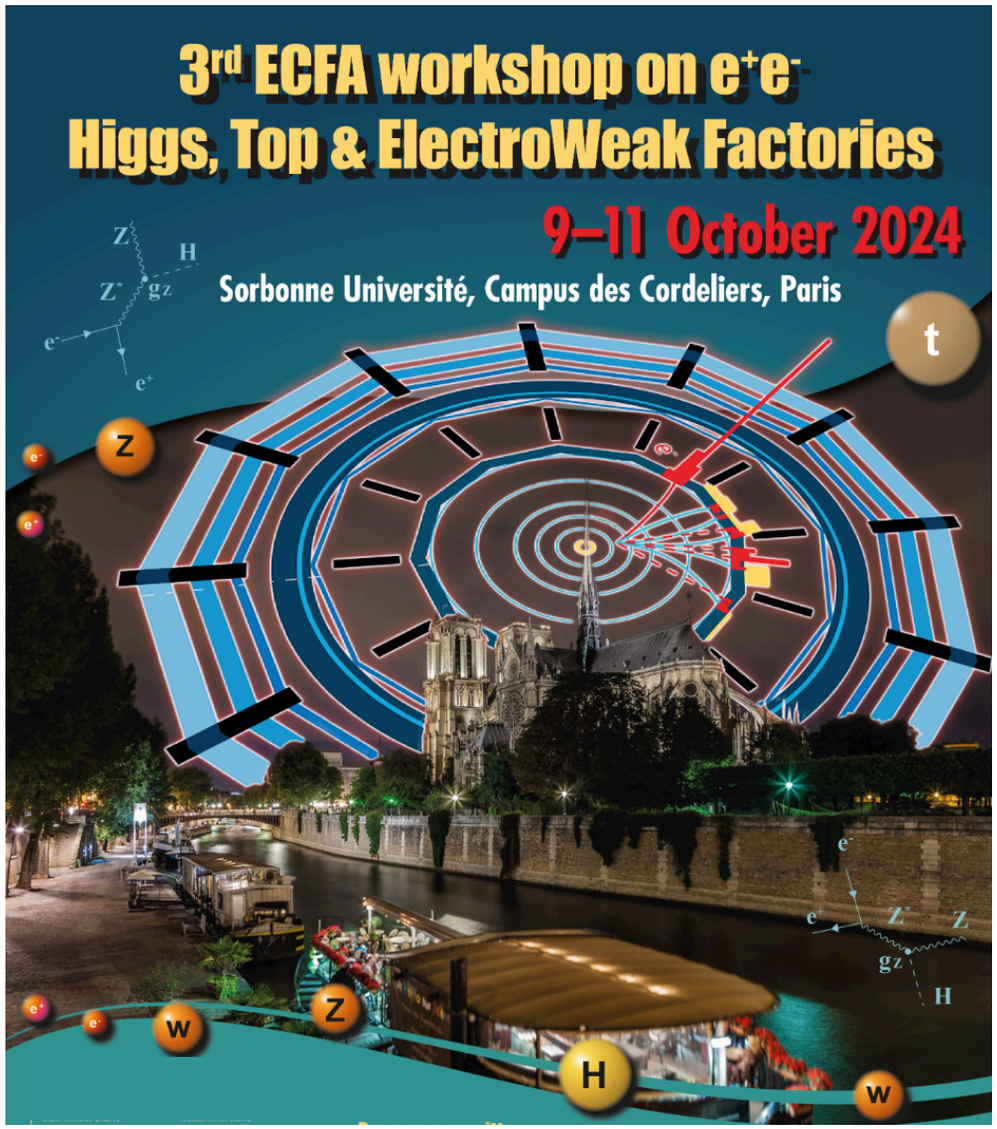
Top properties from ttbar threshold scan at FCC-ee

Matteo Defranchis, Zohreh Bahariyoon, Abideh Jafari, Ankita Mehta, Michele Selvaggi, Marcel Vos



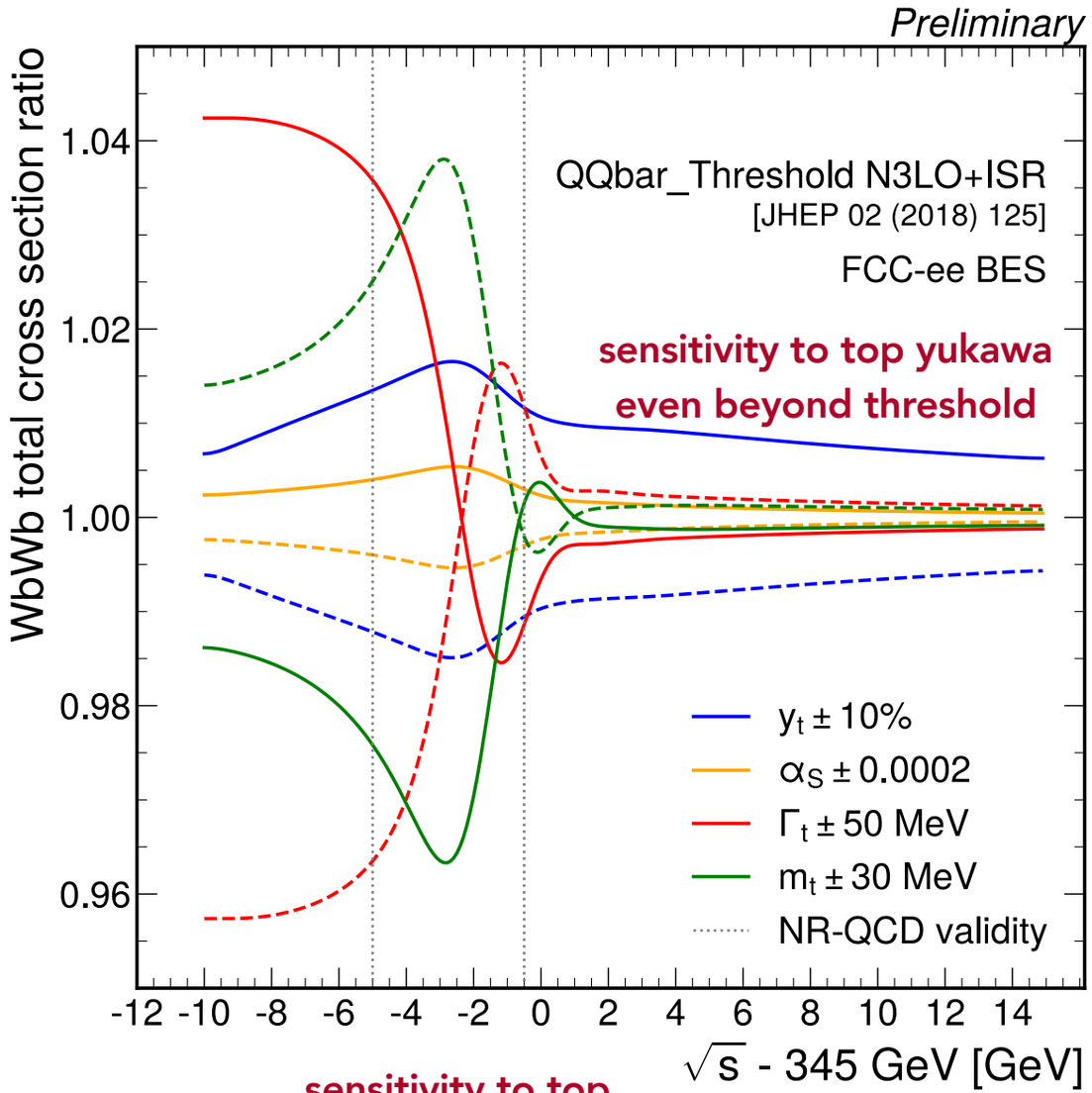
October 10, 2024

Overview

- Measurement of WbWb production cross section at different center-of mass energies (340-365 GeV) around ttbar production threshold in e^+e^- collisions at FCC-ee
- Different center-of mass energy points offer the measurements of top mass, width, top-Yukawa couplings and even look for new physics

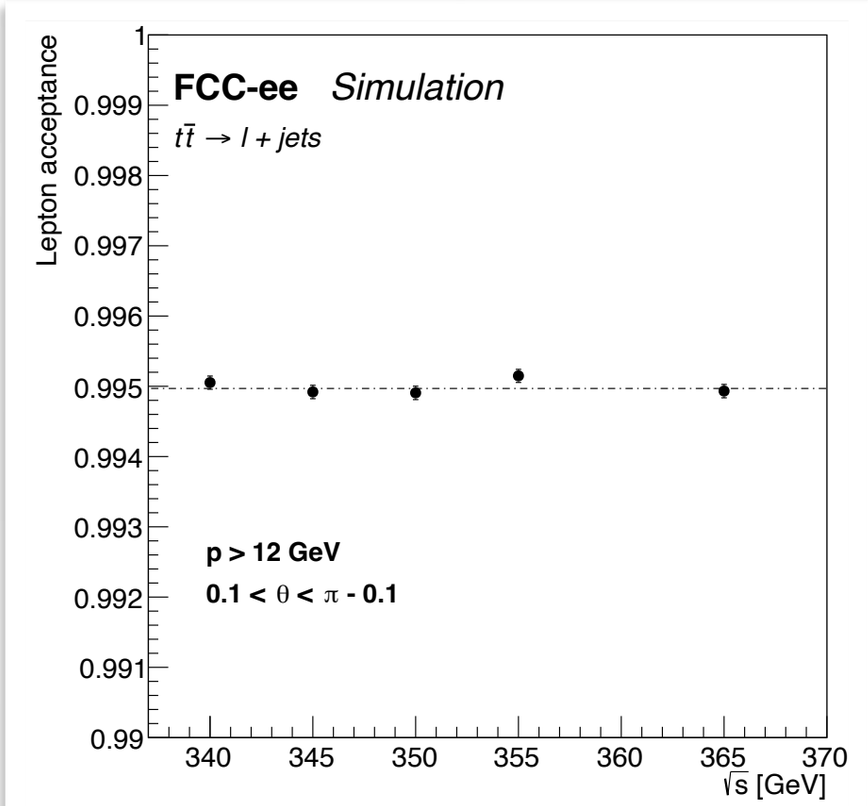
- Targeting semi-hadronic and hadronic decay modes (total branching fractions ~90%) with integrated luminosity of 41/fb per e.c.m at 340-355 GeV and 2.65/ab at 365 GeV

- Dominant background contribution from $e^+e^- \rightarrow WW$
- Assuming 10^{-4} uncertainty on integrated luminosity

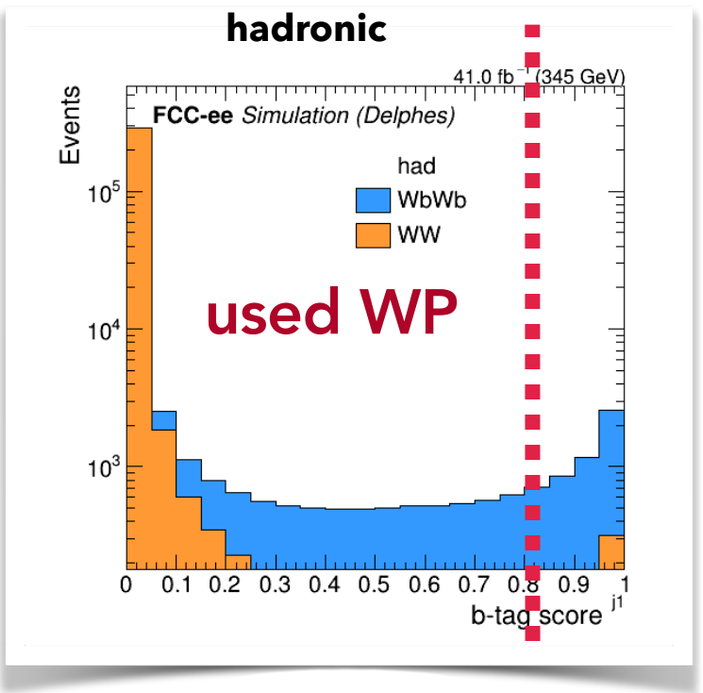


Simulation and object selection

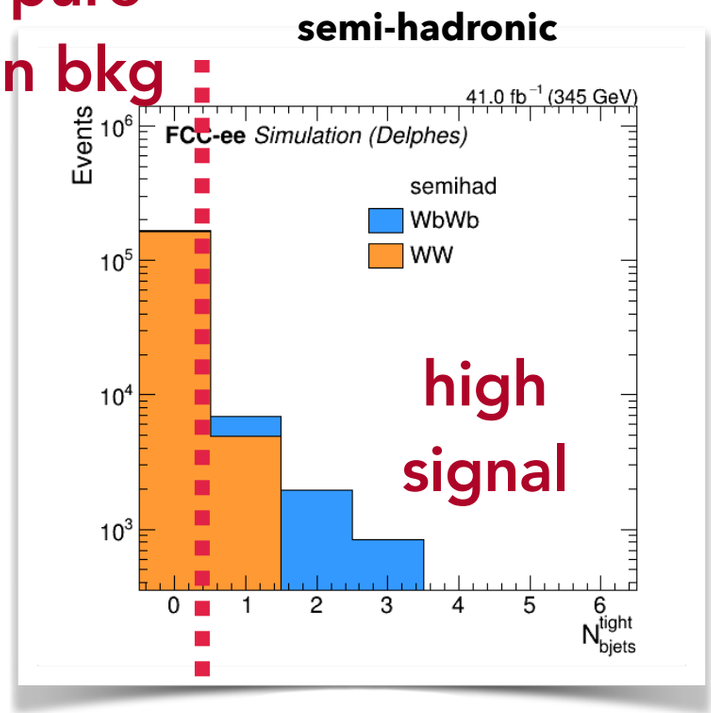
- Signal (WbWb) and background (WW) samples with detector simulation (IDEA) incorporated using DELPHES
- Two event categories:
  - semi-hadronic (hadronic) : exactly one (zero) isolated lepton (muon or electron) with p > 12 GeV
- Exclusive jet clustering
  - four (six) jets for the semi-hadronic (hadronic) channel
- Signal-background discrimination using BDT
- Heavy-flavor jet tagging to control background



Lepton acceptance
~99.5%
(for all energy points)

