Testing Higgs portal dark matter via Z fusion at a linear collider

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S.Kanemura, S.Matsumoto, TN, N.Okada
Phys. Rev. D 82 ,2010.
S.Kanemura, S.Matsumoto, TN, H.Taniguchi
Phys.Lett.B701:591-596,2011.

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Contents

Introduction

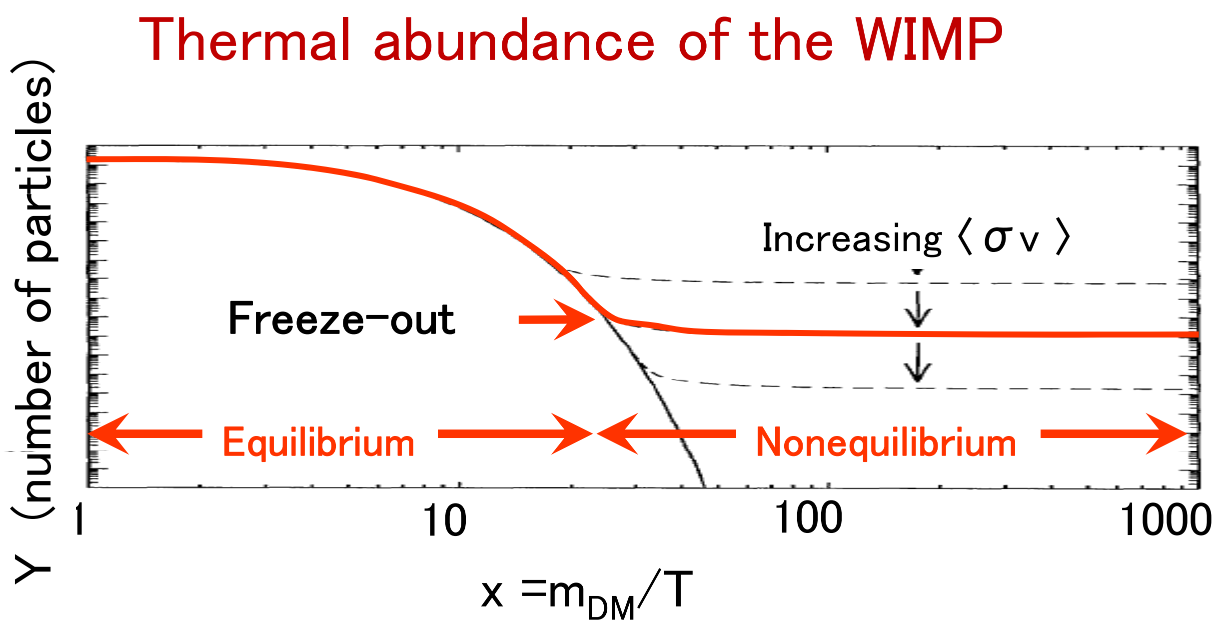
The standard model (SM) is very successful model to describe physics below the O(100)GeV.
However, SM has some problems.

1. Hierarchy problem.
2. Dark matter problem.
3. Baryon asymmetry of the Universe.
4. Masses of a neutrinos. etc.

Especially, the dark matter problem is expected to be related to new physics at the TeV scale.

WIMP dark matter scenario

If the dark matter is Weakly Interacting Massive Particle(WIMP), it explains the its energy density of Universe naturally.



WIMP dark matter scenario

Boltzmann equation →

$$\Omega_{DM} h^2 \simeq \frac{0.1\text{pb} \cdot c}{\langle \sigma v \rangle} \qquad \langle \sigma v \rangle \sim \alpha^2/m^2,\ \alpha \sim g^2/4\pi$$

The WMAP experiment →

$$\Omega_{DM} h^2 = 0.1126 \pm 0.0036 \rightarrow \langle \sigma v \rangle \sim 1\ \text{pb}$$

⬇

g = 0.1−1 → m_{DM} = 10 GeV−1TeV ! (**electro week scale!**)

This dark matter mass scale would indicate that there is connection between Higgs boson (h) and the dark matter (DM).

⬇

The DM−DM−h coupling is important !

Motivation

- The mass scale of WIMP dark matter is similar to that of electroweak scale would indicate that there is connection between Higgs boson and the dark matter. Therefore DM-DM-h coupling is important.
- If the dark matter couples only Higgs boson, it is often called **Higgs portal dark matter**.

J. McDonald, Phys. Rev. D50, 1994
O.Bertolami and R.Rosenfeld, Int. J. Mod. Phys.A23, 2008
etc.

↓

The motivation of the work:
To study whether the Higgs portal dark matter can be observed or not at a TeV scale collider

Model of Higgs portal dark matter

For simplicity, we consider the case where the DM is singlet under the SM gauge groups.

Three possible cases for spin of DM

	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

The stability of the DM is guaranteed by Z_2−symmetry.

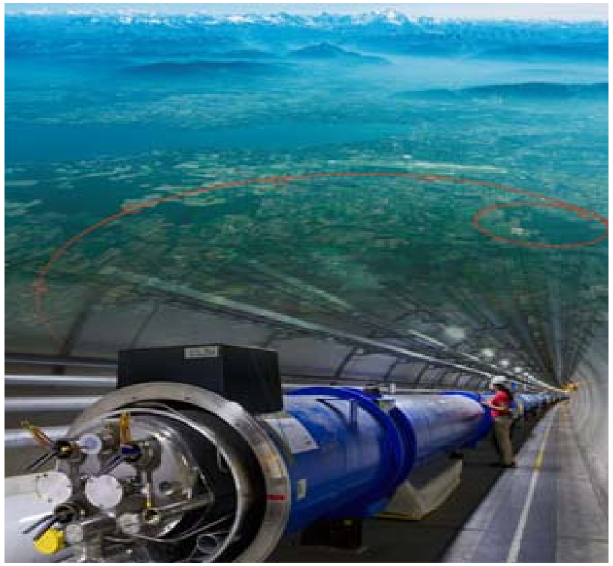
Lagrangian

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

Then, phenomenology related to the DM comes only from the Higgs boson!

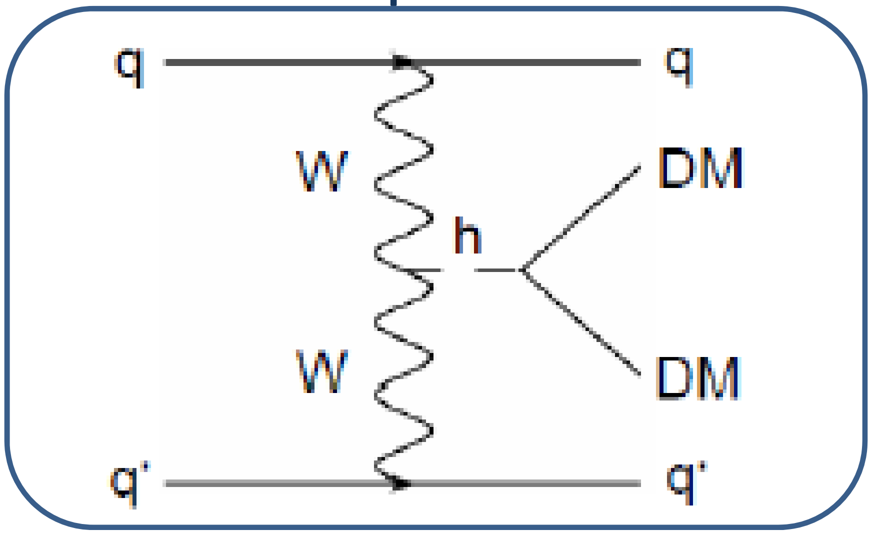
These dark matter are Higgs portal dark matter.

