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SPECTROSCOPY AND BETA DECAY OF FISSION FRAGMENTS WITHIN QRPA APPROACH USING THE GOGNY FORCE

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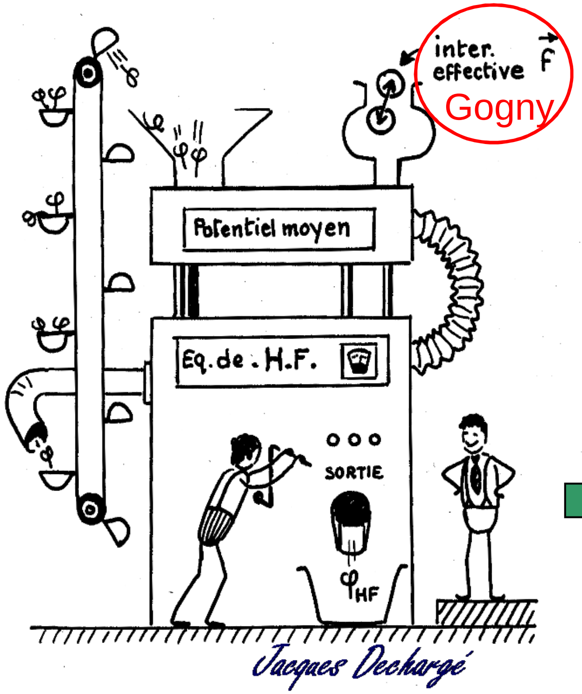
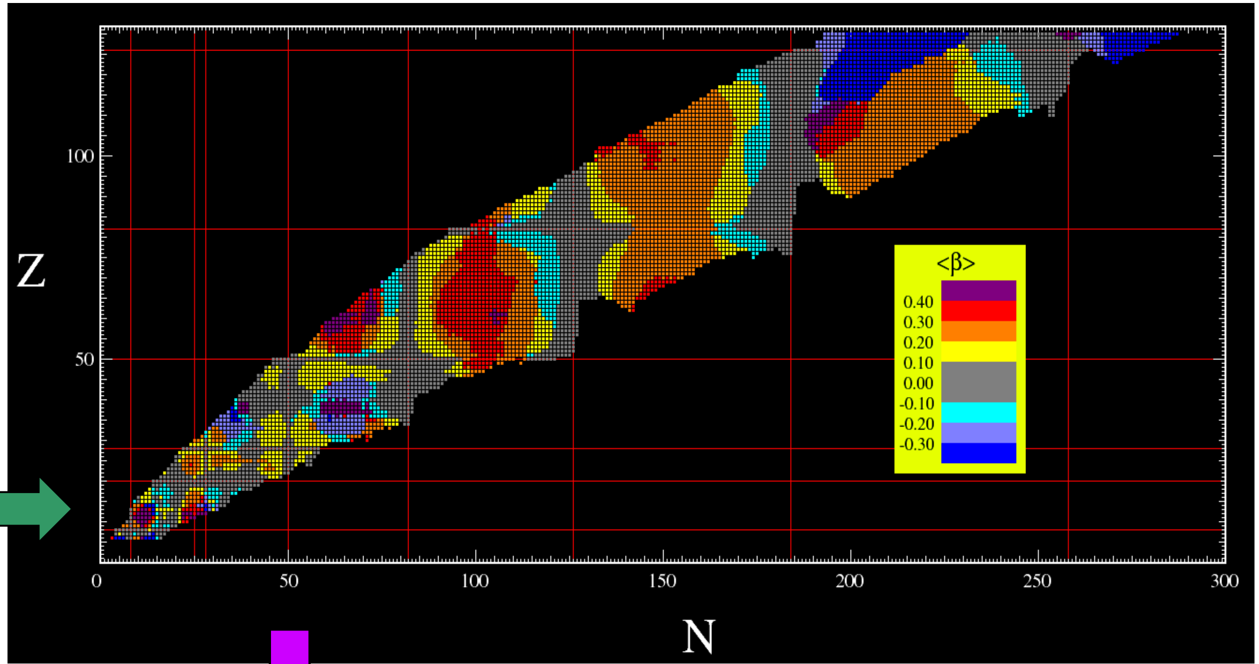
Reminder





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**
- **Radii**
- **(Single particle levels)**
- **Magnetic moment**

Beyond static mean field approximation (for exple QRPA)
for description of Excited State Properties

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

OUTLINE

➢ Ground state and isomer properties within HFB framework

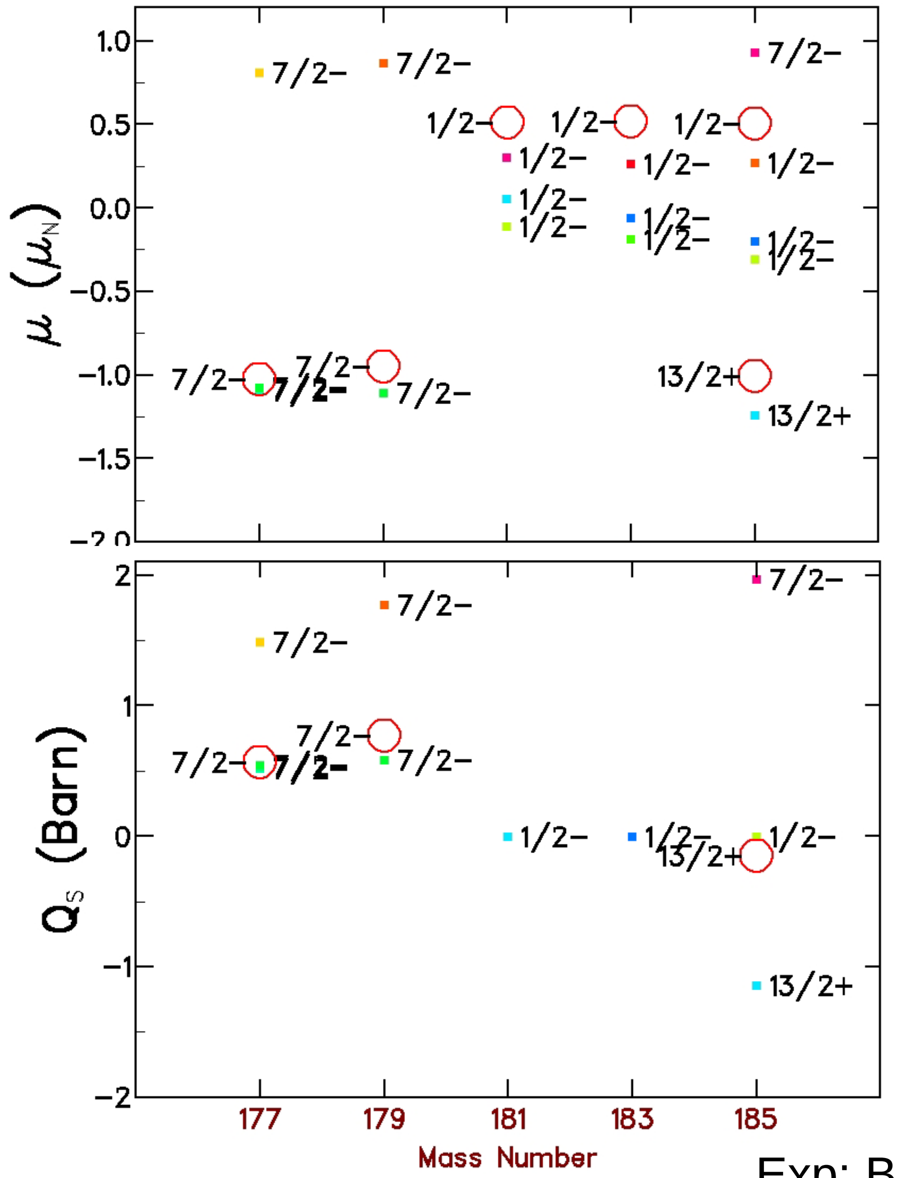
- Magnetic moments and Qs for odd nuclei : Hg isotopes
- Magnetic moments and Qs for ^{188}Bi

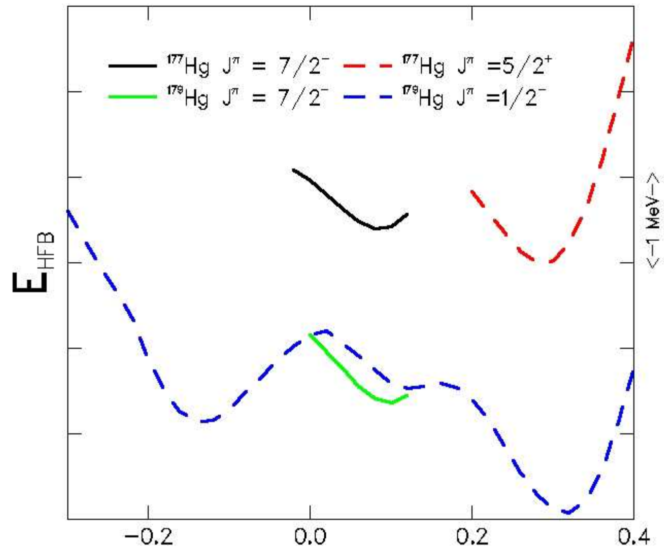
➢ QRPA approach

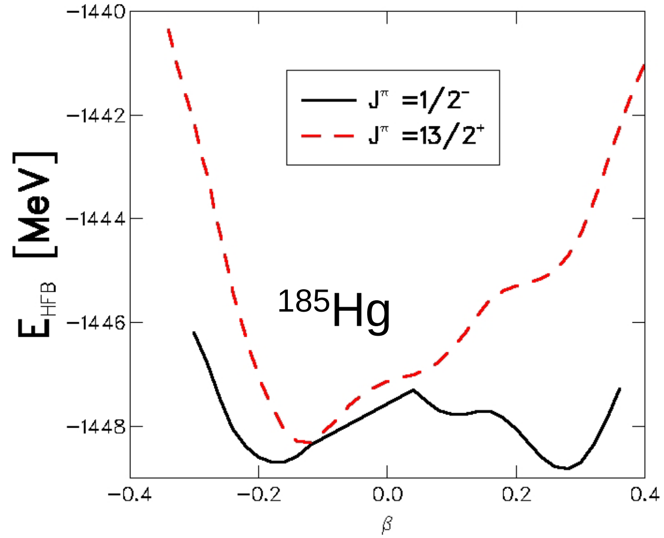
- Generalities
- Unusual application : K isomer in N=100 isotones
- Some perspectives

