Branching ratio study of ZH→qqcc/bb

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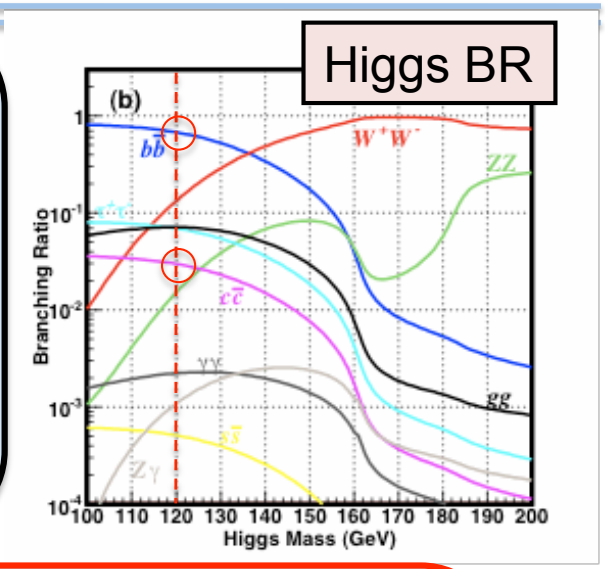
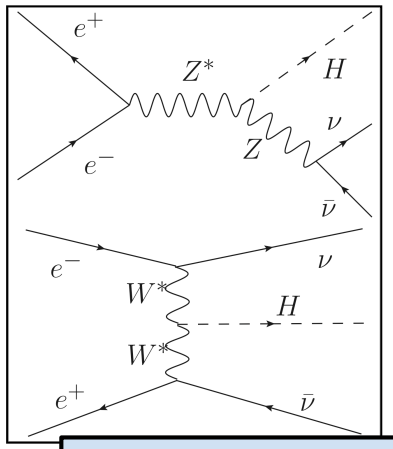
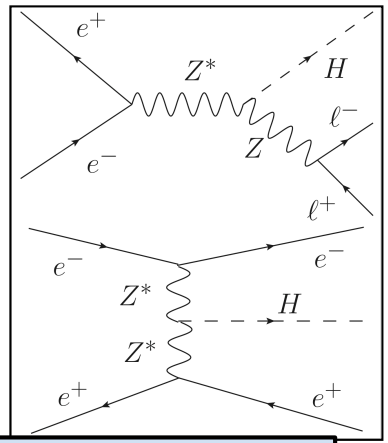
ZH branching ratio (BR) study

Higgs property measurement is one of the important issue for the ILC.
Higgs branching ratio relates to the mass generation mechanism

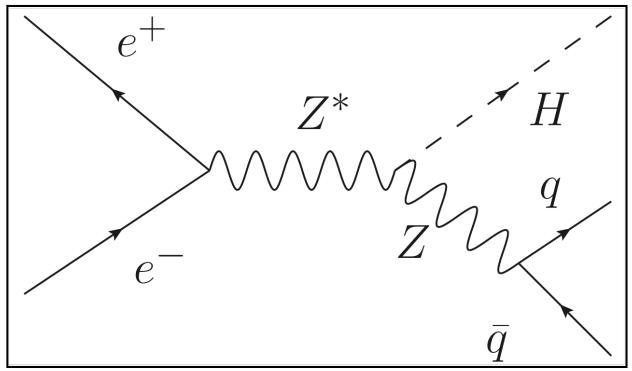
$$\mathrm{BR}(H\to cc)/\mathrm{BR}(H\to bb)=m_c^2/m_b^2$$







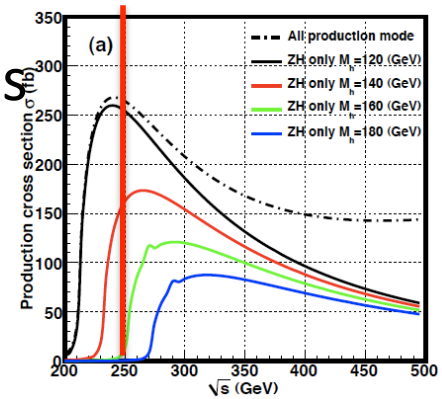
ZH→ννH,ℓℓH (Yoshida)



ZH→qqH (Ono)

Simulation data samples

- Analysis framework : ilcsoft
  - Detector simulation : Mokka (ILD_00 model)
  - Reconstruction, jet clustering : Marline
  - DST samples prepared for LOI benchmark analysis



Signal

ZH→qqH (Mh=120GeV, Ecm=250 GeV)

(Premixed samples : qqH, ννH, ℓℓH, 320fb)

