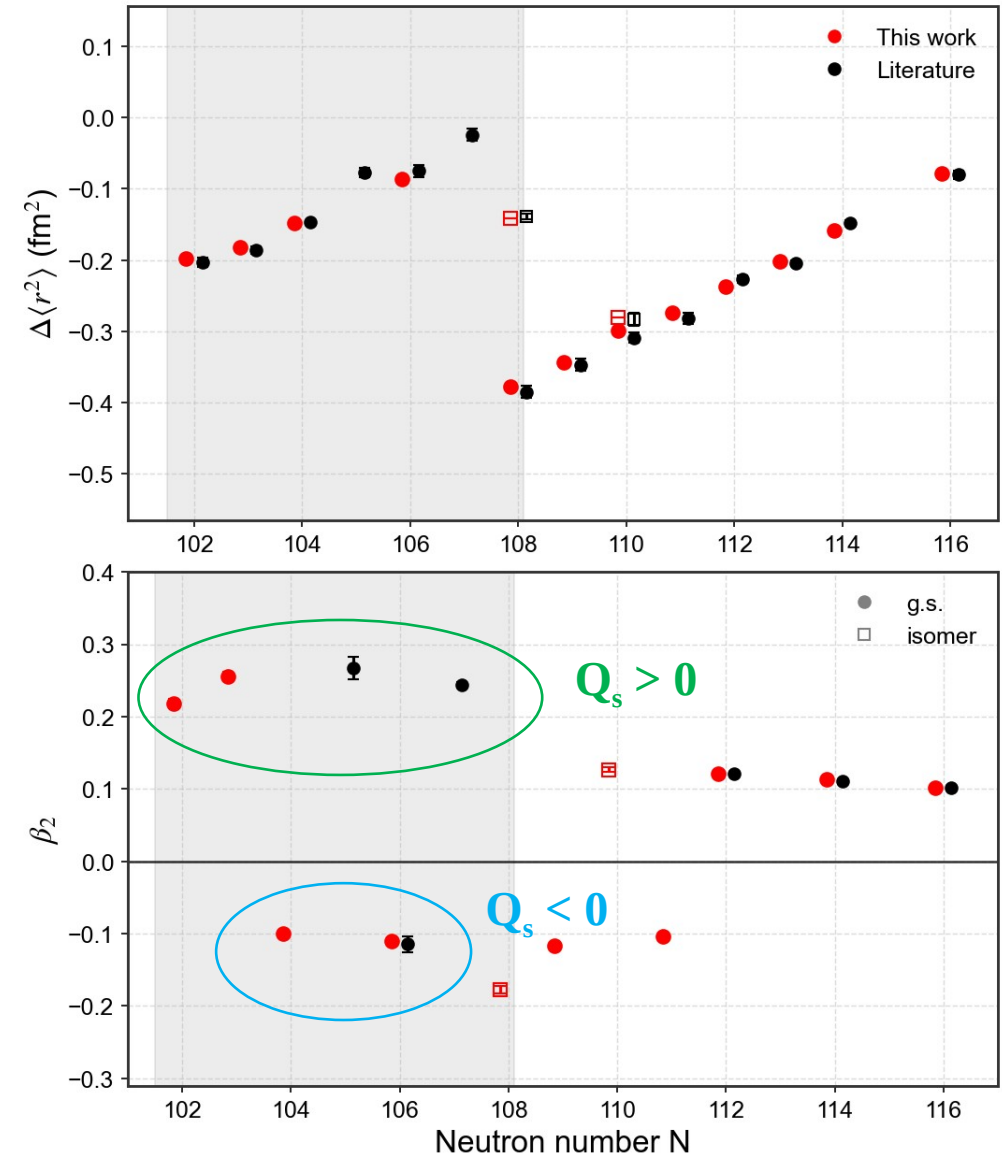
$$Q_s = \frac{3K^2 - I(I + 1)}{(2I + 3)(I + 1)} Q_{\text{intr.}}$$

Strong coupling ($K = I$) assumed to extract β_2 (axial deformation)

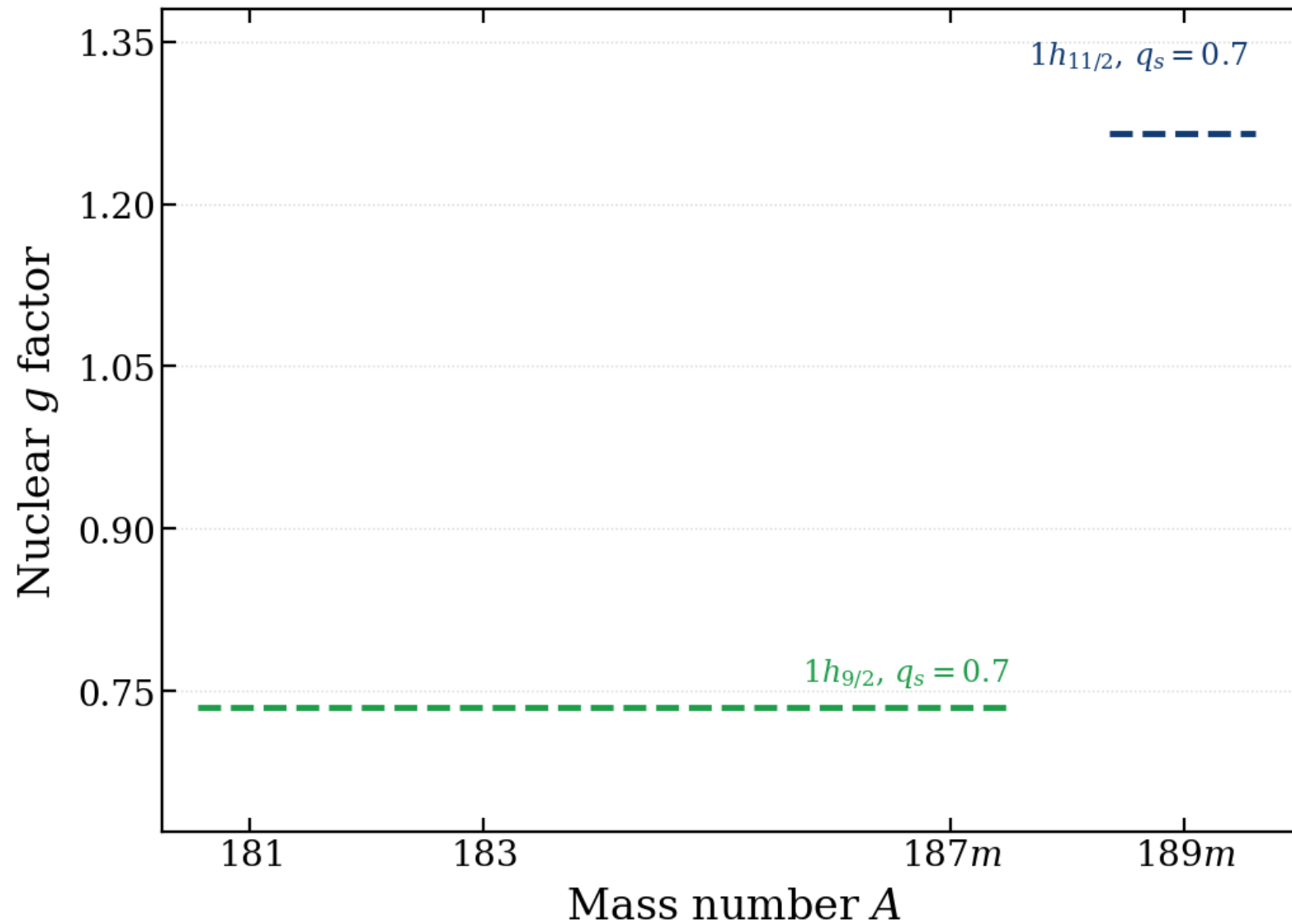
