Probing ~100 GeV wino-like dark matter at the LHC

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SUSY2018, Barcelona

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with Waleed Abdallah, Shaaban Khalil and Stefano Moretti, ArXiv: 1710.05536

CONTENTS

- *Wino(-like) DM in the MSSM*
- *The standard trilepton probe at the LHC*
- *A complimentary signal topology*
- *Signal-to-background analysis*
- *Conclusions*

DARK MATTER IN THE MSSM

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Superpartners of the SM gauge and Higgs bosons

$$\widetilde{\psi}^0 = (-i\widetilde{B}^0, -i\widetilde{W}_3^0, \widetilde{H}_d^0, \widetilde{H}_u^0)$$

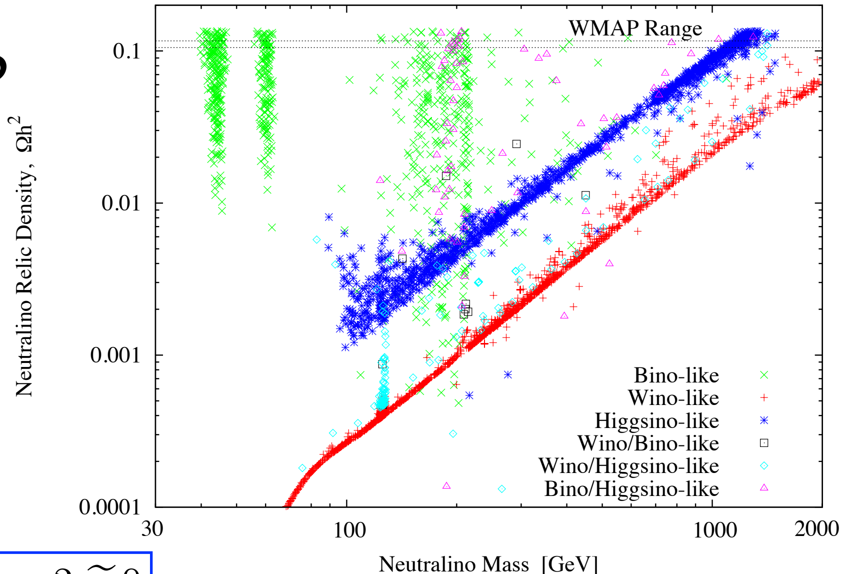
mix together to give four Majorana fermions: Neutralinos

$$\mathcal{M}_{\widetilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_1 v_u}{\sqrt{2}} \\ 0 & M_2 & \frac{g_2 v_d}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} \\ -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_2 v_d}{\sqrt{2}} & 0 & -\mu \\ \frac{g_1 v_u}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & -\mu & 0 \end{pmatrix}$$

$$\mathcal{L}_{\text{mass}} = -\frac{1}{2}(\widetilde{\psi}^0)^T \mathcal{M}_{\widetilde{\chi}^0}\, \widetilde{\psi}^0 + \text{h.c.}$$

- *R-parity conservation*

→ *the lightest neutralino a leading DM candidate*



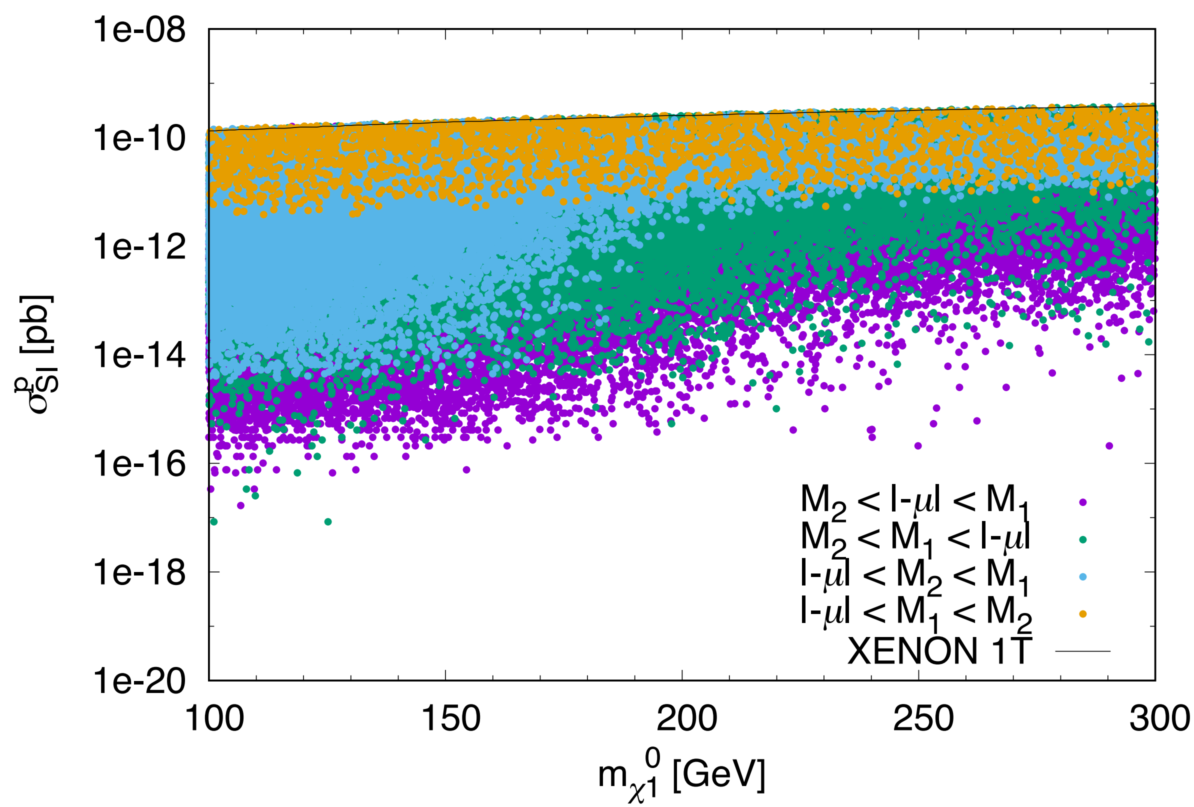
Composition of the DM depends on the sizes of and splittings between M_1, M_2 and μ

