QRPA with the Gogny force with or without charge exchange applied to spherical and deformed nuclei

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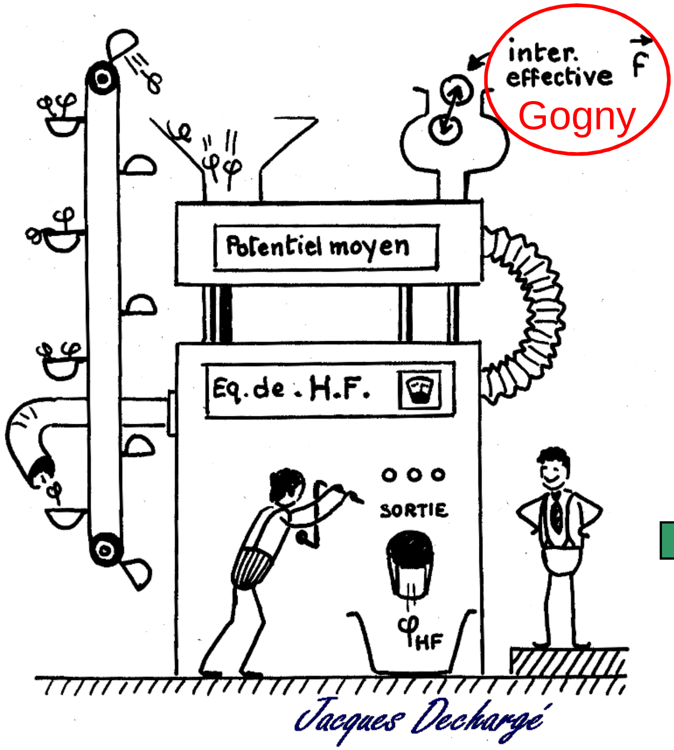
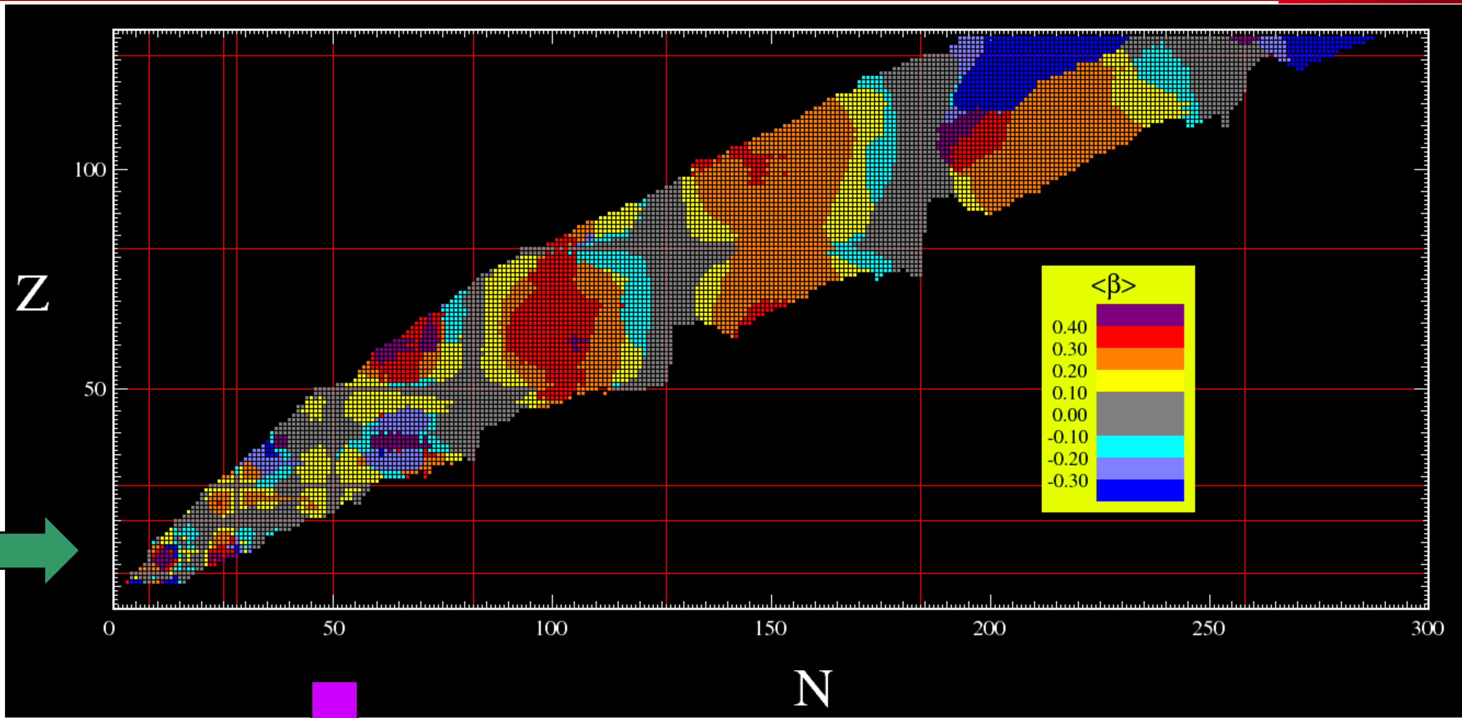
Short Reminder





Amedee database :
http://www-phynu.cea.fr/HFB-Gogny_eng.htm
*S. Hilaire & M. Girod, EPJ **A33** (2007) 237*

Static mean field (HFB)
for Ground State Properties :

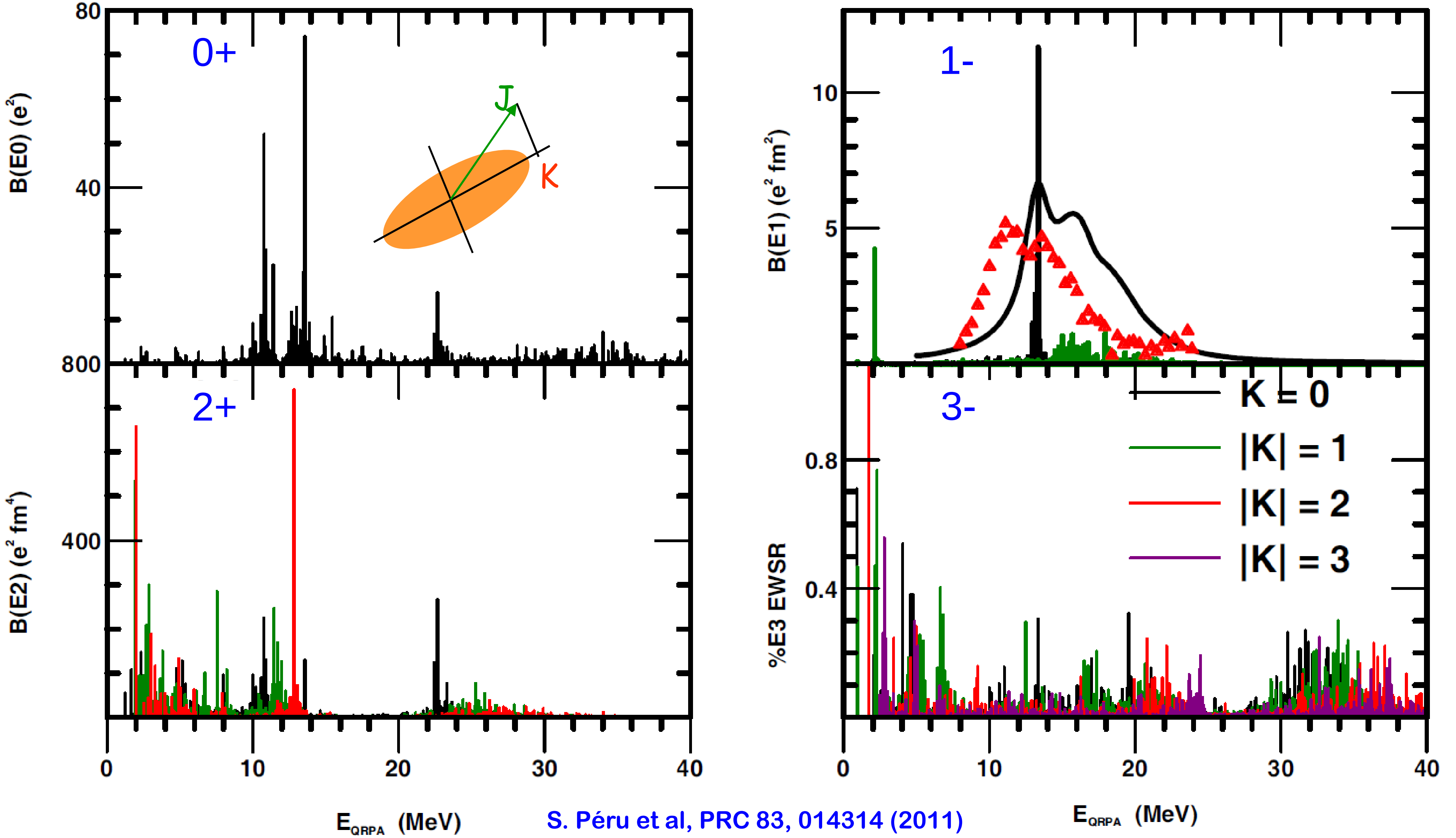
- **Masses**
- **Deformation**
- **(Single particle levels)**

Beyond static mean field approximation (5DCH or QRPA)
for description of Excited State Properties

- **Low-energy collective levels**
- **Giant Resonances**

Multipolar responses for ^{238}U

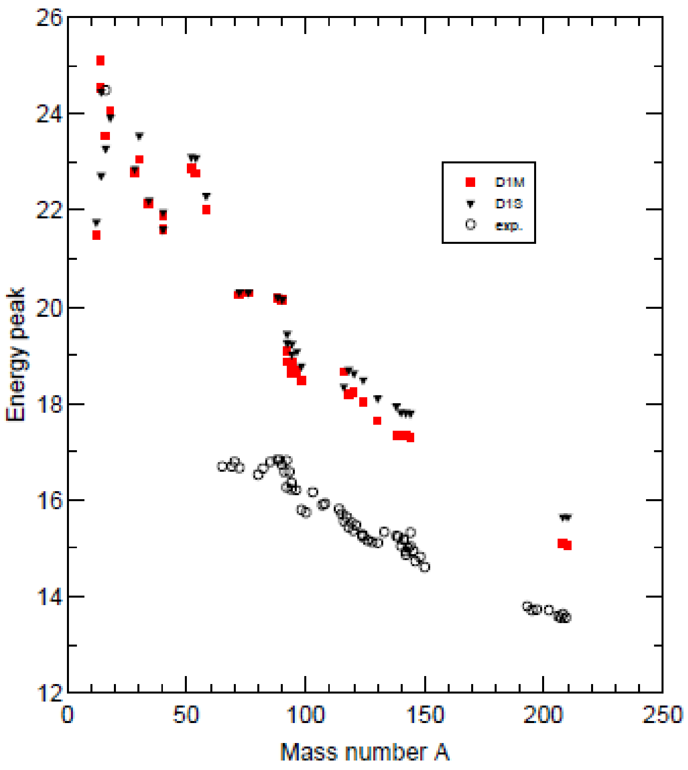
Heavy deformed nucleus ⟶ **massively parallel computation**



