Collider Probes of Gauged lepton Symmetry

John N Ng

Triumf and Univ of British Columbia
Vancouver,B.C.
Canada

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What is lepton number?

- It is a quantum number assigned to colorless fermions in the SM.
- e,μ, τ and their associated neutrinos are given lepton number $\ell = 1$.
- The colored quarks have $\ell = 0$.
- Where this comes from is a mystery?
- In the SM it appears to be largely conserved (accidentally)
- The origin of ℓ is not known and all tests of SM do not require this knowledge. **clrTHis should bother you**

Connection to ν mass

- In the minimal SM it is violated by a small amount due to the very small neutrino masses.
- If neutrino masses arise by the dim 5 Weinberg operator

$$m_\nu \simeq \frac{c}{\Lambda}\nu_L \nu_L HH$$

Λ is some high scale and H is the Higgs.

- After SSB

$$m_\nu = \frac{cv^2}{\Lambda}$$

Lepton number from $U(1)_\ell$ Symmetry

- $U(1)_\ell$ as a broken global symmetry so as to implement seesaw for neutrino mass.
- A massless Majoron exists and can be candid for dark radiation
- $U(1)_\ell$ as a unbroken gauge symmetry
- A massless leptonic photon exists.
- Test of equivalence principle set $\alpha_\ell \lesssim 10^{-49}\alpha_{em}$
- $U(1)_\ell$ broken gauge symmetry similar to $U(1)_Y$.

SM leptons are anomalous under $U(1)_\ell$

The SM is anomalous under $U(1)_\ell$ with or without righthanded singlet neutrino. New anomaly coefficients are

- $$\begin{aligned} \mathcal{A}_1([SU(2)]^2 U(1)_\ell) &= -1/2\,, &(1)\\ \mathcal{A}_2([U(1)_Y]^2 U(1)_\ell) &= 1/2\,, &(2)\\ \mathcal{A}_3([U(1)_Y[U(1)_\ell]^2) &= 0\,, &(3)\\ \mathcal{A}_4([U(1)_\ell]^3) &= -1\,, &(4)\\ \mathcal{A}_5(U(1)_\ell) &= -1\,, &(5) \end{aligned}$$

  where $\mathcal{A}_5$ is for lepton-graviton anomaly.
- Other SM anomalies $\mathcal{A}_6([SU(2)]^2 U(1)_Y)$,$\mathcal{A}_7([U(1)_Y]^3)$ and $\mathcal{A}_8(U(1)_Y)$ remain cencelled.
- To cancel $\mathcal{A}_{1\ldots5}$ we need new leptons.

Two sets of chiral leptons similar to SM

- The first set consist of a $SU(2)$ doublet and a singlet and has the eigenvalue ℓ_1

$$L_{1L} = (N_{1L}, E_{1L});\ \left[\mathbf{2}, -\frac{1}{2}, \ell_1\right], \quad E_{1R};\ \left[\mathbf{1}, -1, \ell_1\right]$$

- A second set with opposite chiral projections and eigenvalue $= \ell_2$

$$L_{2R} = (N_{2R}, E_{2R});\ \left[\mathbf{2}, -\frac{1}{2}, \ell_2\right], \quad E_{2L};\ \left[\mathbf{1}, -1, \ell_2\right].$$

Anomalies Cancellations

- Anomalies equations become

$$\mathcal{A}_1 = -\frac{1}{2}(\ell_1 - \ell_2 + 1)\,, \tag{6a}$$
$$\mathcal{A}_2 = \frac{1}{2}(\ell_1 - \ell_2 + 1)\,, \tag{6b}$$
$$\mathcal{A}_3 = 0\,, \tag{6c}$$
$$\mathcal{A}_4 = -\ell_1^3 + \ell_2^3 - 1\,, \tag{6d}$$
$$\mathcal{A}_5 = -(\ell_1 - \ell_2 + 1)\,. \tag{6e}$$

- Solutions
  1. Solution I

$$\ell_1 = -1 \text{ and } \ell_2 = 0\,,$$

  2. Solution II

$$\ell_1 = 0 \text{ and } \ell_2 = 1\,.$$

- $\mathcal{A}_{6,7,8} = 0$.

