Phenomenology of Lorentz and CPT Violation in Double Beta Decay

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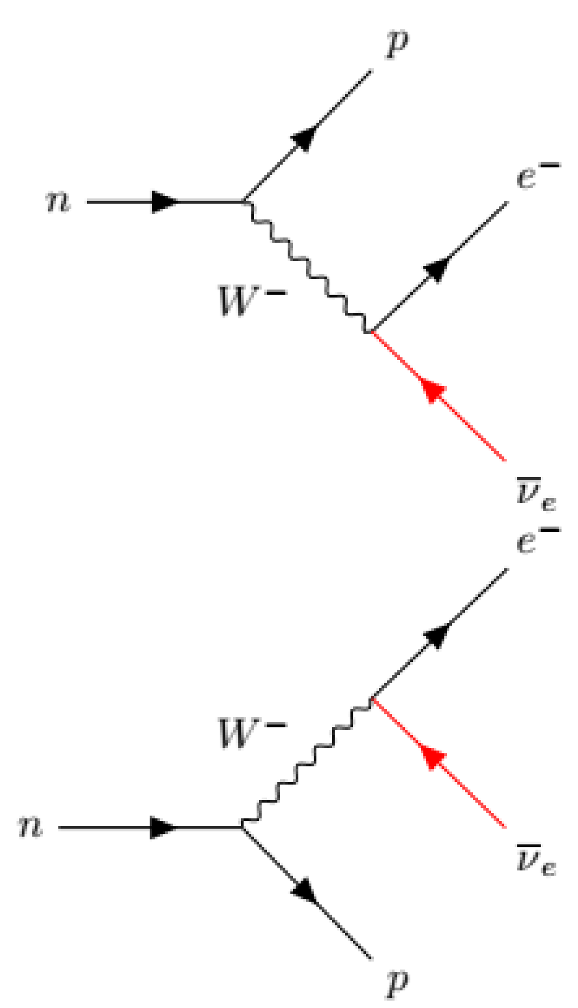
Motivations:

- Neutrinos provide a rich area to study Beyond Standard Model physics
- Can use the Standard Model Extension (SME) to study Lorentz and CPT violations with neutrinos [1]
- The SME neutrino sector has numerous unbound coefficients that could be studied with double beta decay [2]

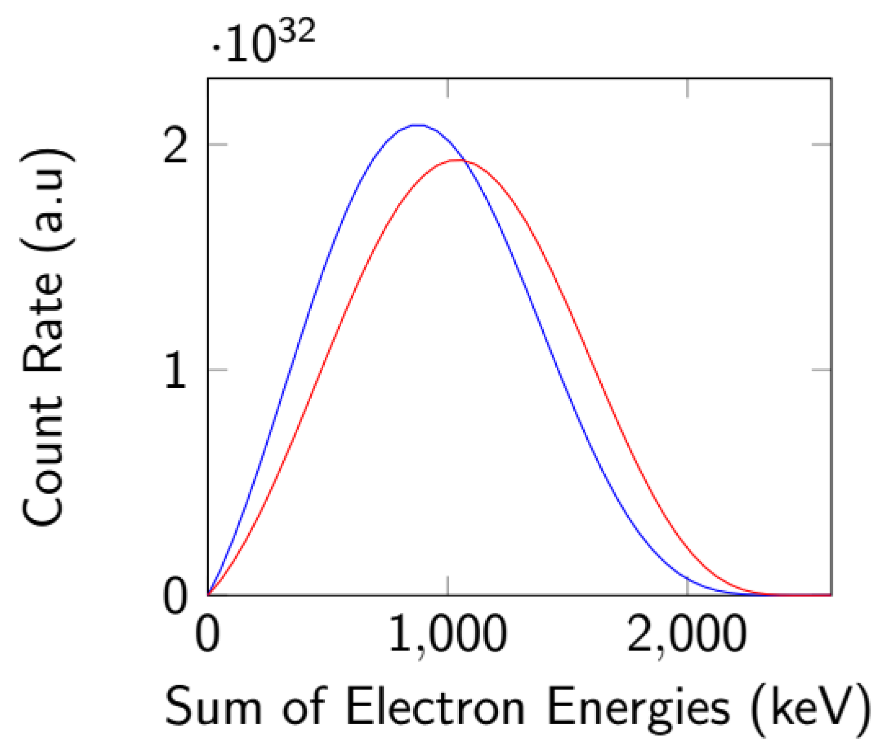
Neutrino Double Beta Decay (Dirac Mass)

