A Comprehensive Study of WIMP DM in Effective Theory Approach

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WIMP DM & its detection

~ WIMP (Weakly interacting massive particle) hypothesis ~

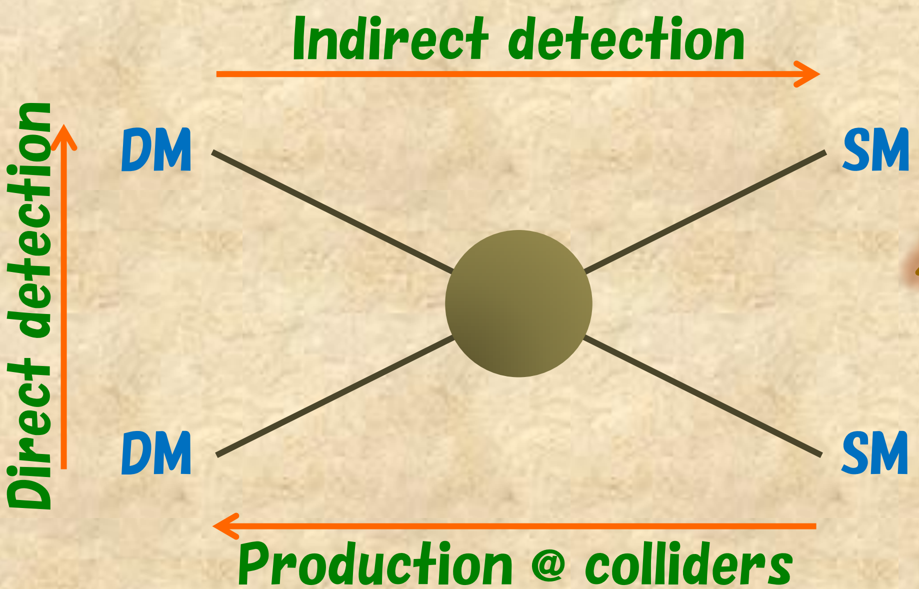
DM is a neutral and stable particle whose mass is O(0.1 - 1)TeV!

It is consistent with DM cosmology.

- Why is DM weakly interacting?
- Why is DM cold in present Univ.?
- Why is the abundance $\Omega_{DM}h^2$ 0.1?

It is consistent with Particle Phys.

Physics models beyond the SM to describe EW symmetry breaking often predict a WIMP candidate.



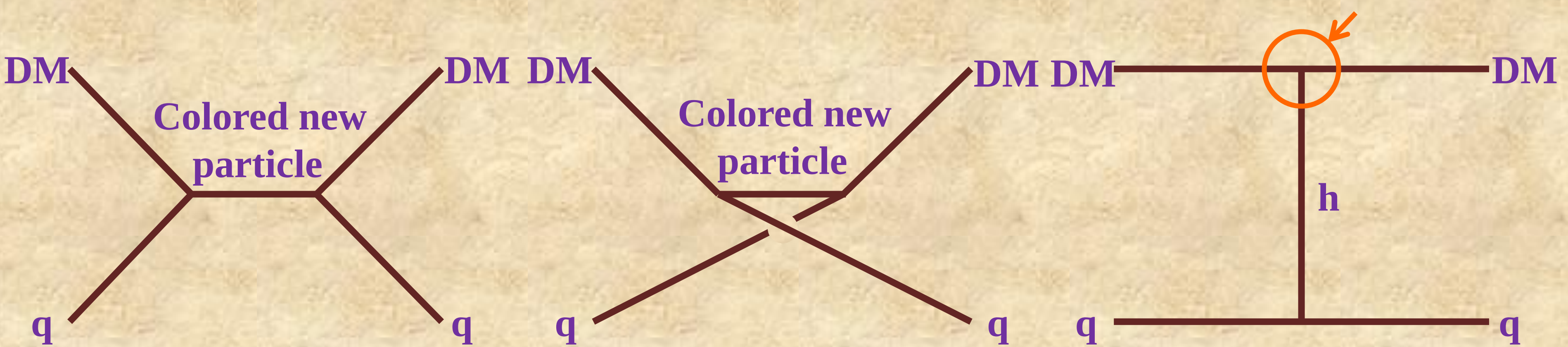
Indirect detections put a limit as $\sigma v < 1 - 10$ pb·c.

