Aspects of the same-sign diboson signature from wino pair production in natural SUSY at LHC

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Overview

Introduction

- Standard Model(SM) has certain drawbacks like fine tuning in Higgs Mass, inability to explain Dark Matter etc.
- Supersymmetry or SUSY is a highly motivated extension of SM where quadratic divergences are neatly cancelled and is also supported indirectly by experimentally obtained values of gauge couplings, m_t, m_h.
- Each Standard Model particle has a *Superpartner* whose spin vary by 1/2 with respect to its corresponding SM particle.
- Superpartner of a boson (fermion) is a fermion (boson)
- But **no** sparticles have been seen in LHC yet.

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Is SUSY Unnatural?

- However, There are Supersymmetric models which are **radiatively-driven natural** and also respect LHC sparticle and Higgs mass constraints.

One such Radiatively- driven Natural SUSY (RNS) model is the two-extra-parameter non-universal Higgs model (NUHM2) which we have used with parameters as follows :

$m_0 = 5$ TeV, $A_0 =$ -1.6m_0, $tan\beta = 10$, $m_A =$1500 GeV, $\mu = 150$ GeV, $m_{1/2} = 800$ GeV

This spectrum has $\tilde{m_g} = 2007.40$ GeV, $\tilde{m_{t1}} = 1470.30$ GeV, $m_h = 124.38$ GeV and $\Delta_{EW} = 9.3$ for just 10.75% finetuning.

The Electroweak fine-tuning parameter (Δ_{EW}) is defined as

$$\Delta_{EW} = max_i |C_i| / (M_Z^2/2) \quad (1)$$

Where, C_i is any one of the parameters on the RHS of the following equation :

$$\frac{M_Z^2}{2} \approx -m_{H_u}^2 - \mu^2 - \Sigma_u^u(\tilde{t}_{1,2}) \quad (2)$$

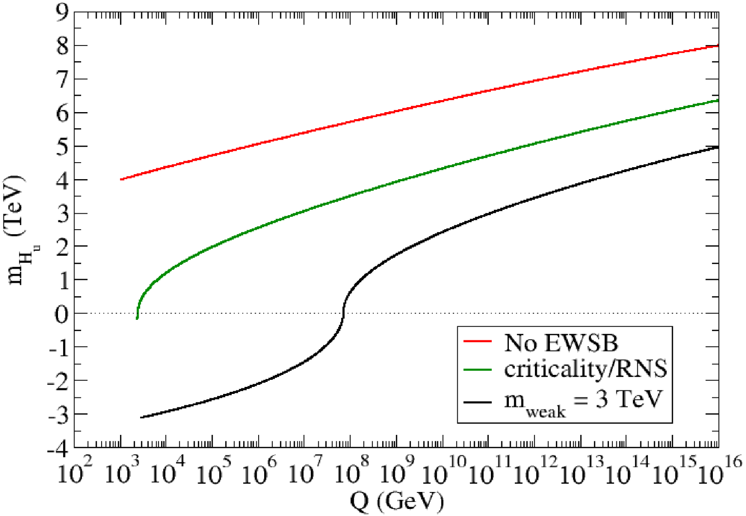


FIG 1: Evolution of the term $sign(m^2_{H_u})\sqrt{m^2_{H_u}}$ for the case of *No EWSB*, criticality as in *RNS* and m_{weak} = 3 TeV as in arXiv : 1602.07697

