Analysis of Little Higgs Model with T-parity at ILC

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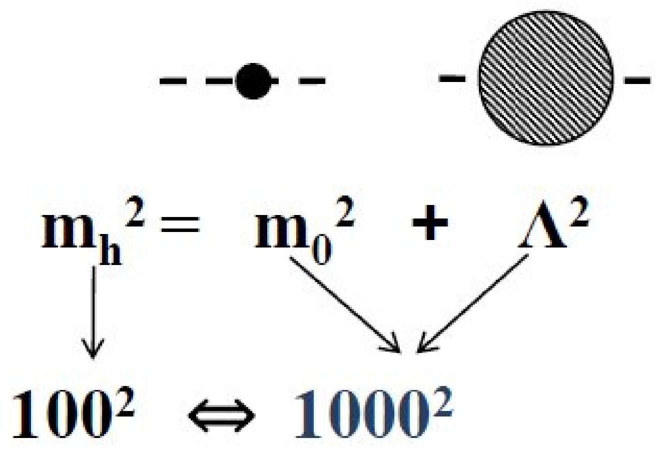
Little hierarchy problem

There are two predictions of the energy scale for new physics (Λ).

- $\Lambda < 1$ TeV : <10% fine tuning of Higgs mass.
- $\Lambda > 10$ TeV : EW precision measurements
  - The global fit of the EW parameters. (Γ_Z, M_W/M_Z, $\sin^2\theta_W$, …)



→ There is a discrepancy between two predictions.

Some physics models are proposed to solve little hierarchy problem.

→ **Little Higgs model (with T-parity)**

Little Higgs mechanism

- Higgs is a pseudo NG boson of a global symmetry of SU(5) .
- The symmetry breaks to SO(5) at $\Lambda \sim 10$ TeV.
  - VEV: $f \sim 1$TeV
  - $[SU(2)_L \times U(1)_Y]$ is a subgroup of SO(5).
- The little Higgs partners contribute to cancel quadratic divergent term of M_h at 1-loop level.
  - The new physics at 1 TeV is not necessary.

→ Little hierarchy problem can be solved.

