Matrix Elements for the $0\nu\beta\beta$ Decay

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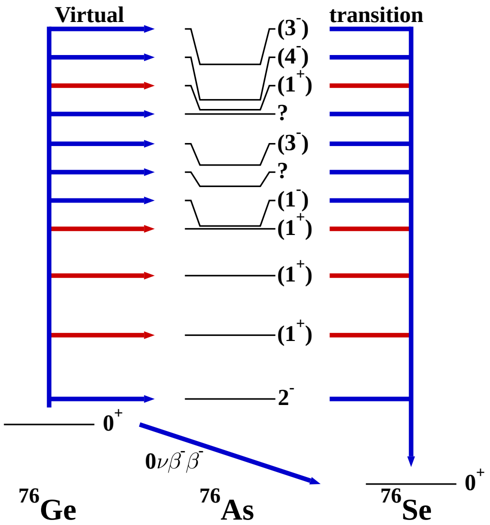
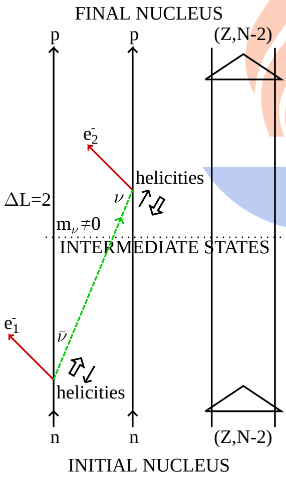
- DBD N.M.E. with Improved Short-Range Correlations
- N.M.E. and Charge-Exchange Reactions

Neutrinoless Double Beta Decay of ^{76}Ge





Short-Range Correlations

For $0\nu\beta\beta$ decay

one has to prevent the two

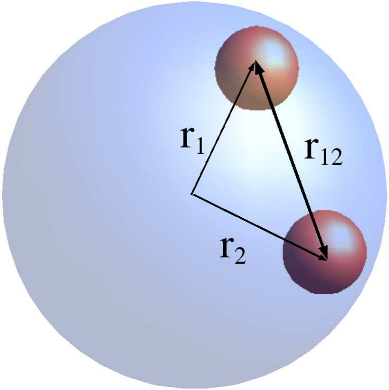
decaying nucleons to overlap

This work is based on

M. Kortelainen, O. Civitarese, J. Suhonen and J. Toivanen, Physics Letters B 647 (2007) 128

M. Kortelainen and J. Suhonen, Physical Review C 75, 051303(R) (2007)

M. Kortelainen and J. Suhonen, Submitted



Matrix Elements of the $0\nu\beta\beta$ Decay

MASS MODE:

$$\left[T_{1/2}^{(0\nu)}\right]^{-1} = G_1^{(0\nu)} \left(\frac{\langle m_\nu \rangle}{m_e}\right)^2 M^{(0\nu)} ,$$

$$M^{(0\nu)} = \left(M_{\rm GT}^{(0\nu)} - \left(\frac{g_{\rm V}}{g_{\rm A}}\right)^2 M_{\rm F}^{(0\nu)} + M_{\rm T}^{(0\nu)}\right)^2 ,$$

$$\langle m_\nu \rangle = \sum_j \lambda_j^{\rm CP} m_j |U_{ej}|^2 ,$$

$$M_{\rm F}^{(0\nu)} = \sum_a (0_f^+ || h_+(r_{mn}, E_a) || 0_i^+) ,$$

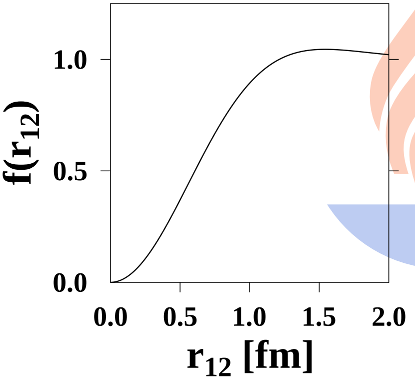
$$M_{\rm GT}^{(0\nu)} = \sum_a (0_f^+ || h_+(r_{mn}, E_a)(\boldsymbol{\sigma}_m \cdot \boldsymbol{\sigma}_n) || 0_i^+) .$$

