Higgs recoil mass study using ZH->qqH @ 250 GeV ILC

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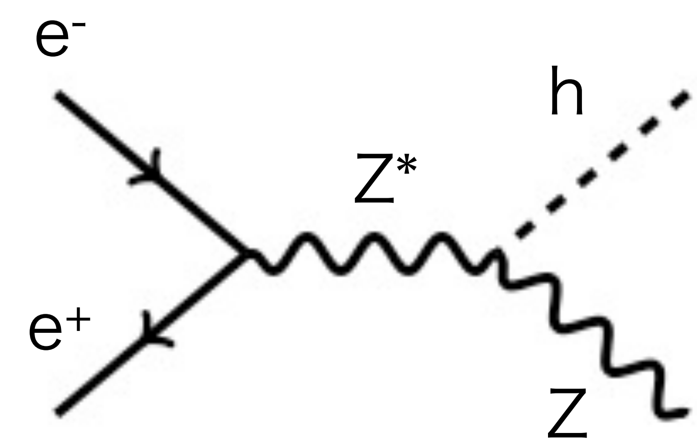
ZH production in 250 GeV ILC



Production process : e^+e^- -> Zh

(-0.8,+0.3) left : 220 fb,
(+0.8,-0.3) right : 142 fb

recoil method $m^2_{\mathrm{recoil}} = (\sqrt{s} - E_Z)^2 - |\vec{p}_Z|^2$

Zh -> llh

- **good S/N**
- more model independent
- small statistics

Zh -> qqh

- **large statistics**
- large backgrounds
- model independent ?

ZH production in 250 GeV ILC

Production process : $e^+e^- \to Zh$

(-0.8,+0.3) left : 289 fb,
(+0.8,-0.3) right : 165 fb

recoil method $m^2_{\mathrm{recoil}} = (\sqrt{s} - E_Z)^2 - |\vec{p}_Z|^2$

Zh -> llh

- good S/N

This talk ->

independent

- small statistics

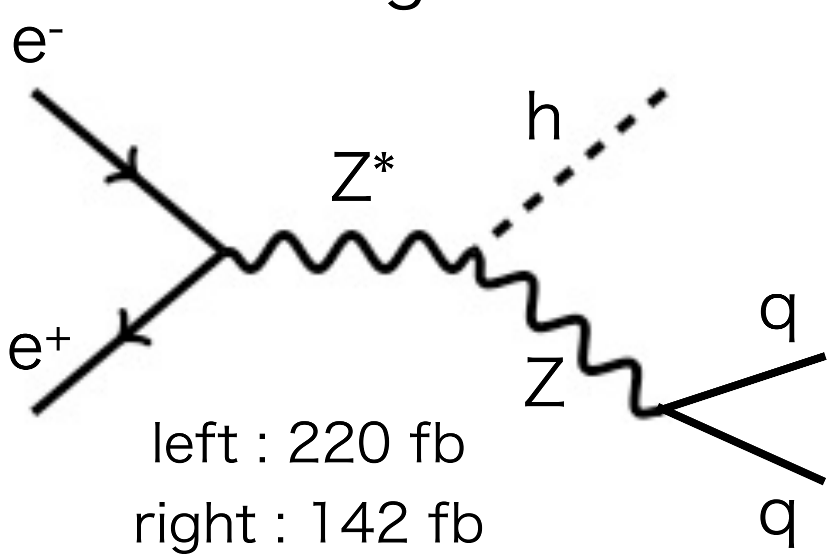
Zh -> qqh

- **large statistics**
- large backgrounds
- model independent ?

Simulation situation

Higgs mass	Ecm	Luminosity	Polarization	Detector
125 GeV	250 GeV	250 fb^{-1}	left: (-0.8, +0.3) right:(+0.8, -0.3)	ILD_o1_v05 DBD ver.

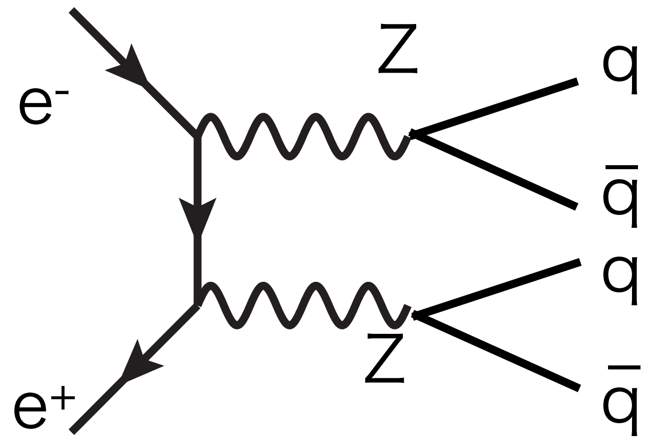
Signal



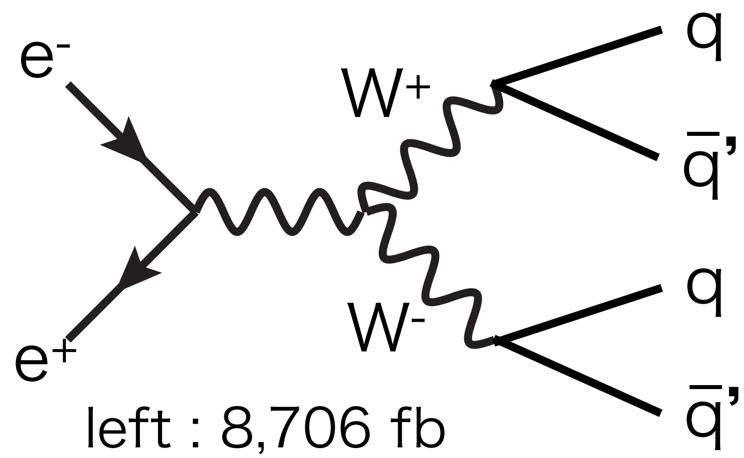
left : 220 fb
right : 142 fb

Semi-leptonic events can also be backgrounds

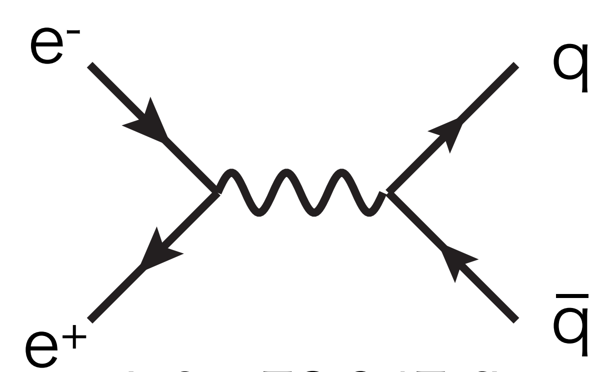
Main background



left : 841 fb
right : 403 fb



left : 8,706 fb
right : 600 fb



left : 78,047 fb
right : 46,214 fb

Analysis flow

Higgs mass	Ecm	Luminosity	Polarization	Detector
125 GeV	250 GeV	250 fb^{-1}	left: (-0.8, +0.3) right:(+0.8, -0.3)	ILD_o1_v05 DBD ver.

