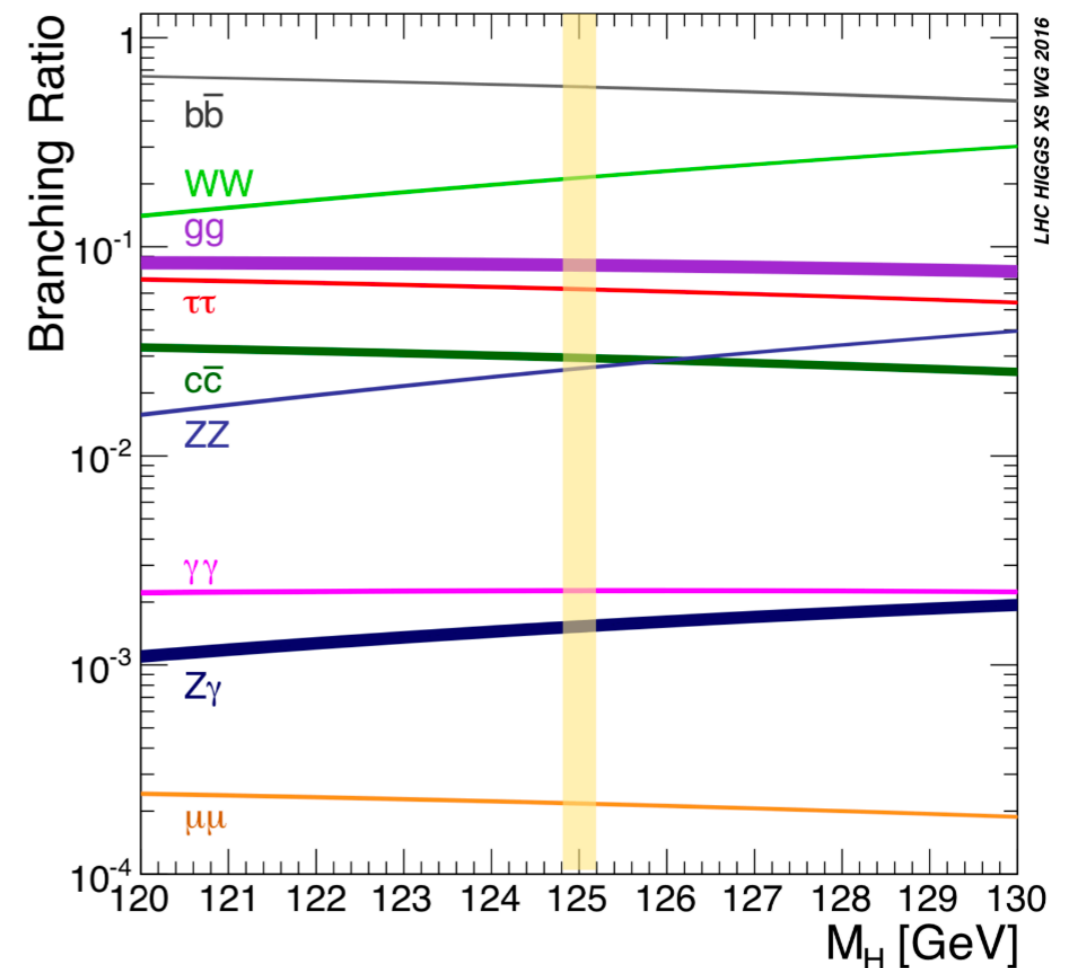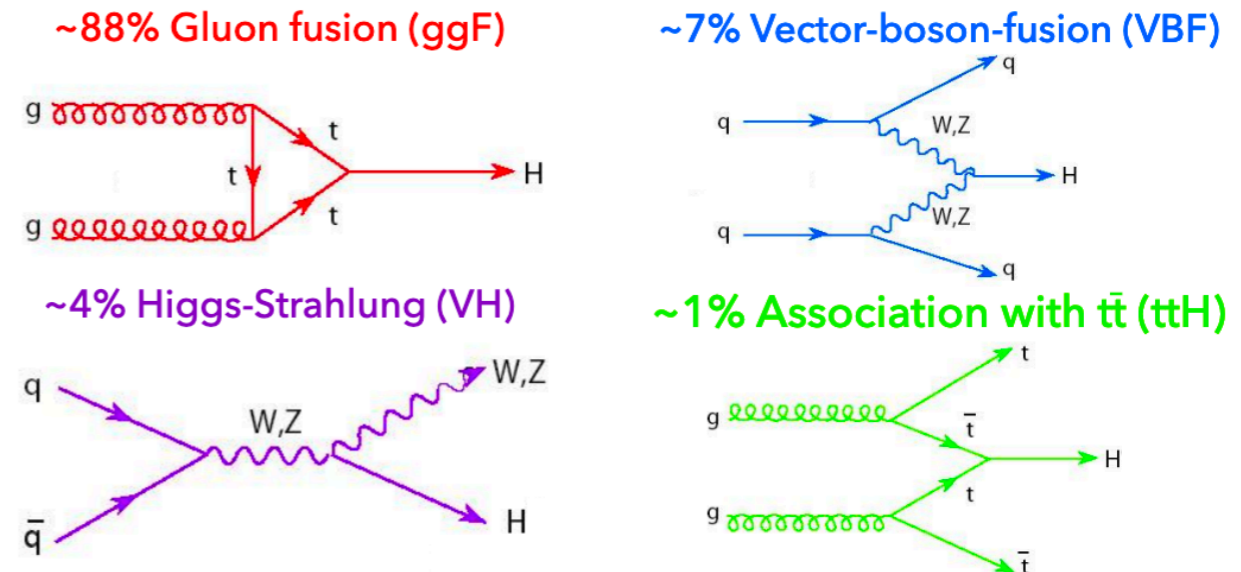# Higgs Boson Couplings to Quarks and Leptons at the ATLAS Experiment
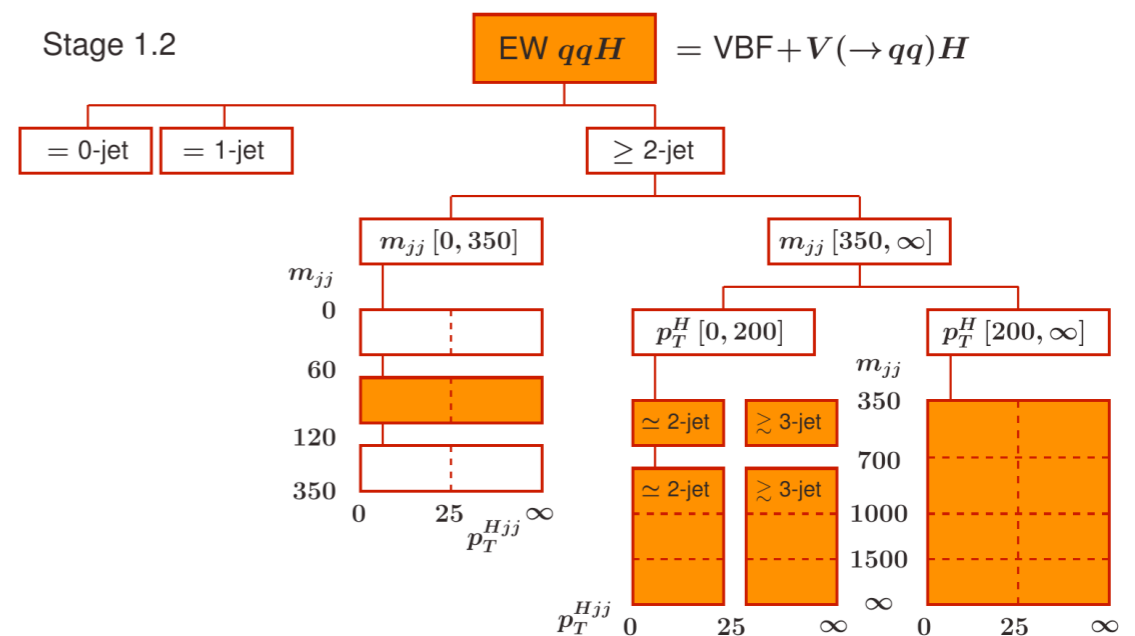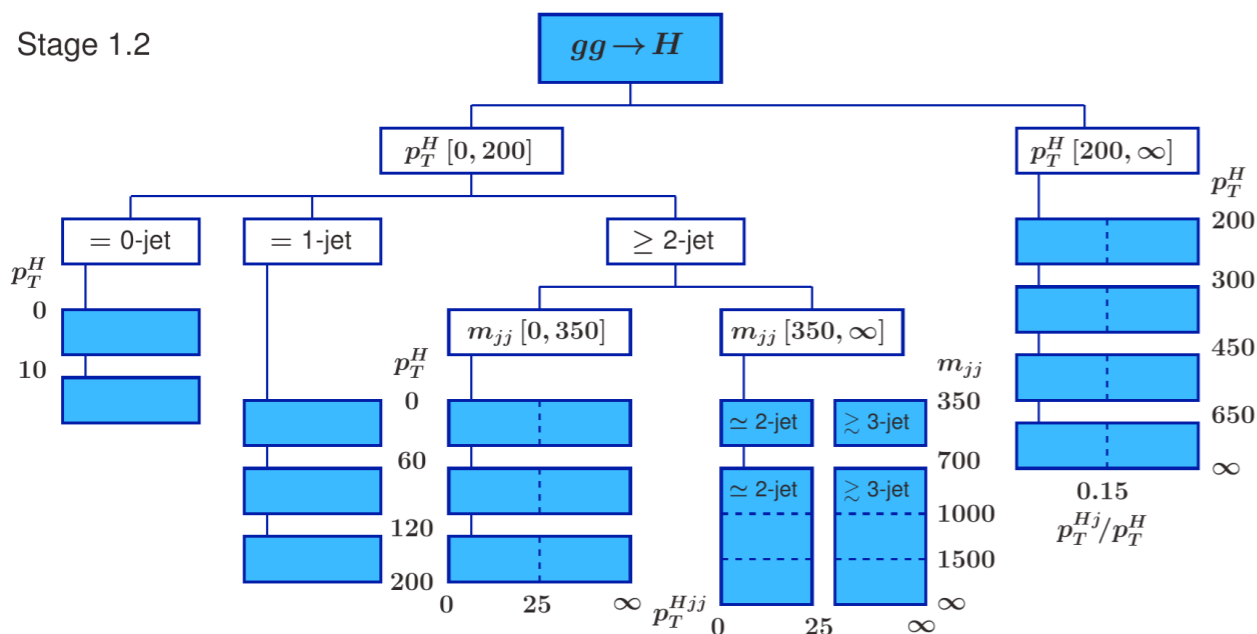
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INFN Sezione di Roma 1

Introduction

- With the data collected during the run-2 of LHC, the focus of Higgs analyses has moved to the measurement of the properties of the new particle

- Measurements of Yukawa couplings to fermions is part of this effort

- In this presentation:

  ○ H→bb

  - VBF production and VBF photon-tagged
  - Associated production, with Z and W

  ○ H→cc: NEW RESULT !

