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

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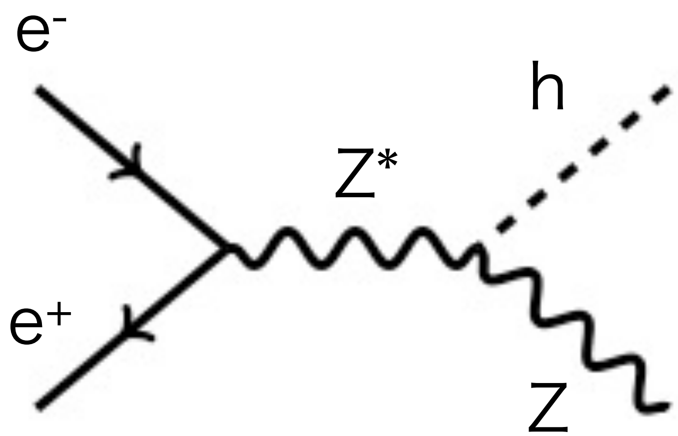
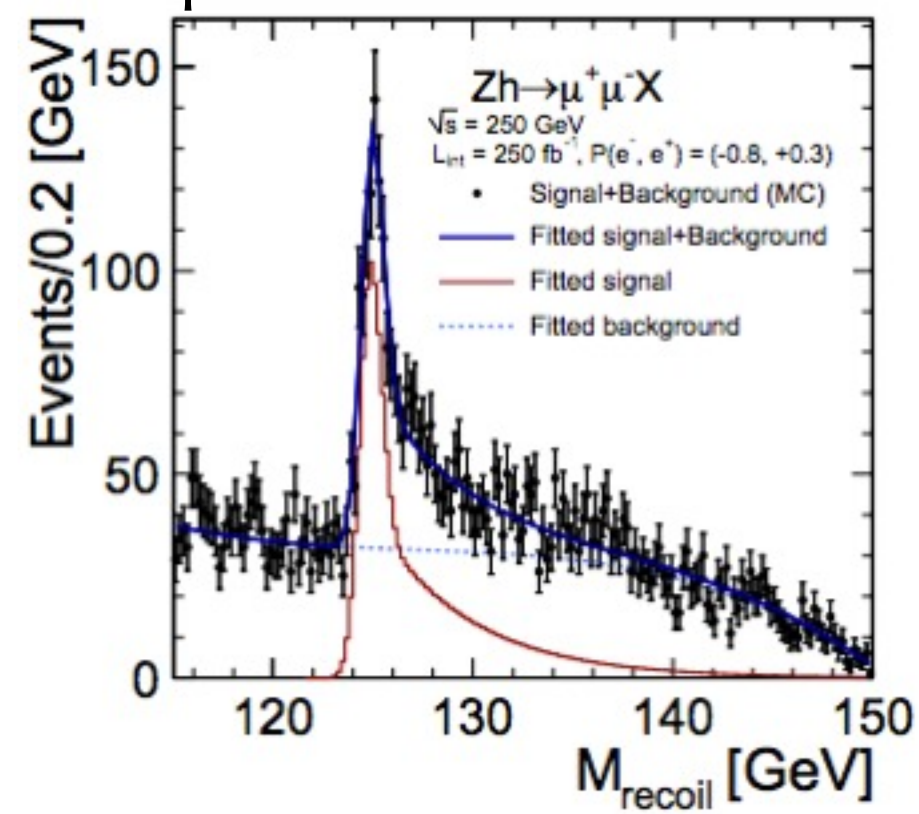
Overview - qqH channel



At lepton collider, we can measure Higgs without looking Higgs directly.

-> Model Independent search



The branching ratio of Z -> leptonic is ~3.5% for each generation.

In contrast, the branching ratio of **Z -> hadronic is ~70%**.

