Neutrinoless double beta decay studied with configuration mixing methods

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GSI theory

cea

Outline

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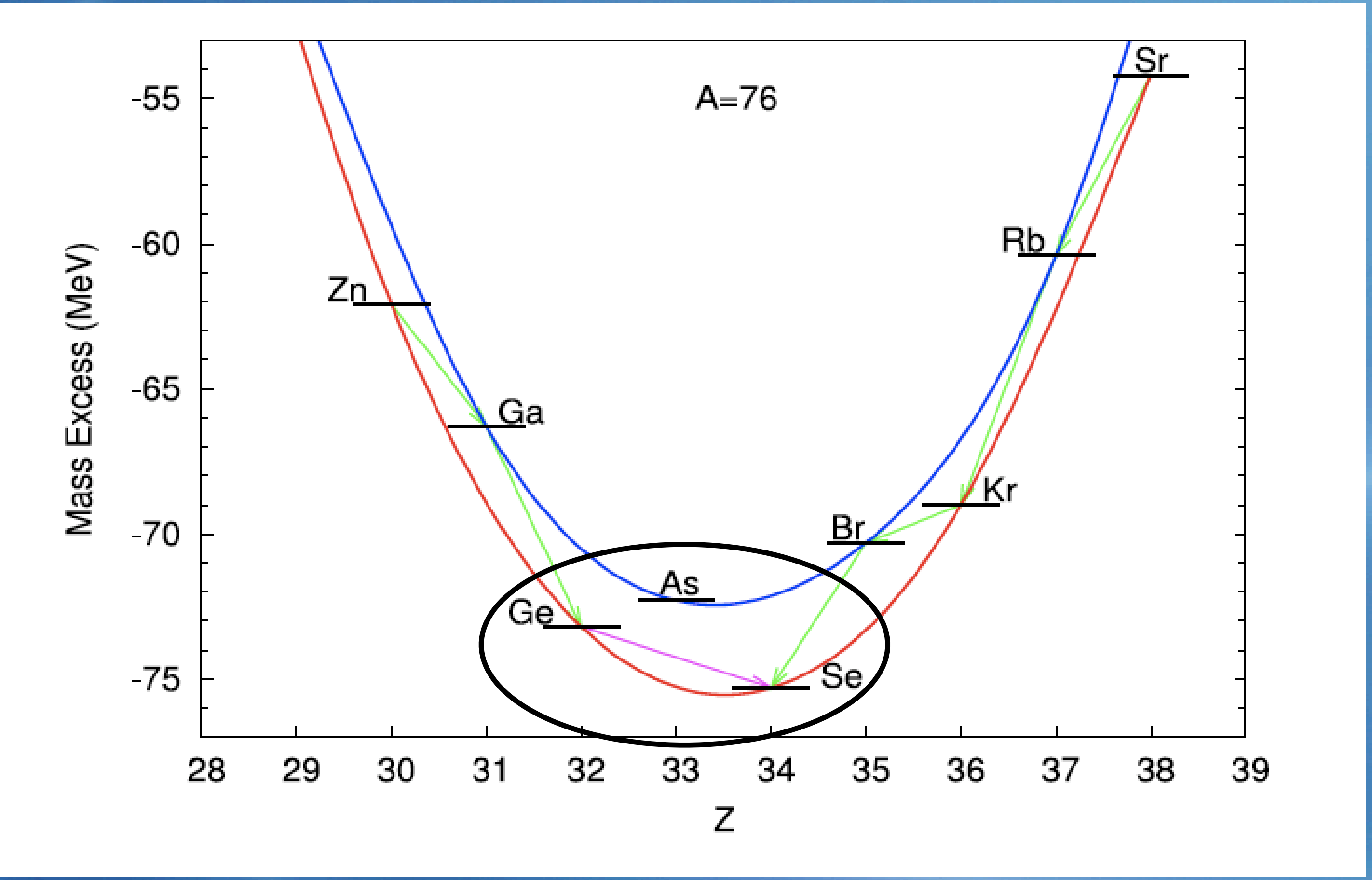
Introduction

Double beta (-) decay: Process mediated by the weak interaction which occurs in those even-even nuclei where the single beta decay is energetically forbidden.



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Introduction

Double beta (-) decay: P ... e v ... h

oc ... eta

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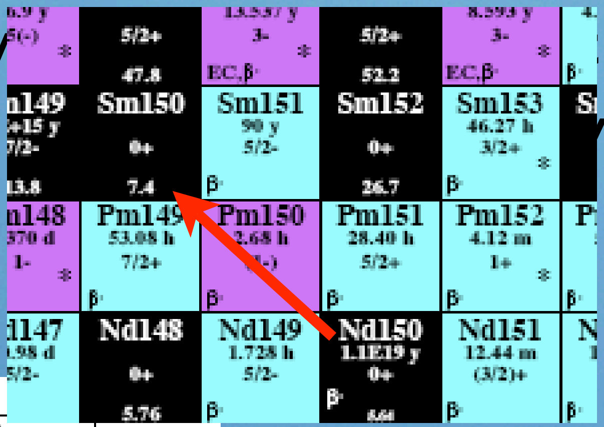

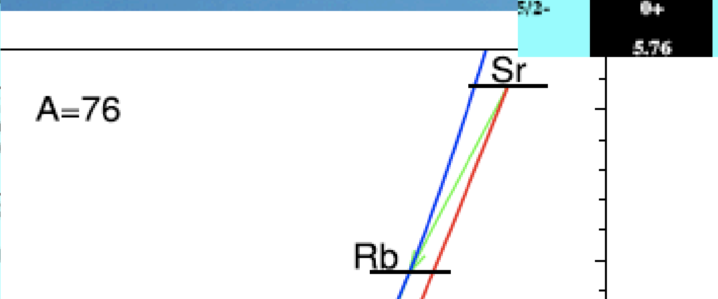

Introduction

Two neutrino double beta decay $2\nu\beta\beta$

$$^{A}_{Z}X_{N} \Rightarrow ^{A}_{Z+2}Y_{N-2} + 2e^{-} + 2\bar{\nu}_{e}$$

- Conserves the leptonic number
- Compatible with massive or massless Dirac/Majorana neutrinos
- Experimentally observed ($T_{1/2}$~10^{19-21} y)
- Within the Standard Model

Neutrinoless double beta decay $0\nu\beta\beta$

$$^{A}_{Z}X_{N} \Rightarrow ^{A}_{Z+2}Y_{N-2} + 2e^{-}$$

- Violates the leptonic number conservation
- Neutrinos are massive Majorana particles
- Except one controversial claim (Klapdor-Kleingrothaus et al. PLB 586, 198, 2004) has not been experimentally observed ($T_{1/2}$ ~10^{25} y)
- Beyond the Standard Model

Introduction

Relevance of neutrinoless double beta decay

• Neutrino oscillation observations (solar, atmospheric and reactors) establish that the neutrinos have a finite mass ⟶ NEW PHYSICS BEYOND THE SM.

• From neutrino oscillation the absolute mass scale cannot be measured (only differences and mixing angles)

• Neutrinoless double beta decay rates depend directly on the effective neutrino mass so there are several experiments running or projected devoted to search for this process

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Table 1

Limits on neutrino-less double β^- decays. $Q_{\beta\beta}$: Q value for the $0^+ \rightarrow 0^+$ ground state transition. $G^{0\nu}$: kinematical factor (phase space volume) in units of 10^{-14} y^{-1}, $T^{0\nu}_{1/2}$: half-life limits in units of 10^{24} y and $\langle m_\nu \rangle$: limit on the effective ν mass in units of eV.

Isotope	$Q_{\beta\beta}$ (MeV)	$G^{0\nu}$	$T^{0\nu}_{1/2}$ (10^{24})	$\langle m_\nu \rangle$ (eV)	Future experiments
^{48}Ca	4.276	4.46	>0.014	<7.2–45	CANDLES
^{76}Ge	2.039	0.44	>19(22)	<0.35(0.32)	GERDA
^{76}Ge	2.039	0.44	>16	<0.33–1.35	MAJORANA
^{82}Se	2.992	1.89	>0.36	<0.9–1.6	S-NEMO MOON
^{100}Mo	3.034	3.17	>1.1	<0.45–0.93	MOON $CaMoO_4$
^{116}Cd	2.804	3.24	>0.17	<1.7	COBRA $CdWO_4$
^{130}Te	2.529	2.86	>3	<0.46	CUORE
^{136}Xe	2.467	3.03	>0.44	<1.8–5.2	EXO KamLAND BOREXINO
^{150}Nd	3.368	13.4	>0.018	<1.7–2.4	S-NEMO SNO+ DCBA

Introduction

Half-life neutrinoless double beta decay (Doi et al (1985))

$$\left(T_{1/2}^{0\nu\beta\beta}(0^+\rightarrow 0^+)\right)^{-1} = G_{01}\left|M^{0\nu\beta\beta}\right|^2\left(\frac{\langle m_\nu\rangle}{m_e}\right)^2$$

light-neutrino exchange mechanism

- Kinematic phase space factor:

$$G_{01} = \frac{(Gg_A(0))^4 m_e^4}{64\pi^5 \ln 2}\int F_0(Z,\varepsilon_1)F_0(Z,\varepsilon_2) \times p_1 p_2 \delta(\varepsilon_1+\varepsilon_2-E_f-E_i)d\varepsilon_1 d\varepsilon_2 d(\hat{\vec{p}}_1\cdot\hat{\vec{p}}_1)$$

- Effective neutrino mass:

$$\langle m_\nu\rangle = \sum_j U_{ej}^2 m_j$$

- Nuclear Matrix Element (NME):

$$M^{0\nu\beta\beta} = -\left(\frac{g_V(0)}{g_A(0)}\right)^2 M_F^{0\nu\beta\beta} + M_{GT}^{0\nu\beta\beta} - M_T^{0\nu\beta\beta}$$

$M_F^{0\nu\beta\beta}$ → Fermi; $M_{GT}^{0\nu\beta\beta}$ → Gamow-Teller; $M_T^{0\nu\beta\beta}$ → Tensor

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Introduction

Nuclear Matrix Elements

$$M^{0\nu\beta\beta} = -\left(\frac{g_V(0)}{g_A(0)}\right)^2 M_F^{0\nu\beta\beta} + M_{GT}^{0\nu\beta\beta} - M_T^{0\nu\beta\beta}$$

- Each term can be written as the expectation value of a transition operator acting on the ground states of the mother and granddaughter nuclei:

$$M_\xi^{0\nu\beta\beta} = \langle 0_f^+|\hat{O}_\xi^{0\nu\beta\beta}|0_i^+\rangle$$

- Nuclear structure methods for calculating these NME:
  - Quasiparticle Random Phase Approximation in different versions: QRPA, RQRPA, SRQRPA. (Tübingen group, Jyüvaskylä group)
  - Interacting Shell Model -ISM- (Strasbourg-Madrid collaboration)
  - Interacting Boson Model -IBM- (Yale group)
  - Projected Hartree-Fock-Bogoliubov -PHFB- (Lucknow-UNAM group)

Introduction

Nuclear Matrix Elements

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Different ways to deal with:
- Finding the best initial and final ground states.
- Handling the transition operator (inclusion of most relevant terms, corrections, approximations, etc.).

Some remarks about these methods:
- Calculations with limited single particle bases.
- Interactions fitted to the specific region (ISM) or to each nucleus individually (rest).
- Difficulties to include collective degrees of freedom.
- Problems with particle number conservation.

Introduction

Nuclear Matrix Elements

$$M^{0\nu\beta\beta}=-\left(\frac{g_V(0)}{g_A(0)}\right)^2 M_F^{0\nu\beta\beta}+M_{GT}^{0\nu\beta\beta}-M_T^{0\nu\beta\beta}$$

- Neglect the tensor term.
- Closure approximation (10% error at most)

$$M_F^{0\nu\beta\beta} = \left(\frac{g_A(0)}{g_V(0)}\right)^2 \langle 0_f^+|\hat{V}_F(1,2)\hat{\tau}_-^{(1)}\hat{\tau}_-^{(2)}|0_i^+\rangle$$

$$M_{GT}^{0\nu\beta\beta} = \langle 0_f^+|\hat{V}_{GT}(1,2)\hat{\tau}_-^{(1)}\hat{\tau}_-^{(2)}|0_i^+\rangle$$

$$\langle\vec{r}_1\vec{r}_2|\hat{V}_F(1,2)|\vec{r}\,'_1\vec{r}\,'_2\rangle = v_F(|\vec{r}_1-\vec{r}_2|)\delta(\vec{r}_1-\vec{r}\,'_1)\delta(\vec{r}_2-\vec{r}\,'_2)$$

$$\langle\vec{r}_1\vec{r}_2|\hat{V}_{GT}(1,2)|\vec{r}\,'_1\vec{r}\,'_2\rangle = v_{GT}(|\vec{r}_1-\vec{r}_2|)\delta(\vec{r}_1-\vec{r}\,'_1)\delta(\vec{r}_2-\vec{r}\,'_2)\hat{\vec{\sigma}}^{(1)}\cdot\hat{\vec{\sigma}}^{(2)}$$

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- Neglect the tensor term.
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$$M_F^{0\nu\beta\beta} = \left(\frac{g_A(0)}{g_V(0)}\right)^2 \langle 0_f^+|\hat{V}_F(1,2)\hat{\tau}_-^{(1)}\hat{\tau}_-^{(2)}|0_i^+\rangle$$

$$M_{GT}^{0\nu\beta\beta} = \langle 0_f^+|\hat{V}_{GT}(1,2)\hat{\tau}_-^{(1)}\hat{\tau}_-^{(2)}|0_i^+\rangle$$

$$\langle \vec{r}_1\vec{r}_2|\hat{V}_F(1,2)|\vec{r}\,'_1\vec{r}\,'_2\rangle = v_F(|\vec{r}_1-\vec{r}_2|)\delta(\vec{r}_1-\vec{r}\,'_1)\delta(\vec{r}_2-\vec{r}\,'_2)$$

$$\langle \vec{r}_1\vec{r}_2|\hat{V}_{GT}(1,2)|\vec{r}\,'_1\vec{r}\,'_2\rangle = v_{GT}(|\vec{r}_1-\vec{r}_2|)\delta(\vec{r}_1-\vec{r}\,'_1)\delta(\vec{r}_2-\vec{r}\,'_2)\hat{\vec{\sigma}}^{(1)}\cdot\hat{\vec{\sigma}}^{(2)}$$

Neutrino potentials

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Introduction

Neutrino potentials

Starting from the weak lagrangian that describes the process some approximations are made:

1. Non-relativistic approach in the hadronic part.
2. Closure approximation in the virtual intermediate state
3. Nucleon form factors taken in the dipolar approximation.
4. Tensor contribution is neglected.
5. High order currents are included (HOC).
6. Short range correlations are included with an UCOM correlator.

