

Branching ratio study in $ZH \rightarrow qqcc/bb$

ILC physics and software meeting

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H. Ono (NDU), Y. Takubo, K. Yoshida (Tohoku)

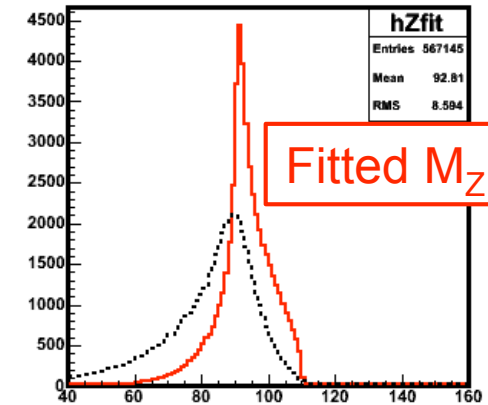
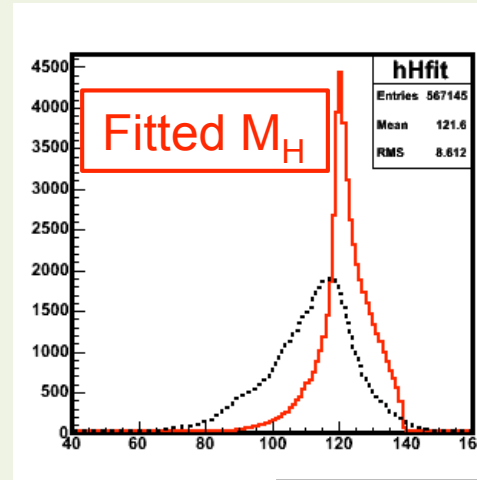
Current status

- Last week
 - Check the event selection inconsistency between the SiD and my analysis
 - ZH background reduction power has large discrepancy
- This week
 - The difference has clarified communicating with SiD group person.
 - Reasons are caused from the miss ordering of the cuts summary table in SiD analysis note.

Event selections (same as SiD)

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

1. # of charged track in each jet > 4
2. $-\log_{10}(Y_{34}) < 2.7$ ($3 \rightarrow 4$ Jet combination threshold Y val)
3. thrust < 0.95
4. $|\cos\theta_{\text{thrust}}| < 0.96$
5. $105 < \theta_{\text{Hjets}} < 165$
6. $70 < \theta_{\text{Zjets}} < 160$
7. $110 < M_{\text{Hfit}} < 140 \text{ GeV}$
8. $80 < M_{\text{Zfit}} < 110 \text{ GeV}$
9. $E_{\gamma} < 10 \text{ GeV}$ in each jet



Kinematical constraint fit

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

Corrected order table from SiD

SiD data

ono data

| | 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) $ \cos\theta_{\text{thrust}} < 0.96$ | 1017 | 1157 | 26322 | 26258 | 7943851 | 2295690 |
| (5) $105 < \theta_{\text{Hj}} < 165$ (hjet) | 979 | 1080 | 26001 | 24334 | 5871237 | 1908300 |
| (6) $70 < \theta_{\text{Zj}} < 160$ (Zjet) | 978 | 1028 | 25687 | 23195 | 4898312 | 1776150 |
| (7) $110 < M_{\text{Hfit}} < 140$ GeV | 966 | 982 | 22533 | 22076 | 1917231 | 1209100 |
| (8) $80 < M_{\text{Zfit}} < 110$ GeV | 963 | 982 | 21877 | 22074 | 1561432 | 1206570 |
| (9) $E_\gamma < 10$ GeV (jets) | 947 | 515 | 15687 | 12601 | 967312 | 570479 |

Highest photon reduction looks large discrepancy and reduce efficiency

Corrected order table (Modified)

