A new approach for detecting compressed bino/wino at the LHC

Chengcheng Han @apctp

Based on arXiv:1409.4533

Collaborated with L. Wu, J. M. Yang, M. Zhang, Y. Zhang

The 4th KIAS workshop

Outline

1. Introduction
2. Our new approach
3. Our simulation results
4. Conclusions

Introduction

Why electroweakino?

I Electroweakinos could still be light (tens to hundreds GeV).

(1) First/second generation squarks have been excluded to 1-2TeV.

(2) Gluino has been excluded to 1.5 TeV.

(3) Stop or sbottom have been excluded hundreds GeV.

II Models of split SUSY or anomaly mediation predict electroweakinos could be much lighter than other sparticles.

III In R-parity conservation SUSY models, neutralino dark matter is one of the electroweakinos.

Introduction

The elecweakinos sector of SUSY

The electroweakinos sector includes:bino $\tilde{B}$ wino $\tilde{W}$ higgsino $\tilde{H}_{1,2}$

Resulting in

four neutralinos $\tilde{\chi}^0_{1,2,3,4}$

two pair of charginos $\tilde{\chi}^\pm_{1,2}$

Generally the search strategies depends on the spectrum and the ingredient:

In the most of cases:$m_{\tilde{\chi}^\pm_1} \sim \mathrm{m}_{\tilde{\chi}^0_2}$

such as: bino LSP-wino NLSP;bino LSP-Higgsino NLSP; Higgsino LSP and etc.

The properties of final state products depending on the $\Delta m = m_{\tilde{\chi}^0_2} - m_{\tilde{\chi}^0_1}$

Introduction

The status of electroweakino study

I ATLAS and CMS have performed multi-leptons search.
Sensitive to $\Delta m > M_Z$.

II Soft leptons can help to search more compressed region.
Sensitive to 15 GeV $\lesssim \Delta m < M_Z$.

III Monojet and VBF may detect the very compressed region.
Sensitive to 5 GeV $< \Delta m$.

IV New methods are emerging.
Sensitive to 5 GeV $< \Delta m <$ 15 GeV ???

Our new approach

Here we focus on $5 \text{ GeV} < \Delta m < 15 \text{ GeV}$ (bino LSP wino NLSP)

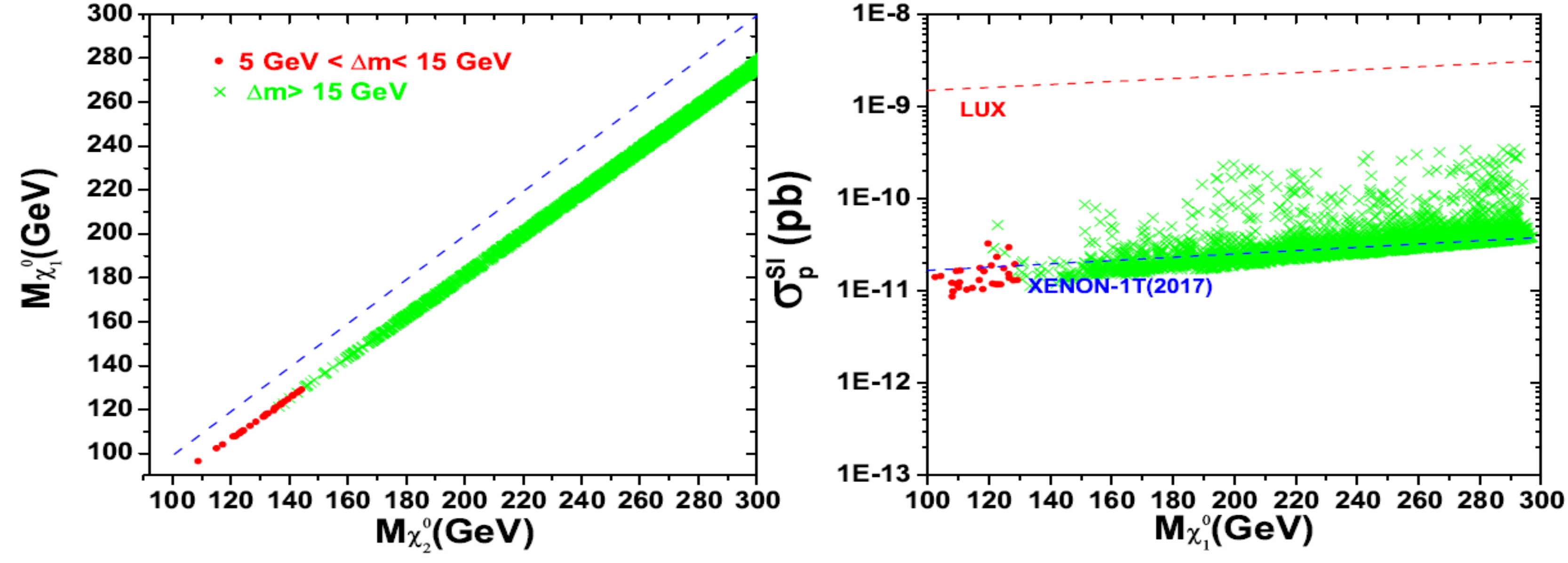
- The limit is weak from the SUSY direct search results.
- This region is also difficult to be probed.
- Dark matter relic density requires the small splitting.

Bino-Wino Co-Annihilation (BWCA) region.

