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

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ILD optimization meeting

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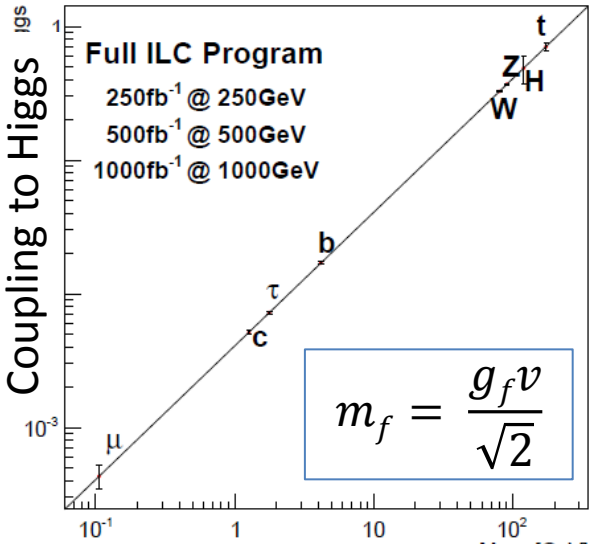
Motivation

- Higgs boson has been discovered by LHC and the higgs mass is ~125 GeV.
- We can directory measure the top quark Yukawa coupling via tth channel.
- Previous tth analysis was performed assuming Mh = 120GeV.

(R. Yonamine et al., PHYSICAL REVIEW D 84, 014033(2011))

- We are working on tth study at $\sqrt{s}$ = 500 GeV assuming Mh=125 GeV.
- Polarization : $(Pe^-, Pe^+)=(-0.8,+0.3)$

	Mh=120GeV→	Mh=125GeV
production cross section (fb)	0.641 →	0.485
Branching ratio of h→bb	0.68 →	0.577



Signal and Background

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

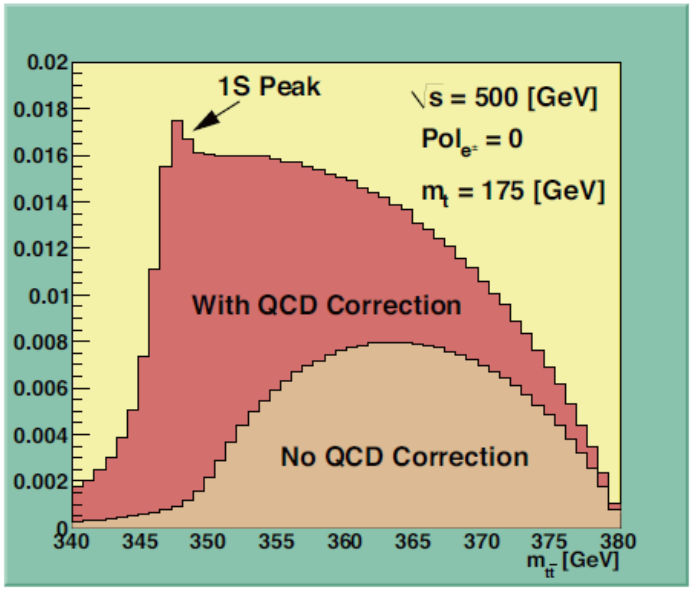
- tth cross section is enhanced
- ttZ cross section is also increased

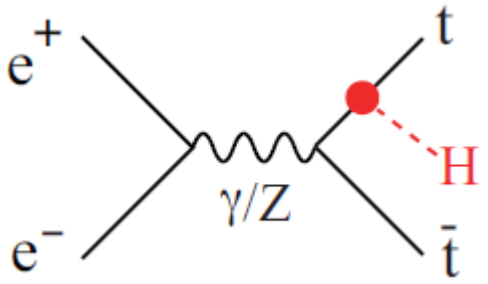
Signals

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

Main Backgrounds

- ttZ, ttg(bb), tbw





expected # of events @ 1000fb^{-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(@1000fb^{-1})

tth(tt6j, hbb)	127.9	tth(ttln4j,hbb)	122.6
tth(ttall, hnobb)	205.2	ttZ	1974
tth(ttlvlv2j, hbb)	29.3	ttg(bb)	1058
		tbW	979807

tth→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 ≥ 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 Mjjj $\geq$ 140 GeV

✓ higgs candidate Mjj $\geq$ 80 GeV

✓ 100 (90)GeV $\leq$ h candidate Mjj $\leq$ 160(150)GeV

tth→ 8 jets channel

Event Selection (tth→8jets)

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

  forced 8 jet clustering

  Select events with large Y8→7 as 8jets category

  if Y8→7 is small, check Y7→6 value

  ✓ "Y8→7 > 0.0009" + "Y8→7<=0.0009 && Y7→6>0.0025"

- Isolated Lepton

  Definition

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

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

  ✓ require no Isolated lepton

✓ B jet candidate ≥ 4 (btag>=0.85 ,0.8, 0.6, 0.2)

- reject events with forward jets

✓ |Jet cosθ| ≤ 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.

