Heavy-ion double-charge-exchange and its relation to neutrinoless double-β decay

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Based on

Santopinto, Garcia Tecocoatzi, Magaña Vsevolodovna,Ferretti, *PRC***98,**061601(R),2018

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12$^{\text{th}}$ **M**atrix **E**lements for the **D**ouble beta decay **Ex**periments

Prague 27-31 May, 2019

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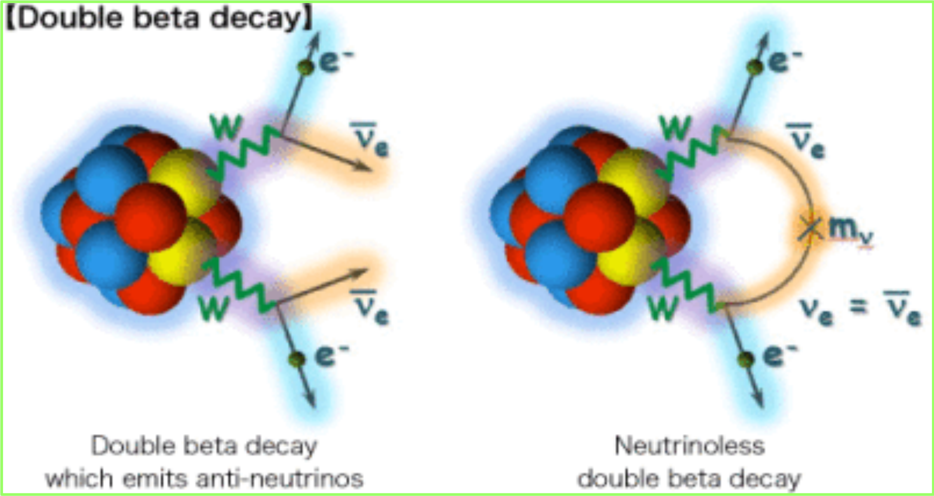
Double beta decay



Double beta decay with neutrinos (observed).

These decays are usually ground state to ground state transitions.

Quenching of g_A

Neutrinoless double beta decay

Lepton number conservation is broken.

Is the neutrino a Majorana particle?

Physics beyond Standard model

Neutrinoless double beta decay

$$\left[T^{0\nu}_{1/2}\left(0^{+}\rightarrow 0^{+}\right)\right]^{-1} = G^{0\nu}(E_0, Z)|M^{0\nu}|^2 \langle m_{\nu_e}\rangle^2$$

0υββ Nuclear Matrix Element

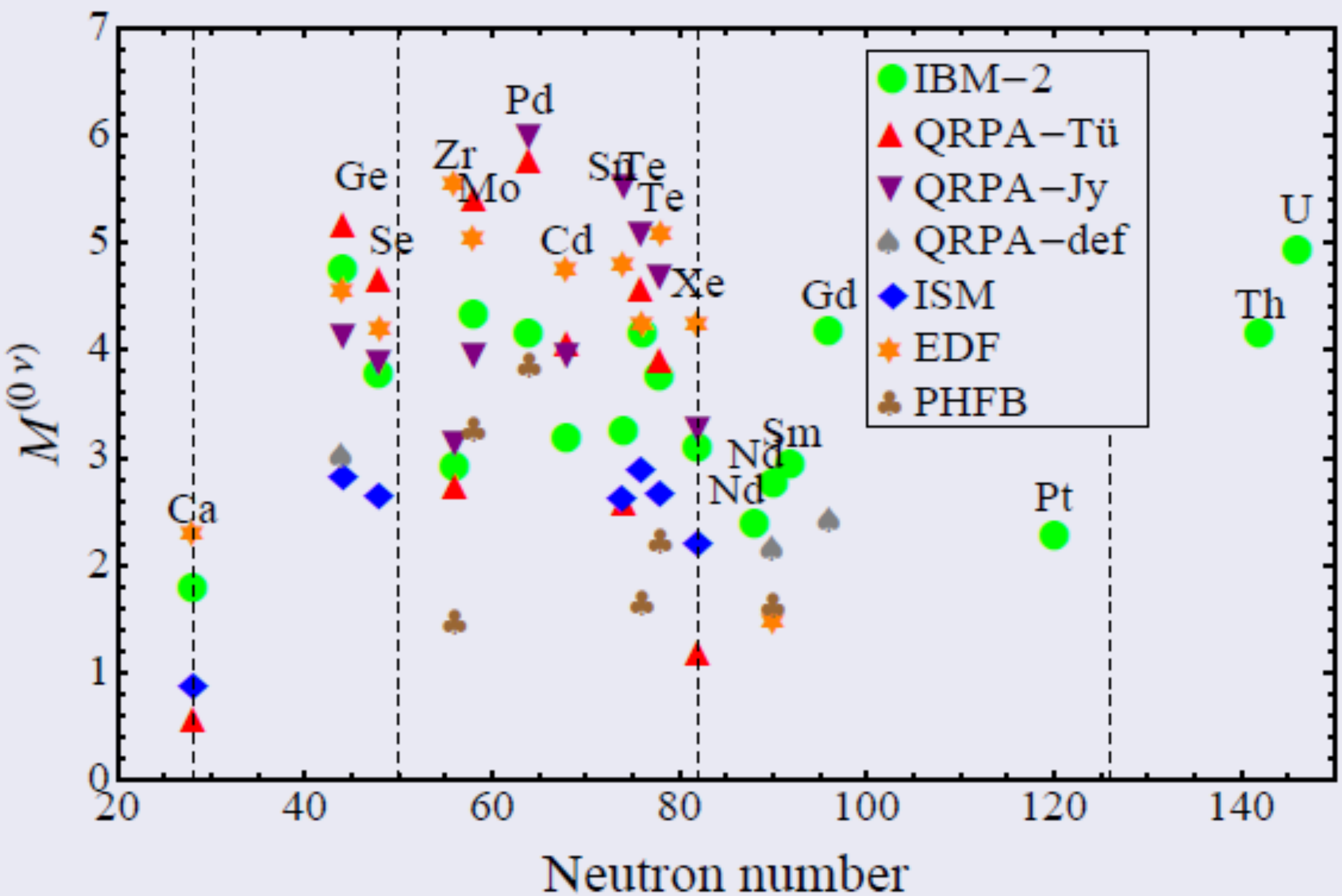
$$\left|M^{0\nu}\right|^2 = \left|\left\langle \Psi_f \middle| \hat{O}_{\varepsilon}^{\beta\beta 0\nu} \middle| \Psi_i \right\rangle\right|^2$$

phase space factor and a factor that depends on the masses and the mixing coefficients of the neutrinos

Nuclear matrix elements for Neutrinoless double beta decay

tensions in NME calculations

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



Double Charge Exchange Experiment

- Canditates isotopes: ^{48}Ca, ^{82}Se, ^{100}Mo, ^{124}Sn, ^{128}Te, ^{130}Te, ^{136}Xe, ^{148}Nd, ^{150}Nd, ^{154}Sm, ^{160}Gd,^{198}Pt .

