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Higgs Hadronic decays at FCCee Collider

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Outline

Part I

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

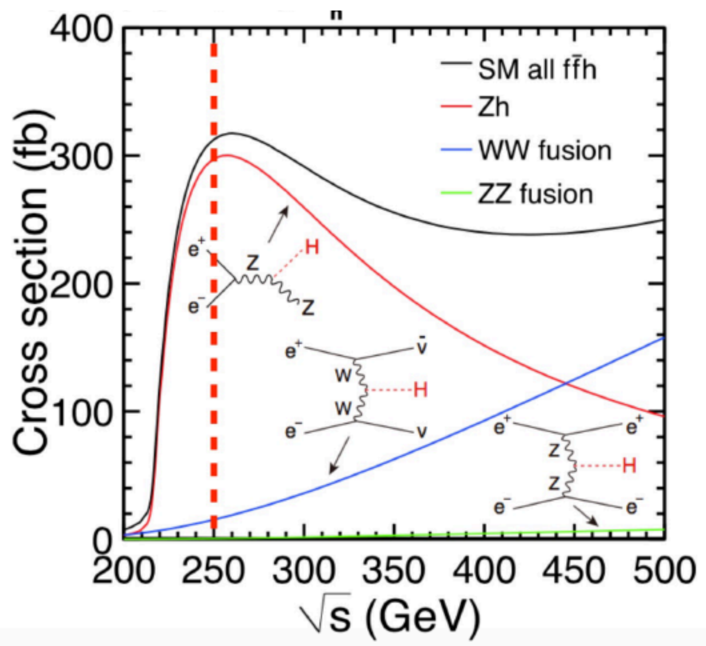
Part II

- Detector Configuration

Overview & Motivation

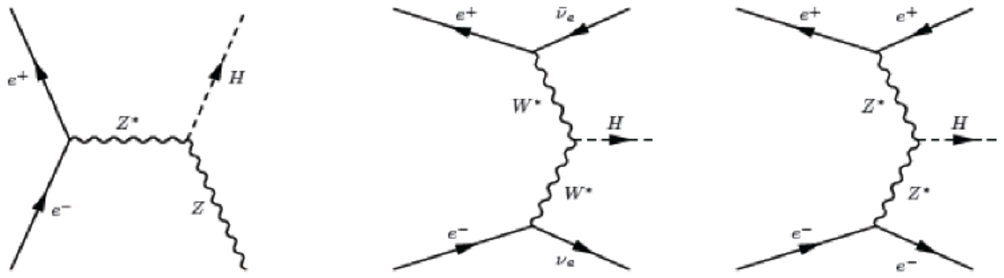
- ZH recoil analysis promising probe for precise Higgs sector measurements:

  - 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)

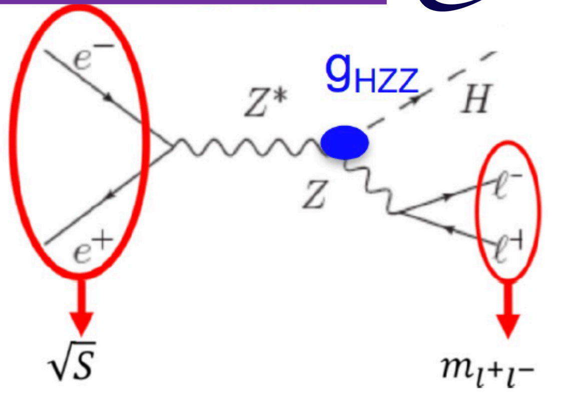


10⁶ ZH events @ 240 GeV 5 /ab

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 Strategy)

- In ZH analysis we can:
  - Measure the inclusive cross section of the Higgs decay using the information of the recoil mass (without reconstruction of the Higgs decays) => a unique advantage of the lepton collider. $\sigma(e^+e^- \to HZ) \; \alpha \; g^2_{HZZ}$



  - measurement of σ(ZH) with O(%) uncertainty. Hence a determination on g_{HZZ}
  - Allow to have uncertainty on Higgs mass measurement ~ O(MeV)

Ang Li slides

Recoil

  - Knowing g_{HZZ} it is possible to measure σ x Br for specific Higgs decays:
    - looking at Higgs decay H->ZZ* allow to measure the Higgs decay width knowing the ration between inclusive and exclusive corss section $\Rightarrow$ $$\sigma_{ZH} \times \mathcal{B}(H \to X\bar{X}) \propto \frac{g^2_{HZZ} \times g^2_{HXX}}{\Gamma_H}$$
    - Then we start to probe the coupling of Higgs with other particles => Looking to events with Higgs decay to bb – gg – cc – ss – WW – tt – μμ - $\gamma\gamma$ - Zγ …..

