ZH recoil at FCCee Collider

Outline

Part I

- Overview & Motivation
- Global Strategy
- Signal and background samples
- Event selection
- Statistical analysis
- Next / Ongoing Step

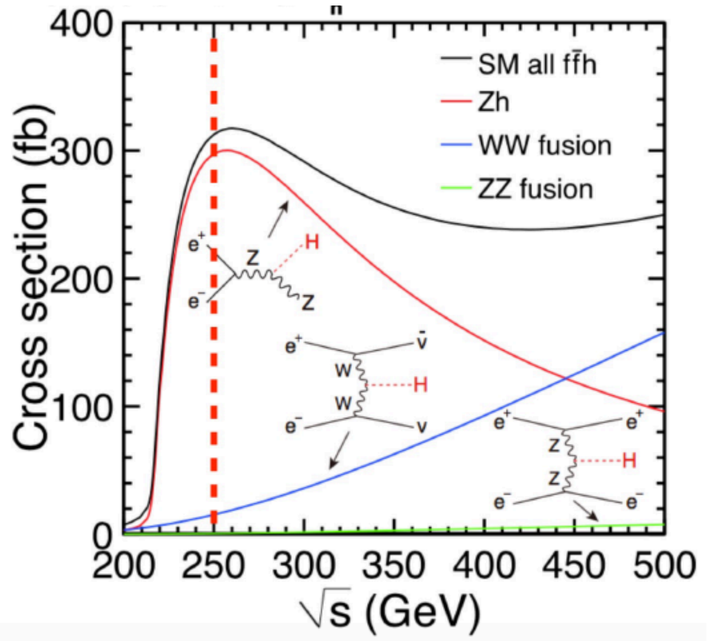
Part II

- Detector Configuration

Overview & Motivation

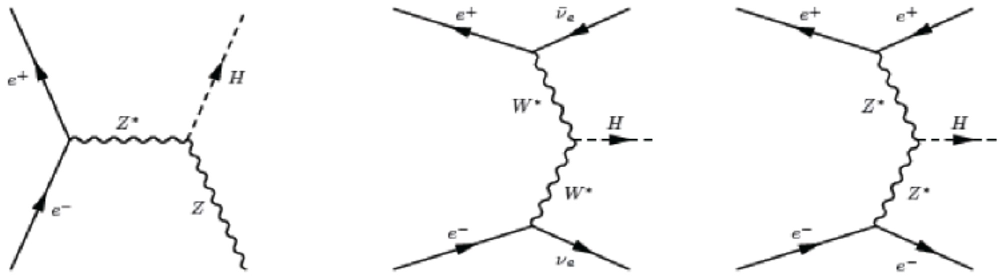
- ZH recoil analysis promising probe for precise Higgs sector measurements:

  - Precise Higgs mass measurement up to ~O(MeV)
  - Model-independent cross-section: sensitive to new physics H → invisible



Higgs production at FCCee:

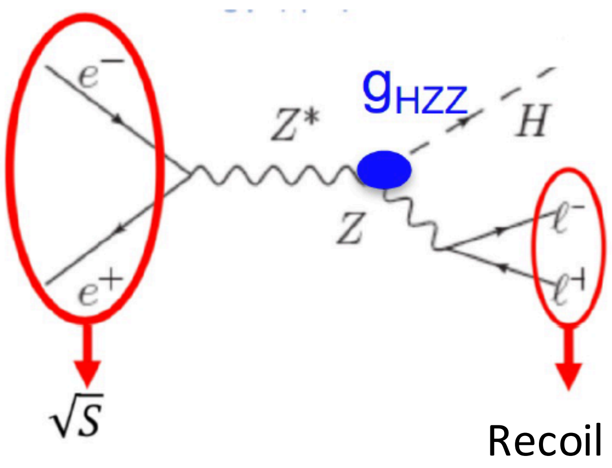
- Higgs-strahlung e e -> ZH
- VBF production e e -> v v H (WW fusion), e e -> e e H (ZZ fusion)



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

Global Strategy of Higgs study (General Stratgy)



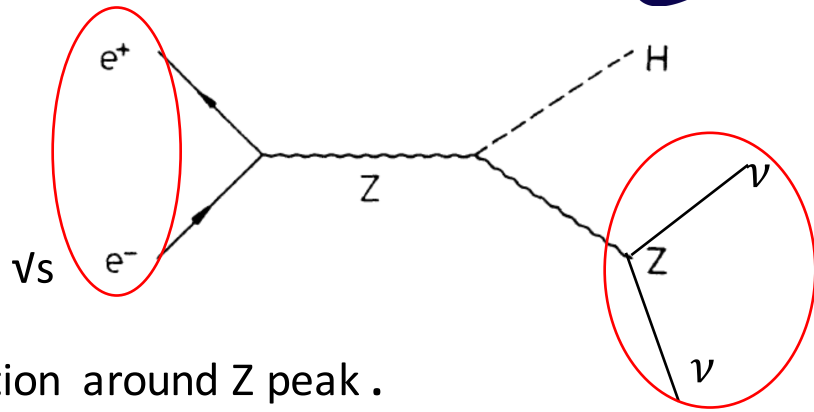
$\sigma(e^+e^- \rightarrow HZ) \propto g^2_{HZZ}$

ZH events tagged by the Z, without reconstructing the Higgs decay. Unique to lepton colliders.

Signal and background samples

Signal: ee → ZH → $\nu\,\nu$ + 2jets

- Considering H decays (gg – bb – cc – ss)
- Considering Z decay to $\nu\,\nu$
- Higgs mass 125 GeV
- **Backgrounds**: vector boson (pair) production (WW, ZZ)
- **Signal extraction:** peak at Higgs mass (reconstructed from jets), recoil mass distribution around Z peak .



Recoil

Monte-Carlo campaign:

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

Signal Samples: “pre_fall2022_training” & “pre_winter2023”

- Z(vv) H (gg) => 0.201868 pb
- Z(vv) H (bb) =>
- Z(vv) H (cc) =>
- Z(vv) H (ss) =>

With nominal Higgs mass 125.00 GeV
Generated with (Whizard+Pythia6)

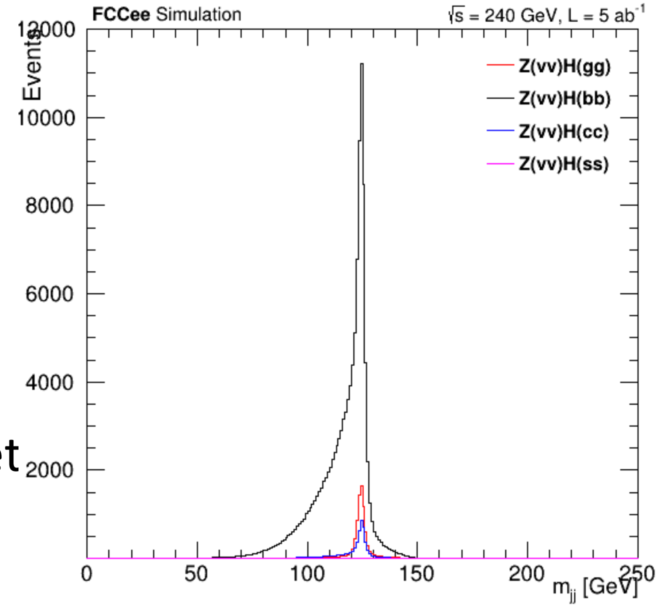
Background Samples: “spring2021”

- ZZ (inclusive decay) => 1.35899 pb
- WW (inclusive decay) => 16.4385 pb

Generated with (Pythia6)

Jet Clustering Algorithm

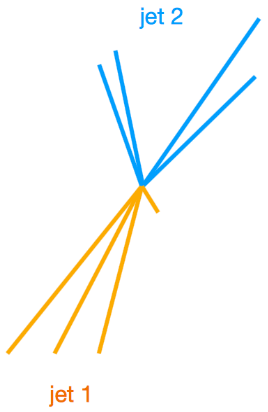
- Reconstruct the hadronic decays of the Higgs boson and separate from backgrounds.
- **Exclusive Durham kt algorithm**
- use distance measures based on energies of particles (E_{ij}) and angles between particles (θ_{ij});
- visible particles: all particles with $\theta_{i,beam} > 0.154$, except neutrinos
- anything that is visible and not an isolated charged lepton is used as input for jet clustering



