Phenomenology of scotogenic models

LHC signals

UNIVERSIDAD DE ANTIOQUIA
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Focus on

arXiv: arXiv:1308.3655 (JHEP), arXiv:1504.07892 (PRD), arXiv:1509.06313 (PRD), arXiv:1511.01873 (JHEP), arXiv:1605.01129 (PRD)

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.).

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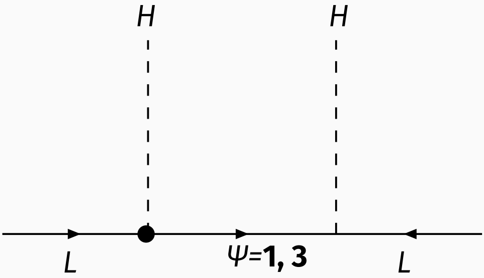
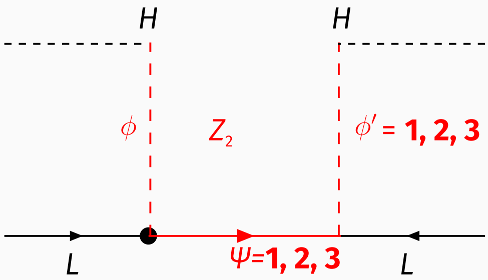
General framework

ν-DM models

small neutrino masses



small neutrino masses $\Leftarrow Z_2 \Rightarrow$ dark matter



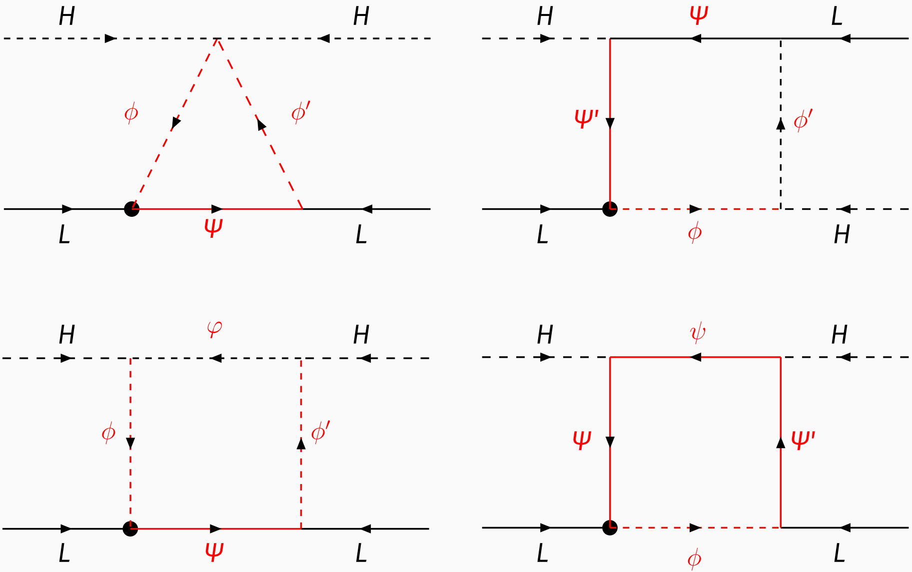
35 non-equivalent dark matter models classified in

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

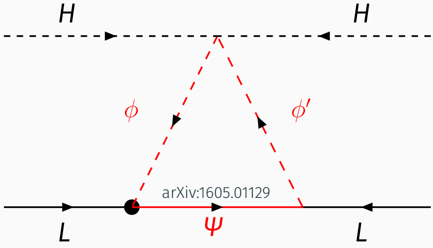
2. Neutrinos talk to a different **Higgs boson**

Weinberg operator at one-loop

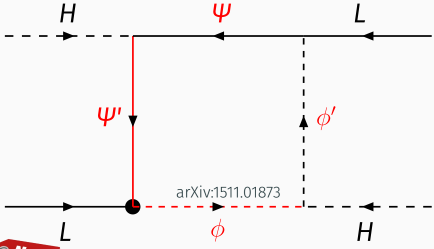
(Z_2-odd fields)



