Two- and Four- quasiparticle states in Z=92 - 108 even-even nuclei In HFB-D1S calculations

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Introduction

- Microscopic method : the HFB approximation with effective force gives the binding energy of the nucleus at the mean field level.
- Effective D1S force
- Time reversal symmetry broken (2 and 4 QP intrinsic excitations)
- Actinides and transactinides Z= 92 to 108
- HFB solutions by expanding on 15 major shells

Theory 1

HFB under constraints

Variational principle :

$$\delta[\langle\Phi\,|\mathbf{H}\ -\lambda_z\,\mathbf{Z}\ -\lambda_n\,\mathbf{N}\ -\Sigma_i\,\mu_i\,\mathbf{Q}_i\ |\Phi\rangle] = 0$$

with $\mathbf{H} = \Sigma_i\ \mathbf{T}_i\ + 1/2\ \Sigma_{i\neq j}\ \mathbf{V}_{ij}$

where V_{ij} is the nucleon-nucleon effective interaction **D1S of GOGNY**

Constraint on

- Particle number: $\langle\Phi\,|\,\mathbf{Z}$ or $\mathbf{N}\,|\Phi\rangle$ = Z or N
- Multipole moments: $\langle\Phi\,|\,\mathbf{Q}_i\ |\Phi\rangle = q_i$

Theory 2

The two-quasiparticle excitations are sought for using blocking calculations.

A trial state is defined as $|\Phi'_{ij}\rangle = \eta_i^+ \eta_j^+ |\Phi_{ij}\rangle$

in which η_i^+ is a quasiparticle creation operator.

Then the equation $\delta\langle\Phi'_{ij}|\widehat{H} - \lambda_N \widehat{N} - \lambda_Z \widehat{Z}|\Phi'_{ij}\rangle = 0$

is solved, and the two-quasiparticle excitation energy is

$$E^{ij}_{2qp} = \langle\Phi'_{ij}|\widehat{H}|\Phi'_{ij}\rangle - \langle\Phi|\widehat{H}|\Phi\rangle.$$

Breaking time-reversal symmetry, the signature partner pairs with angular momentum projections on the z axis,

$K_- = K_1 - K_2$ and $K_+ = K_1 + K_2$,

and parity $\pi = \pi_1 \cdot \pi_2$ are no longer degenerate in energy.

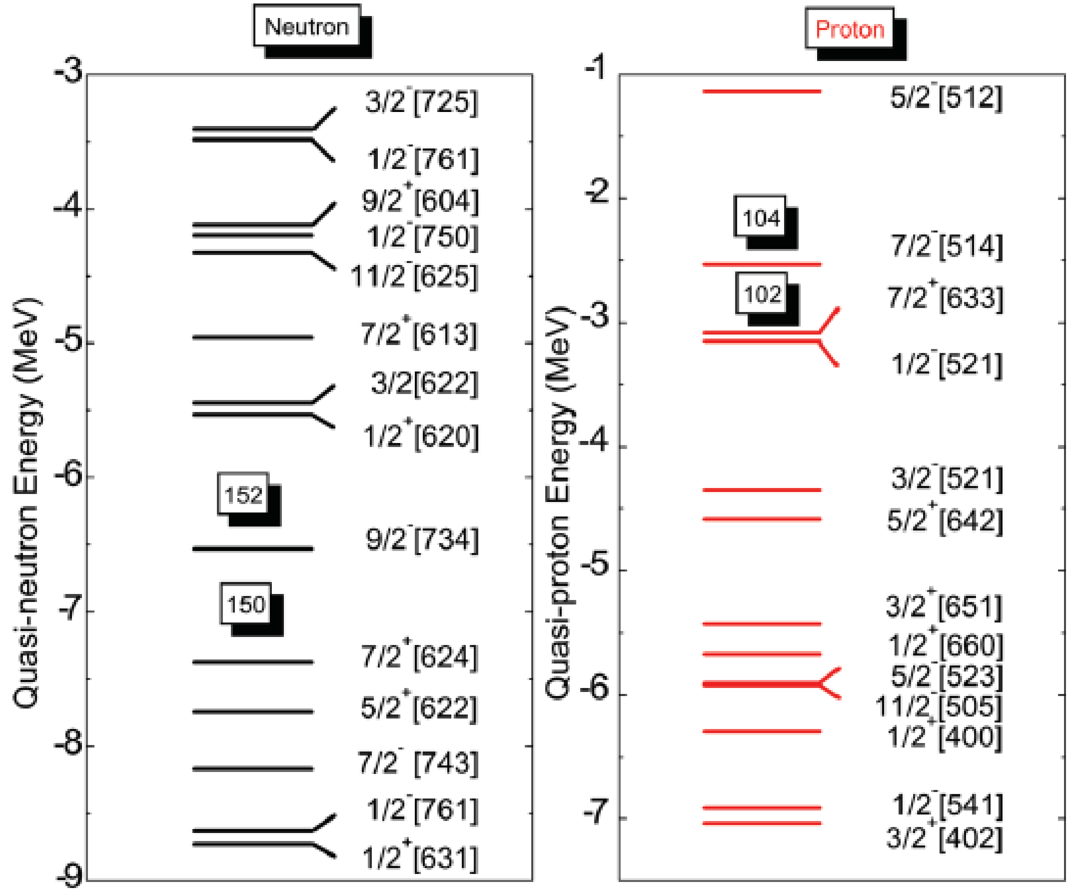
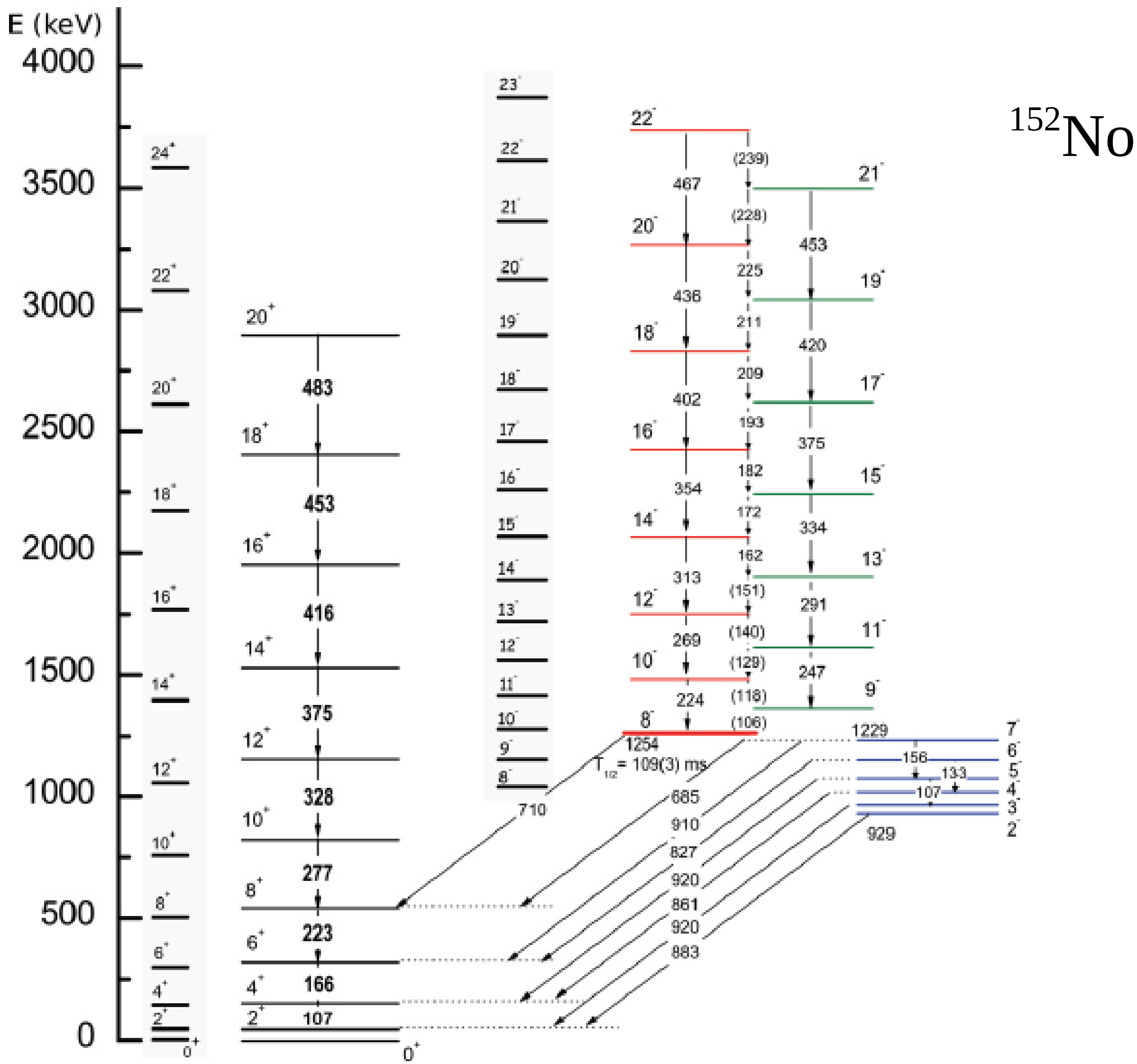


