Qrpa with the Gogny force for low energy spectroscopy, γ strengths and β decay

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and

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S. Hilaire (CEA, DAM)

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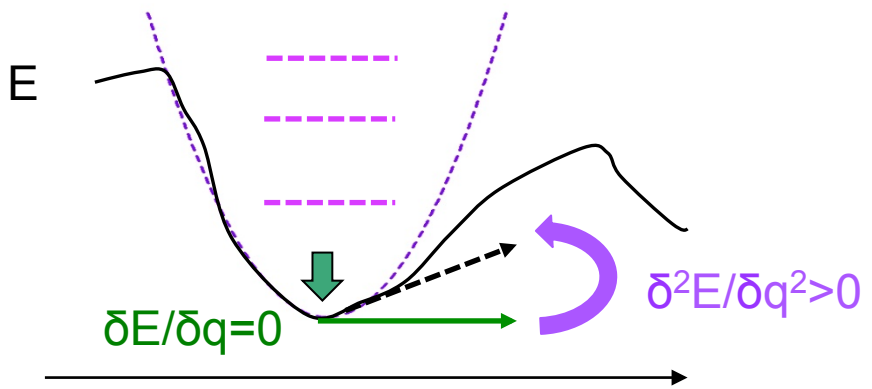
M. Martini (CEA, ESNT)

QRPA for description of Excited State Properties

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

Within the small amplitude approximation, i.e. « harmonic » nuclei

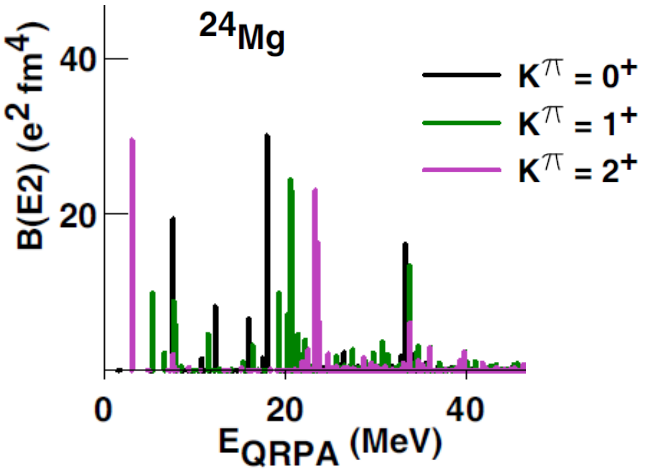


Spherical RPA with Gogny force

J. Dechargé and L.Sips, Nucl. Phys. **A 407**,1 (1983)
J.P. Blaizot et al, Nucl. Phys**. A 591**, 435 (1995)
S. Péru, JF. Berger, PF. Bortignon, Eur. Phys. J. A **26**, 25-32, (2005)

Axially symetric deformed QRPA with Gogny force

S. Péru, H. Goutte, Phys. Rev. C **77**, 044313, (2008)
M. Martini, S. Péru and M. Dupuis, Phys. Rev. C **83**, 034309 (2011)
S. Péru et al, Phys. Rev. C **83**, 014314 (2011)
S. Péru and M. Martini, EPJA 50: 88 (2014)
F. Lechaftois, I. Deloncle, S. Peru, Phys. Rev. C **92**, 034315 (2015)
M. Martini et al, Phys. Rev. C **94**, 014304 (2016)



! QRPA approach does not describe rotational motion !

RPA approaches describe all multipolarities and all parities

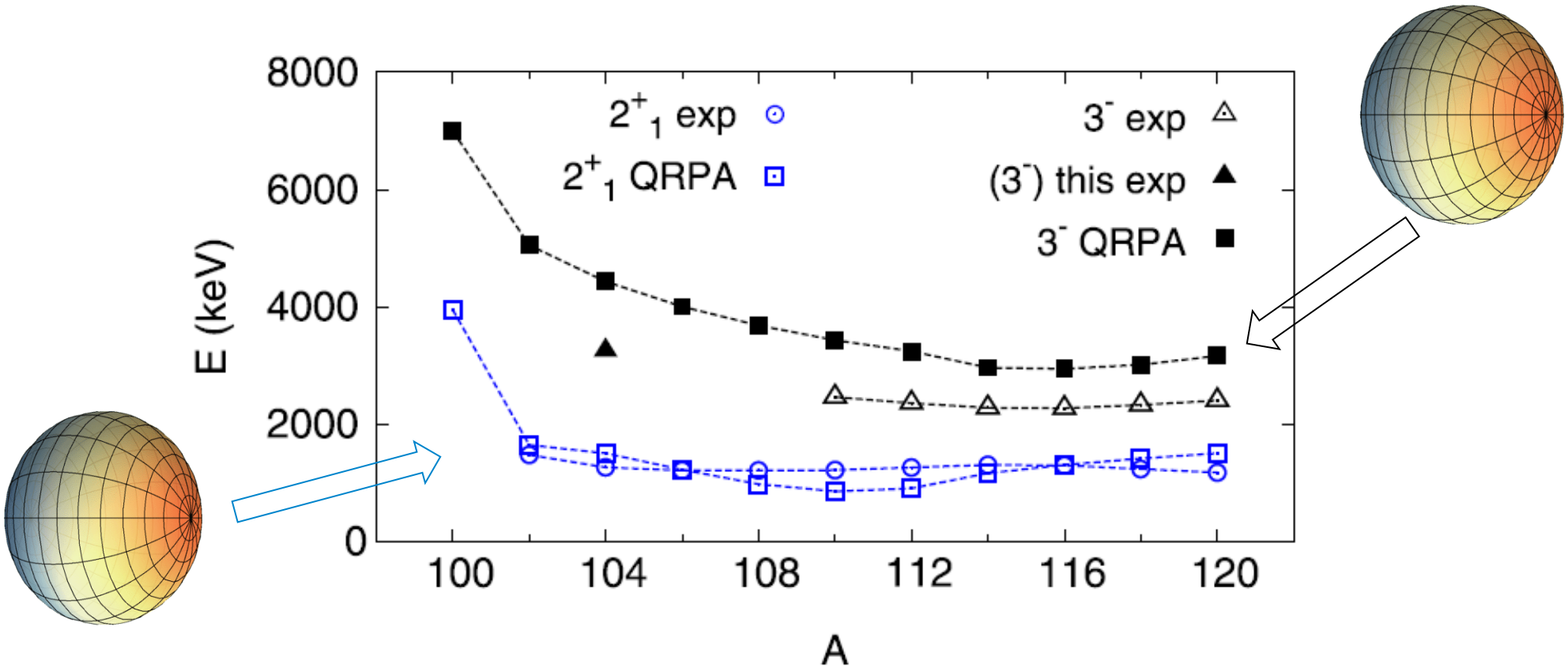
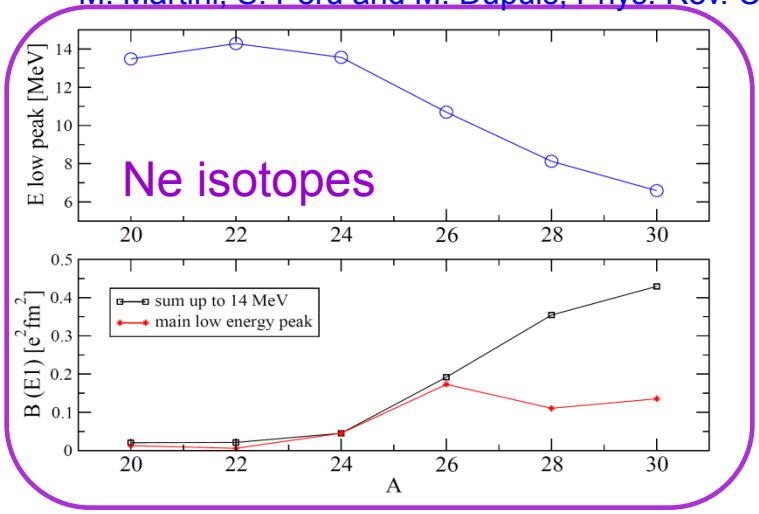


Fig. 3. (Color online.) Systematics of 2^+ and 3^- excitation energies in tin isotopes from experiment and HFB + QRPA calculations using the Gogny D1M interaction.

A. Corsi et al PLB 743 (2015) 451-455

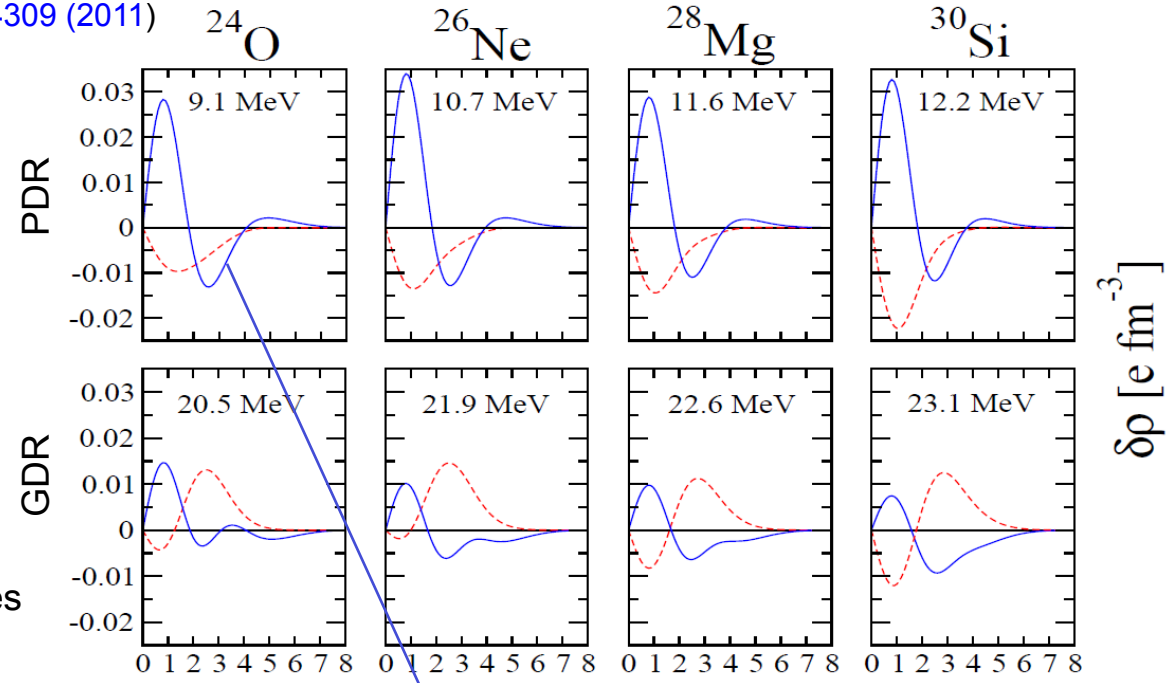
Dipole response for Neon isotopes and N=16 isotones

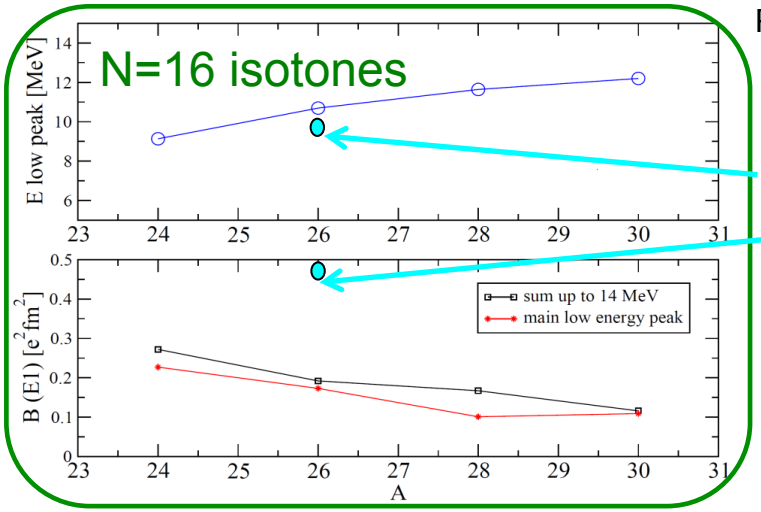
M. Martini, S. Péru and M. Dupuis, Phys. Rev. C **83**, 034309 (2011)



