Testing the dark matter scenario in the inert doublet model by future precision measurements of the Higgs boson couplings

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Introduction

- In spite of the success of the SM, new physics phenomena have been observed so far.

- If origins of phenomena beyond SM are in physics at TeV scale, they are expected to be related to Higgs physics.

  → Higgs sector is extended from the minimal one.

- It is important to investigate theoretical and phenomenological properties of extended Higgs sectors for clarifying new physics phenomena.

DM and Higgs physics

- To clarify the DM is one of the top priority tasks.
- WIMP is a promising scenario for DM, in which $m_{DM}\sim$ EW scale.
- One of the simplest models for the WIMP DM scenario
  → Inert doublet model (IDM)
- DM candidate in IDM have been explored by various experiments for DM search

DM search

Direct and Indirect

Inert scalar as DM

Extra Higgs boson search @ collider

- Direct detection
- Precision measurements of $h(125)$

Extra Higgs boson search is the important approach to test DM scenario.

Contents

- Introduction
- Inert doublet model
- DM scenarios
- Testing DM scenario by *hXX* precision measurements
- Summary

Inert doublet model

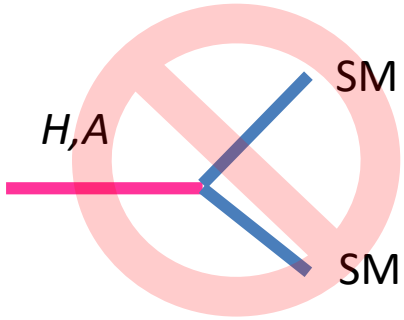
IDM contains additional isospin doublet scalar Φ_2 which is odd under a discrete Z_2 sym.

	I	Y	Z2
Φ1	1/2	1/2	+
Φ2	1/2	1/2	−

$$V = \mu_1^2|\Phi_1|^2 + \mu_2^2|\Phi_2|^2 + \frac{1}{2}\lambda_1|\Phi_1|^4 + \frac{1}{2}\lambda_2|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 + \lambda_4|\Phi_1^\dagger\Phi_2|^2 + \frac{1}{2}\{\lambda_5(\Phi_1^\dagger\Phi_2)^2 + h.c.\},$$

$$\Phi_1 = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}(h + v + iG^0) \end{pmatrix}, \qquad \Phi_2 = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}(H + iA) \end{pmatrix},$$

◆ The lightest neutral CP-odd scalar (*H* or *A*) is stable.
→ The lightest one can be a candidate of DM.
We assume that *A* is DM; i.e. $m_A < m_H$



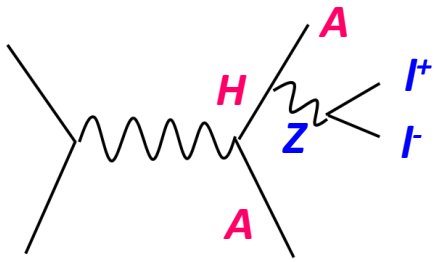
◆ Coupling constants for the vertices hφφ

$$\lambda_{hHH} = -\frac{m_H^2 - \mu_2^2}{v}, \qquad \lambda_{hAA} = -\frac{m_A^2 - \mu_2^2}{v}, \qquad \lambda_{hH^+H^-} = -2\frac{m_{H^+}^2 - \mu_2^2}{v},$$

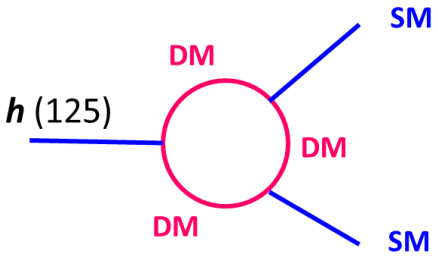
Deviations of Higgs boson couplings as a prove of DM

- Additional Higgs bosons searches(*H, A, H⁺*)

Hadron collider



- Coupling deviations from SM predictions
  - New particle loop contributions can shift the value of *hXX* from the SM prediction.
  - Accuracy of Higgs coupling measurements will be especially improved.



