ν-Dark matter models

Collider phenomenology

Diego Restrepo

July 20, 2019

Instituto de Física
Universidad de Antioquia
Phenomenology Group
`http://gfif.udea.edu.co`

Focus on

arXiv: arXiv:1308.3655 (JHEP), arXiv:1504.07892 (PRD), arXiv:1509.06313, arXiv:1511.01873, arXiv:1511.nnnnn. In collaboration with

G. Palacio, F. von der Pahlen, D. Portillo, A. Rivera, M. Sánchez, O. Zapata (UdeA)
C. Arbeláez (USM), W. Tangarife (Tel Aviv U.), C. Yaguna (Heidelberg, Max Planck Inst.).

Table of Contents

General framework

ν-DM models

If neutrino masses arise radiatively it may originate from new physics at the TeV scale in join with dark matter (DM)

It may be, though, that they are related to each other.

In this direction, models with one-loop radiative neutrino masses and viable dark matter candidates have now a complete classification given in

R.D., Yaguna, C, Zapata, O, arXiv:1308.3655 (JHEP)

There, the new fields are odd under a Z_2 symmetry which ensures the stability of the DM particle, while the SM particles are even.

Discussion - Uniandes School 2014

FeynRules/SARAH

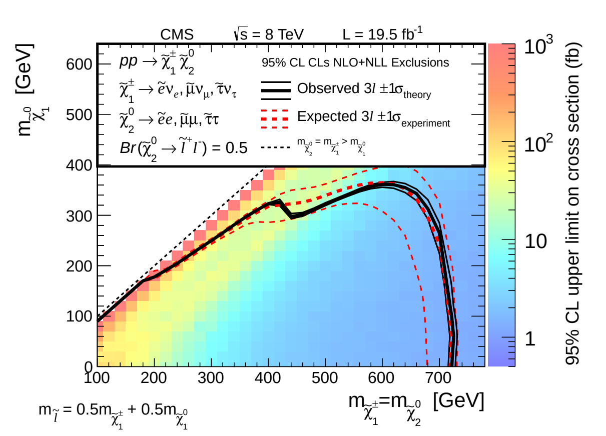
micrOMEGAS (CalcHEP) MadGraph(UFO)

DM LHC

- We have only qualitatively described the particle content and the dark matter candidates of each model. A more specific analysis of some of these models is certainly desirable.
- The collider and dark matter phenomenology of many of these viable models have yet to be studied in detail.
- Some strategies to systematically search for this kind of models at colliders would be designed.
- New particles allowed to be even under Z_2 could give rise to new possibilities.

CMS 1405.7570: Best SUSY simplified model:

Largest Wino-production to three leptons and MET

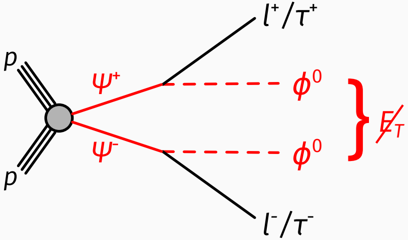


Interpretation of the results of the three-lepton search in the flavor-democratic signal model with slepton mass parameter $\xi_{\tilde{l}} = 0.5$

Simplified SUSY to dileptons and MET: slepton pair production (see below)

Proposal

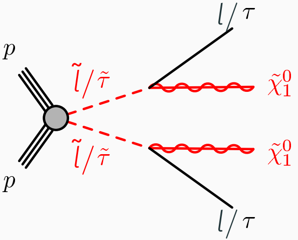
Dilepton plus transverse missing energy signal

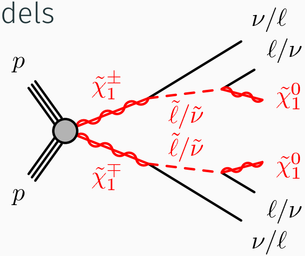


SU(2)$_L$ assignments:

$\Psi = 1, 2, 3\,, \qquad \Phi = 1, 2\,,$ with $m_{\mathrm{DM}} \sim m_h/2\,.$

Simplified SUSY models





Smaller cross sections.

Intermediate states and smaller lepton $\not{p}_T$

New simplified models

Not-susy SO(10) $\rightarrow$ SU(3)$_C \times SU(2)_L \times$ U(1)$_Y \times Z_2$

Standard Model: Z_2-even

Fermions: $\mathbf{16}_F$

Scalars: $\mathbf{10}_H, \mathbf{45}_H \cdots$

New Z_2-odd particles

$\mathbf{10}_F, \mathbf{45}_F, \cdots$

$\mathbf{16}_H, \cdots$

Lightest Odd Particle (LOP) may be a suitable dark matter candidate.

