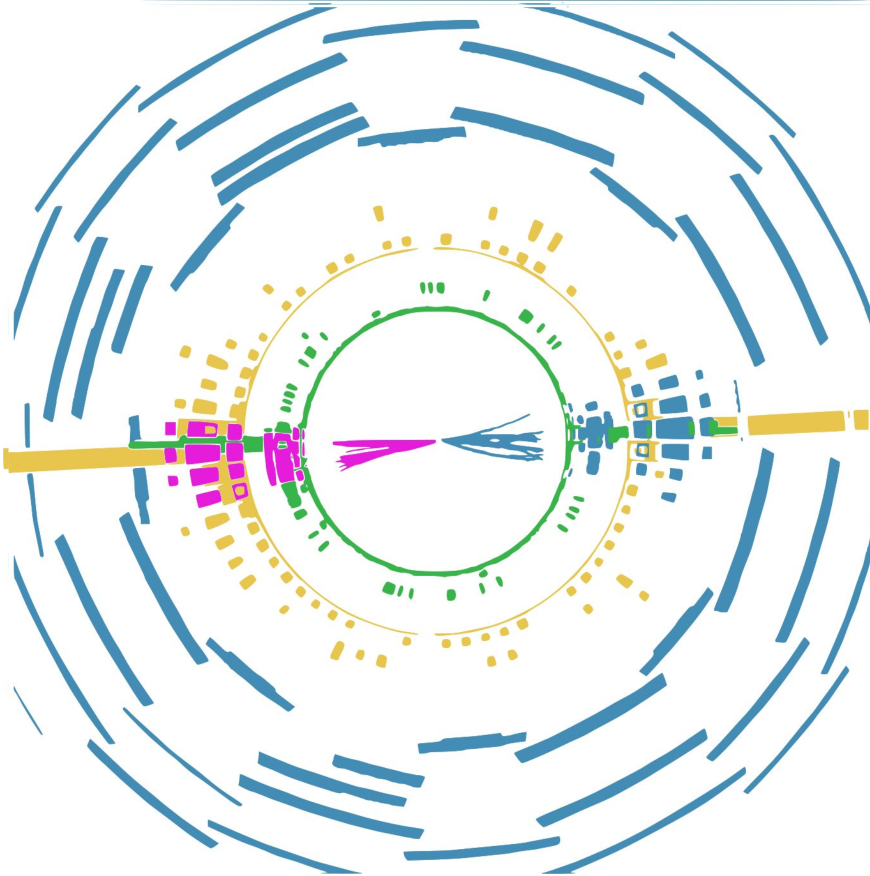
ZH->jjjj



Iza Veliscek

Contributions from: Haider Abidi, Viviana Cavaliere, Jan Eysermans, George Iakovidis, Loukas Gouskos, Andrea Sciandra, Michele Selvaggi

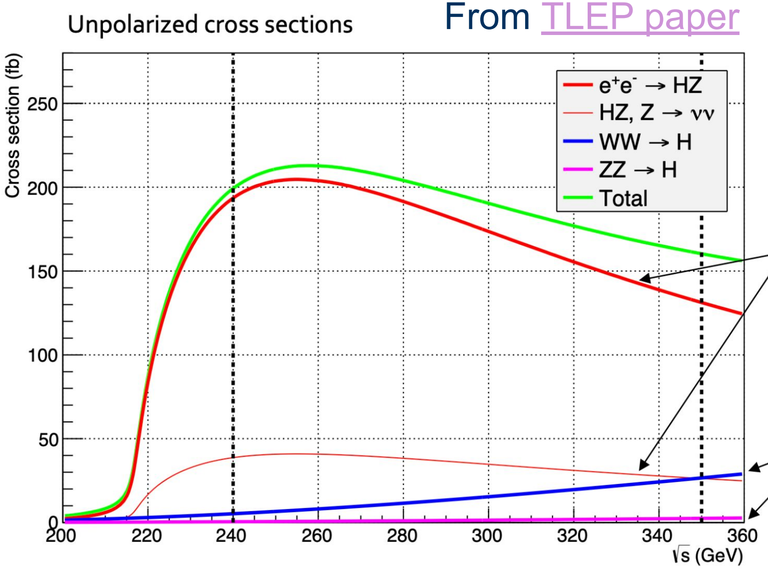
23rd September 2024

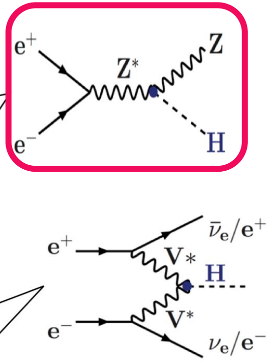
Brookhaven National Laboratory

FUTURE CIRCULAR COLLIDER

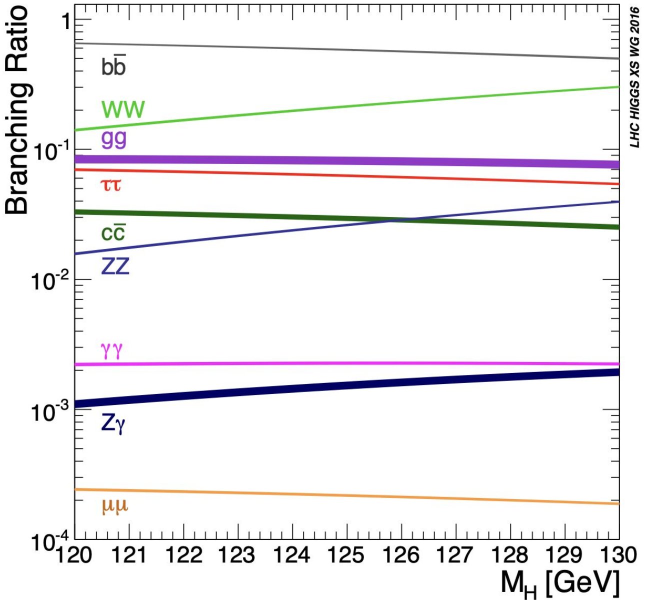
Introduction

From TLEP paper





From Handbook of LHC Higgs cross sections



- ZH leading Higgs production mode
  - \+ All hadronic decay has the largest branching fraction
  - \- Jet combinatorics, flavour identification
- Abundance of Higgs produced @ √s = 240 GeV
  - Focus on IDEA Detector

Samples Considered

- **IDEA Detector**
  - Delphes fast sim
- **Winter2023 Samples**
  - /eos/experiment/fcc/ee/jet_flavour_tagging/winter2023/wc_pt_7classes_12_04_2023
- **Jet Clustering**
  - N = 4 Durham k_T exclusive algorithm
- **ParticleNet jet tagger**
  - fccee_flavtagging_edm4hep_wc
- Build on ZH(full hadronic) analysis presented in Annecy by George [slides]

Background:

- **WW**
- **ZZ**
- **Zqq**
- **Z(bb/cc/ss/qq/)H(tautau)**
- **Z(bb/cc/ss/qq/)H(WW)**
- **Z(bb/cc/ss/qq/)H(ZZ)**
- **Z(bb/cc/ss/qq/)H(Z/ɣ*)**
- **nunuH(jj)**
- **Missing Z(bb/cc/ss/qq/)H(qq)**

Signals:

- **Z(bb/cc/ss/qq/)H(bb)**
- **Z(bb/cc/ss/qq/)H(cc)**
- **Z(bb/cc/ss/qq/)H(ss)**
- **Z(bb/cc/ss/qq/)H(gg)**

Analysis setup

Preselection

- Exactly 4 jet!

Lepton cuts

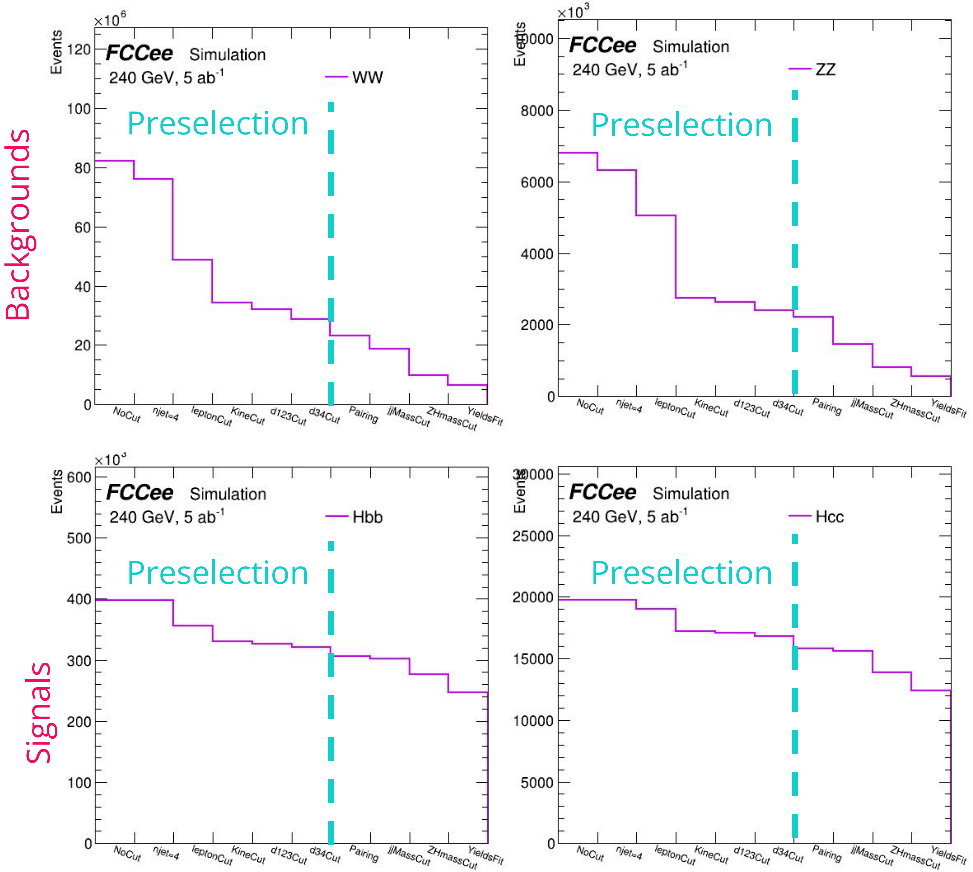
- <= 2 muons and electrons
- Leading muon and electron pT < 20 GeV

