Searching for Singlet Majorana fermion dark matter

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This work is in collaboration with
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Outline

1. Motivation

2. Dark Matter effective operators
   (With help from UV models)

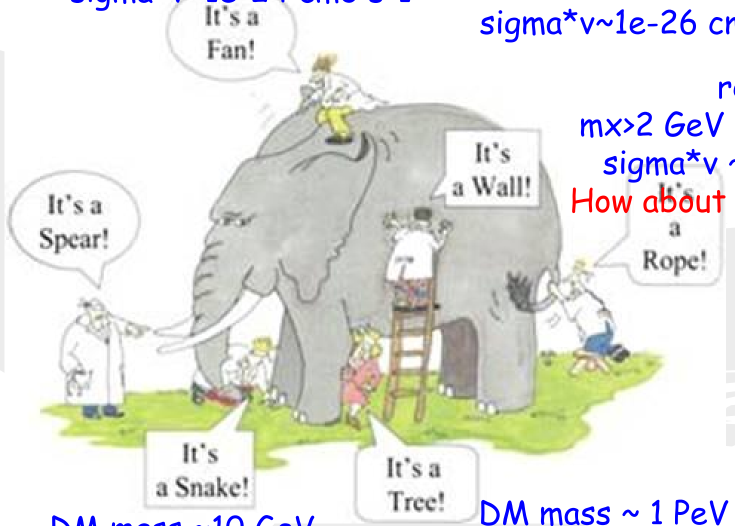
3. Results

4. Summary

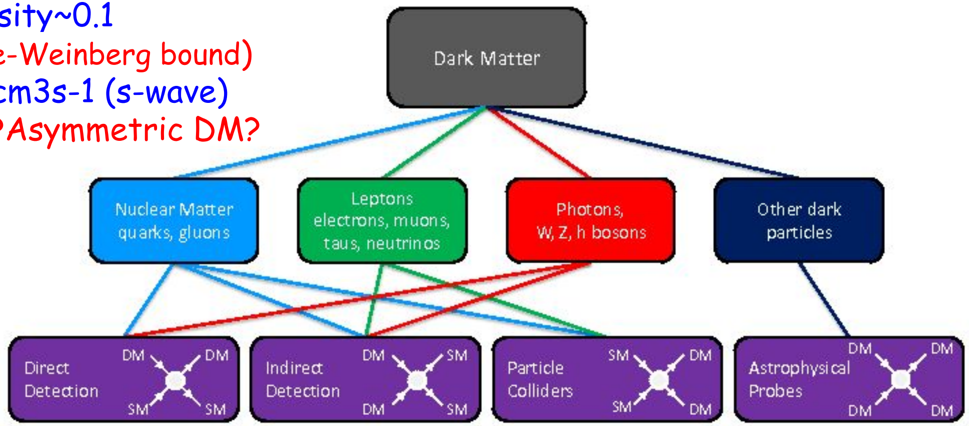
DM mass ~ 4 TeV
sigma*v~1e-24 cm3 s-1

DM mass ~40 GeV
sigma*v~1e-26 cm3 s-1

arXiv:1305.1605
snowmass



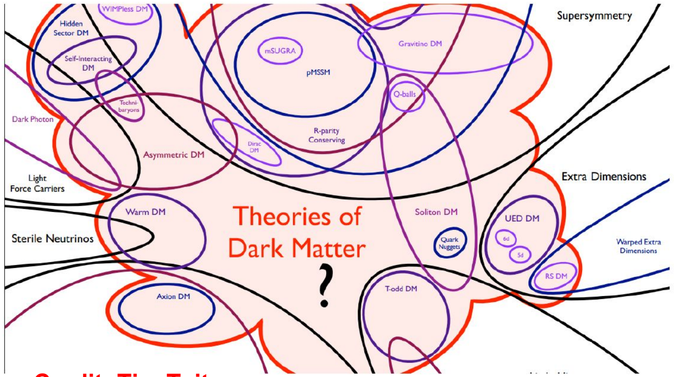
relic density~0.1
mx>2 GeV (The Lee-Weinberg bound)
sigma*v ~1e-26 cm3s-1 (s-wave)
How about p-wave?Asymmetric DM?