Example (arXiv:1509.06313)

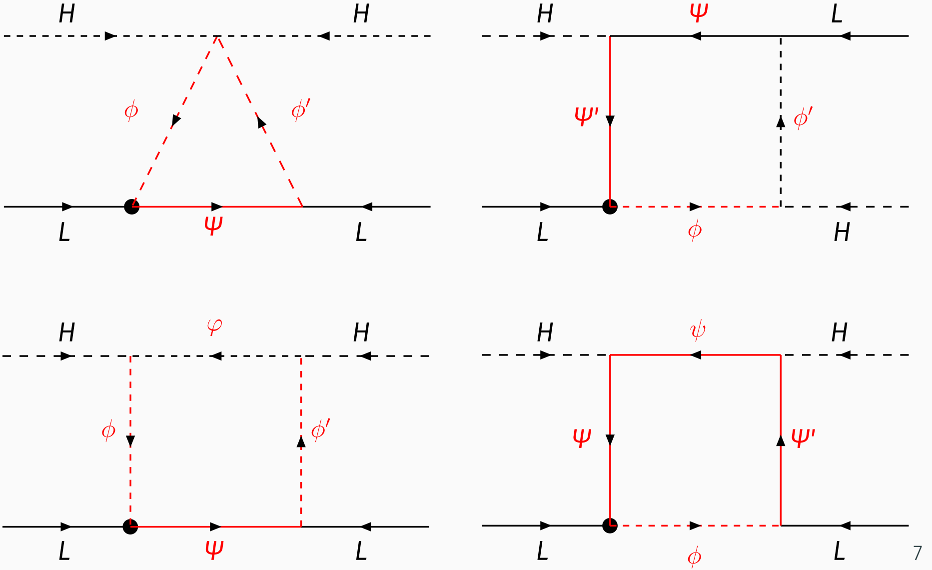
Split-SUSY-like spectrum: bino-higgsino-wino

$+ \qquad\qquad \downarrow$

$\mathbf{10}'_H$ with fermion DM or, $\quad$ $\mathbf{16}_H, \cdots$ with scalar DM

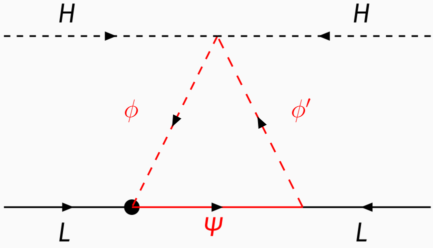
Weinberg operator at one-loop

(Z_2-odd fields)

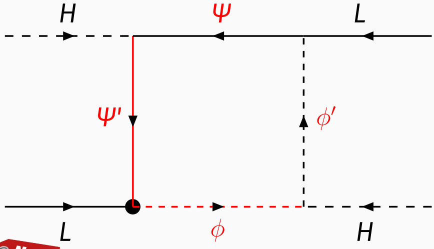


Weinberg operator at one-loop

(Z_2-odd fields)