SiD data

ono data

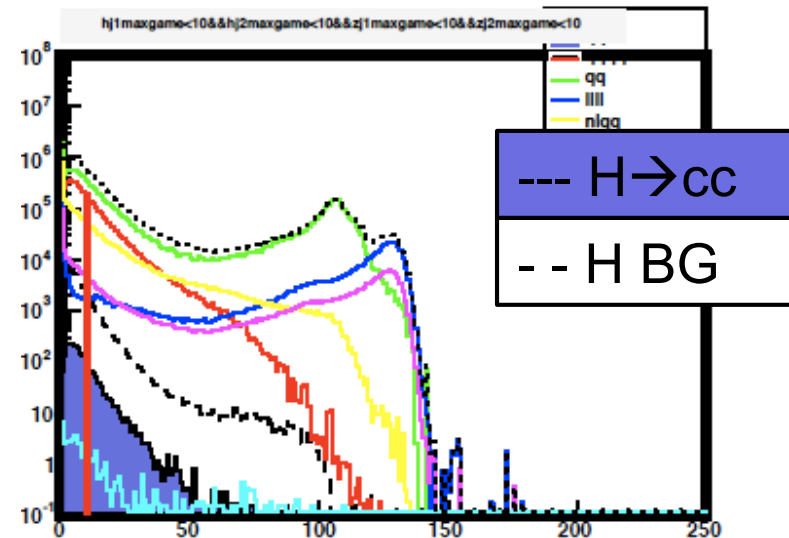
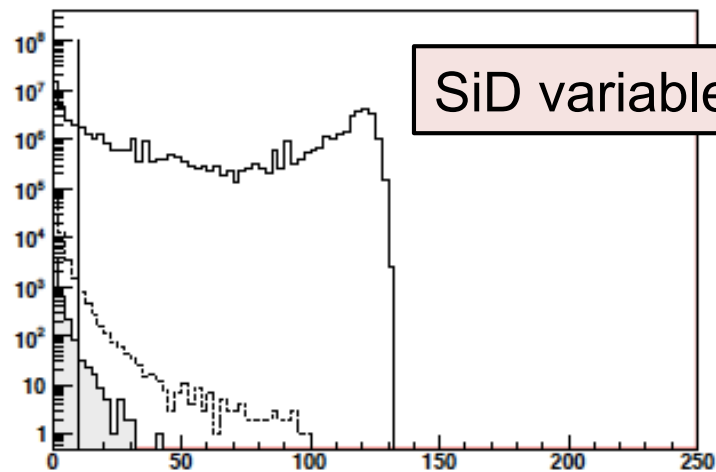
| | H→cc (qqcc) | H→cc (ono) | ZH BG (qqH) | ZH BG (ono) | SM Bkg | SM Bkg (ono) |
|--|----------------|---------------|------------------|-------------|------------|--------------|
| No cuts | 2869 (1931) | 2914 | 76910 (51513) | 76927 | 9275594683 | 4376090000 |
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| (8) $80 < M_{\text{Zfit}} < 110$ GeV | 963 | 982 | 21877 | 22074 | 1561432 | 1206570 |
| (9) $E_{\gamma} < 20$ GeV (jets) | 947 | 895 | 15687 | 20351 | 967312 | 1036990 |

Signal looks almost consistent, Next, SM BG should be considered.

Highest photon energy distribution

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

Photon energy after classification



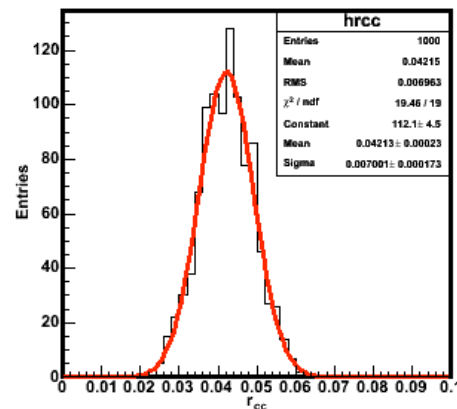
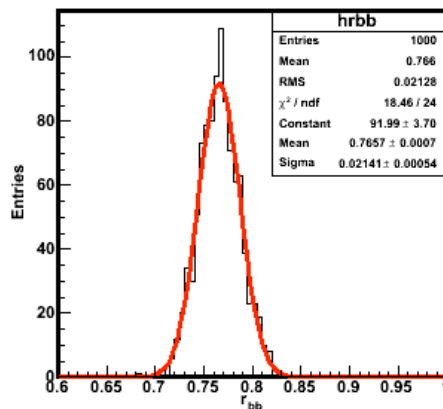
Highest photon energy cut looks large discrepancy and reduce efficiency

I found some difference of their definition of this cut, they also require the "no photon isolation". I will try to correct this point.

