Higgs Branching ratio study

BAW2 meeting @SLAC

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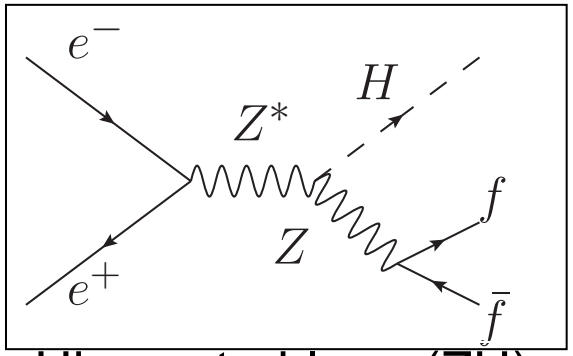
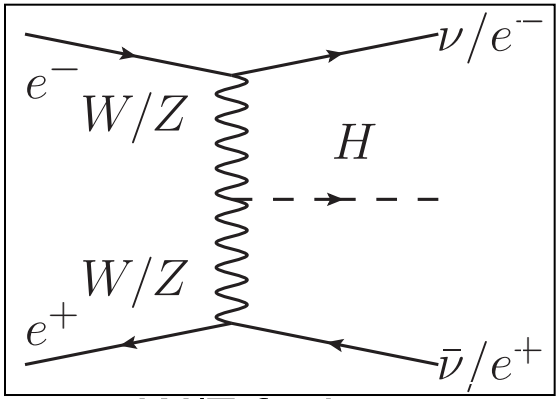
Higgs Branching Ratio measurement

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

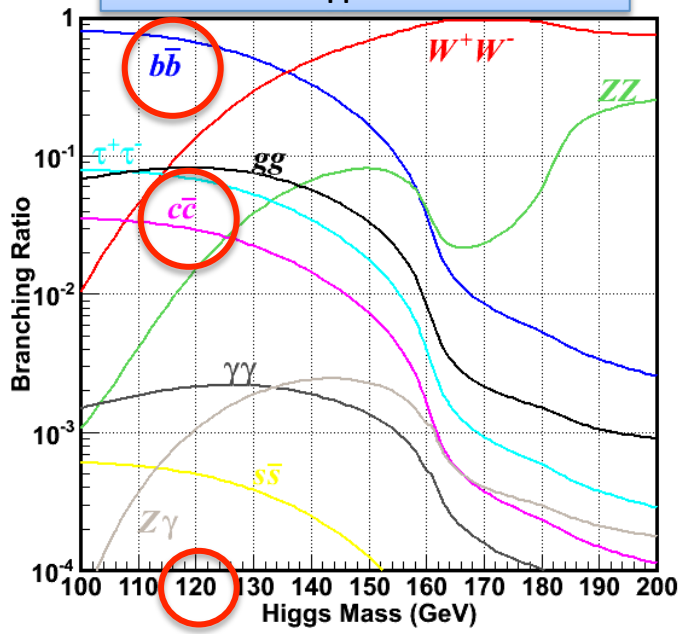


Higgs-strahlung (ZH)



W/Z fusion

BR at M_H=120 GeV



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)

Ecm=250, 350 GeV and Mh=120 GeV are assumed with full-simulation sample (350 GeV prepared in KEK)

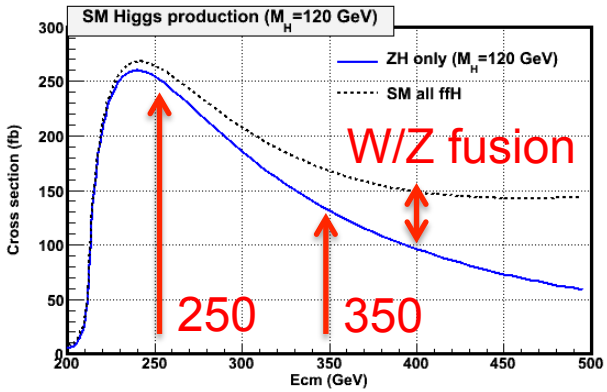
Higgs study with different Ecm

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

- Largest production cross-section with Z/H almost at rest
  - Suit 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



	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

Peak Luminosity is also changed with different Ecm
→Study the effect of different Ecm for BR study

