Measurements of the model parameter in the Littlest Higgs Model with T-parity

Masaki Asano
(ICRR, Univ. of Tokyo)

Collaborator: E. Asakawa (Meiji-gakuin Univ.),
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LHT

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Littlest Higgs model with T-parity (LHT) is one of attractive models for TeV new physics. LHT could solve the **little hierarchy problem**, and contains **a dark matter candidate**.

In LHT,

	Gauge boson	fermion	Higgs
SM	g W Z A	q l	H
NEW	W_H Z_H A_H	q_H l_H	Φ_H

- Particles & these partners are same spin.
- New particles get mass by VEV $f \sim 1$ TeV.
  (New gauge boson masses depend only on VEV f.)

In this study, we estimate…

- measurement accuracy of new gauge boson masses
- determination of VEV f
- determination of new particle spins @ ILC.

Plan

- Introduction
- What is the LHT?
- How to measure the LHT at ILC?
- Simulation results
- Summary

What is the LHT?

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

Hierarchy problem

(related to quadratic divergence to the Higgs mass term)

If we assume that

SM is valid all the way up to the GUTs scale, Λ~10^{15} GeV,

$$m_h^2 = m_0^2 + \Lambda^2$$

$$100^2 \Leftrightarrow 1000000000000000^2$$

EW scale higgs mass require

Fine-tuning!

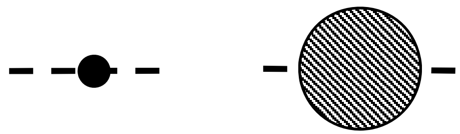
The SM is the successful model describing physics below ~ 100 GeV.
But ...

Hierarchy problem

(related to quadratic divergence to the Higgs mass term)

If we require that

there are no fine-tuning for Higgs mass m_h,



$$m_h^2 = m_0^2 + \Lambda^2$$

$$100^2 \Leftrightarrow 1000^2$$

No fine-tuning ⇨ Cut off scale $\Lambda \sim 1\ \text{TeV}$

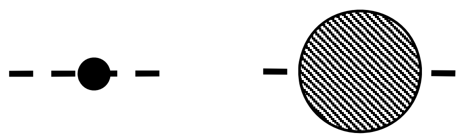
The SM is the successful model describing physics below ~ 100 GeV.
But ...

Hierarchy problem

(related to quadratic divergence to the Higgs mass term)

However…

LEP experiments require that the cut off scale is larger than 5 TeV!



$$m_h^2 = m_0^2 + \Lambda^2$$

$$100^2 \Leftrightarrow 5000^2$$

Still fine-tuning appear!

No fine-tuning ⇒ Cut off scale $\Lambda \sim 1\ \mathrm{TeV}$

LEP experiments ⇒ $\Lambda \gtrsim 5\ \mathrm{TeV}$

Little Hierarchy problem!

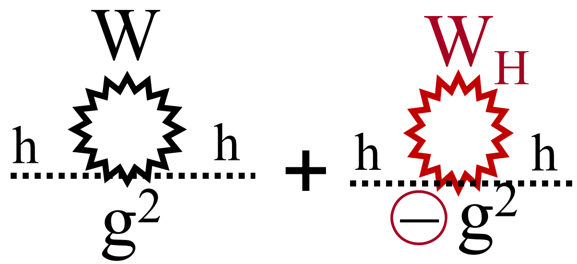
R.Barbieri and A.Strumia ('00)

Little Higgs model with T-parity is solution of little hierarchy problem!
Even if Λ ~ 10TeV, there are still no fine-tuning,

Because of …

- **Collective symmetry breaking (VEV f)** N. Arkani-Hamed, A. G. Cohen, H. Georgi ('01)

  - Higgs boson is regarded as **Pseudo NG boson** of a global symmetry at some higher scale.
  - Explicit breaking of the global symmetry is specially arranged to **cancel quadratic divergent corrections to m_h** at 1-loop level by new gauge bosons and fermions.

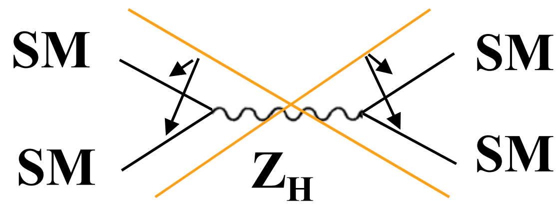


⇨ **Little Higgs mechanism**

- **T-parity** H. C. Cheng, I. Low ('03)

  In order to avoid constraints from EWPM, Z_2 symmetry called T-parity are introduced.

  SM ⇔ SM, New ⇔ - New



The model contains dark matter candidate! (Heavy photon A_H)

In order to Implement the Little Higgs Mechanism…

- LHT is based on the non-linear sigma model breaking **SU(5)/SO(5)** symmetry breaking.
- The subgroup **$[SU(2)\times U(1)]^2$** in SU(5) is gauged, which is broken down to the SM gauge group by vev **f**.

