Nuclear magnetic moments and time-odd properties of density functionals

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University of York

Science & Technology Facilities Council
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University of Warsaw

NucMagMom Collaboration (est. 2017)

- Michael Bender, Lyon
- Witek Nazarewicz, Mengzhi Chen, MSU
- J.D., Alessandro Pastore, a new PDRA, York
- …. all wishing to join are welcome

Literature

- B. Castel and I.S. Towner, *Modern theories of nuclear moments*, (Oxford Studies in Nuclear Physics) vol 12, ed P E Hodgson (Oxford: Clarendon,1990).
- Gerda Neyens, Rep. Prog. Phys. 66 (2003) 633–689.
- N.J. Stone, Atomic Data and Nuclear Data Tables 90 (2005) 75–176.
- L. Bonneau, N. Minkov, Dao Duy Duc, P. Quentin, and J. Bartel, Phys. Rev. C91, 054307 (2015).
- M. Borrajo and J.L. Egido, Phys. Lett. B764, 328 (2017).

Outline

1. Recap on nuclear magnetic moments
2. ^{145}Sm
3. 13/2+ isomers in lead
4. ^{119}In
5. ^{229}Th
6. 9/2- ground states in bismuth
7. Summary

Recap

Basics

The magnetic operator $\bar{\mu}$ is a one-body operator and the magnetic dipole moment μ is the expectation value of $\bar{\mu}_z$. The M1 operator acting on a composed state $|Im\rangle$ can then be written as the sum of single particle M1 operators $\bar{\mu}_z(j)$ acting each on an individual valence nucleon with total momentum j:

$\mu = g_L\, L + g_s\, s$

$$\mu(I) \equiv \left\langle I(j_1, j_2, \ldots, j_n), m = I \left| \sum_{i=1}^{n} \bar{\mu}_z(i) \right| I(j_1, j_2, \ldots, j_n), m = I \right\rangle \tag{2.1}$$

The single particle magnetic moment $\mu(j)$ for a valence nucleon around a doubly magic core is uniquely defined by the quantum numbers l and j of the occupied single particle orbit [22]:

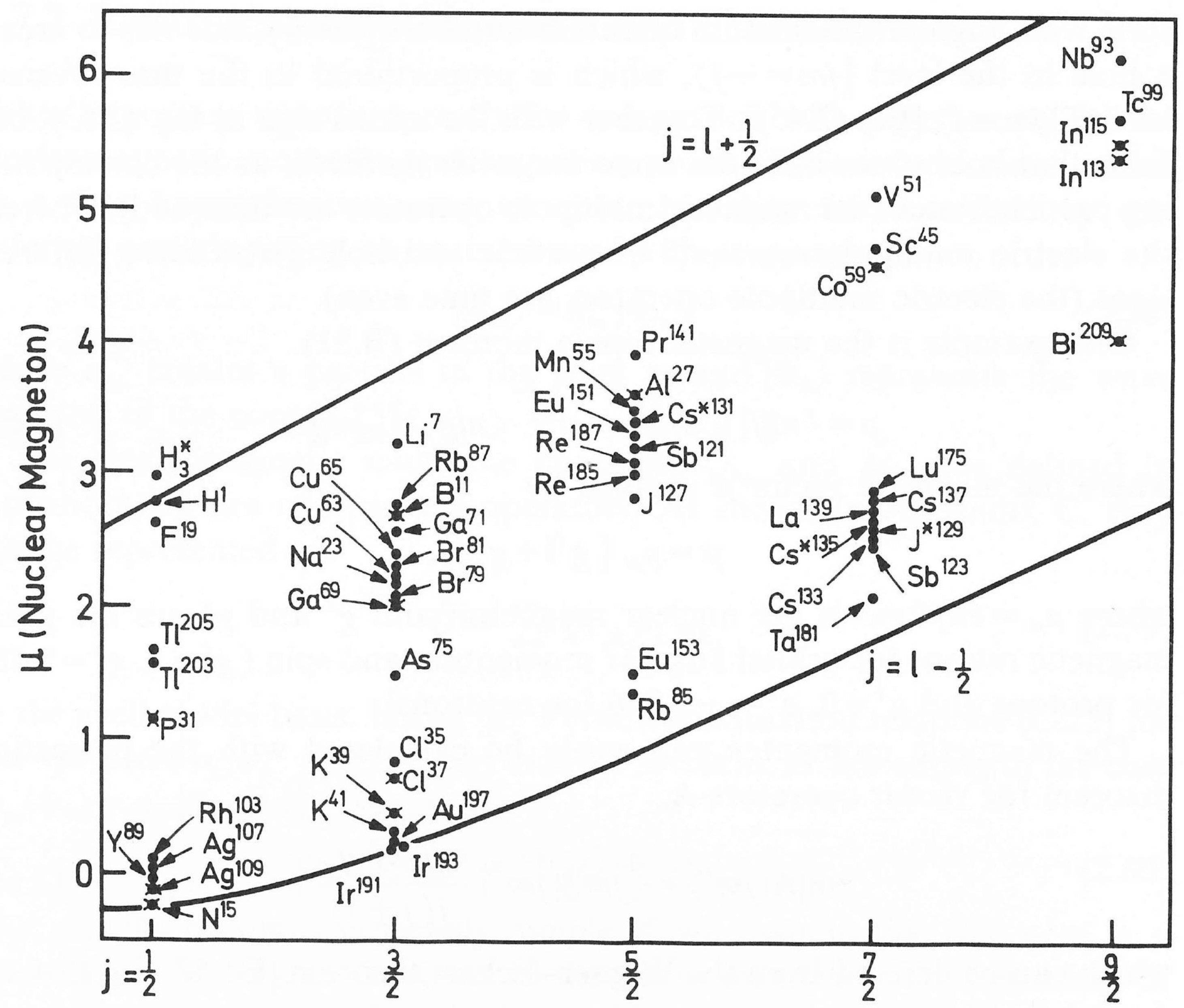
$$\text{for an odd proton: } \begin{cases} \mu = j - \frac{1}{2} + \mu_{\mathrm{p}} & \text{for } j = l + \frac{1}{2} \\ \mu = \dfrac{j}{j+1}\left(j + \dfrac{3}{2} - \mu_{\mathrm{p}}\right) & \text{for } j = l - \frac{1}{2} \end{cases} \tag{2.2}$$

$$\text{for an odd neutron: } \begin{cases} \mu = \mu_{\mathrm{n}} & \text{for } j = l + \frac{1}{2} \\ \mu = -\dfrac{j}{j+1}\mu_{\mathrm{n}} & \text{for } j = l - \frac{1}{2} \end{cases} \tag{2.3}$$

These single particle moments calculated using the free proton and free neutron moments ($\mu_{\mathrm{p}} = +2.793$, $\mu_{\mathrm{n}} = -1.913$) are called the Schmidt moments. In a nucleus, the magnetic

