# Charged Composite Scalar Dark Matter

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**University of Warsaw**

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***based on*** **1705.xxxxx *with* R. Balkin, M. Ruhdorfer and A. Weiler**

# Motivation

- In viable composite Higgs models, Higgs doublet arises as set of (approximate) Goldstone bosons

$$SO(5) \xrightarrow[H]{f} SO(4)$$

- Simple, attractive option for DM: extra Goldstone scalar as WIMP
- Mass and interactions dictated by global symmetry + explicit breaking

**Frigerio, Pomarol, Riva, Urbano 2012**

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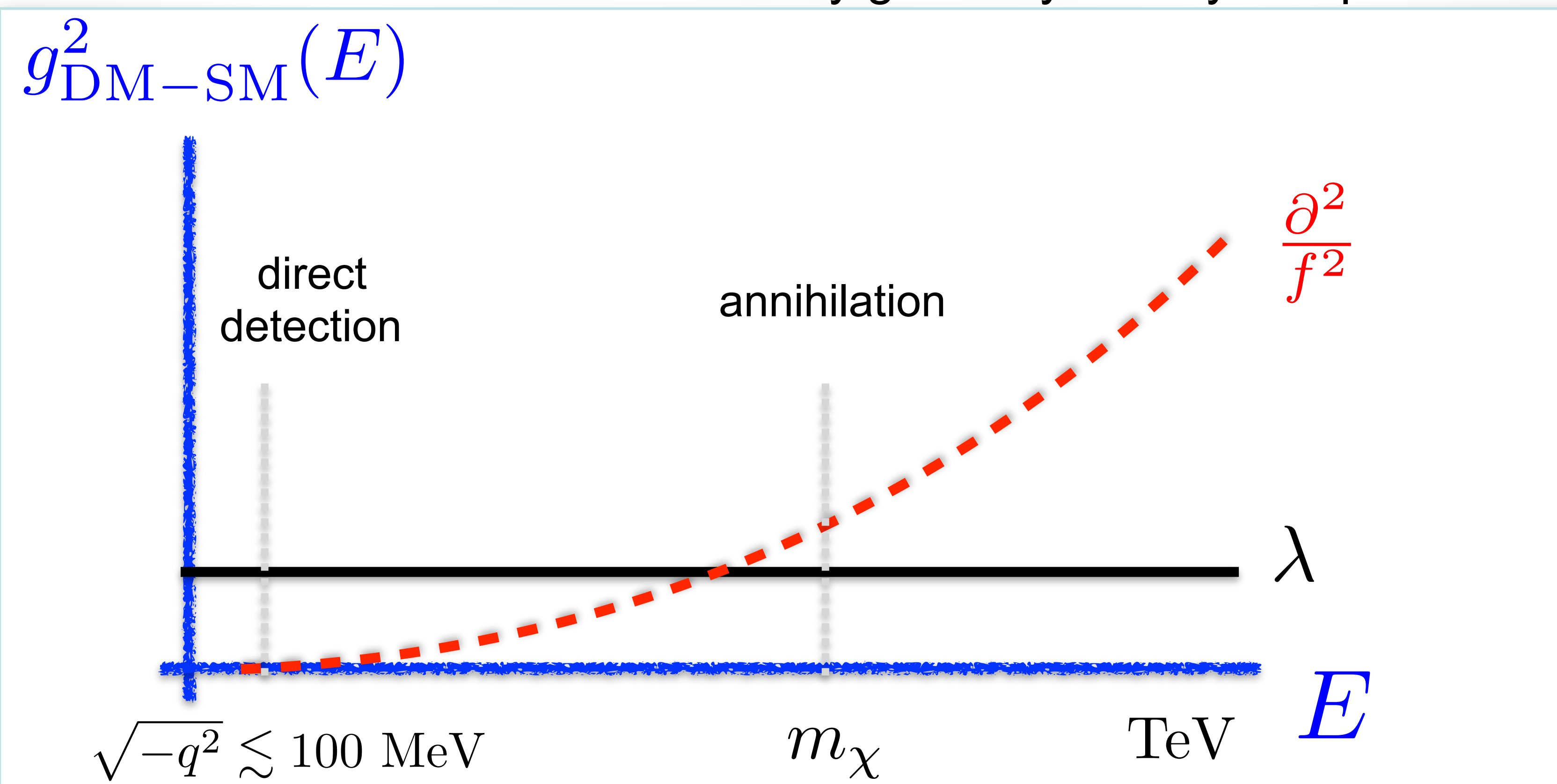
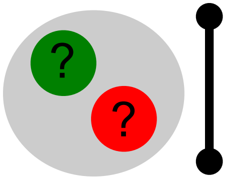


# A pseudo-Goldstone composite Higgs

- The Higgs is a bound state of new degrees of freedom
  The description of the theory changes above ~ TeV,
  Higgs mass naturally 'screened'

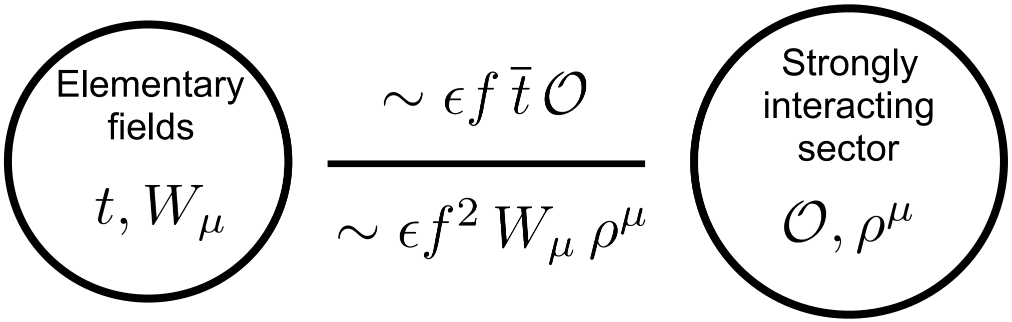
$h$




$r_h \sim (\mathrm{TeV})^{-1}$

- Take analogy with QCD further: **Higgs** as (approximate) **Goldstone** boson, like pions

Agashe, Contino, Pomarol 2004




$$\mathcal{G} \xrightarrow[H]{f} \mathcal{H}$$

$$m_\rho = g_* f$$

Kaplan, 1991

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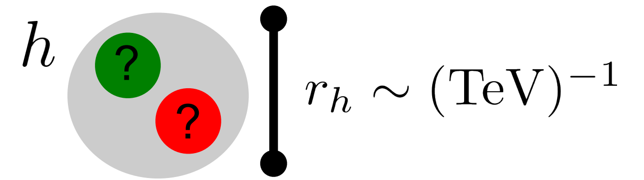