$$\mathcal{L} \supset \bar{\psi}_{\mathrm{A}}\gamma_\mu D^\mu \psi_{\mathrm{B}} - \bar{\psi}_{\mathrm{A}}\gamma_\mu (a^{(5)})^{\mu\alpha\beta}_{\mathrm{AB}} D_{(\alpha}D_{\beta)}\psi_{\mathrm{B}} + \text{h.c.}$$



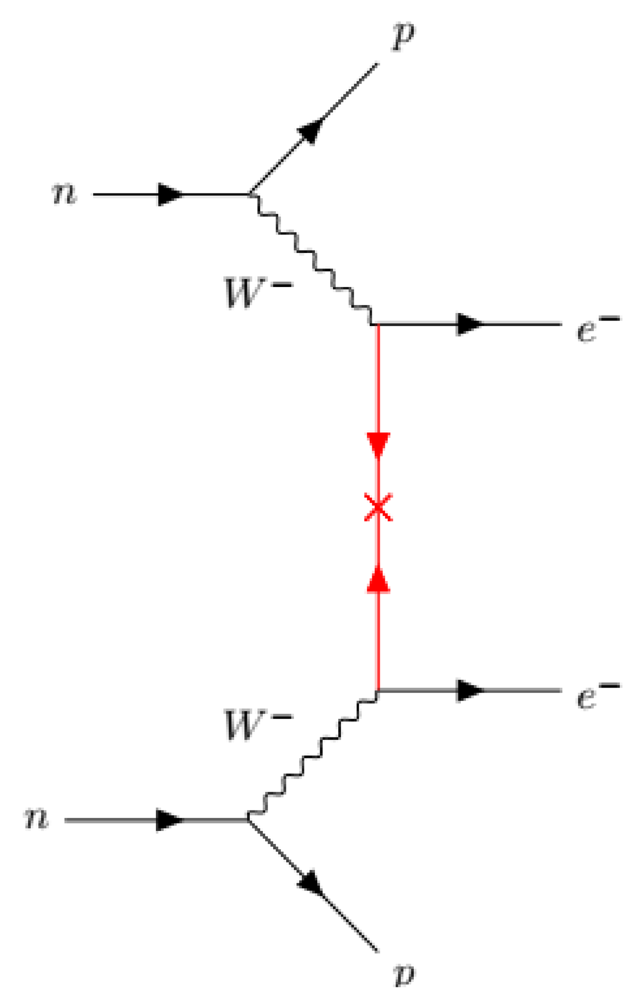
Modified Decay

$$d\Gamma \sim \int |\mathcal{M} + \delta\mathcal{M}(a^{(5)00}_{\mathrm{of}})|^2 d\Pi$$



Neutrinoless Double Beta Decay (Majorana Mass)

$$\mathcal{L} \supset -i\psi_{\mathrm{A}} g^{(6)\lambda\rho\kappa\alpha\beta}_{\mathrm{AB}} \sigma_{\lambda\rho} D_{(\kappa}D_\alpha D_{\beta)}\psi^c_{\mathrm{B}} + \text{h.c.}$$