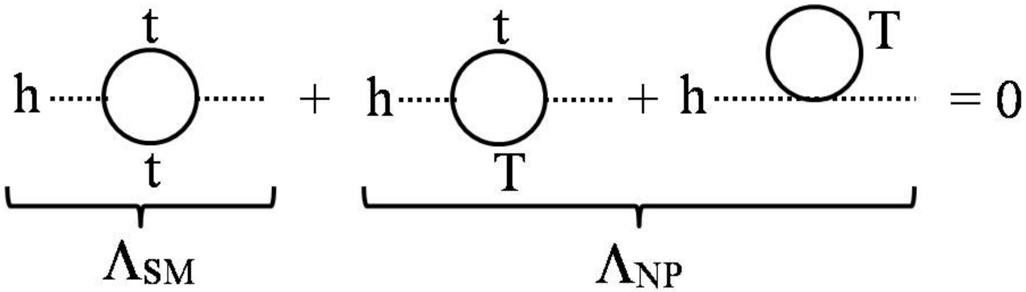
SU(5): $[SU(2) \times U(1)]^2$

↓ $f \sim 1$TeV

SO(5): $SU(2)_L \times U(1)_Y$

↓ $v \sim \langle h \rangle$

$U(1)_Y$



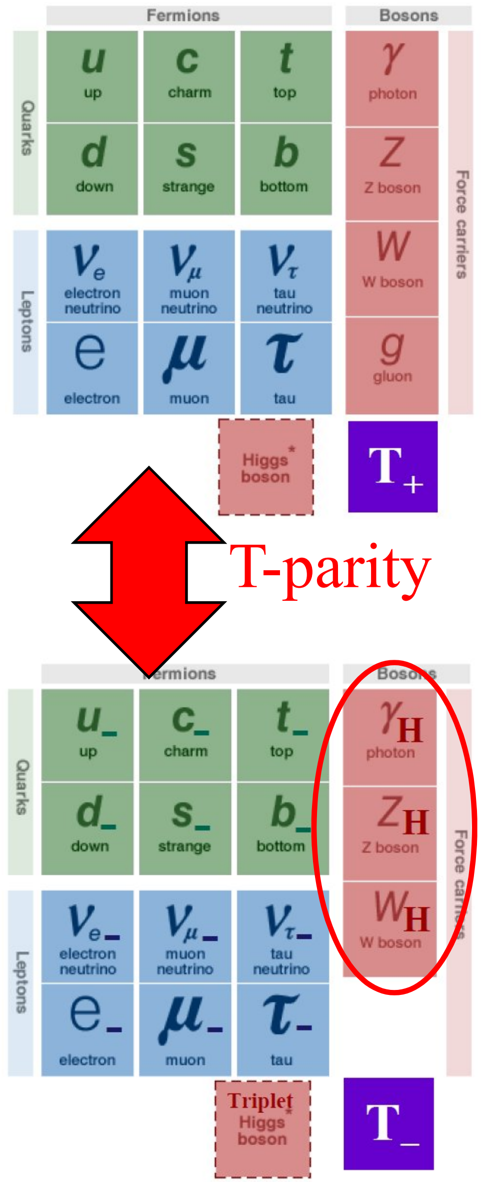
Importance of heavy gauge bosons

Heavy gauge bosons

- The heavy gauge bosons appears as the little Higgs partners of SM gauge bosons.
  - γ, Z, W $\leftrightarrow$ A_H, Z_H, W_H
  - The masses have information of VEV(f).
- A_H becomes stable, requiring T-parity.
  - A_H is a dark matter candidate.

→ VEV and abundance of the dark matter can be evaluated by measurement of heavy gauge bosons.

Sensitivity of ILC to the heavy gauge bosons was studied.

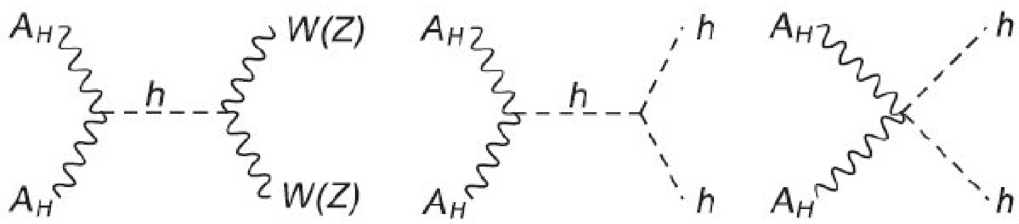


Parameter choice for simulation study

Constraint by WMAP result

- The dark matter density was determined by WMAP.
  - $\Omega h^2 = 1.119 \pm 0.009$
- Annihilation xsec of $A_H \sim F(M_h, f)$
  - M_h and f are restricted by Ωh^2.

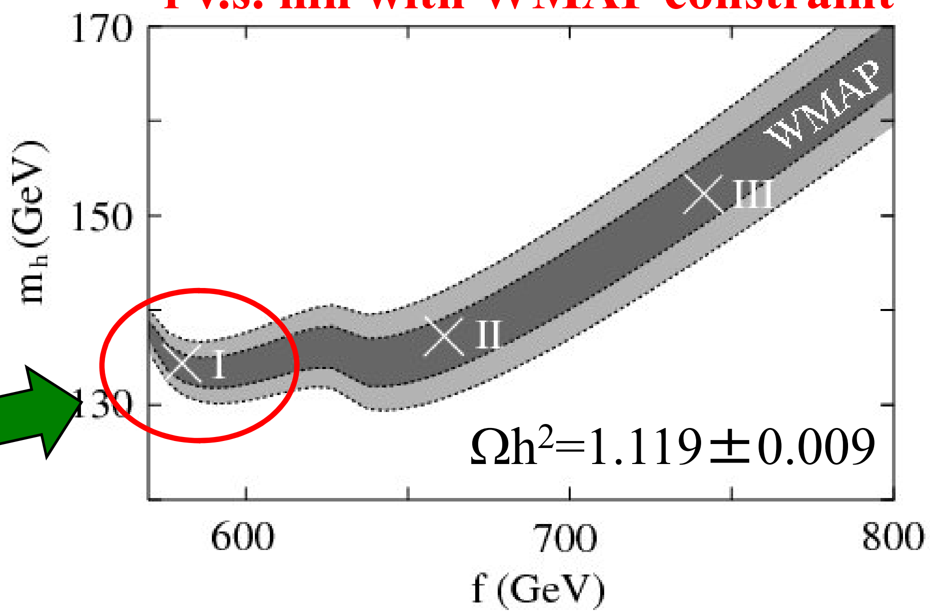
Annihilation processes of A_H



Parameters for this study

- f: 580GeV
- M_h: 134GeV
- M_{AH}: 81.9GeV
- M_{WH}: 368GeV
- M_{ZH}: 369GeV

f v.s. mh with WMAP constraint

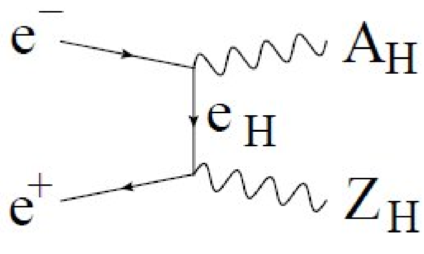


A_H, W_H, and Z_H can be observed at ILC.