Background

main backgrounds are WW/ZZ→4f, 2f

SM background

qqqq, vvqq, vℓqq, ℓℓqq, ℓℓℓℓ, qq, gg

Each sample is scaled to be $\mathcal{L}$=250fb^{-1} with (e^+,e^-)=(+30%, -80%) beam polarization

ZH→qqH analysis procedure

Forced four jet clustering

Jet clustering

Jet et pair combination with min. d

$d=(M_{ij}-M_H)^2+(M_{kl}-M_Z)^2$

Best H/Z candidate

Background reduction

Efficiency ε_{bb}, ε_{cc}

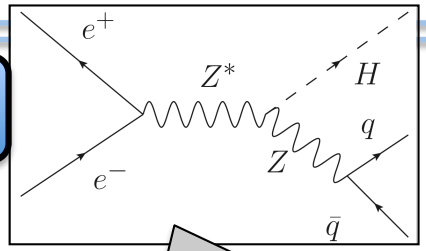
Template fitting

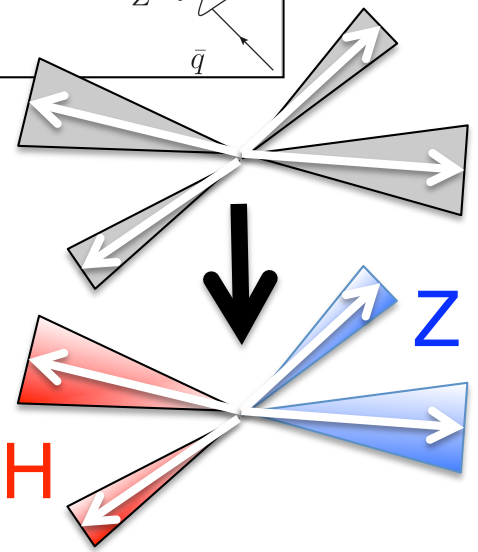
b/c/bc flavor-likeness templates

r_{bb}, r_{cc}

Estimate branching ratio fraction

$$\frac{BR(H \to cc)}{BR(H \to bb)}$$





Same procedure of SiD analysis is applied before the template fitting

Event selections
and Background reduction

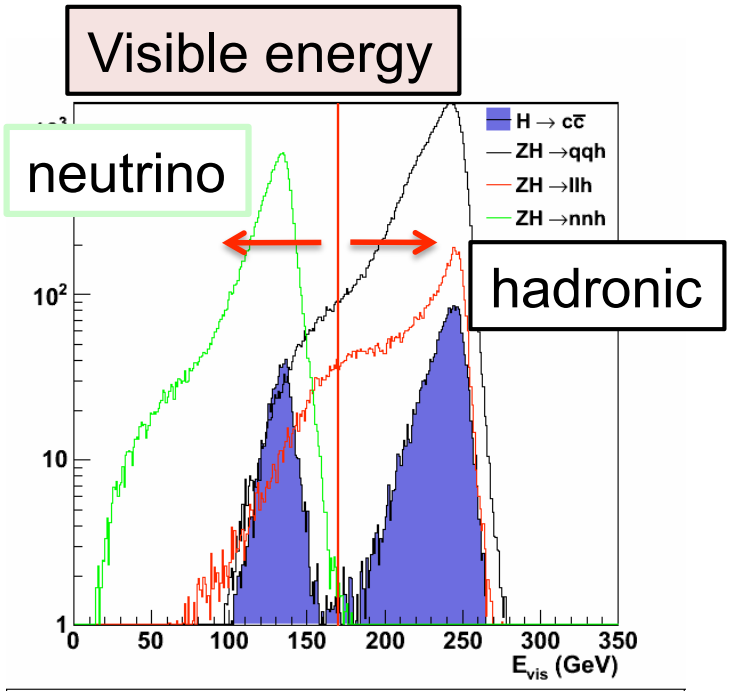
Event selections

After selecting the best candidates of Z/H from minimum d combination, following event selections are applied