The dark matter direct search

Bino-Wino Co-Annihilation (BWCA) region

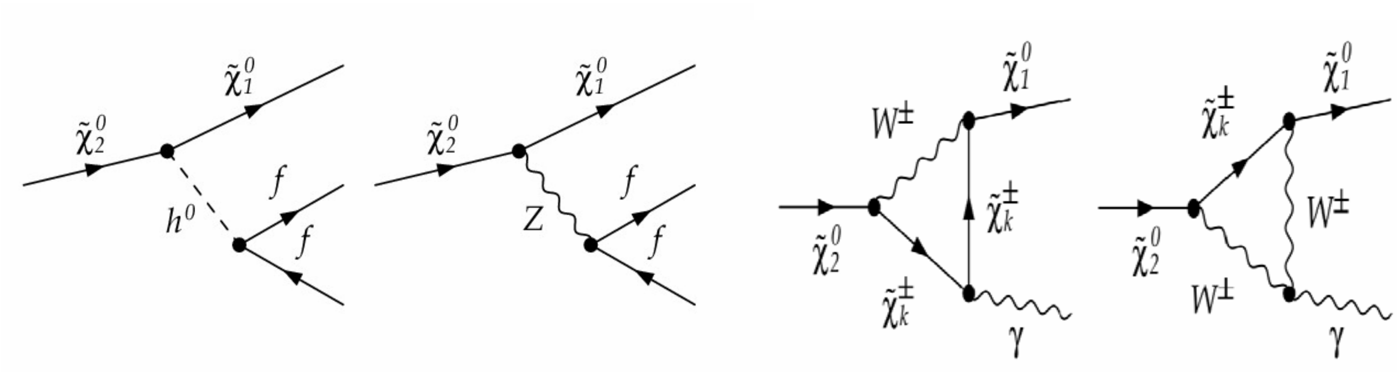
From arXiv:1409.4533
Chengcheng Han et al.



For the region with $\tilde{\chi}_2^0 \lesssim 150$ GeV, the dark matter relic density can be guaranteed by the co-annihilation among $\tilde{\chi}_2^0$, $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ due to their small mass splitting $\Delta M \sim 5 - 15$ GeV. However, such a region could not be covered by the current LUX and future XENON-1T(2017) experiments because of the suppression of the coupling.

Our new approach

In this case, the loop process $\tilde{\chi}_2^0 \to \gamma\tilde{\chi}_0^1$ would become sizably



From arXiv:1409.4533
Chengcheng Han et al.

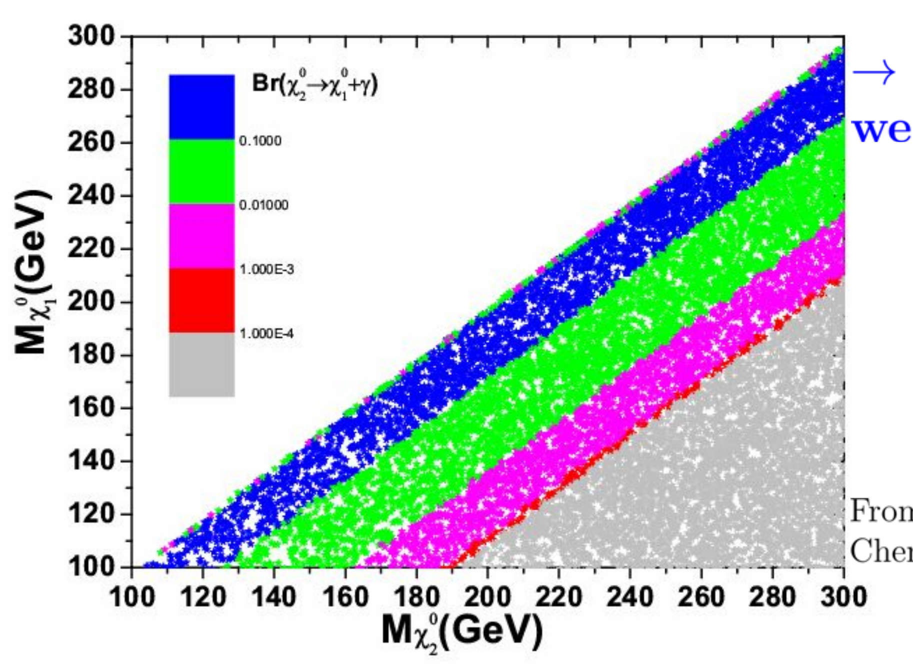
$$\Gamma(\tilde{\chi}_2^0 \to \gamma\tilde{\chi}_0^1) \propto (1 - m_{\tilde{\chi}_2^0}/m_{\tilde{\chi}_1^0})^3$$

$$\Gamma(\tilde{\chi}_2^0 \to f\bar{f}\tilde{\chi}_0^1) \propto (1 - m_{\tilde{\chi}_2^0}/m_{\tilde{\chi}_1^0})^5$$

When splitting become small, the tree level process reduces more quickly than loop process.
When mass splitting is small enough $\tilde{\chi}_2^0 \to \gamma\tilde{\chi}_0^1$ dominates

Our new approach

The dependence of branching ratio of $\tilde{\chi}_2^0 \to \gamma \tilde{\chi}_0^1$ on the masses of $\tilde{\chi}_{1,2}^0$



→ **The blue region we are interested in**

From arXiv:1409.4533
Chengcheng Han et al.

For $\Delta m < 20$ GeV, the decay $\tilde{\chi}_2^0 \to \gamma \tilde{\chi}_0^1$ can have a branching ratio as large as 10%. As the mass splitting gets large, the decay branching ratio reduces rapidly. We should also note that when the mass splitting is very small (< 5 GeV), the decay branching ratio will reduce a bit. This is because for such a tiny mass splitting $\tilde{\chi}_2^0$ would have sizable bino component.

