Charged Lepton Flavor Violating Processes and Scalar Leptoquark Decay Branching Ratios in the Colored Zee-Babu Model

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IBS-KIAS Workshop on Particle Physics and Cosmology
High-1, Korea, Feb. 5-10, 2017

Neutrino mass generation

- $m_\nu \neq 0$. Needs to go beyond the SM
- Key for Majorana ν: Weinberg operator; the only dim-5 SM inv. eff. operator, $L \neq 0$, $B = 0$.

$$\frac{(LH)^2}{\Lambda}$$

- dilepton $L \neq 0, B = 0$: see-saw 1,2,3.
- Leptoquark (LQ) $L \neq 0$, $B \neq 0$ is also a legitimate candidate
- To have $B = 0$, either (1) 2 LQs with $L_1 : L_2 \neq B_1 : B_2$ or (2)LQ + Di-quark (DQ) with $L = 0, B \neq 0$.
- We go for 1LQ+1DQ and address the connection between M_ν and experimental signatures.

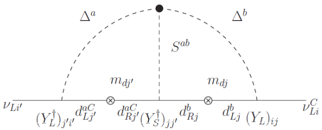
LQ DQ mass bounds

- LQ mass direct search bound (95% CL., GeV, $\beta = 1(0.5)$). LQ decay BR into lq and νq denoted as β and $(1-\beta)$, and λ: Yukawa coupling for $lq\Delta$. The LQ is assumed to decay into leptons within only one specific generation.

	1st gen.	2nd gen.	3rd gen.
CMS	1005(845)	1070(785)	634
ATLAS	660(607)	685(594)	534
ZEUS	699($\lambda = 0.3$)		

- For an E_6-type DQ, CMS study gives $m_S > 6\mathrm{TeV}$.
- Very sensitive to the assumptions of decay BR as well as the flavor dependant coupling strengthes.
- We take $m_S = 7\,\mathrm{TeV}$ and $m_\Delta = 1\,\mathrm{TeV}$ as the benchmark values

Colored Zee-Babu Model



- Relevant Lagrangian for $\Delta(3, 1, -1/3)$ and $S(6, 1, -2/3)$:

$$-\left[\overline{L_i^C}(Y_L)_{ij} i\sigma_2 Q_j + \overline{(\ell_{Ri})^C}(Y_R)_{ij} u_{Rj}\right]\Delta^* - \overline{(d_{Ri})^C}(Y_s)_{ij} d_{Rj} S^*$$
$$+ y_{ij}^{\Delta}\overline{(u_{Ri})^C} d_{Rj}\Delta + \mu\Delta^*\Delta^* S + h.c.$$

  i, j: flavor indices, $SU(3)$ indices suppressed. Y_S: symmetric in flavor

- Proton decay $\propto (Y_{L/R} y_{11}^{\Delta})^2$ can be evaded. (1)A very small y_{11}^{Δ}. (2) y^{Δ} can be eliminated by for example some Z_2 parities $\{-, -, +, +, +, -, +\}$ assigned to $\{L, l_R, Q, u_R, d_R, \Delta, S\}$ respectively.

Colored Zee-Babu Model

$$(M_\nu)_{ii'} = 24\mu (Y_L)_{ij} m_{dj} I_{jj'} (Y_s^\dagger)_{jj'} m_{dj'} (Y_L^T)_{j'i'}\,,$$
$$I_{jj'} = \int \frac{d^4k_1}{(2\pi)^4}\frac{d^4k_2}{(2\pi)^4}\frac{1}{(k_1^2-m_{dj}^2)}\frac{1}{(k_1^2-m_\Delta^2)}\frac{1}{(k_2^2-m_{dj'}^2)}\frac{1}{(k_2^2-m_\Delta^2)}\frac{1}{(k_1+k_2)^2-m_S^2}$$
$$I_{jj'} \simeq I_\nu \equiv \frac{1}{(4\pi)^4}\frac{1}{M^2}\frac{\pi^2}{3}\tilde{I}\left(\frac{m_S^2}{m_\Delta^2}\right), \qquad M \equiv \max(m_\Delta, m_S)$$
$$\tilde{I}(x) = \begin{cases} 1+\frac{3}{\pi^2}(\ln^2 x - 1) & \text{for } x \gg 1\,, \\ 1 & \text{for } x \to 0\,. \end{cases}$$

