Precision Measurements of Littlest Higgs Model with T-parity at ILC

- Littlest Higgs model with T-parity
- Observable to be measured
- Analysis framework
- Analysis of $e^+e^- \rightarrow A_H Z_H$ @500GeV
- Analysis of $e^+e^- \rightarrow W_H^+ W_H^-$ @1TeV
- Discussion of results

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Littlest Higgs model with T-parity

<1. Little Higgs mechanism>

global symmetry : $SU(5)$ (symmetry breaking) $\longrightarrow$ $SO(5)$

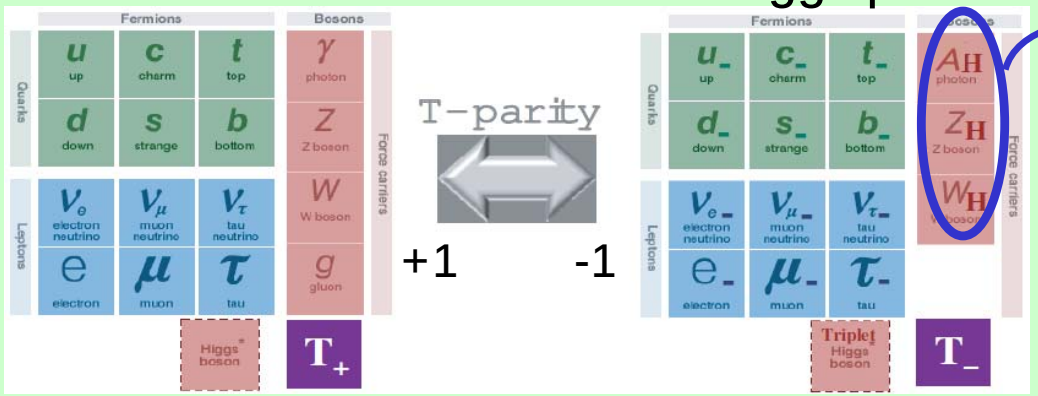
subgroup : $[SU(2) \times U(1)]^2 \longrightarrow SU(2)_L \times U(1)_Y$

〔 VEV : f ~1TeV〕

*VEV=Vacuum Expectation Value

<2. T-parity>

Standard Model Little Higgs partner



Heavy gauge bosons get mass through symmetry breaking

Precision measurement for masses of A_H, Z_H, $W_H^{\pm}$
→ Determination of VEV f

<Representative point of model parameter>

f	m_h
580(GeV)	134(GeV)

m_{A_H}	m_{W_H}	m_{Z_H}
81.9(GeV)	368(GeV)	369(GeV)

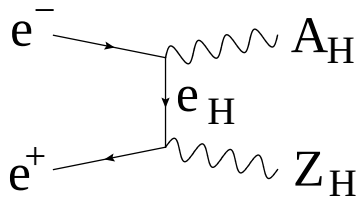
*considering { electroweak precision measurement / WMAP observation

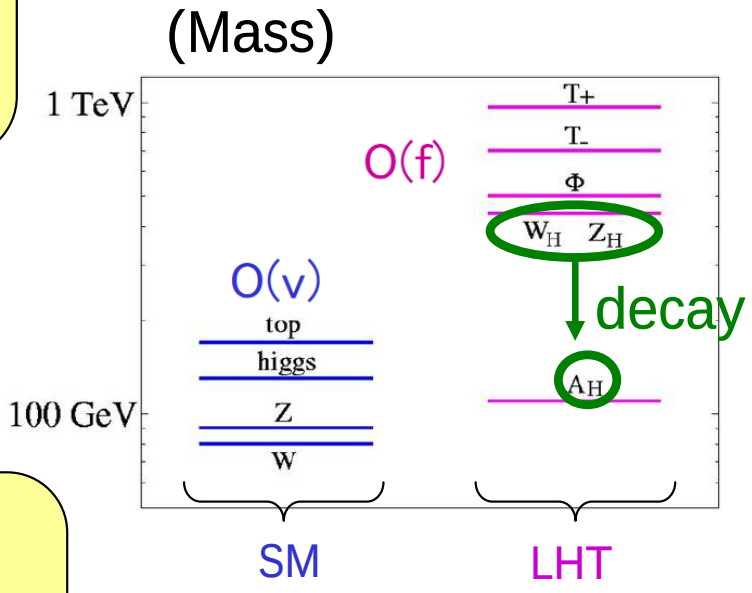
Masses of A_H, Z_H, $W_H^{\pm}$ are less than 500GeV.
→ They can be searched by ILC.

