MEDEX'19

Matrix Elements for the Double beta decay Experiments

Prague 27-31 May, 2019

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Double beta decay NME from deformed QRPA with realistic forces

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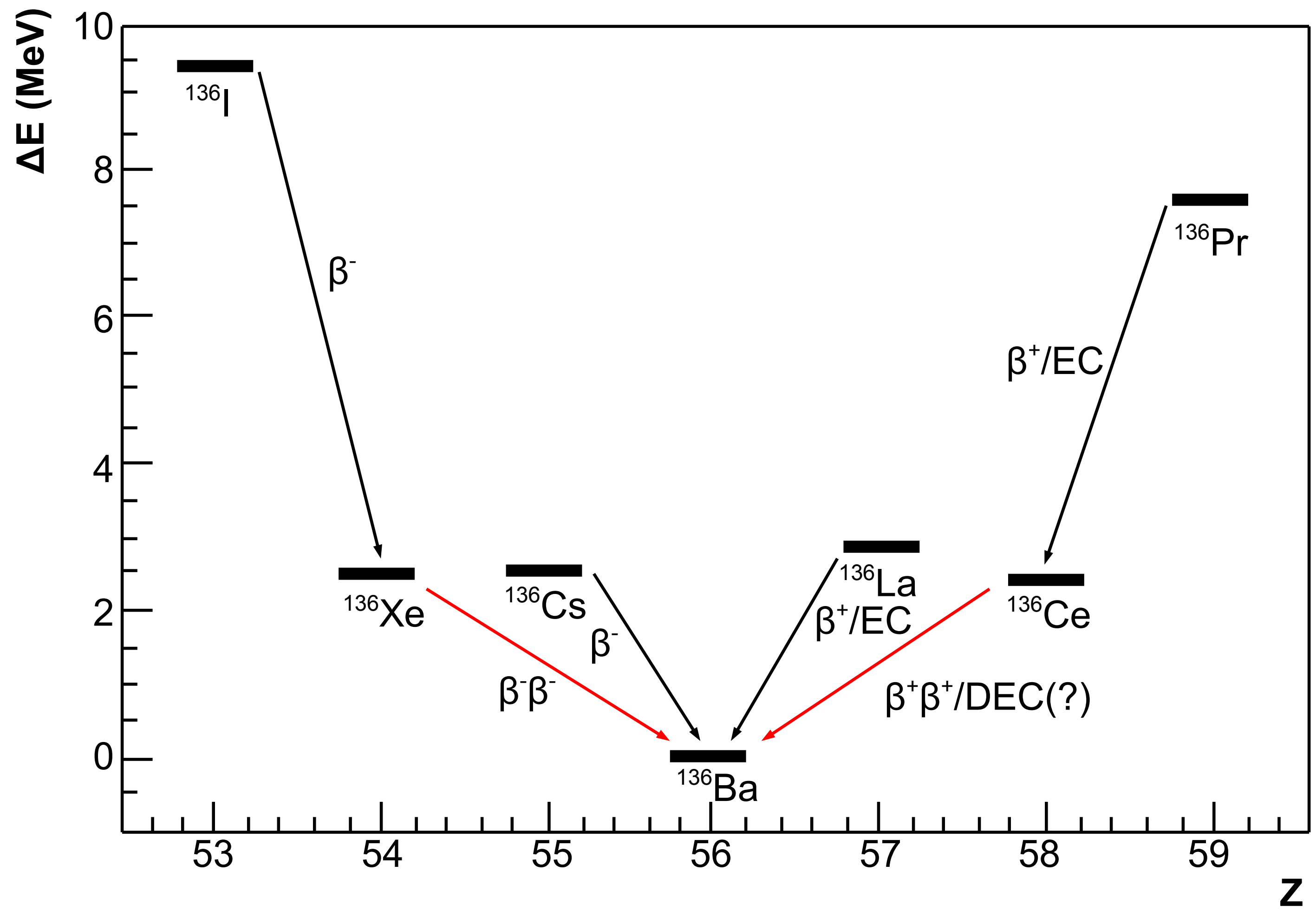
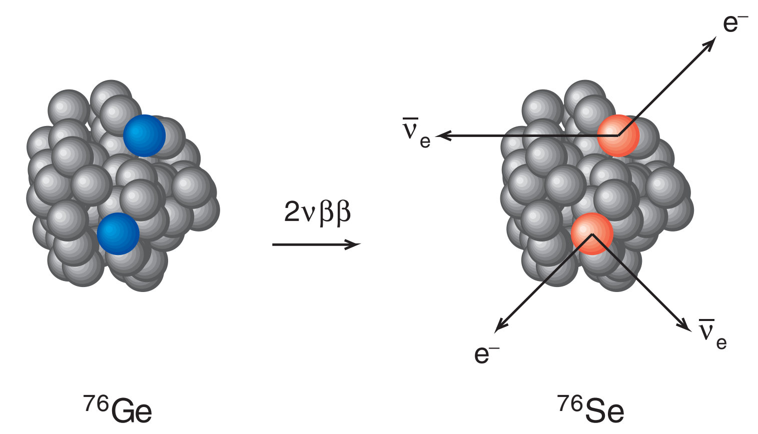
Outline

- Background
- Formalism
- Results
- Conclusion

Background



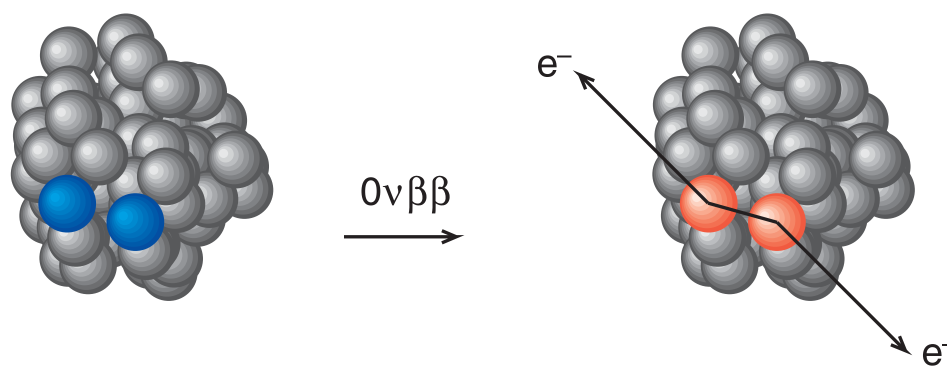


$$\left[T_{1/2}^{2\nu}(0^+_{\text{g.s.}} \to 0^+_{\text{g.s.}})\right]^{-1} = G^{2\nu}\left|M_{\text{GT}}^{2\nu}\right|^2$$

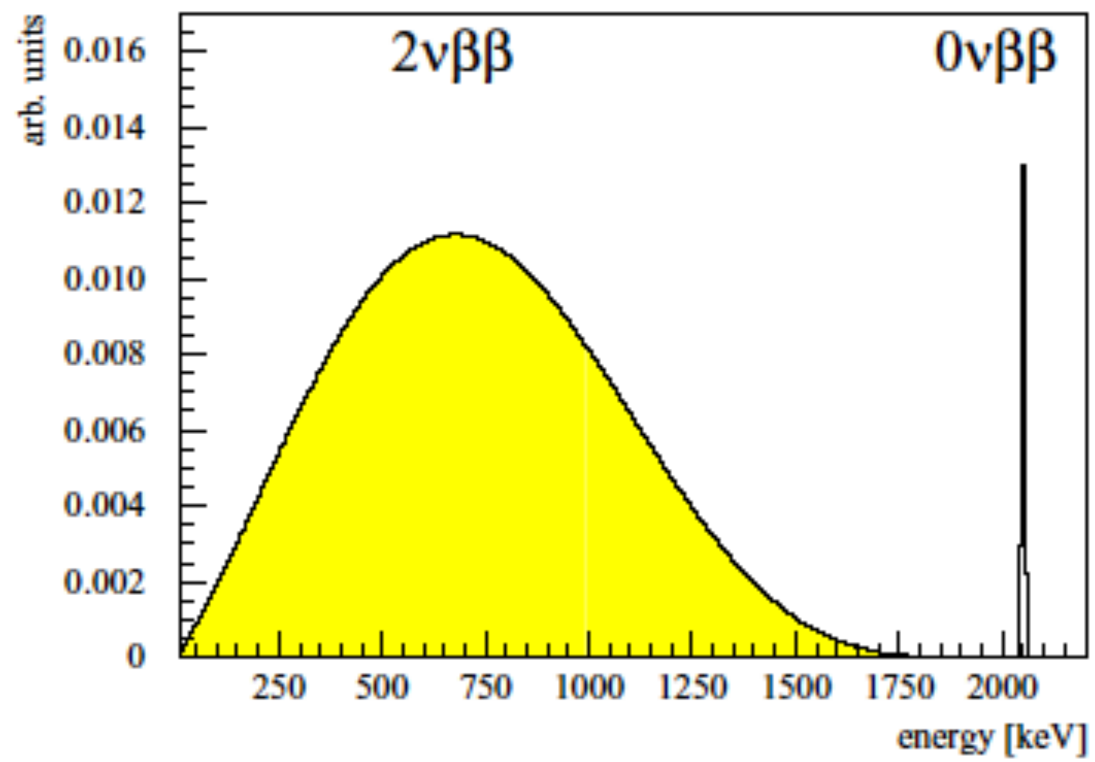
$$M_{\text{GT}}^{2\nu} = \sum_m \frac{\langle 0_f^+ \| \beta^- \| m \rangle \langle m \| \beta^- \| 0_i^+ \rangle}{\bar{\omega}_m}$$

- Nuclear pairing induced odd-odd instability

Background



$$\left[T^{0\nu}_{1/2}\right]^{-1} = G_{01} g_A^4 \left| \eta_{0\nu} M_{0\nu} + \left(\eta^L_{N_R} + \eta^R_{N_R}\right) M_{0N} + \eta_{\tilde{q}} M_{\tilde{q}} + \eta_{\lambda'} M_{\lambda'} + \eta_\lambda X_\lambda + \eta_\eta X_\eta \right|^2 .$$