Traditionally: Jastrow Correlation Function

Jastrow correlation function

$$f_{\rm J}(r) = 1 - e^{-ar}\left(1 - br^2\right) \ ,$$

$$a = 1.1\,{\rm fm}^2 \ , \ b = 0.68\,{\rm fm}^2$$



Cuts away the short-range part of the two-nucleon radial wave function by introducing the correlated operator

$$(0_f^+||\mathcal{O}||0_i^+) \rightarrow (0_f^+||\mathcal{O}_{\rm J}||0_i^+) = (0_f^+||f_{\rm J}\mathcal{O}f_{\rm J}||0_i^+) \, .$$

Unitary Correlation Operator Method = UCOM

The **UCOM** creates the correlated many-nucleon state by a UNITARY correlation operator C:

$$|\tilde{\Psi}\rangle = C|\Psi\rangle \,, \; C = C_\Omega C_r \,,$$

where

$$C_\Omega \leftrightarrow \text{ tensor correlations} \,,$$

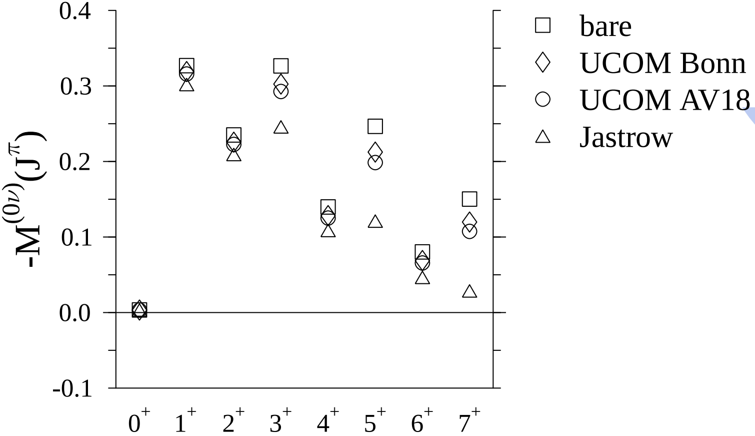
$$C_r \leftrightarrow \text{ central correlations} \,,$$

In this scheme it is equivalent to use correlated states or correlated operators:

$$\langle\tilde{\Psi}|A|\tilde{\Psi}'\rangle = \langle\Psi|C^\dagger A C|\Psi'\rangle = \langle\Psi|\tilde{A}|\Psi'\rangle \,.$$

$0\nu\beta\beta$ Decay of ^{48}Ca in the Nuclear Shell Model: Multipole Decomposition of $M^{(0\nu)}$

$|M^{(0\nu)}|$ for $g_A = 1.0$ Bare: 1.645, Jastrow: 1.056, Bonn: 1.474, AV18: 1.409

