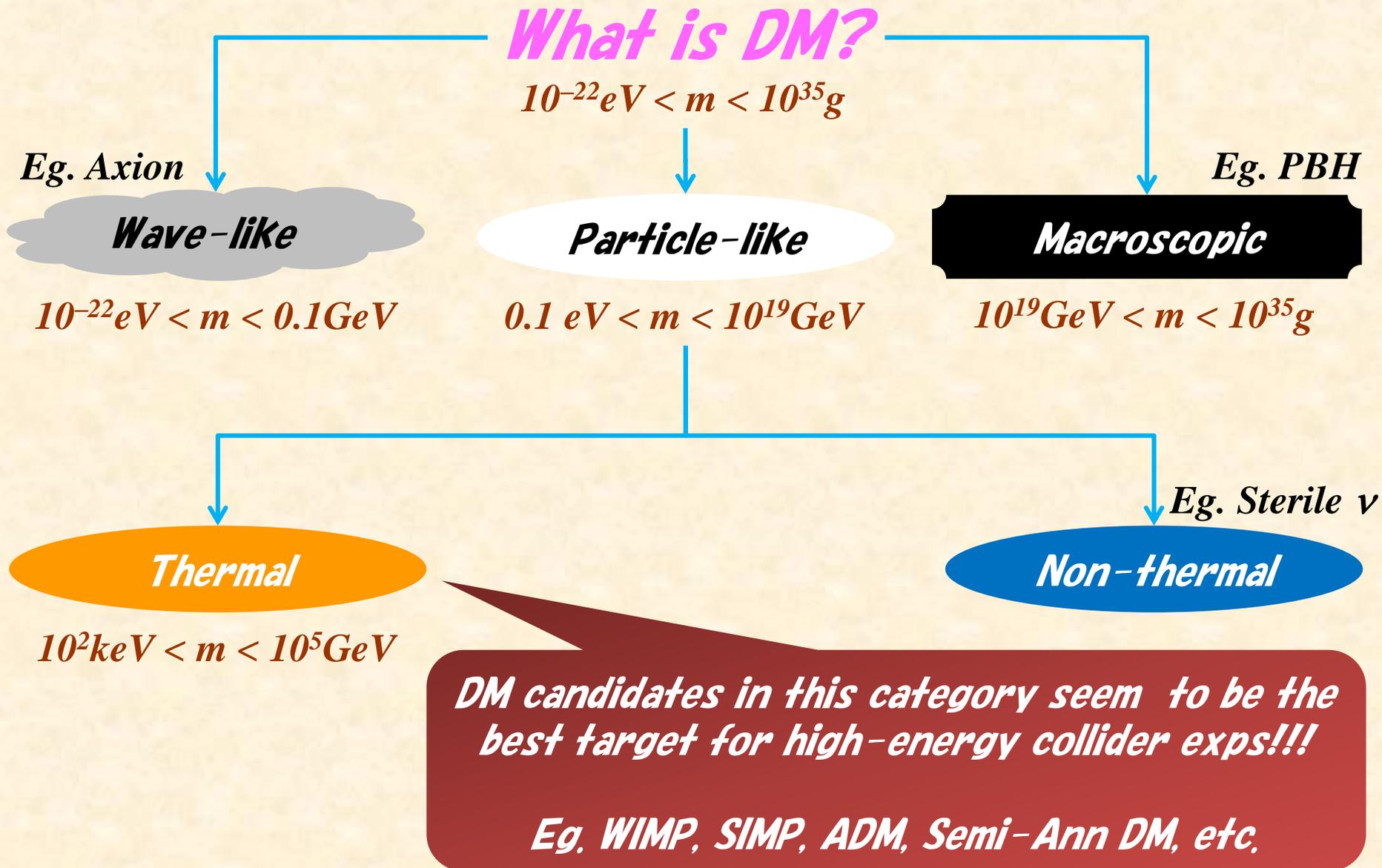


*Does ILC really play an important role to detect dark matter?*

*Shigeki Matsumoto (Kavli IPMU)*

*Many dark matter experiments already exist and are now being planned. It is thus important to quantitatively figure out what kind of role the ILC plays compared to the others.*

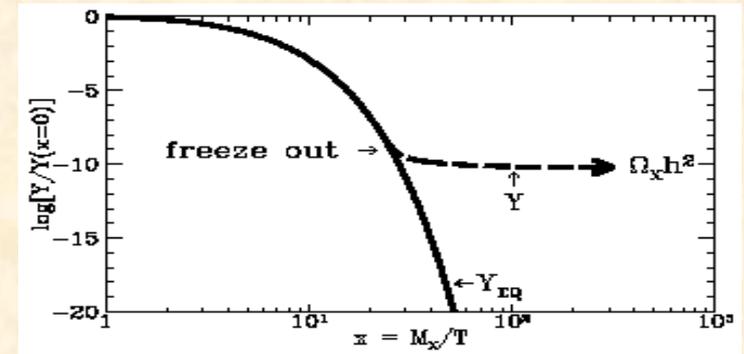
# Dark matter candidates



# WIMP dark matter Hypothesis

We consider *WIMP DM candidates*, where its abundance observed today is mainly generated by *Freeze-out mechanism!!*

The mechanism is known to describe the BBN & the recombination phenomena successfully.



