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

ILD workshop,LAL

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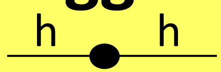
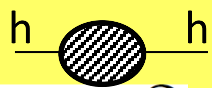
Little Hierarchy problem

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

1. **Fine tuning of Higgs mass**





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

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!**

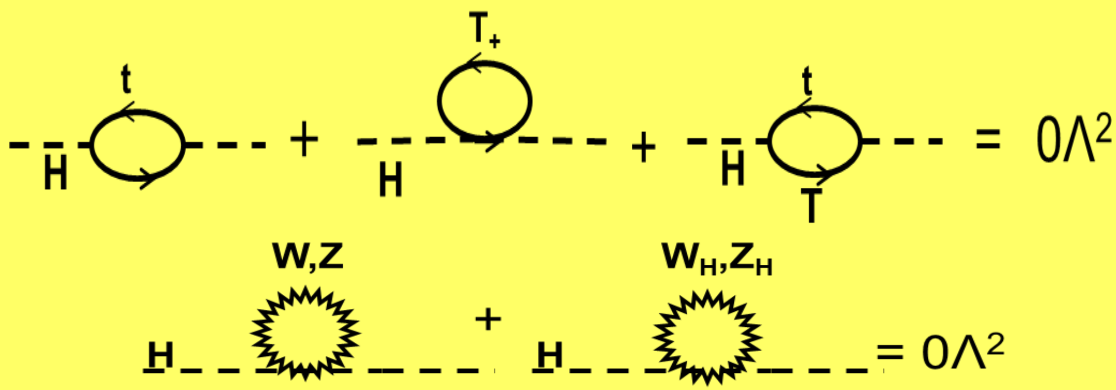
Little Higgs model

<Little Higgs mechanism>

Global Symmetry : SU(5) **f ~ 1 TeV** SO(5) **v ~ <h>**

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

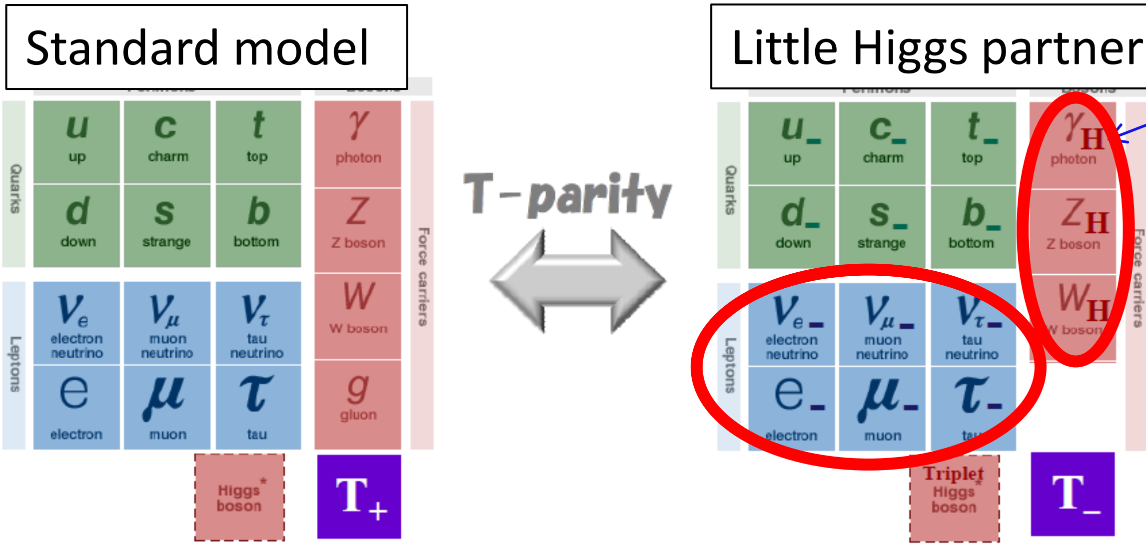
<Higgs mass contribution>



Quadratic divergent terms cancel at 1-loop order

Solves Little hierarchy problem

Littlest Higgs with T-Parity model



A_H :DM candidate

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

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

$$m_{u_-} \sim m_{d_-} \sim \sqrt{2} k_q f$$

$$m_{e_-} \sim m_{\nu_-} \sim \sqrt{2} k_l f$$

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.

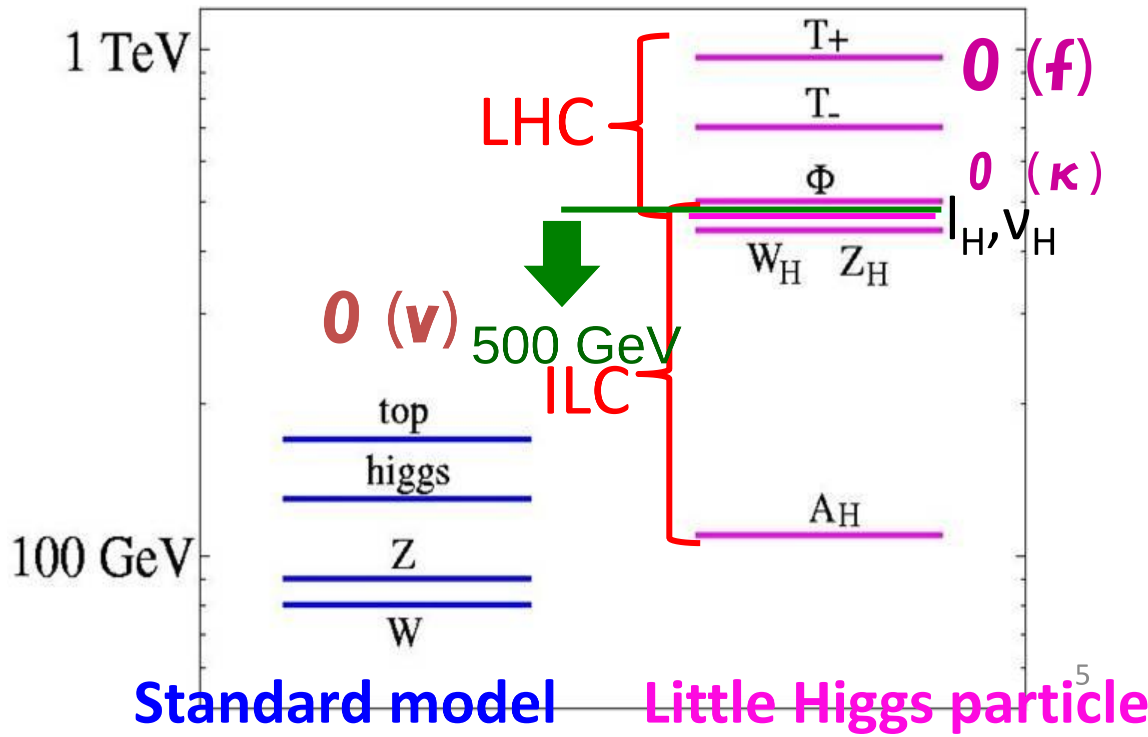
Aim of study

Evaluate ILC's sensitivity on …

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

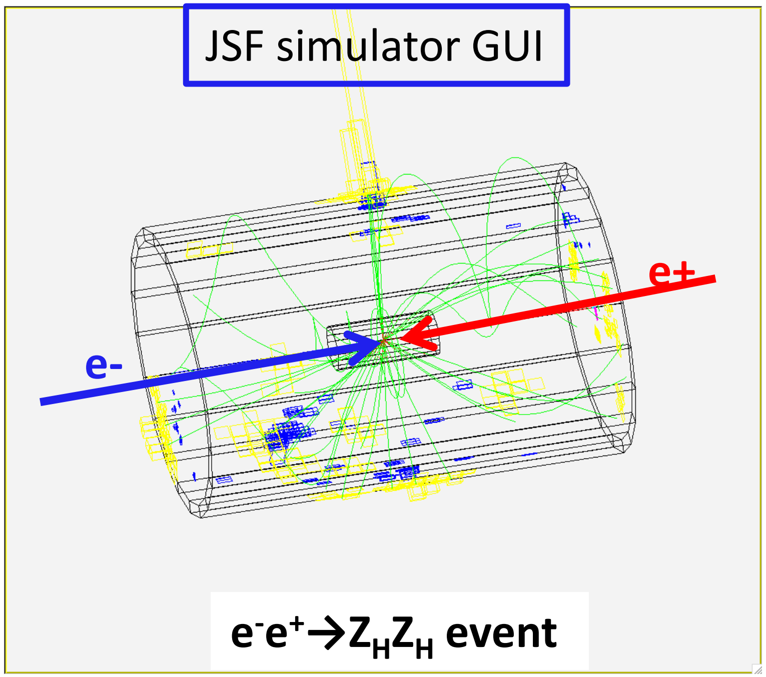
Strong proof that discovered particles are indeed LHT.

