Little Higgs with T-parity model at 1TeV using quick simulator

ILD workshop,LAL

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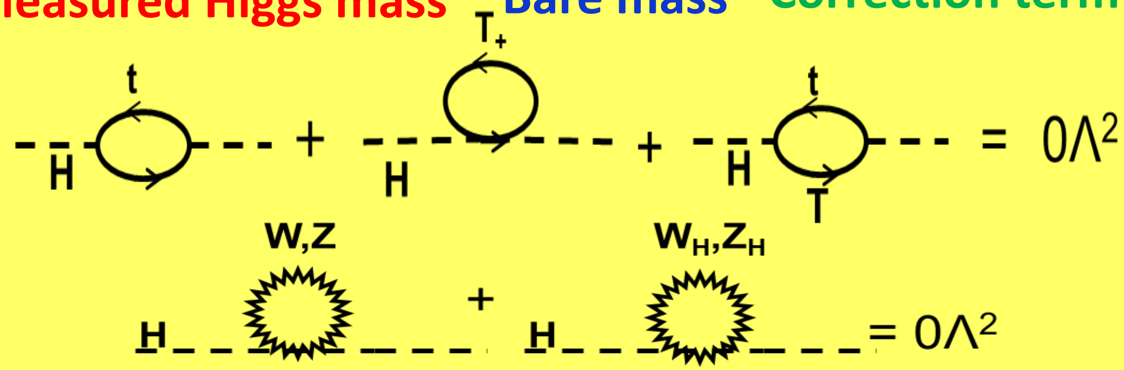
Little Higgs model

- New particles that Little Higgs model predicts contribute to solving Higgs mass fine tuning problem.

Fine tuning of Higgs mass

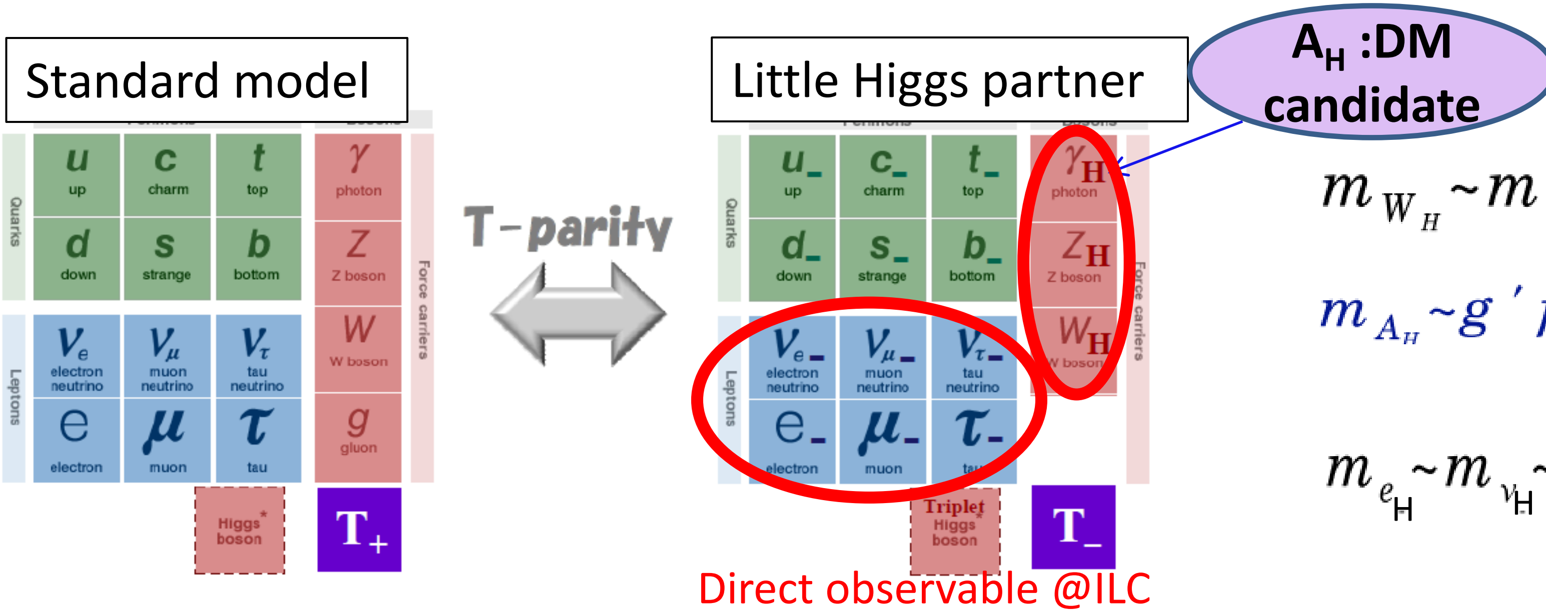
$$m_{Higgs}^2 = m_0^2 + \delta m^2$$

Measured Higgs mass — Bare mass — Correction term



➢ New particles manifest at Terascale.

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 in 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.

