VBF $H \to b\bar{b}/c\bar{c}$ from sensitivity study to full analysis using ATLAS

DPF PHENO 2024

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Motivation: Why study the charm quark?

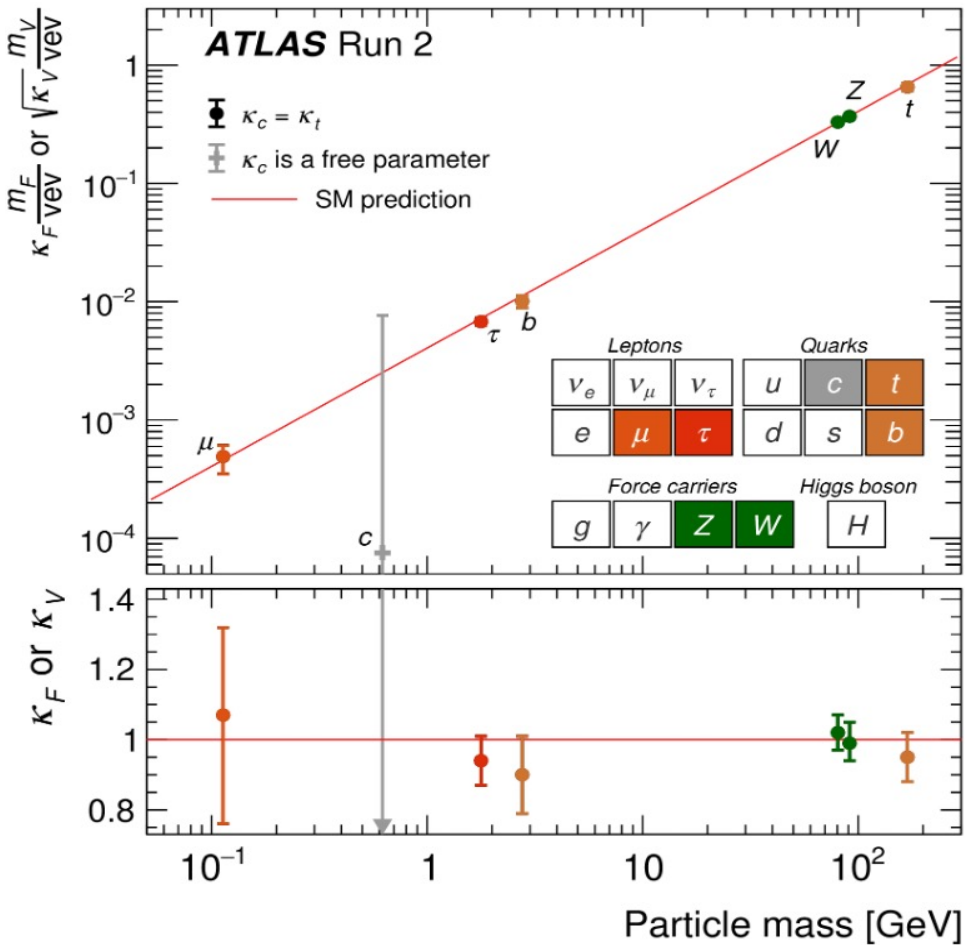
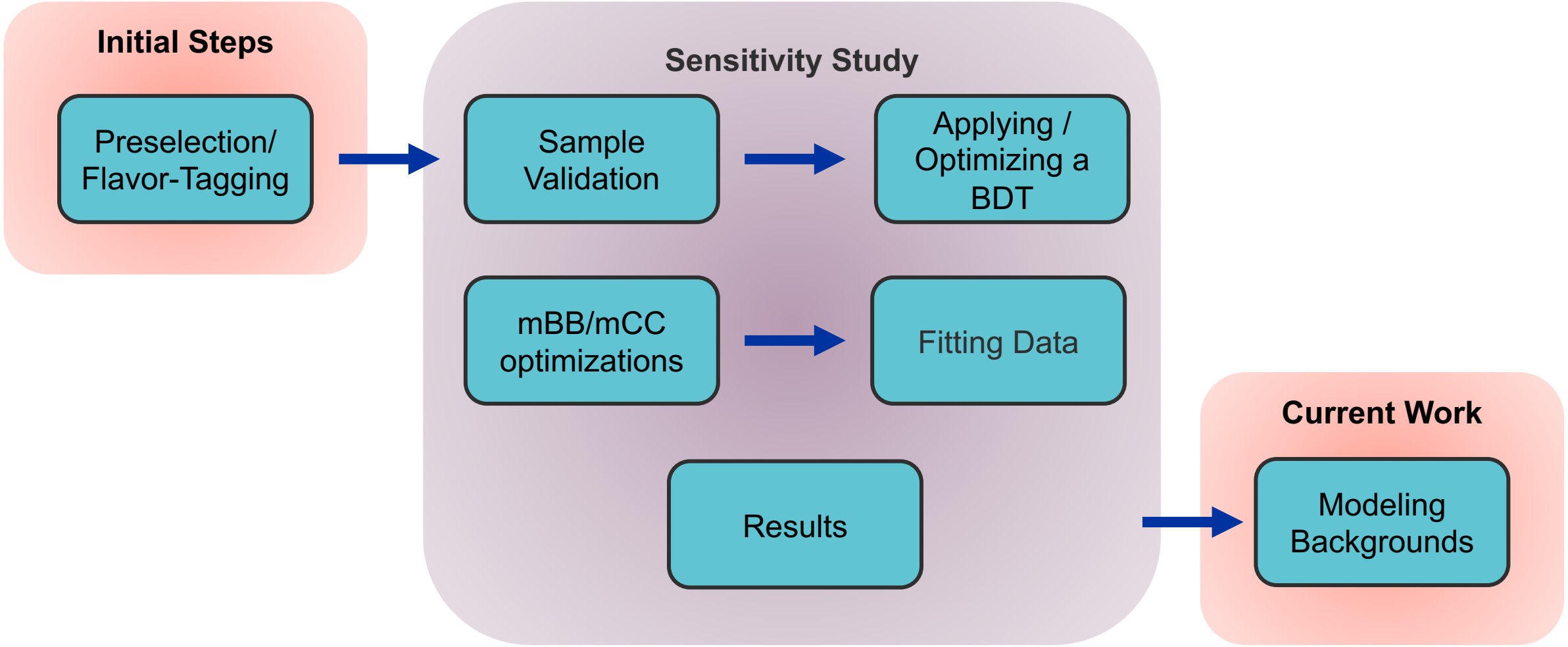