Increasing |N-Z| number :

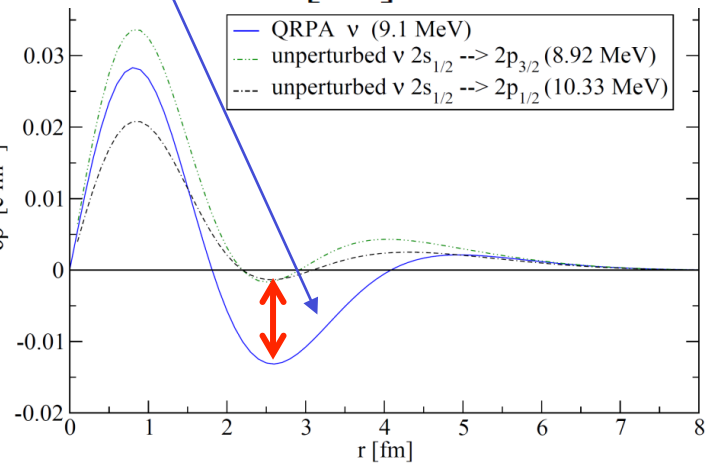
- Low energy dipole resonances shift to low energies
- Increasing of fragmentation and collectivity





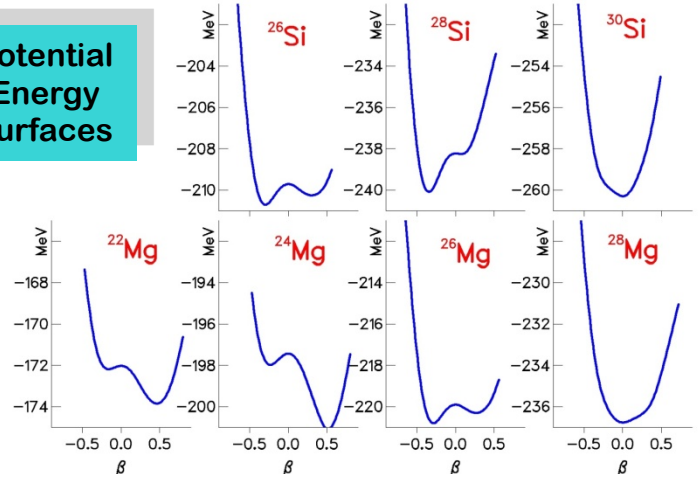
B(E1)↑= 0.49 ± 0.16 e² fm² @ 9 MeV
J. Gibelin et al, PRL 101, 212503 (2008)

