Experimental constraints on the Doublet-triplet dark matter model
MOCa 2018

Amalia Betancur R

In collaboration with: Dr. Óscar Zapata Noreña (advisor)

UNIVERSIDAD EIA 40 años VIGILADA MINEDUCACIÓN

FULBRIGHT COLOMBIA

UNIVERSIDAD DE ANTIOQUIA 1803

Outline

- Motivation
- The Model
- Phenomenology:
  - Collider, Higgs diphoton decay
  - Collider, electroweak production
  - Direct detection experiments
  - Indirect detection, diffuse gamma-ray spectrum
  - Indirect detection, line-like gamma-ray spectrum
- Conclusions

Motivation: WIMP

- Weakly Interacting Massive Particles (WIMPs) are interesting particle Dark Matter candidates.

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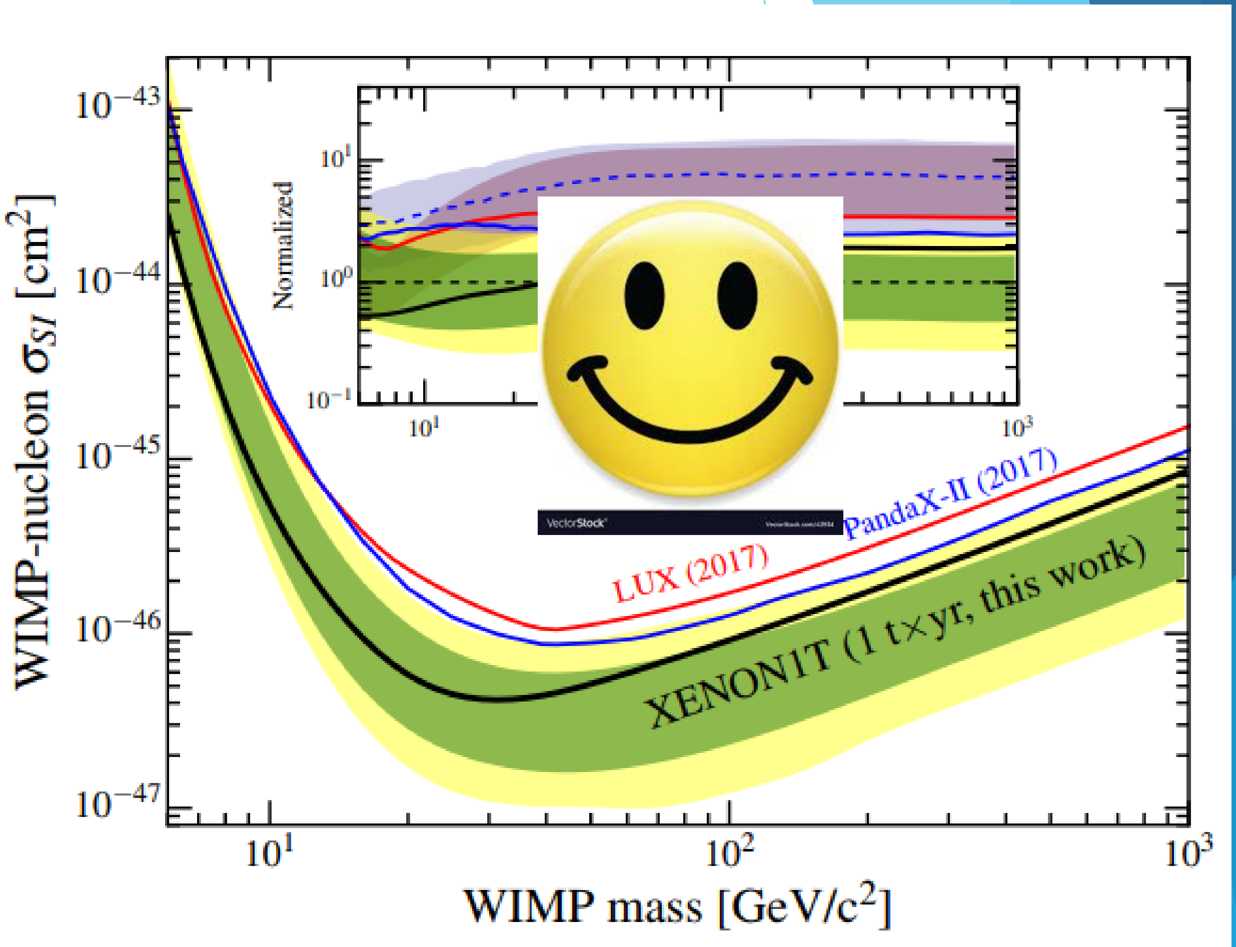
- These particles could be detected through the scattering with heavy nuclei on earth (e.g. direct detection).



E. Aprile et al 2018

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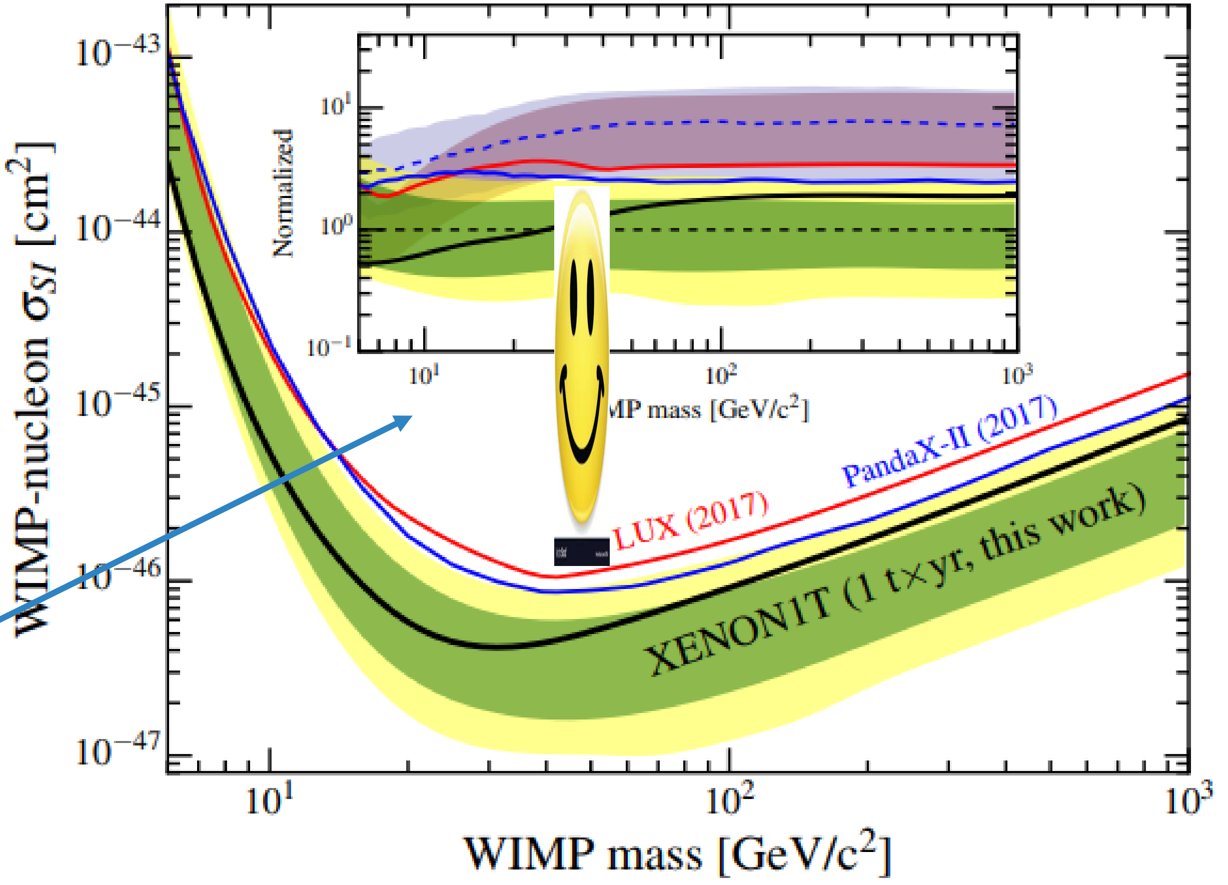
No WIMP evidence so far!



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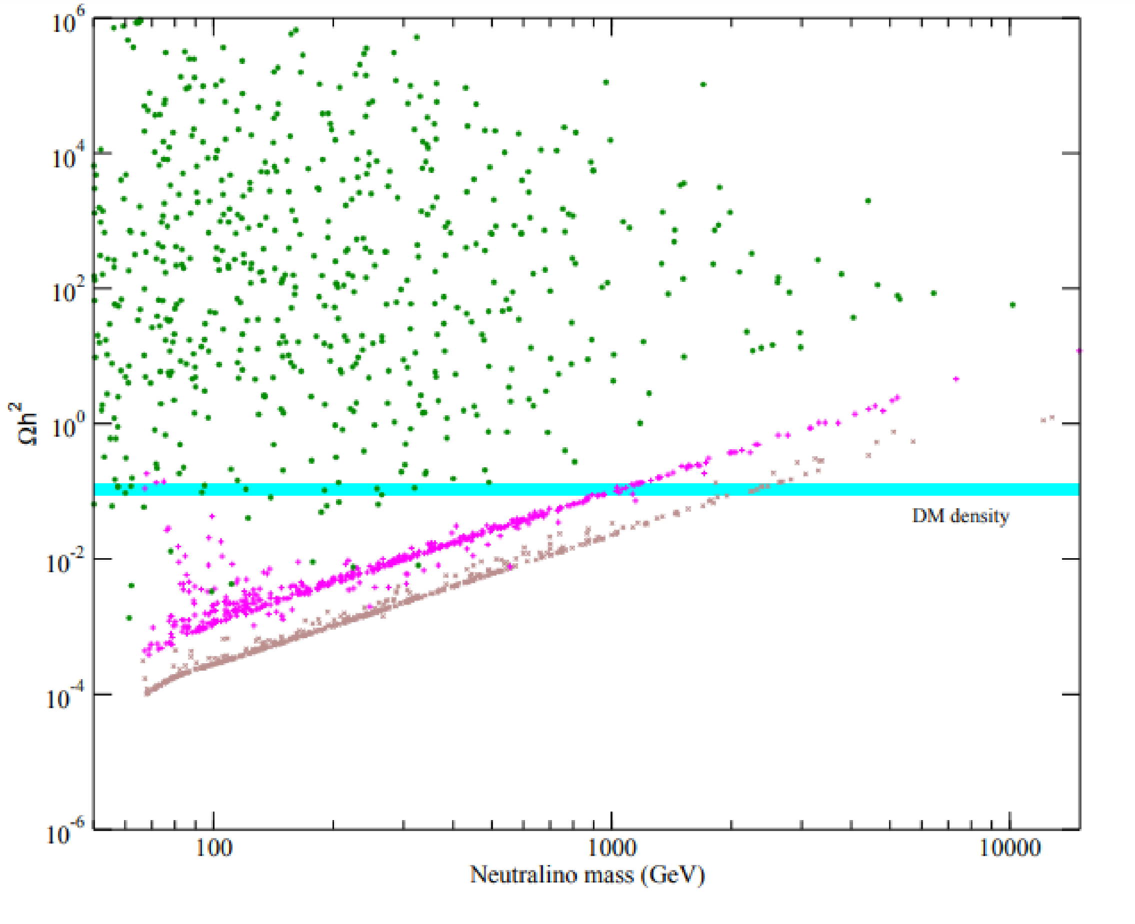
MOTIVATION: WIMP RELIC DENSITY

Satisfying relic abundance and having a WIMP that is not completely excluded or out of reach of experiments is difficult!