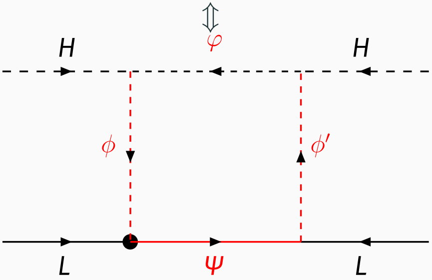
(Z_2-odd fields)

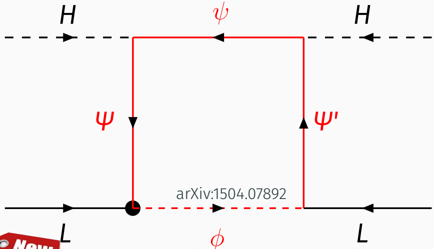


Wino-like scotogenic model



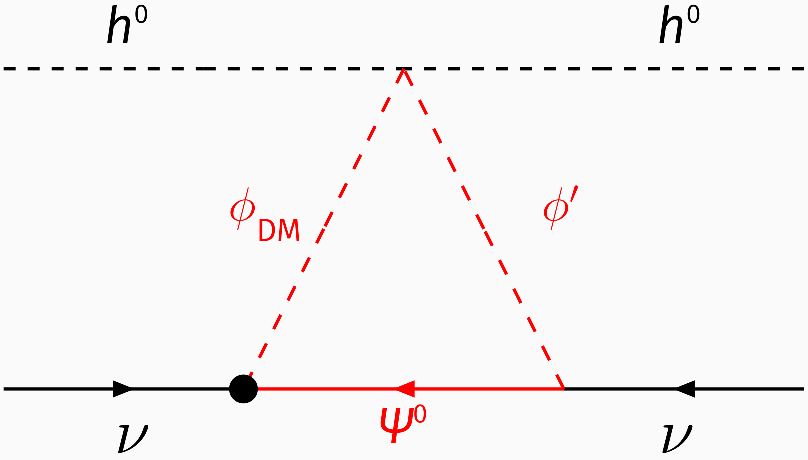
New Higgsino-like Zee model



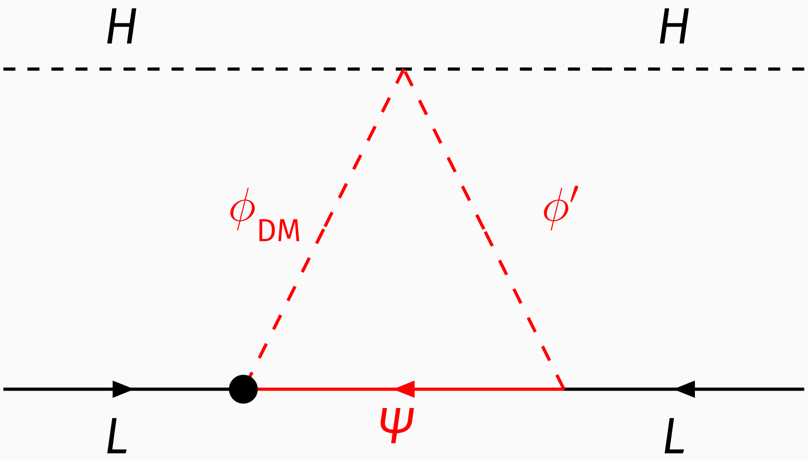


New Higgsino-like scotogenic model

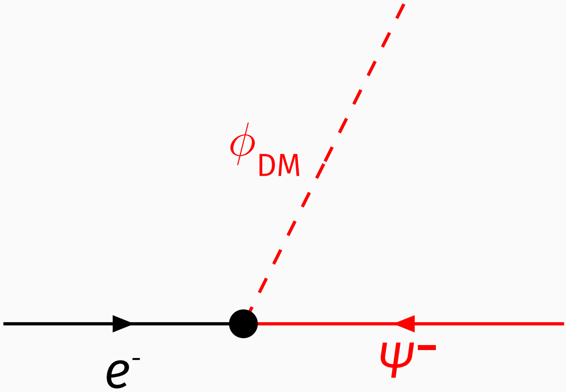
Typical radiative neutrino mass diagram.