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

- check all combinations and choose a pair with minimum χ^2 value

reject large χ^2 events

✓ $\chi^2 \leq 9.5$

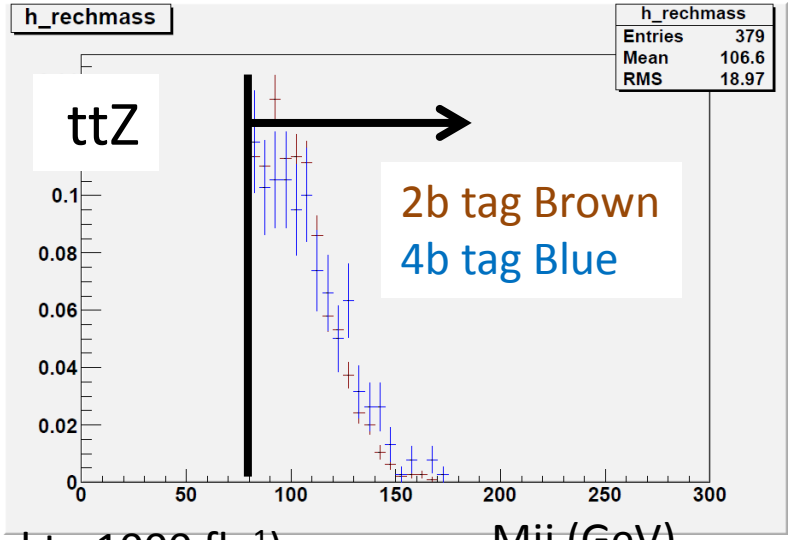
- require b tag $\geq$ 0.2 to j_1, j_2, j_3, j_6
- Mean value and RMS of angle and reconstructed Mass with jets matched MC infomation
  - Mtop = 171.9GeV
  - sigma Mtop = 15.5 GeV
  - MW = 80.385 GeV
  - sigma MW = 9.8 GeV
  - angle(jj) = 2.468
  - sigma angle(jj) = 0.2858

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.
- compare ttz shape of 2 b tag category and 4 b tag category
- check Mjj shape of ttz events
  - 2 b tag + Y8→7 < 0.0008 && Y7→6 < 0.0025
  - 4 b tag + Y8→7 >0.0009 || Y7→6 > 0.0025
- In Mjj ≥ 80 GeV, the Mjj shape of 2 b tag category is similar to 4 b tag category. (KS probability = 0.03)

✓ We estimate Mjj shape of tbW events with 2 b tag category

✓ higgs candidate Mjj ≥ 80 GeV



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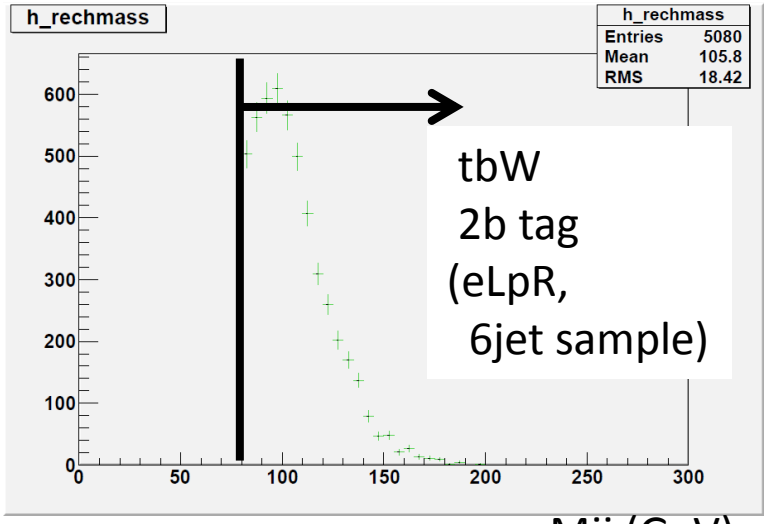


