FORBIDDEN WIMPS (AREN'T)

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with
A. Delgado, A. Martin
160y.xxxxx

Relic density @ Pheno 2016

$$\Omega_\chi h^2 \sim 0.1$$

- ELDERs : Y-D Tsai
- Co-decays : J. Dror
- Shared asymmetry : L. Necib
- Old-fashioned WIMP freezeout : N. R.

Thermal cross-section

α^2/M^2

WIMP miracle

$$\langle \sigma v \rangle_{\rm ann} = 3 \times 10^{-26}\ {\rm cm}^3\ {\rm s}^{-1}$$

Thermal cross-section

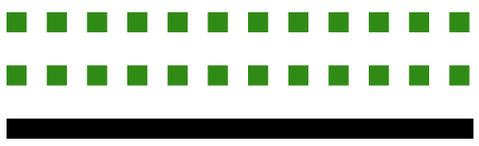
α^2/M^2

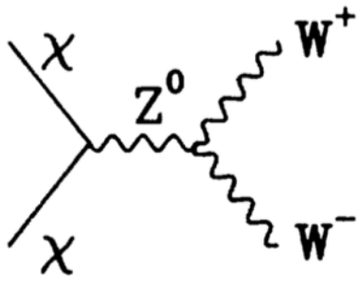
$\chi_i \chi_j \rightarrow \chi_k \mathrm{SM}$

WIMP miracle WIMPless miracle "semi-annihilation"

Feng, Kumar: 0803.4196 D' Eramo, Thaler: 1003.5912

$$\langle \sigma v \rangle_{\mathrm{ann}} = 3 \times 10^{-26}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$$



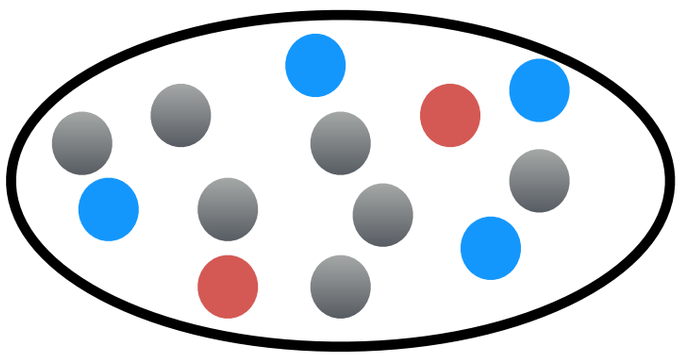


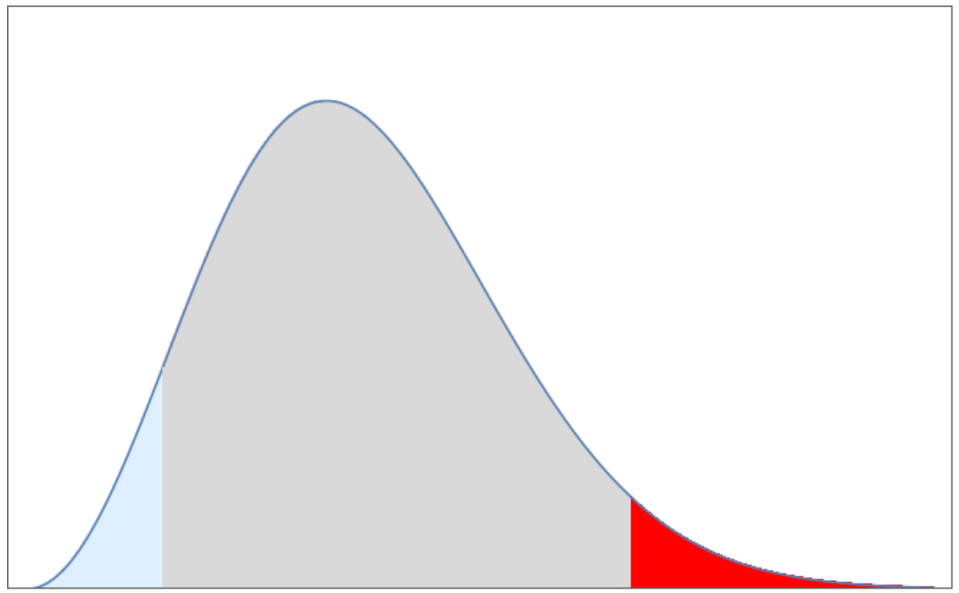
?

co-annihilation resonant forbidden

Griest & Seckel: "Three exceptions in the calculation of relic abundances" Phys.Rev. D43 (1991)

