Electromagnetic moments of ground and excited states calculated in nearly spherical and well-deformed odd nuclei

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The IOP Joint APP, HEPP and NP conference, Liverpool, UK, April 8-11, 2024

Outline

1. Methodology
   a) Polarization
   b) Self-consistency
   c) Symmetry restoration
2. Odd near neighbours of doubly magic nuclei
3. Excited quasiparticle states in odd-N open-shell isotopes from gadolinium to osmium
4. Conclusions

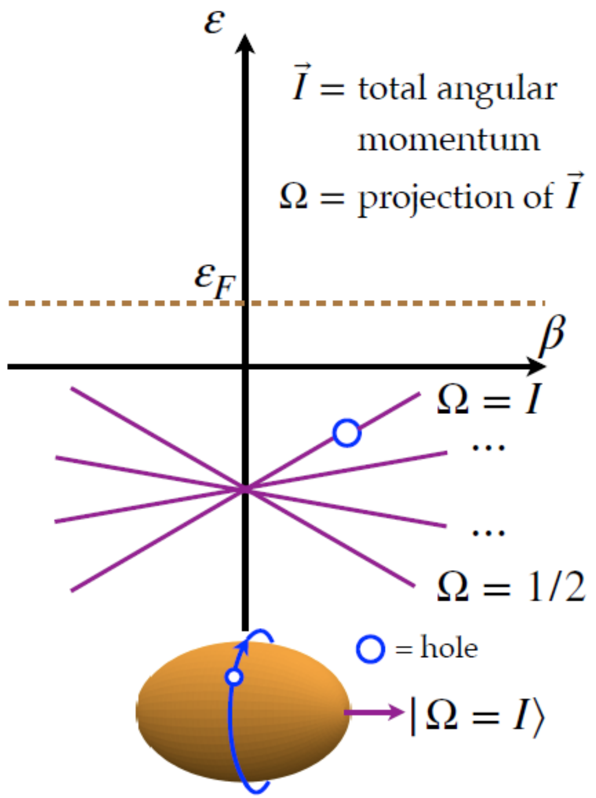
Herlik Wibowo

Collaborators: D. Muir, A. Sánchez-Fernández, X. Sun, and J. Dobaczewski

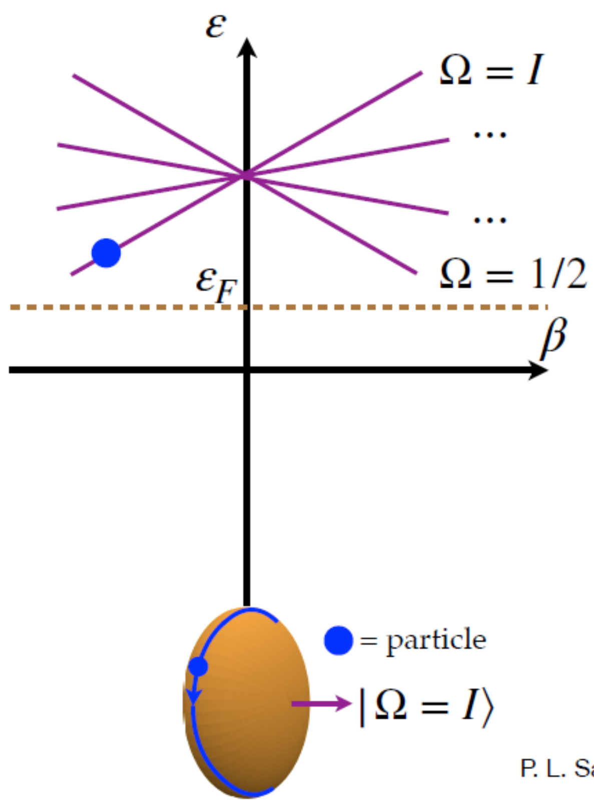
UK Nuclear Physics Conference 2023 at the University of York
April 4-6, 2023

2

Shape and spin core polarizations

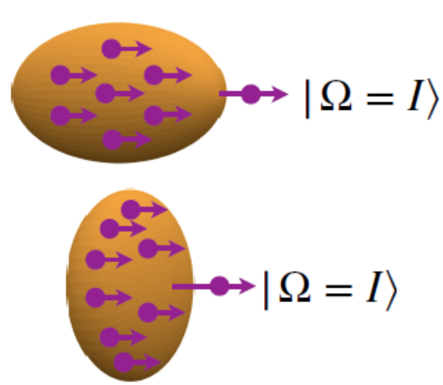


prolate
polarization



oblate
polarization

Spin polarization



Landau parameter g_0' ($g_0' = 1.7$)

$$g_0' = N_0\left(2C_1^s + 2C_1^T(3\pi^2\rho_0/2)^{2/3}\right)$$

$$\frac{1}{N_0} \approx 150\frac{m}{m^*}\ \mathrm{MeV}\cdot\mathrm{fm}^3$$

P. L. Sassarini et al., J. Phys. G: Nucl. Part. Phys. **49**, 11LT01 (2022)

A. Bohr and B. R. Mottelson, *Nuclear Structure* Vol. 1
K. L. G. Heyde, *The Nuclear Shell Model*
I. Ragnarsson and S. G. Nilsson, *Shapes and Shells in Nuclear Structure*

Herlik Wibowo

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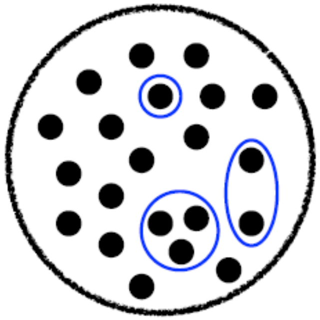
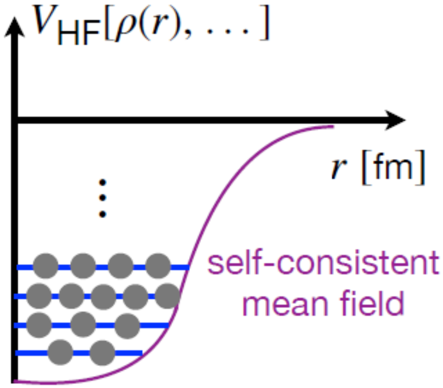
1

Nuclear density functional theory





Trial s.p. wave-function $\{ | \varphi_i^{\mathrm{trial}} \rangle \}$

Calculate the densities $\{\rho, \ldots\}$

Calculate the mean field $V_{\mathrm{HF}}[\rho, \ldots]$

Solve the HF equation

$$\left[\frac{p^2}{2m} + V_{\mathrm{HF}}[\rho, \ldots] \right] | \varphi_i \rangle = \varepsilon_i | \varphi_i \rangle$$

New s.p. wave-function $\{ | \varphi_i^{\mathrm{new}} \rangle \}$

Energy density functional

$$\mathscr{E}[\rho(\mathrm{r}), \mathrm{s}(\mathrm{r}), \tau(\mathrm{r}), \mathrm{T}(\mathrm{r}), \mathrm{j}(\mathrm{r}), \overleftrightarrow{J}(\mathrm{r})]$$

