Measurement of Little Higgs Parameters at International Linear Collider

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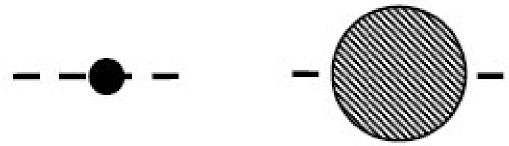
Little hierarchy problem

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



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

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

- $\Lambda < 1$ 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 ~ 1TeV
  - [$SU(2)_L$ x $U(1)_Y$] 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.

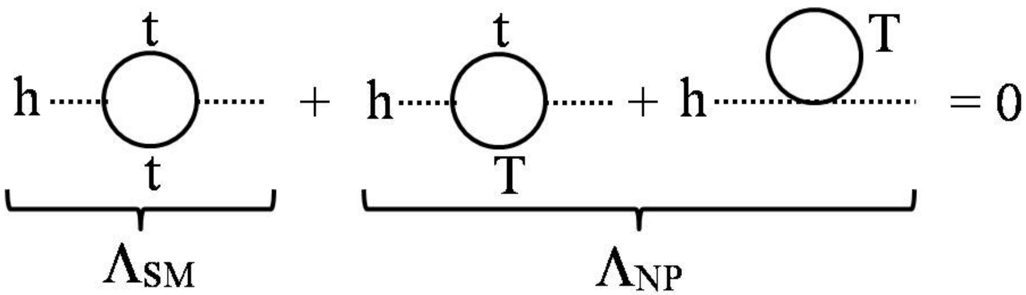
SU(5): $[SU(2) \times U(1)]^2$

↓ f ~1TeV

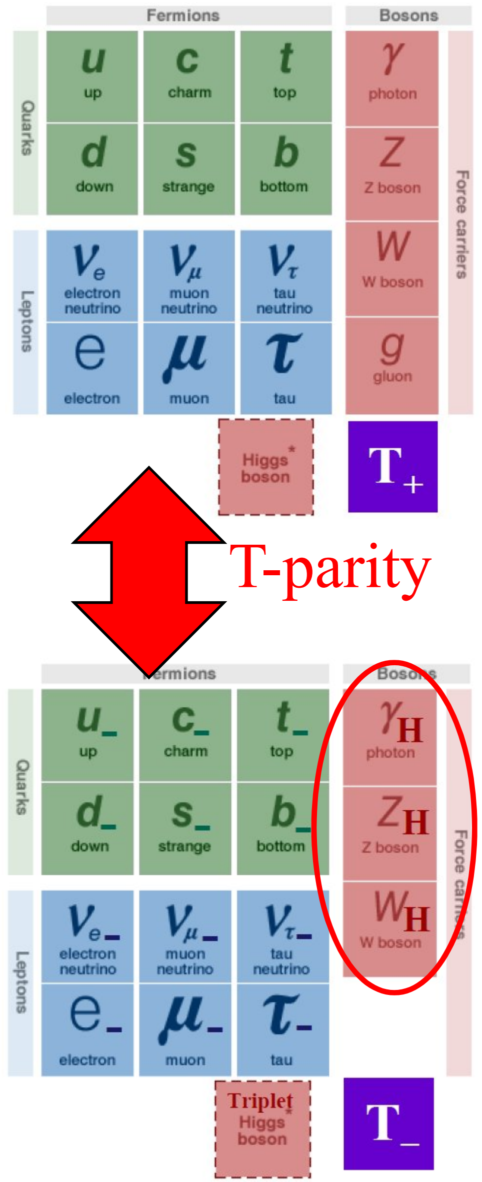
SO(5): $SU(2)_L \times U(1)_Y$

↓ v ~ <h>

$U(1)_Y$



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.

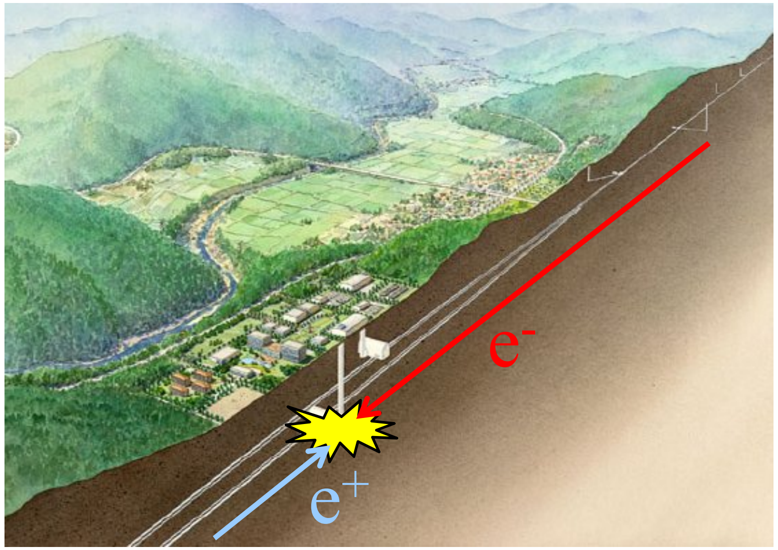
Sensitivity of ILC to the heavy gauge bosons was studied.

