SEARCHES FOR NEW PHYSICS MODELS VIA THE SAME-SIGN DI-BOSON (SSDB) + $\not{E}_T$ AND PRECISE MEASUREMENT OF TOP QUARK FEATURES AT THE LHC

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arXiv: 2106.03888. Published in: Phys.Rev.D 105 (2022) 5, 5

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INTRODUCTION

Till today, though, the Standard Model (SM) is the most celebrated and established theory, there are several reasons to expect new physics beyond SM. At the LHC, we have not seen any clear new physics signal yet. Here, we focus on the novel signal of same-sign diboson (SSdB) + $\not{E}_T$.
Since this signature has very small SM background, observing it would be a clear indication of BSM physics.
The main essence of this work is to point out those BSM models which can possibly be responsible for such a signature, if seen in experiments.
SM Backgrounds: $t\bar{t}$, $tt\bar{t}\bar{t}$, $t\bar{t}W^{\pm}$, $t\bar{t}Z$, $W^{\pm}W^{\pm}jj$, $W^{\pm}W^{\pm}W^{\mp}$, $W^{\pm}Z$, ZZ, $W^{\pm}W^{\mp}Z$ and $W^{\pm}ZZ$.
Potential BSM models $\Longrightarrow$ SSdB + $\not{E}_T$: Supersymmetry, The type-III Seesaw Model, The type-II Seesaw/Georgi-Machacek (GM) model.

Here, I also present a work in progress where we aim to show how precise measurement of quantities related to top quark features can indicate towards a new physics signal.

SUPERSYMMETRY

$m_{sparticles} >> m_{SMparticles}$
LHC Limits : $m_{\tilde{g}} > 2.2$ **TeV,** $m_{\tilde{t}_1} > 1.1$ **TeV** $\Longrightarrow$ **Is SUSY Unnatural?** The measure of Naturalness is the Electroweak fine-tuning parameter (Δ_{EW}) which is defined as $\Delta_{EW} = max_i|C_i|/(M_Z^2/2)$ Where, C_i is any one of the parameters on the RHS of $M_Z^2/2 \approx -m_{H_u}^2 - \mu^2 - \Sigma_u^u(\tilde{t}_{1,2})$ A SUSY model is said to be natural if $\Delta_{EW} < 30$.
We choose a natural SUSY model, namely NUHM2 and generalized it so that gaugino mass unification is not assumed. Though gaugino mass unification is not assumed, the benchmark point that we chose satisfies the mass hierarchy $\mu \ll M_2$ essential to give rise to the SSdB + $\not{E}_T$ signature via the feynman diagram shown in Fig. 1.

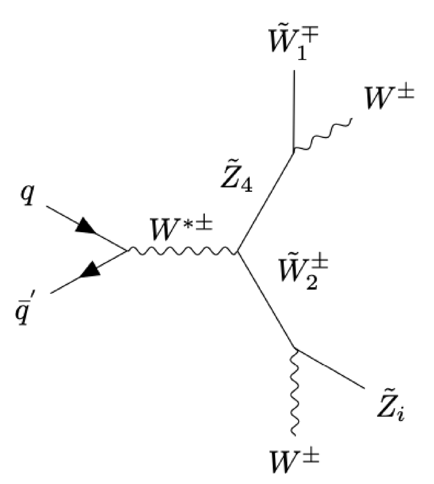

Fig. 1: SSdB production at the LHC in SUSY models with light higgsinos ($\tilde{W}_1^{\mp}$ and $\tilde{Z}_i$ with $i = 1, 2$). Here $\tilde{Z}_4$ and $\tilde{W}_2^{\pm}$ in the intermediate step are winos.

After applying the A3 (A3')-cuts at $\sqrt{s} = 27(100)$ TeV we obtain the significance for various signals as follows:
NUHM2 : 8.06 (13.6) at $\mathcal{L} = 3$ ab^{-1} and 18.01(30.5) at $\mathcal{L} = 15$ ab^{-1}
Type III : 1.21 (1.5) at $\mathcal{L} = 3$ ab^{-1} and 2.71(3.3) at $\mathcal{L} = 15$ ab^{-1}
GM : 0.0135 (0.06) at $\mathcal{L} = 3$ ab^{-1} and 0.03(0.14) at $\mathcal{L} = 15$ ab^{-1}

THE TYPE-III SEESAW MODEL

We consider three generations of $SU(2)_L$ triplet fermions such that the heavier two generations are mass degenerate. Thus the heavier of these fermions can decay into the lighter one via the following feynman diagram and hence give rise to the SSdB + $\not{E}_T$ signature.

