Relaxing LHC constraints on the W_R mass

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The Left-Right Symmetric Model (LRSM)

$$\begin{tikzcd}
SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} \arrow[d, "\Delta_R"] \\
SU(3)_C \times SU(2)_L \times U(1)_Y \arrow[d, "\Phi"] \\
SU(3)_C \times U(1)_{EM}
\end{tikzcd}$$

	Fields	$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
Matter	Q_{L_i}	$(\mathbf{2}, \mathbf{1}, +\frac{1}{3})$
	Q_{R_i}	$(\mathbf{1}, \mathbf{2}, -\frac{1}{3})$
	L_{L_i}	$(\mathbf{2}, \mathbf{1}, -1)$
	L_{R_i}	$(\mathbf{1}, \mathbf{2}, -1)$
Higgs	Φ	$(\mathbf{2}, \mathbf{2}, 0)$
	Δ_L	$(\mathbf{3}, \mathbf{1}, 2)$
	Δ_R	$(\mathbf{1}, \mathbf{3}, 2)$

$$\Phi \equiv \begin{pmatrix} \phi_1^0 & \phi_2^+ \\ \phi_1^- & \phi_2^0 \end{pmatrix} \sim (\mathbf{2}, \mathbf{2}, \mathbf{0})$$

$$Q_{Li} = \begin{pmatrix} u_L \\ d_L \end{pmatrix}_i \sim (\mathbf{2}, \mathbf{1}, \mathbf{1/3})\,, \quad Q_{Ri} = \begin{pmatrix} u_R \\ d_R \end{pmatrix}_i \sim (\mathbf{1}, \mathbf{2}, \mathbf{1/3})\,,$$

$$\Delta_L \equiv \begin{pmatrix} \delta_L^+/\sqrt{2} & \delta_L^{++} \\ \delta_L^0 & -\delta_L^+/\sqrt{2} \end{pmatrix} \sim (\mathbf{3}, \mathbf{1}, \mathbf{2})$$

$$\Delta_R \equiv \begin{pmatrix} \delta_R^+/\sqrt{2} & \delta_R^{++} \\ \delta_R^0 & -\delta_R^+/\sqrt{2} \end{pmatrix} \sim (\mathbf{1}, \mathbf{3}, \mathbf{2})$$

$$L_{Li} = \begin{pmatrix} \nu_L \\ \ell_L \end{pmatrix}_i \sim (\mathbf{2}, \mathbf{1}, \mathbf{-1})\,, \quad L_{Ri} = \begin{pmatrix} \nu_R \\ \ell_R \end{pmatrix}_i \sim (\mathbf{1}, \mathbf{2}, \mathbf{-1})\,,$$

Symmetry Breaking

$$SU(2)_R \otimes U(1)_{B-L} \longrightarrow U(1)_Y$$

$$\langle \Delta_L \rangle = \begin{pmatrix} 0 & 0 \\ v_L e^{i\theta_L}/\sqrt{2} & 0 \end{pmatrix}, \quad \langle \Delta_R \rangle = \begin{pmatrix} 0 & 0 \\ v_R/\sqrt{2} & 0 \end{pmatrix}$$

Symmetry Breaking

$$SU(2)_R \otimes U(1)_{B-L} \longrightarrow U(1)_Y$$

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$$SU(2)_L \otimes U(1)_Y \longrightarrow U(1)_{EM}$$

$$v_R \gg (\kappa_1,\ \kappa_2) \gg v_L, \qquad \sqrt{\kappa_1^2 + \kappa_2^2} = v = 246\text{ GeV}$$

$$\langle \Phi \rangle = \begin{pmatrix} \kappa_1/\sqrt{2} & 0 \\ 0 & \kappa_2 e^{i\alpha}/\sqrt{2} \end{pmatrix}$$

LRSM Lagrangian

$$\mathcal{L}_{\mathrm{LRSM}} = \mathcal{L}_{\mathrm{kin}} + \mathcal{L}_{Y} - V(\Phi, \Delta_L, \Delta_R)$$

