Precision measurements of Little Higgs with T-parity parameters @ ILC

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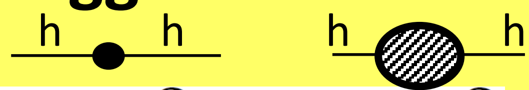
- Little Higgs Model
- Analysis
- Summary

Little Hierarchy problem

There are 2 predictions on where the energy scale of new physics should emerge.

1. Fine tuning of Higgs mass



$$m_{Higgs}^2 = m_0^2 + \delta m^2$$

Measured Higgs mass **Bare mass** **Correction term**

Λ : Energy scale $\delta m^2 \approx (0.27\Lambda)^2$

Λ<1 TeV

2. Electroweak precision measurement Λ>10TeV

➡ Conflict between the 2 energy scales.

➡ **Little Higgs model was proposed!**

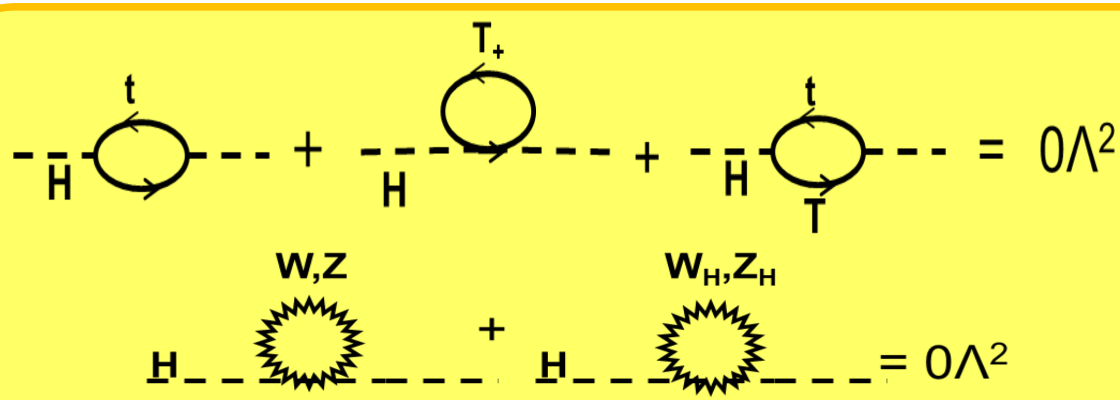
Little Higgs model

<Little Higgs mechanism>

Global Symmetry : SU(5) **f ~ 1 TeV** SO(5) **v ~ <h>**

