Determination of Dark Matter Properties in the Littlest Higgs Model with T-parity

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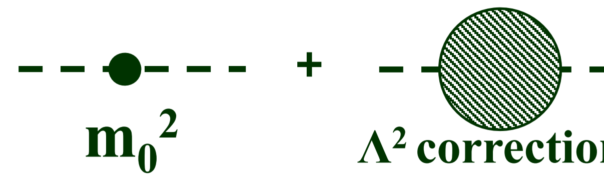
SM is the successful model describing physics below ~ 100 GeV.
But,

- ## Hierarchy Problem

  related to quadratic divergence to the **Higgs boson mass** term.

  $m_h^2 =$ 

  - □ **Fundamental particle**

    The quadratic divergence has to be removed. ⇨ **SUSY**

  - □ **composite particle**

    Little hierarchy prob.

    There is no fine-tuning problem, if $\Lambda \sim 1\,\text{TeV}$

    Experimental results require $\Lambda \gtrsim 5\,\text{TeV}$ ⇨ **LH**

    R.Barbieri and A.Strumia ('00)

- ## Dark Matter

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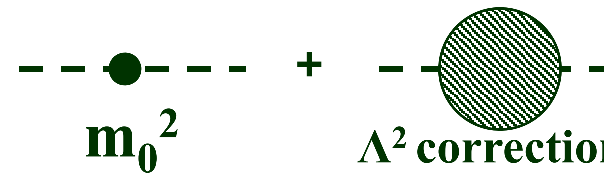
$m_h^2 =$ 

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Experimental results $\rightarrow$ $\Lambda \gtrsim 5\,\mathrm{TeV}$ ⇨ **LH**

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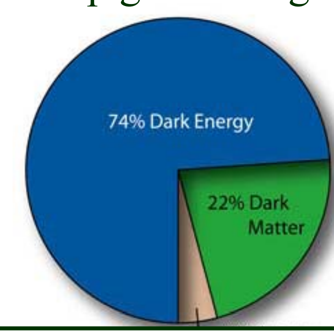
■ Dark Matter

http://map.gsfc.nasa.gov/

Existence of cold dark matter is established by WMAP.



⟹ **WIMP are CDM candidate.**
(Weakly Interacting Massive Particles)

- □ Neutral
- □ Massive
- □ Stable

However, There is no **WIMP** in the SM.

$$\Omega_\chi h^2 \sim \left(\frac{m_\chi}{1\ \mathrm{TeV}}\right)^2 \sim 0.1$$

⇨ the dark matter should be included in physics beyond the SM at **TeV**

The Littlest Higgs Model with T-parity is a new possibility for physics at TeV. This model can solve the **little hierarchy problem**. Moreover, there are new particles (e.g. W_H, Z_H, …) including a **DM** candidate (A_H).

We study the collider phenomenology of new particles in this model, and estimate the accuracy of extracted new particle mass (We mainly consider e+e- → $W_H W_H$ process in this study). **Using this result, we reproduce the DM relic abundance which can be compared with cosmological observations.**

Plan

- Introduction
- Details of the Littlest Higgs model with T-parity
- Process and sample points
- Simulation results and cosmological connection
- summary

Littlest Higgs Model with T-parity

non-linear sigma model describing **SU(5)/SO(5)** symmetry breaking

gauge group $[SU(2)\times U(1)]^2 \longrightarrow SU(2)\times U(1) \longrightarrow U_{em}(1)$

VEV f ~ O(1) TeV $\qquad \langle h \rangle$

To confirm the Littlest Higgs model with T-parity, We should measure the parameters f . We will measure f using $e^+e^- \to W_H^+W_H^-$ in ILC.

dark matter candidate

New particles ⟶ **T-odd**

Z_H

	Higgs	EW gauge	fermion		
	H	W_{SM}	ψ_{SM}		⟵ T-even
NEW	Φ_H	W_H	ψ_H	$m \propto f$	⟵ T-odd