NB : New baseline parameter
TF : beam traveling focus

ZH BR analysis procedure

Report at IWLC2010

ZH→ννH (neutrino)

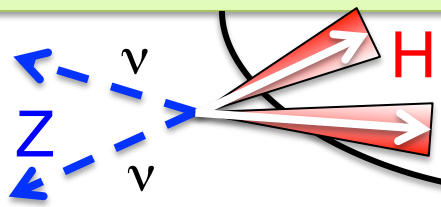
ZH→qqH (hadron)

ZH→llH (lepton)

2 jet clustering

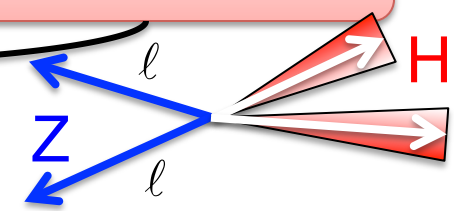
4 jet clustering

di-lepton ID



Z/H combination

2 jet clustering



Categorized with Z decay

ε_{bb}, ε_{cc}

Background reduction

r_{bb}, r_{cc}

Simple flavor cut

Template fitting

Check consistency with template fitting

Relative BR

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

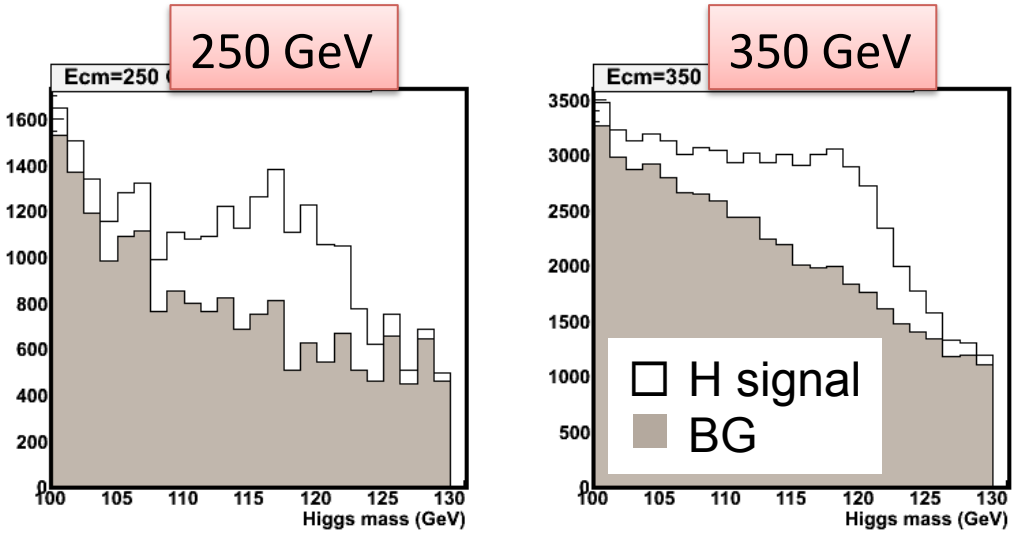
Background reduction (Compare at L=250 fb^{-1})

Neutrino (ννH) mode BG reduction

Selection criteria

1. Missing mass (Mz)
2. Transverse momentum
3. Longitudinal momentum
4. # of charged tracks
5. Maximum momentum
6. Y values (Y values threshold)
7. Di-jet mass (M_H)

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



Each cut position is optimized for 250 and 350 GeV with assuming L=250fb^{-1}

Significance	Sig. cc	Sig. bb
250 GeV	2.27(1.96)	37.14 (32.16)
350 GeV	2.66	42.16

() : L=188fb^{-1} as RDR250 scale

Missing mass cut is loose at 350 GeV from W-fusion contribution

Signal significance improve at 350 GeV

qqH mode analysis (reported at IWLC2010)

Selection criteria

1. Jet paring χ^2
2. # of charged tracks
3. Y_{34} (3→4 Jet paring Y threshold)
4. Thrust
5. Thrust angle
6. H jets angle
7. Z mass
8. H mass