- Neutrinoless double beta decay (0νββ):
- Majorana mass, L-R Mixing

Background

Isotope	$T_{1/2}(2\nu)$ (years)	$M^{2\nu}$
^{48}Ca	$4.4^{+0.6}_{-0.5} \times 10^{19}$	$0.0238^{+0.0015}_{-0.0017}$
^{76}Ge	$(1.5 \pm 0.1) \times 10^{21}$	$0.0716^{+0.0025}_{-0.0023}$
^{82}Se	$(0.92 \pm 0.07) \times 10^{20}$	$0.0503^{+0.0020}_{-0.0018}$
^{96}Zr	$(2.3 \pm 0.2) \times 10^{19}$	$0.0491^{+0.0023}_{-0.0020}$
^{100}Mo	$(7.1 \pm 0.4) \times 10^{18}$	$0.1258^{+0.0037}_{-0.0034}$
^{100}Mo-^{100}Ru(0_1^+)	$5.9^{+0.8}_{-0.6} \times 10^{20}$	$0.1017^{+0.0056}_{-0.0063}$
^{116}Cd	$(2.8 \pm 0.2) \times 10^{19}$	$0.0695^{+0.0025}_{-0.0024}$
^{128}Te	$(1.9 \pm 0.4) \times 10^{24}$	$0.0249^{+0.0031}_{-0.0023}$
^{130}Te	$(6.8^{+1.2}_{-1.1}) \times 10^{20}$	$0.0175^{+0.0016}_{-0.0014}$
^{150}Nd	$(8.2 \pm 0.9) \times 10^{18}$	$0.0320^{+0.0018}_{-0.0017}$
^{150}Nd-^{150}Sm(0_1^+)	$1.33^{+0.45}_{-0.26} \times 10^{20}$	$0.0250^{+0.0029}_{-0.0034}$
^{238}U	$(2.0 \pm 0.6) \times 10^{21}$	$0.0271^{+0.0053}_{-0.0033}$
^{130}Ba; ECEC(2ν)	$(2.2 \pm 0.5) \times 10^{21}$	$0.105^{+0.014}_{-0.010}$

A. S. Barabash, NPA935,52(2015)

- **Measured isotopes**

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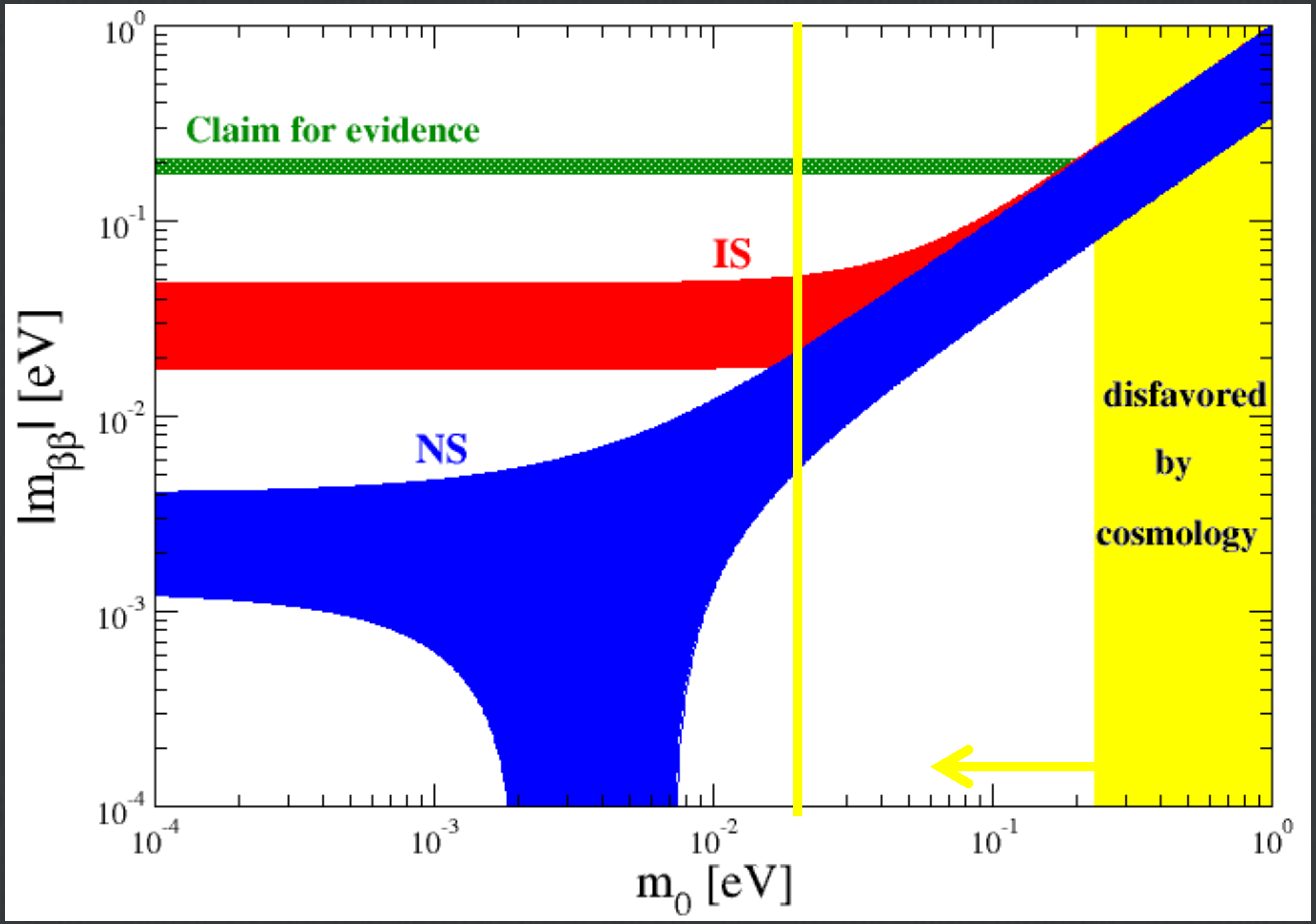

- Effective neutrino mass

$$m_{\beta\beta} = \sum_j U_{ej}^2 m_j$$

Formalism

- Methods adopted for the calculations of NME
  - Closure without involvement of intermediate states
    - IBM, PHFB, DFT, CDFT,……
  - Non-Closure with intermediated states
    - Shell Model
    - QRPA: realistic forces; Skyrme force;……

Formalism

- Introduction of deformed QRPA
  - Adiabatic approx. separate the intrinsic and rotation d.f.
  - Quasi-particle constructed on intrinsic frame
- Why deformation:
  - ^{150}Nd lies in the heavily deformed rare earth region
  - This nucleus has the largest phase space factor

Formalism

Kotila and Iachello, PRC85,034316

Nucleus	$G_{0\nu}^{(0)}$ (10^{-15} yr^{-1})	$G_{0\nu}^{(1)}$ (10^{-15} yr^{-1})	$Q_{\beta\beta}$ (MeV)
^{48}Ca	24.81	−23.09	4.27226(404)
^{76}Ge	2.363	−1.954	2.03904(16)
^{82}Se	10.16	−9.074	2.99512(201)
^{96}Zr	20.58	−18.67	3.35037(289)
^{100}Mo	15.92	14.25	3.03440(17)
^{110}Pd	4.815	−4.017	2.01785(64)
^{116}Cd	16.70	−14.83	2.81350(13)
^{124}Sn	9.040	−7.765	2.28697(153)
^{128}Te	0.5878	−0.3910	0.86587(131)
^{130}Te	14.22	−12.45	2.52697(23)
^{136}Xe	14.58	12.73	2.45783(37)
^{148}Nd	10.10	−8.506	1.92875(192)
^{150}Nd	63.03	−57.76	3.37138(20)
^{154}Sm	3.015	−2.295	1.21503(125)
^{160}Gd	9.559	−7.932	1.72969(126)
^{198}Pt	7.556	−5.868	1.04717(311)
^{232}Th	13.93	−10.95	0.84215(246)
^{238}U	33.61	28.13	1.14498(125)

- Recent results on phase space factor

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- Recent results on phase space factor

Formalism

- Nuclear matrix elements for 2νββ under intrinsic frame

$$M^{2\nu}_{\rm GT} = \sum_{K=0,\pm1}\sum_{m_i m_f} \frac{\langle 0^+_f|\bar{\beta}^-_K|K^+, m_f\rangle\langle K^+, m_f|K^+, m_i\rangle\langle K^+, m_i|\beta^-_K|0^+_i\rangle}{\bar{\omega}_{K,m_i m_f}}$$

- NME for 0νββ

$$M^{0\nu}(K^\pi) = \sum_{m_i,m_f} \langle 0^+_f|c^\dagger_p c_n|K^\pi m_f\rangle\langle K^\pi m_f|K^\pi m_i\rangle\ \langle K^\pi m_i|c^\dagger_{p'}c_{n'}|0^+_i\rangle$$
$$\times \sum_J \sum_{\substack{\eta_p\eta_{p'}\\ \eta_n\eta_{n'}}} F^{JK}_{p\eta_p n\eta_n} F^{JK}_{p'\eta_{p'}n'\eta_{n'}} \sum_{\mathcal{J}} (-1)^{j_n+j_{p'}+J+\mathcal{J}}\hat{\mathcal{J}} \begin{Bmatrix} j_p & j_n & J \\ j_{n'} & j_{p'} & \mathcal{J} \end{Bmatrix} \langle p(1),\ p'(2);\mathcal{J}\|\mathcal{O}_\ell(1,2)\|n(1),\ n'(2);\mathcal{J}\rangle$$

- Overlaps :

