Study of Little Higgs Model with T-parity

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Contents

Little Higgs model with T-parity

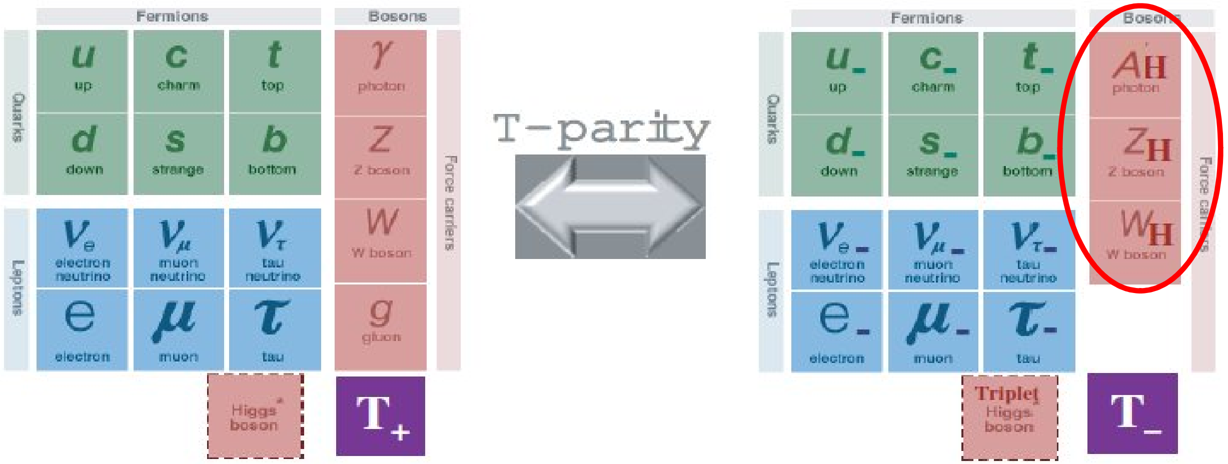
Little Higgs mechanism

Global symmetry: SU(5) —— Symmetry breaking, VEV(f) : ~1TeV ——> SO(5)

Subgroup: $[SU(2) \times U(1)]^2$ —— Symmetry breaking, VEV(f) : ~1TeV ——> $SU(2)_L \times U(1)_Y$

- Heavy gauge bosons obtain their masses through the symmetry breaking.
- Masses of A_H, Z_H, and W_H have information of VEV(f).
- A_H is a dark matter candidate.