Significance	Sig. cc	Sig. bb
250 GeV	1.16(1.00)	19.37 (16.77)
350 GeV	2.03	32.12

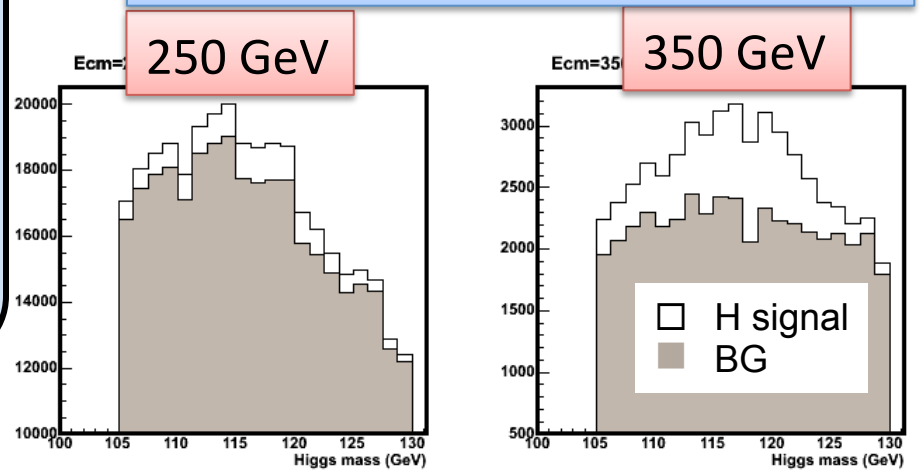
() : L=188fb^{-1} as RDR250 scale

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



Cut positions are optimized for both 250 and 350 GeV with L=250 fb^{-1}

Significance improve at 350 GeV

Lepton (eeH, μμH) mode analysis

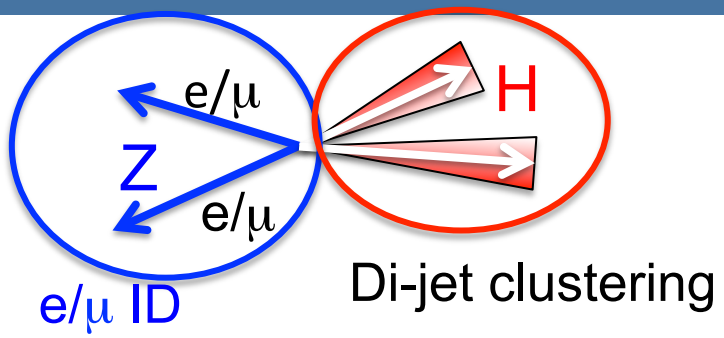
Electron/Muon identification

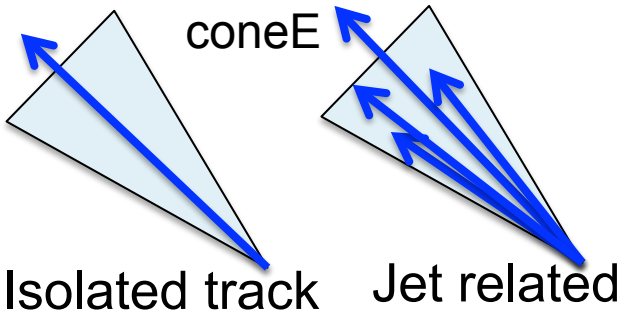
1. Lepton isolation + track energy selection
2. Calorimeter Edep information

