Dim 6 nucleon decay in Anomalous $U(1)_A$ SUSY GUT

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Anomalous U(1)_A SUSY GUT models are attractive because they can solve many difficulties in SUSY GUT models. One of the most important predictions of anomalous U(1)_A SUSY GUT is that nucleon decay amplitudes via dim 6 effective int. are enhanced and rough estimation gives $¥tau(p¥rightarrow ¥pi^0+e^+)¥sim 10^{34}$ years which is nothing but the present experimental lower bound, while nucleon decay amplitudes via dim 5 effective int. are suppressed.Then we calculate dim 6 effective int. and nucleon lifetimes for each decay mode in SU(5),SO(10) or E_6 GUT models with various unitary matrices which diagonalize Yukawa matrices.In this calculation we use more than 50000 model points.

What is the nucleon decay?

Nucleon is stable in SM. ⟶ bSM, especially GUT process

$$p \to \pi^0 + e^+ (1.3\times 10^{34} years)$$

⟶ current limit of life time[1,2]

Nucleon decay happen by mainly 2 effective interaction.

Dim 6 *proton main decay mode* $p \to \pi^0 + e^+$

$X(3,2)$ type gauge boson exchange

Dim 5 *proton main decay mode* $p \to K^+ + \nu^c$

triplet Higgsino or Higgs $h_T(3,1)$ exchange

	dim 6	dim 5
GUT	$\Lambda_{GUT}\sim 10^{14}$GeV $\to \tau_p \sim 10^{30} years$	none
SUSY GUT	superpartner make GUT scale $\Lambda_{SUSY\ GUT}\sim 10^{16}$ GeV $\to \tau_p \sim 10^{38} years$	suppression from mediate particle mass is smaller than dim 6 effective interaction dim 5 interaction is strong
anomalous $U(1)_A$ SUSY GUT	anomalous $U(1)_A$ theory's make GUT scale $\Lambda_A \sim \lambda^{-a}\Lambda_{SUSY\ GUT} < 10^{16}$ GeV dim 6 interaction is strong	natural doublet-triplet splitting realization suppress dim 5 interaction

Decay width of nucleon decay

E_6 27 rep particle: $\psi(27)_i$

E_6	SO(10)	SU(5)	$SU(3)_C\times SU(2)_L\times U(1)_Y$
27	16	10	$q_{L\alpha}(3,2)_{\frac{1}{6}}$, $u^{c\alpha}_R(\bar{3},1)_{-\frac{2}{3}}$, $e^+_R(1,1)_1$
		$\bar{5}$	$d^{c\alpha}_R(\bar{3},1)_{\frac{1}{3}}$, $l_L(1,2)_{-\frac{1}{2}}$
		1	$\nu^c_R(1,1)_0$
	10	$\bar{5}$	$D^{c\alpha}_R(\bar{3},1)_{\frac{1}{3}}$
		5	$L_L(1,2)_{-\frac{1}{2}}$
	1		

E_6 adjoint 78 rep gauge particle

E_6	SO(10)	SU(5)
78	adjoint 45	adjoint 24 $\ni \bar{X}_\alpha(3,2)_{-\frac{5}{6}}$
		$10 \ni X'_\alpha(3,2)_{\frac{1}{6}}$, $\overline{10},1$
	$16 \ni X''_\alpha(3,2)_{\frac{1}{6}}$, $\overline{16},1$	

$$M_X^2 = g_{GUT}^2 x^2,$$
$$M_{X'}^2 = g^2_{GUT}x^2 + g^2_{GUT}v_c^2 \quad , \quad M^2_{X''} = \frac{1}{4}g^2_{GUT}x^2 + g^2_{GUT}v_\phi^2$$

a, v_c, v_ϕ are vev of Higgs.

E_6 27 rep. Higgs C has vev v_c in $SU(5)$ singlet part.

E_6 27 rep. Higgs Φ has vev v_ϕ in $SO(10)$ singlet part.

E_6 78 rep. Higgs has vev x,E_6 78 rep contain $SO(10)$ adjoint.