Heavy Ion Double Charge Exchange

In heavy-ion DCE reactions two protons (neutrons) are converted into two neutrons (protons) in the target, and two neutrons (protons) are converted into two protons (neutrons) in the projectile, while the mass number of the target, A, and of the projectile, a, both remain unchanged.

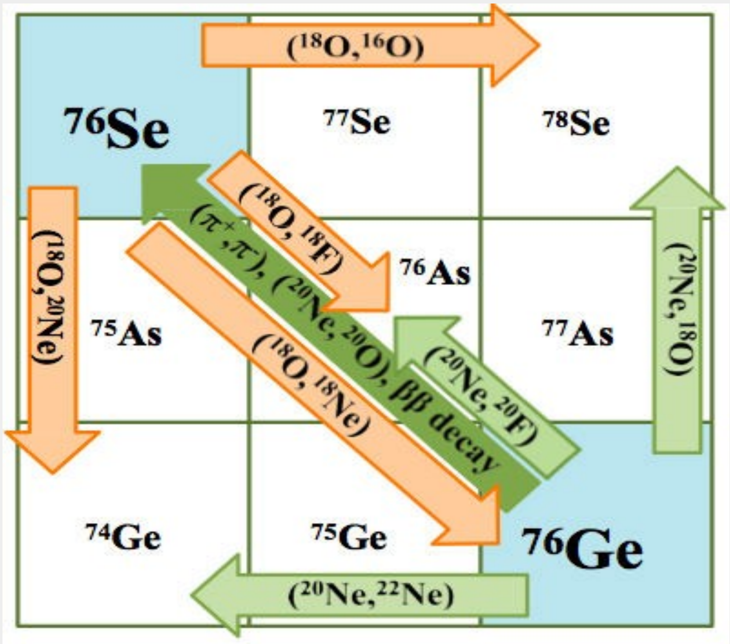
So in heavy ion DCE reactions,

we study the following reactions

with the exchange of two units of charge

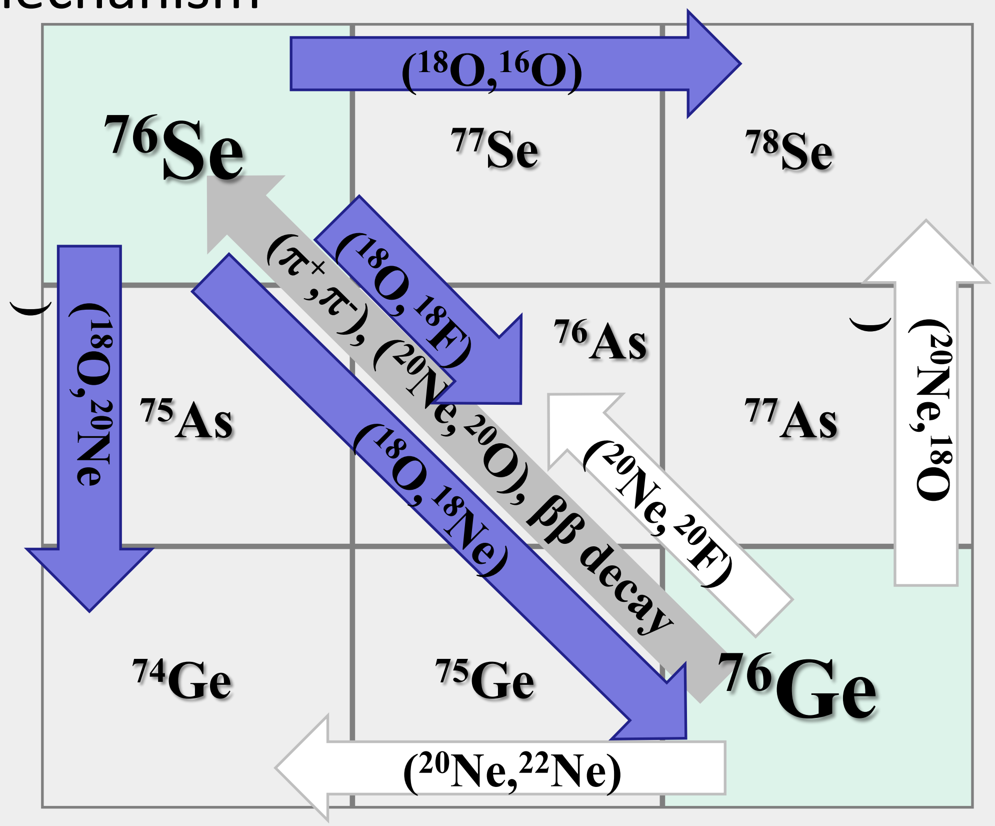
between the target and projectile

$$N_{\mathrm{T}}(A, Z) + N_{\mathrm{p}}(a, z) \rightarrow N_{\mathrm{T}}(A, Z+2) + N_{\mathrm{p}}(a, z-2)$$
$$N_{\mathrm{T}}(A, Z) + N_{\mathrm{p}}(a, z) \rightarrow N_{\mathrm{T}}(A, Z-2) + N_{\mathrm{p}}(a, z+2),$$