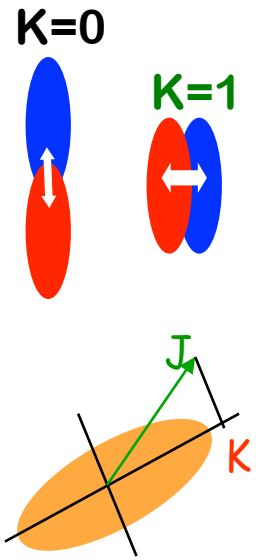
PDR : piccola dipole resonance



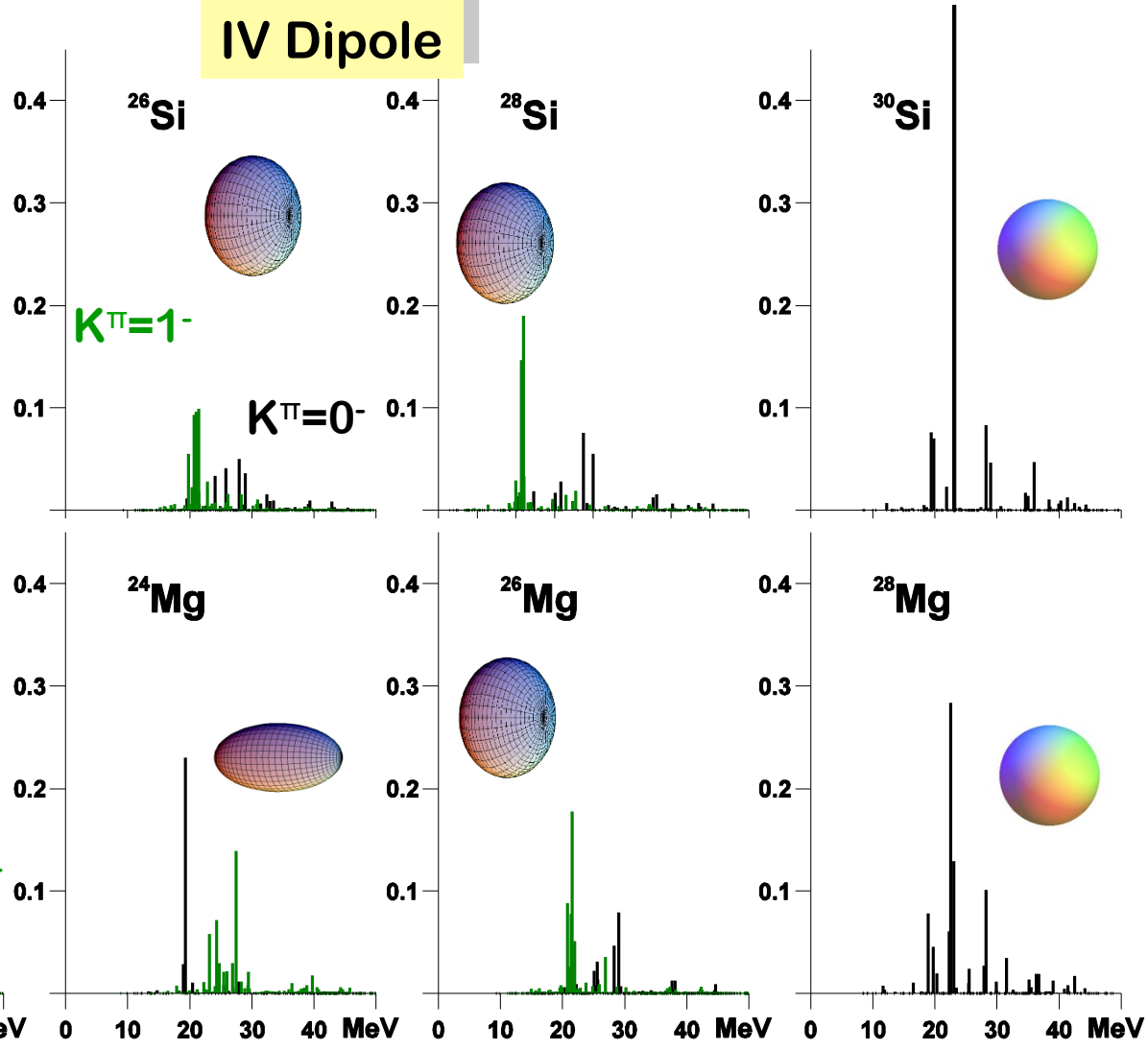
Role of deformation

Potential Energy Surfaces



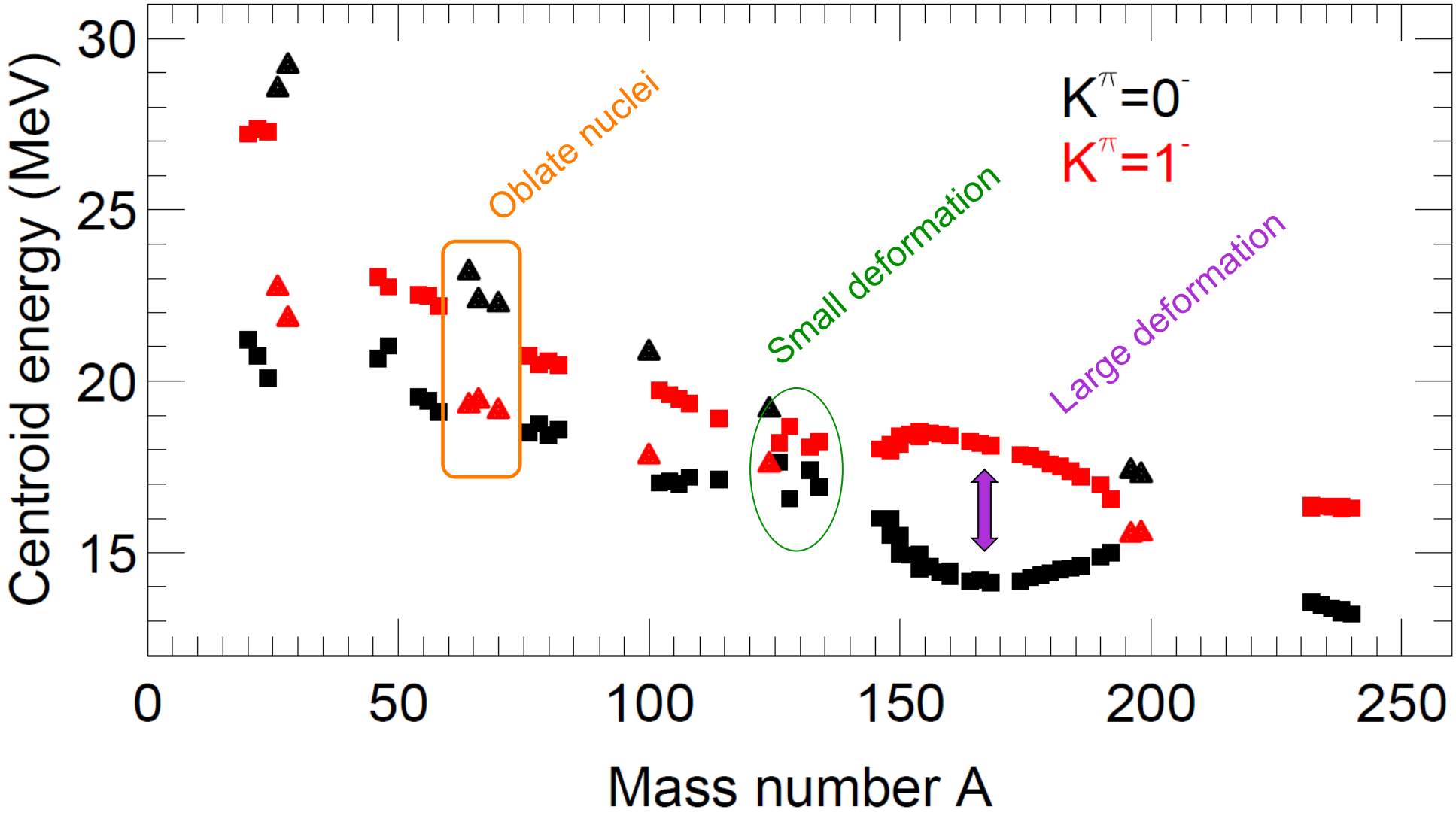


IV Dipole



S. Péru and H. Goutte, Phys. Rev. C 77, 044313 (2008).

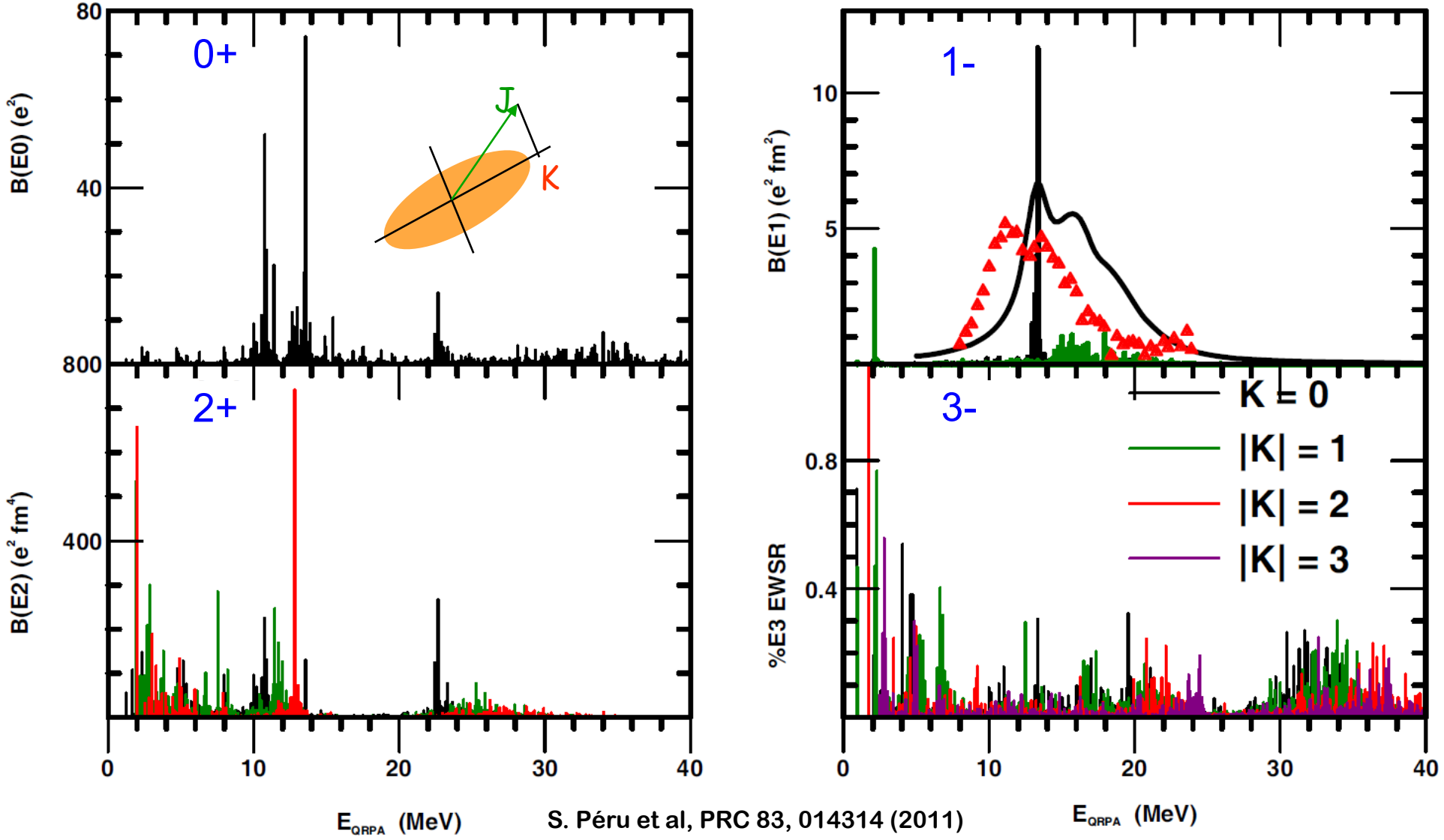
Impact of the deformation on dipole resonances



M. Martini et al, PRC 94, 014304 (2016)

From light to heavy nuclei: case of ^{238}U

Heavy deformed nucleus ⟶ massively parallel computation

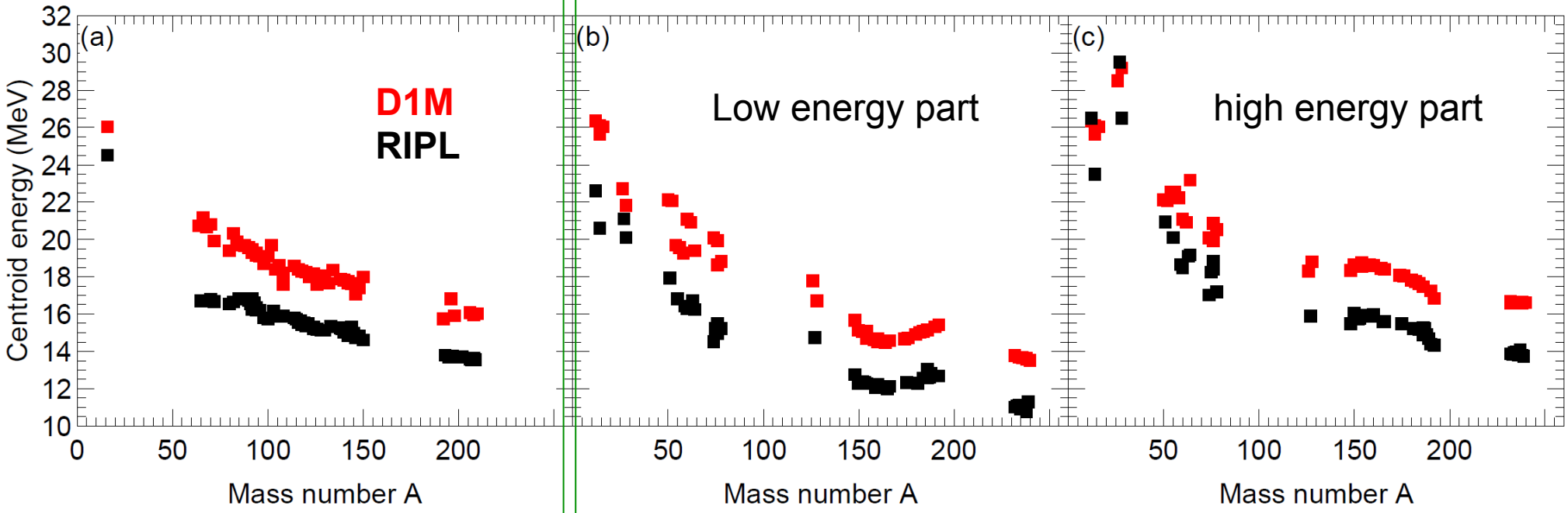


S. Péru et al, PRC 83, 014314 (2011)

Comparison with experimental data

One Lorentzian in RIPL

Two Lorentzians in RIPL



Systematic overestimation of the centroid energies :~ 2MeV

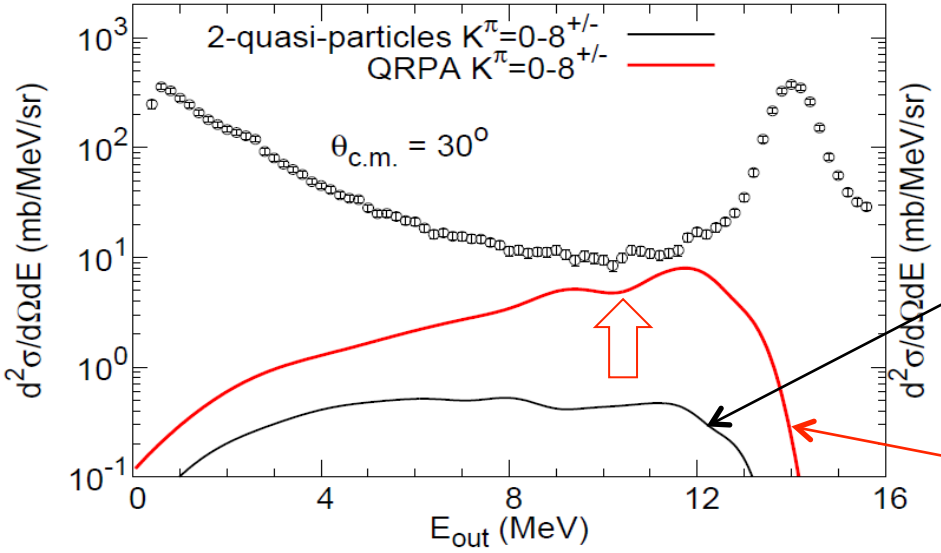
M. Martini et al, PRC 94, 014304 (2016)