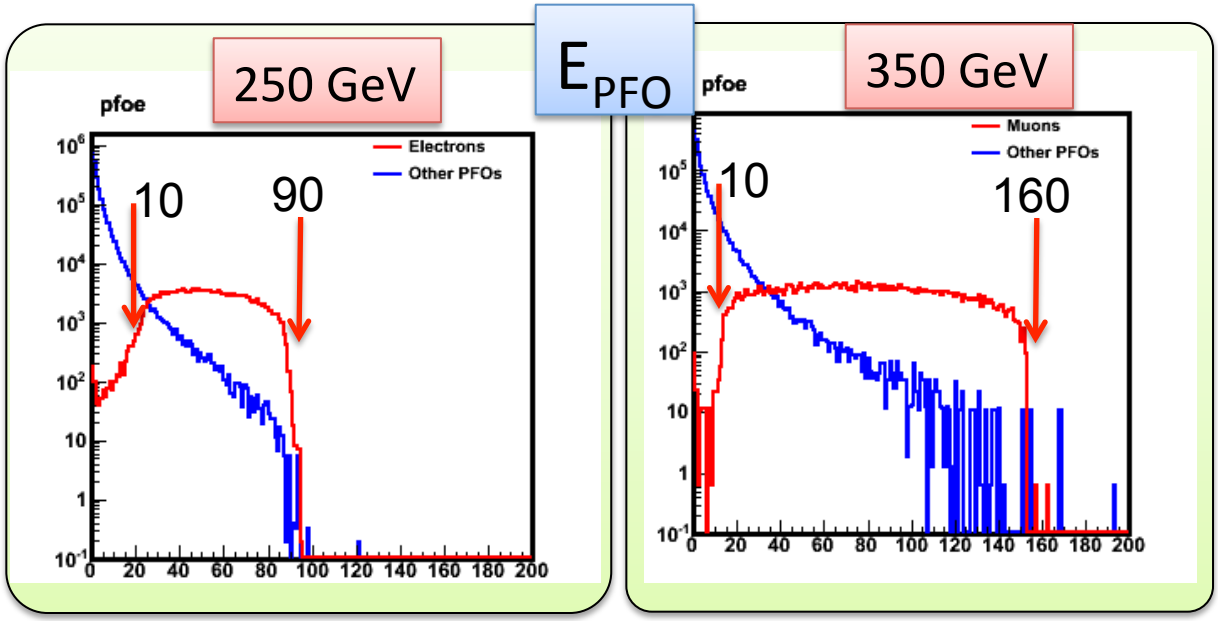
   <u>Electron deposits its most of energy at ECAL</u>

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

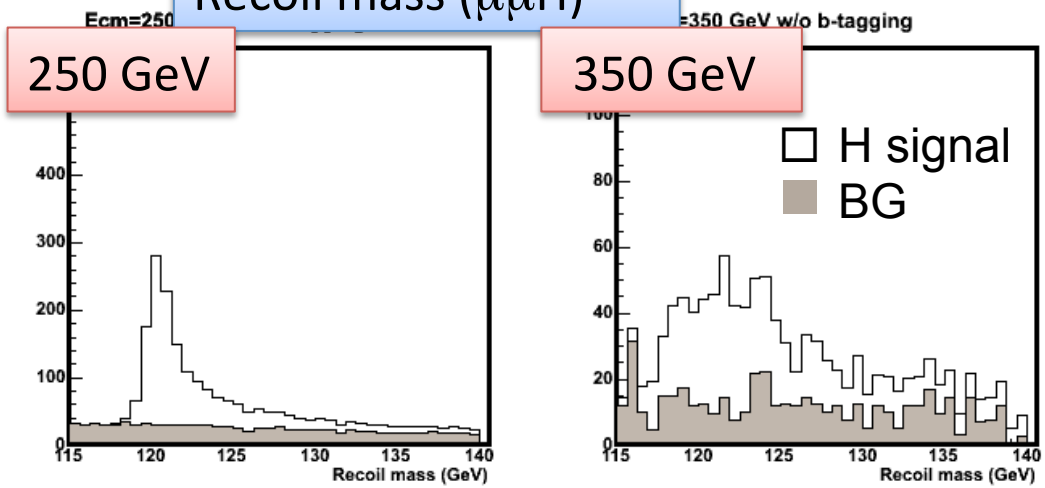
Lepton mode (llH) background reduction

BG reduction

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

Cut optimization for eeH/μμH with L=250fb^{-1}

Recoil mass (μμH)