Jet Energy and M_{top} range

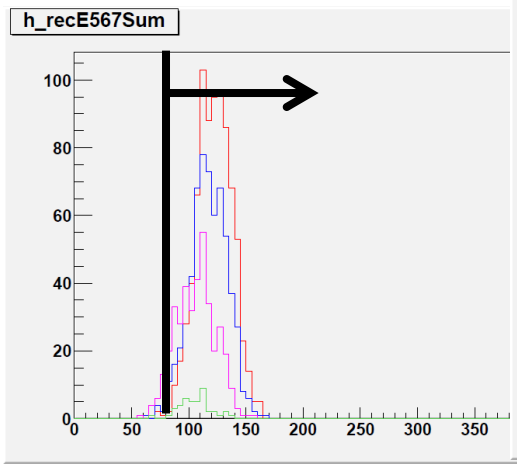
- ttg(bb) and tbw event is assumed to have high energy jets related to top decay.
- ttg(bb) events also have low energy jets related to g

✓ lowest 3 jets energy sum > 86 GeV

✓ highest 2 jets energy sum < 207 GeV

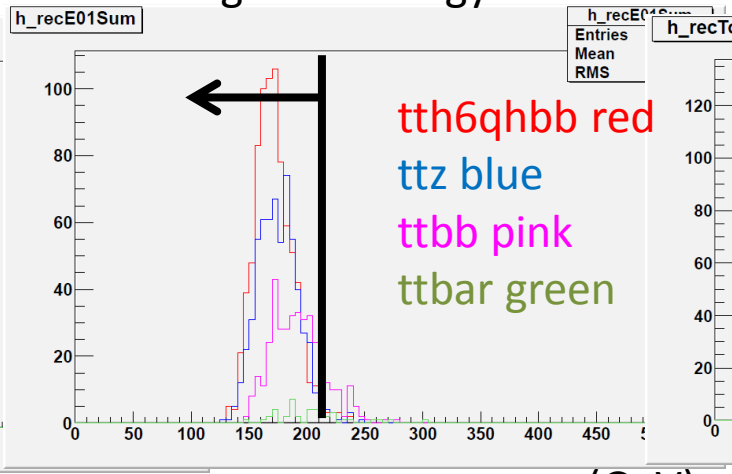
✓ top candidate Mjjj ≥ 140 GeV

Lowest 3 Jet Energy Sum



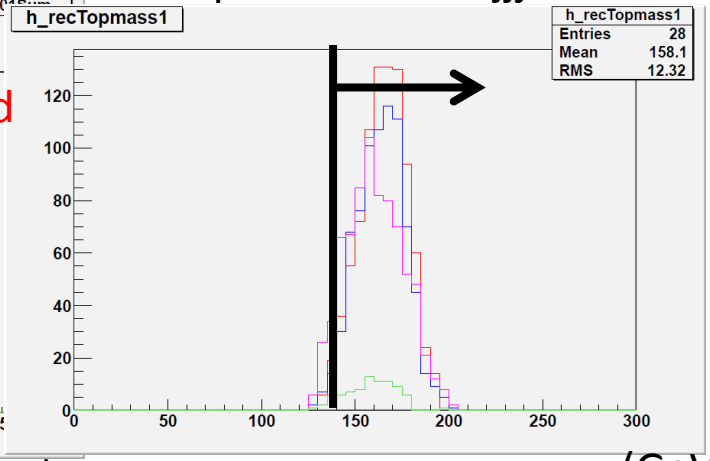
(GeV)

Leading 2 Jet Energy Sum



(GeV)

top candidate Mjjj



(GeV)

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

Result of event selection (tth→8jets)