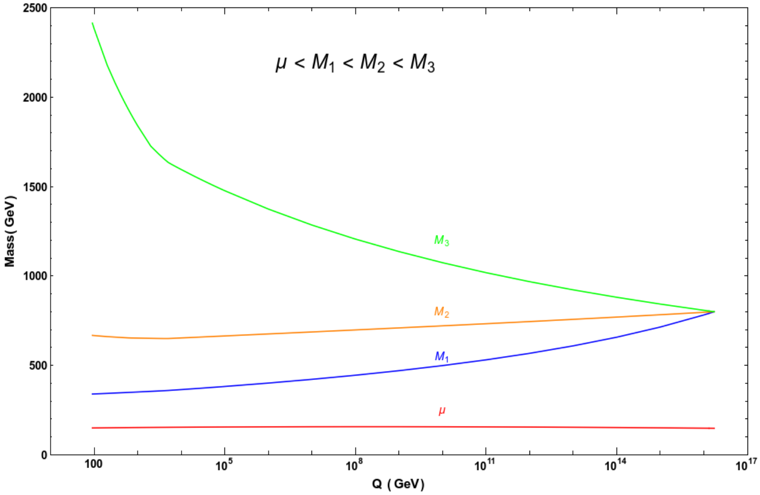


FIG 2

This hierarchy leads to a novel, rather clean same-sign diboson signature from wino pair production at hadron colliders.

Signal Process

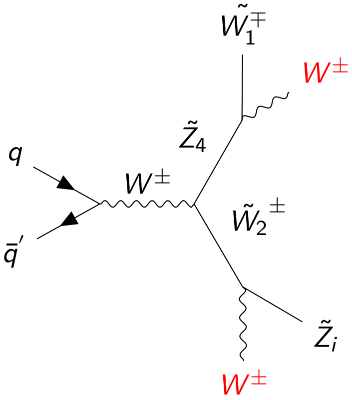
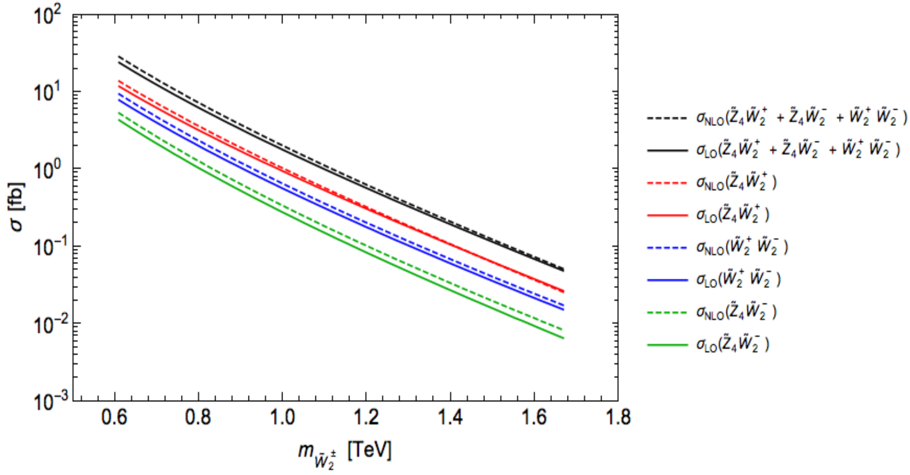


FIG 3 : Same-sign diboson production at LHC in SUSY models with light higgsinos.Here, $\tilde{Z}_4$ and $\tilde{W}_2^{\pm}$ in the intermediate step are winos and $\tilde{W}_1^{\mp}$ and $\tilde{Z}_i$ in the final step are light higgsinos.

SM Background

- $t\bar{t}$
- $W^{\pm}Z$
- $t\bar{t}W^{\pm}$
- $t\bar{t}Z$
- $W^{\pm}W^{\pm}W^{\mp}$
- $t\bar{t}t\bar{t}$
- $W^{\pm}W^{\pm}jj$


10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
σ [fb]
0.6
0.8
1.0
1.2
1.4
1.6
1.8
$m_{\tilde{W}_2^\pm}$ [TeV]
$\sigma_{NLO}(\tilde{Z}_4\tilde{W}_2^+ + \tilde{Z}_4\tilde{W}_2^- + \tilde{W}_2^+\tilde{W}_2^-)$
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$\sigma_{NLO}(\tilde{W}_2^+\tilde{W}_2^-)$
$\sigma_{LO}(\tilde{W}_2^+\tilde{W}_2^-)$
$\sigma_{NLO}(\tilde{Z}_4\tilde{W}_2^-)$
$\sigma_{LO}(\tilde{Z}_4\tilde{W}_2^-)$

FIG 4

C1-Cuts :

