Study of Direct top Yukawa Coupling Measurement at the ILC with $\sqrt{s}$ = 500 GeV

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Yuji Sudo (Kyushu University)

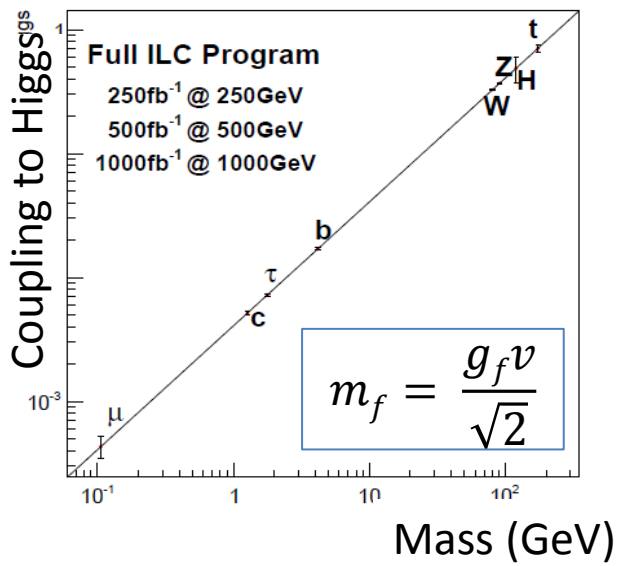
Tomohiko Tanabe (University of Tokyo)

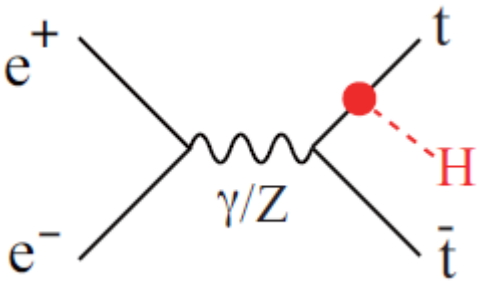
Keisuke Fujii, Junping Tian (KEK)

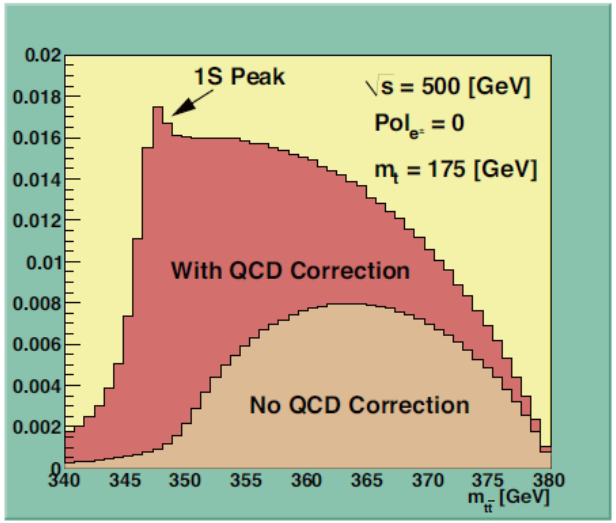
Introduction

- We are working on tth study
  - M_h=125 GeV.
  - Polarization : (Pe^-,Pe^+)=($\mp$0.8,$\pm$0.3)
  - Integrated luminosity 500 fb^{-1} and H20
  - 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.



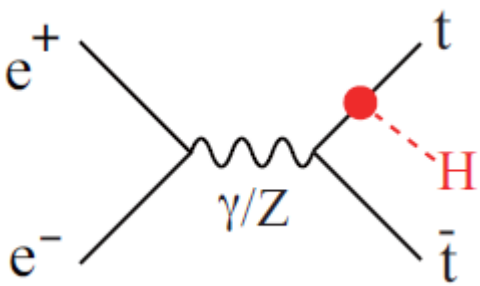




Signal and Background

Signals

- tth→8jets (h→bb)
  tth→lv+6jets (h→bb)
  tth→2l2v+4b jets (h→bb)



Backgrounds

- ttZ, ttg (g→bb), tbW

Updates after ALCW

- apply correction factor 0.843 to the signal cross-section. the factor is related to α_s correction of the physsim.
- Maximum likelihood method for jet pairing
- new large stat. 6f_ttbar MC samples are available. The new 6f_ttbar samples are generated in same condition of the DBD official 6f_ttbar samples.
- use 4 b tagged category for the 6f_ttbar event shape instead of a previous 2 b tagged category.
- to use new 6f_ttbar samples, isolated lepton identification method is backed to cut based event selection.
- optimize event selection cuts

Summary of Updates from ALCW2015

- $\sqrt{s}$ = 500 GeV, 500fb^{-1}, (Pe$^-$,Pe$^+$)=(-0.8,+0.3), M_h = 125 GeV

Changes from ALCW2015	$S/\sqrt{S+B}$ 8jets	lν+6jets	2l2ν+4jets	
Correction factor 0.843	2.17→1.93 11%↓	2.00→1.72 14%↓	1.02→0.88 13.7%↓	wrong →correct
Maximum Likelihood method for jet pairing (first trial)	1.93→1.96 1.5%↑	1.72→2.01 17%↑	0.88→0.88	improvement
4b tagged 6f_ttbar shape + Iso. lepton ID BDT→Cut	1.96→2.01 2.5%↑	2.01→1.91 5%↓		event shape
optimize likelihood templates and event selection cuts	2.01→2.05 2%↑	1.91→1.96 2.6%↑	0.88→0.93 5.6%↑	improvement
tth(other) events are included in signal category	2.05→2.11 3%↑	1.96→2.00 2%↑	0.93→0.94 1%↑	categorization

Production cross section, expected number of events

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

Production cross section

Process	σ (fb)
$e^-e^+ \rightarrow tth$	0.4088
$e^-e^+ \rightarrow ttZ$	1.974
$e^-e^+ \rightarrow ttg(bb)$	1.058
$e^-e^+ \rightarrow tbW$	918.4 (new sample)
($e^-e^+ \rightarrow tbW$	912.5 (DBD sample))

Decay mode	Branching ratio
h→bb	0.577
tt→bqqbqq	0.457
tt→blνbqq	0.438
tt→blνblν	0.105

- Expected # of signals and Backgrounds(@500fb^{-1})

ttH(tt→6j, H→bb)	**53.9**	ttH(tt→all, H(nobb))	86.4
ttH(tt→lν4j,H→bb)	**51.6**	ttZ	987
ttH(tt→lνlν2j, H→bb)	**12.3**	ttg(bb)	529
		tbW	459200

Maximum Log Likelihood Method for Jet Pairing

Jet Pairing with Maximum Likelihood method

- likelihood templates are made with signal events
- use reconstructed jets matching with MC truth within cosθ>0.9
- choose a combination of jets which maximize a log likelihood value

- 8jets

* 2D likelihood template
cos(tt), cos(bb(higgs))
cos(bW(anti-top)), cos(bW(top))
top1 mass, W1 mass
top2mass, W2 mass

- 2l2ν+4jets

* 2D likelihood template
cos(bl(t)bl(tbar)), cos(bb(higgs))
* 1D likelihood template
b1l1 mass
b2l2 mass

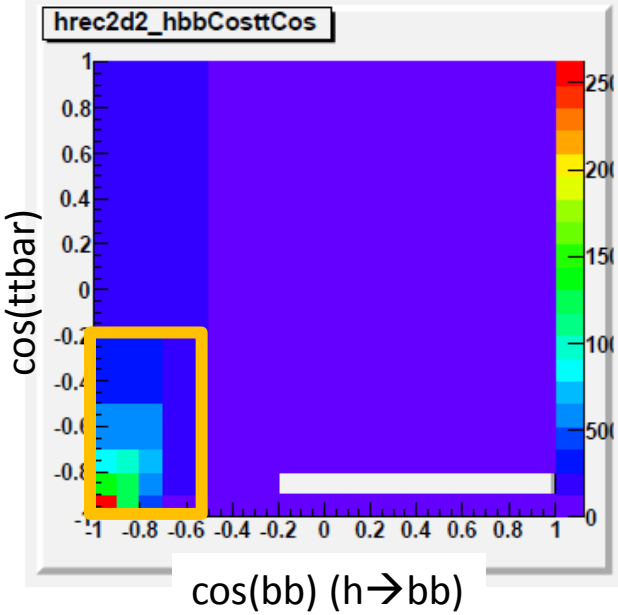
- lν+6jets

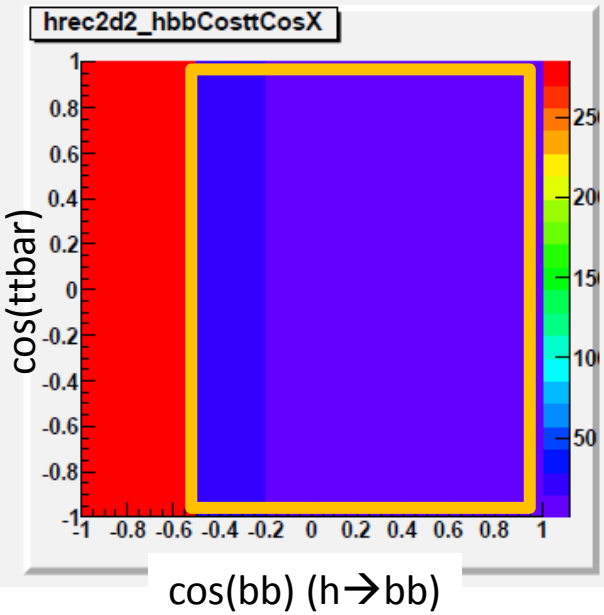
* 2D likelihood template
cos(tt), cos(bb(higgs))
cos(bW(anti-top)), cos(bW(top))
cos(q2(anti-t)e^-), cos(q1(anti-t)e^-)
q1: uptype , q2: down type
* 1D likelihood template
top1mass
W1 mass
top2 mass

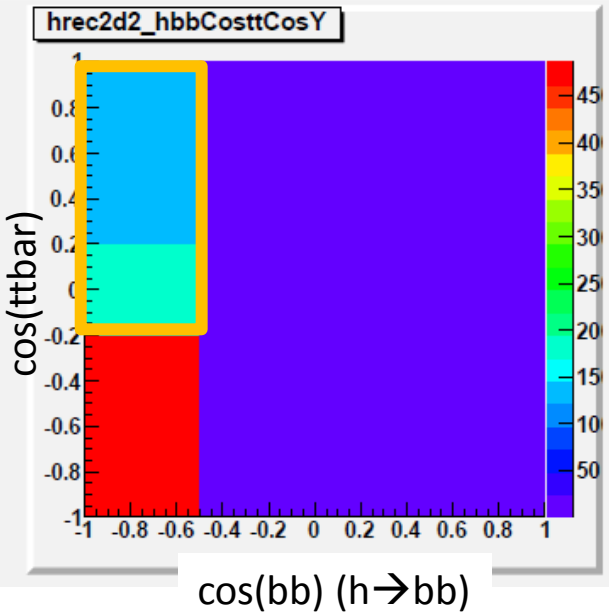
- ~10% improvement on an efficiency of correct higgs bb pair for each signal category

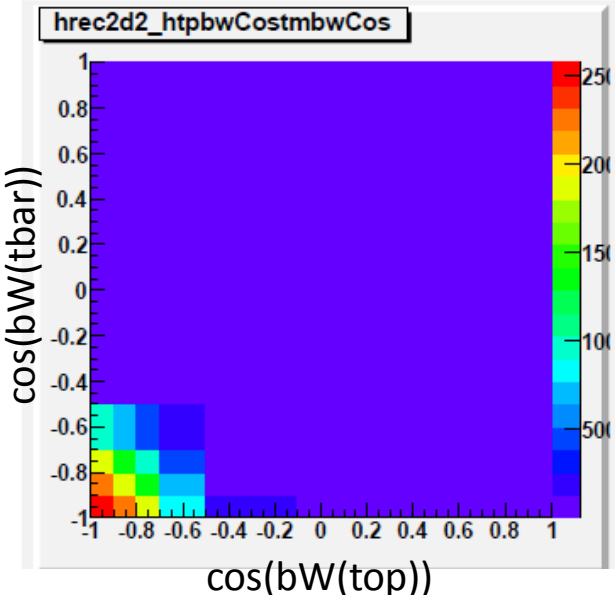
Likelihood templates for jet pairing (tth 8jets)

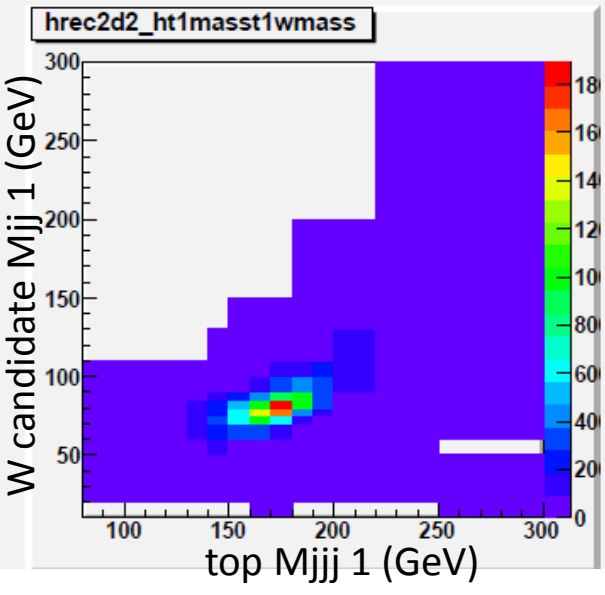
top 3 plots are cos(ttbar) vs cos(bb(higgs)) distribution with different binning

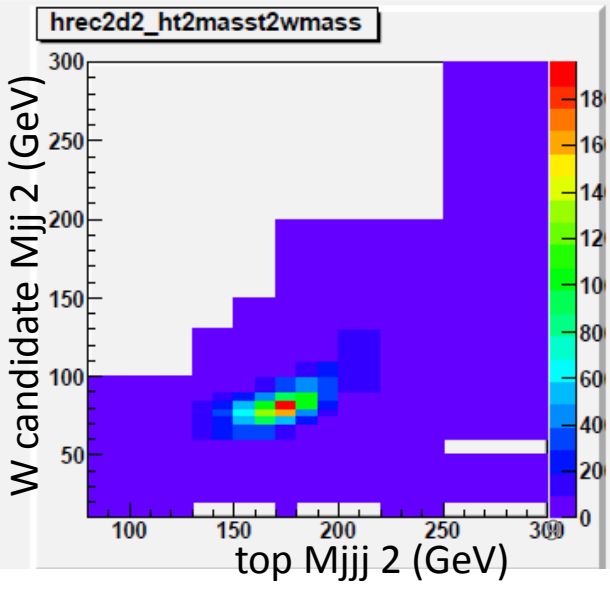












Run scenario H20

arXiv:1506.07830v1 [hep-ex] 25 Jun 2015

total integrated luminosity

	$\int \mathscr{L} dt$ [fb^{-1}]			
$\sqrt{s}$	G-20	H-20	I-20	Snow
250 GeV	500	2000	500	1150
350 GeV	200	200	1700	200
500 GeV	5000	4000	4000	1600

first stage 500 fb^{-1}, after lumi. up 3500 fb^{-1}

	fraction with $\mathrm{sgn}(P(e^-), P(e^+)) =$			
	(-,+)	(+,-)	(-,-)	(+,+)
$\sqrt{s}$	[%]	[%]	[%]	[%]
250 GeV	67.5	22.5	5	5
350 GeV	67.5	22.5	5	5
500 GeV	40	40	10	10

first stage: 200 fb^{-1} for (-,+) and (+,-)

Lumi. up : 1400 fb^{-1} for (-,+) and (+,-)

Event selection and Results

event selection cuts for tth→8jets

- forced 8 jet clustering (Durham algorithm)

- 4 b tagged (b likeness > 0.85, 0.8, 0.6, 0.2)
- Number of isolated lepton = 0
- Y value of Durham jet clustering: Y_{87}>0.00042, Y_{76}>0.0021 && Y_{87}<=0.00042
- detector acceptance $\cos\theta_{jet}$>0.99
- jet pairing by maximum likelihood method : llh value >-15.5
- highest 2 jets energy Sum <190 GeV, lowest 3 jets energy Sum > 94 GeV
- reconstructed 3 jets mass of top candidates > 140 GeV
- reconstructed 2 jets mass of the higgs candidate : (-0.8,+0.3) 85<M_{jj}<175, (+0.8,-0.3) 75<M_{jj}<175

event selection cuts for tth→8jets

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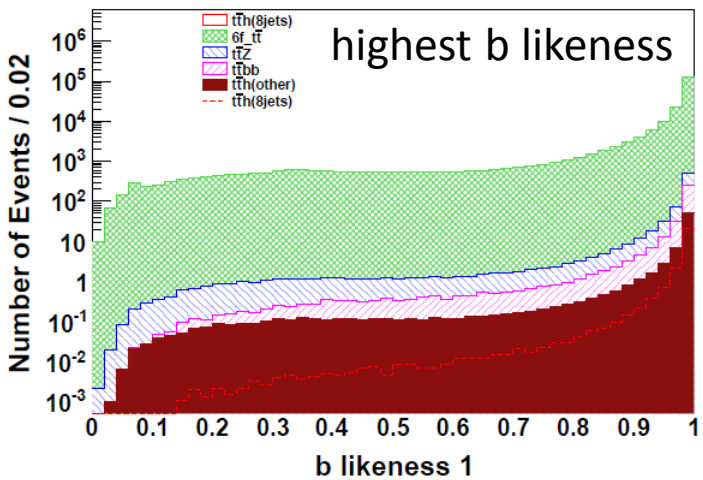
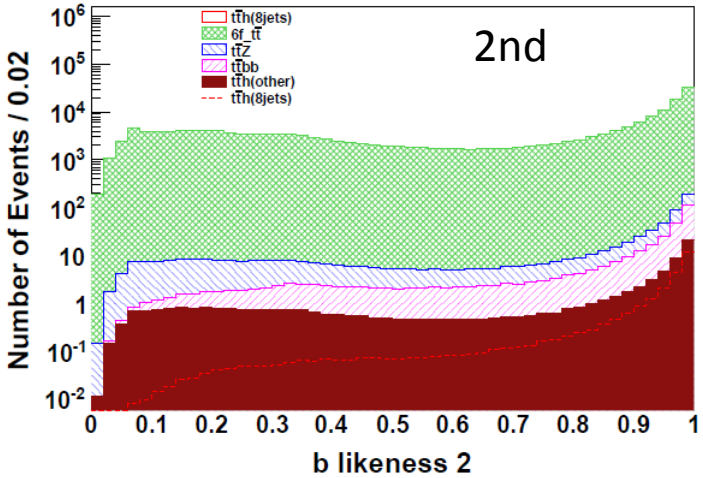
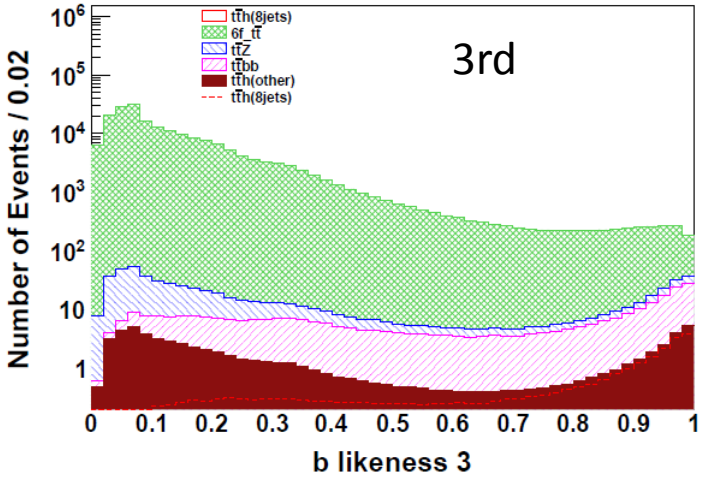
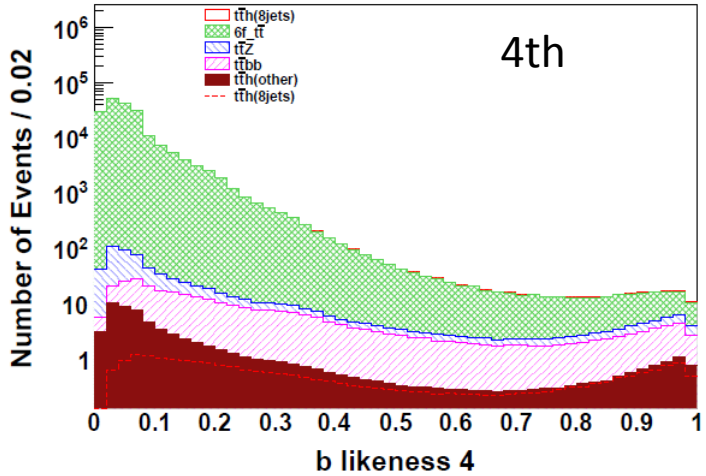




tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)





event selection cuts for tth→8jets

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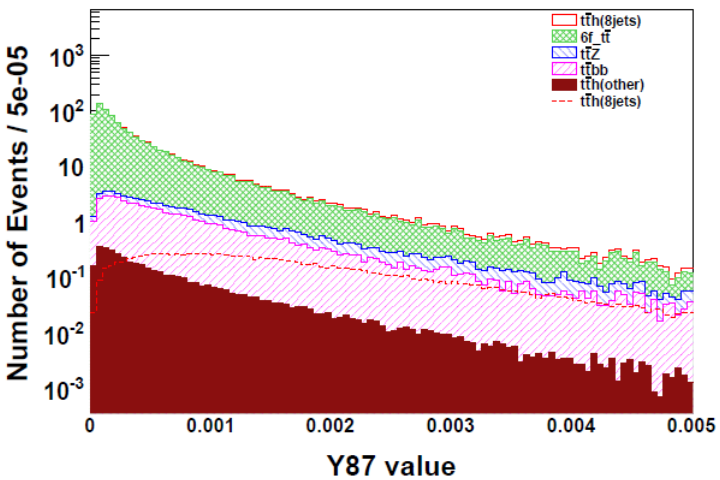
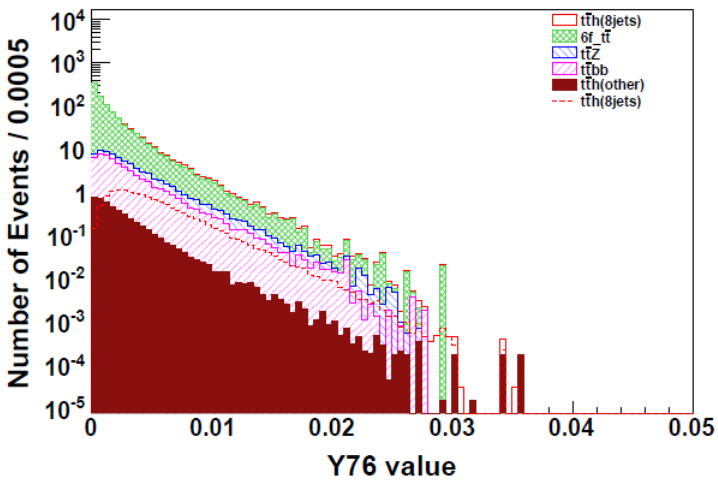
- detector acceptance $\cos\theta_{jet}$>0.99
- jet pairing by maximum likelihood method : llh value >-15.5

tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)

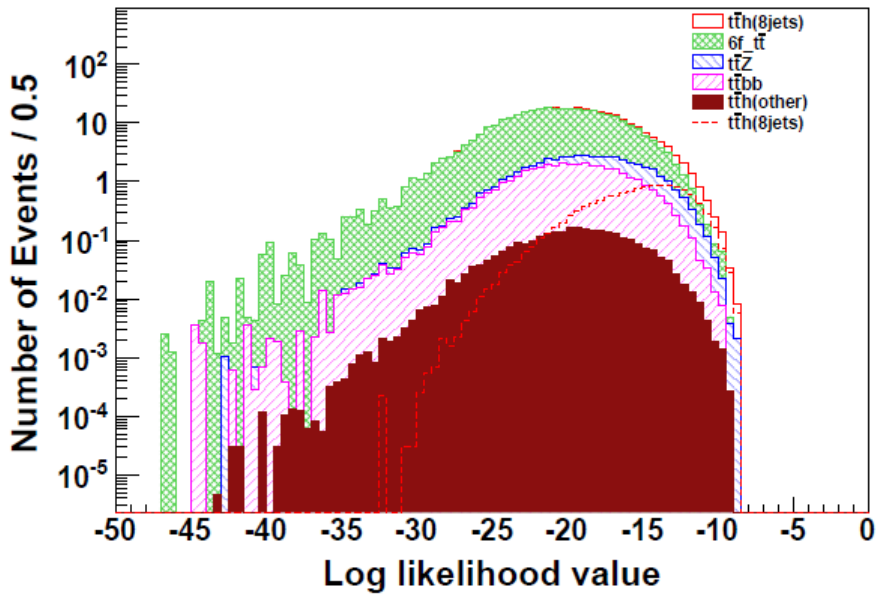
<190 G
> 94 G
of top
of the
0.8,-0.





event selection cuts for tth→8jets

- forced 8 jet
- 4 b tagged
- Number of
- Y value of [
  Y_{76}>0.0021
- detector ac

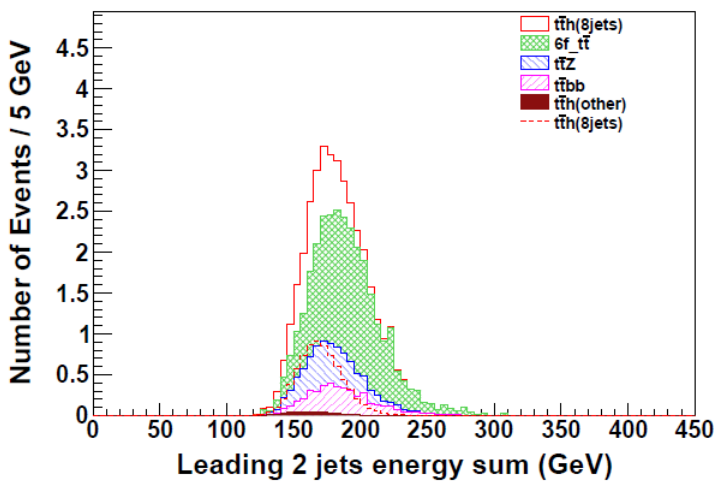


tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)

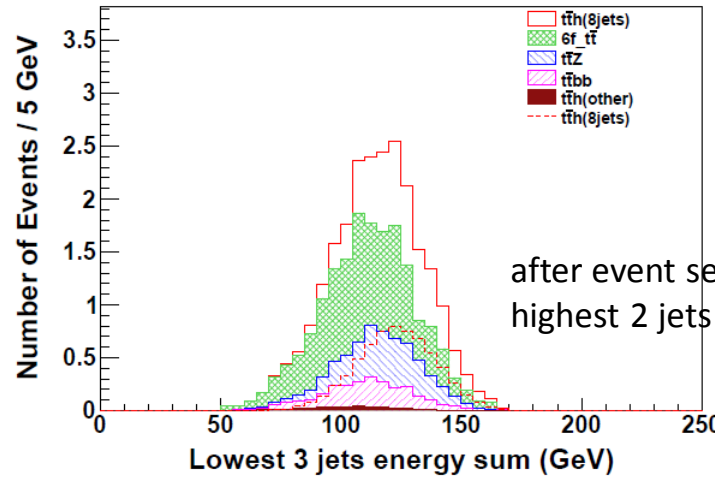
- jet pairing by maximum likelihood method : llh value >-15.5
- highest 2 jets energy Sum <190 GeV,
  lowest 3 jets energy Sum > 94 GeV
- reconstructed 3 jets mass of top candidates > 140 GeV
- reconstructed 2 jets mass of the higgs candidate :
  (-0.8,+0.3) 85<M_{jj}<175, (+0.8,-0.3) 75<M_{jj}<175

event selection cuts for tth→8jets

highest 2 jet energysum



lowest 3 jet energy sum

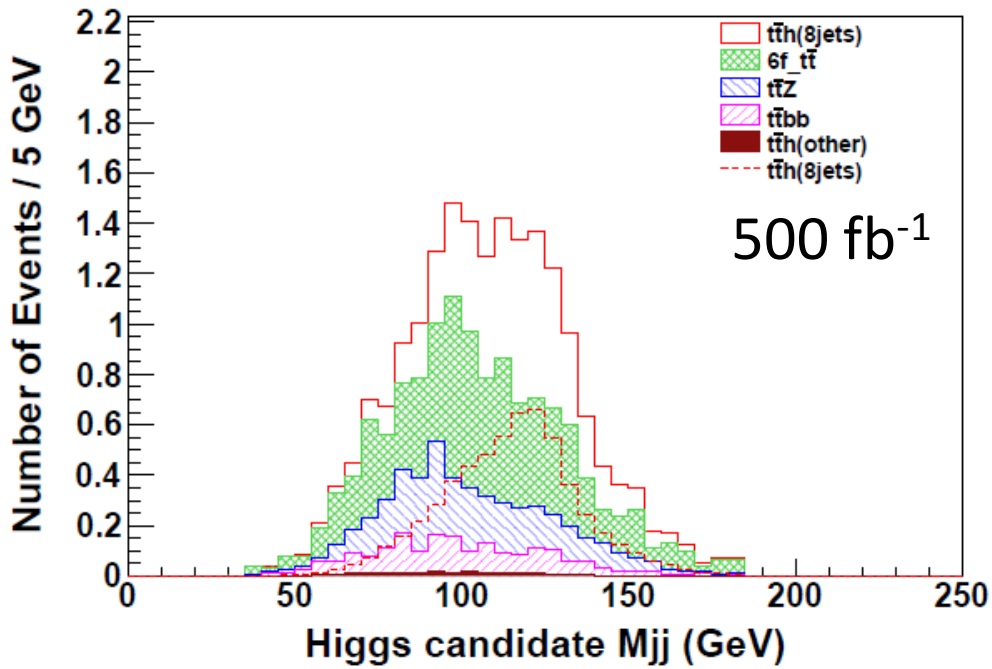


tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)

after event selection cut of highest 2 jets energy sum

- jet pairing by maximum likelihood method : llh value >-15.5
- highest 2 jets energy Sum <190 GeV
- lowest 3 jets energy Sum > 94 GeV
- reconstructed 3 jets mass of top candidates > 140 GeV
- reconstructed 2 jets mass of the higgs candidate : (-0.8,+0.3) $85<M_{jj}<175$, (+0.8,-0.3) $75<M_{jj}<175$

Results of tth→8jets



Integrated luminosity	500 fb^{-1}	500 fb^{-1}
(Pe^-,Pe^+)	(-0.8,+0.3)	(+0.8,-0.3)
tth→8jets	11.23	5.63
tth (other)	0.32	0.17
ttZ	6.15	2.98
ttbb	1.66	1.39
6f	10.49	6.48
bkgd total	**18.31**	**10.87**
Signal	**11.55**	**5.81**
MH rang (GeV)	$85<M_{jj}<175$	$75<M_{jj}<175$

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

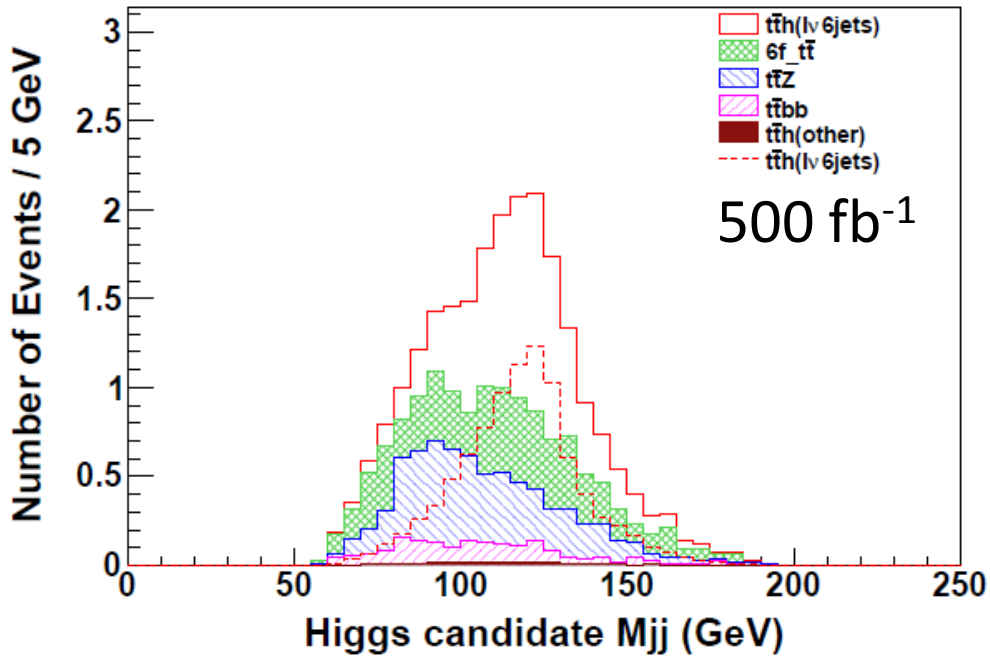
Integrated Lumi. (fb^{-1})	(-0.8,+0.3)	(+0.8,-0.3)
500	2.11	1.42
200	1.33	0.90
1400	3.53	2.38
Mjj range (GeV)	$85<M_{jj}<175$	$75<M_{jj}<175$

event selection cuts for tth→lν+6jets

- forced 6 jet clustering (Durham algorithm)

- 4 b tagged (b likeness > 0.85, 0.8, 0.6, 0.2)
- Number of isolated lepton = 1
- Y value of Durham jet clustering: Y_{65}>0.00088, Y_{54}>0.021 && Y_{65}<=0.00088
- detector acceptance $\cos\theta_{jet}$>0.99
- missing P >20 GeV
- jet pairing by maximum likelihood method : llh value >-20.0
- highest 2 jets energy Sum <198 GeV, lowest 2 jets energy Sum > 68 GeV
- reconstructed 3 jets mass of top candidates > 140 GeV
- reconstructed 2 jets mass of the higgs candidate : (-0.8,+0.3) 90<M_{jj}<175, (+0.8,-0.3) 90<M_{jj}<170

Results of tth→lv+6jets



Integrated luminosity	500 fb^{-1}	500 fb^{-1}
(Pe^-,Pe^+)	(-0.8,+0.3)	(+0.8,-0.3)
tth→lv+6jets	8.49	3.97
ttH (other)	0.17	0.07
ttZ	4.22	1.66
ttbb	1.02	0.61
6f	4.83	2.60
bkgd total	**10.08**	**4.88**
Signal	**8.67**	**4.05**
MH rang (GeV)	$90<M_{jj}<175$	$90<M_{jj}<170$

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

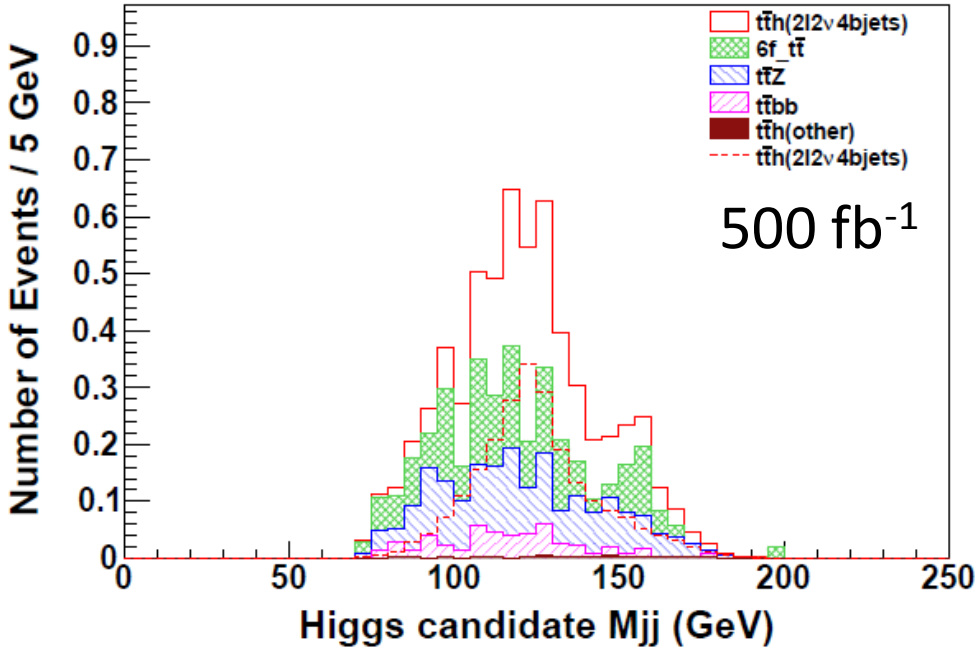
Integrated Lumi. (fb^{-1})	(-0.8,+0.3)	(+0.8,-0.3)
500	2.00	1.35
200	1.26	0.85
1400	3.35	2.26
Mjj range (GeV)	$90<M_{jj}<175$	$90<M_{jj}<170$

event selection cuts for tth→2l2ν+4jets

- forced 4 jet clustering (Durham algorithm)

- 4 b tagged (b likeness > 0.85, 0.8, 0.6, 0.2)
- Number of isolated lepton = 2
- Y value of Durham jet clustering: Y_{43}>0.0062,
- detector acceptance $\cos\theta_{jet}$>0.99
- missing P >20 GeV
- jet pairing by maximum likelihood method : llh value >-10.9
- maximum jet energy < 101 GeV,
  minimum jet energy > 36 GeV
- reconstructed 2 jets mass of the higgs candidate :
  (-0.8,+0.3) $100<M_{jj}<155$, (+0.8,-0.3) $95<M_{jj}<160$

Results of tth→2l2v+4jets



Integrated luminosity	500 fb^{-1}	500 fb^{-1}
(Pe^-,Pe^+)	(-0.8,+0.3)	(+0.8,-0.3)
tth→2l2v+4jets	1.96	0.98
ttH (not Signal)	0.03	0.02
ttZ	1.05	0.51
ttbb	0.31	0.21
6f	1.08	0.47
bkgd total	**2.45**	**1.20**
Signal	**1.99**	**1.00**
MH rang (GeV)	$100<M_{jj}<155$	$95<M_{jj}<160$

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

Integrated Lumi. (fb^{-1})	(-0.8,+0.3)	(+0.8,-0.3)
500	0.94	0.67
200	0.59	0.42
1400	1.58	1.12
Mjj range (GeV)	$100<M_{jj}<155$	$95<M_{jj}<160$

combined result of $S/\sqrt{S+B}$ (w/o systematic uncertainties)