  - Associated production with W and Z

  ○ H→ττ

  - Results from the combination of run-1 and run-2 data

  ○ H→μμ

  - Updated results from the analysis of the full run-2 dataset

  ○ ttH

  - Analysis of the main decay channel H→bb

~88% Gluon fusion (ggF)

~7% Vector-boson-fusion (VBF)

~4% Higgs-Strahlung (VH)
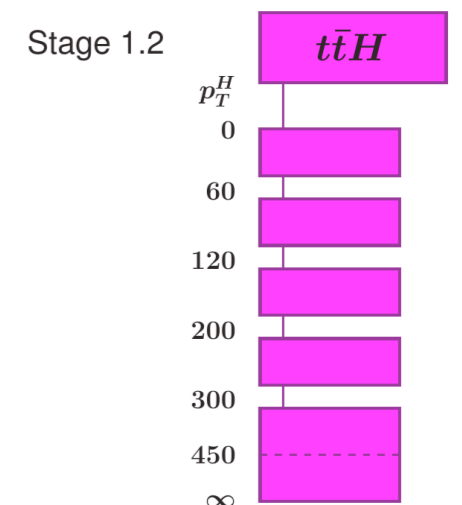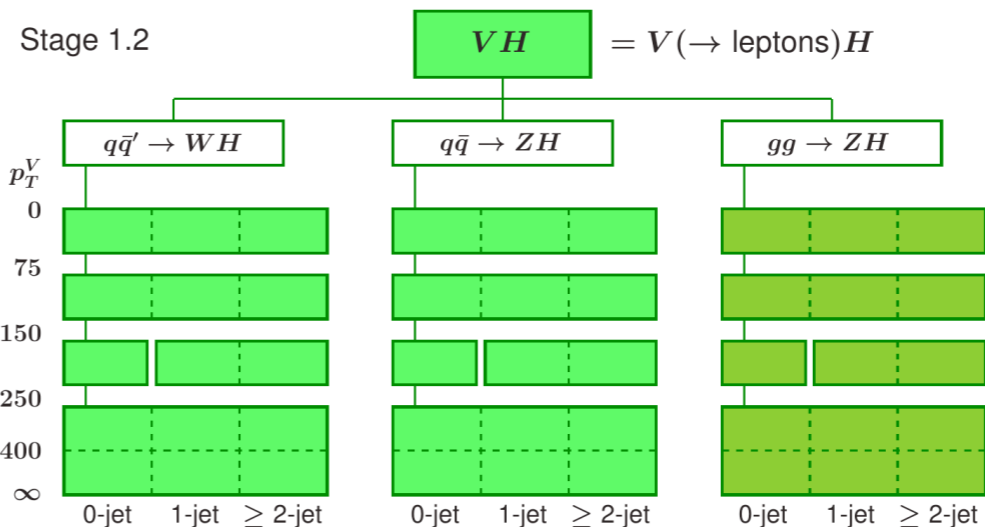
~1% Association with tt̄ (ttH)

Simplified Template Cross Sections (STXS)

- Production modes cross sections are measured separately, and each is categorised in bins of truth quantities (pT(H), Njets, mjj)
- Bins are designed to optimise the signal sensitivity with the given integrated luminosity, and minimise the theoretical uncertainties
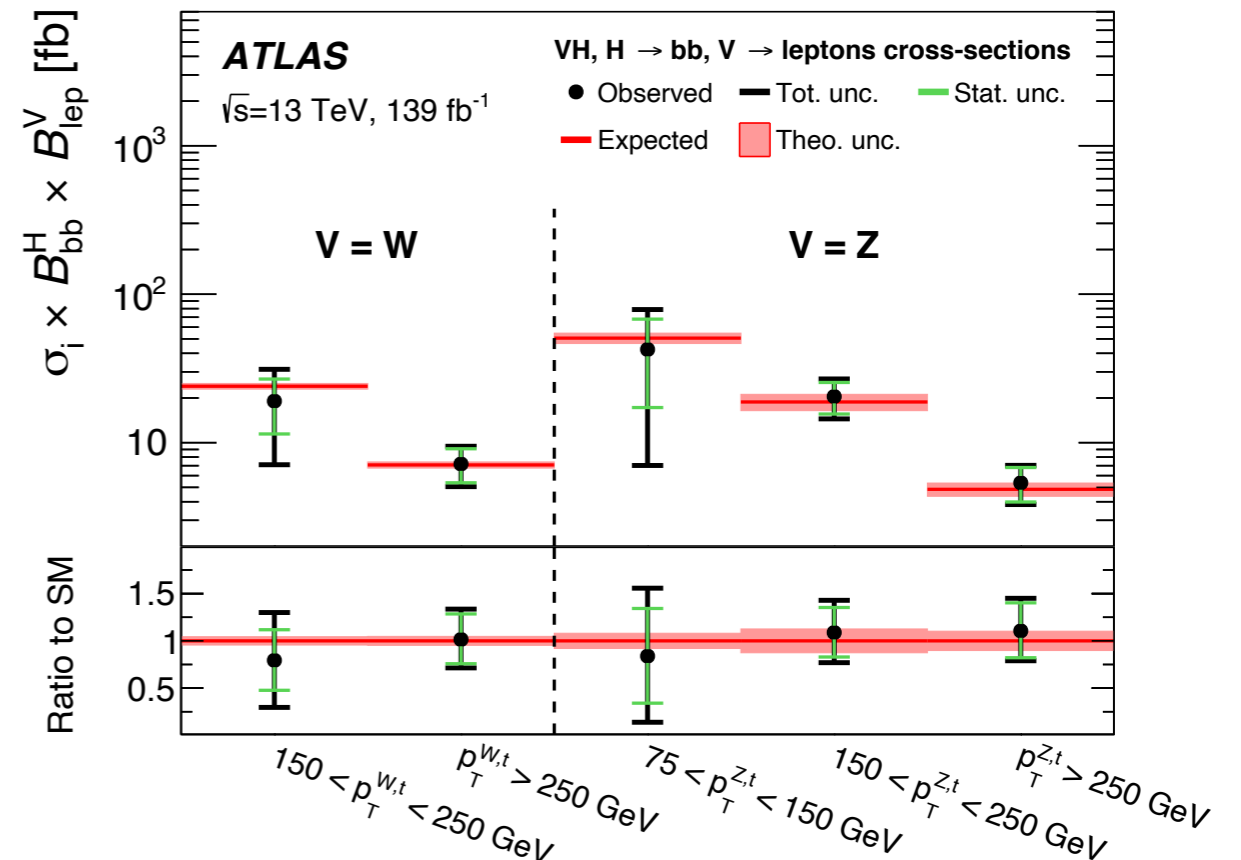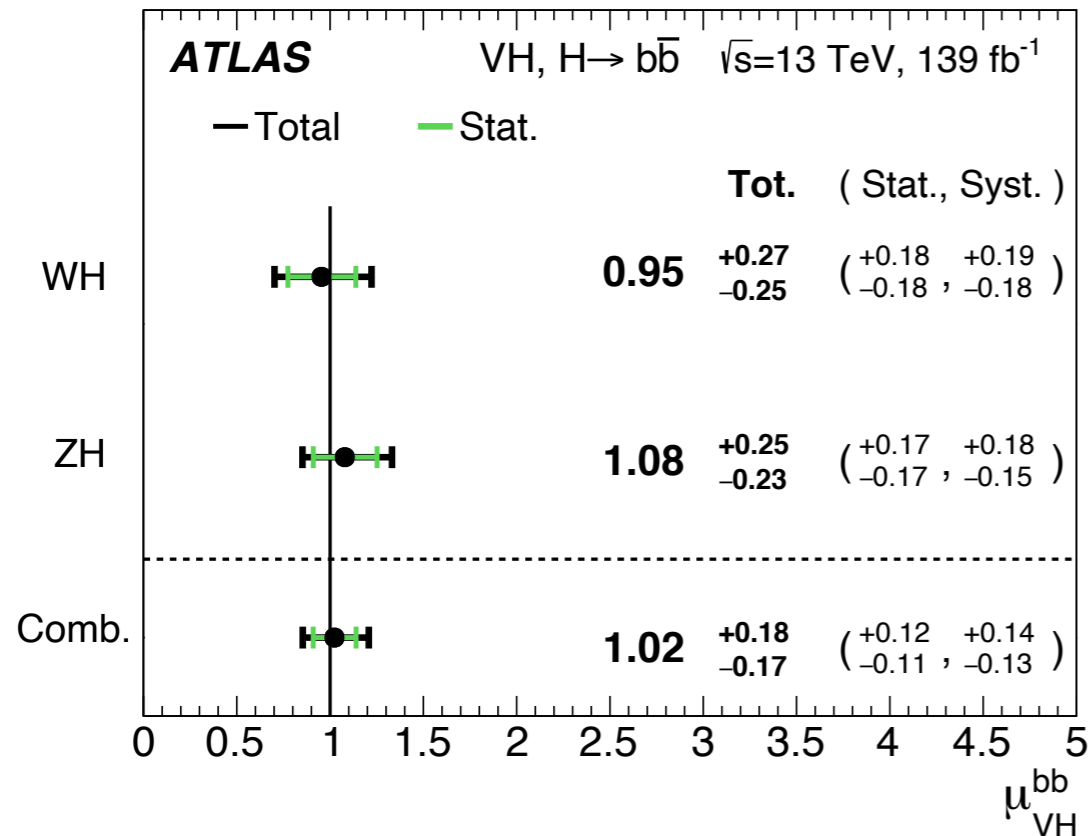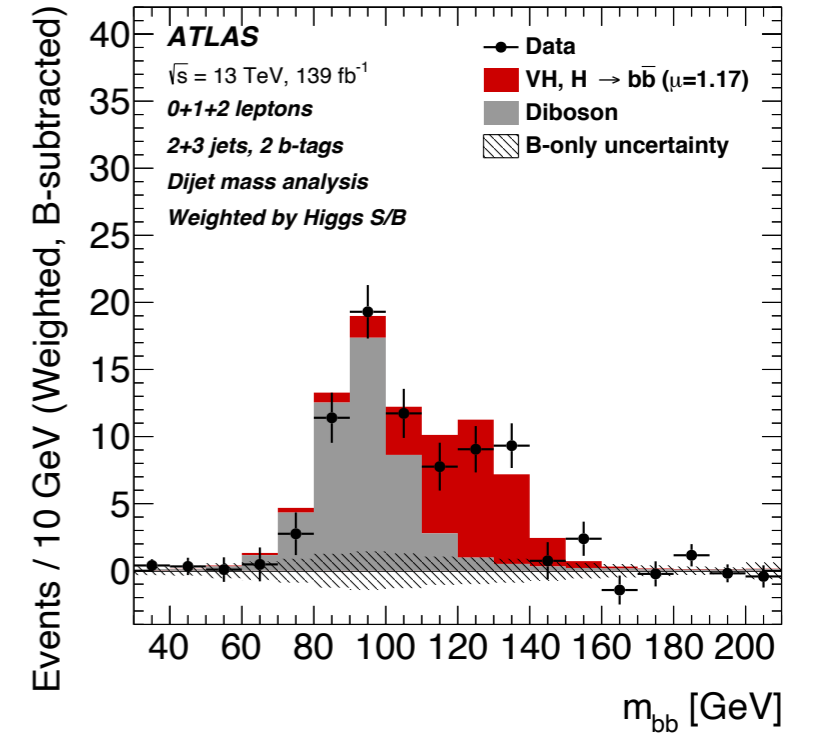