Analysis mode

<ILC @500GeV>

$e^+e^- \rightarrow A_H Z_H$
- $m_{AH}+m_{ZH}<500GeV$ (1.91fb)
- $Z_H \rightarrow A_H h$ (100% ratio)
- Target : $A_H A_H bb$ (bb jets in final state)

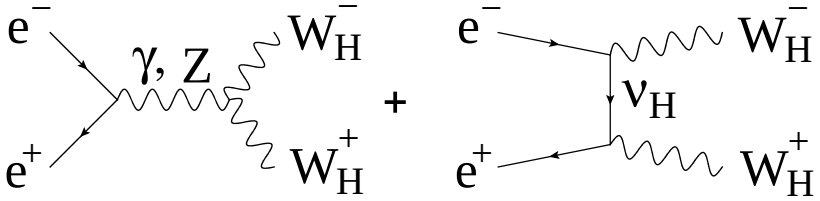




A_H: Dark Matter

<ILC @1TeV>

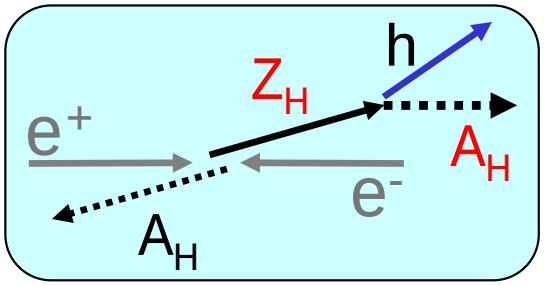
$e^+e^- \rightarrow W_H^+ W_H^-$
- Large cross section (277fb)
- $W_H^{\pm} \rightarrow A_H W^{\pm}$ (100% ratio)
- Target : $A_H A_H qqqq$ (4 jets in final state)



Observable to be measured

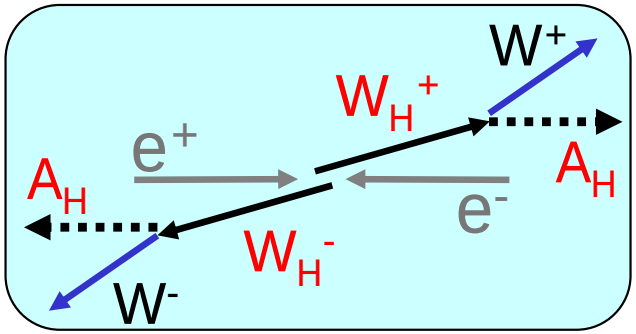
@500GeV

- Energy edges of h
  → Masses of A_H and Z_H

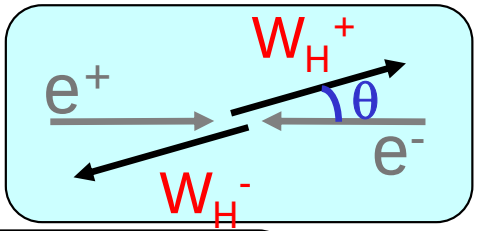


@1TeV

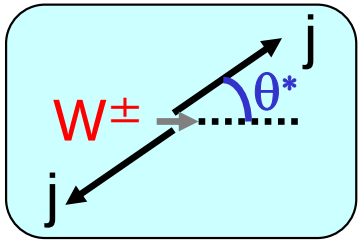
- Energy edges of $W^{\pm}$
  → Masses of A_H and $W_H^{\pm}$



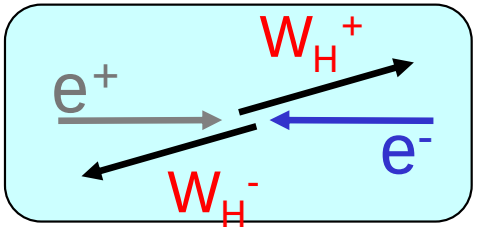
1) Production angle of $W_H^{\pm}$
   → Spin of $W_H^{\pm}$



2) Angular distribution of jets from $W^{\pm}$
   → Helicity of $W^{\pm}$



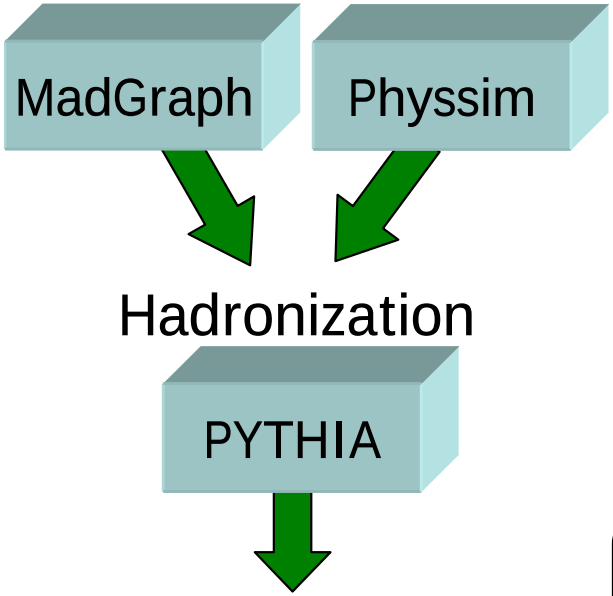
3) Cross section of $e^+e^- \rightarrow W_H^+W_H^-$ (polarized e^-)
   → Gauge charge of $W_H^{\pm}$



Simulation framework

<Simulation flow>

Event generation



*Fast simulator

<Simulation setup>

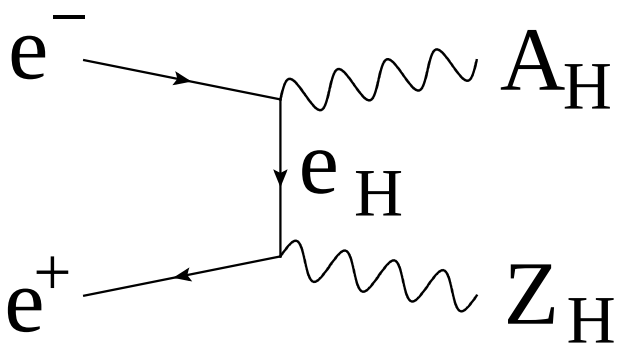
- Center-of-mass energy : 500GeV, 1TeV
- Integrated luminosity : 500 fb^{-1}
- Beam polarization of e^- : -80, 0, 80%
  of e^+ : 0%
- Crossing angle of beams : no
- Beamstrahlung : ignored
- Initial-state radiation : ignored

