

# tth study @ $\sqrt{s} = 500$ GeV

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# Motivation

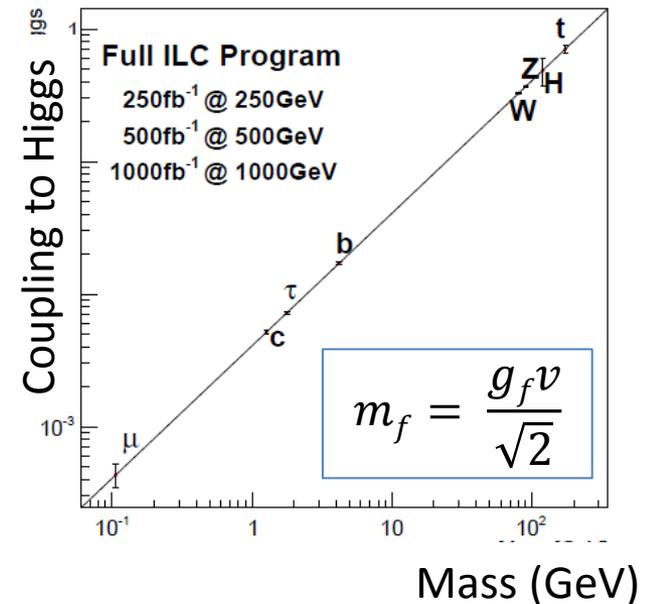
- Higgs boson mass is  $\sim 125$  GeV.
- We can directly measure the top quark Yukawa coupling via  $t\bar{t}h$  channel.
- Previous  $t\bar{t}h$  analysis was performed assuming  $M_h = 120$  GeV.  
(R. Yonamine et al., PHYSICAL REVIEW D 84, 014033(2011))

- We are working on  $t\bar{t}h$  study @  $\sqrt{s} = 500$  GeV assuming  $M_h = 125$  GeV.
- Polarization :  $(P_{e^-}, P_{e^+}) = (-0.8, +0.3)$

$M_h = 120 \text{ GeV} \rightarrow M_h = 125 \text{ GeV}$

production cross section (fb) 0.641  $\rightarrow$  0.485

Branching ratio of  $h \rightarrow b\bar{b}$  0.68  $\rightarrow$  0.577



# Signal and Background

ttbar cross section is increased around ttbar threshold by ttbar bound-state effect

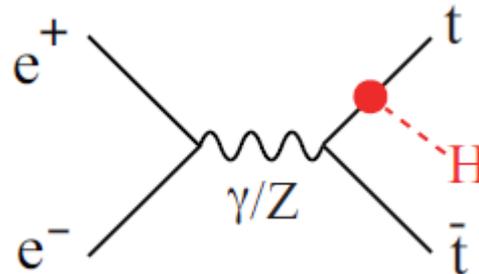
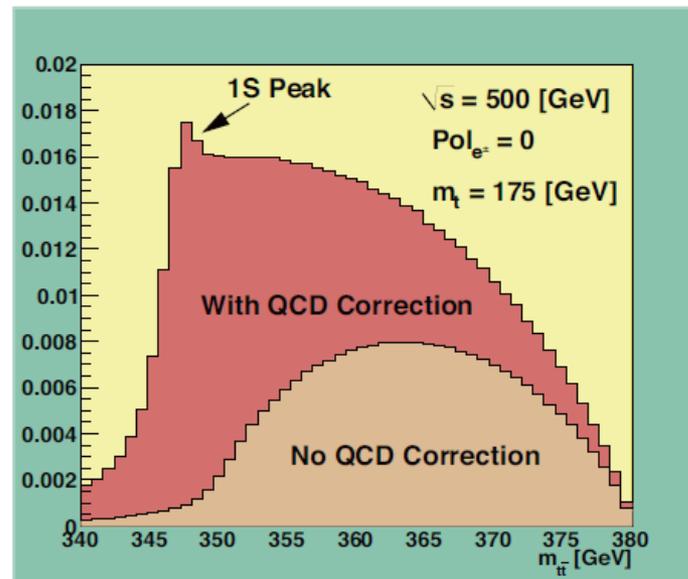
- tth cross section is enhanced
- ttZ cross section is also increased

Signals

- tth  $\rightarrow$  8jets (h  $\rightarrow$  bb)
- tth  $\rightarrow$  ln+6jets (h  $\rightarrow$  bb)

Main Backgrounds

- ttZ, ttg(bb), tbw



# expected # of events @ 1000fb<sup>-1</sup>

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

Process	$\sigma$ (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
$tt \rightarrow bq qbqq$	0.457
$tt \rightarrow blvbqq$	0.438
$tt \rightarrow blvblv$	0.105

- expected # of signals and Backgrounds(@1000fb<sup>-1</sup>)

<b>tth(tt6j, hbb)</b>	<b>127.9</b>	<b>tth(ttl n4j, hbb)</b>	<b>122.6</b>
tth(ttall, hnobb)	205.2	ttZ	1974
tth(ttlvlv2j, hbb)	29.3	ttg(bb)	1058
		tbW	979807

# tth $\rightarrow$ 8jets (ln+6jets) analysis

- tth cross section is proportional to the  $g_t^2$
- cut based event selection and counting

In this analysis, higgs decays into two b jets

- 4 b jets out of 8(6) jets
- No (one) isolated lepton
- large angle between higgs candidate b jets

## Event Selection

- signal topology
- ✓ Y cut (6, 8 jet event)
- ✓ No(one Isolated Lepton)
- ✓ B jet candidate  $\geq 4$
- detector acceptance  
 $|\text{Jet } \cos\theta| \leq 0.99$
- jet pairing
- ✓  $\chi^2 \leq 9.5$  (19)
- kinematics cut
- ✓ Leading 2 Jet Energy Sum
- ✓ Lowest 3 Jet Energy Sum (only 8jet mode)
- reconstructed mass cut
- ✓ top candidate  $M_{jjj} \geq 140$  GeV
- ✓ higgs candidate  $M_{jj} \geq 80$  GeV
- ✓  $100$  (90)GeV  $\leq$  h candidate  $M_{jj} \leq 160$ (150)GeV

tth  $\rightarrow$  8 jets channel

# Event Selection (tth→8jets)

- Jet clustering : Durham algorithm 
$$Y_{ij} = \frac{\min\{E_i^2, E_j^2\}(1 - \cos \theta)}{E_{\text{cm}}^2}$$
  - forced 8 jet clustering
  - Select events with large  $Y_{8 \rightarrow 7}$  as 8jets category
  - if  $Y_{8 \rightarrow 7}$  is small, check  $Y_{7 \rightarrow 6}$  value
  - ✓ “ $Y_{8 \rightarrow 7} > 0.0009$ ” + “ $Y_{8 \rightarrow 7} \leq 0.0009 \ \&\& \ Y_{7 \rightarrow 6} > 0.0025$ ”