$d=(M_{ij}-M_H)^2+(M_{kl}-M_Z)^2$

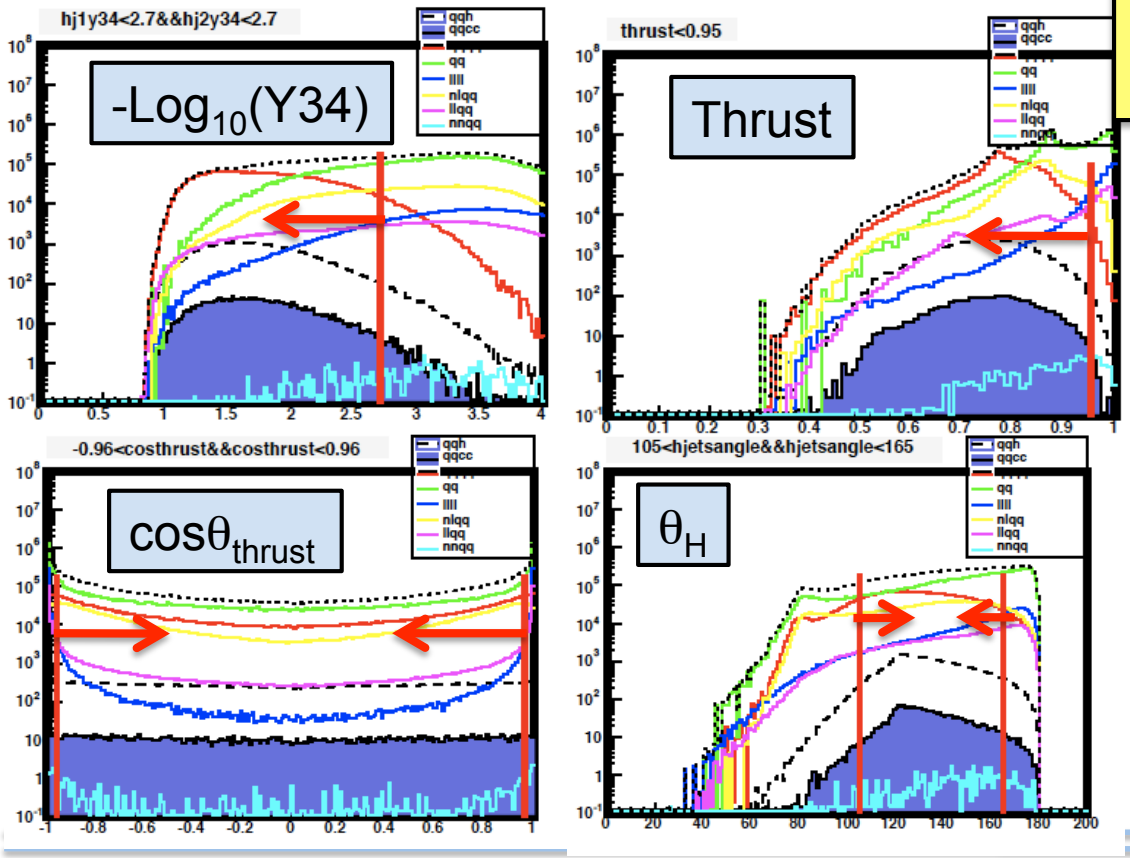
0. Classification (E_{vis} > 170 GeV + No high P leptons(>15GeV))
   →Select the ZH→qqH events from pre-mixed samples

1. # of charged track in each jet > 4
2. -log10(Y34) < 2.7
   3→4 Jet combination threshold Y value
3. thrust < 0.95
4. $|\cos\theta_{thrust}|<0.96$
5. $105 < \theta_{Hjets} < 165^o$ (Angles between H jets)
6. $70 < \theta_{Zjets} < 160^o$ (Angles between Z jets)
7. $110 < M_{Hfit} < 140$ GeV
8. $80 < M_{Zfit} < 110$ GeV
9. E_γ<20 GeV in each jet (Highest photon E cut)



Event topology cuts

Remove leptonic and two-jet like background with event shape



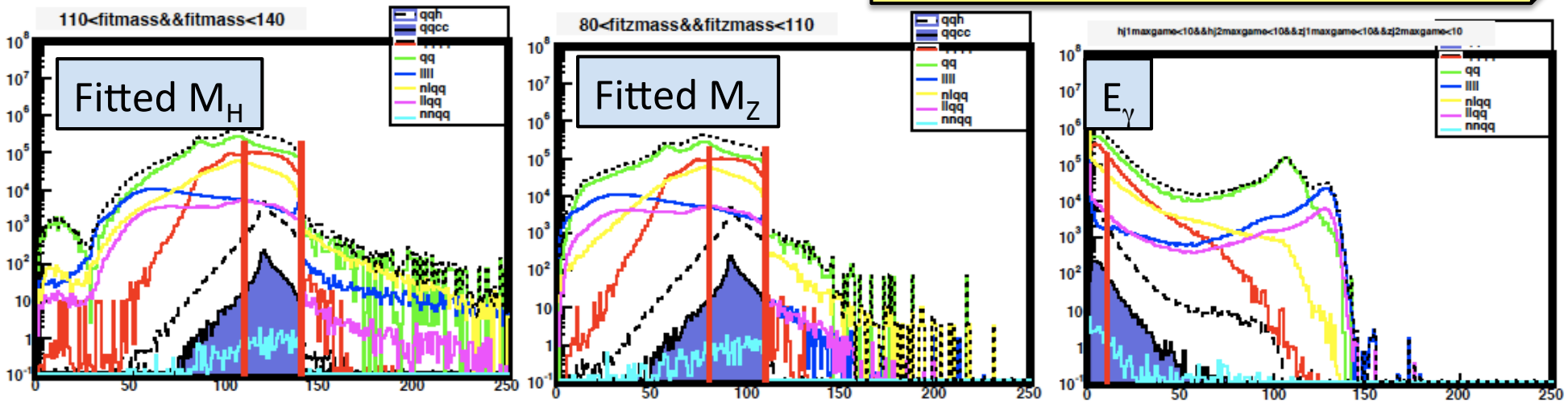
Remove lepton events (N_{tchdrk})
Jet clustering topology (Y34)
Remove back to back event (thrust, jets angle)