LRSM Lagrangian

$$\mathcal{L}_{\mathrm{LRSM}} = \mathcal{L}_{\mathrm{kin}} + \mathcal{L}_Y - V(\Phi, \Delta_L, \Delta_R)$$

$$\mathcal{L}_{\mathrm{kin}} = i \sum \bar{\psi} \gamma^\mu D_\mu \psi$$

$$= \bar{L}_L \gamma^\mu \left(i\partial_\mu + g_L \frac{\vec{\tau}}{2} \cdot \vec{W}_{L\mu} - \frac{g_{B-L}}{2} B_\mu \right) L_L + \bar{L}_R \gamma^\mu \left(i\partial_\mu + g_R \frac{\vec{\tau}}{2} \cdot \vec{W}_{R\mu} - \frac{g_{B-L}}{2} B_\mu \right) L_R$$
$$+ \bar{Q}_L \gamma^\mu \left(i\partial_\mu + g_L \frac{\vec{\tau}}{2} \cdot \vec{W}_{L\mu} + \frac{g_{B-L}}{6} B_\mu \right) Q_L + \bar{Q}_R \gamma^\mu \left(i\partial_\mu + g_R \frac{\vec{\tau}}{2} \cdot \vec{W}_{R\mu} + \frac{g_{B-L}}{6} B_\mu \right) Q_R$$

LRSM Lagrangian

$$\mathcal{L}_{\rm LRSM} = \mathcal{L}_{\rm kin} + \mathcal{L}_Y - V(\Phi, \Delta_L, \Delta_R)$$

$$\mathcal{L}_{\rm kin} = i \sum \bar{\psi} \gamma^\mu D_\mu \psi$$

$$= \bar{L}_L \gamma^\mu \left(i\partial_\mu + g_L \frac{\vec{\tau}}{2} \cdot \vec{W}_{L\mu} - \frac{g_{B-L}}{2} B_\mu \right) L_L + \bar{L}_R \gamma^\mu \left(i\partial_\mu + g_R \frac{\vec{\tau}}{2} \cdot \vec{W}_{R\mu} - \frac{g_{B-L}}{2} B_\mu \right) L_R$$
$$+ \bar{Q}_L \gamma^\mu \left(i\partial_\mu + g_L \frac{\vec{\tau}}{2} \cdot \vec{W}_{L\mu} + \frac{g_{B-L}}{6} B_\mu \right) Q_L + \bar{Q}_R \gamma^\mu \left(i\partial_\mu + g_R \frac{\vec{\tau}}{2} \cdot \vec{W}_{R\mu} + \frac{g_{B-L}}{6} B_\mu \right) Q_R$$

$$\mathcal{L}_Y = - \Big[Y_{L_L} \bar{L}_L \Phi L_R + \tilde{Y}_{L_R} \bar{L}_R \Phi L_L + Y_{Q_L} \bar{Q}_L \tilde{\Phi} Q_R + \tilde{Y}_{Q_R} \bar{Q}_R \tilde{\Phi} Q_L$$
$$+ h_L^{ij} \overline{L}^c_{L_i} i\tau_2 \Delta_L L_{L_j} + h_R^{ij} \overline{L}^c_{R_i} i\tau_2 \Delta_R L_{R_j} + \text{h.c.} \Big] ,$$