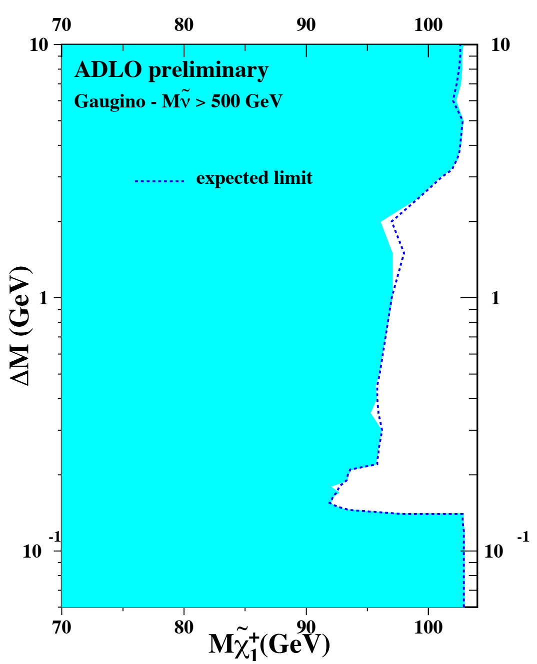
$$\widetilde{\chi}_1^0 = |N_{11}|^2 \widetilde{B}^0 + |N_{12}|^2 \widetilde{W}_3^0 + |N_{13}|^2 \widetilde{H}_d^0 + |N_{14}|^2 \widetilde{H}_u^0$$

[P. Bergeron, S. Profumo, 1312.4445]

CONSISTENCY WITH XENON 1T DATA

Parameter	Scanned range
M_1 (GeV)	$10 - 1000$
M_2 (GeV)	$90 - 1000$
$\|\mu\|$ (GeV)	$90 - 1000$
M_Q (GeV)	$1000 - 5000$
M_L (GeV)	$100 - 3000$
A_0 (GeV)	$-7000 - -500$
$\tan\beta$	$2 - 50$
m_A (GeV)	$125 - 3000$





Parameters defined at the EW scale

$$M_Q \equiv M_{Q_{1,2,3}} = M_{U_{1,2,3}} = M_{D_{1,2,3}}$$

$$M_L \equiv M_{L_{1,2,3}} = M_{E_{1,2,3}}$$

$$M_3 = 2000\,\text{GeV}$$

$$A_0 \equiv A_{\tilde{t}} = A_{\tilde{b}} = A_{\tilde{\tau}}$$

$$m_h = 125 \pm 2\,\text{GeV}$$

CONSISTENCY WITH XENON 1T DATA

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Parameter	Scanned range
M_1 (GeV)	$10 - 1000$
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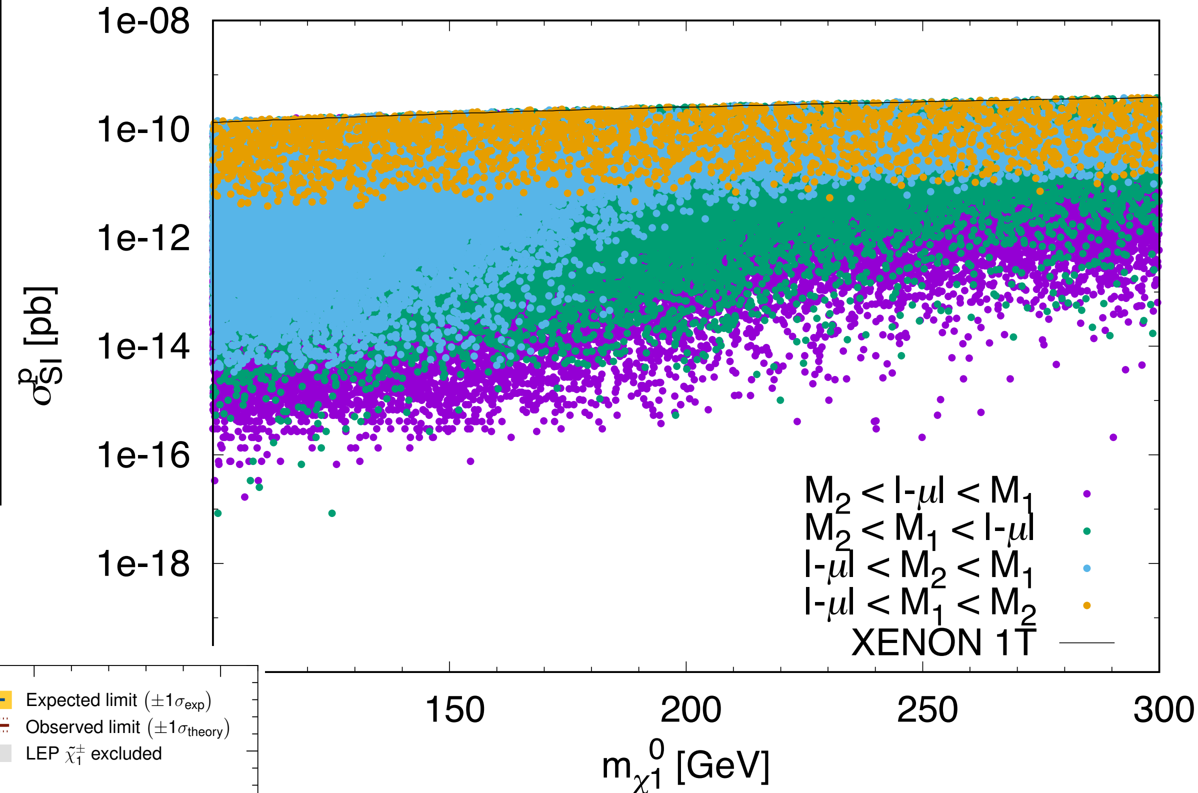
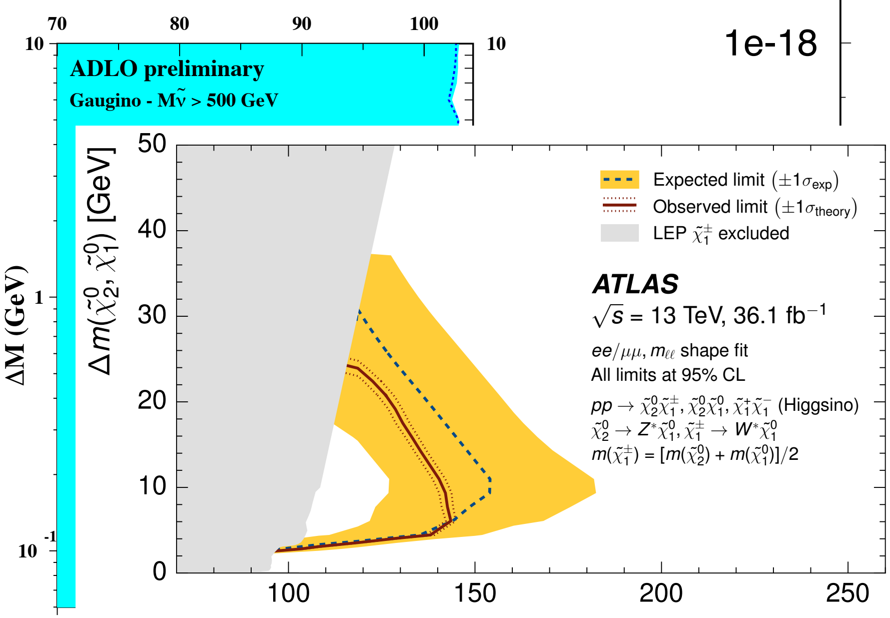