$SO(10)$ adjoint Higgs A has DW-form vev

$$\langle A\rangle = i\sigma_2 \times \begin{pmatrix} x\mathbf{1}_{3\times3} & \\ & \mathbf{0}_{2\times2}\end{pmatrix} \qquad x\sim\lambda^{-a}\Lambda_{SUSY\ GUT} \quad a=-1$$

Dim 6 effective Lagrangian in E_6 GUT

$$\begin{aligned}
\mathcal{L}_{eff} = &- \frac{2\pi\alpha_{GUT}}{M_X^2}\{(\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Li\beta})(\overline{e^+_{Rj}}\gamma_\mu d_{Lj\alpha}) + (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Lj\beta})(\overline{e^+_{Ri}}\gamma_\mu d_{Lj\alpha})\\
&+ (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Li\beta})(\overline{e^+_{Lj}}\gamma_\mu d_{Rj\alpha}) + (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Li\beta})(\overline{E^+_{Lj}}\gamma_\mu D_{Rj\alpha})\\
&- (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu d_{Li\beta})(\overline{\nu^c_{Lj}}\gamma_\mu d_{Rj\alpha}) - (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu d_{Li\beta})(\overline{N^c_{Lj}}\gamma_\mu D_{Rj\alpha})\}\\
&- \frac{2\pi\alpha_{GUT}}{M_{X'}^2}\{(\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Lj\beta})(\overline{e^+_{Li}}\gamma_\mu d_{Rj\alpha}) - (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu d_{Lj\beta})(\overline{\nu^c_{Li}}\gamma_\mu d_{Rj\alpha})\}\\
&- \frac{2\pi\alpha_{GUT}}{M_{X''}^2}\{(\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu u_{Lj\beta})(\overline{E^+_{Li}}\gamma_\mu D_{Rj\alpha}) - (\epsilon^{\alpha\beta\gamma}\overline{u^c_{Ri\gamma}}\gamma^\mu d_{Lj\beta})(\overline{N^c_{Li}}\gamma_\mu D_{Rj\alpha})\}
\end{aligned}$$

Decay width

*eigenstate of each field is gauge eigenstate

$$\begin{aligned}
\Gamma(N\to PS + l^c) &= \frac{1}{2m_N}\int\frac{d^3p}{(2\pi)^3}\frac{1}{2E_p}\frac{d^3q}{(2\pi)^3}\frac{1}{2E_q}|\mathcal{M}(m_N\to p+q)|^2(2\pi)^4\delta^{(4)}(k-p-q)\\
&\simeq \frac{m_N}{32\pi}\left\{1-\left(\frac{m_{PS}}{m_N}\right)^2\right\}^2\left|\sum_i C^i W_0^i(N\to PS)\right|^2
\end{aligned}$$

coefficient of effective Lagrangian:C^i

$$\mathcal{L}_{eff} = \sum_i C^i[\overline{l^c}\mathcal{O}^{\Gamma\Gamma'}_{q_1q_2q_3}]^i$$

- effective Lagrangian of models
- renormalization factor
- mass diagonalize matrix

form factor:W_0

$$\langle PS(\mathbf{p})|\mathcal{O}^{\Gamma\Gamma'}_{q_1q_2q_3}|N(\mathbf{k},s)\rangle \simeq P_{\Gamma'}W_0^{\Gamma\Gamma'}(q^2)u_N(\mathbf{k},s)$$

$$\mathcal{O}^{\Gamma\Gamma'}_{q_1q_2q_3} = \epsilon^{\alpha\beta\gamma}(\overline{q^c_{1\alpha}}P_\Gamma q_{2\beta})P_{\Gamma'}q_{3\gamma}$$

$$\mathcal{O}_{e^+_R} = -2\overline{e^+_R}\mathcal{O}^{LR}_{\psi_2\psi_4\psi_1},\ \mathcal{O}_{l^c} = -2\overline{l^c}\mathcal{O}^{RL}_{\psi_1\psi_4\psi_2}$$

QCD effect : calculated by Lattice QCD[3]

Effect of mass diagonalize matrix

Eigenstate of each field is gauge eigenstate, so we have to operate mass diagonalize matrix (R_ψ,L_ψ;ψ represent flavor) to gain mass eigenstate. $\psi_{Li} = (L^\dagger_\psi)_{ij}\psi'_{Lj}, \psi_{Ri} = (R^\dagger_\psi)_{ij}\psi'_{Rj}$

example

$10_i\times\bar{5}_j\times\bar{5}_H \to u_i M_{ij} u^c_j$ non diagonalized matrix

$\to u'_i M_{dia\,ij} u'^c_j$ diagonalizd matrix

$U_{CKM} = L^\dagger_u L_d$

$U_{MNS} = L^\dagger_\nu L_e$

These mass diagonalize matrices cause mixing of generations.