- Write $M_\nu = Y_L \omega Y_L^T$, $\omega_{jj'} \equiv 24\mu I_\nu m_j m_{j'} (Y_s^\dagger)_{jj'}$.
- Qualitatively,

$$m_\nu \sim \frac{\mu m_b^2 Y_L^2 Y_S}{32\pi^2 M^2} \sim 0.06\text{eV} \times \left(\frac{Y_L^2 Y_S}{10^{-6}}\right) \times \left(\frac{\text{TeV}}{M^2/\mu}\right)\,.$$

  2-loop, typical values $Y_L, Y_S \sim 0.01$ and $\mu, M \sim 1$ TeV, sub-eV m_ν w.o. excessively fine tuning.
- scaling: $Y_L^2 Y_S =$ const, trivial but useful.

Iterative solution for Y_L

- Working assumption:Democratic Y_S (easy in extra-dim).
- Since $m_b \gg m_s \gg m_d$

$$\omega^{(0)} = 24\mu I_\nu \times \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & m_b m_s (Y_S)^*_{23} \\ 0 & m_b m_s (Y_S)^*_{23} & m_b^2 (Y_S)^*_{33} \end{pmatrix}$$

(1) $\mathcal{O}\left(\frac{\omega^{(1)}}{\omega^{(0)}}\right) \sim \mathcal{O}\left(\frac{m_d}{m_b}\right)$. (2)$M_\nu^{(0)} = Y_L \omega^{(0)} Y_L^T$ is of rank-2,
(3) det $M_\nu^{(0)} = 0$. (4) Lightest one $\sim (m_d/m_b) \times \max(m_\nu)$,
(5) quasi-degenerate disfavored.

- once $\{\mu, m_S, m_\Delta, (Y_S)_{13,23,33}, (Y_L)_{13}\}$, Y_L can be determined

$$(Y_L)^{(0)}_{23} = \frac{(Y_L)_{13}}{(M_\nu)_{11}} \left[(M_\nu)_{12} \pm \sqrt{(M_\nu)^2_{12} - (M_\nu)_{11}(M_\nu)_{22}} \right],$$

$$(Y_L)^{(0)}_{33} = \frac{(Y_L)_{13}}{(M_\nu)_{11}} \left[(M_\nu)_{13} \pm \sqrt{(M_\nu)^2_{13} - (M_\nu)_{11}(M_\nu)_{33}} \right],$$

$$(Y_L)^{(0)}_{12} = \frac{(M_\nu)_{11} - B_\nu m_b^2 (Y_L)^2_{13} (Y_S)^{(0)}_{33}}{2 B_\nu m_b m_s (Y_L)_{13} (Y_S)^{(0)}_{23}},$$

$$(Y_L)^{(0)}_{22} = \frac{(M_\nu)_{22} - B_\nu m_b^2 (Y_L)^2_{23} (Y_S)^{(0)}_{33}}{2 B_\nu m_b m_s (Y_L)_{23} (Y_S)^{(0)}_{23}},$$

