Collider signals of scotogenic models

Radiative sessaw Type II and III

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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.).

TeV Particle Astrophysics 2016 - CERN

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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)

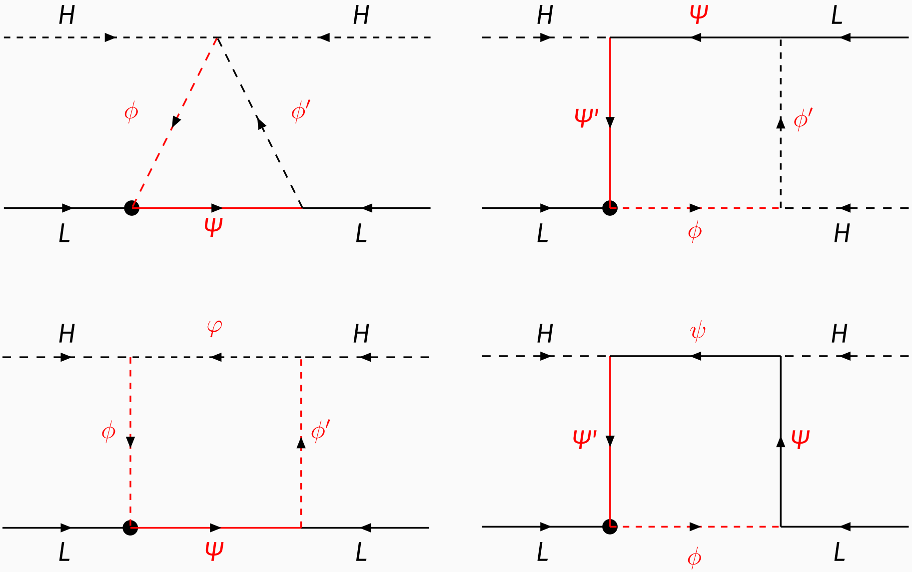
It may be, though, that they are related to each other.

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)

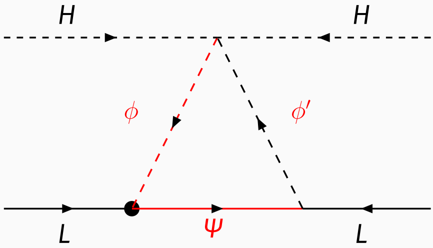
There, the new fields are odd under a Z_2 symmetry which ensures the stability of the DM particle, while the SM particles are even.

(Z_2-odd fields)

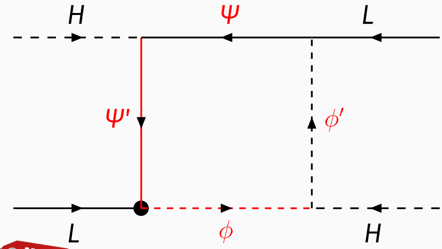


Weinberg operator at one-loop

(Z_2-odd fields)



Wino-like scotogenic model



New Higgsino-like Zee model

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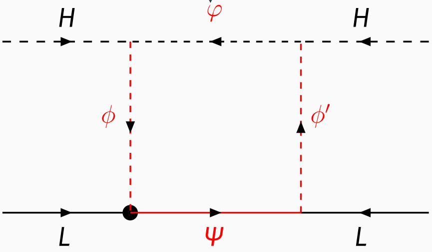
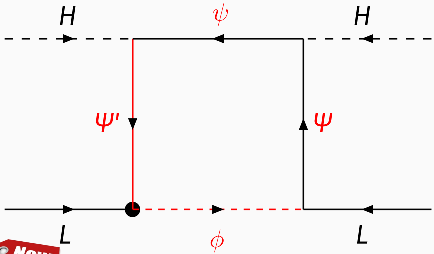
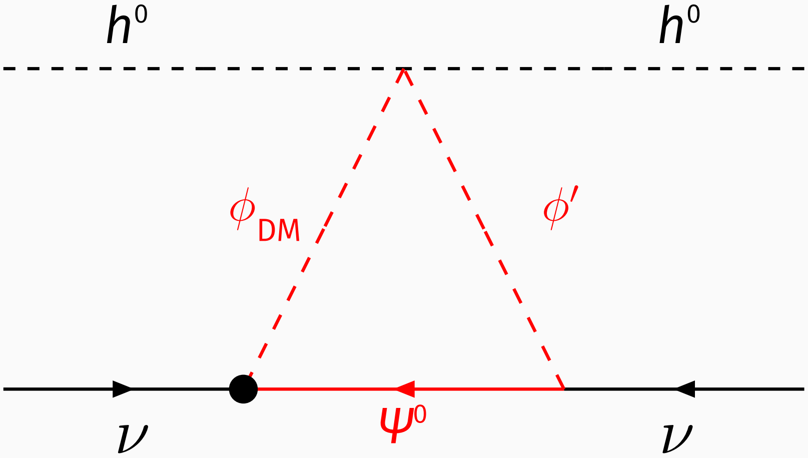