G. Gelmini, 2009

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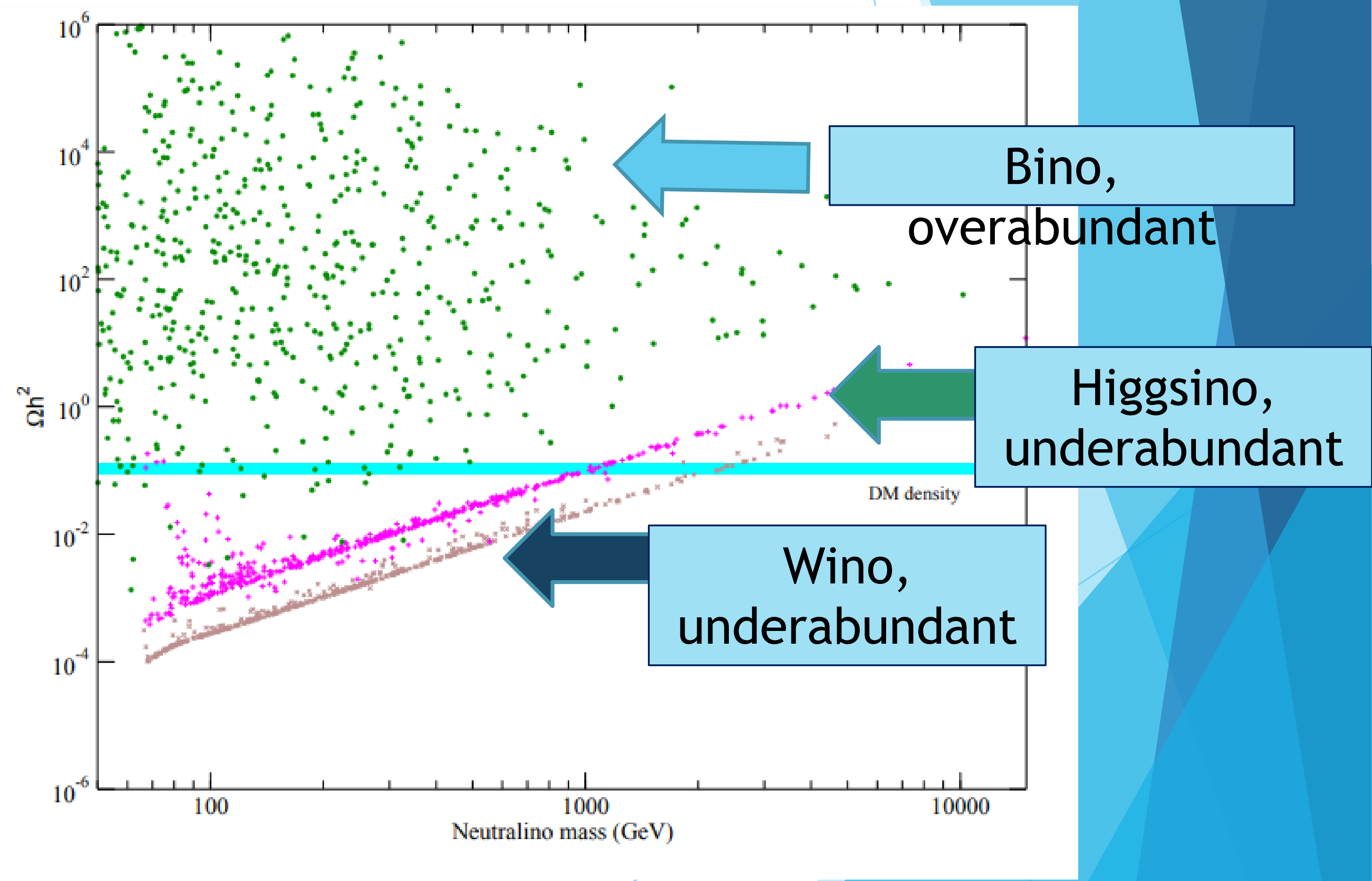

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- WIMP relic density is calculated with assumptions that as of today can not be tested.
- The "standard" picture could be different without really affecting observational evidence (e.g. Big Bang Nucleosynthesis and anything after that).
- It is possible that the relic density is smaller than the one obtained through the standard calculation due to entropy production or larger than the expected due to changes in the expansion rate of the universe or due to additional non-thermal production of DM. [Giudice et al 2001,*G.Gelmini et al 2006, C. Pallis et al 2009, E. Hardi 2018]*

The model:

- Extend the SM with a Majorana Triplet and a Y=1 vector-like doublet, the two fields odd under an additional Z_2 symmetry and SM particles are even:

$$\psi = \begin{pmatrix} \psi^0 \\ \psi^- \end{pmatrix}, \qquad \Sigma_L = \begin{pmatrix} \Sigma_L^0/\sqrt{2} & \Sigma_L^+ \\ \Sigma_L^- & -\Sigma_L^0/\sqrt{2} \end{pmatrix}.$$

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Similar to the Wino-Higgsino model in the MSSM

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the symmetry stays exact which guarantees that the DM is stable!

The model: Invariant lagrangian

$$\mathcal{L}_{\rm I} = -y_1 H^\dagger \bar{\Sigma}_L^c \epsilon \psi_R^c + y_2 \bar{\psi}_L^c \epsilon \Sigma_L H + \text{h.c.}$$

MIXING!

The model: Invariant lagrangian, SPECTRUM

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MIXING!

$\chi_1^0, \chi_2^0, \chi_3^0$

Three Majorana fermions!

$\chi_1^\pm, \chi_2^\pm$

Two charged fermions!

The model: Spectrum

Neutral Mixing Matrix

$$\mathbf{M}_{\Xi^0} = \begin{pmatrix} M_\Sigma & \frac{1}{\sqrt{2}} yv\cos\beta & \frac{1}{\sqrt{2}} yv\sin\beta \\ \frac{1}{\sqrt{2}} yv\cos\beta & 0 & M_\psi \\ \frac{1}{\sqrt{2}} yv\sin\beta & M_\psi & 0 \end{pmatrix}$$

$$y = \sqrt{\frac{y_1^2 + y_2^2}{2}}$$

$$\tan\beta = y_2/y_1$$

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NO CORRECTIONS TO THE OBLIQUE PARAMETERS (S, T, U)

A. Dedes 2014, C. Cai 2016

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DECOUPLED EIGENVALUE!

THE MODEL: INTERACTIONS

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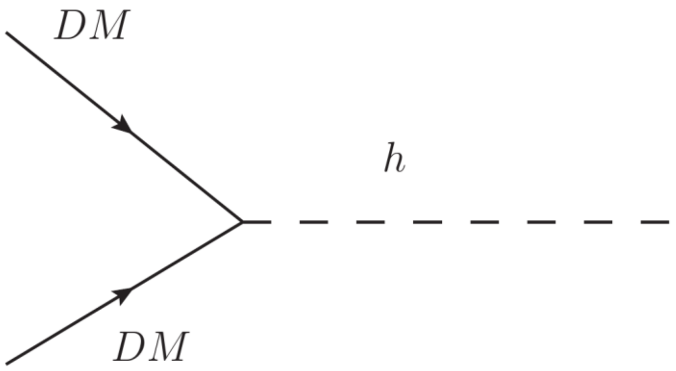
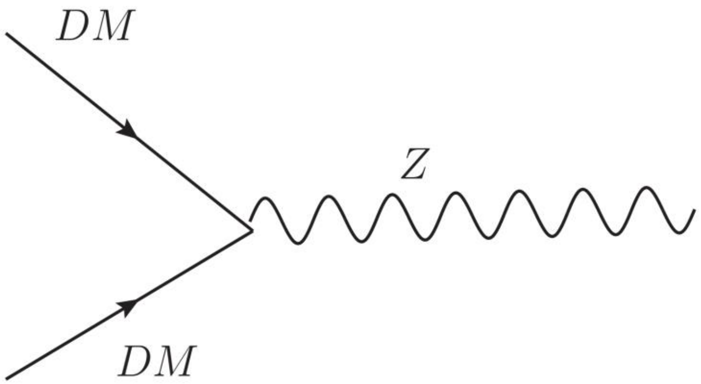
DECOUPLED EIGENVALUE!
ONLY DOUBLET COMPONENT

THE DARK MATTER!!!

$\chi_1^0, m_{\chi_1^0}$





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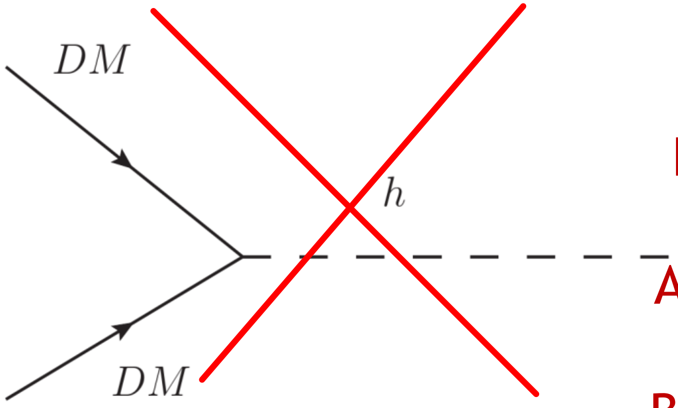
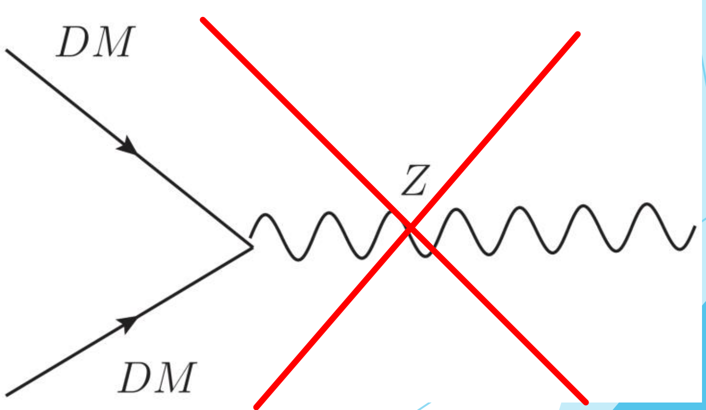
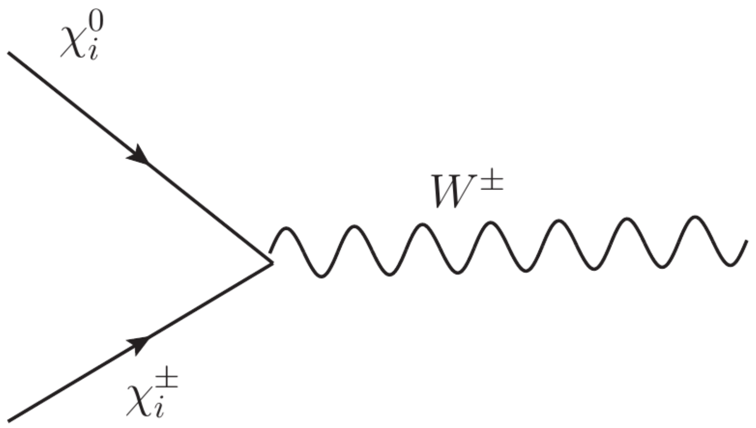
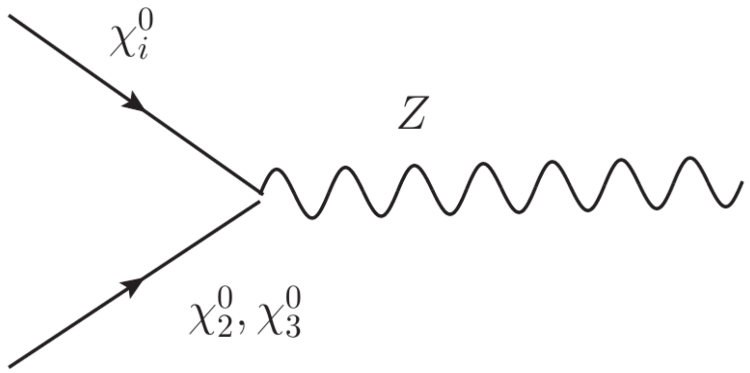


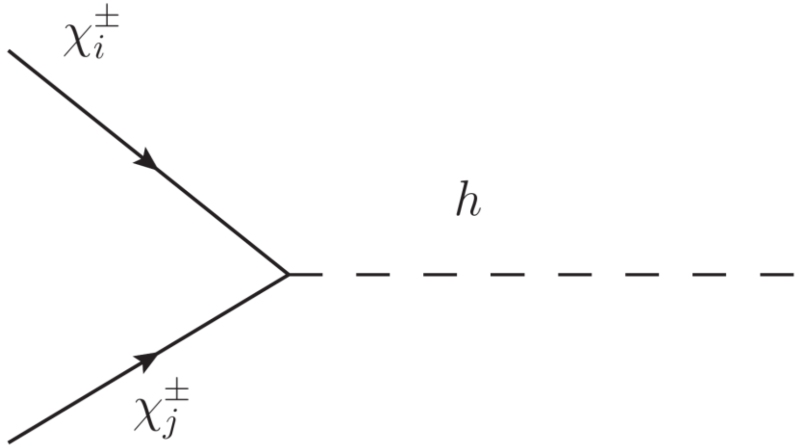
NO DARK MATTER
DARK MATTER HIGGS
INTERACTION
AND NO DARK MATTER
DARK MATTER Z
BOSON INTERACTION!!



