Higgs Branching Ratio study

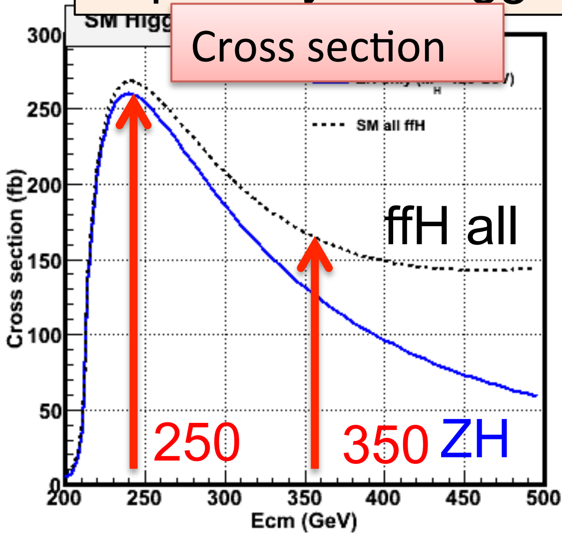
ILDWS 2011
May. 24. 2011

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

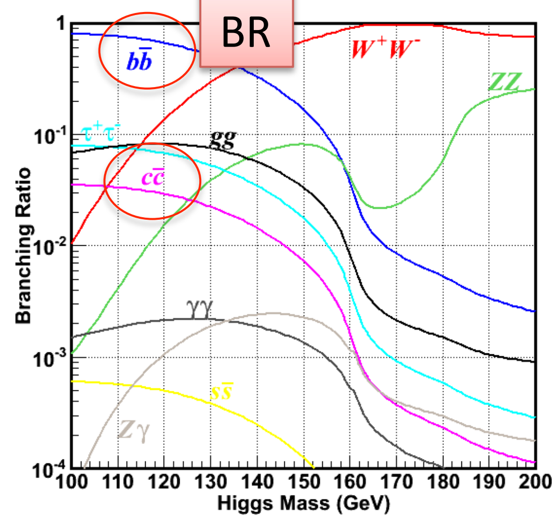
Higgs Branching Fraction study

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

Cross section

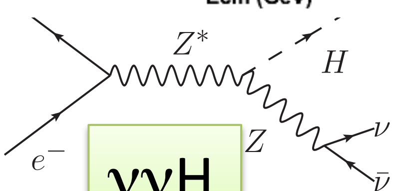


BR

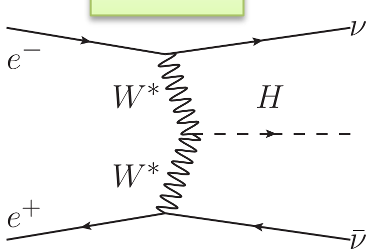


M_H=120 GeV
P(e+,e-)=(+30%, -80%) L=250fb^{-1} is assumed (188fb^{-1} at RDR) with E_{cm}=250 and 350 GeV

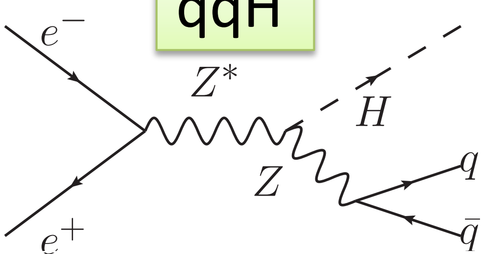
Main background processes
WW/ZZ + qq (tt at 350 GeV)

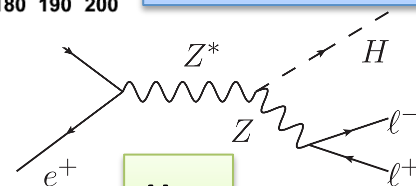


ννH

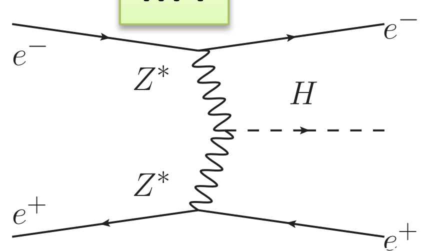


qqH





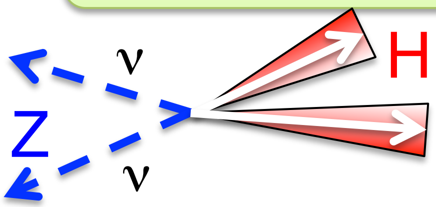
llH



Higgs BR analysis procedure

ZH→ννH (neutrino)

2 jet clustering



ZH→qqH (hadron)

4 jet clustering

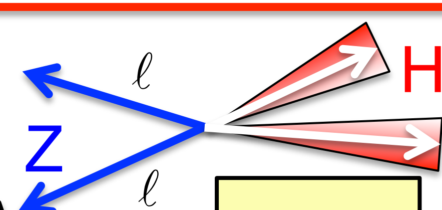
Z/H combination

ZH→llH (lepton)

Study at Bonn Univ.