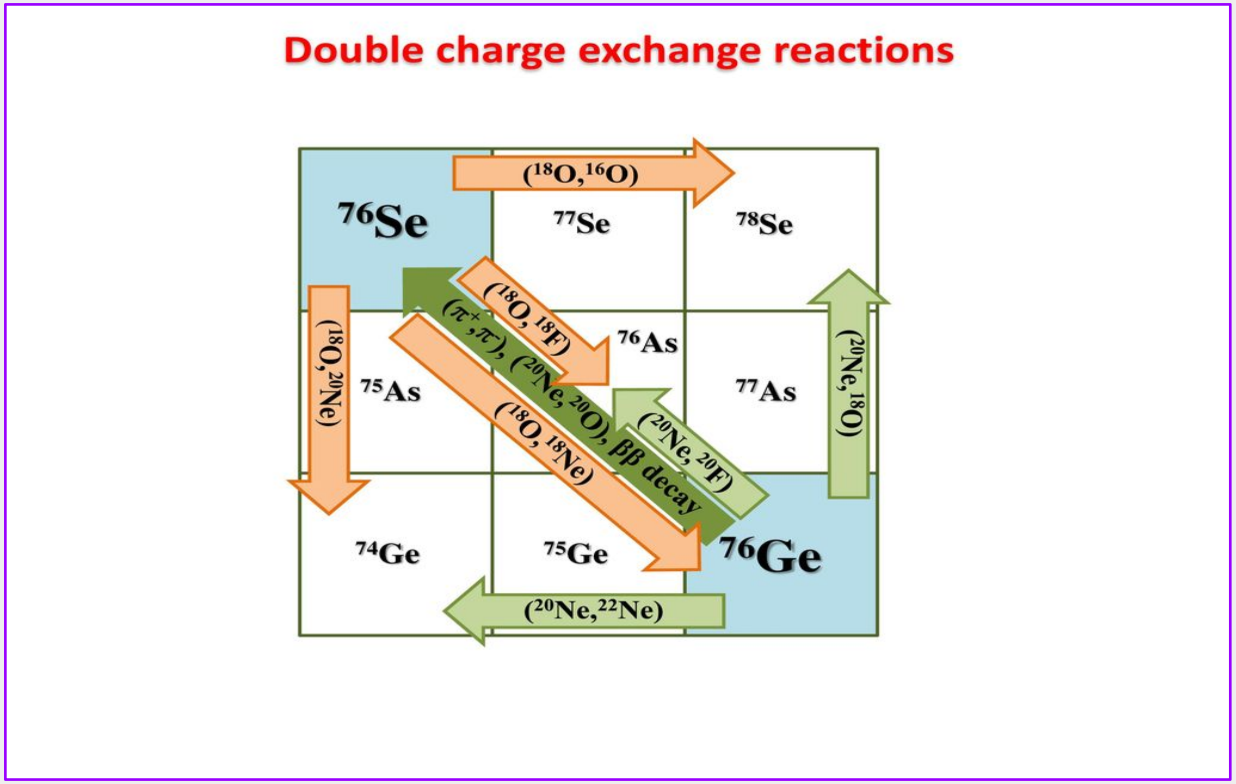


Heavy-Ion Double Charge-Exchange (DCE)

- ✓ Induced by strong interaction
- ✓ Meson exchange mechanism
- ✓ Sequential nucleon transfer mechanism



Heavy ion DCE vs two-proton and two-neutron transfer



We have shown that these competing processes are far from saturating the total detected experimental cross-section, NUMEN collaboration, Eur. Phys. J. A (2018) 54: 72

The nucleon-nucleon charge-exchange effective potential we consider,

$$V_{\mathrm{CE}}(\vec{q}) = V_{\mathrm{OPE}}(\vec{q}) + V_{\mathrm{ZR}} \ ,$$

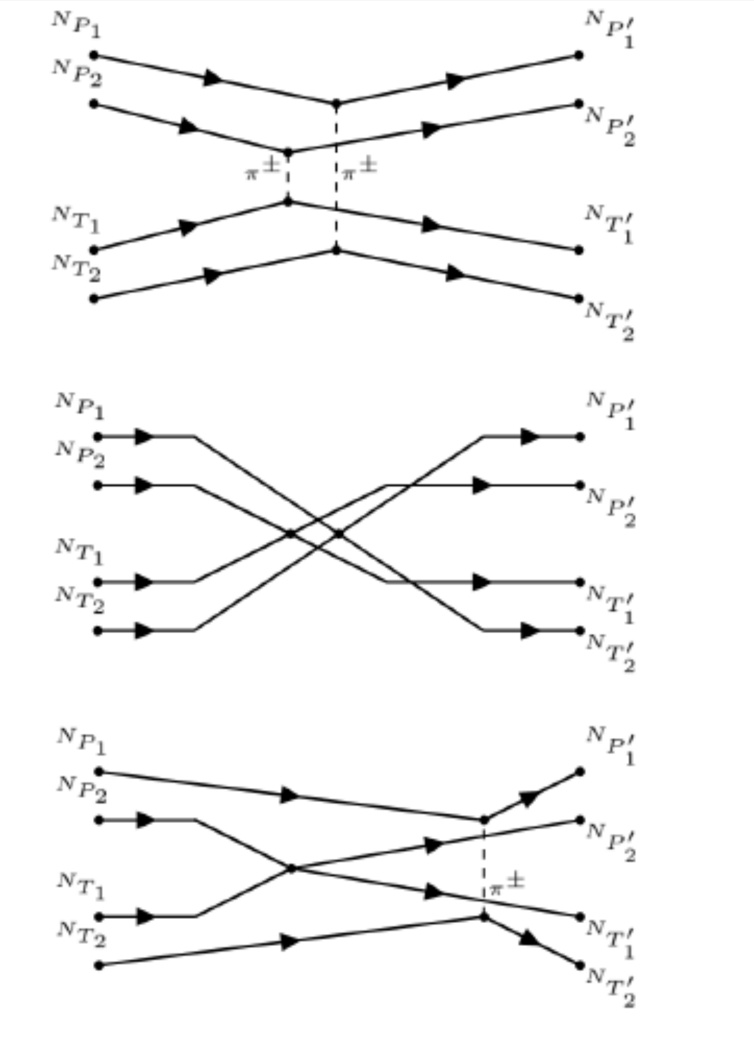
is the sum of a long- and medium-range one-pion exchange (OPE) and an effective zero-range (ZR) contact interaction, as from

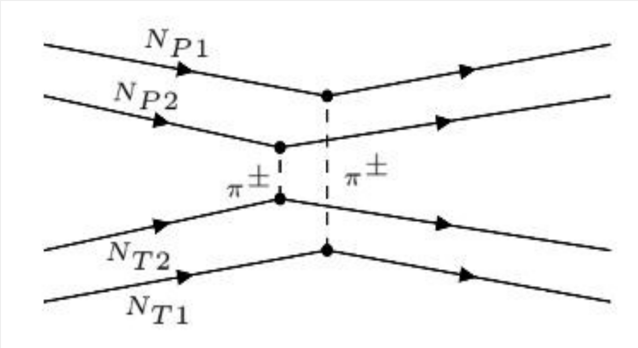
G. F. Bertsch and H. Esbensen, Rep. Prog. Phys. 50, 607 (1987).