LRSM Higgs Potential

$$\begin{aligned}
V(\phi, \Delta_L, \Delta_R) = & -\mu_1^2 \left(\mathrm{Tr}\left[\Phi^\dagger \Phi\right]\right) - \mu_2^2 \left(\mathrm{Tr}\left[\tilde{\Phi}\Phi^\dagger\right] + \left(\mathrm{Tr}\left[\tilde{\Phi}^\dagger \Phi\right]\right)\right) - \mu_3^2 \left(\mathrm{Tr}\left[\Delta_L \Delta_L^\dagger\right] + \mathrm{Tr}\left[\Delta_R \Delta_R^\dagger\right]\right) \\
& + \lambda_1 \left(\left(\mathrm{Tr}\left[\Phi\Phi^\dagger\right]\right)^2\right) + \lambda_2 \left(\left(\mathrm{Tr}\left[\tilde{\Phi}\Phi^\dagger\right]\right)^2 + \left(\mathrm{Tr}\left[\tilde{\Phi}^\dagger \Phi\right]\right)^2\right) + \lambda_3 \left(\mathrm{Tr}\left[\tilde{\Phi}\Phi^\dagger\right] \mathrm{Tr}\left[\tilde{\Phi}^\dagger \Phi\right]\right) \\
& + \lambda_4 \left(\mathrm{Tr}\left[\Phi\Phi^\dagger\right] \left(\mathrm{Tr}\left[\tilde{\Phi}\Phi^\dagger\right] + \mathrm{Tr}\left[\tilde{\Phi}^\dagger \Phi\right]\right)\right) + \rho_1 \left(\left(\mathrm{Tr}\left[\Delta_L \Delta_L^\dagger\right]\right)^2 + \left(\mathrm{Tr}\left[\Delta_R \Delta_R^\dagger\right]\right)^2\right) \\
& + \rho_2 \left(\mathrm{Tr}\left[\Delta_L \Delta_L\right] \mathrm{Tr}\left[\Delta_L^\dagger \Delta_L^\dagger\right] + \mathrm{Tr}\left[\Delta_R \Delta_R\right] \mathrm{Tr}\left[\Delta_R^\dagger \Delta_R^\dagger\right]\right) + \rho_3 \left(\mathrm{Tr}\left[\Delta_L \Delta_L^\dagger\right] \mathrm{Tr}\left[\Delta_R \Delta_R^\dagger\right]\right) \\
& + \rho_4 \left(\mathrm{Tr}\left[\Delta_L \Delta_L\right] \mathrm{Tr}\left[\Delta_R^\dagger \Delta_R^\dagger\right] + \mathrm{Tr}\left[\Delta_L^\dagger \Delta_L^\dagger\right] \mathrm{Tr}\left[\Delta_R \Delta_R\right]\right) + \alpha_1 \mathrm{Tr}\left[\Phi\Phi^\dagger\right] \left(\mathrm{Tr}\left[\Delta_L \Delta_L^\dagger\right] + \mathrm{Tr}\left[\Delta_R \Delta_R^\dagger\right]\right) \\
& + \alpha_2 \left(\mathrm{Tr}\left[\Phi\tilde{\Phi}^\dagger\right] \mathrm{Tr}\left[\Delta_R \Delta_R^\dagger\right] + \mathrm{Tr}\left[\Phi^\dagger \tilde{\Phi}\right] \mathrm{Tr}\left[\Delta_L \Delta_L^\dagger\right]\right) + \alpha_2^* \left(\mathrm{Tr}\left[\Phi^\dagger \tilde{\Phi}\right] \mathrm{Tr}\left[\Delta_R \Delta_R^\dagger\right] + \mathrm{Tr}\left[\tilde{\Phi}^\dagger \Phi\right] \mathrm{Tr}\left[\Delta_L \Delta_L^\dagger\right]\right) \\
& + \alpha_3 \left(\mathrm{Tr}\left[\Phi\Phi^\dagger \Delta_L \Delta_L^\dagger\right] + \mathrm{Tr}\left[\Phi^\dagger \Phi \Delta_R \Delta_R^\dagger\right]\right) + \beta_1 \left(\mathrm{Tr}\left[\Phi \Delta_R \Phi^\dagger \Delta_L^\dagger\right] + \mathrm{Tr}\left[\Phi^\dagger \Delta_L \Phi \Delta_R^\dagger\right]\right) \\
& + \beta_2 \left(\mathrm{Tr}\left[\tilde{\Phi} \Delta_R \Phi^\dagger \Delta_L^\dagger\right] + \mathrm{Tr}\left[\tilde{\Phi}^\dagger \Delta_L \Phi \Delta_R^\dagger\right]\right) + \beta_3 \left(\mathrm{Tr}\left[\Phi \Delta_R \tilde{\Phi}^\dagger \Delta_L^\dagger\right] + \mathrm{Tr}\left[\Phi^\dagger \Delta_L \tilde{\Phi} \Delta_R^\dagger\right]\right)
\end{aligned}$$

Gauge Sector

$$\begin{pmatrix} Z_R^{\mu} \\ B^{\mu} \end{pmatrix} = \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} W_R^{3\mu} \\ V^{\mu} \end{pmatrix}$$

Gauge Sector

$$\begin{pmatrix} Z_R^\mu \\ B^\mu \end{pmatrix} = \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} W_R^{3\mu} \\ V^\mu \end{pmatrix}$$

$$\begin{pmatrix} Z_L^\mu \\ B^\mu \\ Z_R^\mu \end{pmatrix} = \begin{pmatrix} \cos\theta_W & -\sin\theta_W \sin\phi & -\sin\theta_W \cos\phi \\ \sin\theta_W & \cos\theta_W \sin\phi & \cos\theta_W \cos\phi \\ 0 & \cos\phi & -\sin\phi \end{pmatrix} \begin{pmatrix} W_L^{3\mu} \\ W_R^{3\mu} \\ V^\mu \end{pmatrix}$$

$$\begin{aligned} M_A &= 0 \\ M^2_{Z_{1,2}} &= \frac{1}{4}\Big[\left[g_L^2 v^2 + 2v_R^2(g_R^2 + g_{B-L}^2)\right] \\ &\mp \sqrt{\left[g_L^2 v^2 + 2v_R^2(g_R^2 + g_{B-L}^2)\right]^2 - 4g_L^2(g_R^2 + 2g_{B-L}^2)v^2 v_R^2}\,\Big] . \end{aligned}$$