gauge group — VEV

$[SU(2)\times U(1)]^2$

$\downarrow \longleftarrow$ **f** $\sim$ O(1) TeV

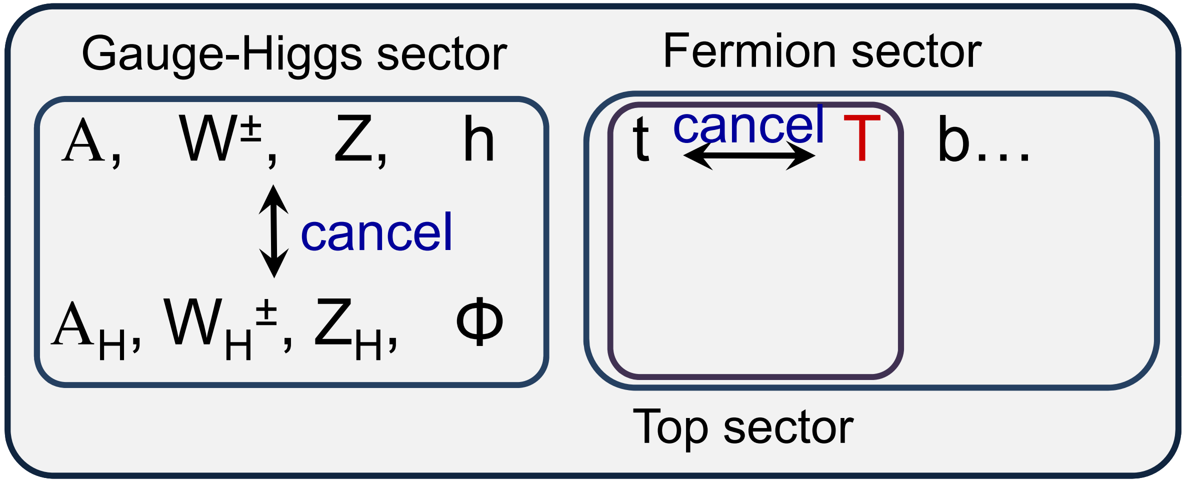
$[SU(2)\times U(1)]_{SM}$

$\downarrow \longleftarrow \langle h \rangle$

$U_{em}(1)$

[Arkani-Hamed, Cohen, Katz and Nelson (2002)]

Particle contents



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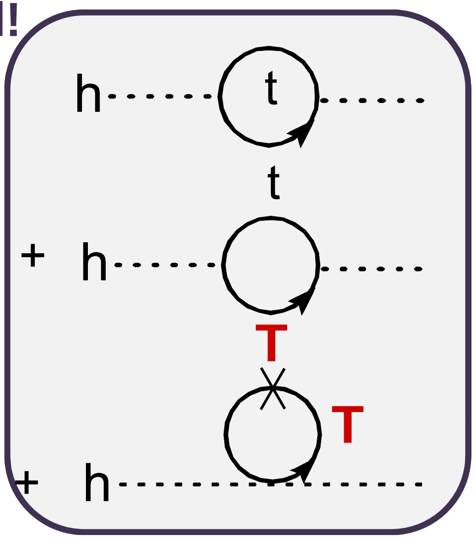


Due to the cancelation of quadratic divergences, partners are introduced. In the fermion sector, only top partner is required to cancel the quadratic divergences because other fermion Yukawa couplings are small.

In order to Implement the Little Higgs Mechanism…

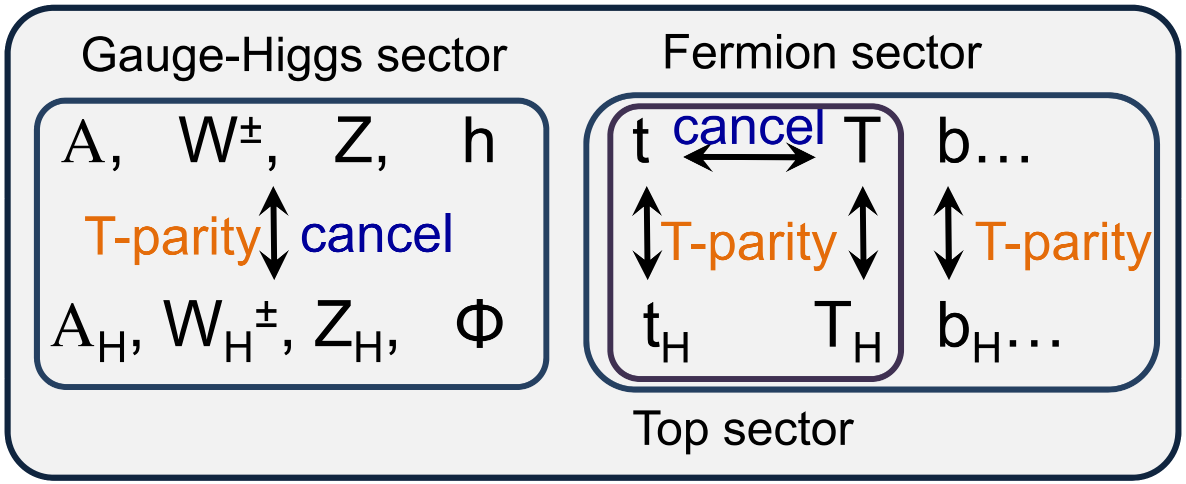
- LHT is based on the non-linear sigma model breaking **SU(5)/SO(5)** symmetry breaking.
- The subgroup **$[SU(2)\times U(1)]^2$** in SU(5) is gauged, which is broken down to the SM gauge group by vev **f**.

gauge group VEV

$$[SU(2)\times U(1)]^2$$
$$\downarrow \longleftarrow \quad f \sim O(1)\ \text{TeV}$$
$$[SU(2)\times U(1)]_{SM}$$
$$\downarrow \longleftarrow \quad \langle h \rangle$$
$$U_{em}(1)$$

[Arkani-Hamed, Cohen, Katz and Nelson (2002)]

