

Status report of ttH analysis at 500 GeV

1/4/2015

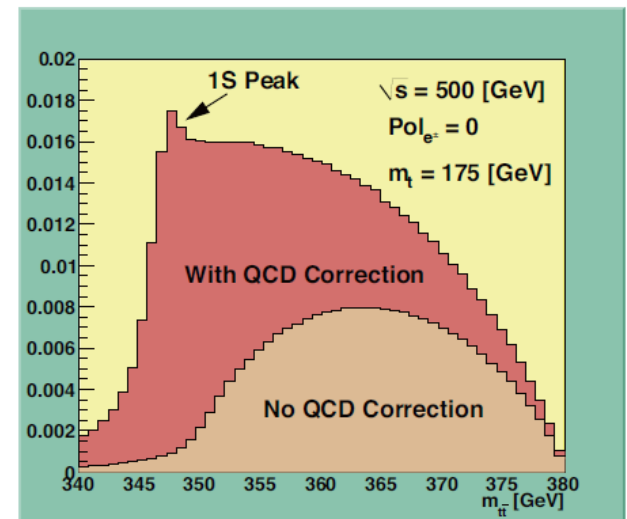
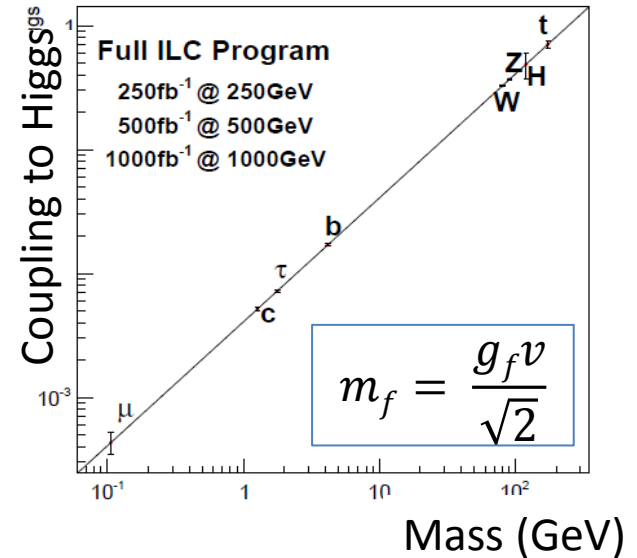
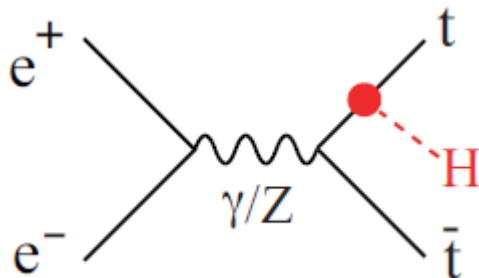
Yuji Sudo

Kyushu University

Introduction

- We are working on ttH study
 - $M_H=125$ GeV.
 - Polarization : $(P_{e^-}, P_{e^+})=(-0.8, +0.3)$
 - Integrated luminosity 500 fb^{-1}
 - ILD full simulation
- ttbar cross section is increased around ttbar threshold by ttbar bound-state effect
- **ttH cross section is enhanced**
- **ttZ cross section is also increased**

We can directly measure the top-Yukawa coupling via tth channel at $\sqrt{s} = 500$ GeV.



Expected # of events @ 500fb⁻¹

- $\sqrt{s} = 500$ GeV, $M_h = 125$ GeV, $(P_{e^-}, P_{e^+}) = (-0.8, +0.3)$
- Production cross section
- Branching ratio

Process	σ (fb)
$e^-e^+ \rightarrow tth$	0.485
$e^-e^+ \rightarrow ttZ$	1.974
$e^-e^+ \rightarrow ttg(bb)$	1.058
$e^-e^+ \rightarrow tbW$	979.8

Decay mode	Branching ratio
$h \rightarrow bb$	0.577
$tt \rightarrow bqqbqq$	0.457
$tt \rightarrow blvbqq$	0.438
$tt \rightarrow blvblv$	0.105

- Expected # of signals and Backgrounds(@500fb⁻¹)

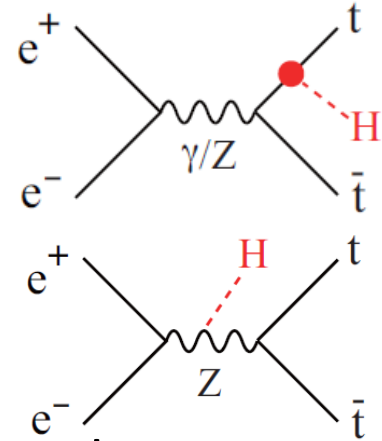
ttH(tt→6j, H→bb)	63.9		
ttH(tt→lv4j, H→bb)	61.3	ttZ	987
ttH(tt→lvlv2j, H→bb)	14.6	ttg(bb)	529
ttH(tt→all, H(nobb))	102.6	tbW	489902

ttH (H→bb) analysis

- interference term is negligible
- counting analysis with cut based event selection

In this analysis, higgs decays into two b jets

- **4 b jets** out of 4-8 jets (b tagging: LCFIPlus)
- Use Kt clustering only for removing low Pt background



Event selection

- **signal topology**
 - ✓ **number of jets**
 - ✓ **# of Isolated Lepton**
 - ✓ **# b jet candidates ≥ 4**
- **kinematics**
 - ✓ energy cut of leading jets
 - ✓ energy cut of low energy jets
 - ✓ Missing momentum > 20 GeV (4, 6jtes mode)
- **detector acceptance**
 - $|\text{Jet } \cos\theta| \leq 0.99$
- **jet paring**
 - ✓ **reconstructed mass**
 - ✓ M_{jj} of top candidates
 - ✓ M_{jj} of higgs candidate

Event selection lv+6 jets channel

- Isolated Lepton ID

- ✓ Exact one Isolated lepton

- jet clustering : Durham algorithm

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

- forced 6 jets clustering is applied to ttH→6jets channel

- ✓ “ $Y_{65} > 0.0016$ ” + “ $Y_{65} \leq 0.0016 \ \&\& \ Y_{54} > 0.006$ ”

- ✓ b jet candidate ≥ 4 (b likeness $\geq 0.85, 0.8, 0.6, 0.2$)

- reject event with very forward jets

- ✓ $|\cos\theta_{\text{jet}}| \leq 0.99$

- Missing Momentum > 20 GeV

- Jet paring, $\chi^2 < 30.5$

- Leading 2 jets energy sum < 197 GeV

- smallest 2 jets energy sum > 66 GeV

- $M_{jjj}, M_{jlv} > 140$ GeV (mass of top candidate)