top

t-T_+ mixing

t_{SM}	T_+
t_H	T_-

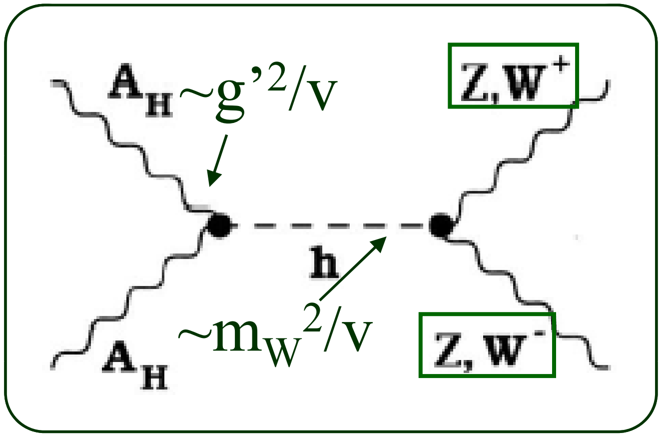
Allowed region for WMAP

J.Hubisz and P.Meade ('05)

- Lightest T-odd particle: A_H

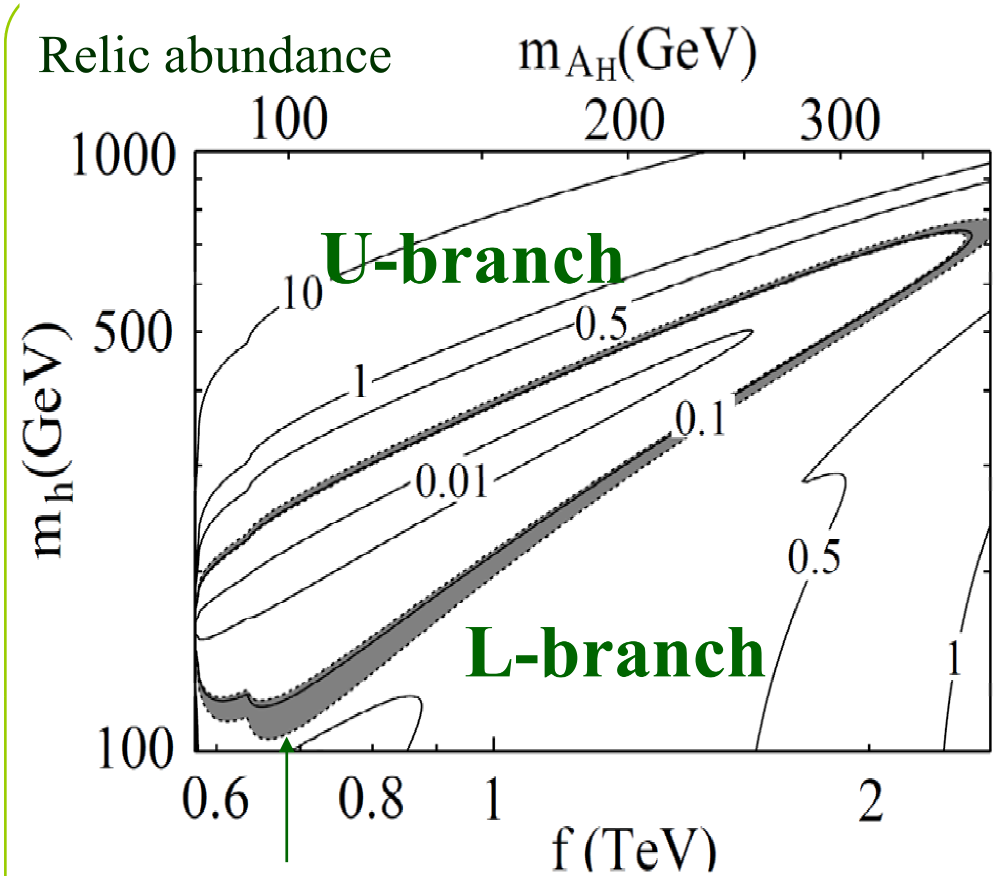
$$m_{A_H} \simeq \frac{g'}{\sqrt{5}} f$$

- A_H annihilates into W, Z



main

➡ **Relic density depends only on f & m_h**



Allowed region for WMAP at 2σlevel

$$0.094 < \Omega h^2 < 0.129$$

M. A, S. Matsumoto, N. Okada, Y. Okada PhysRevD.75.063506

- **In each branch, m_h is determined by f.**

Process & Sample Points

In this model, there are many new heavy particles.