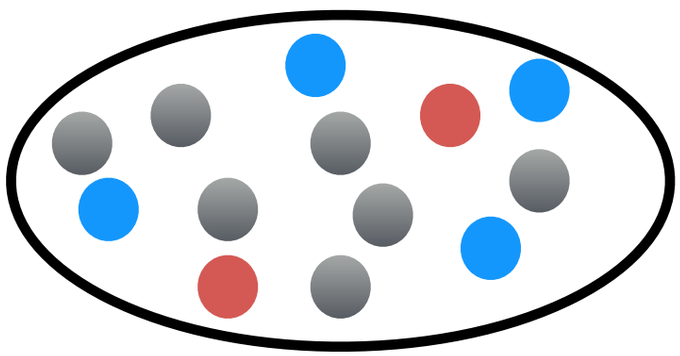
DM velocities

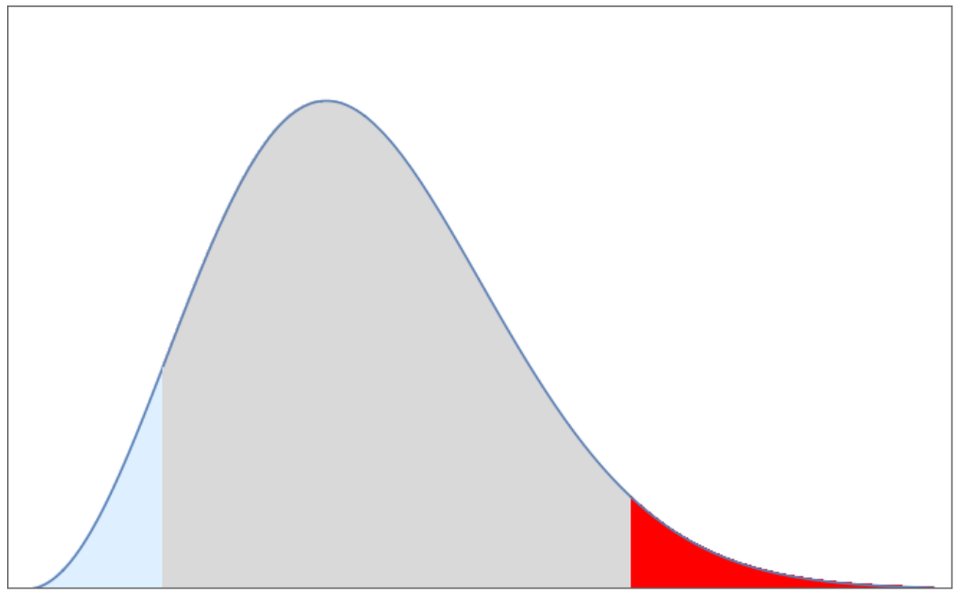




v

DM annihilation

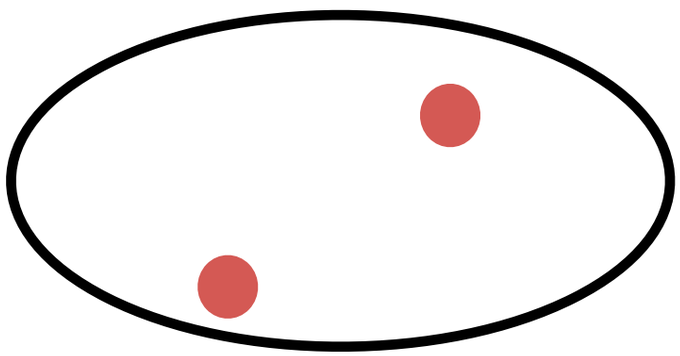


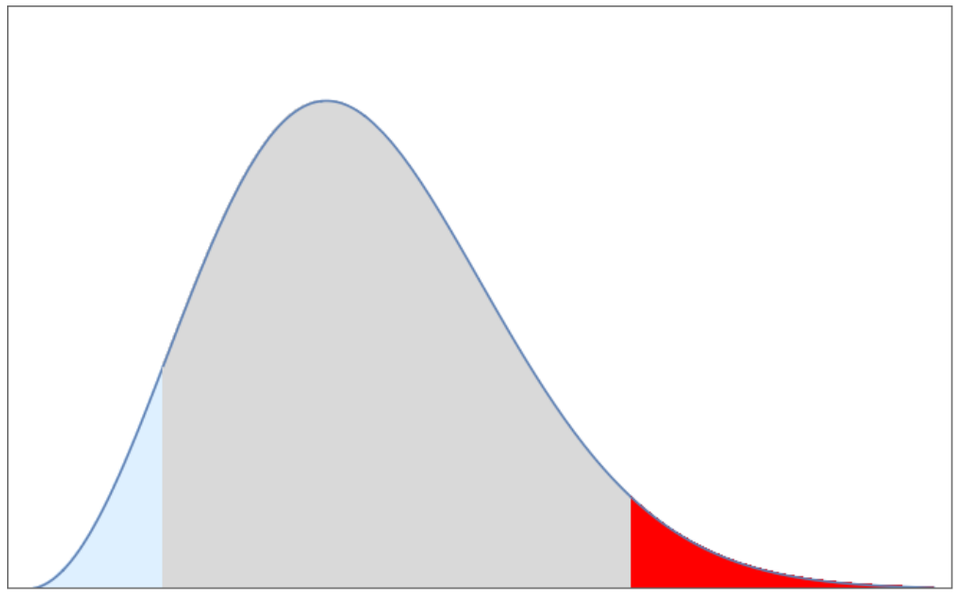


v

$$\left.\chi\bar{\chi} \to f\bar{f}\right\} \; m_\chi > m_f \;, \langle\sigma v\rangle :$$

DM annihilation

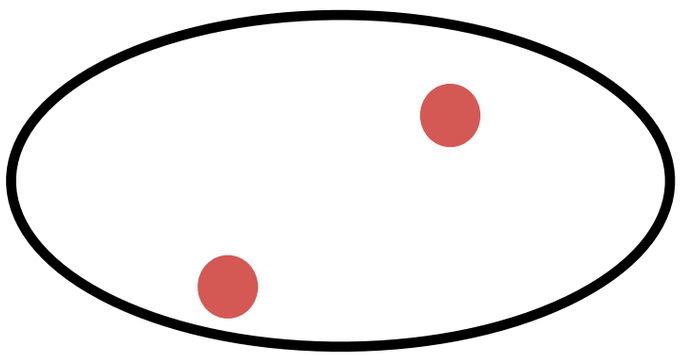


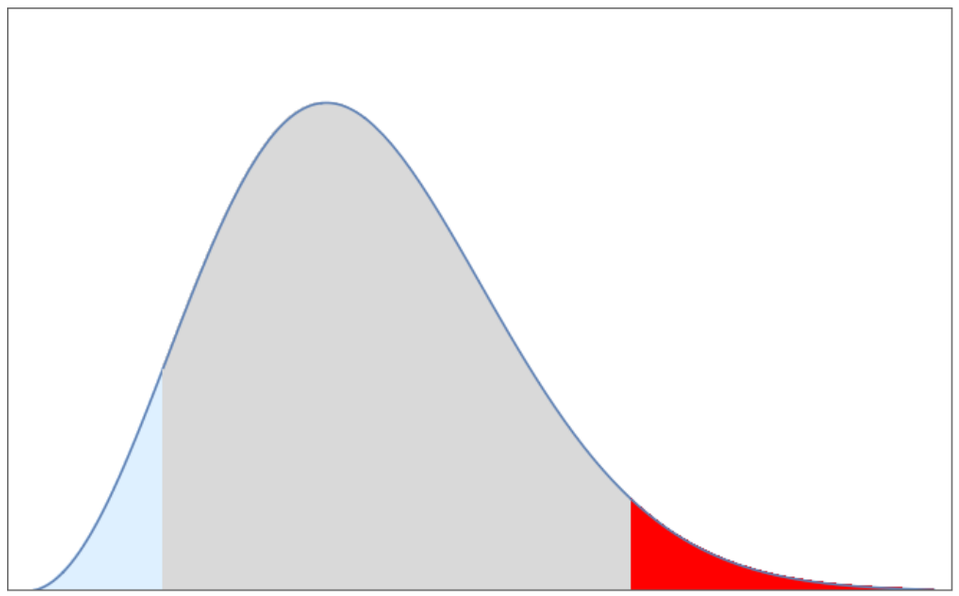


v

$$\chi\bar{\chi} \to f\bar{f} \left.\begin{array}{l} m_\chi > m_f \text{ ,} \langle\sigma v\rangle : \\ \\ m_\chi < m_f \text{ ,} \langle\sigma v\rangle : \end{array}\right\}$$

DM annihilation





v

$$\chi\bar{\chi} \to f\bar{f} \Bigg\} \begin{array}{l} m_\chi > m_f \ , \langle\sigma v\rangle : \\ \underline{m_\chi < m_f} \ , \langle\sigma v\rangle : \end{array}$$

$\langle\sigma v\rangle$= 0 at zero temperature, hence “forbidden” DM.

Key ingredient: large $\sigma \sim |\mathcal{M}|^2$ to begin with, to get $\langle\sigma v\rangle_{\rm ann} = 3 \times 10^{-26}\ {\rm cm}^3\ {\rm s}^{-1}$

Forbidden DM history

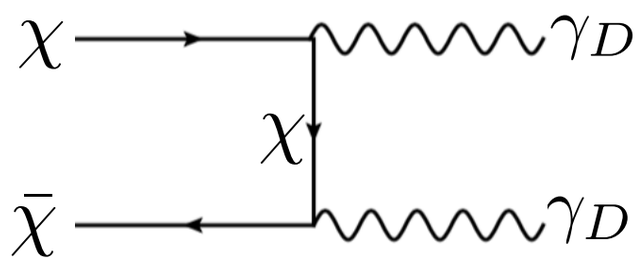
This morning's plenary talk by Mariangela Lisanti

R. D'Agnolo, J. Ruderman: 1505.07107

Large $\sigma \sim |\mathcal{M}|^2$

— light (MeV- GeV) mediators

Relic density from forbidden annihilation



Forbidden DM history

(a) C. Jackson, et al: 0912.0004, 1302.1802, 1303.47

(b) S. Tulin, H. Yu, K. Zurek: 1208.009

(c) R. D'Agnolo, J. Ruderman: 1505.07107

Large $\sigma \sim |\mathcal{M}|^2$ — s-channel pole: (a), (b)
— light (MeV- GeV) mediators: (c)

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Large $\sigma \sim |\mathcal{M}|^2$ — s-channel pole: (a), (b)
— light (MeV- GeV) mediators: (c)

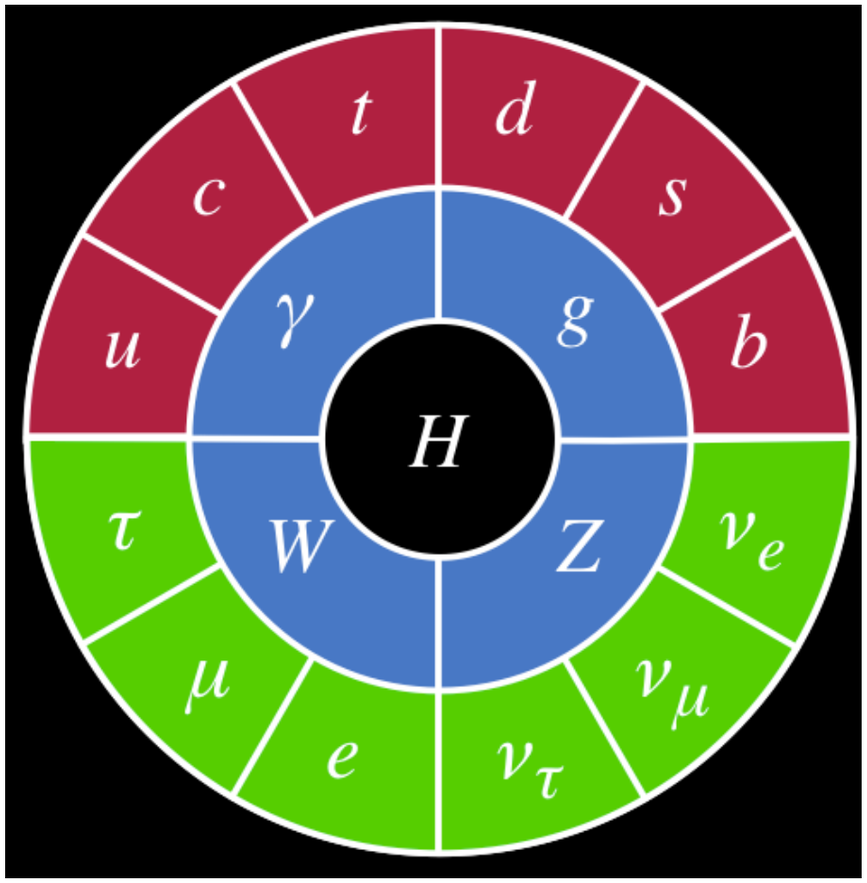
Relic density from forbidden ann.:	(c)
Exotica final states:	(b), (c)
Light final states:	(a)
U(1)′ gauge:	(a), (c)
Main target indirect detection:	(a), (b), (c)