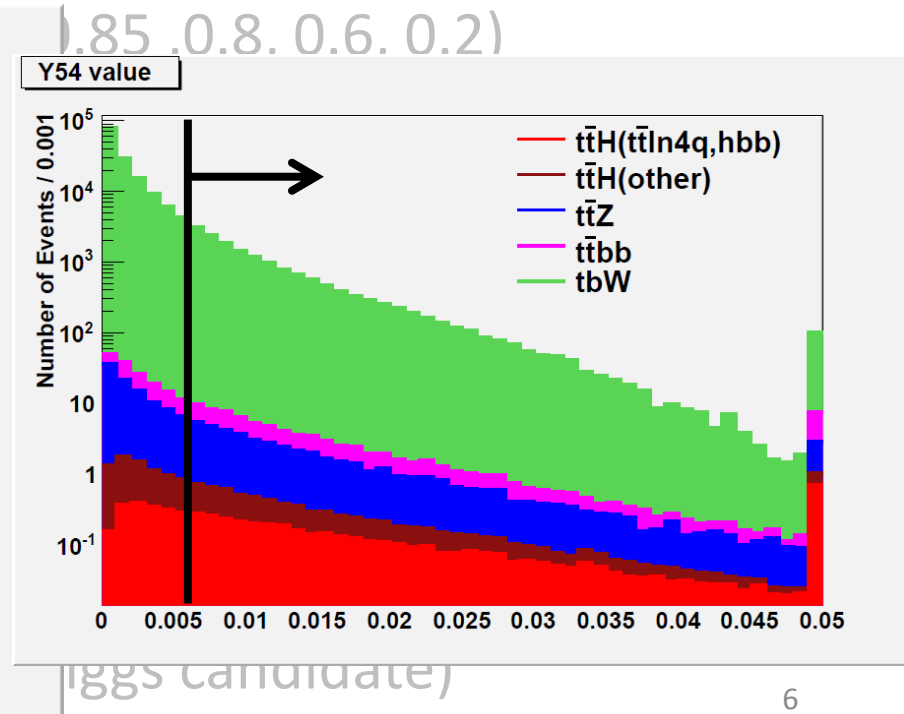
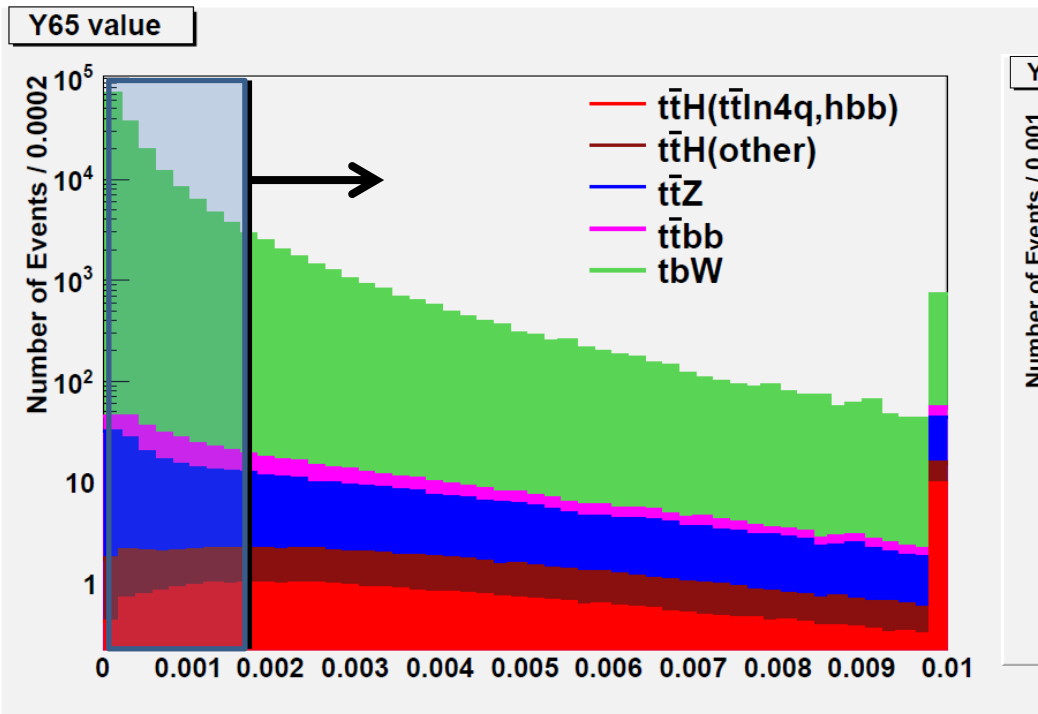
- $95 < M_{jj} < 160$ GeV (2 jets mass of higgs candidate)

Event selection lv+6 jets channel

- Isolated Lepton ID
 - ✓ Exact one Isolated lepton
- jet clustering : Durham algorithm

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

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✓ b jet candidate ≥ 4 (b likeness $\geq 0.85, 0.8, 0.6, 0.2$)