di-lepton ID

2 jet clustering



Background reduction

ε_{bb}, ε_{cc}

Simple flavor cut

Template fitting

r_{bb}, r_{cc}

Check consistency with template fitting

Relative BR

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

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

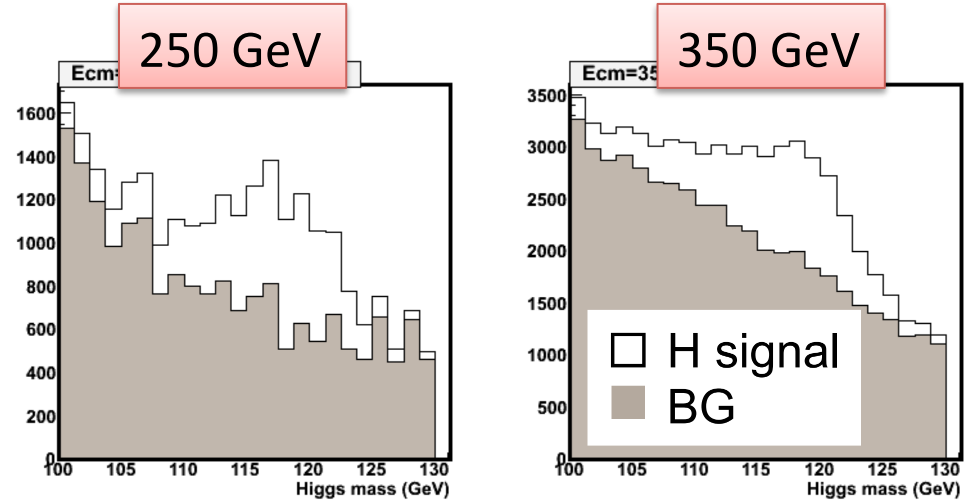
Neutrino (vvH) channel analysis

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

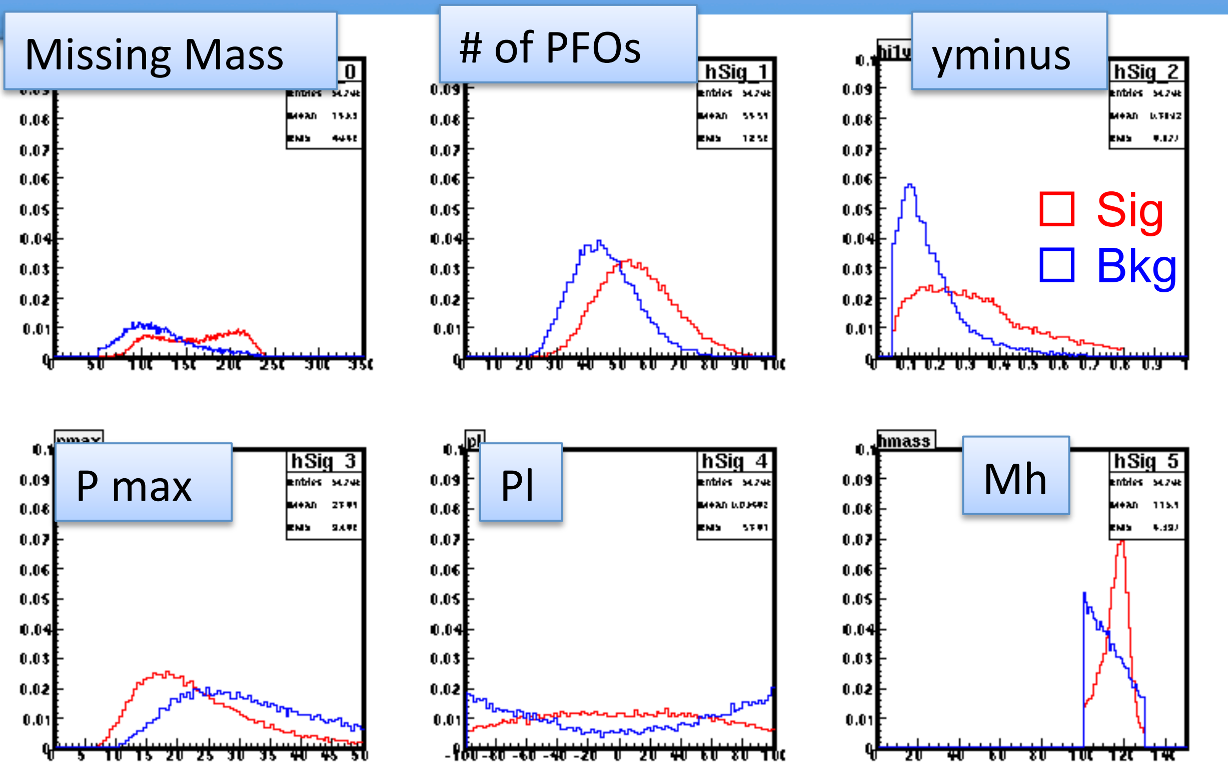
Di-jet mass after all cuts w/o b-tag



		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	42.5
	BG	20855900	71918	

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

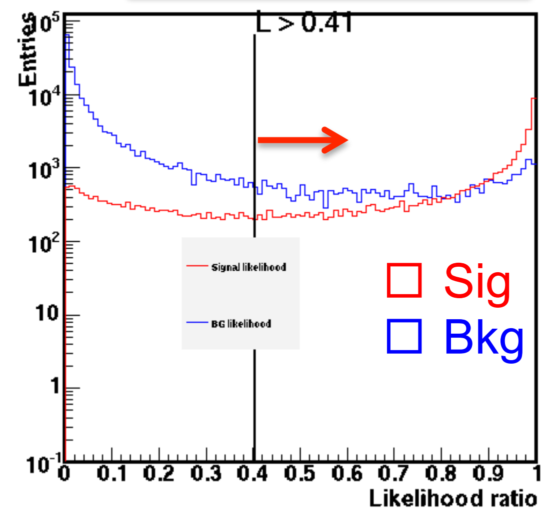
ννH likelihood ratio cut



$L = P_S/(P_S+P_B)$

L cut position is defined as significance maximum

Likelihood ratio



Sample at Ecm=350 GeV

		Generated	After cut	LR cut	S/√(S+B)
250 GeV	Sig	19360	6731	4753	41.9→52.2
	BG	44827100	19059	3593	
350 GeV	Sig	26307	12338	9302	42.5→66.9
	BG	20855900	71918	10029	

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 ($105<M_H<130$)