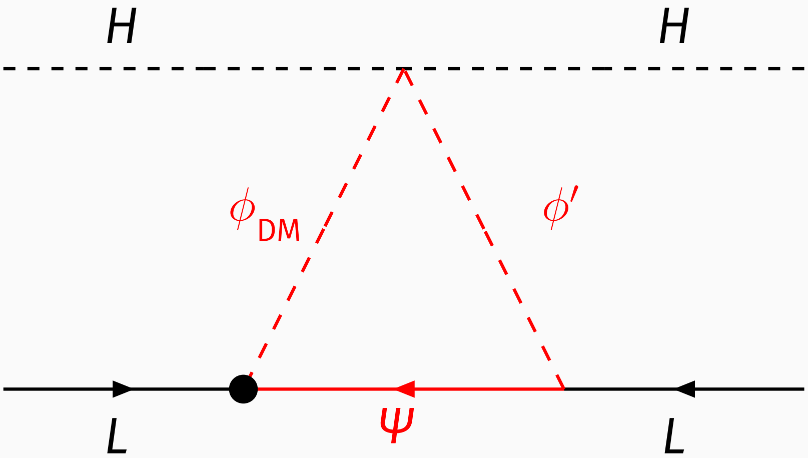


New Higgsino-like scotogenic model

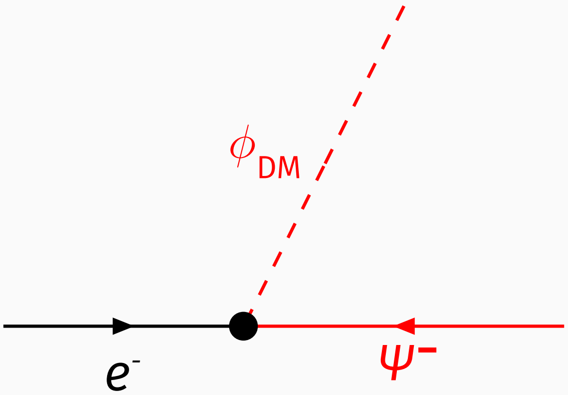
Typical radiative neutrino mass diagram.



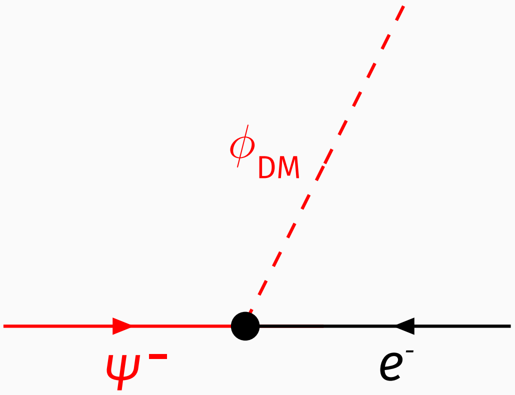
In term of general $SU(2)_L$ multiplets,



may be also contain charged particles,

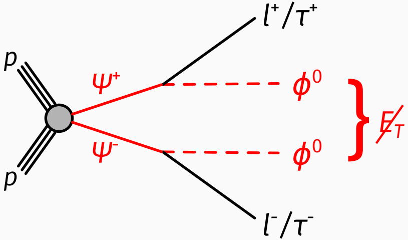


which may decay into the dark matter particle.