Particle contents



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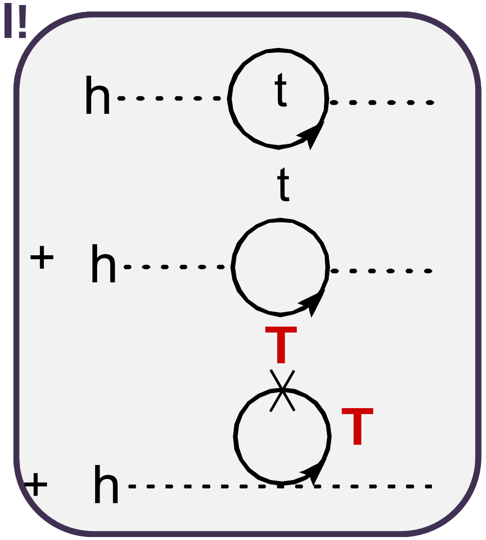
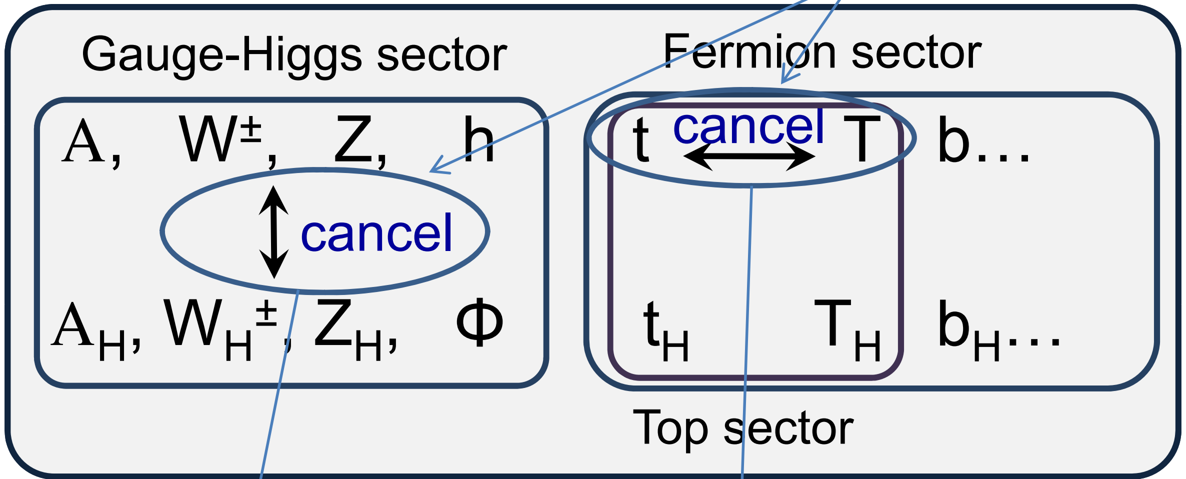


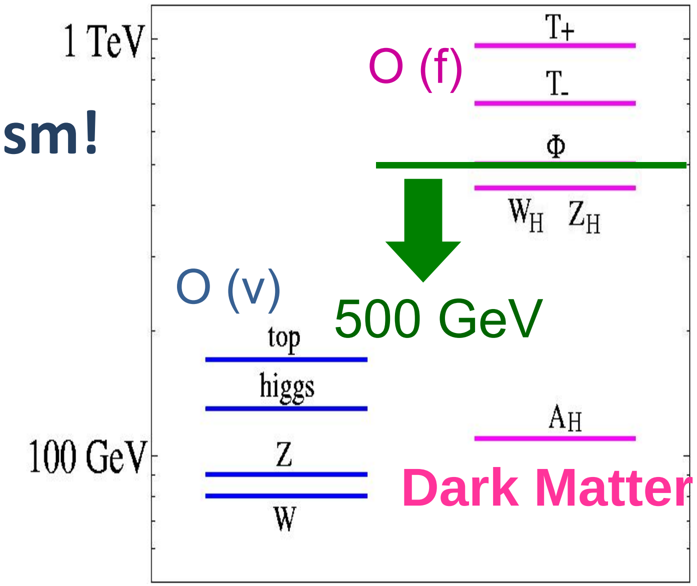
In order to implement the T-parity…

T-odd partners are introduced for each fermions.

How to measure the LHT at ILC?

In order to verify the LHT,
we should measure the **Little Higgs mechanism!**





S. Matsumoto, T. Moroi, K. Tobe (08) and …….

Top sector

- can be measured at LHC.
- too heavy to produced at ILC.

Q. H. Cao, C. R. Chen (07)

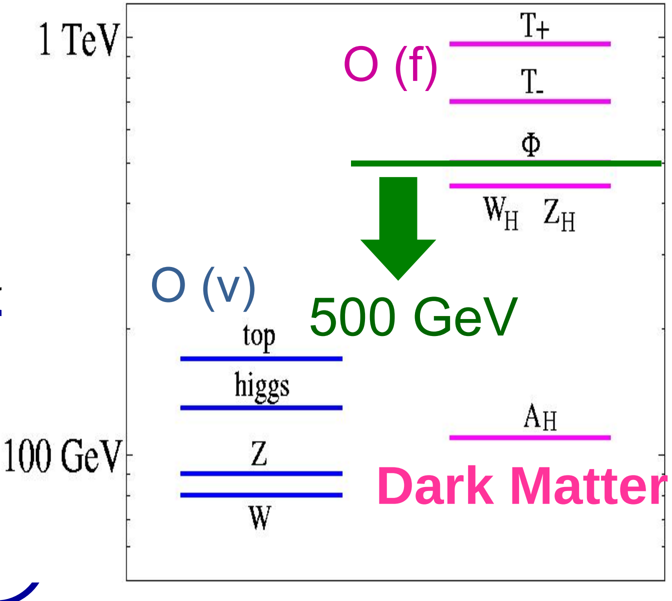
Gauge sector

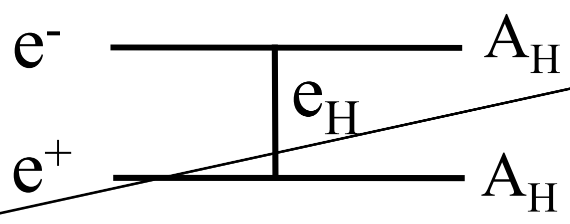
- can be produced at ILC!
- cannot measure masses at LHC
- with good accuracy at ILC

We should measure the gauge sector in the LHT at ILC.