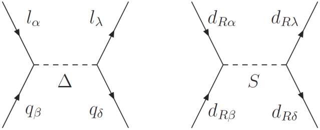
$$(Y_L)^{(0)}_{32} = \frac{(M_\nu)_{33} - B_\nu m_b^2 (Y_L)^2_{33} (Y_S)^{(0)}_{33}}{2 B_\nu m_b m_s (Y_L)_{33} (Y_S)^{(0)}_{23}},$$

$$(Y_L)^{(1)}_{11} = -\frac{m_s}{m_d} \frac{\delta_{23}}{(Y_S)_{13}} (Y_L)^{(0)}_{12} - \frac{m_b}{2m_d} \frac{\delta_{33}}{(Y_S)_{13}} (Y_L)_{13},$$

$$(Y_L)^{(1)}_{21} = -\frac{m_s}{m_d} \frac{\delta_{23}}{(Y_S)_{13}} (Y_L)^{(0)}_{22} - \frac{m_b}{2m_d} \frac{\delta_{33}}{(Y_S)_{13}} (Y_L)^{(0)}_{23},$$

$$(Y_L)^{(1)}_{31} = -\frac{m_s}{m_d} \frac{\delta_{23}}{(Y_S)_{13}} (Y_L)^{(0)}_{32} - \frac{m_b}{2m_d} \frac{\delta_{33}}{(Y_S)_{13}} (Y_L)^{(0)}_{33}.$$

Tree-level FV



$$
\begin{aligned}
\triangle\mathcal{L}_{\text{eff}} = & \left[\frac{(Y_L^*)_{ml}(Y_R)_{ij}}{2m_\Delta^2}\left(-\overline{\nu_m}\mathbb{P}_R\ell_i\cdot\overline{d_l^a}\mathbb{P}_R u_j^a+\overline{\ell_m}\mathbb{P}_R\ell_i\cdot\overline{u_l^a}\mathbb{P}_R u_j^a\right)+h.c.\right] \\
& -\left[\frac{(Y_L^*)_{ml}(Y_L)_{ij}}{2m_\Delta^2}\overline{\nu_m}\gamma^\mu\mathbb{P}_L\ell_i\cdot\overline{d_l^a}\gamma_\mu\mathbb{P}_L u_j^a+h.c.\right] \\
& +\frac{(Y_L^*)_{ml}(Y_L)_{ij}}{2m_\Delta^2}\left(\overline{\nu_m}\gamma^\mu\mathbb{P}_L\nu_i\cdot\overline{d_l^a}\gamma_\mu\mathbb{P}_L d_j^a+\overline{\ell_m}\gamma^\mu\mathbb{P}_L\ell_i\cdot\overline{u_l^a}\gamma_\mu\mathbb{P}_L u_j^a\right) \\
& +\frac{(Y_R^*)_{ml}(Y_R)_{ij}}{2m_\Delta^2}\overline{\ell_m}\gamma^\mu\mathbb{P}_R\ell_i\cdot\overline{u_l^a}\gamma_\mu\mathbb{P}_R u_j^a \\
& +\left[\frac{(Y_L^*)_{ml}(Y_R)_{ij}}{8m_\Delta^2}\left(\overline{\nu_{Lm}}\sigma^{\mu\nu}\mathbb{P}_R\ell_i\cdot\overline{d_l^a}\sigma_{\mu\nu}\mathbb{P}_R u_j^a-\overline{\ell_{Lm}}\sigma^{\mu\nu}\mathbb{P}_R\ell_i\cdot\overline{u_l^a}\sigma_{\mu\nu}\mathbb{P}_R u_j^a\right)+h.c.\right] \\
& +\frac{(Y_s)_{ij}(Y_s^\dagger)_{lm}}{2m_S^2}\left[\overline{d_m^a}\gamma^\mu\mathbb{P}_R d_i^a\right]\left[\overline{d_l^b}\gamma_\mu\mathbb{P}_R d_j^b\right]
\end{aligned}
\quad (3.
$$

- m_ν requires nonzero Y_L.
- Minimal flavor violation and $Y_R = 0$
- from $K - \bar{K}$ mixing, $|Y_S| < 9 \times 10^{-3} \times (m_S/7\mathrm{TeV})$.