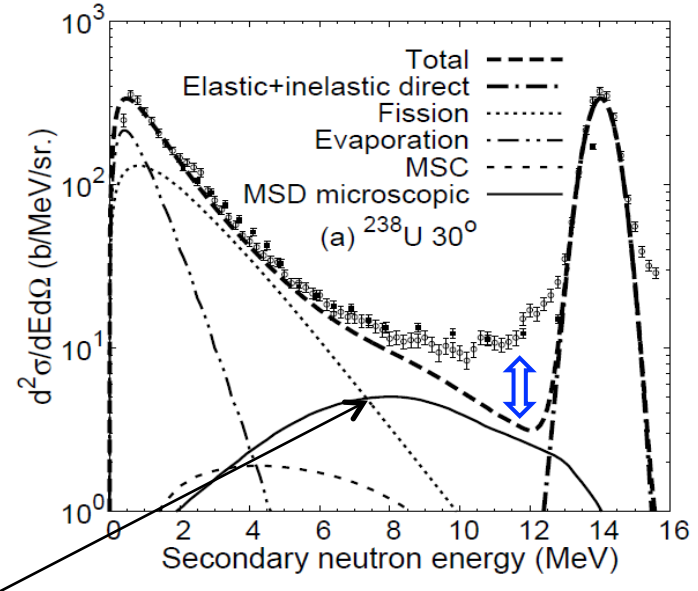
Beyond the nuclear structure

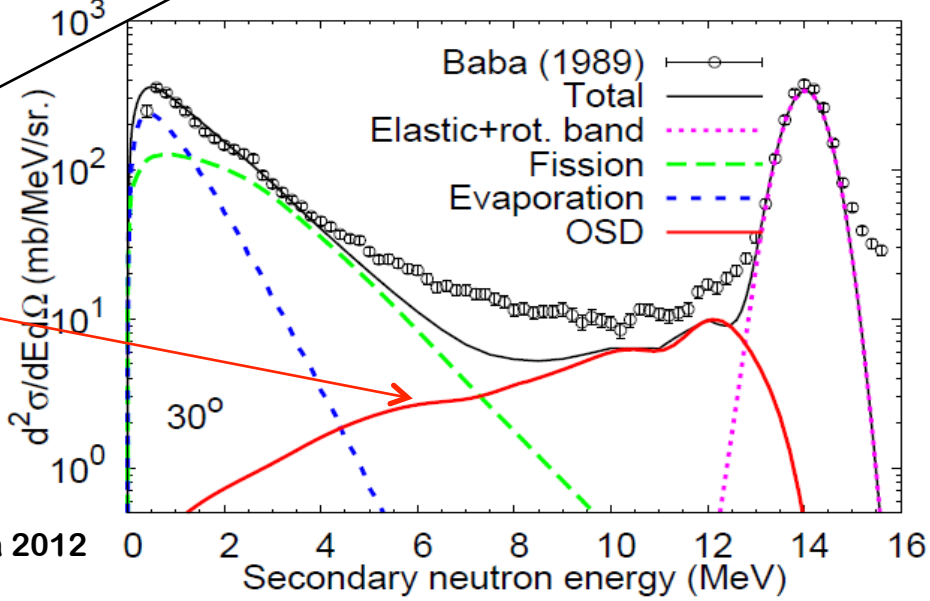
(n, *x* n) cross section on ^{238}U

Problem of underestimation of
n emission cross section at high energy

QRPA provides
enough collective contribution



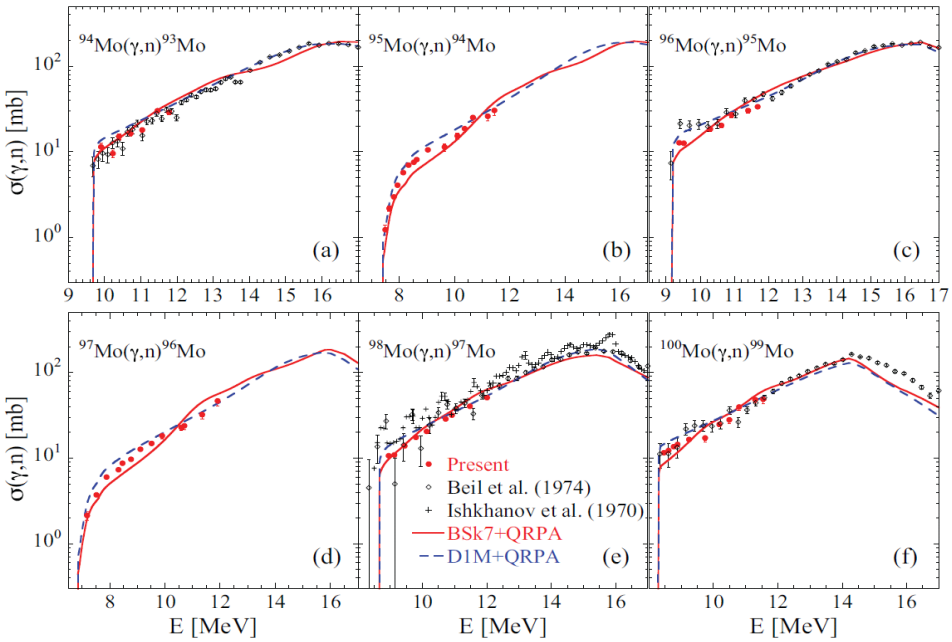


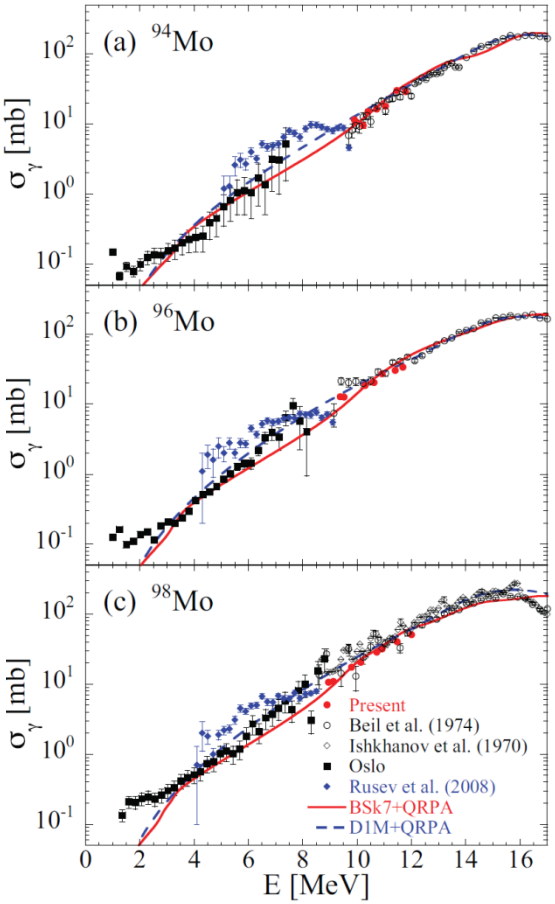


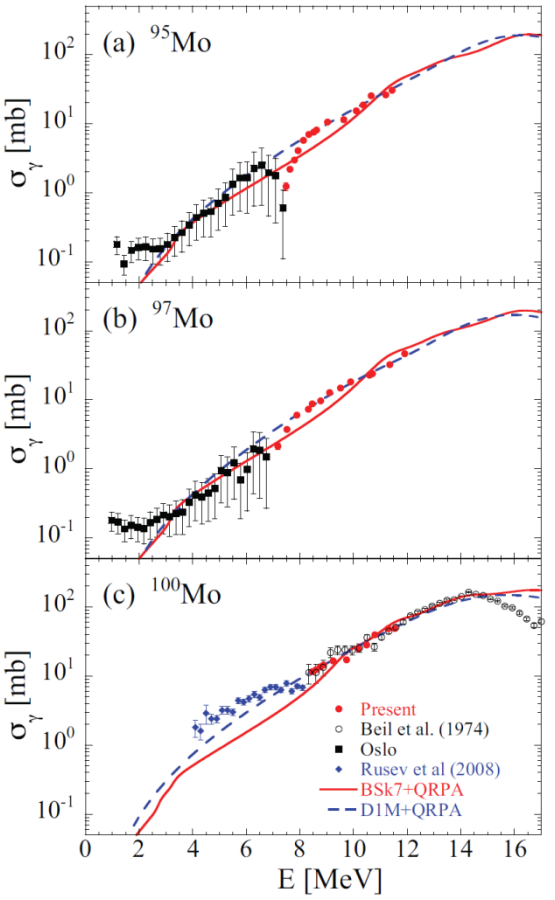
M. Dupuis, S.Péru, E. Bauge and T. Kawano,
13th International Conference on Nuclear Reaction Mechanisms, Varenna 2012
CERN-Proceedings-2012-002, p 95

Photoneutron and Photo-absorption cross sections for Mo

H. Utsunomiya et al, PRC 88, 015805 (2013)



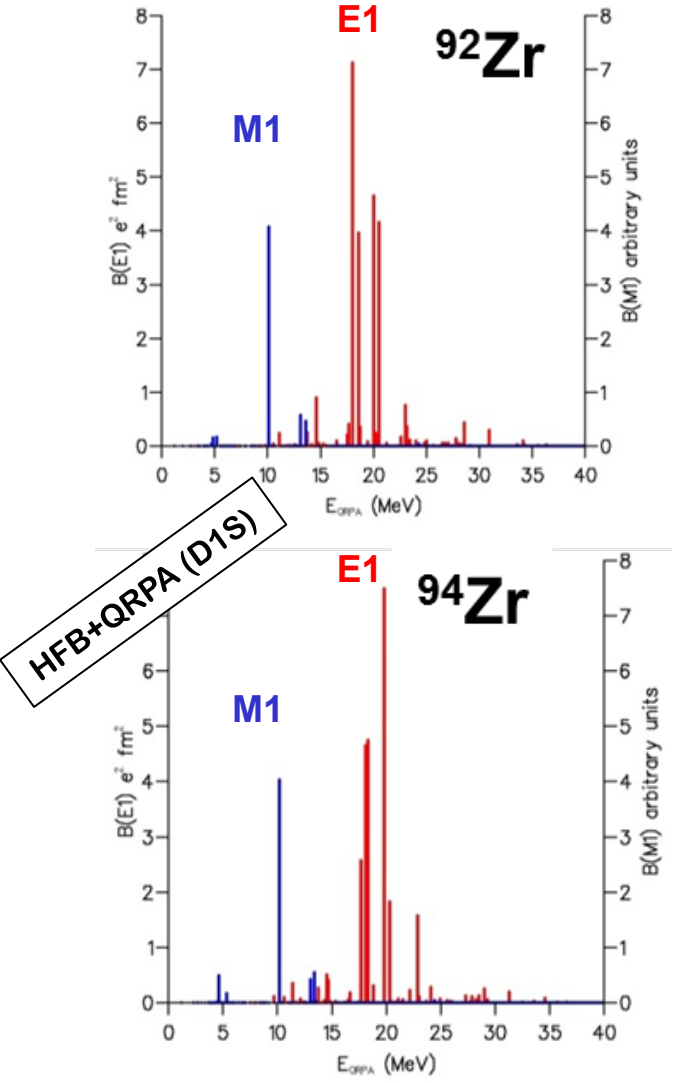


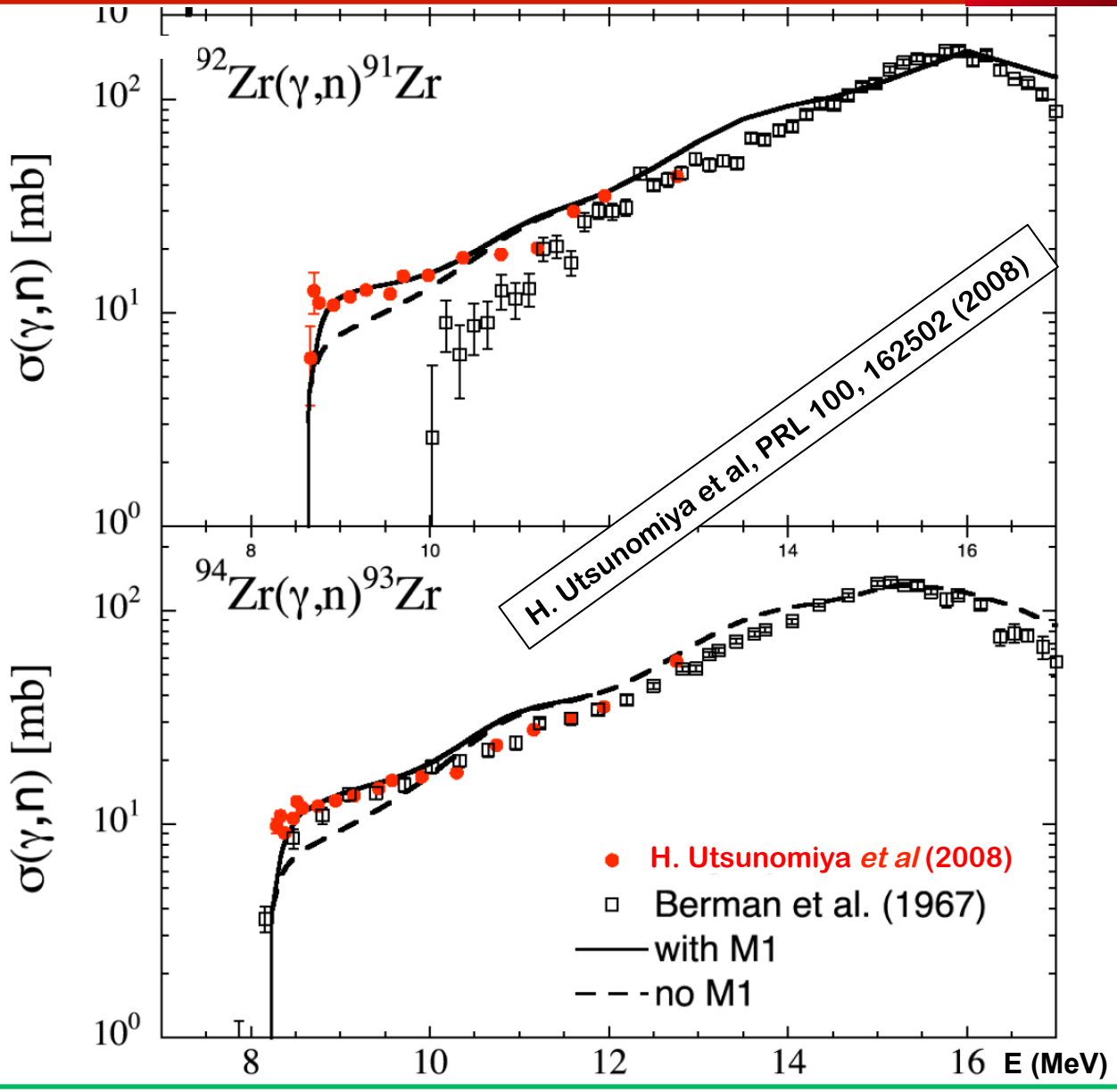


Similar agreement have been obtained for σ(γ,n)

in Sm isotopes: D. M. Filipescu et al, PRC **90**, 064616 (2014)
in Nd isotopes: H.-T. Nyhus et al, PRC **91**, 015808 (2015)