For each family of SM lepton.

Another Solution

Instead of taking all three SM lepton to have $\ell = 1$. They can take different values.

- $\ell = 1$ for muon. $\ell = -1$ for τ.
- All anomalies cancel between 2nd and 3rd families
- Use previous solution for the first family.
- Need only ONE pair of vectorlike leptons.
- Generalize $U(1)_{\mu-\tau}$.
- Our solutions do not require N_R.

Lepton Fields for anomaly free solution

The gauge group is $G = SU(2)_L \times U(1)_Y \times U(1)_\ell$.
The leptons are

Field	$SU(2)$	Y	ℓ
$\ell_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	$\mathbf{2}$	$-\frac{1}{2}$	1
e_R	$\mathbf{1}$	-1	1
$L_{1L} = \begin{pmatrix} N_{1L} \\ E_{1L} \end{pmatrix}$	$\mathbf{2}$	$-\frac{1}{2}$	-1
E_{1R}	$\mathbf{1}$	-1	-1
$L_{2R} = \begin{pmatrix} N_{2R} \\ E_{2R} \end{pmatrix}$	$\mathbf{2}$	$-\frac{1}{2}$	0
E_{2L}	$\mathbf{1}$	-1	0

Table : Lepton fields for anomalies free solution I

Minimal Scalar fields

Form all combinations of lepton bilinears and identify the new scalars to get lepton masses

Field	$SU(2)$	Y	ℓ
$H_0 = \begin{pmatrix} 0 \\ \frac{v+h}{\sqrt{2}} \end{pmatrix}$	$\mathbf{2}$	$\frac{1}{2}$	0
$H_1 = \begin{pmatrix} H_1^+ \\ H_1^0 \end{pmatrix}$	$\mathbf{2}$	$\frac{1}{2}$	2
S	$\mathbf{1}$	1	0
Φ_1	$\mathbf{1}$	0	1
Φ_2	$\mathbf{1}$	0	2

Table : Minimal scalar fields for leptons of solution I

Yukawa Interactions

$$\begin{aligned}\mathcal{L}_y = &y_e \overline{\ell_L} e_R H_0 + Y_2 \overline{L_{1L}} E_{1R} H_0 + Y_3 \overline{L_{2R}} E_{2L} H_0 \\ &+ \lambda_1 \overline{\ell_L} L_{2R} \Phi_1 + \lambda_2 \overline{E_{2L}} e_R \Phi_1^\dagger + \lambda_3 \overline{L_{1L}} L_{2R} \Phi_1^* \\ &+ \lambda_4 \overline{E_{2L}} E_{1R} \Phi_1 + Y_1 \overline{\ell_L} H_1 E_{1R} + f \overline{\ell_L^c} \epsilon L_{1L} S \\ &+ h.c\,.\end{aligned}$$

Can accommodate a charged singlet scalar S.

