

An Effective Theory of Neutrino

Systematic decomposition of the neutrinoless double beta decay operator

Toshihiko Ota



based on

Florian Bonnet, Martin Hirsch, TO, Walter Winter JHEP **1303** (2013) 055 arXiv. 1212. 3045 Saitama University Motivation: Why 0n2b?

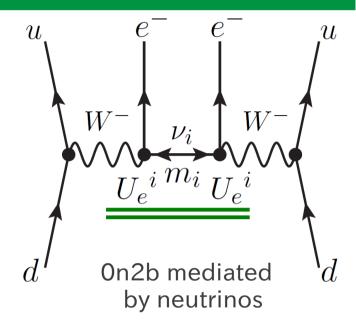
• In SM+3nu, **0n2b exp** are sensitive to Effective nu mass $\langle m_{\beta\beta} \rangle \equiv \sum_{i=1}^{3} (U_e^{\ i})^2 m_i$ $U_e^{\ 1} = c_{12}c_{13}$ $U_e^{\ 2} = s_{12}c_{13}e^{i\alpha}$ $U_e^{\ 3} = s_{13}e^{i\beta}$

Normal hierarchy

$$m_1 = m_0, m_2 = \sqrt{\Delta m_{21}^2 + m_0^2}, m_3 = \sqrt{\Delta m_{31}^2 + m_0^2}$$

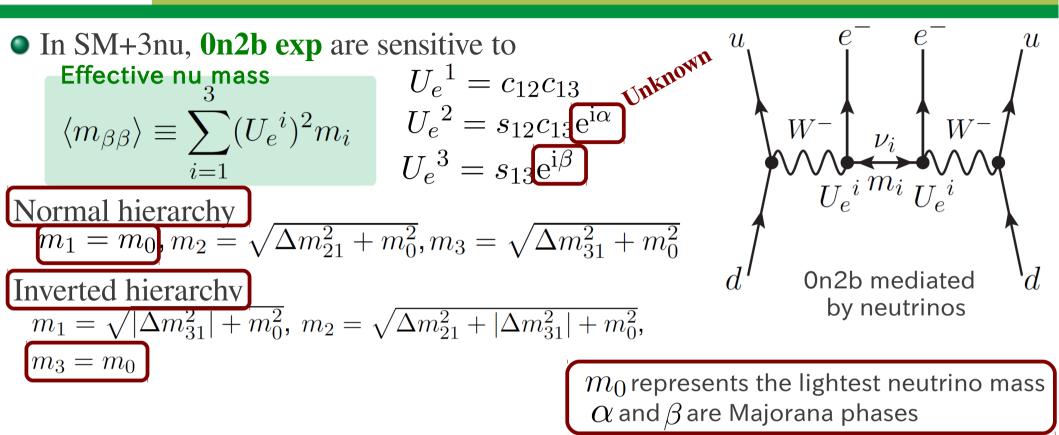
Inverted hierarchy $m_1 = \sqrt{|\Delta m_{31}^2| + m_0^2}, \ m_2 = \sqrt{\Delta m_{21}^2 + |\Delta m_{31}^2| + m_0^2},$ $m_3 = m_0$

 m_0 represents the lightest neutrino mass lpha and eta are Majorana phases



Preface

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Motivation: Why 0n2b?



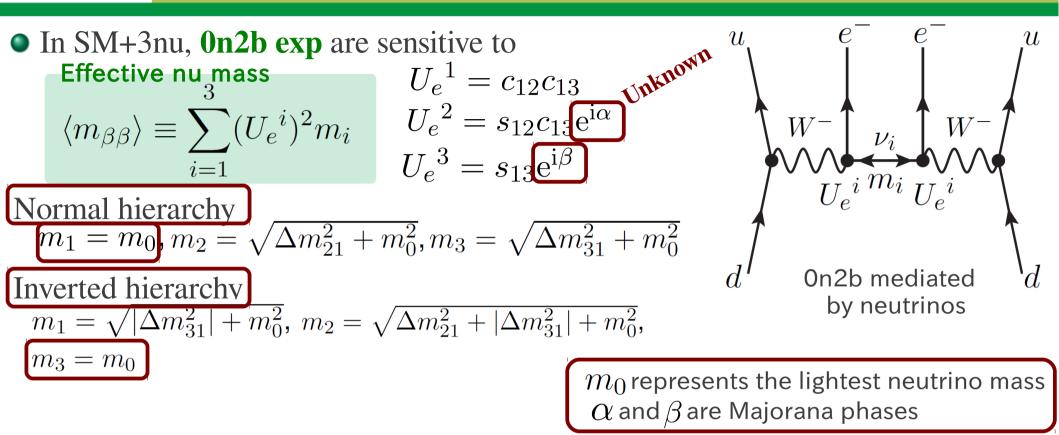
• Oscillation exp told us... e.g., Gonzalez-Garcia Maltoni Salvado Schwetz, JHEP 1212 (2012) 123

$$\begin{split} s_{12}^2 &= 0.3, \qquad s_{23}^2 = 0.41(0.59), \qquad s_{13}^2 = 0.023, \\ \Delta m_{21}^2 &= 7.5 \cdot 10^{-5} \; \mathrm{eV}^2, \quad |\Delta m_{31}^2| = 2.5 \cdot 10^{-3} \; \mathrm{eV}^2 \end{split} \text{ so } \text{far, we know} \end{split}$$

Saitama University

Motivation: Why 0n2b?





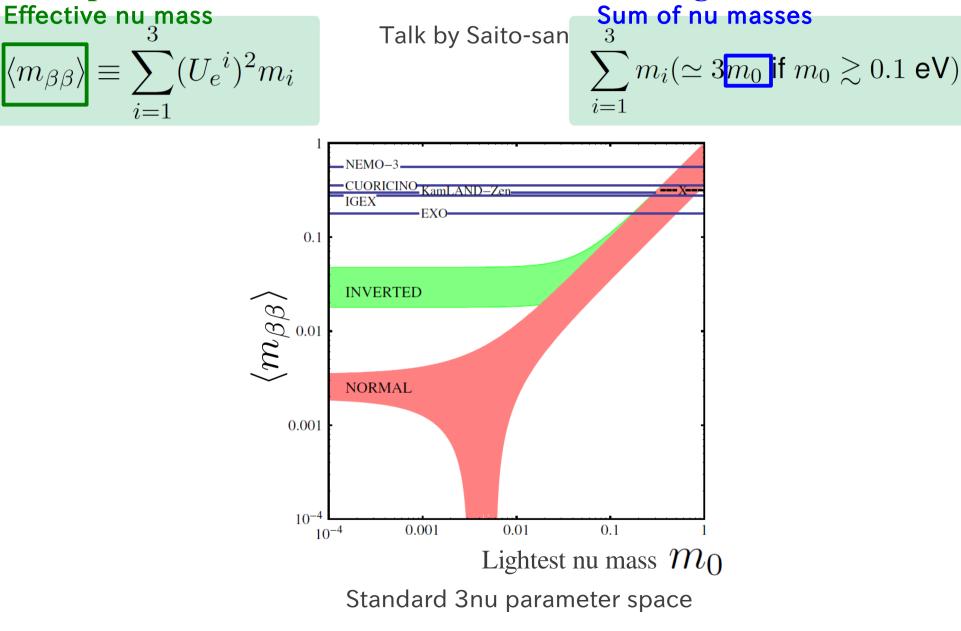
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• Cosmological obs are sensitive to the other combination of params.... \rightarrow Talk by Saito-san

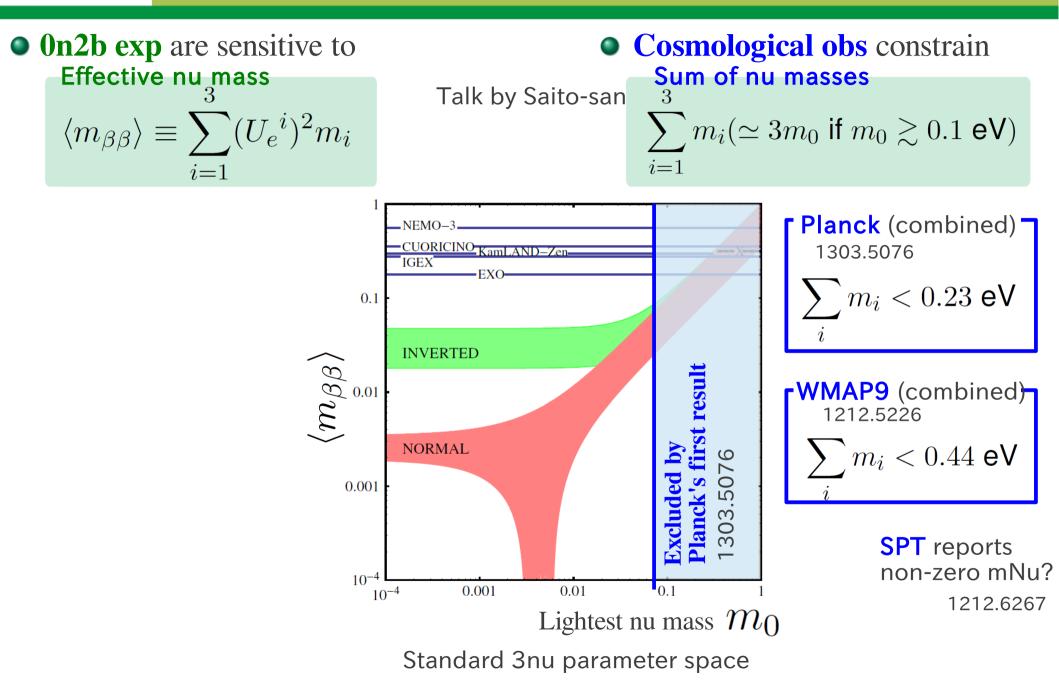
Saitama University 埼玉大学 Motivation: Why 0n2b? Preface • **On2b exp** are sensitive to **Cosmological obs** constrain ۲

 $\langle m_{\beta\beta}$

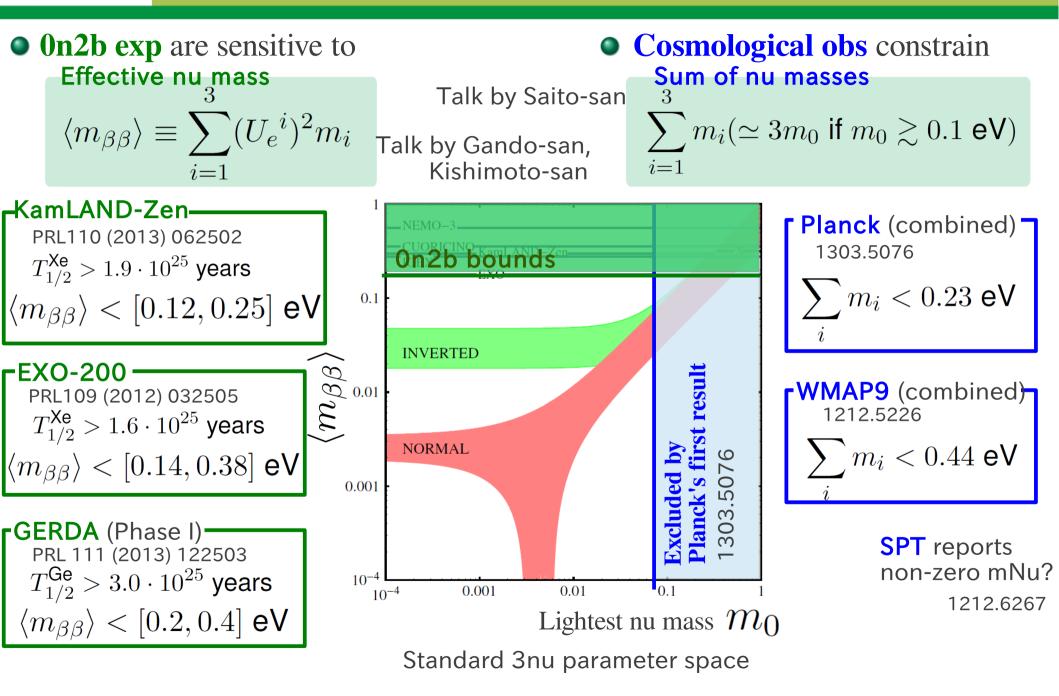


Saitama University 埼玉大学 Motivation: Why 0n2b?

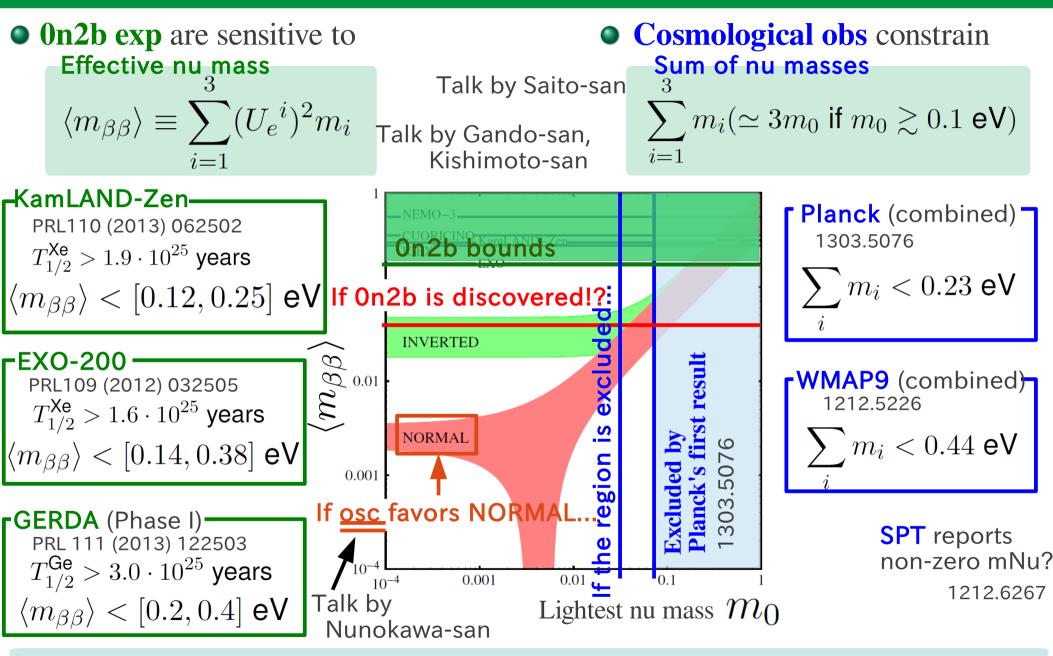
Preface



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Saitama University 埼玉大学 Motivation: Why 0n2b? Preface



Q: If, in future, they will conflict with each other, what can we learn from them?



Outline

New Physics (d=9) contributions in neutrinoless double beta decay (0n2b)



Neutrino mass searches as a frontier to new physics: dim=9 ops $d=9 \text{ ops} \rightarrow \text{half-life time of 0n2b processes}$ "How sensitive 0n2b experiments to the d=9 ops?"



What do the d=9 ops suggest to TeV scale physics?

 $d=9 \text{ ops} \rightarrow \text{decompose them to the fundamental ints.}$

→ list the TeV signatures of each completion *"The list helps us to discriminate the models"*

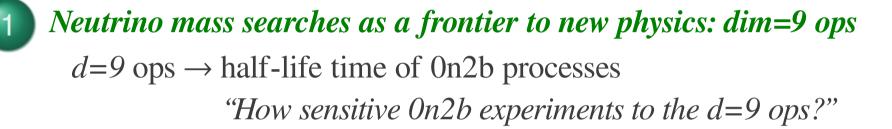
Summary

"Complementarity between 0n2b and LHC (and ILC)"



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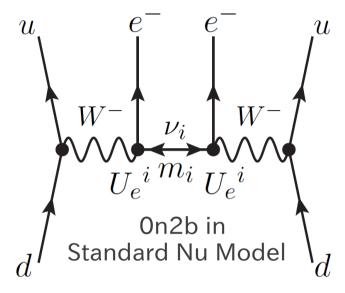
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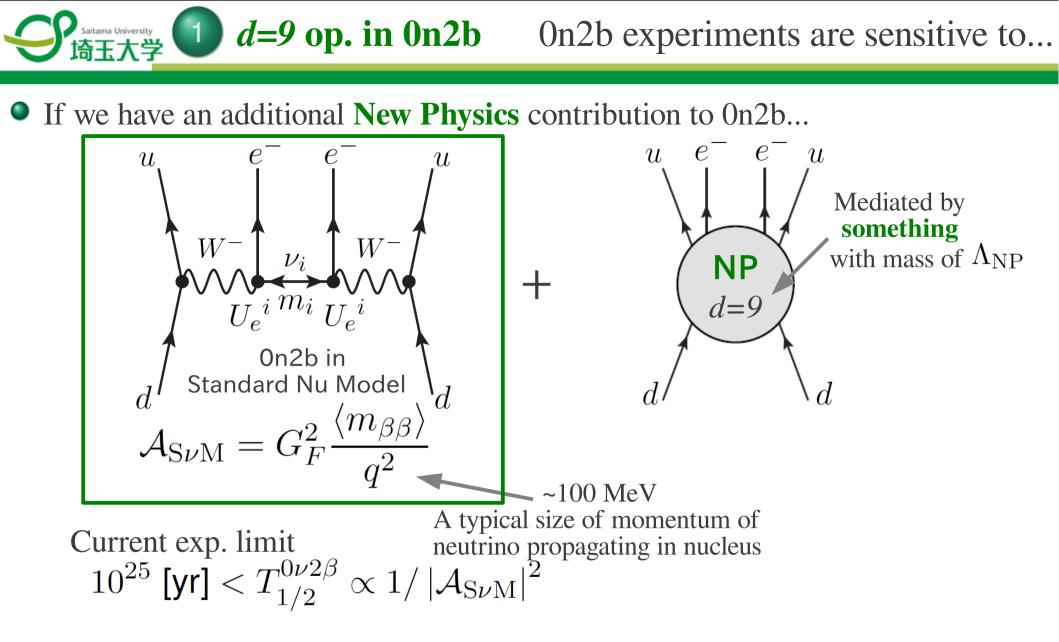
Summary

"Complementarity between 0n2b and LHC (and ILC)"

• If we have an additional **New Physics** contribution to 0n2b...



d=9 op. in 0n2b 0n2b experiments are sensitive to... Saitama University 埼玉大学 • If we have an additional **New Physics** contribution to 0n2b... e^{-} e^{-} u \mathcal{U} e \mathcal{U} \mathcal{U} Mediated by something W^{-} W^{-} with mass of $\Lambda_{\rm NP}$ NP \mathcal{V}_{i} d=9 $U_e{}^i m_i$ 0n2b in Standard Nu Model d



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Current exp. limit Sensitive to $10^{25} \,[\text{yr}] < T_{1/2}^{0\nu2\beta} \propto 1/ \left|\mathcal{A}_{S\nu M}\right|^2 \,\square \,\langle m_{\beta\beta}\rangle < 0.3 \,[\text{eV}]$

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d=9 op. in 0n2b 0n2b experiments are sensitive to... 埼玉大学 If we have an additional New Physics contribution to 0n2b... e \mathcal{U} U \mathcal{U} Mediated by something with mass of $\Lambda_{\rm NP}$ NP $U^{i m_i} U^{i}$ d=90n2b in Standard Nu Model $a^{*} \mathcal{A}_{\mathrm{S}\nu\mathrm{M}} = G_F^2 \frac{\langle m_{\beta\beta} \rangle}{a^2}$ HC range! Current exp. limit Sensitive to $10^{25} \,[\text{yr}] < T_{1/2}^{0\nu2\beta} \propto 1/\left|\mathcal{A}_{\text{S}\nu\text{M}}\right|^2 \qquad \langle m_{\beta\beta} \rangle < 0.3 \,[\text{eV}]$ $\propto 1/\left|\mathcal{A}_{d=9}\right|^2 \qquad \Lambda_{\text{NP}} > \mathcal{O}(1) \,[\text{TeV}]$

On2b exps are sensitive to not only Majorana neutrino mass but also NP at TeV.

d=9 op. in 0n2b Saitama University 埼玉大学

 e^-

u

 e^{-}

NP

d=9

... falls into the following 5 types of effective ops.

