Mono-Boson Searches for Mass Degenerate States

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Various BSM Scenarios , SUSY and non-SUSY, predict mass degenerate states

Exciting DM, Compressed SUSY spectra, light stops, Higgsino-World, Supersoft Spectra.

For SUSY, we have seen that colored states should be heavy due to Higgs sector measurements and squark/gluino mass bounds. Therefore the EW sector may be the best bet for detection.

These scenarios are tricky to detect, light states could be hiding at quite low energies

Weakino-Mass Splitting

- $M_2 < M_1 < \mu$ In this limit, the LSP and the NLSP are pure wino.
- $M_2 \simeq \mu << M_1$ In this limit, the LSP and the NLSP are a wino-Higgsino mixture.
- $\mu \simeq M_2 \simeq M_1$ In this limit, the LSP and the NLSP are pure Higgsino.

$$\Delta M_{\rm tree} = m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0} = \frac{M_W^2}{\mu^2} \frac{M_W^2}{M_1 - M_2} \tan^2\theta_W \sin^2 2\beta + \mathcal{O}\left(\frac{1}{\mu^3}\right)$$

Must add one loop correction

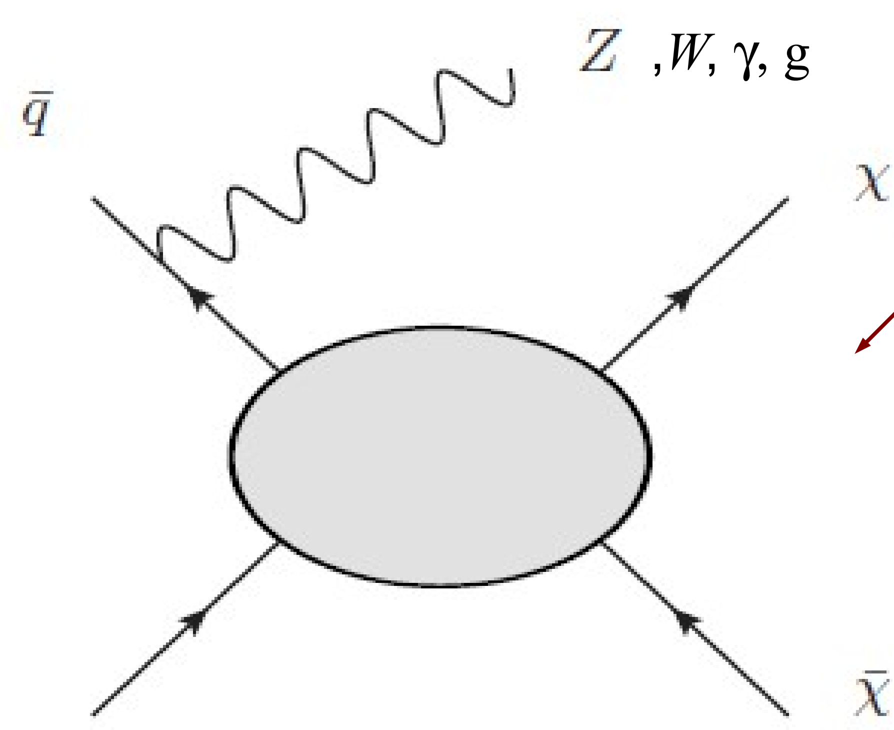
Example Points

Point	μ	M_2	M_1	$m_{\tilde{\chi}_1^+}$	$m_{\tilde{\chi}_1^0}$	ΔM
Wino 1(98% Wino)	700	100	200	98.07	98.06	0.152
Higgsino 1(98% Higgsino)	600	300	3000	292.27	292.26	0.178
Wino 2 (96% Wino)	540	150	180	145.71	145.54	0.321
Higgsino 2 (88% Higgsino)	150	300	1200	136.38	130.26	6.29
Mixed 1(72% Wino and 23 % Bino)	500	200	200	193.22	191.25	2.12
Mixed 2(65% Wino and 23 % Bino)	360	200	200	186.13	182.21	4.07
Mixed 3(28% Wino and 23 % Bino)	180	200	200	138.27	127.75	10.68