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Neutrino potentials

Starting from the weak lagrangian that describes the process some approximations are made:

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4. Tensor contribution is neglected.

5. High order currents are included (HOC).

6. Short range correlations are included with an UCOM correlator.

- Find the initial and final 0^+ states within the GCM+PNAMP method (axial calculations)
- Evaluate the transition operators between these states

Method: GCM+PNAMP

See also P.-H. Heenen's talk (Sunday aternoon)

- **Effective nucleon-nucleon interaction (Density Dependent): Gogny force (D1S)** that is able to describe properly many phenomena along the whole nuclear chart.

$$V(1,2) = \sum_{i=1}^{2} e^{-(\vec{r}_1-\vec{r}_2)^2/\mu_i^2}\left(W_i + B_i P^\sigma - H_i P^\tau - M_i P^\sigma P^\tau\right)$$

$$+iW_0(\sigma_1+\sigma_2)\vec{k}\times\delta(\vec{r}_1-\vec{r}_2)\vec{k} + t_3(1+x_0P^\sigma)\delta(\vec{r}_1-\vec{r}_2)\rho^\alpha\left((\vec{r}_1+\vec{r}_2)/2\right)$$

$$+V_{\mathrm{Coulomb}}(\vec{r}_1,\vec{r}_2)$$

- **Method of solving the many-body problem:**

First step: Particle Number Projection (before the variation) of HFB-type wave functions.

Second step: Simultaneous **Particle Number and Angular Momentum Projection** (after the variation).

Third step: Configuration mixing within the framework of the **Generator Coordinate Method (GCM)**.

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Method: GCM+PNAMP

Determination of mother and granddaughter states (I)

Intrinsic state: Solve the PN-VAP equations with the Gogny D1S interaction

$|\Phi\rangle$ HFB states $\longrightarrow$ $\delta\left(E^{N,Z}\left[|\bar{\Phi}(q)\rangle\right]\right)_{|\bar{\Phi}\rangle=|\Phi\rangle}=0$

$$E^{N,Z}[|\Phi\rangle]=\frac{\langle\Phi|\hat{H}\hat{P}^N\hat{P}^Z|\Phi\rangle}{\langle\Phi|\hat{P}^N\hat{P}^Z|\Phi\rangle}+\varepsilon_{DD}^{N,Z}(|\Phi\rangle)-\lambda_q\langle\Phi|\hat{Q}|\Phi\rangle$$

Particle number and angular momentum projected state:

$$|IMK;NZ;q\rangle=\frac{2I+1}{8\pi^2}\int\mathcal{D}^{I*}_{MK}(\Omega)\hat{R}(\Omega)\hat{P}^N\hat{P}^Z|\Phi(q)\rangle d\Omega$$

General form (GCM state):

$$|IM;NZ\sigma\rangle=\sum_{Kq}f^{I;NZ,\sigma}_{Kq}|IMK;NZ;q\rangle$$

Hill-Wheeler-Griffin equation (GCM)

$$\sum_{K'q'}\left(\mathcal{H}^{I;NZ}_{KqK'q'}-E^{I;NZ;\sigma}\mathcal{N}^{I;NZ}_{KqK'q'}\right)f^{I;NZ;\sigma}_{K'q'}=0$$

$$\mathcal{N}^{I;NZ}_{KqK'q'}\equiv\langle IMK;NZ;q|IMK';NZ;q'\rangle$$

$$\mathcal{H}^{I;NZ}_{KqK'q'}\equiv\langle IMK;NZ;q|\hat{H}|IMK';NZ;q'\rangle+\varepsilon^{IKK';NZ}_{DD}\left[|\Phi(q)\rangle,|\Phi(q')\rangle\right]$$

$\longrightarrow$ generalized eigenvalue problem

Method: GCM+PNAMP

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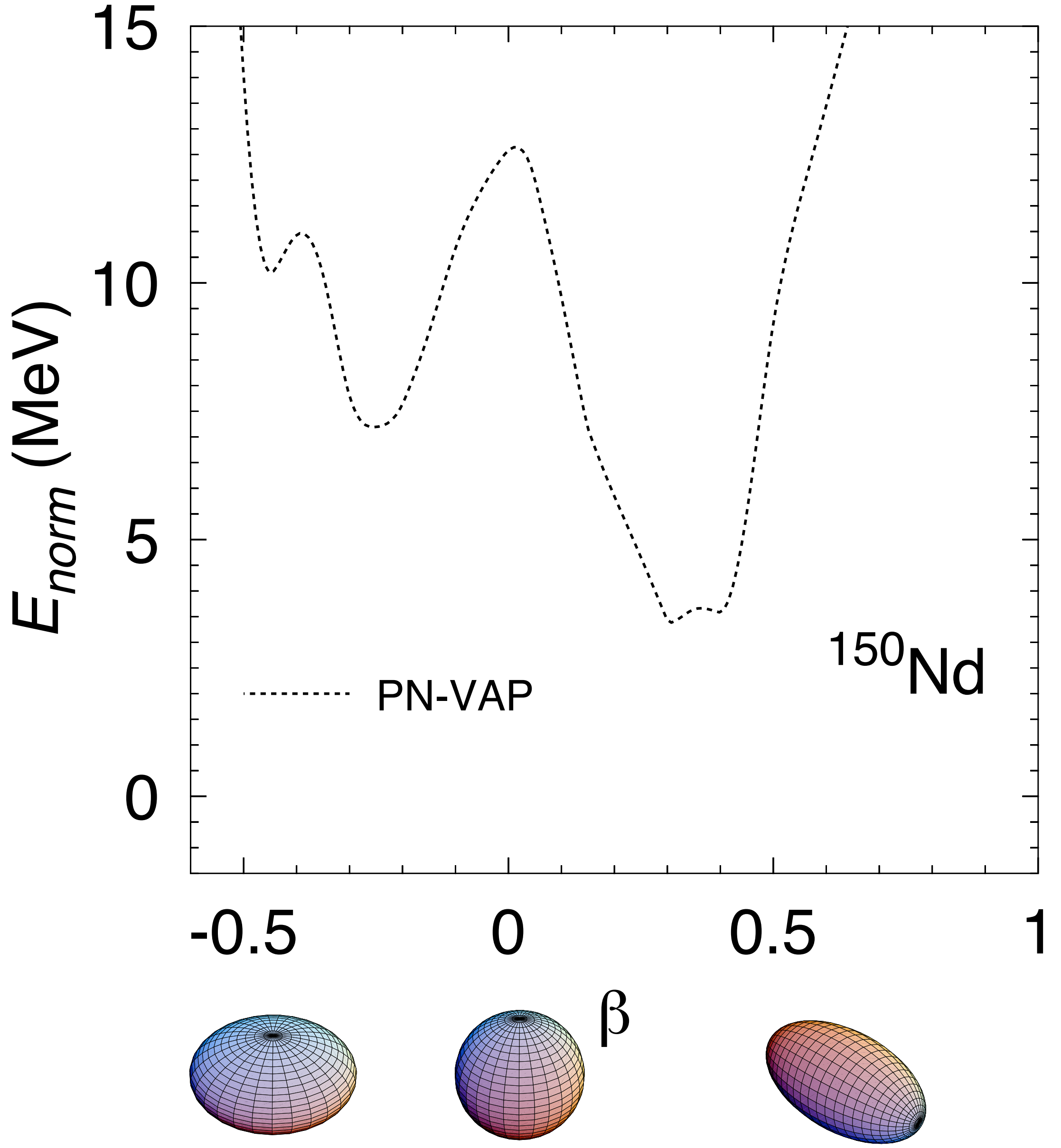
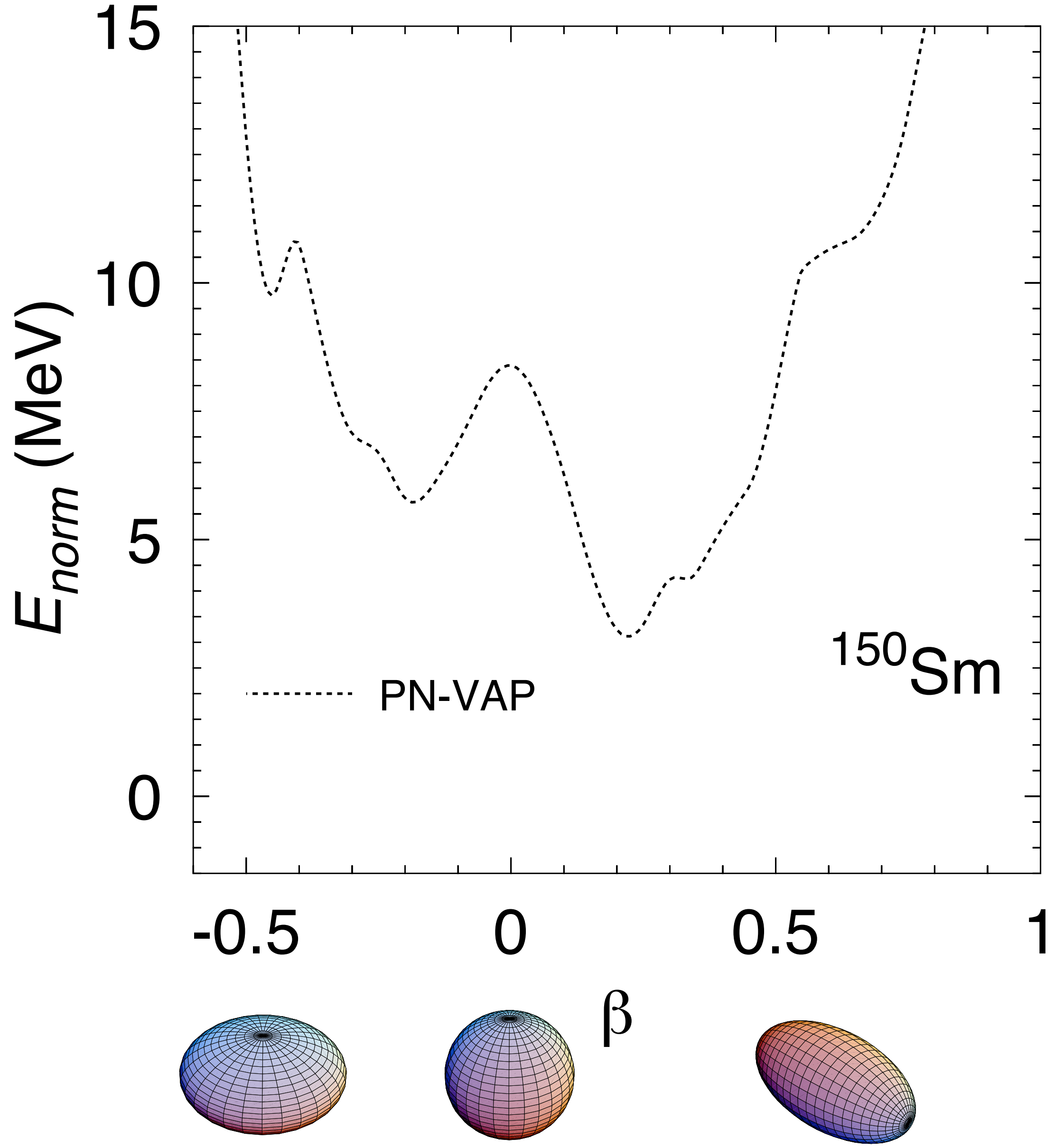
Determination of mother and granddaughter states (I)





Method: GCM+PNAMP

Determination of mother and granddaughter states (II)

Intrinsic state: Solve the VAP-PN equations with the Gogny D1S interaction

$|\Phi\rangle$ HFB states $\longrightarrow$ $\delta\left(E^{N,Z}\left[|\bar{\Phi}(q)\rangle\right]\right)_{|\bar{\Phi}\rangle=|\Phi\rangle}=0$

$$E^{N,Z}[|\Phi\rangle]=\frac{\langle\Phi|\hat{H}\hat{P}^N\hat{P}^Z|\Phi\rangle}{\langle\Phi|\hat{P}^N\hat{P}^Z|\Phi\rangle}+\varepsilon^{N,Z}_{DD}(|\Phi\rangle)-\lambda_q\langle\Phi|\hat{Q}|\Phi\rangle$$

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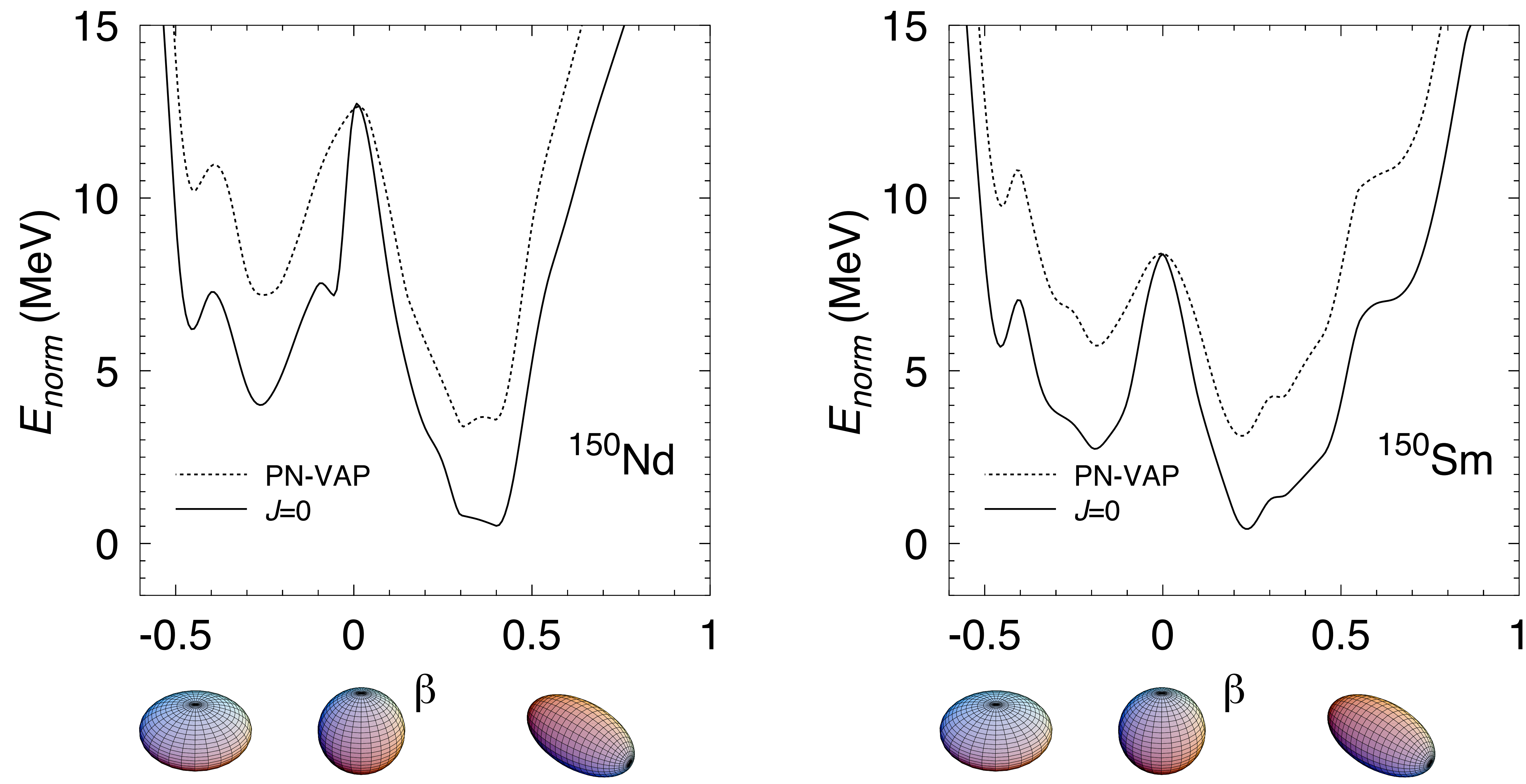