➢ Charge exchange QRPA

Magnetic moments and Qs in Hg isotopes

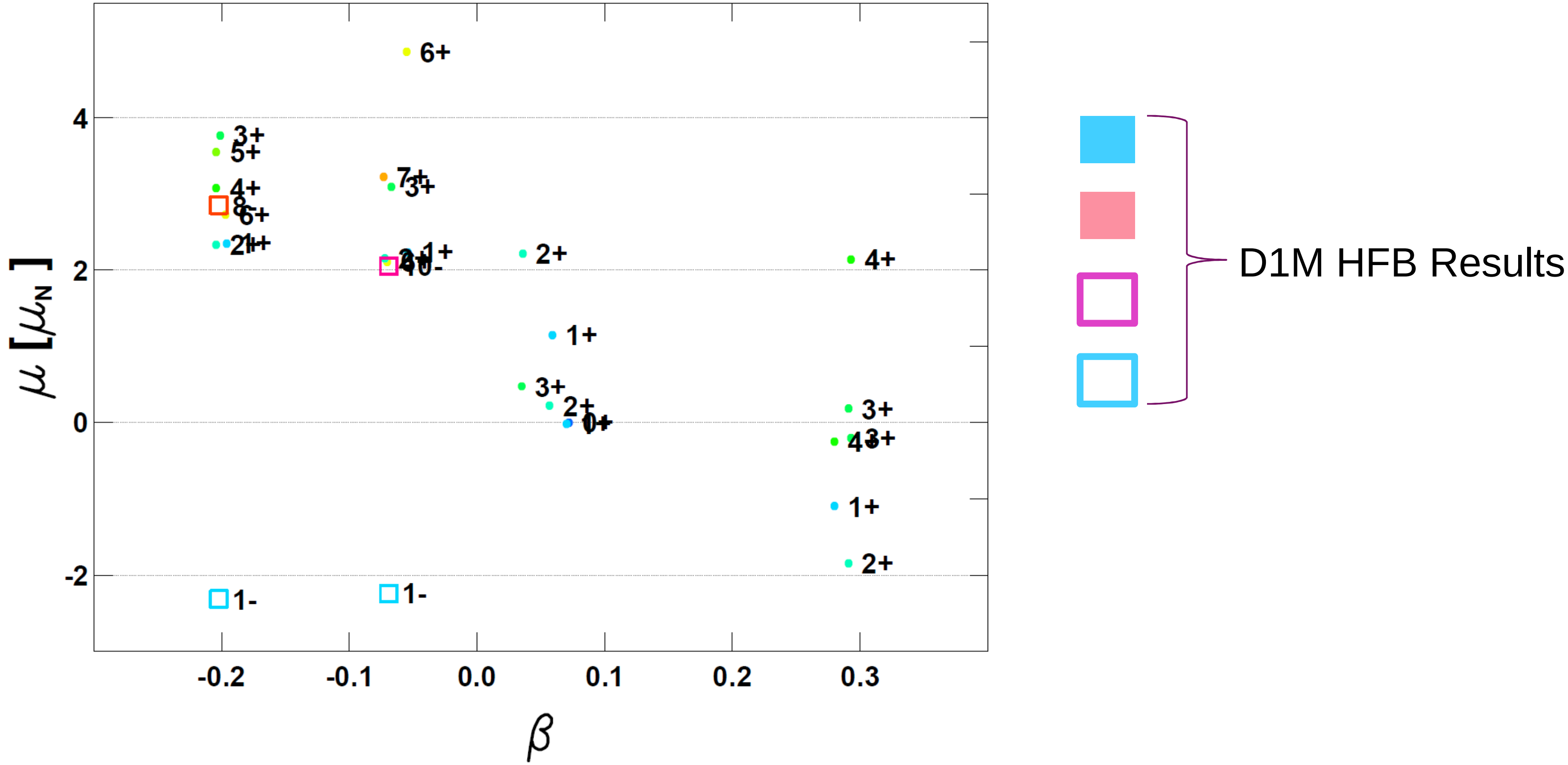




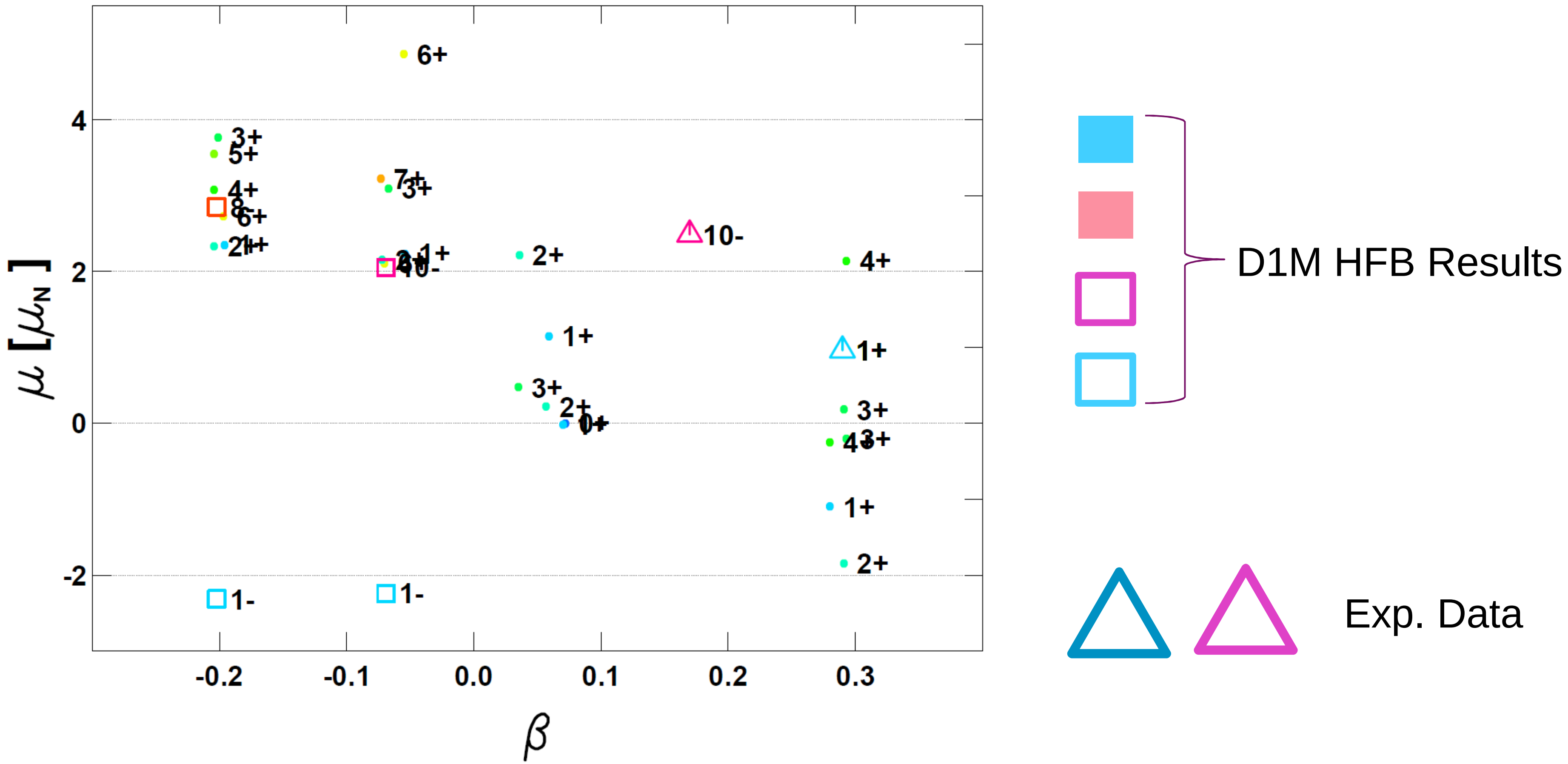


Exp: B.A. Marsh et al, Nature Phys. **14**,1163 (2018)