Detectability at the LHC



1. The most efficient process is the weak gauge boson fusion (WBF) process.
2. The signal is then the two energetic jets with a large pseudo rapidity gap.

WBF process

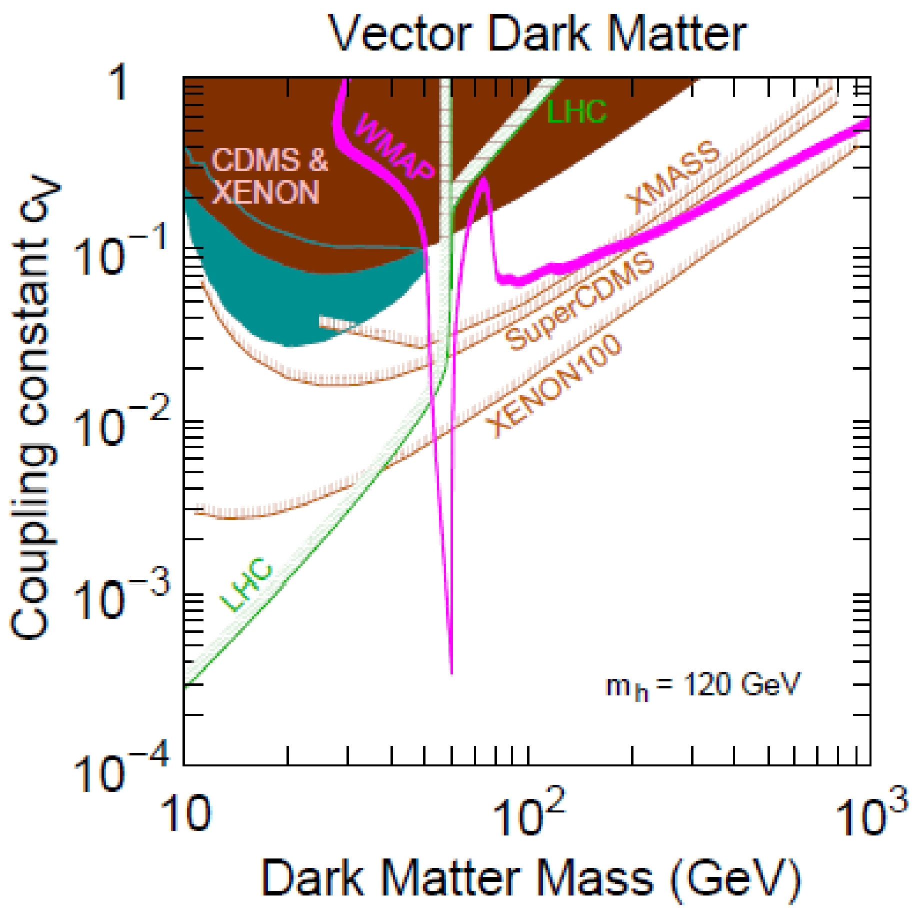


kinematical cuts

$p^j_T > 40$ GeV, $p_{Tinv} > 100$ GeV,
$|\eta_j| < 5.0$, $|\eta_{j1} - \eta_{j2}| > 4.4$,
$\eta_{j1} \cdot \eta_{j2} < 0$,
$M_{j1j2} > 1200$ GeV, $\phi_{j1j2} < 1$.

O. J. P. Eboli and D. Zeqqenfeld, Phys. lett. B495, 2000

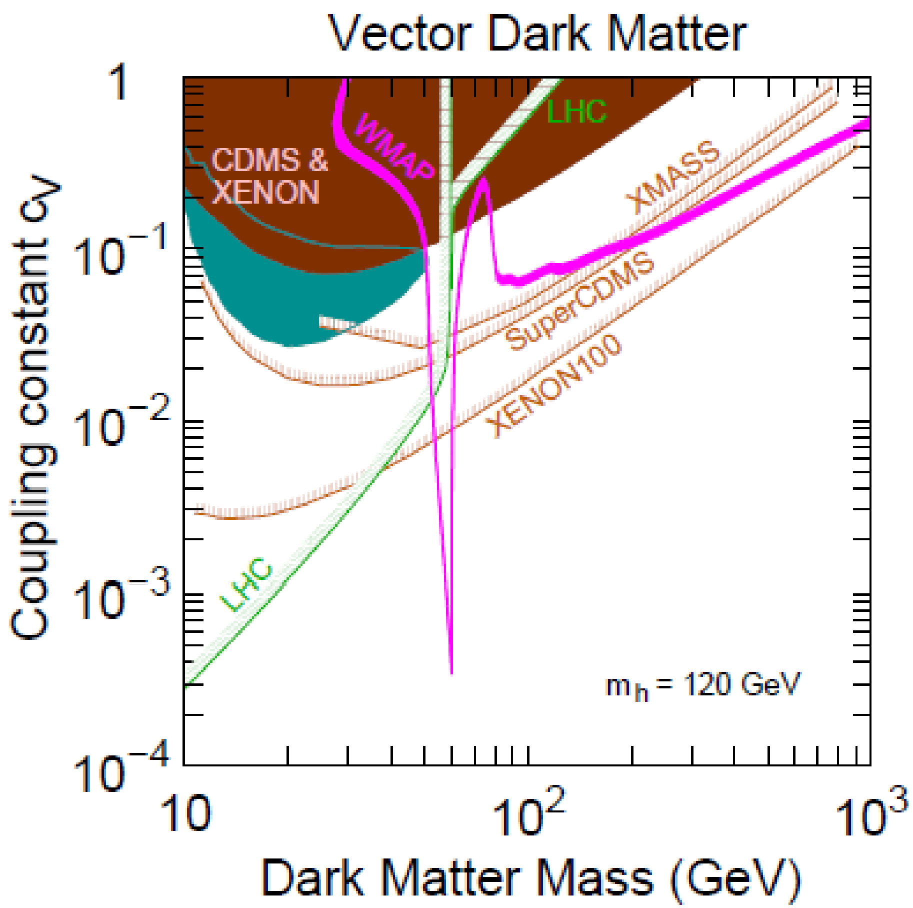
LHC Results



The pink region is consistent with the WMAP data at 95% C.L.