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Solving HWG equation:

1. Diagonalization of the norm overlap:

$$\sum_{K'q'}\mathcal{N}^{I;NZ}_{KqK'q'}u^{I;NZ}_{K'q';\Lambda}=n^{I;NZ}_{\Lambda}u^{I;NZ}_{Kq;\Lambda}$$

2. Natural basis:

$$|\Lambda^{IM;NZ}\rangle=\sum_{Kq}\frac{u^{I;NZ}_{Kq;\Lambda}}{\sqrt{n^{I;NZ}_{\Lambda}}}|IMK;NZ;q\rangle\;\;;n^{I;NZ}_{\Lambda}/n^{I,NZ}_{max}>\zeta$$

3. Normal eigenvalue problem:

$$\sum_{\Lambda'}\langle\Lambda^{I;NZ}|\hat{H}|\Lambda'^{I;NZ}\rangle G^{I;NZ;\sigma}_{\Lambda'}=E^{I;NZ;\sigma}G^{I;NZ;\sigma}_{\Lambda}$$

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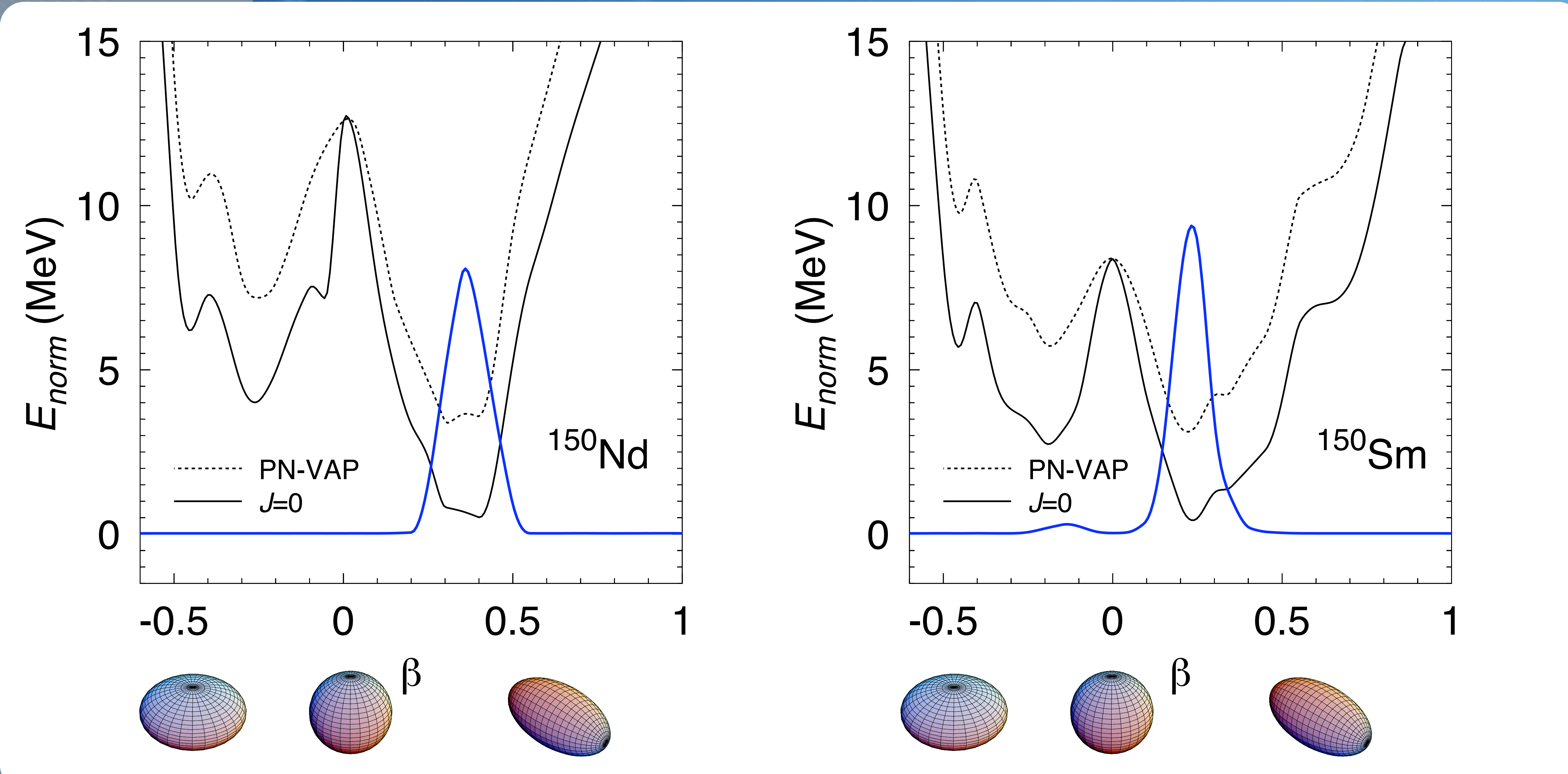

Method: GCM+PNAMP

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Transitions

1. Axial states $K = 0$
2. Angular momentum $I = 0$
3. Ground states $\sigma = 0$
4. Quadrupole deformations $q = q_{20}$

$\longrightarrow$

$$|0; N_i Z_i; \sigma\rangle = \sum_{\Lambda_i} G_{\Lambda_i}^{0;N_i Z_i;\sigma} |\Lambda_i^{0;N_i Z_i}\rangle$$

$$|0; N_f Z_f; \sigma\rangle = \sum_{\Lambda_f} G_{\Lambda_f}^{0;N_f Z_f;\sigma} |\Lambda_f^{0;N_f Z_f}\rangle$$

Method: GCM+PNAMP

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$$|0; N_fZ_f;\sigma\rangle = \sum_{\Lambda_f} G^{0;N_fZ_f;\sigma}_{\Lambda_f} |\Lambda_f^{0;N_fZ_f}\rangle$$

TRANSITIONS:

$$M^{0\nu\beta\beta}_{\xi} = \langle 0^+_f|\hat{O}^{0\nu\beta\beta}_{\xi}|0^+_i\rangle = \langle 0; N_fZ_f|\hat{O}^{0\nu\beta\beta}_{\xi}|0; N_iZ_i\rangle =$$

$$\sum_{\Lambda_f\Lambda_i}\left(G^{0;N_fZ_f}_{\Lambda_f}\right)^*\langle\Lambda_f^{0;N_fZ_f}|\hat{O}^{0\nu\beta\beta}_{\xi}|\Lambda_i^{0;N_iZ_i}\rangle G^{0;N_iZ_i}_{\Lambda_i} = \sum_{q_iq_f;\Lambda_f\Lambda_i}$$

$$\left(\frac{u^{0;N_fZ_f}_{q_f,\Lambda_f}}{\sqrt{n^{0;N_fZ_f}_{\Lambda_f}}}\right)^*\left(G^{0;N_fZ_f}_{\Lambda_f}\right)^*\langle 0; N_fZ_f;q_f|\hat{O}^{0\nu\beta\beta}_{\xi}|0;N_iZ_i;q_i\rangle\left(G^{0;N_iZ_i}_{\Lambda_i}\right)\left(\frac{u^{0;N_iZ_i}_{q_i,\Lambda_i}}{\sqrt{n^{0;N_iZ_i}_{\Lambda_i}}}\right)$$

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TRANSITIONS:

$$M_\xi^{0\nu\beta\beta} = \langle 0_f^+|\hat{O}_\xi^{0\nu\beta\beta}|0_i^+\rangle = \langle 0;N_fZ_f|\hat{O}_\xi^{0\nu\beta\beta}|0;N_iZ_i\rangle =$$

$$\sum_{\Lambda_f\Lambda_i}\left(G_{\Lambda_f}^{0;N_fZ_f}\right)^*\langle\Lambda_f^{0;N_fZ_f}|\hat{O}_\xi^{0\nu\beta\beta}|\Lambda_i^{0;N_iZ_i}\rangle G_{\Lambda_i}^{0;N_iZ_i} = \sum_{q_iq_f;\Lambda_f\Lambda_i}$$

$$\left(\frac{u_{q_f,\Lambda_f}^{0;N_fZ_f}}{\sqrt{n_{\Lambda_f}^{0;N_fZ_f}}}\right)^*\left(G_{\Lambda_f}^{0;N_fZ_f}\right)^*\langle 0;N_fZ_f;q_f|\hat{O}_\xi^{0\nu\beta\beta}|0;N_iZ_i;q_i\rangle\left(G_{\Lambda_i}^{0;N_iZ_i}\right)\left(\frac{u_{q_i,\Lambda_i}^{0;N_iZ_i}}{\sqrt{n_{\Lambda_i}^{0;N_iZ_i}}}\right)$$

Matrix elements of the double beta transition operators between particle number and angular momentum projected states

Method: GCM+PNAMP

CONTENTS

Transitions

1. Axial states $K=0$
2. Angular momentum $I=0$
3. Ground states $\sigma=0$
4. Quadrupole deformations $q=q_{20}$

$\longrightarrow$

$$|0;N_iZ_i;\sigma\rangle = \sum_{\Lambda_i} G_{\Lambda_i}^{0;N_iZ_i;\sigma}|\Lambda_i^{0;N_iZ_i}\rangle$$

$$|0;N_fZ_f;\sigma\rangle = \sum_{\Lambda_f} G_{\Lambda_f}^{0;N_fZ_f;\sigma}|\Lambda_f^{0;N_fZ_f}\rangle$$

TRANSITIONS:

$$M_\xi^{0\nu\beta\beta} = \langle 0_f^+|\hat{O}_\xi^{0\nu\beta\beta}|0_i^+\rangle = \langle 0;N_fZ_f|\hat{O}_\xi^{0\nu\beta\beta}|0;N_iZ_i\rangle =$$

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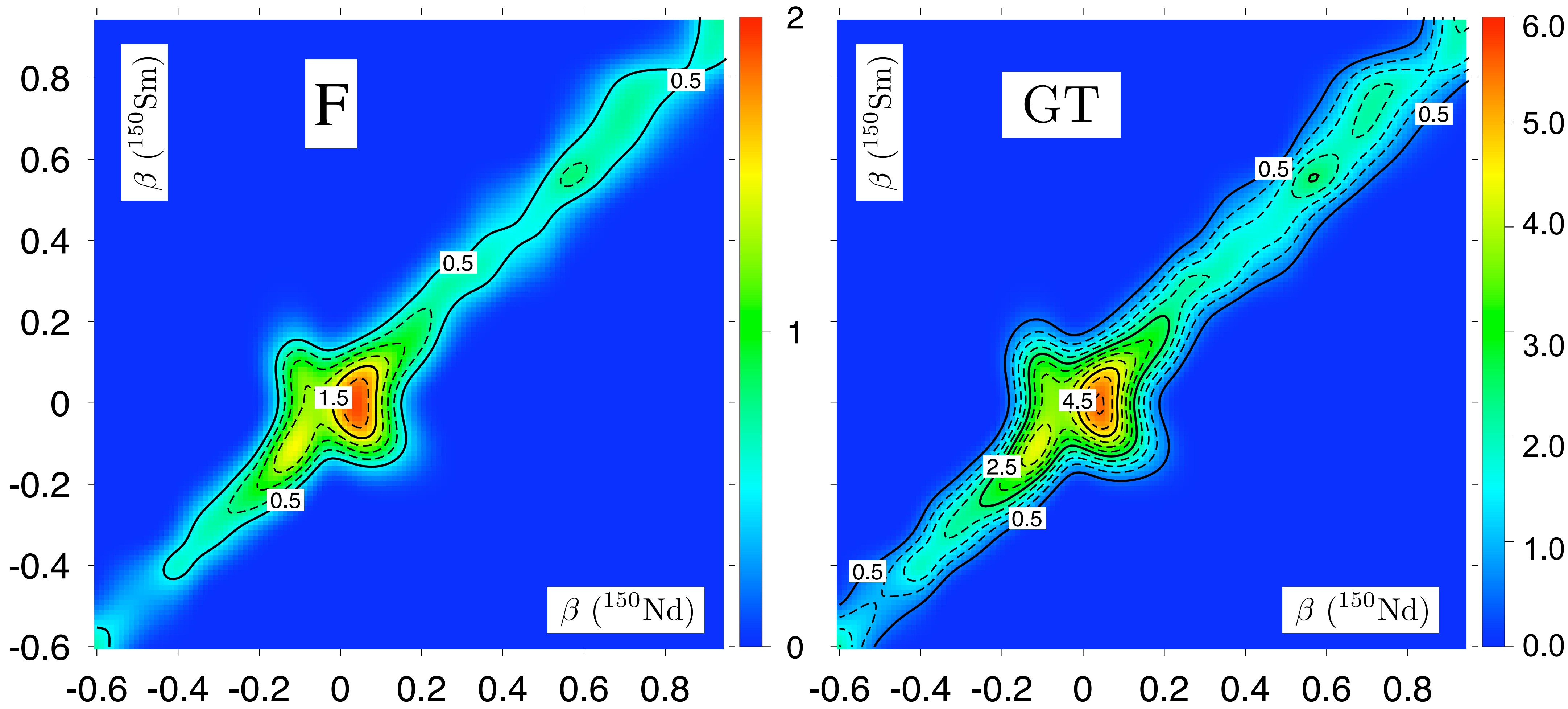
Results: GCM+PNAMP

T.R.R., G. Martinez-Pinedo, arXiv:1008.5260

CONTENTS

A=150

$$\frac{\langle 0; N_f Z_f; q_f | \hat{O}_{\xi}^{0\nu\beta\beta} | 0; N_i Z_i; q_i \rangle}{\sqrt{\langle 0; N_f Z_f; q_f | 0; N_f Z_f; q_f \rangle \langle 0; N_i Z_i; q_i | 0; N_i Z_i; q_i \rangle}}$$