Charged Sector

$$\begin{pmatrix} W_1 \\ W_2 \end{pmatrix} = \begin{pmatrix} \cos\xi & -\sin\xi \\ \sin\xi & \cos\xi \end{pmatrix} \begin{pmatrix} W_L \\ W_R \end{pmatrix}$$

Charged Sector

$$\begin{pmatrix} W_1 \\ W_2 \end{pmatrix} = \begin{pmatrix} \cos\xi & -\sin\xi \\ \sin\xi & \cos\xi \end{pmatrix} \begin{pmatrix} W_L \\ W_R \end{pmatrix}$$

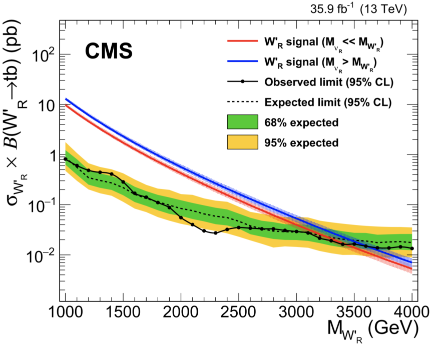
In the limit of $(\kappa_1, \kappa_2) \ll v_R$ and $g_R \sim g_L$ we have $\sin\xi \approx \frac{\kappa_1 \kappa_2}{v_R^2}$, $\sin^2\xi \approx 0$, $\cos\xi \approx 1$, leading to

$$M_{W_1}^2 = \frac{1}{4} g_L^2 v^2 \,, \qquad M_{W_2}^2 = \frac{1}{4}\left[2 g_R^2 v_R^2 + g_R^2 v^2 + 2 g_R g_L \frac{\kappa_1^2 \kappa_2^2}{v_R^2}\right]$$

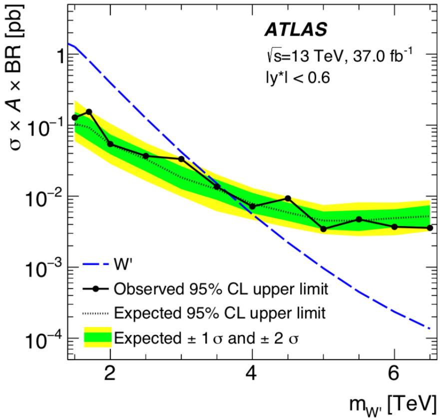
Outline

W_R Mass Limits at the LHC

$W_R \to t\bar{b}$

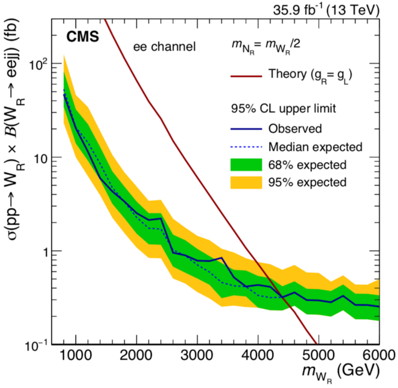


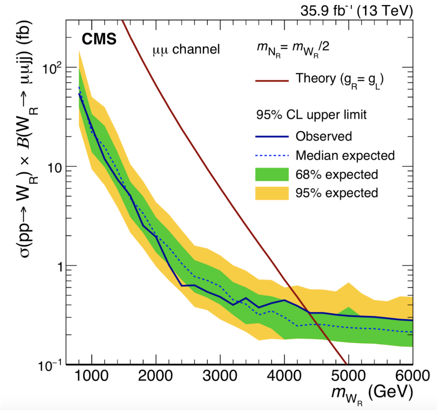
$W_R \to jj$



W_R Mass Limits at the LHC

$$W_R \to \ell\nu_R \to \ell\ell W_R^\star \to \ell\ell q q', \quad \ell = e \text{ or } \mu\,.$$





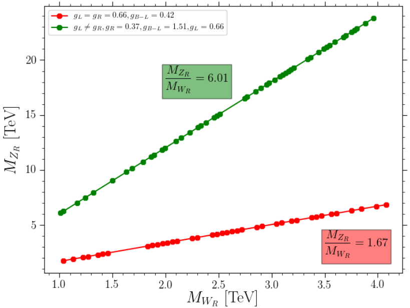
Outline

Motivation for $g_L \neq g_R$

$$\frac{1}{e^2} = \frac{1}{g_L^2} + \frac{1}{g_R^2} + \frac{1}{g_{B-L}^2}\,, \qquad \frac{1}{g_Y^2} = \frac{1}{g_R^2} + \frac{1}{g_{B-L}^2}$$