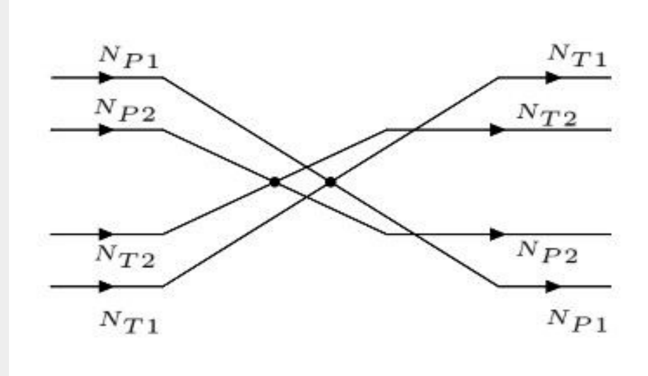
The latter, due to many body correlations, is written in coordinate space as follows

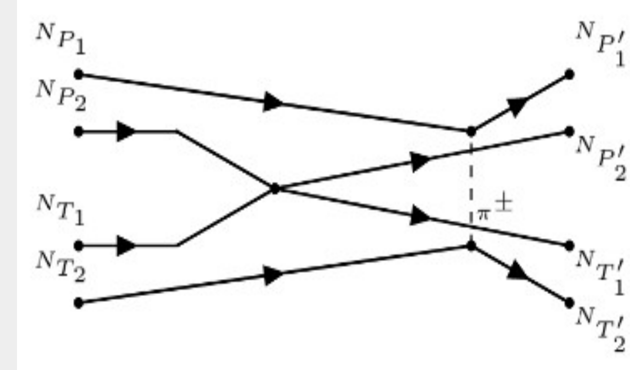
$$V_{\mathrm{ZR}}(\vec{r}) \ = [c_{\mathrm{T}}(\vec{\tau}_1 \cdot \vec{\tau}_2) + c_{\mathrm{GT}}(\vec{\sigma}_1 \cdot \vec{\sigma}_2)(\vec{\tau}_1 \cdot \vec{\tau}_2)]\, \delta^3(\vec{r}) \ ,$$

The OPE and ZR interactions provide the expressions for the vertices which we need in the computation of the diagrams in Fig.









We derived the DCE effective potential (in closure approximation):

$$\begin{aligned}
V^{\mathrm{DCE}}(\vec{q}_1,\vec{q}_2) = {} & \frac{4}{3}\left(\frac{f_\pi}{m_\pi}\right)^4 \left(\frac{(\vec{\sigma}_{\mathrm{P1}}\cdot\vec{q}_1)(\vec{\sigma}_{\mathrm{T1}}\cdot\vec{q}_1)}{\omega_1(\omega_1+\bar{E}_{\mathrm{P}})}\,\vec{\tau}_{\mathrm{P1}}\cdot\vec{\tau}_{\mathrm{T1}}\right)\left(\frac{(\vec{\sigma}_{\mathrm{P2}}\cdot\vec{q}_2)(\vec{\sigma}_{\mathrm{T2}}\cdot\vec{q}_2)}{\omega_2(\omega_2+\bar{E}_{\mathrm{P}})(\omega_2+\bar{E}_{\mathrm{T}})}\,\vec{\tau}_{\mathrm{P2}}\cdot\vec{\tau}_{\mathrm{T2}}\right) \\
& + 2\left[\frac{c_{\mathrm{T}}^2}{\bar{E}_{\mathrm{P}}^{\mathrm{F}}+\bar{E}_{\mathrm{T}}^{\mathrm{F}}} + \frac{c_{\mathrm{GT}}^2(\vec{\sigma}_{\mathrm{P1}}\cdot\vec{\sigma}_{\mathrm{T1}})(\vec{\sigma}_{\mathrm{P2}}\cdot\vec{\sigma}_{\mathrm{T2}})}{\bar{E}_{\mathrm{P}}^{\mathrm{GT}}+\bar{E}_{\mathrm{T}}^{\mathrm{GT}}} + \frac{c_{\mathrm{T}}c_{\mathrm{GT}}(\vec{\sigma}_{\mathrm{P2}}\cdot\vec{\sigma}_{\mathrm{T2}})}{\bar{E}_{\mathrm{P}}^{\mathrm{GT}}+\bar{E}_{\mathrm{T}}^{\mathrm{F}}} + \frac{c_{\mathrm{T}}c_{\mathrm{GT}}(\vec{\sigma}_{\mathrm{P1}}\cdot\vec{\sigma}_{\mathrm{T1}})}{\bar{E}_{\mathrm{P}}^{\mathrm{F}}+\bar{E}_{\mathrm{T}}^{\mathrm{GT}}}\right](\vec{\tau}_{\mathrm{P1}}\cdot\vec{\tau}_{\mathrm{T1}})(\vec{\tau}_{\mathrm{P2}}\cdot\vec{\tau}_{\mathrm{T2}}) \\
& + \left[\left(\frac{f_\pi}{m_\pi}\right)^2\left(\frac{(\vec{\sigma}_{\mathrm{P1}}\cdot\vec{q}_1)(\vec{\sigma}_{\mathrm{T1}}\cdot\vec{q}_1)}{\omega_1(\omega_1+\bar{E}_{\mathrm{P}})(\omega_1+\bar{E}_{\mathrm{T}})}\,\vec{\tau}_{\mathrm{P1}}\cdot\vec{\tau}_{\mathrm{T1}}\right)[c_{\mathrm{T}}(\vec{\tau}_{\mathrm{P2}}\cdot\vec{\tau}_{\mathrm{T2}}) + c_{\mathrm{GT}}(\vec{\sigma}_{\mathrm{P2}}\cdot\vec{\sigma}_2)(\vec{\tau}_{\mathrm{P2}}\cdot\vec{\tau}_{\mathrm{T2}})] + 1 \leftrightarrow 2\right]. \qquad (3)
\end{aligned}$$

and in the low momentum trasfer the DCE potential can be simply written as:

$$V^{\mathrm{DCE}} \xrightarrow[\vec{Q}\to 0]{} 2\left[\frac{c_{\mathrm{T}}^2}{\bar{E}_{\mathrm{P}}^{\mathrm{F}}+\bar{E}_{\mathrm{T}}^{\mathrm{F}}} + \frac{c_{\mathrm{GT}}^2(\vec{\sigma}_{\mathrm{P1}}\cdot\vec{\sigma}_{\mathrm{T1}})(\vec{\sigma}_{\mathrm{P2}}\cdot\vec{\sigma}_{\mathrm{T2}})}{\bar{E}_{\mathrm{P}}^{\mathrm{GT}}+\bar{E}_{\mathrm{T}}^{\mathrm{GT}}} + \frac{c_{\mathrm{T}}c_{\mathrm{GT}}(\vec{\sigma}_{\mathrm{P2}}\cdot\vec{\sigma}_{\mathrm{T2}})}{\bar{E}_{\mathrm{P}}^{\mathrm{GT}}+\bar{E}_{\mathrm{T}}^{\mathrm{F}}} + \frac{c_{\mathrm{T}}c_{\mathrm{GT}}(\vec{\sigma}_{\mathrm{P1}}\cdot\vec{\sigma}_{\mathrm{T1}})}{\bar{E}_{\mathrm{P}}^{\mathrm{F}}+\bar{E}_{\mathrm{T}}^{\mathrm{GT}}}\right](\vec{\tau}_{\mathrm{P1}}\cdot\vec{\tau}_{\mathrm{T1}})(\vec{\tau}_{\mathrm{P2}}\cdot\vec{\tau}_{\mathrm{T2}})$$

since it is dominated by the contact interaction.

Differential cross-section

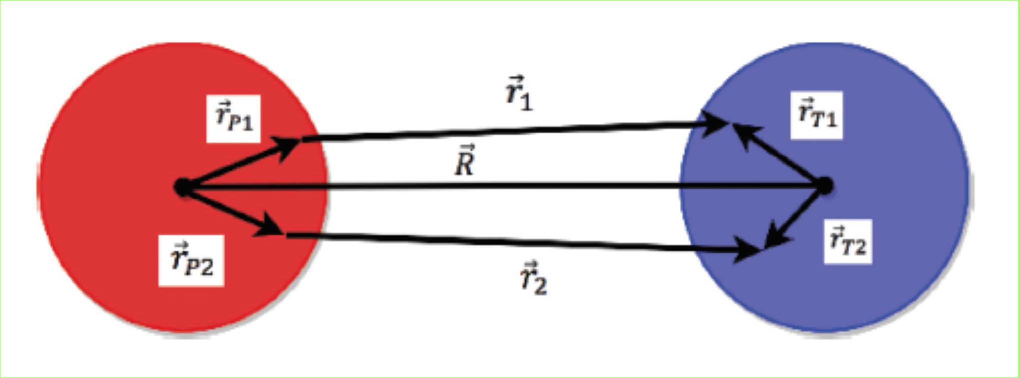
PHYSICAL REVIEW C **98**, 061601(R) (2018)

- We apply our formalism for describing DCE cross section in the Eikonal approximation

$$\frac{d\sigma}{d\Omega} = \frac{k}{k'}\left(\frac{\mu}{4\pi^2\hbar^2}\right)^2 |T_{\text{if}}|^2$$

$$\begin{aligned} T_{\text{if}} &= \langle \Psi^-_{\vec{k}'}\Phi_{\text{f}}|V|\Psi^+_{\vec{k}}\Phi_{\text{i}}\rangle \\ &= \frac{1}{(2\pi)^{3/2}}\int d\vec{R}\, e^{i(\chi(b)-\vec{Q}\cdot\vec{R})} M_{\text{if}}(\vec{m}) \end{aligned}$$

$$\Psi^-_{\vec{k}'}(\vec{R})\Psi^+_{\vec{k}}(\vec{R}) = \frac{1}{(2\pi)^{3/2}} e^{i(\chi(b)-\vec{Q}\cdot\vec{R})}$$



Differential cross-section in low-momentum-transfer limit

Santopinto et al., PRC**98**, 061601(R) (2018)

- The effective DCE potential for small angles

$$V^{\mathrm{DCE}} \xrightarrow[\vec{Q}\to 0]{} 2\left[\frac{c_{\mathrm{T}}^2}{\bar{E}_{\mathrm{P}}^{\mathrm{F}}+\bar{E}_{\mathrm{T}}^{\mathrm{F}}}+\frac{c_{\mathrm{GT}}^2(\vec{\sigma}_{\mathrm{P1}}\cdot\vec{\sigma}_{\mathrm{T1}})(\vec{\sigma}_{\mathrm{P2}}\cdot\vec{\sigma}_{\mathrm{T2}})}{\bar{E}_{\mathrm{P}}^{\mathrm{GT}}+\bar{E}_{\mathrm{T}}^{\mathrm{GT}}}+\frac{c_{\mathrm{T}}c_{\mathrm{GT}}(\vec{\sigma}_{\mathrm{P2}}\cdot\vec{\sigma}_{\mathrm{T2}})}{\bar{E}_{\mathrm{P}}^{\mathrm{GT}}+\bar{E}_{\mathrm{T}}^{\mathrm{F}}}+\frac{c_{\mathrm{T}}c_{\mathrm{GT}}(\vec{\sigma}_{\mathrm{P1}}\cdot\vec{\sigma}_{\mathrm{T1}})}{\bar{E}_{\mathrm{P}}^{\mathrm{F}}+\bar{E}_{\mathrm{T}}^{\mathrm{GT}}}\right](\vec{\tau}_{\mathrm{P1}}\cdot\vec{\tau}_{\mathrm{T1}})(\vec{\tau}_{\mathrm{P2}}\cdot\vec{\tau}_{\mathrm{T2}})$$

$$M_{\mathrm{if}}(\mathbf{m}) = \langle\Phi_{\mathrm{f}}|V^{\mathrm{DCE}}|\Phi_{\mathrm{i}}\rangle\ ,$$