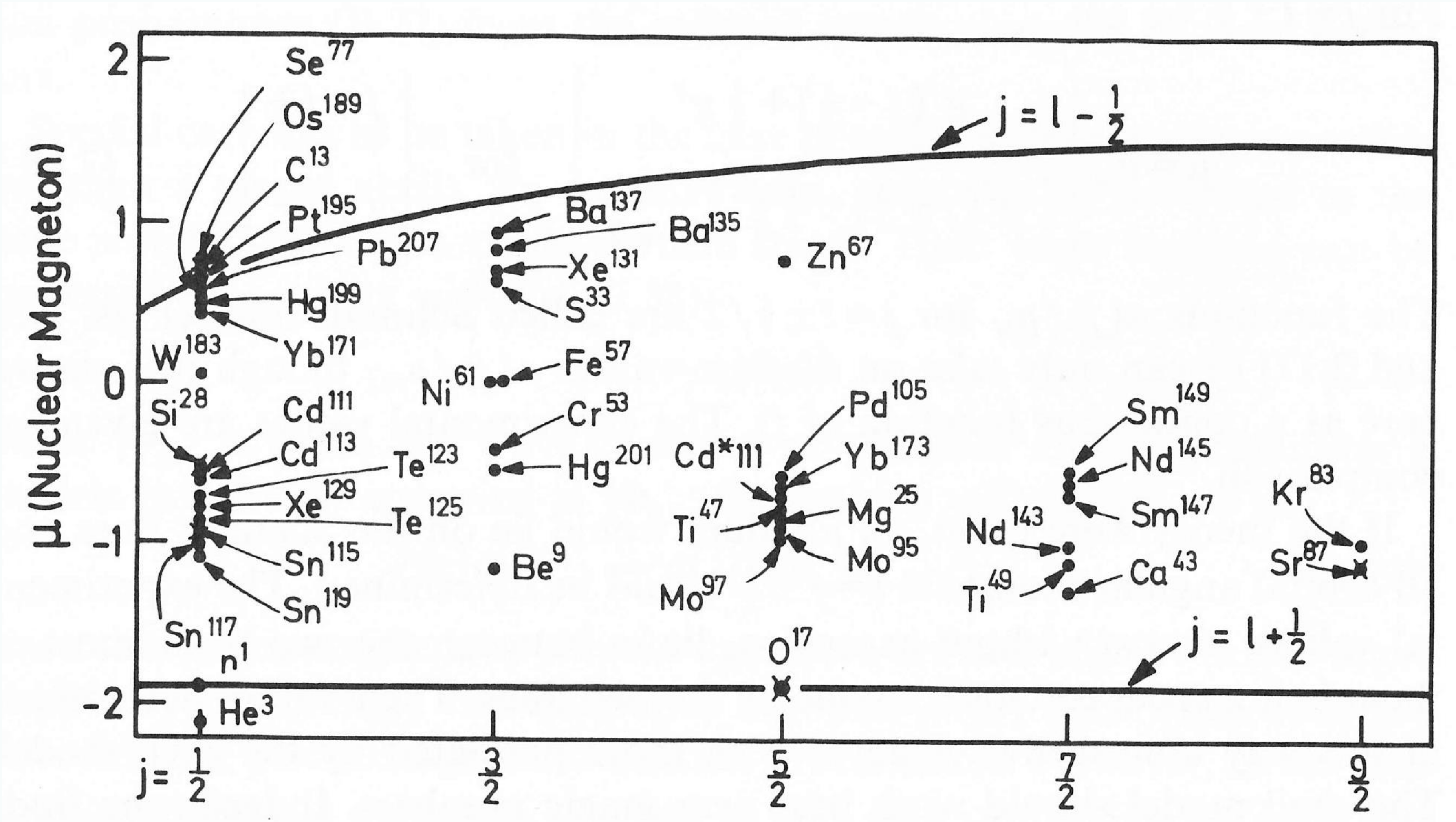
Gerda Neyens, Rep. Prog. Phys. 66 (2003) 633–689

Experiment



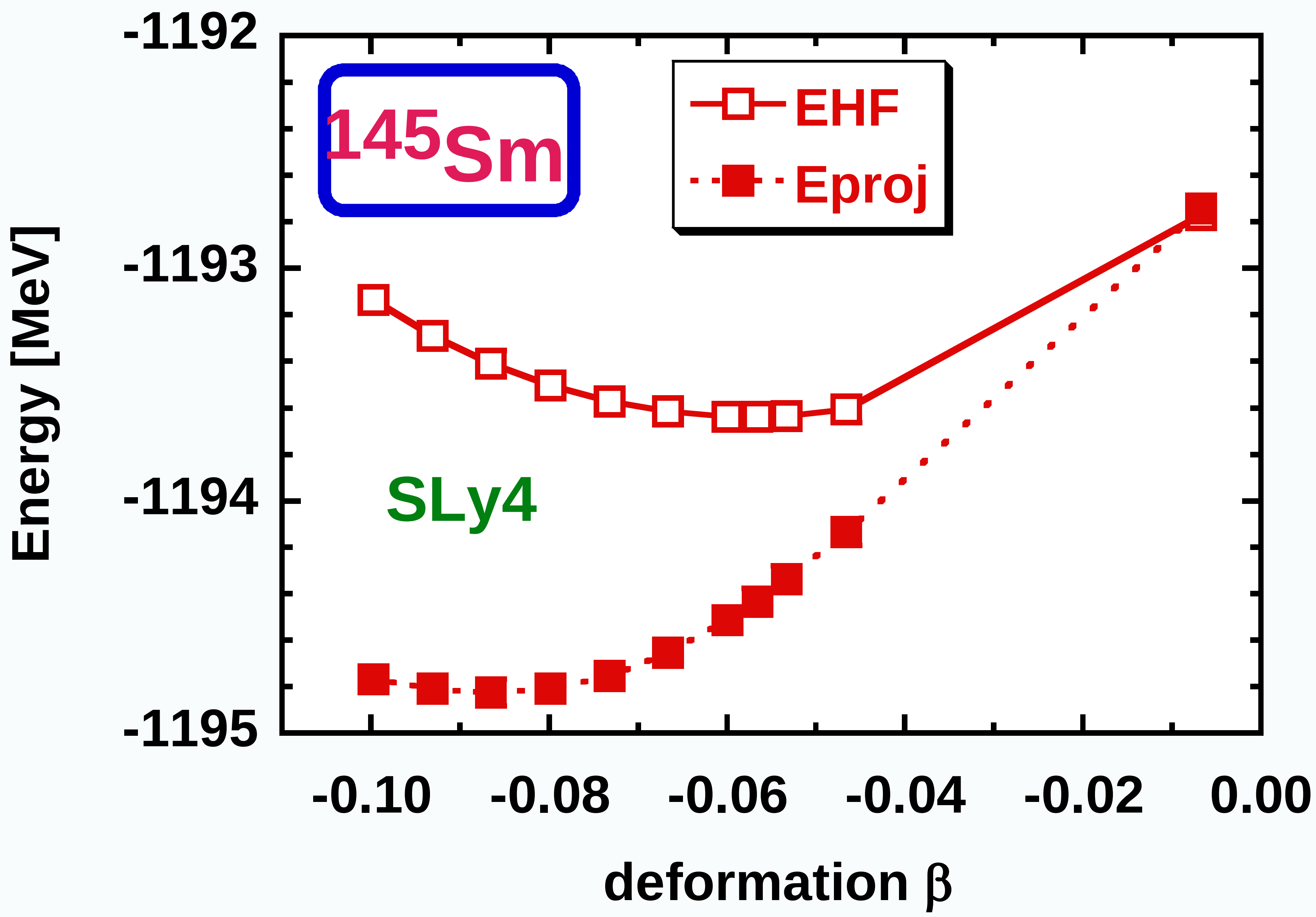
M.G. Mayer and J.H.D. Jensen, *Elementary Theory of Nuclear Shell Structure*, (Wiley, New York, 1955)