Mass diagonalize matrices have two conditons.

- unitarity
- CKM, MNS matrix

But, we can't fix mass diagonalize matirices exactly. ⟶ uncertainty

Result of each model

We use anomalous U(1) models to calculate nucleon lifetimes.

- anomalous U(1) charges decide vev⇒dim 6 are enhanxed
- D-T splittingis realized by D-W mechanism⇒dim 5 are suppressed
- realistic Yukawa couplings(lepton large mixing) are realized

We can realize these features by using all terms they are allowed by symmetries and restricting all coefficients of terms to order 1.

To satisfy MNS matrix, Maekawa(2001) model[4] introduces new 10 rep and all SU(5) $\bar{5}$ rep are mixed. In this model all $\bar{5}$ rep matters' diagonalize matrix have MNS hierarchy, and all 10 rep matters' one have MNS hierarchy. And all uncertainties of diagonalize matrices are order 1.

This time we consider these uncertainties of predicted diagonalize matrices(CKM type or MNS type).

$$U_{CKM} = \begin{pmatrix} 0.97 & 0.23 & 0.0035\\ -0.23 & 0.97 & 0.041\\ 0.0086 & -0.040 & 1.0\end{pmatrix} \quad , \quad U_{MNS} = \begin{pmatrix} 0.83 & 0.54 & 0.15\\ -0.48 & 0.53 & 0.70\\ 0.30 & -0.65 & 0.70\end{pmatrix}$$

$$U_{CKM\ type} = \begin{pmatrix} 1 & \lambda & \lambda^3\\ \lambda & 1 & \lambda^2\\ \lambda^3 & \lambda^2 & 1\end{pmatrix} \quad , \quad U_{MNS\ type} = \begin{pmatrix} 1 & \lambda^{0.5} & \lambda\\ \lambda^{0.5} & 1 & \lambda^{0.5}\\ \lambda & \lambda^{0.5} & 1\end{pmatrix}$$