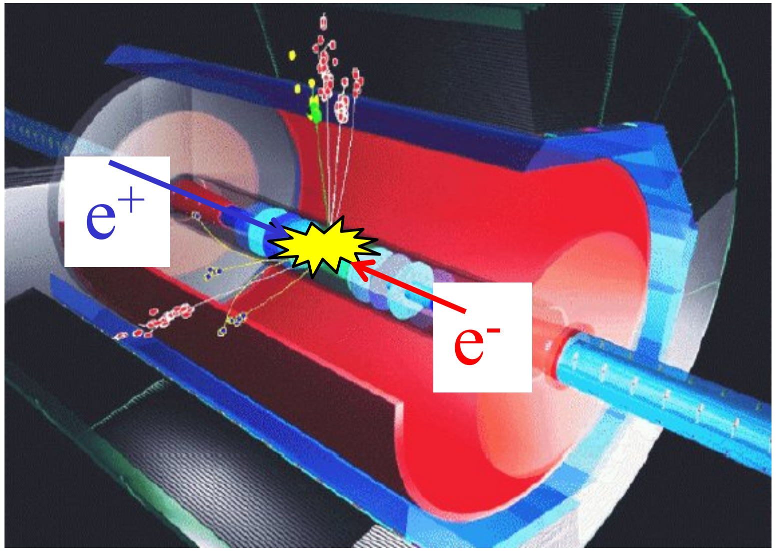
International Linear Collider

International Linear Collider (ILC)

- The future linear accelerator for e^+ and e^-.
  - Total length: ~30km
- E_{CM}: 500 GeV in the first stage
  - 1TeV in the second stage
- Luminosity: 2×10^{34} $cm^{-2}s^{-1}$
- Higgs and new physics will be studied at clean environment.
- R&D has been continued to establish the technology by 2012.

The simulation study was done for E_{CM} = 500GeV and 1TeV.





Parameter choice for simulation study

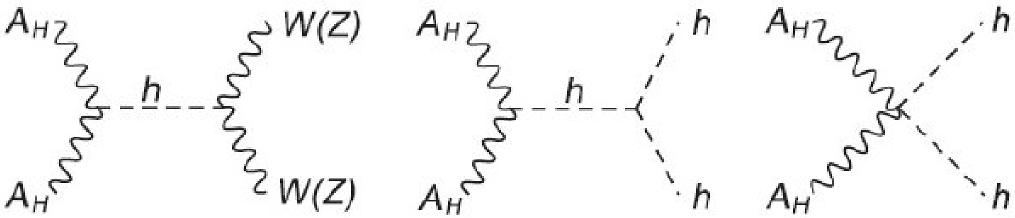
Constraint by WMAP result

- 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.

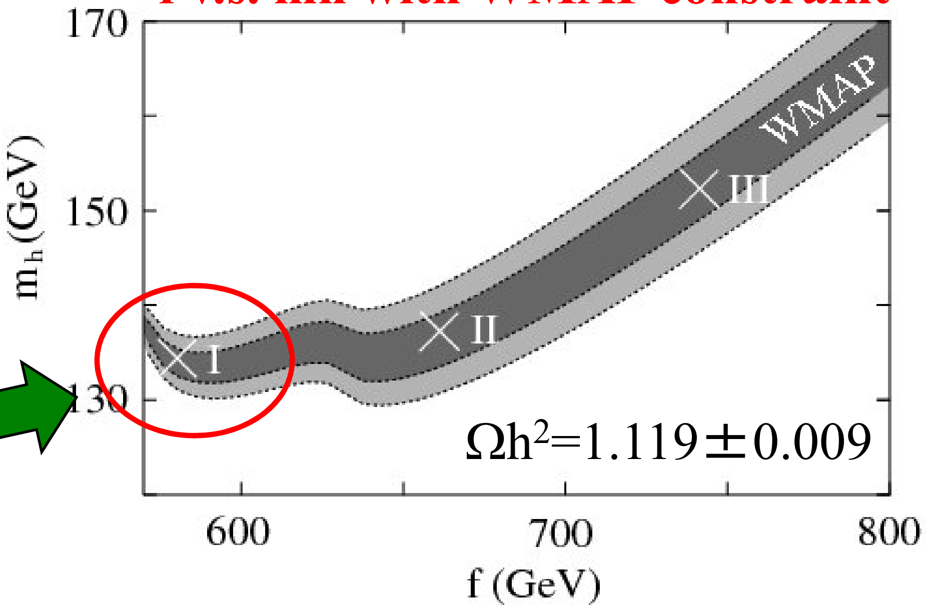
Parameters for this study

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

Annihilation processes of A_H



f v.s. mh with WMAP constraint



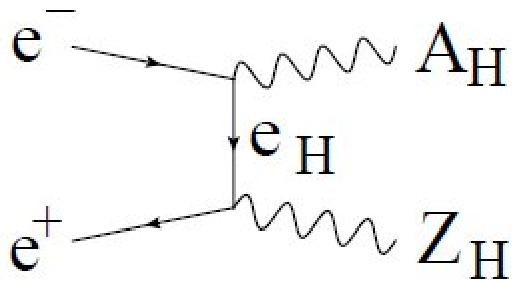
A_H, W_H, and Z_H can be observed at ILC.