$$Q_{\text{intr.}} = \frac{3}{\sqrt{5\pi}} ZR_0^2 \beta_2 (1 + 0.36\beta_2).$$

Positive- Q ($^{181,182}\text{Au}$, $^{184,186}\text{Au}$) reaches $\beta_2 \approx 0.25$ (rigid prolate).

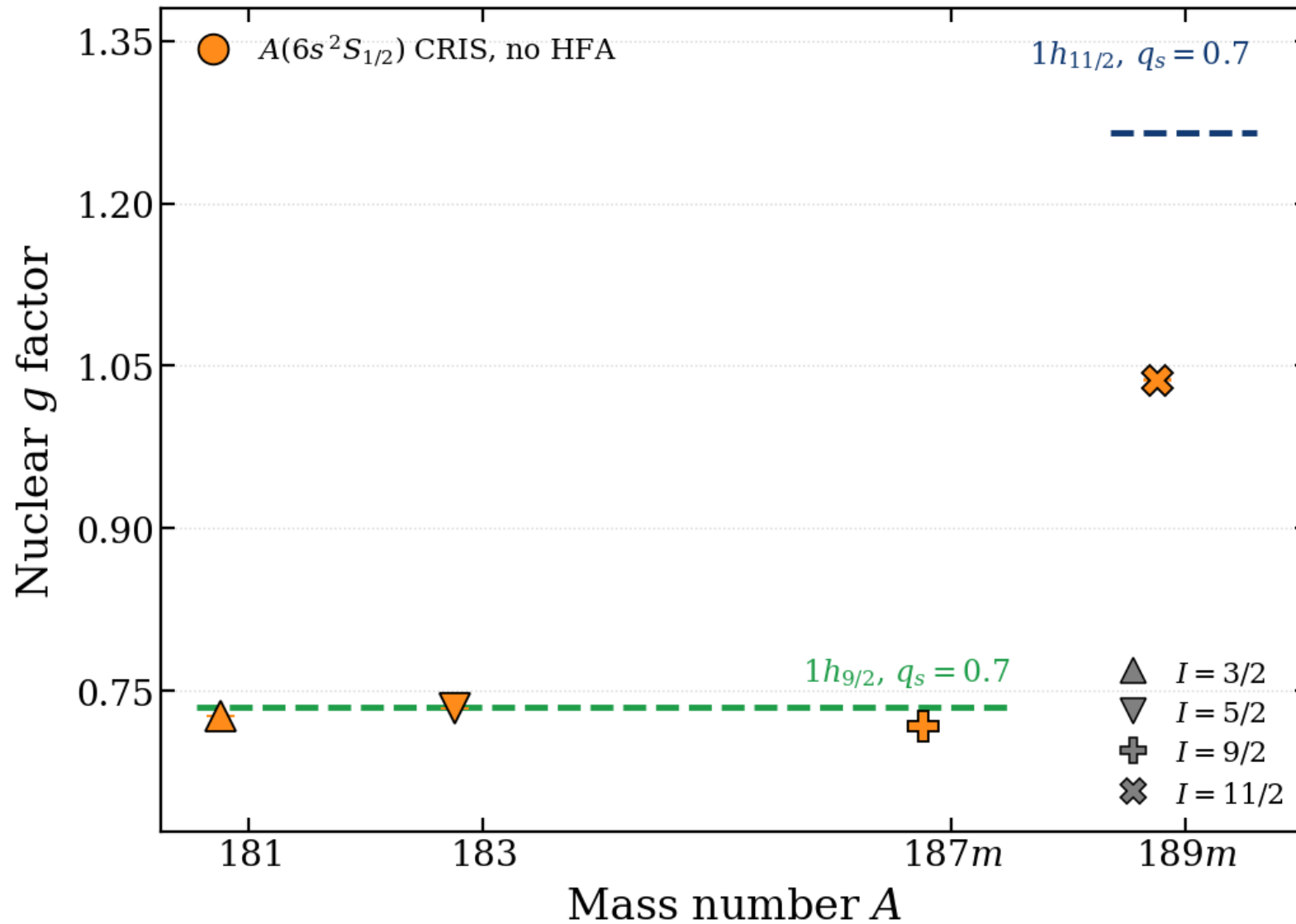
Negative- Q ($^{183,185}\text{Au}$) smaller $\beta_2 \approx -0.10 - -0.11$ (moderate oblate) – **hints of triaxiality or higher order deformation?**



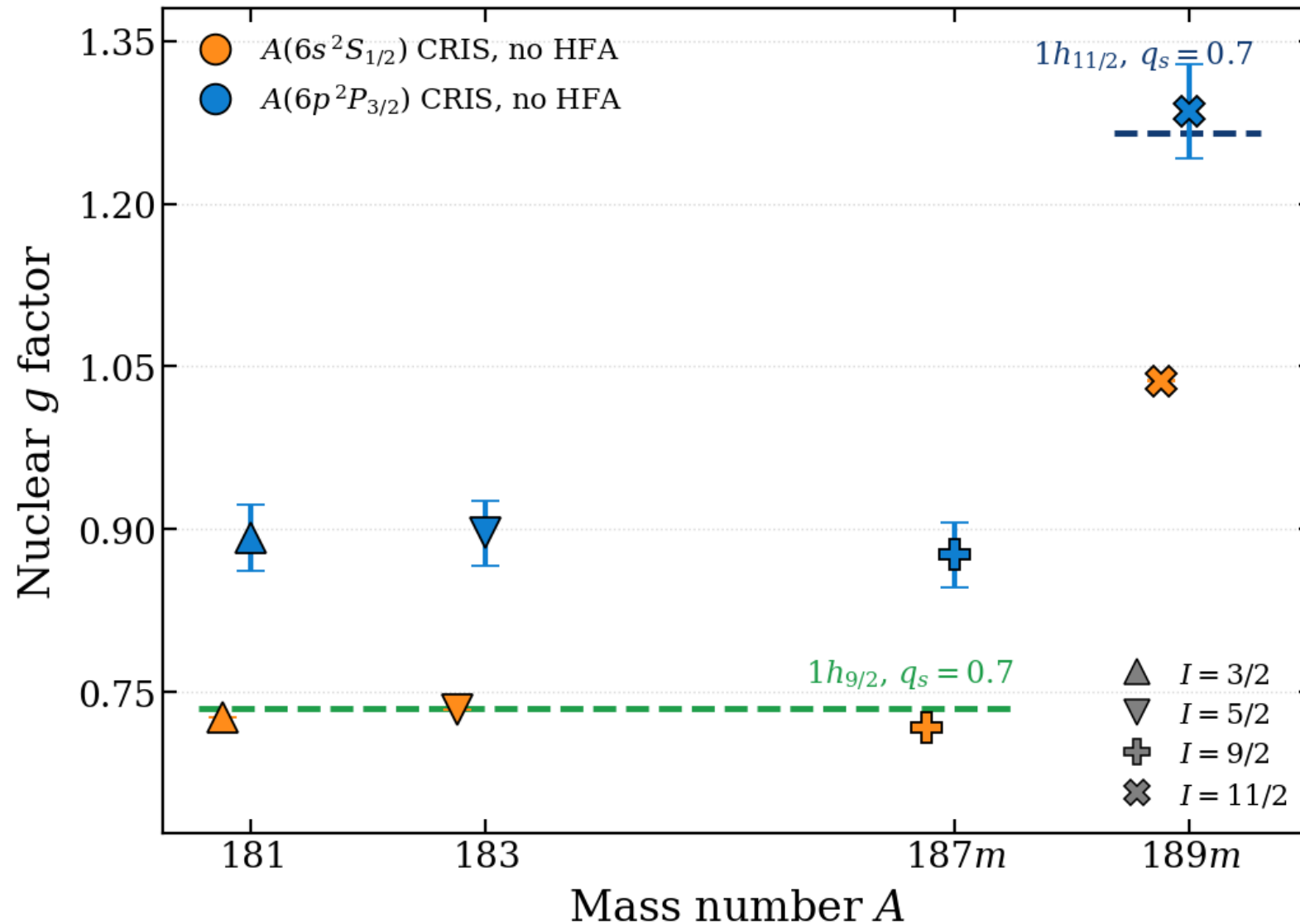
