Higgs Hadronic decays at FCC-ee Collider

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IDEA Physics and Software Meeting

Introduction

- ZH recoil analysis promising probe for precise Higgs sector measurements:
  - Precise Higgs mass measurement up to ~O(MeV)
  - Model-independent cross-section: sensitive to new physics H → invisible

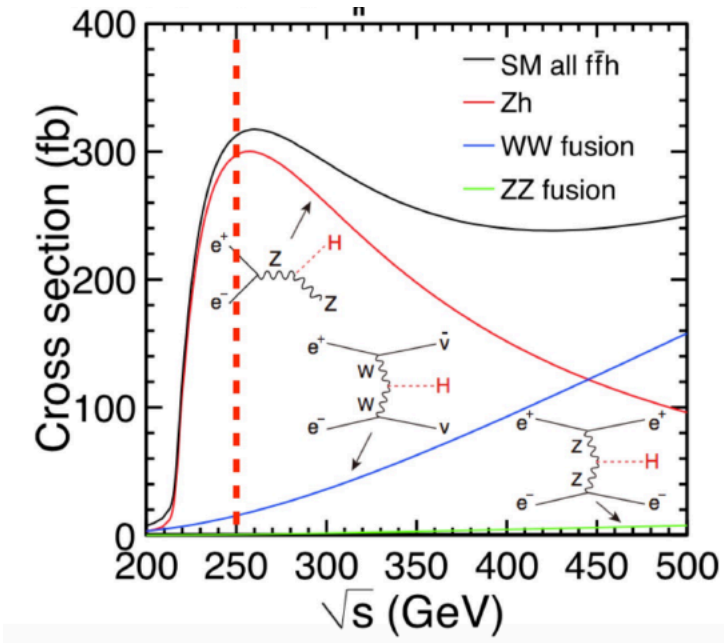
FCCee @ √s = 240 GeV → Higgs factory

↓

Measure Higgs couplings

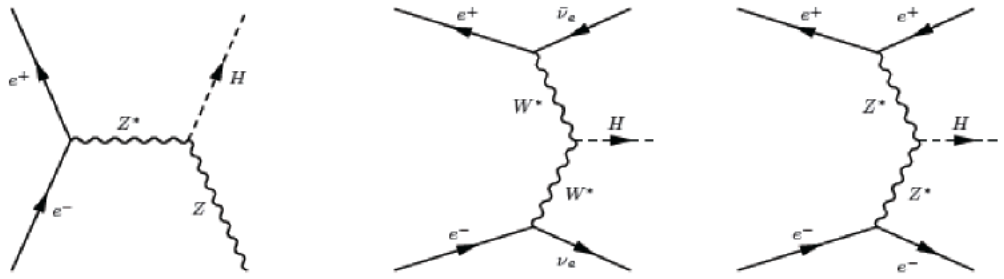
↓

Sensitivity on coupling strength modifiers $K_{\{b,c,s,g\}}$?



Higgs production at FCCee:

- Higgs-strahlung e e -> ZH
- VBF production e e -> v v H (WW fusion), e e -> e e H (ZZ fusion)



10^6 ZH events @ 240 GeV 5 /ab

Higgs production @ FCC-ee		
Threshold	ZH production	VBF production
240 GeV / 5 ab^{-1}	1e6	2.5e4
365 GeV / 1.5 ab^{-1}	2e5	5e4

Signal and background samples

Signal: ee → ZH → Hadrons

- Considering H decays (bb – cc – ss – gg – qq)
- Considering Z decay to (bb – cc – ss – qq)
- Higgs mass 125 GeV

} 20 Sample

- **Backgrounds**: ZH(WW, ZZ, Zγ, $\tau\tau$) – WW – ZZ

Monte-Carlo campaign:

- Center-of-mass 240 GeV, luminosity of 5 ab^{-1}
- IDEA detector; detector response modelled with Delphes

Signal samples

Sample	N. events	Cross section (pb)
Z(bb)H(bb)	100000	7.193e-06
Z(bb)H(cc)	400000	0.0008664
Z(bb)H(ss)	400000	0.01745
Z(bb)H(gg)	200000	0.002454
Z(cc)H(bb)	200000	0.01359
Z(cc)H(cc)	400000	0.0006747
Z(cc)H(ss)	300000	5.607e-06
Z(cc)H(gg)	400000	0.001911
Z(ss)H(bb)	200000	0.01745
Z(ss)H(cc)	300000	0.0008661
Z(ss)H(ss)	300000	7.19e-06
Z(ss)H(gg)	400000	0.002453
Z(qq)H(bb)	500000	0.03107
Z(qq)H(cc)	200000	0.001542
Z(qq)H(ss)	400000	1.28e-05
Z(qq)H(gg)	400000	0.004367

- **Tag : Winter2023**
- With nominal Higgs mass 125 GeV
- Generated with Whizard (wzp6)

Background samples

Sample	N. events	Cross section (pb)
Z(bb)H(tautau)	400000	0.00188
Z(bb)H(ZZ)	1000000	0.0007915
Z(bb)H(WW)	1000000	0.00645
Z(bb)H(Za)	400000	4.594e-05
Z(cc)H(tautau)	400000	0.001464
Z(cc)H(ZZ)	1,200,000	0.0006164
Z(cc)H(WW)	1,200,000	0.005023
Z(cc)H(Za)	400,000	3.578e-05
Z(ss)H(tautau)	400,000	0.001879
Z(ss)H(ZZ)	600,000	0.0007912
Z(ss)H(WW)	1,200,000	0.006447
Z(ss)H(Za)	300,000	4.593e-05
Z(qq)H(tautau)	200,000	0.003346
Z(qq)H(ZZ)	1,200,000	0.001409
Z(qq)H(WW)	1,100,000	0.01148
Z(qq)H(Za)	393,135	8.177e-05

- **Tag : Winter2023**
- Generated with Whizard (wzp6)

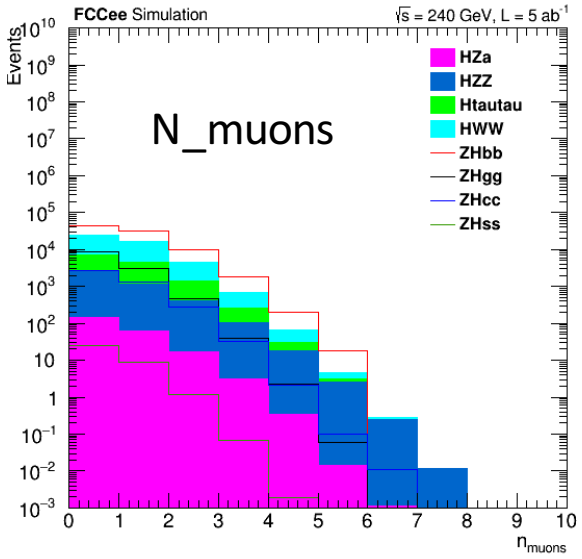
- Missing WW / ZZ / Z backgrounds

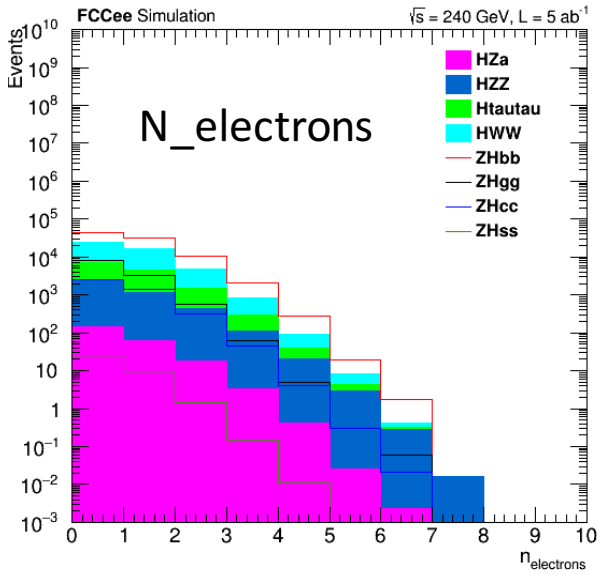
Analysis Strategy in nutshell

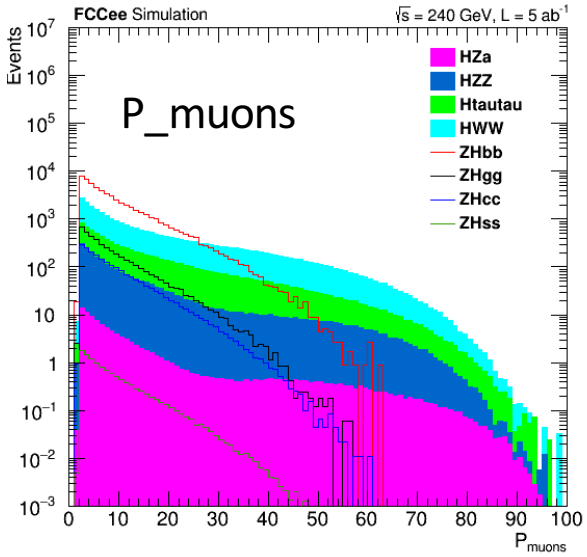
- Jets reconstruction
  - N = 4 Durham ee_kt exclusive algorithm
- Event Selection
  - Reconstruct Higgs and Z candidates depending on the reconstructed di jet mass "the best Jet combination"
  - Defining 3 possible signal regions
  - Fitting analysis
- Jet tagging
  - Evaluate the Jet tagger behavior in 4 jets case since the tagger has been trained on 2 Jet category