Analysis modes

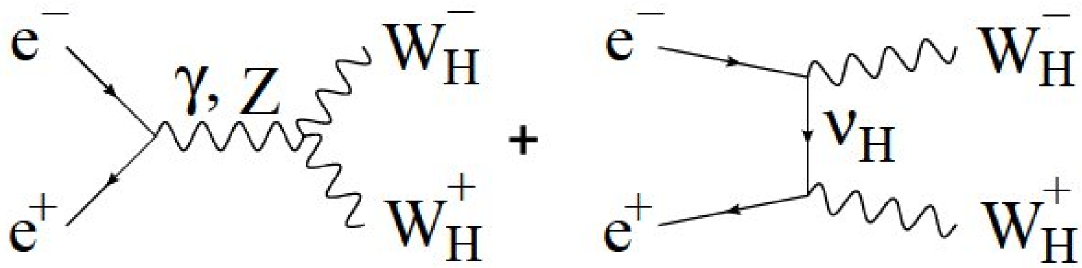
According to the beam energy at ILC, two analysis modes were selected.

Analysis modes

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



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

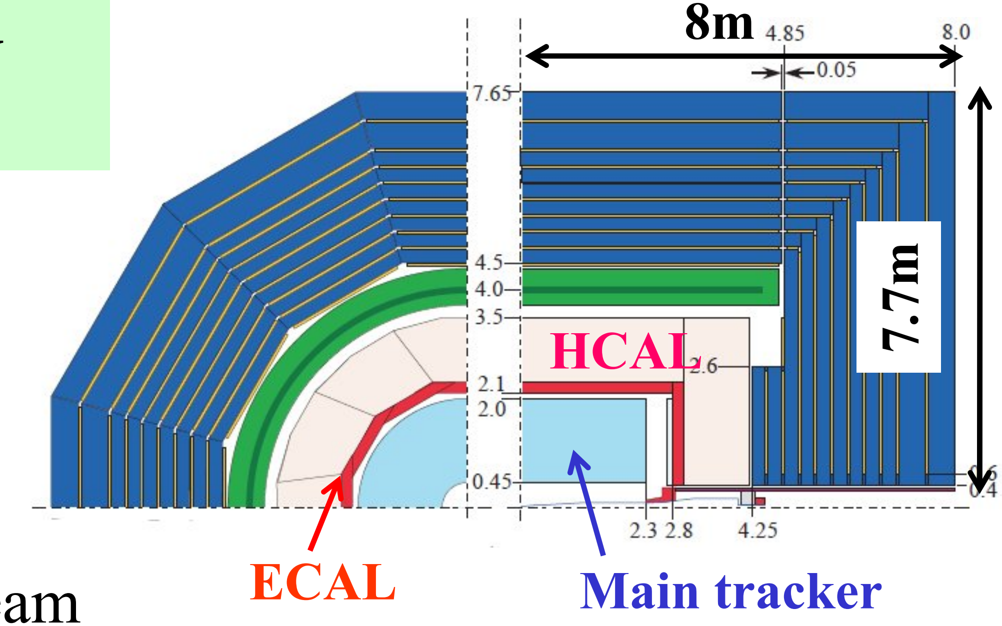


Simulation study

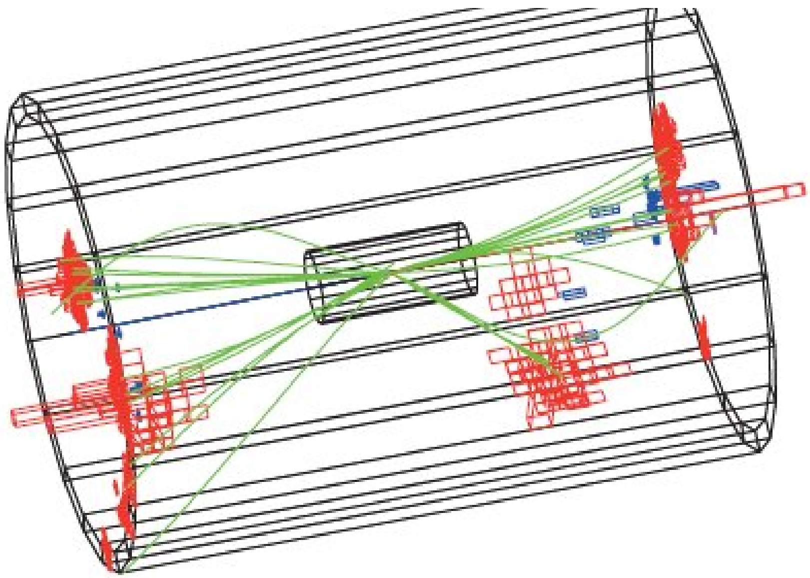
Simulation condition

- Event generator
  - Signal: Physsim
  - BG: MadGraph and Physsim
- ISR, FSR, beamstrahlung, and beam energy spread:
  - E_{CM}=500GeV: not considered.
  - E_{CM}=1TeV: considered.
- The fast-simulator for GLD was used.
  - The detector performance is included properly.
  - GLD was now re-organized as ILD.