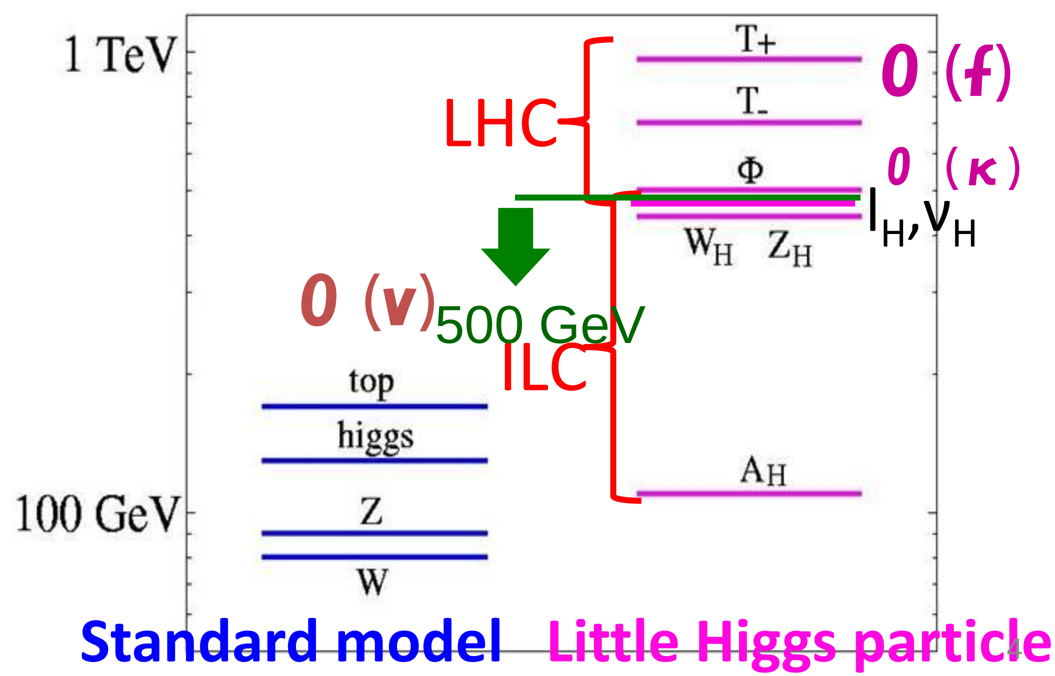
Aim of study

Evaluate ILC's sensitivity on …

- 1st aim : extracting model parameters(f&kappa)
- 2nd aim: completing the mass spectrum and checking consistency with parameters

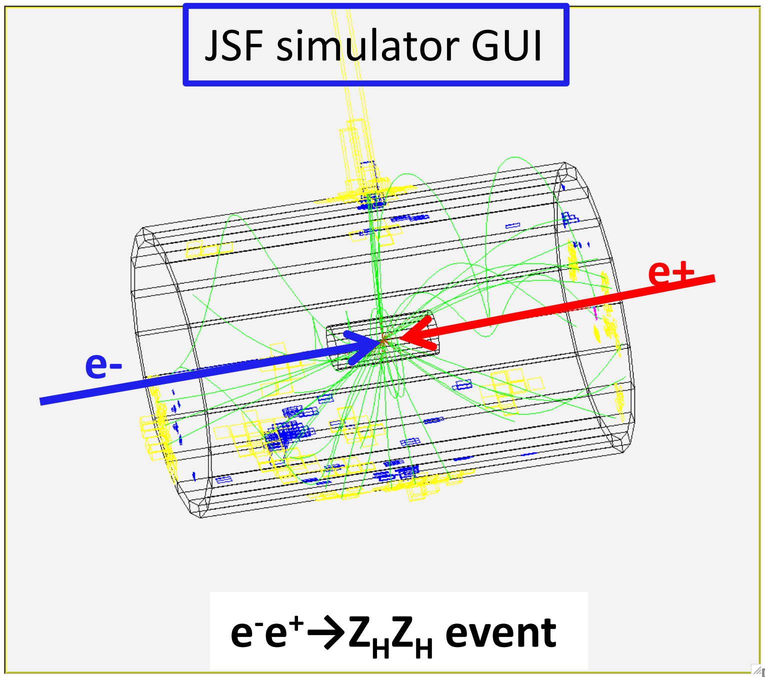
Strong proof that discovered particles are indeed LHT.

κ	f
0.5	580(GeV)



Simulation environment

- **Experiment environment**
  - CM energy: 1TeV
  - luminosity : 500fb^{-1} (4 years)
  - beam/bremstrahlung, beam energy spread are included.
- **Software for quick simulation**
  - Physsim(generate basic particles)
    - Helicity amplitude: HELAS
    - Numerical integration: BASES
    - Event generation: SPRING
  - JSF hadronizer (time evolution)
    - Hadronization: Pythia
    - Tau decay : TAUOLA
  - JSF Quick simulation: LCLIB



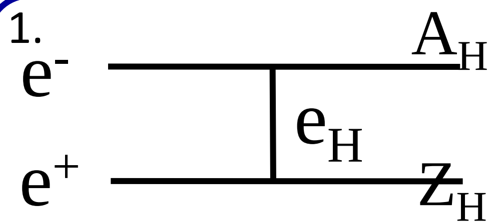
JSF Quick simulator

- Components: beam pipe, VTX detector ,Inner Tracker ,Central drift chamber, ECAL ,HCAL
- Beam cross angle taking into account.
- all detector hits are smeared according to the resolution table below.
- PFA like simulation
  - For charged particles: CDC tracks and calorimeter clusters are linked.
  - For neutral hadrons: charged hadron overlap removed from HCAL cluster.