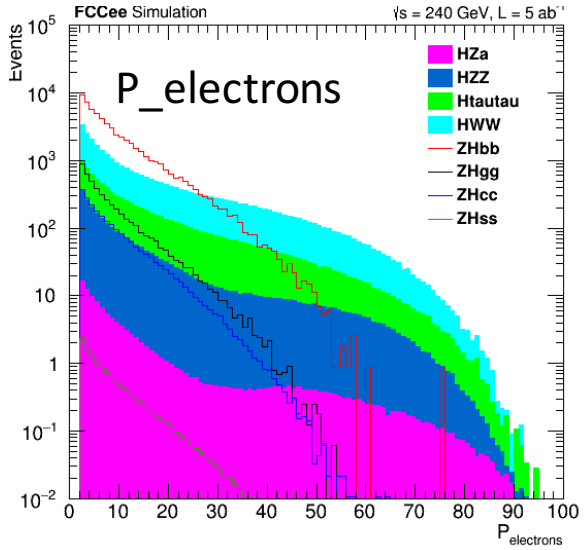
Event Selection

Case: bbH



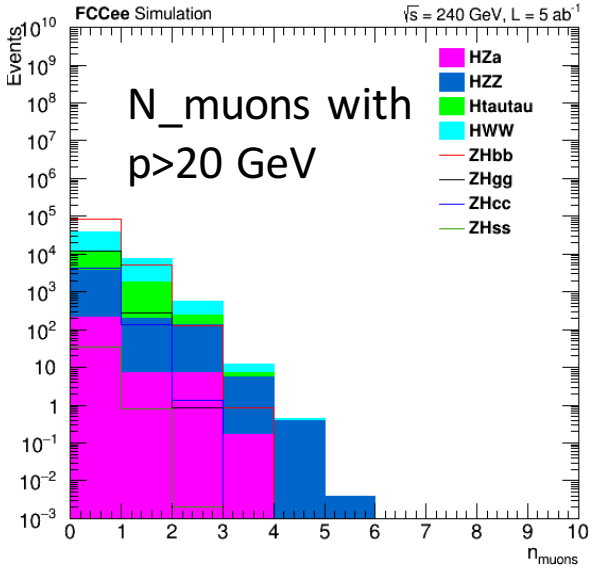


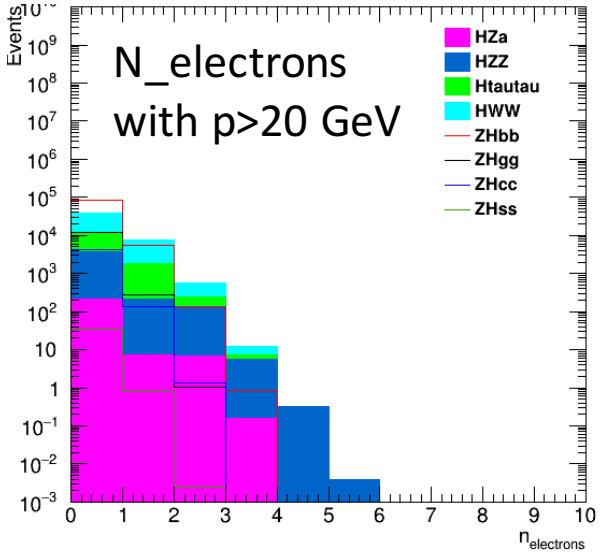




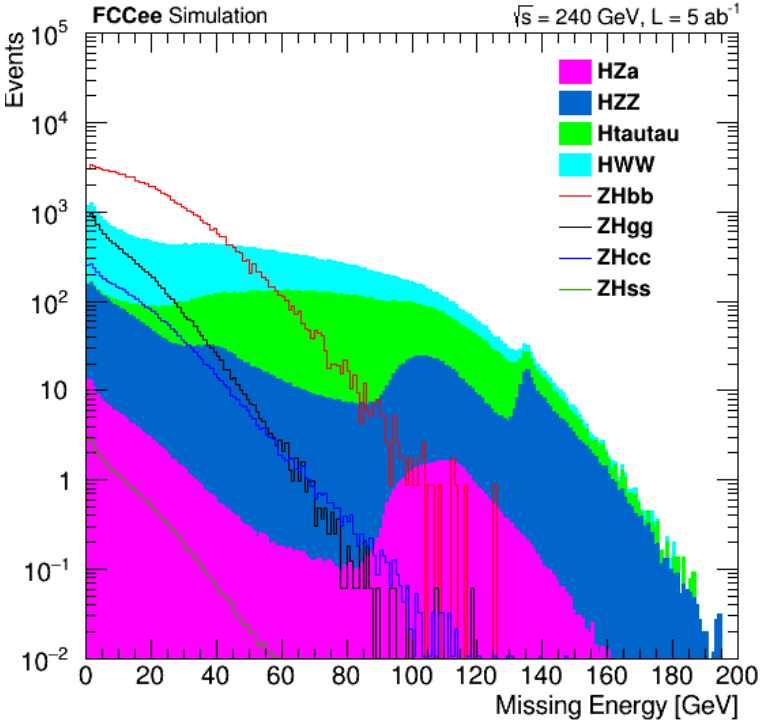
Leptons

(Number of leptons with P> 20 GeV) <2





Event Selection

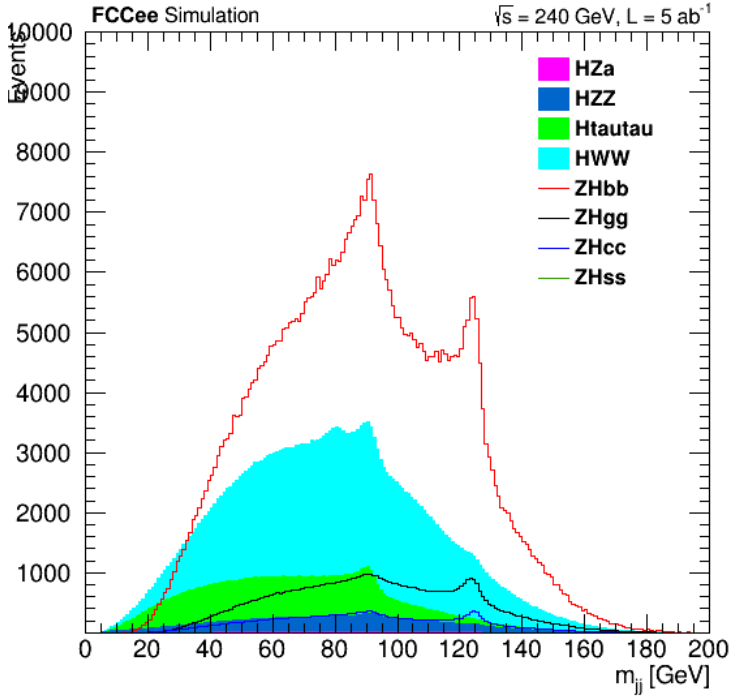


Missing Energy

- Missing energy < 80 GeV

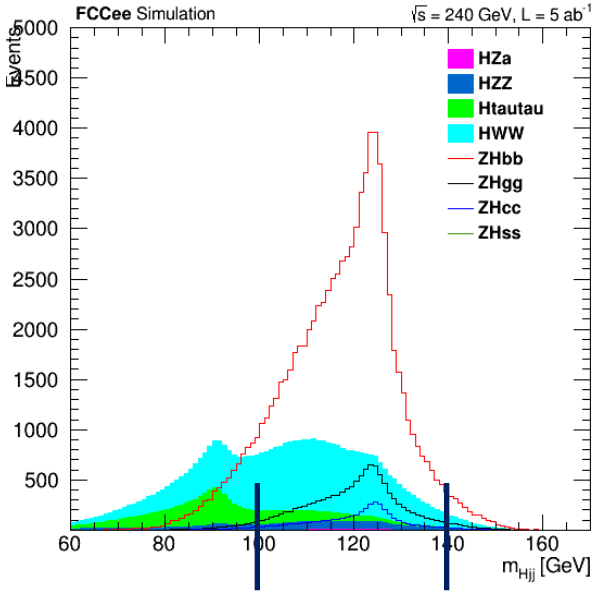
Event Selection

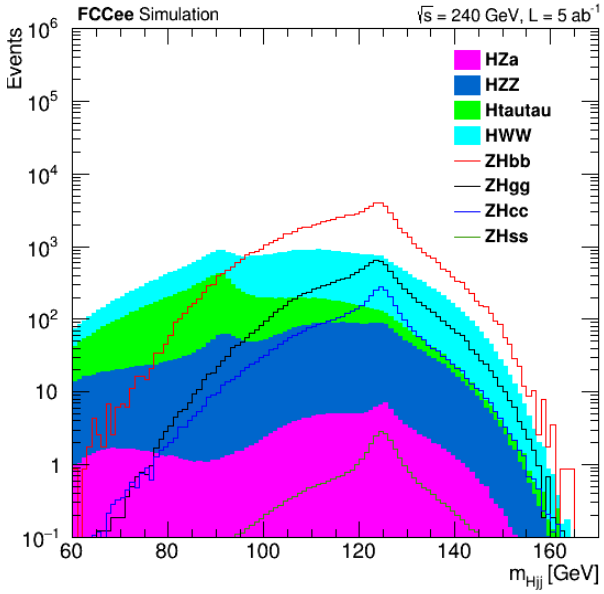
- Build all possible di-jet combination regardless of the Jet flavor
- Choose the best di-jet pair where di-jet mass closes to 125 GeV and the other pair with mass closes to 90 GeV:
  - $\chi_1^2 = (mjj_1 - 125)^2 + (mjj_2 - 91)^2$
  - $\chi_2^2 = (mjj_1 - 91)^2 + (mjj_2 - 125)^2$
  - choose the pair with smallest χ^2
- Check all the kinematic distributions for H, Z cand.



