Observing the coupling between Dark matter & Higgs boson at ILC

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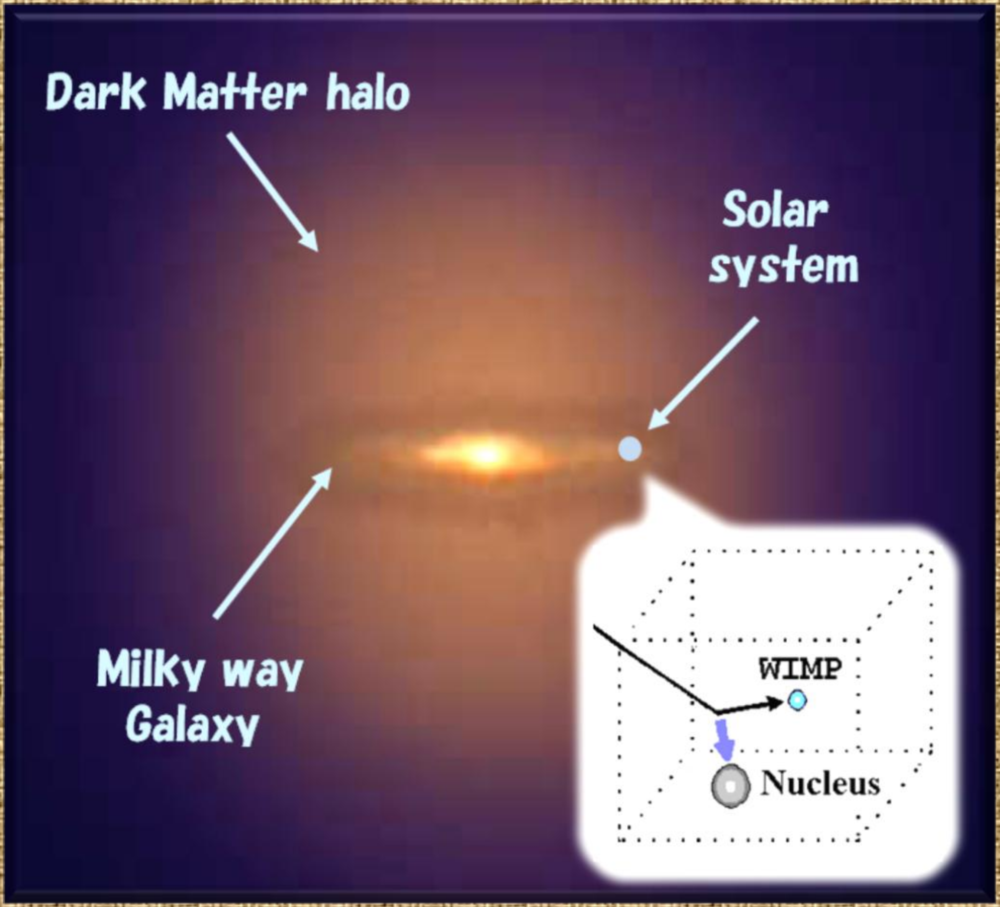
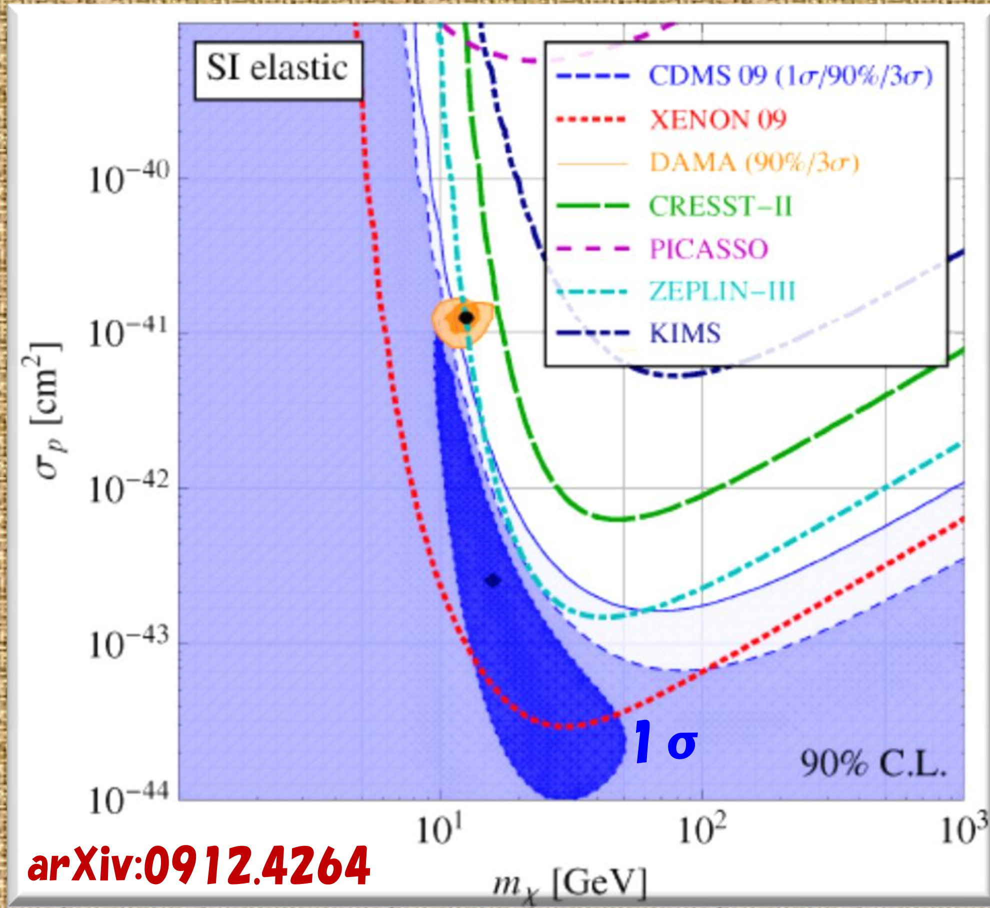
- This work is partially motivated by recent result of the direct detection of dark matter at CDMSII experiment.
- If the observed events are due to the scattering of dark matter, it is important to investigate the coupling.

