A tool for distinguishing different neutrinoless double beta mechanisms

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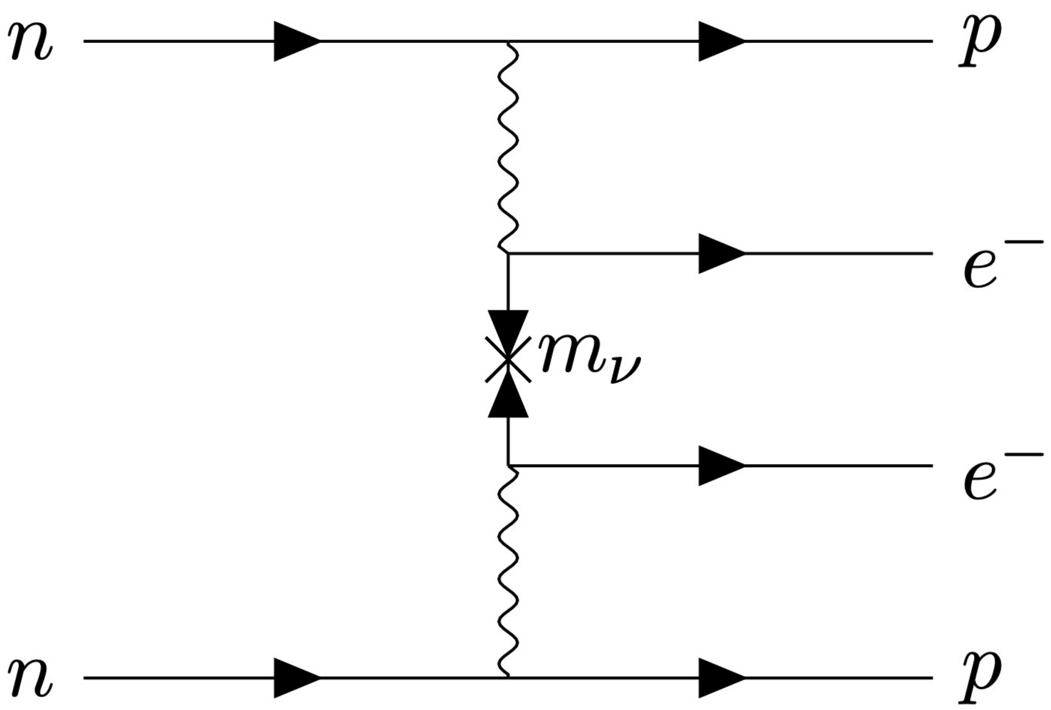
Overview

What we will discuss:

- Classification of 0νββ mechanisms (standard vs non-standard)
- Brief summary of EFT framework
- Ways to distinguish different mechanisms
- A generalized online tool

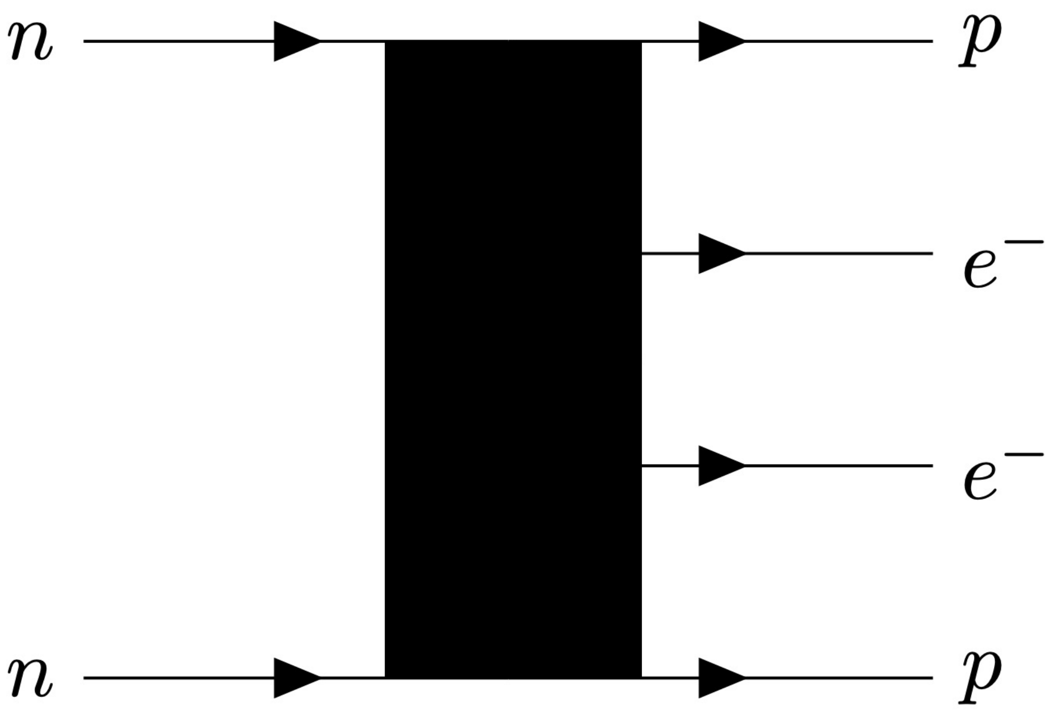
0νββ standard mechanism

Majorana neutrinos => 0νββ-decay



0νββ standard mechanism?

Majorana neutrinos => 0νββ-decay



0νββ non-standard mechanisms

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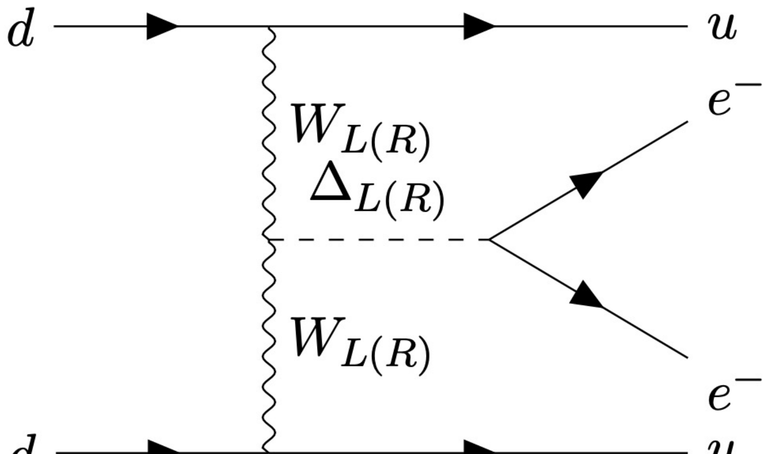
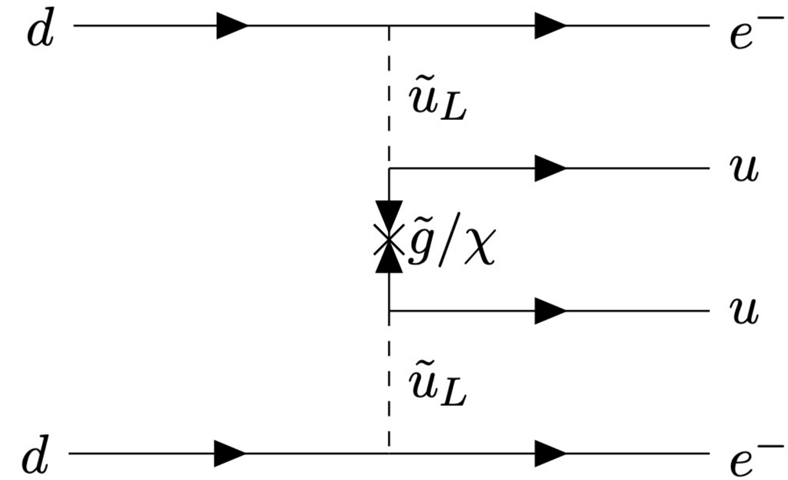
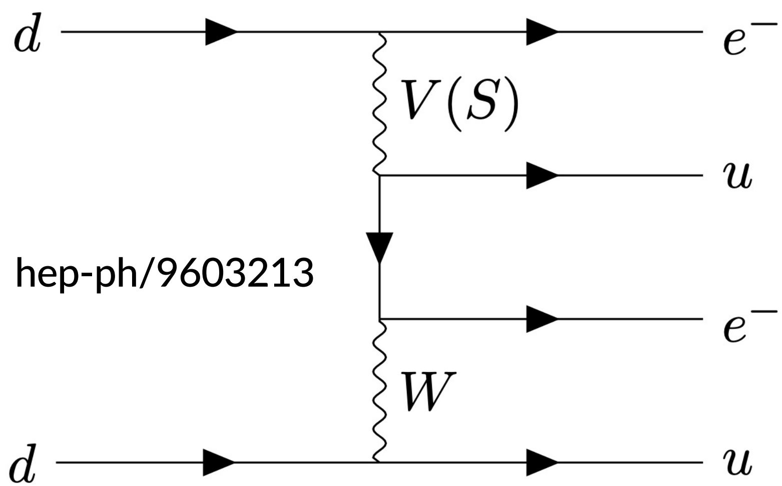
Scalars in minimal LR symmetry