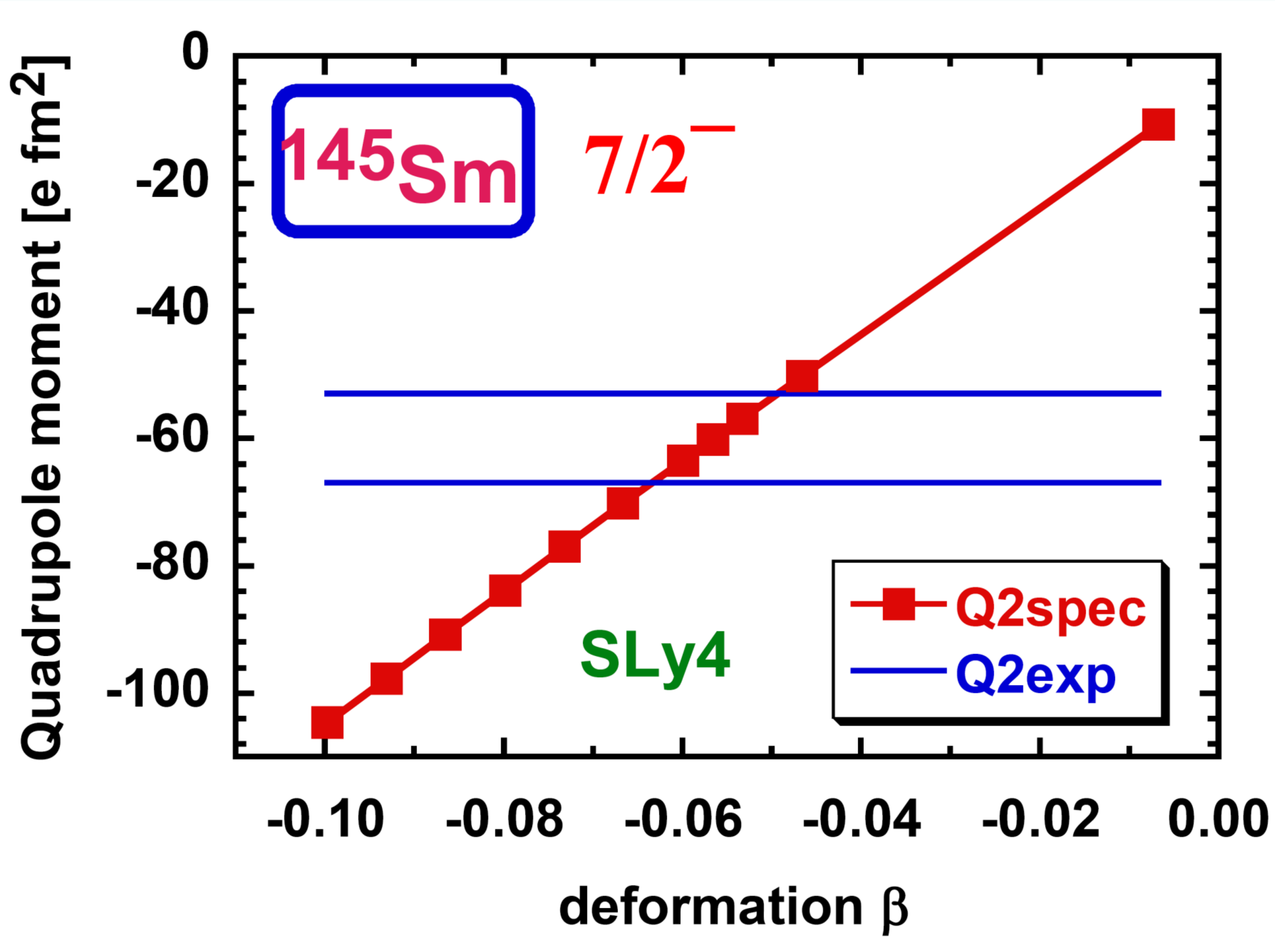
Experiment



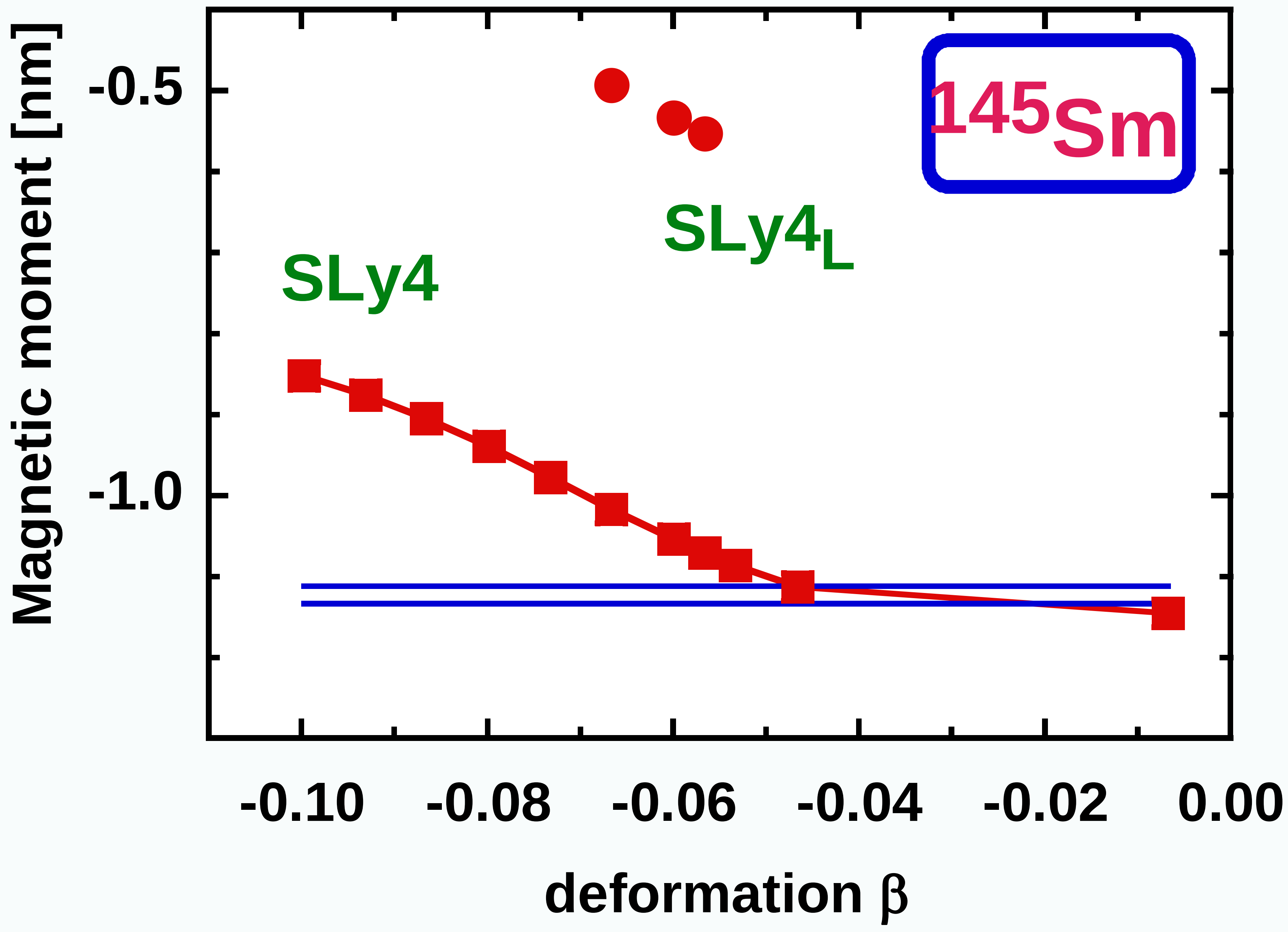
M.G. Mayer and J.H.D. Jensen, *Elementary Theory of Nuclear Shell Structure*, (Wiley, New York, 1955)

^{145}Sm


-1192
-1193
-1194
-1195
Energy [MeV]
145Sm
EHF
Eproj
SLy4
-0.10
-0.08
-0.06
-0.04
-0.02
0.00
deformation β