FIG. 9. (Color online) Single-particle energies for neutron and proton states in ^{252}No at axial equilibrium deformation of the HFB energy, where the charge quadrupole moment is $Q_0 = 13.75\,e$ b. The labels $[Nn_z\Lambda]$ are assigned by analogy with a Nilsson diagram.

B. Sulignano et al., PHYSICAL REVIEW C 86, 044318 (2012)



B. Sulignano et al., PHYSICAL REVIEW C 86, 044318 (2012)

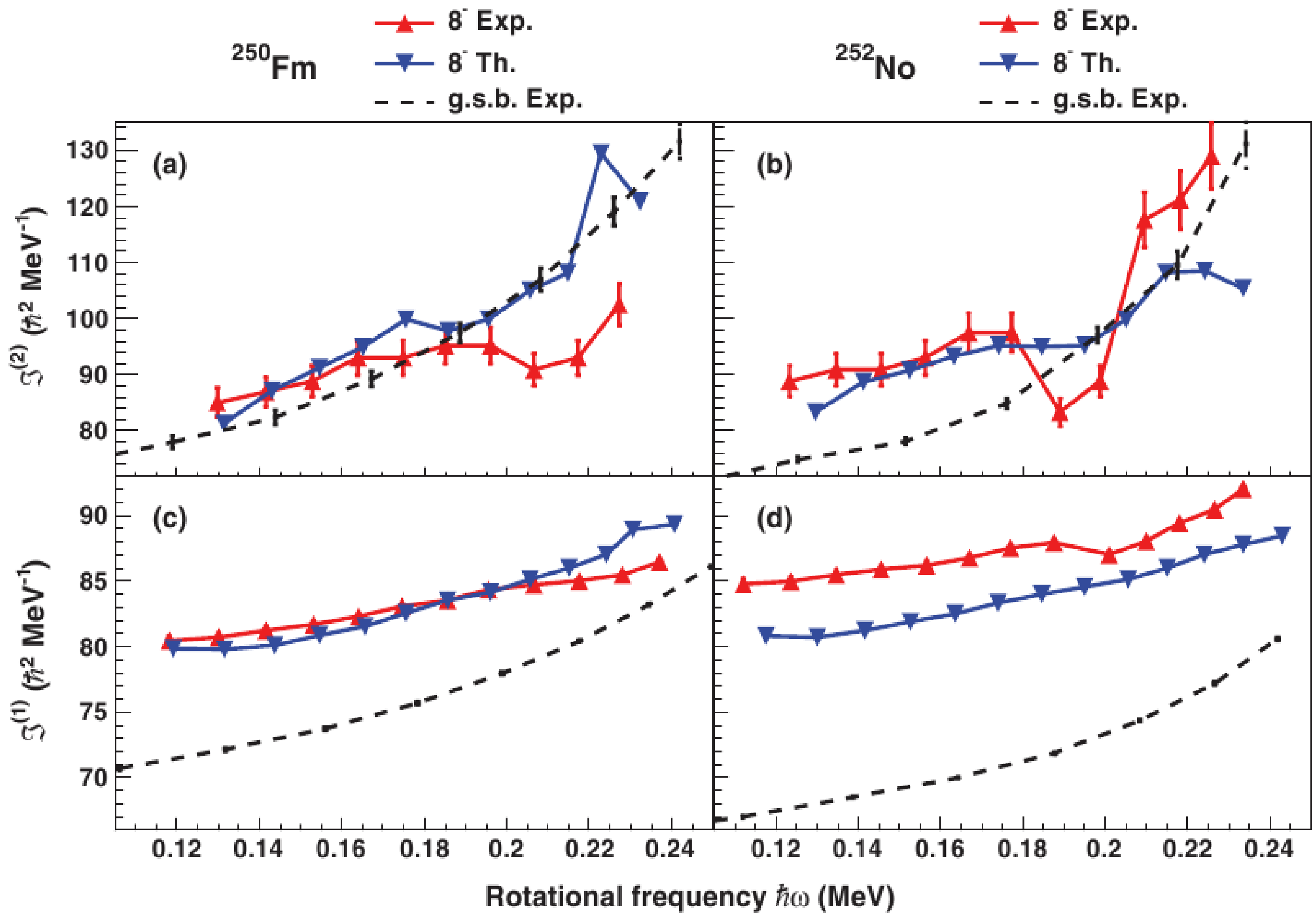
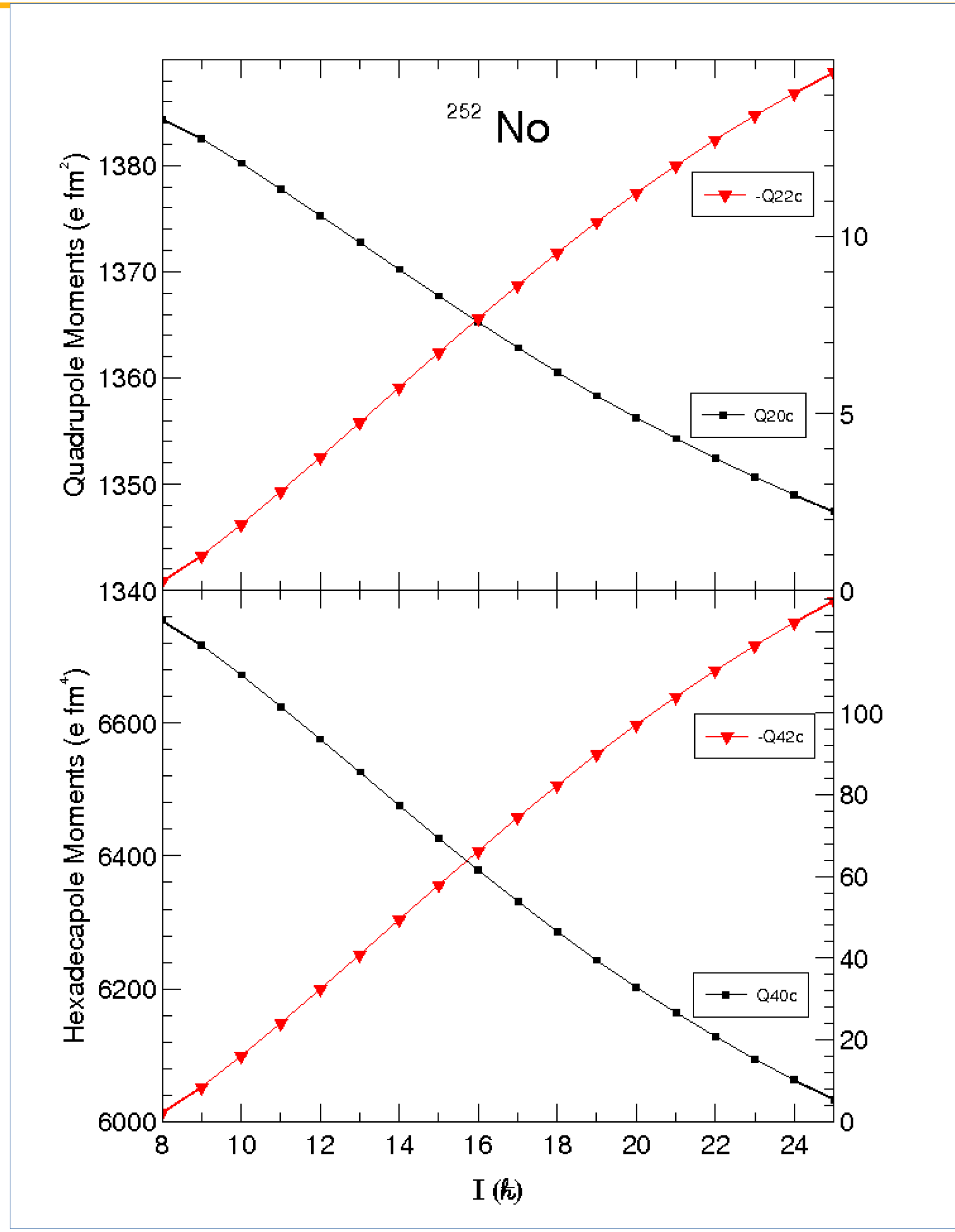
