Charged Higgs search in Triplet Higgs model with $e^+e^- \rightarrow WH$

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Yuko Shinzaki

Jan strube, Akimasa Ishikawa, Keisuke Fujii[a]

Shinya Kanemura[b], Kei Yagyu[c], Hitoshi Yamamoto

Tohoku univ., KEK[a], Toyama univ.[b], National Central univ.[c]

Introduction

Motivation

- In July, 2012, LHC experiments announced the discovery of a neutral Higgs boson. In the Standard Model this is a manifestation of a Higgs doublet field.

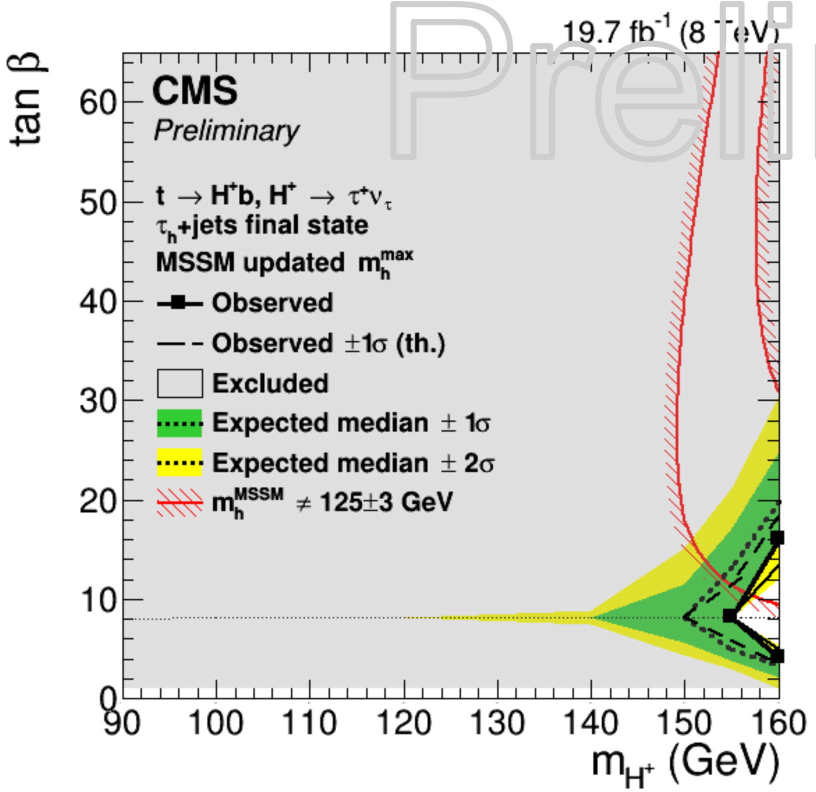
- Extensions of the Standard Model could have charged Higgs bosons in addition to the one that was discovered at the LHC.

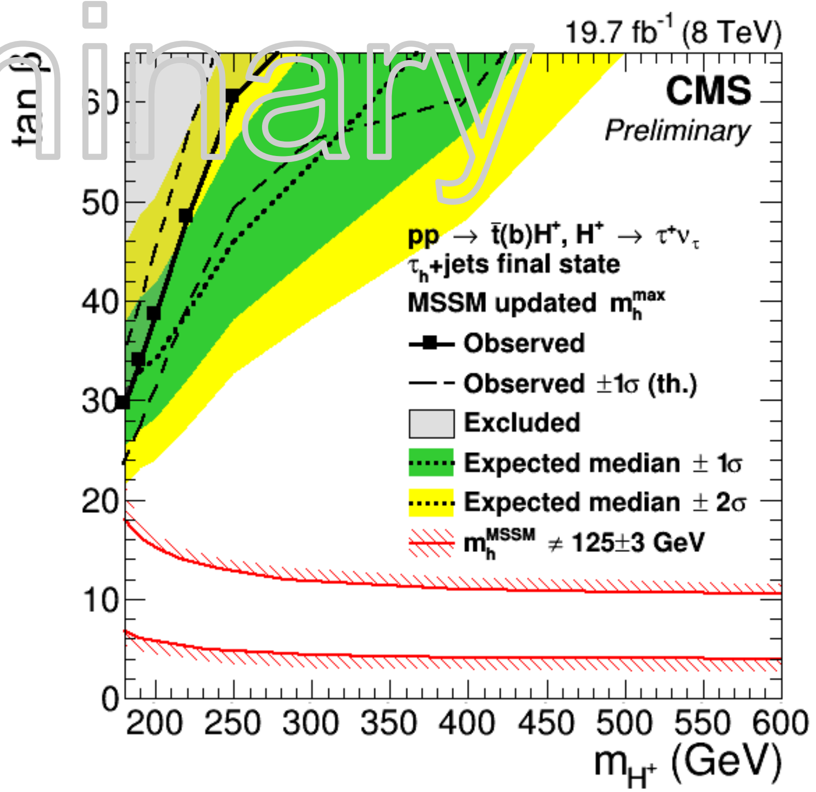
- If charged higgs is light enough , one can search for charged Higgs with e+e-→WH at 250GeV. A tree level coupling of ZWH appears in triplet Higgs models which explain neutrino masses.

(Shinya Kanemura, Kei Yagyu, physical review D 83, 075018(2011))

$$\mathcal{L}_{\text{eff}} = g m_W f_{HWV} H^{\pm} W^{\mp}_{\mu} V^{\mu}$$

Charged Higgs search at the LHC





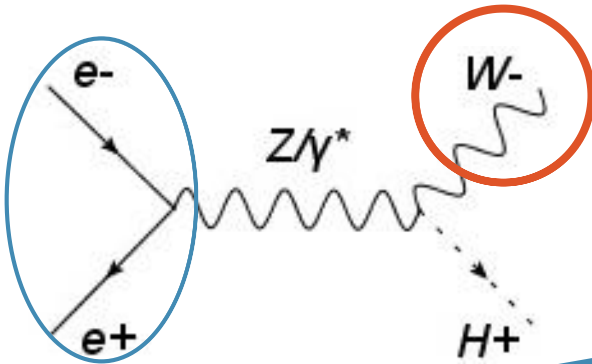
- The CMS experiment searches MSSM charged Higgs at m_h^{max} scenario.
- Charged Higgs mass limit > 150 GeV

Charged Higgs analysis

- In my study, charged Higgs mass is reconstructed from recoil mass against W boson, and measurement accuracy of the mass and cross section are evaluated.
- We want to find Higgs signal inclusively from recoil mass but it is very hard so we first try forced n-jet analysis.

recoil method

get W four momentum Pw, and calculate invariant mass from Pe+e- and Pw.
→ At ILC e+e- collider, initial state energy was known.