Di-jet mass of all possible di-jet candidates

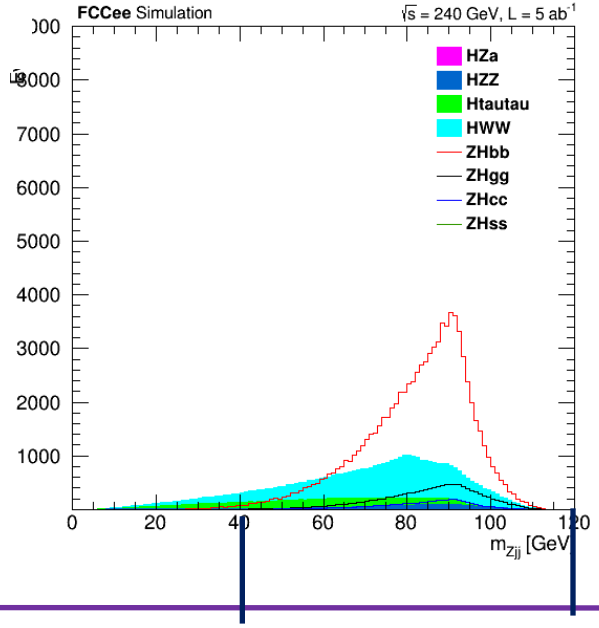
Event Selection

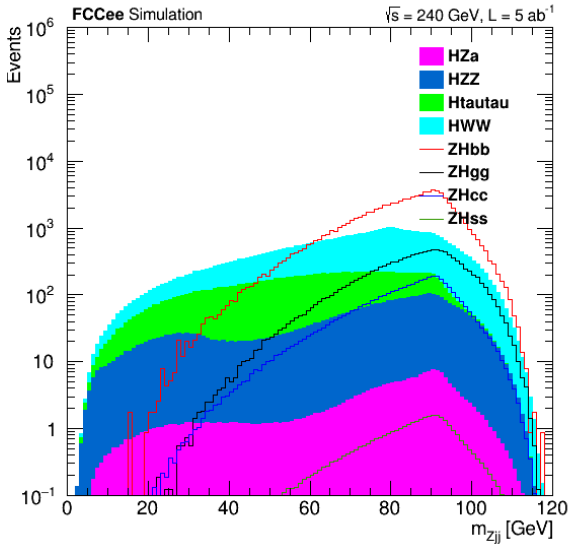




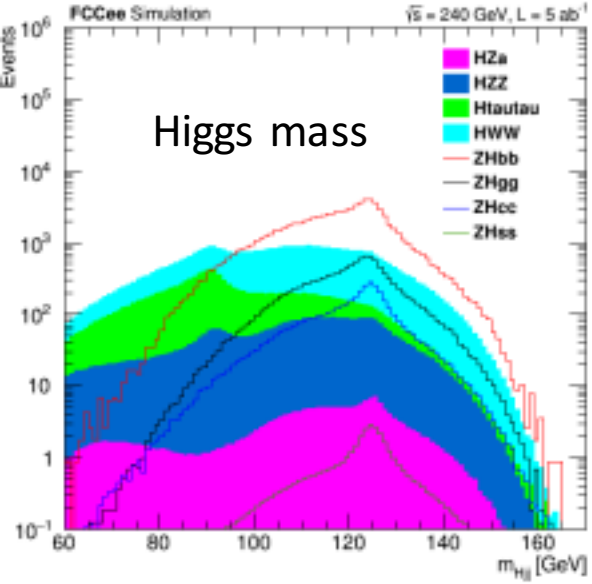
Di-jet mass closes to H mass

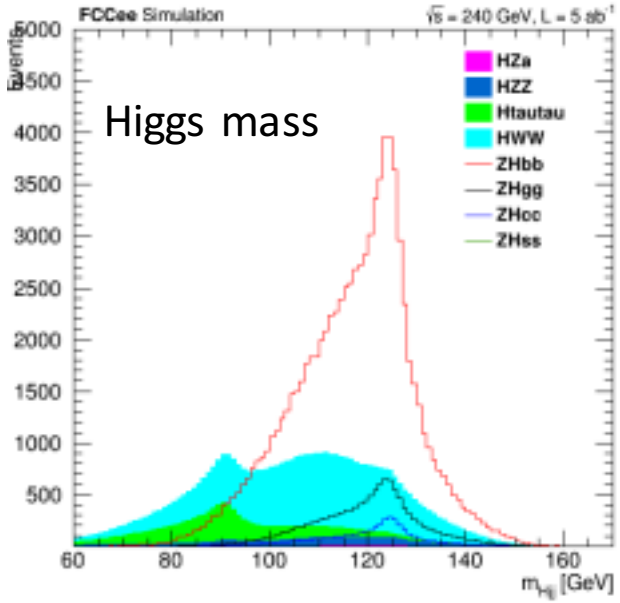
Di-jet mass closes to Z mass

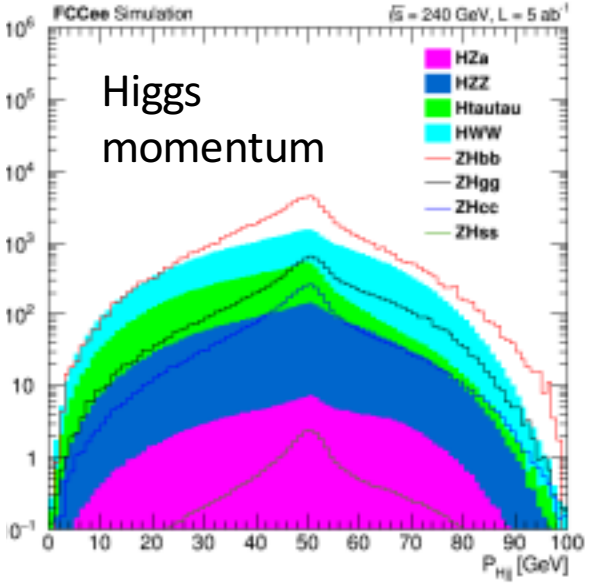


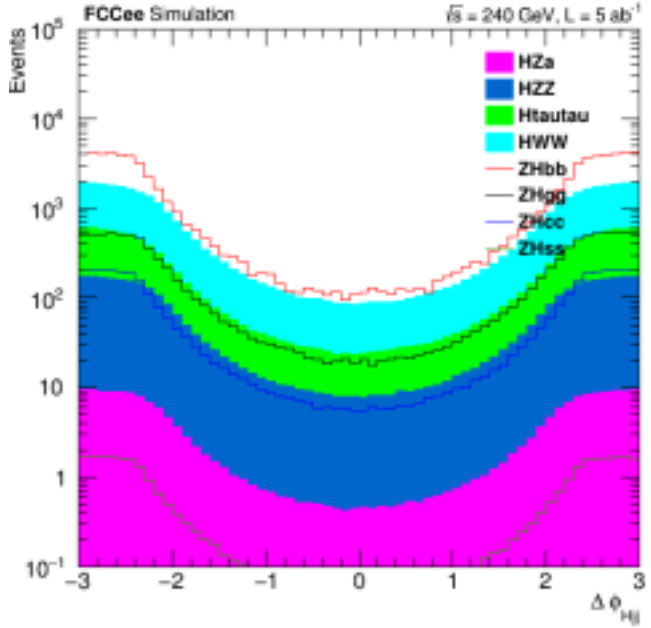


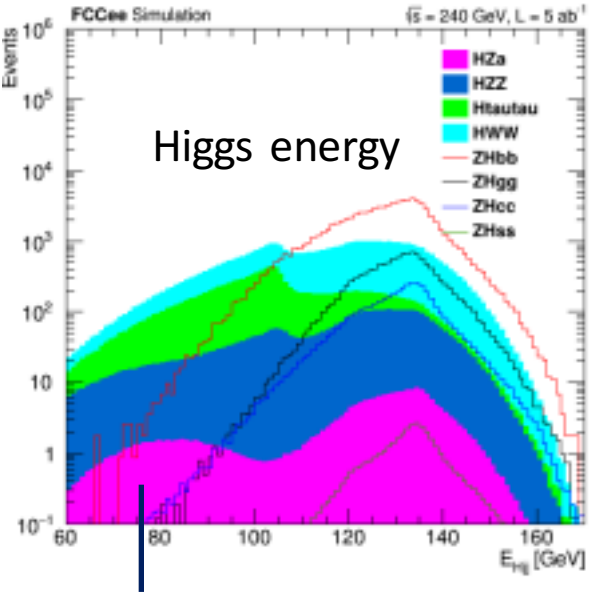
Di jet pair (m~ 125)