all PFOs

Iso lepton finder

remove IsoLep

ISR finder

remove ISR

Initial State Radiation Finder

- 30 GeV && | cos θ | > 0.95
- 80 GeV && | cos θ | > 0.85
- charge == 0
- ECAL/(HCAL+ECAL) > 0.9

Tau finder

remove Tau jet

remaining PFOs

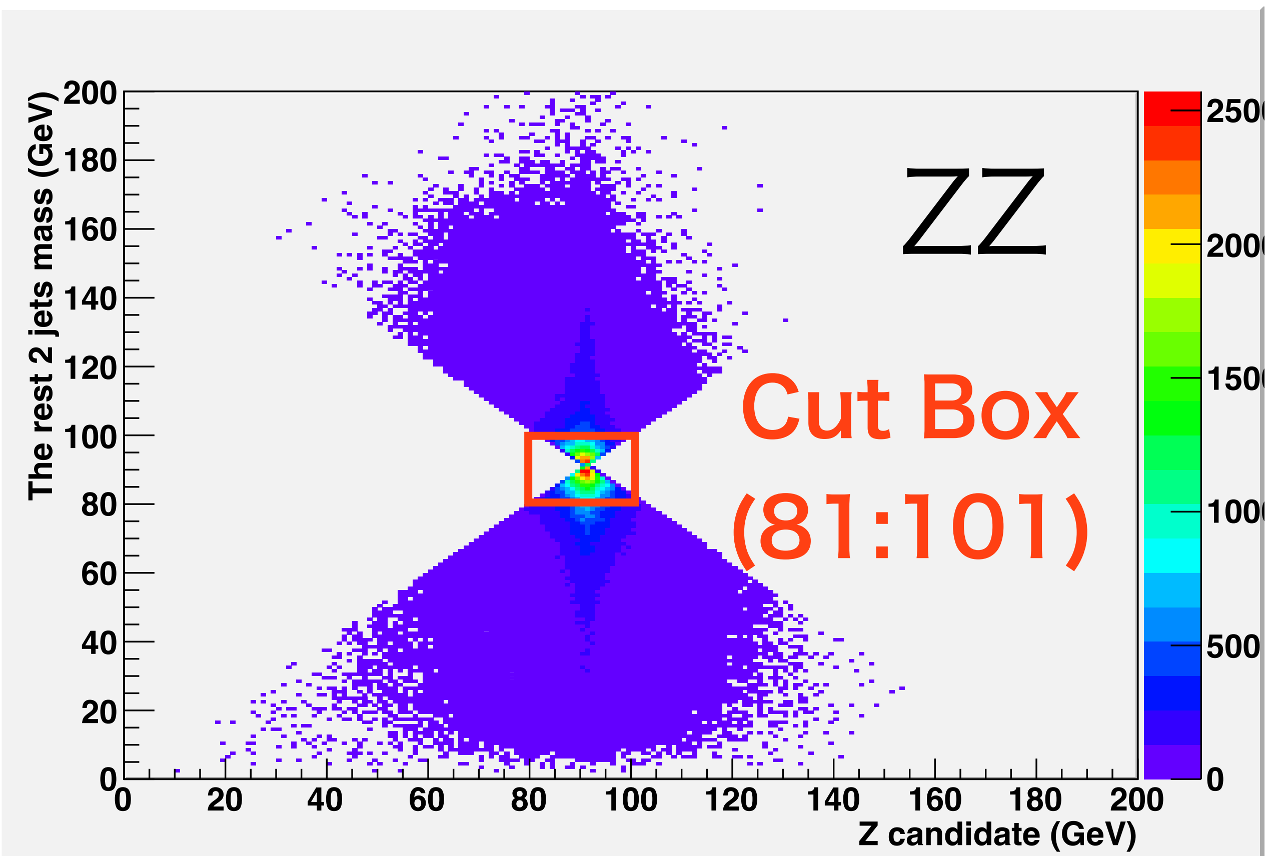
Durham
jet clustering
2 jet, 3 jet, 4jet,
5 jet, y-value