<Detector parameter>

Detector	Performance	Coverage
Vertex detector	$\delta_b \leq 5 \oplus 10/p\beta \sin^{3/2}\theta$ (μm)	$\lvert\cos\theta\rvert \leq 0.93$
Central drift chamber	$\delta p_t/p_t^2 \leq 5 \times 10^{-5}$ (GeV/c)$^{-1}$	$\lvert\cos\theta\rvert \leq 0.98$
EM calorimeter	$\sigma_E/E = 17\%/\sqrt{E} \oplus 1\%$	$\lvert\cos\theta\rvert \leq 0.99$
Hadron calorimeter	$\sigma_E/E = 45\%/\sqrt{E} \oplus 2\%$	$\lvert\cos\theta\rvert \leq 0.99$

*based on GLD parameters

Analysis @500GeV



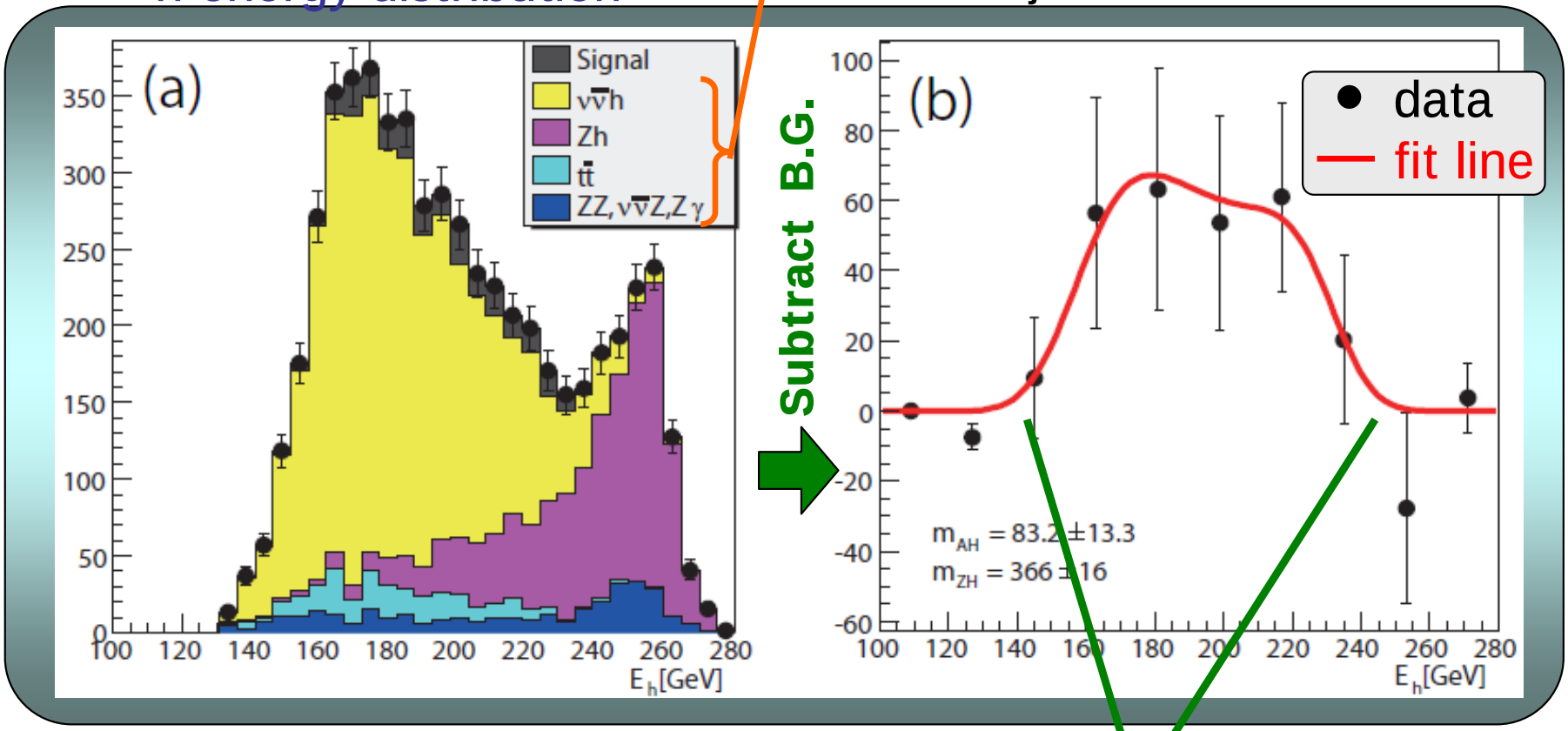