- reject event with very forward jet

✓ $|\cos\theta_{jet}| \leq 0.99$

• Missing Momentum > 20 GeV

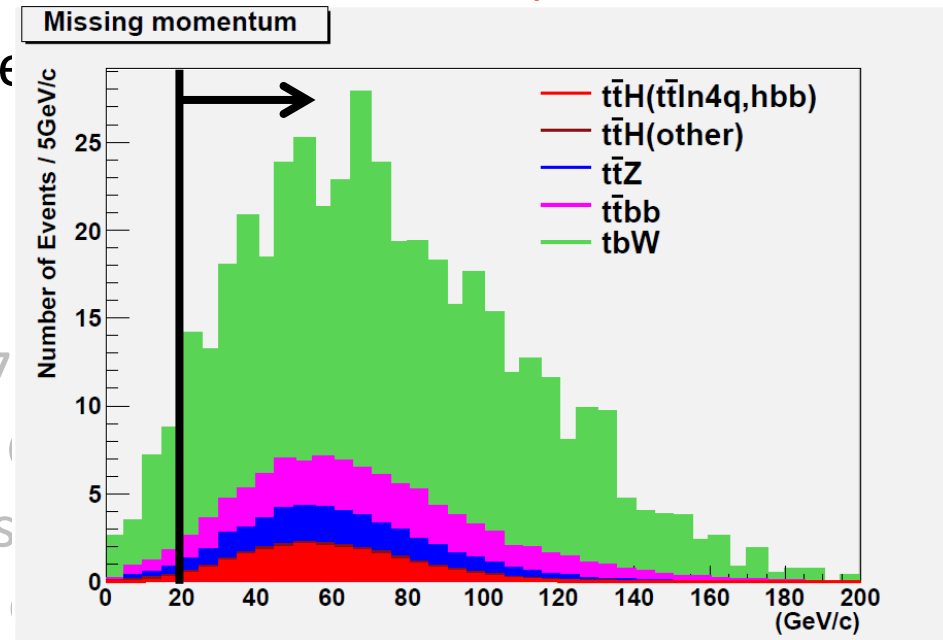
• Jet paring, $\chi^2 < 30.5$

• Leading 2 jets energy sum < 197

• smallest 2 jets energy sum > 66

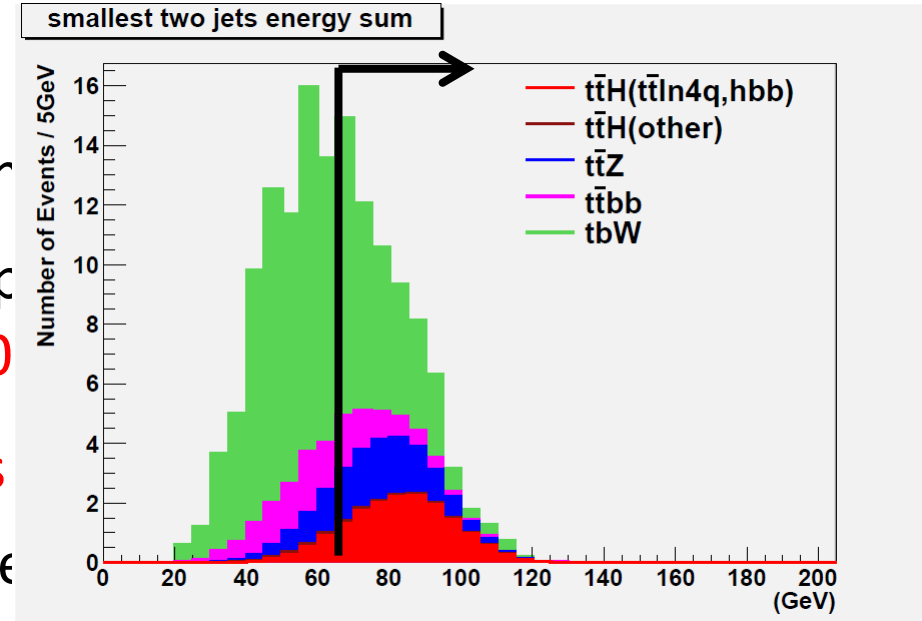
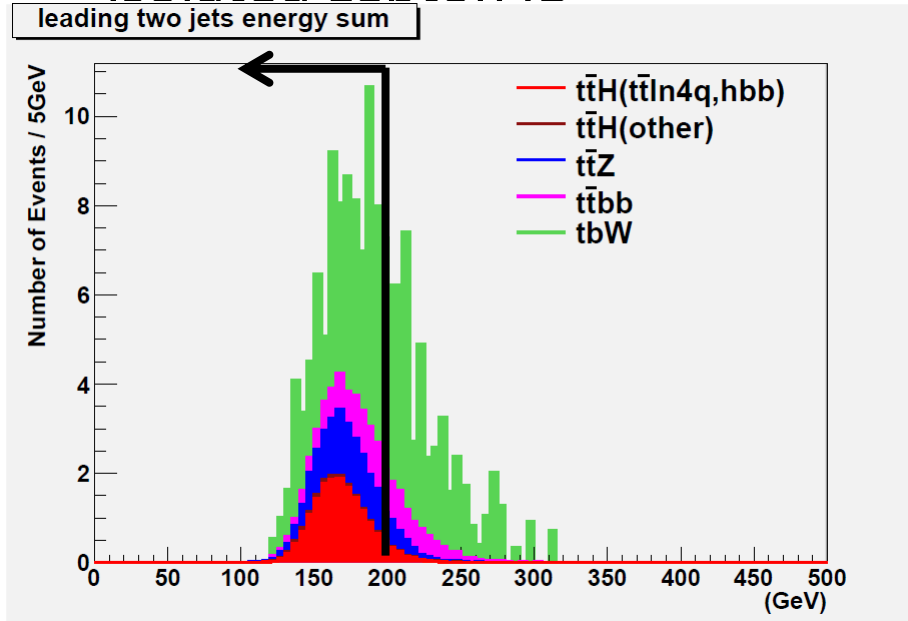
• $M_{jjj}, M_{jlv} > 140$ GeV (3 jets mass)

• $95 < M_{jj} < 160$ GeV (2 jets mass)



Event selection lv+6 jets channel

- Isolated Lepton ID



✓ $|\cos\theta_{jet}| \leq 0.99$

- Missing Momentum > 20 GeV
- Jet paring, $\chi^2 < 30.5$
- Leading 2 jets energy sum < 197 GeV
- smallest 2 jets energy sum > 66 GeV
- $M_{jjj}, M_{jlv} > 140$ GeV (3 jets mass of top candidate)
- $95 < M_{jj} < 160$ GeV (2 jets mass of higgs candidate)

Event selection lv+6 jets channel

- Isolated Lepton ID

✓ Exact one Isolated lepton

- jet clustering : Durham algorithm

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

- forced 6 jets clustering is applied to ttH → 6jets channel

✓ “ $Y_{65} > 0.0016$ ” + “ $Y_{65} \leq 0.0016$ ”

✓ b jet candidate ≥ 4 (b likeness >

- reject event with very forward jet

✓ $|\cos\theta_{jet}| \leq 0.99$

- Missing Momentum > 20 GeV

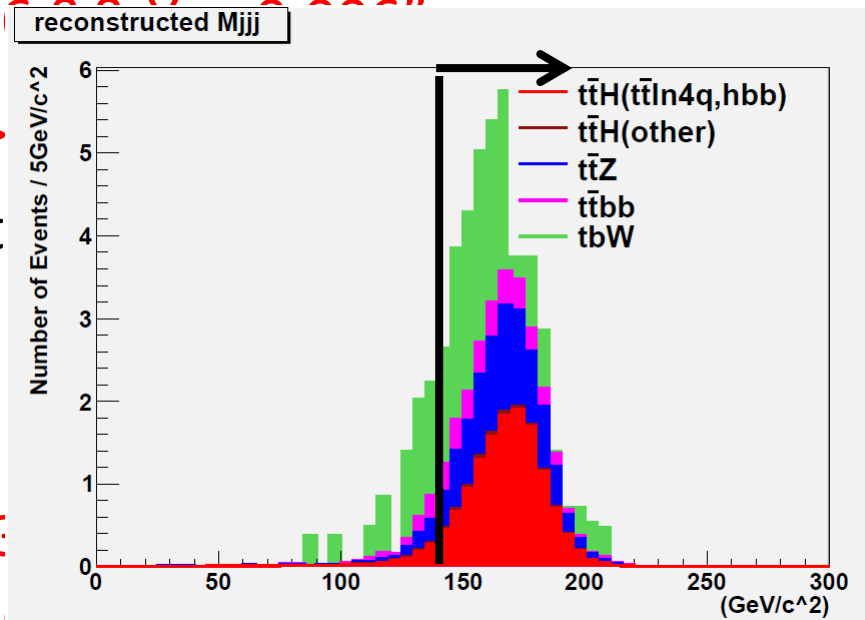
- Jet paring, $\chi^2 < 30.5$

- Leading 2 jets energy sum < 197 GeV

- smallest 2 jets energy sum > 66 GeV

- $M_{jjj}, M_{jlv} > 140$ GeV (3 jets mass of top candidate)