	Integrated Lumi. (fb^{-1})	(-0.8,+0.3)	(+0.8,-0.3)	combined (-0.8,+0.3)&(+0.8,-0.3)
	500	3.05	2.07	3.68
H20	200	1.92	1.30	2.32
	1400	5.11	3.46	6.18
	200&1400	5.46	3.69	6.61

all combined result of H20 scenario

$S/\sqrt{S+B}$ = 6.61, $|\Delta g_t/g_t|$ = 7.85%

measurement precision at different $\sqrt{s}$

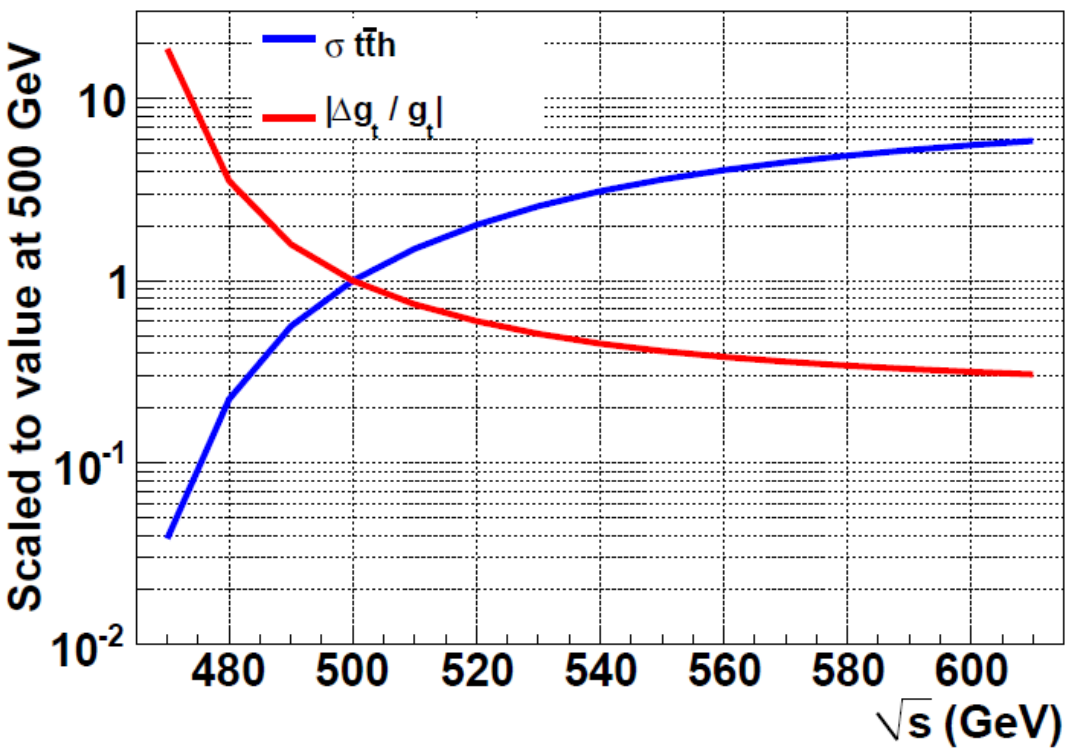
combined result of tth→8jets, lν+6jets and 2l2ν+4b jets channels

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

ttH 200+1400 fb^{-1}

σ_{ttH} = 0.4088 fb @ 500 GeV

$\sqrt{s}$	: $S/\sqrt{S+B}$	: $\lvert\Delta g_t/g_t\rvert$ %
490 :	4.22	: 12.2
500 :	6.61	: 7.85
510 :	8.86	: 5.86
520 :	10.9	: 4.76
530 :	12.7	: 4.06
540 :	14.4	: 3.60
550 :	15.8	: 3.28
600 :	20.5	: 2.53



* MC sample are generated at 500 GeV.

* We just change production cross section of signal and backgrounds for each energy.

Summary

- tth study at 500 GeV
- main target analysis channels are tth→8jets, lν+6jets and 2l2ν+4bjets (h→bb)
- ~ 10% improvement by Maximum likelihood method for jet pairing

- combined result with H20 scenario is

$S/\sqrt{S+B}$ = 6.61, $|\Delta g_t/g_t|$ = 7.85%

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

  Then if we get more energy, sensitivity and measurement precision are greatly improved.

$\sqrt{s}$	$S/\sqrt{S+B}$	$\lvert\Delta g_t/g_t\rvert$ (%)
490	4.22	12.2
500	6.61	7.85
520	10.9	4.76
550	15.8	3.28

Backup

Signal and 6f_ttbar cross-section

Production cross section

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

I forgot to apply correction factor to production cross section of $e^-e^+ \rightarrow$ tth calculated by physsim.
Correction factor = 0.843 : related to α_s correction

$e^-e^+ \rightarrow$ tth 0.485 fb (ALCW2015) ← **wrong**
$e^-e^+ \rightarrow$ tth 0.4088 fb (current) ← **correct**

- Expected # of signals (500 GeV, 500fb^{-1})

Correct Number

ttH(tt→6j, H→bb)	53.9
ttH(tt→lv4j,H→bb)	51.6
ttH(tt→lvlv2j, H→bb)	12.3
ttH(tt→all, H(nobb))	86.4

Wrong Number

ttH(tt→6j, H→bb)	63.9
ttH(tt→lv4j,H→bb)	61.3
ttH(tt→lvlv2j, H→bb)	14.6
ttH(tt→all, H(nobb))	102.6

cross-sections of new 6f samples

- use new 6f_ttbar samples which are generated same condition of DBD samples

New Sample

(fb)	eLpR	eRpL
yyveev	20.14	7.56
yyvelv	39.57	15.03
yyvlev	39.61	15.04
yyvllv	78.70	30.08
yyveyx	117.08	44.51
yyvlyx	231.62	89.05
yyxyev	116.89	44.53
yyxylv	231.25	88.92
yyuyyc	164.44	64.37
yycyyu	165.47	64.06
yyuyyu	166.56	64.54
yycyyc	163.32	60.65
total	**1534.7**	**588.3**

DBD Sample

(fb)	eLpR	eRpL
yyveev	20.17	7.567
yyvelv	39.60	15.04
yyvlev	39.50	15.04
yyvllv	78.72	30.14
yyveyx	117.0	44.54
yyvlyx	232.1	88.91
yyxyev	116.9	44.38
yyxylv	232.0	88.90
bbuyyc	164.2	63.89
bbcyyu	164.0	63.94
bbuyyu	159.3	64.20
bbcyyc	159.8	63.86
total	1524.6	590.45

of events of DBD and new 6f samples

- Number of events of new 6f_ttbar samples which are used in this analysis.

New Sample

	eLpR	eRpL
yyveev	0.31M	0.11M
yyvelv	0.59M	0.22M
yyvlev	0.59M	0.22M
yyvllv	1.1M	0.45M
yyveyx	1.6M	0.66M
yyvlyx	3.2M	1.2M
yyxyev	1.6M	0.66M
yyxylv	3.2M	1.2M
yyuyyc	2.1M	0.91M
yycyyu	2.2M	0.93M
yyuyyu	1.7M	0.95M
yycyyc	2.5M	1.3M

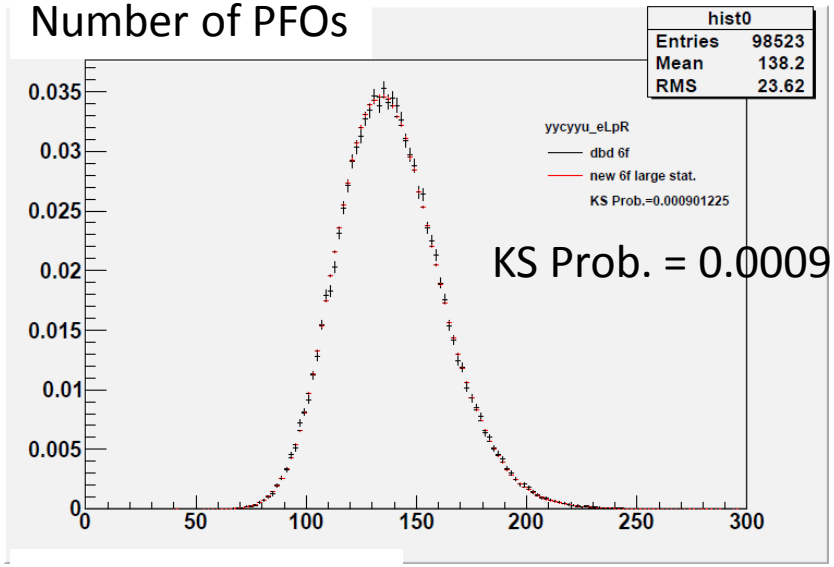
DBD Sample

	eLpR	eRpL
yyveev	19.7k	10k
yyvelv	38.9k	15k
yyvlev	39.2k	15k
yyvllv	76.9k	29.9k
yyveyx	98.8k	38.7k
yyvlyx	196k	81.9k
yyxyev	101k	38.2k
yyxylv	211k	80.9k
yyuyyc	108k	42.8k
yycyyu	98.1k	42.3k
bbuyyu	105k	43k
bbcyyc	96.3k	42.2k

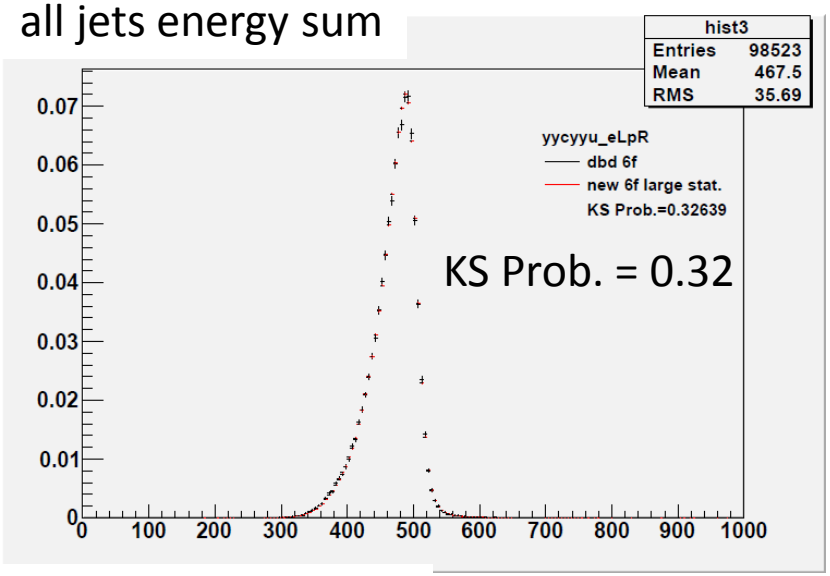
validation plots for 6f_ttbar new sample

6f_ttbar_yycyyu

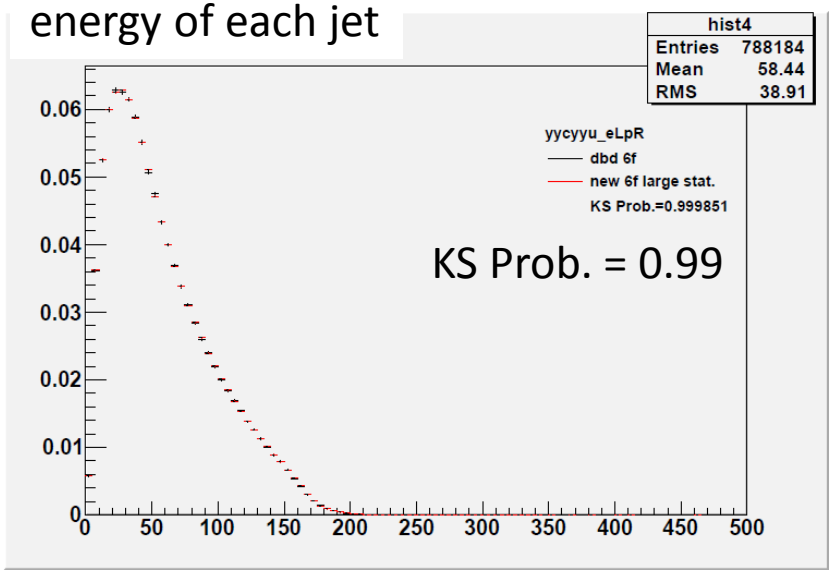
Number of PFOs



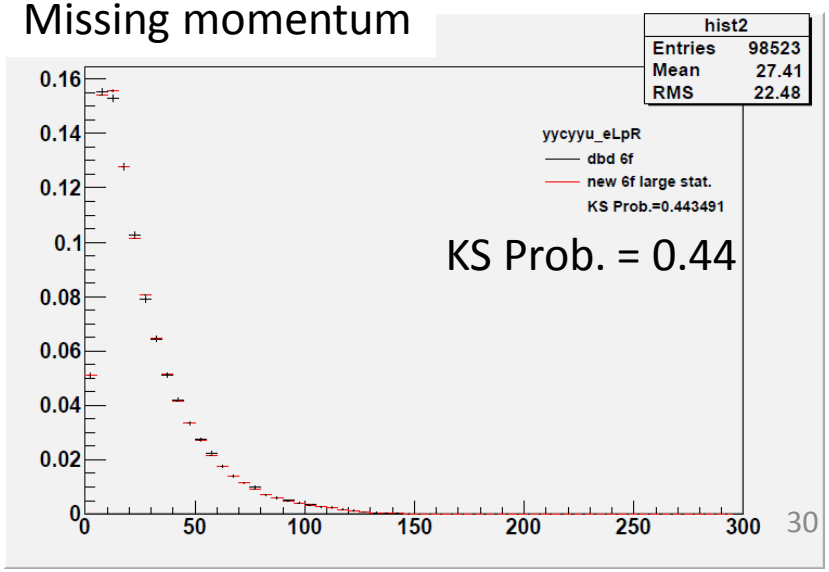
all jets energy sum



energy of each jet



Missing momentum



Event selection

8jets (500 GeV, 500 fb^{-1}, (-0.8,+0.3))

process	noCut	btag	N_iso_lepton	yvalue	cos<0.99	llh(pairing)	jetEsumHigh	jetEsumLow	jjj_mass	bb_cand_mass
tth6q_merged	53.8556	29.8252	28.6815	27.1991	26.7637	15.3946	13.497	12.9752	12.2338	11.2319
tthln4q_merged	51.7929	28.2696	8.47954	5.27816	5.11061	0.581275	0.558099	0.338943	0.265684	0.152272
tth2l2nbb_merged	12.3877	6.76277	0.4897	0.102858	0.0965591	0.000552556	0.000476011	3.72E-06	3.72E-06	1.86E-06
tthallnonbb_merged	86.5526	1.97567	1.07397	0.994145	0.975511	0.303435	0.261959	0.230144	0.210825	0.169413
ttz_merged	984.992	89.7924	51.29	42.8745	42.1008	13.6084	9.89287	8.9546	8.11791	6.15337
ttbb_merged	529.642	188.833	105.138	72.2114	70.2024	6.54104	3.48347	2.83758	2.47011	1.66301
ttbar_all_merged	456340	3287.95	2012.4	715.837	666.895	44.2829	21.1939	16.3798	14.6314	10.494

lv+6jetsjets (500 GeV, 500 fb^{-1}, (-0.8,+0.3))

process	noCut	btag	N_iso_lepton	yvalue	cos<0.99	MissingP<20	llh(pairing)	jetEsumHigh	jetEsumLow	jjj_mass	bb_cand_mass
tth6q_merged	53.7952	28.7761	1.07325	1.06957	1.05095	0.406692	0.0638031	0.0307991	0.0297249	0.0185216	0.0176946
tthln4q_merged	51.7348	27.7163	18.8075	18.2073	17.8627	17.5923	12.1466	11.6279	10.1778	9.20404	8.49736
tth2l2nbb_merged	12.3877	6.70154	2.52099	1.4122	1.33722	1.31469	0.296643	0.29412	0.0819965	0.0564535	0.0347802
tthallnonbb_merged	86.5526	1.84721	0.644547	0.619075	0.603007	0.564798	0.233904	0.216417	0.16823	0.143523	0.127343
ttz_merged	984.992	86.8287	31.1789	28.3547	27.7849	26.3538	11.1139	9.97797	6.73904	5.71409	4.22839
ttbb_merged	529.642	178.184	65.4168	51.3721	49.8332	47.0485	6.37372	4.78728	1.94271	1.5668	1.02898
ttbar_all_merged	457075	2660.93	838.57	399.374	359.352	334.662	33.5759	22.0253	7.98989	6.41502	4.83161

2l2v+4jetsjets (500 GeV, 500 fb^{-1}, (-0.8,+0.3))

process	noCut	btag	N_iso_lepton	yvalue	cos<0.99	MissingP<20	llh(pairing)	jetEsumHigh	jetEsumLow	bb_cand_mass
tth6q_merged	53.7952	20.9295	0.0197837	0.0195234	0.0192499	0.00647803	0.00563128	0	0	0
tthln4q_merged	51.7929	21.4685	0.545281	0.54503	0.537555	0.529569	0.373587	0.023657	0.0224023	0.0151685
tth2l2nbb_merged	12.401	6.02427	3.35224	3.31767	3.28073	3.22743	3.14881	2.63775	2.2911	1.96124
tthallnonbb_merged	86.5526	1.3223	0.113818	0.112415	0.112351	0.106947	0.0867495	0.0395962	0.0263028	0.016962
ttz_merged	985.994	65.6301	5.39562	5.28336	5.22457	5.09757	4.44506	2.84587	1.59257	1.05162
ttbb_merged	528.936	128.857	11.6389	10.189	10.0119	9.81533	7.1546	3.0684	0.448618	0.313013
ttbar_all_merged	456338	1756.94	91.3203	59.2095	51.3526	50.0376	34.4566	13.6121	1.73918	1.08825

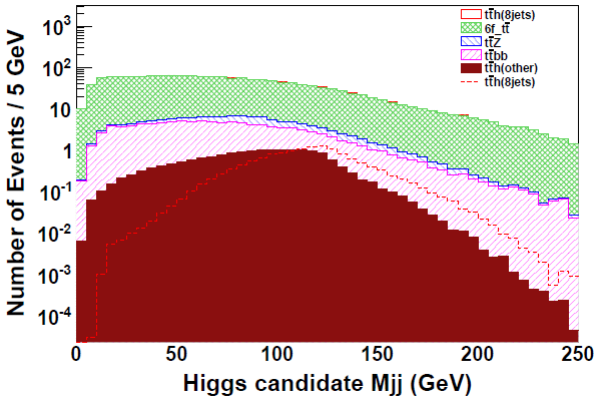
* A half of signal event are used to make likelihood templates for jet pairing.

event selection cuts for tth→8jets

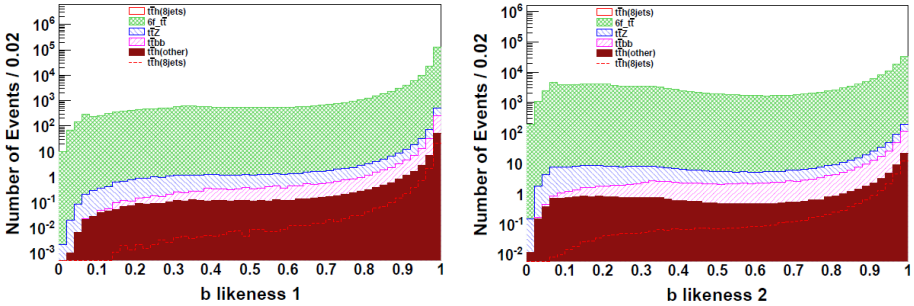
- forced 8 jet clustering
- 4 b tagged (b likeness > 0.85, 0.8, 0.6, 0.2)
- Number of isolated lepton = 0

