Little Higgs with T-parity measurements at the ILC

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Little hierarchy problem

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

1. Fine tuning of Higgs mass

$$m^2_{Higgs} = m^2_0 + \delta m^2$$

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!**

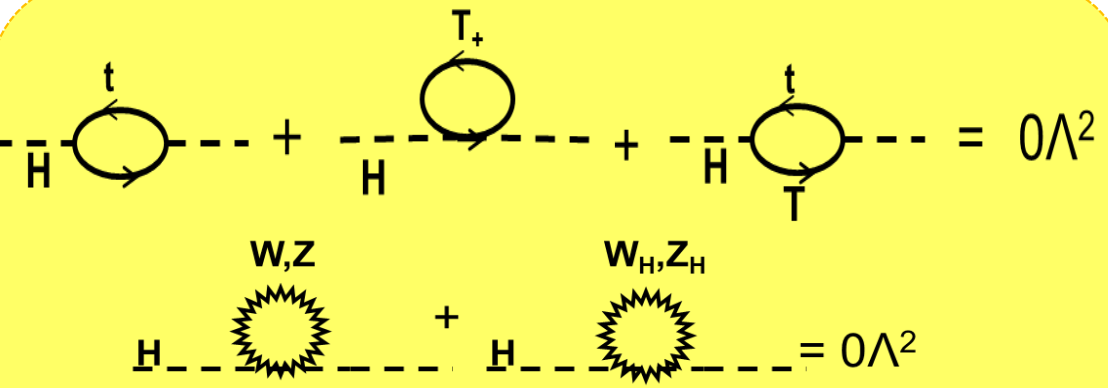
Little Higgs model important features

<Little Higgs mechanism>

Global Symmetry : SU(5) $\xrightarrow{f \sim 1\ \text{TeV}}$ SO(5) $\xrightarrow{v \sim \langle h \rangle}$

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

<Higgs mass contribution>



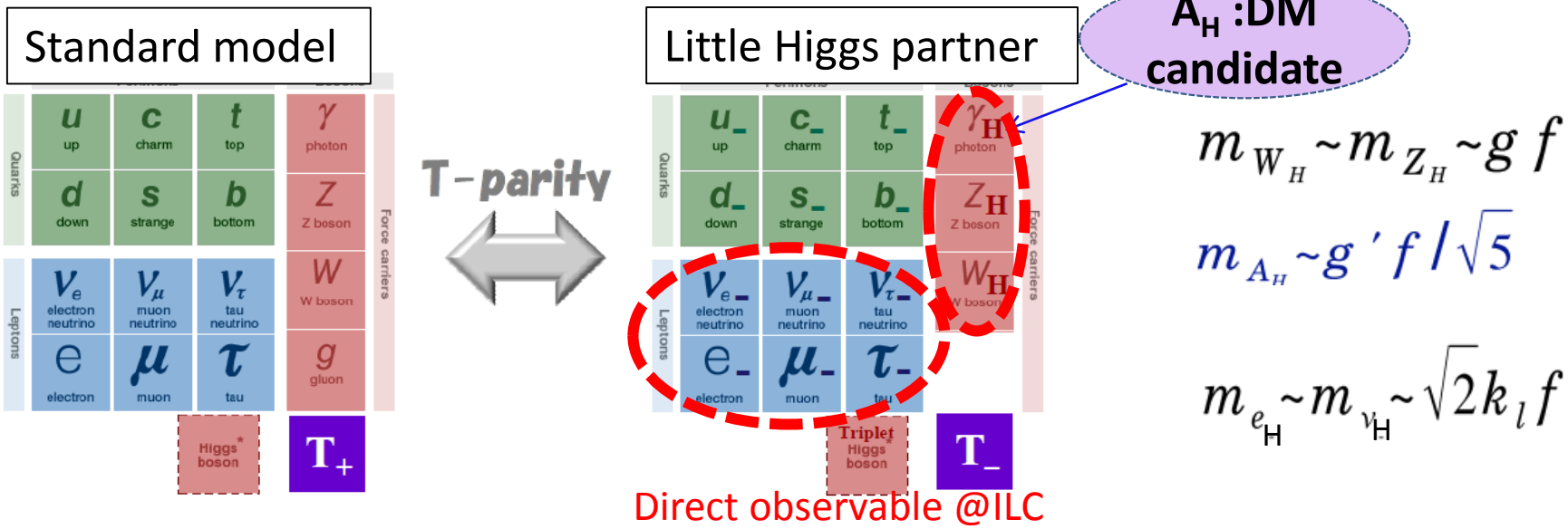
Quadratic divergent terms cancel at 1-loop order

<features of Little Higgs>

- prediction of top partner
- prediction of gauge boson partner
- Definite relation between model parameters (little Higgs mechanism)

Solves Little hierarchy problem

Littlest Higgs with T-Parity model



$$m_{W_H} \sim m_{Z_H} \sim g f$$

$$m_{A_H} \sim g' f / \sqrt{5}$$

$$m_{e_H} \sim m_{\nu_H} \sim \sqrt{2} k_l f$$

LHT masses in gauge & lepton sector can be described with 2 parameters

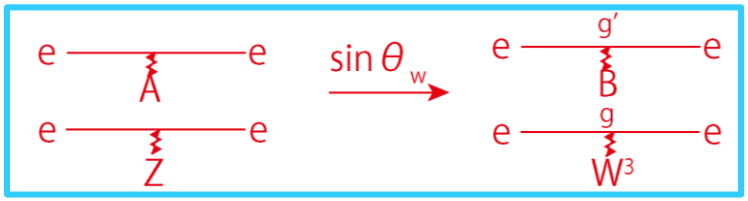
f(VEV): energy scale of global symmetry breaking

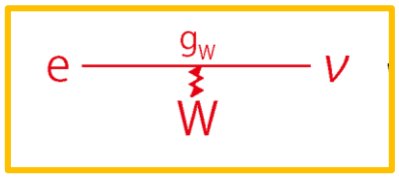
K : lepton Yukawa coupling

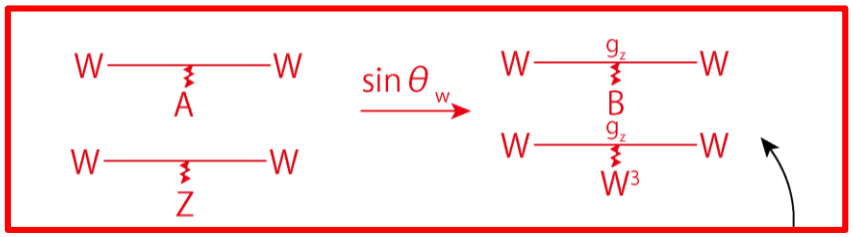
Important parameters which describe how LHT particles obtain masses & solve little hierarchy problem.