Scalar Potential

The minimal G invariant scalar potential is given by

$$
\begin{aligned}
&V(H_0, H_1, \Phi_1, \Phi_2, S) = \\
&-\mu^2 H_0^\dagger H_0 + m_1^2 H_1^\dagger H_1 + \kappa_0 \left(H_0^\dagger H_0\right)^2 + \kappa_1 \left(H_1^\dagger H_1\right)^2 \\
&+ \kappa_2 \left(H_0^\dagger H_0\right) \left(H_1^\dagger H_1\right) + \kappa_3 \left(H_0^\dagger H_1\right) \left(H_1^\dagger H_0\right) \\
&+ m_S^2 S^\dagger S + \kappa_S \left(S^\dagger S\right)^2 - \sum_{i=1,2} \mu_i^2 \Phi_i^\dagger \Phi_i \\
&+ \kappa_{11} \left(\Phi_1^\dagger \Phi_1\right) \left(\Phi_1^\dagger \Phi_1\right) + \kappa_{12} \left(\Phi_1^\dagger \Phi_1\right) \left(\Phi_2^\dagger \Phi_2\right) \\
&+ \kappa_{22} \left(\Phi_2^\dagger \Phi_2\right) \left(\Phi_2^\dagger \Phi_2\right) \\
&+ \sum_{i=1,2} \sum_{j=0,1} \kappa_{\Phi_i H_j} (\Phi_i^\dagger \Phi_i)(H_j^\dagger H_j) \\
&+ \sum_{i=1,2} \kappa_{\Phi_i S} (\Phi_i^\dagger \Phi_i)(S^\dagger S) + \sum_{i=0,1,2} \kappa_{H_i S} (H_i^\dagger H_i)(S^\dagger S) \\
&+ \lambda_{1\ell} H_1 \epsilon H_0 S^\dagger \Phi_2^\dagger + \lambda_{2\ell} H_0^\dagger H_1 (\Phi_1^*)^2 \\
&+ \mu_3 H_0^\dagger H_1 \Phi_2^* + \mu_4 (\Phi_1^*)^2 \Phi_2 + h.c..
\end{aligned}
$$

Charged Lepton masses

- SSB breaking of lepton symmetry is given by $\langle|\Phi_{1,2}|\rangle = w/\sqrt{2} \neq 0$ and is the only such scale in the model.
- In general Φ_1 and Φ_2 need not have the same VEV. However, we shall assume they are equal.
- The charged lepton matrix in the weakbasis $\mathcal{E} = (e_w, E_1, E_2)$.

$$M_E = \frac{w}{\sqrt{2}} \begin{pmatrix} y_e r & 0 & \lambda_2 \\ 0 & Y_2 r & \lambda_4 \\ \lambda_1 & \lambda_3 & Y_3 r \end{pmatrix}$$

where $r \equiv \frac{v}{w} \ll 1$.

Neutral Lepton Masses

- The neutral lepton mass matrix in terms of the chiral states $(\nu_L^w, N_{1L}, N_{2R}^c)$ is

$$M_N = \frac{w}{\sqrt{2}} \begin{pmatrix} 0 & 0 & \lambda_1 \\ 0 & 0 & \lambda_3 \\ \lambda_1 & \lambda_3 & 0 \end{pmatrix} .$$

- This is at tree level.
- Active neutrino remain massless at this level
- Generate them radiatively.

Gauge Interactions

- The covariant derivative is

$$D_\mu = \partial_\mu - i\frac{g}{2}\mathbf{W}_\mu \cdot \boldsymbol{\tau} - ig'YB_\mu - ig_\ell(\ell)Z_{\ell\mu}\,,$$

  Y the hypercharge, and ℓ the lepton number of fields Z_ℓ couples to.
- Mass of Z_ℓ is

$$\begin{aligned} M_X &= g_\ell\sqrt{w_1^2 + 4w_2^2} \\ &= g_\ell \bar{w} \\ &= 2.24 g_\ell w \;\; \text{for } w_1 = w_2 = w. \end{aligned}$$

  and $\bar{w}^2 = w_1^2 + 4w_2^2$ gives the overall lepton number violating scale.

Gauge Interactions of leptons

- Neglect kinetic mixing $U(1)\ell$ and $U(1)_Y$.
- The SM photon, Z and Z_ℓ interactions are