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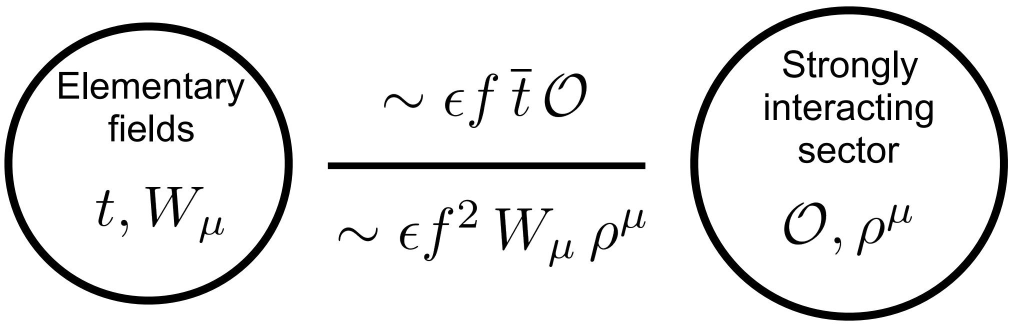


$$\mathcal{G} \xrightarrow[H]{f} \mathcal{H}$$

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- At tree level, the Higgs doublet is exact Goldstone, e.g. $SO(5) \xrightarrow[H]{f} SO(4)$
- Breaking of global sym by $\epsilon$ generates radiative potential, dominated by top **+** vectorlike fermions, the **top partners**

- Coupling $\sim \epsilon f \, \bar{t} \, \mathcal{O}$ implies top partners are charged under QCD

# Composite Scalar Dark Matter

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Gripaios et al. 2009,
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$$SO(6)/SO(5) \quad \rightarrow \quad (H,\eta) \sim \mathbf{4} + \mathbf{1}_0$$

DM can be stabilized by parity, $\eta \xrightarrow{P_\eta} -\eta$ $\qquad P_\eta = \mathrm{diag}(1,1,1,1,-1,1)$

**But** $P_\eta \notin SO(6)$, in general **not respected** by higher order terms in chiral Lagrangian

E.g. Wess-Zumino-Witten (see $\pi_0 \rightarrow \gamma\gamma$ in QCD, breaks $\pi \rightarrow -\pi$ )

$$\tfrac{\eta}{16\pi^2}\left(n_W\, g^2 W^a_{\mu\nu}\tilde{W}^{a\,\mu\nu} + n_B\, g'^{\,2} B_{\mu\nu}\tilde{B}^{\mu\nu}\right)$$

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*see also:*
**Chala et al. 2016**
*for SO(7)/SO(6)*
**Ballesteros et al. 2017**
*for SO(7)/$G_2$*

# Charged Composite Scalar Dark Matter

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- Extend minimal coset *SO*(5)/*SO*(4). **Symmetry stabilizing the DM?**

$$SO(7)/SO(6) \quad \rightarrow \quad (H,\chi) \sim \mathbf{4} + \mathbf{1}_{\pm}$$

**Balkin, Ruhdorfer, ES, Weiler, to appear**

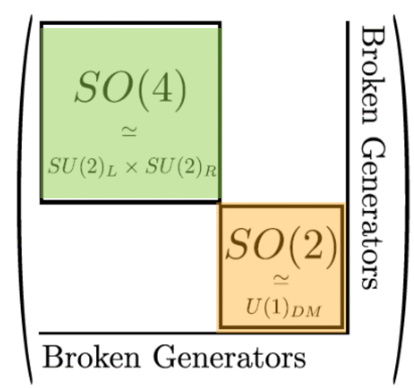
DM candidate is **complex scalar**,

charged under conserved $U(1)_{\mathrm{DM}} \subset SO(6)$

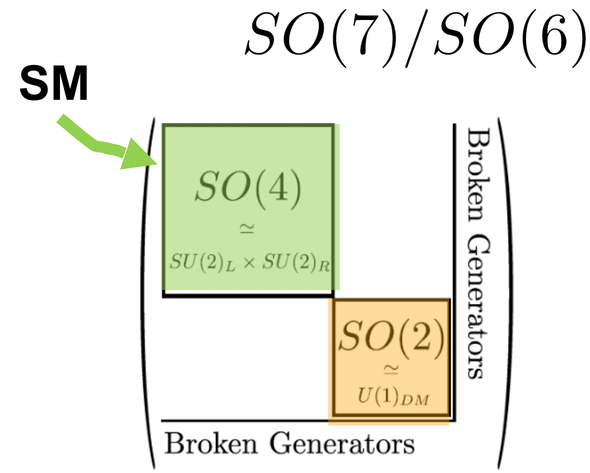
$$\chi \rightarrow e^{i\alpha}\chi$$

Furthermore, no anomalies (no complex reps.)

UV automatically safe



# Coupling to elementary fields




- SM weak gauging preserves $U(1)_{\mathrm{DM}}$
- Fermion partial compositeness

$$\mathcal{L}_{\mathrm{mix}} \sim \epsilon_q \bar{q}_L \mathcal{O}_q + \epsilon_t \bar{t}_R \mathcal{O}_t$$

- If SM fermions embedded in **7** (fundamental), can leave $U(1)_{\mathrm{DM}}$ intact

$$q_L \to \begin{pmatrix} ib_L \\ b_L \\ it_L \\ -t_L \\ 0 \\ 0 \\ 0 \end{pmatrix}, \quad t_R \to \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ t_R \end{pmatrix}$$

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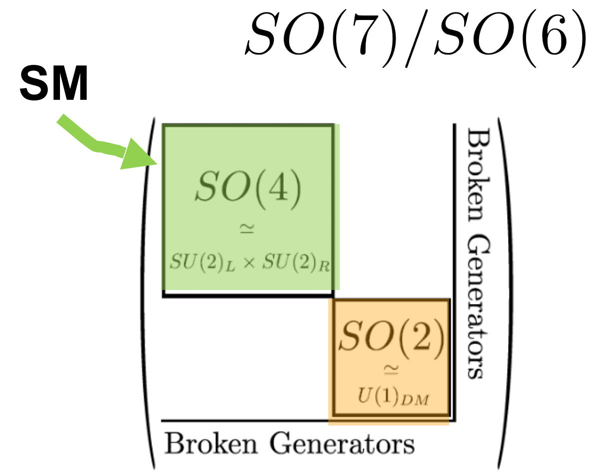


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- Shift symmetry of $\chi$ broken by mixing of $t_R$ , parametrically $m_\chi \sim m_h$

[ for other choices, shift sym. can also be preserved ➡ $m_\chi \ll m_h$

Mass controlled by light fermions + gauging of $U(1)_{\rm DM}$ . E.g. $t_R \sim \mathbf{21}, \mathbf{27}$ ]

# Radiative scalar potential

$$V(h,\chi) = \frac{1}{2}\mu_h^2 h^2 + \frac{\lambda_h}{4}h^4 + \mu_{DM}^2\chi^*\chi + \lambda_{DM}(\chi^*\chi)^2 + \lambda h^2\chi^*\chi$$

$$\mu_{DM}^2 \approx \frac{N_c}{4\pi^2 f^2}\int_0^\infty dp^2 p^2 \left(\sum_{i=1}^{N_S}\frac{|\epsilon_{tS}^i|^2}{p^2+m_{Si}^2} - \sum_{i=1}^{N_Q}\frac{|\epsilon_{tQ}^i|^2}{p^2+m_{Qi}^2}\right)$$