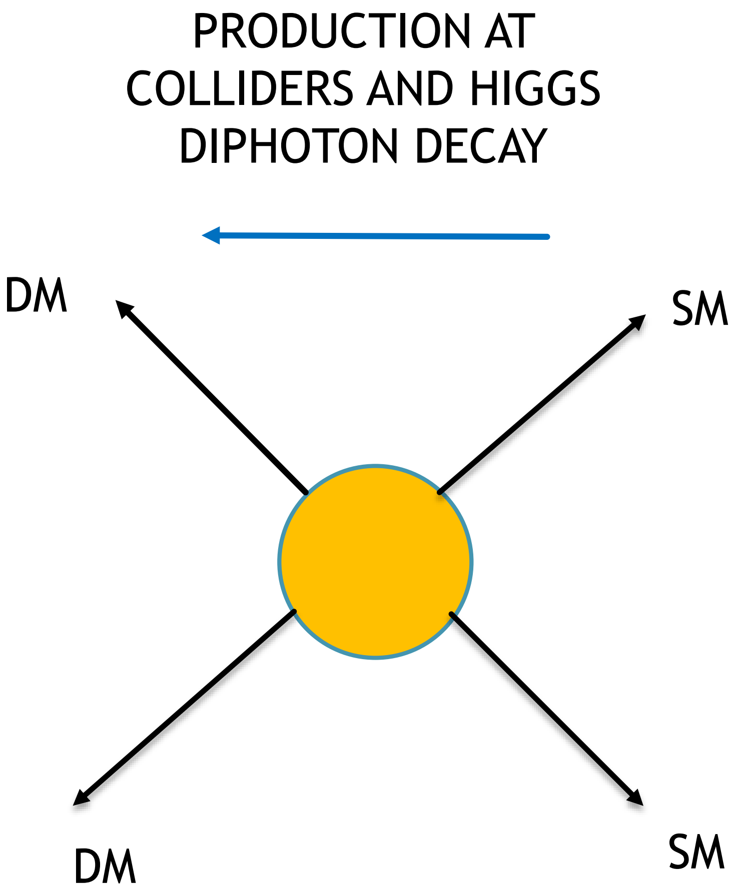
THE MODEL: MOST RELEVANT Interactions







PHENOMENOLOGY



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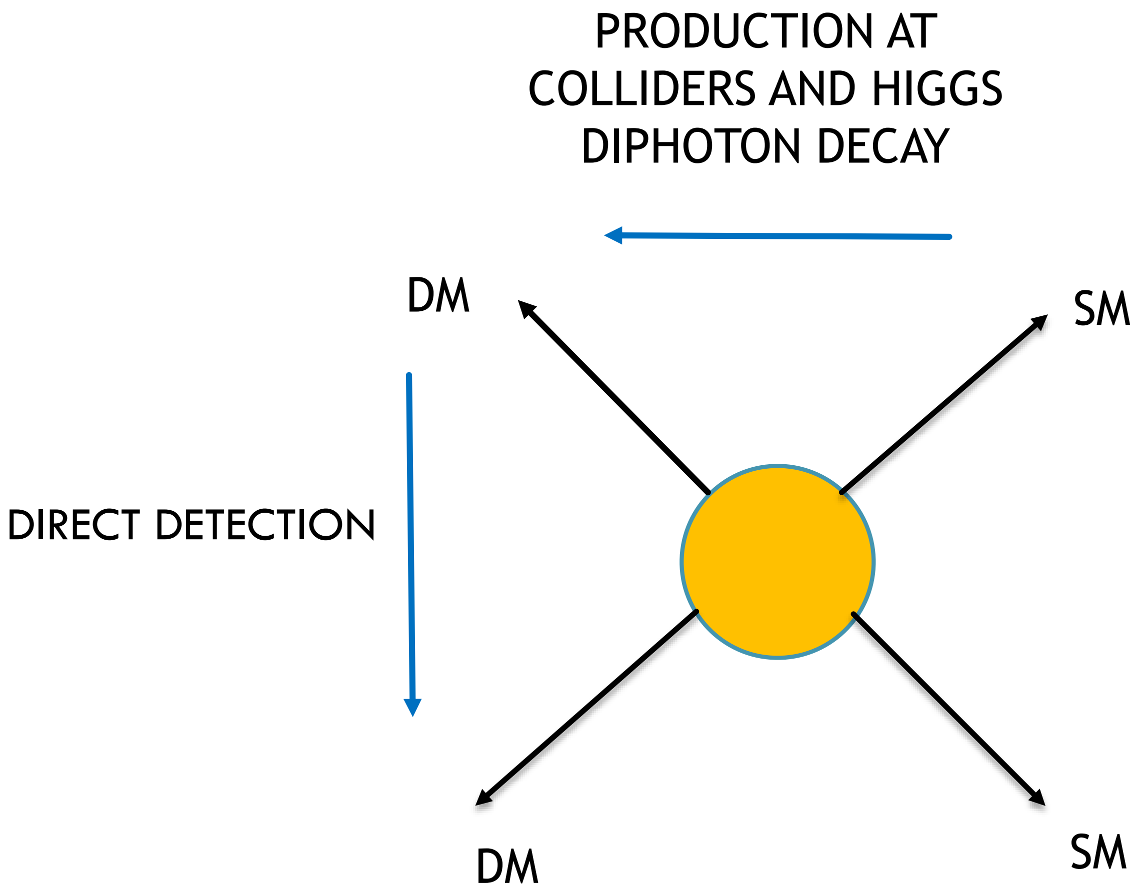

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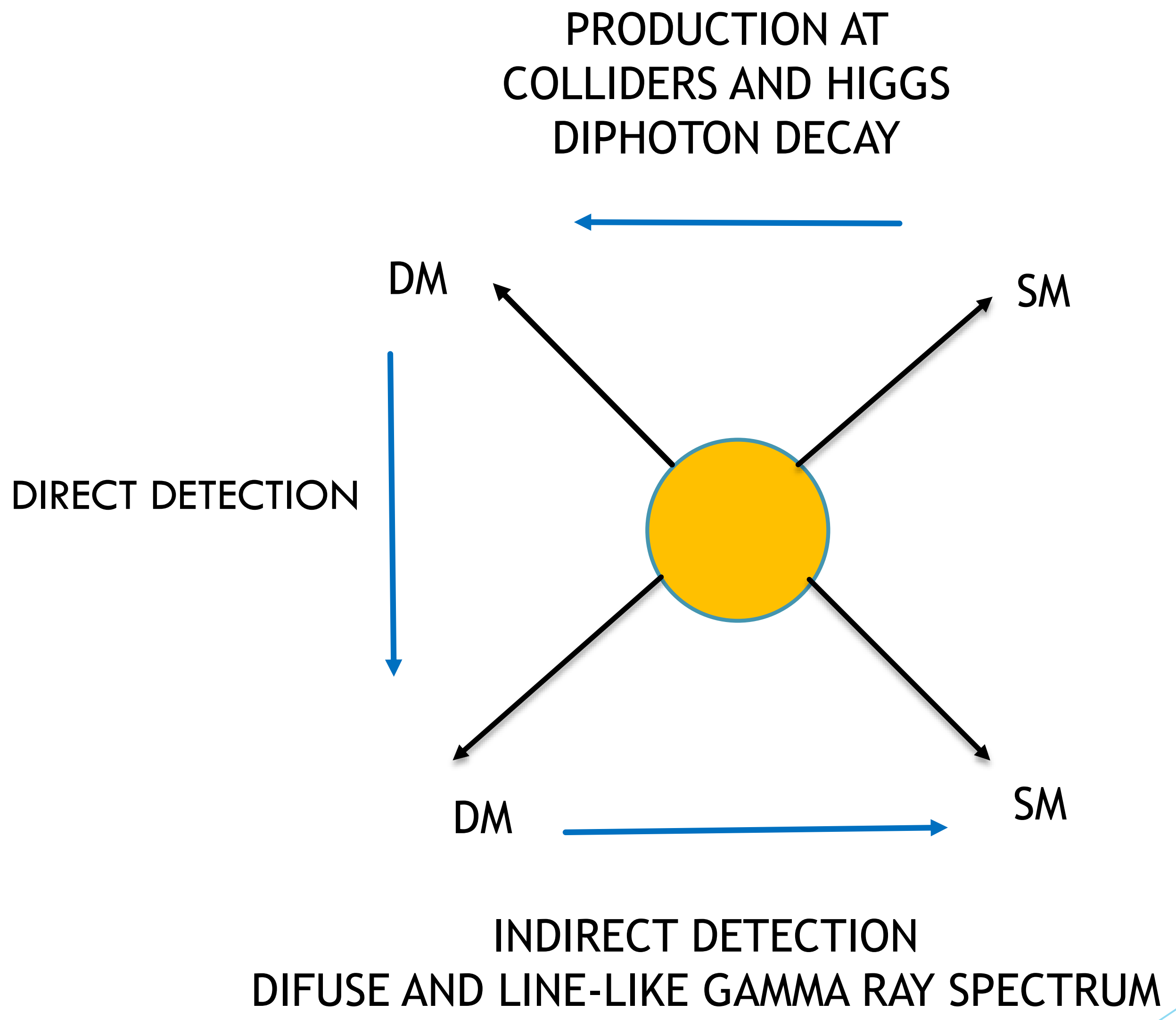

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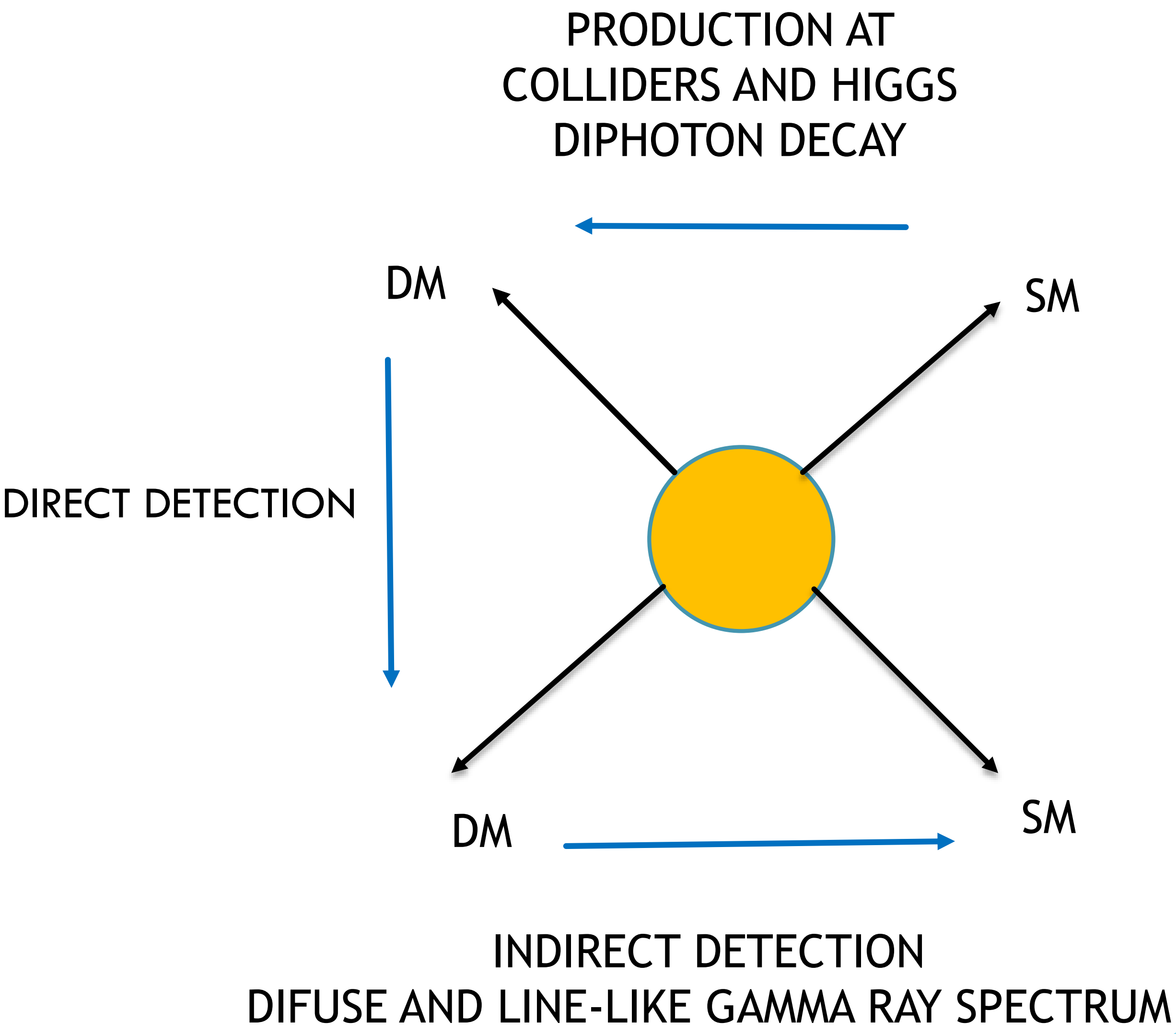
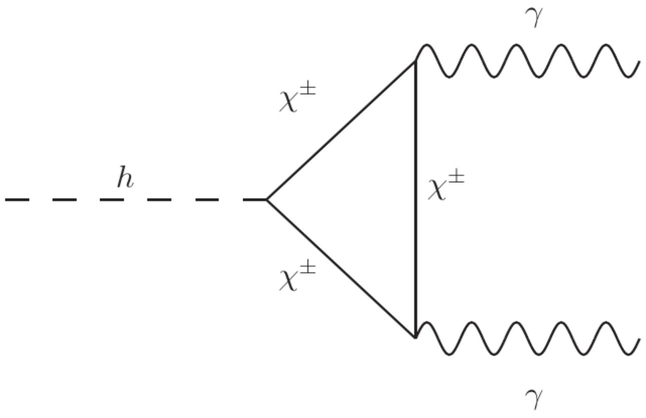


Relevant parameters:
Doublet mass -M_ψ=$m_{\chi 1}$
Triplet mass M_Σ
Yukawa coupling *y*
Two regions:

$$M_\Sigma > -m_{\chi 1}$$
$$M_\Sigma < -m_{\chi 1}$$

COLLIDER: PRECISION MEASUREMENTS

HIGGS DIPHOTON DECAY RATE



This is the channel in which the Higgs boson was discovered by the ATLAS and CMS collaborations.
And both collaborations keep looking at it.