DM mass ~10 GeV
sigsip~1e-4 pb

DM mass ~ 1 PeV
sigma*v > unitarity (s-wave)
How about p-wave?

A global picture helps us carving the parameter space, efficiently and properly.



Credit: Tim Tait

Could we have a particle model independent DM study?

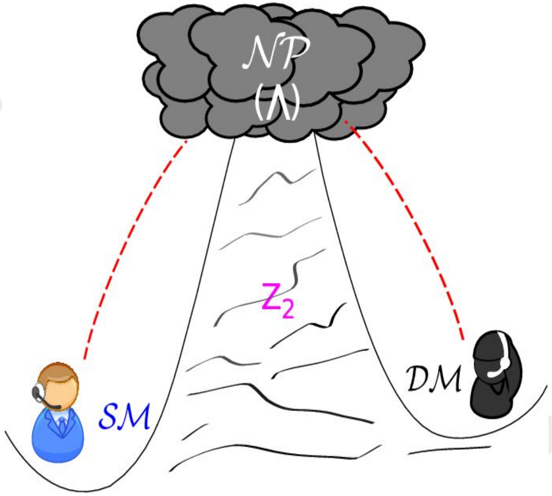
Phenomenological WIMP DM models

Scientific name	Popular name	Spin	$SU(2)_L$	$U(1)_Y$
Singlet scalar	The simplest DM	0	0	0
Doublet scalar	Inert Higgs DM	0	½	½
Triplet scalar		0	1	0
Triplet scalar II		0	1	1
...	...	...	...	...
Singlet fermion	Bino / Singlino	½	0	0
Doublet fermion	Higgsino	½	½	½
Triplet fermion	Wino	½	1	0
Triplet fermion II		½	1	1
...	...			
Singlet vector	Little Higgs DM	1	0	0
Doublet vector		1	½	½
Triplet vector		1	1	0
Triplet vector II		1	1	1
...	...			

Credit: Shigeki Matsumoto

DM still leaves a lot unknown:

- Spin
- Electroweak charge
- Real/Majorana or Complex/Dirac



Credit: Qing-Hong Cao, Chuan-Ren Chen, Chong Sheng Li, Hao Zhang (0912.4511)

Can we use DM EFT all the time?

DM at	Is EFT applied?	Reason
Coillders	Conditionally applied	Only for the region of $\sqrt{s} \ll$ Lambda
Direct detection	YES	small recoil energy (zero moment exchange)
Indirect detection	Applied for region Lambda>2*mx	No matter the DM source located at GC, dSphs, or near the earth, the velocity is very small ($\sqrt{s} \ll$ Lambda).
Relic density	Generally applied	Can be applied at Lambda>>2mx region but more precised at Lambda>3*mx

Advantage: Simple particle contain
Disadvantage: Simple particle contain

DM EFT

DM Minimal model

Dark Matter effective operators

(With help from UV models)

The effective Model to start with

The simplest settings:

- Majorana fermion
- Singlet
- Z2-symmetry
- WIMP
- dimension<7

The DM in this class:

- Bino neutralino
- Singlino neutralino
- Sterile neutrino

EFT requirements:
(Heavy mediator)

- **lambda>2 mx**
- **lambda>3 mx**
- **lambda>Higgs vev**

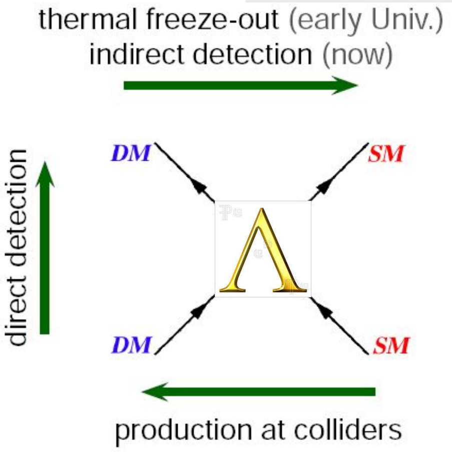
Minimal requirement of not producing mediator particle on shell in a process.