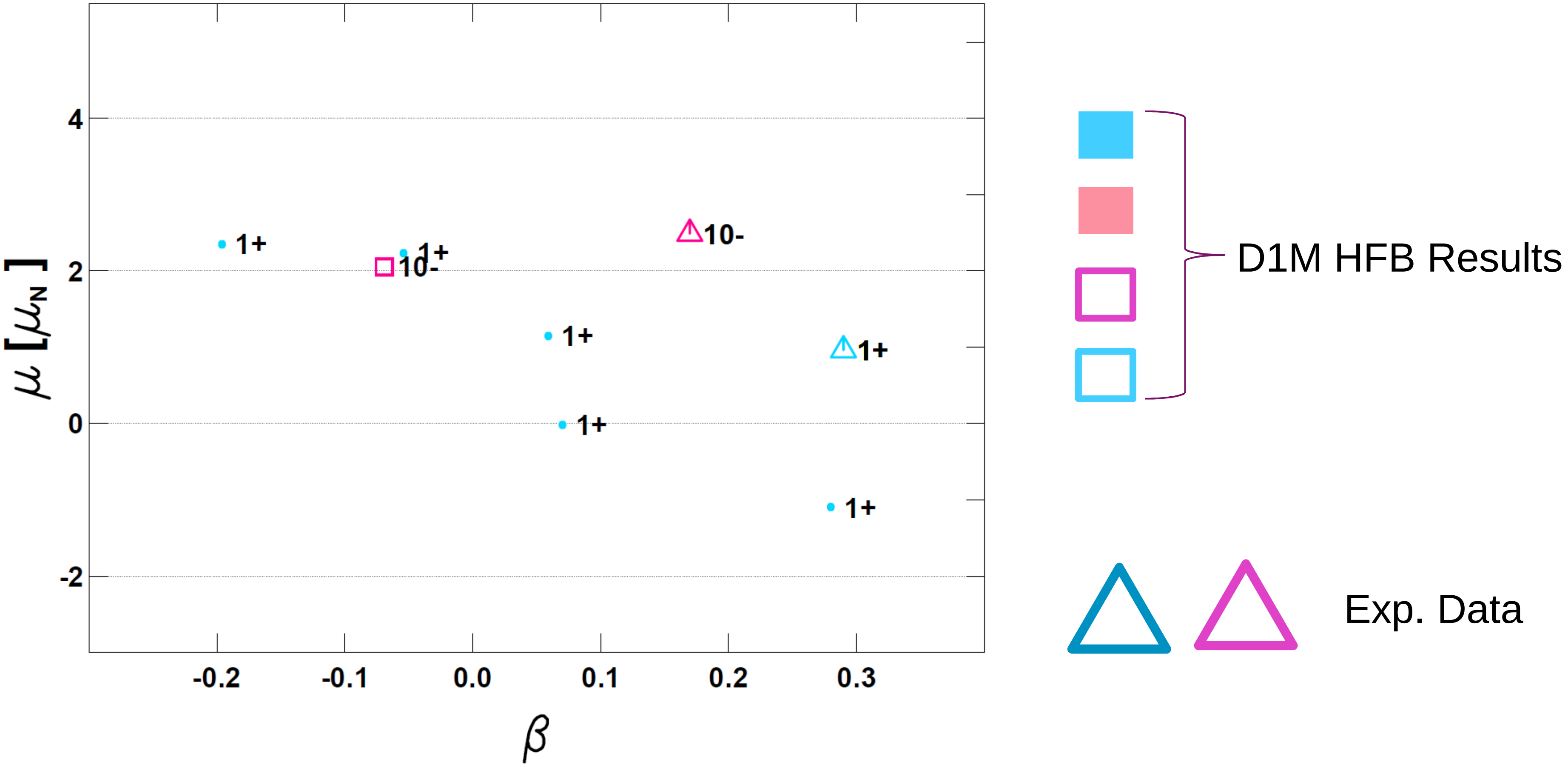
Magnetic moment for ^{188}Bi isotope



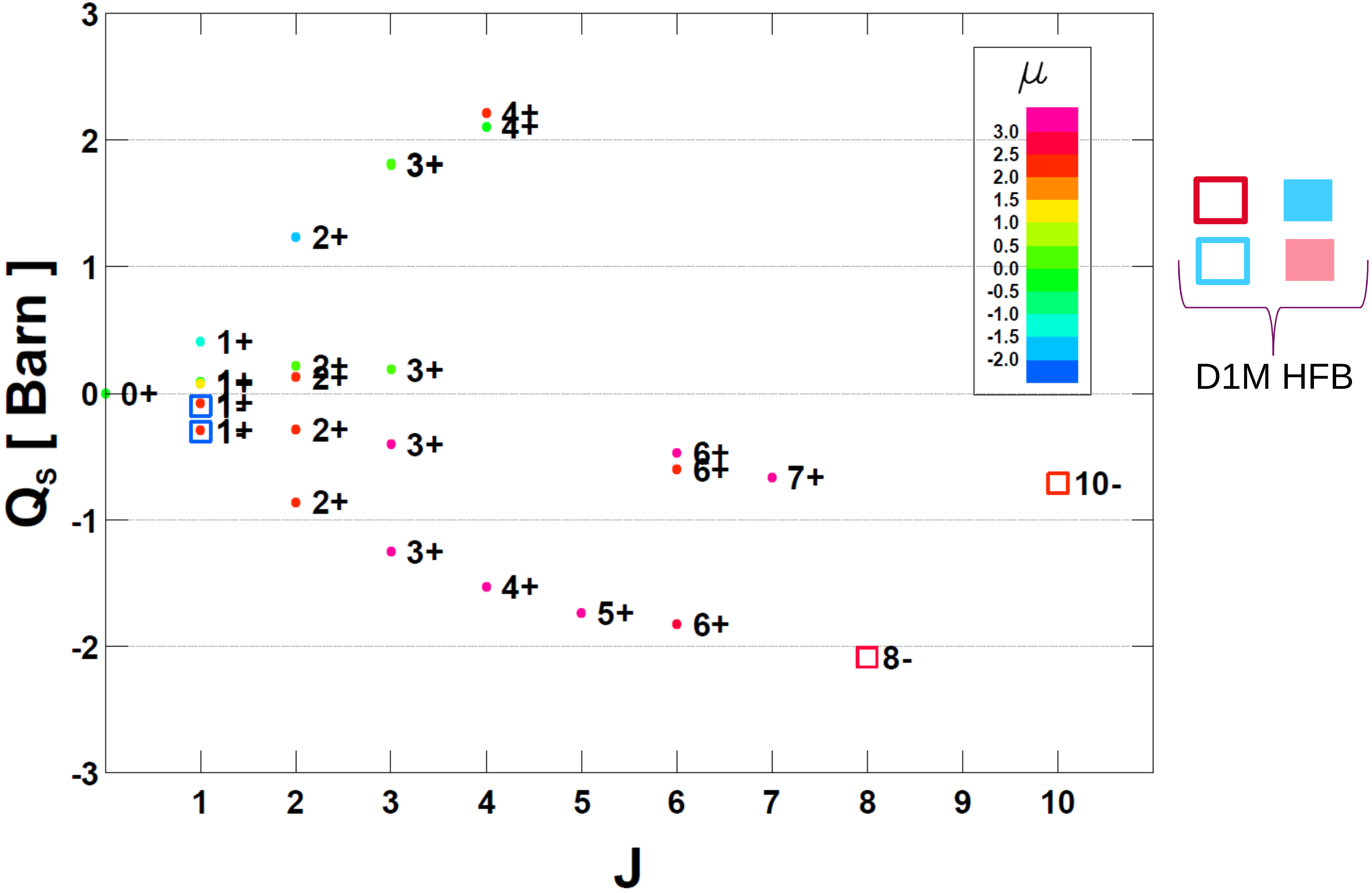
Magnetic moment for ^{188}Bi isotope



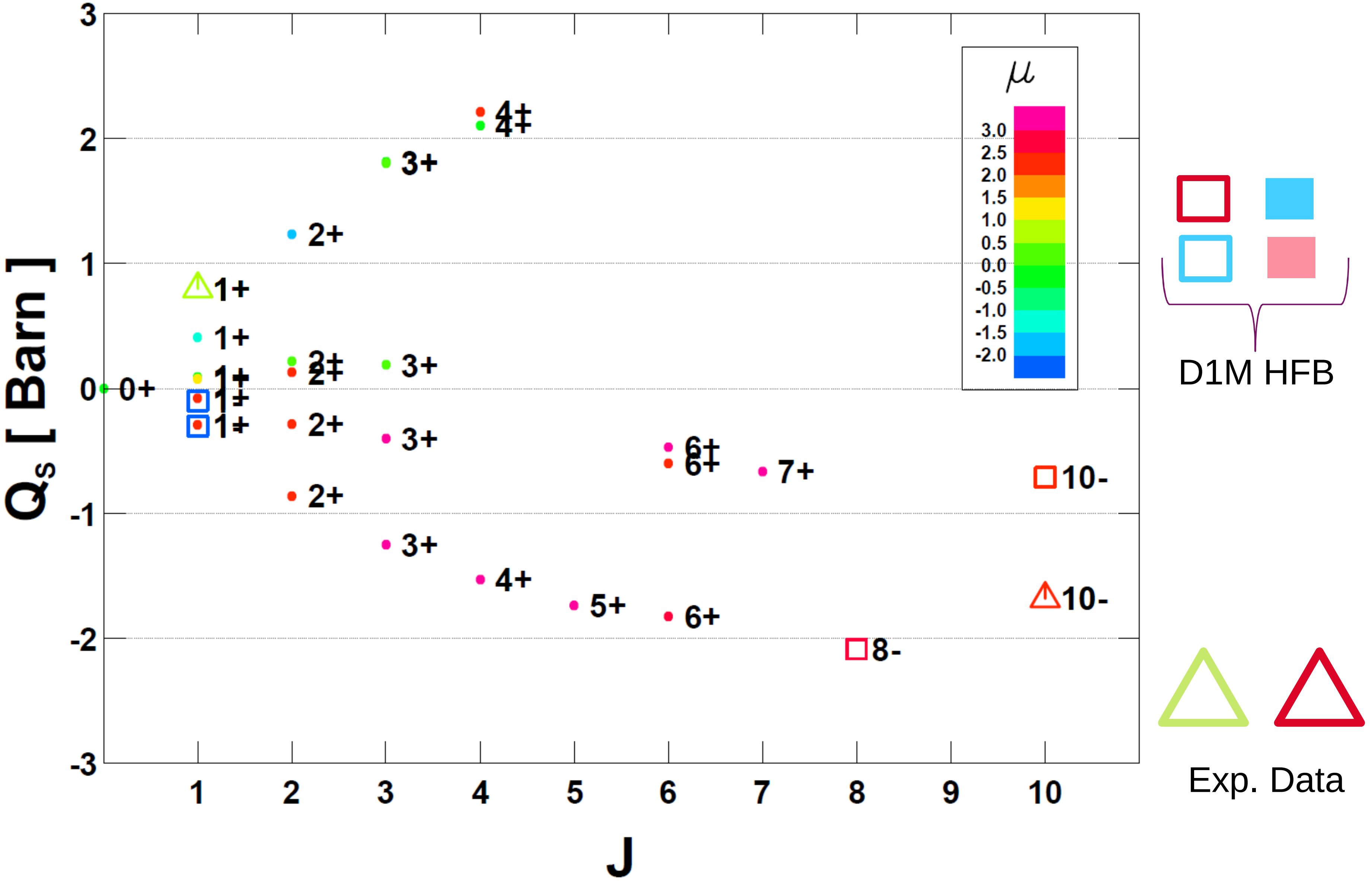
Magnetic moment for ^{188}Bi isotope



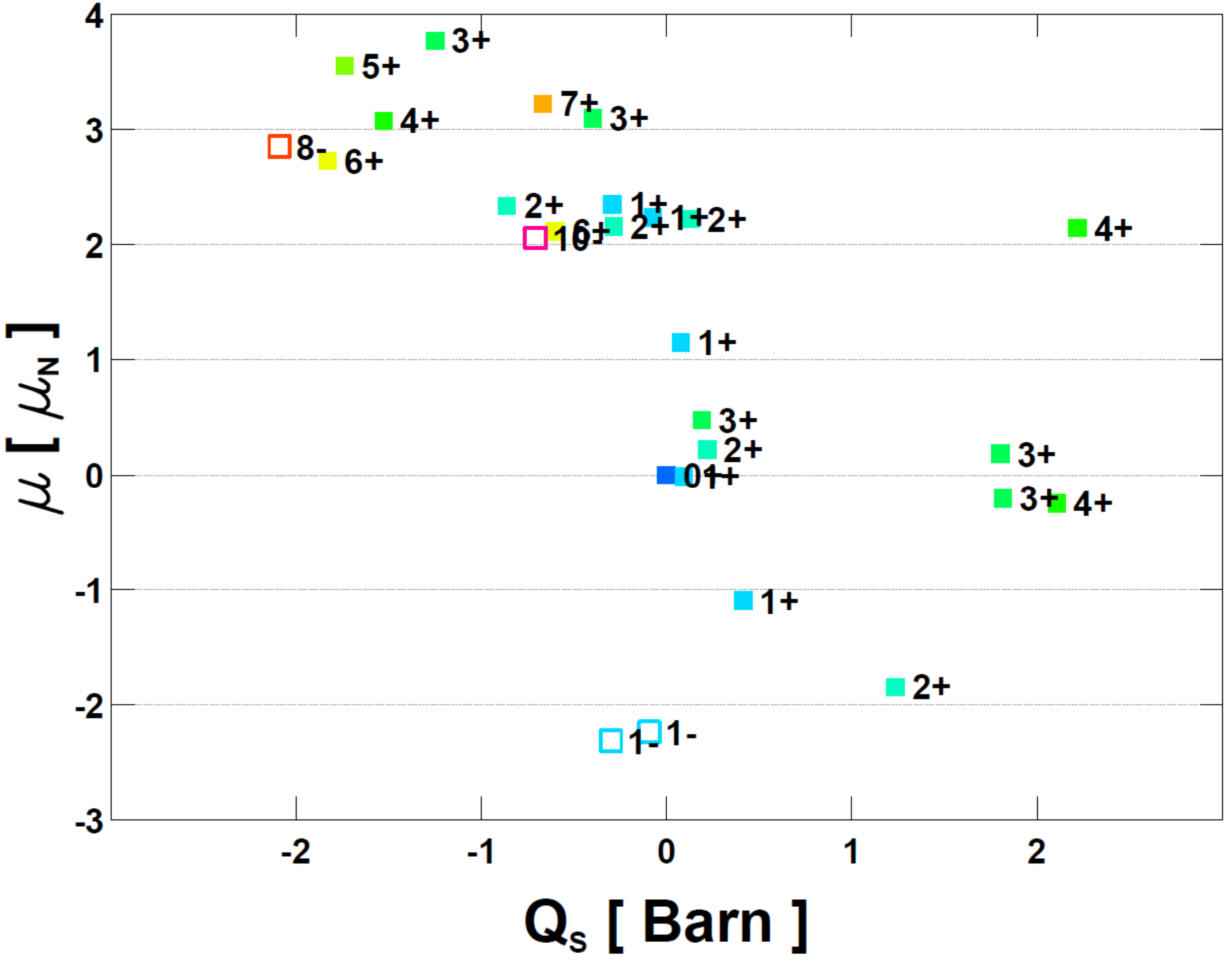
Qs for ^{188}Bi isotope



Qs for ^{188}Bi isotope



Magnetic moment versus Qs for ^{188}Bi isotope



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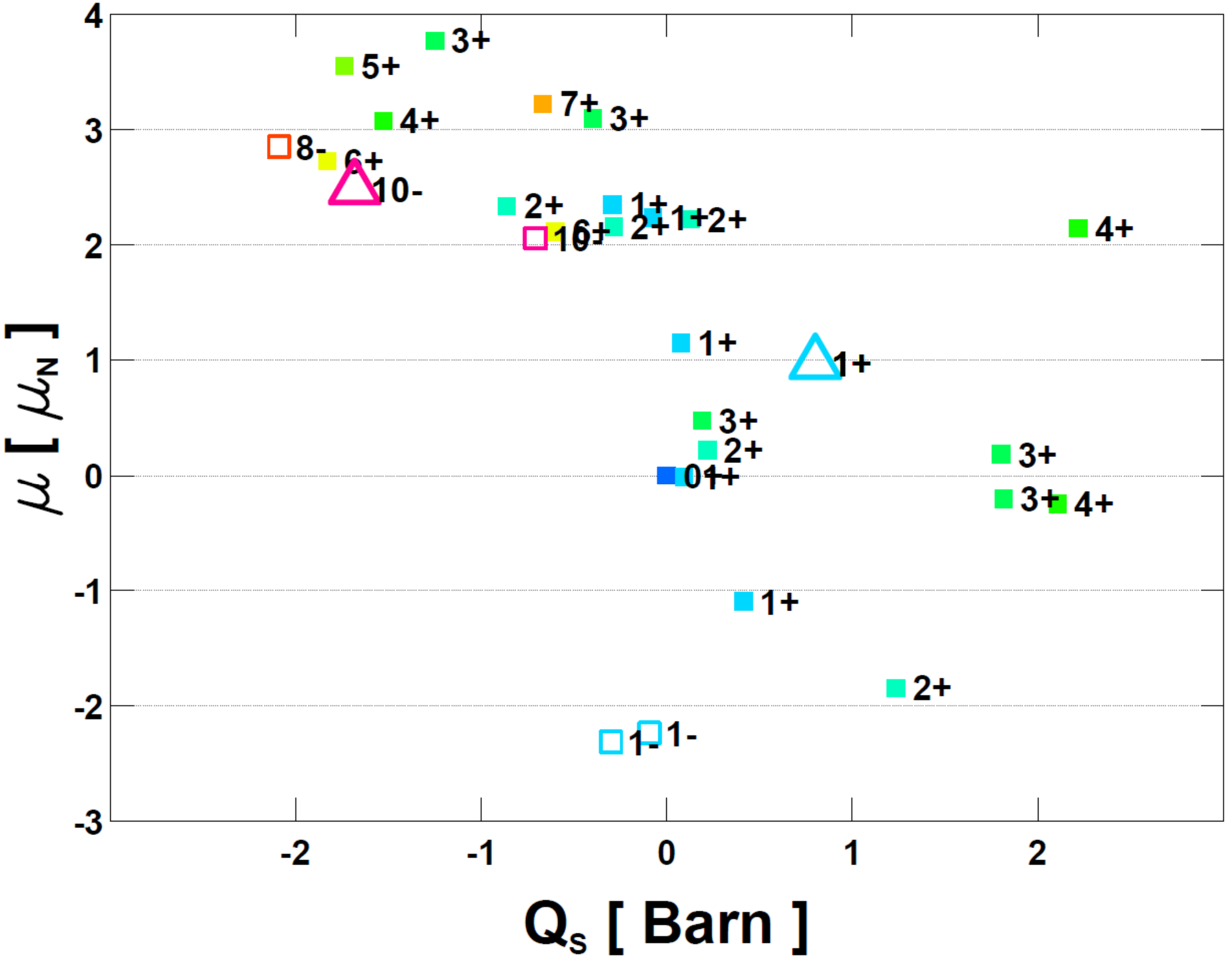
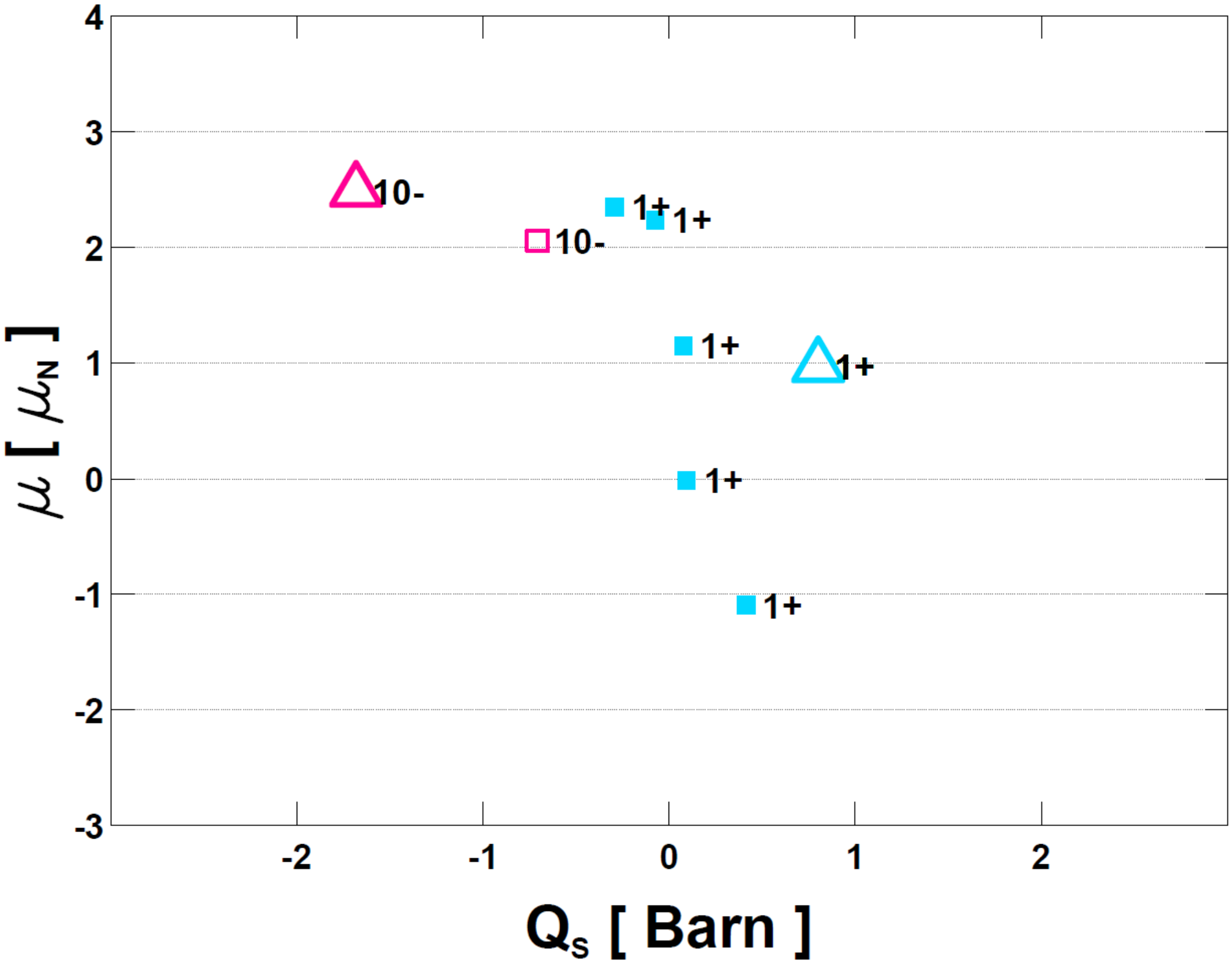


Magnetic moment versus Qs for ^{188}Bi isotope



Ground state and isomer properties within HFB framework

- Magnetic moments and Qs for odd nuclei : Hg isotopes
- Magnetic moments and Qs for 188Bi

QRPA approach

- Generalities
- Unusual application : K isomer in N=100 isotones
- Some perspectives