κ	f
0.5	580(GeV)



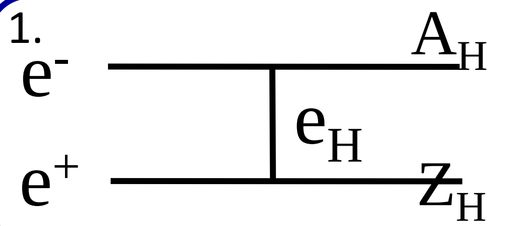
Simulation environment

- Software for fast 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 simulator(simulation)



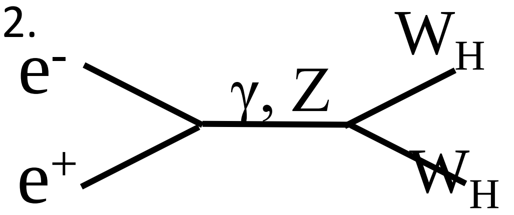
- Experiment environment
- CM energy: 1TeV
- luminosity : 500fb^{-1} (4 years)
- beam/bremstrahlung, beam energy spread are included.

Analysis strategy

1.


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

LOI

2.


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

LOI

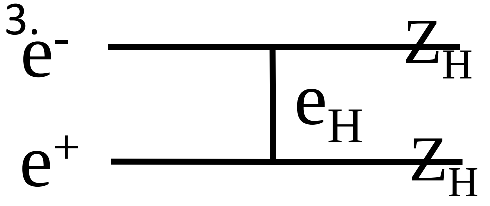
500 GeV

1 TeV

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

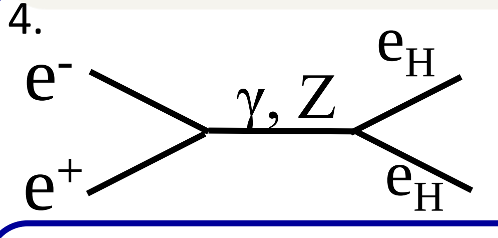
$$m_{A_H} \sim g' f / \sqrt{5}$$

$$m_{e_-} \sim m_{\nu_-} \sim \sqrt{2} k_l f$$

3.


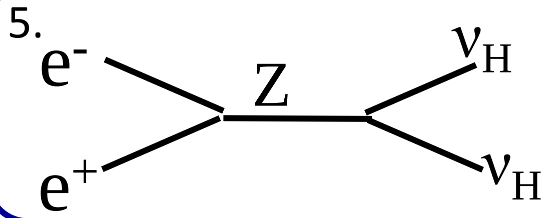
- Determine f.
- **complete mass spectrum in gauge sector**

New

4.


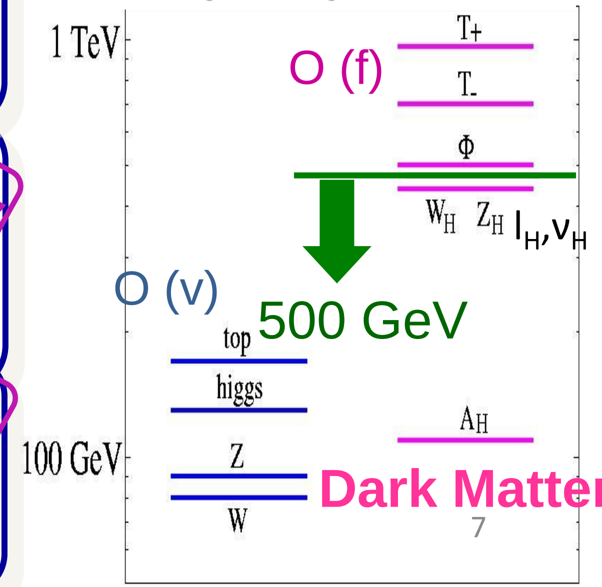
- Determine l_H mass
- **Precision measurement on κ**

New

5.


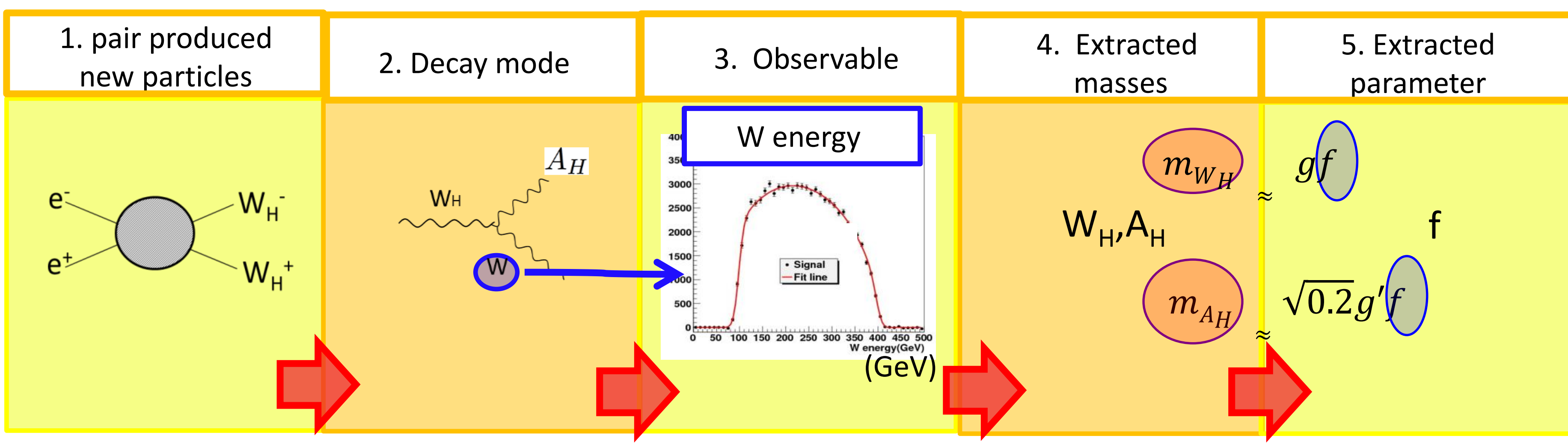
- **Complete mass spectrum in lepton sector**

New



Analysis procedure

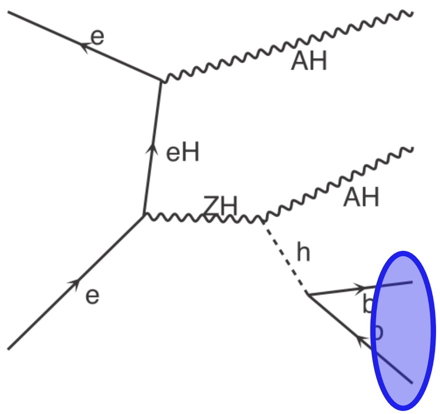
1. T-Parity ➡ new particles are produced in pairs
2. ➡ produced new particles decay into SM and LHT particles.
3. Extract LHT mass information by recognizing end point of SM energy.
4. LHT masses are expressed with model parameters.
5. Extract model parameters.