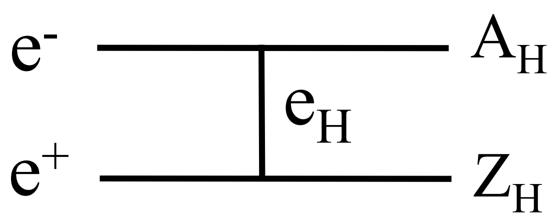
In the gauge sector,

Which mode can be measured at the ILC ?

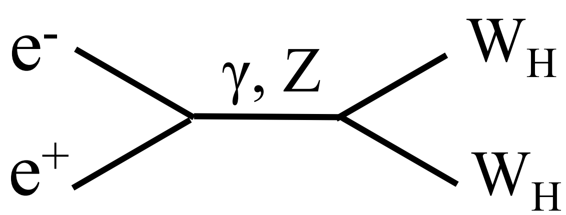




- ~~can produce easily~~
- ~~$m_{AH} + m_{AH} < 500$ GeV~~
- ~~No signal~~



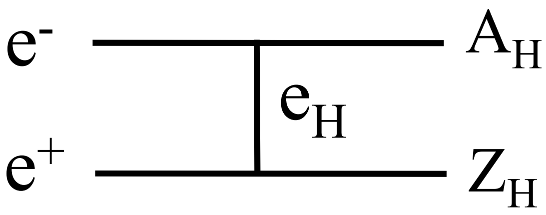
- can produce @ 500 GeV:
  $m_{AH} + m_{ZH} < 500$ GeV
- cross section is small



- It is difficult to produce @ 500 GeV
- cross section is large

Our strategy

1. @ 500 GeV ILC,
   we estimate the measurement of gauge boson masses & vev f using $e^+e^- \to A_H Z_H$
2. Using $e^+e^- \to W_H W_H$,
   we estimate the improvement of gauge boson masses & vev f measurement @ 1 TeV ILC.



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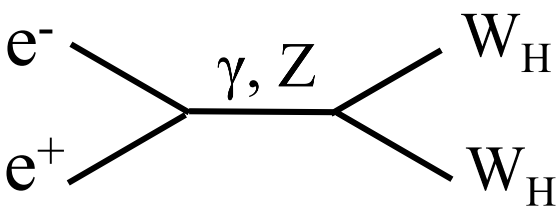


- It is difficult to produce @ 500 GeV
- cross section is large

Representative point
of our simulation

Mode &Representative point

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

Because heavy gauge boson masses depend only on vev f.

$e^+e^- \rightarrow A_H Z_H$

$e^+e^- \rightarrow W_H W_H$

↓ dark matter relic abundance in this model ↓

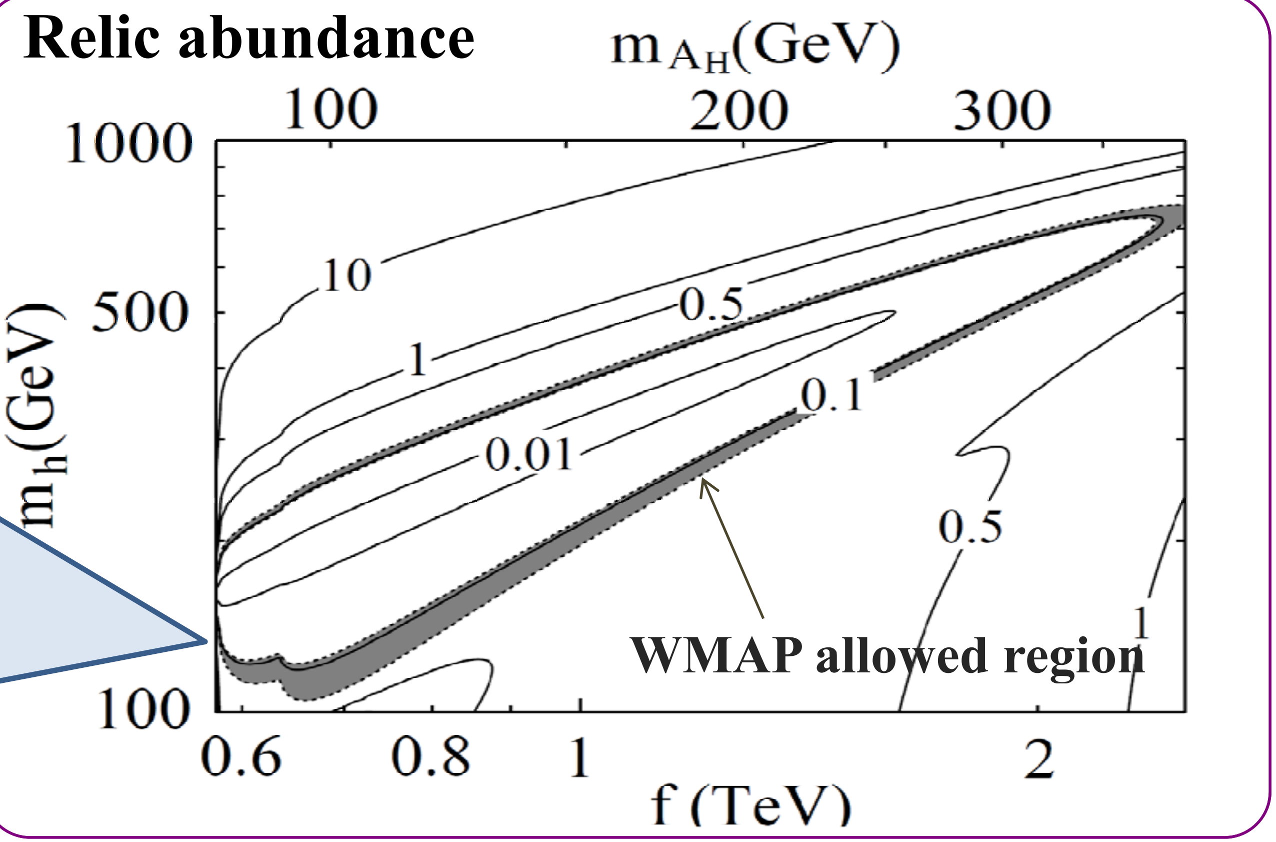
M. A, S. Matsumoto, N. Okada, Y. Okada PhysRevD.75.063506

Dark matter (A_H)

Shaded area is WMAP allowed region .