four momentum P_W

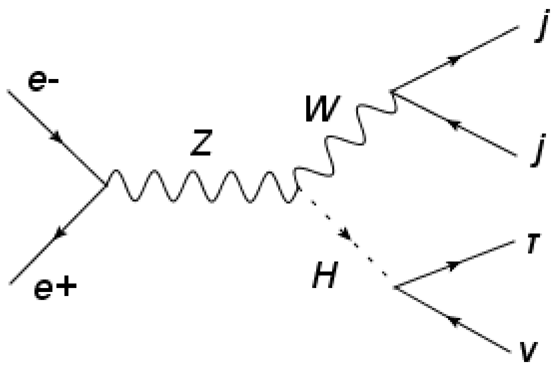
$$m_H^2 = \{P_{e+e-} - P_W\}^2$$

four momentum Pe+e-

Charged Higgs analysis

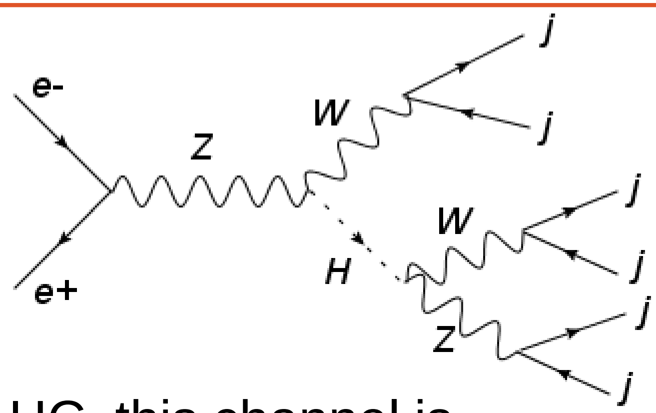
- In my study, charged Higgs mass is reconstructed from recoil mass against W boson, and measurement accuracy of the mass and cross section are evaluated.
- We want to find Higgs signal inclusively from recoil mass but it is very hard so we first try forced n-jet analysis.

3j : H → taunu channel



This channel is easily analyzed.

6j : H → WZ channel



At the LHC, this channel is buried in other hadronic events.

H→taunu channel

Signal and Background

Signal status

- Ecm = 250 GeV
- Integrated luminosity = 250 fb^{-1}
- Polarize

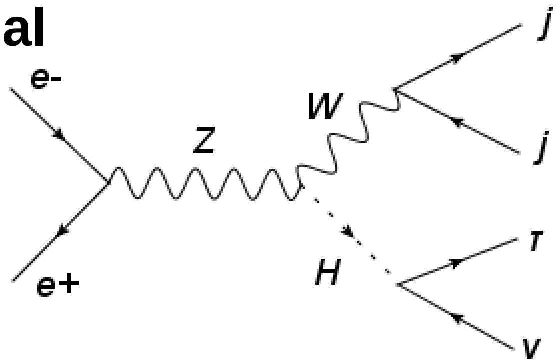
  P(e+, e-) = (-30%, +80%)
- Charged higgs mass

  $m_{H^\pm}$ = 150 GeV
- Detector

  ILD_01_v05 (DBD ver.)
- Form factor

  F_{HWZ}=1, F_{HWA}= 0

Signal



		cross section (fb)	# of event
Sig.	WH → jjτν	107	26k
SM BG	Di-jet	46.2k	12M
	evW →evjj	445	110k
	Zee →jjee	300	74k
	WW →jjlv	758	190k
	WW → jjjj	600	150k
	ZZ →jjll	467	120k
	ZZ → jjjj	402	100k
	ZZorWW → jjjj	565	140k
	Zh → ffh	205	51k

3-jet reconstruction

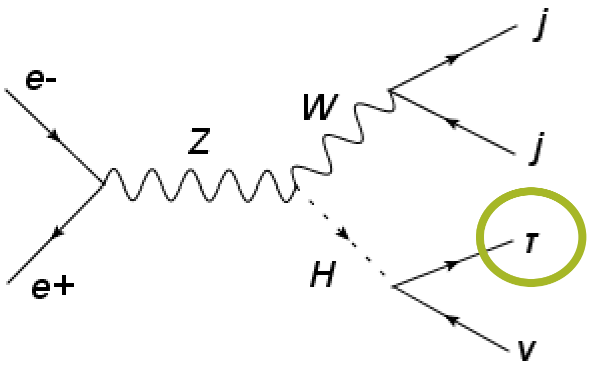
- forced 3-jet analysis using Durham algorithm

- W boson is reconstructed by pairing di-jet which gives the smallest χ^2

$$\chi^2 = \left(\frac{M_j - m_W}{\sigma_W}\right)^2$$

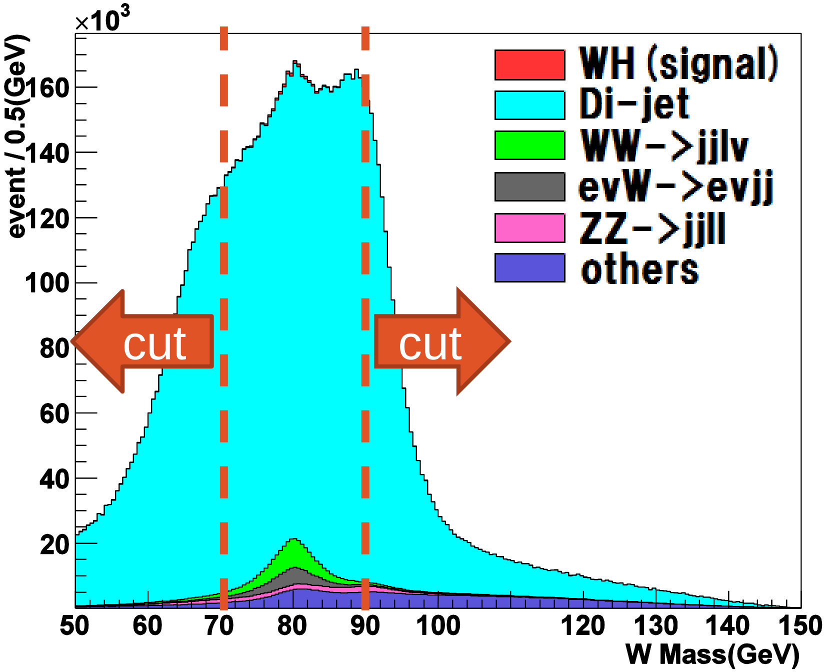
M_j : mass of jet pair
m_W : mass of W(= 80.0GeV)
σ_W : mass resolution(= 4.8GeV)

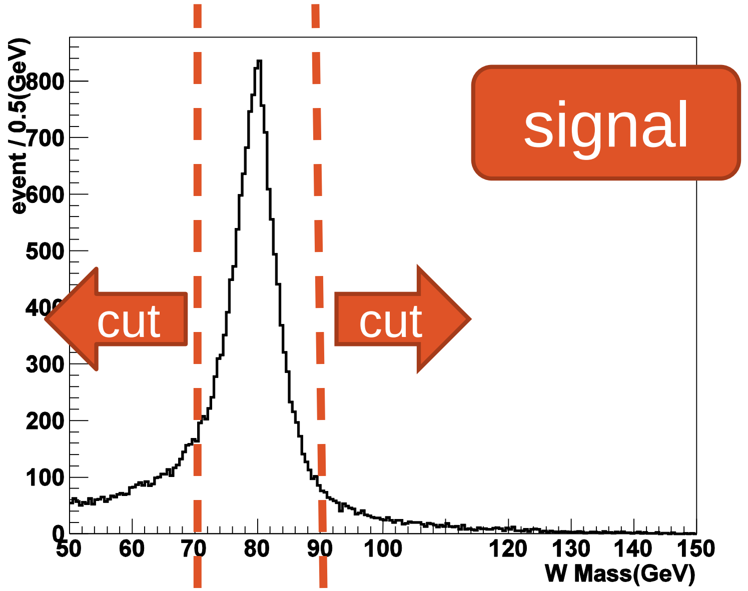
- H mass is calculated by recoil mass method