Figure: Higgs Boson coupling strength and uncertainties

- The charm quark is difficult to measure in the Standard Model due to a variety factors
  - Charm quark production has a “small” cross-section
  - Large amounts of background
  - Charm quark jets look remarkably similar to b-jets
  - Relatively low mass

Introduction: Steps of the sensitivity study



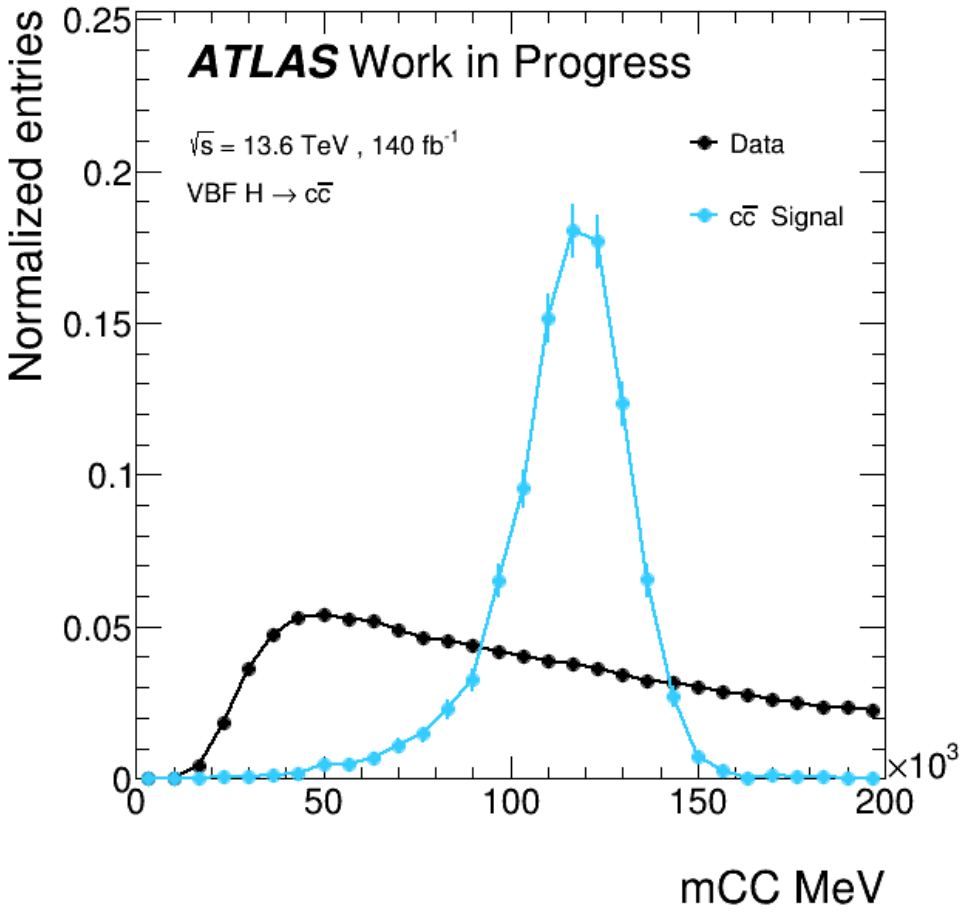
Introduction: Event Selection and Initial Steps

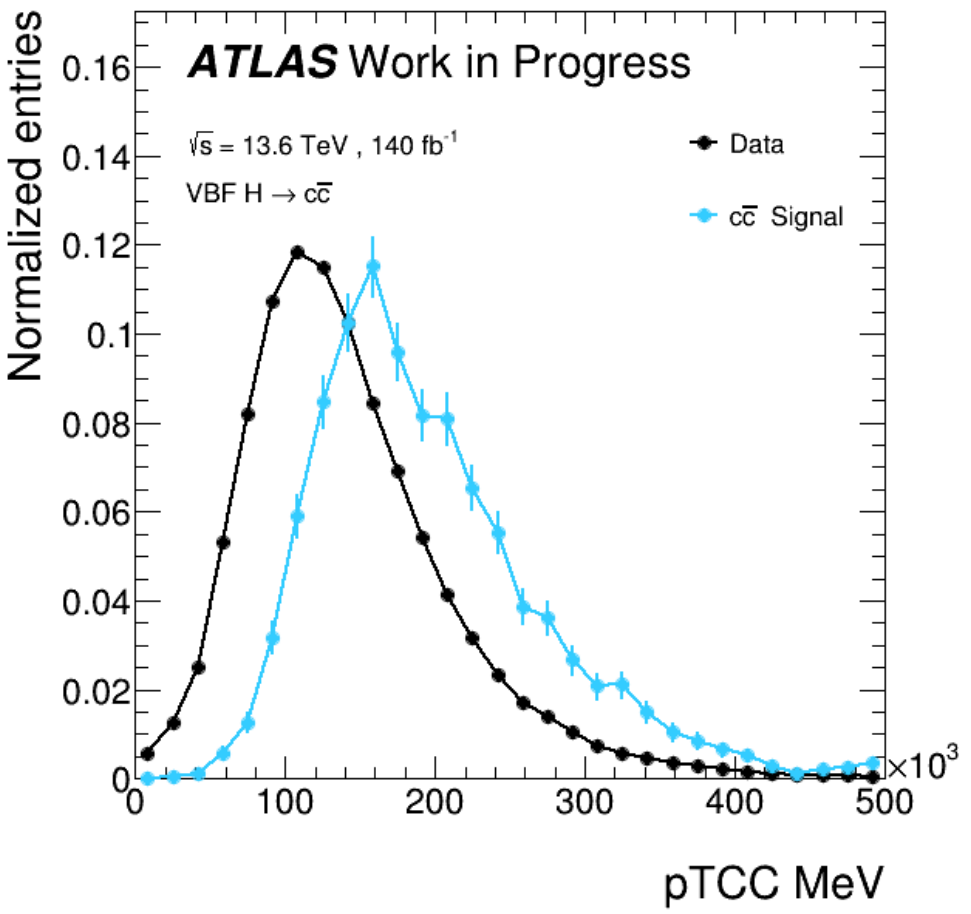
- Background was supplied by early 2022 data and signal samples for VBF H(bb/cc) were generated using Monte Carlo Generation.

