Measurement Precision Study of the top Yukawa Coupling with ILD Full Simulation at ILC 500 GeV

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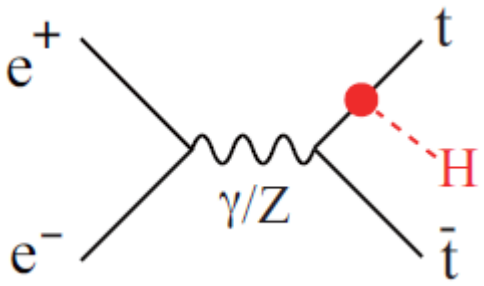
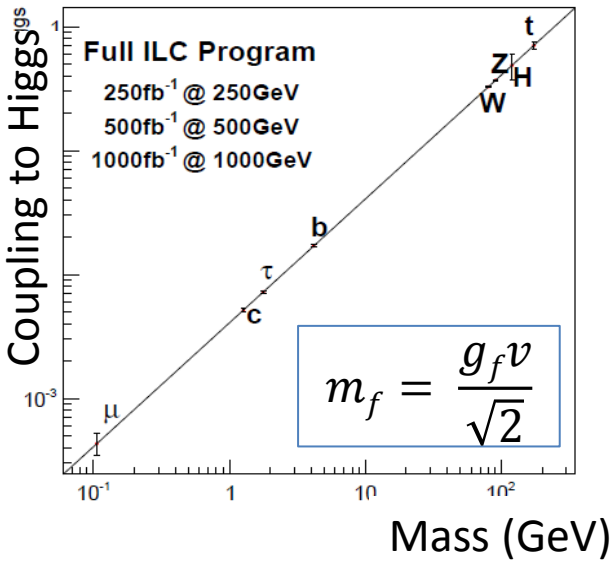
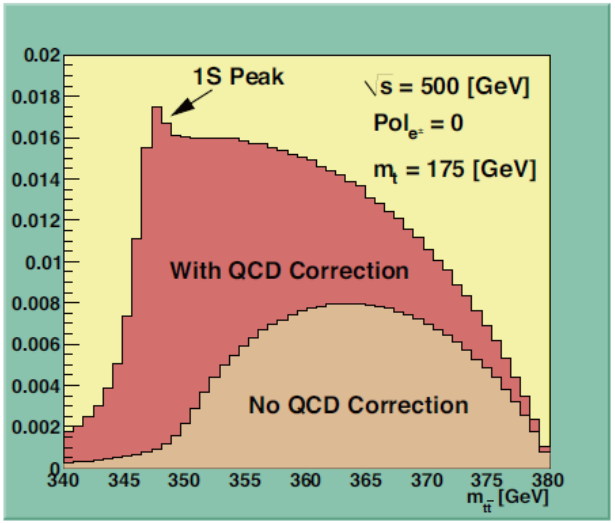
Introduction

- We are working on ttH study
  - M_H=125 GeV.
  - Polarization : (Pe^-,Pe^+)=(-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, (Pe^-,Pe^+)=(-0.8,+0.3)
- Production cross section
- Branching ratio

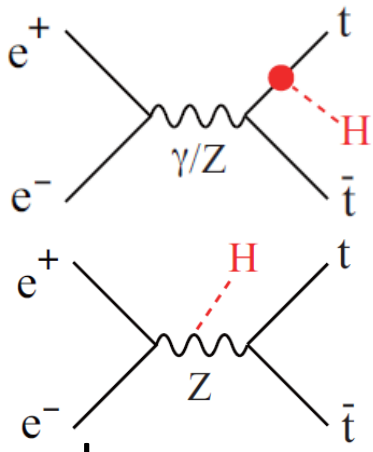
Process	σ (fb)
$e^-e^+ \rightarrow$ tth	0.485
$e^-e^+ \rightarrow$ ttZ	1.974
$e^-e^+ \rightarrow$ ttg(bb)	1.058
$e^-e^+ \rightarrow$ tbW	979.8

Decay mode	Branching ratio
h→bb	0.577
tt→bqqbqq	0.457
tt→blvbqq	0.438
tt→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

- detector acceptance

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

- jet paring

- kinematics

✓ energy cut of leading jets

✓ energy cut of low energy jets

✓ Missing momentum > 20 GeV (4, 6jtes mode)

- reconstructed mass

✓ Mjjj of top candidates

✓ Mjj of higgs candidate

Event Selection lv+6 jets Channel

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

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

  - forced 6 jets clustering is applied to ttH→6jets channel
  - ✓ "$Y_{65} > 0.0016$" + "$Y_{65} <= 0.0016$ && $Y_{54} > 0.006$"
- ✓ b jet candidate ≥ 4 (b likeness >=0.85 ,0.8, 0.6, 0.2)
- reject event with very forward jets
- ✓ $|\cos\theta_{jet}| \leq 0.99$
- Missing Momentum > 20 GeV
- Jet paring, $\chi 2 < 30.5$
- Leading 2 jets energy sum < 197 GeV
- smallest 2 jets energy sum > 66 GeV
- Mjjj, Mjlv > 140 GeV (mass of top candidate)
- 95 < Mjj < 160 GeV (2 jets mass of higgs candidate)

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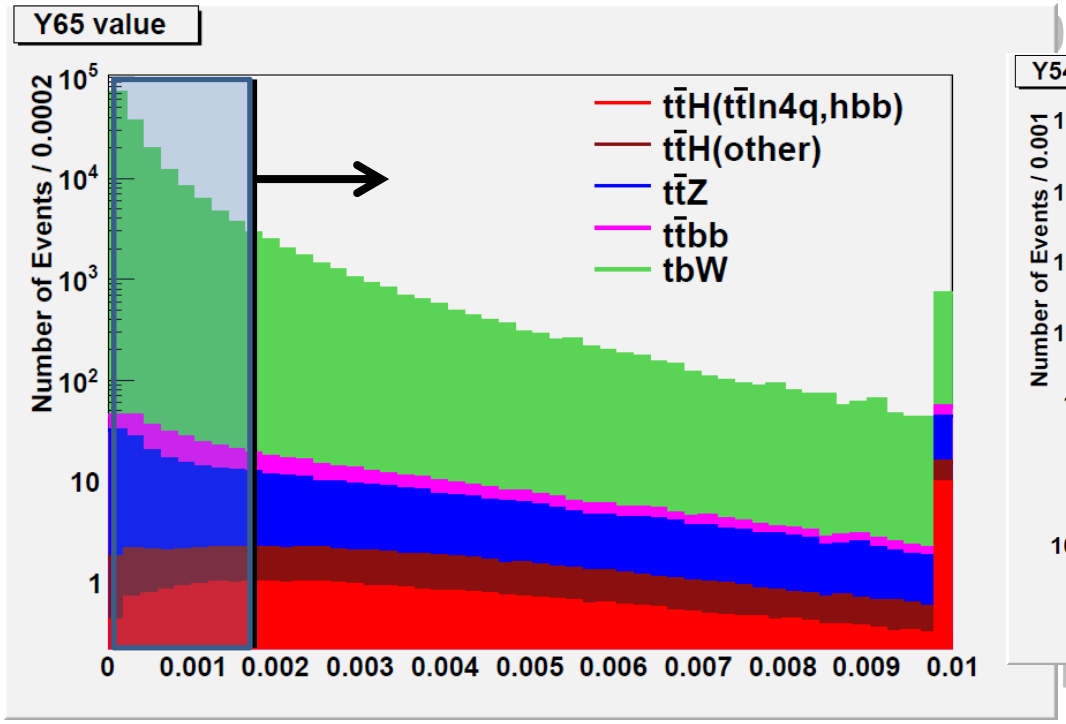