Coupling constants

T-even : $C_t^{\rho}, C_t^{\Delta\rho}, C_t^{\tau}, C_t^{J}, C_t^{\nabla J}$

T-odd : $C_t^{s}, C_t^{\Delta s}, C_t^{T}, C_t^{j}, C_t^{\nabla j}$

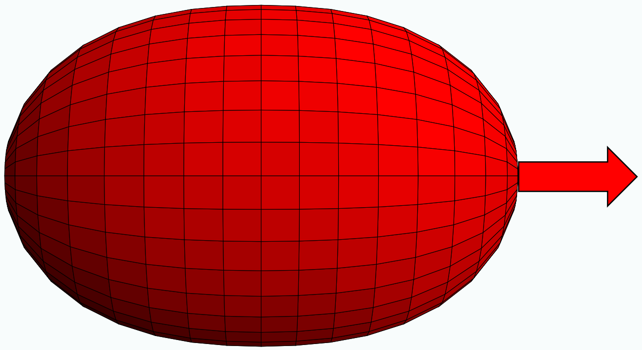
Parametrization: UNEDF1

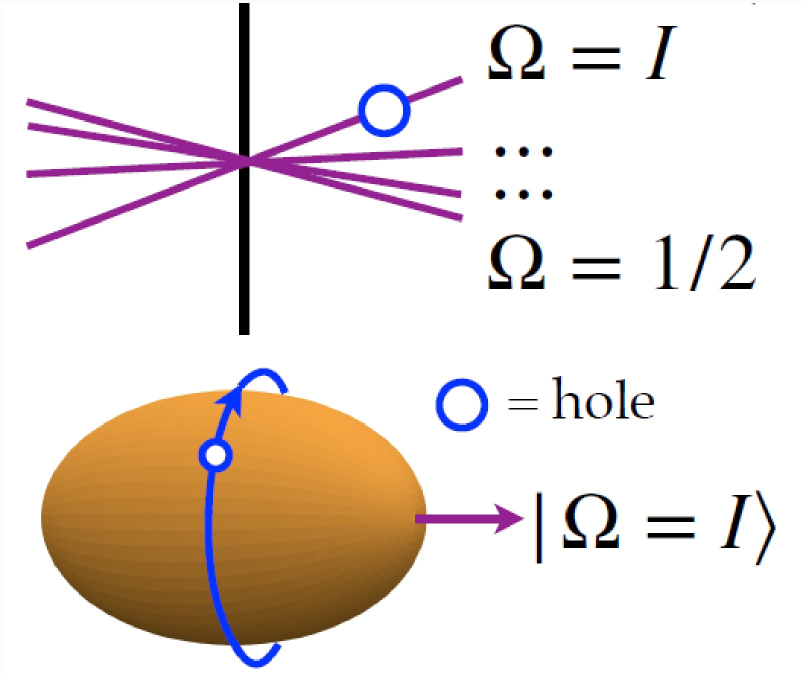
Hartree-Fock (HF) equation

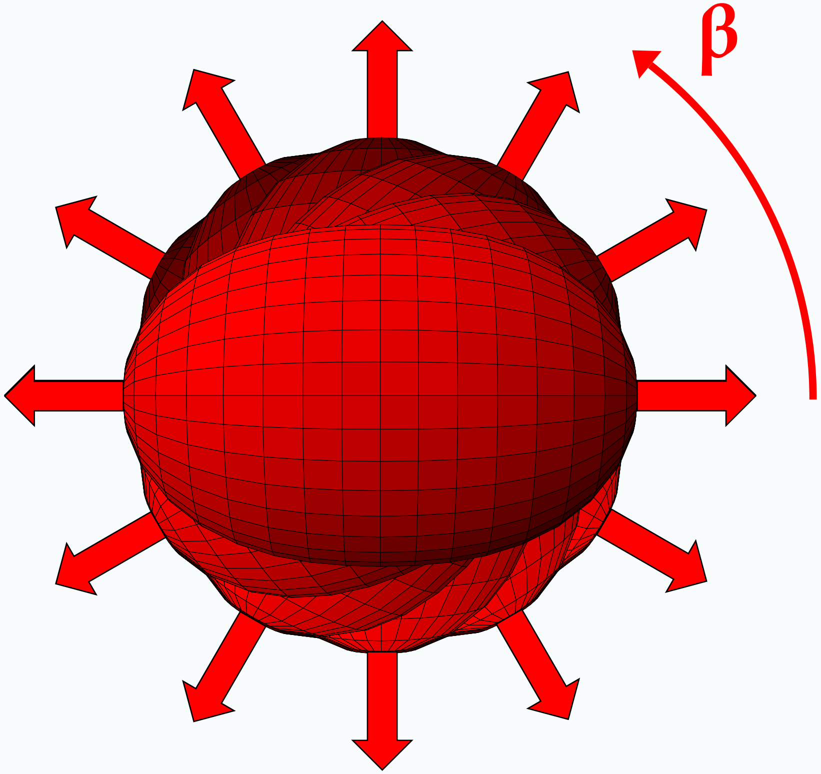
M. Kortelainen et al., Phys. Rev. C **85**, 024304 (2012)

Time-odd spin alignment & symmetry restoration

“Intrinsic”
Symmetry broken





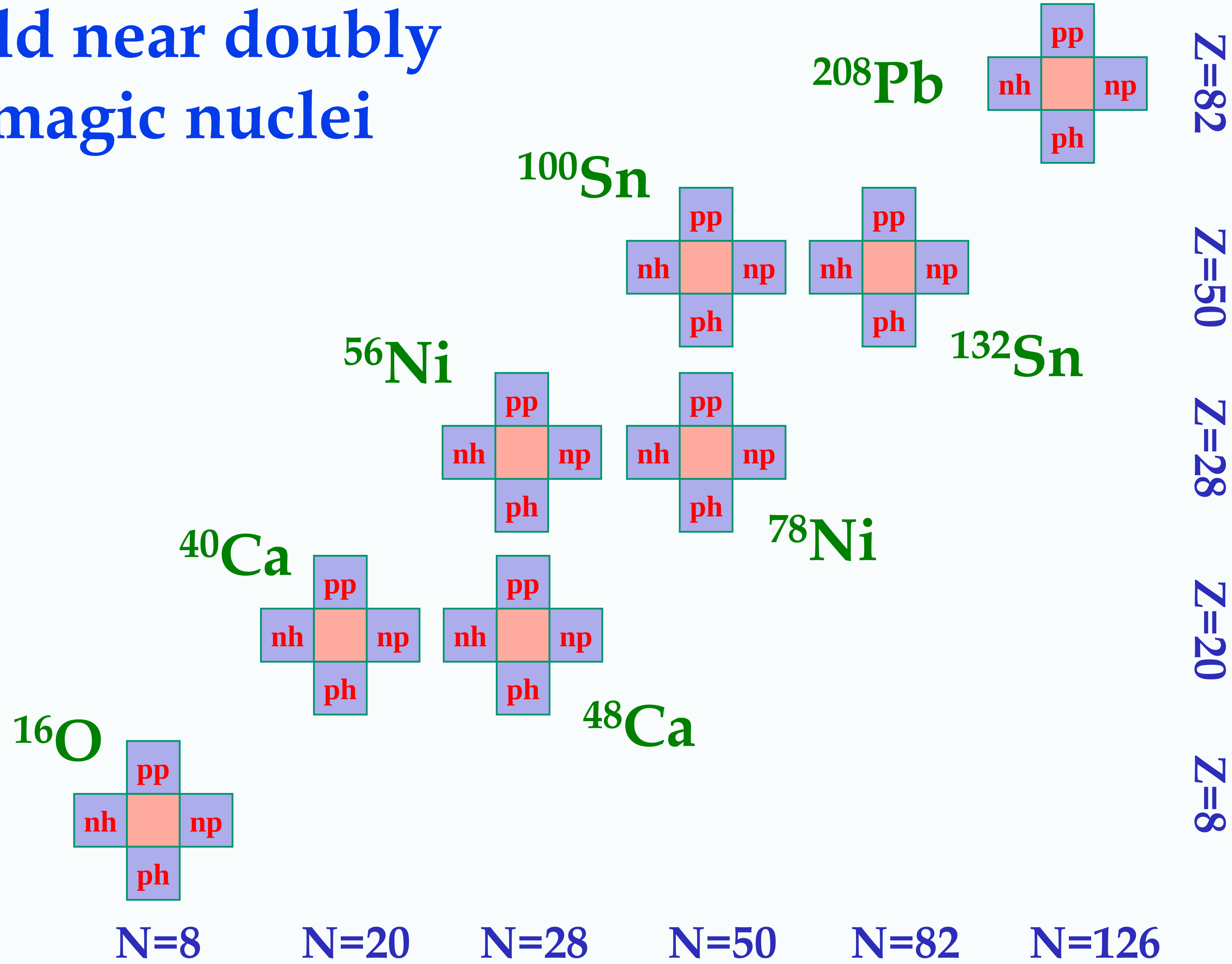


“Laboratory”
Symmetry restored

$$|IM\rangle = \mathcal{N}_I \int_{\beta=0}^{\pi} \mathrm{d}\beta \, d^I_{M\Omega}(\beta) |\Omega, \beta\rangle$$