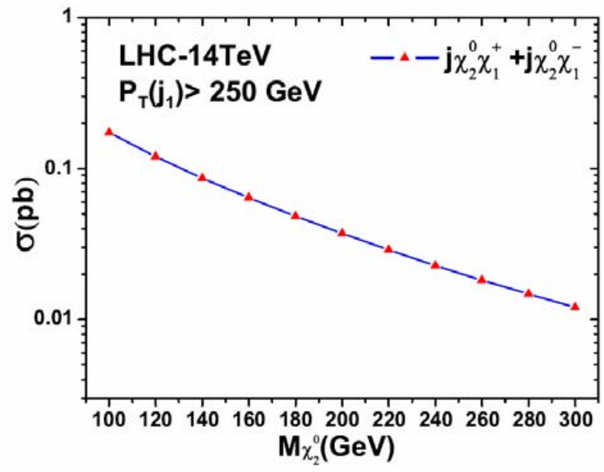
Our new approach

We choose the $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production followed by the decays

$$\tilde{\chi}_1^{\pm} \to W^* \tilde{\chi}_1^0 \to \ell\nu\tilde{\chi}_1^0$$
$$\tilde{\chi}_2^0 \to \gamma\tilde{\chi}_0^1$$

But the signal $\ell + \gamma + E_T^{miss}$ has small E_T^{miss} because $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ are back to back

So we add a hard initial state radiation jet to enhance the E_T^{miss}.
our final signal is $j + \ell + \gamma + E_T^{miss}$.
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 j$ prodution rate (the tree level cross section from MadGraph)



For $m_{\tilde{\chi}_2^0} = 150$ GeV the cross section can reach 0.074 pb.
We will use this mass as benchmark point.

From arXiv:1409.4533
Chengcheng Han et al.

Our new approach

We choose four benchmark points, with $\tilde{\chi}_2^0$ fixed to be 150 GeV and the splitting Δm=20,15,10,5 GeV

$(m_{\tilde{\chi}_1^0},\, m_{\tilde{\chi}_2^0})$ in GeV	(130,150)	(135,150)	(140,150)	(145,150)
$\mathrm{Br}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \gamma)$	0.101	0.2266	0.495	0.834

In the table, the first row is the mass of $(\tilde{\chi}_1^0, \tilde{\chi}_2^0)$. The second row is the decay branching ratio of $\tilde{\chi}_2^0 \to \gamma \tilde{\chi}_0^1$. Here μ and $\tan\beta$ are set to be 1 TeV and 30, respectively. Large μ is to keep the purity of the sparticle. The branching ratio has not much dependence on $\tan\beta$.

Our new approach

Backgrounds (cross section is from madgraph)

- **Wγ j (W on shell or off shell) :**

  Cross section is 0.75pb when $P_T(j_1) > 250$ GeV.

- **Z($\tau\tau$)+j : cross section is 0.84 pb when $P_T(j_1) > 250$ GeV**

- **W+jets : a jet mistagged as a photon $\sim 10^{-4}$.**
  $\sigma_{W+jets}/\sigma_{W\gamma j} \lesssim 100$. **Much smaller than W$\gamma j$.**

- top backgrounds: dilepton decay when one lepton mistagged as a photon.

- **others backgrounds**

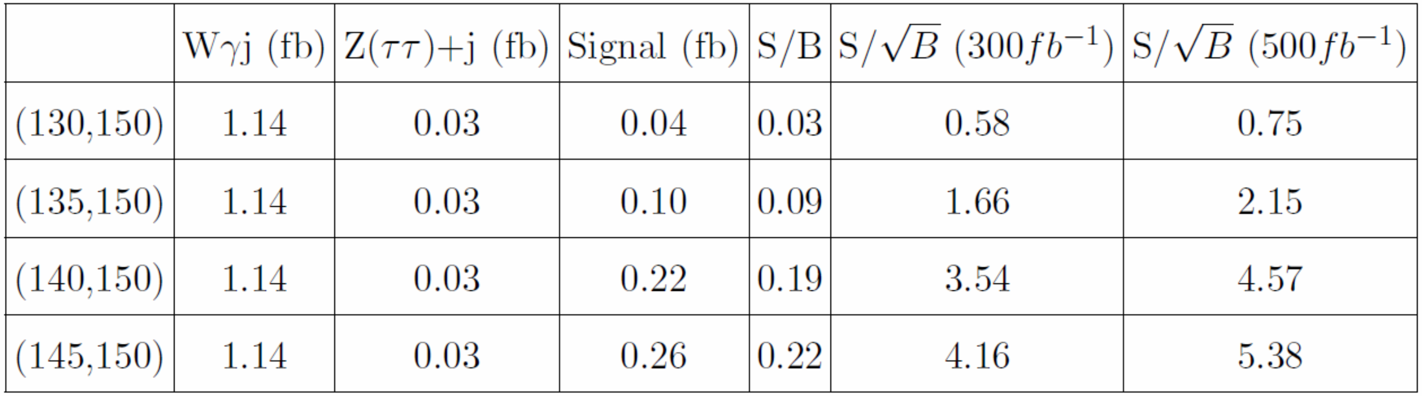
Our new approach

Selection criteria

- **One hard jet: A hard jet with $P_T(j_1) > 300$ GeV (b veto).**
  Events with $P_T(j_2) > 30$ GeV will be vetoed.(To exclude $t\bar{t}$ background)
- $\not{E}_T^{miss} > 300$ **GeV**
- **One isolated soft lepton: 10 GeV$< P_T^l <$ 25 GeV**
- **One isolated photon: 10 GeV$< P_T^\gamma <$ 40 GeV**

Simulation results

Significance



	$W\gamma$j (fb)	$Z(\tau\tau)$+j (fb)	Signal (fb)	S/B	$S/\sqrt{B}$ ($300 fb^{-1}$)	$S/\sqrt{B}$ ($500 fb^{-1}$)
(130,150)	1.14	0.03	0.04	0.03	0.58	0.75
(135,150)	1.14	0.03	0.10	0.09	1.66	2.15
(140,150)	1.14	0.03	0.22	0.19	3.54	4.57
(145,150)	1.14	0.03	0.26	0.22	4.16	5.38

→ smallest splitting has best sensitivity

The signal with a small mass splitting has a good S/B and could be probed at the future LHC. The benchmark point with the smallest mass splitting gives the best result, whose statistical significance can reach 4σ for 300 fb^{-1} and 5σ for 500 fb^{-1}. When the mass splitting is enlarged to 15 GeV, the sensitivity can still reach 2σ for 500 fb^{-1}.