1st cut (W mass & recoil mass)

70 < Mw < 90 (GeV)





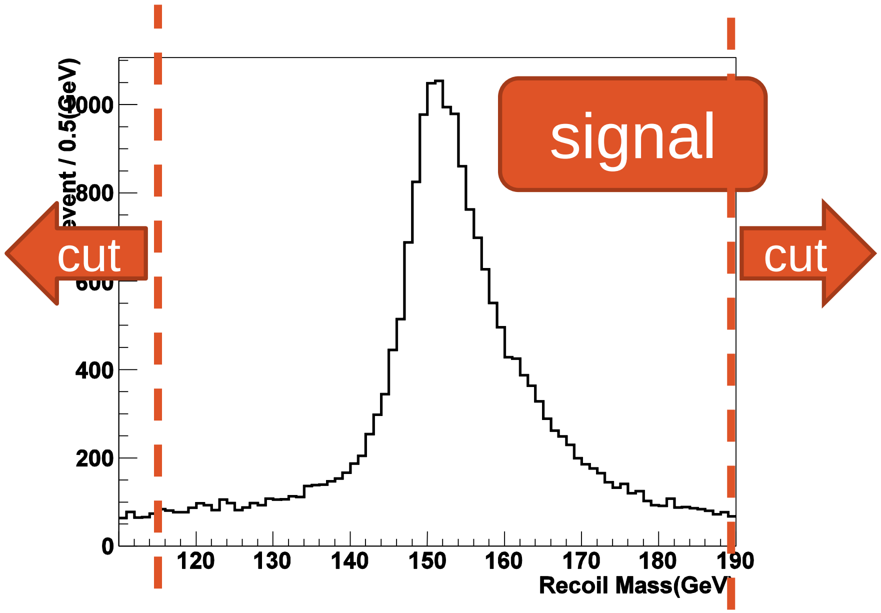
- different event from signal clearly

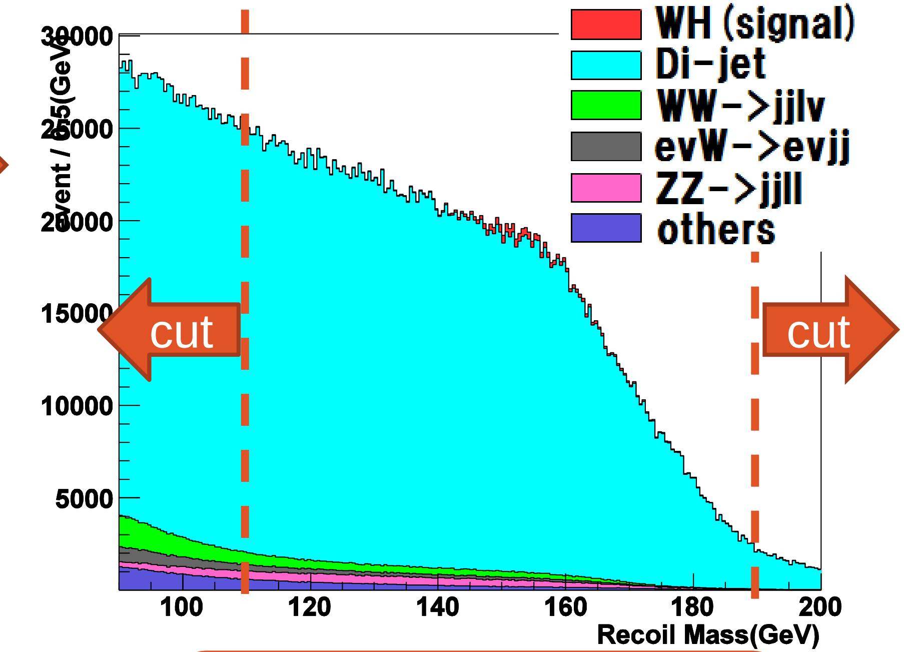
ZZ→jjjj, Di-jet, WW→jjjj, WW→jjlv

others :
Zee →jjee, WW → jjjj
ZZ → jjjj, ZZorWW → jjjj
Zh → ffh

1st cut (W mass & recoil mass)

110 < Mrec < 190 (GeV)





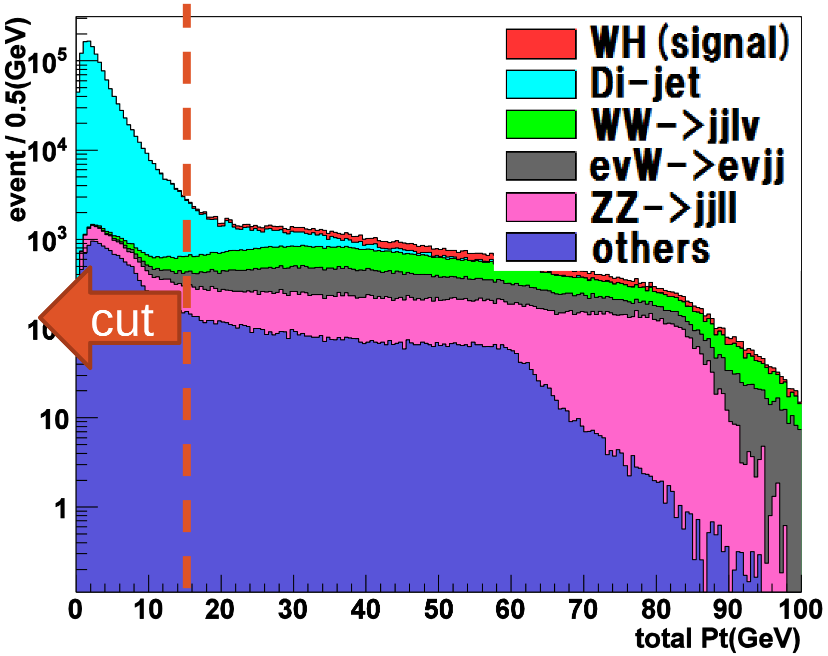
▸ different event from signal clearly
ZZ→jjjj, Di-jet, WW→jjjj, WW→jjlv

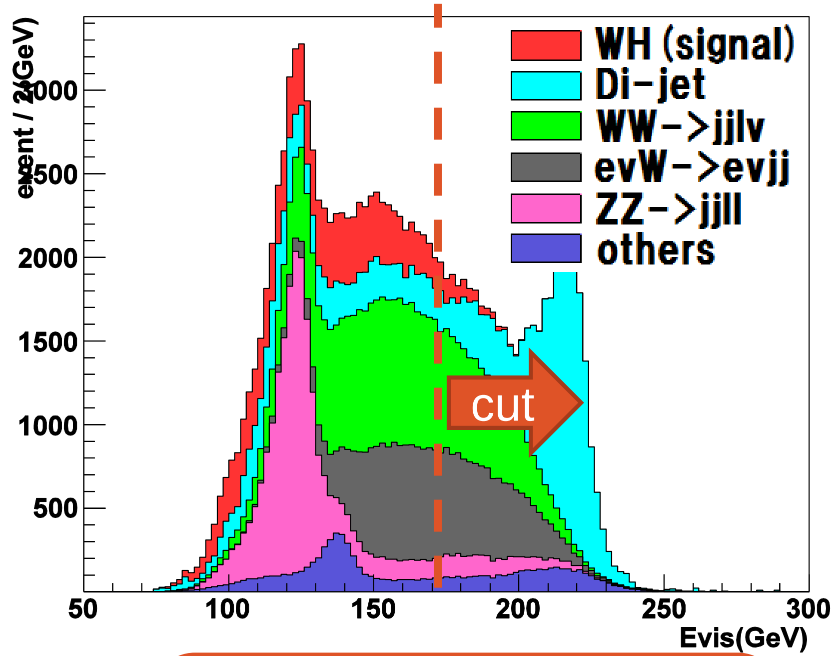
others :
Zee →jjee, WW → jjjj
ZZ → jjjj, ZZorWW → jjjj
Zh → ffh