$$|(Y_S)_{11}(Y_S)^*_{22}| < 1.92 \times 10^{-6} \times (m_S/\mathrm{TeV})^2$$

Some considerations for $Y_R = 0$

- UV: (1) extra-dim (2) U(1) symmetry
- pheno side: If $Y_R \neq 0$, the 1-loop EDM

$$d_\ell \sim \frac{N_c}{16\pi^2}\frac{m_t}{m_\Delta^2}\mathbf{Im}[Y_L Y_R^*]$$

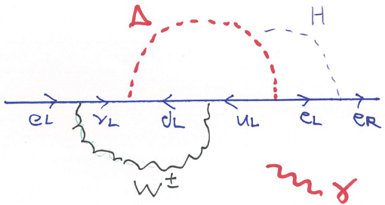
  For $m_\Delta = 1\mathrm{TeV}$, $|Y_L| \sim |Y_R| \sim 0.01$, CP phase of order one, the typical electron EDM is around 10^{-24} e-cm (currently, $|d_e| < 8.7 \times 10^{-29} e$-cm.)

- Like in many models, a pressing theoretical issue. A plain solution: $m_\Delta \gtrsim 100\mathrm{TeV}$ but the phenomenology..

Some considerations for $Y_R = 0$

- If $Y_R = 0$, EDM at 3-loop level.

$$d_\ell \sim \frac{\alpha N_c}{(16\pi)^3} \frac{m_\ell}{m_\Delta^2} \mathbf{Im} \left[(Y_L)_{\ell k} V_{kj}^{CKM} (Y_L^\dagger)_{ji} U_{i\ell}^{PMNS} \right] .$$



- If $Y_L \sim 0.01$, $m_\Delta = 1\mathrm{TeV}$, $\sim \mathcal{O}(1)$ CP phase, $|d_e| \lesssim 10^{-37}$ e-cm. Slightly larger than SM d_e.
- once d_e was measured, either the $Y_R = 0$ assumption with $m_\Delta \sim \mathcal{O}(\mathrm{TeV})$ is out or more NP beyond the cZBM.

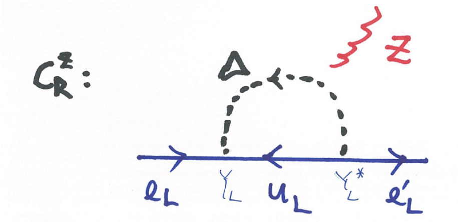
$\mu \to e\gamma$

- $$\mathcal{L} \supset \frac{1}{2}\bar{\ell}' \left(d_L^{ll'} \mathbb{P}_L + d_R^{ll'} \mathbb{P}_R \right) \sigma^{\mu\nu} \ell F_{\mu\nu} + h.c.$$
$$\Gamma(\ell \to \ell' \gamma) \simeq \frac{m_\ell^3}{16\pi}(|d_L^{ll'}|^2 + |d_R^{ll'}|^2)$$
- A straightforward calculation yields
$$d_R^{ll'} = -\frac{N_c e}{16\pi^2 m_\Delta^2} \left[\left(m_{l'} (Y_R^*)_{l'q} (Y_R^T)_{ql} \right. \right.$$
$$\left. \left. + m_l (Y_L^*)_{l'q} (Y_L^T)_{ql} \right) \mathcal{F}_1(r_q) + m_q (Y_L^*)_{l'q} (Y_R^T)_{ql} \mathcal{F}_2(r_q) \right] ,$$
$q = u, c, t$, $r_q \equiv m_q^2 / m_\Delta^2$. $d_L^{ll'}$ by simply $Y_L \leftrightarrow Y_R$. The loop functions have limit $\mathcal{F}_1(x) \to 1/12$ and $\mathcal{F}_2(x) \to 7/6 + 2 \ln x/3$ when $x \to 0$.
- In general, $Y_R = 0$ also minimizes 1-loop cLFV.