Visible Energy

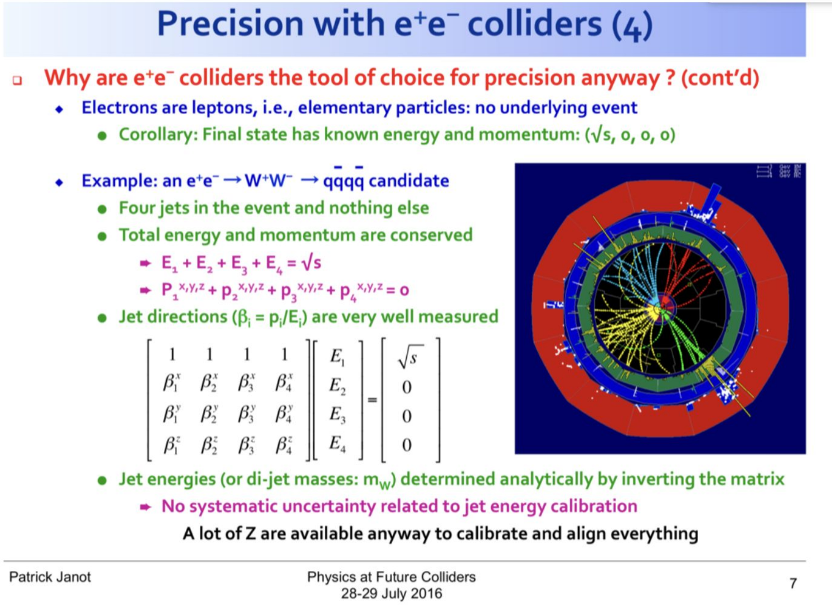
- Visible m > 150 GeV
- Visible E > 150 GeV
- 0.15 <Visible θ < 3.0

d_{ij} Cuts

- $15000 < d_{12} < 58000$
- $400 < d_{23} < 18000$
- $100 < d_{34} < 6000$



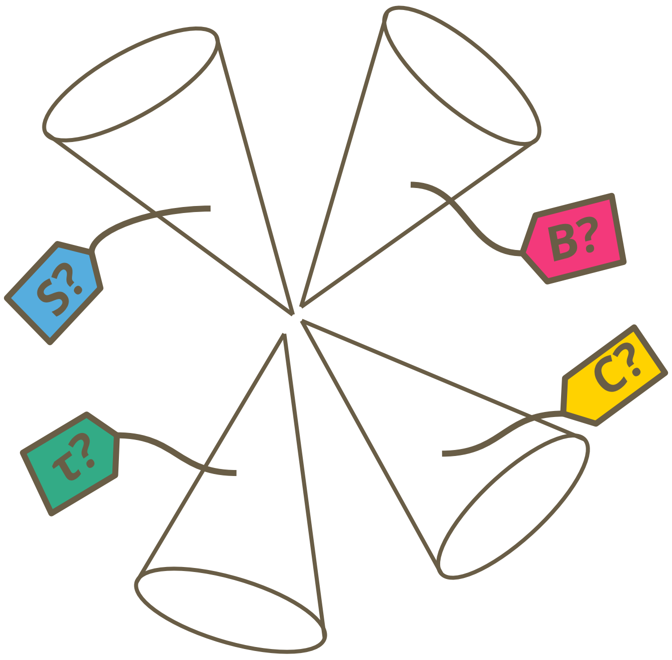
Jet energy correction



- If any jet in event **E<0** OR **E>240** GeV [only a few percent of events]

TOSS EVENT

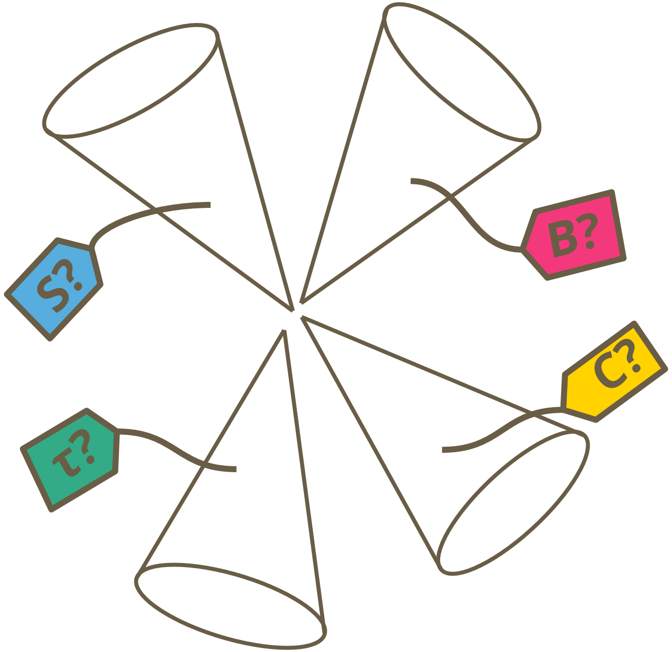
Jet "tagging"



ParticleNet jet tagger

- Scores provided for the "flavours":
  - B, C, S, g, τ, U, D
    - q: U,D
- Scores ~ probability jet is of flavour X
- NOT traditional flavour tagging
  - Maximum flavour score ~ flavor of jet
  - Sums of same flavour scores for jet pairs ~ flavour of jet pair

Jet pairing

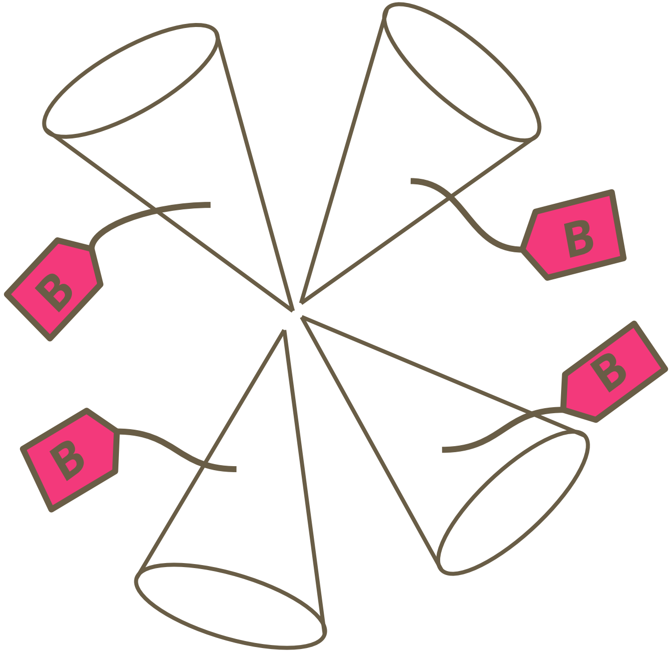


Each jet has a maximum tagger score from a different flavour

-

TOSS EVENT

Jet pairing



CASE 1: All jets have the maximum score from the same flavour

Finding the H&Z candidates

Consider all possible jet pairs

- $\chi_H=(m_{ij} - m_{H,true})^2$
- $\chi_Z=(m_{lk} - m_{Z, true})^2$
- $\chi_{comb}=\chi_H+\chi_Z$

The jet paring that gives the **minimum** $\boldsymbol{\chi_{comb}}$ is chosen!