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

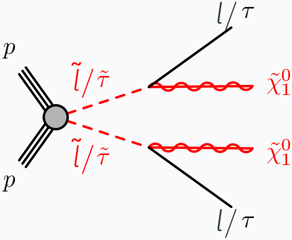
Dilepton plus transverse missing energy signal

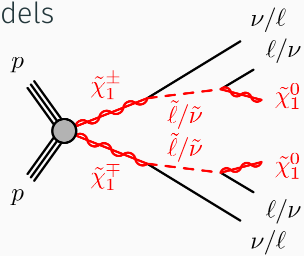


SU(2)$_L$ assignments:

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

Simplified SUSY models

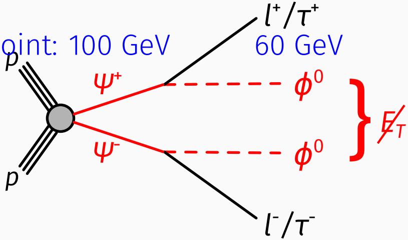




Smaller cross sections. Intermediate states and smaller lepton $\cancel{p}_T$

Dilepton plus transverse missing energy signal

Benchmark point: 100 GeV 60 GeV



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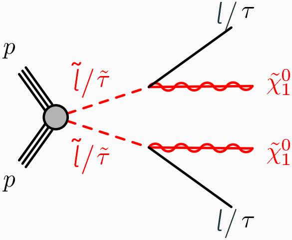
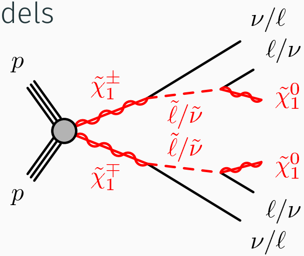
Simplified SUSY models





Smaller cross sections. Intermediate states and smaller lepton $\not{p}_T$

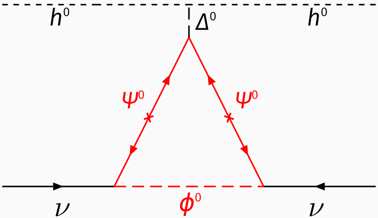
Specific examples

Specific examples

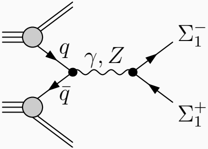
- Wino-like scotogenic models
  - Radiative type-III see-saw: 1605.01129, F. von der Pahlen, G. Palacio, DR, O. Zapata
- Higgsino-like scotogenic models
  1. SDFM with scalars: 1504.07892, DR, *et. al.*.
  2. Inert Zee: 1511.01873, R. Longas, D. Portillo, DR, O. Zapata.
  3. Radiative type-III see-saw: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

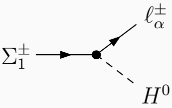
     1609.01018, S. Guo, Z. Han, Y, Liao
- Bino-like scotogenic models [2]