- GT strength greater than Fermi.
- Similar deformation between mother and granddaughter is favored by the transition operators
- Maxima are found close to sphericity although some other local maxima are found

Results: GCM+PNAMP

T.R.R., G. Martinez-Pinedo, arXiv:1008.5260

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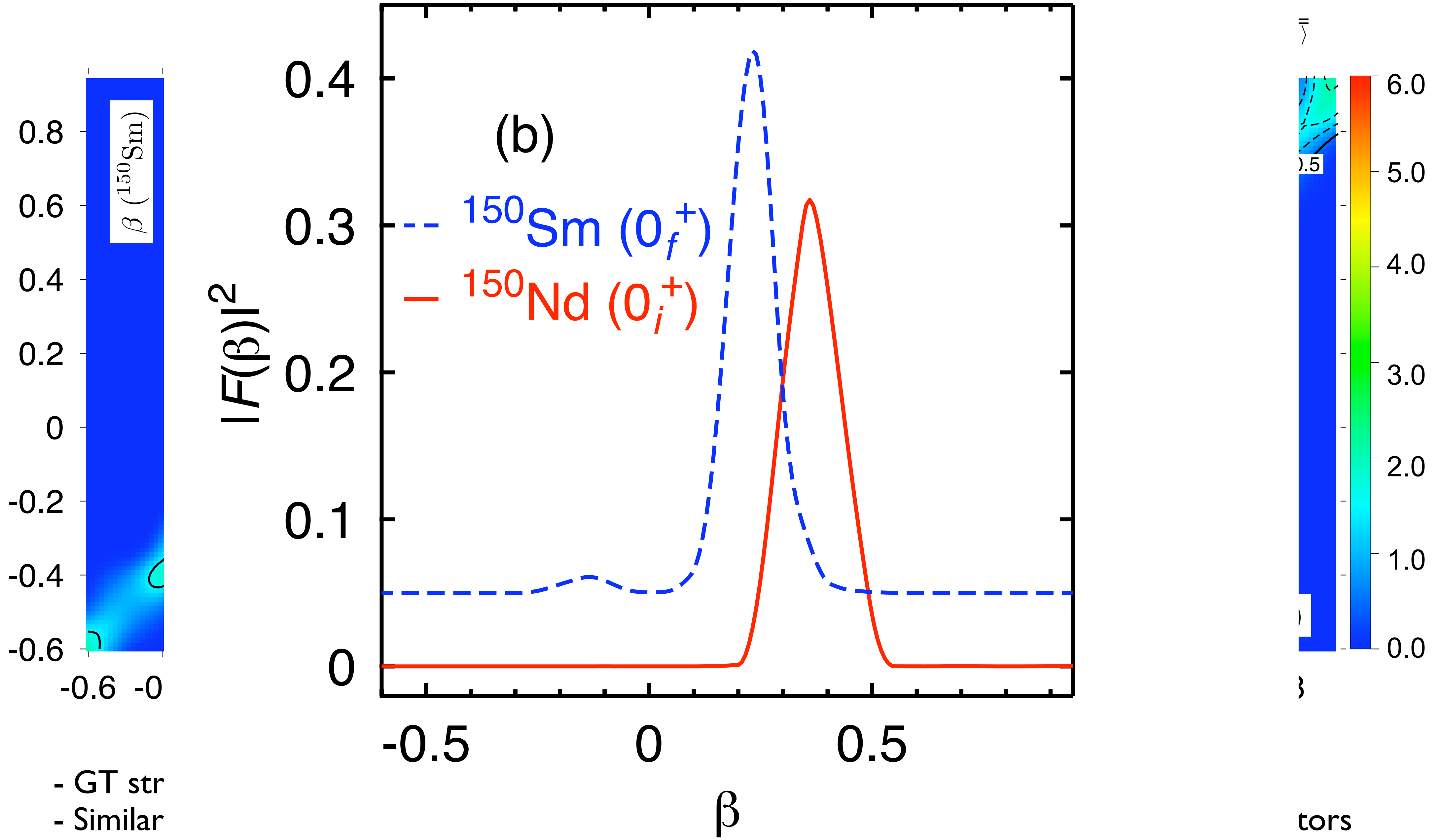


- GT str
- Similar
- Maxim

tors

- Final result depends on the distribution of probability of the corresponding initial and final collective states within this plot

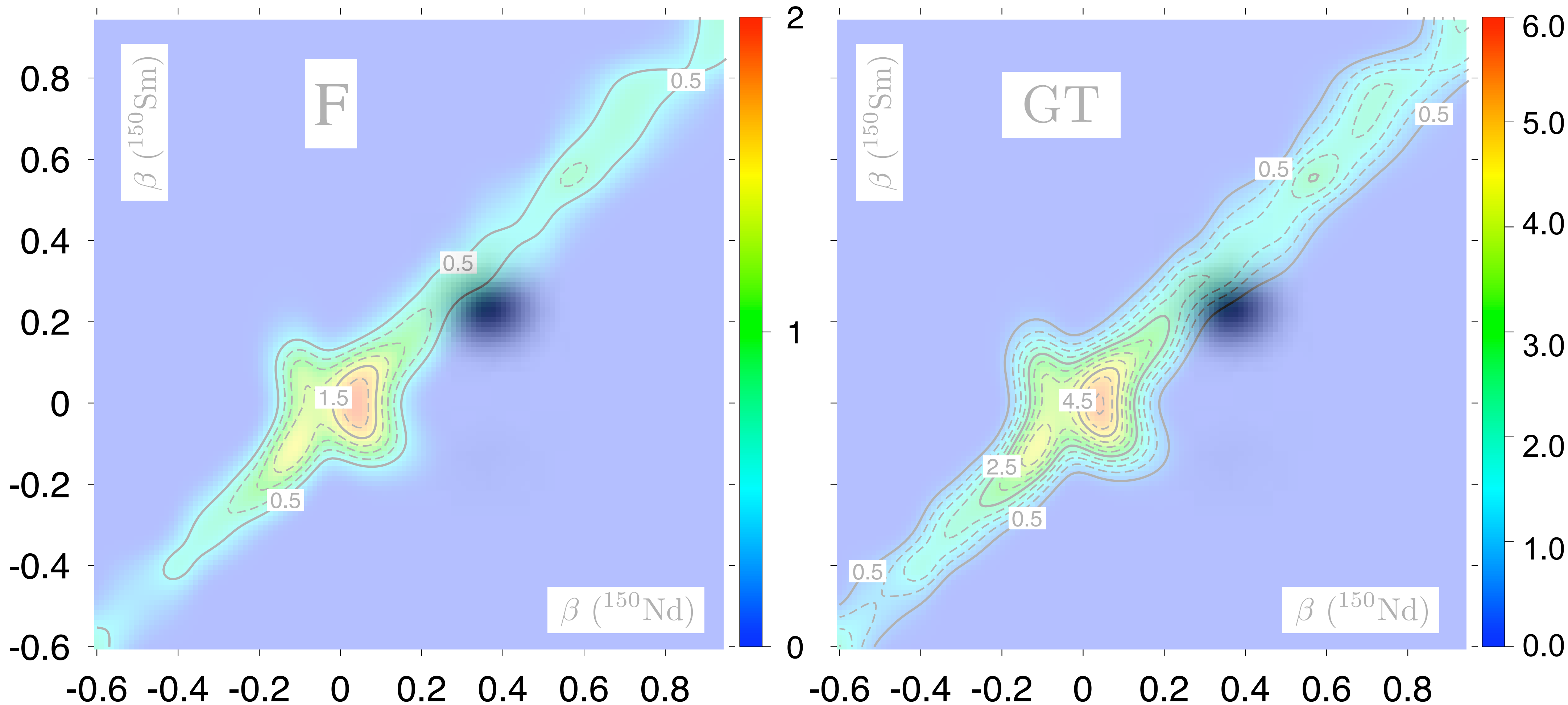
Results: GCM+PNAMP

T.R.R., G. Martinez-Pinedo, arXiv:1008.5260

CONTENTS

A=150

$$\frac{\langle 0; N_f Z_f; q_f | \hat{O}^{0\nu\beta\beta}_{\xi} | 0; N_i Z_i; q_i \rangle}{\sqrt{\langle 0; N_f Z_f; q_f | 0; N_f Z_f; q_f \rangle \langle 0; N_i Z_i; q_i | 0; N_i Z_i; q_i \rangle}}$$



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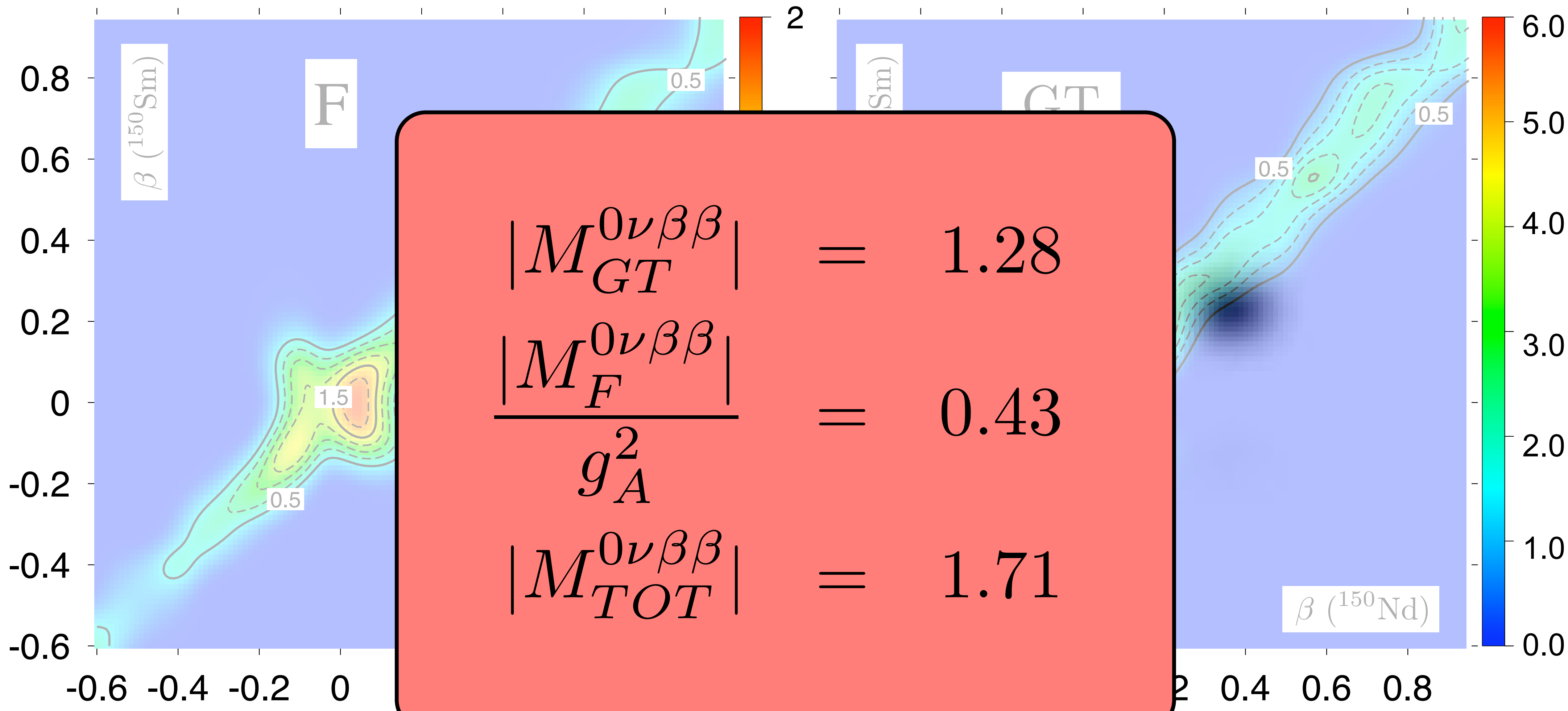

$$|M^{0\nu\beta\beta}_{GT}| = 1.28$$

$$\frac{|M^{0\nu\beta\beta}_{F}|}{g_A^2} = 0.43$$

$$|M^{0\nu\beta\beta}_{TOT}| = 1.71$$

- GT strength greater than Fermi.
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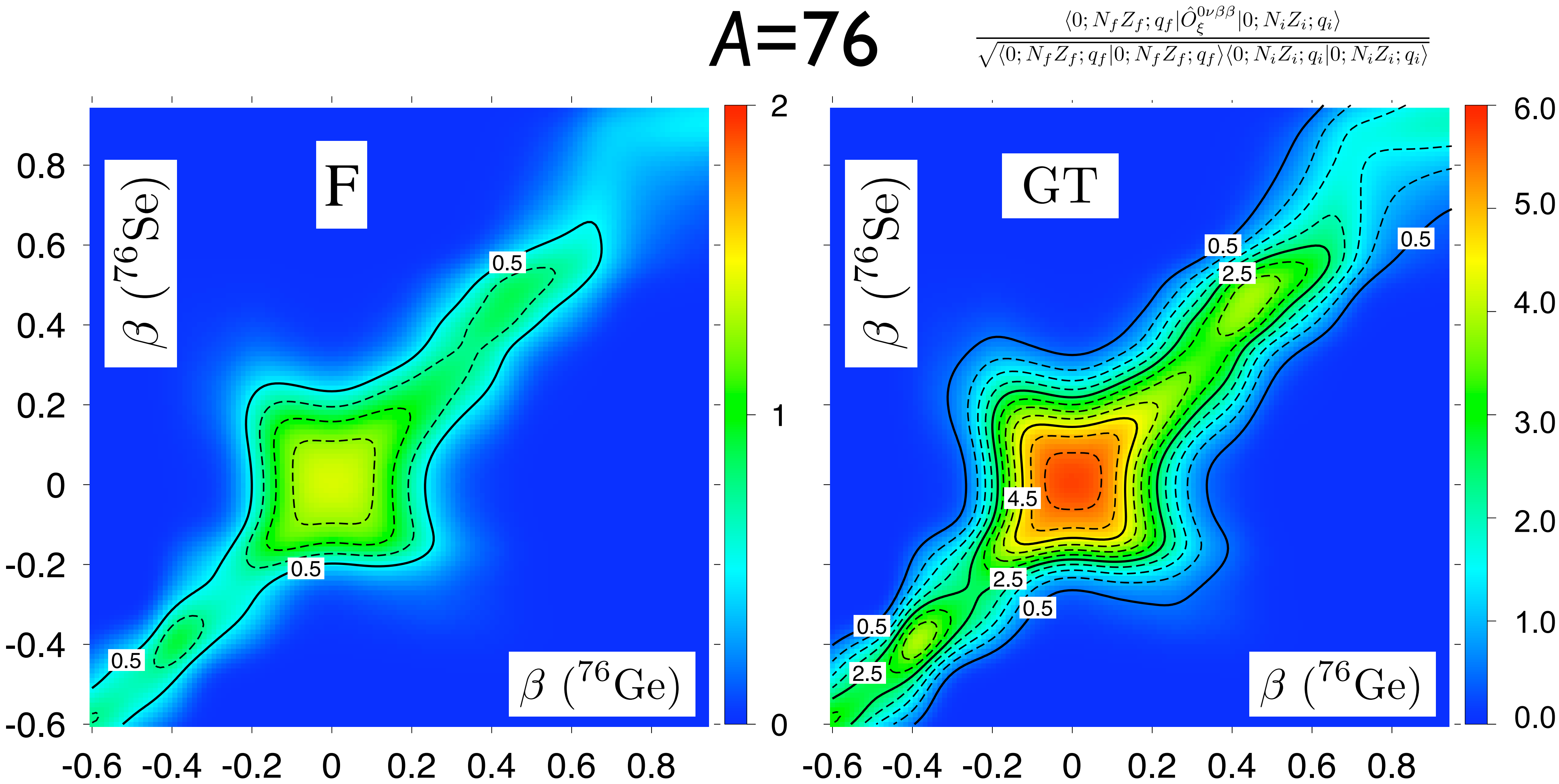