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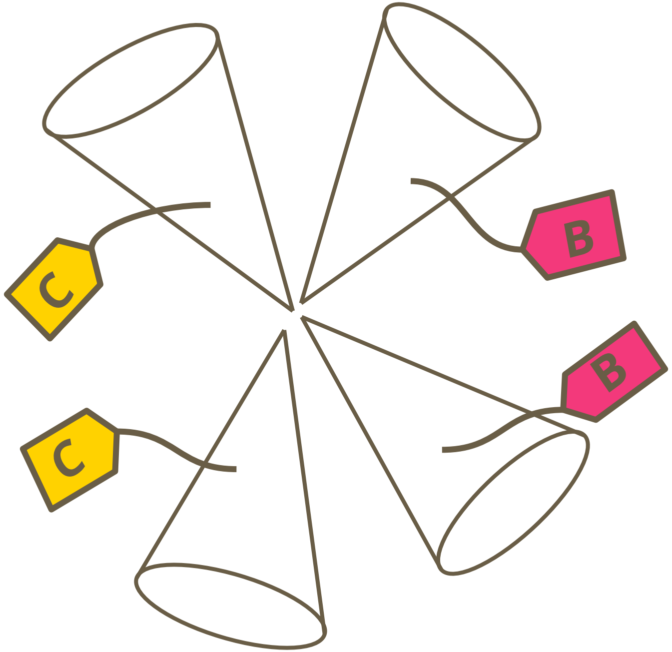
Jet pairing

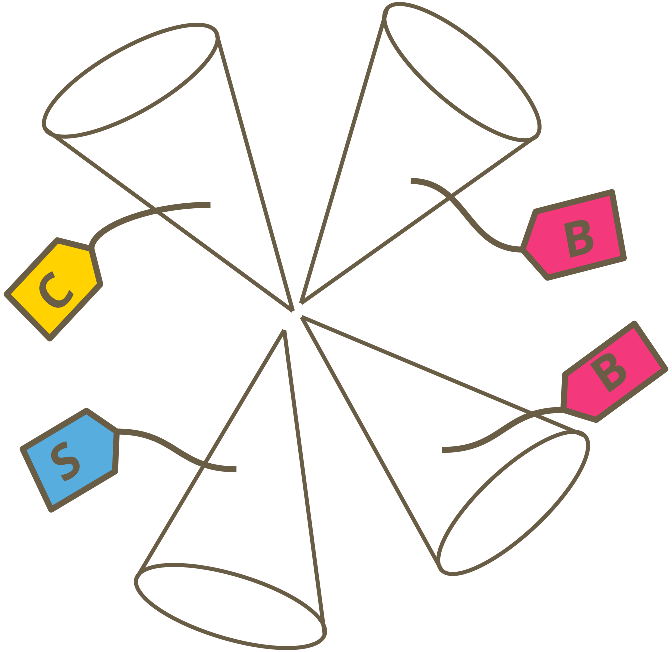


CASE 2: Two jet pairs with same maximum score from the same flavour, but different flavour of the pairs

Finding the H&Z candidates

- Jet paired, if they have the same flavour maximum score
- Z candidate: Pair with minimum $\chi_Z=(m_{lk} - m_{Z,\ true})^2$

Jet pairing



CASE 3: Two jets with maximum score from the same flavour form a pair

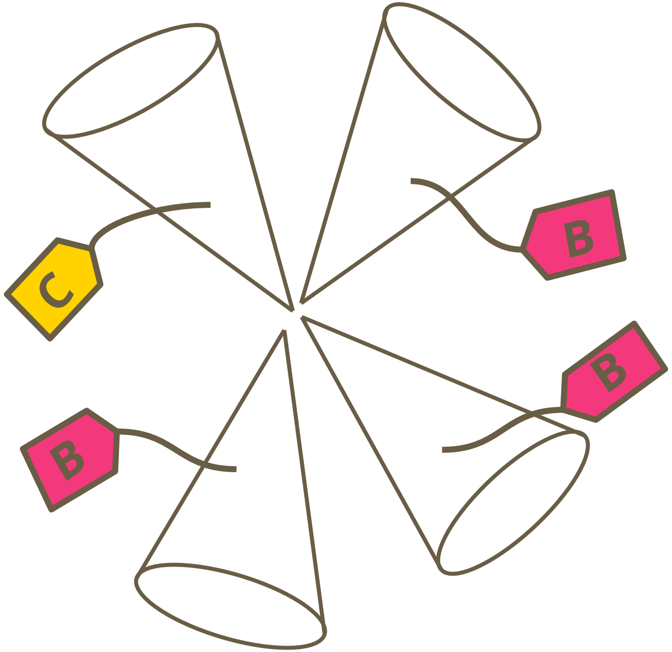
Recover second pair:

- Consider all sums of tagger scores
  - **Max**($\sum_{ij}$Bscore, $\sum_{ij}$Cscore, $\sum_{ij}$Sscore, …)
    - Determines the flavour of the pair

Finding the H&Z candidates

- Same flavour pairs (Case 1)
  - Min($\chi_{comb}=\chi_H+\chi_Z$)
- Different flavour pairs (Case 2)
  - Min($\chi_Z=(m_{lk} - m_{Z, true})^2$

Jet pairing



CASE 4: Three jets with maximum score from the same flavour

Recover first pair: [check code]

- Maximum tagger score sum
  - **Max**($\sum_{ij}$Bscore, $\sum_{ik}$Bscore, $\sum_{jk}$Bscore, …)
    - Determines the flavour of the 1st pair

Recover second pair:

- Consider all sums of tagger scores
  - **Max**($\sum_{ij}$Bscore, $\sum_{ij}$Cscore, $\sum_{ij}$Sscore, …)
    - Determines the flavour of the pair

Finding the H&Z candidates

- Same as for Case 3

A few more cuts

WW & ZZ rejection

$$\sqrt{(m_{z_{jj}} - m_W)^2 + (m_{H_{jj}} - m_W)^2} > 10$$

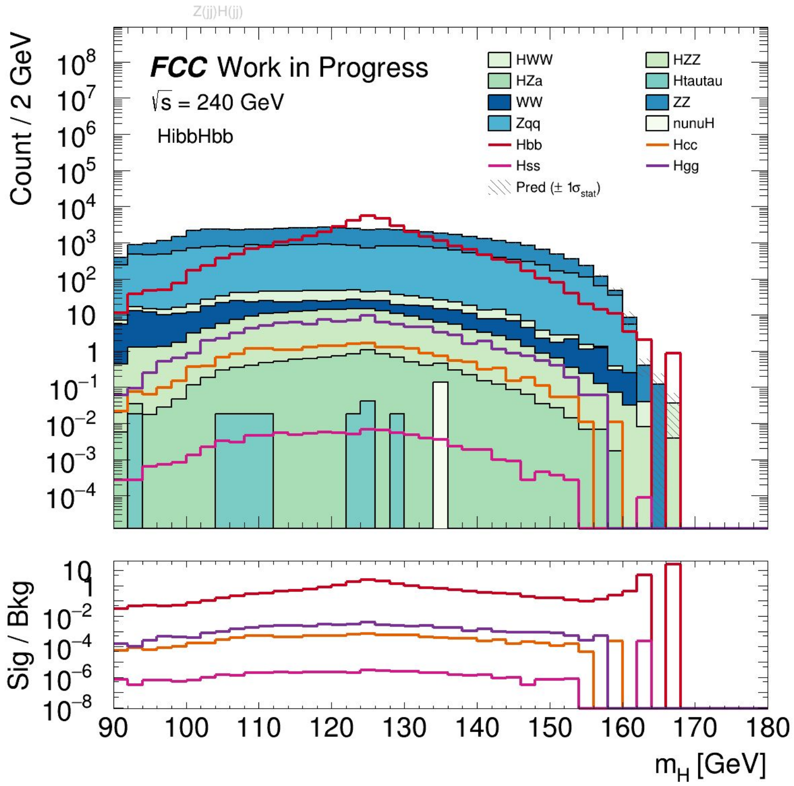
$$\sqrt{(m_{z_{jj}} - m_Z)^2 + (m_{H_{jj}} - m_Z)^2} > 10$$

Mass window

$$50 < m_{Z_{jj}} < 125\,\text{GeV}, m_{H_{jj}} > 90\,\text{GeV}$$

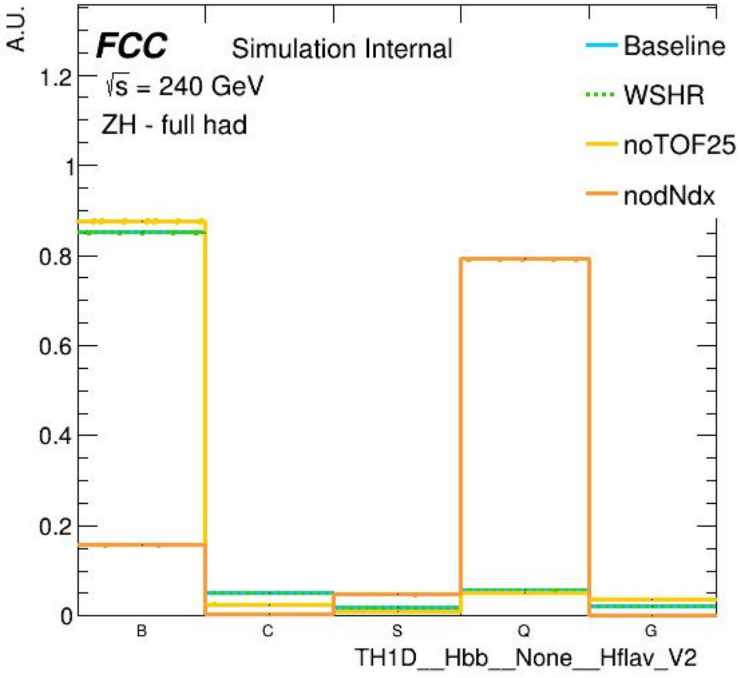
Reject events identified/contain as:

- H->ττ
- H->qq, q=u,d
- Z->ττ
- Z->gg



FUTURE CIRCULAR COLLIDER

Categorization



Hbb signal categorized according to the flavour tagged. Additional split according to H flavour score in fit (purity)

- Categorize by H->j_1j_2 decay
  - Categorize by Z->j_3j_4 decay
  - Additionally by H flavour score
    - **Purity category :**
      - High (>1.8 (1.4 for Hss))
      - Mid(1.1 (0.8) < score < 1.6 (1.4) (Hss cut in ())
      - Low (<1.1 (0.8 for Hss))
- 48 Categorised in total!
- + 1 GeV binning in $m_{jj,H}$
- + 5 GeV binning in $m_{jj,Z}$

Likelihood scan

- **Asimov** (expected) **data = SM = background estimation + SM signal**
  - How compatible are different μ_{xx} to the asimov data set, i.e. how sensitive are we?
  - Compare the **test statistic (λ)** of the different μ_{xx} on this dataset.

$$\lambda(\mu_{xx}) = -2\, ln\left(\frac{L(\mu_{xx}, \hat{\hat{\theta}})}{L(\hat{\mu}_{xx}, \hat{\theta})}\right)$$

Maximize $L(\kappa_\lambda, \theta)$ by holding μ_{xx} fixed and fitting the model.