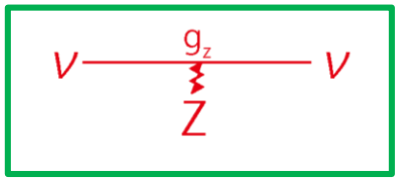
Coupling relation @LHT

- LHT contains a $[\,SU(2)_L \times U(1)_Y]^2$ sub-structure + T-parity









SM diagram

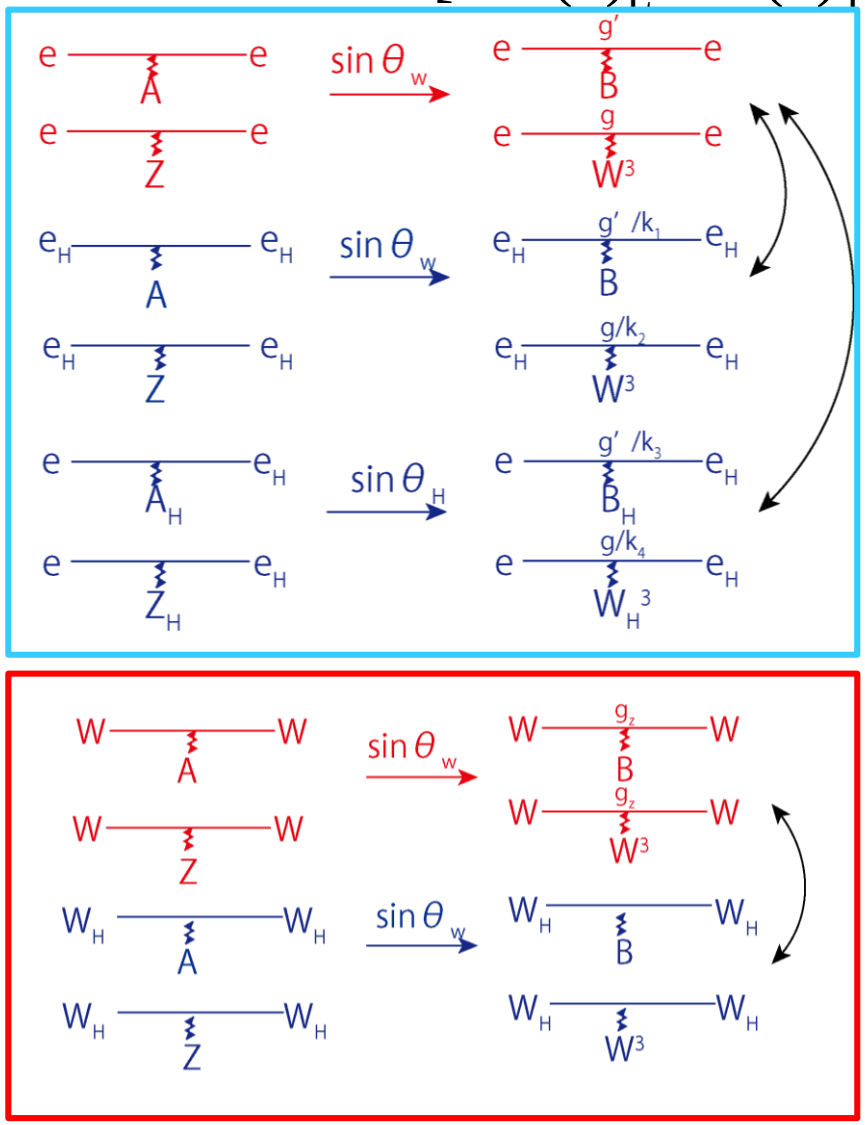
This structure is key feature for the model

LHT coupling relations are the same as SM partner sector

➢ We can test 4 types of electroweak coupling relations

Coupling relation @LHT

- LHT contains a $[\,SU(2)_L \times U(1)_Y]^2$ sub-structure + T-parity

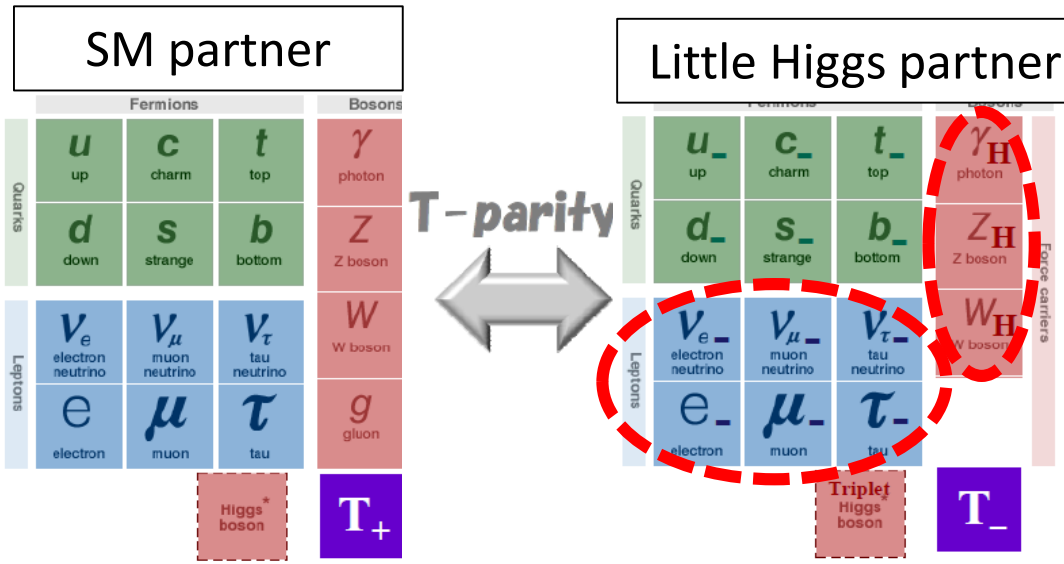


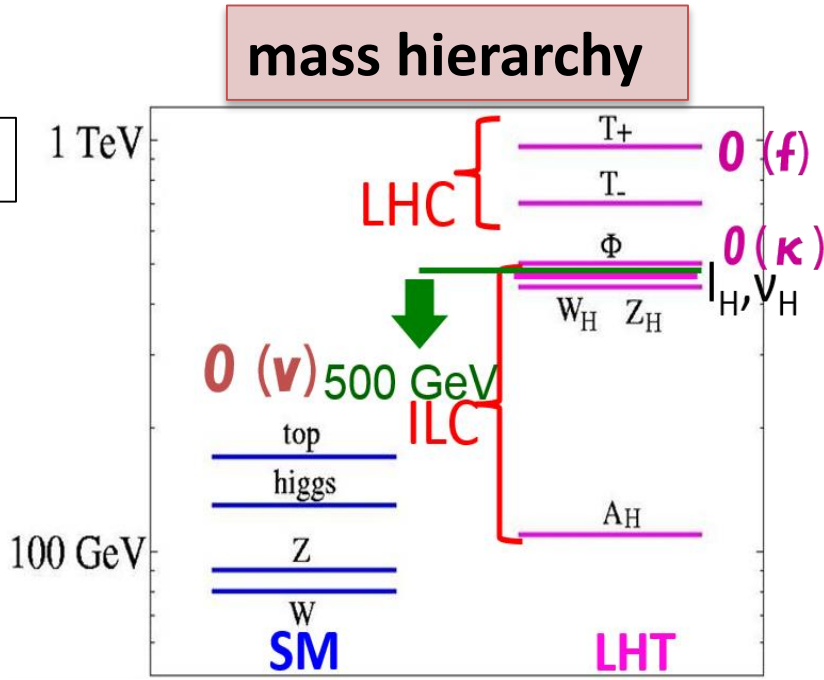
SM diagram

LHT diagram

Study objective @ILC

1. Measure Little Higgs w/ T-Parity (LHT) particle masses (A_H,W_H,Z_H,e_H,ν_H)
2. Extract model parameters (f, κ) from masses and check consistency.
3. Measure as much couplings concerning electroweak sector as possible
4. check consistency among couplings with what is expected at the model.





Parameter space & simulation environment

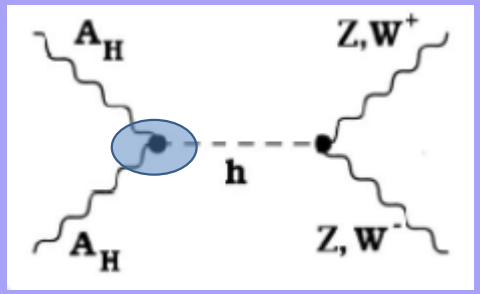
<model parameter space>

Considers..

- Dark matter relic abundance
- Four fermion interaction
- EWPO

κ	f
0.5	580(GeV)

DM Main annihilation mode



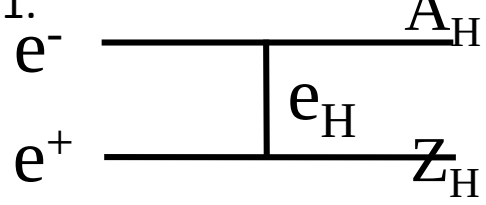
Cross section depends on m_{AH}&m_H

※mh=126GeV is within the allowed parameter region
here we did simulation for mh~134GeV

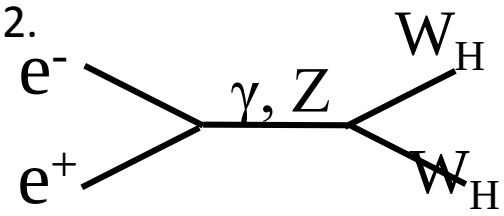
<simulation environment>

- Event generation: PHYSSIM
- Hadronization: PYTHIA,TAUOLA
- Detector simulation: JSFQuickSimulator

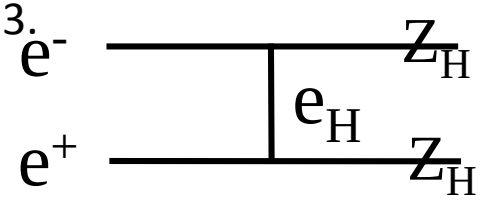
Analysis process mode

1. 