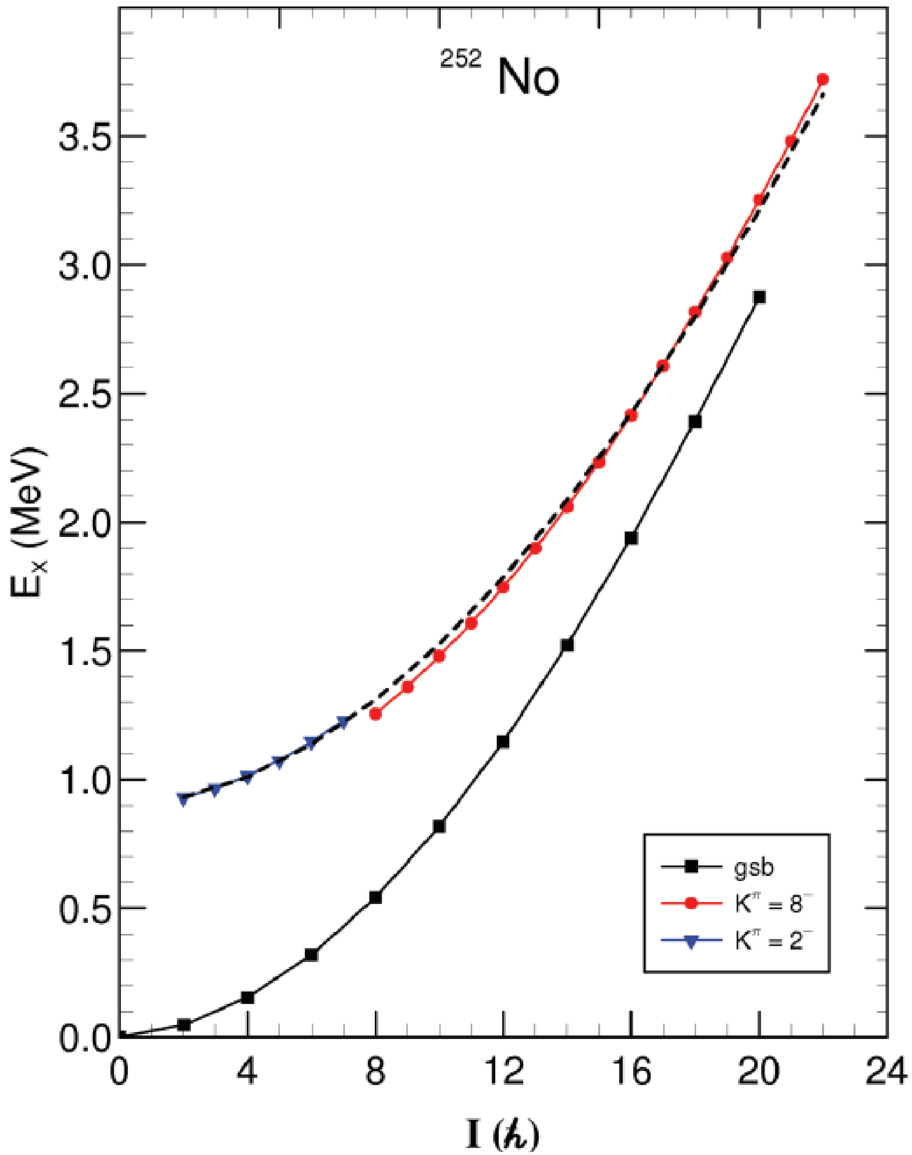


FIG. 6. (Color online) (a) and (b) Dynamic moment of inertia $\mathcal{J}^{(2)}$ vs $\hbar\omega$ for the ground-state rotational band (dashed black lines) and for the isomeric $K^\pi = 8^-$ band, for the ^{250}Fm and ^{252}No (red triangles) isotones. (c) and (d) Same as (a) and (b) but for the kinematic moments of inertia. Triangular blue marks represent theoretical calculations using the D1S Gogny force. See text for details.