[ATLAS Collaboration, 1712.08119]

defined at the EW scale

$M_{U_{1,2,3}} = M_{D_{1,2,3}}$

$_3 = M_{E_{1,2,3}}$

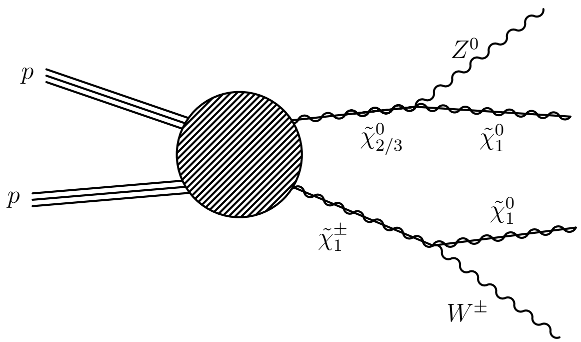
00 GeV

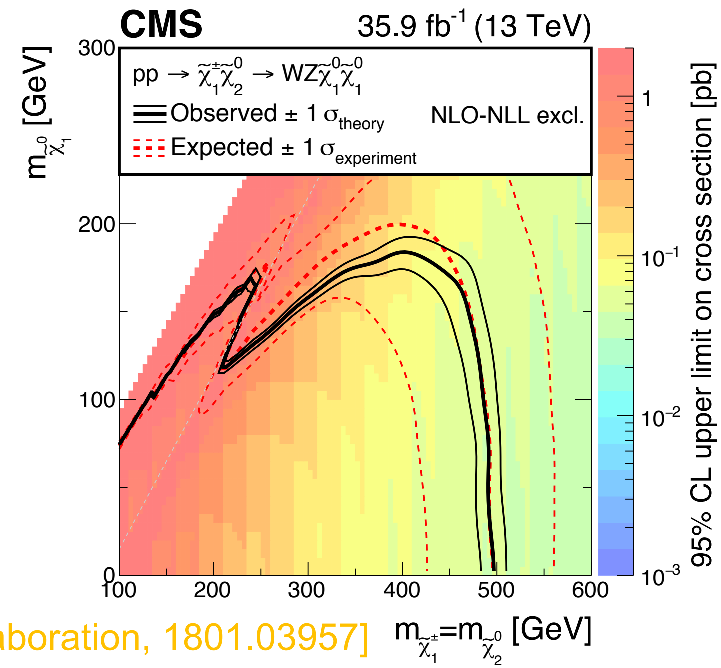
$A_0 \equiv A_{\tilde t} = A_{\tilde b} = A_{\tilde\tau}$

$m_h = 125 \pm 2\,\text{GeV}$

THE TRILEPTON (+ MET) CHANNEL

DM search channel with generally the highest yield - employed by both CMS and ATLAS, assuming the production process

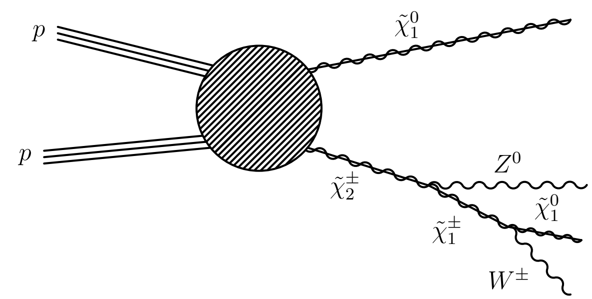




[CMS Collaboration, 1801.03957]

$$S_1^i \;:\; pp \to \tilde{\chi}^0_i \, \tilde{\chi}^\pm_1 \to \tilde{\chi}^0_1 \, Z^{(*)} \, \tilde{\chi}^0_1 \, W^{\pm(*)} \to \tilde{\chi}^0_1 \, \ell^+\ell^- \, \tilde{\chi}^0_1 \, \ell^\pm \, \nu_l \,, \;\; \text{with } i = 2,3,4$$

But three leptons (+ MET) can also result from a different event topology - more so for Wino DM



$$S_2 \;:\; pp \to \tilde{\chi}^0_1 \, \tilde{\chi}^\pm_2 \to \tilde{\chi}^0_1 \, \tilde{\chi}^\pm_1 \, Z^{(*)} \to \tilde{\chi}^0_1 \, \tilde{\chi}^0_1 \, W^{\pm(*)} \, \ell^+\ell^- \to \tilde{\chi}^0_1 \, \tilde{\chi}^0_1 \, \ell^\pm \, \nu_l \, \ell^+\ell^-$$

THE WINO LSP

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For a preliminary comparative estimate, define effective cross sections

$$S_1^{i,\,\mathrm{eff}} \;:\; g^2_{W\widetilde{\chi}_i^0\,\widetilde{\chi}_1^\pm} \times \mathrm{BR}(\widetilde{\chi}_i^0 \to \widetilde{\chi}_1^0\,\mu^+\mu^-) \times \mathrm{BR}(\widetilde{\chi}_1^\pm \to \widetilde{\chi}_1^0\,\mu^\pm\nu_\mu)\,; \quad i = 2,3,4$$

$$S_1^{\mathrm{eff}} = \sum_{i=2}^{4} S_1^{i,\,\mathrm{eff}}$$

$$S_2^{\mathrm{eff}} \;:\; g^2_{W\widetilde{\chi}_1^0\,\widetilde{\chi}_2^\pm} \times \mathrm{BR}(\widetilde{\chi}_2^\pm \to \widetilde{\chi}_1^\pm\,\mu^+\mu^-) \times \mathrm{BR}(\widetilde{\chi}_1^\pm \to \widetilde{\chi}_1^0\,\mu^\pm\nu_\mu)$$