→ **The observation of heavy gauge bosons at ILC was studied.**

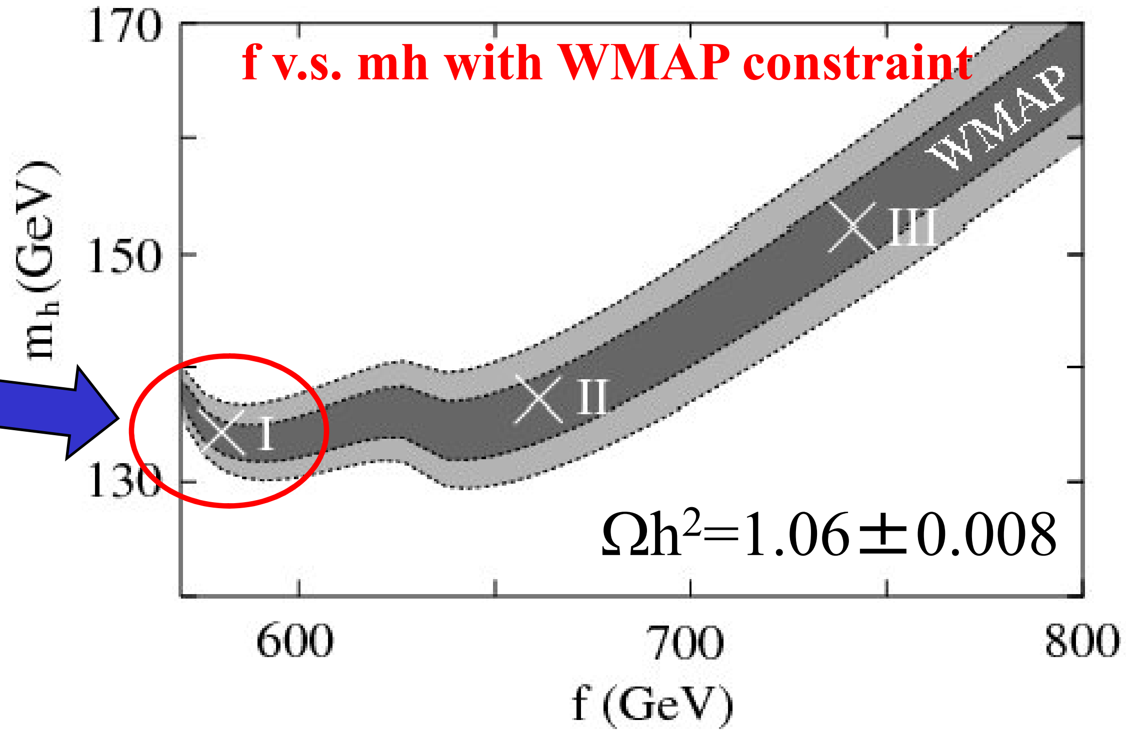


Representative point

The representative point for simulation study was selected with constraint from WMAP observation.

Representative point

- f: 580GeV
- M_h: 134GeV
- M_{AH}: 81.9GeV
- M_{WH}: 368GeV
- M_{ZH}: 369GeV
- M_{eH}: 410GeV (κ_{l1}=0.5)



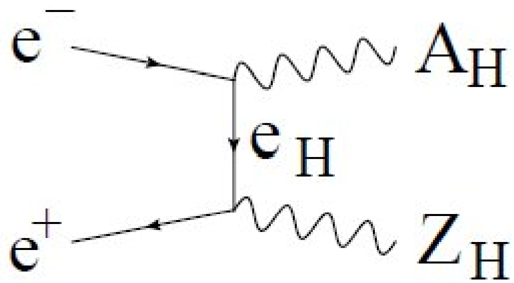
A_H, W_H, and Z_H can be observed at ILC (500GeV – 1TeV).

Analysis modes

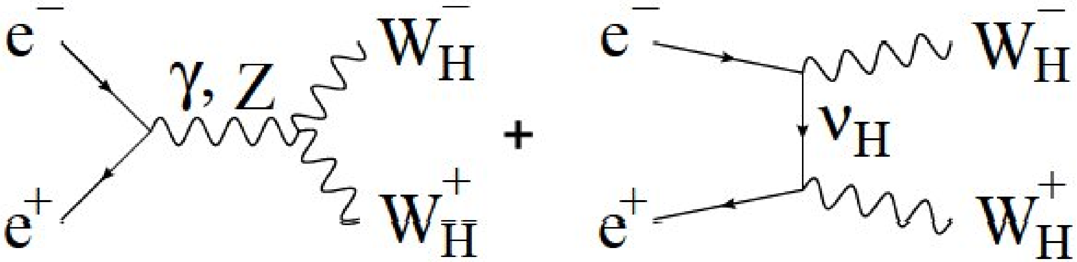
According to the beam energy at ILC, two analysis modes were selected.