$$
\begin{aligned}
& ie\left[\bar{e}_w\gamma^\mu e_w + \bar{E}_1\gamma^\mu E_1 + \bar{E}_2\gamma^\mu E_2\right] A_\mu \\
- \quad & \frac{ig_2}{2c_W}\left[\bar{\nu}_w\gamma^\mu \hat{L}\nu_w + \bar{N}_1\gamma^\mu \hat{L}N_1 + \bar{N}_2\gamma^\mu \hat{R}N_2\right] Z_\mu \\
- \quad & \frac{ig_2}{c_W}\left[\bar{e}_w\gamma^\mu(g_L\hat{L} + g_R\hat{R})e_w + \bar{E}_1\gamma^\mu(g_L\hat{L} + g_R\hat{R})E_1\right. \\
& \quad \left. + \bar{E}_2\gamma^\mu(g_L\hat{R} + g_R\hat{L})E_2\right] Z_\mu \\
- \quad & \frac{ig_2}{\sqrt{2}}\left[\bar{\nu}_w\gamma^\mu \hat{L}e_w + \bar{N}_1\gamma^\mu \hat{L}E_1 + \bar{N}_2\gamma^\mu \hat{R}E_2\right] W^+_\mu + h.c. \\
- \quad & ig_\ell\left[\bar{\nu}_w\gamma^\mu \hat{L}\nu_w + \bar{e}_w\gamma^\mu e_w - \bar{N}_1\gamma^\mu \hat{L}N_1 - \bar{E}_1\gamma^\mu E_1\right](Z_\ell)_\mu \,,
\end{aligned}
\tag{7}
$$

where A denotes the photon, $g_L = -1/2 + s_w^2$ and $g_R = s_w^2$ are SM electron couplings.

Z_ℓ couplings to SM leptons

- The physical mass eigenstates $\mathcal{E}'_\alpha = (e, E_-, E_+)$ where $\alpha = 1, 2, 3$ are related to the weak states by

$$\mathcal{E}'_i = V_{i\alpha}\mathcal{E}_\alpha \,,$$

  where V is the unitary matrix that diagonalizes M_E such that $(V^A)^T \cdot M_E \cdot V^A = \mathrm{diag}\{m_e, -(\bar{\lambda}w - m_e), \bar{\lambda}w + m_e\}$.
- Z_ℓ has vector couplings to $\mathcal{E}$.
  Define a matrix $Q^\mathcal{E}$ representing this coupling by $\overline{\mathcal{E}} Q^\mathcal{E} \gamma_\mu \mathcal{E} Z^\mu_\ell$, where

$$Q^\mathcal{E} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix} \,.$$

- In the mass basis $Q'^\mathcal{E} = V^\dagger Q^\mathcal{E} V$
- In general $Q'^\mathcal{E}$ is not diagonal.
- $Z_\ell - e - e$ coupling strength is

$$Q'^\mathcal{E}_{11} = |V_{e1}|^2 - |V_{E1}|^2$$

- Charged lepton flavor violation couplings are in general expected.

Penomenology of Z_ℓ

Limit on M_X comes from LEP II bound on 4-leptons contact interactions

$$\frac{4\pi}{(\Lambda_{VV})^2}\,(\bar{e}\gamma^\mu e)\,(\bar{l}\gamma_\mu l)\;\; nonr$$

- The limit given is $\Lambda_{VV} > 20.0$ TeV
- The gives

$$M_X \geq \sqrt{\rho}\sqrt{\alpha} \times 20.0\,\text{TeV} \sim 1.77\sqrt{\rho}\,\text{TeV}\,.$$

where $\rho \equiv (g_\ell/e)^2$

Front-back asymmetry (A_{FB}) in $e^+e^- \to \mu^+\mu^-$

Exchange of Z_ℓ will interfere with the SM exchanges of Z, γ.

$$\begin{aligned}
\frac{d\sigma}{d\cos\theta} &= \frac{\pi\alpha^2}{2s}\Big\{|D_{\gamma\ell}|^2(1+\cos^2\theta) \\
&+\frac{1}{4(s_W c_W)^4}|D_Z|^2\Big[(g_L^2+g_R^2)^2(1+\cos^2\theta) \\
&+2(g_L^2-g_R^2)^2\cos\theta\Big] \\
&+\frac{1}{2(s_W c_W)^2}\Re(D^*_{\gamma\ell}D_Z)\Big[(g_L+g_R)^2(1+\cos^2\theta) \\
&+\ 2(g_L-g_R)^2\cos\theta\Big]\Big\}\ ,
\end{aligned} \tag{8}$$

where θ is the scattering angle of μ^-, and s is the center of mass energy squared.

$$\begin{aligned}
D_{\gamma\ell} &= 1+\frac{\rho s}{s-M_X^2+iM_X\Gamma_X}\ , \\
D_Z &= \frac{s}{s-M_Z^2+iM_Z\Gamma_Z}\ ,
\end{aligned}$$

where Γ_X the width of Z_l.