Small Mass splitting implies Soft Decay Products.
For most searches, the chargino decay products look like missing energy

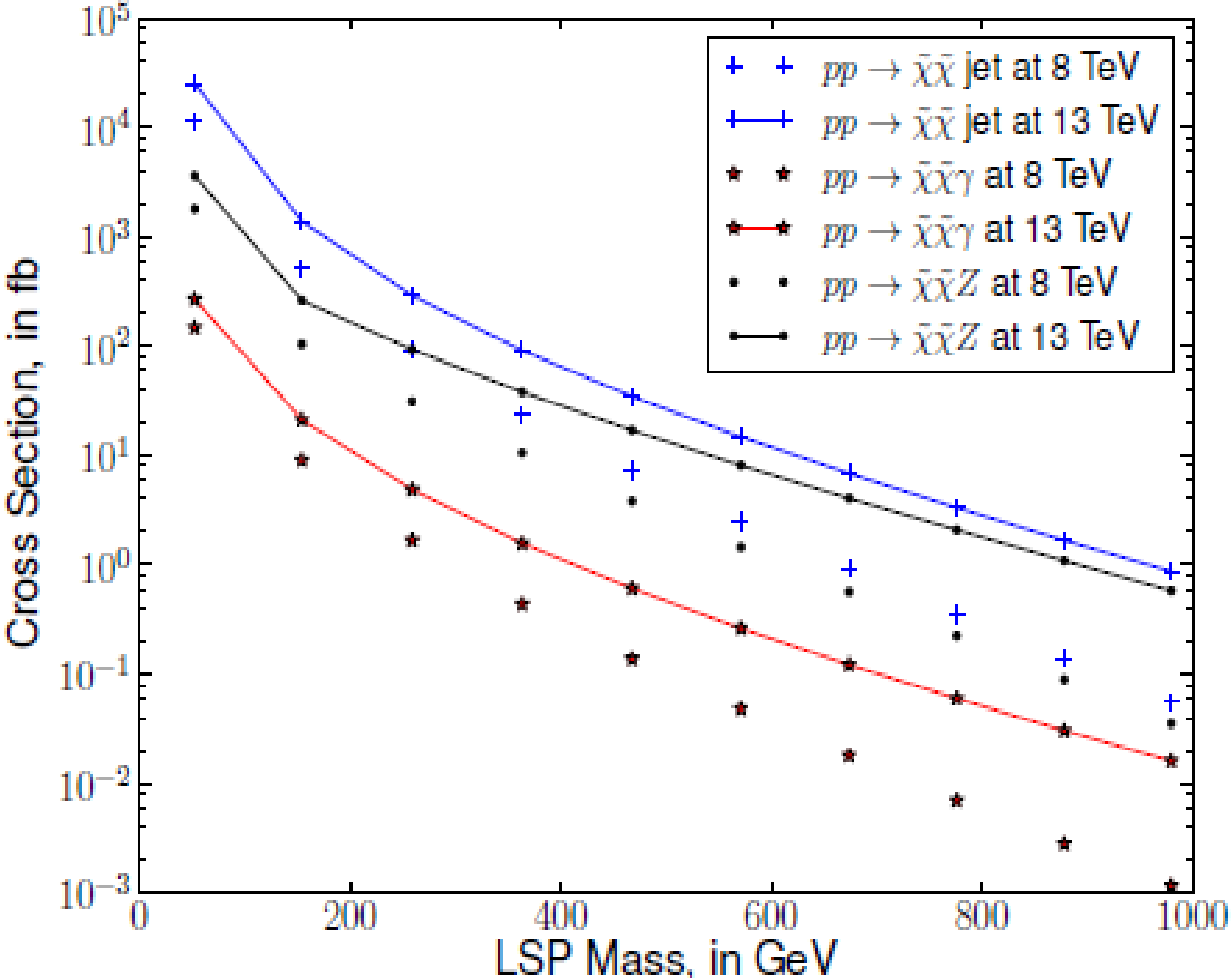
Look for ISR Contributions