Detector	Resolution	Coverage
Vertex detector	$\sigma_b = 7.0 \oplus (20.0/p \sin^{3/2}\theta)\ \mu m$	$\lvert\cos\theta\rvert \leq 0.90$
Drift chamber	$\sigma_{P_T}/P_T = 1.1 \times 10^{-4} p_T \oplus 0.1\%$	$\lvert\cos\theta\rvert \leq 0.95$
ECAL	$\sigma_E/E = 15\%/\sqrt{E} \oplus 1\%$	$\lvert\cos\theta\rvert \leq 0.90$
HCAL	$\sigma_E/E = 40\%/\sqrt{E} \oplus 2\%$	$\lvert\cos\theta\rvert \leq 0.90$

Analysis

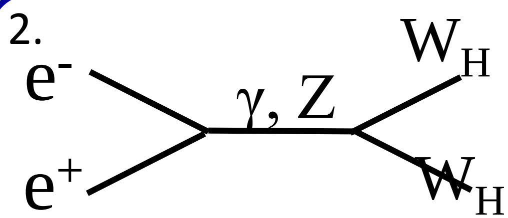
1.



- $m_{AH} + m_{ZH} < 500$ GeV
- producible @ 500 GeV
- **First signal of LHT!**

LOI

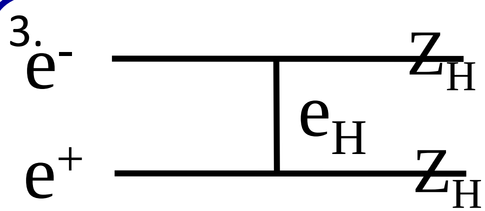
2.



- Large cross section
- **Precision measurement on f.**

LOI

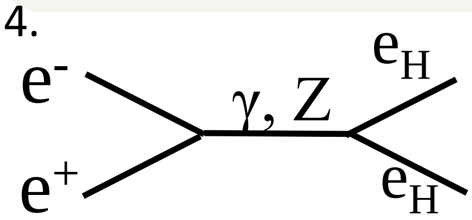
3.



- Determine f.
- **complete mass spectrum in gauge sector**

New

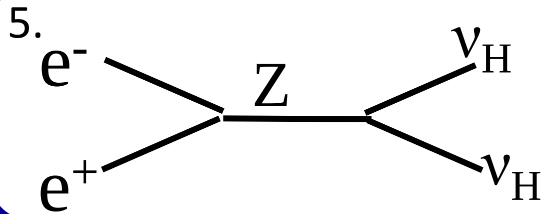
4.



- Determine l_H mass
- **Precision measurement on κ**

New

5.