2^{nd} cut (total Pt) 3^{rd} cut (visible energy)

15 < total Pt (GeV)

Evis < 170 (GeV)





- the event not include neutrinos

Di-jet, ZH→ffh, ZZorWW→jjjj

others :

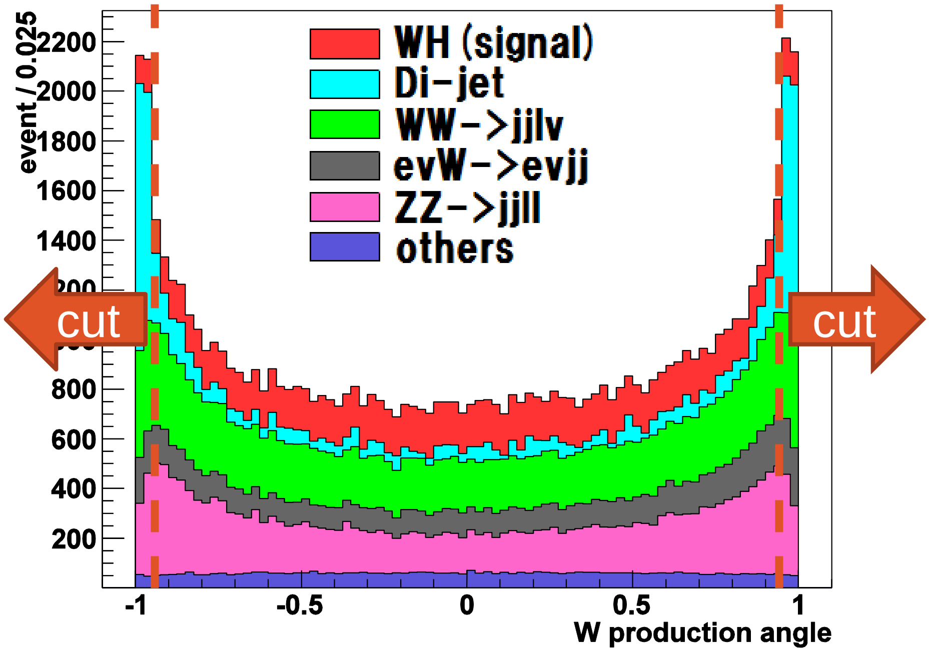
Zee →jjee, WW → jjjj

ZZ → jjjj, ZZorWW → jjjj

Zh → ffh

4th cut (W production angle) & 5th cut

0.95 < | cos(W production angle)|



▸ have peak forward, Di-jet, etc

others :
Zee → jjee, WW → jjjj
ZZ → jjjj, ZZorWW → jjjj
Zh → ffh

140 < Mrec < 160 (GeV)

▸ final selection, Z event,

Cut table

	WH	Di-jet	evW→evjj	WW→jjlv	ZZ→jjll	others
no cut	26803	11553700	111356	189596	116797	518315
mw&mrec	15809	1304890	23786	35738	28599	22220
pt	14627	30613	21994	32379	20977	8127
Evis	13417	9447	11427	21227	18535	4710
Wangle	12876	5368	10427	19448	17136	4506
mrec	9590	2048	3599	6352	4557	1983

S/N=0.00215→0.517

efficiency = 35.8%

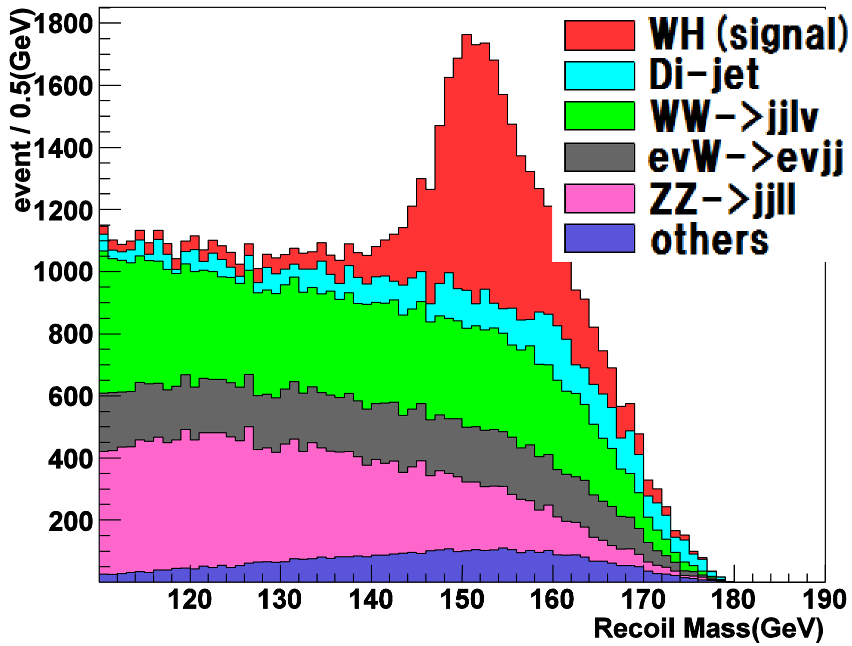
significance = 57.18 → statistic error **1.75%**

(E_{cm}250 GeV, 250fb^{-1})

$$Significance = \frac{N_{signal}}{\sqrt{N_{signal}+N_{bg}}}$$

others :
- Zee →jjee
- WW → jjjj
- ZZ → jjjj
- ZZorWW → jjjj
- Zh → ffh

Recoil mass plot



signal definition

70 < Mw < 90 (GeV)
140 < Mrec < 160 (GeV)
15 < Pt (GeV)
170 < Evis (GeV)
0.95 < |cos(w production angle)|

	WH	Di-jet	evW→evjj	WW→jjlv	ZZ→jjll	others
no cut	26803	11553700	111356	189596	116797	518315
after cut	9590	2048	3599	6352	4557	1983

significance = 57.18 → statistic error **1.75%**(E_{cm}250 GeV, 250fb^{-1})

Less model dependent analysis

- Previous analysis is model dependent.
  - It was considered Higgs goes to taunu; including Evis and Pt cut .

→ We should do less model dependent analysis.