Pair of mass degenerate particles produced

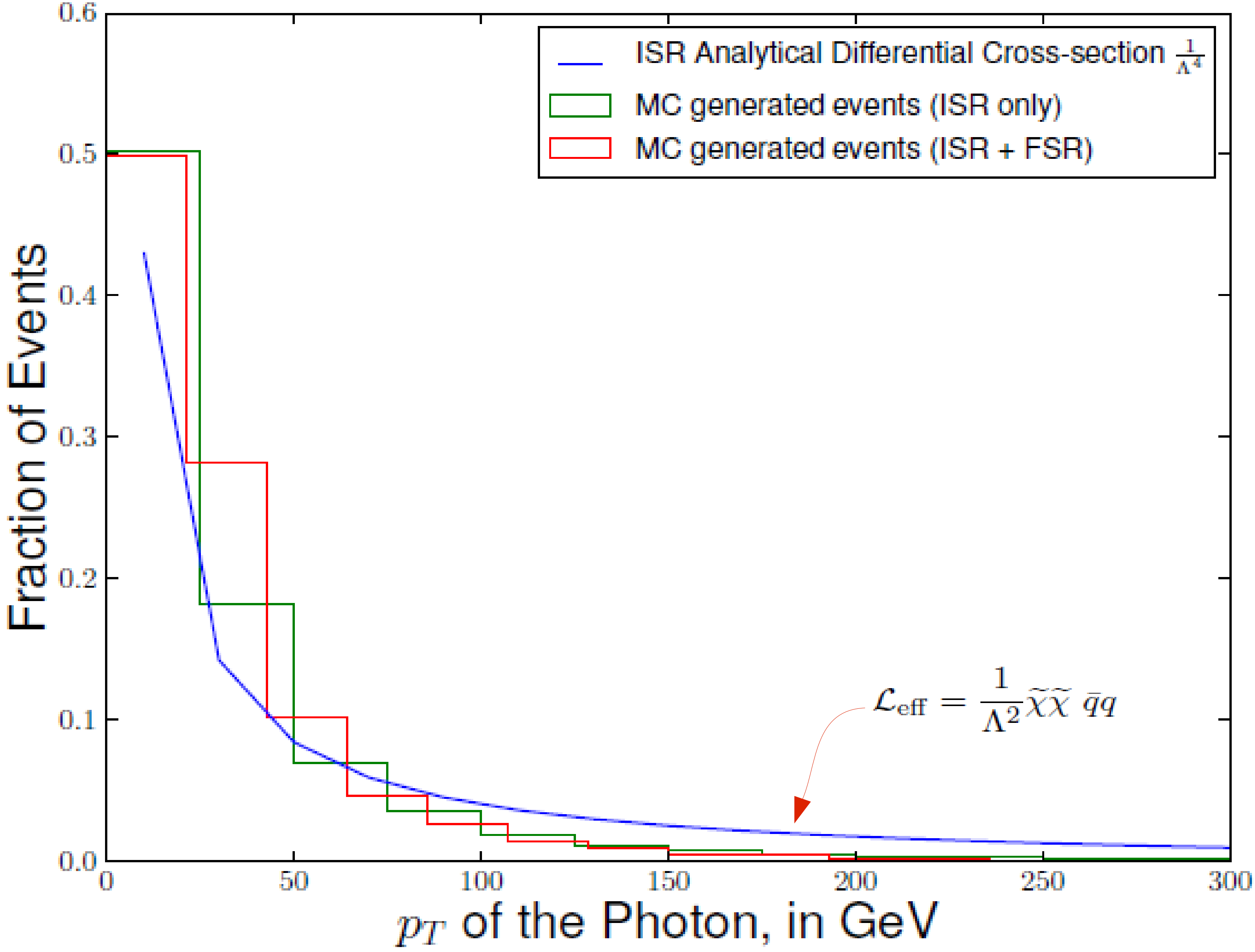


Parton radiates V boson in initial state

Weakino + X production



PT distributions



Discovery Potential:

$$S \geq \max\left[5\sqrt{B}, 5, 0.2B\right]$$

Low Background

No Background

High Background

Detectability:

$$S/\sqrt{B} > 2$$

Mono jet and Photon Searches

Search for mono-photons
• $E_{\mathrm{T}}^{\mathrm{miss}} > 140$ GeV • Photon with $p_T > 145$ GeV and $\|\eta\| < 1.4$ • Veto events with $\geq$ one jet with $p_T > 30$ GeV • The photon is required to be well-separated. $\Delta\phi(\gamma, \not{E}_T) > 2$, $\Delta R(\gamma, \mathrm{jet}) > 0.4$, $\Delta\phi(\mathrm{jet}, \not{E}_T) > 0.4$. • Events with isolated leptons are vetoed.

Search for mono-jets
• $E_{\mathrm{T}}^{\mathrm{miss}} > 120$ GeV • Leading jet with $p_T > 120$ GeV and $\|\eta\| < 2.0$ • Veto events with ≥ 3 jets with $p_T > 30$ GeV and $\|\eta\| < 4.5$ • The jet is required to be well-separated. $\Delta\phi(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}}) > 0.5$ • Events with an isolated lepton are rejected $p_T(e, \mu) > 10$ GeV or $p_T(\tau) > 20$ GeV

ATLAS-CONF-2012-147
CMS-PAS-EXO-12-047

Search cut flows

Monophotons at 8 TeV

	$Z(\nu\nu)+\gamma$	$W(l\nu)+\gamma$	$\tilde{w}1+\gamma$	$\tilde{h}2+\gamma$	$\widetilde{wh}3+\gamma$
Production Cross section (in fb)	7.28×10^3	13.96×10^3	85.2	12	16
Number of events at 19.6 fb^{-1}	142688	273616	1669.9	235	313
Photon $p_T>145$ GeV, $\lvert\eta\rvert<1.4$	473.7	497.98	28	6.6	9.7
Missing Energy > 140 GeV	370.98	103.97	23	5.2	6.5
$\Delta\phi(\gamma,\not{E}_T)>2$	370.98	98.5	23	5	6.4
Jet veto if $p_T>30$ GeV	359.57	82.08	21	4.1	5.3
Lepton Veto	359.57	49.2	21	3.7	4.5
Events in signal region	344.8 (359.57)	102.5 (49.2)	21	3.7	4.5

When we test 13 TeV events weakinos look undiscoverable

Mono- jets at 8 TeV

	$Z(\nu\nu)+j$	$W(\tau\nu)+j$	$W(\mu\nu)+j$	$W(e\nu)+j$	$\tilde{w}1+j$	$\tilde{h}2+j$	$\widetilde{wh}3+j$
Production Cross section (in fb)	1.2×10^6	1.530×10^6	1.530×10^6	1.530×10^6	6.9×10^3	7.6×10^2	8.9×10^2
Number of events at 10.5 fb^{-1}	1.26×10^7	1.6×10^7	1.6×10^7	1.6×10^7	7.24×10^4	8.00×10^3	9.40×10^3
$\not{E}_T > 120$ GeV	327465	197584	119202	118881	7368	1494	1605
Jet $p_T > 120$ GeV, $\lvert\eta\rvert < 2.0$	196276	131302	71328	74541	4223	913	970
Veto events with 3 jets with $p_T > 30$ GeV & $\lvert\eta\rvert < 4.5$	171964	99107	62974	63296	3665	586	609
$\Delta\phi(\not{E}_T, j_1) > 0.5$	171964	83957	62974	63296	3665	585	609
Lepton Veto	171964	83957	15743	22491	3665	548	539
SR1 $\not{E}_T > 120$ GeV, Jet $p_T > 120$ GeV	173600 (171964)	87400 (83957)	34200 (15743)	36700 (22491)	3665	548	539
SR2 $\not{E}_T > 220$ GeV, Jet $p_T > 220$ GeV	15600 (17728)	5580 (4103)	2050 (1927)	1880 (642)	1057	173	176
SR3 $\not{E}_T > 350$ GeV, Jet $p_T > 350$ GeV	1520 (1772)	370 (315)	158 (0)	112 (0)	210	40	33
SR4 $\not{E}_T > 500$ GeV, Jet $p_T > 500$ GeV	270 (0)	39 (0)	42 (0)	16 (0)	36	9.6	4.7