- Preselection
  - VBF jet 1: pT > 75 GeV & |η|< 3.2
  - VBF jet 2: pT > 55 GeV & |η|< 4.5
  - mJJ > 1000 GeV & | Δη|> 4.0 & $\Delta\varphi$<2
  - H-Jets: pT > 20 GeV & |η|< 2.5
    - Choose VBF-jets that maximize the mJJ variable
    - Choose H-Jets to maximize the pTH

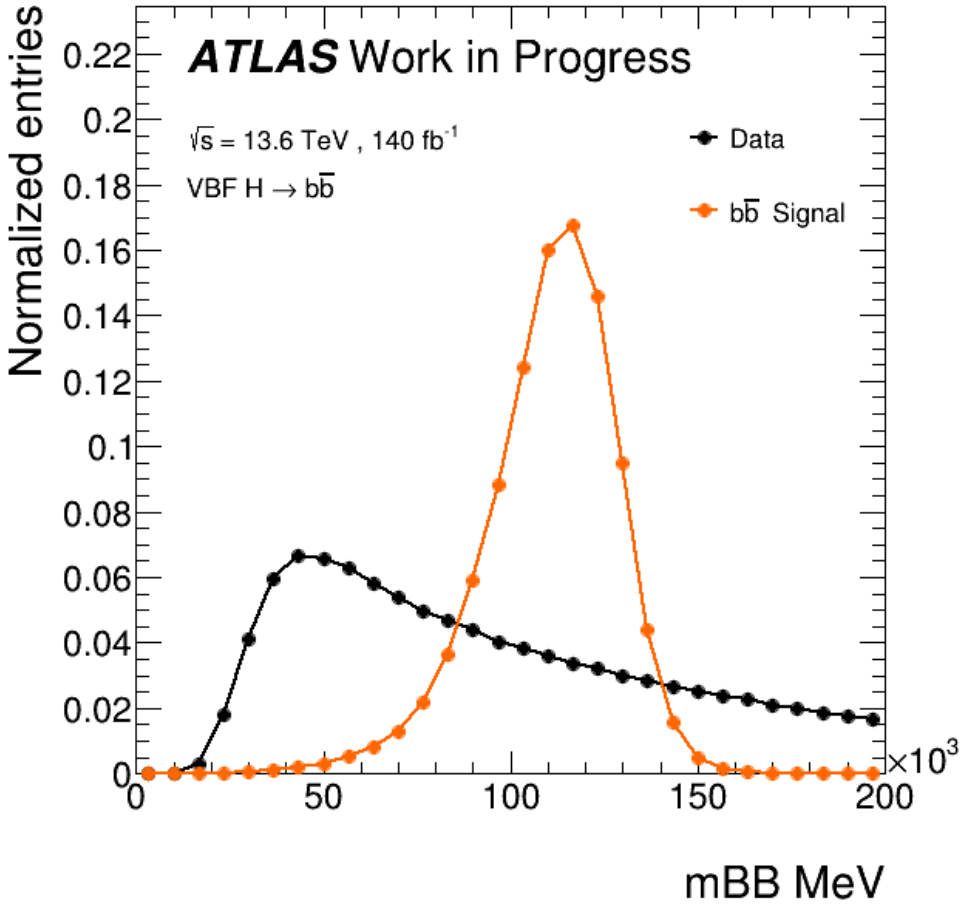
- Flavor Tagging
  - If both VBF jets pass b-tagging, events are categorized as BB
  - If both VBF jets fail b-tagging but pass c-tagging, events are categorized as CC.

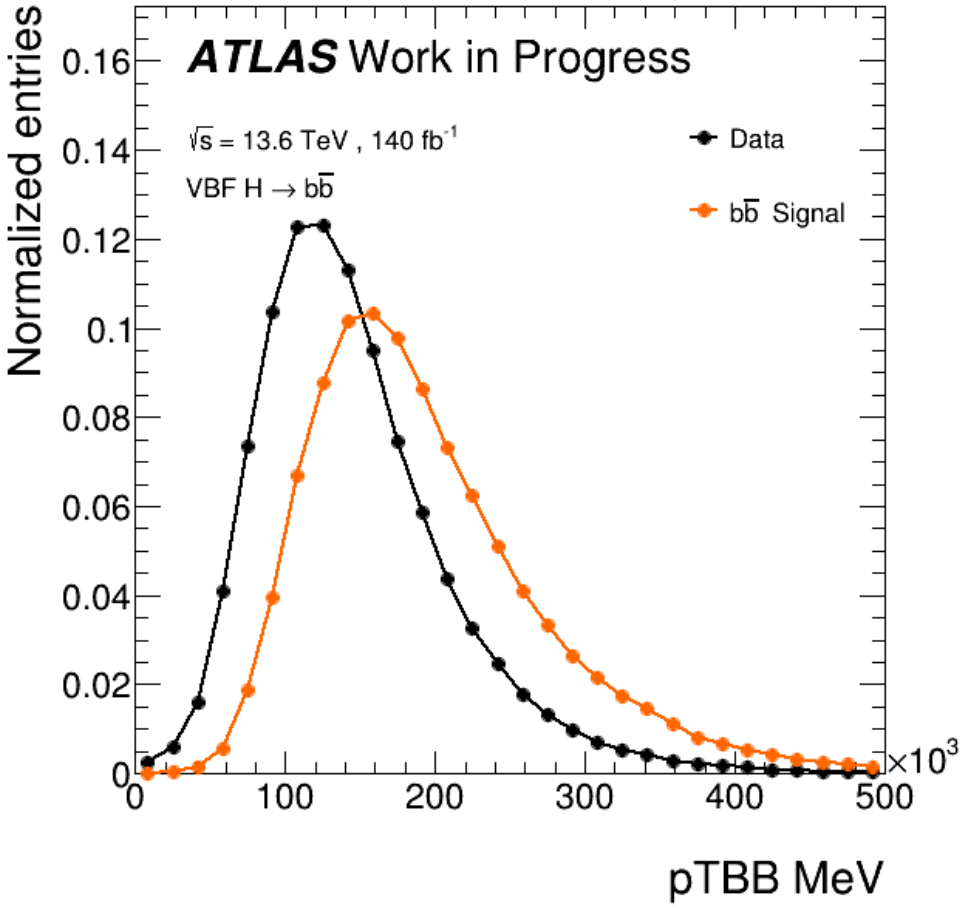
Sample Validation plots for H(cc)