Template fitting and Branching ratio measurement

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} , r_{cc} is obtained from the distribution.



| rbkg free | |
|-----------|--------------------|
| r_{bb} | 0.766 ± 0.02 |
| r_{cc} | 0.0421 ± 0.007 |

Fitted $r_{bb/cc}$ can reproduce the true value : $r_{bb}=0.767$, $r_{cc}=0.0422$

Measurement accuracy of branching ratio

| | My original cuts | SiD cuts only |
|-------------------------------|---------------------|---------------------|
| $\Delta Br(H \rightarrow bb)$ | $2.53 \pm 0.06 \%$ | $2.80 \pm 0.07 \%$ |
| $\Delta Br(H \rightarrow cc)$ | $13.00 \pm 0.28 \%$ | $16.61 \pm 0.42 \%$ |

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

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

$$\begin{aligned} \epsilon_{bb} &= 0.560 \\ \epsilon_{cc} &= 0.529 \end{aligned}$$

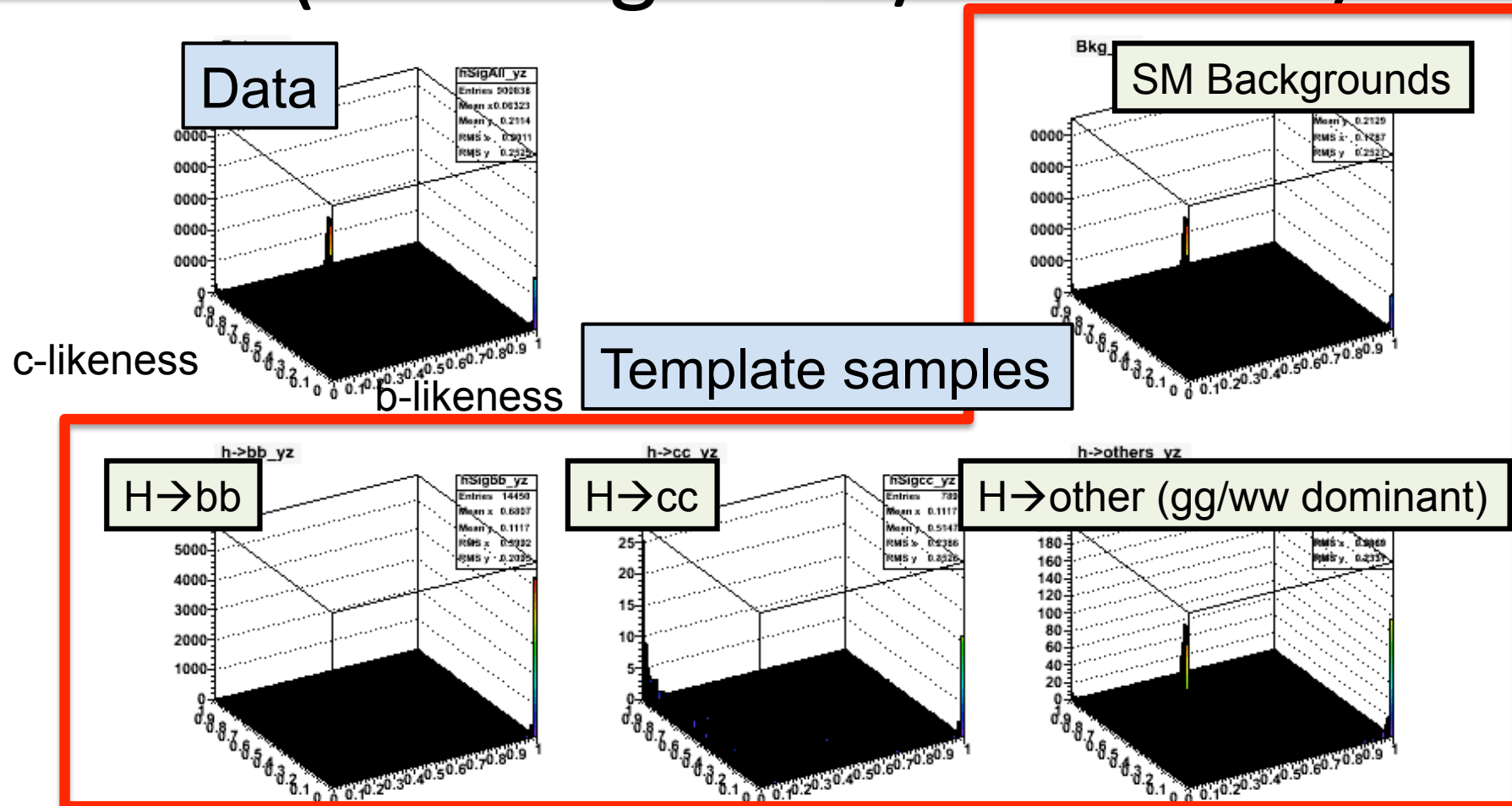
Efficiency is calculated after the classification value

| Relative branching ratio | My original cuts | SiD cuts only |
|--|-------------------|-------------------|
| Ratio of $Br(H \rightarrow cc) / Br(H \rightarrow bb)$ | 0.054 ± 0.010 | 0.058 ± 0.009 |
| Measurement accuracy of ratio | 13.25% | 16.85% |

