Branching ratio study in ZH→qqcc/bb

ILD optimization meeting

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Status of ZH study

- Higgs branching ratio measurement is one of the bench mark process in LOI analysis.
- SiD, ILD update their results from the LOI in ALCPG09.

Br(H→cc) measurement	SiD $\Delta\sigma_{Hcc}$	ILD Br(H→bb)/Br(H→cc)
ννH (neutrino)	10.3→11.6%	13.8% (Yoshida)
qqH (hadronic)	5.8→8.8%	30%→16% (Ono)
llH (leptonic)		28%→20.8% (Yoshida)

Discrepancy between SiD and ILD are still large in hadronic mode, now investigate this reason

SiD ZH analysis note : arXiv:0909.1052v2 [hep-ph]

ZH→qqH (hadronic mode)

- ILD and SiD analysis result has large discrepancy

Use same analysis procedure with SiD to confirm difference

Use premixed ZH sample (qq/ll/νν H)

Four jets

Select best jet pair combination

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

Z/H candidates and kinematic fit

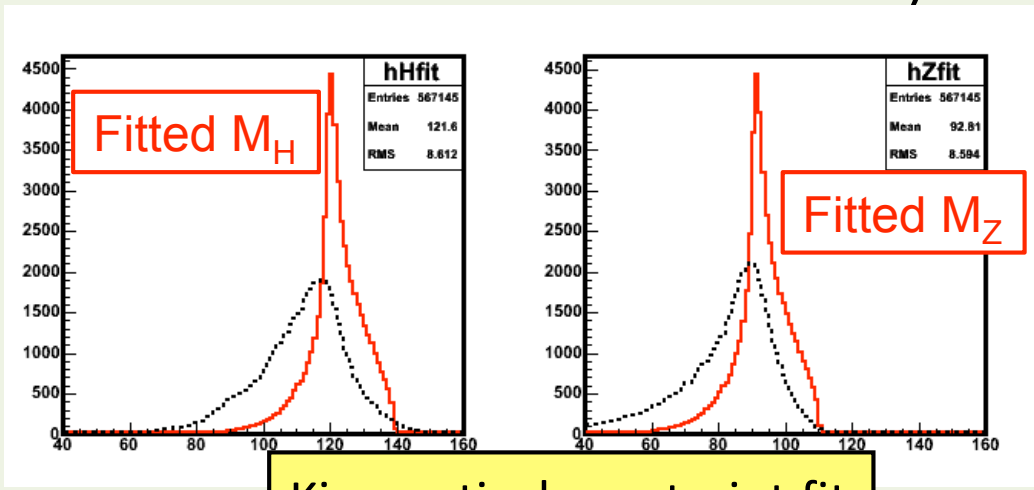
Background reduction

Check the event reconstruction consistency with SiD
(Background samples are not same as SiD analysis)

Event selections (same as SiD)

Classification (E_{vis} > 170 GeV + No high P leptons(>15GeV))

1. # of charged track in each jet > 4
2. -log10(Y34) < 2.7 (3→4 Jet combination threshold of Y value)
3. thrust < 0.95
4. $|\cos\theta_{thrust}|<0.96$
5. $105 < \theta_{Hjets} < 165$
6. $70 < \theta_{Zjets} < 160$
7. $110 < M_{Hfit} < 140$ GeV
8. $80 < M_{Zfit} < 110$ GeV
9. $E\gamma<10$ GeV in each jet



Kinematical constraint fit
- $\Sigma E=250$ GeV
- $\Sigma P=0$
- $M_{ij}-M_{kl}=M_H-M_Z$

There is a mistake in ordering of the reduction summary table in SiD analysis note, corrected version has received and compare the reduction efficiency