Heavy gauge boson sector
~mass & parameter f extraction ~

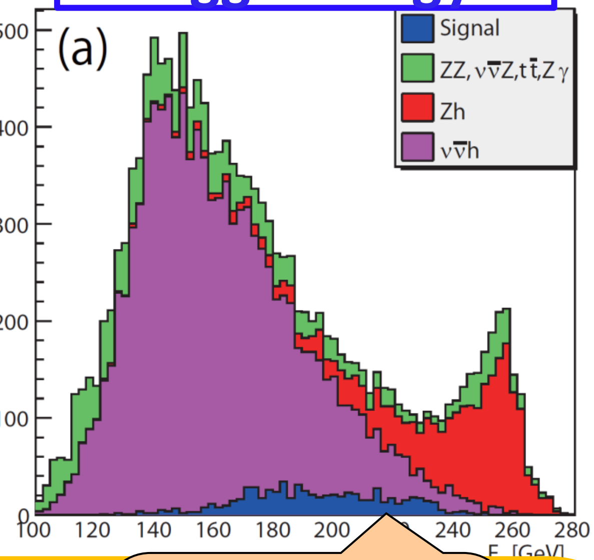
$Z_H A_H$ @500GeV

arXiv:0901.4873v1 [hep-ph]

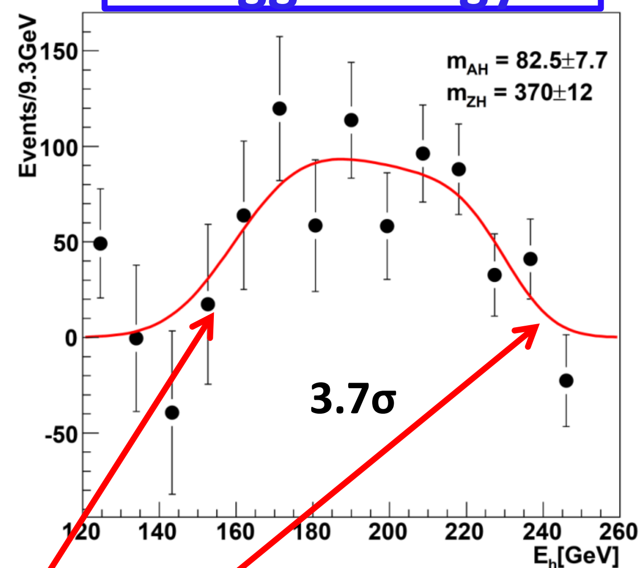


$e^+e^- \rightarrow A_H Z_H \rightarrow A_H A_H h$

Higgs energy



Higgs energy



(event selection)

- Higgs mass
- miss Pt cut
- b-tagging

Cross section small 1.05fb

Signal: $A_H A_H$**bb**

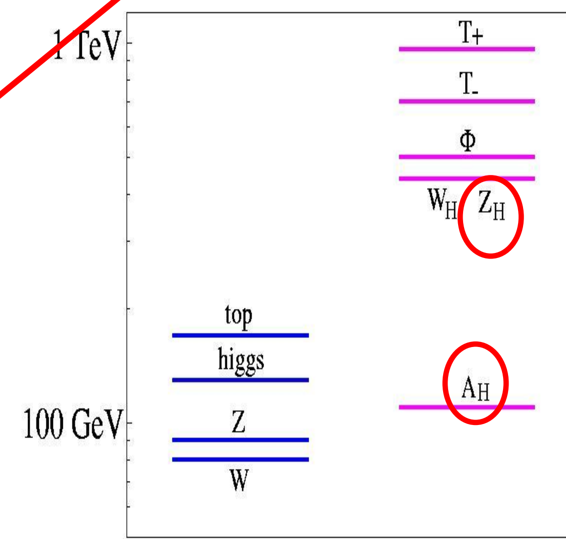
- Mass determination

  m_{AH} = 82.5 ± 7.7 GeV true(81.85)

  m_{ZH} = 370. ± 12. GeV true(368.2)

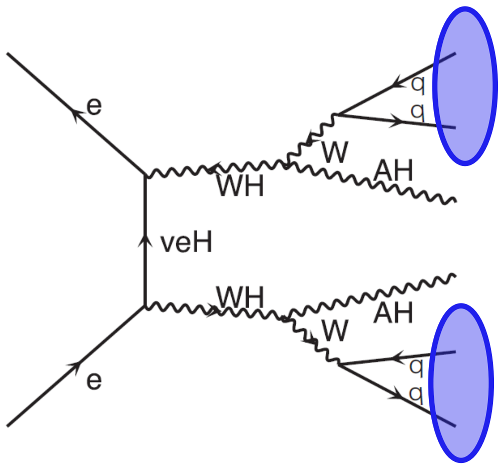
- f determination: f = 581 ±17GeV true(580)

First signal of LHT



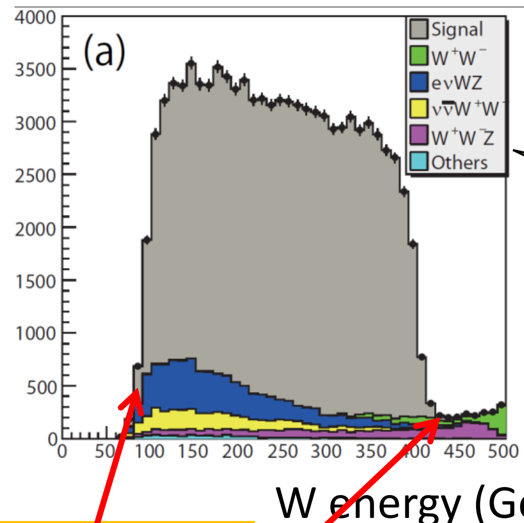
$W_H W_H$ @1TeV

(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

This analysis produces 2 mass solutions.

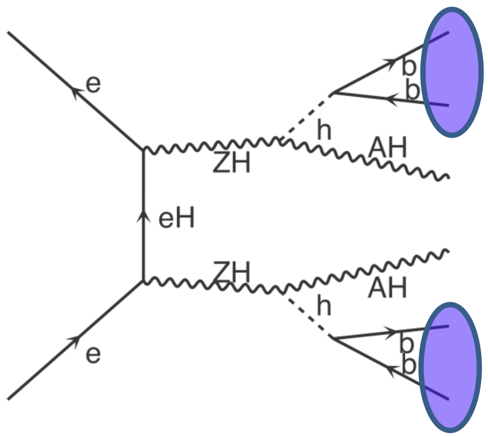
True solution

m_{AH} = 81.6 GeV , 81.0 GeV **1.3%**

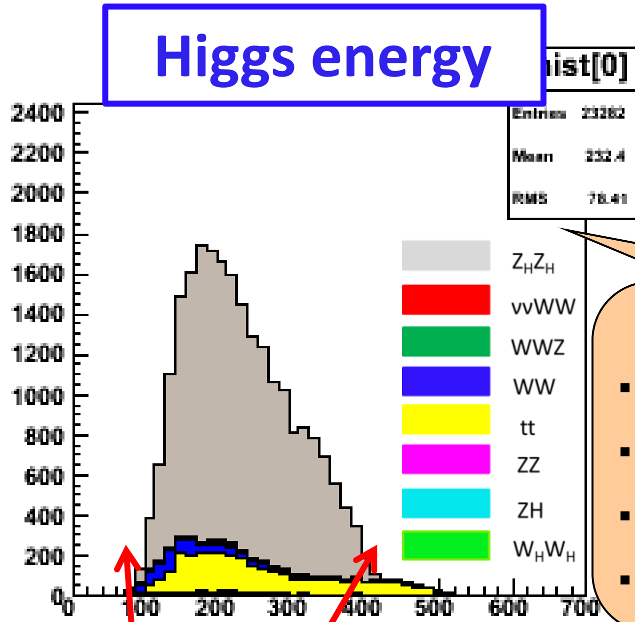
m_{WH} = 368.3 GeV , 218.0 GeV **0.2%**

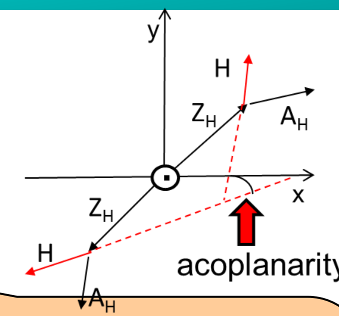
Highly accurate, however true solution needs to be selected

$Z_H Z_H$ @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

This analysis also produces 2 mass solutions.