- Isolated Lepton

Definition

$$\begin{aligned} \cos \theta_{\text{cone}} &= 0.98 \\ E_{\text{cone}} &< \sqrt{6(E_{\text{lep}} - 15)} \end{aligned}$$

- ✓ require no Isolated lepton
- ✓ B jet candidate  $\geq 4$  (btag  $\geq 0.85, 0.8, 0.6, 0.2$ )
- reject events with forward jets
- ✓  $|\text{Jet } \cos \theta| \leq 0.99$

# Jet pairing, $\chi^2$ Cut

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

- $P_{\text{higgs}}$  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  $\chi^2$  value

reject large  $\chi^2$  events

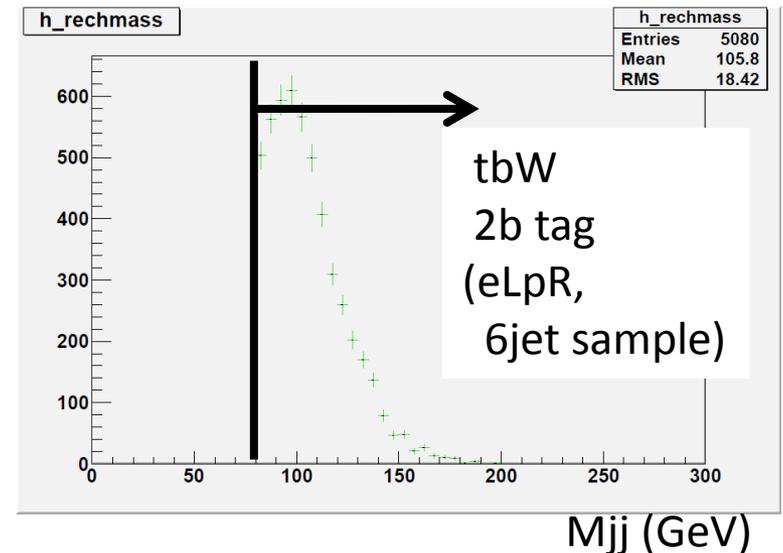
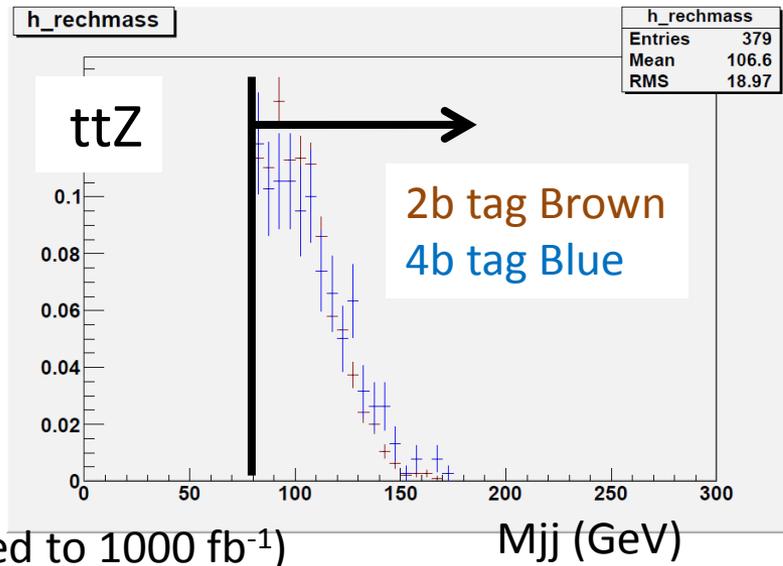
✓  $\chi^2 \leq 9.5$

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

- require b tag  $\geq 0.2$  to  $j_1, j_2, j_3, j_6$ 
  - Mean value and RMS of angle and reconstructed Mass with jets matched MC information
    - $M_{\text{top}} = 171.9\text{GeV}$
    - $\sigma_{M_{\text{top}}} = 15.5\text{ GeV}$
    - $M_W = 80.385\text{ GeV}$
    - $\sigma_{M_W} = 9.8\text{ GeV}$
    - $\text{angle}(jj) = 2.468$
    - $\sigma_{\text{angle}(jj)} = 0.2858$

# Mjj shape of tbW event

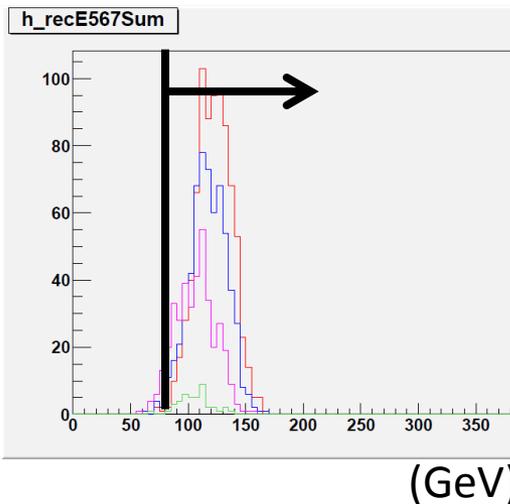
- tbw event shape is difficult to estimate with 4 b tag category due to the small statistics of MC samples. (I will use Junping's large stat. sample.)
  - compare ttz shape of 2 b tag category and 4 b tag category
  - check Mjj shape of ttz events
    - 2 b tag +  $Y8 \rightarrow 7 < 0.0008$  &&  $Y7 \rightarrow 6 < 0.0025$
    - 4 b tag +  $Y8 \rightarrow 7 > 0.0009$  ||  $Y7 \rightarrow 6 > 0.0025$
  - In  $M_{jj} \geq 80$  GeV, the Mjj shape of 2 b tag category is similar to 4 b tag category.
- ✓ We estimate Mjj shape of tbW events with 2 b tag category
- ✓ higgs candidate  $M_{jj} \geq 80$  GeV