Compare the reduction summary

SiD
ono

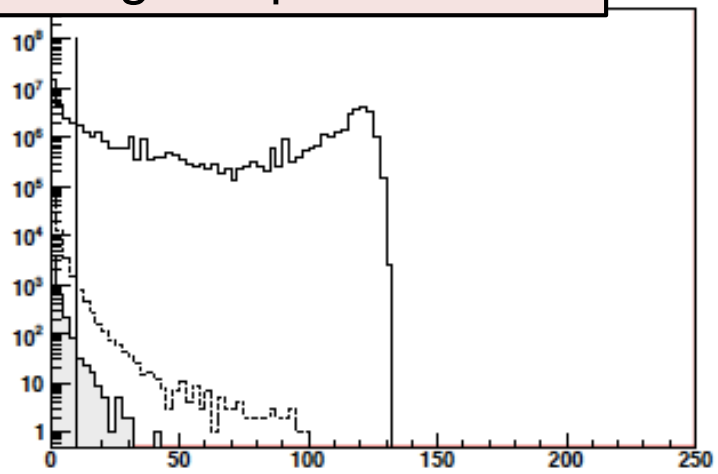
	H→cc (qqcc)	H→cc (ono)	ZH BG (qqH)	ZH BG (ono)	SM Bkg	SM Bkg (ono)
No cuts	2869 (1931)	2914	76910 (51513)	76927	9275594683	4376090000
After classification (Evis>170&&nLeptons=0)	1837	1693	41016	38273	39398366	2410080000
(1) charged track>4 (jet)	1143	1238	30125	27925	18601753	3323060
(2) -log10(Y34) < 2.7	1101	1218	29478	27563	13921271	2635920
(3) thrust < 0.95	1047	1217	27065	27551	8737017	2584510
(4) $\lvert\cos\theta_{thrust}\rvert$ < 0.96	1017	1157	26322	26258	7943851	2295690
(5) 105 < θ_{Hj} < 165 (hjet)	979	1080	26001	24334	5871237	1908300
(6) 70 < θ_{Zj} < 160 (Zjet)	978	1028	25687	23195	4898312	1776150
(7) 110 < M_{Hfit}< 140 GeV	966	982	22533	22076	1917231	1209100
(8) 80 < M_{Zfit}< 110 GeV	963	982	21877	22074	1561432	1206570
(9) Eγ<10 GeV (jets)	947	515	15687	12601	967312	570479

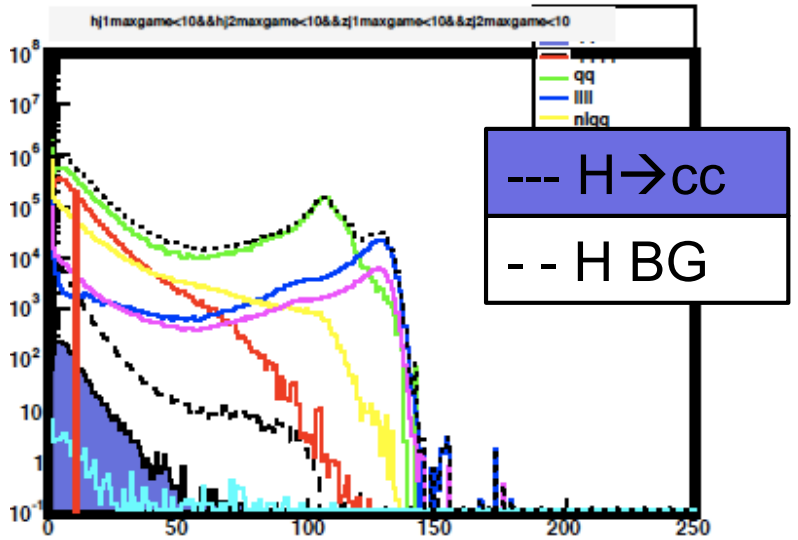
Highest photon reduction looks large discrepancy and reduce efficiency

Highest photon energy distribution

Highest photon energy in each jet
(Signal jet should not have high E photon, reduce ISR photons, hard photons)