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

✓ 100 GeV ≤ higgs candidate Mjj ≤ 160GeV

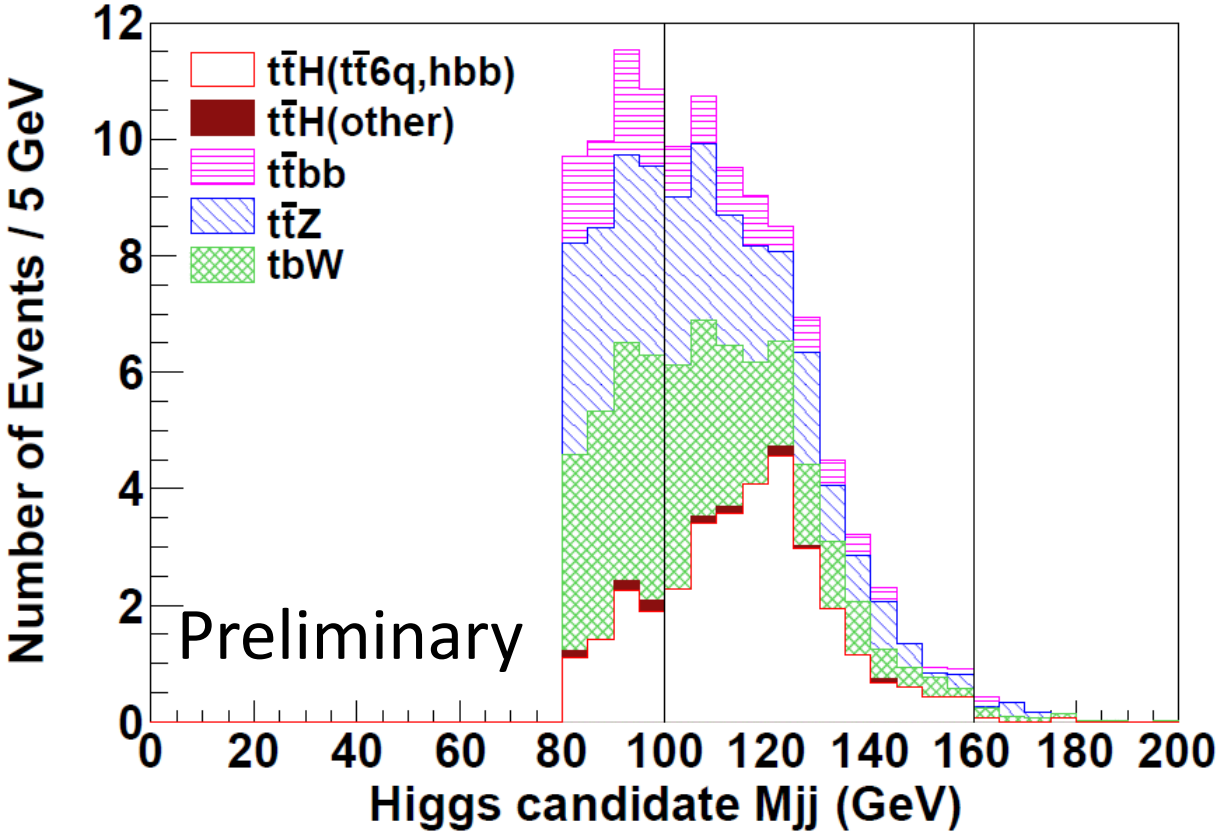
Preliminary

Selection	$t\bar{t}h(t\bar{t}6j\ hbb)$	$t\bar{t}h(t\bar{t}all\ hnobb)$	$t\bar{t}h(t\bar{t}ln4j\ hbb)$	$t\bar{t}h(t\bar{t}2l2n2j\ hbb)$	$t\bar{t}Z$	$t\bar{t}g^*(b\bar{b})$	tbW
No Cut	127.9	205.2	122.6	29.4	1974.6	1058.6	979807.7
$Y_{8\to7}$ (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 ≥ 4	57.0	2.1	3.5	0.003	71.3	111.3	1657.2
$\mid$ Jet $\cos\theta \mid \leq 0.99$	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
$M_{\rm top} \geq 140$ (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

- no overlay of low Pt background

- tth→8jet: Nsig = 26.0
- Nbkgd= 41.74

Significance (tth→8jets)



- no overlay of low Pt background

- $\sqrt{s}$ = 500 GeV, 1000 fb^{-1}
- Cut base + counting analysis
- Nsig/$\sqrt{\text{Nsig} + \text{Nbkgd}}$ = 3.16, $|\Delta g_t/g_t|$ ~ 15.8%

tth→ ln+6jets channel

Event Selection (tth→ln+6jets)

- select 6 jets event

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

  forced 6 jet clustering
  Select events with large Y6→5 as 6jets category
  if Y6→5 is small, check Y5→4 value
  ✓ "Y6→5 > 0.002" + "Y6→5<=0.002 && Y5→4>0.036"