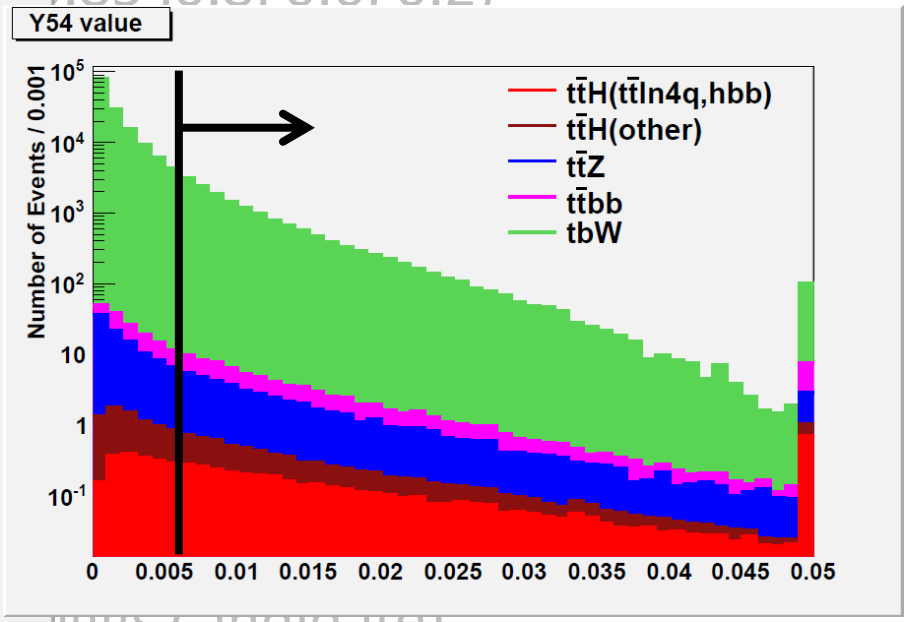

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✓ $|\cos\theta_{jet}| \leq 0.99$

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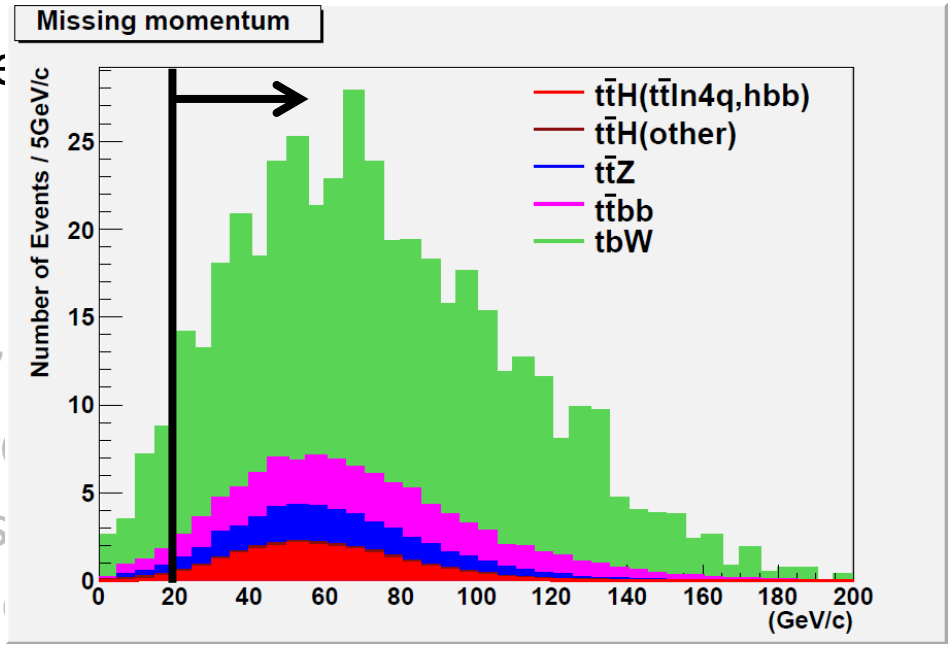