Wino Like state does best

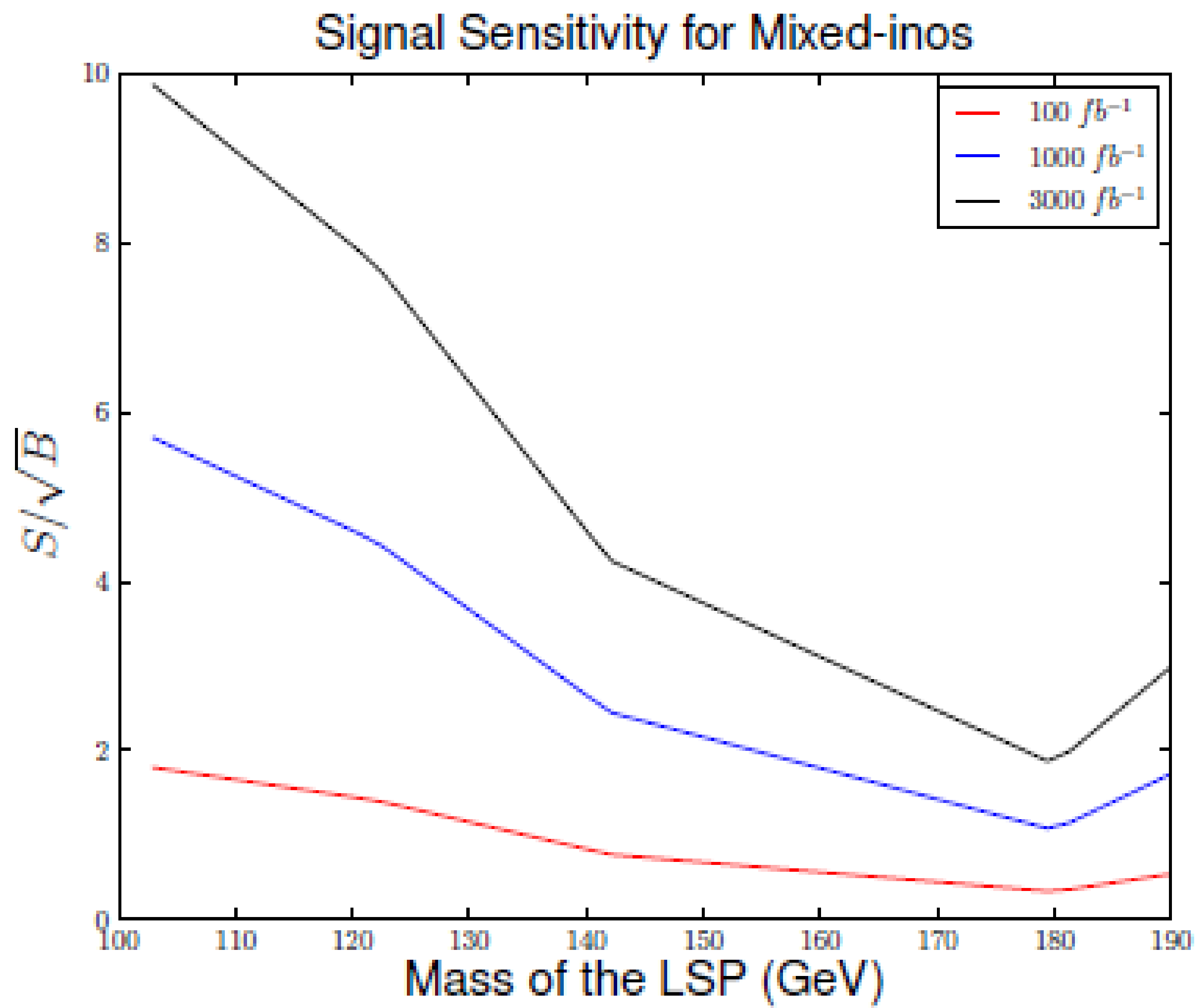
When we check at 13 TeV,
Winos looks discoverable for
Others are undetectable.
The detectability of Higgsinos
At 3 inverse ab has been
Is a topic of debate.