- Isolated Lepton

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

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

  ✓ require exact one Isolated lepton

✓ B jet candidate ≥ 4 (btag>=0.85 ,0.8, 0.6, 0.2)

- reject events with forward jets

✓ |Jet cosθ| ≤ 0.99

higgs and top pairing, χ2 Cut

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

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

a W mass is reconstructed with Isolated lepton and Missing P

- check all combinations and choose a pair with minimum χ^2 value

reject large χ^2 events

✓ $\chi^2 \leq 19$

- require b tag ≥ 0.2 to j_1, j_2, j_3, j_6
- Mean value and RMS of angle and reconstructed Mass with jets matched MC infomation
  - Mtop = 171.9GeV
  - sigma Mtop = 15.5 GeV
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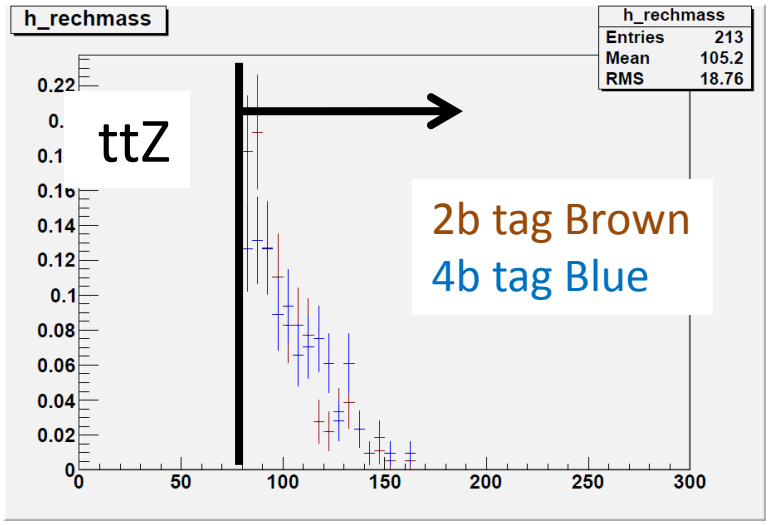
Mjj shape of tbW event

- tbw event shape is difficult to estimate with 4 b tag category due to the small statistics of MC samples.
- compare ttz shape of 2 b tag category and 4 b tag category
- check Mjj shape of ttz events
  - 2 b tag + Y6→5 < 0.002 && Y5→4 < 0.036
  - 4 b tag + Y6→5 >0.002 || Y5→4>0.036
- In Mjj ≥ 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 Mjj ≥ 80 GeV



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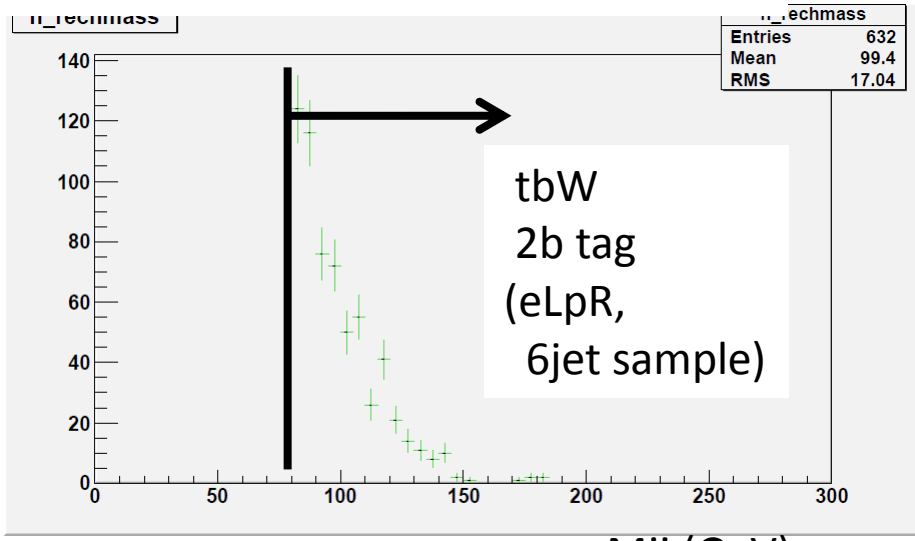