Narrow recoil mass distribution in llH mode

Better momentum resolution at Ecm=250 GeV

Signal significance

μμH	Sig. cc	Sig. bb
250 GeV	1.95(1.69)	23.34 (20.22)
350 GeV	1.57	15.59

eeH	Sig. cc	Sig. bb
250 GeV	1.35(1.17)	17.89(15.49)
350 GeV	1.38	13.18

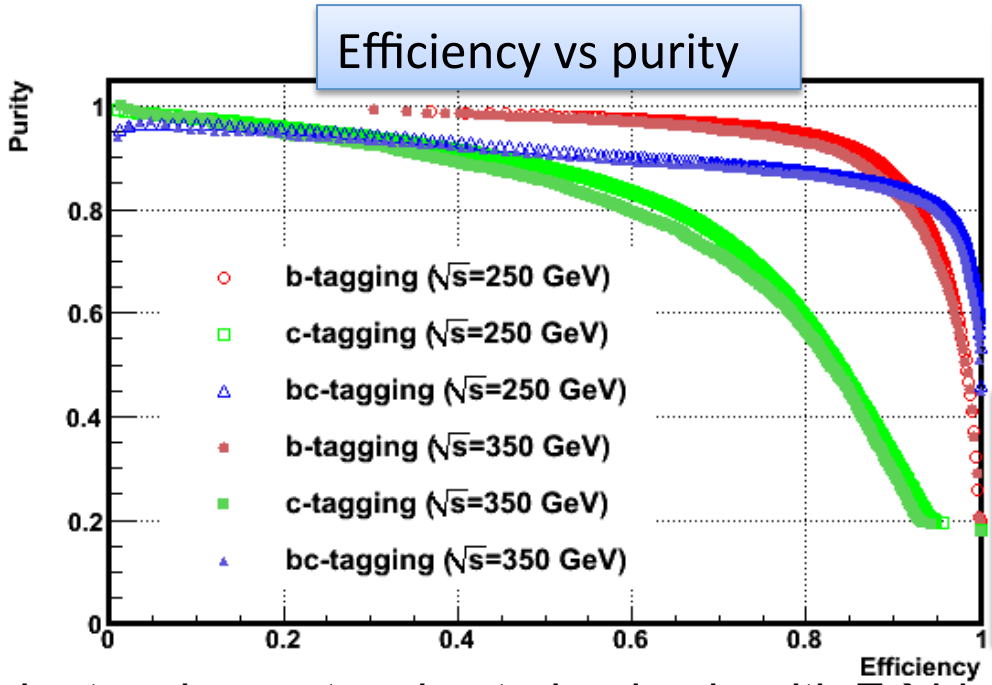
() : L=188fb^{-1} as RDR250 scale

Signal significance becomes better at 250GeV from the better recoil mass cut efficiency

Branching fraction estimation with flavor information

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)



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

Simple BR extraction

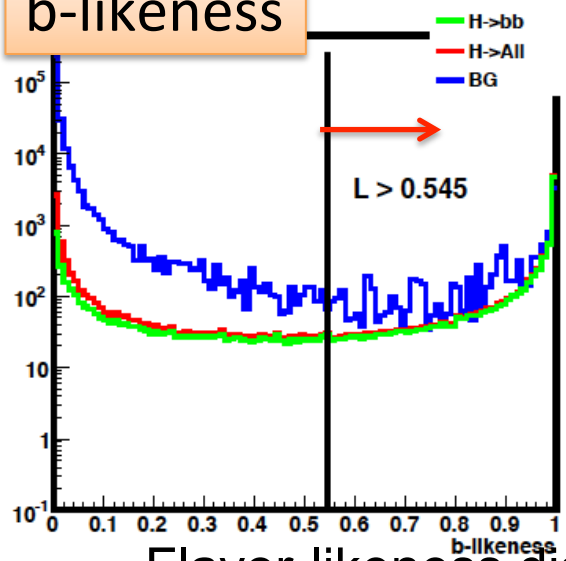
Apply flavor-likeness cut after all the BG reduction to evaluate BR measurement accuracy and consistency with template fitting

Set flavor-likeness cut position at maximizing sig. significance

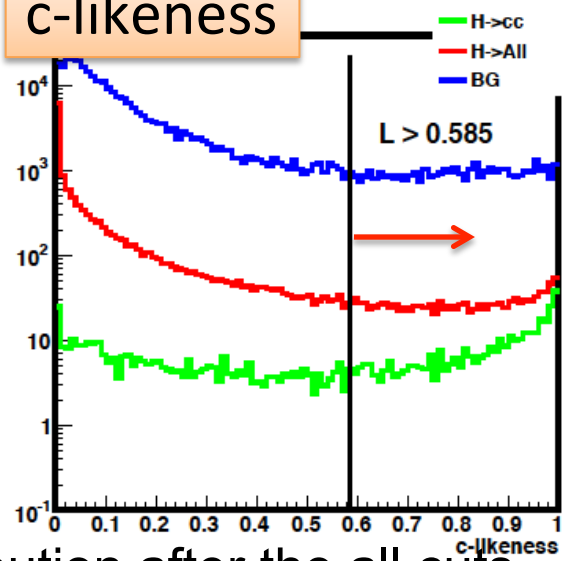
ZH→ννH (250 GeV)