Jet pair combination from 4 jets

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

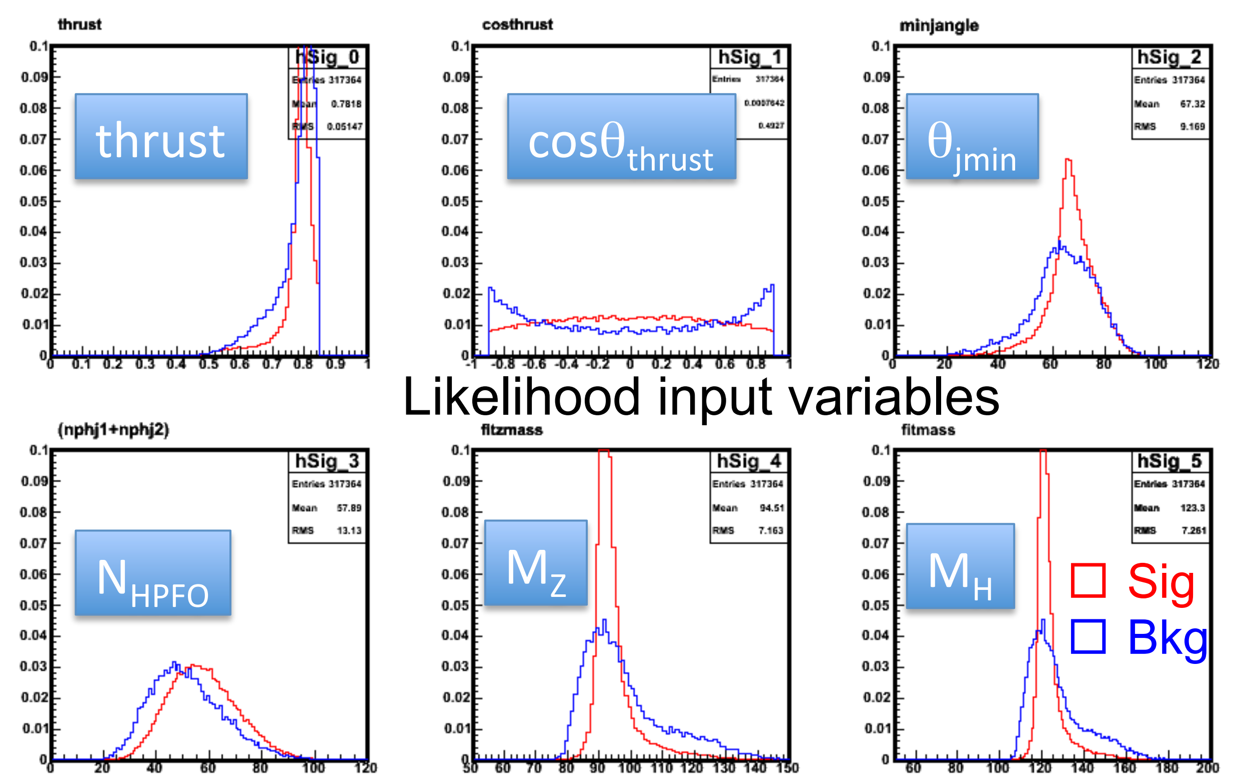
Minimum χ^2 pairs are selected

5 Constraints fit is applied

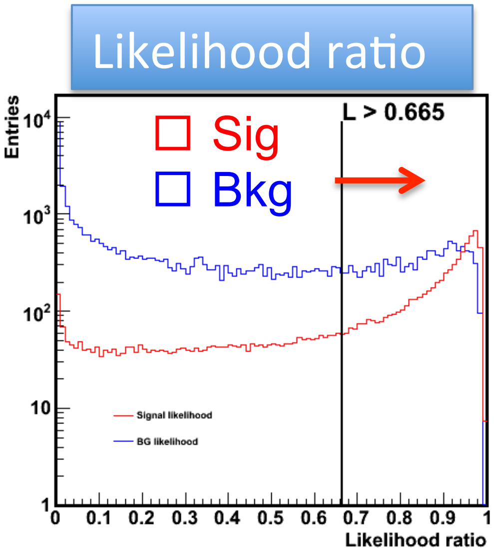
- $\Sigma P_i=0$
- $\Sigma E_i-E_{cm}=0$
- $|M_{12}-M_{34}|=|M_Z-M_H|$

In order to improve the background reduction, likelihood ratio cut is applied after the all the selections

Likelihood variable cut



L cut position is defined at significance maximum



		Generated	After cut	LR cut	$S/\sqrt{(S+B)}$
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

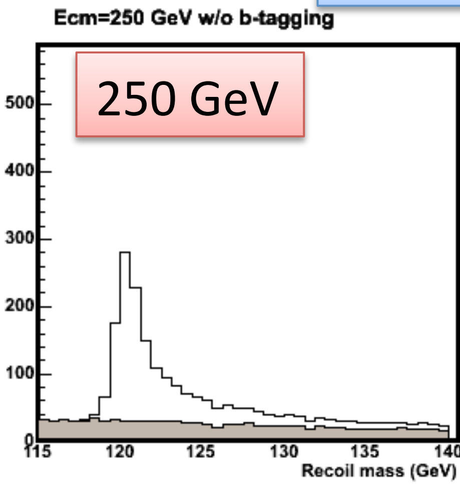
Lepton (llH) channel analysis

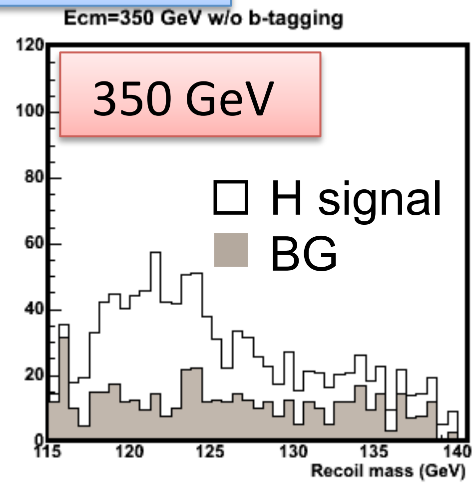
No updates from the last meeting,
Now Nina (Bonn Univ.) analyze this channel

BG reduction

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

Recoil mass (μμH)





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	

Simple BR extraction with flavor cut

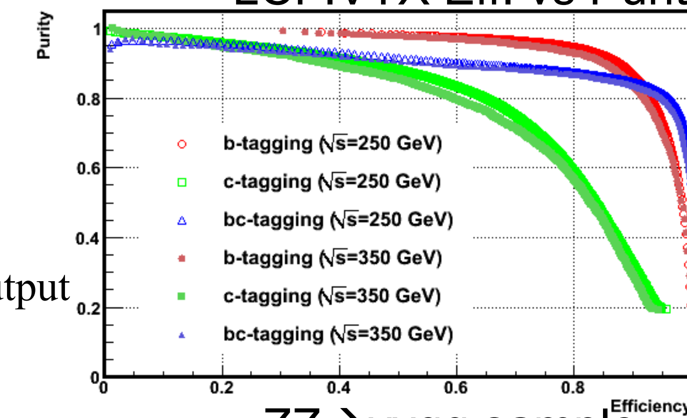
Simple flavor cut is test to evaluate
the measurement accuracy of the relative BR