S. Péru et al, PRC 83, 014314 (2011)

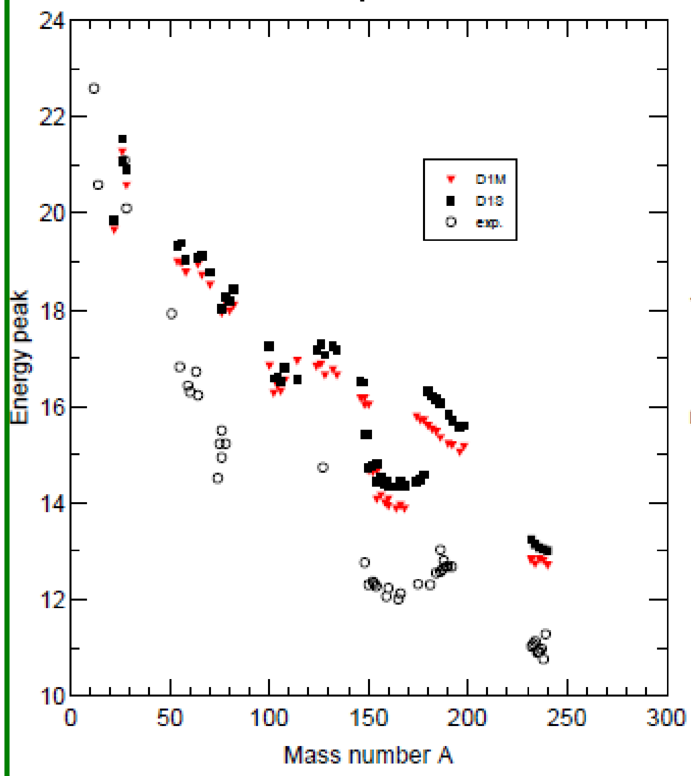
Dipole excitations in QRPA and photoabsorption results

D1S versus D1M

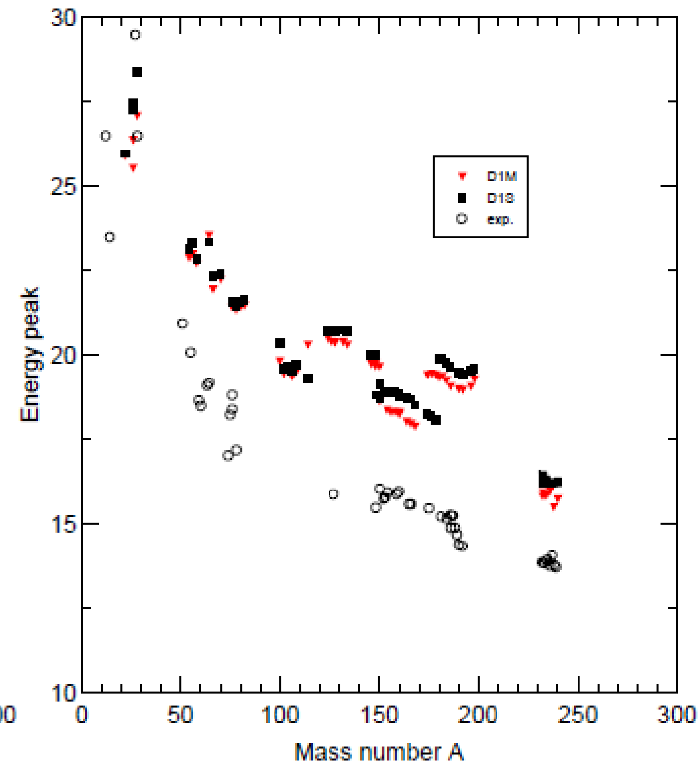


Spherical nuclei

First peak



Second peak



Deformed nuclei

We calculate E1 strength for all the nuclei for which photoabsorption data exist

Semi-empirical broadening of the GDR

To take into account complex configurations as well as coupling with phonons, the deformed QRPA strength $S_{E1}(w)$ is folded with a Lorentzian function $L(E,w)$ of width Γ

$$f_{E1}(E) = \int_{-\infty}^{+\infty} L(E,\omega) S_{E1}(\omega) d\omega \qquad L(E,\omega) = \frac{1}{\pi} \frac{\Gamma^2 E^2}{(E^2 - (\omega - \Delta)^2)^2 + \Gamma^2 E^2}$$

Model 0:

All parameters are independent of the energy and identical for all nuclei.

Δ = 2 MeV and Γ = 2.5 MeV

Model 1:

Γ is adjusted on each photoabsortion cross section

Δ is energy dependent :$\Delta(\omega) = \Delta_0 + \Delta_{4qp}(\omega)$;

Δ_0 is constant and $\Delta_{4qp}(\omega) = \delta_{4qp} \times n_{4qp}(\omega)/n_{4qp}(30\ MeV)$

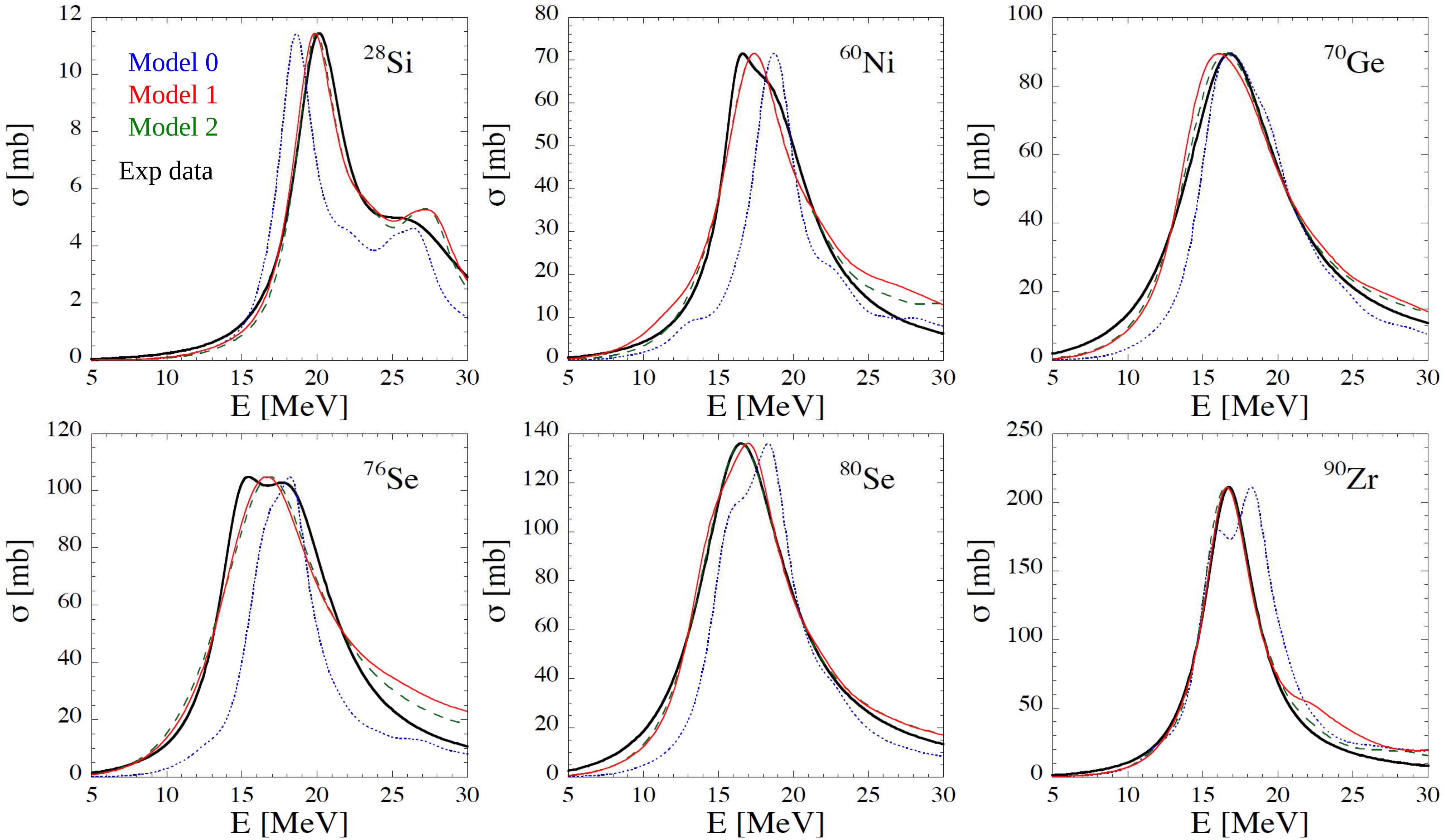
Model 2:

Γ is adjusted on each photoabsortion cross section

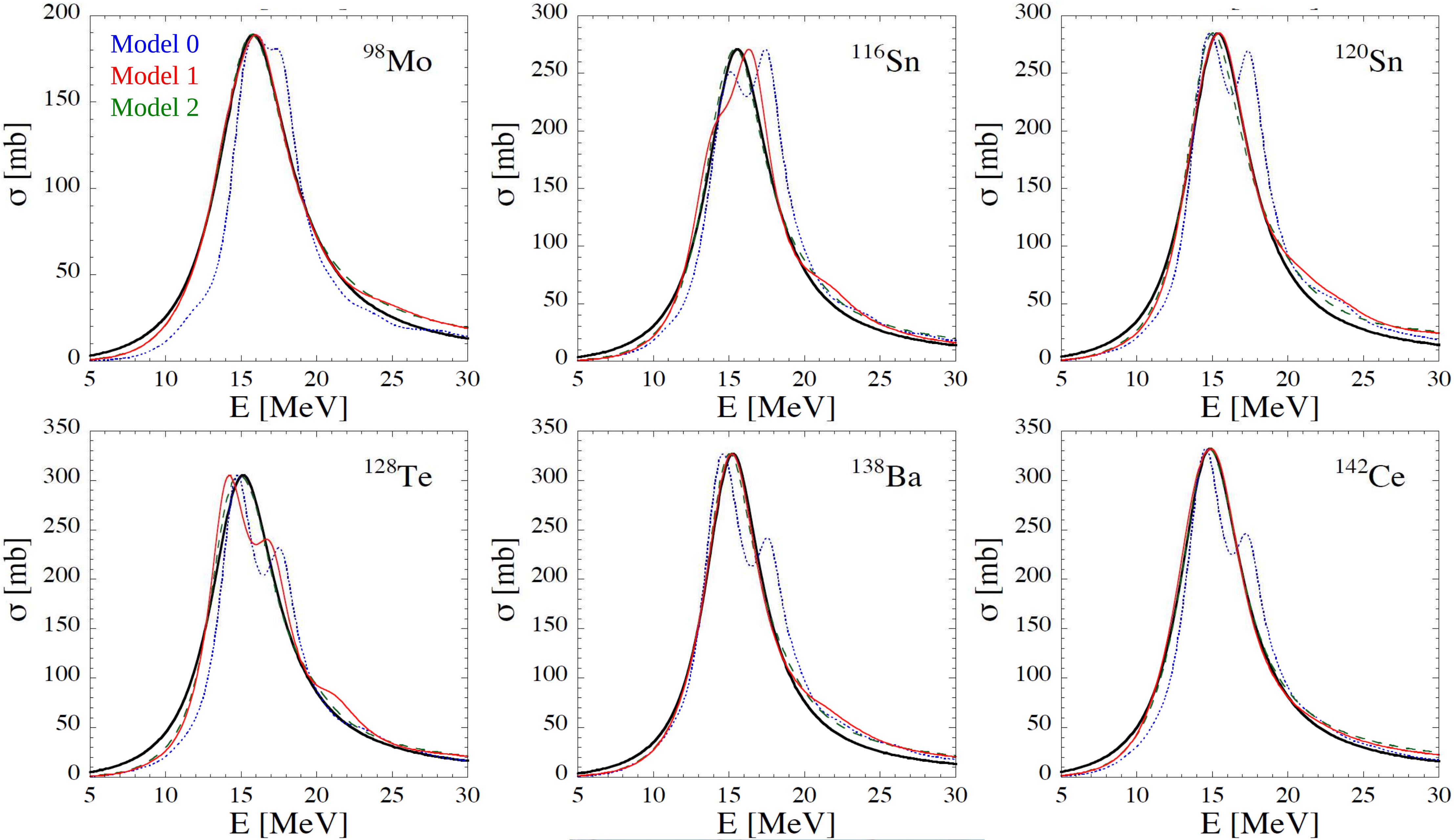
Δ is energy dependent :$\Delta(\omega) = \Delta_0 + \Delta_{4qp}(\omega)$;