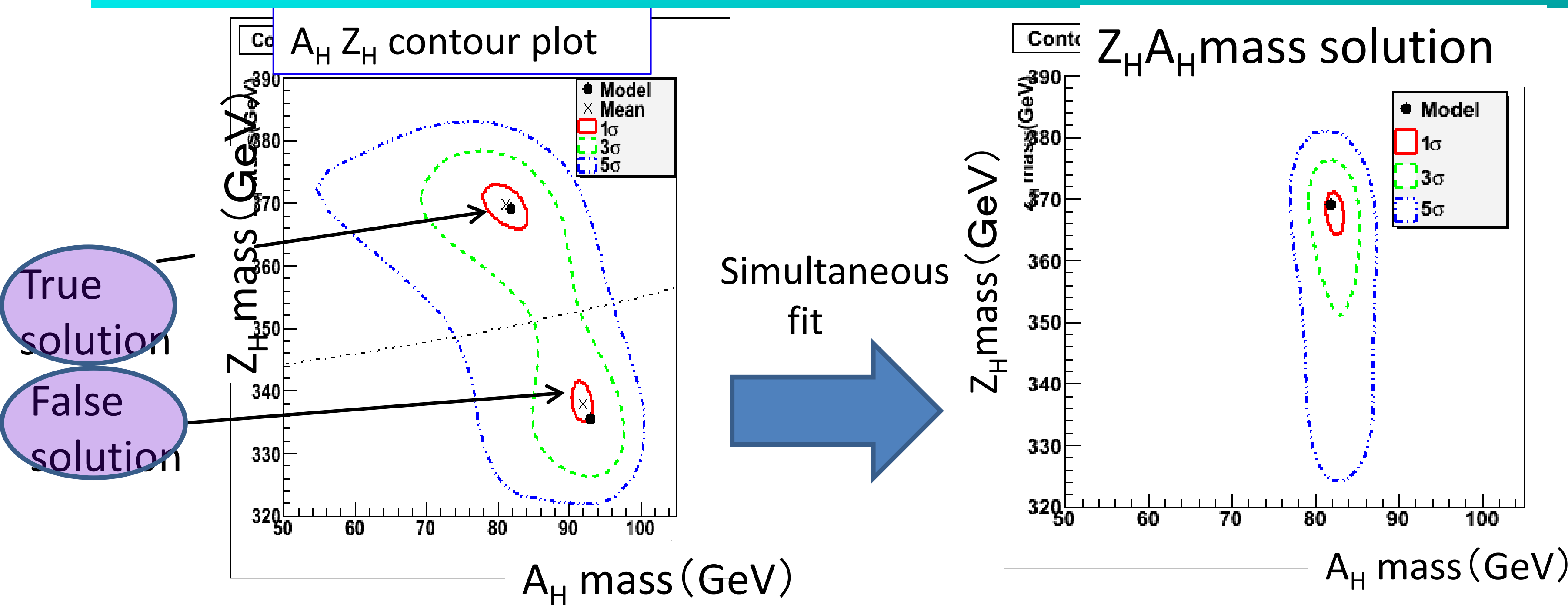
True solution

m_{AH} = 82.7 GeV , 93.1 GeV **4.2%**

m_{ZH} = 366.1 GeV , 335.4 GeV **1.3%**

Highly accurate, however true solution needs to be selected

Mass determination in gauge sector



Through simultaneous fitting $W_H W_H$&$Z_H Z_H$ (both derive $A_H$mass),we were able to derive a single mass solution.

- Mass measurement accuracy: A_H 1.3%, Z_H1.1% W_H0.20%
- parameter measurement accuracy: f 0.16%

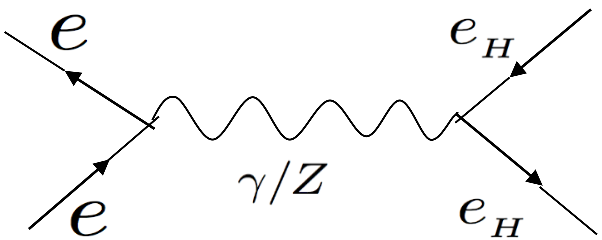
ILC is highly sensitive to f !

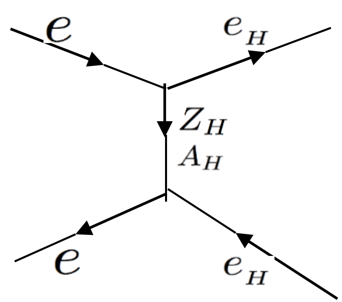
Heavy lepton sector
~mass&parameter κ extraction~

$e_H e_H$ @1TeV

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

Extremely important in knowing lepton sector mass generation mechanism.

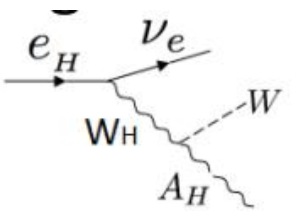




$m_{eH} = \sqrt{2}\kappa f = 410\text{GeV}$

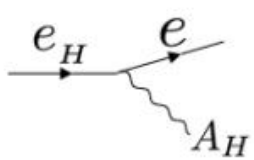
Signal(4.56fb)

$e_H e_H \rightarrow e Z_H e Z_H \rightarrow eeqqqq$



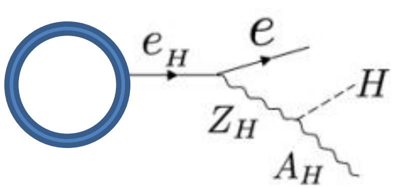
45%

Same signal as $W_H W_H$.
e_H access difficult



30%

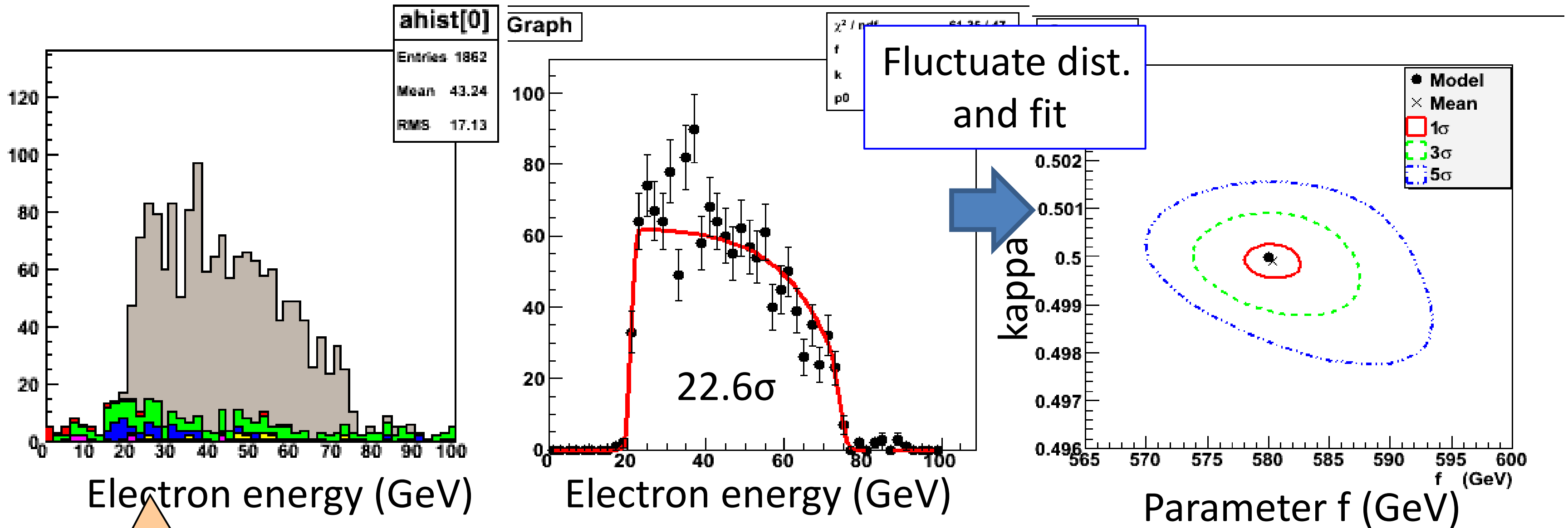
Charge suppressed.
Large SM & LHT background.