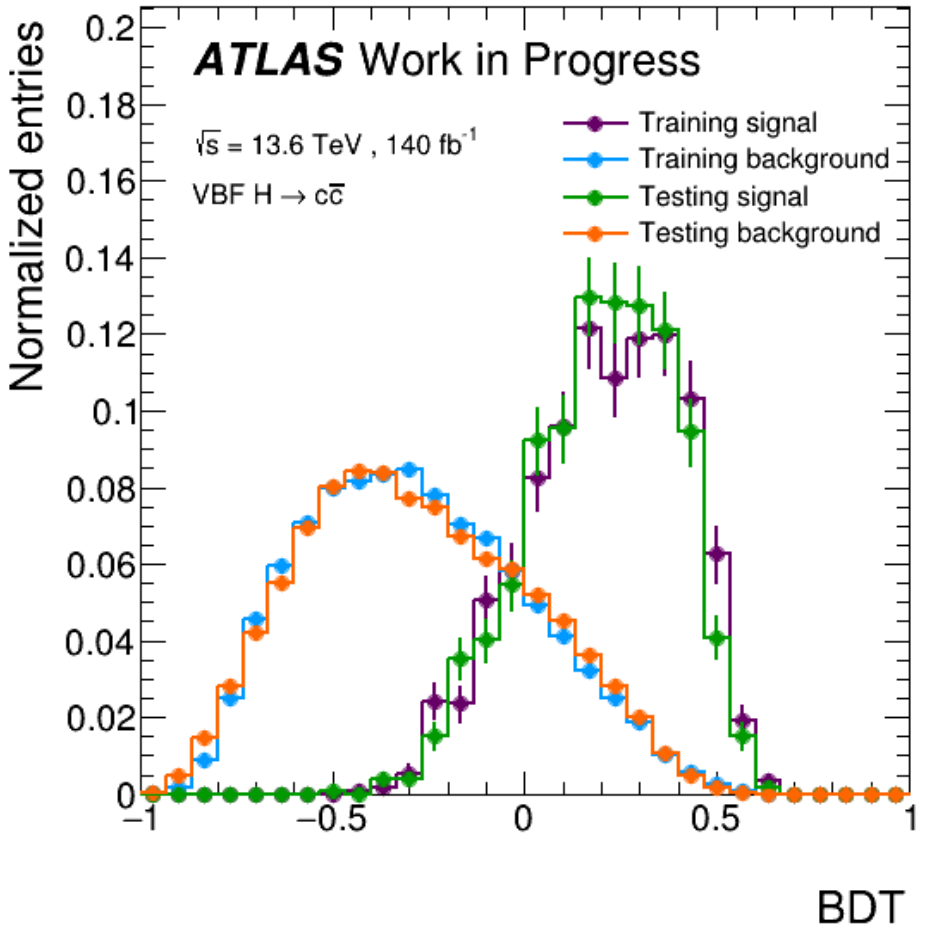


Sample Validation plots for H(bb)