R_P-violating SUSY Phys. Rev. Lett. **75**, 17



Leptoquarks hep-ph/9603213



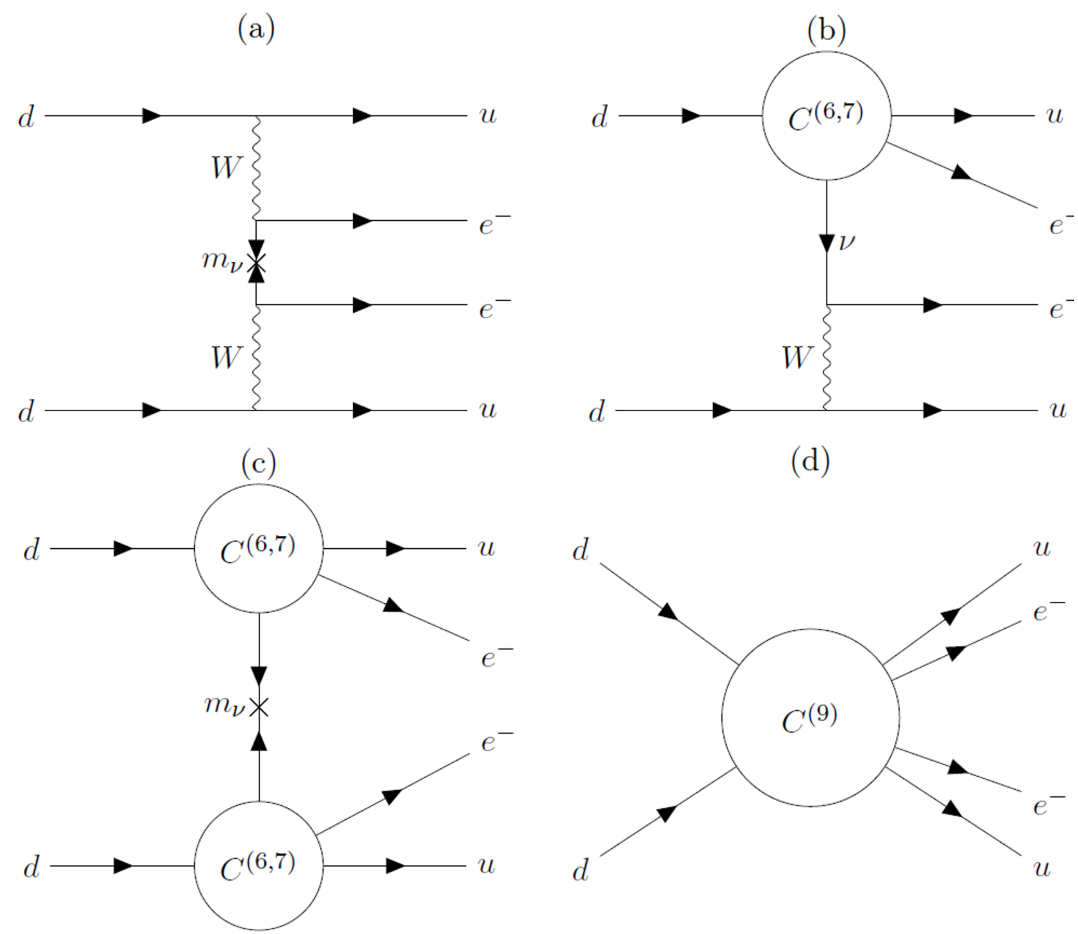
0νββ mechanisms -Classification

a) mass mechanism

b) long-range

c) ignore$_{(suppressed)}$

d) short-range



EFT Approach [Cirigliano et al. ArXiv:1806.02780]

Low-Energy decay process
→ use LEFT (no light new physics!)

32 different operators

1 mass mechanism (dim 3)

7 long-range (dim 6,7)

24 short-range (dim 9)