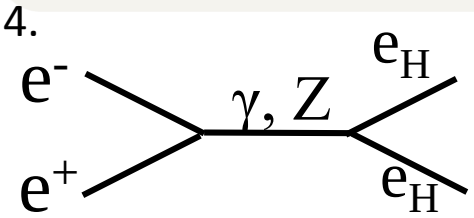
- First signal of LHT!
- coupling

2. 

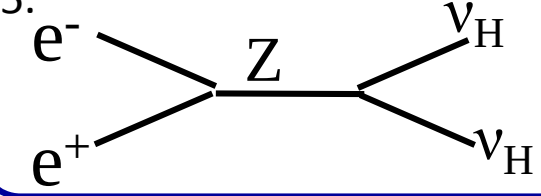
- Parameter f.
- mW_H
- couplings

3. 

- Parameter f
- mZH
- coupling

4. 

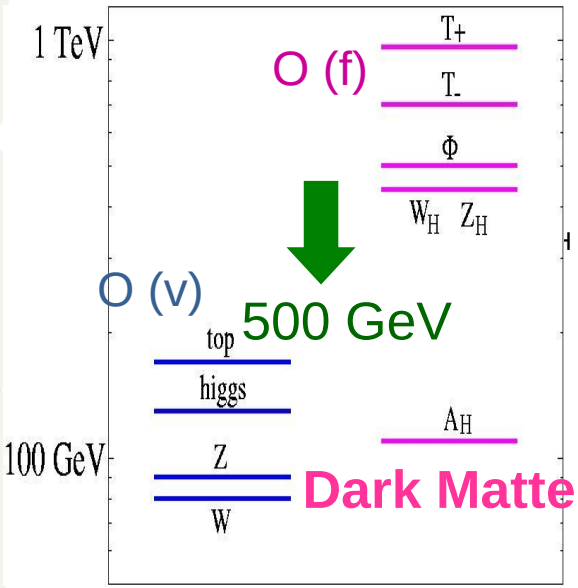
- Parameter κ
- meH
- couplings

5. 

- Parameter κ
- mνH
- coupling

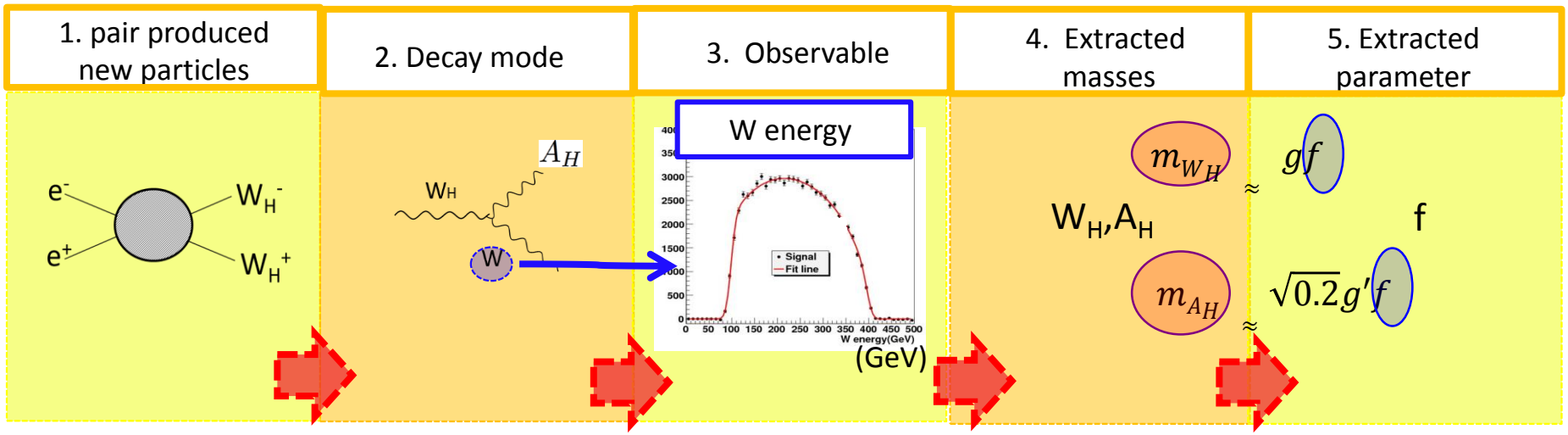
500 GeV

1 TeV



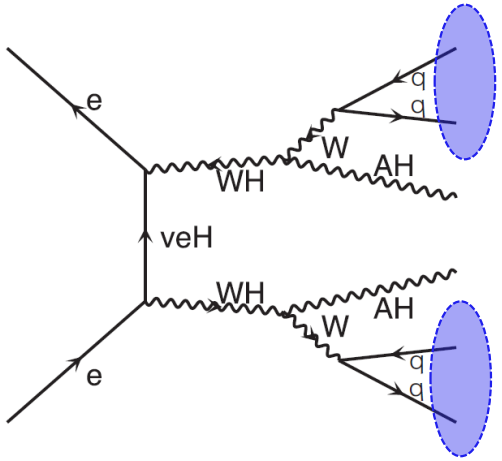
Analysis procedure

1. T-Parity ⇒ new particles are produced in pairs
2. ⇒ produced new particles decay into SM and LHT particles.
3. Extract LHT mass information by recognizing end point of SM energy. cross section can also be measured
4. Extract model parameters, using the fact that LHT masses are expressed with them. Extract coupling from cross section



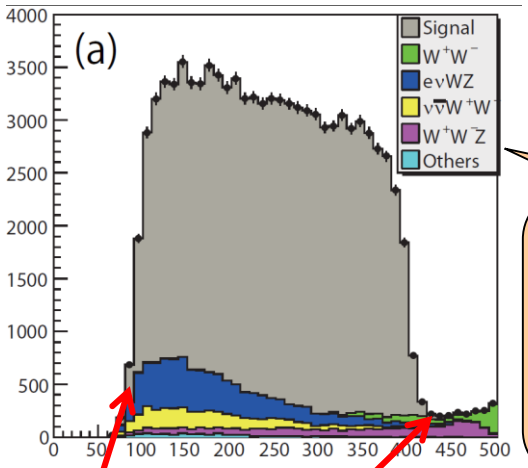
MASS & MODEL PARAMETER MEASUREMENTS(@1TEV 500FB-1)

$W_H W_H$ @1TeV (phys. Rev D79.075013)



$e^+e^- \rightarrow W_H W_H \rightarrow A_H A_H WW$

$W^{\pm}$energy



（event selection）
- **$W^{\pm}$energy**
- **$W^{\pm}$mass**
- **miss Pt**

Large cross section :120fb

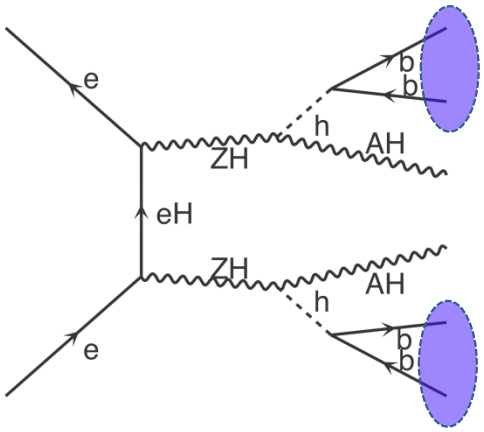
Signal: $A_H A_H qqqq$

m_{AH} = 81.6 GeV **1.3%** f=580±0.9GeV **0.2%**

m_{WH} = 368.3 GeV **0.2%**

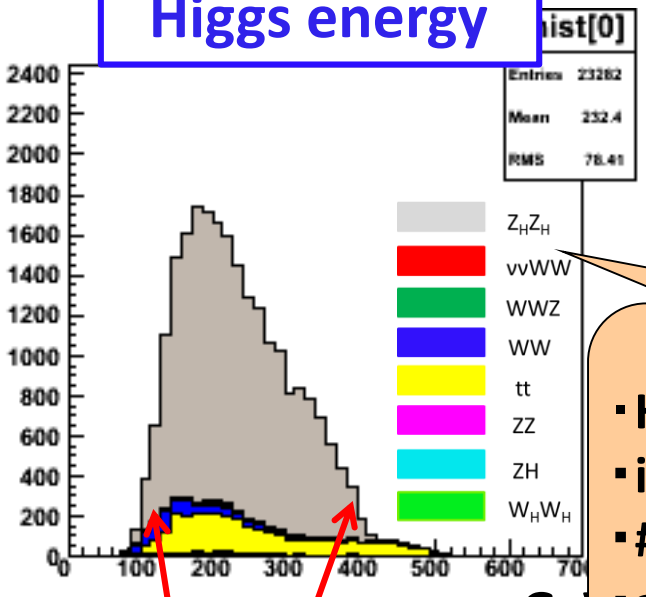
Capable of highly accurate mass/parameter measurement