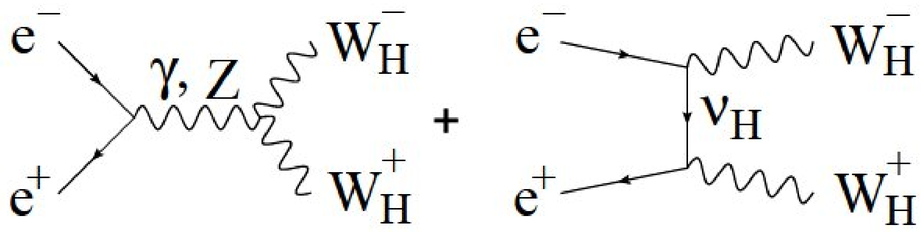
Analysis modes

According to the beam energy at ILC, three analysis modes were selected.

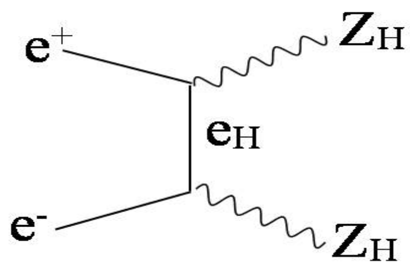
- $A_H + Z_H$ @ $E_{CM} = 500$ GeV
  - xsec: 1.91 fb
  - $M_{AH} + M_{ZH} = 450.9$ GeV



- $W_H^+ + W_H^-$ @ $E_{CM} = 1$ TeV
  - xsec: 277 fb
  - $M_{WH} + M_{WH} = 736$ GeV



- $Z_H + Z_H$ @ $E_{CM} = 1$ TeV
  - xsec: 277 fb
  - $M_{ZH} + M_{ZH} = 736$ GeV



Analysis result for $Z_H Z_H$ is shown.

Simulation study

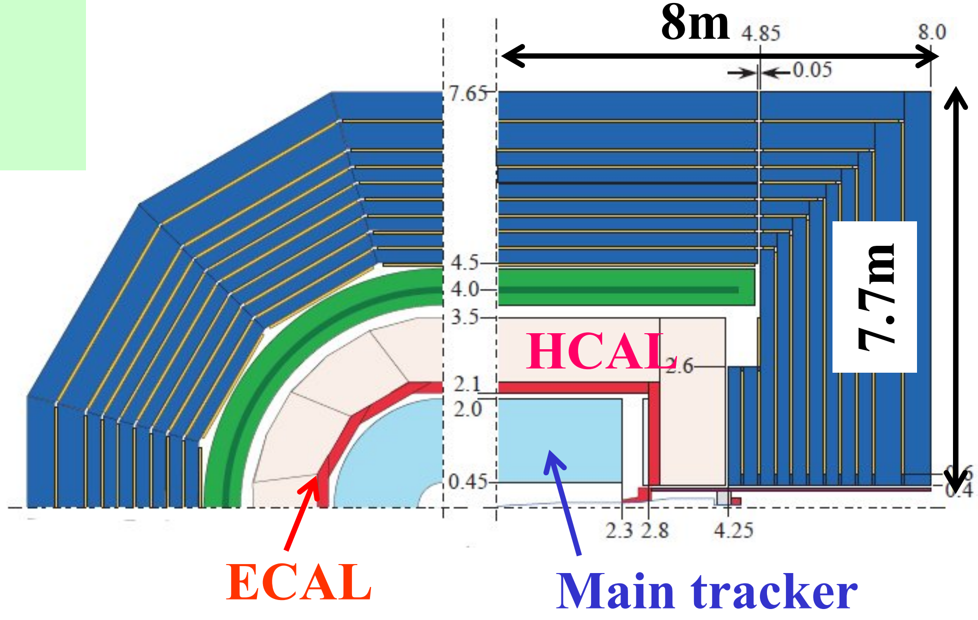
Simulation condition

- Signal: $Z_H Z_H \rightarrow HHA_H A_H$ (98.0fb)
- BG:
  - WWZ (5.9fb)
  - ννWW(6.7fb)
  - WW (3,932fb)
  - tt (193fb)