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- Leading 2 jets energy su
- smallest 2 jets energy su
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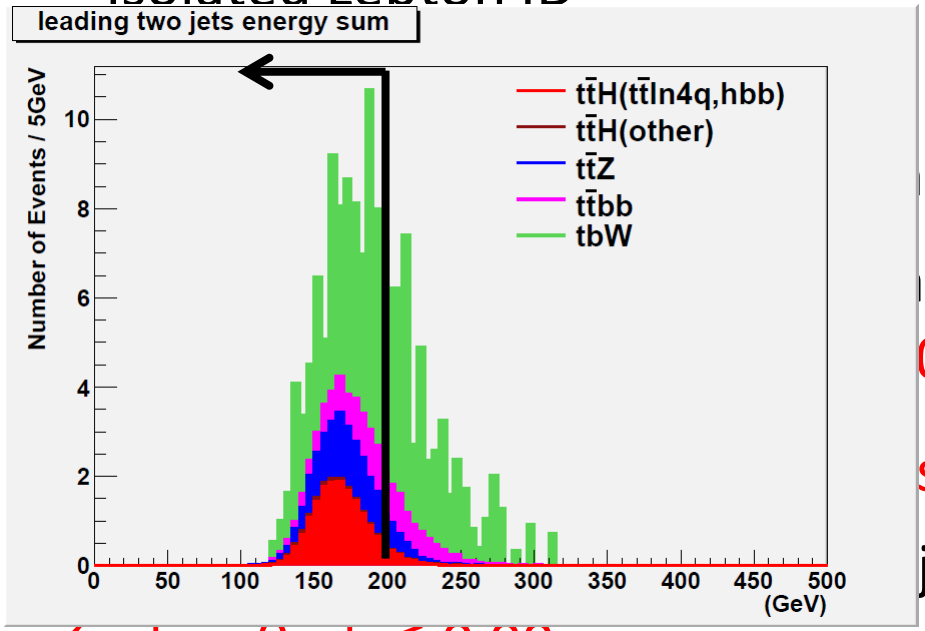
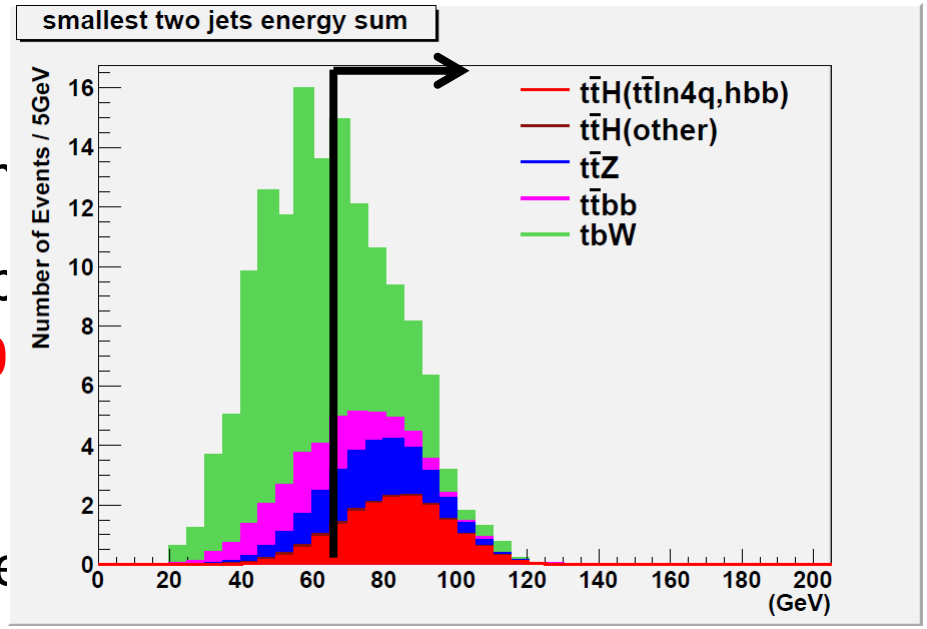
- 95 < Mjj < 160 GeV (2 je

$$\chi^2 = \left(\frac{\Delta angle(j_1,j_2) - \Delta angle(higgs\ jj)}{\sigma_{\Delta angle(higgs\ jj)}}\right)^2 + \left(\frac{m_{j_3j_4j_5} - M_{top}}{\sigma_{M_{top}}}\right)^2 + \left(\frac{m_{j_4j_5} - M_W}{\sigma_{M_W}}\right)^2 + \left(\frac{m_{j_6l\nu} - M_{top}}{\sigma_{M_{top}}}\right)^2$$

Event Selection lv+6 jets Channel

- Isolated Lepton ID





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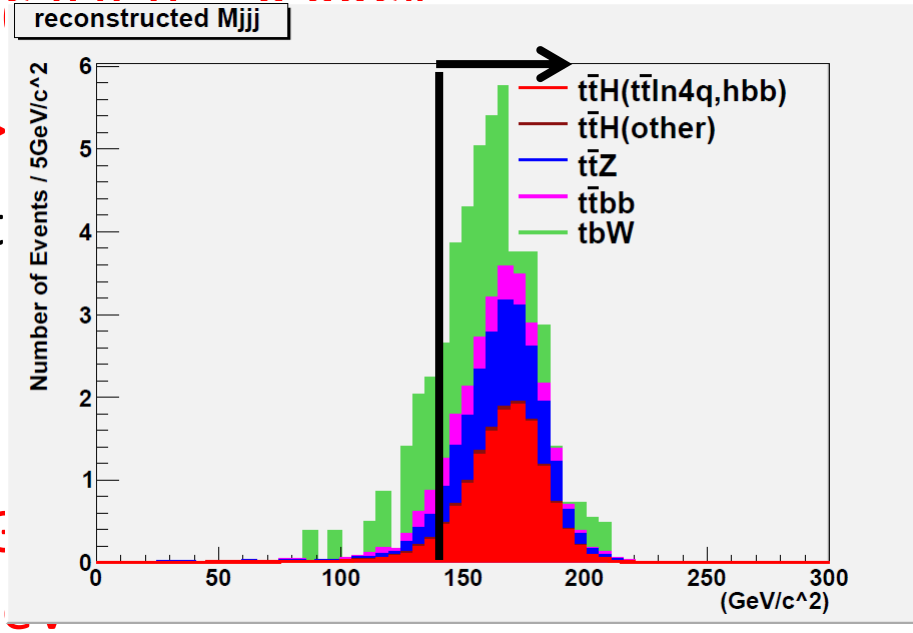
  - forced 6 jets clustering is applied to ttH→6jets channel
  - ✓ "$Y_{65} > 0.0016$" + "Y_{65}<=0.001



- ✓ b jet candidate ≧ 4 (b likeness >
- reject event with very forward jet
- ✓ $|\cos\theta_{jet}| \leq 0.99$
- Missing Momentum > 20 GeV
- Jet paring, χ2< 30.5
- Leading 2 jets energy sum < 197 G
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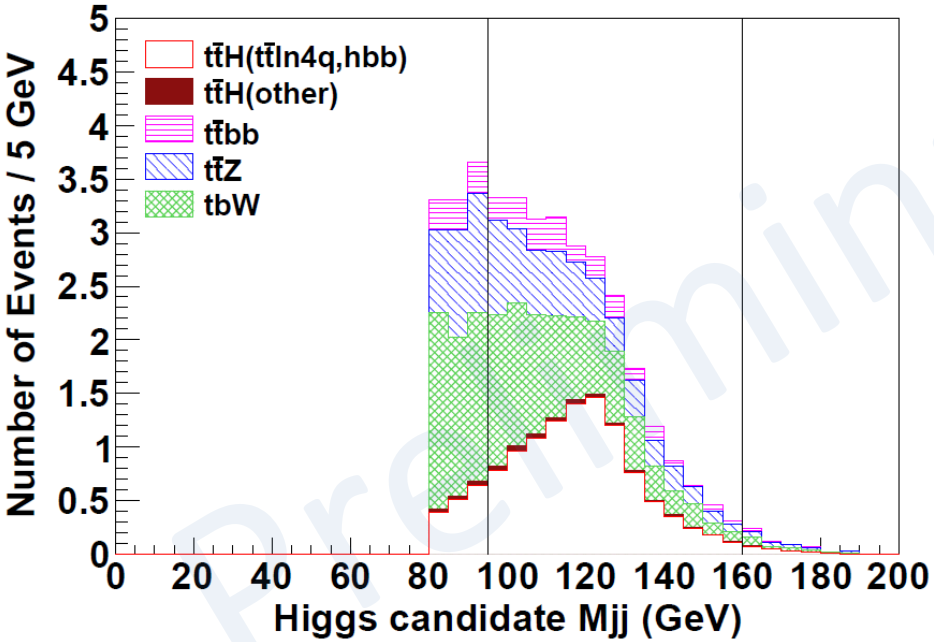
- Mjjj , Mjlv > 140 GeV (3 jets mass of top candidate)
- 95 < Mjj < 160 GeV (2 jets mass of higgs candidate)