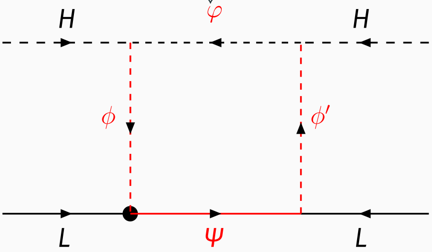


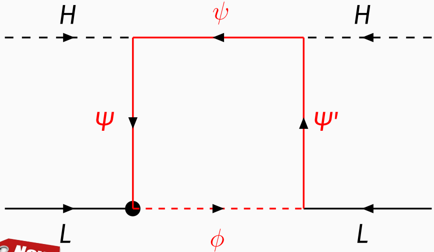
Wino-like scotogenic model



New Higgsino-like Zee model

⇕





New Higgsino-like scotogenic model

H. Okada et. al, arXiv:1408.0961, Inert Zee-babu model

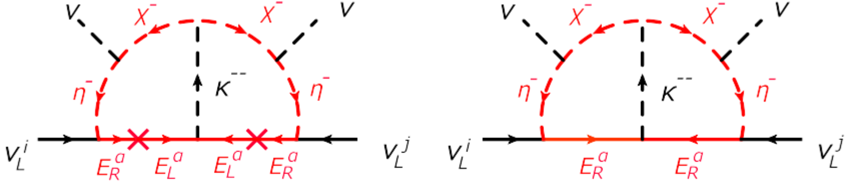
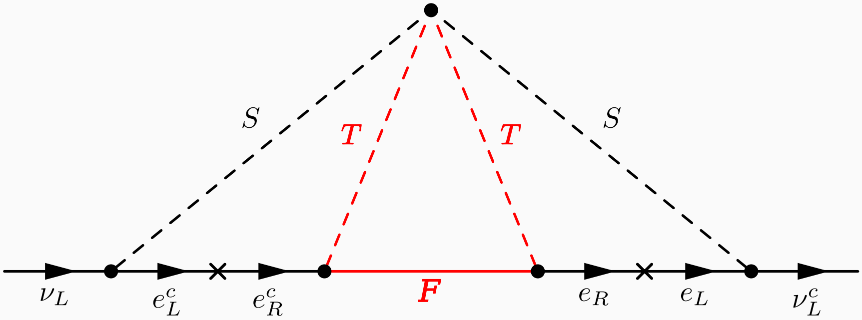


FIG. 2: Feynman diagrams for the neutrino mass generation at the two-loop level. Particles indicated by the red color have the Z_2 odd parity.

A. Ahriche, et. al, arXiv:1508.05881, three-loop ν-DM



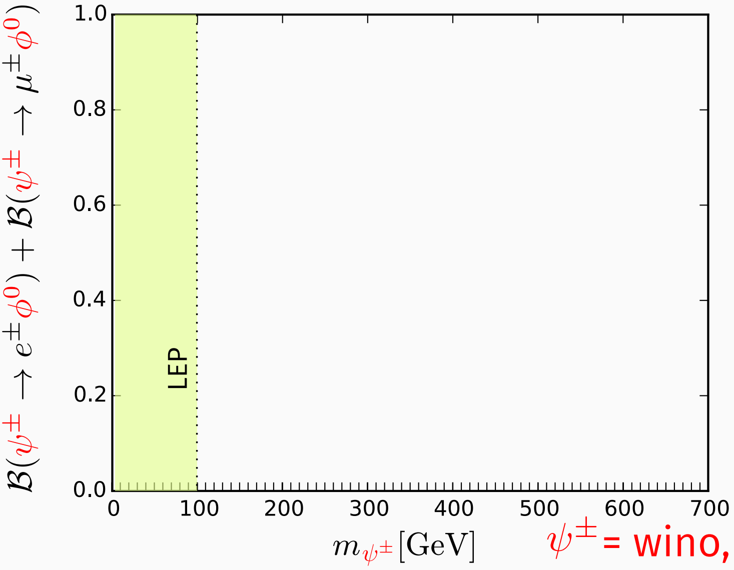
Three-loop diagram for neutrino mass. Here, $S \sim (1, 1, 2)$ and $T \sim (1, 2n+1, 2)$ are beyond-SM scalars while $F \sim (1, 2n+1, 0)$ is a beyond-SM fermion.

Recast at the LHC Run-I

$$pp \to \psi^{\pm}\psi^{\mp} \to l_i^{\pm} l_j^{\mp} \phi^0 \phi^0 \quad l_i = e, \mu, \tau, \quad \phi^0 = H^0, S^0$$

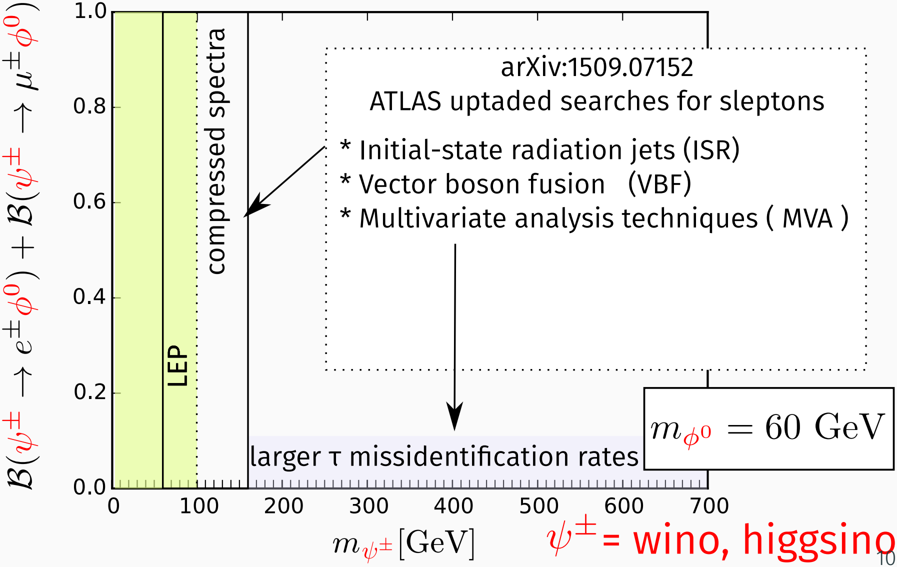
$\psi^{\pm}$ = wino, higgsino

$$pp \to \psi^\pm \psi^\mp \to l_i^\pm l_j^\mp \phi^0 \phi^0 \quad l_i = e, \mu, \tau, \quad \phi^0 = H^0, S^0$$