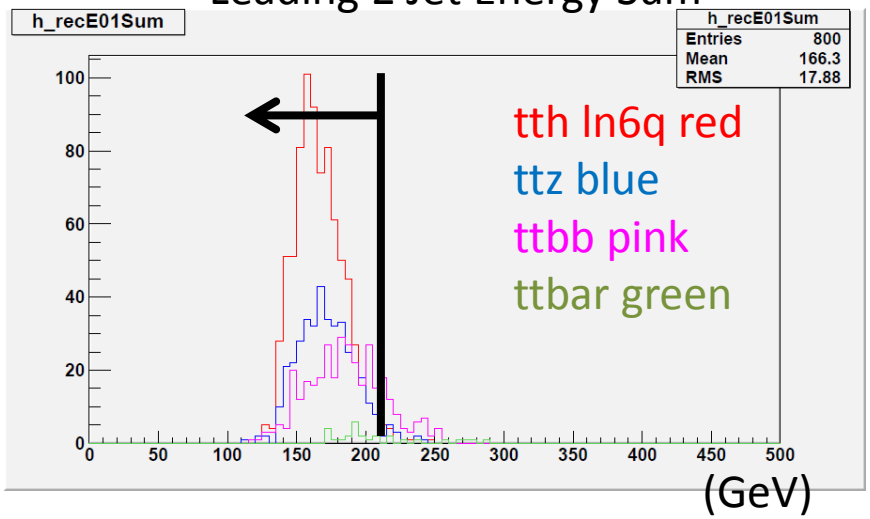
Jet Energy and M_{top} range

- ttg(bb) and tbw event is assumed to have high energy jets related to top decay.

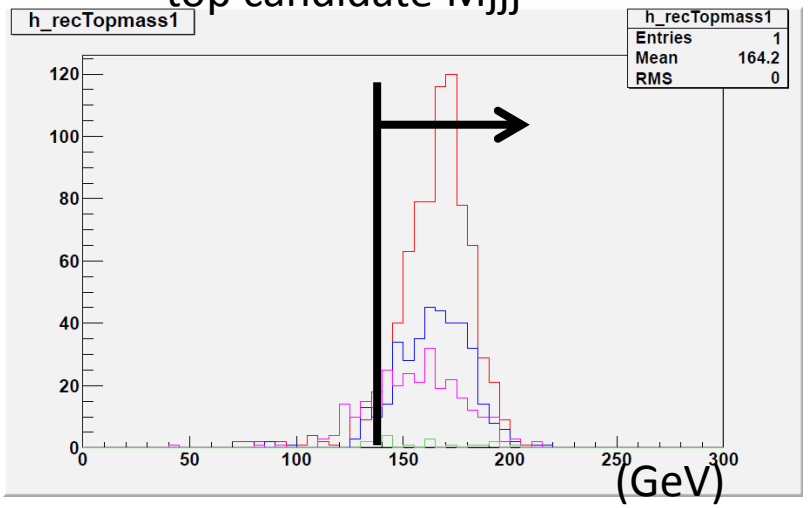
✓ highest 2 jets energy sum < 210 GeV

✓ top candidate Mjjj ≥ 140 GeV

Leading 2 Jet Energy Sum



top candidate Mjjj



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

Result of event selection (tth→ln+6jets)