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Results: GCM+PNAMP

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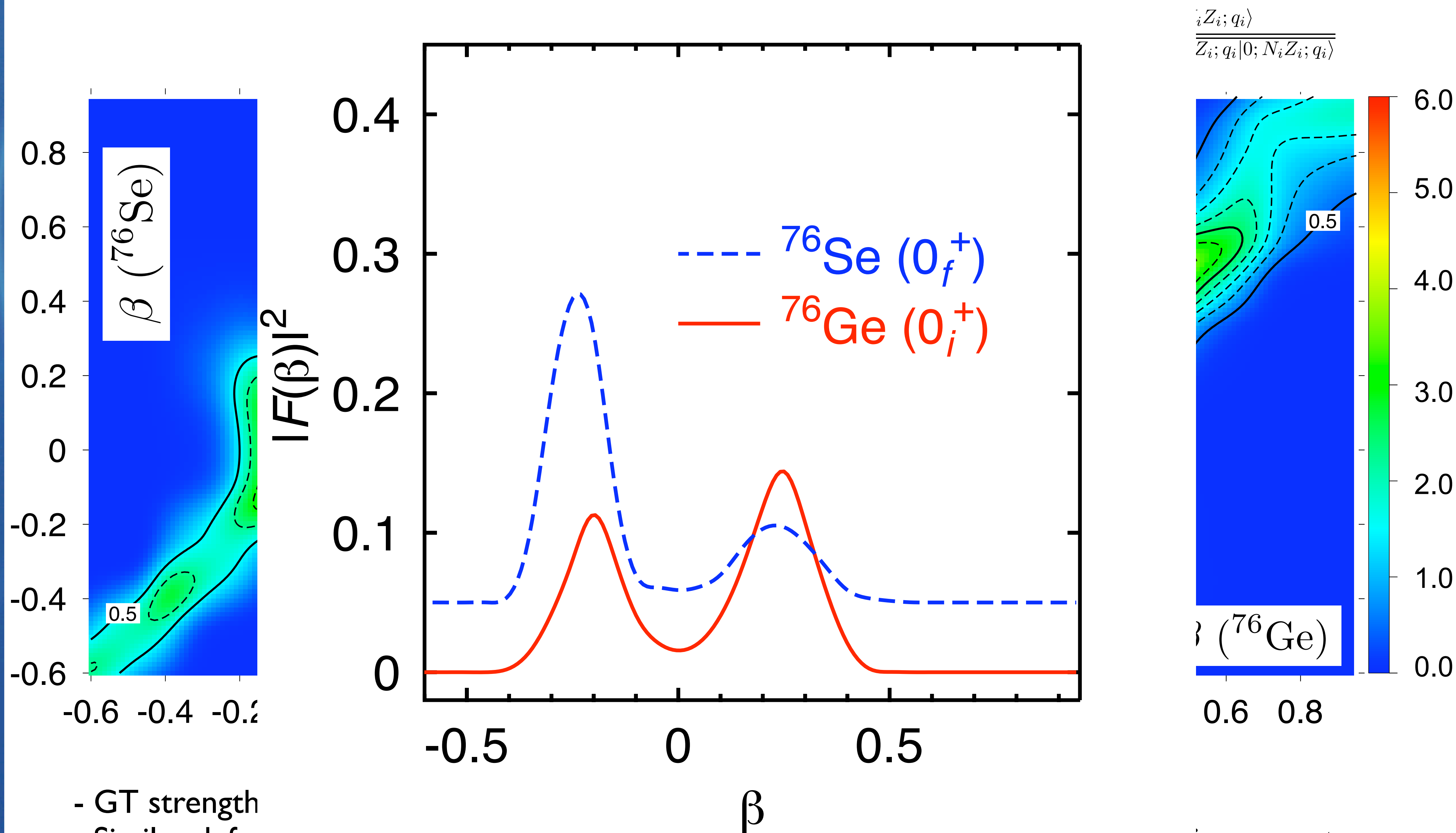


- GT strength
- Similar defo
- Maxima are

ion operators

d

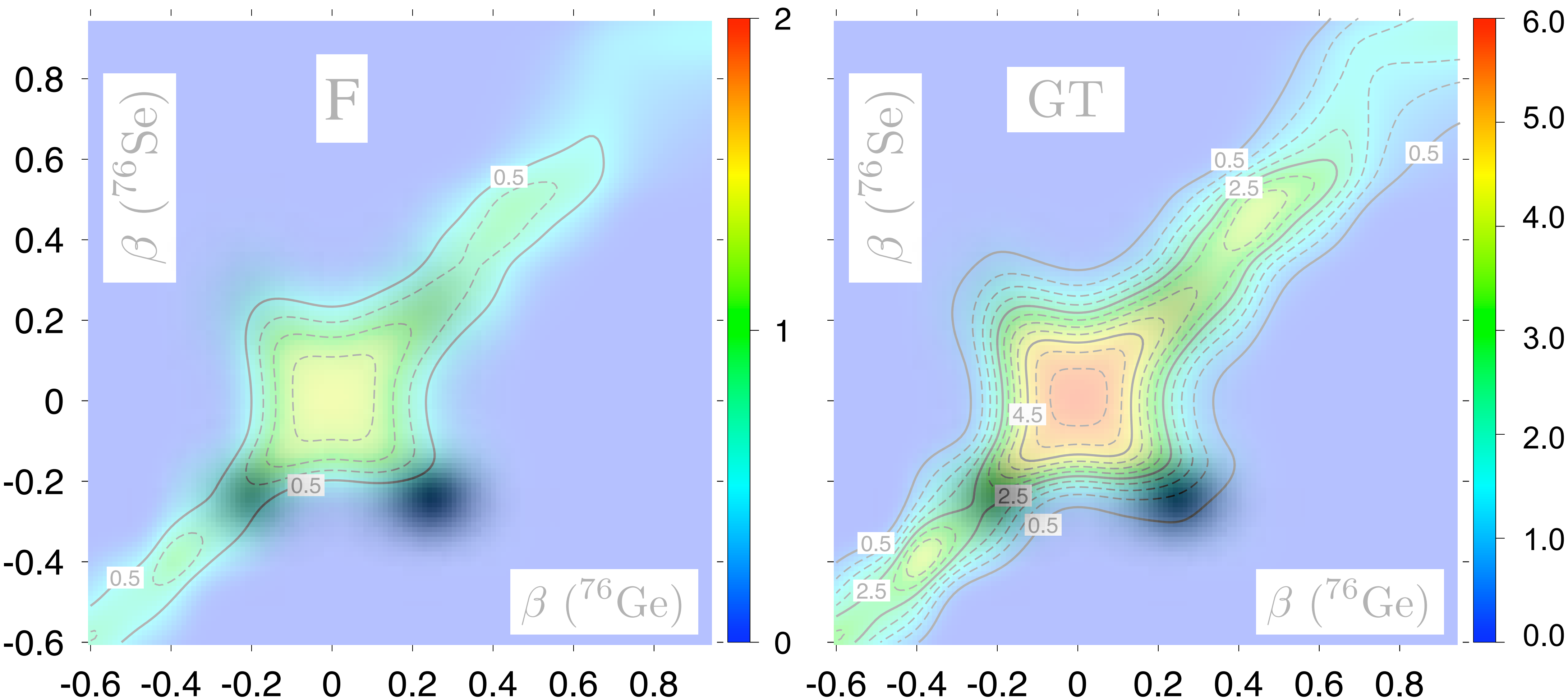
- Final result depends on the distribution of probability of the corresponding initial and final collective states within this plot

CONTENTS

Results: GCM+PNAMP

A=76

$$\frac{\langle 0; N_f Z_f; q_f | \hat{O}_{\xi}^{0\nu\beta\beta} | 0; N_i Z_i; q_i \rangle}{\sqrt{\langle 0; N_f Z_f; q_f | 0; N_f Z_f; q_f \rangle \langle 0; N_i Z_i; q_i | 0; N_i Z_i; q_i \rangle}}$$



- GT strength greater than Fermi.
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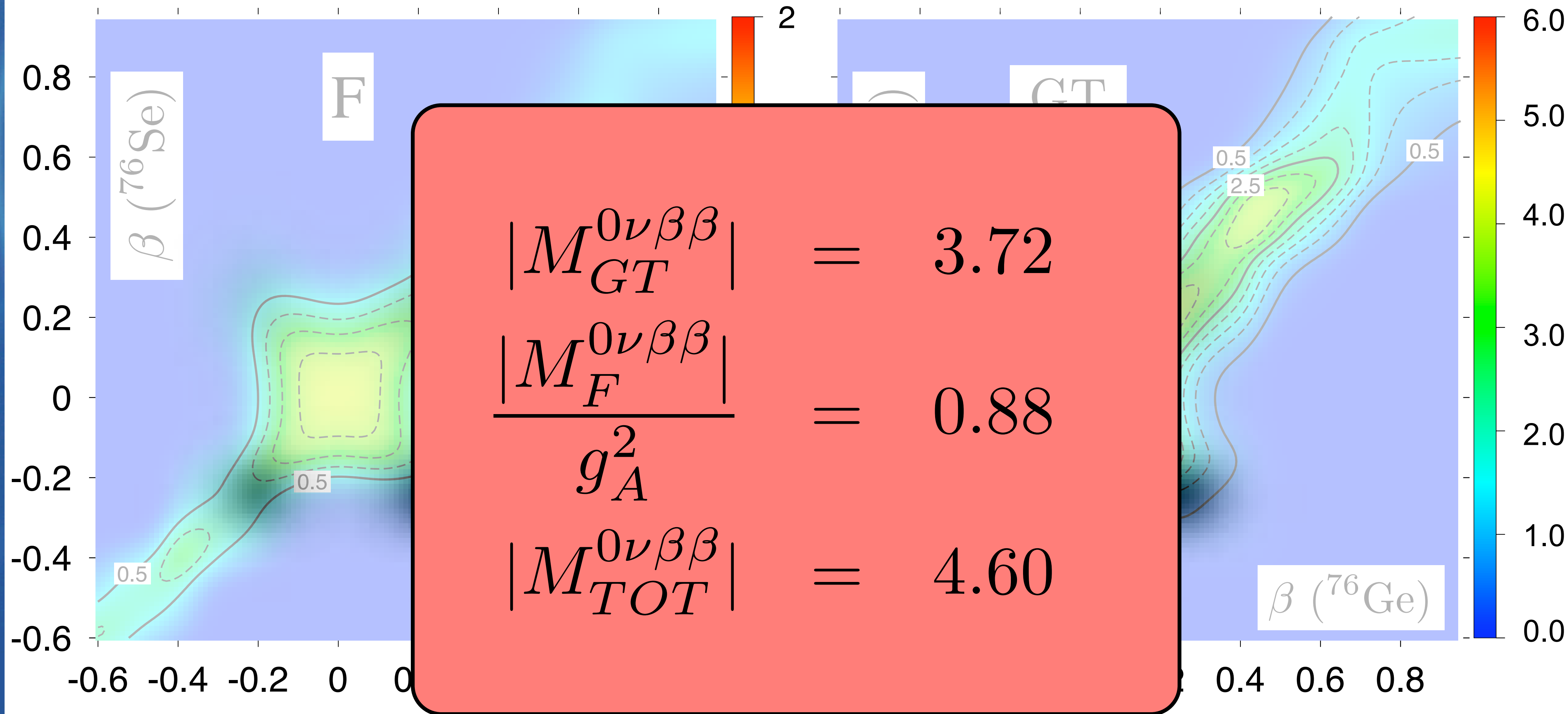
Results: GCM+PNAMP