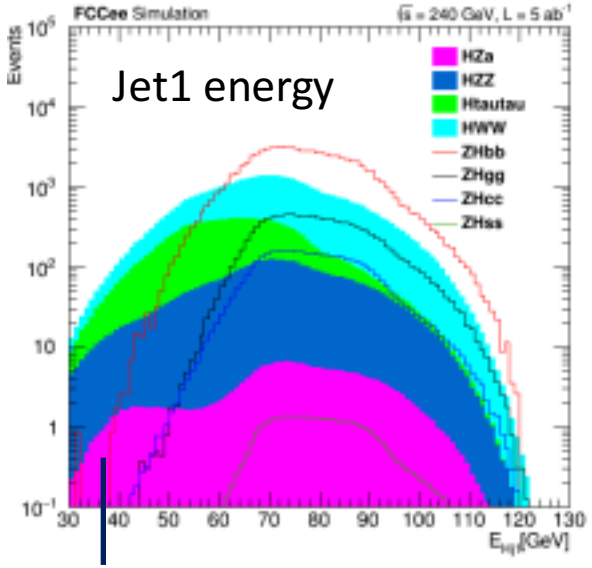


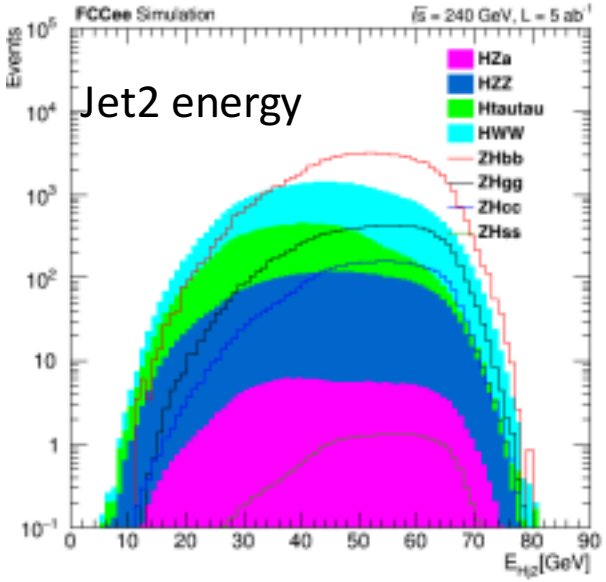






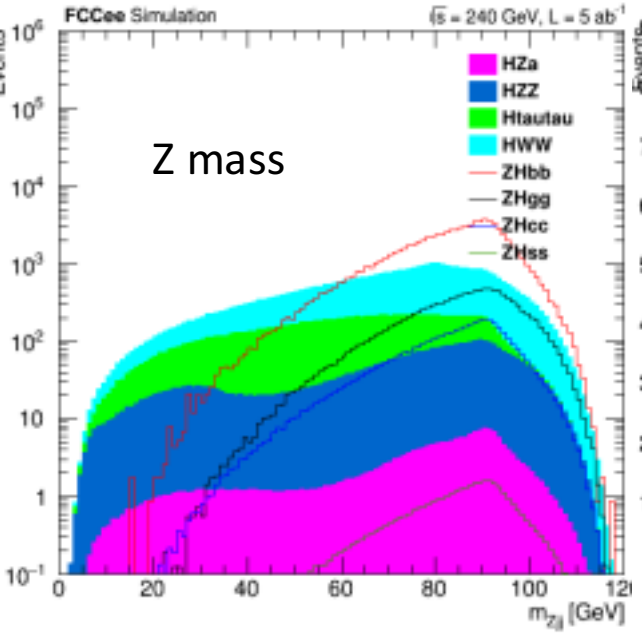


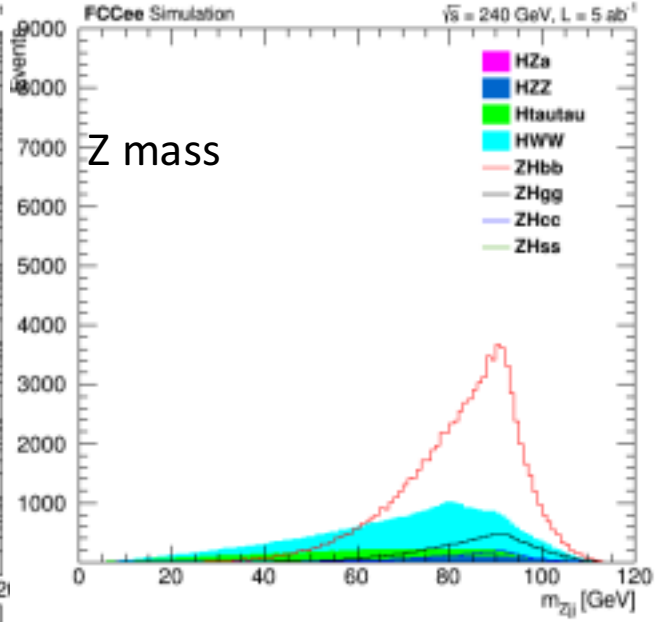


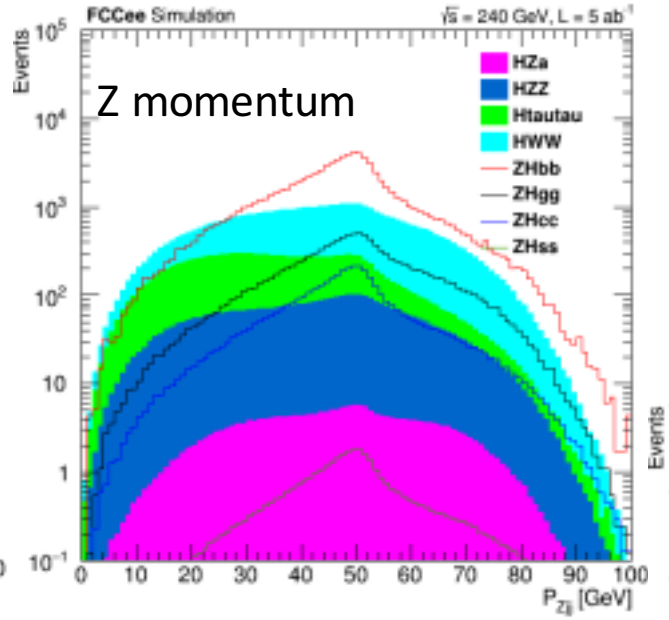


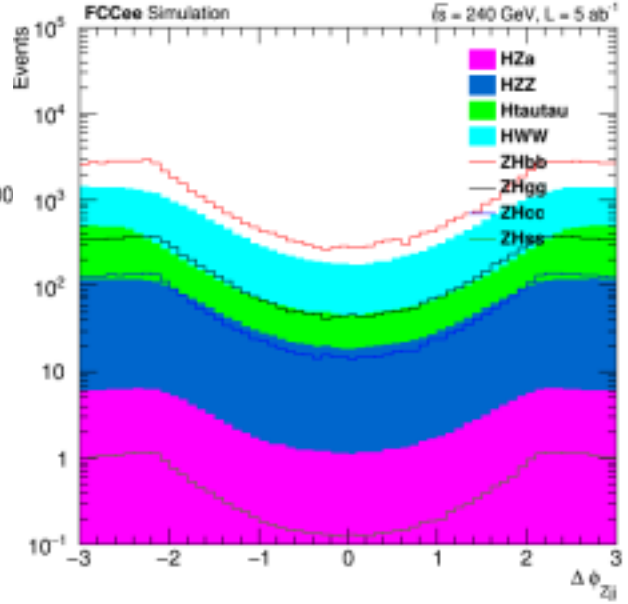
Delta phi between H 2 jets

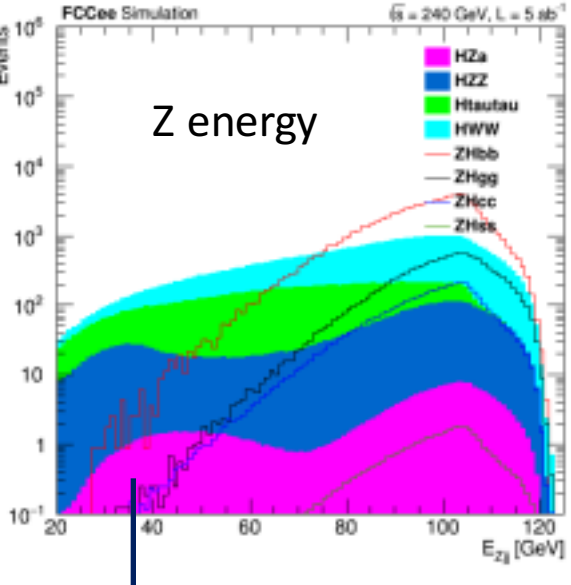
Di jet pair (m ~ 91)