B. Sulignano et al., PHYSICAL REVIEW C 86, 044318 (2012)

Charge multipole moments in the 2QP 8^- rotating nucleus





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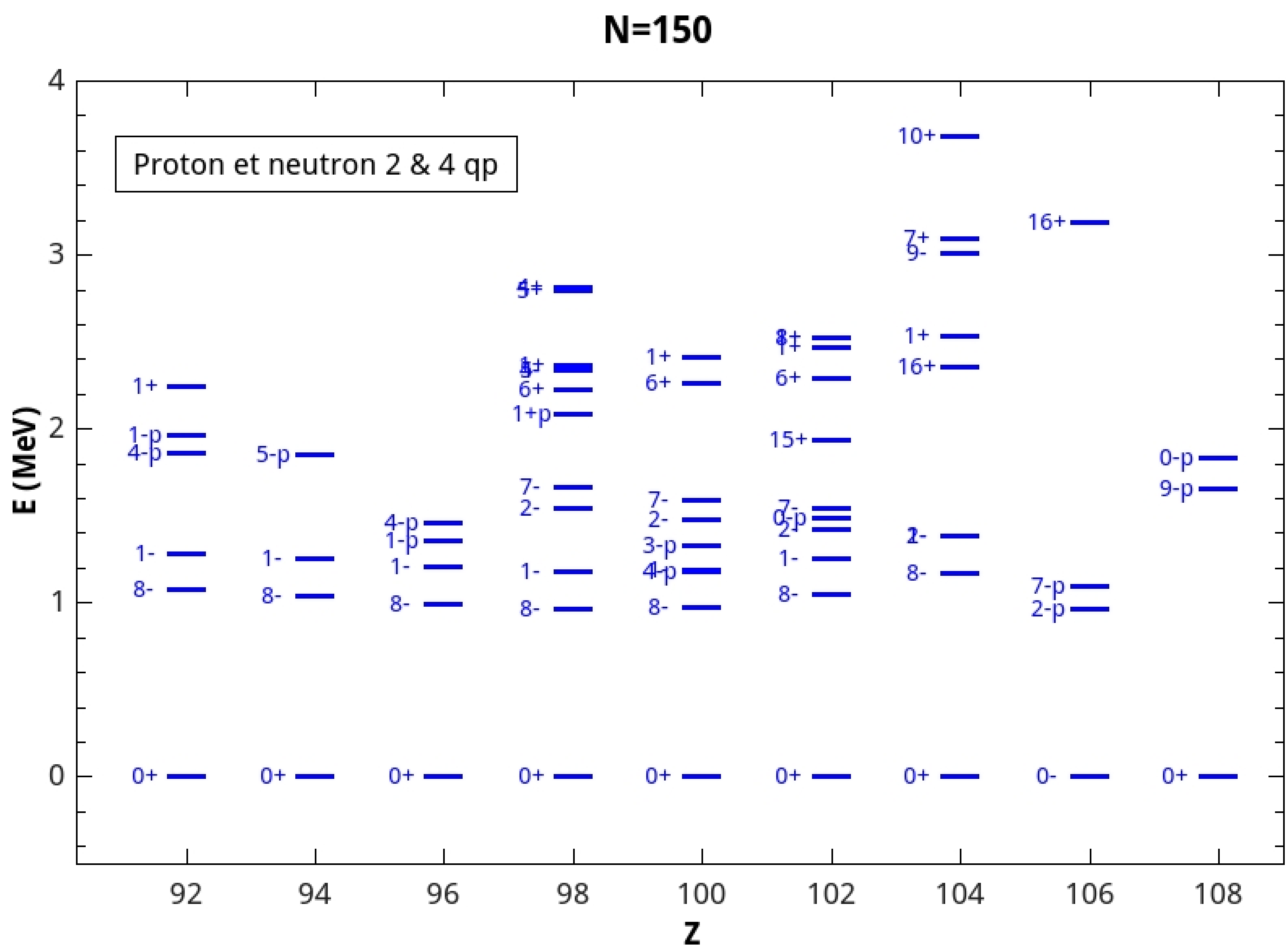
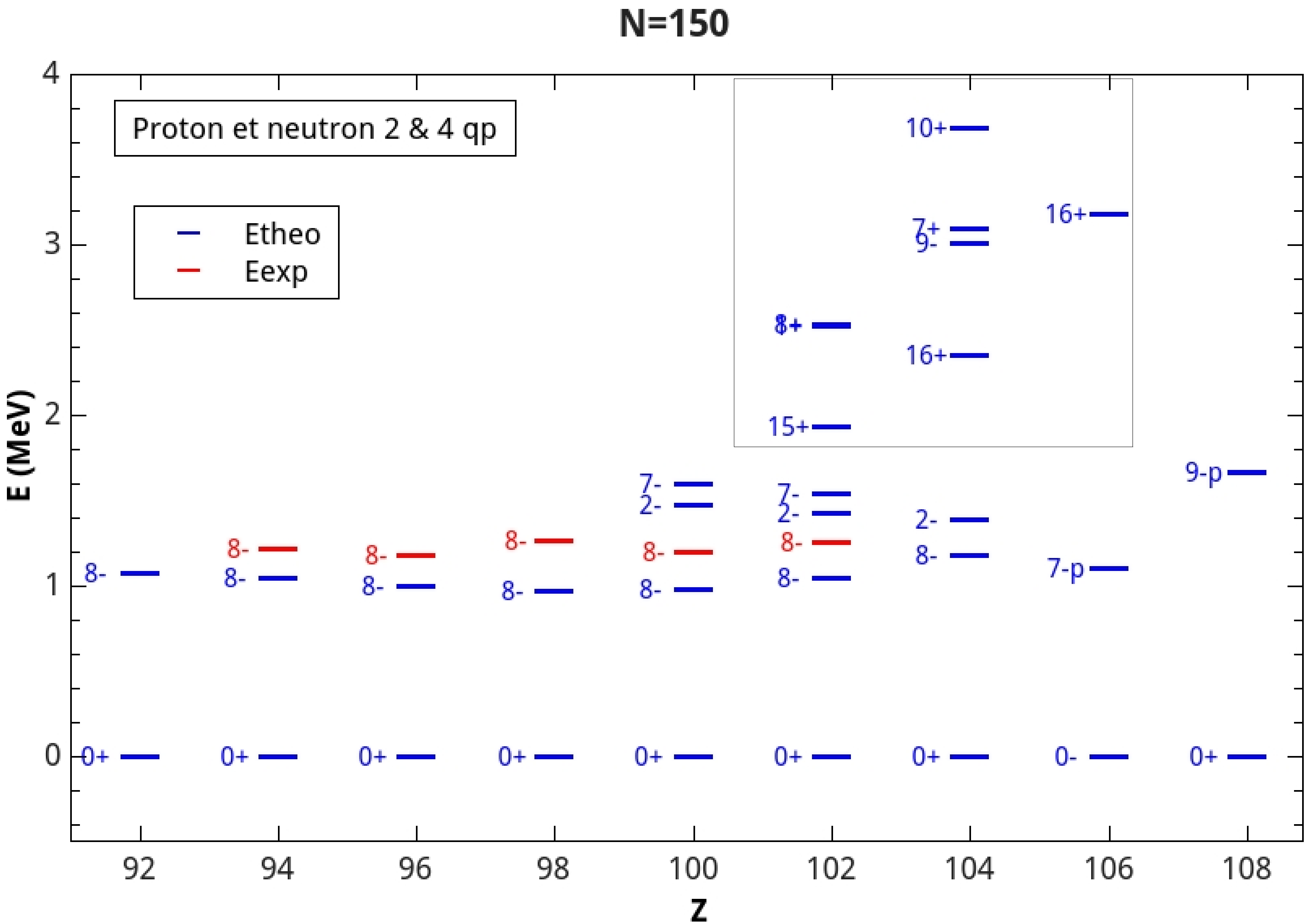
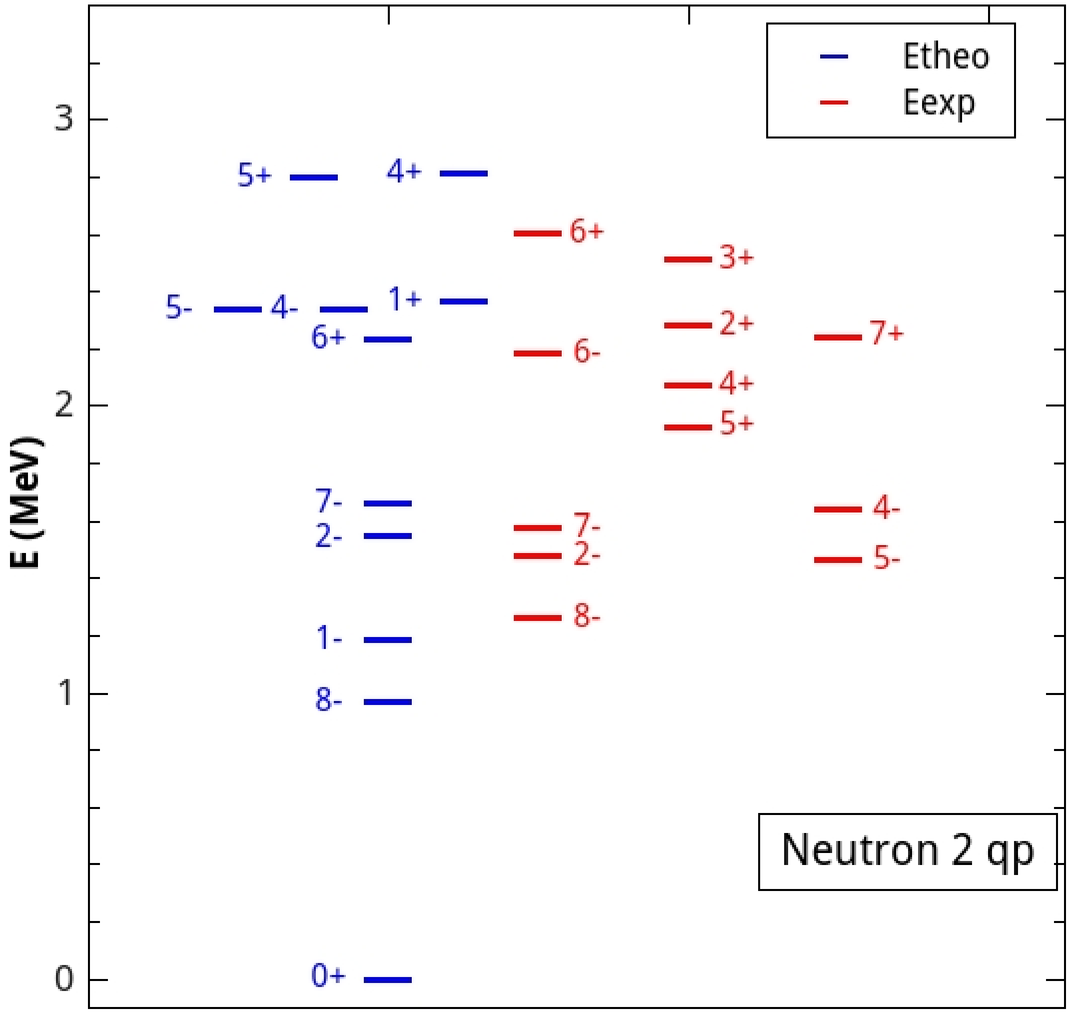