T-odd A_H, $W_H^{\pm}$, Z_H, Φ | t_- T_- | b_- · · ·

Gauge-Higgs sector | Top sector | fermion sector

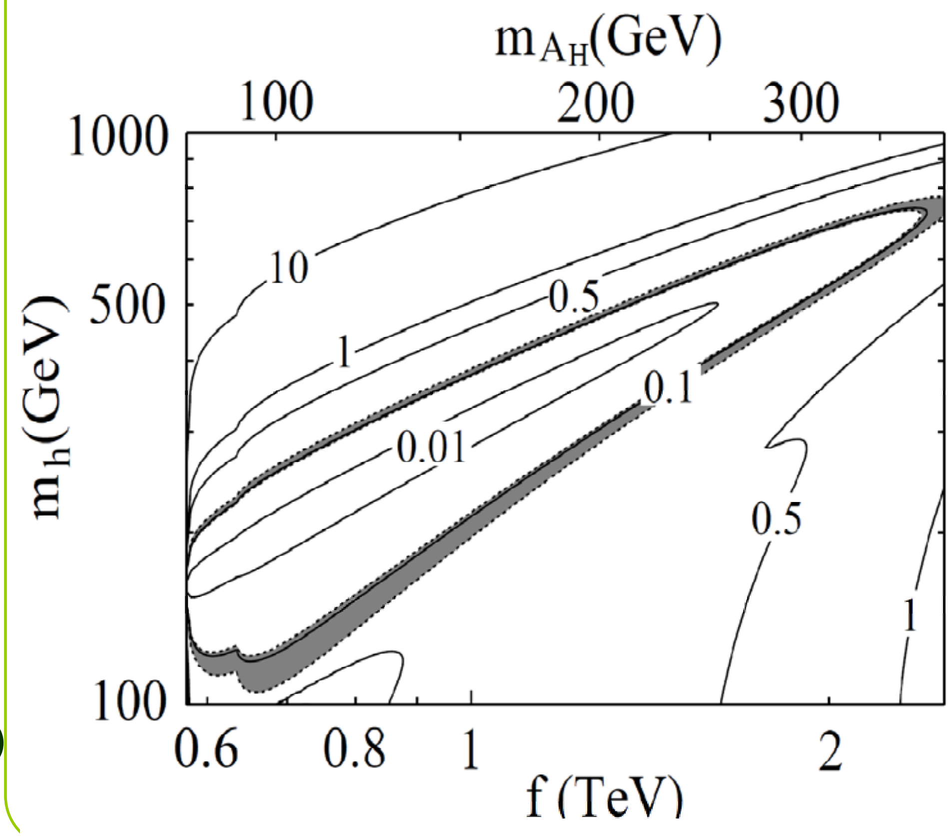
Which particle can produced at the ILC ? → It depends on VEV **f** .

- Direct production of A_H
  (e.g. e+e- → $A_H Z_H$)
  will be possible in ILC.
  - Because AH is missing particle, it is slightly difficult to measure mA_H precisely.

  ⇨ Kusano san's talk

- $W_H W_H$ production
  (e.g. e+e- → $W_H W_H$ → $WWA_H A_H$)
  will be possible in the area.

Relic abundance



Which particle can produced at the ILC ? → It depends on VEV **f** .

- Direct production of AH

  (e.g. e+e- → $A_H Z_H$)

  ⇨ Kusano san's talk

- WHWH production

(e.g. e+e- → $W_H W_H$ → $WWA_H A_H$)