**Marzocca et al. 2012**
**Pomarol, Riva 2012**

UV-finite if $\sim \frac{1}{p^6}$ or faster

obtain calculability through
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Marzocca, Urbano 2014

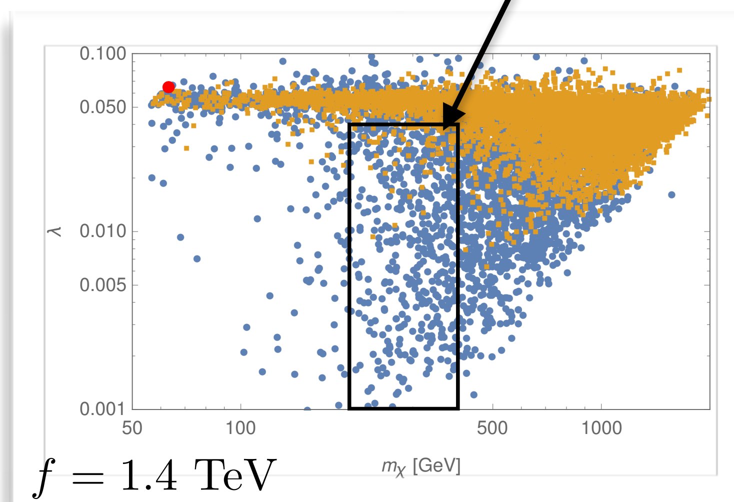
Leading order prediction is $\lambda \sim \frac{\lambda_h}{2} \sim 0.06$ ,
ruled out by direct detection

$\lambda$ reduction is correlated with lighter top partners

**blue**: $M_{\text{lightest}} < 1\ \text{TeV}$, excluded by LHC

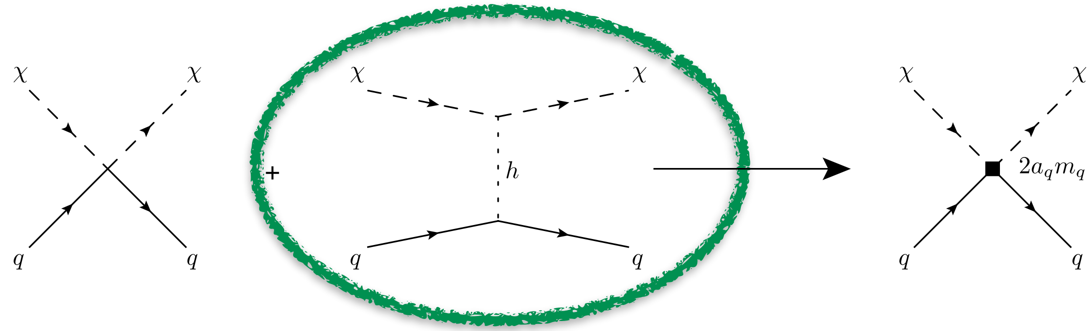
**orange**: LHC ok

**pheno-viable region**



# Pheno: direct detection

- Higgs exchange in t-channel dominates




$$\frac{1}{2f^2} \quad \ll \quad \frac{\lambda}{m_h^2}$$

$$\mathcal{L} \sim \cancel{\frac{1}{f^2}\partial(h^2)\partial(\chi^*\chi)} - \lambda h^2 \chi^* \chi \quad \rightarrow \quad \sigma_{\rm SI}^{\chi N} \simeq \frac{0.3^2}{\pi}\frac{m_N^4 \lambda^2}{m_\chi^2 m_h^4}$$

~ vanilla Higgs portal, with minor corrections

# Pheno: relic abundance

- Annihilation into *tt, WW, ZZ, hh*
- Interplay of derivative and portal couplings

$$\mathcal{L} \sim \frac{1}{f^2}\partial(h^2)\partial(\chi^*\chi) - \lambda h^2 \chi^* \chi \quad \rightarrow \quad \sigma \propto (\frac{2m_\chi^2}{f^2} - \lambda)^2$$

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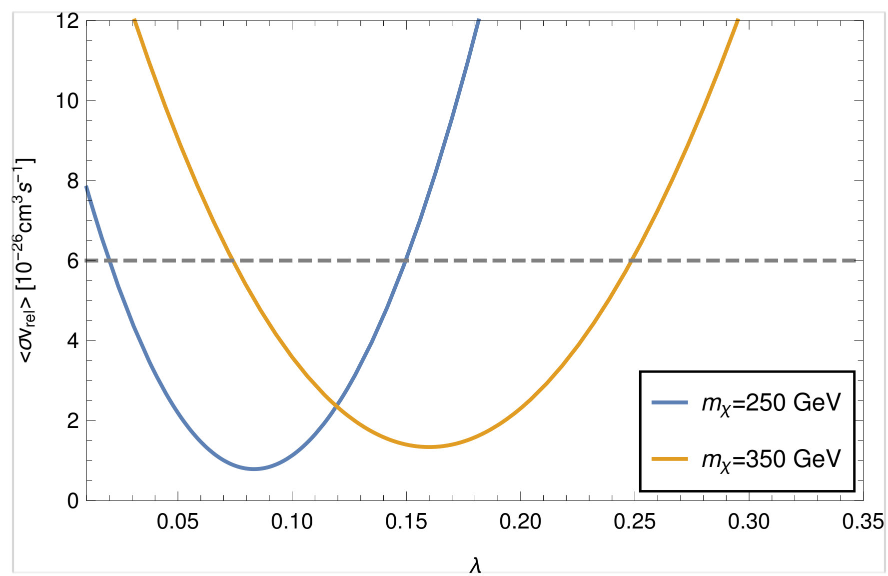


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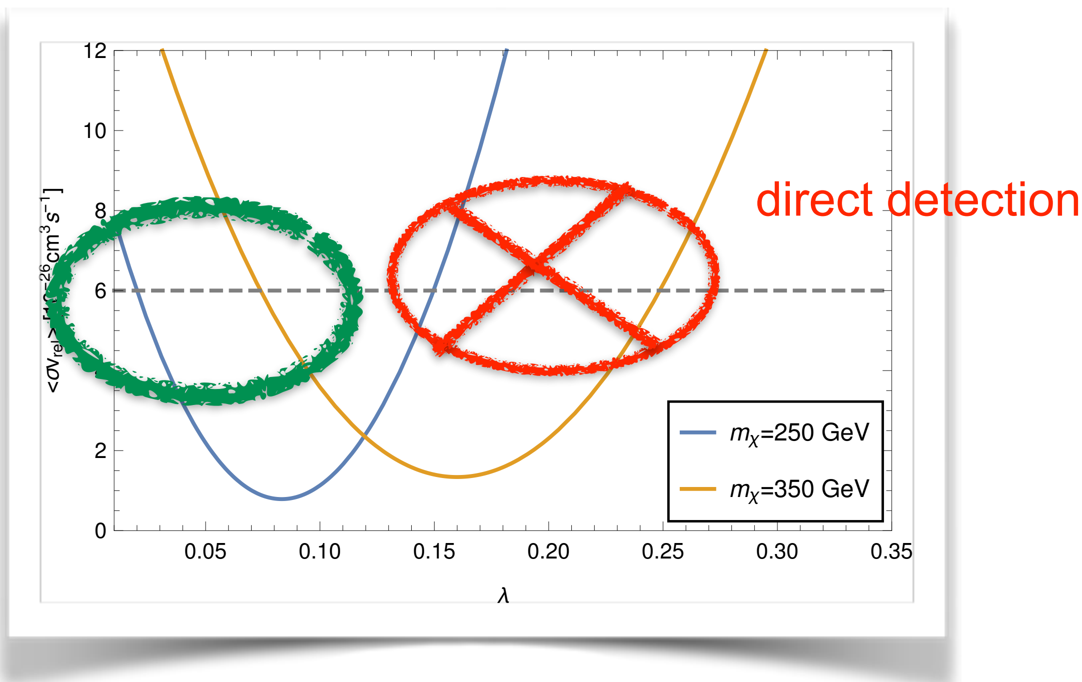


