Weak-charged WIMPs and Role of near-future direct detection experiments

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Electroweakly interacting massive particle (EWIMP), i.e. the WIMP charged under the SM weak interaction is know to be the most important, but uncarted dark matter candidate.

We figure out the role of near-future direct dark matter detections (XENONnT, etc.) to search for the dark matters.

Electroweakly Interacting Massive Particle (EWIMP)

= WIMP interacting with the SM particles via the SM weak interaction.

Motivation:

It is the thermal DM, i.e. it experiences the equilibrium in the early universe.

→ There is no initial condition problem concerning its number density.

→ It will be detected based on the interaction maintaining the equilibrium.

It is the WIMP, i.e. its abundance today is explained by Freeze-out mechanism.

→ Using the mechanism that makes modern cosmology very successful.

→ Using SM weak interaction allows us to naturally explains the abundance.

General properties of weak-charged WIMPs:

✓ EWIMPs having various weak charges: $2_{1/2}$, 3_0, 3_1, $4_{1/2}$, $4_{3/2}$, 5_0, 5_1, 5_2, ….

✓ Its mass is predicted to be O(1)TeV due to the relic abundance condition.

✓ The existence of the $SU(2)_L$ partners that are highly degenerated in mass.

→ The partners become long-lived: E.g. $c\tau$ = 7cm for the case of 3_0.

[H. Cheng, et. al. (1999); Y. Yamada (2010); M. Ibe, S. M., R. Sato (2013)]

→ Annihilation of the WIMPs are boosted by the Sommerfeld effect.

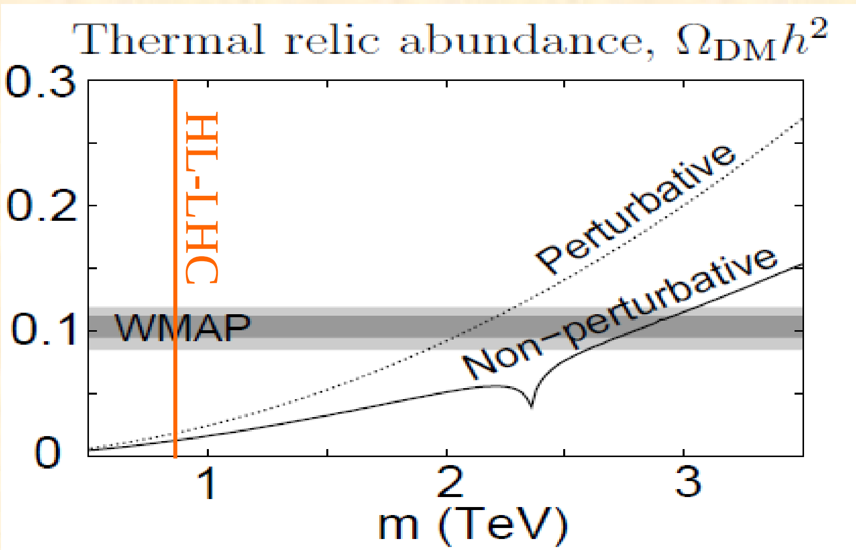
[J. Hisano, S. M., M. Nojiri (2004); J. Hisano, S. M., M. Nojiri, O. Saito (2005)]

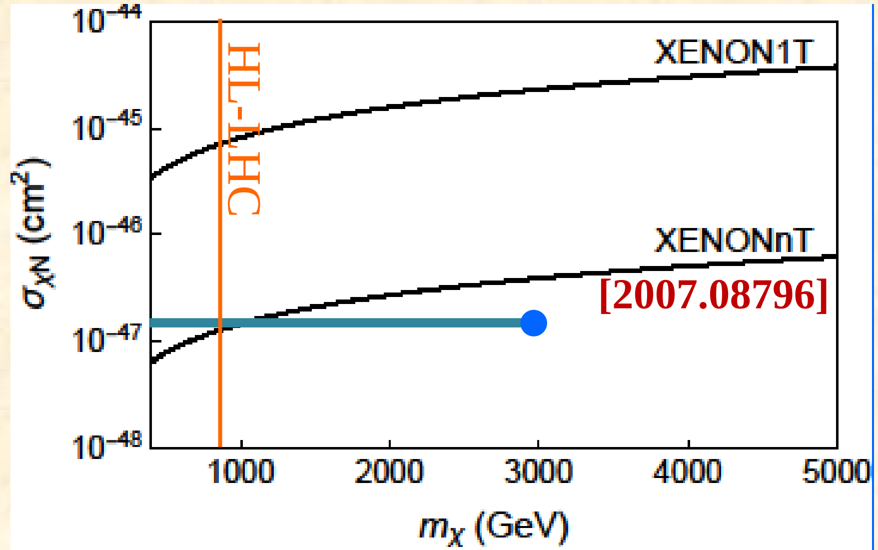
The most famous example: Fermionic 3_0 EWIMP

$$\mathscr{L} = \mathscr{L}_{\rm SM} + (1/2)\bar{\mathcal{X}}(i\not{D} + M)\mathcal{X}$$

This EWIMP can be embedded in SUSY

It is known to be the simplest EWIMP, i.e. NP parameter is only the DM mass M!