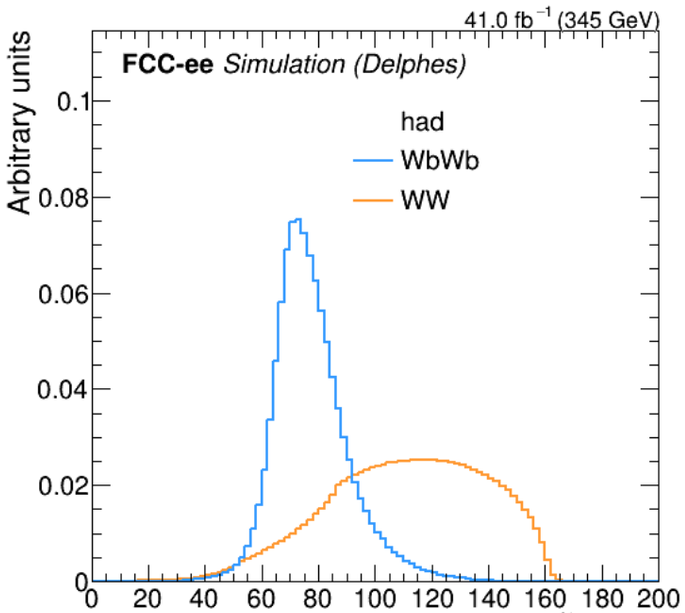


pure in bkg

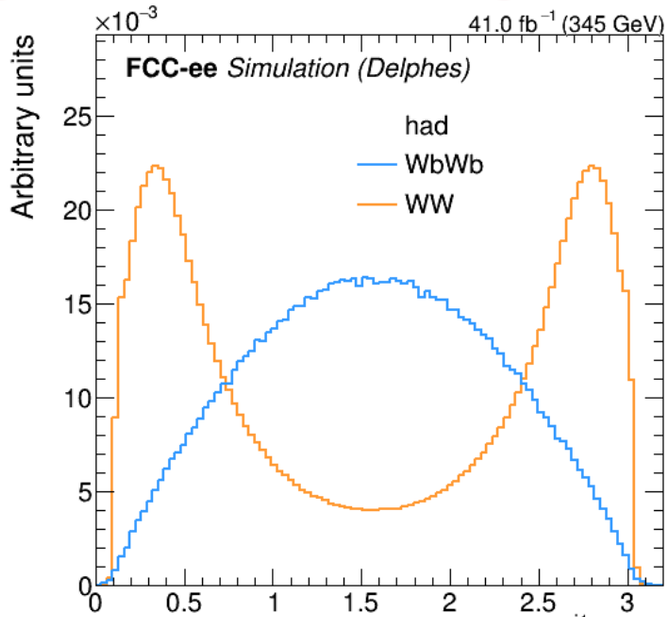


Event kinematics

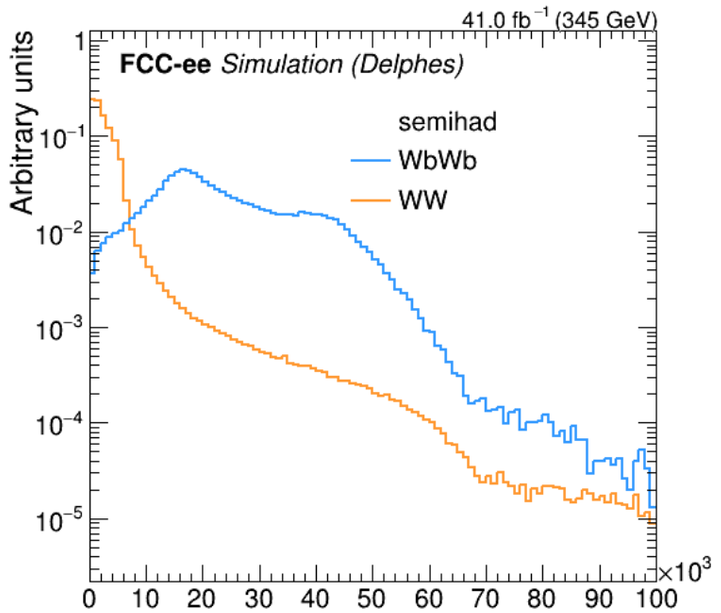
hadronic



larger boost in background



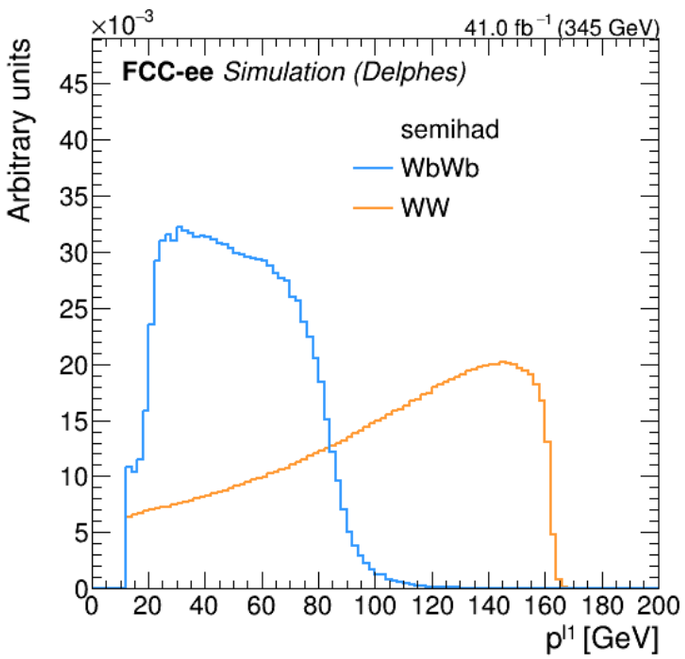
peaks at zero for background

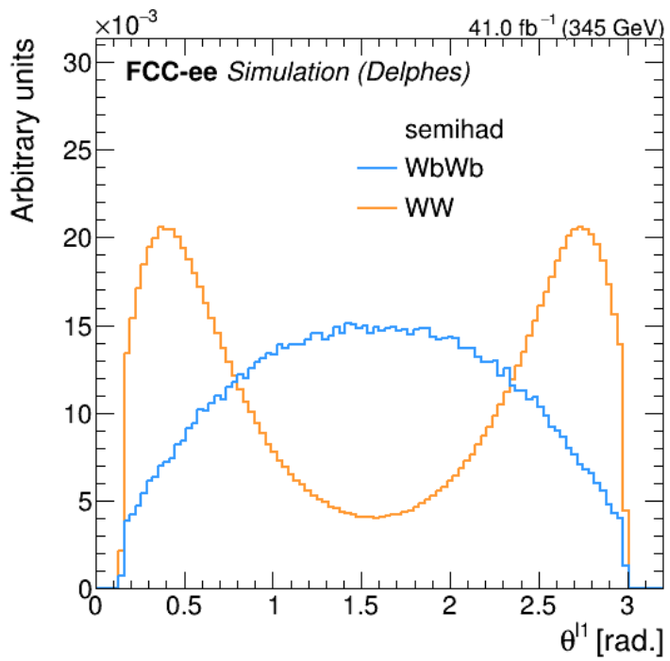


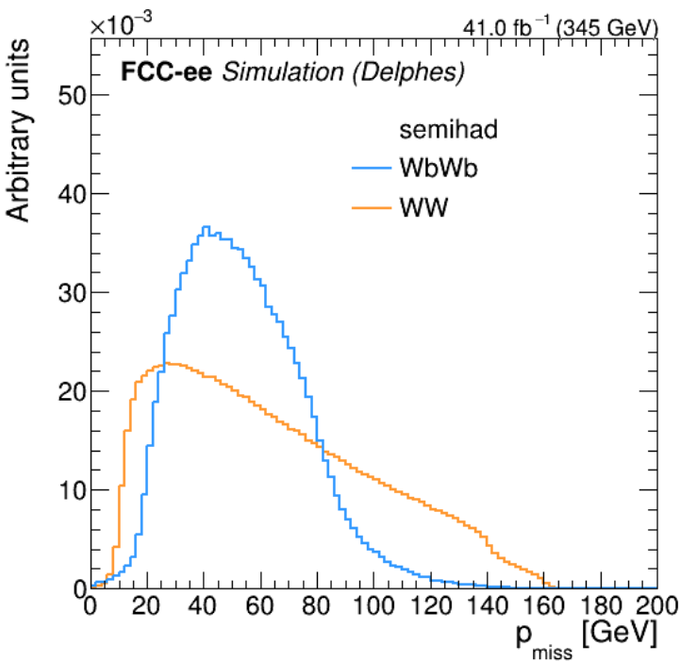
Broader momentum spectrum for WW as compared to signal

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

semi-hadronic



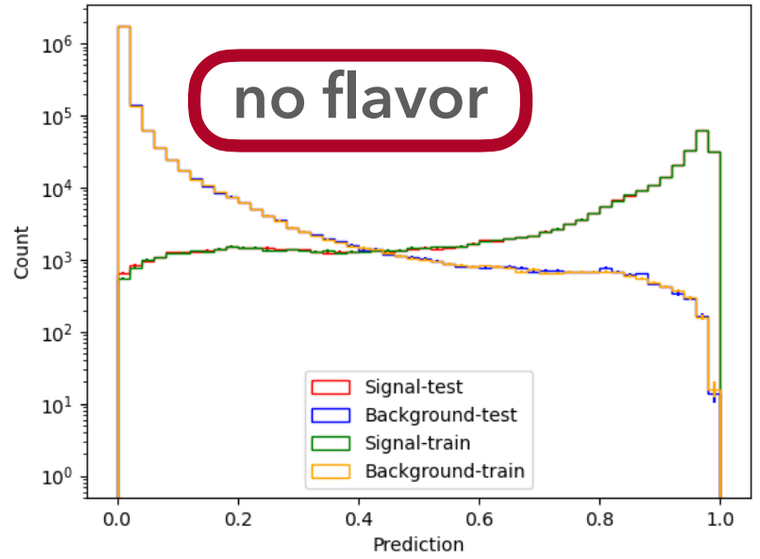




BDT classifier training

- Classifier trained at 345 GeV for semi-hadronic and hadronic cases separately
- Input variables include: lepton and jet kinematics
- Three training configurations depending upon the flavor input
  - without any flavor information
  - with flavor information
  - with b-tagged jets only

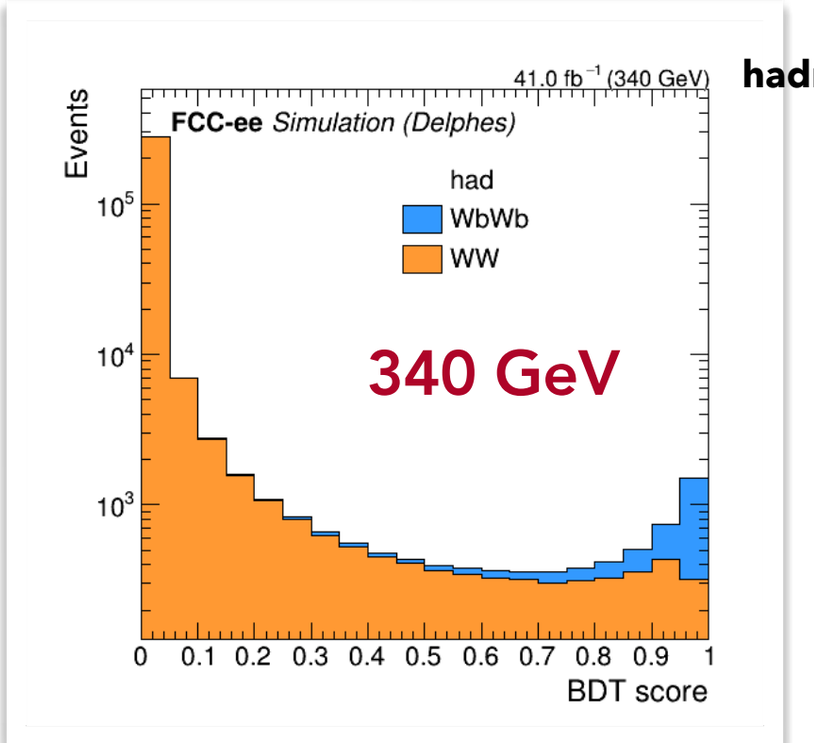
BDT trained without any flavor information already shows good discrimination → less sensitive to tagger-related uncertainties

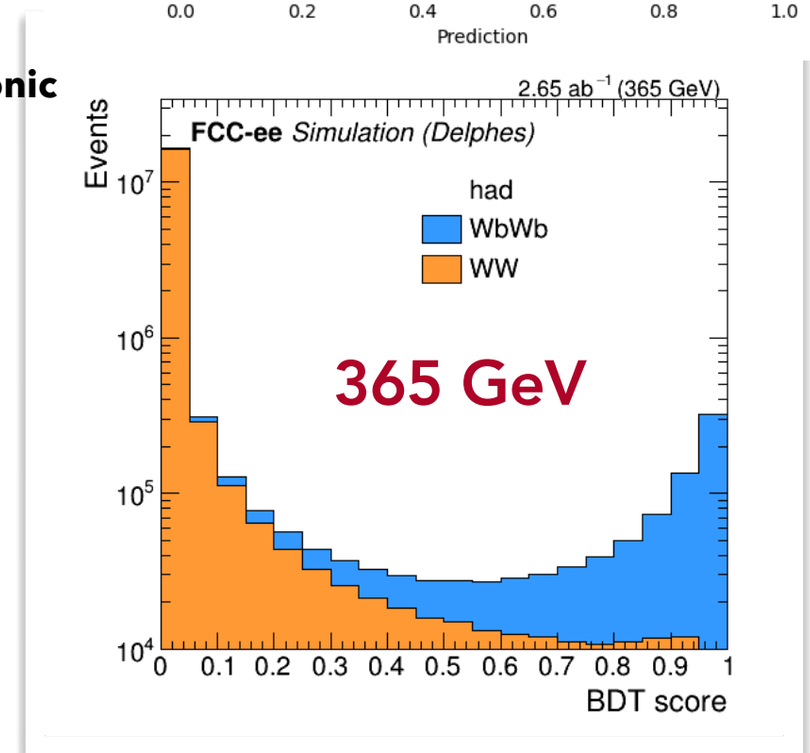


BDT score

same trained model works for all e.c.m points

hadronic



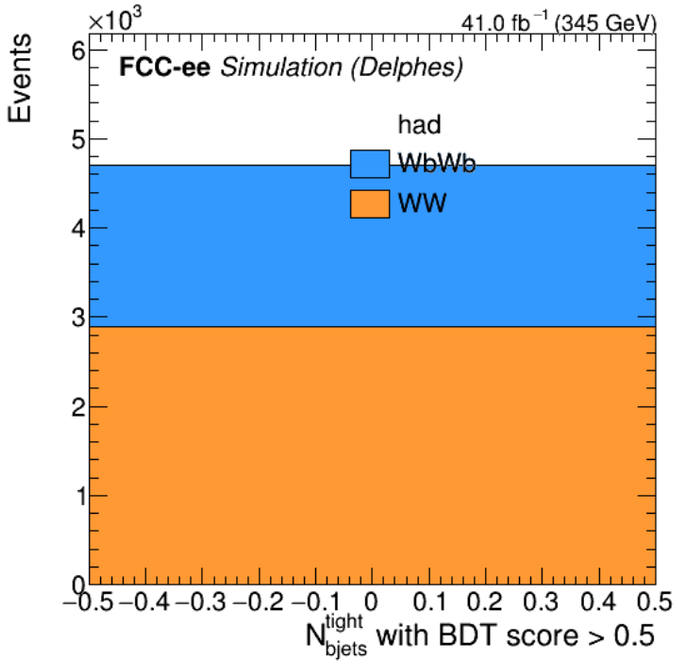


Cross section measurement

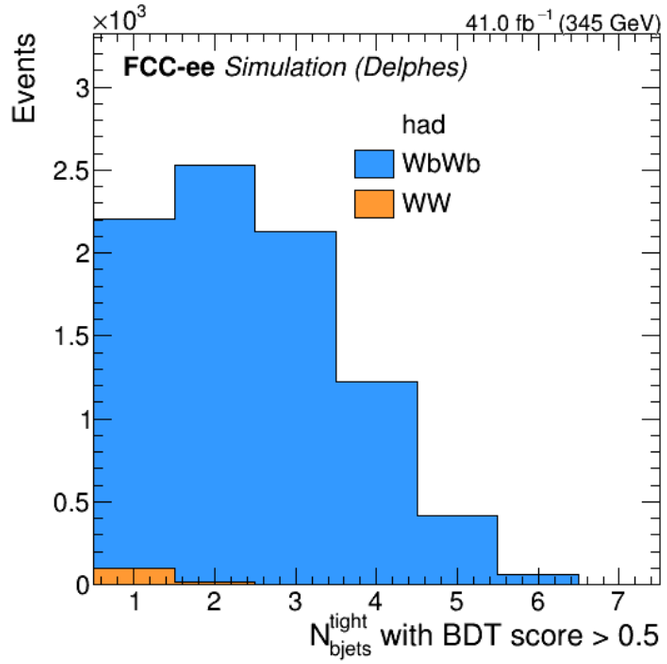
- Perform a simultaneous maximum likelihood fit to the b-tagged jet multiplicity in the signal and control regions in semi-leptonic and hadronic channels, after applying a cut on the BDT classifier
- Normalization of the WW background freely floating in the fit and de-correlated between semi-leptonic and hadronic channels
- Uncertainty on luminosity calibration (0.01%) → correlated between two channels