- **Complete mass spectrum in lepton sector**

New

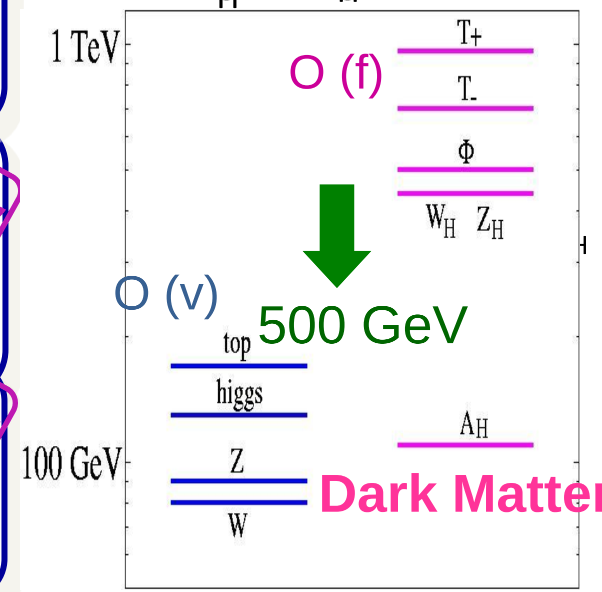
500 GeV

1 TeV

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

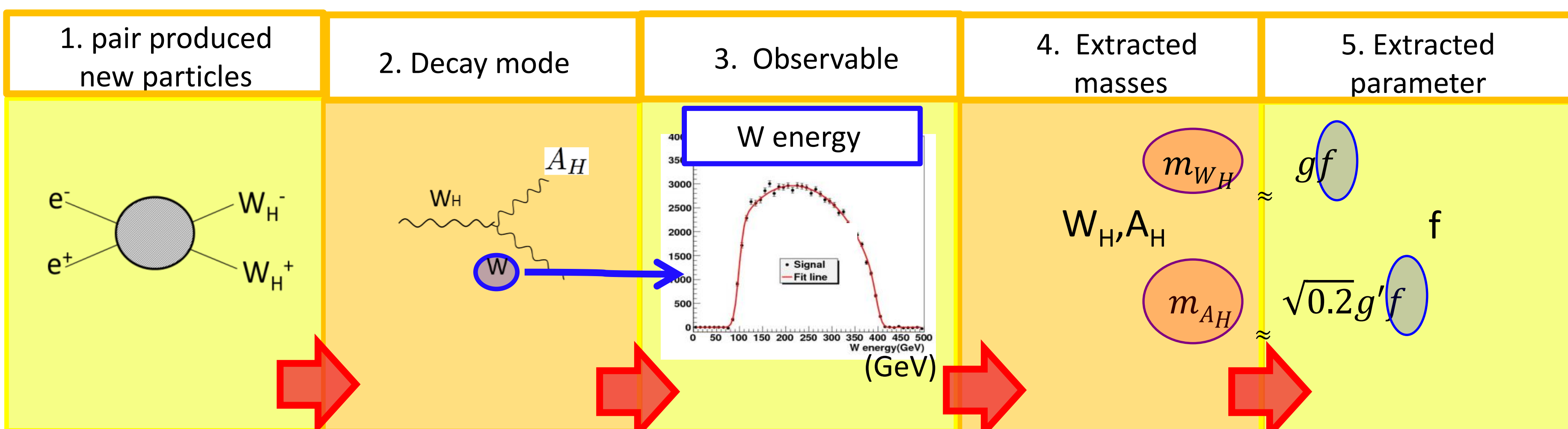
$$m_{A_H} \sim g' f / \sqrt{5}$$

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



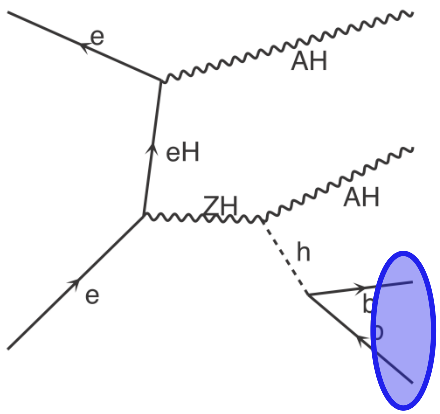
Analysis procedure

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.
4. Extract model parameters, using the fact that LHT masses are expressed in them.



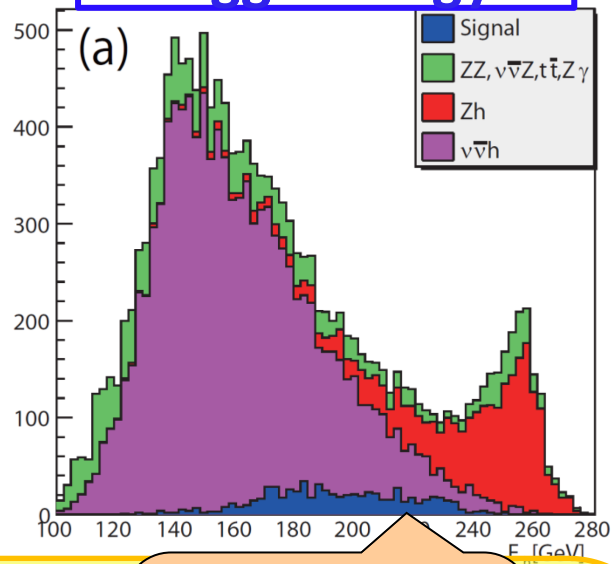
$Z_H A_H$ @500GeV

arXiv:0901.4873v1 [hep-ph]

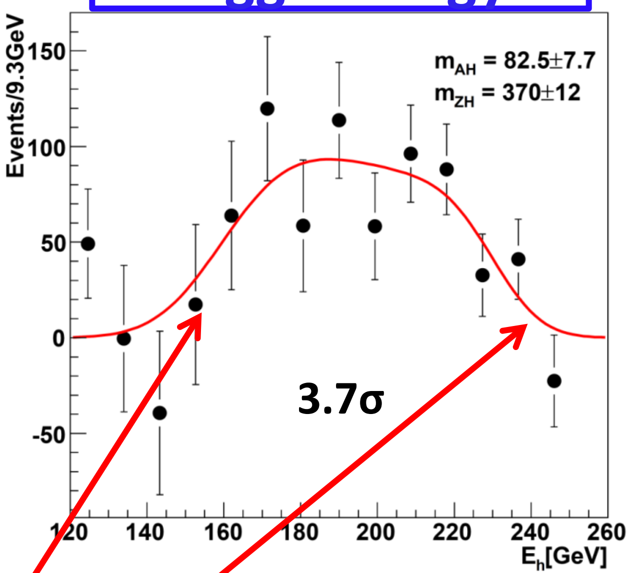


$e^+e^- \to A_H Z_H \to A_H A_H h$

Higgs energy



Higgs energy



(event selection)

- **Higgs mass**
- miss Pt cut
- **b-tagging**

Cross section small 1.05fb

Signal: $A_H A_H$**bb**

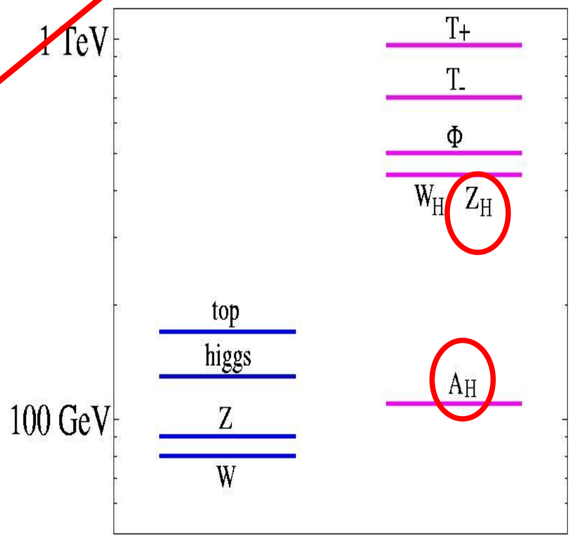
- Mass determination

  m_{AH} = 82.5 ± 7.7 GeV true(81.85)

  m_{ZH} = 370. ± 12. GeV true(368.2)