Δ_0 is constant and $\Delta_{4qp}(\omega) = \delta_{4qp} \times n_{4qp}(\omega)/n_{2qp}(\omega)$

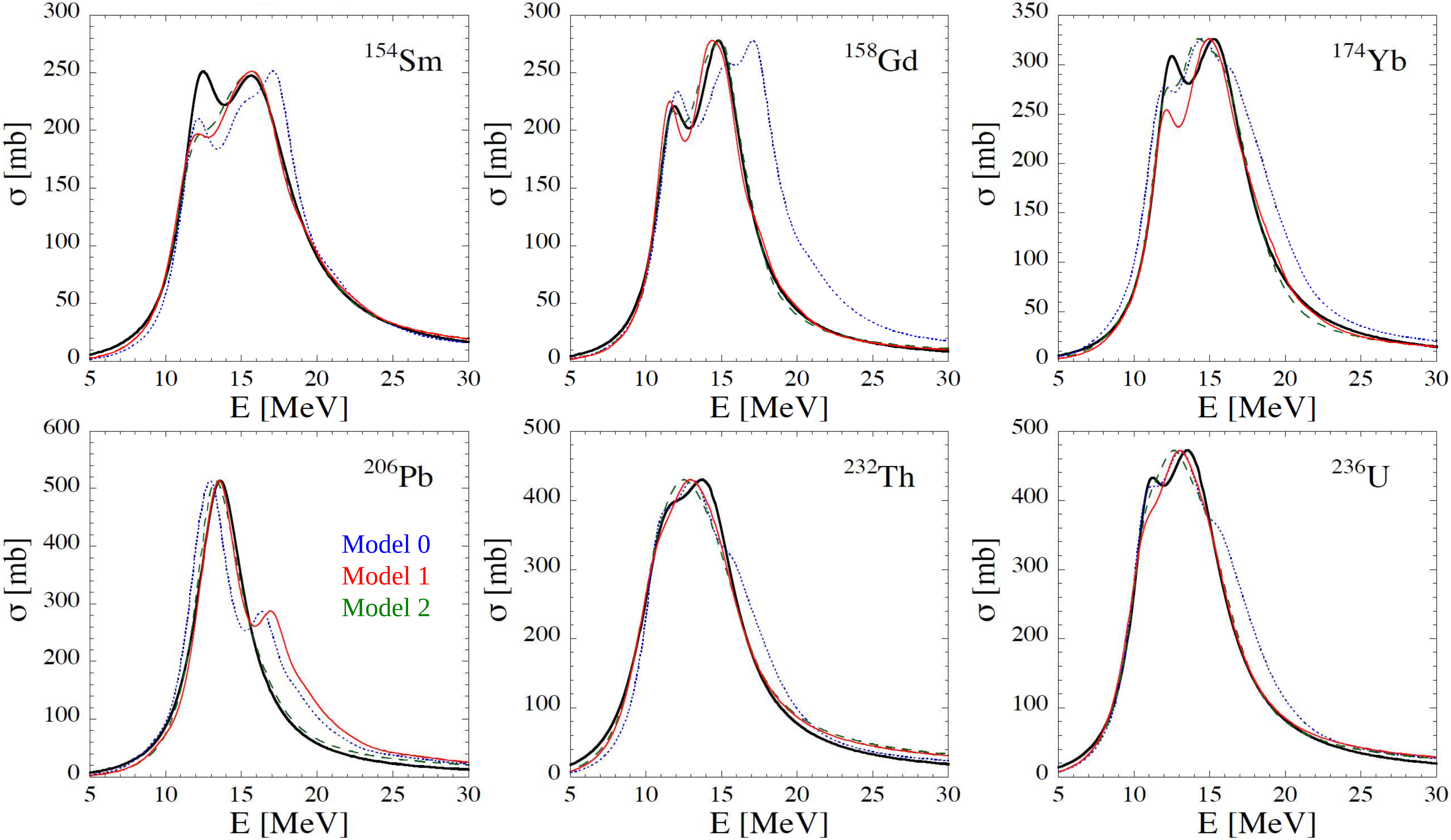
Semi-empirical broadening of the GDR 1/3



Semi-empirical broadening of the GDR 2/3

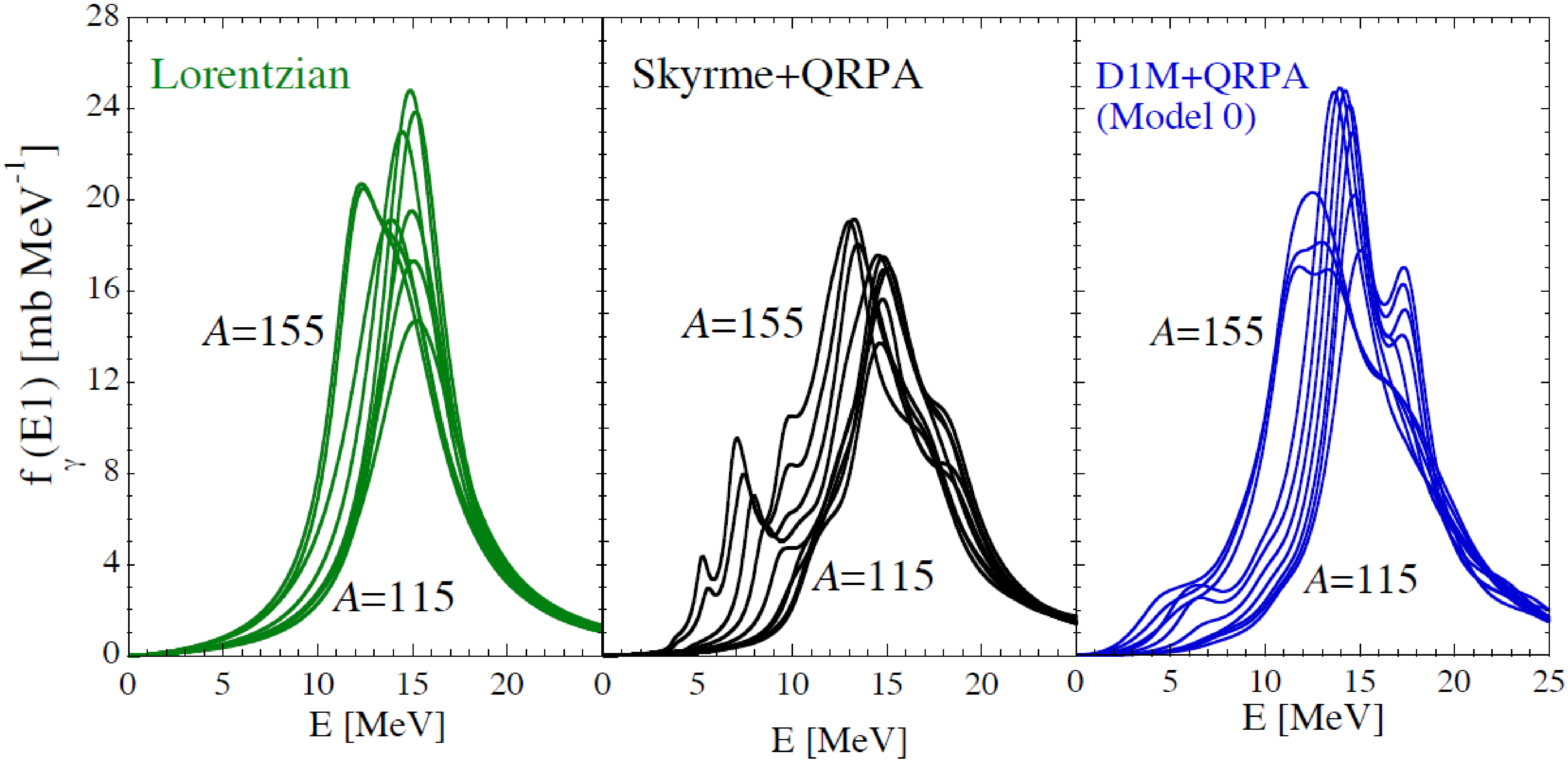


Semi-empirical broadening of the GDR 3/3



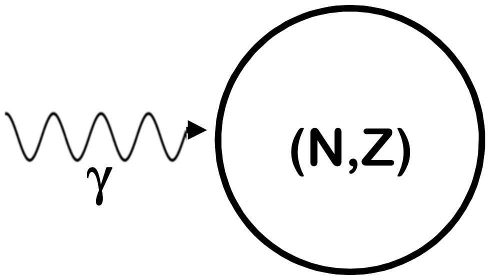
γ- ray strength functions predictions for exotic nuclei

