Study of Higgs Branching fraction measurement

ALCPG11 @Oregon Univ.

Higgs/SUSY/BSM/DM session

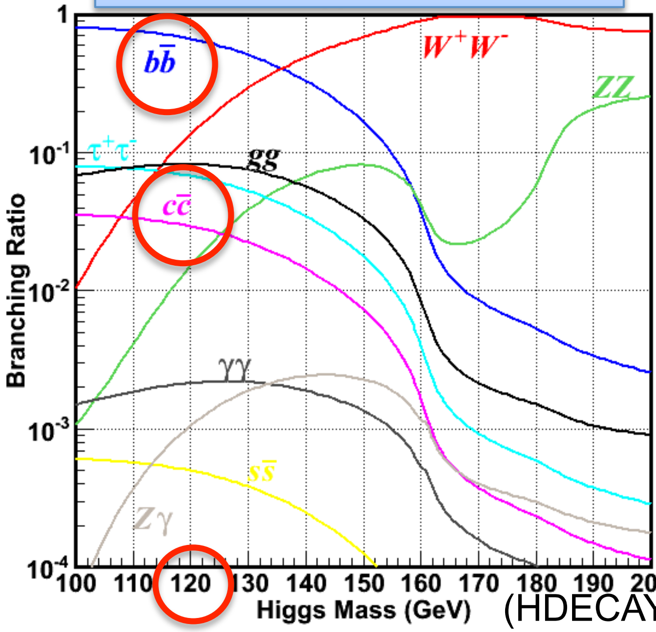
Mar. 20. 2011

H. Ono (NDU), A. Miyamoto (KEK)

Higgs Branching Ratio measurement

Measurement of the branching ratio is one of the issues of ILC especially for Higgs quark decays (H→bb/cc)

BR at M_H=120 GeV

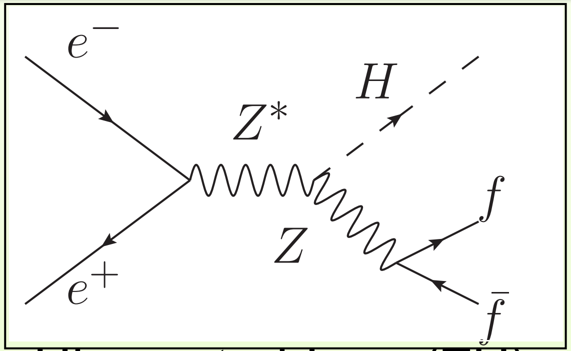


(HDECAY)

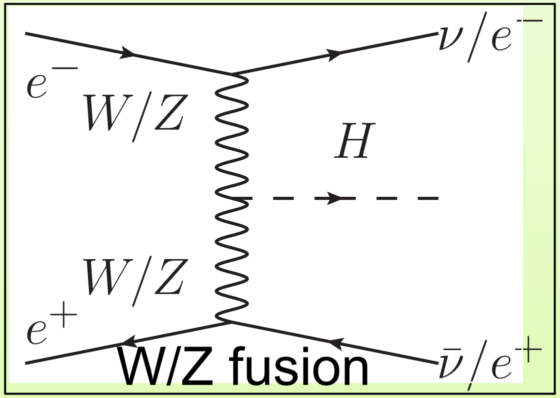
H→xx	BR
H→bb	65.7%
H→WW	15.0%
H→ττ	7.9%
H→gg	5.5%
H→cc	3.6%

(in pythia)

Higgs production processes



Higgs-strahlung (ZH)



W/Z fusion

M_H=120 GeV and P(e+,e-)=(+30%, -80%) is assumed with E_{cm}=250 and 350 GeV with L=250fb^{-1}

Higgs study with different Ecm

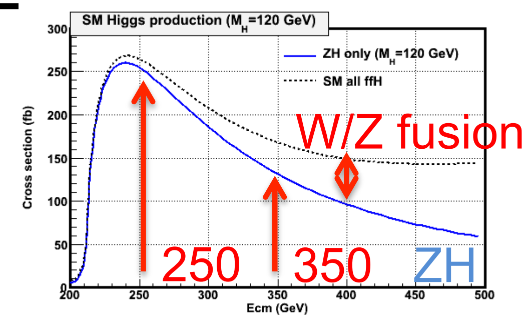
Ecm=250 GeV (ZH production threshold around 230 GeV at Mh=120 GeV)

- ZH Largest production cross-section with Z/H almost at rest
  Suitable for mass and cross-section measurement with recoil study
- Higgs-strahlung (ZH) process dominant

Ecm=350 GeV

- Reduce cross-section and Z/H will be boosted
- Increase W/Z fusion process contribution
- tt background should be considered

→ Higher peak luminosity, better S/N, with top study



	RDR (LOI)			SB2009 w/ TF			NB w/ TF		
Ecm (GeV)	250	350	500	250	350	500	250	350	500
Peak L (10^{34} $cm^{-2}s^{-1}$)	0.75	1.2	2.0	0.27	1.0	2.0	0.8	1.0	2.0
Integrated L (fb^{-1})	188	300	500	67.5	250	500	200	250	500

Evaluate the effect of different Ecm for BR study

NB : New baseline parameter
TF : beam traveling focus

Higgs BR analysis procedure

ZH→ννH (neutrino)

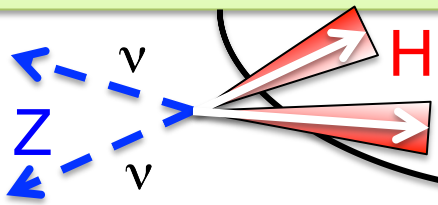
ZH→qqH (hadron)

Categorized with Z decay

2 jet clustering

4 jet clustering

Z/H combination



ZH→llH (lepton)

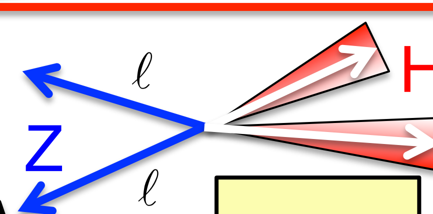
Study by Nina (Bonn Univ.)

di-lepton ID

2 jet clustering

Background reduction

$\varepsilon_{bb}, \varepsilon_{cc}$



Simple flavor cut

Template fitting

r_{bb}, r_{cc}

Check consistency with template fitting

Main background: WW/ZZ, qq+tt (at 350GeV)

Relative BR

$$\frac{BR(H \to c\bar{c})}{BR(H \to b\bar{b})}$$

Background reduction (Assuming $L=250fb^{-1}$)