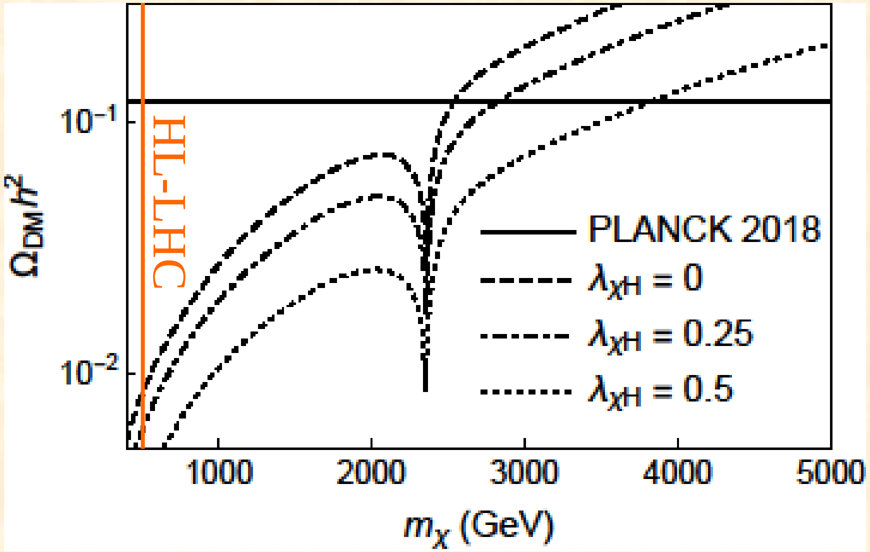
- ✓ *So-called 'WIMP Miracle' condition requires the DM mass to be about 3TeV.*
  [J. Hisano, S.M., M. Nagai, O. Saito, M. Senami (2007).]
- ✓ *Present LHC constraint is m > 460 GeV via the disappearing track search, which will be updated to be m > 850 GeV if no DM signal is detected there.*
  [ATLAS (2019); CMS (2010); ATL-PHYS-PUB-2018-031.]
- ✓ *Scattering cross section between DM and nucleon is about 1.5×10^{-11}pb.*
  [J. Hisano, K. Ishiwata, N. Nagata, (2012).]

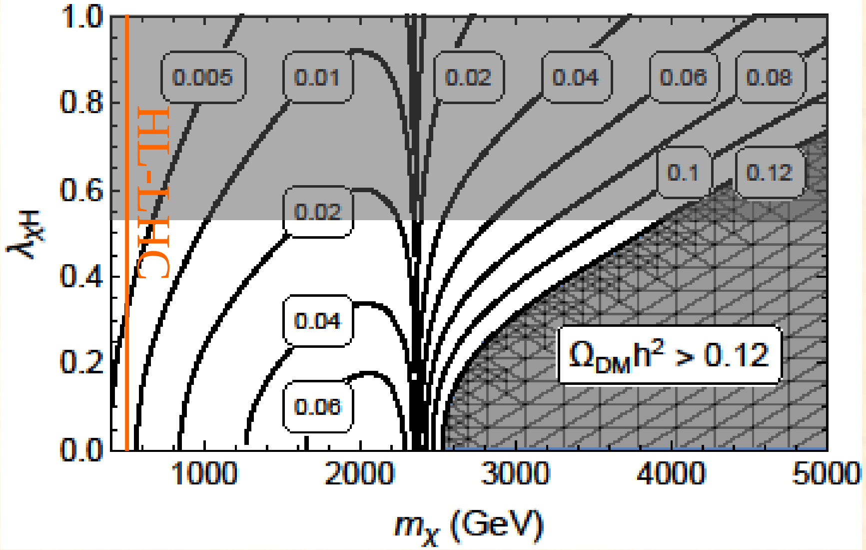
Another interesting example: Scalar 3_0 EWIMP

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\left(\left|D_\mu \chi\right|^2 - \mu_\chi^2 \left|\chi\right|^2\right) - \lambda_{\chi H}\left|H\right|^2\left|\chi\right|^2 - \frac{\lambda_\chi}{4}\left|\chi\right|^4$$

It is a simple EWIMP (a few NP parameters), but was not very much focused on.

Physics of the scalar EWIMP is essentially the same as the fermionic EWIMP's.
Only the difference is the scalar interaction between the DM and Higgs boson.