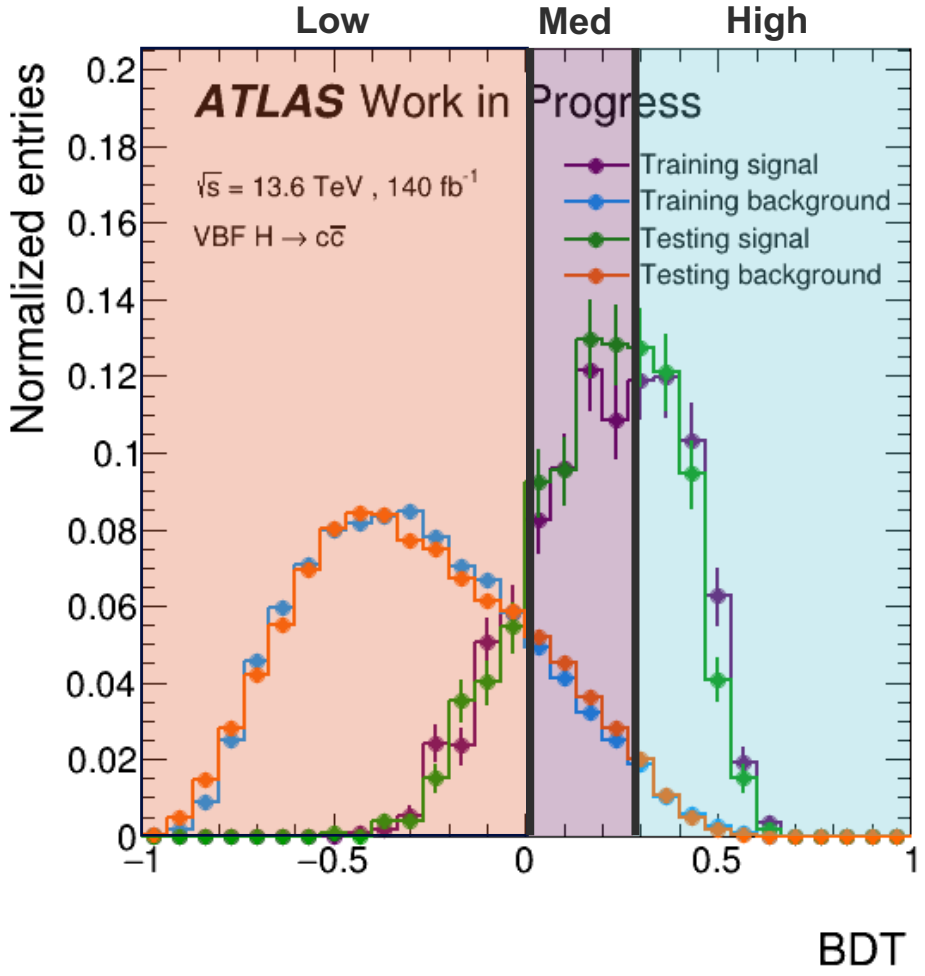


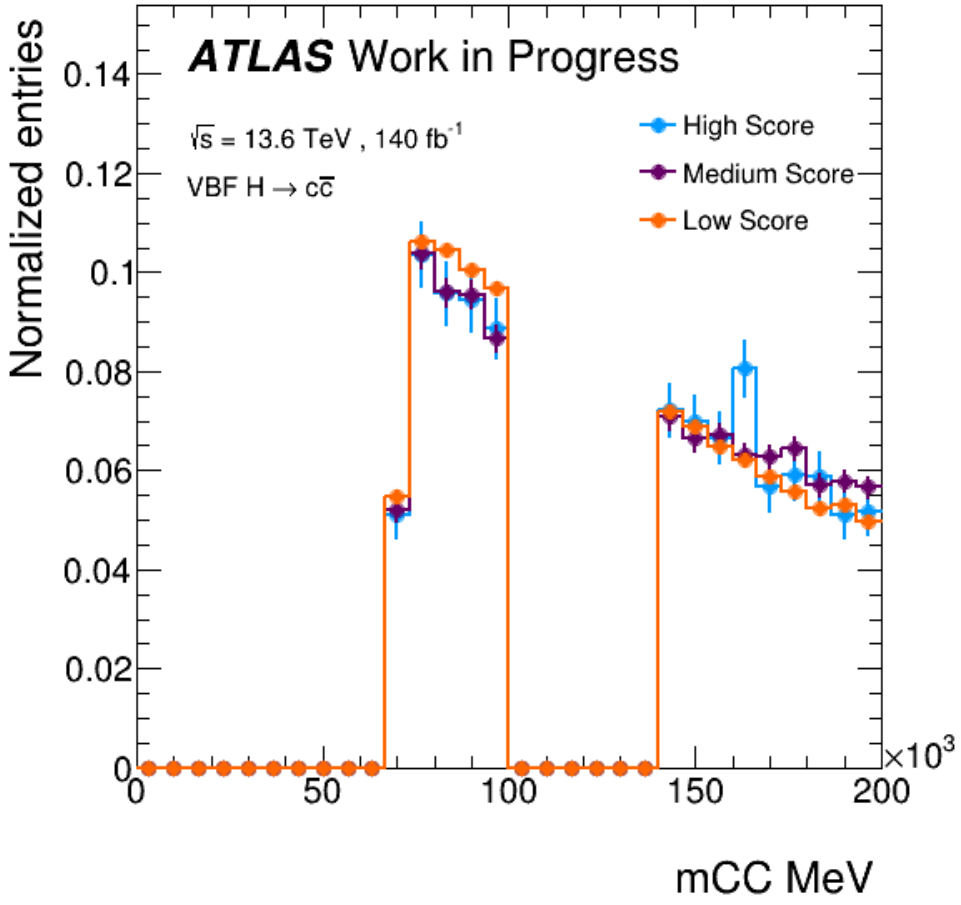
Applying and optimizing a BDT



- To gain significance in the measurement, a simple machine learning algorithm a Boosted Decision Tree (BDT) is applied to the dataset
- Optimizing the BDTs variable-list
  - This was done iteratively by checking previously used variable-lists
- Optimizing the BDTs Hyper-parameters
  - *Number of Trees*
  - *Maximum Depth of Trees*
  - *Minimum Node size*