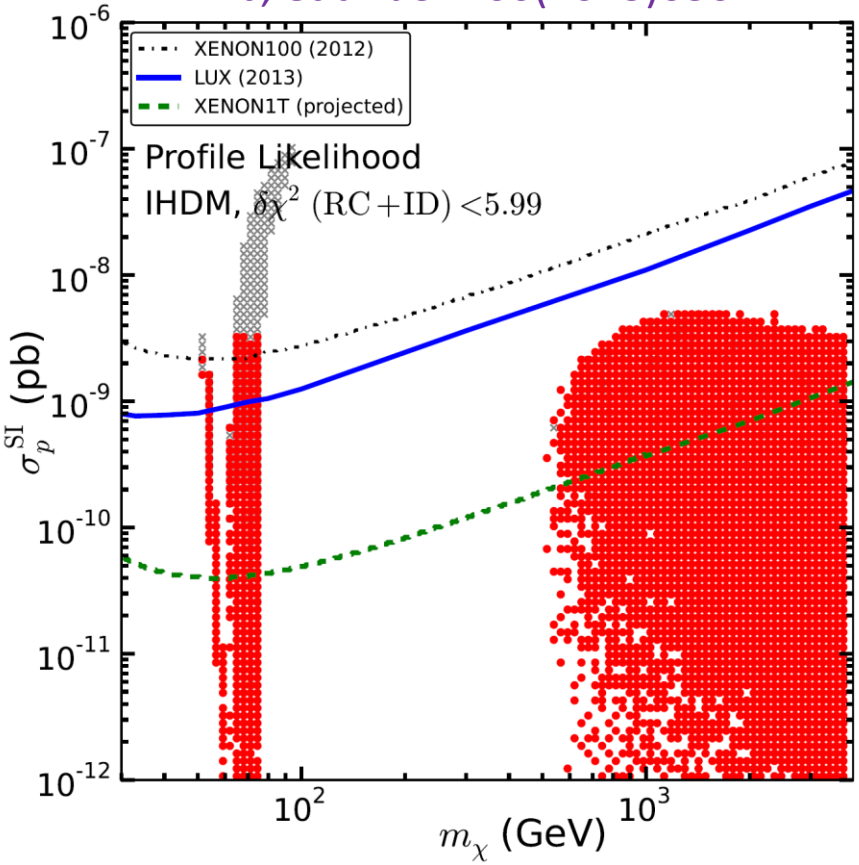
Expected measurement uncertainties of κ_Z (1σ)

LHC(300)	HL-LHC	ILC(250+500)
4%	2%	0.24%

Probe of DM may appear in deviations in the Higgs boson couplings.
→ We investigate the testability of DM scenarios by using precision measurement of Higgs boson couplings.