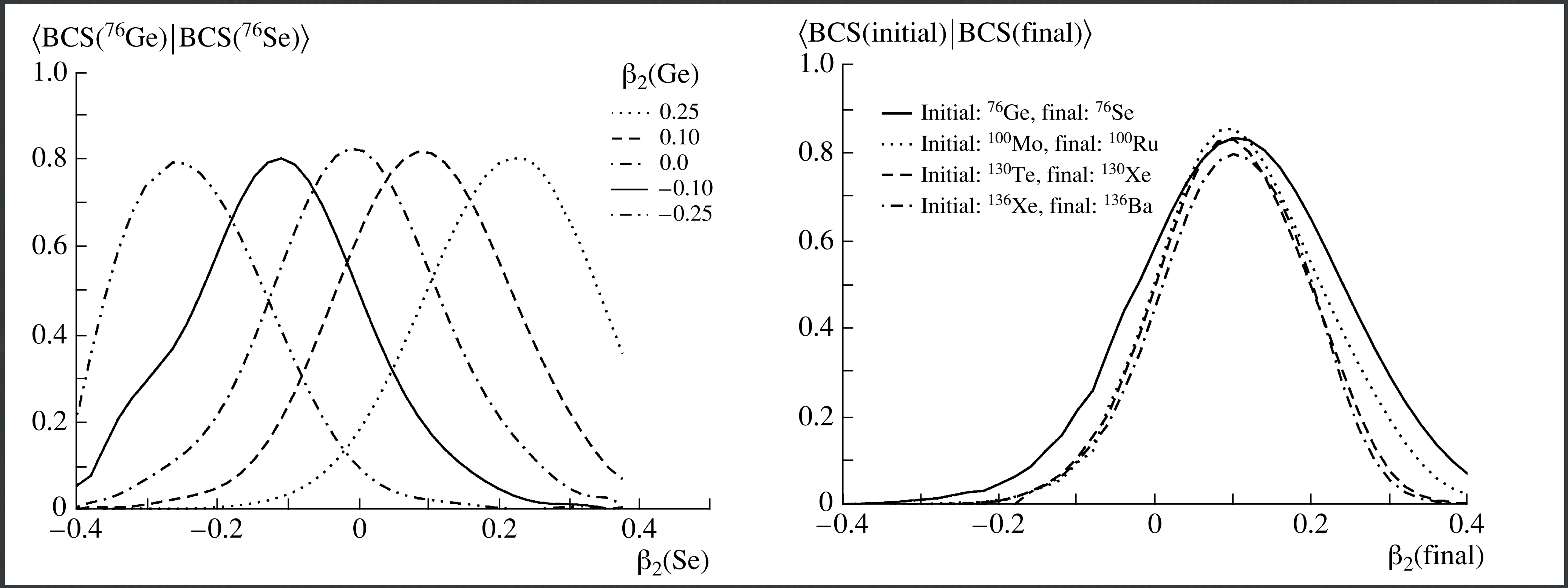
$$\langle K^\pi m_f|K^\pi m_i\rangle = \sum_{l_i l_f}\left[X^{m_f}_{l_f K^\pi}X^{m_i}_{l_i K^\pi} - Y^{m_f}_{l_f K^\pi}Y^{m_i}_{l_i K^\pi}\right]\ \mathcal{R}_{l_f l_i}\langle {\rm BCS}_f|{\rm BCS}_i\rangle$$

Formalism

- Induced weak hadron Current $$J^{\mu}(\vec{x})=\sum_{n=1}^{A}\tau_n^{+}[g^{\mu 0}J^0(\vec{q}^2)+g^{\mu k}J_n^k(\vec{q}^2)]\delta(\vec{x}-\vec{r}_n)$$
- With $$J^0(\vec{q}^2)=g_V(q^2),\quad \vec{J}_n(\vec{q}^2)=g_M(\vec{q}^2)i\frac{\vec{\sigma}_n\times\vec{q}}{2m_p}+g_A(\vec{q}^2)\vec{\sigma}-g_P(\vec{q}^2)\frac{\vec{q}\vec{\sigma}_n\cdot\vec{q}}{2m_p}$$
- Therefore $$M^I_{\text{type}}=\langle H^I_{\text{type}-\text{F}}(r_{12})+H^I_{\text{type}-\text{GT}}(r_{12})\sigma_{12}+H^I_{\text{type}-\text{T}}(r_{12})S_{12}\rangle$$
- Where $$S_{12}=3(\vec{\sigma}_1\cdot\hat{\mathbf{r}}_{12})(\vec{\sigma}_2\cdot\hat{\mathbf{r}}_{12})-\sigma_{12},\quad \sigma_{12}=\vec{\sigma}_1\cdot\vec{\sigma}_2$$
- And $$H^{\text{light}}_{\text{type-}K}(r_{12})=\frac{2}{\pi g_A^2}\frac{R}{r_{12}}\int_0^{\infty}\frac{\sin(qr_{12})}{q+E_J^m-(E^i_{\text{g.s.}}+E^f_{\text{g.s.}})/2}\,h_{\text{type}-K}(q^2)dq$$
- $$H^{\text{heavy}}_{\text{type-}K}(r_{12})=\frac{1}{m_pm_e}\frac{2}{\pi g_A^2}\frac{R}{r_{12}}\int_0^{\infty}\sin(qr_{12})h_{\text{type-}K}(q^2)q\,dq$$

Results

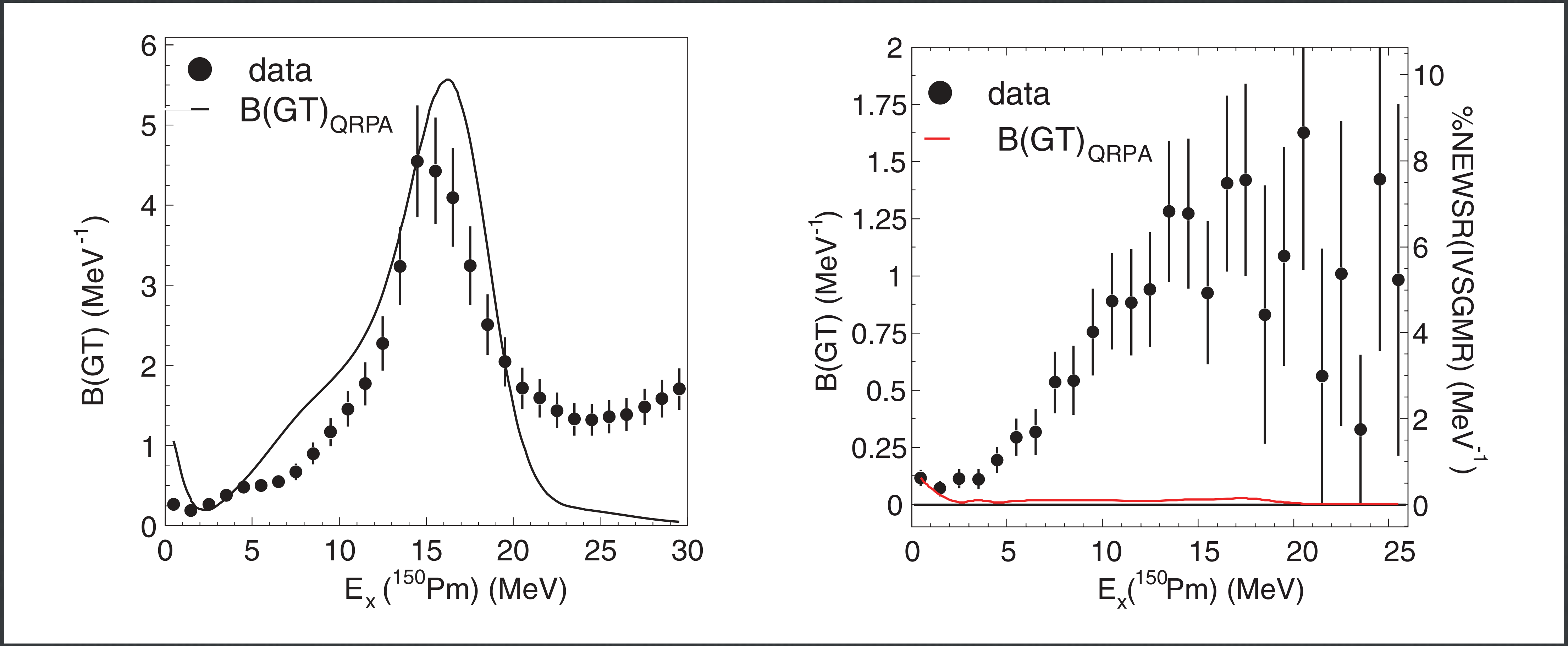
L. Pacerescu et al. Phys. Atom Nucl. 67,1210(2004)



- BCS overlaps

Results

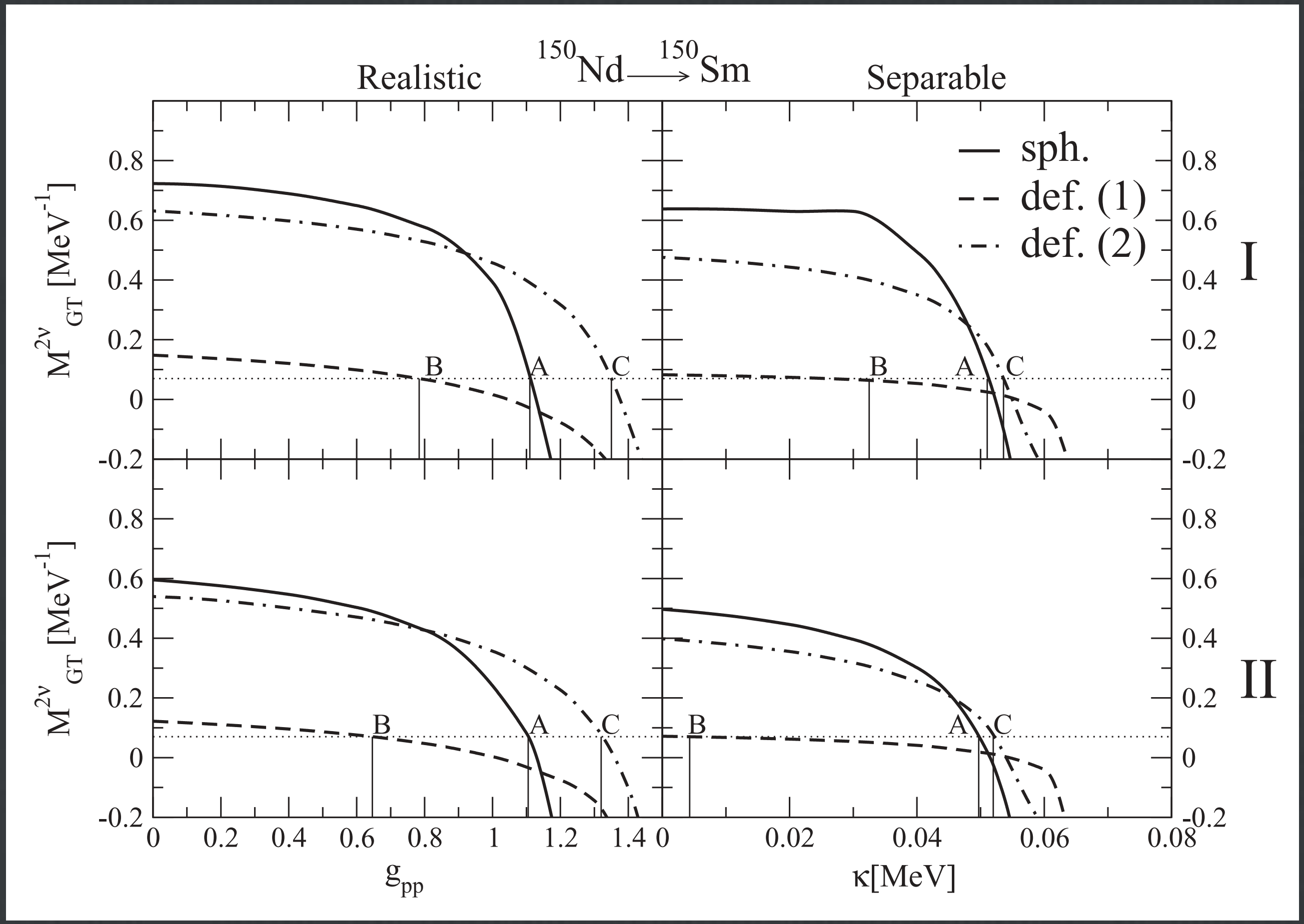
C. J. Guess et al. PRC83,064318(2011)