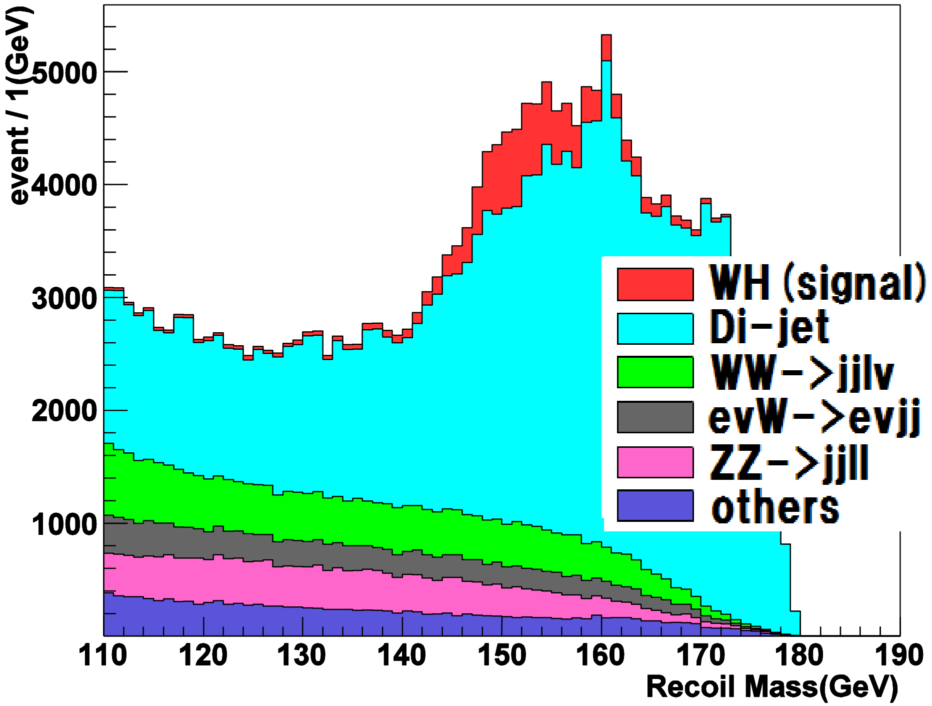
cut parameter

W mass
recoil mass
W production angle

visible energy
total Pt

- use only these three parameters for cut and optimize each cut values again.

Less model dependent analysis



signal definition

70 < Mw < 90 (GeV)

140 < Mrec < 160 (GeV)

0.85 < |cos(w production angle)|

- There is a peak from di-jet around 160GeV.
- It is the reason that candidate W which almost satisfies E_{CM}-M_{W} ~ 170GeV.
  If E_{CM} is larger, we can separate signal and this peak.

efficiency = 38.2%

significance = 19.44 → statistical error **5.14%**

(E_{cm}=250GeV, 250fb^{-1})

H→WZ channel

Signal and Background

Signal status

- Ecm = 250 GeV
- Integrated luminosity = 250 fb^{-1}
- Polarize

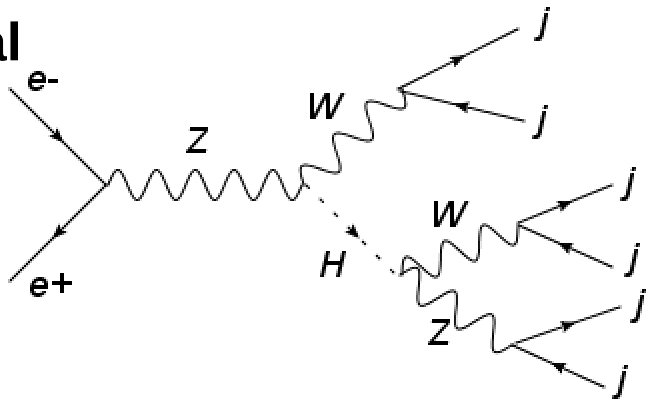
  P(e+, e-) = (+30%, -80%)
- Charged higgs mass

  $m_{H^\pm}$ = 150 GeV
- Detector simulator

  ILD_01_v05 (DBD ver.)
- Form factor

  F_{HWZ}=1, F_{HWA}= 0

Signal



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	ZZ → jjjj	402	100k
	ZZorWW → jjjj	565	140k
	Zh → ffh	205	51k
	WWZ	41.6	10k

6j reconstruction

- forced6-jet analysis using Durham algorithm

- selecting the jet pairs so that χ_1^2 is minimized

$$\chi_1^2 = (p_{j1}^{pair1} + p_{j2}^{pair1})^2 + (p_{j1}^{pair2} + p_{j2}^{pair2})^2 + (p_{j1}^{pair3} + p_{j2}^{pair3})^2$$

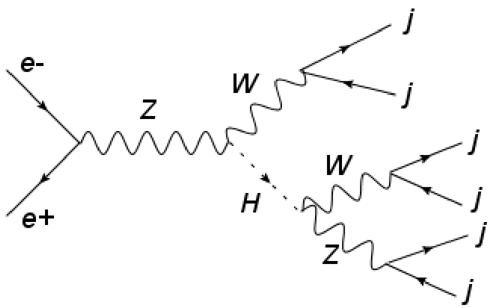
p_j : 3 vector momentum

- find prompt W by minimizing χ_2^2

$$\chi_2^2 = (\frac{M_{pair3} - m_W}{\sigma_W})^2$$

m_W : mass of W(= 80.0GeV)
m_H : mass of H(= 150GeV)
σ_W : mass resolution(= 5.5GeV)
σ_H : mass resolution(= 15GeV)

- get W mass and calculate recoil mass



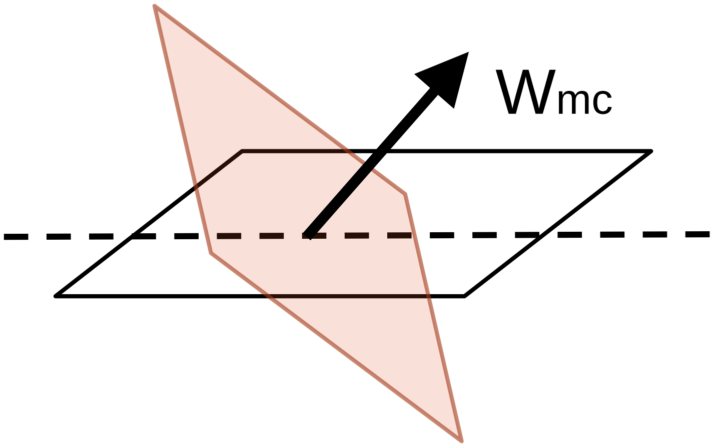
W mass and recoil mass

- Complex hadronic final states
  lower kinematic energy → large jet size
  →higher confusion between jets
- current selection needs improvement.
- Analysis at 350 GeV has easier jet reconstruction, clear separation between W and H thanks to larger boost.

→ χ^2 definition is needed to optimize,
- check the MC particles and that angles are useful for χ^2
- use 3 type χ^2 definitions and get plots

MC particle

- Checking whether the daughters of W (not form H) are same hemisphere with it.



# of daughter in same side with Wmc	**1** (2 daughters are not in same side)			**2** (2 daughters are in same side)		
particles in same side with Wmc	2	3	4	3	4	5
other side with Wmc	4	3	2	3	2	1
# of event	880	3703	883	1962	8192	1999
%	5	21	5	11	46	11

When 2 daughters are in same side, there are also other particles.