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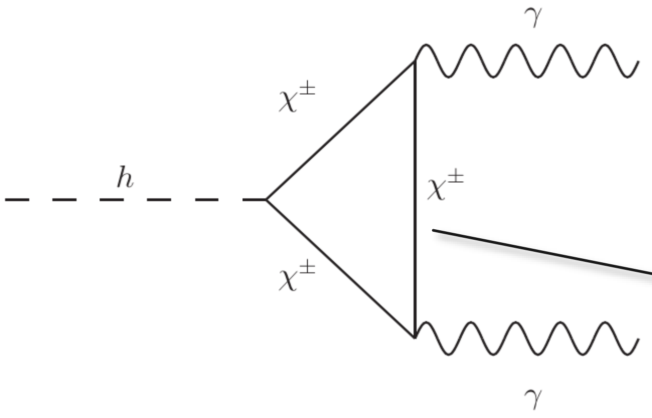

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- SM: Top Quark
- Dark sector: Any of the new charged fermions

COLLIDER: PRECISION MEASUREMENTS

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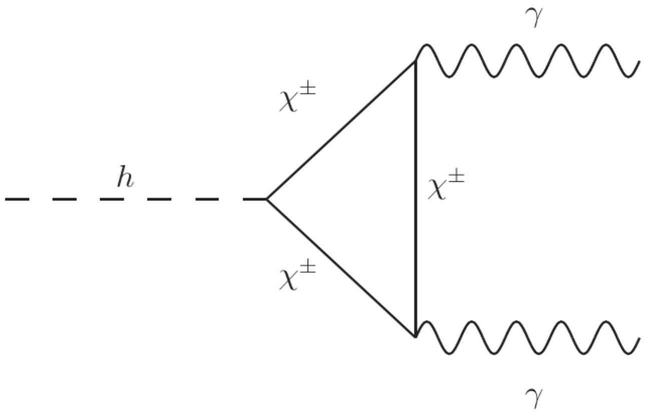

$$R_{\gamma\gamma} = \frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)_{\rm SM}} = \left| 1 + \frac{1}{A_{\rm SM}} \frac{y^2 v^2}{m_{\chi_2^\pm} - m_{\chi_1^\pm}} \left[\frac{A_F(\tau_2)}{m_{\chi_2^\pm}} - \frac{A_F(\tau_1)}{m_{\chi_1^\pm}} \right] \right|^2$$

COLLIDER: PRECISION MEASUREMENTS

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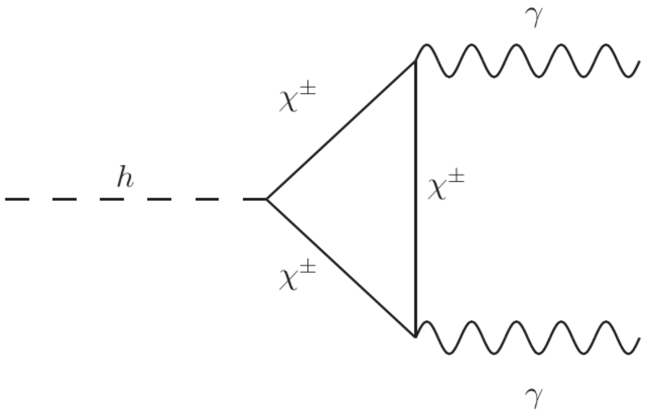

Supression

> 0

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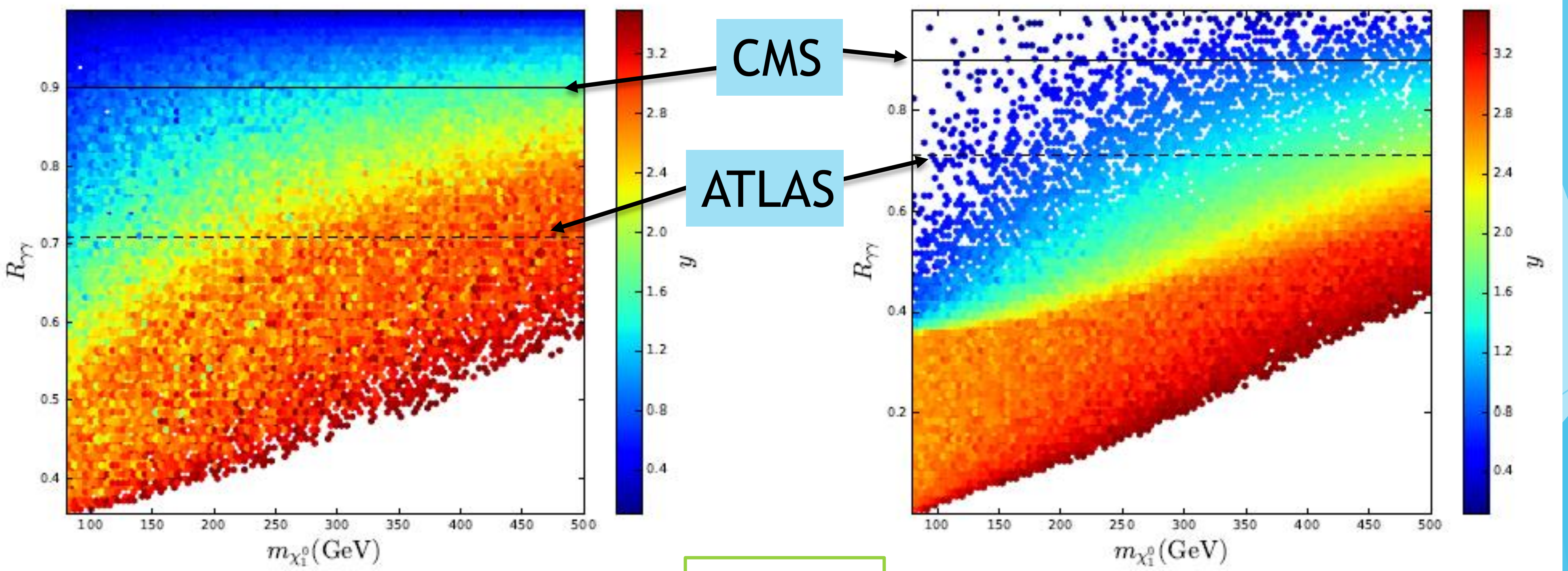
< 0

Colliders: higgs diphoton decay, Yukawa

$M_\Sigma > -m_{\chi 1}$

$M_\Sigma < -m_{\chi 1}$



13 TeV,
~36 fb-1

Colliders: higgs diphoton decay, Yukawa

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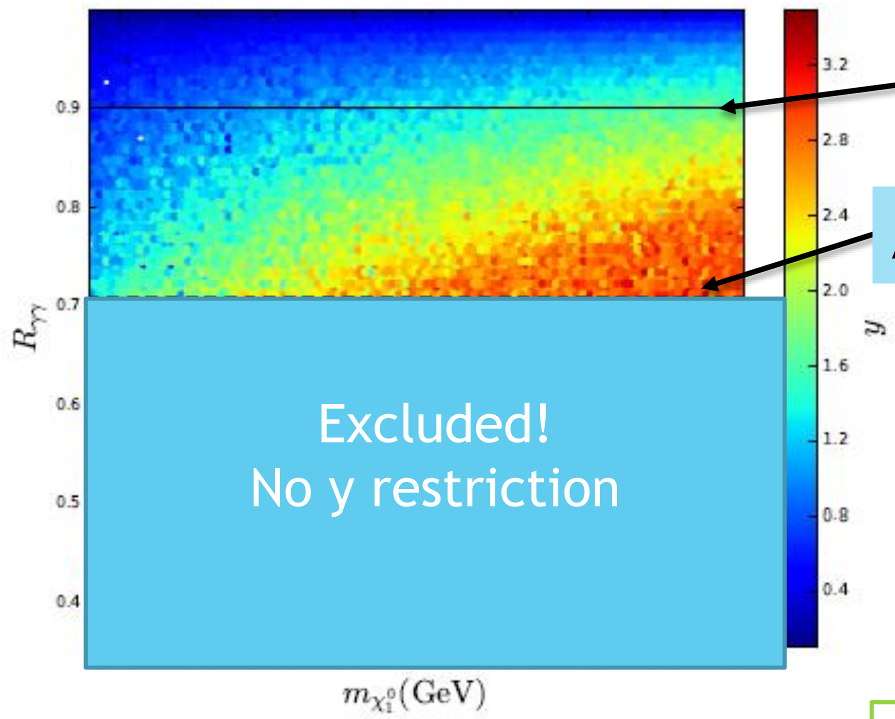
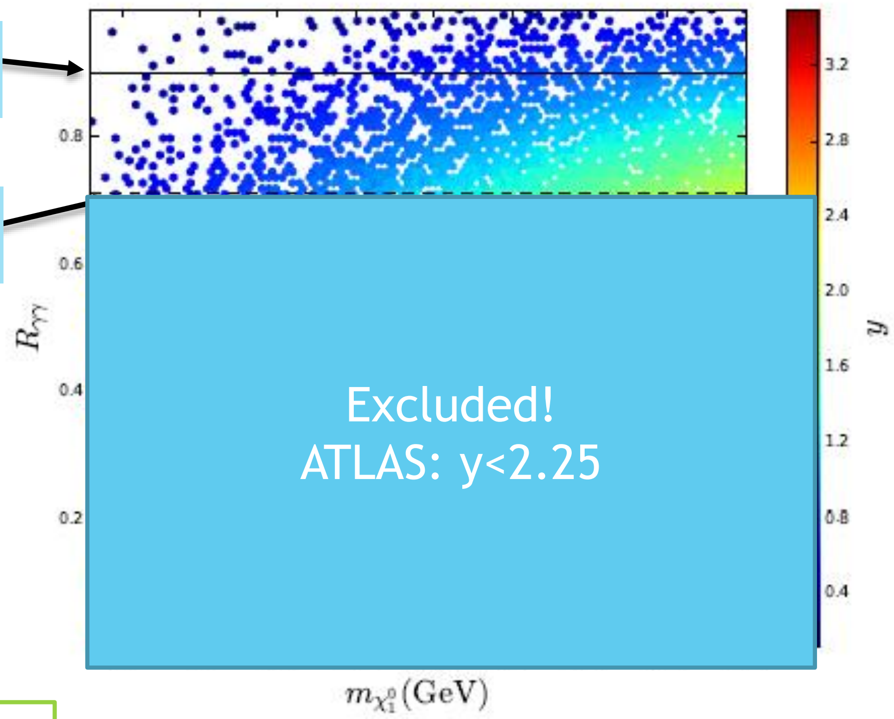


Excluded!
No y restriction

CMS

ATLAS

$M_{\Sigma} < -m_{\chi 1}$



Excluded!
ATLAS: y<2.25

13 TeV,
~36 fb-1

Colliders: higgs diphoton decay, Yukawa

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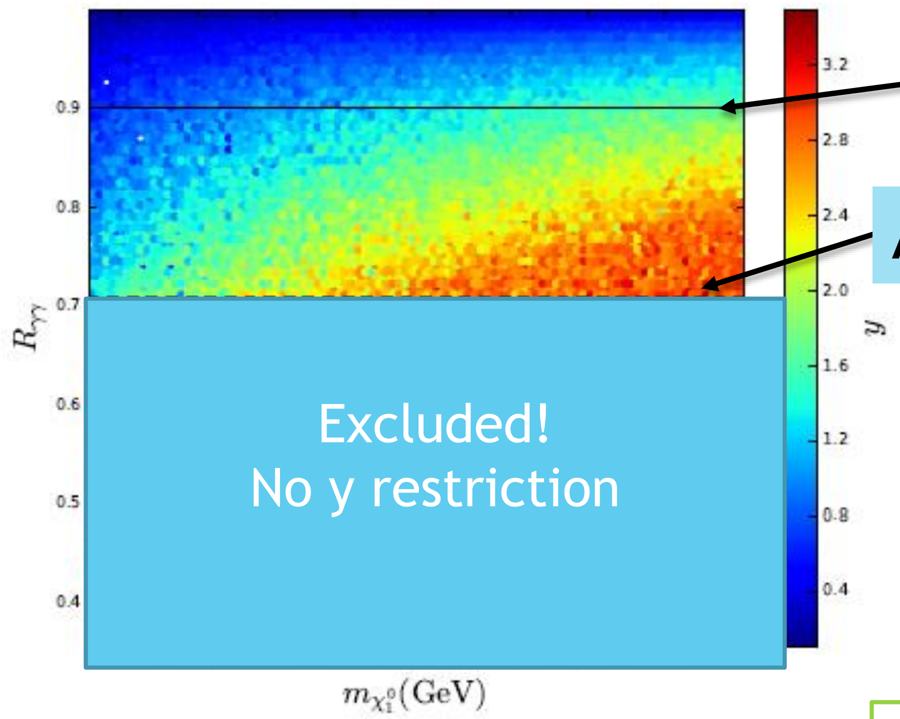