Unmodified Decay Rates

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

Modified Decay

$$(T^{0\nu}_{1/2})^{-1} = \Gamma = G^{0\nu}(Z,Q)|M^{0\nu}|^2\frac{|g^{(6)\lambda\rho\alpha\beta\kappa}_{\beta\beta}|^2}{4R^6}$$

$$(T^{0\nu}_{1/2})^{-1} = \Gamma = G^{0\nu}(Z,Q)|M^{0\nu}|^2\frac{|g^{(8)\lambda\rho\alpha\beta\kappa\zeta\eta}_{\beta\beta}|^2}{4R^{10}}$$

$$(T^{0\nu}_{1/2})^{-1} = \Gamma = G^{0\nu}(Z,Q)|M^{0\nu}|^2\frac{|g^{(10)\lambda\rho\alpha\beta\kappa\zeta\eta\xi\omega}_{\beta\beta}|^2}{4R^{14}}$$

$(T^{0\nu}_{1/2})$ →half life Z→atomic number Q→Q-value
$|M^{0\nu}|$ → nuclear matrix elements R→nuclear radius

Preliminary Results

Neutrino Double Beta Decay

$$|\mathring{a}^{(5)}_{\mathrm{of}}| < 218.1\ \text{GeV}^{-1}$$

Neutrinoless Double Beta Decay

Process	experiment	$\langle g^{(6)\lambda\rho}_{\beta\beta}\rangle(\text{GeV}^{-2})$	$\langle g^{(8)\lambda\rho}_{\beta\beta}\rangle(\text{GeV}^{-4})$	$\langle g^{(10)\lambda\rho}_{\beta\beta}\rangle(\text{GeV}^{-6})$
$^{48}Ca \to ^{48}Ti$	CANDLES-III	6.4×10^{-5}	2.9×10^{-3}	8.3×10^{1}
$^{76}Ge \to ^{76}Se$	CDEX-1	3.2×10^{-4}	2.1×10^{-1}	1.4×10^{2}
$^{76}Ge \to ^{76}Se$	LEGEND-200	6.6×10^{-5}	4.6×10^{-2}	3.2×10^{1}
$^{82}Se \to ^{82}Kr$	CUPID-0 Phase-I	1.7×10^{-4}	6.0×10^{-1}	5.5×10^{2}
$^{82}Se \to ^{82}Kr$	SuperNEMO-Dem	4.1×10^{-5}	3.3×10^{-2}	3.5×10^{1}
$^{100}Mo \to ^{100}Ru$	CUPID-Mo	6.6×10^{-5}	6.6×10^{-2}	6.6×10^{1}
$^{100}Mo \to ^{100}Ru$	AMoRE-I	5.1×10^{-5}	4.8×10^{-2}	4.6×10^{1}
$^{116}Mo \to ^{116}Sn$	COBRA-XDEM	2.3×10^{-5}	3.9×10^{-2}	4.1×10^{1}
$^{130}Te \to ^{130}Xe$	CUORE	5.1×10^{-4}	1.7×10^{-1}	1.3×10^{2}
$^{130}Te \to ^{130}Xe$	SNO+	3.8×10^{-5}	4.0×10^{-2}	1.1×10^{1}
$^{136}Xe \to ^{136}Ba$	KamLAND-Zen-800	8.4×10^{-5}	2.8×10^{-2}	9.4×10^{1}
$^{136}Xe \to ^{136}Ba$	LZ	6.8×10^{-5}	6.3×10^{-2}	9.2×10^{1}
$^{136}Xe \to ^{136}Ba$	PandaX-4T	8.1×10^{-5}	4.3×10^{-2}	2.2×10^{1}
$^{136}Xe \to ^{136}Ba$	XENONnT	3.5×10^{-5}	7.8×10^{-2}	8.5×10^{1}
$^{150}Nd \to ^{150}Sm$	NEMO-3	7.6×10^{-5}	5.6×10^{-2}	9.7×10^{1}