Result of Event Selection
higgs candidate Mjj (lv6jet)

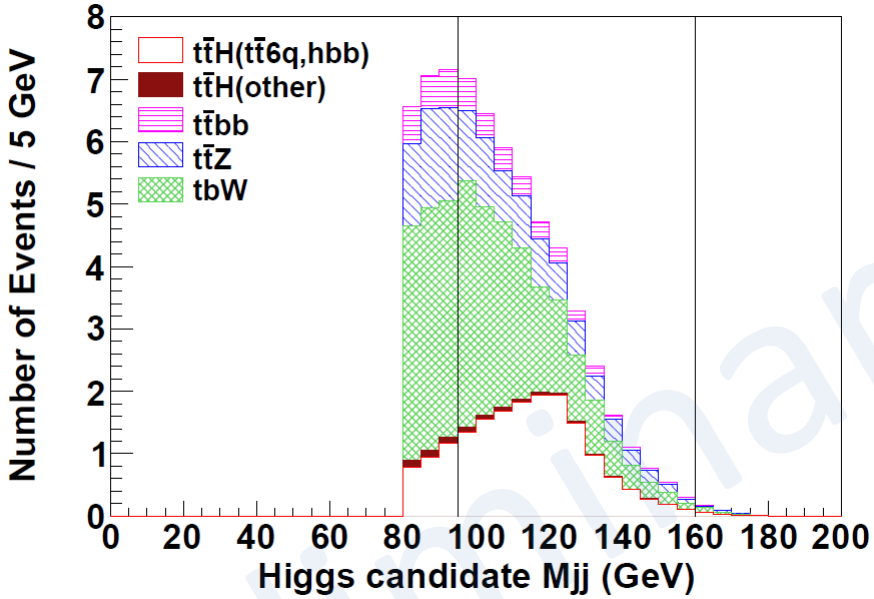
- $\sqrt{s}$ = 500 GeV, L=500 fb^{-1}, (Pe$^-$,Pe$^+$)=(-0.8,+0.3)



Process	# of evt
ttH (not Signal)	0.25
ttZ	5.19
ttbb	2.04
tbW	8.39
bkgd total	**15.88**
ttH→lv6jet	**10.26**

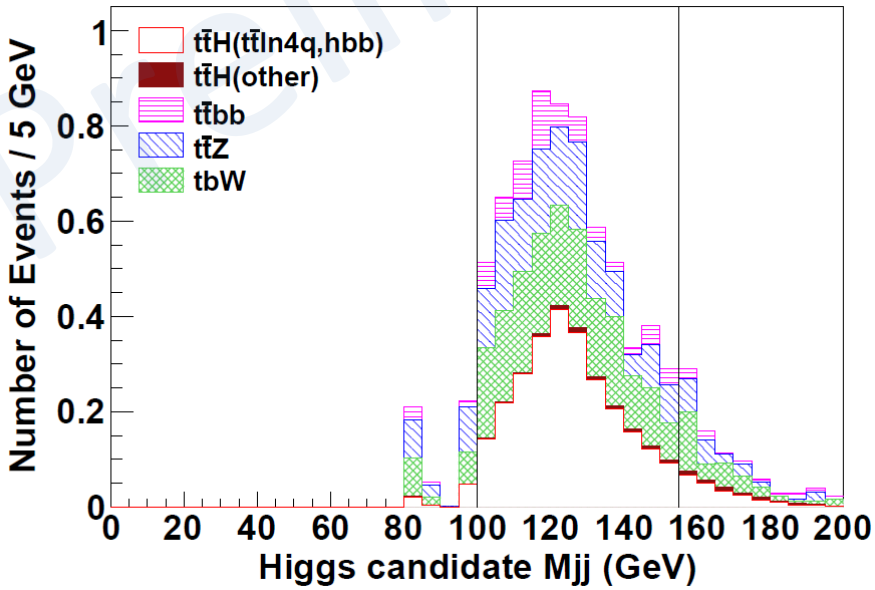
Result of Event Selection
higgs candidate Mjj(8jet, 2l2v4bjet)

ttH→
8jet



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

ttH→
2l2v+4jet



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

Significance of tth (h→bb) Signal

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

(Pe^-,Pe^+)	(-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

- (Pe,Pe+)=(-0.8,+0.3) polarization makes better result.
  -- number of signal is important.

