Thermal Real Scalar Triplet Dark Matter

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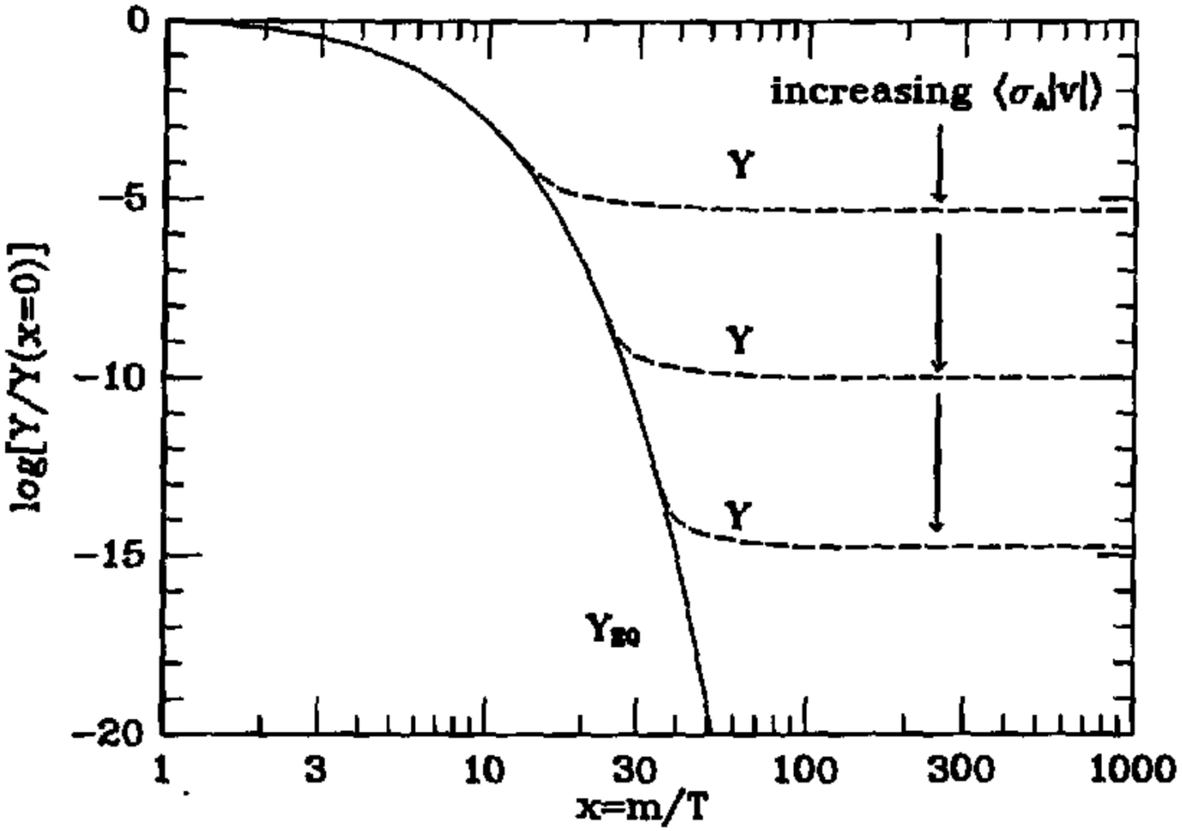
Introduction

- Thermal DM ・・・
  - Experienced equilibriums with SM particles in the early universe.
  - Abundance is determined by freeze-out mecanism.

→ No initial condition problem.

→ Detectable by the interaction dependable on maintaining equilibriums.



$$\Omega h^2 \approx 10^{-27}\mathrm{cm}^3/\mathrm{s}/\ <\sigma \mathrm{v}>$$

- WIMP Miracle

  Assuming $m_{DM} = \mathcal{O}(1)$ TeV,

  $10^{-26}\mathrm{cm}^3/\mathrm{s} \approx \alpha_2^2/\mathrm{m}_{\mathrm{DM}}^2$

Introduction

- EWIMP …

Electroweakly charged WIMP
← uncharted, minimal

SU(2)	fermion	scalar
2	DD ✖ (Higgsino)	IDM Nilendra G.&Ernest ma 1977, etc.
3	wino H.E.Haber&G.L.Kane 1985.etc	
4	DD ✖	
5	MDM M.Cirelli&A.Strumia 2015.etc	LP ✖
6	LP ✖	LP ✖

Real Scalar Triplet

Minimal but not very much studied.

