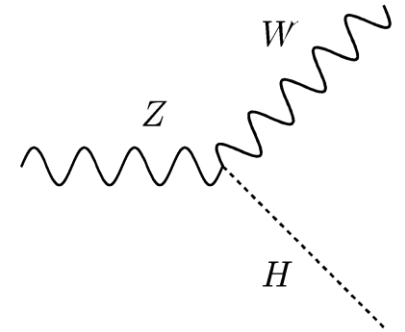
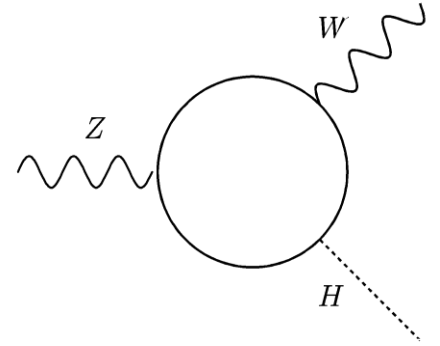


Search for Charged Higgs Production Associated with W boson with the ILD at the ILC

Akimasa Ishikawa for Yuko Shinzaki
(Tohoku University)

Introduction

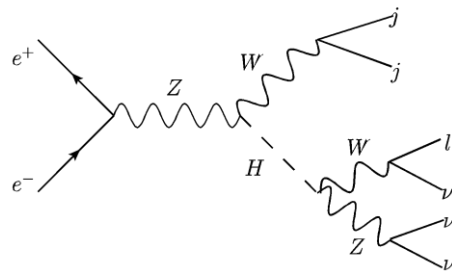
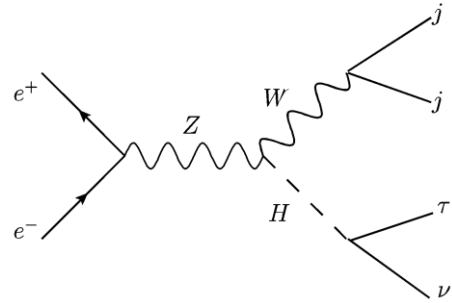
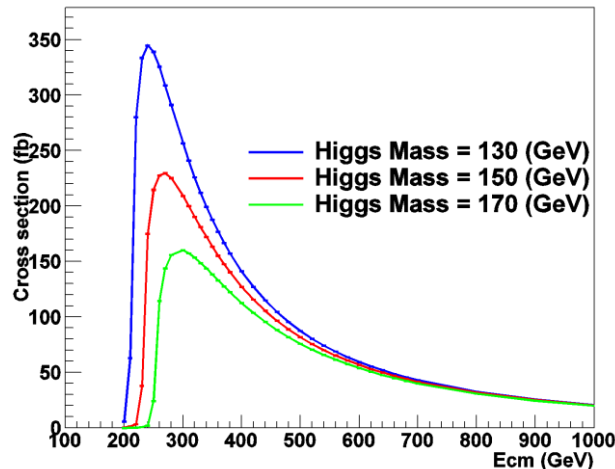
- Charged Higgs bosons can exist in the extended Higgs models.
 - 2HDM
 - Higgs Triplet models
 - Explains neutrino mass
 - Georgi-Machacek model
 - $Y=0$ and $Y=1$ triplet Higgs fields
 - $\rho = 1$
- Which can have HWV coupling
 - One loop in 2HDM
 - Tree level in triplet models
- Effective Lagrangian can be expressed in terms of form factor f_{HWV} which can be constrained from this measurement and can be used for model discrimination



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

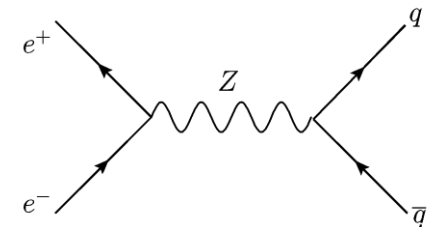
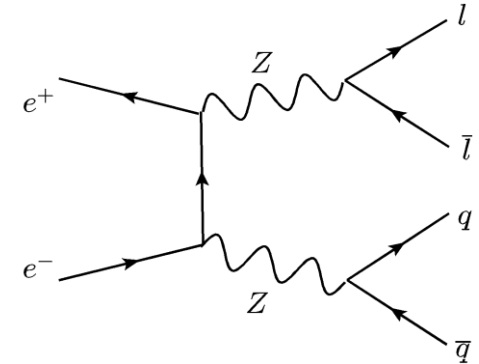
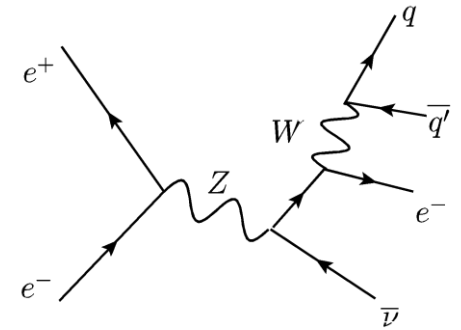
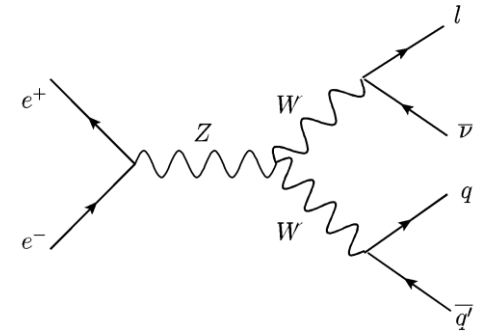
Condition for the Simulation

- Full Simulation
- Process : $e^+e^- \rightarrow WH$
- $f_{HWZ} = 1$ and $f_{HW\gamma} = 0$
 - Only couples to Z
- Decay : $H \rightarrow \tau\nu$ or $H \rightarrow W^{(*)}Z^{(*)} \rightarrow l\nu\nu\nu$
- $E_{cm} = 250\text{GeV}$
- $M_{H^+} = 150\text{GeV}$
 - Pair production very suppressed
 - Almost maximal cross sections
- $P(e^-, e^+) = (+0.8, - 0.3)$
 - Right handed to suppress WW backgrounds



Dominant Backgrounds

- Irreducible
 - $WW \rightarrow jjlv$
 - $evW \rightarrow enjj$
- Reducible
 - $ZZ \rightarrow jjll$
- Large Cross section
 - Di-jet



Cross Section

	Process	Cross section (fb)	Events (k)	
Sig①	WH (H→ $\tau\nu$)	214	54	
Sig②	WH (H→WZ)	214	54	
SM BG	Di-jet	46200	12000	} Dominant background
	evW → evjj	445	110	
	WW → jjlv	758	190	
	WW → jjjj	600	150	
	Zee → jjee	300	74	
	ZZ → jjll	467	120	
	ZZ → jjjj	402	100	
	ZZWWmix → jjjj	565	140	
	Zh → ffh	205	51	