Different stages with various degrees of granularity

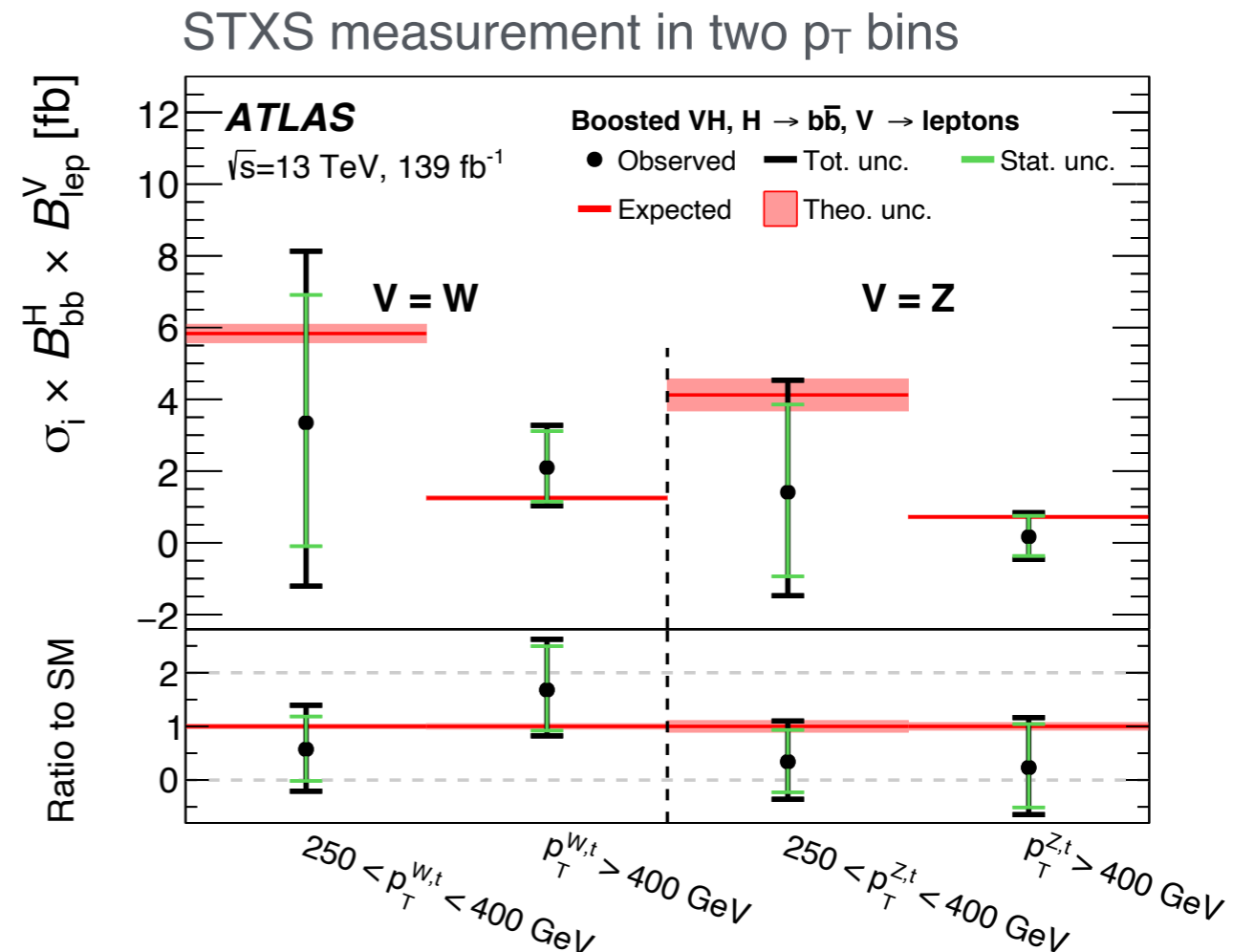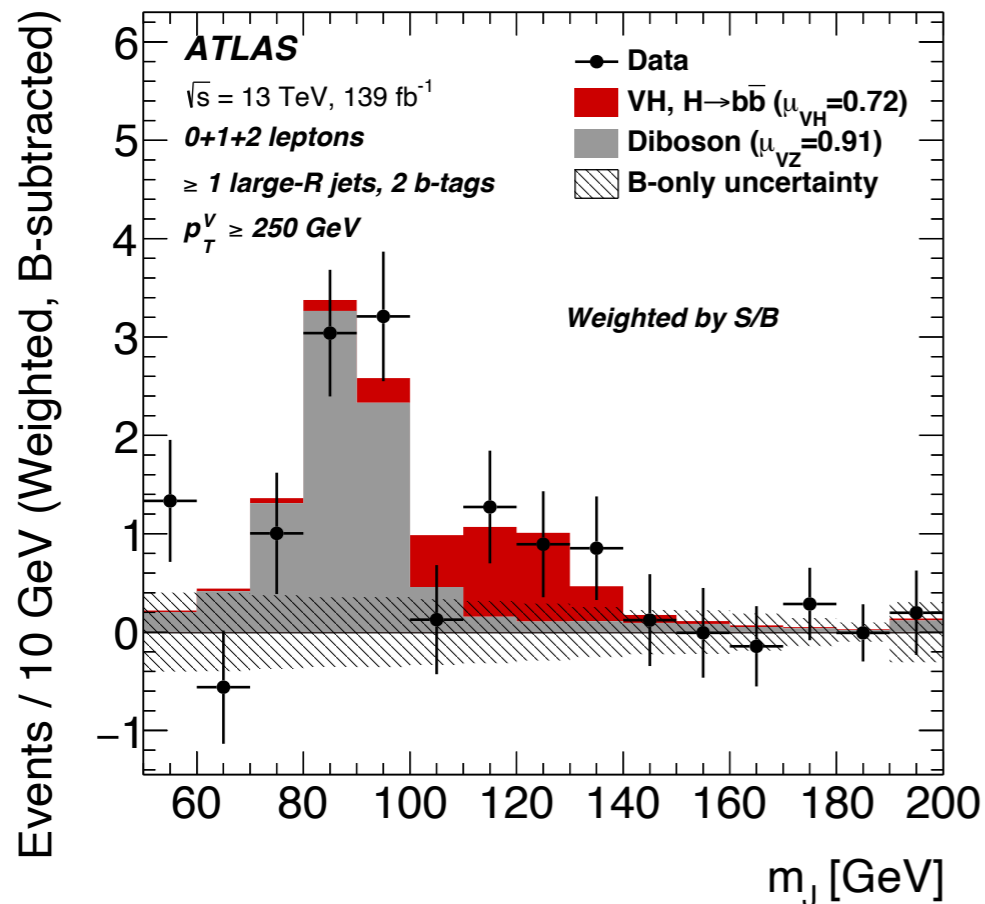Binning can be reduced depending on each channel's statistics

H→bb in associated production

- Events categorised based on the number of charged leptons (0,1,2 , i.e. ννH, νlH, llH, with l=e,μ)

- Multivariate discriminants to optimise the signal sensitivity
  - Based on event kinematics, jet tagging and missing transverse momentum

- Combined VH signal significance is **6.7 σ observed,** with **6.7 σ expected**

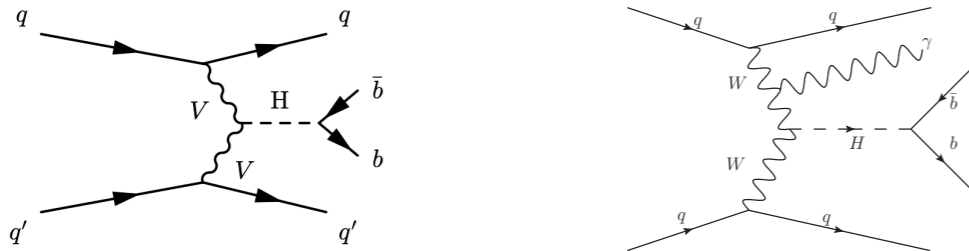- VH cross sections times the H→bb and V→leptons are measured in STXS reduced bins

H→bb in boosted topology

- VH with $p_T(V) > 250$ GeV, events with 0,1,2 leptons (e,μ)
  - Exclusive channel interesting also due to its sensitivity to possible New Physics

- Higgs reconstructed as a single Anti-kt jet with R=1.0
  - Two b's then identified with a p_T dependent radius parameter

- Observed (expected) signal significance is **2.1σ (2.7σ)**
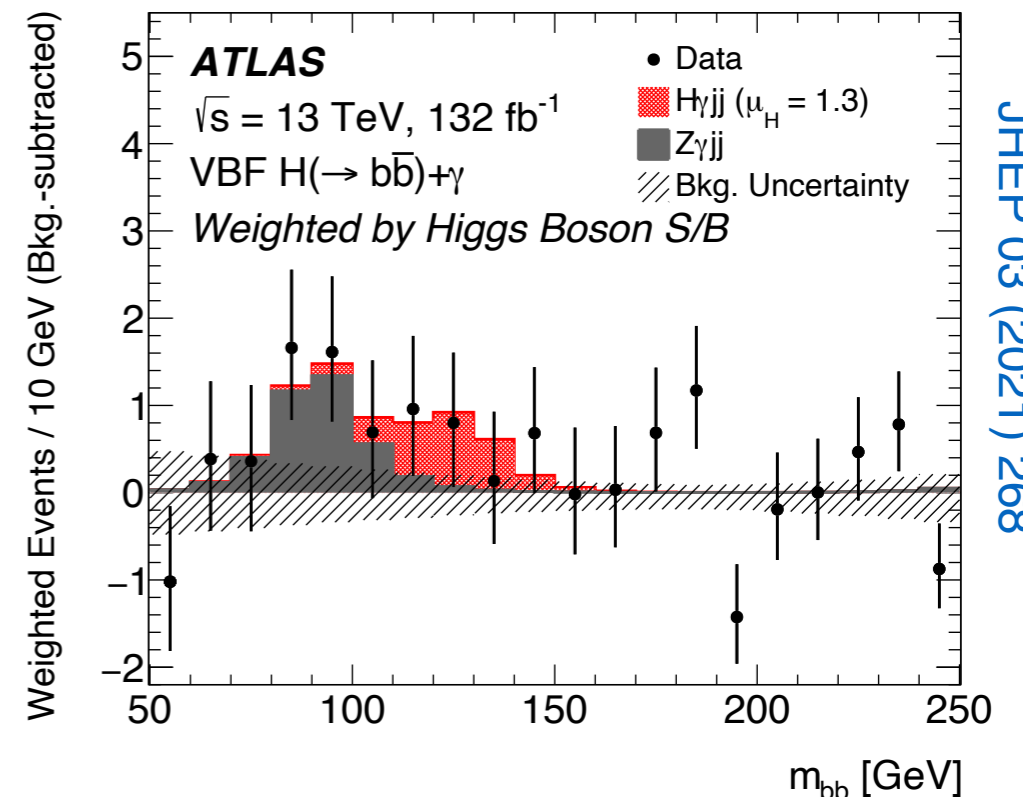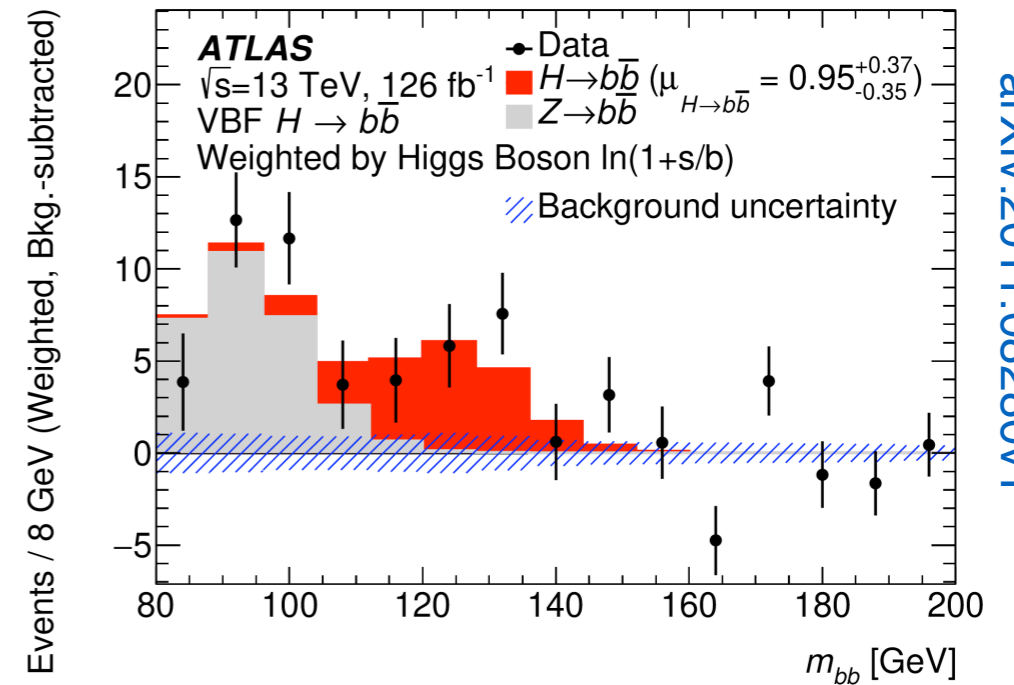 - Signal strength **μ=0.72$^{+0.39}_{-0.36}$**