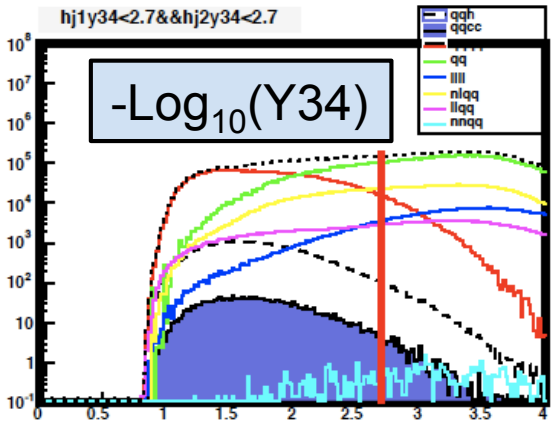
SiD highest photon E cut

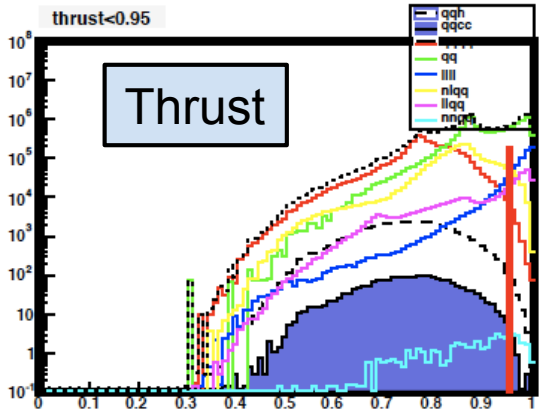


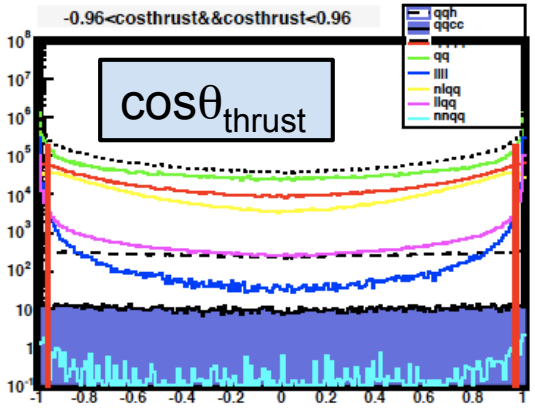


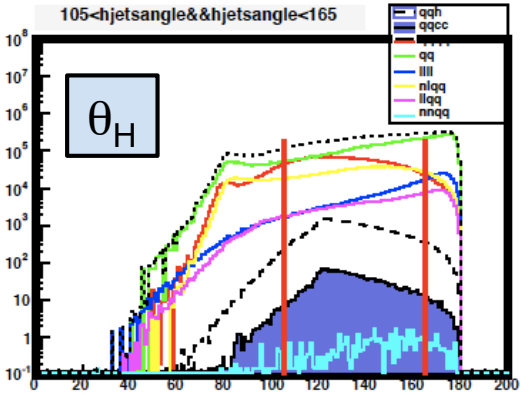
Highest photon energy cut looks large discrepancy and reduce efficiency
That is caused by the different distribution of this cut.

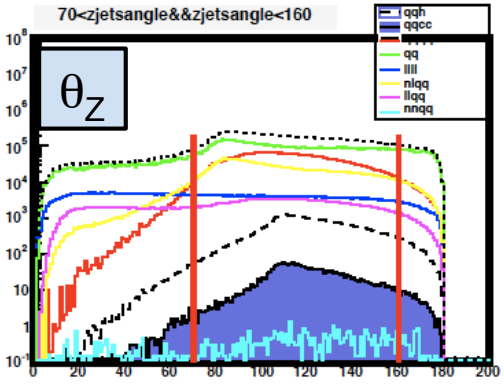
I contact to SiD person, but the selection seems to be same.

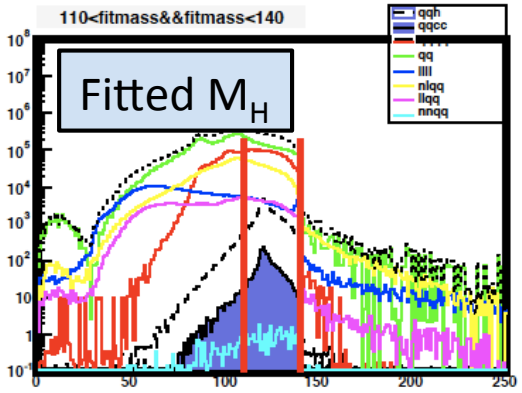


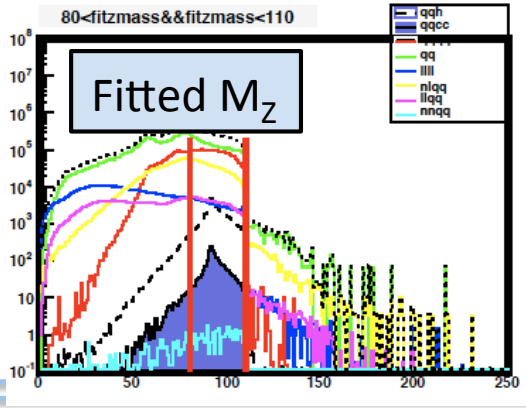












Other distribution looks consistent with SiD

↓

Only change photon E cut to be looser

Loose highest photon energy cut

SiD
ono

	H→cc (qqcc)	H→cc (ono)	ZH BG (qqH)	ZH BG (ono)	SM Bkg	SM Bkg (ono)
No cuts	2869 (1931)	2914	76910 (51513)	76927	9275594683	4376090000
After classification (Evis>170&&nLeptons=0)	1837	1693	41016	38273	39398366	2410080000
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(9) Eγ<20 GeV (jets)	947	895	15687	20351	967312	1036990

Signal looks almost consistent with SiD, SM BG should be considered.