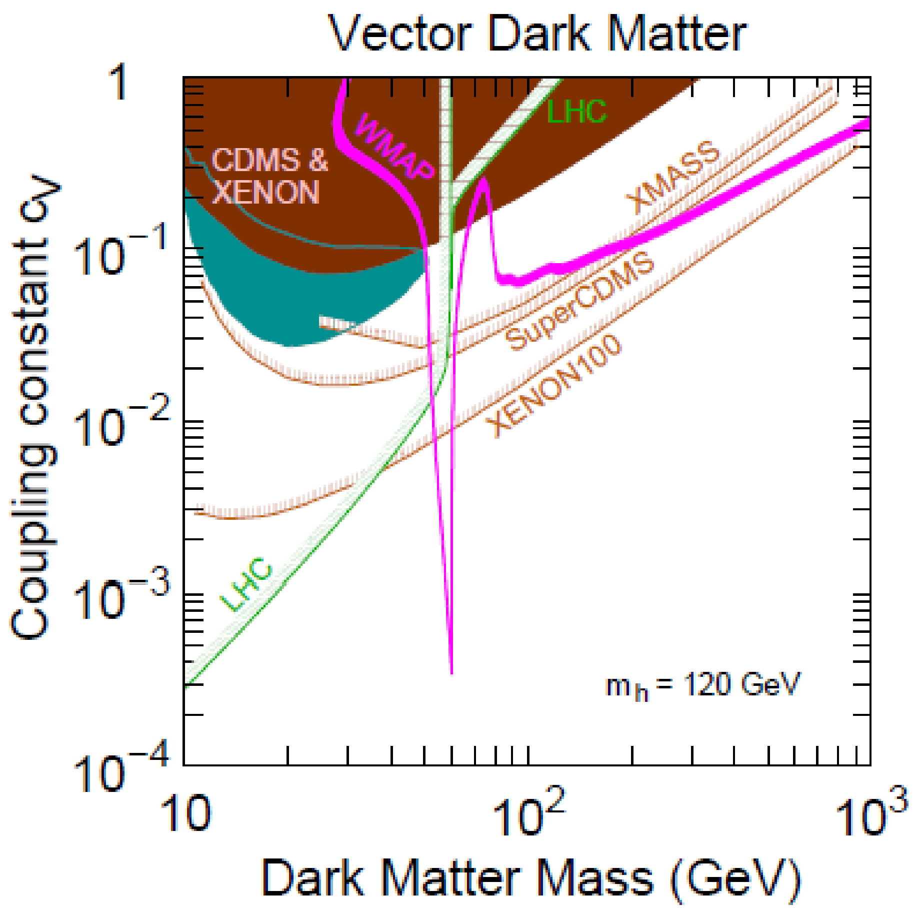
In the region above the green line, the Higgs portal dark matter can be explored at 95% C.L at the LHC.with $\sqrt{s}$=14TeV and 100fb^{-1} data.

LHC Results



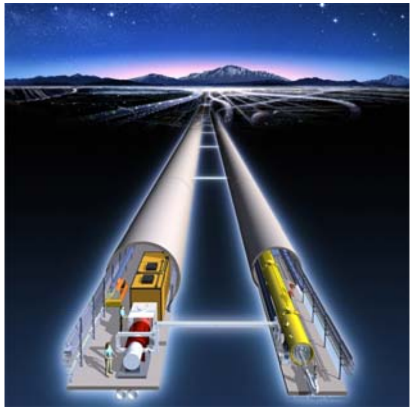
When the decay of the Higgs boson into a pair of dark matters is kinematically allowed, it is possible to observe the signal at the LHC.

LHC Results

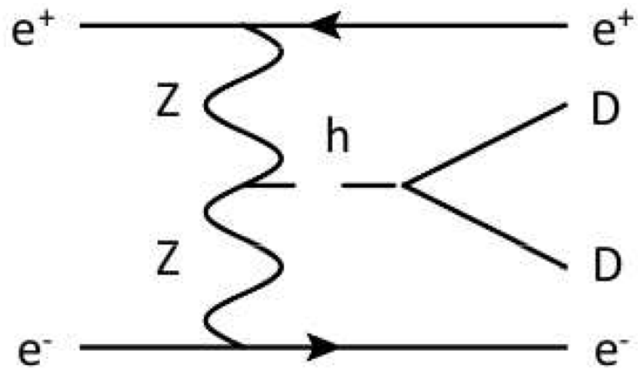


When the decay of the Higgs boson into a pair of dark matters is kinematically forbidden, it is difficult to explore the Higgs portal dark matter.

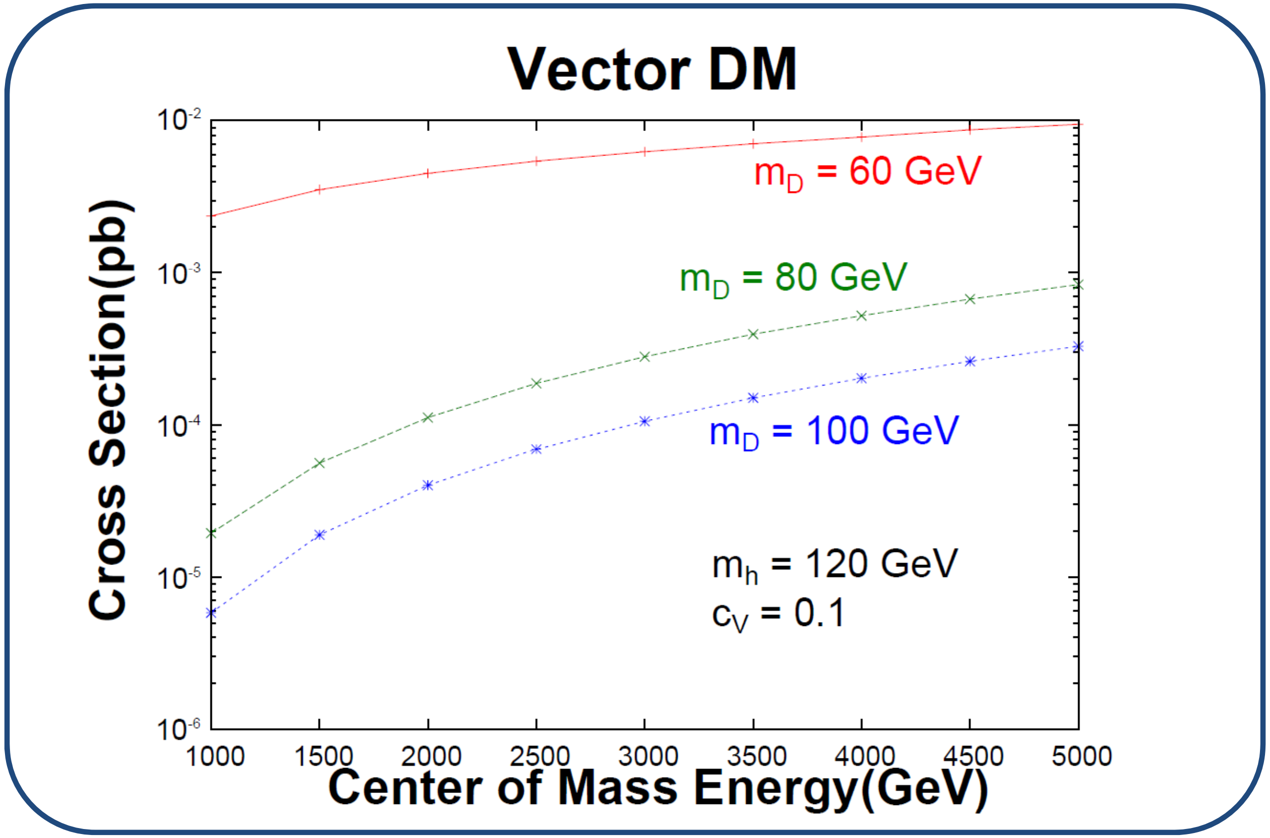
Significance of TeV scale linear collider