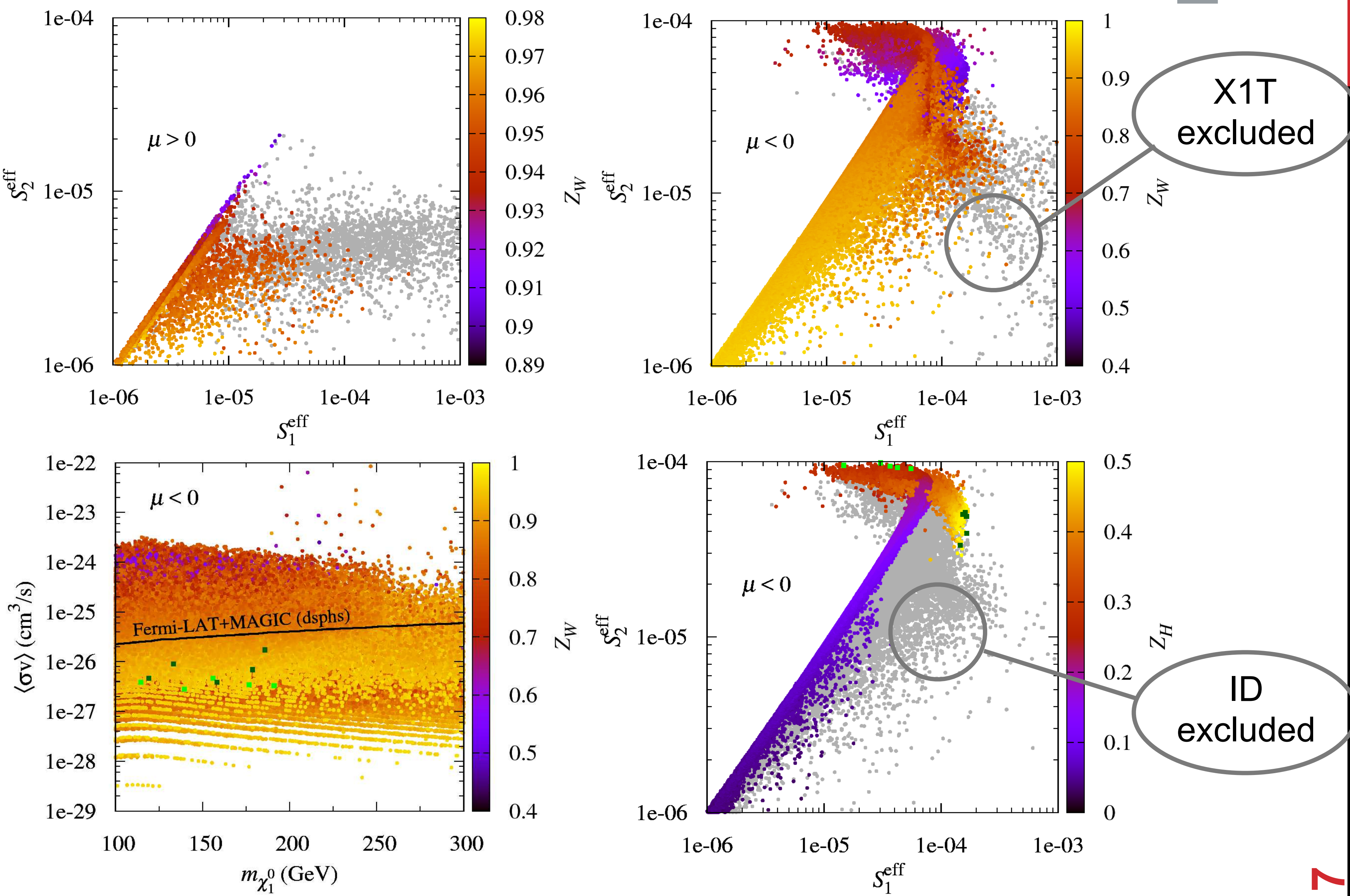
$$\mathrm{BR}(\widetilde{\chi}_i^0 \to \widetilde{\chi}_1^0\,\mu^+\mu^-) = \begin{cases} \mathrm{BR}(\widetilde{\chi}_i^0 \to \widetilde{\chi}_1^0\,\mu^+\mu^-)\,, & \Delta m_{\widetilde{\chi}_i^0} < m_Z \\ \mathrm{BR}(\widetilde{\chi}_i^0 \to \widetilde{\chi}_1^0\,Z) \times \mathrm{BR}(Z \to \mu^+\mu^-)\,, & m_Z < \Delta m_{\widetilde{\chi}_i^0} < m_h \\ \sum\limits_{X=Z,\,h} \mathrm{BR}(\widetilde{\chi}_i^0 \to \widetilde{\chi}_1^0\,X) \times \mathrm{BR}(X \to \mu^+\mu^-)\,, & m_h < \Delta m_{\widetilde{\chi}_i^0} \end{cases}$$

Define also: $Z_B \equiv |N_{11}|^2\,,\; Z_W \equiv |N_{12}|^2\,,\; Z_H \equiv |N_{13}|^2 + |N_{14}|^2$

$$Z_W > \max(Z_B,\, Z_H)$$

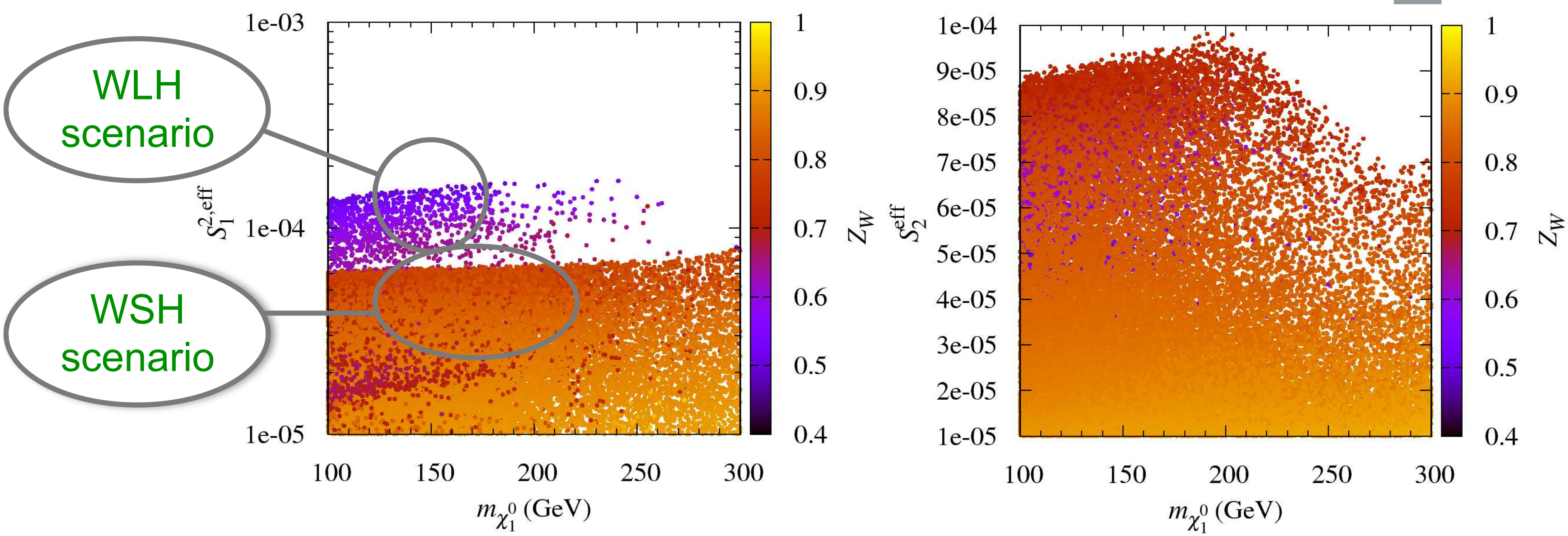
Caveat: Wino LSP always under-abundant for sub-TeV masses; assume either its non-thermal production for consistency with PLANCK or a multicomponent DM