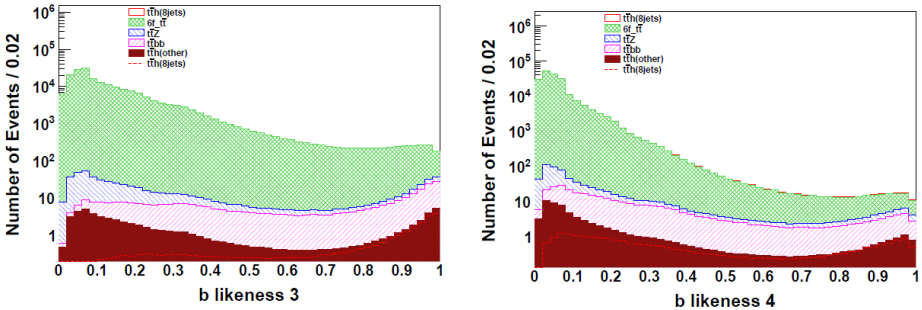
tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)

ue of Durham jet clustering: Y_{87}>0.000
.0021 && Y_{87}<=0.00042
tor acceptance $\cos\theta_{jet}$>0.99
aximum likelihood metl

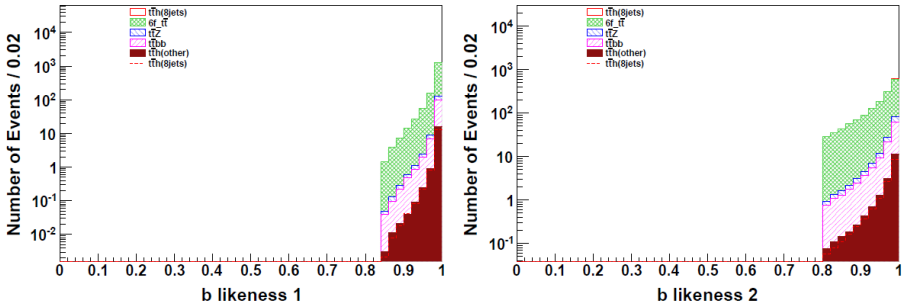


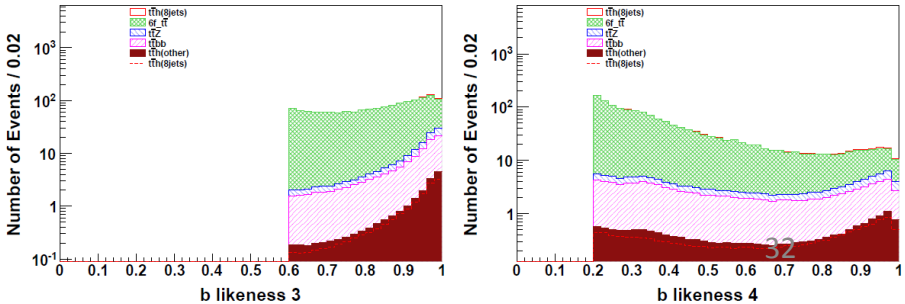
before





after b likeness cut



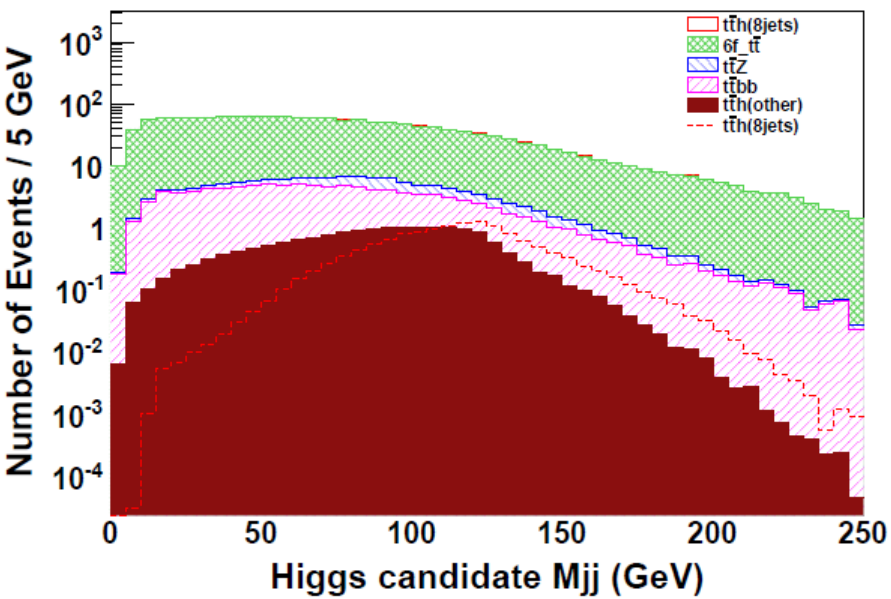


event selection cuts for tth→8jets

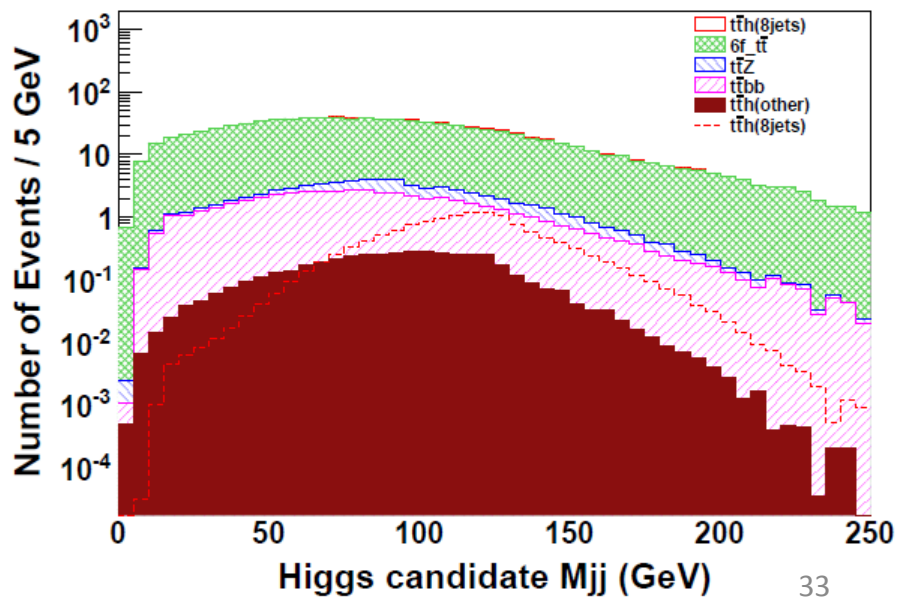
- forced 8 jet clustering
- 4 b tagged (b likeness > 0.85, 0.8, 0.6, 0.2)
- Number of isolated lepton = 0
- Y value of Durham jet clustering: Y_{87}>0.00042, Y_{76}>0.0021 && Y_{87}<=0.00042
- detector acceptance $\cos\theta_{jet}$>0.99
- je ; by maximum likelihood meth

tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)

before



after require 0 iso. lep

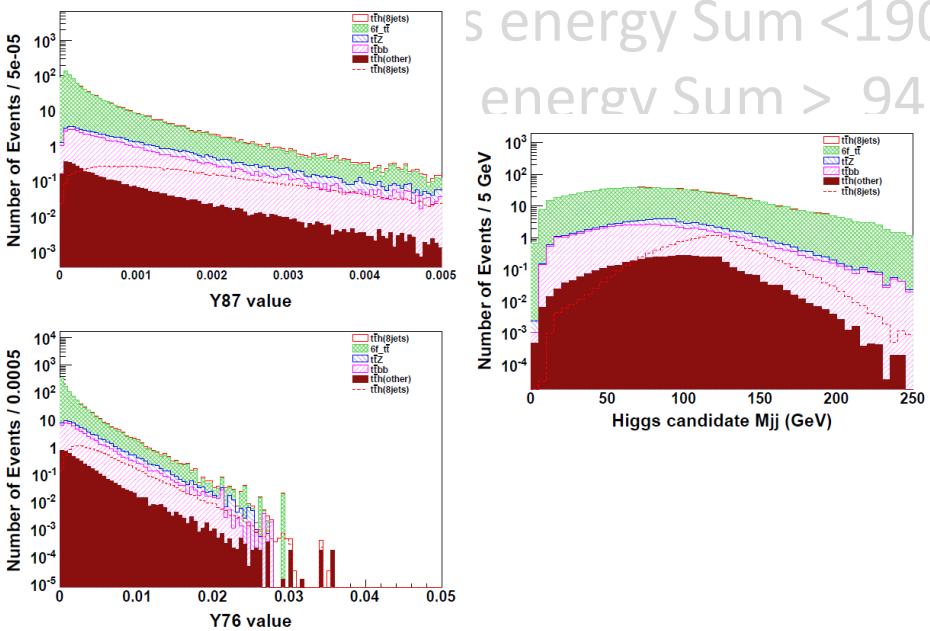


event selection cuts for tth→8jets

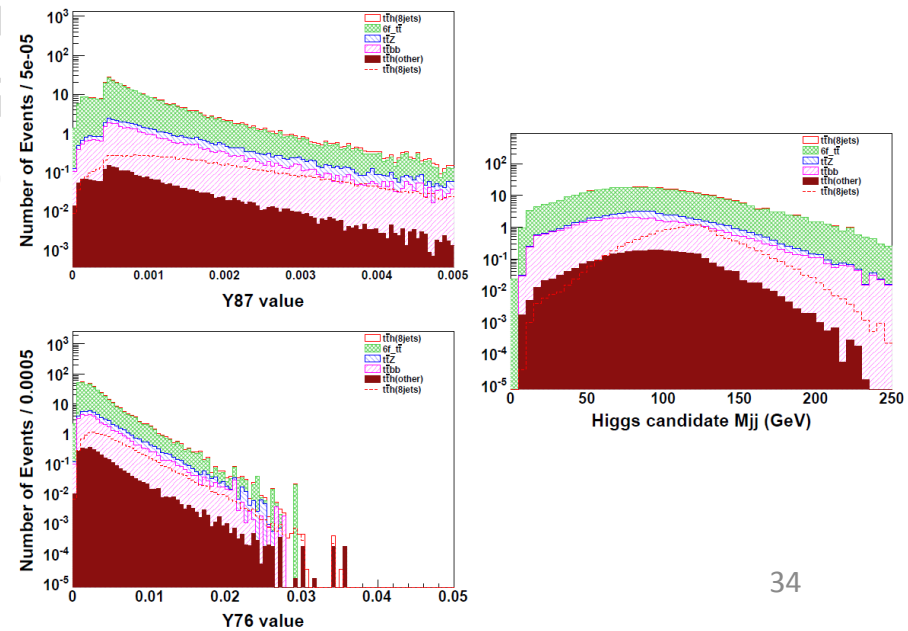
- forced 8 jet clustering
- 4 b tagged (b likeness > 0.85, 0.8, 0.6, 0.2)
- Number of isolated lepton = 0
- Y value of Durham jet clustering: Y_{87}>0.00042, Y_{76}>0.0021 && Y_{87}<=0.00042
- detector acceptance $\cos\theta_{jet}$>0.99
- je g by maximum likelihood meth 5.5
  s energy Sum <190 (
  energy Sum > 94 G
  p
  e
  0

tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)

before



after Y value cut

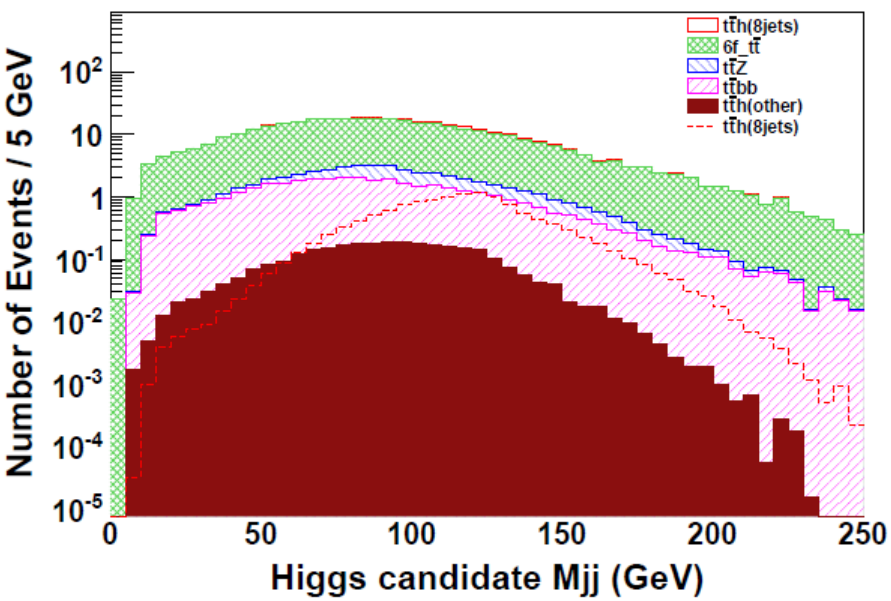


event selection cuts for tth→8jets

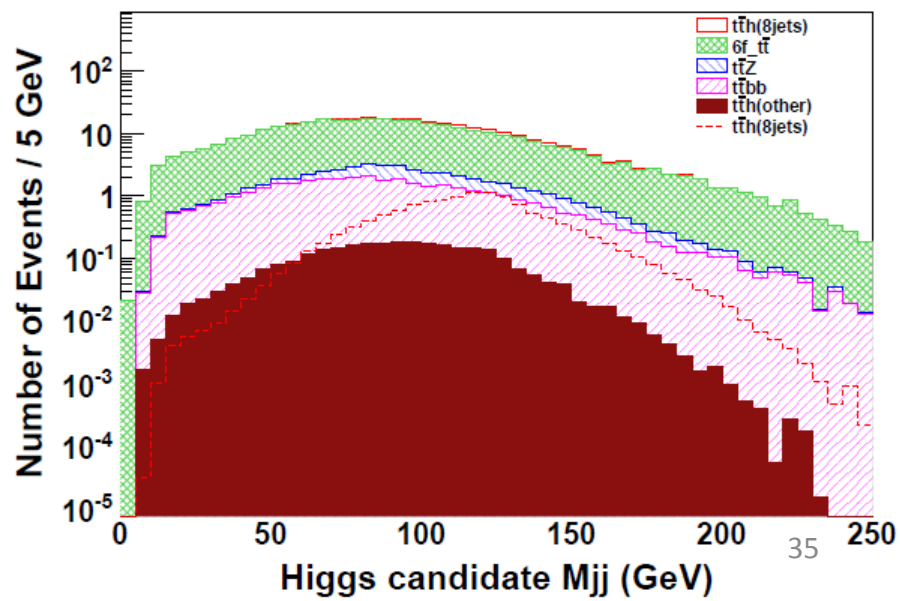
- forced 8 jet clustering
- 4 b tagged (b likeness > 0.85, 0.8, 0.6, 0.2)
- Number of isolated lepton = 0
- Y value of Durham jet clustering: Y_{87}>0.00042, Y_{76}>0.0021 && Y_{87}<=0.00042
- detector acceptance $\cos\theta_{jet}$>0.99
- je by maximum likelihood metl

tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)

before



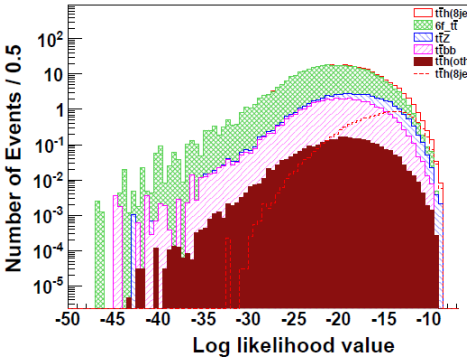
after $\cos\theta_{jet}$>0.99 cut



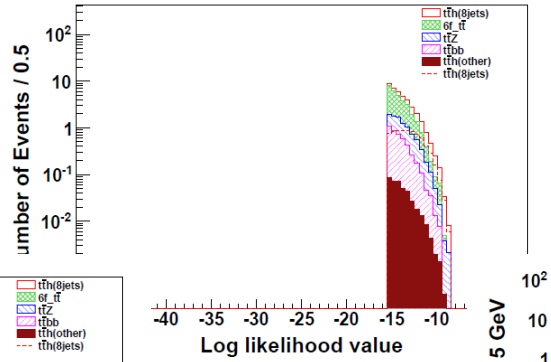
event selection cuts for tth→8jets

before

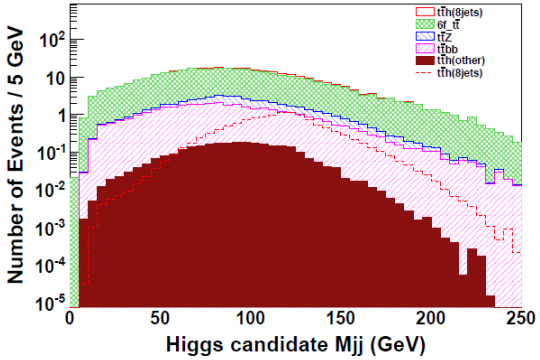
after jet pairing and cut

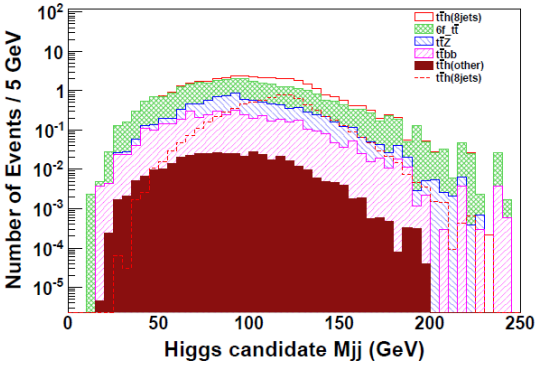


stering



tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)

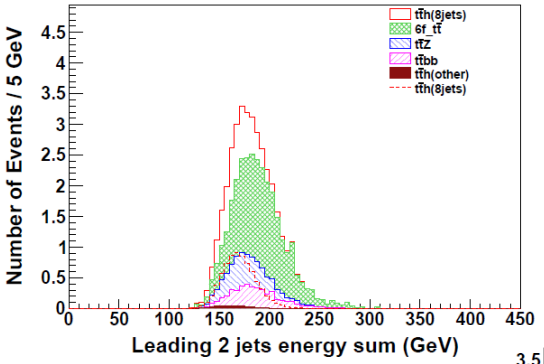




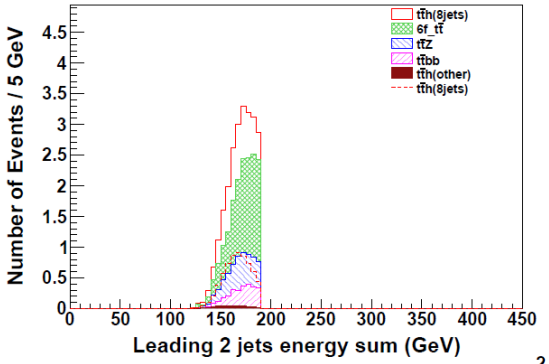
- Number of
- Y value of D
  Y_{76}>0.0021
- detector ac
  Y_{87}>0.00042
- jet pairing by maximum likelihood method : llh value >-15.5
- highest 2 jets energy Sum <190 GeV,
  lowest 3 jets energy Sum > 94 GeV
- reconstructed 3 jets mass of top candidates > 140 GeV
- reconstructed 2 jets mass of the higgs candidate :
  (-0.8,+0.3) 85<M_{jj}<175, (+0.8,-0.3) 75<M_{jj}<175

event selection cuts for tth→8jets

before



after highest 2 jet energy cut

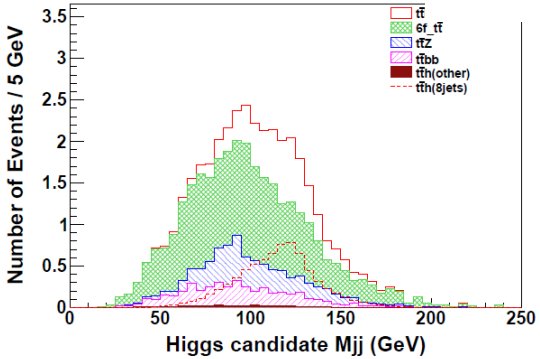


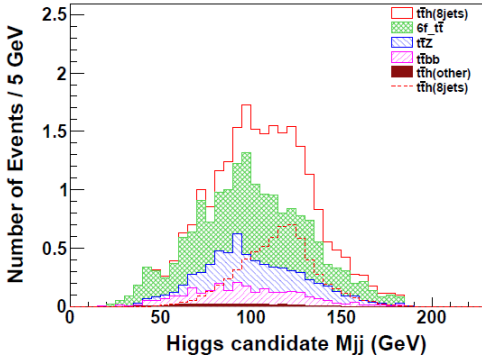
tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)

stering

eness > 0.85,

- Y value of D $'_{87}$>0.00042, Y_{76}>0.0021 &
- detector acc
- jet pairing b method : llh v