We comprehensively studied:
find the parameter region
surviving from the constraints

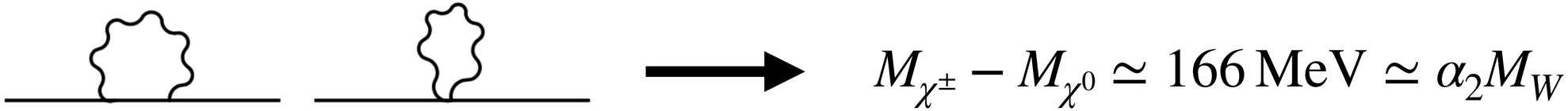
Model

There are only 2 phenomonolgicaly important parameters.

- $\mathscr{L} = \mathscr{L}_{\mathrm{SM}} + \frac{1}{2}(|D_\mu \chi|^2 - \mu_\chi^2 |\chi|^2) - \lambda_{\chi H} |H_{\mathrm{SM}}|^2 |\chi|^2 - \lambda_\chi |\chi|^4$

  $\chi = (\chi^+, i\chi^0, \chi^-)^T$ and χ^0 plays the role of DM

- 1-loop collections make $\chi^\pm$ slightly heavier than χ^0

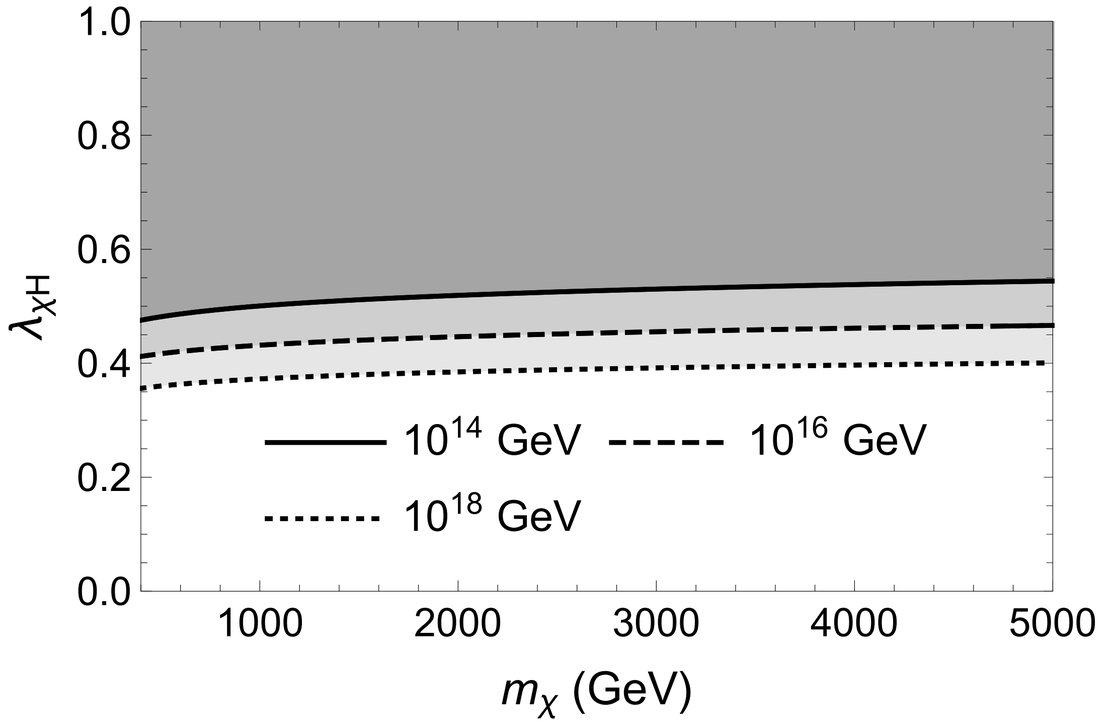


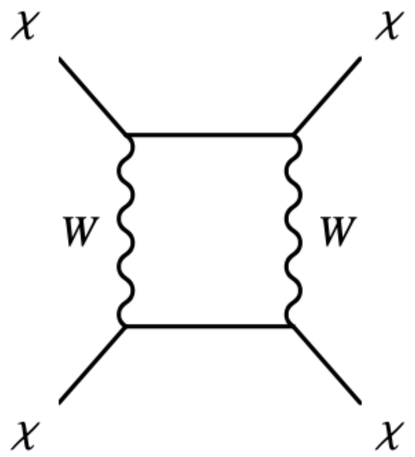
$$M_{\chi^\pm} - M_{\chi^0} \simeq 166\,\mathrm{MeV} \simeq \alpha_2 M_W$$

Landau pole

- λ_χ runs fast → The theory may break down below high energy

- By solving the RGEs, the parameter region in which LP does not appear up to high energy scale is;





Even if $\lambda_\chi = 0$, this diagram induces.