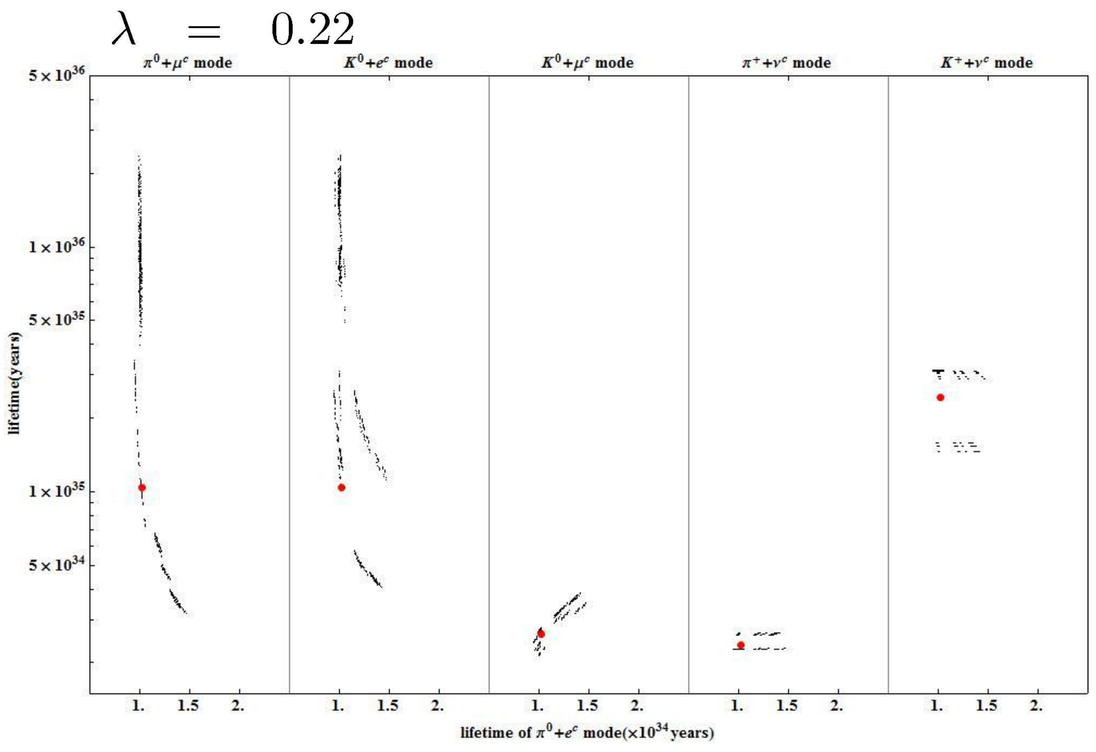
$$\lambda = 0.22$$

SU(5) GUT type1

$$\begin{aligned} R_u = R_d &= \mathbf{1}_{3\times3},\\ L_u, L_d, L_e, R_e &= U_{CKM\ type},\\ L_\nu &= U_{MNS\ type},\\ \alpha_{GUT} &= 0.04 \end{aligned}$$

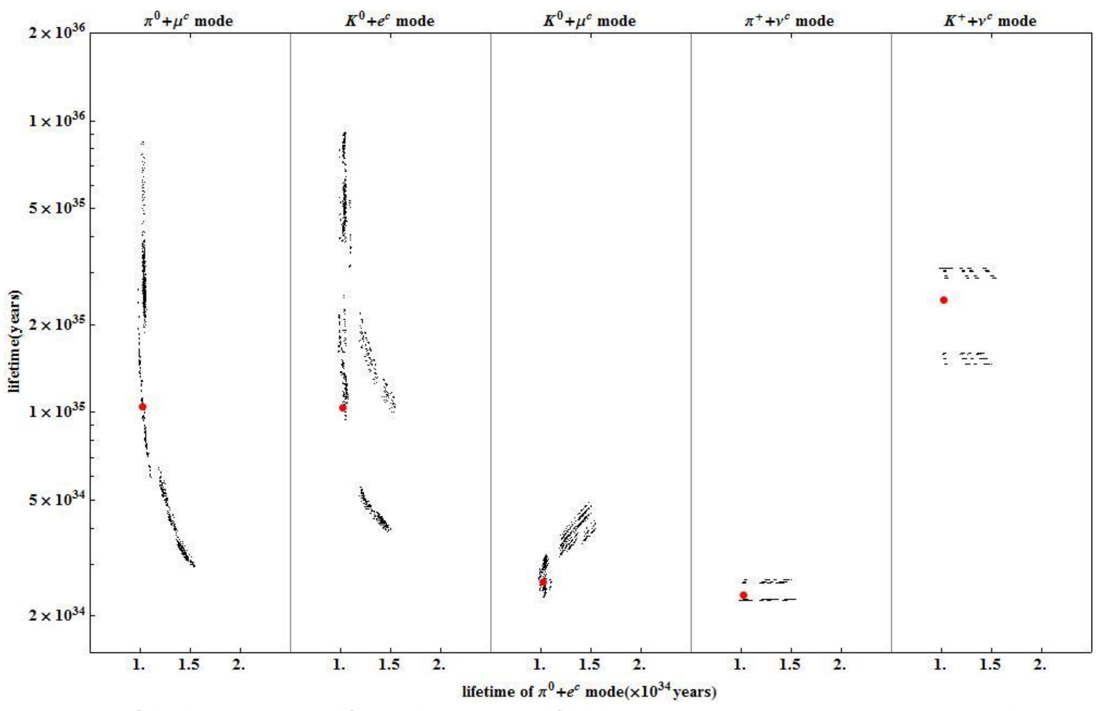
$$\begin{aligned} L_u = L_e = R_u = R_d &= \mathbf{1}_{3\times3},\\ L_d, R_e &= U_{CKM},\\ L_\nu &= U^t_{MNS} \end{aligned}$$