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

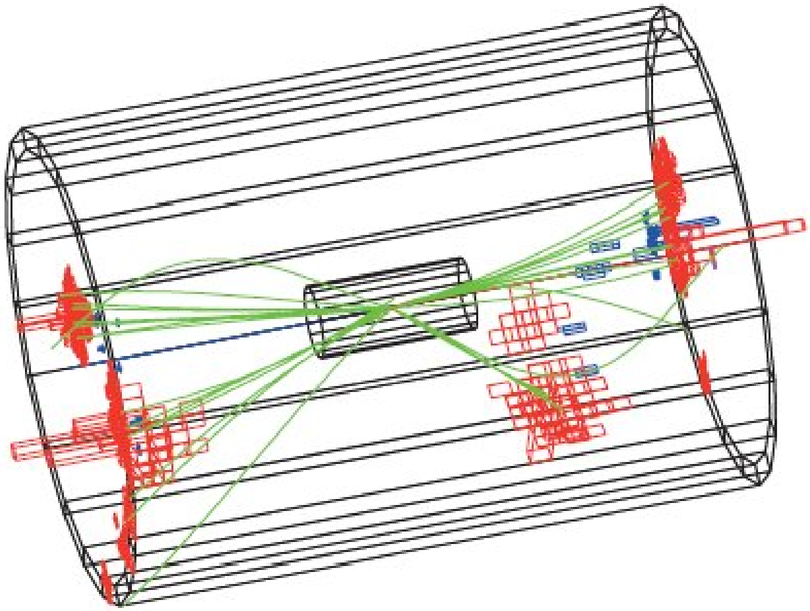
Simulation procedure

- **Event generation**
  - MadGraph or Physsim
  - Hadronization is done by Pythia
  - ISR, FSR, beamstrahlung, and beam energy spread are ignored.

- **Detector simulation**
  - Quick-sim for GLD

- **Analysis**
  - ROOT based analysis

Event display of a $W_H W_H$ event



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

Signal v.s. B.G. 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
$A_H Z_H$	$\rightarrow$	$A_H A_H b\bar{b}$	1.05	525	488	425	272
γZ	$\rightarrow$	$\gamma b\bar{b}$	1,200	600,000	19,296	70	45
tt	$\rightarrow$	$W^+W^-b\bar{b}$	496	248,000	859	413	264
$\nu\nu Z$	$\rightarrow$	$\nu\nu b\bar{b}$	44.3	22,150	635	261	167
$\nu\nu h$	$\rightarrow$	$\nu\nu b\bar{b}$	34.0	17,000	15,170	5,247	3,359
ZZ	$\rightarrow$	$\nu\nu b\bar{b}$	25.5	12,750	404	277	178
Zh	$\rightarrow$	$\nu\nu b\bar{b}$	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

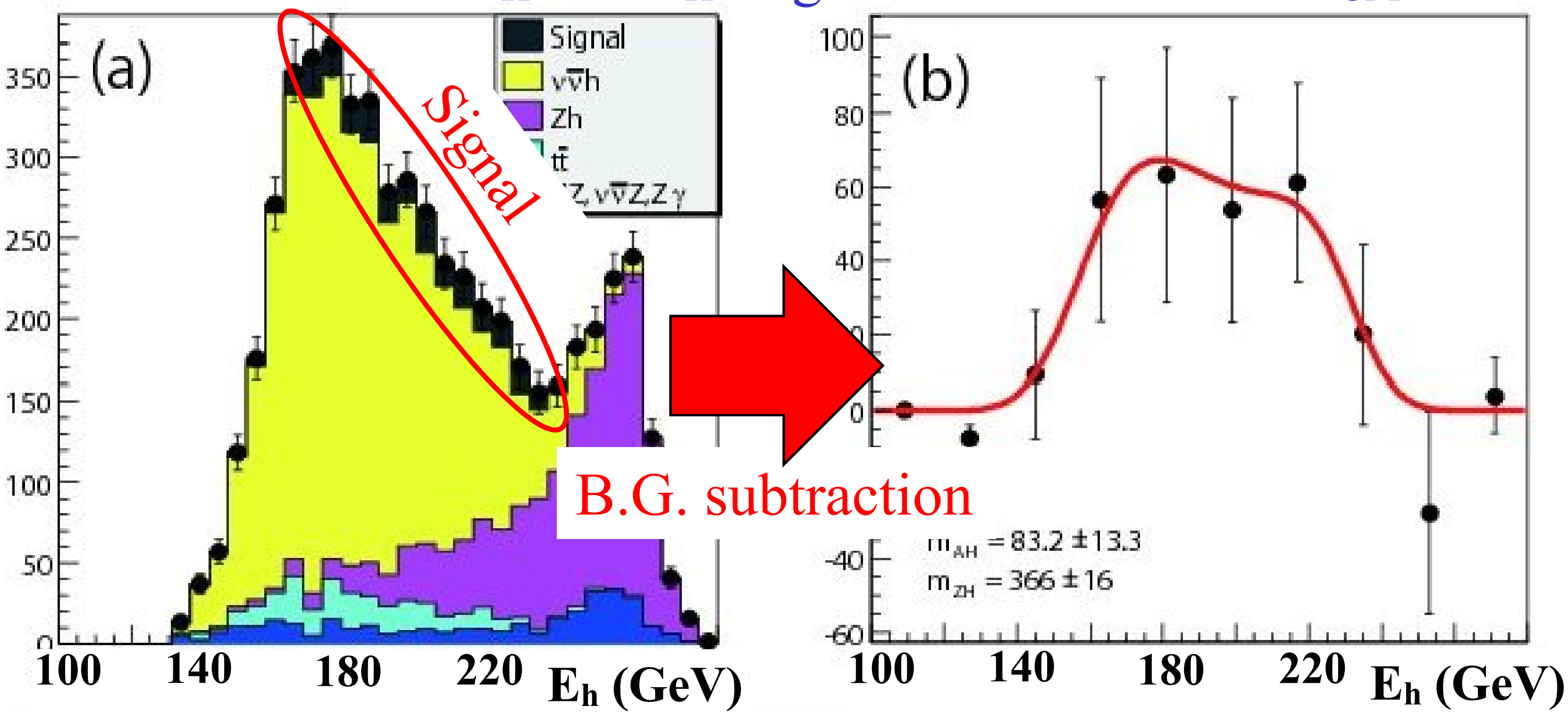
Masses of A_H and Z_H are determined by the edge of E_h distribution.