Conclusion

We proposed to use the signal $\ell + j + \gamma + \not{E}_T^{miss}$ to probe the compressed bino/wino scenario at the LHC.

From detailed Monte Carlo simulations we find that the 14 TeV LHC with luminosity of 500 fb^{-1} can probe the wino NLSP up to 150 GeV for a wino-bino mass splitting 5-15 GeV.

Such a method is also applicable to the compressed bino/higgsino scenario.

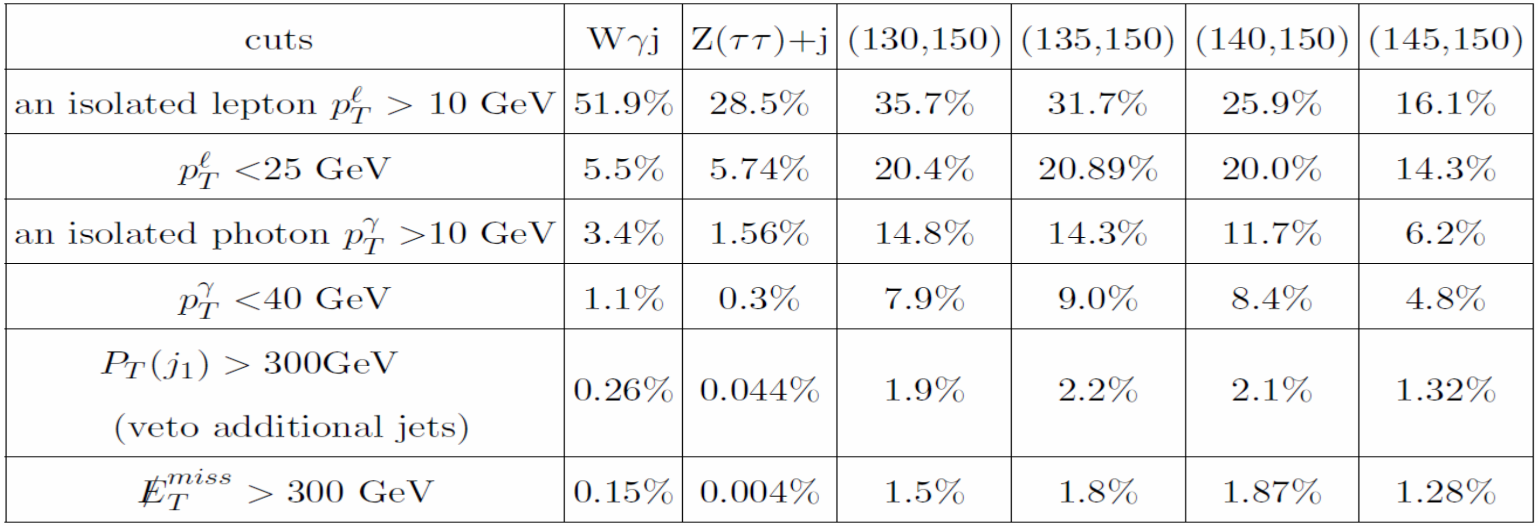
We investigated the dark matter detection sensitivities for this scenario and found that the planned XENON-1T(2017) cannot fully cover the parameter space with wino below 150 GeV allowed by relic density and the LUX limits.

Thanks !

Back up

Simulation results

Cut flow (0.2 million events)



cuts	Wγj	Z($\tau\tau$)+j	(130,150)	(135,150)	(140,150)	(145,150)
an isolated lepton $p_T^{\ell} > 10$ GeV	51.9%	28.5%	35.7%	31.7%	25.9%	16.1%
$p_T^{\ell} <$25 GeV	5.5%	5.74%	20.4%	20.89%	20.0%	14.3%
an isolated photon $p_T^{\gamma} >$10 GeV	3.4%	1.56%	14.8%	14.3%	11.7%	6.2%
$p_T^{\gamma} <$40 GeV	1.1%	0.3%	7.9%	9.0%	8.4%	4.8%
$P_T(j_1) >$ 300GeV (veto additional jets)	0.26%	0.044%	1.9%	2.2%	2.1%	1.32%
$\not{E}_T^{miss} >$ 300 GeV	0.15%	0.004%	1.5%	1.8%	1.87%	1.28%

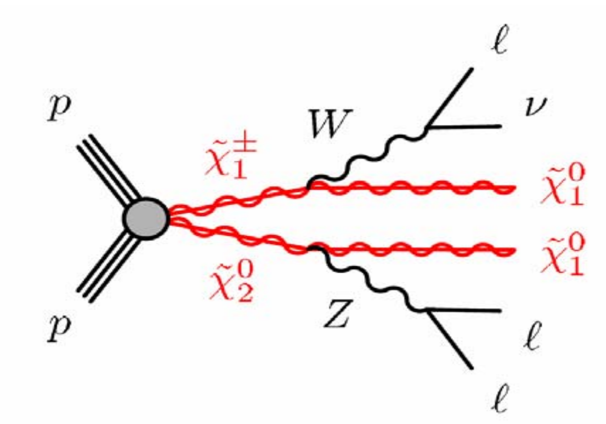
The background $W\gamma j$ can be suppressed by requiring the lepton and photon to be soft. With all the cuts the efficiency of the signal is about an order larger than the $W\gamma j$ background. When the splitting is 5 GeV, the efficiency will reduce largely because the decline of efficiency to identify a lepton.