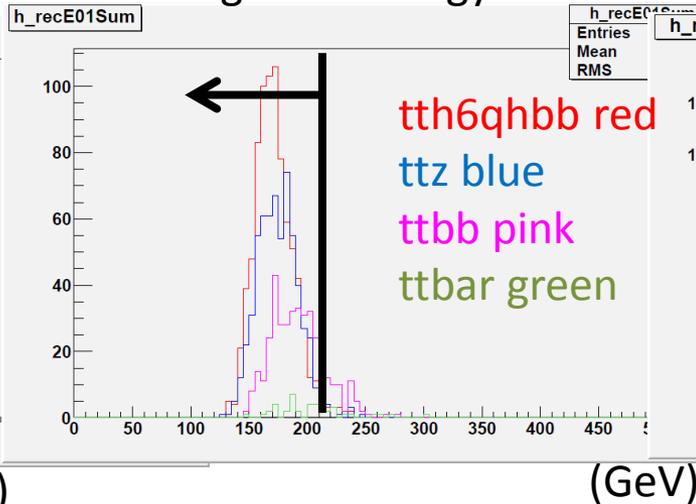
# Jet Energy and $M_{\text{top}}$ range

- ttg(bb) and tbw event is assumed to have high energy jets related to top decay.
- ttg(bb) events also have low energy jets related to g
- ✓ lowest 3 jets energy sum > 86 GeV
- ✓ highest 2 jets energy sum < 207 GeV
- ✓ top candidate  $M_{\text{jij}}$   $\geq 140$  GeV

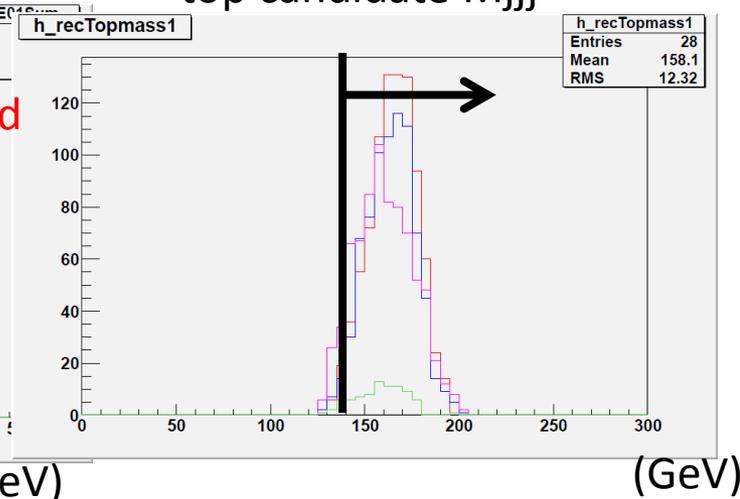
Lowest 3 Jet Energy Sum



Leading 2 Jet Energy Sum



top candidate  $M_{\text{jij}}$



(not scaled to  $1000 \text{ fb}^{-1}$ )

# Result of event selection ( $t\bar{t}h \rightarrow 8\text{jets}$ )

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

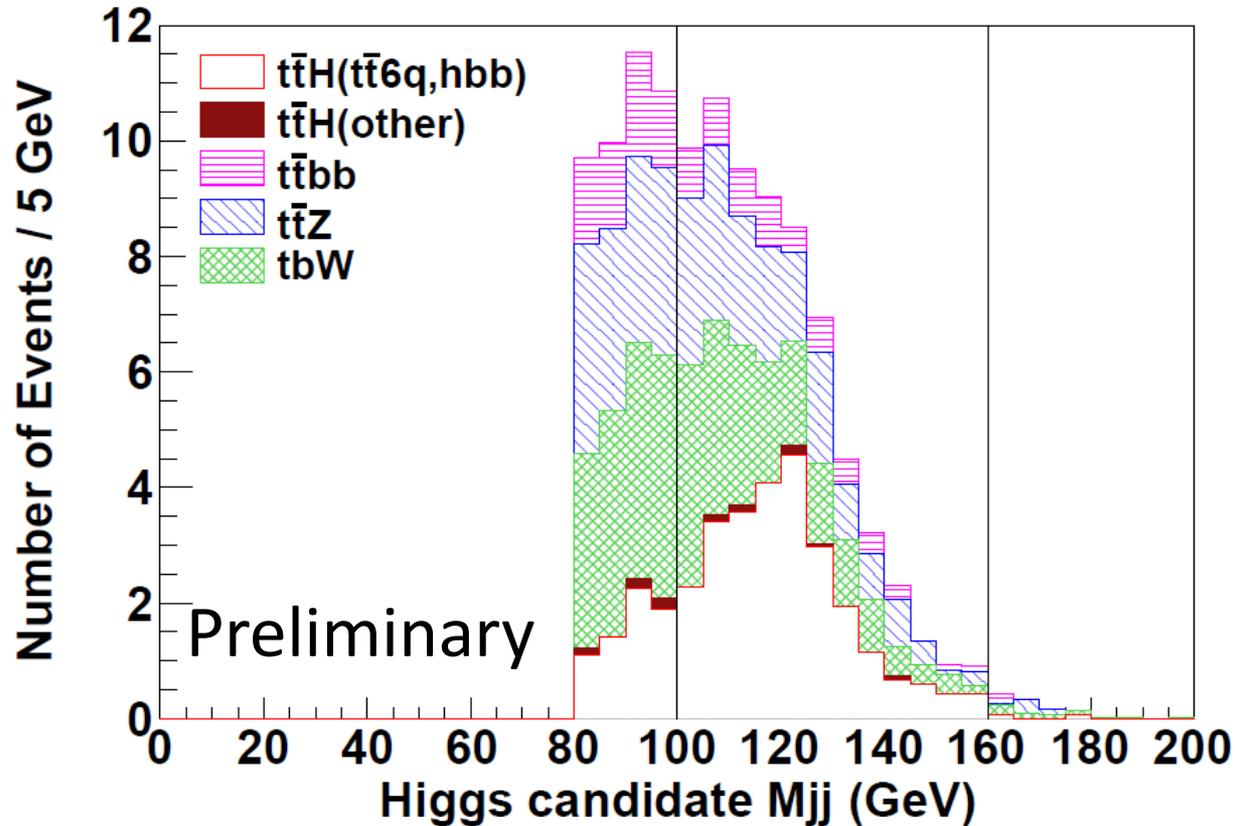
✓  $100 \text{ GeV} \leq \text{higgs candidate } M_{jj} \leq 160 \text{ GeV}$