mCC Optimizations





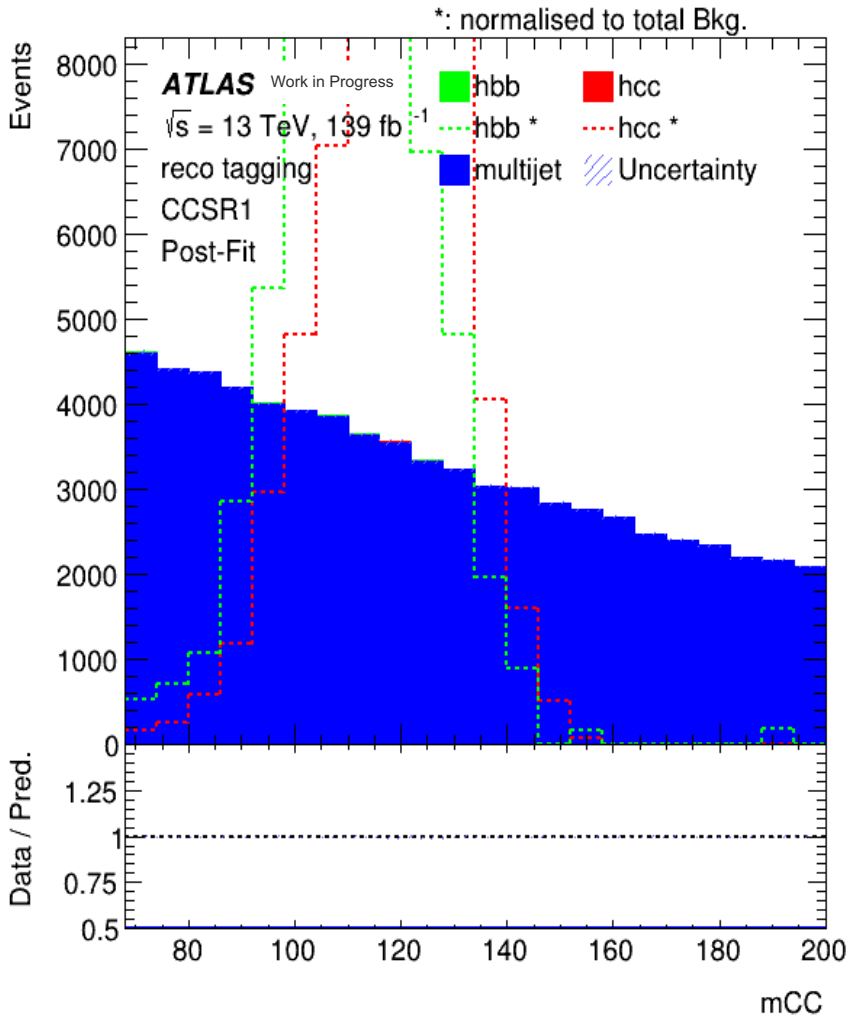
Fitting Data

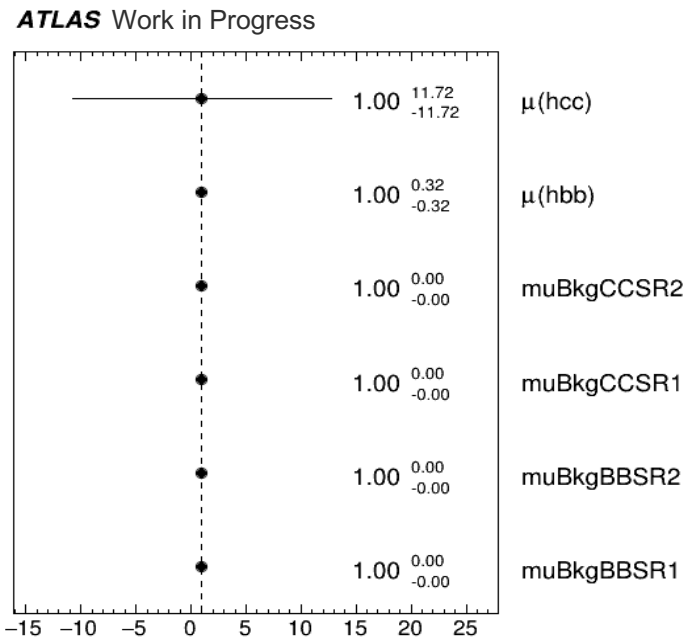
Statistical Likelihood fits have three major components:

- Signal strengths and background normalization
- Systematic uncertainties
- Monte Carlo statistical uncertainties

The quantity the fits will yield is a parameter called μ:

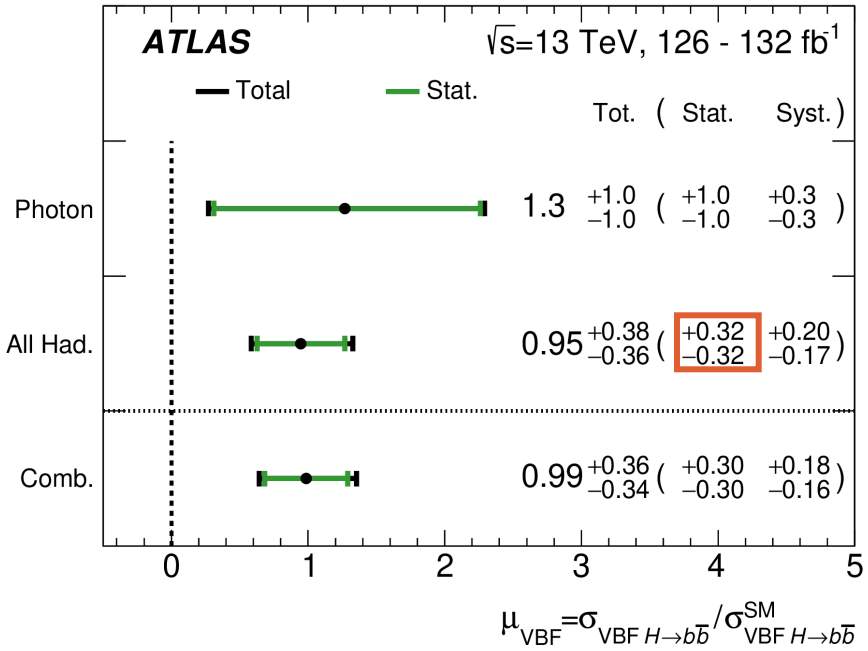
$$\mu_{\text{Higgs}} = \frac{\sigma_{VBF\,H\to cc}}{\sigma^{SM}_{VBF\,H\to cc}}$$

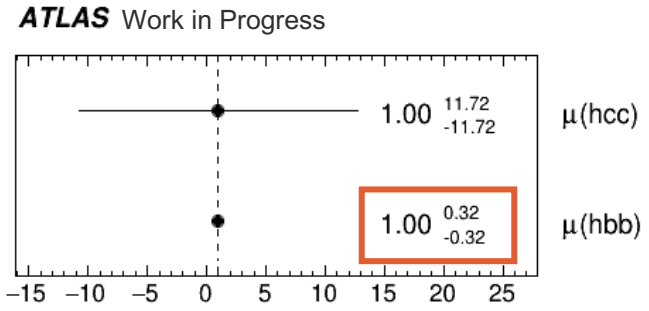




H(cc) Median Limits = 23.1
Correlation of $\mu_{H\to cc}$ and $\mu_{H\to bb}$ = -2.7%

Results and Further Studies





- The results for H(bb) had the same level of uncertainty has the full analysis completed in RUN 2.
- A number of optimizations were applied to the dataset to improve the sensitivity of both processes.