- Exactly two same-sign isolated leptons with pTL1 $>$ 20 GeV and pTL2 $>$ 10 GeV
- Number of b-jets $=$ 0
- Missing Transverse Energy $>$ 200 GeV
- Minimum Transverse Mass $>$ 175 GeV

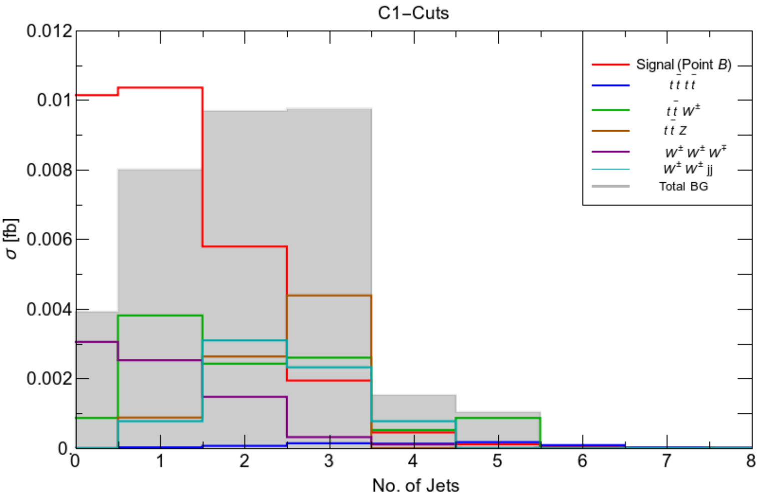

FIG 5 : Jet Multiplicity Distribution for the signal and SM Backgrounds after C1 cuts. (Hence, we require njets $<= 1$)

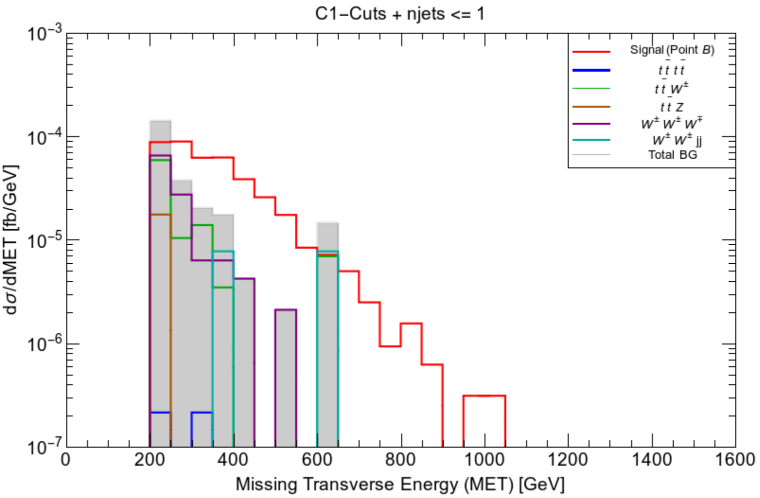

FIG 6 : Missing Transverse Energy distribution for the signal and SM Backgrounds after C1 cuts+ njets $<= 1$.

(Hence, we require MET > 250 GeV)

C2-Cuts :

- Exactly two same-sign isolated leptons with pTL1 $>$ 20 GeV and pTL2 $>$ 10 GeV
- Number of b-jets $=$ 0
- **Missing Transverse Energy $>$ 250 GeV**
- Minimum Transverse Mass $>$ 175 GeV
- **Number of jets $<=$ 1**

Cut-Flow Table

Sigma (in ab)			
Process	σ(NLO)	C1-cuts	C2-cuts
Signal($m_{1/2} = 800$ GeV)	$1.55 \cdot 10^4$	28.8	16.1
$t\bar{t}$	$9.5 \cdot 10^8$	0	0
$W^\pm Z$	$5.2 \cdot 10^7$	0	0
$t\bar{t}W^\pm$	$5.2 \cdot 10^5$	11.1	1.73
$t\bar{t}Z$	$8.8 \cdot 10^5$	7.9	0
$W^\pm W^\pm W^\mp$	$3.2 \cdot 10^5$	7.5	2.3
$t\bar{t}t\bar{t}$	$1.1 \cdot 10^4$	0.6	0.011
$W^\pm W^\pm jj$	$3.9 \cdot 10^5$	7.0	0.8
Total BG	$1.0065 \cdot 10^9$	34.1	4.83

The Signal has been adjusted to include the NLO contribution as well according to the prospino result.
The Background processes include k-factors as obtained from literature and verified using MCFM.