Direct detection of dark matter



1. Our solar system is moving inside the halo composed of DM.
2. DM often pass through the detector prepared.
3. Nucleon inside the detector is expected to be scattered by DM.
4. By observing the release energy, we can detect the DM.

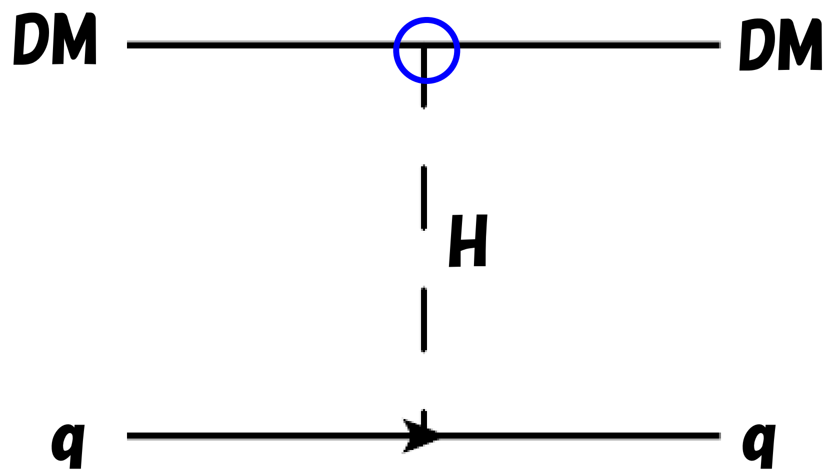
Direct detection of dark matter



1. CDMS has reported two candidate events of DM (77%).
2. If the events are from the elastic scattering between DM & nucleon, the DM may be a WIMMP with 10–100 GeV.
3. The scattering cross section is expected to be 10^{-44} cm^2.

The coupling between DM & H

Which process causes such a large cross section?