## Preliminary

Selection	$t\bar{t}h(tt6j \text{ hbb})$	$t\bar{t}h(ttall \text{ hno}bb)$	$t\bar{t}h(t\bar{t}ln4j \text{ hbb})$	$t\bar{t}h(t\bar{t}l2l2n2j \text{ hbb})$	$t\bar{t}Z$	$t\bar{t}g^*(bb)$	$t\bar{t}bW$
No Cut	127.9	205.2	122.6	29.4	1974.6	1058.6	979807.7
$Y_{8 \rightarrow 7}$ (8 jets)	118.7	96.4	17.6	0.412	1030.4	613.3	582660.8
No Isolated Lepton	97.3	80.8	6.8	0.060	602.2	264.7	83102.9
b jet candidate $\geq 4$	57.0	2.1	3.5	0.003	71.3	111.3	1657.2
$ \text{Jet } \cos \theta  \leq 0.99$	54.1	2.0	3.1	0	67.3	104.8	698.2
$\chi^2 \leq 9.5$	38.1	0.9	0.9	0	42.3	38.3	178.8
$h$ Candidate $M_{jj} \geq 80$ (GeV)	34.9	0.7	0.4	0	34.2	20.2	89.0
Leading 2 JetEnergySum < 207.5 GeV	34.0	0.7	0.4	0	32.6	14.6	52.6
Lowest 3 JetEnergySum > 86.65 GeV	33.8	0.7	0.4	0	31.6	13.0	52.6
$M_{top} \geq 140$ (GeV)	32.8	0.7	0.3	0	30.5	11.8	34.7
$100 \leq h$ Candidate $M_{jj} \leq 160$ (GeV)	26.0	0.5	0.06	0	16.9	5.6	18.7

- $t\bar{t}h \rightarrow 8\text{jet}$ :  $N_{sig} = 26.0$
- $N_{bkgd} = 41.74$

# Significance ( $t\bar{t}H \rightarrow 8\text{jets}$ )



- $\sqrt{s} = 500 \text{ GeV}, 1000 \text{ fb}^{-1}$
- Cut base + counting analysis
- $N_{\text{sig}}/\sqrt{N_{\text{sig}} + N_{\text{bkgd}}} = \underline{3.16}, |\Delta g_t/g_t| \sim 15.8\%$

tth  $\rightarrow$  ln+6jets channel

# Event Selection ( $t\bar{t}h \rightarrow l\nu + 6\text{jets}$ )

- select 6 jets event

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

forced 6 jet clustering

Select events with large  $Y_{6 \rightarrow 5}$  as 6jets category

if  $Y_{6 \rightarrow 5}$  is small, check  $Y_{5 \rightarrow 4}$  value

✓ “ $Y_{6 \rightarrow 5} > 0.002$ ” + “ $Y_{6 \rightarrow 5} \leq 0.002 \ \&\& \ Y_{5 \rightarrow 4} > 0.036$ ”

- Isolated Lepton

$$\cos\theta_{\text{cone}} = 0.98$$

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

✓ require exact one Isolated lepton

✓ B jet candidate  $\geq 4$  (btag  $\geq 0.85, 0.8, 0.6, 0.2$ )

- reject events with forward jets

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

# higgs and top pairing, $\chi^2$ Cut

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

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

a W mass is reconstructed with Isolated lepton and Missing P

- try all combination and choose a pair with minimum  $\chi^2$  value

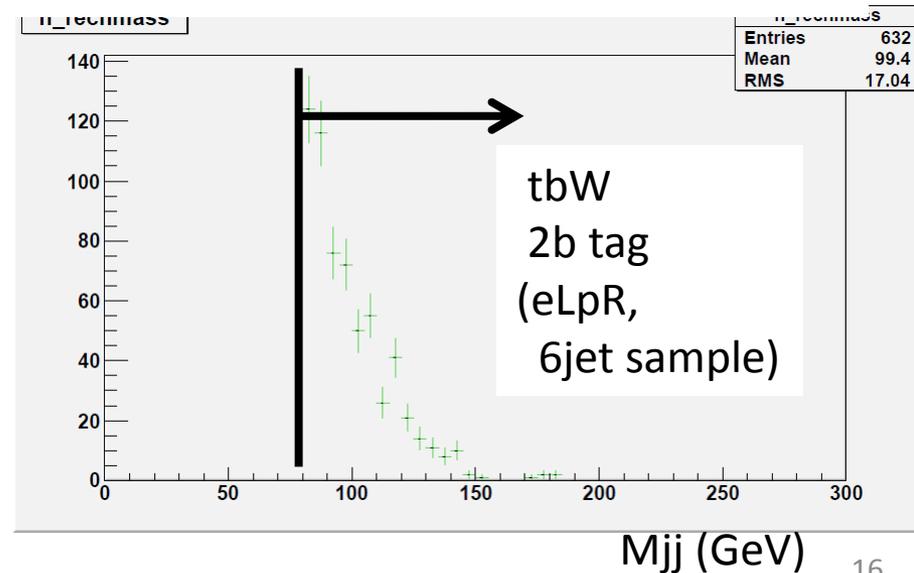
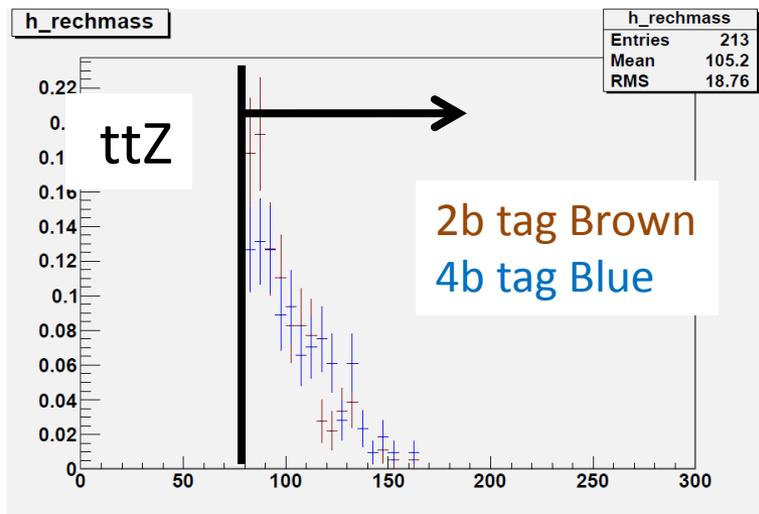
reject large  $\chi^2$  events

✓  $\chi^2 \leq 19$

- require b tag  $\geq 0.2$  to  $j_1, j_2, j_3, j_6$ 
  - Mean value and RMS of angle and reconstructed Mass with jets matched MC information
    - $M_{\text{top}} = 171.9 \text{ GeV}$
    - $\sigma_{M_{\text{top}}} = 15.5 \text{ GeV}$
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    - $\text{angle}(jj) = 2.468$
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# Mjj shape of tbW event