Probing the nuclear configuration



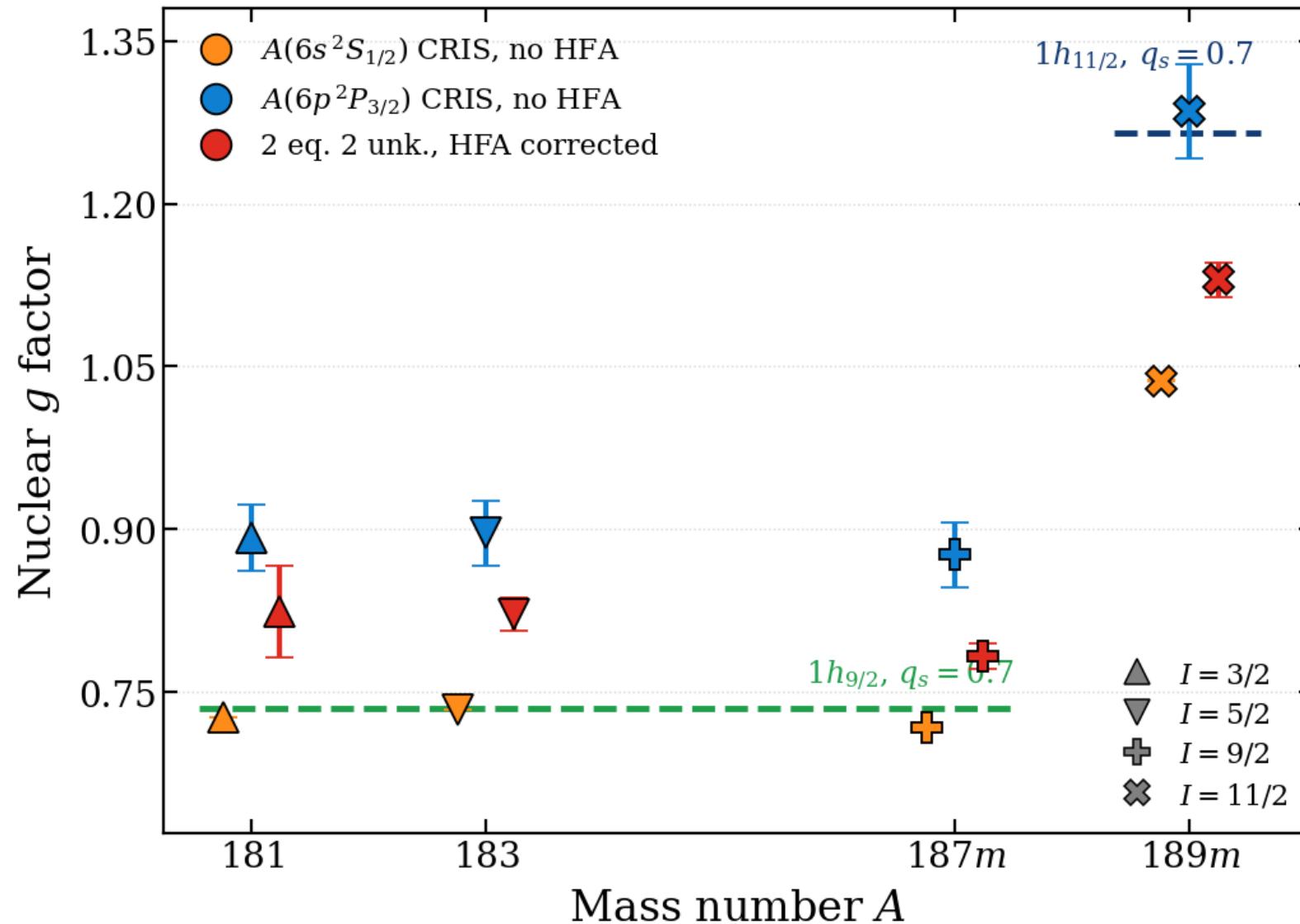
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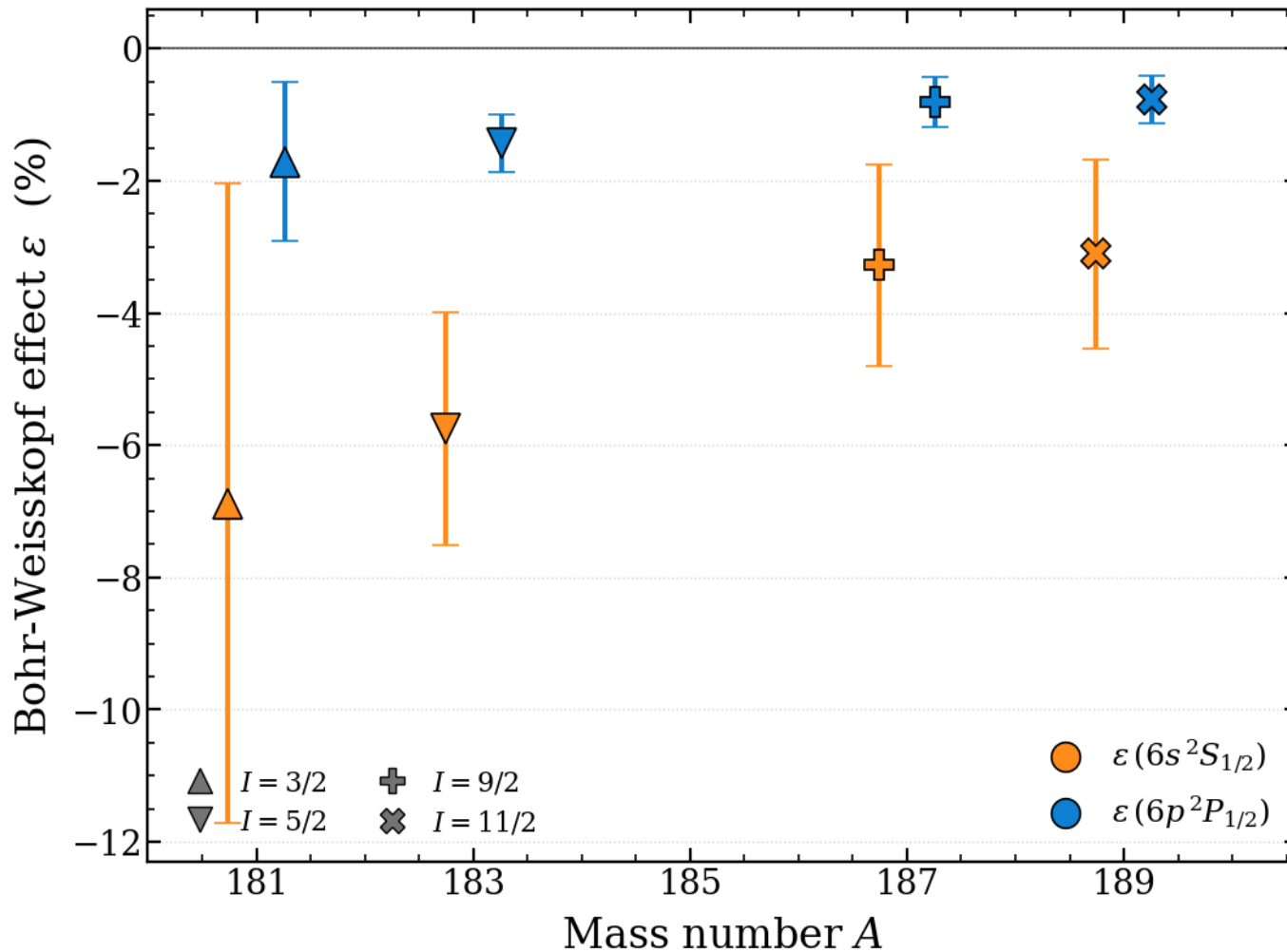