CMS

ATLAS

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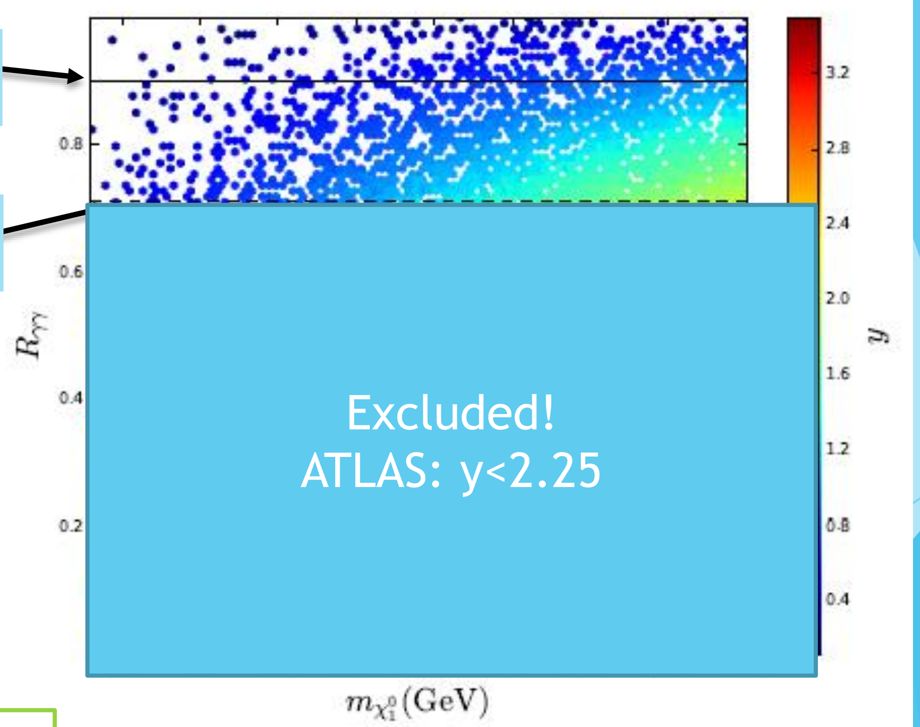
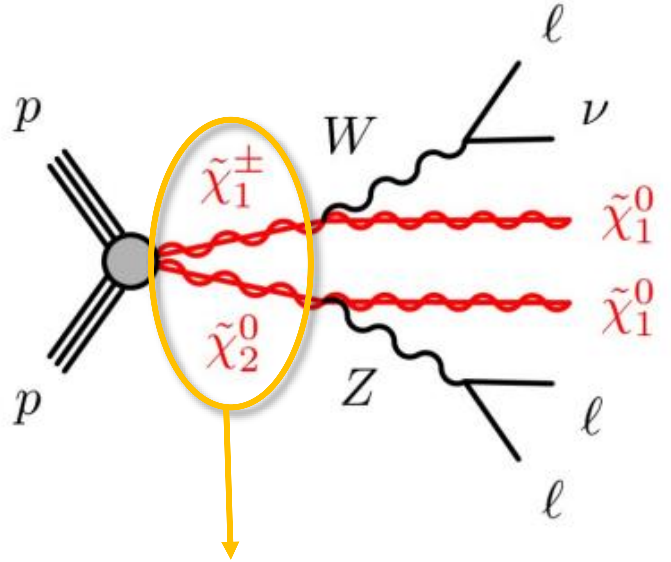


13 TeV,
~36 fb-1

Also, only negative triplet masses

COLLIDERS: ELECTROWEAK PRODUCTION OF THE CHARGED AND NEUTRAL FERMIONS



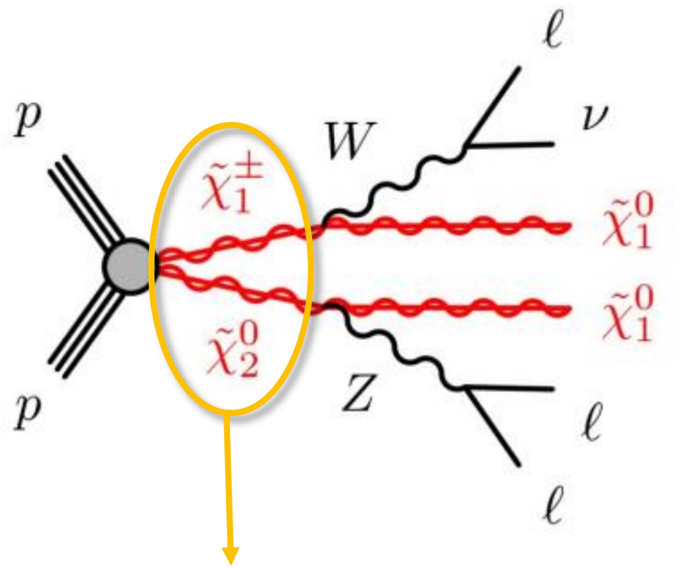
Combined search for electroweak production of charginos and neutralinos in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration*

JHEP 1803 (2018) 160

- CMS search: Wino, mass degenerate

COLLIDERs: ELECTROWEAK PRODUCTION OF THE CHARGED AND NEUTRAL FERMIONS



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JHEP 1803 (2018) 160

- CMS search: Wino, mass degenerate
- DTF model: Wino-higgsino, also mass degenerate

Collider: electroweak production OF THE CHARGED AND NEUTRAL FERMIONS

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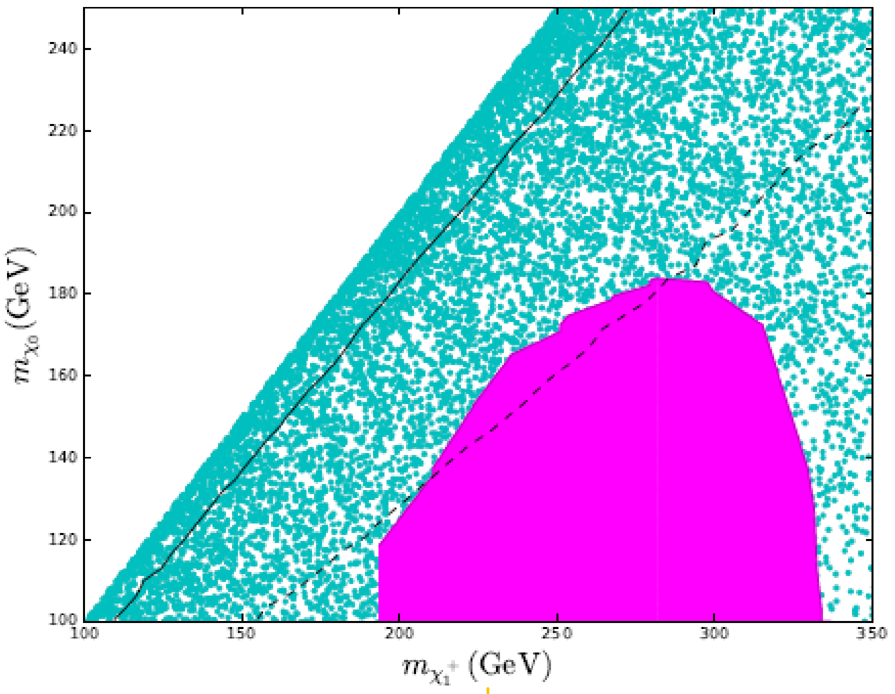
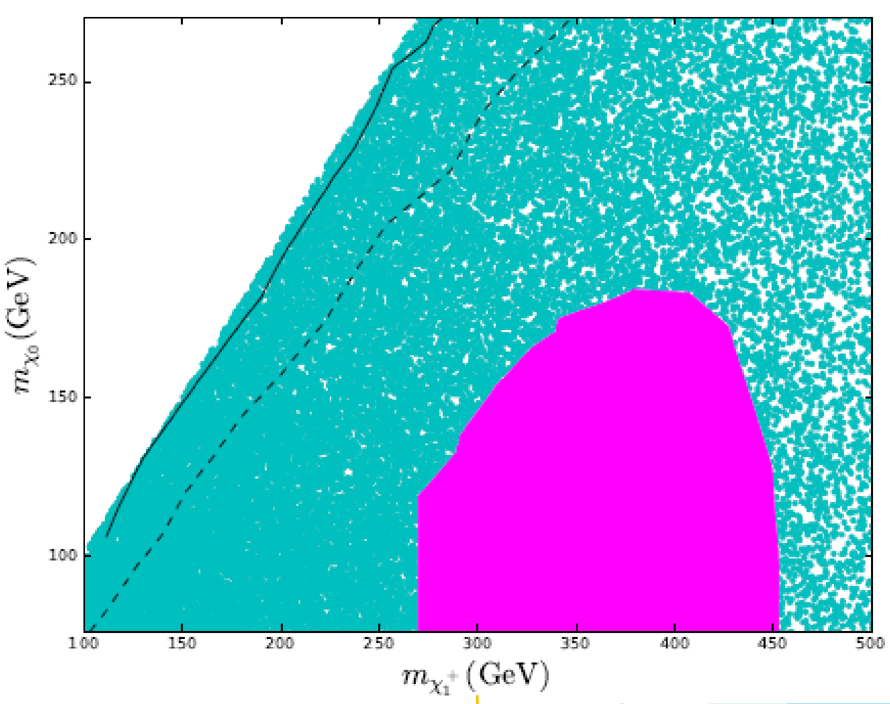


Mostly doublet due to $R_{\gamma\gamma}$

$M_{\Sigma} < -m_{\chi 1}$



Mostly triplet due to $R_{\gamma\gamma}$

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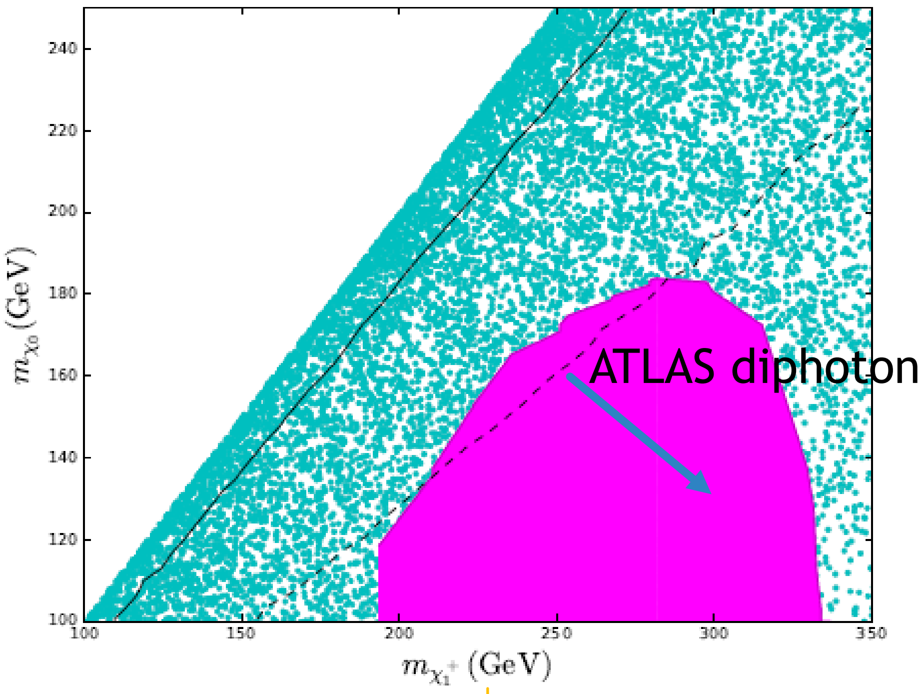