- tbw event shape is difficult to estimate with 4 b tag category due to the small statistics of MC samples. (I will use Junping's large stat. sample.)
- compare ttz shape of 2 b tag category and 4 b tag category
- check Mjj shape of ttz events
  - 2 b tag +  $Y6 \rightarrow 5 < 0.002$  &&  $Y5 \rightarrow 4 < 0.036$
  - 4 b tag +  $Y6 \rightarrow 5 > 0.002$  ||  $Y5 \rightarrow 4 > 0.036$
- In  $M_{jj} \geq 80$  GeV, the Mjj shape of 2 b tag category is similar to 4 b tag category. (KS probability = 0.02)
- ✓ We estimate Mjj shape of tbW events with 2 b tag category
- ✓ higgs candidate  $M_{jj} \geq 80$  GeV



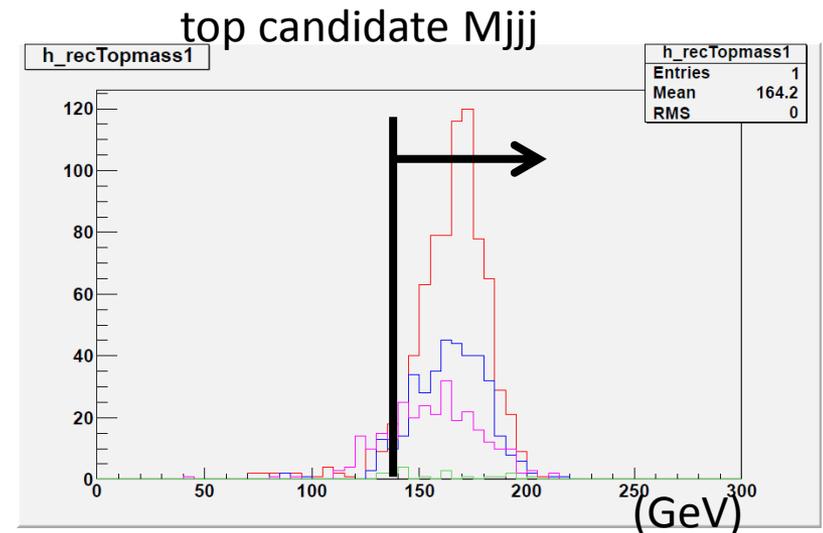
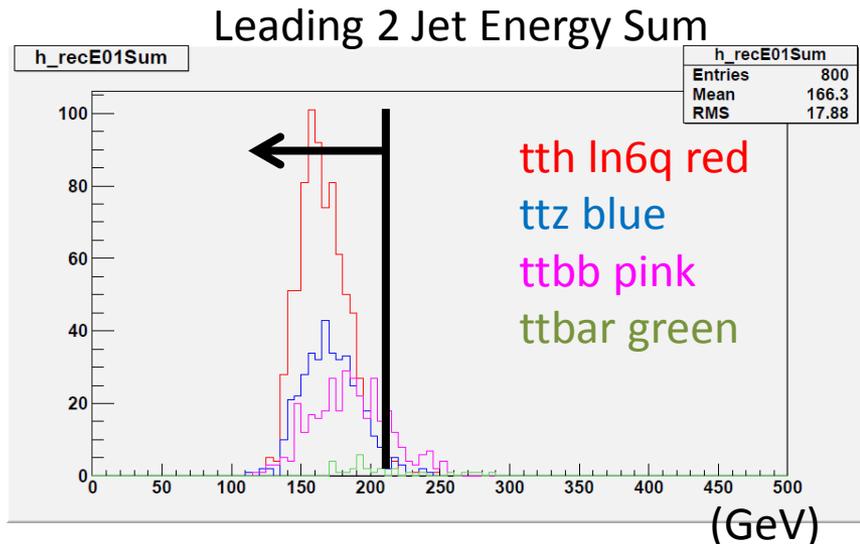
(not scaled to  $1000 \text{ fb}^{-1}$ )

Mjj (GeV)

Mjj (GeV)

# Jet Energy and $M_{\text{top}}$ range

- ttg(bb) and tbw event is assumed to have high energy jets related to top decay.
- ttg(bb) events also have low energy jets related to g
- ✓ ~~lowest 3 jets energy sum > 86 GeV~~
- ✓ highest 2 jets energy sum < 210 GeV
- ✓ top candidate  $M_{\text{jij}}$   $\geq 140$  GeV



(not scaled to  $1000 \text{ fb}^{-1}$ )

# Result of event selection ( $t\bar{t}h \rightarrow l n + 6 \text{jets}$ )

At last, We select a range of higgs candidate  $M_{jj}$  to maximize  $S/\sqrt{S+B}$

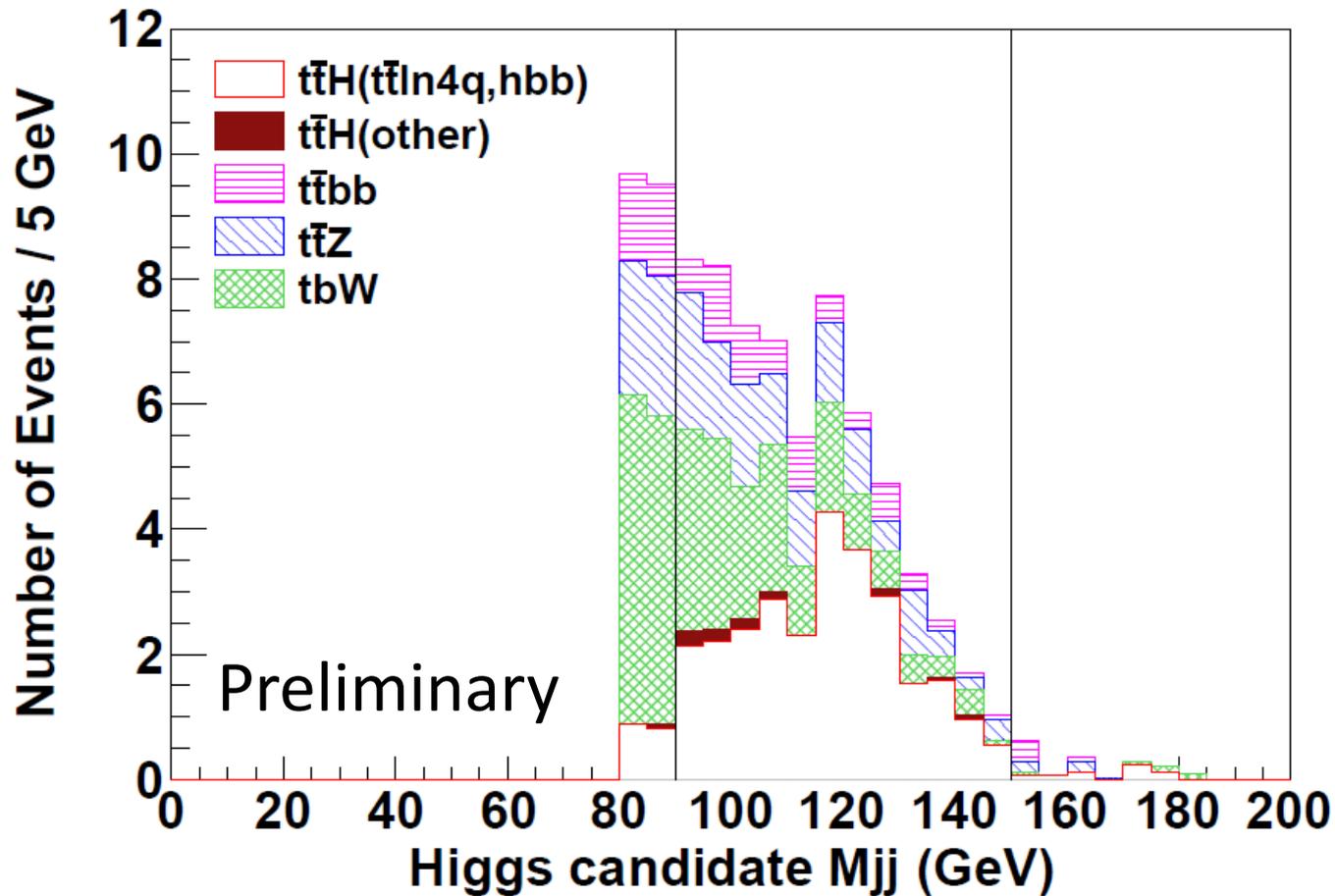
✓  $90 \text{ GeV} \leq \text{higgs candidate } M_{jj} \leq 150 \text{ GeV}$