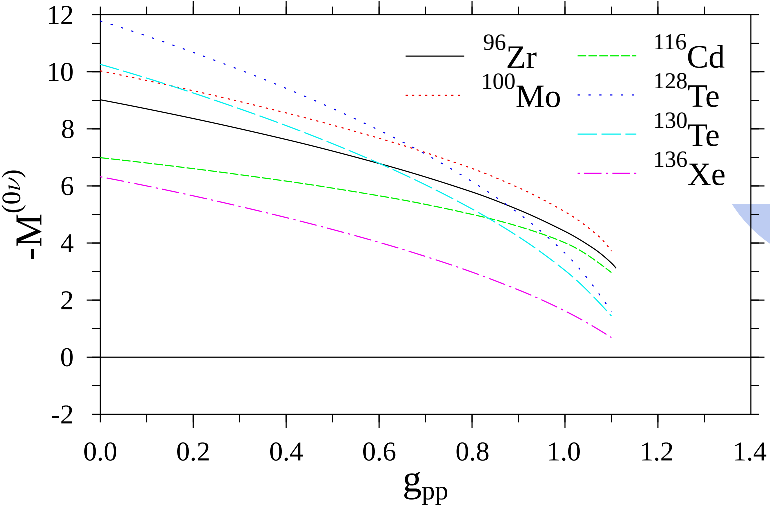


More Complete Calculations

Take into account

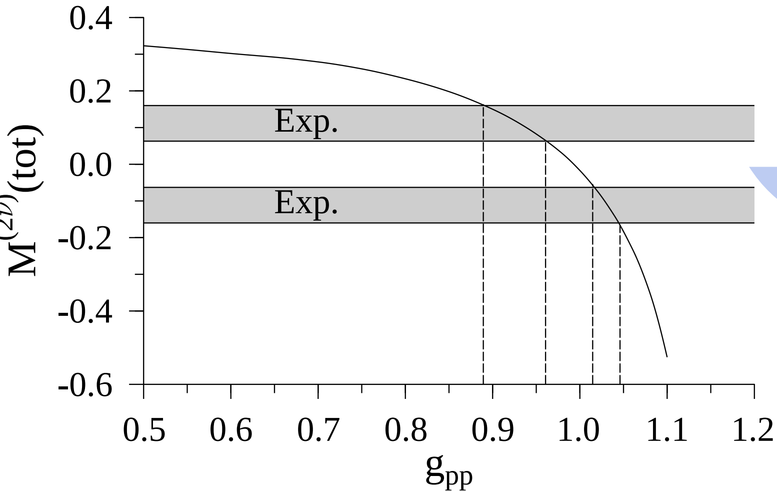
finite nucleon size (form factors)
and
higher-order terms in nucleonic weak current
and
short-range correlations
and
use the pnQRPA

g_{pp} Dependence of $M^{(0\nu)}$

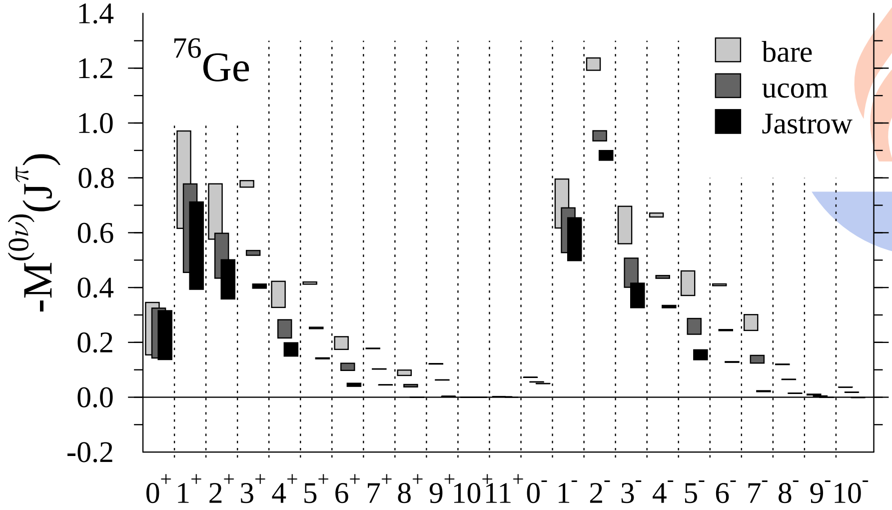


Determination of g_{pp} from $M^{(2\nu)}$

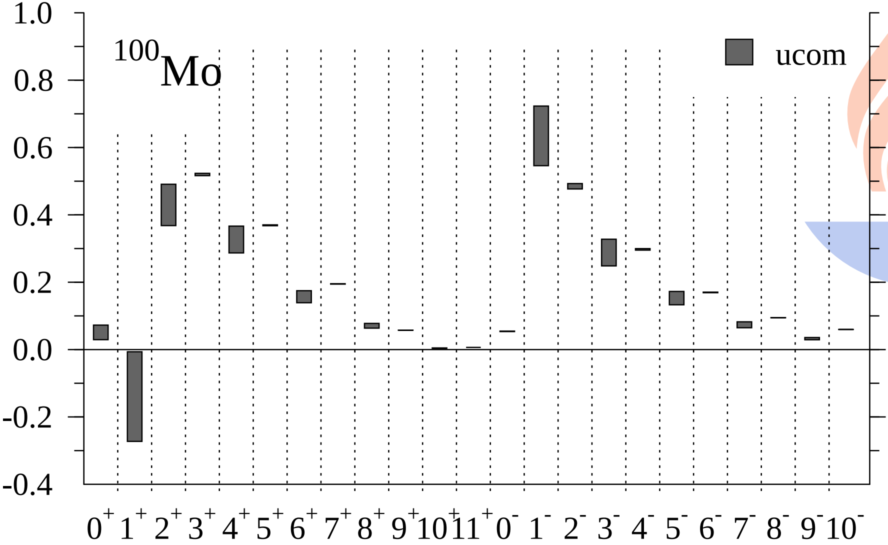
Use only the **UPPER** deduced band for $M^{(2\nu)}$(exp.)



