KYUSHU UNIVERSITY

Impact of Systematic Uncertainties on the Top Yukawa Coupling Measurement

ILD Meeting at Oshu

Sep. 9th 2014

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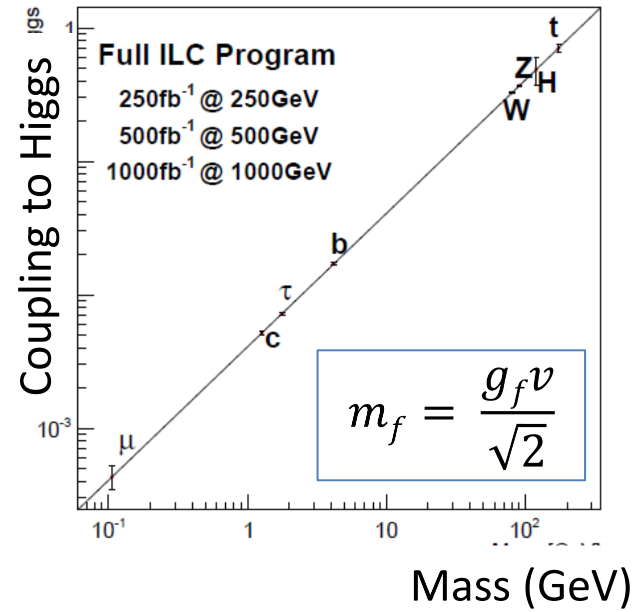
Introduction

- We can directly measure the top-Yukawa coupling via tth channel at $\sqrt{s}$ = 500 GeV.
- We are working on tth study assuming
  - Mh=125 GeV.
  - Polarization : $(Pe^-, Pe^+) = (-0.8, +0.3)$
  - Integrated luminosity 500 fb^{-1}
- ILD full simulation

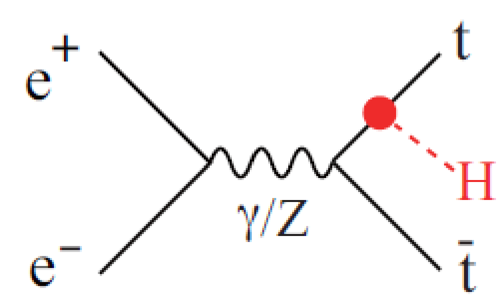


Signals

- tth→8jets (h→bb)
  tth→lν+6jets (h→bb)

Main Backgrounds

- ttZ, ttg(bb), tbW



expected # of events @ $500fb^{-1}$

- $\sqrt{s}$ = 500 GeV, Mh = 125 GeV, $(Pe^-,Pe^+)=(-0.8,+0.3)$

- production cross section

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

- Branching ratio

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(tt6j, hbb)	63.9	tth(ttlv4j,hbb)	61.3
tth(ttall, hnobb)	102.6	ttZ	987
tth(ttlvlv2j, hbb)	14.6	ttg(bb)	529
		tbW	489902

tth→8jets(lν+6jets) 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 8(6) jets
- No (one) isolated lepton
- Use Kt clustering only for removing low Pt background

Event Selection

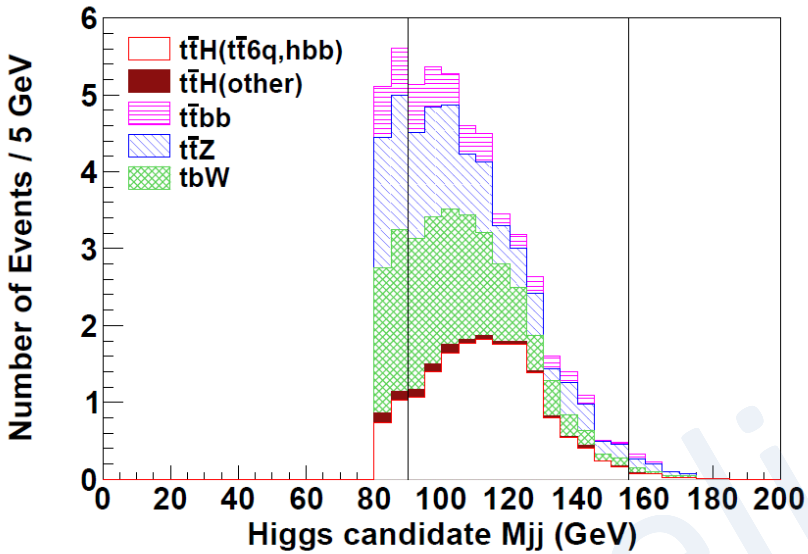
- signal topology
  - ✓ Y cut (6, 8 jet event)
  - ✓ No(one Isolated Lepton)
  - ✓ B jet candidate ≥ 4
- detector acceptance