- N_{chdtrk} in jet > 4
- -log10(Y34) < 2.7
- thrust < 0.95
- $|\cos\theta_{thrust}|$<0.96
- 105 < θ_{Hjets} < 165°
- 70 < θ_{Zjets} < 160°

Mass distribution and γ energy cuts

Kinematic constraint fit has applied for better B.G. reduction with H/Z mass distribution

Kinematical 5C fit for four jets
- $\Sigma E_j = 250$ GeV
- $\Sigma P_j = 0$
- $M_{ij} - M_{kl} = M_H - M_Z$



- $110 < M_{Hfit} < 140$ GeV
- $80 < M_{Zfit} < 110$ GeV

- $E_\gamma < 20$ GeV in each jet (remove hard photons)

Background reduction summary

	H→cc	H→bb	Higgs BG	SM Bkg
No cuts (ZH mixed samples)	2914	53480	23447	53333000
After classification (Evis>170&&nLeptons=0)	1693	29075	9198	20528900
(1) charged track>4 (jet)	1238	22204	5721	3323060
(2) -log10(Y34) < 2.7	1218	21869	5694	2635920
(3) thrust < 0.95	1217	21858	5693	2584510
(4) $\lvert\cos\theta_{thrust}\rvert < 0.96$	1157	20831	5427	2295690
(5) $105^o < \theta_{Hj} < 165^o$	1080	19393	4941	1908300
(6) $70^o < \theta_{Zj} < 160^o$	1028	18490	4705	1776150
(7) $110 < M_{Hfit} < 140$ GeV	982	17666	4411	1209100
(8) $80 < M_{Zfit} < 110$ GeV	982	17665	4409	1206570
(9) Eγ<20 GeV (jets)	895	16288	4063	1036990
Cut efficiency after classification	52.9%(ε_{bb})	56.0%(ε_{cc})	44.0%	5.0%

Template fitting
and estimate relative BR

Template fitting for BR estimation

Background reduction

Cut efficiencies ε_{bb}, ε_{cc}

Template fitting

$r_{bb/cc}=N_{bb/cc}/N_{ZH}$ after B.G. reduction

r_{bb}, r_{cc}

b/c/bc flavor-likeness templates

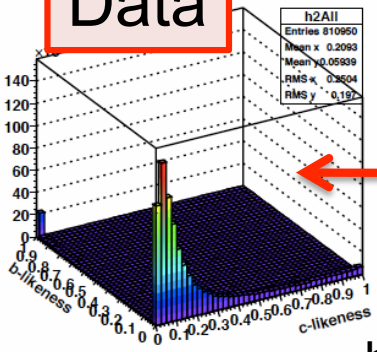
$$x-likeness=\frac{x_1x_2}{x_1x_2+(1-x_1)(1-x_2)}$$

$x_{1,2}$: b/c/bc tagging LCFIVTX NN output

Estimate branching ratio fraction

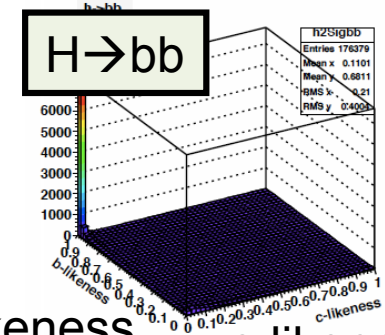
$$\frac{\mathrm{BR}(H\to cc)}{\mathrm{BR}(H\to bb)}=\frac{r_{cc}/\varepsilon_{cc}}{r_{bb}/\varepsilon_{bb}}$$