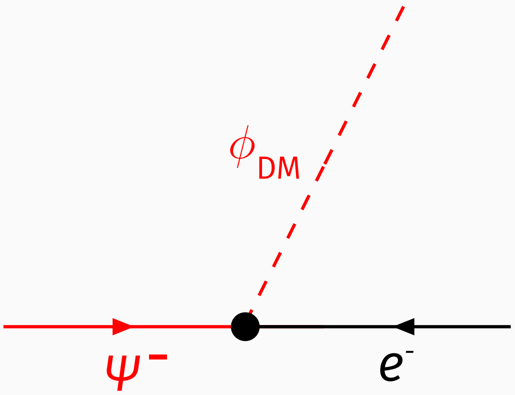
In term of general SU(2)$_L$ multiplets,



may be also contain charged particles,

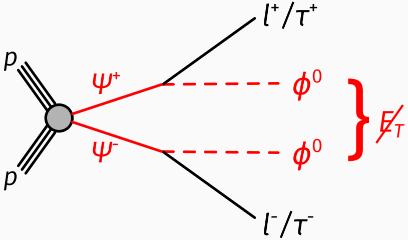


which may decay into the dark matter particle.



Proposal: $pp \to l^+ l^- + E_T^{\text{miss}}$

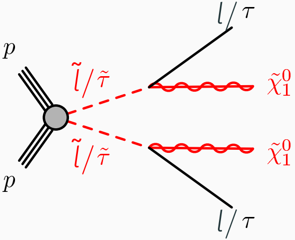
Dilepton plus transverse missing energy signal

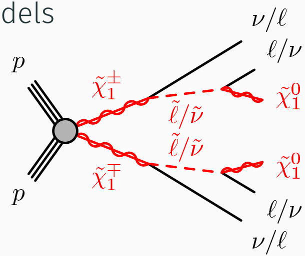


SU(2)$_L$ assignments:

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

Simplified SUSY models





Smaller cross sections. Intermediate states and smaller lepton $\not p_T$

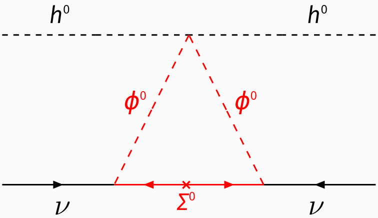
Specific examples

Specific examples

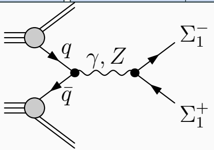
- Wino-like scotogenic models
  - Radiative type-III seesaw: 1605.01129, F. von der Pahlen, G. Palacio, DR, O. Zapata
- Higgsino-like scotogenic models
  1. SDFM with scalars: 1504.07892, DR, *et. al.*.
  2. Inert Zee: 1511.01873, R. Longas, D. Portillo, DR, O. Zapata.
  3. Radiative type-II seesaw: 1511.06375, S. Fraser, C. Kownacki, E. Ma, O. Popov

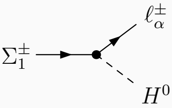
     1609.01018, S. Guo, Z. Han, Y, Liao
- Bino-like scotogenic models
  - In progress ...