- The most general $Z \to \bar{l}l'$ amplitude:

$$i\mathcal{M} = ie\bar{u}(p')\left[(c_R^Z \mathbb{P}_R + c_L^Z \mathbb{P}_L)\left(-g_{\mu\nu} + \frac{q_\mu q_\nu}{m_Z^2}\right)\gamma^\nu + \frac{1}{m_Z}\left(d_L^Z \mathbb{P}_L + d_R^Z \mathbb{P}_R\right)(i\sigma_{\mu\nu}q^\nu)\right] v(-p)\epsilon^\mu(q)\,,$$

  (c, d: dimensionless, projection on anti-particle.)
- only c_R^Z is kept in the study.



- $c_R^Z \sim Y_L^2 (M_Z/m_\Delta)^2$. $d/c_R^Z \sim (m_l/M_Z)$ and $c_L^Z/c_R^Z \sim (m_l/M_Z)^2$

$Z \to ll'$

- final result in numerical form:

$$\mathcal{B}(Z \to \bar{\ell}\ell') \simeq 1.46\times10^{-7} \left| \sum_{q=u,c,t} a_q^Z (Y_L)^*_{\ell' q} (Y_L)_{\ell q} \right|^2 \times \left(\frac{\mathrm{TeV}}{m_\Delta} \right)^4 ,$$

  where $a_u^Z = a_c^Z \simeq -0.125 - 0.077\mathbf{i} = -0.1468 e^{i31.63^\circ}$ and $a_t^Z = 1$.
- The imaginary part of $a_{u,c}^Z$ comes from the on-shell light quarks in the Z decay. CP violation is observable.

Numerical study

- once $\{\mu, m_S, m_\Delta, (Y_S)_{13,23,33}\}$ plus anyone of Y_L's are fixed, all remaining 8 Y_L's iteratively determined from m_ν matrix and U_{PMNS}. $m_\Delta = 1\mathrm{TeV}$ and $m_S = 7\mathrm{TeV}$. For each config. μ randomly chosen from $[0.1, 1]\mathrm{TeV}$, $sin^2\theta_{12,13,23}$, Dirac phase δ_{cp}: 1 sigma from global fit
- (1)All $|Y_L|$'s are less than one. (2) all TLFV (3) 1-loop cLFV :

$\mathcal{B}(\mu^+ \to e^+\gamma)$	$< 5.7 \times 10^{-13}$, 90% C.L.
$\mathcal{B}(\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$, 90% C.L.
$\mathcal{B}(\tau \to e\gamma)$	$< 3.3 \times 10^{-8}$, 90% C.L.
$\mathcal{B}^Z_{\tau\mu}$	$< 1.2 \times 10^{-5}$, 95% C.L.
$\mathcal{B}^Z_{\tau e}$	$< 9.8 \times 10^{-6}$, 95% C.L.
$\mathcal{B}^Z_{\mu e}$	$< 7.5 \times 10^{-7}$, 95% C.L.

4Fermi bound

- Dimensionless parameter:

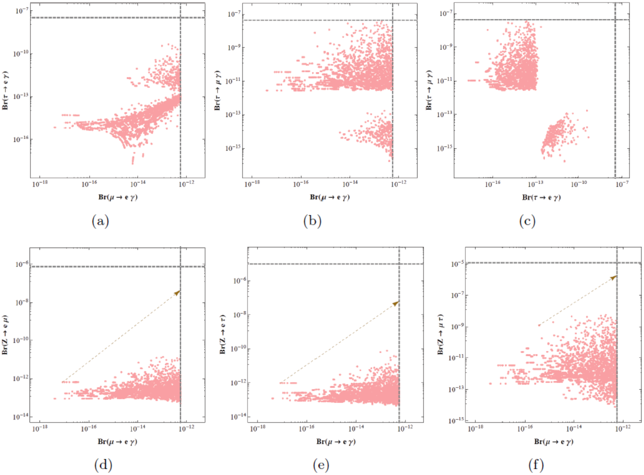
$$\epsilon_{ijkn} \equiv \frac{(Y_L)_{ik}(Y_L)_{jn}}{4\sqrt{2}G_F m_\Delta^2},$$