Reconstruction

- Forced three jet analysis with Durham
 - Final states for both channels are di-jet and lepton with missing energy

$$Y_{ij} = \frac{2\min(E_i, E_j)(1 - \cos \theta_{ij})}{E_{vis}^2}$$

- W boson mass with χ^2

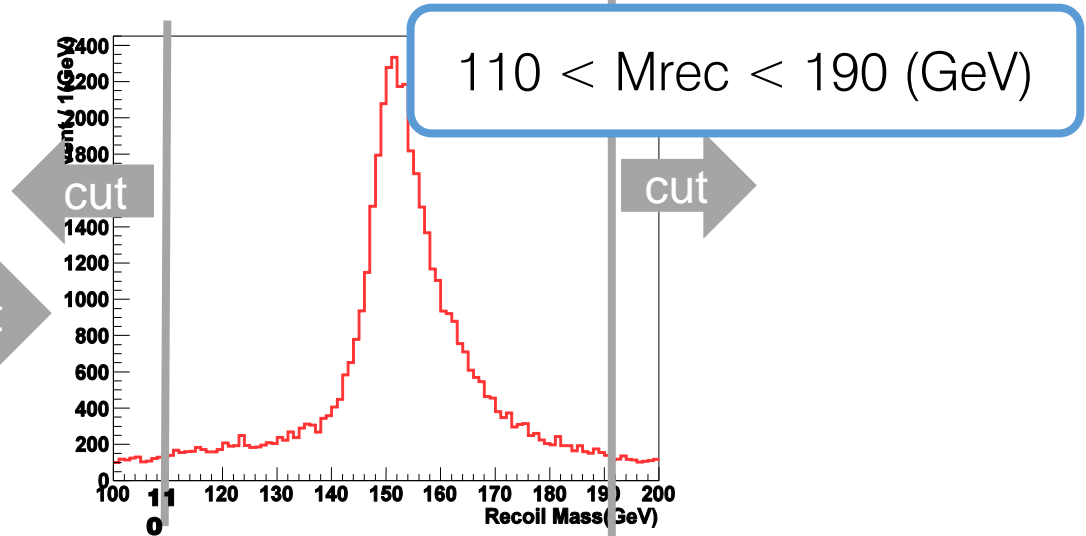
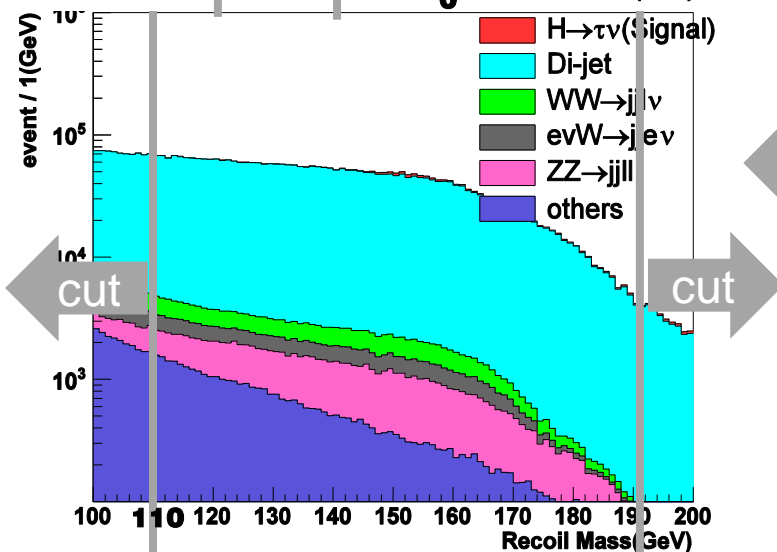
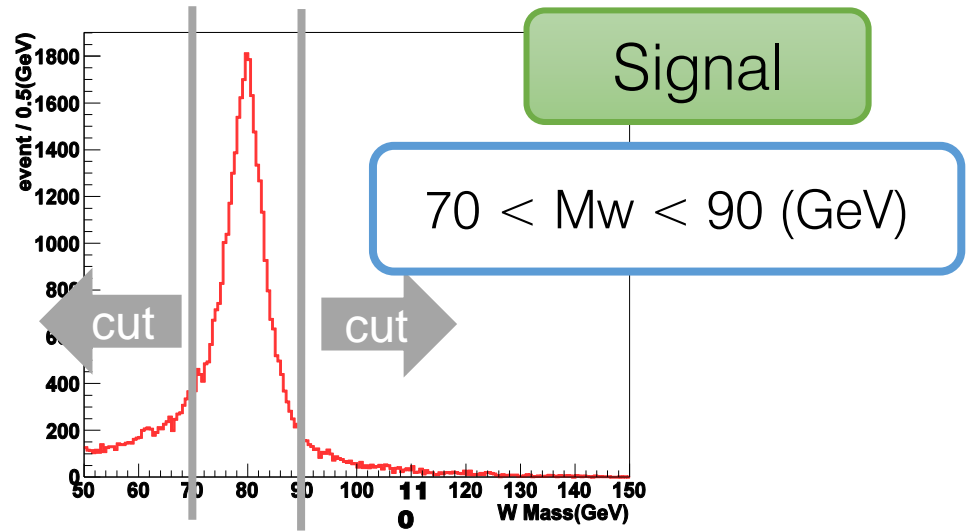
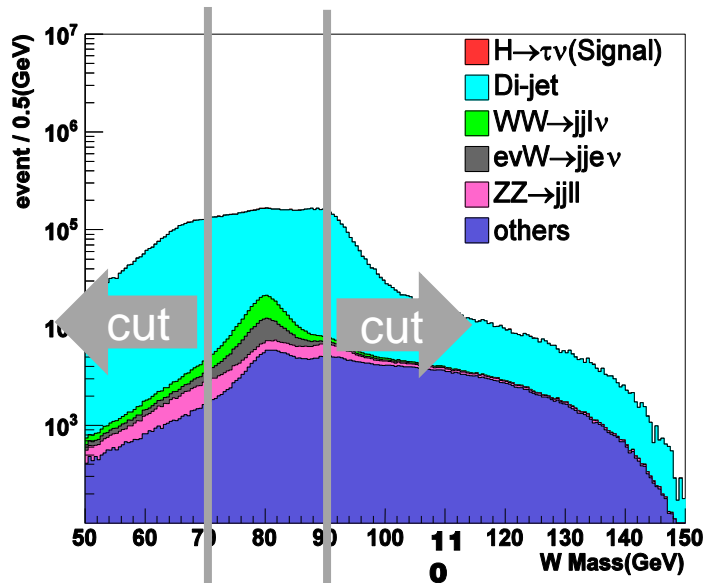
$$\chi^2 = \left(\frac{M_{jetpair} - m_W}{\sigma_W} \right)^2$$