Saitama University ① *d=9* op. in 0n2b

 $e^{-}u$

...falls into the following 5 types of effective ops.

$$\mathscr{L}_{d=9} = \frac{G_F^2}{2m_P} \left[\sum_{i=1}^3 \overline{\epsilon_i^{\{XY\}Z}} (\mathcal{O}_i)_{\{XY\}Z} + \sum_{i=5}^4 \overline{\epsilon_i^{XY}} (\mathcal{O}_i)_{XY} \right],$$

$$(\mathcal{O}_1) \equiv J_X J_Y j_Z, \quad (\mathcal{O}_4) \equiv (J_X)^{\mu\nu} (J_Y)_{\mu} (j)_{\nu}, \quad J_X = \overline{u} \Gamma P_X d_{\nu} (\mathcal{O}_2) \equiv (J_X)^{\mu\nu} (J_Y)_{\mu\nu} j_Z, \quad (\mathcal{O}_5) \equiv J_X (J_Y)_{\mu} (j)_{\mu}, \quad j_X = \overline{e} \Gamma P_X e^{Q_Y} (\mathcal{O}_3) \equiv (J_X)^{\mu} (J_Y)_{\mu} j_Z,$$

• Nice (&compact) formula to calculate the half-life time: Paes et al. PLB498 (2001) 35 $\left(T_{1/2}^{0\nu2\beta}\right)_{\underline{d=9}}^{-1} = G_1 \left|\sum_{i=1}^{3} \overline{\epsilon_i} \mathcal{M}_i\right|^2 + G_2 \left|\sum_{i=4}^{5} \overline{\epsilon_i} \mathcal{M}_i\right|^2 + G_3 \operatorname{Re} \left[\left(\sum_{i=1}^{3} \overline{\epsilon_i} \mathcal{M}_i\right) \left(\sum_{i=4}^{5} \overline{\epsilon_i} \mathcal{M}_i\right)^*\right] \right]$ $\left(T_{1/2}^{0\nu2\beta}\right)_{\mathrm{S}\nu\mathrm{M}}^{-1} = G_1 \left|\frac{\langle m_{\beta\beta} \rangle}{m_e} \left[\mathcal{M}_{\mathrm{GT}} - \frac{g_V^2}{g_A^2} \mathcal{M}_{\mathrm{F}}\right]\right|^2$ $\mathcal{M}_i \operatorname{Nuclear matrix elements}$ $G_i \operatorname{Phase space factors}$

 $\begin{array}{cccc} u & e^- & e^- & u \\ & 1 & 1 & / \end{array}$... falls into the following 5 types of effective ops.

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Q: What is the high E (TeV) origin of these d=9 effective ops? d=9 ops. Saitama University の d=9 op. in 0n2b

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• Exhaustive bottom-up approach

A well-known example: 3 types of Seesaw mechanism

Theory at $\Lambda_{\rm EW}$

 $\mathscr{L}_{\text{eff}} = \mathscr{L}_{\mathrm{SM}}$

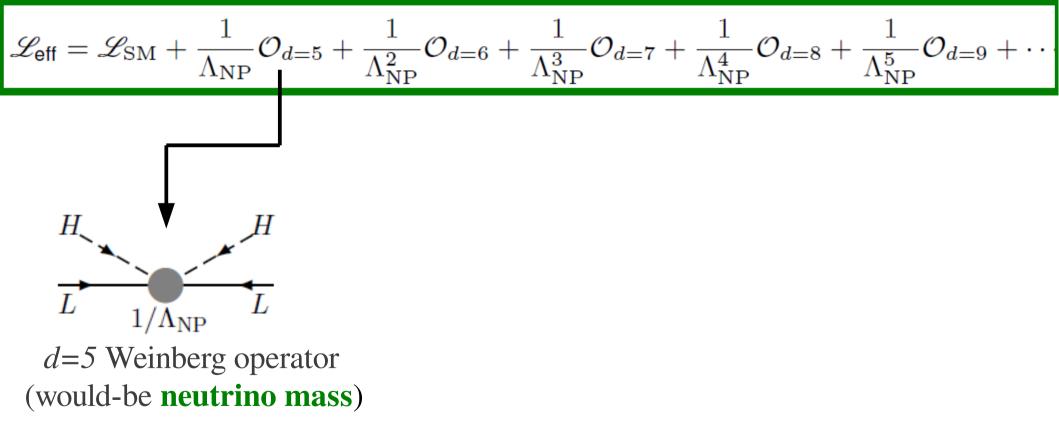
• Exhaustive bottom-up approach

A well-known example: 3 types of Seesaw mechanism

$$\mathscr{L}_{\mathsf{eff}} = \mathscr{L}_{\mathrm{SM}} + \frac{1}{\Lambda_{\mathrm{NP}}}\mathcal{O}_{d=5} + \frac{1}{\Lambda_{\mathrm{NP}}^2}\mathcal{O}_{d=6} + \frac{1}{\Lambda_{\mathrm{NP}}^3}\mathcal{O}_{d=7} + \frac{1}{\Lambda_{\mathrm{NP}}^4}\mathcal{O}_{d=8} + \frac{1}{\Lambda_{\mathrm{NP}}^5}\mathcal{O}_{d=9} + \cdots$$

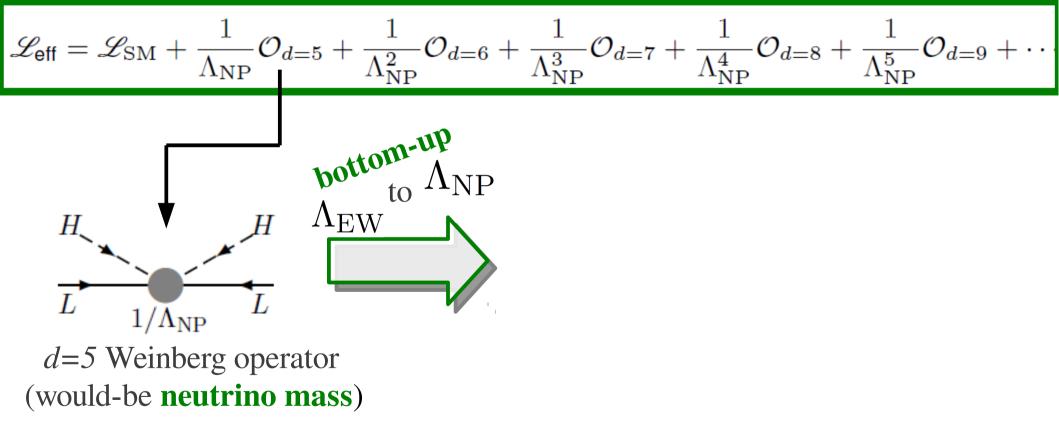
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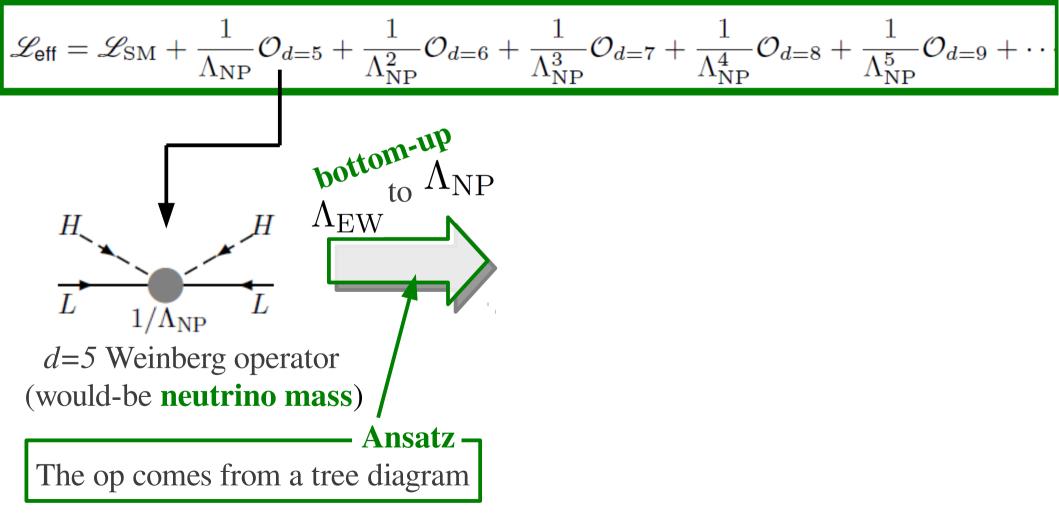
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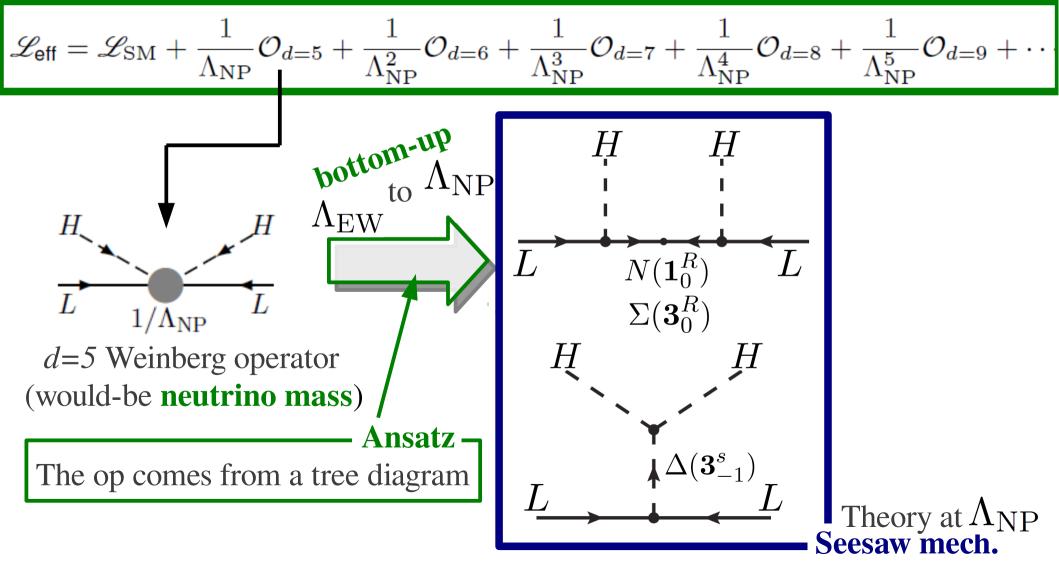
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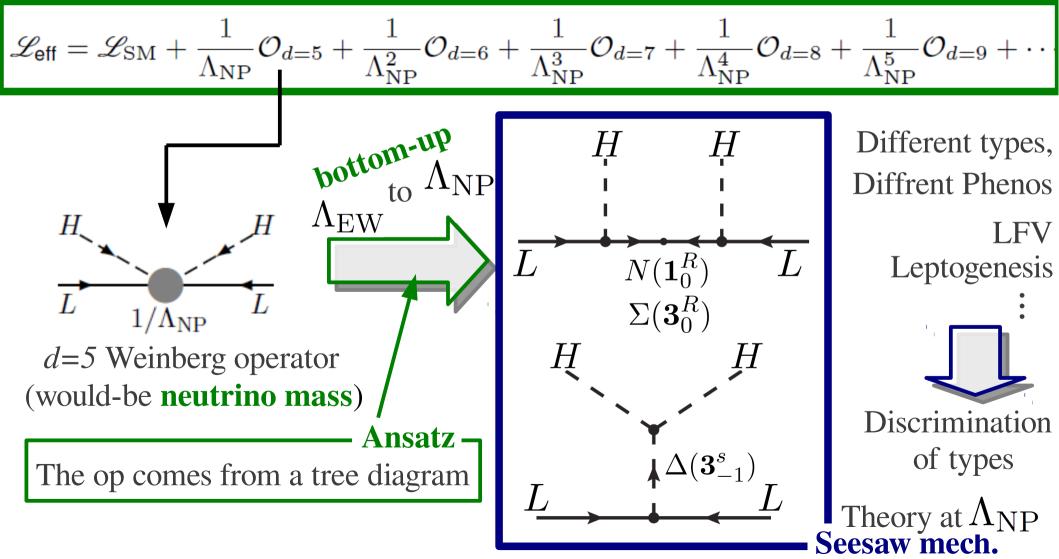
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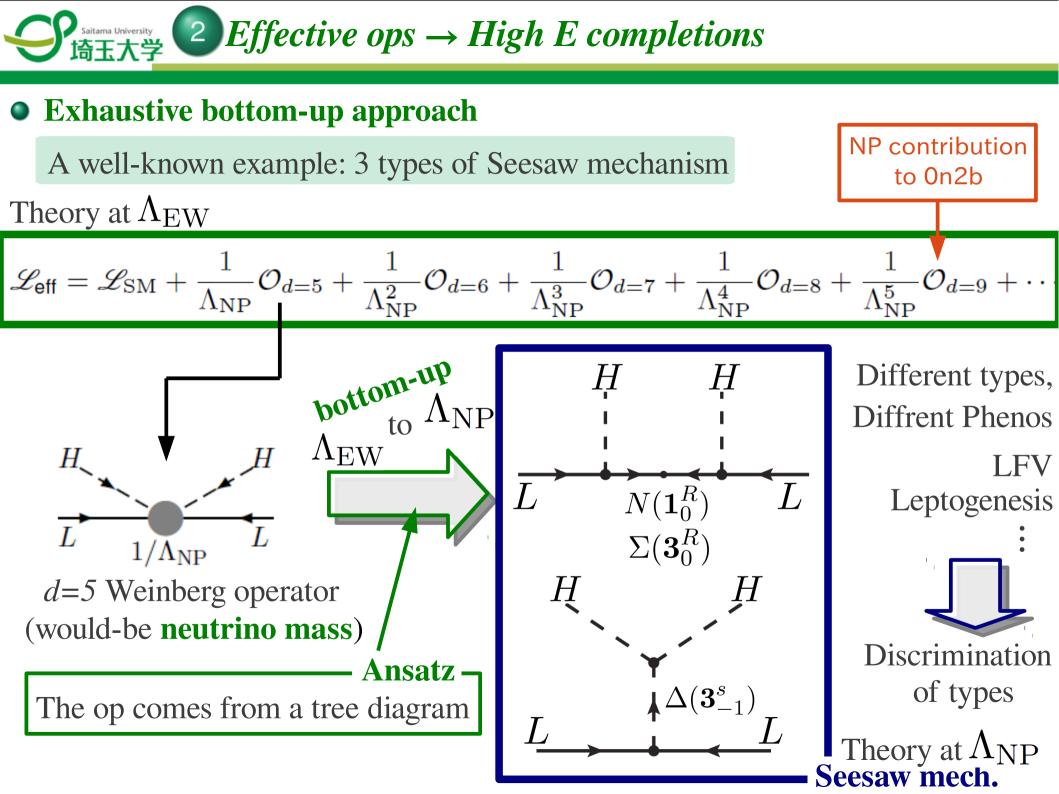
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Exhaustive bottom-up approach

A well-known example: 3 types of Seesaw mechanism







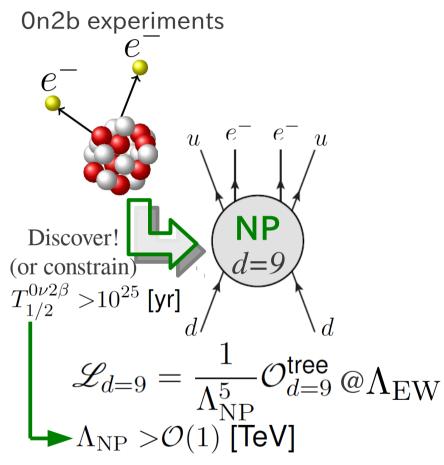
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0n2b experiments

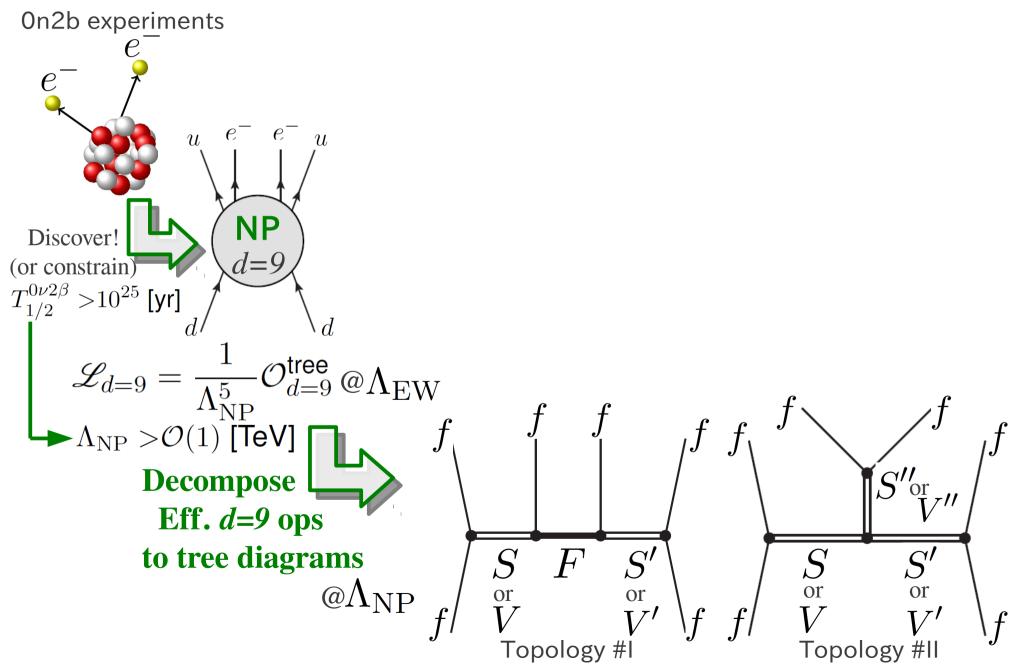
e⁻ /

Discover! (or constrain) $T_{1/2}^{0\nu2\beta}$ >10²⁵ [yr]

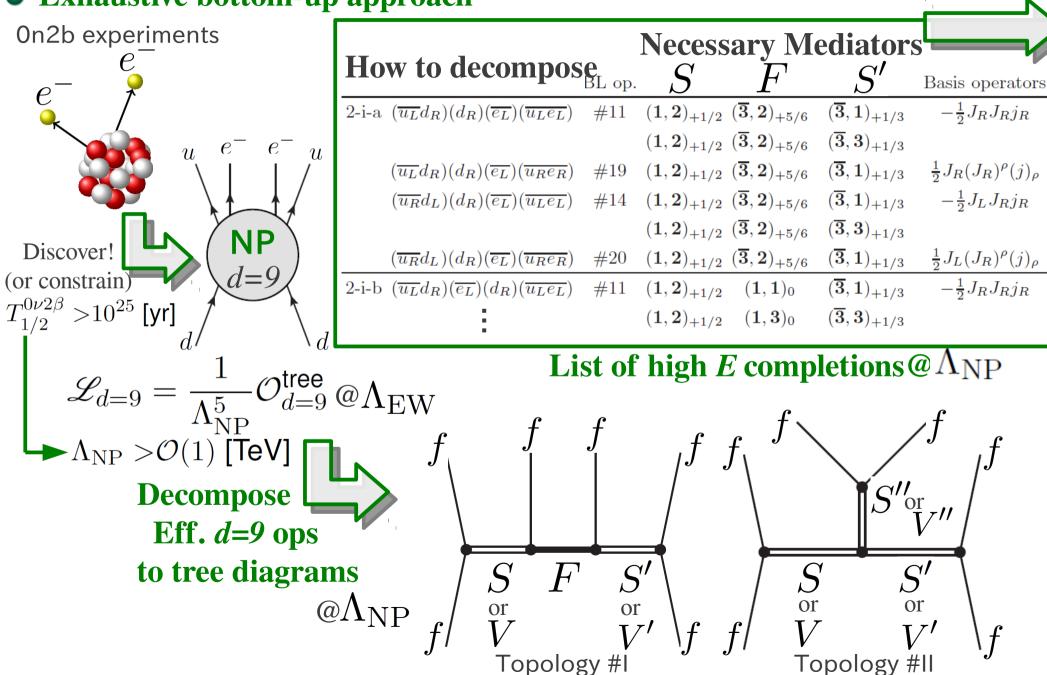
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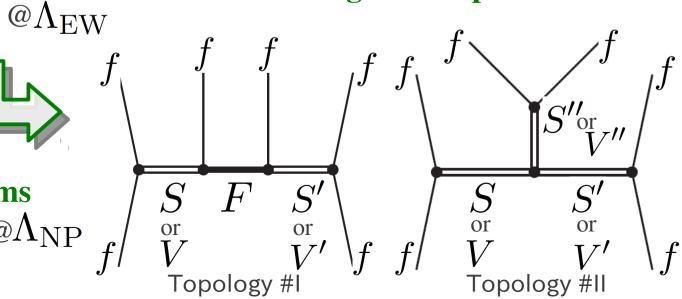
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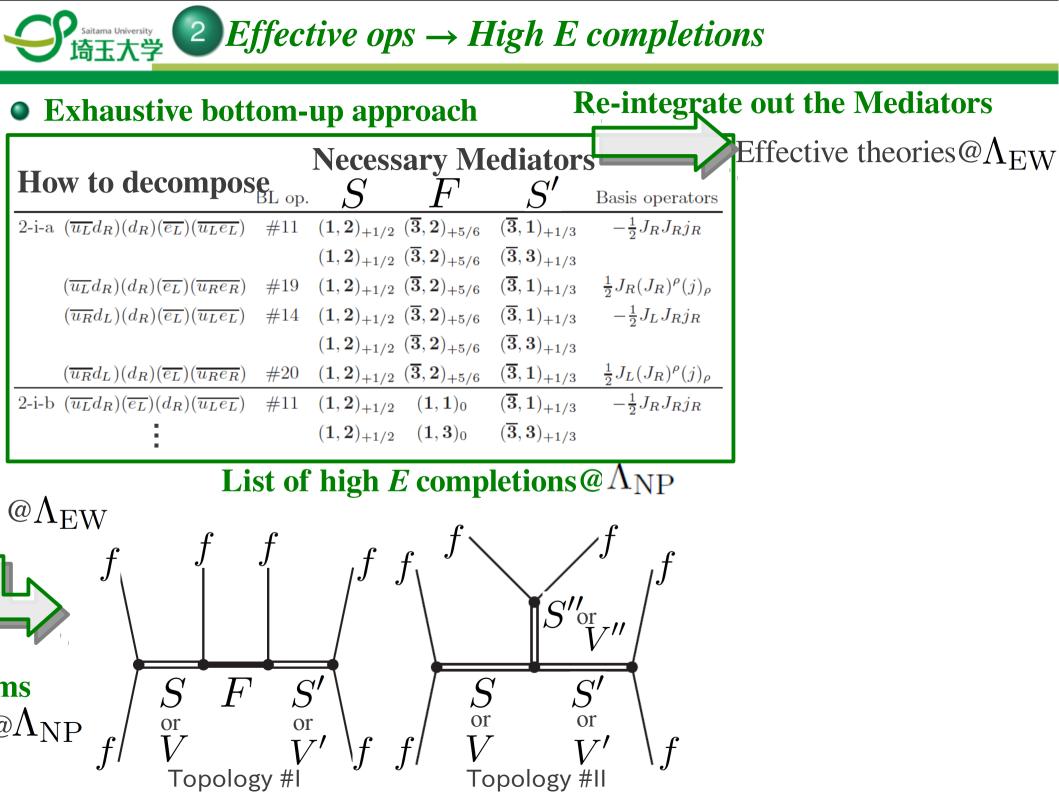