Charge exchange QRPA

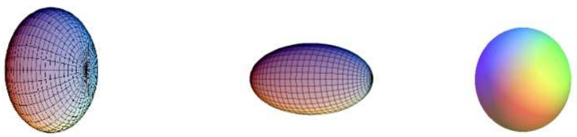
What is the standard QRPA approach ?

The QRPA methods describe nuclear excited states for all multipoles and both parities whatever the intrinsic deformation of the ground state.

Quadrupole, octupole and higher multipolarities can be obtained even on top of spherical HFB calculations. But standard QRPA approaches don't describe rotational motion.

What can we do in CEA/DIF?

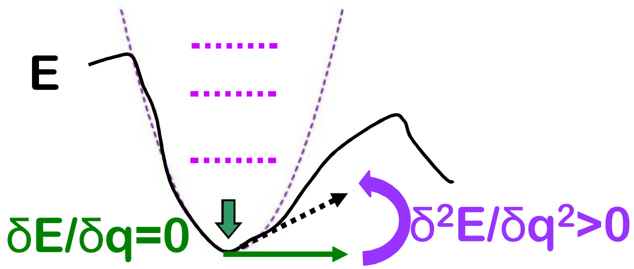
ISAAC describes excited states, transition probabilities for intrinsic deformed nuclei with axial symmetry.



Intrinsic or static deformation

Main approximation:

Linear response, i.e. harmonic potential approximation



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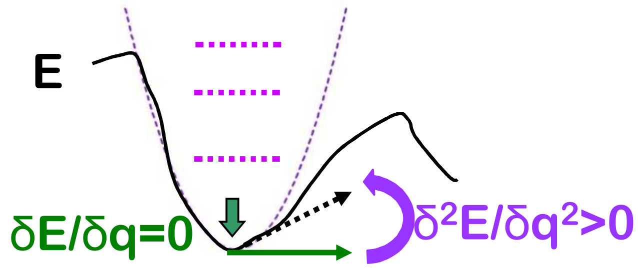
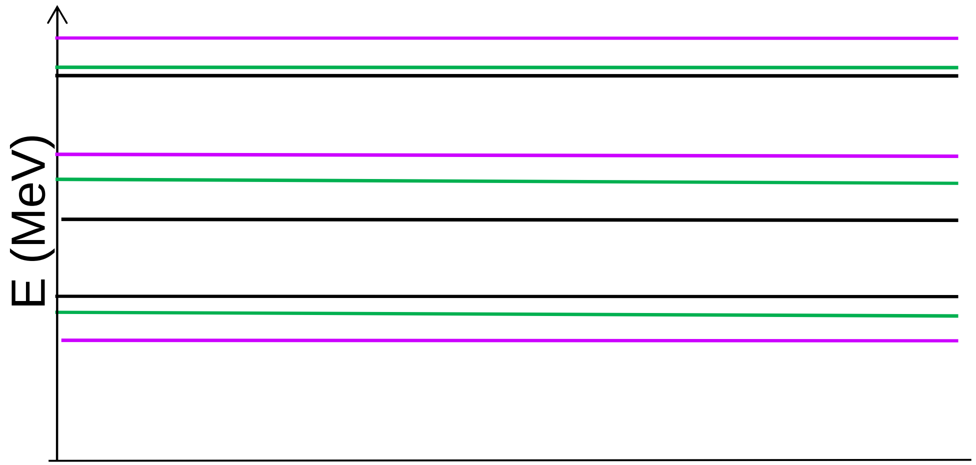