DM abundance is determined by the Higgs mass & vev f.

At this WMAP allowed region, the model also satisfys other experimental constraints!



Mode &Representative point

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

Because heavy gauge boson massed depend only on vev f.

$e^+e^- \rightarrow A_H Z_H$

$e^+e^- \rightarrow W_H W_H$

If f is larger than ~800GeV, the hierarchy problem appears again.

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

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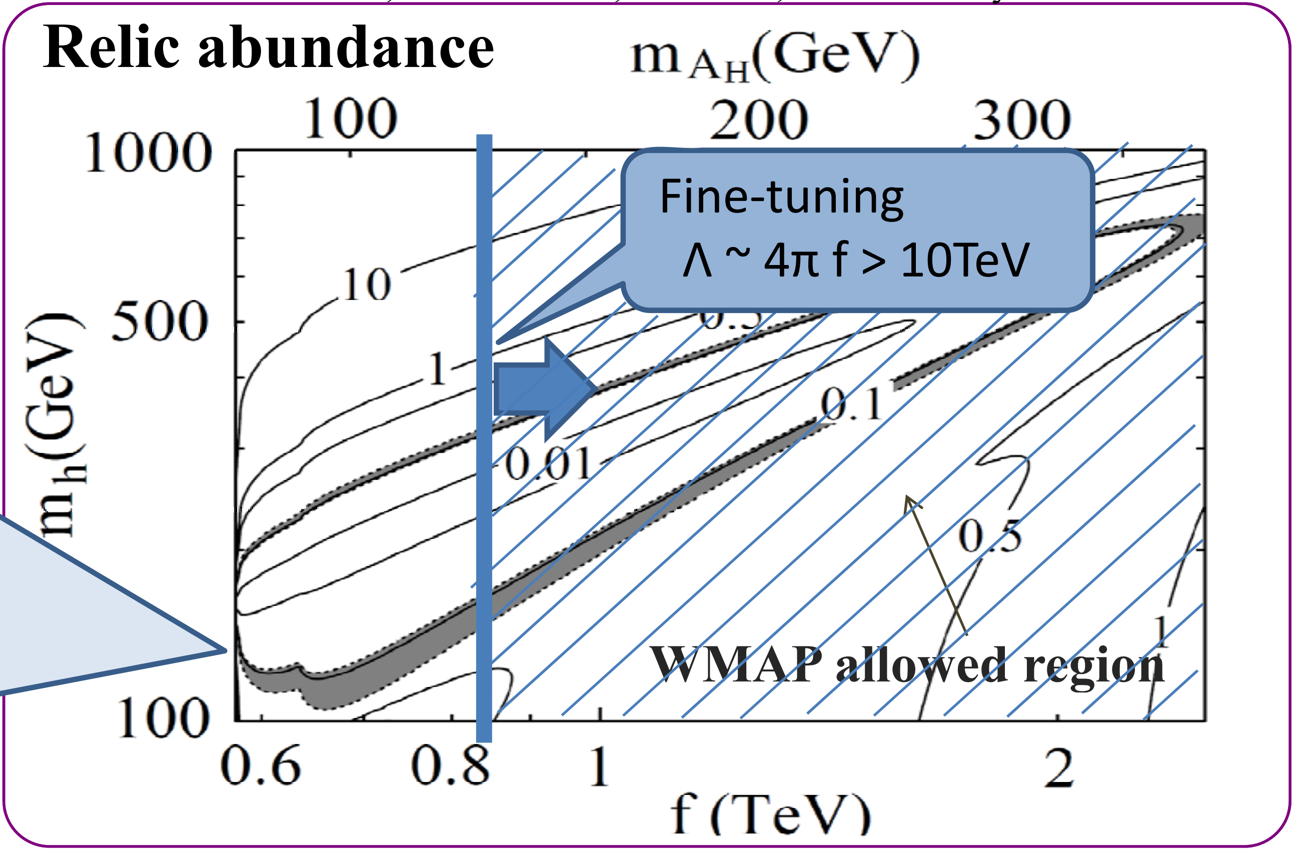