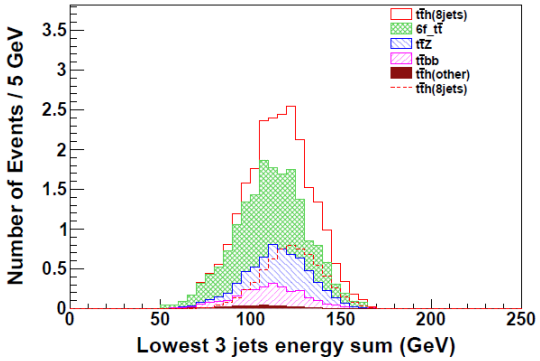




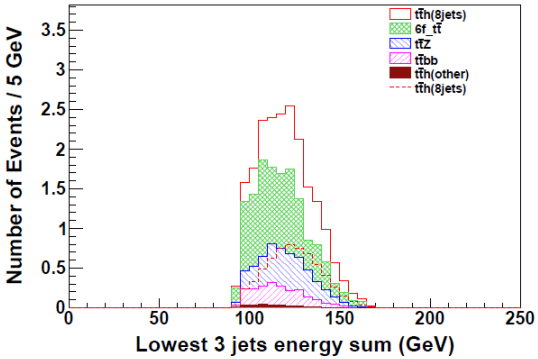
- highest 2 jets energy Sum <190 GeV
- lowest 3 jets energy Sum > 94 GeV
- reconstructed 3 jets mass of top candidates > 140 GeV
- reconstructed 2 jets mass of the higgs candidate : (-0.8,+0.3) $85<M_{jj}<175$, (+0.8,-0.3) $75<M_{jj}<175$

event selection cuts for tth→8jets

before event selection



after lowest 3 jets energy cut



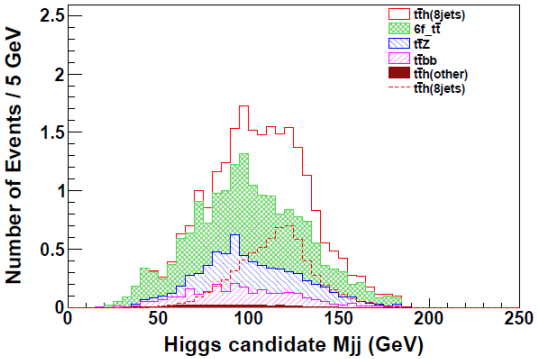
tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)

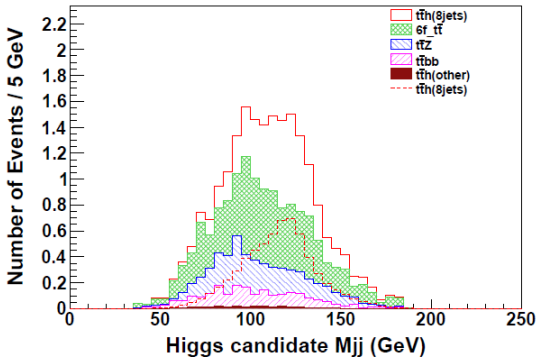
stering

keness > 0.85,

ated lepton =

- Y value ... ing: Y_{87}>0.00042 Y_{76}>0.0
- detecto ... 0.99
- jet pair ... hood method : l
- highest ... 90 GeV





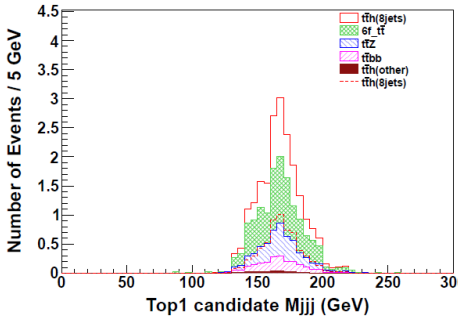
- lowest 3 jets energy Sum > 94 GeV
- reconstructed 3 jets mass of top candidates > 140 GeV
- reconstructed 2 jets mass of the higgs candidate : (-0.8,+0.3) 85<M_{jj}<175, (+0.8,-0.3) 75<M_{jj}<175

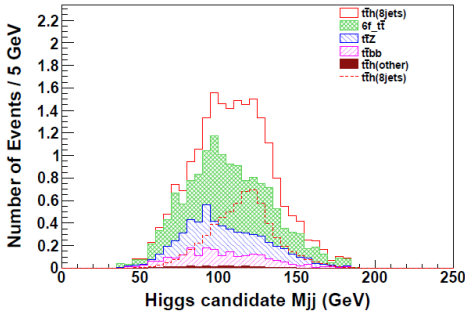
event selection cuts for tth→8jets

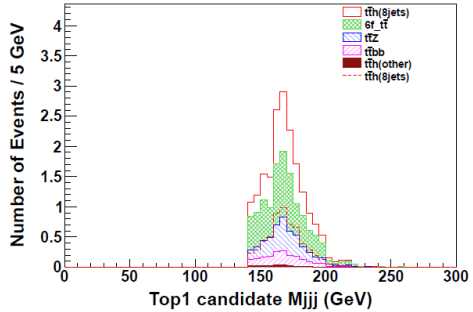
before event selection

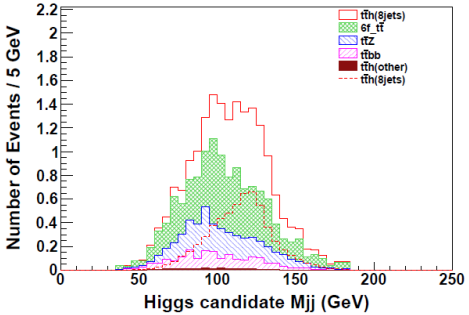
after Mjjj cut

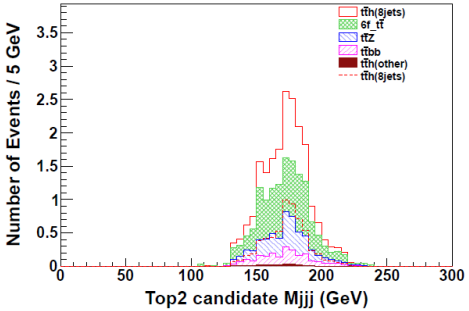
tth→8jets
6f_ttbar
ttZ
ttbb
tth(other)

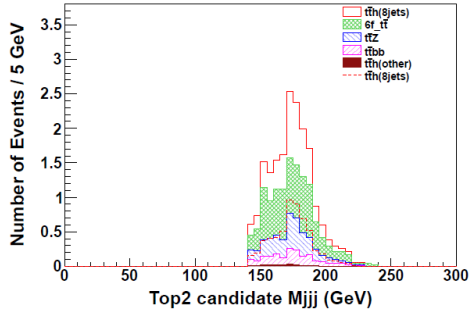








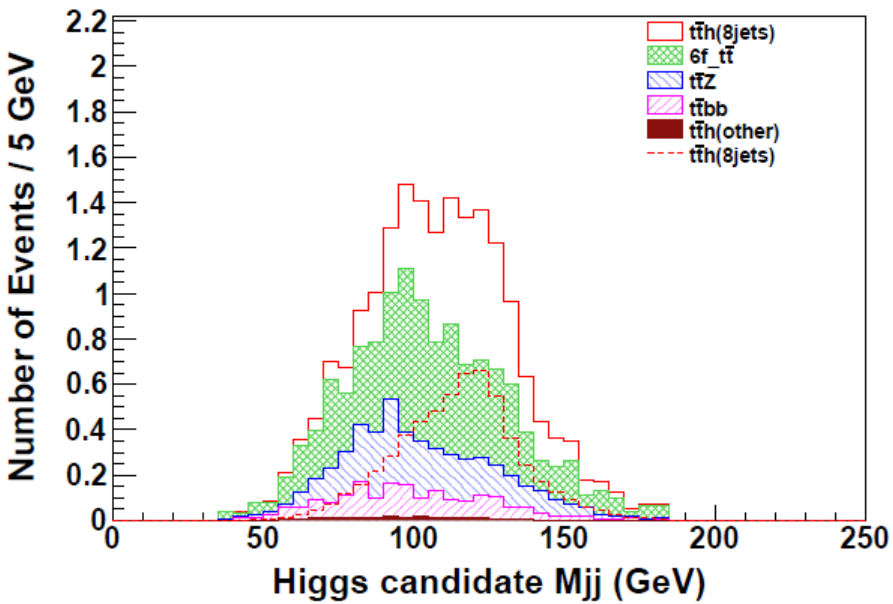




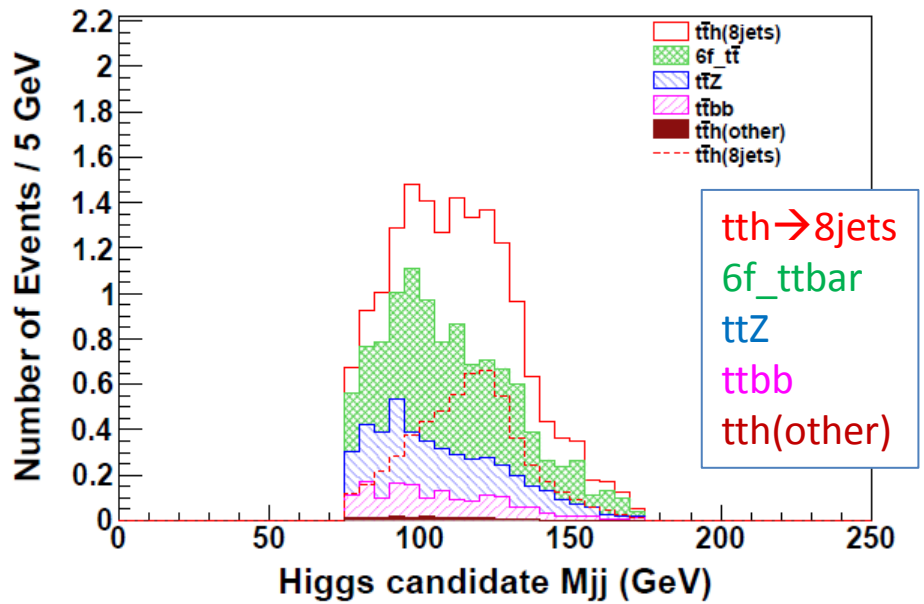
- Y value of D clustering
- g: Y_{23}>0.00042
- eptance $\cos\theta_{jet}$>0
- y maximum likelih alue >-15.5
- s energy Sum <19
- lowest 3 jets energy Sum > 94 GeV
- reconstructed 3 jets mass of top candidates > 140 GeV
- reconstructed 2 jets mass of the higgs candidate : (-0.8,+0.3) 85<M_{jj}<175, (+0.8,-0.3) 75<M_{jj}<175

event selection cuts for tth→8jets

before event selection



after Mjj cut

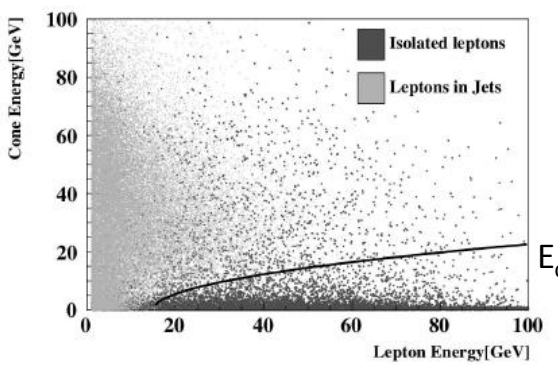


- highest 2 jets energy Sum <190 GeV
- lowest 3 jets energy Sum > 94 GeV
- reconstructed 3 jets mass of top candidates > 140 GeV
- reconstructed 2 jets mass of the higgs candidate : (-0.8,+0.3) $85<M_{jj}<175$, (+0.8,-0.3) $75<M_{jj}<175$

Isolated Lepton ID

Isolated lepton identification 1

- muon selection
- electron selection
- hadronic tau selection



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

PHYSICAL REVIEW D **84**, 014033 (2011)

muon selection

- pre-selection cuts for muon

✓ target PFO has track(s)

✓ $E_{PFO} > 9$ GeV

✓ $E_{yoku} > 1.2$ GeV

✓ $E_{had}/E_{em} > 0.5$

✓ $E_{cal}/E_{PFO} < 0.5$

- isolated muon selection

$E_{PFO} > 15$ GeV

$6*(E_{PFO}-15) - (E_{cone\ without\ Seed})^2 > 0$

E_{PFO} : Energy of Particle Flow Object

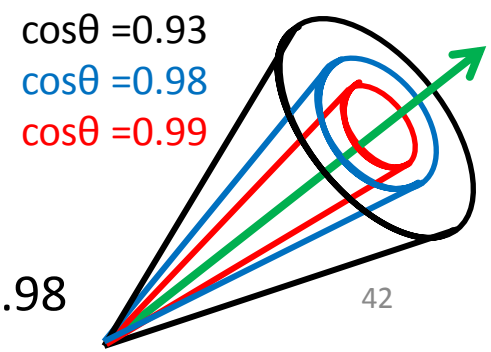
E_{yoku} : measured energy at yoku

E_{had} : measured energy at HCAL

E_{em} : measured energy at ECAL

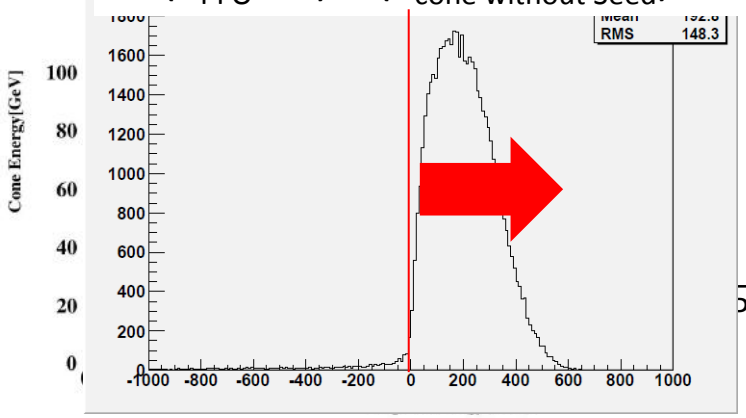
E_{cal} : measured energy sum of ECAL and HCAL

$E_{cone\ without\ Seed}$: measured energy in a cone. cone size is $\cos\theta = 0.98$



Isolated lepton identification 1

- muon selection
- electron selection
- [$6*(E_{PFO}-15) - (E_{cone\ without\ Seed})^2$



PFO−15)

PHYSICAL REVIEW D **84**, 014033 (2011)

muon selection

- pre-selection cuts for muon

✓ target PFO has track(s)

✓ $E_{PFO} > 9$ GeV

✓ $E_{yoku} > 1.2$ GeV

✓ $E_{had}/E_{em} > 0.5$

✓ $E_{cal}/E_{PFO} < 0.5$

- isolated muon selection

$E_{PFO} > 15$ GeV

$6*(E_{PFO}-15) - (E_{cone\ without\ Seed})^2 > 0$

E_{PFO} : Energy of Particle Flow Object

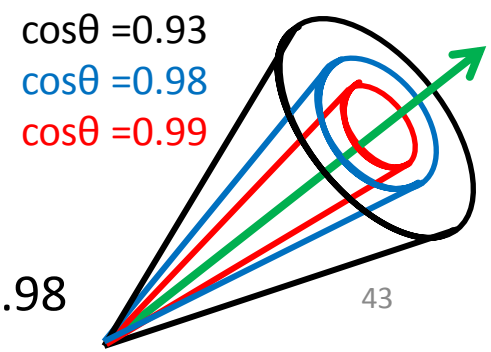
E_{yoku} : measured energy at yoku

E_{had} : measured energy at HCAL

E_{em} : measured energy at ECAL

E_{cal} : measured energy sum of ECAL and HCAL

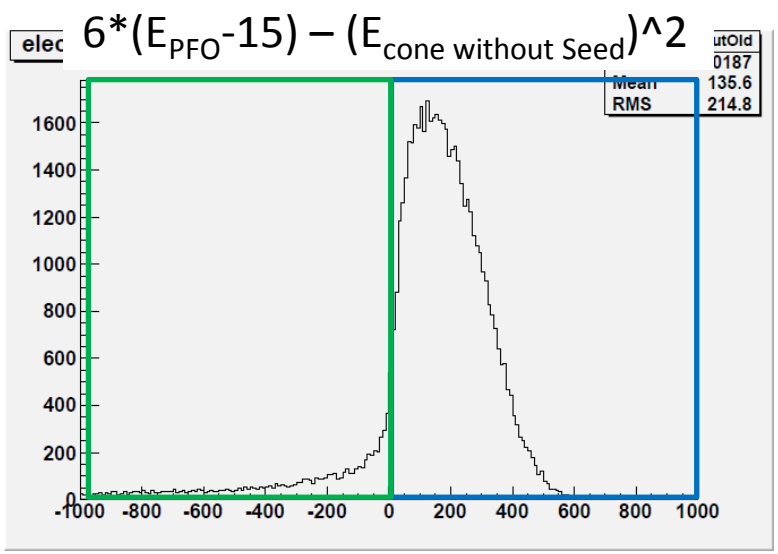
$E_{cone\ without\ Seed}$: measured energy in a cone. cone size is $\cos\theta = 0.98$



Isolated lepton identification 2

- muon selection

- electron selection



E_{cal} : measured energy sum of ECAL and HCAL

$E_{cone\ without\ Seed}$: measured energy in a cone without the target PFO. cone size is cosθ = 0.98

electron selection

- pre-selection cuts for electron

✓ target PFO has track(s)

✓ $E_{PFO} > 2$ GeV

✓ $E_{yoku} < 0.2$ GeV

✓ $E_{had}/E_{em} < 0.1$

- isolated electron selection 1

✓ $E_{PFO} > 15$ GeV

✓ $6*(E_{PFO}-15) - (E_{cone\ without\ Seed})^2 > 0$

- isolated electron selection 2

$6*(E_{PFO}-15) - (E_{cone\ without\ Seed})^2 <= 0$

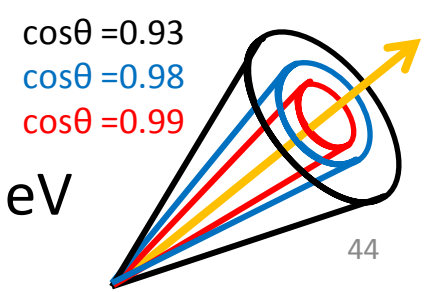
$E_{cone(\cos\theta=0.99)}/E_{cone(\cos\theta=0.98)} > 0.99$