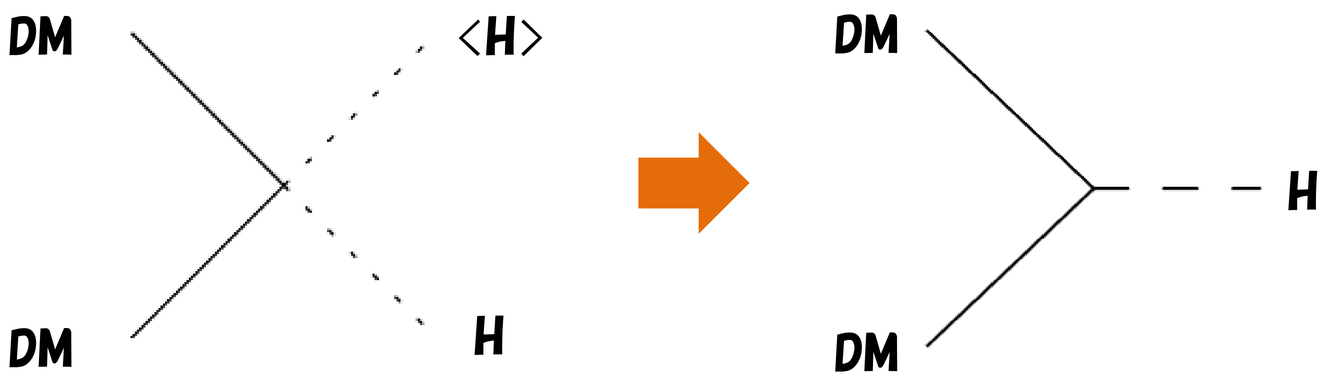
The process in which higgs boson is exchanged!

There are other type of diagrams causing the scattering between DM and a nucleon, however their contributions are usually not so large compared to above one.

→ It is important to study the coupling between DM and higgs boson at collider experiments such as LHC & ILC.

The coupling between DM & H

What kind of interaction causes the coupling?



The $DM^2|H|^2$ interaction if the DM is singlet.

1. We consider the simplest case where the DM is singlet under SM gauge interactions.

The coupling between DM & H

	Spin	DM Field	Comments
Case S	0	$\phi(x)$	Neutral scalar
Case F	1/2	$\chi(x)$	Majorana fermion
Case V	1	$V_\mu(x)$	Neutral vector

$$|H|^2\phi^2 \qquad |H|^2\bar{\chi}\chi \qquad |H|^2 V_\mu V^\mu$$

1. We consider the simplest case where the DM is singlet under SM gauge interactions.

2. On the other hand, we consider three cases about the spin of the DM (spin 0, 1/2, and 1).

The coupling between DM & H

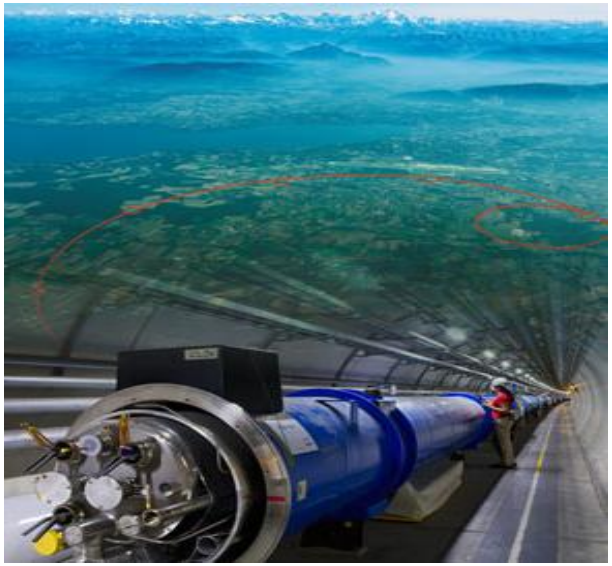
$$
\begin{aligned}
\mathcal{L}_S &= \mathcal{L}_{\rm SM} + \frac{1}{2}(\partial\phi)^2 - \frac{M_S^2}{2}\phi^2 - \frac{c_S}{2}|H|^2\phi^2 - \frac{d_S}{4!}\phi^4, \\
\mathcal{L}_F &= \mathcal{L}_{\rm SM} + \frac{1}{2}\bar{\chi}\,(i\partial\!\!\!/ - M_F)\,\chi - \frac{c_F}{2\Lambda}|H|^2\bar{\chi}\chi - \frac{d_F}{2\Lambda}\bar{\chi}\sigma^{\mu\nu}\chi B_{\mu\nu}, \\
\mathcal{L}_V &= \mathcal{L}_{\rm SM} - \frac{1}{4}V^{\mu\nu}V_{\mu\nu} + \frac{M_V^2}{2}V_\mu V^\mu + \frac{c_V}{2}|H|^2V_\mu V^\mu - \frac{d_V}{4!}(V_\mu V^\mu)^2,
\end{aligned}
$$