Masses of A_H and Z_H

<Event selection>

100GeV<m_h<140GeV & P_t^{miss}>80GeV & b-tag

<h energy distribution>

B.G. are bb jets in final states



<Signal significance>

$$\frac{\#signal}{\sqrt{\#background}} = 3.7\sigma$$

<Masses from fitting edges>

m_{AH} = 83.2 ±13.3 GeV

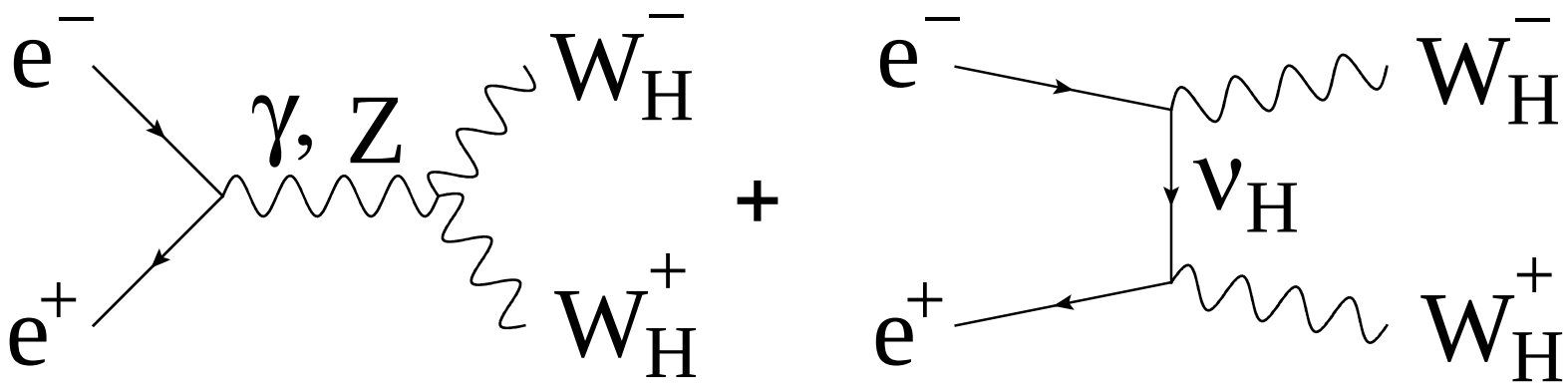
m_{WH} = 366.0±16.0 GeV

<Accuracy>

16.2%

4.3%

Analysis @1TeV



Masses of A_H and $W_H^{\pm}$

<Event selection>

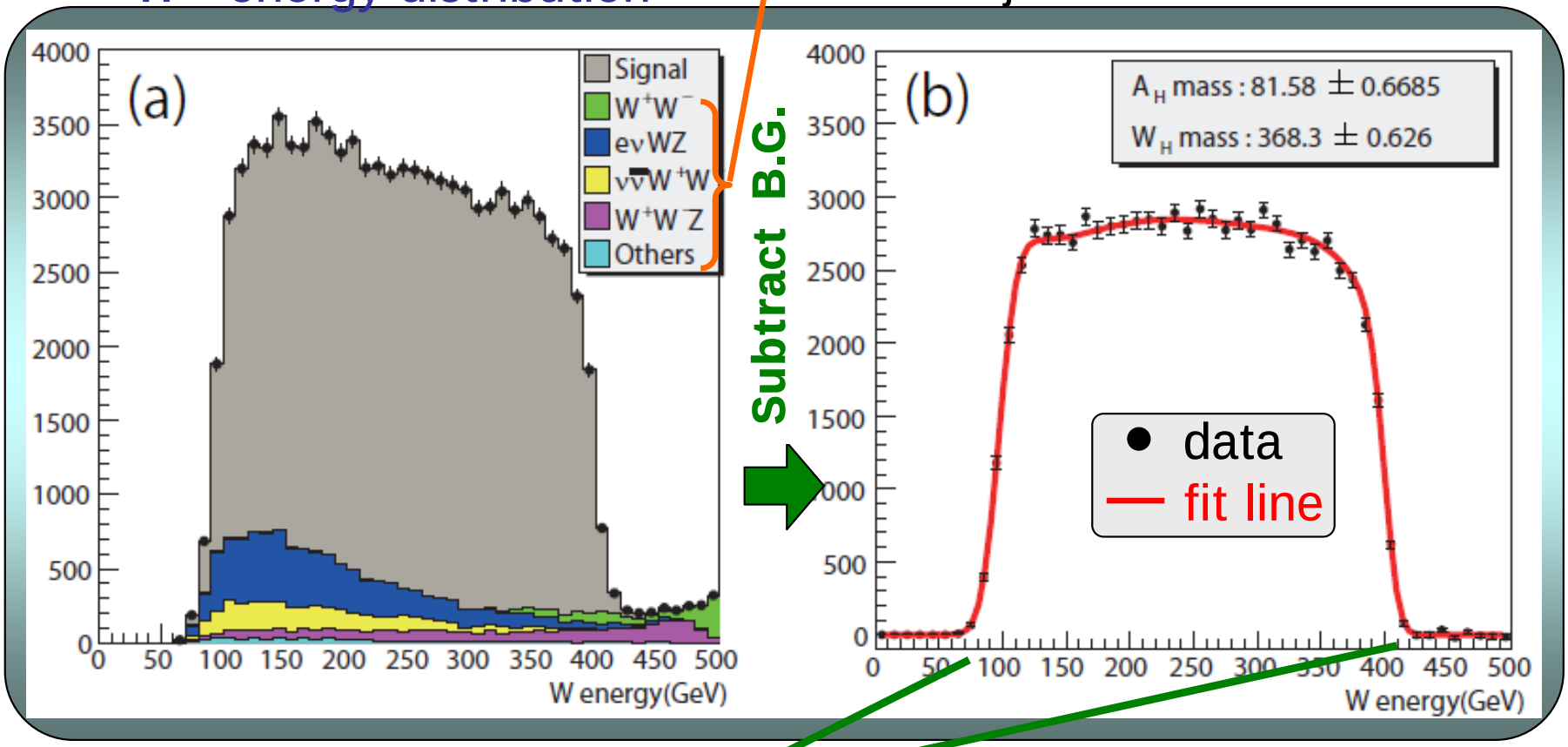
0GeV<E_W<500GeV & χ_W^2 <26 & P_t^{miss}>84GeV