χ^2

- use these 3 type χ^2;

$$\chi^2 = \sum_{pair1,2,3} \left(\frac{|p_{j1}| + |p_{j2}|}{\sigma_p}\right)^2 + \left(\frac{M_{pair3} - m_W}{\sigma_W}\right)^2$$

σ_W : mass resolution(= 5.5GeV)
σ_Z : mass resolution(= 4.8GeV)
σ_p : momentum resolution(= 4GeV)
$\sigma_{cos\theta}$: cosθ resolution(= 0.01GeV)
(guess)

$$\chi^2 = \sum_{pair1,2,3} \left(\frac{|p_{j1}| - |p_{j2}|}{\sigma_p}\right)^2 + \sum_{pair1,2,3} \left(\frac{cos\theta_{j1j2} + 1}{\sigma_{cos\theta}}\right)^2 + \left(\frac{M_{pair3} - m_W}{\sigma_W}\right)^2$$

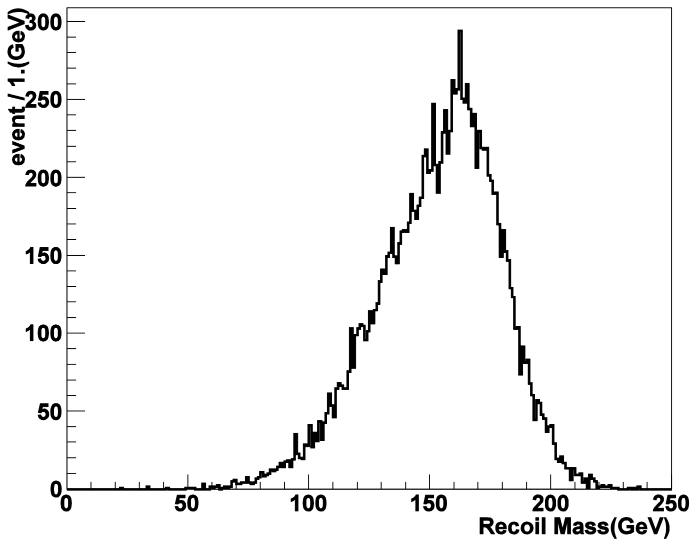
$$\chi_1^2 = \left(\frac{M_{pair1} - m_Z}{\sigma_Z}\right)^2 + \left(\frac{M_{pair3} - m_W}{\sigma_W}\right)^2$$

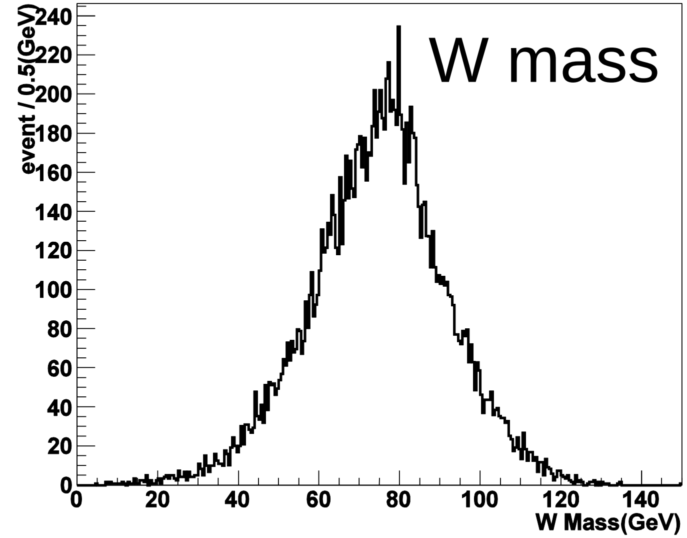
$$\chi_2^2 = \left(\frac{M_{pair2} - m_W}{\sigma_W}\right)^2 + \left(\frac{M_{pair3} - m_W}{\sigma_W}\right)^2$$

- take smaller one

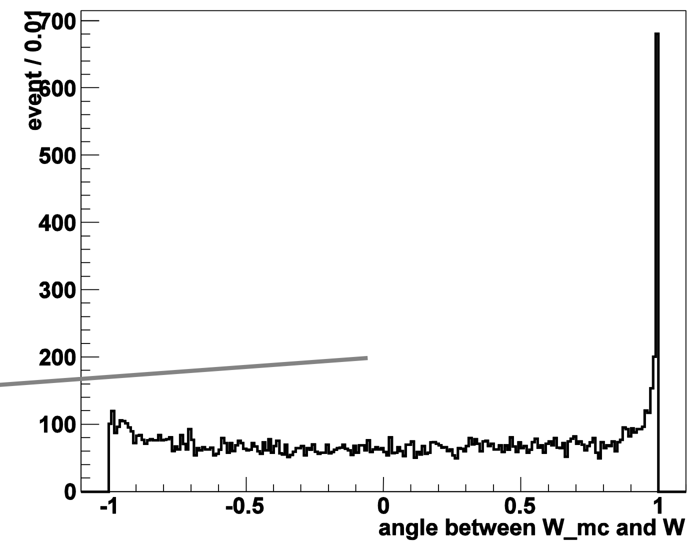
$$\chi^2 = \sum_{pair1,2,3} \left(\frac{|p_{j1}| + |p_{j2}|}{\sigma_p}\right)^2 + \left(\frac{M_{pair3} - m_W}{\sigma_W}\right)^2$$

recoil mass





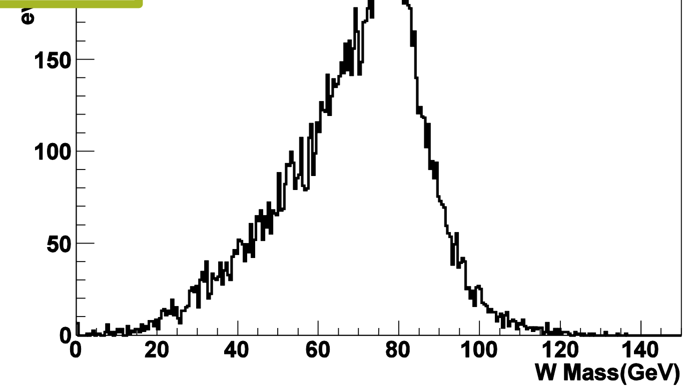
angle between W and Wmc



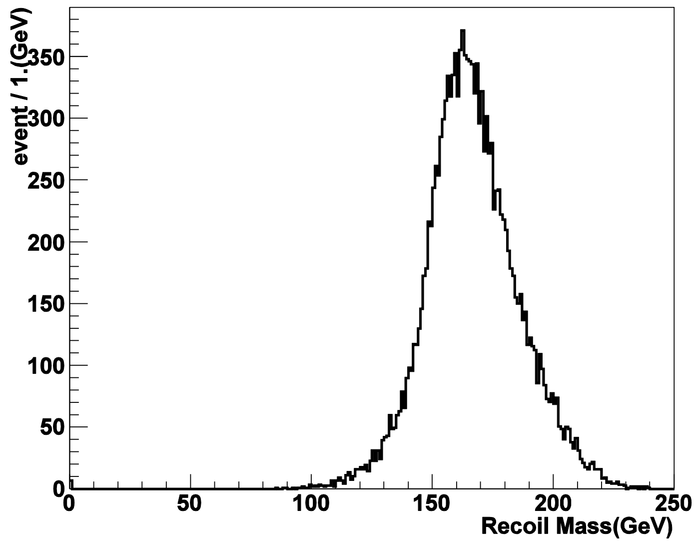
cos_theta > 0.9 : 2592
cos_theta < 0.9 : 23756

$$\chi^2 = \sum_{pair1,2,3} \left(\frac{|p_{j1}| - |p_{j2}|}{\sigma_p}\right)^2 + \sum_{pair1,2,3} \left(\frac{cos\theta_{j1j2} + 1}{\sigma_{cos\theta}}\right)^2 + \left(\frac{M_{pair3} - m_W}{\sigma_W}\right)^2$$