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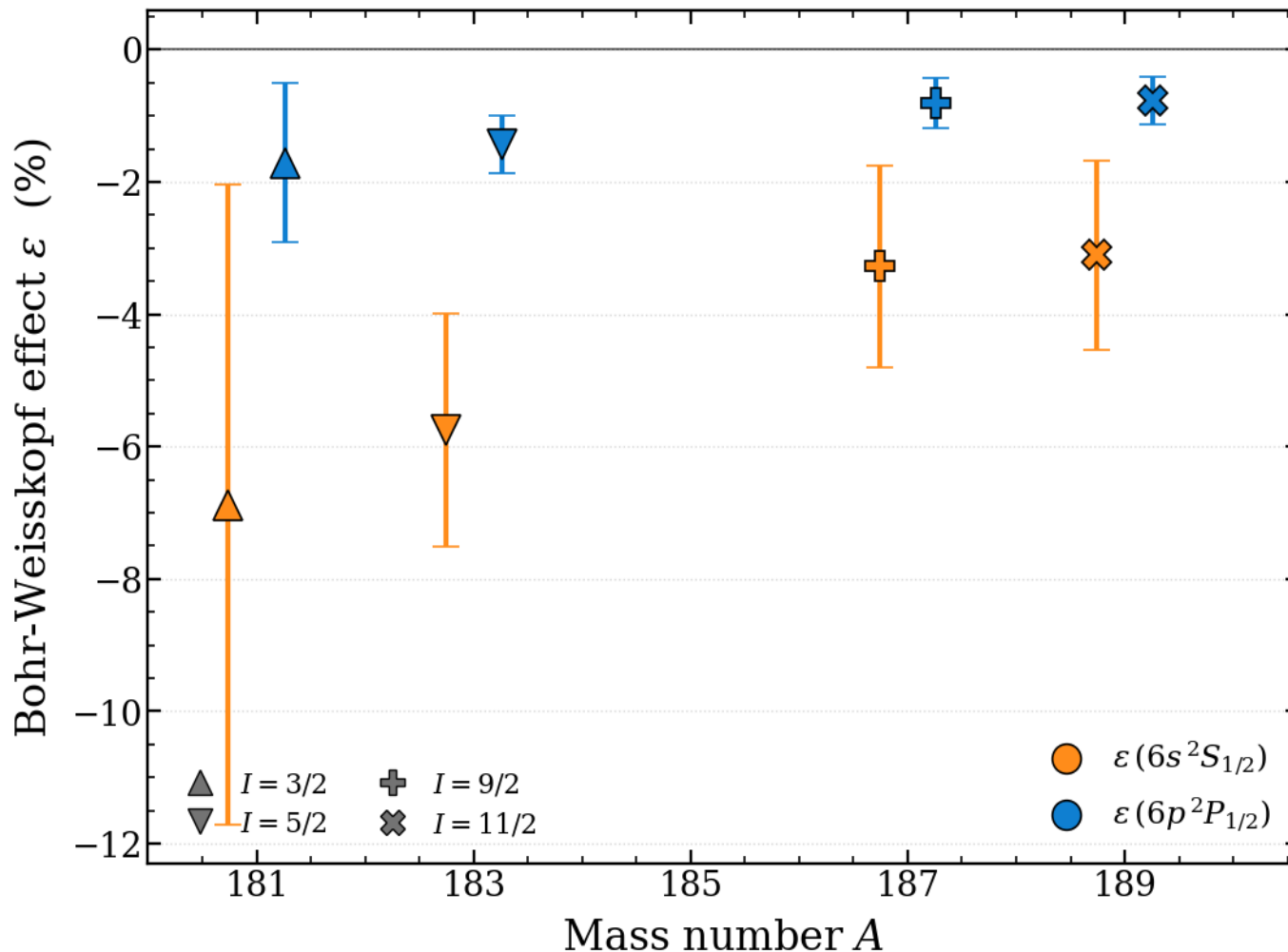


Bohr-Weisskopf contribution in Au isotopes



Bohr-Weisskopf contribution from $A(6s^2S_{1/2})$ and $A(6p^2P_{1/2})$ levels)