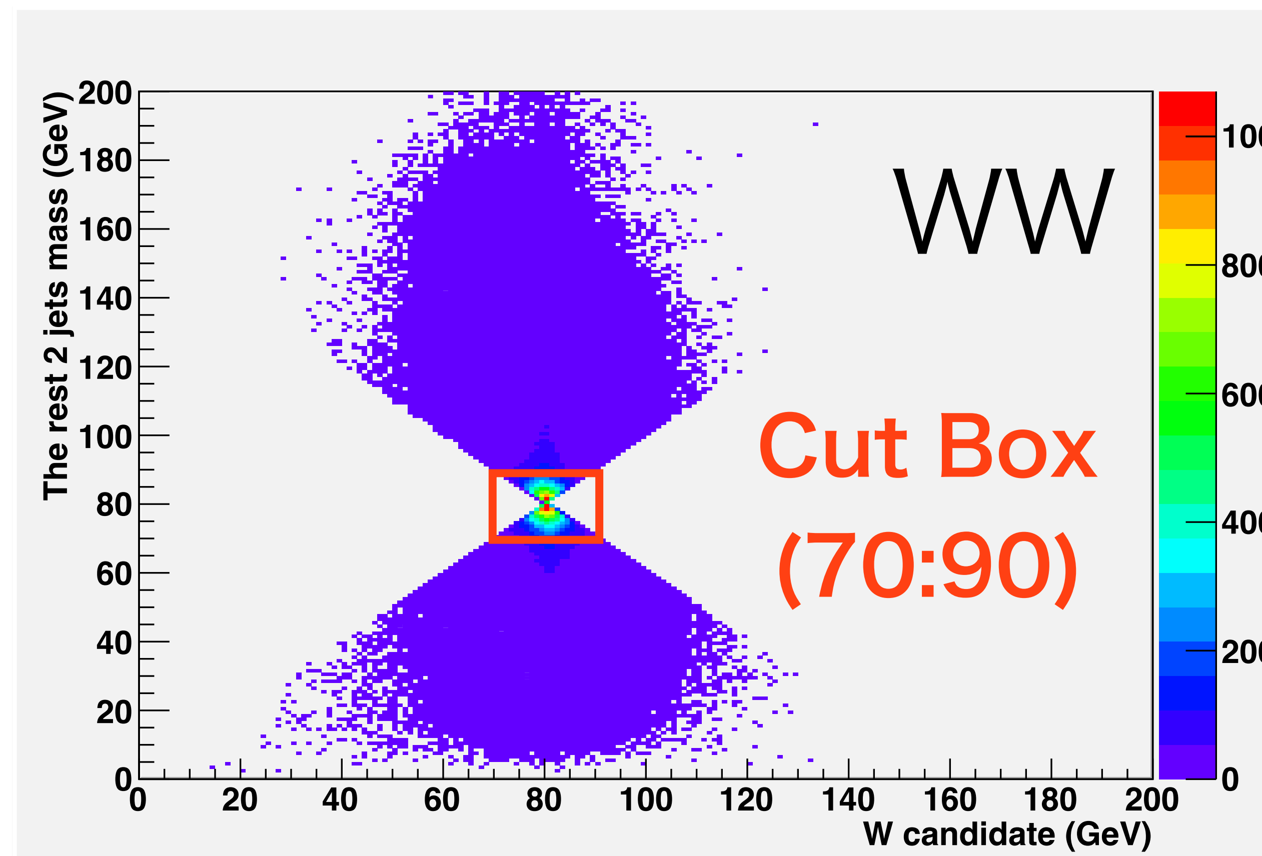
Background reduction

- ZZ/WW hadronic backgrounds
- 2 fermion background
- The other backgrounds
- Event selection