The present QRPA **approach (ISAAC code) using matrix representation allows to provide excited state wave functions, excitation energies and transitions (probabilities and densities) from the GS for deformed nuclei with axial symmetry.**



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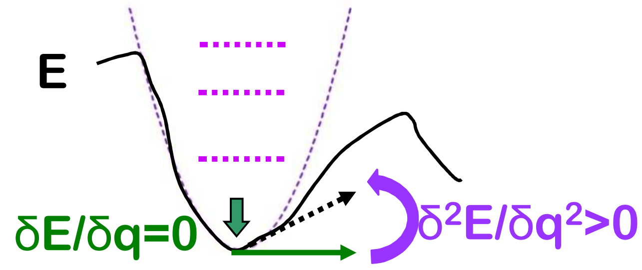

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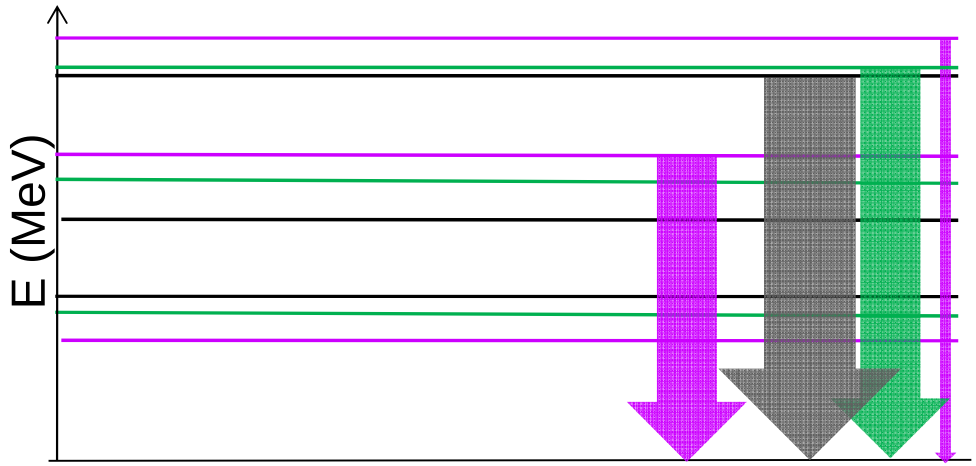

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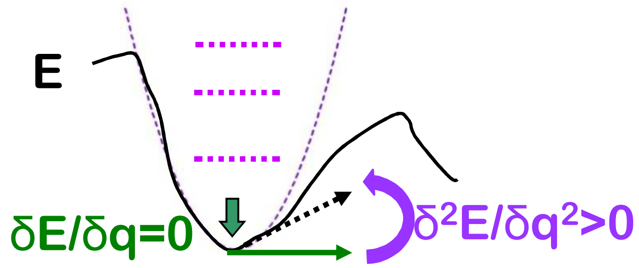

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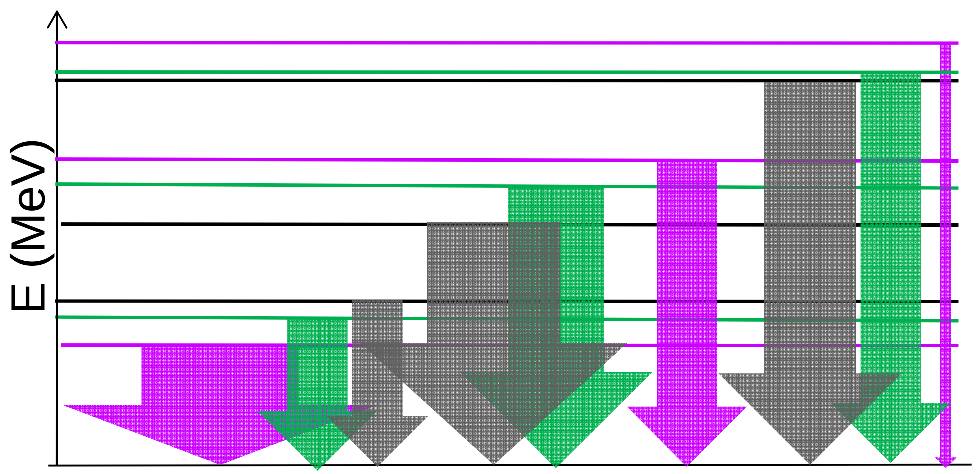

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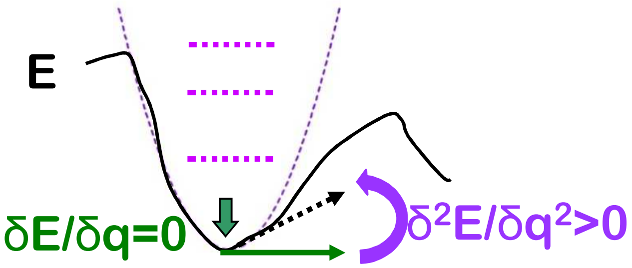

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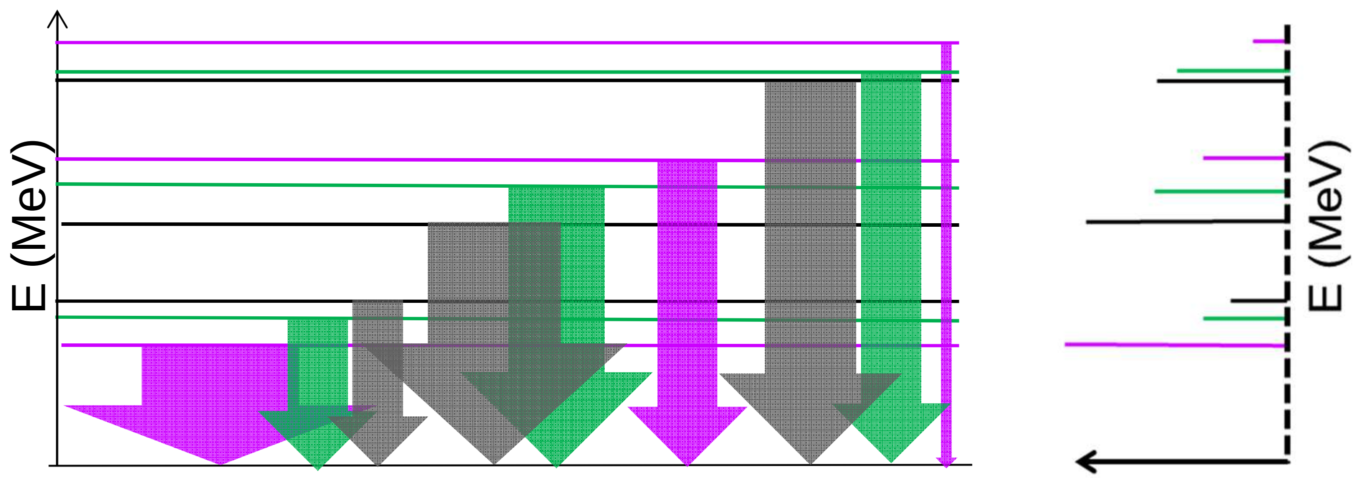

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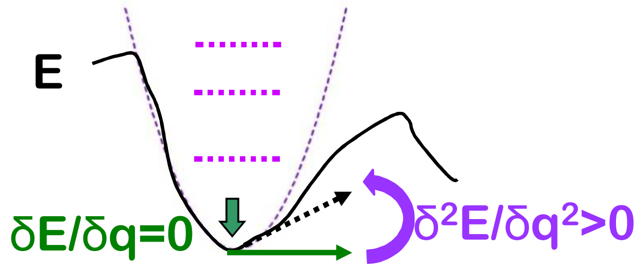

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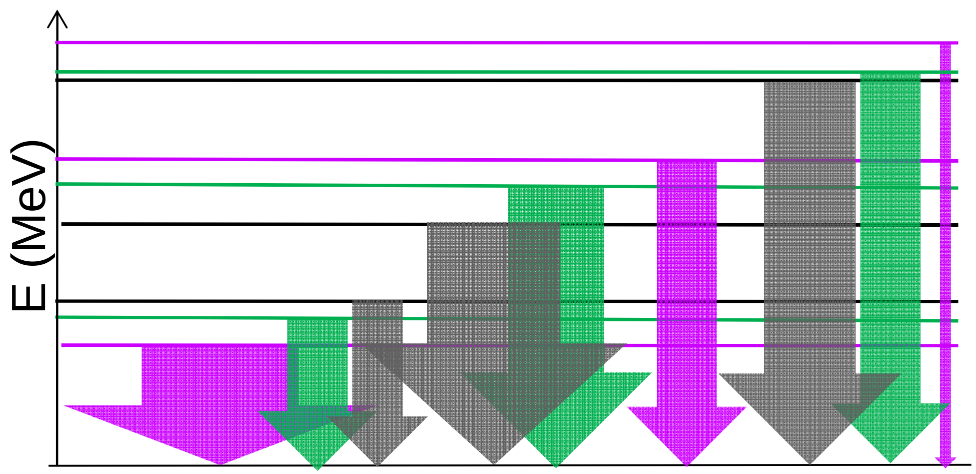

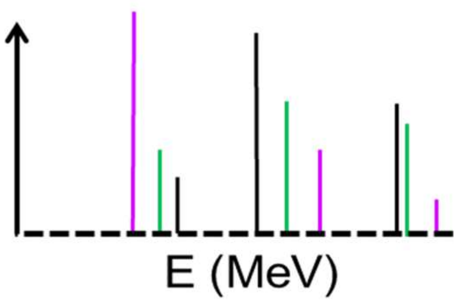

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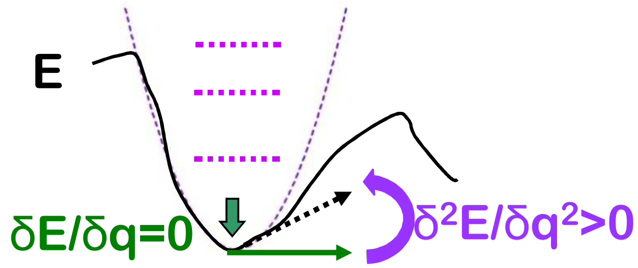