Comparison with other models

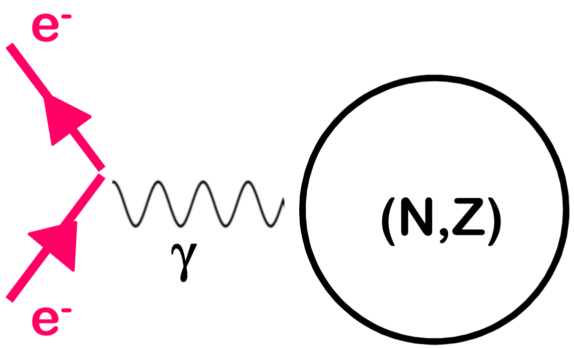


Nuclear Excitations

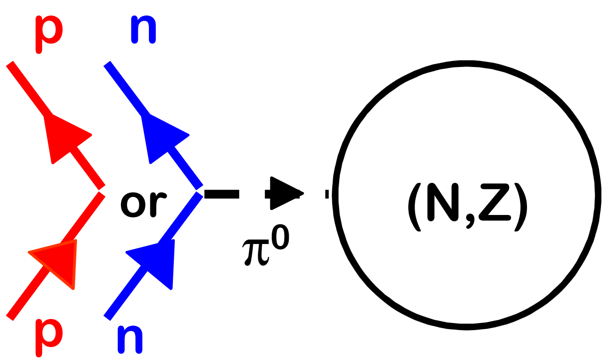
Photo-absorption

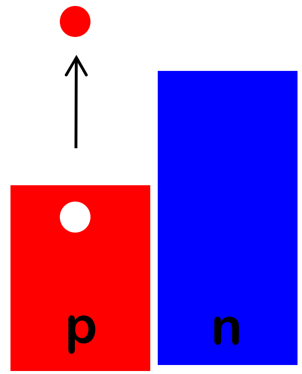


Electron scattering



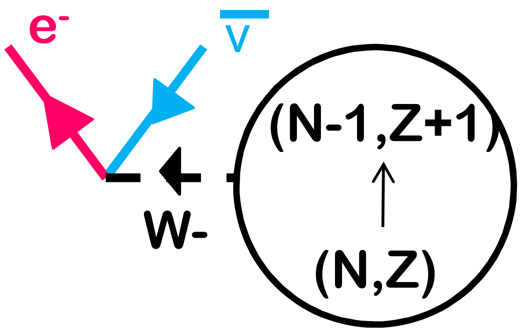
(p,p) or (n,n)



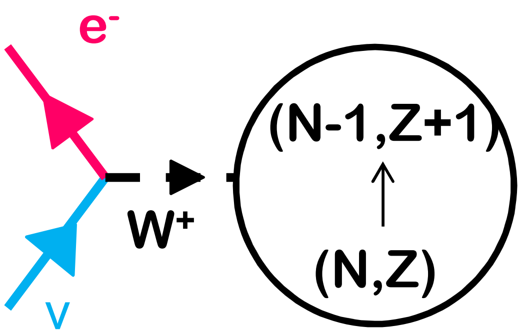


Charge exchange:

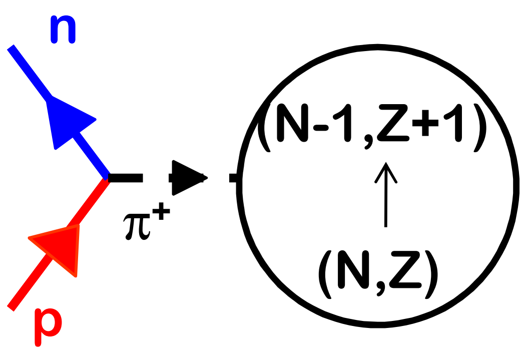
β decay

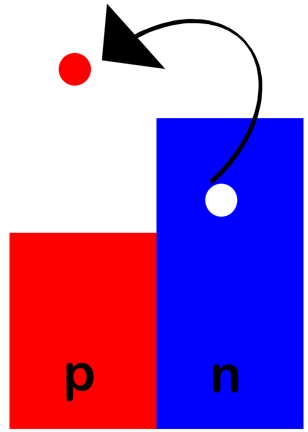


Neutrino scattering



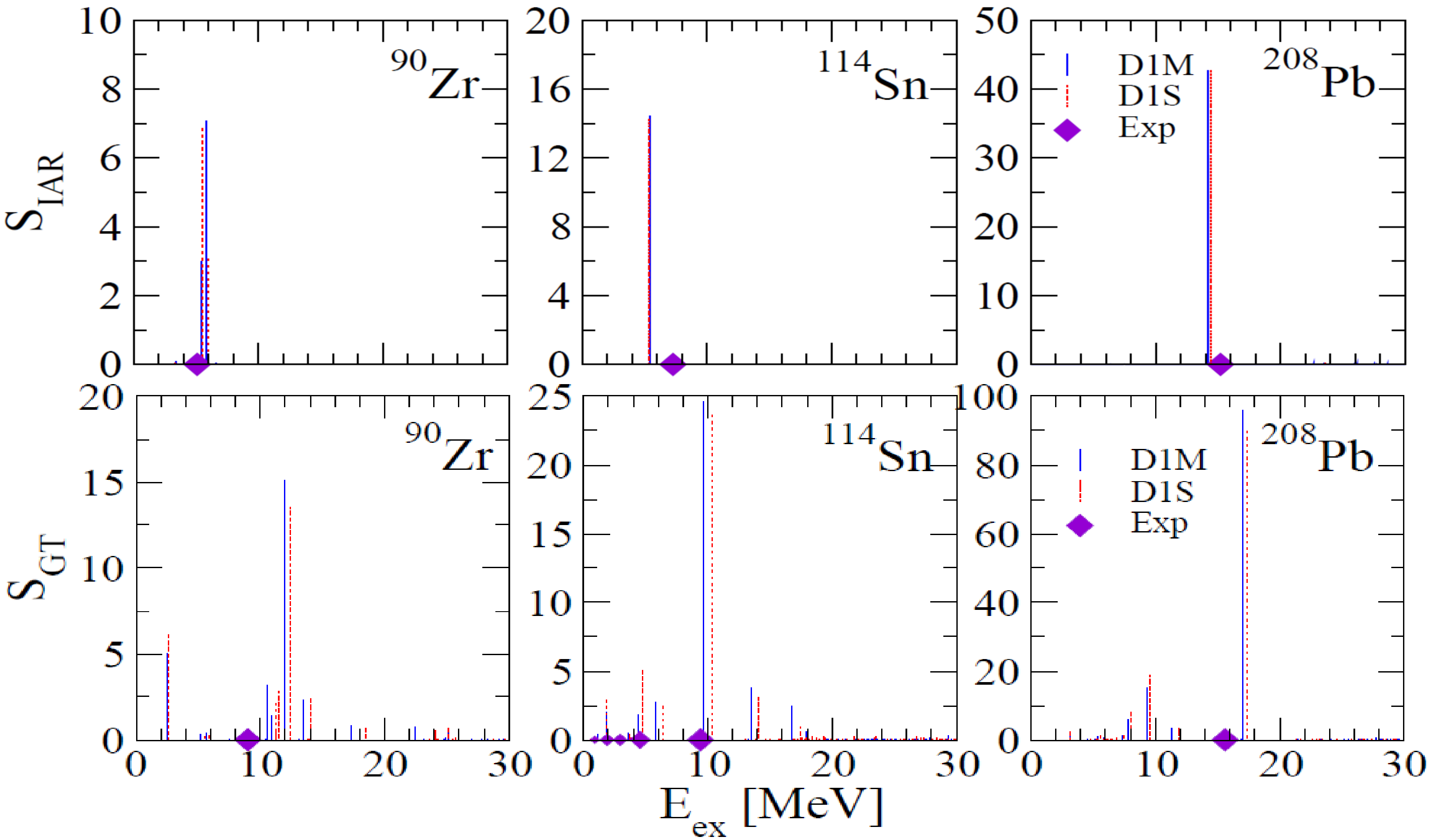
(p,n) or ([3]He,t)





Gogny pnQRPA Strength Distributions

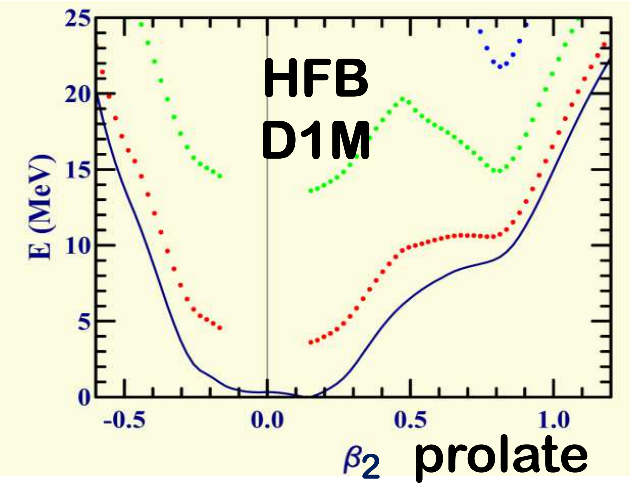
M. Martini, S. Péru and S. Goriely, Phys. Rev. C **89**, 044306 (2014)



Good agreement with experimental data ◆

An example of deformed nucleus : ^{76}Ge

GT $J^{\pi}=1^{+}$ distributions obtained by adding twice the $K^{\pi}=1^{+}$ result to the $K^{\pi}=0^{+}$ one