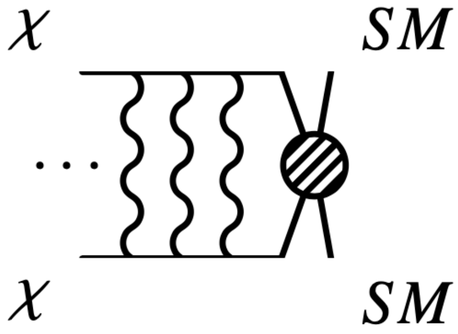
Relic abundance

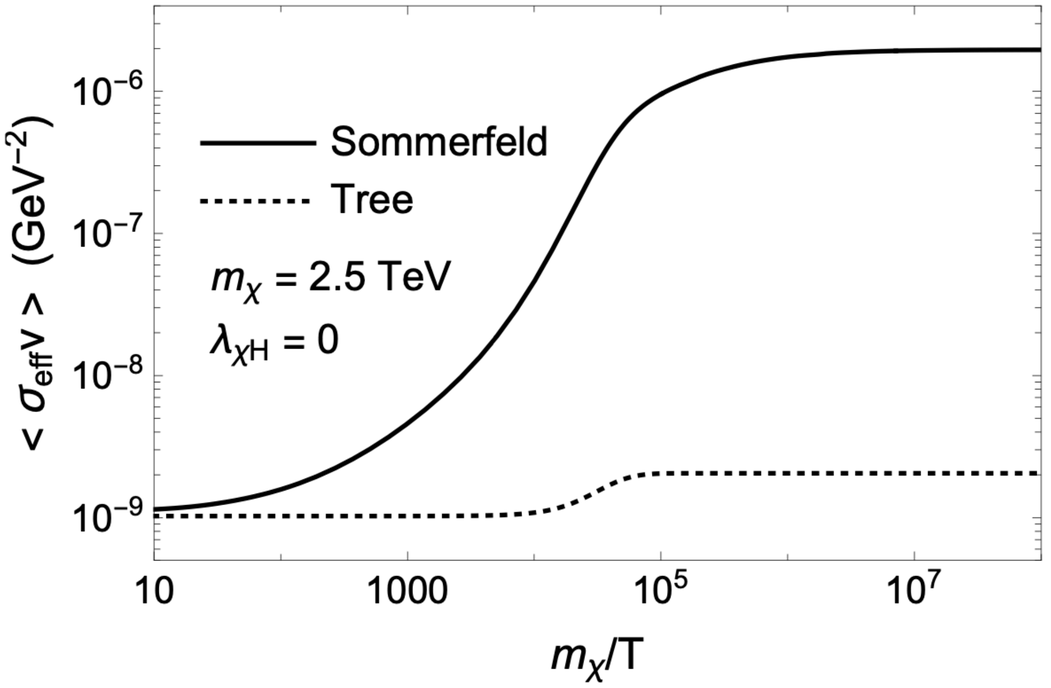
- Relic abundance can be obtained by Boltzmann equation.
- $m_{\chi^\pm} \simeq m_{\chi^0}$ → **Coannihilation** is important.
- $m_\chi \gg m_{SM}$ → **Sommerfeld effect** is important.