Distance form IP < 0.05 mm

Eem > 15 GeV

$E_{had}/E_{em} < 0.03$

$E_{cone(0.93 < \cos < 0.98)} < 2$GeV

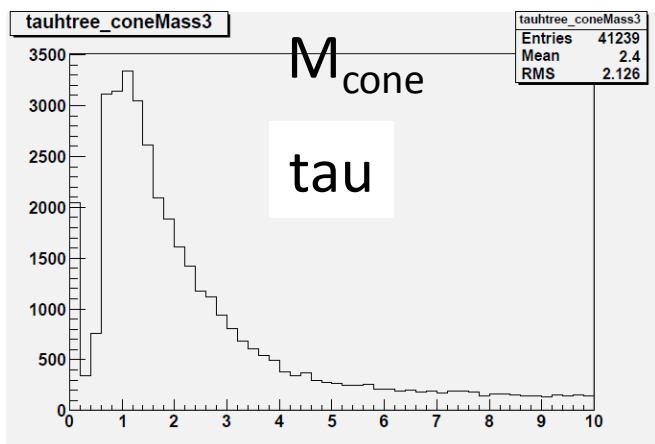


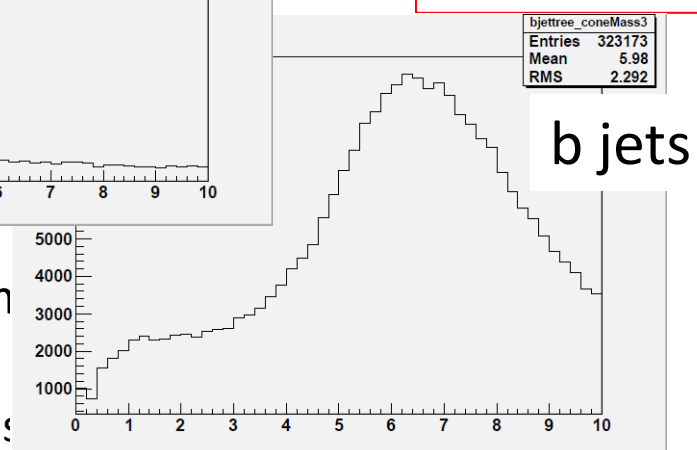
Isolated lepton identification 3

- muon selection
- electron selection
- hadronic tau selection

hadronic tau selection

- pre-selection cuts for hadronic tau
  - ✓ target PFO has track(s)
  - ✓ $E_{PFO} > 5$ GeV
- isolated hadronic tau selection
  - ✓ $E_{cone(\cos\theta=0.99)}/E_{cone(\cos\theta=0.98)} > 0.8$
  - ✓ $M_{cone(\cos\theta=0.93)} < 2$ GeV
  - ✓ no energetic track (Etrk> 2 GeV) in $0.93 < \cos\theta < 0.99$
  - ✓ 1 or 3 tracks in a cone($\cos\theta$ =0.99)





ECAL and HCAL

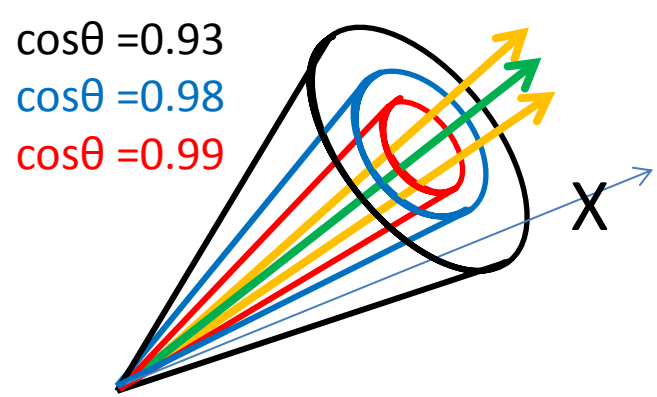
$E_{cone\ without\ Seed}$: n

energy in a cone

target PFO. cone s

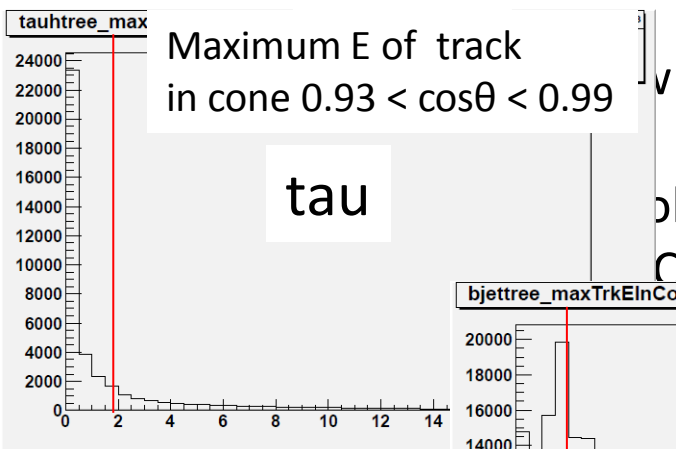
M_{cone} : reconstructed mass using PFOs in a cone

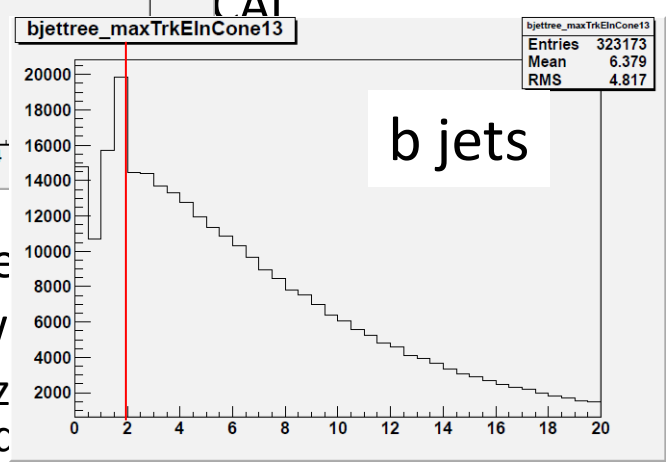
E_{trk} : track energy



Isolated lepton identification 3

- muon selection
- electron selection
- hadronic tau selection





ECAL and HCAL

$E_{cone\ without\ Seed}$: me
energy in a cone w
target PFO. cone siz

M_{cone} : reconstructed

E_{trk} : track energy

hadronic tau selection

- pre-selection cuts for hadronic tau
  - ✓ target PFO has track(s)
  - ✓ $E_{PFO} > 5$ GeV
- isolated hadronic tau selection
  - ✓ $E_{cone(\cos\theta=0.99)}/E_{cone(\cos\theta=0.98)} > 0.8$
  - ✓ $M_{cone(\cos\theta=0.93)} < 2$ GeV
  - ✓ no energetic track (Etrk> 2 GeV) in $0.93 < \cos\theta < 0.99$
  - ✓ 1 or 3 tracks in a cone($\cos\theta = 0.99$)

Isolated lepton ID efficiency 6f_ttbar(yyxyev, yyxylv, yyuyyc)

(%)	0 lepton	1 lepton	>2 leptons
yyxyev	12.37	83.17	4.45
yyxylv	6.75	88.96	4.28
yyxylv	48.66	48.73	2.59
yyuyyc	94.84	4.97	0.18

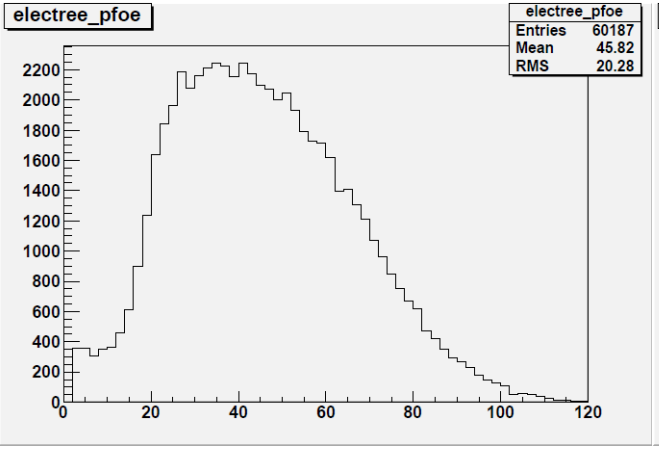
yyuyyc
nevent = 23919
npfos = 3.32*10^6

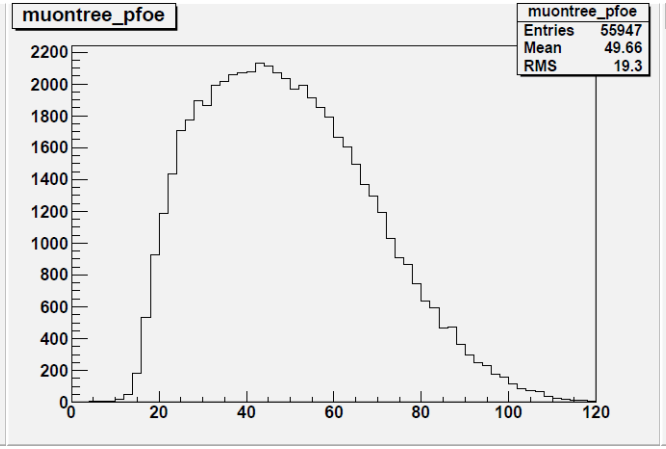
n fake lepton = 23919*(0.049+ 2.*0.18)
= 1258
miss id probability = 1258/(3.32*10^6)
= 0.0003789
→ 0.038%/(pfo of jets)

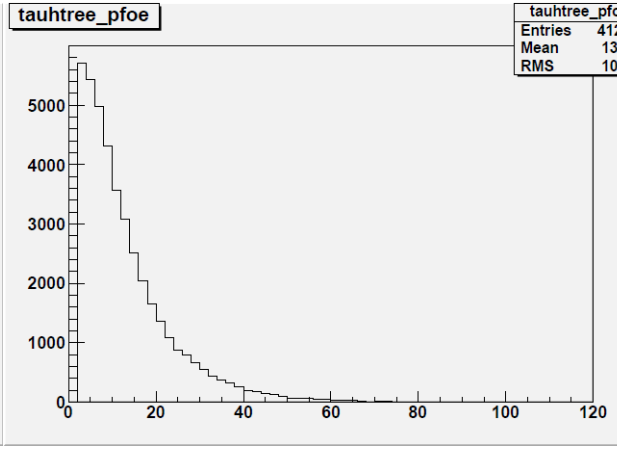
PFO kinematics plots (for iso. lepton ID)

electron muon tau(hadronic)

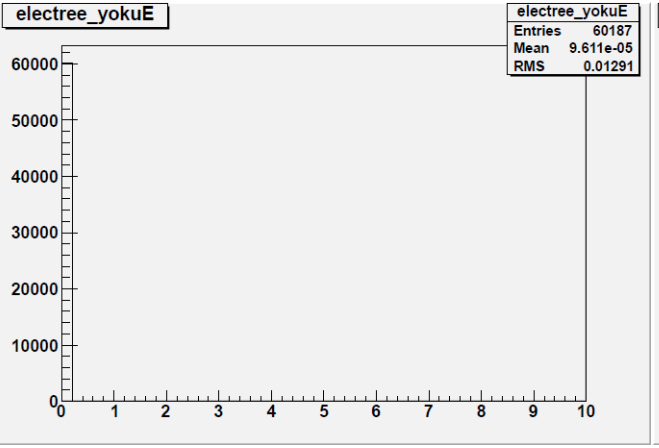
Epfo

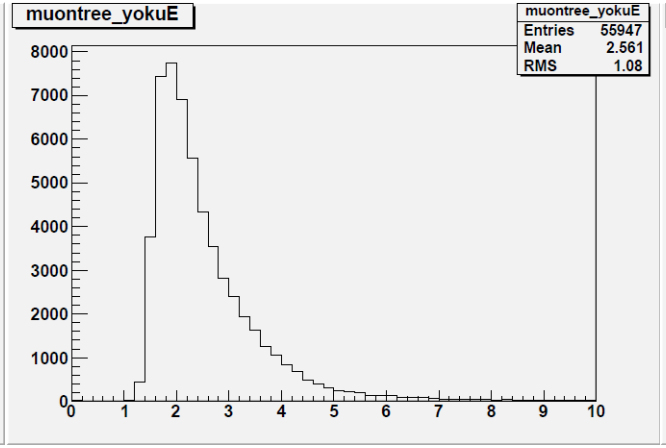


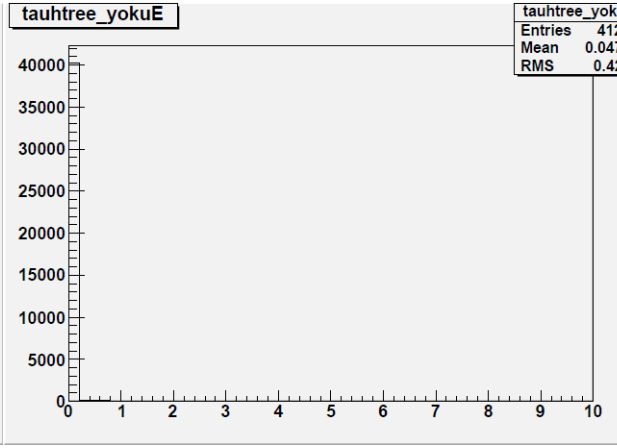




Eyoku



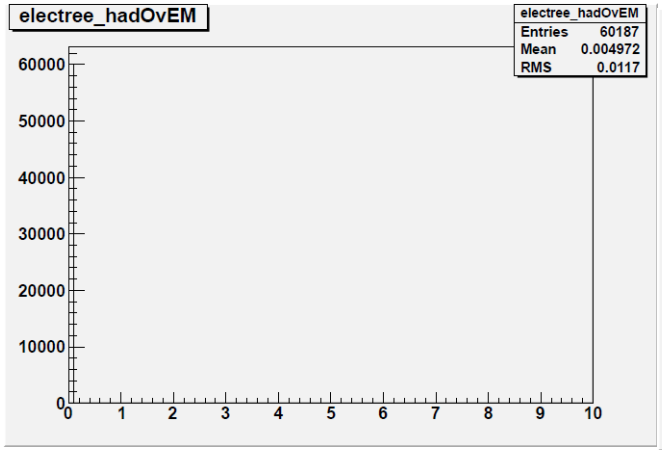


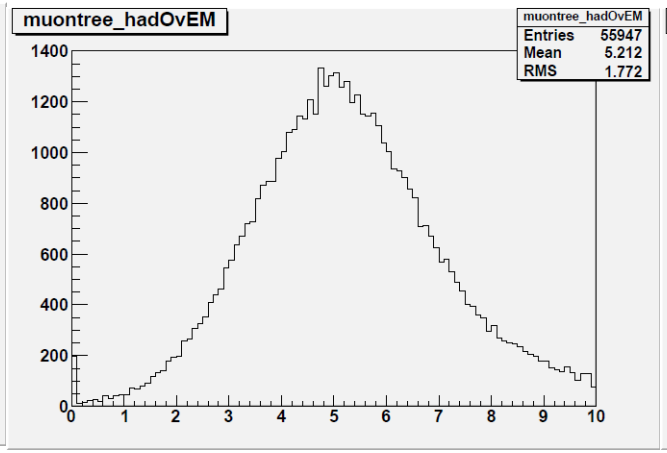


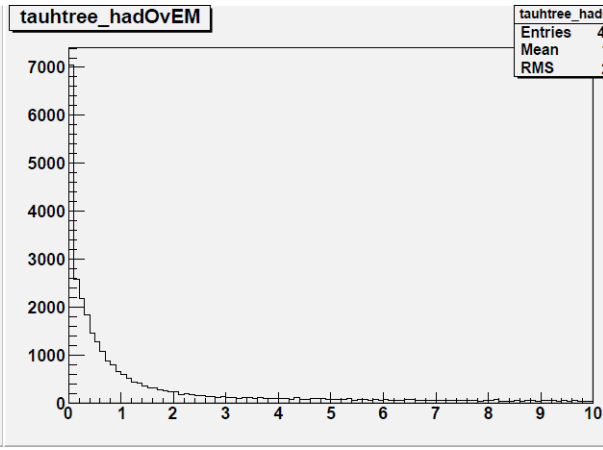
PFO kinematics plots (for iso. lepton ID)

electron muon tau(hadronic)

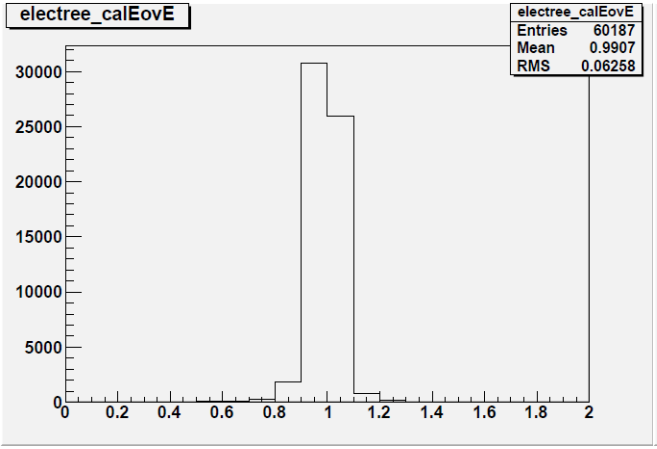
Ehad/Eem

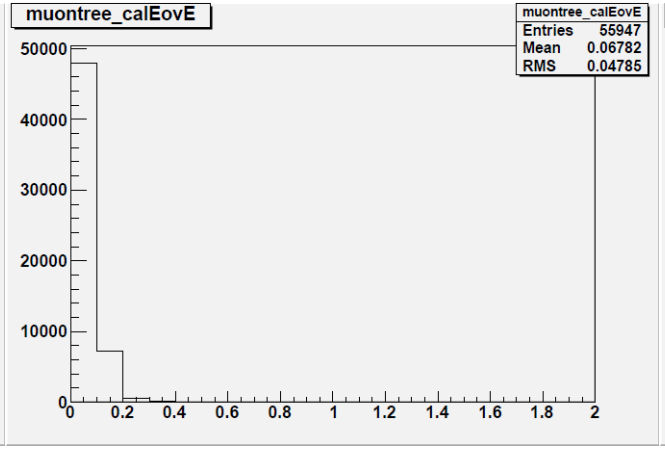


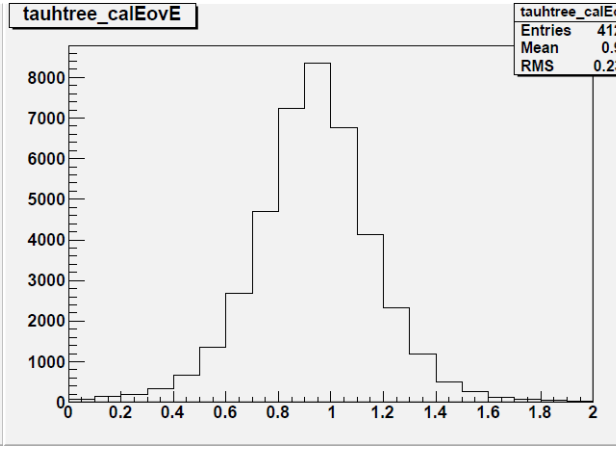




Ecal/E



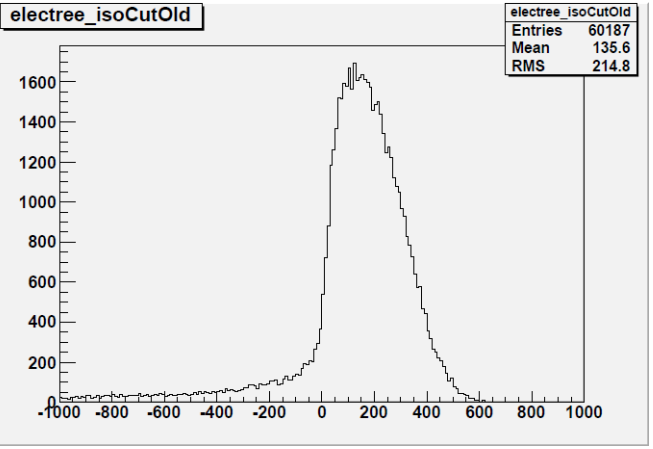


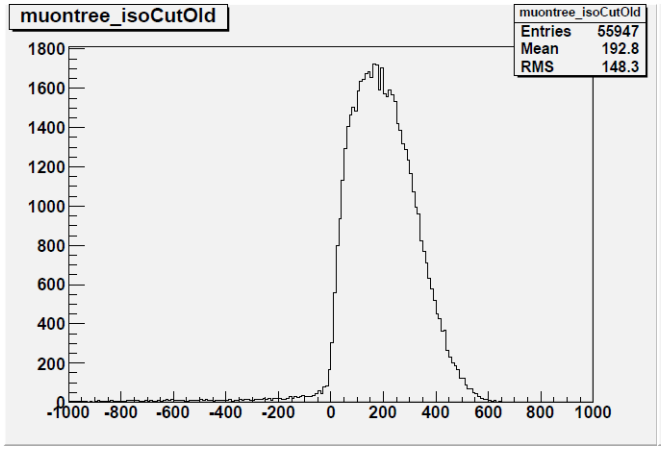


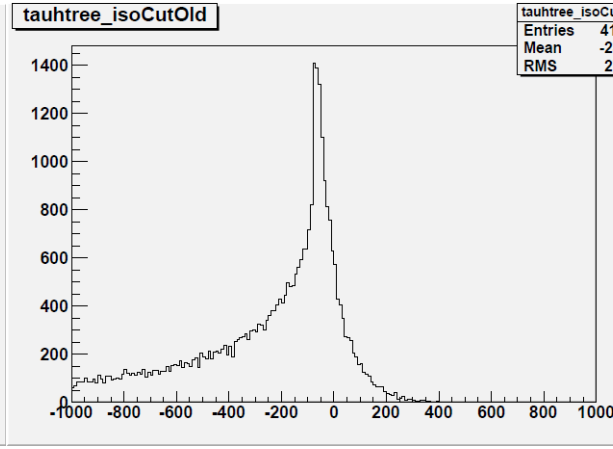
PFO kinematics plots (for iso. lepton ID)

electron muon tau(hadronic)