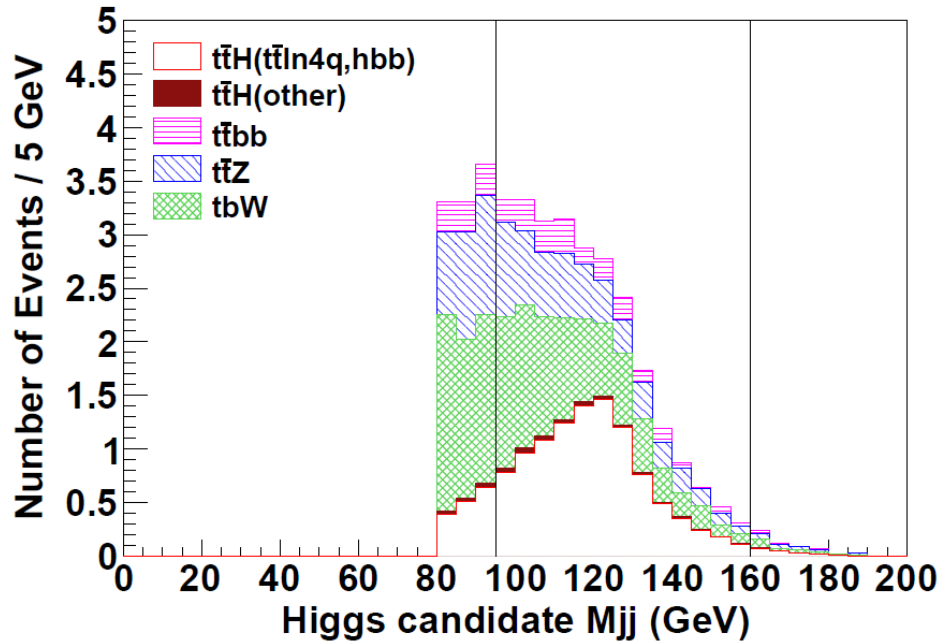
- $95 < M_{jj} < 160$ GeV (2 jets mass of higgs candidate)



Result of Event selection

higgs candidate M_{jj} (lv6jet)

- $\sqrt{s} = 500 \text{ GeV}$, $L=500 \text{ fb}^{-1}$, $(P_{e^-}, P_{e^+})=(-0.8, +0.3)$

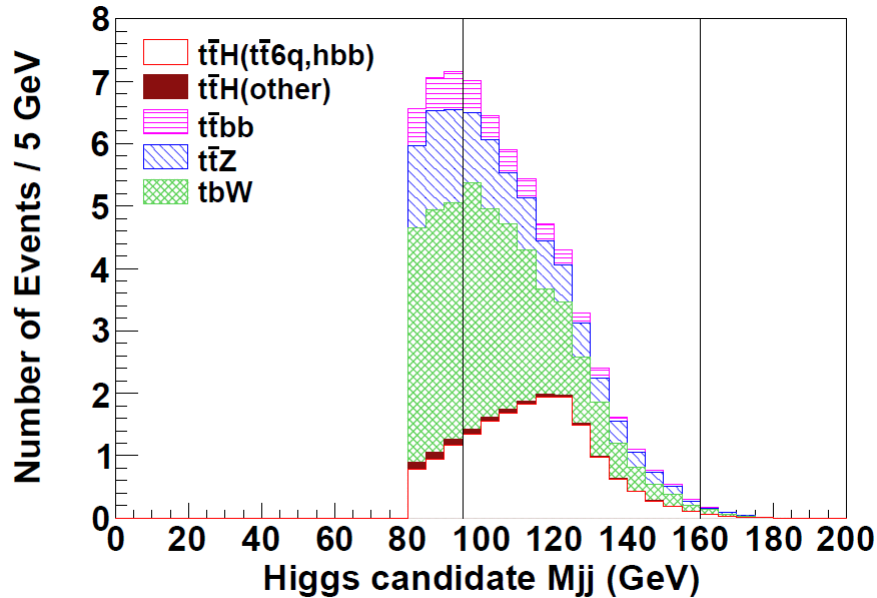


Process	# of evt
$t\bar{t}H$ (not Signal)	0.25
$t\bar{t}Z$	5.19
$t\bar{t}bb$	2.04
$t\bar{t}W$	8.39
bkgd total	15.88
$t\bar{t}H \rightarrow lv6jet$	10.26

Result of Event selection

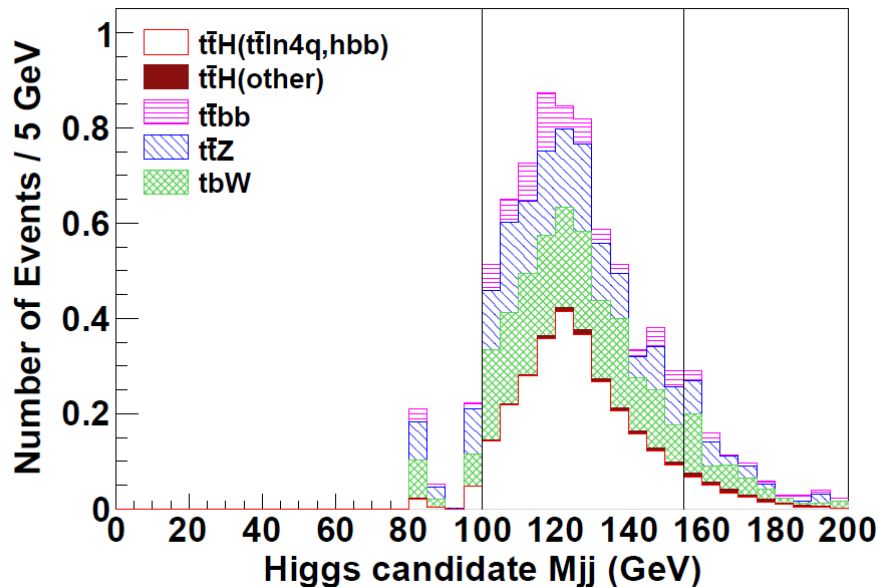
higgs candidate $M_{jj}(8jet, 2l2v4bjet)$

$ttH \rightarrow 8jet$



Process	# of evt
ttH (not Signal)	0.42
ttZ	7.17
ttbb	2.59
tbW	19.24
bkgd total	29.43
ttH \rightarrow 8jet	14.37