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

Measurement accuracy

- 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

Signal v.s. B.G. at E_{CM}=1TeV

- Xsec of $W_H W_H$ is very large, comparing to the SM background.
  → Easy to observe the signal at 1TeV
- The excellent SN was obtained with simple selection cuts.
  - E_W < 500 GeV
  - χ_2 < 26
  - missing P_T > 84 GeV

Process		**xsec(fb)**	**No cut**	$E_W < 500$	$\chi^2_W < 26$	$P_t^{miss} > 84$
$W_H^+ W_H^-$	$\rightarrow A_H A_H q\bar{q}q\bar{q}$	120	60,000	59,880	48,135	41,190
$W^+ W^-$	$\rightarrow q\bar{q}q\bar{q}$	1307	653,500	551,688	16,1120	678
$e^+ e^- W^+ W^-$	$\rightarrow e^+ e^- q\bar{q}q\bar{q}$	490	245,000	237,640	128,904	46
$e\nu_e W Z$	$\rightarrow e\nu_e q\bar{q}q\bar{q}$	24.5	12,250	11,946	6,994	3,797
$Z_H Z_H$	$\rightarrow A_H A_H q\bar{q}q\bar{q}$	18.8	9,400	9,389	266	213
$\nu\bar{\nu} W^+ W^-$	$\rightarrow \nu\bar{\nu} q\bar{q}q\bar{q}$	7.23	3,615	3,602	2,607	1,597
$Z W^+ W^-$	$\rightarrow \nu\bar{\nu} q\bar{q}q\bar{q}$	5.61	2,805	2,744	1,839	1,533
Total			926,570	817,009	301,730	7,864