Neutrino (vvH) channel analysis

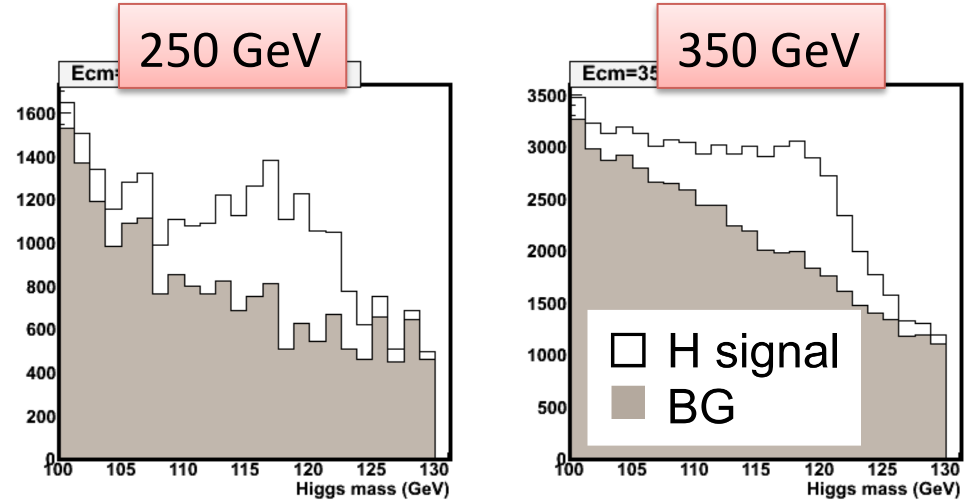
Selection criteria

1. Missing mass (Mz) (80<MM<140 or 50<MM<240)
2. Transverse momentum (20<Pt<70 or 10<Pt<140)
3. Longitudinal momentum (|Pl|<60 or 130)
4. # of charged tracks (N<10)
5. Maximum momentum (Pm<30 or 60)
6. Y value (Y_{23}<0.02, 0.2<Y_{12}<0.8)
7. Di-jet mass (M_H) (100<M_H<130)

4f, 2f background is considered
tt is also considered at 350 GeV

Better signal significance is obtained at 350 GeV

Di-jet mass after all cuts w/o b-tag



		Generated	After cut	S/√(S+B)
250 GeV	Sig	19360 (14520)	6731 (5048)	41.9 (36.3)
	BG	44827100 (33811100)	19059 (14294)	
350 GeV	Sig	26307	12338	49.0
	BG	18991000	50993	

L=250fb^{-1} (): L=188fb^{-1} at 250 GeV as RDR param.

Hadronic (qqH) channel analysis

Selection criteria

1. Jet paring χ^2 (χ^2 <10)
2. # of charged tracks in jet (N<4)
3. Y_{34} (3→4 Jet pairing Y threshold) (Y_{34}<2.7)
4. Thrust (<0.9 or <0.85)
5. Thrust angle ($|\cos\theta|$<0.9)
6. H jets angle ($105<\theta<160$ or $70<\theta<120$)
7. Fitted Z mass ($85<M_Z<100$)
8. Fitted H mass ($105<M_H<130$)

5 Constraints fit is applied

- $\Sigma P_i=0$
- $\Sigma E_i - E_{cm}=0$
- $|M_{12}-M_{34}|=|M_Z-M_H|$

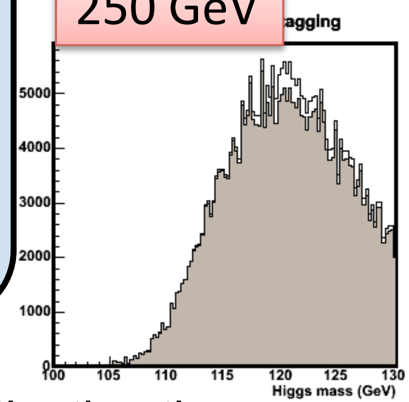
Jet pair combination from 4 jets

$$\chi^2 = \left(\frac{M_{12}-M_Z}{\sigma_Z}\right)^2 + \left(\frac{M_{34}-M_H}{\sigma_H}\right)^2$$