Preliminary

Selection	$t\bar{t}h(t\bar{t}l n 4j \text{ } hbb)$	$t\bar{t}h(t\bar{t}all \text{ } hnobb)$	$t\bar{t}h(t\bar{t}6j \text{ } hbb)$	$t\bar{t}h(t\bar{t}2l2n2j \text{ } hbb)$	$t\bar{t}Z$	$t\bar{t}g^*(bb)$	$t\bar{t}bW$
No Cut	122.6	205.2	127.9	29.3	1974.6	1058.6	979807.7
$Y_{cut}$ (6 jets)	99.6	76.9	8.9	6.3	695.4	378.5	342027.9
One Isolated Lepton	82.3	67.5	8.7	1.8	419.9	176.7	49812.8
b jet candidate $\geq 4$	45.4	1.2	4.6	1.0	41.4	76.6	806.3
$ \text{Jet } \cos \theta  \leq 0.99$	44.4	1.2	4.2	1.0	40.2	73.4	339.8
Missing P $> 20$	44.1	1.2	1.1	1.0	36.8	66.2	311.6
$\chi^2 \leq 19$	39.1	1.0	0.6	0.7	30.5	46.5	185.8
$h$ Candidate $M_{jj} \geq 80$ (GeV)	34.0	0.6	0.4	0.3	21.2	19.7	72.1
Leading 2 JetEnergySum $< 210$ GeV	33.5	0.6	0.3	0.3	20.0	15.5	49.3
$M_{top} \geq 140$ (GeV)	29.6	0.6	0.06	0.17	17.1	9.2	26.8
$90 \leq h$ Candidate $M_{jj} \leq 150$ (GeV)	27.4	0.5	0.06	0.17	12.4	6.0	16.4

- $t\bar{t}h \rightarrow l n + 6 \text{jet}$ :  $N_{sig} = 27.4$
- $N_{bkgd} = 35.64$

# Significance ( $t\bar{t}H \rightarrow l n + 6\text{jets}$ )



- $\sqrt{s} = 500 \text{ GeV}, 1000 \text{ fb}^{-1}$
- Cut base + counting analysis
- $N_{\text{sig}}/\sqrt{N_{\text{sig}} + N_{\text{bkgd}}} = \underline{3.45}, |\Delta g_t/g_t| \sim 14.5\%$

# Summary and Plan

- $\sqrt{s} = 500 \text{ GeV}$ ,  $L = 1000 \text{ fb}^{-1}$ ,  $M_h = 125 \text{ GeV}$
- $t\bar{t}h \rightarrow 8\text{jets}$   $S/\sqrt{S+B} = 3.16$
- $t\bar{t}h \rightarrow 1n+6\text{jets}$   $S/\sqrt{S+B} = 3.45$
- combine  $\rightarrow$  significance = 4.67  
 $|\Delta g_t/g_t| = 10.6\%$

to do

- increase MC samples
- tbw shape
- systematics
  - b tagging efficiency
  - jet energy scale
  - $t\bar{t}b\bar{a}$  bound-state effect .....
- MVA

# Rough estimation of significance and $|\Delta g_t/g_t|$

$$\sqrt{s} = 480-610 \text{ GeV}$$

1000fb<sup>-1</sup>, tth → 8jet only

@ 2014/03

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

490 : 1.89 : 26.4

500 : 2.92 : 17.1

510 : 3.87 : 12.8

520 : 4.74 : 10.5

530 : 5.53 : 9.03

540 : 6.22 : 8.02

550 : 6.81 : 7.33

cross section (fb)