- Comprehensive study: 1008.0280

ϵ_{ee11}	10^{-3}	ϵ_{ee12}	9.4×10^{-6}	ϵ_{ee13}	3.9×10^{-3}
ϵ_{ee22}	10^{-2}	ϵ_{ee23}	10^{-3}	ϵ_{ee33}	9.2×10^{-2}
$\epsilon_{\mu\mu11}$	7.3×10^{-3}	$\epsilon_{\mu\mu12}$	9.4×10^{-6}	$\epsilon_{\mu\mu13}$	3.9×10^{-3}
$\epsilon_{\mu\mu22}$	1.2×10^{-1}	$\epsilon_{\mu\mu23}$	10^{-3}	$\epsilon_{\mu\mu33}$	6.1×10^{-2}
$\epsilon_{\tau\tau11}$	10^{-2}	$\epsilon_{\tau\tau12}$	9.4×10^{-6}	$\epsilon_{\tau\tau13}$	3.9×10^{-3}
$\epsilon_{\tau\tau22}$	1.2×10^{-1}	$\epsilon_{\tau\tau23}$	10^{-3}	$\epsilon_{\tau\tau33}$	8.6×10^{-2}
$\epsilon_{e\mu11}$	8.5×10^{-7}	$\epsilon_{e\mu12}$	9.4×10^{-6}	$\epsilon_{e\mu13}$	3.9×10^{-3}
$\epsilon_{e\mu21}$	9.4×10^{-6}	$\epsilon_{e\mu22}$	0.24	$\epsilon_{e\mu23}$	10^{-3}
$\epsilon_{e\mu31}$	3.9×10^{-3}	$\epsilon_{e\mu32}$	10^{-3}	$\epsilon_{e\mu33}$	6.6×10^{-2}
$\epsilon_{e\tau11}$	8.4×10^{-4}	$\epsilon_{e\tau12}$	9.4×10^{-6}	$\epsilon_{e\tau13}$	3.9×10^{-3}
$\epsilon_{e\tau21}$	9.4×10^{-6}	$\epsilon_{e\tau22}$	0.24	$\epsilon_{e\tau23}$	10^{-3}
$\epsilon_{e\tau31}$	3.9×10^{-3}	$\epsilon_{e\tau32}$	10^{-3}	$\epsilon_{e\tau33}$	0.2
$\epsilon_{\mu\tau11}$	9.4×10^{-4}	$\epsilon_{\mu\tau12}$	9.4×10^{-6}	$\epsilon_{\mu\tau13}$	3.9×10^{-3}
$\epsilon_{\mu\tau21}$	9.4×10^{-6}	$\epsilon_{\mu\tau22}$	0.24	$\epsilon_{\mu\tau23}$	10^{-3}
$\epsilon_{\mu\tau31}$	3.9×10^{-3}	$\epsilon_{\mu\tau32}$	10^{-3}	$\epsilon_{\mu\tau33}$	1

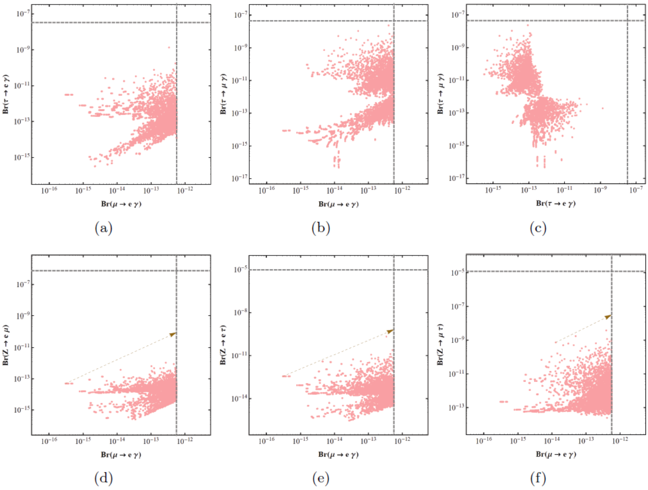
cLFV for IH

$m_\Delta = 1\mathrm{TeV}$ and $|(Y_S)_{33}| = 0.0097$. Dashed lines: current limits at 90%C.L. If $Y_S \to Y_S/\lambda$, $BR \to \lambda^2 BR$.