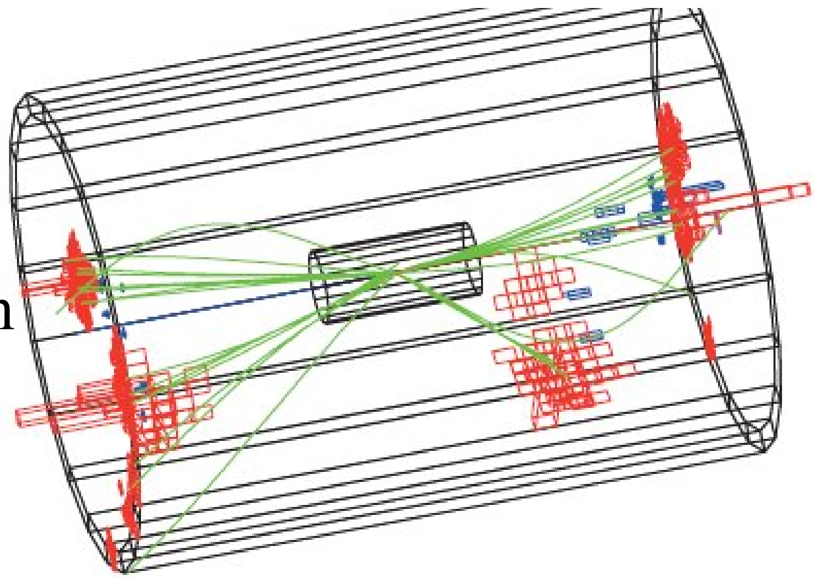
Simulation tools

- Event generator: Physsim
  - ISR, FSR, beamstrahlung, and beam energy spread are considered.
- The fast-simulator for GLD was used.

GLD detector concept



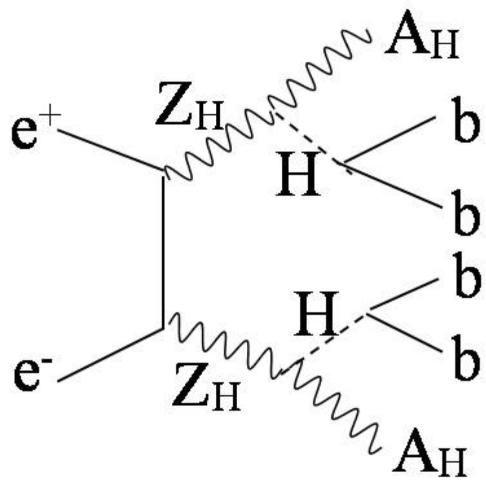
Event display of a $W_H W_H$ event



Event reconstruction

- All the events are reconstructed as 4-jet events.
- Two Higgs masses are reconstructed to minimize χ^2 value:

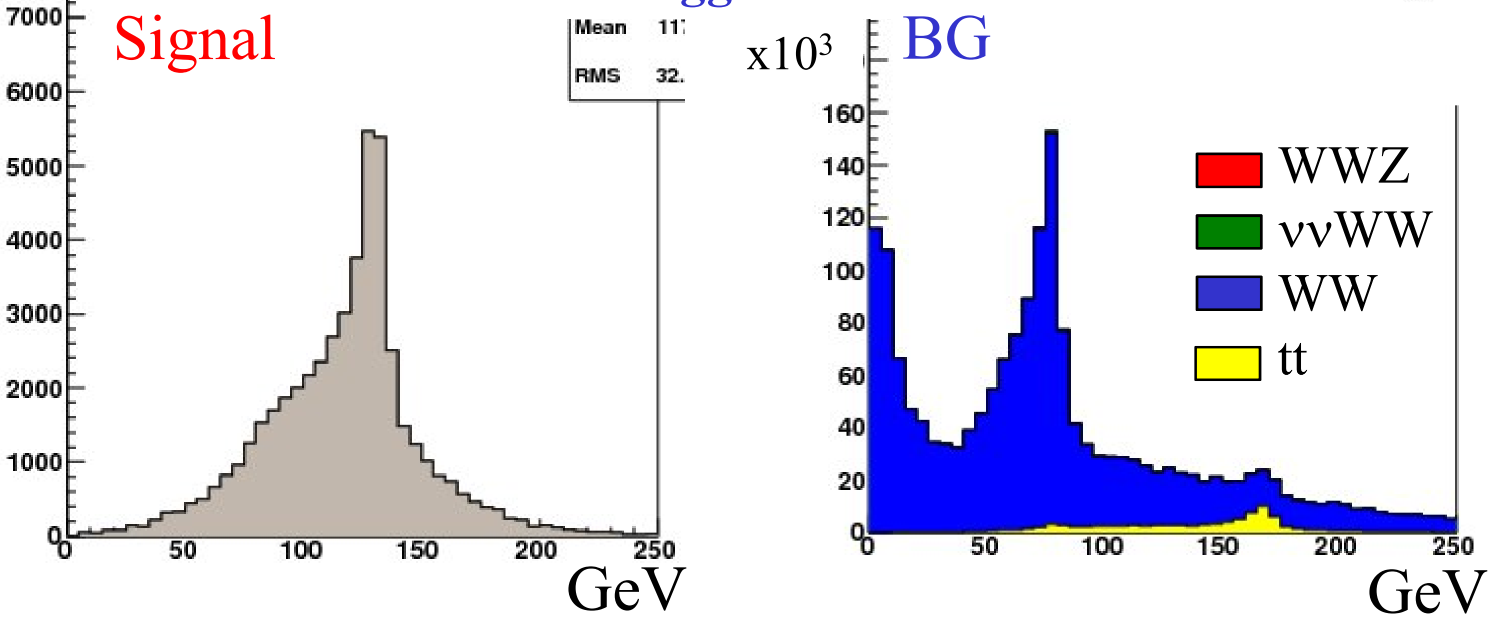
$$\chi^2 = \frac{(M_{H1} - M_H)^2}{\sigma_{MH}^2} + \frac{(M_{H2} - M_H)^2}{\sigma_{MH}^2}$$



- Many BG events contaminate in the signal region.