DM scenarios

Arhrib, et al. JCAP06(2013)030



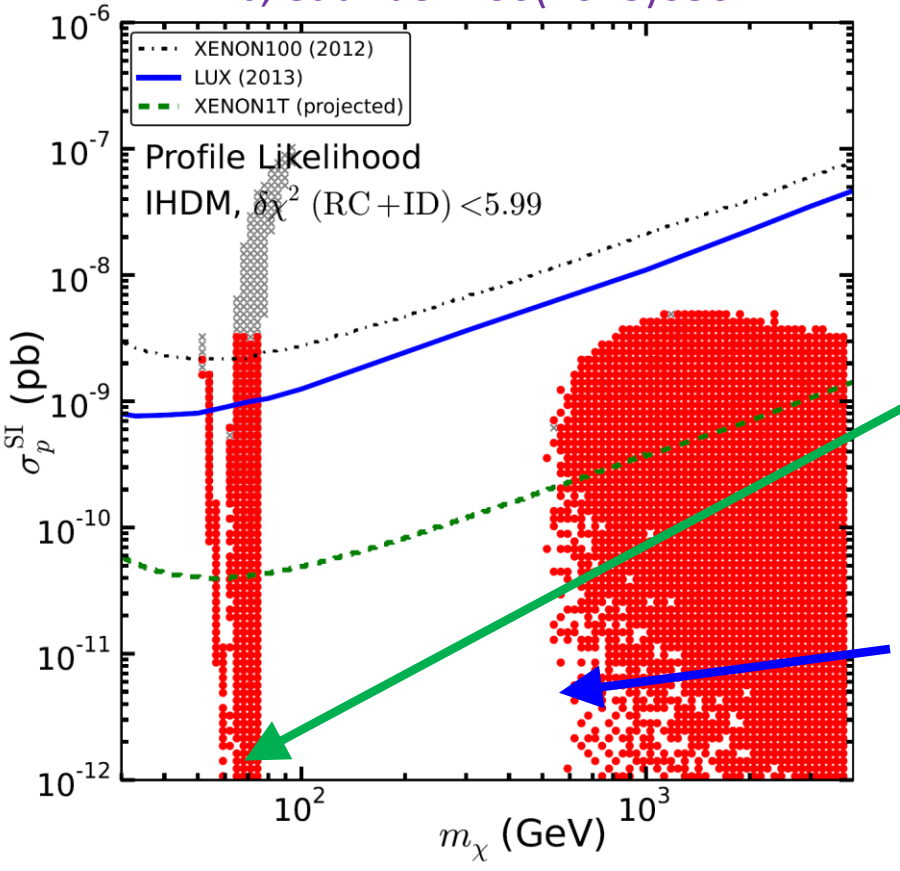
Regions satisfying Relic density

- It is hard to completely explore the remaining region at future experiments of direct searches.

Can we test DM scenarios in the challenging regions of direct searches by using future precision measurements of Higgs boson couplings?

DM scenarios

Arhrib, et al. JCAP06(2013)030



Regions satisfying Relic density

◆Bench mark scenarios

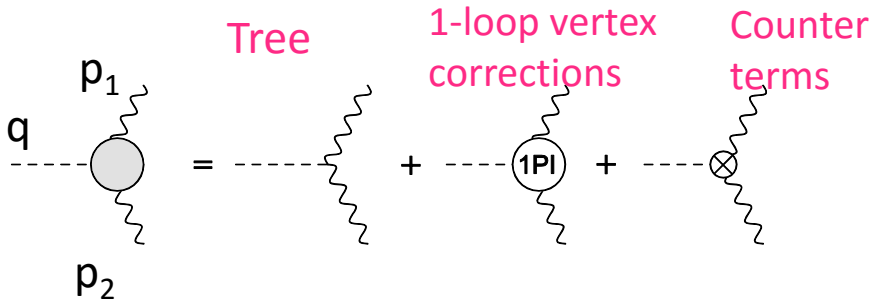
Scenario A : ($\Omega h^2 \simeq 0.01$)
m_A = 65 GeV , $\lambda_{hAA} \sim O(10^{-13})$

Scenario B : ($\Omega h^2 < 0.01$)
m_A = 500 GeV , $\lambda_{hAA} \sim O(10^{-13})$

Our work

- We calculate the renormalized *hZZ* couplings at the 1-loop level by on-shell scheme.