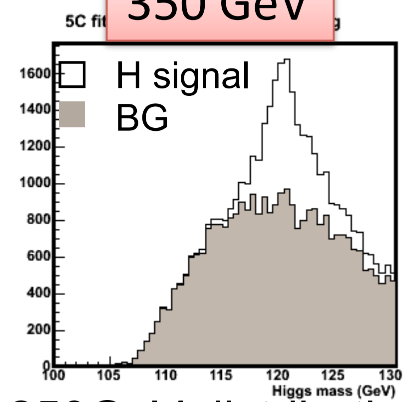
Minimum χ^2 pairs are selected

Higgs mass after all cuts w/o b-tag

250 GeV



350 GeV

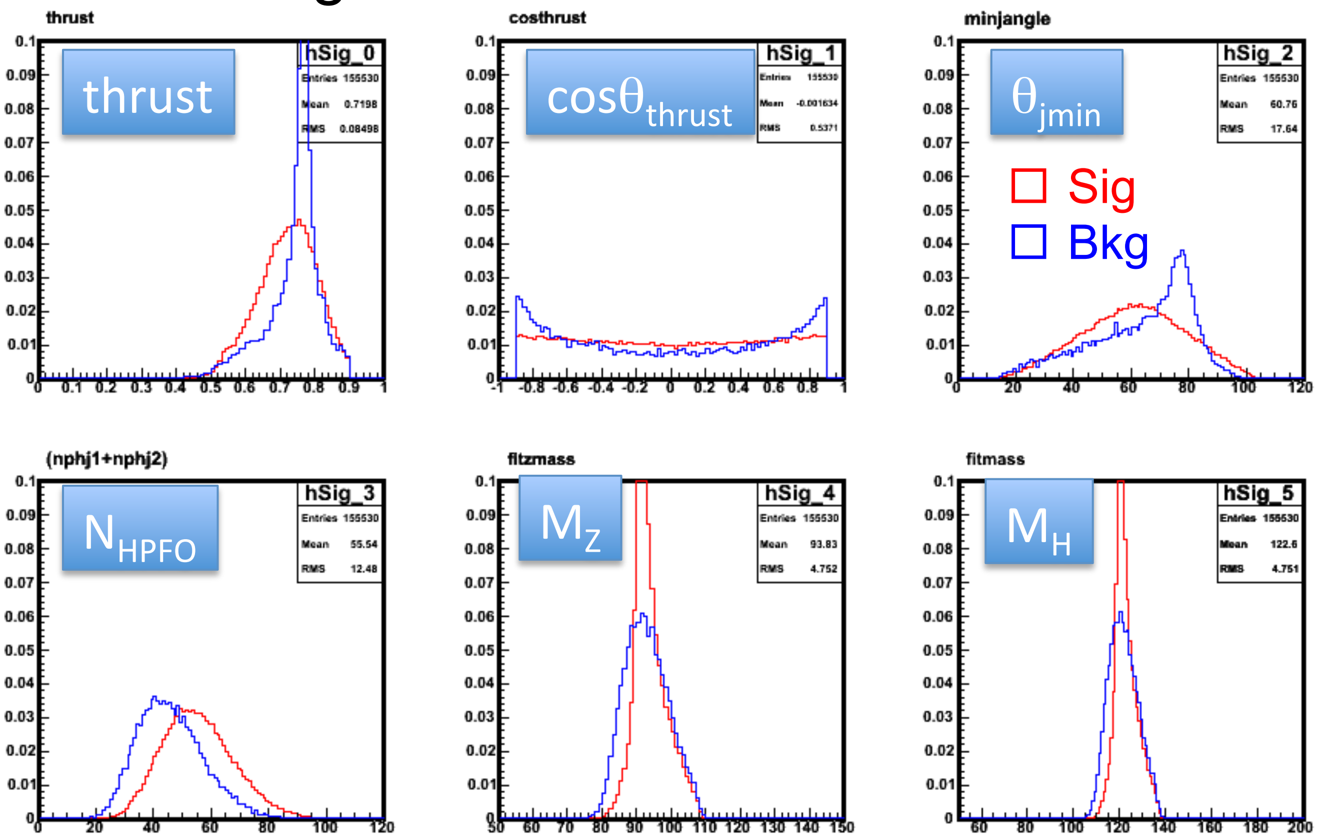


Now investigating the reason of 250GeV distribution

Better signal significance has been obtained at 350 GeV

Likelihood variable cut for qqH 250 GeV

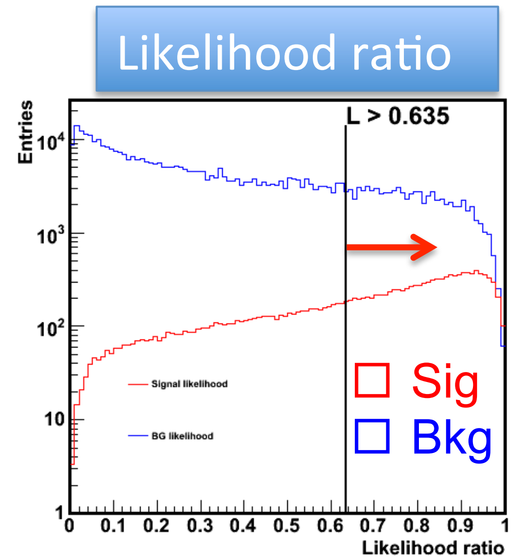
Likelihood variable cut is tried to improve the background reduction



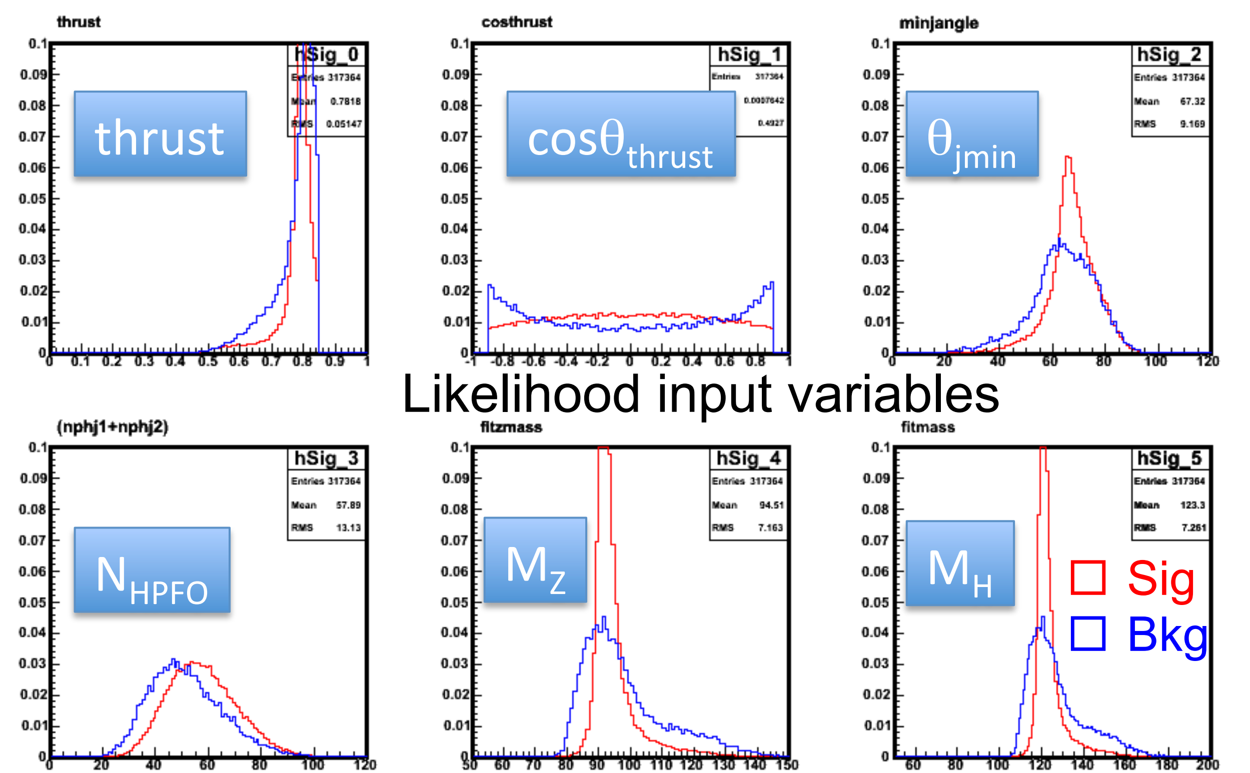
Likelihood input variables

$L=P_S/(P_S+P_B)$

L cut position is defined as significance maximum

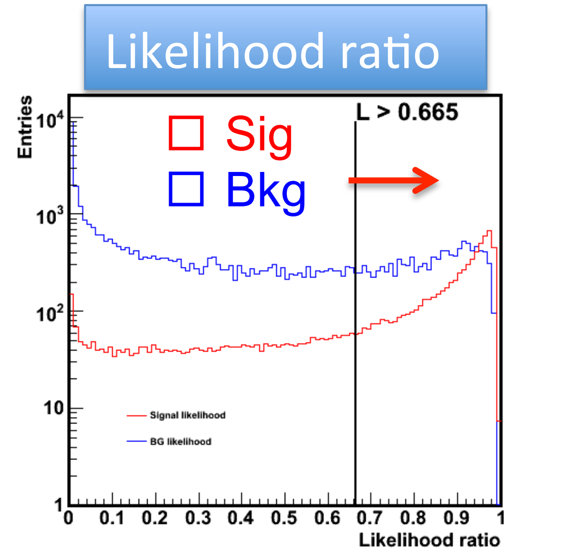


Likelihood variable cut at 350 GeV



Likelihood input variables

L cut position is defined at significance maximum



		Generated	After cut	LR cut	S/√(S+B)
250 GeV	Sig	52507	16350	15329	25.0→29.9
	BG	44827100	411785	246724	
350 GeV	Sig	36099	9447	8695	40.7→47.0
	BG	20544400	44395	25490	