|Jet cosθ| ≤ 0.99

- jet pairing
  - ✓ $\chi 2 \leq 11.2$ (16.5)
- kinematics
  - ✓ Leading 2 Jet Energy Sum
  - ✓ Lowest 3 Jet Energy Sum (for 8jets mode)
    (Lowest 2 Jet Energy Sum (for 6jets mode))
  - ✓ Missing momentum > 20 GeV (for 6jtes mode)
- reconstructed mass
  - ✓ top candidate Mjjj ≥ 140 GeV
  - ✓ higgs candidate Mjj ≥ 80 GeV
  - ✓ 90GeV ≤ h candidate Mjj ≤ 155GeV

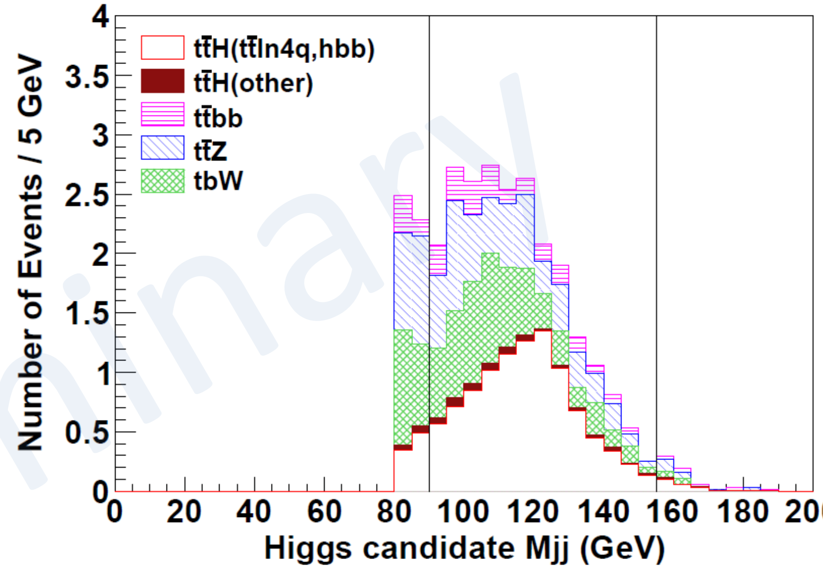
Full Simulation Result

tth→8jets



- $\sqrt{s}$ = 500 GeV, 500 fb^{-1}
- Nsig = 14.73
- Nbkgd = 24.52
- $\text{Nsig}/\sqrt{\text{Nsig} + \text{Nbkgd}}$ = 2.351,

tth→lv+6jets



- $\sqrt{s}$ = 500 GeV, 500 fb^{-1}
- Nsig = 9.768
- Nbkgd = 13.41
- $\text{Nsig}/\sqrt{\text{Nsig} + \text{Nbkgd}}$ = 2.029,

- W→e, μ, τ +ν inclusive analysis

Systematic uncertainties

$$(\Delta\sigma/\sigma) = \sqrt{\frac{S+B}{S^2} + \left(\frac{\Delta B}{S}\right)^2 + \left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta Br}{Br}\right)^2 + \left(\frac{\Delta Pol}{Pol}\right)^2 + \left(\frac{\Delta \varepsilon}{\varepsilon}\right)^2}$$

statistical

systematics

- counting analysis

→ simply consider systematic uncertainties related to # of events

- blikeness and Jet Energy Scale Factor (JESF) will be dominant source of systematic uncertainties.