Setting $\sin\phi = \dfrac{g_{B-L}}{\sqrt{g_R^2 + g_{B-L}^2}}$ and $\sin\theta_W = \dfrac{g_Y}{\sqrt{g_L^2 + g_Y^2}}$, we get

$$\tan\theta_W = \frac{g_R \sin\phi}{g_L} \leq \frac{g_R}{g_L}\,,$$



Theoretical constraint on g_R gauge coupling

$$g_L \tan\theta_W \leq g_R$$

Outline

Analysis

Observable	Constraints	Observable	Constraints
ΔB_s	[10.2-26.4]	ΔB_d	[0.294-0.762]
ΔM_K	$< 5.00 \times 10^{-15}$	$\frac{\Delta M_K}{\Delta M_K^{SM}}$	[0.7-1.3]
ϵ_K	$< 3.00 \times 10^{-3}$	$\frac{\epsilon_K}{\epsilon_K^{SM}}$	[0.7-1.3]
$\mathrm{BR}(B^0 \to X_s\gamma)$	$[2.99, 3.87] \times 10^{-4}$	$\frac{BR(B^0 \to X_s\gamma)}{BR(B^0 \to X_s\gamma)_{SM}}$	[0.7-1.3]
M_h	[124, 126] GeV	$M_{H^{\pm\pm}_{1,2}}$	> 535 GeV
$M_{H_4, A_2, H_2^{\pm}}$	$> 4.75 \times M_{W_R}$		

Table: Current experimental bounds imposed for consistent solutions.

Parameter	Scanned range
v_R	[2.2, 20] TeV
V^R_{CKM}: c^R_{12}, c^R_{13}, c^R_{23}	$[-1, 1]$
$\mathrm{diag}(h^{ij}_R)$	[0.001, 1]

Table: Scanned parameter space.

$$M^{ij}_{\nu_R} = h^{ij}_R v_R$$

$$V^R_{\mathrm{CKM}} = \begin{bmatrix} c^R_{12}c^R_{13} & s^R_{12}c^R_{13} & s^R_{13}e^{i\delta_R} \\ -s^R_{12}c^R_{23} - c^R_{12}s^R_{23}s_{13}e^{i\delta_R} & c^R_{12}c^R_{23} - s^R_{12}s^R_{23}s^R_{13}e^{i\delta_R} & s^R_{23}c^R_{13} \\ s^R_{12}s^R_{23} - c^R_{12}c^R_{23}s^R_{13}e^{i\delta_R} & -c^R_{12}c^R_{23} - s^R_{12}c^R_{23}s^R_{13}e^{i\delta_R} & c^R_{23}c^R_{13} \end{bmatrix}$$

Scenario I: $M_{\nu_R} > M_{W_R}$

$g_L \neq g_R = 0.37$, tan $\beta = 0.01$, $V^L_{\text{CKM}} = V^R_{\text{CKM}}$

$$\left.\begin{array}{l}\text{BR}(W_R \to W_L h) \\ \text{BR}(W_R \to W_L Z_L)\end{array}\right\} \text{invisible}$$

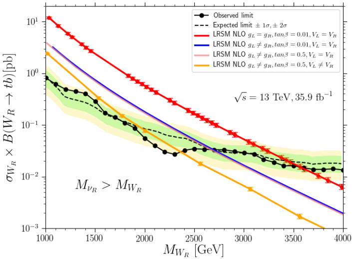
$\text{BR}(W_R \to t\bar{b}) \sim 32\%$ - 33%

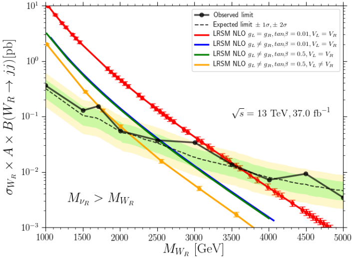
$g_L \neq g_R = 0.37$, tan $\beta = 0.5$, $V^L_{\text{CKM}} = V^R_{\text{CKM}}$

$\text{BR}(W_R \to W_L h) \sim 1.95\%$
$\text{BR}(W_R \to W_L Z_L) \sim 2.0\%$
$\text{BR}(W_R \to t\bar{b}) \sim 31.0\%$ - 31.8%

$g_L \neq g_R = 0.37$, tan $\beta = 0.5$, $V^L_{\text{CKM}} \neq V^R_{\text{CKM}}$

$\text{BR}(W_R \to t\bar{b}) \sim 20\%$ for high M_{W_R} (4 TeV)
$\sim 29\%$ for low M_{W_R} (1.5 TeV)