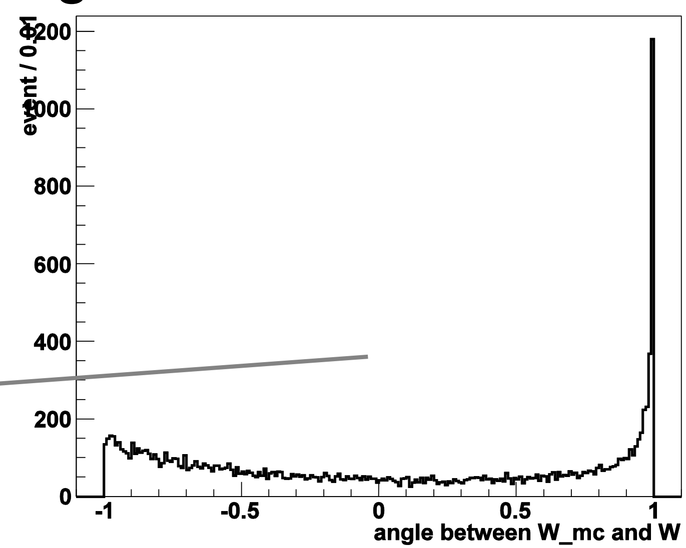
W mass



recoil mass



angle between W and W_{mc}

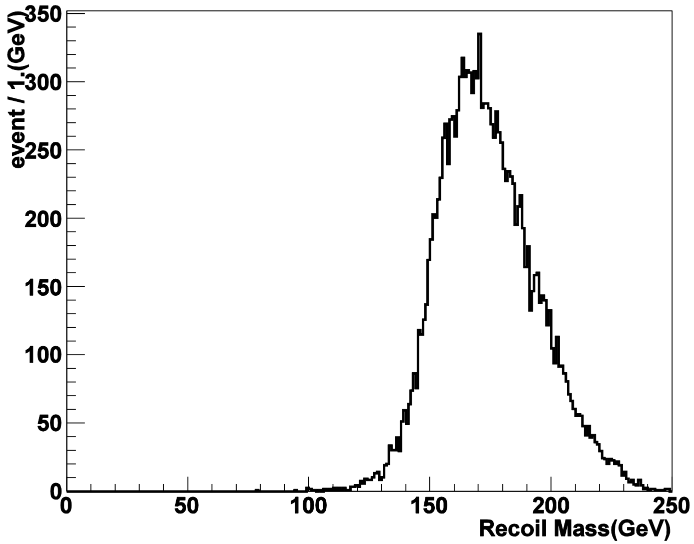


cos_theta > 0.9 : 5557
cos_theta < 0.9 : 20793

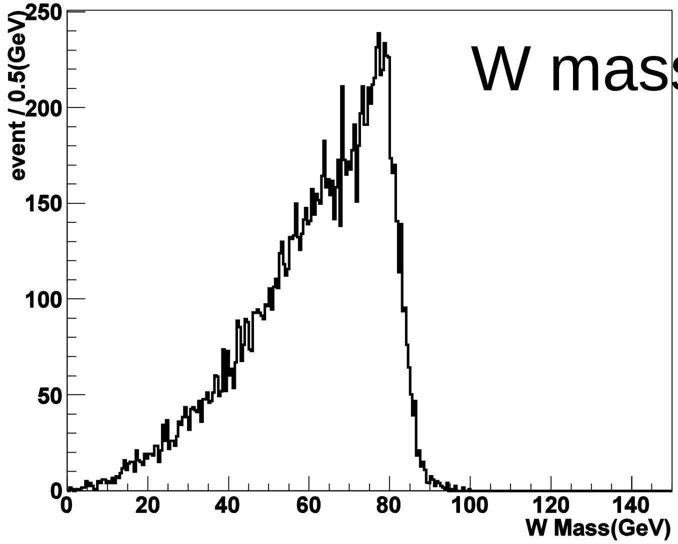
$$\chi_1^2 = \left(\frac{M_{pair1} - m_Z}{\sigma_Z}\right)^2 + \left(\frac{M_{pair3} - m_W}{\sigma_W}\right)^2$$

$$\chi_2^2 = \left(\frac{M_{pair2} - m_W}{\sigma_W}\right)^2 + \left(\frac{M_{pair3} - m_W}{\sigma_W}\right)^2$$

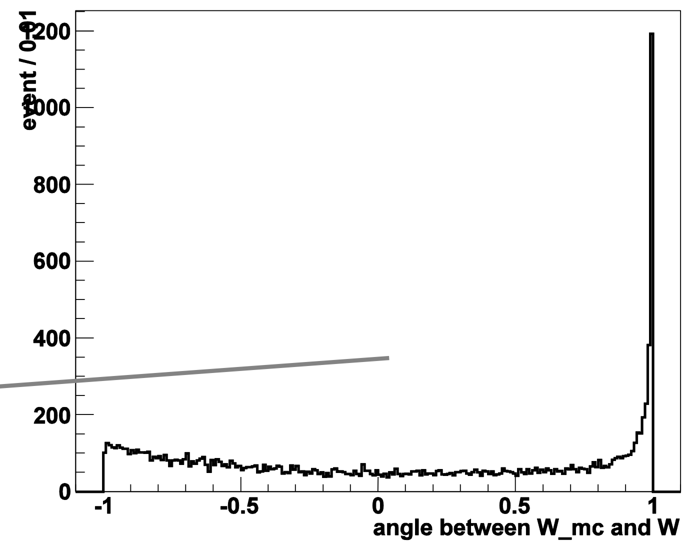
recoil mass



W mass



angle between W and Wmc



cos_theta > 0.9 : 6766
cos_theta < 0.9 : 19582

Summary and plan

Summary

Charged higgs search at ILC 250 GeV

- 3j analysis …H→taunu channel
  - integrated luminosity = 250 fb-1, mh = 150GeV, form factor FHWZ = 1
  - we can measure this signal with statistical error **1.75%**
  - less model dependent analysis : statistical error **5.14%**
- 6j analysis …H→WZ channel
  - we still optimizing this selection.