- assuming $\pm$1% or $\pm$3% uncertainty on blikeness and JESF.
  E^i_{jet}(syst) = E^i_{jet}(1+ ΔJESF) , i = 1-8.
  Same procedure as E_{jet}(syst) is applied to estimate blikeness syst.

Systematic uncertainties

$$(\Delta\sigma/\sigma) = \sqrt{\frac{S+B}{S^2} + \left(\frac{\Delta B}{S}\right)^2 + \left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta Br}{Br}\right)^2 + \left(\frac{\Delta Pol}{Pol}\right)^2 + \left(\frac{\Delta \varepsilon}{\varepsilon}\right)^2}$$

statistical

systematic
related
Background

$$\left(\frac{\Delta B}{S}\right)^2 = (\Delta B^2(\text{btag}) + \Delta B^2(\text{JESF}))/S^2$$

$$\Delta B^2 = \Delta N^2_{ttZ} + \Delta N^2_{ttbb} + \Delta N^2_{tbW} + \Delta N^2_{tth(w/o\ signal)}$$

$$\Delta N = N_{systematic} - N_{center\ value}$$

N: Number of events after event selection

Systematic uncertainties

$$(\Delta\sigma/\sigma) = \sqrt{\frac{S+B}{S^2} + \left(\frac{\Delta B}{S}\right)^2 + \left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta Br}{Br}\right)^2 + \left(\frac{\Delta Pol}{Pol}\right)^2 + \left(\frac{\Delta \varepsilon}{\varepsilon}\right)^2}$$

statistical

systematics related Background

systematic Luminosity

systematic h→bb Branching ratio

systematic polarization

$$\left(\frac{\Delta B}{S}\right)^2 = (\Delta B^2(\text{btag}) + \Delta B^2(\text{JESF}))/S^2$$

$$\Delta B^2 = \Delta N^2_{ttZ} + \Delta N^2_{ttbb} + \Delta N^2_{tbW} + \Delta N^2_{tth(\text{w/o signal})}$$

$$\Delta N = N_{\text{systematic}} - N_{\text{center value}}$$

$$\left(\frac{\Delta L}{L}\right) \sim 0.1\%$$

$$\left(\frac{\Delta Br}{Br}\right) \sim 1\%$$

$$\left(\frac{\Delta Pol}{Pol}\right) \sim 0.1\%$$

Systematic uncertainties

$$(\Delta\sigma/\sigma) = \sqrt{\frac{S+B}{S^2} + \left(\frac{\Delta B}{S}\right)^2 + \left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta Br}{Br}\right)^2 + \left(\frac{\Delta Pol}{Pol}\right)^2 + \left(\frac{\Delta \varepsilon}{\varepsilon}\right)^2}$$

- statistical
- systematics related Background
- systematics Luminosity
- systematics h→bb Branching ratio
- systematics polarization
- **systematics signal event selection**

$$\left(\frac{\Delta B}{S}\right)^2 = (\Delta B^2(btag)+\Delta B^2(JESF))/S^2$$

$$\left(\frac{\Delta \varepsilon}{\varepsilon}\right)^2 = (\Delta S(btag)/S)^2 + (\Delta S(JESF)/S)^2$$

$$\Delta S^2 = \Delta N^2_{tth \rightarrow 8jets/l\nu+6jets}$$

$$\Delta N = N_{systematic} - N_{center\ value}$$

$$\left(\frac{\Delta L}{L}\right) \sim 0.1\%$$

$$\left(\frac{\Delta Br}{Br}\right) \sim 1\%$$

$$\left(\frac{\Delta Pol}{Pol}\right) \sim 0.1\%$$

Current status of Systematic uncertainties

b likeness $\pm$1%
Jet energy scale factor $\pm$1%

tth→8 jets	blikeness	JESF
signal	1 %	1 %
ttZ	1 %	3%
ttbb	1 %	3%
tbW →6jets	<2 %	<4 %

tth→lν+6jets	blikeness	JESF
signal	1%	2 %
ttZ	2%	5 %
ttbb	2%	5 %
tbW →ln+4jets	<3%	<9%

b likeness $\pm$3%
Jet energy scale factor $\pm$3%

tth→8 jets	blikeness	JESF
signal	2 %	7 %
ttZ	2 %	15 %
ttbb	3 %	5%
tbW	<4 %	<15%

tth→lν+6jets	blikeness	JESF
signal	2 %	7 %
ttZ	5 %	14 %
ttbb	5 %	15 %
tbW→ln+4jets	<4 %	<20 %