GLD detector concept



Event display of a $W_H W_H$ event



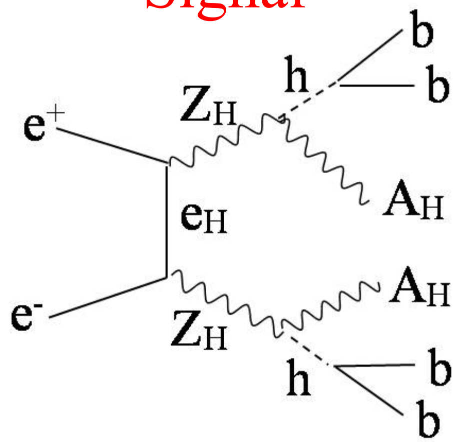
$A_H Z_H$ at E_{CM}=500GeV

Signal v.s. B.G. at E_{CM}=500GeV

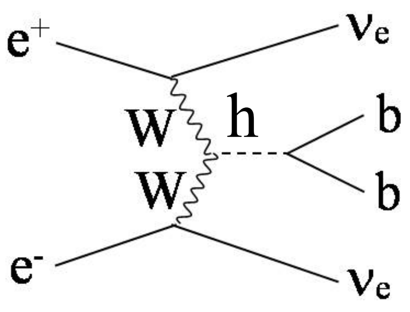
Signal v.s. BG

- Signal: $A_H Z_H \rightarrow A_H A_H hh$ ($h \rightarrow bb$)
  - Xsec: 1.05fb
  - BR($h \rightarrow bb$): 55.3% for Mh=134GeV
- BG: $\nu\nu h$ and Zh are serious BG.
  - $\nu\nu h \rightarrow \nu\nu bb$: 34fb
  - $Zh \rightarrow \nu\nu bb$: 5.57fb
- The selection cut was applied.
  - 100GeV< Mh <140GeV
  - ${}^{miss}p_t$>80GeV/c
  - b-tagging

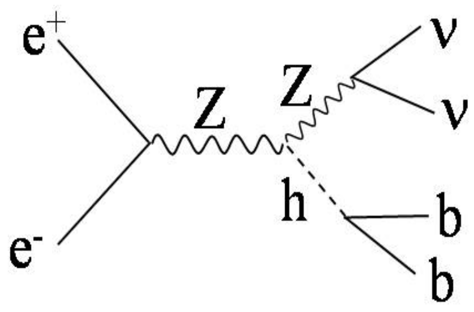
Signal



$\nu\nu h \rightarrow \nu\nu bb$



$Zh \rightarrow \nu\nu bb$



The number of events after the selection cut was checked.

Event selection at E_{CM}=500GeV

Event selection

- Assumption of b-tag performance
  - 80% efficiency for b-jet
  - 10% mis-identification of light quarks
- Signal significance: 3.7

→ **We will obtain the indication of new physics at E_{CM}=500GeV.**

Process			xsec(fb)	No cut	$100<m_h<140$	$P_t^{miss}>80$	b-tag
$A_H Z_H$	$\to$	$A_H A_H b\bar{b}$	1.05	525	488	425	272
γZ	$\to$	$\gamma b\bar{b}$	1,200	600,000	19,296	70	45
tt	$\to$	$W^+W^-b\bar{b}$	496	248,000	859	413	264
$\nu\nu Z$	$\to$	$\nu\nu b\bar{b}$	44.3	22,150	635	261	167
$\nu\nu h$	$\to$	$\nu\nu b\bar{b}$	34.0	17,000	15,170	5,247	3,359
ZZ	$\to$	$\nu\nu b\bar{b}$	25.5	12,750	404	277	178
Zh	$\to$	$\nu\nu b\bar{b}$	5.57	2,785	2,390	2,196	1,406
Total				860,105	38,727	8,464	5,419