Class	Op. Name	Op. Structure
Dim 3		
Ψ^2	$\mathcal{O}_{m_{\beta\beta}}$	$-\frac{1}{2}m_{ee}\overline{\nu_{L,e}^C}\nu_{L,e}$
Dim 6		
Ψ^4	$\mathcal{O}_{SL}^{(6)}$	$[\overline{u_R}d_L]\,[\overline{e_L}\nu_L^C]$
	$\mathcal{O}_{SR}^{(6)}$	$[\overline{u_L}d_R]\,[\overline{e_L}\nu_L^C]$
	$\mathcal{O}_{VL}^{(6)}$	$[\overline{u_L}\gamma^\mu d_L]\,[\overline{e_R}\gamma_\mu\nu_L^C]$
	$\mathcal{O}_{VR}^{(6)}$	$[\overline{u_R}\gamma^\mu d_R]\,[\overline{e_R}\gamma_\mu\nu_L^C]$
	$\mathcal{O}_{T}^{(6)}$	$[\overline{u_L}\sigma^{\mu\nu}d_R]\,[\overline{e_L}\sigma_{\mu\nu}\nu_L^C]$
Dim 7		
$\Psi^4\partial$	$\mathcal{O}_{VL}^{(7)}$	$[\overline{u_L}\gamma^\mu d_L]\,[\overline{e_L}\overleftrightarrow{\partial}_\mu\nu_L^C]$
	$\mathcal{O}_{VR}^{(7)}$	$[\overline{u_R}\gamma^\mu d_R]\,[\overline{e_L}\overleftrightarrow{\partial}_\mu\nu_L^C]$
Dim 9		
Ψ^6	$\mathcal{O}_{1L,R}^{(9)}$	$[\overline{u_L}\gamma_\mu d_L]\,[\overline{u_L}\gamma^\mu d_L]\,[\overline{e_{L,R}}e_{L,R}^C]$
	$\mathcal{O}_{1L,R}^{(9)\prime}$	$[\overline{u_R}\gamma_\mu d_R]\,[\overline{u_R}\gamma^\mu d_R]\,[\overline{e_{L,R}}e_{L,R}^C]$
	$\mathcal{O}_{2L,R}^{(9)}$	$[\overline{u_R}d_L]\,[\overline{u_R}d_L]\,[\overline{e_{L,R}}e_{L,R}^C]$
	$\mathcal{O}_{2L,R}^{(9)\prime}$	$[\overline{u_L}d_R]\,[\overline{u_L}d_R]\,[\overline{e_{L,R}}e_{L,R}^C]$
	$\mathcal{O}_{3L,R}^{(9)}$	$[\overline{u_R}^\alpha d_L^\beta]\,[\overline{u_R}^\beta d_L^\alpha]\,[\overline{e_{L,R}}e_{L,R}^C]$
	$\mathcal{O}_{3L,R}^{(9)\prime}$	$[\overline{u_L}^\alpha d_R^\beta]\,[\overline{u_L}^\beta d_R^\alpha]\,[\overline{e_{L,R}}e_{L,R}^C]$
	$\mathcal{O}_{4L,R}^{(9)}$	$[\overline{u_L}\gamma^\mu d_L]\,[\overline{u_R}\gamma_\mu d_R]\,[\overline{e_{L,R}}e_{L,R}^C]$
	$\mathcal{O}_{5L,R}^{(9)}$	$[\overline{u_L}^\alpha\gamma^\mu d_L^\beta]\,[\overline{u_R}^\beta\gamma_\mu d_R^\alpha]\,[\overline{e_{L,R}}e_{L,R}^C]$
	$\mathcal{O}_{6}^{(9)}$	$[\overline{u_L}\gamma_\mu d_L]\,[\overline{u_L}d_R]\,[\bar{e}\gamma^\mu\gamma_5 e^C]$
	$\mathcal{O}_{6}^{(9)\prime}$	$[\overline{u_R}\gamma_\mu d_R]\,[\overline{u_R}d_L]\,[\bar{e}\gamma^\mu\gamma_5 e^C]$
	$\mathcal{O}_{7}^{(9)}$	$[\overline{u_L}t^A\gamma_\mu d_L]\,[\overline{u_L}t^A d_R]\,[\bar{e}\gamma^\mu\gamma_5 e^C]$
	$\mathcal{O}_{7}^{(9)\prime}$	$[\overline{u_R}t^A\gamma_\mu d_R]\,[\overline{u_R}t^A d_L]\,[\bar{e}\gamma^\mu\gamma_5 e^C]$
	$\mathcal{O}_{8}^{(9)}$	$[\overline{u_L}\gamma_\mu d_L]\,[\overline{u_R}d_L]\,[\bar{e}\gamma^\mu\gamma_5 e^C]$
	$\mathcal{O}_{8}^{(9)\prime}$	$[\overline{u_R}\gamma_\mu d_R]\,[\overline{u_L}d_R]\,[\bar{e}\gamma^\mu\gamma_5 e^C]$
	$\mathcal{O}_{9}^{(9)}$	$[\overline{u_L}t^A\gamma_\mu d_L]\,[\overline{u_R}t^A d_L]\,[\bar{e}\gamma^\mu\gamma_5 e^C]$
	$\mathcal{O}_{9}^{(9)\prime}$	$[\overline{u_R}t^A\gamma_\mu d_R]\,[\overline{u_L}t^A d_R]\,[\bar{e}\gamma^\mu\gamma_5 e^C]$

EFT Approach [Cirigliano et al. ArXiv:1806.02780]

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Standard Formula

$$\left(T_{1/2}^{0\nu}\right)^{-1} = |m_{\beta\beta}|^2 \left|\mathrm{M}^{0\nu}\right|^2 G^{0\nu}(Q, Z)$$

0νββ "Master-Formula"

$$\begin{aligned}\left(T_{1/2}^{0\nu}\right)^{-1} =& g_A^4 \Big[G_{01} \left(|\mathcal{A}_\nu|^2 + |\mathcal{A}_R|^2 \right) - 2\left(G_{01} - G_{04}\right) \mathrm{Re}\left[\mathcal{A}_\nu^* \mathcal{A}_R\right] \\ & + 4G_{02} |\mathcal{A}_E|^2 + 2G_{04} \left(|\mathcal{A}_{m_e}|^2 + \mathrm{Re}\left[\mathcal{A}_{m_e}^* \left(\mathcal{A}_\nu + \mathcal{A}_R\right)\right] \right) \\ & - 2G_{03}\, \mathrm{Re}\left[\left(\mathcal{A}_\nu + \mathcal{A}_R\right)\mathcal{A}_E^* + 2\mathcal{A}_{m_e}\mathcal{A}_E^*\right] \\ & + G_{09} |\mathcal{A}_M|^2 + G_{06}\, \mathrm{Re}\left[\left(\mathcal{A}_\nu - \mathcal{A}_R\right)\mathcal{A}_M^*\right] \Big]\end{aligned}$$

Input: Wilson Coefficients + 3 numerical inputs (NMEs, PSFs, LECs)

EFT Approach [Cirigliano et al. ArXiv:1806.02780]

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

Standard Formula

$$\left(T_{1/2}^{0\nu}\right)^{-1} = |m_{\beta\beta}|^2 \left|\mathrm{M}^{0\nu}\right|^2 G^{0\nu}(Q, Z)$$

0νββ "M… Formula"

$$\left(T_{1/2}^{0\nu}\right)^{-1} \ldots {}^{2}\big) - 2\left(G_{01} - G_{04}\right) \mathrm{Re}\left[\mathcal{A}_\nu^* \mathcal{A}_R\right]$$

$$\ldots \left(\mathcal{A}_\nu + \mathcal{A}_R\right)\big]\big)$$

$$- 2G_{03}\,\mathrm{Re}\ldots$$

$$+ G_{09}\left|\mathcal{A}_M\right|^2 + G_{06}\,\mathrm{Re}\left[\left(\mathcal{A}_\nu \ldots\right.\right.$$

$$\mathcal{A}_\nu = \frac{m_{\beta\beta}}{m_e}\mathcal{M}_\nu^{(3)} + \frac{m_N}{m_e}\mathcal{M}_\nu^{(6)}\left(C_{SL}^{(6)}, C_{SR}^{(6)}, C_T^{(6)}, C_{VL}^{(7)}, C_{VR}^{(7)}\right) + \frac{m_N^2}{m_e v}\mathcal{M}_\nu^{(9)}\left(C_{1L}^{(9)}, C_{1L}^{(9)\prime}, C_{2L}^{(9)}, C_{2L}^{(9)\prime}, C_{3L}^{(9)}, C_{3L}^{(9)\prime}, C_{4L}^{(9)}, C_{5L}^{(9)}\right)$$

Input: Wilson Coefficients + 3 numerical inputs (NME…, …, LECs)

EFT Approach [Cirigliano et al. ArXiv:1806.02780]

Standard Formula

$$\left(T_{1/2}^{0\nu}\right)^{-1} = |m_{\beta\beta}|^2 \left|\mathrm{M}^{0\nu}\right|^2 G^{0\nu}(Q,Z)$$