Direct Event Counting

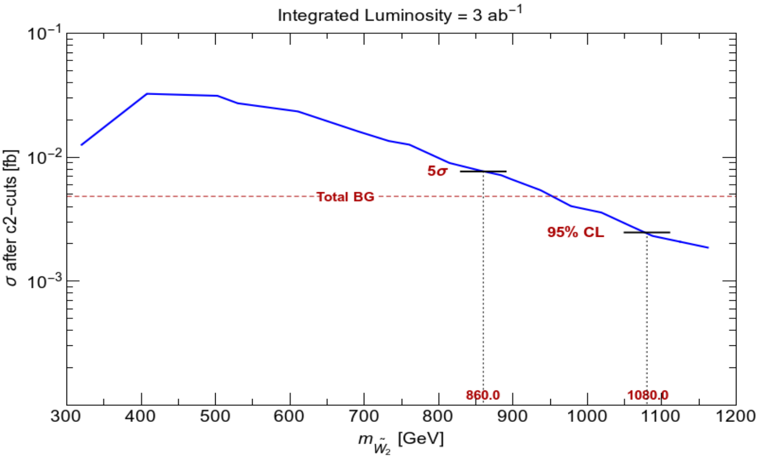

FIG 7 : Production cross-section of $\tilde{W}_2\tilde{W}_2 + \tilde{W}_2\tilde{Z}_4$ vs Mass of wino.

Charge Asymmetry

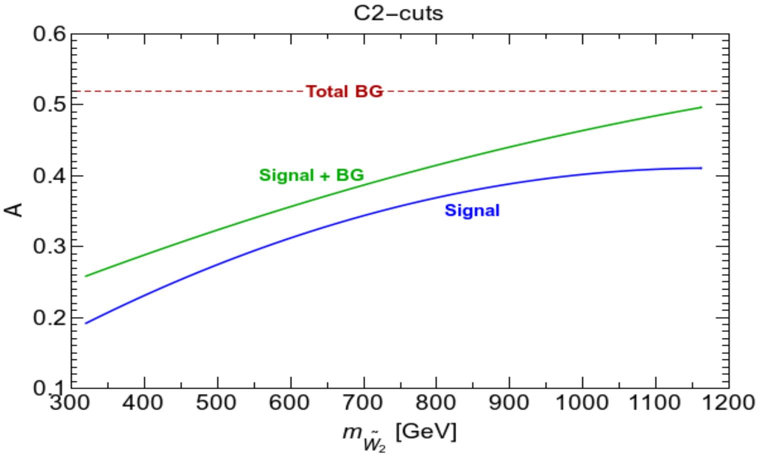

FIG 8 : Same-Sign Diboson Charge Asymmetry vs Mass of wino $m_{\tilde{W}_2}$, with Charge Asymmetry $A = \frac{\sigma(++)-\sigma(--)}{\sigma(++)+\sigma(--)}$.

Fits to Distribution

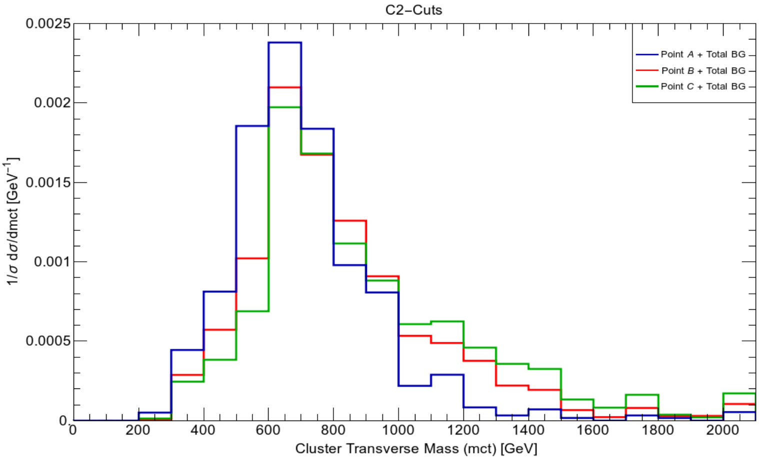

FIG 9 : Distribution in Cluster Transverse Mass for three signal benchmark points and summed SM backgrounds in SSdB production after C2 cuts.