Exhaustive bottom-up approach

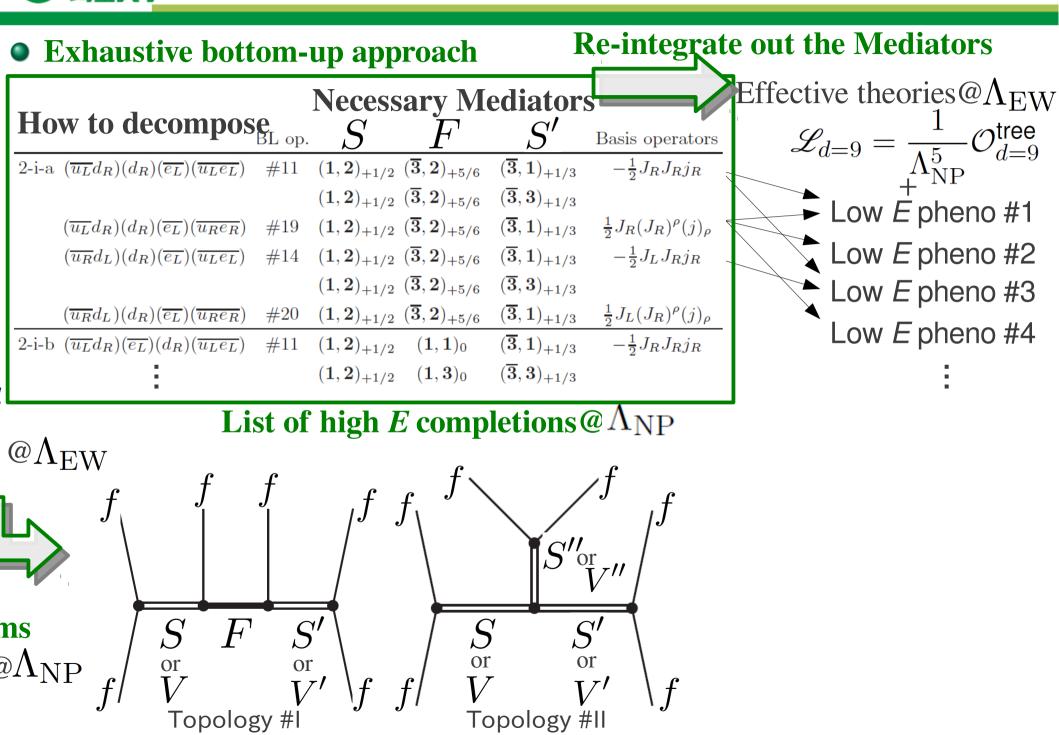


• Exhaustive bottom-up approach **Necessary Mediators** How to decompose BL op. FS S'Basis operators $(1,2)_{+1/2}$ $(\overline{3},2)_{+5/6}$ $(\overline{3},1)_{+1/3}$ 2-i-a $(\overline{u_L}d_R)(d_R)(\overline{e_L})(\overline{u_L}e_L)$ #11 $-\frac{1}{2}J_R J_R j_R$ $(1,2)_{+1/2}$ $(\overline{3},2)_{+5/6}$ $(\overline{3},3)_{+1/3}$ $(\overline{u_L}d_R)(d_R)(\overline{e_L})(\overline{u_R}e_R) = \#19 \quad (\mathbf{1},\mathbf{2})_{+1/2} \quad (\mathbf{\overline{3}},\mathbf{2})_{+5/6} \quad (\mathbf{\overline{3}},\mathbf{1})_{+1/3} = \frac{1}{2}J_R(J_R)^{\rho}(j)_{\rho}$ $(\overline{u_R}d_L)(d_R)(\overline{e_L})(\overline{u_L}e_L) = \#14 \quad (\mathbf{1},\mathbf{2})_{+1/2} \quad (\mathbf{\overline{3}},\mathbf{2})_{+5/6} \quad (\mathbf{\overline{3}},\mathbf{1})_{+1/3}$ $-\frac{1}{2}J_L J_R j_R$ $(\mathbf{1},\mathbf{2})_{+1/2}$ $(\overline{\mathbf{3}},\mathbf{2})_{+5/6}$ $(\overline{\mathbf{3}},\mathbf{3})_{+1/3}$ $(\overline{u_R}d_L)(d_R)(\overline{e_L})(\overline{u_R}e_R)$ #20 $(1,2)_{+1/2}$ $(\overline{3},2)_{+5/6}$ $(\overline{3},1)_{+1/3}$ $\frac{1}{2}J_L(J_R)^{\rho}(j)_{\rho}$ 2-i-b $(\overline{u_L}d_R)(\overline{e_L})(d_R)(\overline{u_Le_L})$ $({\bf \overline{3}},{\bf 1})_{+1/3}$ $-\frac{1}{2}J_RJ_Rj_R$ #11 $(\mathbf{1},\mathbf{2})_{+1/2}$ $(\mathbf{1},\mathbf{1})_0$ $(1,2)_{+1/2}$ $(1,3)_0$ $(\overline{3},3)_{+1/3}$ List of high *E* completions $@\Lambda_{NP}$

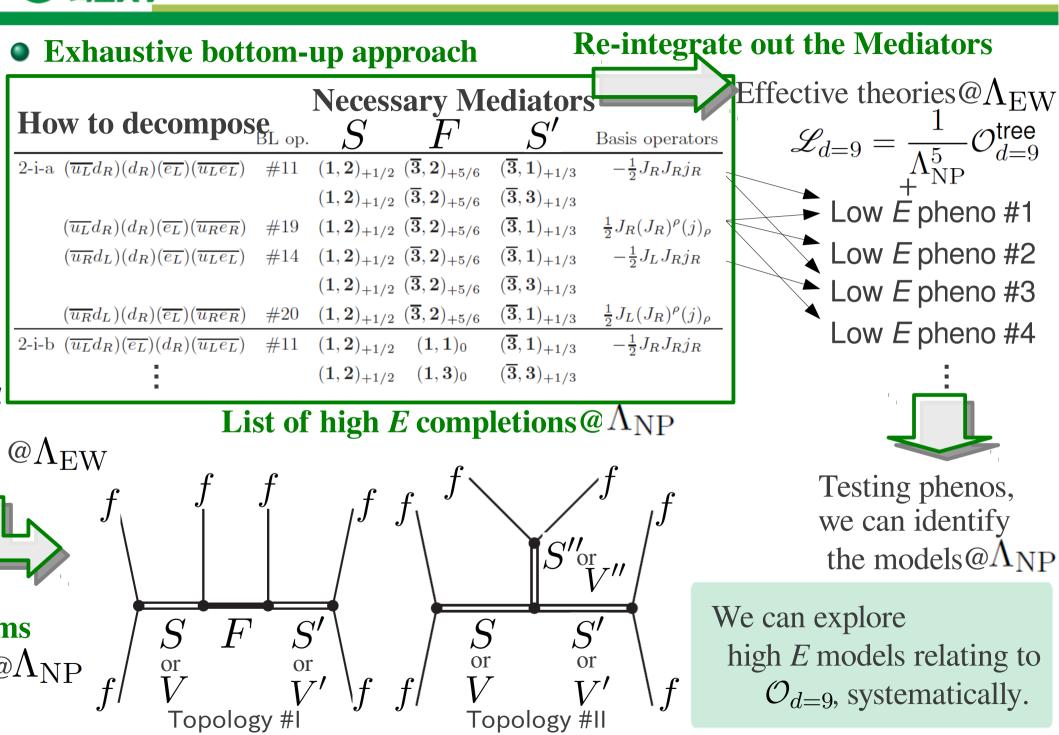




Saitama University 2 Effective ops \rightarrow High E completions



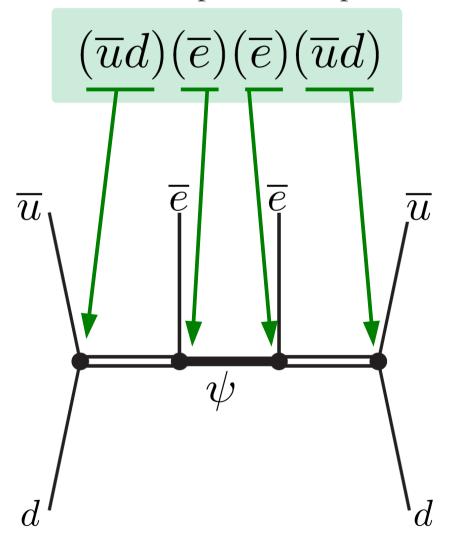
Saitama University $2Effective ops \rightarrow High E completions$ 埼玉大学





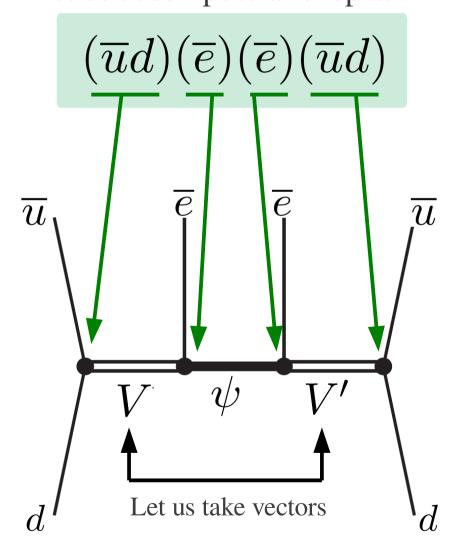
• An example, Taking Topology

Taking Topology #I let us decompose d=9 op as





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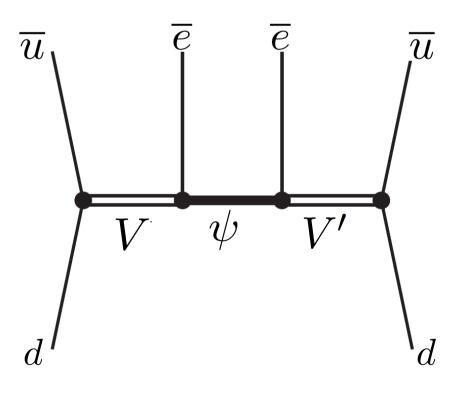




 An example, Taking Topology #I

let us decompose d=9 op as

 $(\overline{u}d)(\overline{e})(\overline{e})(\overline{u}d)$



Necessary mediators

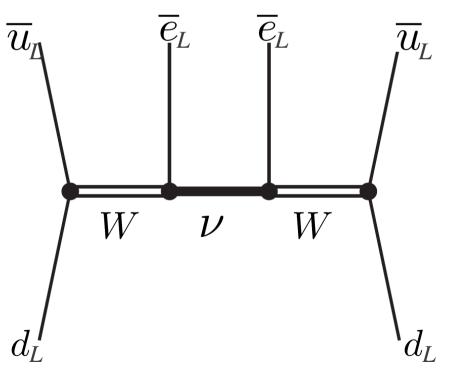
 $egin{aligned} V(+1, {f 1}) \ V'(-1, {f 1}) \ \psi(0, {f 1}) \end{aligned}$

where $(U(1)_{em}, SU(3)_{c})$



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 $(\overline{u}d)(\overline{e})(\overline{e})(\overline{u}d)$



Necessary mediators

$$egin{array}{lll} V(+1,{f 1}) & W^+ \ V'(-1,{f 1}) & W^- \ \psi(0,{f 1}) & {m {\cal V}} \end{array}$$

where $(U(1)_{em}, SU(3)_{c})$

Rediscovery of the standard neutrino mass contribution

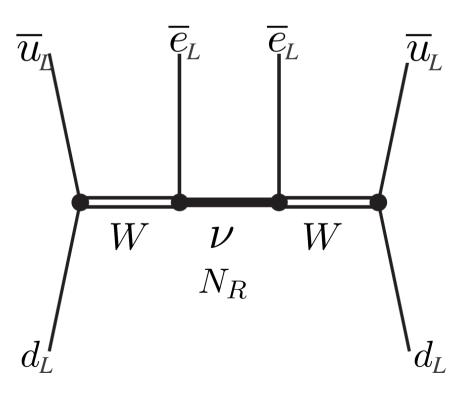
All the outer fermions must be left-handed



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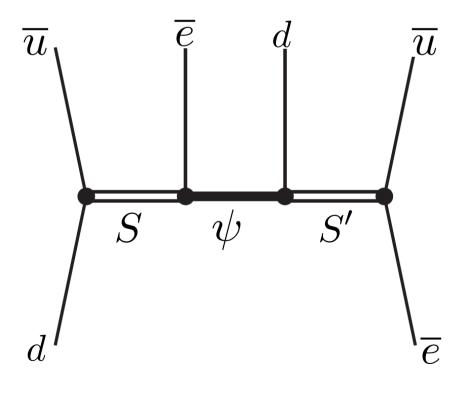
In Seesaw model, right-handed neutrinos (sterile neutrinos) can also mediate this diagram.



• Another example,

Decomposition

$$(\overline{u}d)(\overline{e})(d)(\overline{u}\overline{e})$$



Necessary mediators

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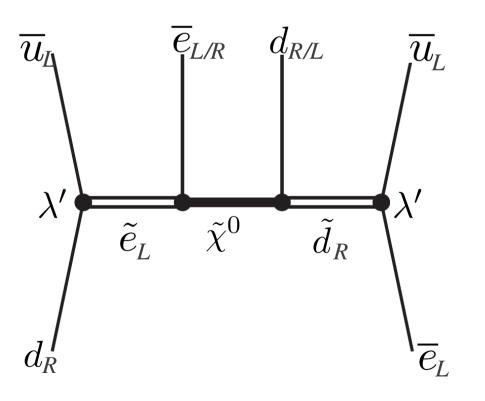
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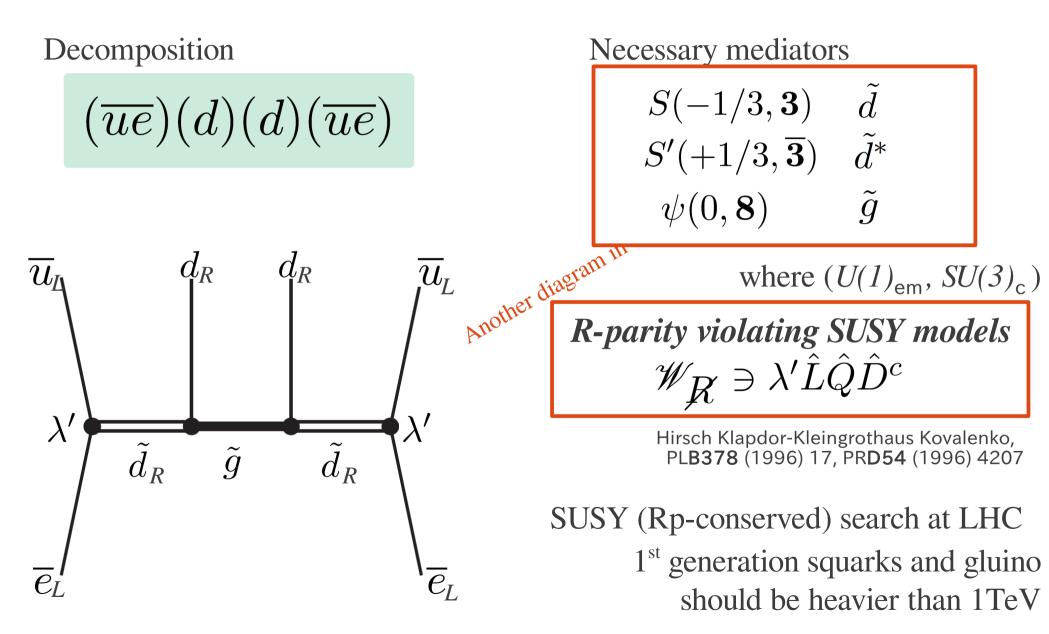
R-parity violating SUSY models $\mathscr{W}_{\mathcal{R}} \ni \lambda' \hat{L} \hat{Q} \hat{D}^c$

Hirsch Klapdor-Kleingrothaus Kovalenko, PL**B378** (1996) 17, PR**D54** (1996) 4207

SUSY (Rp-conserved) search at LHC 1st generation squarks and gluino should be heavier than 1TeV