STXS measurement in two p_T bins

VBF H→bb and H→bb γ-tagged

- Select events with two jets and two b-tagged jets

- H→bb:
  - Two categories forward and central, based on the tagged jets
  - Sensitivity boosted by the usage of a NN + ANN classifier trained on signal MC and m_{bb} sidebands

- H→bb γ-tagged:
  - The search in association with a high-energy photon
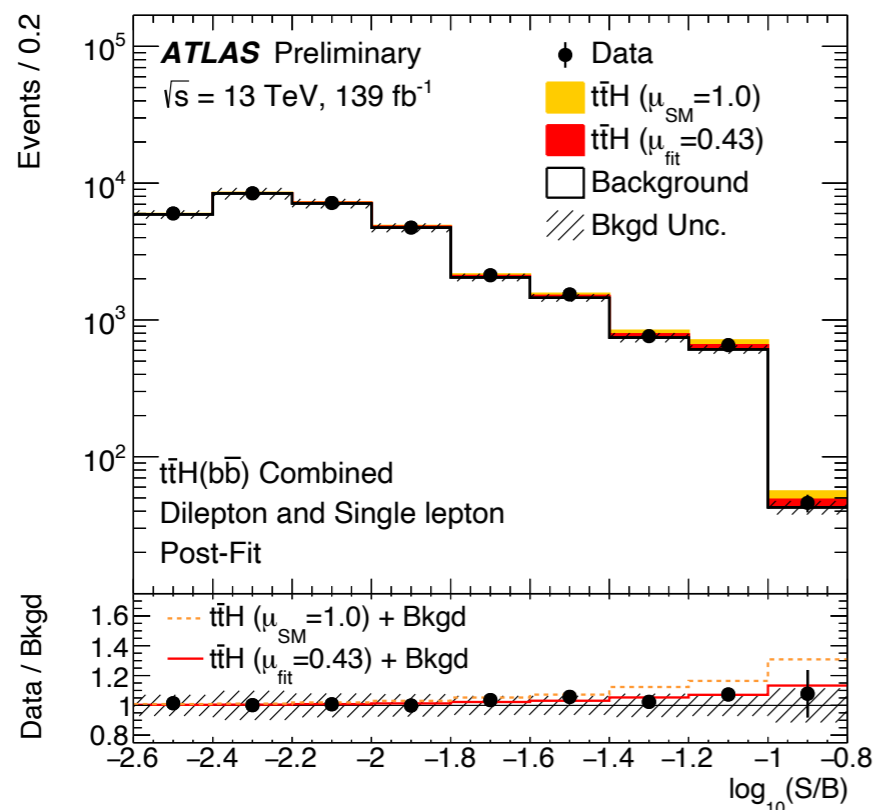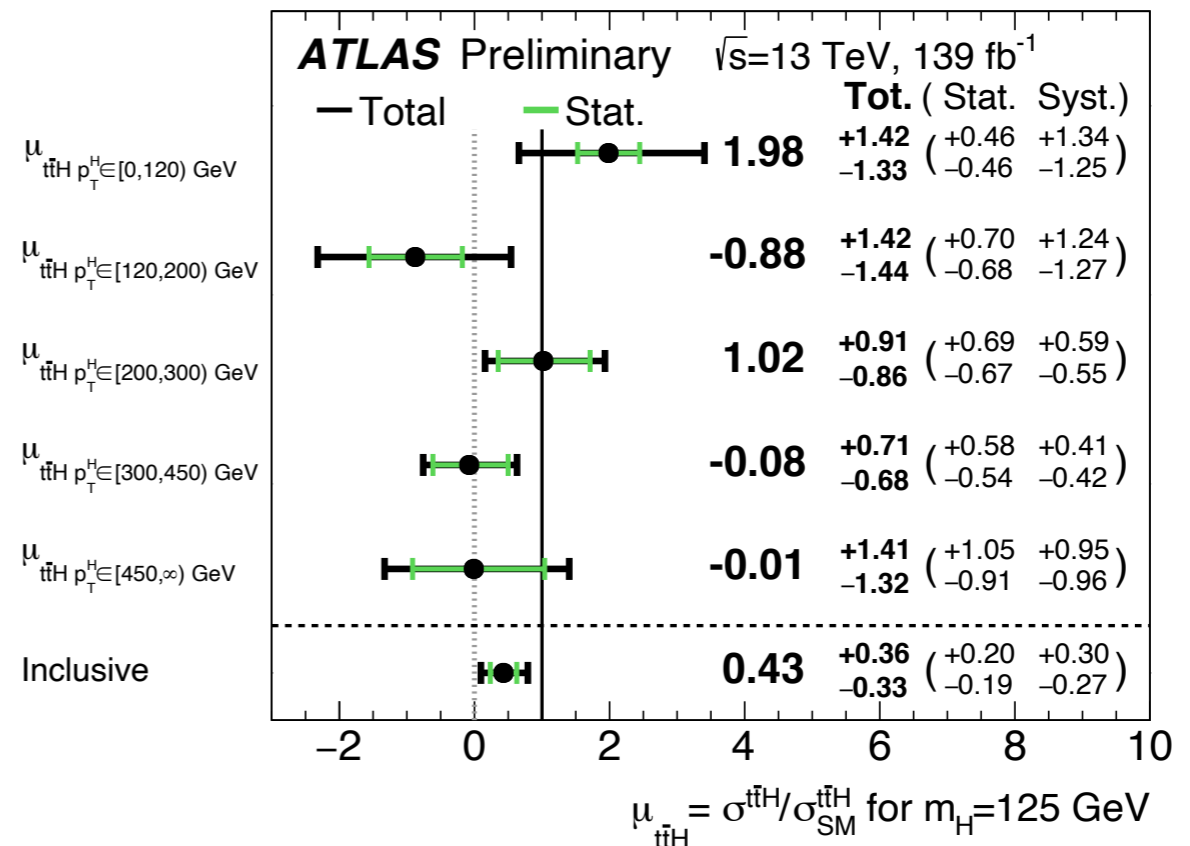   benefits from a significant reduction of the multi-jet background

ttH, H→bb

- ttH production mode observed via the combination of all decay channels with 36-80 fb^{-1}

- H→bb analysis updated with the full run-2 luminosity

- Analysis with 2 channels, single- and di-lepton
  - Single-lepton includes dedicated category targeting boosted topology
  - Events further categorised in 11 signal regions based on p$_T$(H)

- Multivariate discriminants to identify signal events

- Inclusive signal strength $\mu = 0.43^{+0.20}_{-0.19}(stat.)^{+0.30}_{-0.27}(syst.)$ with observed significance **1.3σ**

Signal and bkgnd distributions for 1- and 2- lepton channels

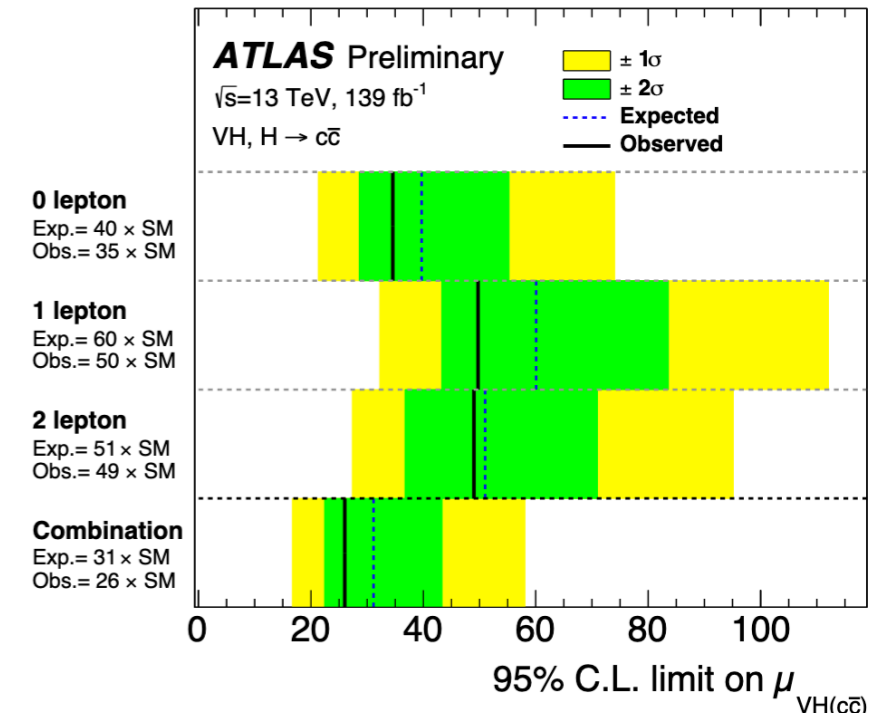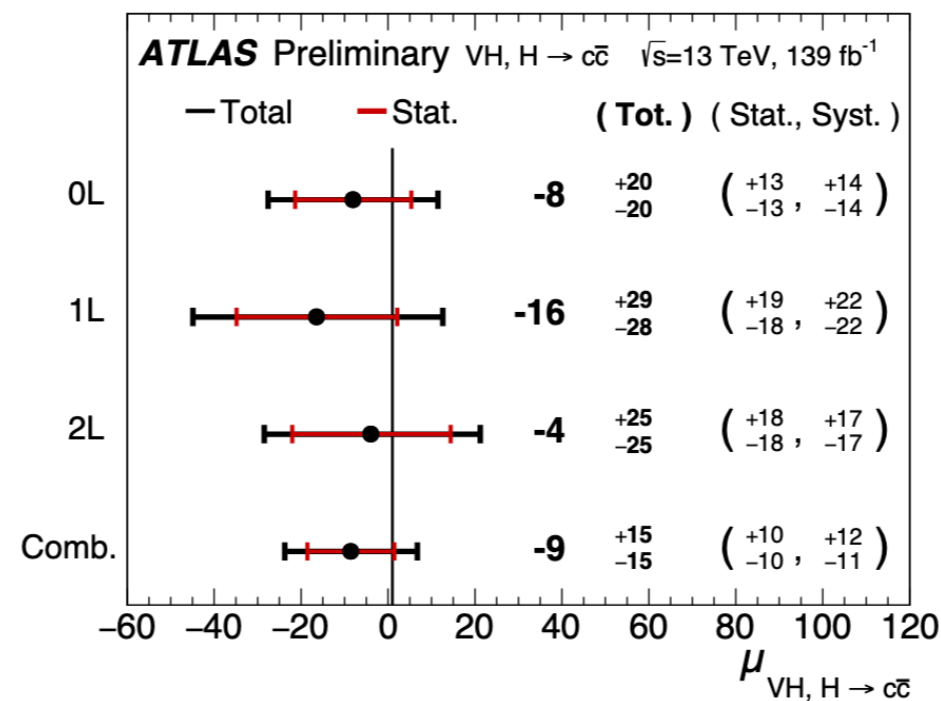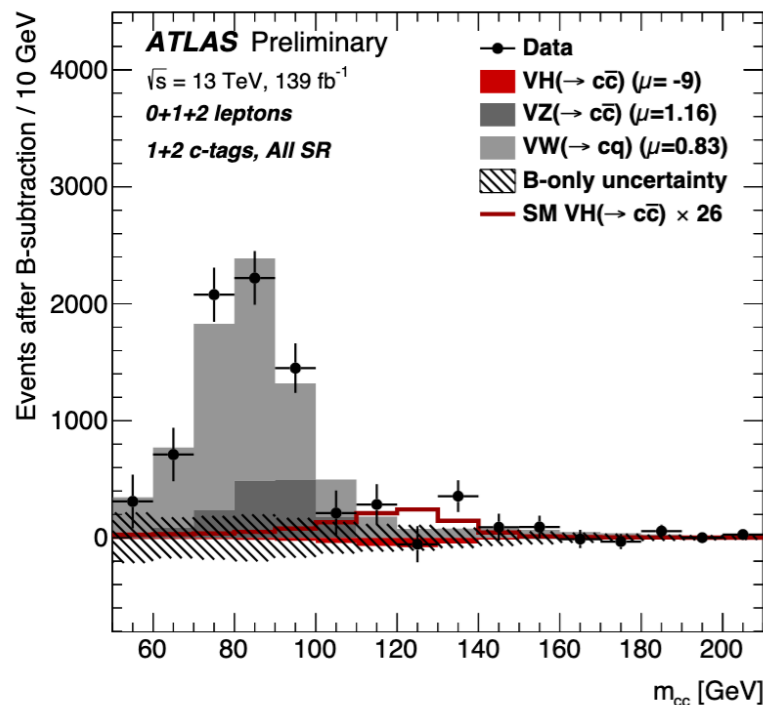Signal strengths in STXS pTH bins