25%

2 higgs characteristic final state
Small background.

e_H mass/parameter extraction



（event selection）

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

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

■ No multiple solution.

extracted value: f=579.6±3.0(GeV) κ=0.5±4e-4

True value: f=580(GeV) , κ=0.5

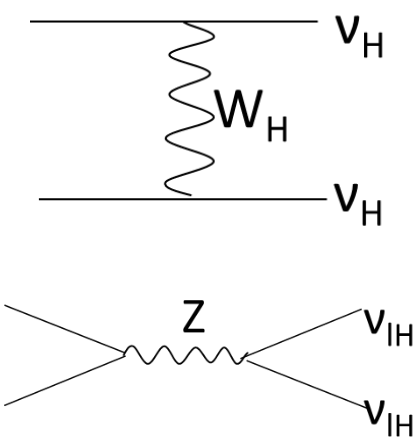
mass accuracy: e_H:412.8 ±1.7(GeV) Z_H :371.2 ±1.5(GeV)

Successfully extract mass and parameters.

$\nu_H\nu_H$@1TeV

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

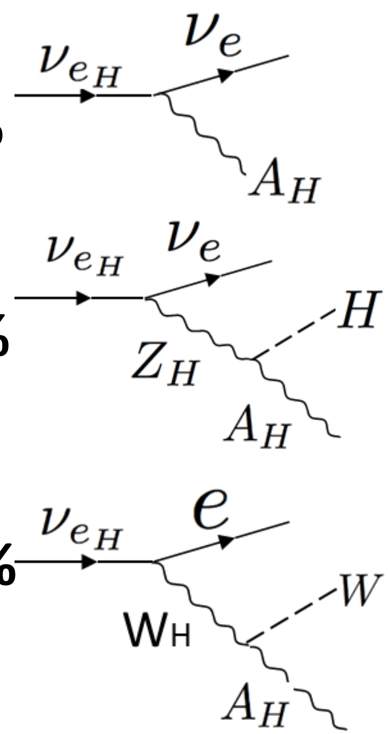
    $M_{\nu H} \fallingdotseq \sqrt{2}\kappa f = 400$GeV



✗ **Br = 65.4%** — No signal!!

✗ **Br = 11.1%** — Same signal as Z_HZ_H (smaller cross section)

○ **Br = 23.5%** — **signal**



ν_H mass/parameter extraction

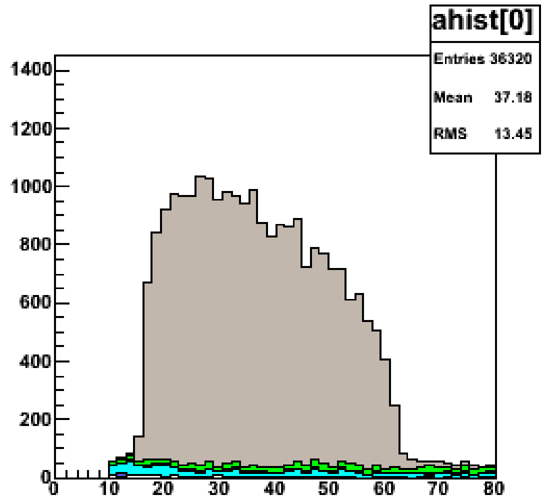
SG: eW_HeW_H(eeqqqq)

BG: $\nu_{\tau H}\ \nu_{\tau H}, e_He_H, \tau_H\tau_H$,
tt,ttZ,tth
evWZ,eeWW,ZZZ

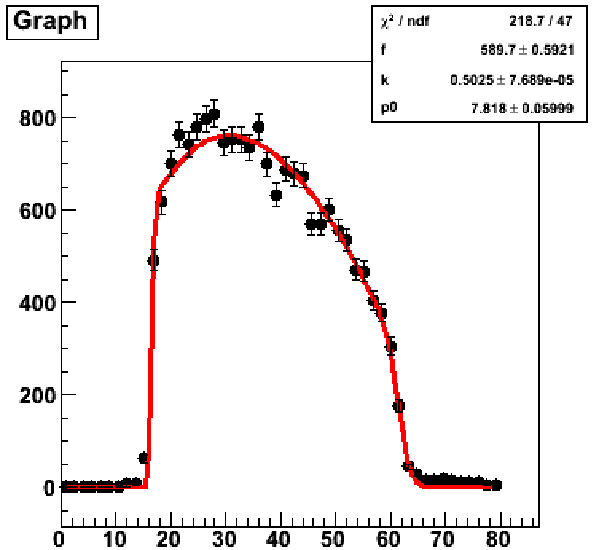
（event selection）

・#Isolated e =2

・W mass



Electron energy (GeV)



Electron energy (GeV)

- No multiple solution.

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.

Summary

- Results show that ILC is capable of doing highly accurate precision measurements on LHT masses and parameters.
- Parameter extraction is extremely important in studying LHT's mass generation mechanism.
- Little Higgs model's characteristic mass spectrum (expressed with 2 parameters) can be confirmed by high precision mass measurement.

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.
- Coupling will be derived.

Cross section measurement

Mode	σ@0%pol	σ meas. accuracy
Z_HZ_H	99fb	0.89%
e_He_H	3.6fb	2.7%
N_HN_H	25fb	0.77%
W_HW_H	1 06fb	0.41%

backup

Selection of model parameters

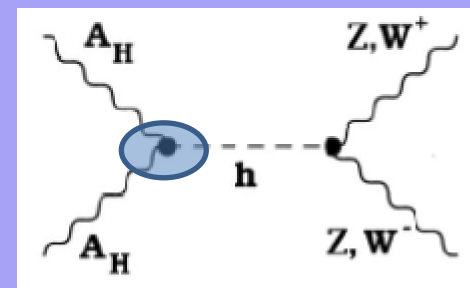
lepton and gauge sector are described with 2 model parameters

κ	f	m_H
0.5	580(GeV)	134(GeV)

*K small→l_H,ν_H mass too small
*K large→4 fermi interaction contribution increases and large discrepancy from SM.