cLFV for NH

$m_\Delta = 1\mathrm{TeV}$ and $|(Y_S)_{33}| = 0.0097$. Dashed lines: current limits at 90%C.L. If $Y_S \to Y_S/\lambda$, $BR \to \lambda^2 BR$.



Predictions

- $$\mathcal{B}^Z_{\ell\ell'} \equiv \mathcal{B}(Z \to \bar{\ell}\ell') + \mathcal{B}(Z \to \ell\bar{\ell}')$$
  $$\eta_{\ell\ell'} \equiv \mathcal{B}(Z \to \bar{\ell}\ell') - \mathcal{B}(Z \to \bar{\ell}'\ell)\,.$$
- Interesting at Z-factory $\sim 10^{12-13}$ per year. [NH(IH)]

	lower bounds	upper bounds (for $Y_R = 0$)
$\mathcal{B}(\mu \to e\gamma)$	3.05×10^{-16} (3.98×10^{-18})	$5.7(5.7) \times 10^{-13}$
$\mathcal{B}(\tau \to e\gamma)$	3.16×10^{-16} (2.03×10^{-18})	$2.3(0.51) \times 10^{-9}$
$\mathcal{B}(\tau \to \mu\gamma)$	4.67×10^{-17} (1.68×10^{-16})	$3.4(2.8) \times 10^{-8}$
$\mathcal{B}^Z_{e\mu}$	2.5×10^{-16} (4.9×10^{-14})	$2.2(8.7) \times 10^{-11}$
$\mathcal{B}^Z_{e\tau}$	2.9×10^{-16} (4.6×10^{-14})	$3.6(1.0) \times 10^{-10}$
$\mathcal{B}^Z_{\mu\tau}$	2.5×10^{-14} (7.8×10^{-15})	$5.5(4.5) \times 10^{-9}$
$\eta_{\mu e}$	${}^{+.68}_{-.67}\left({}^{+2.1}_{-.97}\right) \times 10^{-13}$	${}^{+2.6}_{-5.4}\left({}^{+9.3}_{-8.1}\right) \times 10^{-13}$
$\eta_{\tau e}$	${}^{+2.4}_{-.20}\left({}^{+.20}_{-1.2}\right) \times 10^{-12}$	${}^{+2.3}_{-.56}\left({}^{+.22}_{-.10}\right) \times 10^{-11}$
$\eta_{\tau\mu}$	${}^{+2.3}_{-.78}\left({}^{+1.3}_{-1.3}\right) \times 10^{-11}$	${}^{+3.7}_{-8.1}\left({}^{+3.0}_{-3.1}\right) \times 10^{-11}$