• Another example,



Saitama University 2 Decompositions

	Decomposition	Long	Mediat S or V.	or $(U(1)_{em}, u)$		Models/Refs./Comments	_	Possible decompositions
# 1-i	$(\bar{u}d)(\bar{e})(\bar{e})(\bar{u}d)$	(a)	(+1,1)	(0, 1)	(-1, 1)	Mass mechan., RPV [58–60],		Possible decompositions
	()(-)()	()	(1-,-)	(-,-)	(-,-)	LR-symmetric models [39],	SnuM	and
						Mass mechanism with ν_S [61		
			(11.8)	(0.8)	(-1.8)	TeV scale seesaw, e.g., [62, 63 [64]	3]	• Necessary mediators
1-ii-a	$(\bar{u}d)(\bar{u})(d)(\bar{e}\bar{e})$		(+1, 0) (+1, 1)	(+5/3, 3)	(+2, 1)	[04]		(only Topology #I)
			(+1, 8)	(+5/3, 3)	(+2, 1)			(only ropology "1)
1-ii-b	$(\bar{u}d)(d)(\bar{u})(\bar{e}\bar{e})$		(+1, 1)	(+4/3, 3)	(+2, 1)			
	/- P / P / - b / - b		(+1,8)	$(+4/3, \overline{3})$	(+2,1)		- 0	4 possibilities for each decom.
2-i-a	$(\bar{u}d)(d)(\bar{e})(\bar{u}\bar{e})$		(+1, 1)	$(+4/3, \overline{3})$	(+1/3, 3)		-	+ possibilities for each decom.
2-i-b	$(\bar{u}d)(\bar{e})(d)(\bar{u}\bar{e})$	(b)	(+1, 8) (+1, 1)	$(+4/3, \overline{3})$ (0, 1)	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$	RPV [58-60], LQ [65, 66]	7	S- F - S , V - F - V , S - F - V ,
2-1-0	(uu)(c)(u)(uc)	(0)	(+1, 1) (+1, 8)	(0, 1)	(+1/3, 3) (+1/3, 3)	11 V [56-00], 1.42 [65,00]	RPV	S-I'-S, V-I'-V, S-I'-V,
2-ii-a	$(\bar{u}d)(\bar{u})(\bar{e})(d\bar{e})$		(+1,0)	(+5/3, 3)	(+2/3, 3)			and VEC
			(+1,8)	(+5/3, 3)	(+2/3, 3)			and V-F-S
2-ii-b	$(\bar{u}d)(\bar{e})(\bar{u})(d\bar{e})$	(b)	(+1, 1)	(0, 1)	(+2/3, 3)	RPV [58–60], LQ [65, 66]		
			(+1, 8)	(0, 8)	(+2/3, 3)			<i>Mediators</i> are specified with
2-iii-a	$(d\bar{e})(\bar{u})(d)(\bar{u}\bar{e})$	(c)	(-2/3, 3)	(0, 1)	(+1/3, 3)	RPV [58-60]		L
01	(1-)(1)(-)()		(-2/3, 3)	(0,8)	(+1/3, 3)	RPV [58–60]		U(1) EM charge
2-iii-b	$(d\bar{e})(d)(\bar{u})(\bar{u}\bar{e})$		$(-2/3, \overline{3})$	(-1/3, 3)	$(+1/3, \overline{3})$			C C
3-i	$(\bar{u}\bar{u})(\bar{e})(\bar{e})(dd)$		$(-2/3, \overline{3})$ $(+4/3, \overline{3})$	$(-1/3, \overline{6})$ $(+1/3, \overline{3})$	$(+1/3, \overline{3})$ $(-2/3, \overline{3})$	only with V_{ρ} and V'_{ρ}		SU(3) colour charge
0-1	(uu)(c)(c)(uu)		(+4/3, 6) (+4/3, 6)	(+1/3, 6) (+1/3, 6)	(-2/3, 6) (-2/3, 6)	only with v_{ρ} and v_{ρ}		
3-ii	$(\bar{u}\bar{u})(d)(d)(\bar{e}\bar{e})$		$(+4/3, \overline{3})$	(+5/3, 3)	(+2,1)	only with V_{ρ}		Hana wa do not anonify the
	(/(-/(-/		(+4/3, 6)	(+5/3, 3)	(+2, 1)	, p	•	Here, we do not specify the
3-iii	$(dd)(\bar{u})(\bar{u})(\bar{e}\bar{e})$		(+2/3, 3)	(+4/3, 3)	(+2, 1)	only with V_{ρ}		chiralities of outer fermions
			$(+2/3, \overline{6})$	(+4/3, 3)	(+2, 1)			cimanues of outer remnons
4-i	$(d\bar{e})(\bar{u})(\bar{u})(d\bar{e})$	(c)	(-2/3, 3)	(0, 1)	(+2/3, 3)	RPV [58–60]		$(SU(2)_1 \text{ and } U(1)_Y)$
	() (1) () (1)		$(-2/3, \overline{3})$	(0,8)	(+2/3, 3)	RPV [58-60]		$(50(2))$ and $0(1)\gamma$
4-ii-a	$(\bar{u}\bar{u})(d)(\bar{e})(d\bar{e})$		$(+4/3, \overline{3})$	(+5/3, 3)	(+2/3, 3)	only with V_ρ see Sec. 4 (this work)		\rightarrow Decom of chirality-specified ops
4-ii-b	$(\bar{u}\bar{u})(\bar{e})(d)(d\bar{e})$		(+4/3, 6) $(+4/3, \overline{3})$	(+5/3, 3) $(+1/3, \overline{3})$	(+2/3, 3) (+2/3, 3)	only with V_{ρ}		
4-11-0	(uu)(e)(u)(ue)		(+4/3, 6) (+4/3, 6)	(+1/3, 3) (+1/3, 6)	(+2/3, 3) (+2/3, 3)	only with v_{ρ}		Bonnet Hirsch O Winter
5-i	$(\bar{u}\bar{e})(d)(d)(\bar{u}\bar{e})$	(c)	(-1/3, 3)	(0, 1)	(+1/3, 3)	RPV [58-60]		
	(///// /	~ /	(-1/3, 3)	(0,8)	(+1/3, 3)	RPV [58-60]	RPV	$I \sim 0$ $D \sim 0$
5-ii-a	$(\bar{u}\bar{e})(\bar{u})(\bar{e})(dd)$		(-1/3, 3)	(+1/3, 3)	(-2/3, 3)	only with V'_{ρ}	- U	Long Range?
			(-1/3, 3)	(+1/3, 6)	(-2/3, 6)			
5-ii-b	$(\bar{u}\bar{e})(\bar{e})(\bar{u})(dd)$		(-1/3, 3)	(-4/3, 3)	(-2/3, 3)	only with V'_{ρ}		Decomposition which can
			(-1/3, 3)	(-4/3, 3)	(-2/3, 6)		_	contain neutrino propagation
For To	n #II → Bor	net Hi	irsch O	Winter				contain neutrino propagation

For Top #II \rightarrow Bonnet Hirsch O Winter

Saitama University 2 Decompositions

# 1-i 1-ii-a	Decomposition $(\bar{u}d)(\bar{e})(\bar{e})(\bar{u}d)$ $(\bar{u}d)(\bar{u})(d)(\bar{e}\bar{e})$	Long Range? (a)	$\begin{array}{c} \text{Mediat} \\ S \text{ or } V_{\rho} \\ (+1, 1) \\ (+1, 1) \\ (+1, 1) \\ (+1, 8) \end{array}$	or $(U(1)_{em}, \frac{\psi}{(0, 1)}$ (0, 1) (+5/3, 3) (+5/3, 3)	$SU(3)_c)$ $S' \text{ or } V'_{\rho}$ (-1, 1) (-1, 8) (+2, 1) (+2, 1)	Models/Refs./Comments Mass mechan., RPV [58–60], LR-symmetric models [39], Mass mechanism with ν_S [61], TeV scale seesaw, e.g., [62, 63] [64]	Possible decompositions and Necessary mediators (only Topology #I)
1-ii-b 2-i-a	$(\bar{u}d)(d)(\bar{u})(\bar{e}\bar{e})$ $(\bar{u}d)(d)(\bar{e})(\bar{u}\bar{e})$		(+1, 1) (+1, 8) (+1, 1)	$(+4/3, \overline{3})$ $(+4/3, \overline{3})$ $(+4/3, \overline{3})$	(+2, 1) (+2, 1) $(+1/3, \overline{3})$		• 4 possibilities for each decom.
2-i-b 2-ii-a	$(\bar{u}d)(\bar{u})(\bar{v})(\bar{u}\bar{v})$ $(\bar{u}d)(\bar{u})(\bar{d})(\bar{u}\bar{v})$ $(\bar{u}d)(\bar{u})(\bar{e})(d\bar{e})$	(b)	(+1, 1) (+1, 8) (+1, 1) (+1, 8) (+1, 1) (+1, 8)	$(+4/3, \overline{3})$ $(+4/3, \overline{3})$ (0, 1) (0, 8) (+5/3, 3) (+5/3, 3)	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$ $(+1/3, \overline{3})$ (+2/3, 3) (+2/3, 3)	RPV [58–60], LQ [65, 66]	S-F-S, V-F-V, S-F-V, and V-F-S
2-ii-b	$(\bar{u}d)(\bar{e})(\bar{u})(d\bar{e})$	(b)	(+1, 0) (+1, 1) (+1, 8)	(0,1) (0,8)	(+2/3, 3) (+2/3, 3) (+2/3, 3)	RPV [58–60], LQ [65, 66]	• <i>Mediators</i> are specified with
2-iii-a	$(d\bar{e})(\bar{u})(d)(\bar{u}\bar{e})$	(c)	$(-2/3, \overline{3})$ $(-2/3, \overline{3})$	(0, 1) (0, 8)	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$	RPV [58–60] RPV [58–60]	U(1) EM charge
2-iii-b 3-i	$(d\bar{e})(d)(\bar{u})(\bar{u}\bar{e})$ $(\bar{u}\bar{u})(\bar{u})(\bar{u}\bar{e})(dd)$		$(-2/3, \overline{3})$ $(-2/3, \overline{3})$	(-1/3, 3) $(-1/3, \overline{6})$	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$	and with V and V/	SU(3) colour charge
3-1 3-ii	$(\bar{u}\bar{u})(\bar{e})(\bar{e})(dd)$ $(\bar{u}\bar{u})(d)(d)(\bar{e}\bar{e})$		$(+4/3, \overline{3})$ $(+4/3, \overline{6})$ $(+4/3, \overline{3})$	$(+1/3, \overline{3})$ (+1/3, 6) (+5/3, 3)	$(-2/3, \overline{3})$ (-2/3, 6) (+2, 1)	only with V_{ρ} and V'_{ρ} only with V_{ρ}	 Here, we do not specify the
3-iii	$(dd)(\bar{u})(\bar{u})(\bar{e}\bar{e})$		(+4/3, 6) (+2/3, 3) $(+2/3, \overline{6})$	(+5/3, 3) $(+4/3, \overline{3})$ $(+4/3, \overline{3})$	(+2, 1) (+2, 1) (+2, 1)	only with V_ρ	chiralities of outer fermions
4-i	$(d\bar{e})(\bar{u})(\bar{u})(d\bar{e})$	(c)	$(-2/3, \overline{3})$ $(-2/3, \overline{3})$	(0, 1) (0, 8)	(+2/3, 3) (+2/3, 3)	RPV [58–60] RPV [58–60]	$(SU(2)_1 \text{ and } U(1)_Y)$
4-ii-a	$(\bar{u}\bar{u})(d)(\bar{e})(d\bar{e})$		$(+4/3, \mathbf{\overline{3}})$ (+4/3, 6)	(+5/3, 3) (+5/3, 3)	(+2/3, 3) (+2/3, 3)	only with V_{ρ} see Sec. 4 (this work)	\rightarrow Decom of chirality-specified ops
4-ii-b	$(\bar{u}\bar{u})(\bar{e})(d)(d\bar{e})$		$(+4/3, \overline{3})$ (+4/3, 6)	$(+1/3, \overline{3})$ (+1/3, 6)	(+2/3, 3) (+2/3, 3)	only with V_{ρ}	Bonnet Hirsch O Winter JHEP 1303 (2013) 055
5-i 5-ii-a	$(\bar{u}\bar{e})(d)(d)(\bar{u}\bar{e})$ $(\bar{u}\bar{e})(\bar{u})(\bar{e})(dd)$	(c)	(-1/3, 3) (-1/3, 3) (-1/3, 3)	(0, 1) (0, 8) (+1/3, $\overline{3}$)	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$ $(-2/3, \overline{3})$	RPV [58–60] RPV [58–60] only with V'_{ρ}	• Long Range?
5-ii-b	$(\bar{u}\bar{e})(\bar{e})(\bar{u})(dd)$		(-1/3, 3) (-1/3, 3) (-1/3, 3)	(+1/3, 6) (-4/3, 3) (-4/3, 3)	(-2/3, 6) (-2/3, 3) (-2/3, 6)	only with V'_{ρ}	Decomposition which can
For To	on #II → Boi	nnet H	irsch O	Winter			contain neutrino propagation

For Top #II → Bonnet Hirsch O Winter

2 **Decompositions** Saitama University 埼玉大学

# 1-i	Decomposition $(\bar{u}d)(\bar{e})(\bar{e})(\bar{u}d)$	Long Range? (a)	Mediate $S \text{ or } V_{\rho}$ (+1, 1) (+1, 8)	(0, 8)	$\frac{S' \text{ or } V'_{\rho}}{(-1,1)}$	Models/Refs./Comments Mass mechan., RPV [58–60], LR-symmetric models [39], Mass mechanism with ν_S [61], TeV scale seesaw, e.g., [62, 63] [64]	Possible decompositions and Necessary mediators
1-ii-a	$(\bar{u}d)(\bar{u})(d)(\bar{e}\bar{e})$		(+1, 8) (+1, 1) (+1, 8)	(0, 8) (+5/3, 3) (+5/3, 3)	(-1, 8) (+2, 1) (+2, 1)	[04]	(only Topology #I)
1-ii-b	$(\bar{u}d)(d)(\bar{u})(\bar{e}\bar{e})$		(+1, 8) (+1, 1) (+1, 8)	$(+3/3, \overline{3})$ $(+4/3, \overline{3})$ $(+4/3, \overline{3})$	(+2, 1) (+2, 1) (+2, 1)		
2-i-a	$(\bar{u}d)(d)(\bar{e})(\bar{u}\bar{e})$		(+1,1) (+1,8)	$(+4/3, \overline{3})$ $(+4/3, \overline{3})$	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$		4 possibilities for each decom.
2-i-b	$(\bar{u}d)(\bar{e})(d)(\bar{u}\bar{e})$	(b)	(+1, 0) (+1, 1) (+1, 8)	(0, 1) (0, 8)	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$	RPV [58–60], LQ [65, 66]	S- F - S , V - F - V , S - F - V ,
2-ii-a	$(\bar{u}d)(\bar{u})(\bar{e})(d\bar{e})$		(+1, 0) (+1, 1) (+1, 8)	(+5/3, 3) (+5/3, 3)	(+2/3, 3) (+2/3, 3)		and V-F-S
2-ii-b	$(\bar{u}d)(\bar{e})(\bar{u})(d\bar{e})$	(b)	(+1, 0) (+1, 1) (+1, 8)	(0, 1) (0, 8)	(+2/3, 3) (+2/3, 3) (+2/3, 3)	RPV [58–60], LQ [65, 66]	• <i>Mediators</i> are specified with
2-iii-a	$(d\bar{e})(\bar{u})(d)(\bar{u}\bar{e})$	(c)	$(-2/3, \overline{3})$ $(-2/3, \overline{3})$	(0, 3) (0, 1) (0, 8)	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$	RPV [58–60] RPV [58–60]	*
2-iii-b	$(d\bar{e})(d)(\bar{u})(\bar{u}\bar{e})$		$(-2/3, \overline{3})$ $(-2/3, \overline{3})$ $(-2/3, \overline{3})$	(-1/3, 3) $(-1/3, \overline{6})$	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$ $(+1/3, \overline{3})$	11 1 [35-00]	U(1) EM charge
3-i	$(\bar{u}\bar{u})(\bar{e})(\bar{e})(dd)$		$(+4/3, \overline{3})$ $(+4/3, \overline{6})$	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$ $(+1/3, \overline{6})$	$(-2/3, \overline{3})$ $(-2/3, \overline{6})$	only with V_{ρ} and V'_{ρ}	SU(3) colour charge
3-ii	$(\bar{u}\bar{u})(d)(d)(\bar{e}\bar{e})$		(+4/3, 3) (+4/3, 3) (+4/3, 6)	(+5/3, 3) (+5/3, 3)	(-2/3, 0) (+2, 1) (+2, 1)	only with V_ρ	Here, we do not specify the
3-iii	$(dd)(\bar{u})(\bar{u})(\bar{e}\bar{e})$		(+2/3, 3) (+2/3, 3) (+2/3, 6)	$(+3/3, \overline{3})$ $(+4/3, \overline{3})$ $(+4/3, \overline{3})$	(+2, 1) (+2, 1) (+2, 1)	only with V_ρ	chiralities of outer fermions
4-i	$(d\bar{e})(\bar{u})(\bar{u})(d\bar{e})$	(c)	$(-2/3, \overline{3})$ $(-2/3, \overline{3})$	(0,1) (0,8)	(+2/3, 3) (+2/3, 3)	RPV [58–60] RPV [58–60]	$(SU(2)_1 \text{ and } U(1)_Y)$
4-ii-a	$(\bar{u}\bar{u})(d)(\bar{e})(d\bar{e})$		$(+4/3, \overline{3})$ (+4/3, 6)	(+5/3, 3) (+5/3, 3)	(+2/3, 3) (+2/3, 3) (+2/3, 3)	only with V_{ρ} see Sec. 4 (this work)	\rightarrow Decom of chirality-specified ops
4-ii-b	$(\bar{u}\bar{u})(\bar{e})(d)(d\bar{e})$		$(+4/3, \overline{3})$ $(+4/3, \overline{6})$	$(+1/3, \overline{3})$ $(+1/3, \overline{6})$	(+2/3, 3) (+2/3, 3) (+2/3, 3)	only with V_{ρ}	Bonnet Hirsch O Winter
5-i	$(\bar{u}\bar{e})(d)(d)(\bar{u}\bar{e})$	(c)	(-1/3, 3) (-1/3, 3)	(0, 1) (0, 8)	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$	RPV [58–60] RPV [58–60]	JHEP 1303 (2013) 055
5-ii-a	$(\bar{u}\bar{e})(\bar{u})(\bar{e})(dd)$		(-1/3, 3)	(+1/3, 3)	(-2/3, 3)	only with V'_{ρ}	Long Range?
5-ii-b	$(\bar{u}\bar{e})(\bar{e})(\bar{u})(dd)$		(-1/3, 3) (-1/3, 3) (-1/3, 3)	(+1/3, 6) (-4/3, 3) (-4/3, 3)	(-2/3, 6) $(-2/3, \overline{3})$ (-2/3, 6)	only with V_{ρ}'	Decomposition which can
For To	op #II → Bor	nnet H	irsch O	Winter			contain neutrino propagation