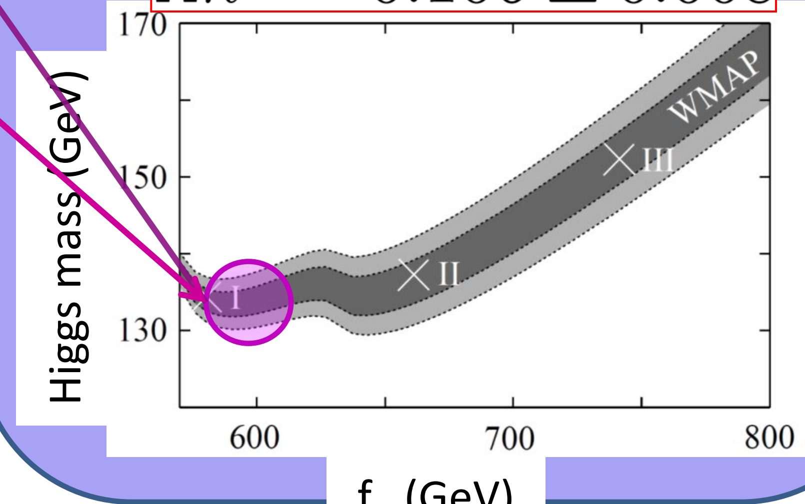
relic density measure from WMAP

Main annihilation mode



Cross section depends on m_{AH}&m_H

$$\Omega h^2 = 0.106 \pm 0.008$$

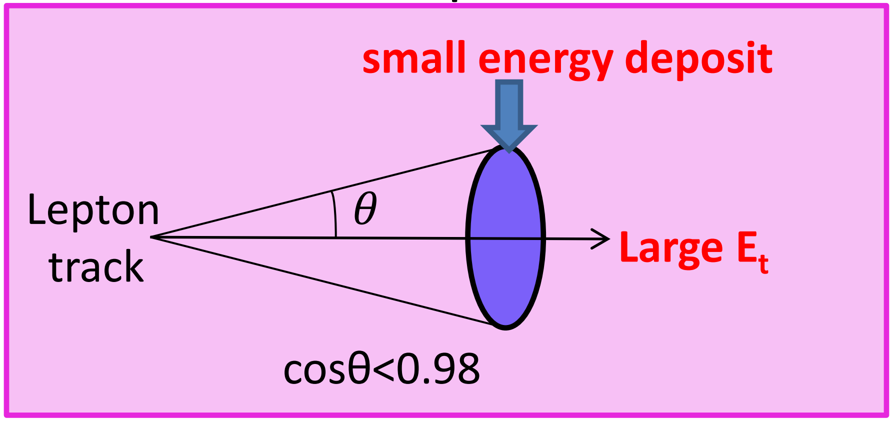


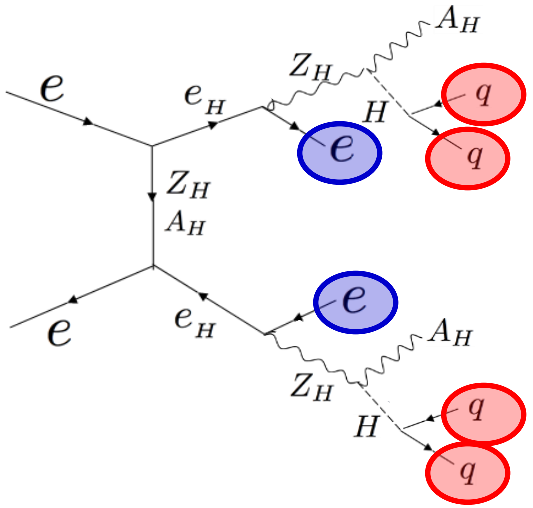
Event reconstruction

1. Select 2 Isolated lepton with maximum energy
2. Reconstruct and force the rest of the tracks as 4 jets.
3. Select reconstructed jet pair that minimizes χ^2 .

$$\chi^2_H = \left(\frac{M_{H1} - M_H}{\sigma_{M_H}}\right)^2 + \left(\frac{M_{H2} - M_H}{\sigma_{M_H}}\right)^2 \quad M_H = 134.0(GeV)$$

Isolated Lepton ID



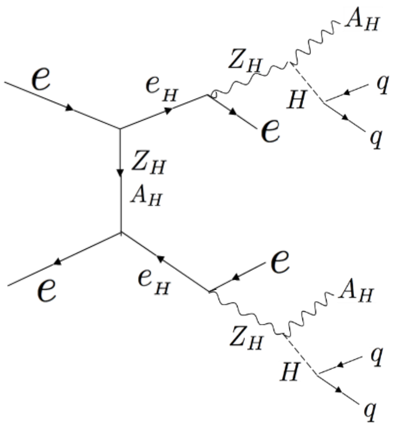


Signal Electron selection

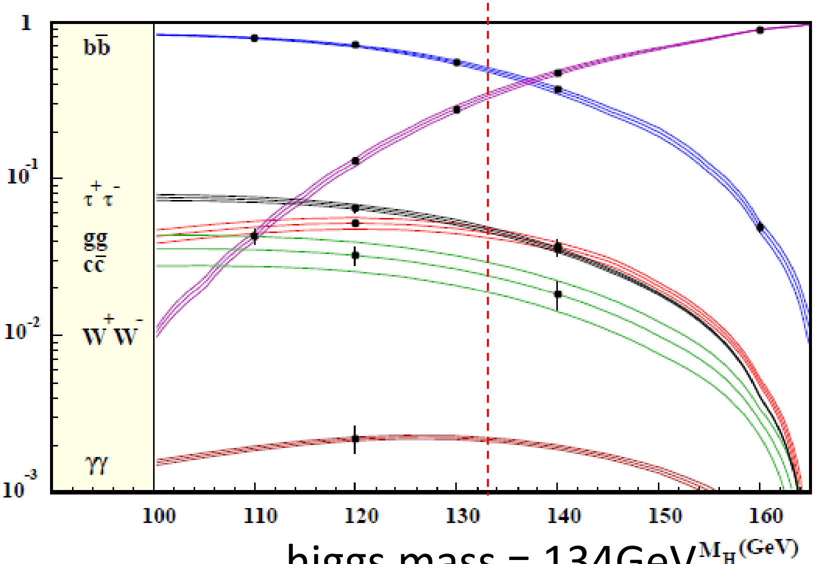
- $e_H e_H \to e Z_H e Z_H$ analysis: 2e + 4jet
- Higgs decay: ○save full hadronic events

  × lose isolated electron emitting events

⇒ optimize isolated electron selection



Higgs branching ratio



higgs mass = 134GeV

Br(h→bb) =42.35% ○

Br(h→WW)=39.57%

Br(h→ZZ) =5.50%

Br(h→ττ)= 5.21%

× **Isolated electron emitting decay**

○**non electron emitting Full hadronic decay**

Br(h→gg) =4.49% ○

Br(h→cc)= 2.31% ○

e_H Branching ratio study

$$\mathcal{L}_{\rm L}^{(\rm Gauge)} = \ldots + \frac{g}{\sqrt{2}} \left[\bar{e}_H \not{W}_H P_L \nu \right.$$
$$- \frac{g}{2} \left[\bar{e}_H \not{Z}_H \left(c_H - \frac{s_W}{5 c_W} s_H \right) P_L e \right.$$
$$- \frac{g}{2} \left[\bar{e}_H \not{A}_H \left(s_H + \frac{s_W}{5 c_W} c_H \right) P_L e \right.$$