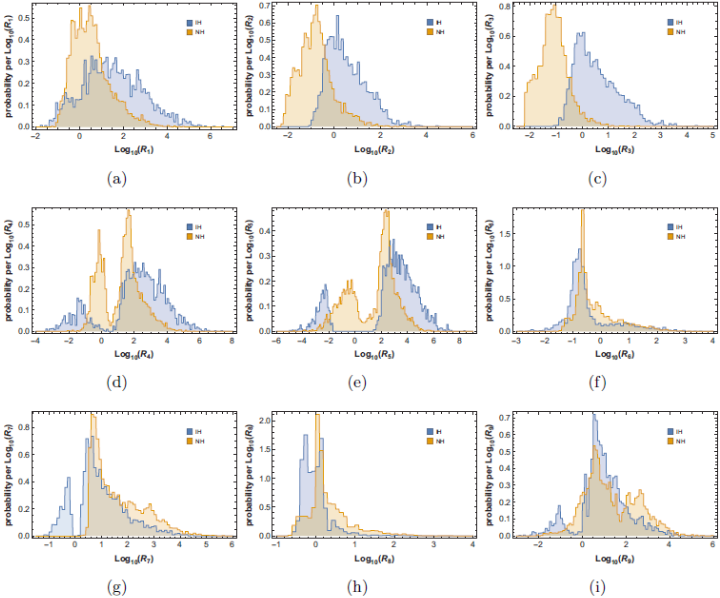
Double Ratios

- Double ratios are useful .
- Neutrino mass hierarchy can be determined if meet any of the following

Double Ratio	IH	NH
$R_1 \equiv \mathcal{B}^Z_{\mu\tau}/\mathcal{B}(\mu \to e\gamma)$	$R_1 > 10^4$ or $R_1 < 0.1$	N.A.
$R_2 \equiv \mathcal{B}^Z_{e\tau}/\mathcal{B}(\mu \to e\gamma)$	$R_2 > 10^3$	$R_2 < 0.1$
$R_3 \equiv \mathcal{B}^Z_{e\mu}/\mathcal{B}(\mu \to e\gamma)$	$R_3 > 10^2$	$R_3 < 0.1$
$R_4 \equiv \mathcal{B}(\tau \to \mu\gamma)/\mathcal{B}(\mu \to e\gamma)$	$R_4 > 10^6$	$R_4 < 0.003$
$R_5 \equiv \mathcal{B}(\tau \to \mu\gamma)/\mathcal{B}(\tau \to e\gamma)$	N.A.	$0.03 < R_5 < 30$
$R_6 \equiv \mathcal{B}(\tau \to e\gamma)/\mathcal{B}(\mu \to e\gamma)$	$R_6 < 0.03$	N.A.
$R_7 \equiv \mathcal{B}^Z_{\mu\tau}/\mathcal{B}^Z_{\mu e}$	$R_7 < 1.0$	$R_7 > 3 \times 10^4$
$R_8 \equiv \mathcal{B}^Z_{e\tau}/\mathcal{B}^Z_{e\mu}$	N.A.	$R_8 > 10^2$
$R_9 \equiv \mathcal{B}^Z_{\tau\mu}/\mathcal{B}^Z_{\tau e}$	$R_9 < 0.01$	$R_9 > 3 \times 10^4$

- R_5(NH) and R_7(IH) look promising.

Double Ratios



LQ decay BRs

- IH:
  (1) $B_e^\Delta \sim 1.0$ or (2) $B_\mu^\Delta \sim 55\%$ and $B_\tau^\Delta \sim 45\%$.
- NH:
  $0.7 \lesssim B_\mu^\Delta + B_\tau^\Delta \lesssim 1.0$ and $0.2 \lesssim B_\tau^\Delta \lesssim 0.8$. In other words, $B_e^\Delta \lesssim 0.3$
- Current direct search assumptions are not founded.

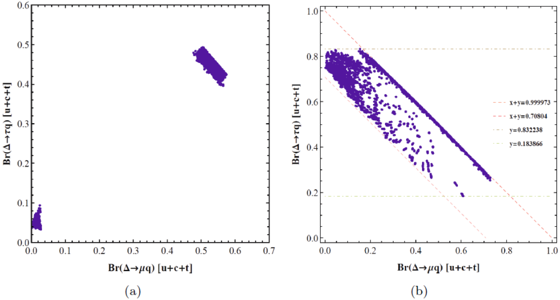


Figure 7. LQ decay branching ratios for (a) IH, (b) NH.

Summery

- Working assumption: democratic Y_S, $Y_R = 0$, Y_L determined by m_ν
- interesting lower bounds on cLFV (Z-factory)
- double ratios and nu mass hierarchy
- definite LQ decay BRs.