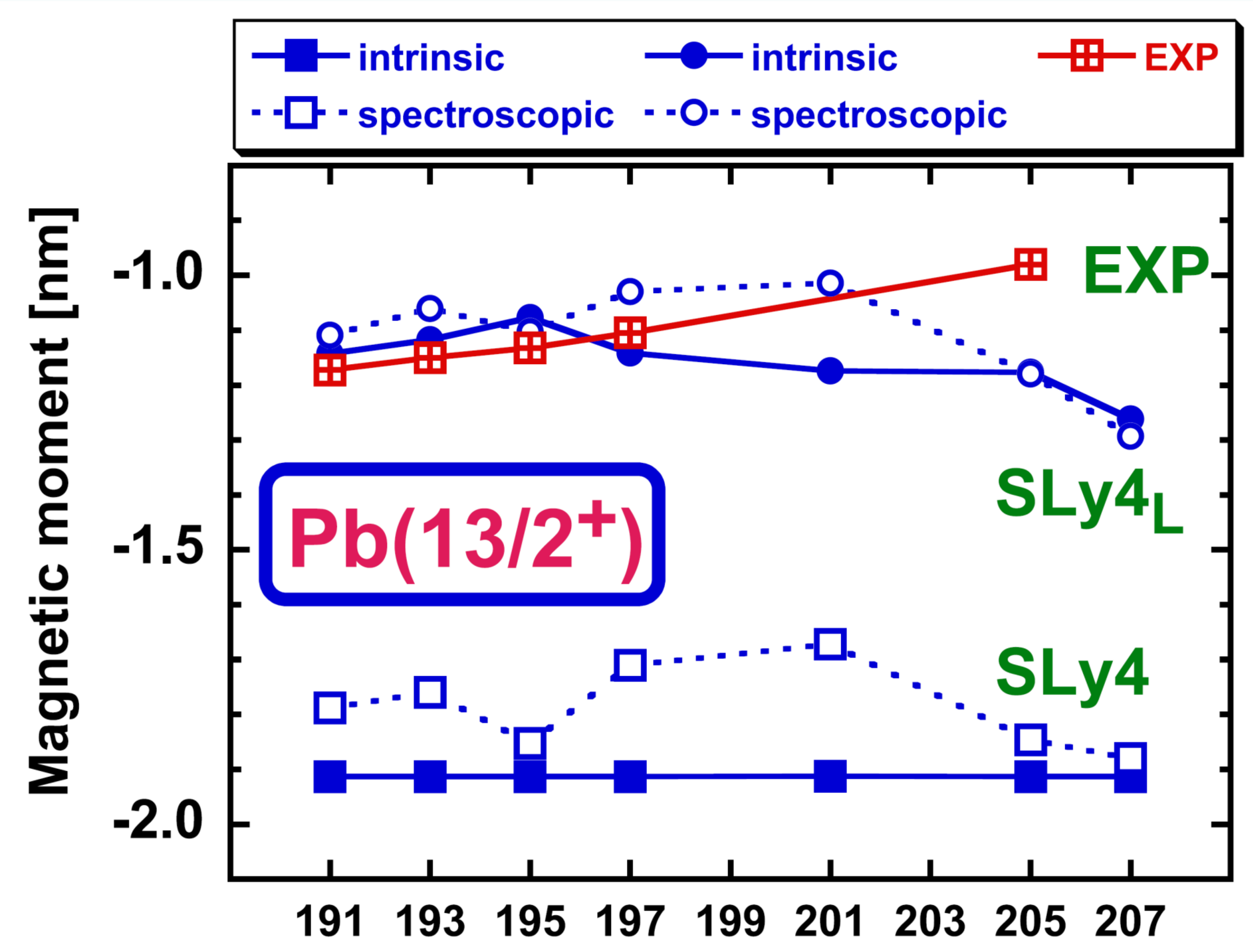


145Sm
7/2−
Quadrupole moment [e fm2]
0
-20
-40
-60
-80
-100
SLy4
Q2spec
Q2exp
-0.10
-0.08
-0.06
-0.04
-0.02
0.00
deformation β

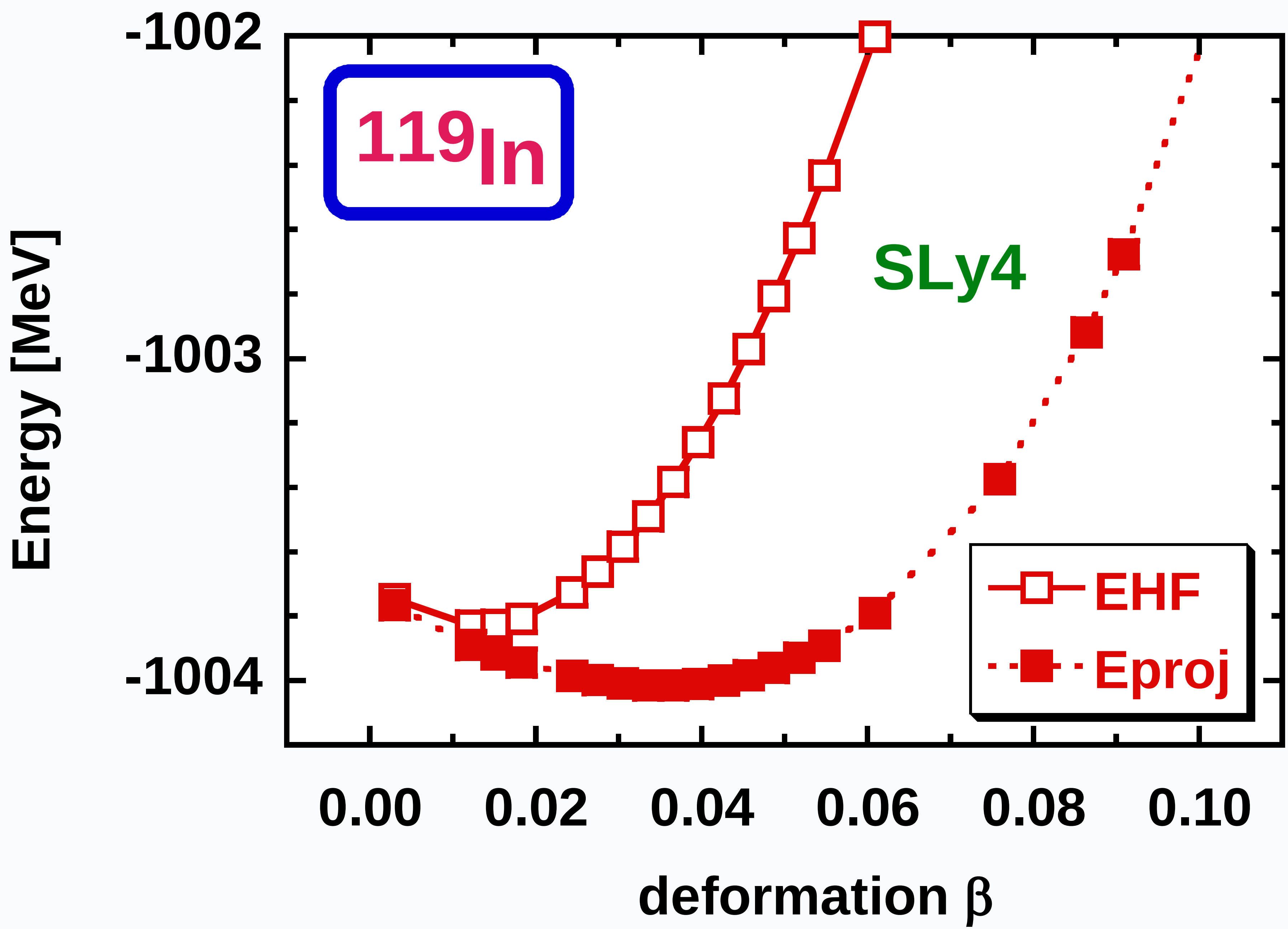


Magnetic moment [nm]
-0.5
-1.0
SLy4
SLy4L
145Sm
-0.10
-0.08
-0.06
-0.04
-0.02
0.00
deformation β