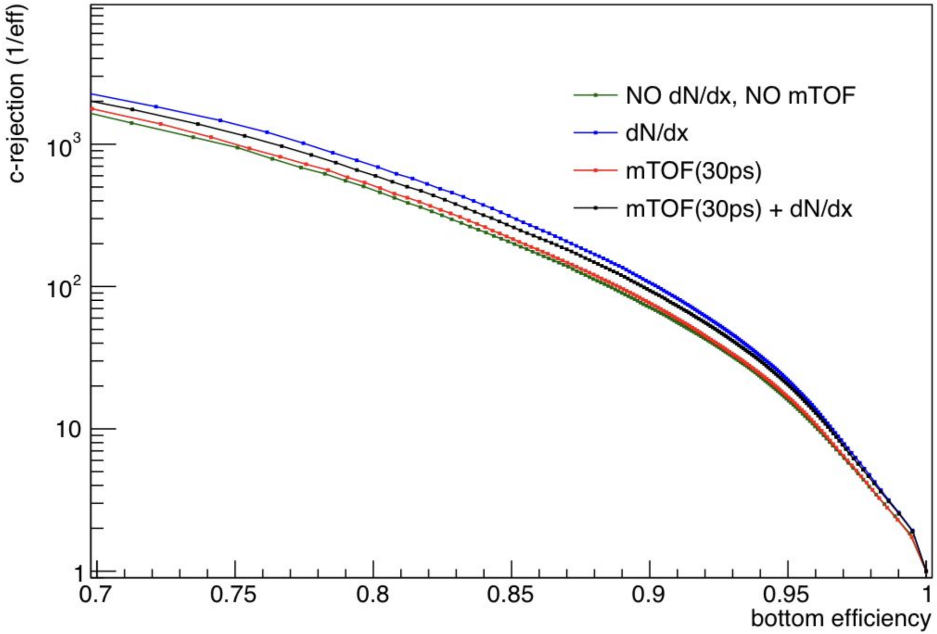
Nuisance parameters

Best-fit coupling

Find μ_{xx} that maximizes ***L*** for the data, i.e. let μ_{xx} vary in a global fit.

Removing information from the tagger

by Andrea Sciandra



- No TOF - Removing time of flight information
- No dN/dx -Removing number of clusters information

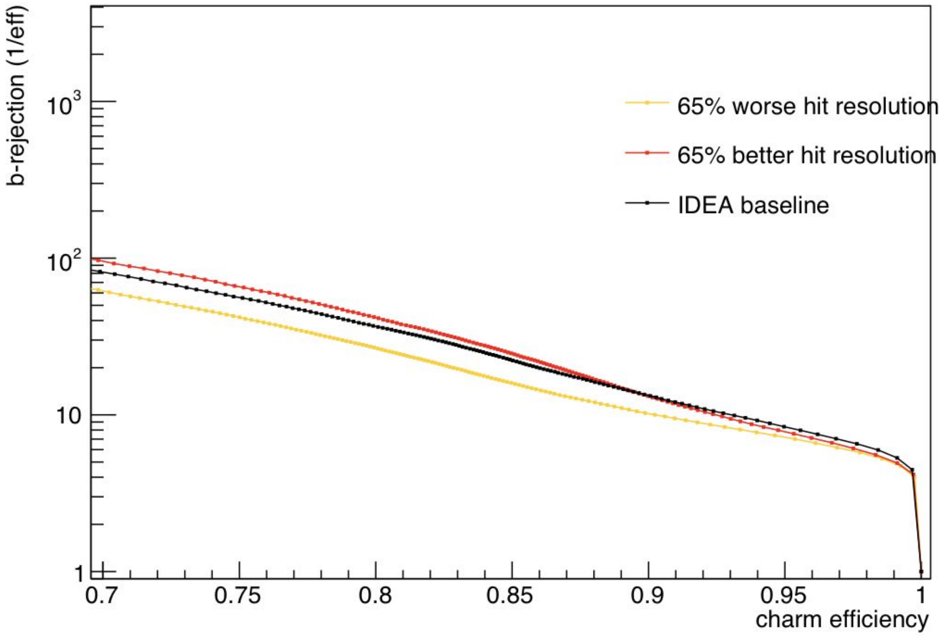
*__Note__ overall the tagger performance is a bit worse compared to the official FCC ParticleNet as it is trained on a smaller set of jets

Changing geometry of the tracker

by Andrea Sciandra

Realistic variations considered

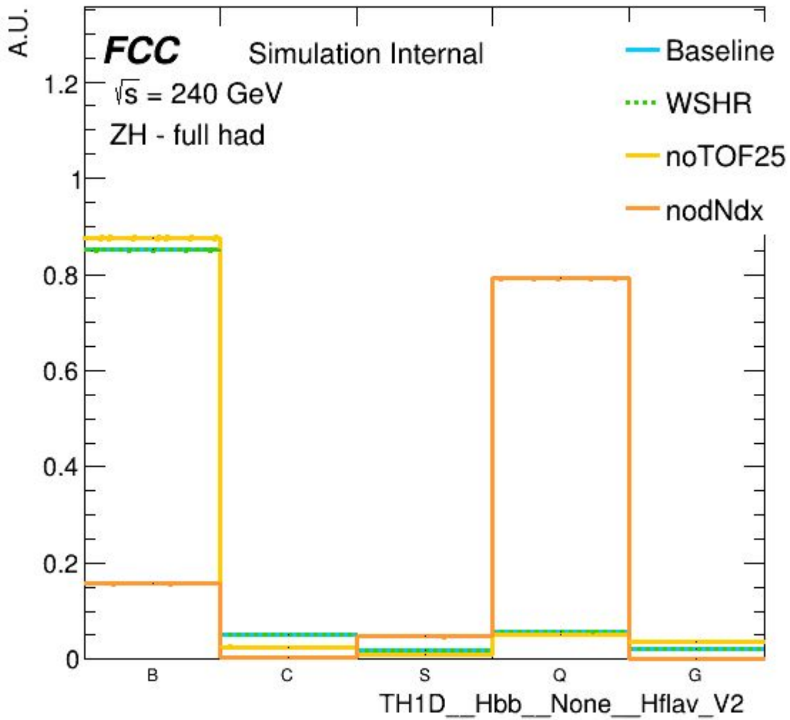
- 65% Worse single hit resolution
- 50% Heavier VXD
- No intermediate layer



Overall observations

- Note differences notable only at lower efficiencies
- Baseline IDEA pretty close to a "perfect" detector
  - Will focus variation that make the tracker worse only

Robustness of flavour tagging strategy



- Realistic changes of tracker
  - Summing the flavour scores guarantees the robustness of flavour tagging
    - Very little migration between the flavour categories
  - Only showing 65% Worse single hit resolution (WSHR on the plot) for clarity
- nodNdx biggest impact on mis-tagging
  - As expected from ROC curves
- *Assumption - only changed the tagger training not the simulated samples