$\mu > 0$ vs. $\mu < 0$

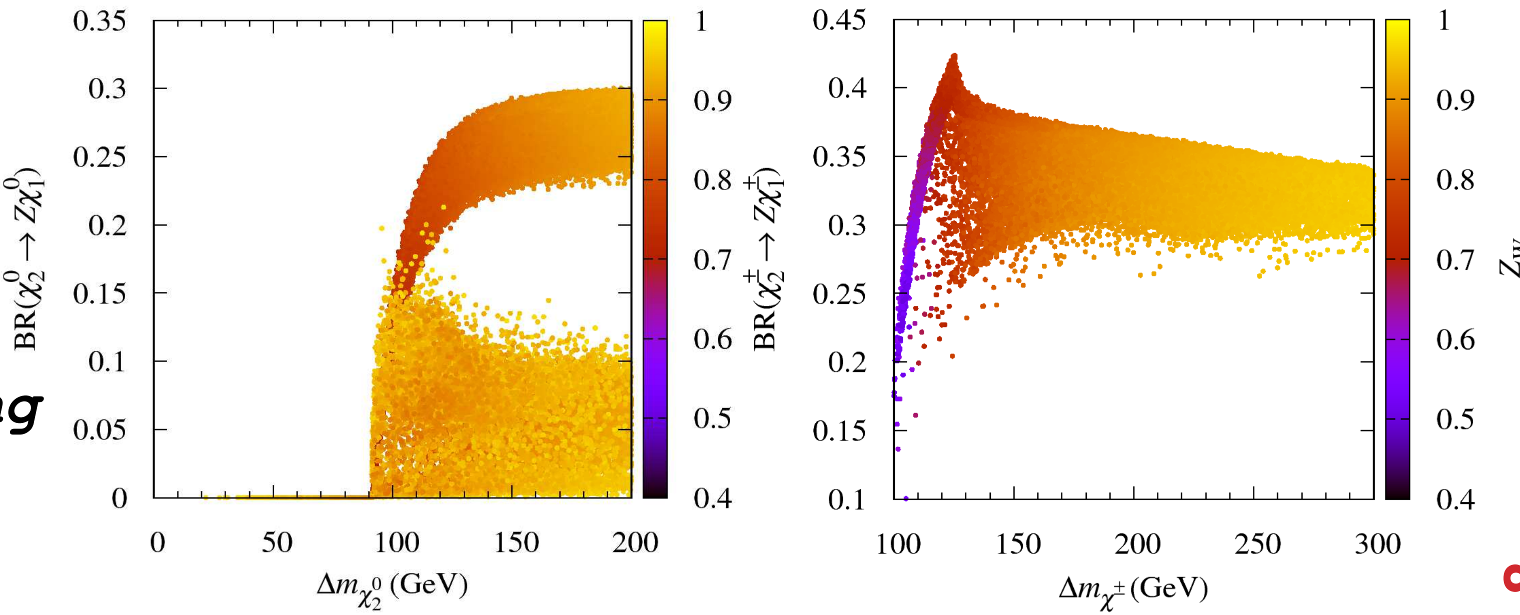


μ > 0
μ < 0
S_1^eff
S_2^eff
Z_W
Z_H
1e-06
1e-05
1e-04
1e-03
X1T excluded
ID excluded
Fermi-LAT+MAGIC (dsphs)
⟨σv⟩ (cm^3/s)
m_χ1^0 (GeV)
100
150
200
250
300
1e-22
1e-23
1e-24
1e-25
1e-26
1e-27
1e-28
1e-29