Determination of A_H & Z_H mass

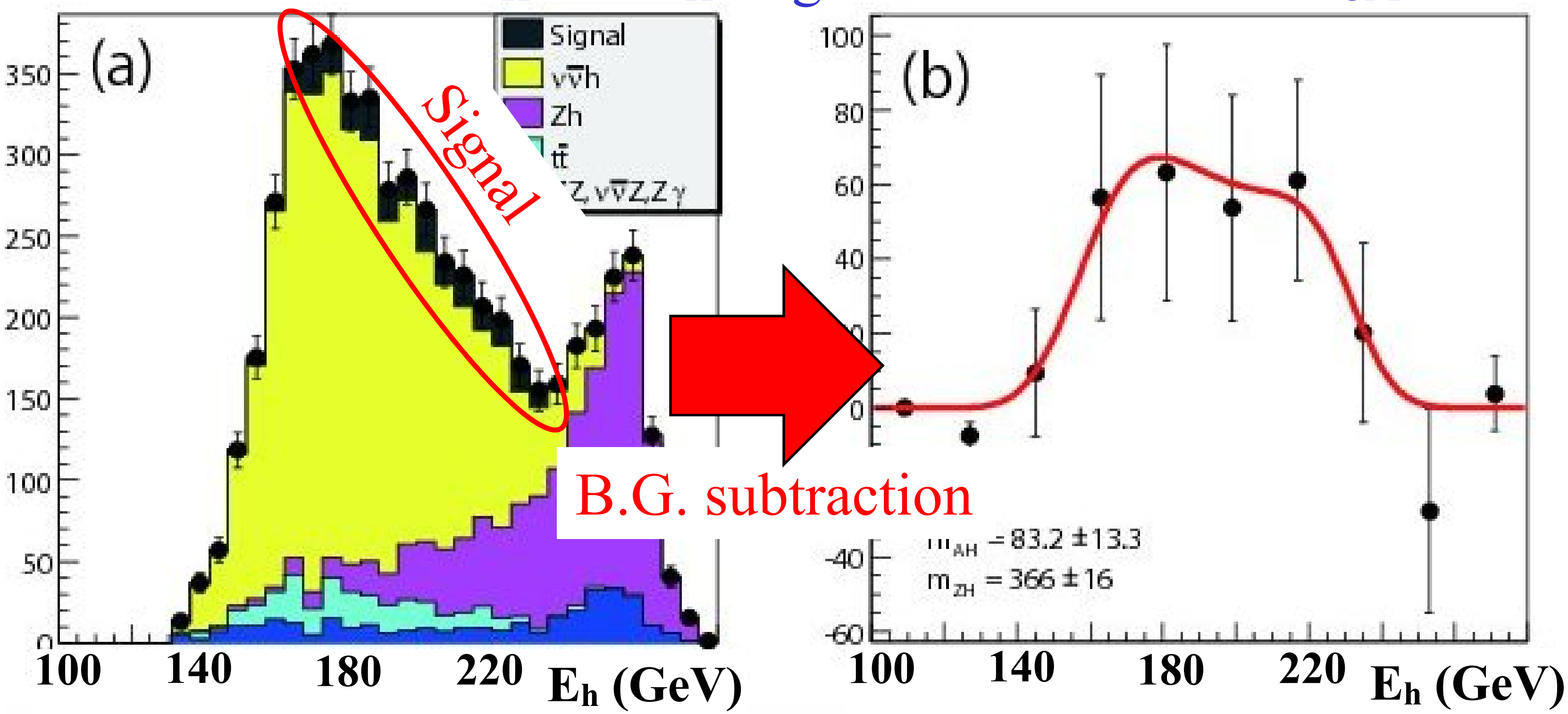
Masses of A_H and Z_H are determined by the edge of E_h distribution.

Measurement accuracy

- M_{AH} : 83.2 ±13.3 GeV
- M_{ZH} : 366.0 ±16.0 GeV

- M_{AH} : 16.2%
- M_{ZH} : 4.3%

Masses of A_H and Z_H might be determined at E_{CM}=500GeV.



$W_H W_H$ at E_{CM}=1TeV

Event selection at E_{CM}=1TeV

- Xsec of $W_H W_H$ is very large, comparing to the SM background.
- The hadronic decay modes of W was selected as the signal.
  - $W_H W_H \rightarrow A_H A_H WW \rightarrow A_H A_H qqqq$
- SN of 4.2 was obtained with simple selection cuts.

→ **The confident signal significance will be obtained at E_{CM}=1TeV.**

	Xsec(fb)	No cut	E_W<500GeV	χ^2<26	${}^{miss}p_T$>84GeV
$W_H W_H \rightarrow A_H A_H qqqq$	106.5	53,258	53,045	43,171	37,560
$WW \rightarrow qqqq$	1773.5	886,770	757,047	271,409	306
$eeWW \rightarrow eeqqqq$	464.9	282,500	269,075	150,957	23
$e\nu WZ \rightarrow e\nu qqqq$	25.5	12,770	12,271	7,033	3,696
$Z_H Z_H \rightarrow A_H A_H qqqq$	99.5	49,741	49,609	4,346	3,351
$\nu\nu WW \rightarrow \nu\nu qqqq$	6.5	3,227	3,203	2,373	1,486
Total		1,235,008	1,091,205	436,118	8,862

Determination of A_H & W_H mass

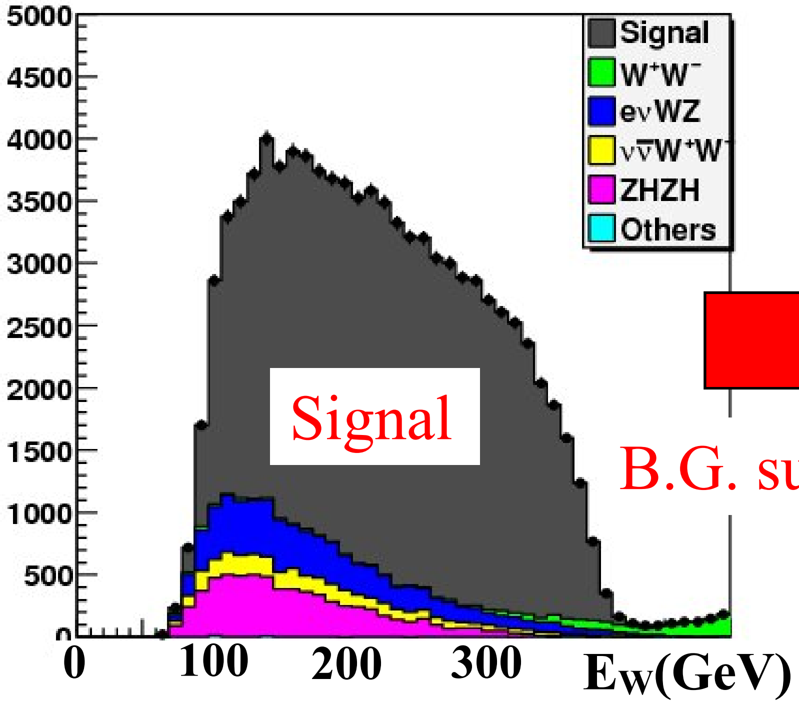
Masses of A_H and W_H are determined by the edge of E_h distribution.