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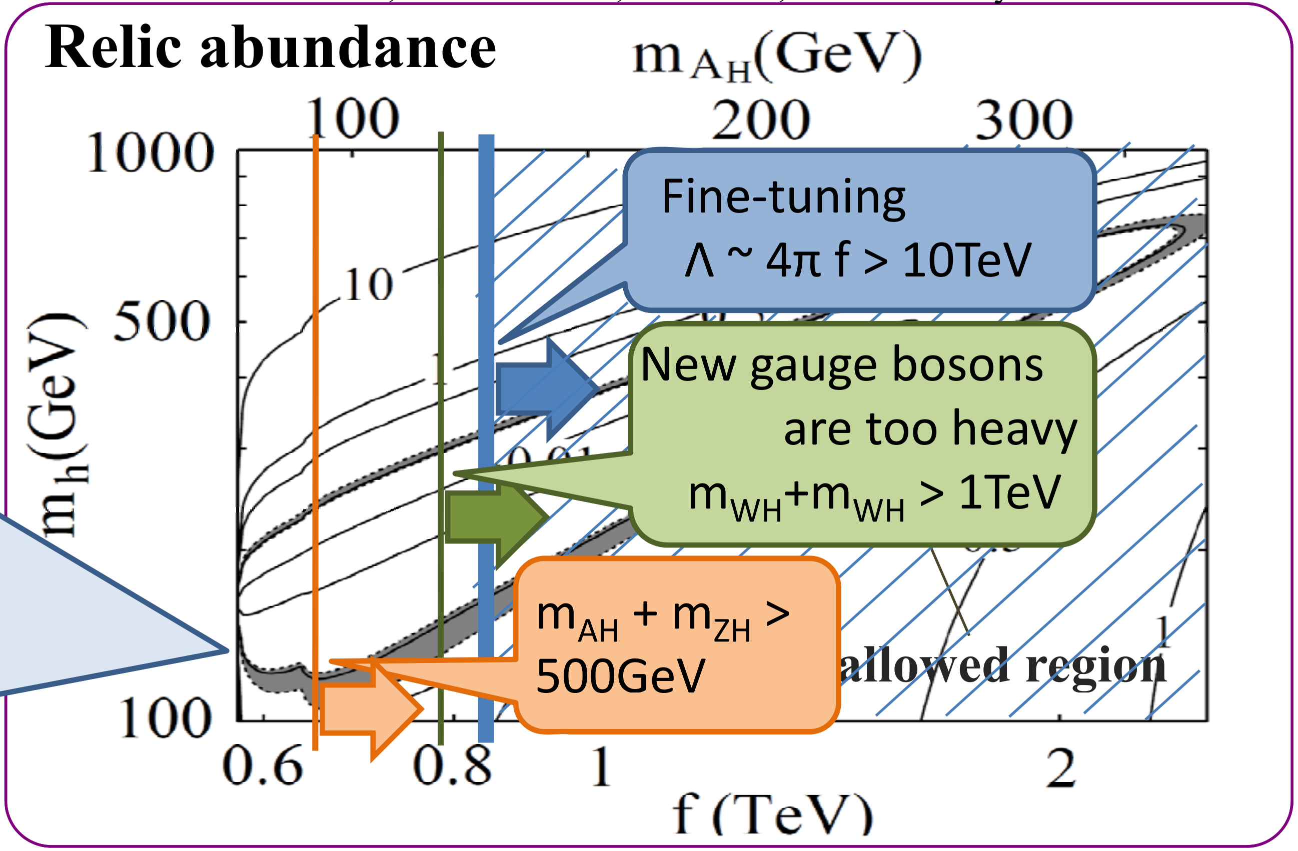

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Because heavy gauge boson massed depend only on vev f.

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$e^+e^- \rightarrow W_H W_H$

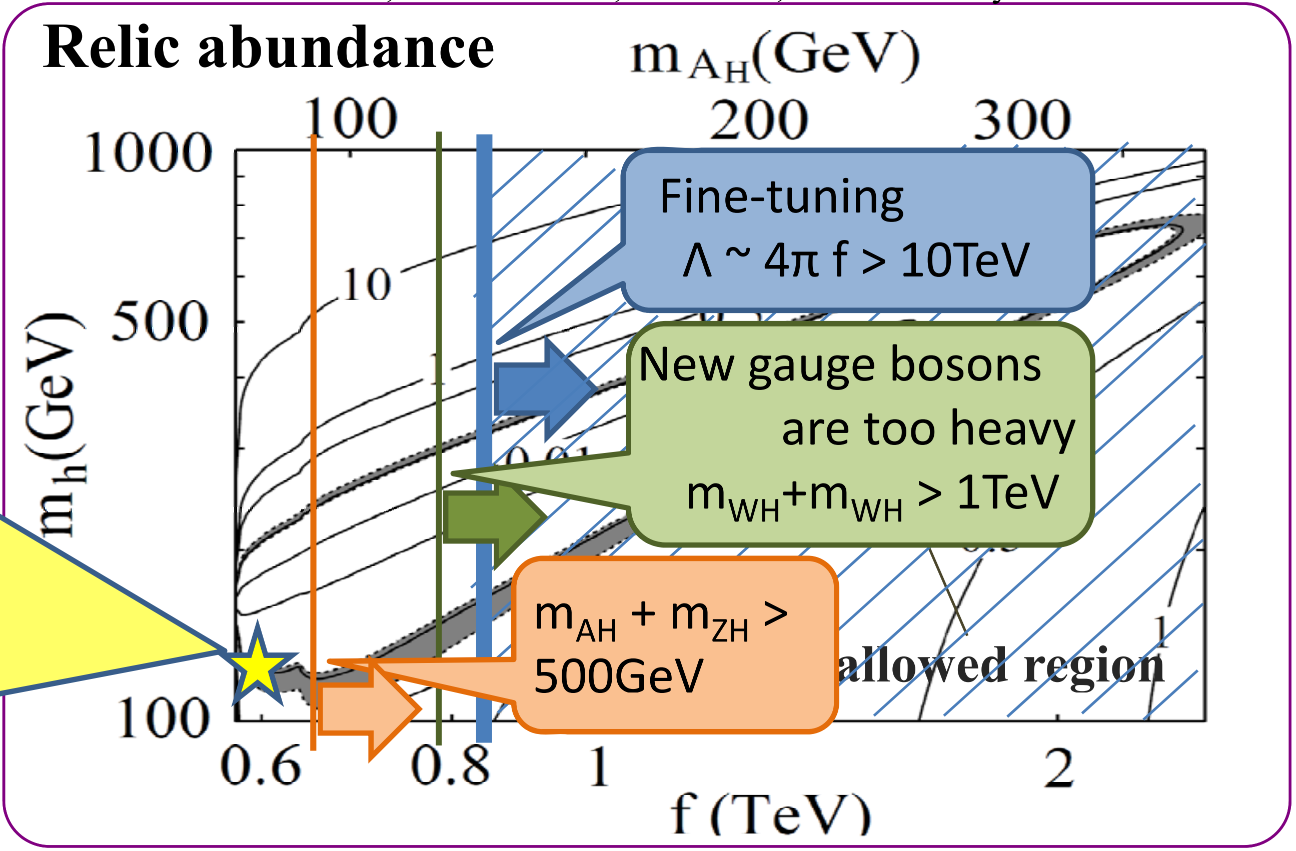
Mass spectrum

f	580
e_H	410
Z_H	369
W_H	368
A_H	82
Higgs	134

Point I (GeV)

Sample points satisfy all experimental & cosmological constraints.