$$\sqrt{s} : \text{tth(total)} : \text{ttz} : \text{ttbb} : \text{tbw}$$

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

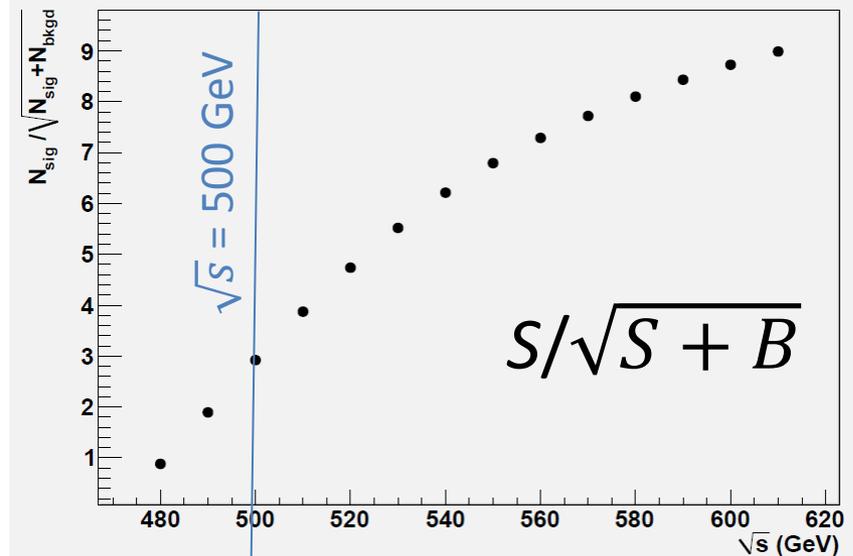
520 : 0.981 : 2.753 : 1.151 : 953.5

530 : 1.244 : 3.118 : 1.199 : 939.4

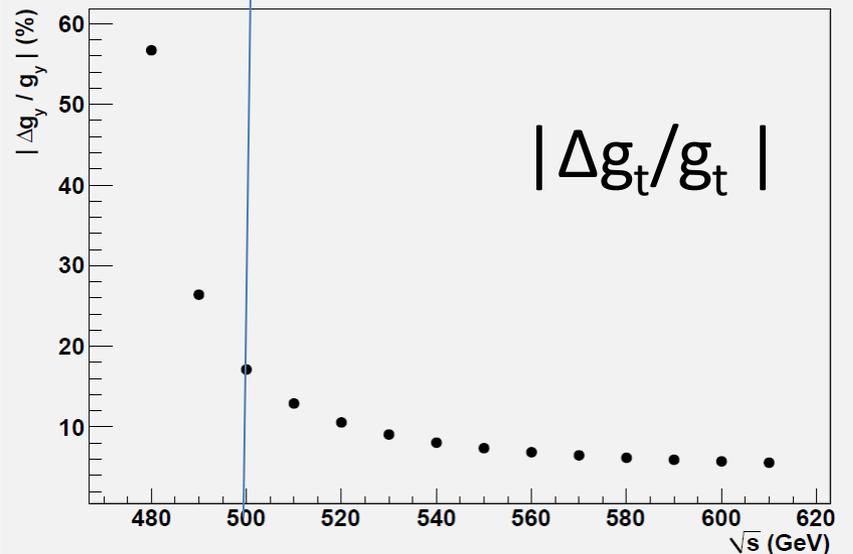
540 : 1.504 : 3.469 : 1.243 : 924.5

550 : 1.743 : 3.806 : 1.285 : 909.5

Graph



Graph



backup

# 事象選別

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

強制的に8ジェットにしているため

Y8→7が大きい事象を選別して8jet事象とする

(結合したクラスター間の距離が長いとYi→jが大きくなる)

✓ “Y8→7 > 0.0009”

- Isolated Lepton

Definition

$$\cos \theta_{\text{cone}} = 0.98$$

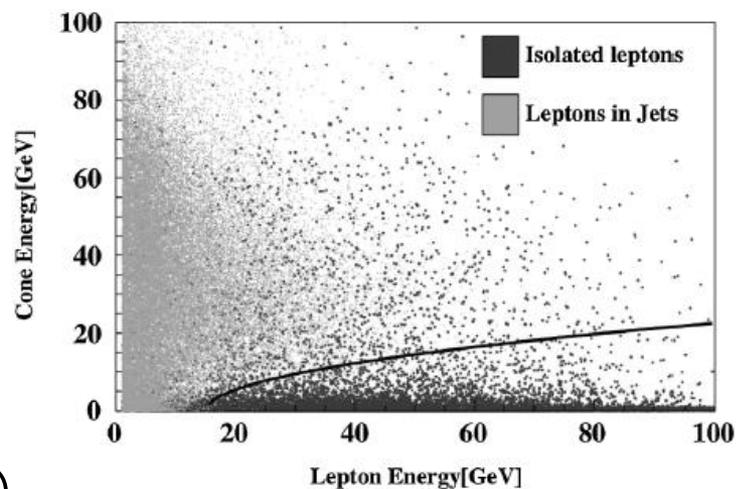
$$E_{\text{cone}} < \sqrt{6(E_l - 15)}$$

✓ Isolated leptonがないことを要求

- ✓ B jet candidate  $\geq 4$  (シグナル4q4b)

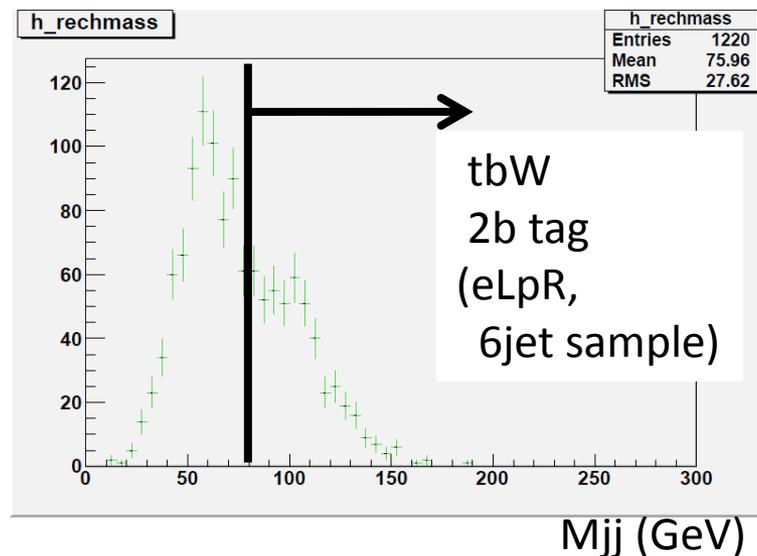
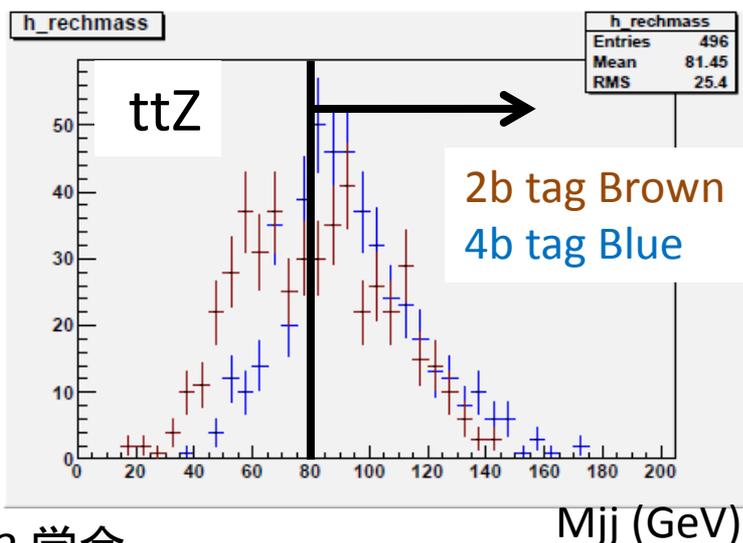
- 前方jetを含む事象をカット