Wino-like scotogenic model

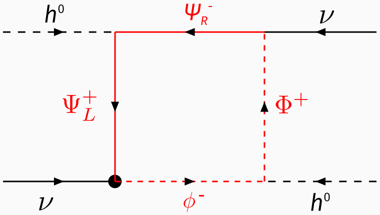


	$SU(2)_L$	$U(1)_Y$	Z_2	S
H	2	1	$+$	0
Φ	2	1	$-$	0
L_α	2	-1	$+$	$1/2$
Σ_k	3	0	$-$	$1/2$





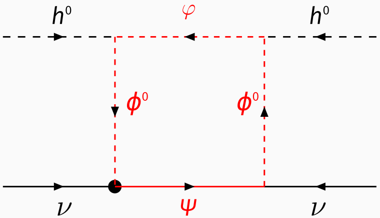
Higgsino-like inert Zee model



	$SU(2)_L$	$U(1)_Y$	Z_2	S
ϕ^-	1	-2	$-$	0
Φ	2	–	0	-
ψ^-	1	-2	$-$	0
$\Psi_{L,R}$	2	±1	$-$	$1/2$

$$\Sigma^+ \to \psi^+$$

Wino-like scotogenic model



	$SU(2)_L$	$U(1)_Y$	Z_2	S
H	2	1	$+$	0
Φ	2	1	$-$	0
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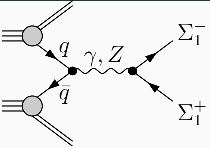
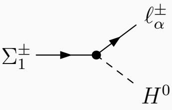
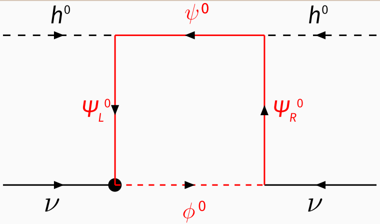
Σ_k	3	0	$-$	1/2





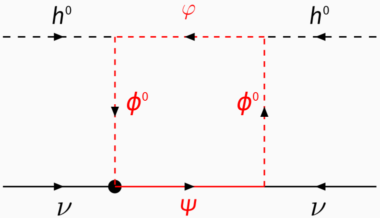
Higgsino-like scotogenic model



	$SU(2)_L$	$U(1)_Y$	Z_2	S
ϕ^-	1	-2	$-$	0
Φ	2	$-$	0	-
ψ^-	1	-2	$-$	0
$\Psi_{L,R}$	2	± 1	$-$	1/2
ψ	1	0	-	1/2
ϕ	1	0	-	0

$$\Sigma^+ \to \psi^+$$

Wino-like scotogenic model



	$SU(2)_L$	$U(1)_Y$	Z_2	S
H	2	1	$+$	0
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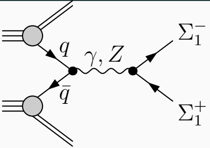
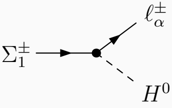
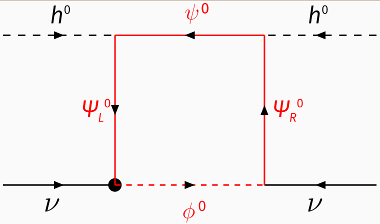