measurement precision at different $\sqrt{s}$

combined result of ttH→8jets, lν+6jets and 2l2ν+4b jets channels

M_H = 125 GeV, $(Pe^-, Pe^+)=(-0.8,+0.3)$

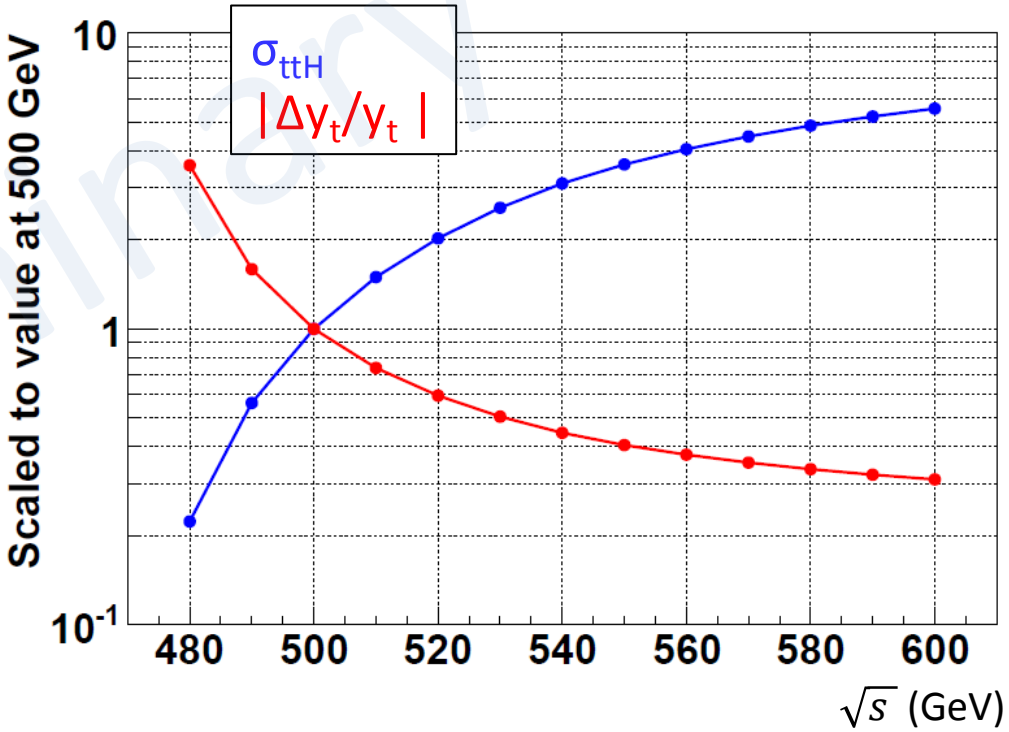
σ_{ttH} = 0.485 fb @ 500 GeV

ttH (H→bb) 500 fb^{-1}

$\sqrt{s}$	$S/\sqrt{S+B}$	$\lvert\Delta y_t/y_t\rvert$ %
500	3.13	16.6
520	5.26	9.88
550	7.72	6.73

ttH (H→bb) 1600 fb^{-1}

$\sqrt{s}$	$S/\sqrt{S+B}$	$\lvert\Delta y_t/y_t\rvert$ %
500	5.60	9.28
520	9.45	5.50
550	13.9	3.73



* Same MC samples are used for all analysis. MC sample are generated at 500 GeV.
* We just change production cross section of signal and backgrounds for each energy.

Summary

- Counting analysis of ttH (H→bb)
- Significance (stat. only) at 500 GeV

  ttH (H→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 %
- @ $\sqrt{s}$ = 480 GeV, direct measurement of top Yukawa coupling is impossible.

Backup

Lepton ID Efficiency

- Lepton ID efficiency with TMVA BDT (cut base) lepton selection

ttH → 2l2v + 4 jets

(%)	elec	muon	taue	taum	tauh1	tauh3	bjet	ljet
Identified as a lepton	92.4 (90.91)	96.53 (95.35)	73.51 (63.09)	74.63 (65.78)	56.56 (47.08)	49.3 (38.82)	0.016 (0.017)	N/A

ttZ

(%)	elec	muon	taue	taum	tauh1	tauh3	bjet	ljet
Identified as a lepton	92.5 (89.8)	96.61 (95.71)	72.97 (63.38)	73.41 (65.56)	55.64 (45.81)	48.27 (38.12)	0.11 (0.14)	0.6 (0.66)

- Lepton ID efficiency and miss ID efficiency are improved by BDT method
- ID efficiency is almost same to ttZ and ttH → 2l2v + 4 jets.

Event Selection 8 jets

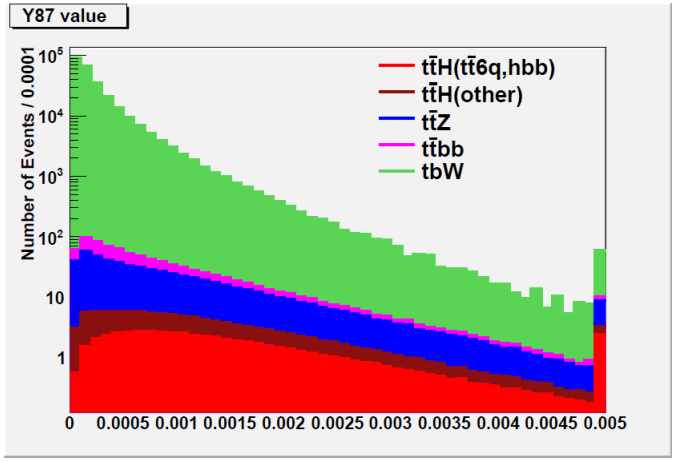
- Isolated Lepton ID with BDT
  - ✓ require no Isolated lepton
- Jet clustering : Durham algorithm

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

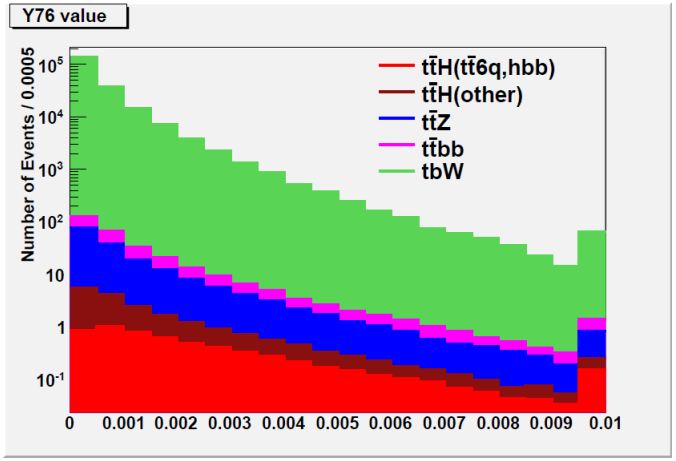
  - forced 8 jet clustering for ttH→8jets channel
  - ✓ "Y_{87} > 0.00038" + "Y_{87}<=0.00038 && Y_{76}>0.004"
- ✓ b candidate jets ≥ 4 (b likeness >=0.85 ,0.8, 0.6, 0.2)
- reject events with very forward jets
- ✓ |Jet cosθ| ≤ 0.99
- Jet paring, χ2< 13.3
- Leading 2 jets energy sum < 188 GeV
- smallest 3 jets energy sum > 60 GeV
- Mjjj > 140 GeV (top candidate 3 jet mass)
- 95 < Mjj < 160 (GeV) (range of higgs candidate Mjj)

some variables used event selection (ttH→8jets)