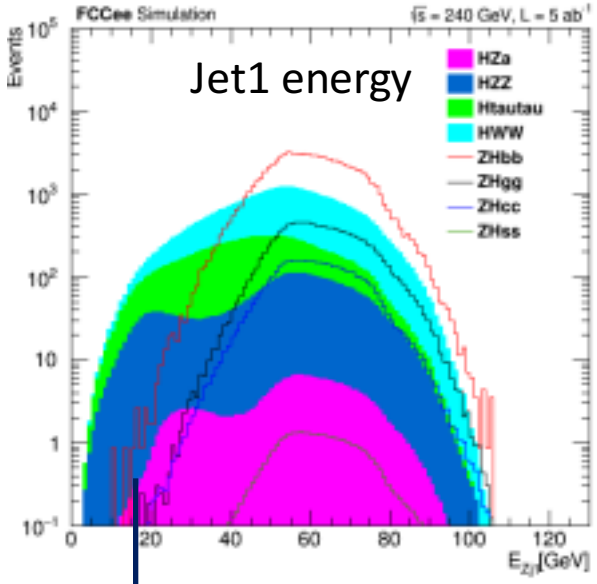


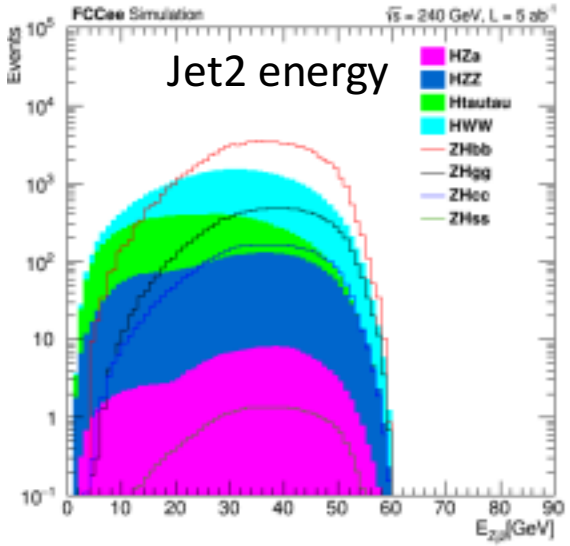












Delta phi between Z 2 jets

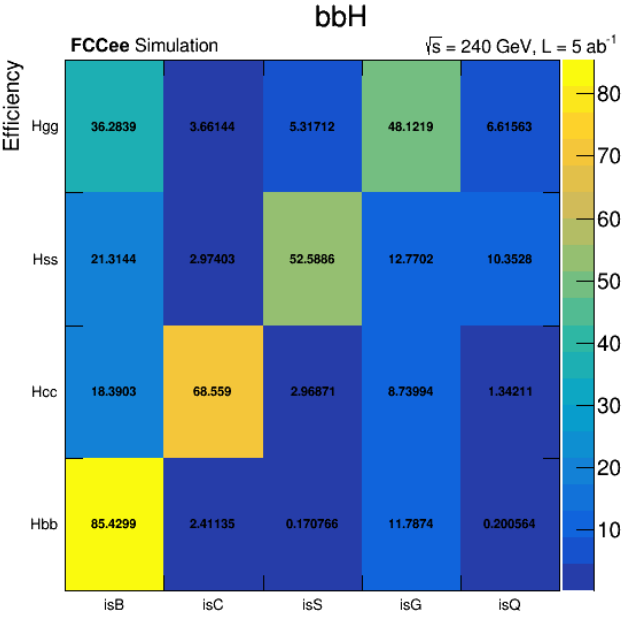
Event Selection

- Signal Region:
  - (Number of leptons with P> 20 GeV) <2
  - Missing energy < 80 GeV
  - $100<mH_{jj}<140$ GeV
  - Energy H_{jj} > 80 GeV
  - Energy H_{j1} > 40 GeV
  - $40<mZ_{jj}<120$ GeV
  - Energy Z_{jj} > 40 GeV
  - Energy Z_{j1} > 20 GeV

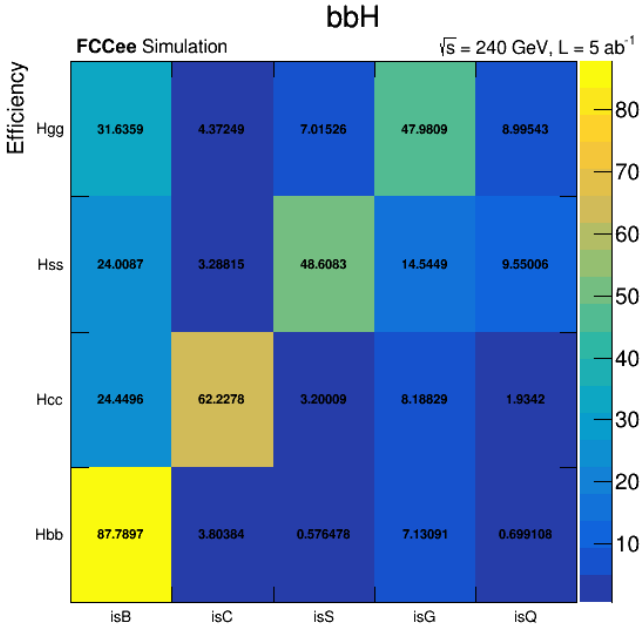
Jet Flavor

- Check the Jet flavors from H and Z candidates

Case: Z(bb) H (bb – cc – ss – gg)

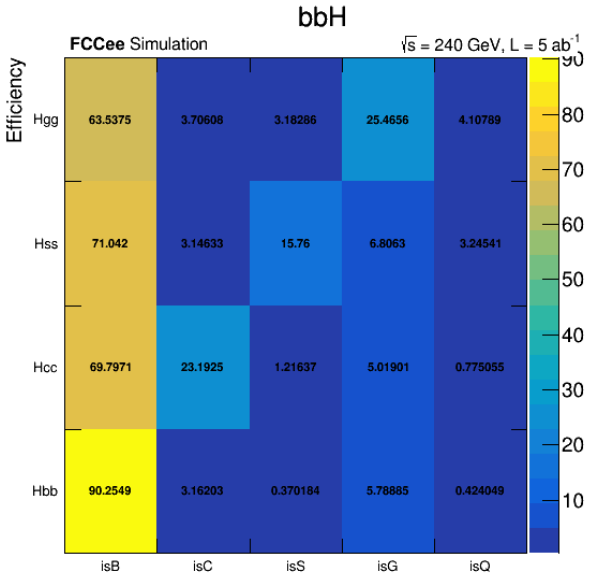


Jet1 coming from Higgs

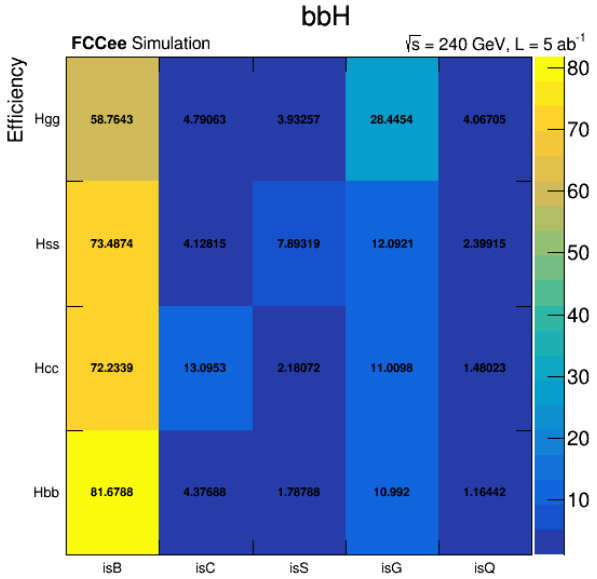


Jet2 coming from Higgs

Jet1 coming from Z



Jet2 coming from Z



Signal Regions

- Defining 3 signal Region

Case 1: Pure case

- Define Jet flavor with the highest jet score
- Hjet1 flavor = Hjet2 flavor
- Zjet1 flavor = Zjet2 flavor

Case 2: sum score

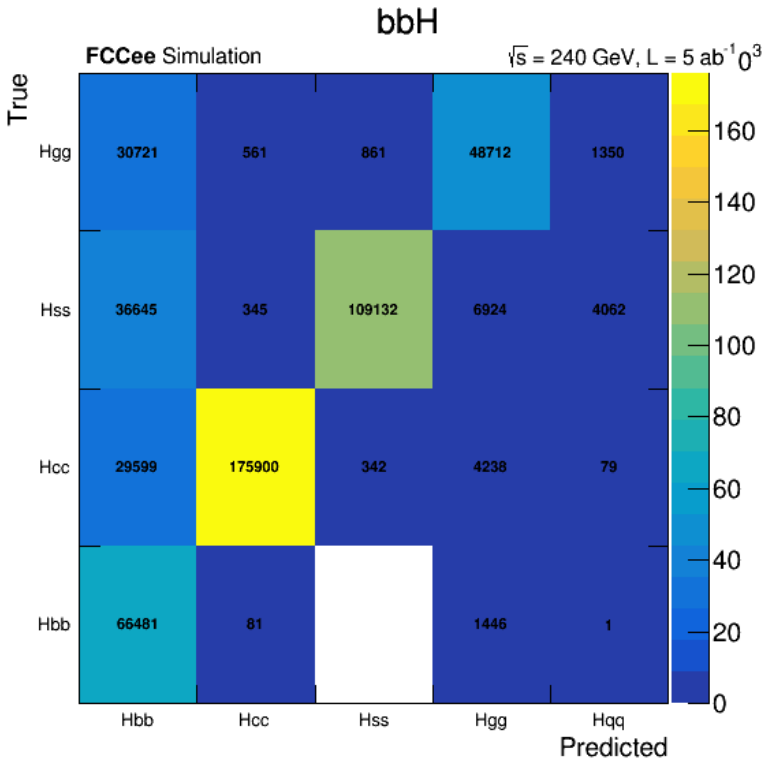
- Sum score of 2 jets
- Consider the H flavor depending on the highest sum
- Consider the Z flavor depending on the highest sum

Case 3: Jet flavor of Highest Jet score

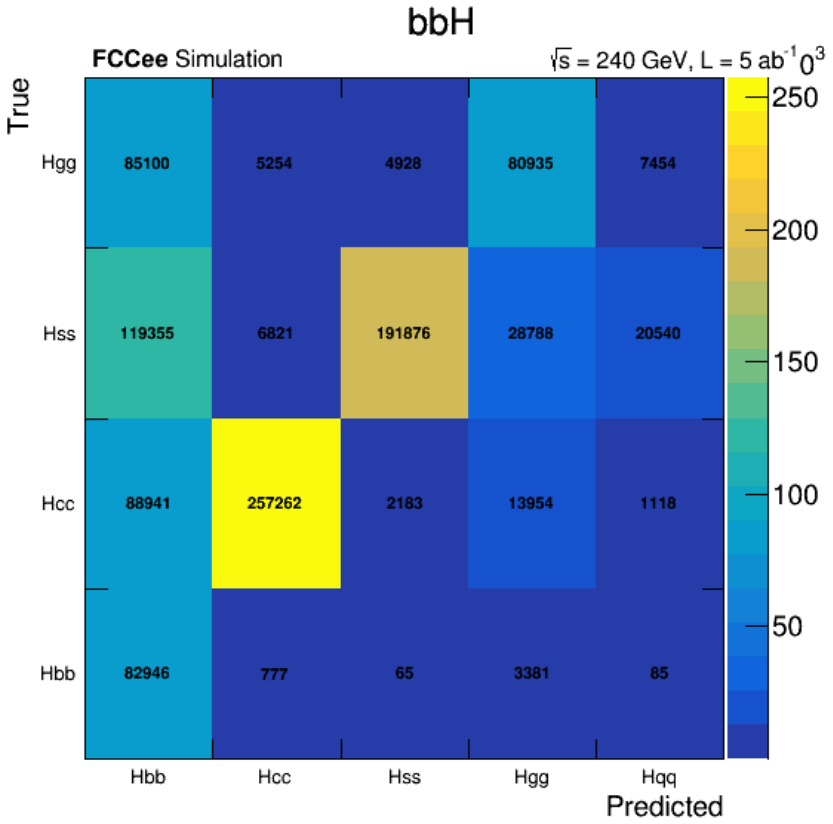
- Define the H tag depending on the jet tag of the highest score between the 2 jets coming from H