Determination of A_H & W_H mass

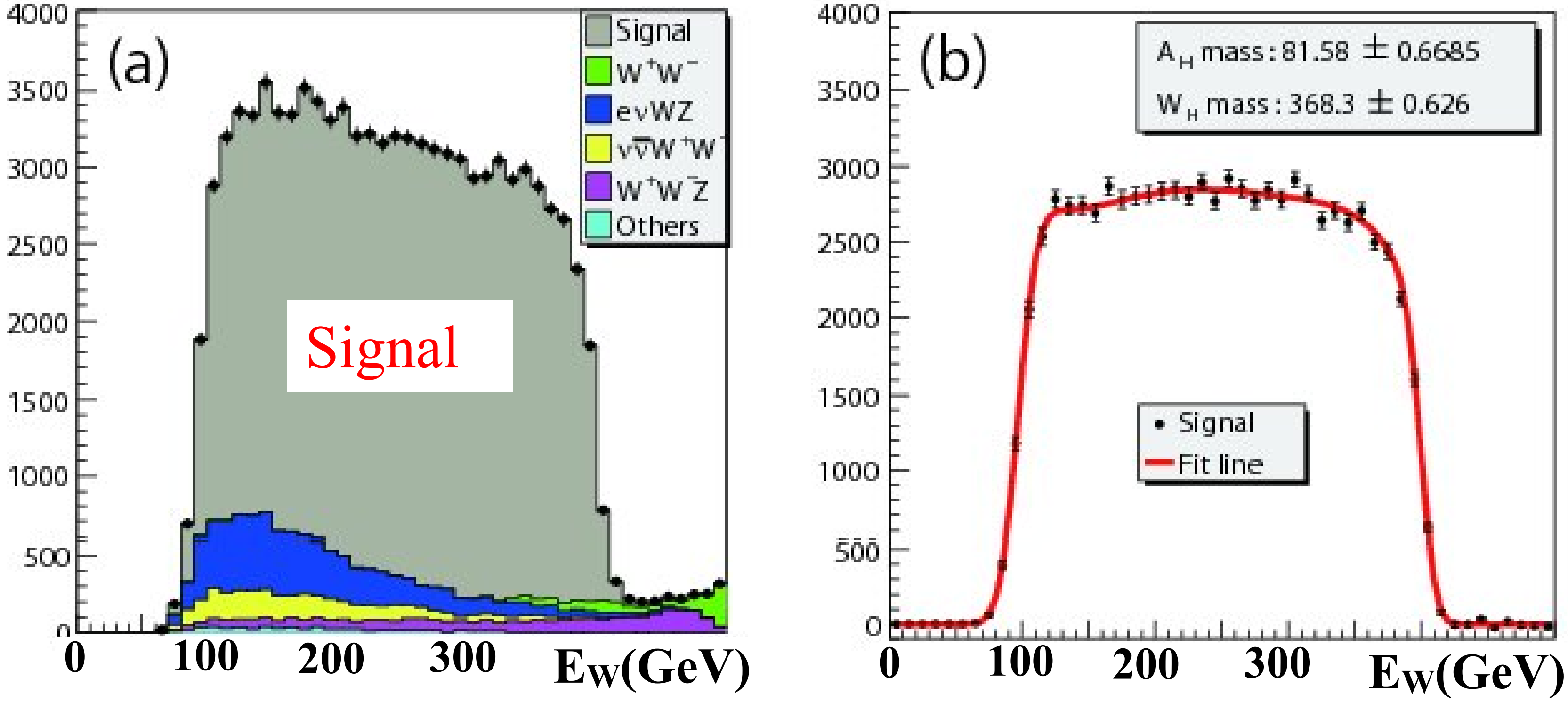
Masses of A_H and W_H are determined by the edge of E_h distribution.

- M_{AH} : 81.58±0.67 GeV
- M_{WH} : 368.3 ±0.63 GeV

Measurement accuracy

- M_{AH} : 0.8%
- M_{WH} : 0.2%

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



Spin of W_H & helicity of W

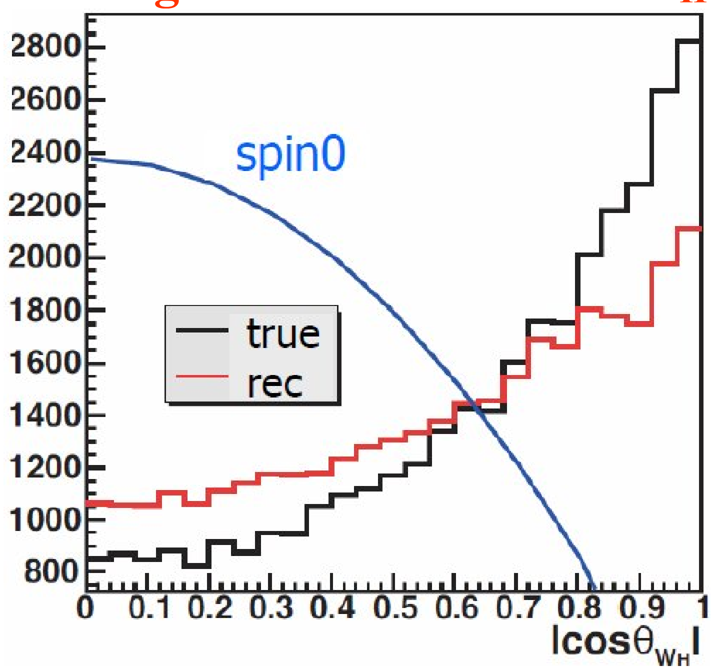
- The angular distribution of W_H is different from that of spin-0.

  → We can distinguish the type of new particle from new physics.