*Reconstruct $W^{\pm}$ from 4 jets

$$\chi_W^2 \equiv \left(\frac{m_{W_1} - m_W}{\sigma_{m_W}}\right)^2 + \left(\frac{m_{W_2} - m_W}{\sigma_{m_W}}\right)^2$$

<$W^{\pm}$ energy distribution>

B.G. are 4 jets in final states



<Masses from fitting edges>

m_{AH} = 81.58±0.67 GeV

m_{WH} = 368.3±0.63 GeV

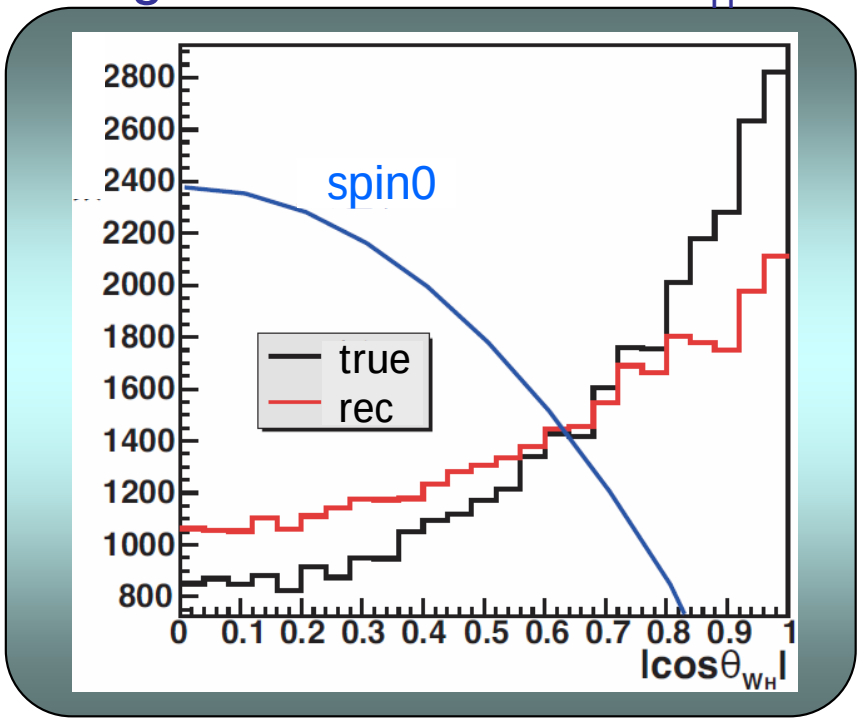
<Accuracy>

0.8%

0.2%

Spin of $W_H^{\pm}$ & helicity of $W^{\pm}$

<Angular distribution of $W_H^{\pm}$>



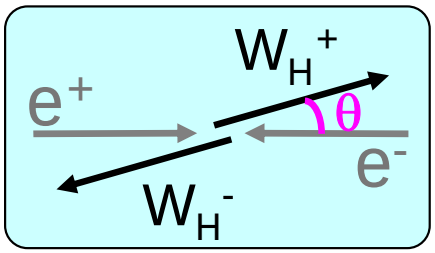
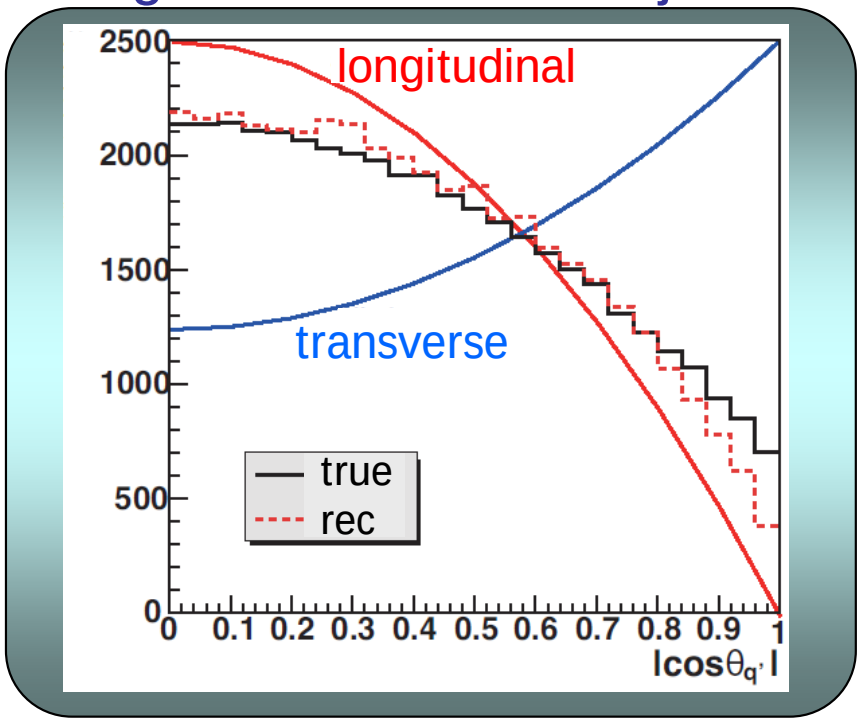
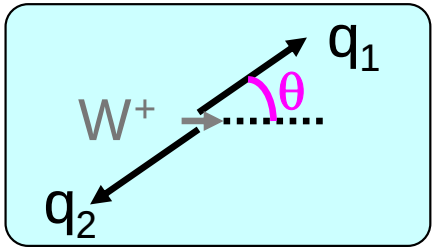