Event Selection

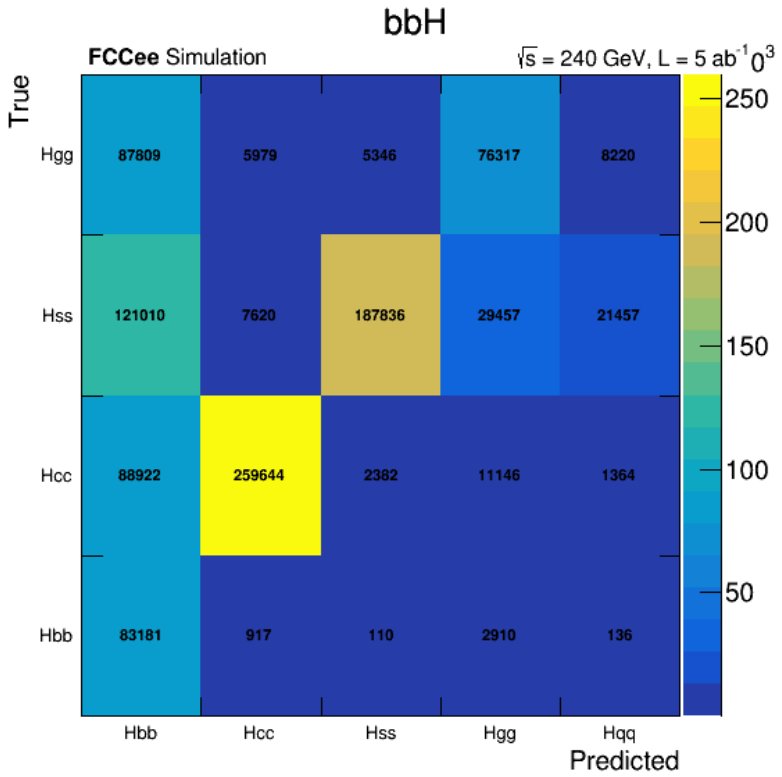
- Higgs Confusion Matrix



Case 1



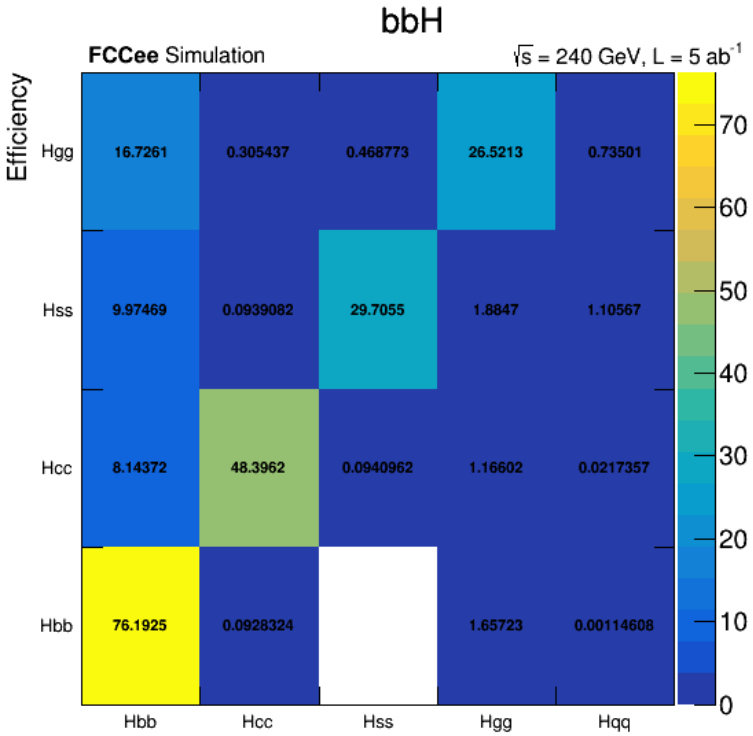
Case 2



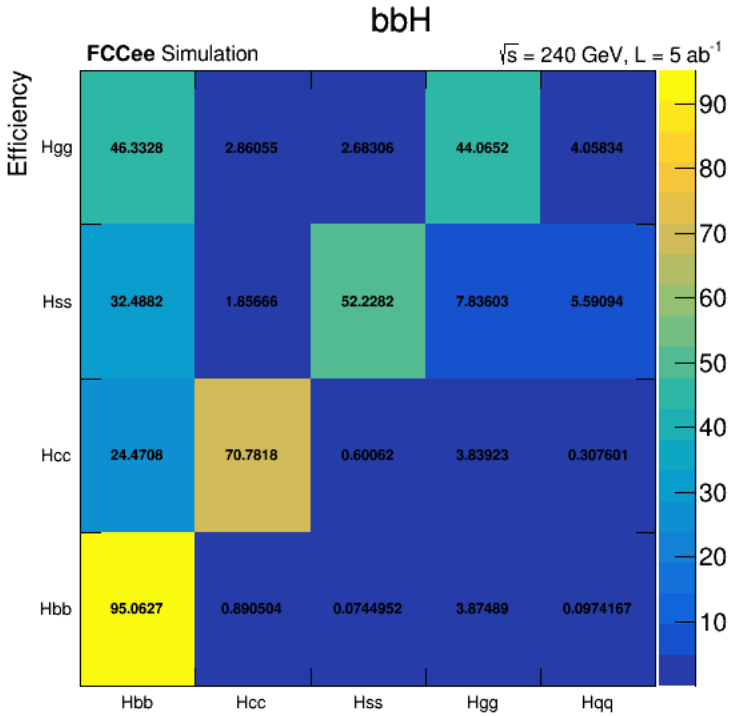
Case 3

Event Selection

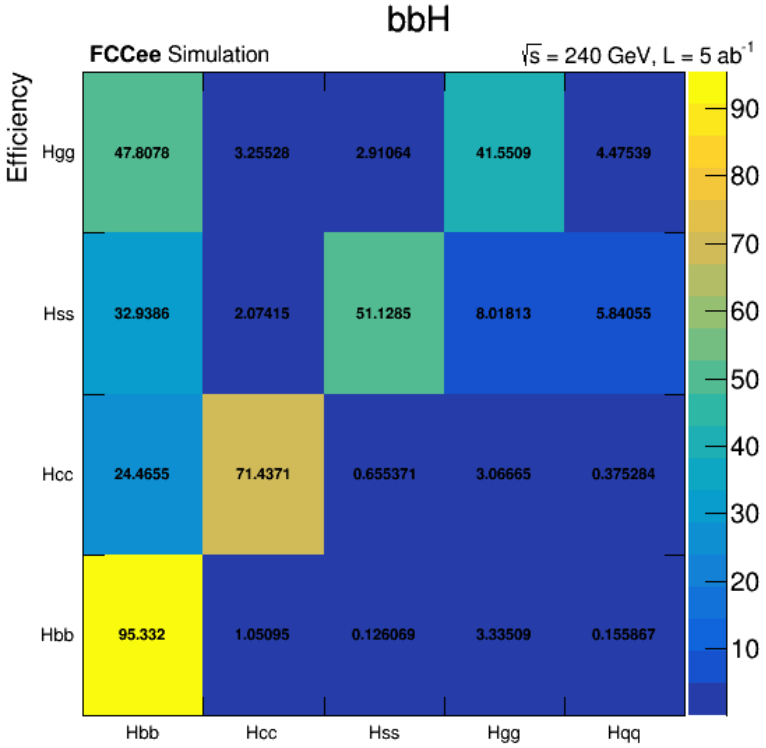
- Higgs Efficiency Matrix



Case 1



Case 2



Case 3

Statistical analysis

- Statistical analysis performed using Combine, the CMS statistical framework developed in context of Higgs analyses
- Signal and background shapes are fitted to pseudo-data Asimov dataset
- The normalizations of all processes (including backgrounds) are floating
- without accounting for systematic uncertainties
- Using di-jet mass reconstructed closes to H mass
- Uncertainties in signal strength (μ) has been extracted in different categories:
- All the signal rates in Z decay are correlated

Statistical analysis

- Case 1 (Pure case):
  - rate_Hbb = 1 +/- 0.0292422
  - rate_Hcc = 1 +/- 0.786621
  - rate_Hgg = 1 +/- 0.363345
  - rate_Hss = 1 +/- 51.9707

- Case 2 (sum score) & case 3
  - rate_Hbb = 1 +/- 0.0319205
  - rate_Hcc = 1 +/- 0.529288
  - rate_Hgg = 1 +/- 0.229877
  - rate_Hss = 1 +/- 38.3112