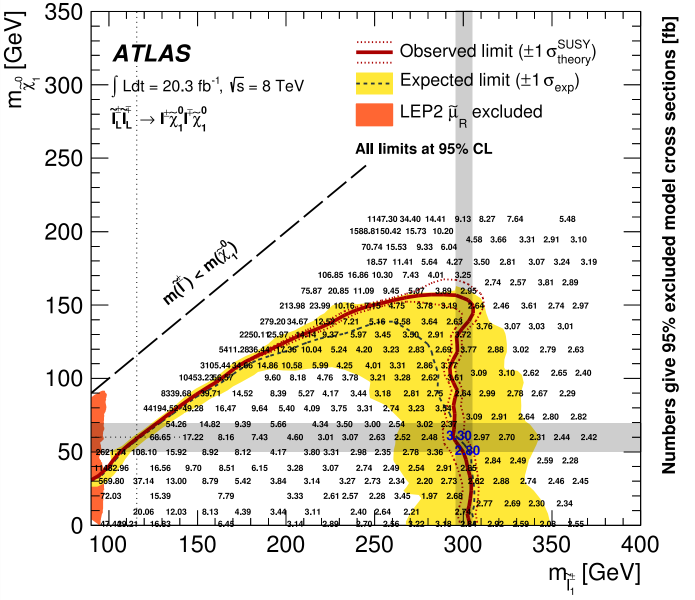
$\psi^\pm$ = wino, higgsino

$$pp \to \psi^{\pm}\psi^{\mp} \to l_i^{\pm} l_j^{\mp} \phi^0 \phi^0 \quad l_i = e, \mu, \tau, \quad \phi^0 = H^0, S^0$$



$\psi^{\pm}$ = wino, higgsino

ATLAS arXiv:1403.5294 (JHEP)