- More statistics

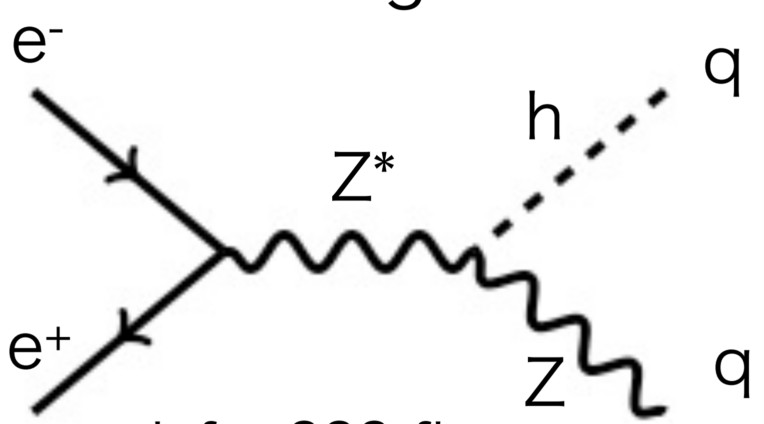
Model independent?

- More background

dataset and 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.

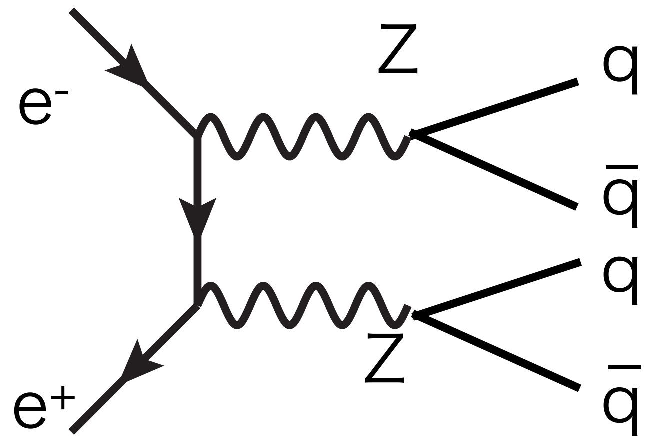
Signal



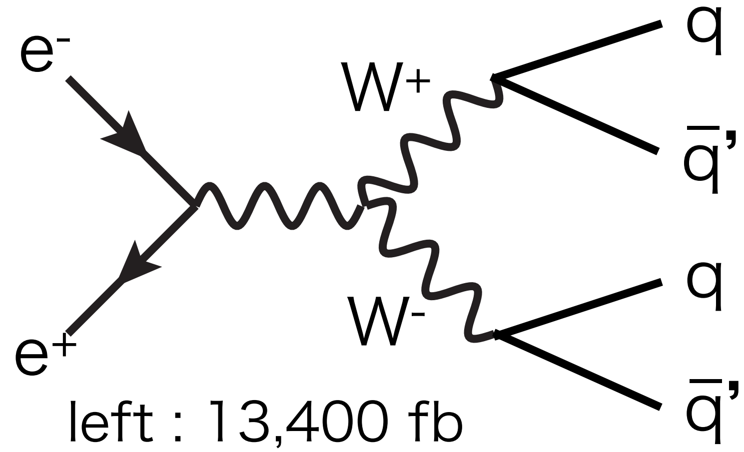
left : 333 fb
right : 234 fb

Semi-leptonic events can also be backgrounds

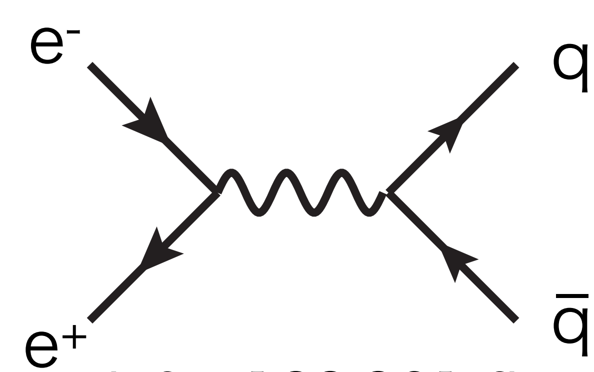
Main background



left : 1,322 fb
right : 685 fb



left : 13,400 fb
right : 1,610 fb



left : 123,361 fb
right : 77,059 fb

dataset and analysis flow

Higgs mass	Ecm	Luminosity	Polarization	Detector
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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