- ☐ Validation of the theory

Results

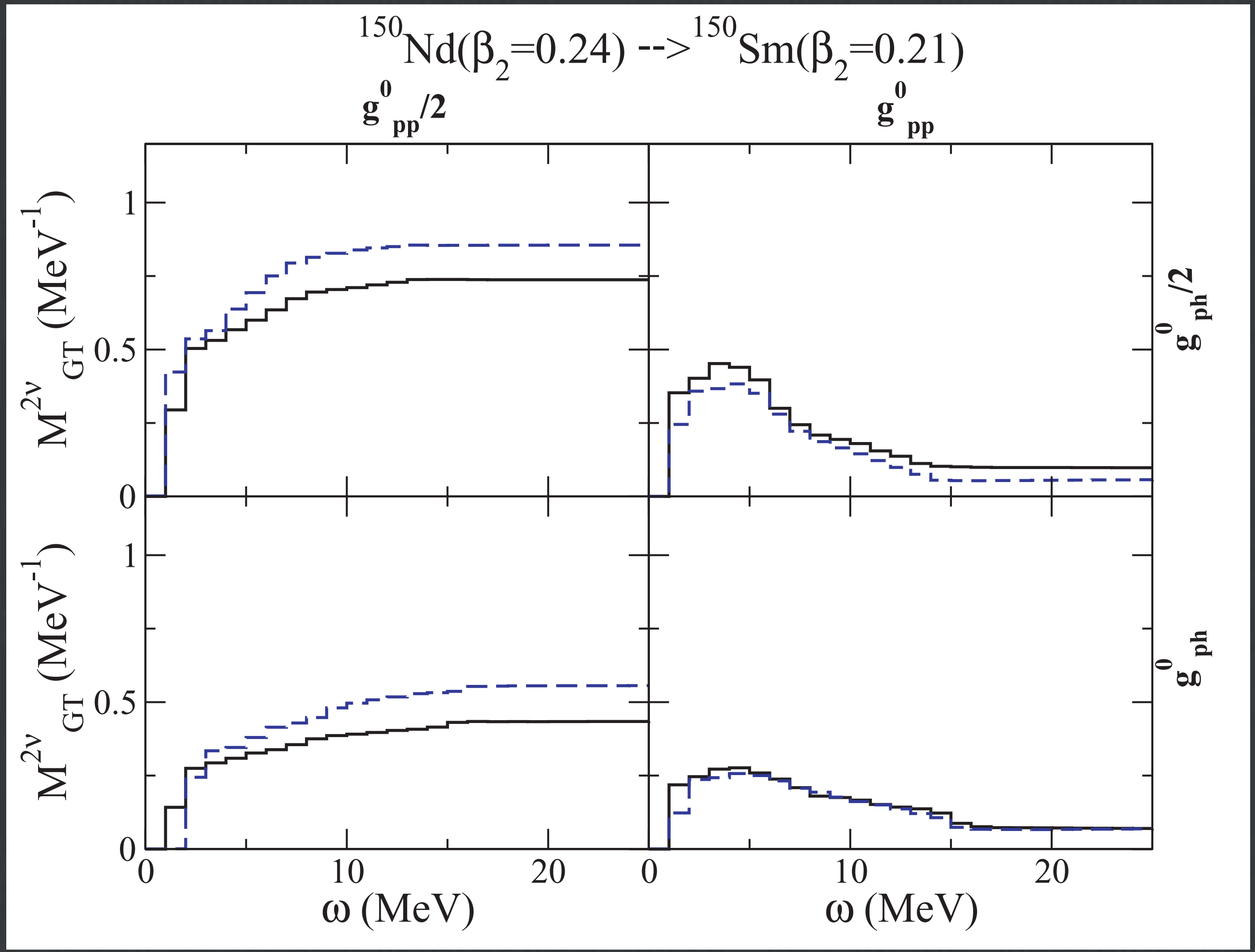
M.S.Yousef et. al. PRC79,014314(2009)



- Dependance of NME for 2νββ on residual interactions

Results

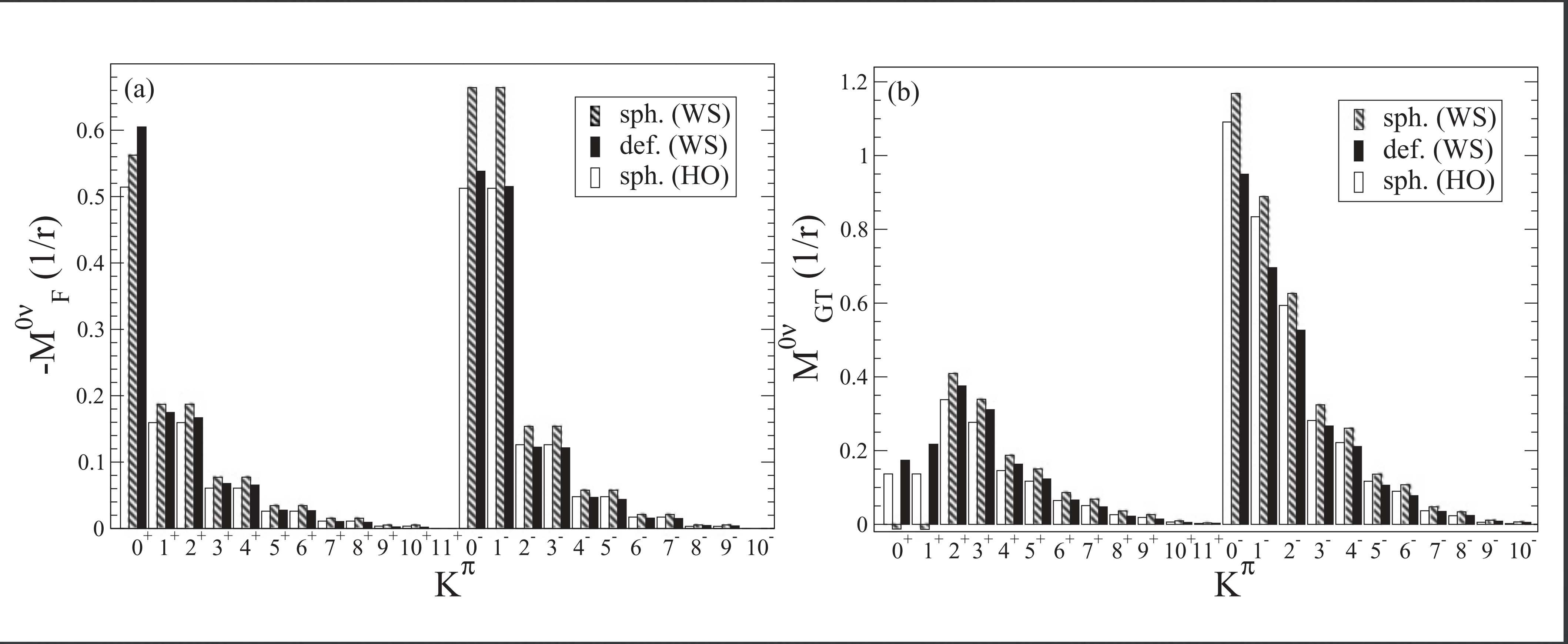
DLF et al. PRC81,037303(2010)



- ☐ Lowlying states dominance

Results

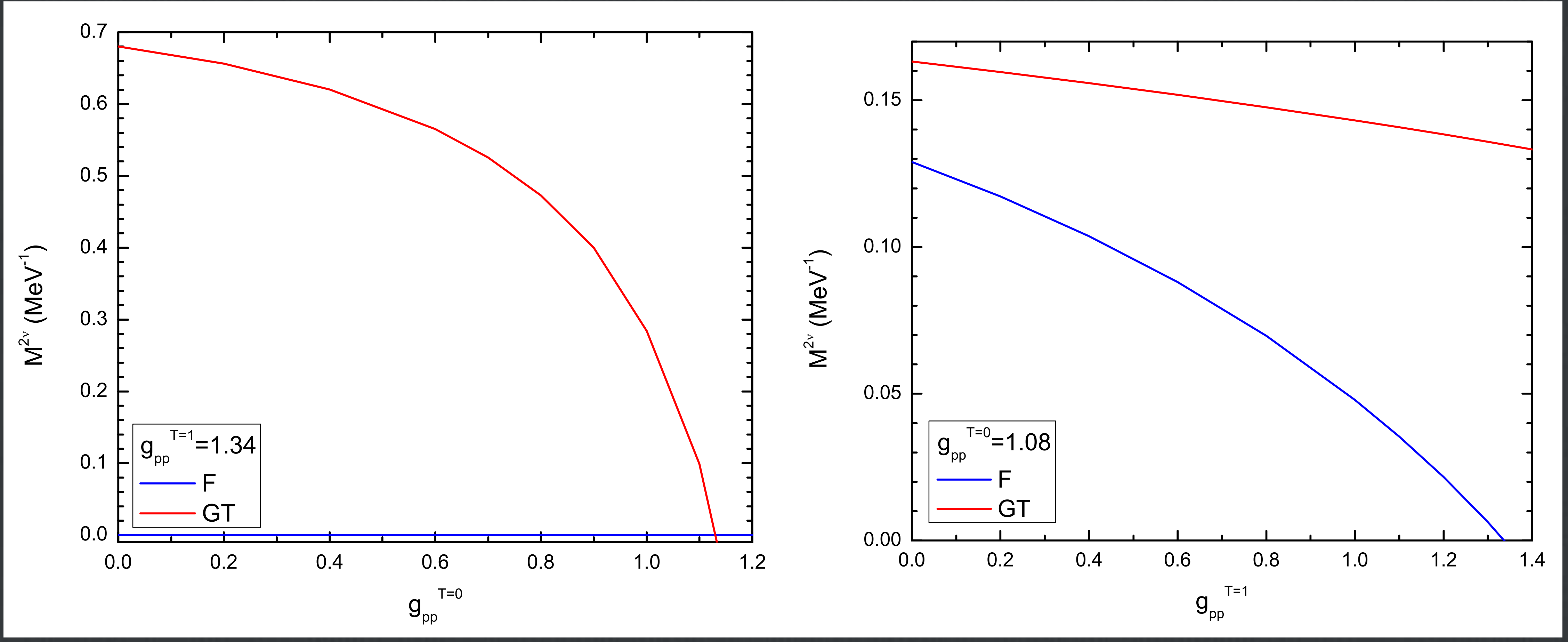
DLF et al. PRC83,034320(2011)