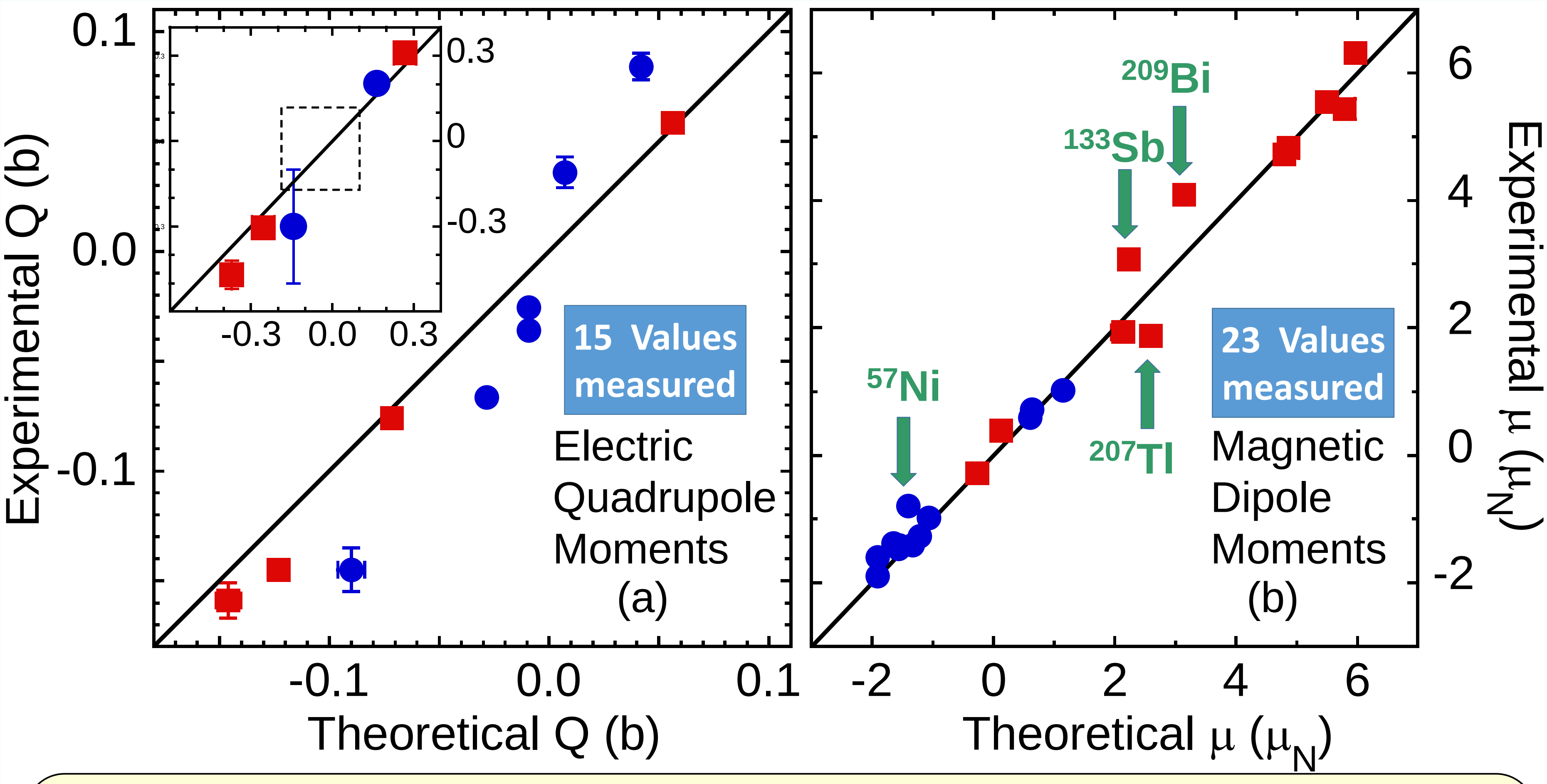
J. A. Sheikh et al., J. Phys. G48, 123001 (2021)

Odd near doubly magic nuclei



Quadrupole & dipole moments

P. Sassarini *et al.*, J. Phys. G49 (2022) 11LT01



- **Proton-odd (squares) & neutron-odd (circles) nuclei**
- **Average of UNEDF1, SLy4, SkO′, D1S, N3LO functionals**
- **RMS deviations much smaller than the residuals**

Effective spin g-factor? Who ordered that?

P. Sassarini *et al.*, J. Phys. G49 (2022) 11LT01

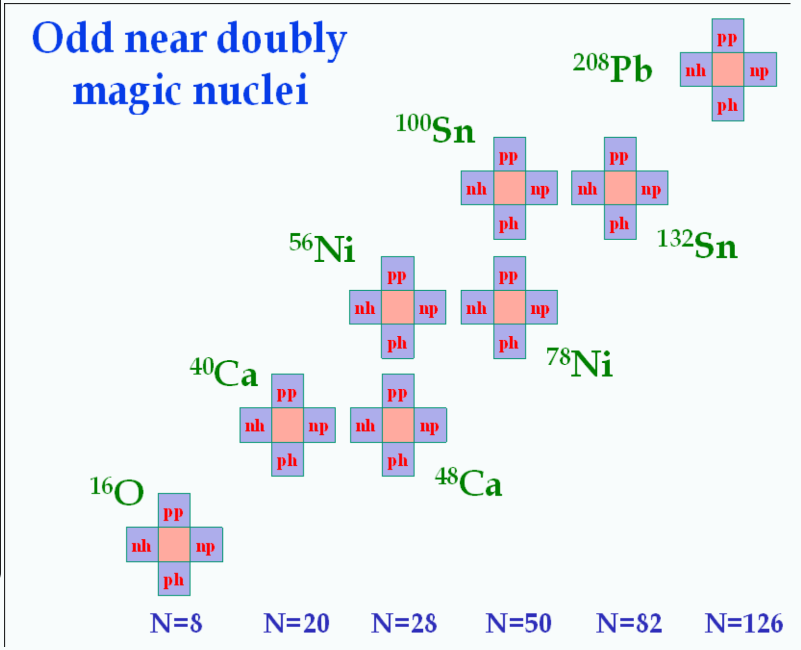
$$g_s^{(i)} = g_p(g_n) = 5.59(-3.83) \times g^{\text{eff}} ???$$

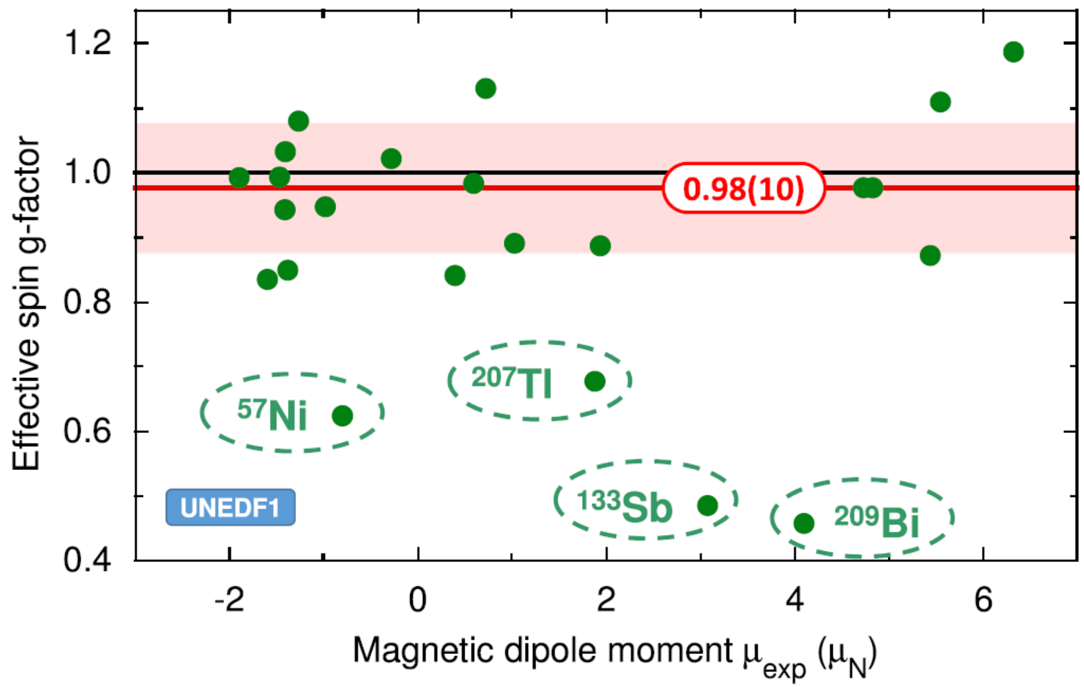
$$g_\ell^{(i)} = 1(0)$$

Landau parameter g_0' ($g_0' = 1.7$)