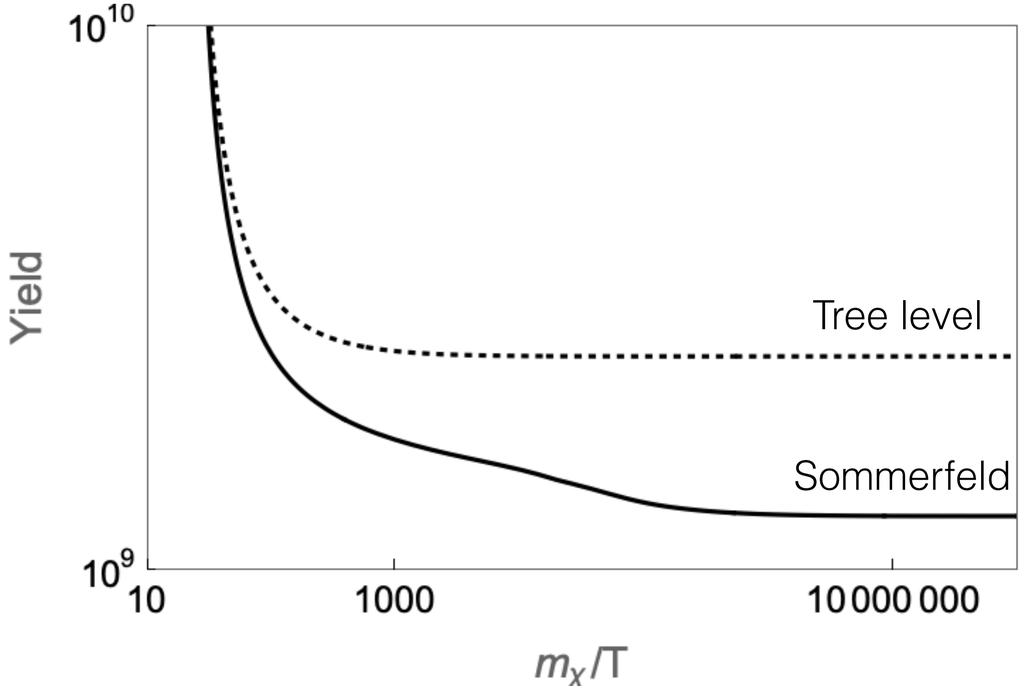
||

Nonperturbative effect of long range forces induced by exchanging SM bosons.