- Comparison of results from different wave functions

Results

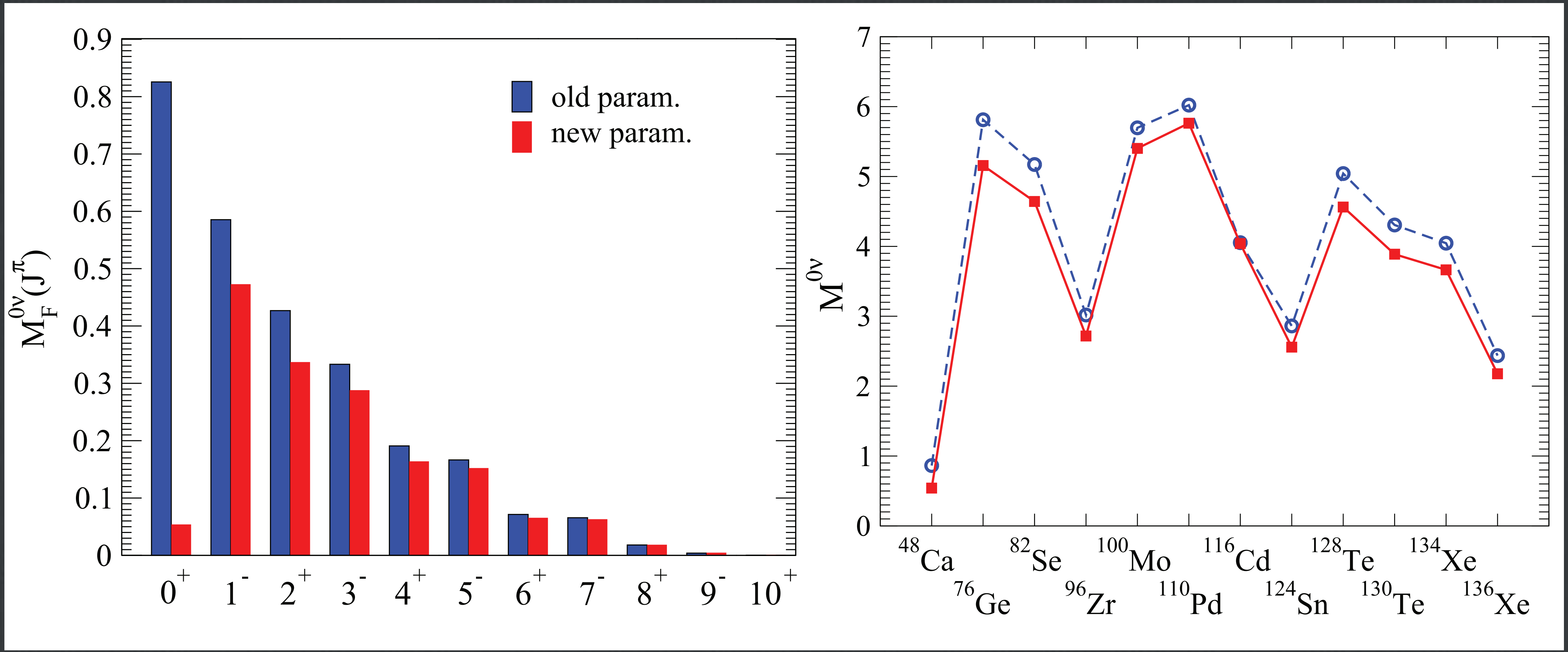
V. Rodin and A. Faessler PRC84,014322(2011)



- Restoration of isospin symmetry $M_F^{2\nu}=0$

Results

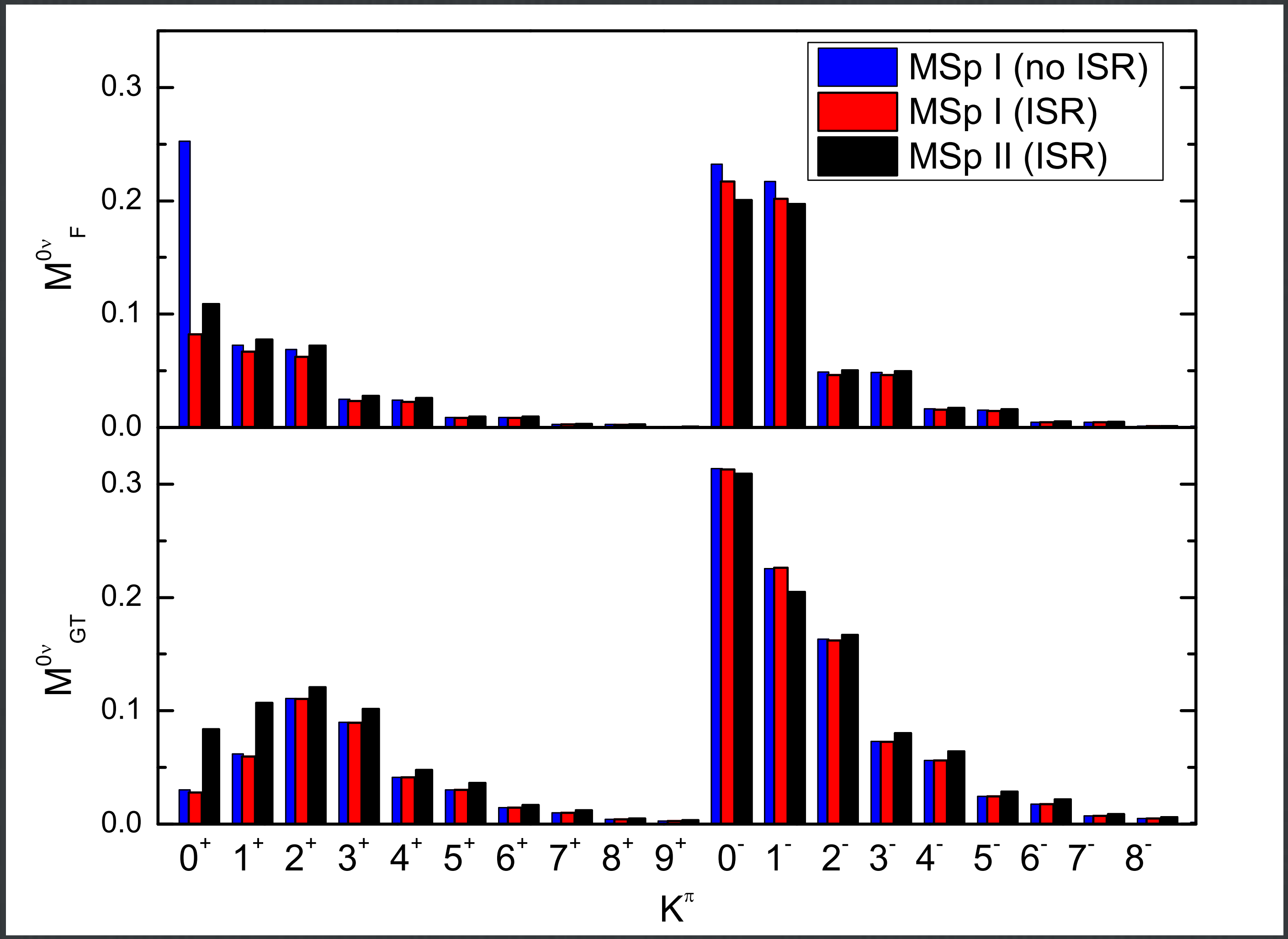
F. Simkovic et al. PRC87,045501(2013)



