

Lepton Flavour Non-Universality in U(1) Extended MSSMs

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- Supersymmetry (SUSY) is one of the most studied NP theories at LHC, since it has remarkable advantages.,
 - The Hierarchy Problem.
 - Natural light Higgs boson.
 - Unification of the gauge couplings.
 - WIMP candidate in order to solve the DM puzzle.
- Minimal Supersymmetric Standard Model (MSSM) is the simplest SUSY extension of the SM.

$$W_{MSSM} = \mu H_u H_d + Y_u \hat{Q} H_u \hat{U} + Y_d \hat{Q} H_d \hat{D} + Y_e \hat{L} H_d \hat{E}$$

UMSSMs

- U(1) extended MSSMs (UMSSMs) have been broadly worked upon the literature, e.g. E_6 motivated, $B - L$ and Secluded UMSSMs.
- Such extensions can stem from Superstring and Grand Unified Theories (GUTs).
- These models can dynamically generate the μ term at the EW scale by introducing new singlet Higgs field as $\mu = \frac{1}{2}\lambda \langle S \rangle$.
- They also introduce a new massive neutral gauge boson, called Z' and U(1)' charges must satisfy the Anomaly Cancellation Conditions (ACCs) stemming from the additional U(1)' group insertion.

Motivations

- ACCs can be satisfied with two different ways.
 - Adding exotics into the model.
 - Using non-holomorphic terms without any exotics, called minimal UMSSM in which the $U(1)'$ **charges can be flavour non-universal**.
- A family non-universal Z' boson can explain the experimental results on R_K and R_{K^*} that deviate from SM.
- Numerous well-motivated $U(1)'$ sub-models which give new and different signals for the detection of the extra Z' .

Gauge Structure:

$$SU(3) \times SU(2) \times U(1) \times U(1)'$$

Superpotential:

$$\widehat{W} = h_u \widehat{Q} \cdot \widehat{H}_u \widehat{U} + h_d \widehat{Q} \cdot \widehat{H}_d \widehat{D} + h_\tau \widehat{L}_3 \cdot \widehat{H}_d \widehat{E}_3 + \lambda \widehat{S} \widehat{H}_u \cdot \widehat{H}_d + h_\nu \widehat{L} \cdot \widehat{H}_u \widehat{N} + \kappa \widehat{S} \widehat{D}_x \widehat{D}_x^-$$

Non-Holomorphic Terms:

$$-\mathcal{L}^{NH} = T'_e \tilde{L}_1 H_u \tilde{E}_1^c + T'_\mu \tilde{L}_2 H_u \tilde{E}_2^c + h.c.$$

The Charges:

Gauge group/Field	\widehat{Q}	\widehat{U}	\widehat{D}	\widehat{L}_i	\widehat{N}_i	\widehat{E}_i	\widehat{H}_u	\widehat{H}_d	\widehat{S}	\widehat{D}_x	\widehat{D}_x^-
$SU(3)_C$	3	$\bar{3}$	$\bar{3}$	1	1	1	1	1	1	3	$\bar{3}$
$SU(2)_L$	2	1	1	2	1	1	2	2	1	1	1
$U(1)_Y$	1/6	-2/3	1/3	-1/2	0	1	1/2	-1/2	0	Y_{D_x}	$-Y_{D_x}$
$U(1)'$	Q_Q	Q_U	Q_D	Q_{L_i}	Q_{N_i}	Q_{E_i}	Q_{H_u}	Q_{H_d}	Q_S	Q_{D_x}	$Q_{D_x^-}$

Constraints

$$m_h = 122 - 128 \text{ GeV},$$

$$m_{\tilde{g}} \geq 2 \text{ TeV},$$

$$0.8 \times 10^{-9} \leq \text{BR}(B_s \rightarrow \mu^+ \mu^-) \leq 6.2 \times 10^{-9} \text{ (} 2\sigma \text{ tolerance),}$$

$$m_{\tilde{\chi}_1^\pm} \geq 103.5 \text{ GeV},$$

$$m_{\tilde{\tau}} \geq 105 \text{ GeV},$$

$$2.99 \times 10^{-4} \leq \text{BR}(B \rightarrow X_s \gamma) \leq 3.87 \times 10^{-4} \text{ (} 2\sigma \text{ tolerance),}$$

$$0.15 \leq \frac{\text{BR}(B_u \rightarrow \tau \nu_\tau)_{\text{UMSSM}}}{\text{BR}(B_u \rightarrow \tau \nu_\tau)_{\text{SM}}} \leq 2.41 \text{ (} 3\sigma \text{ tolerance),}$$

$$0.0913 \leq \Omega_{\text{CDM}} h^2 \leq 0.1363 \text{ (} 5\sigma \text{ tolerance).}$$