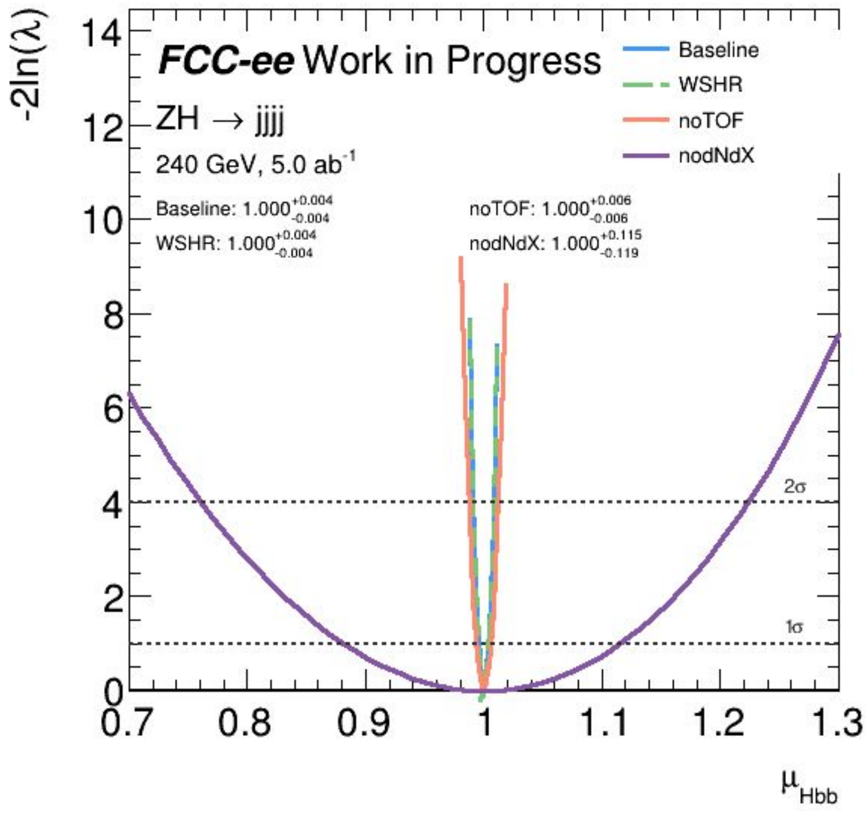
Impact on the ZH fully hadronic analysis

Tracker variations considered

- **No notable change in the limits** from 65% Worse single hit resolution, 50% Heavier VXD, no intermediate layer

Removing PID information

- Huge impact from removing dNdX information
  - From 0.4% precision on Hbb coupling strength to 12 % precision
  - Hcc, Hgg struggle to converge as very little signal tagged
  - Removing TOF has a few percent impact on the coupling measurements



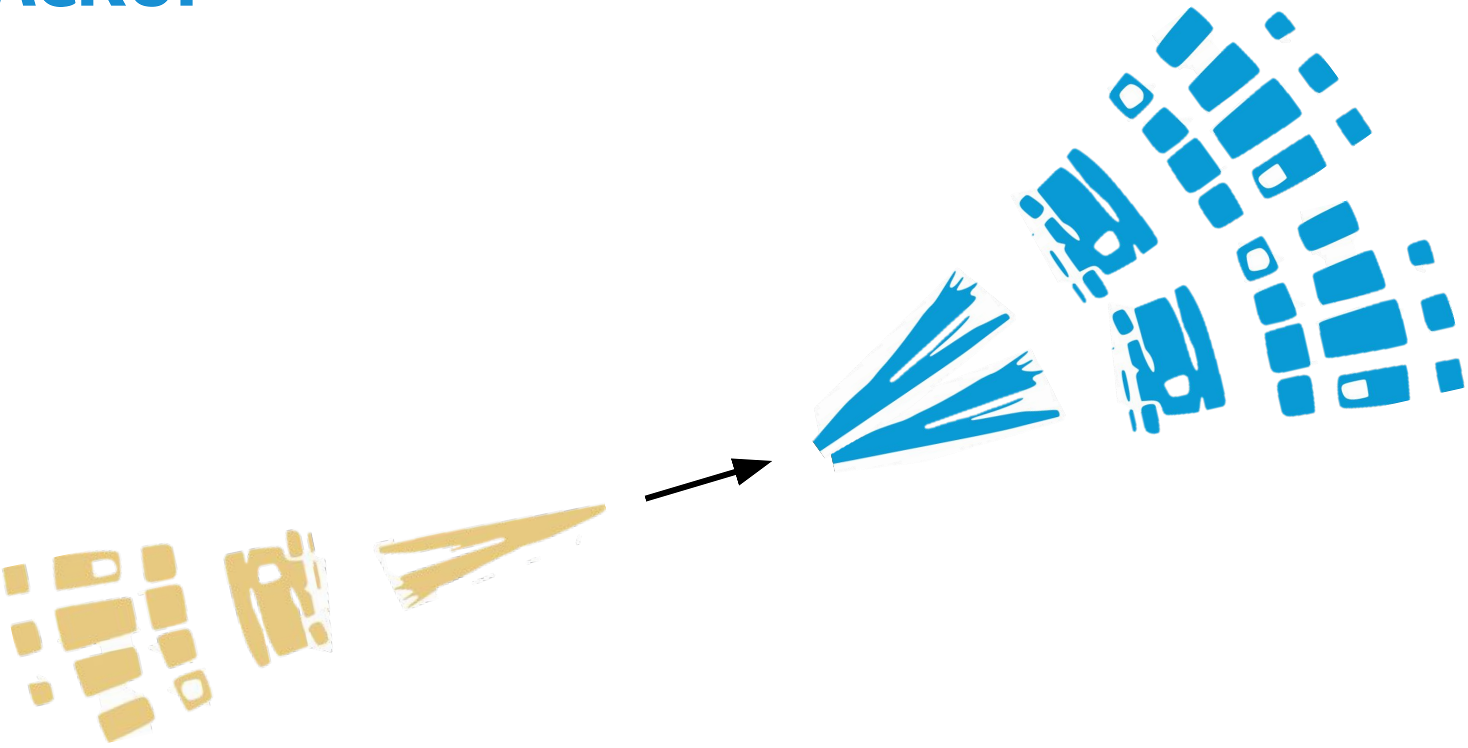
Conclusions

- Changing the tracker does not impact the fully hadronic ZH analysis significantly
  - Might be underestimated as flavour tagging strategy might be too robust
  - Only change the flavour tagging training not IDEA simulation
- However, time of flight and cluster information are crucial and have a significant impact on the sensitivity of the measurements
  - Without the number of cluster information x100 worse precision!

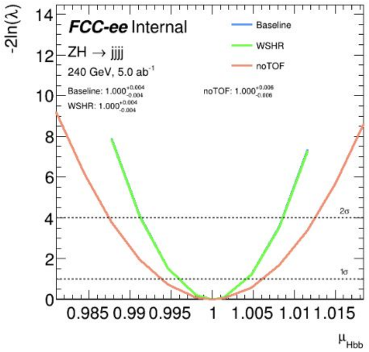
Next Steps

- Checking the impact on the ZvvHjj analysis [To be wrapped up this week!]
  - Most sensitive channel
  - Higgs/top group simulated each changes in the tracker configuration
  - Additionally considering change of the beam pipe to tracker distance (500 μm) [check]
- Rerun the analysis with the 7 flavour tagger
  - Score for taus, u- and d- quarks added