- Determine distance $\mathbf{d_{ij}}$ between each pair of particles *i*, *j*

$$\boxed{d_{ij} = 2\min(E_i^2, E_j^2)(1 - \cos\theta_{ij})}$$

ask for 2 jets

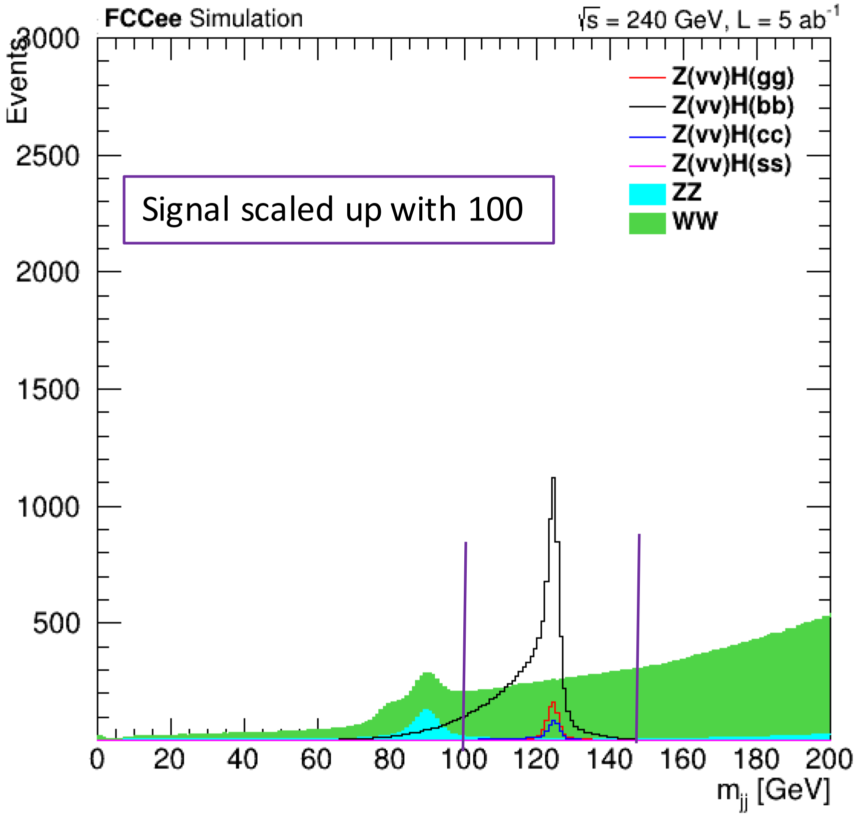


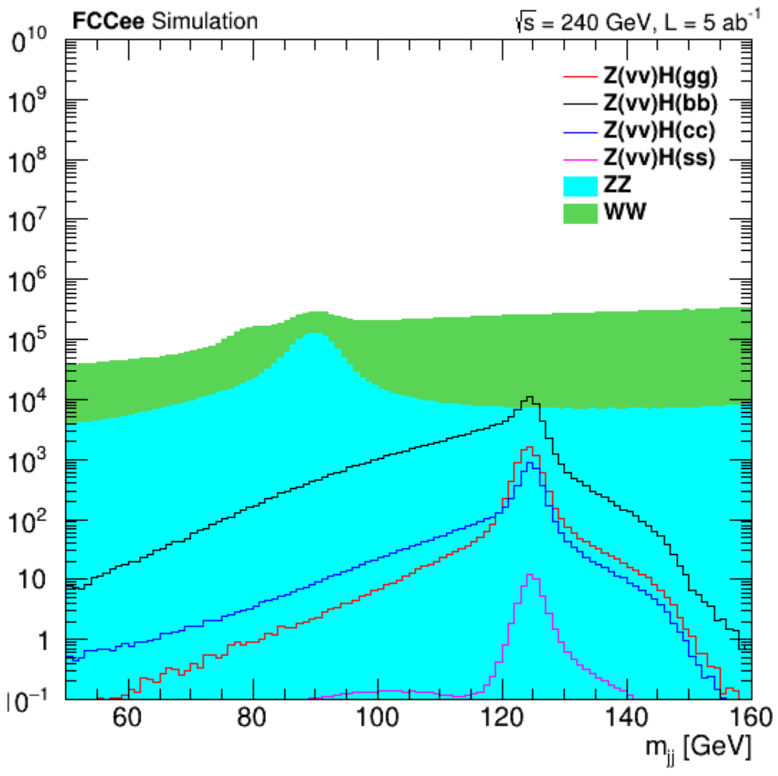
- recombine *i*, *j* pair with smallest *dij*, and update all distances
- Stop when you have reached a predetermined number of jets "<u>**N jets mode**</u>"

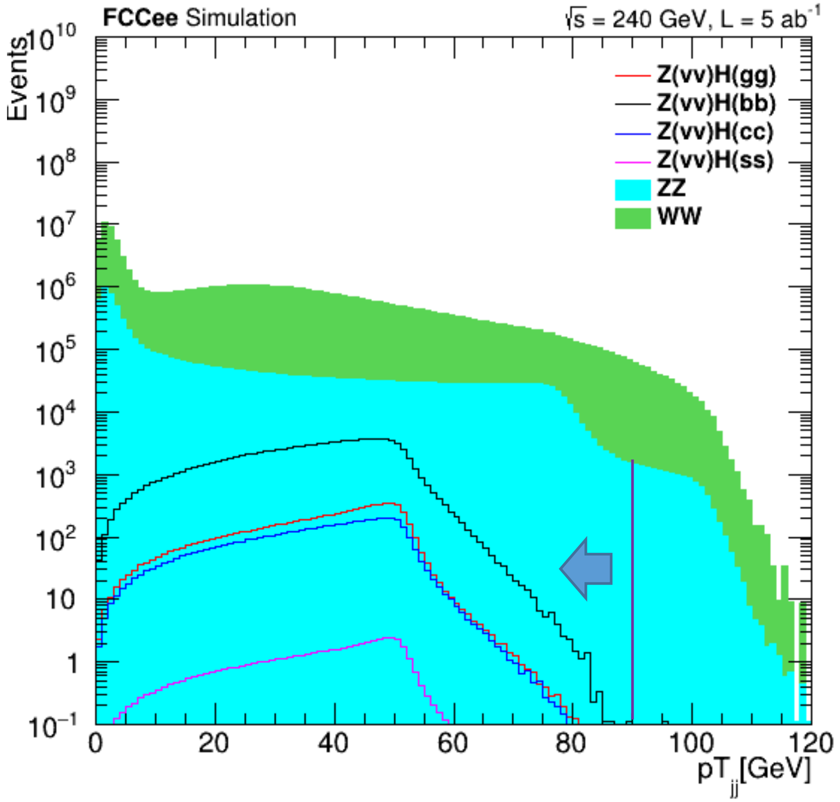
Event Selection

- Using FCCSW analysis tools
- Required at Least 2 Jets in the event
- Dijet mass ($50 < m_{jj} < 160$ GeV) to focus on the H kinematic phase space
- Di jet pT ($pT_{jj} < 90$) signal mainly within this region; can suppress part of background