Significance and Precision of top-Yukawa coupling measurement with Systematic Uncertainties

- Mh=125 GeV, $\sqrt{s}$ = 500 GeV, 500 fb^{-1}
- systematics: blikenss$\pm$1,3%, JESF$\pm$1,3%
  Br 1%, L 0.1%, pol 0.1%

tth→8 Jets

with systematics	signficance	$|\Delta g_t/g_t|$
0% (stat. only)	2.351	22.11%
1% (b, JESF)	2.345	22.17%
3% (b, JESF)	2.252	23.09%

tth→lν+6jets

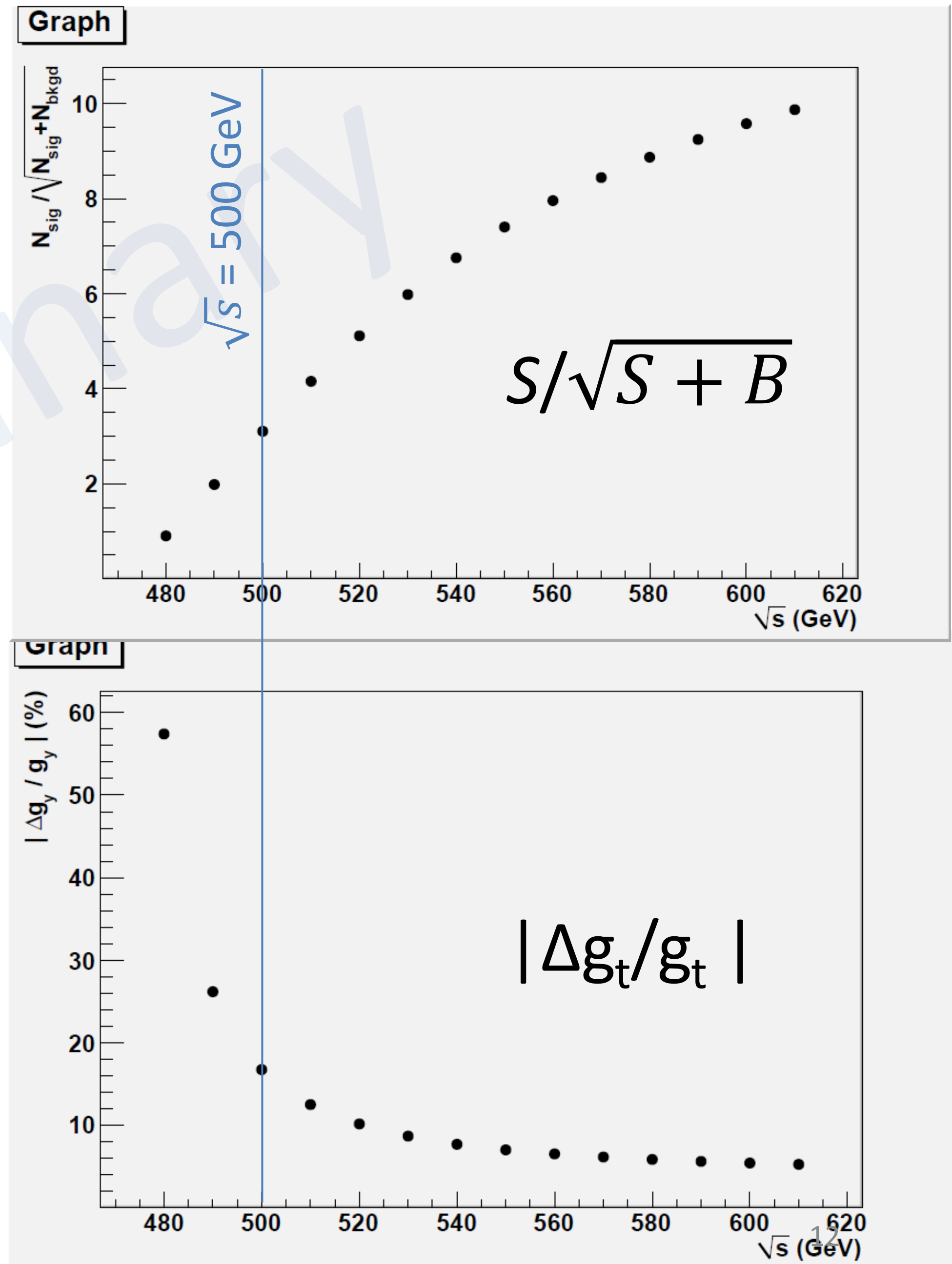
with systematics	signficance	$|\Delta g_t/g_t|$
0% (stat. only)	2.029	25.62%
1% (b, JESF)	2.016	25.79%
3% (b, JESF)	1.965	26.46%