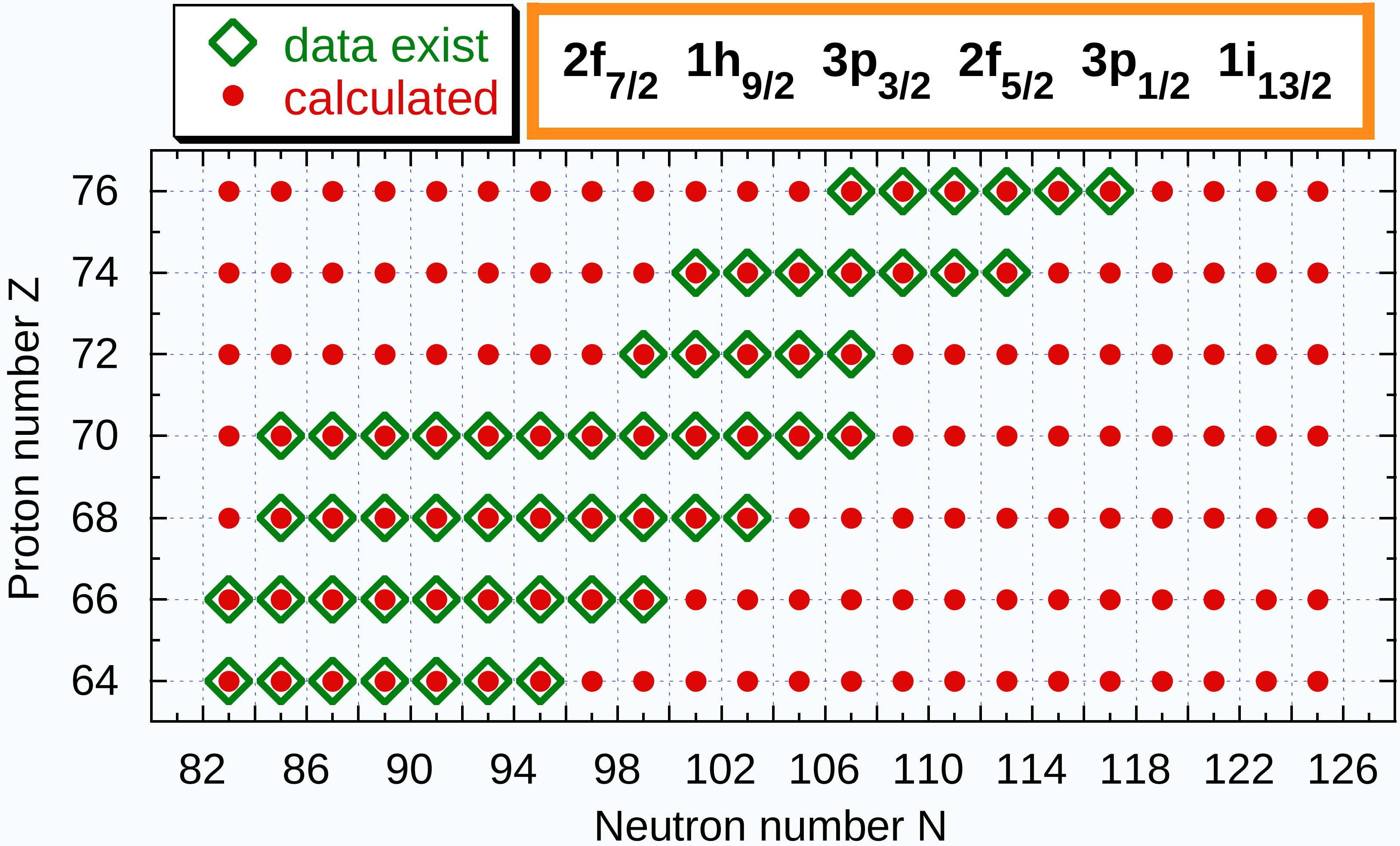
$$g_0' = N_0\left(2C_1^s + 2C_1^T(3\pi^2\rho_0/2)^{2/3}\right)$$

$$\frac{1}{N_0} \approx 150\frac{m}{m^*}\ \text{MeV}\cdot\text{fm}^3$$





The first systematic nuclear-DFT analysis of the electromagnetic moments in excited quasiparticle states



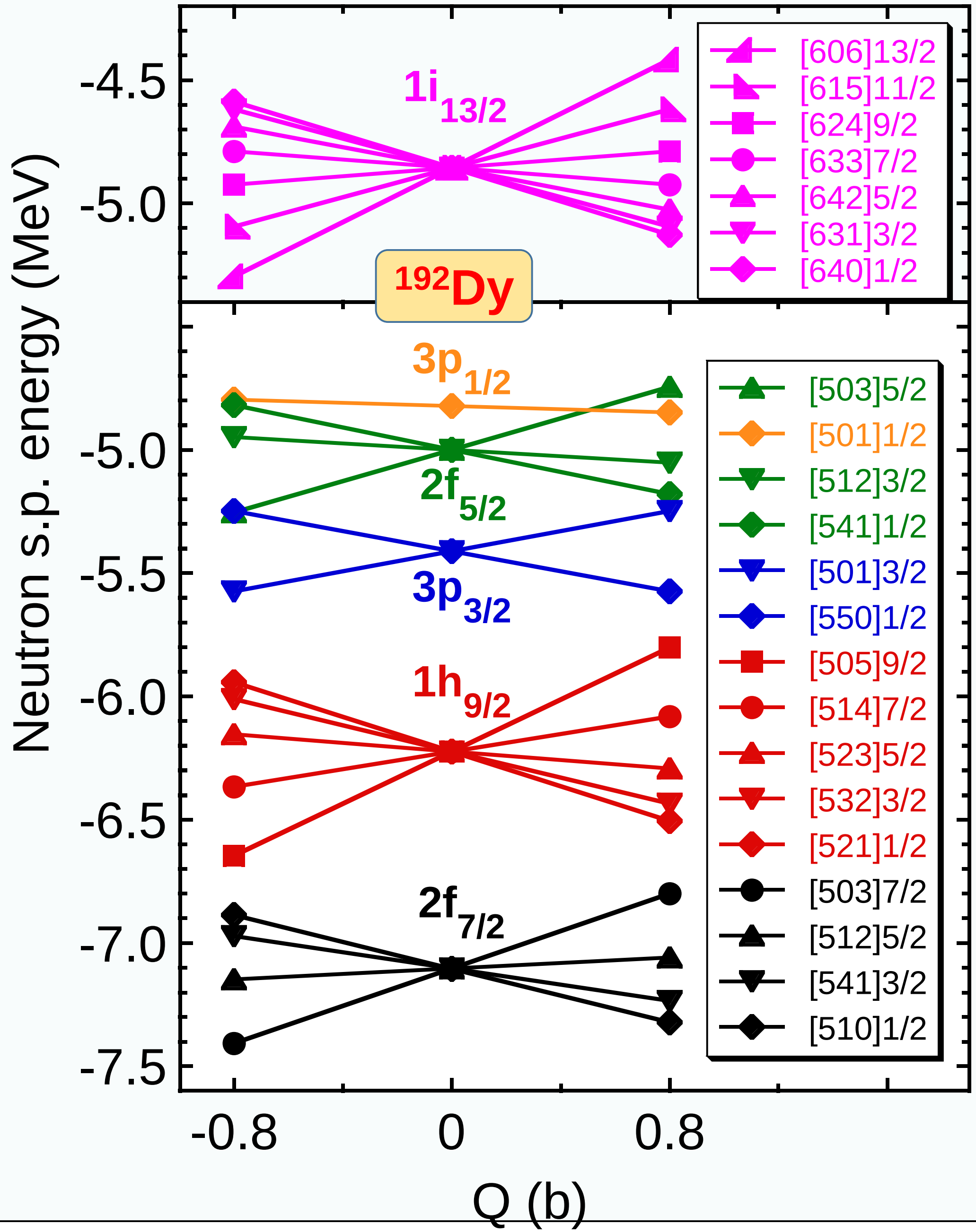
J. Dobaczewski *et al.*, to be published

Standard UNEDF1 nuclear functional used, no parameters (re)adjusted in this work

75 measured magnetic dipole moments (plus 3 rotational bands)