- Recoil mass

$$m_H^2 = (P_{Ecm} - P_W)^2$$

$$H \rightarrow \tau\nu$$

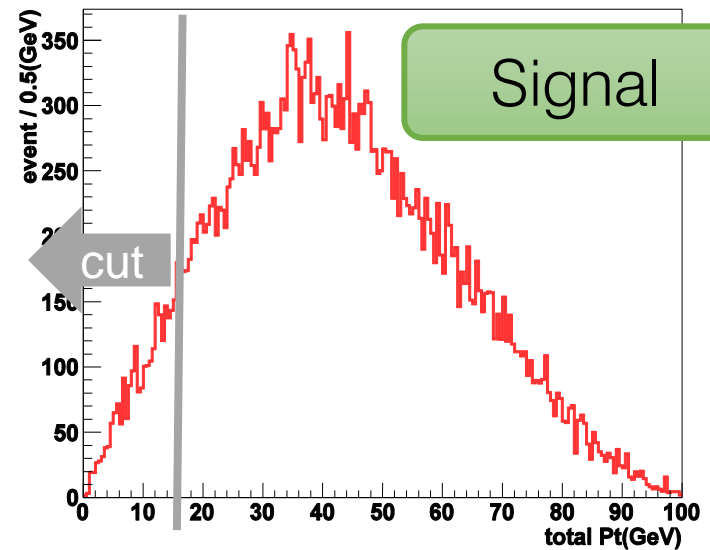
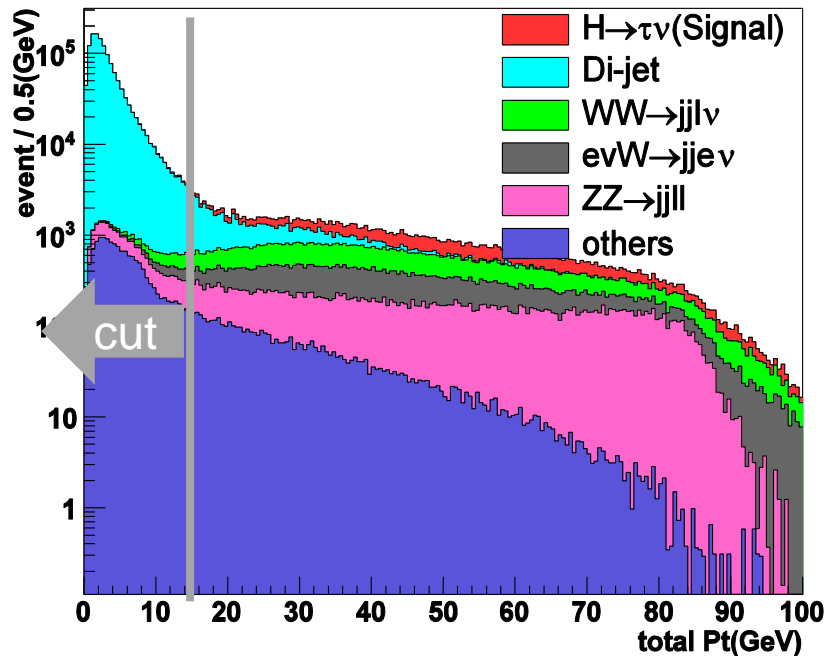
W mass and Recoil Mass