Z boson fusion process



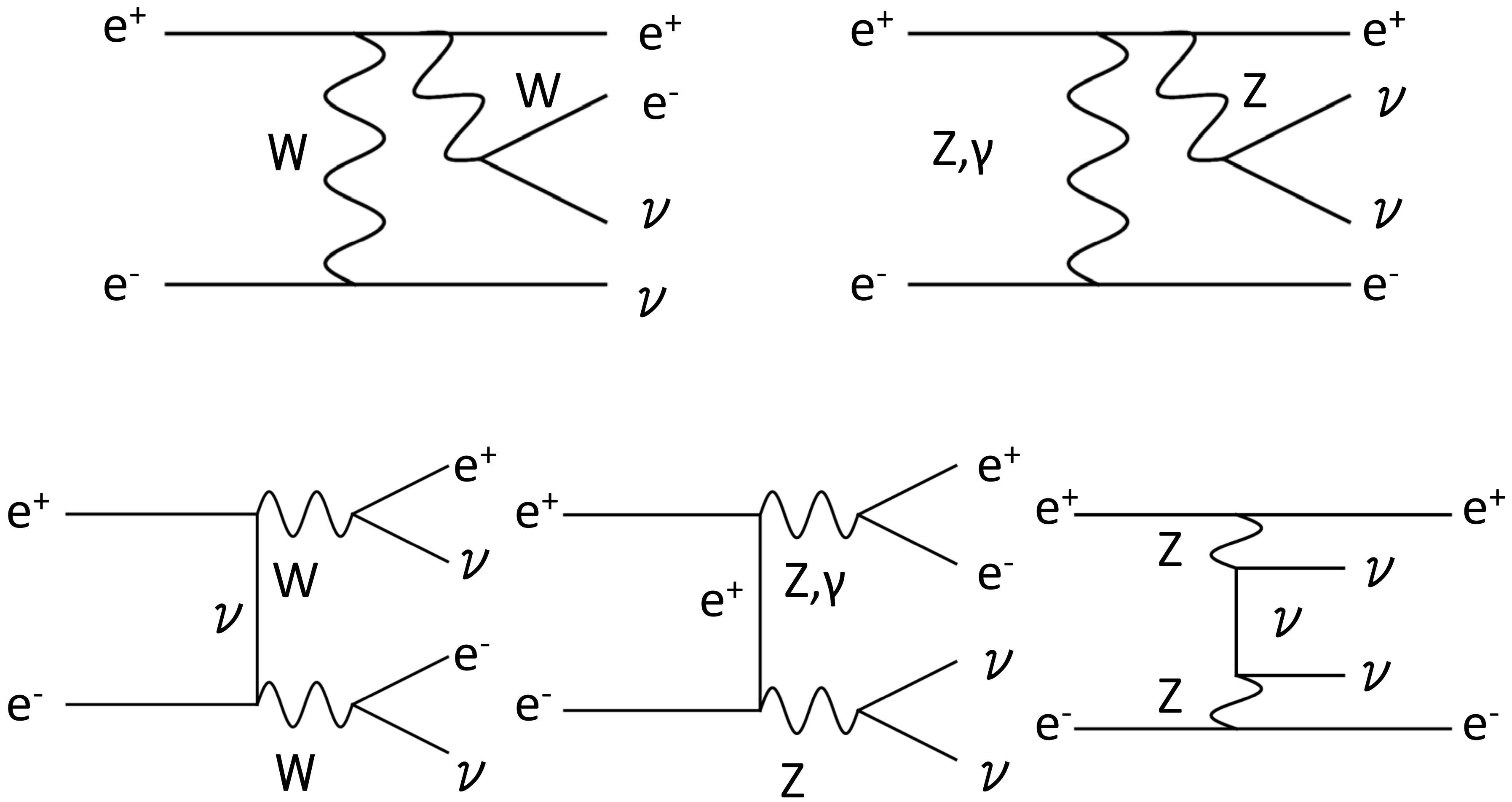
1. We investigate delectability of the Higgs portal dark matter at the ILC ($\sqrt{s}$ = 1 TeV) and the CLIC ($\sqrt{s}$ = 5 TeV) at the Higgs boson cannot decaying into pair of the dark matter .
2. The efficient process at a high energy linear collider to observe the Higgs portal dark matter is the Z boson fusion process.
3. The energy momentum conservation is used to detect the dark matter.
4. Background processes are the final state of e^+e^- with a missing momentum.



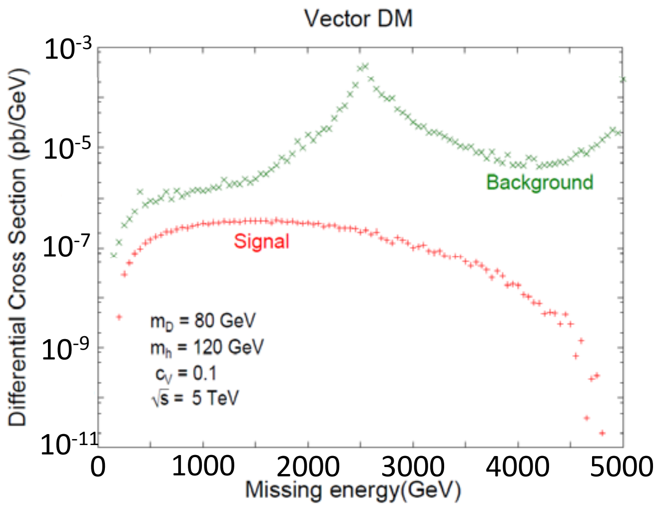
The cross section of the signal process is the larger as the collision energy $\sqrt{s}$ increases, and its behavior is ln s.

The higher collision energy may be more useful to detect the signal.