48 measured electric quadrupole moments (plus 3 rotational bands)

How to calculate odd nuclei in nuclear DFT?



without pairing

A even, $p > A$, $h \leq A$

$$|\Psi\rangle^{\text{even}}_{\text{HF}} = a^+_A \ldots a^+_2 a^+_1 |0\rangle$$

$$|\Psi\rangle^{\text{odd}}_{\text{HF}} = \begin{cases} a^+_p |\Psi\rangle^{\text{even}}_{\text{HF}} \\ a_h |\Psi\rangle^{\text{even}}_{\text{HF}} \end{cases}$$

with pairing

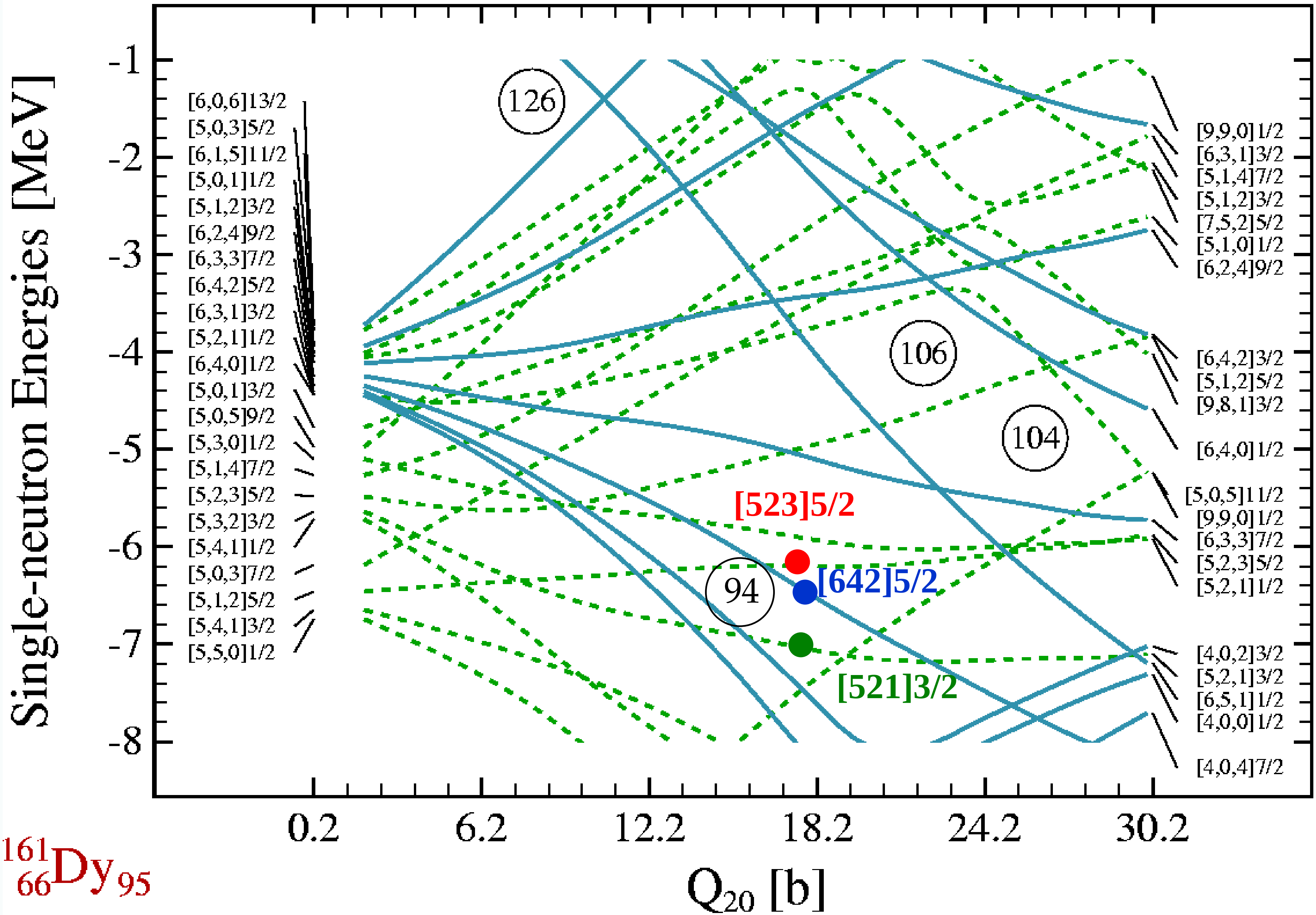
$$|\Psi\rangle^{\text{even}}_{\text{HFB}} = \prod_{\mu>0} \left(u_\mu + v_\mu a^+_{\bar{\mu}} a^+_\mu \right) |0\rangle$$

$$|\Psi\rangle^{\text{odd}}_{\text{HFB}} = \beta^+_\nu |\Psi\rangle^{\text{even}}_{\text{HFB}}$$

$$= a^+_\nu \prod_{\nu \neq \mu > 0} \left(u_\mu + v_\mu a^+_{\bar{\mu}} a^+_\mu \right) |0\rangle$$

tagging quasiparticle states

$$\max_\mu \left\{ \langle \varphi_\nu | \phi^{\text{upper}}_\mu \rangle, \langle \varphi_\nu | \phi^{\text{lower}}_\mu \rangle \right\}$$