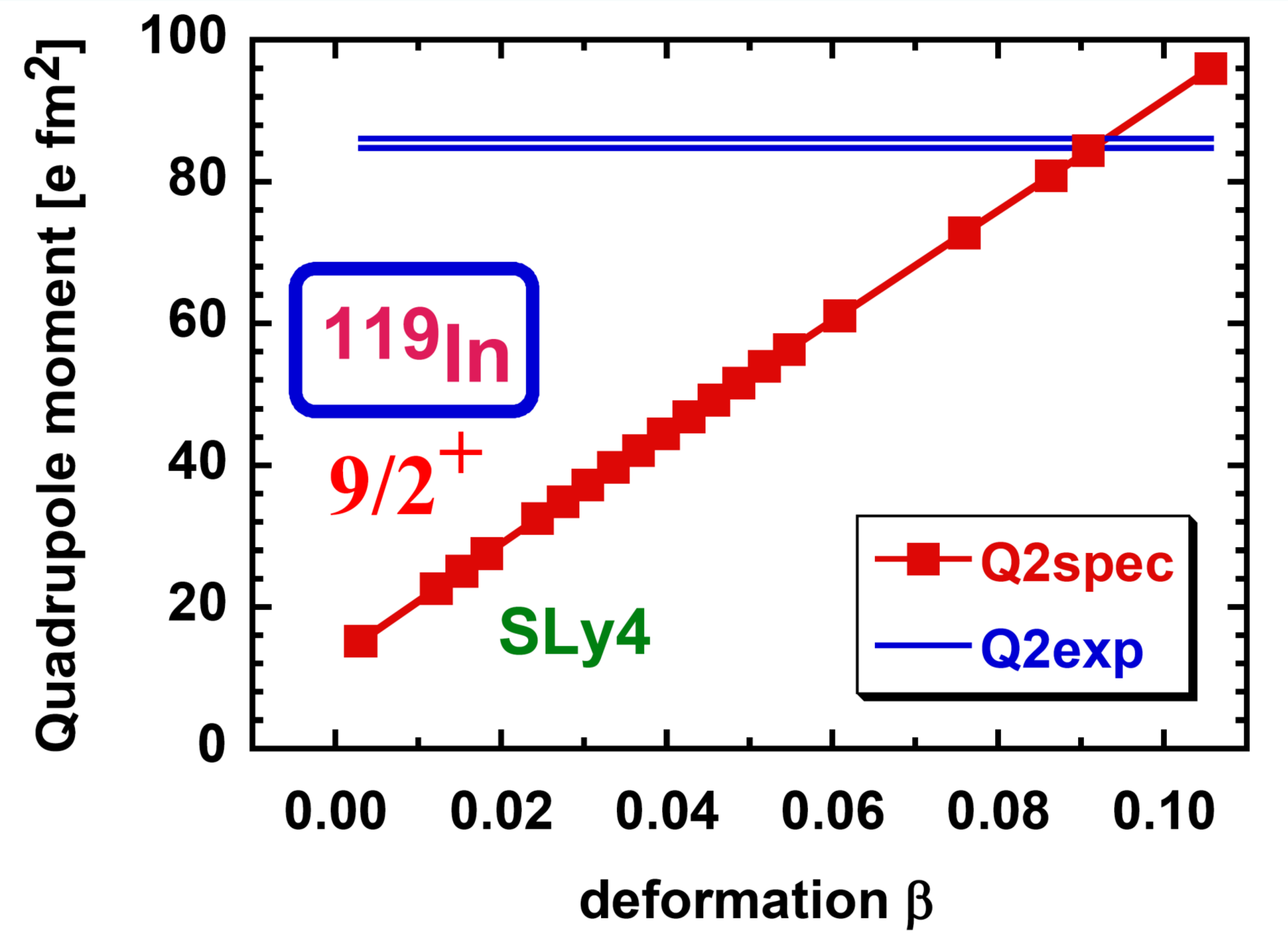
13/2+ isomers in lead

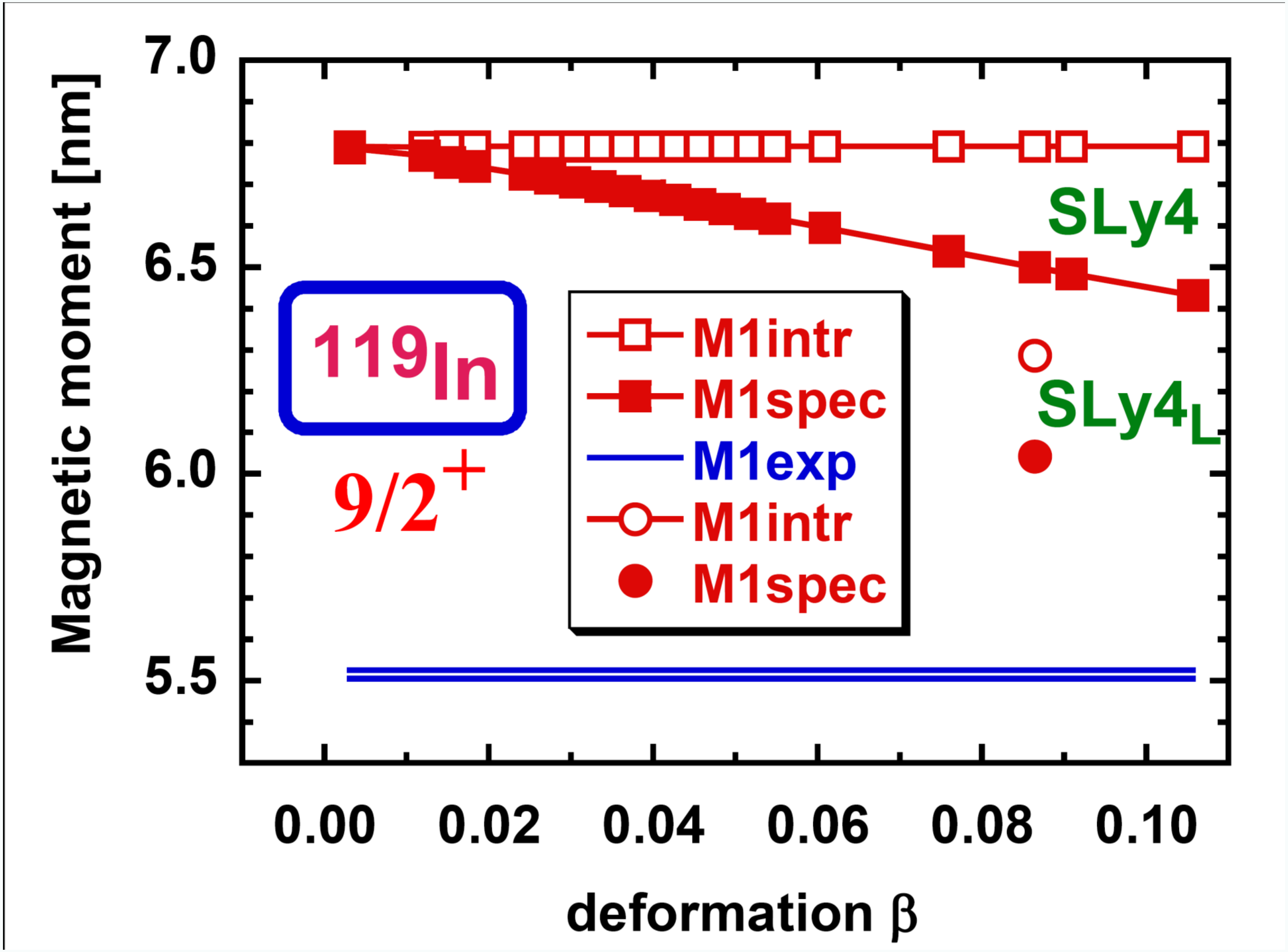

intrinsic
spectroscopic
intrinsic
spectroscopic
EXP
Magnetic moment [nm]
-1.0
-1.5
-2.0
EXP
SLy4$_L$
Pb(13/2$^+$)
SLy4
191
193
195
197
199
201
203
205
207

^{119}In



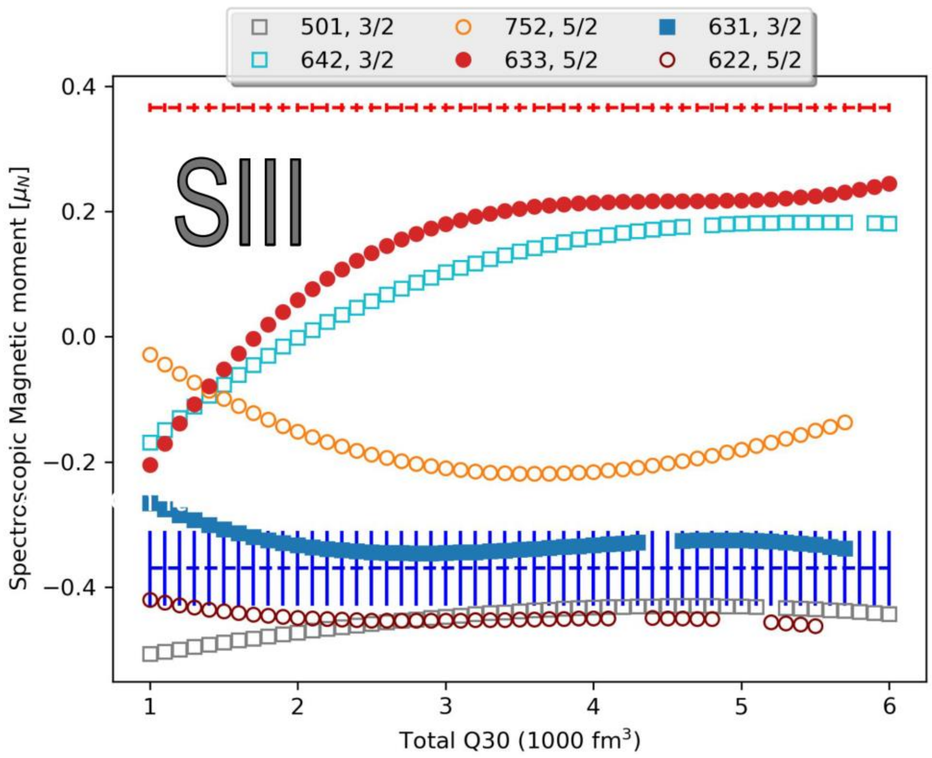
-1002
-1003
-1004
Energy [MeV]
119In
SLy4
EHF
Eproj
0.00
0.02
0.04
0.06
0.08
0.10
deformation β