Model wishlist vs Virtues

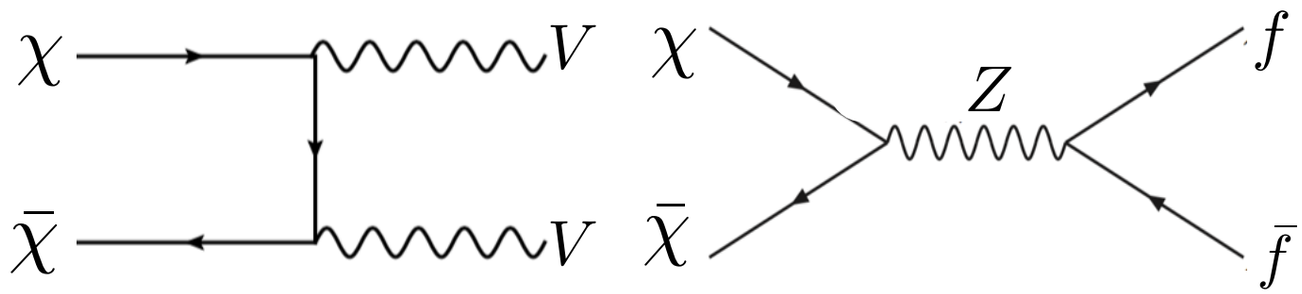
Weak scale masses	LHC, LUX can now probe all “exceptions”
No gauge group extension	Minimal assumptions (no gauge kinetic mixing, etc.)
Annihilation to SM states	DM mass roughly known (~90% SM mass)
	Enforce communication between dark & luminous sectors

MicroOmegas already computes forbidden rates near thresholds.
But can a WIMP be <u>entirely</u> forbidden?

“Truly” forbidden?



SU(2) charged



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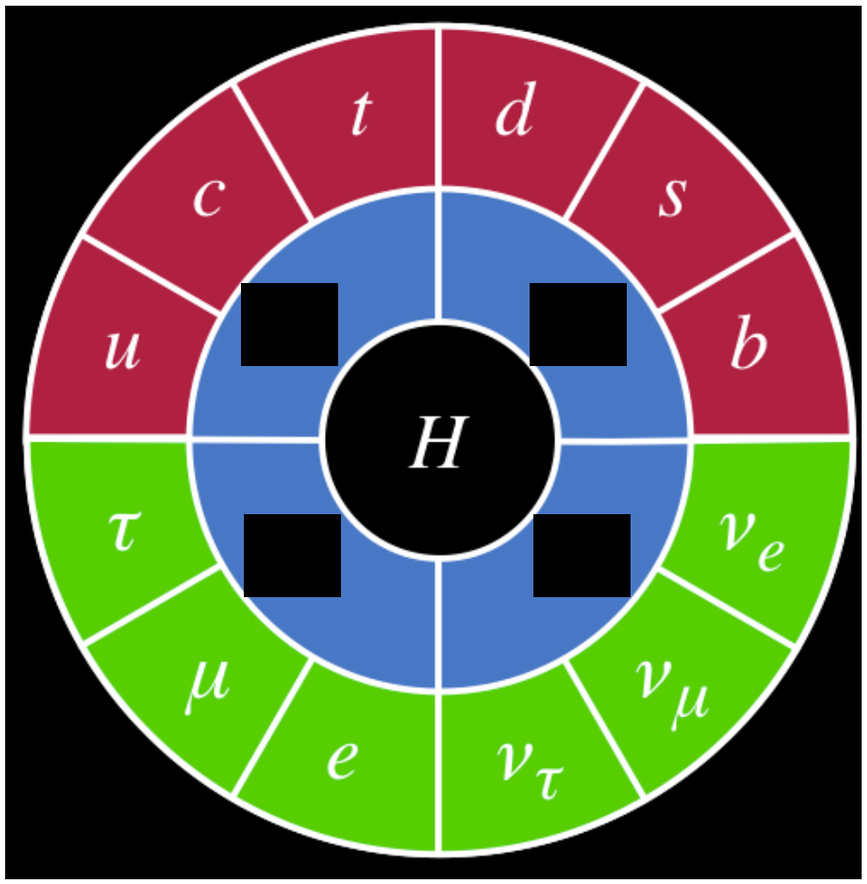

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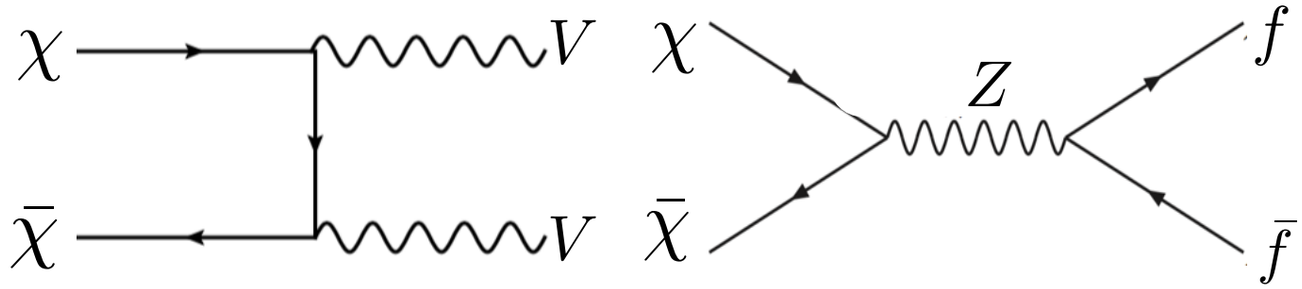
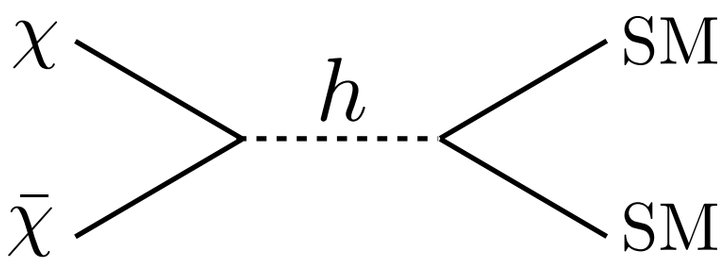


Higgs portal

$\chi\bar{\chi} \to hh$



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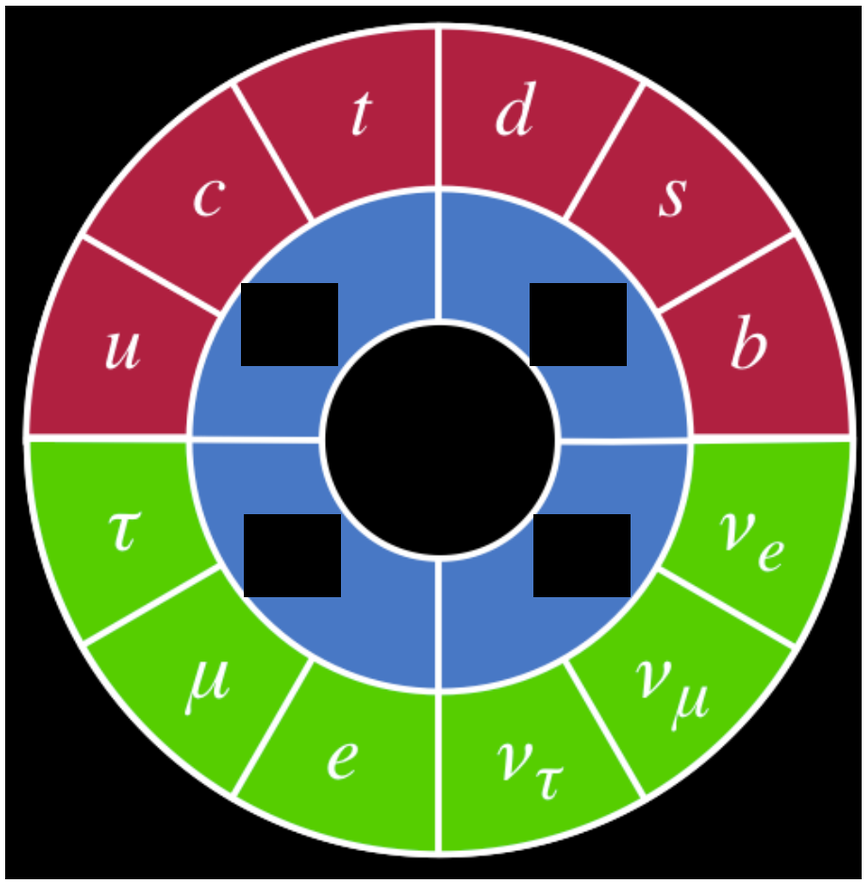