A=76

$$\frac{\langle 0; N_f Z_f; q_f | \hat{O}^{0\nu\beta\beta}_{\xi} | 0; N_i Z_i; q_i \rangle}{\sqrt{\langle 0; N_f Z_f; q_f | 0; N_f Z_f; q_f \rangle \langle 0; N_i Z_i; q_i | 0; N_i Z_i; q_i \rangle}}$$



$$|M^{0\nu\beta\beta}_{GT}| = 3.72$$

$$\frac{|M^{0\nu\beta\beta}_{F}|}{g_A^2} = 0.88$$

$$|M^{0\nu\beta\beta}_{TOT}| = 4.60$$

- GT strength greater than Fermi.
- Similar deformation between mother and granddaughter is favored by the transition operators
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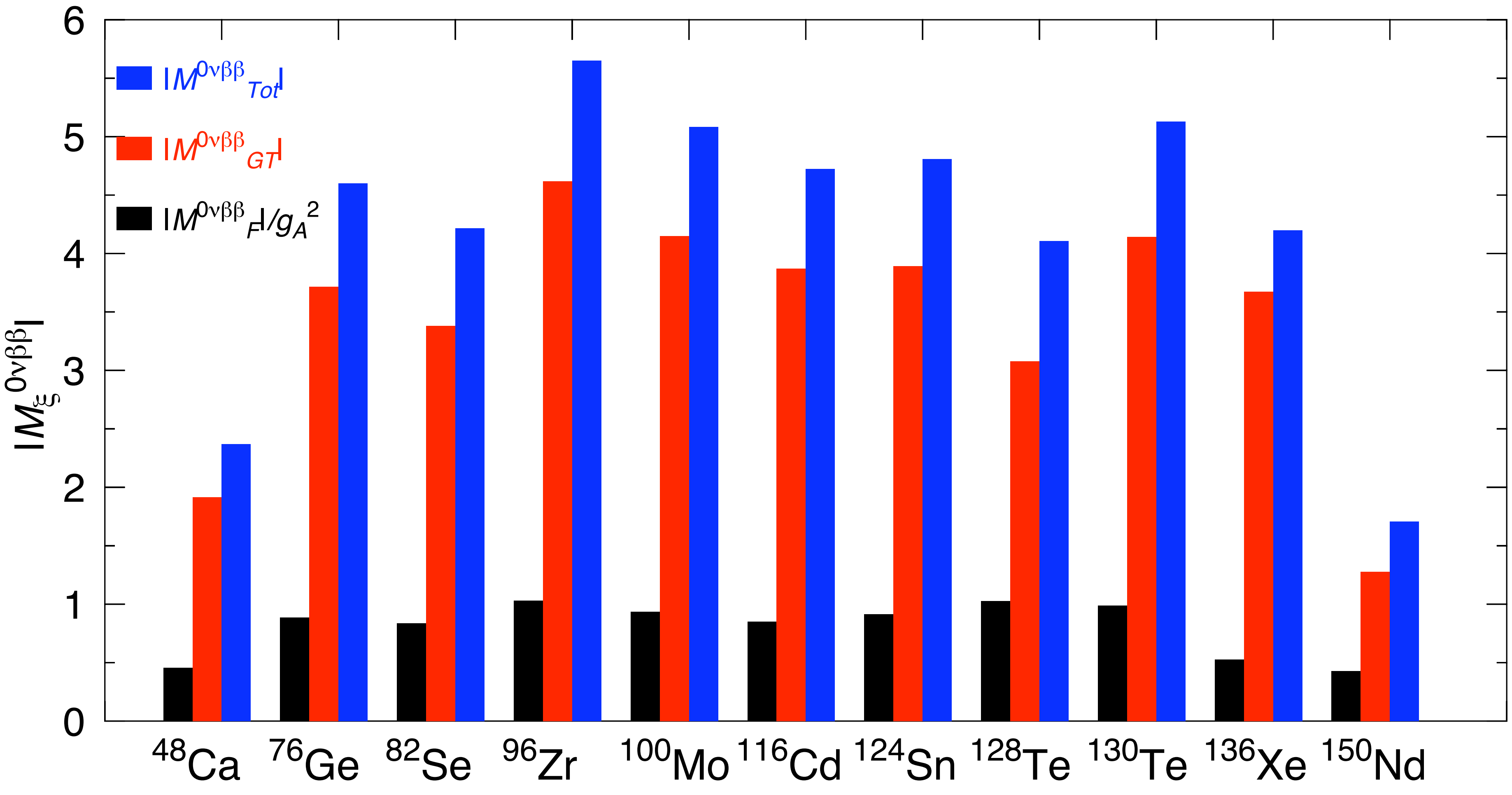
Results: GCM+PNAMP



- Small contribution of Fermi compared to Gamow-Teller.
- Small value for A=150 transition due to the difference in deformation.
- Small value for A=48 due to the small value of the strength of the operator.

CONTENTS

Results: GCM+PNAMP

T.R.R., G. Martinez-Pinedo, arXiv:1008.5260

TABLE I: Difference between theoretical and experimental Q values, kinematical phase space factors, NME and predicted half-lives for several $0\nu\beta\beta$ decaying nuclei assuming $\langle m_{\beta\beta}\rangle = 0.5$ eV.

Nucleus	$Q_{\rm theo} - Q_{\rm exp}$ (MeV)	G_{01} ($\times 10^{-14}$ y^{-1})	$M^{0\nu}$	$T_{1/2}$ ($\times 10^{23}$ y)
^{48}Ca	0.265	6.52	2.37	28.5
^{76}Ge	0.271	0.64	4.60	76.9
^{82}Se	−0.366	2.83	4.22	20.8
^{96}Zr	2.580	5.97	5.65	5.48
^{100}Mo	1.879	4.68	5.08	8.64
^{116}Cd	1.365	5.08	4.72	9.24
^{124}Sn	−0.830	2.79	4.81	16.2
^{128}Te	−0.564	0.18	4.11	343.1
^{130}Te	−0.348	4.49	5.13	8.84
^{136}Xe	−1.027	4.68	4.20	12.7
^{150}Nd	−0.380	21.74	1.71	16.5

- Good agreement between experimental and theoretical *Q*-values

Results: GCM+PNAMP

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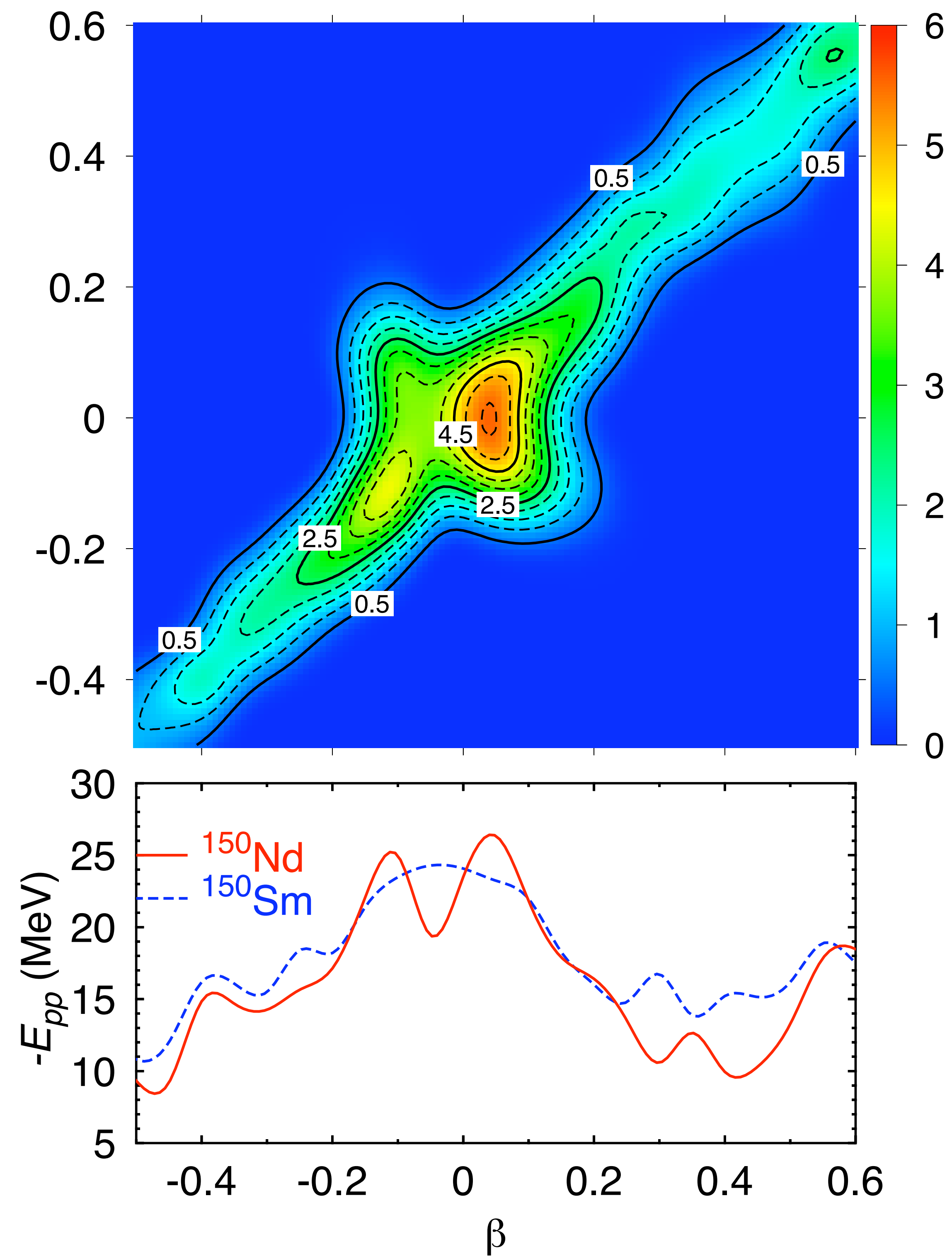

- The structure is related to the pairing energy (particle-particle) of the nuclei involved in the transition

- Maxima of the strength correspond to maxima in pairing energy

- In agreement with seniority arguments (increasing seniority decreases NME)

- Pairing energy and NME involve similar Wick theorem's contractions in this formalism

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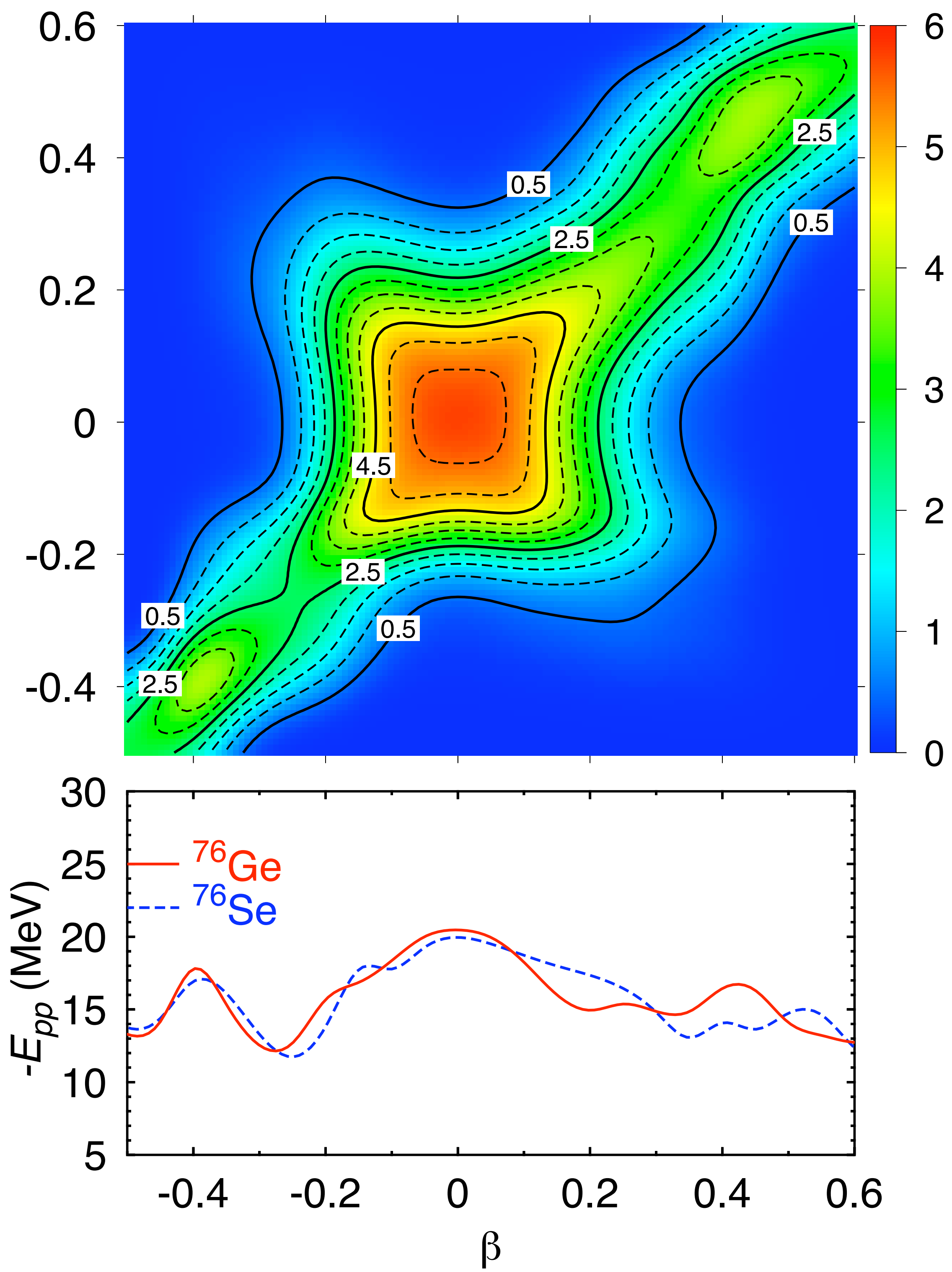

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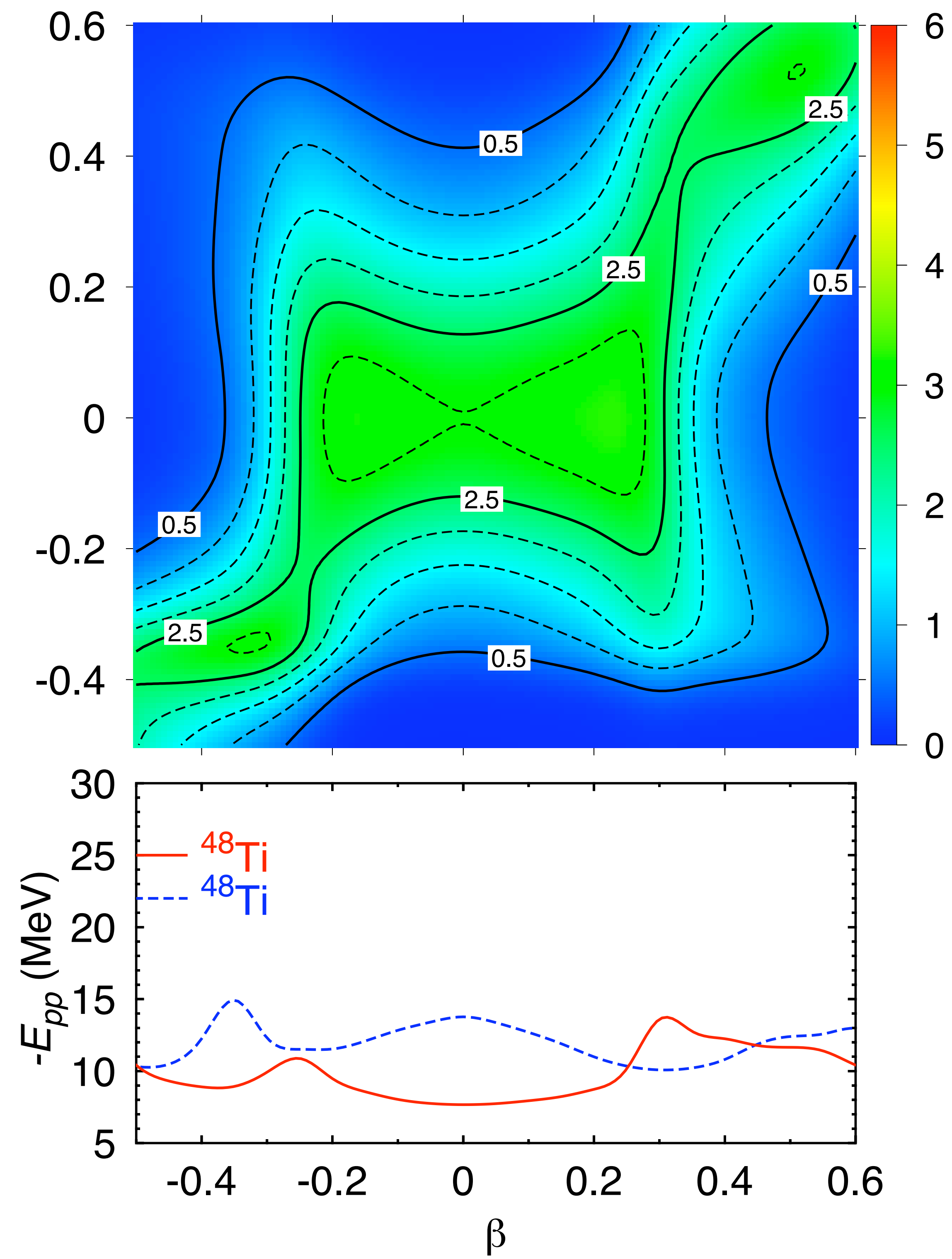