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



Simulation results

Simulation

We simulate using Physsim & PYTHIA for generating BG,
MadGraph for generating signal,
JSFQuickSimulator for simulating detector.

@ 500 GeV ILC

$e^+e^- \rightarrow A_H Z_H \rightarrow A_H A_H h$

We determine heavy gauge masses from edges of higgs energy distribution.

- Integrated luminosity 500 fb^{-1}
- Cross section
  - **Signal $A_H Z_H$ 1.9 fb**
  - BG $\nu\nu Z \rightarrow \nu\nu b\bar{b}$ 44.3 fb
  - $\nu\nu Z \rightarrow \nu\nu c\bar{c}$ 34.8 fb
  - $\nu\nu h \rightarrow \nu\nu b\bar{b}$ 34.0 fb
  - ……

@ 1 TeV ILC

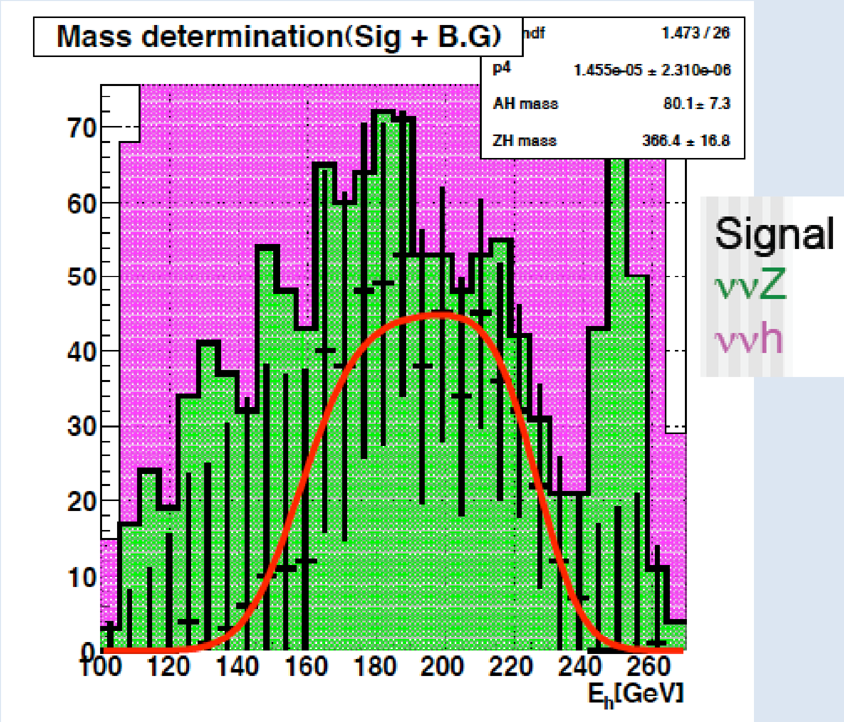
$e^+e^- \rightarrow W_H W_H \rightarrow A_H A_H W W$

from edges of W± energy distribution.

- Integrated luminosity 500 fb^{-1}
- Cross section
  - **Signal $W_H^+ W_H^-$ 121 fb**
  - BG W^+W^- 1308 fb
  - $e^+e^-W^+W^-$ 491 fb
  - ……