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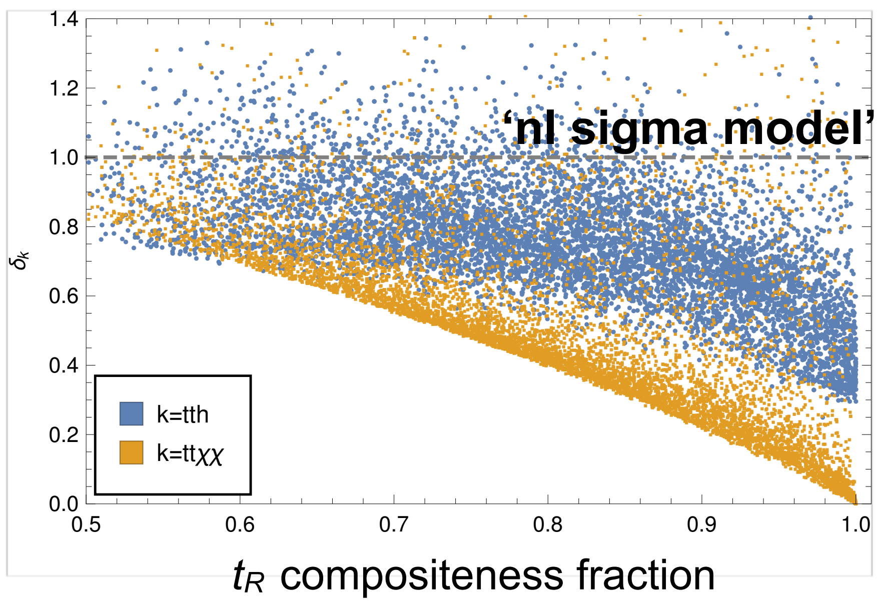
# Top partner mixing matters




when $t_R$ is fully composite,
it respects $\chi$ shift symmetry

non-derivative couplings vanish

orange: $tt\chi\chi$ coupling

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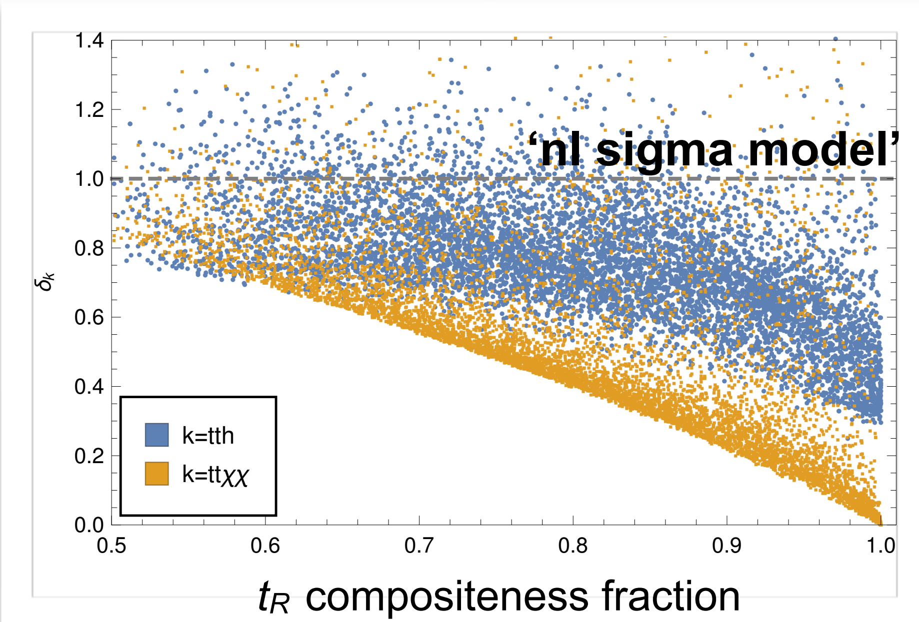