A_{FB} contd

- The cross section is parameterized as

$$\frac{d\sigma}{d\cos\theta} = \frac{\pi\alpha^2}{2s}\left[A(1+\cos^2\theta) + B\cos\theta\right] \ .$$

- A_{FB} is given by

$$A_{FB} = \frac{\int_0^1 d\cos\theta \frac{d\sigma}{d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d\sigma}{d\cos\theta}}{\int_{-1}^1 d\cos\theta \frac{d\sigma}{d\cos\theta}} = \frac{3B}{8A} \, ,$$

A_{FB} graph

We give a plot of A_{FB}, for $M_X = 2$ TeV and $\rho = 0.3, 1.0$.

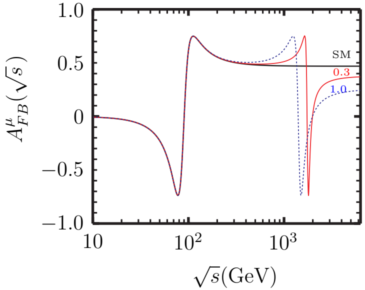

Figure : The A_{FB} vs $\sqrt{s}$ with $M_X = 2$TeV. The black curve is for the SM, and the red(blue) curve is for a Z_ℓ with $\rho = 0.3(1.0)$.

Z_ℓ Production at LHC

The mechanism is $pp \to e^+e^- Z_\ell \to e^+e^-(\mu^+\mu^-)$ sharp resonance in $\mu^+\mu^-$ pair. The expect cross section

$\frac{\sqrt{s}}{\mathrm{TeV}}$		$\frac{M_X}{\mathrm{TeV}} = 0.5$	$\frac{M_X}{\mathrm{TeV}} = 1.0$	$\frac{M_X}{\mathrm{TeV}} = 2.0$	$\frac{M_X}{\mathrm{TeV}} = 5.0$
14	$\frac{\sigma}{g_\ell^2}$	5.4×10^{-5}	1.7×10^{-6}	1.9×10^{-8}	9.8×10^{-13}
	σ_{BG}	2.2×10^{-5}	1.4×10^{-6}	5.4×10^{-8}	6.2×10^{-11}
	$\frac{\bar{w}_{max}}{\mathrm{TeV}}$	0.61	0.43	-	-
30	$\frac{\sigma}{g_\ell^2}$	2.6×10^{-4}	1.5×10^{-5}	5.1×10^{-7}	1.0×10^{-9}
	σ_{BG}	6.8×10^{-5}	7.1×10^{-6}	4.2×10^{-7}	5.7×10^{-9}
	$\frac{\bar{w}_{max}}{\mathrm{TeV}}$	1.02	0.85	-	-
100	$\frac{\sigma}{g_\ell^2}$	1.7×10^{-3}	1.5×10^{-4}	1.1×10^{-5}	1.8×10^{-7}
	σ_{BG}	3.0×10^{-4}	3.2×10^{-5}	2.8×10^{-6}	7.6×10^{-8}
	$\frac{\bar{w}_{max}}{\mathrm{TeV}}$	1.79	1.85	1.83	-

Oblique parameters S, T

They constrain the mass splittings of the pair (E, N).