Rough estimation of significance and $|\Delta g_t/g_t|$ @$\sqrt{s}$ = 480-610 GeV, 500 fb^{-1} 8 jets & lv6jtes combined result (with only statistical uncertainty)

$\sqrt{s}$	$S/\sqrt{S+B}$	$\lvert\Delta g_t/g_t\rvert$ %
490	1.985	26.18
500	3.105	16.74
510	4.156	12.51
520	5.113	10.16
530	5.983	8.691
540	6.755	7.697
550	7.403	7.023

cross section (fb)

$\sqrt{s}$	tth(total)	ttz	ttbb	tbw
490	0.272	1.569	1.009	991.1
500	0.485	1.974	1.058	979.8
510	0.725	2.373	1.105	967.0
520	0.981	2.753	1.151	953.5
530	1.244	3.118	1.199	939.4
540	1.504	3.469	1.243	924.5
550	1.743	3.806	1.285	909.5



top Yukawa coupling measurement @ILC and HL-LHC

- Cut base event selection & counting analysis
- ILC 500 fb^{-1}

$\sqrt{s}$	$S/\sqrt{S+B}$	$\|\Delta g_t/g_t\|$ %
500	3.105	16.74
520	5.113	10.16
550	7.403	7.023

- ILC 1600fb^{-1} at $\sqrt{s}$ = 500 GeV

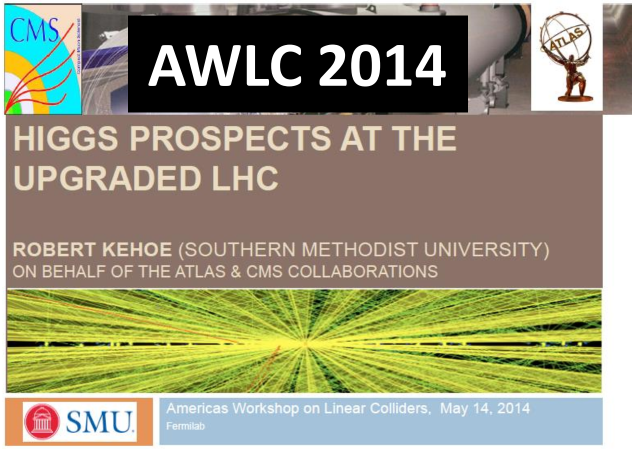
$|\Delta g_t/g_t|$ ~ 9.4%

*Number of signals and backgrounds scaled by a factor of 1600fb^{-1}/500fb^{-1}.

- HL-LHC 3000fb^{-1} at $\sqrt{s}$ = 14 TeV

  ATLAS 9-20% (individual 3 channels)

  CMS 7-10 %



Summary

- estimate impact of systematic uncertainties on sensitivity
- systematic uncertainties are not small,
  but statistical uncertainty is dominant in this study.