A way to systematically study WIMP DM candidates:

*New physics models beyond SM.*



*Effective theories for the WIMP DMs.*



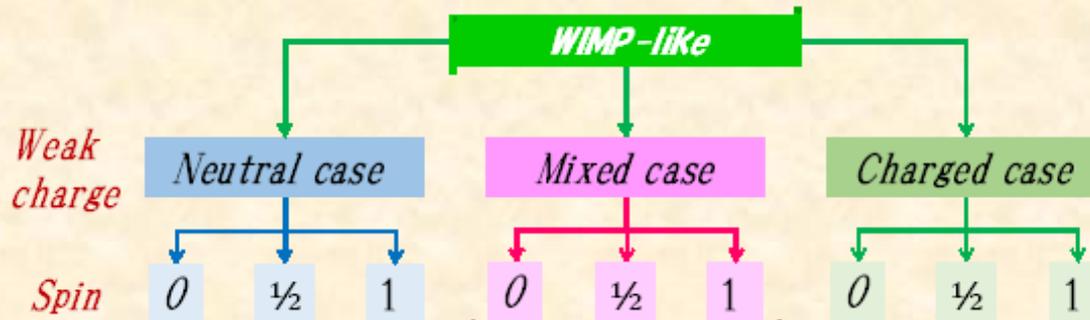
*Signals at various DM experiments.*

- 1. Phenomenology of WIMP dark matter candidates is essentially determined by their quantum numbers (spin and weak isospin).*
- 2. Effective theories of WIMP dark matter candidates can be (almost uniquely) determined by minimality & renormalizability viewpoint.*
- 3. The role of New physics models is to explain why DM has such a quantum number, to give non-trivial relations among interactions.*

# WIMP dark matter Hypothesis

We take the following method to study WIMP DMs systematically.

1. **Classifying the dark matter in terms of its quantum numbers and constructing the *minimal renormalizable Lagrangian* in each case.**



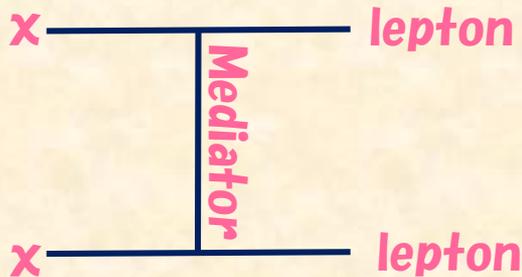
2. **Putting the thermal relic abundance condition and imposing all the (expected) limits from DM searches before future lepton colliders.**
3. **Discussing the role of the colliders in allowed parameter regions.**

**Uncharted fermionic WIMPs urgently requiring ILC are**

- ✓ **Leptophilic DM:** Singlet WIMP interacting mainly with leptons.
- ✓ **CPV H-portal DM:** Singlet WIMP governed by the  $\chi_i \gamma_5 \chi |H|^2$  int.
- ✓ **Light DM:** Singlet WIMP whose mass is much below EW scale.
- ✓ **Weak-charged DM:** WIMP closed to  $SU(2)_L$  gauge eigenstate.

# Leptophilic WIMP

## ● What is the leptophilic WIMP?

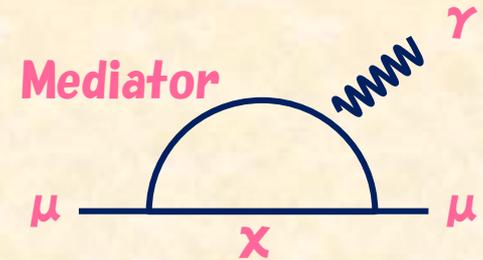


*It is difficult to detect the WIMP at direct and indirect detections, as well as hadron-collider experiments, in particular when the mediator has TeV mass or degenerates with the WIMP!*

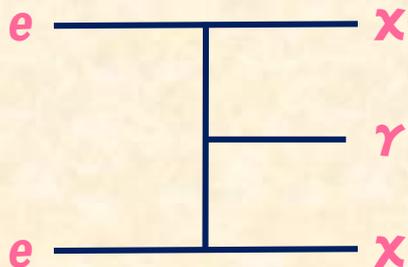
## ● Is the WIMP motivated more?