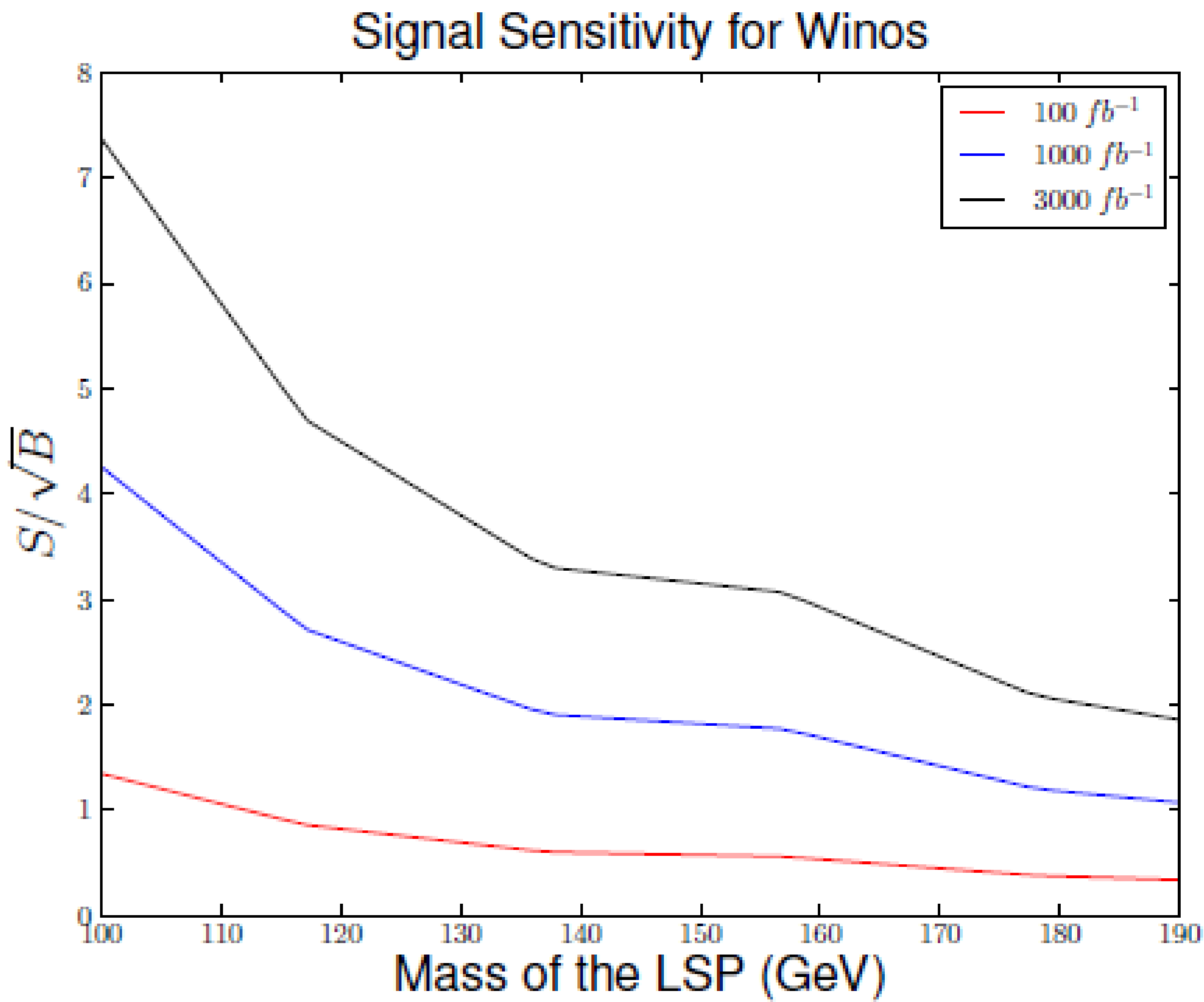
Mono-Z Search Cut Flow 13 TeV

	$Z(\nu\nu)Z(l^+l^-)$	$W(l\nu)Z(l^+l^-)$	$\tilde{w}1+Z$	$\tilde{h}2+Z$	$\widetilde{wh}3+Z$
Production Cross section (in fb)	162	160.9	56	102.3	376
Number of events at 100 fb^{-1}	16200	16200	5600	10230	37600
Events with a Z ($m_{ll} \epsilon [76, 106]$)	10949	11014	199	394	1248
$\Delta\phi(p_T^Z, \not{E}_T) > 2.5$	9365	6555	175	290	887
$p_T^Z/\not{E}_T > 0.5$	7926	4110	155	208	571
Jet veto if $p_T > 25$ GeV	7073	3357	118	108	353
Lepton Veto	7072	1948	118	97	319
SR1 ($\not{E}_T > 150$ GeV)	369	66.7	28.5	25	22.56