Preliminary







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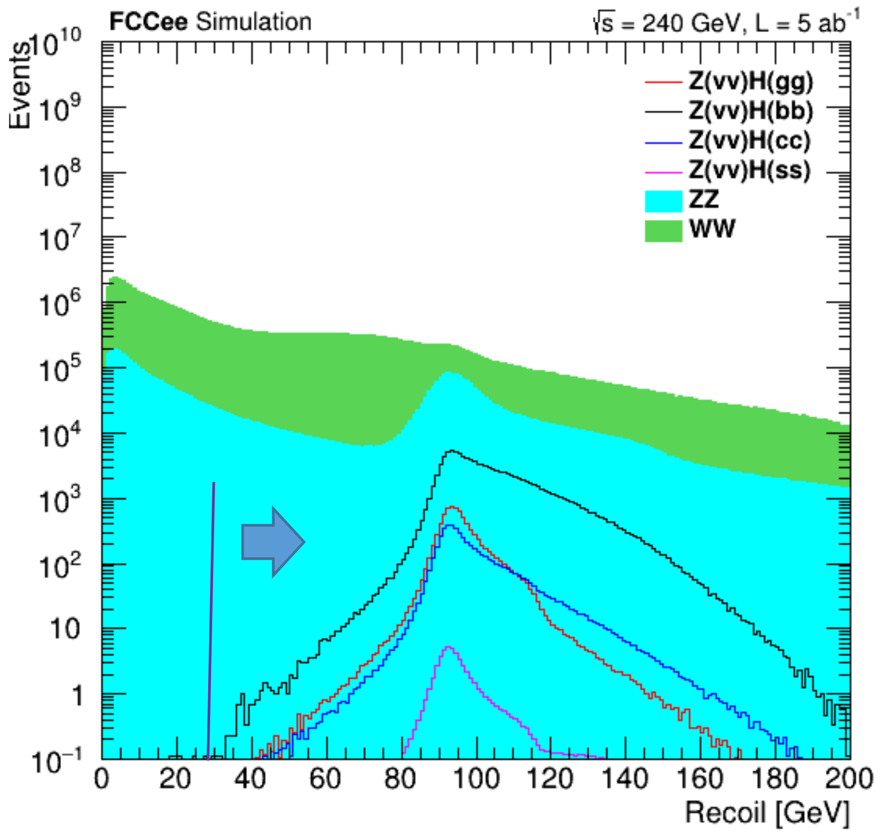
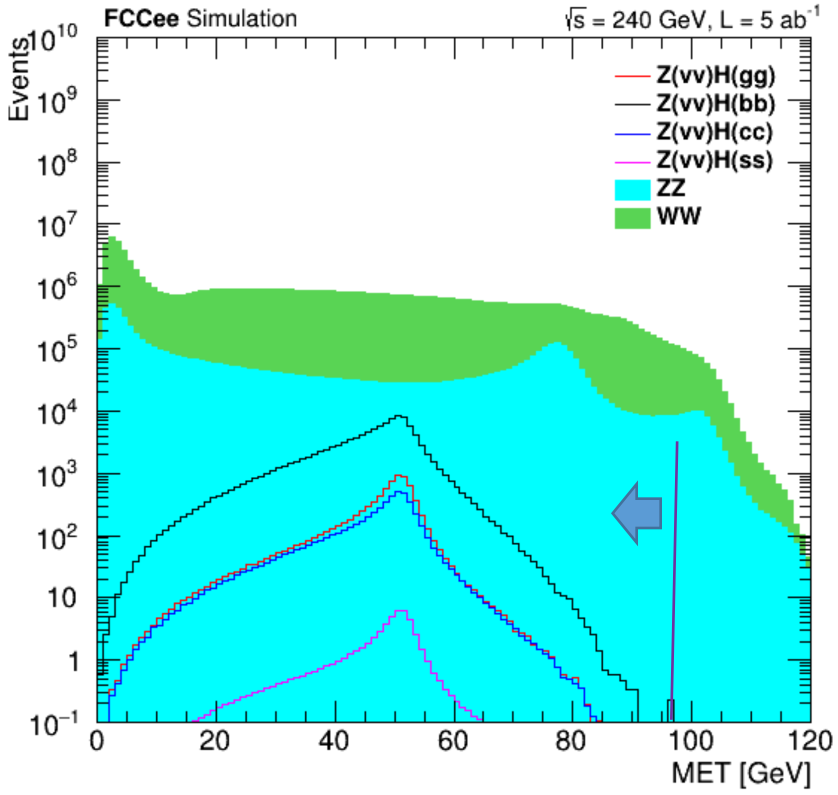
Event Selection

- ➢ Additional cut on recoil mass distribution:
- $M_{rec} > 30$ GeV , recoil around Z peak
- Cut on Missing energy < 90 GeV, suppress WW/ZZ background

Preliminary





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Event Yields

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
- Likelihood scans to extract cross-sections
- without accounting for systematic uncertainties → stat-only result

- **Aim:** study which detector design maximizes expected precision for H → gg, bb, cc , ss final states ?

Signal: e+ e- → Z H → $\nu\,\nu$ + Jets

Signal extraction: peak at Higgs mass (reconstructed from jets), recoil mass distribution around Z peak **. Peak width dominated by detector resolution**.

- visible energy (mass) reconstruction: where resolution is crucial in particular for rare channels

➢ The calorimeter energy resolution playing an important role in the jet energy measurement

- **S** : is the stochastic or "sampling" term, related to statistic fluctuations in the signal.
- **b** : is the "noise" term, related to electronics noise, pileup, etc.
- **C** : is the "constant" term, related to imperfections, non-uniformities, dead material.

HCAL energy resolution

$$\boxed{\frac{\sigma}{E} = \frac{s}{\sqrt{E}} \oplus \frac{b}{E} \oplus c}$$

Stochastic noise Constant

Resolution improves with energy

Part II: Detector Configuration

- Since the calorimeter energy resolution playing an important role in the jet energy measurement, we are studying the effect of

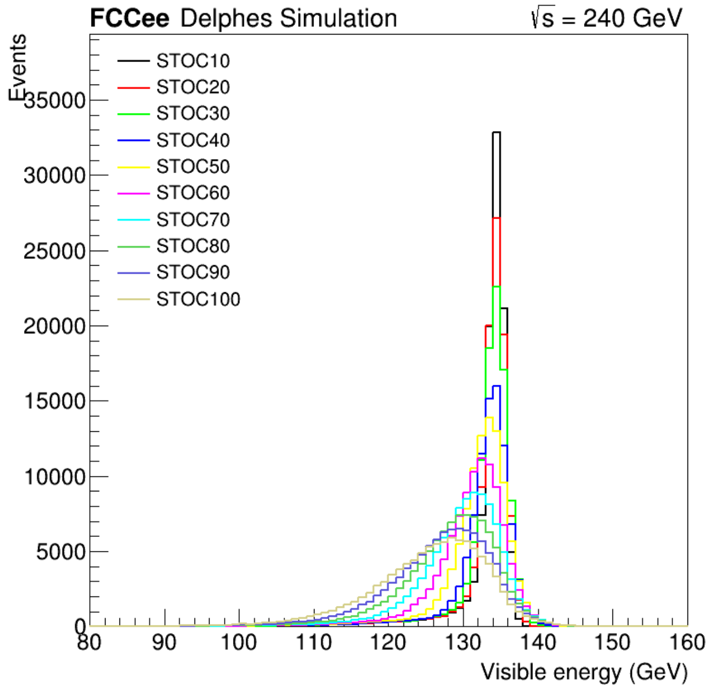
1- Tuning HCAL energy resolution parameters:

- Tuning the stochastic, constant and Noise terms in Delphas cards

2- Tuning the ECAL energy significance

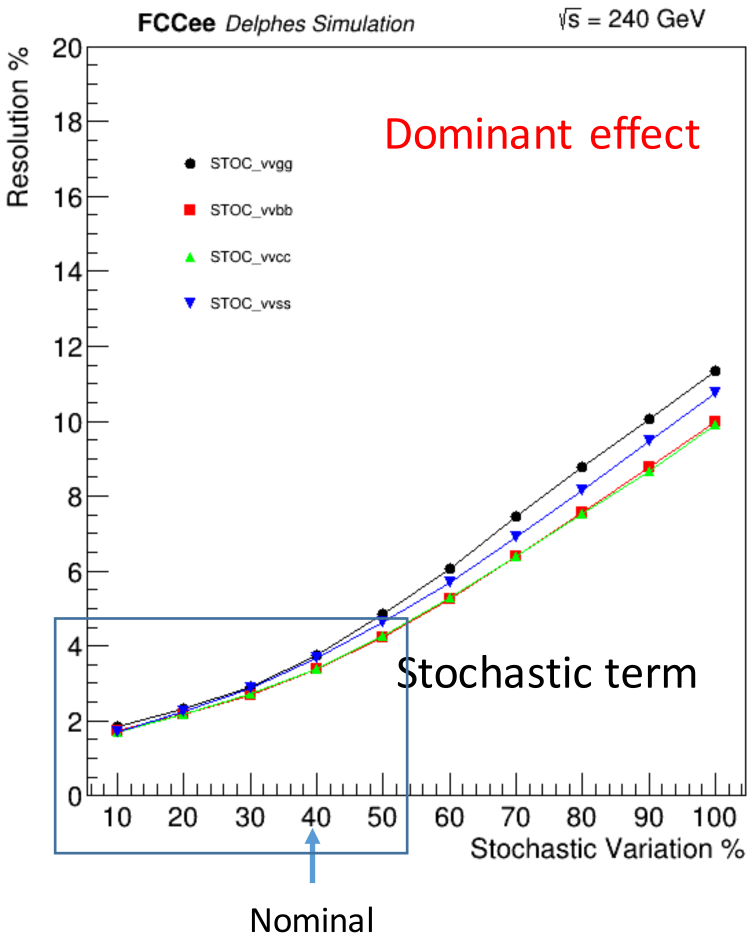
No Jet clustering

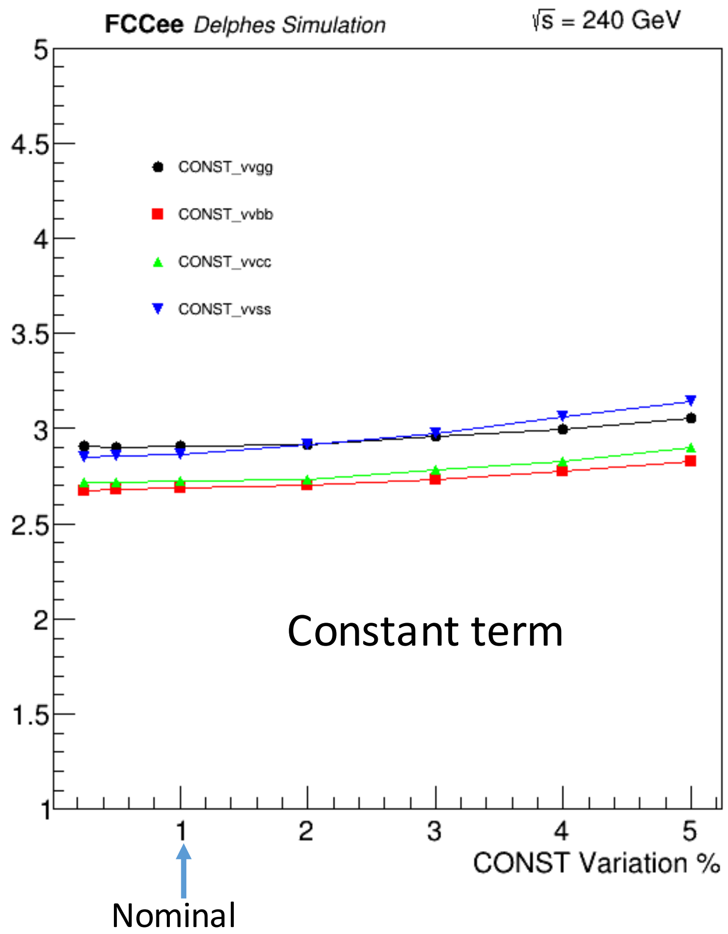
Reconstructed visible Energy

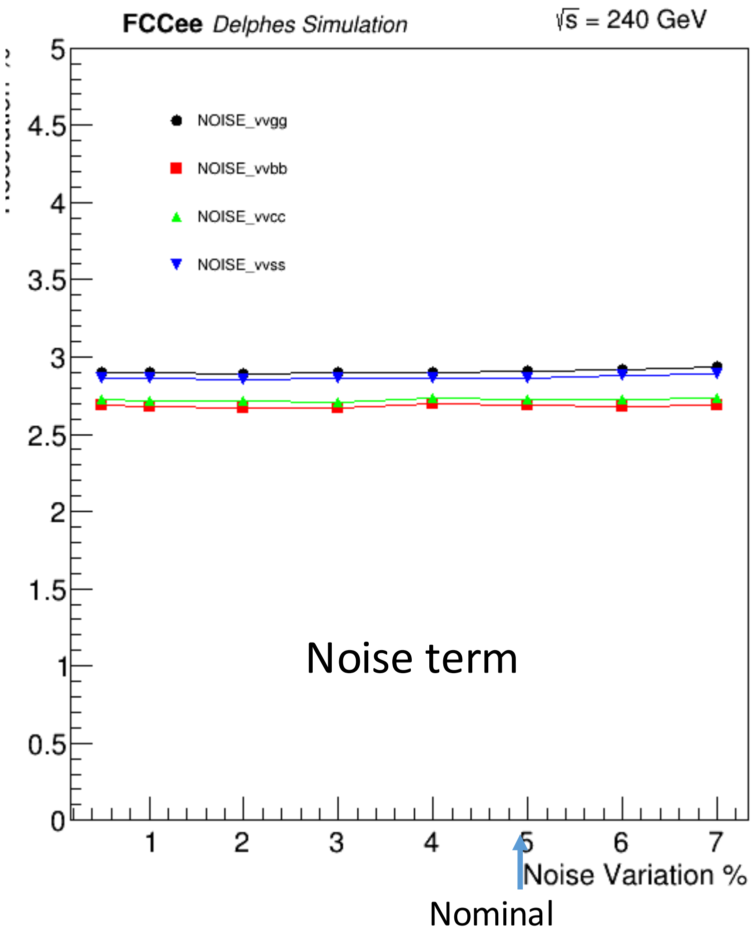


Important: To validate the Delphes card for the MC campaign.

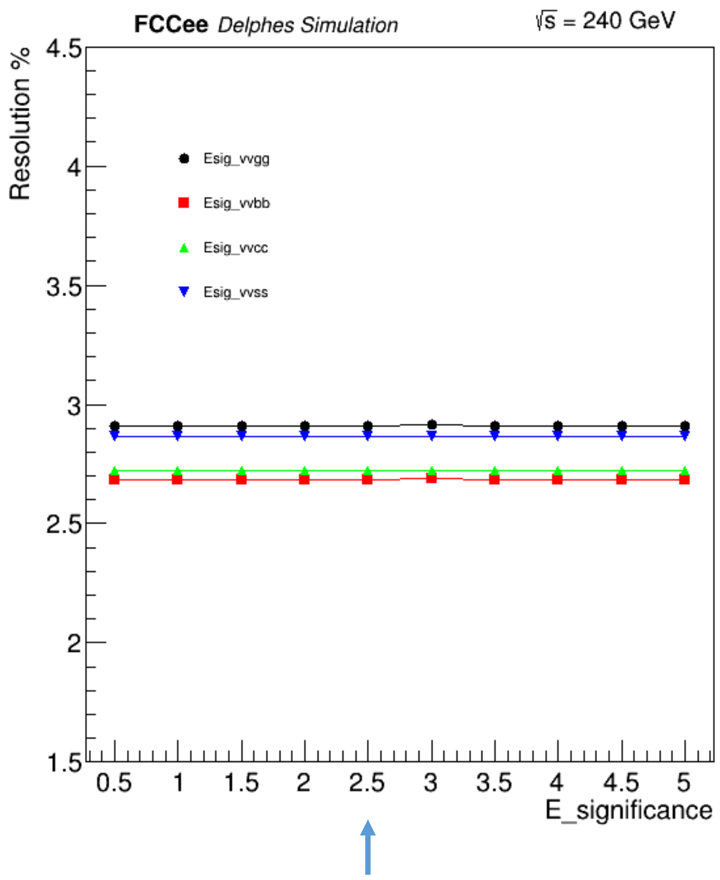
Part II: Detector Configuration







- HCAL energy resolution should not suffer from Constant and Noise terms
- HCAL energy resolution should not suffer from low threshold in stochastic term



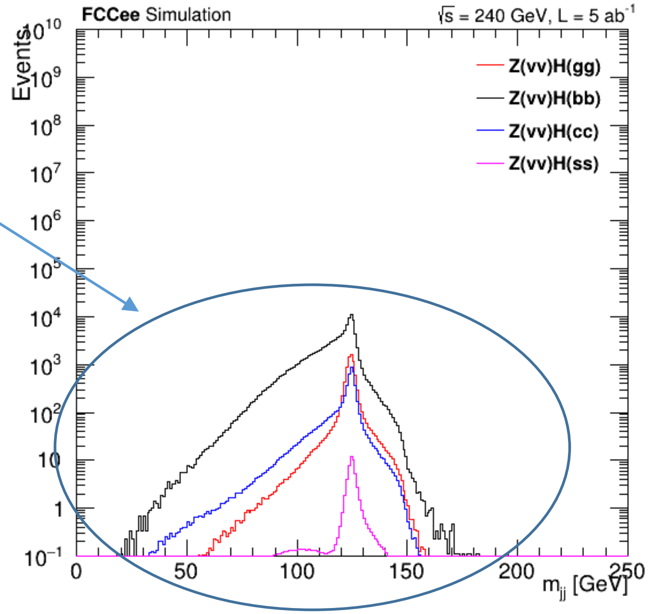
HCAL Energy significance

- HCAL mass resolution should not suffer from low threshold

Next Step

- The analysis is in early stage with a working framework /setup using FCCSW toals

- Compare different Jet clustering algorithms with the aim of improving the resolution.
- Introduce the Jet flavor tagging to the analysis (Particle Net)
- Improve the optimization of event selection to reject more backgrounds, Introducing Boosted Decision Trees !!
- Add the systematic uncertainties