Flavor likeness

$$x-\text{likeness}=\frac{x_1x_2}{x_1x_2+(1-x_1)(1-x_2)}$$

$x_{1,2}$: LCFIVTX output

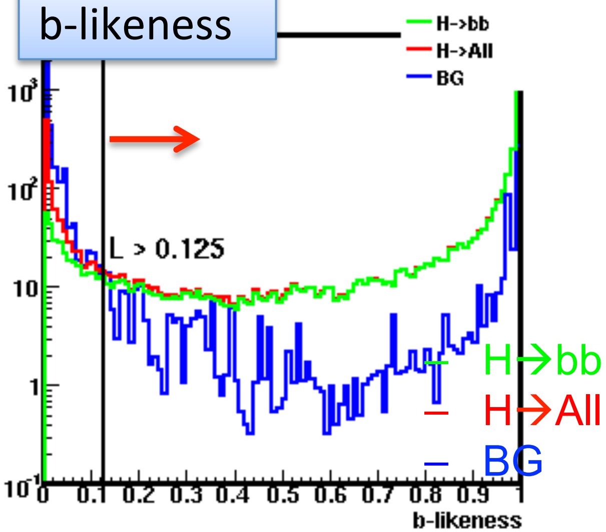
LCFIVTX Eff. vs Purity



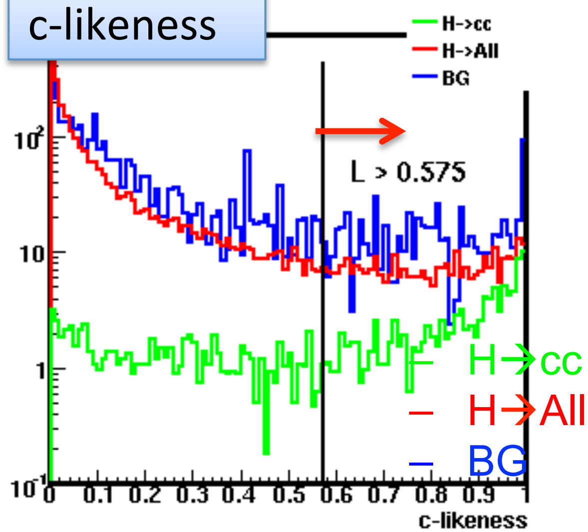
ZZ→vvqq sample
at 250/350 GeV

vvH 250 GeV

b-likeness



c-likeness



L cut position is selected at the maximum signal significance.

Measurement accuracy of BR

Accuracy of Relative BR

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

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

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

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 (ννH)	250	1.8%	29.1%
	350	1.3%	17.1%
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%

Small improvement is obtained with likelihood cut

250GeV: 30.9%→29.1%
350GeV: 24.0%→17.1%

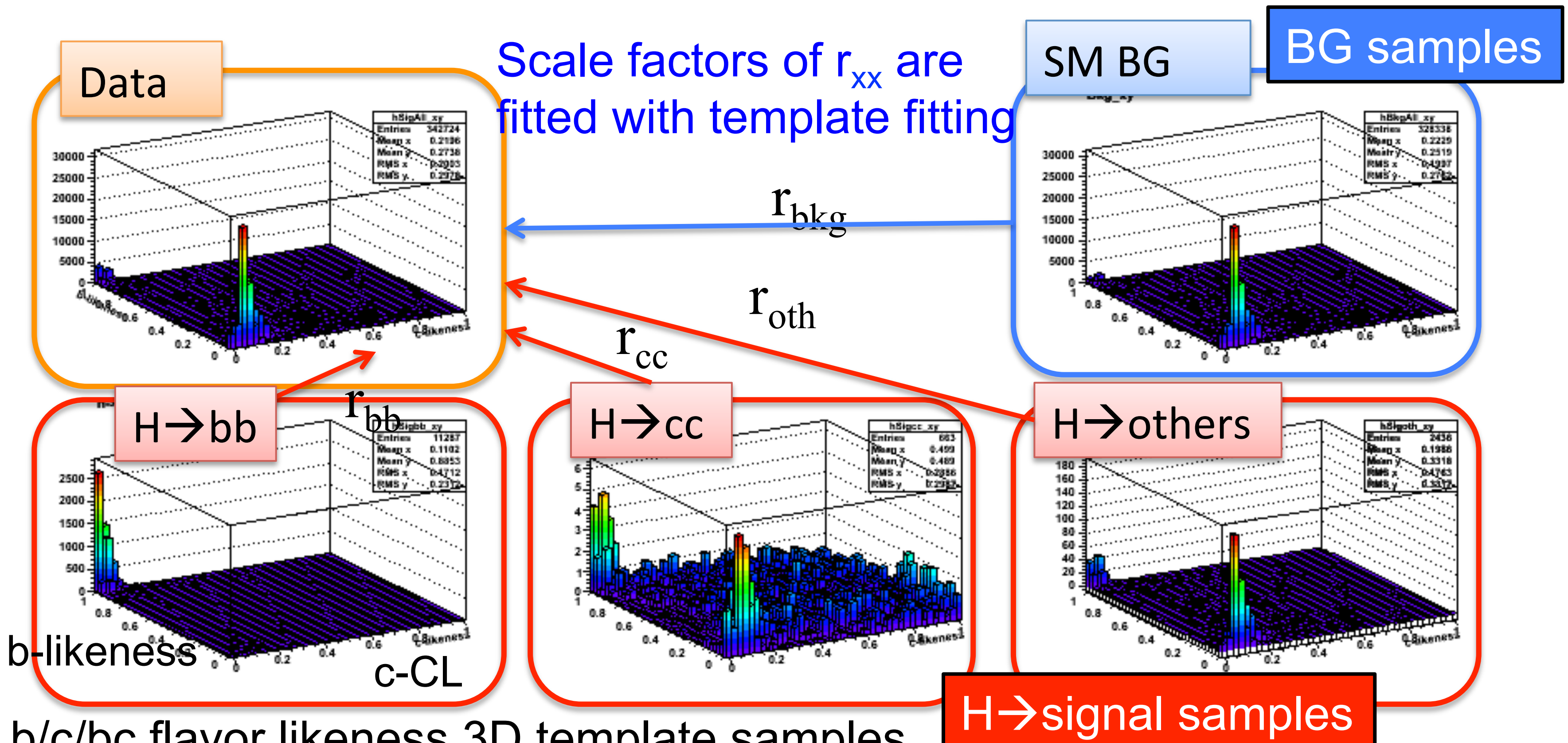
Better measurement accuracy is obtained at 350 GeV

→Apply the template fitting to improve the flavor separation

Template fitting analysis

Flavor template samples for fitting

Template sample statistics is increased
to $1000fb^{-1}$ to reduce the fluctuation of fitting result



b/c/bc flavor likeness 3D template samples

Relative BR with template fitting

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_{xx}/N_{Hall} fraction after BG reduction
ε_{xx} : BG reduction efficiency