N=150
Proton et neutron 2 & 4 qp
E (MeV)
Z
92
94
96
98
100
102
104
106
108
0
1
2
3
4

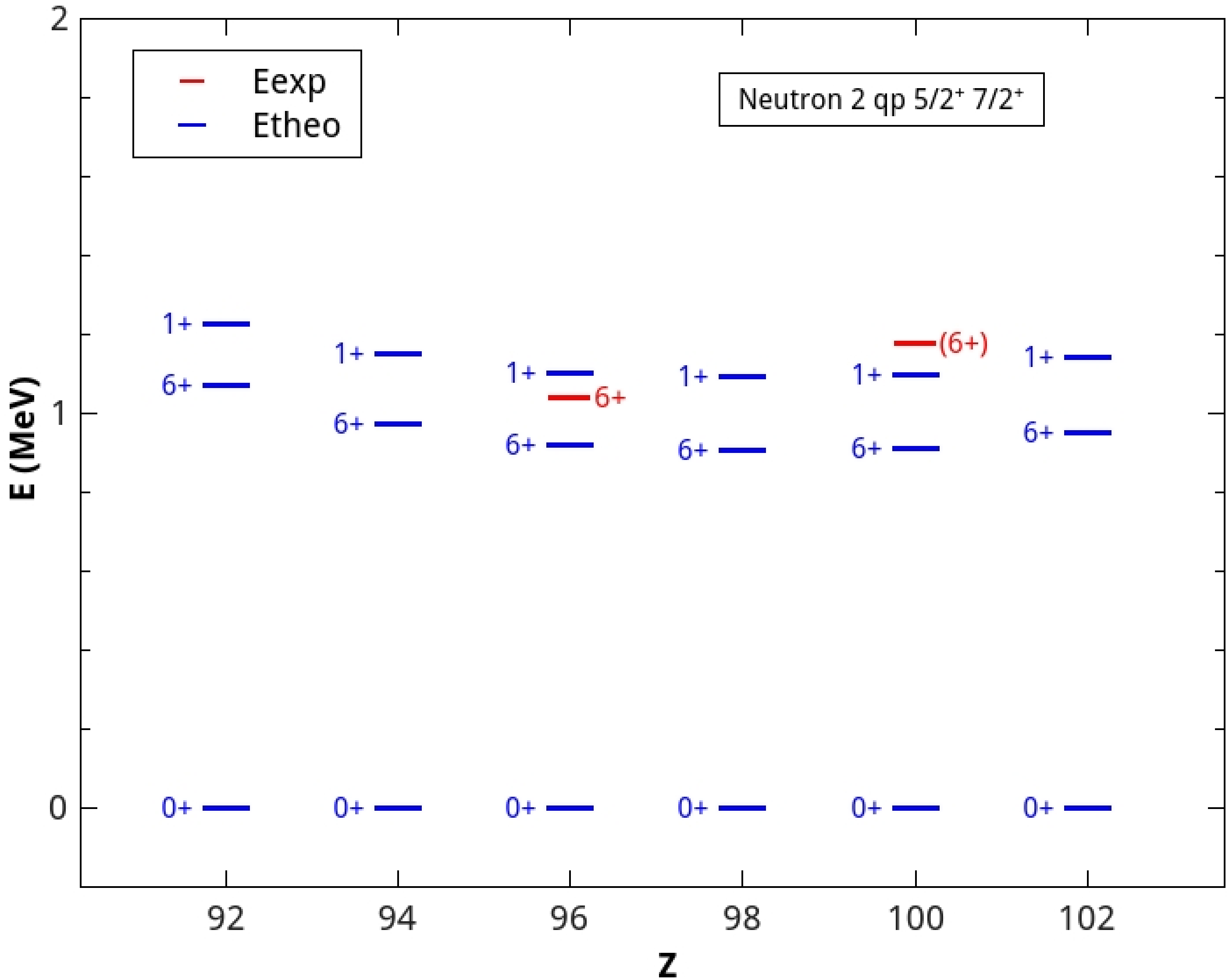

N=150
Proton et neutron 2 & 4 qp
Etheo
Eexp
E (MeV)
Z
4
3
2
1
0
92
94
96
98
100
102
104
106
108
8-
0+
8-
8-
0+
8-
8-
0+
8-
8-
0+
7-
2-
8-
8-
0+
7-
2-
8-
8-
0+
15+
8+
10+
7+
9-
16+
2-
8-
0+
16+
7-p
0-
9-p
0+

$^{248}_{98}Cf_{150}$



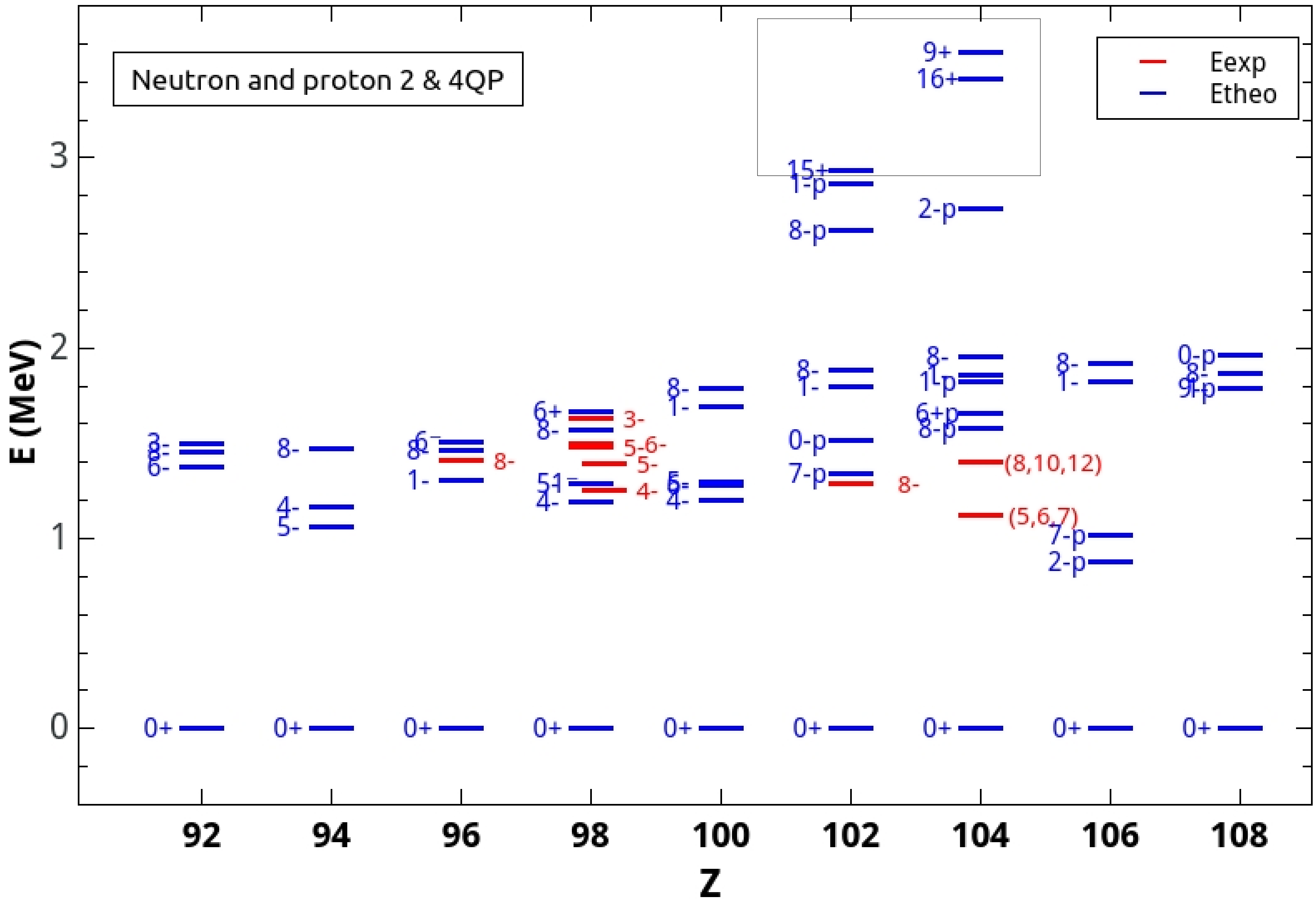
Etheo
Eexp
E (MeV)
0
1
2
3
5+
4+
5-
4-
1+
6+
7-
2-
1-
8-
0+
6+
6-
7-
2-
8-
3+
2+
4+
5+
7+
4-
5-
Neutron 2 qp