- M_{AH} : 82.46±1.18 GeV
- M_{WH} : 367.8 ±0.83 GeV

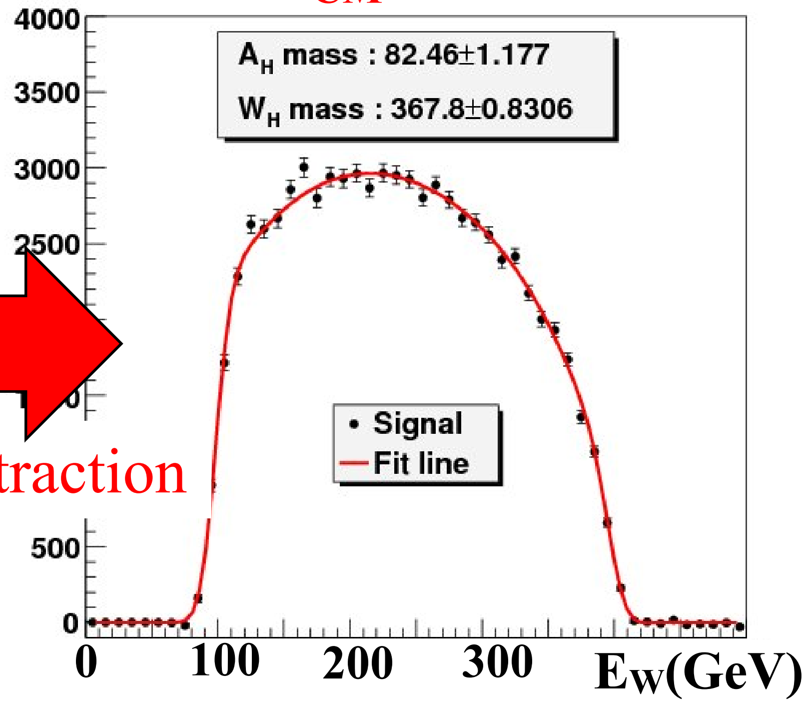
Measurement accuracy

- M_{AH} : 1.4%
- M_{WH} : 0.2%

Masses of A_H and W_H can be determined with 1% level at E_{CM}=1TeV.