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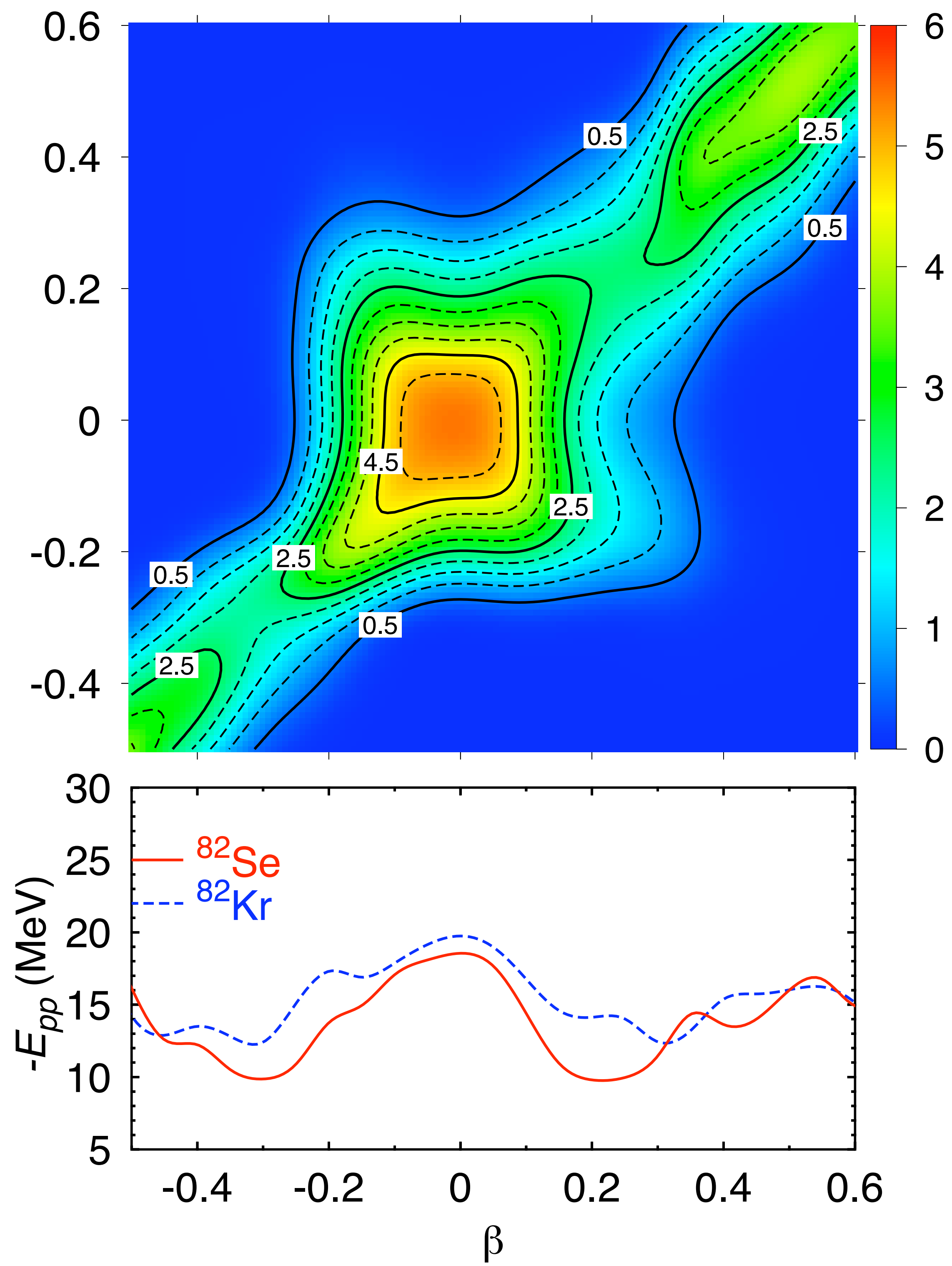

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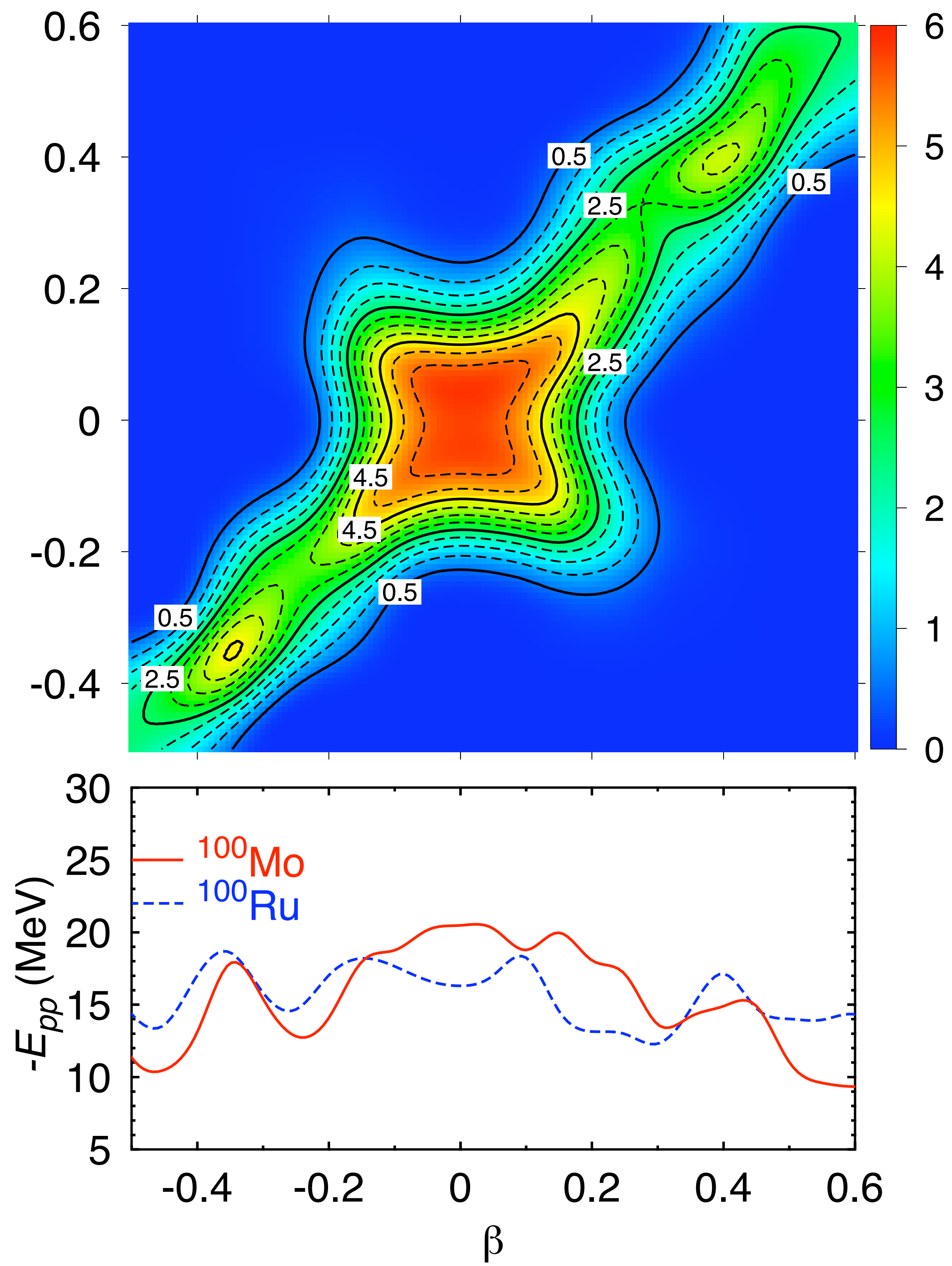

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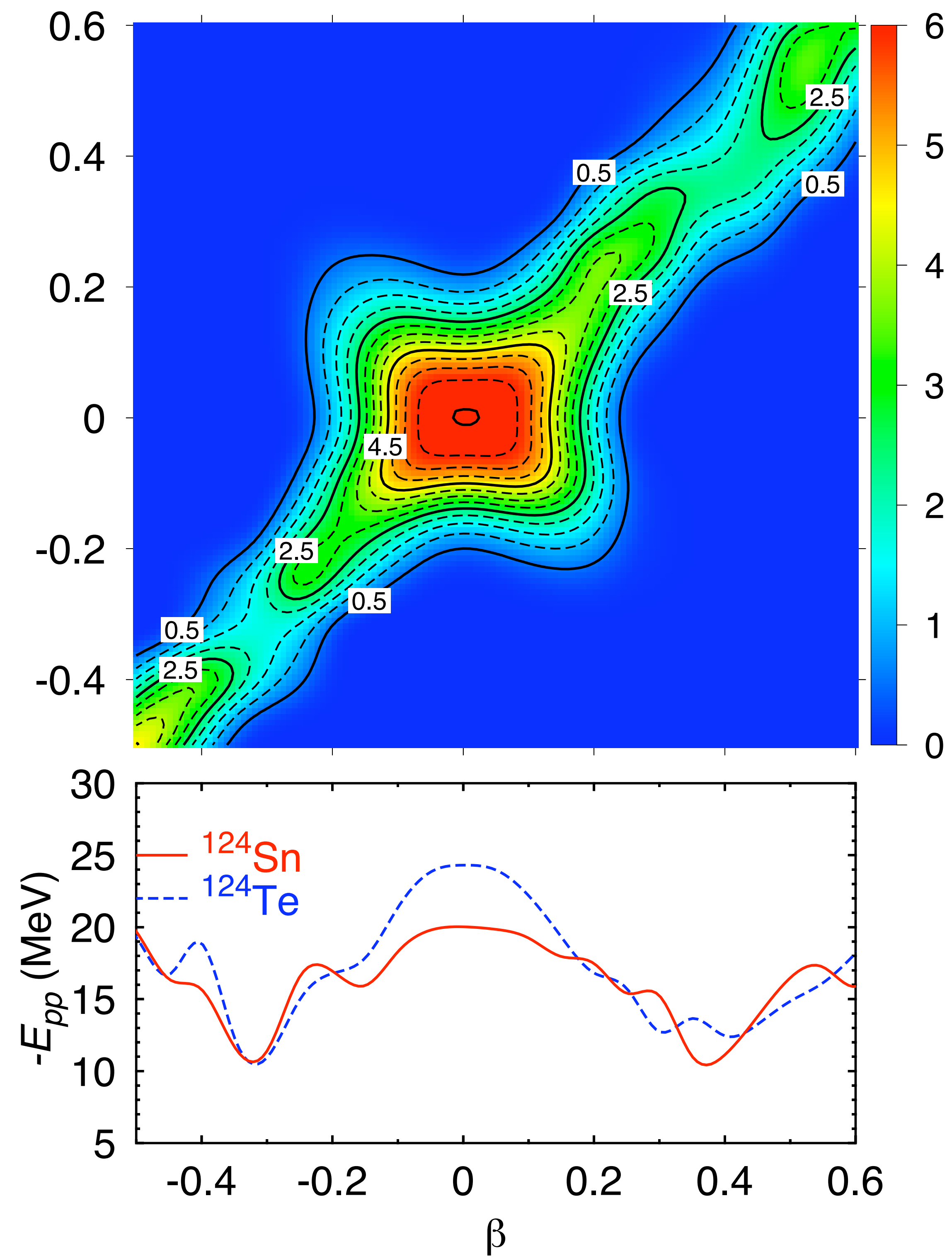

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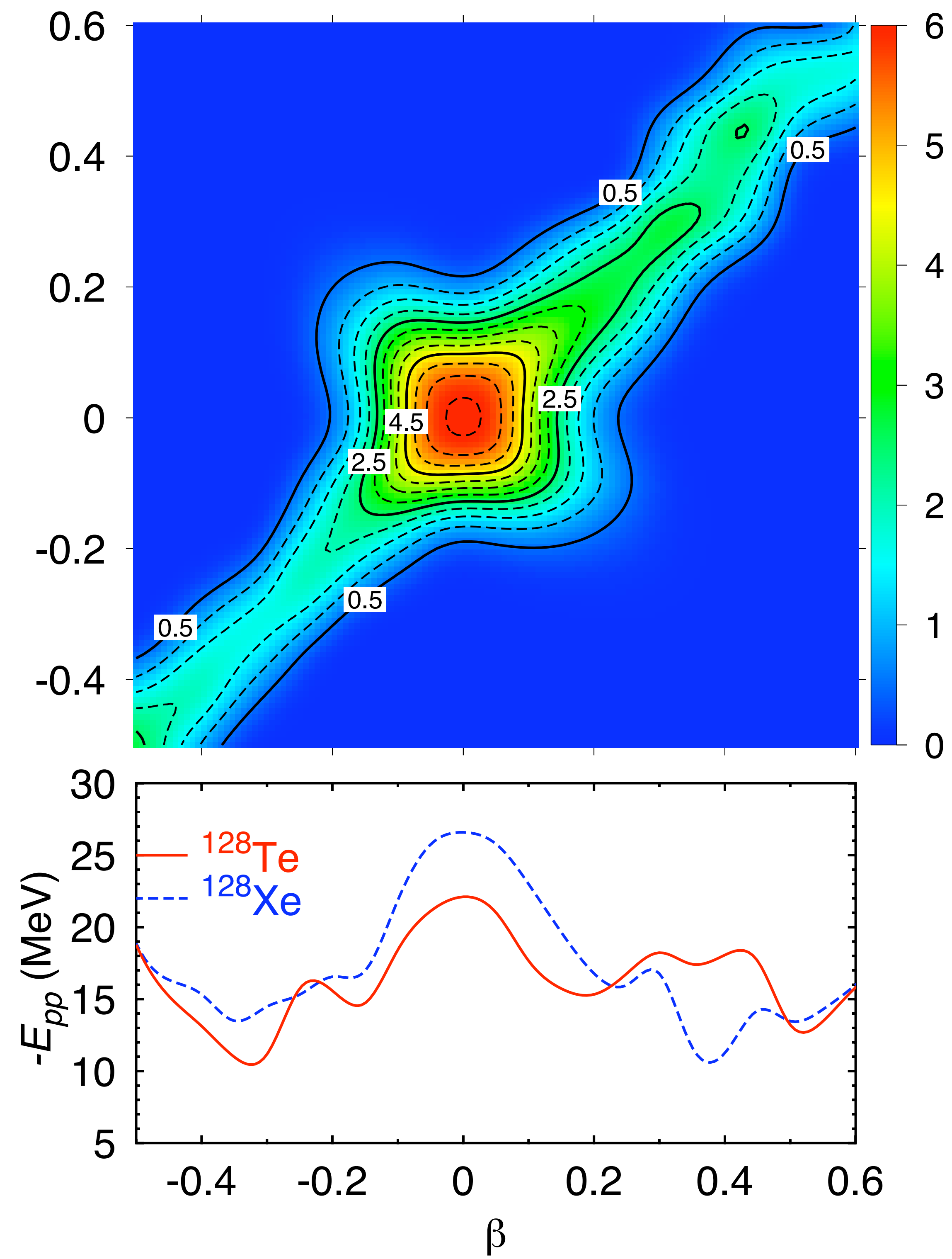