For Top #II → Bonnet Hirsch O Winter

Saitama University 2 Decompositions

		Long		or $(U(1)_{em})$			D 11 1
#	Decomposition	Range?	$S \text{ or } V_{\rho}$	10	$S' \text{ or } V'_{\rho}$	Models/Refs./Comments	Possible decompositions
1-i	$(\bar{u}d)(\bar{e})(\bar{e})(\bar{u}d)$	(a)	(+1, 1)	(0, 1)	(-1, 1)	Mass mechan., RPV [58–60], LR-symmetric models [39],	and
						Mass mechanism with ν_S [61],	
						TeV scale seesaw, e.g., [62, 63]	Necessary mediators
			(+1, 8)	(0,8)	(-1, 8)	[64]	
1-ii-a	$(\bar{u}d)(\bar{u})(d)(\bar{e}\bar{e})$		(+1,1)	(+5/3, 3)	(+2, 1)		(only Topology #I)
1-ii-b	$(\bar{u}d)(d)(\bar{u})(\bar{e}\bar{e})$		(+1,8) (+1,1)	(+5/3, 3) $(+4/3, \overline{3})$	(+2, 1) (+2, 1)		
1-11-0	(uu)(u)(u)(ee)		(+1, 1) (+1, 8)	(+4/3, 3) (+4/3, 3)	(+2, 1) (+2, 1)		
2-i-a	$(\bar{u}d)(d)(\bar{e})(\bar{u}\bar{e})$		(+1,1)	(+4/3, 3)	(+1/3, 3)		• 4 possibilities for each decom.
			(+1, 8)	(+4/3,3)	(+1/3, 3)		*
2-i-b	$(\bar{u}d)(\bar{e})(d)(\bar{u}\bar{e})$	(b)	(+1, 1)	(0, 1)	(+1/3, 3)	RPV [58–60], LQ [65, 66]	S- F - S , V - F - V , S - F - V ,
2-ii-a	$(\bar{u}d)(\bar{u})(\bar{e})(d\bar{e})$		(+1,8) (+1,1)	(0, 8) (+5/3, 3)	$(+1/3, \overline{3})$ (+2/3, 3)		
2-11-4	(<i>uu</i>)(<i>u</i>)(<i>c</i>)(<i>uc</i>)		(+1, 1) (+1, 8)	$(\pm 5/3, 3)$ $(\pm 5/3, 3)$	(+2/3, 3) (+2/3, 3)		and V-F-S
2-ii-b	$(\bar{u}d)(\bar{e})(\bar{u})(d\bar{e})$	(b)	(+1, 1)	(0, 1)	(+2/3, 3)	RPV [58-60], LQ [65, 66]	
			(+1, 8)	(0, 8)	(+2/3, 3)		Mediators are specified with
2-iii-a	$(d\bar{e})(\bar{u})(d)(\bar{u}\bar{e})$	(c)	$(-2/3, \overline{3})$	(0, 1)	(+1/3, 3)	RPV [58-60]	*
2-iii-b	$(d\bar{e})(d)(\bar{u})(\bar{u}\bar{e})$		$(-2/3, \overline{3})$ $(-2/3, \overline{3})$	(0, 8) (-1/3, 3)	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$	RPV [58–60]	U(1) EM charge
2-111-0	(ue)(u)(u)(ue)		(-2/3, 3) (-2/3, 3)	(-1/3, 3) $(-1/3, \overline{6})$	(+1/3, 3) (+1/3, 3)		
3-i	$(\bar{u}\bar{u})(\bar{e})(\bar{e})(dd)$		$(+4/3, \overline{3})$	$(+1/3, \overline{3})$	$(-2/3, \overline{3})$	only with V_{ρ} and V'_{ρ}	SU(3) colour charge
			(+4/3,6)	(+1/3, 6)	(-2/3, 6)	r P	
3-ii	$(\bar{u}\bar{u})(d)(d)(\bar{e}\bar{e})$		(+4/3, 3)	(+5/3, 3)	(+2, 1)	only with V_{ρ}	Here, we do not specify the
0 :::	(11)(-)(-)(-=)		(+4/3, 6)	(+5/3, 3)	(+2, 1)	and with V	
3-iii	$(dd)(\bar{u})(\bar{u})(\bar{e}\bar{e})$		(+2/3, 3) $(+2/3, \overline{6})$	$(+4/3, \overline{3})$ $(+4/3, \overline{3})$	(+2, 1) (+2, 1)	only with V_{ρ}	chiralities of outer fermions
4-i	$(d\bar{e})(\bar{u})(\bar{u})(d\bar{e})$	(c)	(-2/3, 3)	(0, 1)	(+2, 1) (+2/3, 3)	RPV [58-60]	
	· //-//-//-/	1-7	$(-2/3, \overline{3})$	(0, 8)	(+2/3, 3)	RPV [58-60]	$(SU(2)_L \text{ and } U(1)_Y)$
4-ii-a	$(\bar{u}\bar{u})(d)(\bar{e})(d\bar{e})$		$(+4/3, \bar{3})$	(+5/3, 3)	(+2/3, 3)	only with V_{ρ}	
	()(-)(1)(1-)		(+4/3, 6)	(+5/3, 3)	(+2/3, 3)	see Sec. 4 (this work)	\rightarrow Decom of chirality-specified ops
4-ii-b	$(\bar{u}\bar{u})(\bar{e})(d)(d\bar{e})$		$(+4/3, \overline{3})$ (+4/3, 6)	(+1/3, 3) (+1/3, 6)	(+2/3, 3) (+2/3, 3)	only with V_{ρ}	Bonnet Hirsch O Winter
5-i	$(\bar{u}\bar{e})(d)(d)(\bar{u}\bar{e})$	(c)	(-1/3, 3)	(0, 1)	(+2/3, 3) (+1/3, 3)	RPV [58-60]	IHEP 1303 (2013) 055
	(/(-/()	(-)	(-1/3, 3)	(0, 8)	$(+1/3, \overline{3})$	RPV [58-60]	I and Danaa?
5-ii-a	$(\bar{u}\bar{e})(\bar{u})(\bar{e})(dd)$		(-1/3, 3)	(+1/3, 3)	(-2/3, 3)	only with V'_{ρ}	Long Range?
	() () (>		(-1/3, 3)	(+1/3, 6)	(-2/3, 6)		Decomposition which can
5-ii-b	$(\bar{u}\bar{e})(\bar{e})(\bar{u})(dd)$		(-1/3, 3) (-1/3, 3)	(-4/3, 3) (-4/3, 3)	$(-2/3, \overline{3})$ (-2/3, 6)	only with V'_{ρ}	Decomposition which can
			(-1/0,0)	(-4/0,0)	(-2/0,0)		contain neutrino propagation
For To	n #II → Bor	net H	irsch O	Winter			

For Top #II → Bonnet Hirsch O Winter

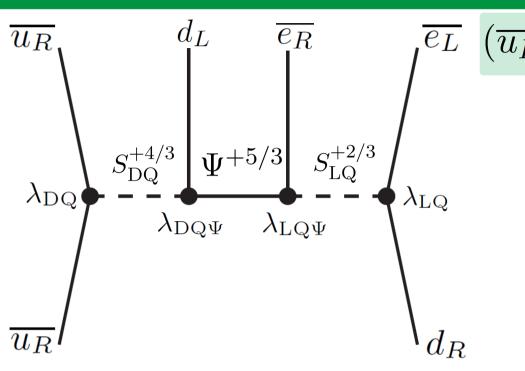
Saitama University 2 Decompositions

		Long	Mediat	or $(U(1)_{em})$	$SU(3)_c)$		
#	Decomposition	Range?	$S \text{ or } V_{\rho}$	ψ	S' or V'_{ρ}	Models/Refs./Comments	Possible decompositions
1-i	$(\bar{u}d)(\bar{e})(\bar{e})(\bar{u}d)$	(a)	(+1, 1)	(0, 1)	(-1, 1)	Mass mechan., RPV [58–60], LR-symmetric models [39],	and
						Mass mechanism with ν_S [61],	
			(11.0)	(0, 0)	(1 0)	TeV scale seesaw, e.g., [62, 63]	Necessary mediators
1-ii-a	$(\bar{u}d)(\bar{u})(d)(\bar{e}\bar{e})$		(+1, 8) (+1, 1)	(0, 8) (+5/3, 3)	(-1, 8) (+2, 1)	[64]	(anly Tonalogy #I)
1-11-4	(<i>aa</i>)(<i>a</i>)(<i>a</i>)(<i>ee</i>)		(+1, 1) (+1, 8)	(+5/3, 3) (+5/3, 3)	(+2, 1) (+2, 1)		(only Topology #I)
1-ii-b	$(\bar{u}d)(d)(\bar{u})(\bar{e}\bar{e})$		(+1, 1)	$(+4/3, \overline{3})$	(+2, 1)		
			(+1,8)	(+4/3, 3)	(+2, 1)		1 pageibilitize for each decom
2-i-a	$(\bar{u}d)(d)(\bar{e})(\bar{u}\bar{e})$		(+1, 1)	$(+4/3, \overline{3})$	(+1/3, 3)		4 possibilities for each decom.
2-i-b	$(\bar{u}d)(\bar{z})(d)(\bar{u}\bar{z})$	(b)	(+1,8)	$(+4/3, \overline{3})$	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$	RPV [58-60], LQ [65, 66]	$\mathbf{C} \mathbf{F} \mathbf{C} \mathbf{V} \mathbf{F} \mathbf{V} \mathbf{C} \mathbf{F} \mathbf{V}$
2-1-0	$(\bar{u}d)(\bar{e})(d)(\bar{u}\bar{e})$	(D)	(+1, 1) (+1, 8)	(0, 1) (0, 8)	(+1/3, 3) (+1/3, 3)	KF V [58-60], LQ [65, 66]	S- F - S , V - F - V , S - F - V ,
2-ii-a	$(\bar{u}d)(\bar{u})(\bar{e})(d\bar{e})$		(+1, 0) (+1, 1)	(+5/3, 3)	(+2/3, 3)		and V-F-S
			(+1,8)	(+5/3, 3)	(+2/3, 3)		απα ν-Γ-5
2-ii-b	$(\bar{u}d)(\bar{e})(\bar{u})(d\bar{e})$	(b)	(+1, 1)	(0, 1)	(+2/3, 3)	RPV [58–60], LQ [65, 66]	Madintena and an additional excition
2-iii-a	(d=)(a)(d)(a=)	(a)	(+1, 8)	(0,8)	(+2/3, 3)	RPV [58-60]	Mediators are specified with
2-111-a	$(d\bar{e})(\bar{u})(d)(\bar{u}\bar{e})$	(c)	$(-2/3, \overline{3})$ $(-2/3, \overline{3})$	(0, 1) (0, 8)	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$	RPV [58–60]	$U(1) \sum M$ abarra
2-iii-b	$(d\bar{e})(d)(\bar{u})(\bar{u}\bar{e})$		$(-2/3, \overline{3})$				U(1) EM charge
			(-2/3, 3)	$(-1/3, \overline{6})$	(+1/3, 3)	ok	SU(2) colour charge
3-i	$(\bar{u}\bar{u})(\bar{e})(\bar{e})(dd)$		(+4/3, 3)	(+1/3, 3)	(-2/3, 3)	only with V_{ρ} and V'_{ρ}	SU(3) colour charge
a ::	()(J)(J)()		(+4/3, 6)	(+1/3, 6)	(-2/3, 6)	dose mple.	
3-ii	$(\bar{u}\bar{u})(d)(d)(\bar{e}\bar{e})$		$(+4/3, \overline{3})$ (+4/3, 6)	(+5/3, 3) (+5/3, 3)	(+2, 1) (+2, 1)	only with a a Croxaline	• Here, we do not specify the
3-iii	$(dd)(\bar{u})(\bar{u})(\bar{e}\bar{e})$		(+4/3, 0) (+2/3, 3)	(+4/3, 3) (+4/3, 3)	(+2, 1) (+2, 1)	havenis	
			$(+2/3, \overline{6})$	(+4/3, 3)	(+2,1)	t US Lat U	chiralities of outer fermions
4-i	$(d\bar{e})(\bar{u})(\bar{u})(d\bar{e})$	(c)	(-2/3, 3)	(0, 1)	(+2/3, 3)	et [58-60]	$(SU(2)_1 \text{ and } U(1)_Y)$
	$\langle\rangle \langle 1\rangle \langle -\rangle \langle 1-\rangle$		$(-2/3, \overline{3})$	(0,8)	(+2/3, 3)	only with V_{ρ} and V' LOOK only with V_{ρ} and V' LOOK only with V_{ρ} at this example. APV [58-60] only with V_{ρ}	$(SO(2)_L \text{ and } O(1)_Y)$
4-ii-a	$(\bar{u}\bar{u})(d)(\bar{e})(d\bar{e})$		$(+4/3, \overline{3})$ (+4/3, 6)	(+5/3, 3) (+5/3, 3)	(+2/3, 3) (+2/3, 3)	only with V_{ρ} see Sec. 4 (this work)	\rightarrow Decom of chirality-specified ops
4-11-D	(uu)(e)(a)(ae)		(+4/3, 3) (+4/3, 3)	(+1/3,3)	(+2/3,3)	only with V_{ρ}	Bonnet Hirsch O Winter
	· ////////////////////////////////////		(+4/3,6)	(+1/3,6)	(+2/3, 3)	- P	
5-i	$(\bar{u}\bar{e})(d)(d)(\bar{u}\bar{e})$	(c)	(-1/3, 3)	(0, 1)	(+1/3, 3)	RPV [58–60]	JHEP 1303 (2013) 055
5.0.0	$(\overline{a}\overline{a})(\overline{a})(\overline{a})(\overline{a})(\overline{a})$		(-1/3, 3)	(0,8)	$(+1/3, \overline{3})$	RPV $[58-60]$	Long Range?
5-ii-a	$(\bar{u}\bar{e})(\bar{u})(\bar{e})(dd)$		(-1/3, 3) (-1/3, 3)	$(+1/3, \overline{3})$ (+1/3, 6)	$(-2/3, \overline{3})$ (-2/3, 6)	only with V'_{ρ}	
5-ii-b	$(\bar{u}\bar{e})(\bar{e})(\bar{u})(dd)$		(-1/3, 3)	(-4/3, 3)	$(-2/3, \overline{3})$	only with V'_{a}	Decomposition which can
	× ////////////////////////////////////		(-1/3, 3)	(-4/3, 3)	(-2/3, 6)	- 4	
For To	op #II → Bor	nnet Hi	rsch O	Winter			contain neutrino propagation

For Top #II \rightarrow Bonnet Hirsch O Winter

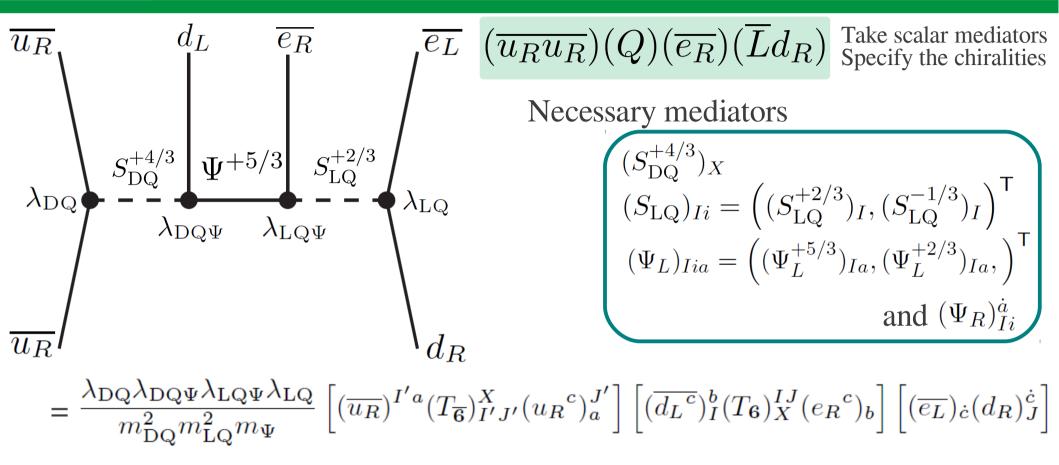


Collider testability



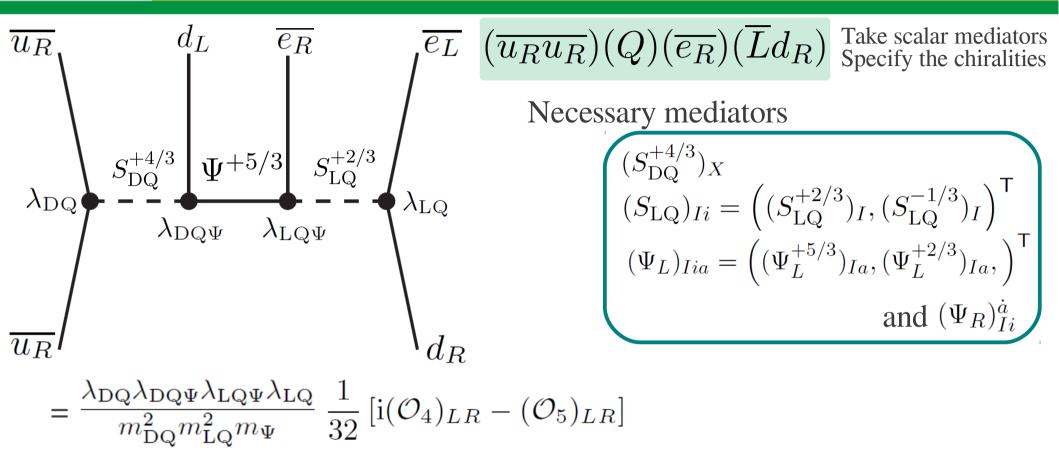
 $(\overline{u_R u_R})(Q)(\overline{e_R})(\overline{L}d_R) \quad \text{Take scalar mediators} \\ \text{Specify the chiralities} \\ \text{Necessary mediators} \\ (S_{\text{DQ}}^{+4/3})_X \\ (S_{\text{LQ}})_{Ii} = \left((S_{\text{LQ}}^{+2/3})_I, (S_{\text{LQ}}^{-1/3})_I\right)^{\mathsf{T}} \\ (\Psi_L)_{Iia} = \left((\Psi_L^{+5/3})_{Ia}, (\Psi_L^{+2/3})_{Ia}, \right)^{\mathsf{T}} \\ \text{and } (\Psi_R)_{Ii}^{\dot{a}} \end{bmatrix}$







Collider testability





$$\frac{\overline{u_R}}{\lambda_{DQ}} \xrightarrow{d_L} \frac{\overline{e_R}}{\lambda_{DQ}} \xrightarrow{q_{+2/3}} \sqrt{\overline{e_L}} (\overline{u_R u_R})(Q)(\overline{e_R})(\overline{L}d_R) \text{ Take scalar mediators Specify the chiralities Necessary mediators } \\
\frac{(S_{DQ}^{+4/3})_X}{(S_{LQ})_{Ii}} = \left((S_{LQ}^{+2/3})_I, (S_{LQ}^{-1/3})_I\right)^{\mathsf{T}} (\Psi_L)_{Iia} = \left((\Psi_L^{+5/3})_{Ia}, (\Psi_L^{+2/3})_{Ia}, 0\right)^{\mathsf{T}} \text{ and } (\Psi_R)_{Ii}^{\dot{a}} \\
= \frac{\lambda_{DQ}\lambda_{DQ\Psi}\lambda_{LQ\Psi}\lambda_{LQ\Psi}\lambda_{LQ}}{m_{DQ}^2 m_{LQ}^2 m_{\Psi}^2} \frac{1}{32} [i(\mathcal{O}_4)_{LR} - (\mathcal{O}_5)_{LR}] \quad \text{Take } \lambda \text{'s = 1, } m = \Lambda \\
\text{ On 2b half-life: } \left(T_{1/2}^{0\nu2\beta}\right)^{-1} = G_2 \left|\frac{2m_P}{G_F^2} \frac{1}{32} \frac{1}{\Lambda^5} [i\mathcal{M}_4 - \mathcal{M}_5]\right|^2$$

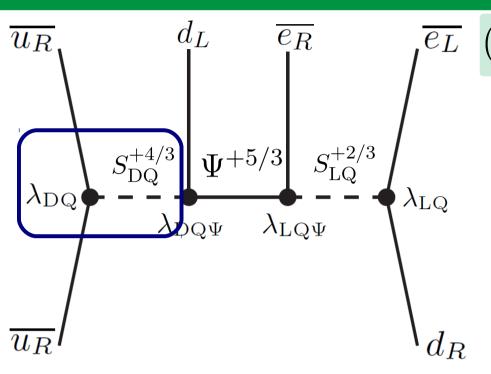


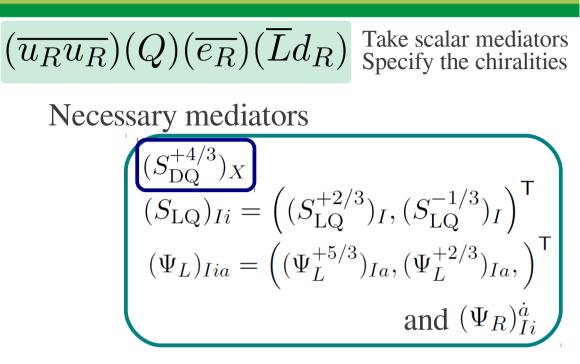
$$\frac{\overline{u}_{R}}{\lambda_{DQ}} \xrightarrow{d_{L}} \overline{e_{R}} \xrightarrow{\overline{e}_{L}} \overline{e_{L}} (\overline{u}_{R}u_{R})(Q)(\overline{e_{R}})(\overline{L}d_{R}) \xrightarrow{\text{Take scalar mediators Specify the chiralities Necessary mediators}} \\
\xrightarrow{\lambda_{DQ}} \xrightarrow{\lambda_{DQ\Psi}} \xrightarrow{\lambda_{LQ\Psi}} \xrightarrow{\lambda_{LQ\Psi}} \xrightarrow{\lambda_{LQ}} \overline{d_{R}} \xrightarrow{\overline{e}_{L}} (\overline{u}_{R}u_{R})(Q)(\overline{e_{R}})(\overline{L}d_{R}) \xrightarrow{\text{Take scalar mediators Specify the chiralities}}} \\
\xrightarrow{(S_{LQ}^{+4/3})_{X}} (S_{LQ})_{Ii} = ((S_{LQ}^{+2/3})_{I}, (S_{LQ}^{-1/3})_{I})^{\mathsf{T}}} (\Psi_{L})_{Iia} = ((\Psi_{L}^{+5/3})_{Ia}, (\Psi_{L}^{+2/3})_{Ia},)^{\mathsf{T}}} \\
\xrightarrow{u_{R}} \xrightarrow{d_{DQ}\lambda_{DQ\Psi}\lambda_{LQ\Psi}\lambda_{LQ\Psi}} \frac{1}{32} [i(\mathcal{O}_{4})_{LR} - (\mathcal{O}_{5})_{LR}] \xrightarrow{\text{Take } \lambda's = 1, m = \Lambda} \\
\xrightarrow{(0,2)} \xrightarrow{(0,2)} \xrightarrow{(0,2)} \xrightarrow{(1,2)} \xrightarrow{(1$$

Q: What does this model suggest to LHC observables?