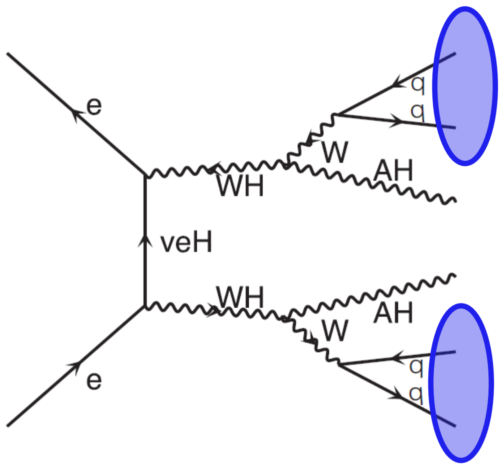
- f determination: f = 581 ±17GeV true(580)

First signal of LHT



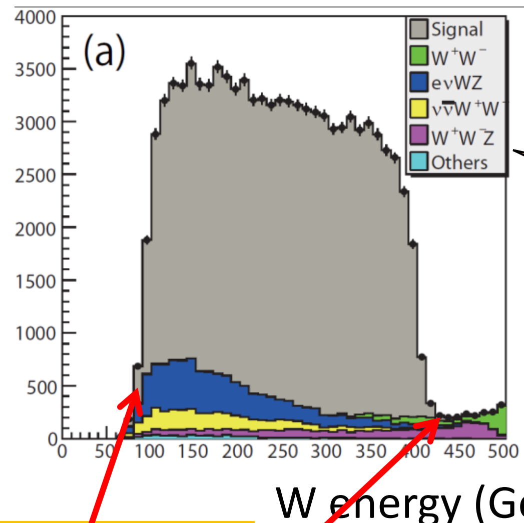
$W_H W_H$ @1TeV

(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

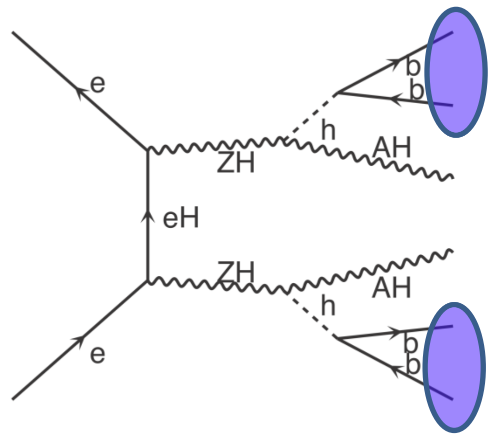
Signal: $A_H A_H$qqqq

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

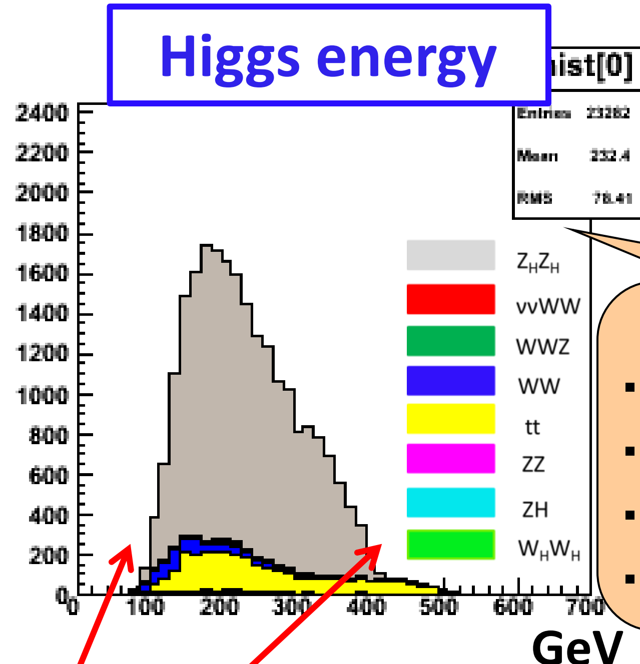
m_{WH} = 368.3 GeV **0.2%**

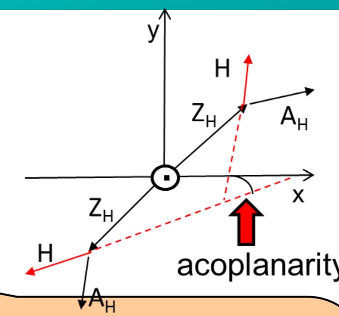
Capable of highly accurate mass/paramter measurement

$Z_H Z_H$ @1TeV



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





（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 **4.2%**

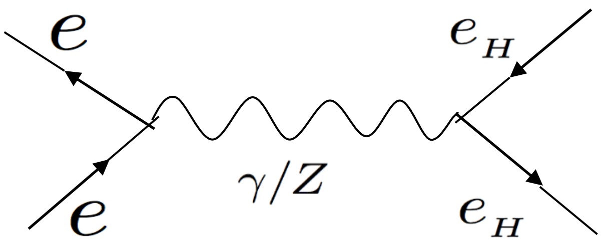
m_{ZH} = 366.1 GeV **1.3%**

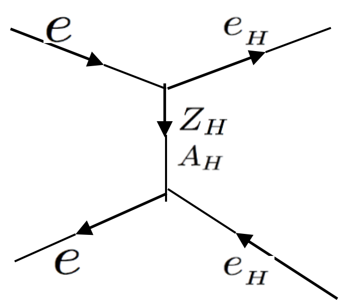
Capable of highly accurate mass measurement

$e_H e_H$ @1TeV

- **Aim: extract lepton Yukawa coupling κ by measuring e_H mass.**

Extremely important in knowing lepton sector mass generation mechanism.