Z' Mass Limits

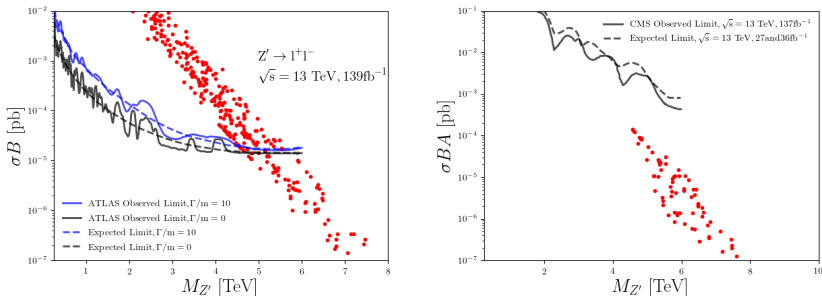


Figure 1: The Z' boson mass limits on $\sigma(pp \rightarrow Z' \rightarrow ll)$ vs $M_{Z'}$ (left panel) and $\sigma(pp \rightarrow Z' \rightarrow \text{jets})$ vs $M_{Z'}$ (right panel), where l describes electron and muon while jets refer to contributions from both the SM and exotic quarks. All points plotted here satisfy all experimental constraints given in the previous section. In the right panel, we have additionally applied the Z' mass constraint from the left panel.

$U(1)'$ Charges

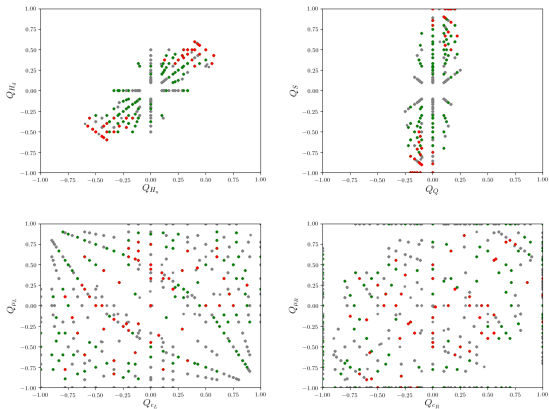


Figure 2: The distributions of the $U(1)'$ charges allowed by various theoretical and experimental conditions over the following planes. All points are consistent with REWSB, ACCs and neutralino LSP. Green points are a subset of the gray ones as they also satisfy all experimental constraints. Red points are a subset of the green ones as they are also compatible with the Z' boson mass bounds.

Z' Decays

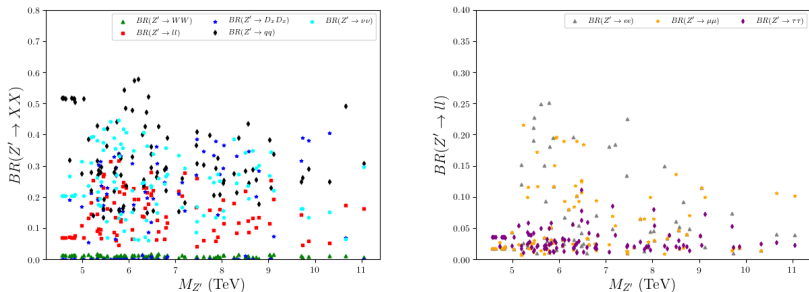


Figure 3: The BRs of the Z' for different decay channels, $BR(Z' \rightarrow XX)$ as a function on $M_{Z'}$ (left panel) and $BR(Z' \rightarrow ll)$ as a function on $M_{Z'}$ (right panel), where XX represents all two-body final states while ll describes individual leptonic final states.

SUSY Mass Spectrum

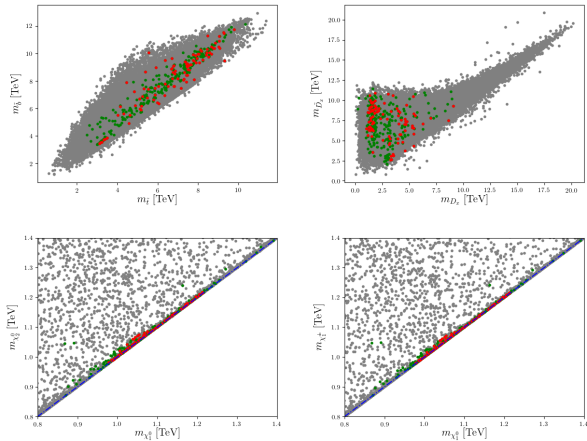


Figure 4: The mass spectrum of the lightest chargino, two lightest neutralinos, stops, sbottoms and exotic (both fermionic and scalar) states.