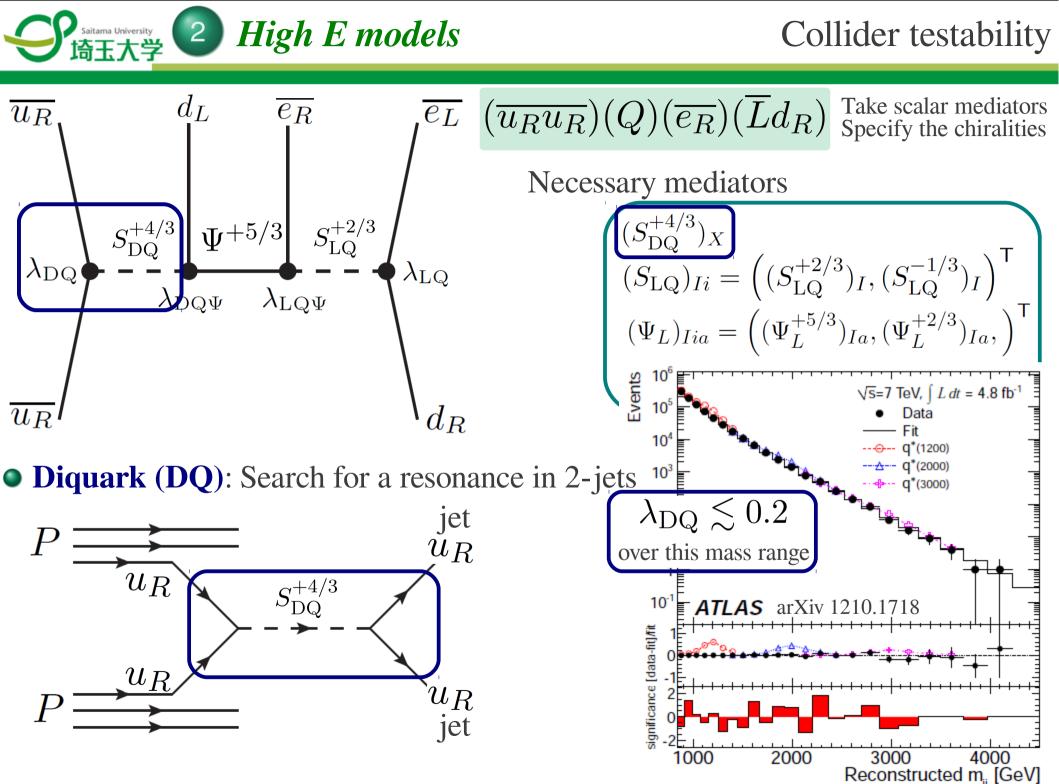


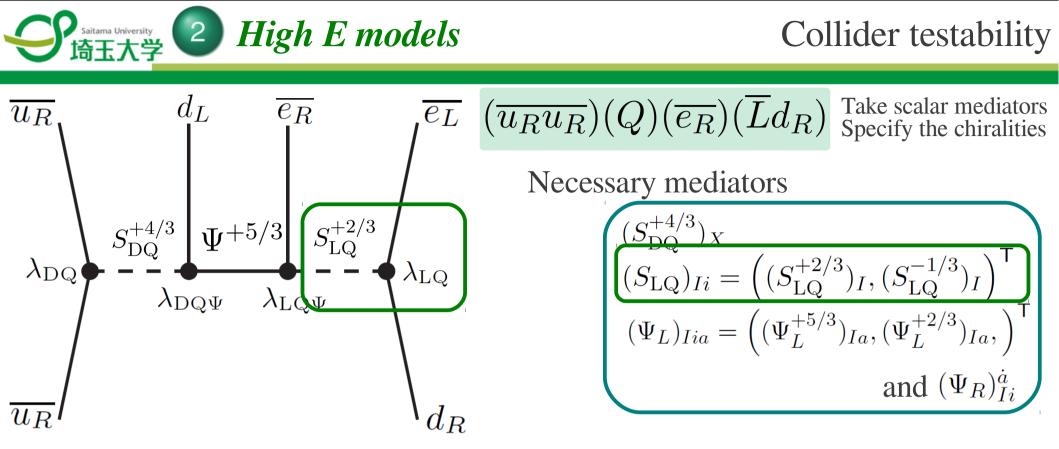
Collider testability





• Diquark (DQ):

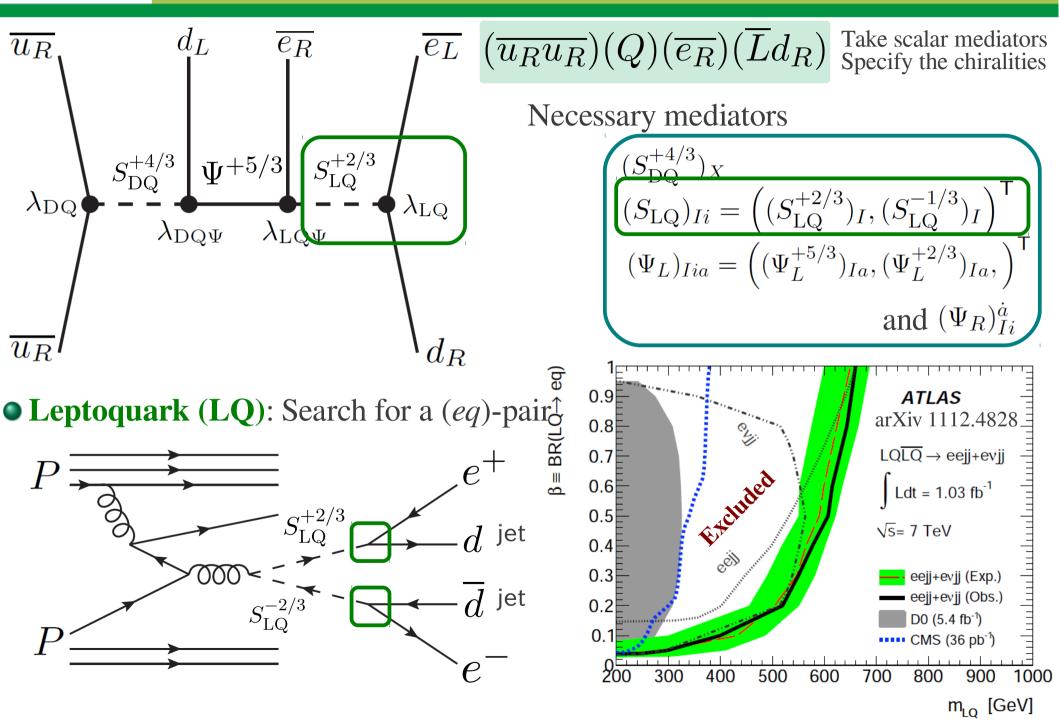


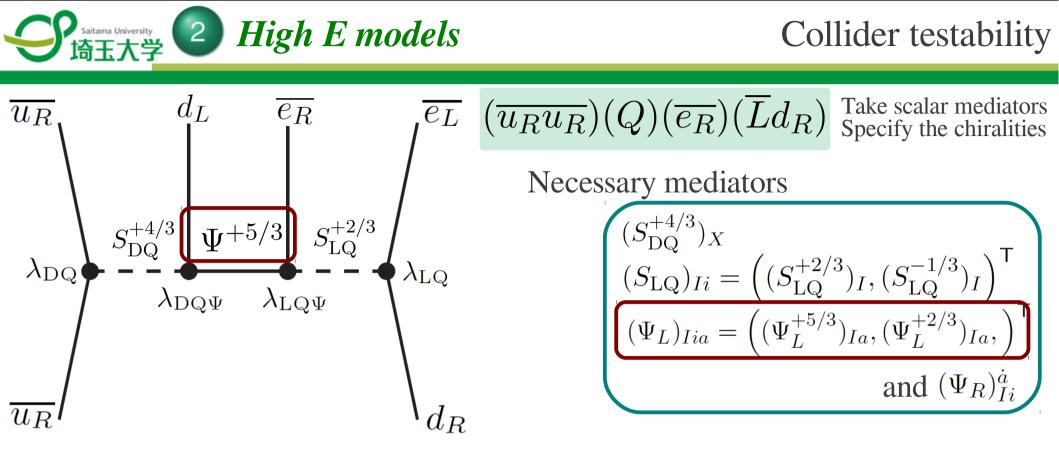


• Leptoquark (LQ):

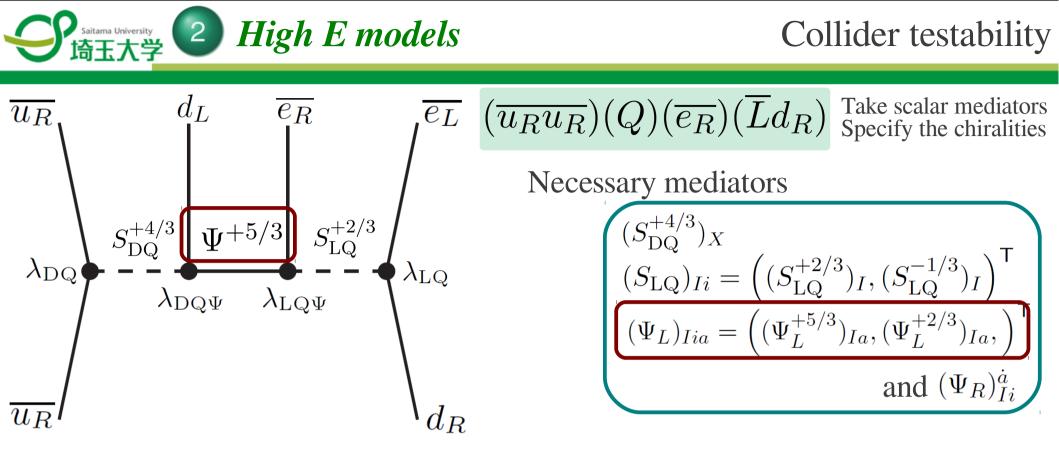
Saitama University 2 High E models

Collider testability

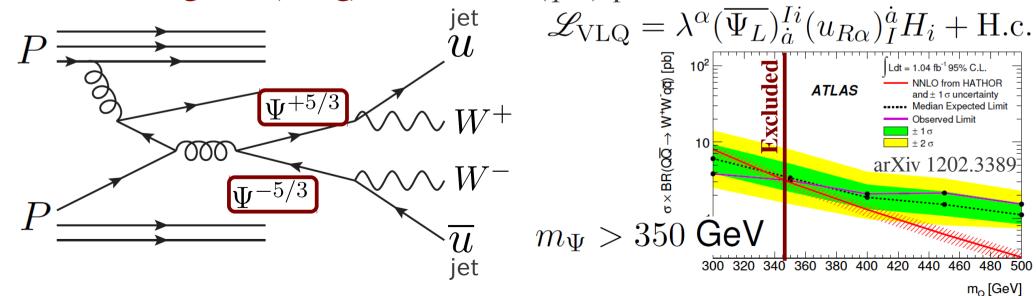




• Vector-like Quark (VLQ):



• Vector-like Quark (VLQ): Search for a (*qW*)-pair





Outline

New Physics (*d=9*) contributions in neutrinoless double beta decay (0n2b)



Neutrino mass searches as a frontier to new physics: dim=9 ops $d=9 \text{ ops} \rightarrow \text{half-life time of 0n2b processes}$ "How sensitive 0n2b experiments to the d=9 ops?"



What do the d=9 ops suggest to TeV scale physics?

 $d=9 \text{ ops} \rightarrow \text{decompose them to the fundamental ints.}$

 \rightarrow list the TeV signatures of each completion

"The list helps us to discriminate the models"

Summary

"Complementarity between 0n2b and LHC (and ILC)"

Saitama University d=9 op. : Bridge between neutrino and TeV scale



		Long	Mediat	or $(U(1)_{em})$	$SU(3)_c$		
#	Decomposition	Range?	S or V_{ρ}	ψ	S' or V'_{ρ}	Models/Refs./Comments	What can we learn from this table?
1-i	$(\bar{u}d)(\bar{e})(\bar{e})(\bar{u}d)$	(a)	(+1,1)	(0, 1)	(-1,1)	Mass mechan., RPV [58-60],	Ji china and a second
						LR-symmetric models [39],	$\mathbf{If} \mathbf{O}_{\mathbf{r}} \mathbf{O}_{\mathbf{r}} = \mathbf{O}_{\mathbf{r}} \mathbf{O}_{$
						Mass mechanism with ν_S [61]	If 0n2b conflicts with
			<i></i>	(0 -		TeV scale seesaw, e.g., [62, 63	
	(- P (-)(P ()		(+1,8)	(0,8)	(-1, 8)	[64]	cosmological obs.,
1-ii-a	$(\bar{u}d)(\bar{u})(d)(\bar{e}\bar{e})$		(+1, 1)	(+5/3, 3)	(+2, 1)		
	(- n (n (-) ()		(+1,8)	(+5/3, 3)	(+2, 1)		
1-ii-b	$(\bar{u}d)(d)(\bar{u})(\bar{e}\bar{e})$		(+1, 1)	(+4/3, 3)	(+2, 1)		It could be a large $d=9$ contribution
0.1	(=,1)(-1)(-;-)		(+1,8)	$(+4/3, \overline{3})$	(+2, 1)		-
2-i-a	$(\bar{u}d)(d)(\bar{e})(\bar{u}\bar{e})$		(+1,1)	$(+4/3, \overline{3})$	$(+1/3, \overline{3})$		
2-i-b	$(\bar{u}d)(\bar{z})(d)(\bar{u}\bar{z})$	(b)	(+1, 8)	$(+4/3, \overline{3})$ (0, 1)	$(+1/3, \overline{3})$ $(+1/3, \overline{3})$	RPV [58-60], LQ [65, 66]	
2-1-0	$(\bar{u}d)(\bar{e})(d)(\bar{u}\bar{e})$	(b)	(+1, 1)		(+1/3, 3) (+1/3, 3)	RF v [58-00], LQ [05,00]	
2-ii-a	$(\bar{u}d)(\bar{u})(\bar{e})(d\bar{e})$		(+1,8) (+1,1)	(0, 8) (+5/3, 3)	(+1/3, 3) (+2/3, 3)		
2-11-8	(uu)(u)(e)(ue)		(+1, 1) (+1, 8)	(+5/3, 3) (+5/3, 3)	(+2/3, 3) (+2/3, 3)		
2-ii-b	$(\bar{u}d)(\bar{e})(\bar{u})(d\bar{e})$	(b)	(+1, 0) (+1, 1)	(+5/3, 3) (0, 1)	(+2/3, 3) (+2/3, 3)	RPV [58-60], LQ [65, 66]	
2-11-0	(uu)(c)(u)(uc)	(D)	(+1, 1) (+1, 8)	(0, 1) (0, 8)	(+2/3, 3) (+2/3, 3)	11 v [55-00], 1.Q [05,00]	
2-iii-a	$(d\bar{e})(\bar{u})(d)(\bar{u}\bar{e})$	(c)	$(-2/3, \overline{3})$	(0, 0) (0, 1)	$(+1/3, \overline{3})$	RPV [58-60]	
2-11-4	(uc)(u)(u)(uc)	(0)	$(-2/3, \overline{3})$	(0, 1)	$(+1/3, \overline{3})$	RPV [58-60]	
2-iii-b	$(d\bar{e})(d)(\bar{u})(\bar{u}\bar{e})$		$(-2/3, \overline{3})$	(-1/3, 3)	$(+1/3, \overline{3})$		
	(/(-/(/		$(-2/3, \overline{3})$	$(-1/3, \overline{6})$	$(+1/3, \overline{3})$		
3-i	$(\bar{u}\bar{u})(\bar{e})(\bar{e})(dd)$		(+4/3, 3)	(+1/3, 3)	$(-2/3, \overline{3})$	only with V_{ρ} and V'_{ρ}	-
	(/(-/(-/		(+4/3, 6)	(+1/3, 6)	(-2/3, 6)	p p	
3-ii	$(\bar{u}\bar{u})(d)(d)(\bar{e}\bar{e})$		(+4/3, 3)	(+5/3, 3)	(+2, 1)	only with V_{ρ}	
			(+4/3, 6)	(+5/3, 3)	(+2, 1)	- P	
3-iii	$(dd)(\bar{u})(\bar{u})(\bar{e}\bar{e})$		(+2/3, 3)	(+4/3, 3)	(+2, 1)	only with V_{ρ}	
			$(+2/3, \overline{6})$	(+4/3, 3)	(+2, 1)		
4-i	$(d\bar{e})(\bar{u})(\bar{u})(d\bar{e})$	(c)	(-2/3, 3)	(0, 1)	(+2/3, 3)	RPV [58–60]	_
			(-2/3, 3)	(0, 8)	(+2/3, 3)	RPV [58-60]	
4-ii-a	$(\bar{u}\bar{u})(d)(\bar{e})(d\bar{e})$		(+4/3, 3)	(+5/3, 3)	(+2/3, 3)	only with V_{ρ}	
			(+4/3, 6)	(+5/3, 3)	(+2/3, 3)	see Sec. 4 (this work)	
4-ii-b	$(\bar{u}\bar{u})(\bar{e})(d)(d\bar{e})$		(+4/3, 3)	(+1/3, 3)	(+2/3, 3)	only with V_{ρ}	
			(+4/3, 6)	(+1/3, 6)	(+2/3, 3)		
5-i	$(\bar{u}\bar{e})(d)(d)(\bar{u}\bar{e})$	(c)	(-1/3, 3)	(0, 1)	(+1/3, 3)	RPV [58–60]	
			(-1/3, 3)	(0,8)	(+1/3, 3)	RPV [58–60]	
5-ii-a	$(\bar{u}\bar{e})(\bar{u})(\bar{e})(dd)$		(-1/3, 3)	(+1/3, 3)	(-2/3, 3)	only with V'_{ρ}	
			(-1/3, 3)	(+1/3, 6)	(-2/3, 6)		
5-ii-b	$(\bar{u}\bar{e})(\bar{e})(\bar{u})(dd)$		(-1/3, 3)	(-4/3, 3)	(-2/3, 3)	only with V'_{ρ}	
			(-1/3, 3)	(-4/3, 3)	(-2/3, 6)		
							_

Seitama University d=9 op. : Bridge between neutrino and TeV scale



# 1-i	Decomposition $(\bar{u}d)(\bar{e})(\bar{e})(\bar{u}d)$	Long Range? (a)	Mediat $S \text{ or } V_{\rho}$ (+1, 1)	or $(U(1)_{em}, \psi)$ (0, 1)	$SU(3)_c)$ $S' \text{ or } V'_{\rho}$ (-1, 1)	Models/Refs./Comments Mass mechan., RPV [58–60], LR-symmetric models [39],	What can we learn from this table?
	Со	lou	r 8	(0.8)	(-1.8)	Mass mechanism with ν_S [61] TeV scale seesaw, e.g., [62, 63 [64]	
1-ii-a	$(\bar{u}d)(\bar{u})(d)(\bar{e}\bar{e})$		(+1, 1)	$(\pm 5/3, 3)$	(+2, 1)		cosmological obs.,
1-ii-b	$(\bar{u}d)(d)(\bar{u})(\bar{e}\bar{e})$		(+1,8) (+1,1) (+1,8)	(+5/3, 3) (+4/3, 3) (+4/3, 3)	(+2, 1) (+2, 1) (+2, 1)	Colour 3	It could be a large $d=9$ contribution
2-i-a	$(\bar{u}d)(d)(\bar{e})(\bar{u}\bar{e})$		(+1,1)	(+4/3.3)	$(\pm 1/3, 3)$		_
2-i-b	$(\bar{u}d)(\bar{e})(d)(\bar{u}\bar{e})$	(b)	(+1, 8) (+1, 1) (+1, 8)	(+4/3, 3) (0, 1) (0, 8)	(+1/3.3) (+1/3.3) (+1/3.3)	$\rm RPV \ [58-60], \ LQ \ \ [65, 66]$	Such a large $d=9$ contribution
2-ii-a	$(\bar{u}d)(\bar{u})(\bar{e})(d\bar{e})$		(+1, 1)	(+5/3,3)	$(\pm 2/3, 9)$		should leave the trace in LHC
2-ii-b	$(\bar{u}d)(\bar{e})(\bar{u})(d\bar{e})$	(b)	(+1, 8) (+1, 1) (+1, 8)	(+5/3, 3) (0, 1) (0, 8)	(+2/3.3) (+2/3.3) (+2/3.3)	$\rm RPV \ [58-60], \ LQ \ \ [65, 66]$	except for T-I-1-i (and T-II-1)
2-iii-a	$(d\bar{e})(\bar{u})(d)(\bar{u}\bar{e})$	(c)	(-2/3.3)	(0, 1)	(+1/3, 3)	RPV [58–60]	that does not contain
2-iii-b	$(d\bar{e})(d)(\bar{u})(\bar{u}\bar{e})$		(-2/3, 3) (-2/3, 3) (-2/3, 3)	(0, 8) (-1/3, 3) (-1/3, 6)	(+1/3 3) (+1/3 3) (+1/3 3)	RPV [58–60]	a coloured mediator
3-i	$(\bar{u}\bar{u})(\bar{e})(\bar{e})(dd)$		(+4/3,3)	(+1/3,3)	(-2/3,3)	only with V_{ρ} and V'_{ρ}	—
3-ii	$(\bar{u}\bar{u})(d)(d)(\bar{e}\bar{e})$		(+4/3, 6) (+4/3, 3) (+4/3, 6)	(+1/3, 6) (+5/3, 3) (+5/3, 3)	(+2,3,6) (+2,1) (+2,1)	only with V_{ρ}	
3-iii	$(dd)(\bar{u})(\bar{u})(\bar{e}\bar{e})$		(+2/3,3) (+2/3,3)	$(\pm 4/3, 3)$ $(\pm 4/3, 3)$	(+2, 1) (+2, 1) (+2, 1)	only with V_ρ	
4-i	$(d\bar{e})(\bar{u})(\bar{u})(d\bar{e})$	(c)	(-2/3,3)	(0, 1)	(+2/3, 3)	RPV [58-60]	_
4-ii-a	$(\bar{u}\bar{u})(d)(\bar{e})(d\bar{e})$		(-2/3, 3) (+4/3, 9) (+4/3, 6)	(0.8) $(\pm 5/3.3)$ $(\pm 5/3.3)$	$(\pm 2/3, 3)$ $(\pm 2/3, 3)$ $(\pm 2/3, 3)$	RPV [58–60] only with V_{ρ}	
4-ii-b	$(\bar{u}\bar{u})(\bar{e})(d)(d\bar{e})$		(+4/3, 3) (+4/3, 3) (+4/3, 6)	(+1/3.3) (+1/3.6)	(+2/3,3) (+2/3,3)	see Sec. 4 (this work) only with V_{ρ}	
5-i	$(\bar{u}\bar{e})(d)(d)(\bar{u}\bar{e})$	(c)	(-1/3, 3)	(0, 1)	$(\pm 1/3, 3)$	RPV [58–60]	_
5-ii-a	$(\bar{u}\bar{e})(\bar{u})(\bar{e})(dd)$		(-1/3.3) (-1/3.3) (-1/3.3)	(0, 8) (+1/3, 3) (+1/3, 6)	(+1/3, 3) (-2/3, 3) (-2/3, 6)	RPV [58–60] only with V'_{ρ}	
5-ii-b	$(\bar{u}\bar{e})(\bar{e})(\bar{u})(dd)$		(<u>1/2,9</u>) (<u>-1/3,3</u>)	(-4/3.3) (-4/3.3)	(-2/3,3) (-2/3,6)	only with V_{ρ}'	
					(Colour 6	