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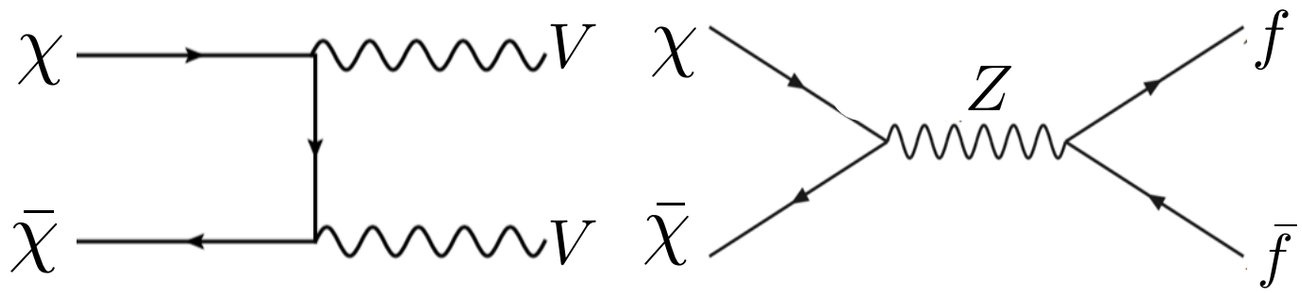

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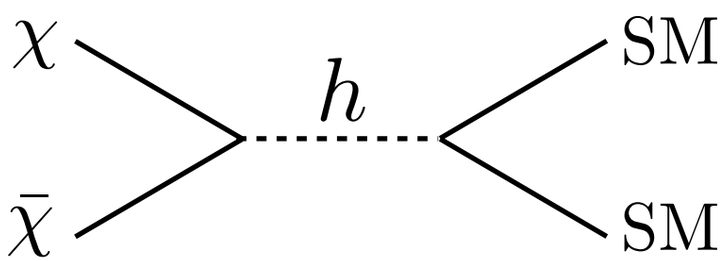
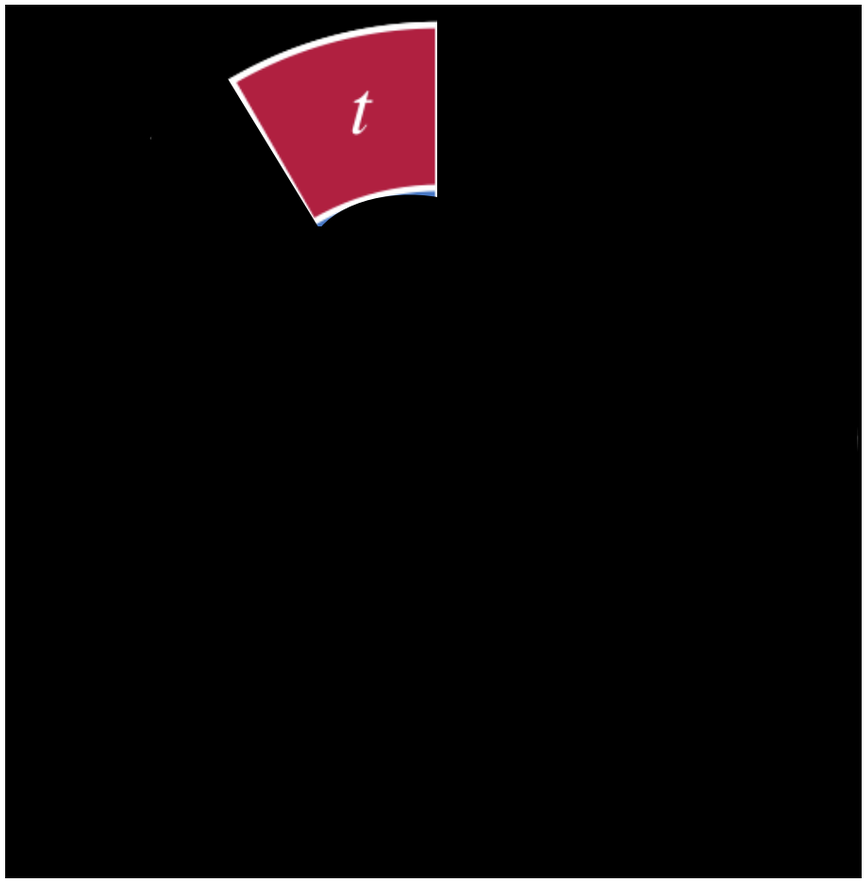


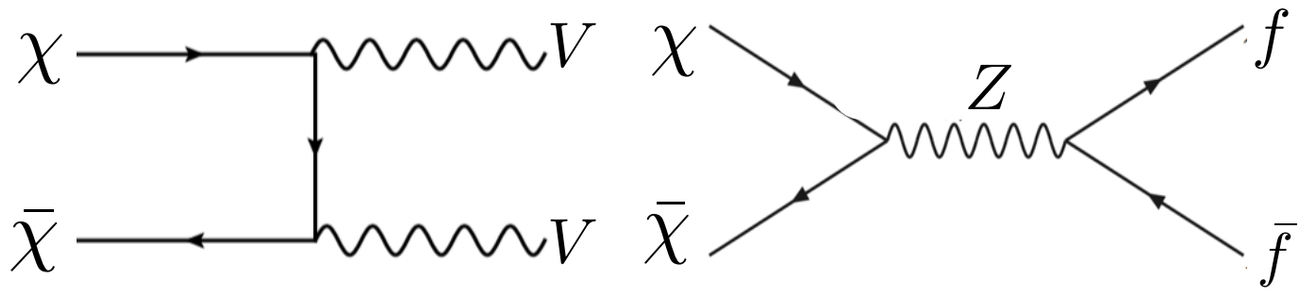
Fermion portals

Fermion lighter than 100 GeV => mediator mass < O(10 GeV); ruled out by LEP or lack of resonances

“Truly” forbidden?

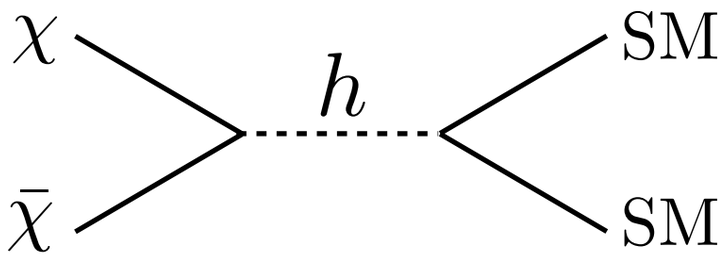


SU(2) charged



Higgs portal

$\chi\bar{\chi} \to hh$



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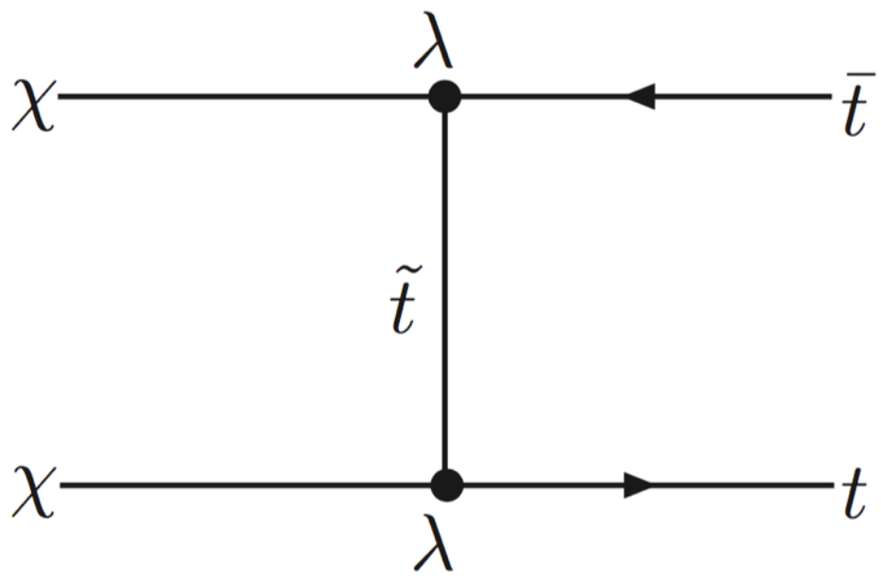
Top Portal