Data

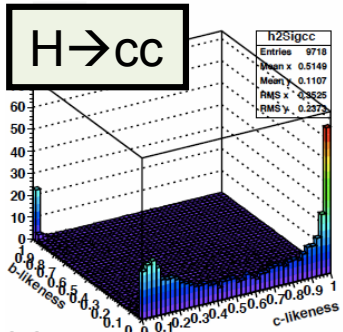


Template samples fraction for fitting data : $r_{bb/cc}$

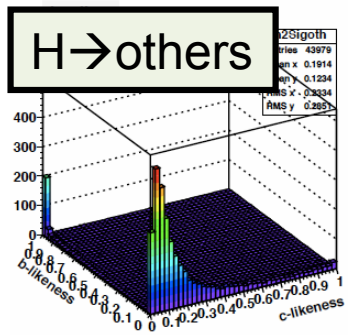
H→bb



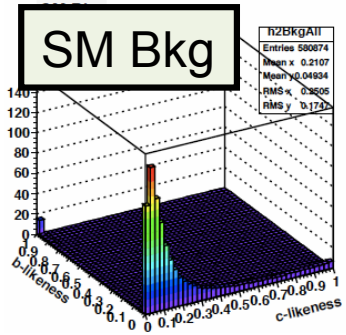
H→cc



H→others



SM Bkg



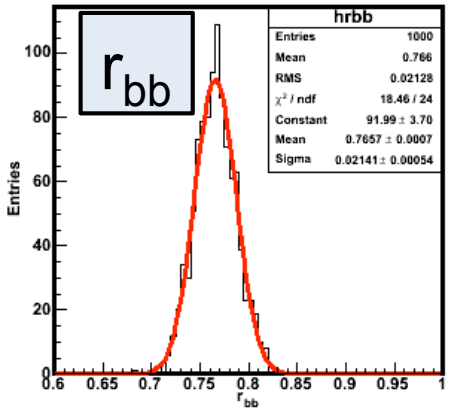
2D image of the 3D template samples

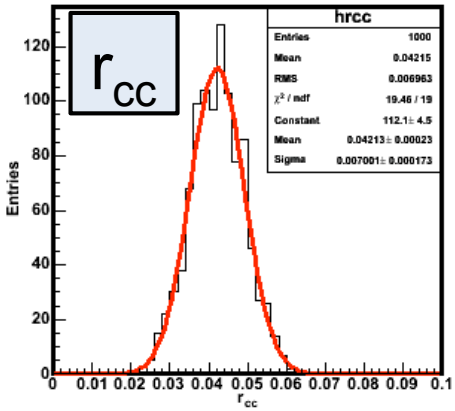
Template fitting toy MC

Template fitting Toy MC is applied for 1,000 times
with minimizing following χ^2 and estimate the $r_{bb/cc}$ by fitting

$$\chi^2 = \sum_{i=1}^{n_b}\sum_{j=1}^{n_c}\sum_{k=1}^{n_{bc}} \left(\frac{N_{ijk}^{data} - \sum_{s=bb/cc/others} r_s \left(\frac{N^{ZH}}{N^s}\right) N_{ijk}^s - r_{bkg} N_{ijk}^{bkg}}{\sigma_{N_{ijk}^{all}}} \right)^2$$

sample nBins : 40x40x40
MC : 1000 times





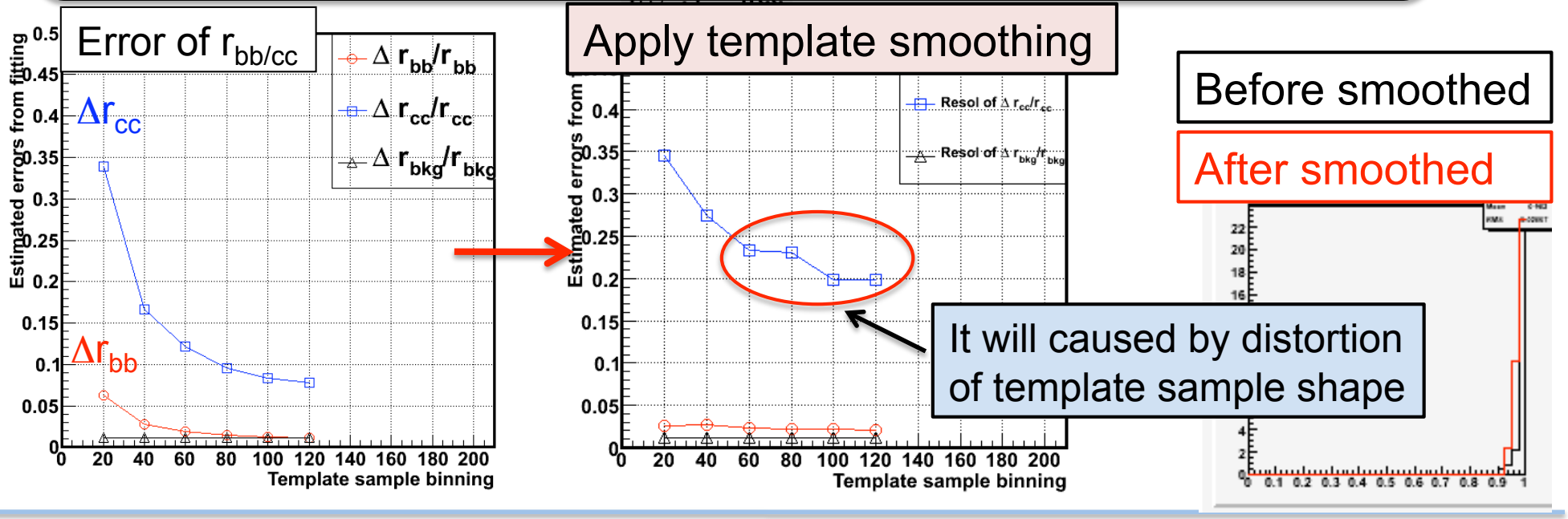
	r_{bkg} (free)	r_{bkg}=1
r_{bb} (true)	0.766±0.02 (0.767)	0.767±0.01
r_{cc} (true)	0.0421±0.007 (0.0422)	0.0421±0.007