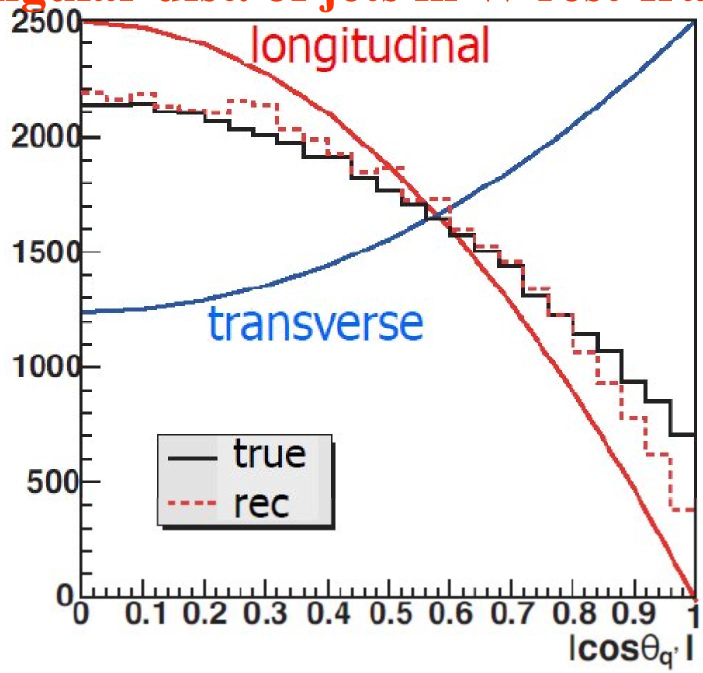
- Angular distribution of jets in W rest-frame shows the contribution of longitudinal component.

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

Angular distribution of W_H



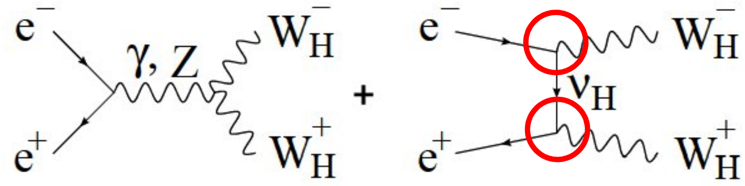
Angular dist. of jets in W rest-frame



Gauge charge of W_H

W_H coupling

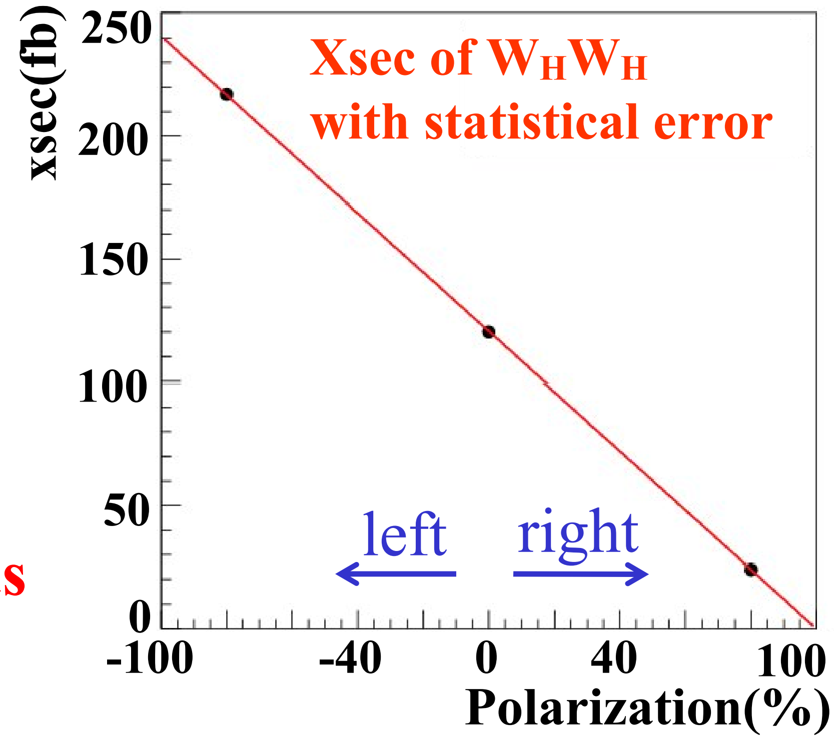
- W_H has SU(2) charge with no U(1) charge.
- At high energy, $Z \sim W^3$ almost couples to left-handed.