subgroup : $[\,SU(2)_L \times U(1)_Y]^2$ → $SU(2)_L \times U(1)_Y$ → $U(1)_Y$

<Higgs mass contribution>

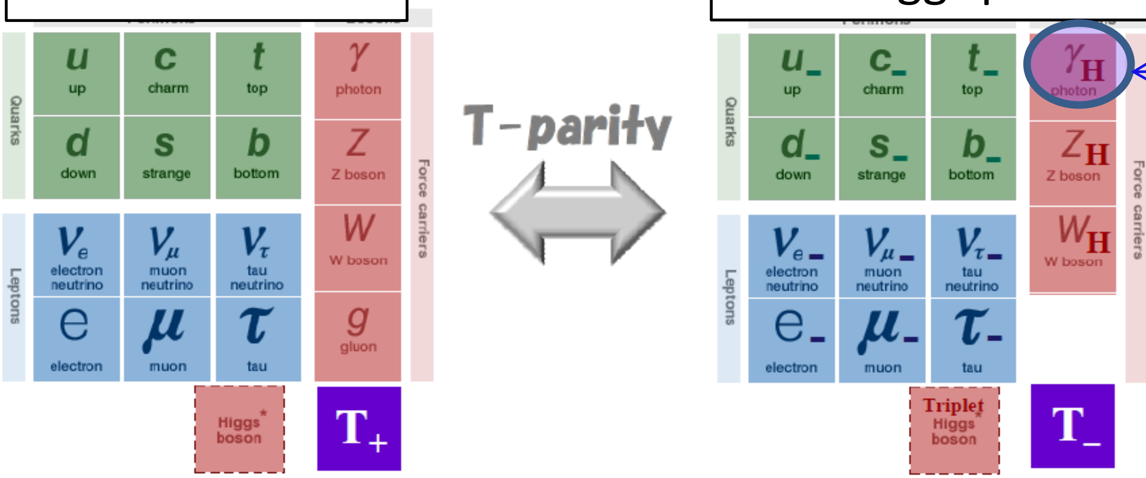


Quadratic divergent terms cancel at 1-loop order

Solves Little hierarchy problem

Littlest Higgs with T-Parity model

Standard model — Little Higgs partner



A_H :dark matter candidate

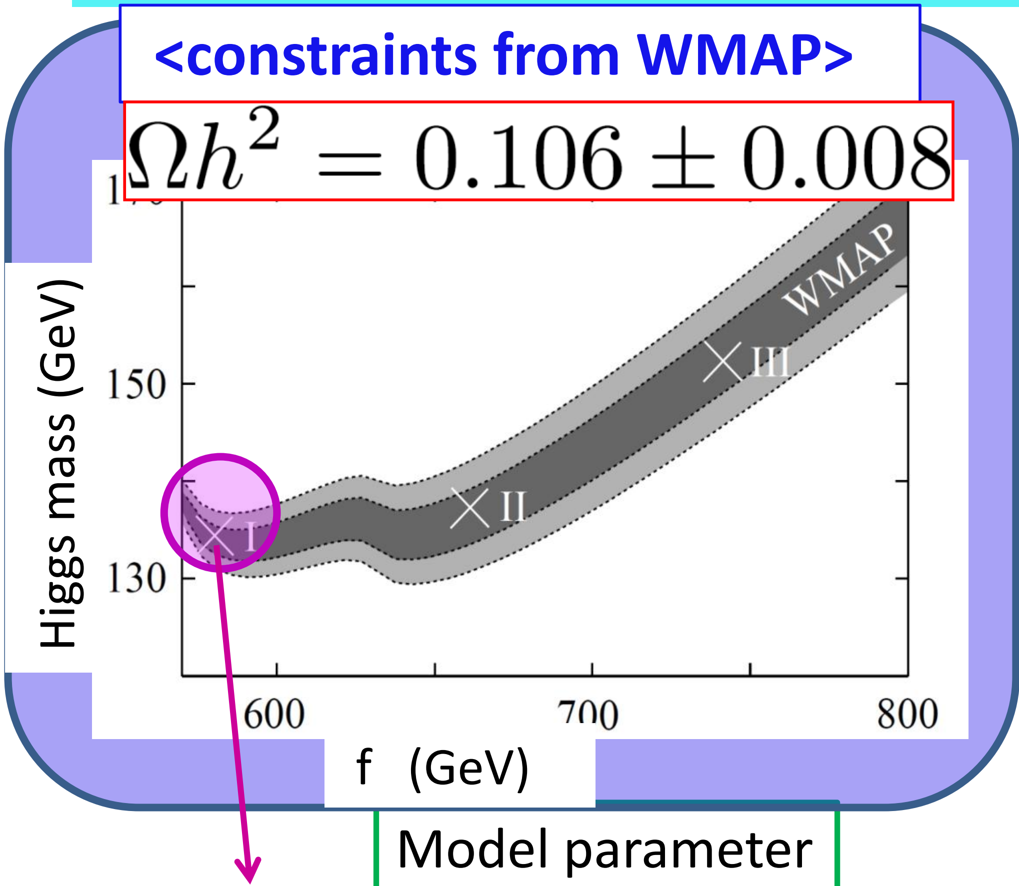
$$m_{A_H} \approx \sqrt{0.2}\, g' f$$

$$m_{Z_H} \approx g f$$

- **Heavy gauge bosons acquire mass through global symmetry breaking**
- $A_H Z_H W_H$ masses are proportional to f .
- **f can be determined through $A_H Z_H W_H$ mass precision measurements .**

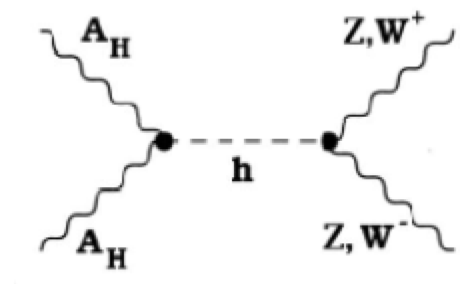
Mass measurement of heavy gauge bosons extremely important !!