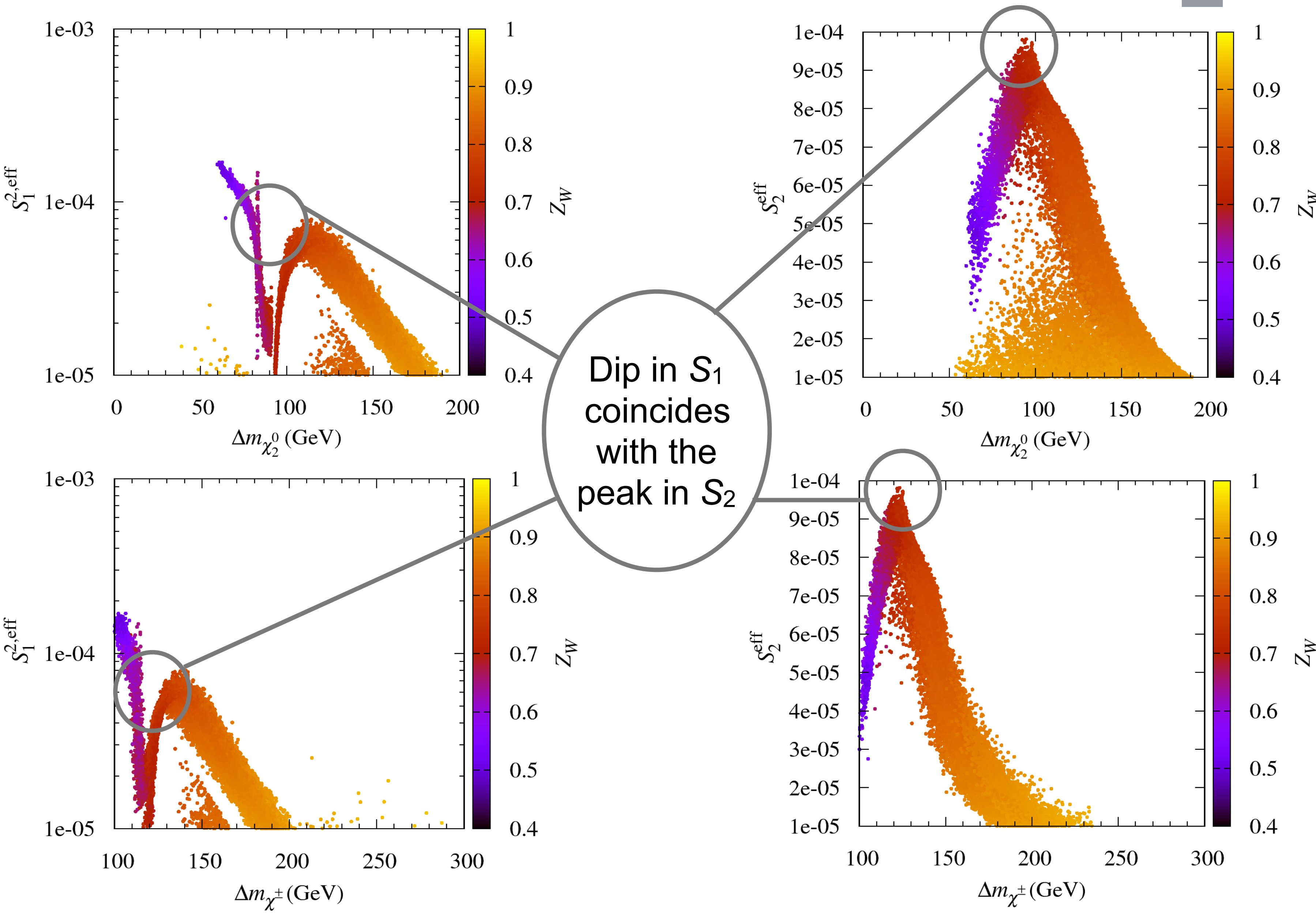
CROSS SECTION ESTIMATES



Driven mainly by branching ratios



S_1 vs. S_2



Dip in S1 coincides with the peak in S2
S1^{2,eff}
S2^{eff}
Δm χ2^0 (GeV)
Δm χ^± (GeV)
Z_W

EVENT ANALYSIS

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- ***SPheno for mass spectra***
- ***MadGraph5 for cross sections***
- ***Event generation with Pythia 6.4***
- ***Detector simulation with DELPHES 3***

$\sqrt{s} = 14\,\text{TeV}$ $\mathcal{L} = 300\,\text{fb}^{-1}$

Cuts		Backgrounds			Signals		Significances		
		$W^\pm Z$	W^+W^-	ZZ	S_1	S_2	$\mathcal{Z}_1$	$\mathcal{Z}_2$	$\mathcal{Z}_{3\ell}$
Events before cuts		778670	4444650	73213	5084	5616	2.21	2.44	4.65
$\lvert\eta(\ell)\rvert < 2.4$		701373	3538624	59515	4537	5046	2.19	2.43	4.62
$n(\ell) \geq 1$ with $p_T > 20\,\text{GeV}$		674906	3295789	56633	4366	4902	2.18	2.44	4.62
$\Delta R(\ell, j) > 0.4$		428099	1616502	27309	2543	2887	1.77	2.01	3.78
$p_T(j) > 30\,\text{GeV}$		343438	1280660	21741	2154	2457	1.68	1.92	3.60
$\lvert\eta(j)\rvert < 2.5$		270703	1017195	18403	1943	2222	1.70	1.94	3.64
b-jet veto		267997	984850	17870	1859	2127	1.65	1.89	3.54
M_T	$> 160\,\text{GeV}$	516	16	2	1	1	0.04	0.04	0.08
	$120 - 160\,\text{GeV}$	750	54	2	1	1	0.04	0.04	0.08
	$0 - 120\,\text{GeV}$	35705	1827	34	9	7	0.05	0.04	0.09
$\not{E}_T > 100\,\text{GeV}$		21026	60391	3411	666	917	2.29	3.15	5.44
$75\,\text{GeV} < M_{\ell^+\ell^-} < 105\,\text{GeV}$		7452	2793	1511	319	459	2.94	4.23	7.17

EVENT ANALYSIS

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BP (scenario)	$m_{\tilde{\chi}_1^0}$ [GeV]	$m_{\tilde{\chi}_2^0}$ [GeV]	$m_{\tilde{\chi}_3^0}$ [GeV]	$m_{\tilde{\chi}_4^0}$ [GeV]	$m_{\tilde{\chi}_1^\pm}$ [GeV]	$m_{\tilde{\chi}_2^\pm}$ [GeV]	σ_{S_1} [fb]	σ_{S_2} [fb]
1 (WSH)	115	214	234	891	117	243	17	18.7
2 (WLH)	119	183	216	844	123	223	63.7	9.66

$$\mathcal{Z}_i \equiv \frac{N_{S_i}}{\sqrt{N_B}}$$

$$M_T = \sqrt{2\, \not{E}_T\, p_{T(\ell_3)}\, (1 - \cos\Delta\phi_{\ell_3, \not{E}_T})}$$