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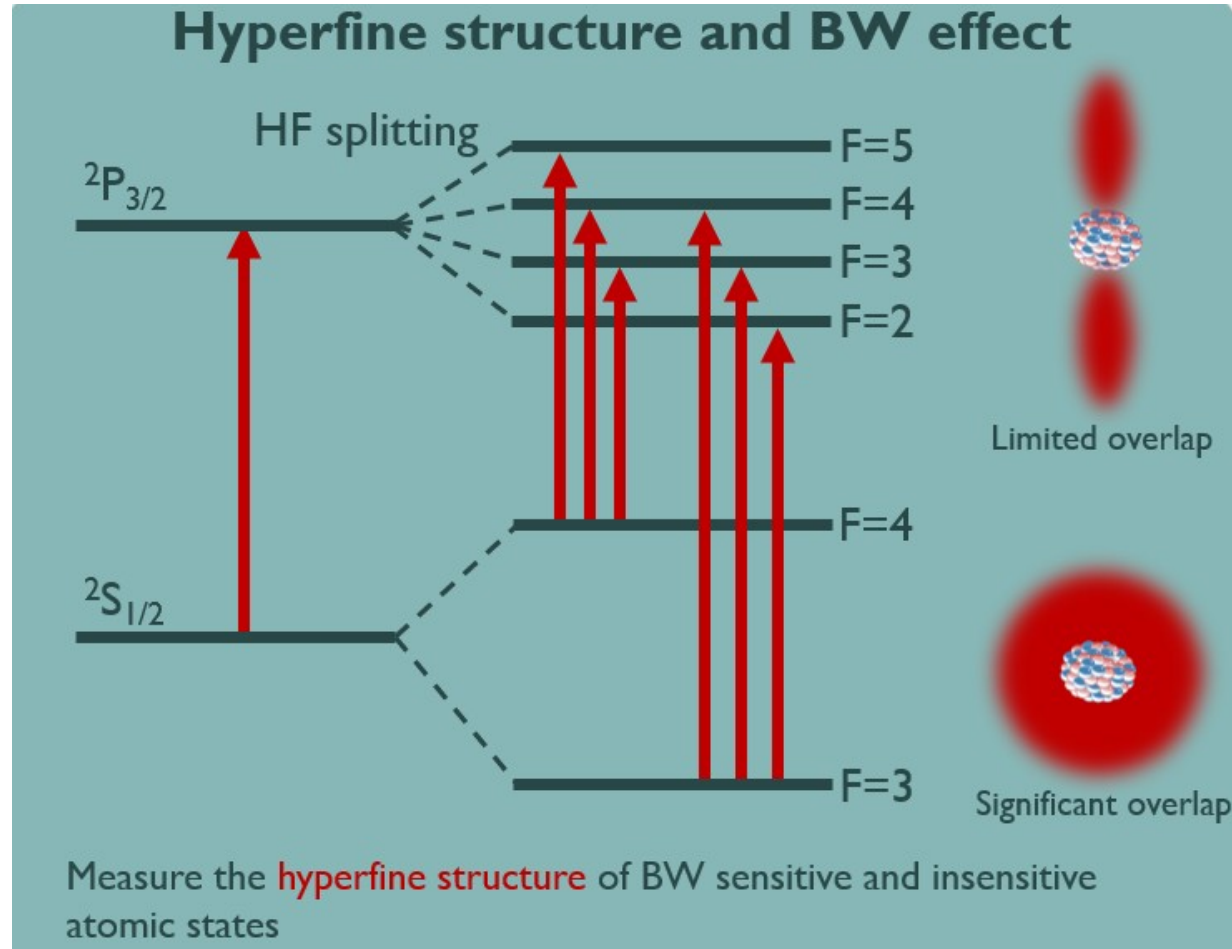


A	I	$\varepsilon(6s\ ^2S_{1/2})\%$	$\varepsilon(6p\ ^2P_{1/2})\%$
181	3/2	-6.9(48)	-1.7(12)
183	5/2	-5.8(18)	-1.4 (4)