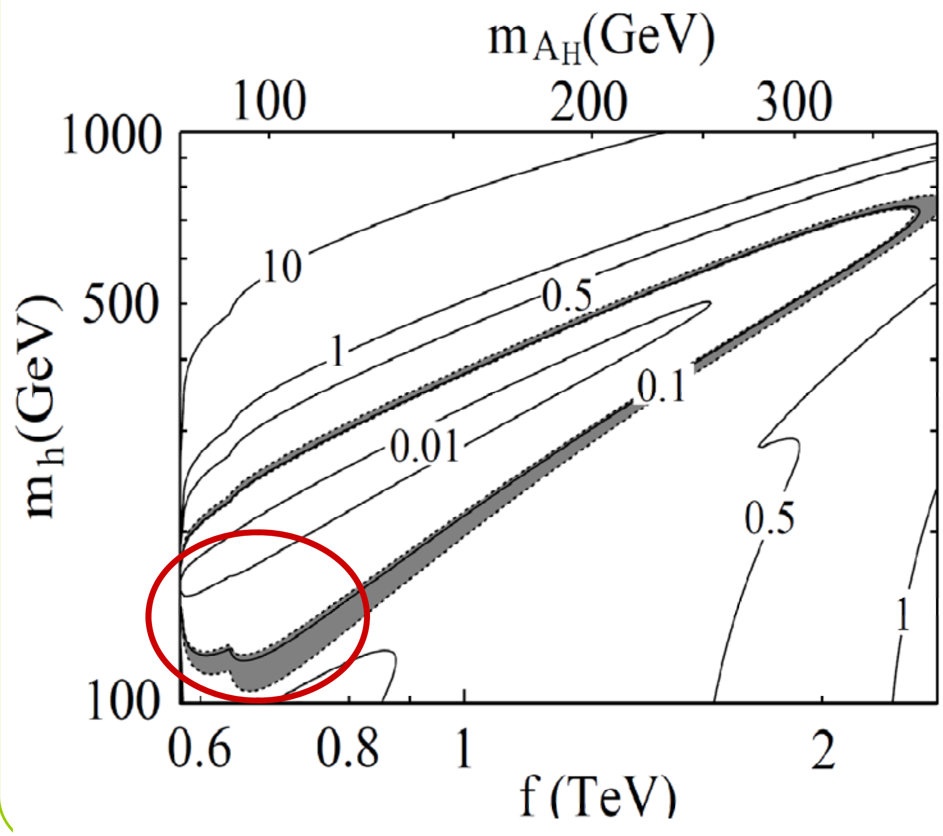
will be also possible in the area

Qing-Hong Cao et. al. 0707.0877

- we can measure the mAH precisely using the two standard weak gauge boson.

$(W_H^{\pm} \to A_H + W^{\pm}$ with 100% branching ratio!)

Relic abundance

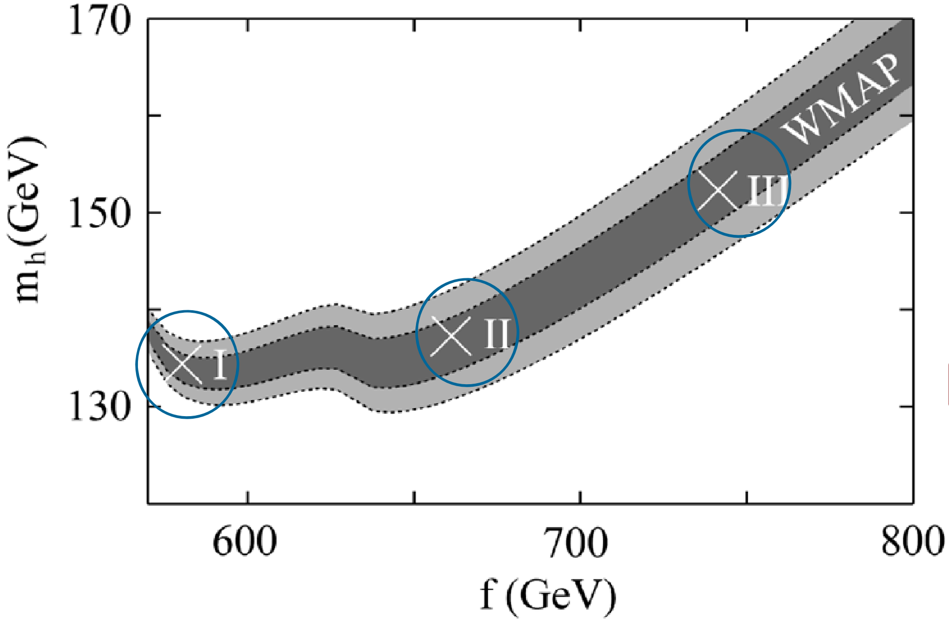


- In this region, Higgs mass is also small. Small Higgs mass region is also favored by EW Precision Measurements.

We study the WHWH pair production process.

We focuse on WHWH process in 1 TeV ILC.