- ☐ Impact of Isospin restoration on $0\nu\beta\beta$

Results

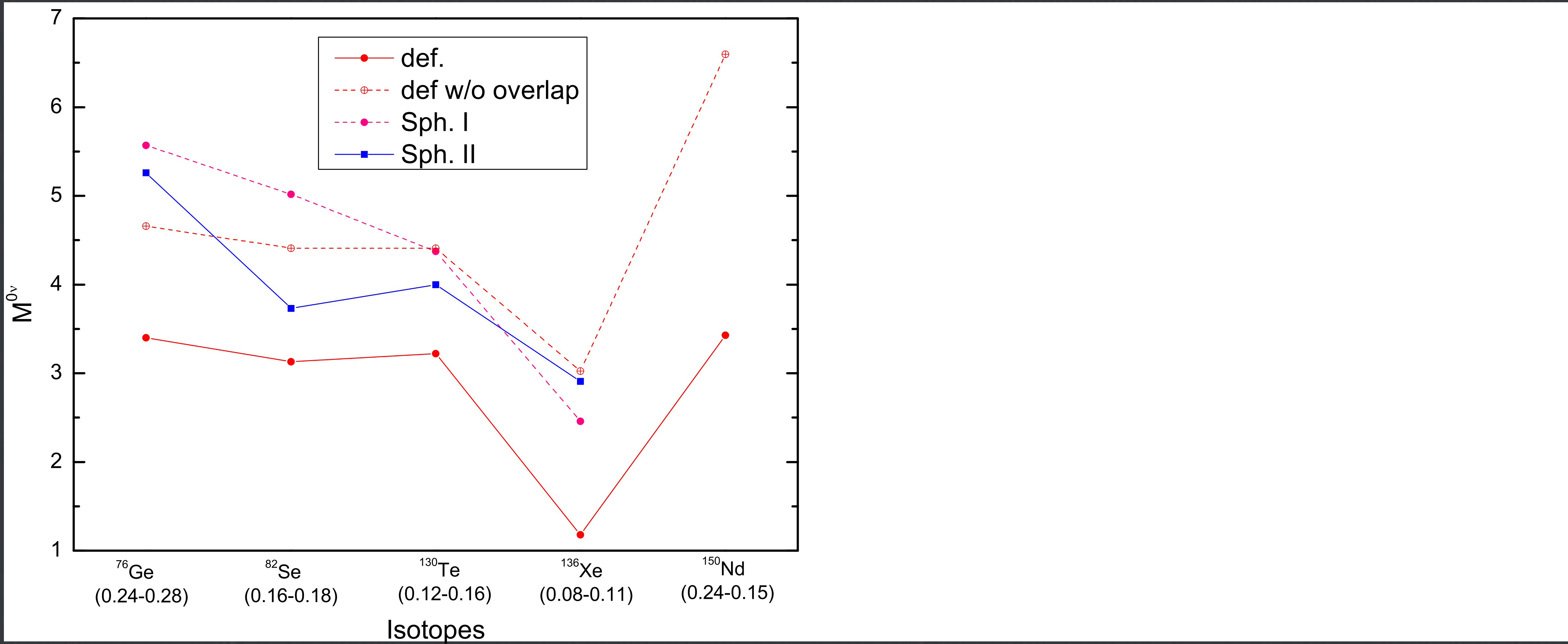
DLF et al. PRC92,044301(2015)



- $0\nu\beta\beta$ matrix elements with isospin symmetry restoration

Results

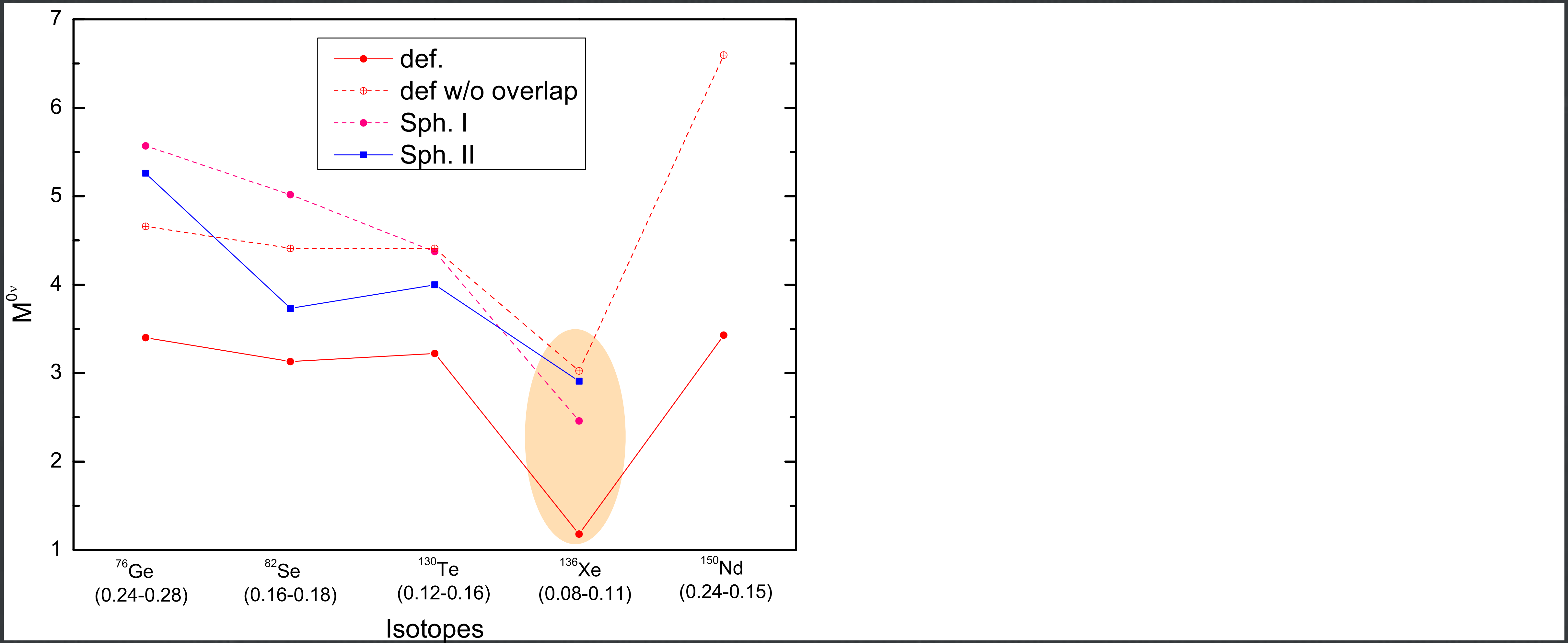
DLF et al. PRC97,045503(2018)



- NME of double beta decay and role of deformation and overlap factors

Results

DLF et al. PRC97,045503(2018)



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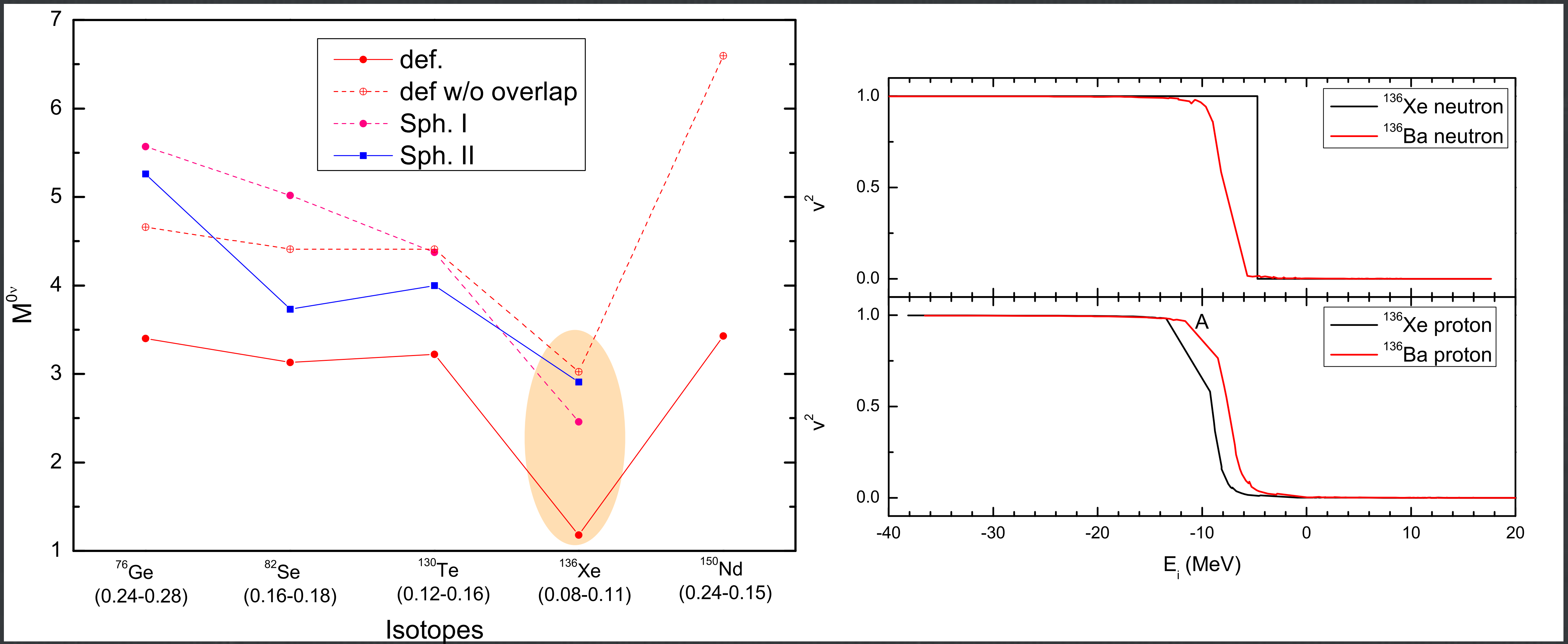