H→cc in associated production

- Recent update of the search for this decay, using the full run-2 luminosity of 139 fb-1
  - Search in VH associated production with W,Z bosons, decaying into 0-, 1- and 2-leptons (e or μ)
- Multivariate discriminant for c-tagging and b-tagged jets veto
  - Analysis fully orthogonal to VH with H→bb
- Signal and VZ, VW signal strengths extracted from the fit of the m_{cc} distribution after the subtraction of the other backgrounds
- The observed(expected) significances of VW→(cq) and VZ→(cc) are **3.8(4.6)** and **2.6(2.2) σ**, respectively
- An upper limit of **26(31$^{+12}_{-8}$)** is observed (expected) on the signal strength μ, at 95% C.L.
- The |κ$_c$| modifier of the Yukawa coupling can be constrained to **|κ$_c$|<8.5 (9.4)**observed(expected), at 95% C.L.

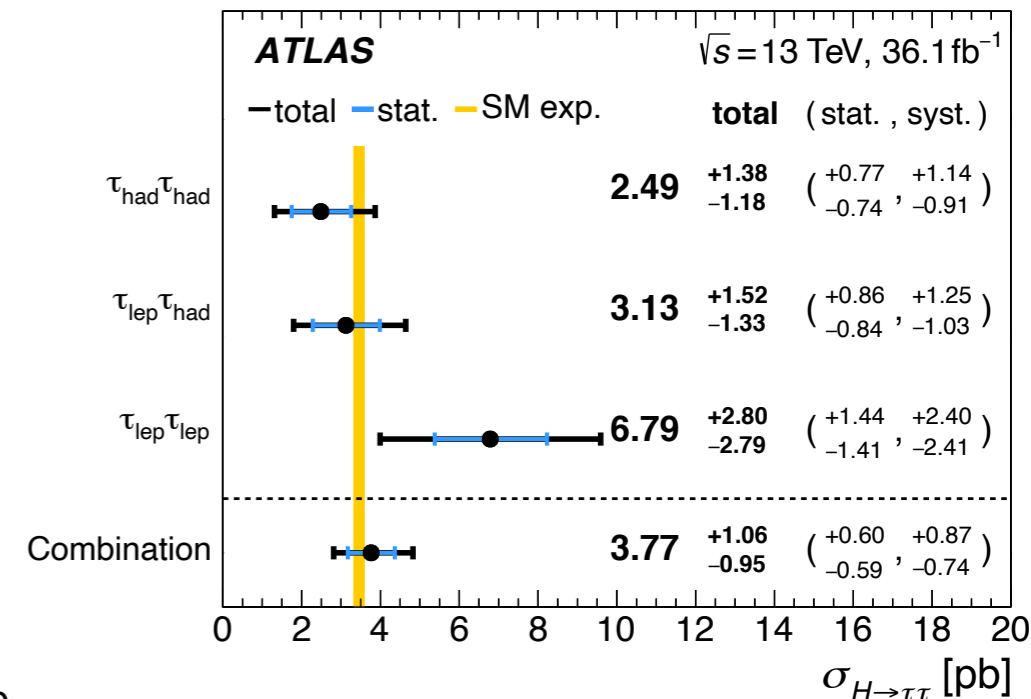$$\mu_{VH(c\bar{c})} = -9 \pm 10 \text{ (stat.)} \pm 12 \text{ (syst.)}$$
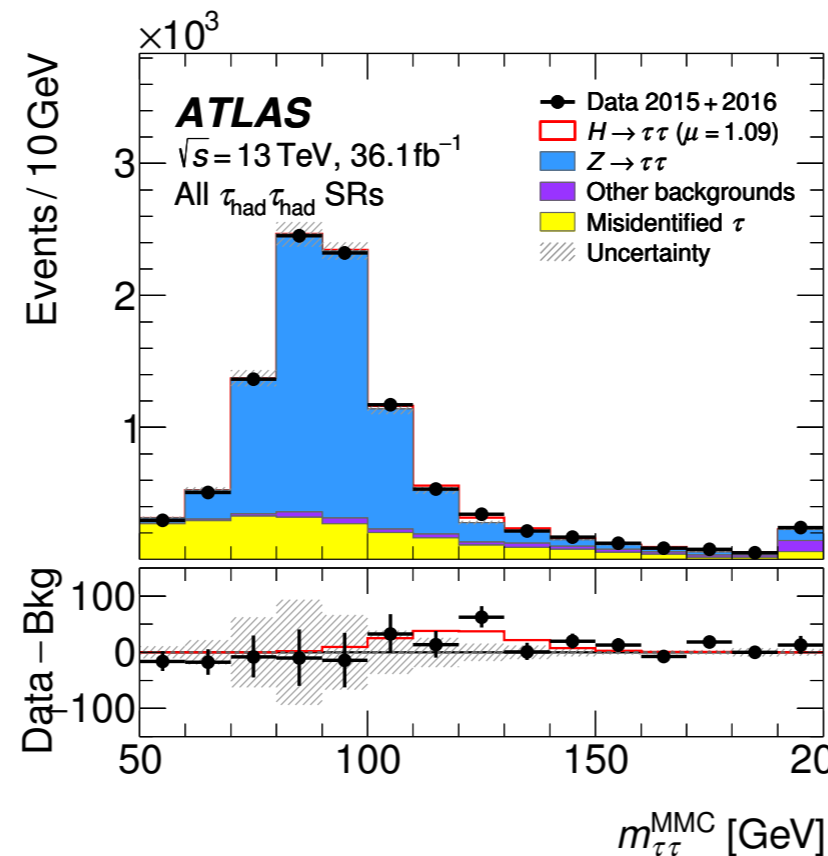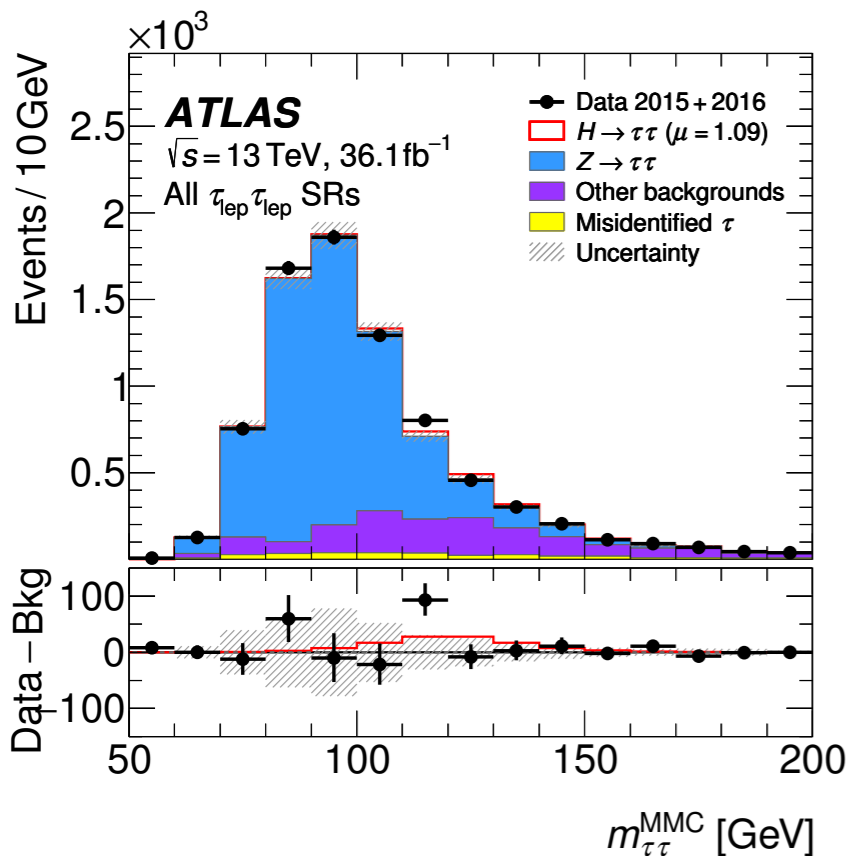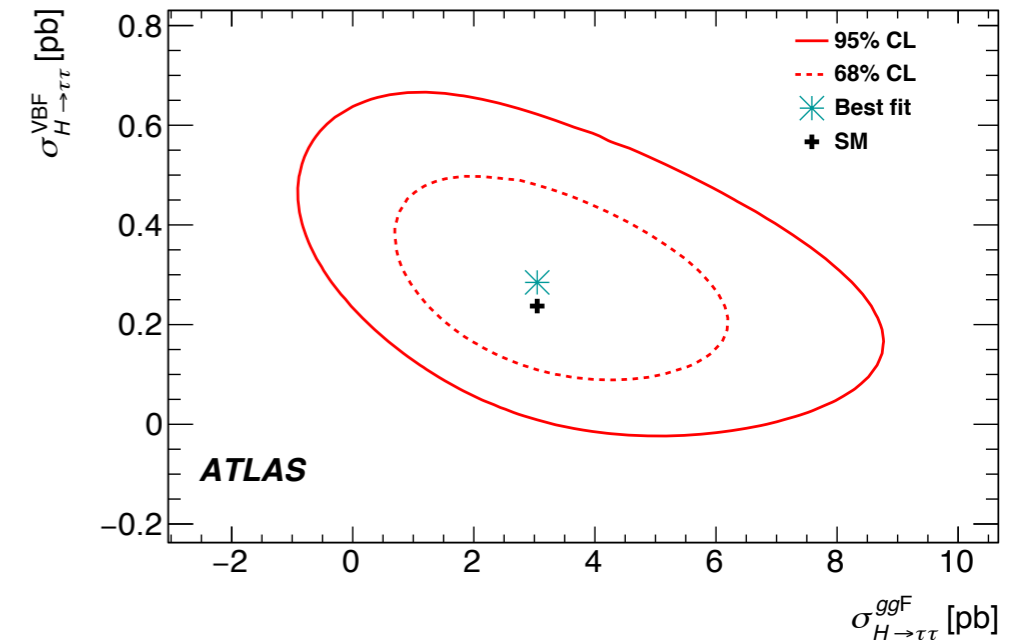$$\mu_{VW(cq)} = 0.83 \pm 0.11 \text{ (stat.)} \pm 0.21 \text{ (syst.)}$$
$$\mu_{VZ(c\bar{c})} = 1.16 \pm 0.32 \text{ (stat.)} \pm 0.36 \text{ (syst.)}$$
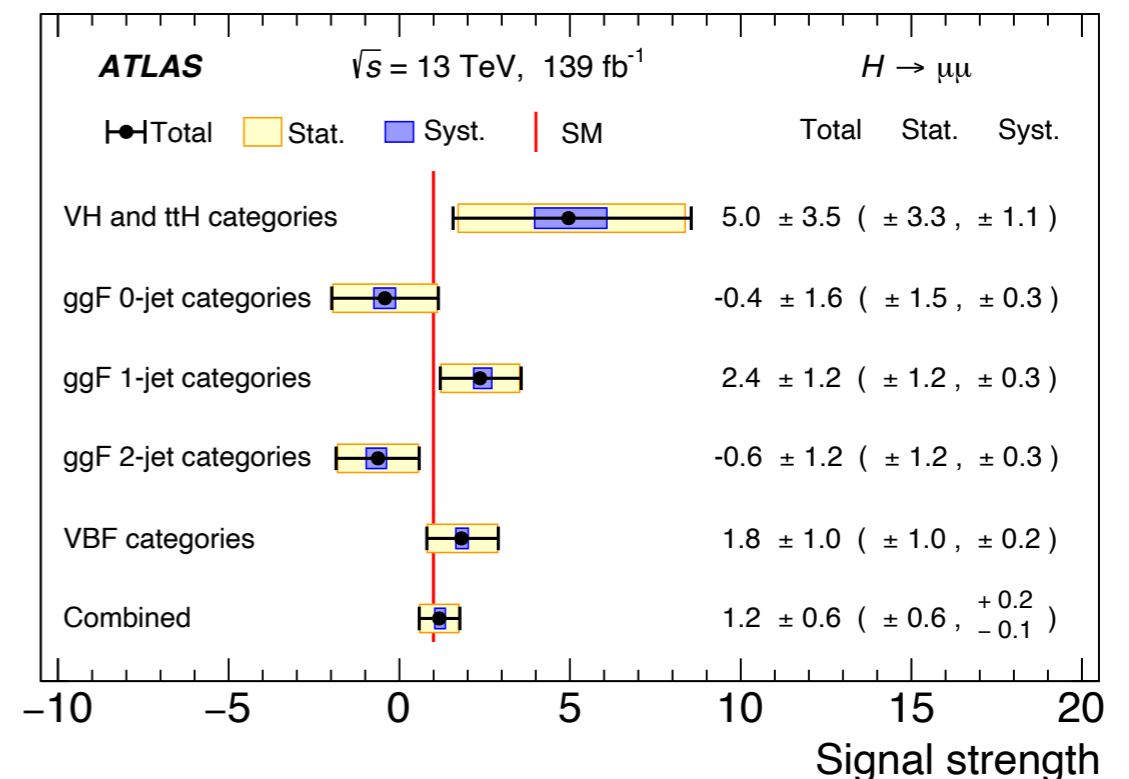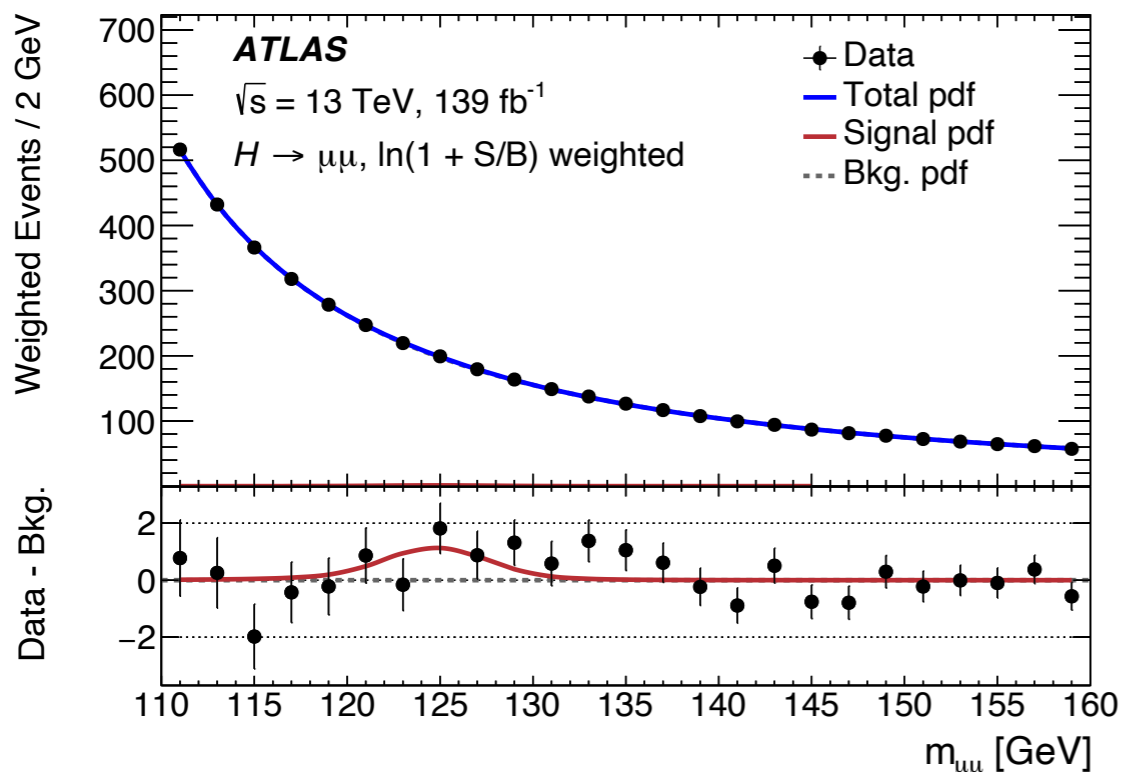
H→ττ