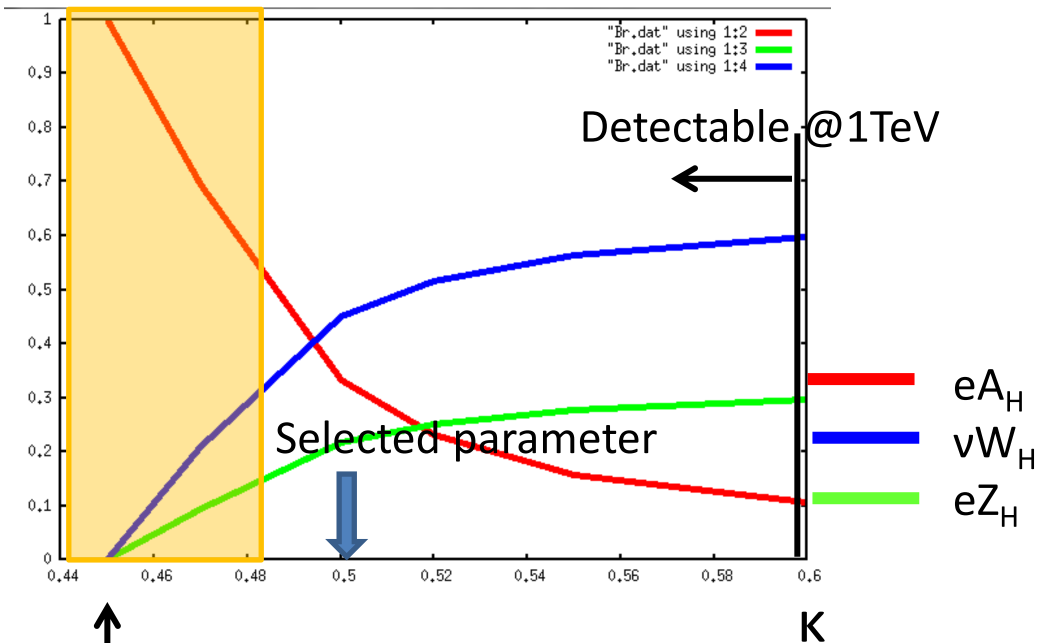
Charge suppressされている。

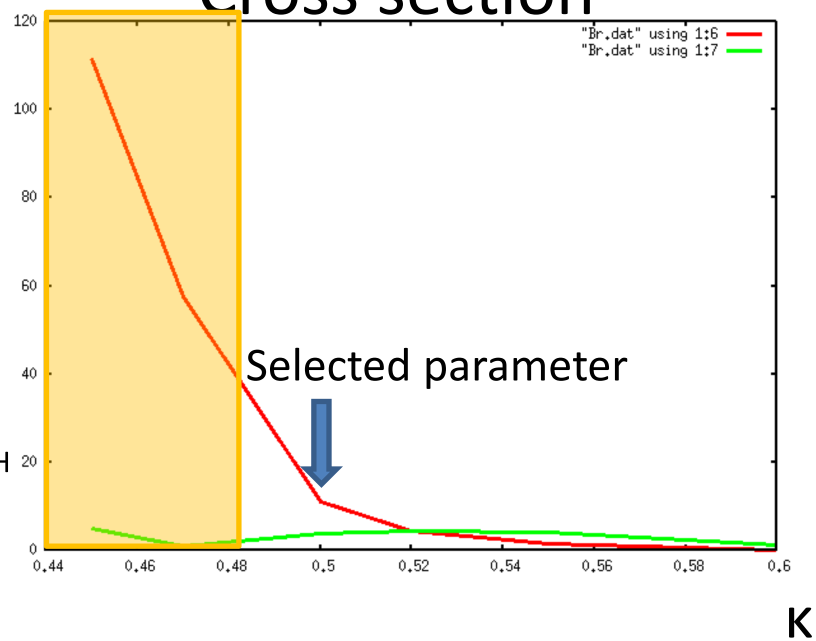
Mixing angle非常に小さい
s_H~0.1

Reference :arXiv: 4632v2 "T-Parity odd heavy lepton at LHC"

e_H Branching ratio study

Branching ratio @f = 580[GeV] Cross section





$me_H \fallingdotseq mZ_H, mW_H$

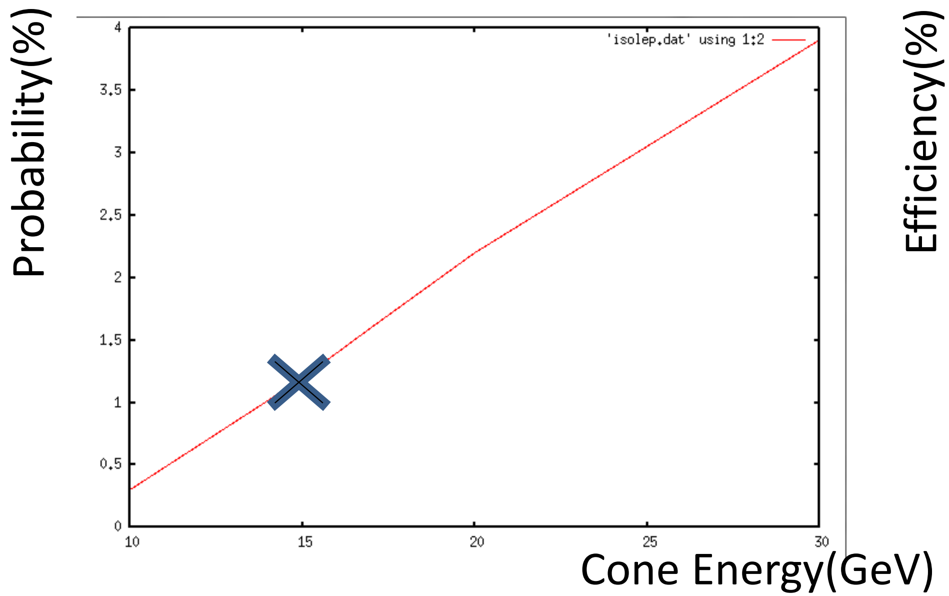
detectable@3fb^{-1} LHC. 2011-12ATLAS+CMS

- Large K→ heavy l_H small cross section
  eA_H small branching ratio
- K>0.5 300fb^{-1} LHC 4.2σ(νW_H)
- eA_H: large SM & NP background
- eZ_H :2higgs(134GeV) characteristic final state small background

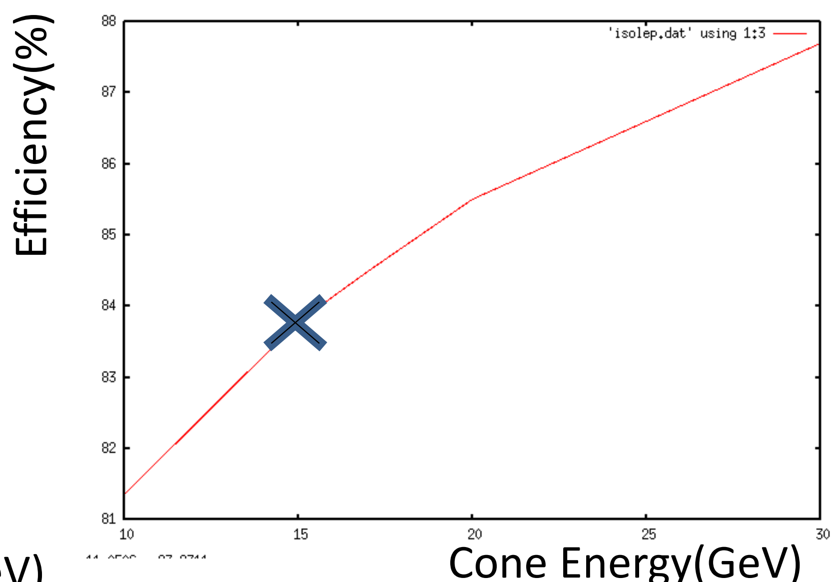
Signal Electron selection

- Probability of missIDing e from b jet is small.(signal:H→bb)
  ⇒Optimize with selection efficiency of e from e_H.
  – Select point right before slope becomes shallow.
- Cone Energy <15GeV :P(missID)=1.2%,signal efficiency=84%