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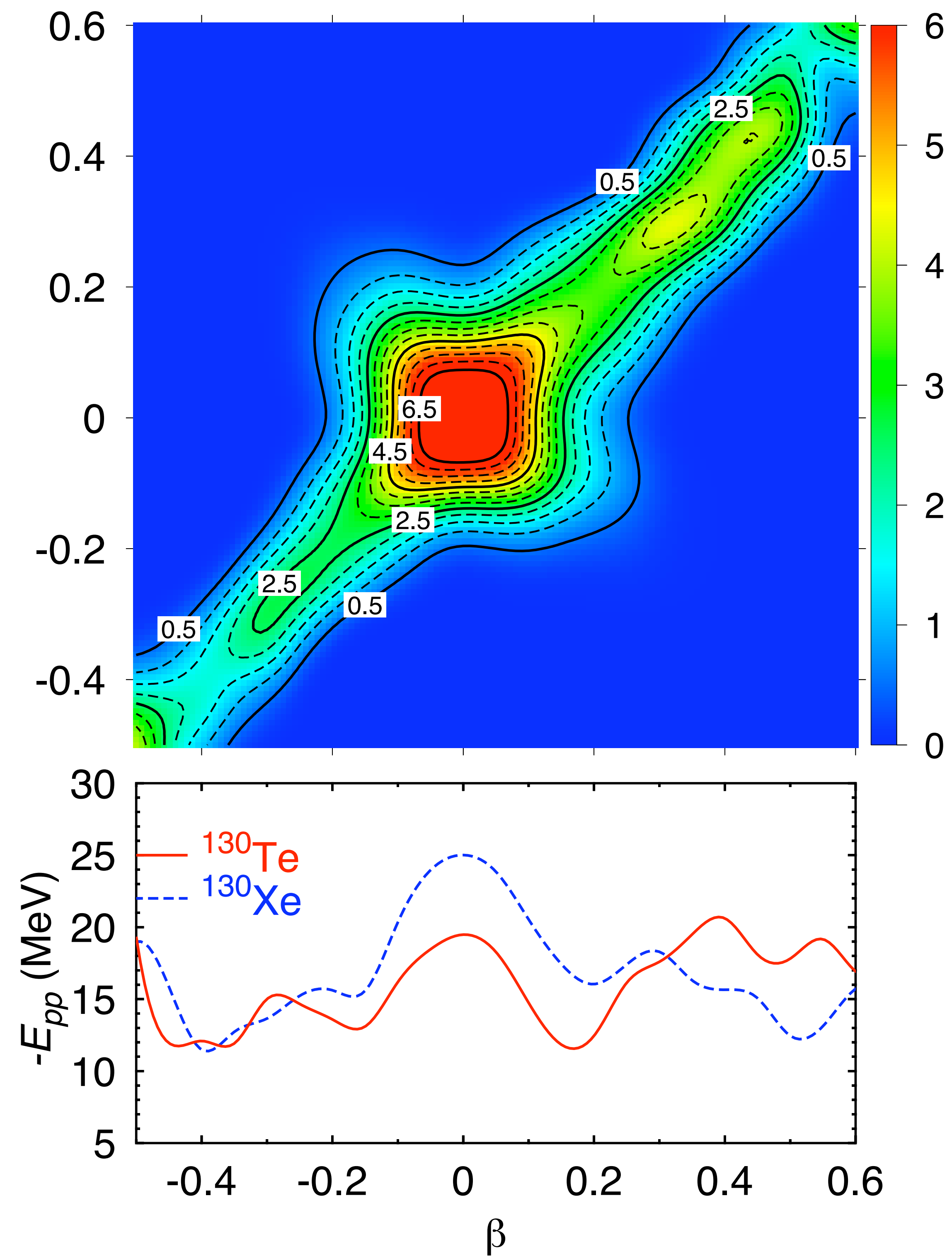

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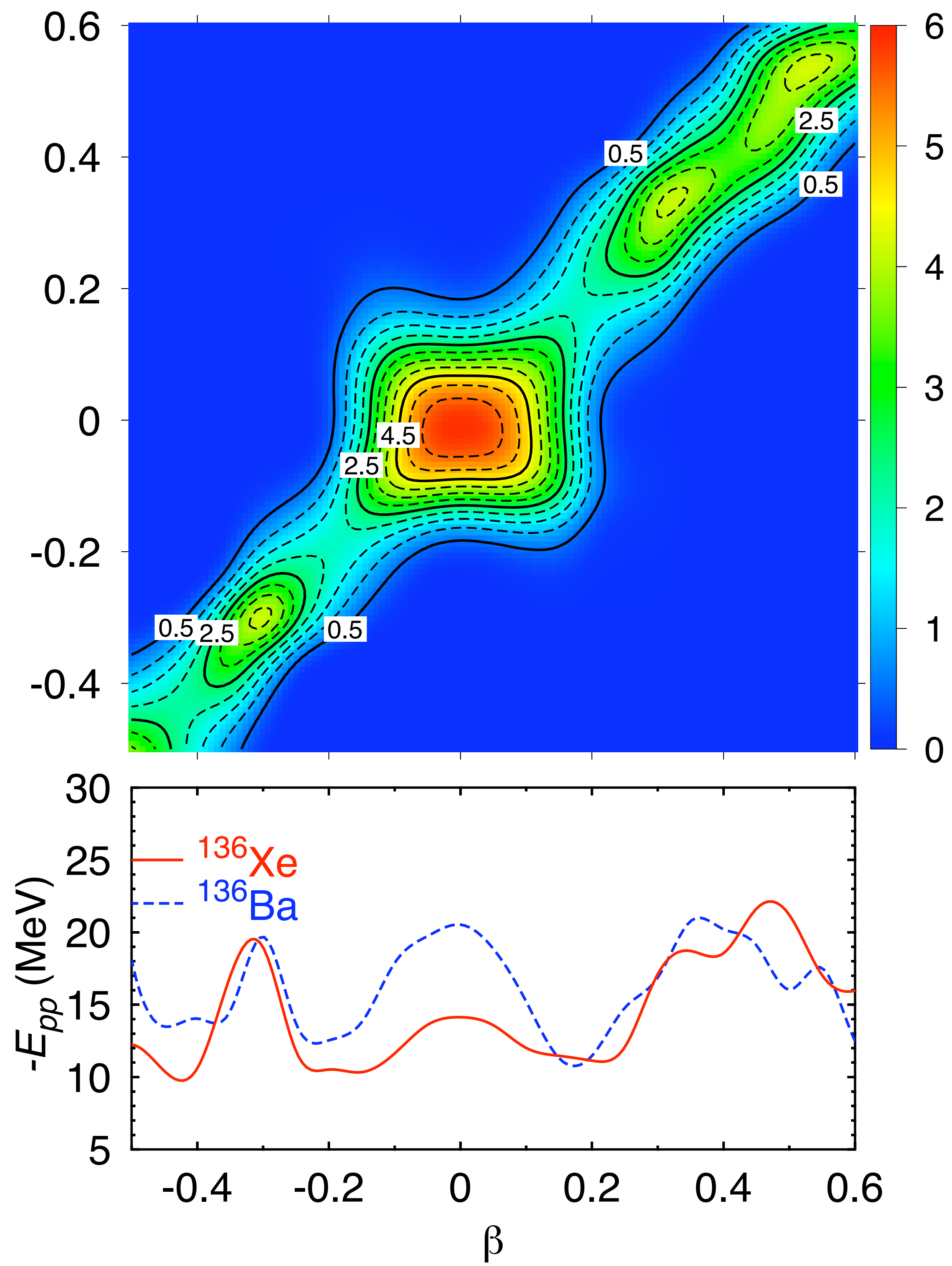

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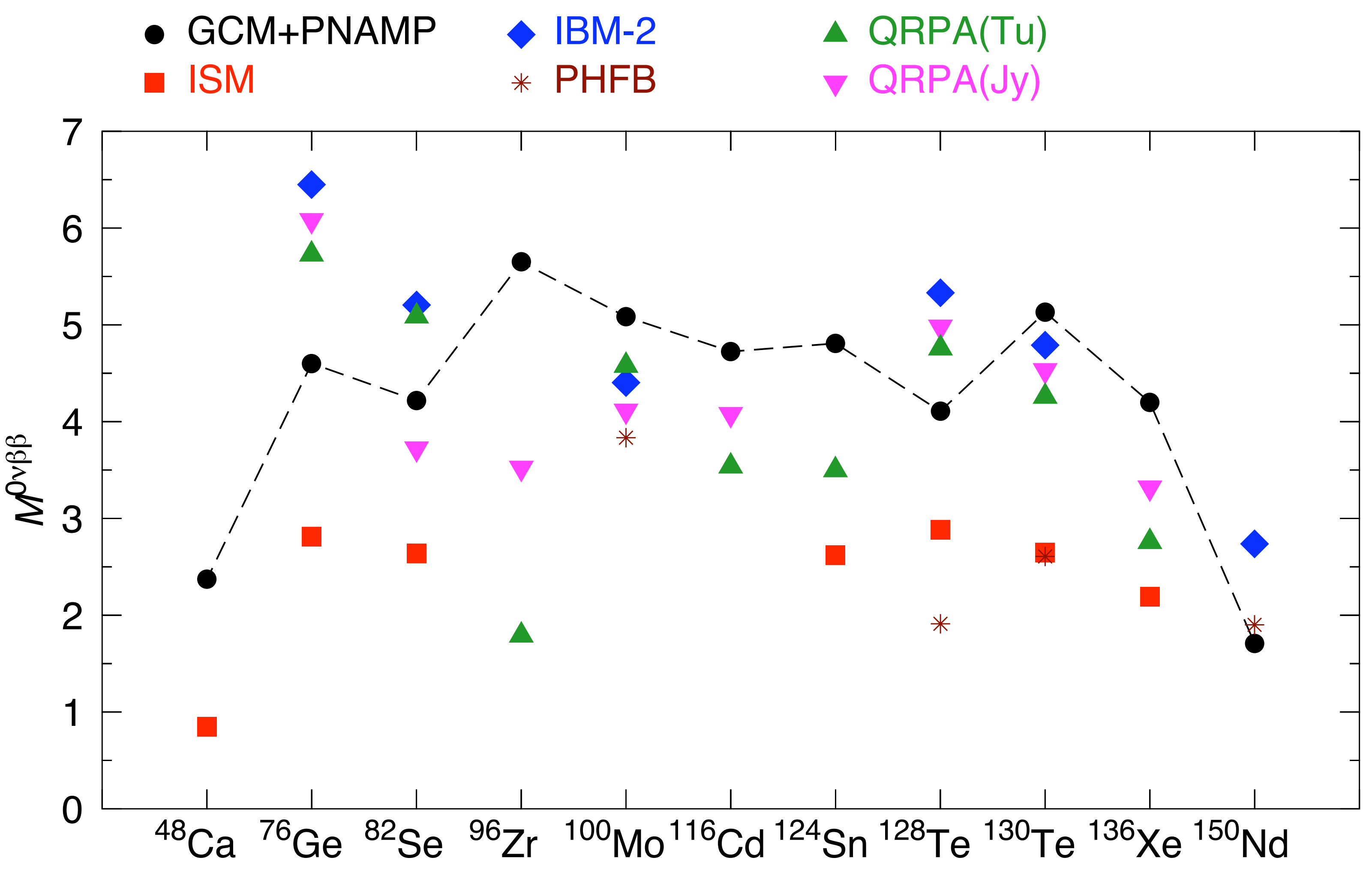

QRPA (Jy):)M. Kortelainen, J. Suhonen, PRC 75, 051303(R) (2007) and PRC 76, 024315 (2007)

QRPA(Tu): F. Simkovic et al., PRC 77, 045503 (2008)

ISM: J. Menendez et al., PRL 100, 52503 (2008)

IBM-2:J. Barea, F. Iachello, PRC 77, 045503 (2008)

PHFB: K. Chaturvedi et al. PRC 78, 054302 (2008)

- Higher values than the ones predicted by ISM calculations (larger valence space, lower seniority components).
- For *A*=76, 82, 128, 150 we predict smaller values than the ones given by QRPA and/or IBM while for *A*=96, 100, 116, 124, 130, 136 larger values are obtained.
- Consistent results with the rest of the models. Notice that we are using the same interaction for all the nuclei.
- Further studies are needed to understand what is missing in the different models.

CONTENTS

Summary and Conclusions (I)

- First calculations of neutrinoless double beta decay using GCM+PNAMP with the Gogny D1S interaction.
- First calculations with Particle Number Projection for different number of particles in bra and ket states.
- Formalism equivalent to a pairing term in the multi-reference EDF formalism.
- Explicit inclusion of deformation and shape mixing.
- Axial calculations with parity and time reversal conservation.

CONTENTS

Summary and Conclusions (II)

- Transition operators favor similar deformation for mother and granddaughter nuclei.
- Fermi contributions are smaller than Gamow-Teller.
- The structure can be understood studying the p-p channel of the nuclei involved in the transition.
- For A = 76, 82, 96, 100, 116, 124, 128, 130, 136 values between 4.1-5.6 are obtained
- For A = 150 the difference between deformation of the initial and final states lowers the value of the NME.
- For A = 48 the small pairing correlations in Ca and Ti produces a small NME.
- Results of the same order of magnitude than ISM, QRPA and IBM are obtained.
- Similarities and differences between different models will be investigated

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