Background reduction

- ZZ/WW hadronic backgrounds

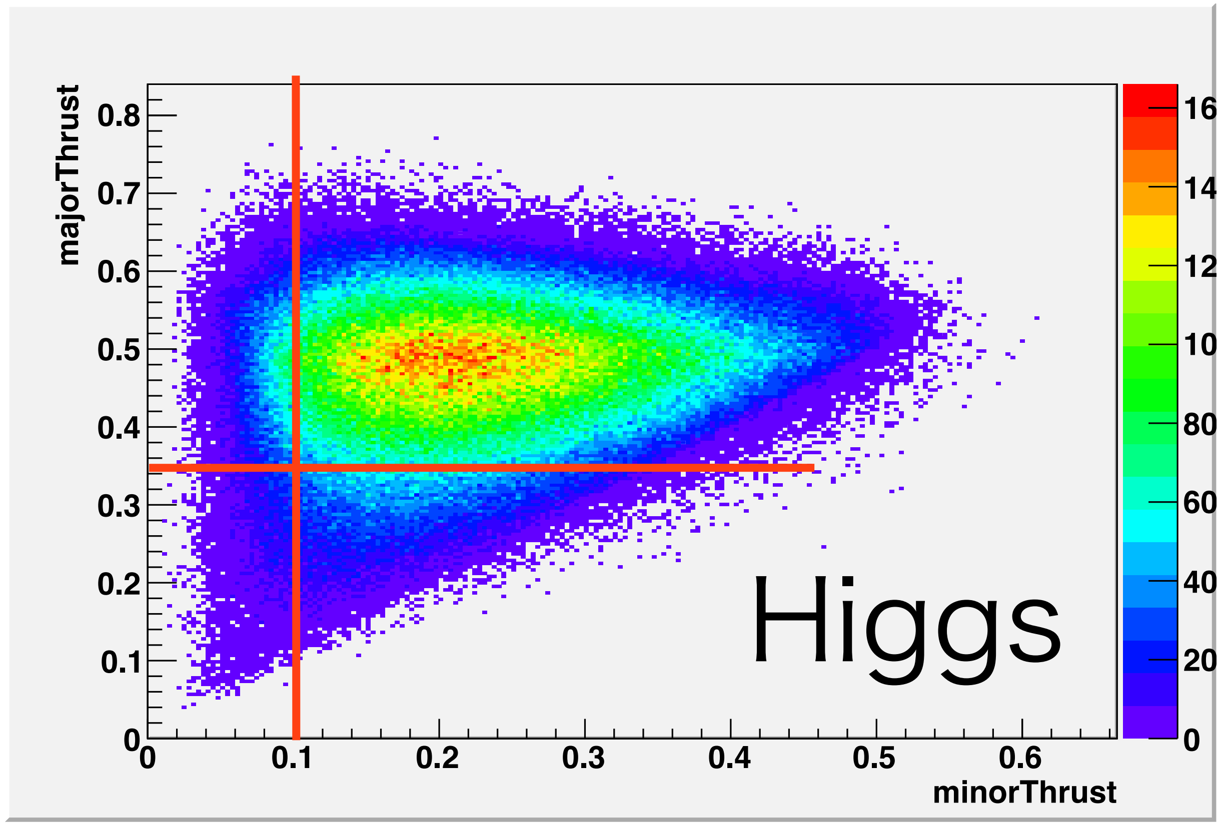


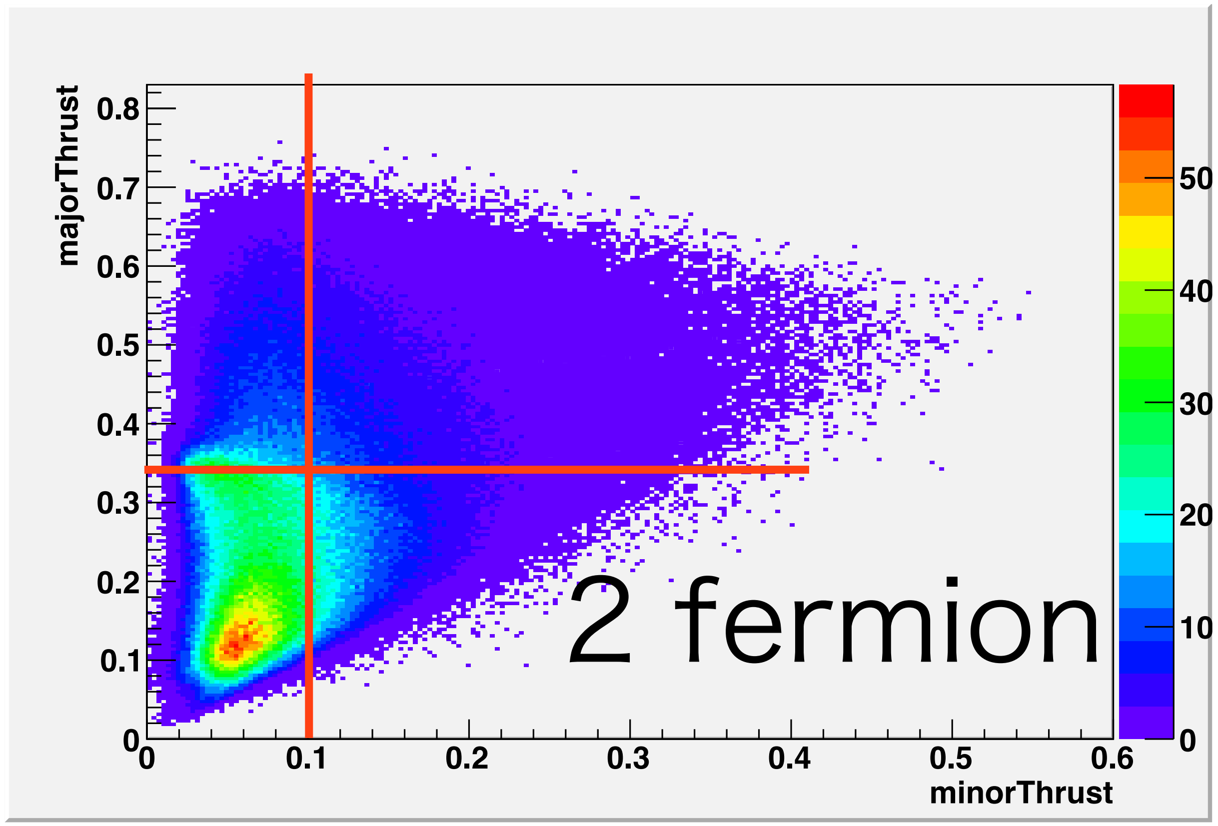


Using forced-4jet clustering

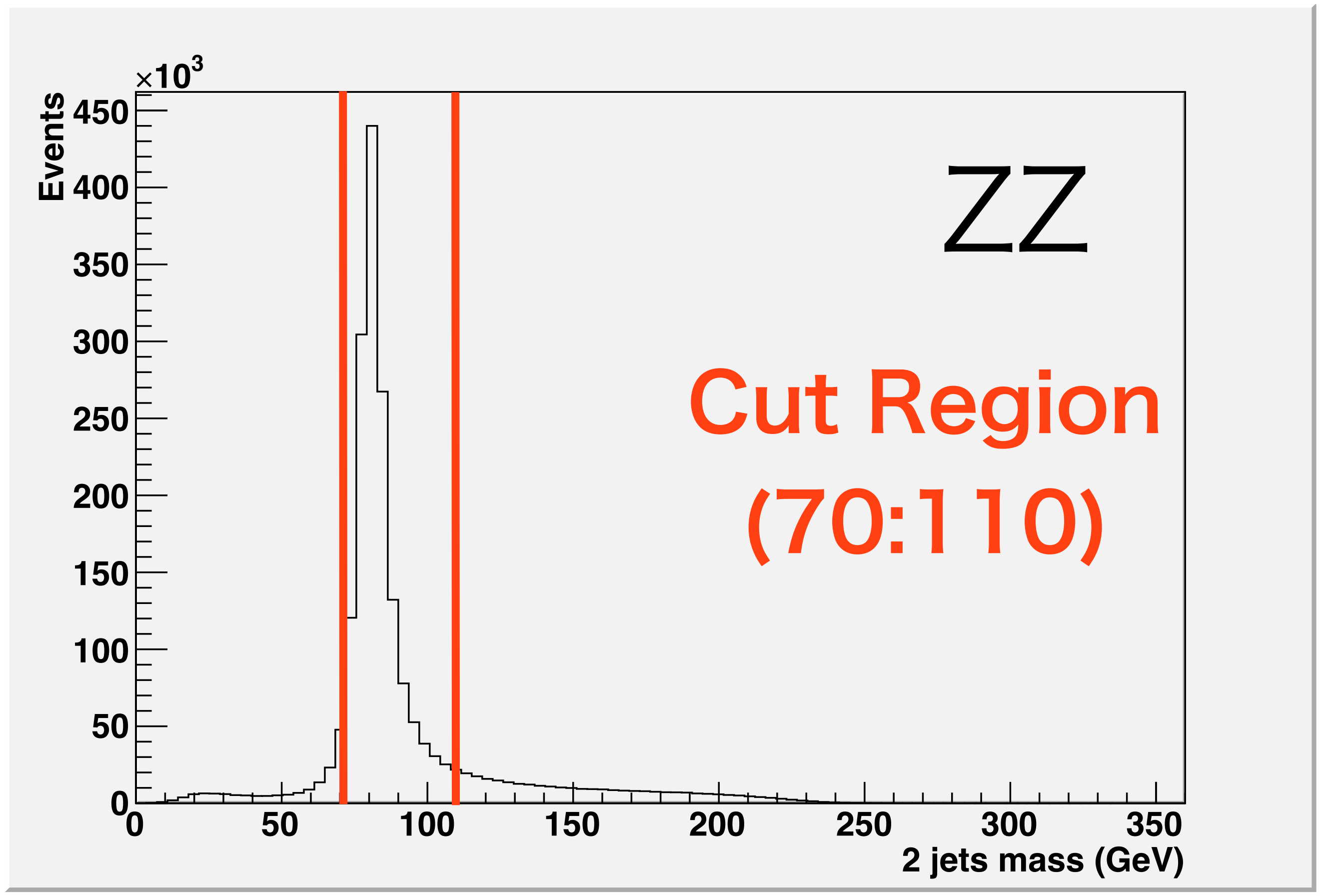
Background reduction

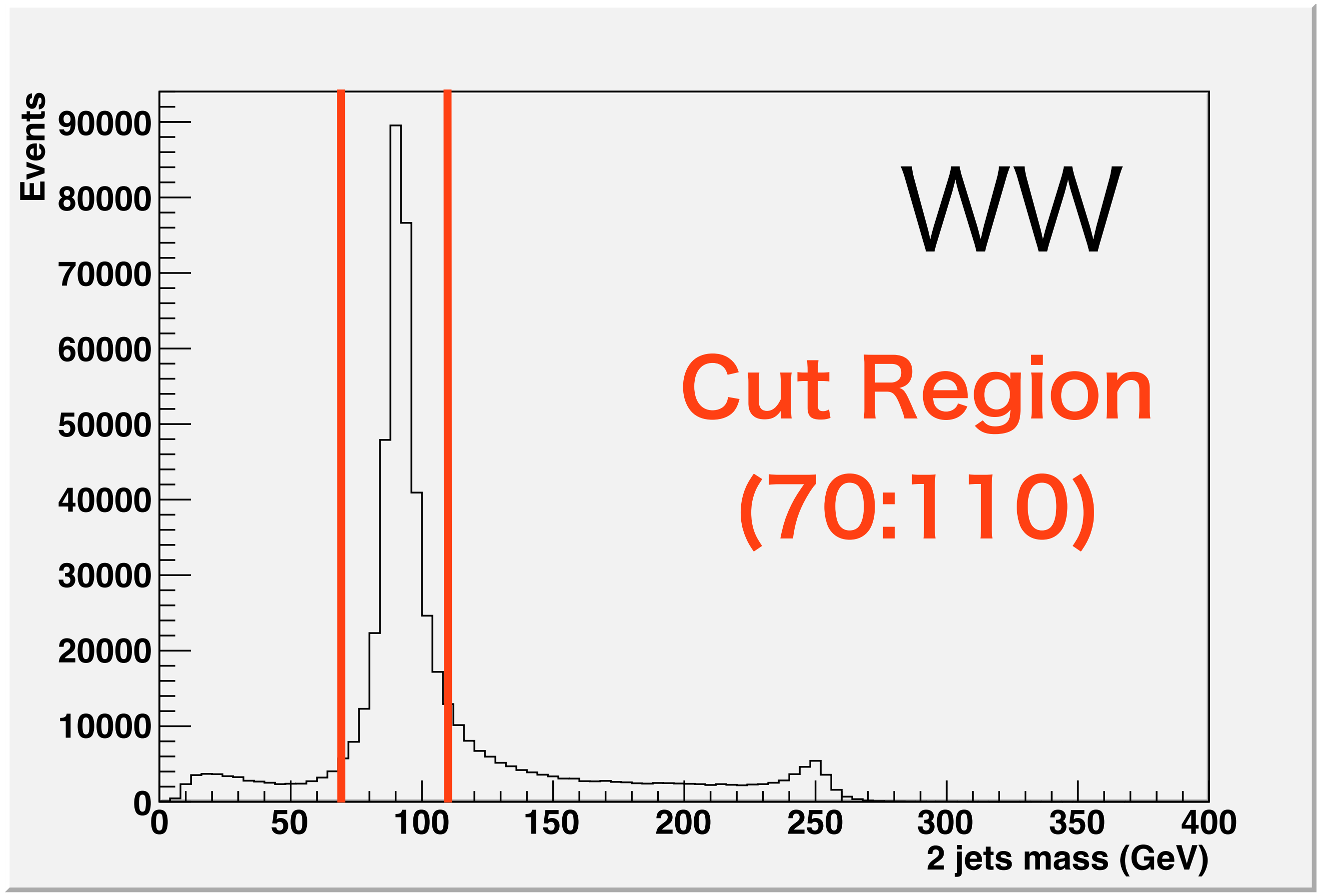
- Cut with majorThrust > 0.35, minorThrust > 0.1