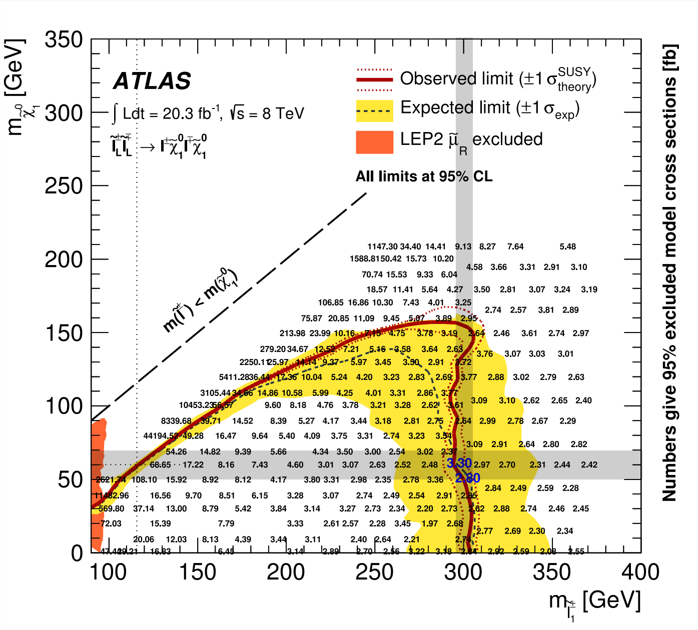
Higgsino-like model



	$SU(2)_L$	$U(1)_Y$	Z_2	S
ϕ^-	1	-2	$-$	0
Φ	2	$-$	0	-
ψ^-	1	-2	$-$	0
$\Psi_{L,R}$	2	±1	$-$	1/2
ψ	1	0	-	1/2
ϕ	1	0	-	0

$$\Sigma^+ \to \psi^+$$

ATLAS arXiv:1403.5294 (JHEP)

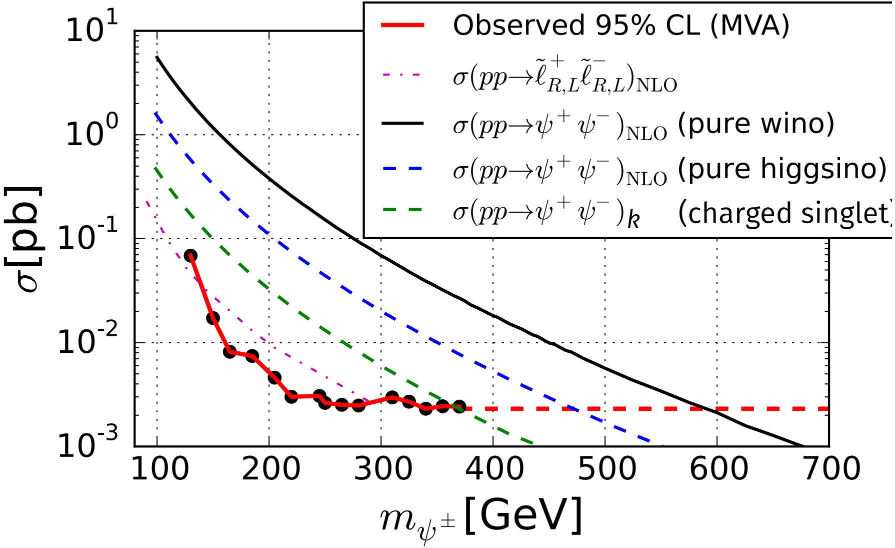


CMS

$\gtrsim$ 260 GeV

arXiv:1405.7570

$m_{\phi^0} = 60$ GeV



Observed 95% CL (MVA)
$\sigma(pp\to\tilde{\ell}^+_{R,L}\tilde{\ell}^-_{R,L})_{\text{NLO}}$
$\sigma(pp\to\psi^+\psi^-)_{\text{NLO}}$ (pure wino)
$\sigma(pp\to\psi^+\psi^-)_{\text{NLO}}$ (pure higgsino)
$\sigma(pp\to\psi^+\psi^-)_k$ (charged singlet
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
σ[pb]
100
200
300
400
500
600
700
$m_{\psi^\pm}$[GeV]

Lepton flavor dependence

Neutrino masses

$$(\mathcal{M}_\nu)_{\alpha\beta} = \sum_{k=1}^{n_\Sigma} \left[Y^T \Lambda Y\right]_{\alpha\beta} \,, \qquad \alpha, \beta = 1, 2, 3 \,,$$