Scenario II: $M_{\nu_R} < M_{W_R}$

$g_L = g_R$,tan $\beta = 0.01$, $V^L_{\text{CKM}} = V^R_{\text{CKM}}$

BR($W_R \to \nu_R \ell$) ~ 5.8% (each family)
BR($W_R \to t\bar{b}$) ~ 26.5% - 27.3%

$g_L \neq g_R = 0.37$, tan $\beta = 0.01$, $V^L_{\text{CKM}} = V^R_{\text{CKM}}$

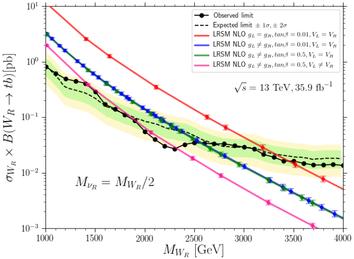
BR($W_R \to \nu_R \ell$) ~ 6.7% (each family)
BR($W_R \to t\bar{b}$) ~ 25.7% - 26.5%

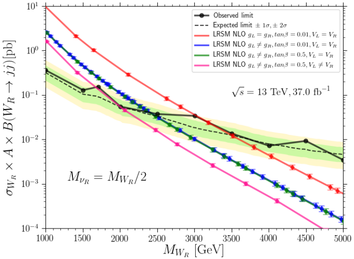
$g_L \neq g_R = 0.37$, tan $\beta = 0.5$, $V^L_{\text{CKM}} = V^R_{\text{CKM}}$

BR($W_R \to \nu_R \ell$) ~ 6.7% (each family)
BR($W_R \to W_L h$) ~ 1.95%
BR($W_R \to W_L Z_L$) ~ 2.0%
BR($W_R \to t\bar{b}$) ~ 24.8% - 25.6%

$g_L \neq g_R = 0.37$, tan $\beta = 0.5$, $V^L_{\text{CKM}} \neq V^R_{\text{CKM}}$

BR($W_R \to t\bar{b}$) ~ 15.7% for high M_{W_R} (4 TeV)
~ 24.7% for low M_{W_R} (1.5 TeV)

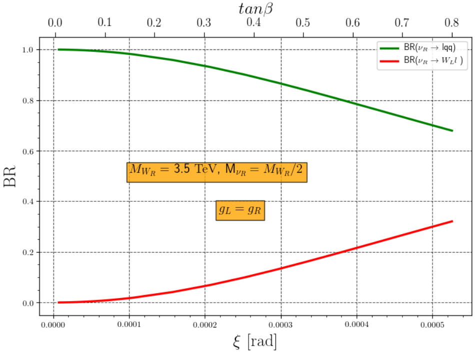


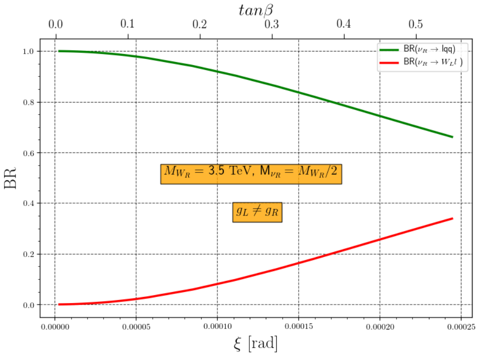


Scenario II: $M_{\nu_R} < M_{W_R}$

$$W_R \to \ell\nu_R \to \ell\ell W_R^\star \to \ell\ell qq', \quad \ell = e \text{ or } \mu\,.$$

$$W_R \to \ell\nu_R \to \ell\ell W_L \to \ell\ell qq', \quad \ell = e \text{ or } \mu\,.$$





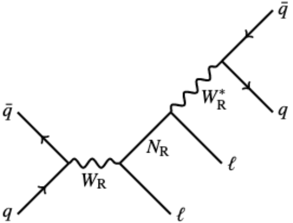
$$\overline{\nu} W_L^{+\mu} \ell \longrightarrow \frac{i}{\sqrt{2}} \gamma^\mu \left(g_L P_L K_L \cos\xi - g_R P_R K_R \sin\xi \right)$$

$$\overline{\nu} W_R^{+\mu} \ell \longrightarrow \frac{i}{\sqrt{2}} \gamma^\mu \left(g_R P_R K_R \cos\xi - g_L P_L K_L \sin\xi \right)$$

K_L and K_R are PMNS mixing matrices in the left and right leptonic sectors, defined as