$$\Gamma_{hZZ}^{THDM}[p_1^2, p_2^2, q^2] =$$



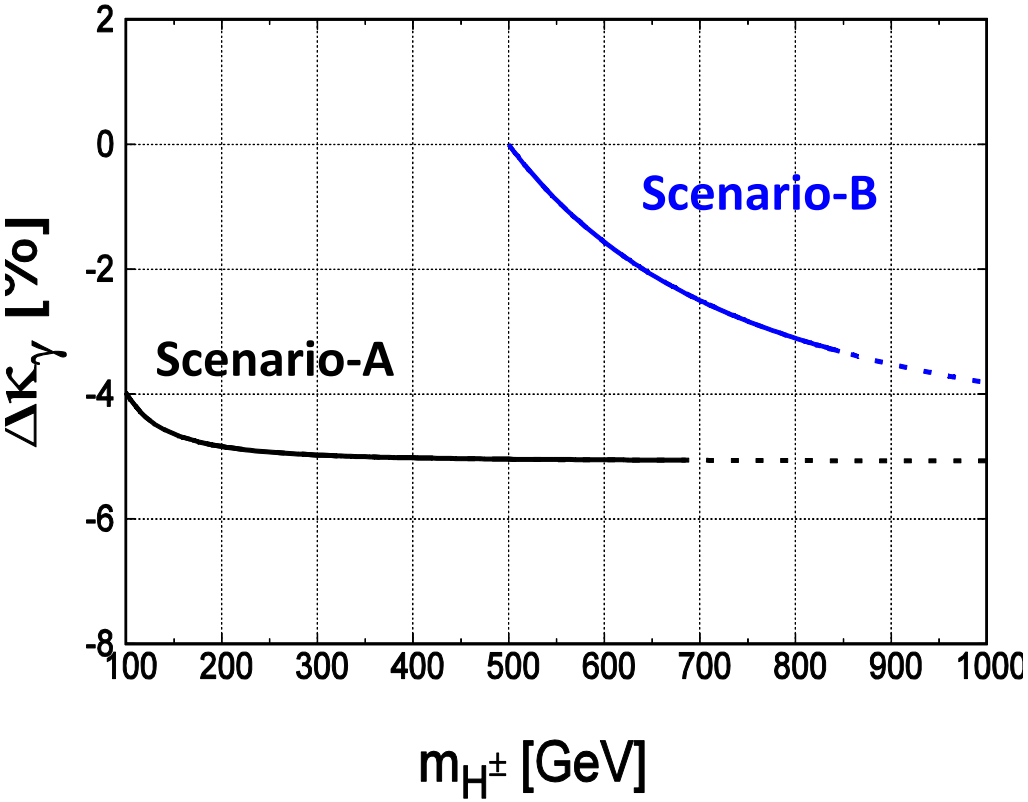
- We numerically evaluate deviations of one-loop scaling factors from unity Δκ

$$\Delta\kappa_V \equiv \frac{\Gamma_{hVV}^{HSM}\left[\left(m_h + m_V\right)^2, m_V^2, m_h^2\right]}{\Gamma_{hVV}^{SM}\left[\left(m_h + m_V\right)^2, m_V^2, m_h^2\right]} - 1$$

- We also numerically calculate the deviation on the decay rate of the process $h \to \gamma\gamma$ from the SM prediction at the one-loop level

$$\Delta\kappa_\gamma \equiv \sqrt{\frac{\Gamma[h \to \gamma\gamma]_{\mathrm{IDM}}}{\Gamma[h \to \gamma\gamma]_{\mathrm{SM}}}} - 1.$$

$h \to \gamma\gamma$



$$\Gamma^{IDM}_{h\to\gamma\gamma} = \frac{\sqrt{2}G_F\alpha^2_{cm}m_h^2}{256\pi^3}|\lambda_3 I_S + C_F + C_V|^2$$

$$\simeq \frac{\sqrt{2}G_F\alpha^2_{cm}m_h^2}{256\pi^3}\left|-\frac{1}{3}\left(1-\frac{\mu_2^2}{m^2_{H+}}\right) + C_F + C_V\right|^2$$