0νββ “M... Formula”

$$\left(T_{1/2}^{0\nu}\right)^{-1} \ldots$$

$$\mathcal{A}_\nu = \frac{m_{\beta\beta}}{m_e}\mathcal{M}_\nu^{(3)} \ldots$$

$$\ldots C_{3L}^{(9)}, C_{3L}^{(9)\prime}, C_{4L}^{(9)}, C_{5L}^{(9)}\Big)$$

$$\mathcal{A}_{\mathrm{R}} = \frac{m_{\mathrm{N}}^2}{m_e v}\mathcal{M}_{\mathrm{R}}^{(9)}\left(C_{1\mathrm{R}}^{(9)}, C_{1\mathrm{R}}^{(9)\prime}, C_{2\mathrm{R}}^{(9)}, C_{2\mathrm{R}}^{(9)\prime}, C_{3\mathrm{R}}^{(9)}, C_{3\mathrm{R}}^{(9)\prime}, C_{4\mathrm{R}}^{(9)}, C_{5\mathrm{R}}^{(9)}\right),$$

$$\mathcal{A}_{\mathrm{E}} = \mathcal{M}_{\mathrm{E,L}}^{(6)}\left(C_{\mathrm{VL}}^{(6)}\right) + \mathcal{M}_{\mathrm{E,R}}^{(6)}\left(C_{\mathrm{VR}}^{(6)}\right),$$

$$\mathcal{A}_{m_e} = \mathcal{M}_{m_e,\mathrm{L}}^{(6)}\left(C_{\mathrm{VL}}^{(6)}\right) + \mathcal{M}_{m_e,\mathrm{R}}^{(6)}\left(C_{\mathrm{VR}}^{(6)}\right),$$

$$\mathcal{A}_{\mathrm{M}} = \frac{m_{\mathrm{N}}}{m_e}\mathcal{M}_{\mathrm{M}}^{(6)}\left(C_{\mathrm{VL}}^{(6)}\right) + \frac{m_{\mathrm{N}}^2}{m_e v}\mathcal{M}_{\mathrm{M}}^{(9)}\left(C_6^{(9)}, C_6^{(9)\prime}, C_7^{(9)}, C_7^{(9)\prime}, C_8^{(9)}, C_8^{(9)\prime}, C_9^{(9)}, C_9^{(9)\prime}\right)$$

Inpu... ...cients + 3 numerical inputs (NM..., ..., LECs)

EFT Approach [Cirigliano et al. ArXiv:1806.02780]

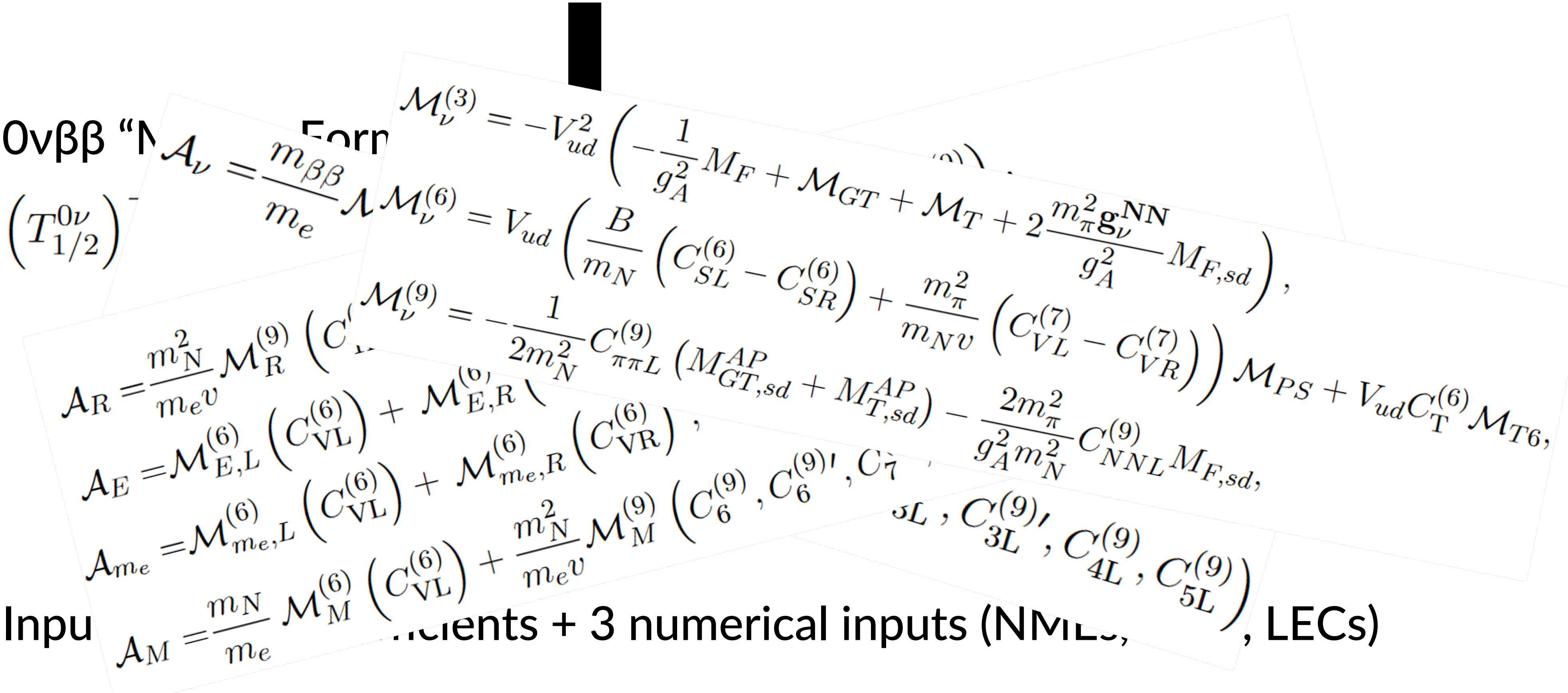
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

Standard Formula

$$\left(T_{1/2}^{0\nu}\right)^{-1} = |m_{\beta\beta}|^2 \left|\mathrm{M}^{0\nu}\right|^2 G^{0\nu}(Q,Z)$$

0νββ “M… Form…

$\left(T_{1/2}^{0\nu}\right)^{-}$…



Inpu… …cients + 3 numerical inputs (NME…, …, LECs)

EFT Approach [Cirigliano et al. ArXiv:1806.02780]

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

Standard Formula

$$\left(T^{0\nu}_{1/2}\right)^{-1} = |m_{\beta\beta}|^2 \left|\mathrm{M}^{0\nu}\right|^2 G^{0\nu}(Q,Z)$$

0νββ "M… Form…

$$\left(T^{0\nu}_{1/2}\right)^{-1} \ldots$$

$$\mathcal{A}_\nu = \frac{m_{\beta\beta}}{m_e}\mathcal{M} \ldots$$

$$\mathcal{M}^{(3)}_\nu = -V_{ud}^2\left(-\frac{1}{g_A^2}M_F + \mathcal{M}_{G\ldots}\right)$$

$$\mathcal{M}^{(6)}_\nu = V_{ud}\left(\frac{B}{m_N}\left(C \ldots\right.\right.$$

$$\mathcal{M}^{(9)}_\nu = -\frac{1}{2m_N^2}C^{(9)}_{\pi\pi L}\left(\mathcal{M} \ldots\right.$$

$$\ldots - C^{(7)}_{VR}\Big)\Big)\mathcal{M}_{PS} + V_{ud}C^{(6)}_T\mathcal{M}_{T6},$$

$$\ldots + M^{AP}_{T,sd}) - \frac{2m_\pi^2}{g_A^2 m_N^2}C^{(9)}_{NNL}M_{F,sd},$$

$$\ldots C^{(9)}_{3L}, C^{(9)\prime}_{3L}, C^{(9)}_{4L}, C^{(9)}_{5L}\Big)$$

$$\mathrm{M}^{(6)}_{\mathrm{E,L}} = -\frac{V_{ud}C^{(6)}_{\mathrm{VL}}}{3}\left(\frac{g_{\mathrm{V}}^2}{g_{\mathrm{A}}^2}M_F + \frac{1}{3}\left(2M^{AA}_{GT} + M^{AA}_{T}\right) + \frac{6\mathbf{g}^{\mathbf{E}}_{\mathbf{V\,L}}}{g_{\mathrm{A}}^2}M_{F,sd}\right),$$