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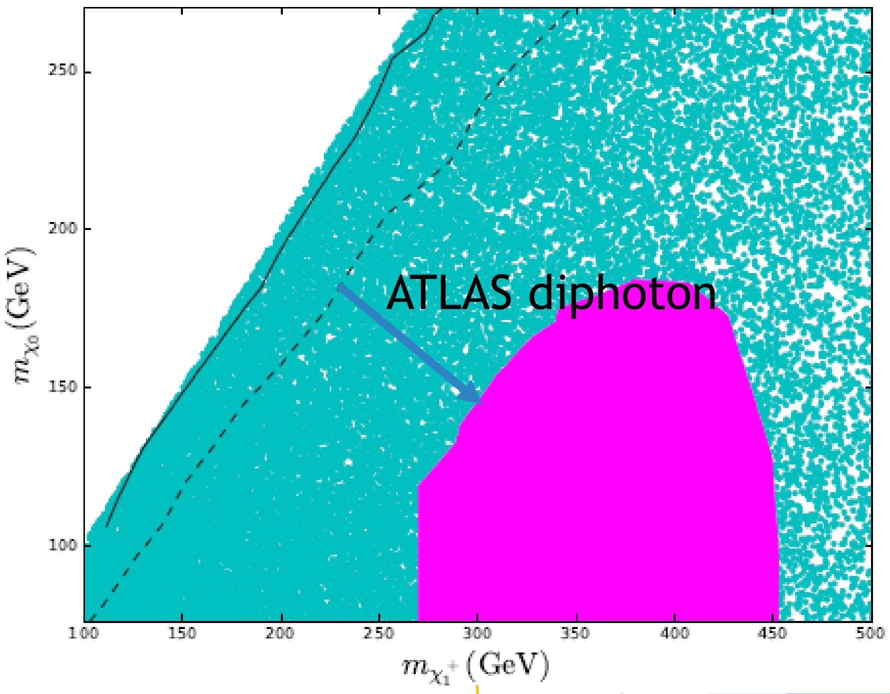

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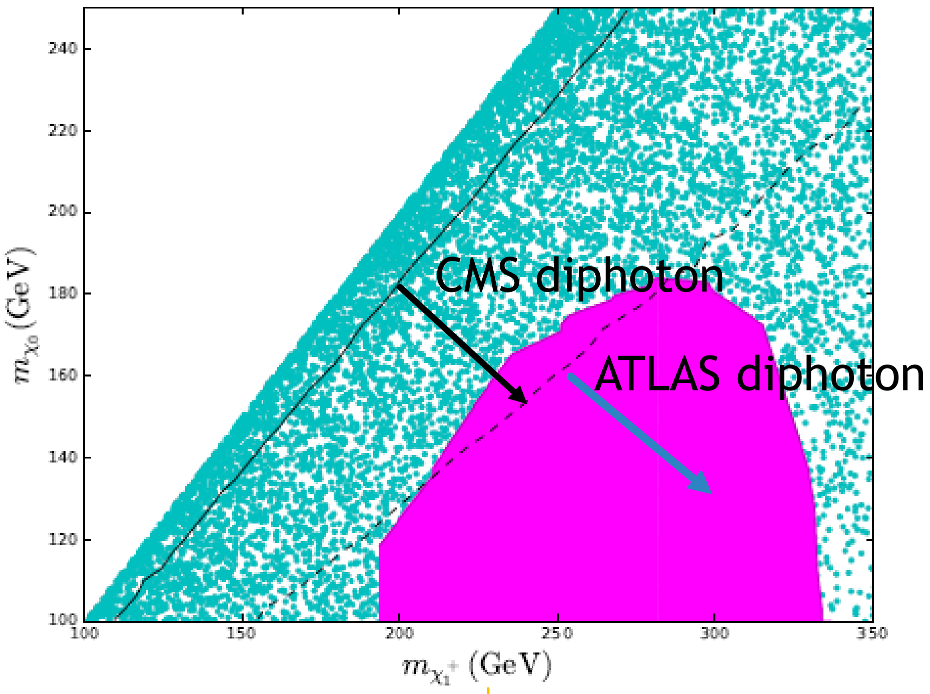

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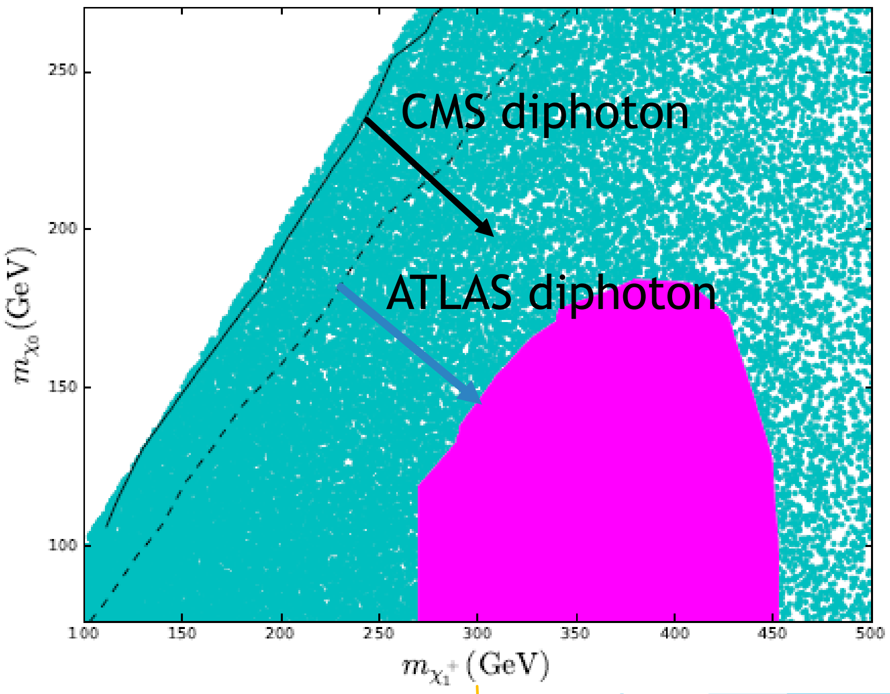

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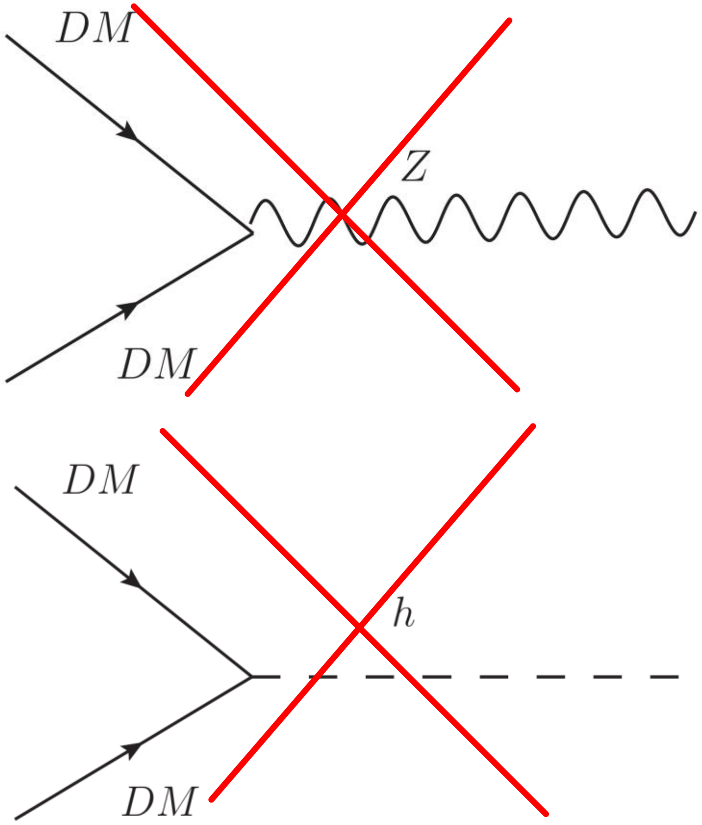
Direct detection



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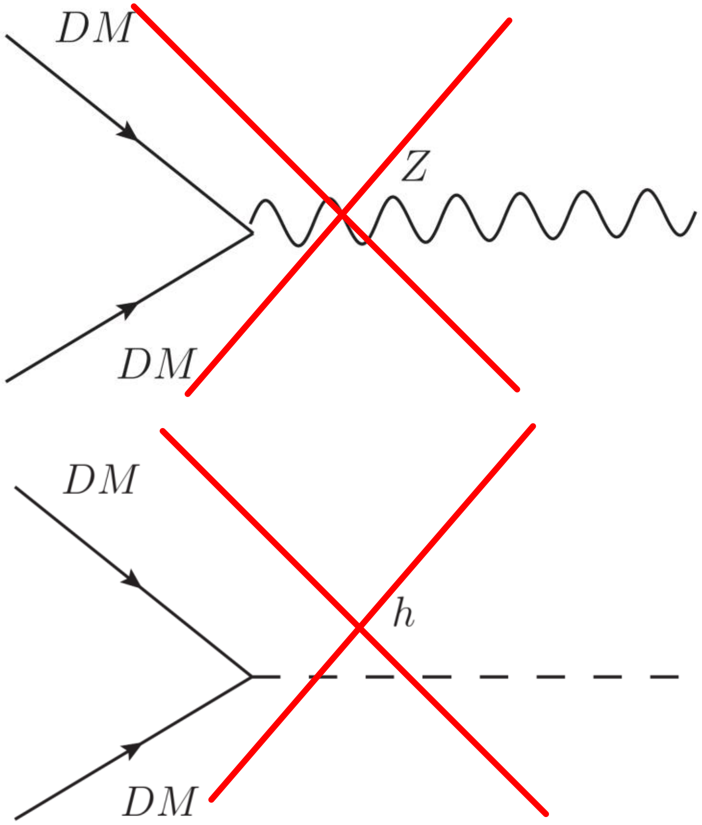
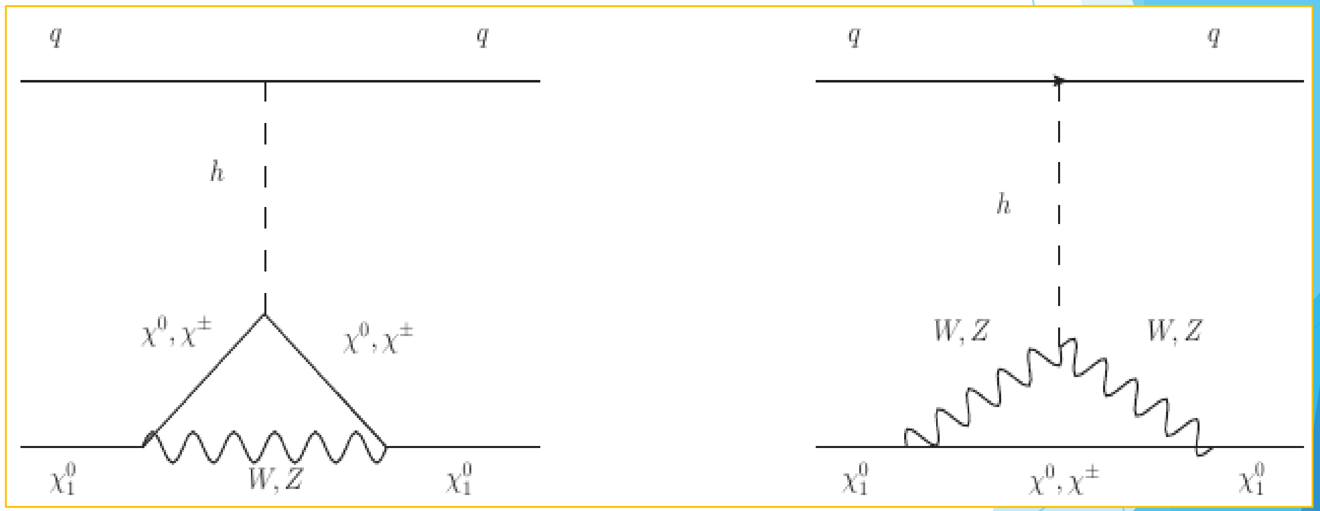
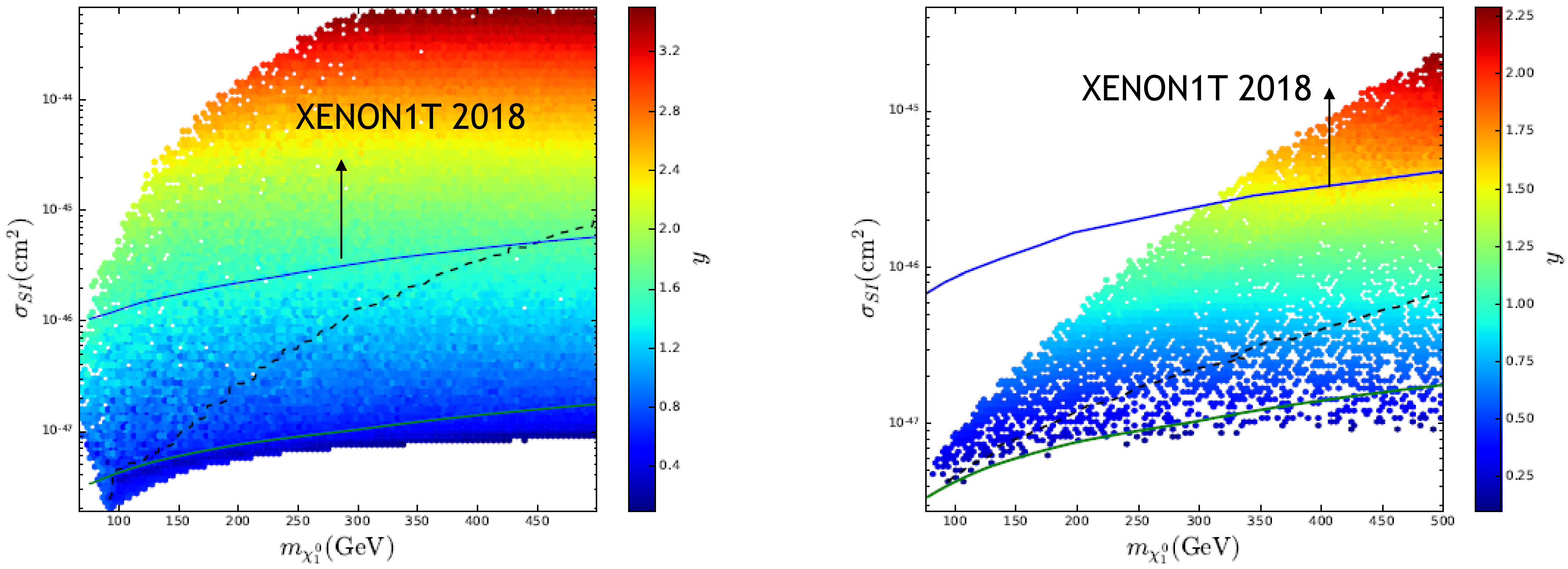