Ongoing/Next Steps

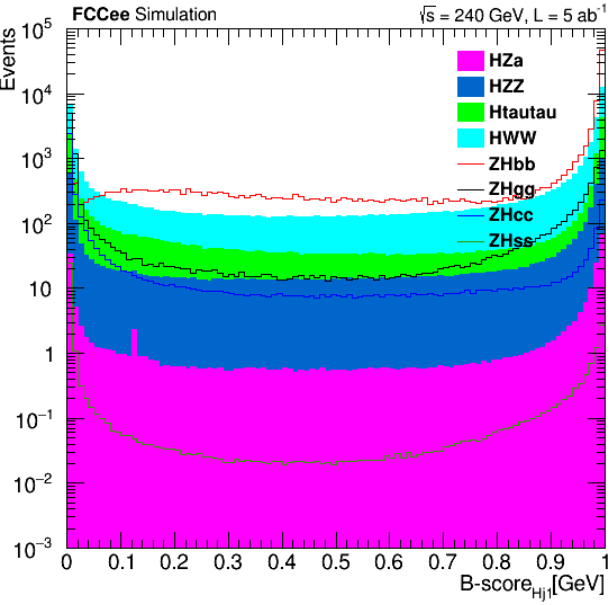
- Add missing background (WW/ZZ) samples
- Build classifier and use as input for Statistical analysis
- Check the impact on the uncertainties
- Impact on detector performance
- Documentation => Get the first draft of the note for the midterm report.