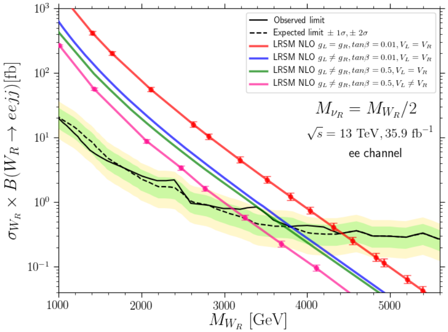
$$K_L = V_L^{\nu\,\dagger} V_L^{\ell}\,,$$

$$K_R = V_R^{\nu\,\dagger} V_R^{\ell}\,.$$

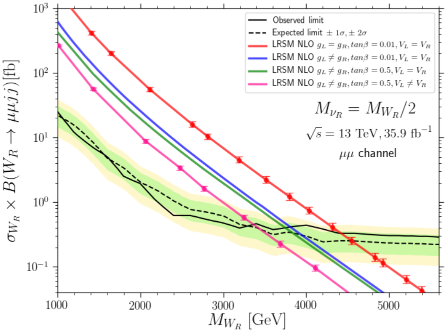


Scenario II: $M_{\nu_R} < M_{W_R}$

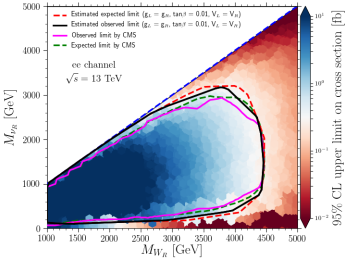
eejj final state

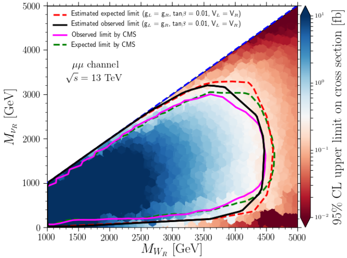


$\mu\mu$jj final state

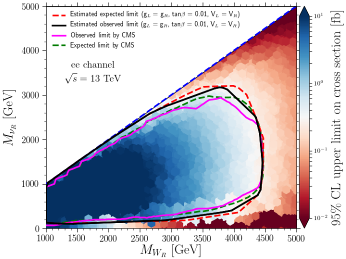


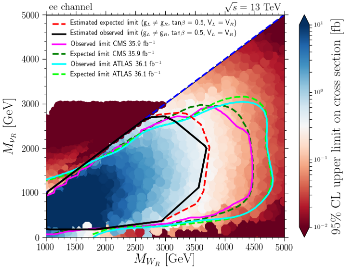
Correlating W_R and ν_R mass bounds

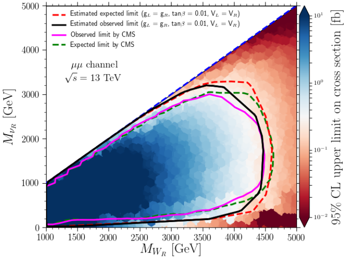


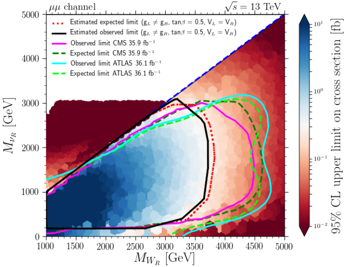


Correlating W_R and ν_R mass bounds

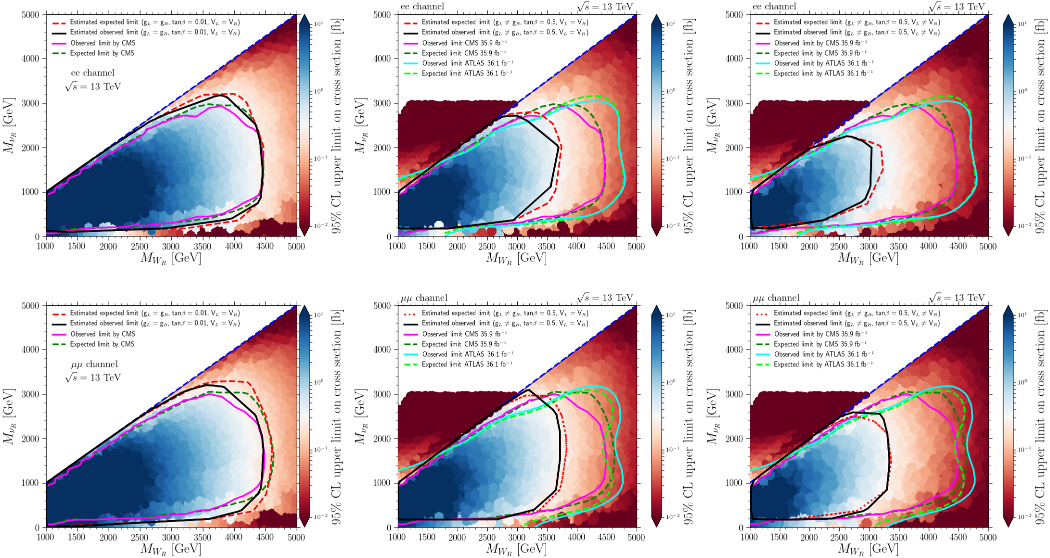








Correlating W_R and ν_R mass bounds



Outline

Conclusion

Scenario I: $M_{\nu_R} > M_{W_R}$	Lower limits for M_{W_R} (GeV)		Exclusion channel
	Expected	Observed	
$g_L = g_R$, $\tan\beta = 0.01$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	3450	3600	$W_R \to tb$
$g_L \neq g_R$, $\tan\beta = 0.01$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	2700	2700	$W_R \to tb$
$g_L \neq g_R$, $\tan\beta = 0.5$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	2675	2675	$W_R \to tb$
$g_L \neq g_R$, $\tan\beta = 0.5$, $V^L_{\mathrm{CKM}} \neq V^R_{\mathrm{CKM}}$	1940	2360	$W_R \to tb$
$g_L = g_R$, $\tan\beta = 0.01$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	3625	3620	$W_R \to jj$
$g_L \neq g_R$, $\tan\beta = 0.01$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	2700	2555	$W_R \to jj$
$g_L \neq g_R$, $\tan\beta = 0.5$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	2650	2500	$W_R \to jj$
$g_L \neq g_R$, $\tan\beta = 0.5$, $V^L_{\mathrm{CKM}} \neq V^R_{\mathrm{CKM}}$	2010	2000	$W_R \to jj$

Table: Lower limits for M_{W_R} in GeV, when $M_{\nu_R} > M_{W_R}$.

Conclusion