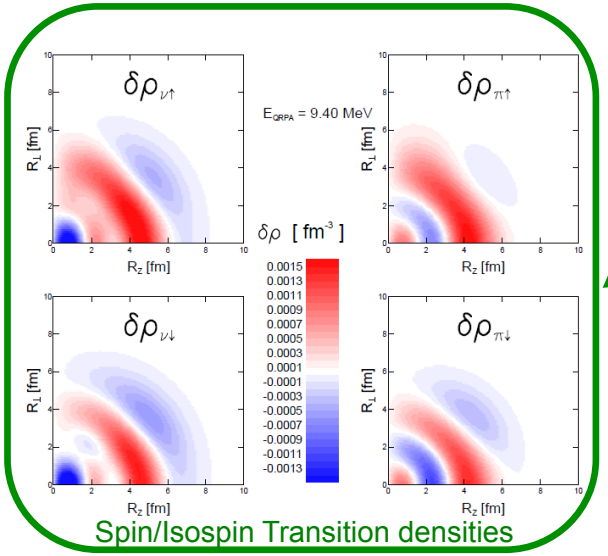
Dipole electric and magnetic excitations for Zr isotopes



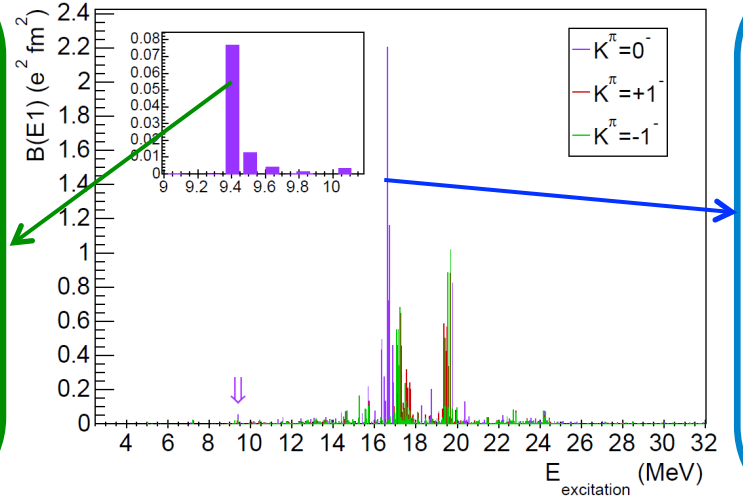


Low Energy Enhancement in the γ Strength of the Odd-Even Nucleus ^{115}In

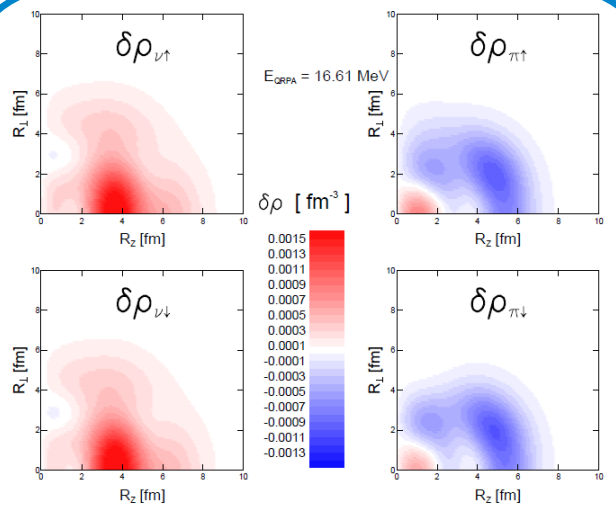
PDR Iso Scalar dipole



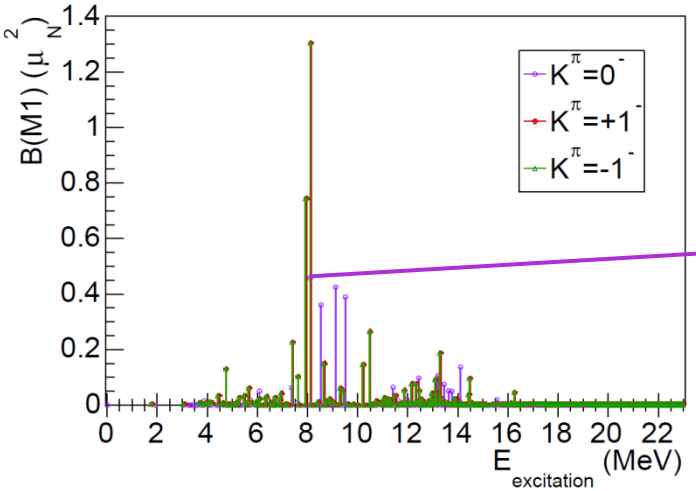
Spin/Isospin Transition densities



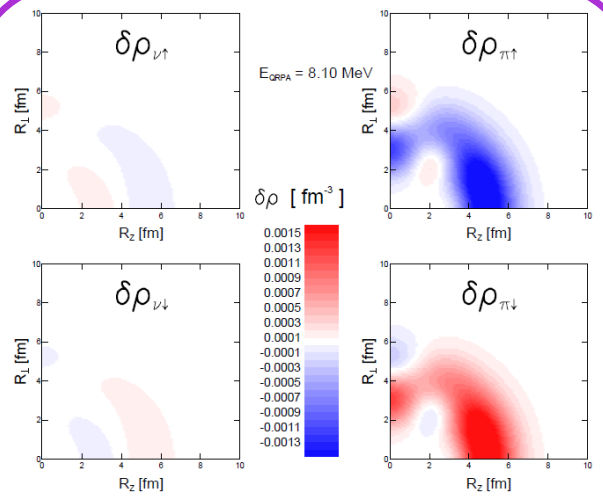
Iso Vector dipole



Spin/Isospin Transition densities



M. Versteegen et al, submitted in PLB



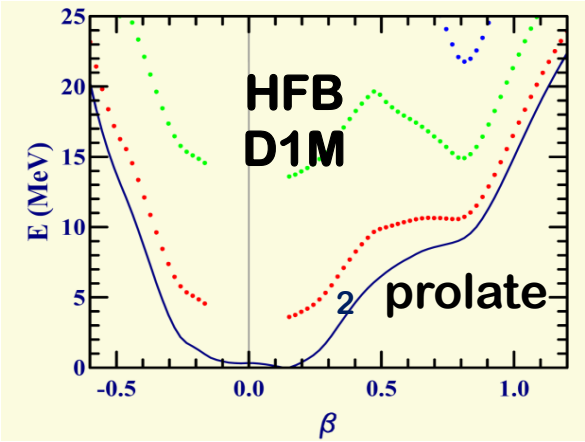
Spin/Isospin Transition densities

Spin flip

Charge exchange QRPA : GT resonances for β decay

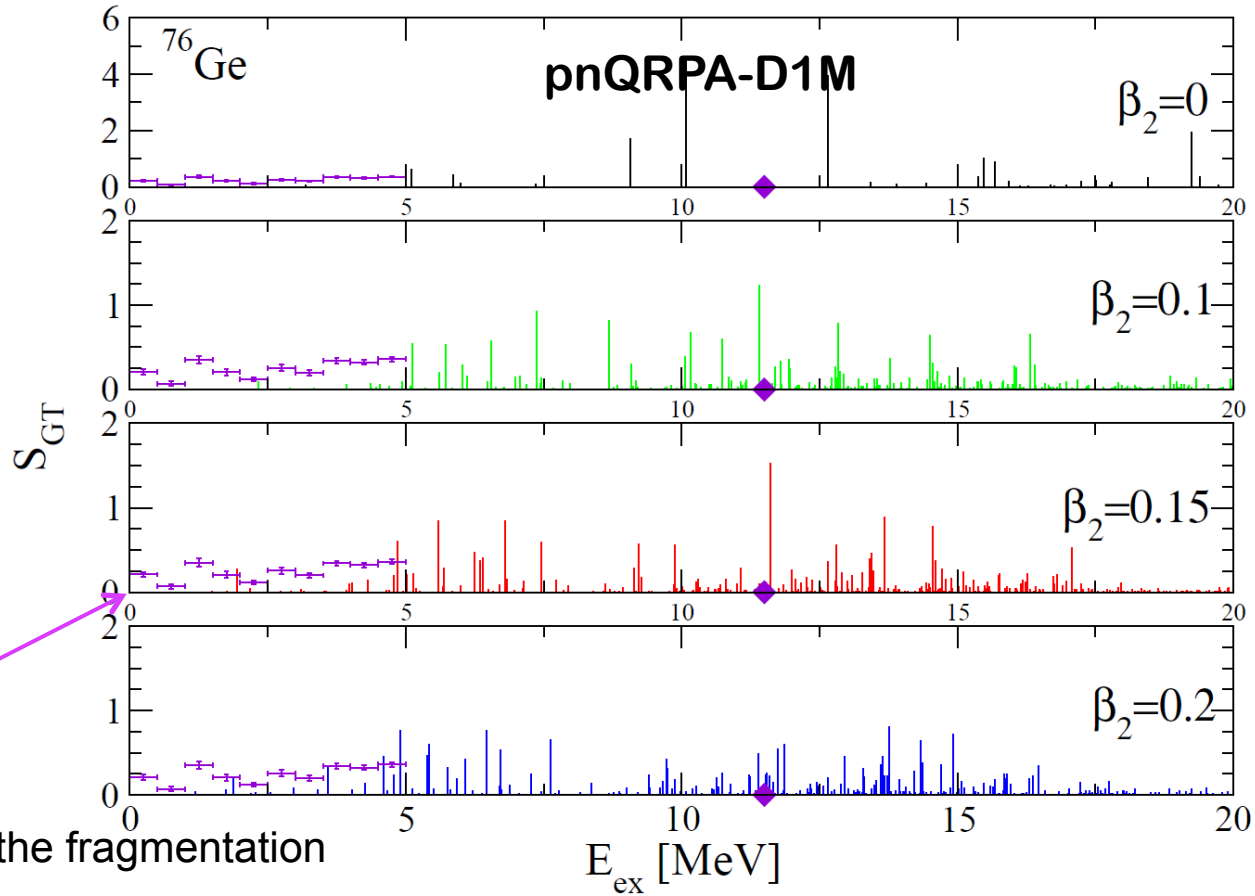
An example of deformed nucleus : ^{76}Ge