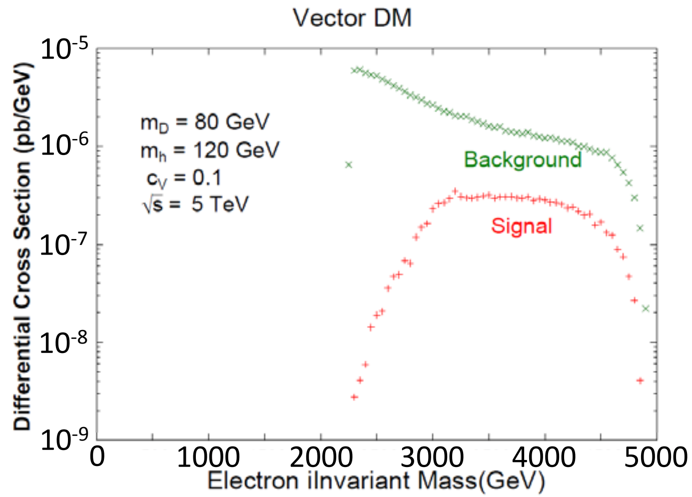
Background processes



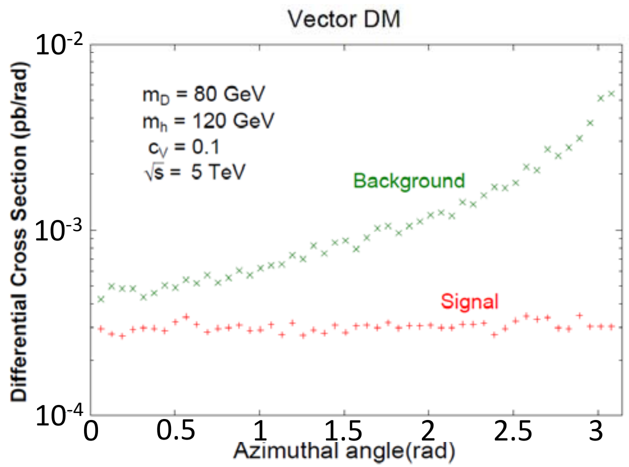
Cuts for the vector case at $\sqrt{s}$ = 5 TeV



E_{inv} < 2000 GeV



M_{ee} < 3000 GeV



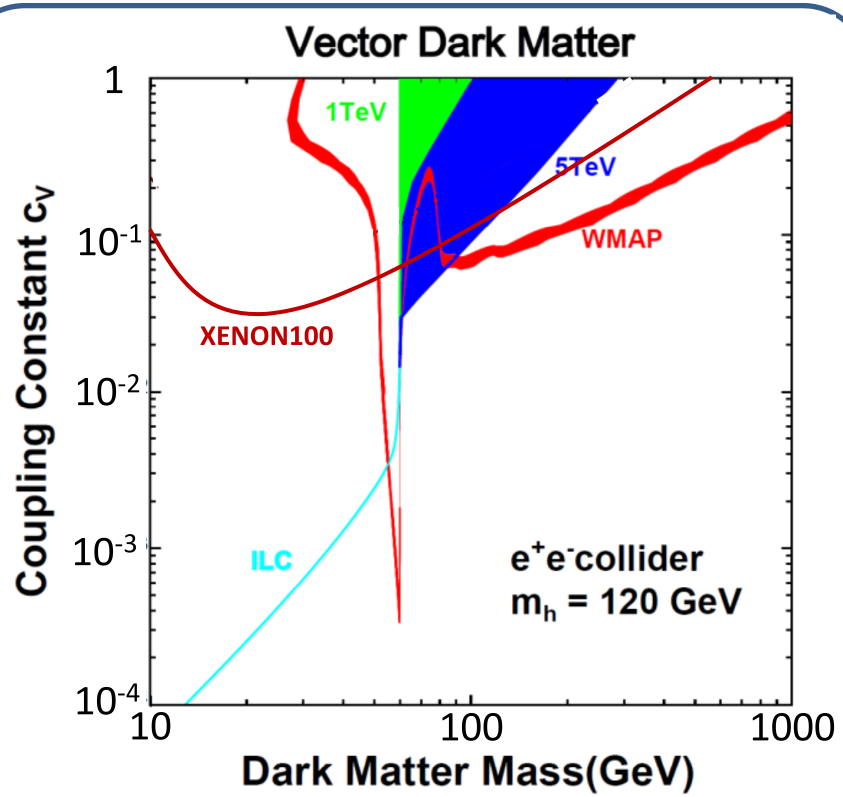
ϕ < 2.3

$|\cos\theta| < 0.9999416$, $M_{inv} > 120$ GeV,
$E_{inv} < 2000$ GeV, $M_{ee} < 3000$ GeV, $\phi < 2.3$,

Polarized electron−beam (80%),
positron−beam(50%) is used!

The backgrounds can be reduced!

Results

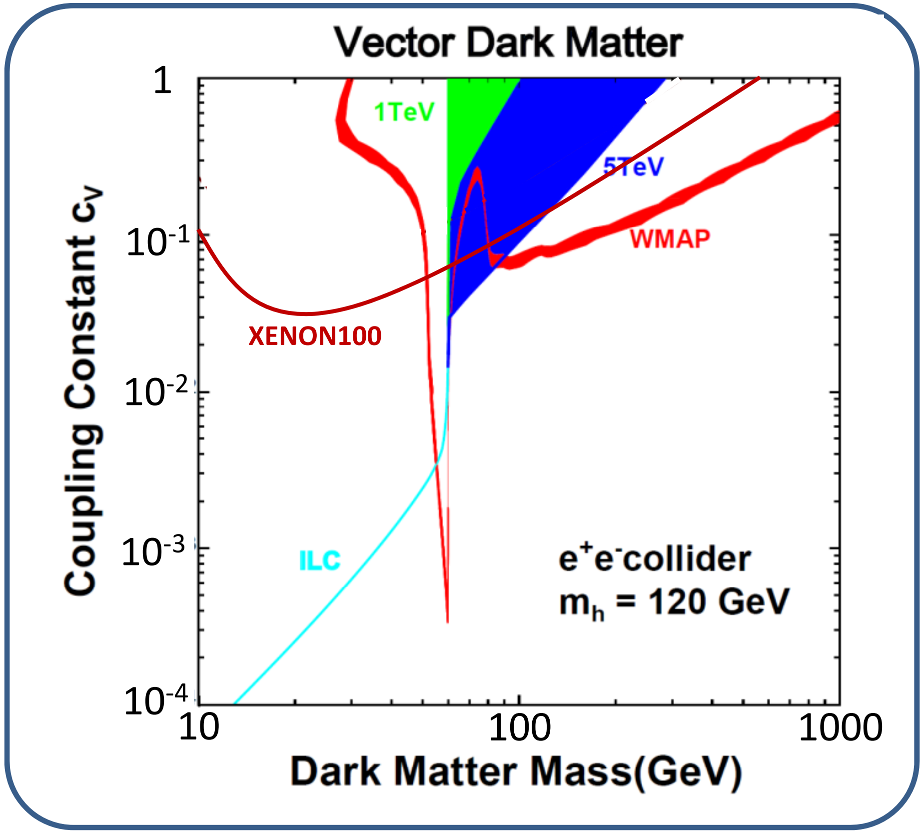


Red & Brown regions:

The red region is consistent with the WMAP data at 3σ C.L.