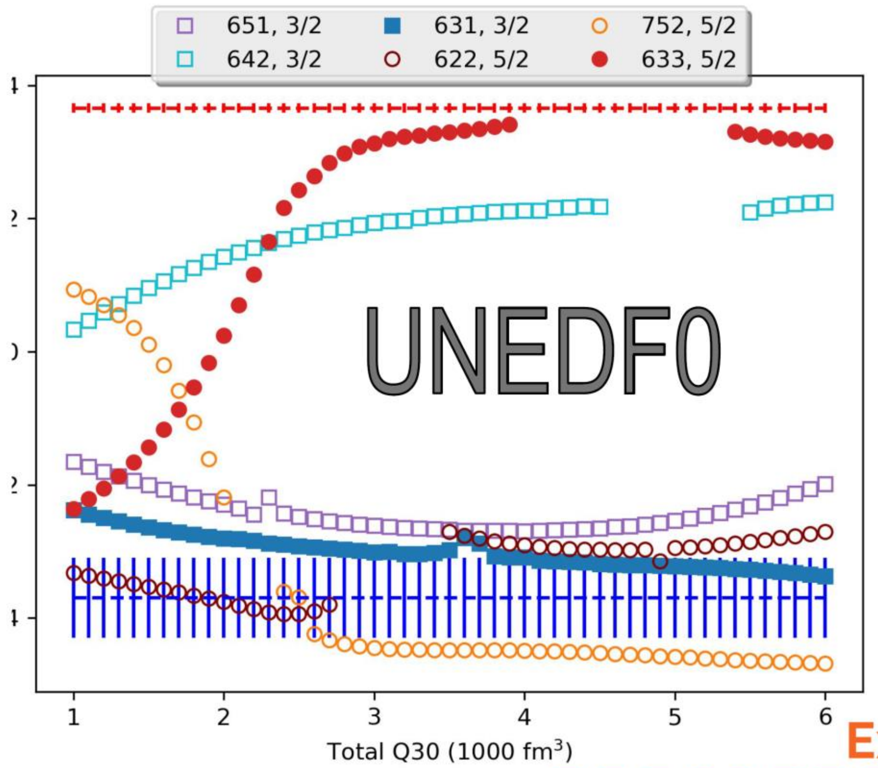

Quadrupole moment [e fm2]
100
80
60
40
20
0
0.00
0.02
0.04
0.06
0.08
0.10
deformation β
119In
9/2+
SLy4
Q2spec
Q2exp



7.0
6.5
6.0
5.5
Magnetic moment [nm]
0.00
0.02
0.04
0.06
0.08
0.10
deformation β
119In
9/2+
M1intr
M1spec
M1exp
M1intr
M1spec
SLy4
SLy4L