N=148

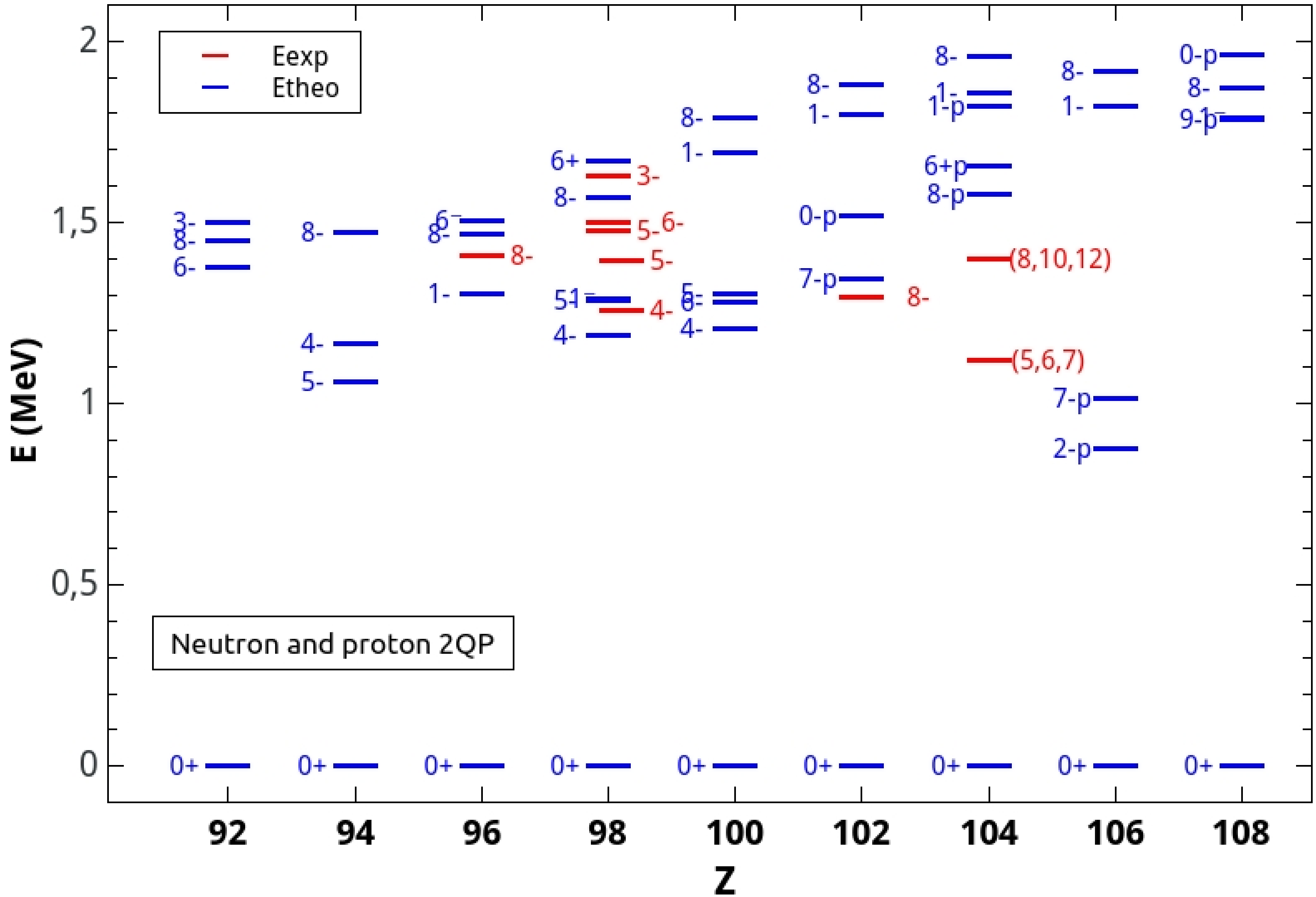


Eexp
Etheo
Neutron 2 qp 5/2+ 7/2+
E (MeV)
2
1
0
1+
6+
0+
6+
(6+)
92
94
96
98
100
102
Z

N=152


Neutron and proton 2 & 4QP
Eexp
Etheo
E (MeV)
Z
0
1
2
3
92
94
96
98
100
102
104
106
108
0+
9+
16+
2-p
8-p
1-p
15+
0-p
7-p
8-
(8,10,12)
(5,6,7)
7-p
2-p
4-
5-
1-
3-
5-6-
4-
8-
1-
6+
0-p