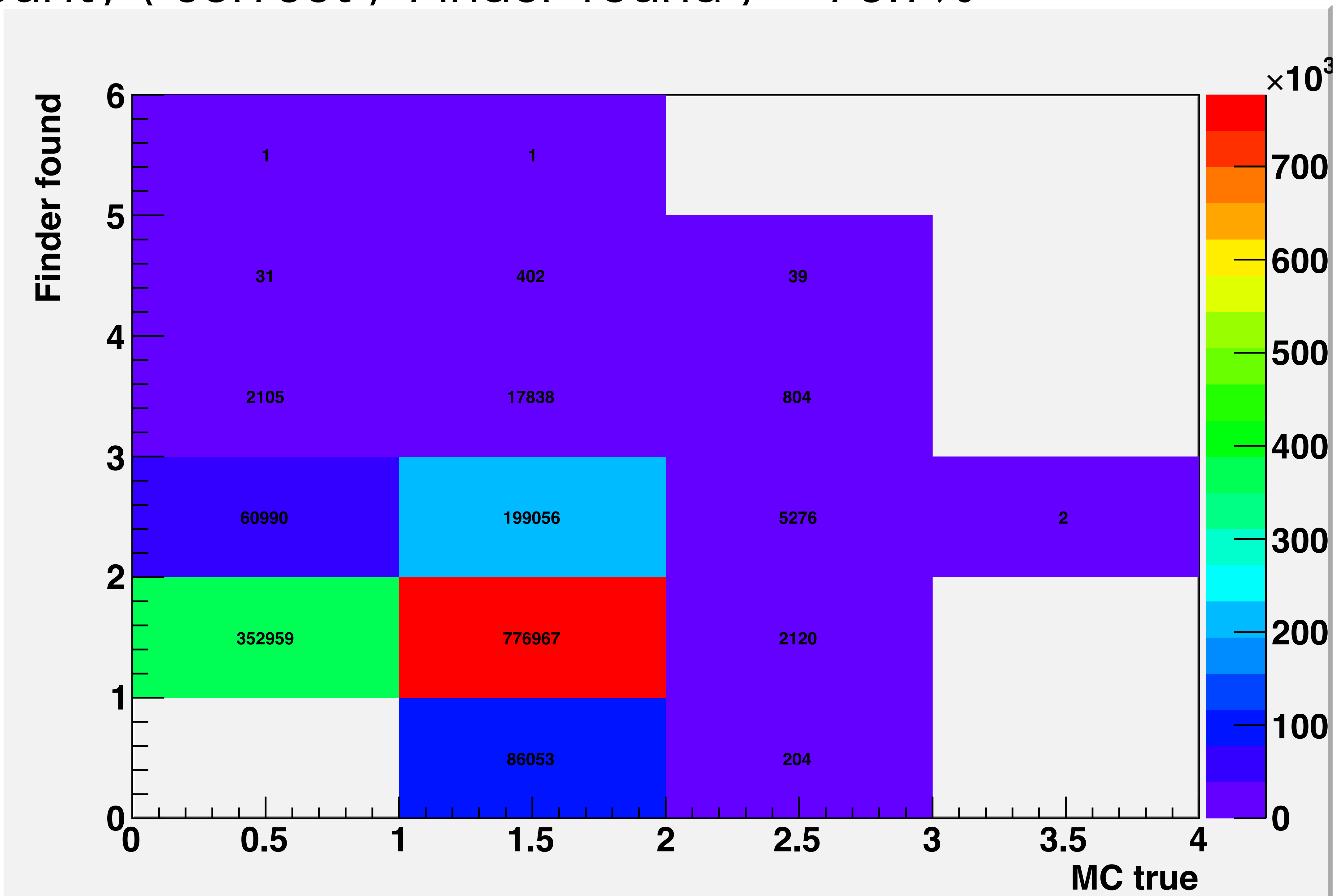
remove Tau jet

remaining PFOs

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

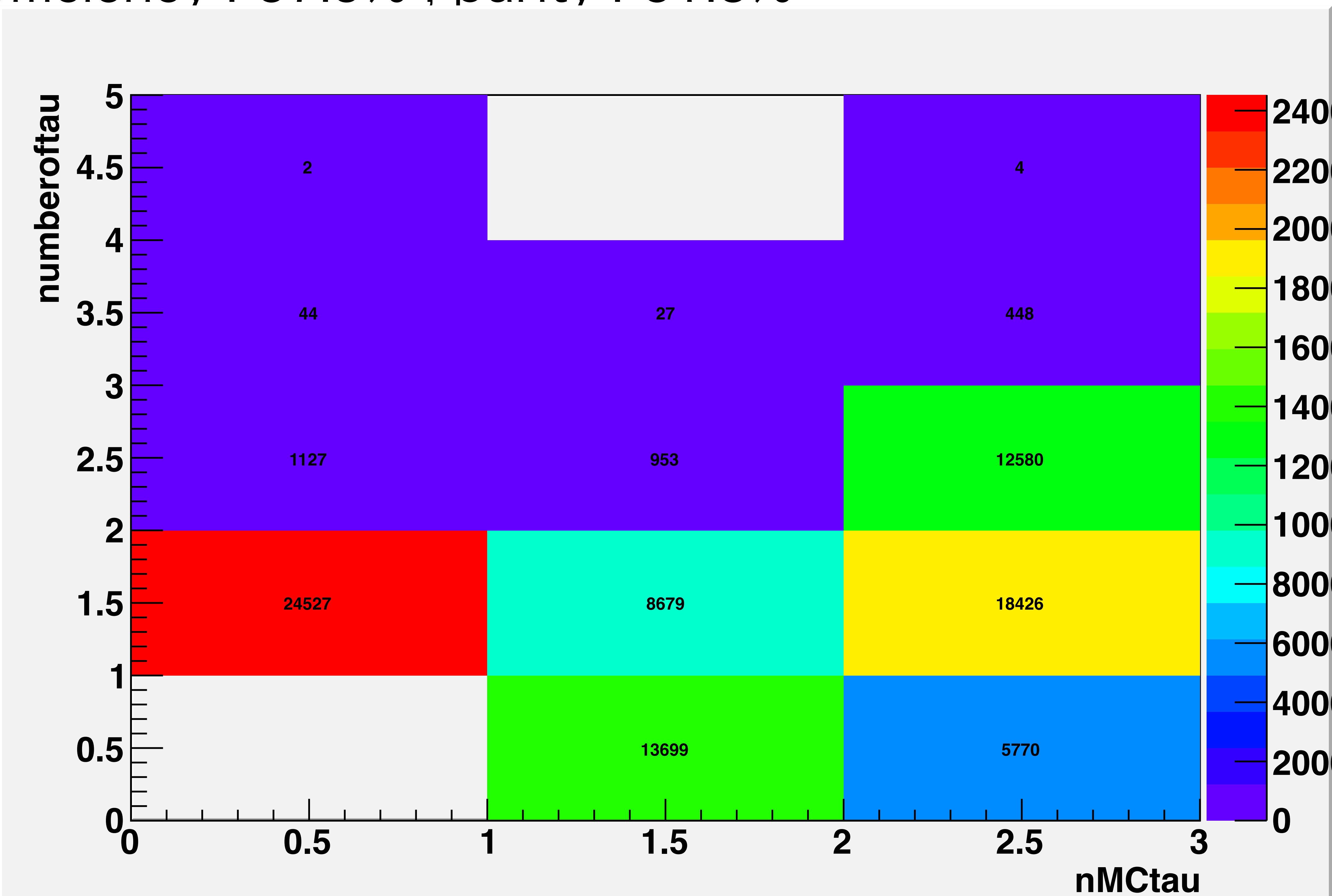
Review of ISR finder

- efficiency (Finder output / MC true) = 92.1%
- purity (correct / Finder found) = 70.7%



Review of Tau finder

- Target : hadronic tau (lepton can be found in IsoLep finder)
- efficiency : 67.9% , purity : 61.5%



List of Cuts

- mass box cut with 4 jet clustering
  (81,101) for ZZ BG, (70,90) for WW BG.

- di-jet mass cut with 2 jet clusetring
  (70,110) to reduce leptonic BG.

- Sphericity (> 0.15)
  - to cut 2 fermion BG.

$$S^{ab} = \frac{\sum_i p_i^a p_i^b}{\sum_i p_i^2} \quad a, b = x, y, z$$

- Thrust value (major > 0.35 , minor > 0.1)
  - to cut 2 fermion BG.