Selection of model parameters



Used relic density measurement from WMAP.

Main annihilation mode



Cross section depends on m_{AH} and m_H

f	m_H	m_{AH}	m_{ZH}	m_{WH}
580(GeV)	134(GeV)	81.9(GeV)	369(GeV)	368(GeV)

$A_H Z_H W_H$ can be produced under CM energy 1TeV.

LHT heavy gauge bosons @LHC

Boson pair production cross section

Largest cross section: $W_H W_H$ ~100fb

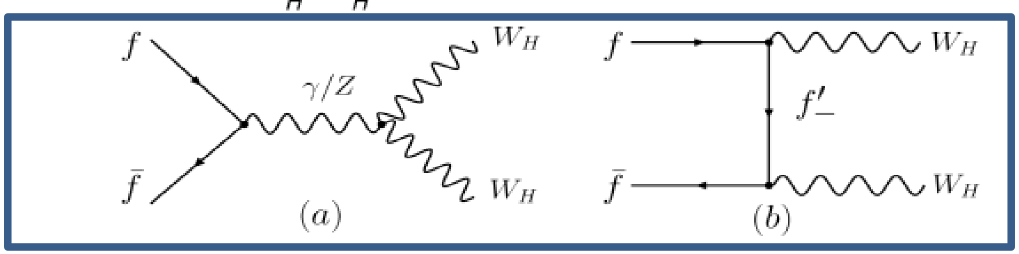
Signal : $l\,l\,\not{E}$ (~5fb)

Large background: SM gauge boson

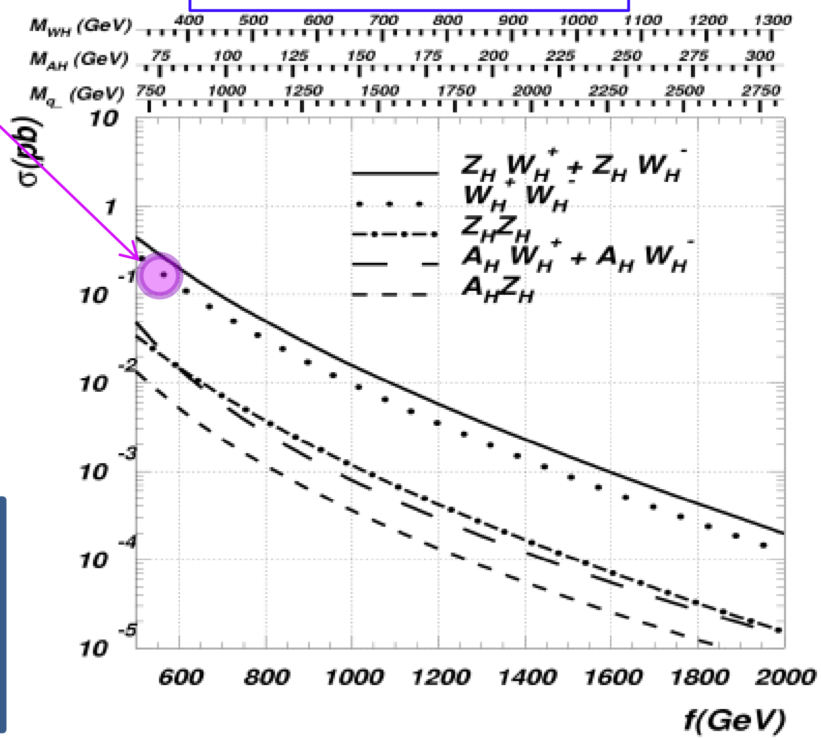
tt production

Extremely difficult to see.