^{229}Th





No time-odd terms

Exp

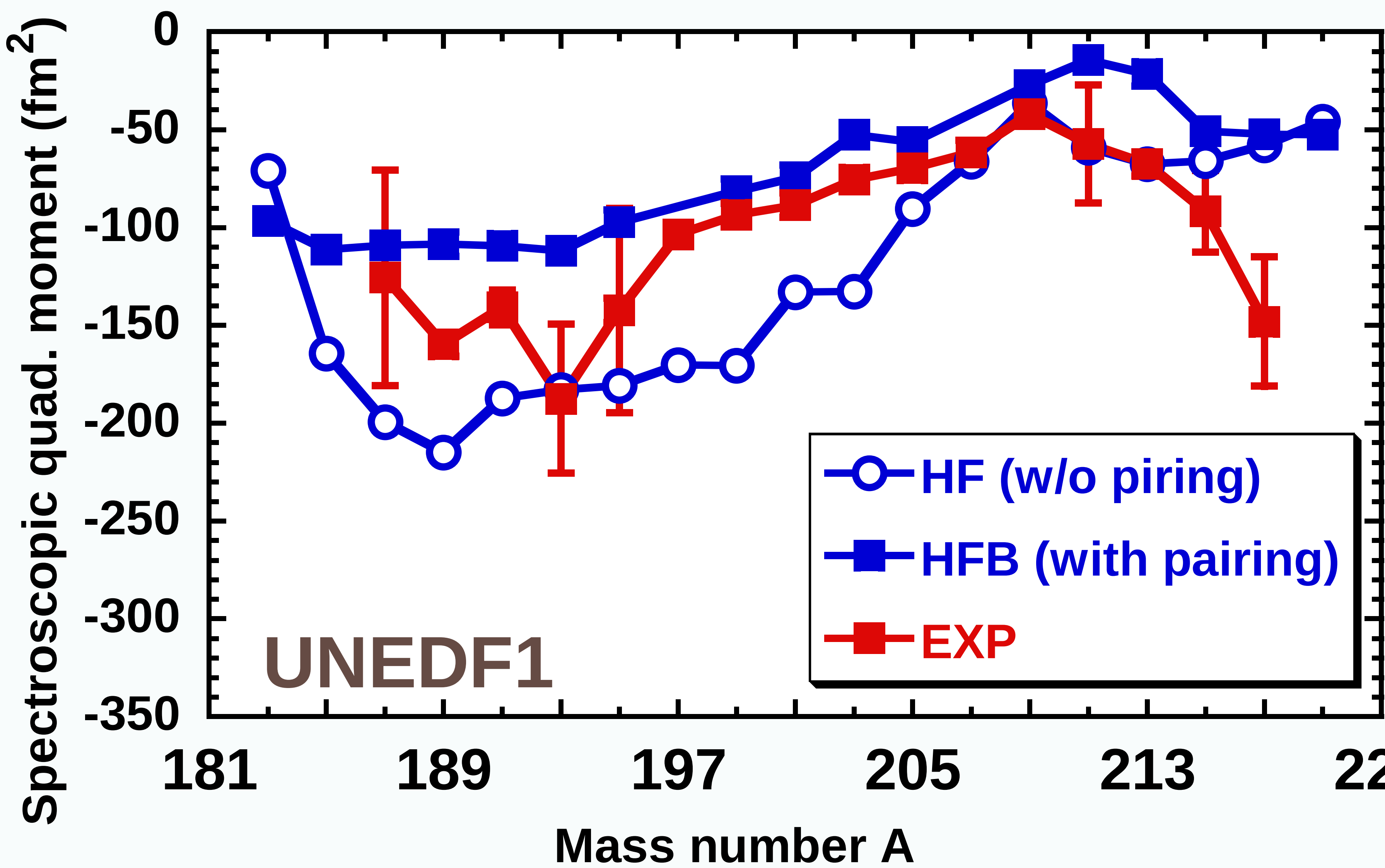
-- $\mu_{5/2}$ = 0.360(7) μ_N

-- $\mu_{3/2}$ = -0.37(6) μ_N

Evolution of the spectroscopic total magnetic moment for the blocked ^{229}Th

9/2- ground states in bismuth

Bismuth ground states 9/2-



ISOLDE Experiment, A.E. Barzakh, private communication

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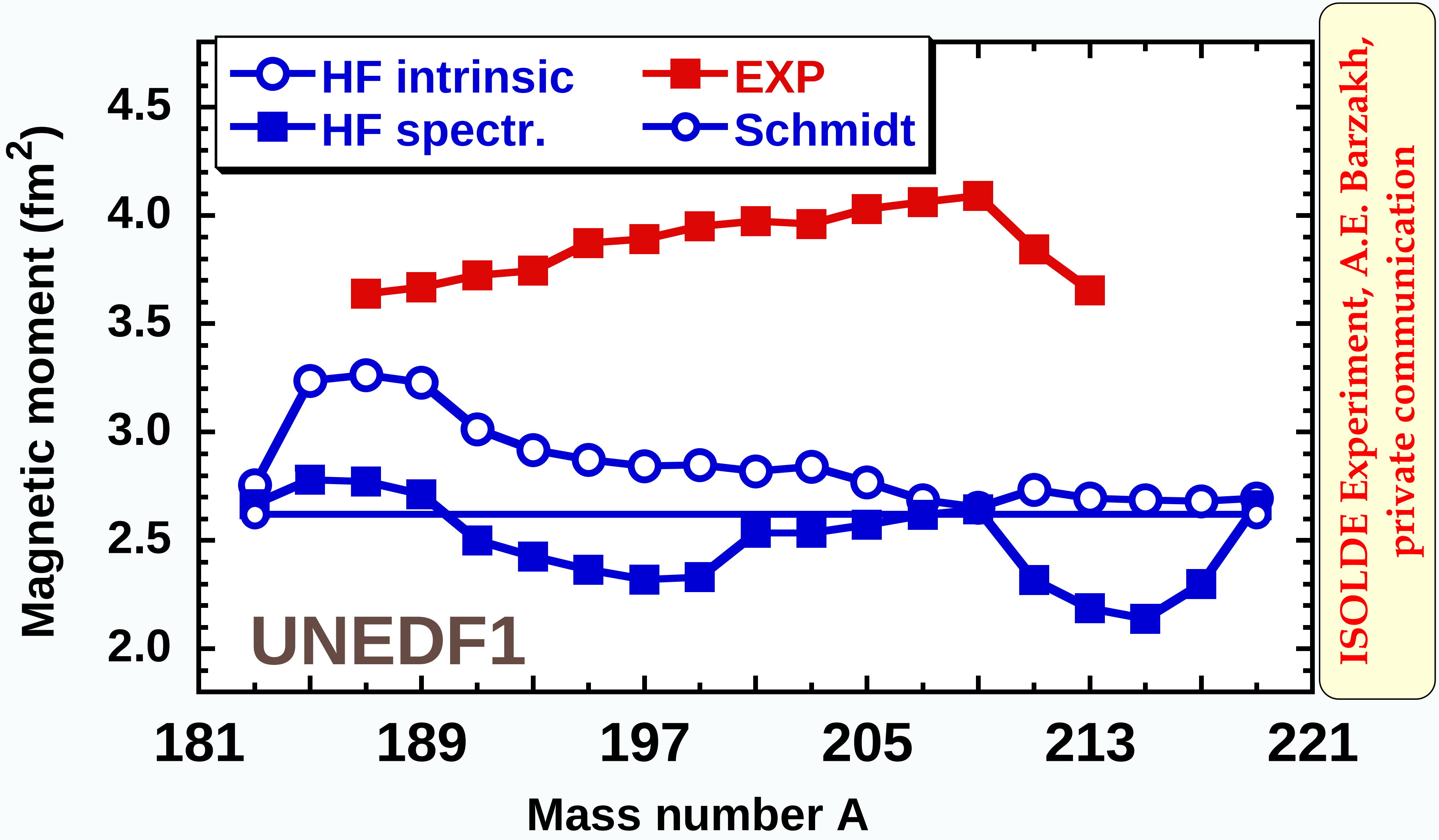
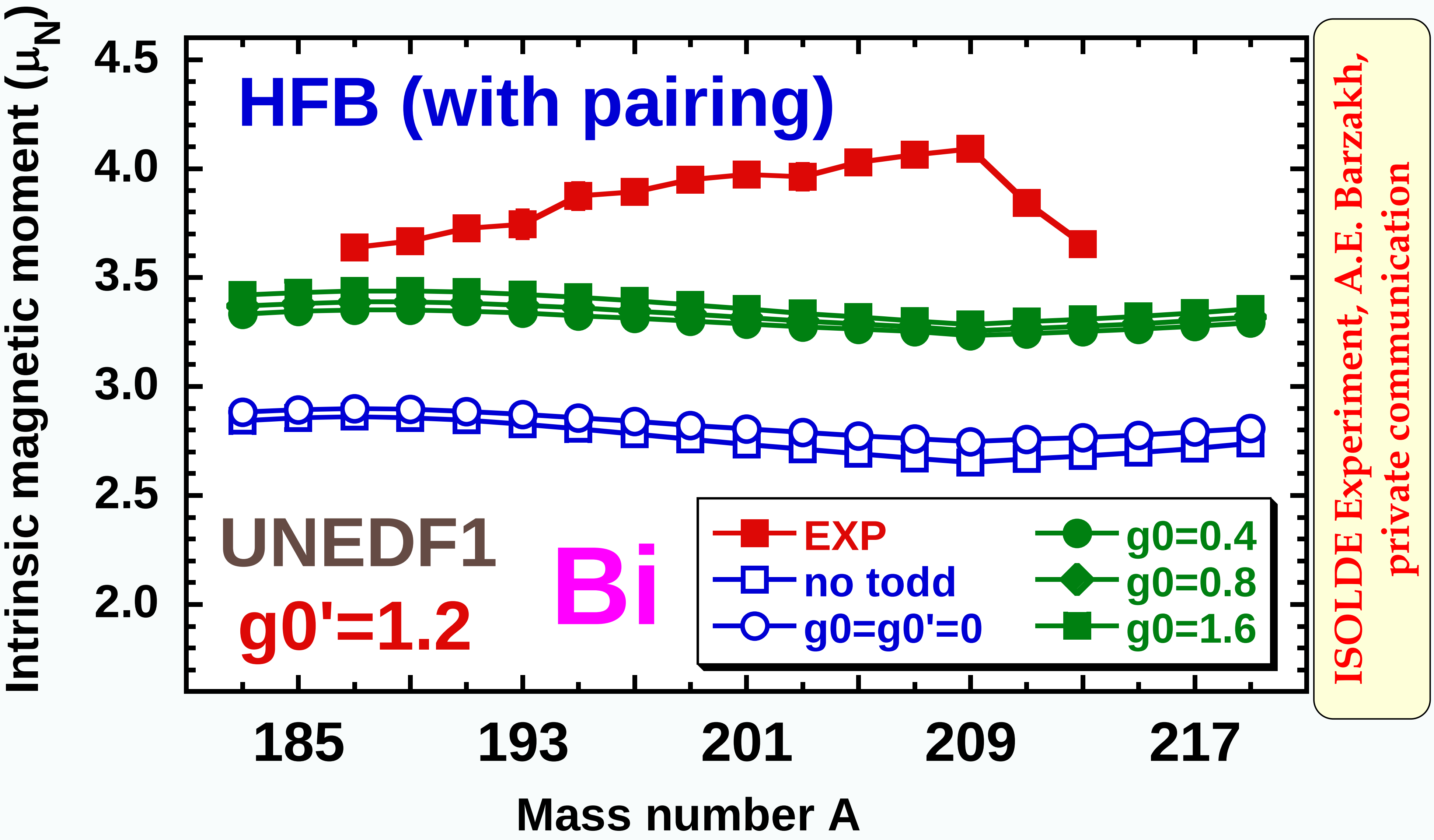
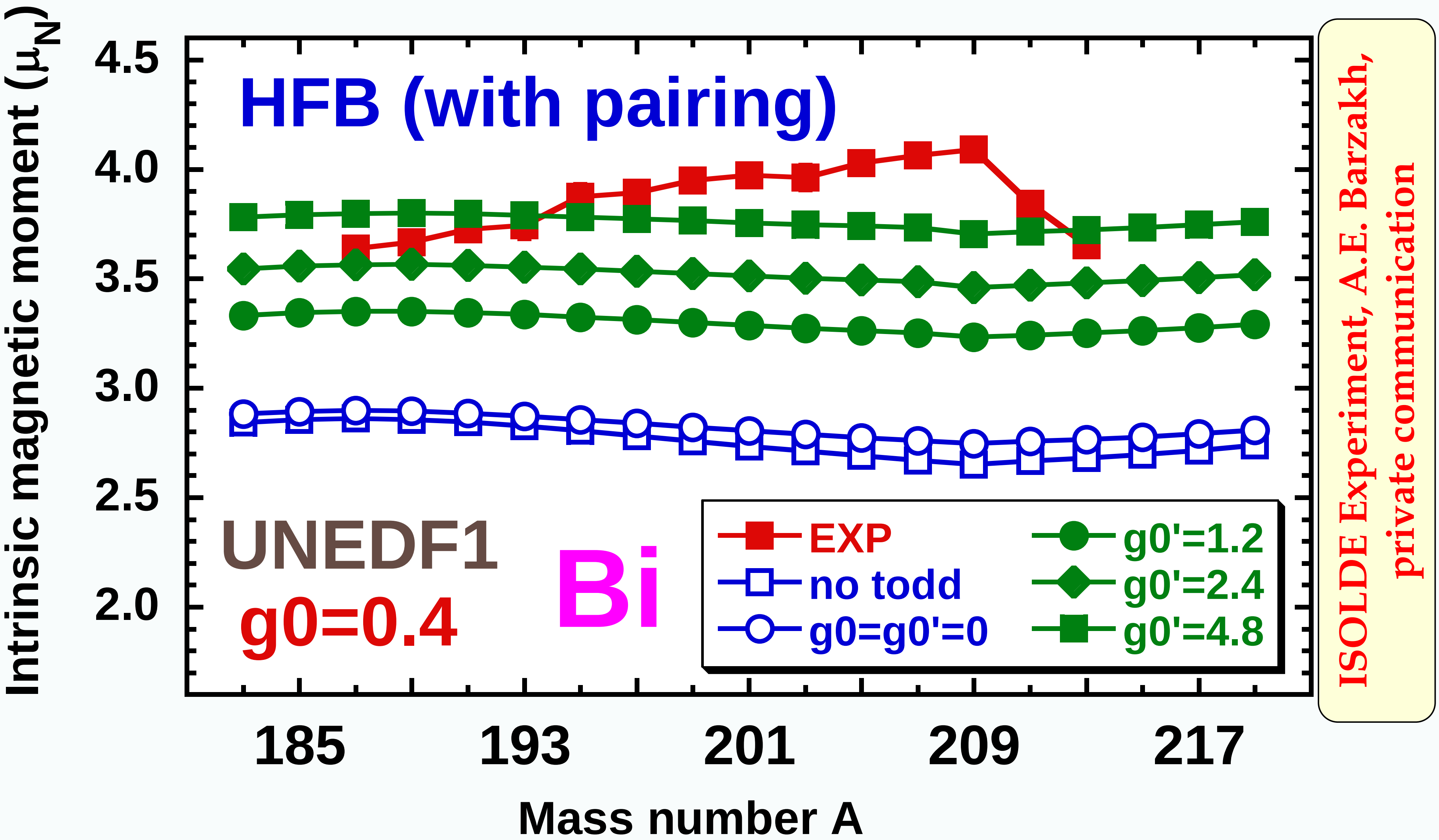
Bismuth ground states 9/2-