Wino-like scotogenic model

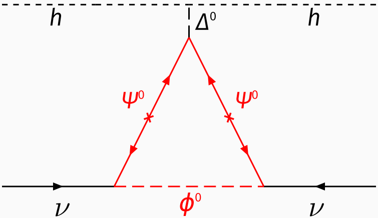


	$SU(2)_L$	$U(1)_Y$	Z_2	S
Φ_{SM}	2	1	$+$	0
Φ	2	1	$-$	0
L_α	2	-1	$+$	$1/2$
Σ_k	3	0	$-$	$1/2$



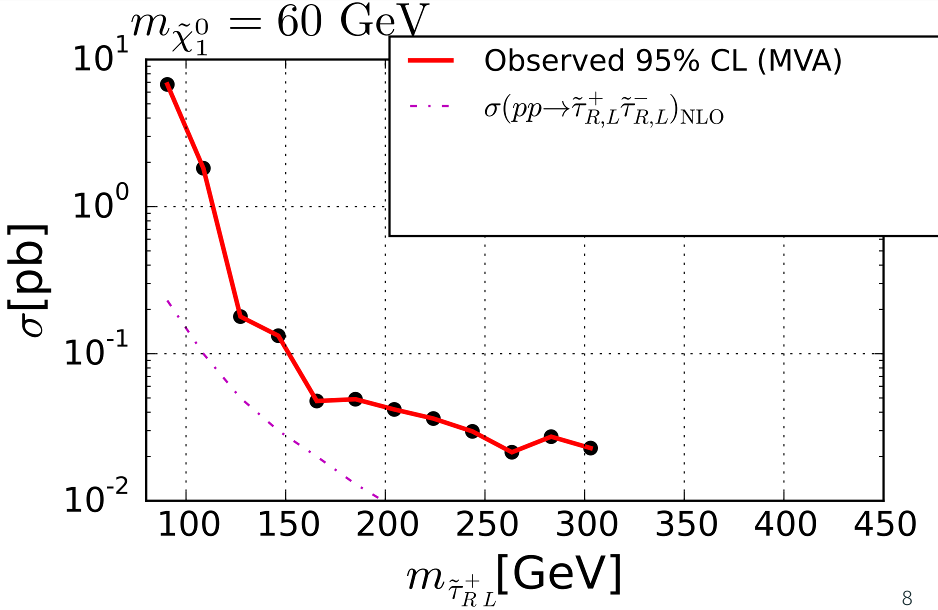


Higgsino-like scotogenic model

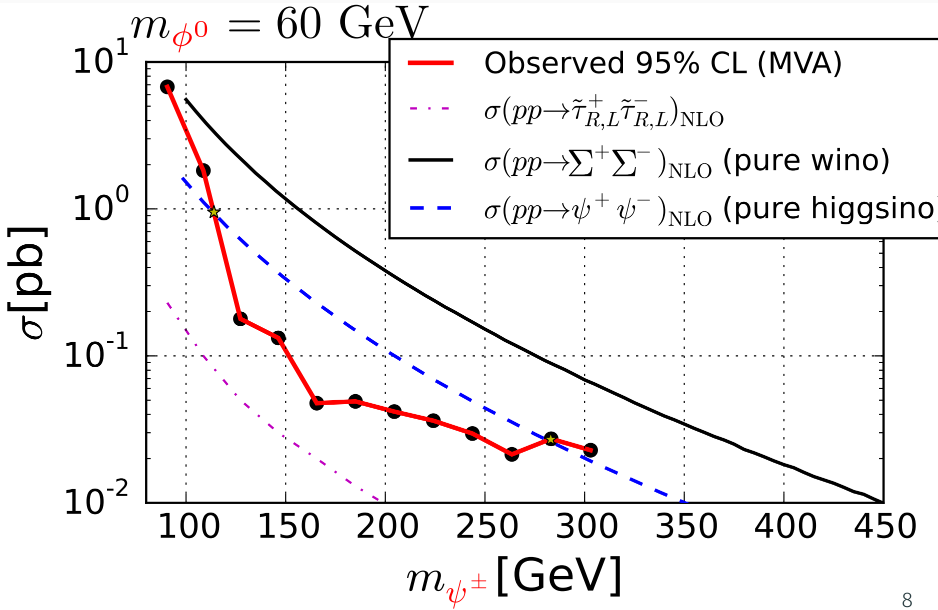


	$SU(2)_L$	$U(1)_Y$	Z_2	S
Δ	3	2	$+$	0
Φ	1	0	$-$	0
$\Psi_{L,R}$	2	± 1	$-$	$1/2$

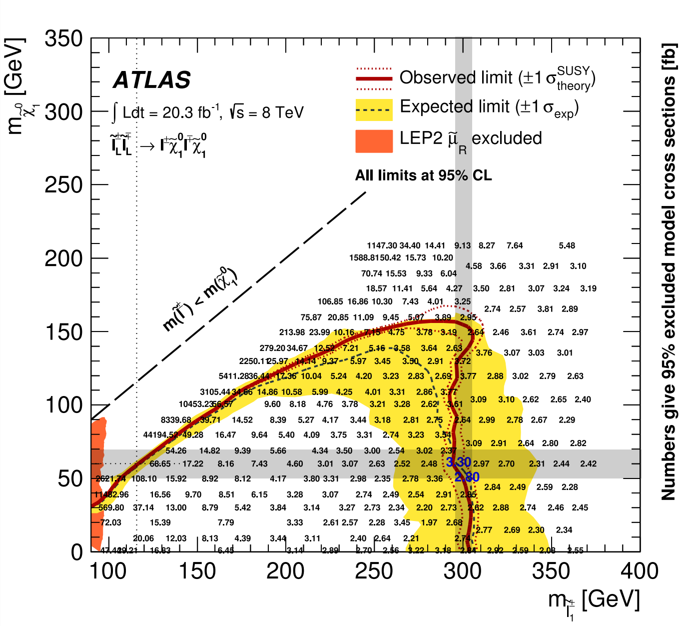
$$\Sigma^+ \to \psi^+$$


$m_{\tilde{\chi}^0_1} = 60$ GeV
Observed 95% CL (MVA)
$\sigma(pp \to \tilde{\tau}^+_{R,L}\tilde{\tau}^-_{R,L})_{\mathrm{NLO}}$
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)