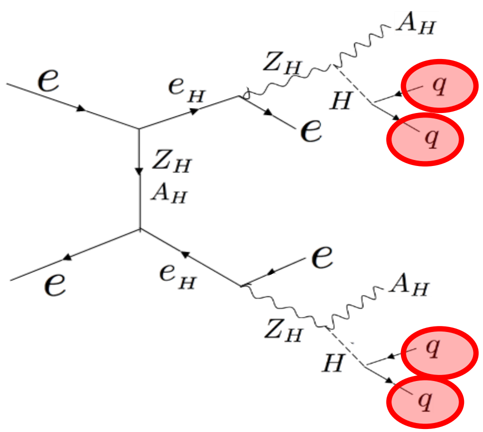
Probability of miss IDing e from b jet



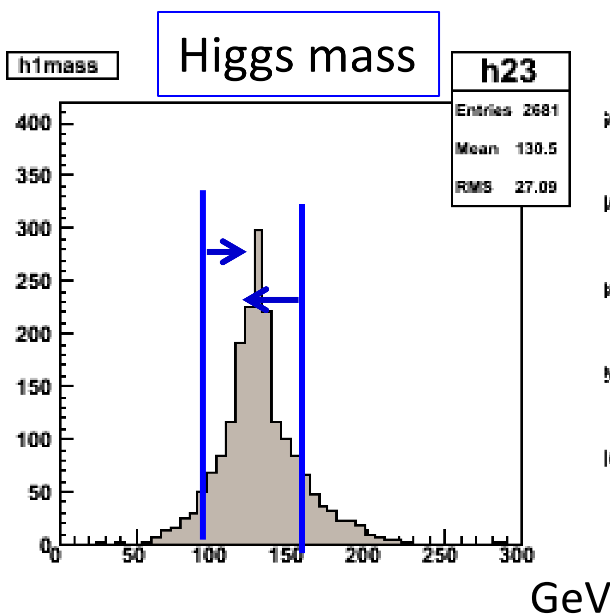
Selection efficiency of e from eH

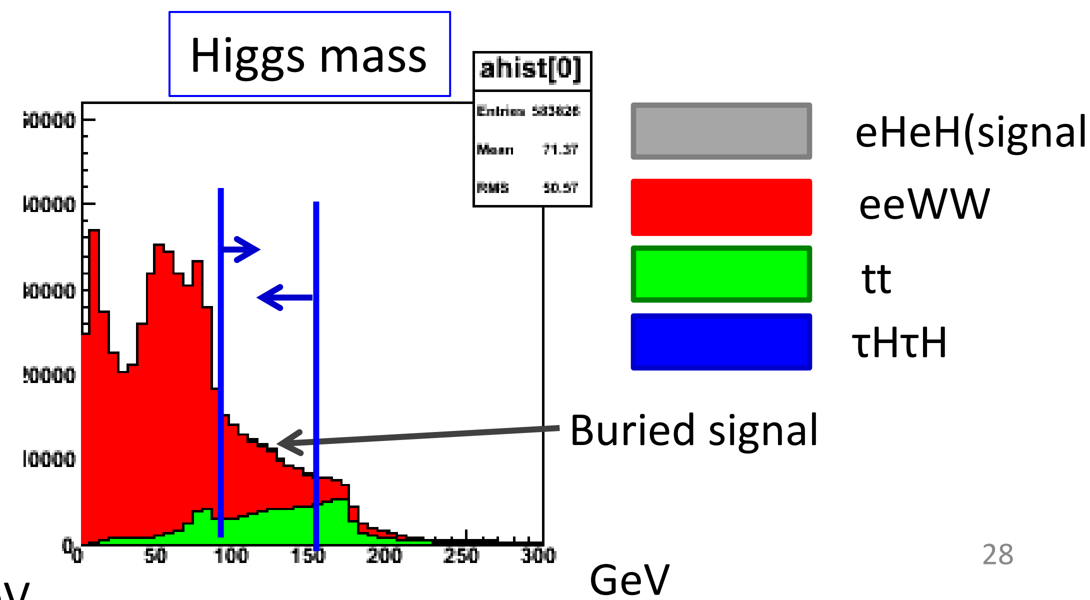


Reconstructed Higgs mass



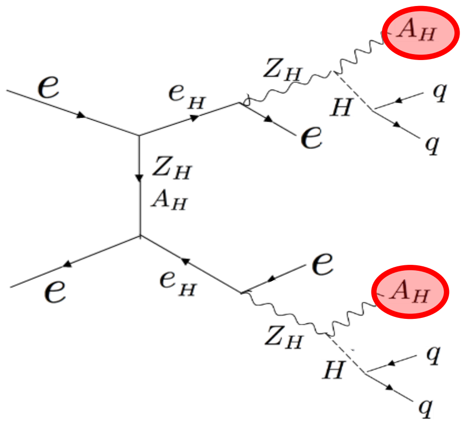
Decay mode	Reconstructed particle
$e_H e_H$	Higgs
eeWW	W boson
tt	B meson
$\tau_H \tau_H$	Higgs

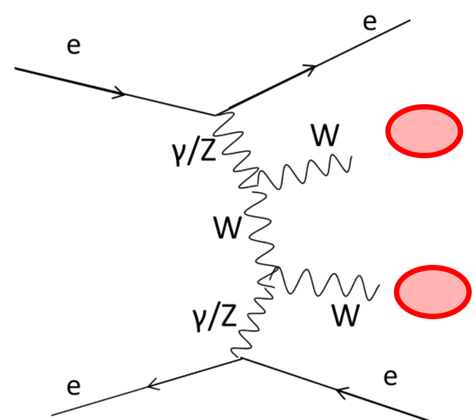


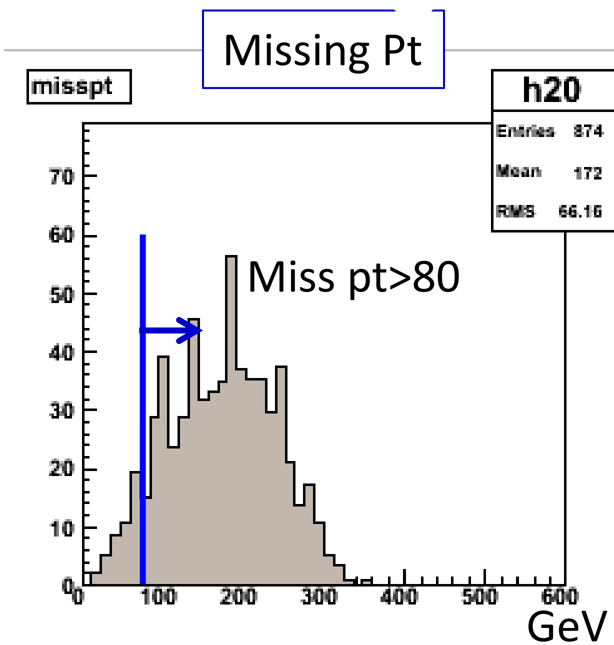


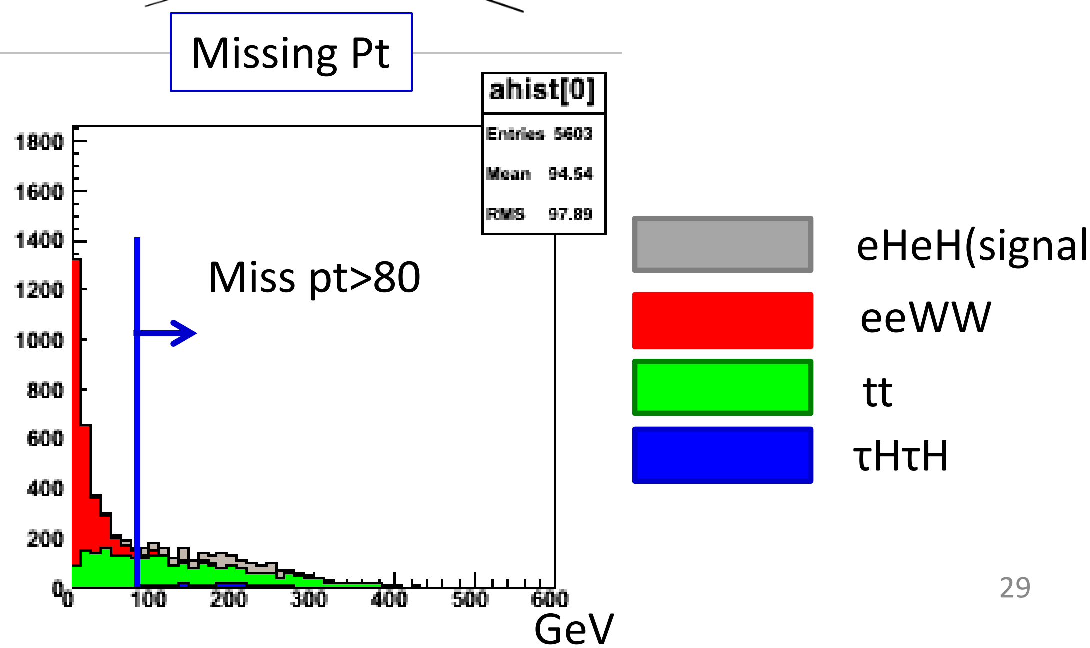
Missing transverse momentum

- Signal has large missing transverse momentum





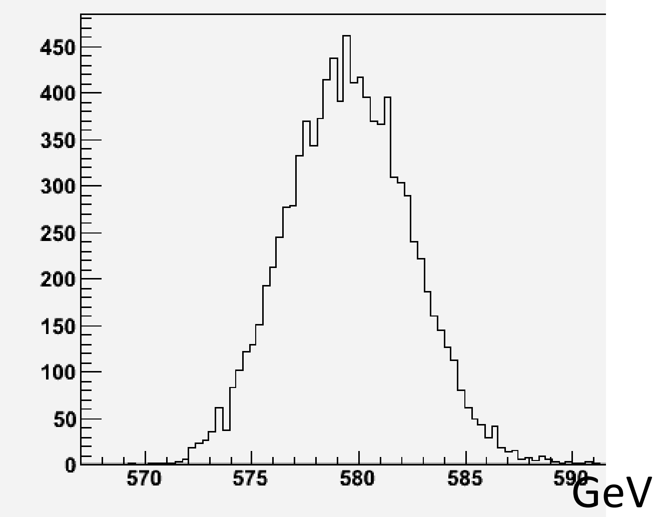




Parameter extraction

- **Through Toy MC, Confirmed that fitting is valid.**
  - extracted value: f=579.6±3.0(GeV) , κ=0.5±4e-4
  - True value: f=580(GeV) , κ=0.5
- Extracted parameters include true value

f (vacuum expectation value)



kappa(lepton yukawa coupling)