- Cut with Sphericity > 0.15
- 2 fermion background





Background reduction



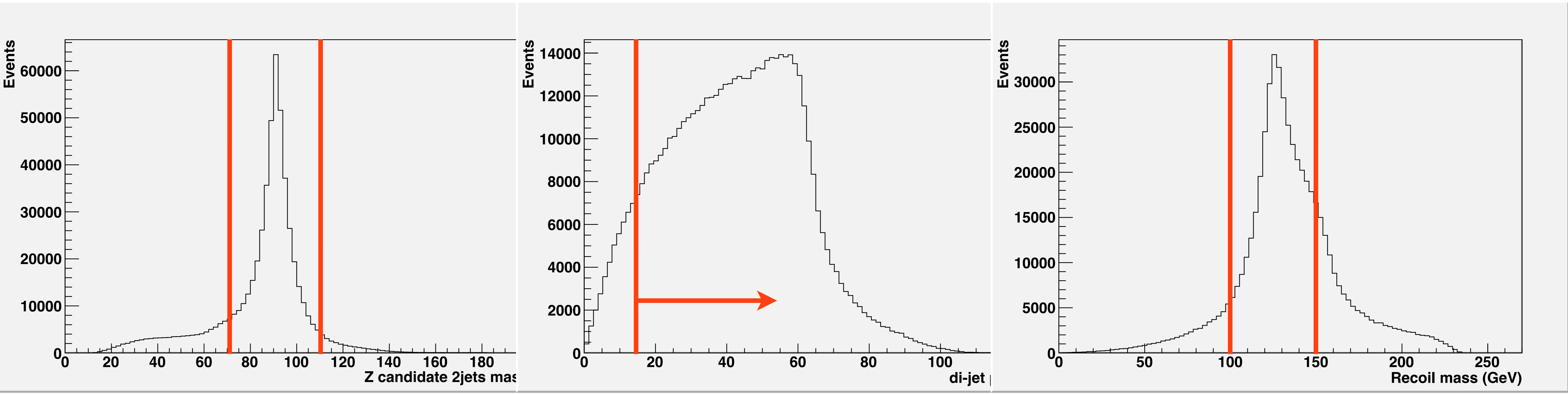


- The other backgrounds

Using forced-2jet clustering

Background reduction

- Z candidate di-jetmass selection (70,110) GeV
- Z candidate di-jetp_T selection > 15 GeV
- Recoil mass selection (100,150) GeV