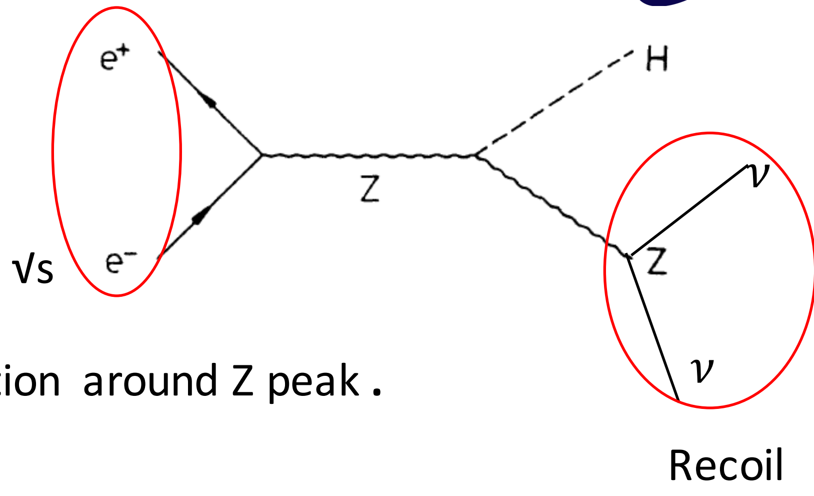
g_{Hbb} , g_{Hcc} , g_{Hgg} , g_{HWW} , g_{Htt} , $g_{H\gamma\gamma}$, $g_{H\mu\mu}$, $g_{HZ\gamma}$, … $\Rightarrow$ Higgs Hadronic Decay

- **ZH analysis with Z(νν)H (hadronic) is IDEAL analysis:**
  - ideal jet regime where all jets are known to come from the Higgs
  - We have explicit signal samples for each Higgs decay mode, meaning a perfect disentanglement of the final stats ("perfect tagger").

Signal and background samples

Signal: $ee \rightarrow ZH \rightarrow \nu\,\nu + 2\text{jets}$

- 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 .



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) => 0.0033053866 pb
- Z(vv) H (bb) => 0.023513584 pb
- Z(vv) H (cc) => 0.0011672008 pb
- Z(vv) H (ss) => 1.2112080e-05 pb

~ 1- 2 Million events

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

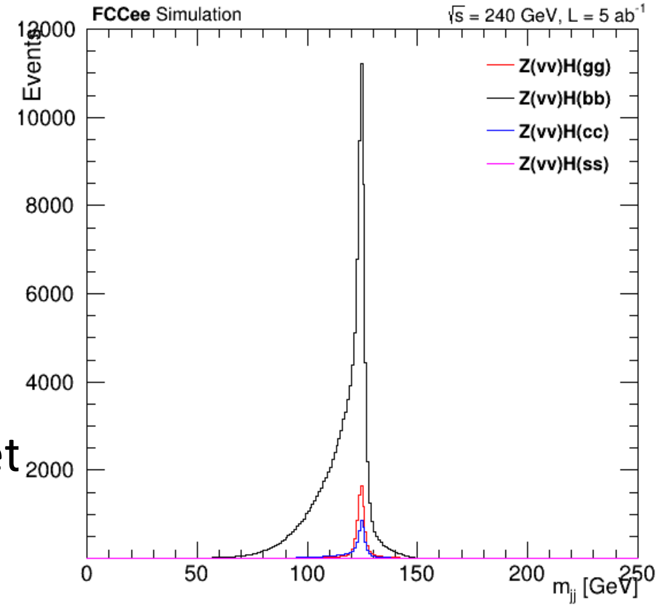
Background Samples: "spring2021"

- ZZ(inclusive decay) => 1.35899 pb — 59,800,000 events
- WW(inclusive decay) => 16.4385 pb — 10,000,000 events

Generated with (Pythia6)