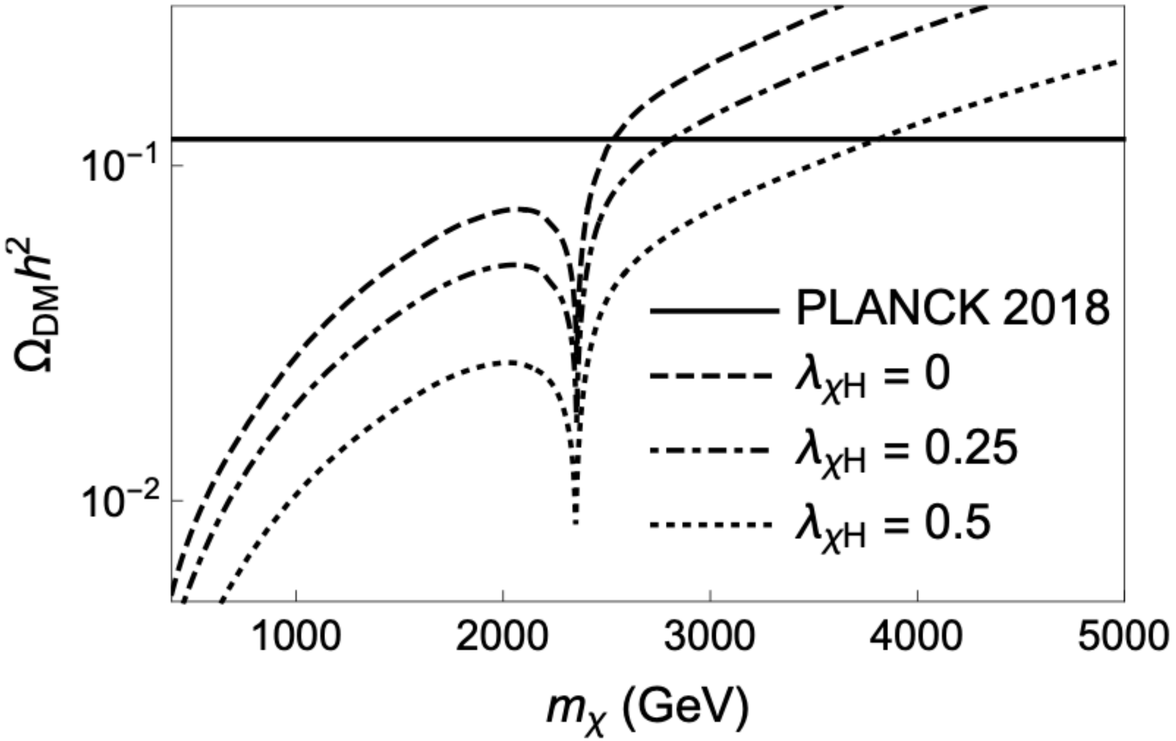
= summing all ladder diagrams







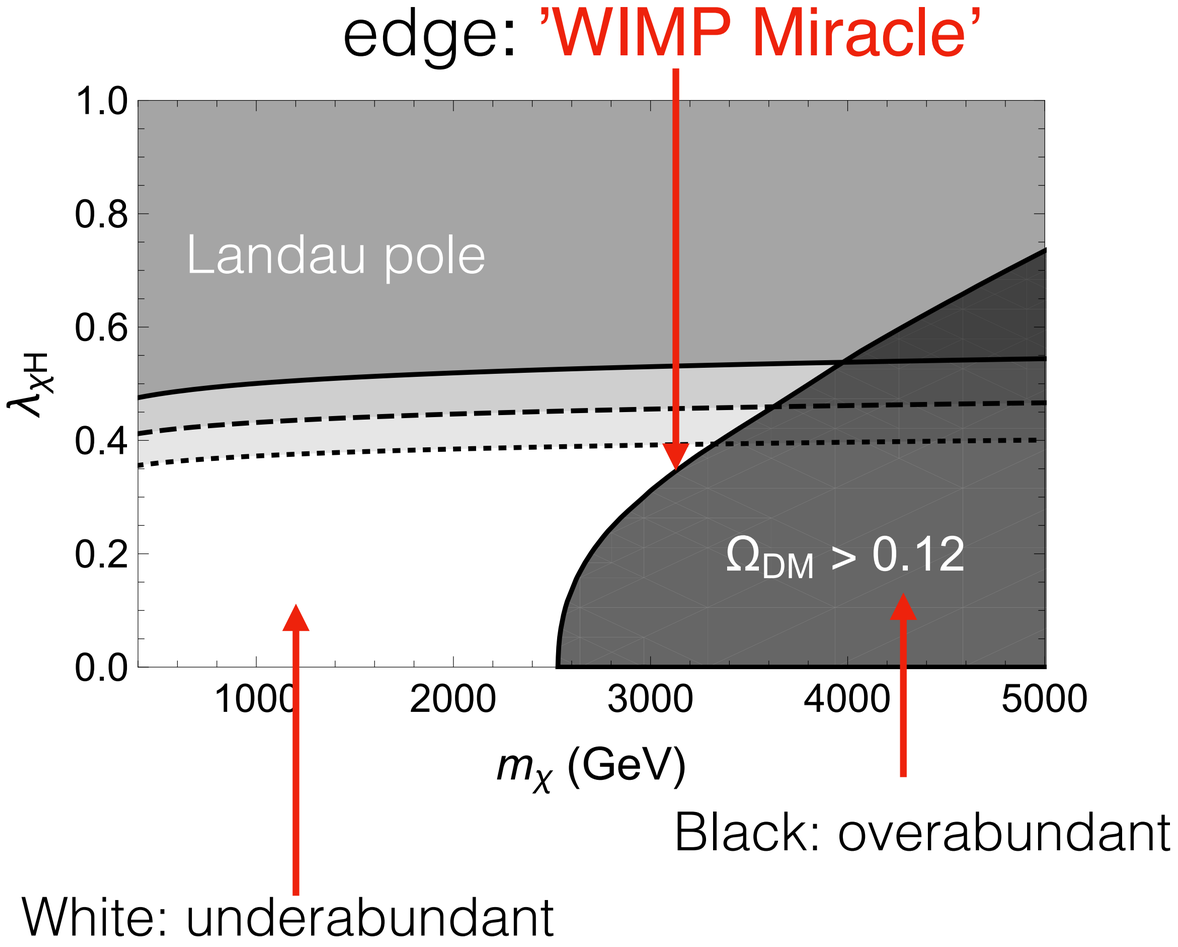
Relic abundance



Resonanse

Mass difference ≃ binding energy

$$\alpha_2 M_w \simeq (\alpha_2 + (\lambda_{\chi H} v/M)^2/4\pi)^2 M$$



- Triplet explains the **whole** observed DM density by non-thermal process.
- Triplet contributes **in part** to the observed DM density.

Experiments

1. Collider

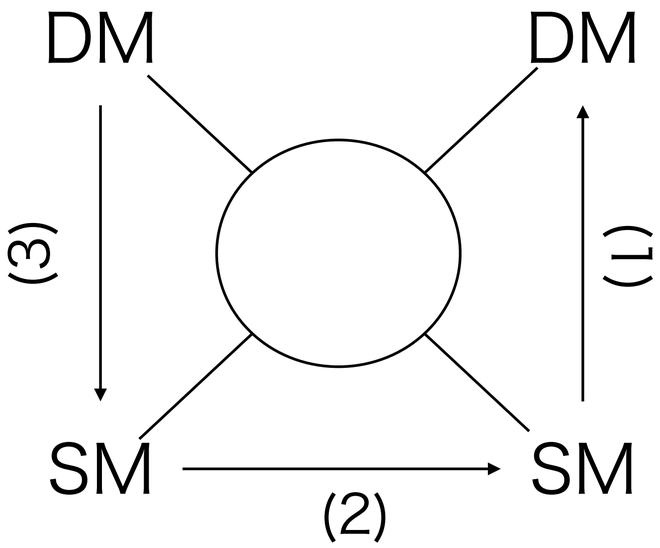
   Produce DM by collision of high energy SM particles