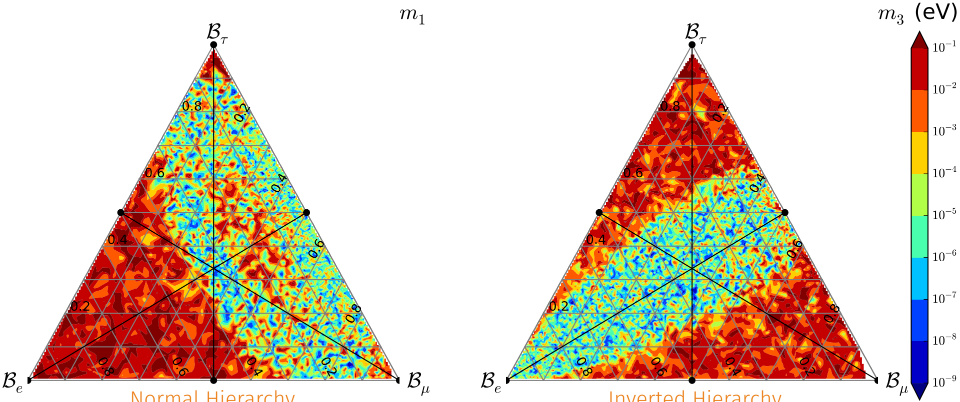
From neutrino oscillation data, we can get a set of Y choosing the angles for R, an arbitrary *complex orthogonal matrix*

$$Y = \sqrt{\Lambda}^{-1} R \ \mathrm{diag}(\sqrt{m_{\nu_1}}, \sqrt{m_{\nu_2}}, \sqrt{m_{\nu_3}}) U^\dagger_{\mathrm{PMNS}} \,, \tag{1}$$

$$\hat{Y}_\alpha \equiv \hat{Y}_{1\alpha} = Y_{1\alpha} / \sqrt{\sum_{\alpha=e,\mu,\tau} |Y_{1\alpha}|^2} \qquad \mathcal{B}_\alpha \equiv \mathrm{Br}(\Sigma_1^\pm \to \ell_\alpha H^0) = |\hat{Y}_\alpha|^2 \,.$$

Input parameters: 3 complex angles and 1 phase.

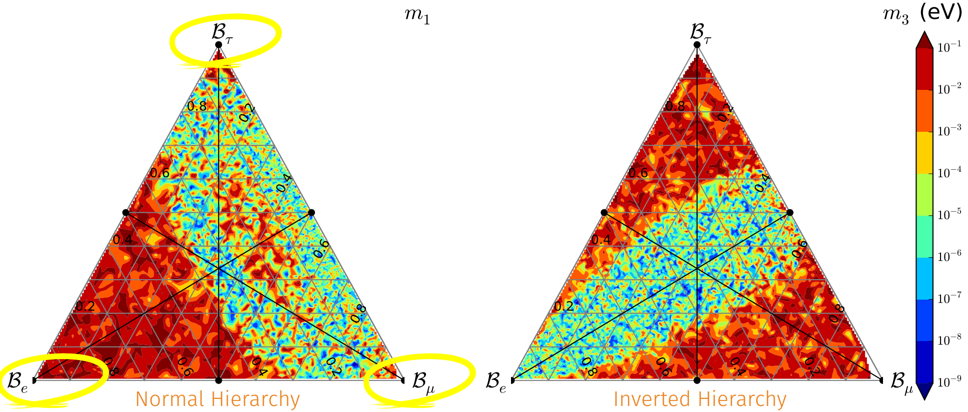
In wino-like scotogenic model (may be in general)



Normal Hierarchy Inverted Hierarchy

$$\mathcal{B}_l = \mathcal{B}\left(\Sigma^{\pm} \to l^{\pm} H^0\right)$$

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



$$\mathcal{B}_l = \mathcal{B}\left(\Sigma^\pm \to l^\pm H^0\right)$$

Exploration of flavor space

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

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

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

`SARAH/FeynRules`

$\Downarrow$

`micrOMEGAS` (Experimental and theoretical constraints)