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

✓ 90 GeV ≤ higgs candidate Mjj ≤ 150GeV

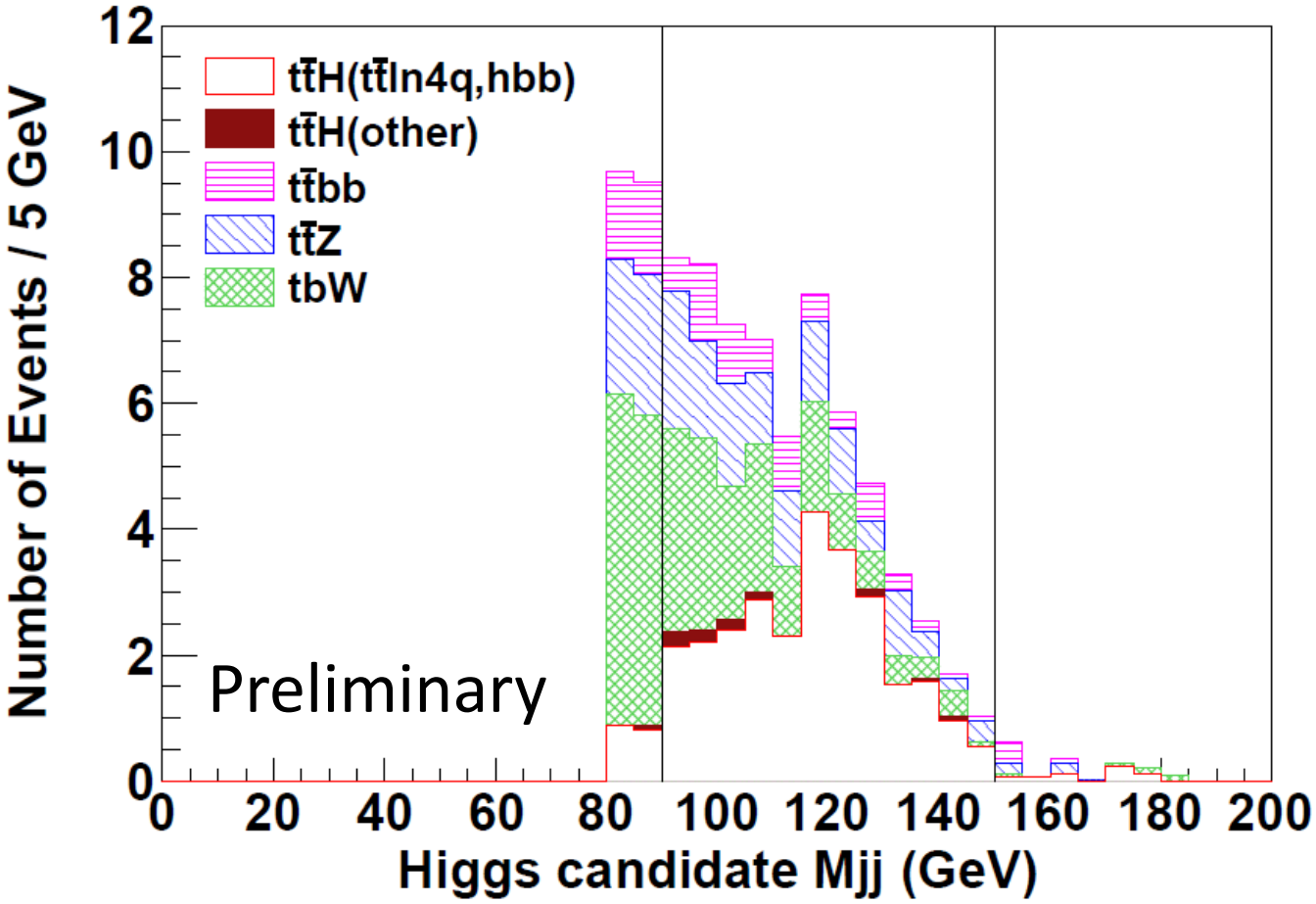
Preliminary

Selection	$t\bar{t}h(t\bar{t}ln4j\ hbb)$	$t\bar{t}h(t\bar{t}all\ hnobb)$	$t\bar{t}h(t\bar{t}6j\ hbb)$	$t\bar{t}h(t\bar{t}2l2n2j\ hbb)$	$t\bar{t}Z$	$t\bar{t}g^*(b\bar{b})$	tbW
No Cut	122.6	205.2	127.9	29.3	1974.6	1058.6	979807.7
$Ycut$ (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 ≥ 4	45.4	1.2	4.6	1.0	41.4	76.6	806.3
$\mid$ Jet $\cos\theta \mid \leq 0.99$	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
$M_{\rm top} \geq 140$ (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

- no overlay of low Pt background

- tth→ln+6jet: Nsig = 27.4
- Nbkgd= 35.64

Significance (tth→ln+6jets)



- $\sqrt{s}$ = 500 GeV, 1000 fb^{-1}
- Cut base + counting analysis
- Nsig/$\sqrt{\text{Nsig} + \text{Nbkgd}}$ = 3.45, $|\Delta g_t/g_t|$ ~ 14.5%
- no overlay of low Pt background