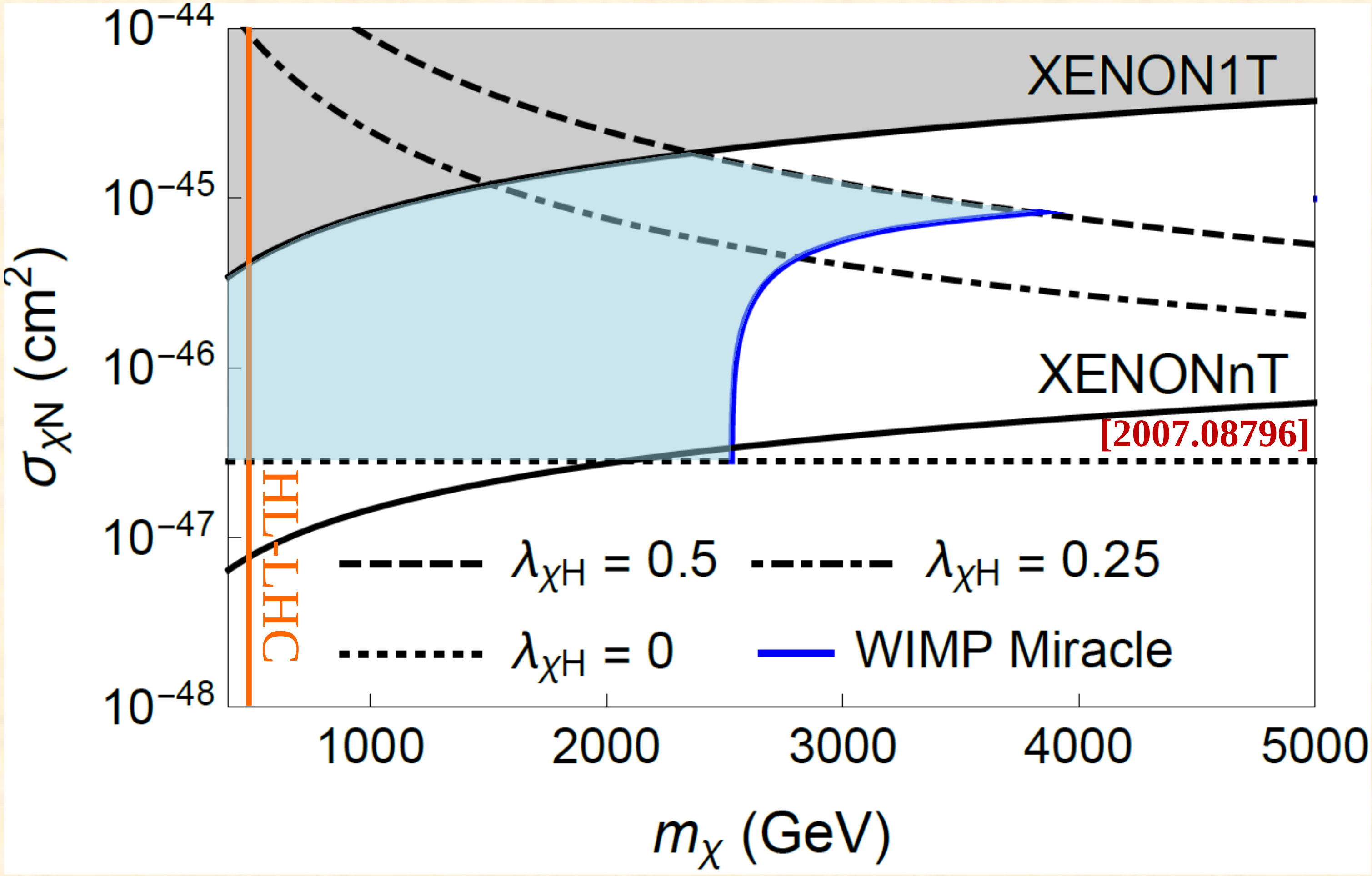


- ✓ WIMP Miracle' condition requires m > 2.5TeV. When postulating the theory does not breaks down up to high-energy, it requires m < 4TeV ($\lambda_{\chi H}$ < 0.5).
- ✓ Present LHC (future expected HL-LHC) constraint is m > 300 (500)GeV.

[C. Chiang, G. Cottin, Y. Du, K. Fuyuto and M. J. Ramsey-Musolf, JHEP01, 2021.]

Another interesting example: Scalar 3_0 EWIMP

The prediction of the scalar 3_0 EWIMP on the direct dark matter detection is



- ✓ The gray shaded region is excluded by the XENON1T experiment at present.
- ✓ Light-blue shaded region is the prediction of the scalar EWIMP dark matter.
- ✓ Blue line is the prediction of the EWIMP satisfying 'WIMP Miracle' condition.

Summary

Electroweakly interacting massive particles (EWIMPs) are known to be a attractive thermal WIMP candidate that are not very much searched for so far. Among various topics of the EWIMPs, we have particularly focused on their signals at direct dark matter detection experiments.

After reviewing the (Majorana) fermionic 3_0 EWIMP (wino-like EWIMP), where it turns out the EWIMP requires to go beyond the near future direct dark matter detection such as the XENONnT experiment. We discuss the (real) scalar 3_0 EWIMP in some detail, and found that the EWIMP will be well tested in the near future direct detection thanks to the scalar interaction between the EWIMP and the Higgs boson.

Backup (Indirect detection)