The region above brown line, it have been already excluded by current direct detection experiments at 90% C.L.

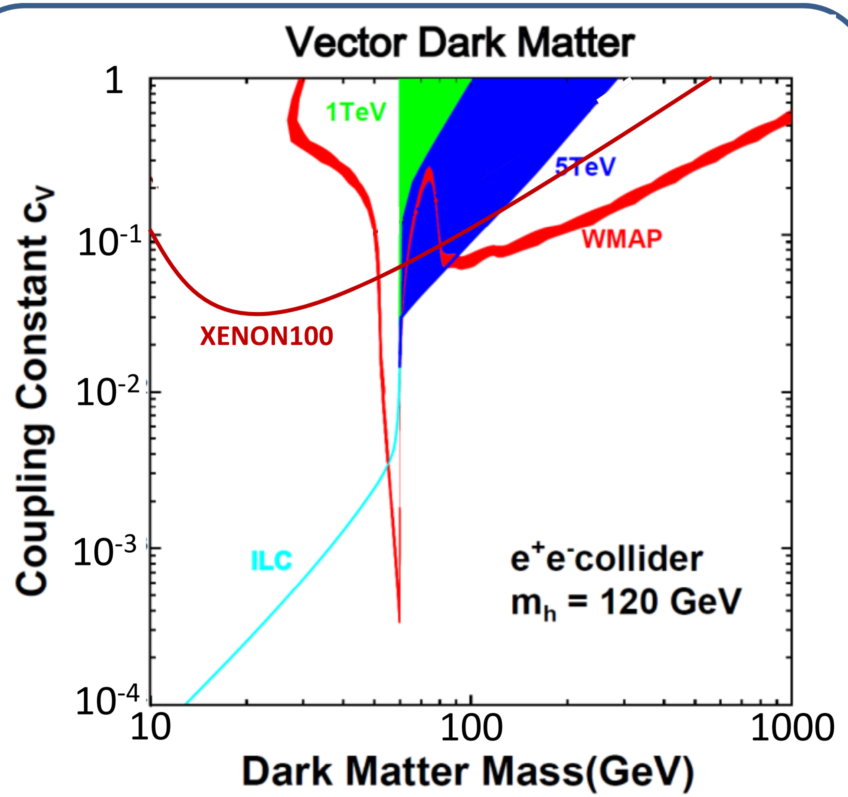
Results



cyan regions:

The region above cyan line, the Higgs portal dark matter can be explored at 3σ C.L. at $\sqrt{s}$ = 350 GeV with $500 fb^{-1}$ data.

Results

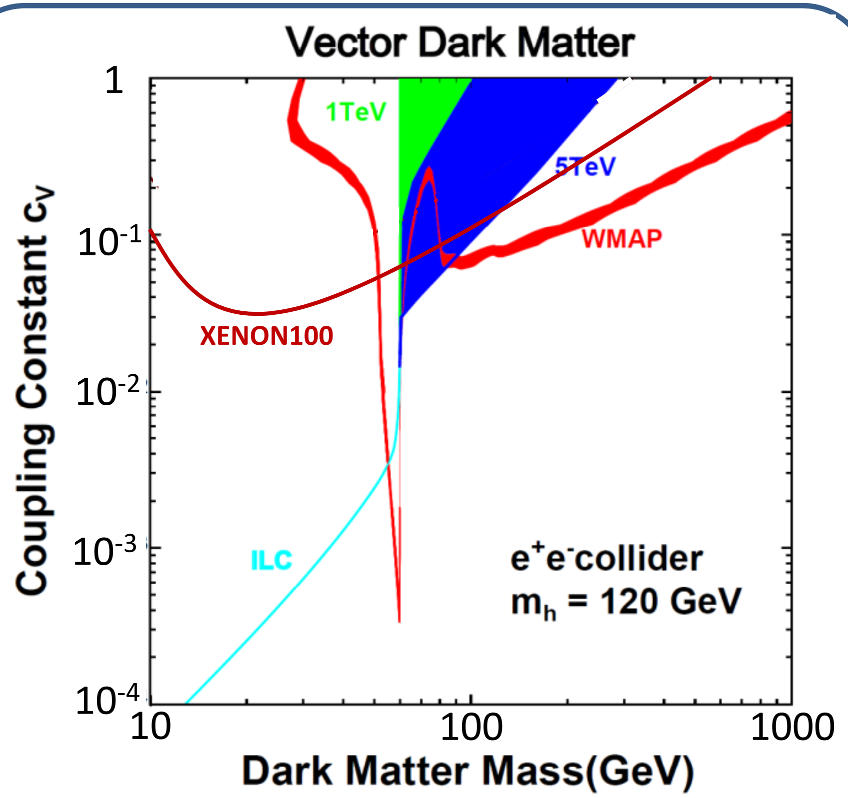


Green & Blue regions:

The green region, the Higgs portal dark matter can be explored at 3σ C.L at $\sqrt{s}$ = 1 TeV collider with $1ab^{-1}$ data.

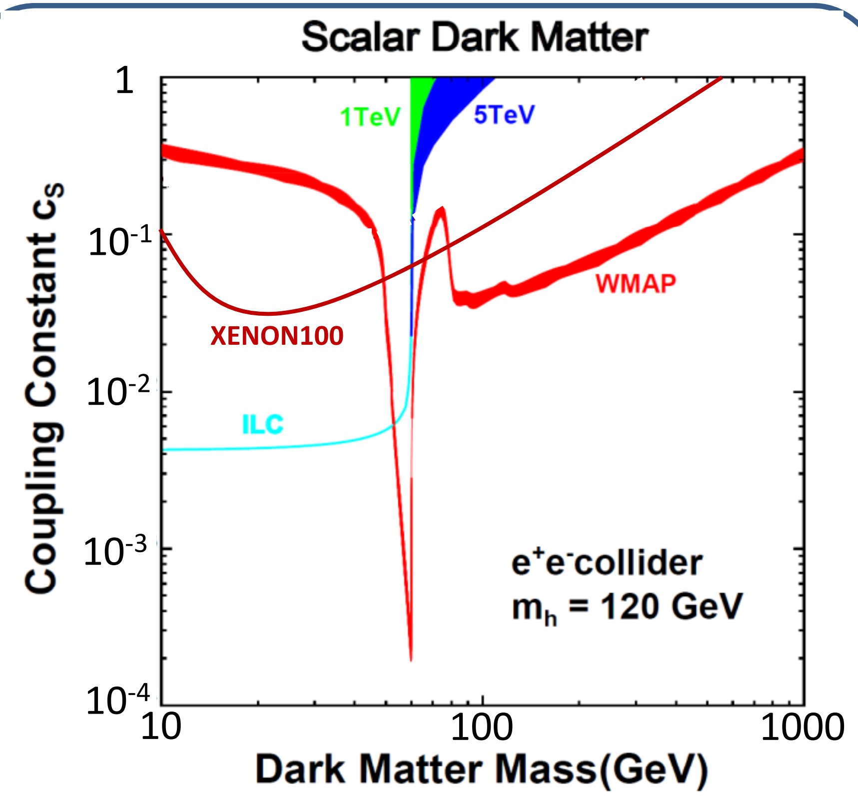
On the other hand, in the blue region, the dark matter can be explored at 3σ C.L. at $\sqrt{s}$ = 5 TeV collider with $1ab^{-1}$ data.