Fitting procedure can reproduce the true $r_{bb/cc}$ values
and no influence is found from the r_{bkg} parameter

Template binning dependence

Because of the low statistics of template samples, template fitting has some binning dependence

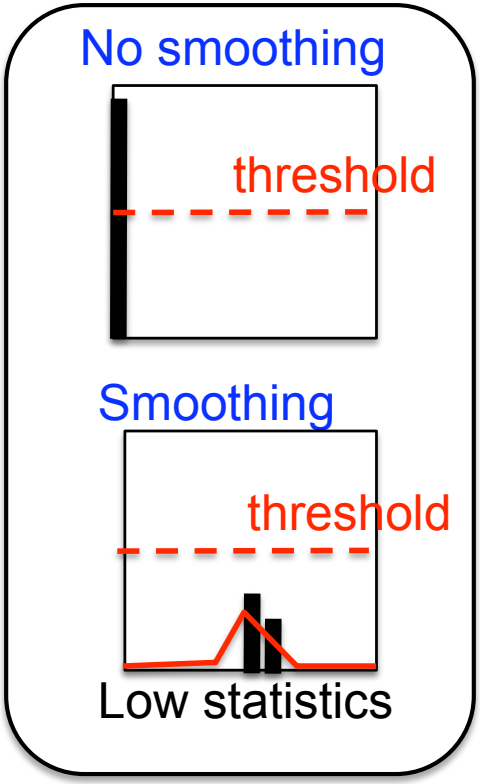
Consider the template smoothing to reduce the template binning dependence



Smoothing threshold optimization

- Sample shape distortion will appear if smoothing is applied for sharp peak shape sample
  →the error of $r_{bb/cc}$ increase by smoothing

- Set threshold to smooth or not smooth for the histogram with its # of entries in bin