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°



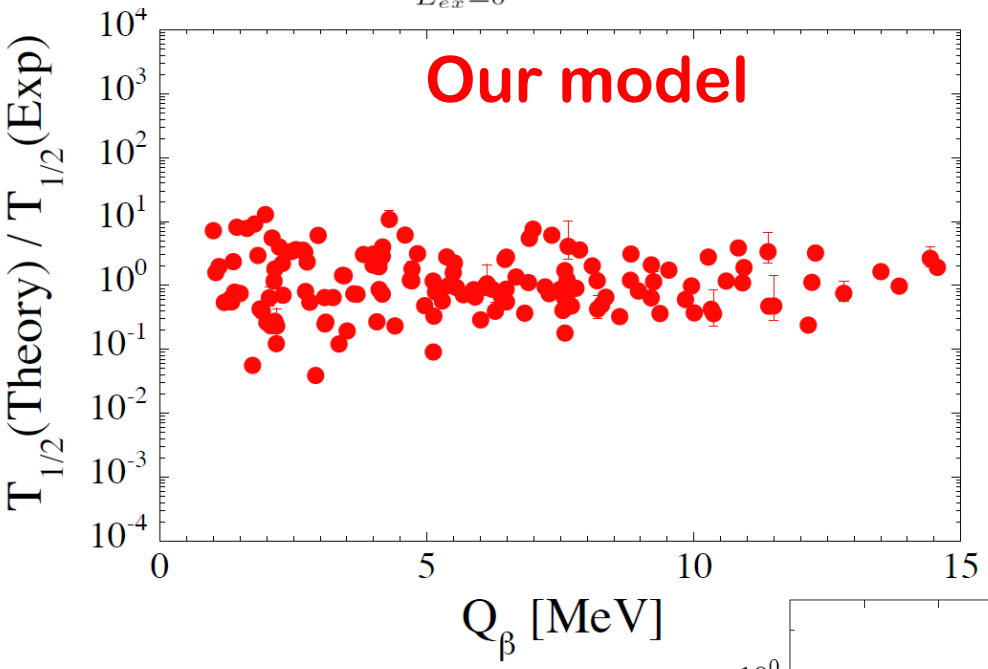
Experiment
Thies et al., Phys. Rev. C 86, 014304 (2012)

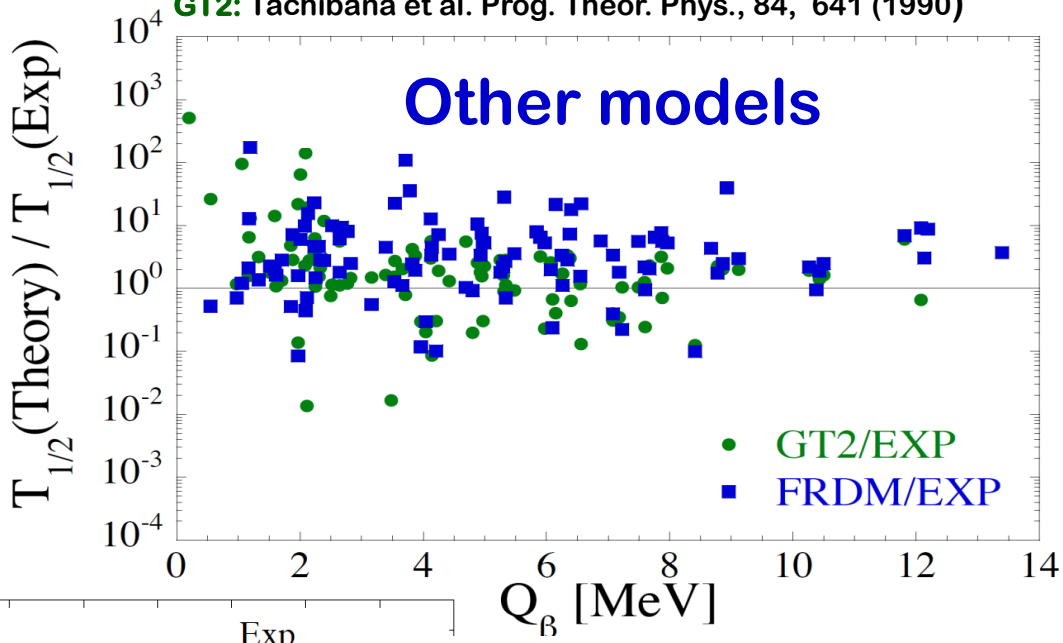
- The deformation tends to increase the fragmentation
- Displacements of the peaks
- Deformation influences the low energy strength hence β decay half-lives are expected to be affected

β^- decay half-life $T_{1/2}$: Comparison with other models

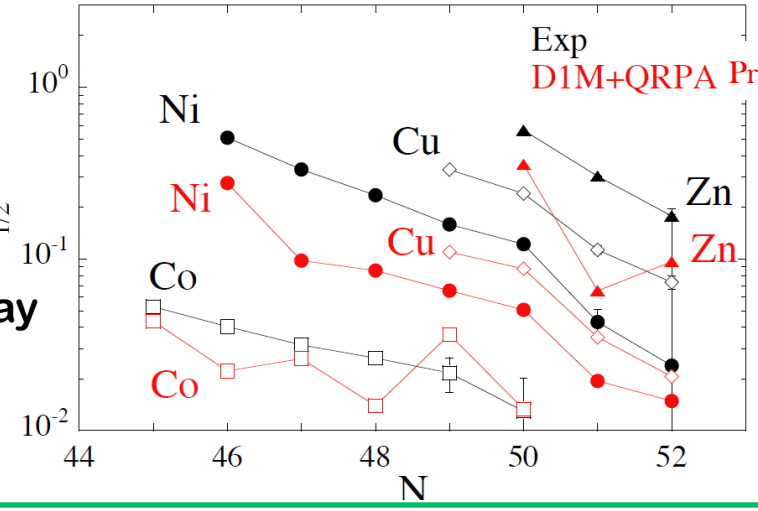
$$\frac{\ln 2}{T_{1/2}} = \frac{(g_A/g_V)^2_{\text{eff}}}{D} \sum_{E_{ex}=0}^{Q_\beta} f_0(Z, A, Q_\beta - E_{ex}) S_{GT}(E_{ex})$$

FRDM: Moller et al., ADNDT, 66,131 (1997)
GT2: Tachibana et al. Prog. Theor. Phys., 84, 641 (1990)





Extension to odd systems in collaboration with Isabelle Deloncle (CSNSM) Orsay



Recent experimental results

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

Beyond static mean field with the Gogny finite range force:

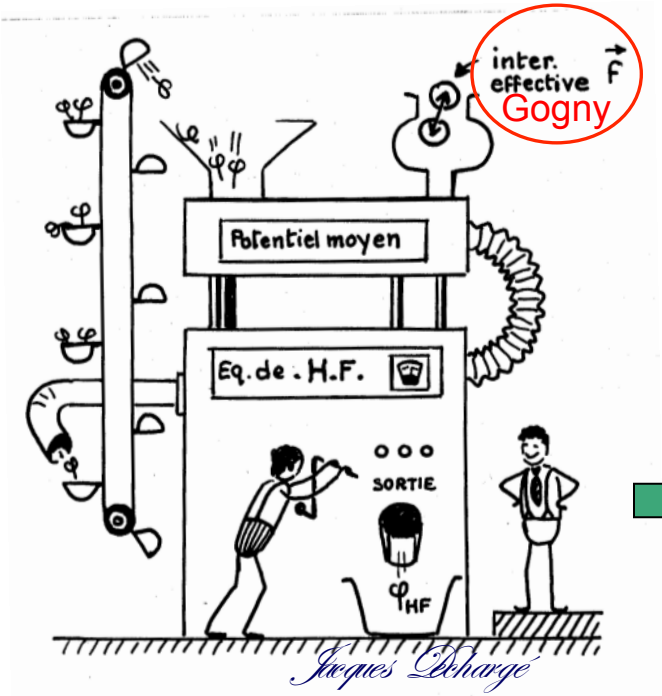
- Self-consistent QRPA approach has been applied to the deformed nuclei up to heavy ones.
- All multipolarities (electric and magnetic) can be reached.
- The GDR energy position with QRPA is systematically predicted ~2MeV above the experimental values.

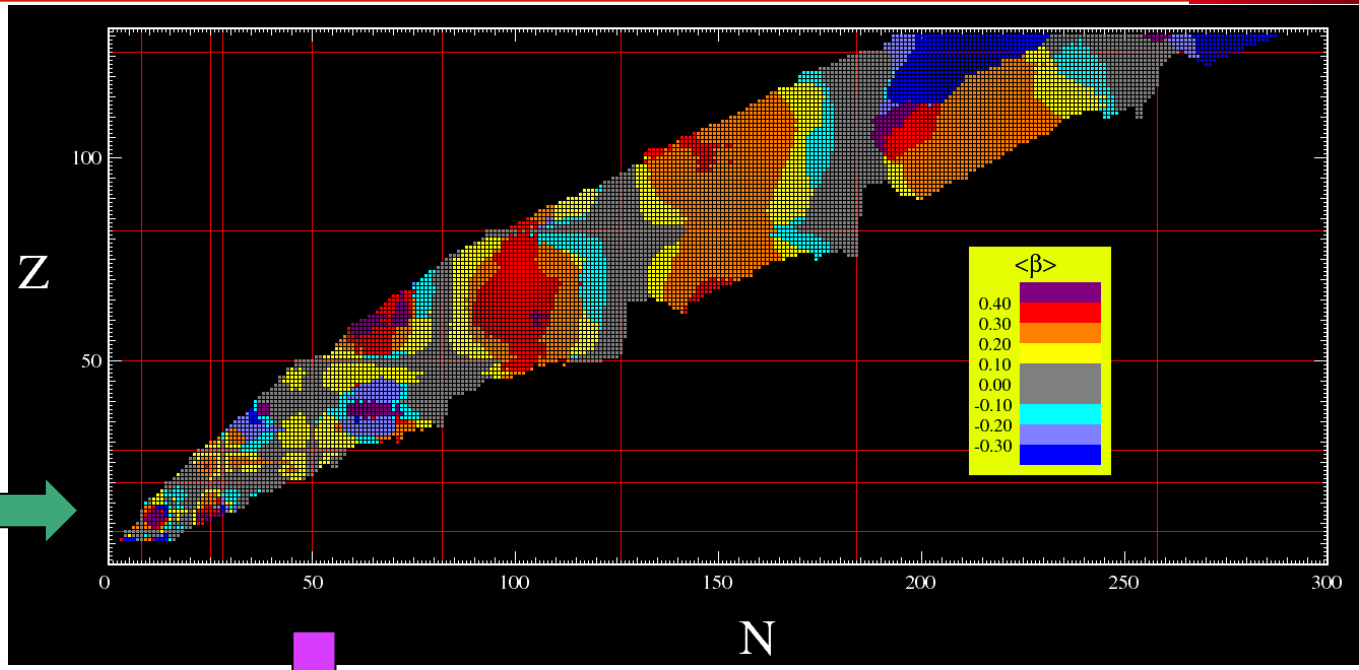
Extension of QRPA to charge exchange :

- The role of the intrinsic deformation has been proved for prolate ^{76}Ge.
- Calculated β decay half-lives are compatible with experimental data.

- Promising preliminary results for odd nuclei.