Preliminary result

Consideration of template fitting

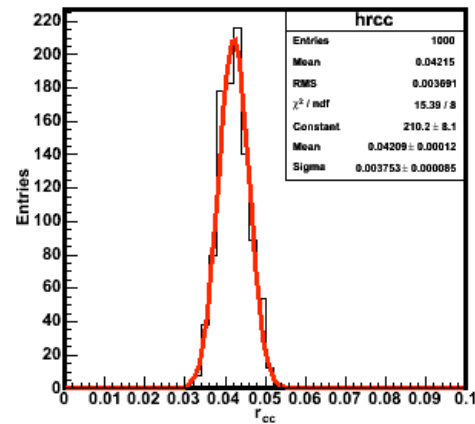
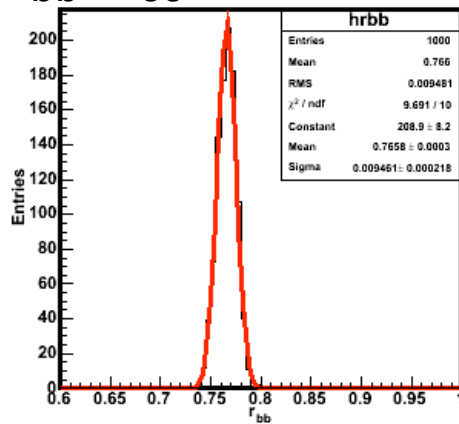
Granular binning template samples (2D image of b/c likeness)



S/N separation will be improved from previous binning, optimization will be need

Distribution of $r_{bb/cc}$ with finer binning (S/N improve in template)

Toy-MC is performed and apply the fitting for 1000 times.
Fitted r_{bb} , r_{cc} is obtained from the distribution.



$$r_{bb} = 0.7658 \pm 0.0003$$

$$r_{cc} = 0.0421 \pm 0.0001$$

Fitted $r_{bb/cc}$ can reproduce the true value : $r_{bb} = 0.7664$, $r_{cc} = 0.0419$
Error of the $r_{bb/cc}$ are reduced from the previous binning case...
I do not understand why such behavior happens.

Measurement accuracy of branching ratio

| | SiD cuts only | Finer binning |
|---|---------------------|--------------------|
| $\Delta\text{Br}(H \rightarrow b\bar{b})$ | $2.80 \pm 0.07 \%$ | $1.24 \pm 0.03 \%$ |
| $\Delta\text{Br}(H \rightarrow c\bar{c})$ | $16.61 \pm 0.42 \%$ | $8.92 \pm 0.20 \%$ |

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

$$\frac{\text{Br}(H \rightarrow c\bar{c})}{\text{Br}(H \rightarrow b\bar{b})} = \frac{r_{cc} / \epsilon_{cc}}{r_{bb} / \epsilon_{bb}}$$