- Analysis of all decays combinations (leptonic, hadronic) of the two taus

- Signal region further divided in two main categories VBF and boosted, based on the presence of forward separated jets and on the tau pair p_T

- Observed(expected) significance is **4.4(4.1)** with 36 fb^{-1} of run-2 data, that give **6.4 (5.4)** in combination with run-1 data
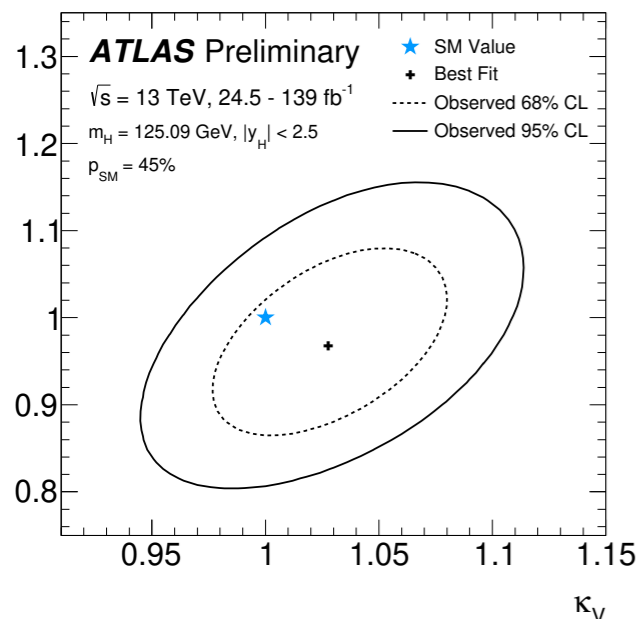
Search for the H→μμ decay

- The H→μμ decay offers the best opportunity to measure the Higgs interactions with a second-generation fermion

- Events are categorized in 20 mutually exclusive categories

  ○ Di-lepton mass fit in the 110-160 GeV region

  ○ Correct for muon QED FSR

  ○ Background modeling from core function (LO DY mass shape) convolved with di-lepton mass dependent resolution x empirical functions, category dependent

- Result improve by a factor ~2.5 previous ATLAS result, with a factor ~2 coming from the increased int. luminosity an additional ~25% from analysis improvements

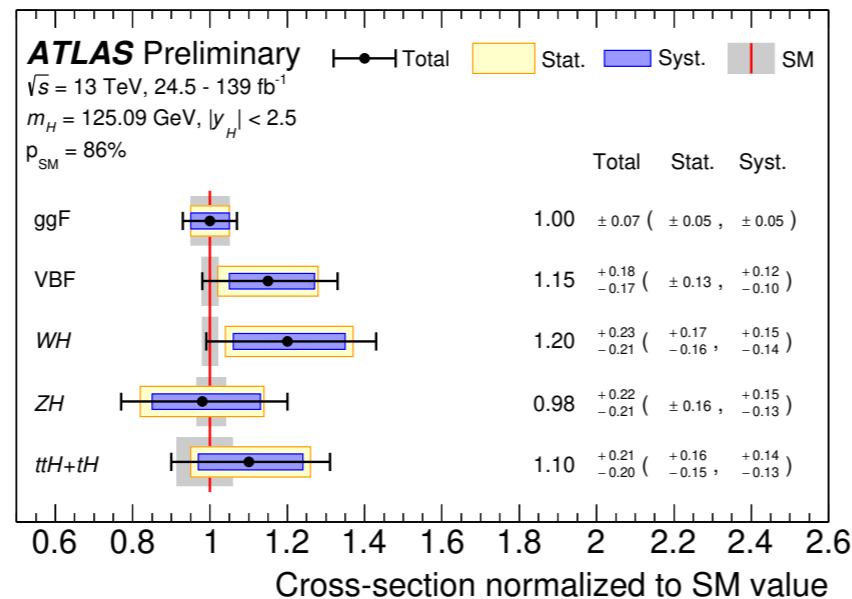 ○ Signal strength **μ=1.2±0.6** corresponding to an observed(expected) significance of **2.0σ (1.7σ)**

- Results from the combination of all production modes and decay channels, with up to 136 fb^{-1} of run-2 data

- All main production modes have been observed with a significance larger than 5σ

- Multiplicative factors κ can be applied to SM cross sections and BR to constrain the couplings
  - E.g. κ_F, κ_V for fermions, vector bosons