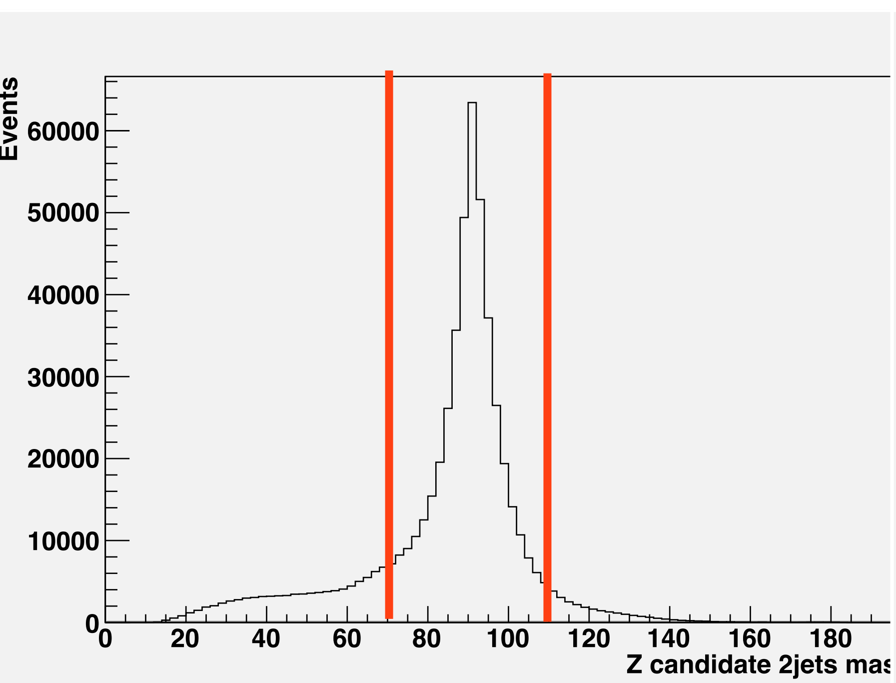
$$T = \max_{|n|=1} \frac{\sum_i |\, p_i \cdot n \,|}{\sum_i |\, p_i \,|}$$