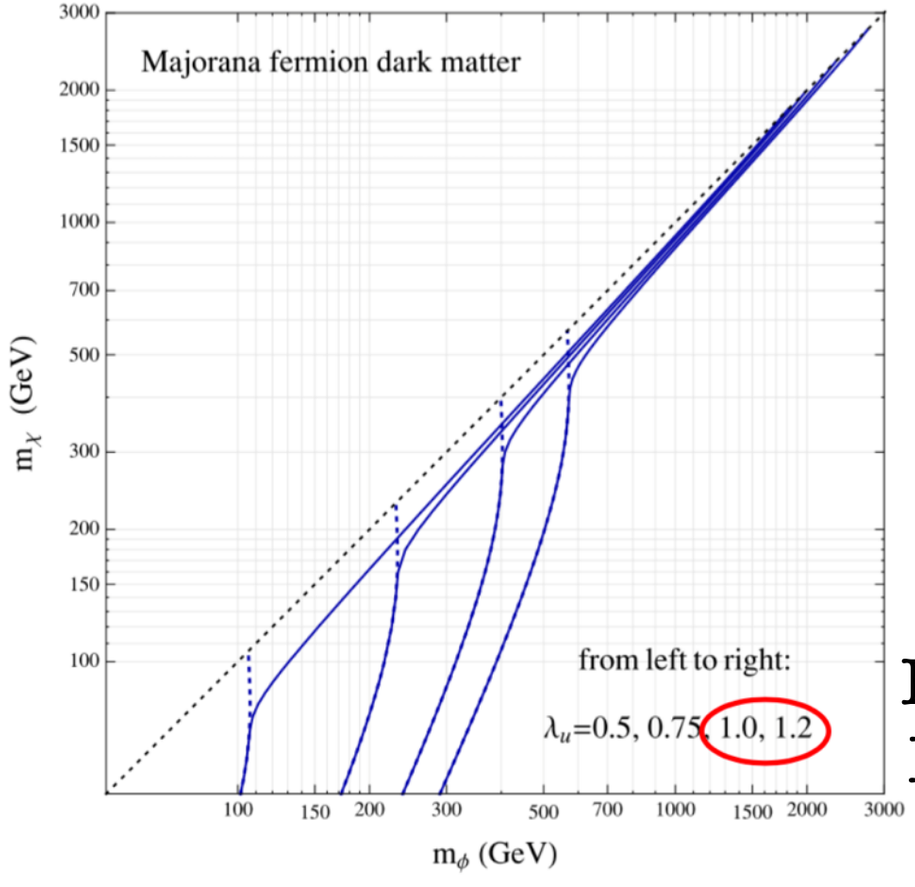
Accomplishing large $\sigma \sim |\mathcal{M}|^2$



Effective coupling large

Model		Relic Abundance
χ	Q	
Majorana fermion	Complex scalar	$a \sim m_q^2$ $\lambda \sim 0.5 - 2$
Dirac fermion	Complex scalar	$\lambda \sim 0.2 - 1$

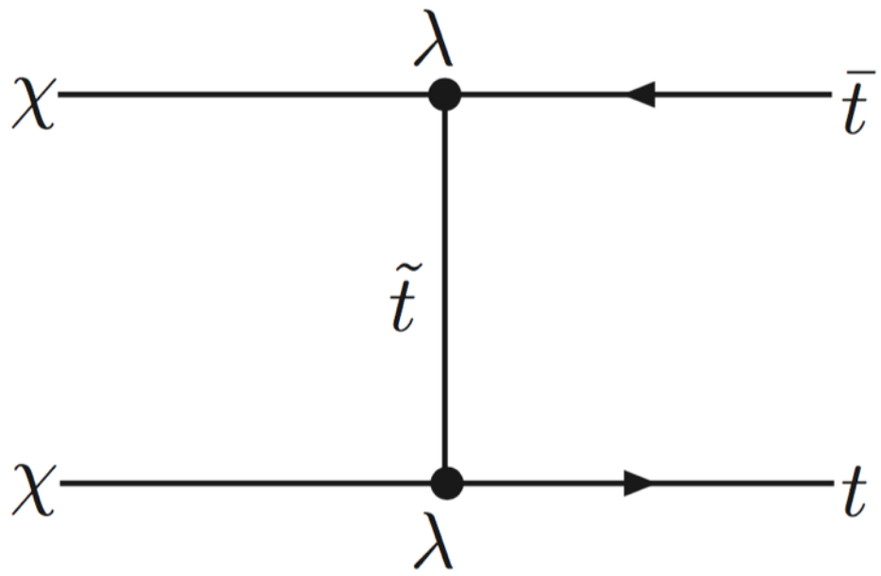
Chang, Luty, et al;1307.8120



Bai, Berger 1308.0612

Top Portal

Accomplishing large $\sigma \sim |\mathcal{M}|^2$



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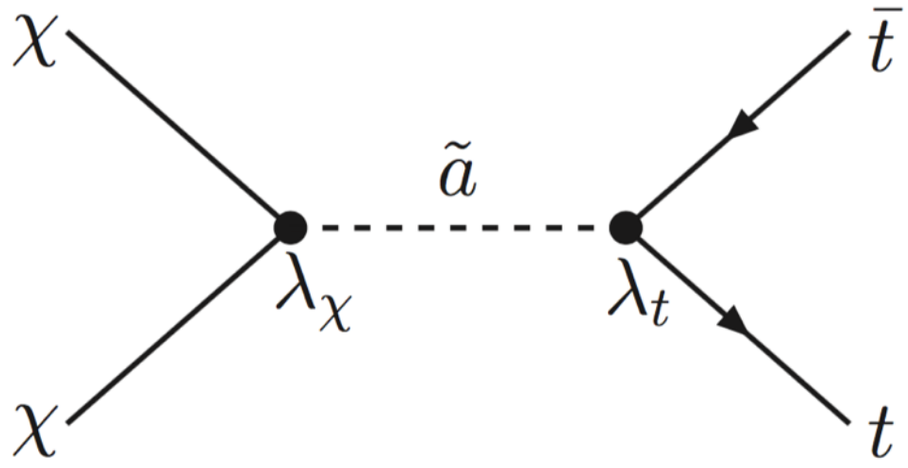
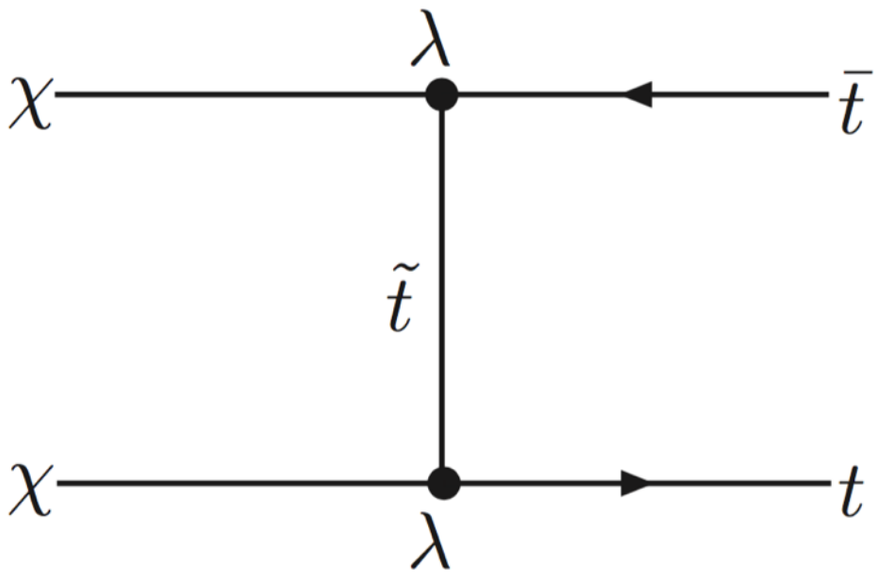