$^{136}Xe \to ^{136}Ba$	NEXT-100	5.5×10^{-5}	7.9×10^{-2}	2.2×10^{1}
$^{136}Xe \to ^{136}Ba$	JUNO	7.5×10^{-7}	8.9×10^{-4}	3.3×10^{-1}
$^{130}Te \to ^{130}Xe$	JUNO	6.7×10^{-7}	3.3×10^{-4}	2.6×10^{-1}
$^{76}Ge \to ^{76}Se$	CDEX-300ν	6.4×10^{-6}	2.9×10^{-3}	0.7
$^{76}Ge \to ^{76}Se$	LEGEND-1000	5.1×10^{-7}	3.8×10^{-4}	5.2×10^{-1}
$^{82}Se \to ^{82}Kr$	SuperNEMO	1.4×10^{-7}	5.1×10^{-4}	6.2×10^{-1}
$^{82}Se \to ^{82}Kr$	Selena	4.5×10^{-5}	5.6×10^{-2}	8.4
$^{82}Se \to ^{82}Kr$	IFC	9.3×10^{-6}	7.4×10^{-3}	1.3
$^{100}Mo \to ^{100}Ru$	AMoRE-II	5.3×10^{-6}	7.8×10^{-3}	4.5
$^{100}Mo \to ^{100}Ru$	BINGO	8.7×10^{-7}	2.1×10^{-4}	4.6×10^{-1}
$^{100}Mo \to ^{100}Ru$	CROSS	7.8×10^{-7}	2.0×10^{-4}	1.1×10^{-1}
$^{100}Mo \to ^{100}Ru$	CUPID Stage-I	7.1×10^{-7}	8.4×10^{-4}	6.7×10^{-1}
$^{116}Mo \to ^{116}Sn$	China-Europe	8.5×10^{-7}	2.8×10^{-4}	4.7×10^{-1}
$^{116}Mo \to ^{116}Sn$	Nano-Tracking	5.1×10^{-5}	3.8×10^{-2}	8.0×10^{1}
$^{124}Sn \to ^{124}Te$	TIN.TIN	4.5×10^{-7}	8.6×10^{-4}	7.7×10^{-1}
$^{136}Xe \to ^{136}Ba$	nEXO	6.6×10^{-6}	2.7×10^{-3}	1.8
$^{136}Xe \to ^{136}Ba$	NEXT-HD	2.1×10^{-7}	2.8×10^{-4}	7.7×10^{-1}
$^{136}Xe \to ^{136}Ba$	AXEL	5.0×10^{-6}	8.6×10^{-3}	7.0
$^{136}Xe \to ^{136}Ba$	KamLAND2-Zen	6.7×10^{-7}	8.3×10^{-4}	6.5×10^{-1}
$^{136}Xe \to ^{136}Ba$	XLZD	2.8×10^{-7}	3.9×10^{-4}	1.6×10^{-1}
$^{136}Xe \to ^{136}Ba$	R2D2	3.7×10^{-6}	8.8×10^{-3}	3.9
$^{136}Xe \to ^{136}Ba$	LAr TPC	7.1×10^{-6}	9.4×10^{-3}	6.2
$^{136}Xe \to ^{136}Ba$	PandaX-xT	2.5×10^{-7}	7.8×10^{-4}	4.2×10^{-1}
$^{136}Xe \to ^{136}Ba$	Slow-Fluor	7.9×10^{-6}	3.2×10^{-3}	5.1
$^{130}Te \to ^{130}Xe$	Slow-Fluor	3.5×10^{-6}	4.0×10^{-3}	3.4
$^{136}Xe \to ^{136}Ba$	Theia	4.1×10^{-6}	7.0×10^{-3}	5.2
$^{130}Te \to ^{130}Xe$	Theia	7.8×10^{-6}	5.2×10^{-3}	4.3
Various	NuDot	TBA	TBA	TBA

References

[1] D. Colladay and V. A. Kostelecky, "Lorentz violating extension of the standard model," *Phys. Rev. D*, vol. 58, p. 116002, 1998.

[2] V. A. Kostelecky and N. Russell, "Data Tables for Lorentz and CPT Violation," *Rev. Mod. Phys.*, vol. 83, pp. 11–31, 2011.