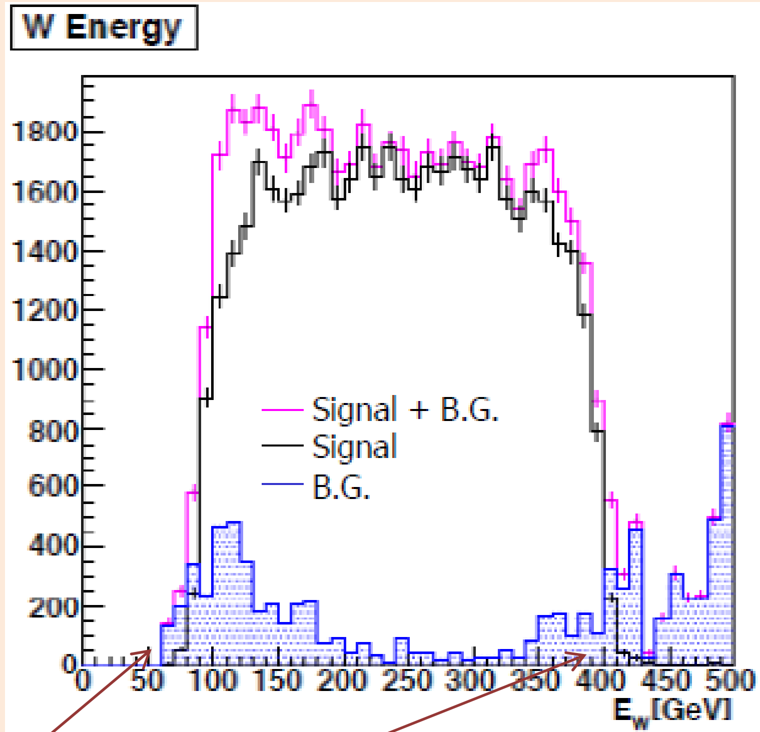
@ 500 GeV ILC

$e^+e^- \rightarrow A_H Z_H \rightarrow A_H A_H h$



@ 1 TeV ILC

$e^+e^- \rightarrow W_H W_H \rightarrow A_H A_H W W$



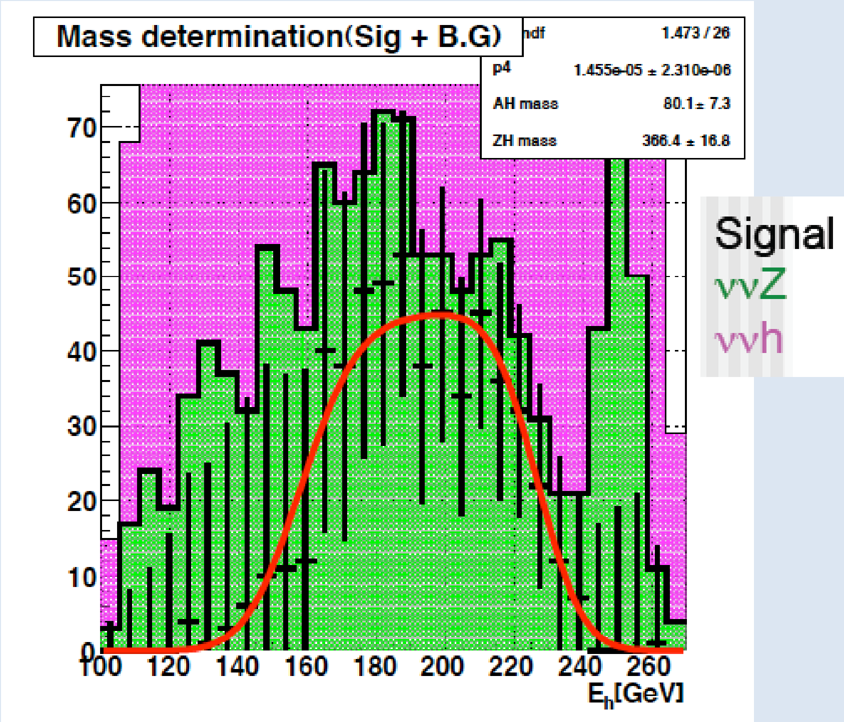
For details,
see next talk (T. Kusano).

For details,
see next next talk (R. Sasaki).

Because the **simulation shows end points clearly,**
It allow us to extract the property of heavy gauge bosons and DM!

@ 500 GeV ILC

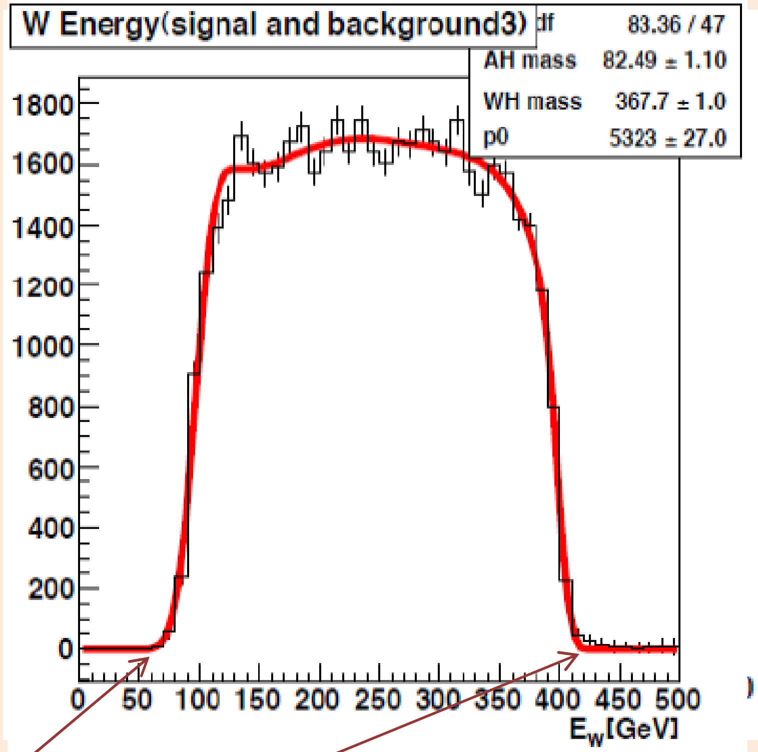
$e^+e^- \rightarrow A_H Z_H \rightarrow A_H A_H h$



For details, see next talk (T. Kusano).

@ 1 TeV ILC

$e^+e^- \rightarrow W_H W_H \rightarrow A_H A_H WW$



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Because the **simulation shows end points clearly,**
It allow us to extract the property of heavy gauge bosons and DM!

Simulation results

@ 500 GeV ILC

$e^+e^- \rightarrow A_H Z_H \rightarrow A_H A_H h$

- Mass determination
  - Fit results

    m_{AH} = 80.1 ± 7.3 GeV
    true(81.85)

    m_{ZH} = 366 ± 17 GeV
    true(368.1)
- f determination
  - f = 580 ± 22 GeV

  true(580)

@ 1 TeV ILC

$e^+e^- \rightarrow W_H W_H \rightarrow A_H A_H WW$

- Mass determination
  - Fit results

    m_{AH} = 82.42 ± 1.09 GeV
    true(81.85)

    m_{WH} = 368.0 ± 0.9 GeV
    true(368.1)
- f determination
  - f = 580 ± 1.3 GeV

  true(580)

We can also determine

- W_H spin using production angle of W_H^+.
- W helicity using angular distribution of jets.

Summary

- **Littest Higgs model with T-parity (LHT)** is one of attractive models for physics beyond the SM.
- Important model parameter (f) can be determined by gauge boson sector with good accuracy.
  - @ 500 GeV ILC, we can measure LHT using $\mathbf{e^+e^- \rightarrow A_H Z_H}$.
  - @ 1 TeV ILC, we can measure LHT using $\mathbf{e^+e^- \rightarrow W_H W_H}$ with very high accuracy.
- Our 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

→ Cosmological impact will be talked by S. Matsumoto in today's cosmological session.