It is easy to confirm that the $DM^2|H|^2$ interaction governs phenomenology of DM, if we consider the following scenario,

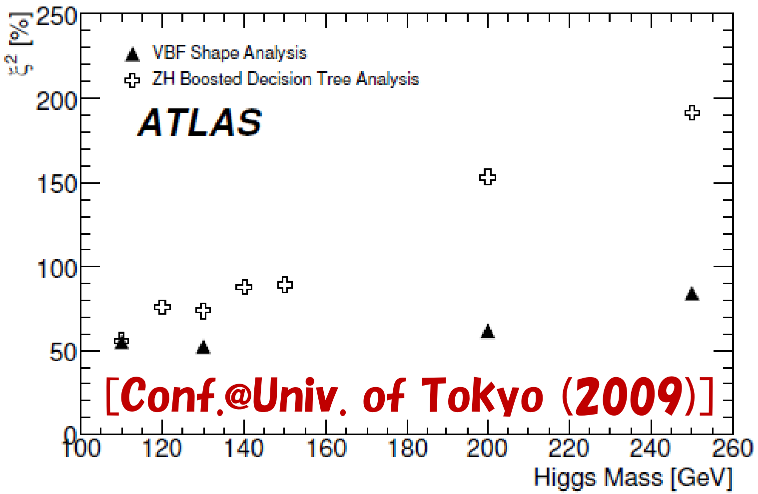
1. New particles are heavy enough compared to the DM.
2. The stability of the DM is guaranteed by Z_2-symmetry.
3. The effective lagrangean at the scale of m_{DM} is given above, (Interactions as low dimensional ones as possible)
4. Last term in L_S(L_V) is not relevant for following analysis, while Last term in L_F is loop-suppressed.

→ The $DM^2|H|^2$ is quite important for DM phenomenology!