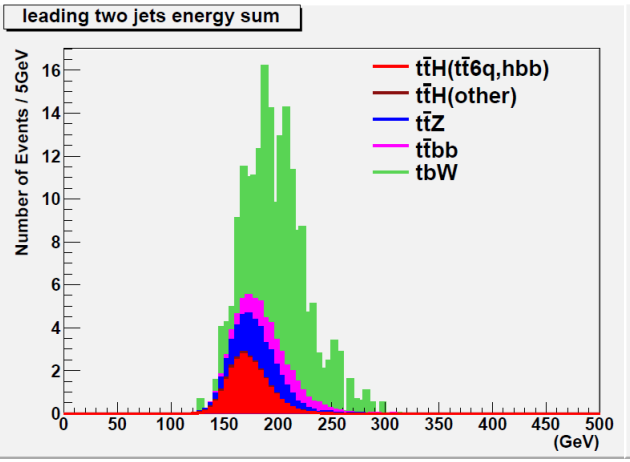
$Y_{87} > 0.00038$



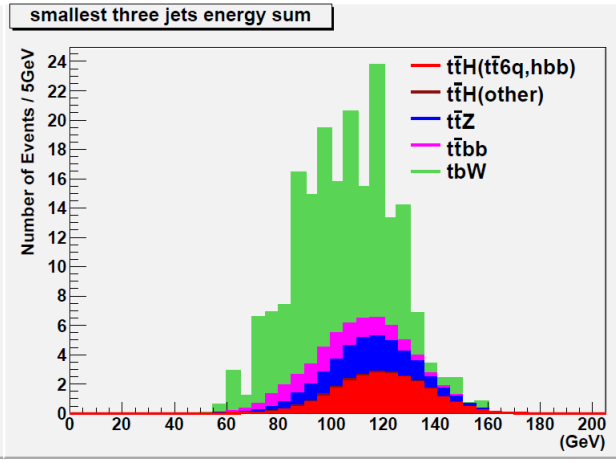
$Y_{87}<=0.00038$ && $Y_{76}>0.004$



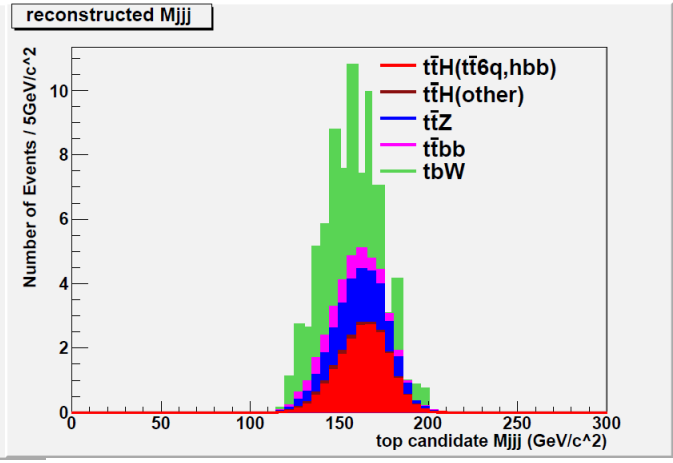
Leading 2 jets energy sum < 188 (Gev)



smallest 3 jets energy sum > 60 GeV



Mjjj > 140 GeV



Event selection lv+6 jets channel

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

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

  - forced 6 jets clustering is applied to ttH→6jets channel
  - ✓ "$Y_{65} > 0.0016$" + "$Y_{65} <= 0.0016$ && $Y_{54} > 0.006$"
- ✓ b jet candidate ≥ 4 (b likeness >=0.85 ,0.8, 0.6, 0.2)
- reject event with very forward jets
- ✓ $|\cos\theta_{jet}| \leq 0.99$
- Missing Momentum > 20 GeV
- Jet paring, $\chi 2 < 30.5$
- Leading 2 jets energy sum < 197 GeV
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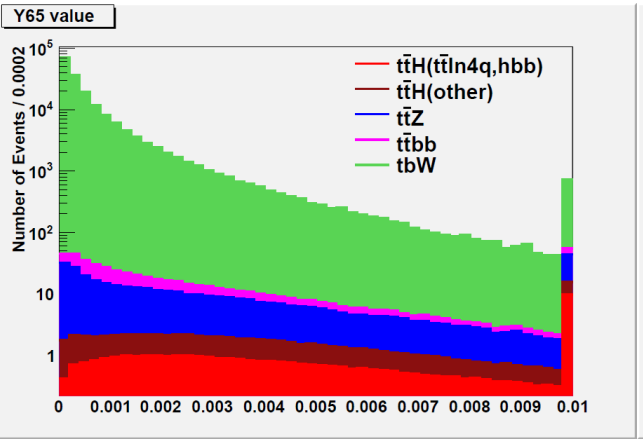
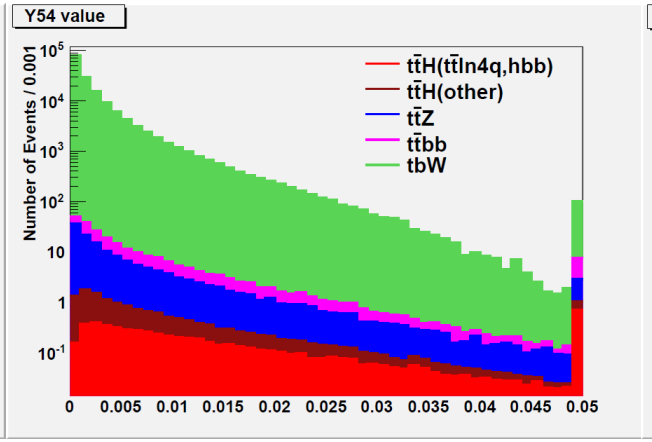
- Mjjj , Mjlv > 140 GeV (3 jets mass of top candidate)
- 95 < Mjj < 160 GeV (2 jets mass of higgs candidate)

some variables used event selection (ttH→lv+6jets)