EFT calculation of annihilation rate accurate to O(25%) when compared to s-channel UV completions.

The Model to start with

Dimension-5	$\mathcal{O}_S = (\bar{\chi}\chi)\|H\|^2$	$\mathcal{O}_{PS} = (\bar{\chi}i\gamma_5\chi)\|H\|^2$	
Dimension-6	$\mathcal{O}_Q = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{Q}_i\gamma_\mu Q_j)$	$\mathcal{O}_U = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{U}_i\gamma_\mu U_j)$	$\mathcal{O}_D = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{D}_i\gamma_\mu D_j)$
	$\mathcal{O}_L = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{L}_i\gamma_\mu L_j)$	$\mathcal{O}_E = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{E}_i\gamma_\mu E_j)$	$\mathcal{O}_H = (\bar{\chi}\gamma^\mu\gamma_5\chi)(H^\dagger i\overleftrightarrow{D}_\mu H)$

Table 1: *SM gauge invariant operators describing interactions between the DM and the SM particles.*



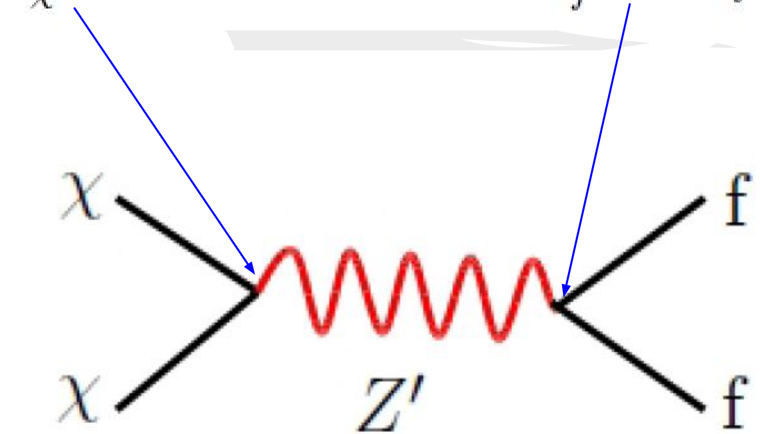
$$\mathcal{L}_{\mathrm{EFT}} = \mathcal{L}_{\mathrm{SM}} + \frac{1}{2}\bar{\chi}(i\partial\!\!\!/ - M_\chi)\chi + \frac{1}{2}\sum_{a,n} c_a \frac{\mathcal{O}_a}{\Lambda_a^{n-4}}$$

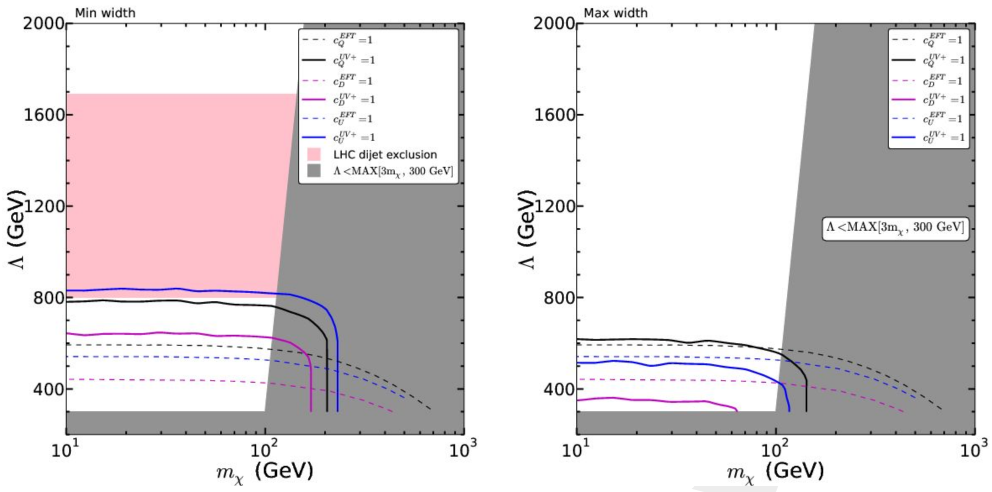
- Family universality assumed
- All the opertaors included