$ttH \rightarrow 2l2v+4jet$



Process	# of evt
ttH (not Signal)	0.06
ttZ	1.41
ttbb	0.54
tbW	1.88
bkgd total	3.91
ttH \rightarrow 2l2v4jet	2.62

tth ($h \rightarrow bb$) significance

$$S/\sqrt{S+B}$$

(P_e, P_{e^+})	(-0.8,+0.3)		(0.8,-0.3)	
Lumi. (fb^{-1})	500	1600	500	1600
8 jets	2.17	3.89	1.40	2.53
lv + 6 jets	2.00	3.58	1.29	2.32
2l2v + 4 jets	1.02	1.83	0.72	1.31

- (P_e, P_{e^+})=(-0.8,+0.3) polarization makes better result.
-- number of signal is important.

measurement precision at different \sqrt{s}

$M_H = 125 \text{ GeV}, (P_{e^-}, P_{e^+}) = (-0.8, +0.3)$

$ttH (H \rightarrow bb) 500 \text{ fb}^{-1}$

$\sqrt{s} : S/\sqrt{S+B} : |\Delta y_t/y_t| \%$

500 : 3.13 : 16.6

520 : 5.26 : 9.88

550 : 7.72 : 6.73

$ttH (H \rightarrow bb) 1600 \text{ fb}^{-1}$

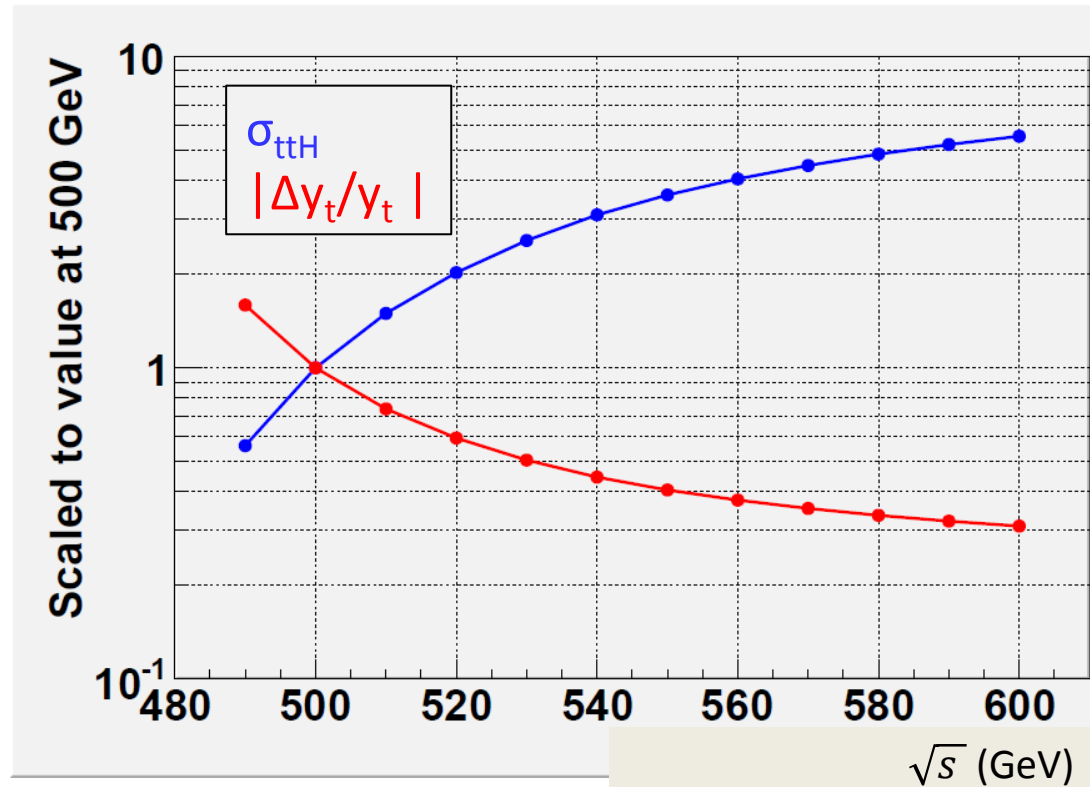
$\sqrt{s} : S/\sqrt{S+B} : |\Delta y_t/y_t| \%$

500 : 5.60 : 9.28

520 : 9.45 : 5.50

550 : 13.9 : 3.73

$\sigma_{ttH} = 0.485 \text{ fb @ } 500 \text{ GeV}$



* Same MC samples are used for all analysis.

Summary

- Counting analysis of ttH ($H \rightarrow bb$)
- Significance (stat. only) at 500 GeV
ttH ($H \rightarrow bb$) $S/\sqrt{S+B}$ ($|\Delta y_t/y_t|$)
500 fb⁻¹ : 3.13 (16.6 %)
1600fb⁻¹ : 5.60 (9.28 %)
- @ $\sqrt{s} = 520$ GeV, 500 fb⁻¹ : $S/\sqrt{S+B} = 5.26$
 $|\Delta y_t/y_t| = 9.88 \%$

Backup

Event Selection 8 jets

- Isolated Lepton ID with BDT

✓ require no Isolated lepton

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

- Jet clustering : Durham algorithm

- forced 8 jet clustering for ttH→8jets channel

✓ “ $Y_{87} > 0.00038$ ” + “ $Y_{87} \leq 0.00038 \ \&\& \ Y_{76} > 0.004$ ”

✓ b candidate jets ≥ 4 (b likeness $\geq 0.85, 0.8, 0.6, 0.2$)

- reject events with very forward jets

✓ $|\text{Jet } \cos\theta| \leq 0.99$

- Jet paring, $\chi^2 < 13.3$

- Leading 2 jets energy sum < 188 GeV

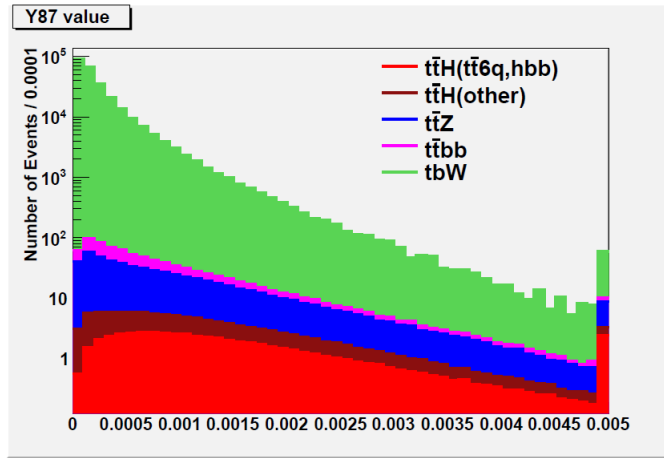
- smallest 3 jets energy sum > 60 GeV

- $M_{jjj} > 140$ GeV (top candidate 3 jet mass)