Jet Clustering Algorithm

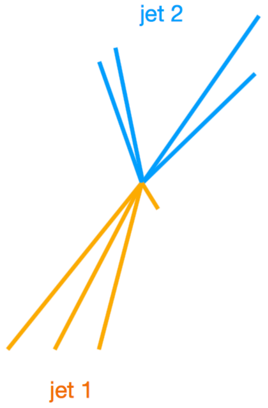
- Reconstruct the hadronic decays of the Higgs boson and separate from backgrounds.
- **Exclusive Durham kt algorithm**
- use distance measures based on energies of particles (E_{ij}) and angles between particles (θ_{ij});
- visible particles: all particles with $\theta_{i,beam} > 0.154$, except neutrinos
- 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



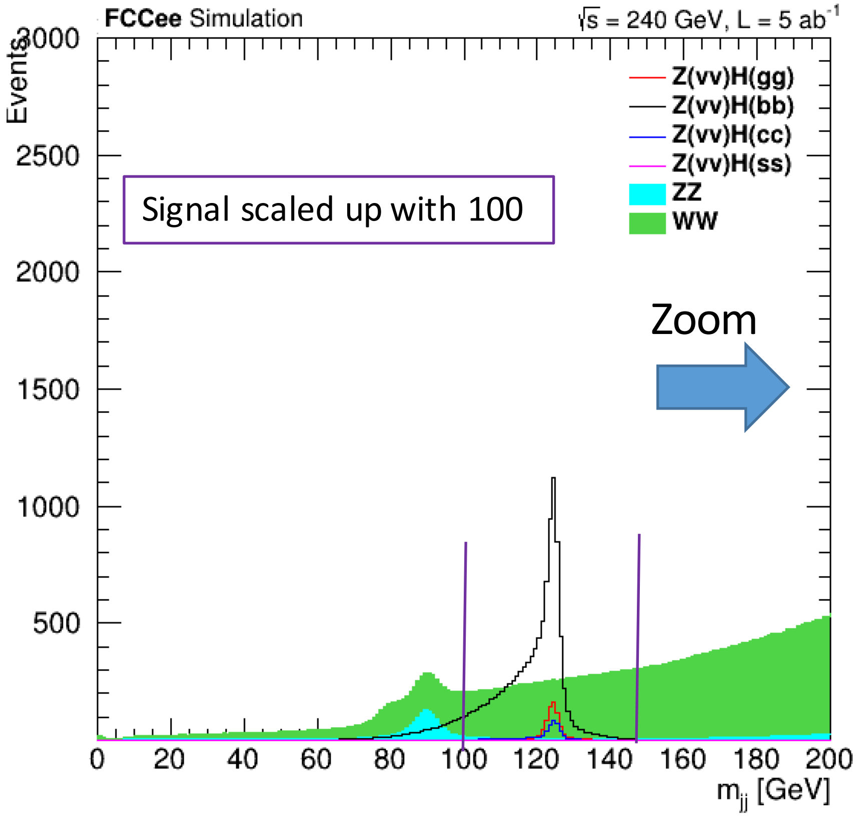
- recombine *i, j* pair with smallest *dij*, and update all distances
- Stop when you have reached a predetermined number of jets "**N jets mode**"

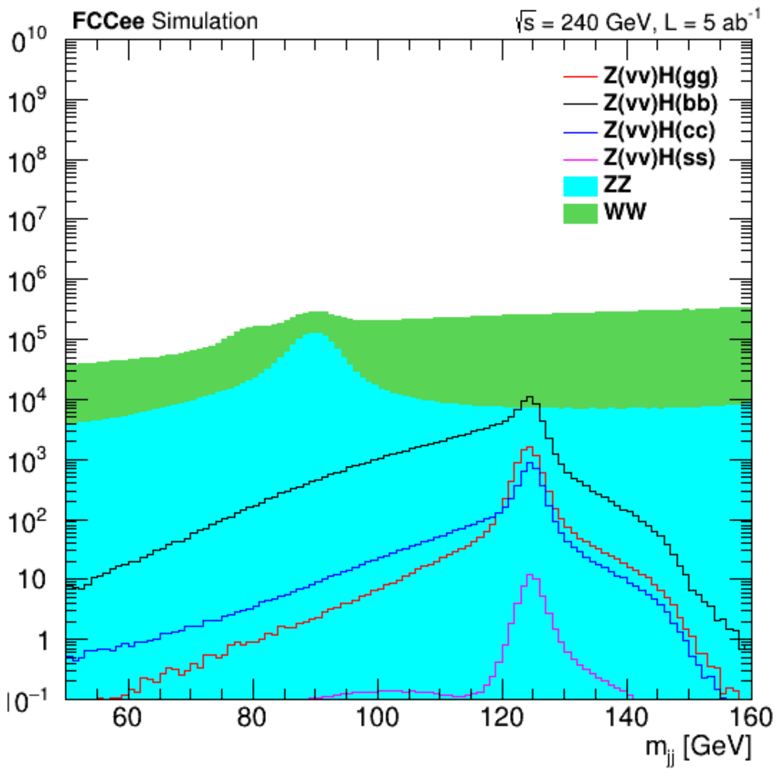
- Still studies ongoing in optimizing the jet algorithm and parameters.