UV Plus models (s-ch)

$$\mathcal{L}_f^{(+)} = -\frac{1}{4}(X_f)_{\mu\nu}(X_f)^{\mu\nu} + \frac{\Lambda_f^2}{2}(X_f)_\mu(X_f)^\mu - \frac{d_\chi^{(X)}}{2}(\bar{\chi}\gamma^\mu\gamma_5\chi)(X_f)_\mu - d_f^{(X)}(\bar{f}\gamma^\mu f)(X_f)_\mu$$

$d_\chi^{(X)} = -1$ and $d_f^{(X)} = c_f$





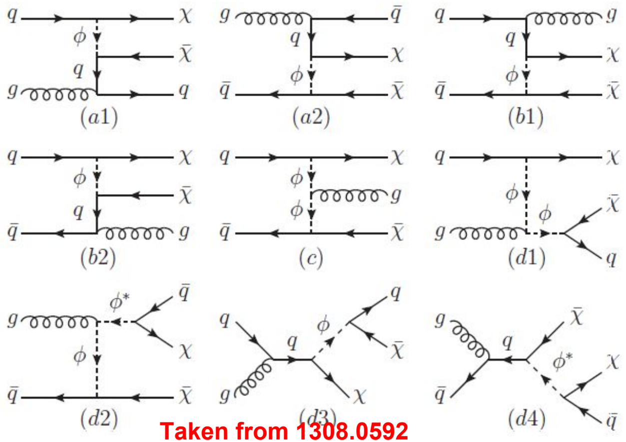
Min width: Width/Mass=0.15

Max width: Width/Mass=0.5

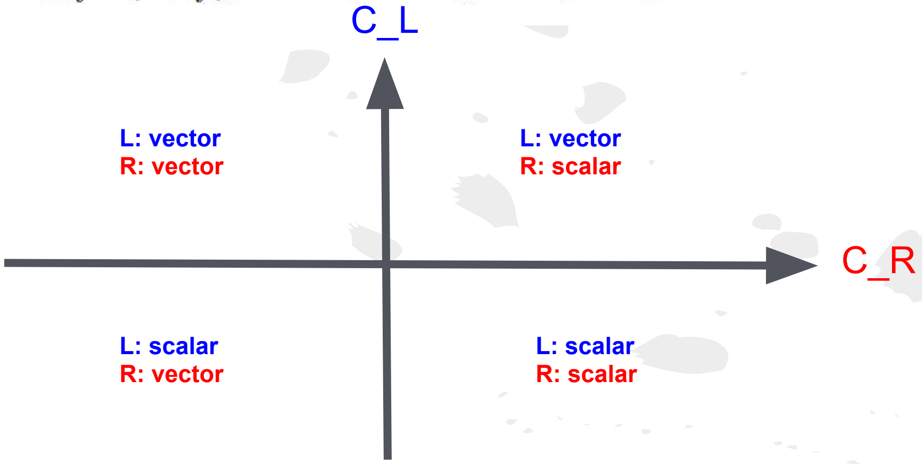
UV Minus models (t-ch)

$$\mathcal{L}_f^{(-)} = -\frac{1}{2}(V_f)^\dagger_{\mu\nu}(V_f)^{\mu\nu} + \Lambda_f^2 (V_f)^\dagger_\mu (V_f)^\mu - d_f^{(V)} \bar{f}\gamma^\mu \chi (V_f)_\mu - (d_f^{(V)})^* (V_f)^\dagger_\mu \bar{\chi}\gamma^\mu f$$
$$+|D_\mu \phi_f|^2 - \Lambda_f^2 |\phi_f|^2 - d_f^{(\phi)} \bar{f}\chi\phi_f - (d_f^{(\phi)})^* \phi_f^\dagger \bar{\chi} f \, .$$

$$d_f^{(V)} = \sqrt{-c_f}\,\theta(-c_f) \quad \text{and} \quad d_f^{(\phi)} = \sqrt{2c_f}\,\theta(c_f) \quad \text{for} \quad f = U, D \text{ and } E\,,$$
$$d_f^{(V)} = \sqrt{c_f}\,\theta(c_f) \quad \text{and} \quad d_f^{(\phi)} = \sqrt{-2c_f}\,\theta(-c_f) \quad \text{for} \quad f = Q \text{ and } L\,.$$