ATLAS arXiv:1403.5294 (JHEP)

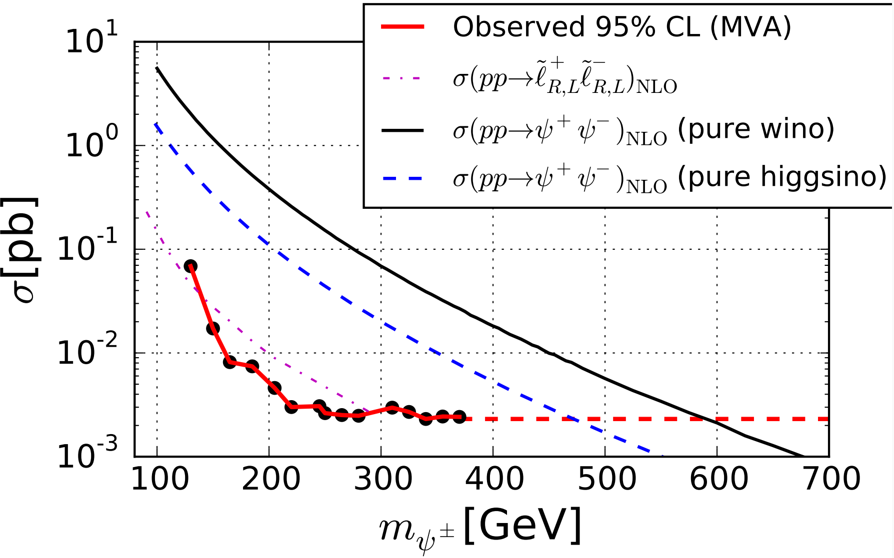


CMS

$\gtrsim 260$ GeV

arXiv:1405.7570

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



Observed 95% CL (MVA)
$\sigma(pp\to\tilde{\ell}^+_{R,L}\tilde{\ell}^-_{R,L})_{\rm NLO}$
$\sigma(pp\to\psi^+\psi^-)_{\rm NLO}$ (pure wino)
$\sigma(pp\to\psi^+\psi^-)_{\rm NLO}$ (pure higgsino)
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

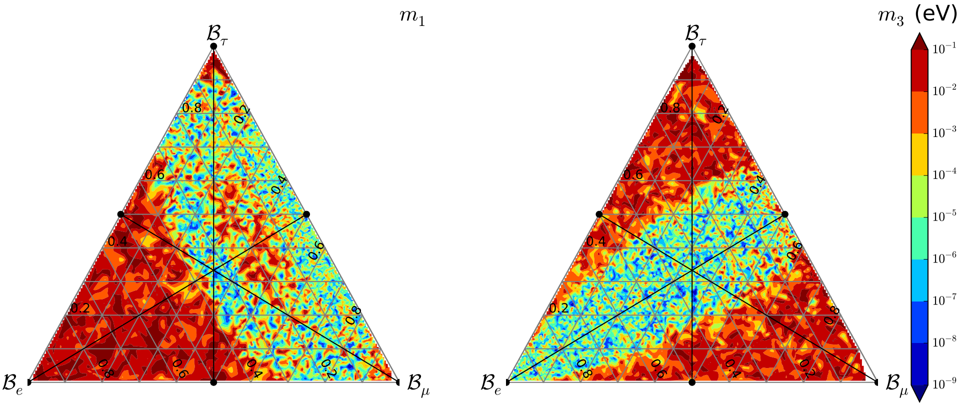
$$(\mathcal{M}_\nu)_{\alpha\beta} = \sum_{k=1}^{n_\Sigma} \left[Y^T \Lambda Y\right]_{\alpha\beta} \,, \qquad \alpha, \beta = 1, 2, 3 \,,$$