Production of $W_H W_H$



VEV vs Cross section

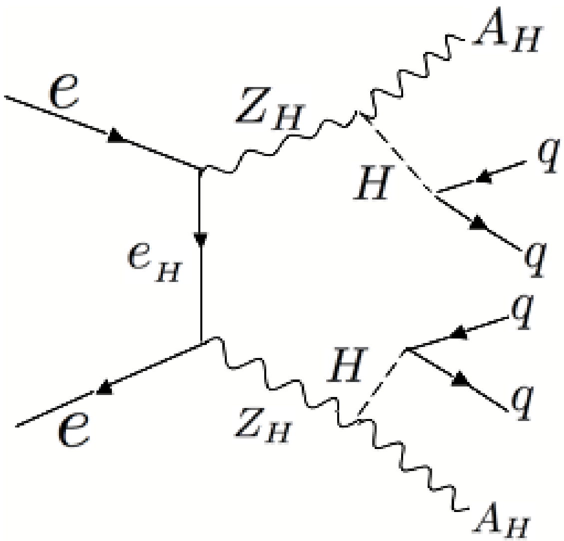


Reference: Alexander Belyaev, Chuan-ren Chen etal Phys Rev D74,115020

simulation

<simulation environment>

Fast simulator
Center mass energy :1TeV
Beam polarization 0%
Integrated luminosity :500fb^{-1}



<Signal event>

- **$e^+e^- \rightarrow Z_H Z_H$(99.52fb)**
  —$Z_H \rightarrow A_H$ H (branching ratio100%)
  —**A_H** is a **dark matter** candidate
  —Higgs decays mostly to H→bb(42%)
  → used **4 jet final state as signal.**

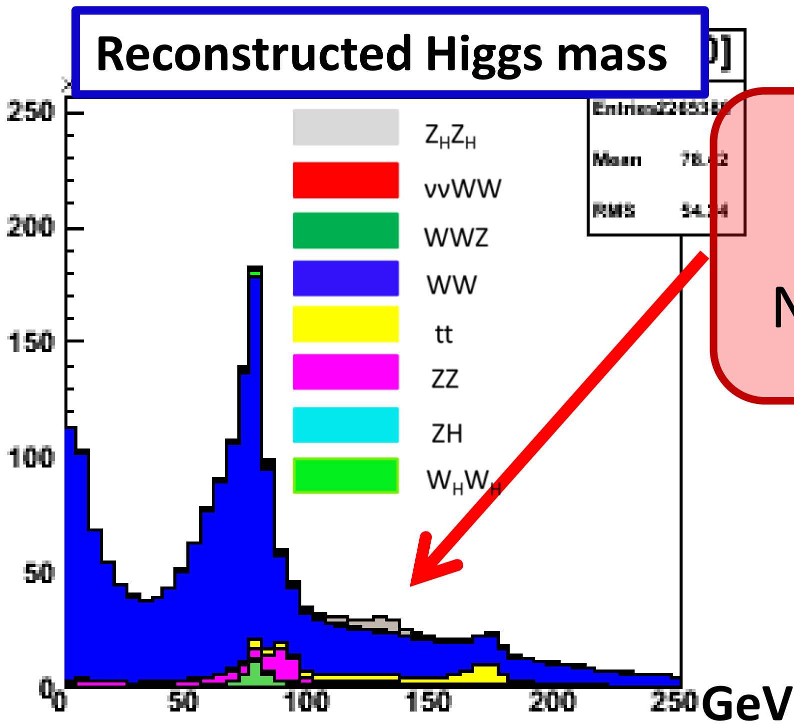
<background event（4 jet）>

- WW (3069fb)
- tt (192.9fb)
- WWZ (63.86fb)
- ννWW (14.67fb)
- ZZ (202.2fb)
- ZH (17.98fb)
- $W_H W_H$ (108.6fb)

Event reconstruction

- Reconstruct by forcing every event to be a 4 jet event.
- Select reconstructed pair that minimizes χ^2 .

$$\chi_H^2 = \left(\frac{M_{H1} - M_H}{\sigma_{M_H}}\right)^2 + \left(\frac{M_{H2} - M_H}{\sigma_{M_H}}\right)^2 \quad M_H = 134.0(GeV)$$