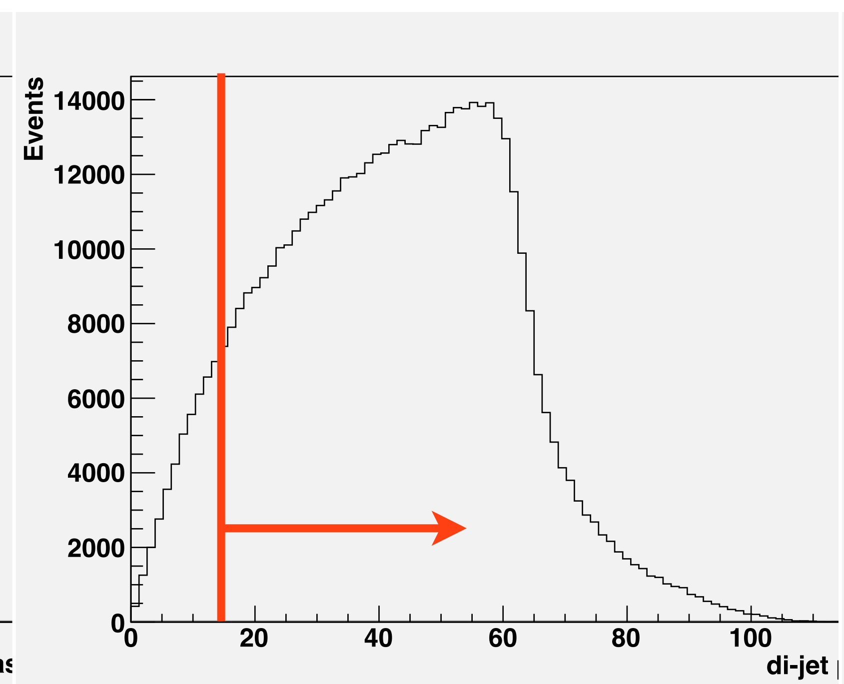
Selections

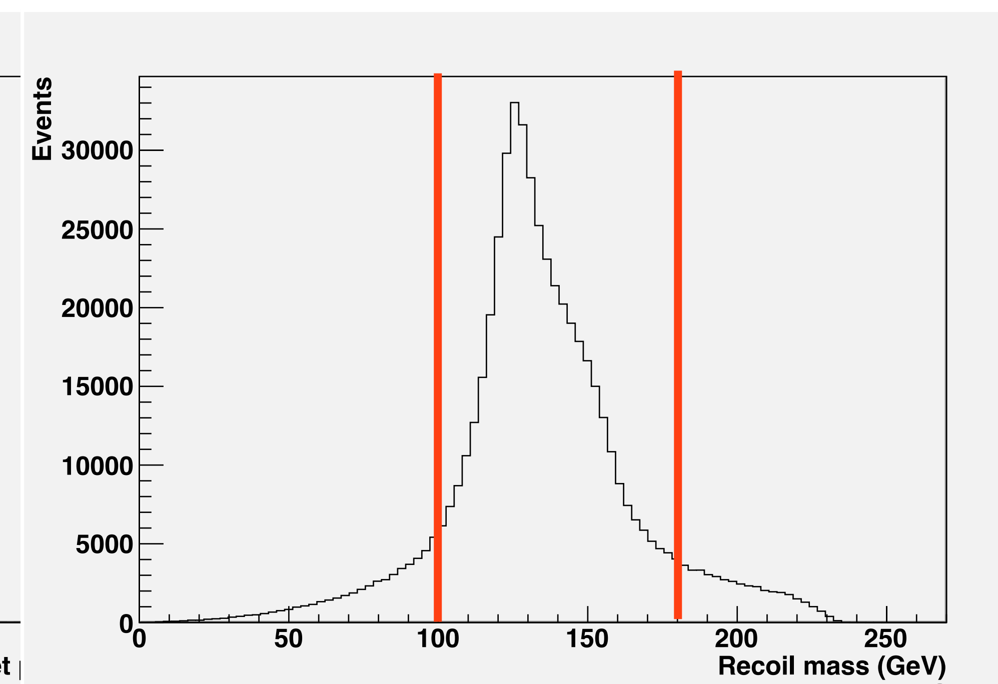
- Using y value clustering for recoil method, (0.0025 fixed)

$$y = \frac{2\min(E_i^2, E_j^2)(1 - \cos\theta_{ij})}{Q^2}$$

- Z candidate di-jetmass selection (70,110) GeV
- Z candidate di-jetp_T selection > 15 GeV
- Recoil mass selection (100,180) GeV