inputs to the fit

hadronic

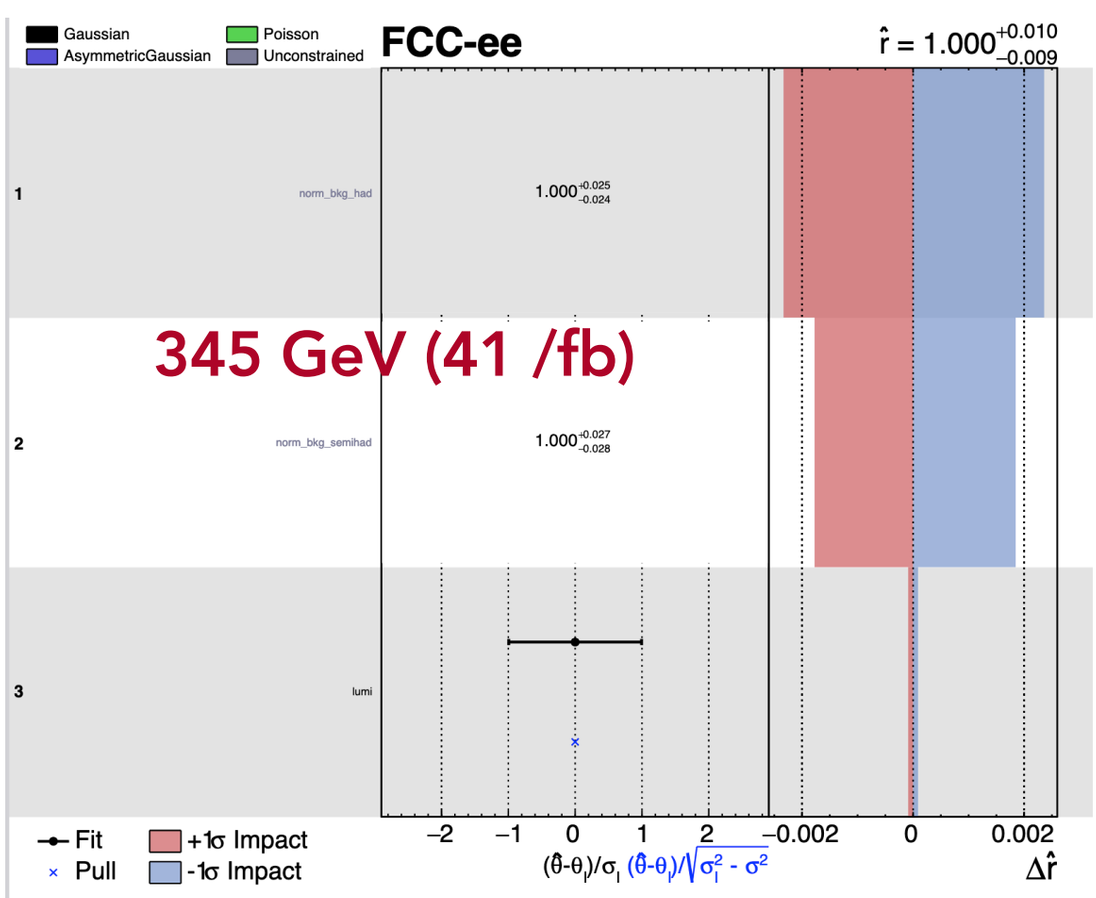


control region with zero b-tagged jets



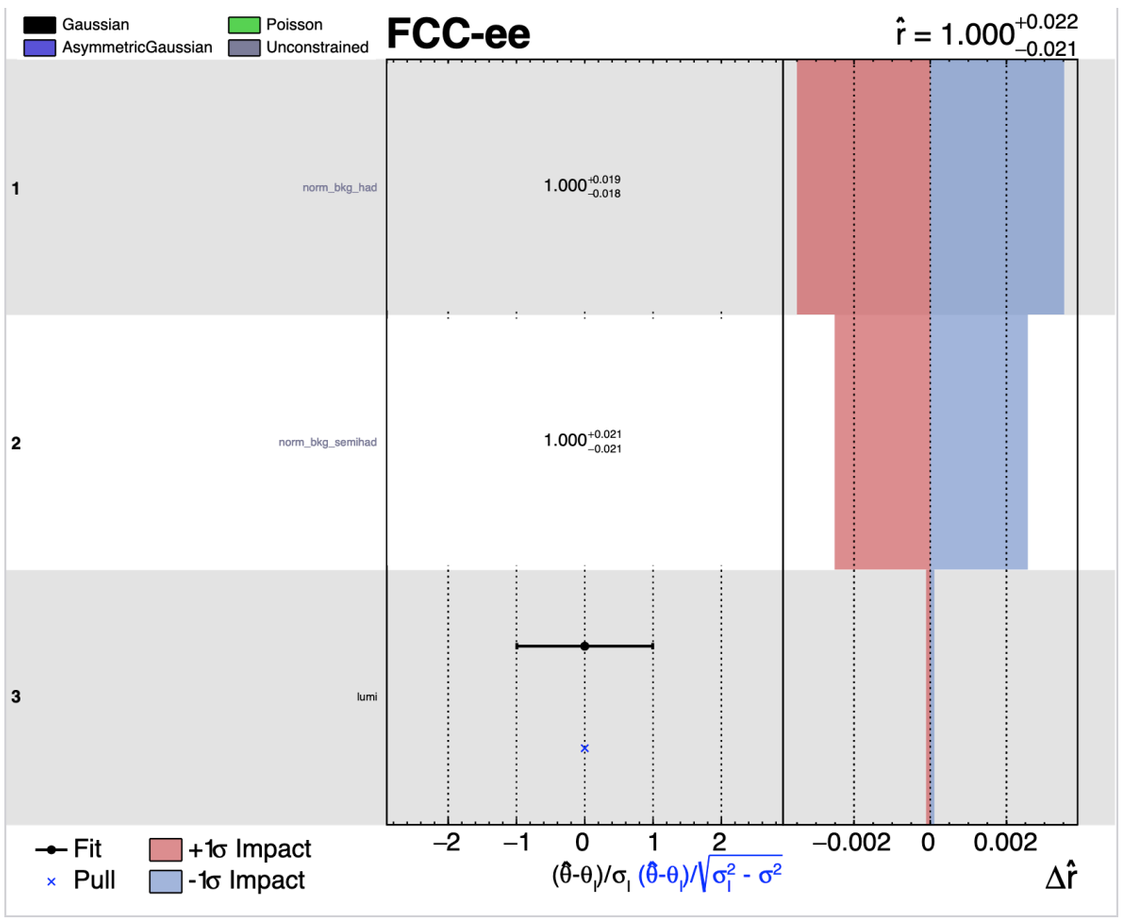
signal region with at least one b-tagged jet

1% total uncertainty



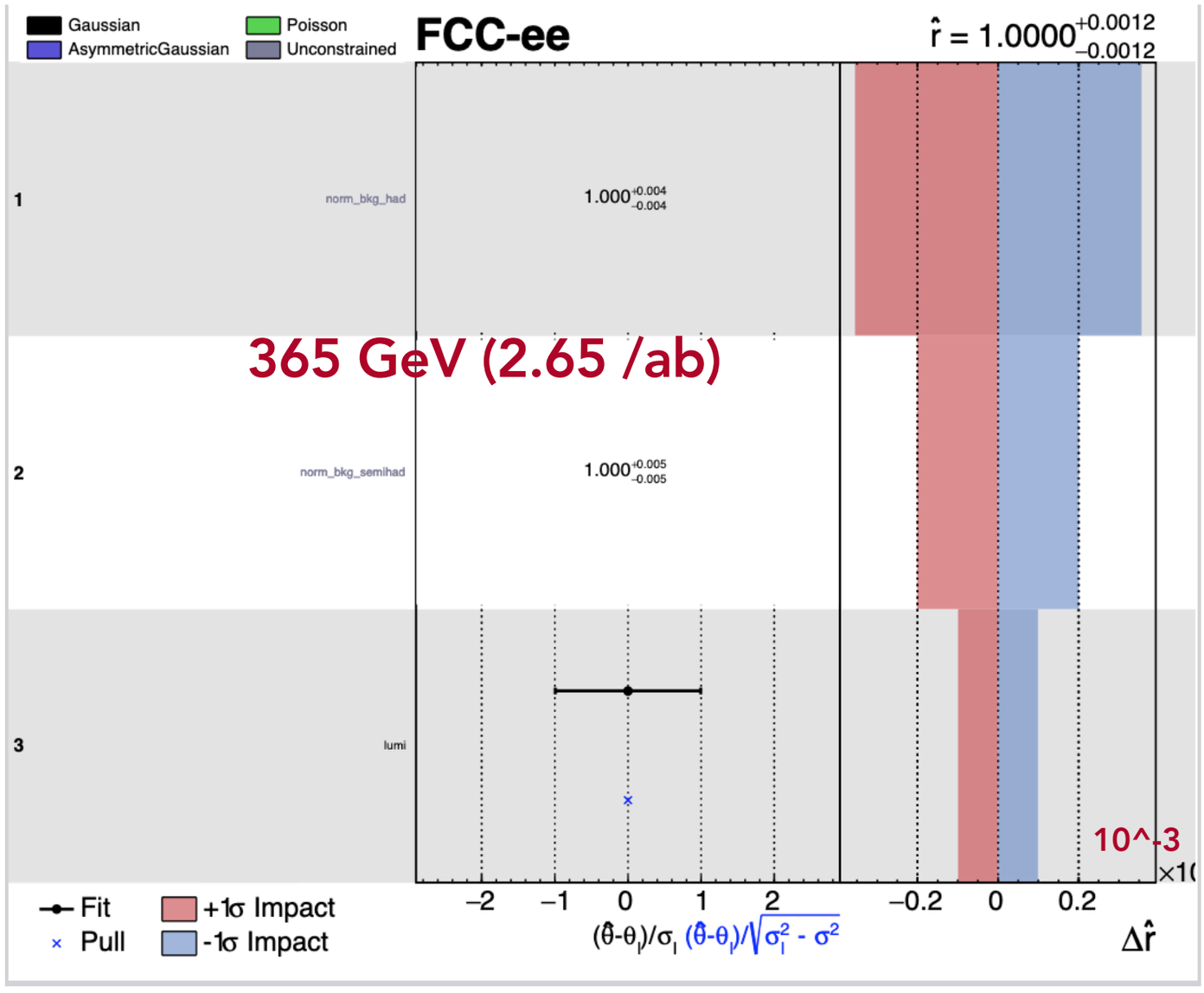
Cross section measurement-ii

340 GeV (41 /fb)



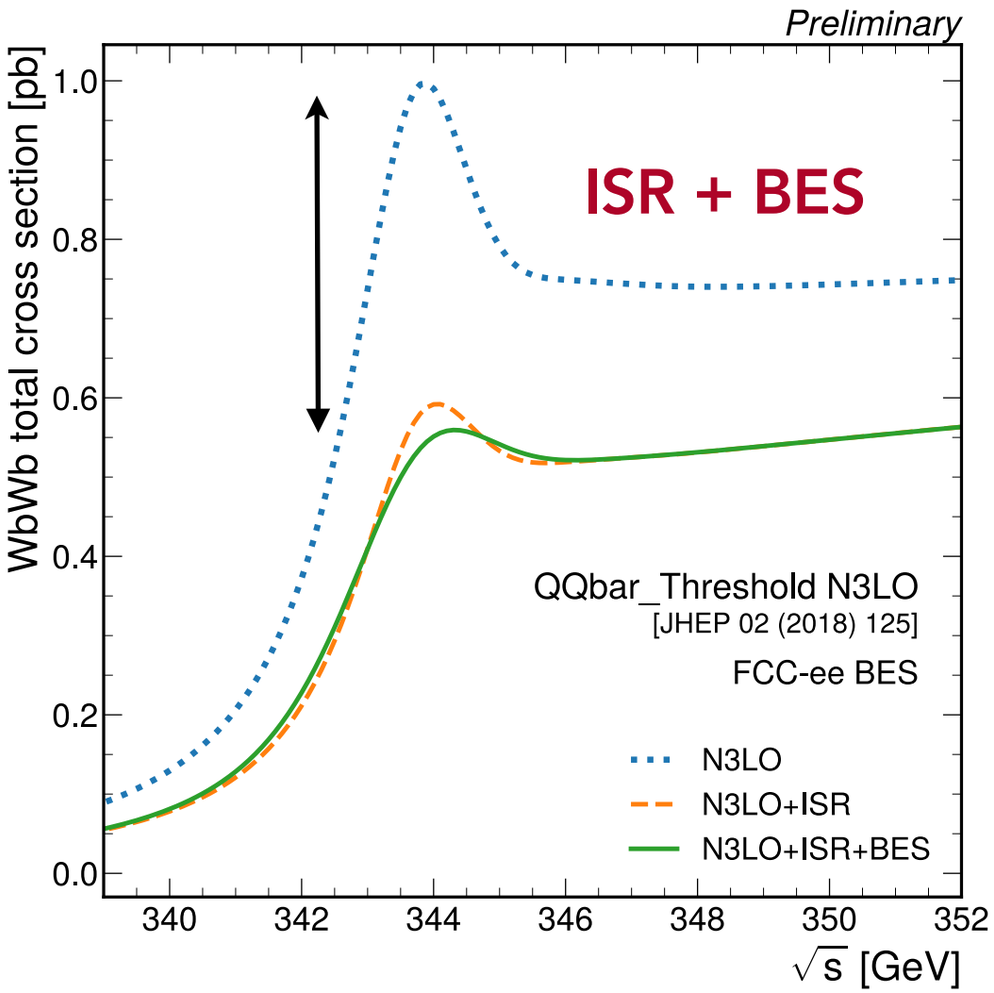
2.2% total uncertainty dominated by background normalization