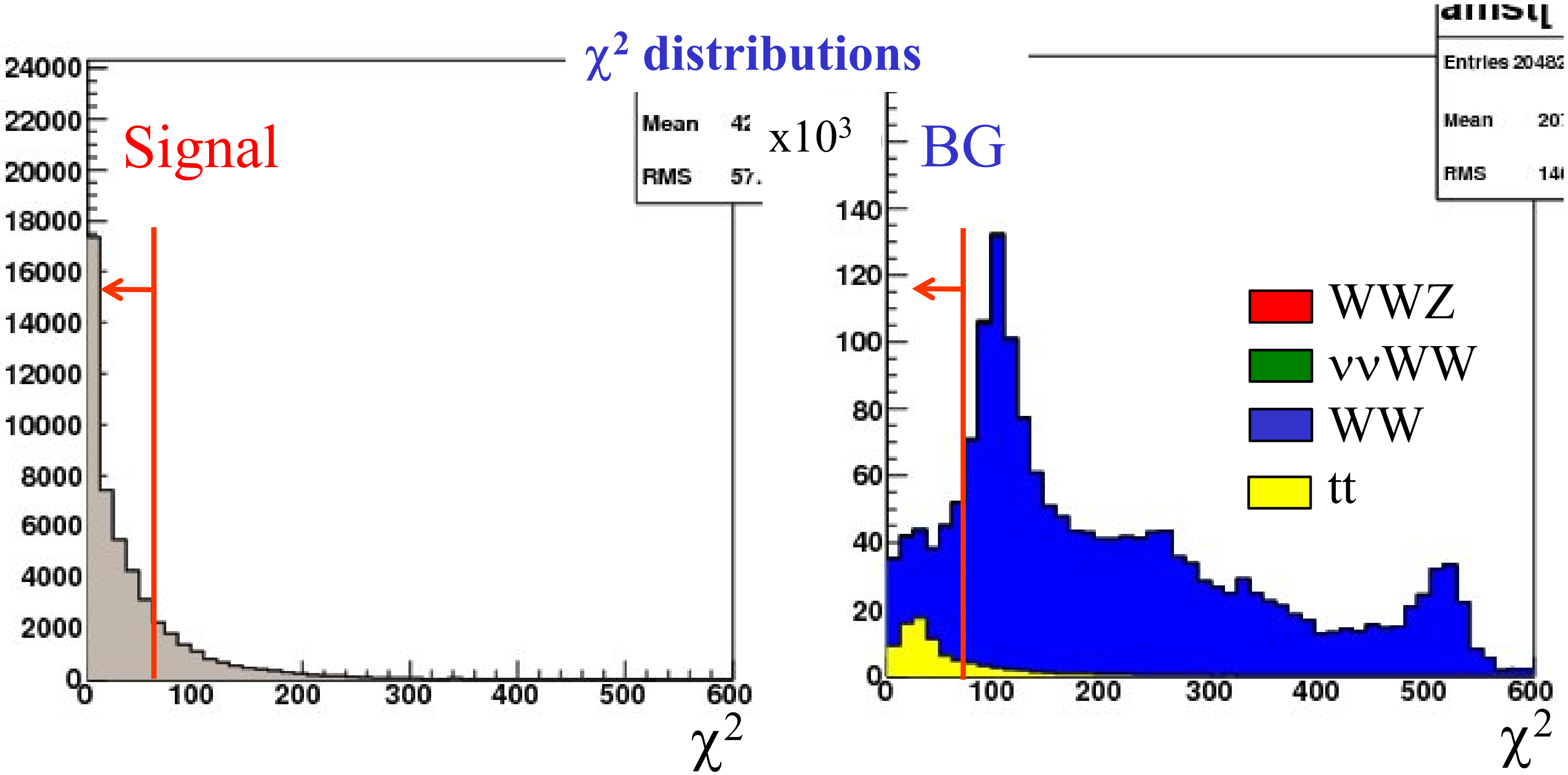
  → The selection cut was applied.