$$\frac{\delta y}{2}\chi_1^0\chi_1^0 h$$

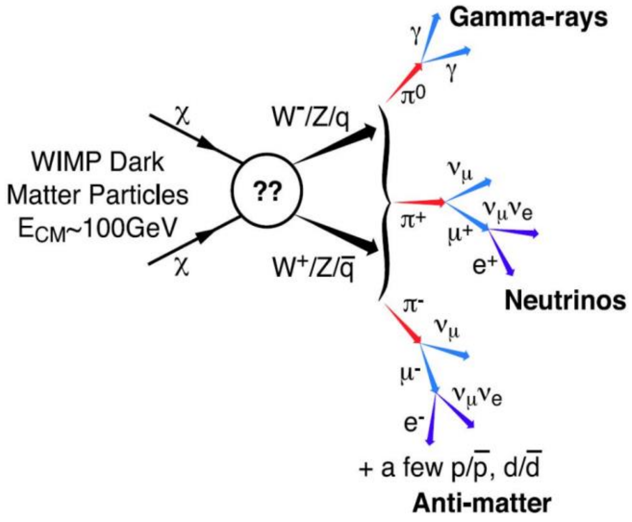
Freitas, JHEP, 2015



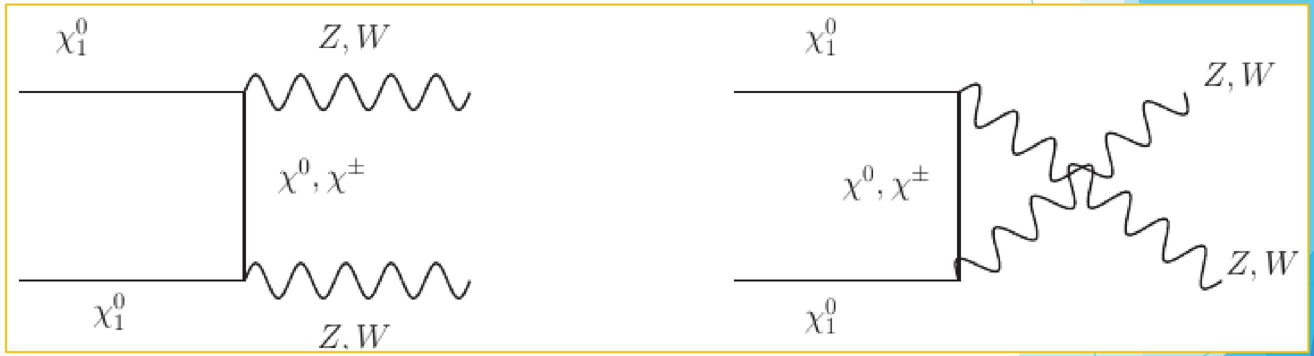
Direct detection



INDIRECT DETECTION: DIFFUSE SPECTRUM



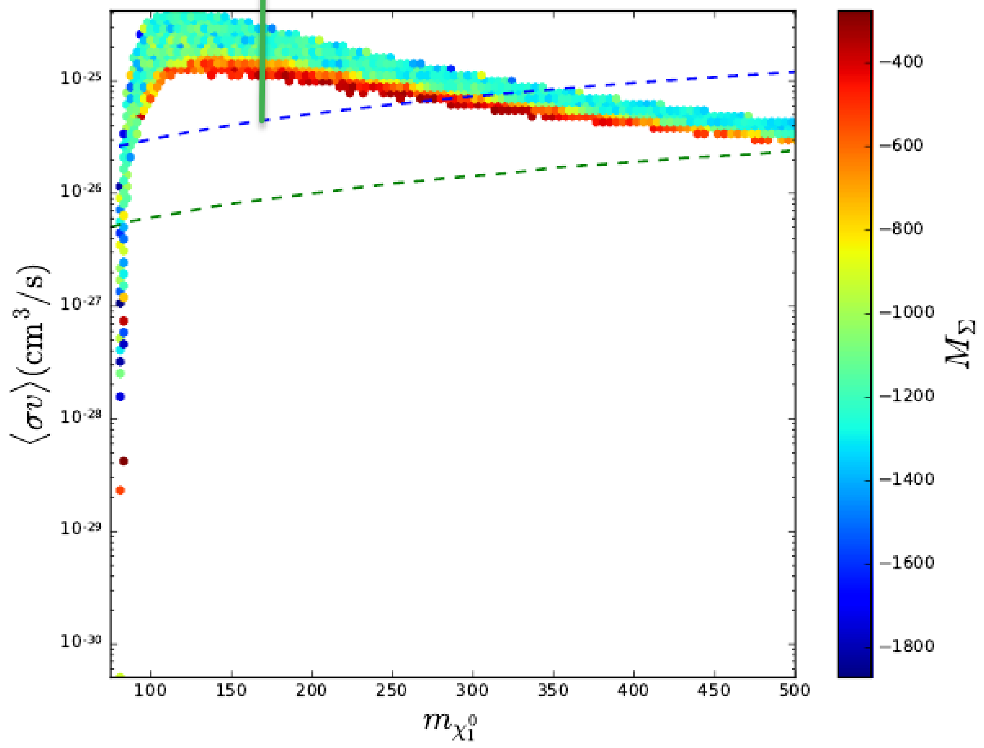
DTF MODEL



Images retrieved from: https://astrobites.org

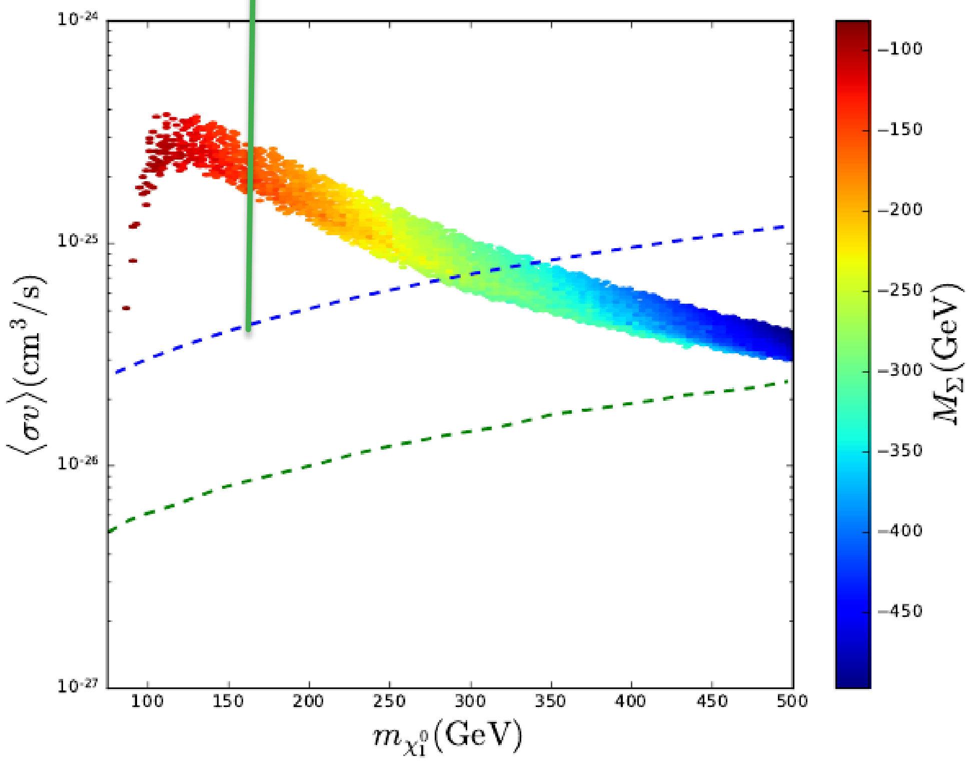
INDIRECT DETECTION: DIFFUSE SPECTRUM

Fermi 15 dSph, 6y



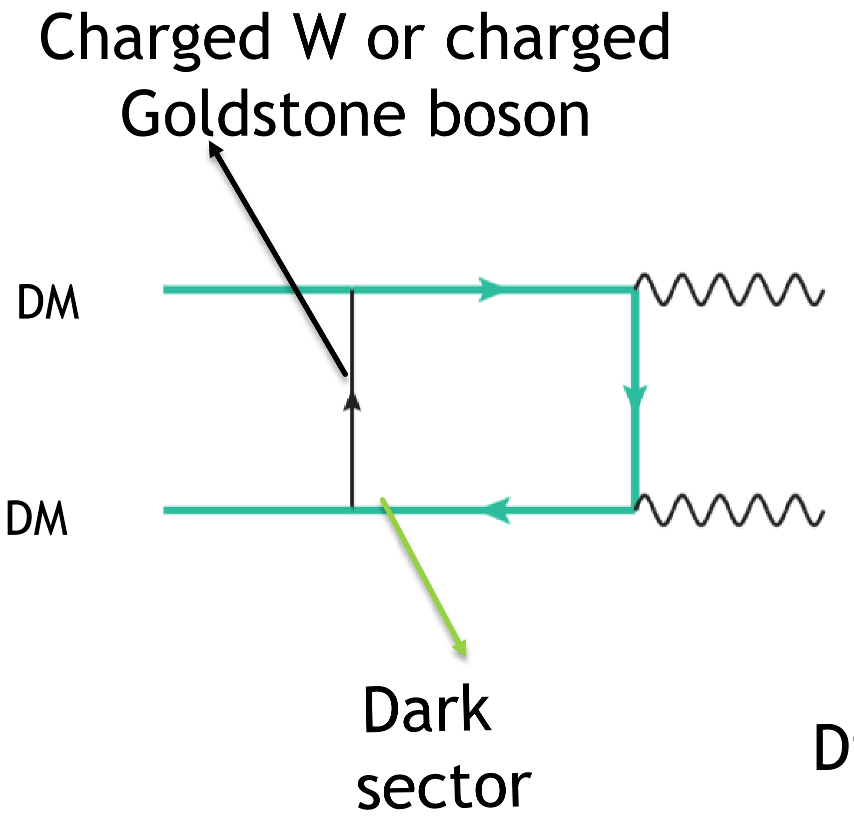
$m_{\chi_1^0} < 80$ (GeV) or $m_{\chi_1^0} > 220$ (GeV)

Fermi 15 dSph, 6y



$m_{\chi_1^0} > 220$ (GeV) and $M_\Sigma <\sim -230$ (GeV)