The transition amplitude in the low-momentum-transfer limit is

$$\begin{aligned} M_{\mathrm{if}}(\mathbf{m}) \xrightarrow[\vec{Q}\to 0]{} & 6\sum_J \begin{Bmatrix} 1 & 1 & J \\ 1 & 1 & J \\ 0 & 0 & 0 \end{Bmatrix} \langle\phi_{\mathrm{f}}^{\mathrm{T1}}\phi_{\mathrm{f}}^{\mathrm{P1}}\phi_{\mathrm{f}}^{\mathrm{T2}}\phi_{\mathrm{f}}^{\mathrm{P2}}|\left\{\frac{c_{\mathrm{GT}}^2(2J+1)}{\bar{E}_{\mathrm{P}}^{\mathrm{GT}}+\bar{E}_{\mathrm{T}}^{\mathrm{GT}}}[[\vec{\sigma}_{\mathrm{P1}}\times\vec{\sigma}_{\mathrm{P2}}]^{(J)}[\vec{\sigma}_{\mathrm{T1}}\times\vec{\sigma}_{\mathrm{T2}}]^{(J)}]^{(0)}\right. \\ & \left. +\frac{c_{\mathrm{T}}^2\delta_{J,0}}{\bar{E}_{\mathrm{P}}^{\mathrm{F}}+\bar{E}_{\mathrm{T}}^{\mathrm{F}}}+\sqrt{3}c_{\mathrm{T}}c_{\mathrm{GT}}\delta_{J,0}\left(\frac{[\vec{\sigma}_{\mathrm{P2}}\times\vec{\sigma}_{\mathrm{T2}}]^{(0)}}{\bar{E}_{\mathrm{P}}^{\mathrm{GT}}+\bar{E}_{\mathrm{T}}^{\mathrm{F}}}+\frac{[\vec{\sigma}_{\mathrm{P1}}\times\vec{\sigma}_{\mathrm{T1}}]^{(0)}}{\bar{E}_{\mathrm{P}}^{\mathrm{F}}+\bar{E}_{\mathrm{T}}^{\mathrm{GT}}}\right)\right\}(\tau_{\mathrm{T1}}^{+}\tau_{\mathrm{T2}}^{+}\tau_{\mathrm{P1}}^{-}\tau_{\mathrm{P2}}^{-})|\phi_{\mathrm{i}}^{\mathrm{T1}}\phi_{\mathrm{i}}^{\mathrm{P1}}\phi_{\mathrm{i}}^{\mathrm{T2}}\phi^{\mathrm{P2}}\rangle, \end{aligned}$$

If we study transitions 0+ ground state to 0+ ground state we can rewrite in a compact form

Transition amplitude between ground states

PHYSICAL REVIEW C **98**, 061601(R) (2018)

- The amplitude between ground states can be computed as follows

$$M_{\rm if}(\mathbf{m}) \xrightarrow[\vec{Q}\to 0]{} 2\left[\left(\frac{\mathcal{M}^{\rm DGT}_{\rm T\to T'}\mathcal{M}^{\rm DGT}_{\rm P\to P'}}{\bar{E}^{\rm GT}_{\rm P}+\bar{E}^{\rm GT}_{\rm T}}\right)+\left(\frac{\mathcal{M}^{\rm DF}_{\rm T\to T'}\,\mathcal{M}^{\rm DF}_{\rm P\to P'}}{\bar{E}^{\rm F}_{\rm P}+\bar{E}^{\rm F}_{\rm T}}\right)\right],$$

$$\mathcal{M}^{\rm DGT}_{\rm A\to A'} = c_{\rm GT}\left\langle \Phi^{(\rm A')}_{J'}\right| \sum_{n,n'} [\vec{\sigma}_n \times \vec{\sigma}_{n'}]^{(0)} \vec{\tau}_n \vec{\tau}_{n'} \left|\Phi^{(\rm A)}_{J}\right\rangle,$$

$$\mathcal{M}^{\rm DF}_{\rm A\to A'} = c_{\rm T}\left\langle \Phi^{(\rm A')}_{J'}\right| \sum_{n,n'} \vec{\tau}_n \vec{\tau}_{n'} \left|\Phi^{(\rm A)}_{J}\right\rangle$$

$$\frac{d\sigma}{d\Omega} \xrightarrow[\vec{Q}\to 0]{} \frac{k}{k'}\left(\frac{\mu}{4\pi^2\hbar^2}\right)^2 \left|2F(\theta)\left(\frac{\mathcal{M}^{\rm DGT}_{\rm T\to T'}\mathcal{M}^{\rm DGT}_{\rm P\to P'}}{E^{\rm GT}_{p}+E^{\rm GT}_{t}} + \frac{\mathcal{M}^{\rm DF}_{\rm T\to T'}\,\mathcal{M}^{\rm DF}_{\rm P\to P'}}{E^{\rm F}_{p}+E^{\rm F}_{t}}\right)\right|^2$$

$$F(\theta) \xrightarrow[Q_z\to 0]{} 2\pi \int_{-\infty}^{\infty} dz \int_0^{\infty} db\, e^{-izQ_z}\, bJ_0(kb\sin\theta)\, e^{i\chi(b)}$$

- The cross-section in the eikonal approximation and low-momentum transfer limit is given as follows

$$\frac{d\sigma}{d\Omega}\Big|_{[\vec{Q}\to 0]} \rightarrow \frac{k}{k'}\left(\frac{\mu}{4\pi^2\hbar^2}\right)^2 \Big|2F(\theta)\Big(\frac{\mathcal{M}^{\mathrm{DGT}}_{\mathrm{T}\to\mathrm{T}'}\,\mathcal{M}^{\mathrm{DGT}}_{\mathrm{P}\to\mathrm{P}'}}{\bar{E}^{GT}_{P}+\bar{E}^{GT}_{T}} + \frac{\mathcal{M}^{\mathrm{DF}}_{\mathrm{T}\to\mathrm{T}'}\,\mathcal{M}^{\mathrm{DF}}_{\mathrm{P}\to\mathrm{P}'}}{\bar{E}^{F}_{P}+\bar{E}^{F}_{T}}\Big)\Big|^2,$$

where μ is the reduced mass of the target-projectile system and *F* (θ) is the scattering angular distribution.

DCE Nuclear Matrix Elements

DCE-Double-Gamow-Teller (DGT) and DCE-Double-Fermi (DF) matrix elements, respectively, for a given nuclear transition of the projectile/target (A = P, T), defined as

$$\mathcal{M}^{\mathrm{DF}}_{\mathrm{A}\to\mathrm{A}'} = c_{\mathrm{T}} \left\langle \Phi^{(\mathrm{A}')}_{J'} \right| \sum_{n,n'} \tau^{\dagger}_{n}\tau^{\dagger}_{n'} \left| \Phi^{(\mathrm{A})}_{J} \right\rangle \ ,$$

and

$$\mathcal{M}^{\mathrm{DGT}}_{\mathrm{A}\to\mathrm{A}'} = c_{\mathrm{GT}} \left\langle \Phi^{(\mathrm{A}')}_{J'} \right| \sum_{n,n'} [\vec{\sigma}_n \times \vec{\sigma}_{n'}]^{(0)} \tau^{\dagger}_{n}\tau^{\dagger}_{n'} \left| \Phi^{(\mathrm{A})}_{J} \right\rangle \ ,$$

where the sum is over the nucleons $(n, n\ )$ involved in the process.