Colliders Signatures at LHC-Exotics

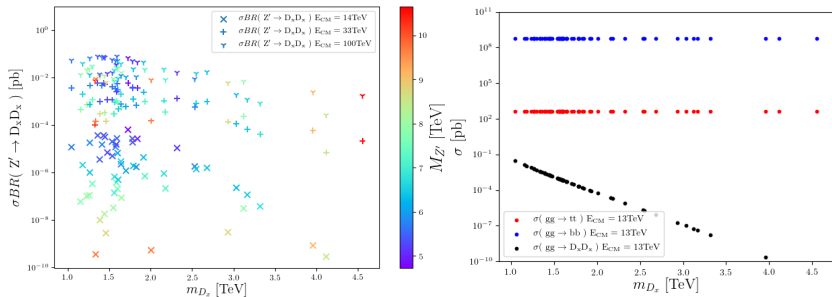


Figure 5: The pair production cross sections of all exotic quarks through Z' mediation in terms of relevant Z' mass (left panel) at the HL-LHC (14 TeV), HE-LHC (33 TeV) and VLHC/FCC-hh (100 TeV) and those mediated by QCD (right panel), the latter alongside those for top and bottom quarks at 13 TeV.

Colliders Signatures at LHC-Non-Universality

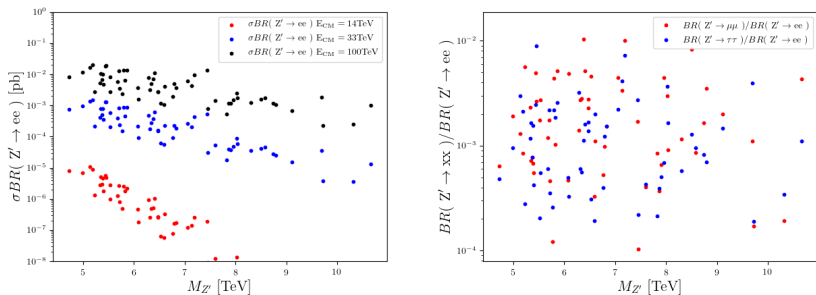


Figure 6: The production cross sections of electron pairs (left panel) through the Z' at the HL-LHC, HE-LHC and VLHC/FCC-hh and the ratio of the BRs of $Z' \rightarrow \mu\mu$ and $Z' \rightarrow \tau\tau$ relative to that of $Z' \rightarrow ee$ (right panel).

Colliders Signatures at CLIC-Exotics

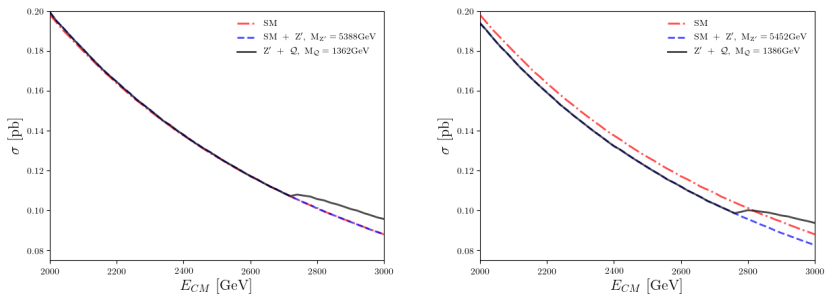


Figure 7: The predicted cross section for quark pair production versus collision energy at CLIC in the case of the SM, SM + Z' and SM + Z' + exotic quarks for BP-I (left) and BP-II (right).

Colliders Signatures at CLiC-Non-Universality

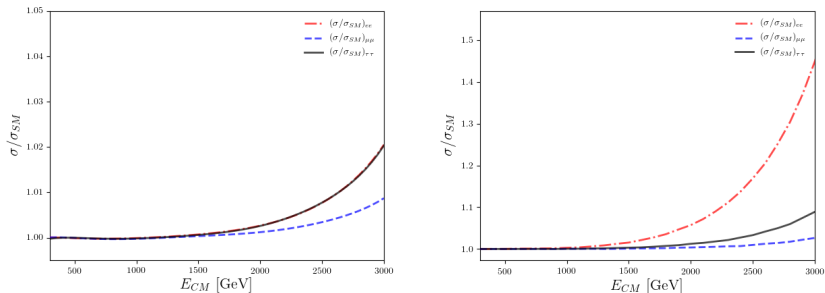


Figure 8: The ratio of the predicted cross section for electron, muon and tauon pair production in the UMSSM relative to the SM values as a function of the collision energy at CLiC for BP-I (left) and BP-II (right).

- Studied potential effects of family non-universal $U(1)'$ charges emerging in an UMSSM containing exotic coloured states onto observables at colliders, both present and future ones.
- The surviving charges produce UMSSM configurations inducing phenomenological manifestations that could be probed at hadronic (HL-LHC, HE-LHC and VLH/FCC-hh) and leptonic (CLiC) accelerators.
- A future e^+e^- machine operating well beyond the TeV scale would be the ideal laboratory almost free from backgrounds to test this dynamics while future pp ones would suffer from limitations connected to either small signal cross sections or overwhelming QCD noise.
- The study of the processes $e^+e^- \rightarrow \text{hadrons}$ and $e^+e^- \rightarrow l\bar{l}$ could result in the possibility of extracting the parameters of both the exotic and leptonic sector so as to guide the formulation of the true theory yielding the UMSSM as its low scale manifestation.

Thank You for Your Attention!!!