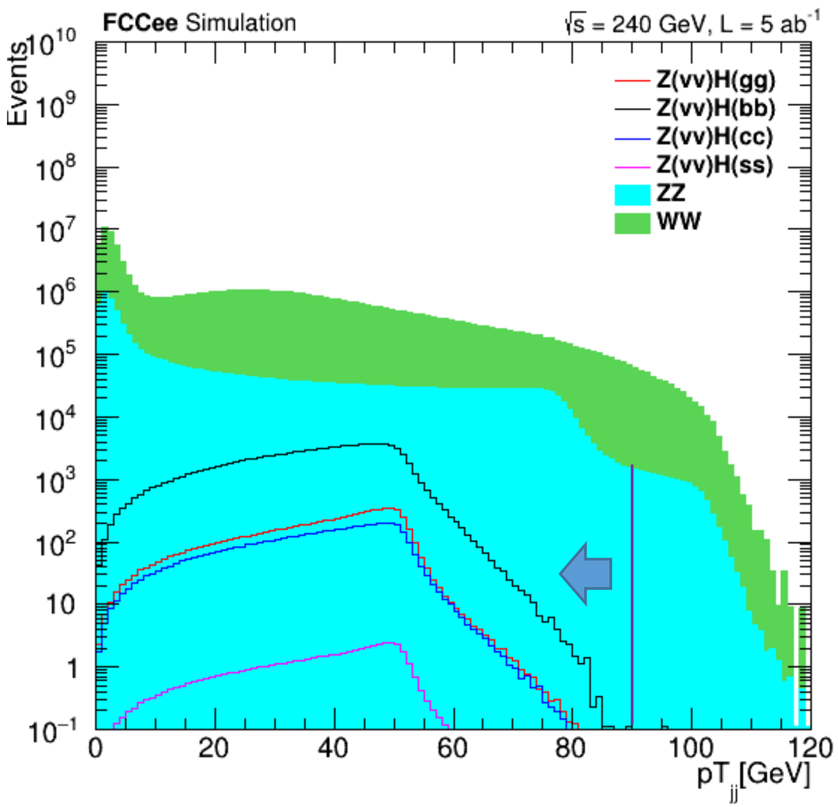
Event Selection

Preliminary to be optimized

- Using FCCSW analysis tools
- Exactly 2 Jets in the event, as required by the jet clustering algorithm
- Dijet mass ($95 < m_{jj} < 150$ 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