Theoretical description of $^{40}Ca(^{18}O,\ ^{18}Ne)^{40}Ar$

- We describe the reaction for small angles

Reaction	$\mathcal{M}^{P,DGT}_{DCE}$	$\mathcal{M}^{P,DF}_{DCE}$
$^{18}O \rightarrow\ ^{18}Ne$	0.86	0.35
Reaction	$\mathcal{M}^{T,DGT}_{DCE}$	$\mathcal{M}^{T,DF}_{DCE}$
$^{40}Ca \rightarrow\ ^{40}Ar$	0.42	0.17

- Our cross-section is $8.9\ \mu b/sr$ which is in good agreement with the experimental data Eur. Phys. J. A **51**, 145 (2015).

Results for $^{40}Ca(^{18}O, ^{18}Ne)^{40}Ar$

We computed the $^{40}Ca(^{18}O, ^{18}Ne)^{40}Ar$ DCE cross-section at $\theta = 0$.

We obtained a value of 8.9μb/sr inside the experimental range, (8.0 − 10.5)μb/sr (Eur. Phys J.A (2015) 51 145).

Calculation of DGT- DF NME's for 0νββ decay candidate with microscopic IBM2

- We compute DGT-DF NME in microscopic IBM, PRC **98**, 061601(R) (2018)

Reaction	$\mathcal{M}_{\mathrm{DCE}}^{\mathrm{T,DGT}}$	$\mathcal{M}_{\mathrm{DCE}}^{\mathrm{T,DF}}$	$\mathcal{M}_{0\nu\beta\beta}^{\mathrm{T,DGT}}$	$\mathcal{M}_{0\nu\beta\beta}^{\mathrm{T,DF}}$	$\mathcal{M}_{0\nu\beta\beta}^{\mathrm{TOT}}$
$^{116}\mathrm{Cd} \rightarrow {}^{116}\mathrm{Sn}$	0.20	0.05	0.21	−0.02	0.25
$^{82}\mathrm{Se} \rightarrow {}^{82}\mathrm{Kr}$	0.28	0.08	0.31	−0.21	0.50
$^{128}\mathrm{Te} \rightarrow {}^{128}\mathrm{Xe}$	0.27	0.07	0.28	−0.16	0.43
$^{76}\mathrm{Ge} \rightarrow {}^{76}\mathrm{Se}$	0.34	0.10	0.40	−0.25	0.63

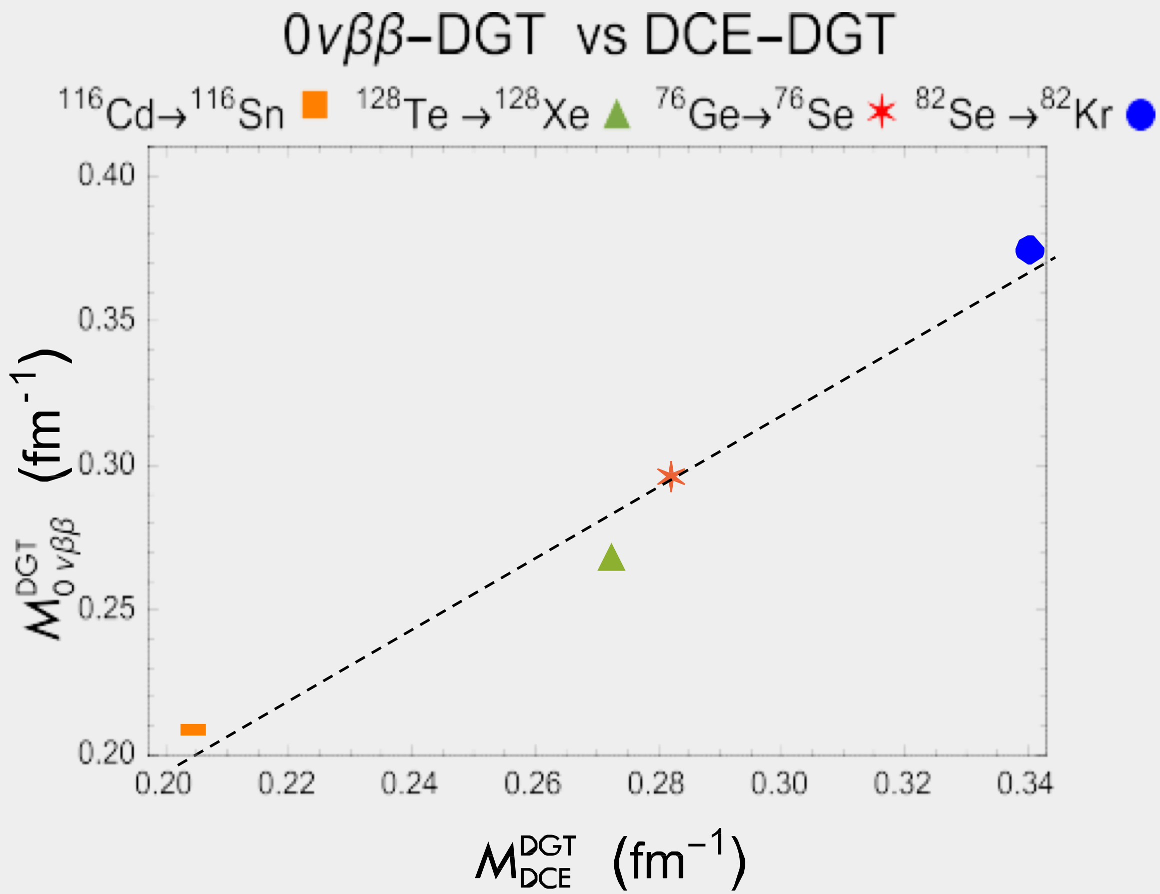
The matrix elements are in fm-1. The value of the constants are c_t = 151 MeV fm^3 and c_{gt} = 217 MeV fm^3 from G.F Bertsch et al., Rep. Prog. Phys. 50 607 (1987) . **We can observe that the dominant contribution is the Double Gamow-Teller.**

- The 0νββ NME's where taken from Ref. Phys. Rev. C **87**, 014315,2013, with g_A=1,using

$$\mathcal{M}_{0\nu\beta\beta}^{\mathrm{TOT}} = \mathcal{M}_{0\nu\beta\beta}^{\mathrm{GT}} - \left(\frac{g_{\mathrm{V}}}{g_{\mathrm{A}}}\right)^2 \mathcal{M}_{0\nu\beta\beta}^{\mathrm{F}} + \mathcal{M}_{0\nu\beta\beta}^{\mathrm{T}}$$