Template fitting and Branching ratio measurement

Branching ratio measurement

- Observable of Branching ratio is

$$Br(H \to xx)_{meas} = r_{xx} \times Br(H \to xx)_{SM} \times \frac{\sigma(ZH)_{SM}}{\sigma(ZH)_{meas}}$$

- Relative branching ratio is estimated to be

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

- Efficiency $\varepsilon_{bb/cc}$ are evaluated from the BG reduction summary

Efficiency	ε_{bb}	ε_{cc}
ZH→qqH	0.560	0.529

- $r_{bb/cc}$ are evaluated from the ratio of $N^{bb/cc}/N^{ZH}$ (Ratio of H→bb/cc to ZH→qqH after all cuts)
- r_{bb} and r_{cc} are evaluated from the **template fitting**

3D template samples of b/c/bc-likenss and template fitting

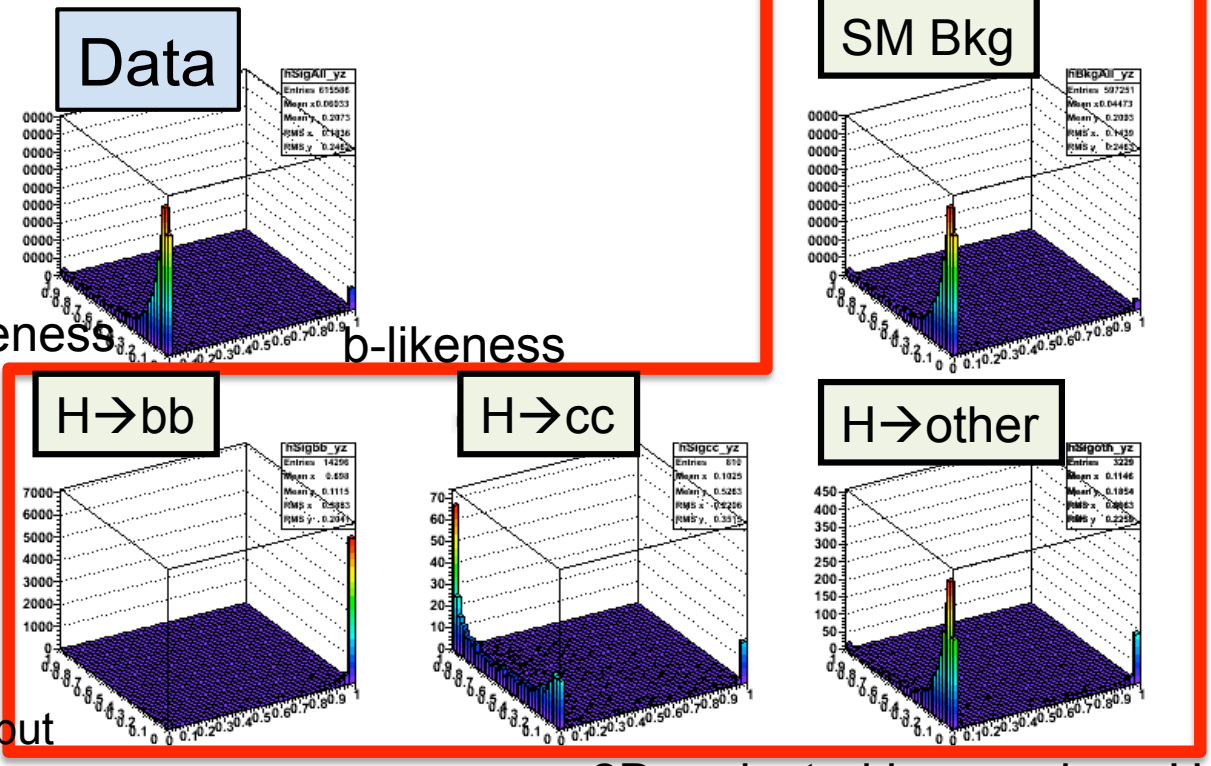
$$\chi^2 = \sum_{i=1}^{n_b}\sum_{j=1}^{n_c}\sum_{k=1}^{n_{bc}} \frac{\left(N_{ijk}^{data} - \sum_{s=bb/cc/others} r_s \left(\frac{N^{ZH}}{N^s}\right) N_{ijk}^s - r_{bkg} N_{ijk}^{bkg} \right)^2}{N_{ijk}^{data}}$$