$$\mathrm{M}^{(6)}_{\mathrm{E,R}} = -\frac{V_{ud}C^{(6)}_{\mathrm{VR}}}{3}\left(\frac{g_{\mathrm{V}}^2}{g_{\mathrm{A}}^2}M_F - \frac{1}{3}\left(2M^{AA}_{GT} + M^{AA}_{T}\right) + \frac{6\mathbf{g}^{\mathbf{E}}_{\mathbf{V\,L}}}{g_{\mathrm{A}}^2}M_{F,sd}\right),$$

$$\mathcal{A}_{\mathrm{R}} = \frac{m_{\mathrm{N}}^2}{m_e v}\mathcal{M}^{(9)}_{\mathrm{R}}\left(C \ldots\right.$$

$$\mathcal{A}_{\mathrm{E}} = \mathcal{M}^{(6)}_{\mathrm{E,L}}\left(C^{(6)}_{\mathrm{VL}}\right) + \mathcal{M}^{(6)}_{\mathrm{E,R}}\left(C^{(6)}_{\mathrm{VR}}\right),$$

$$\mathcal{A}_{m_e} = \mathcal{M}^{(6)}_{m_e,\mathrm{L}}\left(C^{(6)}_{\mathrm{VL}}\right) + \mathcal{M}^{(6)}_{m_e,\mathrm{R}}\left(C^{(6)}_{\mathrm{VR}}\right),$$

$$\mathcal{A}_{\mathrm{M}} = \frac{m_{\mathrm{N}}}{m_e}\mathcal{M}^{(6)}_{\mathrm{M}}\left(C^{(6)}_{\mathrm{VL}}\right) + \frac{m_{\mathrm{N}}^2}{m_e v}\mathcal{M}^{(9)}_{\mathrm{M}}\left(C^{(9)}_6, C^{(9)\prime}_6, C_7 \ldots\right.$$

Inpu… …icients + 3 numerical inputs (NME…, …, LECs)

EFT Approach [Cirigliano et al. ArXiv:1806.02780]

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

Standard Formula

$$\left(T^{0\nu}_{1/2}\right)^{-1} = |m_{\beta\beta}|^2 \left|\mathrm{M}^{0\nu}\right|^2 G^{0\nu}(Q,Z)$$

0νββ “M... Form...

$$\left(T^{0\nu}_{1/2}\right) ...$$

$$\mathcal{A}_\nu = \frac{m_{\beta\beta}}{m_e}\mathcal{M} ...$$

$$\mathcal{A}_{\mathrm{R}} = \frac{m_{\mathrm{N}}^2}{m_e v}\mathcal{M}^{(9)}_{\mathrm{R}}\left(C ...\right.$$

$$\mathcal{A}_{\mathrm{E}} = \mathcal{M}^{(6)}_{\mathrm{E,L}}\left(C^{(6)}_{\mathrm{VL}}\right) + ...$$

$$\mathcal{A}_{m_e} = \mathcal{M}^{(6)}_{m_e,\mathrm{L}}\left(C^{(6)}_{\mathrm{VL}}\right) ...$$

$$\mathcal{A}_{\mathrm{M}} = \frac{m_{\mathrm{N}}}{m_e}\mathcal{M}^{(6)}_{\mathrm{M}}\left(C ...\right.$$

$$\mathcal{M}^{(3)}_\nu = -V_{ud}^2\left(-\frac{1}{g_A^2}M_F + \mathcal{M}_{G...} ...\right)$$

$$\mathcal{M}^{(6)}_\nu = V_{ud}\left(\frac{B}{m_N}\left(...\right.\right.$$

$$\mathcal{M}^{(9)}_\nu = -\frac{1}{...} ...$$

$$... + \frac{6\mathbf{g}^{\mathbf{E}}_{\mathbf{V\,L}}}{g_A^2}M_{F,sd}\right),$$

$$\mathcal{M}^{(6)}_{\mathrm{E,L}} = -\frac{V_{ud}C^{(6)}_{VL}}{3}\left(\frac{g_V^2}{g_A^2}M_F + \frac{1}{3}\left(2M^{AA}_{GT} + M^{AA}_T\right) + \frac{6\mathbf{g}^{\mathbf{E}}_{\mathbf{V\,L}}}{g_A^2}M_{F,sd}\right),$$

$$\mathcal{M}^{(6)}_{...} = -\frac{V_{ud}C^{(6)}_{VR}}{3}\left(\frac{g_V^2}{g_A^2}M_F - \frac{1}{3}\left(2M^{AA}_{GT} + M^{AA}_T\right) ...\right.$$

$$... L - C^{(7)}_{VR}\,)\,)\ ... \mathcal{M}_{T6},$$

$$\mathcal{M}^{(6)}_{m_e,L} = \frac{V_{ud}C^{(6)}_{VL}}{6}\left(\frac{g_V^2}{g_A^2}M_F - \frac{1}{3}\left(M^{AA}_{GT} - 4M^{AA}_T\right) - 3\left(M^{AP}_{GT} + M^{PP}_{GT} + M^{AP}_T + M^{PP}_T\right) - \frac{12\mathbf{g}^{\mathbf{m_e}}_{\mathbf{V\,L}}}{g_A^2}M_{F,sd}\right),$$

$$\mathcal{M}^{(6)}_{m_e,R} = \frac{V_{ud}C^{(6)}_{VR}}{6}\left(\frac{g_V^2}{g_A^2}M_F + \frac{1}{3}\left(M^{AA}_{GT} - 4M^{AA}_T\right) + 3\left(M^{AP}_{GT} + M^{PP}_{GT} + M^{AP}_T + M^{PP}_T\right) - \frac{12\mathbf{g}^{\mathbf{m_e}}_{\mathbf{V\,L}}}{g_A^2}M_{F,sd}\right),$$

Inpu...

EFT Approach [Cirigliano et al. ArXiv:1806.02780]