Results



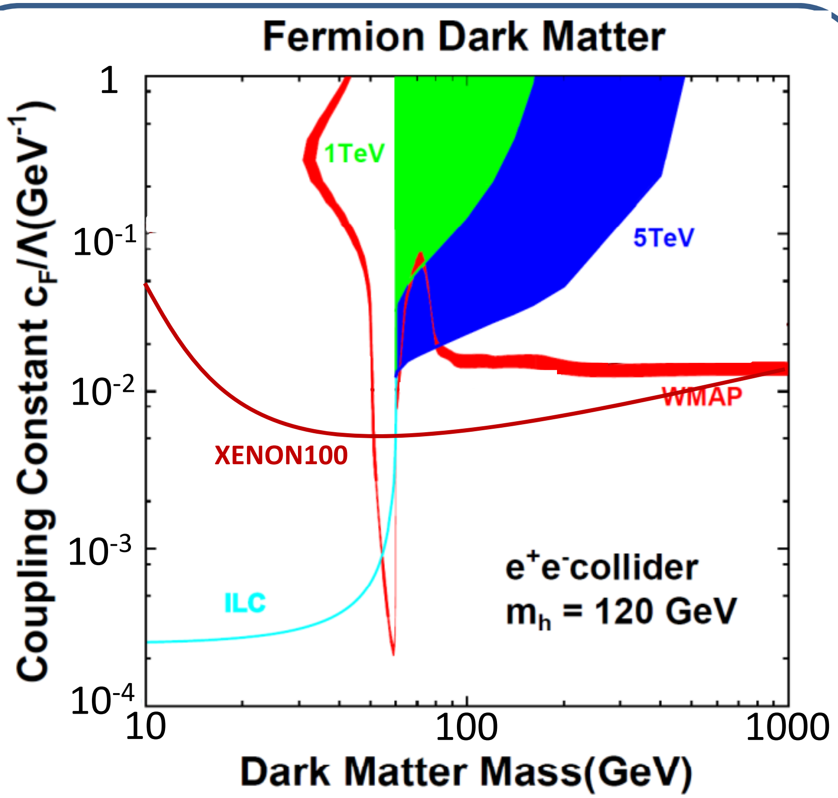
When the dark matter is vector, It can be tested with the mass up to about 100 GeV at $\sqrt{s}$ = 5 TeV collider!

Results



When the dark matter is scalar, It would be difficult to explore the dark matter when decay of the Higgs boson into a pair of dark matters is kinematically forbidden.

Results



When the dark matter is fermion, It would be excluded by current XENON100 experiment data.

Summary

① We consider the possibility to explore the Higgs portal dark matter.

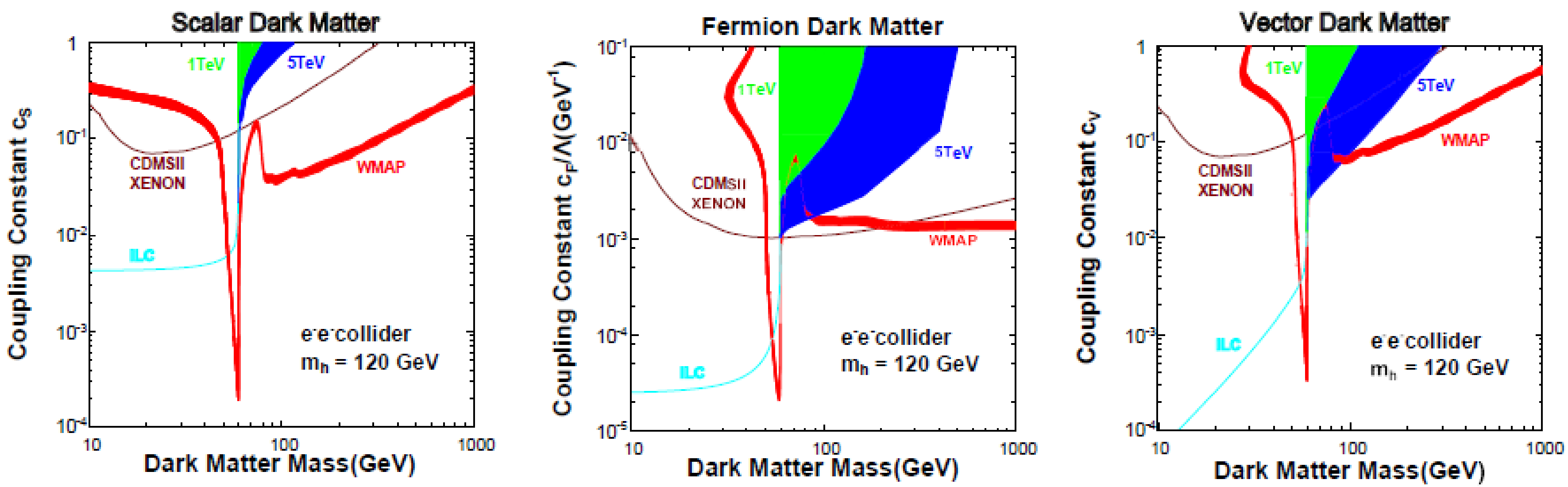
② When the decay of the Higgs boson into a pair of dark matters is kinematically allowed, it is possible to observe the signal at the LHC and ILC.

③ When the dark matter is vector, It can be tested with the mass up to about 100 GeV at $\sqrt{s} = 5$ TeV linear collider.