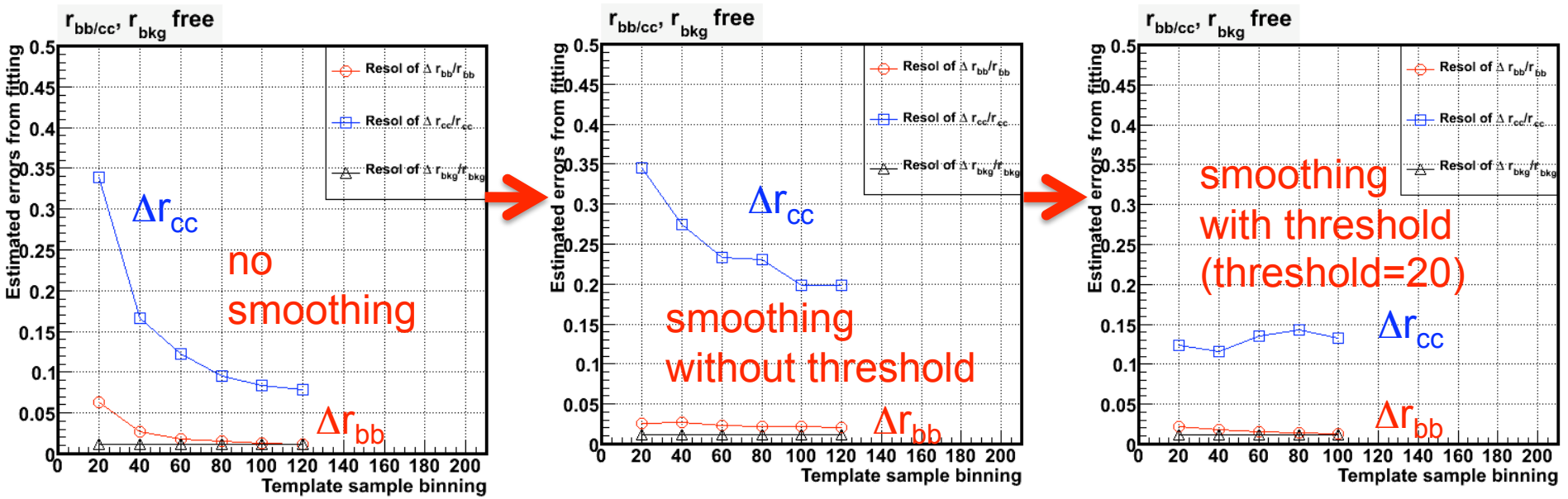


Entries < threshold : Apply smoothing
Entries >= threshold : Not apply smoothing

bc-likeness with
(i,j) b/c likeness using
TH1D::Smooth() in ROOT

Smoothing applied with threshold

Template samples smoothing is applied with threshold

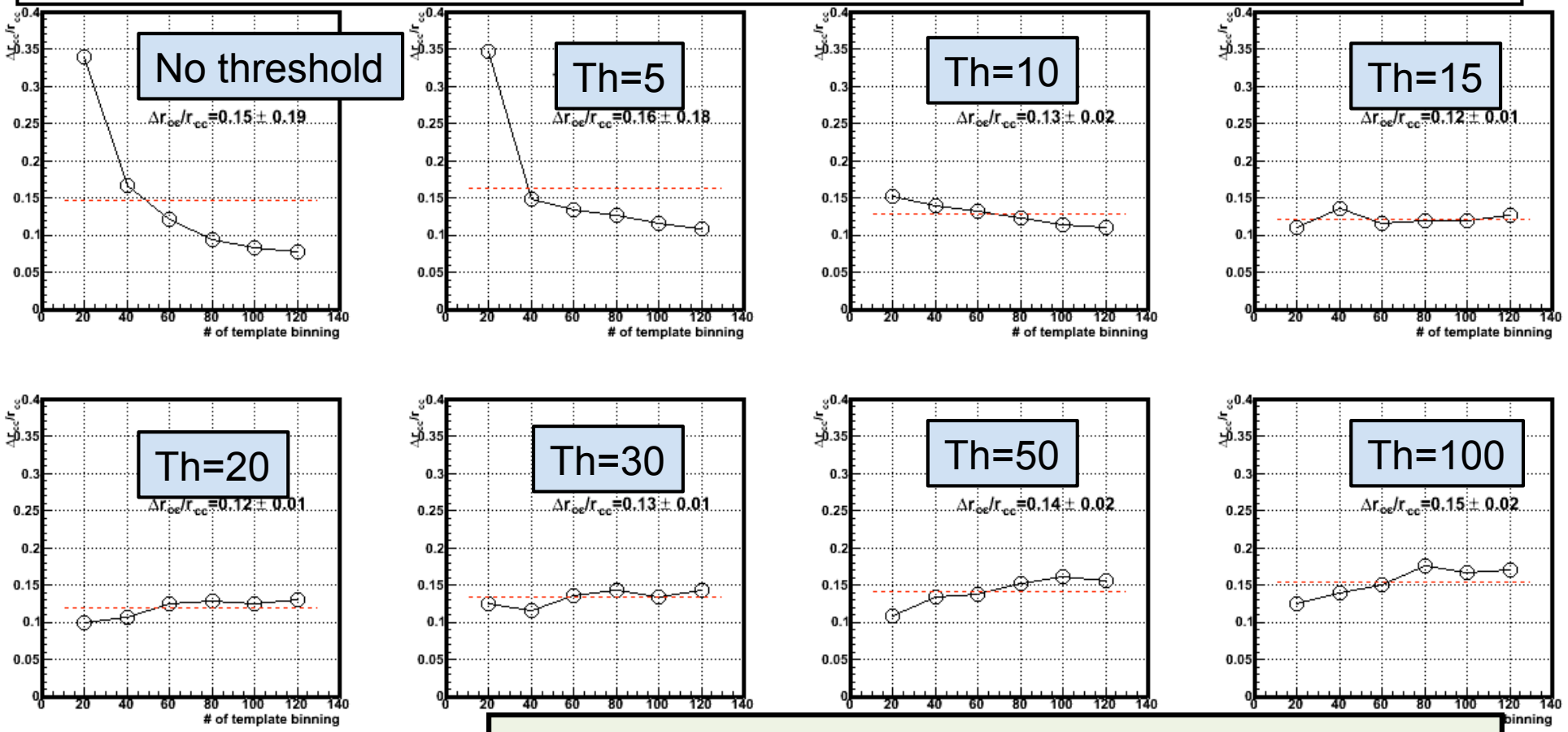


Binning dependence can be decreased with applying smoothing with threshold

Optimize the threshold value to minimize binning dependence

Deviation by template sample binning

Check deviation after smoothing with several threshold for several binning

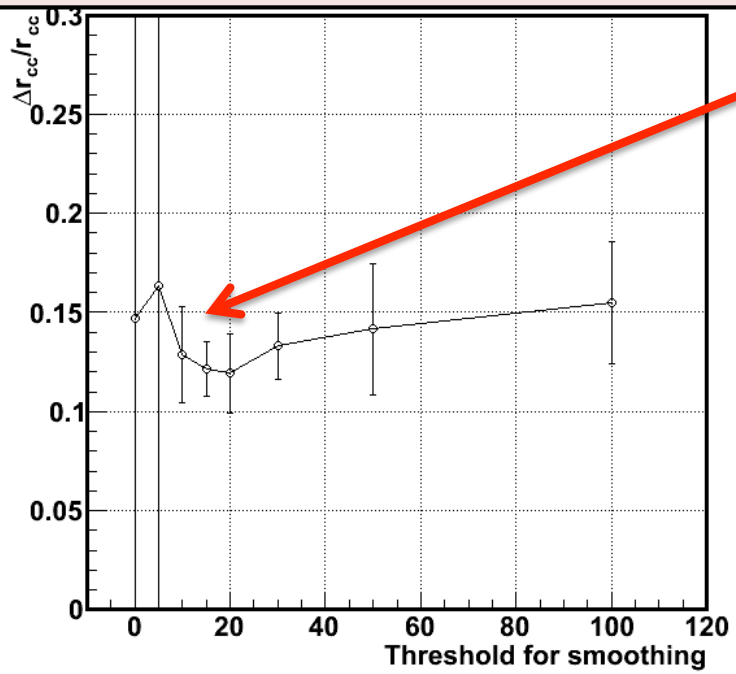


Minimum binning deviation threshold is searched

Threshold optimization result

Smallest fluctuation threshold is estimated by threshold scan

Δr_{cc} from template sample binning with smoothing + threshold



Minimum fluctuation at smoothing threshold = 15

ΔBR(cc)=1.4% (sys)

Accuracy of relative branching ratio