$\Downarrow$

`MadGraph`

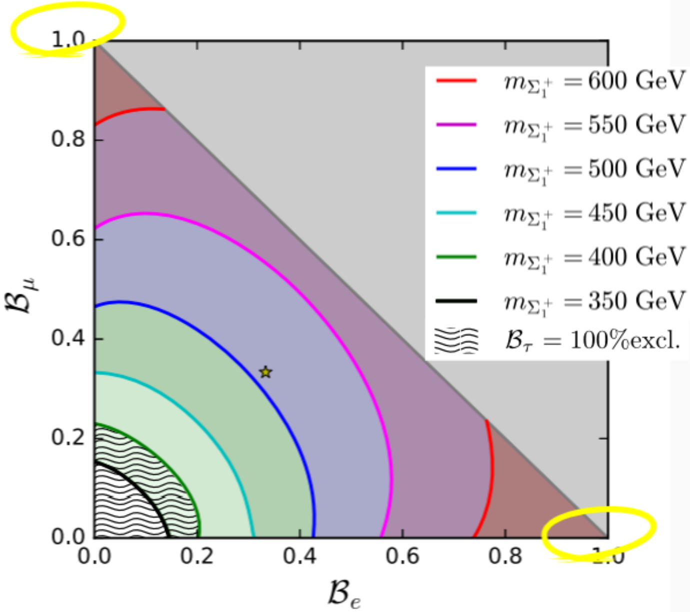
$\Downarrow$

`Pythia 6` (`hep` format)

$\Downarrow$

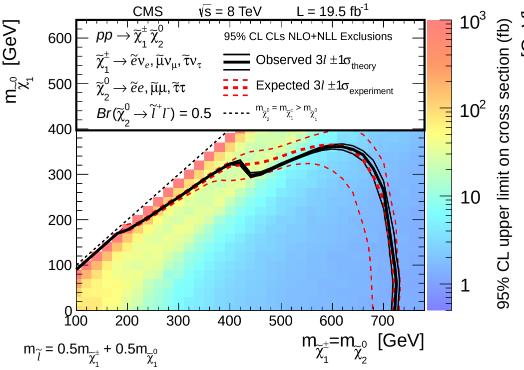
`checkMATE` (CL-calculation)

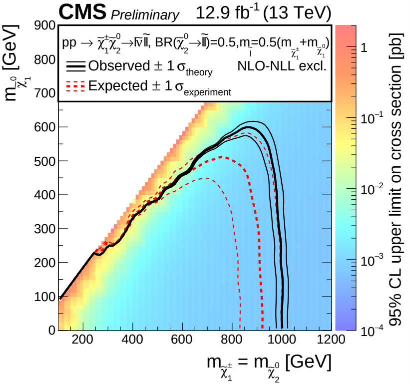
Combination



Prospects for run-II

Golden EW SUSY channel: trilepton and $\not{E}_T$





arxiv:1405.7570 (8 TeV) SUS-16-024 (13 TeV)

Improvement by a factor of 1.4

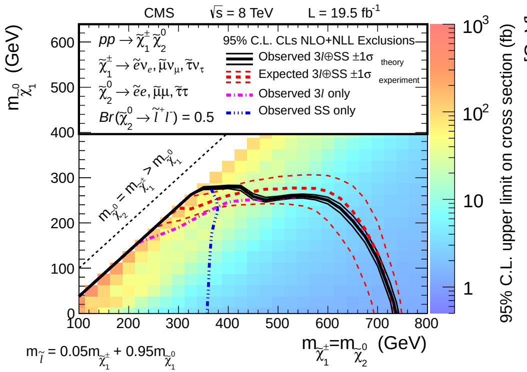
For a similar improvement we could expect exclusions at the level of