Signal significance is improved with likelihood variable cut

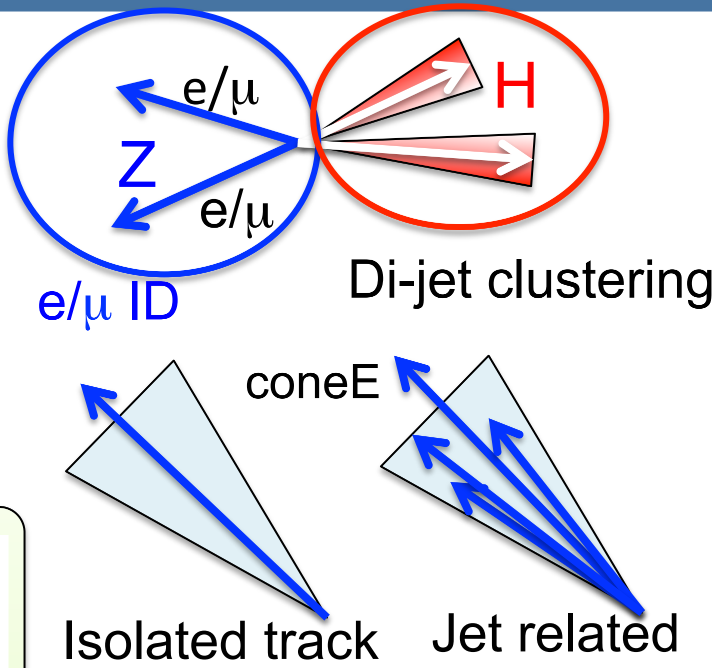
Lepton (eeH, μμH) channel analysis

Now Nina studies this channel, so no update

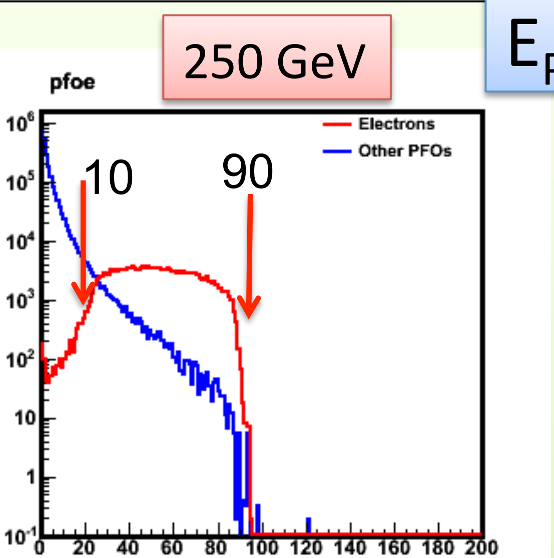
Electron/Muon identification

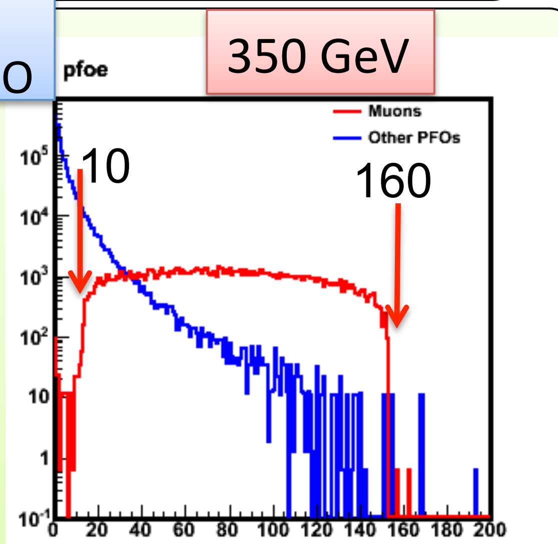
1. Lepton isolation + track energy selection
2. Calorimeter Edep information
   Electron deposits its most of energy at ECAL

If # of candidates > 2 :
select di-lepton whose mass is closest to Mz



E_{PFO}





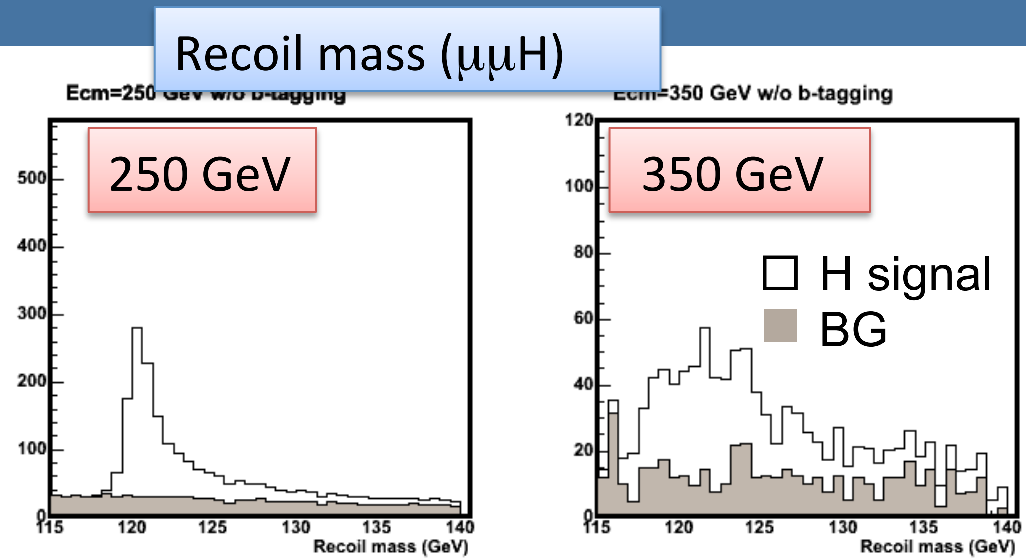
Eff.	Electron	Muon
250 GeV	93.3%	95.7%
350 GeV	93.1%	96.7%