Transverse Momentum

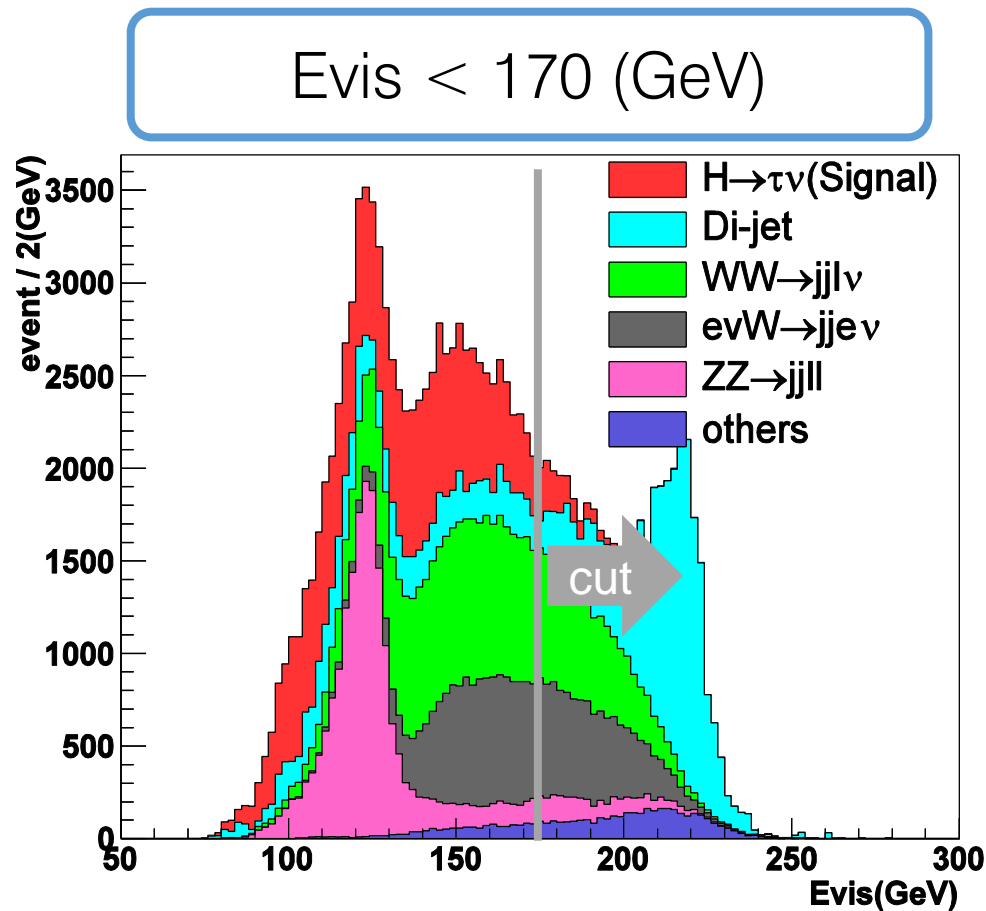
- Suppress neutrinoless processes

$15 < \text{total Pt (GeV)}$



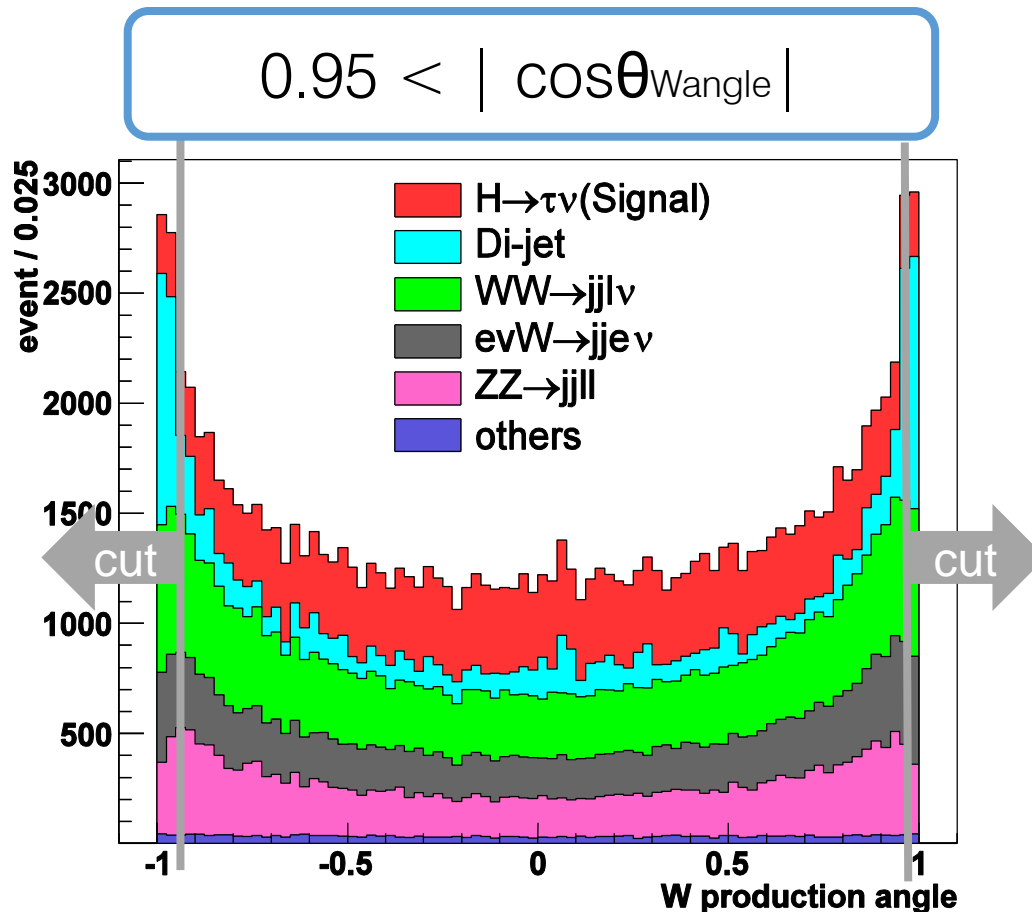
Visible Energy

- Suppress neutrinoless processes



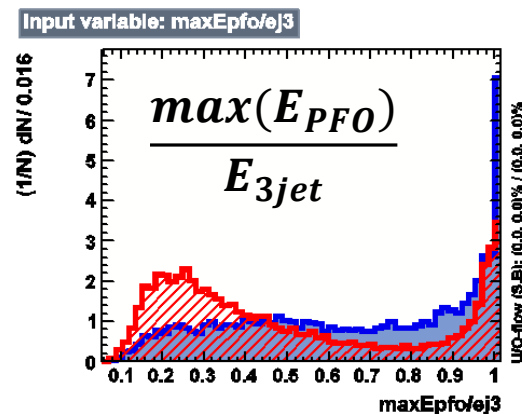
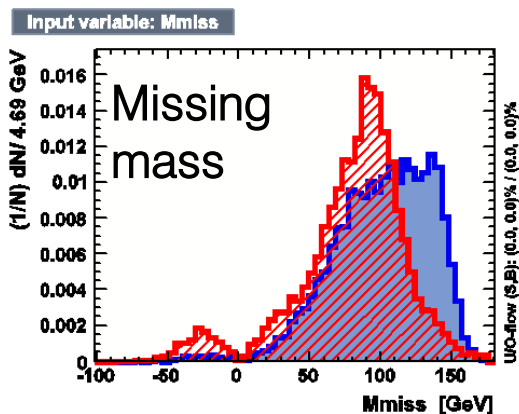
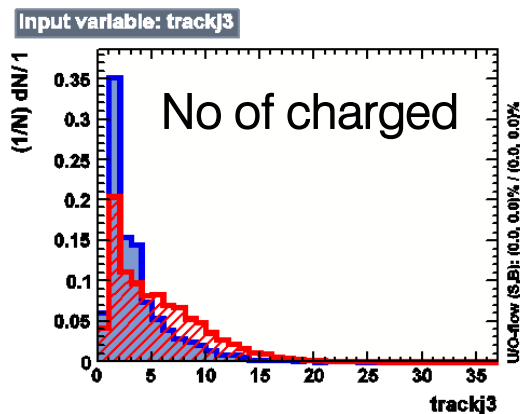
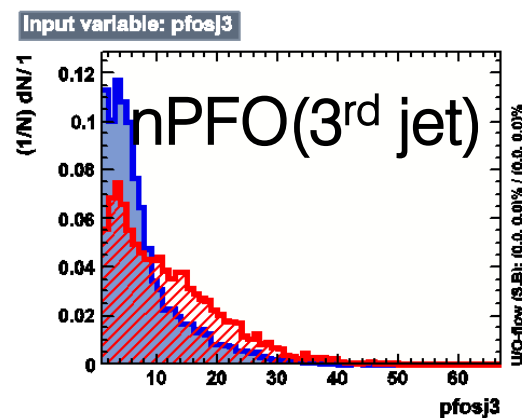
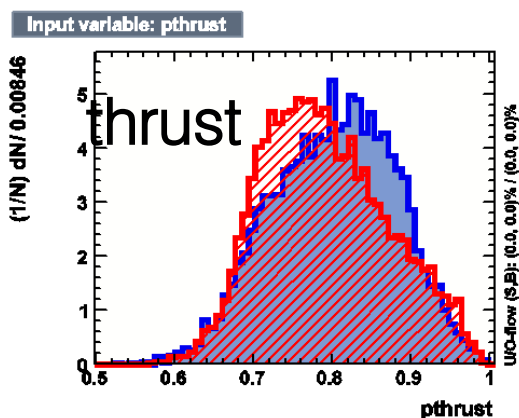
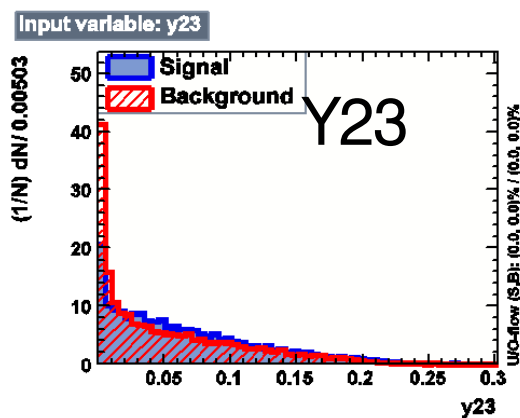
Production angle of W boson