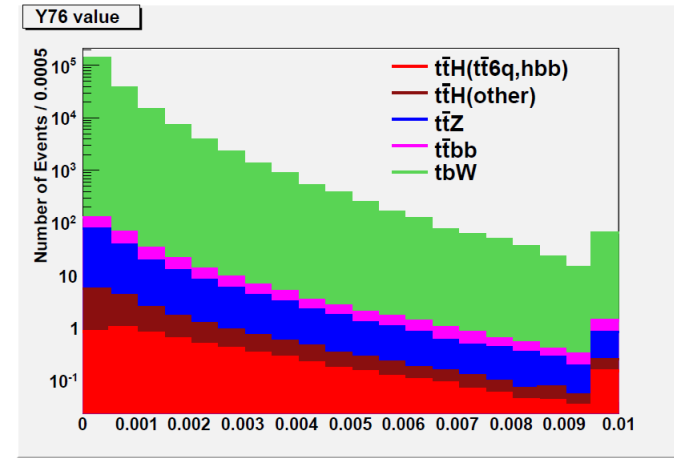
- $95 < M_{jj} < 160$ (GeV) (range of higgs candidate M_{jj})

some variables used event selection ($ttH \rightarrow 8\text{jets}$)

$Y_{87} > 0.00038$



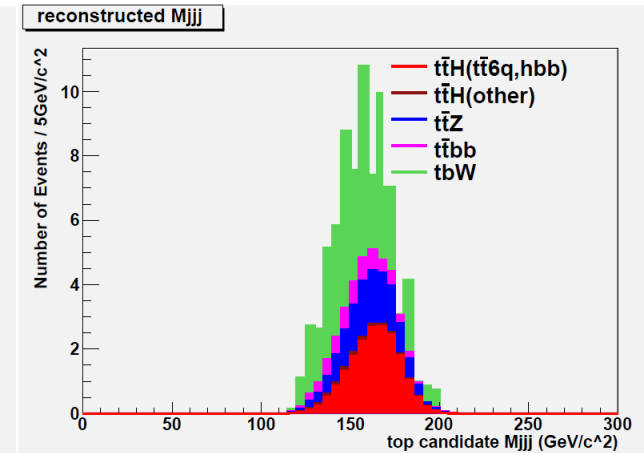
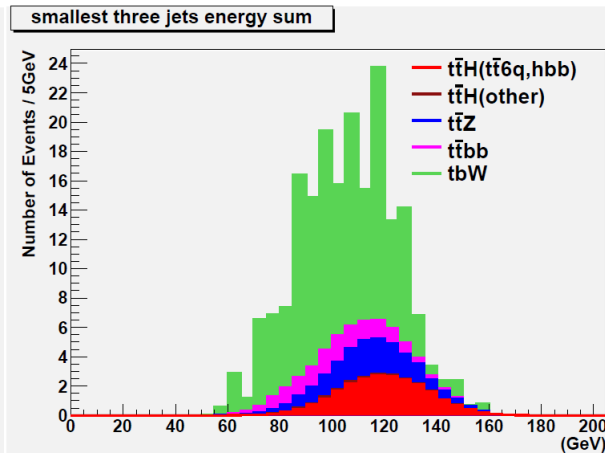
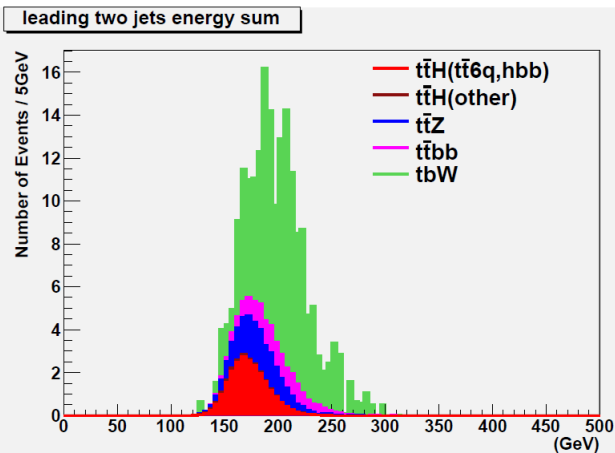
$Y_{87} \leq 0.00038$ && $Y_{76} > 0.004$



Leading 2 jets
energy sum < 188 (GeV)

smallest 3 jets
energy sum > 60 GeV

$M_{jjj} > 140$ GeV



Event selection lv+6 jets channel

- Isolated Lepton ID

- ✓ Exact one Isolated lepton

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

- jet clustering : Durham algorithm

- forced 6 jets clustering is applied to ttH→6jets channel

- ✓ “ $Y_{65} > 0.0016$ ” + “ $Y_{65} \leq 0.0016 \ \&\& \ Y_{54} > 0.006$ ”

- ✓ b jet candidate ≥ 4 (b likeness $\geq 0.85, 0.8, 0.6, 0.2$)

- reject event with very forward jets

- ✓ $|\cos\theta_{\text{jet}}| \leq 0.99$

- Missing Momentum > 20 GeV

- Jet paring, $\chi^2 < 30.5$

- Leading 2 jets energy sum < 197 GeV

- smallest 2 jets energy sum > 66 GeV

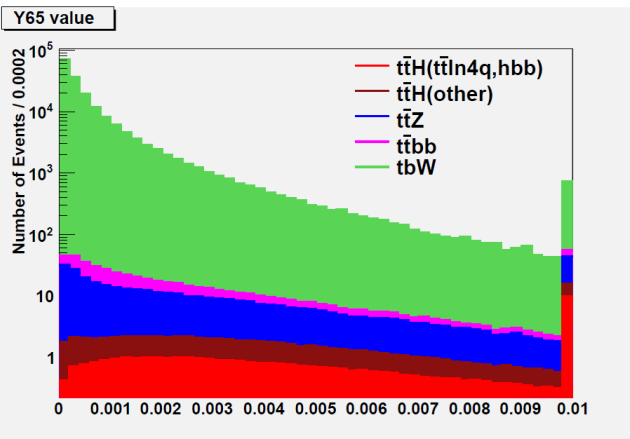
- $M_{\text{jjj}}, M_{\text{jl}v} > 140$ GeV (3 jets mass of top candidate)

- $95 < M_{\text{jj}} < 160$ GeV (2 jets mass of higgs candidate)

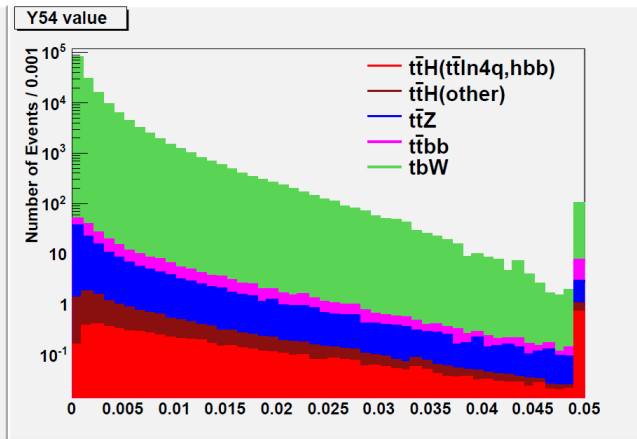
some variables used event selection

($t\bar{t}H \rightarrow l\nu + 6\text{jets}$)