$\sqrt{s} = 14\,\text{TeV}$ $\mathcal{L} = 300\,\text{fb}^{-1}$

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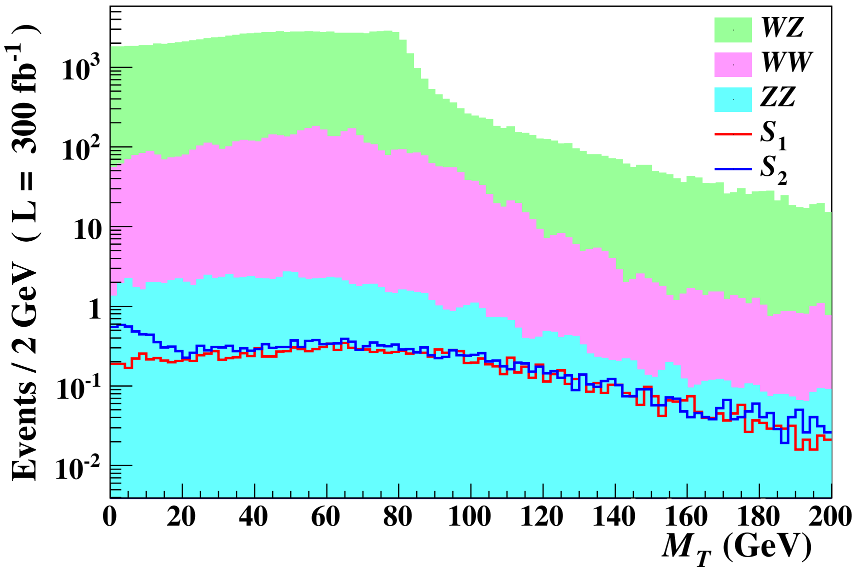
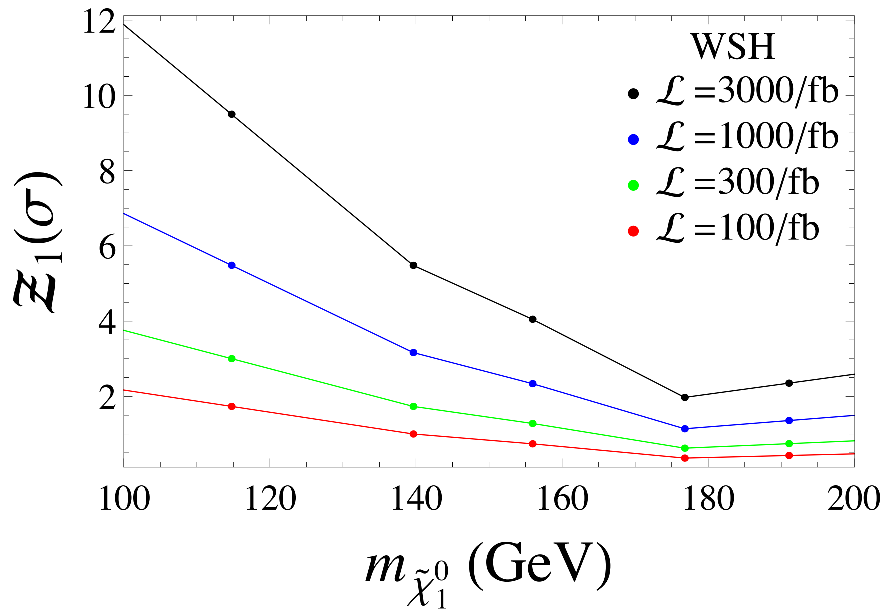
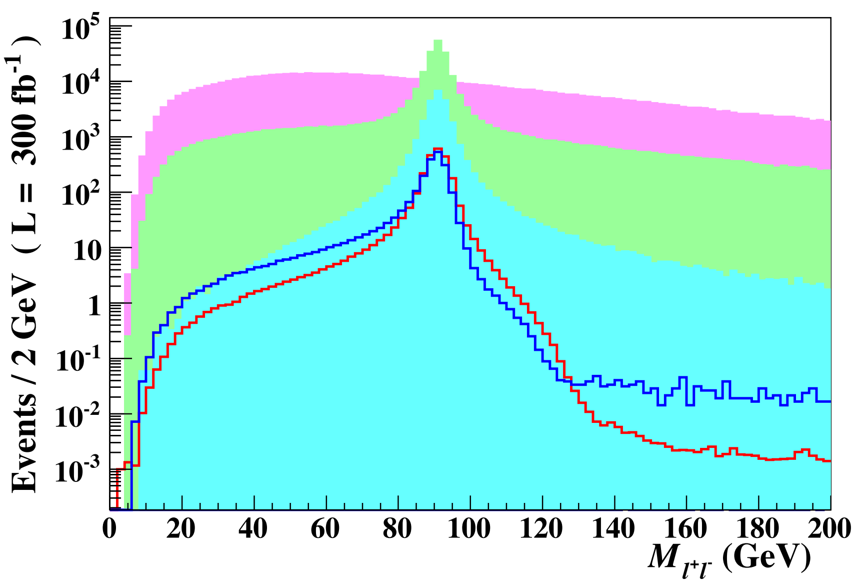
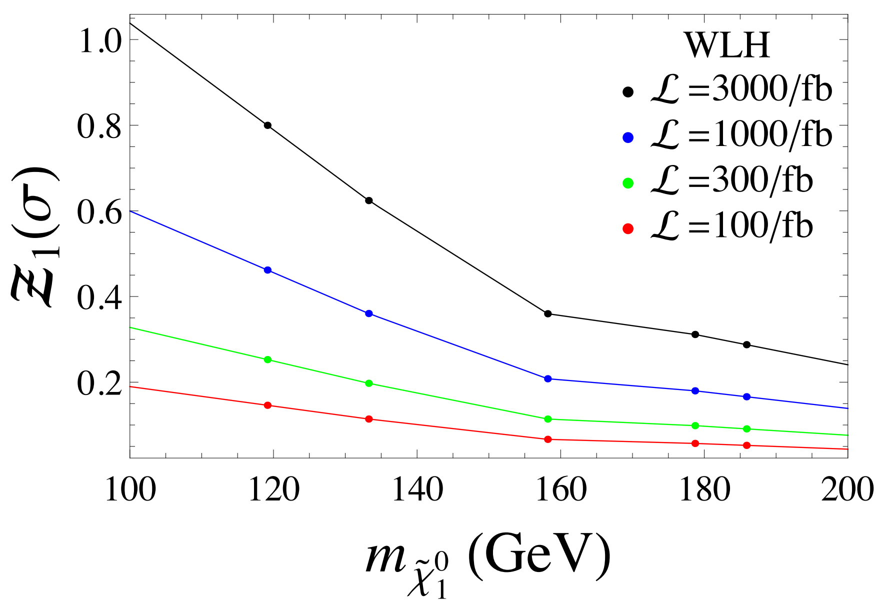
THE ‘STANDARD’ TRILEPTON CHANNEL









COMBINED SIGNAL SIGNIFICANCE

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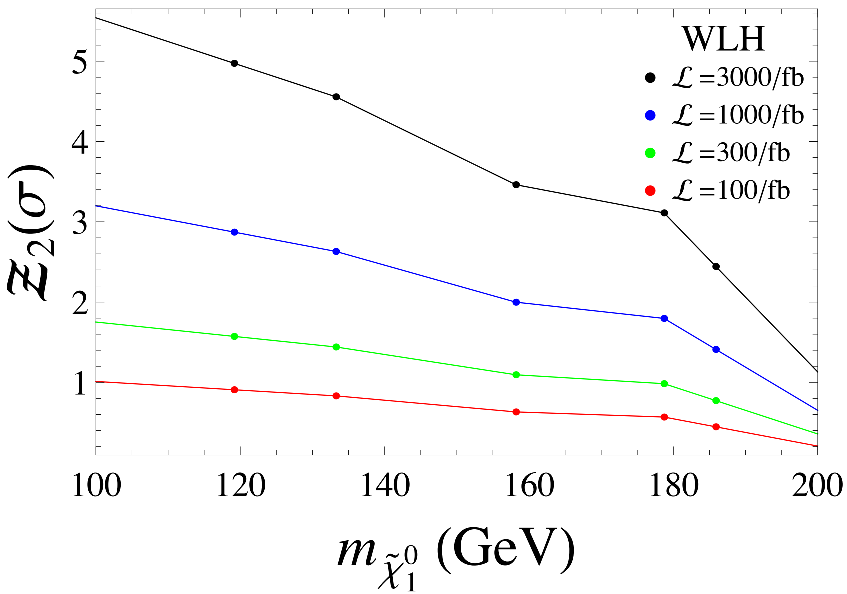