- Suppress dijet



BDT inputs

- Input variables
 - Y23, thrust, nPFO, No of charged, Missing mass, $\max(E_{\text{PFO}})/E_{3\text{jet}}$



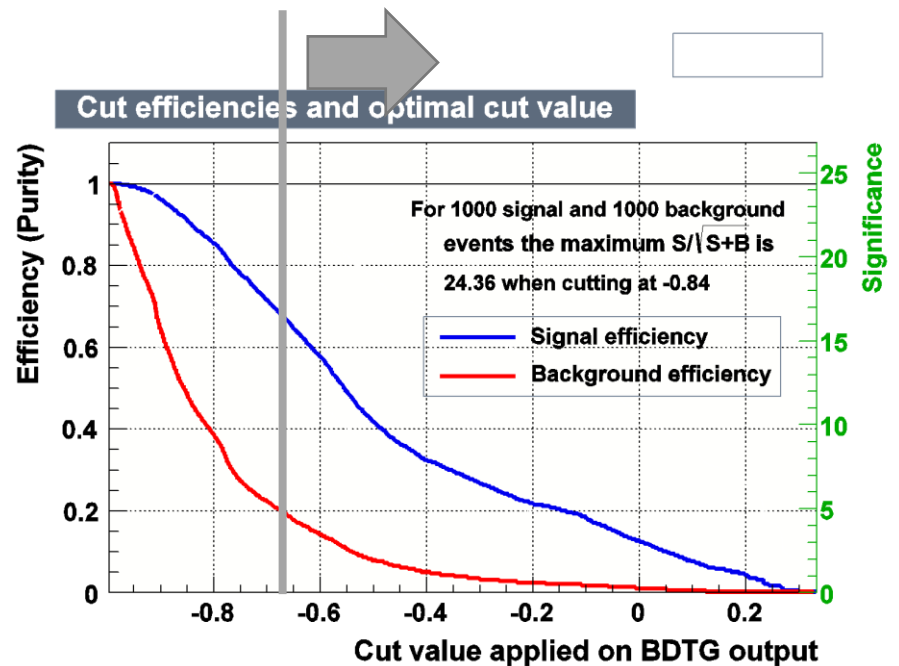
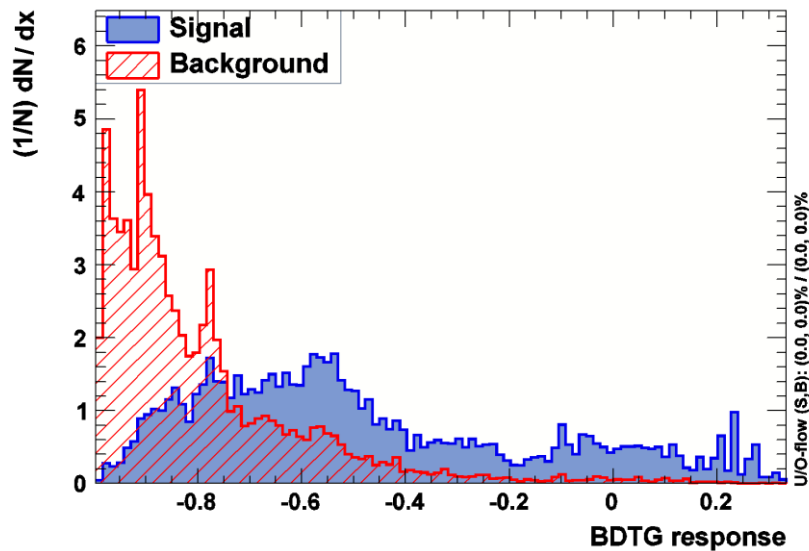
青
: 信号

赤
: 背景

BDT output

- Keeping 70% signal while reducing 80% backgrounds

$$-0.675 < \text{BDTG}$$

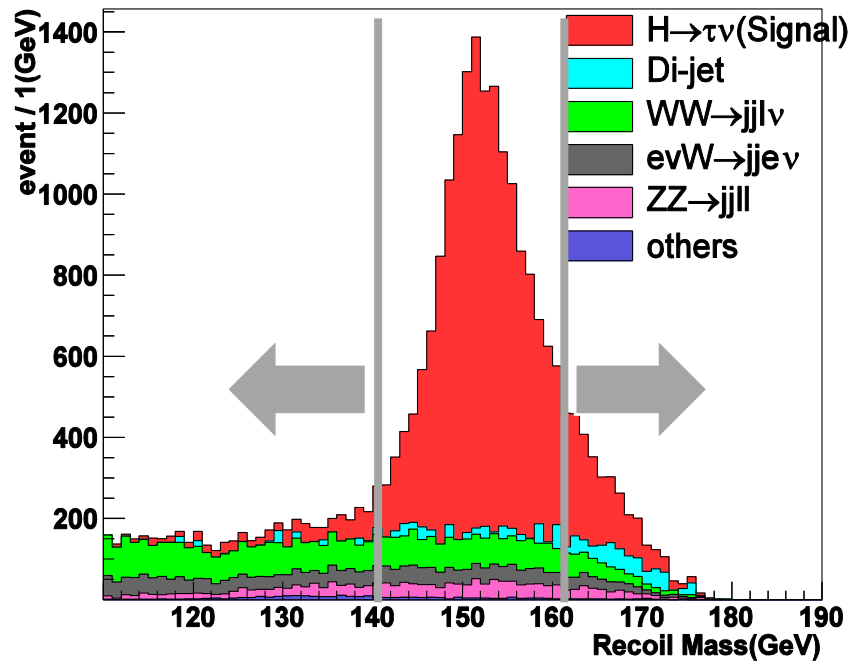


Cut-flow Table for $H^+ \rightarrow \tau \nu$

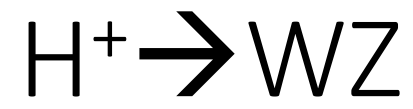
	WH($\tau\nu$)	Di-jet	$e\nu W \rightarrow e\nu jj$	$WW \rightarrow jjl\nu$	$ZZ \rightarrow jjll$	others
no cut	53618	11553700	111356	189596	116797	518315
mw&mrec	31958	1307060	23795	35671	28561	18920
pt	29624	31281	22005	32323	21021	4873
Evis	27255	9375	11437	21191	18580	1219
Wangle	26177	5421	10423	19408	17205	1147
BDTG	17961	1459	2131	5025	1834	230

Recoil mass distribution for $H^+ \rightarrow \tau \nu$

- Efficiency 26.6%
- Significance $S=105$



	WH($\tau\nu$)	Di-jet	evW \rightarrow evjj	WW \rightarrow jjlv	ZZ \rightarrow jjll	others
no cut	53618	11553700	111356	189596	116797	518315
after cut	14276	581	837	1729	863	95