B.G. subtraction



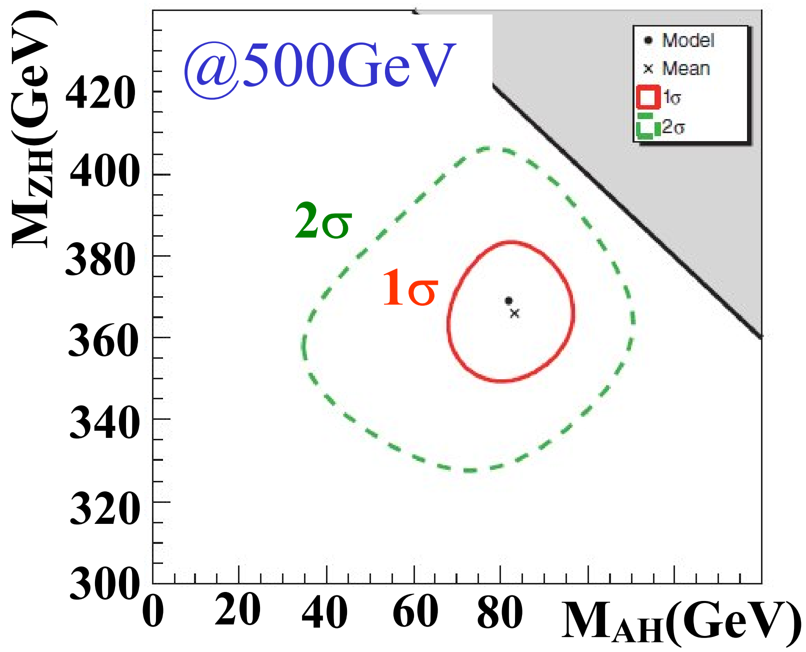
Determination of VEV & Ωh^2

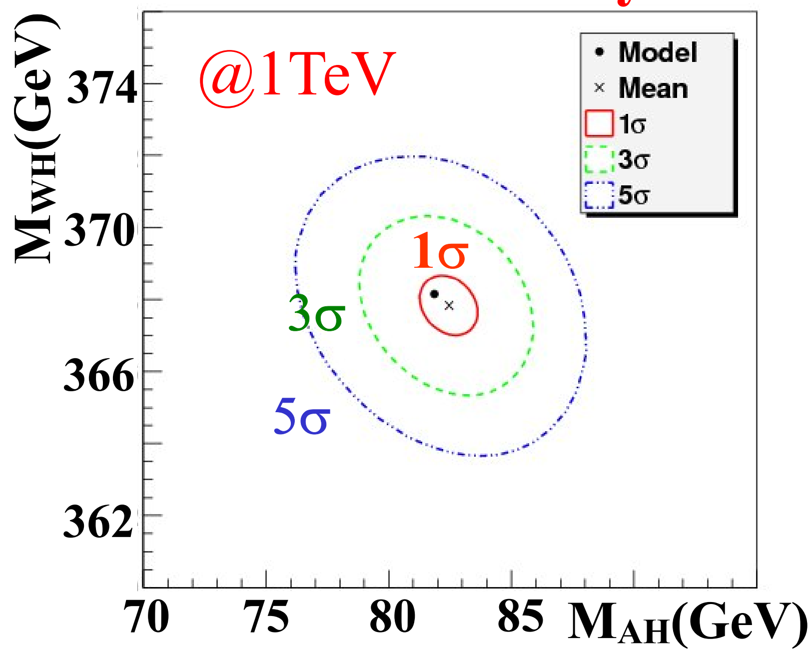
Sensitivity to VEV(f)

Sensitivity to VEV(f) was estimated by measurement accuracy of the heavy gauge bosons.

- $M_{AH} \sim$ sqrt(0.2) g' f, $M_{ZH, WH} \sim$ g f
  - f = 576.0±25.0 (4.3%) @ 500GeV
  - f = 579.8±1.1 (0.2%) @ 1TeV

ILC has excellent sensitivity to VEV.





Sensitivity to relic abundance

Finally, sensitivity to the relic abundance was investigated.

Relic abundance of A_H :

$$\Omega_{DM} h^2 = \frac{1.07 \times 10^9 x_f \mathrm{GeV}^{-1}}{\sqrt{g_*} m_{Pl} < \sigma v >}$$

Annihilation xsec of A_H

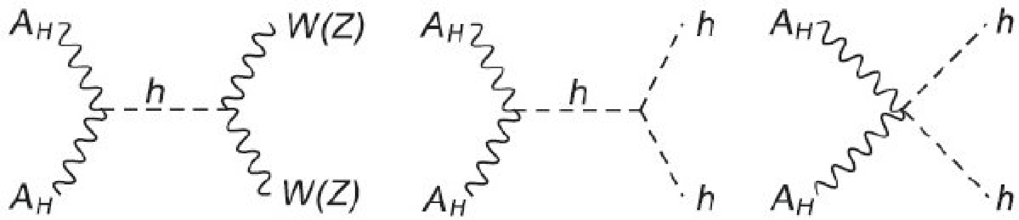
- Function of f

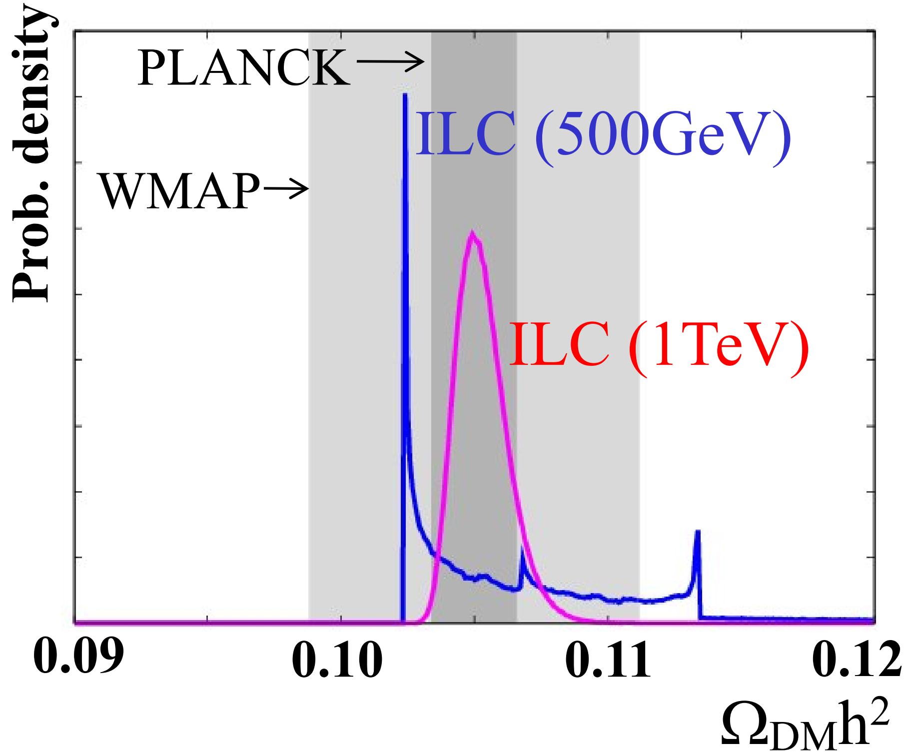
Sensitivity to Ωh^2 depends on the measurement accuracy of f .

- ~10% @500GeV
- ~1% @1TeV

ILC has the similar sensitivity to Ωh^2 with PLANK at E_{CM} = 1TeV.