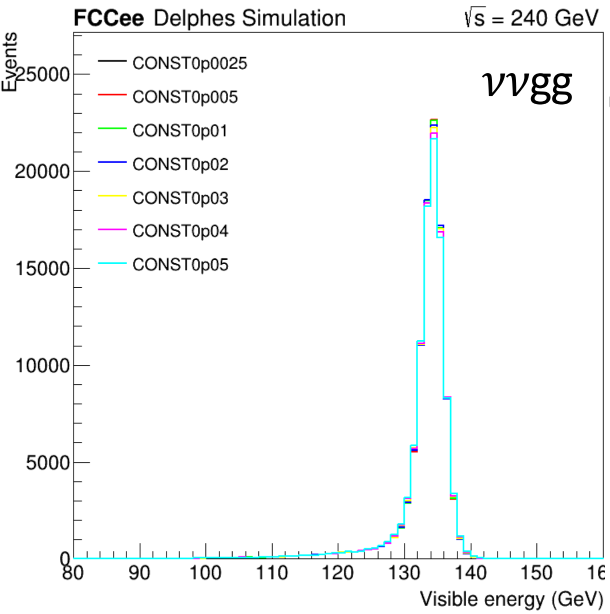


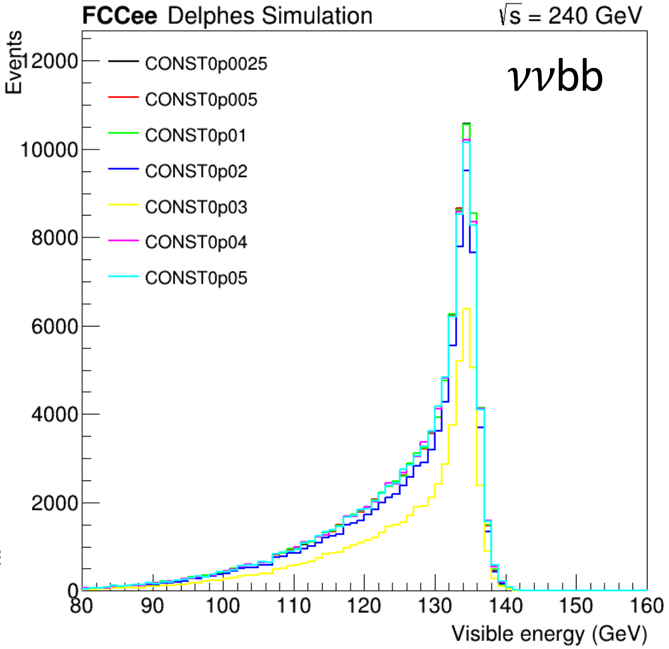
- The analysis is the seed for the ZH analysis with the fully hadronic decay.

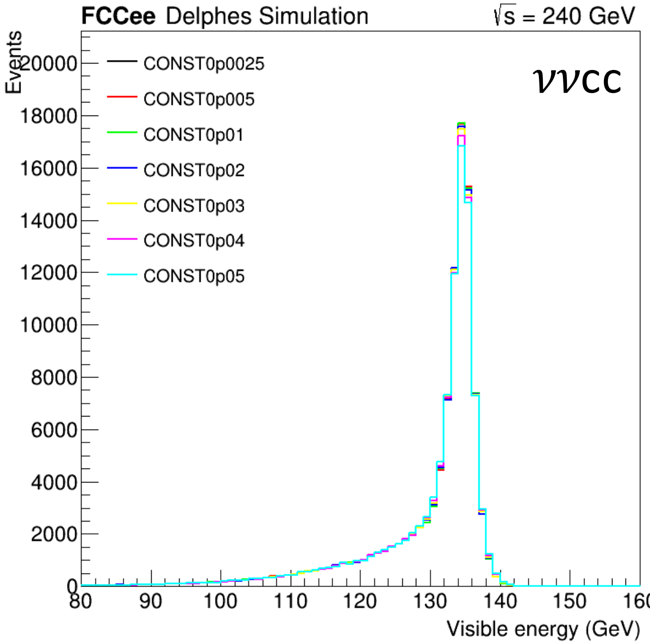
Backup

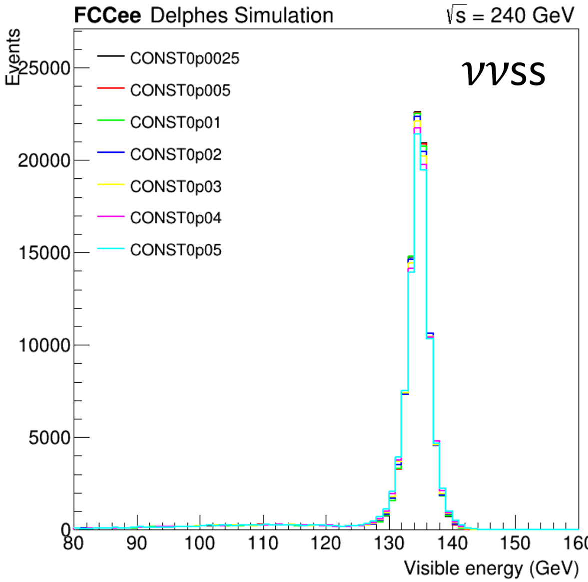
Constant Term

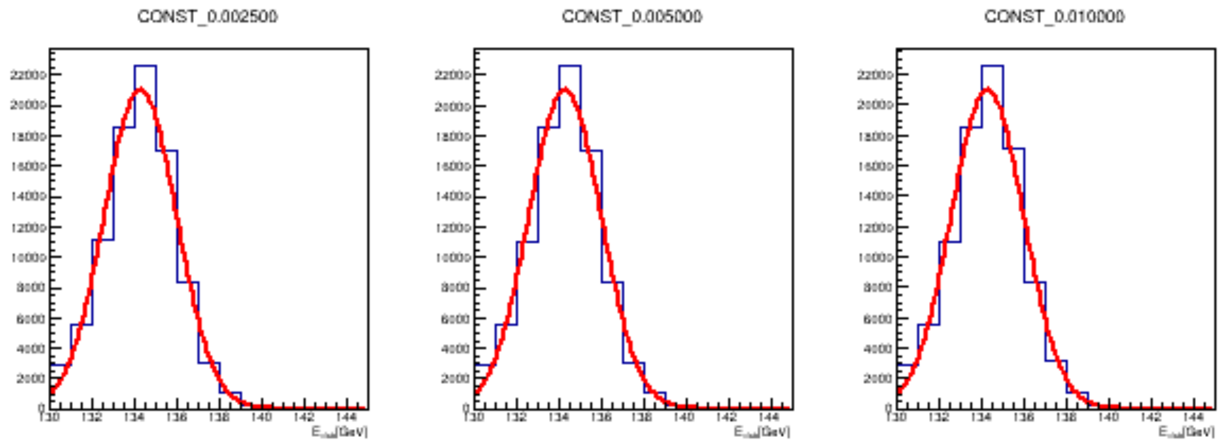
- The nominal value in Delphes Card is 0.01
- We varied this value from 0.0025 to 0.05 [0.0025 – 0.005 – 0.01 – 0.02 – 0.03 – 0.04 – 0.05]