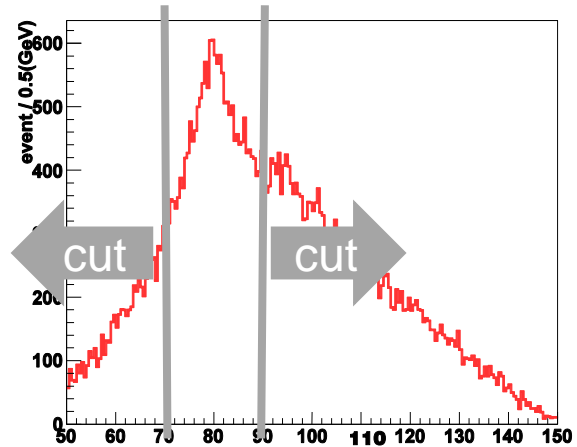
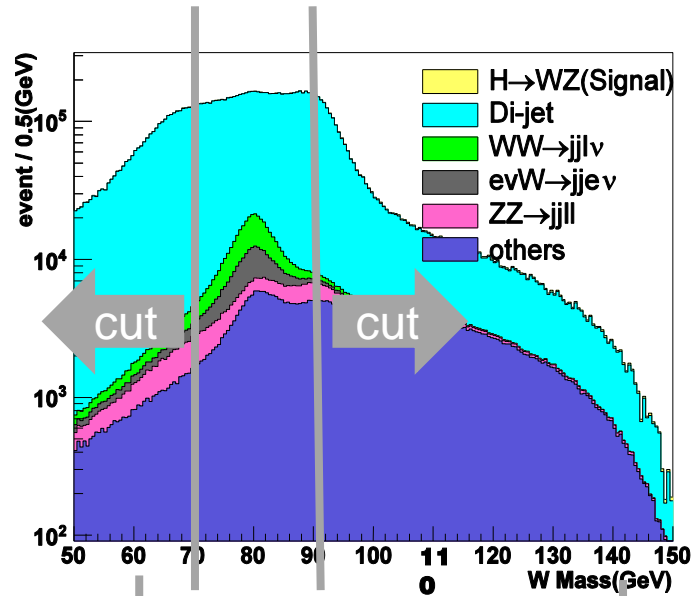


Process

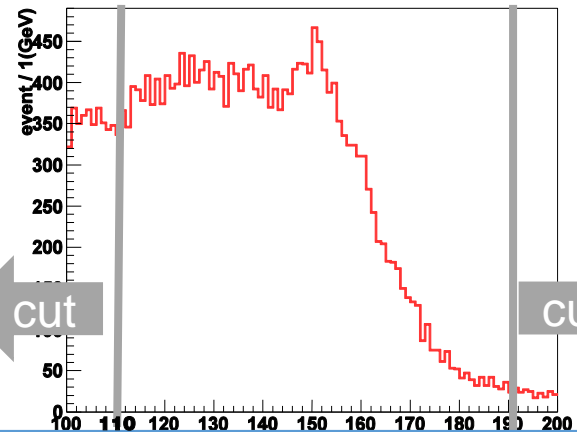
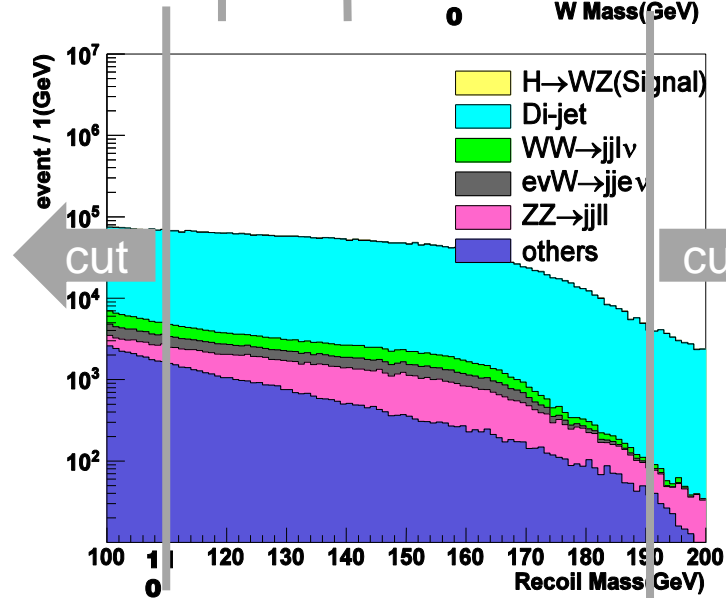
- Final states used is $H \rightarrow WZ \rightarrow jjlvvv$
 - The BF is about 6%
 - Not major decay process but easy to extend from $H \rightarrow \tau\nu$

	$Z \rightarrow qq$ ($\sim 70\%$)	$Z \rightarrow ll$ ($\sim 10\%$)	$Z \rightarrow \nu\nu$ ($\sim 20\%$)
$W \rightarrow qq$ ($\sim 70\%$)	49%	7%	14%
$W \rightarrow l\nu$ ($\sim 30\%$)	21%	3%	6%

W mass and Recoil Mass



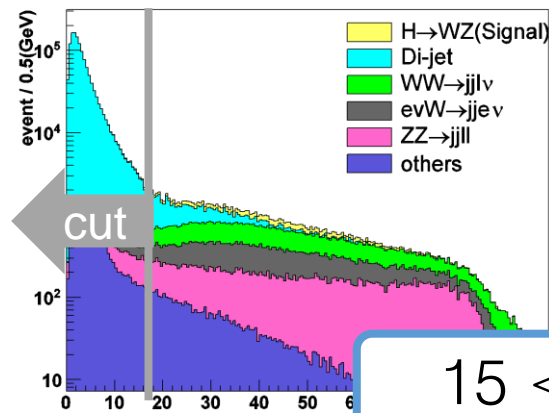
$$70 < M_w < 90 \text{ (GeV)}$$



$$110 < M_{\text{rec}} < 190 \text{ (GeV)}$$

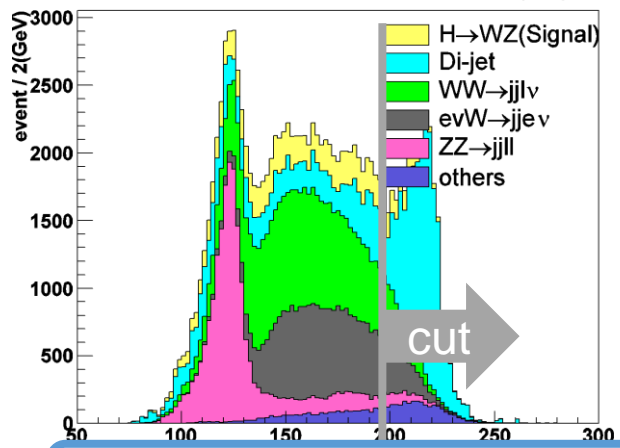
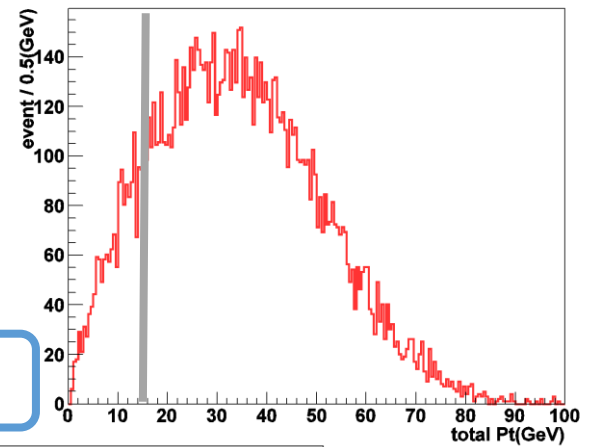
Other Selections for $H \rightarrow WZ$