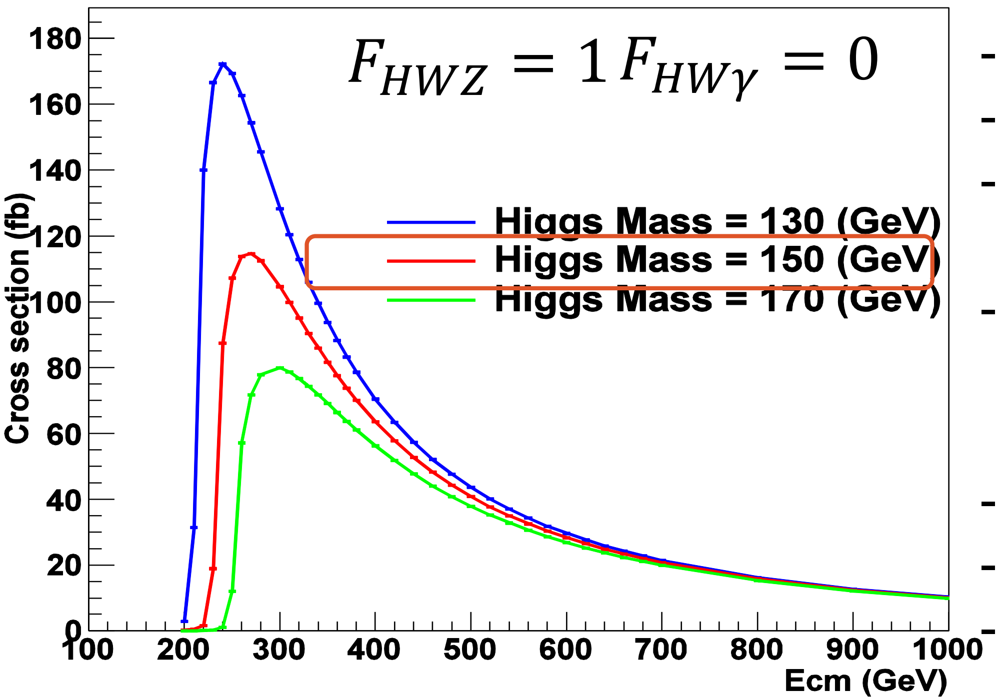
If E_{CM} is larger, we can separate signal and this peak.

Plan

- 3j analysis…H→taunu
  - mh vs Fhwz limit
- 6j analysis …H→WZ channel
  - optimization of jet pairing and boson selection **on going**
  - WWZ analysis at Ecm 350 GeV

Backup

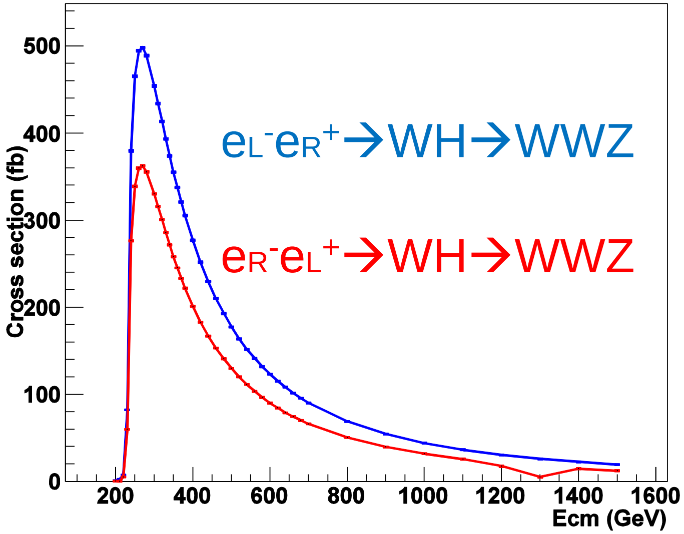
Total cross section of e+e-→WH→jjtaunu channel



- Ecm = 250 GeV
- Integrated luminosity = 250 fb^{-1}
- Polarize : P(e+, e-) = (-30%, +80%)
- Charged higgs mass $m_{H^\pm}$ = 150 GeV

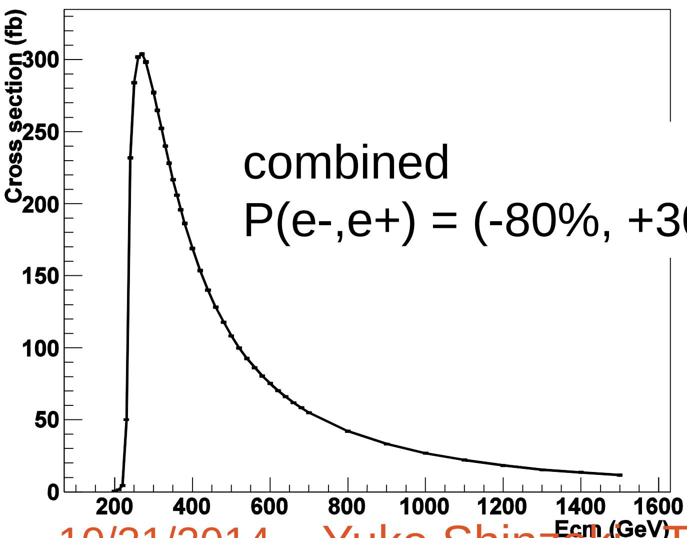
- Form factor : F_{HWZ}=1, F_{HWA}= 0
- beamstrahlung = 0
- bremsstrahlung = 0

Total cross section of e+e-→WH→WWZ channel



- Charged higgs mass = 150 GeV
- Ecm = 200 - 1500 GeV
- beamstrahlung = 0
- bremsstrahlung = 0
- Form factor : F_{HWZ}=1, F_{HWA}= 0

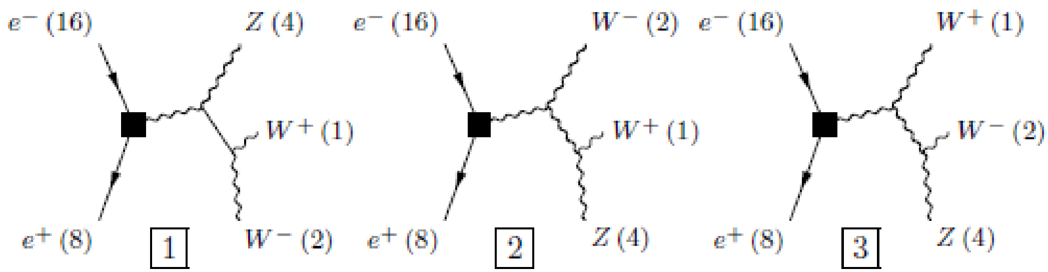
- cross section = 284.1 (fb)
 at Ecm = 250 GeV
 P(e-,e+) = (-80%, +30%)



WWZ standard model BG

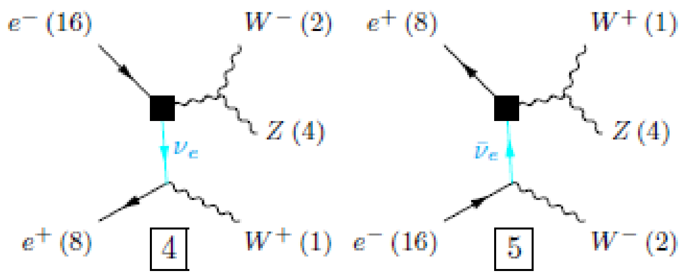
Grove 1

Multiplicity: 3
Resonances: 0
Log-enhanced: 0
Off-shell: 2
t-channel: 0



Grove 2

Multiplicity: 3
Resonances: 0
Log-enhanced: 1
Off-shell: 1
t-channel: 1



Grove 3

Multiplicity: 3
Resonances: 0
Log-enhanced: 1
Off-shell: 1
t-channel: 1