Our sample points

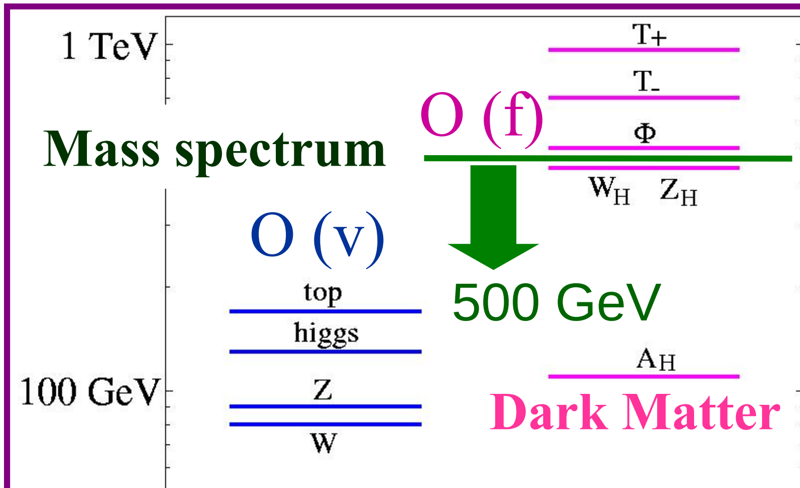


Mass spectrum

	Point I	Point II	Point III
f	580 (GeV)	660 (GeV)	740 (GeV)
m_h	134 (GeV)	137 (GeV)	152 (GeV)
$\Omega_{\rm DM}h^2$	0.106	0.104	0.106
m_{A_H}	81.9 (GeV)	95.9 (GeV)	110 (GeV)
m_{W_H}	368 (GeV)	421 (GeV)	474 (GeV)
m_{Z_H}	369 (GeV)	422 (MeV)	474 (MeV)
m_{Φ}	440 (GeV)	513 (GeV)	640 (GeV)

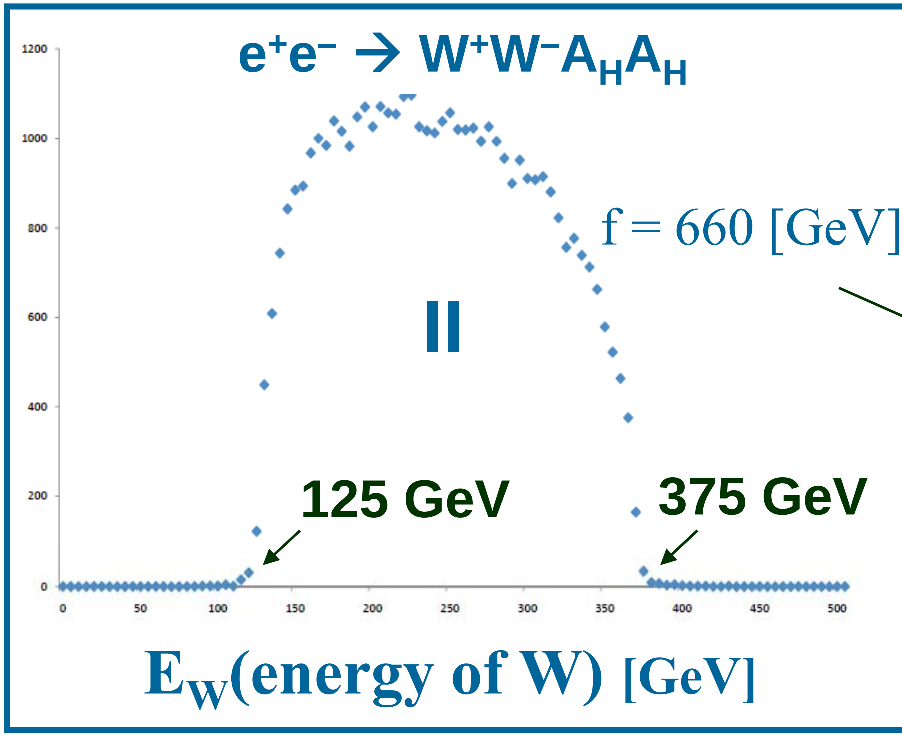
- All sample points satisfy all experimental & cosmological constraints.
- Heavy gauge bosons turns out to be less than 500 GeV.

  → It is possible to produce them in pair at the ILC.



Simulation at ILC

We have done the simulation using **CalcHep**. Because the **simulation shows end points clearly,** It allow us to extract the property of DM.