Reminder





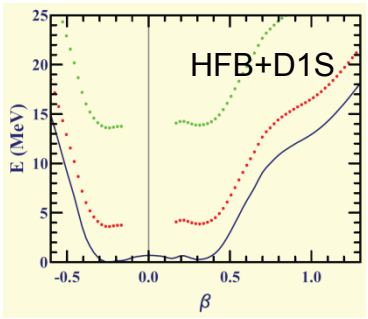
Static mean field (HFB)
for Ground State Properties :
- **Masses**
- **Deformation**
- **(Single particle levels)**

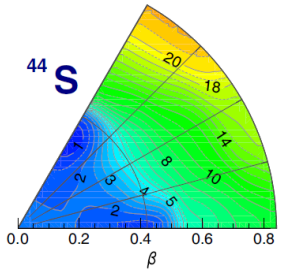
Amedee database :
http://www-phynu.cea.fr/HFB-Gogny_eng.htm
*S. Hilaire & M. Girod, EPJ **A33** (2007) 237*

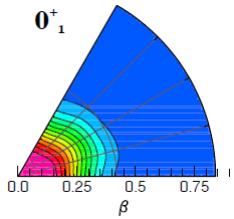
Beyond static mean field approximation (5DCH or QRPA)
for description of Excited State Properties
- **Low-energy collective levels**
- **Giant Resonances**

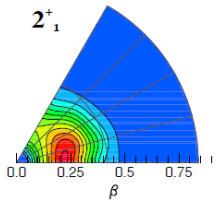
Beyond static mean field … with 5DCH or QRPA

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

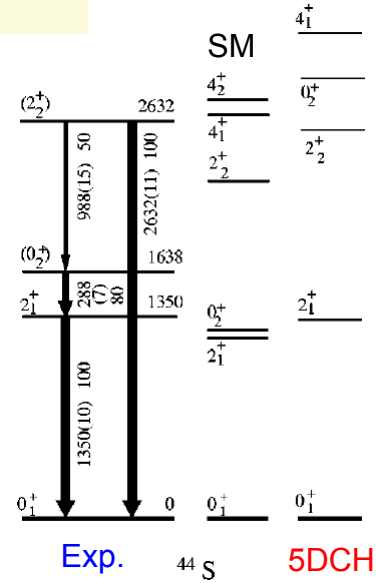








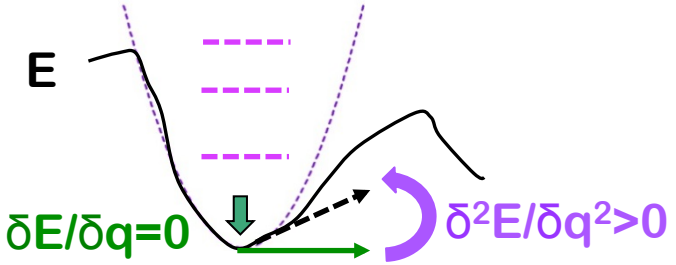
S.Péru and M. Martini, EPJA (2014) 50: 88.



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

(Q)RPA approaches describe all multipolarties 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

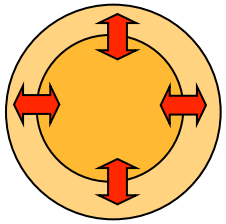


! Even for deformed nuclei QRPA approach does not describe rotational motion !

High energy collective states: giant resonances

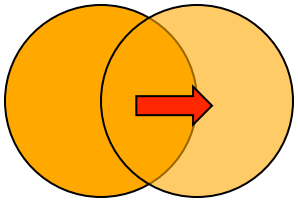
Giant resonances are related to nuclear matter properties

Monopole



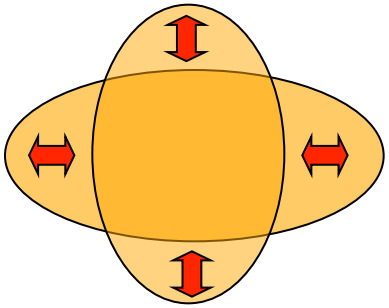
IS GMR

Dipole

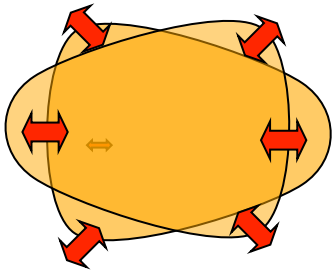


spurious state

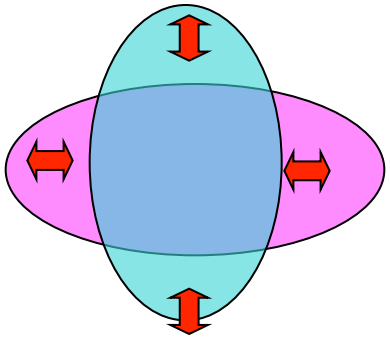
Quadrupole

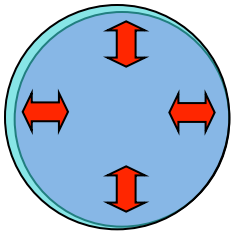


Octupole

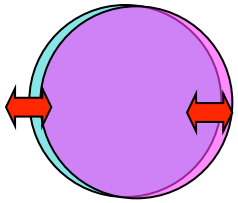


GQR

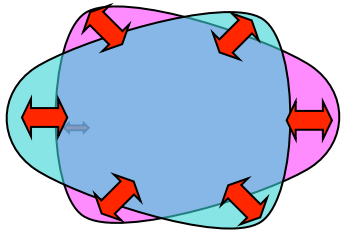




IV GMR

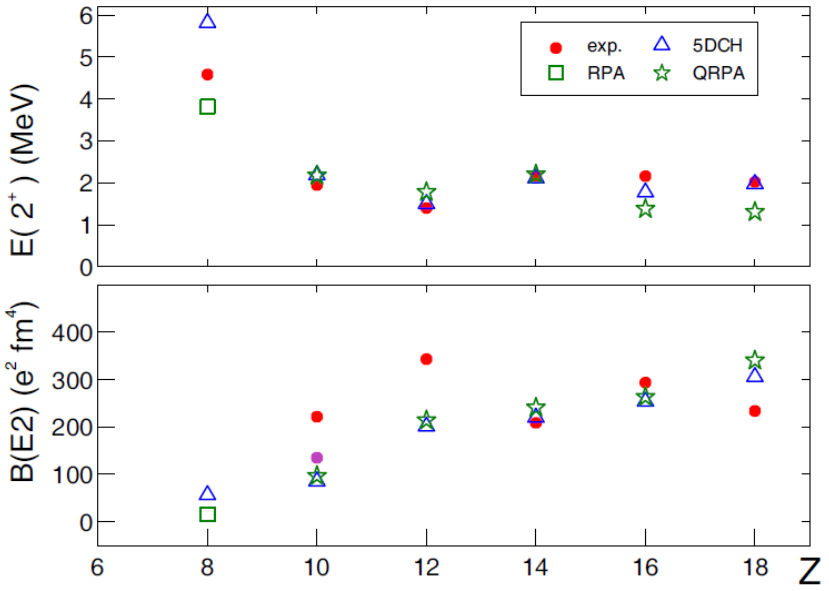


IV GDR



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

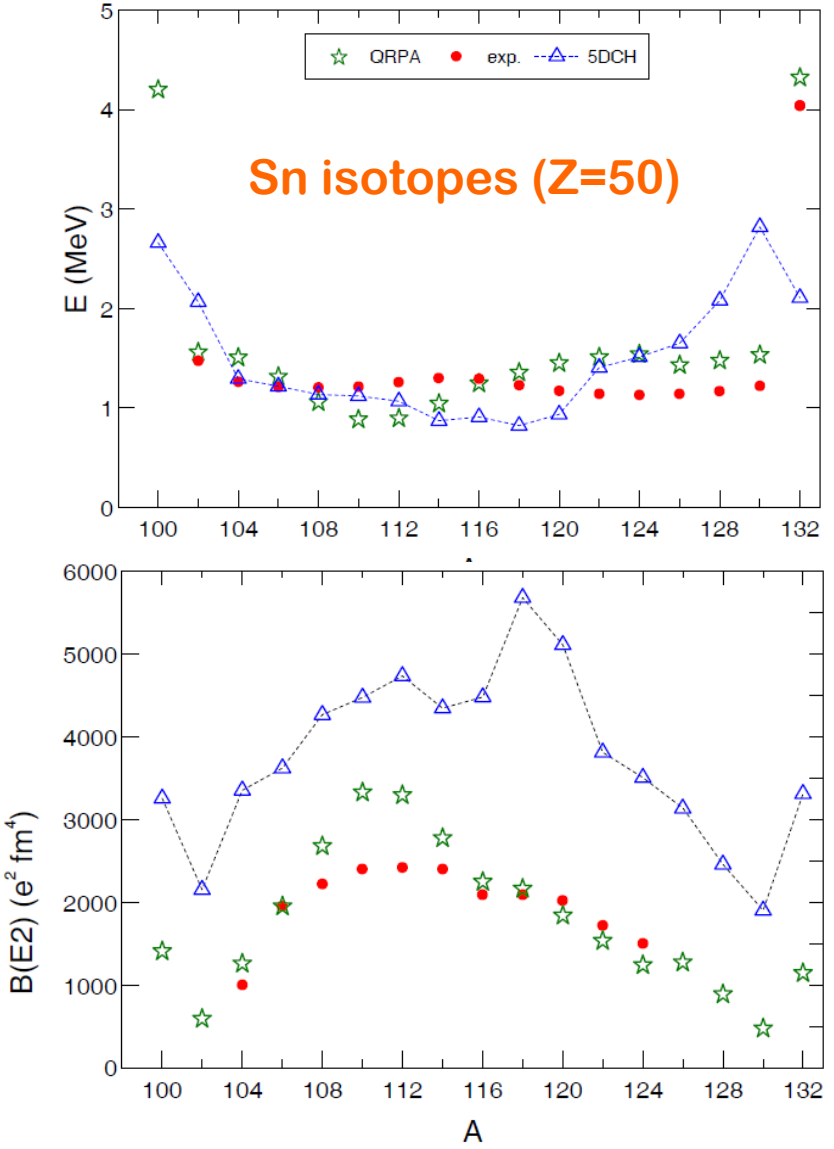
N=16 isotones



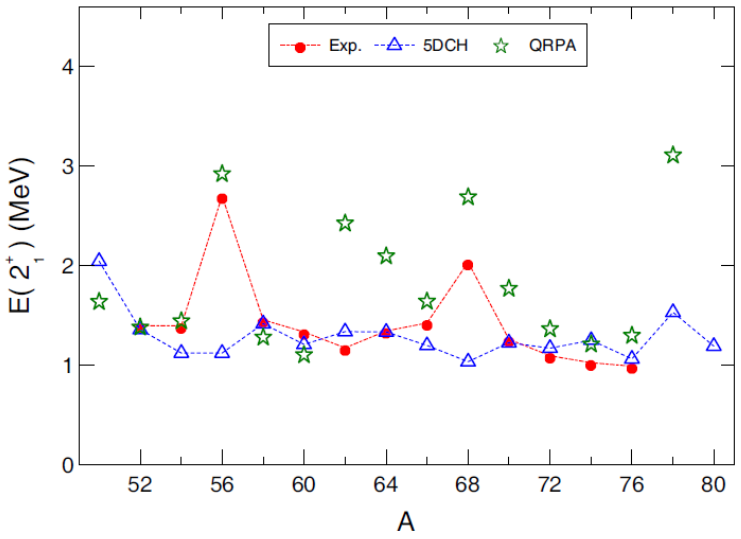
5DCH : A. Obertelli, et al, Phys. Rev. C **71**, 024304 (2005)

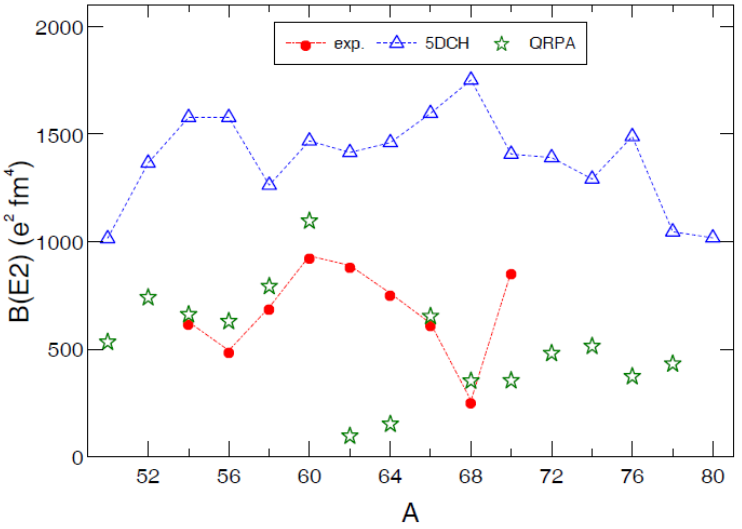
S. Péru and M. Martini, EPJA (2014) 50: 88.