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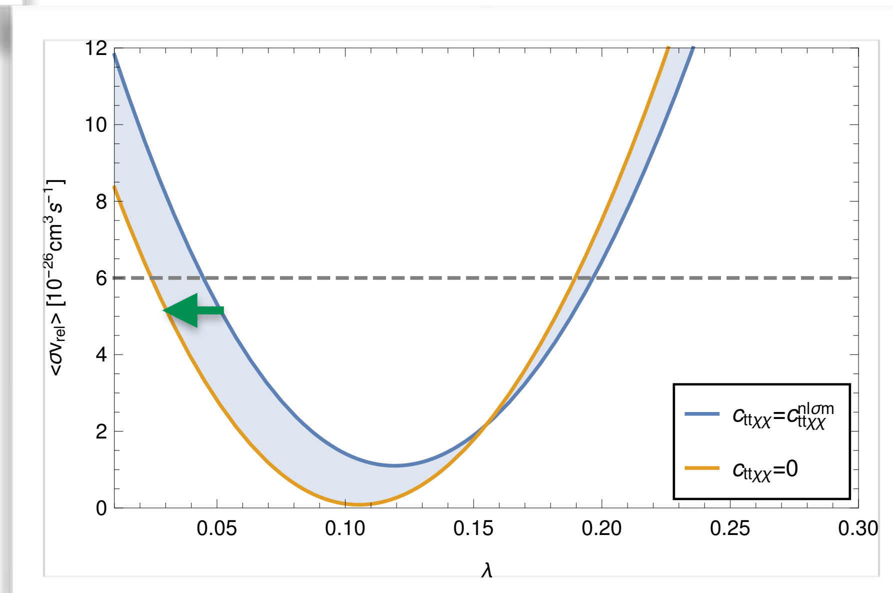
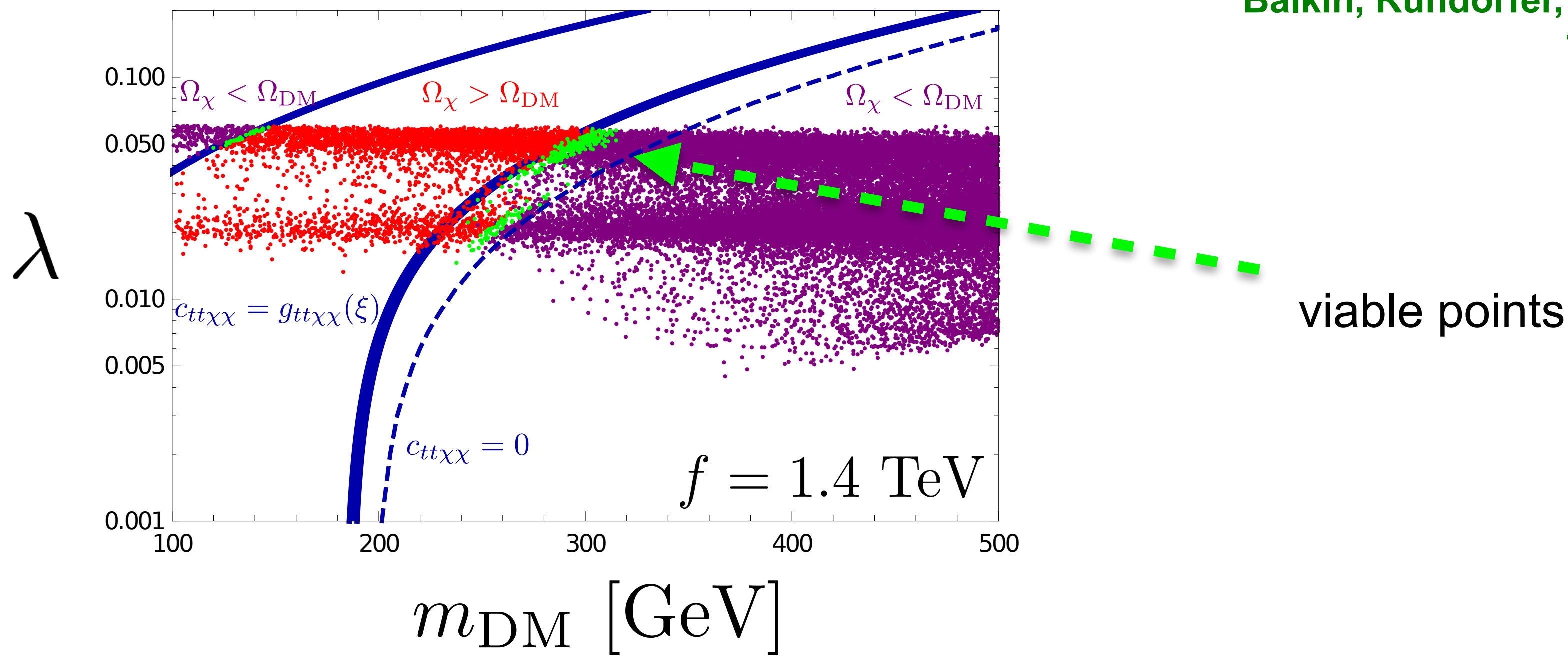



top partner mixing lowers $\lambda$,
**helps with direct detection**

# Relic Abundance

Balkin, Ruhdorfer, ES, Weiler
1705.xxxxx



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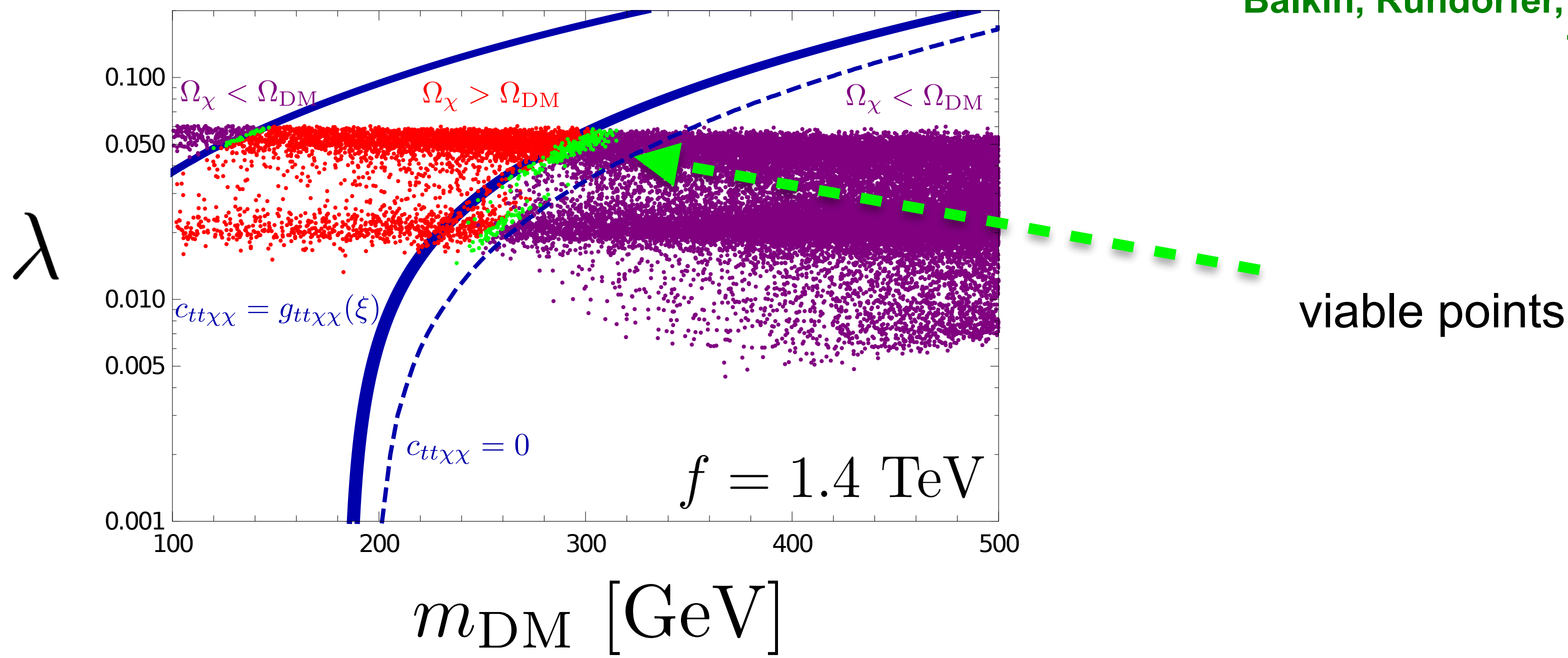
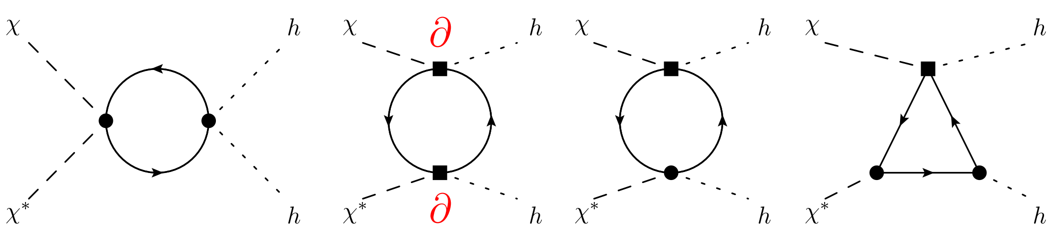