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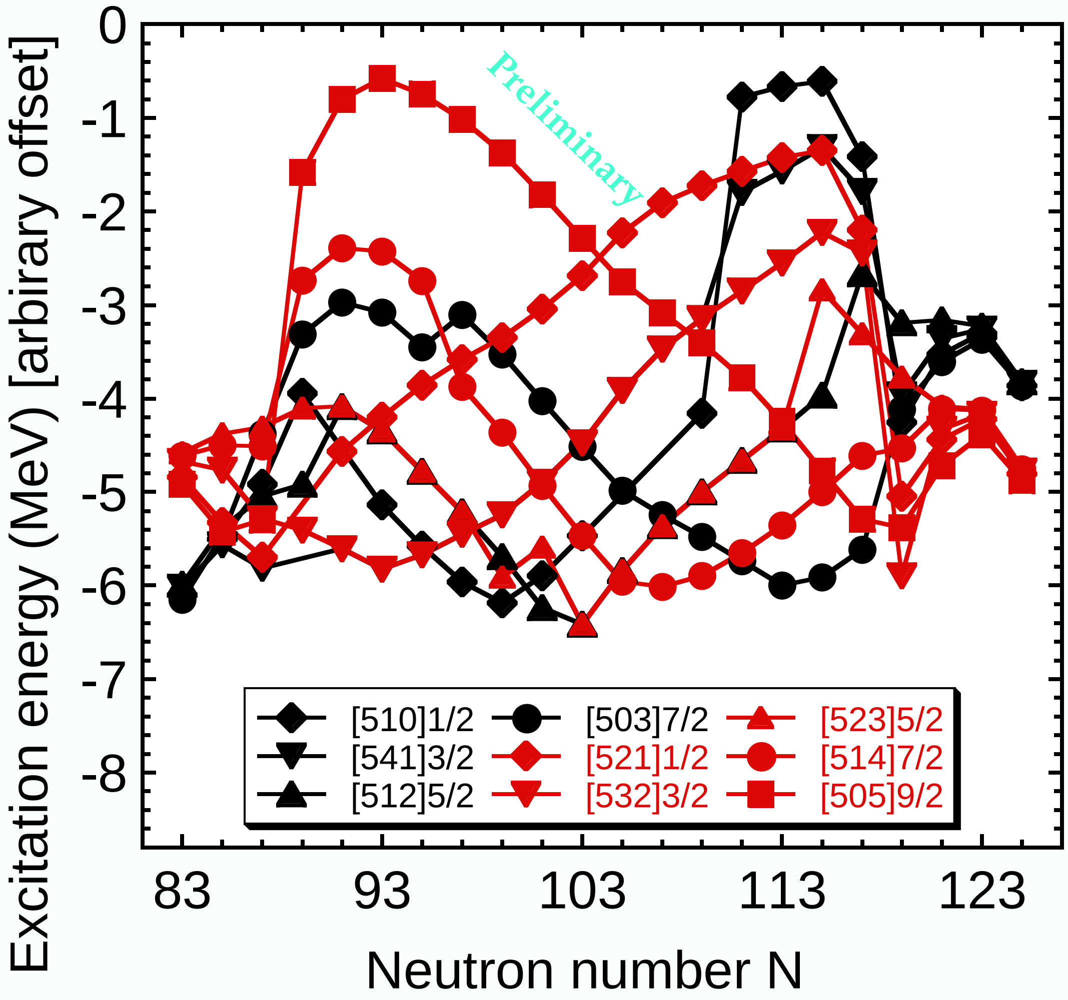
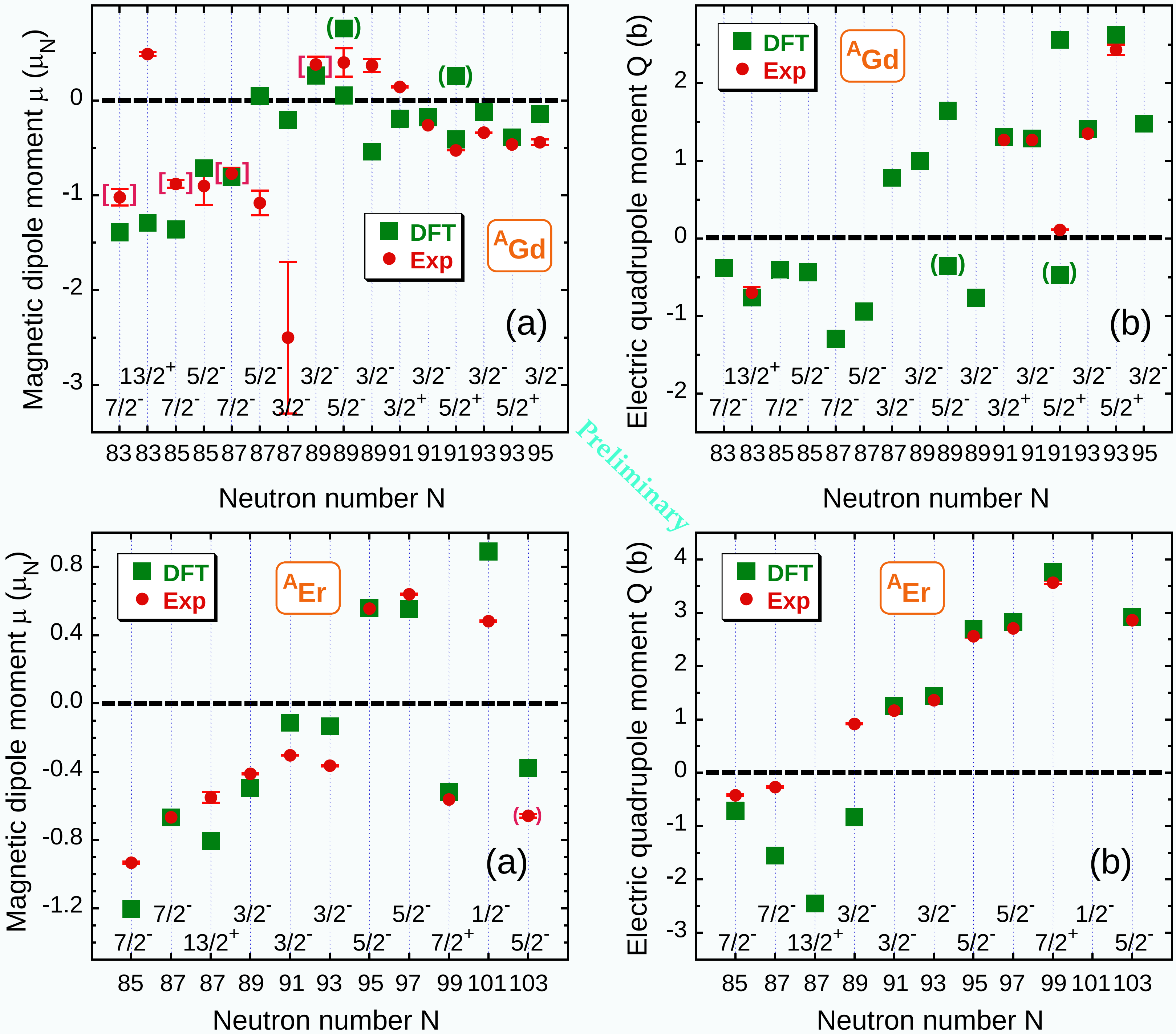
Excitation energies of odd dysprosium isotopes