$S/\sqrt{S+B}$ ($|\Delta g_t/g_t|$): stat. only → 1% syst. on JESF and blikeness

tth→8jets : 2.351 (22.11%) → 2.345 (22.17%)

tth→lν+6jets: 2.029 (25.62%) → 2.016 (25.79%)

- There are still room to improve tth analysis
  - counting analysis and cut base event selection → MVA
  - W→e, μ, τ +ν inclusive analysis → separate hadronic tau
  - Lepton identification
  - h→WW channel

Backup

Systematic uncertainties on tbW events

$\left(\frac{\Delta B}{S}\right)^2$ = $(\Delta B^2(\mathrm{btag})+\Delta B^2(\mathrm{JESF}))/S^2$

- in signal category (4 b tagged), 0~a few MC events are passed all event selection
- too low statistics to estimate systematic uncertainty

I used 2 b tagged category to estimate uncertainty on tbW background event selection.

In this analysis, definition of ΔN(tbW,4btag) is

- ΔN(tbW,4btag) = N(tbW,4btag)x($\frac{\Delta N(tbW,2btag)}{N(tbW,2btag)}$)

Event Selection (tth→8jets)

- Jet clustering : Durham algorithm

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

  forced 8 jet clustering
  Select events with large Y_{87} as 8jets category
  if Y_{87} is small, we use Y_{76} value
  ✓ "$Y_{87} > 0.00055$" + "$Y_{87} <= 0.00055$ && $Y_{76} > 0.0012$"
- Isolated Lepton

Definition

$\cos\theta_{cone} = 0.98$
$E_{cone} < \sqrt{6(Elep - 15)}$

  ✓ require no Isolated lepton

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

- reject events with forward jets

✓ $|\text{Jet} \cos\theta| \leq 0.99$

Jet pairing, χ2 Cut

- $\sqrt{s}$ = 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.

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

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

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

reject large χ^2 events

✓ $\chi^2 \leq 11.2$

Jet Energy, M_{top} and Mjj range (8jets)

- ttg(bb) and tbW events are assumed to have high energy jets related to top decay.
- ttg(bb) events also have low energy jets related to g

✓ energy sum of lowest 3 jets > 72 GeV

✓ energy sum of highest 2 jets < 189 GeV

✓ top candidate Mjjj $\geq$ 140 GeV

- select a range of higgs candidate Mjj to maximize $S/\sqrt{S+B}$

✓ 90 GeV $\leq$ higgs candidate Mjj $\leq$ 155 GeV

energy sum of lowest 3 jets

tth6qhbb red
ttz blue
ttbb pink
ttbar green

energy sum of highest 2 jets

tth6qhbb red
ttz blue
ttbb pink
ttbar green

Event Selection (tth→ln+6jets)

- select 6 jets event

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

forced 6 jet clustering

Select events with large Y_{65} as 6jets category

if Y_{65} is small, we use Y_{54} value

✓ "$Y_{65} > 0.00165$" + "$Y_{65} <= 0.00165$ && $Y_{54} > 0.005$"

- Isolated Lepton

$\cos\theta_{cone} = 0.98$

$E_{cone} < \sqrt{6(Elep - 15)}$

✓ require exact one isolated lepton

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

- reject events with forward jets

✓ $|\text{Jet} \cos\theta| \leq 0.99$

- events with large missing momentum

✓ MP > 20 GeV

higgs and top pairing, χ2 Cut

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

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

A W mass is reconstructed with Isolated lepton and Missing P

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

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

reject large χ^2 events

✓ $\chi^2 \leq 16.5$

Jet Energy, M_{top} and Mjj range

- ttg(bb) and tbw events are assumed to have high energy jets related to top decay.
- ttg(bb) events also have low energy jets related to g

✓ energy sum of lowest 2 jets > 58 GeV

✓ energy sum of highest 2 jets < 195 GeV

✓ top candidate Mjjj(Mjlv) $\geq$ 140 GeV

- select a range of higgs candidate Mjj to maximize S/$\sqrt{S+B}$

✓ 90 GeV $\leq$ higgs candidate Mjj $\leq$ 155GeV

energy sum of
lowest 2 jets

tth6qhbb red
ttz blue
ttbb pink
ttbar green

energy sum of
highest 2 jets

tth6qhbb red
ttz blue
ttbb pink
ttbar green