N=152

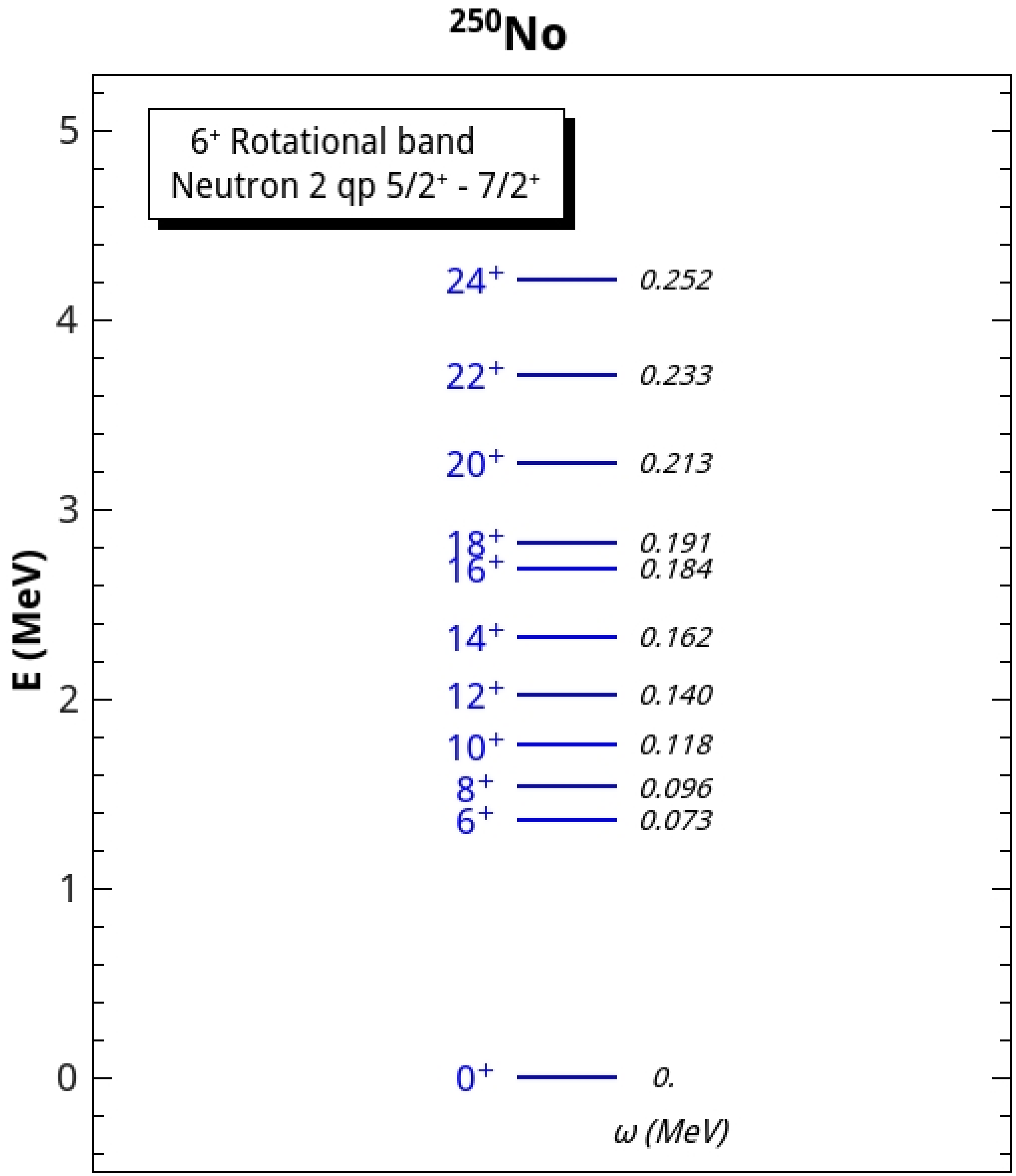

Eexp
Etheo
Neutron and proton 2QP
E (MeV)
Z
0
0,5
1
1,5
2
92
94
96
98
100
102
104
106
108
(8,10,12)
(5,6,7)

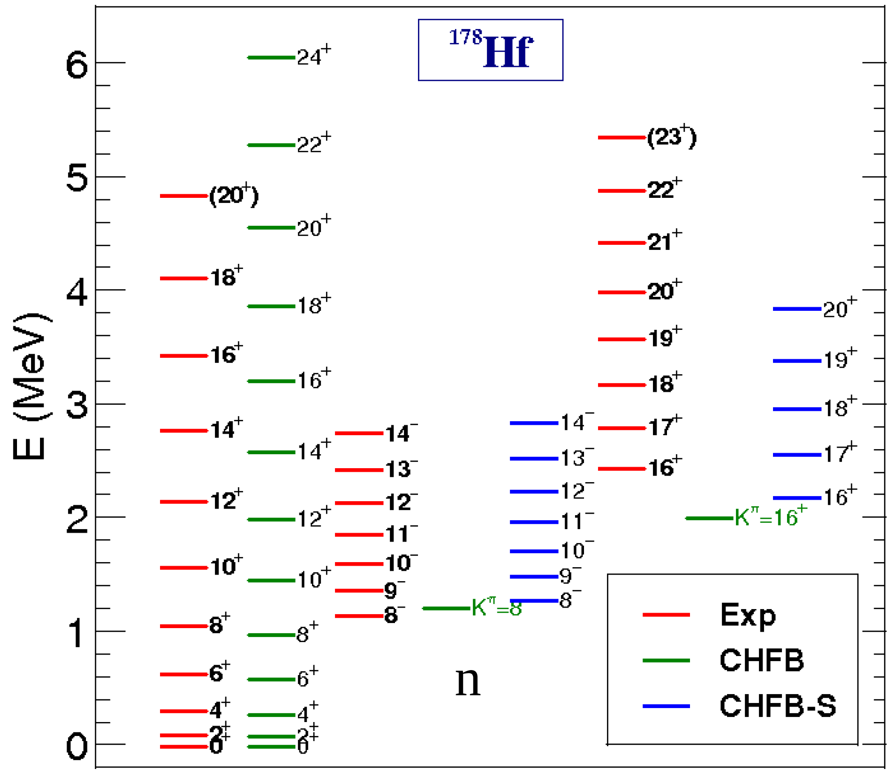
Theoretical rotational band

Quasiparticle excitations

Rotation along the x-axis does break $S_z = ie^{-i\pi J_z}$, the z-signature symmetry

The z-signature is broken because J_x and S_z do not commute.





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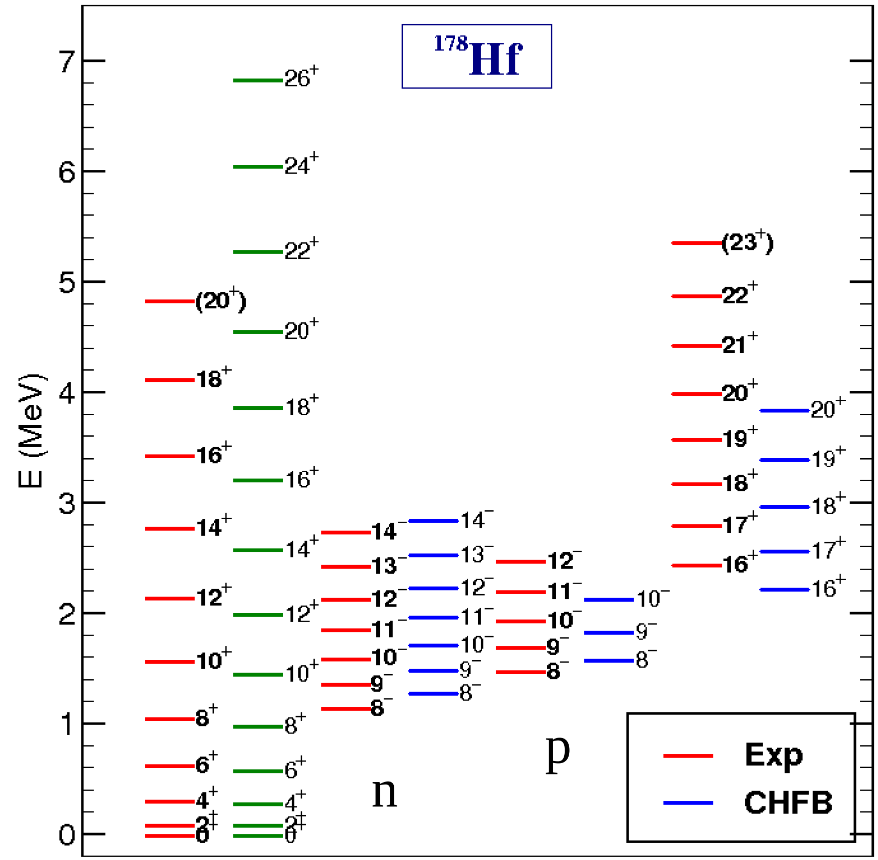
Ph.D. thesis



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Conclusions and perspectives

- 2QP and 4QP calculated at the mean-field level;
- Fair agreement with data; N=148, 150, 152;
- 2QP and 4QP rotation: underway;
- Galagher rule not always fulfilled…
- HFB-D1S blocking 2QP $\longrightarrow$ QRPA-D1S
- Breaking parity : underway;
- Including particle-vibration coupling will change "single particle" level schemes (see R.V.Afanasjev and E. Litvinova, PRC 92, 044317 (2015);
- Are blocking calculations still pertinent?