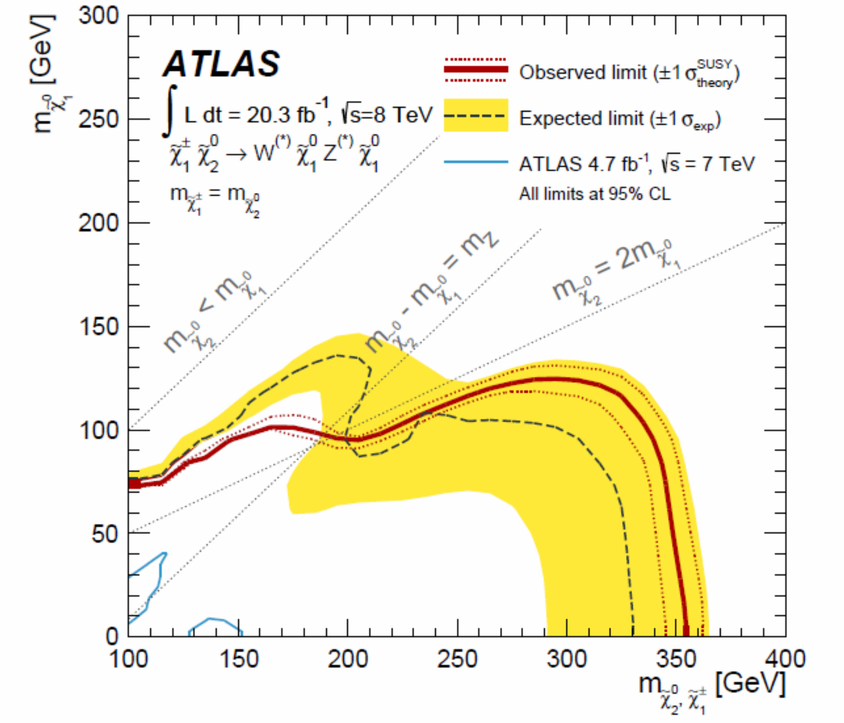
The status of electroweakino study

The ATLAS 3l results

Associated production of $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ with decaying via intermediate gauge bosons and the LSP.

Sensitive to $\Delta m > M_Z$





It can reach 350 GeV when LSP is massless

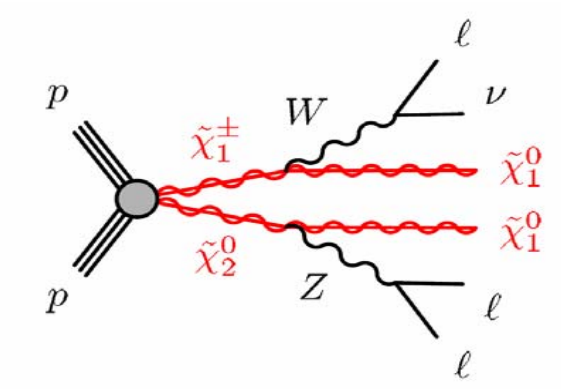
The status of electroweakino study

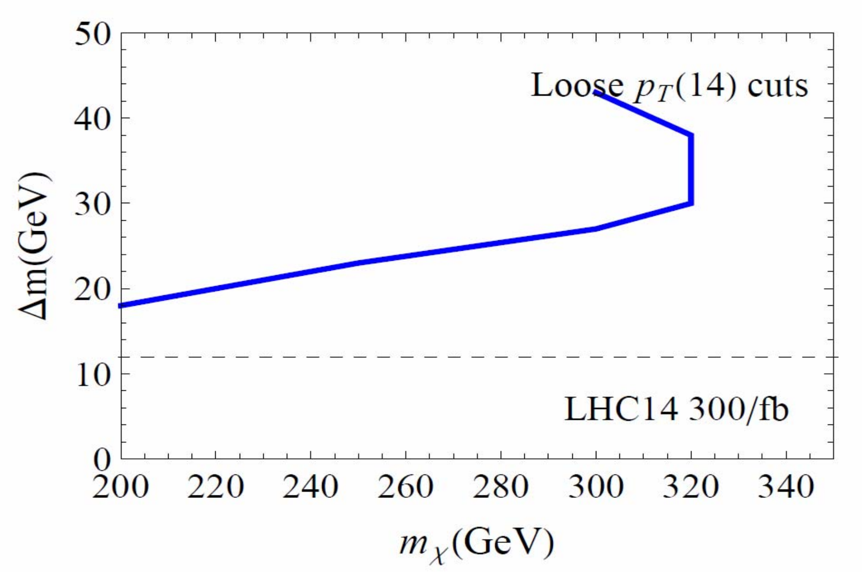
S. Gori, S. Jung, L.T. Wang JHEP 1310 (2013) 191

Soft 3 leptons signal

When intermediate gauge bosons is off shell.