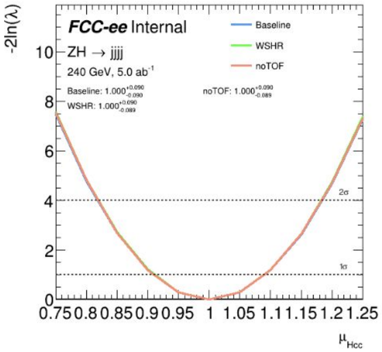
BACKUP



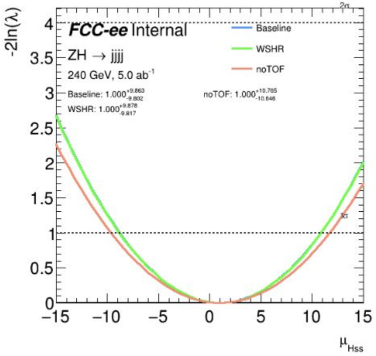
Impact on the analysis



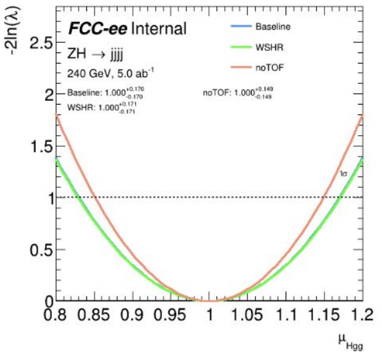
(a) μ_{Hbb}



(b) μ_{Hcc}

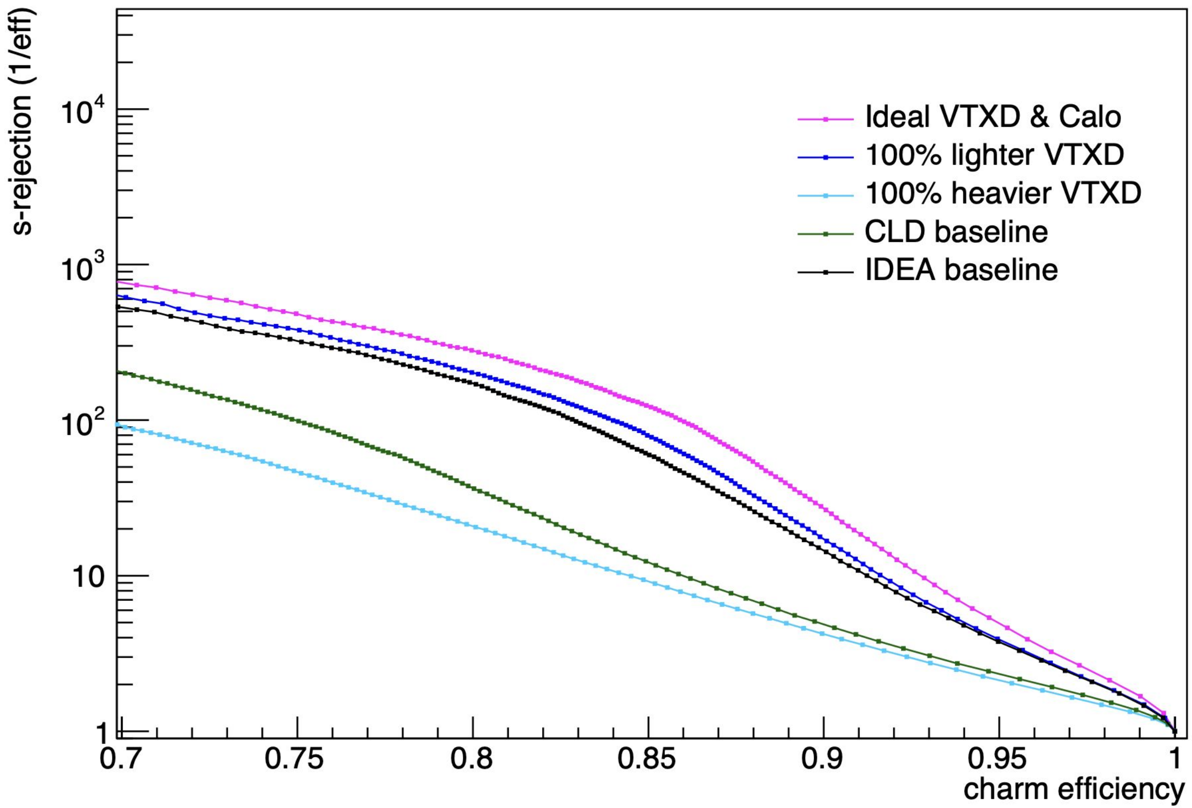


(c) μ_{Hss}

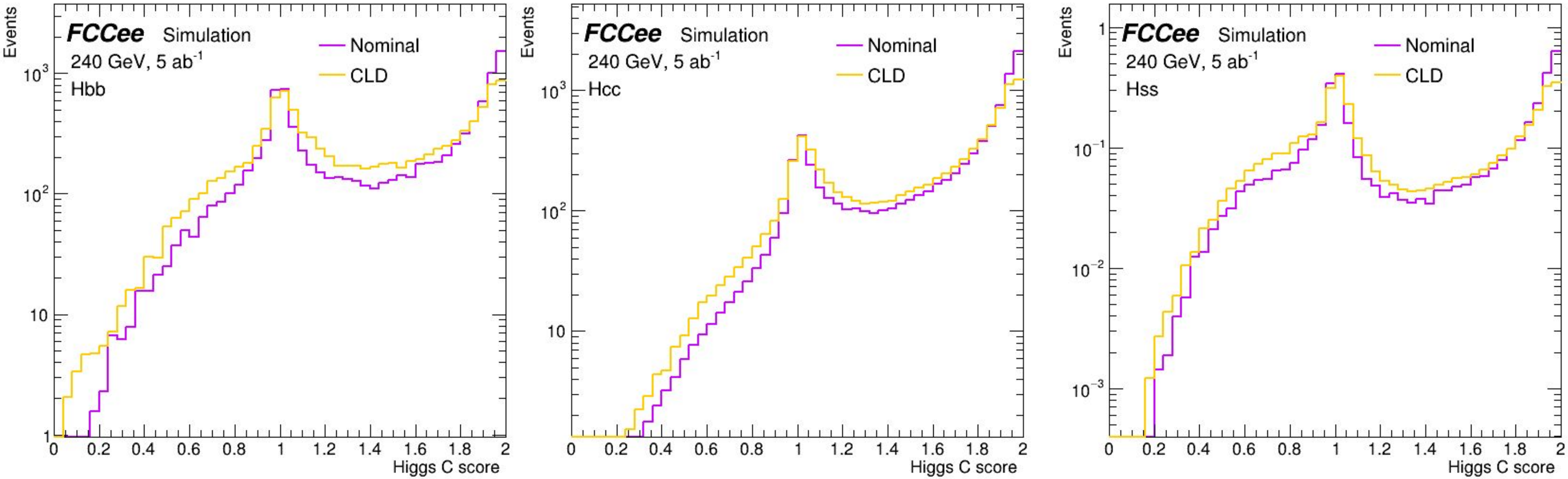


(d) μ_{Hgg}

Tagger performance

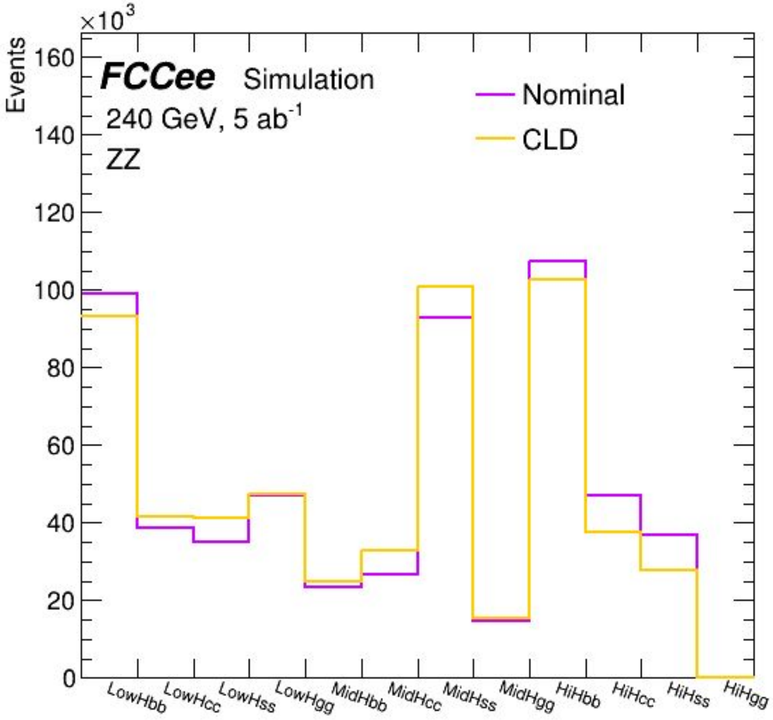


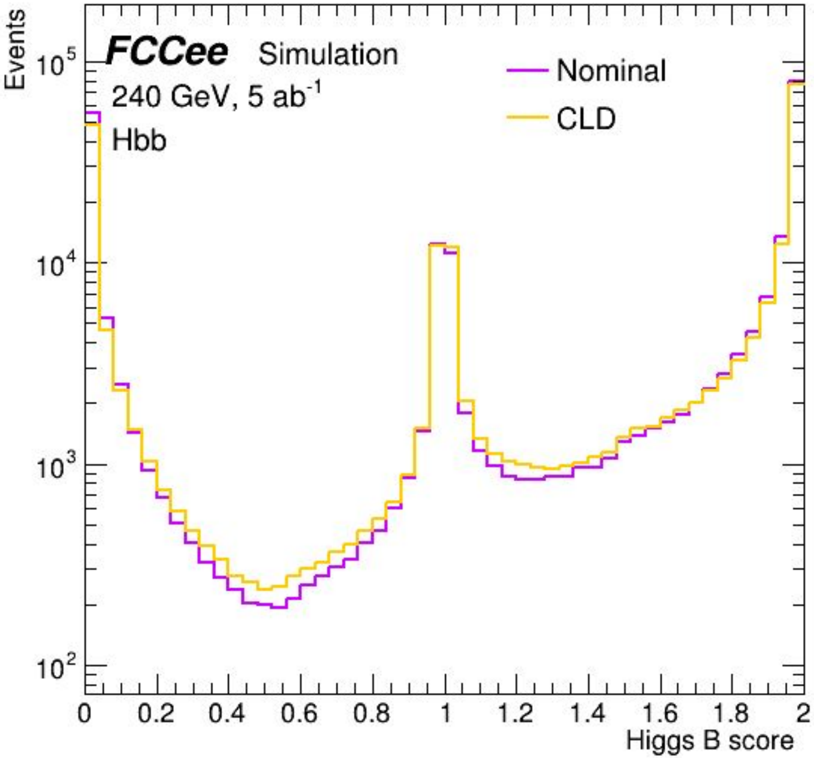
Impact on the analysis - Higgs C score



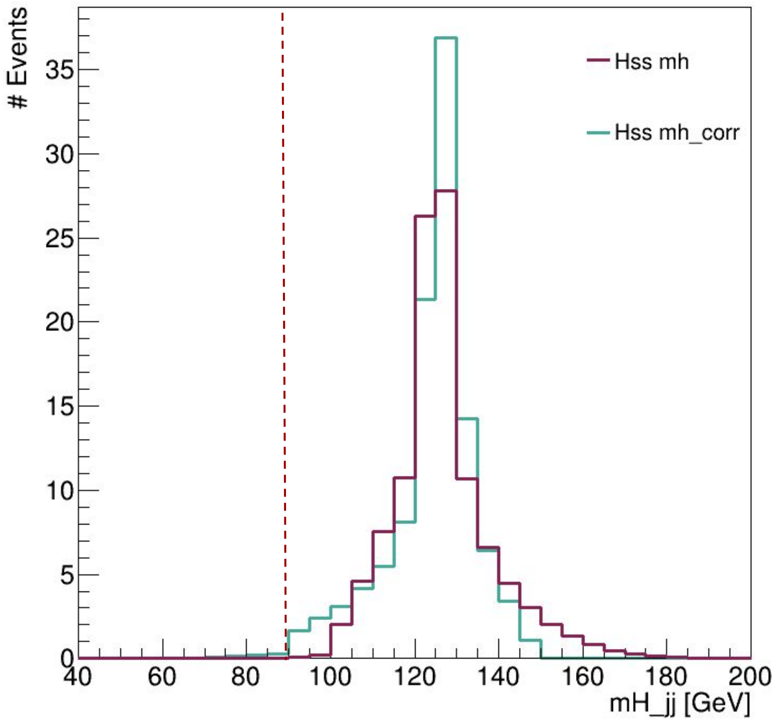
Truth H->cc jets flavour: The better rejection of the Nominal tagger is reflected in a higher fraction of truth H->cc events, with a very high Higgs C score. [see next slide]