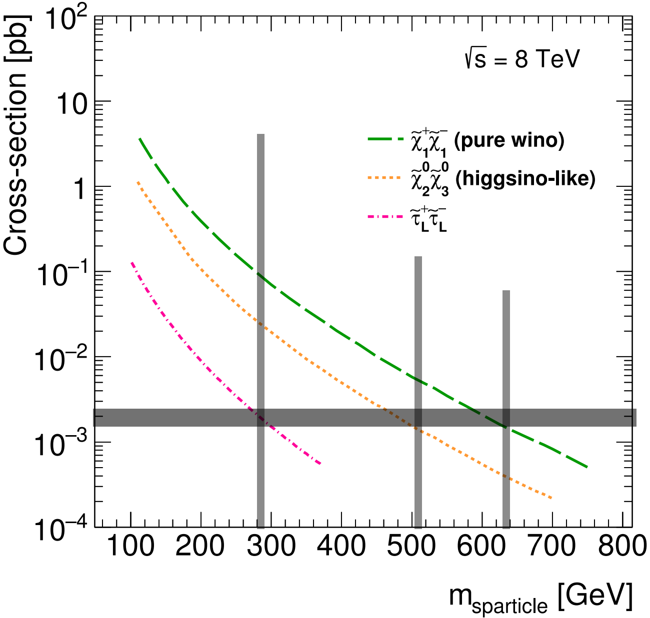


CMS

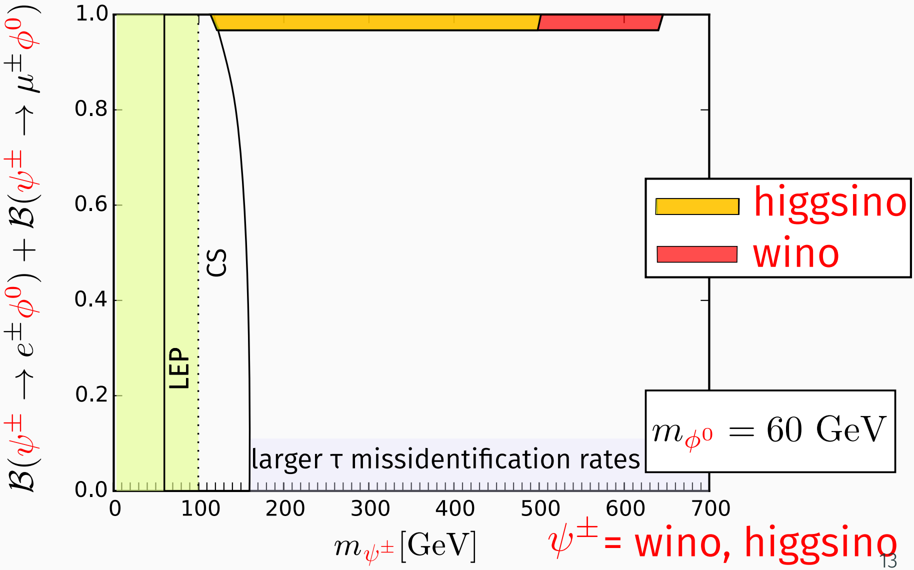
$\gtrsim 260$ GeV

arXiv:1405.7570

Excluded cross section for higgsino and wino fermions



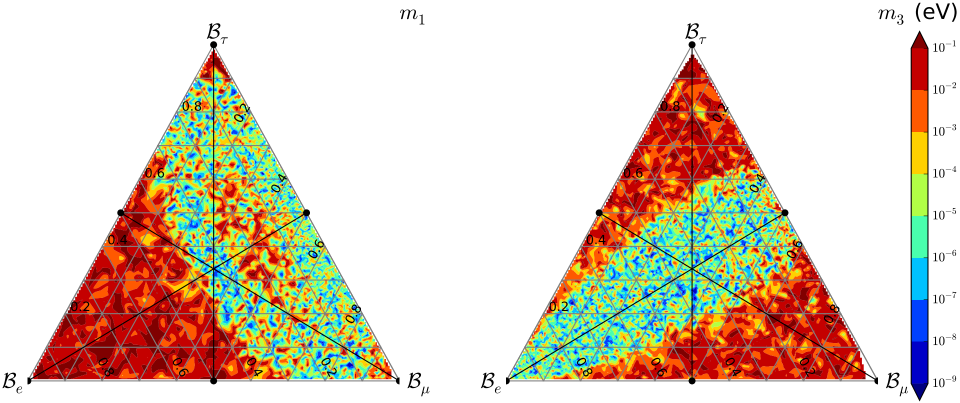
$$pp \to \psi^\pm \psi^\mp \to l_i^\pm l_j^\mp \phi^0 \phi^0 \quad l_i = e, \mu, \tau, \quad \phi^0 = H^0, S^0$$



$\psi^\pm$ = wino, higgsino

Lepton flavor dependence

In wino-like scotogenic model (may be in general)



$$\mathcal{B}_l = \mathcal{B}\left(\psi^{\pm} \to lH^0\right)$$

Exploration of flavor space

Wino-like escotogenic model: Recast for $B_\mu + B_e \gtrsim 0.1$ and

$$m_{H^0} < m_{\psi^\pm} = m_{\psi^0} < m_{A^0}, m_{H^\pm}$$

Start with Signal regions as in ATLAS-arXiv:1403.5294 for $\not{E}_T$ with e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\mp$.

`FeynRules`

$\Downarrow$

`micrOMEGAS` (Experimental and theoretical constraints)

$\Downarrow$

`MadGraph`

$\Downarrow$

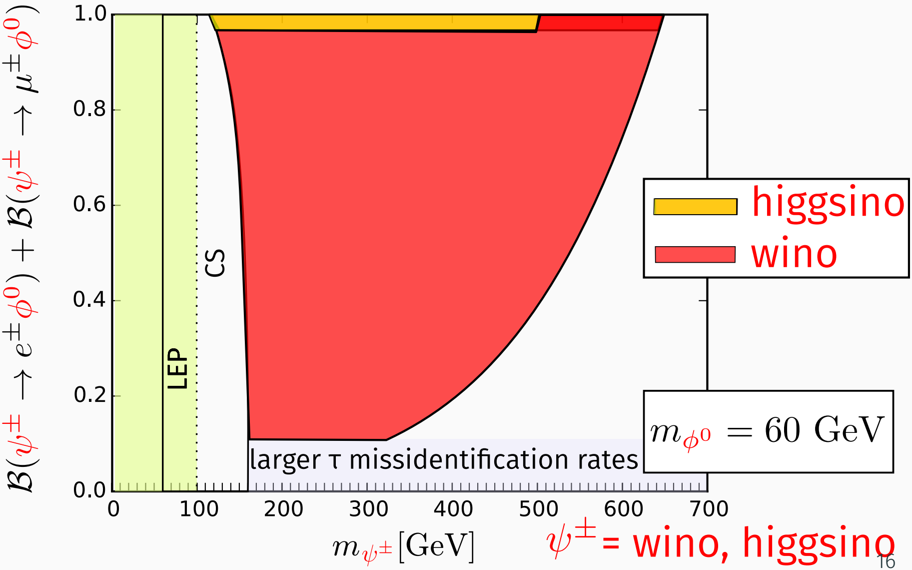
`Pythia 6` (`hep` format)