Looser criteria compare with Nina's study

Lepton mode (llH) background reduction

BG reduction

1. ee/μμ ID
2. Z mass cut
3. Z cosθ
4. Mh
5. Recoil Mass



eeH		Gen.	After cut	S/√(S+B)
250	Sig	3132	1179	22.3
	BG	4518350	1610	
350	Sig	2740	567	16.7
	BG	3825980	581	

μμH		Gen.	After cut	S/√(S+B)
250	Sig	2917	1387	28.5
	BG	4518210	980	
350	Sig	1789	639	19.2
	BG	3826930	465	

Better signal significance is obtained
at Ecm=250 GeV from narrower recoil mass distribution

Simple flavor selection analysis

Simple flavor-likeness cut analysis

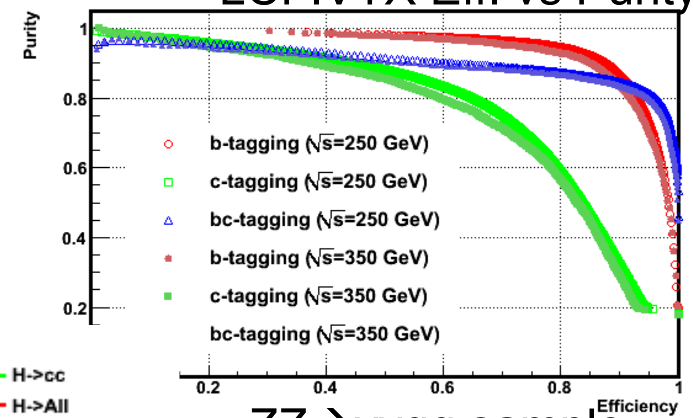
At first, we apply the simple flavor cut to evaluate the measurement accuracy of the relative BR

Flavor likeness

$$x - \text{likeness} = \frac{x_1 x_2}{x_1 x_2 + (1 - x_1)(1 - x_2)}$$

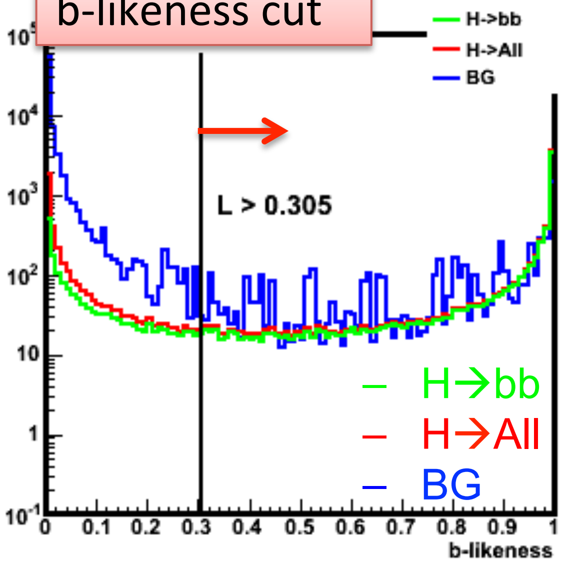
$x_{1,2}$: LCFIVTX output

LCFIVTX Eff. vs Purity

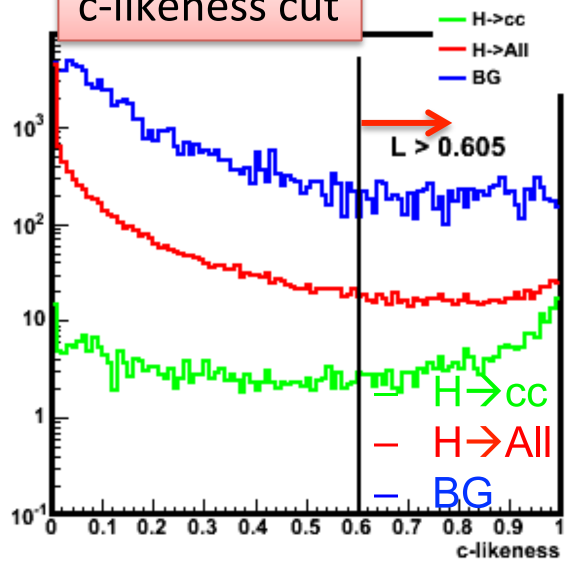


ZZ→vvqq sample at 250/350 GeV

b-likeness cut



c-likeness cut



L cut position is selected at the maximum signal significance.

Summary of flavor cut selection

vvH cut summary

νν H (250GeV)	Gen.	All cut	b-like	c-like
vvcc	698	315	33	156
vvbb	12904	5863	5390	159
ZH all	19124	6731	5456	327
SM BG	44827100	19059	2966	2100
Significance			58.7	3.2

νν H (350GeV)	Gen.	All cut	b-like	c-like
vvcc	1296	427	28	207
vvbb	24051	7245	9108	235
ZH all	36099	9165	9200	464
SM BG	18234100	43638	4356	1691
Significance			78.2	4.2

qqH cut summary

qqH (250GeV)	Gen.	All cut	b-like	c-like
qqcc	1916	388	36	187
qqbb	34963	7832	6221	369
ZH all	52507	10101	6478	686
SM BG	44827100	79401	5958	7739
Significance			55.8	2.0

qqH (350GeV)	Gen.	All cut	b-like	c-like
qqcc	1315	293	23	135
qqbb	24022	5083	4532	185
ZH all	36099	6395	4624	363
SM BG	20544400	10789	1394	687
Significance			58.4	4.2

Measurement accuracy of BR

Accuracy of Relative branching fraction

$$\frac{\Delta \mathrm{RelBR}}{\mathrm{RelBR}} = \sqrt{\left(\frac{\Delta\sigma_{cc}}{\sigma_{cc}}\right)^2 + \left(\frac{\Delta\sigma_{bb}}{\sigma_{bb}}\right)^2}$$

$BR(H \rightarrow s) = \sigma_s / \sigma_{H \rightarrow all}$, $RelBR = \sigma_{cc} / \sigma_{bb}$

$$\frac{\Delta\sigma_s}{\sigma_s} = \frac{\sqrt{N_s + N_{BG}}}{N_s}$$

N_s: Num. of H→s
N_{BG}: Num. of BG

Relative BR is dominated by H→cc accuracy

Channel	Ecm	Δσ/σ(bb)	Δσ/σ(cc)
Neutrino (nnH)	250	1.7%	30.9%
	350	1.3%	24.0%
Hadron (qqH)	250	1.8%	49.2%
	350	1.7%	24.1%
Muon (mmH)	250	4.1%	51.4%
	350	5.8%	56.8%
Electron (eeH)	250	3.6%	41.4%
	350	5.3%	59.2%