Figure shows $W_H^{\pm}$ is not spin-0.
→ *Spin info of $W_H^{\pm}$ can be got!!*

<Angular distribution of jets>



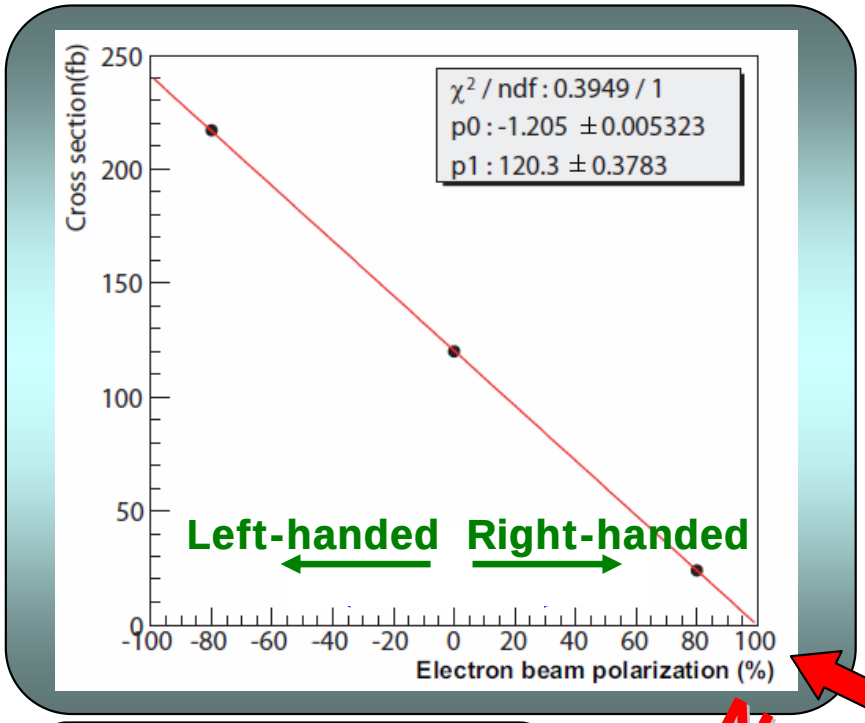


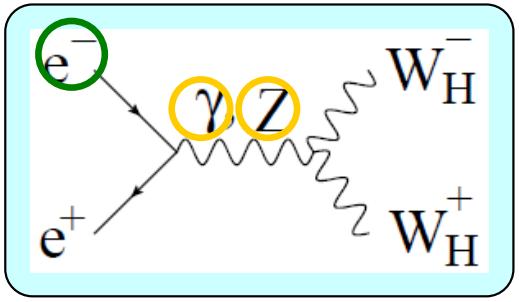
*at rest frame of $W^{\pm}$

Figure shows $W^{\pm}$ is mainly longitudinal.
→ *Helicity info of $W^{\pm}$ can be got!!*

Gauge charge of $W_H^{\pm}$

<$W_H^+ W_H^-$ cross section using polarized e^->





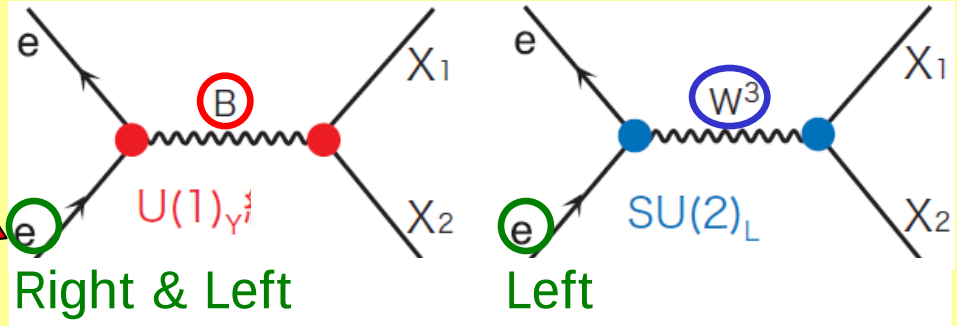
No right handed

(Propagator)

Equation of neutral gauge mixing

$$\begin{pmatrix} B \\ W^3 \end{pmatrix} = \begin{pmatrix} \cos\theta_W & -\sin\theta_W \\ \sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} A \\ Z \end{pmatrix}$$

At high energy interaction,
B and W^3 propagate.