Saitama University d=9 op. : Bridge between neutrino and TeV scale



		Long	Mediat	or $(U(1)_{em})$	$SU(3)_c$		
#	Decomposition	Range?	$S \text{ or } V_{\rho}$	ψ	S' or V'_{ρ}	Models/Refs./Comments	What can we learn from this table?
1-i	$(\bar{u}d)(\bar{e})(\bar{e})(\bar{u}d)$	(a)	(+1, 1)	(0, 1)	(-1, 1)	Mass mechan., RPV [58–60], LR-symmetric models [39],	
						Mass mechanism with ν_S [61]	If 0n2b conflicts with
			(+1,8)	(0.8)	(-1, 8)	TeV scale seesaw, e.g., [62, 63] [64]	
1-ii-a	$(\bar{u}d)(\bar{u})(d)(\bar{e}\bar{e})$		(+1,1)	(+5/3.3)	(+2, 1)	[0 *]	cosmological obs.,
1-ii-b	$(\bar{u}d)(d)(\bar{u})(\bar{e}\bar{e})$		(+1,8) (+1,1)	$(\pm 5/3, 3)$ $(\pm 4/3, 3)$	(+2, 1) (+2, 1)		It could be a large d. O contribution
1-11-0	(<i>uu</i>)(<i>u</i>)(<i>u</i>)(<i>cc</i>)		(+1,1) $(+1,8)$	(+4/3.3)	(+2, 1) (+2, 1)		It could be a large $d=9$ contribution
2-i-a	$(\bar{u}d)(d)(\bar{e})(\bar{u}\bar{e})$		(+1, 1) (+1, 8)	(+4/3, 3) (+4/3, 3)	$(\pm 1/3, 3)$ $(\pm 1/3, 3)$		_
2-i-b	$(\bar{u}d)(\bar{e})(d)(\bar{u}\bar{e})$	(b)	$(\pm 1, 8)$ $(\pm 1, 1)$	$(\pm 4/3, 3)$ (0, 1)	$(\pm 1/3, 3)$ $(\pm 1/3, 3)$	RPV [58-60], LQ [65, 66]	Such a large $d=9$ contribution
	(- T) (-) (T-)		(+1.8)	(0, 8)	$(\pm 1/3 9)$ $(\pm 9/3 9)$		e
2-ii-a	$(\bar{u}d)(\bar{u})(\bar{e})(d\bar{e})$		(+1, 1) (+1, 8)	(+5/3, 3) (+5/3, 3)	$(\pm 2/3, 3)$		should leave the trace in LHC
2-ii-b	$(\bar{u}d)(\bar{e})(\bar{u})(d\bar{e})$	(b)	(+1, 1)	(0, 1)	$(\pm 2/3, 3)$	RPV [58–60], LQ $[65, 66]$	except for T-I-1-i (and T-II-1)
2-iii-a	$(d\bar{e})(\bar{u})(d)(\bar{u}\bar{e})$	(c)	(+1,8) (-2/3,3)	(0, 8) (0, 1)	(+2/3, 3) (+1/3, 3)	RPV [58-60]	
		N 2	(-2/3.3)	(0,8)	$(\pm 1/3, 3)$	RPV [58–60]	that does not contain
2-iii-b	$(d\bar{e})(d)(\bar{u})(\bar{u}\bar{e})$		(-2/3, 3) (-2/3, 3)	(-1/3, 3) (-1/3, 6)	$(\pm 1/3, 3)$ $(\pm 1/3, 3)$		a coloured mediator
3-i	$(\bar{u}\bar{u})(\bar{e})(\bar{e})(dd)$		(-2/3, 3) (+4/3, 3)	$(\pm 1/3, 3)$	(-2/3, 3)	only with V_{ρ} and V'_{ρ}	—
3-ii	()(-)(-)()		(+4/3,6	(+1/3,6)	(-2/3, 6)	and a mith W	
3-11	$(\bar{u}\bar{u})(d)(d)(\bar{e}\bar{e})$		(+4/3, 3) (+4/3, 6)	(+5/3, 3) (+5/3, 3)	(+2, 1) (+2, 1)	only with V_{ρ}	TII: con he construct of TIC!
3-iii	$(dd)(\bar{u})(\bar{u})(\bar{e}\bar{e})$		(+2/3.3)	(+4/3, 3)	(+2, 1)	only with V_{ρ}	T-I-1-i can be examined at ILC!
4-i	$(d\bar{e})(\bar{u})(\bar{u})(d\bar{e})$	(c)	$(\pm 2/3, \frac{6}{3})$	(+4/3 3) (0,1)	(+2, 1) (+2/3, 3)	RPV [58-60]	 exotic interactions with electron!
		N /	(-2/3, 3)	(0, 8)	(+2/3, 3)	RPV [58-60]	
4-ii-a	$(\bar{u}\bar{u})(d)(\bar{e})(d\bar{e})$		$(\pm 4/3.9)$ $(\pm 4/3.6)$	$(\pm 5/3, 3)$ $(\pm 5/3, 3)$	$(\pm 2/3, 3)$ $(\pm 2/3, 3)$	only with V_{ρ} see Sec. 4 (this work)	
4-ii-b	$(\bar{u}\bar{u})(\bar{e})(d)(d\bar{e})$		$(\pm 4/3, 3)$	$(\pm 1/3, 3)$	(+2/3,3)	only with V_{ρ}	
F :			(+4/3.6)	(+1/3.6)	(+2/3.3)	DDV [20 00]	_
5-i	$(\bar{u}\bar{e})(d)(d)(\bar{u}\bar{e})$		(-1/3, 3) (-1/3, 3)	(0, 1) (0, 8)	(+1/3, 3) (+1/3, 3)	RPV [58–60] RPV [58–60]	
5-ii-a	$(\bar{u}\bar{e})(\bar{u})(\bar{e})(dd)$		(-1/3.3)	$(\pm 1/3, 3)$	(-2/3, 3)	only with V'_{ρ}	
5-ii-b	$(\bar{u}\bar{e})(\bar{e})(\bar{u})(dd)$		(-1/3.9)	(+1/3, 6) (-4/3, 3)	(-2/3, 6) (-2/3, 3)	only with V'_{a}	
0.1.0	(30)(0)(40)		(-1/3.3)	(-4/3, 3)	(-2/3, 6)		

Saitama University d=9 op. : Bridge between neutrino and TeV scale



		Long	Mediat	or $(U(1)_{em})$			
# 1-i	Decomposition $(\bar{u}d)(\bar{e})(\bar{e})(\bar{u}d)$	Range? (a)	$S \text{ or } V_{\rho}$ (+1, 1)	$\frac{\psi}{(0, 1)}$	$\frac{S' \text{ or } V'_{\rho}}{(-1, 1)}$	Models/Refs./Comments Mass mechan., RPV [58–60],	What can we learn from this table?
1-1	(aa)(c)(c)(aa)	(4)	(14,4)	(0, 1)	(1, 1)	LR-symmetric models [39], Mass mechanism with ν_S [61]	If 0n2b conflicts with
						TeV scale seesaw, e.g., $[62, 63]$	II 0II20 contracts with
1-ii-a	$(\bar{u}d)(\bar{u})(d)(\bar{e}\bar{e})$		(+1, 8) (+1, 1)	(0.8) (+5/3.3)	(-1.8) (+2,1)	[64]	cosmological obs.,
1-ii-b	$(\bar{u}d)(d)(\bar{u})(\bar{e}\bar{e})$		(+1,8) (+1,1) (+1,8)	(+5/3, 3) (+4/3, 3) (+4/3, 3)	(+2, 1) (+2, 1) (+2, 1)		It could be a large $d=9$ contribution
2-i-a	$(\bar{u}d)(d)(\bar{e})(\bar{u}\bar{e})$		(+1,1)	(+4/3,3)	$(\pm 1/3, 3)$		
2-i-b	$(\bar{u}d)(\bar{e})(d)(\bar{u}\bar{e})$	(b)	(+1, 8) (+1, 1) (+1, 8)	(+4/3, 3) (0, 1) (0, 8)	(+1/3,3) (+1/3,3) (+1/3,3)	RPV [58–60], LQ [65, 66]	Such a large $d=9$ contribution
2-ii-a	$(\bar{u}d)(\bar{u})(\bar{e})(d\bar{e})$		(+1, 1)	(+5/3,3)	(19/9.9)		should leave the trace in LHC
2-ii-b	$(\bar{u}d)(\bar{e})(\bar{u})(d\bar{e})$	(b)	(+1, 8) (+1, 1)	(+5/3.3) (0,1)	(+2/3.3) (+2/3,3)	RPV [58–60], LQ [65, 66]	except for T-I-1-i (and T-II-1)
2-iii-a	$(d\bar{e})(\bar{u})(d)(\bar{u}\bar{e})$	(c)	(+1,8) (-2/3,3)	(0,8) (0,1)	(+2/3,3) (+1/3,3)	RPV [58–60]	that does not contain
2-iii-b	$(d\bar{e})(d)(\bar{u})(\bar{u}\bar{e})$		(-2/3.3) (-2/3.3)	(0, 8) (-1/3, 3)	$(\pm 1/3, 3)$ $(\pm 1/3, 3)$	RPV [58–60]	a coloured mediator
3-i	$(\bar{u}\bar{u})(\bar{e})(\bar{e})(dd)$		(-2/3, 3) (+4/3, 3)	(-1/3, 6) (+1/3, 3)	(+1/3,3)	only with V_{ρ} and V'_{ρ}	
			(+4/3, 6)	(+1/3,6)	(-2/3, 6)	· •	
3-ii	$(\bar{u}\bar{u})(d)(d)(\bar{e}\bar{e})$		(+4/3, 3) (+4/3, 6)	(+5/3, 3) (+5/3, 3)	(+2, 1) (+2, 1)	only with V_{ρ}	
3-iii	$(dd)(\bar{u})(\bar{u})(\bar{e}\bar{e})$		$(\pm 2/3.3)$	(+4/3.3) (+4/3.3)	(+2, 1) (+2, 1) (+2, 1)	only with V_ρ	T-I-1-i can be examined at ILC!
4-i	$(d\bar{e})(\bar{u})(\bar{u})(d\bar{e})$	(c)	(-2/3.3)	(0,1)	(+2/3, 3)	RPV [58–60]	 exotic interactions with electron!
4-ii-a	$(\bar{u}\bar{u})(d)(\bar{e})(d\bar{e})$		(-2/3, 3) (+4/3, 3)	(0, 8) (+5/3, 3)	(+2/3.3) (+2/3.3)	RPV [58–60] only with V_{ρ}	
			$(\pm 4/3, 6)$	(+5/2.9)	$(\pm 2/3, 3)$	see Sec. 4 (this work)	My last massage.
4-ii-b	$(\bar{u}\bar{u})(\bar{e})(d)(d\bar{e})$		$(+4/3, \frac{3}{3})$ (+4/3, 6)	(+1/3, 3) (+1/3, 6)	(+2/3.3) (+2/3.3)	only with V_{ρ}	My last message:
5-i	$(\bar{u}\bar{e})(d)(d)(\bar{u}\bar{e})$	(c)	(-1/3, 8) (-1/3, 8)	(0, 1) (0, 8)	$(\pm 1/3, 3)$ $(\pm 1/3, 3)$	RPV [58–60] RPV [58–60]	0n2b exps, cosmological obs,
5-ii-a	$(\bar{u}\bar{e})(\bar{u})(\bar{e})(dd)$		(-1/3.3)	$(\pm 1/3, 3)$ $(\pm 1/3, 6)$	(-2/3, 3) (-2/3, 6)	only with V'_{ρ}	LHC and ILC
5-ii-b	$(\bar{u}\bar{e})(\bar{e})(\bar{u})(dd)$		(-1/2.9	(-4/3, 3)	(-2/3, 3)	only with V'_{ρ}	
			(-1/3.3)	(-4/3.3)	(-2/3.6)	-	are complementary!



Back-up

New Physics (*d=9*) contributions in neutrinoless double beta decay (0n2b)

In proper disc under disc seeking a relation to the models at the TeV scale

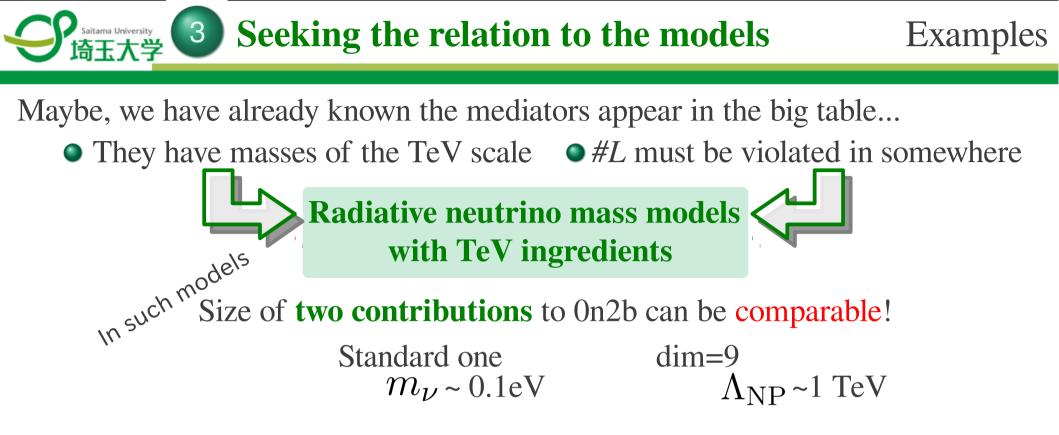
TeV scale models with $LNV \rightarrow Models$ for radiative neutrino masses

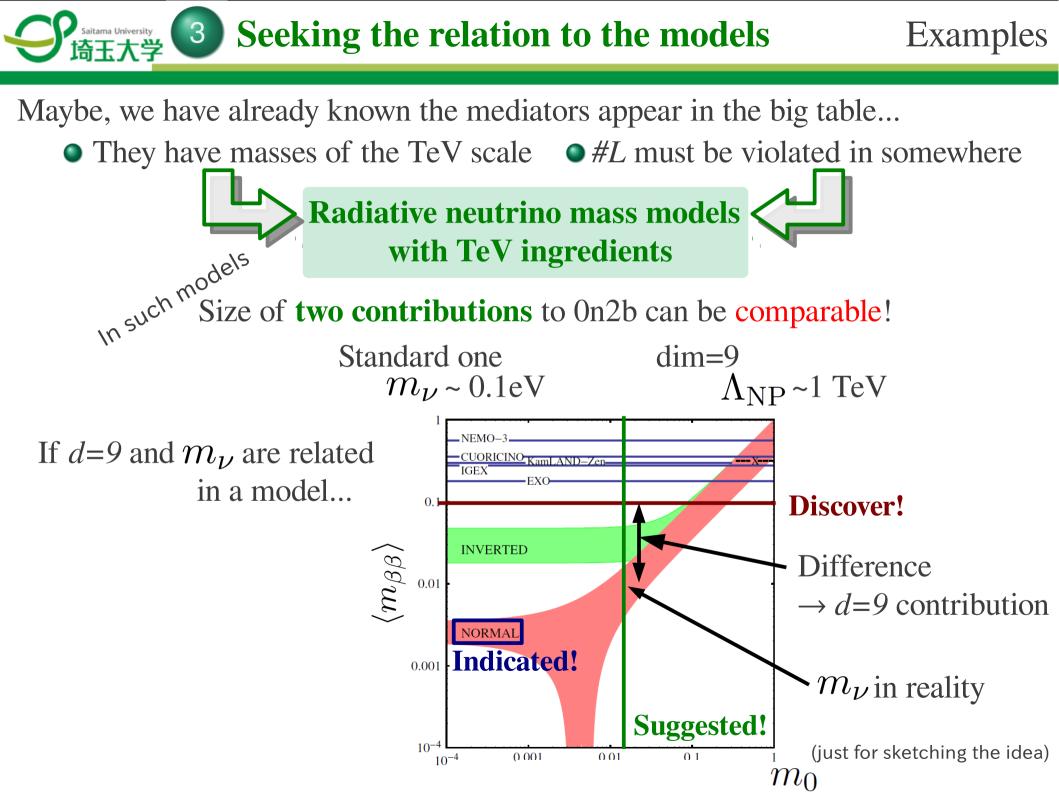
Seeking the relation to the models
 協
 広
 大
学

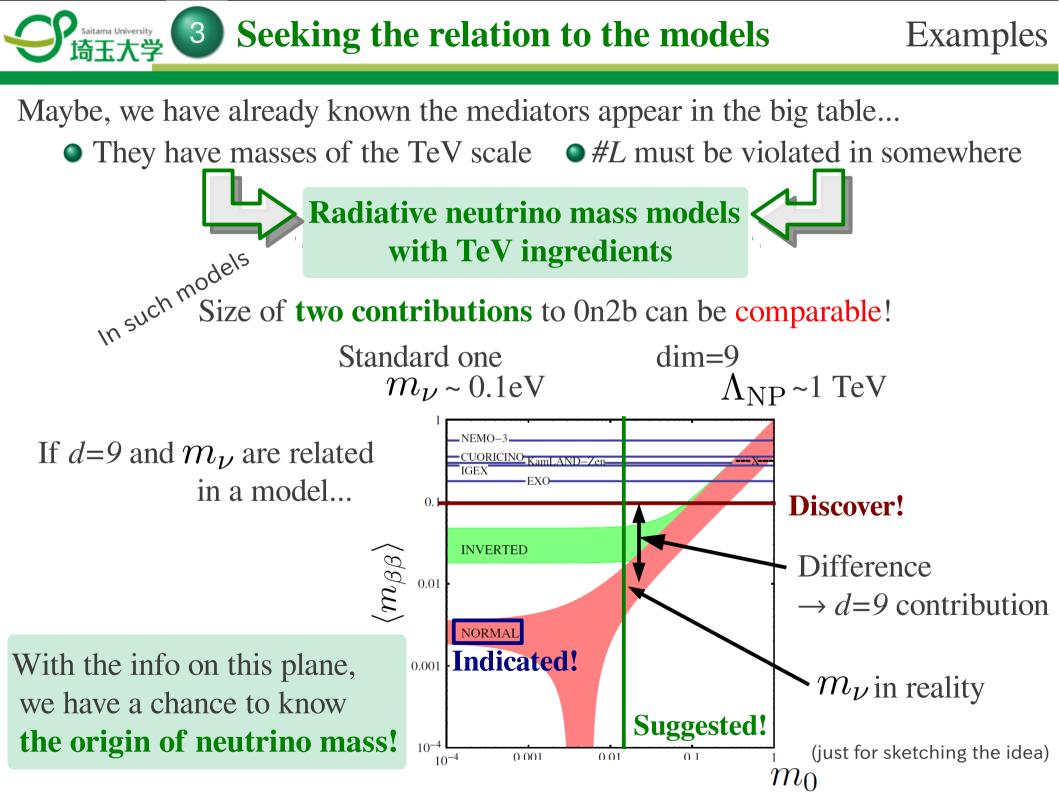
Maybe, we have already known the mediators appear in the big table...