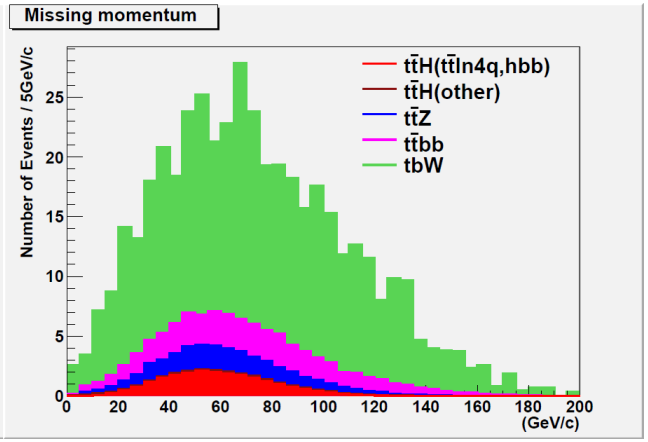
Y_{65} > 0.0016



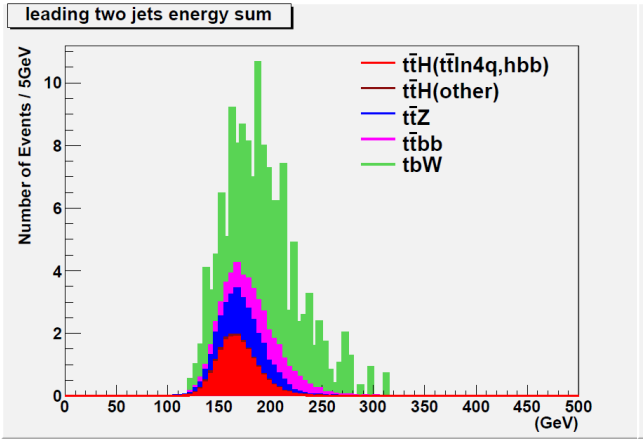
Y_{65}<=0.0016 && Y_{54}>0.006



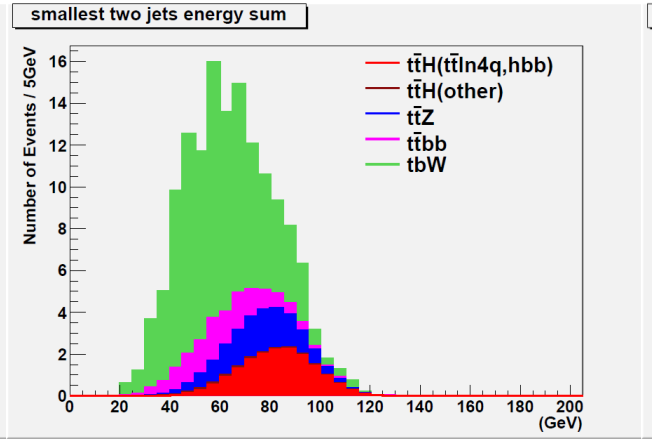
Missing Momentum > 20 GeV



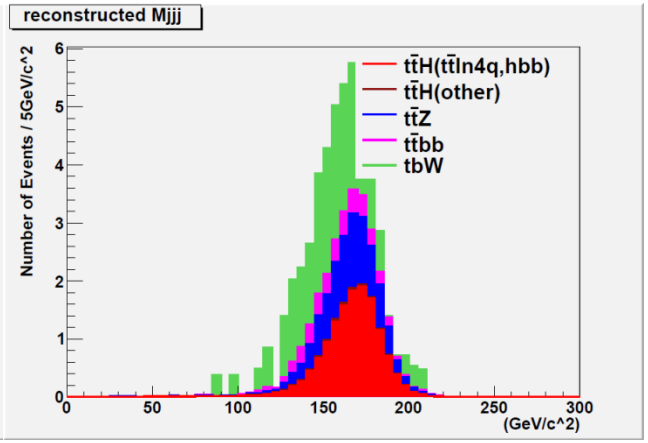
Leading 2 jets energy sum < 197 GeV



smallest 2 jets energy sum > 66 GeV



Mjjj > 140 GeV



Event Selection 2l2n+4 jets

- Isolated Lepton ID with BDT
  - ✓ require exact two Isolated leptons
- Jet clustering : Durham algorithm $Y_{ij} = \frac{2\min\{E_i^2, E_j^2\}(1-\cos\theta)}{E_{\rm cm}^2}$
  - forced 6 jet clustering for ttH→4jets channel
  - ✓ "$Y_{43} > 0.002$"

✓ 4 b jets (b likeness >=0.85 ,0.8, 0.6, 0.2)

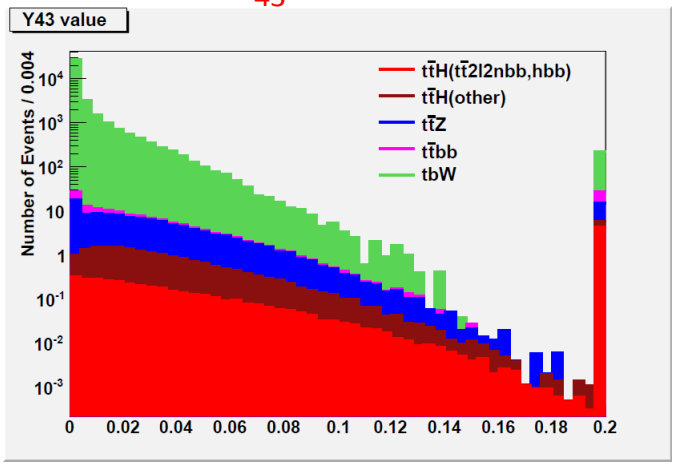
- reject events with very forward jets

✓ |Jet cosθ| ≤ 0.99

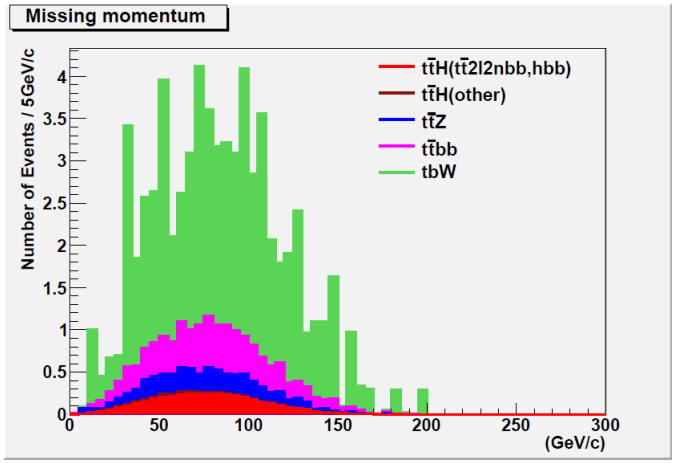
- Missing momentum > 20 GeV
- Jet paring, χ2< 12.5
- Leading jet energy < 112 (Gev)
- smallest jet energy > 38 (GeV)
- 100 < Mjj < 155 (GeV) (range of higgs candidate Mjj)

some variables used event selection (ttH→2l2v+4b)