Collider experiments (LHC) put a limit as $\sigma < 1 - 10$ fb.

Direct detections put a limit stringently as s < 1 - 10 zb!

WIMP DM & its detection

Direct detection experiments put stringent limits on the WIMP scattering off a nuclei, so that those already give an important implication to its property.



DM-DM-h vertex is induced by EW symmetry breaking and must be suppressed.

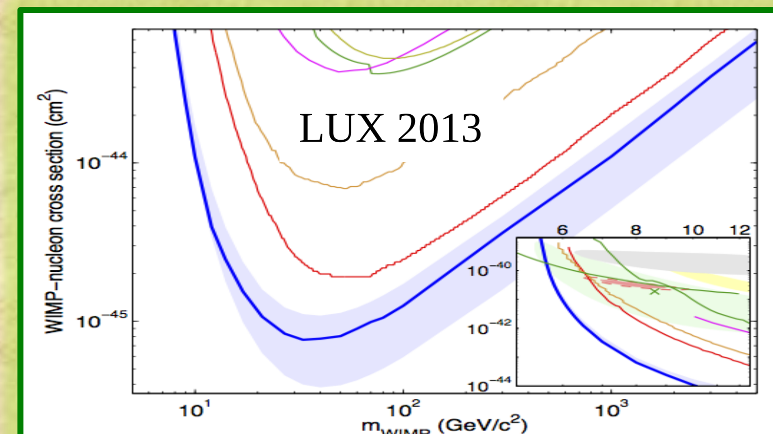
$L_{int} = c(\chi\chi h) \rightarrow \sigma = c^2 \cdot 10^{-42}\,cm^2$

↓

Observation requires $\sigma < 10^{-45} cm^2$

L_{int} is induced by EWSB. (mixing eff.)

DM is close to a Weak eigenstate!!



Phenomenological WIMP DM models

1. DM + SM system is considered, where the DM field is introduced as a SM gauge multiplet, namely the DM particle is introduced as its component.
2. All interaction terms involving the DM field respecting Lorentz and SM gauge symmetries are introduced up to appropriate mass dimensions.
3. Stability of the DM particle is guaranteed by imposing Z_2-symmetry, under which the DM and the SM fields behave as DM(x) → −DM(x) & SM(x) → SM(x).

Scientific name	Popular name	Spin	$SU(2)_L$	$U(1)_Y$	
Singlet fermion	Bino / Singlino	½	1	0	← CMSSM
Doublet fermion	Higgsino	½	2	½	← FP
Triplet fermion	Wino	½	3	0	← PGM
Triplet fermion II		½	3	1	[Ibe, Yanagida, SM.]
...	...	...	...	...	
Singlet scalar	The simplest DM	0	1	0	
Doublet scalar	Inert Higgs DM	0	2	½	
...	...	...	...	...	
Singlet vector	Little Higgs DM	1	1	0	
...	...	...	...	...	

DM candidates predicted by the most of new physics models can be covered.