Red point



SU(5) GUT type2

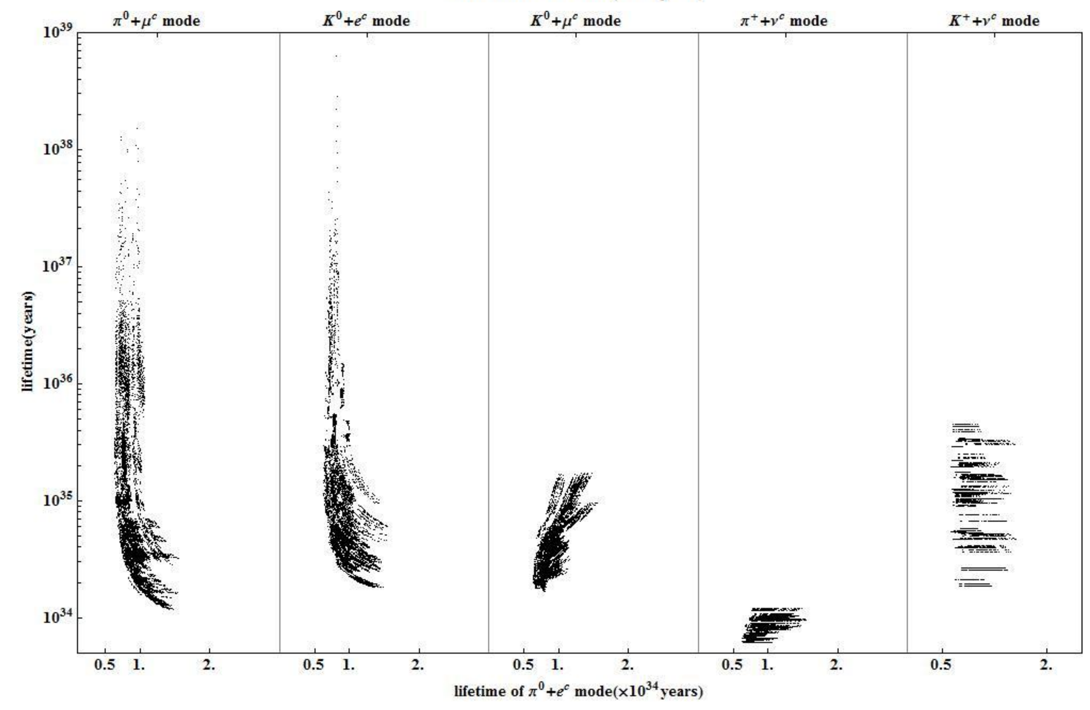
$$\begin{aligned} R_u = R_d &= \mathbf{1}_{3\times3},\\ L_u, L_d, L_e, R_e &= U_{CKM\ type},\\ L_\nu &= U_{MNS\ type},\\ \alpha_{GUT} &= 0.04 \end{aligned}$$



SO(10) GUT with 10 rep.

$$\begin{aligned} R_u &= \mathbf{1}_{3\times3},\\ L_u, L_d, R_e &= U_{CKM\ type},\\ L_e, L_\nu, R_d &= U_{MNS\ type},\\ \alpha_{GUT} &= 0.05 \end{aligned}$$