Migration of ZZ events





Yet another correction to $m_{jj,H}$



- Besides the energy correction to the jets based on COM
- After all selection:
  - mH_jj_corr = mH_jj + mZ_jj - mZ_{truth}
- As before fit mH_jj_corr against mZ_jj

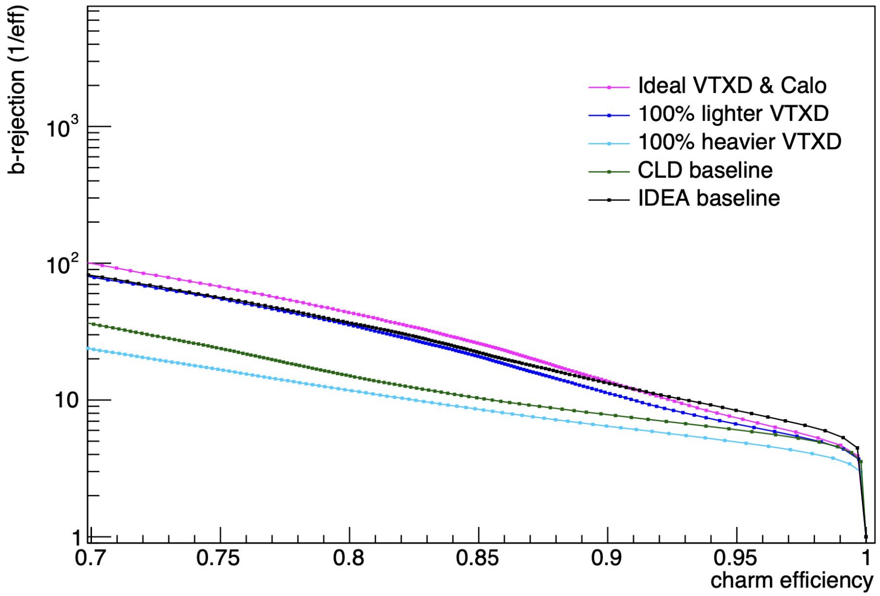
68% CL precision / variation	μ_{Hbb}	μ_{Hcc}
BASE	±0.3	±3.9
Base (fit Mh_jj_corr_Mz_jj	±0.3	±3.9

IDEA tracker variations: Approximating the impact of tagging performance on the analysis

Andrean re-trained tagger for different detectors [see Andrea' presentation]:

- **Baseline:** IDEA baseline
- **idealVXDCalo:**
  - Best material budget, hit resolution and calorimeter granularity
- **lighterVXD_100pc:**
  - ~ No material interaction (X_0>>1m)
- **heavierVXD_100pc:**
  - Super small radiation length (X_0<<1m)
- **CLD**
  - Fast sim of the CLD **o1_v01**

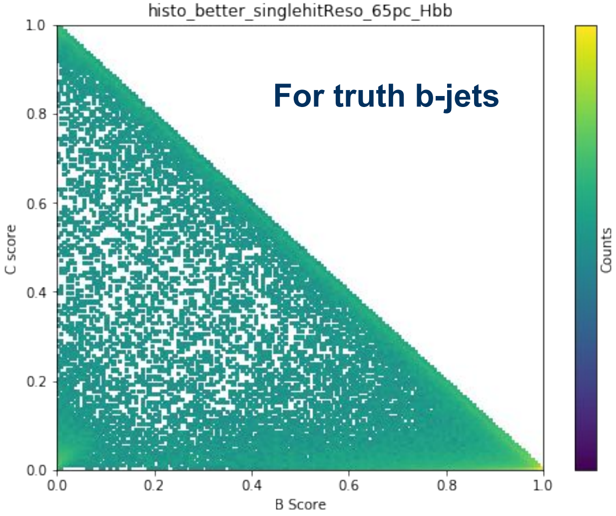
Plot from Andrea



Approximating the impact on tagging

Propagating the impact of retraining the tagger:

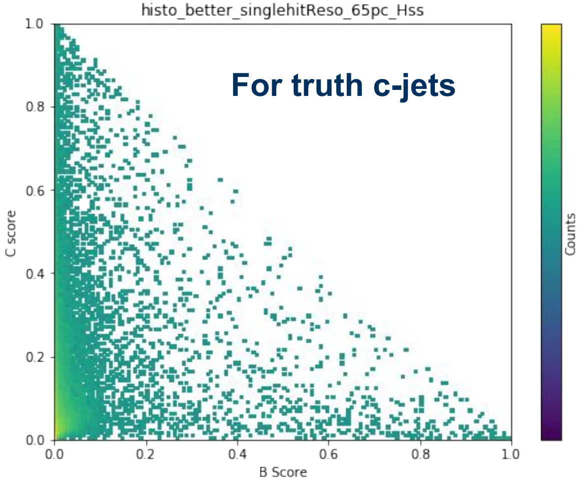
- Account only for impact on **b-,c- and s-score**
- Histo per jet flavour (4x) per detector variation **[Thanks Andrea!]**
  - Sample from histogram to update the b- c- and s-score score
    - Depends on the jet truth label!



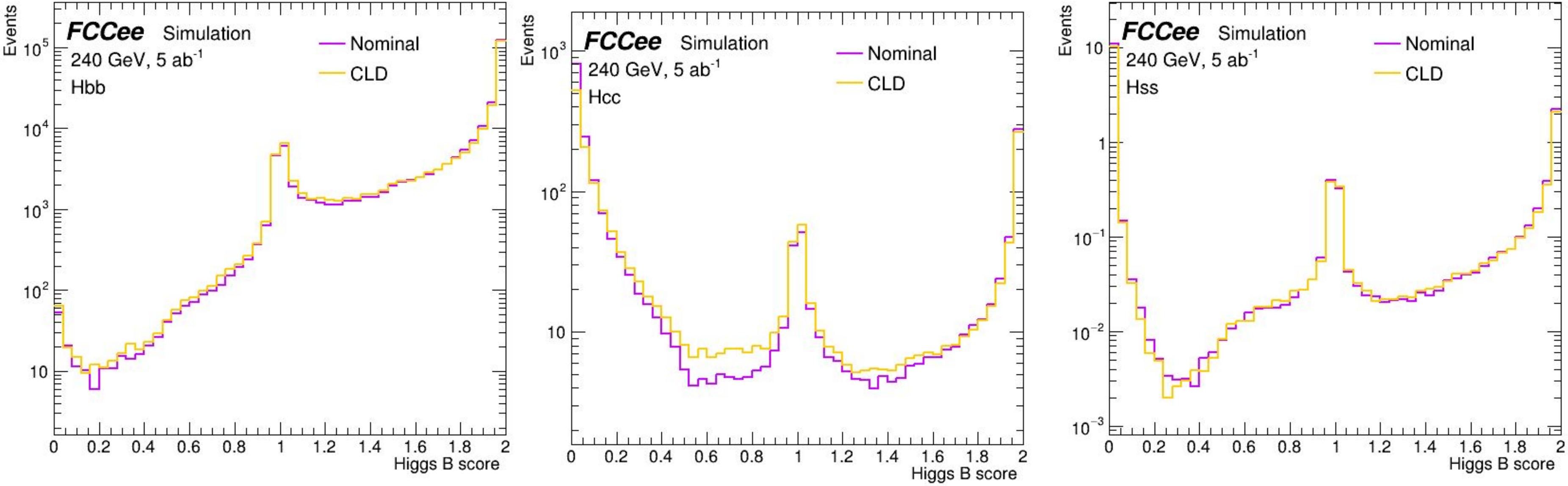
Drawbacks of the strategy

- Jet truth labelling not optimal
  - 88% accuracy in Z(qq)H(bb) samples [**Thanks Jan E.!**]
  - Does not tag gluon jets
- Ignoring some correlations
  - Correlation of the b-,c-, s- score to u/d, gluon score neglected