Multipole Decomposition of $M^{(0\nu)}$ for ^{76}Ge



Multipole Decomposition of $M^{(0\nu)}$ for ^{100}Mo



Contributions of Various Corrections to $M^{(0\nu)}$

A=higher-order terms in the nucleonic current
B=finite nucleon size effect
C=Jastrow short-range correlations
D=UCOM short-range correlations

Nucleus	g_{pp}	b.m.e.	+A	+A+B	+A+B+C	+A+B+D
^{76}Ge	1.00	−8.529	−7.720	−6.356	−4.723	−6.080
^{82}Se	1.00	−5.398	−4.826	−3.914	−2.771	−3.722
^{96}Zr	1.085	−5.308	−4.814	−3.736	−2.454	−3.521
^{100}Mo	1.08	−6.126	−5.571	−4.358	−2.914	−4.113
^{116}Cd	0.99	−5.726	−5.172	−4.263	−3.169	−4.076
^{128}Te	0.905	−7.349	−6.673	−5.260	−3.563	−4.979
^{130}Te	0.87	−6.626	−6.021	−4.777	−3.285	−4.530
^{136}Xe	0.74	−4.715	−4.269	−3.478	−2.537	−3.317

Comparison with F. Šimkovic *et al.*

Matrix element $|M^{(0\nu)}|$ for ^{76}Ge

Present calculation compared with
[SIM99] = F. Šimkovic, G. Pantis, J.D. Vergados, and A. Faessler, Phys. Rev. C **60**, 055502 (1999)

without s.r.c.		with s.r.c.		
Present	[SIM99]	Jastrow	UCOM	[SIM99]
6.36	5.16	4.72	6.08	2.80

Comparison with Other Calculations

[ROD06] = V.A. Rodin *et al.*, Nucl. Phys. A **766**, 107 (2006)
[SIM99] = F. Šimkovic *et al.*, Phys. Rev. C **60**, 055502 (1999)
[CIV05] = O. Civitarese and J. Suhonen,
Phys. Lett. B **626**, 80 (2005), *ibid* Nucl. Phys. A **761**, 313 (2005)

Nucleus	Present	[ROD06]	[SIM99]	[CIV05]
^{76}Ge	5.36 – 6.56	2.26 – 2.74	2.80	4.03 – 5.92
^{82}Se	3.72 – 4.60	1.86 – 2.45	2.64	2.82 – 4.14

$M^{(0\nu)}$ and the Corresponding Half-lives (+A+B+D)

The half-lives are given in units of $\text{yr}/(\langle m_\nu \rangle [\text{eV}])^2$