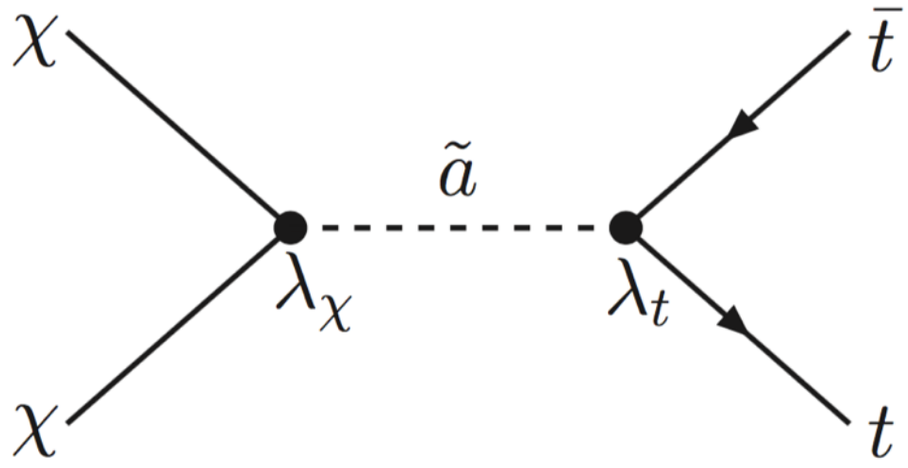
Annihilate near pole

Top Portal Simplified Models

Field	$SU(3)_c \otimes SU(2)_W \otimes U(1)_Y$	Z_2	Spins: t-channel		Spins: s-channel
χ	**(1,1,0)**	**-1**	**1/2**	**0**	**1/2**
$\widetilde{t}$	**(3,1,2/3)**	**-1**	**0**	**1/2**	
$\widetilde{a}$	**(1,1,0)**	**+1**			**0**



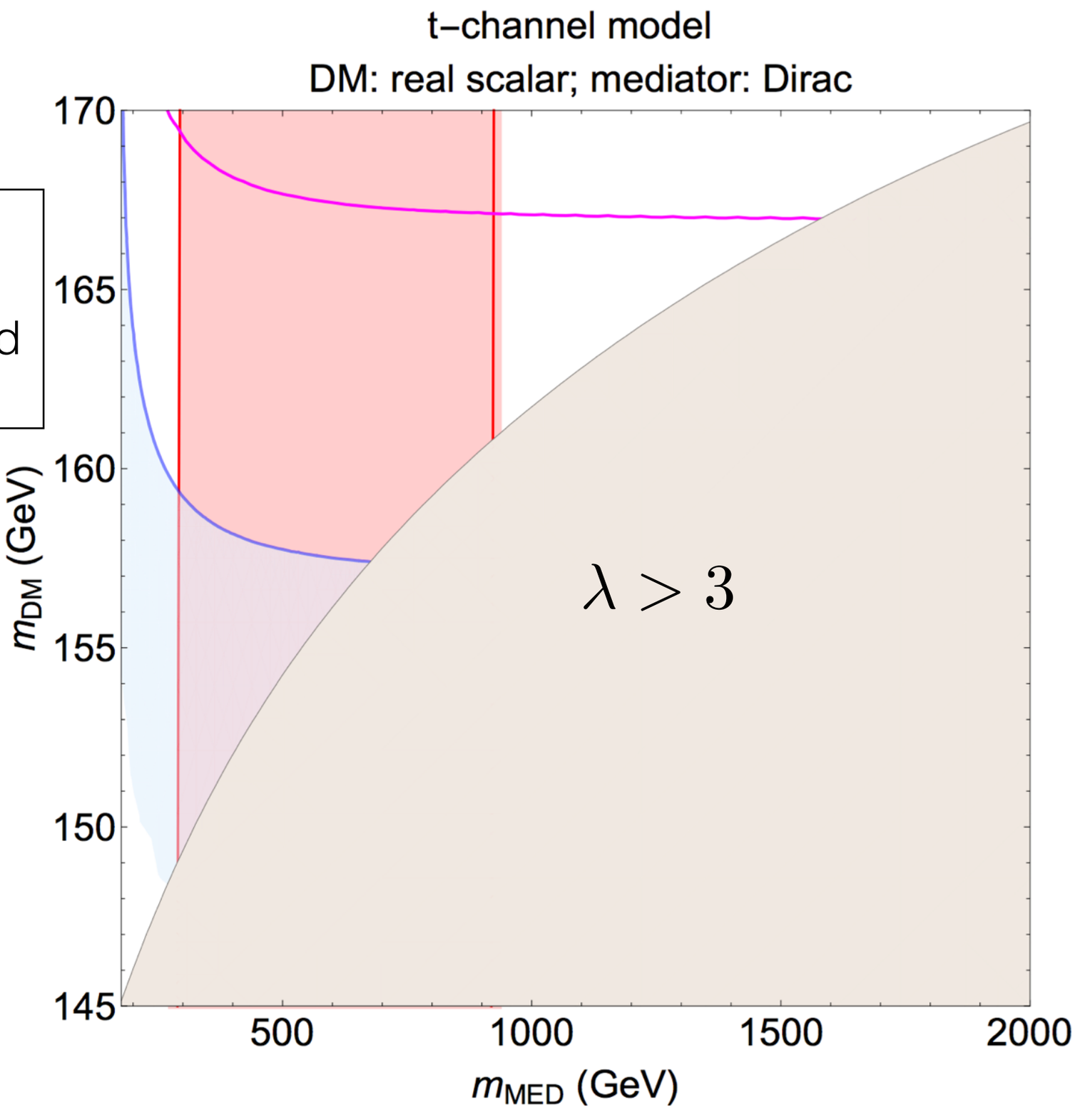
No qualitative difference if fermion DM Majorana/Dirac, scalar DM complex/real



If mediator CP-even, LUX kills model

Limits & prospects: t-channel

Coupling fixed to give observed abundance



8 TeV ATLAS stop search

LUX

XENON 1T

Limits & prospects: t-channel

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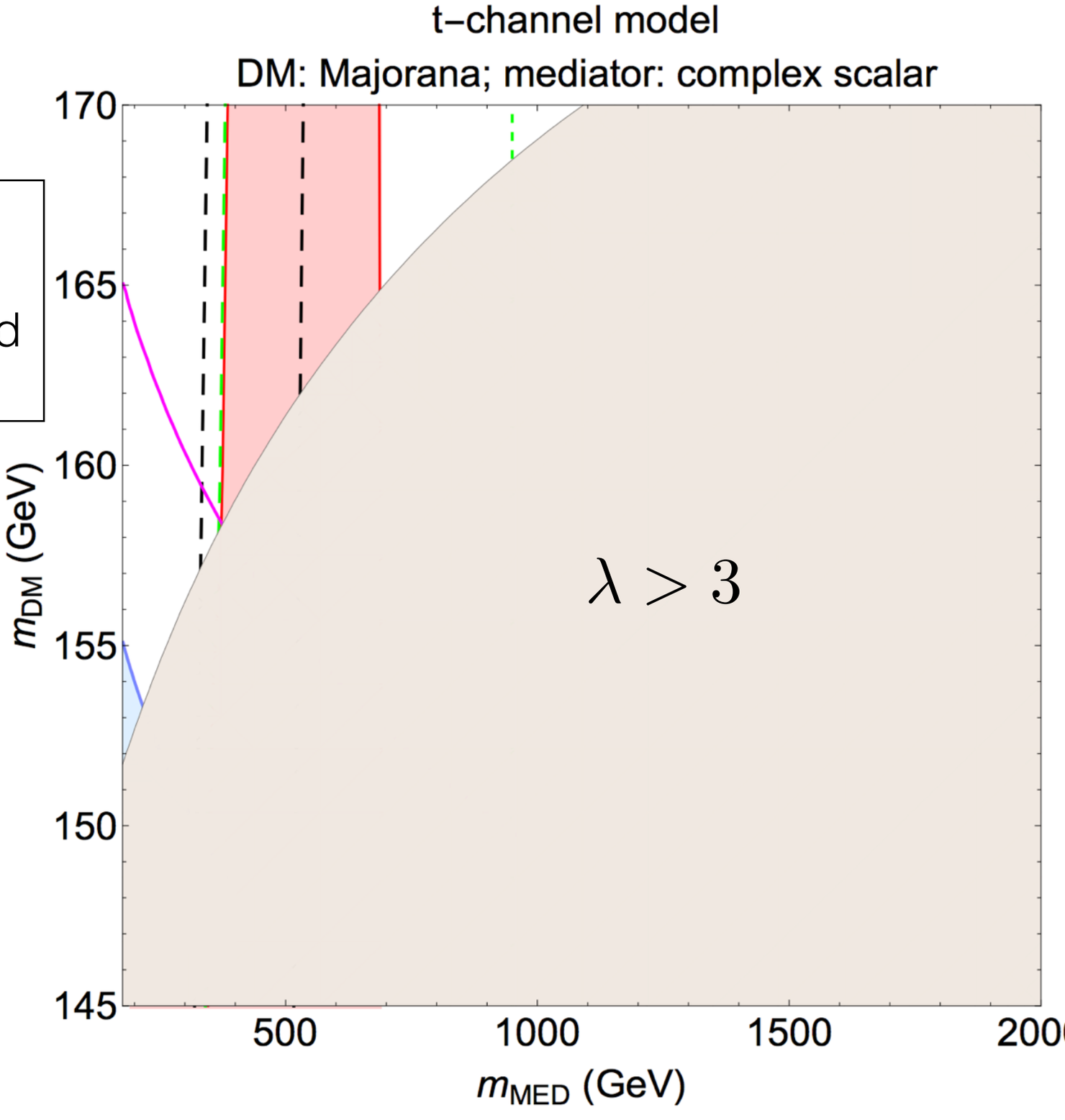