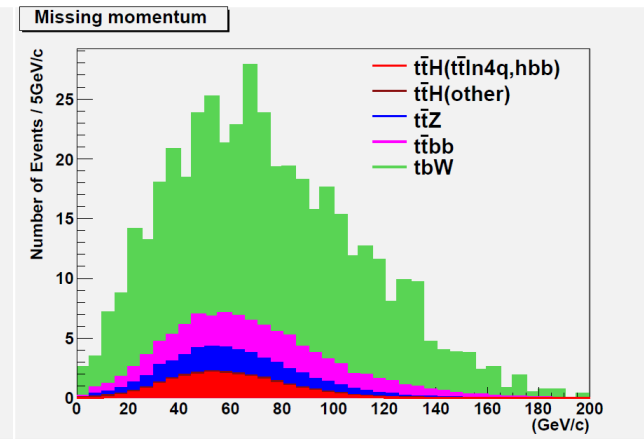
$Y_{65} > 0.0016$



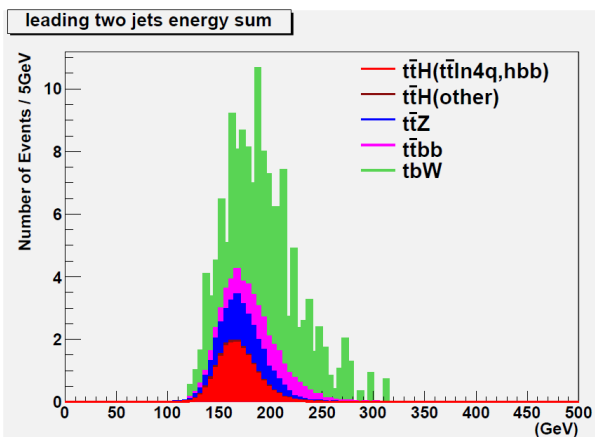
$Y_{65} \leq 0.0016 \ \&\& \ Y_{54} > 0.006$



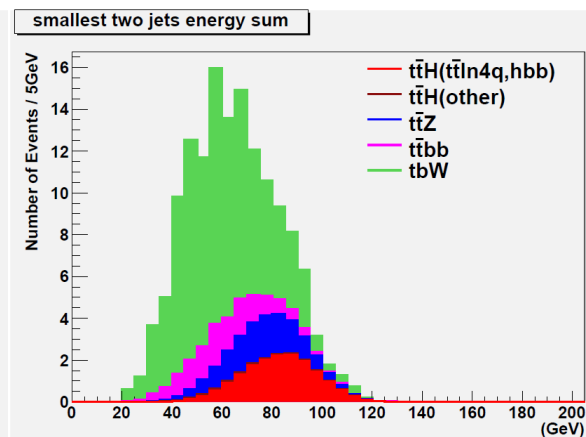
Missing Momentum > 20 GeV



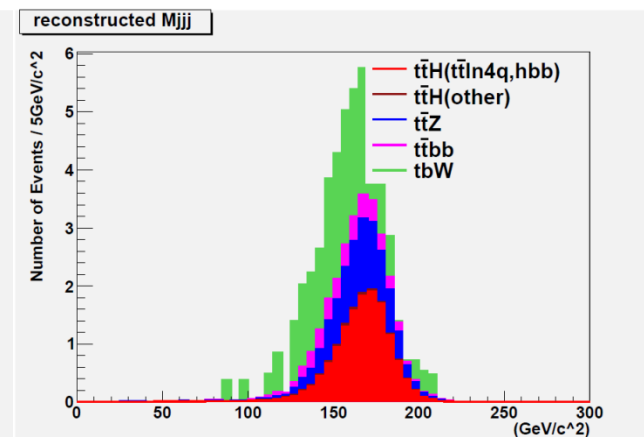
Leading 2 jets
energy sum < 197 GeV



smallest 2 jets
energy sum > 66 GeV



$M_{jjj} > 140 \text{ GeV}$



Event Selection 2l2n+4 jets

- Isolated Lepton ID with BDT

- ✓ require exact two Isolated leptons

- Jet clustering : Durham algorithm $Y_{ij} = \frac{2\min\{E_i^2, E_j^2\}(1 - \cos\theta)}{E_{\text{cm}}^2}$

- forced 6 jet clustering for ttH→4jets channel

- ✓ “ $Y_{43} > 0.002$ ”

- ✓ 4 b jets (b likeness $\geq 0.85, 0.8, 0.6, 0.2$)

- reject events with very forward jets

- ✓ $|\text{Jet } \cos\theta| \leq 0.99$

- Missing momentum > 20 GeV

- Jet paring, $\chi^2 < 12.5$

- Leading jet energy < 112 (Gev)

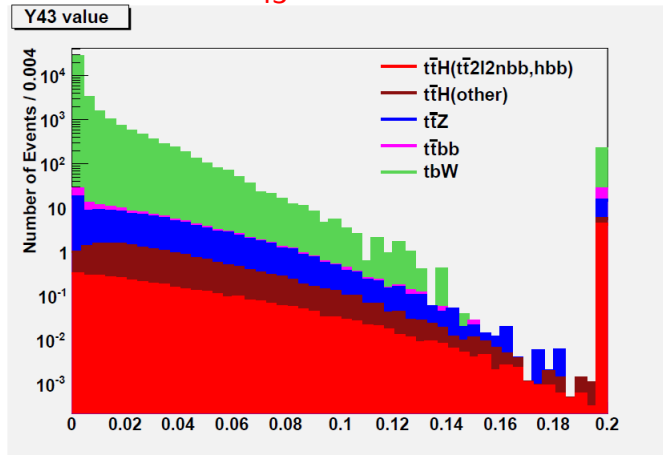
- smallest jet energy > 38 (GeV)

- $100 < M_{jj} < 155$ (GeV) (range of higgs candidate M_{jj})