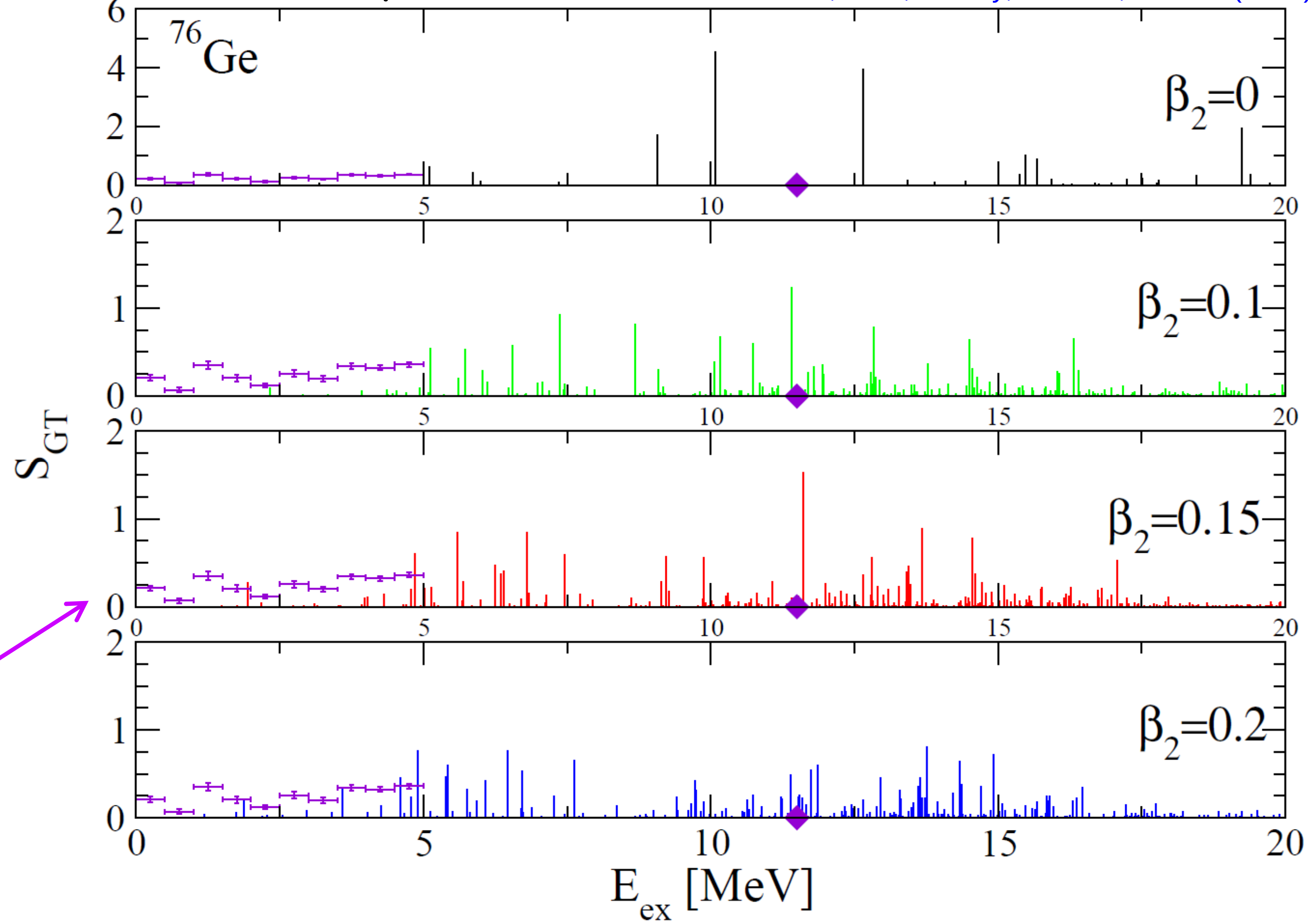


β_2(min. HFB) = 0.15 **γ(min.HFB) = 0°**

β_2 (0^{+}_{1}:5DCH) = 0.26 **γ(0^{+}_{1}:5DCH) = 26°**

pnQRPA-D1M

Martini, Péru, Goriely, PRC **89**, 044306 (2014)



Experiment
Thies et al., Phys. Rev. C 86, 014304 (2012)

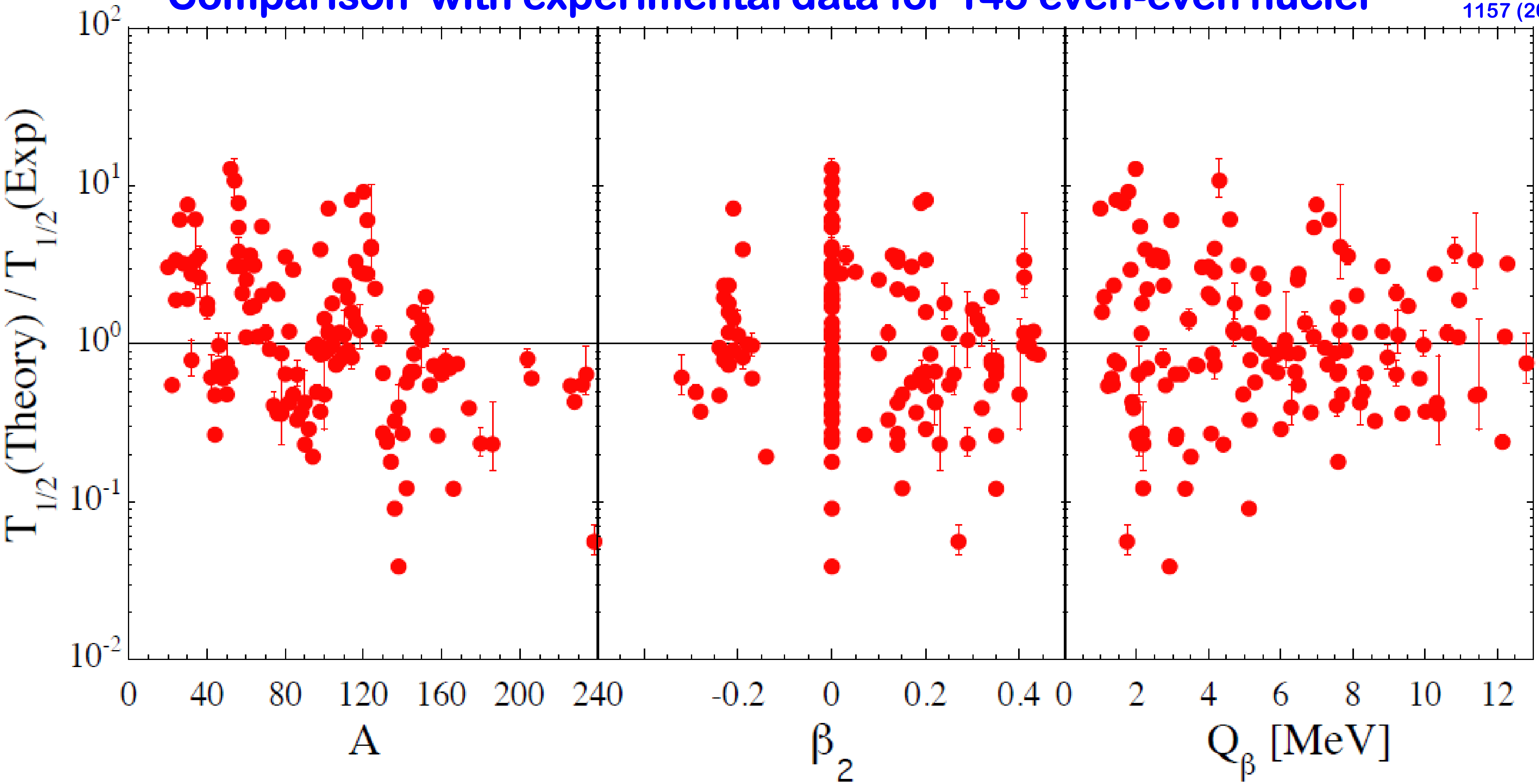
- The deformation tends to increase the fragmentation
- Displacements of the peaks
- Deformation influences the low energy strength hence β decay half-lives are expected to be affected

β^- decay half-life $T_{1/2}$

$$\frac{\ln 2}{T_{1/2}} = \frac{(g_A/g_V)^2_{\text{eff}}}{D} \sum_{E_{ex}=0}^{Q_\beta} f_0(Z, A, Q_\beta - E_{ex}) S_{GT}(E_{ex})$$

Comparison with experimental data for 145 even-even nuclei

G.Audi *et al.* Chinese Phys. C **36**, 1157 (2012)

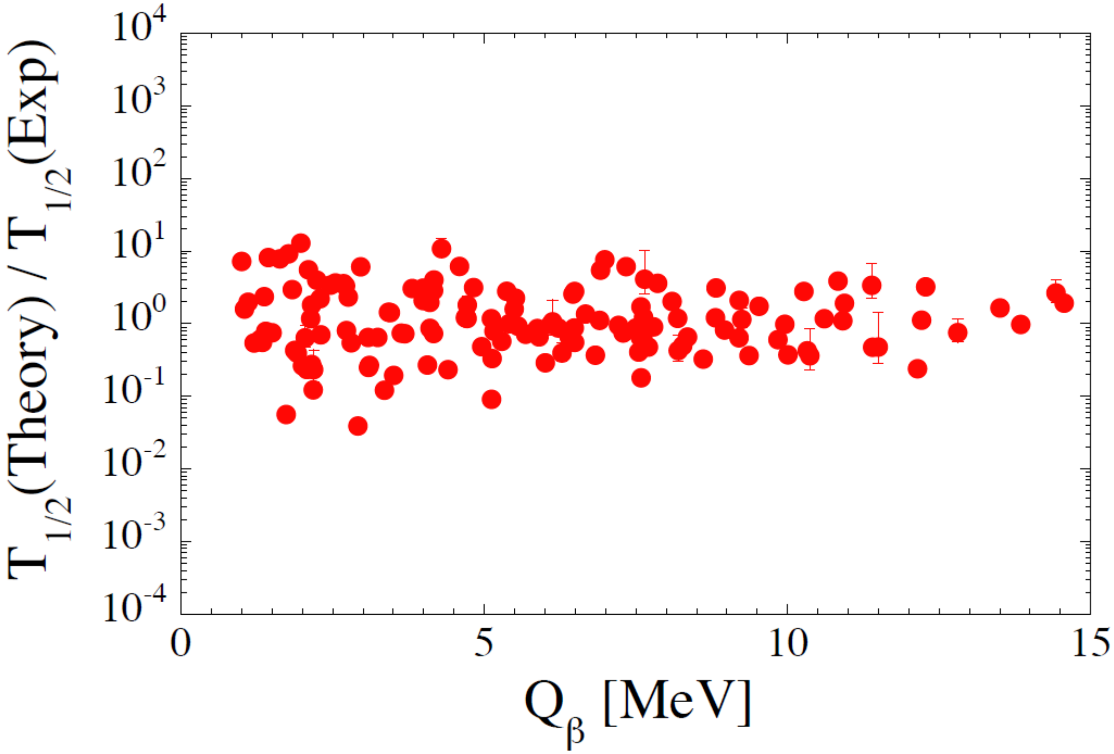


Martini, Péru, Goriely, PRC **89**, 044306 (2014)

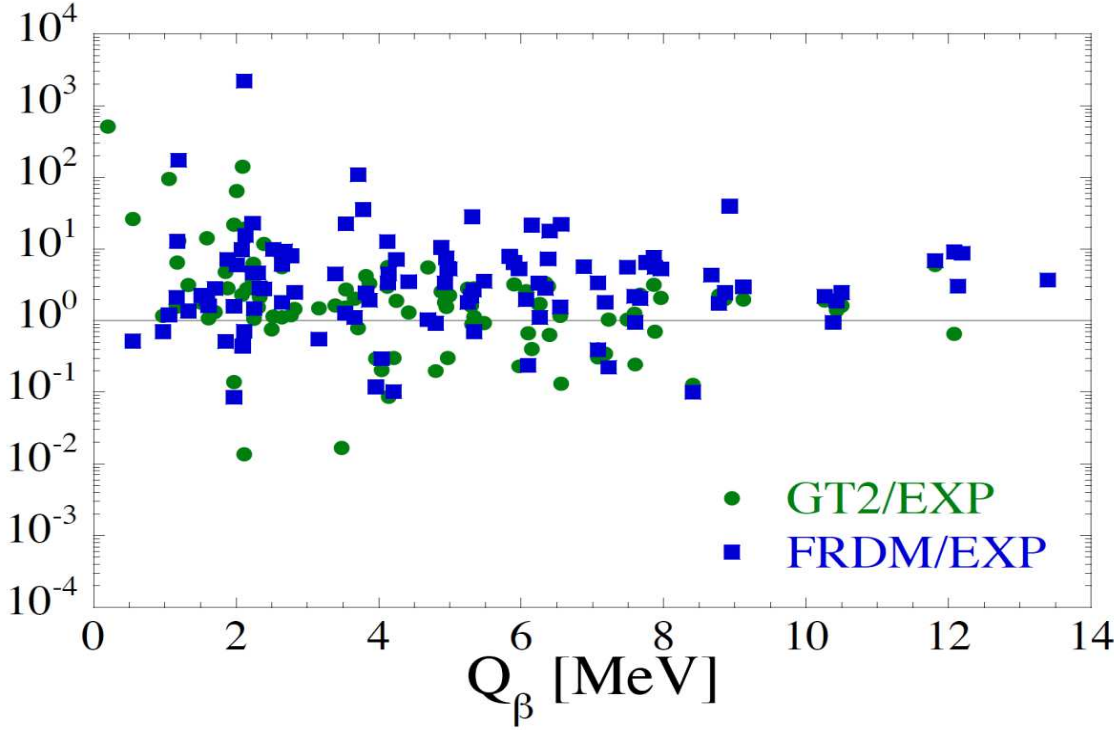
- **Deviation with respect to data rarely exceeds one order of magnitude**
- **Larger deviations for nuclei close to the valley of β-stability, as found in most models**