Measurement accuracies are improved at 350 GeV for both case

Maximizing signal significance is a key for BR measurement

→Apply the template fitting to improve the flavor separation

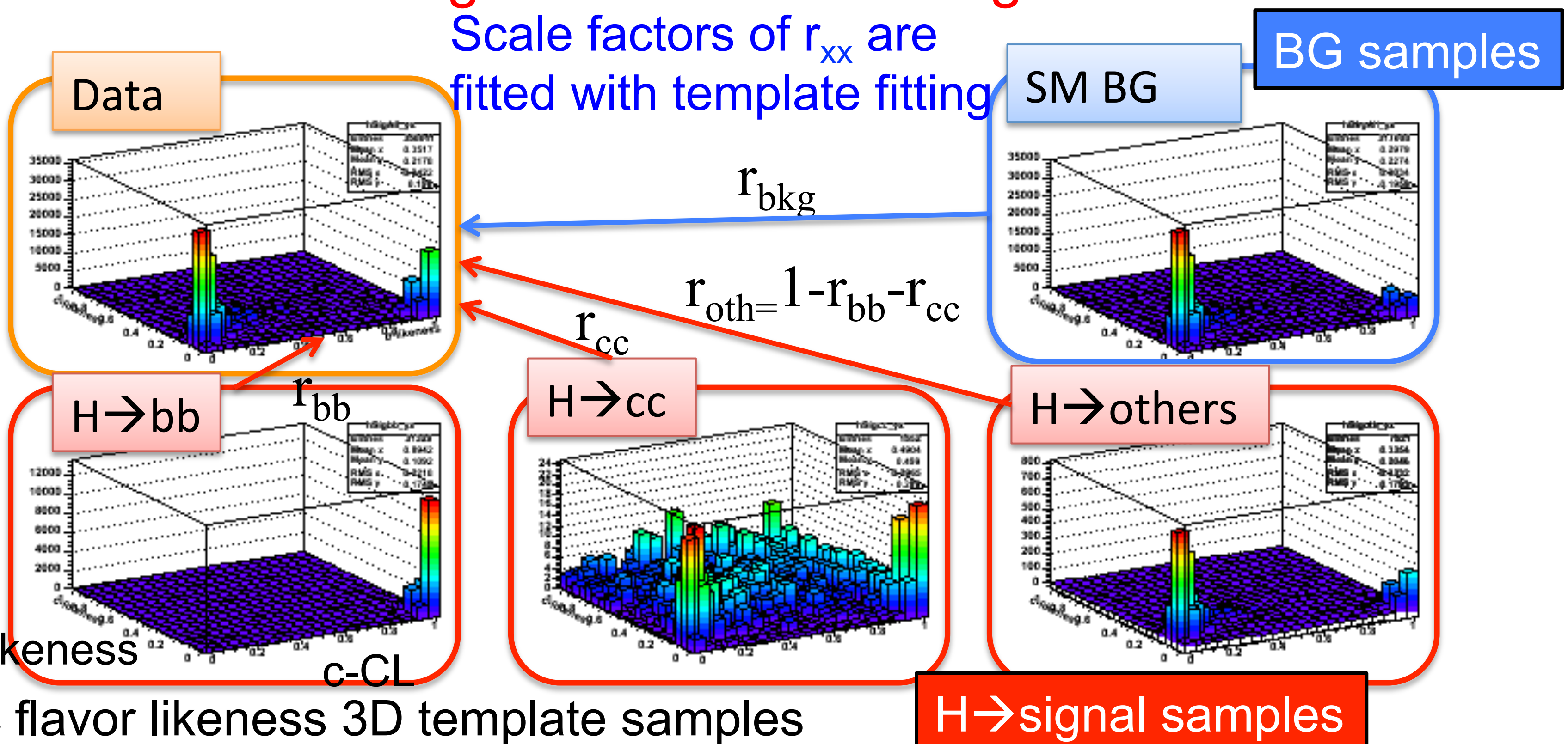
Template fitting analysis

3D template samples histogram

Apply 1,000 times Toy MC and evaluate relative errors

From the MC sample statistics limitation,

low statistic bins are ignored from the fitting



b/c/bc flavor likeness 3D template samples
(2D image)

r_{xx} : N_{xx}/N_{Hall} fraction after BG reduction

Evaluate relative BR with template fitting

To improve the flavor cut efficiency and measurement accuracy of BR template fitting has been applied and evaluate the relative BR

Relative branching fraction

$$\frac{Br(H \to c\bar{c})}{Br(H \to b\bar{b})} = \frac{r_{cc}/\varepsilon_{cc}}{r_{bb}/\varepsilon_{bb}}$$

r_{xx} : $N_{H \to xx}/N_{H \to all}$ fraction after BG reduction
ε_{xx} : BG reduction efficiency

Fitted parameter r_{bb}/r_{cc} are extracted with the template fitting

Poisson statistics are considered for each template sample bin

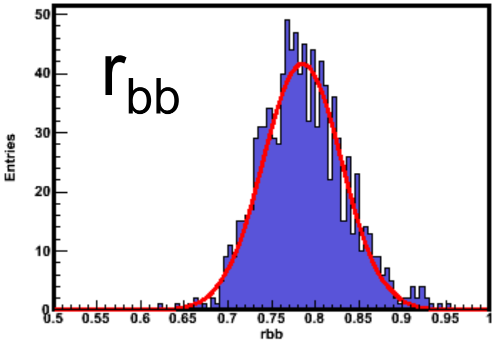
$$p_{ijk} = \frac{\mu^X e^{-\mu}}{X!} \quad X = N_{ijk}^{data} \quad \mu = N_{ijk}^{template} = \sum_{s=bb,cc,others} r_s \left(\frac{N^{Hall}}{N^s} \right) N_{ijk}^s + r_{bkg} N_{ijk}^{bkg}$$

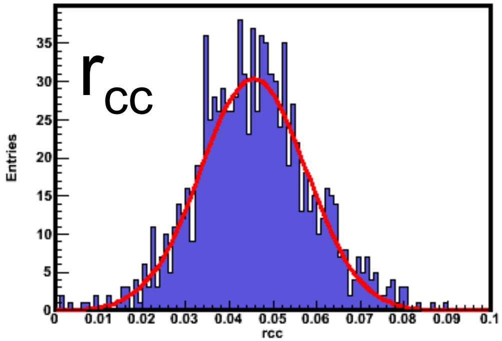
$$L = -\log P = -\log\left(\prod_{i,j,k} P_{ijk} \right) = -\sum_{i,j,k} \left(\log P_{ijk} \right)$$

Template fitting is applied with minimizing L

Fitted results with toy MC

Fitted distribution of rbb, rcc with 1000 times Toy MC





True r_s	ννH		qqH	
Ecm	250	350	250	350
rbb	0.87	0.85	0.78	0.79
rcc	0.047	0.049	0.046	0.047