**But** [tree-level + CW] calculation receives **large corrections**:

$$c\,\frac{1}{f^2}\partial_\mu|H|^2\partial^\mu|\chi|^2$$



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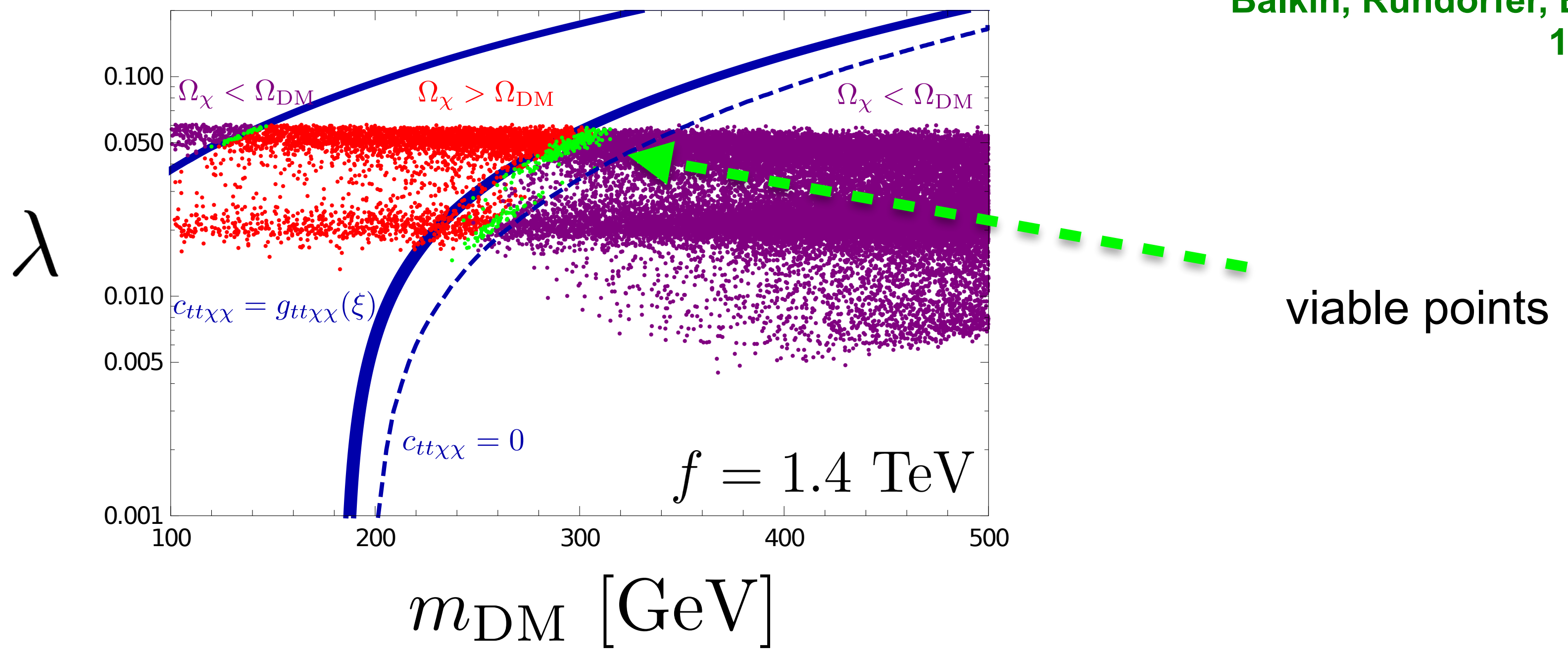


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$$c_{\rm tree} = 1\,, \qquad c_{1-{\rm loop}} = \underbrace{\frac{N_c}{2\pi^2 f^2}\left(\epsilon_t^2 - \frac{\epsilon_q^2}{8}\right)}\log\frac{\Lambda^2}{m_\psi^2}$$

irreducible uncertainty of ~ 50% on cross section

# Composite DM pheno

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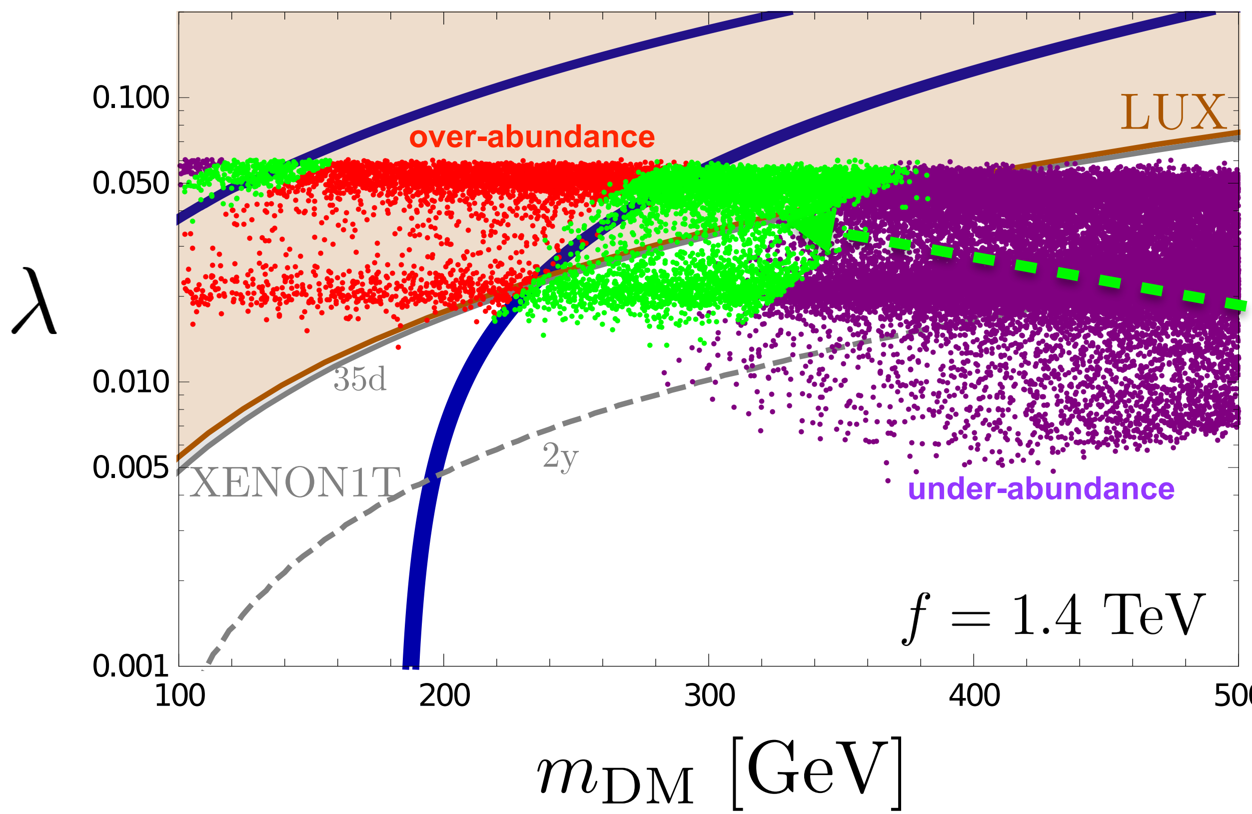
1705.xxxxx