* Older tagger training, tau's not included

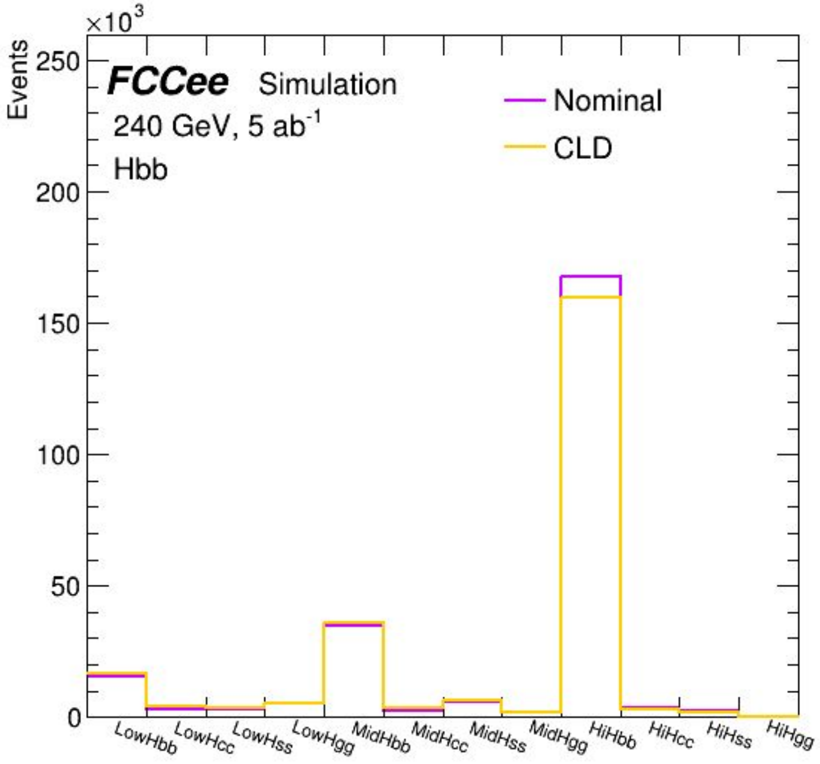


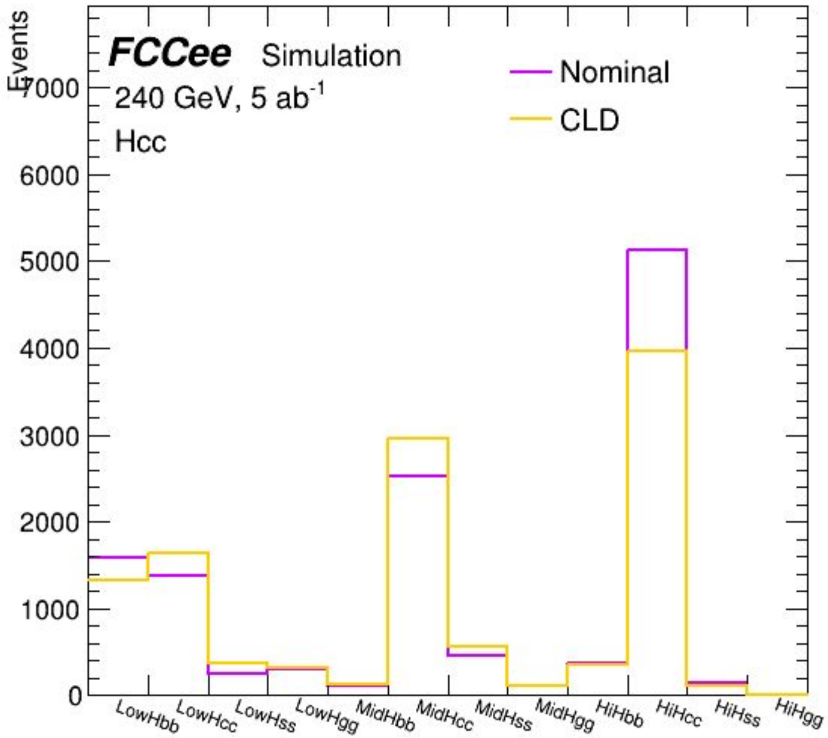
Impact on the analysis - Higgs B score



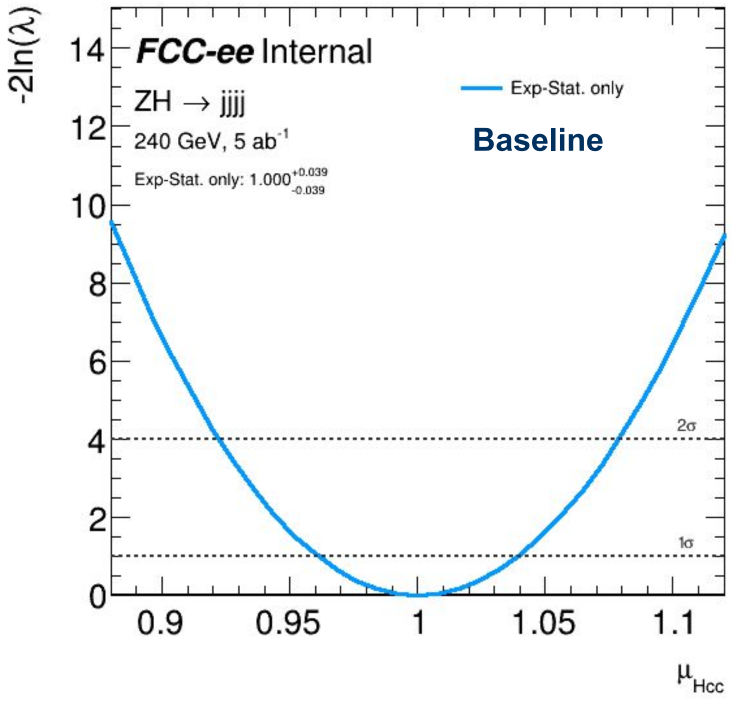
Truth H->bb jets flavour: The hit in performance of the tagger has the largest effect on the Higgs C-score. Smaller c-jet rejection leads to a larger Higgs C score.

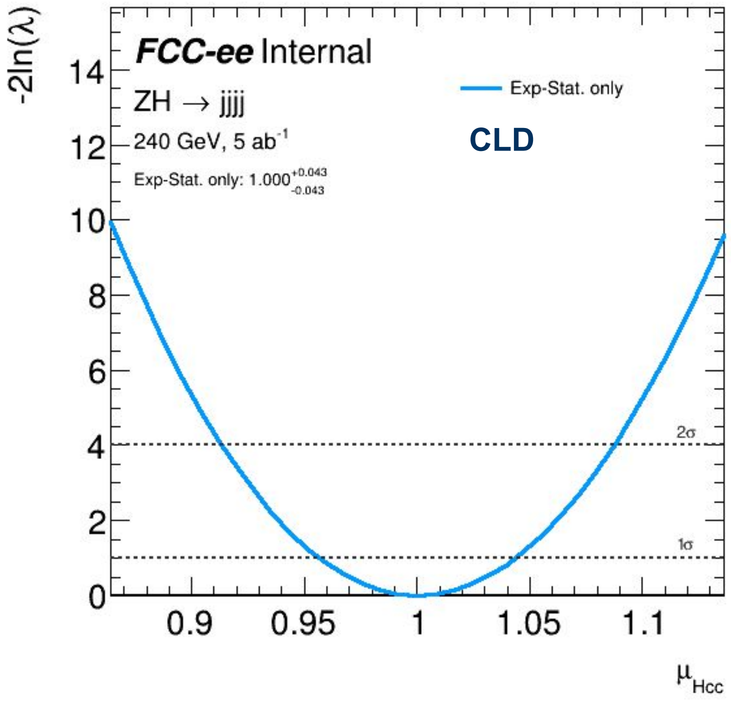
Impact on the analysis - Migration between fit categories





Likelihood scans - μ_{Hcc}





Largest change in expected precision on μ_{Hcc} observed when the tagger is re-trained with the CLD simulation.

Results

- **IDEA baseline very close to ideal vertex & calo detector**
- Robust analysis strategy
  - Small change in event selection
  - Main effect is migrates events between categories, dues to changes in performance
- No change in μ_{Hgg} as expected
  - G-score not varied nor truth gluon jet score corrected
- Largest impact on μ_{Hcc} w/ CLD trained tagger
- Caveats remainder!
  - Only approximate propagation of tagging effects
  - Ignored correlations of between b/c/s with g and light scores

variation \ 68% CL precision	μ_{Hbb}	μ_{Hcc}
BASE	±0.3%	±3.9%
idealVXDCalo	±0.3%	+3.9% -3.8%
lighterVXD_100pc	±0.3%	±3.9%
heavierVXD_100pc	±0.4%	+4.6% -4.5%
CLD	±0.4%	±4.3%

Conclusion

- Correction of the reconstructed Higgs mass does not significantly improve the expected precision on μ_{Hxx}
  - mH_jj_corr = mH_jj + mZ_jj - mZ_{truth}
- First look at the impact of flavour tagging given different detector layouts
  - Partricle net retrained for various detector layouts
  - Changes in tagger performance propagated to the ZH->jjjj analysis
    - Sever approximation taken to have a quick estimation of the impact
      - Determine how big of a change in the tagging performance is worth rerunning the whole analysis chain
  - The analysis roubouts
    - Very small impact on the expected μ_{Hxx} precision measurement