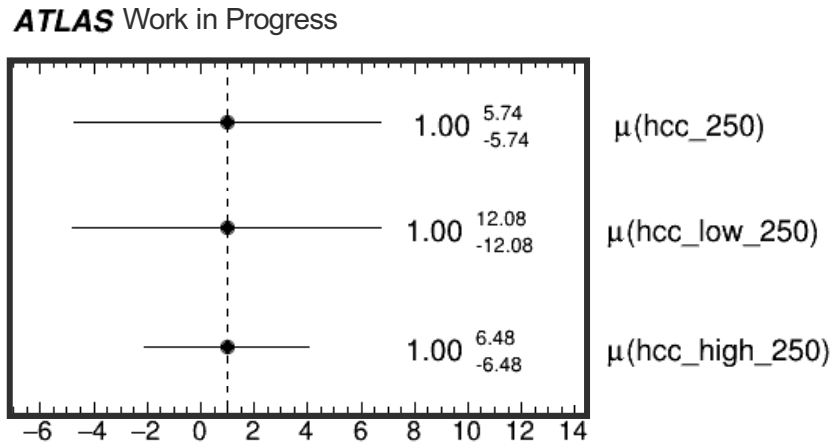
Best Results for bb/cc

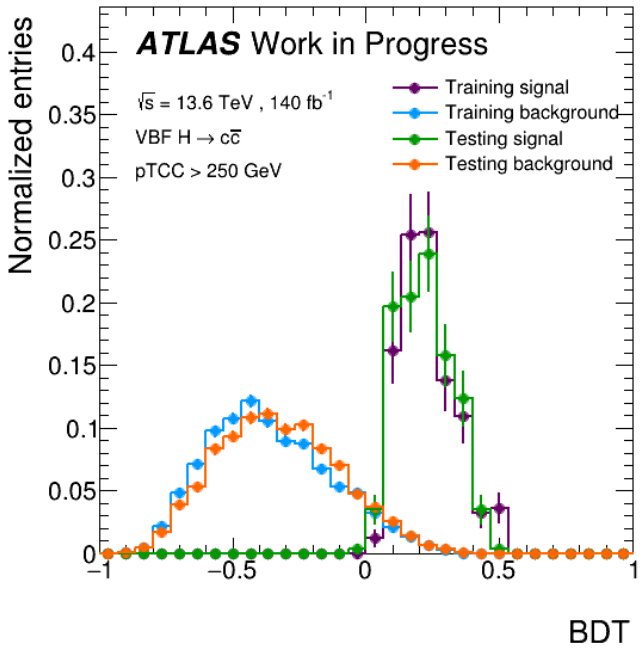
VBF H(bb)	$\mu \pm uncer.$
Initial Result	1 ± 0.32
2018 Result	1 ± 0.64
L1 topoinc Trigger	1 ± 0.28
topoinc pTBB split at 100 GeV	1 ± 0.32
topoinc pTBB split at 150 GeV	1 ± 0.30
topoinc pTBB split at 200 GeV	1 ± 0.28
topoinc pTBB split at 250 GeV	1 ± 0.24
topoinc pTBB split at 300 GeV	1 ± 0.23
L1 topo Trigger	1 ± 0.26
topo pTBB split at 100 GeV	1 ± 0.28
topo pTBB split at 150 GeV	1 ± 0.27
topo pTBB split at 200 GeV	1 ± 0.26
topo pTBB split at 250 GeV	1 ± 0.23
topo pTBB split at 300 GeV	$\mathbf{1 \pm 0.18}$

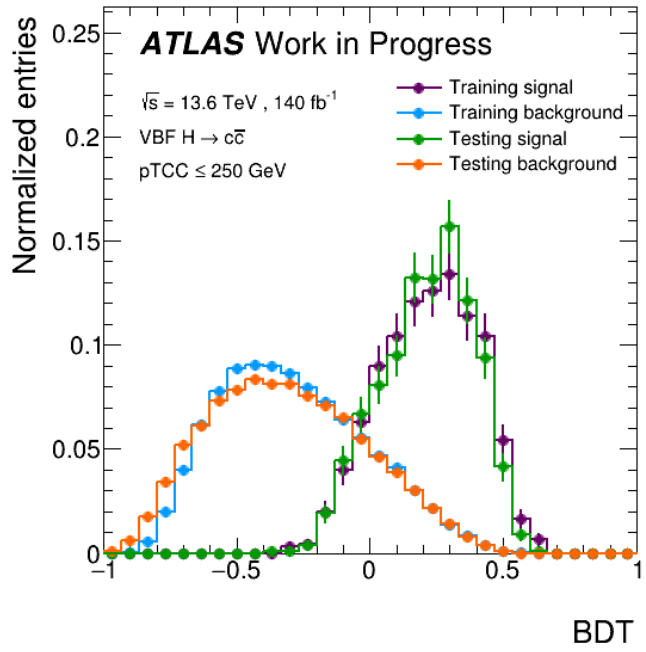
VBF H(cc)	$\mu \pm uncer.$	Median Limits
Initial Result	1 ± 11.72	23.10
2018 Result	1 ± 15.11	30.10
pTCC split at 150 GeV	1 ± 6.86	14.02
pTCC split at 200 GeV	1 ± 7.43	14.69
pTCC split at 250 GeV	$\mathbf{1 \pm 5.74}$	**11.34**

Conclusions

- In RUN 3, much sensitivity can be gained when looking at VBF Higgs to cc.
- This study motivated the Higgs working group to approve a VBF Higgs bb/cc analysis using a partial Run 2 and Run 3 dataset.
- (hopefully) The unblinding for this analysis will be this year.



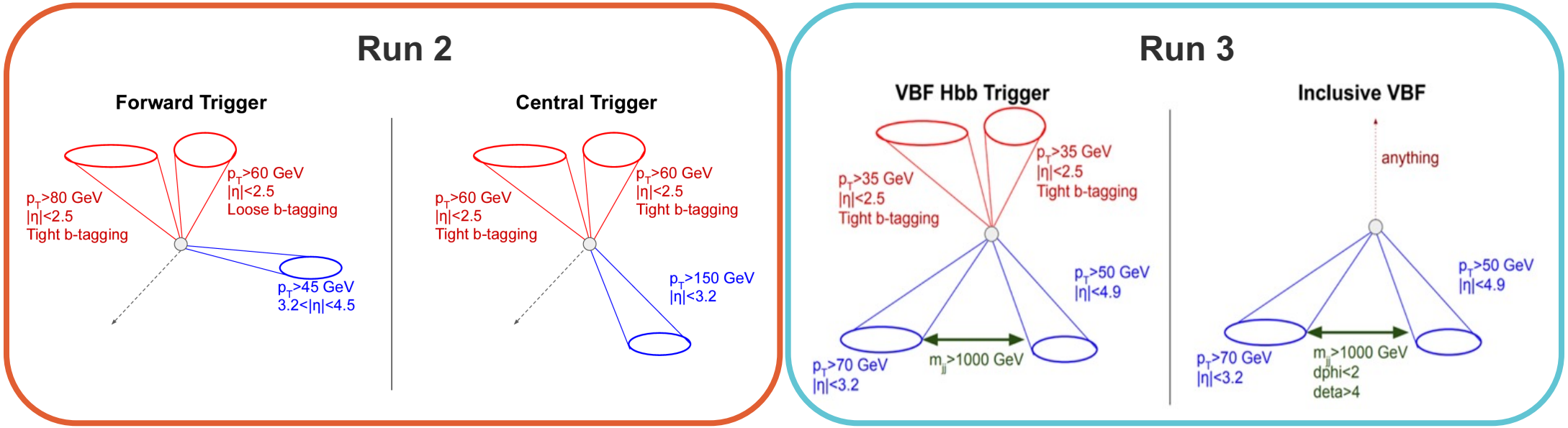




Questions?