0.12% total uncertainty

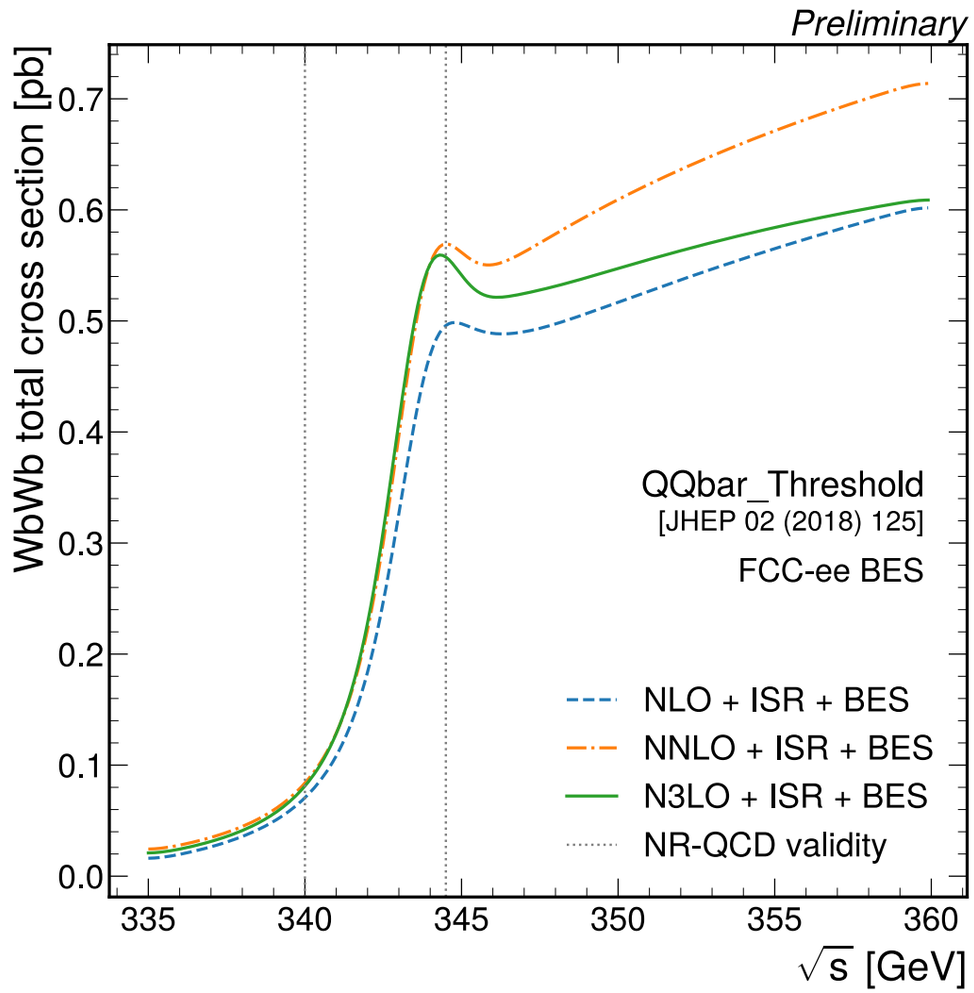


365 GeV (2.65 /ab)

Fit of theory predictions to pseudo-data



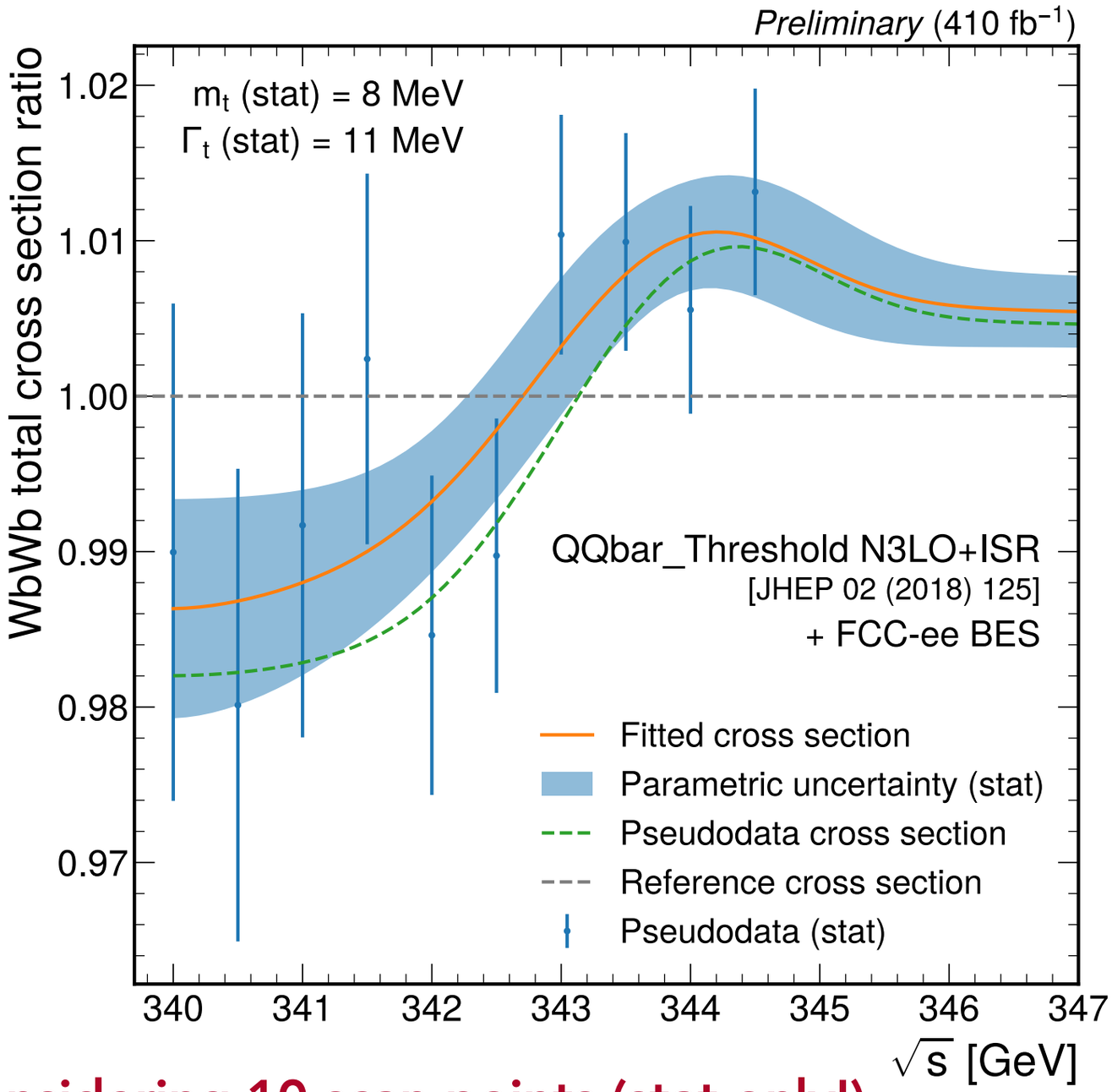
Calculated cross section at N3LO, illustrating the effect of ISR and FCC-ee beam energy spectrum (0.23% gaussian spread per beam)

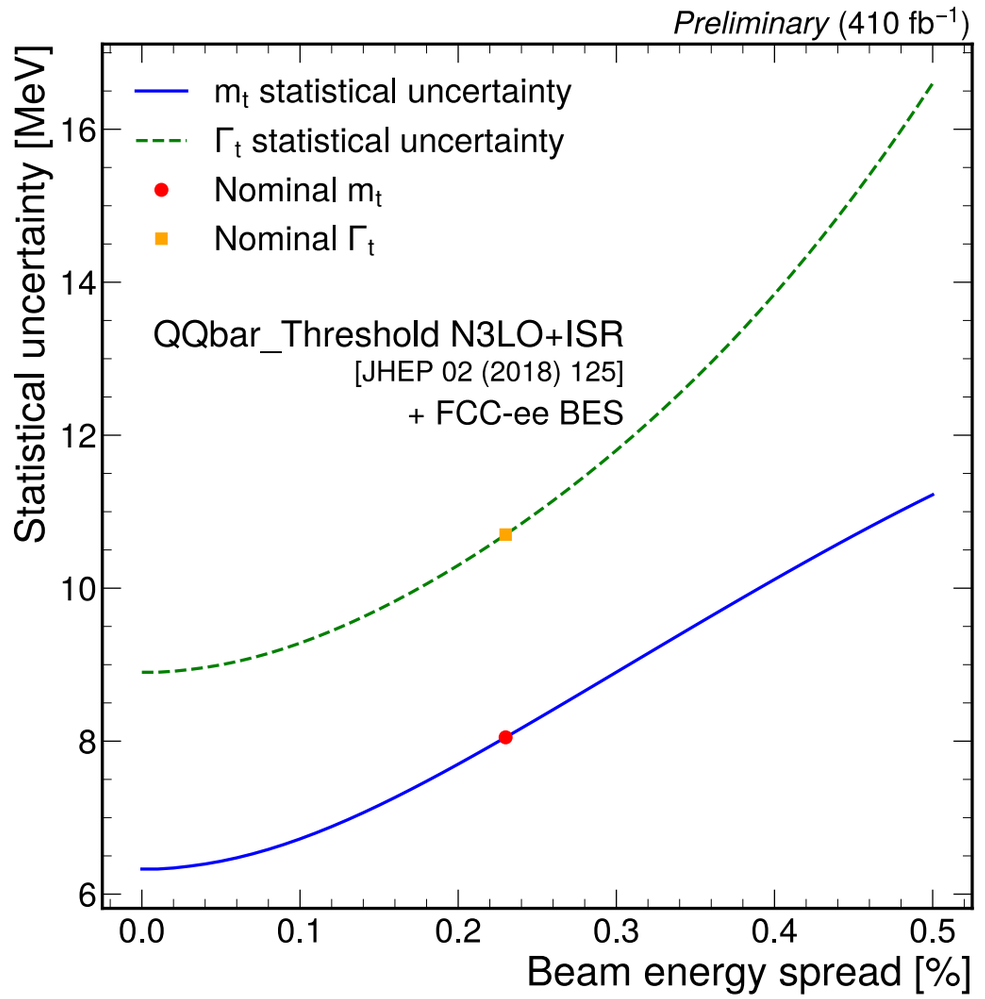


Plot illustrating the perturbative convergence of the non-relativistic (NR) QCD prediction for WbWb production around the tt production threshold

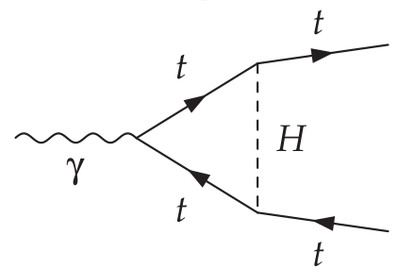
[More details in Matteo's plenary talk tomorrow!]

Fitted cross section





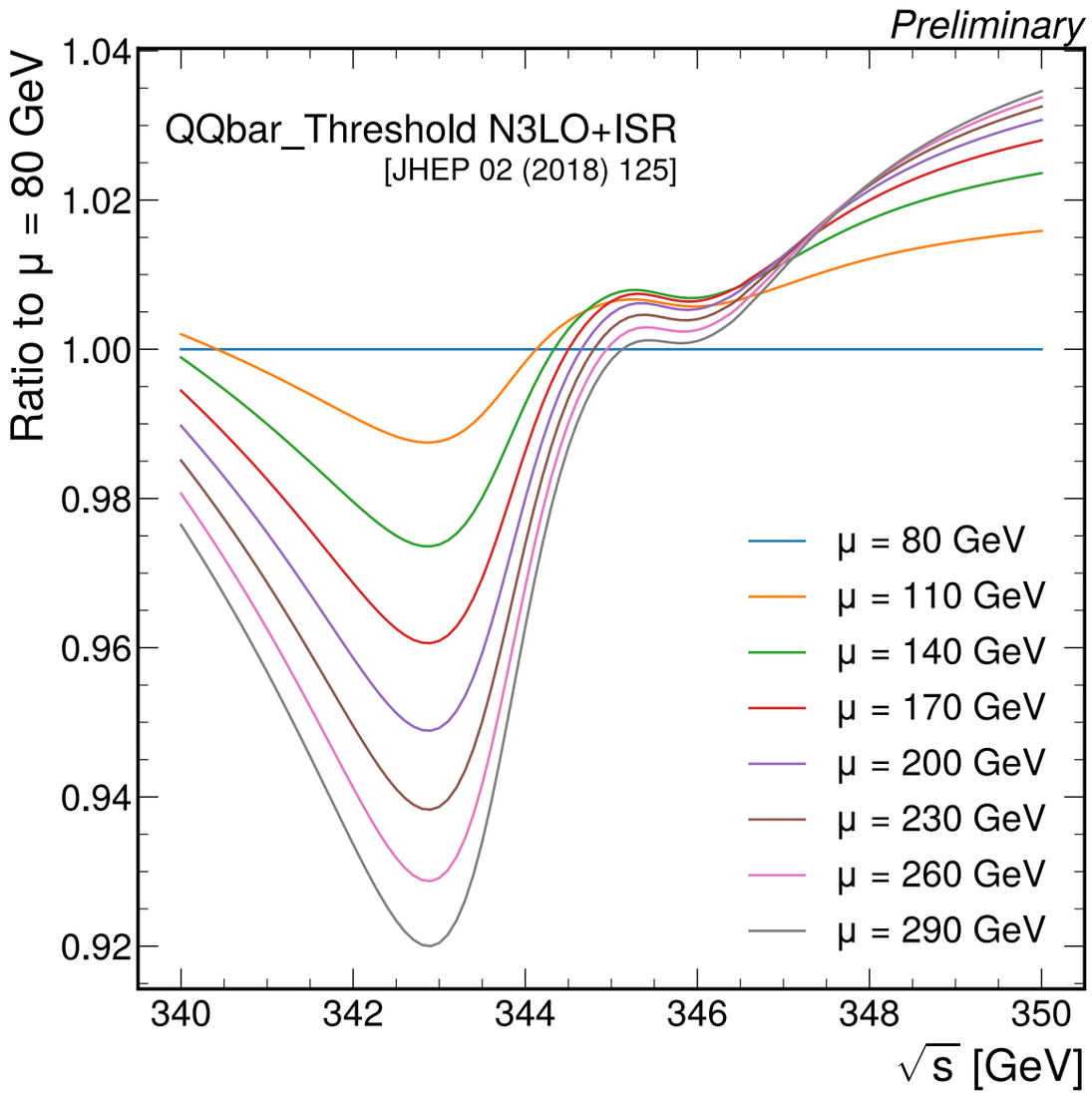
Dependence on the beam energy resolution of the statistical uncertainty in the fitted mass and width

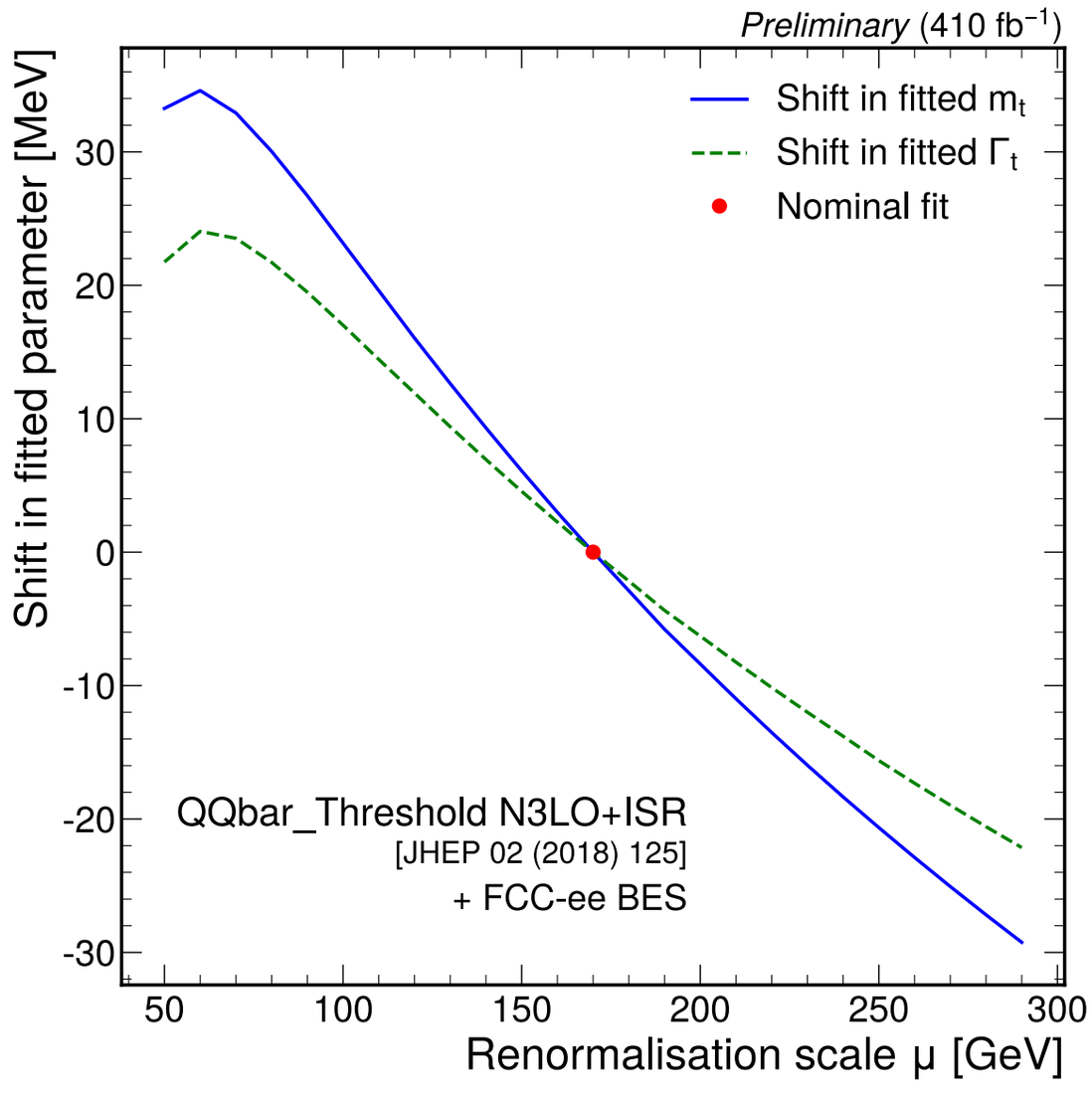


considering 10 scan points (stat only!)