$\Downarrow$

`checkMATE` (CL-calcutation)

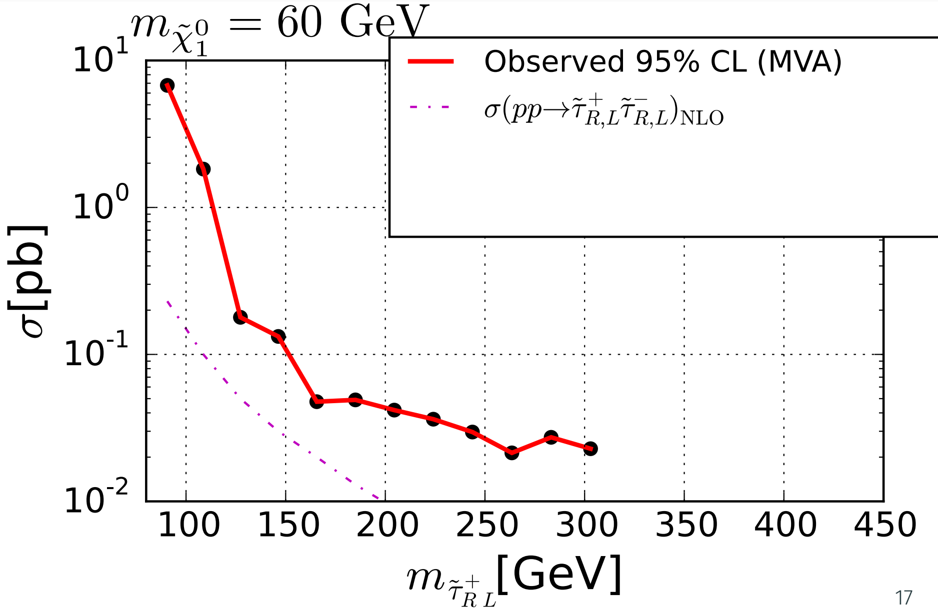
$$CL = CL^{ee} CL^{\mu\mu} CL^{\mu e}$$

$$pp \to \psi^\pm \psi^\mp \to l_i^\pm l_j^\mp \phi^0 \phi^0 \quad l_i = e, \mu, \tau, \quad \phi^0 = H^0, S^0$$