$r_{others} = 1 - r_{bb} - r_{cc}$

r_{bkg} = *free or fixed (=1)*

Template fitting is applied with minimizing χ^2 to estimate the $r_{bb/cc}$

Template samples



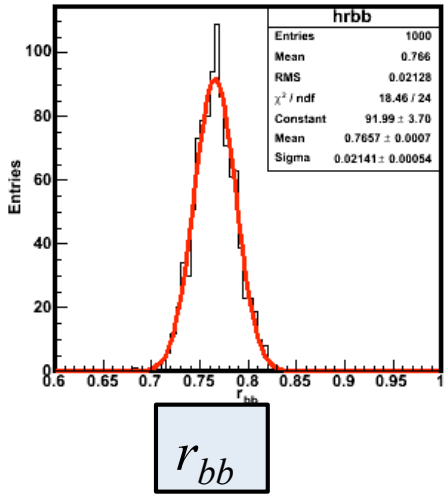
2D projected images in qqH

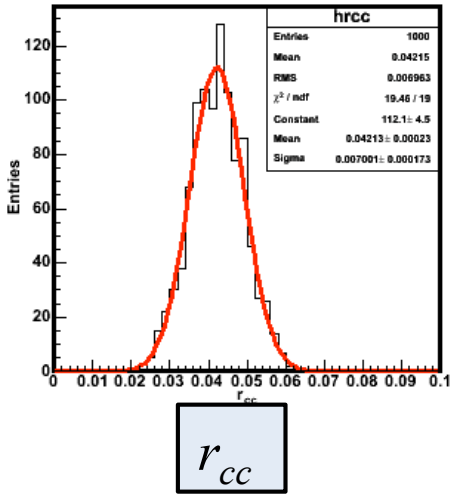
$$x - likeness = \frac{x_1 x_2}{x_1 x_2 + (1-x_1)(1-x_2)}$$

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

Fitted results of $r_{bb/cc}$

Toy-MC is performed by fluctuating the data by Poisson distribution and apply the template fitting for 1000 times. Fitted $r_{bb/cc}$ is obtained from the distribution.





	r_{bkg} (free)	$r_{bkg}=1$ (fixed)
r_{bb} (0.767)	0.766±0.02	0.767±0.01
r_{cc} (0.0442)	0.0421±0.007	0.0421±0.007

Fitted $r_{bb/cc}$ can reproduce the true $r_{bb/c}$ value ($N^{bb/cc}/N^{ZH}$)
r_{bkg} fixed case is also consistent with r_{bkg} free case.

Measurement accuracy of branching ratio

	My original cuts	SiD cuts
ΔBr(H→bb)	2.58 ± 0.06 %	2.80 ± 0.07 %
ΔBr(H→cc)	13.46 ± 0.31 %	16.61 ± 0.42 %

Relative branching ratio is calculated from the fitted parameters $r_{bb/cc}$ and the selection efficiency of $\varepsilon_{bb/cc}$ from the reduction table

Efficiency is calculated after the classification value

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

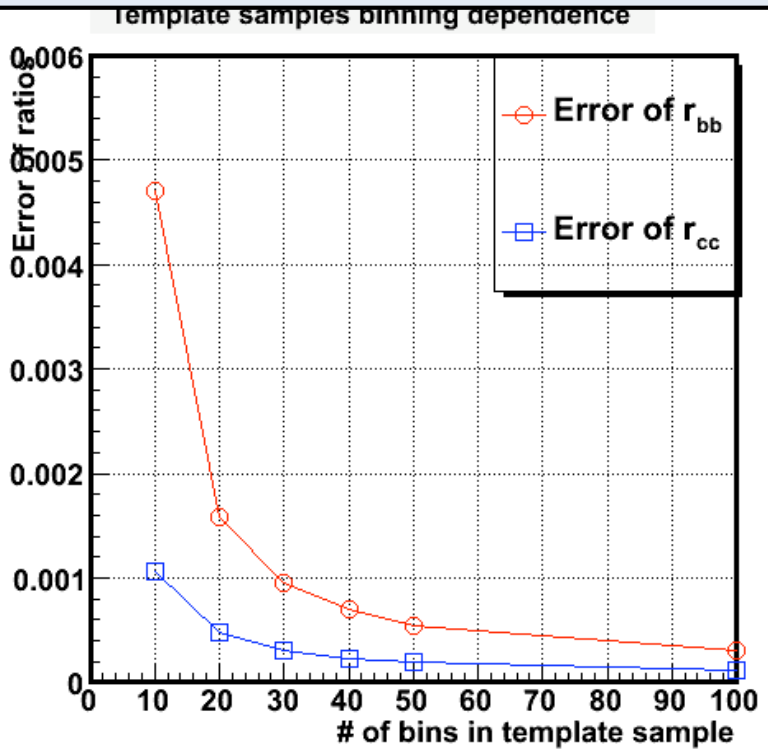
ε_{bb}=0.560 (my:0.307)
ε_{cc}=0.529 (my:0.337)