*The WIMP is realized in the framework of MSSM, say the slepton-Bino system. The WIMP is also known to be possible to explain  $g_\mu - 2$  anomaly!*

[N. Yokozaki, et al., arXiv:1210.3122; L. Calibbi, et. al, arXiv:1804.00009]



## ● How the WIMP can be detected at ILC?

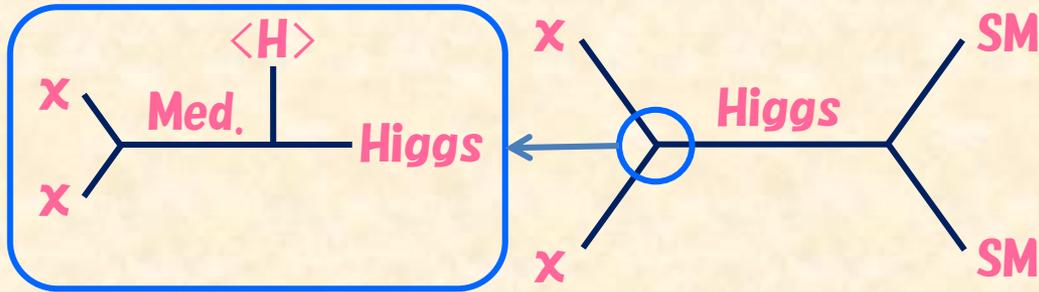


*Since the leptophilic WIMPs has interactions with leptons with a certain strength, it is possible to search for the WIMP by observing the so-called mono-gamma signals with  $\sigma(ee \rightarrow \chi\chi\gamma) < 0(1)fb!$*

[C. Bartels, M. Berggren, J. List, arXiv:1206.6639]

# CPV H-portal WIMP

## ● What is the CPV H-portal WIMP?

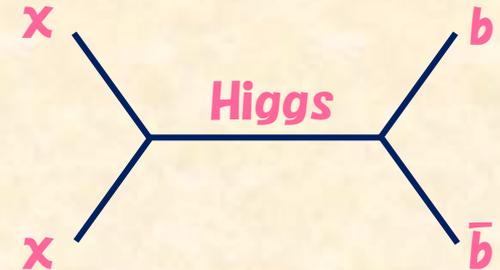


*It is hard to detect the WIMP at direct DM detection exps due to the pseudo-scalar int. between the WIMP and Higgs!*

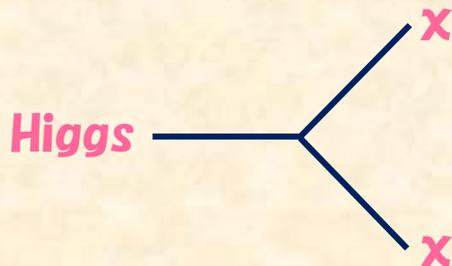
## ● Is the WIMP motivated more?

*The WIMP is known to be the simplest one for anomalies found at  $\gamma$ -ray obs at Fermi-LAT &  $p$  obs. at AMS-02 when its mass is  $\sim 50$  GeV!*

[I. Cholis, et al, arXiv:1903.02549]



## ● How the WIMP can be detected at ILC?



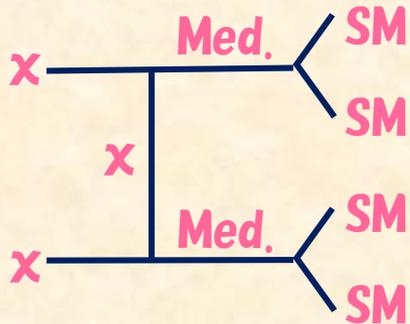
*Since the interesting WIMP mass region is below  $m_h/2$ , it is efficiently detected via the invisible Higgs decay search with  $Br(h \rightarrow \chi\chi) < 0.003!!$*

[T. Barklow, K. Fujii, S. Jung, R. Karl, J. List, T. Ogawa, M. E. Peskin,

J. Tian, arXiv:1708.08912]

# Light WIMP

## ● What is the Light WIMP (with scalar mediator)?

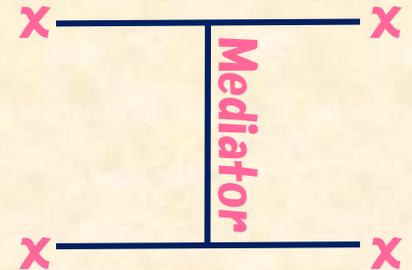


*It is hard to detect the WIMP at direct DM detection experiments due to its small mass. Furthermore, the Indirect DM detection signal is also weak due to the  $p$ -wave suppressed DM annihilation cross section.*

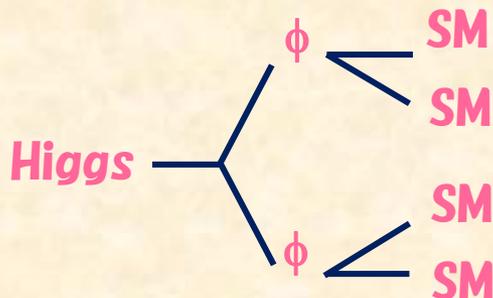
## ● Is the WIMP motivated more?