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

Template fitting

Poisson statistics are considered for each template sample bin

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

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

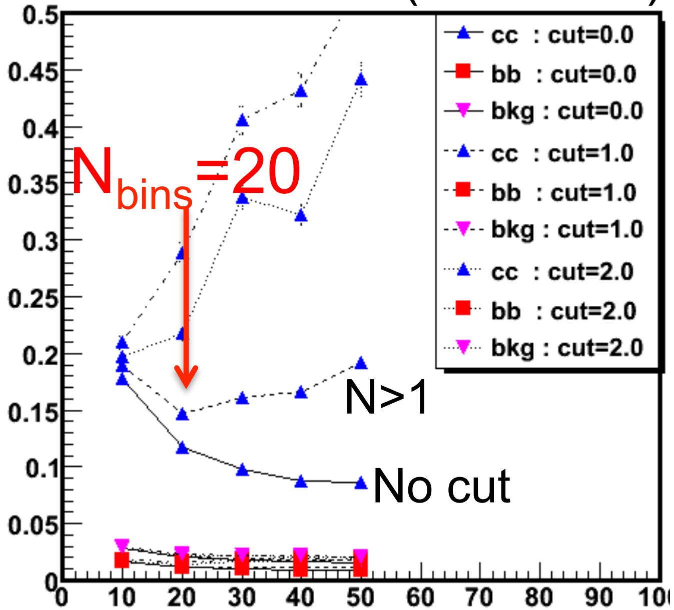
r_{xx} are fitted with minimizing L

Apply 1,000 times Toy MC and evaluate relative errors or r_{xx}

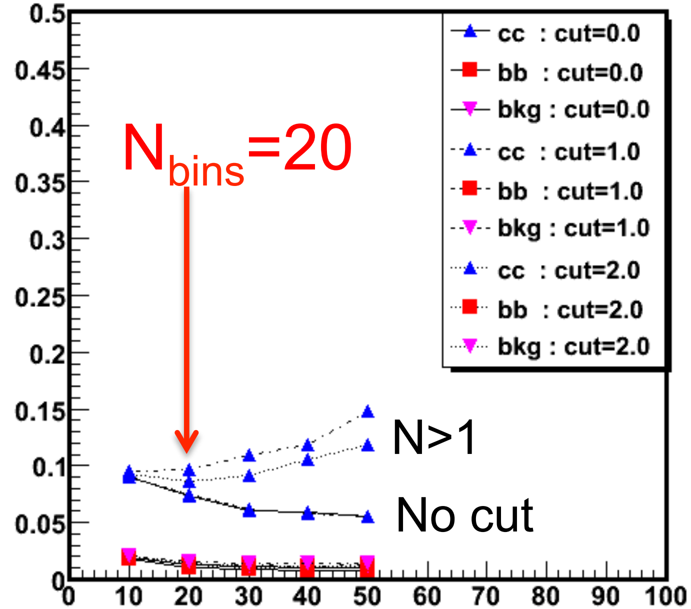
Binning dependence consideration

Apply entries cut to reduce the small entry bin's affect
→N≤1 bins are eliminated from the template fitting

ννH 250 GeV (L=250fb^{-1})



ννH 350 GeV (L=250fb^{-1})



Select N_{bins} individually for 250 and 350 GeV

These cut value depends on the template sample entries.

Template samples statistics is increased from 250fb^{-1} to 1000fb^{-1}

Summary of template fitting results

Measurement accuracy of Relative BR is evaluated with 1000fb^{-1} samples

	Ecm	Rel Error of RelBR
Neutrino (nnH)	250	14.8%
	350	7.7%
Hadron (qqH)	250	13.1%
	350	12.7%
Muon (mmH)	250	39.5%
	350	43.9%
Electron (eeH)	250	47.5%
	350	37.8%
Combined	250	9.3%
	350	6.4%

Low statistics bins are ignored
to suppress the over estimation (N_{ijk}>1)

llH mode analysis will be improved by Nina (Bonn Univ.)

Worse accuracy is caused from the low statistics of signal sample and low template sample luminosity

(Statistical error only)

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

Summary and status

- Measurement accuracy of Higgs BR is evaluated at 250 and 350 GeV Ecm.
  - Use LR cut to improve the BG reduction
  - 10~15 % measurement accuracy is obtained with the template fitting analysis

- Consider toward DBD analysis (vvH @1TeV)

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)	65.6±0.8%	65.7±0.6%	65.8±1.6%	65.7±1.7%	65.6±0.7%	65.7±0.6%
BR(cc)	3.6±0.5%	3.6+0.3%	3.6±0.5%	3.6±0.5%	3.6±0.3%	3.6±0.2%
Relative ΔBR(bb)	1.2%	1.0%	2.4%	2.5%	1.0%	0.9%
Relative ΔBR(cc)	14.7%	7.7%	12.9%	12.5%	9.2%	6.4%

(including llH analysis)