$$\text{Significance} = \frac{S}{\sqrt{S+B}} = \frac{N_s}{\sqrt{N_s + N_{BG}}}$$

b-likeness



c-likeness



Flavor-likeness distribution after the all cuts

Accuracy of H→bb/cc cross-section is extracted with following equation

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

σ_s: cross-section of H→s

N_s: Number of signal

Simple flavor-likeness cut analysis

Accuracy of Relative branching fraction

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

Relative BR is dominated by H→cc accuracy

- Absolute relative errors are worse by loose cut in qqH, rely on the template fitting
- llH mode become worse from low statistics

	Ecm	Δσ/σ(bb)	Δσ/σ(cc)
Neutrino (ννH)	250	1.7%	30.9%
	350	1.3%	24.0%
Hadron (qqH)	250	1.8%	58.2%
	350	1.9%	30.6%
Muon (μμH)	250	4.1%	51.4%
	350	5.8%	56.8%
Electron (eeH)	250	3.6%	41.4%
	350	5.3%	59.2%

Measurement accuracies of H→cc are improved at 350 GeV except for lepton mode from the better significance at 250GeV (Especially by narrow recoil mass distribution)

Maximizing signal significance is a key for BR measurement

→Check this tendency with template fitting analysis case

Template fitting analysis

Relative BR with template fitting

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

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 <u>template fitting</u> as fit parameter

Poisson statistics are considered for each template sample bin

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

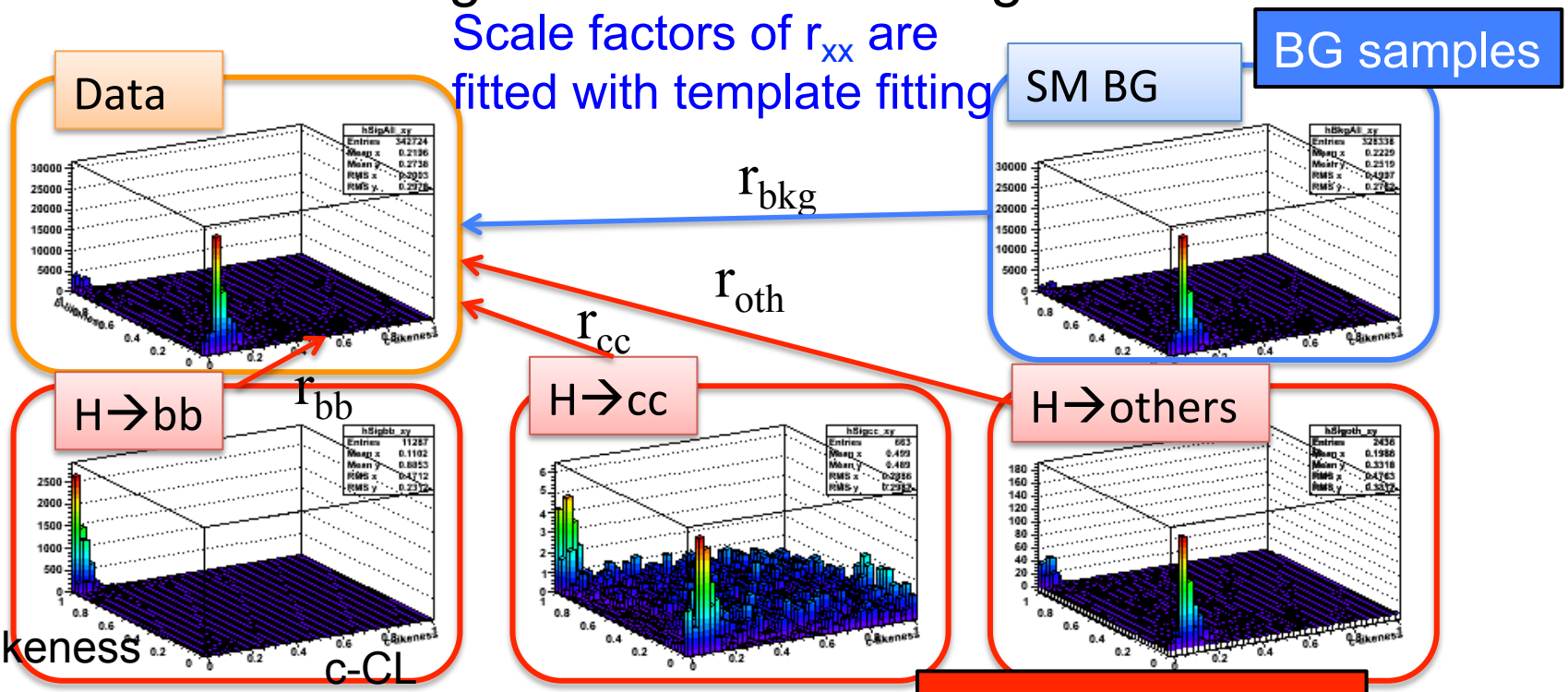
$$L = -\log P = -\log\left(\prod_{i,j,k} P_{ijk}\right) = -\sum_{i,j,k}\left(\log P_{ijk}\right)$$