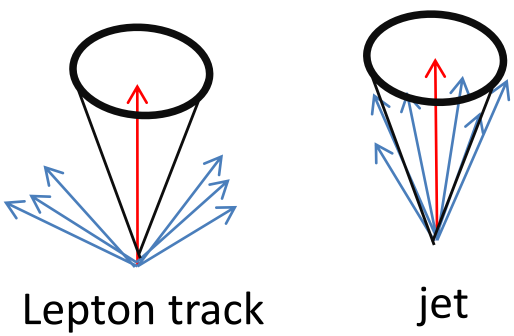


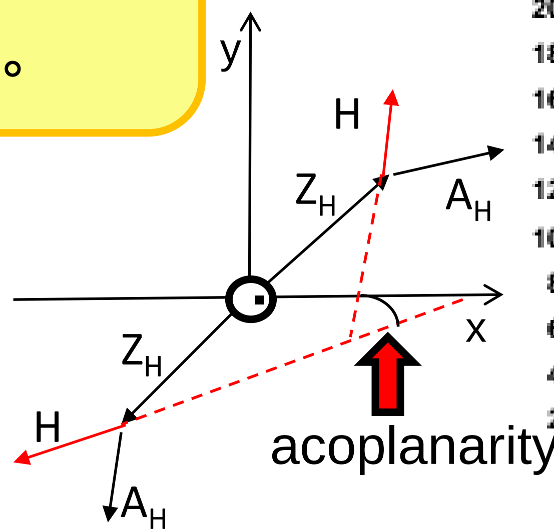
Buried signal

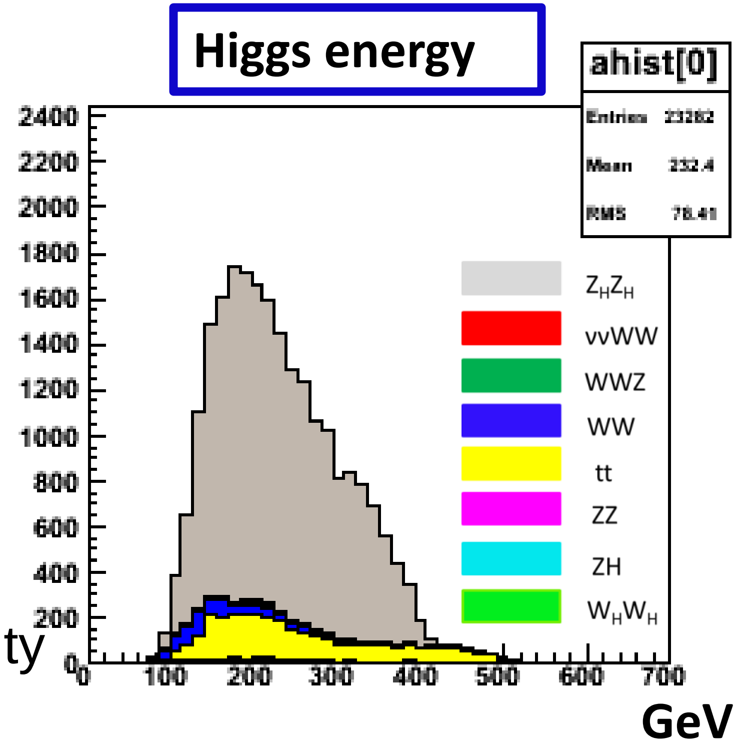
Need of background rejection

Selection criteria

- $\chi^2<60$
- Lepton track rejection
- # b-tag jets>1
- Acoplanarity > 20 °







# event	Pre-cut	Post-cut
Signal event(Z_HZ_H)	49760	18989
Background event（SM）	2193232	3217
（background W_HW_H）	54343	87

Success in effectively rejecting background

Z_H A_H mass extraction

The edge of Higgs energy possesses information of Z_H A_H mass

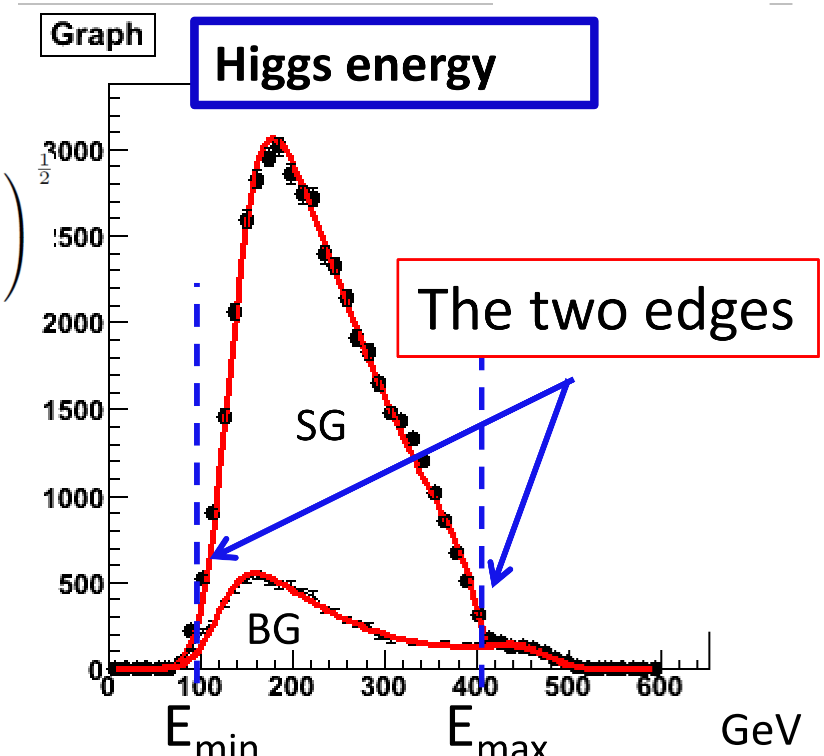
Fit energy and derive mass

<relation between edge and mass>