Scenario-A : $\mu_2 \simeq 65$ GeV

Scenario-B : $\mu_2 \simeq 500$ GeV

LHC Run-I data (ATLAS+CMS) 1σ

$$\Delta\kappa_\gamma = -10^{+10}_{-9}\%$$

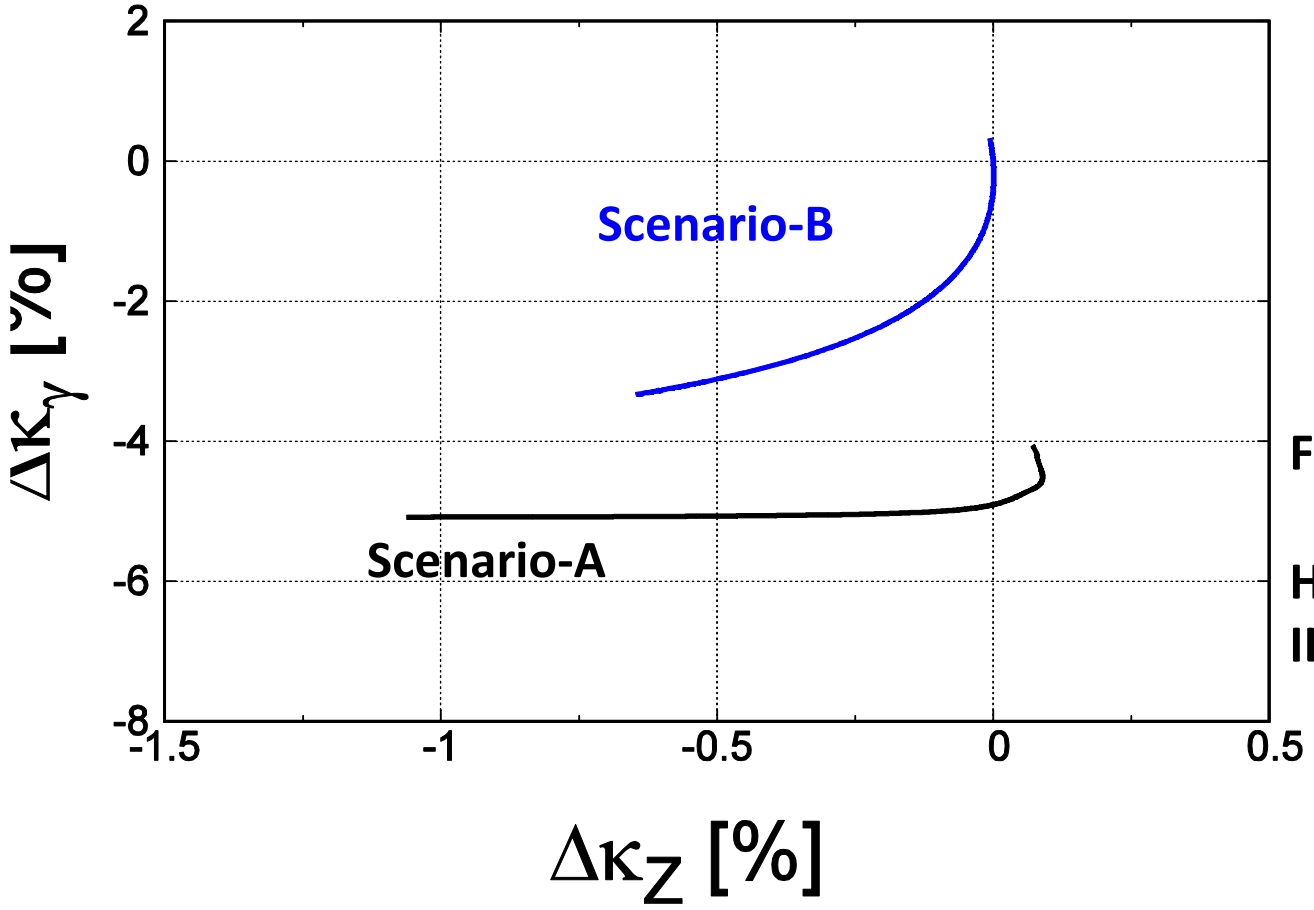
High Luminosity LHC 1σ

$$\sigma(\kappa_\gamma) = 2-4 \quad \%$$

In Scenario A, *hγγ* coupling deviates from the SM prediction by about -4 %.