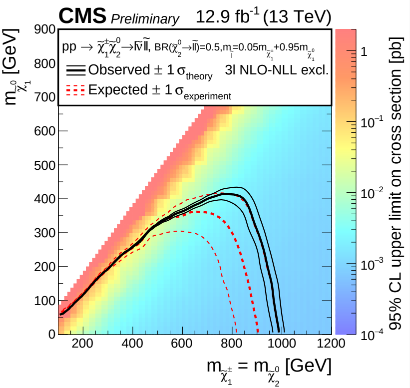
900 GeV in the wino-like scotogenic model,

700 GeV in Higgsino-like scotogenic models.

500 GeV in Bino-like scotogenic models.

Golden EW SUSY channel: trilepton and $\not{E}_T$





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Vector-like fermion mediation

Vector-like fermion mediation

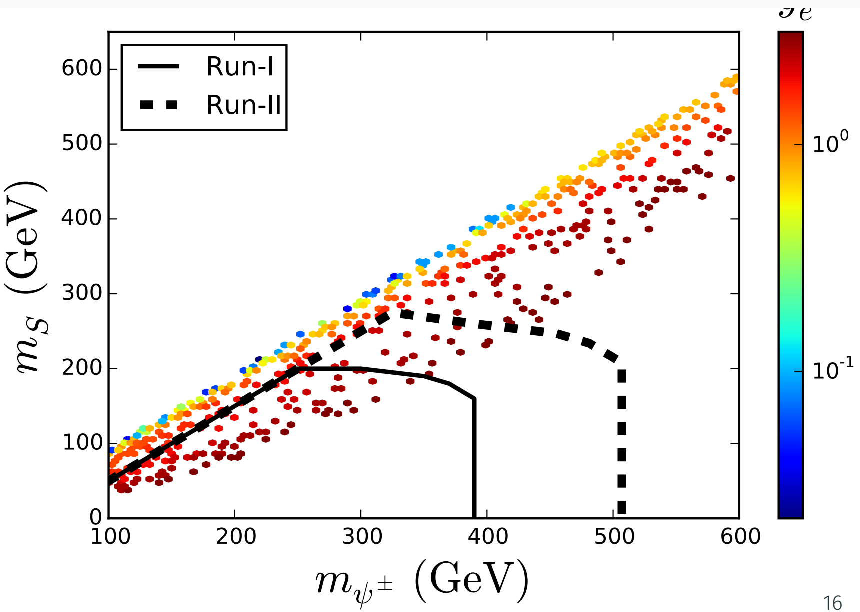
Straightforward way to avoid DD constraints in scalar dark matter:

Name	Symbol	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$\begin{pmatrix} \nu_L & e_L \end{pmatrix}^T$	$\begin{pmatrix} \xi_{1\alpha} & \xi_{2\alpha} \end{pmatrix}^T$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	$+1$
$(e_R)^\dagger$	η_1^α	$\mathbf{1}$	$\mathbf{1}$	$+1$	$+1$
$(\psi_R)^\dagger$	η_2^α	$\mathbf{1}$	$\mathbf{1}$	$+1$	-1
ψ_L	$\xi_{3\alpha}$	$\mathbf{1}$	$\mathbf{1}$	-1	-1
S		$\mathbf{1}$	$\mathbf{1}$	0	-1

$$\mathcal{L} \supset y_e S (e_R)^\dagger \psi_L + m_{\psi^\pm} (\psi_R)^\dagger \psi_L + \text{h.c} + \frac{1}{2} m_S S^2 + \cancel{\lambda_{HS} S^2 H^\dagger H}$$

See: arXiv:1307.6181 and arXiv:1307.6480

LHC constraints: Preliminary



Conclusions

Opposite sign dilepton plus missing transverse energy signal at LHC

The use of scotogenic models to interpret dilepton plus missing transverse energy searches, allow for larger sensitivities and full lepton flavor exploration

Additional motivation for fermion vectorlike mediation with zero three-level direct detection cross section and challenging compressed spectra.

Thanks!