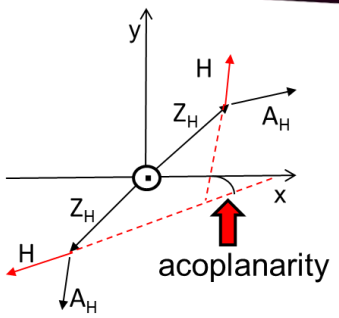
$Z_H Z_H$ @1TeV



$e^+e^- \rightarrow Z_H Z_H \rightarrow A_H A_H hh$

Higgs energy





（event selection）
- **Higgs mass**
- **isolated lepton rejection**
- **# b-tag jets**
- **acoplanarity**

Large cross section :99fb

Signal: $A_H A_H qqqq$

m_{AH} = 82.7 GeV **1.3%**

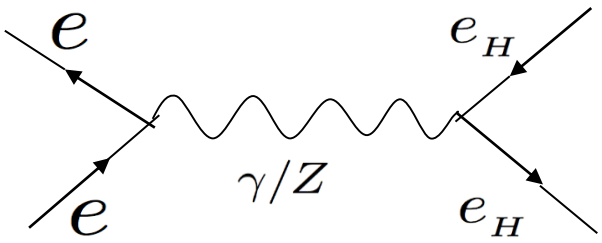
m_{ZH} = 366.1 GeV **0.56%**

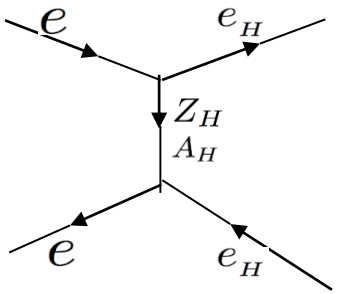
Capable of highly accurate mass measurement

e_He_H @1TeV

■ **extract lepton Yukawa coupling κ by measuring e_H mass.**

Extremely important in knowing lepton sector mass generation mechanism.

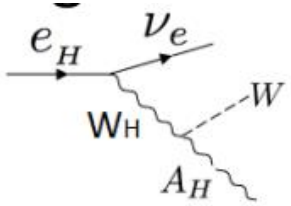




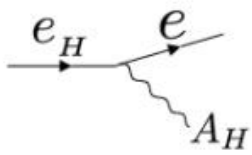
$m_{eH}=\sqrt{2}\kappa f=410GeV$

[Signal(4.56fb)]

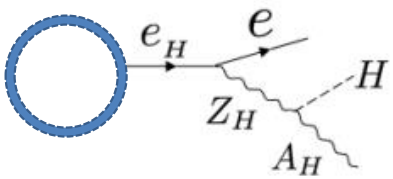
$e_He_H \rightarrow eZ_HeZ_H \rightarrow eehhA_HA_H$



45% Same signal as W_HW_H. e_H access difficult



30% Charge suppressed. Large SM & LHT background.

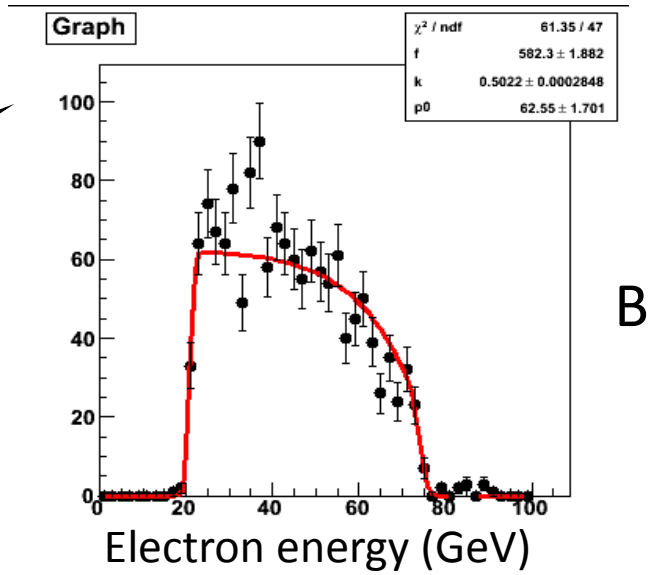


25% 2 higgs characteristic final state Small background.

e_H mass/parameter extraction

（event selection）

- **#Isolated e =2 with opp. charge**
- **h mass**
- **miss Pt**



BG: $\tau_H\tau_H$,
tt,ttZ,tth
evWZ,eeWW,ZZZ

extracted value: f=579.6±3.0(GeV) **κ**=0.5±2.8e-3

True value: f=580(GeV) , κ=0.5

mass accuracy: **e_H**:412.8 ±1.7(GeV) Z_H :371.2 ±1.5(GeV)

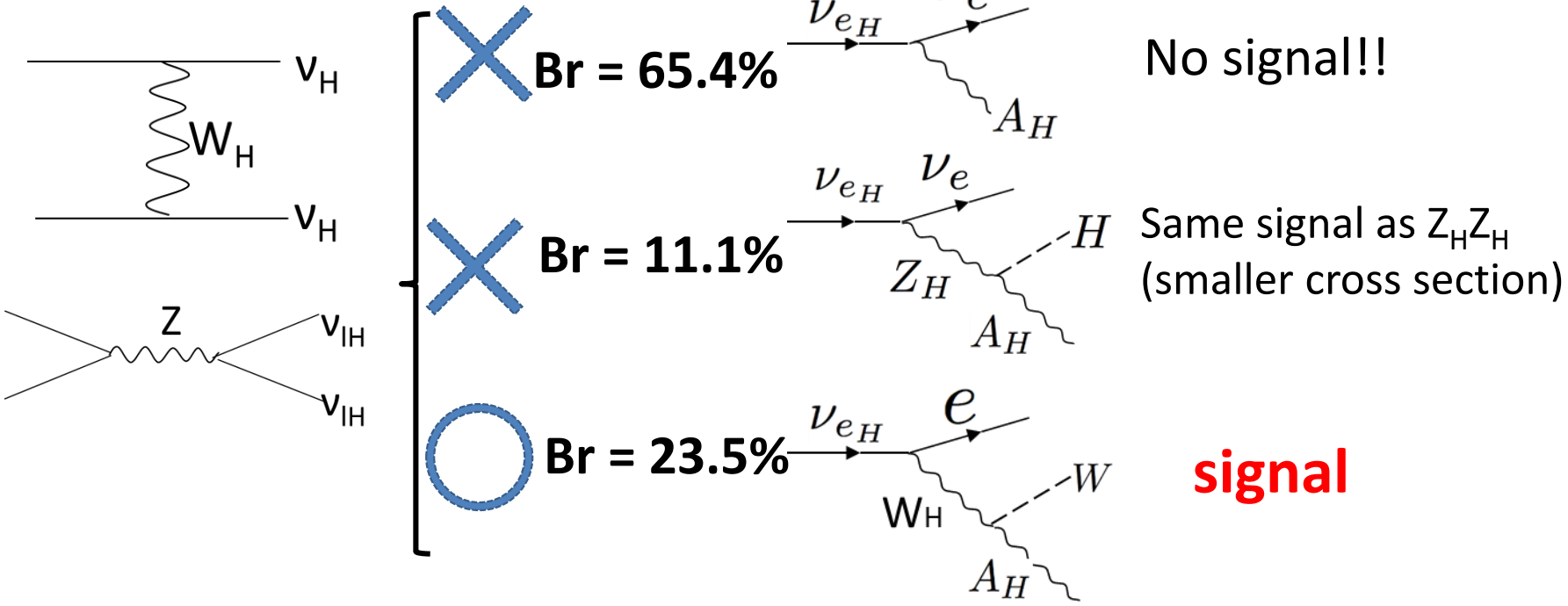
0.46%

Successfully extract mass and parameters.