Integrated Luminosity: 500fb$^-$

From this E_W, we get

f = 656.1 [GeV]

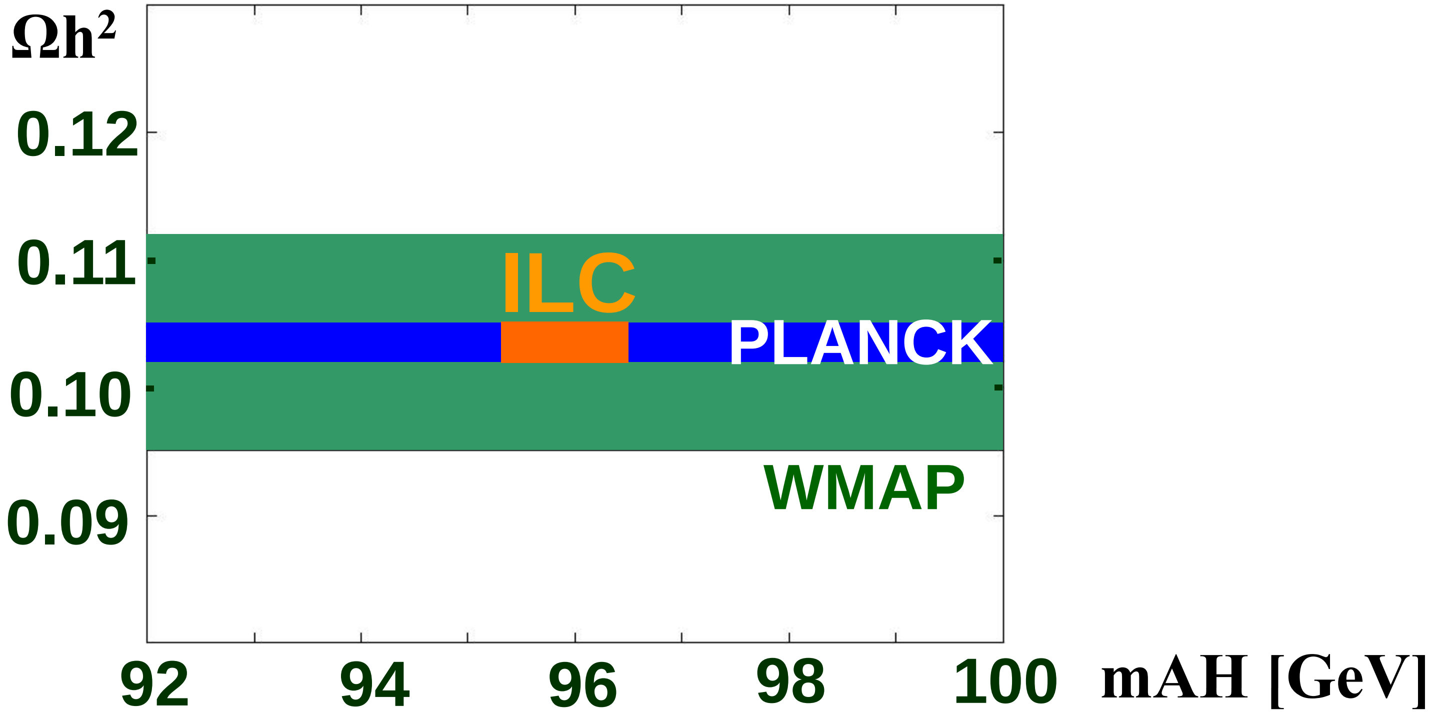
δ= **0.6% accuracy**

DM mass is determine less than 2% accuracy.

[Model dependent]

Cosmological Impact

We reproduce the DM abundance from parameters which will be determined by ILC.



- Because DM mass and Higgs mass is determined precisely, the DM abundance is also determined precisely less than 2%.
- It is possible to consistency check of the model using PLANCK.

Summary

- **Littest Higgs model with T-parity** is one of attractive models for physics beyond the SM.
- From the **WMAP** observation, heavy gauge bosons will be copiously produced at the **ILC**.
- $\mathbf{e^+e^- \rightarrow W_H W_H}$ is the best process to investigate the property of the DM predicted in the model.
- Simulation shows **the clear edge** in signal events, which allow us to extract the model parameters precisely.
- Results obtained from the collider experiments will be compared to those from astrophysical experiments
- DM abundance is determined precisely with uncertainty which less than 2%. It is possible to consistency check of the model using PLANCK.