$$m_{Z_H} = \sqrt{s}\left(\frac{(E_+^2 - E_-^2 + m_H^2) \pm \sqrt{(E_+^2 - E_-^2 + m_H^2)^2 - 4E_+^2 m_H^2}}{8E_+^2}\right)^{\frac{1}{2}}$$

$$m_{A_H} = \left(m_H^2 + \left(1 - \frac{4E_+}{\sqrt{s}}\right) m_{Z_H}^2\right)^{\frac{1}{2}}$$

$$\left(\begin{array}{l} E_- \equiv \dfrac{E_{max} - E_{min}}{2} \\ E_+ \equiv \dfrac{E_{max} + E_{min}}{2} \end{array}\right)$$



Contour plot of Z_H & A_H

<Z_H $A_H$mass solution>

2 mass solutions appear

if we select the true solution …

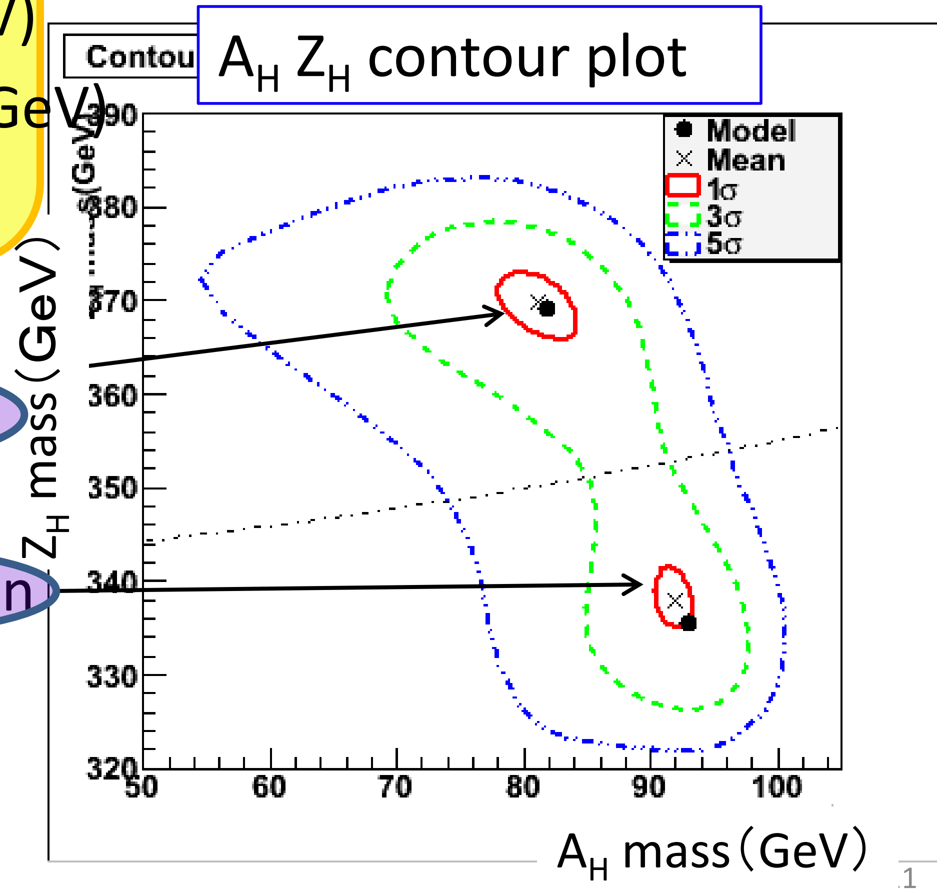
- A_H :82.7±3.5GeV(True value81.9GeV)
- Z_H :366.1±4.7GeV(True value 369.0GeV)