2. Direct detection

   Observe DM-SM scattering in underground laboratory

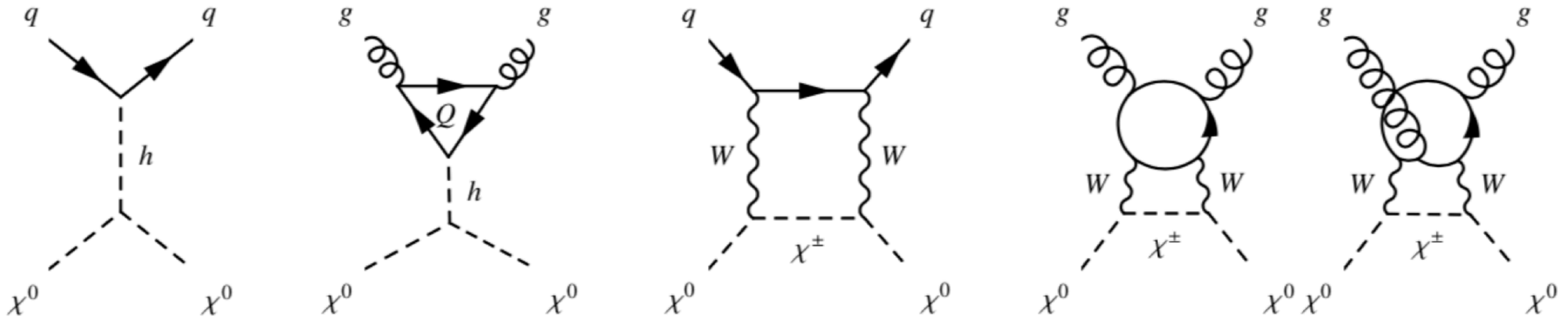
3. Indirect detection

   Observe SM particles produsedby annihilations of DM



Direct detection

Effective interaction between DM and q,g → scattering between DM and nucleon

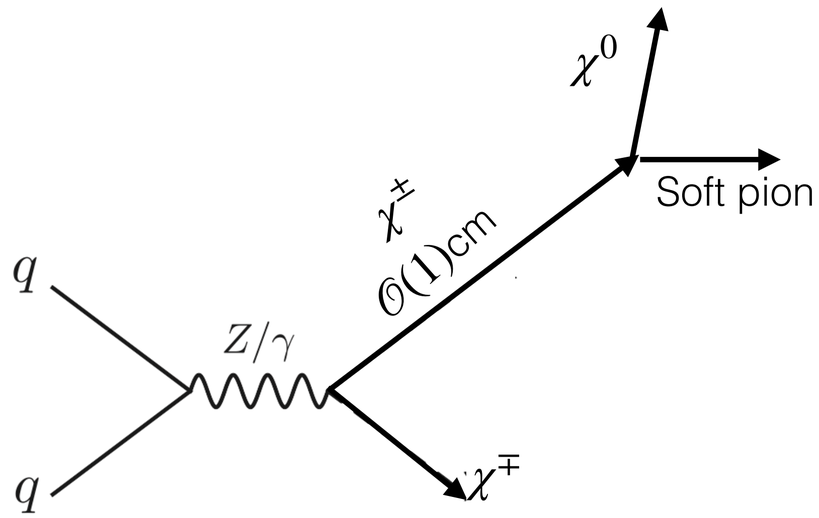


$(\chi^0)^2 m_q \bar{q} q$ $(\chi^0)^2 G^a_{\mu\nu} G^{a\mu\nu}$ $\chi^0 (i\partial^\mu)(i\partial^\nu)\chi^0 O^q_{\mu\nu}$ $(\chi^0)^2 G^a_{\mu\nu} G^{a\mu\nu}$

XENON1T(XENONnT) is most stringent at present (in the near future).