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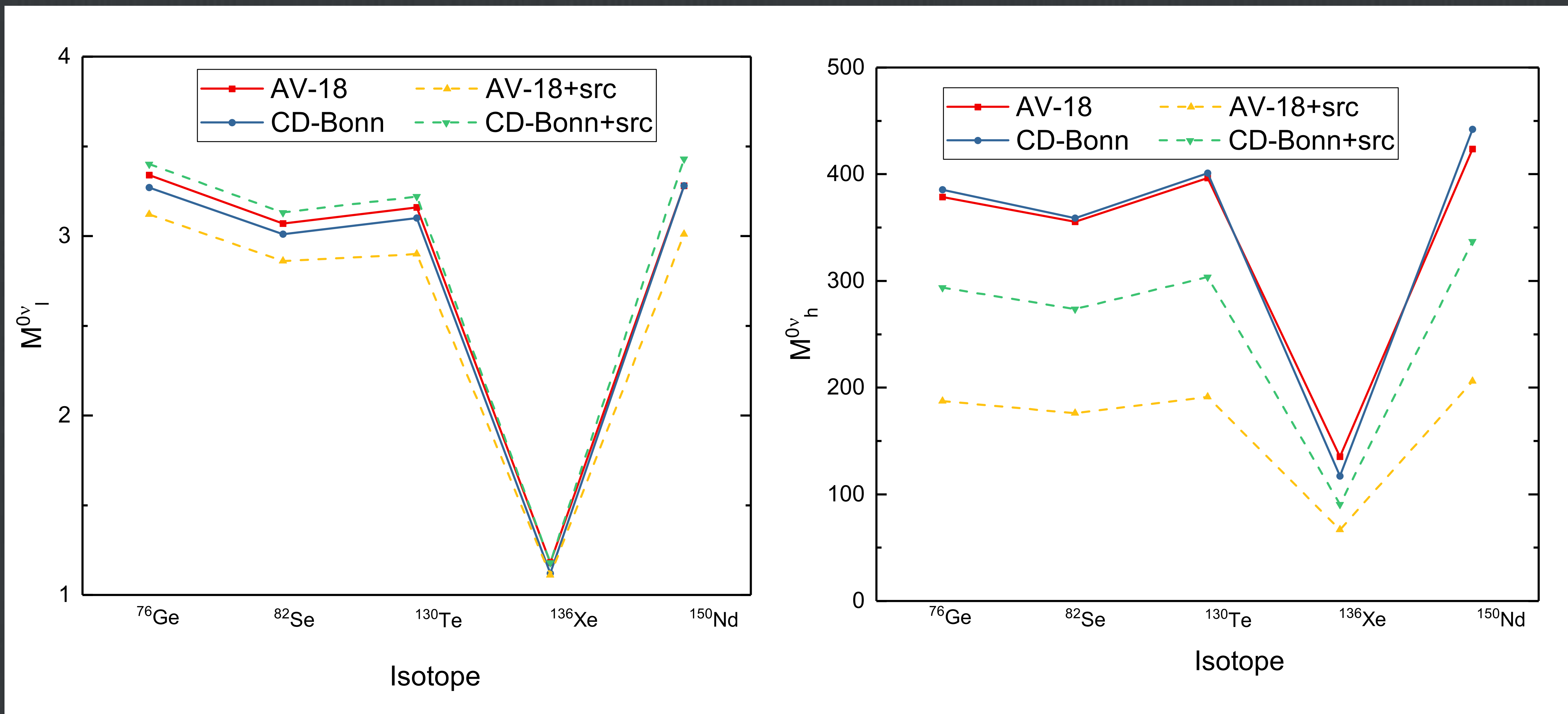
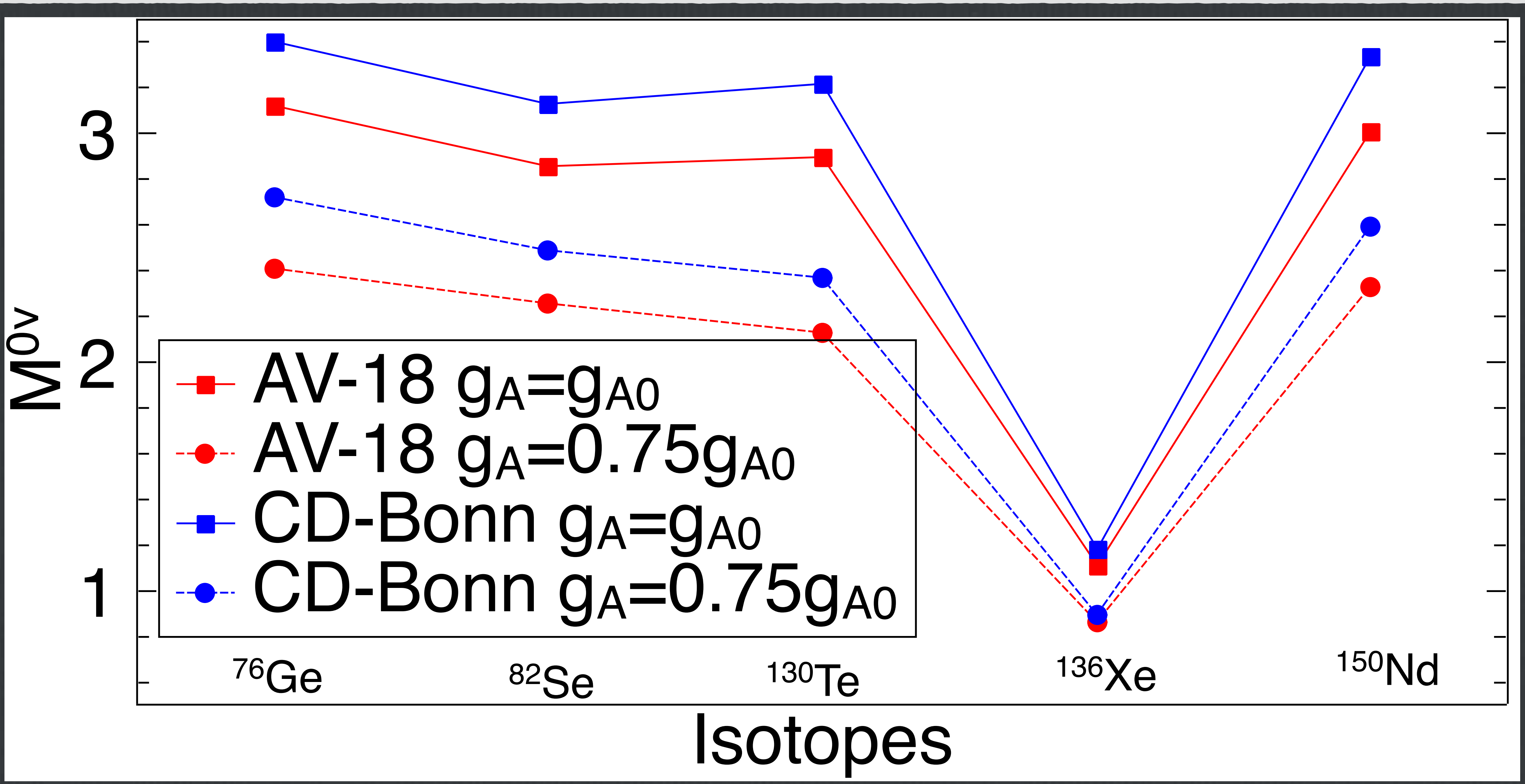
DLF et al. PRC97,045503(2018)



- ☐ **Impact from Short-Range Correlation**

Results

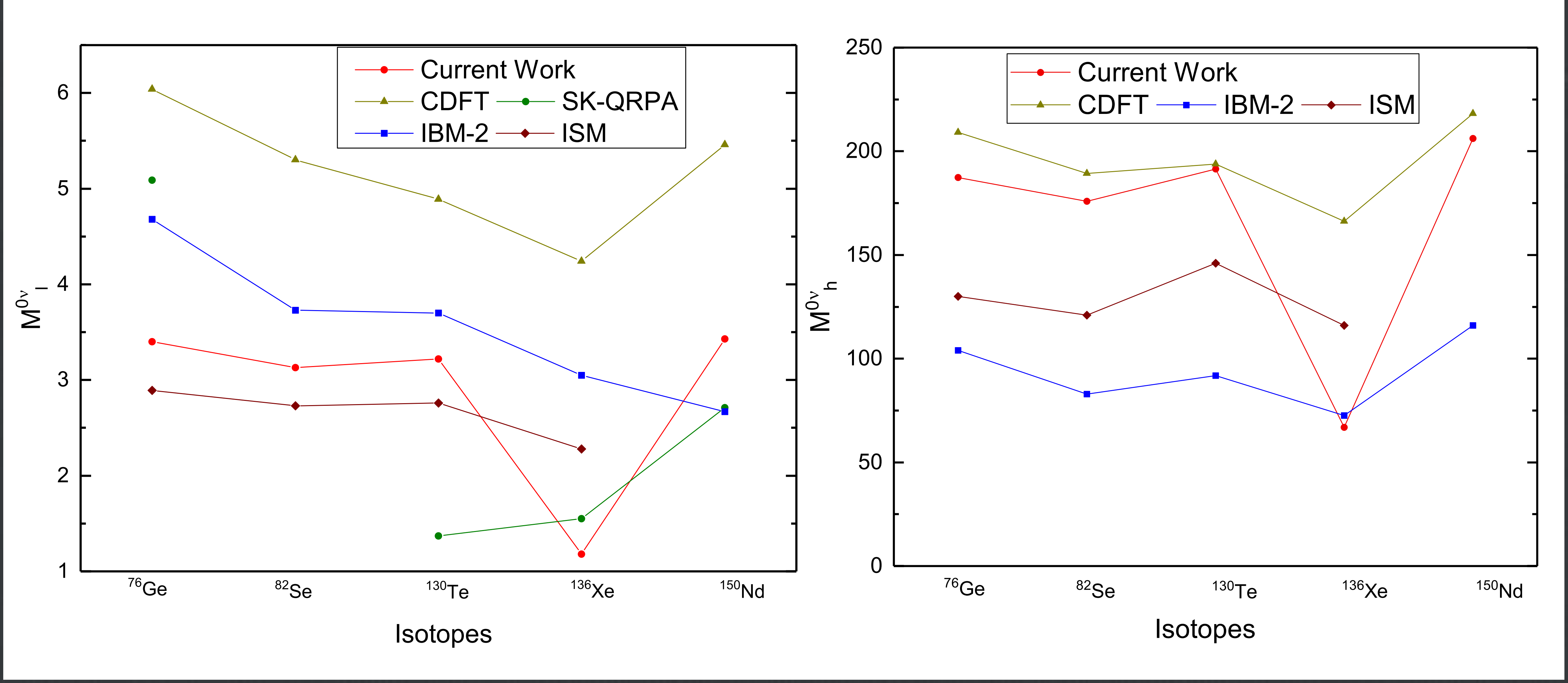
DLF et al. PRC97,045503(2018)