Scenario II: $M_{\nu_R} < M_{W_R}$	Lower limits for M_{W_R} (GeV)		Exclusion channel
	Expected	Observed	
$g_L = g_R$, $\tan\beta = 0.01$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	4420	4420	$W_R \to qqee$
$g_L \neq g_R$, $\tan\beta = 0.01$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	3800	3800	$W_R \to qqee$
$g_L \neq g_R$, $\tan\beta = 0.5$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	3720	3725	$W_R \to qqee$
$g_L \neq g_R$, $\tan\beta = 0.5$, $V^L_{\mathrm{CKM}} \neq V^R_{\mathrm{CKM}}$	3300	3100	$W_R \to qqee$
$g_L = g_R$, $\tan\beta = 0.01$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	4500	4420	$W_R \to qq\mu\mu$
$g_L \neq g_R$, $\tan\beta = 0.01$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	3950	3800	$W_R \to qq\mu\mu$
$g_L \neq g_R$, $\tan\beta = 0.5$, $V^L_{\mathrm{CKM}} = V^R_{\mathrm{CKM}}$	3900	3750	$W_R \to qq\mu\mu$
$g_L \neq g_R$, $\tan\beta = 0.5$, $V^L_{\mathrm{CKM}} \neq V^R_{\mathrm{CKM}}$	3400	3350	$W_R \to qq\mu\mu$

Table: Lower limits for M_{W_R} in GeV when $M_{\nu_R} < M_{W_R}$.

Conclusion

	BM I : $M_{\nu_R} > M_{W_R}$	**BM II** : $M_{\nu_R} < M_{W_R}$
m_{W_R} [GeV]	2557	3689
m_{ν_R} [GeV]	16797	1838
$\sigma(\mathrm{pp} \to W_R)$ [fb] @13 TeV	48.7	3.98
$\sigma(\mathrm{pp} \to W_R)$ [fb] @27 TeV	478.0	77.3
$\mathrm{BR}(W_R \to t\bar{b})$ [%]	26.3	19.9
$\mathrm{BR}(W_R \to jj)$ [%]	58.6	45.8
$\mathrm{BR}(W_R \to \nu_R \ell)$ [%]	-	6.5 (each family)
$\mathrm{BR}(W_R \to h_1 W_L)$ [%]	1.8	1.5
$\mathrm{BR}(W_R \to W_L Z)$ [%]	2.0	1.6
$\mathrm{BR}(\nu_R \to \ell q q')$ [%]	-	65.3
$\mathrm{BR}(\nu_R \to W_L \ell)$ [%]	1.1×10^{-4}	33.1
$\mathrm{BR}(\nu_R \to W_R \ell)$ [%]	99.9	-

Table: Related Branching Ratios and Cross Sections for **BM I** and **BM II**.

Thank you!