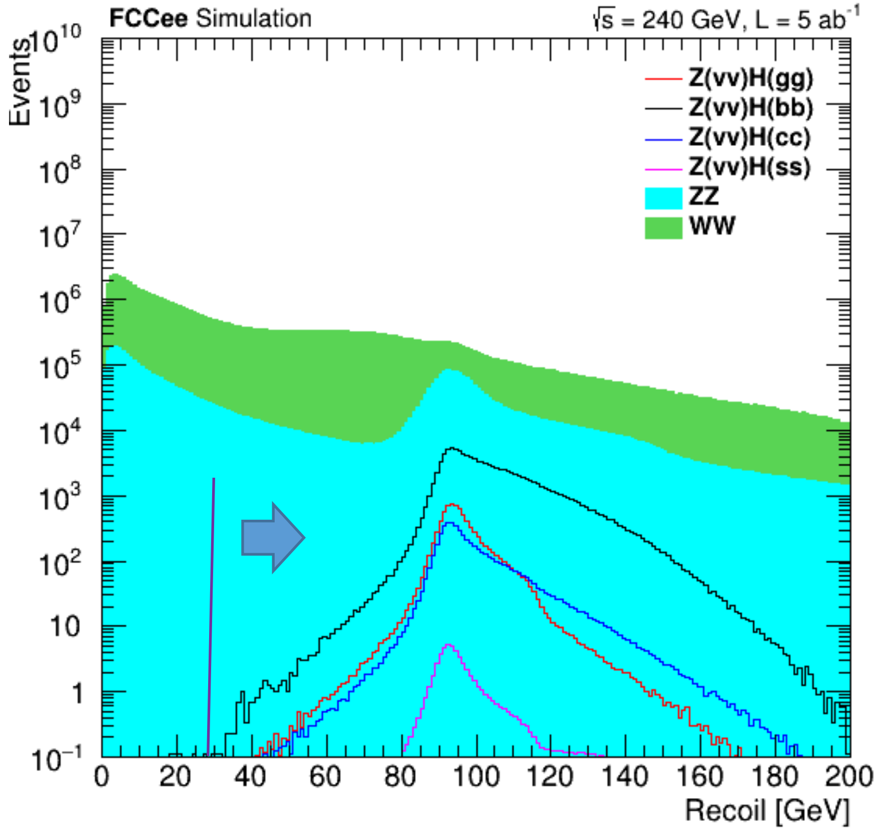




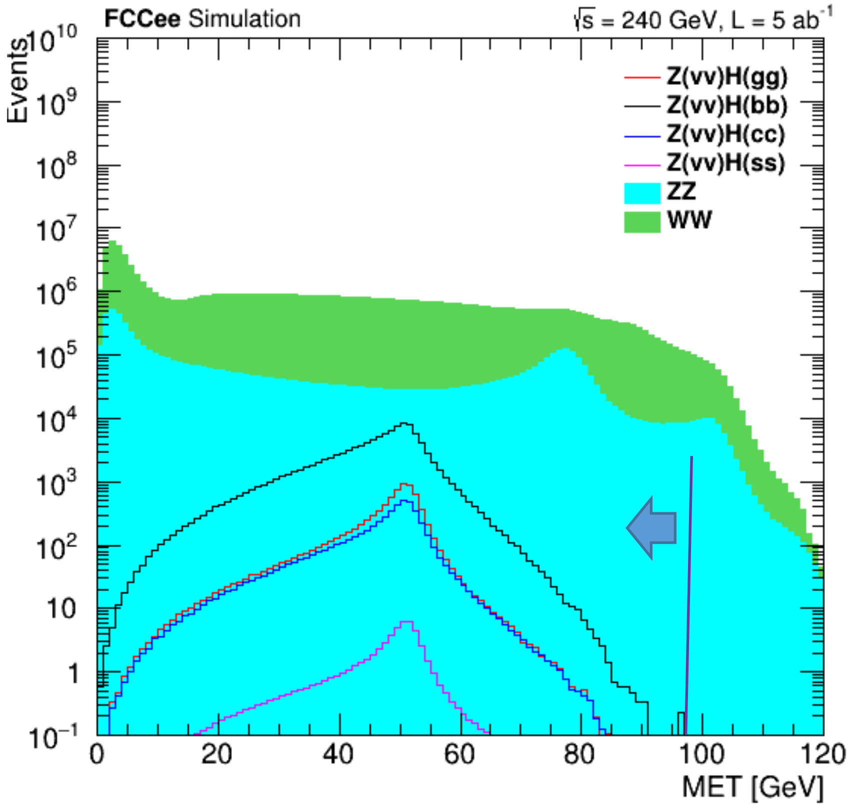
Event Selection

- 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 to be optimized



Around 90 GeV as Z-> $\nu\nu$



Cut Flow & Event Yields

- **Cut Flow:**

Process/cuts	H→ bb	H→ gg	H→ cc	H→ ss	ZZ	WW
Initial	113002	8098	5340	56	6450312	79261507
dijet pt	113002	8098	5340	56	6436452	78813706
Recoil	113000	8098	5340	56	2340264	23850915
Dijet mass	98731	7409	4856	55	915215	11633173

Effective cuts:

- **Final Yields:**

Signal	Yield	Significance = $\frac{s}{\sqrt{s+b}}$
H→ bb	98731	27.76
H→ gg	7409	2.09
H→ cc	4856	1.37
H→ ss	55	0.0155