- ☐ The quenching of g_A

Results

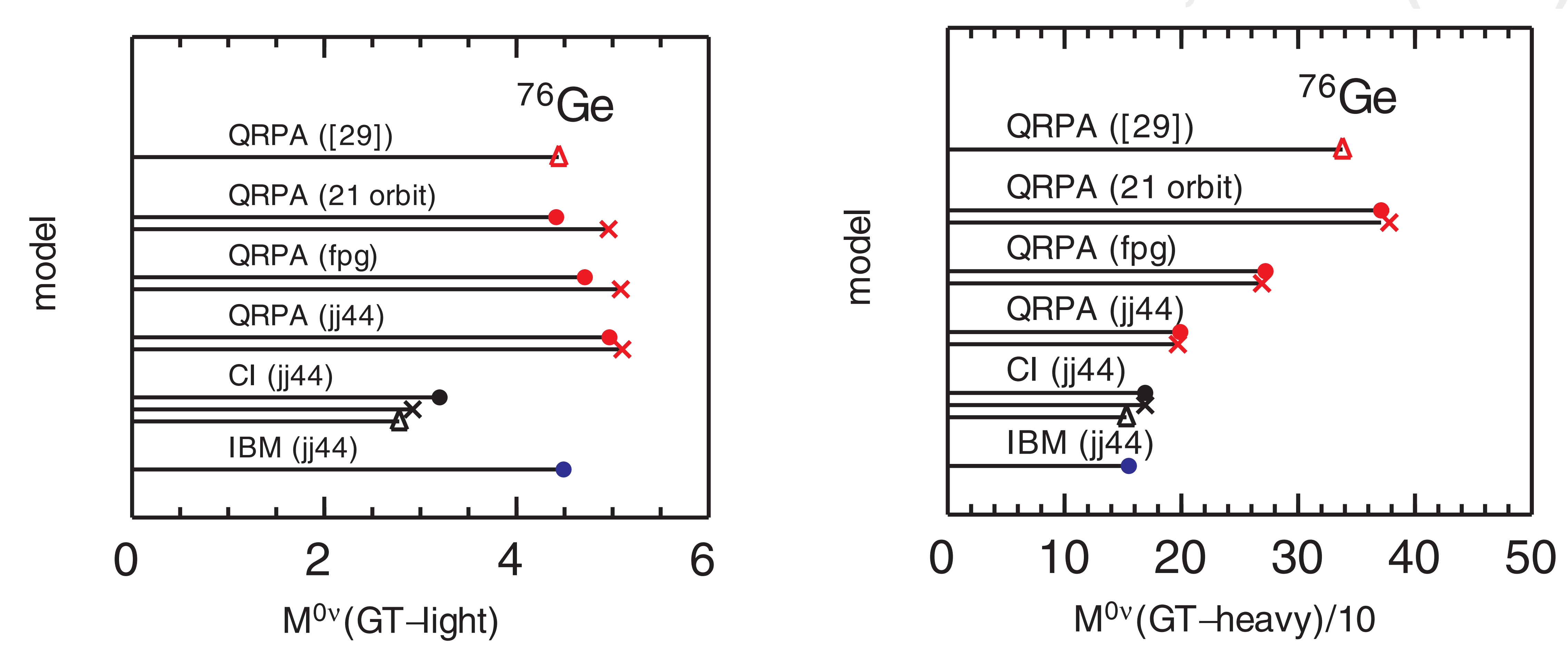
DLF et al. PRC97,045503(2018)



- Results from different models

Results

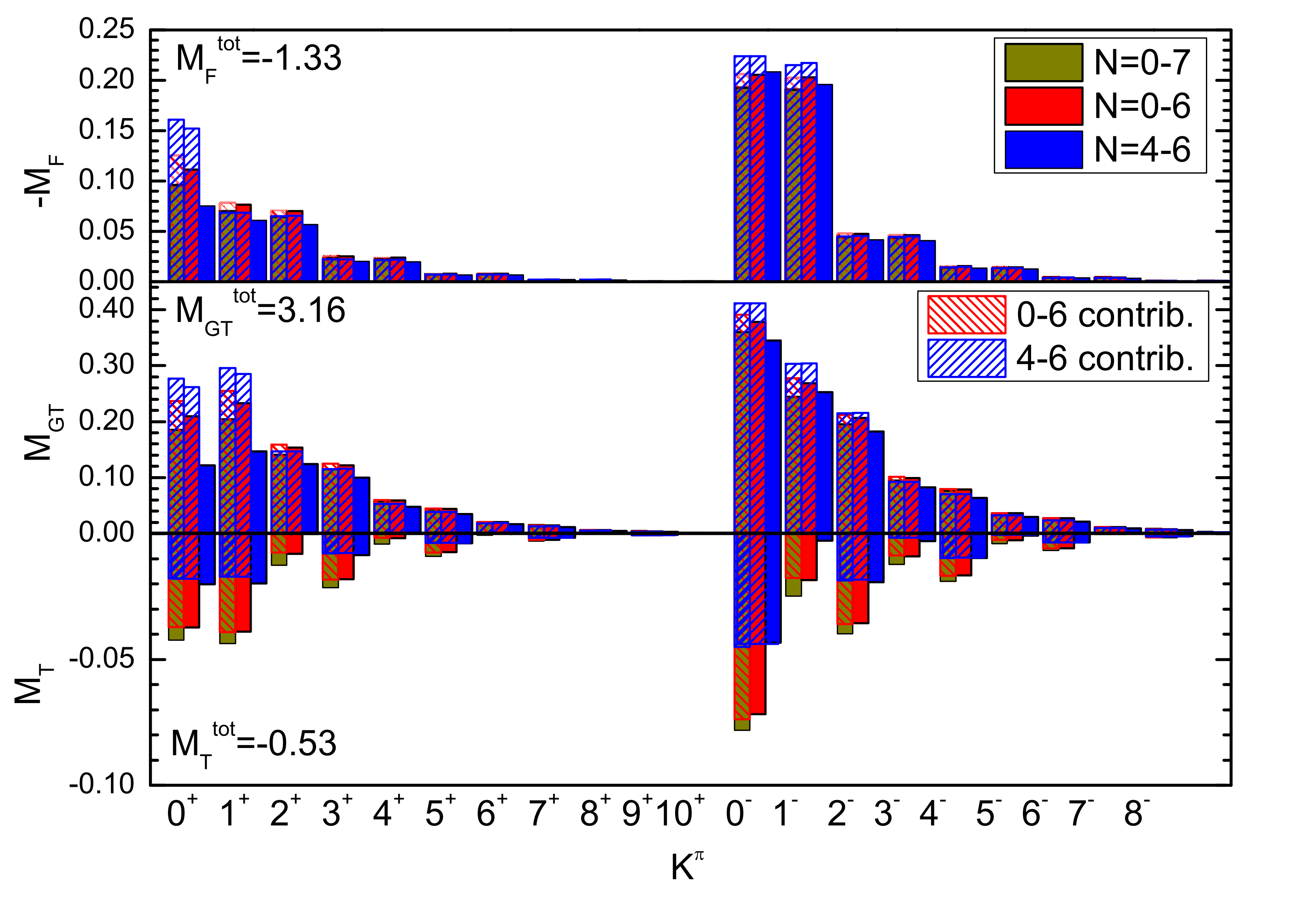
B.A. Brown et. al. PRC92,041301(2015)



- How the deviations come out?

Results

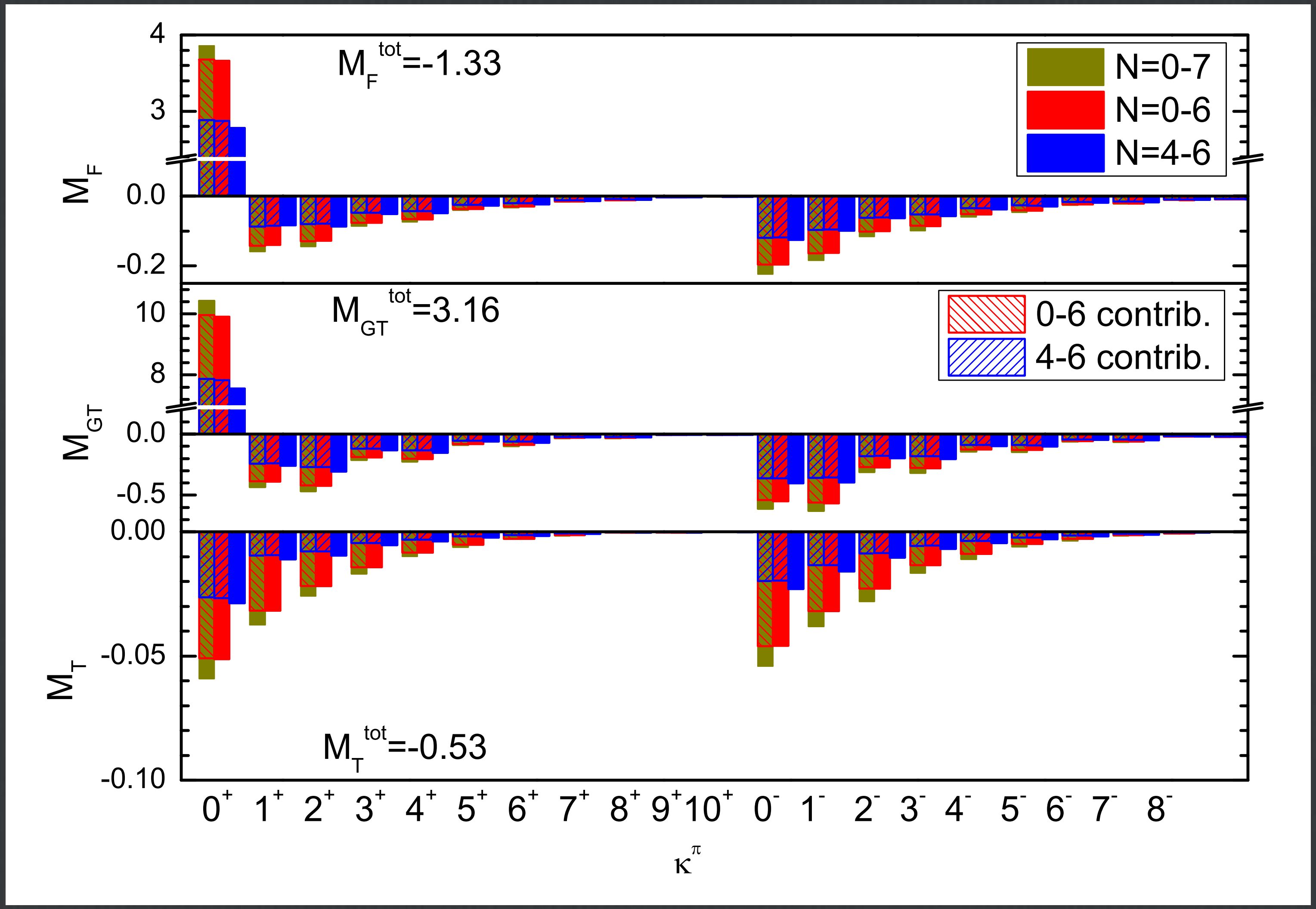
DLF et al. PRC97,045503(2018)



- Contribution from different intermediate states

Results

DLF et al. PRC97,045503(2018)



- Contribution from different nucleon pairs

Conclusion

- We adopted deformed QRPA method with realistic force for the calculation of nuclear matrix elements for double beta decay
- The major effects of deformation comes from the BCS overlaps
- This correction will bring an about 30% reduction

Thanks