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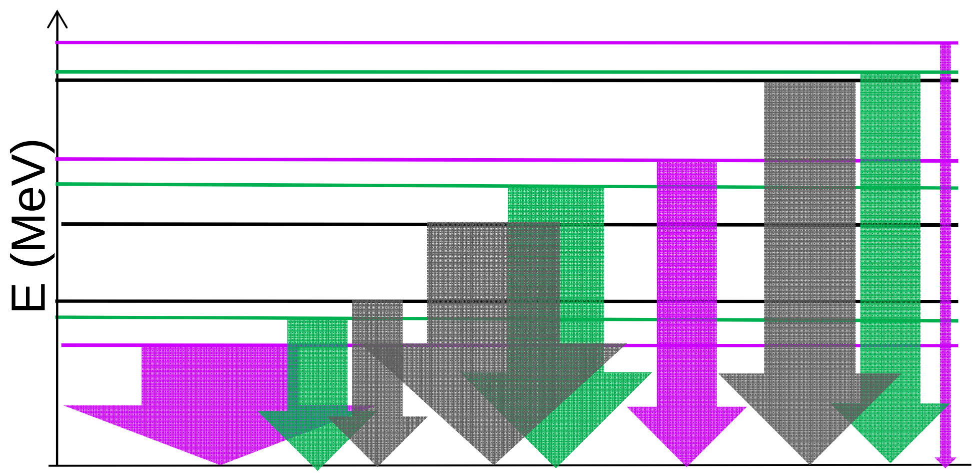
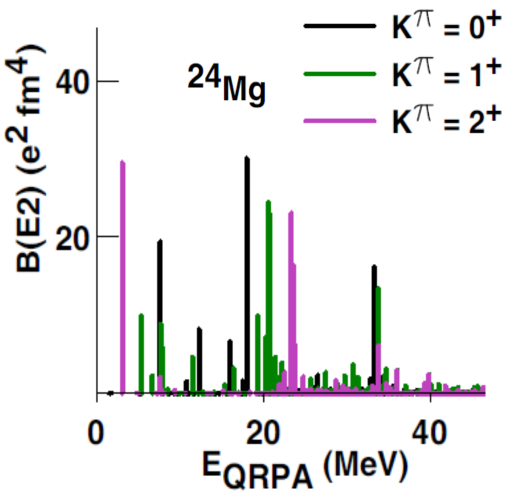
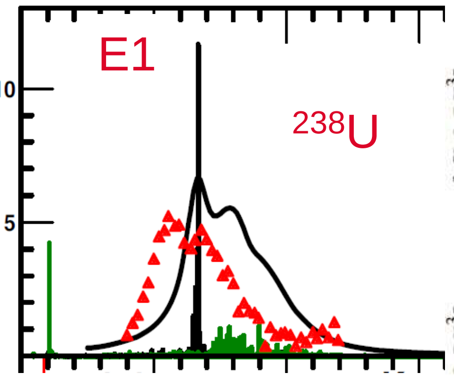
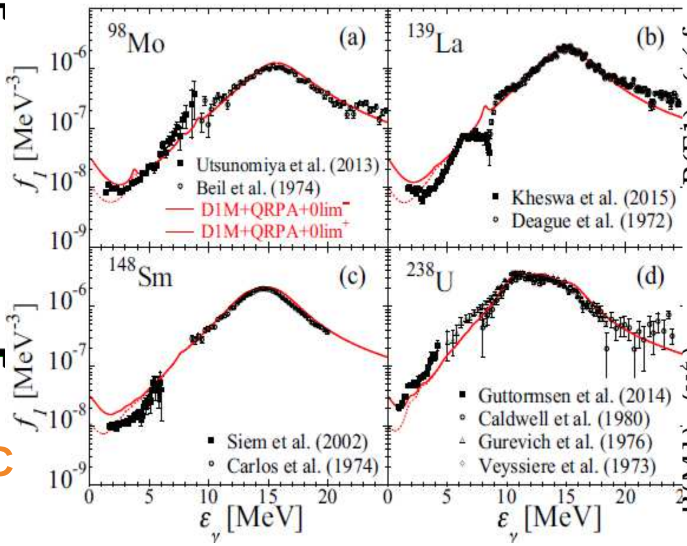




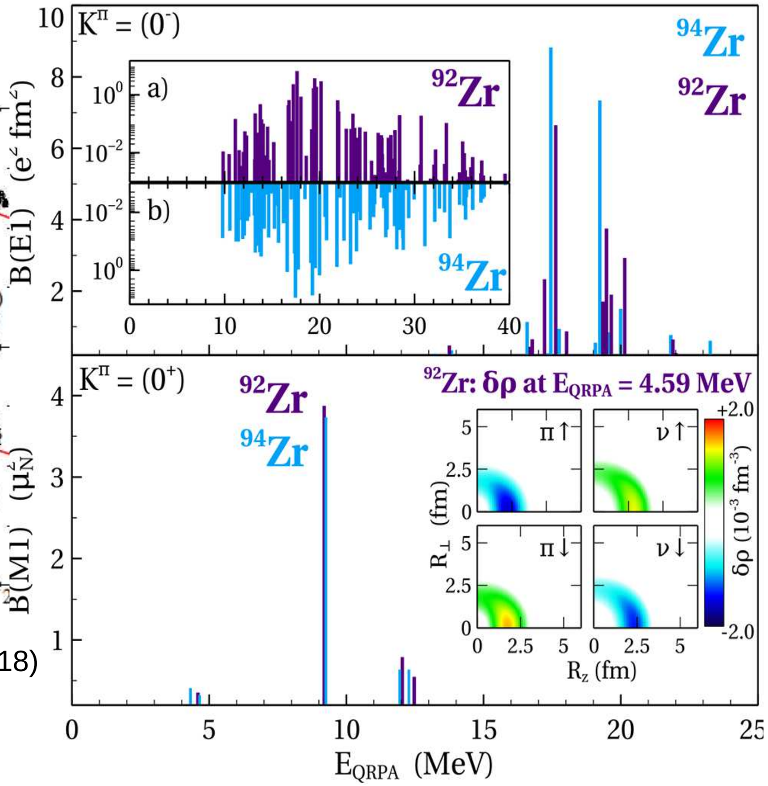
Usual application: Giant and pygmy resonances, γ strength functions

S. Péru et al, PRC 83, 014314 (2011)



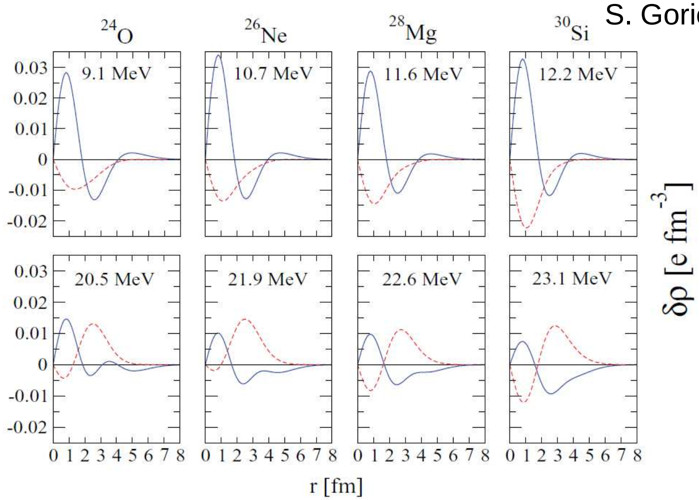


S. Goriely et al, PRC98,014327 (2018)

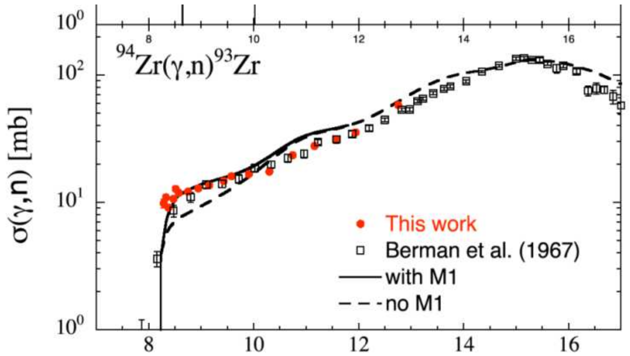


I.Deloncle et al,EPJA 53 : 170 (2017)

Some results of ISAAC with D1M or D1S



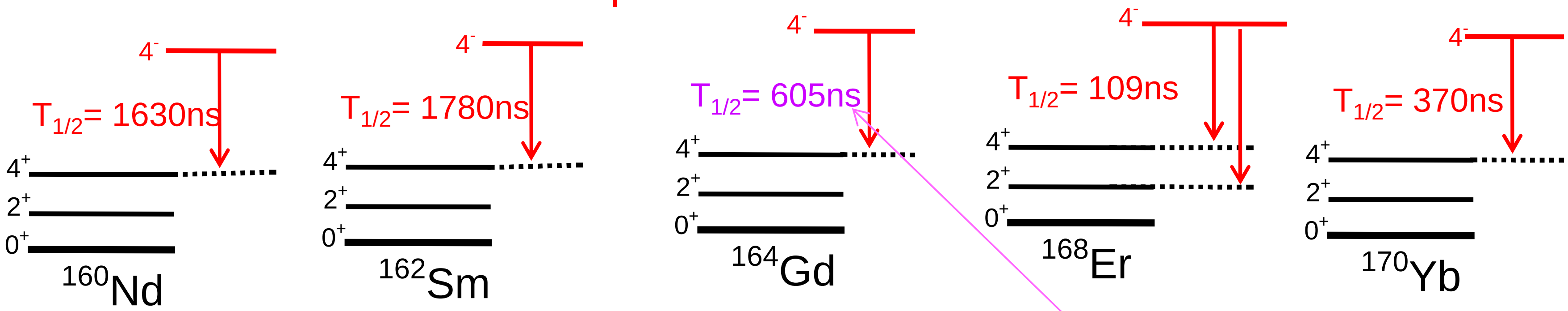
M. Martini et al, PRC 83, 034309 (2011)



H.Utsunomia et al, PRL 100, 162502 (2008)

Unusual application: 4^- isomers in N=100 isotones

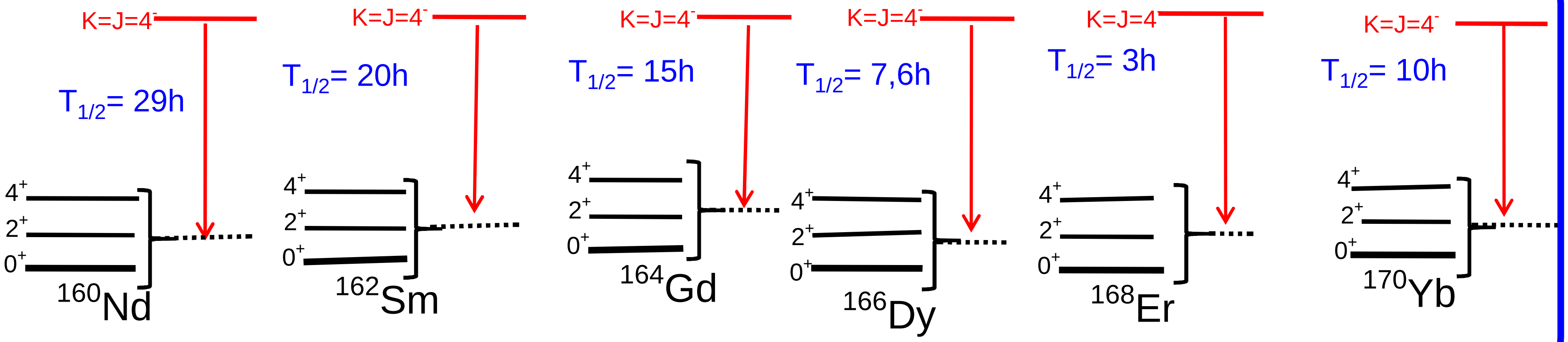
Experimental half-lives



The $4^- \rightarrow 4^+$ transition is expected to be E1

Laurent Gaudefroy, CEA,DAM,DIF
Spontaneous fission of ^{252}Cf

HFB+QRPA in axial symmetry with D1M Gogny force for $K^\pi = 4^-$



Only M4 and E5 transitions are allowed ← $\lambda \geq K=4$

➔Decay of these isomers?