Additional high-statistic point (2.65/ab) at 365 GeV allows to measure top Yukawa coupling to 1.7% statistical uncertainty (assuming only Yukawa corrections to Ztt vertex)

Theoretical uncertainty





- Strong dependence on renormalisation scale at threshold, even at N3LO
- Uncertainty from theory dependence much larger than experimental precision
- Theory improvements needed to maximise precision

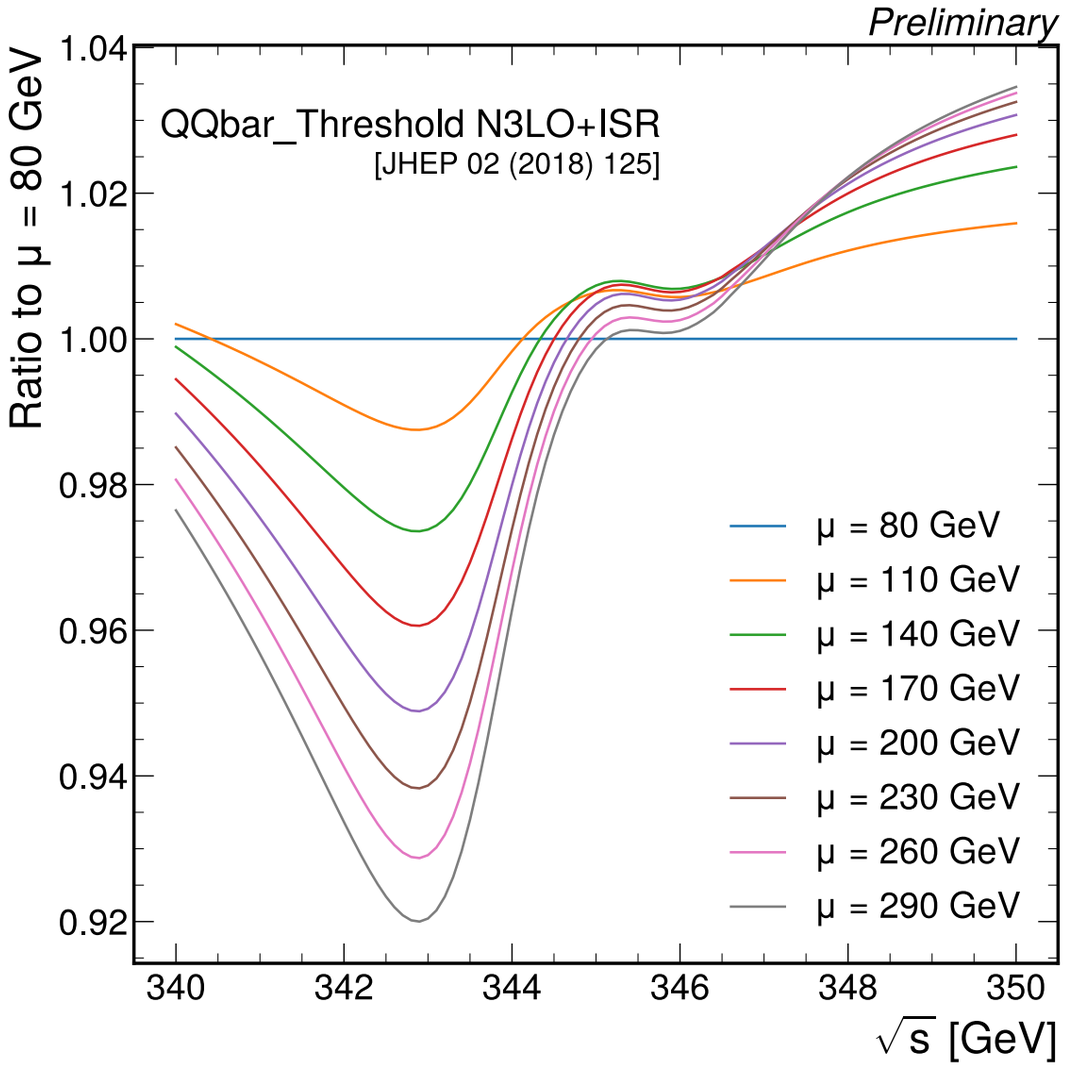
Conclusions

- Performed a study of WW and WbWb production around the ttbar threshold for different values of center-of-mass energy points
- Targeted events in semi-hadronic and hadronic categories
- High lepton acceptance at all center-of-mass energy points (after a minimal cut on momentum) and 100% for jets (no event selection)
- BDT classifier used for signal and background discrimination

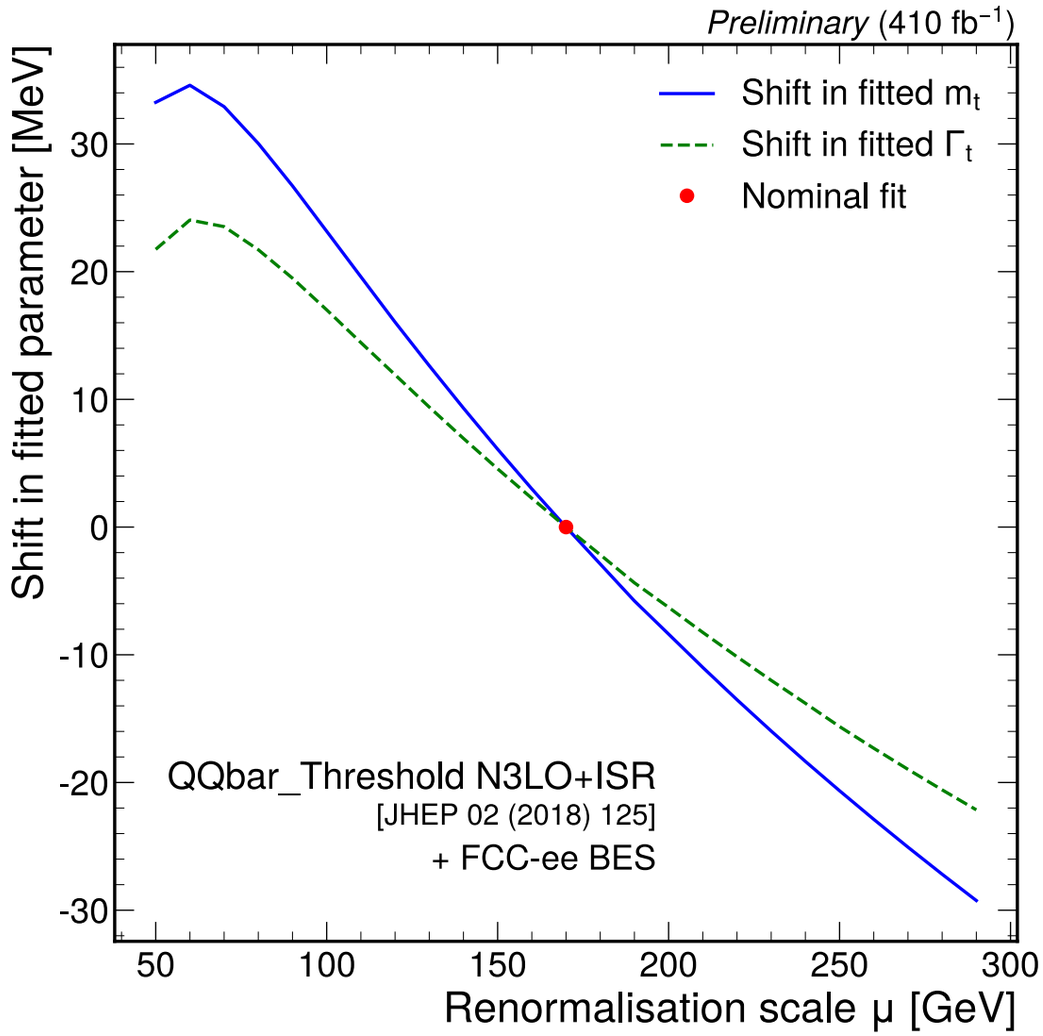
- Performed a simultaneous binned maximum likelihood fit to b-tagged jet distributions in the signal and background control regions to extract cross section
- WW background well under control (per-mille level impact on WbWb cross section)

- Simultaneous fit of N3LO theory prediction to measured cross section
  - 8 MeV (stat.) uncertainty in top mass
  - 11 MeV (stat.) uncertainty in top width
  - 1.7% (stat) uncertainty in top Yukawa, assuming only effect on Ztt vertex
- Measurement of mass and width limited by QCD scale variations
- Effect of theory uncertainties on top Yukawa to be studied

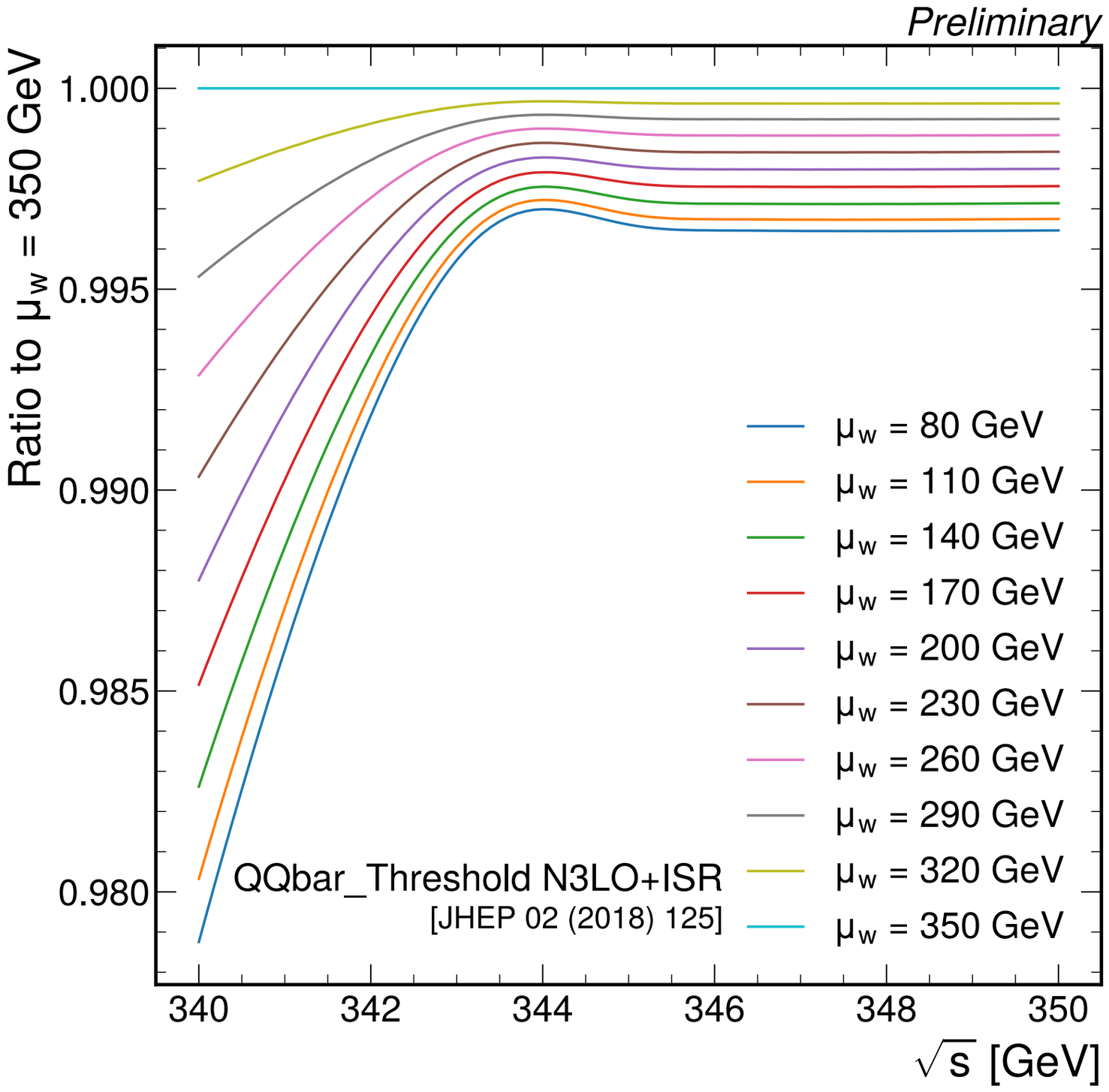
backup



Dependence of the total WbWb cross section on the renormalisation scale



Dependence of the fitted mass and width on the renormalisation scale

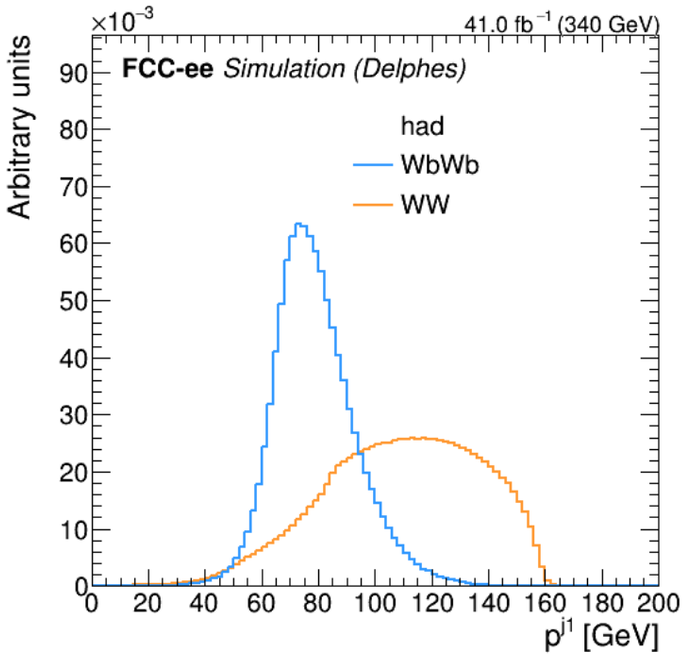


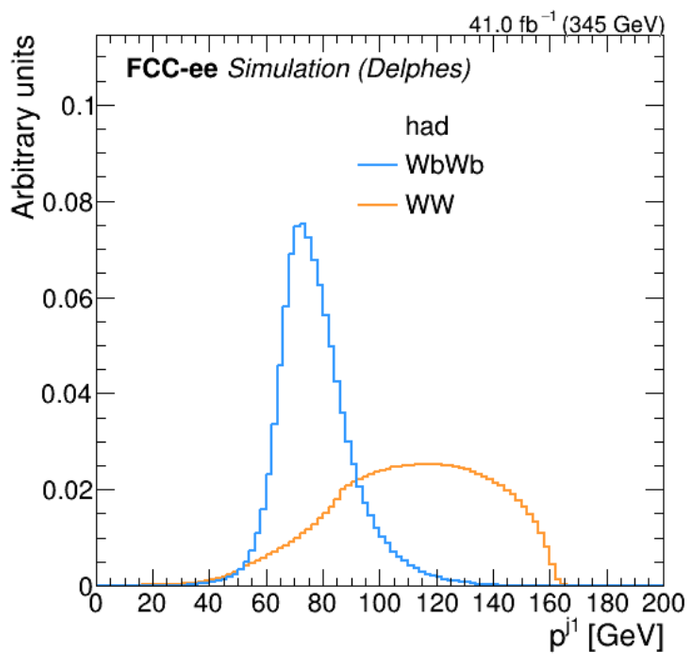
Dependence of the total WbWb cross section on the factorisation scale of the finite width effects. This dependence is expected to vanish when N3LO corrections for the non-resonant diagrams are included (currently NNLO)