8 TeV ATLAS stop search

LUX

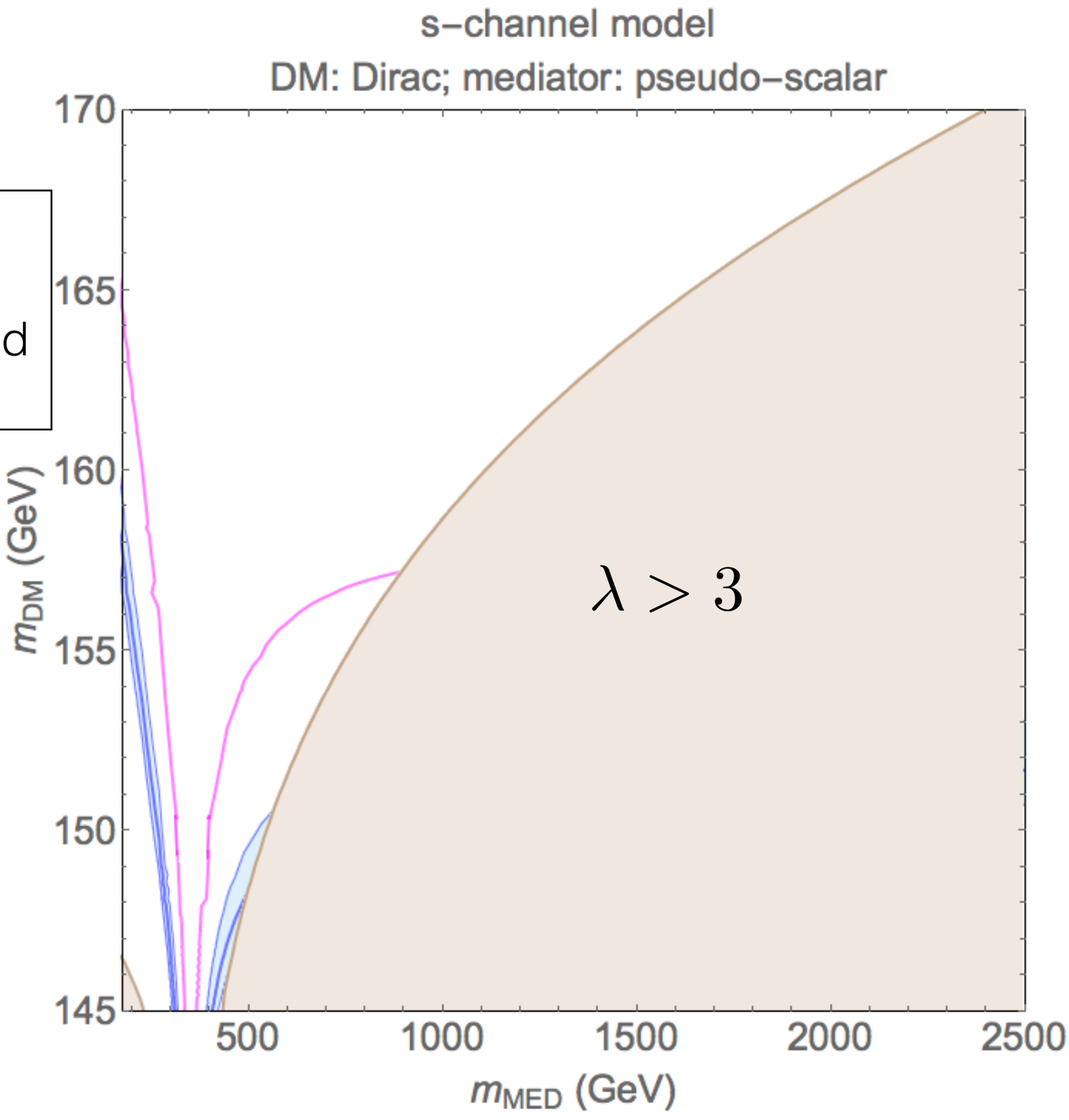
XENON 1T

14 TeV, 300 ifb CMS discovery projection

"Compressed stop" strategy: An&Wang, 1506.00653

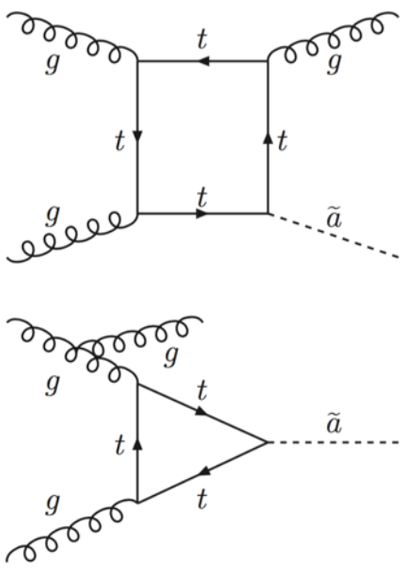
Limits & prospects: s-channel

Coupling fixed to give observed abundance



Monojet @ 8 TeV, 20 ifb

Monojet @ 14 TeV, 3 iab



Final remarks

Truly forbidden WIMP already possible;
Discovery prospects —
s-channel model: need to get lucky,
t-channel models: high coverage @ LHC and XENON1T

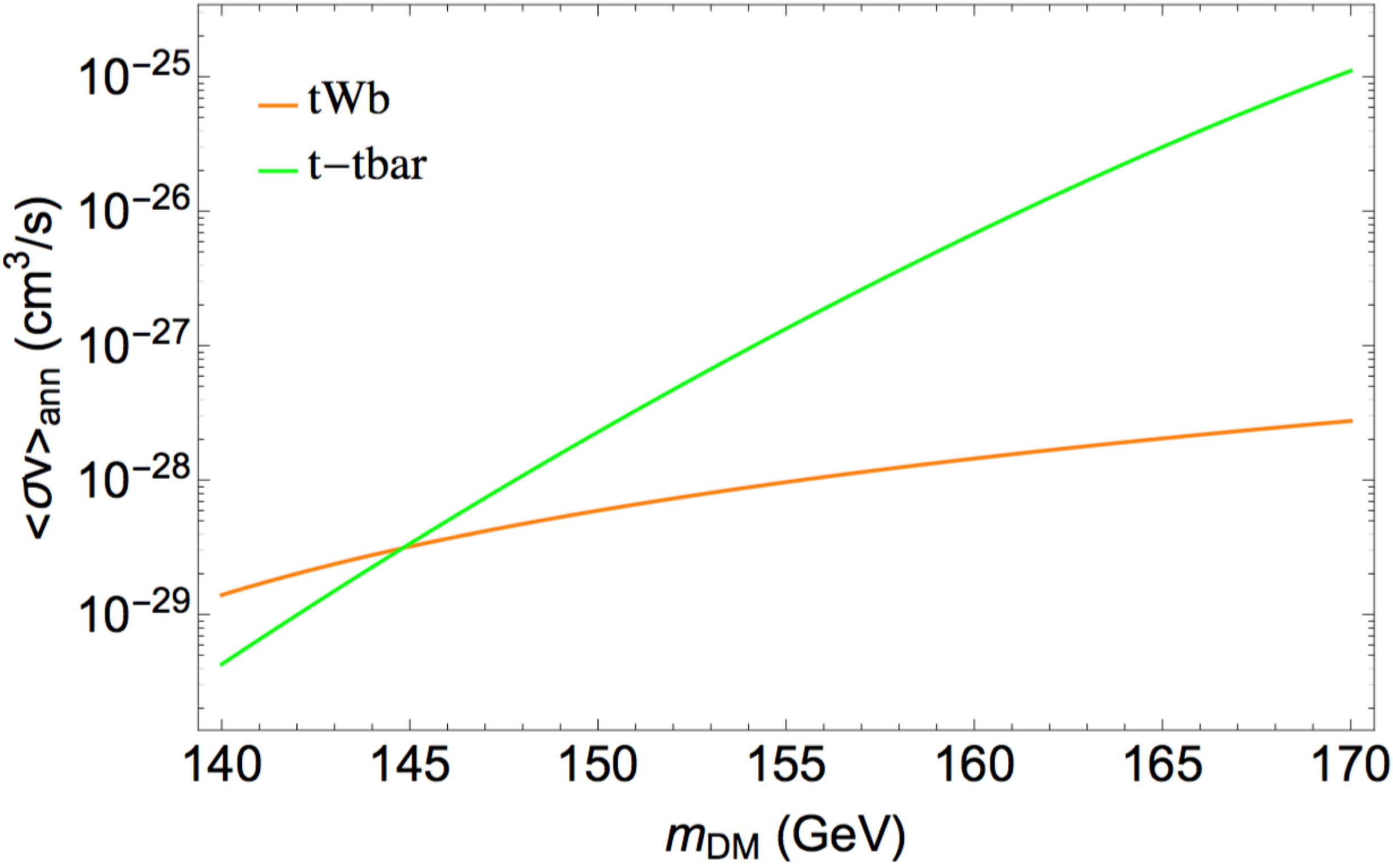
Forbidden WIMP vs "secluded WIMP" [Pospelov, et al 0711.4866]
good at direct detection & colliders, bad at indirect detection
bad at " , built for "