Reconstructed Higgs mass distributions



χ^2 cut

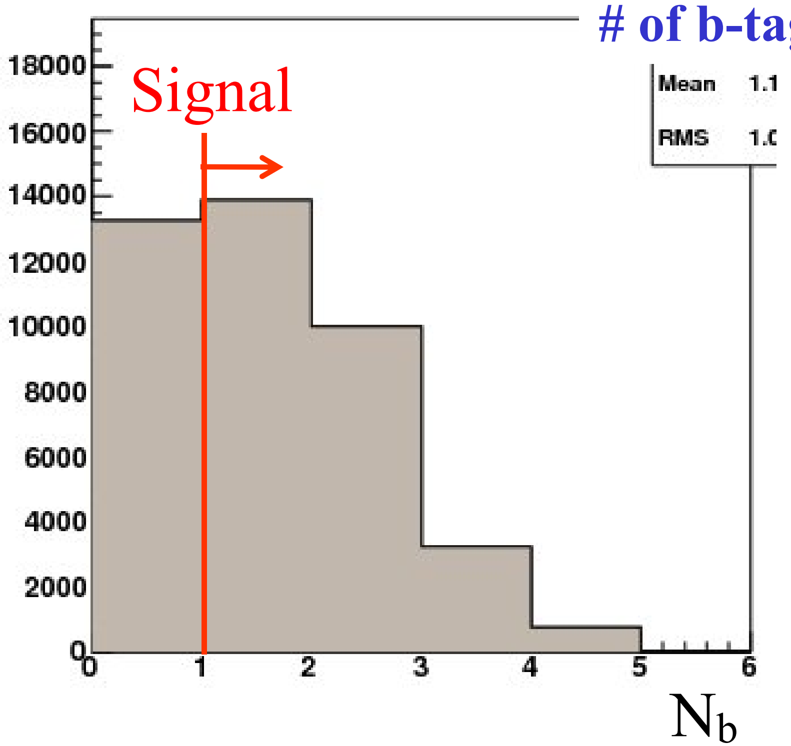
- The χ^2 cut was applied to select well reconstructed events.
  - $\chi^2 < 80$ was selected.
- The main part of WW background can be rejected.

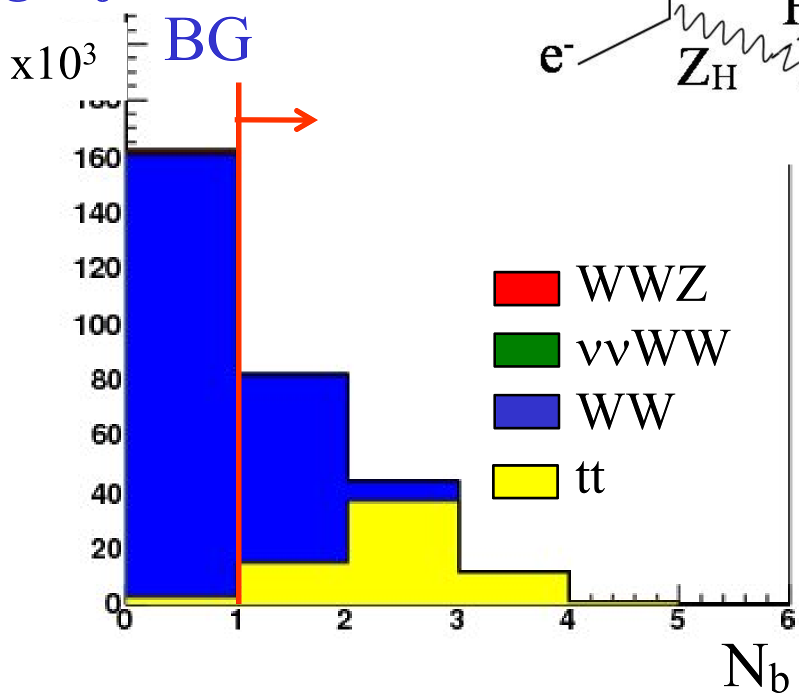


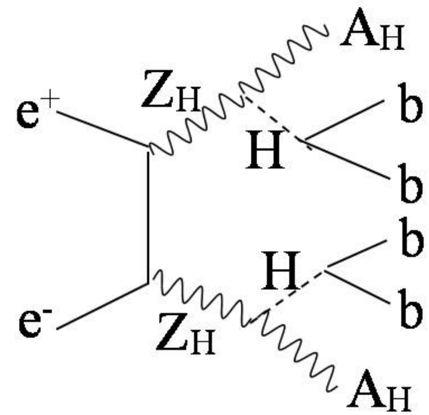
of b-tagged jets

- The b-tagging is applied to select H→bb.
  - b-tag requirement: 2 tracks with 3 sigma displacement from IP.
- Selection: $N_b \geq 1$

→ tt events become the main background.