- Selections are same as $H \rightarrow \tau\nu$ analysis except
 - Evis was loosened from 170 GeV to 200 GeV
 - No BDT since sensitivity not improved.

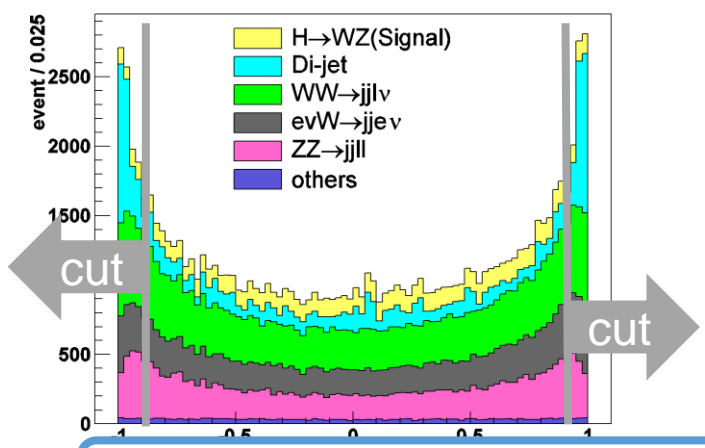


15 < total Pt (GeV)

cut



Evis < 200 (GeV)

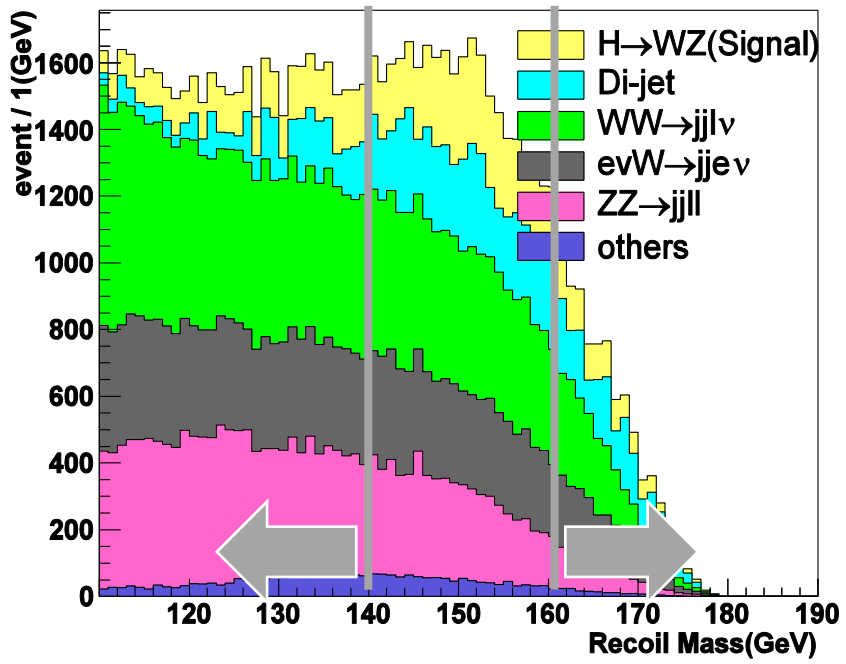


0.95 < | cos θ_{Wangle} |

Cut-flow Table for $H^+ \rightarrow WZ$

	WH(WZ)	Di-jet	$evW \rightarrow evjj$	$WW \rightarrow jjlv$	$ZZ \rightarrow jjll$	others
no cut	53613	11553700	111356	189596	116797	518315
mw&mrec	13399	1307060	23795	35671	28561	18920
pt	11575	31281	22005	32323	21021	4873
Evis	10435	14339	19568	30155	20351	2677
Wangle	9938	10048	17827	27496	18853	2511

Recoil Mass



	WH(WZ)	Di-jet	evW→evjj	WW→jjlv	ZZ→jjll	others
no cut	53613	11553700	111356	189596	116797	518315
after cut	4768	4792	5835	8697	5438	987

検出効率 $\epsilon = 8.89\%$

信号有意度 $S = 27.29$

($F_{HWZ} = 1, F_{HW\gamma} = 0, BR(H \rightarrow WZ) = 100\%$)

Upper Limits on σ and F_{HWZ}

- From the obtained efficiency and number of backgrounds, upper limits are calculated.
- $H \rightarrow \tau \nu$