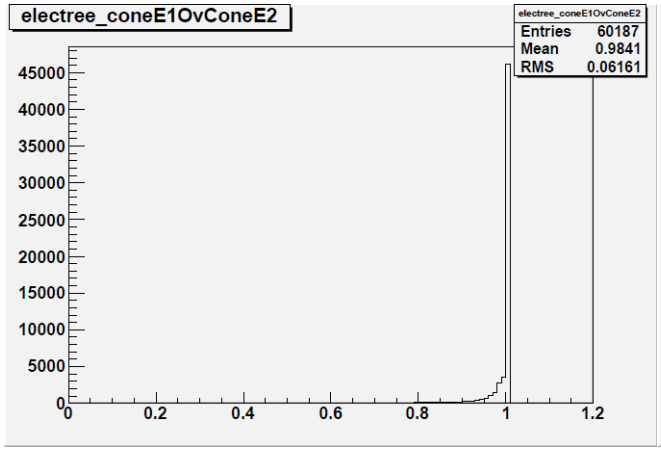
$6*(E_{PFO}-15) - (E_{cone\ without\ Seed})^2$

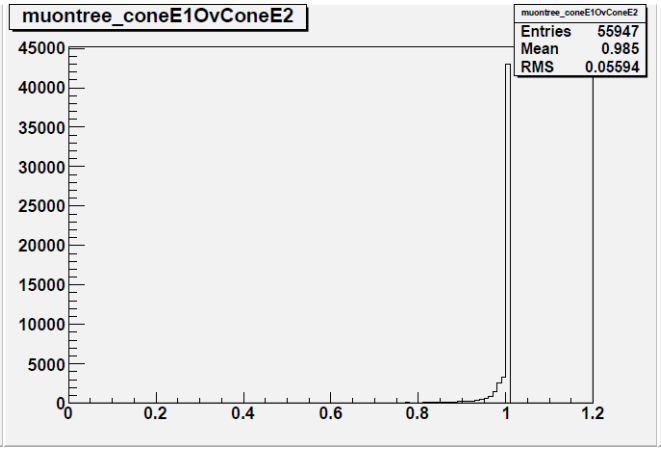


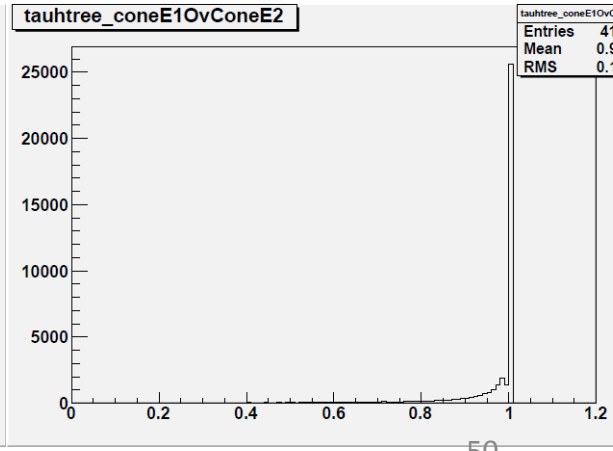




Econe1/Econe2



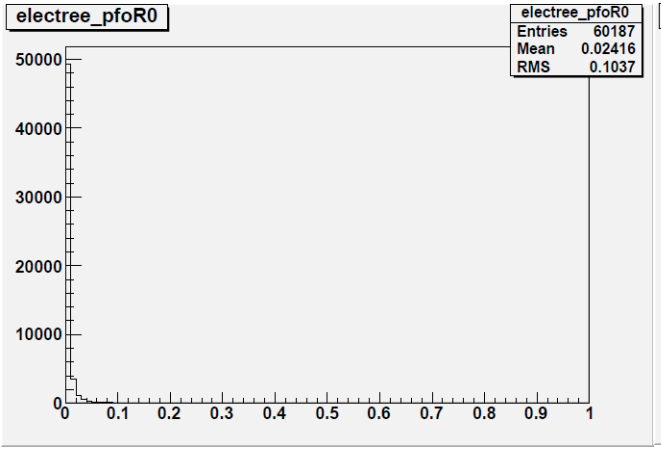


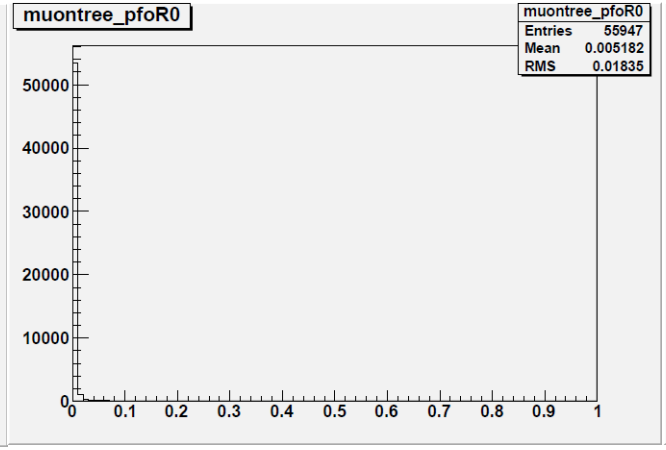


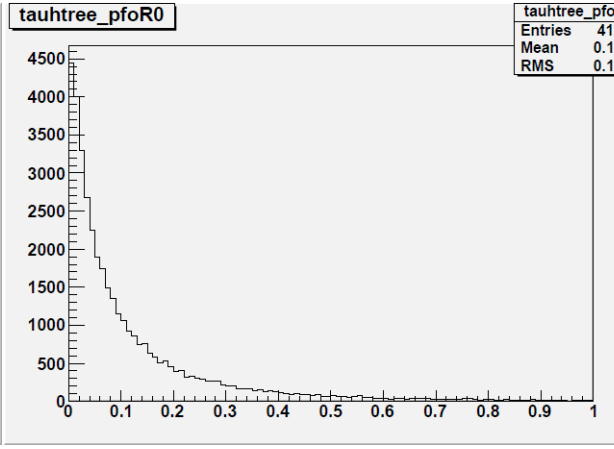
PFO kinematics plots (for iso. lepton ID)

electron muon tau(hadronic)

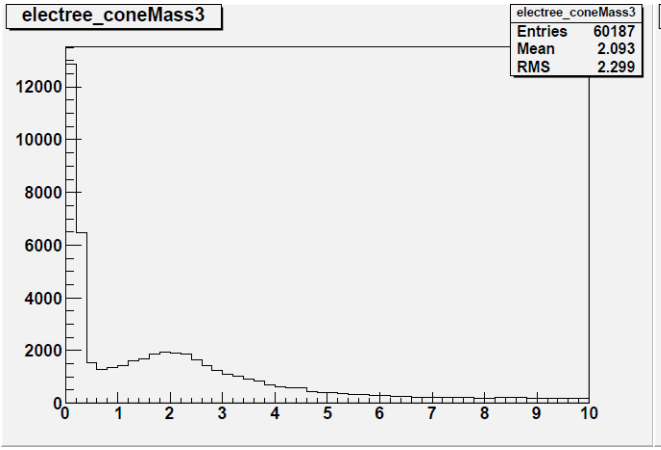
R0: distance from IP

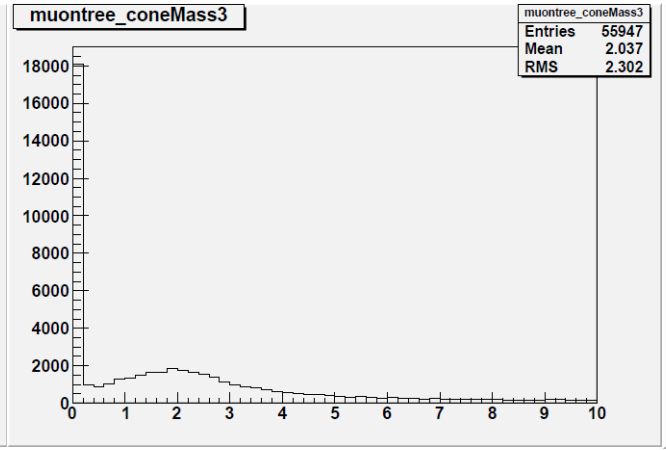


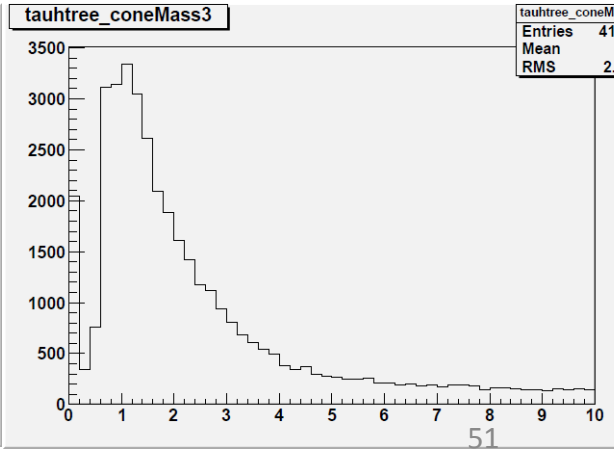




cone3 mass



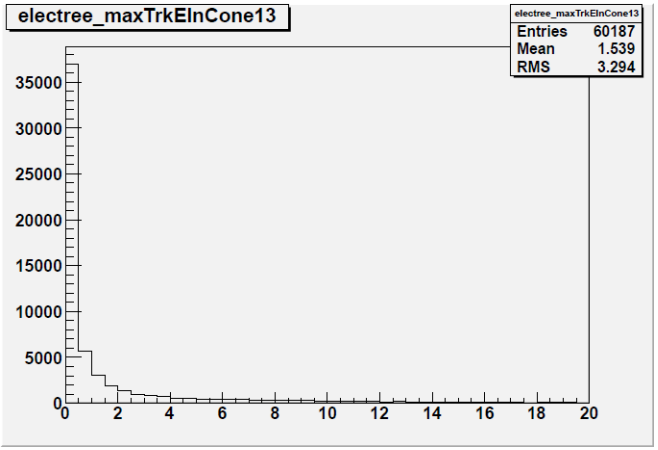


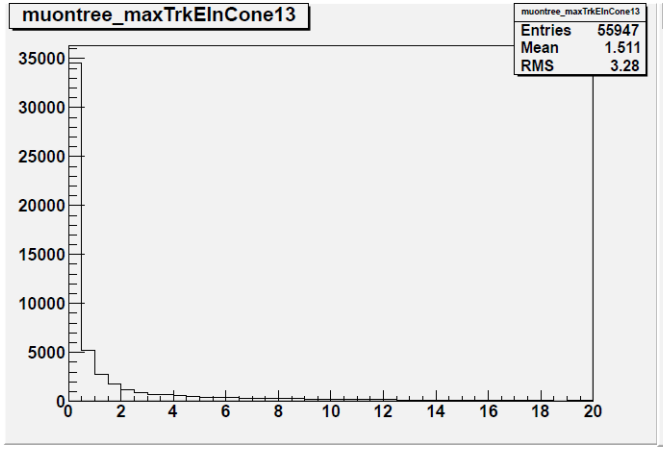


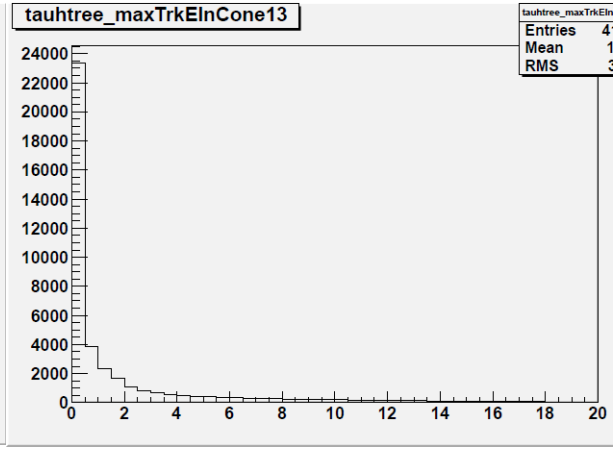
PFO kinematics plots (for iso. lepton ID)

electron muon tau(hadronic)

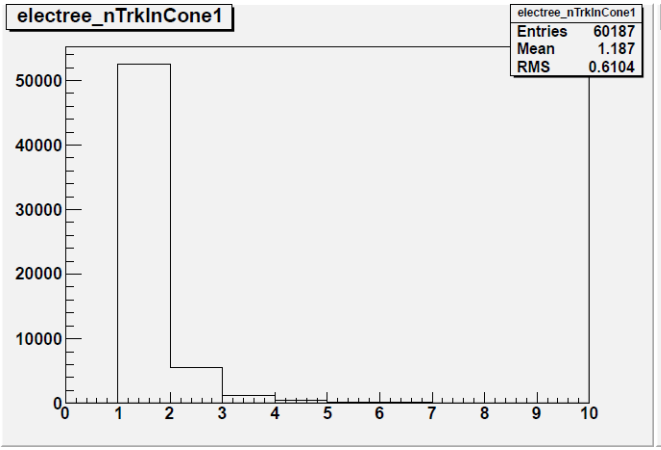
maximum track energy between cone1 and cone3

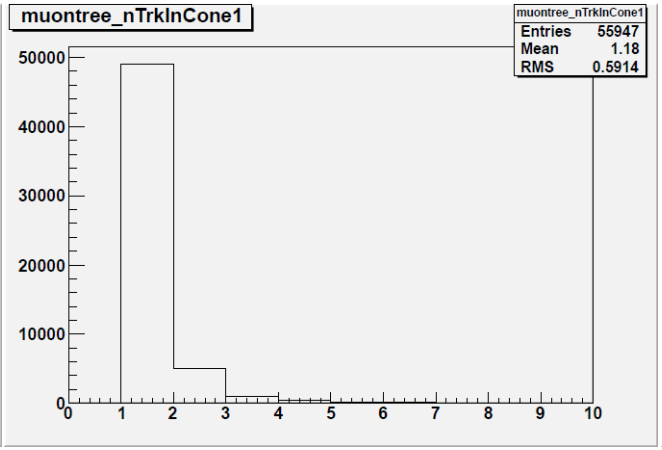


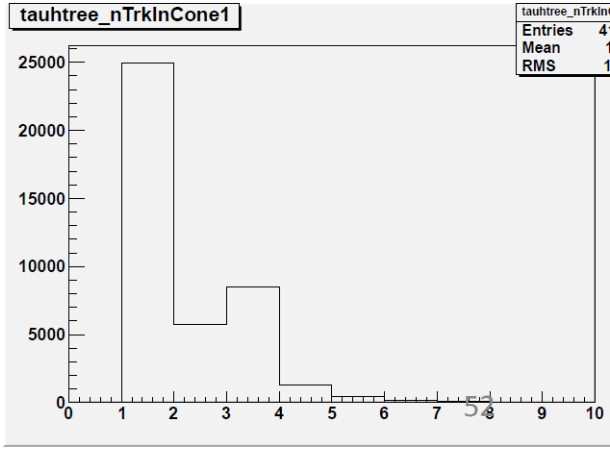




N tracks in cone1



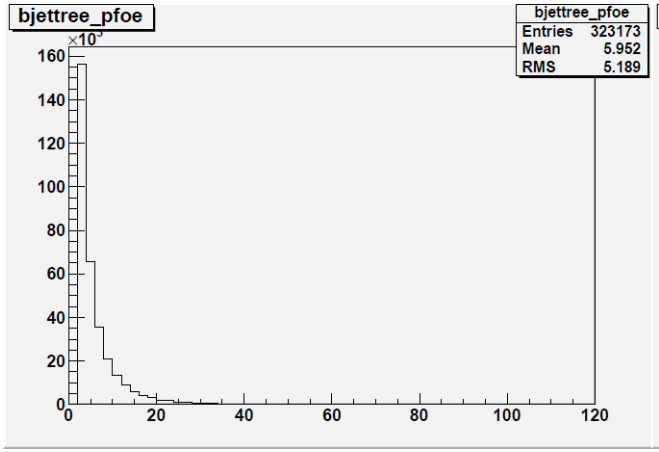




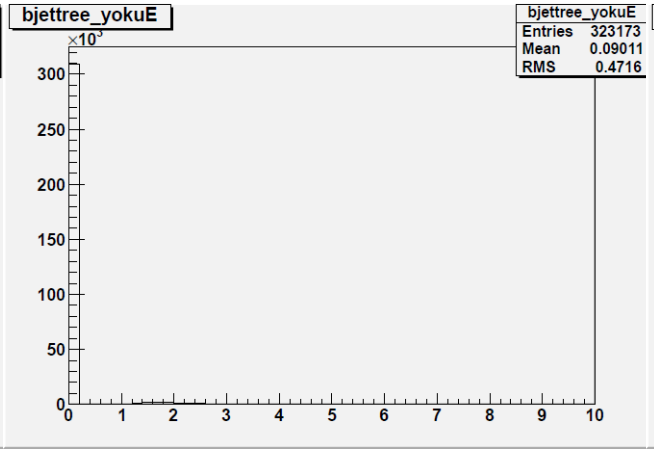
PFO kinematics plots (for iso. lepton ID)