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



# tbW事象のMjj shapeの見積もり

- 最終的にMjjの分布を用いてシグナル、背景事象の数を見積もるが現状MCの数が少なく、事象選別後のtbW事象数がたいへん少ない
  - まずttzのMjjの形を確認
    - 2 b tag + Y8 $\rightarrow$ 7 < 0.0008 (shape見積もり用)
    - 4 b tag + Y8 $\rightarrow$ 7 > 0.0009 (解析用)
  - 上記の2条件の場合Mjj  $\geq$  80 GeVの範囲では、ttzのMjj shapeは似ている。(KS probability = 0.69)
- ✓ tbW事象のMjjの形は 2 b tag + Y8 $\rightarrow$ 7 < 0.008 categoryを使用
- ✓ higgs candidate Mjj  $\geq$  80 GeV



# 事象選別の結果

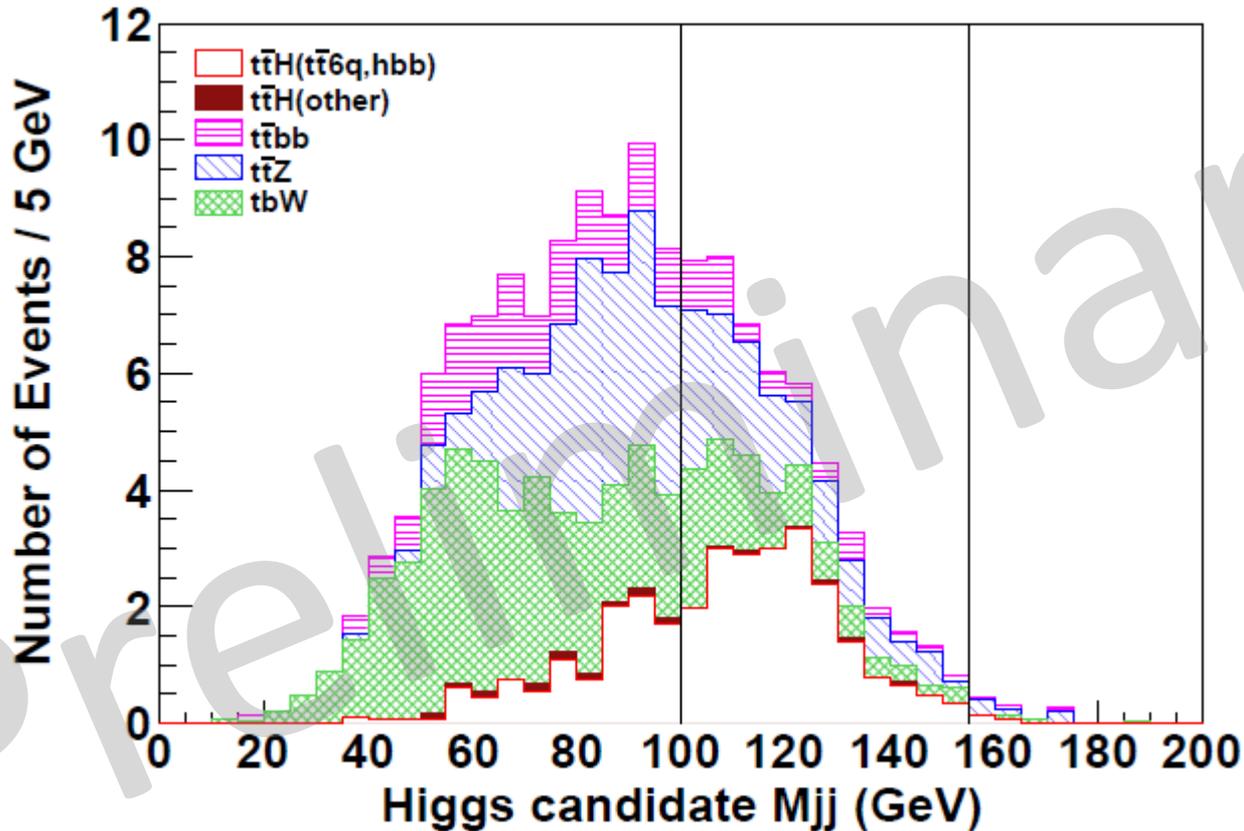
最後にヒッグス候補の $M_{jj}$ の範囲を $s/\sqrt{S+B}$ が最大になるようにとる

✓  $100 \text{ GeV} \leq \text{higgs candidate } M_{jj} \leq 155 \text{ GeV}$

Selection	$tth(tt6j \text{ hbb})$	$tth(ttall \text{ hnob})$	$tth(ttl4j \text{ hbb})$	$tth(tt2l2n2j \text{ hbb})$	$ttZ$	$ttg^*(bb)$	$tbW$
No Cut	127.9	205.2	122.6	29.3	2409.6	1159.1	979807.7
$Y_{8 \rightarrow 7}$ (8 jets)	87.0	105.2	18.4	0.4	698.4	231.7	60394.6
No Isolated Lepton	81.6	71.3	3.6	0	582.0	201.6	53871.2
b jet candidate $\geq 4$	47.3	1.9	1.7	0	71.3	87.6	1106.3
$ \text{Jet } \cos \theta  \leq 0.99$	45.1	1.8	1.6	0	67.3	82.8	491.5
$\chi^2 \leq 9.5$	33.2	1.1	0.6	0	46.5	33.7	148.8
Leading 2 JetEnergySum < 207.5 GeV	32.1	1.1	0.6	0	42.7	22.2	75.8
Lowest 3 JetEnergySum > 86.65 GeV	31.6	1.0	0.4	0	41.0	19.0	67.4
$M_{top} \geq 140$ (GeV)	30.7	1.0	0.3	0	39.6	17.9	49.5
$h$ Candidate $M_{jj} \geq 80$ (GeV)	27.0	0.7	0.05	0	29.2	8.5	19.3
$100 \leq h$ Candidate $M_{jj} \leq 155$ (GeV)	20.2	0.3	0	0	13.2	4.1	10.0

- $tth \rightarrow 8\text{jet}$ シグナル数  $N_{sig} = 20.2$
- 背景事象の数  $N_{bkgd} = 27.7$

# Significance ( $t\bar{t}h \rightarrow 8\text{jets}$ )



- Cut base+countingの解析
- $N_{\text{sig}}/\sqrt{N_{\text{sig}} + N_{\text{bkgd}}} = \underline{2.92}$ ,  $|\Delta g_t/g_t| \sim 17\%$
- $l+6\text{jets}$ チャンネルの含めればさらに最善される