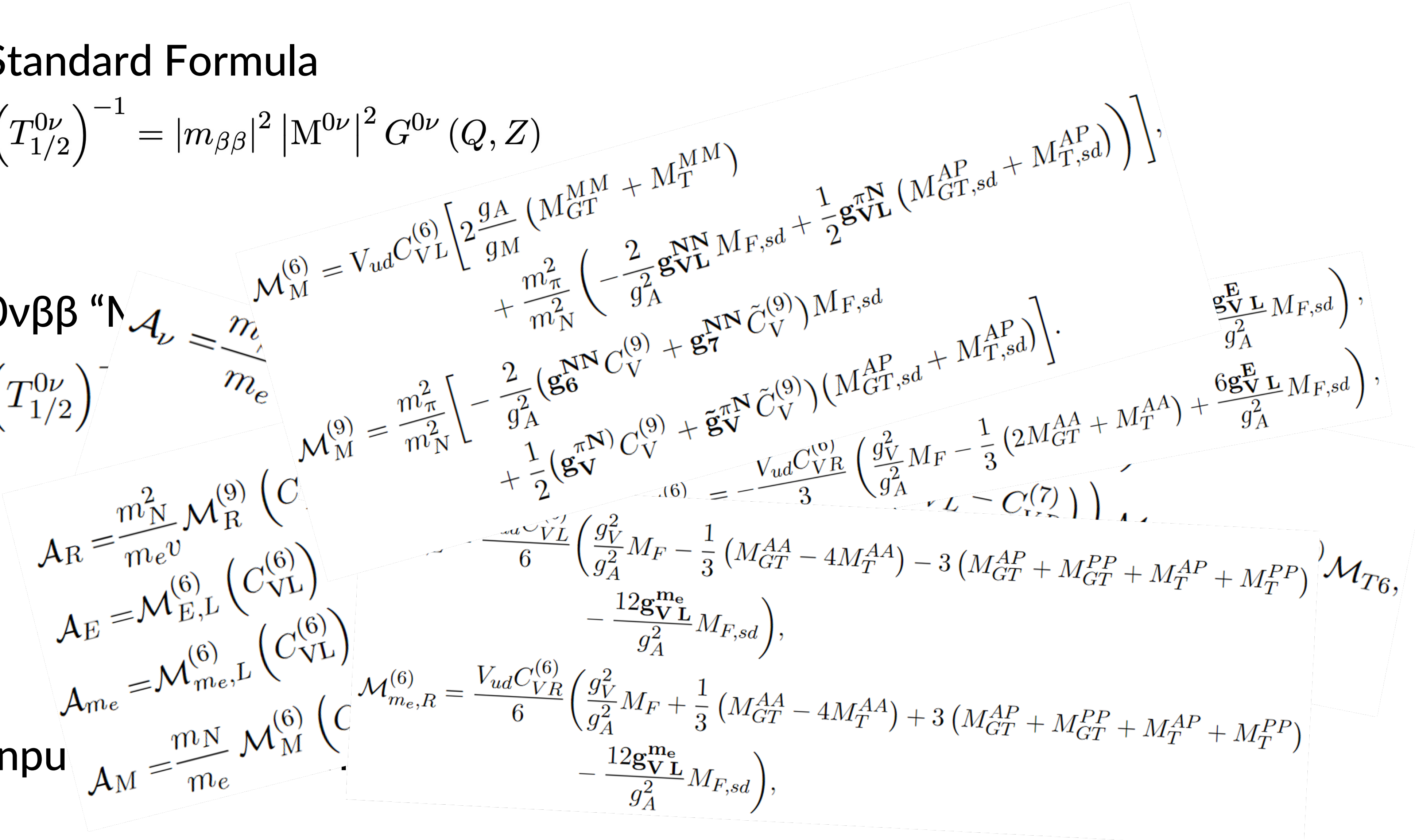
Max-Planck-Institut für Kernphysik Heidelberg

Standard Formula

$$\left(T^{0\nu}_{1/2}\right)^{-1} = |m_{\beta\beta}|^2 \left|\mathrm{M}^{0\nu}\right|^2 G^{0\nu}(Q,Z)$$

0νββ “N

$\left(T^{0\nu}_{1/2}\right)^{-}$



Inpu

EFT Approach [Cirigliano et al. ArXiv:1806.02780]

S… Formula

$$\mathcal{M}_{GT} = M_{GT}^{AA} + M_{GT}^{AP} + M_{GT}^{PP} + M_{GT}^{MM},$$

$$\mathcal{M}_{T} = M_{T}^{AP} + M_{T}^{PP} + M_{T}^{MM},$$

$$\mathcal{M}_{PS} = \frac{1}{2}M_{GT}^{AP} + M_{GT}^{PP} + \frac{1}{2}M_{T}^{AP} + M_{T}^{PP},$$

$$\mathcal{M}_{T6} = 2\frac{\mathbf{g_T'} - \mathbf{g_T^{NN}}}{g_A^2}\frac{m_\pi^2}{m_N^2}M_{F,sd} - \frac{8g_T}{g_M}\left(M_{GT}^{MM} + M_T^{MM}\right) + \mathbf{g_T^{\pi N}}\frac{m_\pi^2}{4m_N^2}\left(M_{GT,sd}^{AP} + M_{T,sd}^{AP}\right) + \mathbf{g_T^{\pi\pi}}\frac{m_\pi^2}{4m_N^2}\left(M_{GT,sd}^{PP} + M_{T,sd}^{PP}\right).$$

$$\mathcal{A}_{\rm R} = \frac{m_{\rm N}^2}{m_e v}\mathcal{M}_{\rm R}^{(9)}\left(C \ldots\right.$$

$$\mathcal{A}_{\rm E} = \mathcal{M}_{\rm E,L}^{(6)}\left(C_{\rm VL}^{(6)}\right)$$

$$\mathcal{A}_{m_e} = \mathcal{M}_{m_e,L}^{(6)}\left(C_{\rm VL}^{(6)}\right)$$

$$\mathcal{A}_{\rm M} = \frac{m_{\rm N}}{m_e}\mathcal{M}_{\rm M}^{(6)}\left(C \ldots\right.$$

$$\ldots \frac{\ldots C_{VL}^{(\ldots)}}{6}\left(\frac{g_V^2}{g_A^2}M_F - \frac{1}{3}\left(M_{GT}^{AA} - 4M_T^{\ldots}\right) - 3\left(M_{GT}^{AP} + M_{GT}^{PP} + M_T^{AP} + M_T^{PP}\right) - \frac{12\mathbf{g_{V\,L}^{m_e}}}{g_A^2}M_{F,sd}\right),$$

$$\mathcal{M}_{m_e,R}^{(6)} = \frac{V_{ud}C_{VR}^{(6)}}{6}\left(\frac{g_V^2}{g_A^2}M_F + \frac{1}{3}\left(M_{GT}^{AA} - 4M_T^{AA}\right) + 3\left(M_{GT}^{AP} + M_{GT}^{PP} + M_T^{AP} + M_T^{PP}\right) - \frac{12\mathbf{g_{V\,L}^{m_e}}}{g_A^2}M_{F,sd}\right),$$

Inpu…

EFT Approach [Cirigliano et al. ArXiv:1806.02780]

S... Formula

$$\mathcal{M}_{GT} = M_{GT}^{AA} + M_{GT}^{AP} + M_{GT}^{PP}$$
$$\mathcal{M}_{T} = M_{T}^{AP} + M_{T}^{PP}$$
$$\mathcal{M}_{PS} = \frac{1}{2} M^{AP} \ldots$$

$$C_V^{(9)} = C_6^{(9)} + C_6^{(9)\prime} + C_8^{(9)} + C_8^{(9)\prime}, \quad \tilde{C}_V^{(9)} = C_7^{(9)} + C_7^{(9)\prime} + C_9^{(9)} + C_9^{(9)\prime}$$

$$C_{\pi\pi L}^{(9)} = g_2^{\pi\pi}\left(C_{2L}^{(9)} + C_{2L}^{(9)\prime}\right) + g_3^{\pi\pi}\left(C_{3L}^{(9)} + C_{3L}^{(9)\prime}\right) - g_4^{\pi\pi} C_{4L}^{(9)} - g_5^{\pi\pi} C_{5L}^{(9)} - \frac{5}{3} g_1^{\pi\pi} m_\pi^2 \left(C_{1L}^{(9)} + C_{1L}^{(9)\prime}\right)$$

$$C_{\pi N L}^{(9)} = \left(\mathbf{g_1^{\pi N}} - \frac{5}{6} g_1^{\pi\pi}\right)\left(C_{1L}^{(9)} + C_{1L}^{(9)\prime}\right)$$

$$C_{NNL}^{(9)} = \mathbf{g_1^{NN}}\left(C_{1L}^{(9)} + C_{1L}^{(9)\prime}\right) + \mathbf{g_2^{NN}}\left(C_{2L}^{(9)} + C_{2L}^{(9)\prime}\right) + \mathbf{g_3^{NN}}\left(C_{3L}^{(9)} + C_{3L}^{(9)\prime}\right) + \mathbf{g_4^{NN}} C_{4L}^{(9)} + \mathbf{g_5^{NN}} C_{5L}^{(9)}$$