*The WIMP predicts a large enough self-scattering cross section, and it is known to resolve the small scale crisis of the universe (core-cusp problem)!!*

[E.g. H. Baer, et al, arXiv:1912.06643 for Focus point SUSY]



## ● How the WIMP can be detected at ILC?

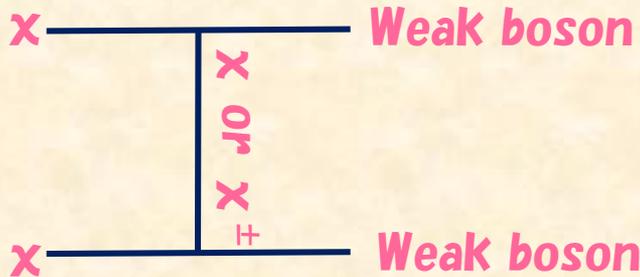


*Mediator  $\phi$  is feebly interacting with SM particles except the Higgs boson, so that it is efficiently detected by observing the exotic Higgs decay!! It covers the most important parameter region!*

[S.M., Y. S. Tsai, P. Y. Tsng, JHEP07, 2019]

# Weak charged WIMP

## ● What is the weak-charged

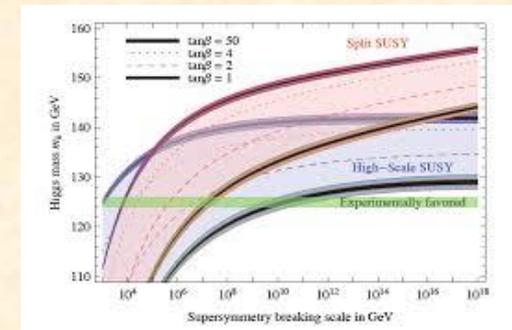


*It is hard to detect the WIMP at direct DM detection, as the scattering with a nucleon is generated only radiatively. Moreover, it is hard to be detected at hadron colliders.*

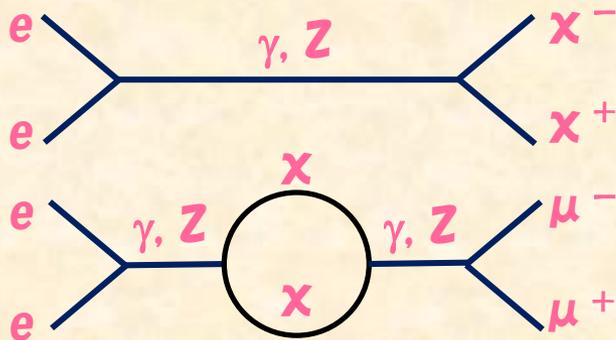
## ● Is the WIMP motivated more?

*The WIMP is predicted by various SUSY scenarios, which predicts the Higgs boson with 125 GeV mass: Focus point, mini-Split, Spread, PeV SUSY, and PGM.*

[Sean Tulin and Hai-Bo Yu, arXiv:1705.02358]



## ● How the WIMP can be detected at ILC?



*The WIMP is efficiently detected if its mass is less than  $s^{1/2} / 2$  at ILC. Even if the mass is larger, the WIMP can be detected indirectly by precise measurement of SM processes!!*

[H. Baer, M. Berggren, K. Fujii, J. List, et al. 1912.06643, K. Harigaya, K. Ichikawa, A. Kundu, S. M., S. Shirai, 1504.03402]

*Future lepton collider ILC can indeed play important roles to detect WIMP dark matter candidates!!! Well-motivated ones are as follows:*

<i>DM candidates</i>	<i>Motivation</i>	<i>Signal @ ILC</i>
✓ <i>Leptophilic WIMP</i>	<i><math>g_\mu - 2</math></i>	<i>Mono-photon process</i>
✓ <i>CPV H-portal WIMP</i>	<i><math>\gamma</math> and <math>\bar{p}</math> anomalies</i>	<i>Invisible Higgs decay</i>
✓ <i>Light WIMP</i>	<i>Small scale crisis</i>	<i>Exotic Higgs decay</i>
✓ <i>Weak-charged WIMP</i>	<i>SUSY models</i>	<i>Direct prod./Oblique corr.</i>

*Above regions were obtained by assuming minimality, renormalizability (and flavor blindness), so that there could be other interesting WIMP candidates that the ILC will play crucial roles for detecting those!!*