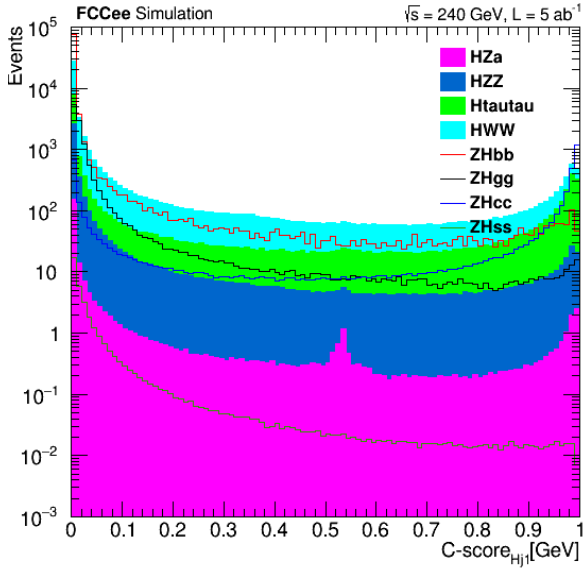
Ongoing

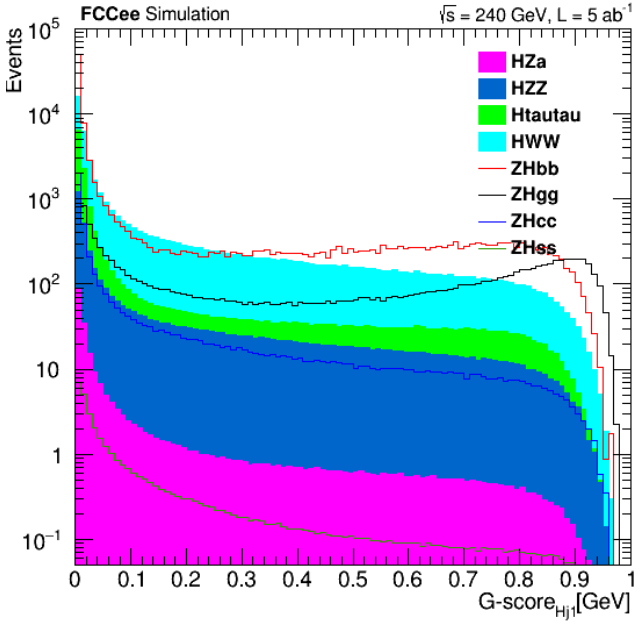
Backup

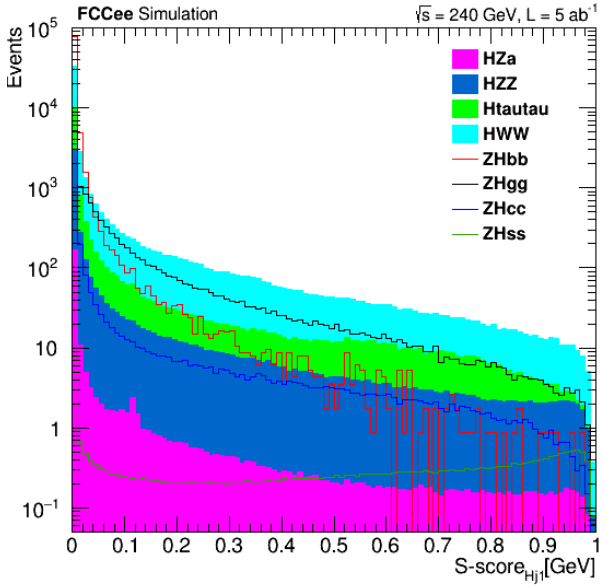
Jet Score distributions

Jet 1 from H



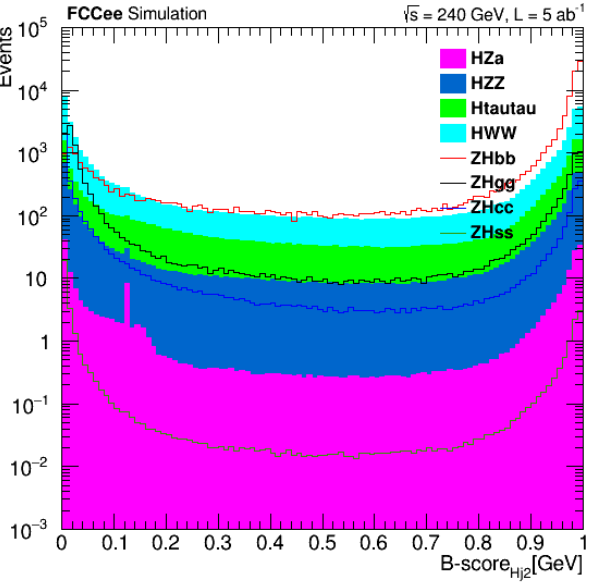


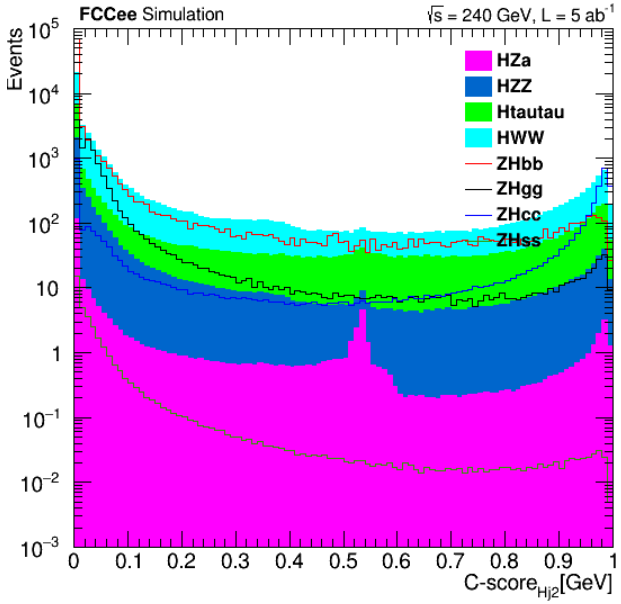


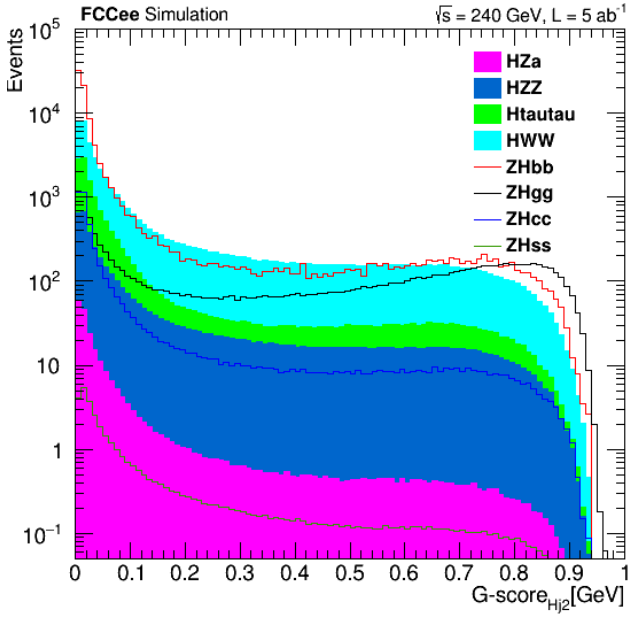


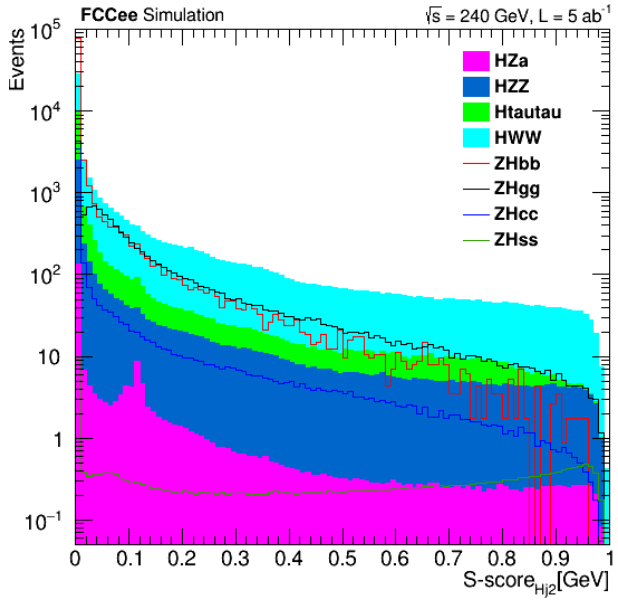
Jet Score distributions

Jet 2 from H





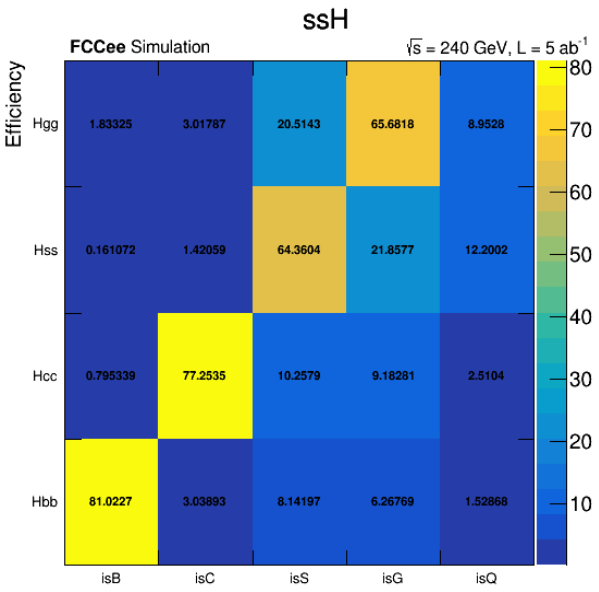




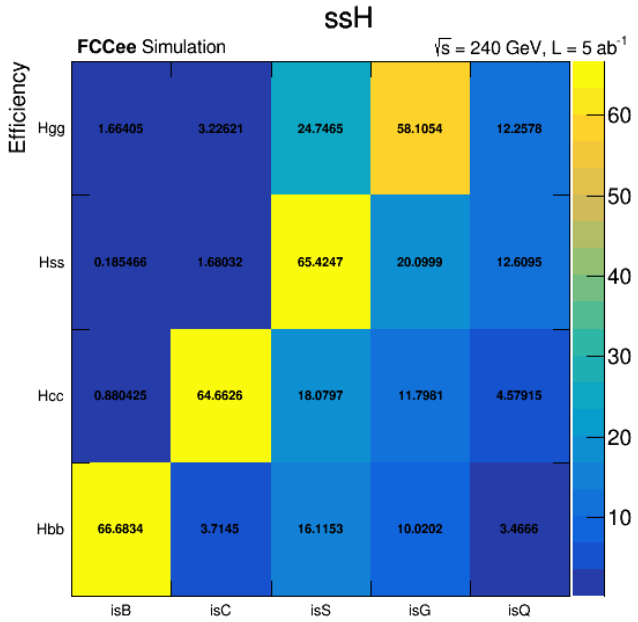
Event Selection

Case: Z(ss) H (bb – cc – ss – gg)

- Check the Jet flavors from H and Z candidates

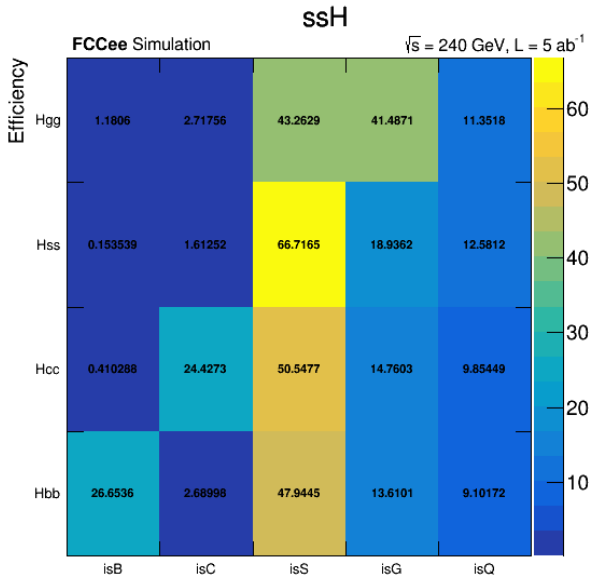


Jet1 coming from Higgs

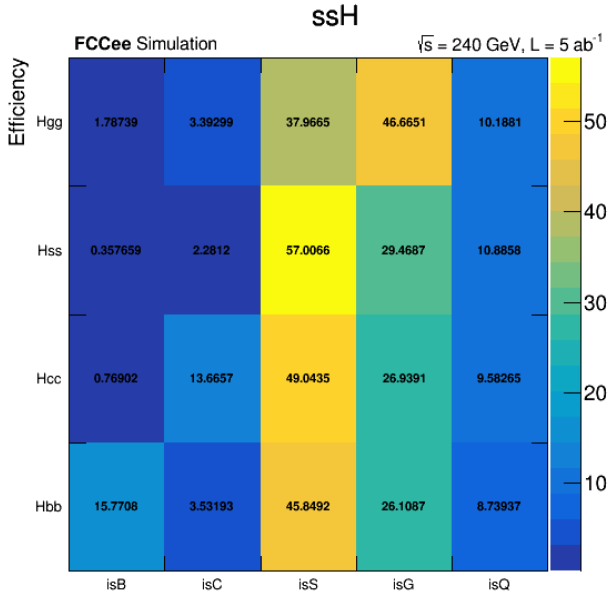


Jet2 coming from Higgs

Jet1 coming from Z



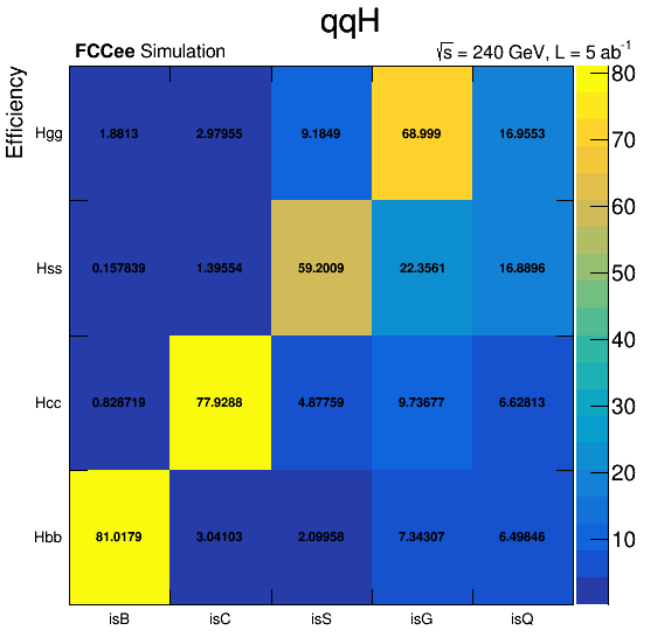
Jet2 coming from Z



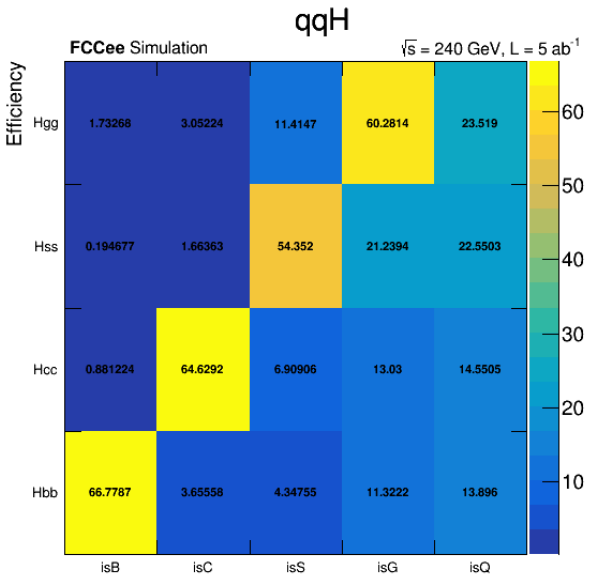
Event Selection

Case: Z(qq) H (bb – cc – ss – gg)

- Check the Jet flavors from H and Z candidates

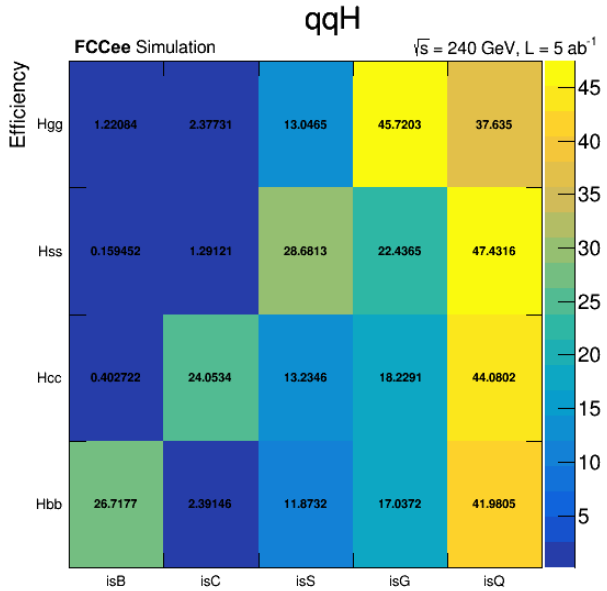


Jet1 coming from Higgs



Jet2 coming from Higgs

Jet1 coming from Z



Jet2 coming from Z