$\nu_H\nu_H$@1TeV

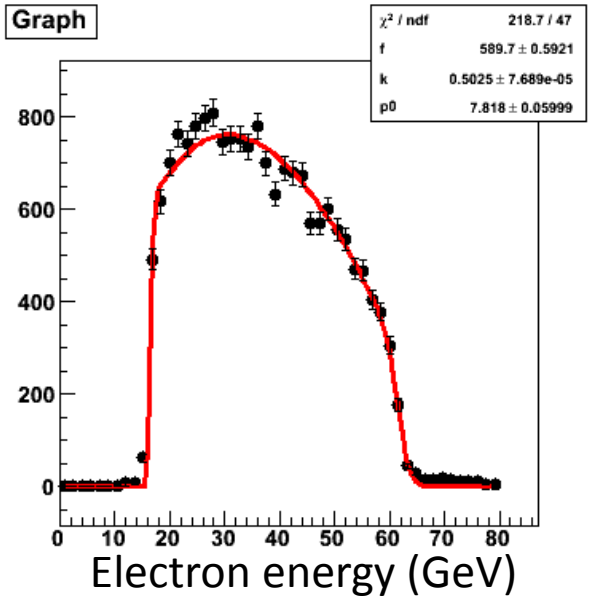
- **extract ν_H mass and complete LHT mass spectrum**
- **$\nu_H\nu_H(eW_HeW_H)$ (tot xsec :1036fb)**
  - Signal: eeqqqq(2W)A_HA_H (25.96fb)

$M_{\nu H} \doteqdot \sqrt{2}\kappa f = 400\text{GeV}$



ν_H mass/parameter extraction

（event selection）
- #Isolated e =2
- **W mass**



SG: eW_HeW_H(eeqqqq)
BG: $\nu_{\tau H}$ $\nu_{\tau H}$,e_He_H,$\tau_H\tau_H$,
tt,ttZ,tth
evWZ,eeWW,ZZZ

extracted value: f=582.0±0.6(GeV) κ=0.5±0.6e-3 **0.12%**

True value: f=580(GeV) , κ=0.5

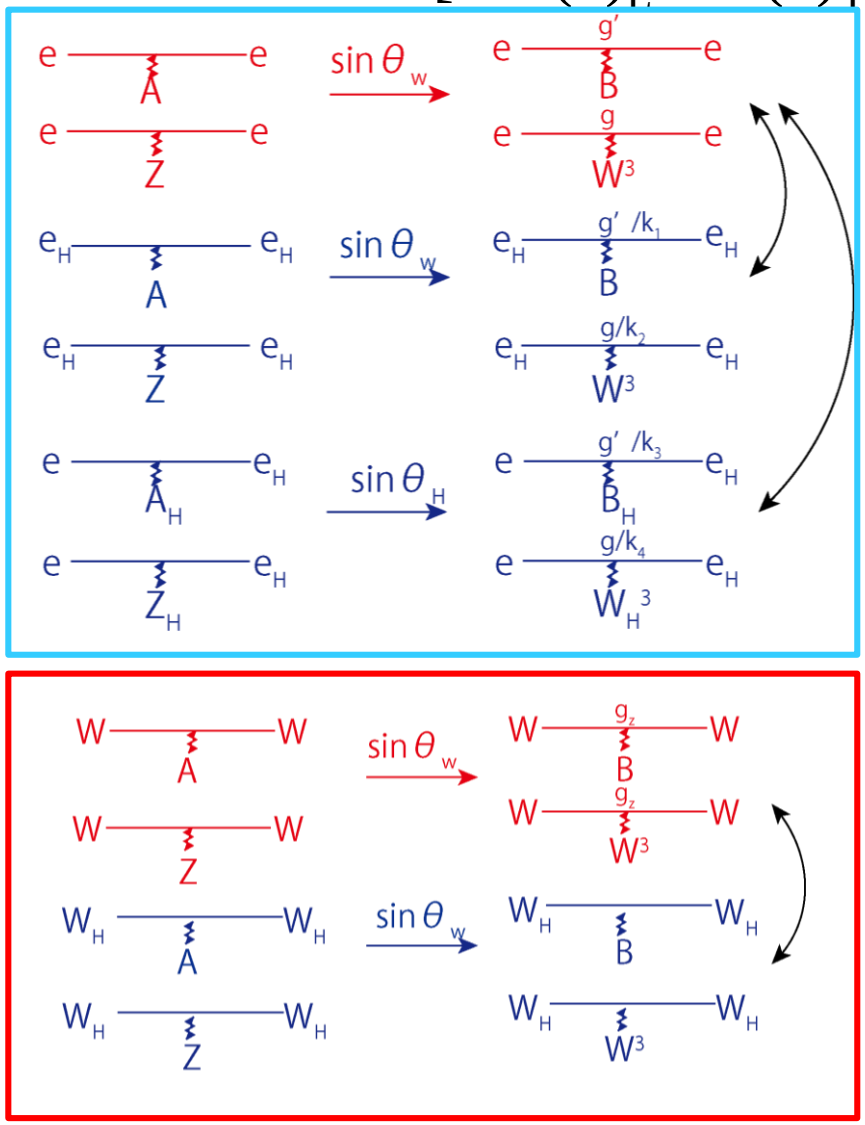
mass accuracy: ν_H:400.8 ±0.4(GeV) W_H :369.6 ±0.4(GeV)
0.10%

Successfully extract mass and parameters.

VERIFYING LHT COUPLING RELATIONS

Coupling relation @LHT

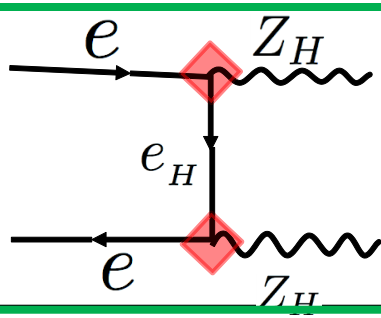
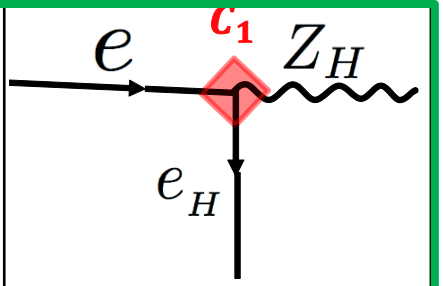
- LHT contains a $[\,SU(2)_L \times U(1)_Y]^2$ sub-structure + T-parity



SM diagram

LHT diagram

Coupling determination strategy

Process mode	Branch	Derived coupling	Coupling meas. accuracy
			0.21%

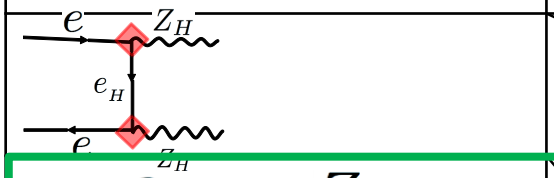
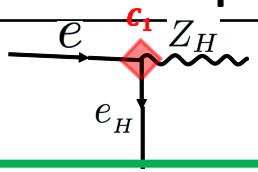
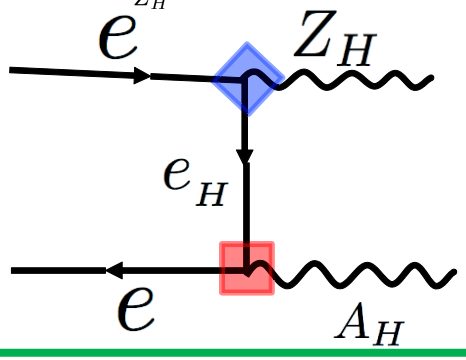
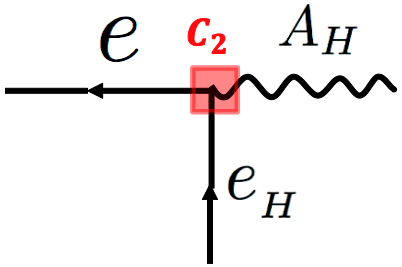
- ILC has various observables which can be used for coupling meas.
  - Cross section
  - Polarization dependence
  - Angular dependence(differential cross section)
  - Etc..

➢ Can be used to disentangle various coupling contributions.