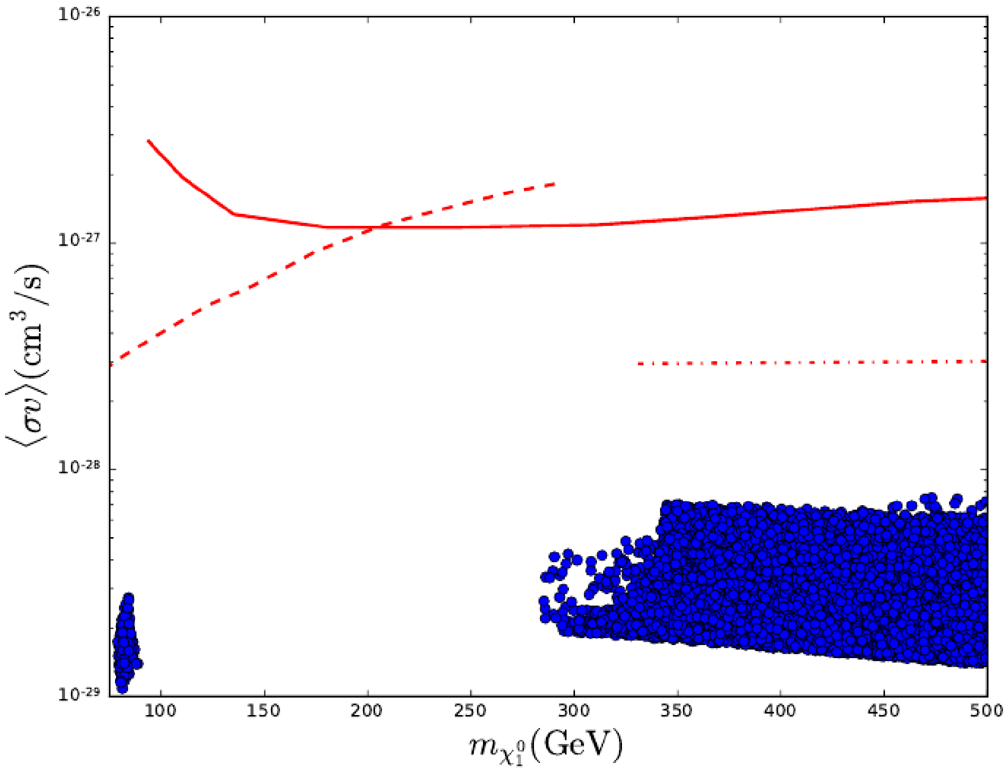
Indirect detection: gamma-ray lines

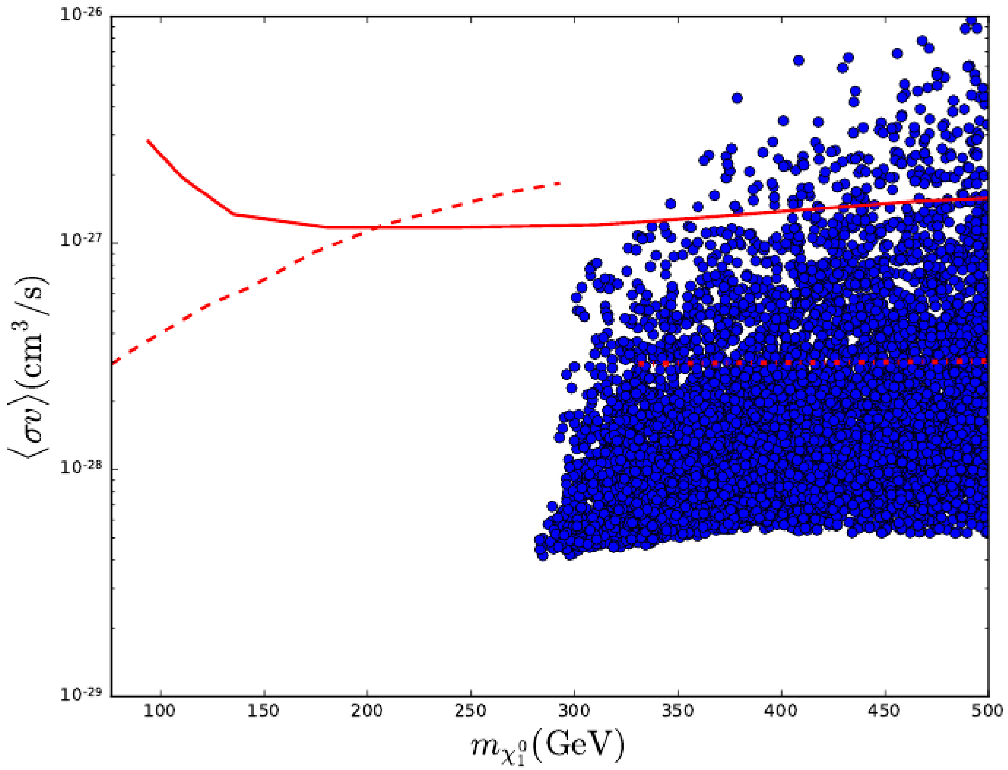


In regions with high DM density, the DM may annihilate directly into photons (mediated by loops), this gives a line-like feature in the gamma-ray spectrum. The thermally averaged cross section is loop suppressed.

Diagrams in the DTF (using the results from García-Cely , et al 2016)

Indirect detection: Gamma-ray lines





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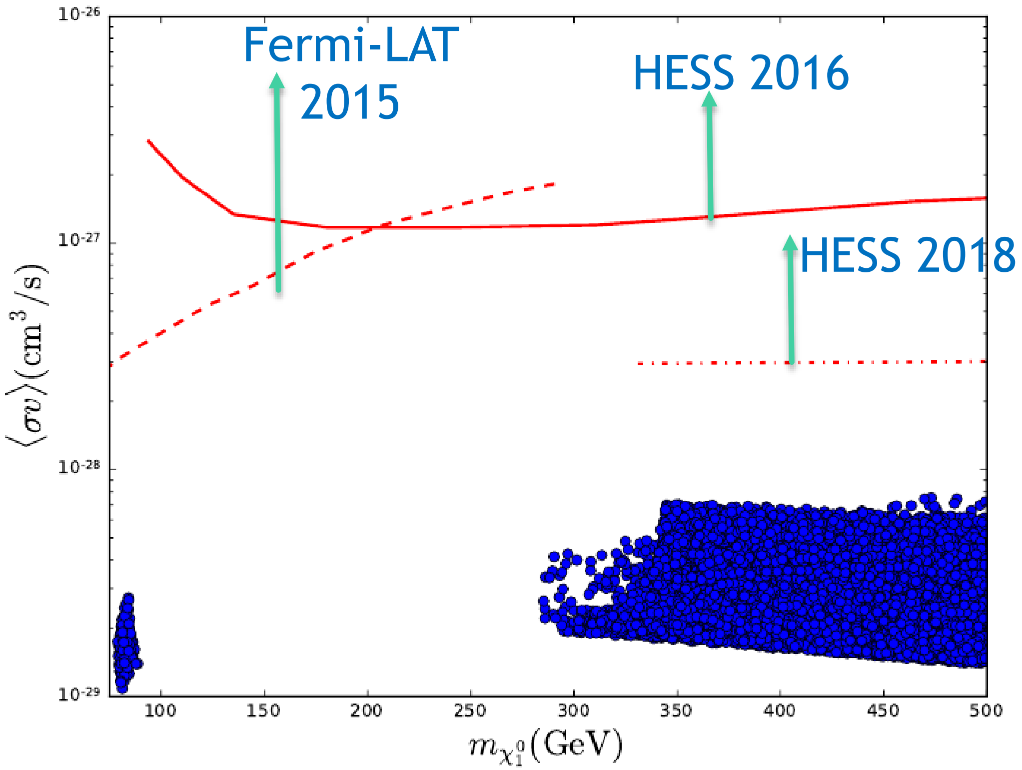

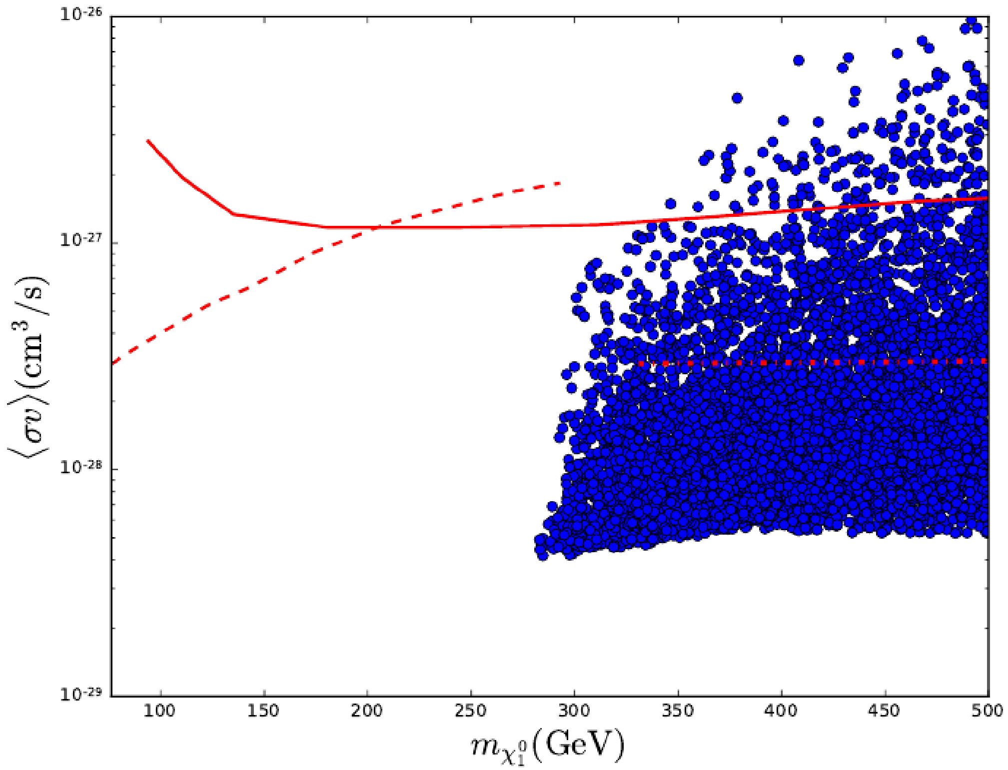

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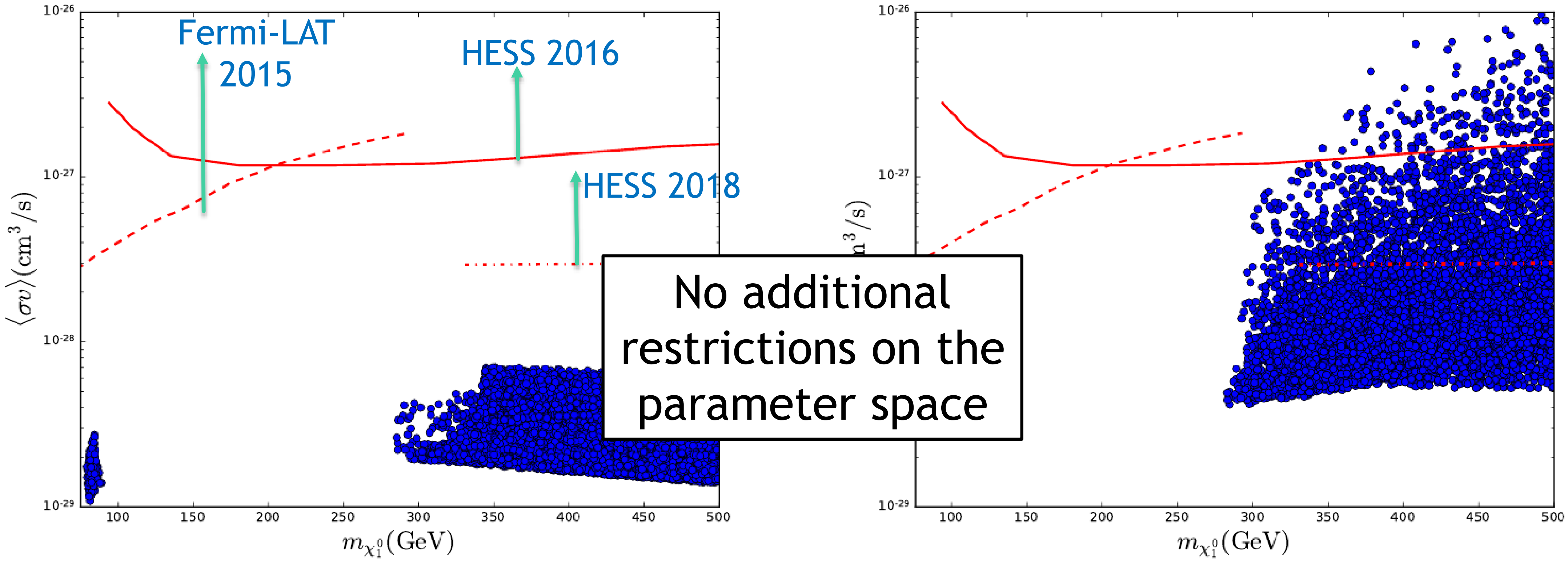

Conclusions:

- The DTF model is a viable DM candidate when considered under non-standard cosmology larger portions of the parameter space are available.
- Under an $SU(2)_R$ symmetry, the model is not constrained from S, T, U and direct detection only happens at loop level.
- The strongest constraints on parameter space of the model come from Higgs diphoton decay, direct detection and indirect detection from diffuse spectrum gamma-rays.
- It is important to note the complementarity of different DM searches.

Thank you

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Indirect detection: gamma-ray lines

In regions with high DM density, the DM may annihilate directly into photons (mediated by loops), this gives a line-like feature in the gamma-ray spectrum. The thermally averaged cross section is loop suppressed.

Diagrams in the DTF model (using the results from García-Cely , et al 2016)