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

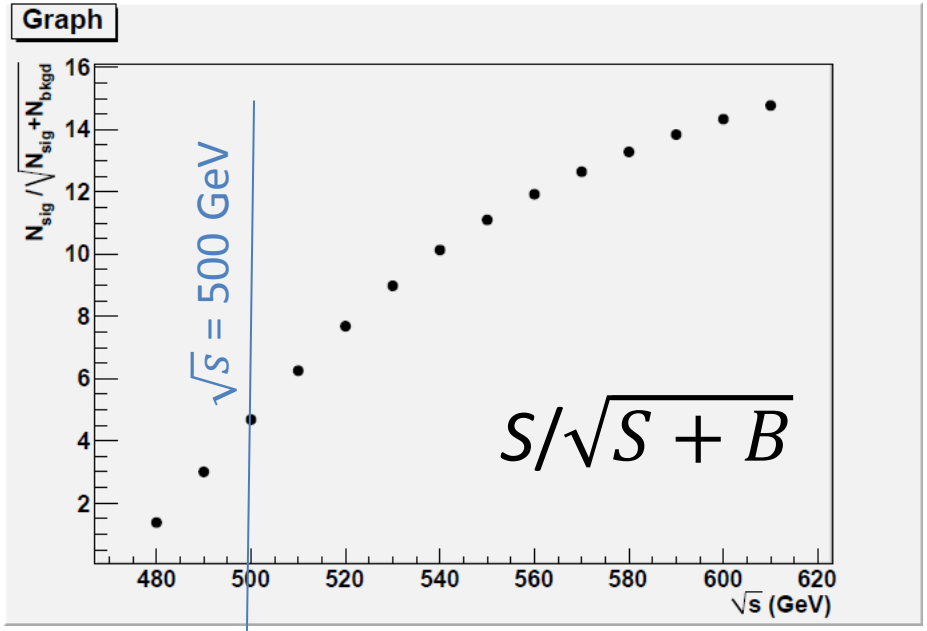
$\sqrt{s}$ = 480-610 GeV

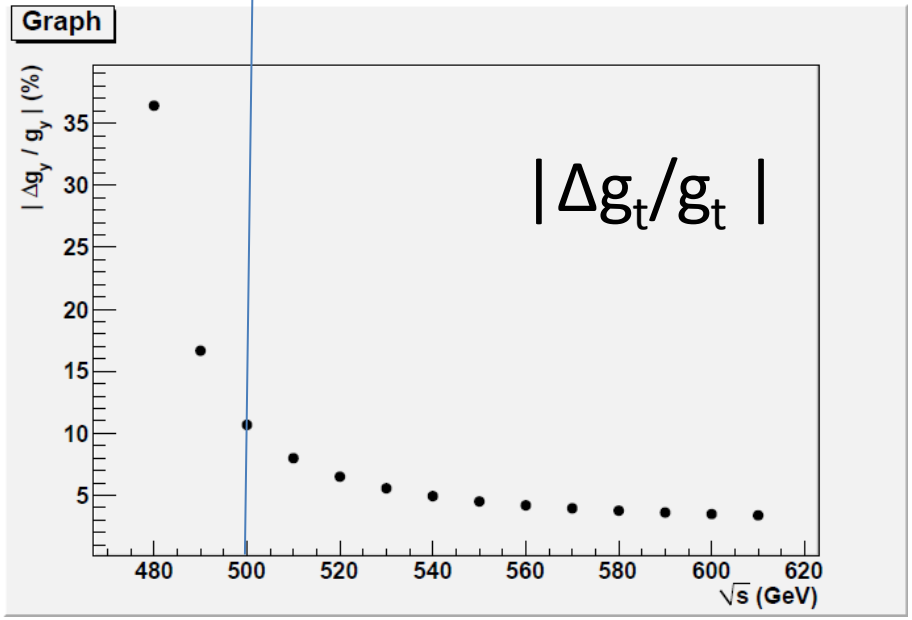
1000fb^{-1}, tth→ 8jets & ln6jets

$\sqrt{s}$	: $S/\sqrt{S+B}$	: $\lvert\Delta g_t/g_t\rvert$ %
490	: 3.00	: 16.6
500	: 4.67	: 10.6
510	: 6.25	: 7.99
520	: 7.68	: 6.50
530	: 8.98	: 5.56
540	: 10.1	: 4.93
550	: 11.1	: 4.50

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





Summary and Plan

- $\sqrt{s}$ = 500 GeV, L = 1000 fb^{-1} , Mh = 125 GeV
- no overlay of low Pt background
- tth→8jets S/$\sqrt{S+B}$ = 3.16
- tth→ln+6jets S/$\sqrt{S+B}$ = 3.45
- combine → significance = 4.67

  $|\Delta g_t/g_t|$ = 10.6%
- higher cms energy is preferable for tth channel.

to do

- increase MC samples (now running)
- tbw shape
- systematics
  - b tagging efficiency
  - jet energy scale
  - ……
- MVA

backup