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

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

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

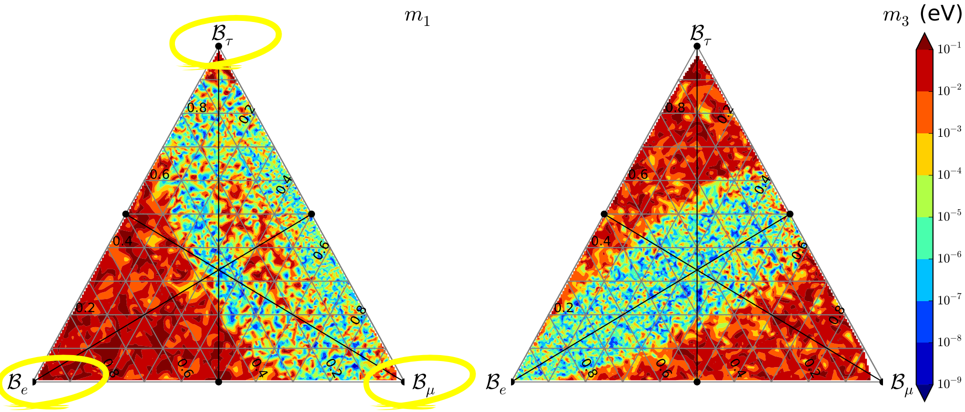
In wino-like scotogenic model (may be in general)



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

Casas-Ibarra parametrization

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`

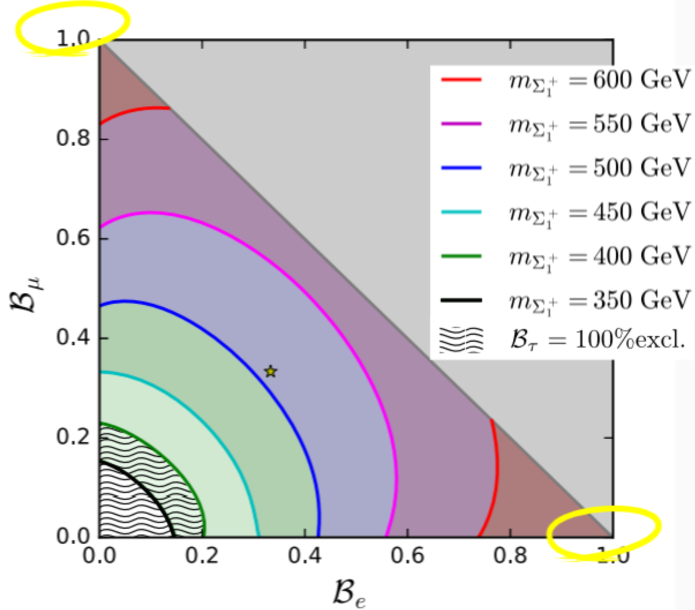
$\Downarrow$

`Pythia 6` (`hep` format)

$\Downarrow$

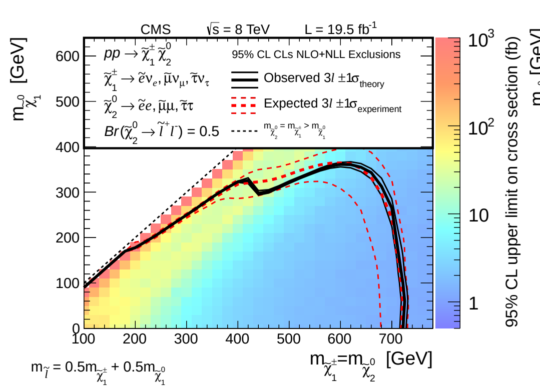
`checkMATE` (CL-calcutation)

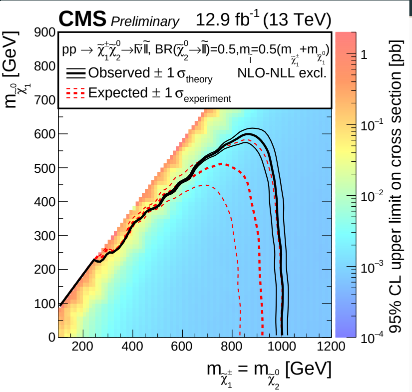
Combination



Prospects for run-II

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





Improvement by a factor of 1.4

For a similar improvement in the wino-like sctogenic model, we could expect exclusions at the level of 900 GeV.

700 GeV in Higgsino-like scotogenic models.

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 sensitivity and full lepton flavor exploration

Thanks!