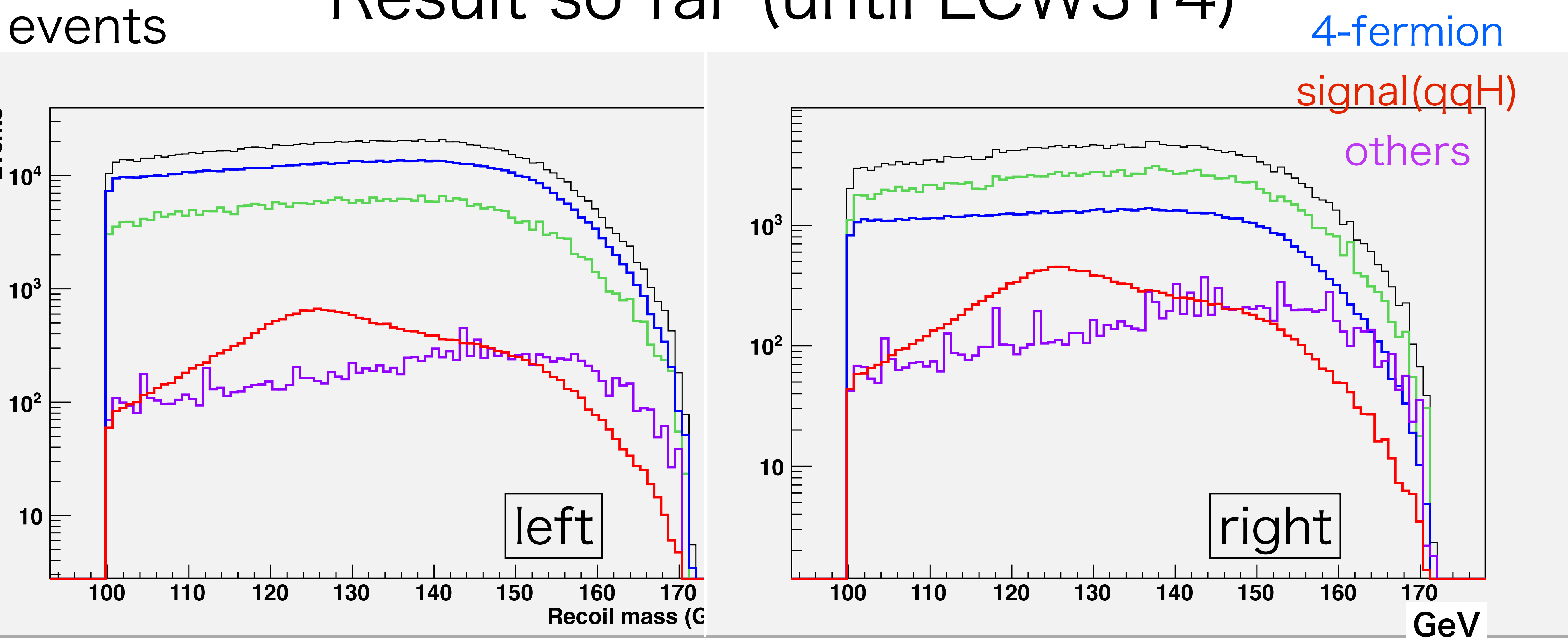


- Event selection

Cuts and Selections table

cuts	qqH	4 fermion	2 fermion	other
left	50,816	9,361,676	19,315,415	216,171,025
right	34,308	1,084,045	12,556,240	222,597,419
box	78.4%	41.1%	66.1%	96.0%
z pt	71.4%	26.1%	22.1%	2.5%
y dijet	58.2%	18.1%	7.5%	0.2%
recoil	47.0%	8.1%	2.3%	0.1%
sphericity	46.3%	7.2%	1.5%	0.07%
thrust	45.2%	6.9%	1.3%	0.06%

Result so far (until LCWS14)



significance was calculated in (110,150) GeV

polarization	significance	$\Delta\sigma/\sigma$
left (-0.8, +0.3)	21.5σ	4.7%
right (+0.8, -0.3)	30.5σ	3.3%

Model Independent ?

mode	before	after	difference / mean
H->all	549,279	258,159 (47.0%)	-----
H->bb	310,799	138,627 (44.6%)	-5.1%
H->WW(l)	12,622	1,575 (12.5%)	-73.4%
H->WW(sl)	53,607	27,843 (51.9%)	+10.4%
H->WW(h)	56,065	35,926 (64.1%)	+36.4%
H->gg	48,419	30,016 (62.0%)	+31.9%
H->$\tau\tau$	35,801	7,989 (22.3%)	-52.6%
H->ZZ	15,103	7,665 (50.8%)	+8.1%
H->cc	14,429	7,367 (51.1%)	+8.7%
H->$\gamma\gamma$	2,051	990 (48.3%)	+2.8%

Model Independent ?

mode	before	after	difference / mean
H->all	549,279	258,159 (47.0%)	-----
H->bb	310,799	138,627 (44.6%)	-5.1%
H->WW(l)	12,622	1,57[illegible]	-73.4%
H->WW(sl)	53,607	[illegible]%)	+10.4%
H->WW(h)	[illegible]	35,926 (64.1%)	+36.4%
H-[illegible]	[illegible],419	30,016 (62.0%)	+31.9%
H->[illegible]	35,801	7,989 (22.3%)	-52.6%
H->ZZ	15,103	7,665 (50.8%)	+8.1%
H->cc	14,429	7,367 (51.1%)	+8.7%
H->$\gamma\gamma$	2,051	990 (48.3%)	+2.8%

Unfortunately NOT...

strategy for resolving efficiency issue -1

To resolve efficiency inconsistent issue, we will categorize events using

- the number of tau jets (0, 1, and >= 2)
- the number of isolated lepton (0, 1, and >= 2)

$$\mathrm{N}^i = \sum_n \sigma_{\mathrm{tot}} \cdot \mathrm{BR}_n \cdot \theta_n^i \cdot \epsilon_n^i$$

$$\mathrm{n} = (\mathrm{b}, \mathrm{W}, \mathrm{g}, \tau, ...)$$

N^i is a number of events in category i, σ_{tot} is total cross section, BR_n is Higgs decay branching ratio, θ_n^i is fraction into category i , ϵ_n^i is cut efficiency for category i .

If the cut efficiency of each decay mode can be assumed to be the same as ϵ^i($=\epsilon_n^i$).

$$\frac{\mathrm{N}^i}{\epsilon^i} = \sigma_{\mathrm{tot}} \sum_n \mathrm{BR}_n \cdot \theta_n^i$$

Then we can get

$$\sum_i \frac{\mathrm{N}^i}{\epsilon^i} = \sigma_{\mathrm{tot}} \sum_n \sum_i \mathrm{BR}_n \cdot \theta_n^i = \sigma_{\mathrm{tot}}$$

strategy for resolving efficiency issue -2

If the cut efficiency is not exactly the same,
we should consider the systematic effect caused by the difference.

$$\delta\epsilon_n^i = \epsilon_n^i - \epsilon^i$$

And the cross section is

$$\sigma_{\rm tot} = \frac{\sum_i \frac{{\rm N}^i}{\epsilon^i}}{1 + \sum_n \sum_i {\rm BR}_n \cdot \theta_n^i \cdot \frac{\delta\epsilon_n^i}{\epsilon^i}}$$

We want to keep systematic uncertainty is less than 1 % to make the analysis model independent.

If we don't assume any models, we should keep $\theta_n^i \cdot \frac{\delta\epsilon_n^i}{\epsilon^i}$ << 1 %.

If we can assume SM like higgs, we should keep ${\rm BR}_n \cdot \theta_n^i \cdot \frac{\delta\epsilon_n^i}{\epsilon^i}$ << 1 %.

Categories

		visene≧180	visene<180				
category	0lep,0tau	0lep,1tau	0lep,1tau	0lep,≧2tau	1lep,0tau	1lep,≧1tau	≧2lep,≧0tau
H->all 549,279	81.6%	3.5%	4.6%	2.7%	5.5%	1.3%	0.75%
H->bb 310,799	96.8%	2.3%	0.5%	0.04%	0.33%	0.01%	~0.0%
H->WW(l) 12,622	8.3%	0.04%	11.4%	6.9%	24.1%	26.3%	23.0%
H->WW(sl) 53,607	29.7%	8.9%	10.9%	1.4%	45.4%	3.4%	0.2%
H->WW(h) 56,065	91.9%	6.8%	0.4%	0.3%	0.5%	0.07%	0.0%
H->gg 48,419	96.6%	2.7%	3.0%	0.06%	0.3%	0.01%	0.0%
H->$\tau\tau$ 35,801	12.2%	2.8%	42.9%	35.4%	2.4%	4.2%	0.1%
H->ZZ 15,103	78.2%	5.0%	3.4%	1.5%	3.2%	2.7%	6.0%
H->cc 14,429	96.3%	2.9%	0.5%	0.05%	0.3%	0.01%	0.0%
H->$\gamma\gamma$ 2,051	91.3%	3.1%	2.1%	0.5%	0.7%	0.5%	1.9%

number of lepton > 1
number of tau : any
box Z(81,101), W(70,90)
yzjetpt > 15
sphericity > 0.15
Thrust > (major)0.3||(minor)0.1
ydijetmass (70,110)
recoil (110,150) --- > OK