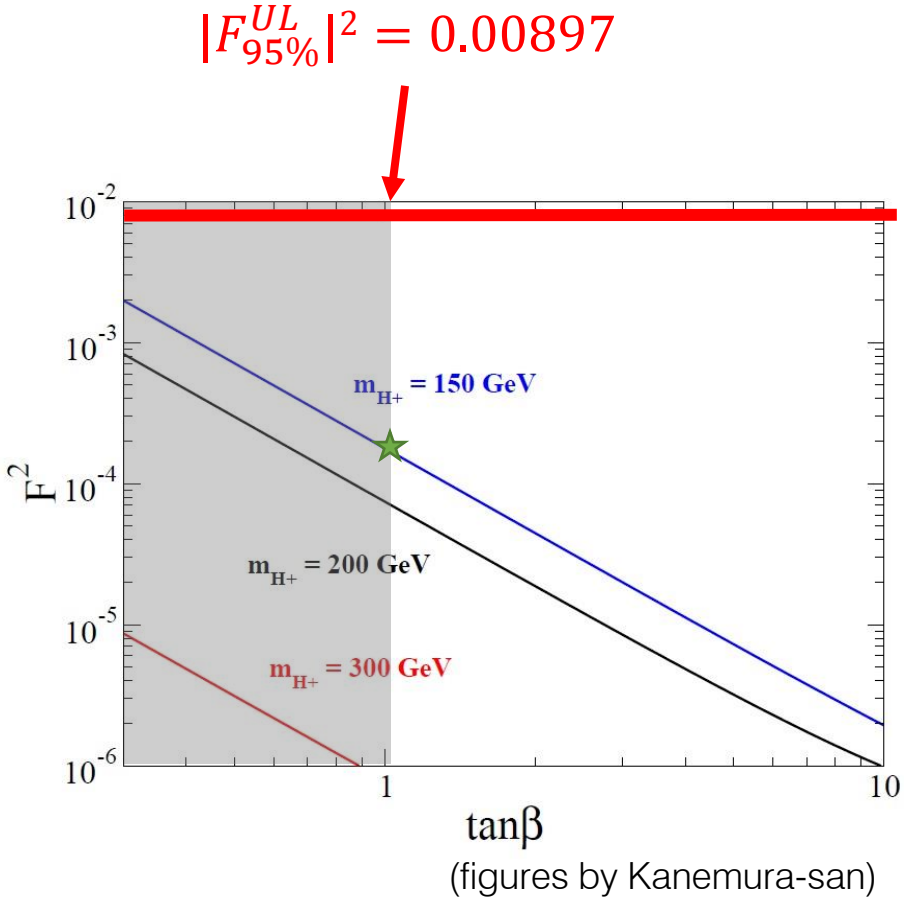
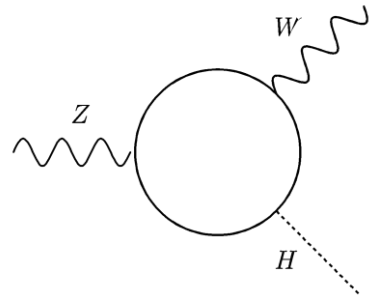
$$\sigma_{95\%}^{UL} = 1.92 \text{ fb} \rightarrow F_{95\%}^{UL} = 0.0974$$
$$(|F_{95\%}^{UL}|^2 = 0.00897)$$

- $H \rightarrow WZ$

$$\sigma_{95\%}^{UL} = 14.4 \text{ fb} \rightarrow F_{95\%}^{UL} = 0.259$$
$$(|F_{95\%}^{UL}|^2 = 0.0673)$$

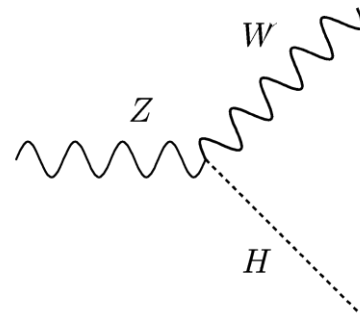
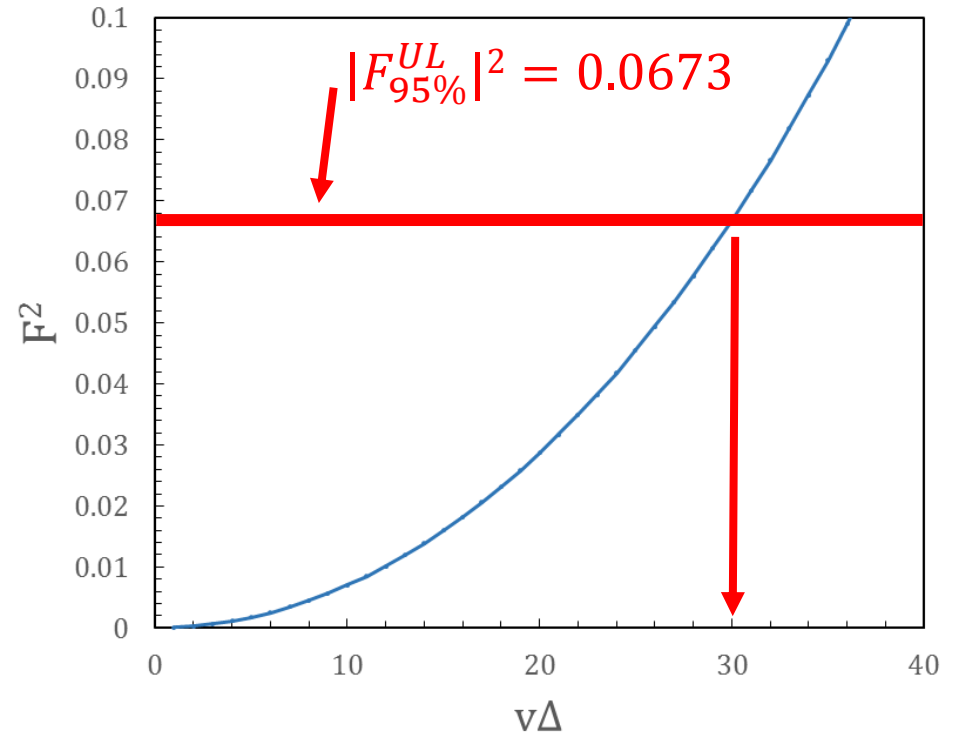
Interpretation to 2HDM type-X with $H \rightarrow \tau\nu$

- 2HDM type-X
 - Lepton specific
 - $H^+ \rightarrow \tau\nu$ can be dominant
 - Type-II is strongly constraint by LHC
- Shaded region ($\tan\beta < 1$) is constraint from B-B-bar mixing
- We cannot set better limit on 2HDM type-X
 - Since loop suppressed



Interpretation to Georgi-Machacek model with $H \rightarrow WZ$

- GM
 - Tree level ZWH coupling
 - One H^+ only decay to WZ
 - The other only to fermion pairs.
- Relation btw triplet VEV and FF
$$F^2 = \frac{4v_\Delta^2}{\cos^2\theta_W (v^2 + 4v_\Delta^2)}$$
- LHC result can make a constraint from κ_F and κ_V
 - $v_\Delta < 70 \text{ GeV}$ (arXiv:1501.04257)
- This study can set better limit on triplet VEV $v_\Delta < 30 \text{ GeV}$



Summary

- We studied charged Higgs production associated with W boson.
- Two charged Higgs decays are considered
 - $H \rightarrow \tau \nu$
 - $H \rightarrow WZ \rightarrow l \nu \nu$
- Interpretations to 2HDM type-X and GM model.
 - No constraint on 2HDM type-X with $H \rightarrow \tau \nu$
 - Better constraint on GM model with $H \rightarrow WZ$
- Possible Improvements
 - Exclusive analysis
 - Inclusion of other decay processes $H \rightarrow WZ \rightarrow l \nu l$

backup

Cross Section

	Process	Cross section (fb)	Events (k)
Sig①	WH (H→tv)	214	54
Sig②	WH (H→WZ)	214	54
SM BG	Di-jet	46200	12000
	evW → evjj	445	110
	Zee → jjee	300	74
	WW → jjlv	758	190
	WW → jjjj	600	150
	ZZ → jjll	467	120
	ZZ → jjjj	402	100
	ZZWWmix → jjjj	565	140
	Zh → ffh	205	51