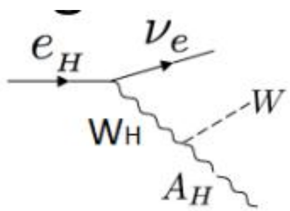




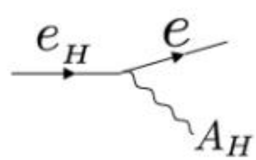
$m_{eH} = \sqrt{2}\kappa f = 410\text{GeV}$

Signal(4.56fb)

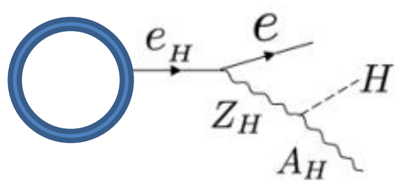
$e_H e_H \rightarrow eZ_H eZ_H \rightarrow eehhA_H A_H$



45% Same signal as $W_H W_H$. e_H access difficult

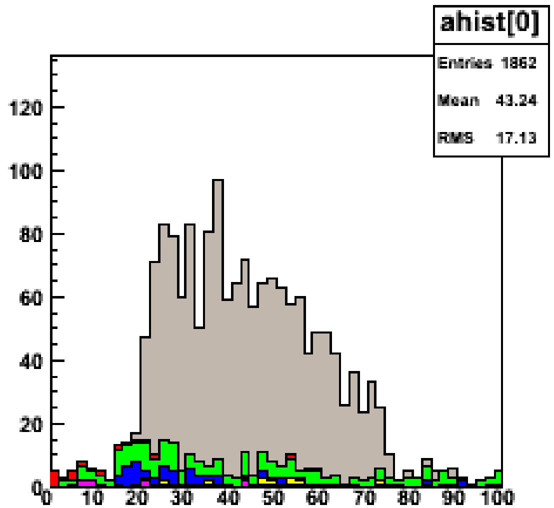


30% Charge suppressed. Large SM & LHT background.

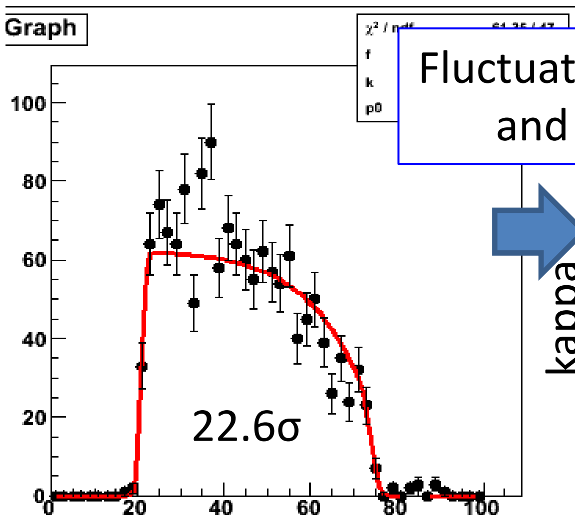


25% 2 higgs characteristic final state. Small background.

e_H mass/parameter extraction

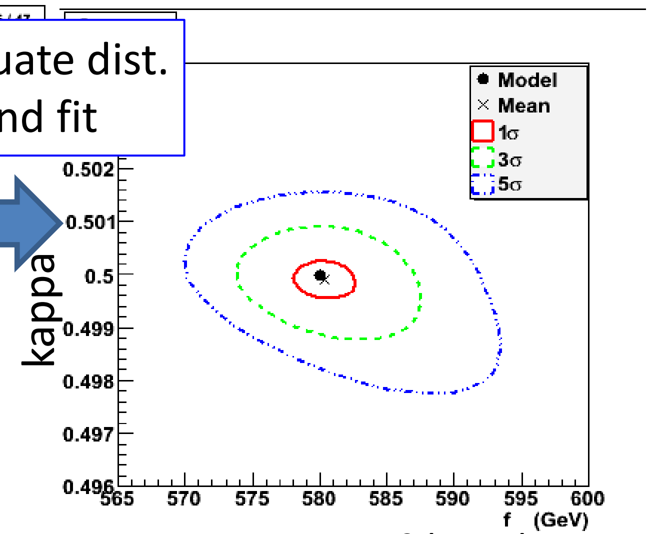


Electron energy (GeV)



Electron energy (GeV)

Fluctuate dist. and fit



Parameter f (GeV)

(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±4e-4

True value: f=580(GeV) , κ=0.5

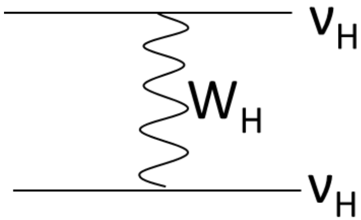
mass accuracy: e_H:412.8 ±1.7(GeV) Z_H :371.2 ±1.5(GeV)

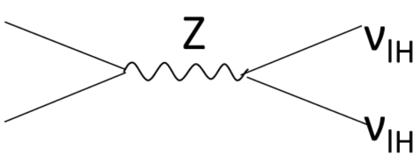
Successfully extract mass and parameters.