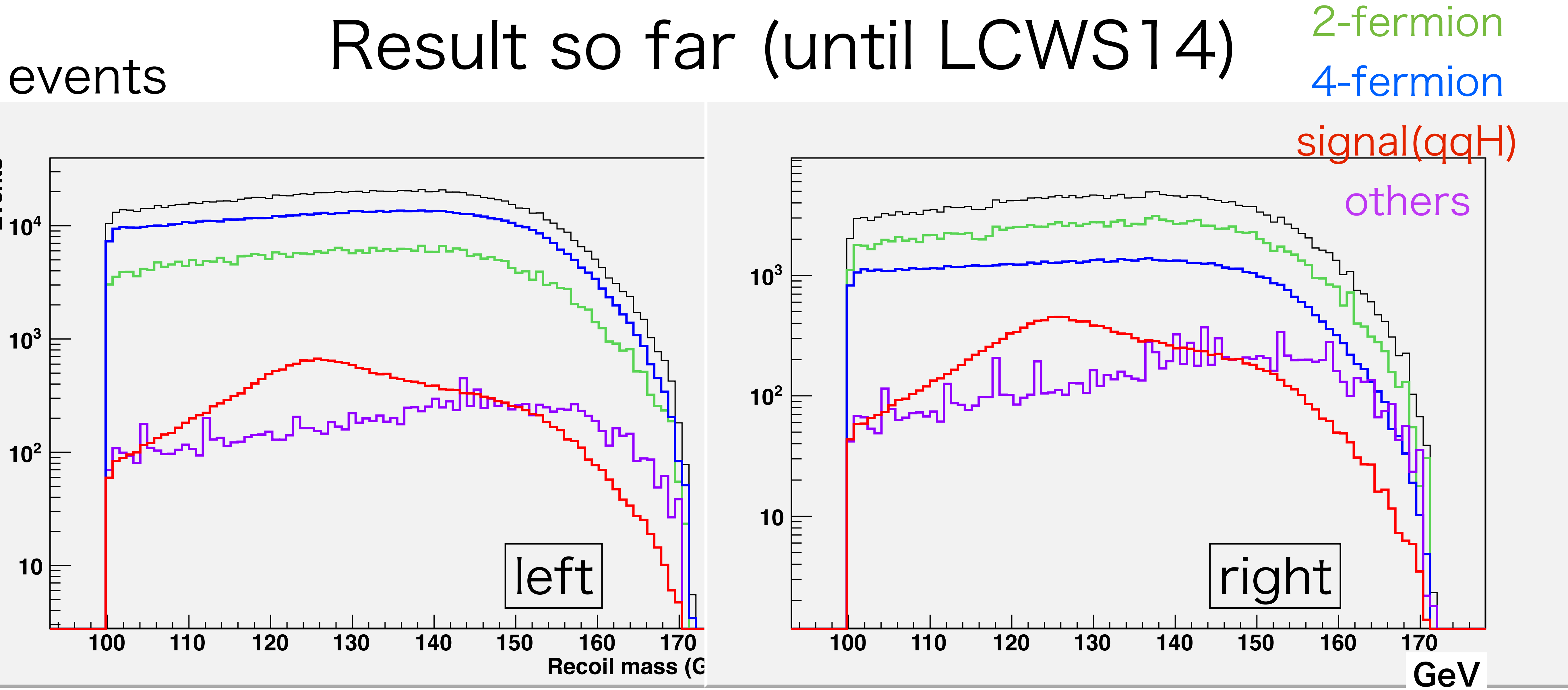




Cuts and Selections table

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	53.7%	16.5%	6.3%	0.2%
recoil	49.3%	8.3%	2.2%	0.1%
sphericity	47.1%	6.9%	1.2%	0.06%
thrust	47.0%	6.8%	1.1%	0.05%

Result so far (until LCWS14)



significance was calculated in (110,150) GeV

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

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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%
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Unfortunately NOT...

Using categorization

- Categorization is a powerful tool to reduce difference of efficiency among Higgs decay modes.
  - Categorize events using number of jets, leptons, taus, etc.
  - Minimize the difference of efficiency in each category (decay modes with too small fraction in the category are negligible.)
  - Calculate partial cross section from each category
  - Combine all cross section from categories to get the total cross section of ZH production.

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->ττ 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->γγ 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	1,862 (45.4%)	-----
H->bb (~0.0%)	1	0 (0.0%)	~0.0%
H->WW(l) (23.0%)	2,900	1,319 (45.5%)	0.05%
H->WW(sl) (0.2%)	62	44 (71.0%)	0.1%
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	433 (47.8%)	0.3%
H->cc (0.0%)	0	0 (0.0%)	~0.0%
H->$\gamma\gamma$ (1.9%)	38	22 (57.9%)	0.5%
2f	637,657	1,015 (0.16%)	+0.15%(前0.01%)
4f	470,679	18,938 (4.0%)	+3.1%(前0.9%)

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
	7,195	3,113 (43.3%)	-----
H->bb (0.01%)	40	10 (25.0%)	~0.0%
H->WW(l) (26.3%)	3,318	1,399 (42.2%)	0.7%
H->WW(sl) (3.4%)	1,849	842 (45.5%)	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	630 (41.7%)	0.2%
H->ZZ (2.7%)	410	202 (49.3%)	0.4%
H->cc (0.01%)	2	1 (50.0%)	~0.0%
H->$\gamma\gamma$ (0.5%)	10	6 (60.0%)	0.2%
2f	325,765	665 (0.2%)	+0.18%(前0.02%)
4f	458,467	11,456 (2.5%)	+2.0%(前0.5%)

1lep, 0tau

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

	before	after	fraction * difference / mean
	30,270	13,675 (45.2%)	-----
H->bb (0.33%)	1,052	332 (31.6%)	0.1%
H->WW(l) (24.1%)	3,045	1,323 (43.4%)	1.0%
H->WW(sl) (45.4%)	24,335	11,239 (46.2%)	1.0%
H->WW(h) (0.5%)	306	122 (39.9%)	0.06%
H->gg (0.3%)	141	52 (36.9%)	0.06%
H->$\tau\tau$ (2.4%)	848	393 (46.3%)	0.06%
H->ZZ (3.2%)	482	197 (40.9%)	0.3%
H->cc (0.3%)	42	13 (31.0%)	0.09%
H->$\gamma\gamma$ (0.7%)	14	4 (28.6%)	0.3%
2f	216,126	906 (0.42%)	+0.21%(前0.21%)
4f	2,430,014	125,036 (5.1%)	+3.6%(前1.5%)