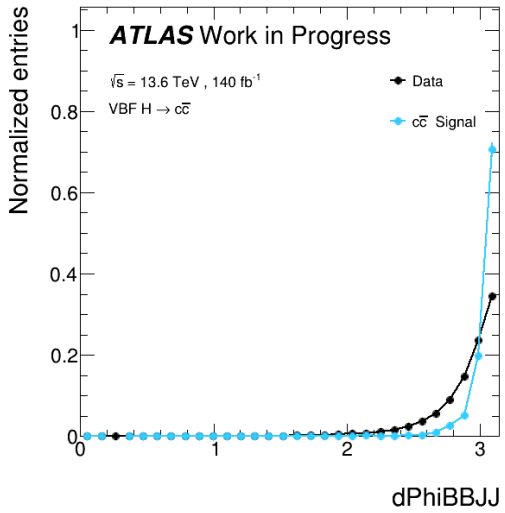
Backup

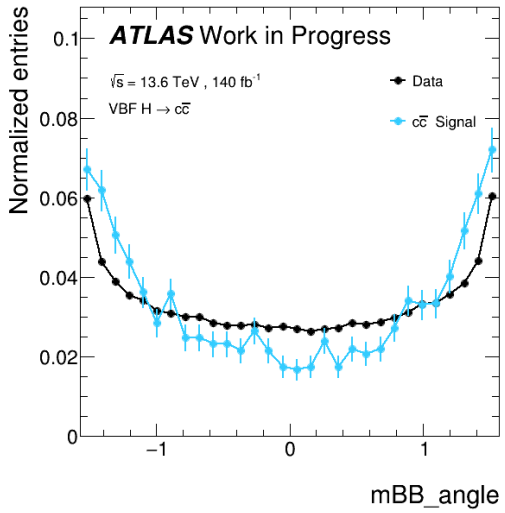
VBF Trigger

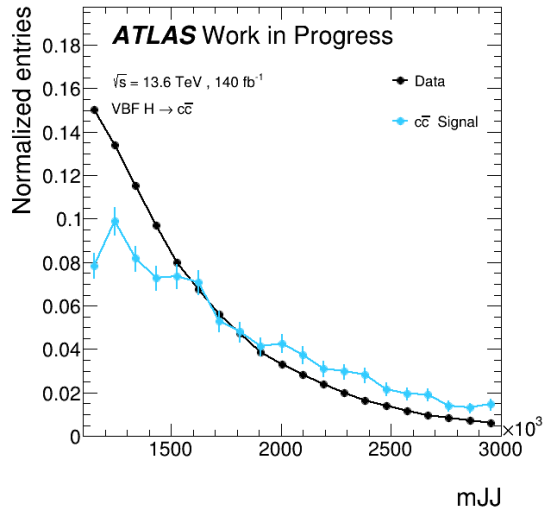

Run 2
Forward Trigger
p_T>80 GeV
|η|<2.5
Tight b-tagging
p_T>60 GeV
|η|<2.5
Loose b-tagging
p_T>45 GeV
3.2<|η|<4.5
Central Trigger
p_T>60 GeV
|η|<2.5
Tight b-tagging
p_T>60 GeV
|η|<2.5
Tight b-tagging
p_T>150 GeV
|η|<3.2
Run 3
VBF Hbb Trigger
p_T>35 GeV
|η|<2.5
Tight b-tagging
p_T>35 GeV
|η|<2.5
Tight b-tagging
p_T>50 GeV
|η|<4.9
p_T>70 GeV
|η|<3.2
m_{jj}>1000 GeV
Inclusive VBF
anything
p_T>50 GeV
|η|<4.9
p_T>70 GeV
|η|<3.2
m_{jj}>1000 GeV
dphi<2
deta>4

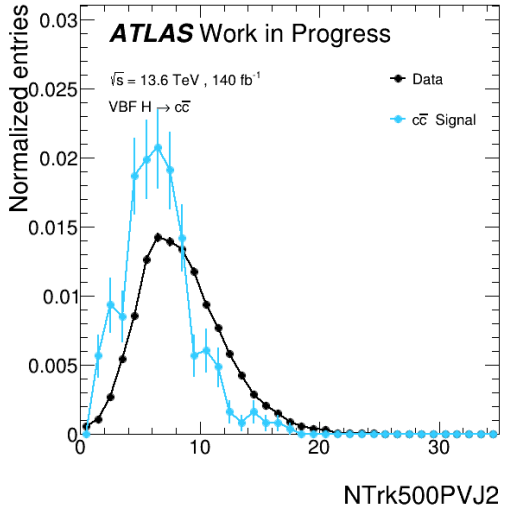
BDT Variables for VBF H(cc)

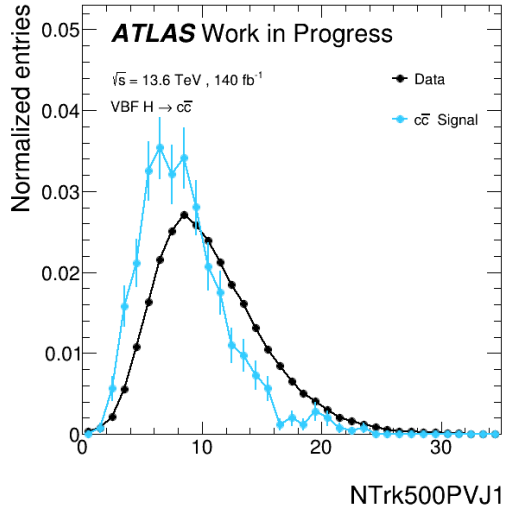
- mJJ
- pT_balance
- nJets20pt
- asymJJ
- mBB_angle
- dEtaBBJJ
- dPhiBBJJ
- mindRJ1_Ex
- mindRJ2_Ex
- NTrk500PVJ1
- NTrk500PVJ2
- pTJJ
- cweightB1
- cweightB2

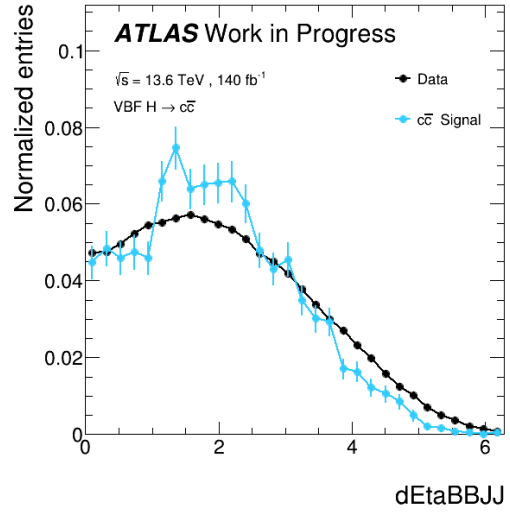












mBB Optimizations