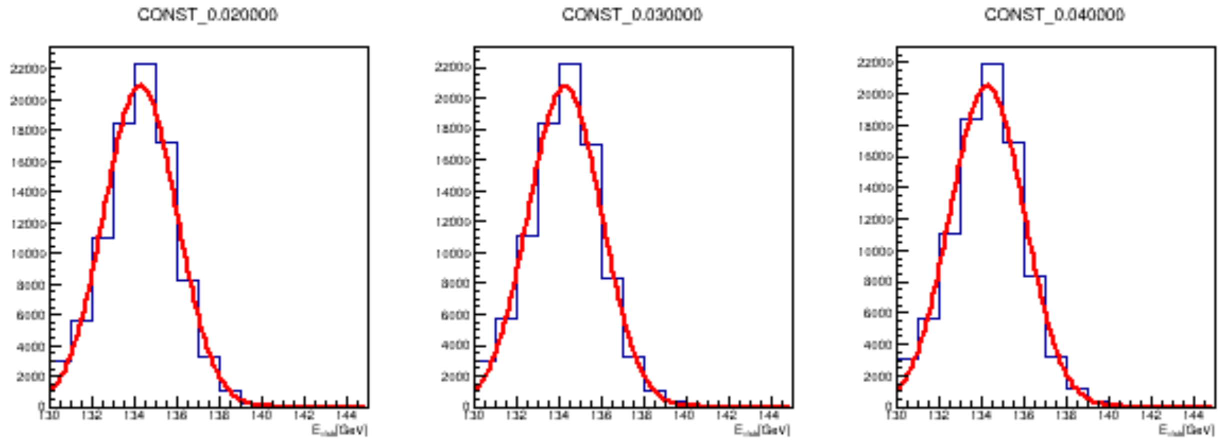


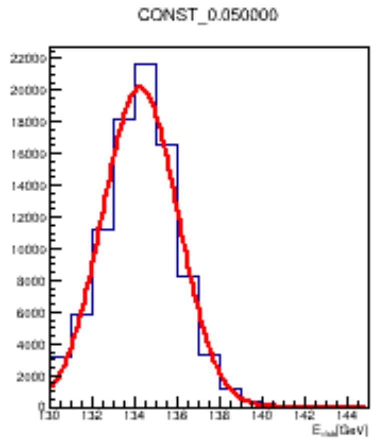




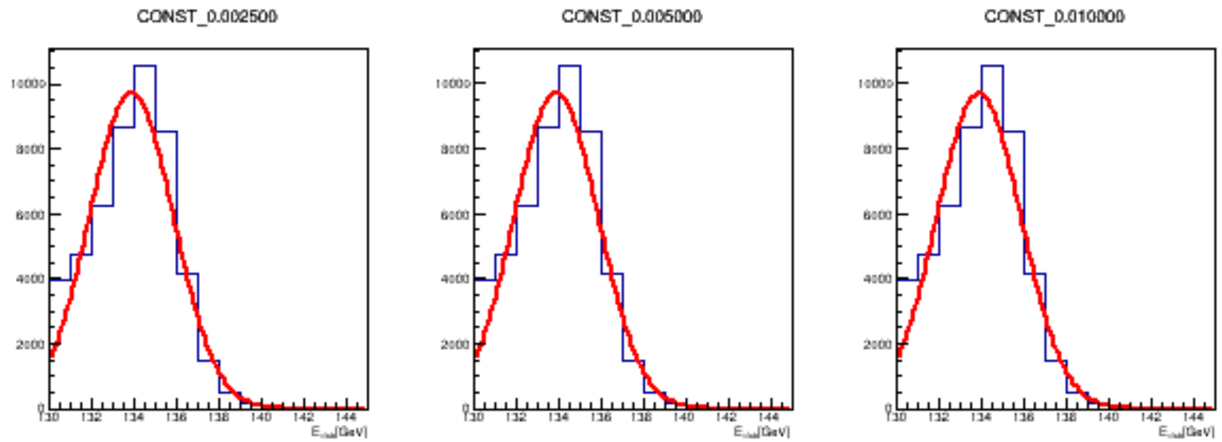


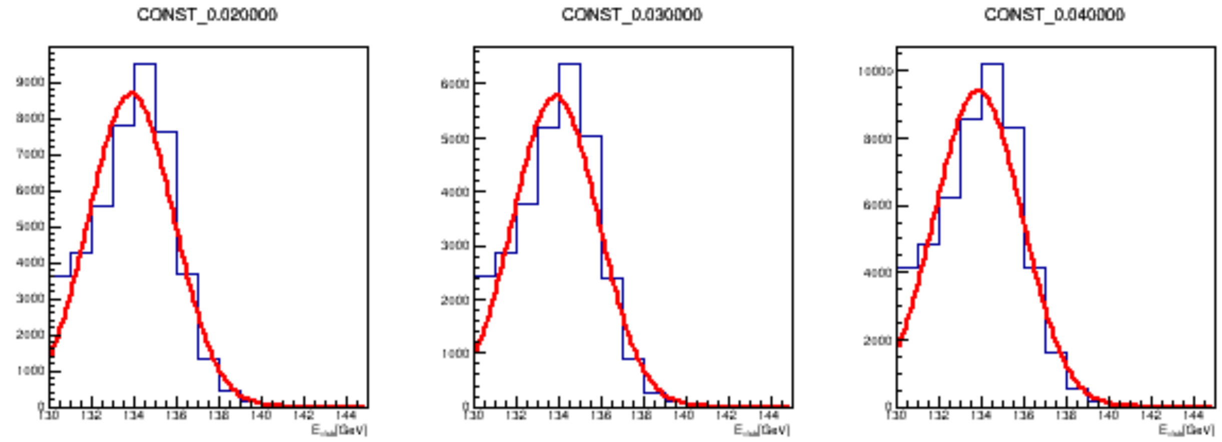


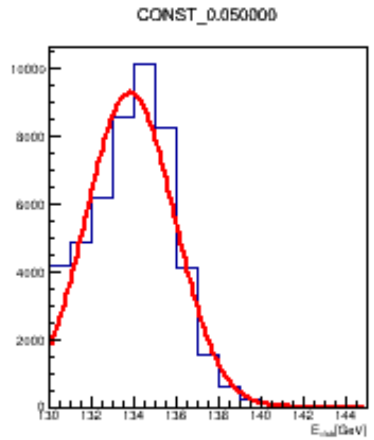




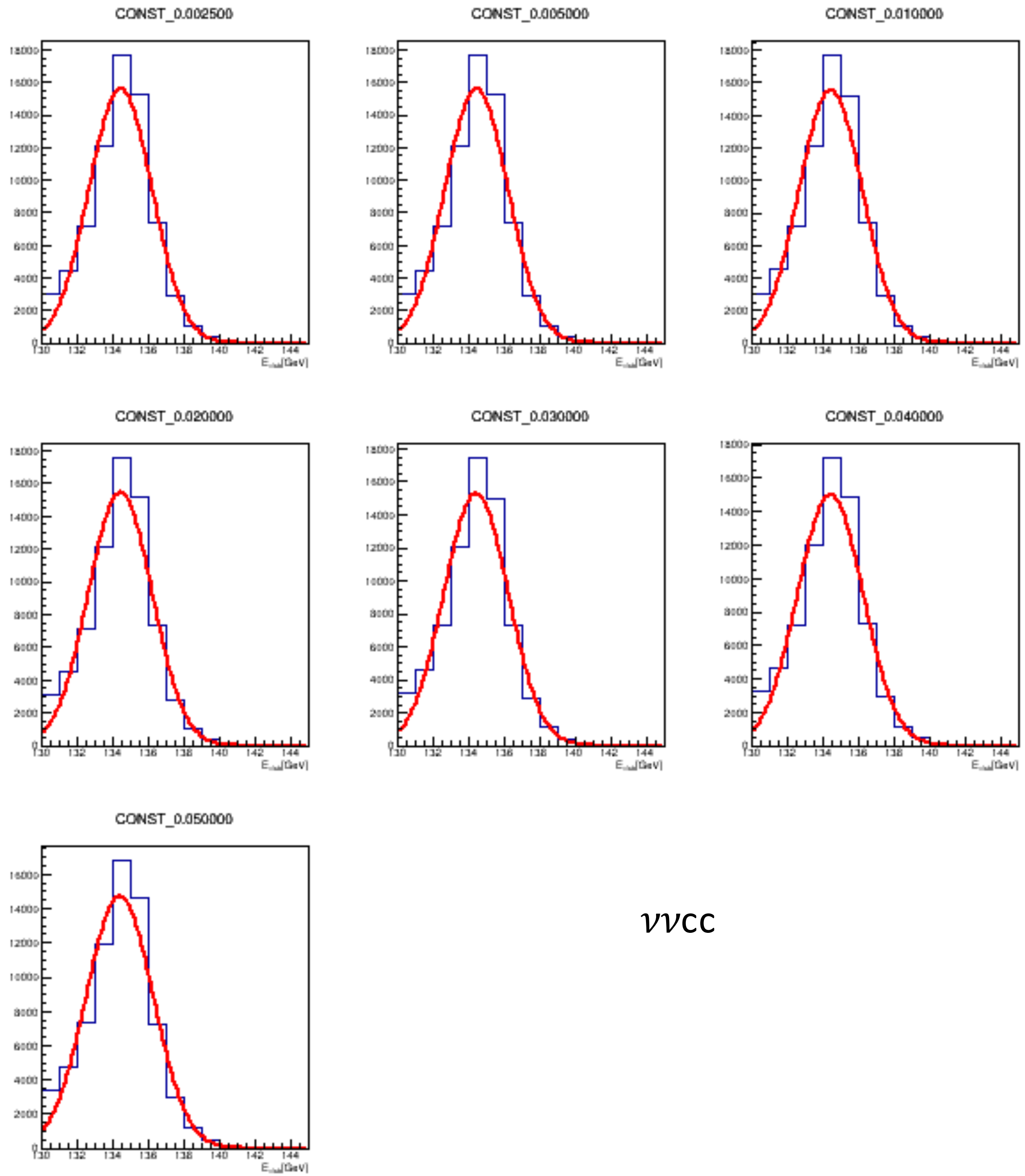
$\nu\nu$gg



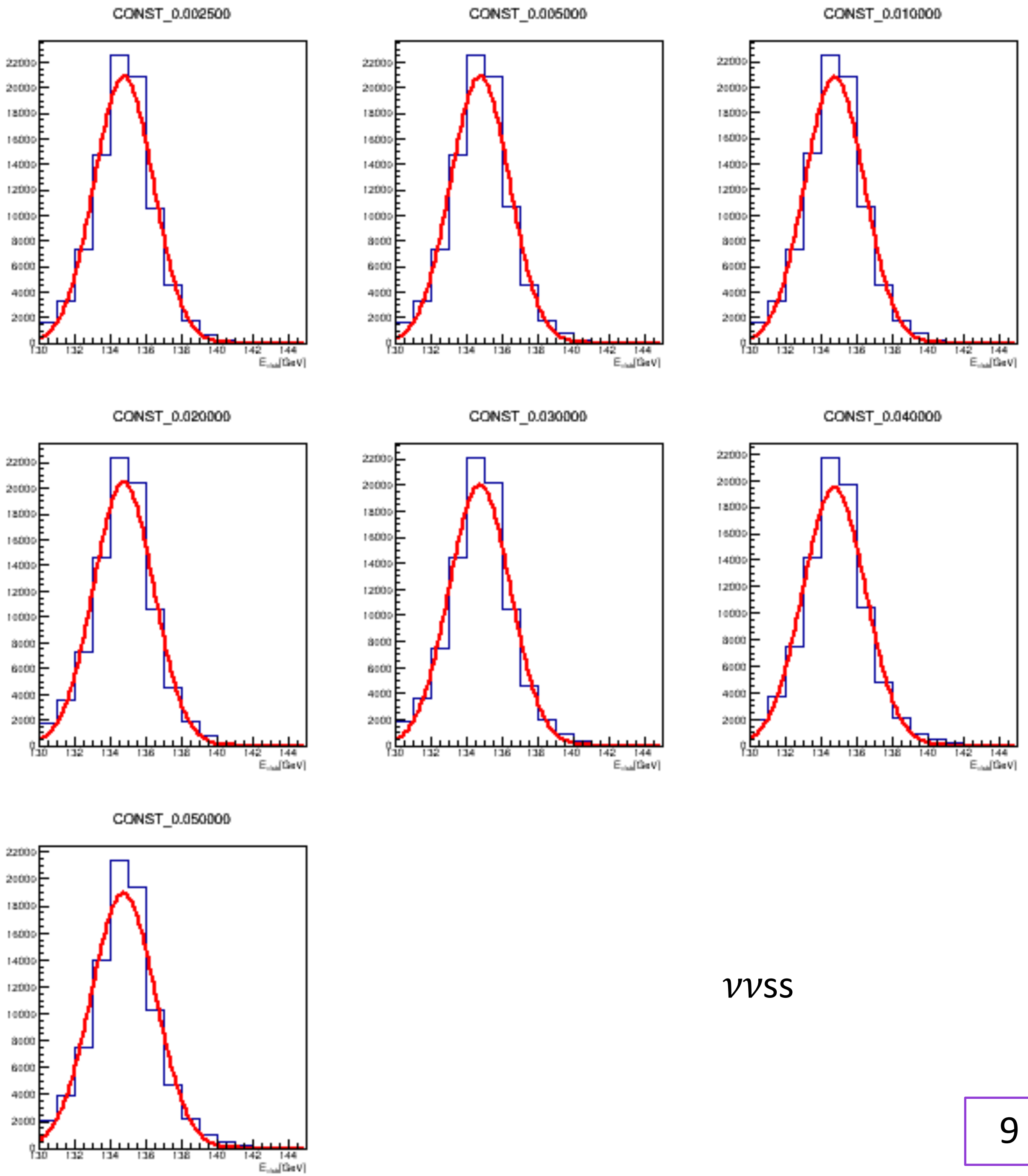