- Observable for Z_HZ_H process: cross section

※vertex structure(spin, L-R coupling mixed rate) are assumed & fixed

Coupling determination strategy

Process mode	Branch	Derived coupling
		
		

Coupling meas. accuracy

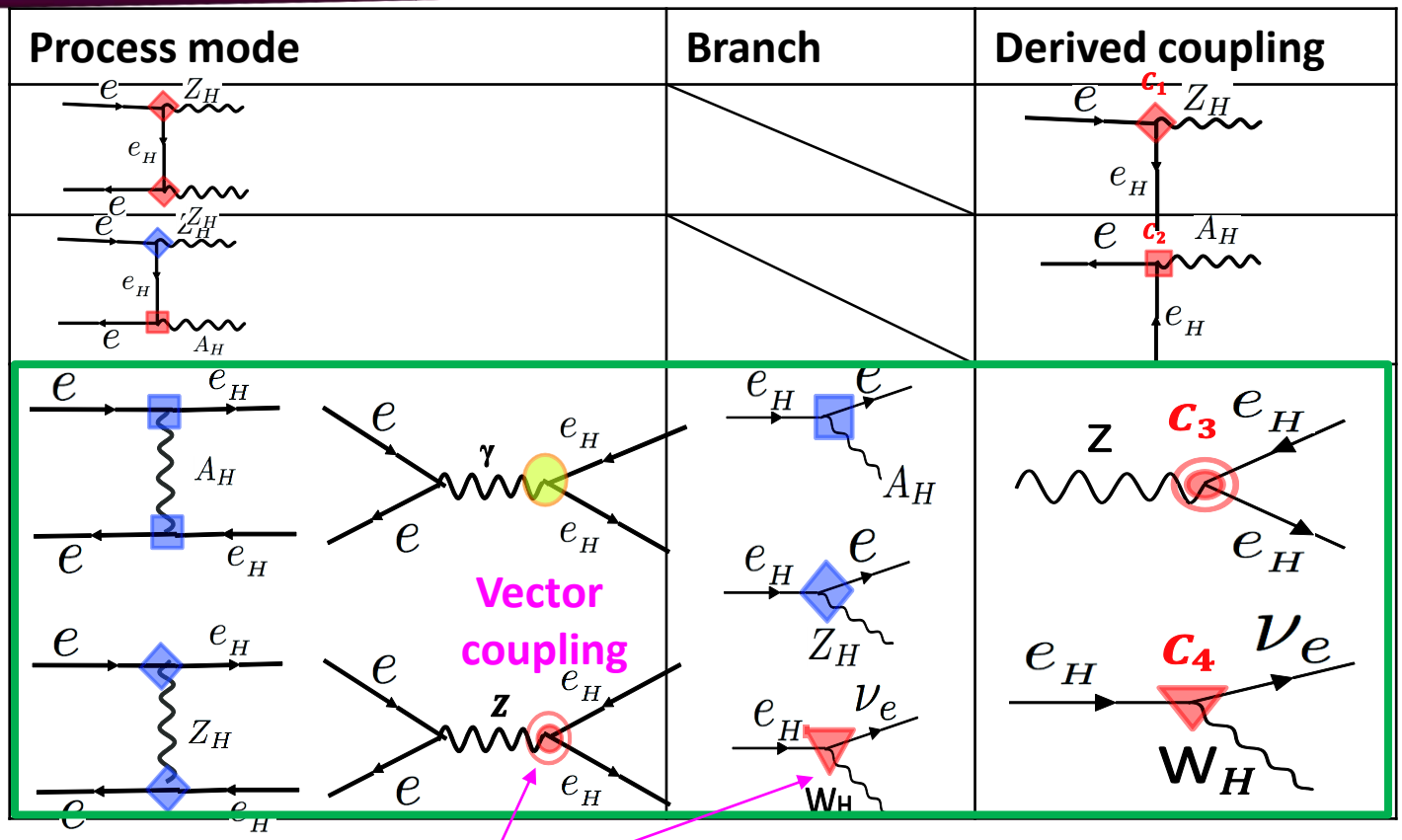
3.9%

Known/previously measured coupling

Coupling that we want to measure

- Observable for $Z_H A_H$ process: cross section

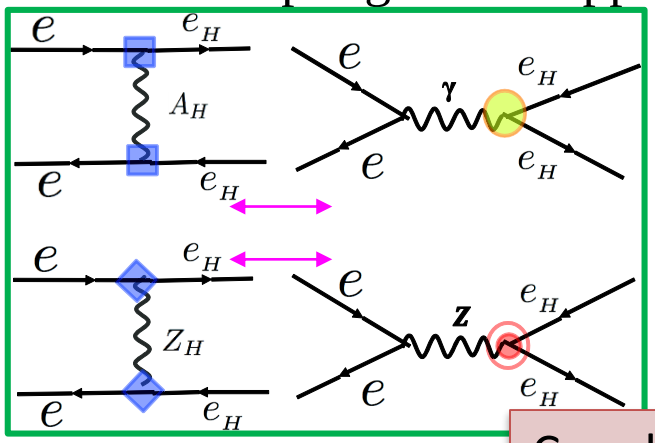
Coupling determination strategy



- Observable for $e_H e_H$ process: cross section (@ e^- pol $\pm 80\%$)

Cross section polarization dependence

- e_He_H process cross section polarization dependence
  - Both couplings are not dependent on polarization. However…
  - zeHeH coupling should appear in the interference term!

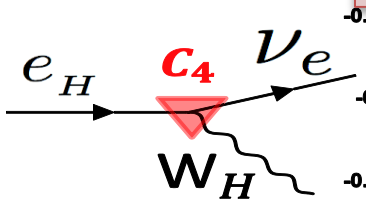


eHWHv

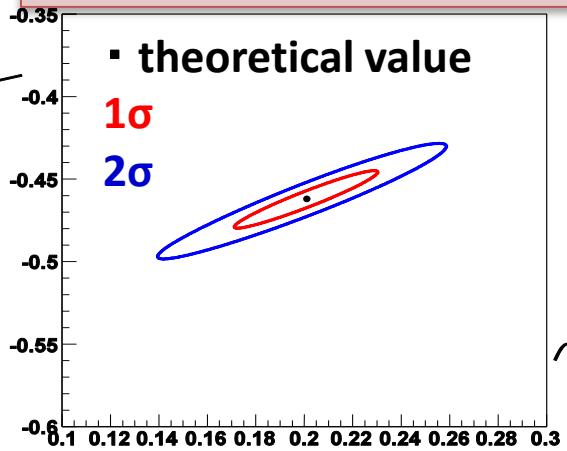
$$\sigma_{tot} = \sigma_s + \sigma_t + \sigma_{s+t}$$

Polarization dependent!