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Hyperfine anomaly

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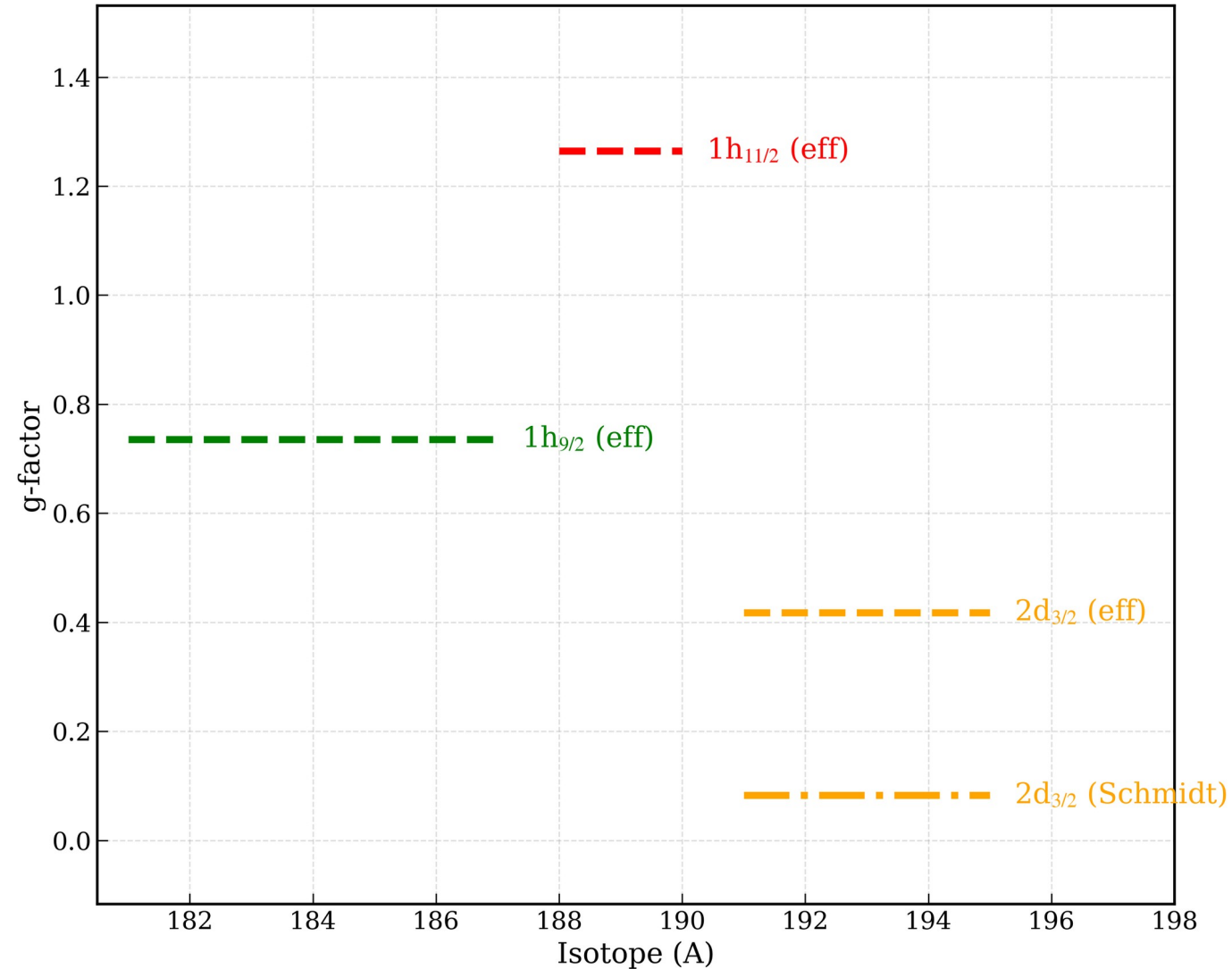
g-factors configuration

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