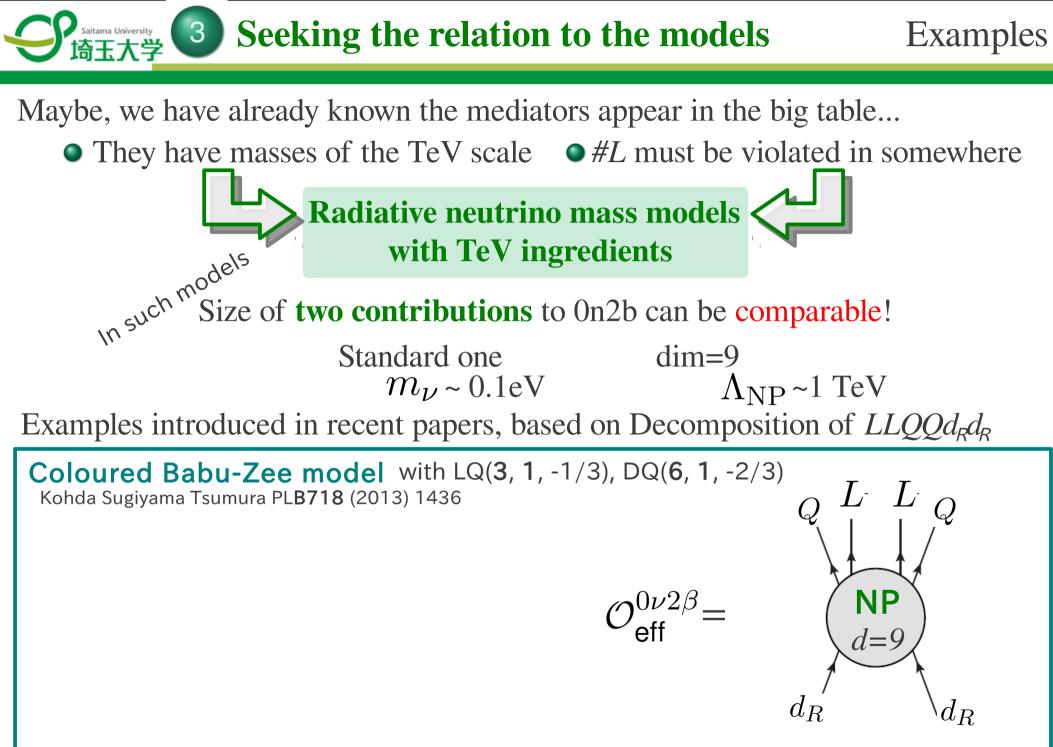
• They have masses of the TeV scale • #L must be violated in somewhere

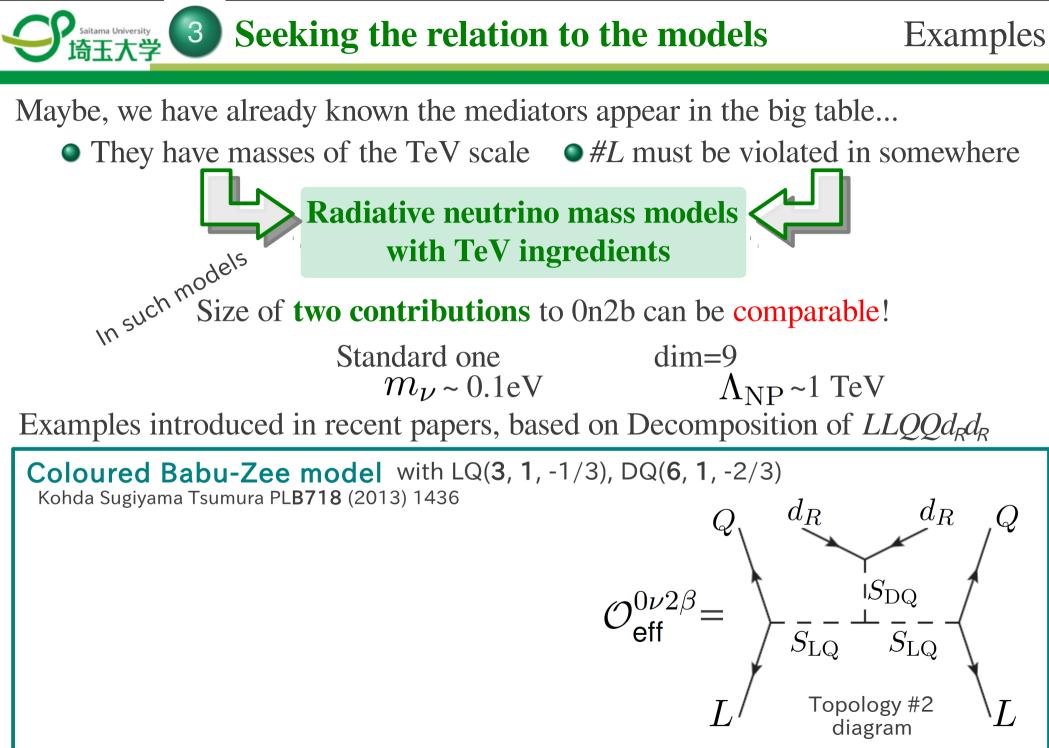
Examples

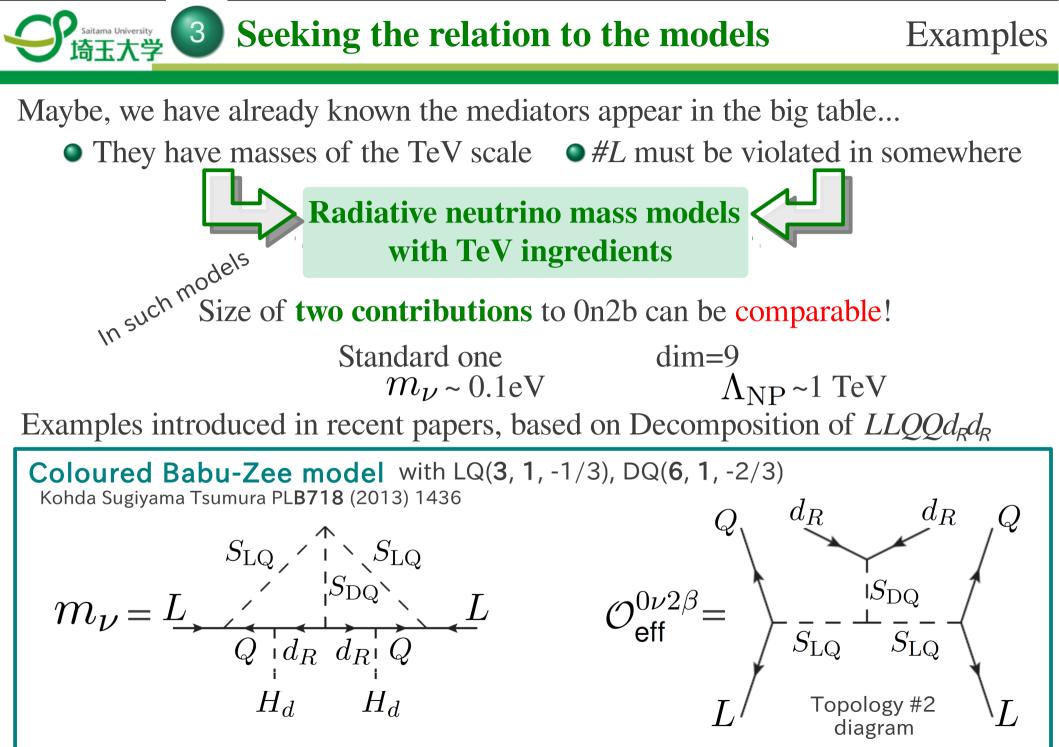


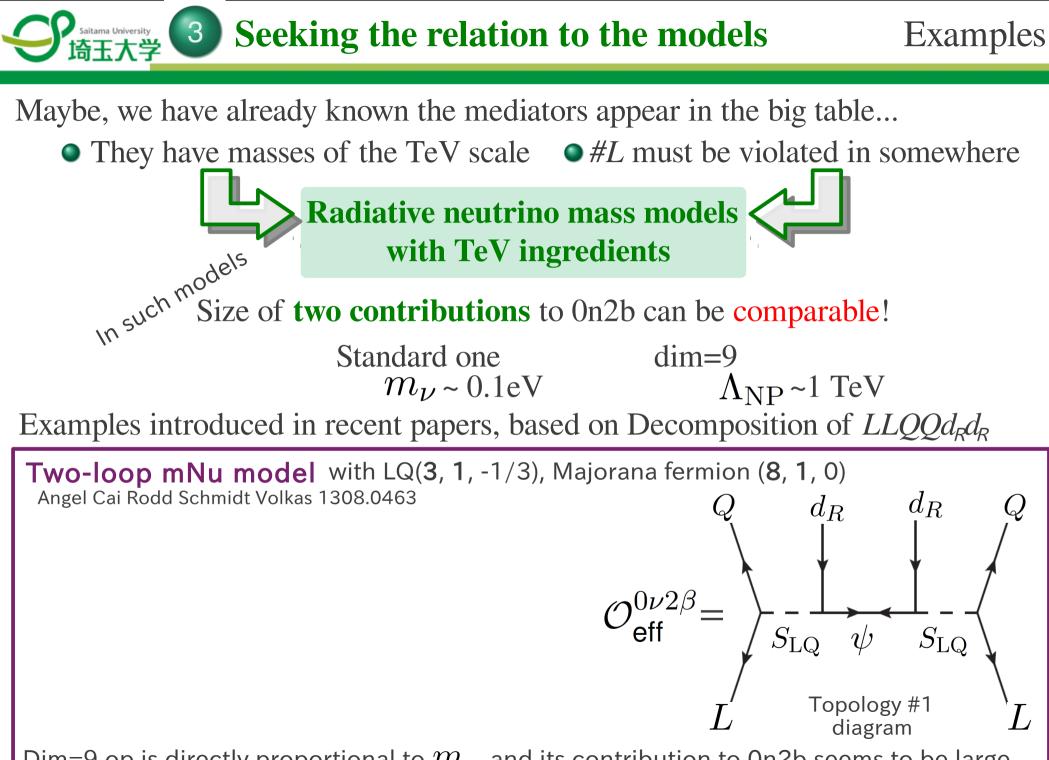


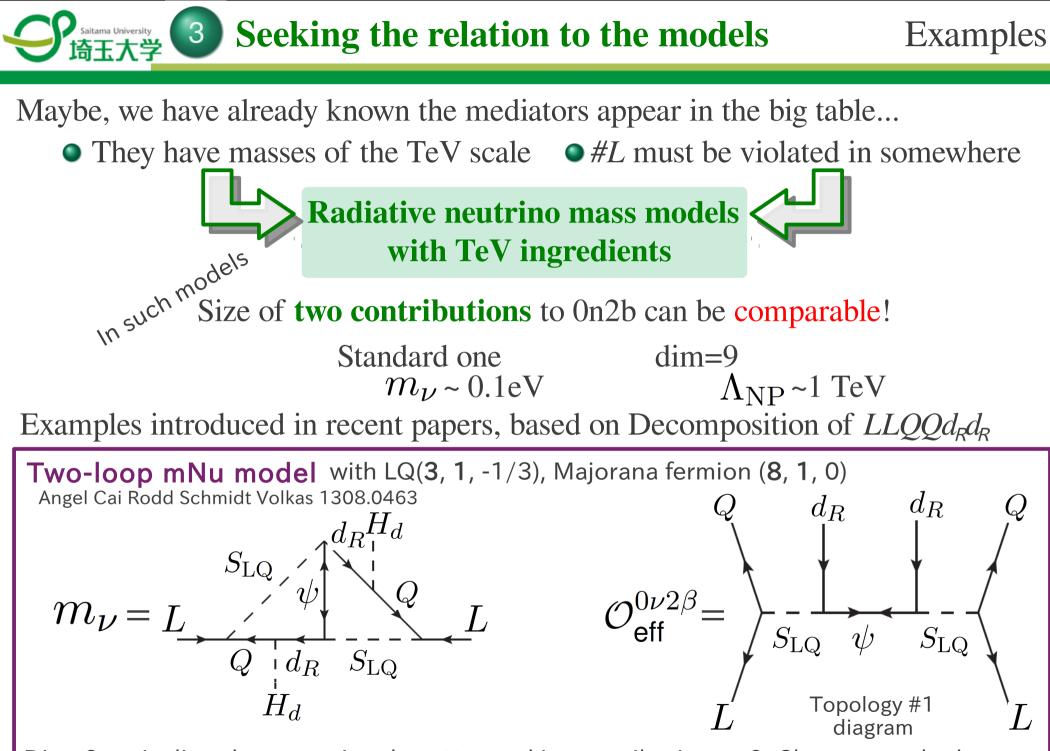


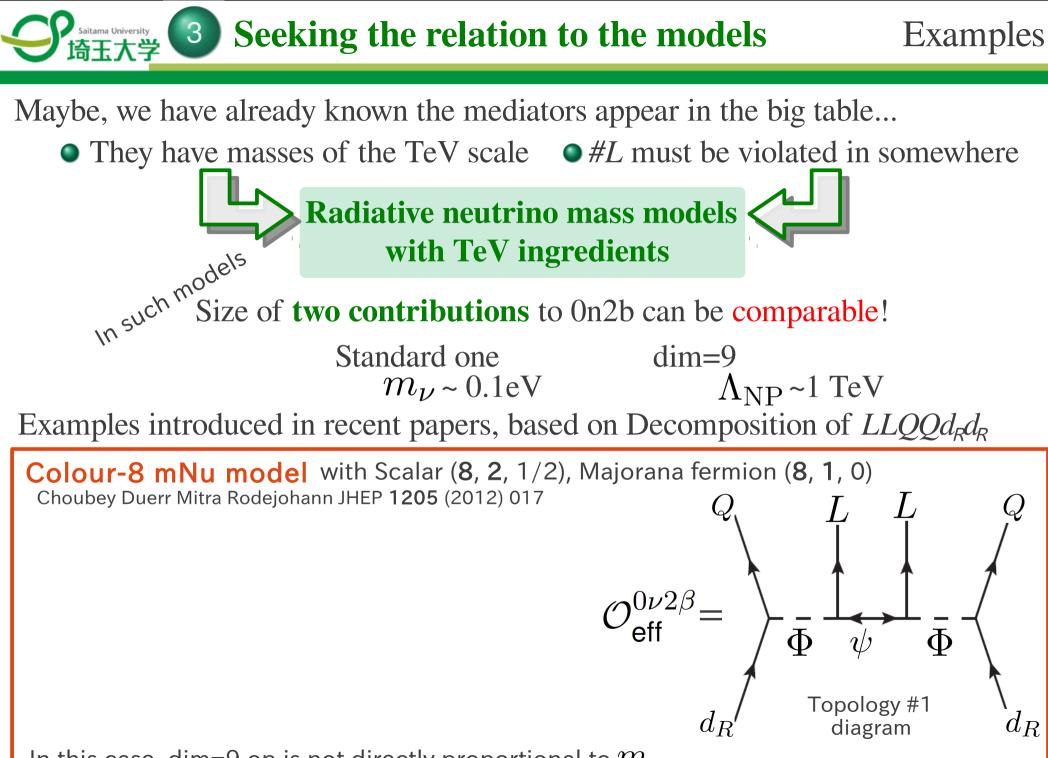




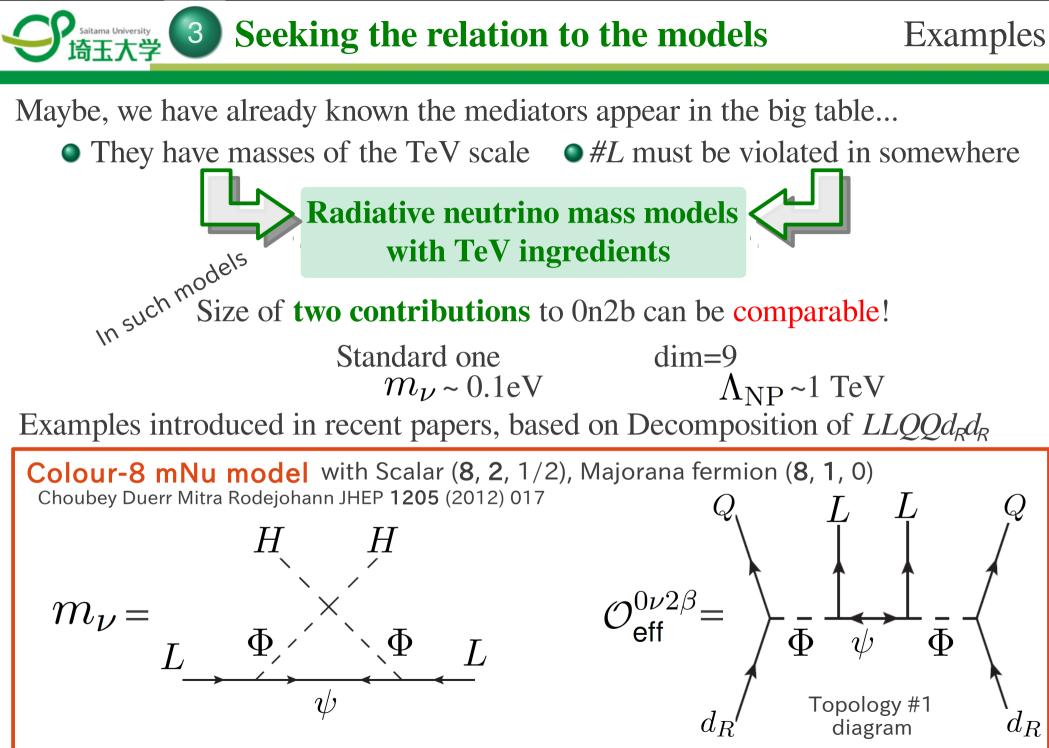




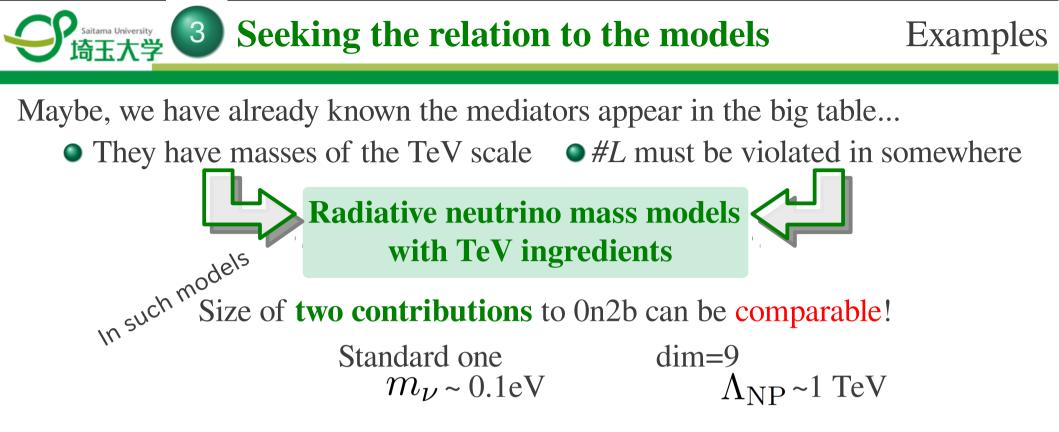




In this case, dim=9 op is not directly proportional to $m_{
u}$



In this case, dim=9 op is not directly proportional to $m_{
u}$



Neutrino mass models based on the effective operator approach

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Babu Leung Nucl Phys B619 (2001) 667

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and more...