Coupling meas. accuracy



3.5%



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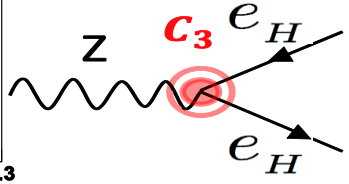
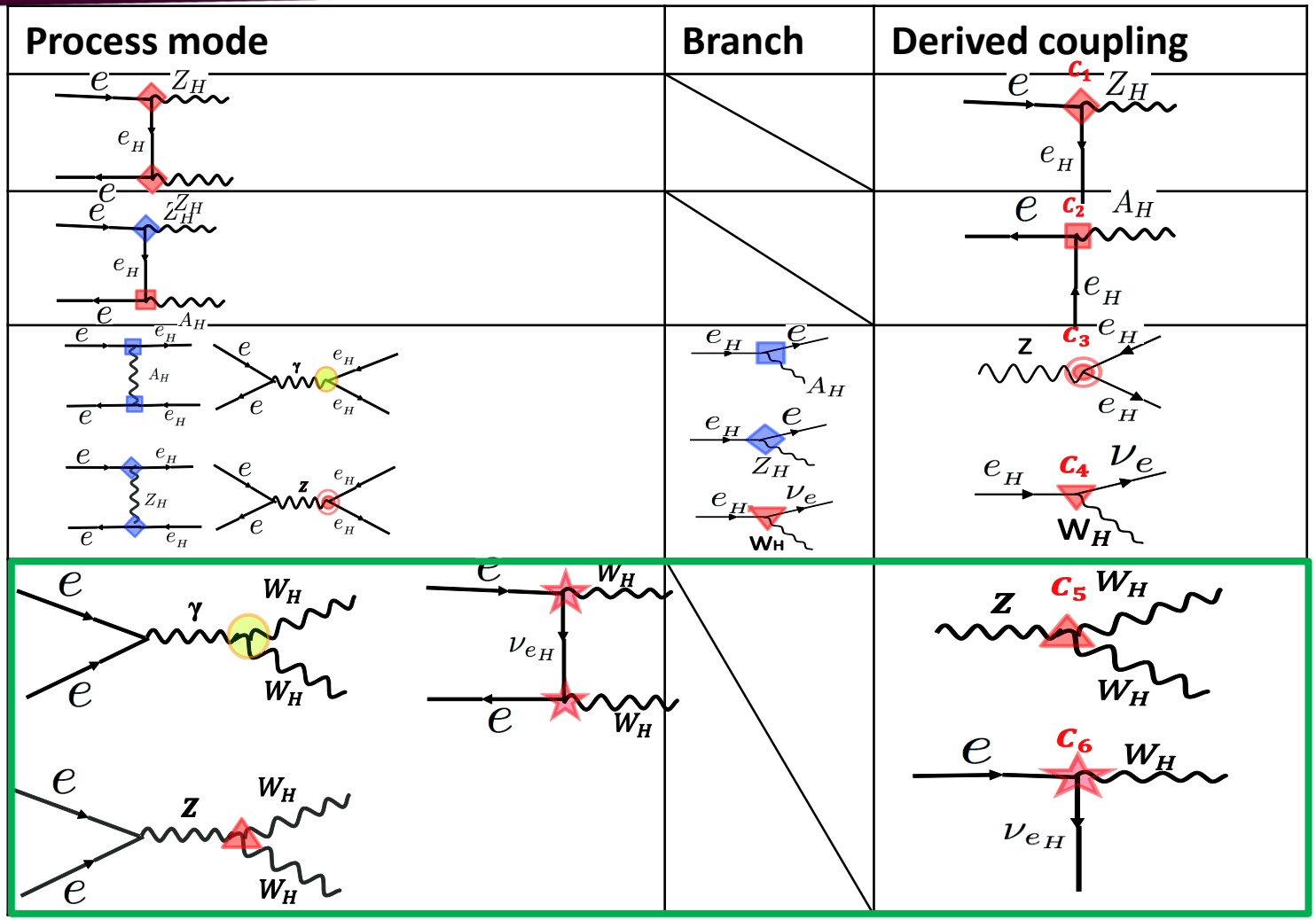


zeHeH

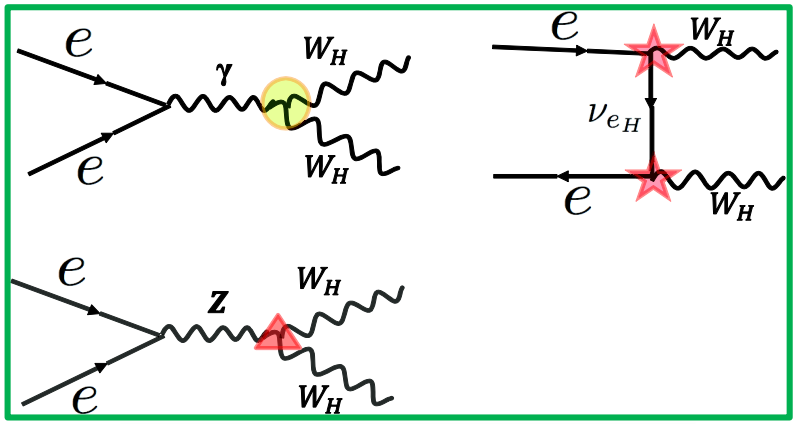
Coupling determination strategy



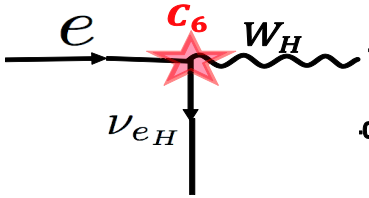
- Observable for $W_H W_H$ process: cross section (@ e^- pol $\pm 80\%$)

Cross section polarization dependence

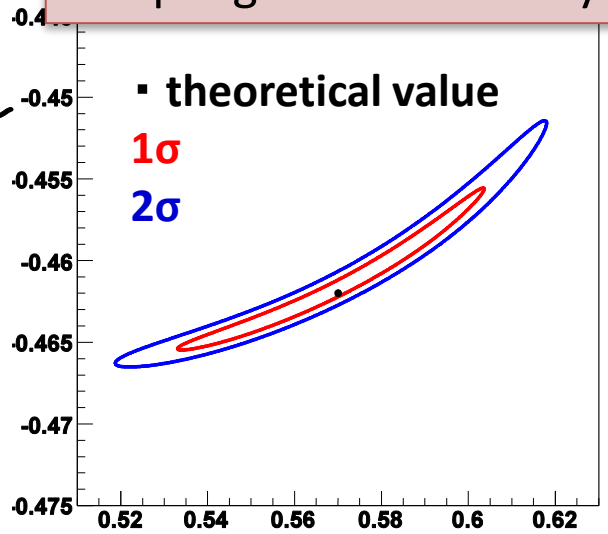
- $W_H W_H$ process cross section polarization dependence
  - Both couplings are dependent on cross section