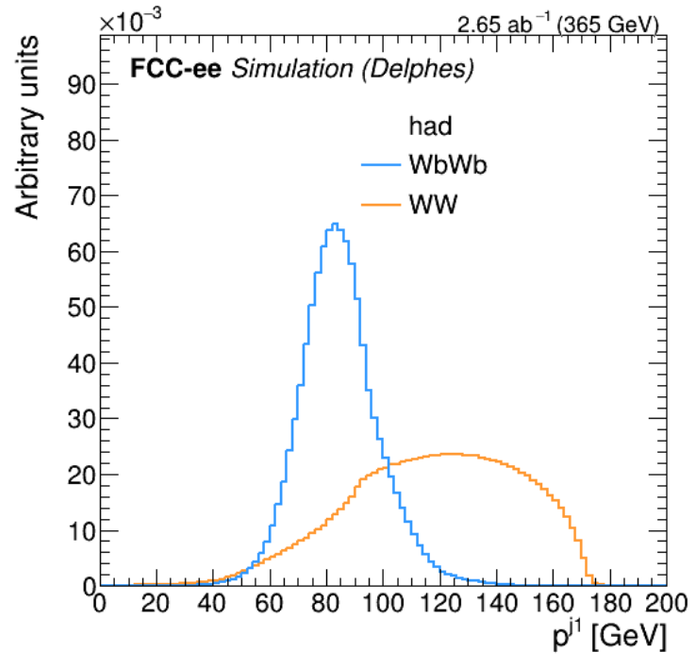
Event kinematics (jets) -i

hadronic

leading jet momentum

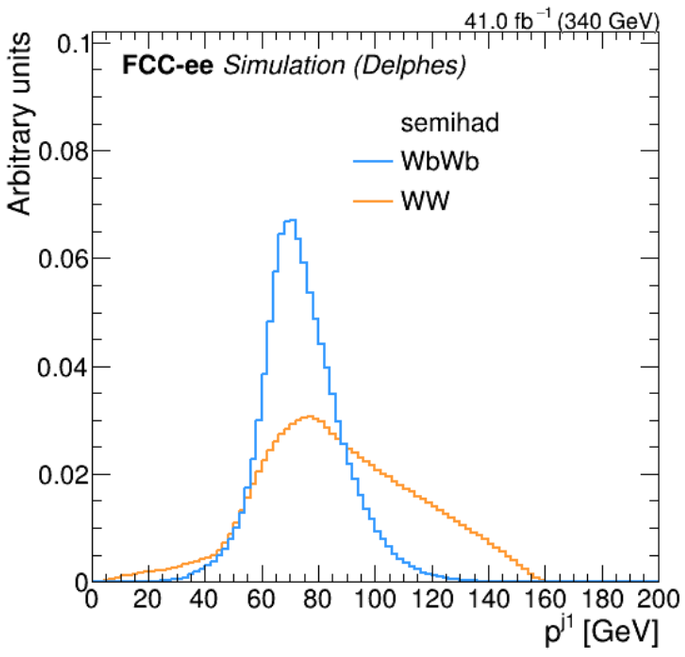


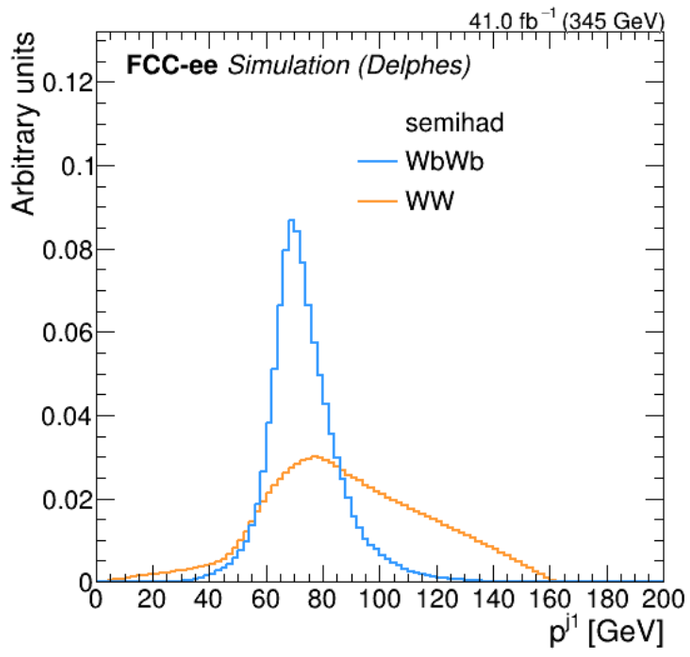


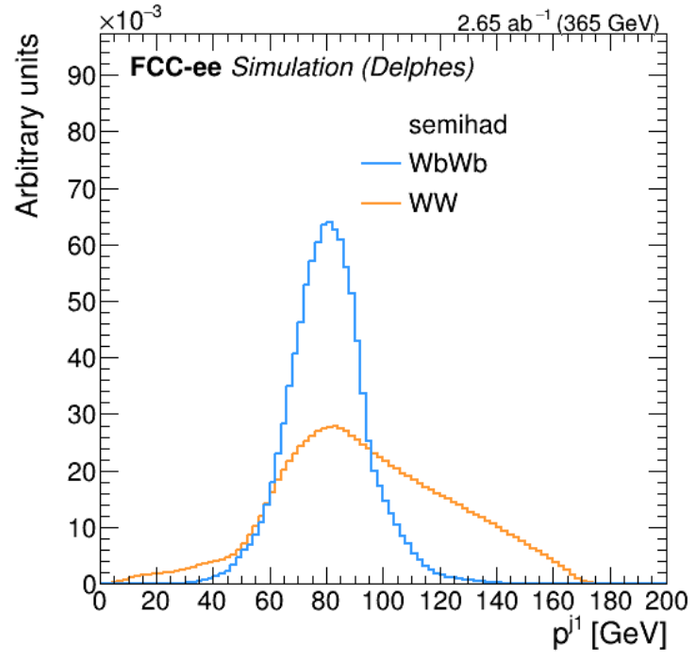


e.c.m

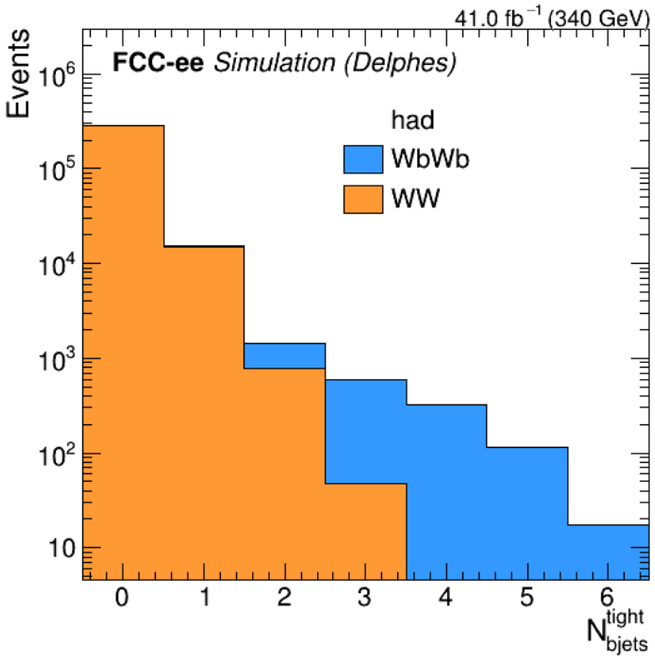
semi-leptonic

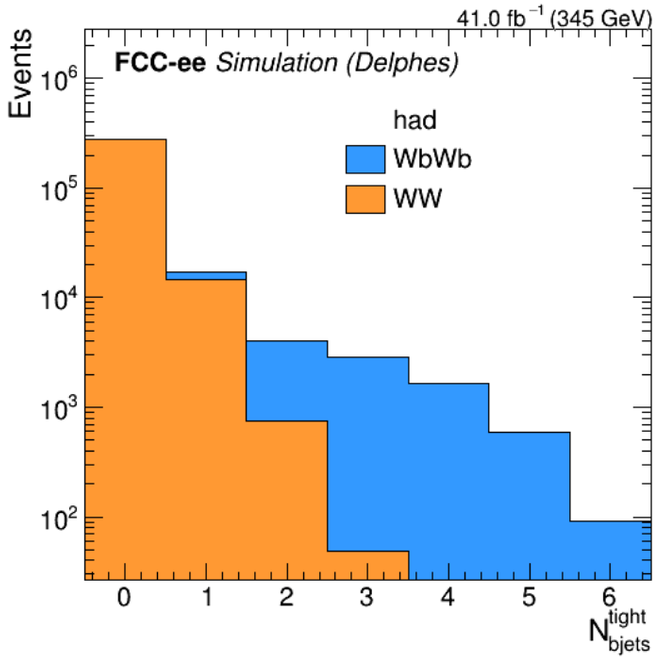


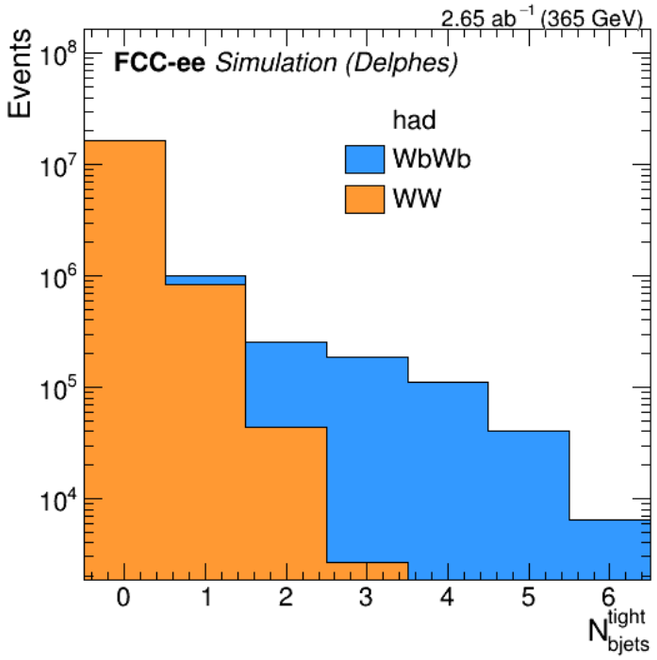


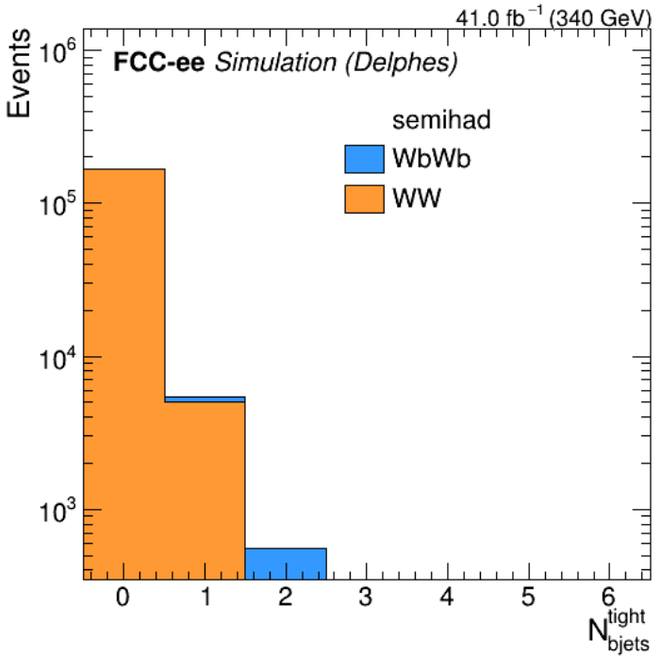


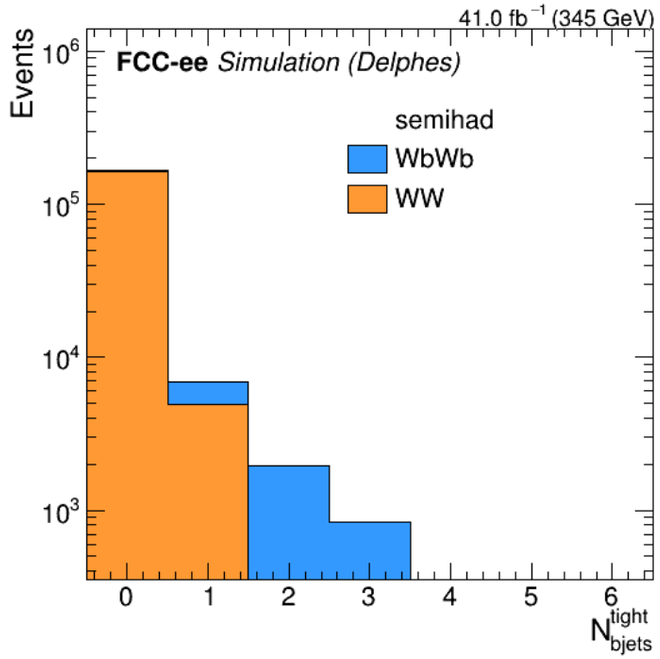
b-tagged jets (tight working point)