We can test Scenario A by the precision measurement of hγγ at LHC.

$\Delta\kappa_Z$ VS $\Delta\kappa_\gamma$



Future prospects

HL-LHC : κ_γ 2% (1σ)
ILC500up : κ_Z 0.24% (1σ)

DM scenarios can be discriminated by precision measurements of *h*→γγ and *hZZ*.

If $\Delta\kappa_Z$ is measured to be smaller than -1%, Scenario-A and B are excluded.

Summary

- We investigate the possibility to test Inert DM scenarios in the challenging regions of direct searches by using future precision measurements of Higgs boson couplings.

- In Light DM scenario, $h \to \gamma\gamma$ deviates by about 4% from the SM prediction.

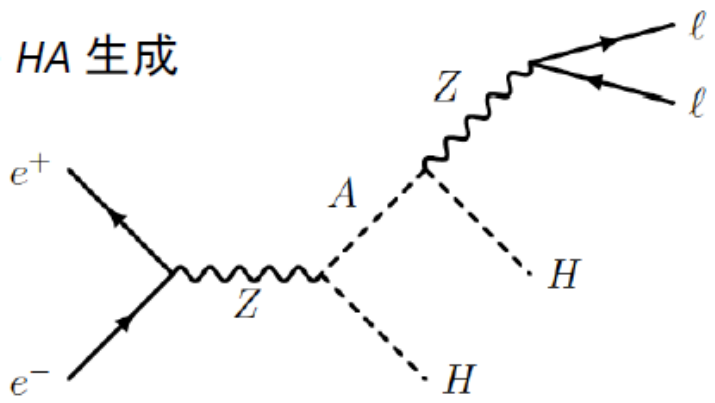
  → Testable at LHC

- In Inert DM scenario, $|\Delta\kappa Z|$ cannot be larger than 1%.
  → If such deviation is measured in hZZ at ILC, Inert DM scenarios are excluded.