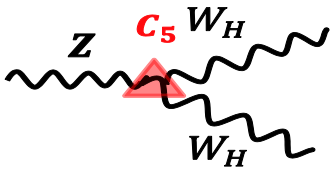
Coupling meas. accuracy



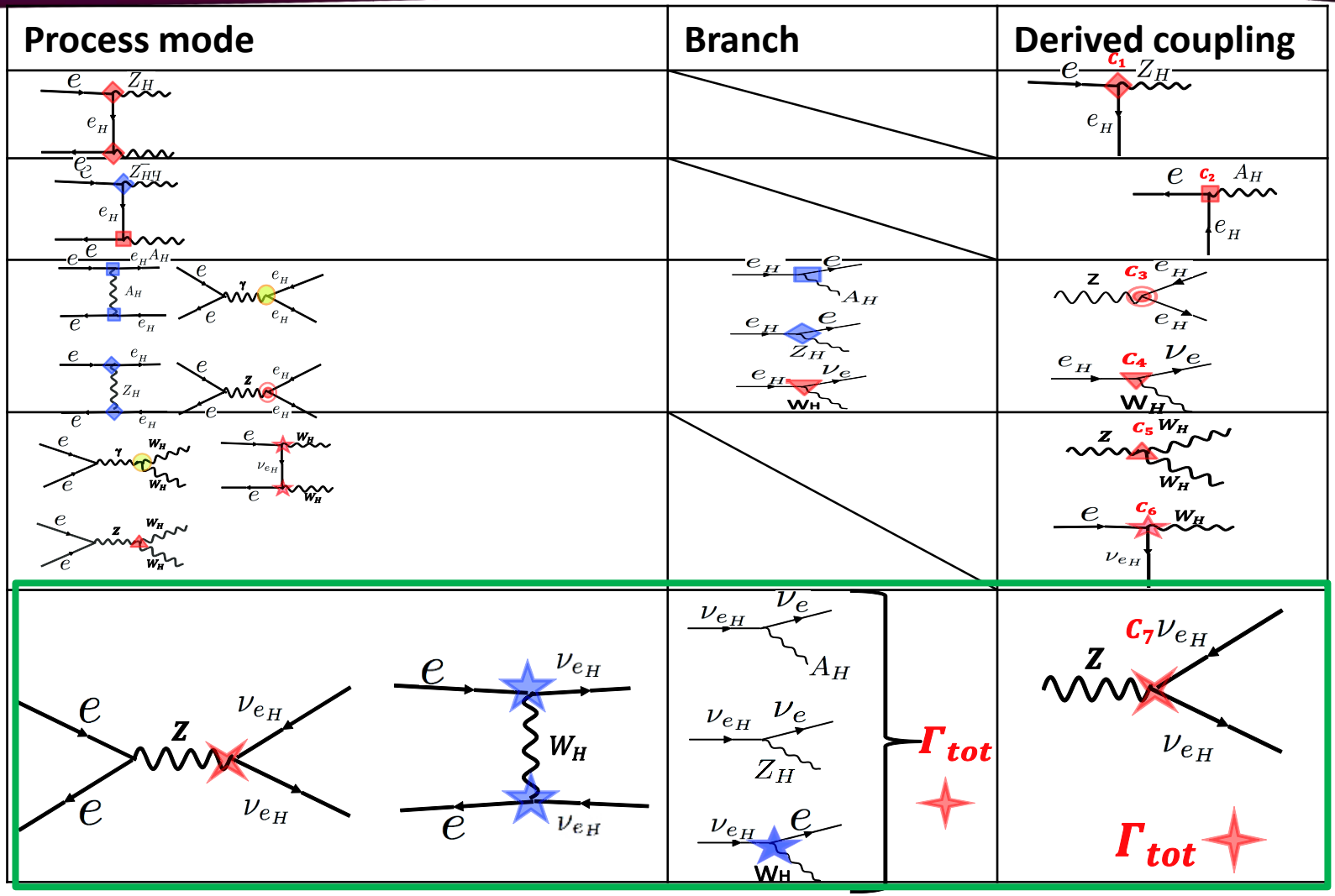
1.1%



6.2%



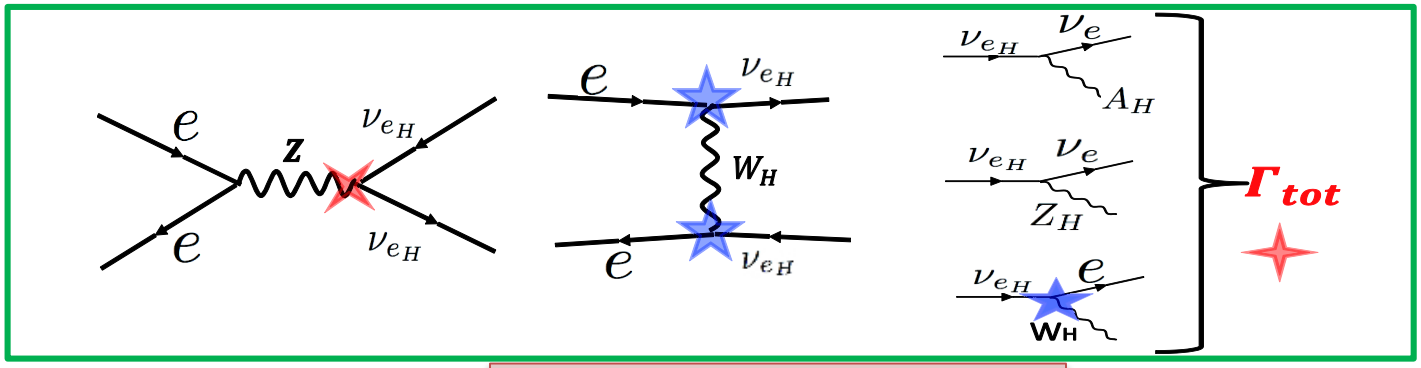
Coupling determination strategy



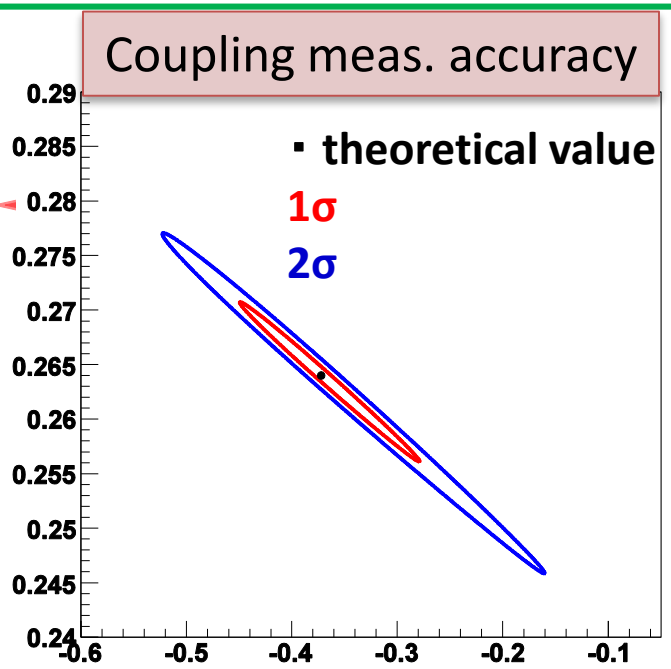
■ Observable for $\nu_H\nu_H$ process: cross section (@ e^- pol $\pm 80\%$)

Cross section polarization dependence

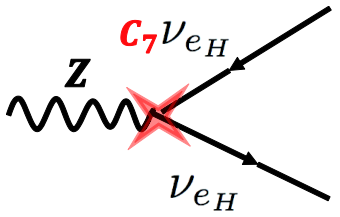
- $\nu_H\nu_H$ process cross section polarization dependence
  - Both couplings are dependent on cross section



2.6% Γ_{tot}



21%



Result summary

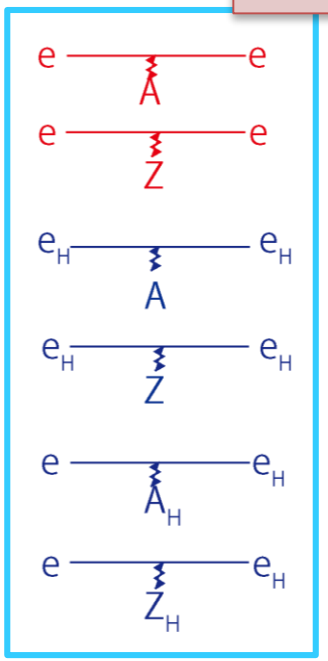
parameter meas. accuracy

Para.	True value	accuracy
f	580(GeV)	0.16%
K	0.5	0.12%

mass meas. accuracy

particle	Mass(GeV)	accuracy
A_H	81.9	1.3%
W_H	369	0.20%
Z_H	368	0.56%
e_H	410	0.46%
ν_H	400	0.10%

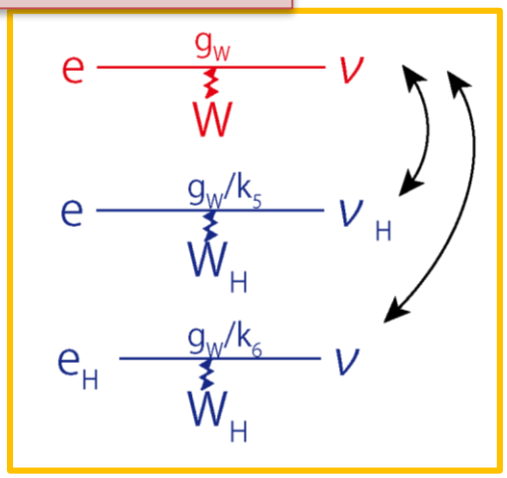
Coupling meas. accuracy



14%

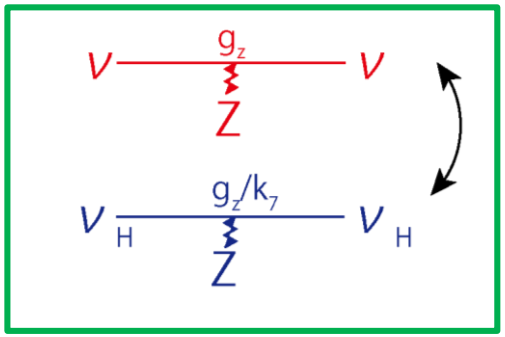
3.9%

0.21%

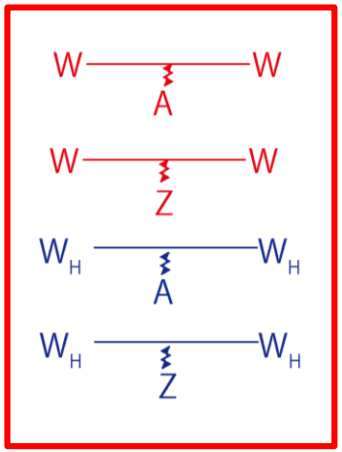


1.1%

3.5%



21%



6.2%

$\Gamma_{tot}(\nu_H)$ 2.6%

SM diagram

LHT diagram

summary

- Little Higgs model is one of the attractive new physics models which solves little hierarchy problem and the dark matter problem.
- Key characteristics of Little Higgs models are it's mass hierarchy and coupling relations

- We tested Littlest Higgs with T-Parity(LHT) model, by measuring mass and couplings concerning electroweak sector and checking consistency with the model.
  - ILC 1TeV 500fb^{-1} can measure masses of heavy gauge bosons and leptons at a percent level or less. With additional measurements using (for example) polarization ILC can measure 8 different couplings
  - Which can be strong evidence of LHT.