Collider

- dissapearing track search ∵ less background



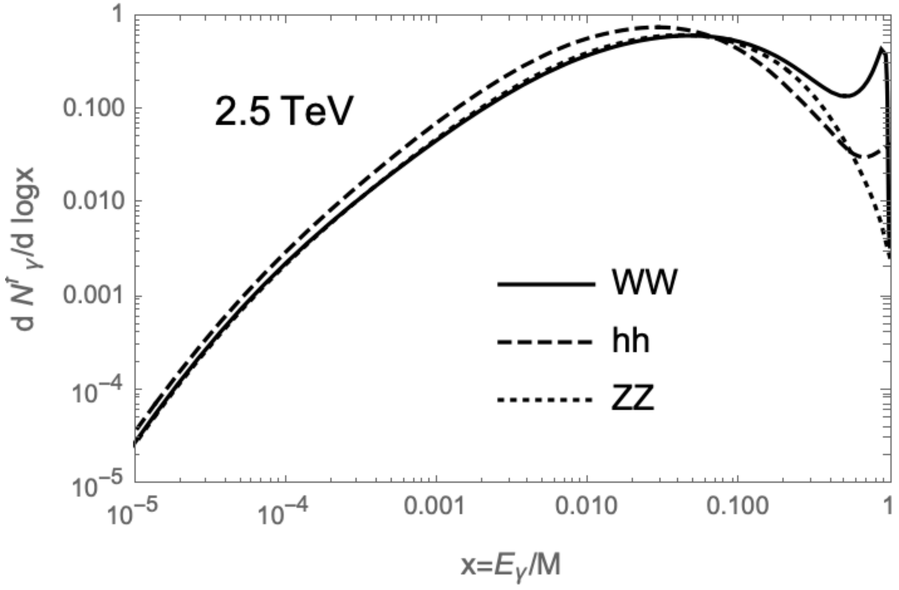
Indirect detection

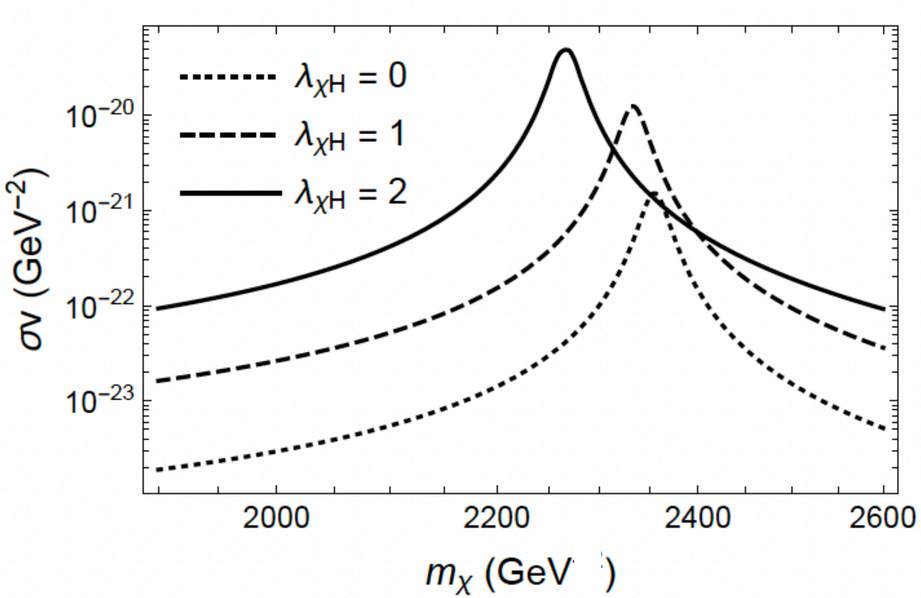
$$\frac{d\Phi_\gamma}{dE_\gamma} \simeq \underbrace{\left[\frac{\langle\sigma v\rangle_{\rm tot}}{8\pi m_\chi^2} \sum \mathrm{Br}(\chi^0\chi^0 \to f)\, \frac{dN_\gamma}{dE_\gamma}\bigg|_f\right]}_{\text{Particle physics}} \times \underbrace{\left[\int_{\Delta\Omega} d\Omega \int_{\rm l.o.s} ds\, \rho^2_{\rm DM}\right]}_{\text{Astrophysics}}$$