Example : ^{162}Sm

$T_{1/2}$= 1780ns

$K^{\pi}=0^{-}$

B(E1)
B(M2)

$T_{1/2} \approx$ 0,5 ps

K=1

B(E1)
B(M2)

$T_{1/2} \approx$ 300 ps

K=2

B(E3)
B(M2)

$T_{1/2} \approx$ 20 ns

K=3

B(E3)
B(M4)

$T_{1/2} \approx$ 700 µs

K=4

B(E5)
B(M4)

$T_{1/2} \approx$ 20 h

A very small K=1 component in the wave function would explain the observations.

There are 3 main mechanisms for K admixture :
F. G. Kondev, G.D. Dracoulis and T. Kibedi, ADNDT 103, 50 (2015)

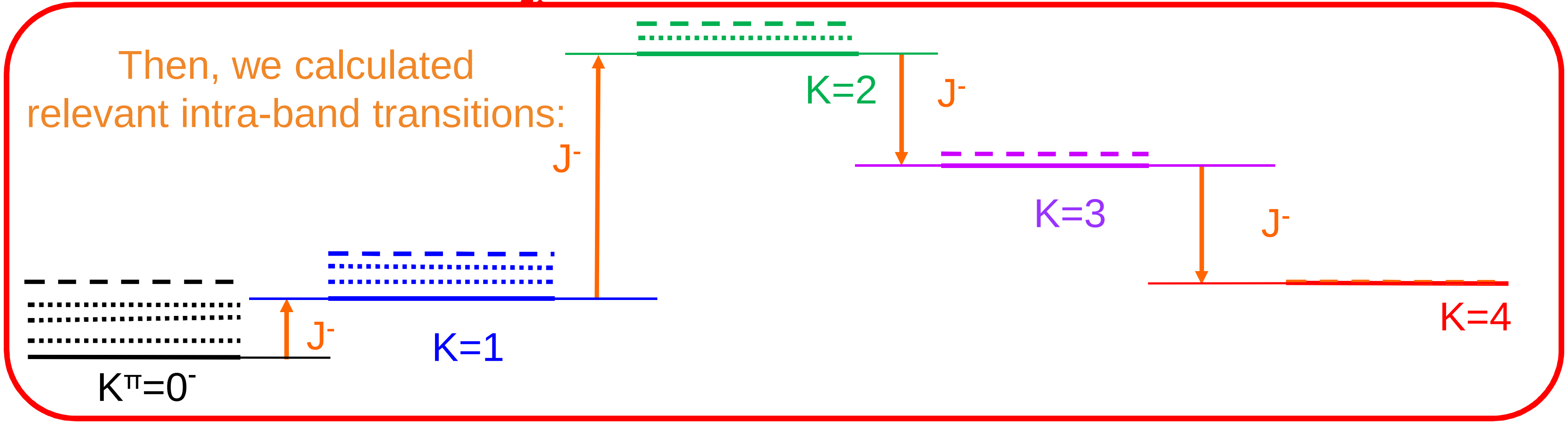
- Important level density
- Triaxial shape
- Mixing with Coriolis interaction

How to fix it?

K-mixing with Coriolis effect and $j\pm$ operators,
i.e. to calculate transitions between QRPA excited states, in order to fill a coupling matrix

$$\langle K \,|\, H_c \,|\, K+1 \rangle = -\frac{\hbar}{2I}\sqrt{(J-K)(J+K+1)}\;\langle K \,|\, j^- \,|\, K+1 \rangle$$

Then, we calculated relevant intra-band transitions:



T ½ ns	^{160}Nd	^{162}Sm	^{164}Gd	^{166}Dy	^{168}Er	^{170}Yb	^{172}Hf
Exp.	1670(210)	1780(70)	605(30)	?	109(7)	370(15)	~1
QRPA	6970	11105	3980	285	365	260	1,5
QRPA/Exp.	4,17	6,24	6,57	?	3,35	0,703	1,5

mixing	^{160}Nd	^{162}Sm	^{164}Gd	^{166}Dy	^{168}Er	^{170}Yb	^{172}Hf
K=0	0,0000	0,0000	0,0005	0,0000	0,0002	0,0015	0,0026
K=1	0,0001	0,0001	0,0004	0,0022	0,0021	0,0011	0,0509
K=2	0,0171	0,0178	0,0236	0,0048	0,0069	0,0500	0,0086
K=3	0,0005	0,0005	0,0005	0,0324	0,0329	0,0108	0,0017
K=4	0,9998	0,9998	0,9997	0,9995	0,9994	0,9987	0,9987

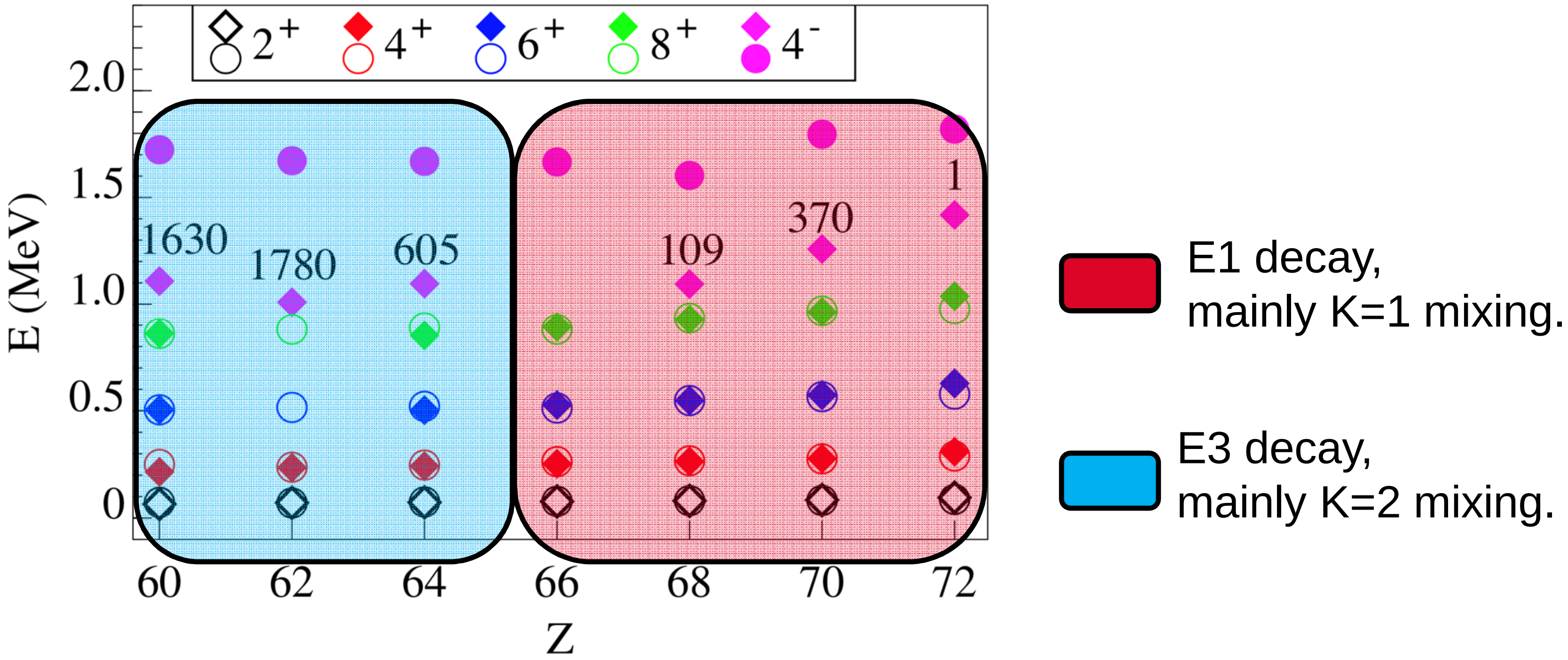
Main mode of decay	^{160}Nd	^{162}Sm	^{164}Gd	^{166}Dy	^{168}Er	^{170}Yb	^{172}Hf
	E3	E3	E3, E1	E1	E1	E1, E3	E1

Conclusion on J=4$^-$ isomers in N=100 isotones

✓ J=4$^-$, mainly K=4 observed in ^{164}Gd.

✓ Systematic occurrence in even-Z N=100.

✓ Lifetime evolution explained.



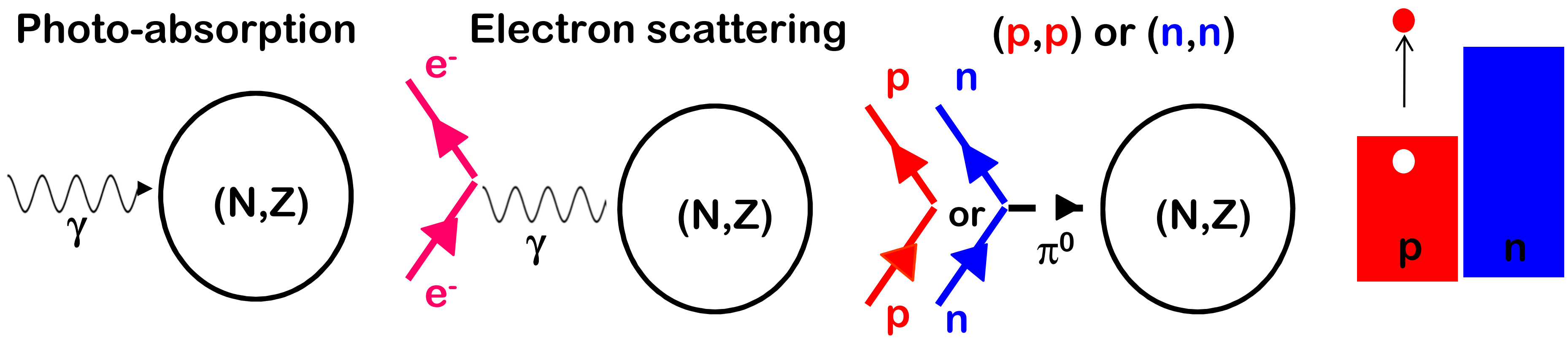
✓ Theoretical dev^t applicable to intra-band decay.