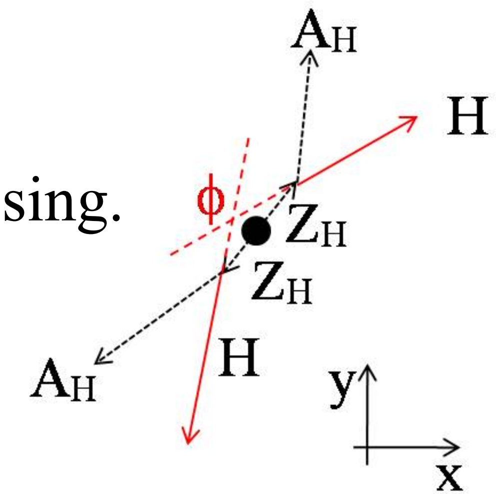




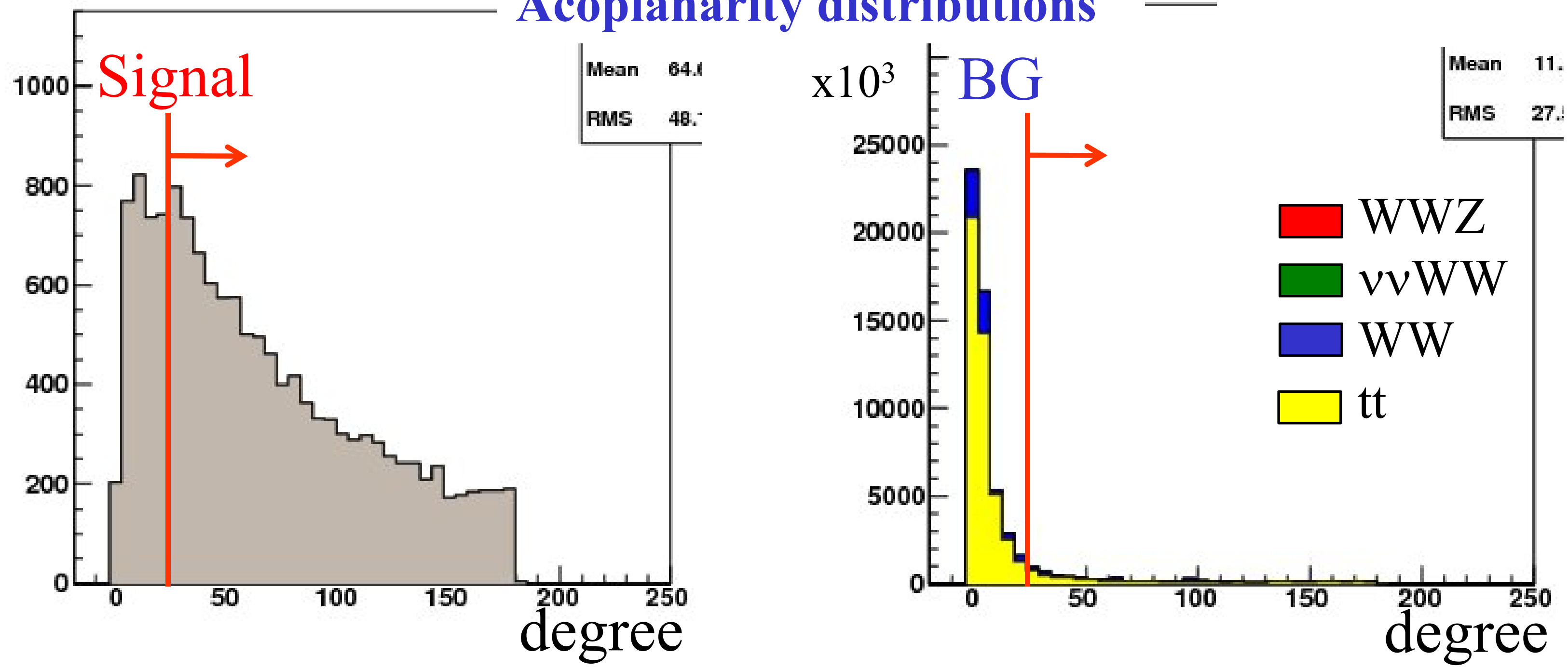


Acoplanarity cut

- Acoplanarity distribution is investigated.
  - Acoplanarity = $\pi - \phi$
- The signal has larger acoplanarity because A_H is missing.
  - tt events have a sharp peak around 0 degree.
- Acoplanarity > 25 degree is selected.



Acoplanarity distributions



Cut summary

A number of events at each selection cut are summarized.