Singlet fermion DM case

$$\mathcal{L}_{\mathrm{F}_0} = \mathcal{L}_{\mathrm{SM}} + \frac{1}{2}\bar{\chi}\left(i\partial\!\!\!/ - M_\chi\right)\chi + \sum_{n,i}\frac{c_i^{(n)}}{\Lambda^{n-4}}\mathcal{O}_i^{(n)}$$

$$\mathcal{O}_S^{(5)} = (\bar{\chi}\chi)|H|^2,$$

~~$\mathcal{O}_{PS}^{(5)} = i(\bar{\chi}\gamma_5\chi)|H|^2$~~, CPV

$$\mathcal{O}_H^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(H^\dagger i\overleftrightarrow{D_\mu} H),$$

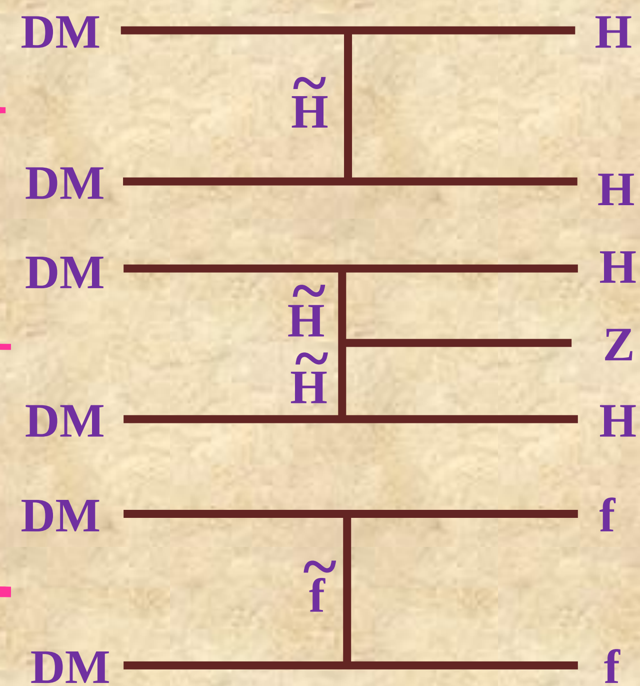
$$\mathcal{O}_Q^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{Q}\gamma_\mu Q),$$

$$\mathcal{O}_U^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{U}\gamma_\mu U)$$

$$\mathcal{O}_D^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{D}\gamma_\mu D)$$

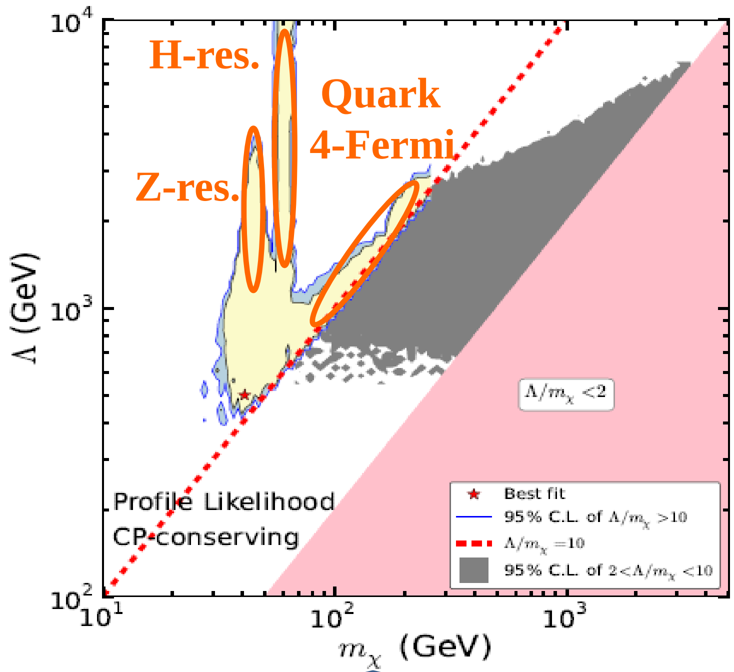
$$\mathcal{O}_L^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{L}\gamma_\mu L)$$