Comparison with other models

Our model



Other models

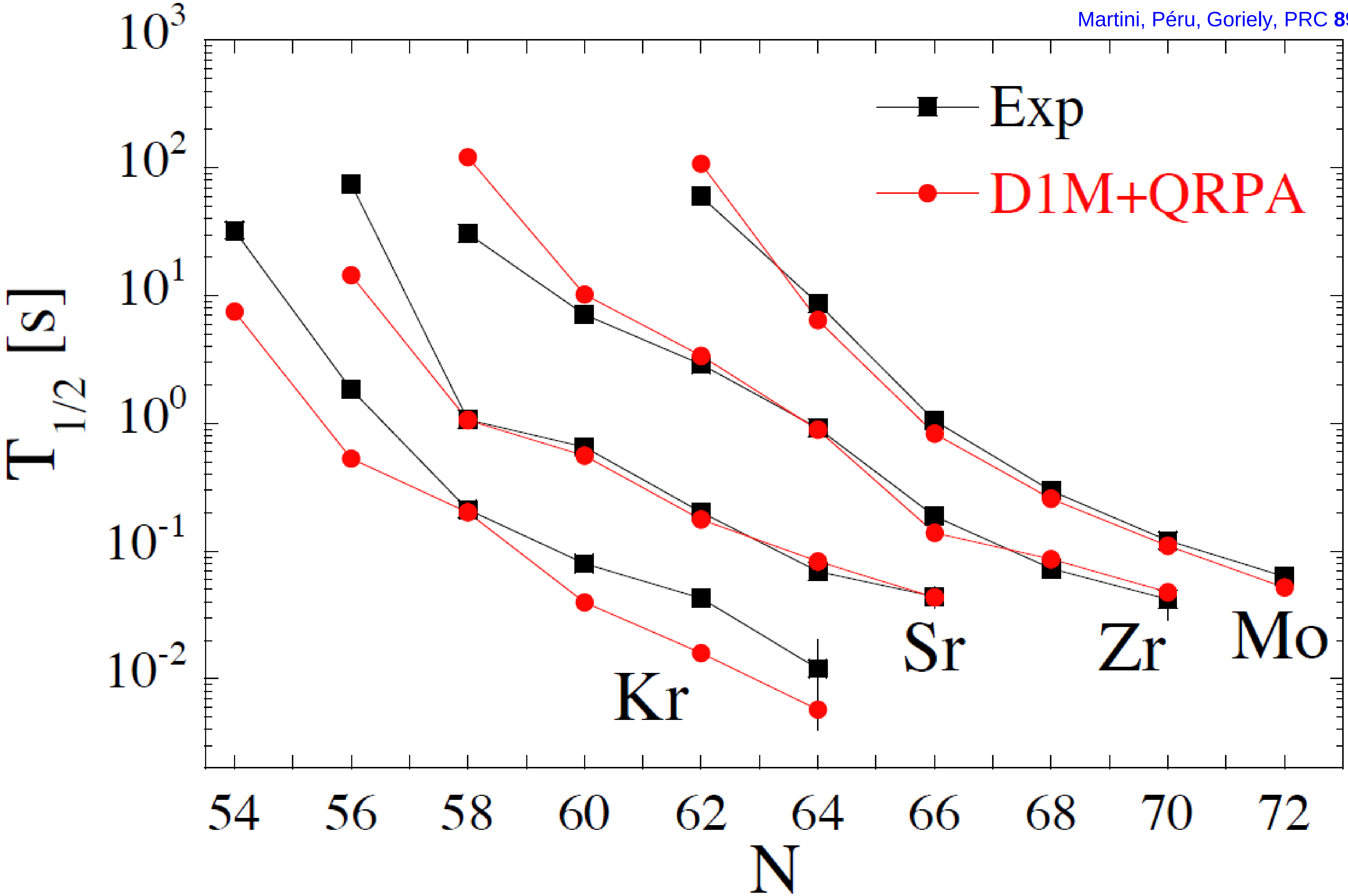


FRDM: Moller et al., ADNDT, 66,131 (1997)

GT2: Tachibana et al.
Prog. Theor. Phys., 84, 641 (1990)

β^- decay half-lives of deformed isotopic chains

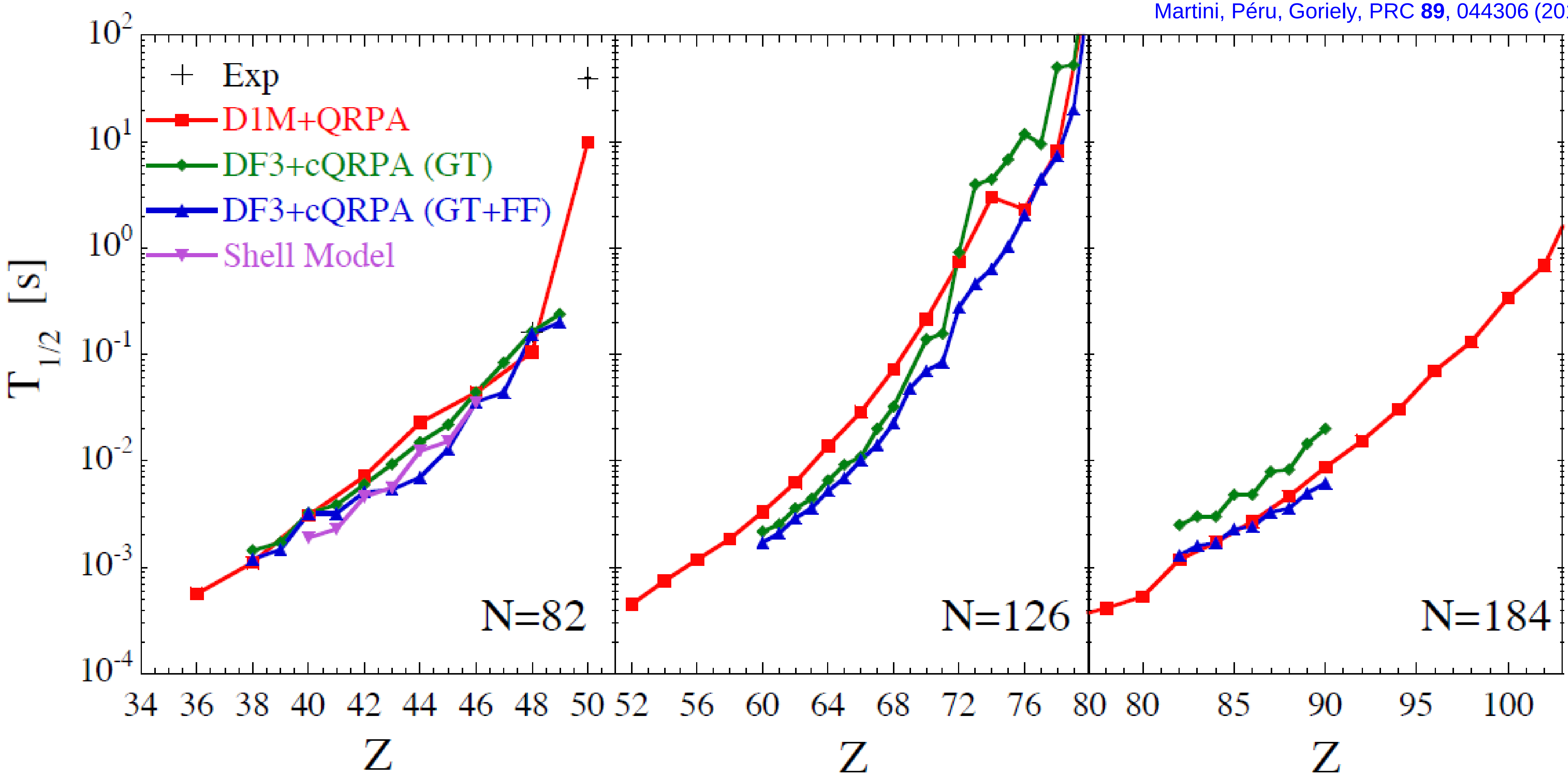
Martini, Péru, Goriely, PRC **89**, 044306 (2014)



β⁻ decay half-lives of the N=82, 126, 184 isotones

Relevance for the r-process nucleosynthesis

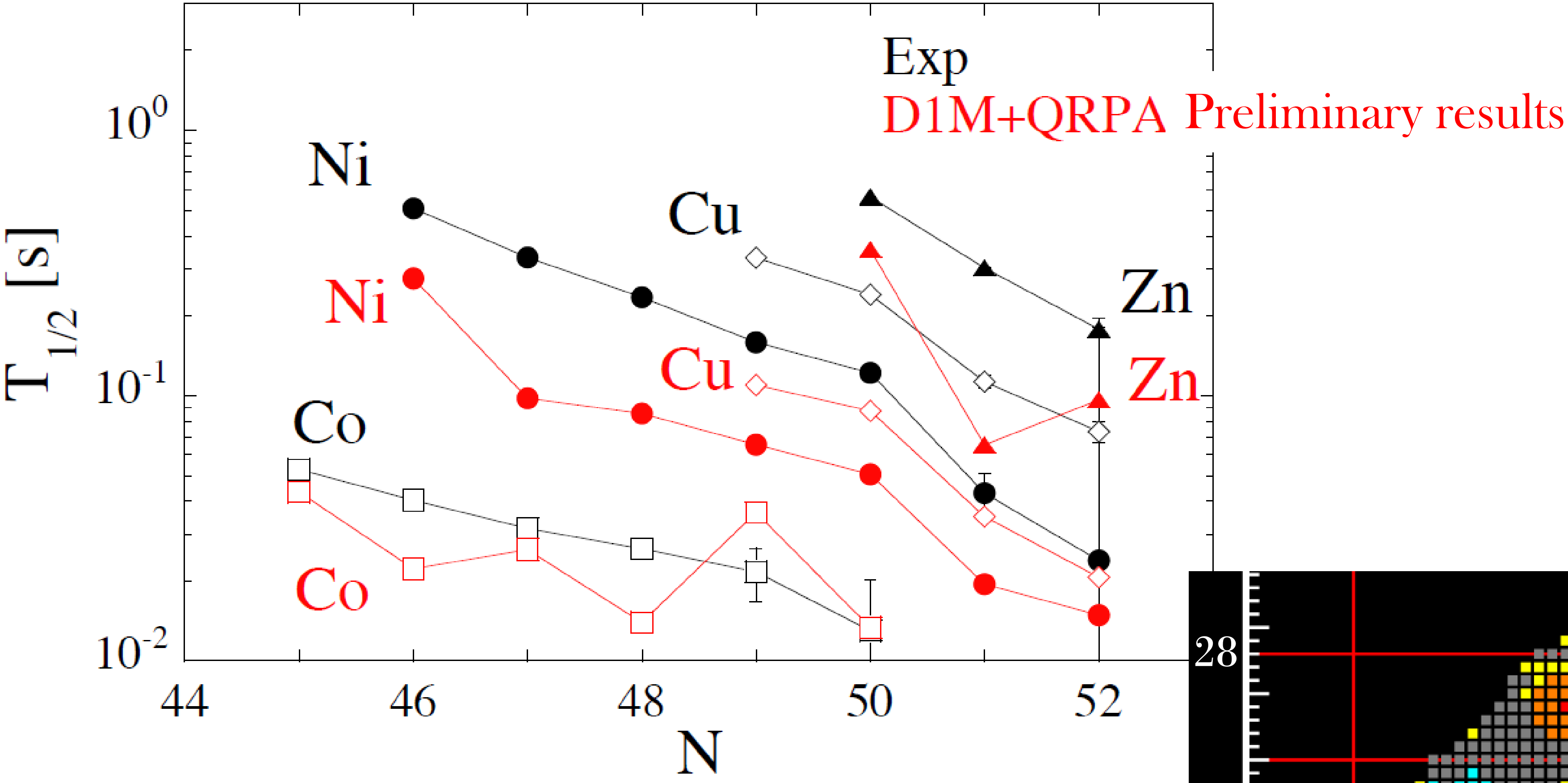
Martini, Péru, Goriely, PRC **89**, 044306 (2014)