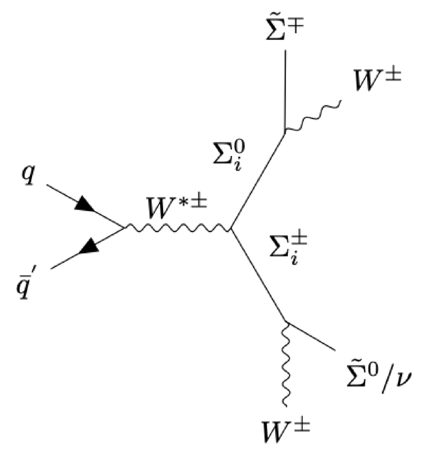

Fig. 2: SSdB + $\not{E}_T$ signature at the LHC in the type-III seesaw model, where $\tilde{\Sigma}^0$ and $\tilde{\Sigma}^{\pm}$ are members of the lightest fermionic triplets.

After applying the B2 (B2')-cuts at $\sqrt{s} = 27(100)$ TeV we obtain the significance for various signals as follows:
NUHM2 : 0.52 (0.8) at $\mathcal{L} = 3$ ab^{-1} and 1.2(1.8) at $\mathcal{L} = 15$ ab^{-1}
Type III : 3.5 (4.3) at $\mathcal{L} = 3$ ab^{-1} and 7.8(9.6) at $\mathcal{L} = 15$ ab^{-1}
GM : 0.45 (1.4) at $\mathcal{L} = 3$ ab^{-1} and 1.0(3.1) at $\mathcal{L} = 15$ ab^{-1}

THE TYPE-II SEESAW/GEORGI-MACHACEK MODEL

In this scenario, the SSdB signature originates from the decay of a doubly-charged scalar. In the type-II Seesaw model, beside the SM spectrum, present is an $SU(2)_L$ triplet scalar $\Delta = (\Delta^{++}, \Delta^{+}, \Delta^{0})$ with hypercharge $Y = 1$. The accompanying jets, being forward, are most likely to escape detection. Then assuming leptonic decay of the W bosons, the final state mimics the signature of our interest.

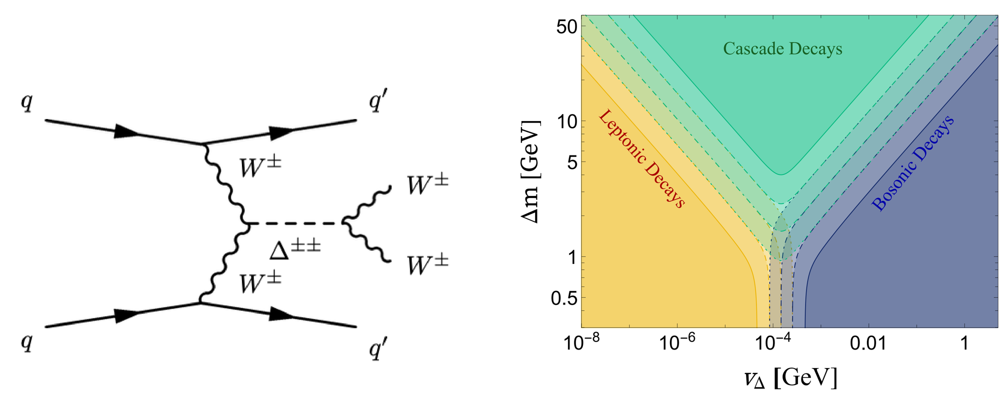

Fig. 3: (a)SSdB + forward jets production at LHC in the type-II seesaw models.(b)Decay phase diagram of doubly-charged scalar ($\Delta^{\pm\pm}$) with mass = 300 GeV.

After applying the C3 (C3')-cuts at $\sqrt{s} = 27(100)$ TeV we obtain the significance for various signals as follows:
NUHM2 : 0 (0.22) at $\mathcal{L} = 3$ ab^{-1} and 0(0.48) at $\mathcal{L} = 15$ ab^{-1}
Type III : 0.22 (1.23) at $\mathcal{L} = 3$ ab^{-1} and 0.5(2.7) at $\mathcal{L} = 15$ ab^{-1}
GM : 2.5 (3.02) at $\mathcal{L} = 3$ ab^{-1} and 5.5(6.75) at $\mathcal{L} = 15$ ab^{-1}

NEW PHYSICS FROM MEASUREMENT OF TOP QUARK FEATURES

- The LHC, being a "top quark factory", helps in precise measurement of various properties of the top quark.
- Deviation from the SM prediction in measuring these properties of the top quark can, very efficiently, shed light on new physics signal.
- Here we study a particular observable, namely, the invariant mass of the b-jet and the lepton ($m_{b\ell}$) assuming leptonic decay of the $W^{\pm}$ boson arising from pair produced top quarks.
- Our goal is to check if there exist a BSM particle with mass around m_t, can it cause any deviation in the $m_{b\ell}$ distribution.