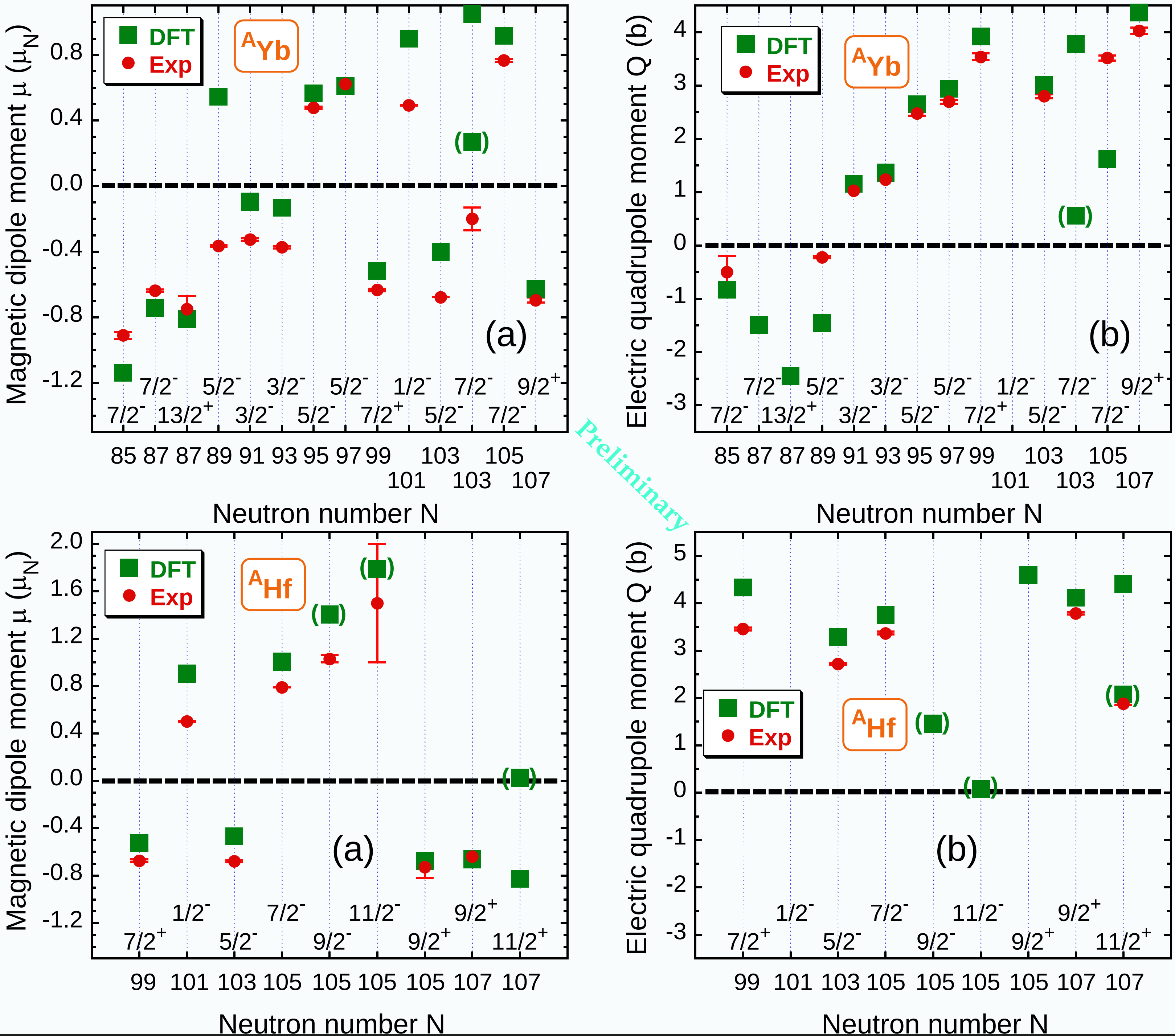


J. Dobaczewski et al., to be published

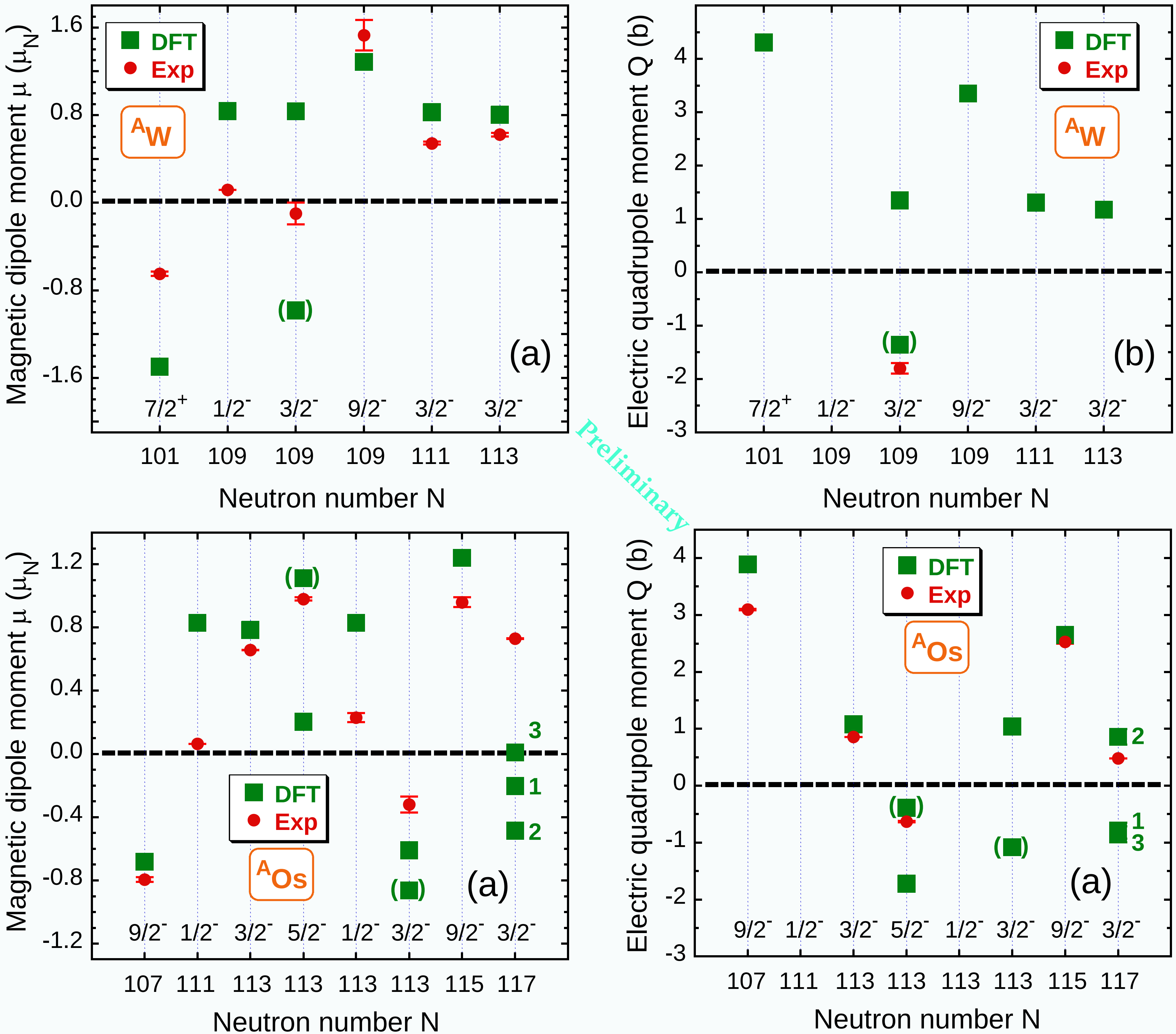
66 band-head states were associated with the lowest calculated quasiparticle states of the given spin and parity. Among those were 27 calculated ground states and 21 were calculated low-lying excited states below 300 keV.



J. Dobaczewski *et al.*, to be published



J. Dobaczewski *et al.*, to be published



J. Dobaczewski *et al.*, to be published

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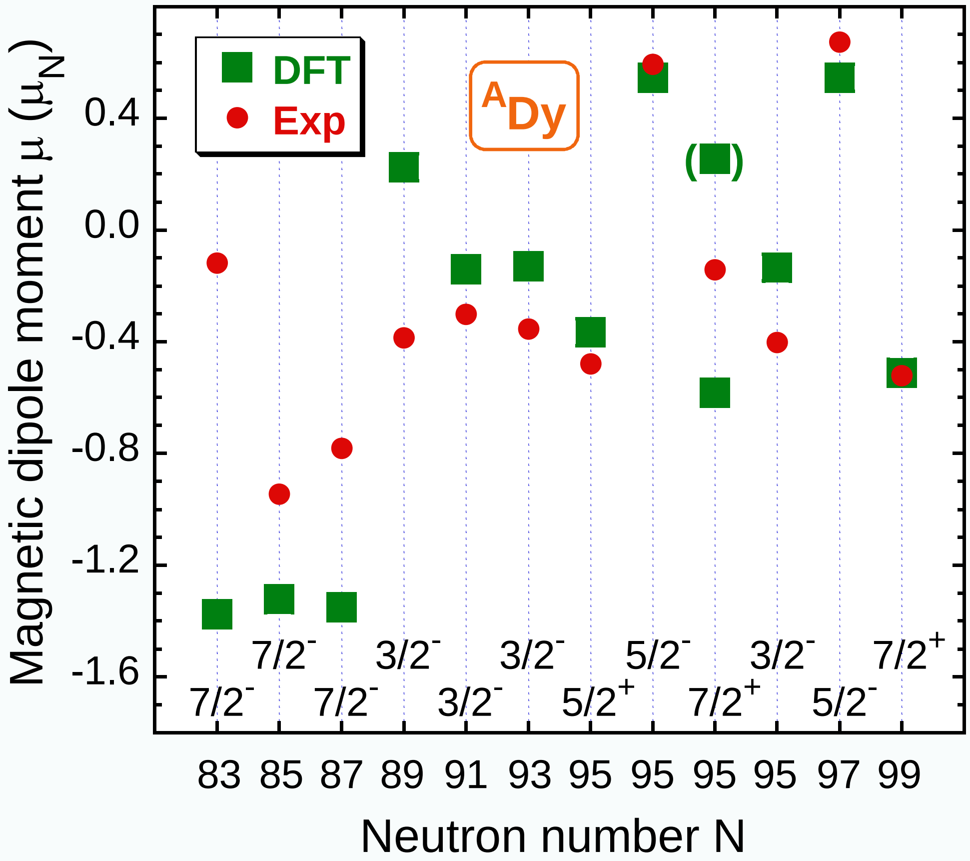
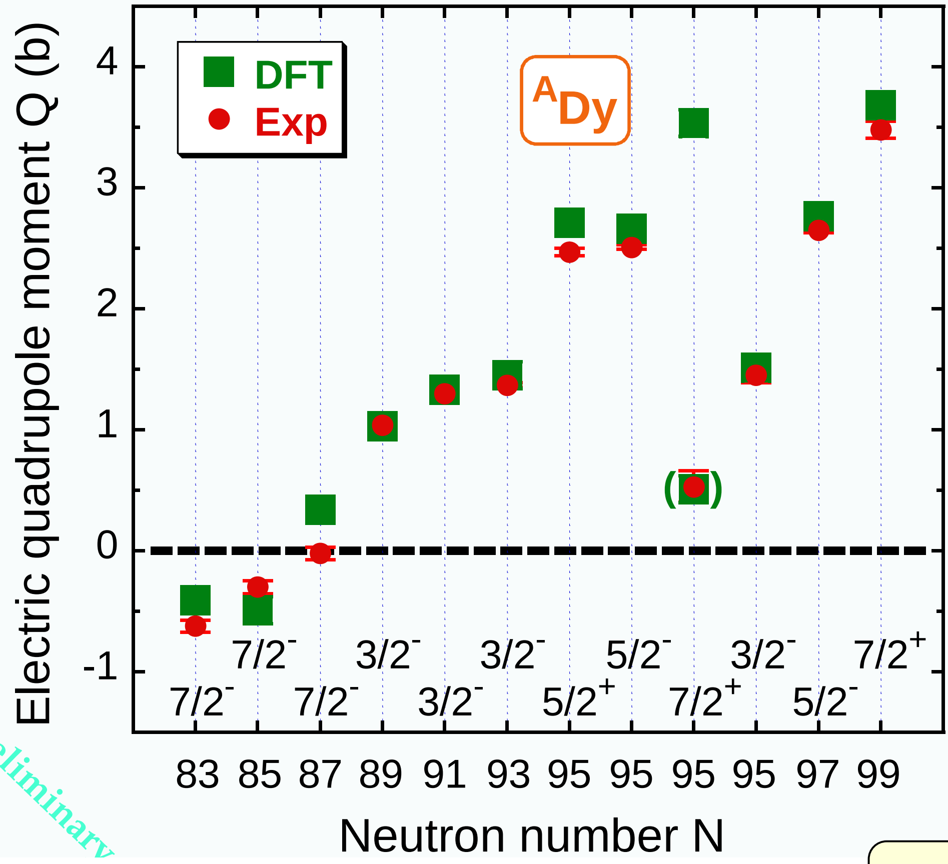
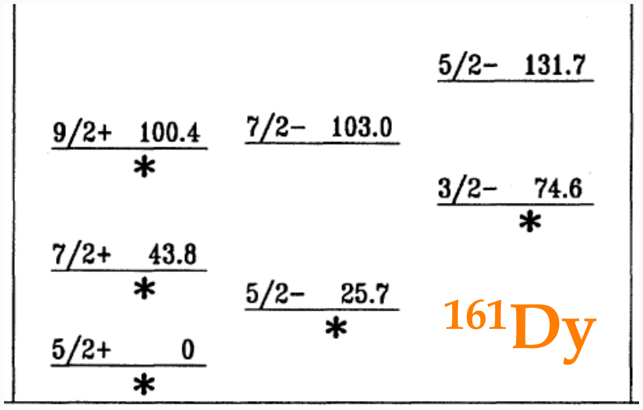
Electromagnetic moments of odd dysprosium isotopes