→ 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.**



Determination of VEV & Ωh^2

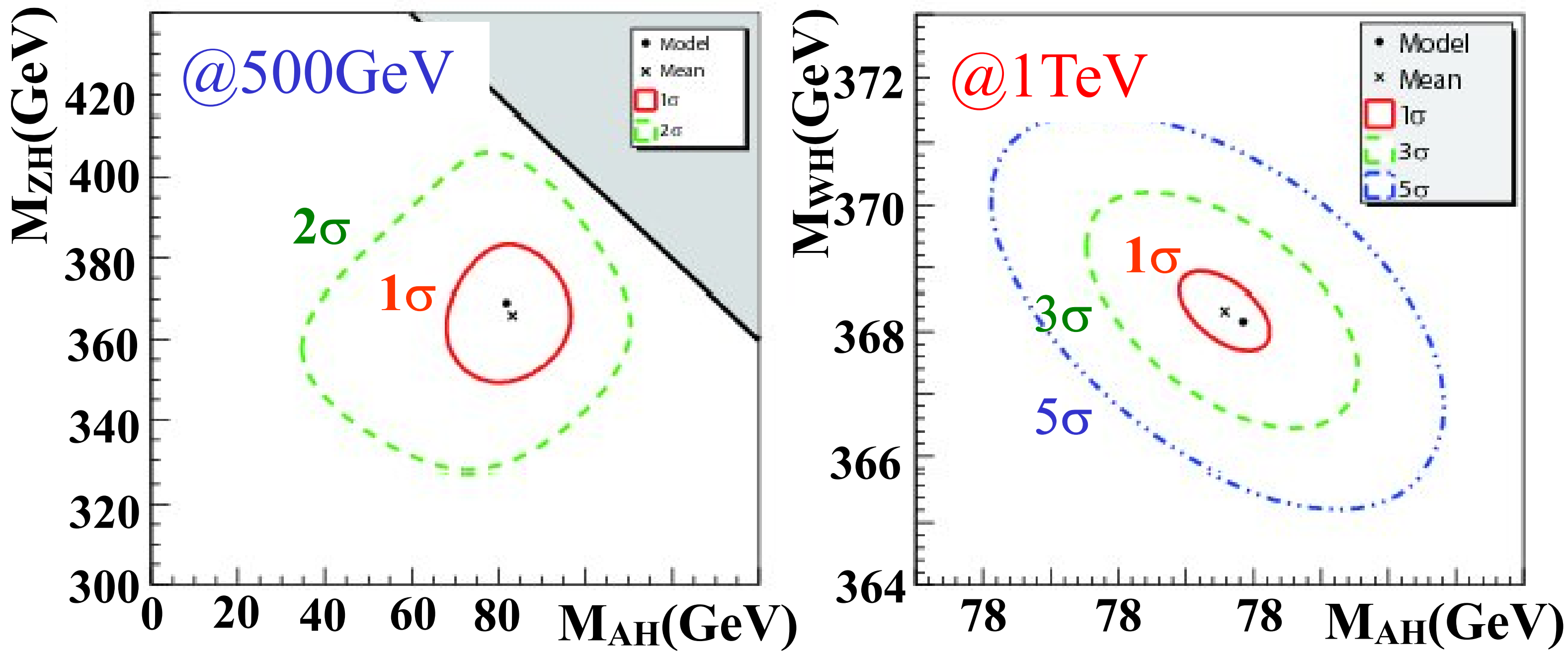
Sensitivity to VEV(f)

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

- $M_{AH} \sim \mathrm{sqrt}(0.2)\, g' f$, $M_{ZH,\,WH} \sim g f$

  - $f = 576.0 \pm 25.0$ @ 500GeV
  - $f = 580.0 \pm 0.69$ @ 1TeV

ILC has excellent sensitivity to VEV.



Sensitivity to relic abundance

Finally, sensitivity to the relic abundance was investigated.