Linear Correlation of DGT NME's

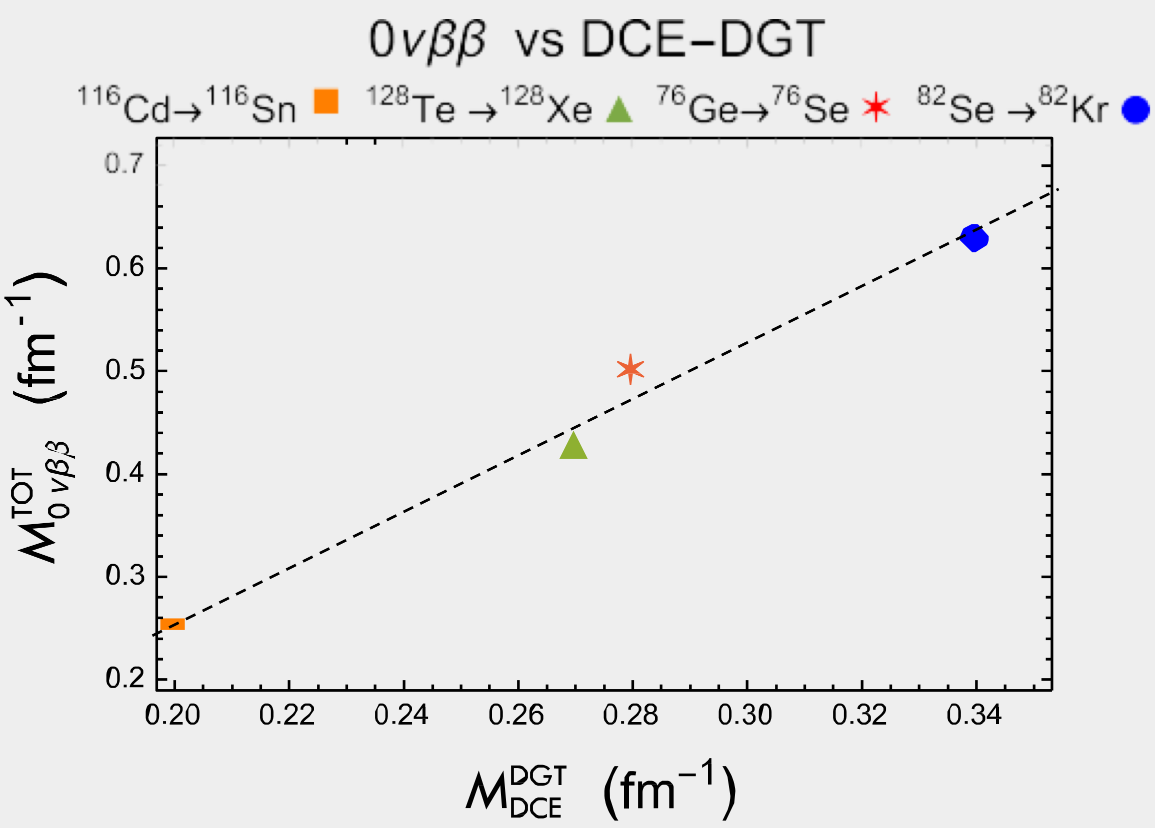
PHYSICAL REVIEW C **98**, 061601(R) (2018)



See also N. Shimitzu Phys. Rev. Lett 120 142502 (2018).

Linear Correlation

There is linear correlation between total nuclear matrix elements of 0νββ-decay and Double Gamow Teller in DCX too.



The linear correlation

We investigate a linear correlation between $0\nu\beta\beta$ and DCE NME's that was found in Phys. Rev. Lett. 120, 142502 (2018) for DGT transitions , and we confirm

$$B(\mathrm{DGT}^{\pm}; \lambda; i \to f) = \frac{1}{2J_i + 1} |\langle f || \mathcal{O}_{\pm}^{(\lambda)} || i \rangle|^2,$$

However, there is a strong dependence on gA

$$\mathcal{M}^{\mathrm{TOT}}_{0\nu\beta\beta} = \mathcal{M}^{\mathrm{GT}}_{0\nu\beta\beta} - \left(\frac{g_{\mathrm{V}}}{g_{\mathrm{A}}}\right)^2 \mathcal{M}^{\mathrm{F}}_{0\nu\beta\beta} + \mathcal{M}^{\mathrm{T}}_{0\nu\beta\beta}$$

$$g_{\mathrm{A}} = \begin{cases} 1.269, \\ 1, \\ 1.269\,A^{-0.18}, \end{cases}$$

Linear correlation

PHYSICAL REVIEW C **98**, 061601(R) (2018)

- We find also a linear correlations between the Total NME's, but it depends on g_A

$$\mathcal{M}^{\mathrm{TOT}}_{0\nu\beta\beta}\Big|_{g_A=1} = -0.29 + 2.74\mathcal{M}^{\mathrm{T,DGT}}_{\mathrm{DCE}}$$

$$\mathcal{M}^{\mathrm{TOT}}_{0\nu\beta\beta}\Big|_{g_A=1.269\ A^{-0.18}} = -0.78 + 5.84\mathcal{M}^{\mathrm{T,DGT}}_{\mathrm{DCE}}$$

For the DGT-DCE we got

$$\mathcal{M}^{\mathrm{DGT}}_{0\nu\beta\beta} = -0.07 + 1.36\mathcal{M}^{\mathrm{T,DGT}}_{\mathrm{DCE}}$$

Conclusions

- We derived, for the first time, an effective potential that describes the DCE reactions.
- For the first time, we demonstrated that the expression for the DCE-differential cross-section can be factorized in the DCE-NME's and the reaction part, in Eikonal appproximation and very forward angles.
- For the first time, we identified a DGT and DF NME's at $\theta=0$
- We observed a linear correlation between DGT-DCE and $0\nu\beta\beta$ NME, but the total NME's depend on g_A. Which is in agreement with N. Shimitzu Phys. Rev. Lett 120 142502 (2018).
- In DCE, the DCE-DGT contribution is the dominant one.

Conclusions and future work

- The DCE differential cross-section is dominated by contact interactions at $\theta=0$.The factorization plus the linear correlation open the possibility of placing constraints in $0\nu\beta\beta$ NME, using future data by NUMEN.

Future Work

- Calculate the differential cross-section for more angles.

Thank you for your attention