Sensitive to 15 GeV $\lesssim \Delta m < M_Z$





It can reach 220 GeV when Δm=20 GeV @ LHC 14TeV 300 fb^{-1}

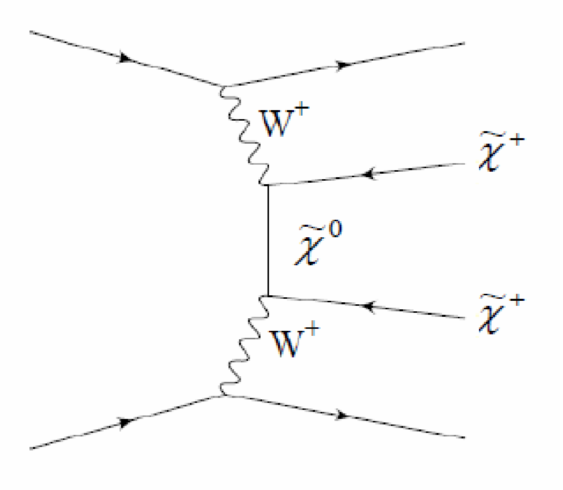
The status of electroweakino study

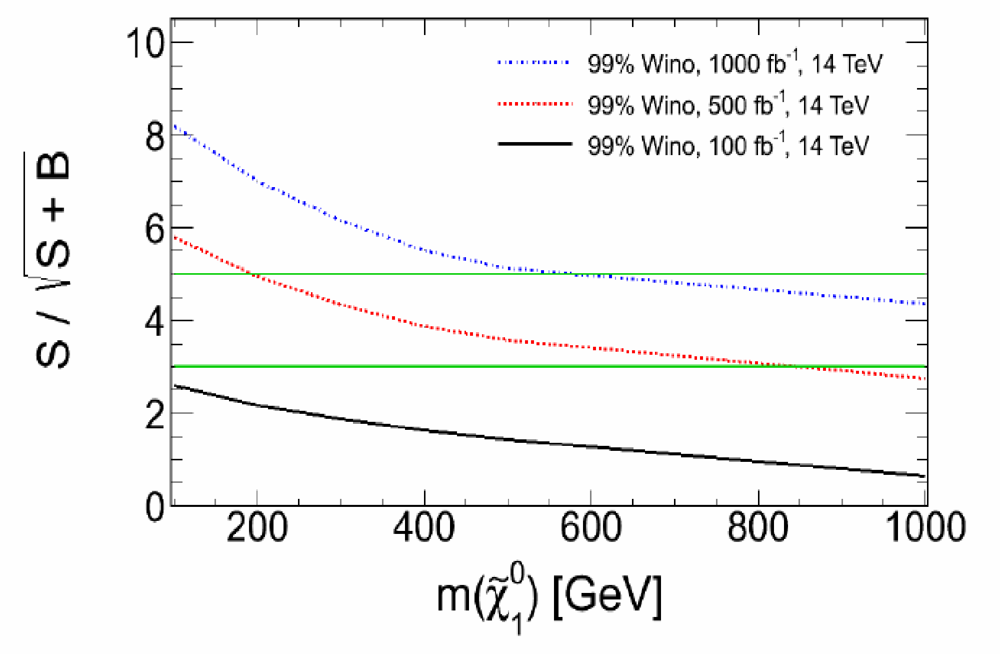
Andres G. Delannoy et al . Phys.Rev.Lett. 111 (2013) 061801

2 jets plus missing energy (VBF channel)

Small splitting makes the electroweakinos behave as missing energy

Sensitive to $\Delta m < 5$ GeV





It can reach 200 GeV @14TeV LHC 100 fb^{-1}

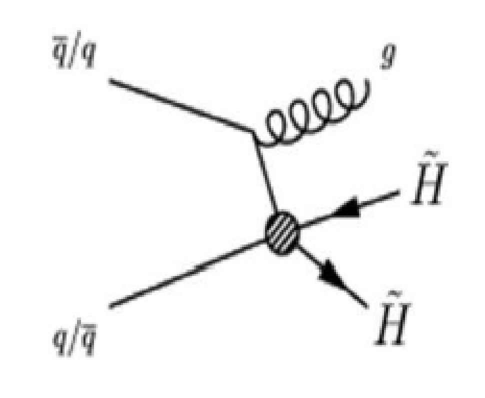
The status of electroweakino study

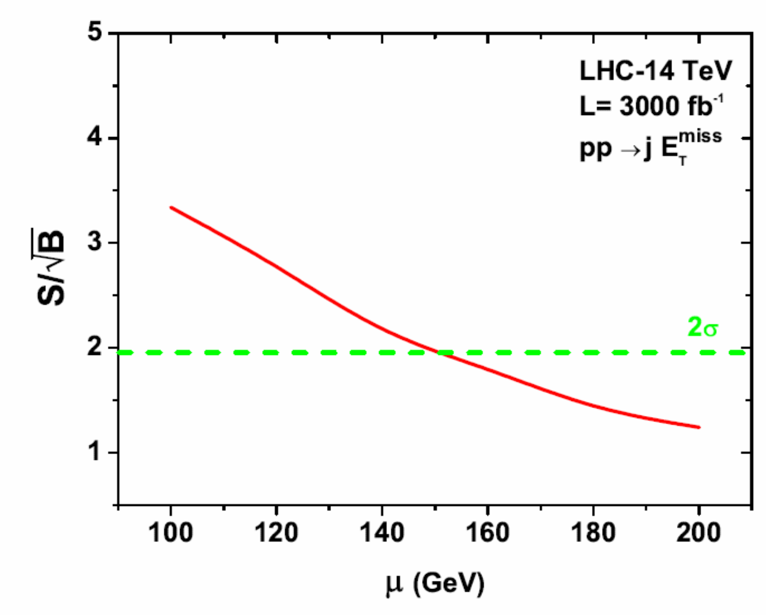
Chengcheng Han, A. Kobakhidze, N. Liu, A. Saavedra, L. Wu, J. M. Yang
JHEP 1402 (2014) 049 arXiv:1310.4274

Mono-jet plus missing energy

Initial State Radiation jet (Higgsino LSP)