Annihilation processes of A_H





Summary

- Little Higgs model with T-parity gives solution for the little hierarchy problem.
- ILC has excellent sensitivity to the Little Higgs parameters.
  - M_{AH}: 16.2%, M_{ZH}: 4.3% @ 500 GeV
  - M_{AH}: 1.4%, M_{WH}: 0.2% @ 1TeV
  - VEV (f): 4.3% @500GeV, 0.2% @1TeV
- The relic abundance of A_H can be determined with the similar sensitivity of PLANK.
  - ~10% @ 500GeV, ~1% @ 1TeV
- The paper on this study was published by PRD.
  - Phys. Rev. D79, 075013 (2009)/arXiv:0901.1081[hep-ph]

Spin of W_H & helicity of W

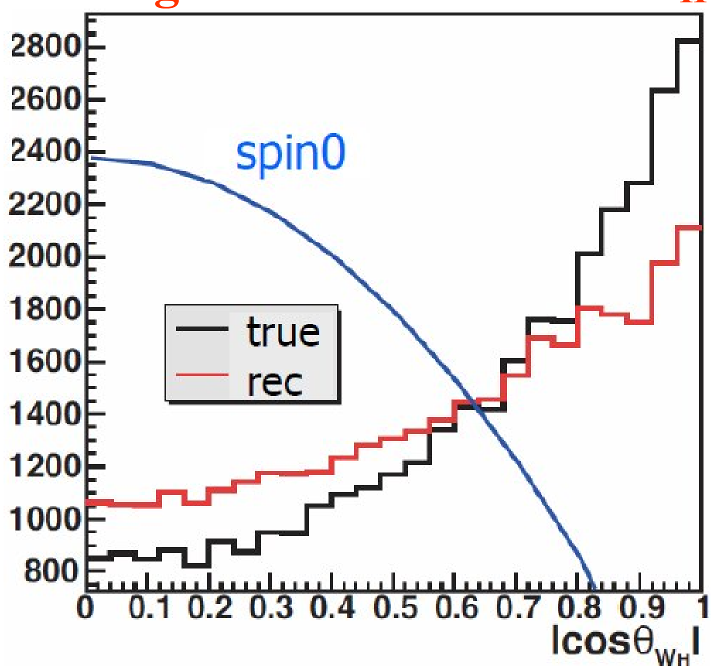
- The angular distribution of W_H is different from that of spin-0.

  → We can distinguish from spin-0 particles.

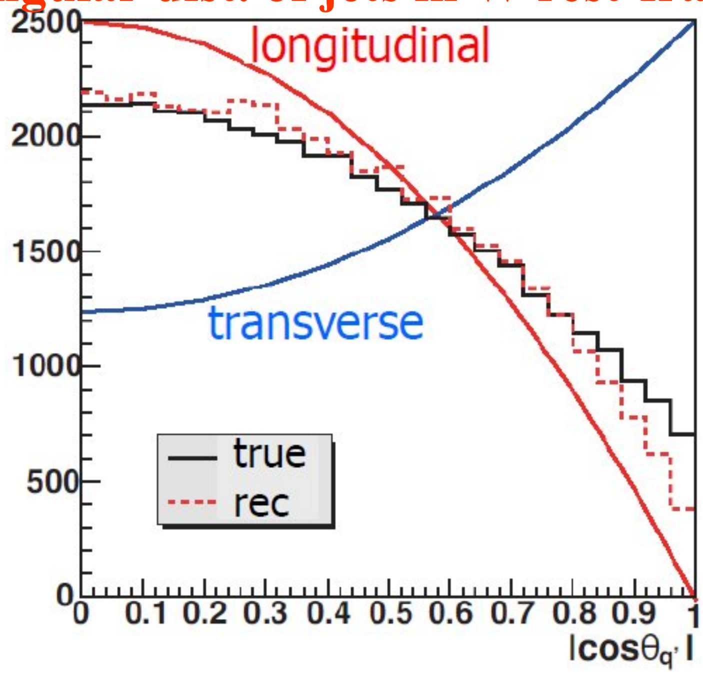
- Angular distribution of jets in W rest-frame shows the contribution of longitudinal component.

  → The coupling is confirmed to arise from the symmetry breaking.

Angular distribution of W_H



Angular dist. of jets in W rest-frame

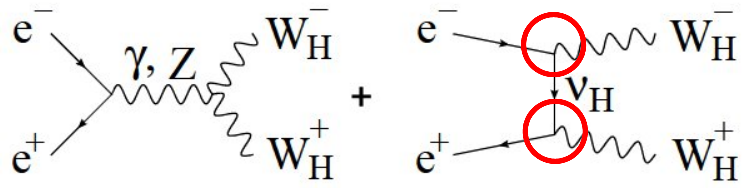


Gauge charge of W_H

W_H coupling

- W_H has SU(2) charge without U(1) charge.
- At high energy, $Z \sim W^3$ almost couples to left-handed.

→ W_H charge can be checked by relation of xsec. and the beam polarization.



Zero xsec. for fully right-handed polarization can be observed.

→ **At ILC, we can confirm that W_H has no U(1) charge.**