SR1 ($\not{E}_T > 250$ GeV)	61	7.7	11.7	4.09	0
SR1 ($\not{E}_T > 350$ GeV)	15	1.62	2.2	1.02	0
SR1 ($\not{E}_T > 450$ GeV)	2.5	0.97	1.1	1.02	0

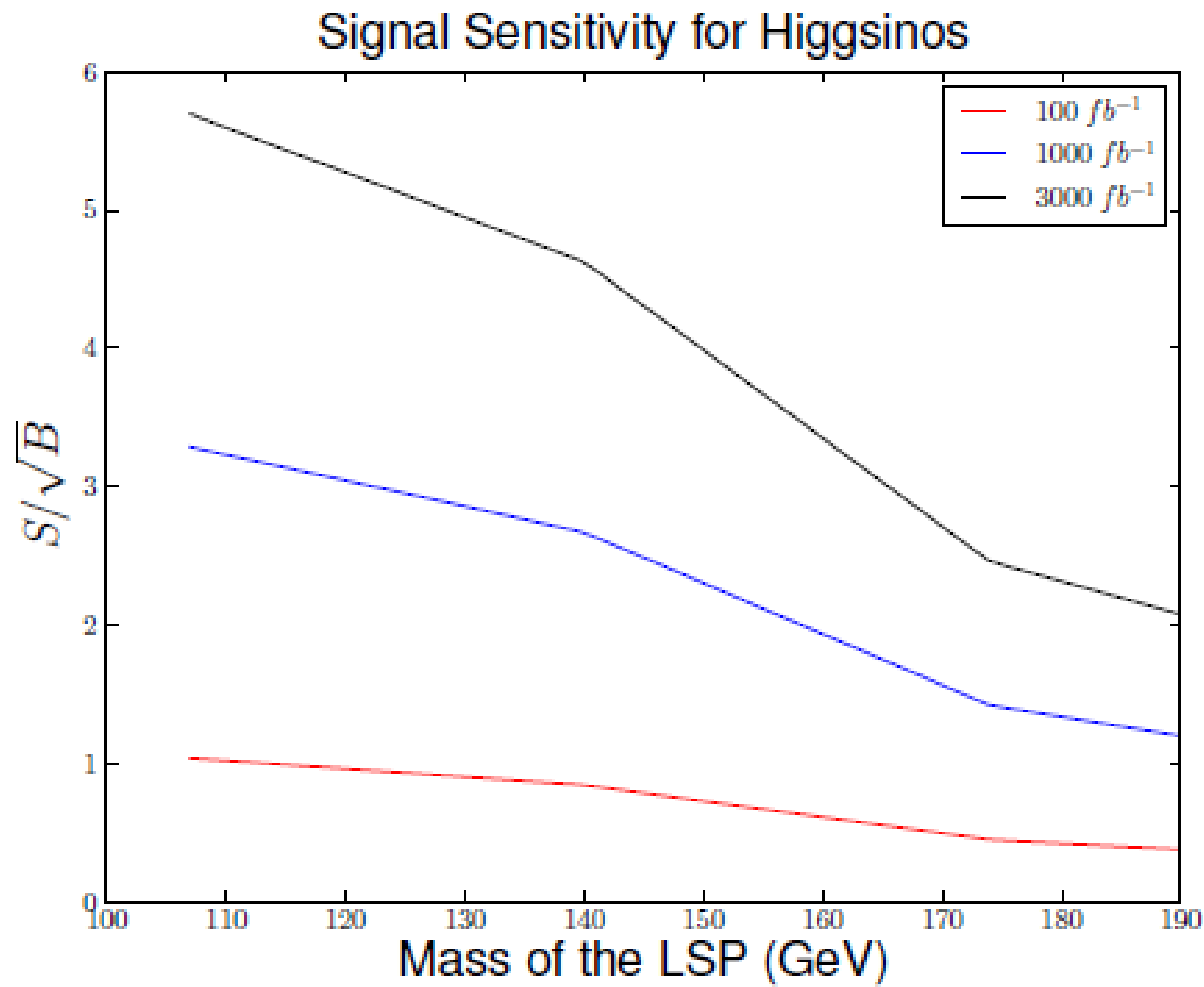
- Two same-flavor opposite-sign electrons or muons, each with $p_T^\ell > 20$ GeV, $|\eta^\ell| < 2.5$;
- Di-lepton invariant mass close to the Z boson mass: $m_{\ell\ell} \in [76, 106]$ GeV;
- No particle level jet with $p_T^j > 25$ GeV and $|\eta^j|$ <4.5;
- $p_T^Z/E_T^{miss} > 0.5$;
- $\Delta\phi(p_T^Z, E_T^{miss}) > 2.5$
- $E_T^{miss} > 150,\ 250,\ 350,\ 450$ GeV