Future directions

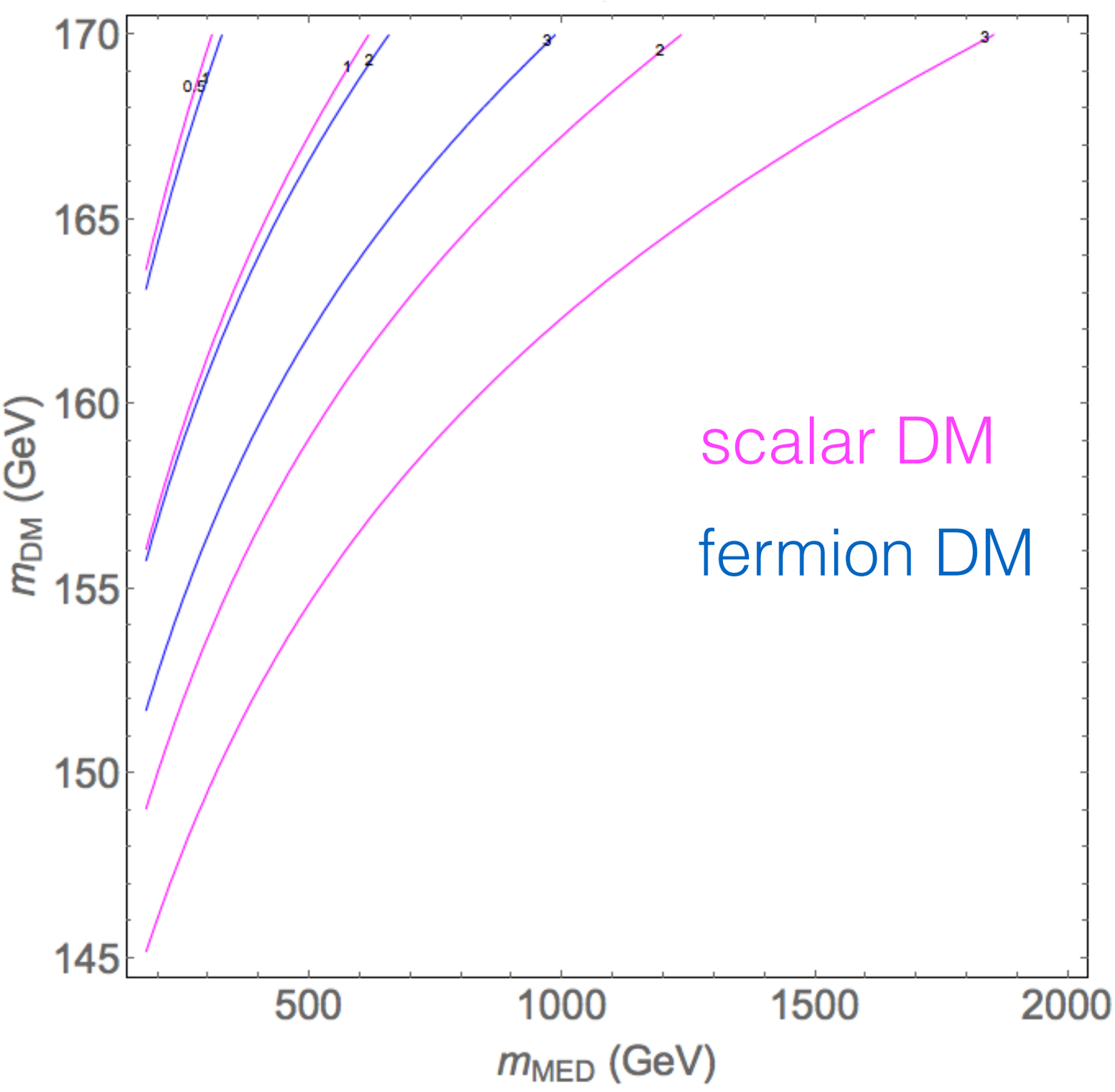
- Partially forbidden: multiple SM final states, more pheno
- Mediator final states
- Co-annihilation effects
- Incorporation into SUSY

Back-up Slides

3-body annihilations



Couplings


170
165
160
155
150
145
500
1000
1500
2000
m_{DM} (GeV)
m_{MED} (GeV)
0.5
1
2
3
2
3
scalar DM
fermion DM

Relic abundance

$$\langle \sigma v \rangle_{\chi\chi \to t\bar{t}} = \left(\frac{n_t^{\rm eq}}{n_\chi^{\rm eq}} \right)^2 \langle \sigma v \rangle_{t\bar{t} \to \chi\chi}$$

$$\langle \sigma v \rangle_{\chi\chi \to t\bar{t}} = \langle \sigma v \rangle_{t\bar{t} \to \chi\chi} (1+\delta)^3 e^{-2\delta x}$$

$$\Omega_\chi h^2 \approx \frac{1.07 \times 10^9 \ {\rm GeV}^{-1}}{M_{\rm Pl}} \frac{x_F}{\sqrt{g_*}} \frac{1}{I_a + 3 I_b / x_F}$$

$$I_a = x_F (1+\delta)^3 \int_{x_F}^\infty \frac{dx}{x^2} \, e^{-2\delta x} \, a$$

$$I_b = 2 x_F^2 (1+\delta)^3 \int_{x_F}^\infty \frac{dx}{x^3} \, e^{-2\delta x} \, b$$

Taylor coefficients of $\langle \sigma v \rangle_{t\bar{t} \to \chi\chi}$

Monojet recast

Haisch & Re, 1503.00691

Recast of

CMS collaboration, *Search for dark matter, extra dimensions and unparticles in monojet events in proton-proton collisions at* $\sqrt{s} = 8$ *TeV*, *Eur. Phys. J.* **C 75** (2015) 235 [arXiv:1408.3583] [INSPIRE].

$$p_{T,j_1} > 110\,\text{GeV}\,, \quad |\eta_{j_1}| < 2.4\,, \quad p_{T,j_2} > 30\,\text{GeV}\,, \quad |\eta_{j_2}| < 4.5\,, \quad \Delta\phi_{j_1 j_2} < 2.5\,, \tag{3.1}$$

where $\Delta\phi_{j_1 j_2}$ is the azimuthal separation of the two leading jets, which are reconstructed using a radius parameter of $R = 0.5$. Another important selection criterion is the imposed jet veto [21], which rejects events if they contain a tertiary jet with $p_{T,j_3} > 30\,\text{GeV}$ and $|\eta_{j_3}| < 4.5$. The CMS measurement is performed in seven distinct $\not{E}_T$ regions, and we find that in the case of the operators $O^t_{S,P}$ the highest sensitivity is obtained for $\not{E}_T > 450\,\text{GeV}$. The corresponding 95% confidence level (CL) limit on the fiducial cross section reads

$$\sigma_{\text{fid}}(pp \to \not{E}_T + j) < 7.8\ \text{fb}\,. \tag{3.2}$$