$$C_{\{\pi\pi,\pi N,NN\}R} = C_{\{\pi\pi,\pi N,NN\}L}|_{L\to R}\,.$$

$$\mathcal{A}_R \ldots$$
$$\mathcal{A}_E = \mathcal{M}_{E,L}^{(6)}\left(C_{\mathrm{VL}}^{(6)} \ldots\right.$$
$$\mathcal{A}_{m_e} = \mathcal{M}_{m_e,L}^{(6)}\left(C_{\mathrm{VL}}^{(6)} \ldots\right.$$
$$\mathcal{A}_M = \frac{m_N}{m_e}\mathcal{M}_M^{(6)}\left(C \ldots\right.$$

$$\ldots \frac{\ldots}{4m_N^2}\left(M_{GT,sd}^{PP} + M_{T,sd}^{PP}\right).$$

$$\ldots \frac{V_{ud} C_{VL}^{(6)}}{6}\left(\frac{g_V^2}{g_A^2} M_F - \frac{1}{3}\left(M_{GT}^{AA} - 4M_T^{AA}\right) - 3\left(M_{GT}^{AP} + M_{GT}^{PP} + M_T^{AP} + M_T^{PP}\right) - \frac{12\mathbf{g_{V\,L}^{m_e}}}{g_A^2} M_{F,sd}\right),$$

$$\mathcal{M}_{m_e,R}^{(6)} = \frac{V_{ud} C_{VR}^{(6)}}{6}\left(\frac{g_V^2}{g_A^2} M_F + \frac{1}{3}\left(M_{GT}^{AA} - 4M_T^{AA}\right) + 3\left(M_{GT}^{AP} + M_{GT}^{PP} + M_T^{AP} + M_T^{PP}\right) - \frac{12\mathbf{g_{V\,L}^{m_e}}}{g_A^2} M_{F,sd}\right),$$

Inpu...

How to distinguish?

Standard or non-standard mechanism?

3 different observables in decay experiments

1) Half-Life

2) Single Electron Spectra

3) Angular Correlation

1) Half-Life → Ratios

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NMEs depend on (A,Z)

Study Ratios of Half-Lifes [see Deppisch and Päs arXiv:hep-ph/0612165]

$$R^{\mathcal{O}_i}(^{\mathrm{A}}\mathrm{X}) \equiv \frac{T^{\mathcal{O}_i}_{1/2}(^{\mathrm{A}}\mathrm{X})}{T^{\mathcal{O}_i}_{1/2}(^{76}\mathrm{Ge})} = \frac{|\mathcal{M}^{\mathcal{O}_i}(^{76}\mathrm{Ge})|^2 G^{\mathcal{O}_i}(^{76}\mathrm{Ge})}{|\mathcal{M}^{\mathcal{O}_i}(^{\mathrm{A}}\mathrm{X})|^2 G^{\mathcal{O}_i}(^{\mathrm{A}}\mathrm{X})}$$

1) Half-Life → Ratios

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NMEs depend on (A,Z)

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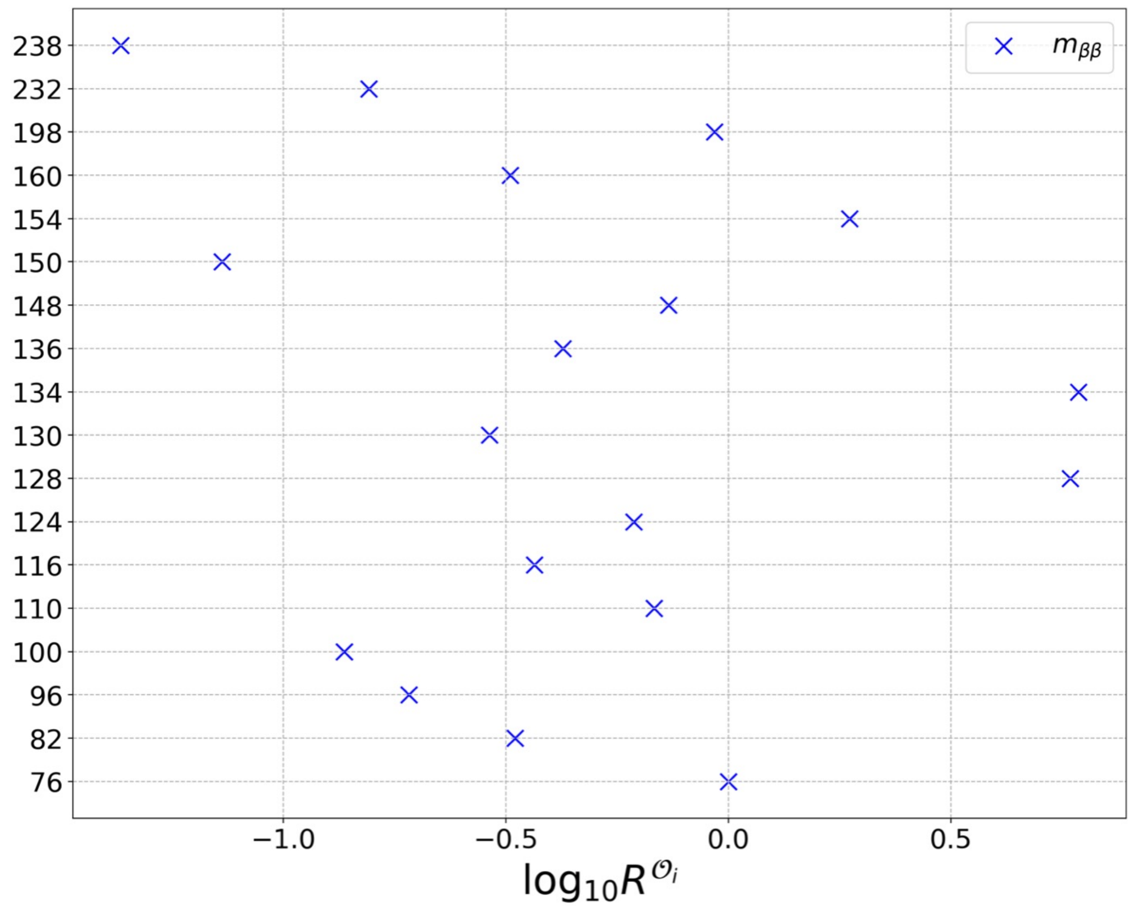
$$R^{\mathcal{O}_i}(^{\rm A}{\rm X}) \equiv \frac{T_{1/2}^{\mathcal{O}_i}(^{\rm A}{\rm X})}{T_{1/2}^{\mathcal{O}_i}(^{76}{\rm Ge})}$$