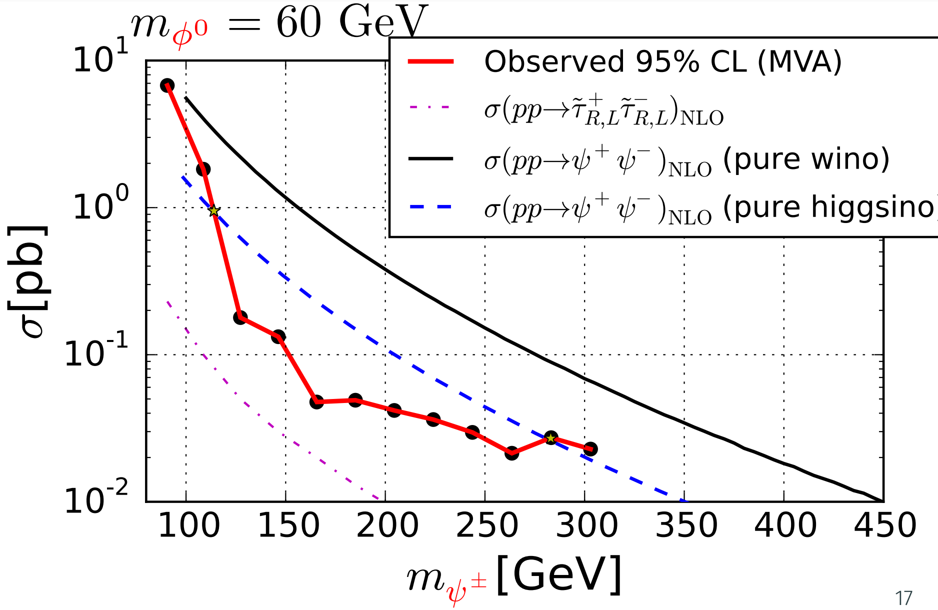
$\psi^\pm$ = wino, higgsino

Pure τ case

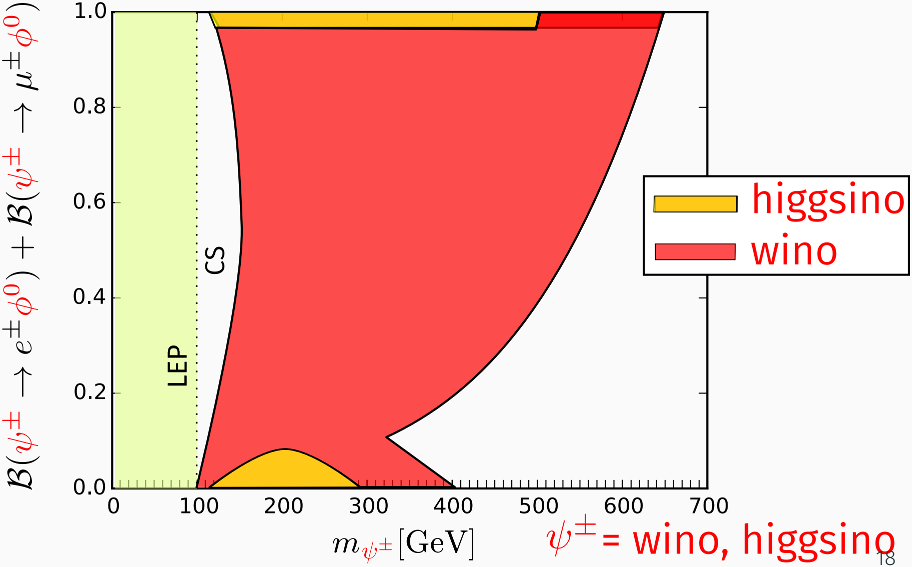


$m_{\tilde{\chi}^0_1} = 60$ GeV
Observed 95% CL (MVA)
$\sigma(pp\to\tilde{\tau}^+_{R,L}\tilde{\tau}^-_{R,L})_{\rm NLO}$
σ[pb]
10^1
10^0
10^{-1}
10^{-2}
100
150
200
250
300
350
400
450
$m_{\tilde{\tau}^+_{R\,L}}$[GeV]

ATLAS arXiv:1509.07152, $X^+X^- \to 2 \times \tau\, \phi_{\rm DM}$: $X^+ = \psi^+, \tilde{\tau}^+_{R,L}$ (MVA)



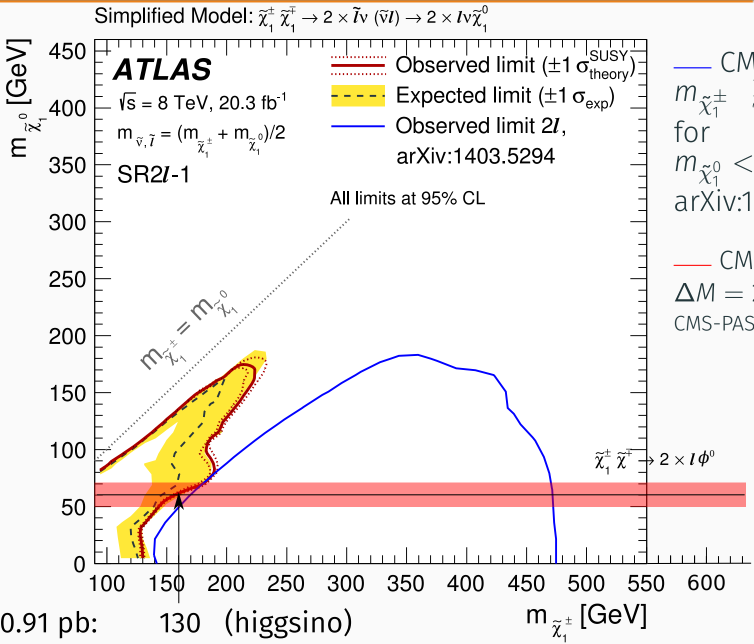
$$pp \to \psi^{\pm}\psi^{\mp} \to l_i^{\pm} l_j^{\mp} \phi^0\phi^0 \quad l_i = e, \mu, \tau, \quad \phi^0 = H^0, S^0$$