- STXS measurements updated using the best possible granularity
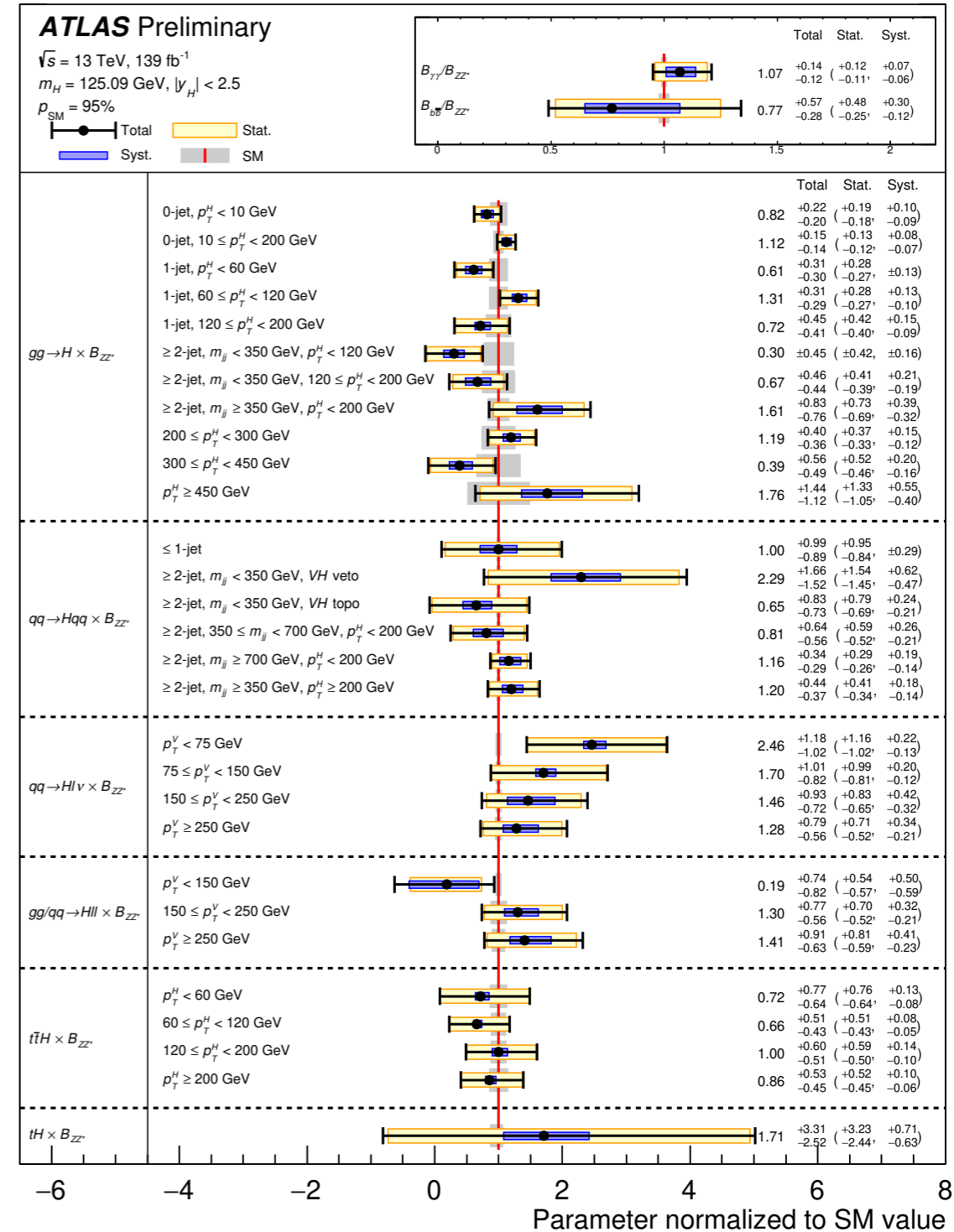 - Compatibility with the SM hypothesis corresponds to a p-value p_{SM}=95%

STXS parameters

κ_F VS κ_V
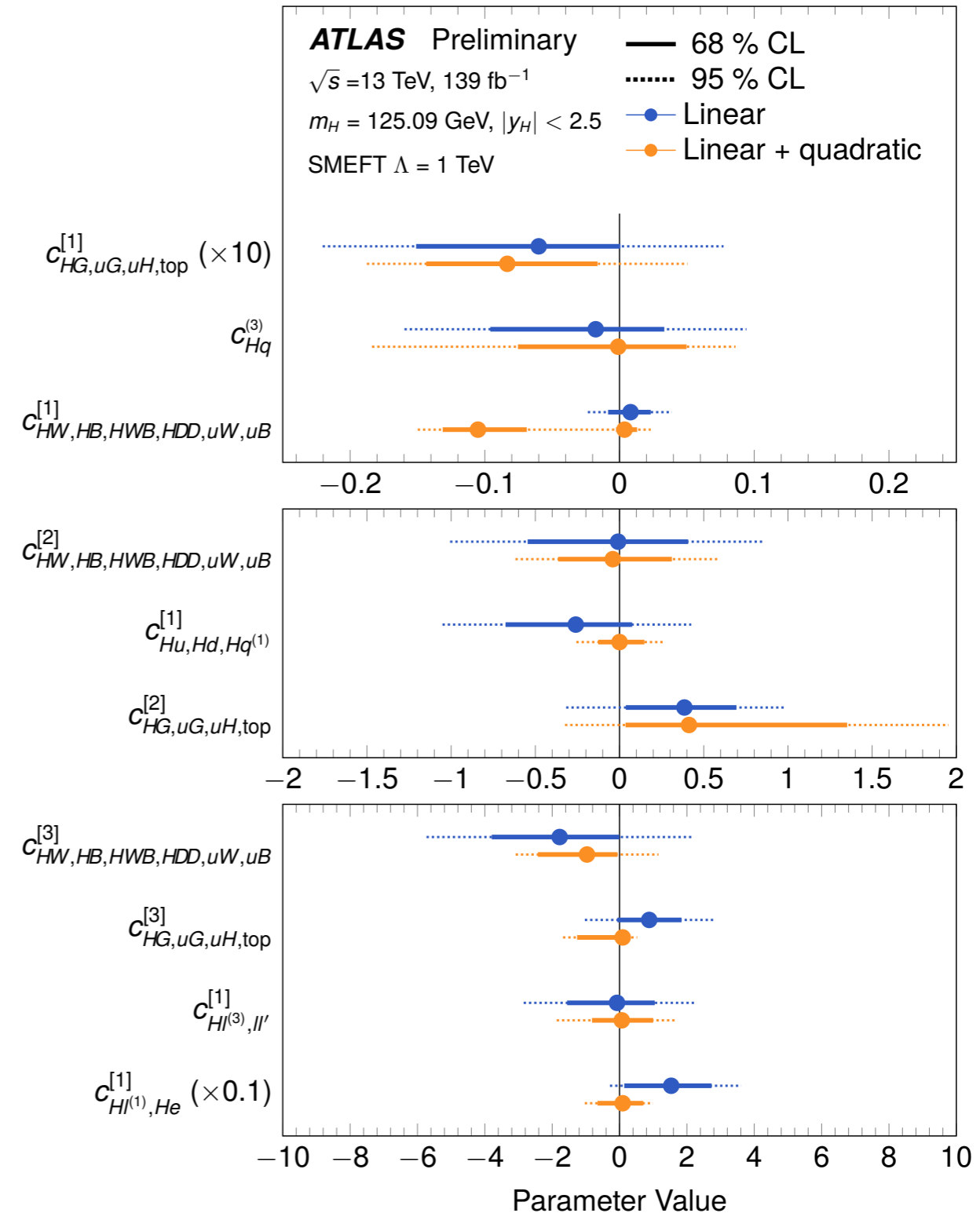

Production mode cross sections

Combined measurements interpretation

- STXS can be interpreted in the framework of SM Effective Field Theory (EFT)

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i^{N_{d6}} \frac{c_i}{\Lambda^2} O_i^{(6)} + \sum_j^{N_{d8}} \frac{b_j}{\Lambda^4} O_j^{(8)} + \dots,$$

Model independent parametrisation of possible BSM contributions to the couplings with d=6 and d=8 operators
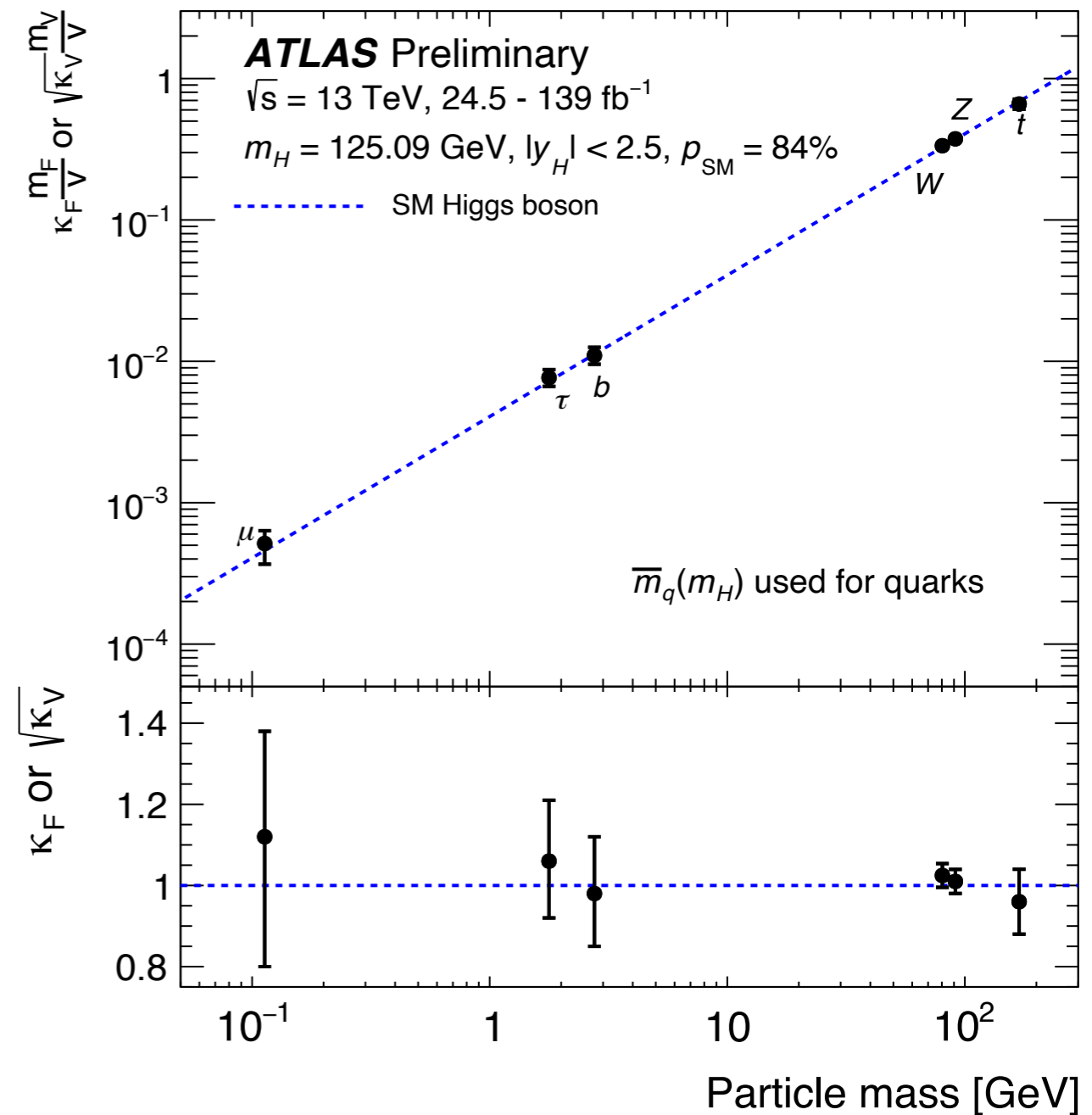
- Constrain d=6 operators (in the "Warsaw" basis)
  - Eigenvector decomposition to determine the combinations of c_i coefficients that the STXS analysis is sensitive to