Template fitting has applied with minimizing L

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

Scale factors of r_{xx} are fitted with template fitting



b/c/bc flavor likeness 3D template samples

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

Fitting results with c-likeness smoothed

From the template fitting analysis for 250 and 350 GeV, we improve the measurement accuracy and obtain the same tendency for 250 and 350 GeV with simple cut analysis

Absolute value of the accuracy of relative BR has changed from IWLC2010 because low statistics bins are ignored to suppress the over estimation

llH modes are relatively worse from the smaller entries and obtain the better accuracy again at 250 GeV ($\mu\mu$H)

- ~25% becomes better in accuracy at Ecm=350 GeV with $\nu\nu$H, qqH mode.
- Luminosity reduction makes accuracy worse ~25% as same as luminosity scaling

	Ecm	ΔBR(cc)/BR(bb)
Neutrino ($\nu\nu$H)	250	20.7%(28.9%)
	350	14.2%
Hadron (qqH)	250	23.0%(31.3%)
	350	16.4%
Muon ($\mu\mu$H)	250	39.5%(45.3%)
	350	43.9%
Electron (eeH)	250	47.5%(50.9%)
	350	37.8%
Combined	250	13.7%(18.0%)
	350	10.0%

Preliminary results

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

Statistical error only

Summary

- Obtain slightly better BR measurement accuracy at 350 GeV
  - ~25% improvement from 250 GeV with same L=250fb^{-1}
  - ~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)
- Significant difference of flavor tagging performance is not observed in $\nu\nu$qq sample comparison
- Better selection efficiency at <u>350 GeV</u> because of better mass resolution and signal separation from background
- Recoil mass resolution is much better at <u>Ecm=250 GeV</u>

Backup

vvH BG reduction summary

Ecm=250 GeV with L=250 fb^{-1} (188fb^{-1} for RDR250)

Processes	$H \to c\bar{c}$	$H \to b\bar{b}$	$\nu\bar{\nu}H$ all	SM BG
Generated	698 (523)	12904 (9678)	19360 (14343)	44827141 (33811100)
All cuts	315 (237)	5863 (4397)	6731 (5048)	19059 (14294)
Efficiency	ε_{cc} : 45.20%	ε_{bb} : 45.44%	34.77%	0.04%
$S/\sqrt{S+B}$	2.27 (1.96)	37.14 (32.16)		

Ecm=350 GeV with L=250 fb^{-1}

Processes	$H \to c\bar{c}$	$H \to bb$	$\nu\bar{\nu}H$ all	SM BG
Generated	930	17604	26307	18509500
All cuts	603	10424	12338	50947
Efficiency	ε_{cc} : 64.86%	ε_{bb} : 59.21%	46.90%	0.28%
$S/\sqrt{S+B}$	2.66	42.08		

Better signal significance is achieved at 350 GeV

qqH BG reduction summary

Ecm=250 GeV with L=250 fb^{-1} (188fb^{-1} for RDR250)