	ννH		qqH	
Ecm	250	350	250	350
Luminosity (fb^{-1})	250 (188)	250	250 (188)	250
rbb	0.87±0.02	0.85±0.02	0.78±0.03	0.79±0.03
rcc	0.047±0.010	0.049±0.007	0.045±0.008	0.048±0.008
Relative BR	0.055±0.011	0.053±0.008	0.055±0.010	0.058±0.010
Accuracy of Rel BR	20.7%(28.9%)	14.2%	18.7% (26.0%)	16.7%

True r_{xx} is well reproduced with template fitting

Summary of template fitting results

From the template fitting analysis for 250 and 350 GeV, better measurement accuracy has been obtained at Ecm=350 GeV

Preliminary results

	Ecm	Rel Error of RelBR
Neutrino (nnH)	250	20.7%(28.9%)
	350	14.2%
Hadron (qqH)	250	18.4%(26.0%)
	350	16.7%
Muon (mmH)	250	39.5%(45.3%)
	350	43.9%
Electron (eeH)	250	47.5%(50.9%)
	350	37.8%
Combined	250	12.6%(16.8%)
	350	10.1%

(): L=188fb^{-1} scaled as RDR250 Statistical error only

Absolute value of the accuracy of relative BR has changed from IWLC2010 because low statistics bins are ignored to suppress the over estimation (N_{ijk}>1)

- ~20% becomes better in accuracy at Ecm=350 GeV with vvH, qqH mode.
- Luminosity reduction makes accuracy worse ~25% as same as luminosity scaling
- llH channel are relatively worse accuracy from the smaller statistics

Increase the template sample statistics

To improve the measurement accuracy of BR,
template sample statistics are increased to reduce the fluctuation

	qqH (250fb^{-1} samples)	
Ecm	250	350
Lumi (fb^{-1})	250	250
rbb	0.78±0.03	0.79±0.03
rcc	0.045±0.008	0.048±0.008
Relative BR	0.055±0.010	0.058±0.010
Accuracy of Rel BR	18.7% (26.0%)	16.7%

qqH (1000fb^{-1} sample)	
250	350
250	250
0.78±0.02	0.79±0.02
0.045±0.007	0.048±0.007
0.055±0.008	0.055±0.008
15.3%	14.6%

Try to apply likelihood cut and increase the template sample statistics for $\nu\nu H$ channel

These study is still in progress

Summary and next steps

- BR measurement accuracy has been improved at the Ecm=350 GeV about 20%.
- ~25% degradation with L=188fb^{-1} (RDR250 parameter)
  as same fraction as peak luminosity reduction

- tt background contribution looks not so large at the 350 GeV (set just 1GeV above the threshold in this sample)

- Recoil mass resolution is much better at Ecm=250 GeV

Backup

BR extraction from fitted parameters

$$BR(H \to s) = \frac{r_s}{r_s^{SM}} \cdot BR(H \to s)^{SM}$$

$BR(H \to bb)^{SM}$=65.7%
$BR(H \to cc)^{SM}$=3.6%
(in pythia)

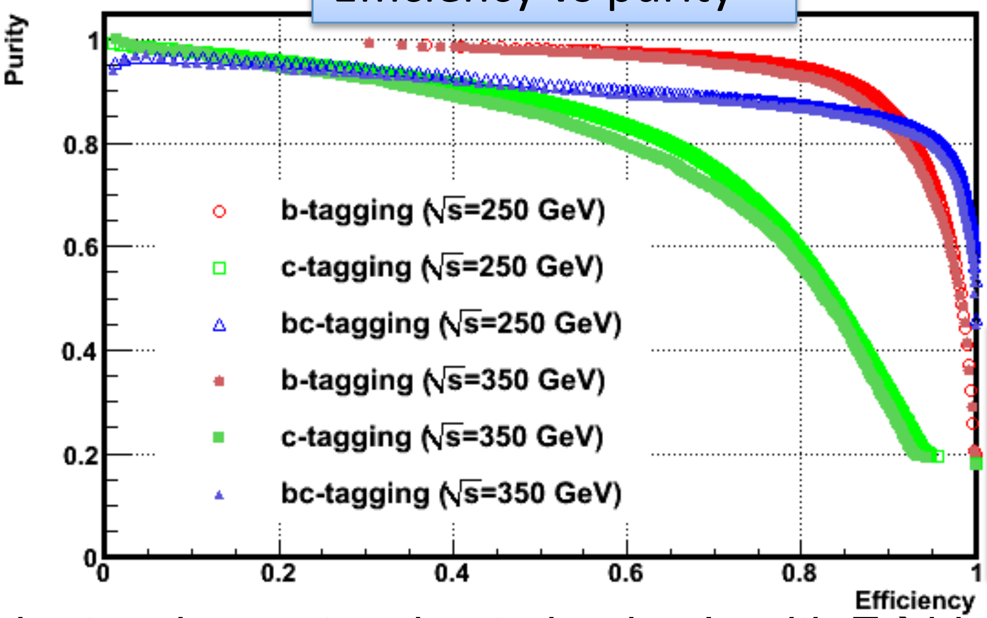
	vvH		qqH		Combined	
Ecm	250	350	250	350	250	350
Lumi (fb^{-1})	250	250	250	250	250	250
BR(bb)	65.7±1.4%	65.8±1.3%	65.8±3.0%	65.8±1.9%	65.8±1.2%	65.8±1.0%
BR(cc)	3.6±0.7%	3.6+0.5%	3.6±0.6%	3.6±0.6%	3.6±0.5%	3.6±0.4%
Relative ΔBR(bb)	2.1%	2.0%	4.5%	2.9%	1.7%	1.5%
Relative ΔBR(cc)	20.6%	14.1%	22.6%	16.6%	13.6%	10.0%

(including llH analysis)

Flavor tagging performance comparison

In LCFIVertex package,
flavor tagging is trained with Z→qq (Ecm=91.2GeV)
Flavor tagging performance is compared with ZZ→ννqq sample at Ecm=250, 350 GeV (Including Z→qq same quark composition)

Efficiency vs purity



Flavor tagging performance is slightly better at Ecm=250 GeV but not so large difference