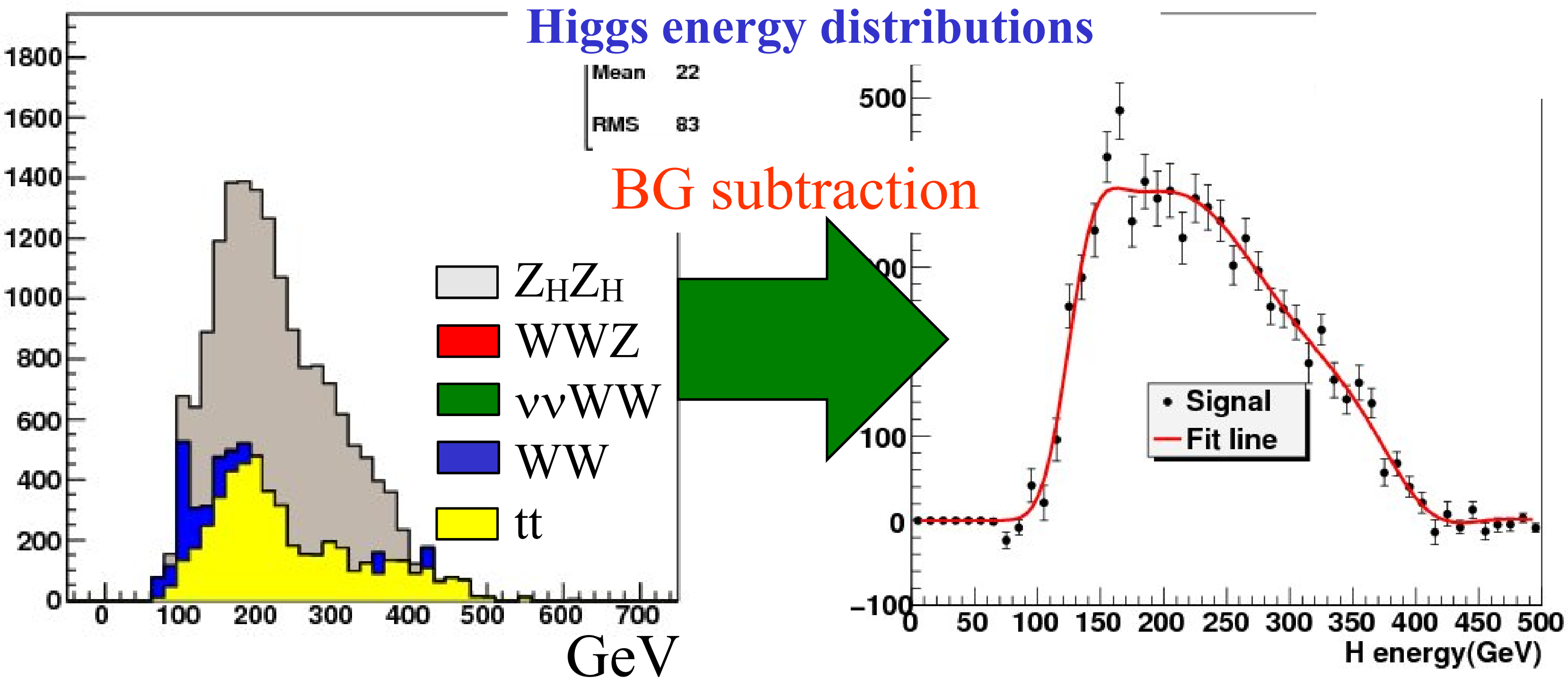
- The backgrounds are rejected efficiently.

	$Z_H Z_H$	WWZ	ννWW	WW	tt
Xsec (fb)	98.0	5.9	6.9	3,932	192.9
No cut	49,730	2,961	3,340	894,500	96,470
$\chi^2 < 80$	41,550	871	1,607	144,900	66,680
$N_b \geq 1$	27,980	115	537	13,210	64,120
Acop > 25 deg.	21,360	96	443	8,463	8,354

The masses of A_H and Z_H are extracted.

Extraction of M_{AH} and M_{ZH}

- The edge of the Higgs energy distribution has information of masses of A_H and Z_H.
- The masses are extracted by fitting the Higgs energy distribution.
  - M_{AH}: 81.9±5.1 GeV (True value: 81.9GeV) → **6.2%**
  - M_{ZH}: 368.0±5.2 GeV (True value: 369.0GeV) → **1.4%**



Mass resolution of heavy gauge bosons

The measurement accuracy of the heavy gauge bosons is summarized.

E_{CM} = 500GeV

- $A_H + Z_H$
  - M_{AH} : 83.2 ±13.3 GeV (16.2%)
  - M_{ZH} : 366.0 ±16.0 GeV (4.3%)

E_{CM} = 1TeV

- $W_H^+ + W_H^-$
  - M_{AH} : 82.46±1.18 GeV (1.4%)
  - M_{WH} : 367.8 ±0.83 GeV (0.2%)

Previous study
(Phys. Rev. D79, 075013 (2009))

- $Z_H + Z_H$
  - M_{AH} : 81.9 ±5.2 GeV (6.2%)
  - M_{ZH} : 368.0 ±5.2 GeV (1.4%)

Precision measurement of heavy gauge bosons is possible at ILC.

Summary

- Little Higgs model with T-parity is one of the candidate of the new physics.
- Measurement of the heavy gauge bosons is important to confirm Little Higgs model.
- $Z_H Z_H$ is analyzed to extract masses of A_H and Z_H at $E_{CM} =$ 1 TeV.
    - Masses of A_H and Z_H can be measured with 6.2% and 1.4% acuuracy, respectively, at $E_{CM} = 1$ TeV.
- The simultaneous mass fitting will be performed with $W_H W_H$ and $Z_H Z_H$ analyses.