- Matrix element depend on linear c_i/Λ^2 and quadratic $c_i c_j/\Lambda^4$
  - d=8 operators and their interference with d=6 not considered
  - Contribution of quadratic terms not negligible

- All fitted values compatible with the SM expectation (=0)

Summary

- ATLAS has made significant progress in the measurements of Yukawa couplings to quarks and leptons

- All major production modes have been observed

- Higgs coupling to 3rd generation fermions has been confirmed

- Significant improvements in the analysis of the couplings to 2nd generation fermions c and μ

  - Couplings to muons figuring as measurement, not as limit, for the first time

- Measurements of STXS and interpretation in the EFT framework give access to possible New BSM Physics

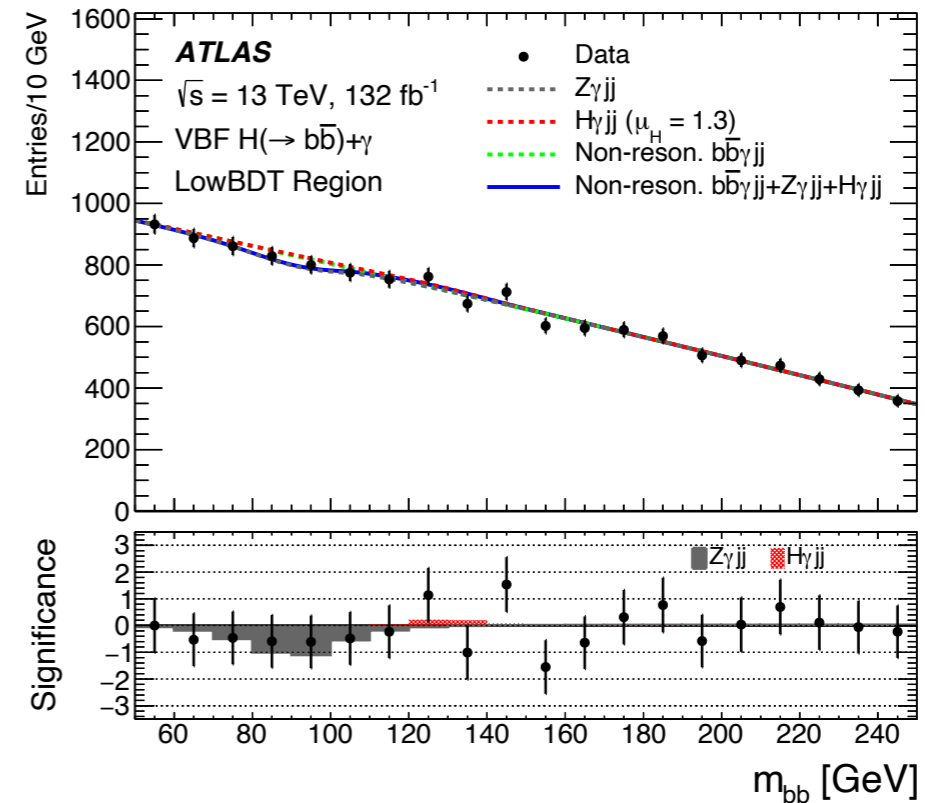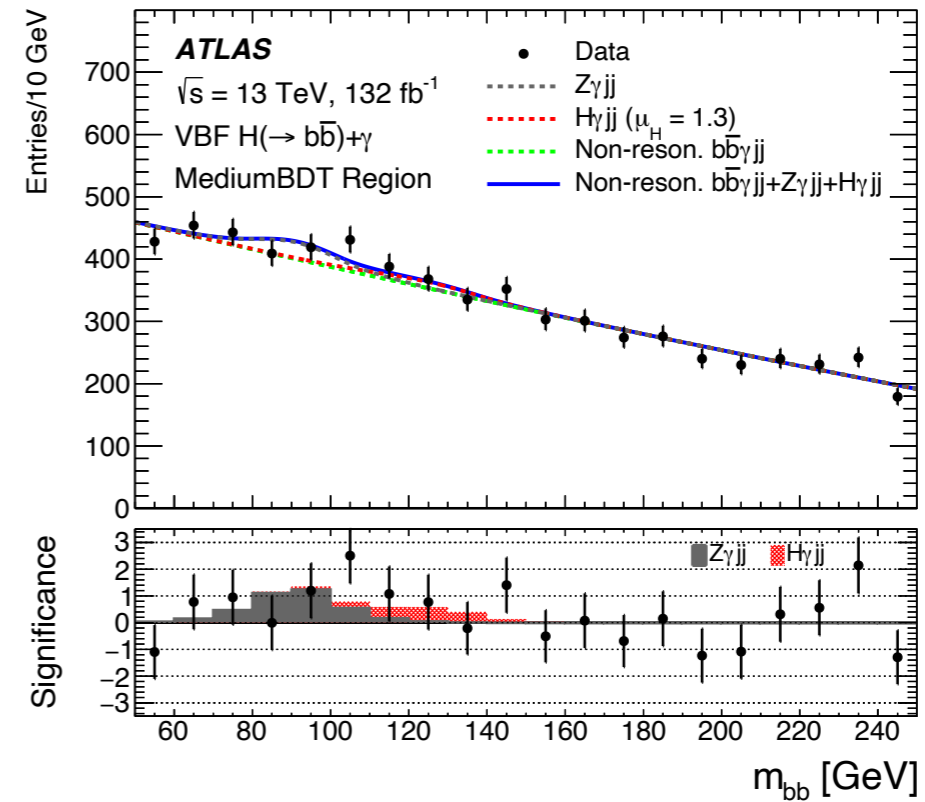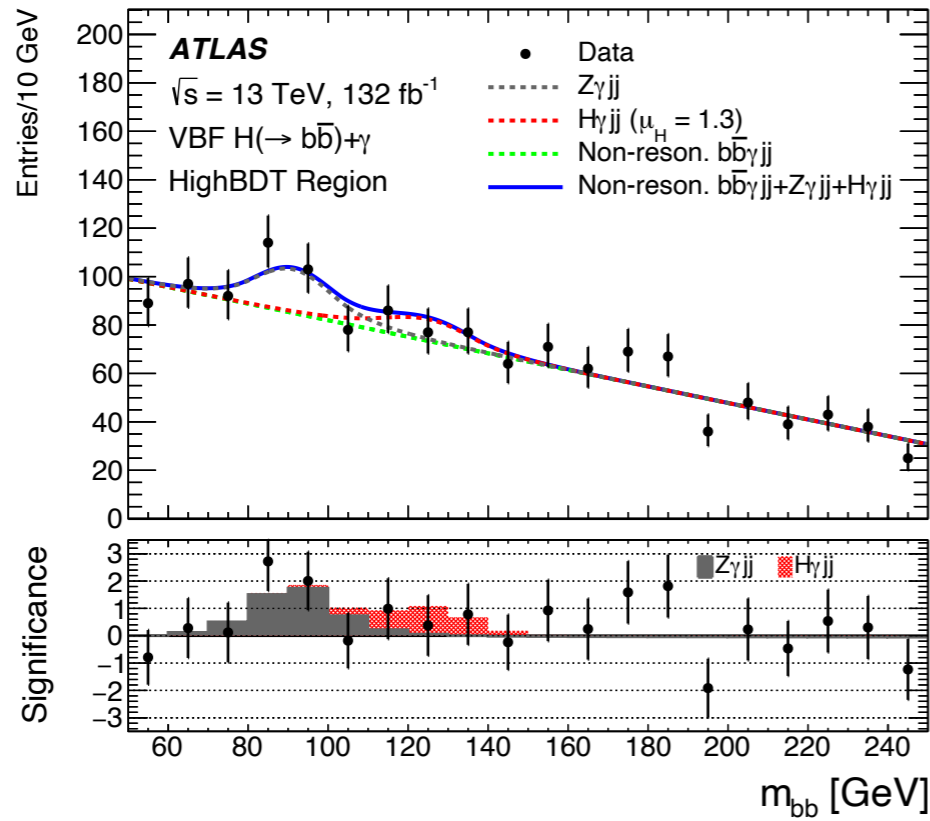- No significant deviations from the SM have been observed up to now

BACKUP SLIDES

H→bb photon tagged
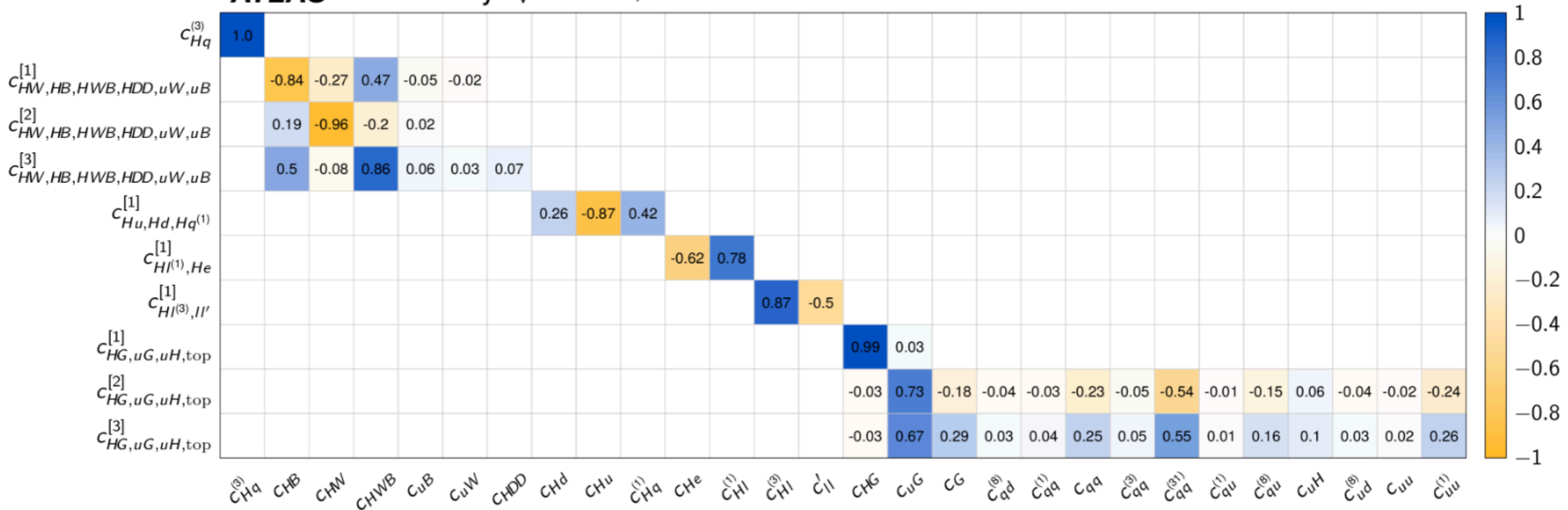
- Signal and background mass distributions in BDT regions

EFT coefficients

- EFT coefficients combination, eigenvalues

Constraint on H-charm couplings modifiers

- The H→cc result can be interpreted in terms of a constraint on the H-c couplings modifiers
- The $|\kappa_c|$ modifier of the Yukawa coupling can be constrained to $|\kappa_c|<8.5$ (9.4) observed(expected), at 95% C.L.