Sn isotopes (Z=50)



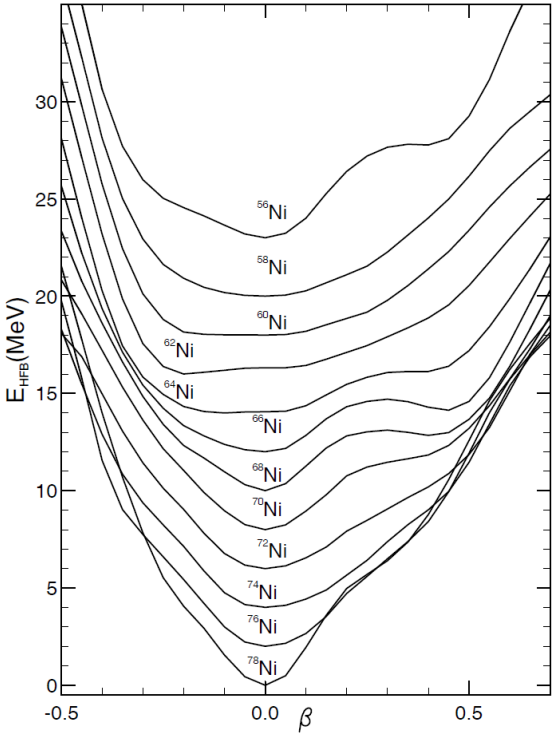
HFB+QRPA versus HFB+5DCH with the same interaction



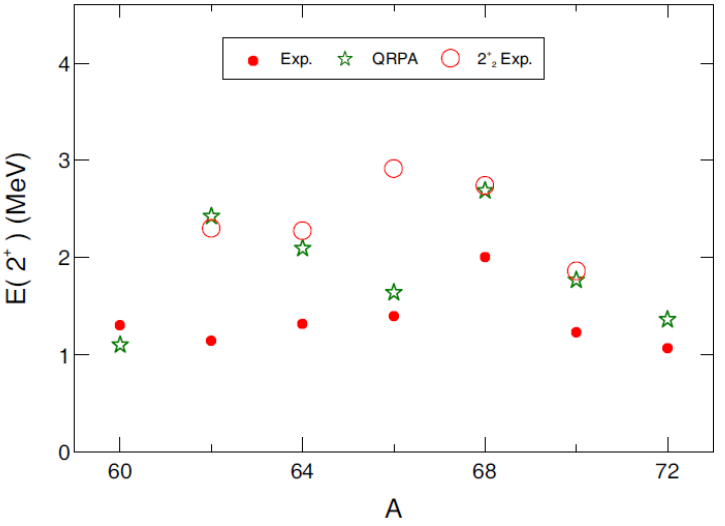


Ni isotopes (Z=28)

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



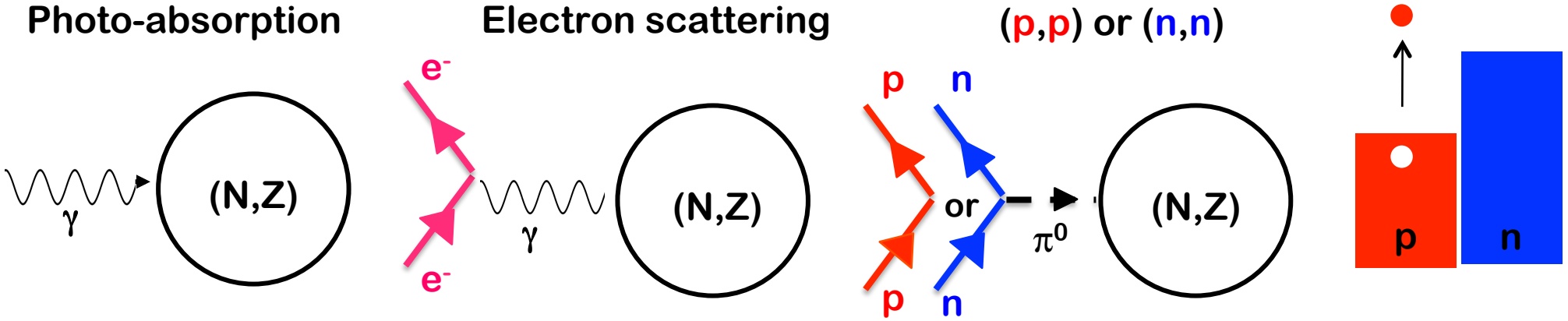
^{78}Ni is predicted doubly magic



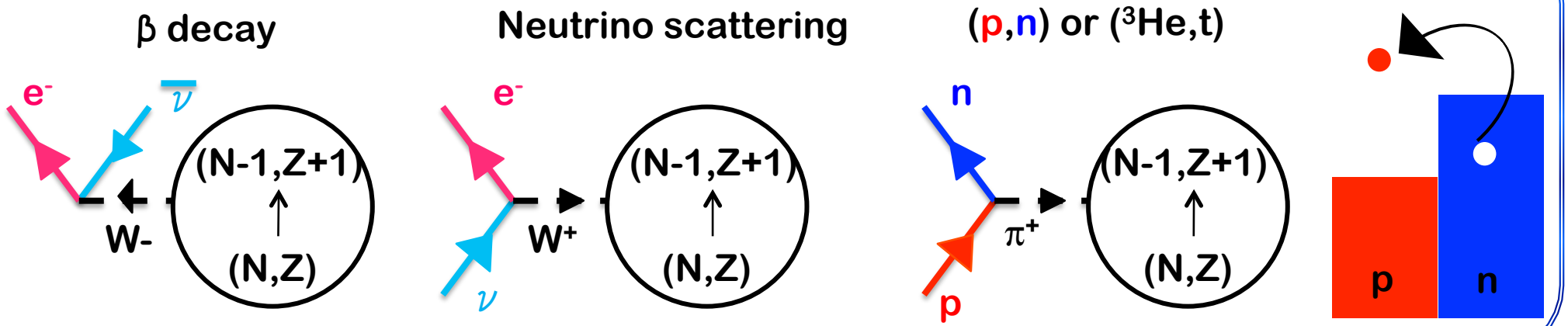
For deformed nuclei the first 2⁺ state is rotational

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

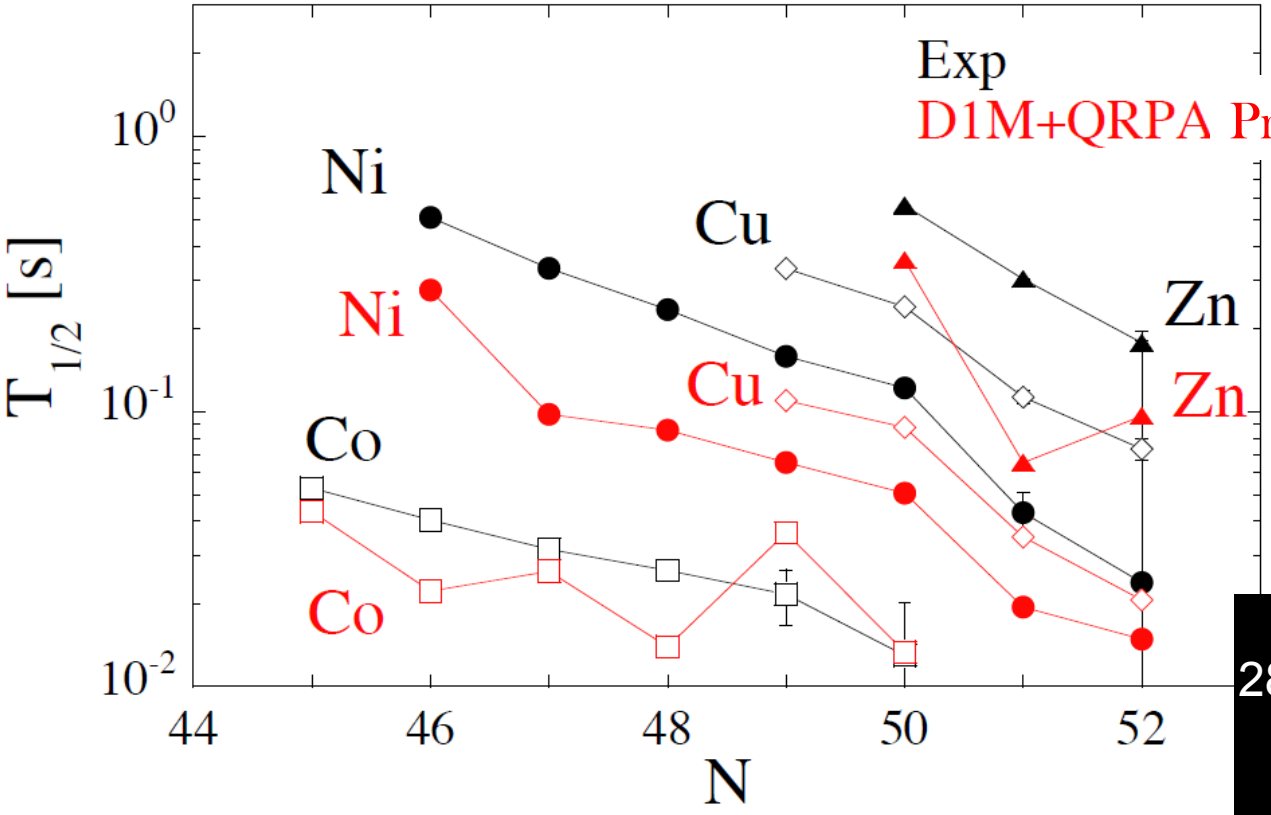
Nuclear Excitations



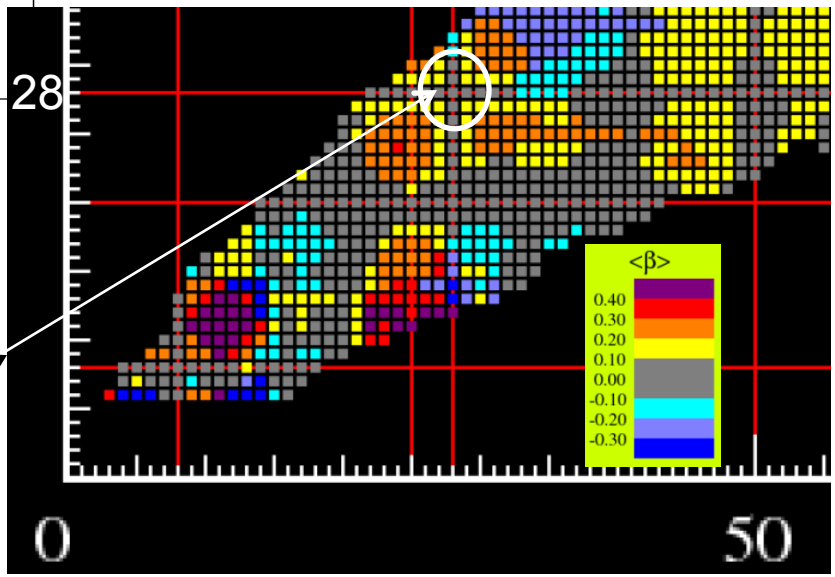
Charge exchange:



Even and odd systems, deformed and spherical nuclei



Extension to odd systems in collaboration with Isabelle Deloncle (CSNSM) Orsay



Recent experimental results

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