Taken from 1308.0592



Results

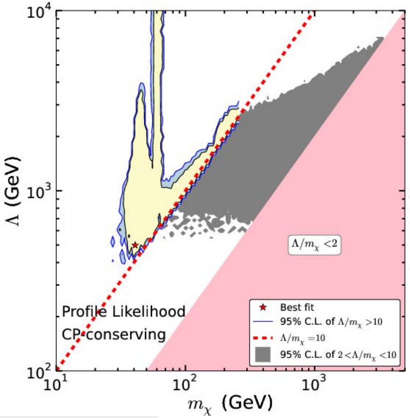
The global study of Singlet Majorana DM

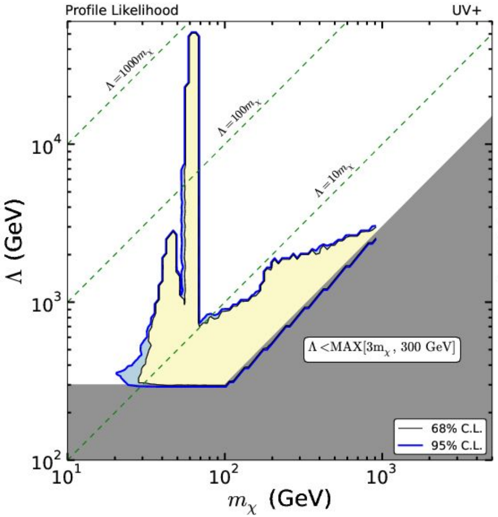
$$10^{-2} < \frac{m_\chi}{\mathrm{TeV}} < 5$$

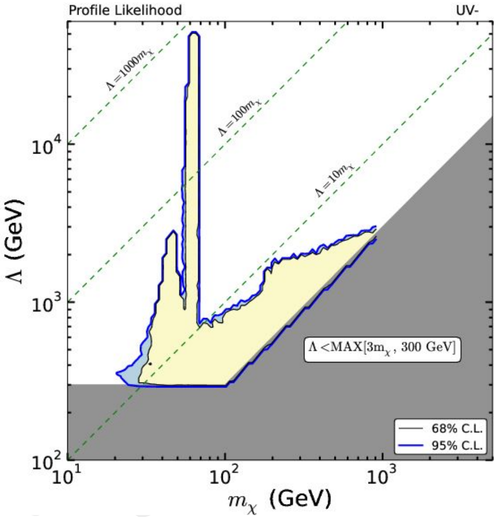
$$\max[3m_\chi, 0.3] < \frac{\Lambda}{\mathrm{TeV}} < 6$$