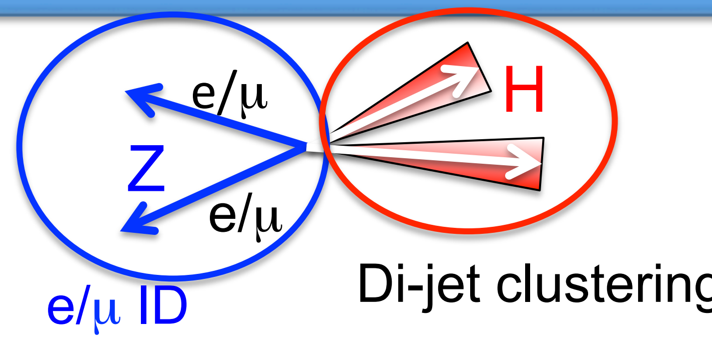
Lepton (eeH, μμH) channel analysis

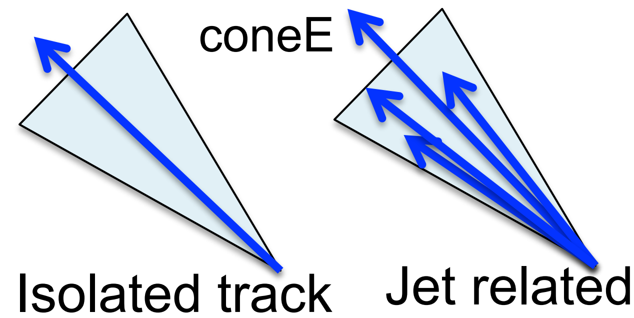
Electron/Muon identification

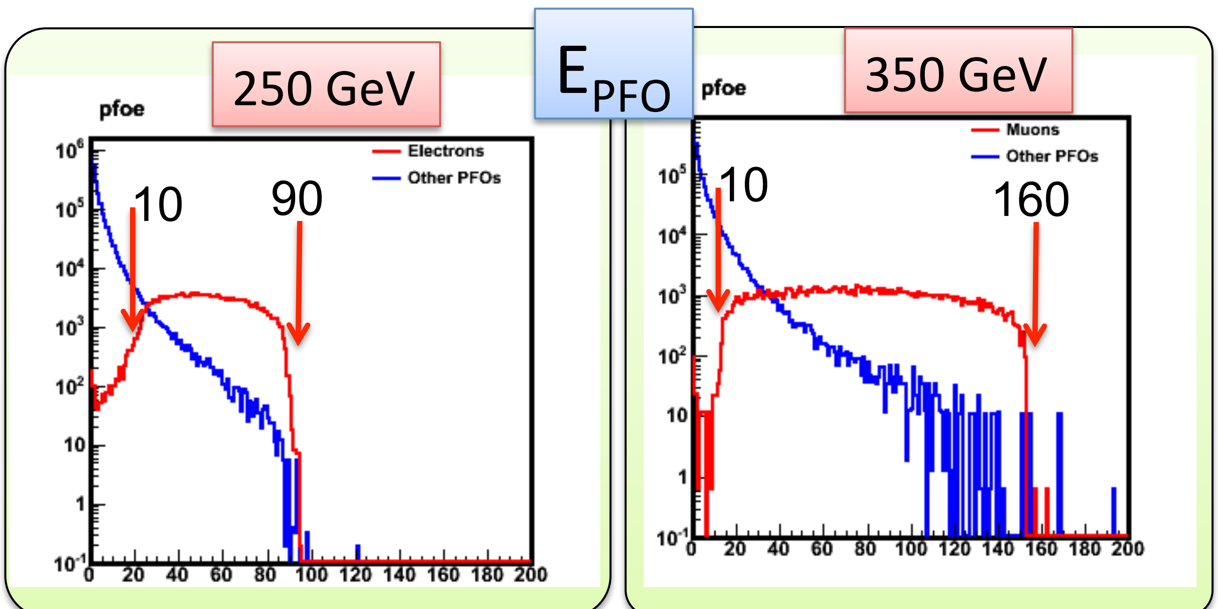
1. Lepton isolation + track energy selection
2. Calorimeter Edep information