- Ground state and isomer properties within HFB framework
  - Magnetic moments and Qs for odd nuclei : Hg isotopes
  - Magnetic moments and Qs for 188Bi

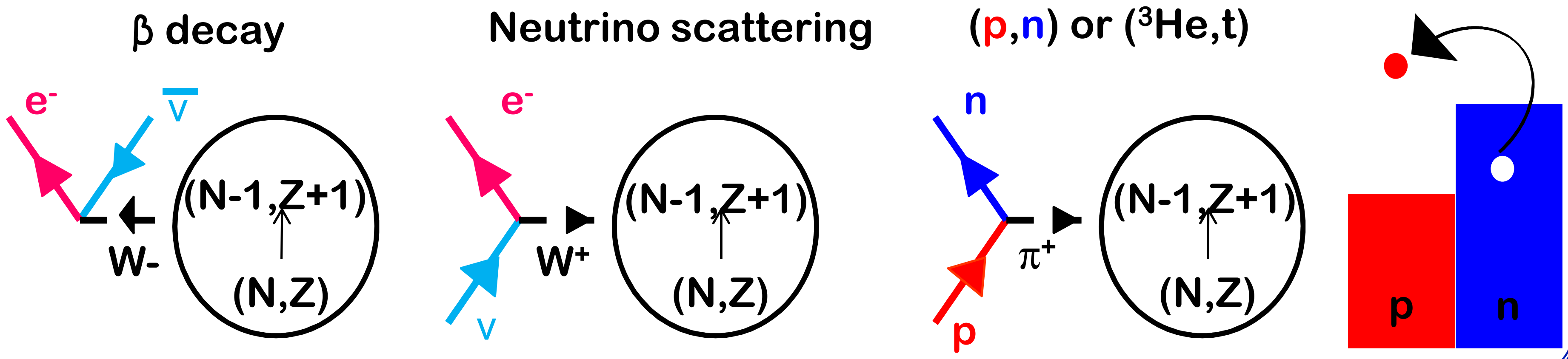
- QRPA approach
  - Generalities
  - Unusual application : K isomer in N=100 isotones
  - Some perspectives

- Charge exchange QRPA

NUCLEAR EXCITATIONS

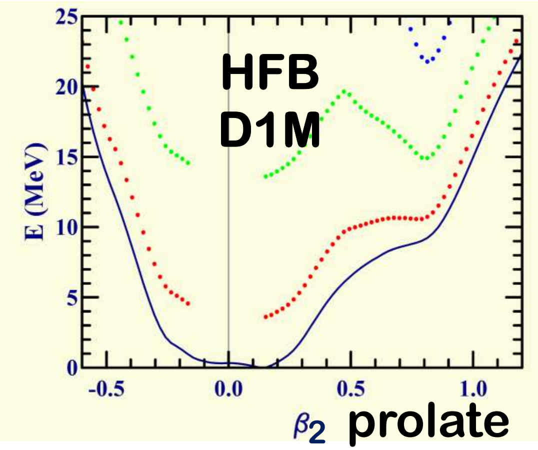


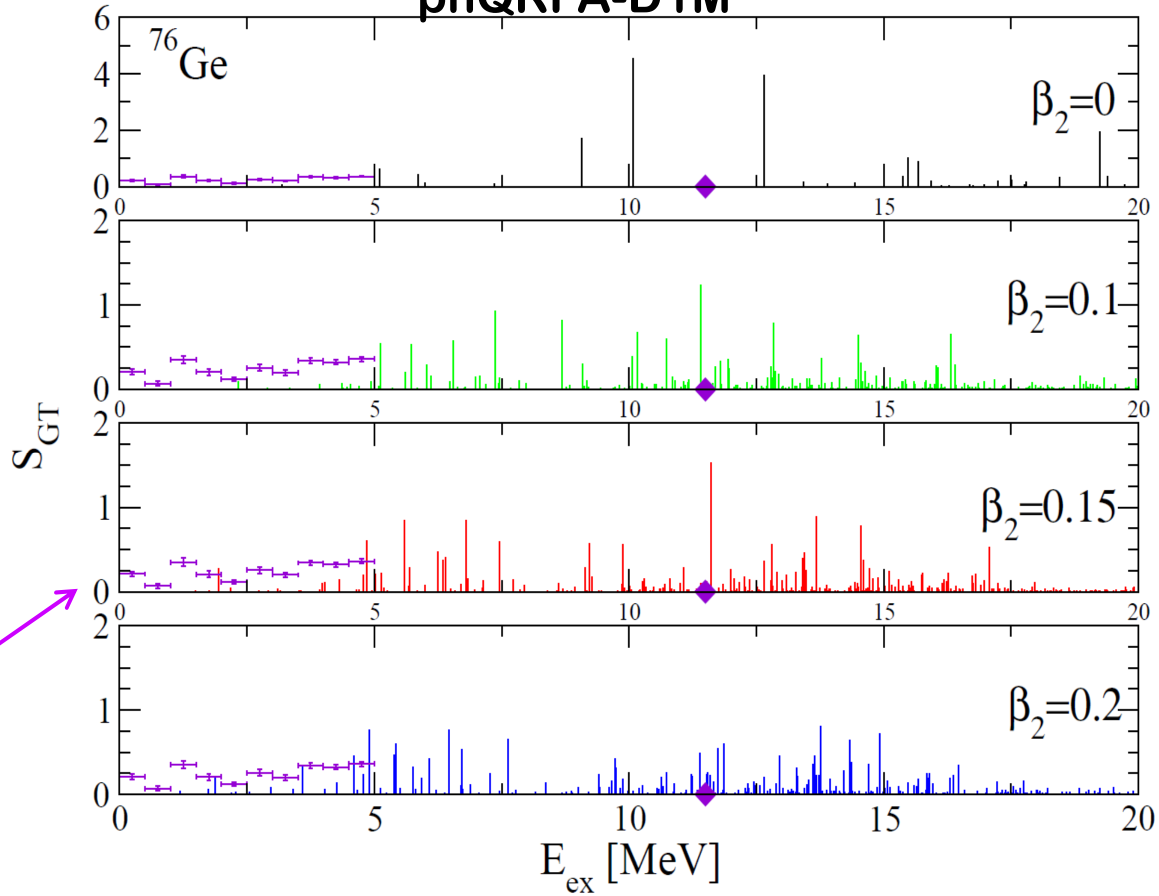
Charge exchange:



Charge exchange QRPA : ^{76}Ge a deformed nucleus

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

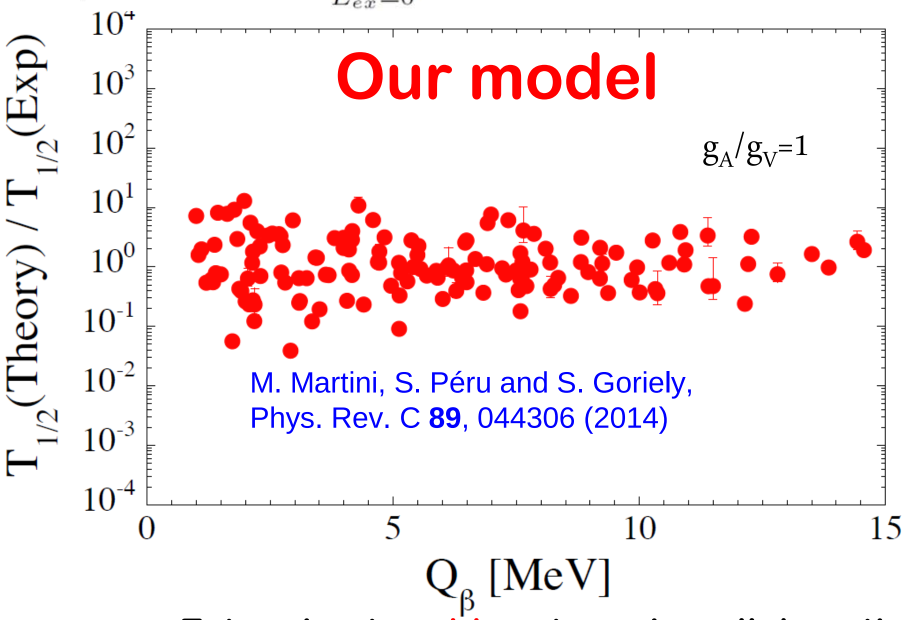
M. Martini, S. Péru and S. Goriely, Phys. Rev. C **89**, 044306 (2014)

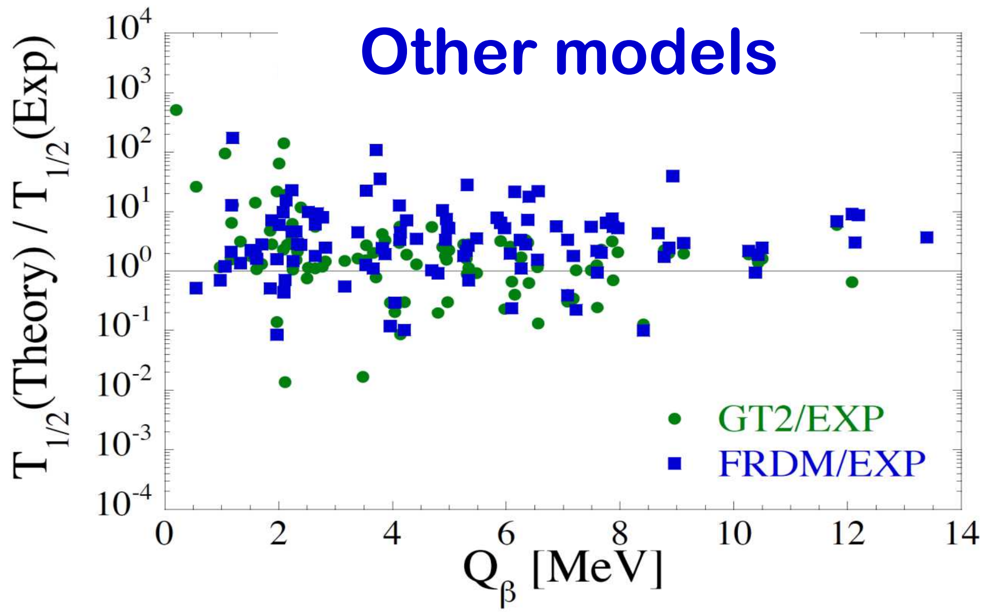
β^- decay half-life $T_{1/2}$: Comparison with other models

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

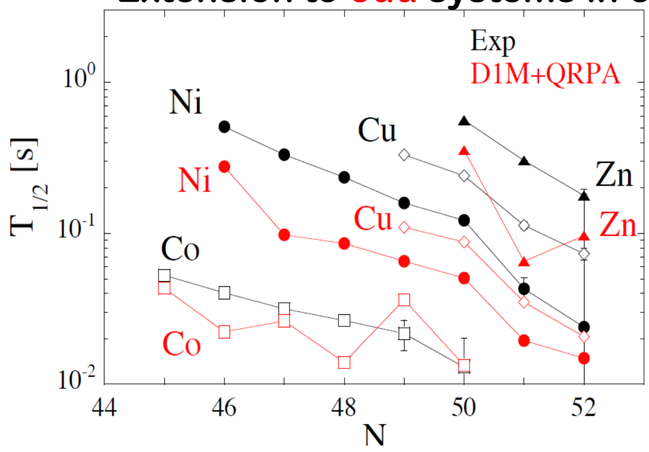
FRDM: Moller et al., ADNDT, 66,131 (1997)

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





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



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

Application to Bi isotopes work in progress

SUMMARY

- Interesting results obtained for magnetic and quadrupole moments in odd and odd-odd nuclei

Odd Hg isotopes
Tentative description of isomeric states in ^{188}Bi isotope

- QRPA approach

Many systematic studies leading to reaction model improvement
K-mixing of QRPA states with Coriolis interaction
Perspectives: Intra-band transition for up-bend

- Charge exchange QRPA

Work in progress for Bi isotopes