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

0lep, ≧2tau

	before	after	fraction * difference / mean
	14,856	6,251 (42.1%)	-----
H->bb (0.04%)	132	43 (32.6%)	~0.0%
H->WW(l) (6.9%)	869	358 (41.2%)	0.1%
H->WW(sl) (1.4%)	759	364 (48.0%)	0.2%
H->WW(h) (0.3%)	156	73 (46.8%)	0.03%
H->gg (0.06%)	30	11 (36.7%)	~0.0%
H->$\tau\tau$ (35.4%)	12,662	5,304 (41.9%)	0.2%
H->ZZ (1.5%)	231	90 (39.0%)	0.1%
H->cc (0.05%)	7	3 (42.9%)	~0.0%
H->$\gamma\gamma$ (0.5%)	10	5 (50.0%)	0.1%
2f	212,460	158 (0.07%)	+0.062% (前0.008%)
4f	194,430	7,085 (3.6%)	+2.9%(前0.7%)

1tau (visible energy ≧ 180)

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)
ynjets<6
recoil (110,150) --- > OK

	before	after	fraction * difference / mean
[illegible]	19,337	6,402 (33.1%)	-----
[illegible]	7,148	2,007 (28.1%)	0.3%
H->WW(l) (0.04%)	5	2 (40.0%)	~0.0%
H->WW(sl) (8.9%)	4,793	1,752 (36.6%)	0.9%
H->WW(h) (6.8%)	3,837	1,297 (33.8%)	0.1%
H->gg (2.7%)	1,303	474 (36.4%)	0.3%
H->$\tau\tau$ (2.8%)	1,008	432 (42.9%)	0.8%
H->ZZ (5.0%)	752	281 (37.4%)	0.6%
H->cc (2.9%)	412	133 (32.3%)	0.1%
H->$\gamma\gamma$ (3.1%)	64	17 (26.6%)	0.6%
2f	8,885	440 (5.0%)	-0.1%(前5.1%)
4f	127,489	23,061 (18.1%)	-0.6%(前18.7%)

1tau (visible energy < 180)

number of lepton == 0
number of tau == 1
box Z(81,101),W(70,90)
yzjetpt > 15
sphericity > 0.15 , < 0.7
Thrust > (major)0.3||(minor)0.1
ydijetmass (70,110)
recoil (110,150) --- > OK

	before	after	fraction * difference / mean
	25,191	12,614 (50.1%)	-----
H->bb (0.5%)	1,581	623 (39.4%)	0.2%
H->WW(l) (11.4%)	1,435	700 (48.8%)	0.3%
H->WW(sl) (10.9%)	5,829	3,192 (54.8%)	1.0%
H->WW(h) (0.4%)	205	74 (36.1%)	0.1%
H->gg (3.0%)	142	52 (36.6%)	0.8%
H->$\tau\tau$ (42.9%)	15,363	7,673 (49.9%)	0.1%
H->ZZ (3.4%)	516	250 (48.4%)	0.1%
H->cc (0.5%)	74	27 (36.5%)	0.1%
H->$\gamma\gamma$ (2.1%)	43	20 (46.5%)	0.2%
2f	533,323	2,819 (0.5%)	+0.4%(前0.1%)
4f	1,473,190	115,206 (7.4%)	+5.7%(前1.7%)

0lep, 0tau

Under optimizing

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]	1.2%
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->$\tau\tau$ (12[illegible]	[illegible],366	1,720 (39.4%)	1.5%
H->ZZ (78.2[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	2,627,965	56,192 (2.1%)	+0.5%(前1.6%)
4f	3,579,458	440,072 (12.3%)	+2.0%(前10.3%)

Summary and Prospects

summary

- The precision of total cross section
  left 5.6% -> 4.7%, right 4.0% -> 3.3% from AWLC.
  (but still not satisfactory.)

- Categorization can reduce difference of efficiency.
  Cut efficiencies are consistent within 1%,
  except for 0lep, 0tau category

prospects

- Use likelihood to improve statistical precision.

- Equalize the cut efficiency of 0 lepton, 0 tau category.

- Improve tau separation by optimizing tau finder.

- Estimate systematic errors.

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 %.