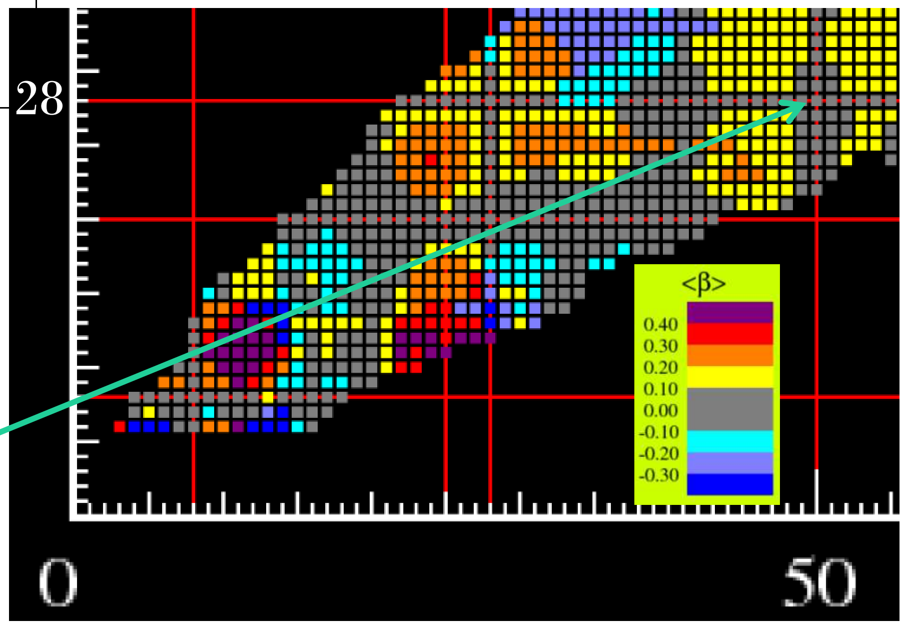


Shell Model : Martinez-Pinedo et al., PRL 83, 4502 (1999)

DF3+cQRPA : Borzov et al., PRC 62, 035501 (2000)

Even and <u>odd</u> systems, deformed and spherical nuclei





<u>Recent experimental results</u>

Z.Y. Xu et al, PRL 113, 032505 (2014)

β-decay Half lives of ^{76,77}Co, ^{79,80}Ni and ^{81}Cu :

Experimental indication of a Doubly Magic ^{78}Ni

To summarize

Great successes using the finite range Gogny force:

- Self-consistent QRPA approach has been applied to the deformed nuclei up to heavy ones.
- The GDR energy position with QRPA is systematically predicted ~2MeV above the experimental values.
- Systematic studies have been undertaken for dipole response over the whole nuclear chart.

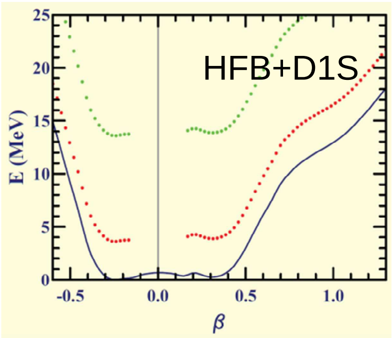
Extension of QRPA to charge exchange :

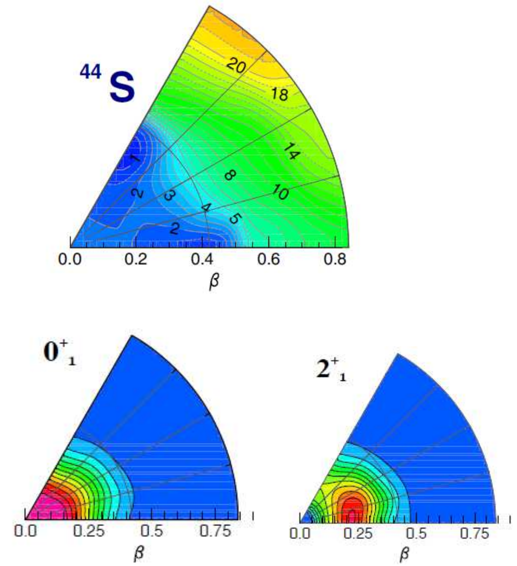
- For magic spherical nuclei, IAR and GT results in good agreement with data.
- The role of the intrinsic deformation has been shown for prolate ^{76}Ge.
- Predictions of the β decay half-lives are compatible with experimental data.
- Satisfactory agreement with experimental half-lives which justifies the additional study on the exotic neutron-rich N = 82, 126 and 184 isotonic chains (r-process).

- Promising preliminary results for odd nuclei.

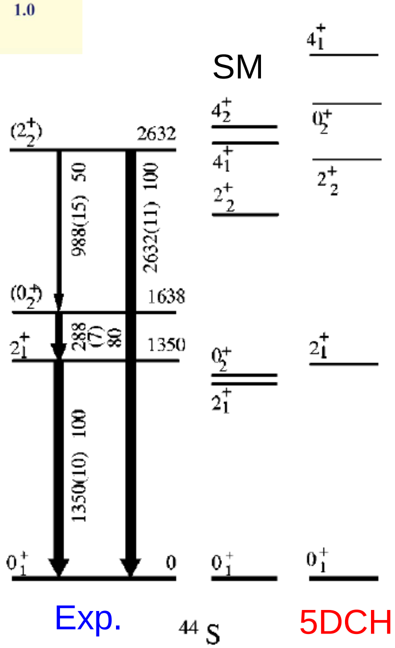
Some perspectives

5 Dimension Collective Hamiltonian
describes ground state and excited states within configuration mixing :
quadrupole vibration and rotational degrees of freedom.





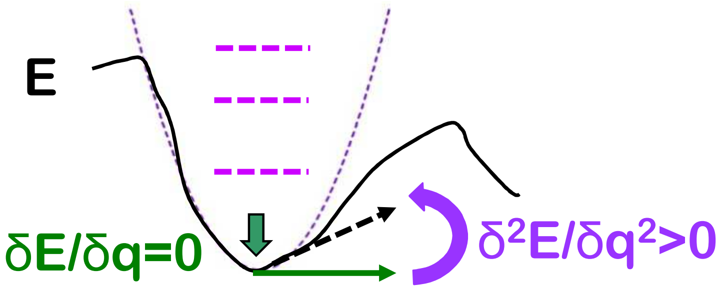
S.Péru and M. Martini, EPJA (2014) 50: 88.

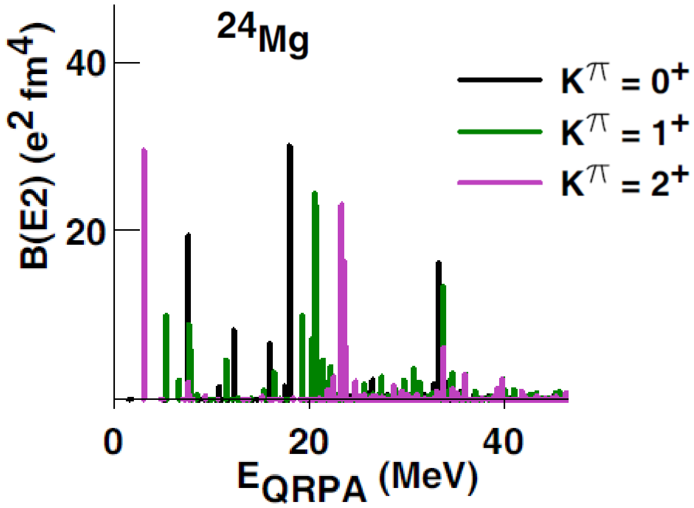


D. Sohler et al, PRC 66, 054302 (2002)

(Q)RPA approaches describe all multipolarities and all parities, collective states and individual ones, low energy and high energy states with the same accuracy.