Significant difference in flavor tag will not be observed between 250 and 350 GeV

bc-tagging : c-tagging trained only with Z→bb background

Fitted results

	vvH			qqH			mumuh			eeh		
Ecm (GeV)	250		350	250		350	250		350	250		350
Lumi (fb^{-1})	188	250	250	188	250	250	188	250	250	188	250	250
r_{bb}	0.8697	0.8712	0.8465	0.7831	0.7817	0.7947	0.7601	0.7595	0.7502	0.7644	0.7631	0.7353
Δr_{bb}	0.0222	0.0182	0.0167	0.0349	0.0287	0.0279	0.0488	0.0408	0.0338	0.0708	0.0609	0.0426
r_{cc}	0.0469	0.0473	0.0494	0.0452	0.0453	0.0482	0.0454	0.0454	0.0539	0.0467	0.0474	0.0622
Δr_{cc}	0.0135	0.0097	0.0069	0.0116	0.0083	0.0078	0.0203	0.0178	0.0236	0.0234	0.0222	0.0233
Rel BR	0.0542	0.0546	0.0532	0.0546	0.0548	0.0576	0.0531	0.0531	0.0569	0.0548	0.0557	0.0574
ΔRel BR	0.0156	0.0113	0.0076	0.0142	0.0103	0.0096	0.0240	0.0210	0.0250	0.0279	0.0265	0.0217
resol (%)	28.9%	20.7%	14.2%	26.0%	18.7%	16.7%	45.3%	39.5%	43.9%	50.9%	47.5%	37.8%
εbb	0.4544	0.4544	0.5921	0.3421	0.3421	0.2116	0.5386	0.5386	0.4041	0.4286	0.4286	0.2330
εcc	0.4520	0.4520	0.6486	0.3619	0.3619	0.2226	0.6062	0.6062	0.5104	0.4783	0.4783	0.3434

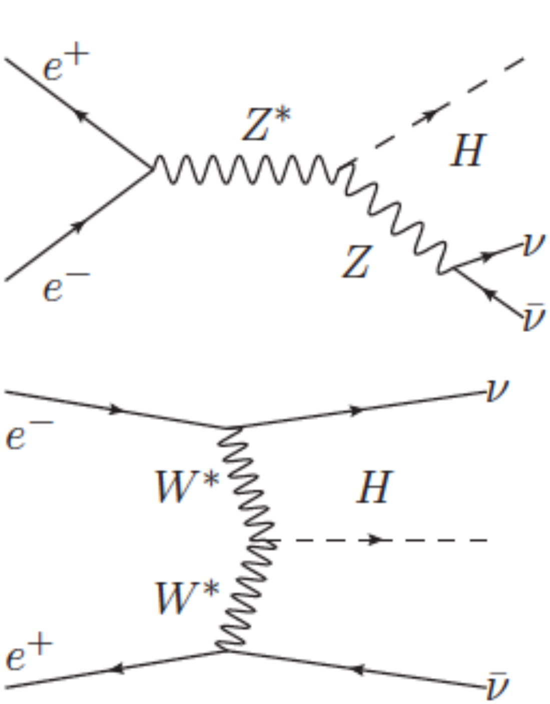
Increase template sample statistics

After template sample statistics for qqH sample

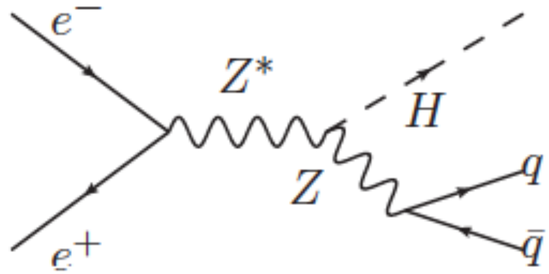
	$\nu\nu H$		qqH (Increase sample statistics)	
Ecm	250	350	250	350
Lumi (fb^{-1})	250	250	250	250
rbb	0.87±0.02	0.85±0.02	0.78±0.02	0.79±0.02
rcc	0.047±0.010	0.049±0.007	0.045±0.007	0.048±0.007
Relative BR	0.055±0.011	0.053±0.008	0.055±0.008	0.055±0.008
Accuracy of Rel BR	20.7%(28.9%)	14.2%	15.3%	14.6%

Higgs generation diagram

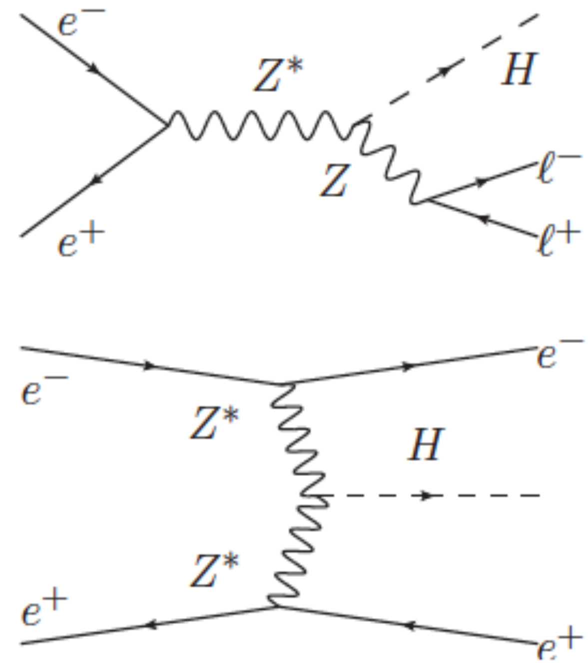
Higgs generation: ZH(Higgs-strahlung) and W/Z fusion



(a). $\nu_e \bar{\nu}_e W^* W^* / ZH \to \nu \bar{\nu} H$



(b). $ZH \to q\bar{q}H$



(c).

$e^+ e^- Z^* Z^* / ZH \to \ell^+ \ell^- H$

Generated samples

Z decay mode	Production process	$\sqrt{s} = 250\text{GeV}$	$\sqrt{s} = 350\text{GeV}$
Neutrino	$e^+e^- \to ZH/\nu_e\bar{\nu}_e W^* W^* \to \nu\bar{\nu}H$	77.4 fb	105.2 fb
Hadron	$e^+e^- \to ZH \to q\bar{q}H$	210.0 fb	144.4 fb
Lepton	$e^+e^- \to ZH/e^+e^-Z^*Z^* \to \ell^+\ell^-H$	35.9 fb	25.3 fb
	$(e^+e^-H/\mu^+\mu^-H/\tau^+\tau^-H)$	(12.6/11.7/11.7 fb)	(11.0/7.2/7.1 fb)

BG processes	$\sqrt{s} = 250\text{GeV}$	$\sqrt{s} = 350\text{GeV}$
$q\bar{q}q\bar{q}$	16193.5 fb	12498.0 fb
$q\bar{q}$	141413.0 fb	38529.4 fb
$t\bar{t}$	Not considered	656.8 fb
$\nu\bar{\nu}q\bar{q}$	599.9 fb	608.5 fb
$\nu\ell q\bar{q}$	16456.8 fb	13409.8 fb
$\ell\ell q\bar{q}$	1593.3 fb	1879.8 fb
$\ell\ell\ell\ell$	3051.9 fb	6393.0 fb