➢ Mass resolution A_H 4.2% Z_H 1.3%

True solution

False solution

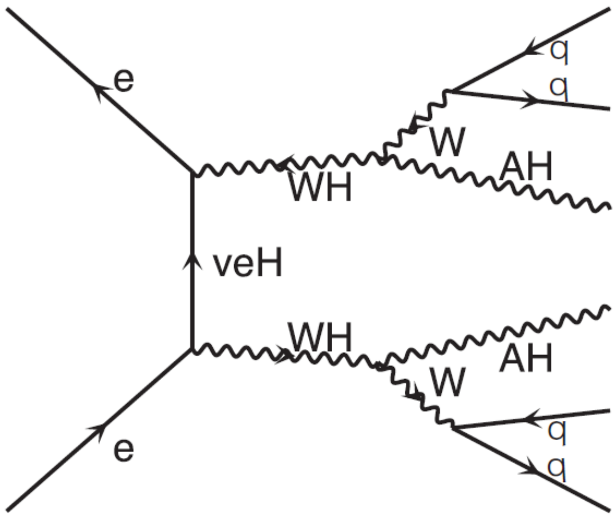
We can select the
true solution
By using other modes



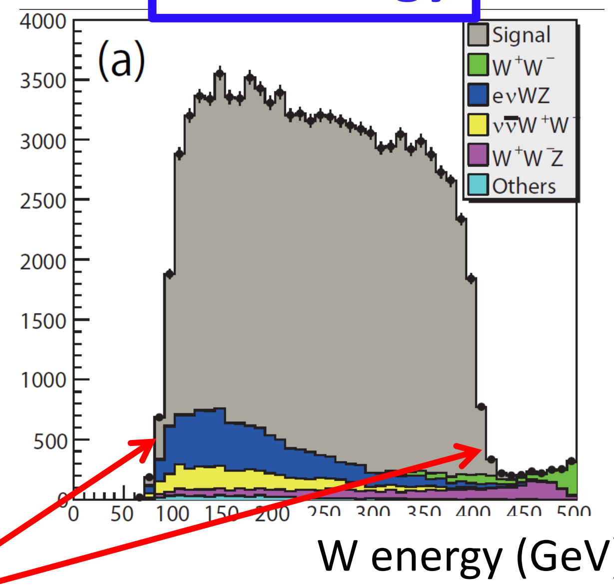
$e^+e^- \rightarrow W_H W_H$ mode

Used $e^+e^- \rightarrow W_H W_H$ mode to select true mass solution

1TeV : $e^+e^- \rightarrow W_H W_H$



$W^{\pm}$energy



Can determine $A_H W_H$ mass from $W^{\pm}$energy distribution

True solution

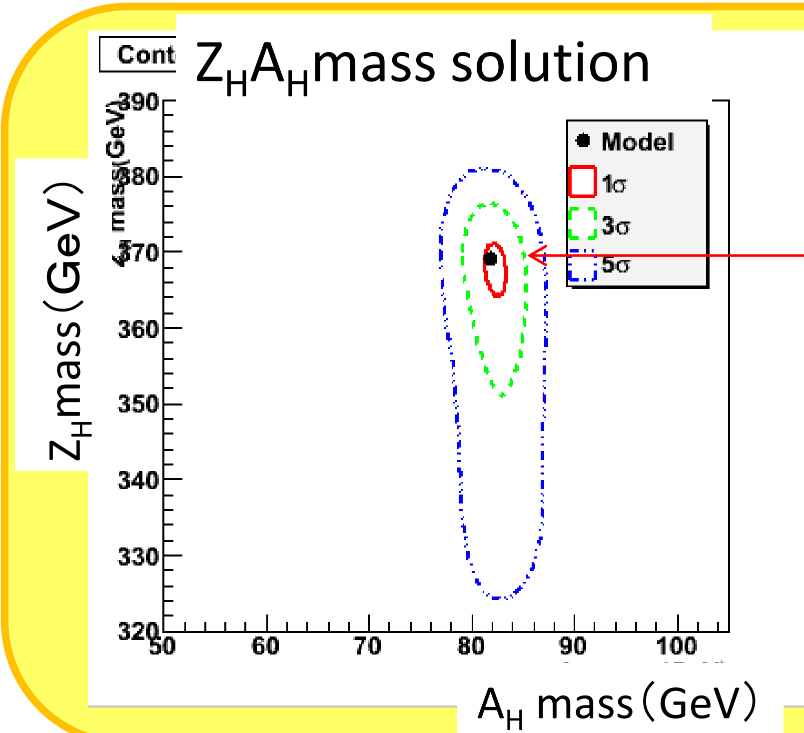
This analysis also produces 2 mass solutions.