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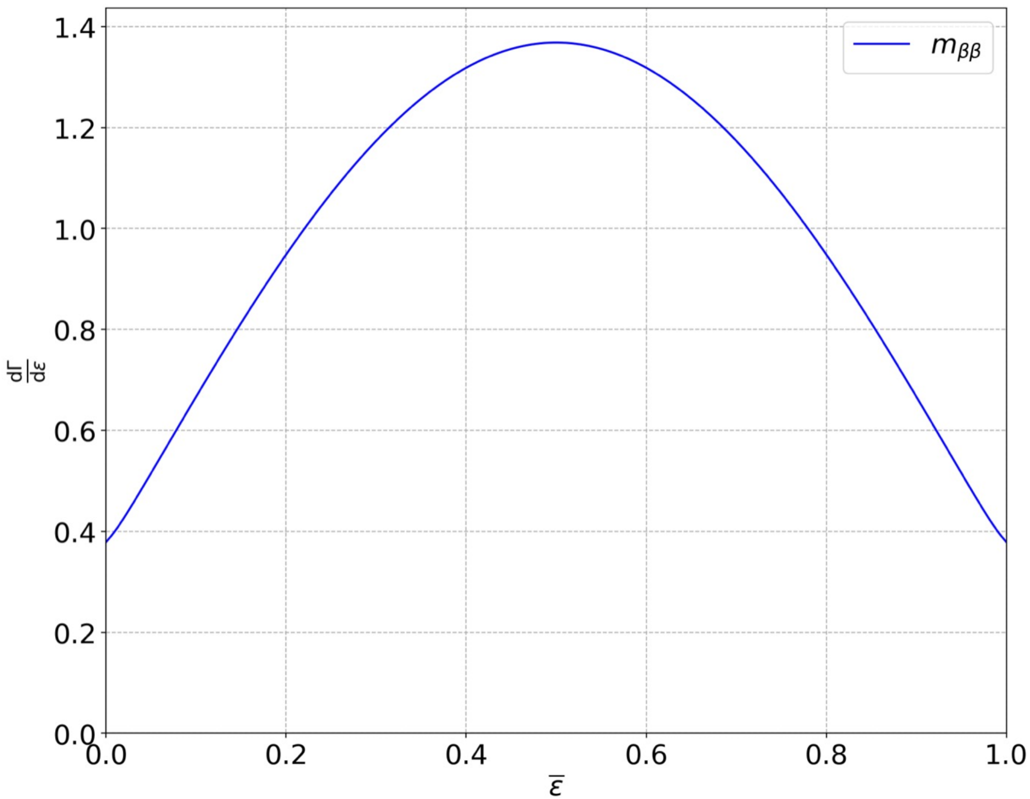
Distinguish 2 operators i, j by

$$R_{ij}(^{A}X) = \frac{R^{\mathcal{O}_i}(^{A}X)}{R^{\mathcal{O}_j}(^{A}X)}$$

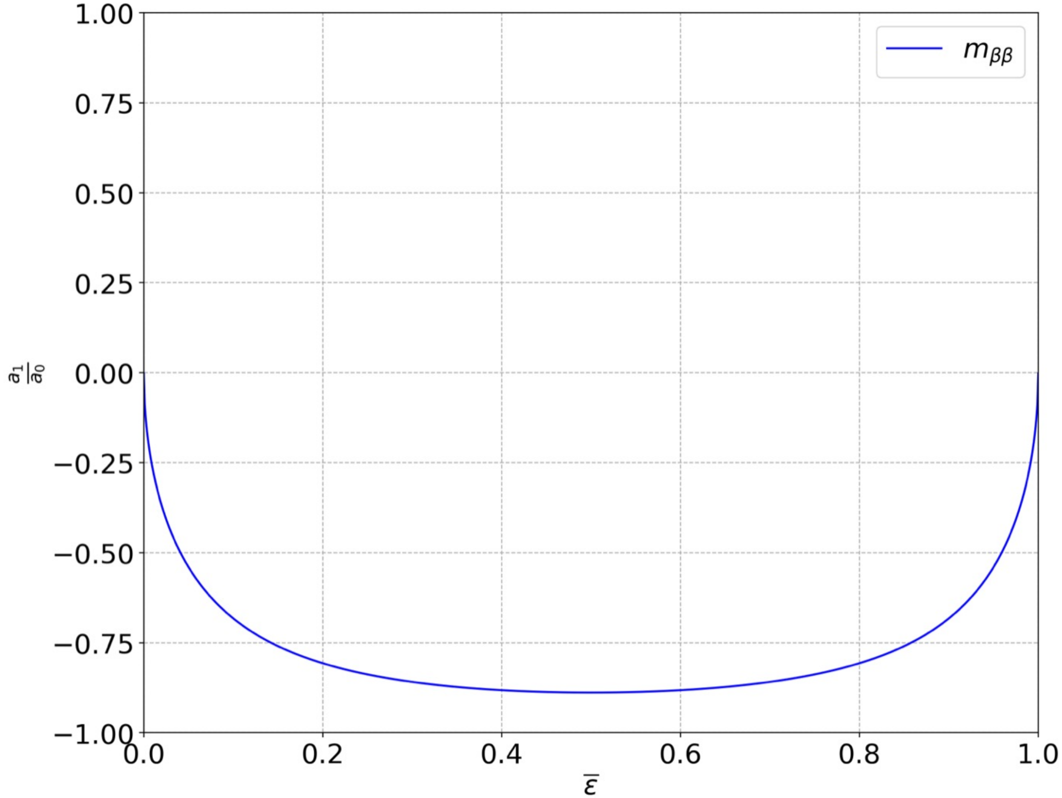
Similar for more complex models

2) + 3) Phase Space Observables

Single Electron Spectra



Angular Correlation



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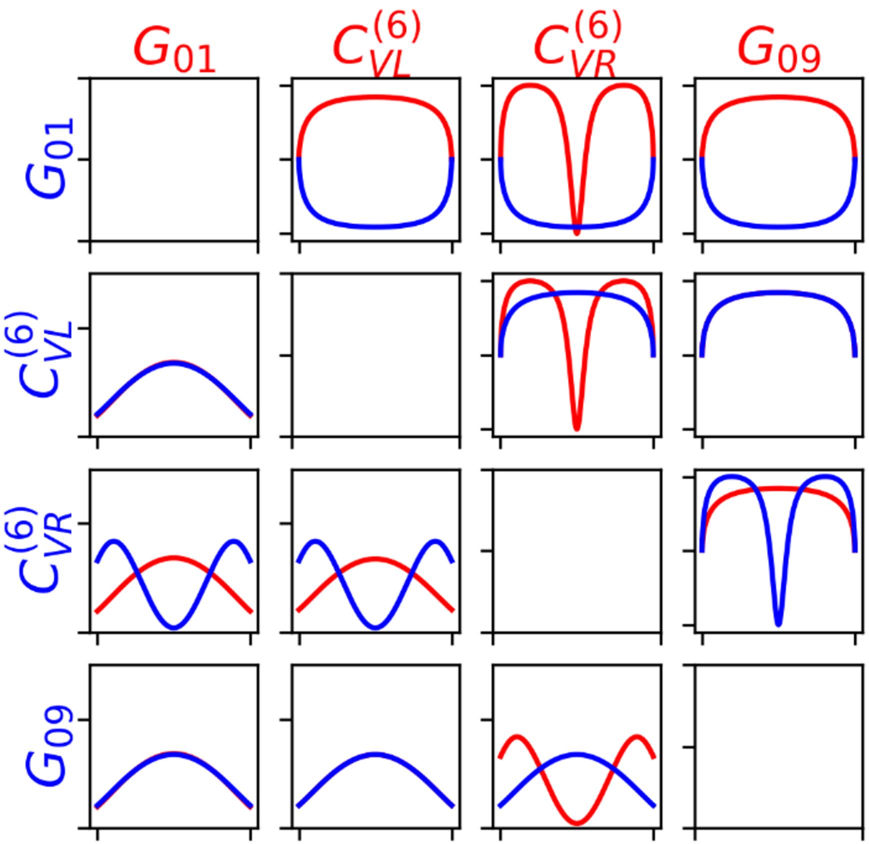
2) + 3) Phase Space Observables

→ 4 different groups (plot for 136Xe)

Angular correlation



Normalized Spectra

Tool for 0νββ-models

Tool to study all possible EFT models:

- 0νββ observables
- Distinguishability from standard-mechanism
- Operator Limits

Thank you for attention!