$\nu\nu$bb



$\nu\nu cc$



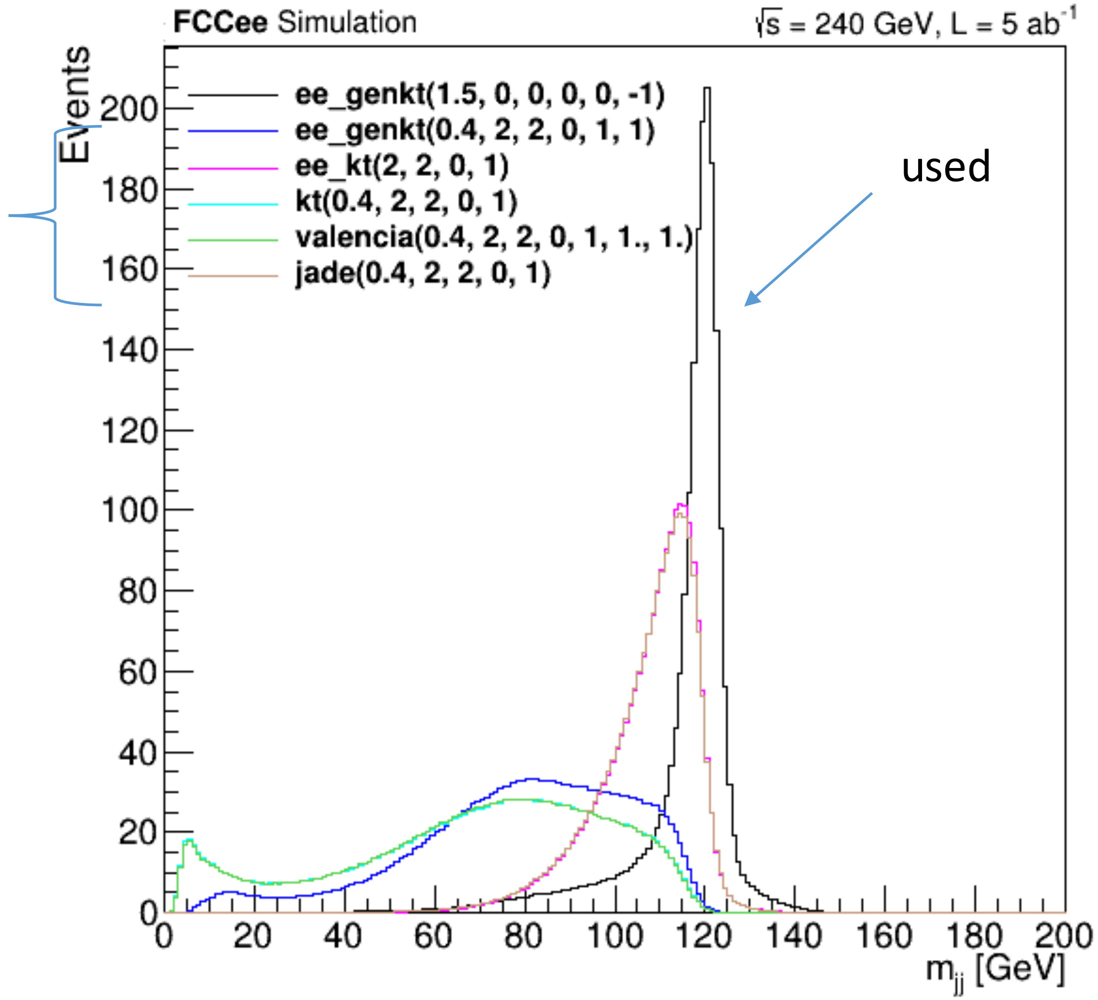
$\nu\nu ss$

Jet Clustering Algorithm

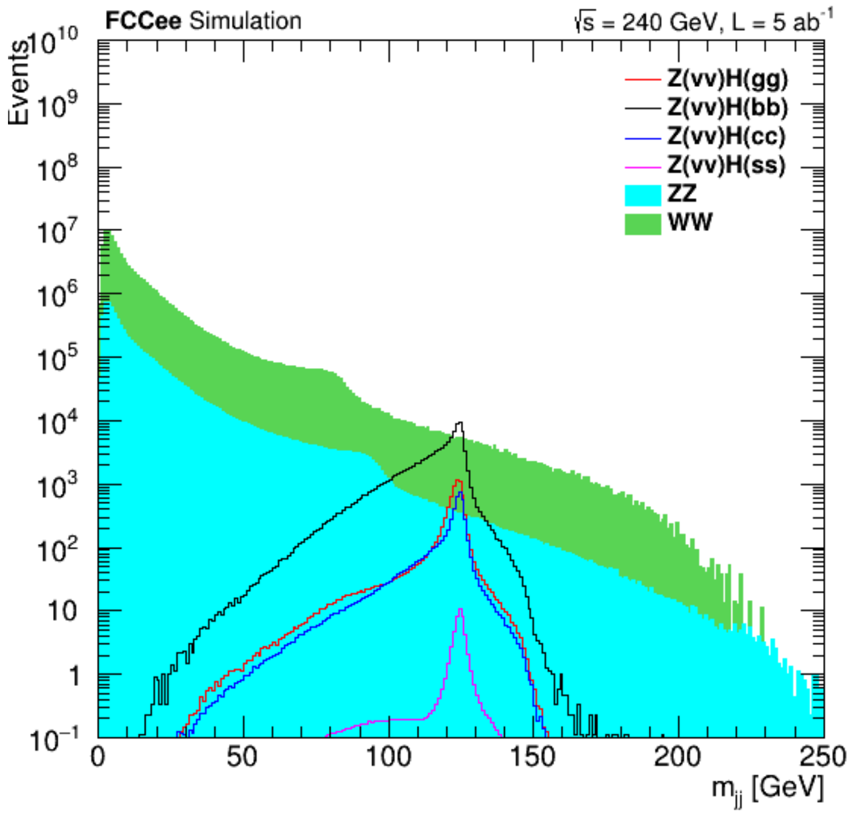
- Different Jet clustering Algorithms have been tested (ee_genkt – ee_kt - kt – valencia - jade) from FCCSW "JetClustering"