$m_{\tilde{W}_2} \approx 530$ GeV; $m_{\tilde{W}_2} \approx 692$ GeV; $m_{\tilde{W}_2} \approx 884$ GeV

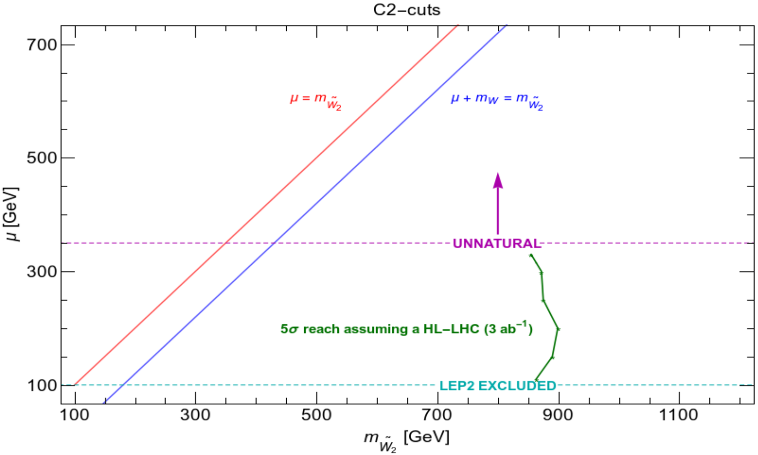

FIG 10 : Simplified model for SSdB discovery in the $m_{\tilde{W}_2}$ vs μ plane.

Conclusion

- In this project we have used a radiatively-driven natural Supersymmetric Model with light higgsino, thereby giving rise to a clean same-sign diboson signal from wino pair production.
- Certain cuts have been selected in order to efficiently reduce the background so that the signal is clean enough to be detected experimentally.
- For an integrated luminosity of 3000 fb^{-1} this Same-Sign diboson signal should be observable at LHC14 for wino mass upto 860 GeV.
- Assuming gaugino mass unification, this result is consistent with the gluino mass reach ($\approx$ 2.8 TeV) in the paper arXiv : 1612.00795 (H.Baer *et.al.*)
- We recommend to extract the wino mass through three different channels : Event Counting, Charge Asymmetry, Fits to Distribution. Thus we can have a better measurement and consistency check of the Wino mass.

THANK YOU

QUESTIONS ?

Back Up Slides

Δ_{EW}, Δ_{HS}, Δ_{BG}

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The Electroweak Measure Δ_{EW}

$$\frac{m_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d^d) - (m_{H_u}^2 + \Sigma_u^u)tan^2\beta}{(tan^2\beta - 1)} - \mu^2 \tag{3}$$

$$\approx -m_{H_u}^2 - \mu^2 - \Sigma_u^u(\tilde{t}_{1,2}) \tag{4}$$

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Sensitivity to High Scale Parameters Δ_{BG}

$$m_Z^2 \approx -2m_{H_u}^2 - 2\mu^2 \tag{5}$$

The Large Log Measure Δ_{HS}

$$m_h^2 \approx \mu^2 + m_{H_u}^2(\Lambda) + \delta m_{H_u}^2 \quad (6)$$

where Λ is a high energy scale up to which MSSM is valid. Λ can be as high as m_{GUT} or even m_P.

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A simple fix for Δ_{HS} is to regroup the dependent terms as follows :

$$m_h^2 \approx \mu^2 + (m_{H_u}^2(\Lambda) + \delta m_{H_u}^2) \tag{7}$$

This regrouping now leads back to Δ_{EW} measure because now $(m_{H_u}^2(\Lambda) + \delta m_{H_u}^2) = m_{H_u}^2(Weak)$.