Relative branching ratio	My original cuts	SiD cuts
Ratio of Br(H→cc)/Br(H→bb)	0.059±0.008	0.058±0.009
Measurement accuracy of ratio	13.70 %	16.85 %

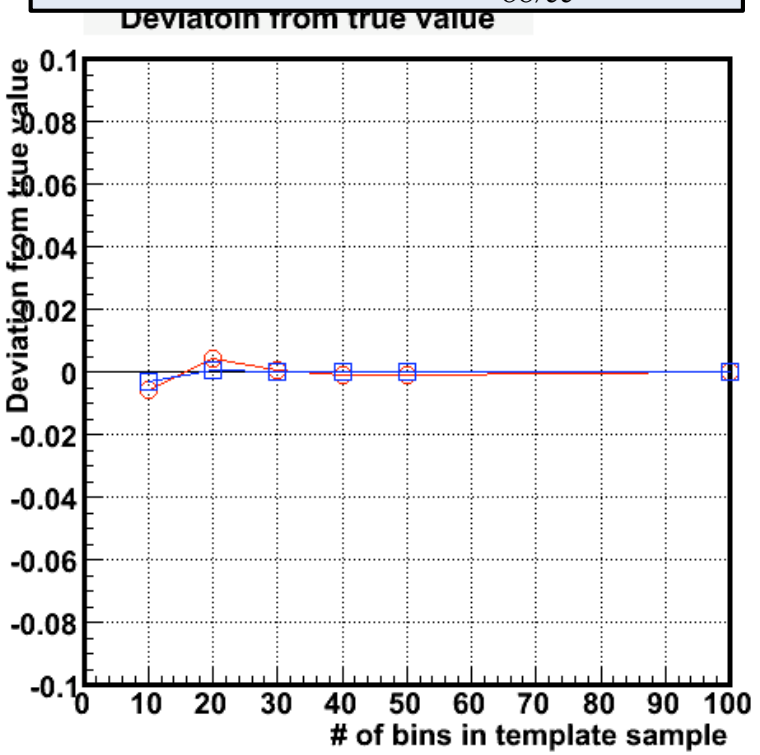
Preliminary result

Dependence of template sample

Error of $r_{bb/cc}$ with template sample binning



Deviation from true $r_{bb/cc}$ value



There are some template sample binning dependence in error estimation.
Optimize binning or consider different χ^2 minimized formula

Event selections (My original cuts)

1. d<100 (d value same definition as SiD)
2. 200 < Evis < 270 GeV
3. # of charged tracks >20
4. Longitudinal momentum of Z |Pl|<70 GeV
5. # of PFOs (NPOs>10 in each jet)
6. Y34<2.7
7. thrust<0.90
8. $|\cos\theta\_H| < 0.95$
9. Jet energy fraction ($E_{jmin}/E_{jmax}>0.25$)
10. Momentum fraction ($50<P_{jmax}<100$ GeV)
11. Minimum jets angle between H and Z ($20<\theta min<135$)
12. Maximum jets angle between H and Z($110<\theta max<170$)
13. Fitted Higgs mass($105<M_H$ fit<135 GeV)
14. Fitted Zmass($80<M_Z$ fit<110 GeV)
15. Highest photon energy(gamemax<40 GeV)

Summary

- Check discrepancy with SiD results in ZH→qqH mode
  - BG reduction becomes almost consistent with SiD
  - S/N looks worse compare to previous my cut
- Need to understand the template fitting behavior
  - Template samples binning and its error estimation
- Finalize Br(H→cc) measurement accuracy by template fitting method.