Sensitivity in Mono-Z channel 13TeV





Signal Sensitivity for Winos
$S/\sqrt{B}$
Mass of the LSP (GeV)
100 fb^{-1}
1000 fb^{-1}
3000 fb^{-1}
0
1
2
3
4
5
6
7
8
100
110
120
130
140
150
160
170
180
190



Signal Sensitivity for Higgsinos
100 fb^{-1}
1000 fb^{-1}
3000 fb^{-1}
$S/\sqrt{B}$
0
1
2
3
4
5
6
100
110
120
130
140
150
160
170
180
190
Mass of the LSP (GeV)

Conclusion and Extensions

Searches for mass degenerate states are well motivated, but difficult

New Mono-boson searches in low background final states give extended sensitivity to mass degenerate states

- Other W/Z Searches
- Mono-X combination?
- Check sensitivities of W/Z searches for other BSM scenarios

Mono-W ATLAS 8 TeV 20.3 inv fb

- 1 Cambridge-Aachen jet with $R = 1.2$, $p_{\rm T} > 250$ GeV, $|\eta| < 1.2$, $\sqrt{y} > 0.4$
- $\not{E}_T > 350$ GeV
- $\leq$ 1 narrow jet with $p_{\rm T} > 40$ GeV, $|\eta| < 4.5$, ΔR(narrow jet, fat jet) > 0.9
- No electrons, muons, or photons with $p_{\rm T} > 10$ GeV and $|\eta| < 2.47$, $|\eta| < 2.5$, and $|\eta| < 2.37$ respectively

Look for Hadronically decaying W boson

Process	$\not{E}_T > 350$ GeV	$\not{E}_T > 500$ GeV
$Z \to \nu\bar{\nu}$	402^{+39}_{-34}	54^{+8}_{-10}
$W \to \ell^{\pm}\nu$, $Z \to \ell^{\pm}\ell^{\mp}$	210^{+20}_{-18}	22^{+4}_{-5}
WW, WZ, ZZ	57^{+11}_{-8}	$9.1^{+1.3}_{-1.1}$
$t\bar{t}$, single t	39^{+10}_{-4}	$3.7^{+1.7}_{-1.3}$
Total	707^{+48}_{-38}	89^{+9}_{-12}
Data	705	89