Relic abundance of A_H :

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

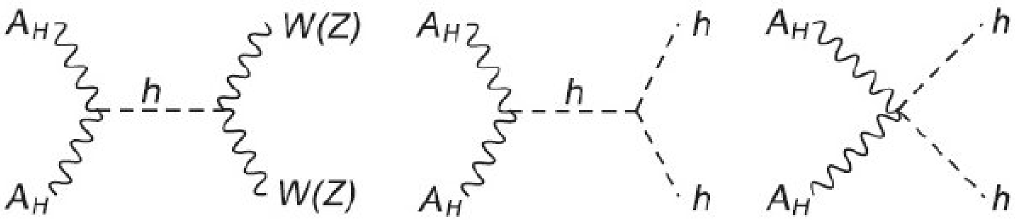
Annihilation xsec of A_H

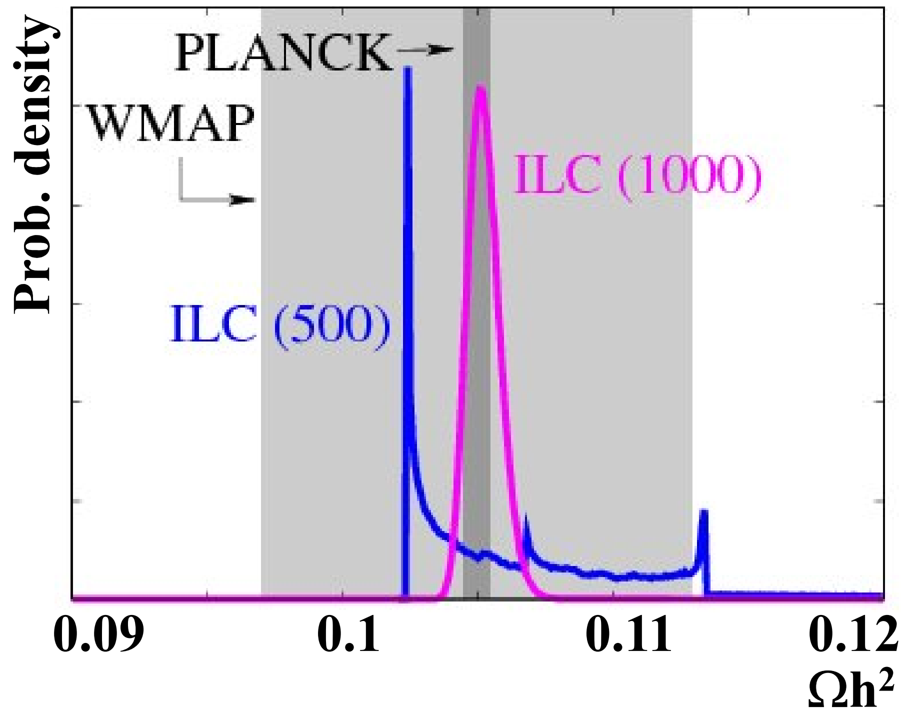
- Function of M_{AH}

Sensitivity to Ωh^2 depends on the measurement accuracy of M_{AH} .

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

Annihilation processes of A_H





Summary

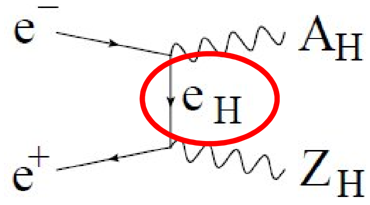
- ILC has excellent sensitivity to the Little Higgs parameters.
  - M_{AH}: 16.2%, M_{ZH}: 4.3% @ 500 GeV
  - M_{AH}: 0.8%, M_{WH}: 0.2% @ 1TeV
  - VEV (f): 4.3% @500GeV, 0.1% @1TeV
  - κ_l : 9.5% @500GeV, 0.8% @1TeV
- The relic abundance of A_H also can be confirmed precisely.
  - ~10% @ 500GeV, ~1% @ 1TeV
- The paper on this study was accepted by PRD.

(arXiv:0901.1081[hep-ph])

Sensitivity to κ_l

Sensitivity to κ_l is estimated by using that to f.

- $M_{eH} = \mathrm{sqrt}(2)\ \kappa_l\ f$
- $M_{\nu H} \sim \mathrm{sqrt}(2)\ \kappa_l\ f$



⇒ Sensitivity to κ_l:
- 9.5% @500GeV
- 0.8% @1TeV