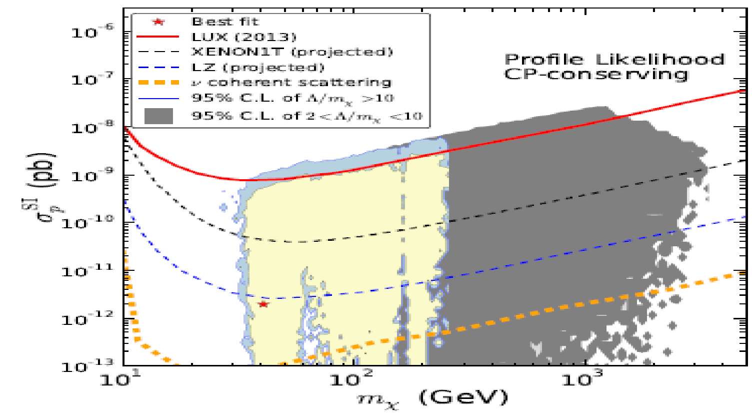
$$\mathcal{O}_E^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{E}\gamma_\mu E)$$

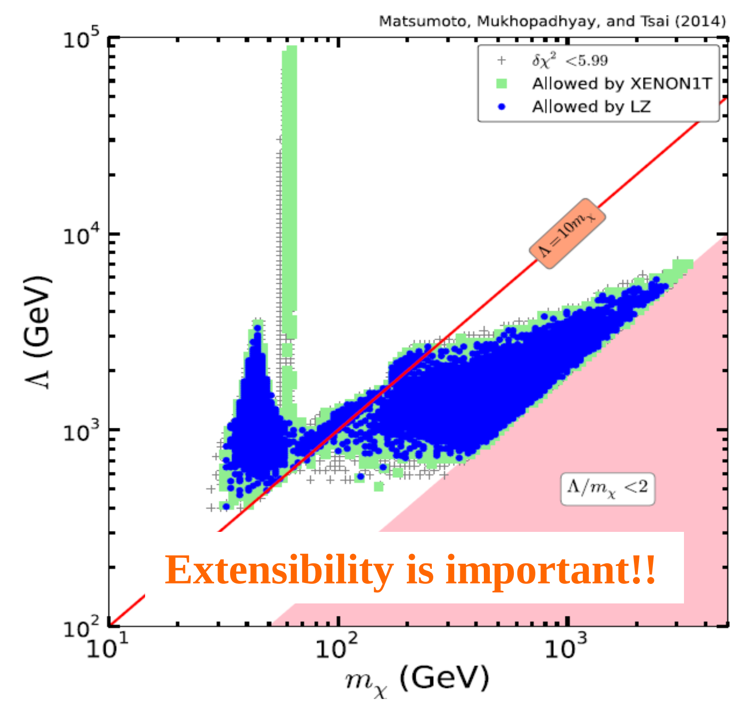


- Only the mass dimension 5 operator O_{PS} breaks the CP-symmetry.
- Flavor blindness is assumed for each 4-Fermi (mass dimension 6) operators.
- The regions of the cutoff $\Lambda > 10m_{DM}$ and $10m_{DM} > \Lambda > 2m_{DM}$ are considered.

Singlet fermion DM case







- Thermal relics: $\Omega_{TH} h^2 < 0.12$.
- DD: LUX, XENON100, IceCube
- IDD: Fermi-LAT (γ from dSphs)
- LHC: H inv.-decay, mono-jet
- LEP: Z inv.-decay, mono-g

All coefficients of the operators are varied within the range $|c_i| < 1$.

Summary

- Direct detection experiments of the WIMP DM currently give the most stringent limit on properties of the DM. Combining with the latest LHC data, the WIMP DM is expected to be close to a gauge eigenstate of $SU(2)_L \times U(1)_Y$ interactions of the SM. According to this fact, the WIMP DM will be comprehensively studied by phenomenological WIMP DM model for each multiplet of SM gauge symmetry and Lorentz symmetry (up to spin 1).
- As an example, we have shown the result of the model for the case of the singlet fermion DM. Typical example of the DM is the Bino-like DM in the MSSM. According to the result, direct detection experiments play an important role to explore the DM also in future. In particular, the experiments having good extensibility will be more and more important.