- For each generation new leptons we have

$$\triangle T = \frac{1}{16\pi s_w^2} \sum_{i=1,2} \frac{M_{E_i}^2}{M_W^2} \left(1 + x_i + \frac{2x_i}{1-x_i} \ln x_i\right) , \tag{9}$$

$$\triangle S = \frac{1}{6\pi} \sum_{i=1,2} (1 + \ln x_i) ,$$

  where $x_i = M_{N_i}^2 / M_{E_i}^2$.

- For the new Higgs doublet

$$\triangle T = \frac{1}{16\pi s_w^2} \frac{M_{H^+}^2}{M_W^2} \frac{1}{z} \left[1 + z + \frac{2z}{1-z} \ln z\right] ,$$

$$\triangle S = -\frac{1}{12\pi} \ln z ,$$

  where $z \equiv M_{H^+}^2 / M_{H_1^0}^2$.

- $\triangle T$ from fermions and doublet scalar are both positive, but $\triangle S$ from the doublet scalar can be either positive or negative.

S, T graph

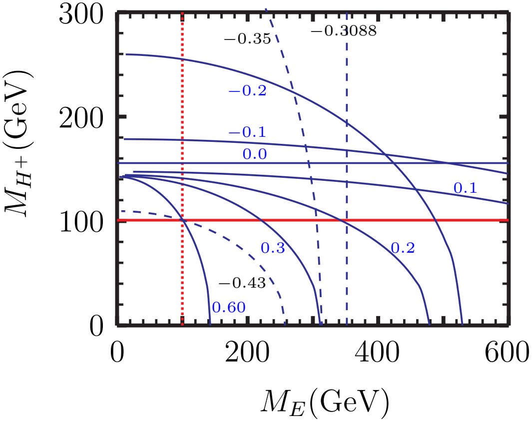

Figure : Contours from $\triangle S$ and $\triangle T$ constraints for different $\ln x$. For a given $\ln x$, the allowed masses region is above the direct search bound on M_{H^+}, the horizontal red line, to the right of the direct search bound on M_E, the vertical dashed red line, and to the lower left of the blue (dash)curve.

Impact on Higgs physics

Impact comes from the new charged leptons and charged scalars. New terms are

$$\mathcal{L} \supset -\sum_{i=1}^{6} y_{E_i} \bar{E}_i E_i h - \sum_{i=1,2} \lambda_i M_W h H_i^+ H_i^- \,.$$

- $H \to \gamma\gamma$

$$\begin{aligned}\Gamma(H \to \gamma\gamma) = \frac{G_F \alpha^2 M_H^3}{128\sqrt{2}\pi^3} \Bigg| & F_1(\tau_W) + \frac{4}{3} F_{1/2}(\tau_t) \\ & + \sum_{j=1,2} \lambda_i \frac{M_W^2}{g_2 M_{H_i}^2} F_0(\tau_{H_i}) \\ & + \sum_{i=1}^{6} y_{E_i} \frac{2M_W}{g_2 M_{E_i}} F_{1/2}(\tau_{E_i}) \Bigg|^2 \,, \end{aligned} \qquad (10)$$

where $\tau_i \equiv (m_H/2m_i)^2$and

$$\begin{aligned} F_0(\tau) &= -[\tau - f(\tau)]/\tau^2 \,, \\ F_{1/2}(\tau) &= 2[\tau + (\tau - 1) f(\tau)]/\tau^2 \,, \\ F_1(\tau) &= -[2\tau^2 + 3\tau + 3(2\tau - 1) f(\tau)]/\tau^2 \,, \end{aligned} \qquad (11)$$

Higgs physics

- Diphoton width

$$\Gamma(H \to \gamma\gamma) = \frac{G_F \alpha^2 M_H^3}{128\sqrt{2}\pi^3} \times \Big| -8.324 + 1.834 + 8.3 \times 10^{-4}(1.3 \times 10^{-2}) \times \lambda_2 + 0.087(0.42) \times \lambda_1 + \sum_{i=1}^{6} 0.32(3.64) \times y_{E_i} \Big|^2$$

  for $M_{E_i} = 1000(100)$GeV, $M_{H_2} = 2.0(0.5)$TeV, and $M_{H_1} = 200(100)$GeV. The first two terms are SM W and top quark contributions.