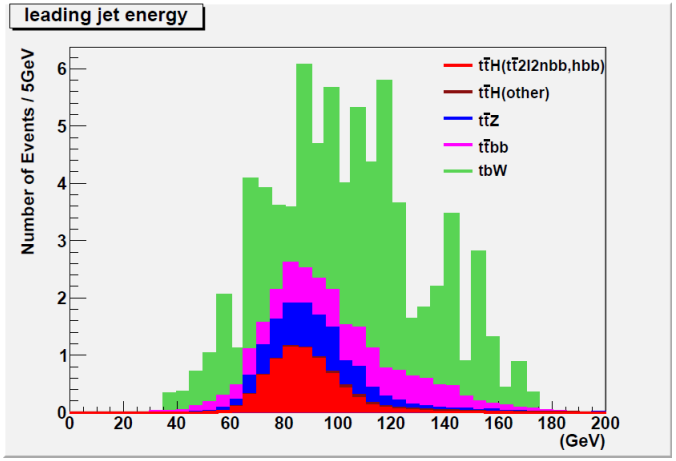
Y_{43} > 0.002



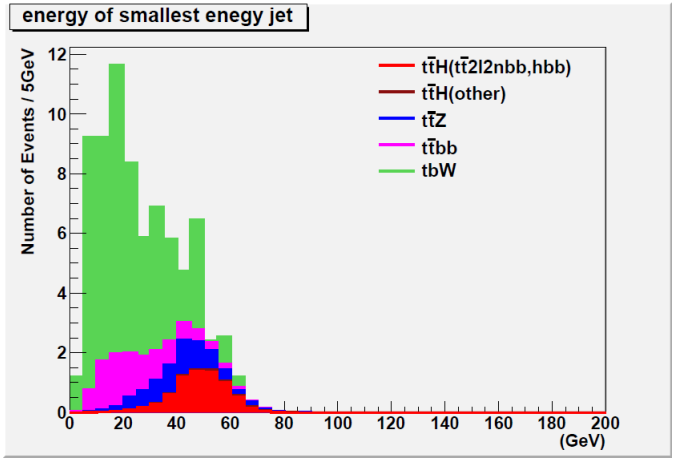
Missing momentum > 20 GeV



Leading jet energy < 112 (Gev)



smallest jet energy > 38 (GeV)



Jet pairing, χ2 Cut (8 jets mode)

- $\sqrt{s}$ = 500GeV 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

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

require b likeness $\geq$ 0.2 to j_1, j_2, j_3, j_6

- Reference values are made from reconstructed jets which are matched with MC information
  - Mtop = 171.5GeV
  - sigma Mtop = 16.8 GeV
  - MW = 80. 5GeV
  - sigma MW = 9.9 GeV
  - angle(jj) = 2.448
  - sigma angle(jj) = 0.277

higgs and top pairing, χ2 Cut (6 jets mode)

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

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

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 $\geq$ 0.2 to j_1, j_2, j_3, j_6

- Reference values are made from reconstructed jets which are matched with MC information

- Mtop = 171.5GeV
- sigma Mtop = 16.8 GeV
- MW = 80. 5GeV
- sigma MW = 9.9 GeV
- angle(jj) = 2.448
- sigma angle(jj) = 0.277

higgs and top pairing, χ2 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 Mjj $\geq$ 80 GeV

ttH → 8jets, 500 fb^{-1}

$\sqrt{s}$	: $S/\sqrt{S+B}$	: $\lvert\Delta g_t/g_t\rvert$ %
480	: 0.59042	: 88.0717
490	: 1.34733	: 38.5949
500	: 2.1717	: 23.9444
510	: 2.96893	: 17.5147
520	: 3.70795	: 14.0239
530	: 4.38629	: 11.8551
540	: 4.993	: 10.4146
550	: 5.50563	: 9.44488
560	: 5.94584	: 8.74562
570	: 6.33231	: 8.21186
580	: 6.6747	: 7.79062
590	: 6.97431	: 7.45594
600	: 7.24148	: 7.18085

ttH → ln + 6jets, 500 fb^{-1}

$\sqrt{s}$	$S/\sqrt{S+B}$	$\lvert\Delta g_t/g_t\rvert$ %
480	0.57541	90.3704
490	1.27453	40.7994
500	2.00677	25.9123
510	2.69726	19.2788
520	3.32768	15.6265
530	3.90086	13.3304
540	4.41032	11.7905
550	4.83863	10.7469
560	5.2051	9.9902
570	5.52592	9.4102
580	5.80966	8.95062
590	6.05733	8.58464
600	6.27784	8.2831

ttH → 2l2n + 4b jets, 500 fb^{-1}

$\sqrt{s}$	: $S/\sqrt{S+B}$	: $\lvert\Delta g_t/g_t\rvert$ %
480	: 0.29792	: 174.538
490	: 0.654923	: 79.3986
500	: 1.0257	: 50.697
510	: 1.37375	: 37.8526
520	: 1.69079	: 30.7549
530	: 1.97869	: 26.28
540	: 2.23437	: 23.2728
550	: 2.4491	: 21.2322
560	: 2.6327	: 19.7516
570	: 2.7933	: 18.6159
580	: 2.93529	: 17.7154
590	: 3.05914	: 16.9982
600	: 3.16936	: 16.4071

ttH → 8jets, 1600 fb^{-1}

$\sqrt{s}$	$S/\sqrt{S+B}$	$\lvert\Delta g_t/g_t\rvert$ %
480	1.04733	49.6498
490	2.40384	21.632
500	3.89502	13.3504
510	5.34728	9.72456
520	6.70016	7.76101
530	7.94612	6.54407
540	9.06307	5.73757
550	10.008	5.19582
560	10.8202	4.80585
570	11.5334	4.50863
580	12.1657	4.27433
590	12.7189	4.08841
600	13.2122	3.93575

ttH → ln + 6 jets, 1600 fb^{-1}

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

480 : 1.02932 : 50.5185

490 : 2.27995 : 22.8076

500 : 3.58981 : 14.4854

510 : 4.825 : 10.7772

520 : 5.95273 : 8.73549

530 : 6.97807 : 7.45192

540 : 7.88943 : 6.5911

550 : 8.6556 : 6.00767

560 : 9.31117 : 5.58469

570 : 9.88506 : 5.26046

580 : 10.3926 : 5.00355

590 : 10.8357 : 4.79896

600 : 11.2301 : 4.63039

ttH → 2l2n + 4b jets, 1600 fb^{-1}

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

480 : 0.53295 : 97.5699

490 : 1.17156 : 44.3852

500 : 1.83483 : 28.3405

510 : 2.45744 : 21.1603

520 : 3.02458 : 17.1925

530 : 3.53958 : 14.691

540 : 3.99696 : 13.0099

550 : 4.38109 : 11.8692

560 : 4.70951 : 11.0415

570 : 4.99681 : 10.4066

580 : 5.25081 : 9.90324

590 : 5.47236 : 9.50229

600 : 5.66952 : 9.17186