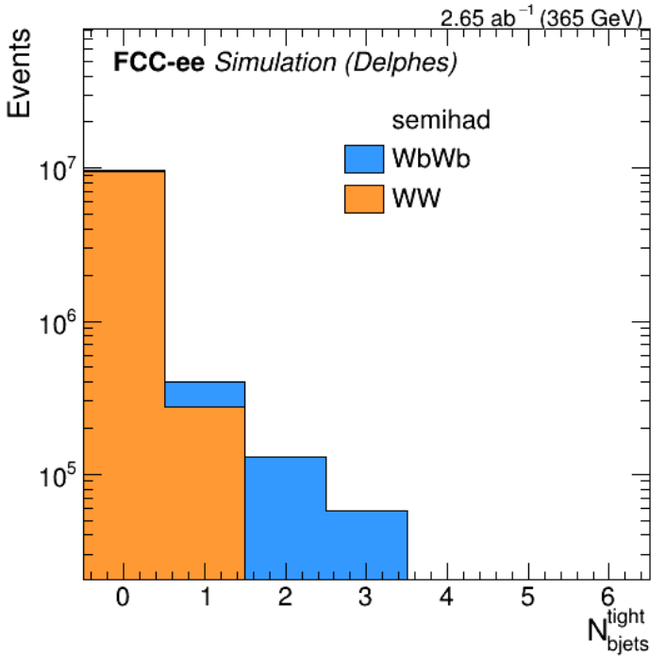










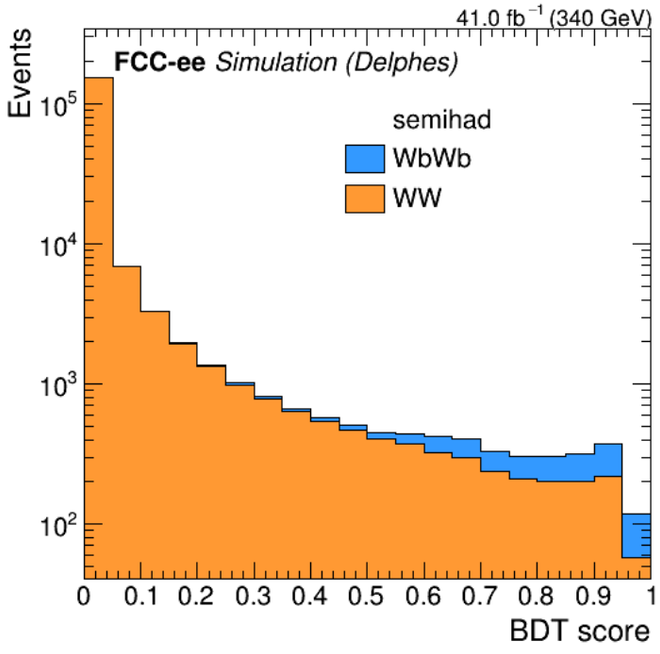


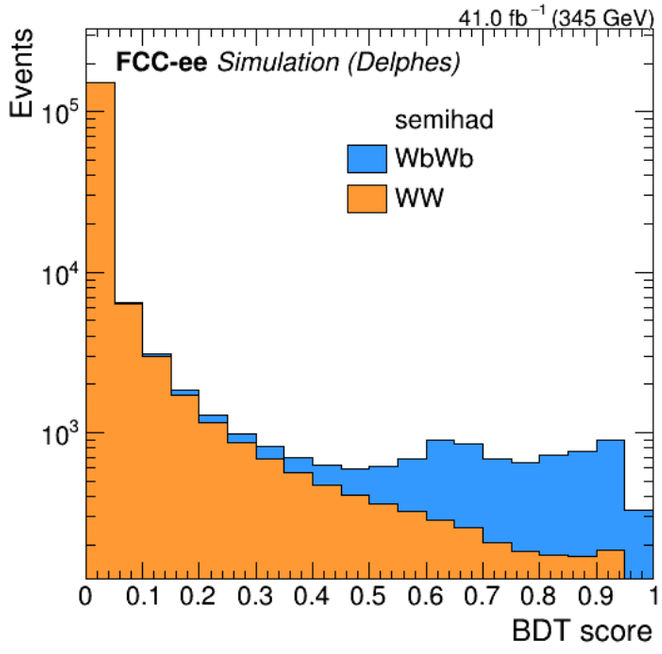
BDT classifier outputs

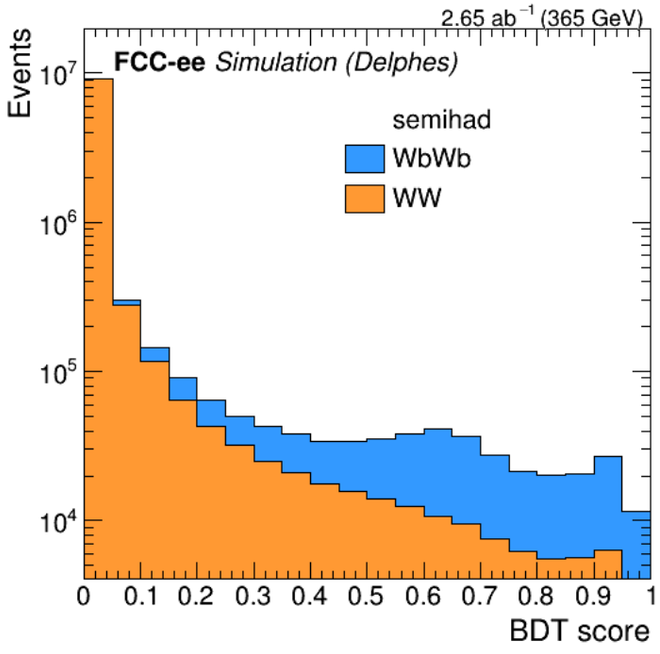
hadronic

e.c.m

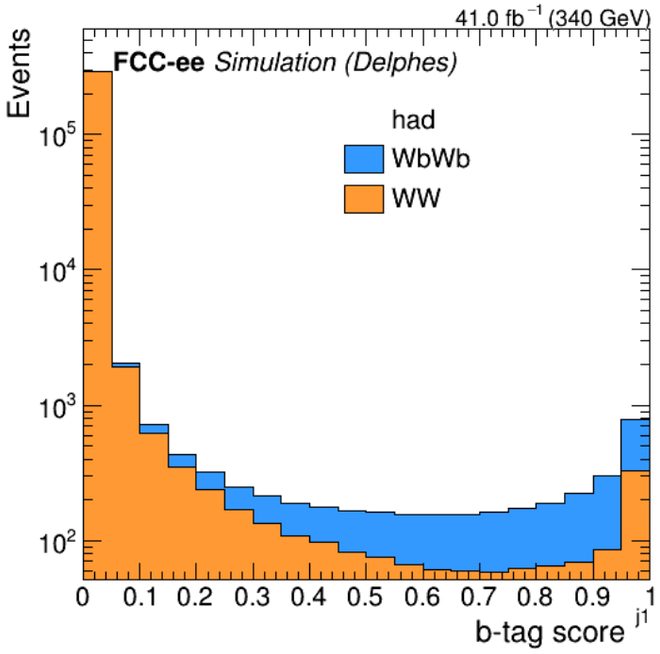
semi-leptonic

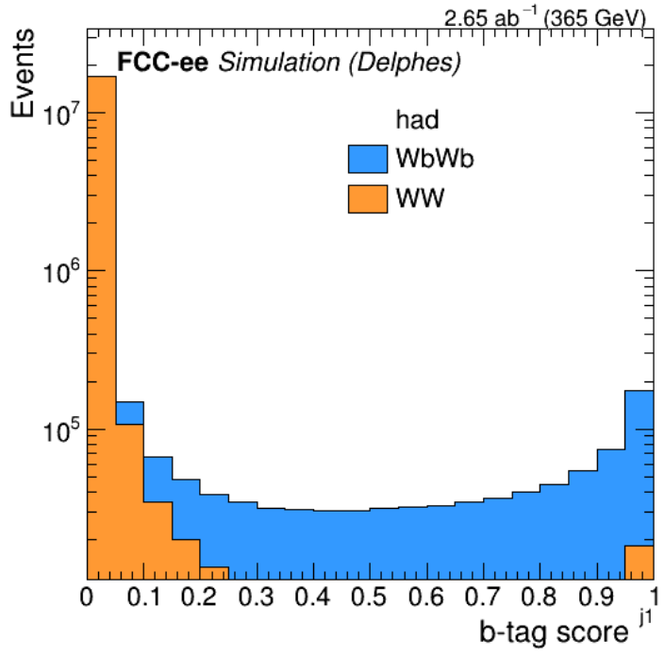


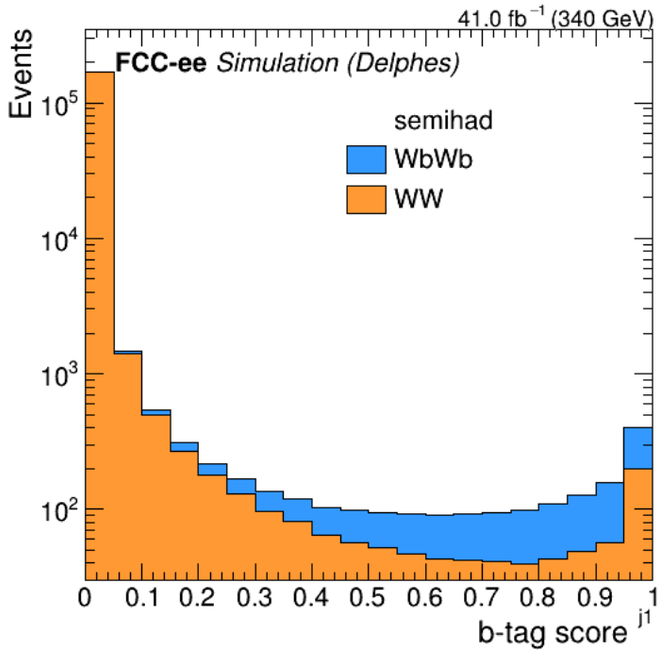


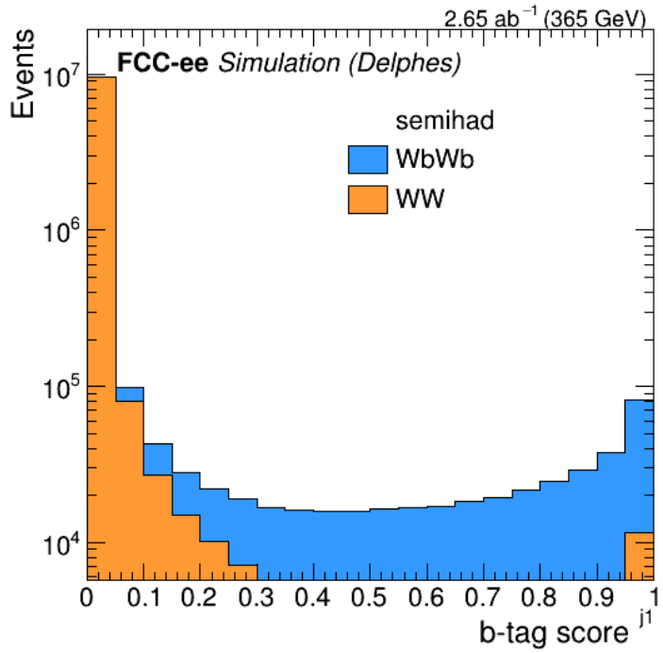


b-tagging score (semihad)

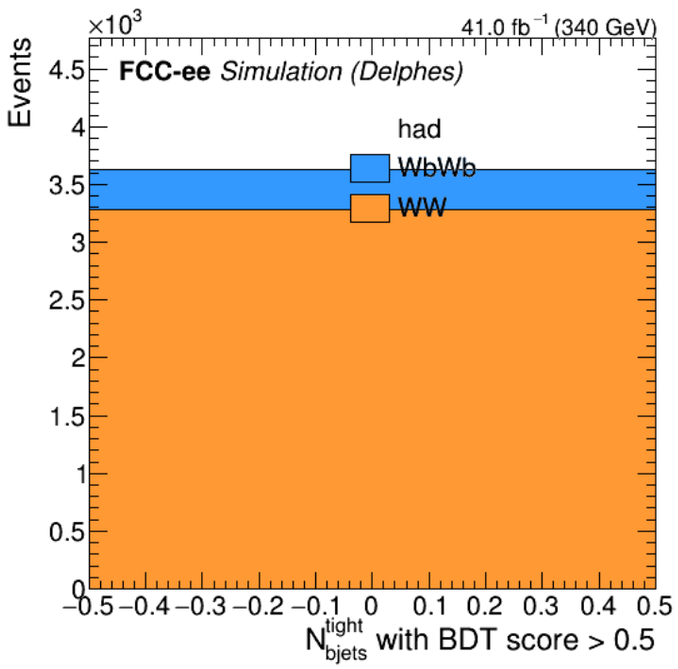


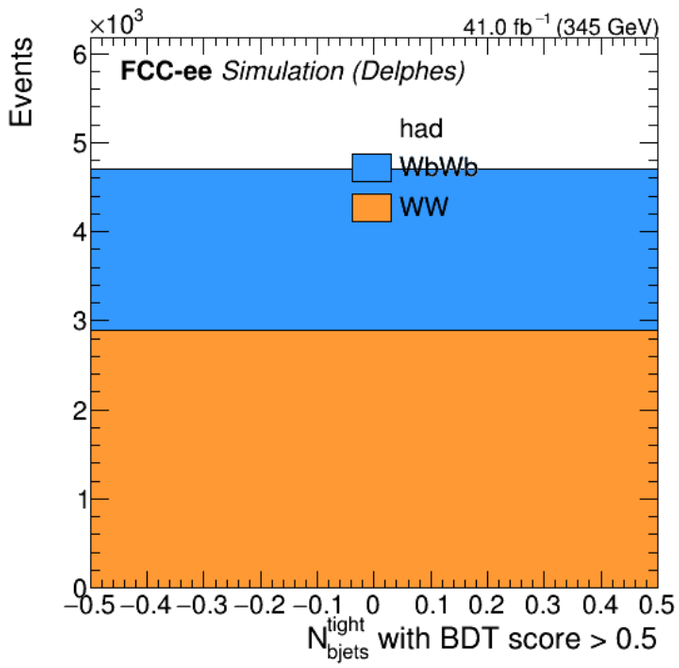


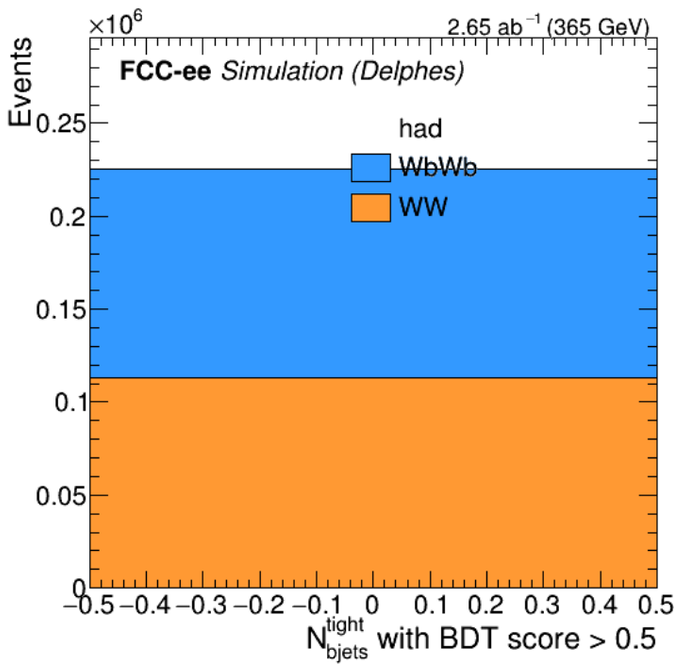


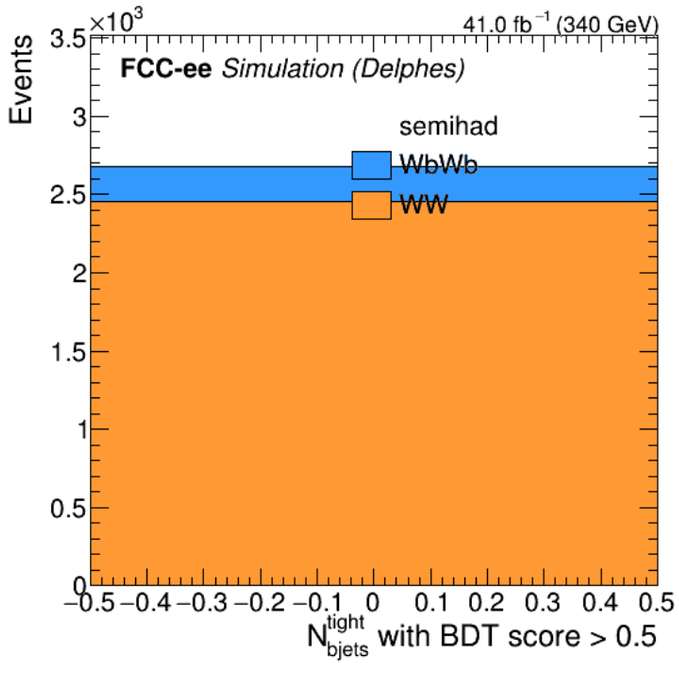


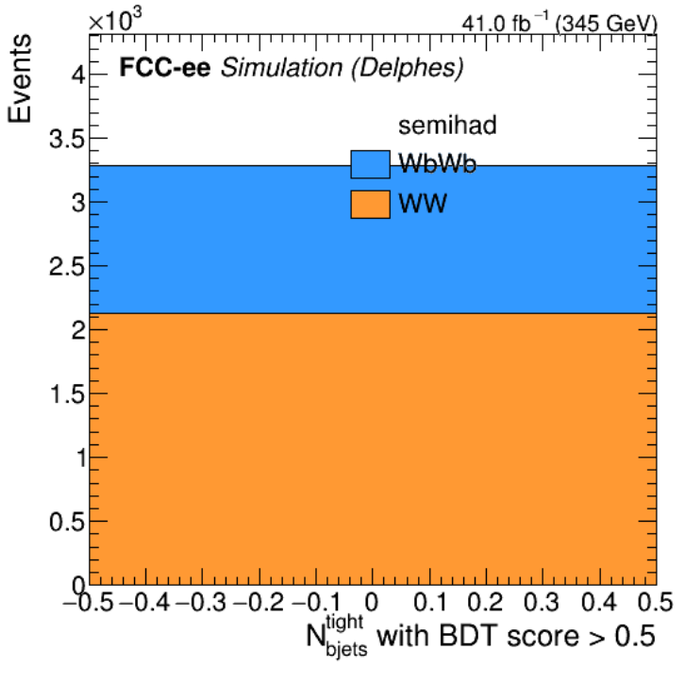
b-tagged jets post BDT cut (CR)