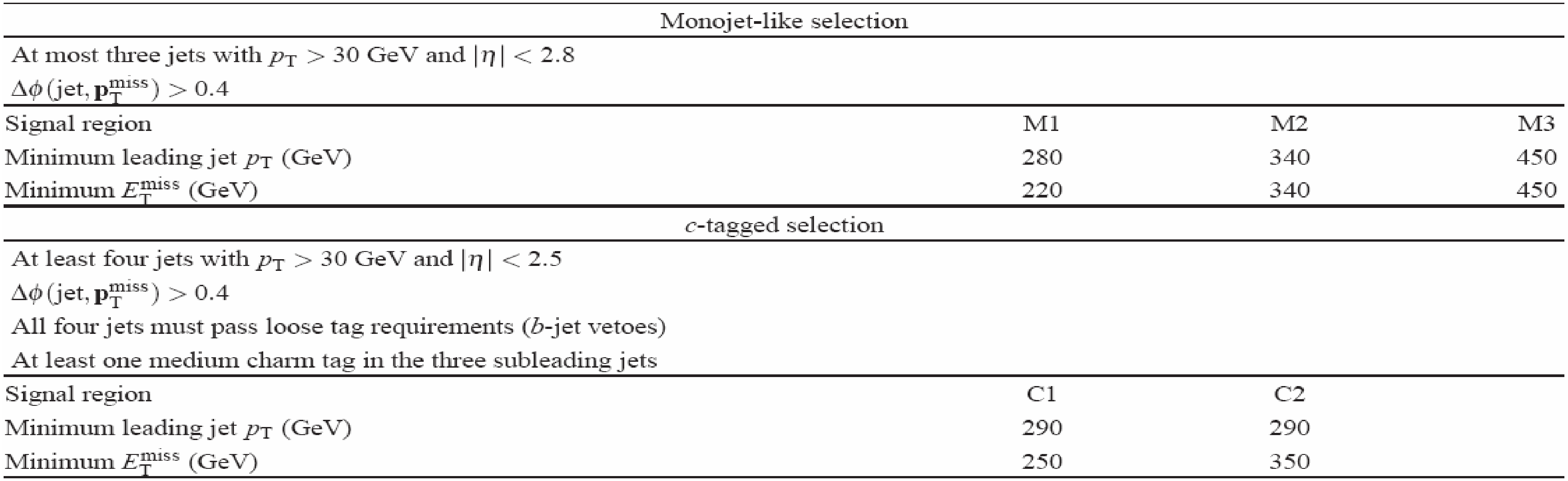
Sensitive to $\Delta m < 5$ GeV



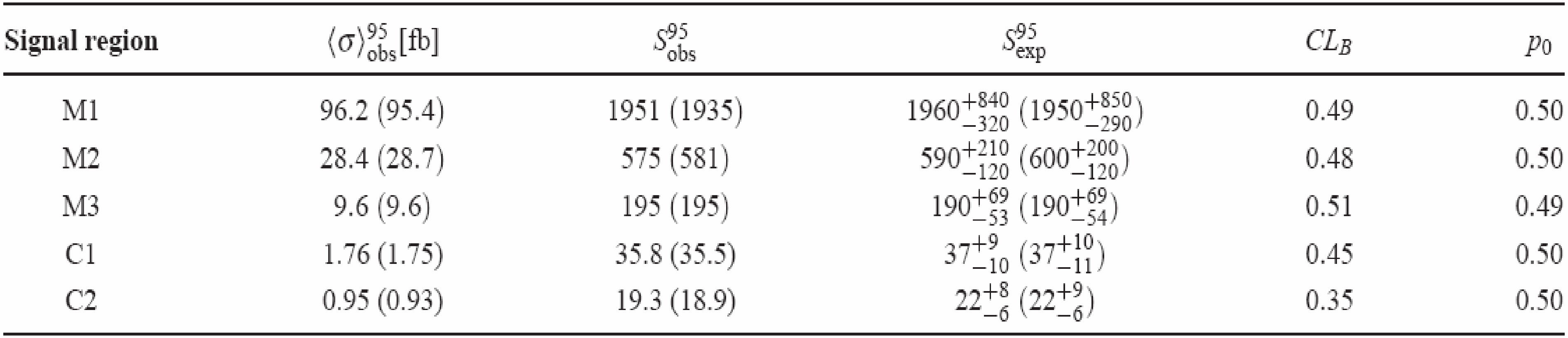


It can reach 150 GeV @14TeV LHC 3000 fb^{-1}

The status of monojet search



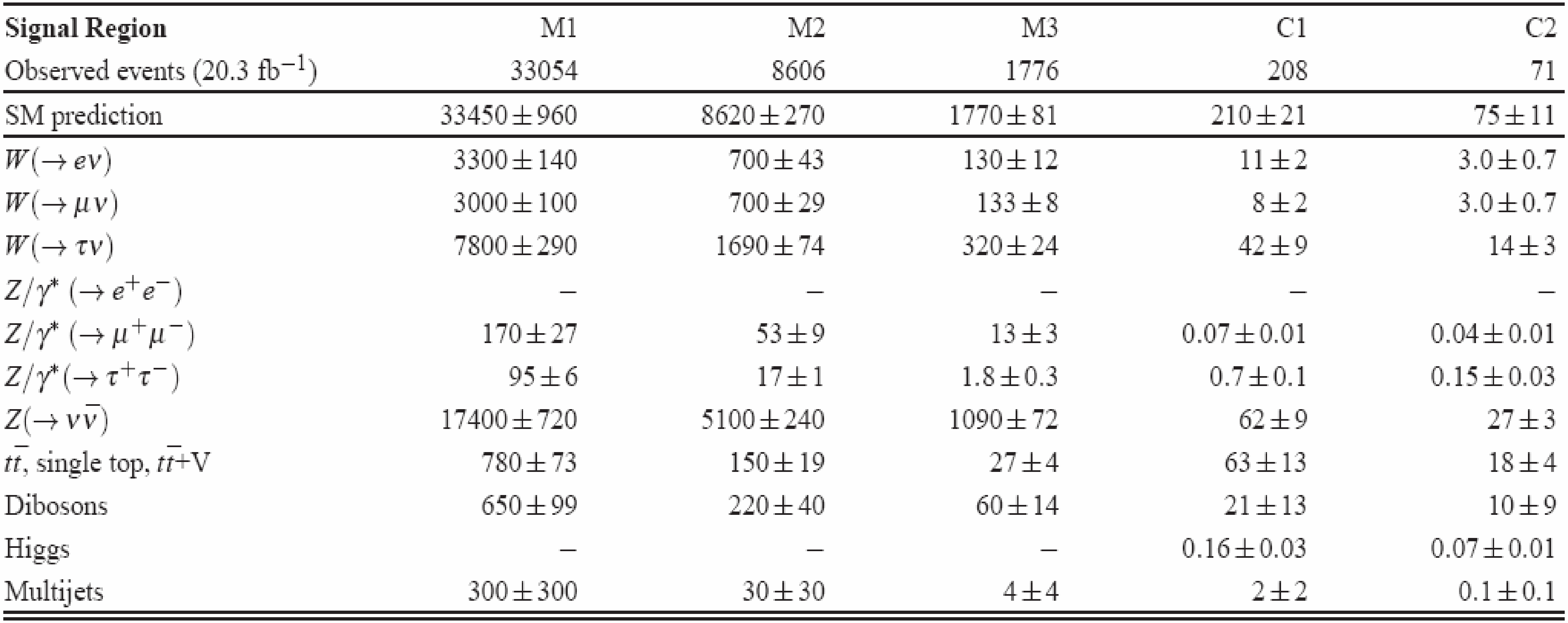
Monojet-like selection			
At most three jets with $p_T > 30$ GeV and $\|\eta\| < 2.8$			
$\Delta\phi(\text{jet}, \mathbf{p}_T^{\text{miss}}) > 0.4$			
Signal region	M1	M2	M3
Minimum leading jet p_T (GeV)	280	340	450
Minimum E_T^{miss} (GeV)	220	340	450
c-tagged selection			
At least four jets with $p_T > 30$ GeV and $\|\eta\| < 2.5$			
$\Delta\phi(\text{jet}, \mathbf{p}_T^{\text{miss}}) > 0.4$			
All four jets must pass loose tag requirements (*b*-jet vetoes)			
At least one medium charm tag in the three subleading jets			
Signal region	C1	C2	
Minimum leading jet p_T (GeV)	290	290	
Minimum E_T^{miss} (GeV)	250	350	



Signal region	$\langle\sigma\rangle_{\text{obs}}^{95}$[fb]	S_{obs}^{95}	S_{exp}^{95}	CL_B	p_0
M1	96.2 (95.4)	1951 (1935)	1960^{+840}_{-320} (1950^{+850}_{-290})	0.49	0.50
M2	28.4 (28.7)	575 (581)	590^{+210}_{-120} (600^{+200}_{-120})	0.48	0.50
M3	9.6 (9.6)	195 (195)	190^{+69}_{-53} (190^{+69}_{-54})	0.51	0.49