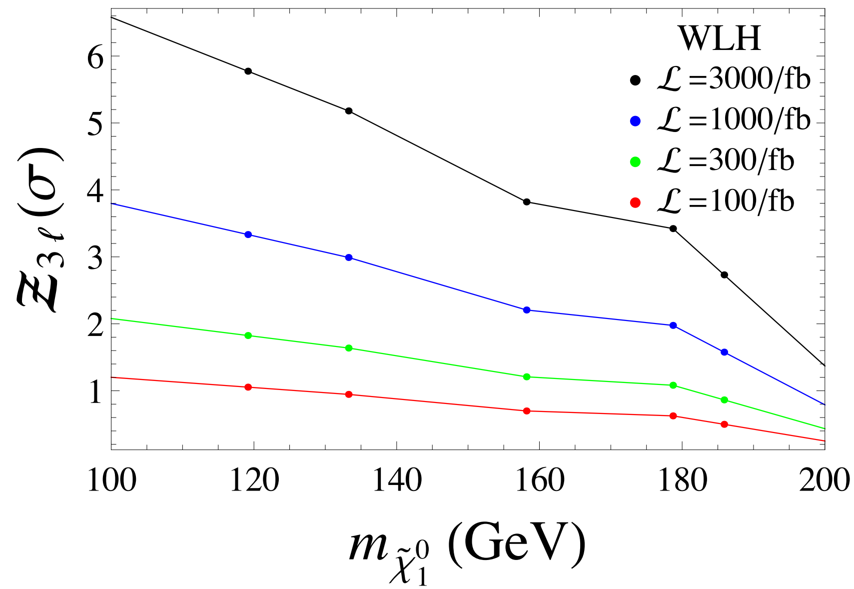

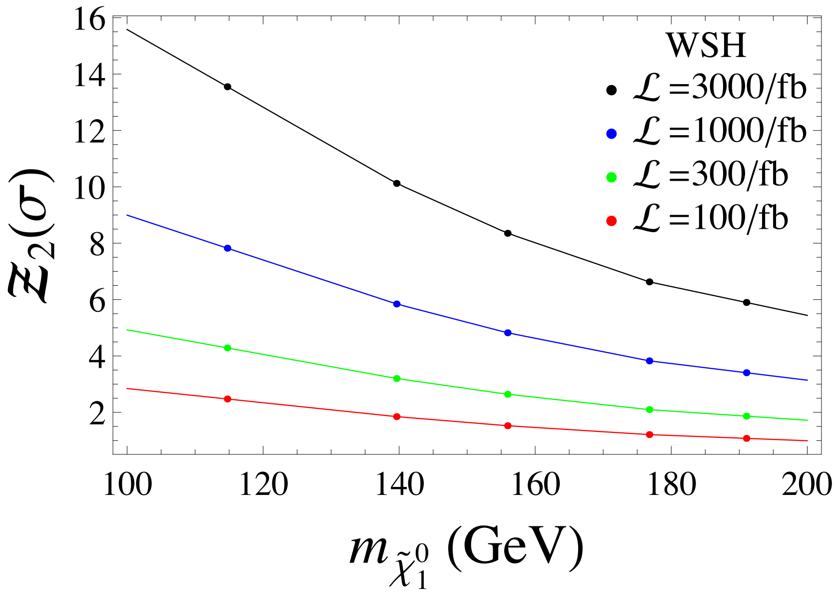

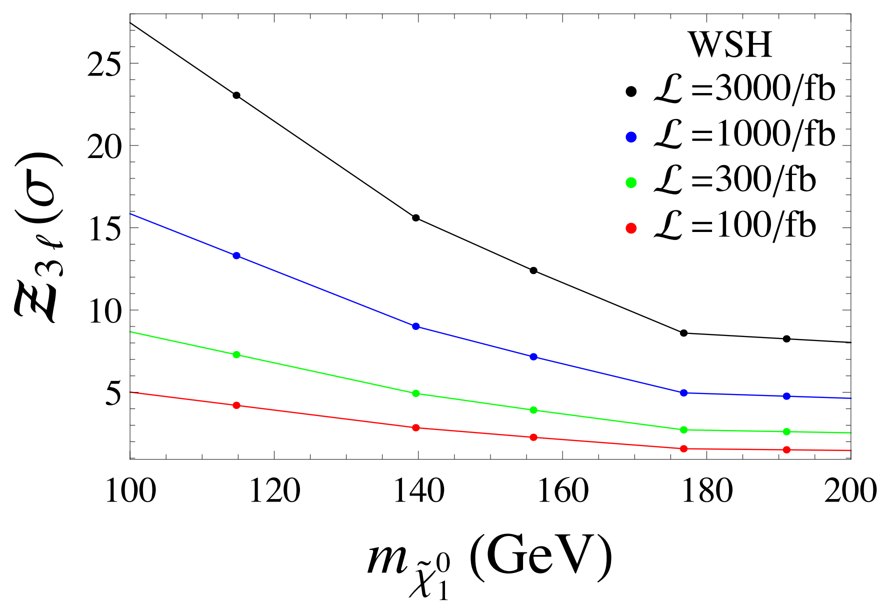

CONCLUSIONS

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- *The trilepton final state could serve as an important probe of the Wino LSSP, thanks to contribution from a non-standard event topology*
- *A ~100 GeV Wino might be accessible at the 14 TeV LHC even with 300/fb luminosity – through optimisation of the current kinematical cuts*
- *Observation of such a DM may hint at*
  - $\mu < 0$
  - $|\mu|$ *consistent with naturalness*
  - *inverted electroweakino soft mass hierarchy (inconsistent with mSUGRA)*
  - *Anomaly-mediated SUSY-breaking*

THANK YOU!

감사합니다!