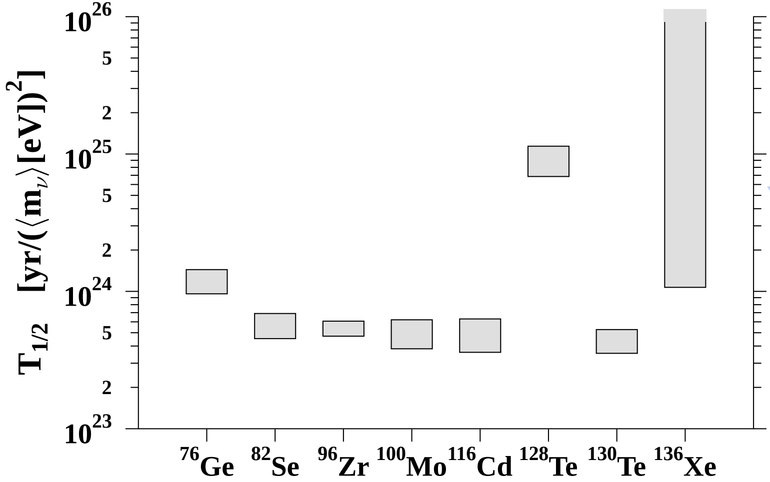
Nucleus	g_{pp}	g_A	$M^{(0\nu)}$	$t_{1/2}^{(0\nu)}$
^{76}Ge	1.02	1.00	-6.555	1.4×10^{24}
	1.06	1.25	-5.355	9.6×10^{23}
^{82}Se	0.96	1.00	-4.597	6.9×10^{23}
	1.00	1.25	-3.722	4.5×10^{23}
^{96}Zr	1.06	1.00	-4.319	6.1×10^{23}
	1.11	1.25	-3.117	4.7×10^{23}
^{100}Mo	1.07	1.00	-4.849	6.2×10^{23}
	1.09	1.25	-3.931	3.8×10^{23}

$M^{(0\nu)}$ and the Half-lives (+A+B+D) (Continued...)

The half-lives are given in units of $\mathrm{yr}/(\langle m_\nu \rangle [\mathrm{eV}])^2$

Nucleus	g_{pp}	g_{A}	$M^{(0\nu)}$	$t_{1/2}^{(0\nu)}$
^{116}Cd	0.82 (β^- decay)	1.25	-4.928	2.3×10^{23}
	0.97	1.00	-4.682	6.3×10^{23}
	1.01	1.25	-3.935	3.6×10^{23}
^{128}Te	0.86 (β^- decay)	1.25	-5.509	5.2×10^{24}
	0.89	1.00	-5.841	1.1×10^{25}
	0.92	1.25	-4.790	6.9×10^{24}
^{130}Te	0.84	1.00	-5.442	5.3×10^{23}
	0.90	1.25	-4.221	3.5×10^{23}
^{136}Xe	0.74	1.00	-3.719	1.1×10^{24}