b jets

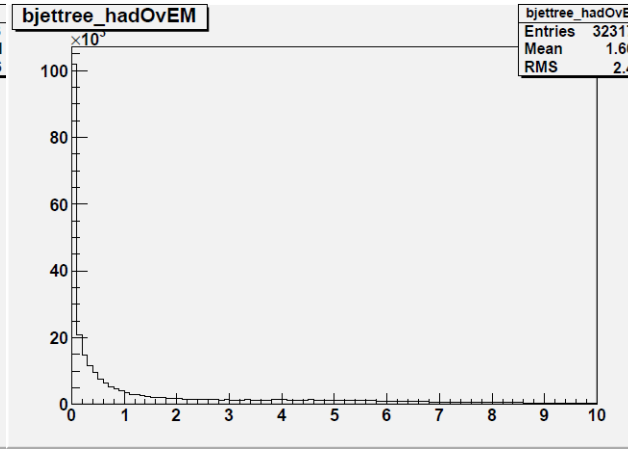
Epfo



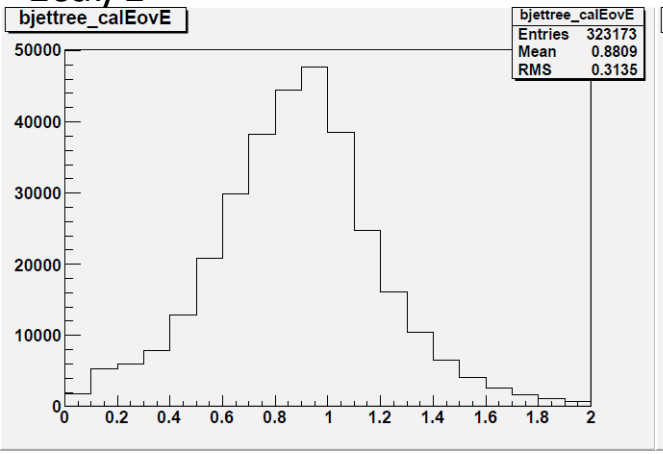
Eyoku



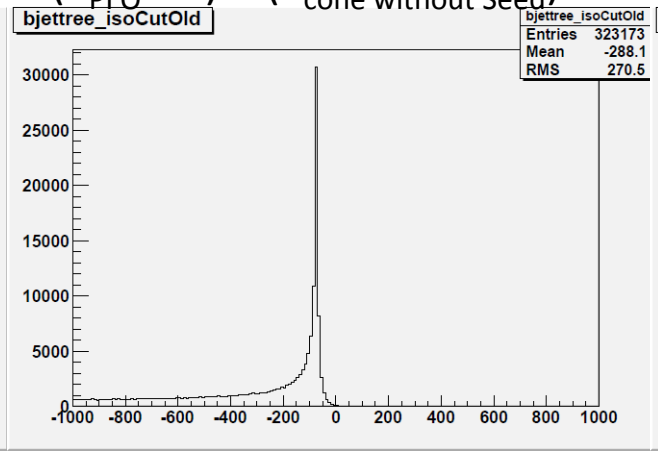
Ehad/Eem



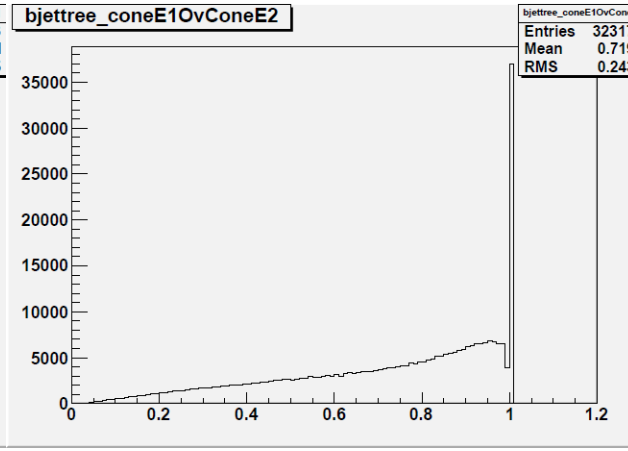
Ecal/E



$6*(E_{PFO}-15) - (E_{cone\ without\ Seed})^2$



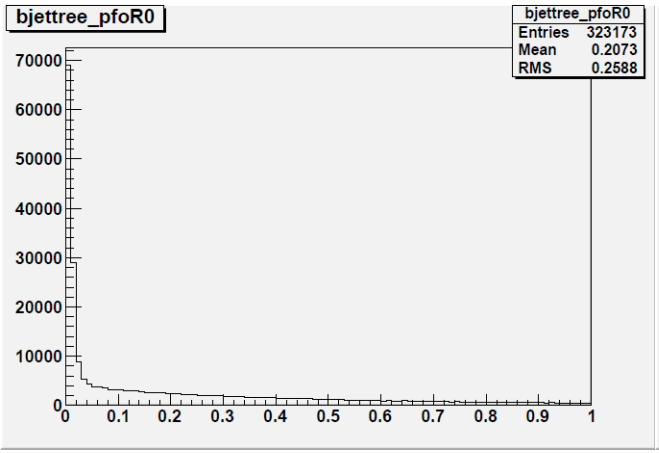
Econe1/Econe2



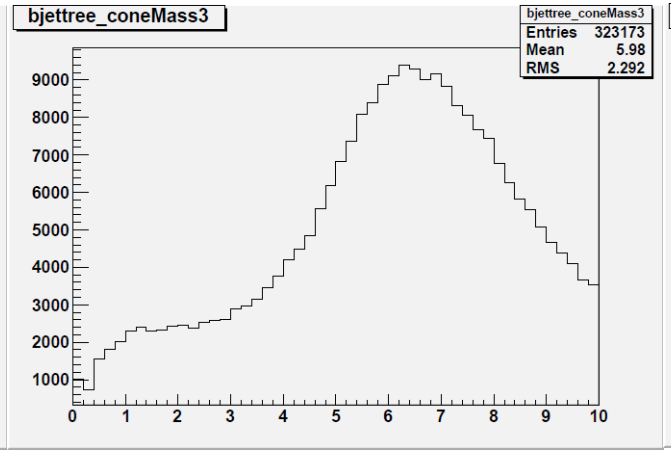
PFO kinematics plots (for iso. lepton ID)

b jets

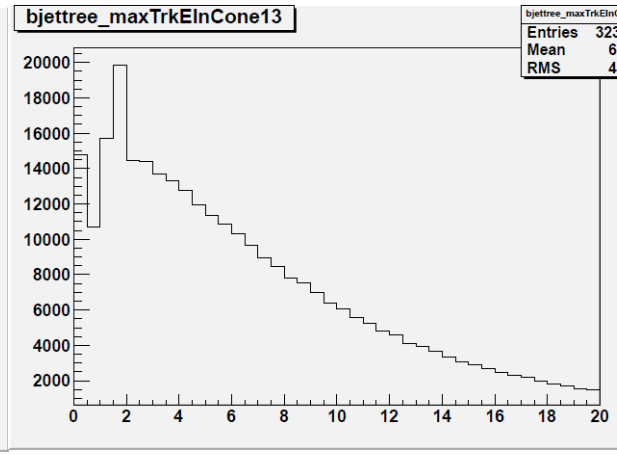
R0: distance from IP



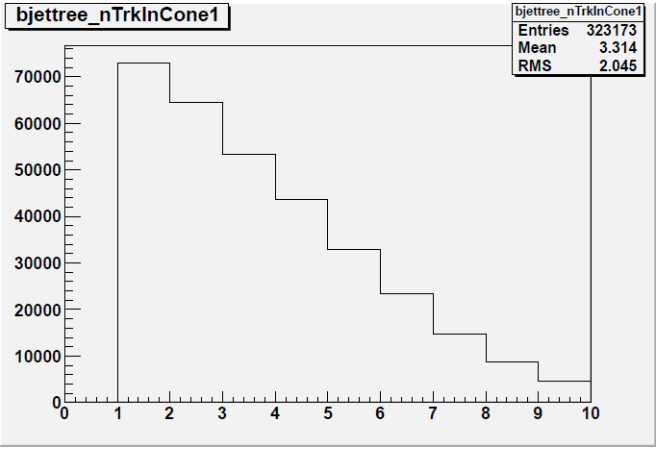
cone3 mass



maximum track energy between cone1 and cone3



N tracks in cone1



Isolated Lepton ID Efficiency

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

ttH → 2l2ν + 4 jets

(%)	method	elec	muon	taue	taum	tauh1	tauh3	bjet	ljet
Identified as a lepton	BDT	93.2	96.53	73.51	74.63	56.56	49.3	0.016	N/A
	cut	90.91	95.35	63.09	65.78	47.08	38.82	0.017	

ttZ

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

- Lepton ID efficiency and miss ID efficiency are improved by BDT method
- ID efficiency is almost same to ttZ and ttH → 2l2ν + 4 jets.

new 6f_ttbar samples are generated as DBD samples
→ apply cut based isolated lepton selection to all signal and background events.

Iso. lep.: training and test sample

signal : e, mu, tau(e), tau(mu), tau(1-prong), tau(3-prong)
training and test samples: tth→2l2nbbbb

background: mu, tau(e), tau(mu), tau(1-prong), tau(3-prong), b jet, lf jet
training and test samples: ttZ for light flavor jet
: tth→2l2nbbbb for the other background

- PFOs which can be traced to MC information are used to make samples.

BDTs:

Backgrounds

Signals

	e	mu	tau(e)	tau(mu)	tau 1-prong	tau 3-prong	bjet	lf jet
e	-	x	x	x	x	x	x	x
mu		-	x	x	x	x	x	x
tau(e)			-	x	x	x	x	x
tau(mu)				-	x	x	x	x
tau(1-prong)					-	x	x	x
tau(3-prong)						-	x	x

Input variables

✓ Input variables are chosen to maximize a area of ROC curve from the following parameters

- hadOvEM: E_{hcal}/E_{ecal}
- calEovE: $(E_{hcal}+E_{ecal})/Epfo$
- coneE2woSeed: E_{cone2} without seed E_{PFO}
- isoCutOld: $6(E_{PFO}-15)^2 - (coneE2woSeed)^2$
- pfoR0 : $sqrt(trkD0^2+trkZ0^2)$
- coneE1OvConeE2: E_{cone1}/E_{cone2}
- coneMass1: reconstructed mass with PFOs in cone1
- coneMass3: reconstructed mass with PFOs in cone3
- clusterShape0: χ2 of fit
- clusterShape1: maximum deposited energy (GeV)
- clusterShape2: shower Max (mm)
- clusterShape3: transverse absorption length(mm)
- clusterShape5: shower Max/ Expected shower Max
- clusterShape16: xl20 (mm)
- yokuE: deposited energy in the yoku
- pfoe: PFO energy
- pt: Pt of PFO
- cone1E
- maxTrkEInCone13: Maximum energy of a PFO with track between cone1 and cone2
- nNeutralCone1: Number of PFOs with no track in cone1
- eNeutralCone1: Energy sum of PFOs with no track in cone1

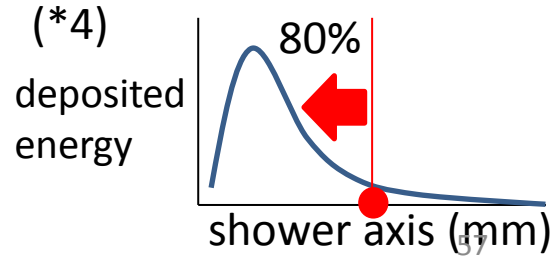
(*1) cone1: cosθ>0.99
cone2: cosθ>0.98
cone3: cosθ>0.93

(*2)cluster shape variables
- choose the highest energy cluster
- electron shower shaped is used to fit

(*3) transverse absorption length : distance btw shower center and location where cluster energy goes down to 1/e

(*4) xl20:length to the positon where the deposited energy reaches 80 % of total energy on shower axis

(*4)



tth 2l2n

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

* in this table,
0 means less than 0.01%

particles

Selection

(%)	elec	muon	taue	taum	tauh1	tauh3	bjet	ljet
elec	92 (85.08)	0 (0)	43.42 (28.82)	0 (0)	0.42 (0.31)	0 (0.06)	0 (0)	N/A
muon	0 (0)	95.11 (92.14)	0 (0)	40.36 (18.19)	0.03 (0.01)	0 (0)	0 (0)	N/A
taue	0.94 (2.24)	0 (0)	29.32 (18.76)	0 (0)	0.33 (0.42)	0 (0)	0.04 (0.02)	N/A
taum	0 (0)	1.34 (2.66)	0 (0)	34.22 (35.07)	0.11 (0.09)	0 (0)	0.04 (0.03)	N/A
tauh1	0.28 (3.56)	0.06 (0.53)	0.71 (15.4)	0.04 (12.46)	55.64 (46.21)	0 (0)	0.04 (0.06)	N/A
tauh3	0 (0)	0 (0.01)	0.04 (0.08)	0 (0.04)	0 (0)	49.29 (38.74)	0.01 (0.04)	N/A
nonlep	6.76 (9.09)	3.47 (4.65)	26.49 (36.91)	25.37 (34.22)	43.44 (52.92)	50.7 (61.18)	99.84 (99.83)	N/A

ttZ

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

* in this table,
0 means less than 0.01%

particles

Selection

(%)	elec	muon	taue	taum	tauh1	tauh3	bjet	ljet
elec	90.92 (84.62)	0.01 (0.01)	44.3 (28.27)	0 (0)	0.15 (0.11)	0 (0.11)	0.01 (0.02)	0.01 (0.02)
muon	0 (0)	94.93 (92.23)	0 (0)	39.98 (18.28)	0 (0)	0.11 (0)	0.01 (0)	0 (0.01)
taue	1.16 (1.96)	0 (0.01)	28.08 (20.01)	0 (0)	0.34 (0.23)	0 (0)	0.02 (0.02)	0 (0)
taum	0 (0)	1.59 (2.93)	0 (0)	33.42 (36.28)	0.15 (0.07)	0 (0)	0.02 (0.03)	0 (0)
tauh1	0.31 (3.14)	0.05 (0.49)	0.56 (15.08)	0 (10.98)	54.97 (45.37)	0 (0)	0.01 (0.02)	0.38 (0.4)
tauh3	0.09 (0.05)	0 (0)	0 (0.08)	0 (0)	0 (0)	48.14 (37.99)	0 (0.02)	0.18 (0.2)
nonlep	7.5 (10.2)	3.39 (4.29)	27.03 (36.62)	26.59 (34.44)	44.36 (54.19)	51.73 (61.88)	99.89 (99.86)	99.4 (99.34)

tth analysis using BDT

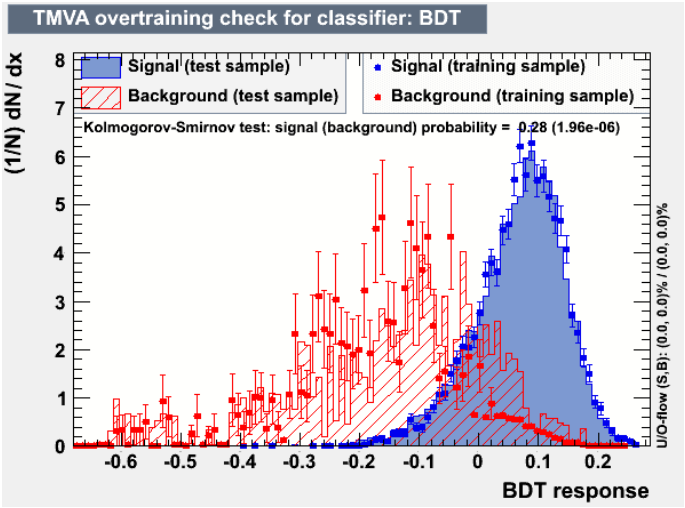
- Just try to use TMVA BDT, BDTG, MLPBNN

Number of events of training samples and test samples are less than 5,000 for each category.

This BDT weights seems over trained due to the small statistics of f6_ttbar samples.

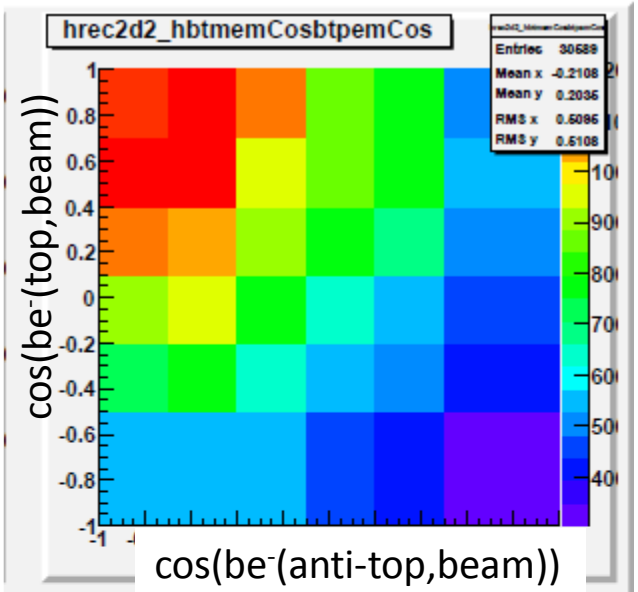
- We maybe can get ~20 % analysis gain.

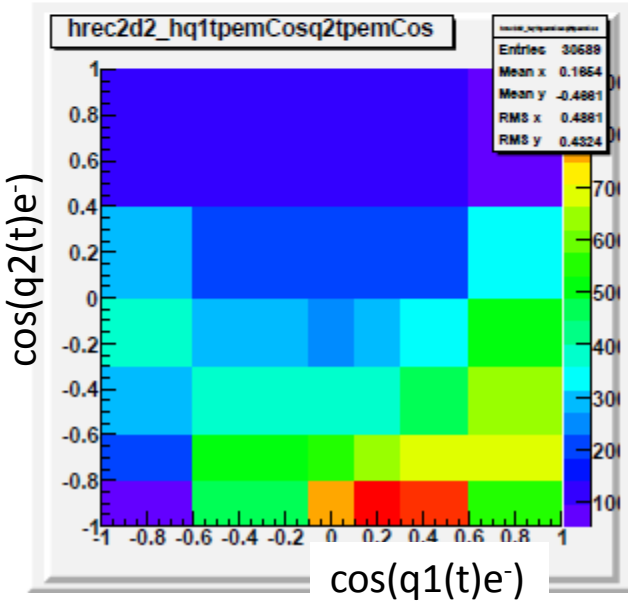
(low statistics of 6f samples)

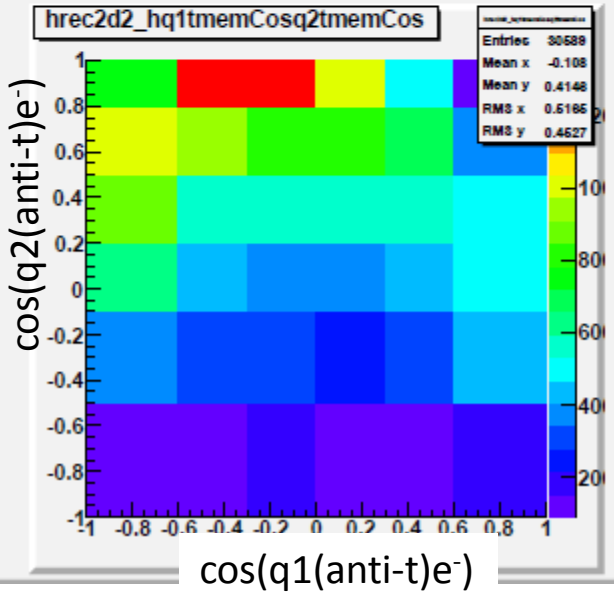


ttH→8 jets
nominal 4 b tagged
BDT output

8jets







e⁻: beam
q1: uptype
q2: down type