m_{AH} = 81.6 GeV , 81.0 GeV **1.3%**

m_{WH} = 368.3 GeV , 218.0 GeV **0.2%** (phys. Rev D79.075013)

Selected true solution by analyzing both $W_H W_H$ & $Z_H Z_H$

Result of simultaneous fit



Result of $Z_H Z_H$ & $W_H W_H$ simultaneous fit

A_H mass 81.7 ± **1.1** GeV
Z_H mass 367.3 ± **4.1** GeV

able to select 1 solution

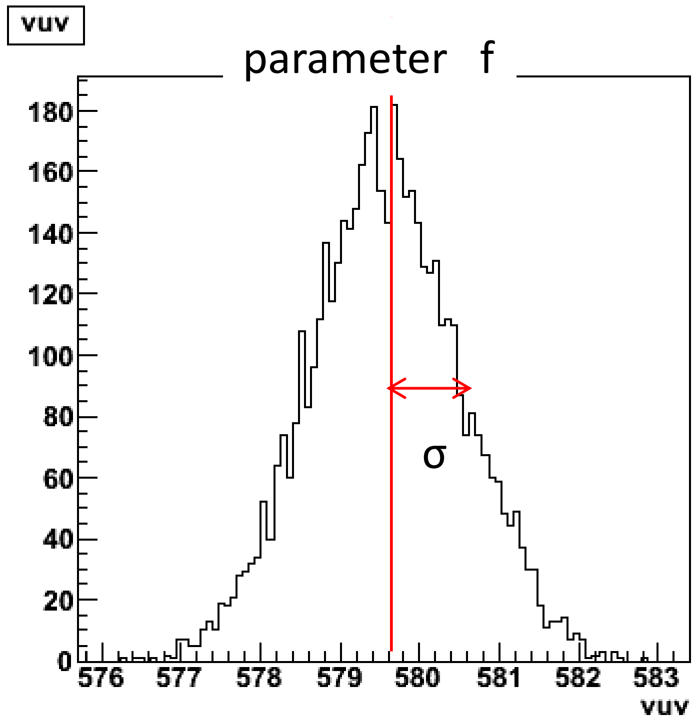
<mass resolution>

A_H : 1.3% Z_H : 1.1% W_H : 0.20%

All heavy gauge boson mass resolutions improved through simultaneous fit

Model parameter f

Evaluated the measurement accuracy of f



GeV

Because A_H Z_H masses depends on f, we can determine f through simultaneous fitting.

$$m_{A_H} \approx \sqrt{0.2}g'f$$

$$m_{Z_H} \approx gf$$

Measurement accuracy : **f resolution : 0.16%**

ILC can measure f with high resolution

Summary

The Little Higgs with T-Parity model is a new physics model that solves the little hierarchy problem and the dark matter problem.

<$\sqrt{s}$=1TeV: $e^+e^- \rightarrow Z_H Z_H$ analysis>

2 neighboring mass solutions(A_H,Z_H) were obtained.

Necessary to select true solution.

<$\sqrt{s}$=1TeV: $e^+e^- \rightarrow Z_H Z_H$ & $W_H W_H$ simultaneous fit>

Able to select one true mass solution.

Through simultaneous fit all mass resolution improved.

Mass resolution A_H 1.3% Z_H 1.1% W_H 0.20%

Vacuum expectation value: f 0.16%