Compilation of the Calculated $0\nu\beta\beta$ Half-lives

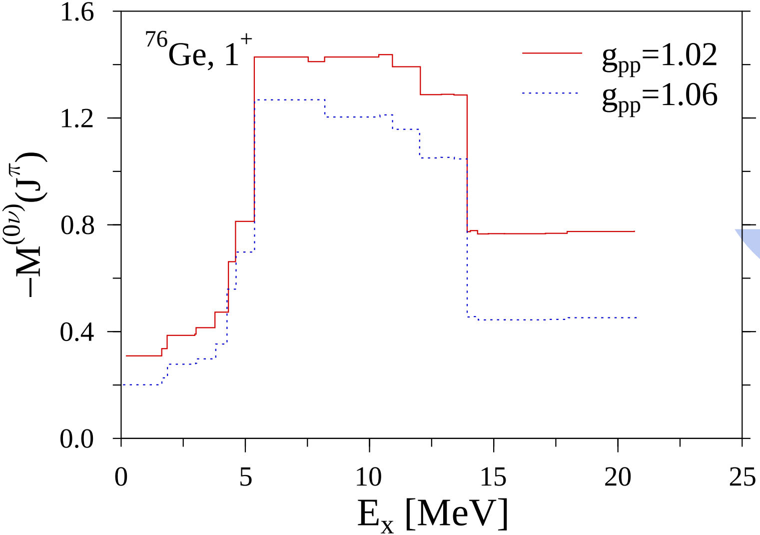


Experimental Probes for $0\nu\beta\beta$ Matrix Elements

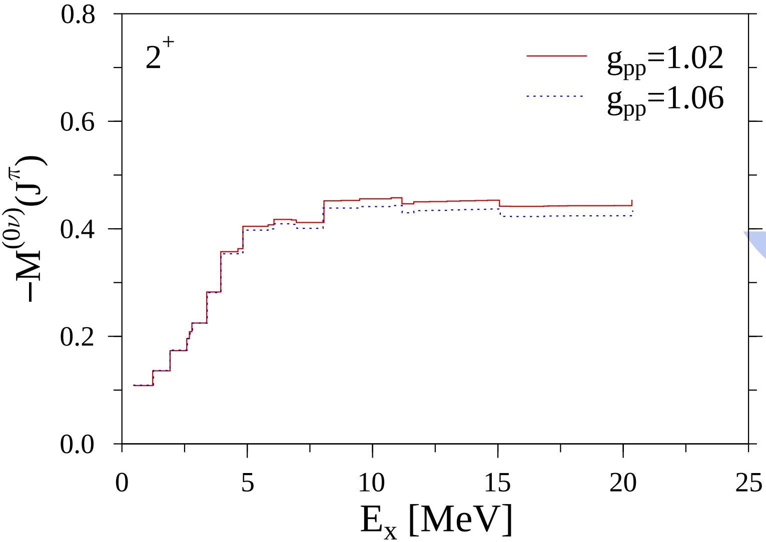
Some Possible Probes:

- Beta decays (Need more data!)
- Charge-exchange reactions
- Neutrino-nucleus charged-current scattering (science fiction?)
- Two-neutrino double beta decay (The T-B-C recipe)
- Ordinary muon capture (begins to be experimentally feasible $\longleftarrow$ MEDEX'07 contributions)

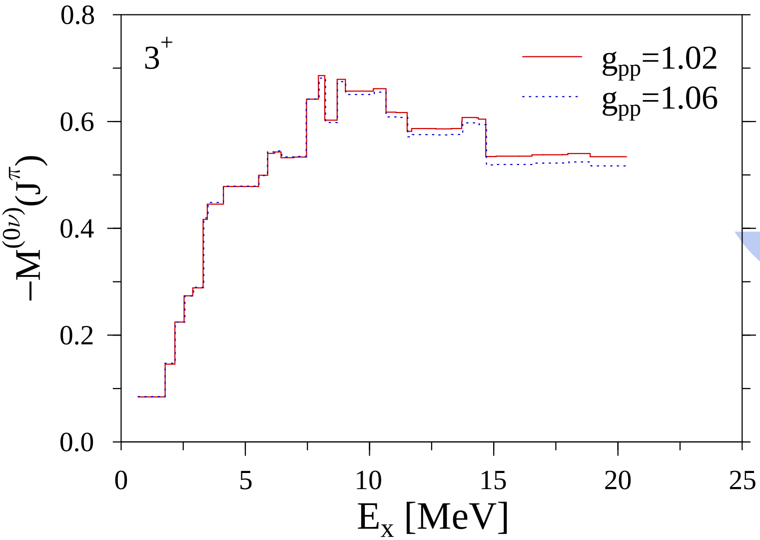
$M^{(0\nu)}$ for ^{76}Ge: Running Sum for 1^+ Contributions



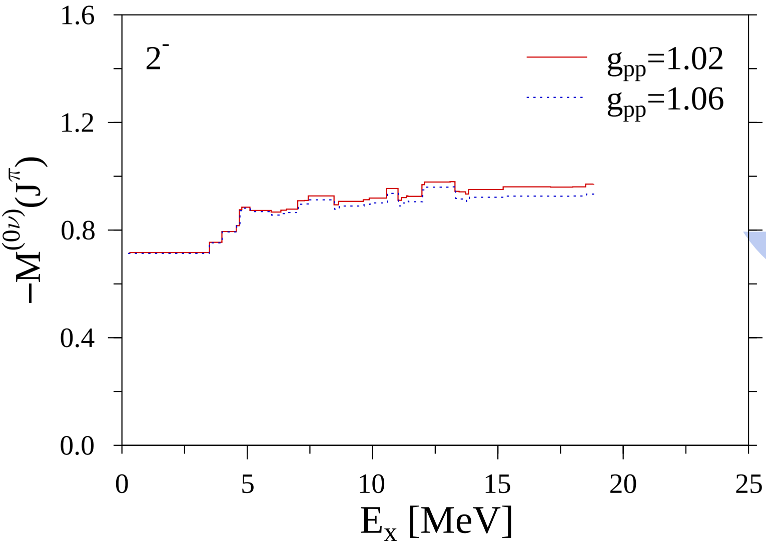
$M^{(0\nu)}$ for ^{76}Ge: Running Sum for 2^+ Contributions