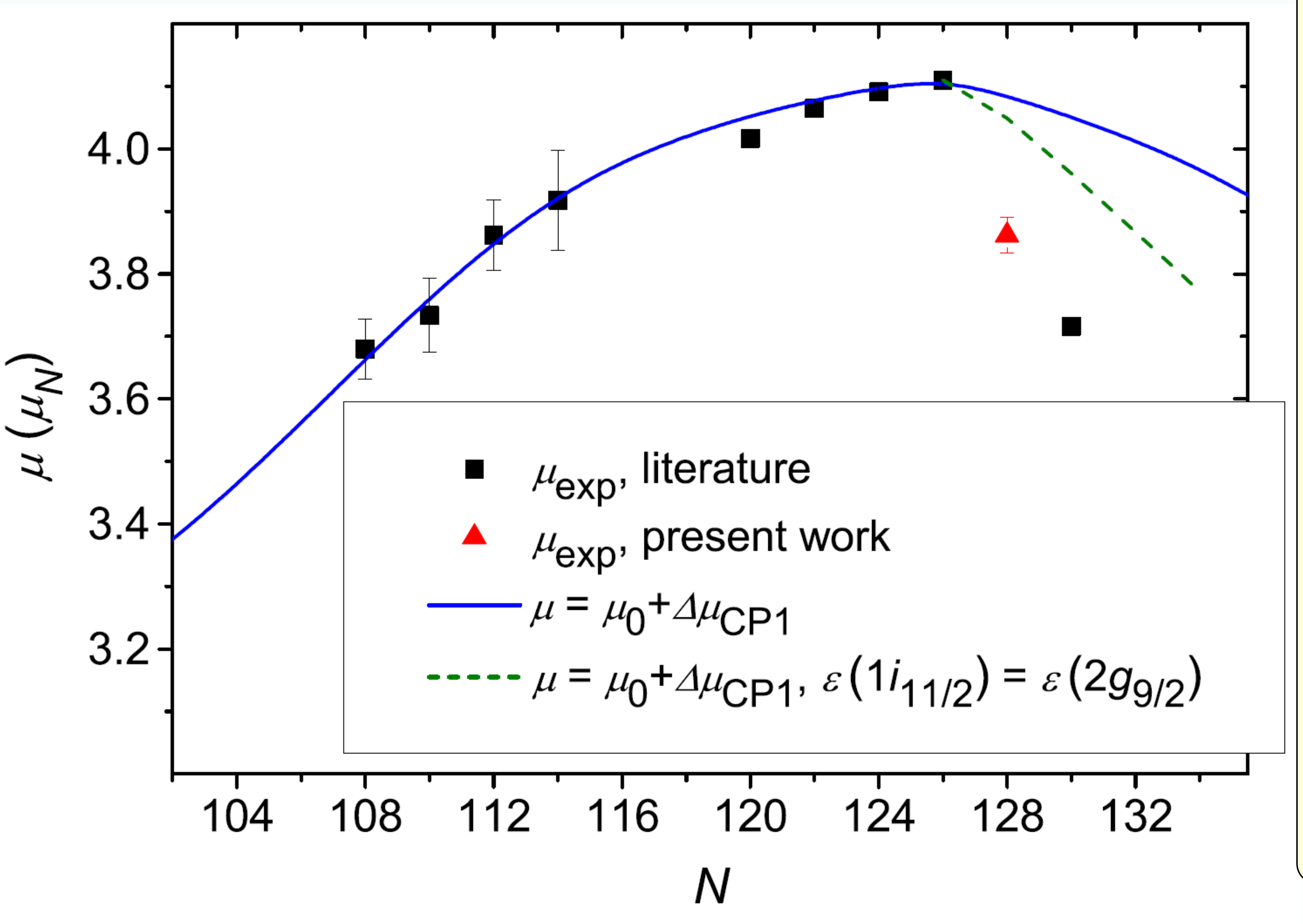
Bismuth ground states 9/2-



Bismuth ground states 9/2-



Bismuth ground states 9/2-



A.E. Barzakh *et al.*, Phys. Rev. C 97, 014322 (2018)

Summary

1. Ground-state and isomeric magnetic moments are known in hundreds of odd and odd-odd nuclei, measured by atomic spectroscopic methods up to a **very high precision**.
2. In the standard shell-model calculations, agreement with data is achieved by using the concept of **effective g-factors**.
3. In the nuclear DFT calculations, magnetic moment have been up to now **rarely considered**.
4. Poorly known **time-odd sector** of the nuclear DFT crucially influences the magnetic moments.
5. **Adjustments of the nuclear DFT coupling constants** to data should take the magnetic moments into account.

Thank you