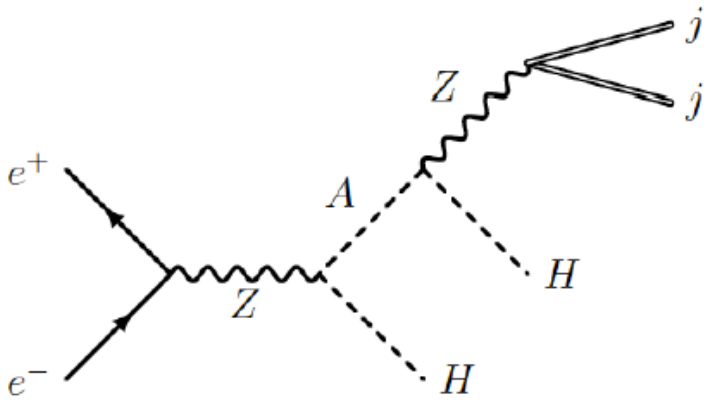
Direct search for extra scalar @LC

M. Hashemi, M. Krawczyk, S. Najjari, A. F. Zarnecki, arXiv:1512.01175

- *HA* 生成

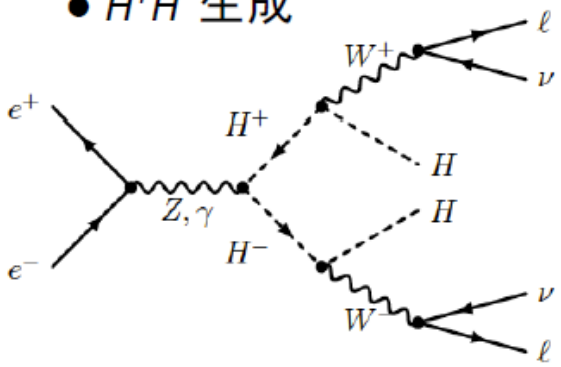


$e^+e^- \to HA \to \ell^+\ell^- HH$

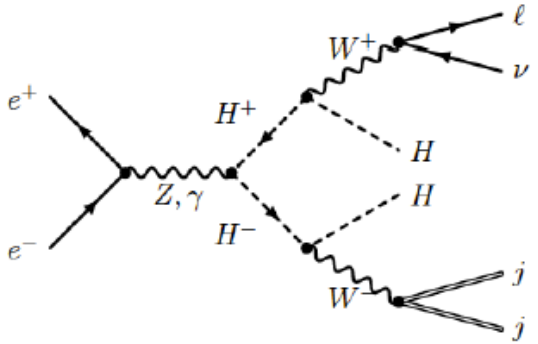


$e^+e^- \to HA \to jjHH$

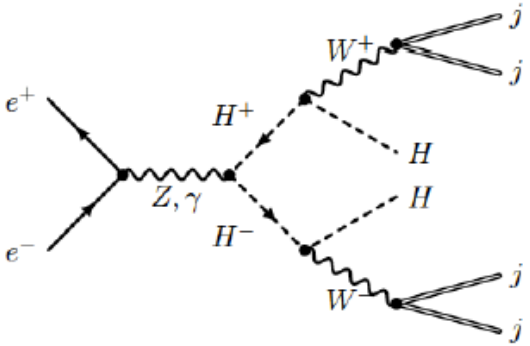
- H^+H^- 生成



$e^+e^- \to H^+H^- \to \ell^+\nu\ell^-\nu HH$

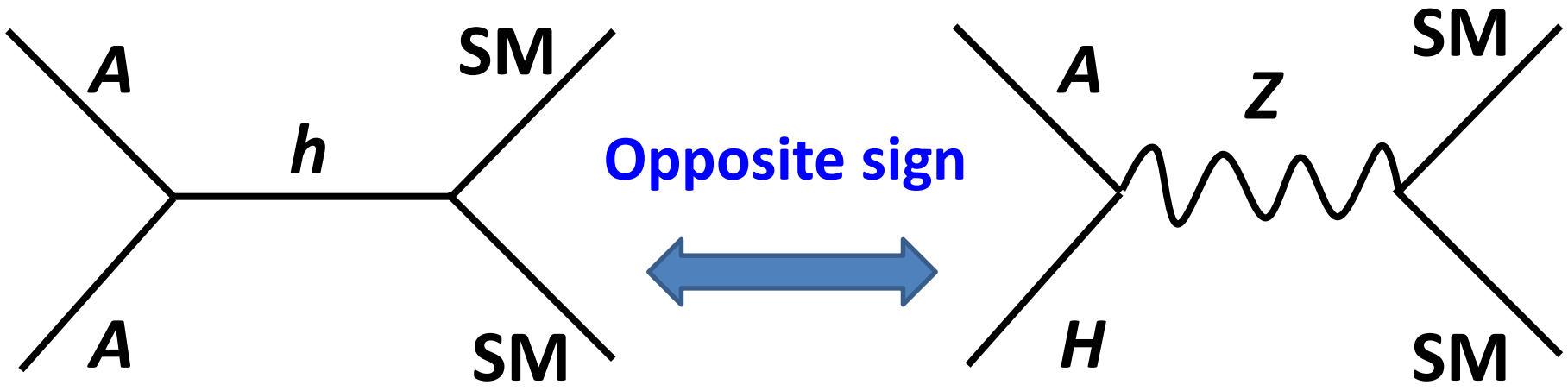


$e^+e^- \to H^+H^- \to \ell^+\nu jjHH$



$e^+e^- \to H^+H^- \to jjjjHH$

Relic abundance



~ $\exp(-m_H+m_A)$

If the difference between mH and mA increase (~O(10) GeV), cross section of co-annihilation process becomes to be small.

$\Omega h2 \lesssim 0.11$

In case with mA = 500 GeV and mH-mA > O(10) GeV, another DM candidate exist apart from *A*.