$\nu_H \nu_H$@1TeV

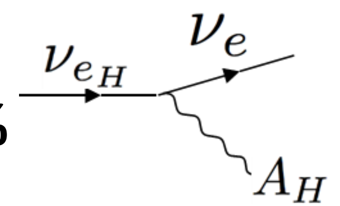
- **AIM: extract ν_H mass and complete LHT mass spectrum**
- **$\nu_H \nu_H (eW_H eW_H)$ (tot xsec :1036fb)**
  - Signal: eeqqqq(2W)$A_H A_H$ (25.96fb)

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



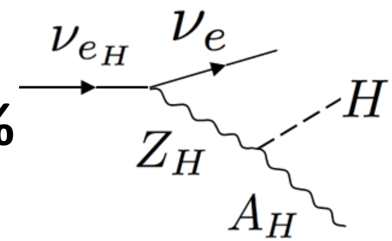


✗ **Br = 65.4%**



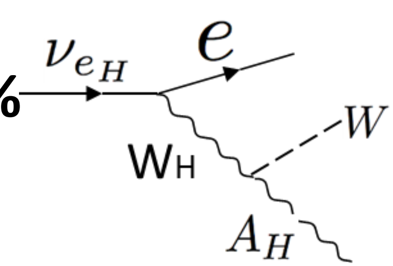
No signal!!

✗ **Br = 11.1%**



Same signal as $Z_H Z_H$ (smaller cross section)

○ **Br = 23.5%**

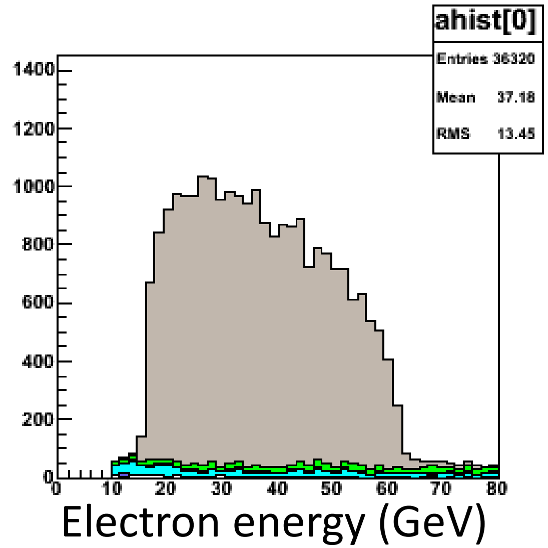


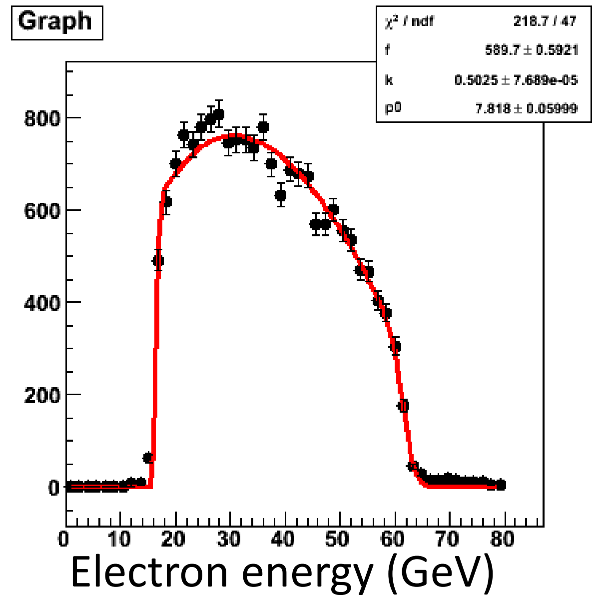
signal

ν_H mass/parameter extraction

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

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





extracted value: f=582.0±0.6(GeV) κ=0.5±1e-4

True value: f=580(GeV) , κ=0.5

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

Successfully extract mass and parameters.

Jet energy resolution

- Jet energy is used for determining LHT masses & determining masses used for background rejection.
  - Difficult to reconstruct jets in LHC →can't perform LHT mass precision measurement.

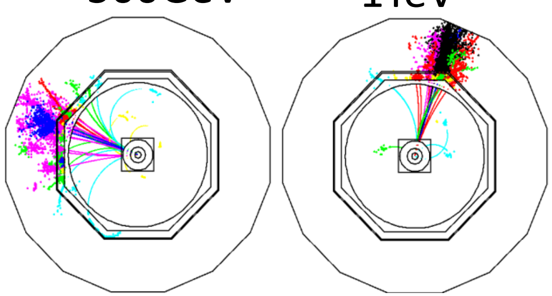
➢ (jet) energy resolution determines mass measurement precision.

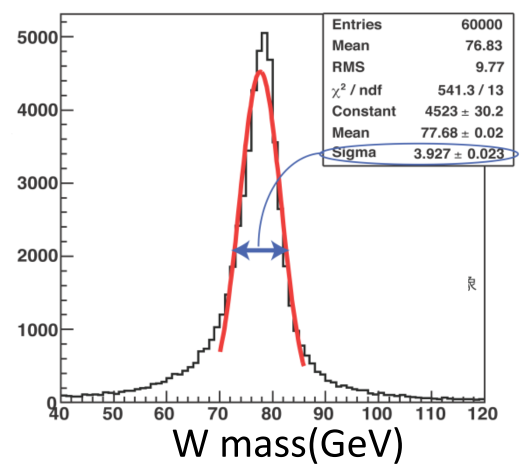
$$\frac{\sigma_m}{m} \propto \frac{E}{m}\frac{\sigma_E}{E}$$

Mass resolution is proportional to energy resolution &energy

- @1TeV Jet density increases.
- Reconstruction becomes difficult.