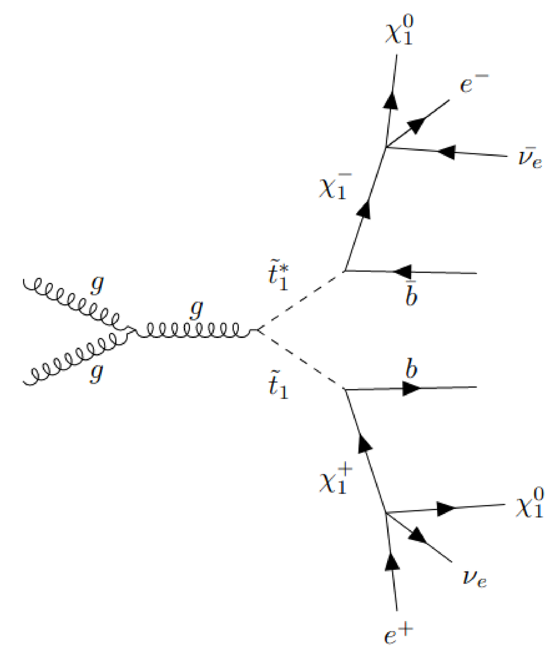

Fig. 4: MSSM signal.

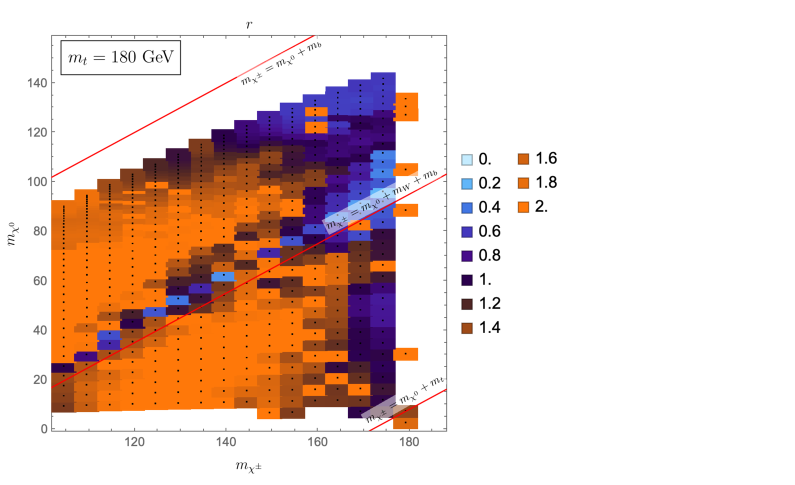

Fig. 5: r < 1 implies that a parameter space point is allowed by the current experimental constraints.

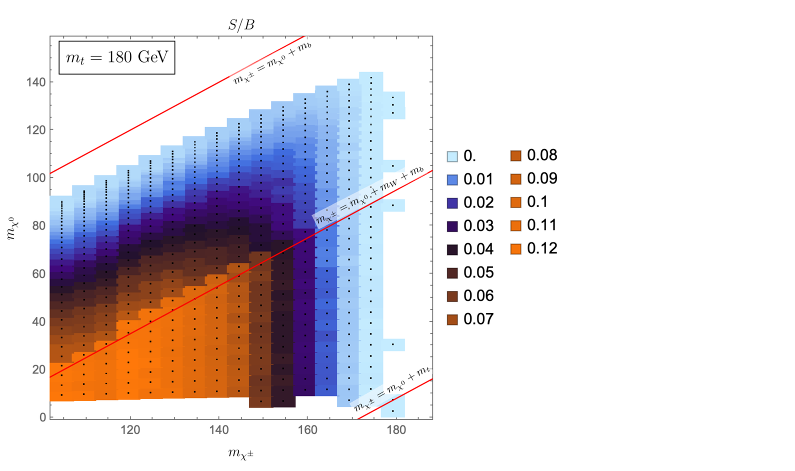

Fig. 6: S/B at $\sqrt{s} = 13$ TeV after acceptance cuts: $p_T(\ell) \geq 25$ GeV, $p_T(j) \geq 25$ GeV, $|\eta(\ell)| < 2.5$, $|\eta(j)| < 2.5$, $\Delta_R(jj) > 0.4$, $\Delta_R(\ell\ell) > 0.1$, $\Delta_R(\ell j) > 0.2$.

CONCLUSION

- We find that it is possible to observe the SSdB + $\not{E}_T$ signature in three well-motivated BSM scenarios, namely: (i) NUHM2 model (ii) type-III seesaw model and (iii) type-II seesaw/Georgi-Machacek model, while still being consistent with the existing theoretical and experimental limits; the first being visible at IL = 3ab^{-1} while the latter two at IL = 15ab^{-1}.
- We chose a simple MSSM BM point with stop mass close to top quark mass such that the stop decays to a b quark, ℓ and $\not{E}_T$ so as to mimic the top decay assuming leptonic decay of $W^{\pm}$ boson.
- We were able to see some excess due to this signal BM point in $m_{b\ell}$ distribution after the acceptance cuts at $\sqrt{s} = 13$ TeV.

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