← less uncertainty for dSphs

Indirect detection

- Continuum





← Fermi-LAT

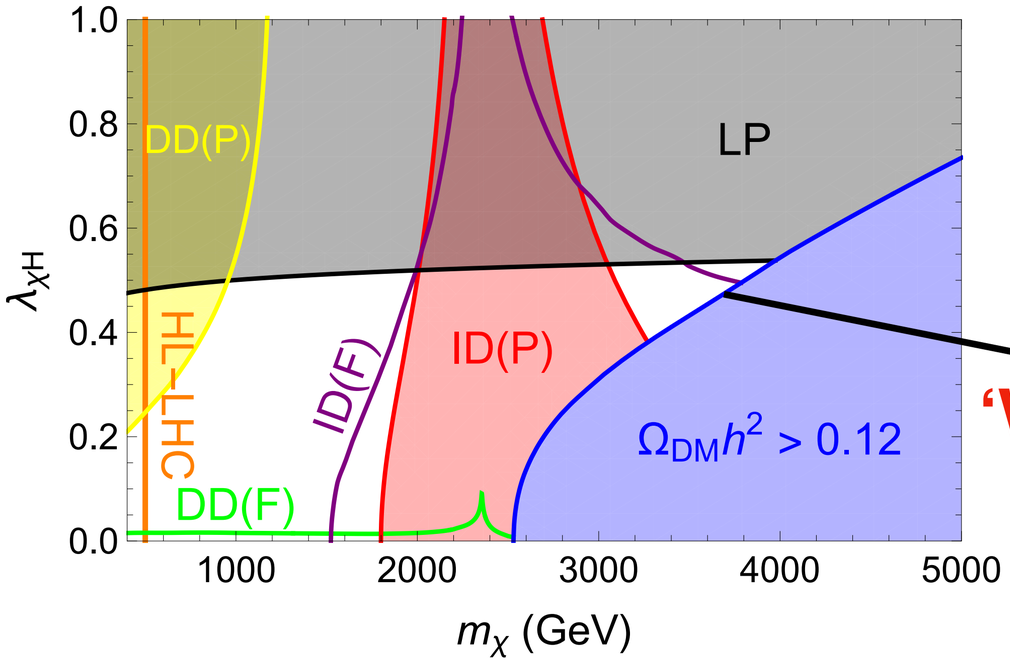
- Line

$$\delta(E - m_\chi)$$

← MAGIC,CTA

Results

- Triplet contributes **in part** to the observed DM density.



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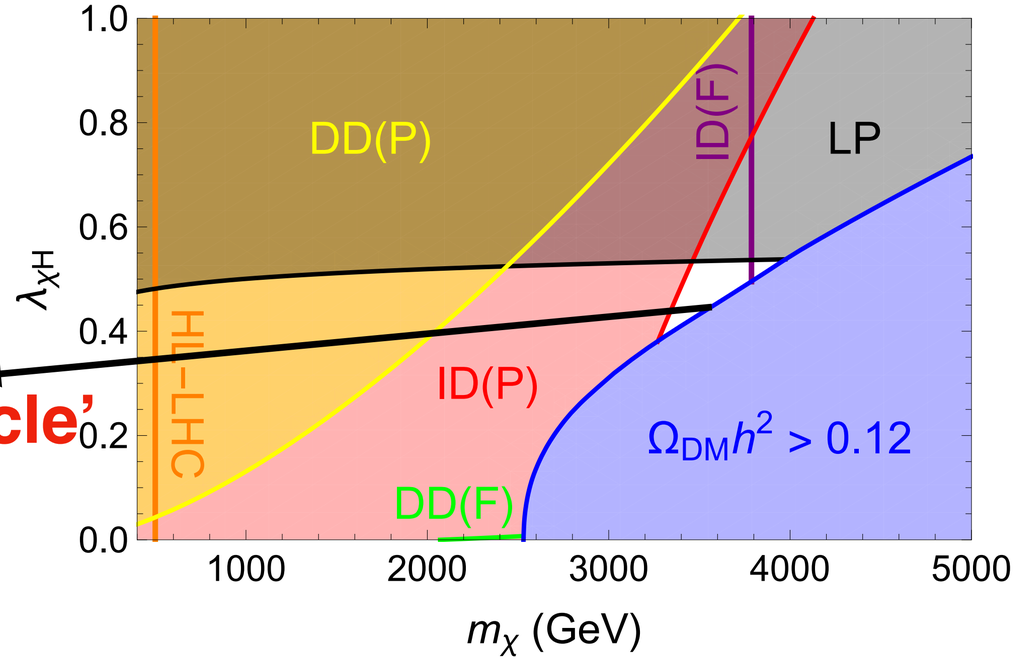

'WIMP Miracle' region

Summary

- **Real scalar triplet** is an attractive DM candidate, so we comprehensively studied it.
- **'WIMP Miracle'** region is still **surviving** from constraints at **present**.
- Such region can be effectively **searched for** by **near future** experiments, especially XENONnT.