ΔBR(H→cc)/BR(H→bb) = 12.0 % with 1.4% binning dependence systematic

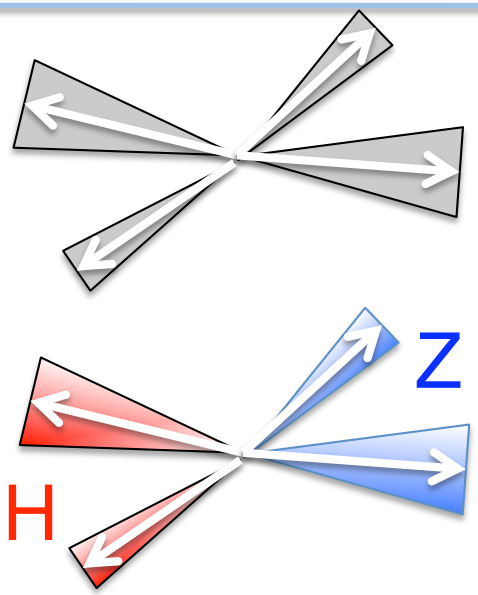
Summary and future

- ZH relative BR is studied with template fitting
- Template sample binning systematic uncertainty is evaluated with smoothing + threshold optimization
  - Br(H→cc)/Br(H→bb)=12.0 % (Stat.)
  - 1.4% systematic uncertainty is estimated for Th=15
- Now considering better evaluation way without smoothing+threshold

BACKUP

Jet pair combination

- Jet pair combination
  - Durham based jet clustering in Marline
  - Forced four jet clustering



Two jet invariant mass should be consistent with M_Z and the other two jet should be consist with M_H

$$d=(M_{ij}-M_H)^2+(M_{kl}-M_Z)^2$$

Minimum d combination is selected as best ZH candidate

0. Classification (E_{vis} > 170 GeV + No high P leptons(>15GeV))
   →Select the ZH→qqH events from pre-mixed samples

Threshold optimization result

Smallest fluctuation threshold is estimated by threshold scan