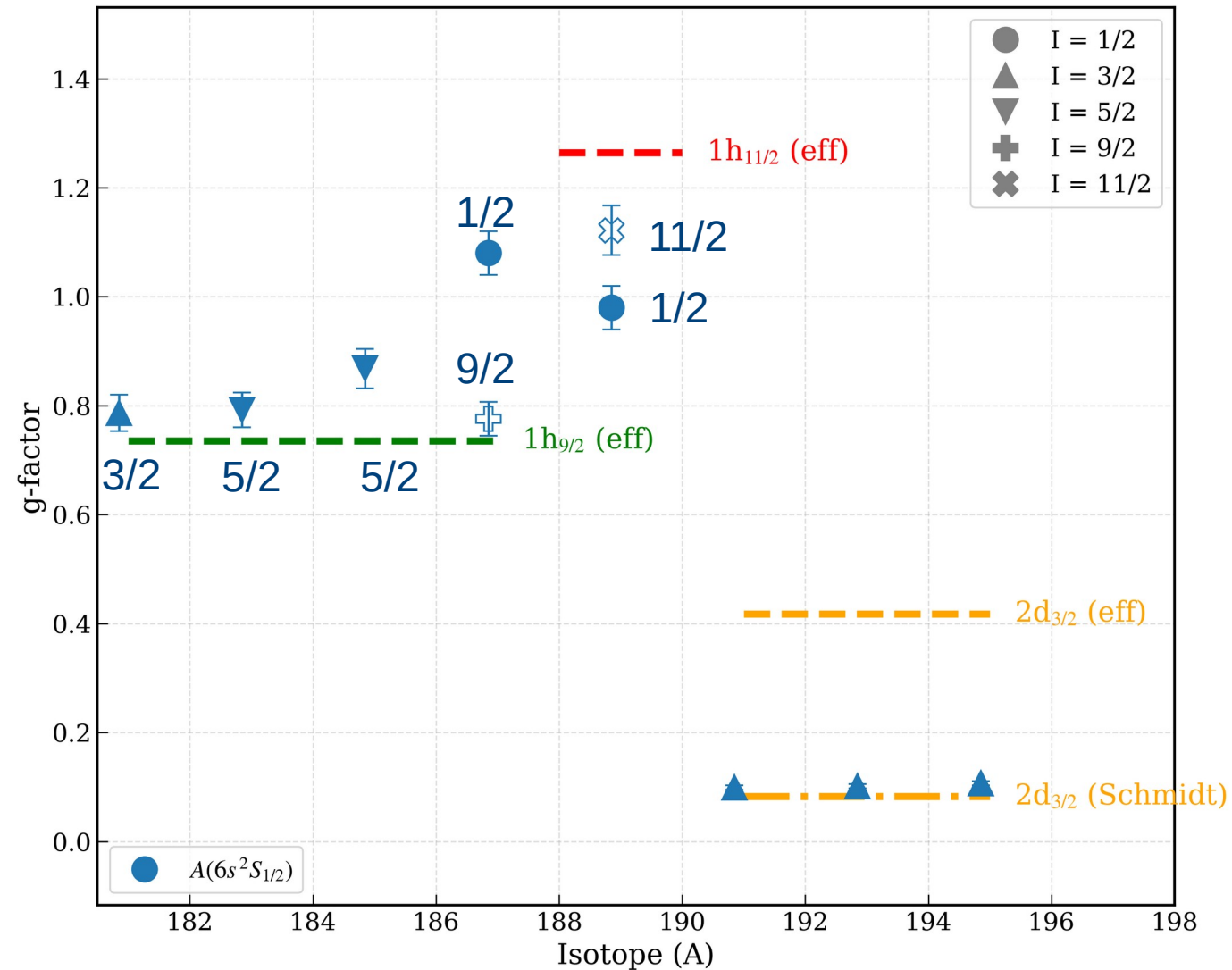


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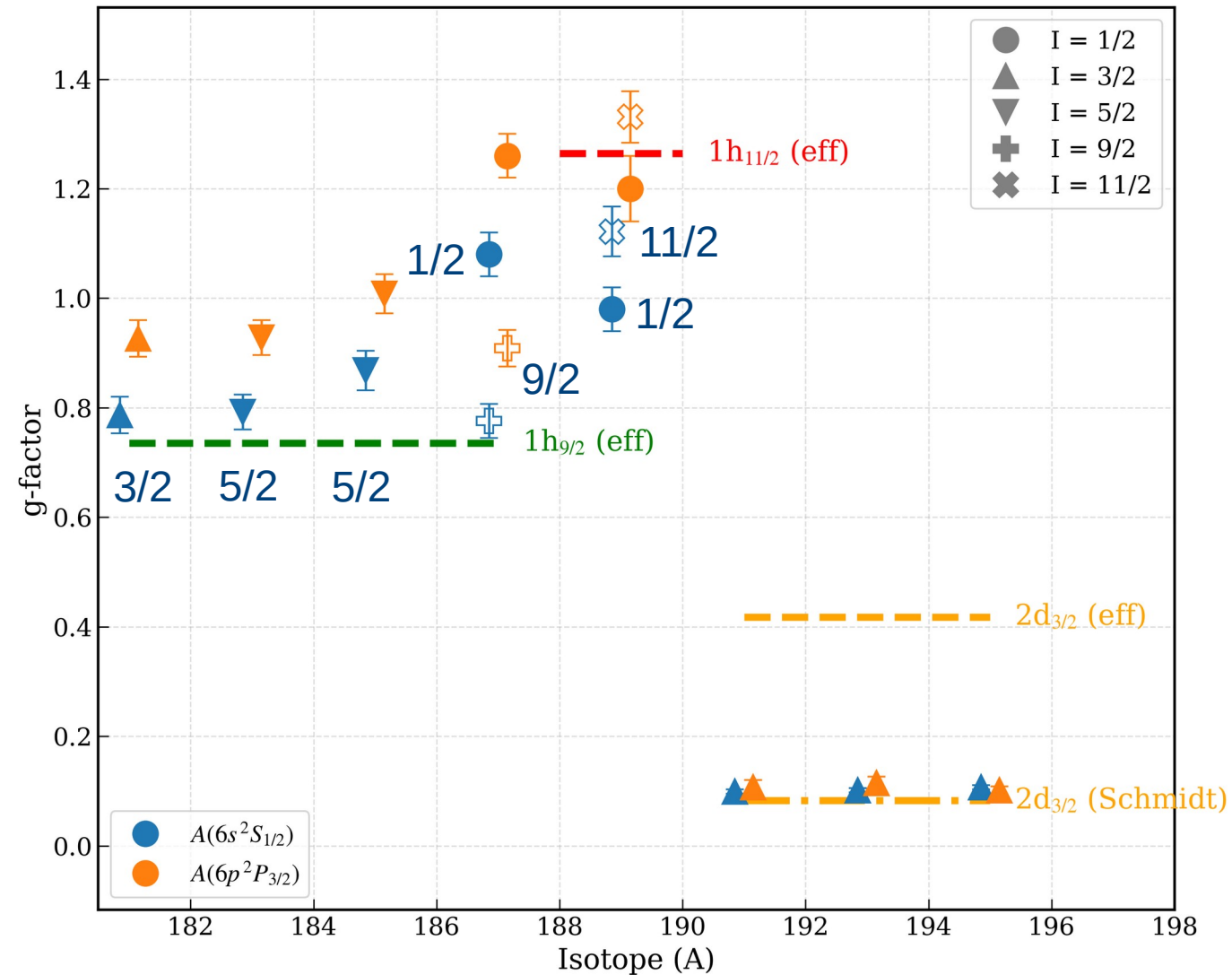
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