$\psi^{\pm}$= wino, higgsino

Compressed spectra

wino production to dilepton plus missing energy (ISR)



0.91 pb: 130 (higgsino)

CMS

$m_{\tilde{\chi}_1^{\pm}} \gtrsim 510$ GeV for $m_{\tilde{\chi}_1^0} < 100$ GeV

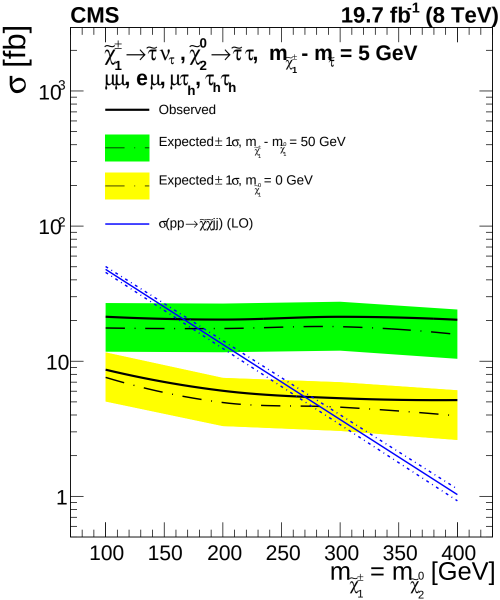
arXiv:1405.7570

CMS $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^0$

$\Delta M = 20$ GeV (ISR)

CMS-PAS-SUS-14-021

CMS 1508.07628: di-tau plus missing energy (VBF)

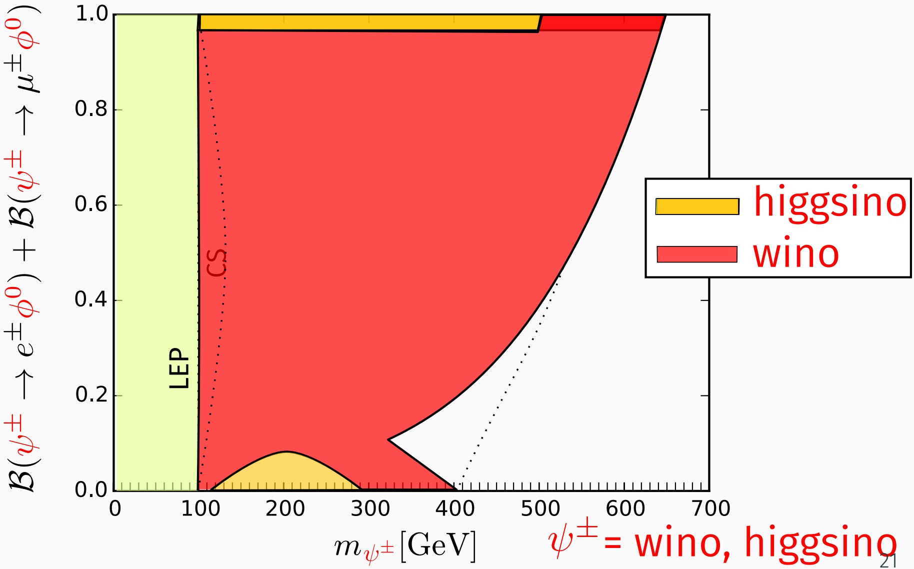


$\cancel{\psi^{\pm}\psi^{0}}$

$\psi^{\pm}\psi^{\mp}$

$\psi^{\pm}\psi^{\pm}$

$$pp \to \psi^{\pm}\psi^{\mp} \to l_i^{\pm} l_j^{\mp} \phi^0 \phi^0 \quad l_i = e, \mu, \tau, \quad \phi^0 = H^0, S^0$$



$\psi^{\pm}$= wino, higgsino

Conclusions

Conclusions

The wino-like scotogenic model (*radiative type-III seesaw*) with $\mathcal{B}(\psi^+ \to l_i \phi^0) = 1$ is a a good simplified model for the interpretation of experimental results at the LHC.

At Run-I, the charged fermion have been excluded until 630 GeV (400 GeV) for $\mathcal{B}(\psi^+ \to e^+ \phi^0) = 1$ $\left(\mathcal{B}(\psi^+ \to \tau^+ \phi^0) = 1\right)$,

Including the compressed-spectra region

TODO: Higgsino-like case

Thanks!