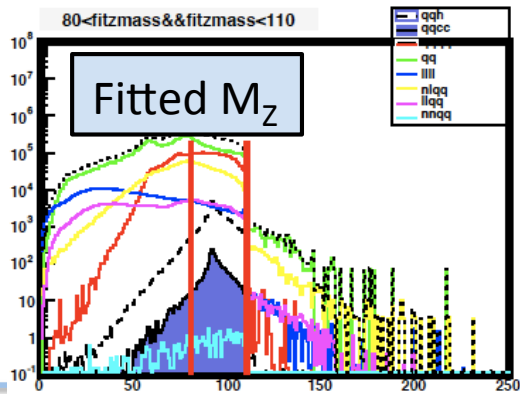
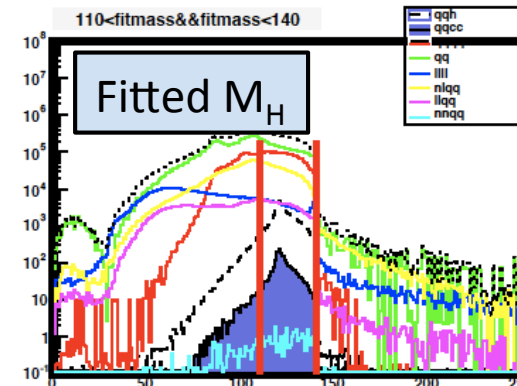
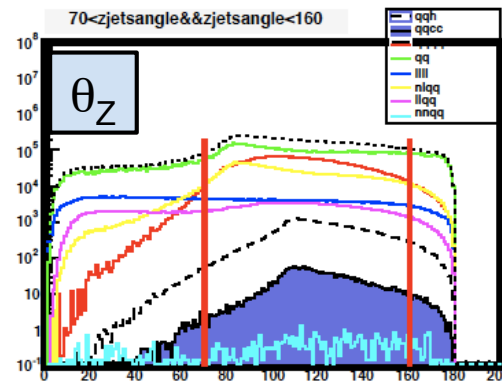
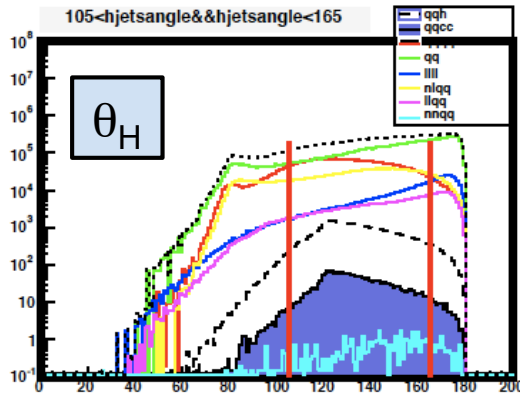
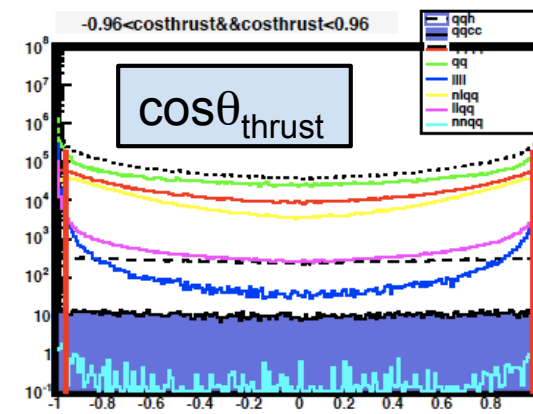
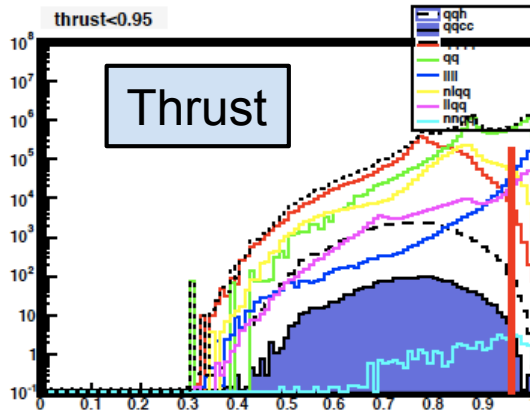
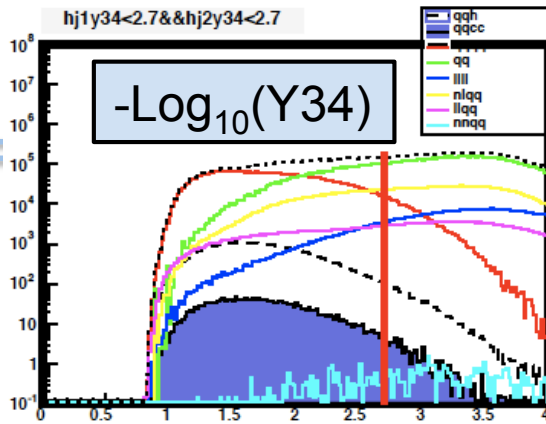
Preliminary result

| Relative branching ratio | SiD cuts | Finer binning |
|--|-------------------|-------------------|
| Ratio of $\text{Br}(H \rightarrow c\bar{c}) / \text{Br}(H \rightarrow b\bar{b})$ | 0.058 ± 0.009 | 0.055 ± 0.005 |
| Measurement accuracy of ratio | 16.85% | 9.00% |

Need to optimize template fitting method

Summary

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



Other distribution looks consistent with SiD



Apply all the cuts and check the efficiency