500GeV 1TeV



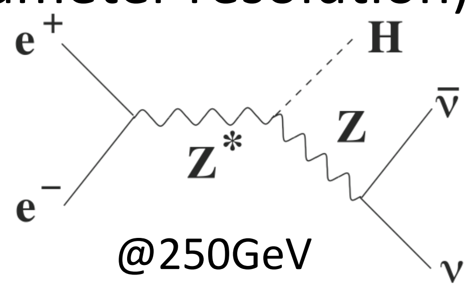


Other important performances

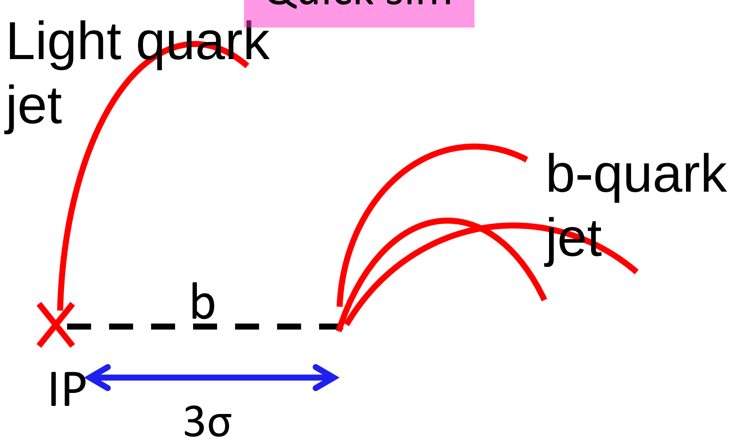
Flavor tagging

- Flavor tagging is also used as a power tool for background rejection.
- b-tagging requirement: existence of over 2 tracks with 3σ displacement from the IP.(σ :impact parameter resolution)
- Efficiency approx.55% @ Z-Higgs study.

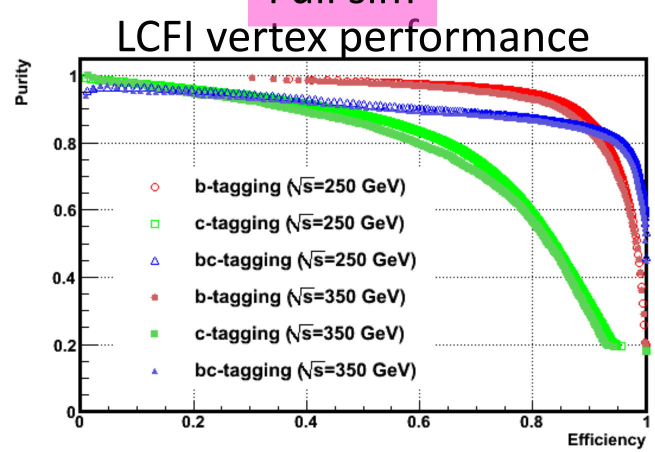
➢ Can be improved with Full simulation.



Quick sim



Full sim



Summary

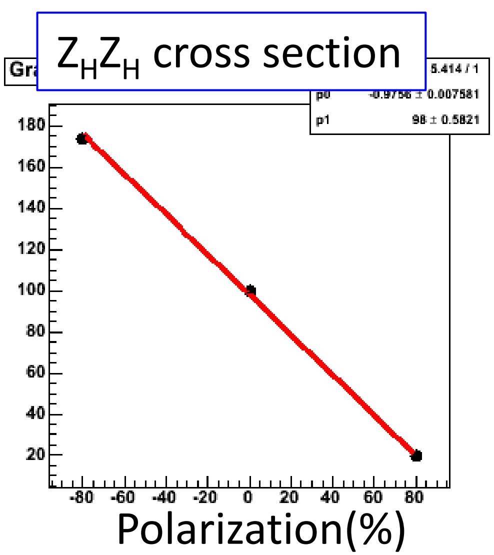
- High precision parameter extraction & mass measurement are extremely important in studying LHT's mass generation mechanism and verifying the model.
  - To achieve high precision, good jet energy resolution and reasonable flavor tagging performance are needed.

particle	mass	sensitivity
A_H	81.9(GeV)	1.3%
W_H	369(GeV)	0.20%
Z_H	368(GeV)	0.56%
e_H	410(GeV)	0.46%
ν_H	400(GeV)	0.001%

parameter	True value	Measurement accuracy
f	580(GeV)	0.16%
K	0.5	0.0001%

plan

- ■ Cross section can be measured when changing polarization.
- Normalization h_0 → cross section: $\sigma \rightarrow \sigma_{LH}, \sigma_{RH} \rightarrow$ coupling
- Error = $\Delta h_0 / h_0$
- Assuming 0.25% polarization error.
- ➢ Coupling will be derived.



Mode	σ@0%pol	σ meas. accuracy
$Z_H Z_H$	99fb	0.89%
$e_H e_H$	3.6fb	2.7%
$N_H N_H$	25fb	0.77%
$W_H W_H$	1 06fb	0.41%