$$-1.0 < c_i < 1.0$$

SM gauge couplings:
g1=0.35, g2=0.65,
g3=1.22







7 independent couplings

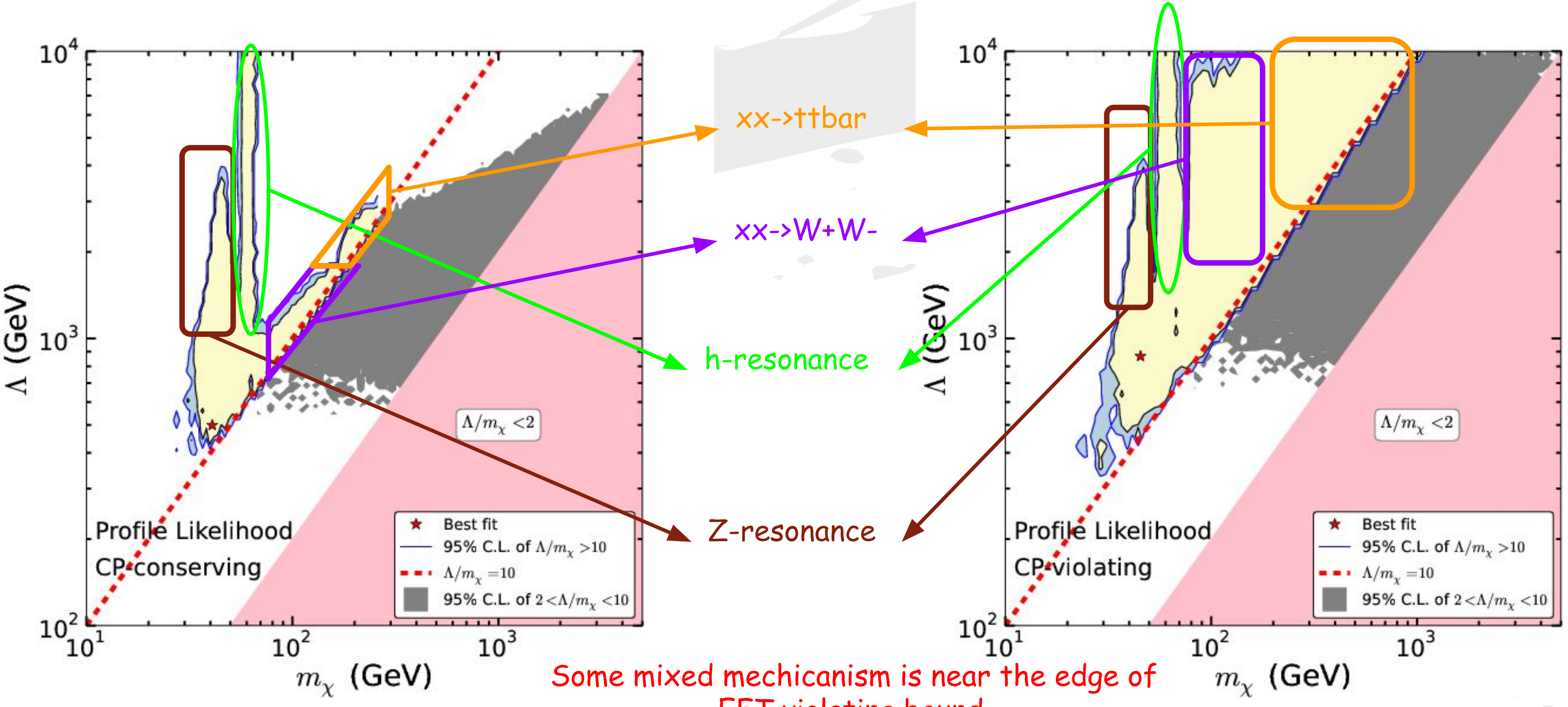
Relic density constraint dominates the shape of 2sigma allowed region in mx-lambda plane!

Constraints	PLANCK (relic)	LUX (SI)	PICO-2L (SD, xp)	X100 (SD, xn)	gamma-ray	Mono-jet	Mono-photon	inv. Z	inv. H
constrained couplings	ALL	c_S	Quark, c_D	Quark, c_D	ALL	Quark, c_D	Lepton, c_D	c_D	c_S

Summary and Conclusion

- A new skill to test collider constraints in DM EFT.
- Relic density still dominates the shape of allowed region in (mx, Lambda) plane.
- Considering the relationships between UV model and EFT, we are able to put more solid limit on DM (mx,Lambda) plane. If mediator is heavy enough, lambda>3 mx, DM has a mass limit, mx/GeV<900.
- The collider constraints becames weaker in lower DM mass region.
- Our limits can be applied to bino/siglino/sterile neutrino dark matter. However, the range of Lambda less than max[3mx,300GeV] shall be treated carefully.

CP conserving and violating



Some mixed mechicanism is near the edge of
EFT violating bound.