Processes	$H \to c\bar{c}$	$H \to bb$	All Higgs	SM B.G.
Generated	1916 (1437)	34963 (26222)	52507 (39380)	44827100 (33620300)
All cuts	663 (498)	11287 (8465)	14386 (10790)	328338 (246253)
Efficiency	ε_{cc} : 34.64%	ε_{bb} : 32.28%	27.40%	0.73%
$S/\sqrt{S+B}$	1.16 (1.00)	19.37 (16.77)		

Ecm=350 GeV with L=250 fb^{-1}

Processes	$H \to c\bar{c}$	$H \to bb$	All Higgs	SM BG
Generated	1296	24051	36099	18496100
All cuts	427	7245	9165	43638
Efficiency	ε_{cc} : 32.97%	ε_{bb} : 30.12%	26.82%	0.35%
$S/\sqrt{S+B}$	2.03	32.12		

μμH BG reduction summary

Ecm=250 GeV with L=250 fb^{-1} (188fb^{-1} for RDR250)

Processes	$H \to c\bar{c}$	$H \to bb$	All Higgs	SM BG
No cuts	104 (78)	1945 (1466)	2917 (2188)	4518210 (3388920)
All cuts	63 (47)	1052 (789)	1387 (1040)	980 (735)
Efficiency	ε_{cc} : 60.62%	ε_{bb} : 53.86%	47.55%	0.02%
$S/\sqrt{S+B}$	1.95(1.69)	23.34(20.22)		

Ecm=350 GeV with L=250 fb^{-1}

Processes	$H \to c\bar{c}$	$H \to b\bar{b}$	All Higgs	SM BG
No cuts	69	1186	1789	3826930
All cuts	35	479	639	465
Efficiency	ε_{cc} : 51.04%	ε_{bb} : 40.41%	35.70%	0.01%
$S/\sqrt{S+B}$	1.57	15.59		

eeH BG reduction summary

Ecm=250 GeV with L=250 fb^{-1} (188fb^{-1} for RDR250)

Processes	$H \to c\bar{c}$	$H \to b\bar{b}$	All Higgs	SM BG
No cuts	115 (87)	2088(1566)	3132(2349)	4518350(3388760)
All cuts	55 (41)	895 (671)	1179 (885)	1610 (1207)
Efficiency	ε_{cc} : 47.83%	ε_{bb} : 42.86%	37.66%	0.04%
Significance	1.35 (1.17)	17.89 (15.49)		

Ecm=350 GeV with L=250 fb^{-1}

Processes	$H \to c\bar{c}$	$H \to b\bar{b}$	All Higgs	SM BG
No cuts	99	1787	2740	3825980
All cuts	34	416	567	581
Efficiency	ε_{cc} : 34.34%	ε_{bb} : 23.30%	20.68%	0.02%
Significance	1.38	13.18		

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	0.7859	0.7860	0.7920	0.7601	0.7595	0.7502	0.7644	0.7631	0.7353
Δr_{bb}	0.0222	0.0182	0.0167	0.0465	0.0355	0.0234	0.0488	0.0408	0.0338	0.0708	0.0609	0.0426
r_{cc}	0.0469	0.0473	0.0494	0.0464	0.0457	0.0468	0.0454	0.0454	0.0539	0.0467	0.0474	0.0622
Δr_{cc}	0.0135	0.0097	0.0069	0.0143	0.0103	0.0075	0.0203	0.0178	0.0236	0.0234	0.0222	0.0233
Rel BR	0.0542	0.0546	0.0532	0.0551	0.0542	0.0540	0.0531	0.0531	0.0569	0.0548	0.0557	0.0574
ΔRel BR	0.0156	0.0113	0.0076	0.0173	0.0125	0.0088	0.0240	0.0210	0.0250	0.0279	0.0265	0.0217
resol (%)	28.9%	20.7%	14.2%	31.3%	23.0%	16.4%	45.3%	39.5%	43.9%	50.9%	47.5%	37.8%
εbb	0.4544	0.4544	0.5921	0.3228	0.3228	0.3012	0.5386	0.5386	0.4041	0.4286	0.4286	0.2330
εcc	0.4520	0.4520	0.6486	0.3464	0.3464	0.3297	0.6062	0.6062	0.5104	0.4783	0.4783	0.3434