Not $U(1)_Y$ coupling by B,
but $SU(2)_L$ coupling by W^3.

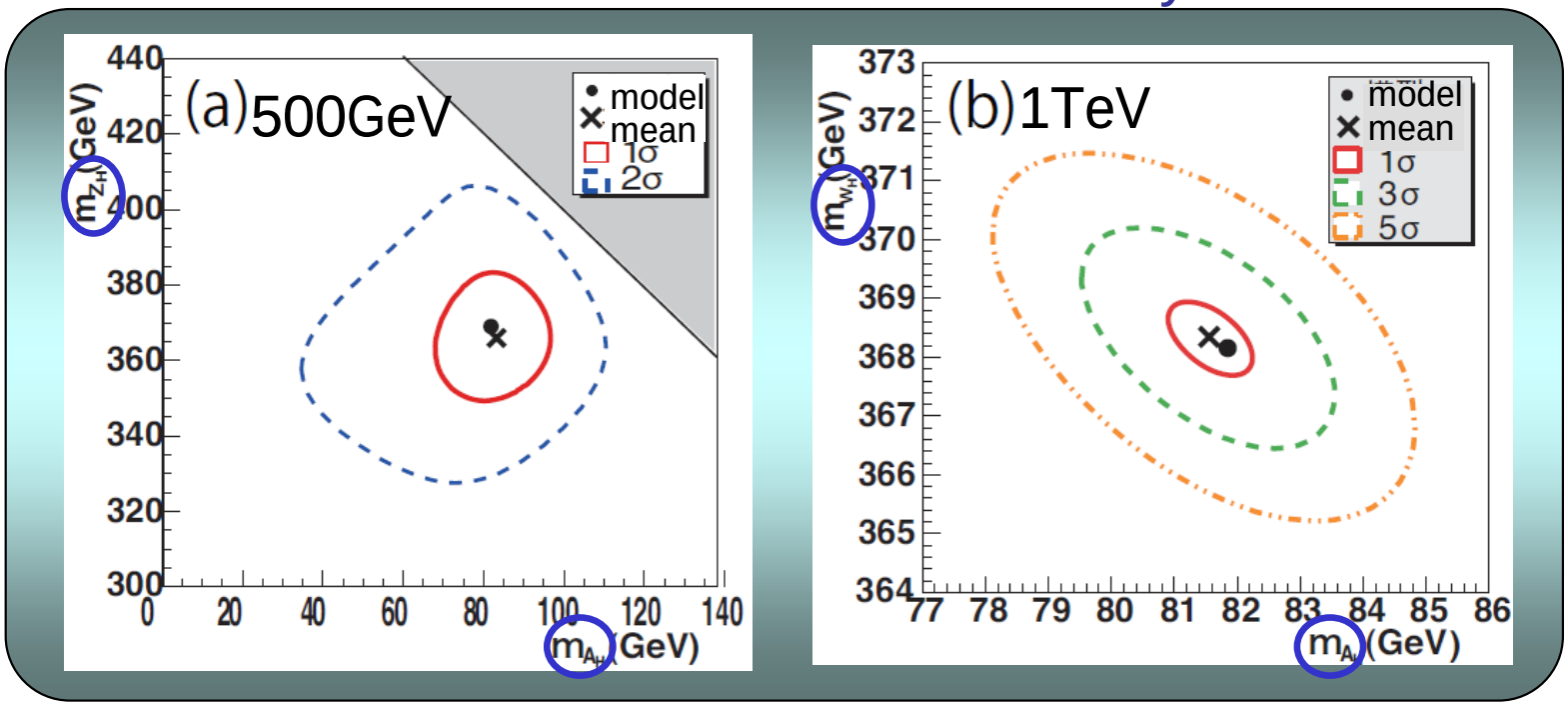
$W_H^{\pm}$ has not $U(1)_Y$ charge but $SU(2)_L$ charge.
→ ***Gauge charge info of $W_H^{\pm}$ can be got !!***

Disscussion

about results
@500GeV & @1TeV

Model parameter f

<Contours of mass-determination accuracy>



$$\begin{cases} m_{A_H} \approx \sqrt{0.2}\, g' f \\ m_{Z_H} \approx g f \end{cases}$$

*There is relation between f & mass.

$$\begin{cases} m_{A_H} \approx \sqrt{0.2}\, g' f \\ m_{W_H} \approx g f \end{cases}$$