C1	1.76 (1.75)	35.8 (35.5)	37^{+9}_{-10} (37^{+10}_{-11})	0.45	0.50
C2	0.95 (0.93)	19.3 (18.9)	22^{+8}_{-6} (22^{+9}_{-6})	0.35	0.50

For $m_{\tilde{\chi}_2^0} = 150$ GeV the cross section only 5.4 fb(8TeV only $P_{Tj} > 340$GeV).
The cut efficinecy $\sim 30\%$

The status of monojet search



Signal Region	M1	M2	M3	C1	C2
Observed events (20.3 fb^{-1})	33054	8606	1776	208	71
SM prediction	33450 ± 960	8620 ± 270	1770 ± 81	210 ± 21	75 ± 11
$W(\rightarrow e\nu)$	3300 ± 140	700 ± 43	130 ± 12	11 ± 2	3.0 ± 0.7
$W(\rightarrow \mu\nu)$	3000 ± 100	700 ± 29	133 ± 8	8 ± 2	3.0 ± 0.7
$W(\rightarrow \tau\nu)$	7800 ± 290	1690 ± 74	320 ± 24	42 ± 9	14 ± 3
$Z/\gamma^*\ (\rightarrow e^+e^-)$	–	–	–	–	–
$Z/\gamma^*\ (\rightarrow \mu^+\mu^-)$	170 ± 27	53 ± 9	13 ± 3	0.07 ± 0.01	0.04 ± 0.01
$Z/\gamma^*(\rightarrow \tau^+\tau^-)$	95 ± 6	17 ± 1	1.8 ± 0.3	0.7 ± 0.1	0.15 ± 0.03
$Z(\rightarrow \nu\bar{\nu})$	17400 ± 720	5100 ± 240	1090 ± 72	62 ± 9	27 ± 3
$t\bar{t}$, single top, $t\bar{t}$+V	780 ± 73	150 ± 19	27 ± 4	63 ± 13	18 ± 4
Dibosons	650 ± 99	220 ± 40	60 ± 14	21 ± 13	10 ± 9
Higgs	–	–	–	0.16 ± 0.03	0.07 ± 0.01
Multijets	300 ± 300	30 ± 30	4 ± 4	2 ± 2	0.1 ± 0.1