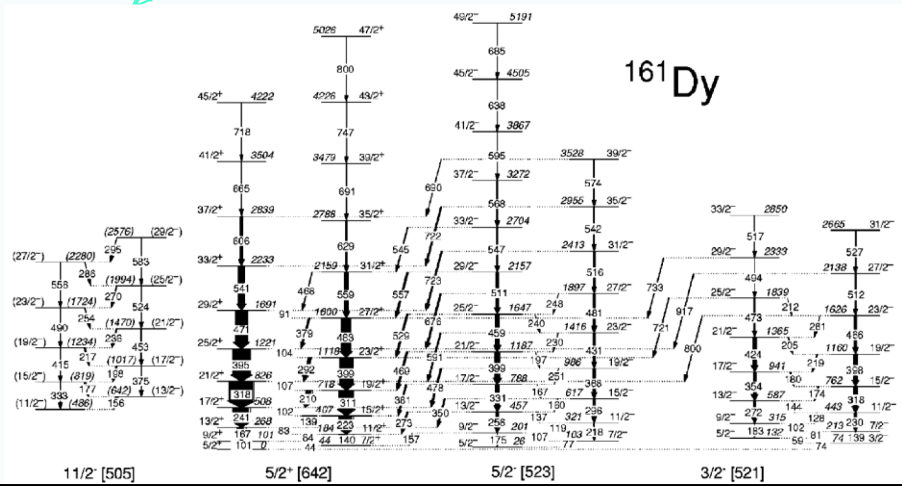




Preliminary



S. J. Margraf *et al.*, Phys. Rev. C52, 2429 (1995)



A. Jungclaus *et al.*, Phys. Rev. C67, 034302 (2003)

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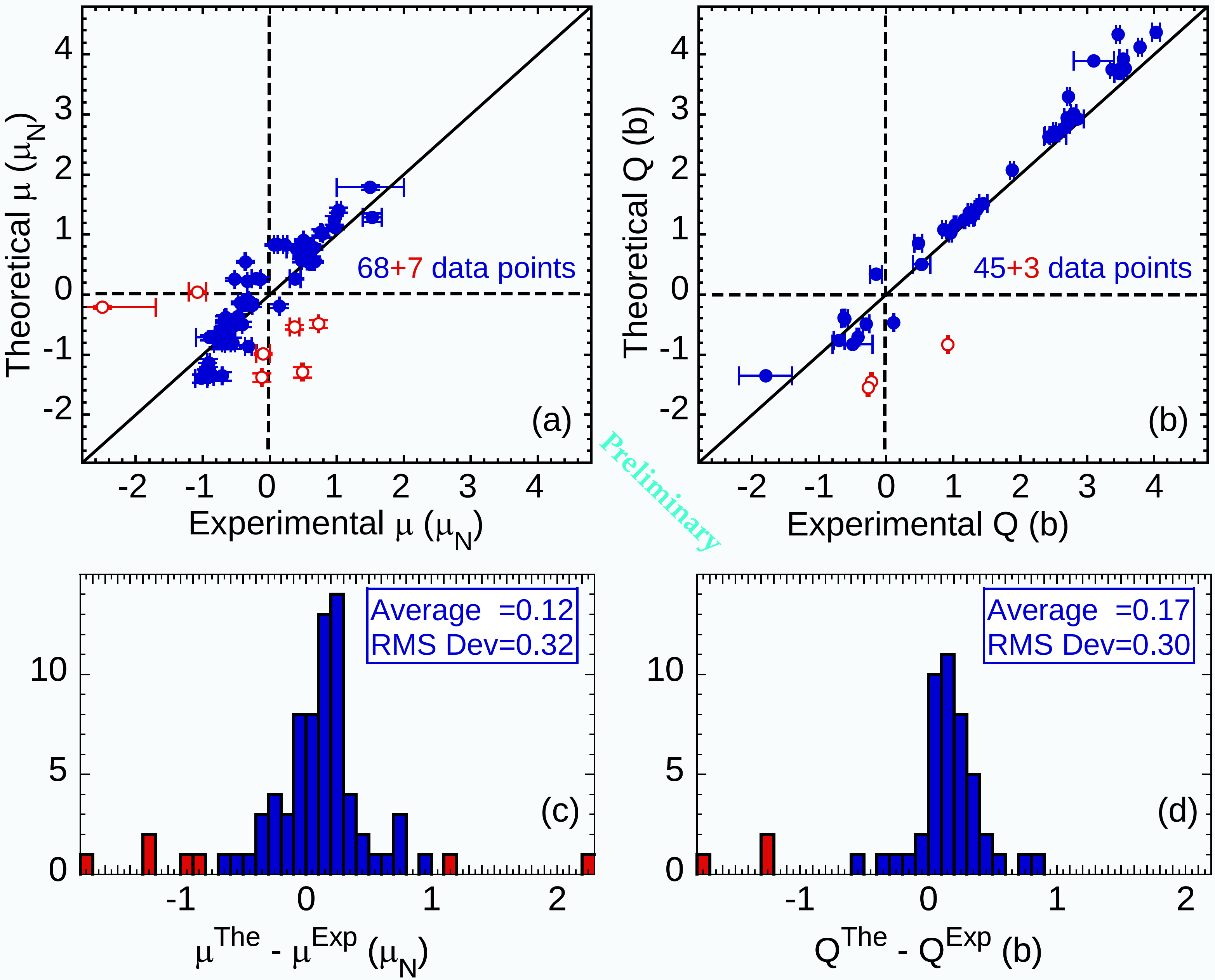
Summary of results obtained in the Gd – Os isotopes



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Conclusions

1. Essential role of **simultaneously** taking into account:
   a) Polarization
   b) Self-consistency
   c) Symmetry restoration
2. Isovector spin-spin interaction is essential in determining the spin polarisation and magnetic dipole moments.
3. A single parameter, the isovector Landau parameter of $g_0'=1.7(4)$, has been adjusted to data across the mass table.
4. Large single-particle phase space (well beyond the valence space) allows using the bare effective charges and bare g-factors. (No adjustable "effective" values are needed.)
5. The calculated magnetic dipole moments μ and electric quadrupole moments Q reproduce the known experimental data in odd-N open-shell isotopes of Gd-Os with the RMS deviations of $\Delta\mu=0.32\ \mu_N$ and $\Delta Q=0.30$ b, respectively.
6. The effects of the triaxiality, octupolarity, two-body currents, K-mixing, and configuration interaction (…) remain to be studied.

Thank you