- Clustering parameters (Jet cone radius , Exclusive, Cut, Sorted, recombination, exponent)

- Most of algorithms using
  - Jet radius = 0.4
  - Exclusive clustering "2"
  - With Njets = 2
  - Sorted with pT Ordering
  - pT recombination scheme
- Except ee_genkt (1.5, 0,0,0, 0, -1) => antikt



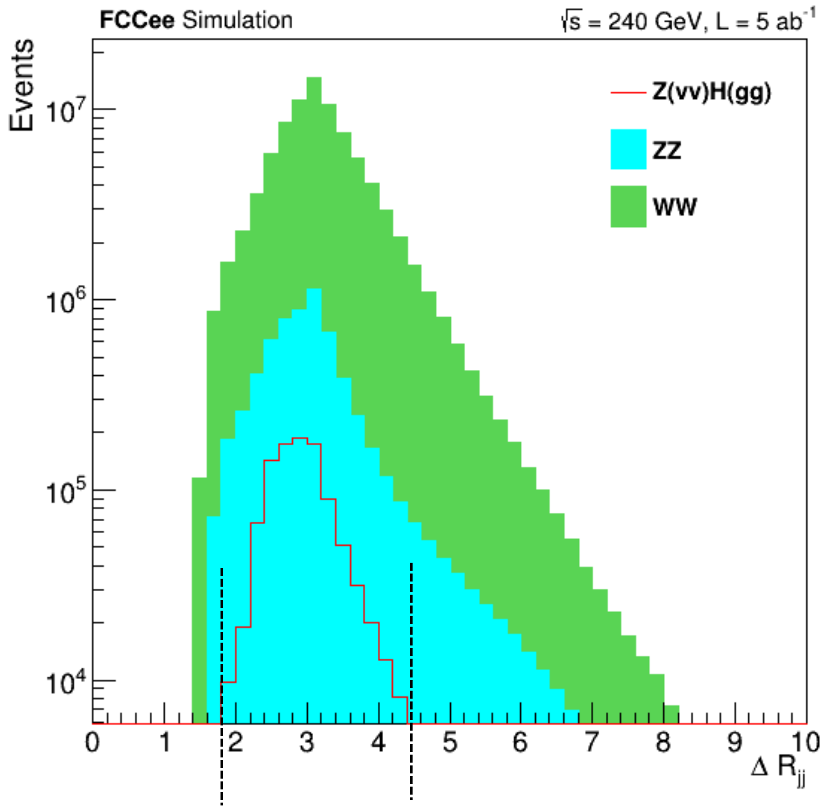
Outline



FCCee Simulation
√s = 240 GeV, L = 5 ab-1
Events
Z(vv)H(gg)
Z(vv)H(bb)
Z(vv)H(cc)
Z(vv)H(ss)
ZZ
WW
m_jj [GeV]

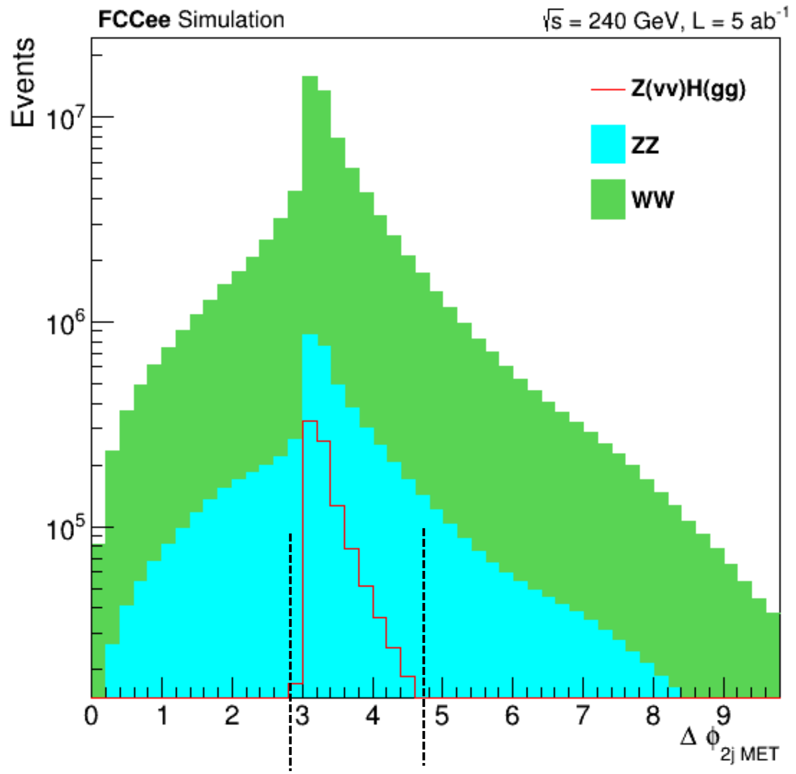
Objects

ΔR (j1, j2)



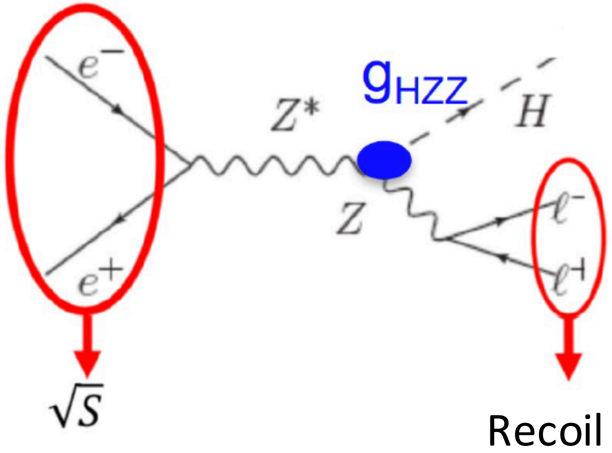
2 > ΔR > 4

ΔR (dijet, MET)



3 > ΔR > 4.5

Global Strategy of Higgs study (General Stratgy)



$\sigma(e^+e^- \to HZ) \;\alpha\; g^2_{HZZ}$

ZH events tagged by the Z, without reconstructing the Higgs decay. Unique to lepton colliders.

A fit to the recoil/Higgs mass distribution allows :

- measurement of $\sigma(ZH)$ independent of the Higgs decay mode with O(%) uncertainty.

Hence an absolute determination on g_{HZZ}

→ $\delta g_{HZZ}/g_{HZZ}$ ~ 0.2 % (also including Z→had)

a precise meas. of the **Higgs mass** → $\delta m_H/m_H$ ~ O(MeV)

Known g_{HZZ} it is possible to measure σ x BR for specific Higgs decays

$$\sigma_{ZH} \times \mathcal{B}(H \to X\overline{X}) \propto \frac{g^2_{HZZ} \times g^2_{HXX}}{\Gamma_H}$$

- $H \to ZZ^*$ provides Γ_H
- $H \to XX$ provides g_{HXX}

$H \to ZZ^*$ provides Γ_H :
$$\frac{\sigma(e^+e^- \to ZH)}{BR(H \to ZZ^*)} = \frac{\sigma(e^+e^- \to ZH)}{\Gamma(H \to ZZ^*)/\Gamma_H} \simeq \left[\frac{\sigma(e^+e^- \to ZH)}{\Gamma(H \to ZZ^*)}\right]_{SM} \times \Gamma_H$$

→ $\delta\Gamma_H / \Gamma_H$ ~ several %

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