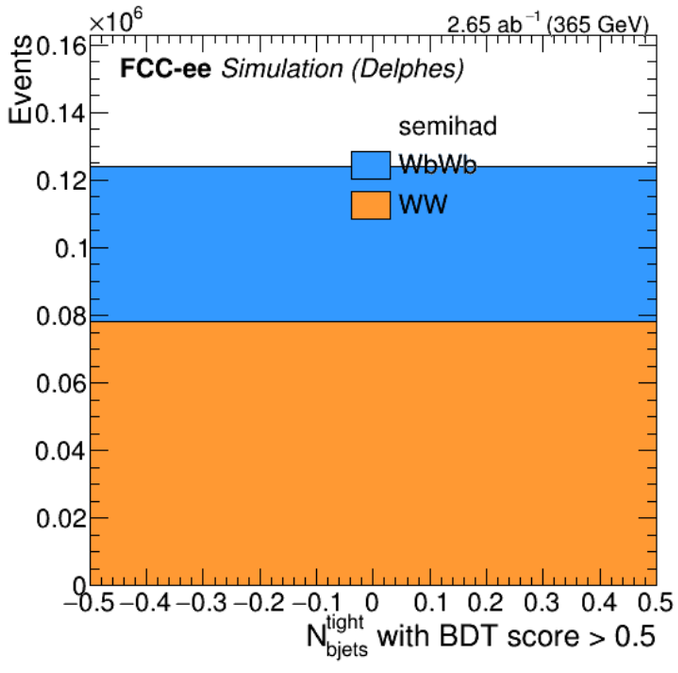




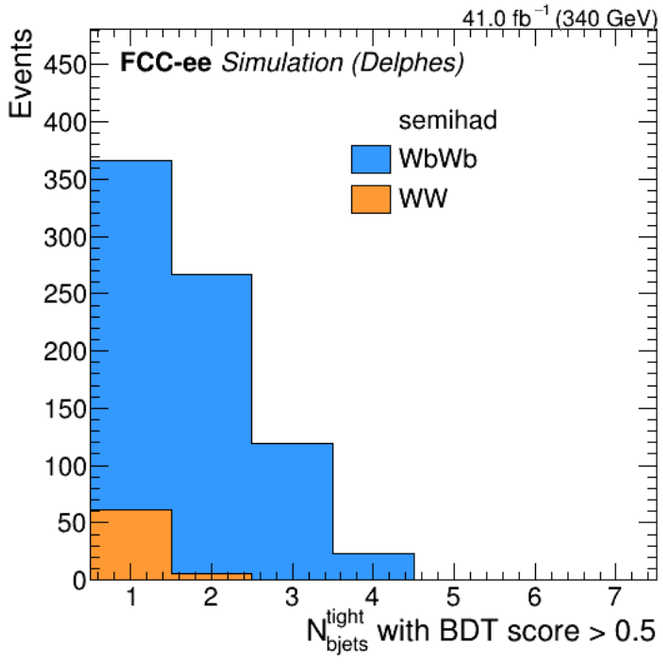


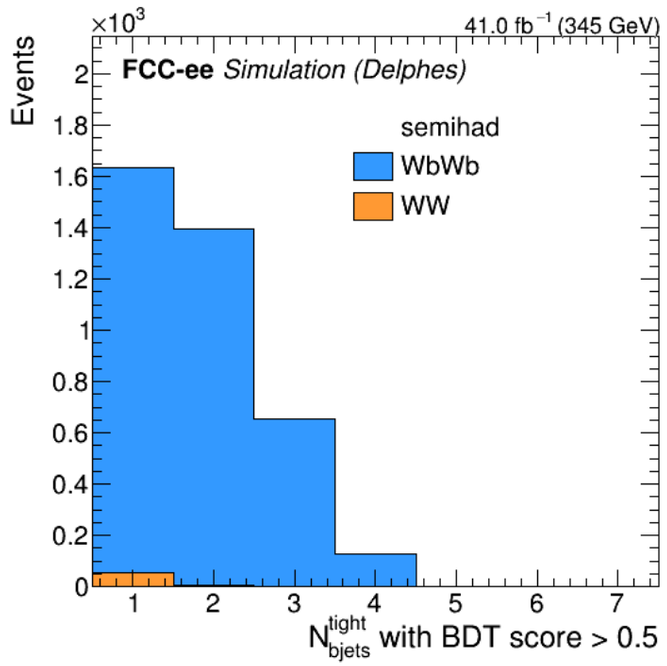


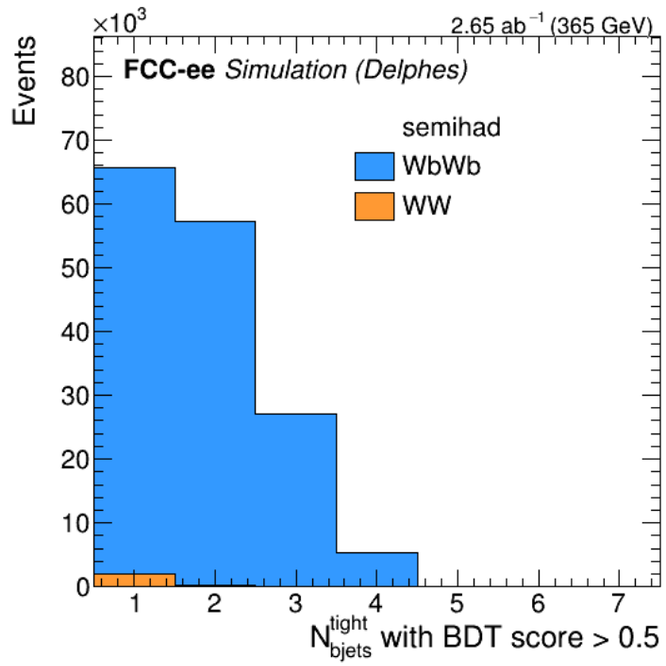


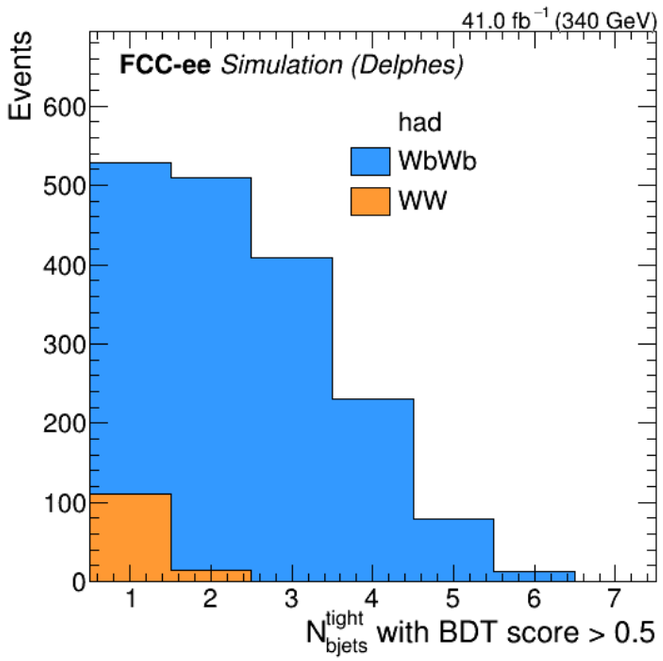


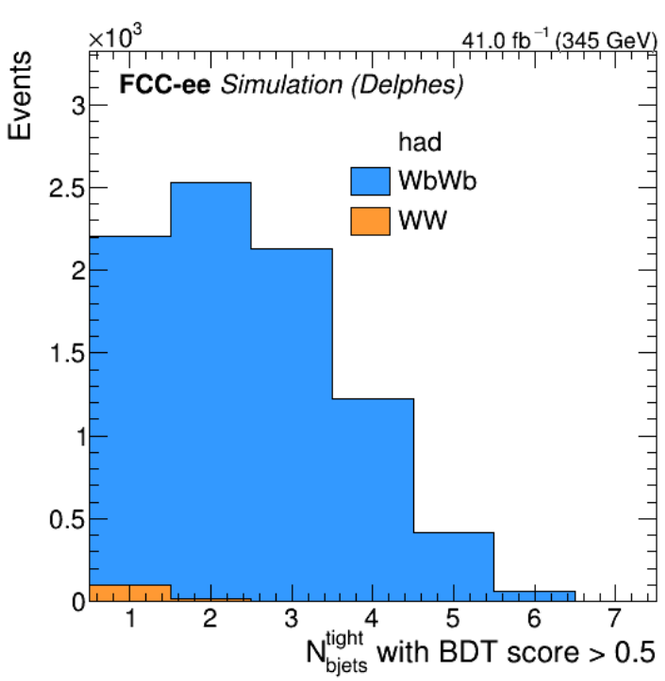
b-tagged jets SR post BDT cut

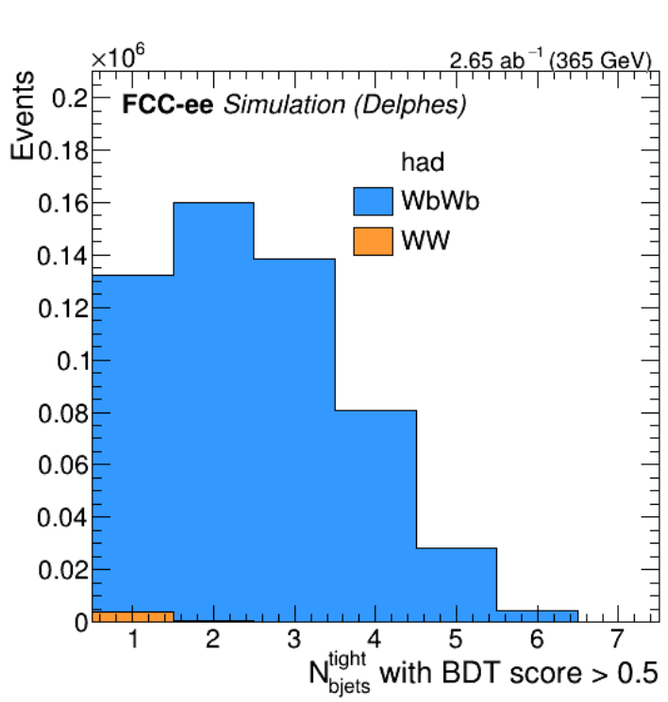




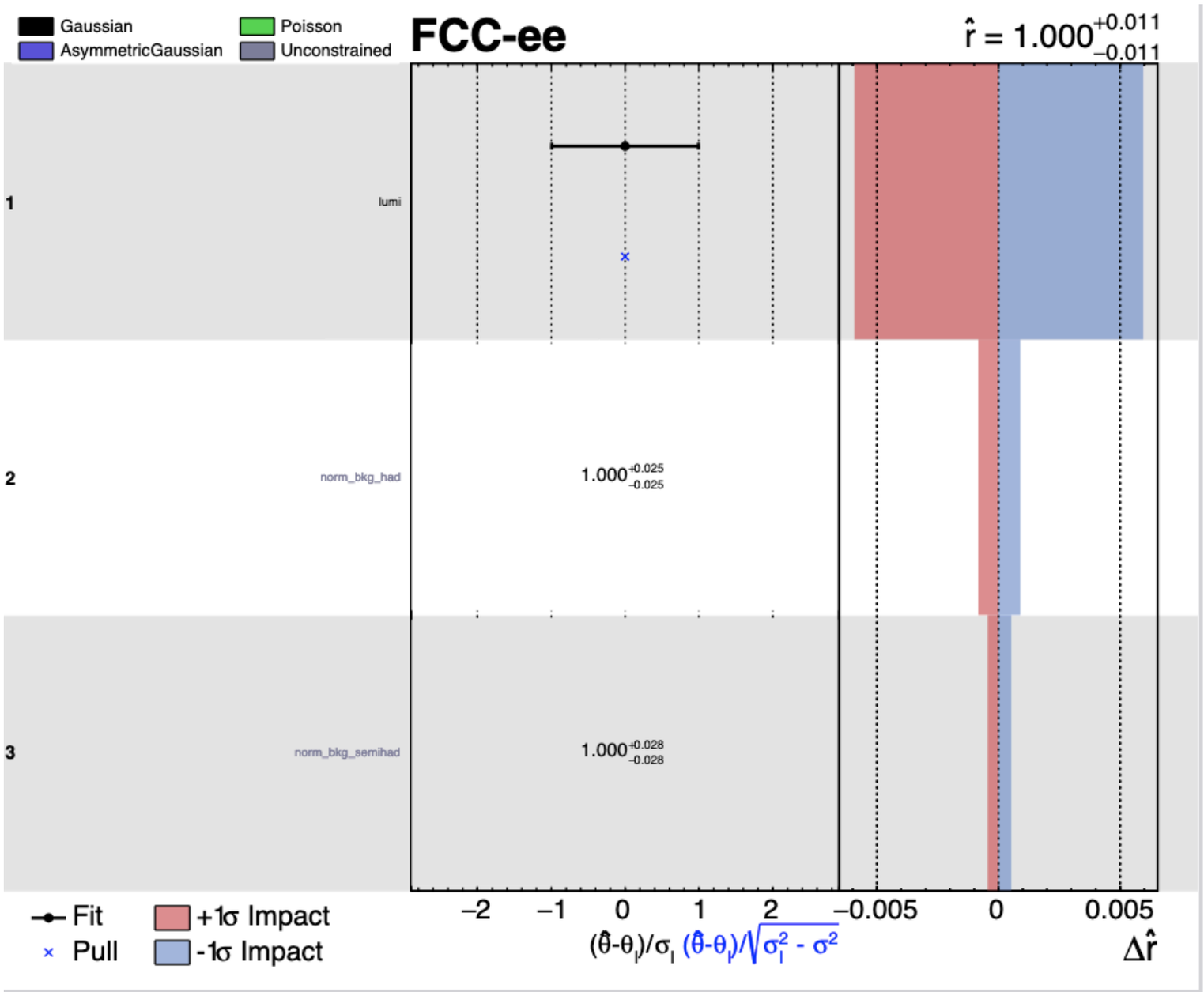




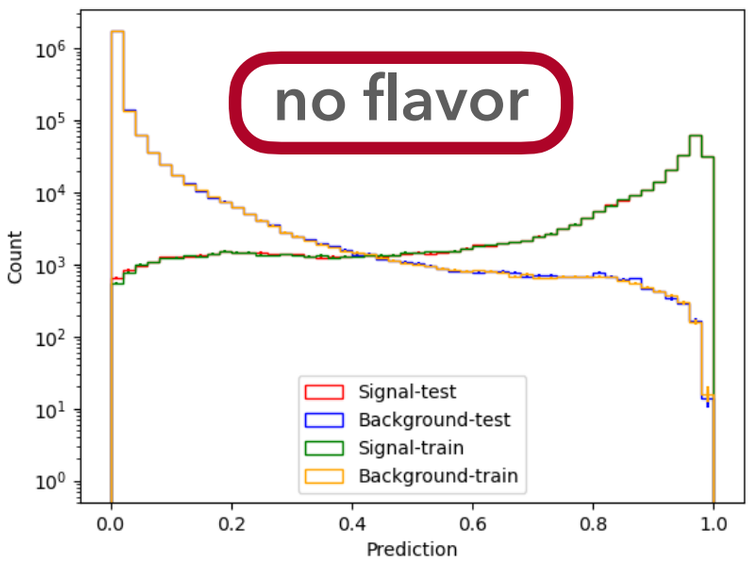


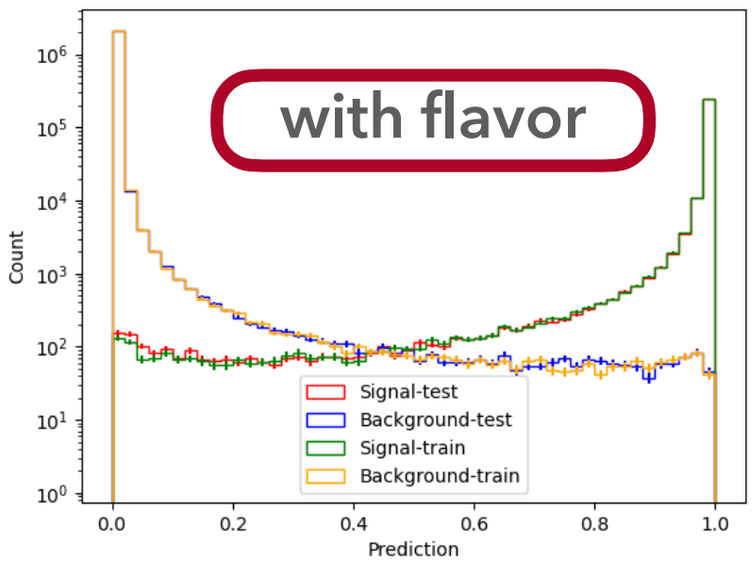


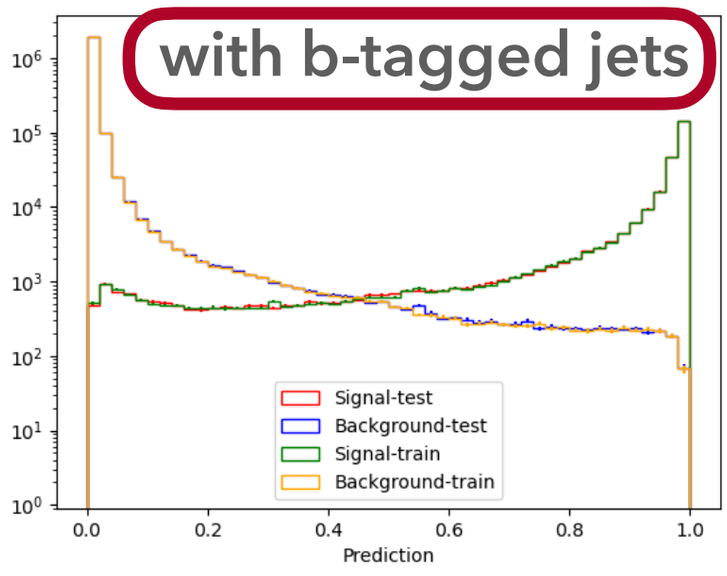
Results: 345 GeV, 41/fb

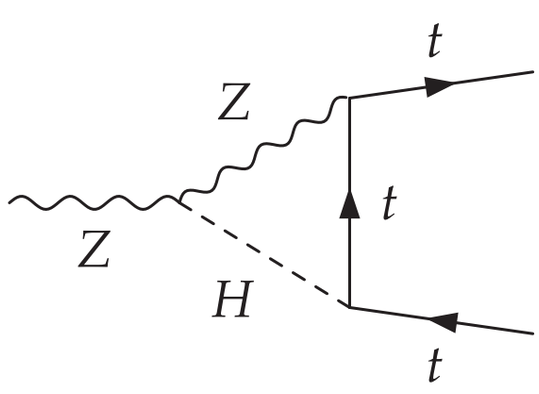


Same as previous slide, but for 345 GeV


no flavor
Count
Prediction
Signal-test
Background-test
Signal-train
Background-train


with flavor
Count
Prediction
Signal-test
Background-test
Signal-train
Background-train


with b-tagged jets
Prediction
Signal-test
Background-test
Signal-train
Background-train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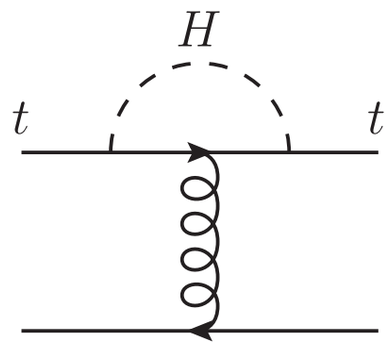
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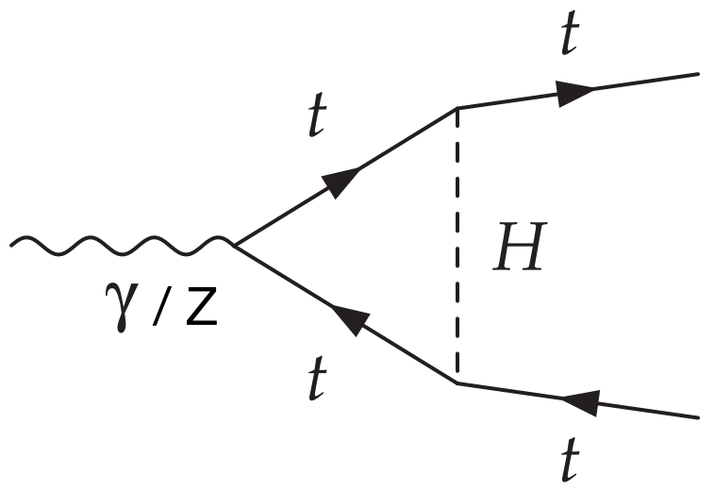
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