≧2lep, any tau

	before	after	fraction * difference / mean
	4,099	1,873 (45.7%)	-----
H->bb (~0.0%)	1	0 (0.0%)	~0.0%
H->WW(l) (23.0%)	2,900	1,322 (45.5%)	0.05%
H->WW(sl) (0.2%)	110	45 (71.0%)	0.02%
H->WW(h) (0.0%)	0	0 (0.0%)	~0.0%
H->gg (0.0%)	0	0 (0.0%)	~0.0%
H->$\tau\tau$ (0.1%)	43	15 (34.9%)	0.02%
H->ZZ (6.0%)	905	439 (47.8%)	0.4%
H->cc (0.0%)	0	0 (0.0%)	~0.0%
H->$\gamma\gamma$ (1.9%)	38	23 (57.9%)	0.6%
2f	637,657	1,015 (0.16%)	+ 10 times
4f	470,679	18,938 (4.0%)	+ 4 times

1lep, ≧1tau

number of lepton == 1
number of tau > 0
box Z(81,101), W(70,90)
yzjetpt > 15
sphericity > 0.15
Thrust > (major)0.3||(minor)0.1
ydijetmass (70,110)
recoil (110,150) --- > OK

	before	after	fraction * difference / mean
	7,201	3,155 (43.8%)	-----
H->bb (0.01%)	43	16 (37.2%)	~0.0%
H->WW(l) (26.3%)	3,318	1,407 (42.4%)	0.8%
H->WW(sl) (3.4%)	1,848	862 (46.6%)	0.2%
H->WW(h) (0.07%)	37	16 (43.2%)	~0.0%
H->gg (0.01%)	7	3 (42.9%)	~0.0%
H->$\tau\tau$ (4.2%)	1,511	632 (41.8%)	0.2%
H->ZZ (2.7%)	413	207 (50.1%)	0.4%
H->cc (0.01%)	2	1 (50.0%)	~0.0%
H->$\gamma\gamma$ (0.5%)	11	7 (63.6%)	0.2%
2f	325,765	665 (0.2%)	+ 10 times
4f	458,467	11,456 (2.5%)	+ 5 times

1lep, 0tau

number of lepton == 1
number of tau == 0
box Z(81,101),W(70,90)
yzjetpt > 15
sphericity > 0.15
Thrust > (major)0.3||(minor)0.1
ydijetmass (70,110)
recoil (110,150) --- > OK

	before	after	fraction * difference / mean
	30,324	14,269 (47.1%)	-----
H->bb (0.33%)	1,075	427 (39.7%)	0.05%
H->WW(l) (24.1%)	3,044	1,381 (45.4%)	0.9%
H->WW(sl) (45.4%)	24,362	11,653 (47.8%)	0.7%
H->WW(h) (0.5%)	307	126 (41.0%)	0.07%
H->gg (0.3%)	140	54 (38.6%)	0.05%
H->$\tau\tau$ (2.4%)	852	405 (47.5%)	0.02%
H->ZZ (3.2%)	484	207 (42.8%)	0.3%
H->cc (0.3%)	42	14 (33.3%)	0.08%
H->$\gamma\gamma$ (0.7%)	13	2 (15.4%)	0.4%
2f	216,126	906 (0.42%)	+ 2 times
4f	2,430,014	125,036 (5.1%)	+ 3 times

0lep, ≧2tau

number of lepton == 0
number of tau > 1
box Z(81,101), W(70,90)
yzjetpt > 15
sphericity > 0.15
Thrust > (major)0.35||(minor)0.1
ydijetmass (70,110)
recoil (110,150) --- > OK

	before	after	fraction * difference / mean
	14,859	6,282 (42.1%)	-----
H->bb (0.04%)	135	61 (32.6%)	~0.0%
H->WW(l) (6.9%)	869	359 (41.2%)	0.2%
H->WW(sl) (1.4%)	759	373 (48.0%)	0.2%
H->WW(h) (0.3%)	156	74 (46.8%)	0.03%
H->gg (0.06%)	30	11 (36.7%)	~0.0%
H->$\tau\tau$ (35.4%)	12,660	5,302 (41.9%)	0.3%
H->ZZ (1.5%)	232	94 (39.0%)	0.1%
H->cc (0.05%)	8	3 (42.9%)	~0.0%
H->$\gamma\gamma$ (0.5%)	10	5 (50.0%)	0.1%
2f	212,460	158 (0.07%)	+ 10 times
4f	194,430	7,085 (3.6%)	+ 5 times

1tau (visible energy ≧ 180)

number of lepton == 0
number of tau == 1
box Z(81,101), W(70,90)
yzjetpt > 15
sphericity > 0.12
Thrust > (major)0.35||(minor)0.1
ydijetmass (70,110)
recoil (110,150) --- > OK

	before	after	fraction * difference / mean
	19,871	8253 (41.5%)	-----
H->bb (2.3%)	7,589	2,908 (38.3%)	0.2%
H->WW(l) (0.04%)	6	2 (33.3%)	~0.0%
H->WW(sl) (8.9%)	4,805	1,947 (40.5%)	0.2%
H->WW(h) (6.8%)	3,839	1,804 (47.0%)	0.9%
H->gg (2.7%)	1,303	581 (44.6%)	0.2%
H->$\tau\tau$ (2.8%)	1,073	487 (45.4%)	0.3%
H->ZZ (5.0%)	752	349 (46.4%)	0.6%
H->cc (2.9%)	423	149 (35.2%)	0.4%
H->$\gamma\gamma$ (3.1%)	66	19 (28.8%)	1.0%
2f	8,885	440 (5.0%)	- 0.2 %
4f	127,489	23,061 (18.1%)	- 0.05 %

1tau (visible energy < 180)

number of lepton == 0
number of tau == 1
box Z(81,101),W(70,90)
yzjetpt > 15
sphericity > 0.15 , < 0.65
Thrust > (major)0.3||(minor)0.1
ydijetmass (70,110)
recoil (110,150) --- > OK

	before	after	fraction * difference / mean
	25,205	11,832 (46.9%)	-----
H->bb (0.5%)	1,588	697 (43.9%)	0.03%
H->WW(l) (11.4%)	1,435	653 (45.5%)	0.3%
H->WW(sl) (10.9%)	5,829	2,969 (50.9%)	0.9%
H->WW(h) (0.4%)	205	66 (32.1%)	0.1%
H->gg (3.0%)	142	48 (33.8%)	0.08%
H->$\tau\tau$ (42.9%)	15,370	7,131 (46.3%)	0.5%
H->ZZ (3.4%)	517	223 (43.1%)	0.3%
H->cc (0.5%)	74	23 (31.1%)	0.2%
H->$\gamma\gamma$ (2.1%)	42	19 (45.2%)	0.1%
2f	533,323	2,819 (0.5%)	+ 5 times
4f	1,473,190	115,206 (7.4%)	+ 4 times