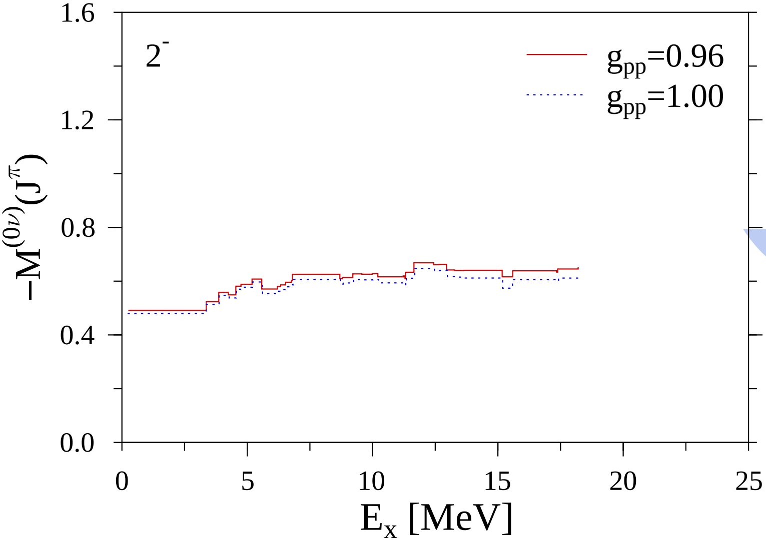
$M^{(0\nu)}$ for ^{76}Ge: Running Sum for 3^+ Contributions



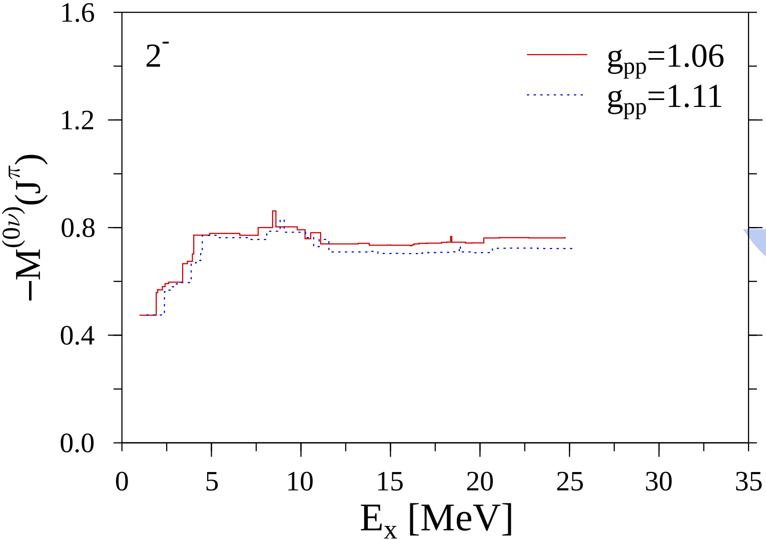
$M^{(0\nu)}$ for ^{76}Ge: Running Sum for 2^- Contributions



$M^{(0\nu)}$ for ^{82}Se: Running Sum for 2^- Contributions



$M^{(0\nu)}$ for ^{96}Zr: Running Sum for 2^- Contributions



Conclusions and Outlook

Conclusions:

- Jastrow method cuts off relevant parts of the many-body wave function and leads to excessive reduction of the magnitudes of the $0\nu\beta\beta$ matrix elements
- The more refined UCOM method predics only moderate effects of s.r.c. upon the $0\nu\beta\beta$ matrix elements
- Charge-exchange reactions are needed to probe the strong 2^-_1 contributions to $0\nu\beta\beta$ matrix elements, in particular for the pf-shell nuclei

Outlook:

- The new matrix element results will affect SENSITIVITIES of PRESENT and FUTURE $0\nu\beta\beta$ experiments