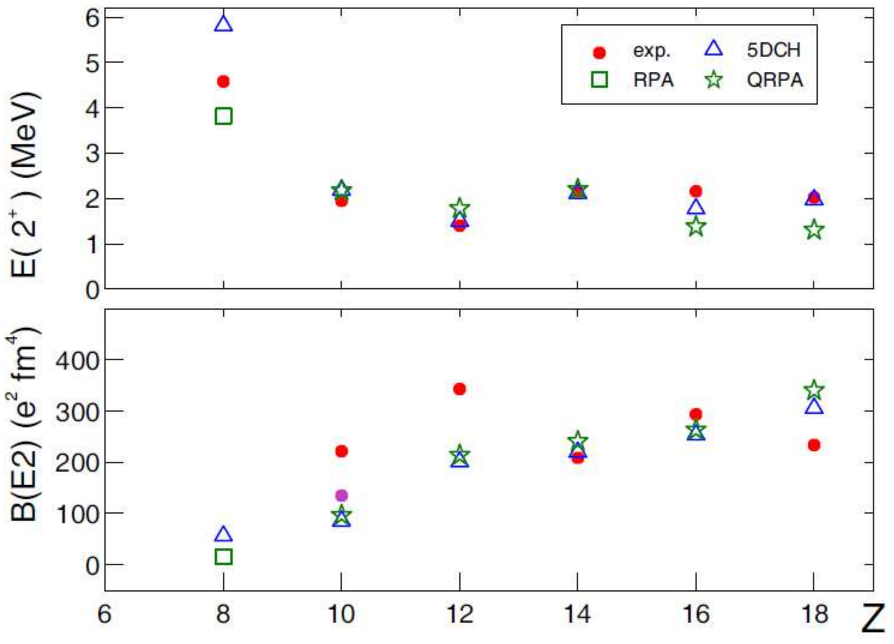
But small amplitude approximation i.e. « harmonic » nuclei



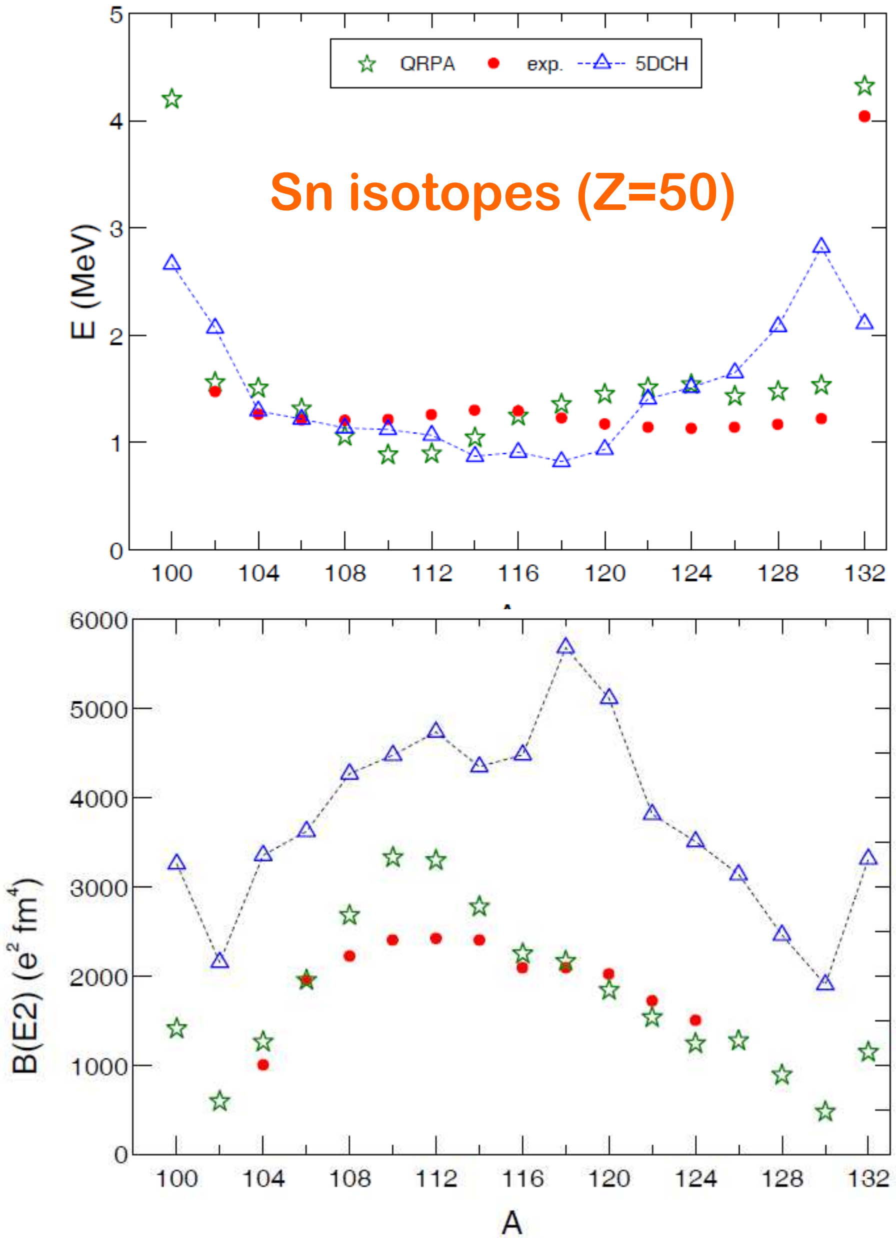


HFB+QRPA versus HFB+5DCH with the same interaction

N=16 isotones

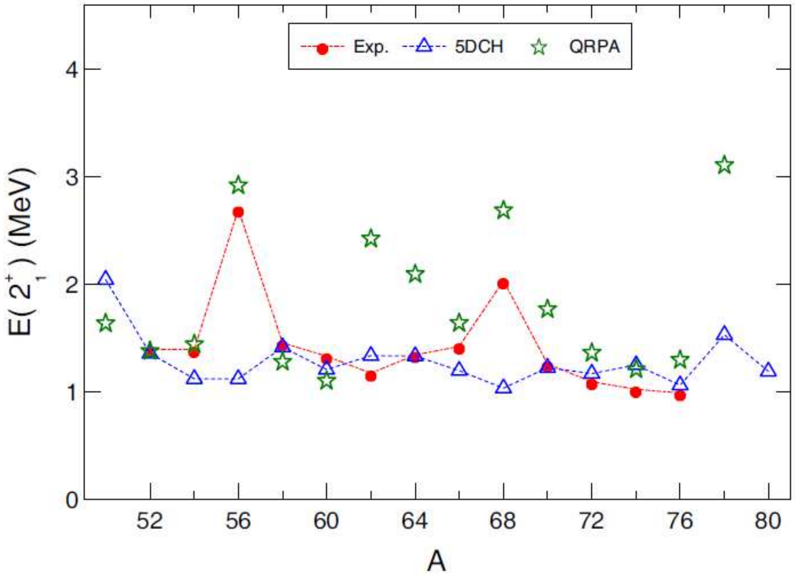


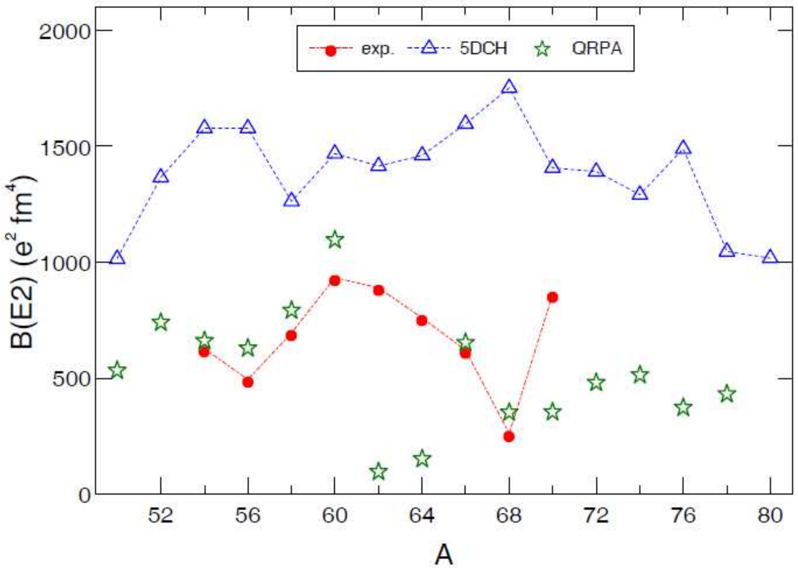
5DCH : A. Obertelli, et al, Phys. Rev. C **71**, 024304 (2005)



S.Péru and M. Martini, EPJA (2014) 50: 88.

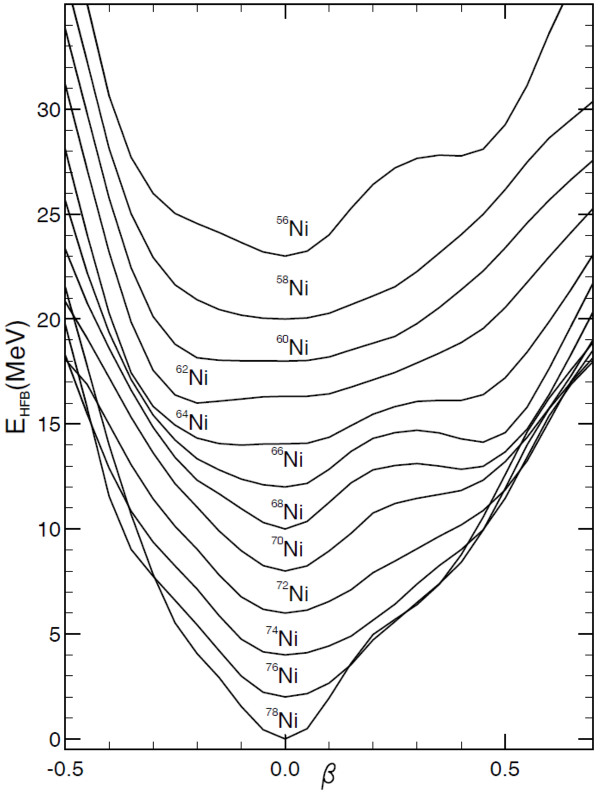
HFB+QRPA versus HFB+5DCH with the same interaction



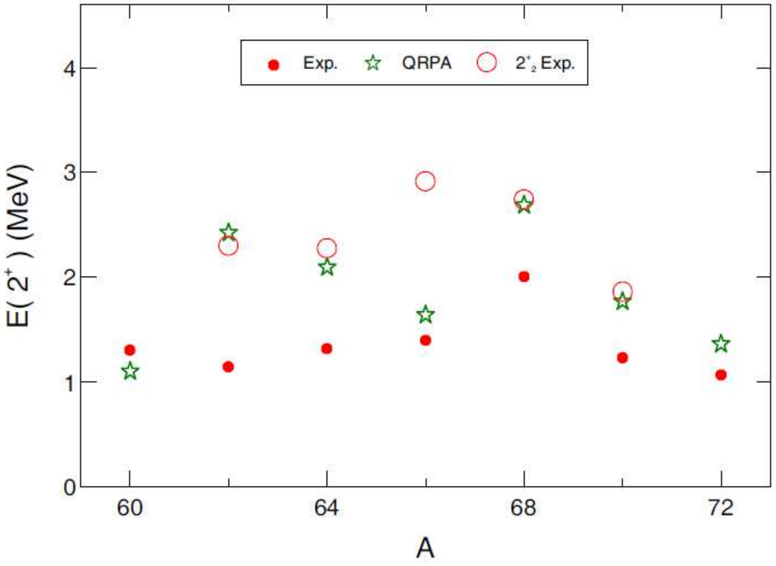


Ni isotopes (Z=28)

Two shell (N= 28, 50) and one sub-shell (N=40) closures



^{78}Ni is predicted doubly magic



For deformed nuclei the first 2^+ state is rotational

S.Péru and M. Martini, EPJA (2014) 50: 88.

According to the great successes using the finite range Gogny force:

5DCH : good reproduction of collective low energy spectra and shell effects

QRPA : good description of pygmy and giant resonances in spherical or deformed nuclei

QRPA and 5DCH complete each other.

We plan to use QRPA results to improve 5DCH

➔ **See next talk:**

Introduction of a valence space in QRPA:
impact on vibrational mass parameters and spectroscopic properties
by François Lechaftois