Categories

category	0lep,0tau	0lep,1tau (visene≧180)	0lep,1tau (visene<180)	0lep,≧2tau	1lep,0tau	1lep,≧1tau	≧2lep,≧0tau
H->all 549,279	81.6%	——	——	——	——	——	——
H->bb 310,799		0.2%	0.03%	~0.0%	0.05%	~0.0%	~0.0%
H->WW(l) 12,622		~0.0%	0.3%	0.2%	[illegible]	0.8%	0.05%
H->WW(sl) 53,607		0.2%	0.9%	0.2%	[illegible]	[illegible]	0.02%
H->WW(h) 56,065		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	~0.0%
H->gg 48,419		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	~0.0%
H->ττ 35,801		0.3%	0.5%	0.3%	[illegible]	0.2%	0.02%
H->ZZ 15,103		0.6%	0.3%	0.1%	[illegible]	0.4%	0.4%
H->cc 14,429		0.4%	0.2%	~0.0%	0.08%	~0.0%	~0.0%
H->γγ 2,051		1.0%	0.1%	0.1%	0.4%	0.2%	0.6%

OK !

0lep, 0tau

mode	before	after	fraction * difference / mean
H->all (81.6%)	448,331	202,288 (45.1%)	-----
H->bb (96.8%)	300,845	126,305 (42.0%)	6.7%
H->WW(l) (8.3%)	1,050	540 (51.[illegible]	[illegible]2%
H->WW(sl) (29.7%)	15,932	[illegible]	1.3%
H->WW(h) (91.9%)	51,52[illegible]	[illegible]3.9%)	17.9%
H->gg (96.6%)	[illegible]	25,655 (54.8%)	20.8%
H->$\tau\tau$ ([illegible]	[illegible],366	1,720 (39.4%)	1.5%
H->[illegible]	11,807	5,769 (48.9%)	6.6%
H->cc (96.3%)	13,892	6,596 (47.5%)	5.1%
H->$\gamma\gamma$ (91.3%)	1,872	912 (48.7%)	7.3%
2f	542,208	2,548 (0.47%)	+0.27%(前0.2%)
4f	1,600,679	115,206 (7.2%)	+4.1%(前3.1%)

Most difficult category

btag & ctag fraction

	b = 1, c = 1	b = 1, c = 0	b = 0, c = 1	b = 0, c = 0
bb	4.2%	53.9%	8.4%	30.2%
ww lep	0.1%	0.5%	2.4%	5.4%
ww slep	0.3%	1.9%	10.2%	17.3%
ww had	1.6%	9.0%	28.5%	52.8%
gg	1.3%	10.4%	13.8%	71.2%
tautau	0.2%	1.1%	4.4%	6.6%
zz	2.6%	13.9%	15.2%	46.5%
cc	2.1%	16.5%	41.4%	36.3%
$\gamma\gamma$	0.7%	8.4%	8.9%	73.0%

0lep, 0tau using btag & ctag

		ynjets<4	ynjets>3	ynjets<4	ynjets>3	ynjets<4	ynjets>3
	b = 1, c = 1	b = 1, c = 0	b = 1, c = 0	b = 0, c = 1	b = 0 c = 1	b = 0, c = 0	b = 0, c = 0
bb	0.05%	0.2%	0.3%	0.2%	1.0%	0.1%	0.7%
ww lep	0.04%	0.3%	0.1%	1.0%	0.1%	1.3%	0.03%
ww slep	0.1%	0.2%	0.3%	0.1%	1.8%	0.03%	1.2%
ww had	0.1%	0.01%	0.8%	0.0%	0.4%	0.04%	1.0%
gg	0.02%	0.3%	0.2%	0.1%	7.8%	1.1%	7.7%
tautau	0.05%	0.1%	0.1%	0.4%	1.1%	0.1%	0.7%
zz	0.07%	0.8%	0.9%	0.3%	0.6%	1.6%	0.9%
cc	0.05%	1.1%	1.0%	0.4%	6.2%	0.3%	0.5%
γ γ	0.2%	1.0%	0.8%	0.1%	0.6%	1.6%	0.2%

Summary & Prospects

- Summary
  - Categorization is one of the powerful solutions to reduce inconsistent of cut efficiency.
  - Currently, B tagger has low efficiency and purity.
    I will fix my program and update my result.

- Prospects
  - Use likelihood to improve statistical precision.
  - Estimate systematic uncertainties.

backup

strategy for resolving efficiency issue -1

To resolve efficiency inconsistent issue, we will categorize events using

- the number of jets (2, 3, 4, and >= 5)
- the number of isolated lepton (0, 1, and >= 2)

$$\mathrm{N}^i = \sum_n \sigma_{\mathrm{tot}} \cdot \mathrm{BR}_n \cdot \theta_n^i \cdot \epsilon_n^i$$

$$\mathrm{n} = (\mathrm{b}, \mathrm{W}, \mathrm{g}, \tau, ...)$$

N^i is a number of events in category i, σ_{tot} is total cross section, BR_n is Higgs decay branching ratio, θ_n^i is fraction into category i, ϵ_n^i is cut efficiency for category i.

If the cut efficiency of each decay mode can be assumed to be the same as ϵ^i($=\epsilon_n^i$).

$$\frac{\mathrm{N}^i}{\epsilon^i} = \sigma_{\mathrm{tot}} \sum_n \mathrm{BR}_n \cdot \theta_n^i$$

Then we can get

$$\sum_i \frac{\mathrm{N}^i}{\epsilon^i} = \sigma_{\mathrm{tot}} \sum_n \sum_i \mathrm{BR}_n \cdot \theta_n^i = \sigma_{\mathrm{tot}}$$

strategy for resolving efficiency issue -2

If the cut efficiency is not exactly the same,
we should consider the systematic effect caused by the difference.

$$\delta\epsilon_n^i = \epsilon_n^i - \epsilon^i$$

And the cross section is

$$\sigma_{\mathrm{tot}} = \frac{\sum_i \frac{\mathrm{N}^i}{\epsilon^i}}{1 + \sum_n \sum_i \mathrm{BR}_n \cdot \theta_n^i \cdot \frac{\delta\epsilon_n^i}{\epsilon^i}}$$

We want to keep systematic uncertainty is less than 1 % to do model independent analysis.

If we don't assume any models, we should keep $\theta_n^i \cdot \frac{\delta\epsilon_n^i}{\epsilon^i}$ << 1 %.

If we can assume SM like higgs, we should keep $\mathrm{BR}_n \cdot \theta_n^i \cdot \frac{\delta\epsilon_n^i}{\epsilon^i}$ << 1 %.