   Electron deposits its most of energy at ECAL

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





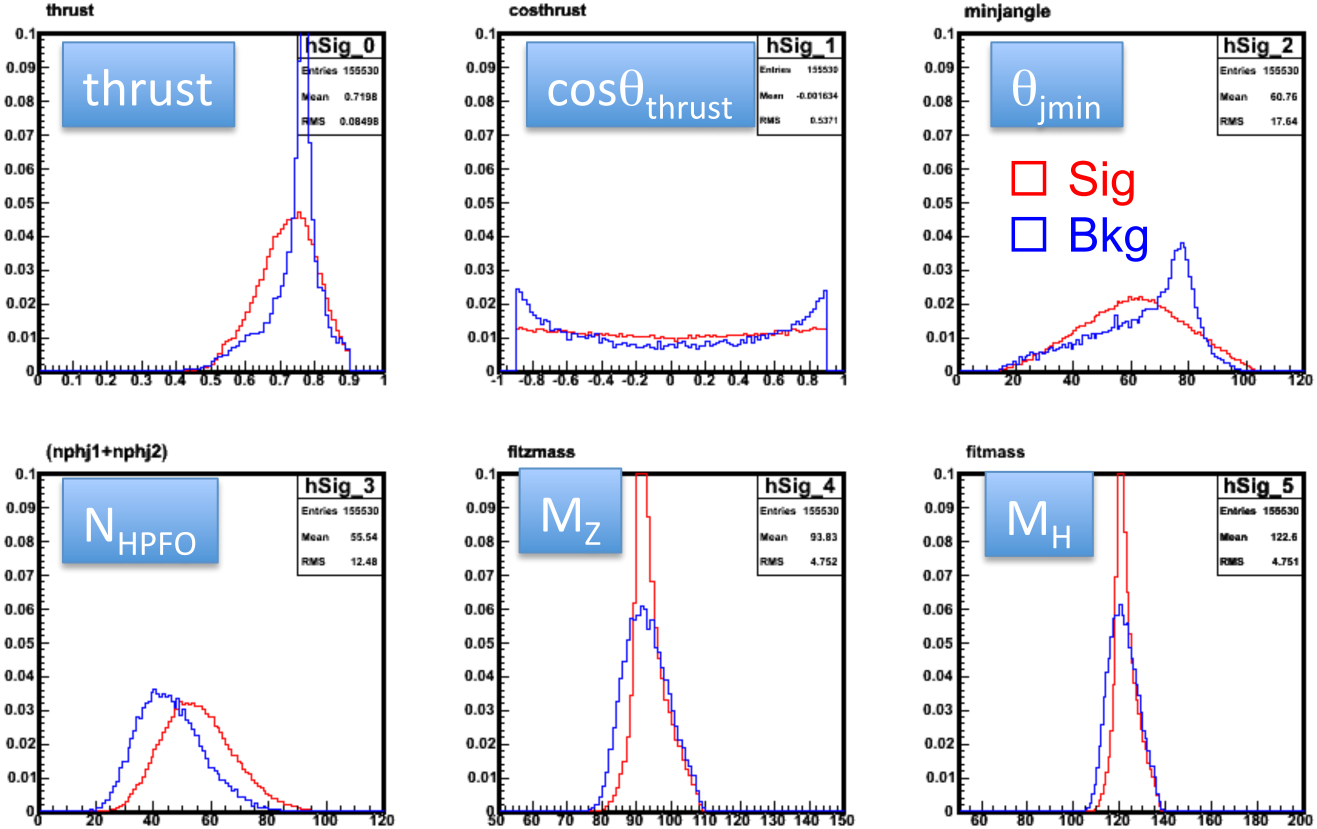


Eff.	Electron	Muon
250 GeV	93.3%	95.7%
350 GeV	93.1%	96.7%

No large difference in Lepton ID efficiency

Likelihood variable cut for qqH 250 GeV

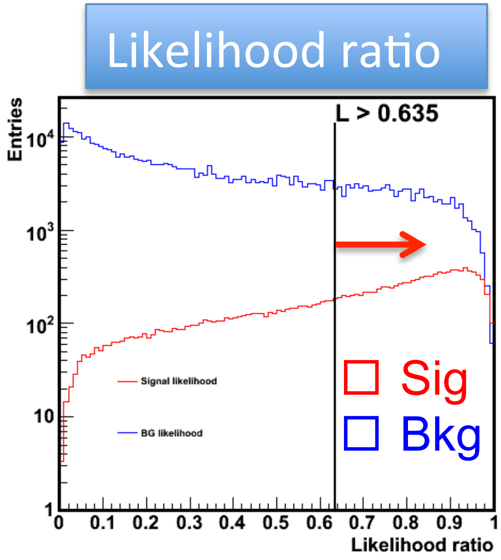
Likelihood variable cut is tried to improve the background reduction



Likelihood input variables

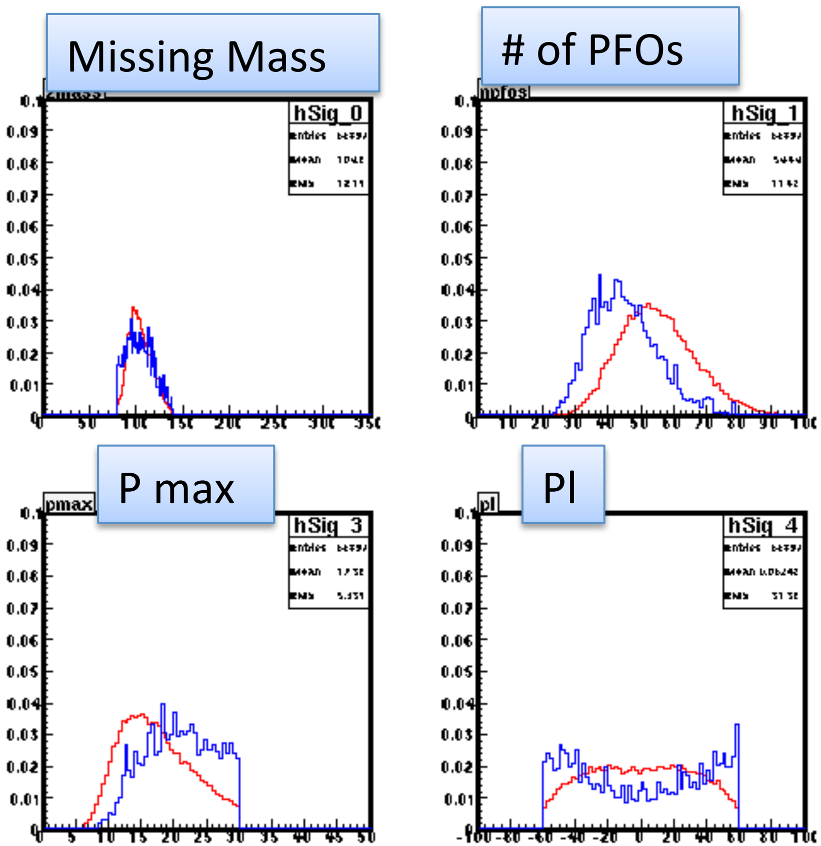
$L = P_S/(P_S+P_B)$

L cut position is defined as significance maximum



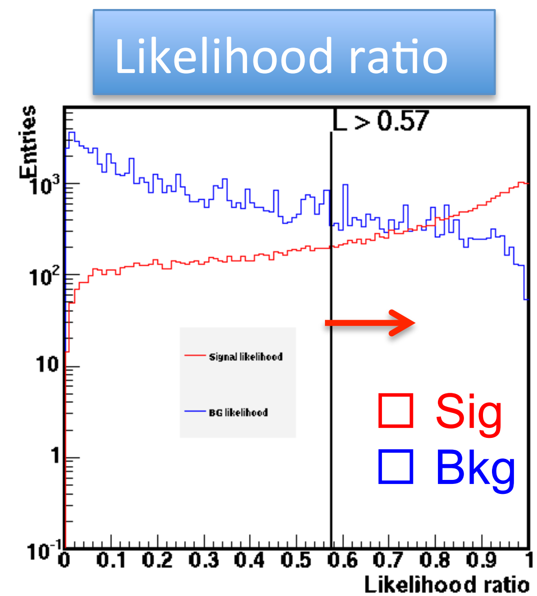
ννH 250 GeV likelihood cut

Likelihood variable cut is tried to improve the background reduction



$L=P_S/(P_S+P_B)$

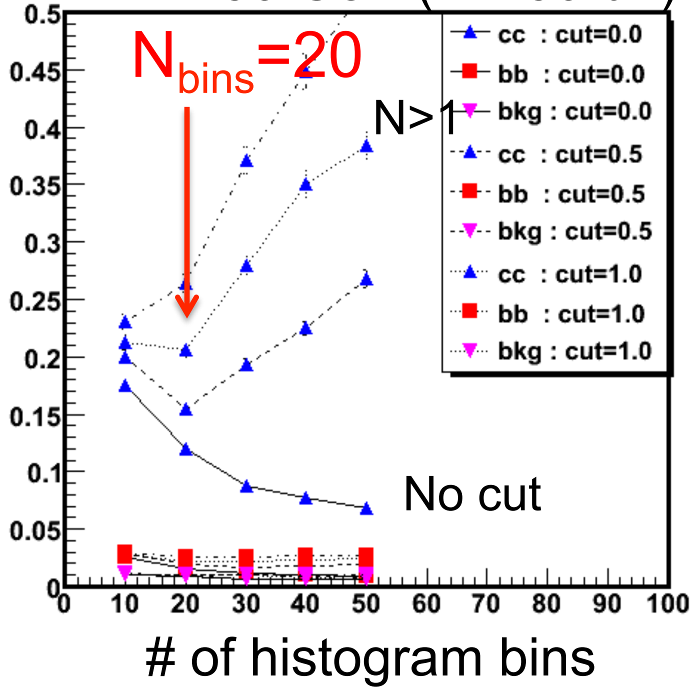
L cut position is defined as significance maximum