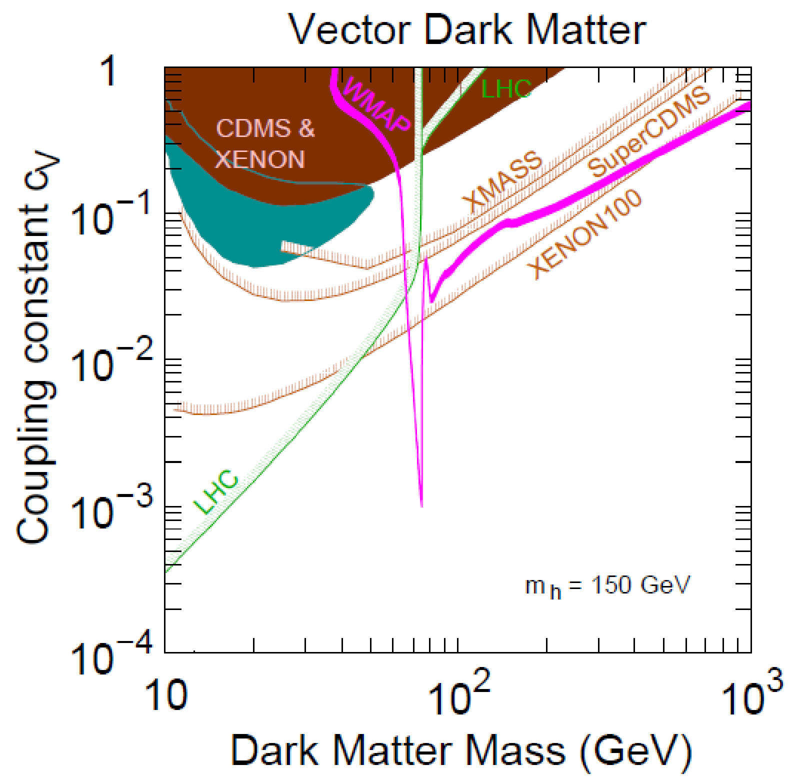
④ A multi-TeV collider can be more useful to explore the dark matter in these models than the 1 TeV collider when the invisible decay of the Higgs boson into a pair of dark matters is kinematically forbidden.

Back up

e^-e^-collider

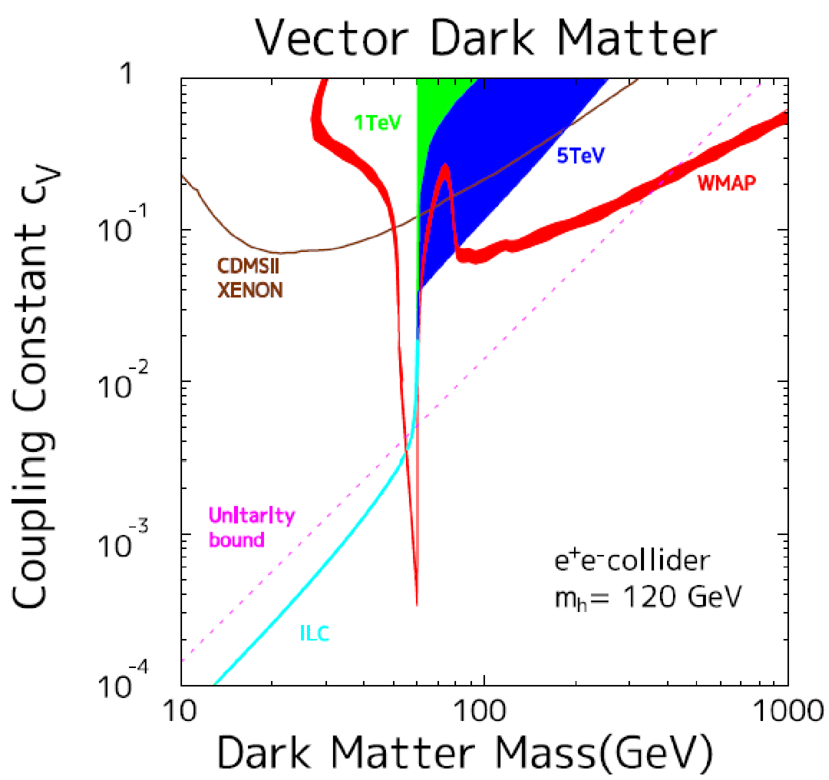


The results are very similar to those for the e^+e^- collision.



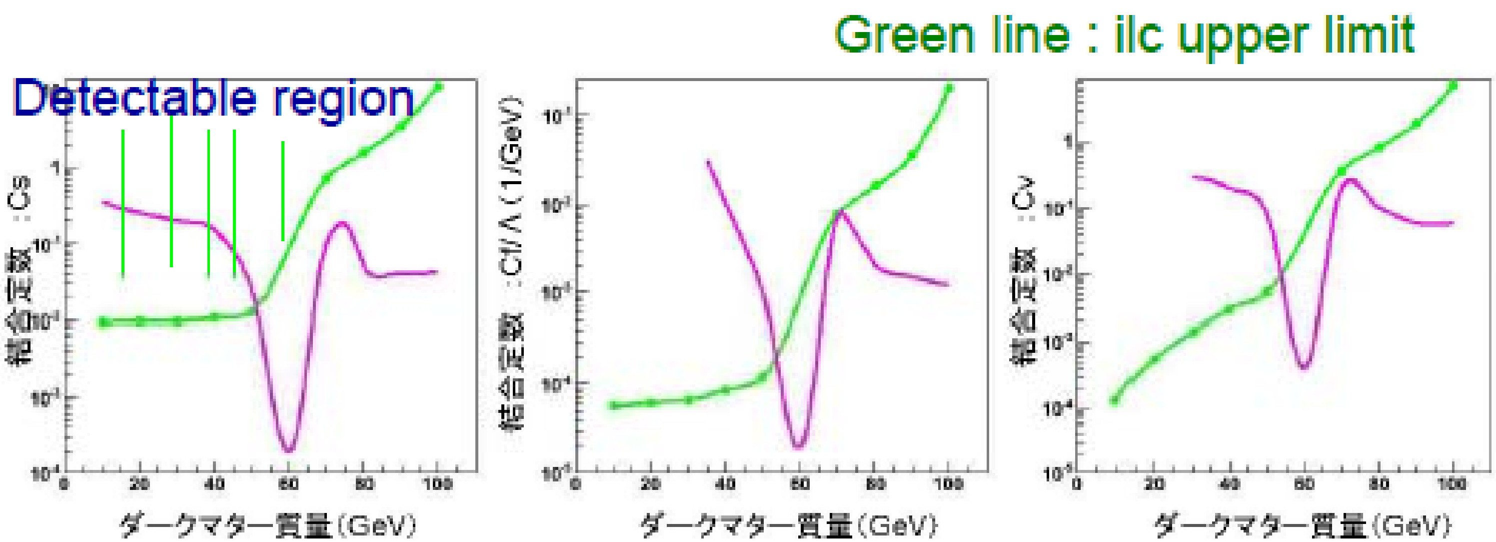
When the mass of higgs is about 150GeV, it is difficult to explore the signal even in the 5 TeV linear collider.

Unitarity bound



Unitarity bound can be relax, if we add higher dimensional operaters to the our effective Lagrangian.
Because this bound is related to O(1)TeV Lagrangian.

Results



The region above green line, the Higgs portal dark matter can be explored at 90% C.L. at $\sqrt{s}$ = 300 GeV collider with $2ab^{-1}$ data.