<f given by mass determination>

f = 576.0 ±25.0 GeV $\left(\sqrt{s} = 500\text{GeV}\right)$

f = 580.0 ±0.69 GeV $\left(\sqrt{s} = 1\text{TeV}\right)$

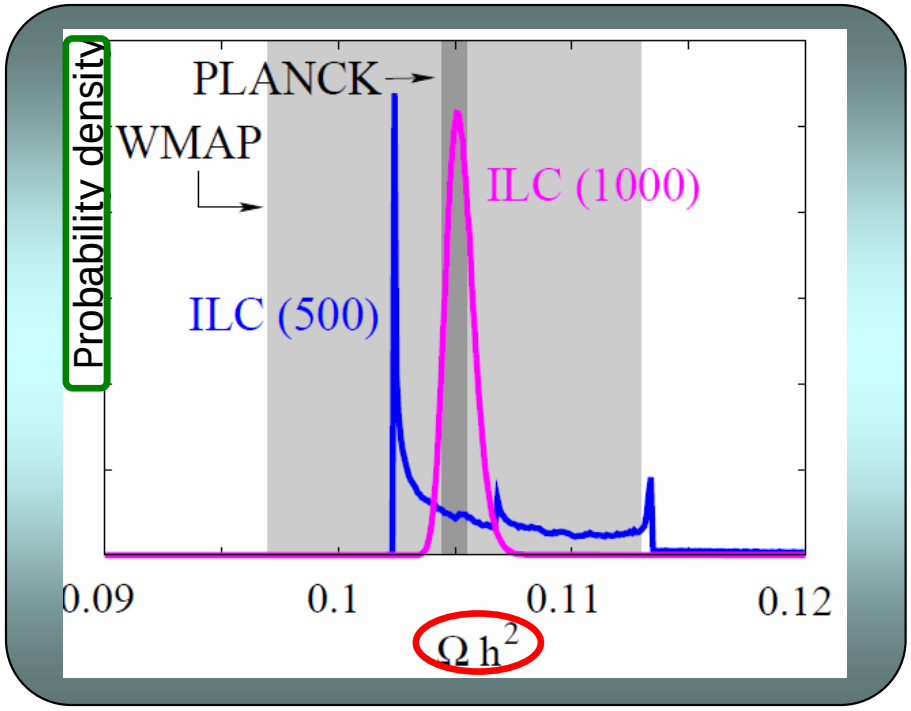
<Accuracy of f determination>

4.3 % $\left(\sqrt{s} = 500\text{GeV}\right)$

0.1 % $\left(\sqrt{s} = 1\text{TeV}\right)$

Relic abundance of dark matter(A_H)

<Probability density of Ωh^2>



*WMAP, PLANCK : cosmological observation

<Accuracy of Ωh^2 determination>

O(10%) $\left(\sqrt{s} = 500\text{GeV}\right)$

O(1%) $\left(\sqrt{s} = 1\text{TeV}\right)$

*There is relation between Ωh^2 & f.

Relic abundance of DM

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

Annihilation cross section of DM

$$\langle \sigma v \rangle = \sigma v_{WW} + \sigma v_{ZZ} + \sigma v_{hh}$$

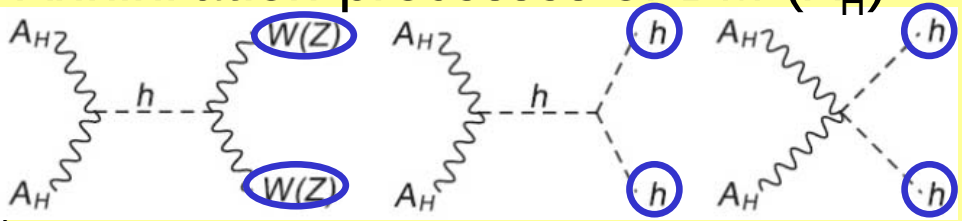
$$\sigma v|_{WW} = \frac{1}{96\pi m_{A_H}^2} \frac{(g^2 v^2 c)^2}{(4m_{A_H}^2 - m_h^2)^2 + m_h^2 \Gamma_h^2} \left(4\frac{m_{A_H}^4}{m_W^4} - 4\frac{m_{A_H}^2}{m_W^2} + 3\right) \sqrt{1 - \frac{m_W^2}{m_{A_H}^2}}$$

$$\sigma v|_{ZZ} = \frac{1}{192\pi m_{A_H}^2} \frac{\{(g^2 + g'^2) v^2 c\}^2}{(4m_{A_H}^2 - m_h^2)^2 + m_h^2 \Gamma_h^2} \left(4\frac{m_{A_H}^4}{m_Z^4} - 4\frac{m_{A_H}^2}{m_Z^2} + 3\right) \sqrt{1 - \frac{m_Z^2}{m_{A_H}^2}}$$

$$\sigma v|_{hh} = \frac{c^2}{48\pi m_{A_H}^2} \left| 1 + \frac{3m_h^2}{4m_{A_H}^2 - m_h^2 + i m_h \Gamma_h} \right|^2 \sqrt{1 - \frac{m_h^2}{m_{A_H}^2}}$$

$m_{AH} \propto f$

Annihilation processes of DM (A_H)



Summary

<$\sqrt{s}$=500GeV : $e^+e^- \rightarrow A_H Z_H$>

- Signal significance : 3.7σ
- Accuracy of mass mesurement : 16.2%(A_H), 4.3%(Z_H)

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

- Accuracy of mass measurement : 0.8%(A_H), 0.2%($W_H^{\pm}$)
- Spin of $W_H^{\pm}$, helicity of $W^{\pm}$and gauge charge of $W_H^{\pm}$ can be analyzed.

<Discussion>

Accuracy of model-parameter determination

- VEV f : 4.3% $\left(\sqrt{s} = 500\mathrm{GeV}\right)$, 0.1% $\left(\sqrt{s} = 1\mathrm{TeV}\right)$
- DM relic abundance : O(10%) $\left(\sqrt{s} = 500\mathrm{GeV}\right)$, O(1%) $\left(\sqrt{s} = 1\mathrm{TeV}\right)$

<Paper>

- arXiv hep-ph 0901.1081 (9 Jan)
- Phys. Rev. D (21 Jan)