**viable points**, 50% uncertainty on RA

**Effect of top partner mixing pushes $\lambda$ down, relaxes direct detection constraint**

# Tuning

- Simple estimate of tuning is $\frac{1}{\Delta} \sim 2\xi$ ~ 6% for *f* = 1.4 TeV
- However, most natural value of portal coupling is $\lambda \sim \frac{\lambda_h}{2} \approx 0.06$

**Too large for direct detection.**

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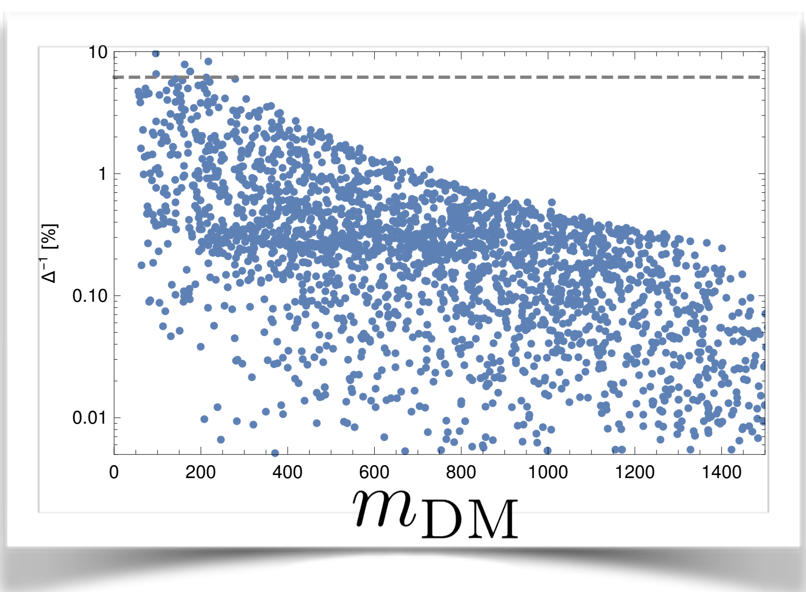
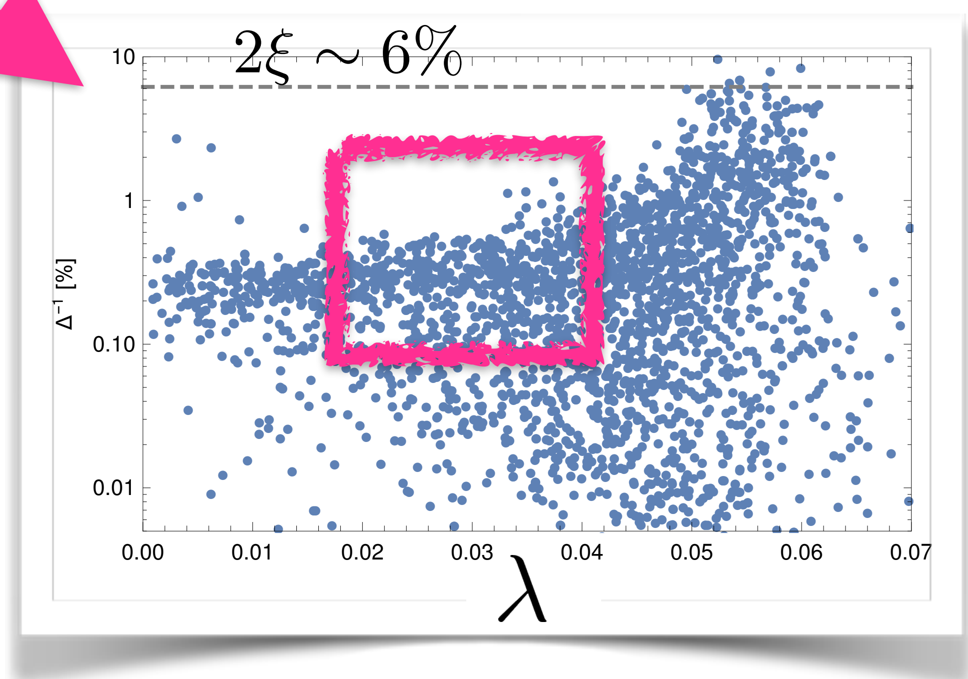
**Too large for direct detection.**