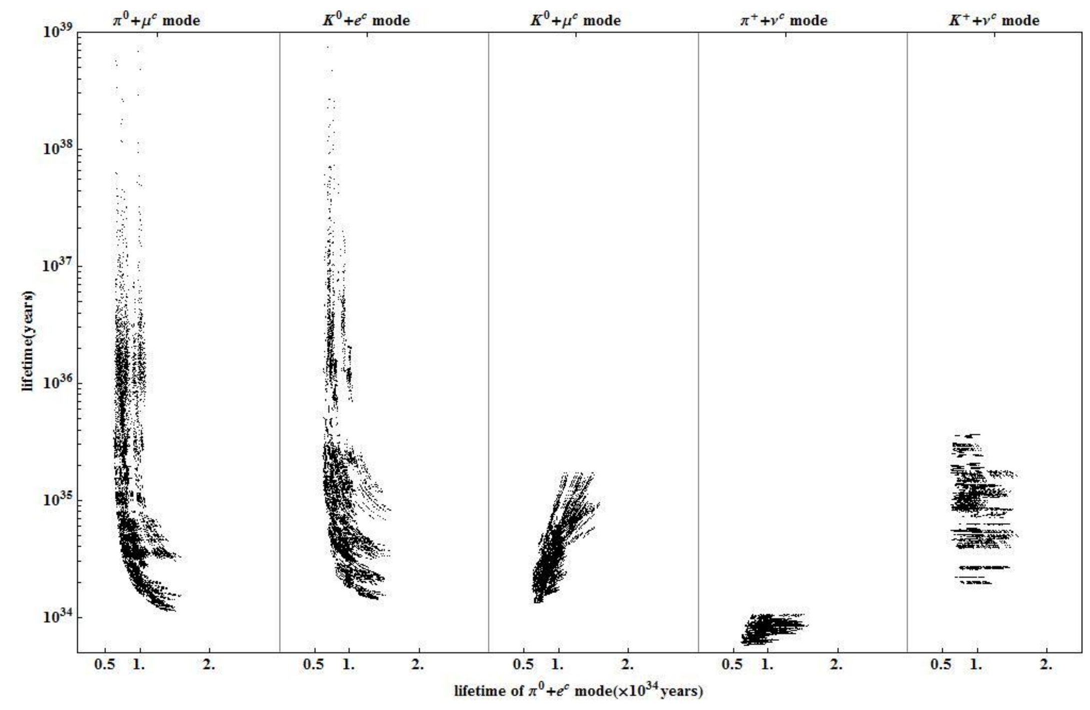
$$\begin{pmatrix}\bar{5}_{\Psi1}\\ \bar{5}_{\Psi2}\\ \bar{5}_{\Psi3}\\ \bar{5}_T\end{pmatrix} = \begin{pmatrix} \bar{5}_1 + \lambda^3\bar{5}_M\\ \bar{5}_3 + \lambda^2\bar{5}_M + \lambda^{4.5}\bar{5}_2 + \lambda^5\bar{5}_1\\ \bar{5}_M + \lambda^3\bar{5}_1 + \lambda^{2.5}\bar{5}_2 + \lambda^2\bar{5}_3\\ \bar{5}_2 + \lambda^{2.5}\bar{5}_M + \lambda^{4.5}\bar{5}_3\end{pmatrix}$$



E_6 GUT

$$\begin{aligned} R_u &= \mathbf{1}_{3\times3},\\ L_u, L_d, R_e &= U_{CKM\ type},\\ L_e, L_\nu, R_d &= U_{MNS\ type},\\ \alpha_{GUT} &= 0.15 \end{aligned}$$

$$\begin{pmatrix}\bar{5}_{\Psi1}\\ \bar{5}_{\Psi2}\\ \bar{5}_{\Psi3}\\ \bar{5}_{T_1}\\ \bar{5}_{T_2}\\ \bar{5}_{T_3}\end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & \lambda^{1.5} & \lambda^3 & \lambda^{3.5}\\ 0 & 0 & 1 & \lambda^{0.5} & \lambda^2 & \lambda^{2.5}\\ \lambda^3 & \lambda^{2.5} & \lambda^2 & \lambda^{1.5} & 1 & \lambda^{0.5}\\ 0 & 1 & 0 & \lambda & \lambda^{2.5} & \lambda^3\\ \lambda^{1.5} & \lambda & \lambda^{0.5} & 1 & \lambda^{1.5} & \lambda^2\\ \lambda^{3.5} & \lambda^3 & \lambda^{2.5} & \lambda^2 & \lambda^{0.5} & 1\end{pmatrix}\begin{pmatrix}\bar{5}_1\\ \bar{5}_2\\ \bar{5}_3\\ \bar{5}_{M_1}\\ \bar{5}_{M_2}\\ \bar{5}_{M_3}\end{pmatrix}$$



$$x = 5.0\times10^{15}[GeV], v_c = 7.1\times10^{13}[GeV], v_\phi = 8.9\times10^{15}[GeV] \quad [6]$$

Conclusion and Future work

In this calculation, we cannot establish model distinction method.

We will calculate nucleon lifetime by restricting the generation.

[1] M. Miura *et al.*[Super-Kamiokande Collaboration], Presentation in JPS 2011 Autumn

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[4]N. Maekawa, Prog. Theor. Phys. **106**, 401 (2001) [arXiv:hep-ph/0104200].

[5]DAYA-BAY Collaboration [arXiv:hep-ph/12031669].

[6]N. Maekawa and T. Yamashita, Prog. Theor. Phys. **107**, 1201 (2002) [arXiv:hep-ph/0202050].