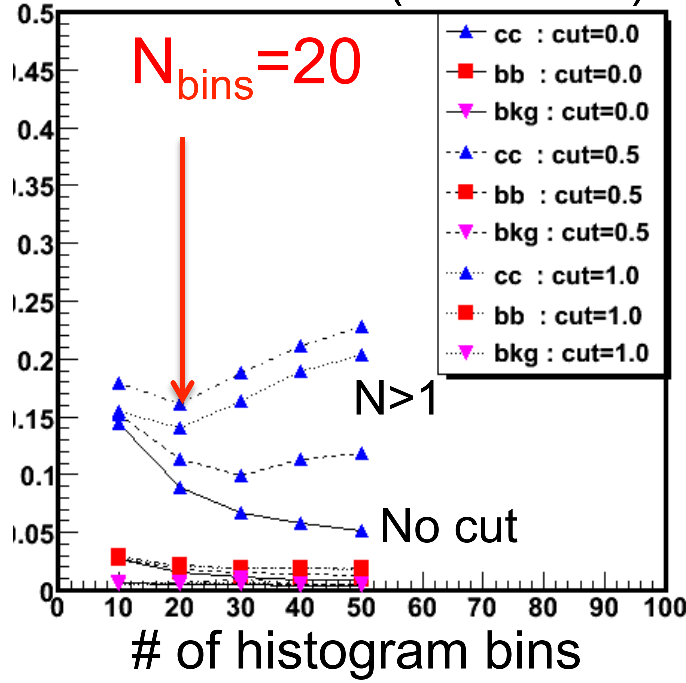
ννH channel template bins

Apply entries cut to reduce the small entry bin's effect
→N≤1 bins are ignored from the fitting at this moment

vvH 250 GeV (L=250fb^{-1})



vvH 350 GeV (L=250fb^{-1})



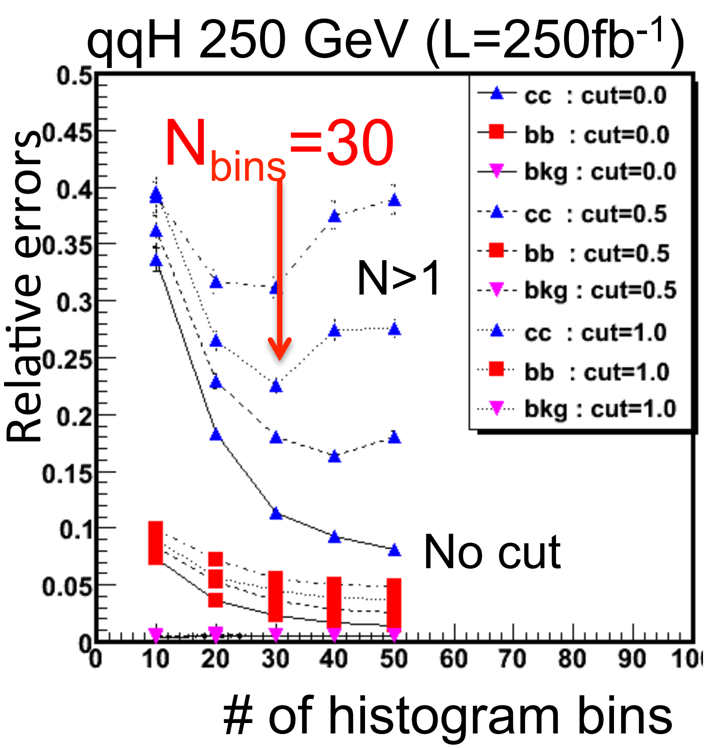
Select template bins for 250 and 350 GeV separately from the different # of events after the BG reduction

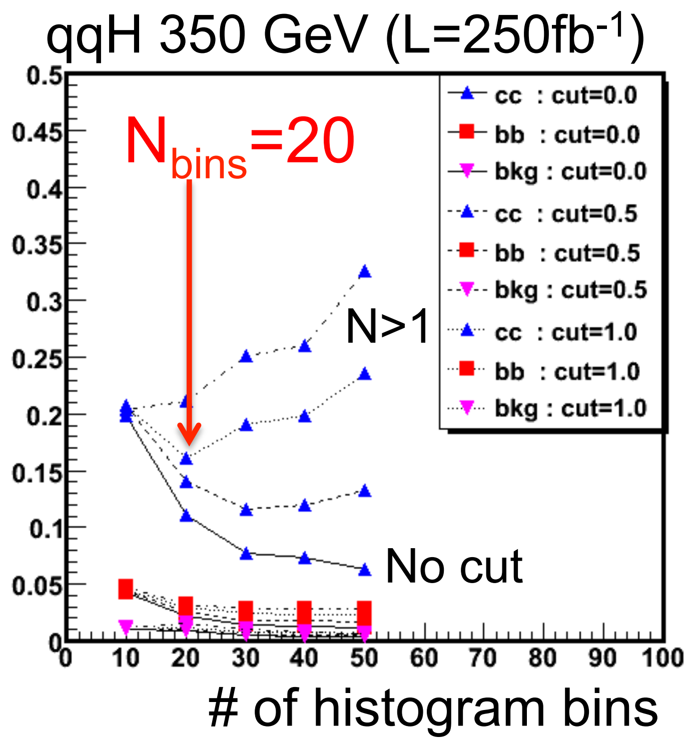
Consideration of binning dependence

Apply entries cut to reduce the small entry bin's affect

→<u>N≤1 bins are eliminated</u> for the fitting at this moment

→We determin the each template binning with <u>best accuracy point</u>





Set N_{bins} individually for 250 and 350 GeV

These cut value depends on the template sample entries.

Higgs study with different Ecm

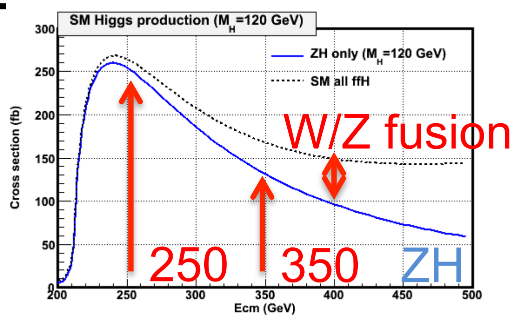
Ecm=250 GeV (ZH production threshold around 230 GeV at Mh=120 GeV)

- 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)			NB w/ TF			SB2009 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	0.8	1.0	2.0	0.27	1.0	2.0
Integrated L (fb^{-1})	188	300	500	200	250	500	67.5	250	500

Evaluate the effect of different Ecm for BR study