Suppressing it costs extra tuning

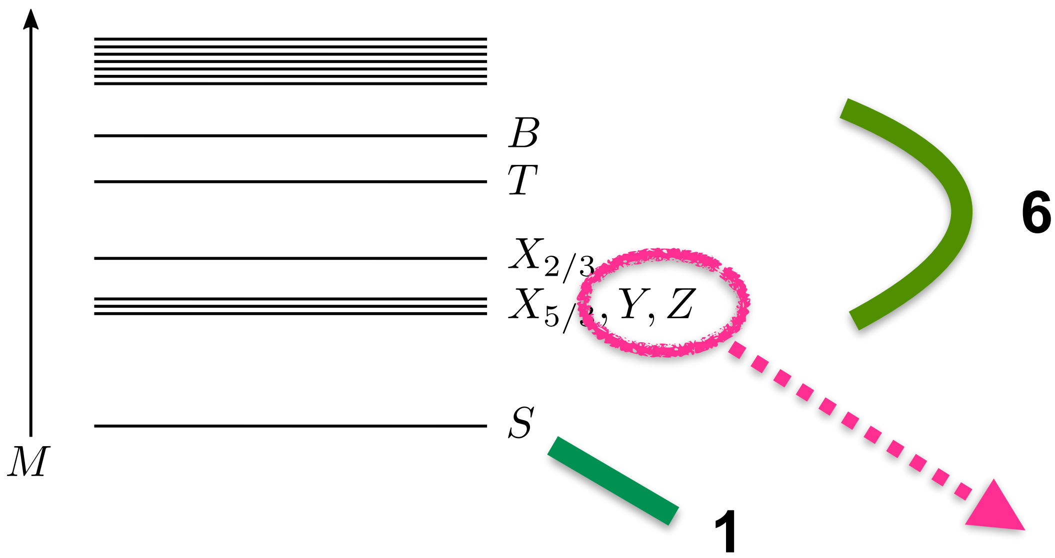


# Collider pheno, sketch

$$SO(7)/SO(6)$$

$$\mathbf{7} = \mathbf{6} \oplus \mathbf{1}$$




*typical spectrum*

top partners charged under

$$U(1)_{\mathrm{DM}}$$

$$Y, Z \to t + \chi$$

see e.g. Serra 2015

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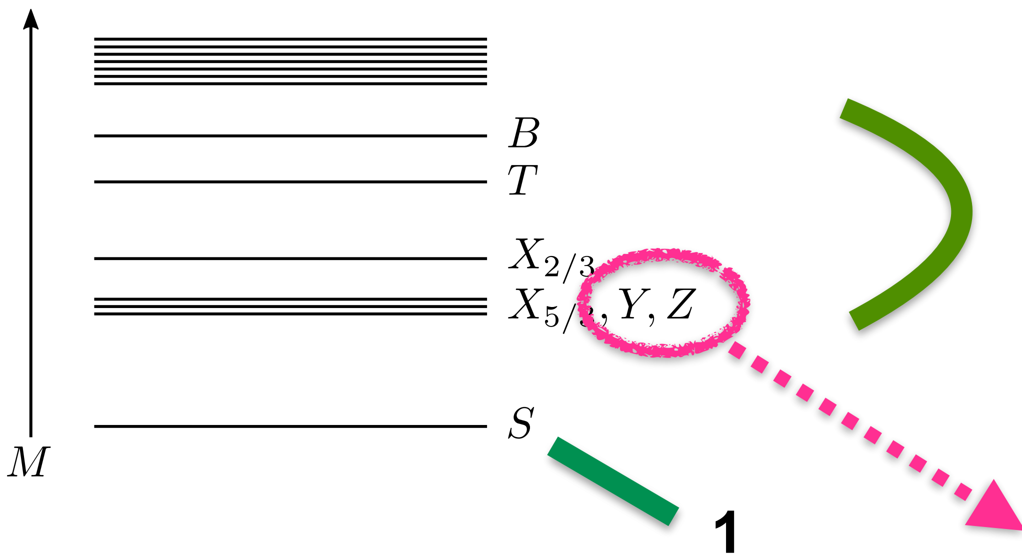


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**current bounds:**

$$M_{\rm singlet} > 1 \text{ TeV}, \qquad M_{\rm doublets} > 1.2 \text{ TeV}, \qquad M_{Y,Z} > 1.4 \text{ TeV}$$

# Summary & Outlook

- Composite Higgs model with **UV-safe DM stabilization**
- DM is pGB scalar with 200 - 400 GeV mass

  **Will be fully tested by XENON1T**
- Typically $t_R$ is very composite, mixing with top partners

  has important effects in annihilation

  **+** large radiative corrections to derivative operators
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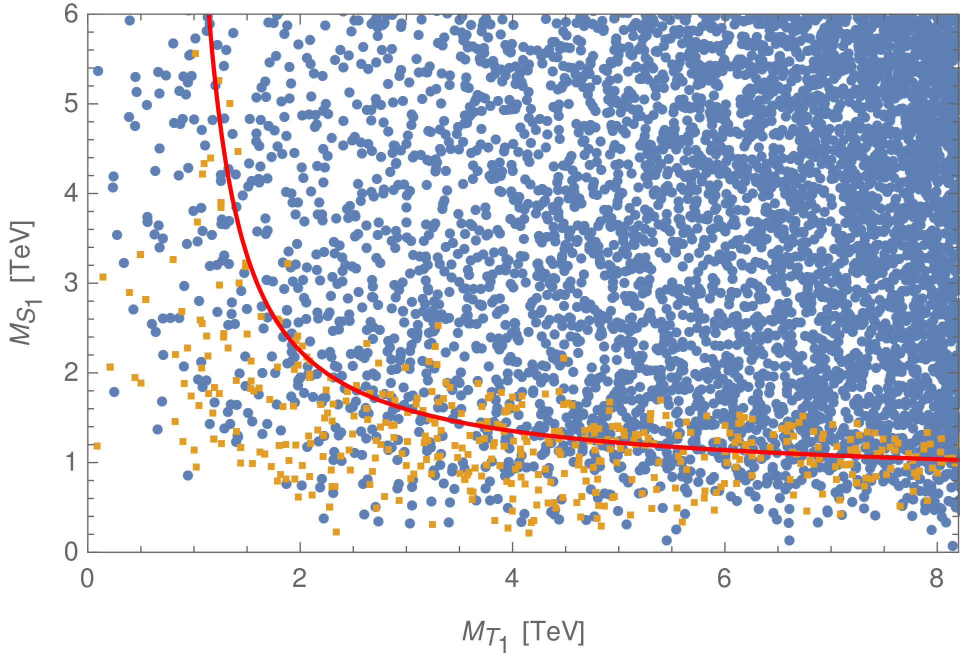
- $U(1)_{\mathrm{DM}}$ can be weakly gauged **Agrawal, Cyr-Racine, Randall, Scholtz 2016**

- Indirect detection: antiproton constraints? (AMS-02)

# Backup

# Light top partners

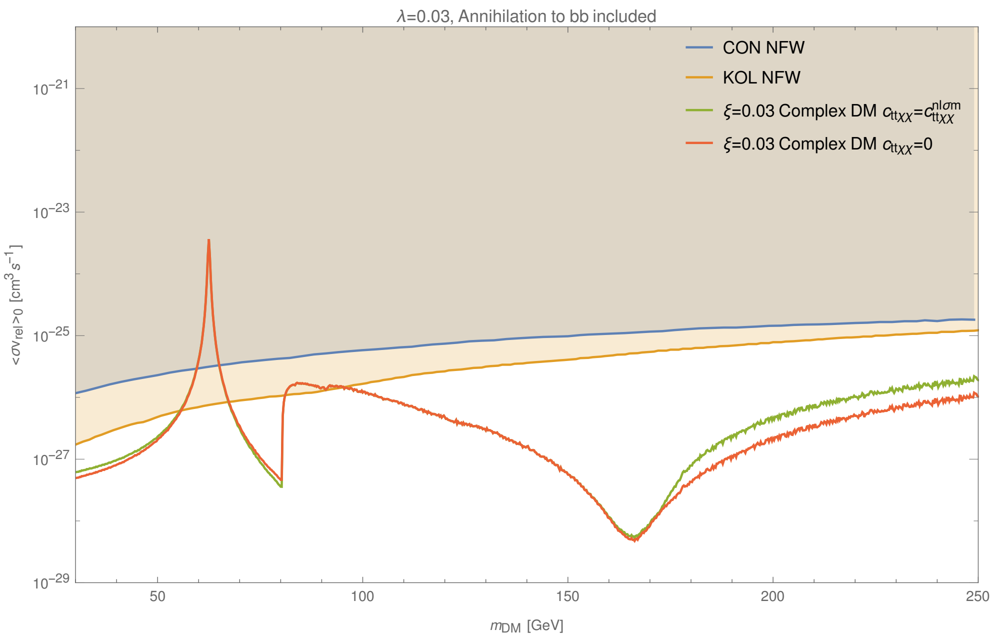



$f = 1.4\ \text{TeV}$

**orange**: 120 GeV < $m_h$ < 130 GeV

**red**: $\frac{m_h^2}{m_t^2} \approx \frac{N_c}{\pi^2 f^2} \frac{M_T^2 M_S^2}{M_T^2 - M_S^2} \log(M_T^2/M_S^2)$

# Indirect detection: antiprotons




Bounds from PAMELA: recast from complete analysis in **Marzocca and Urbano, 2014**