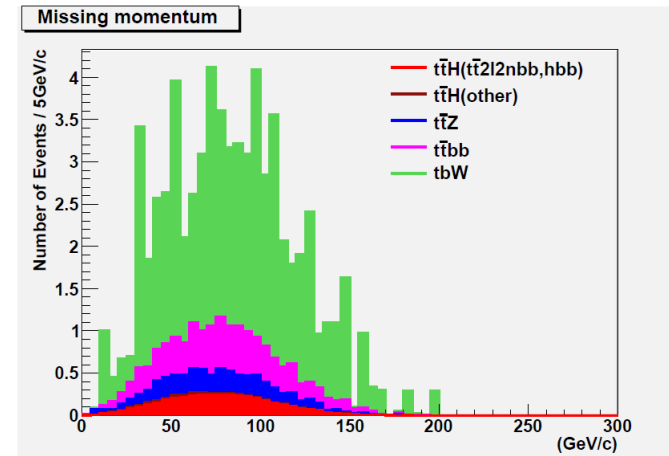
some variables used event selection

$(ttH \rightarrow 2l2\nu+4b)$

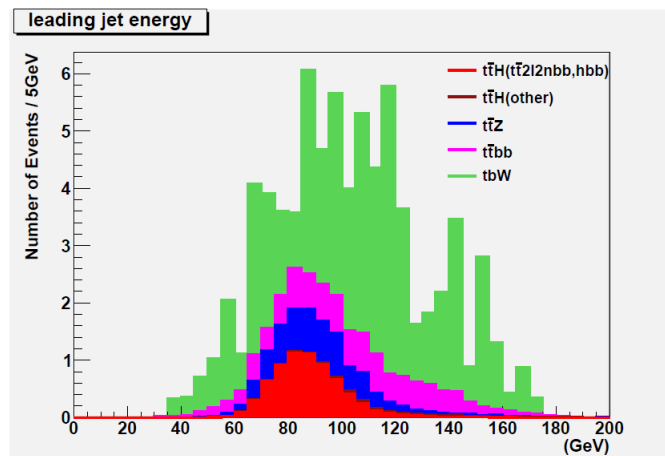
$Y_{43} > 0.002$



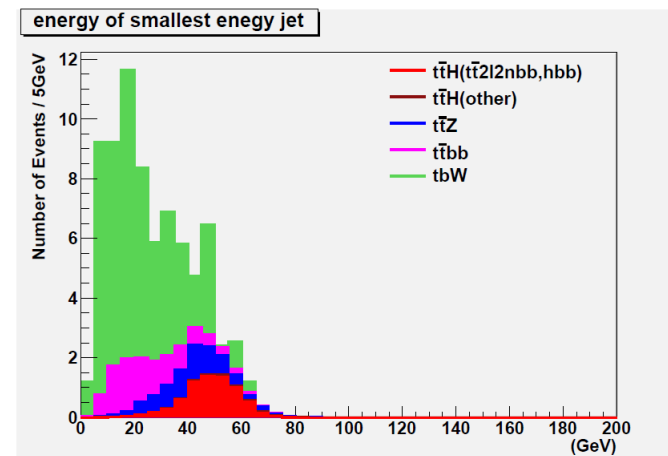
Missing momentum > 20 GeV



Leading jet energy < 112 (GeV)



smallest jet energy > 38 (GeV)



Jet pairing, χ^2 Cut (8 jets mode)

- $\sqrt{s} = 500\text{GeV}$ is near by threshold of the ttH production

- P_{higgs} should be small
- Dijet angle becomes large

→ Angle information between higgs candidate jets is effective to choose correct jet pair.

- try all combination and choose a pair with minimum χ^2 value

$$\chi^2 = \left(\frac{\Delta\text{angle}(j_1, j_2) - \Delta\text{angle}(\text{higgs } jj)}{\sigma_{\Delta\text{angle}(\text{higgs } jj)}} \right)^2 + \left(\frac{m_{j_3 j_4 j_5} - M_{\text{top}}}{\sigma_{M_{\text{top}}}} \right)^2 + \left(\frac{m_{j_4 j_5} - M_W}{\sigma_{M_W}} \right)^2 + \left(\frac{m_{j_6 j_7 j_8} - M_{\text{top}}}{\sigma_{M_{\text{top}}}} \right)^2 + \left(\frac{m_{j_7 j_8} - M_W}{\sigma_{M_W}} \right)^2$$

require b likeness ≥ 0.2 to j_1, j_2, j_3, j_6

- Reference values are made from reconstructed jets which are matched with MC information
 - $M_{\text{top}} = 171.5\text{GeV}$
 - $\sigma_{M_{\text{top}}} = 16.8\text{ GeV}$
 - $M_W = 80.5\text{GeV}$
 - $\sigma_{M_W} = 9.9\text{ GeV}$
 - $\text{angle}(jj) = 2.448$
 - $\sigma_{\text{angle}(jj)} = 0.277$

higgs and top pairing, χ^2 Cut (6 jets mode)

Angle information between higgs candidate jets is effective to choose correct jet pair.

$$\chi^2 = \left(\frac{\Delta angle(j_1, j_2) - \Delta angle(higgs jj)}{\sigma_{\Delta angle(higgs jj)}} \right)^2 + \left(\frac{m_{j_3 j_4 j_5} - M_{top}}{\sigma_{M_{top}}} \right)^2 + \left(\frac{m_{j_4 j_5} - M_W}{\sigma_{M_W}} \right)^2 + \left(\frac{m_{j_6 l \nu} - M_{top}}{\sigma_{M_{top}}} \right)^2$$

A W mass is reconstructed with Isolated lepton and Missing P

- try all combination and choose a pair with minimum χ^2 value

require b likeness ≥ 0.2 to j_1, j_2, j_3, j_6

- Reference values are made from reconstructed jets which are matched with MC information
 - $M_{top} = 171.5 \text{ GeV}$
 - $\sigma_{M_{top}} = 16.8 \text{ GeV}$
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 - $\sigma_{M_W} = 9.9 \text{ GeV}$
 - $\text{angle}(jj) = 2.448$
 - $\sigma_{\text{angle}(jj)} = 0.277$

higgs and top pairing, χ^2 Cut (4 jets mode)

$$\chi^2 = \left(\frac{\Delta angle(j_1, j_2) - \Delta angle(higgs jj)}{\sigma_{\Delta angle(higgs jj)}} \right)^2$$

Angle information between higgs candidate jets is used to choose a jet pair.

try all combination and choose a pair with minimum χ^2 value

- Reference values are made from reconstructed jets which are matched with MC information
 - angle(jj) = 2.448
 - sigma angle(jj) = 0.277

event selection

MC stat.

tth, ttz, ttbb: 100k~200k events

tbW(DBD samples): 10k~100k events

Lepton ID

- muon selection



- electron selection



- tau (e)



- tau(muon)



- tau (1-prong)



- tau(3-prong)

Mjj shape estimation of tbW events in 4 b jets category

- tbW event: 6 fermion events including ttbar, single top etc..
- It is difficult to estimate Mjj shape of tbW events in 4b jets category, because of low statistics of tbW MC events
- At first, compare Mjj shapes of ttZ event in 2/4b jets category
- check event shape of variables which are used event selection. (ttZ, tbW)
- ✓ use Mjj shape of tbW event in 2b jets category
higgs candidate $M_{jj} \geq 80$ GeV