Observing the coupling at the LHC



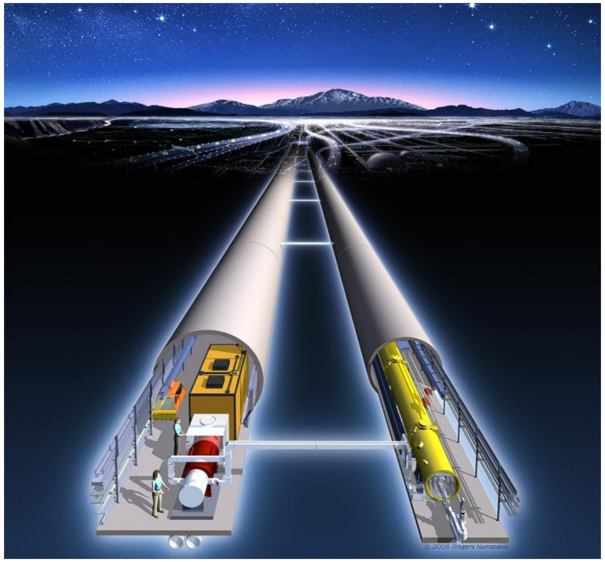
Invisibly Decaying Higgs



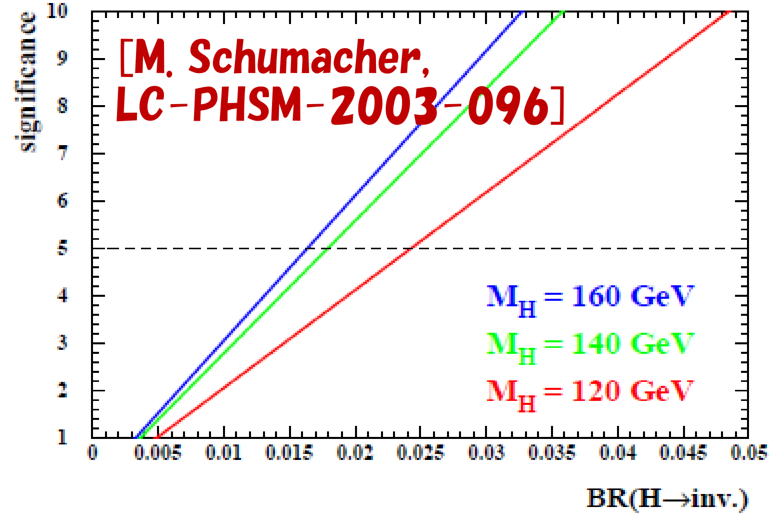
When the mass of the dark matter is less than a half of the Higgs mass, the Higgs boson is possible to decay into a pair of dark matters.

1. In this case, the signal will be observed as an invisible decay width of the higgs boson ($s^{1/2}$ = 14 TeV).
2. As shown in the figure above, the signal can be observed at 95% C.L. with the 30 fb^{-1} data through the process of the vector boson fusion, when its branching ratio exceeds about 50%.

Observing the coupling at the ILC



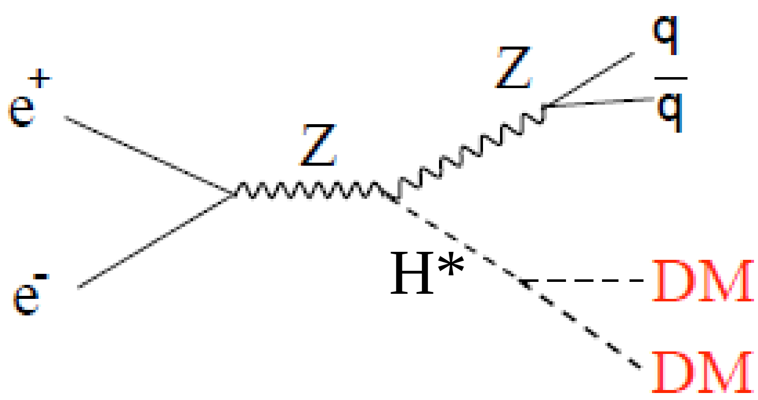
Invisibly Decaying Higgs



When the mass of the dark matter is less than a half of the Higgs mass, the Higgs boson is possible to decay into a pair of dark matters.

1. Situation to observe the invisible decay width of the Higgs boson changes drastically at the ILC ($s^{1/2}$ = 350 GeV).
2. As shown in the figure above, the signal can be observed at 95% C.L. with the 500 fb^{-1} data through the process of the $e^+e^- \rightarrow ZH$ process, when its branching ratio exceeds about 0.95%.

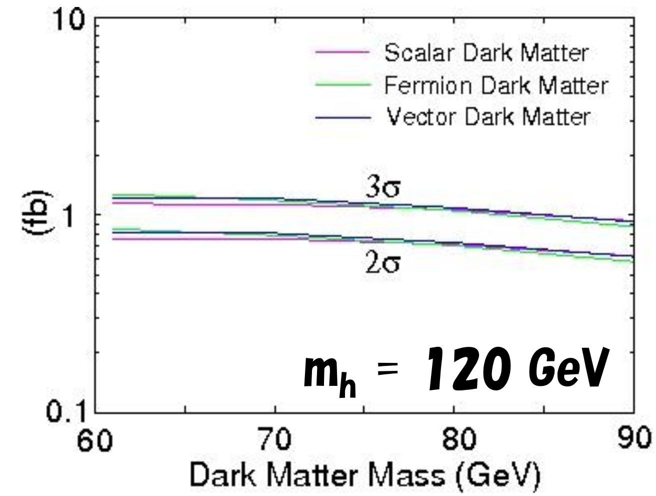
Observing the coupling at the ILC



Background processes:

ZZ, WW, Zνν, eeZ, eνW

Cross section for the observation

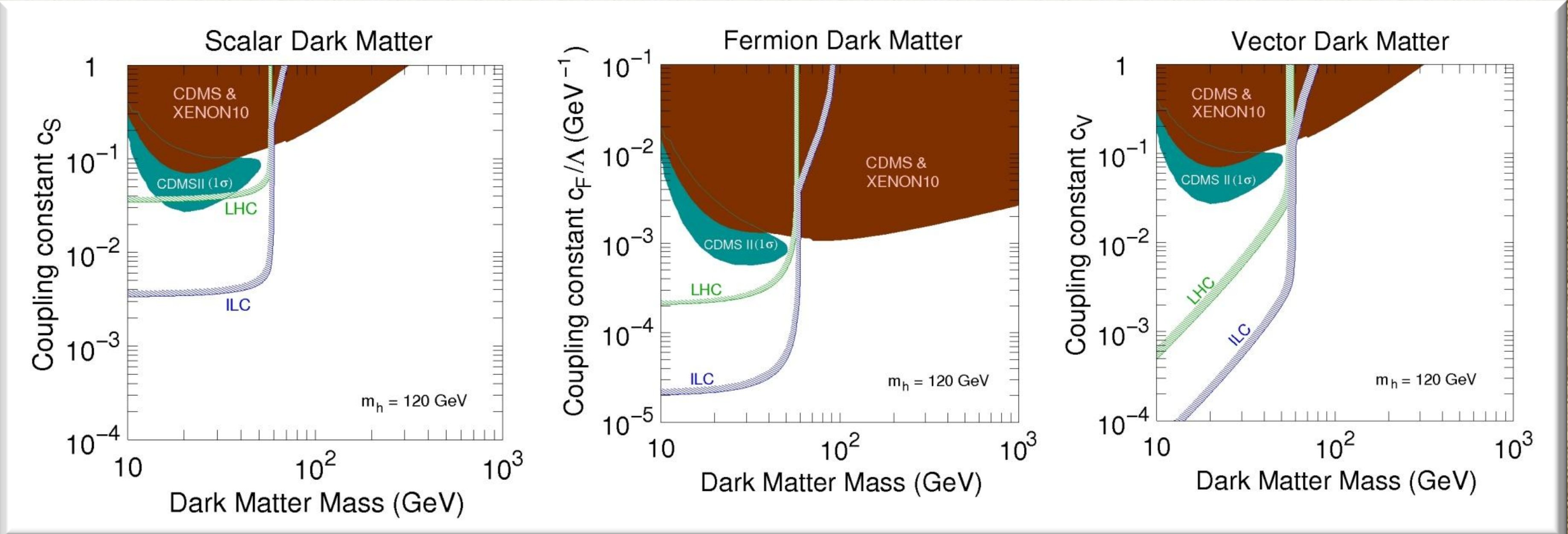


e^- polarization (80%) used.

When the mass of the dark matter is more than a half of the Higgs mass, the Higgs boson can not decay into a pair of dark matters.

1. It may still be possible to detect the signal at the ILC even in this case when we accumulate enough data ($s^{1/2}$ = 300 GeV).
2. As shown in the figure above, the signal can be observed at 95% C.L. with the 2 ab^{-1} data through the process of the $e^+e^- \to ZH$ process, when the signal cross section exceeds about 1(fb).

Result



1. **Brown regions**: Excluded by CDMS & XENON experiment (2σ).
2. **Dark green region**: Consistent with the CDMSII result (1σ).
3. **Green line**: Sensitivity to detect the signal at the LHC (2σ)
4. **Blue line**: Sensitivity to detect the signal at the ILC (2σ)

1. Interesting region (Dark green one) will be covered by the ILC.
2. When the coupling constant between DM and H is large enough, it is possible to detect the signal at the region $m_{DM} > m_h/2$.

(Direct detection experiments are expected to have large ambiguities.)

Summary

① We have considered the possibility to observe the DM-DM-h coupling at the LHC & ILC.

② When the mass of the dark matter is less than a half of the higgs mass (as suggested by the recent CDMSII result at 1σ level), it is possible to observe the signal at the ILC even if the spin of DM is 0.

③ When the mass of the dark matter is more than a half of the higgs boson mass, the observation of the coupling becomes challenging. It may be possible to observe the coupling if the interaction between dark matter and higgs boson is large enough.

④ It may be better to use the Z-boson fusion process at the 1 TeV ILC to observe the coupling.