- **Signal Efficiency :**

Signal	Efficiency
H→ bb	87 %
H→ gg	91 %
H→ cc	91 %
H→ ss	98 %

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 → stat-only result
- Uncertainties in signal strength (μ) has been extracted

Signal	Uncertainty in μ
H→ bb	1 +/- 0.0355027 (3 %)
H→ gg	1 +/- 0.28956
H→ cc	1 +/- 0.531074
H→ ss	1 +/- 34.6709

Very Preliminary

Part II: Detector Configuration

- **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

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

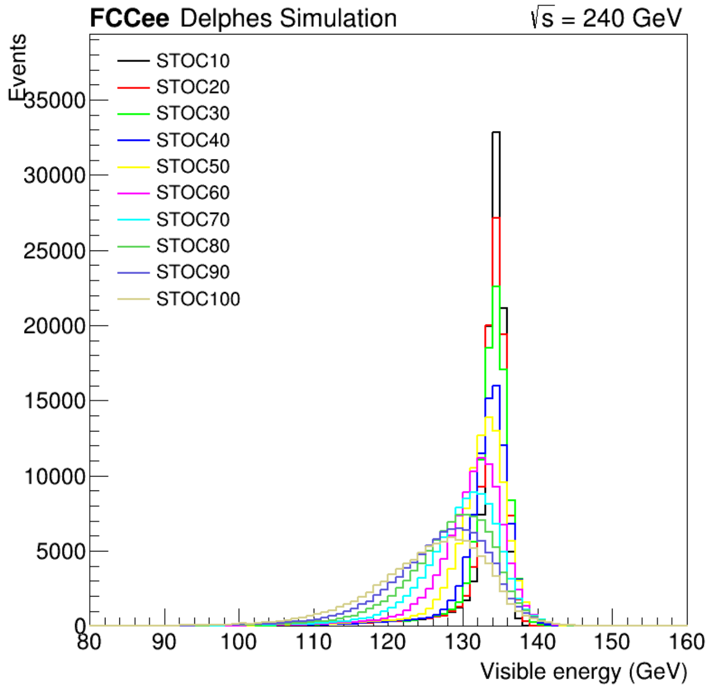
1- Tuning HCAL energy resolution parameters:

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

2- Tuning the ECAL energy significance

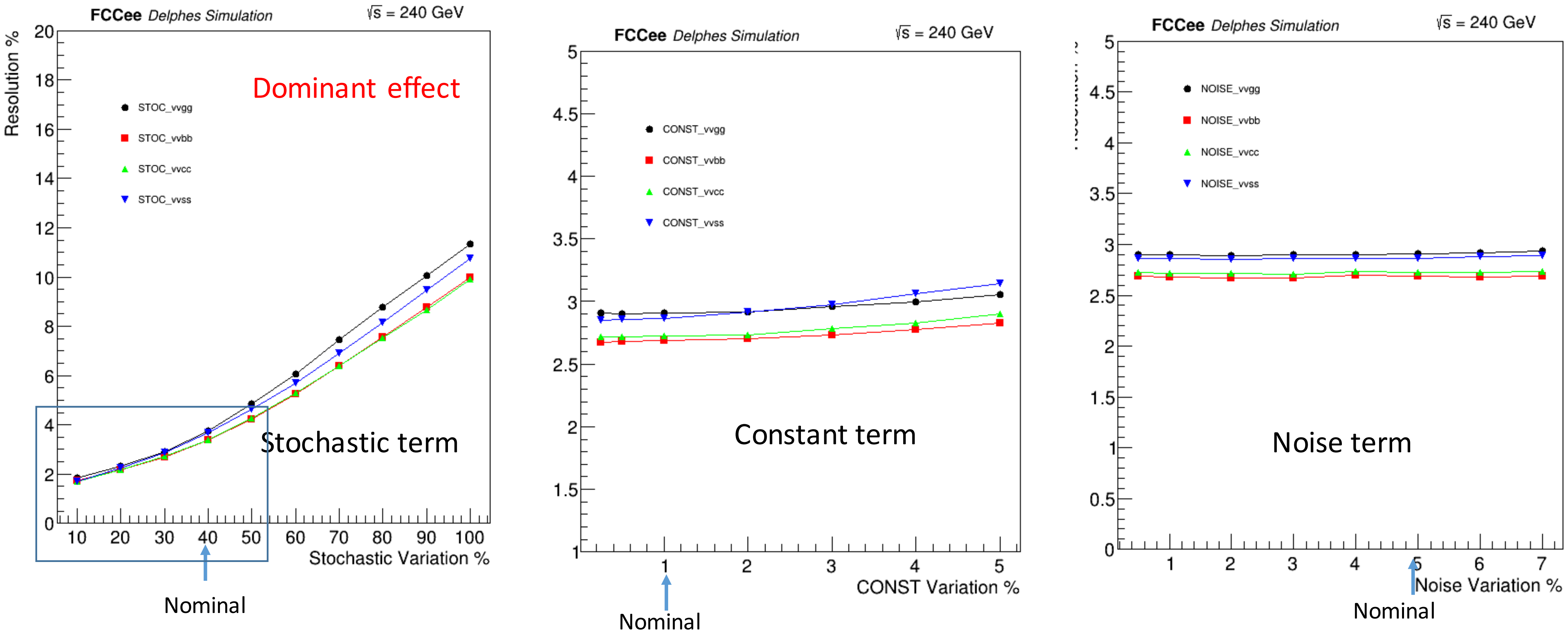
No Jet clustering

Reconstructed visible Energy



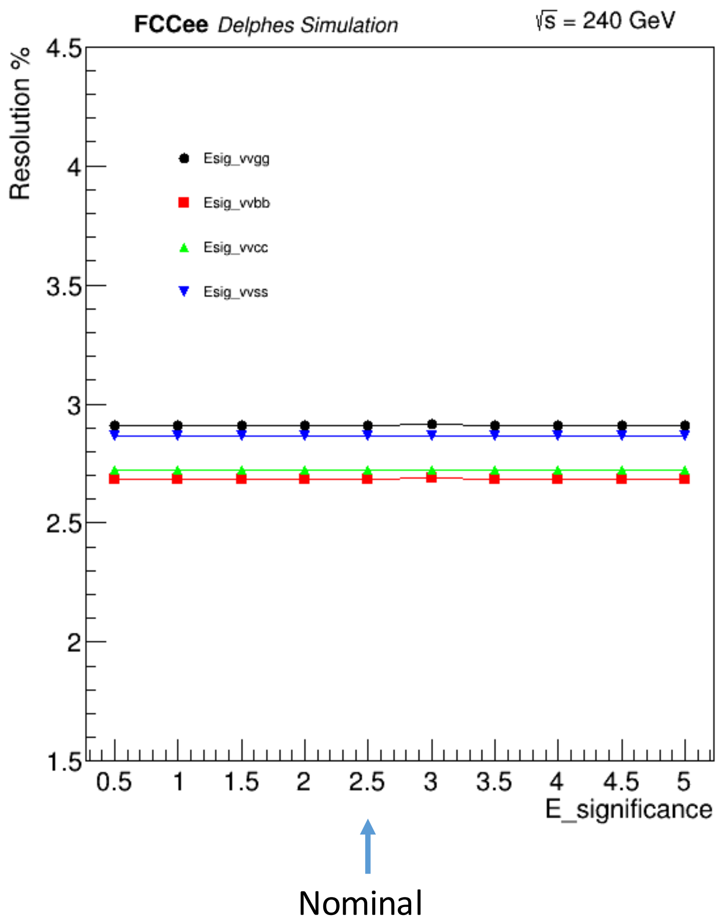
Important: To validate the Delphes card for the MC campaign.

Part II: Detector Configuration



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

Part II: Detector Configuration



HCAL Energy significance

- HCAL mass resolution should not depend on the energy significance value

Conclusion & Next Steps

- The analysis is in early stage **but** with a working framework /setup using FCCSW toals.
- Studies on jet clustering algorithm still ongoing where we need to evaluate the effect of using different jet clustering algorithms with the aim of improving the signal peak resolution.
- Introduce the Jet flavor tagging to the analysis "Jet tagger" (Particle Net).
- Optimize the event selection to suppress more backgrounds.
- Introducing Boosted Decision Trees which could help in the signal background separation.
- Define Systematic uncertainties affecting the analysis and evaluate the main contributors.
- The analysis is the seed for the ZH analysis with the fully hadronic decay.

Thank you