- Higgs to 4 leptons

$$h_{SM} \to 2h_1(2a_1) \to \bar{\ell}_i \ell_i + \bar{\ell}_j \ell_j \,.$$

- The decay width is $\Gamma(h_{SM} \to h_1 h_1(a_1 a_1)) = \frac{v^2(\kappa_2+\kappa_3)^2}{32\pi M_H}\left(1 - \frac{4m_1^2}{M_H^2}\right)^{\frac{1}{2}}$ where $M_H(= 125\text{GeV})$ and m_1 are the masses of h_{SM} and $h_1(a_1)$ respectively.

Production of New leptons at e^+e^- colliders

- Cross section for $e^+e^- \to E\bar{E}$ is

$$
\begin{aligned}
&\sigma(e^+e^- \to E\bar{E}) \simeq \\
&2\frac{4\pi\alpha^2}{3s}\sqrt{1-4x_E}\left\{\left(1+\frac{\rho s}{s-M_X^2}\right)^2(1+2x_E)\right. \\
&+\frac{(g_L^e)^2+(g_R^e)^2}{4(s_W c_W)^4}\left[(1-x_E)((g_L^E)^2+(g_R^E)^2)+6x_E g_L^E g_R^E\right] \\
&\left.+\frac{(g_L^e+g_R^e)}{2(s_W c_W)^2}(g_L^E+g_R^E)\left(1+\frac{\rho s}{s-M_X^2}\right)(1-x_E)\right\}
\end{aligned}
$$

where $x_E \equiv M_E^2/s$, $g_L^E \simeq g_L^e = -1/2 + s_W^2$, $g_R^E \simeq g_R^e = s_W^2$

contd

Production of heavy neutral leptons via $e^+e^- \to N\bar{N}$ is

$$\sigma(e^+e^- \to N\bar{N}) \simeq$$
$$\frac{4\pi\alpha^2}{3s}\sqrt{1-4x_N}\left\{\left(\frac{\rho s}{s-M_X^2}\right)^2(1+2x_N)\right.$$
$$+\frac{(g_L^e)^2+(g_R^e)^2}{8(s_W c_W)^4}(1+2x_N)$$
$$\left.+\frac{(g_L^e+g_R^e)}{2(s_W c_W)^2}\left(\frac{\rho s}{s-M_X^2}\right)(1-x_N)\right\}$$

Production Cross Sections

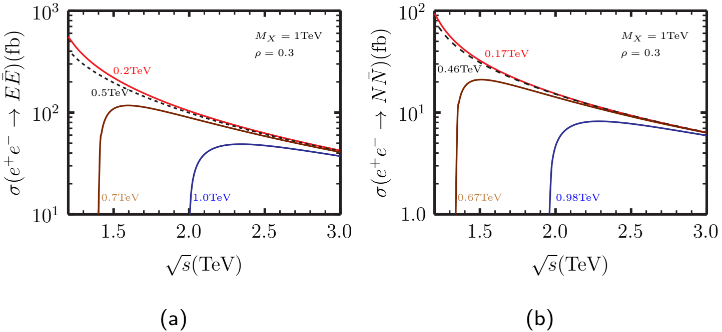

Figure : (a) The $E\bar{E}$, and (b)$N\bar{N}$ production cross sections v.s $\sqrt{s}$ at an e^+e^- collider. The masses of $E(N)$ are labeled next to the curves.

Conclusions

- Solve the anomalies for gauge $U(1)_\ell$ for each family.
- Solution does not require singlet N_R.
- Existence of Z_ℓ is universal to all gauged lepton models.
- Best studied at lepton colliders.
- A_{FB} can reveal its existence even before it can be kinematicall produced.
- Production at hadron colliders are challenging.
- Oblique parameters strong constrain on the new leptons to be quite degenerate.