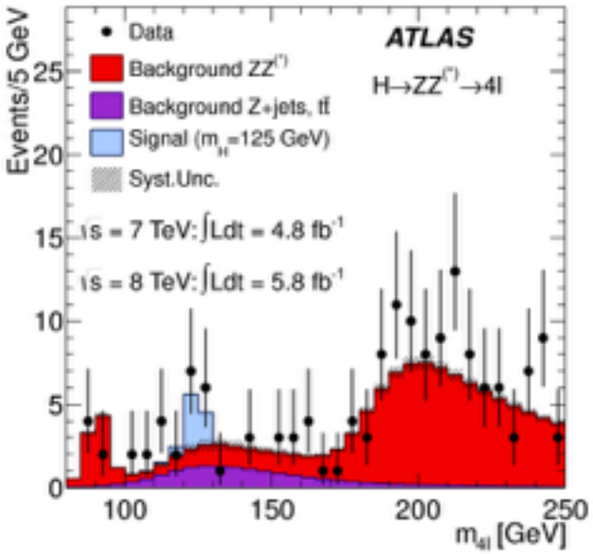
QFTHEP2017
Karri Folan DiPetrillo for the ATLAS Collaboration

Measurement of Cross Sections and Couplings of the Higgs Boson using the ATLAS detector

INTRODUCTION

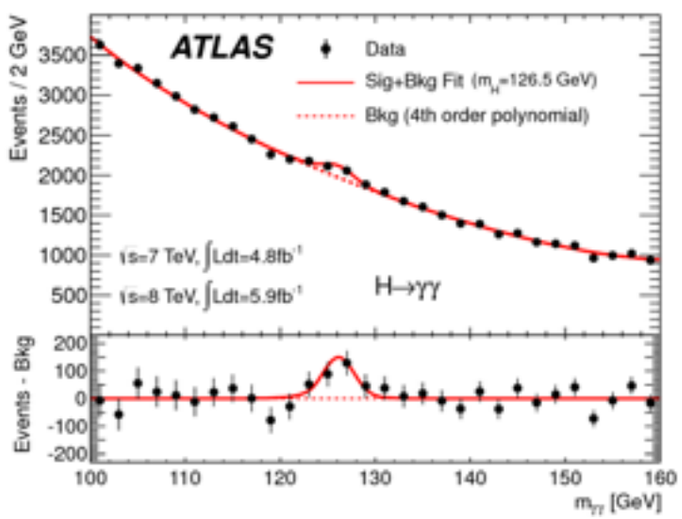
- In 2012 we discovered a new particle with mass ~125 GeV
  - so far all measurements suggest it is consistent with Standard Model Higgs Boson
  - BUT even small deviations in couplings have dramatic implications for physics beyond SM
  - many channels are no longer statistics limited



- Today: Summarize Higgs cross sections and couplings measurements in ATLAS

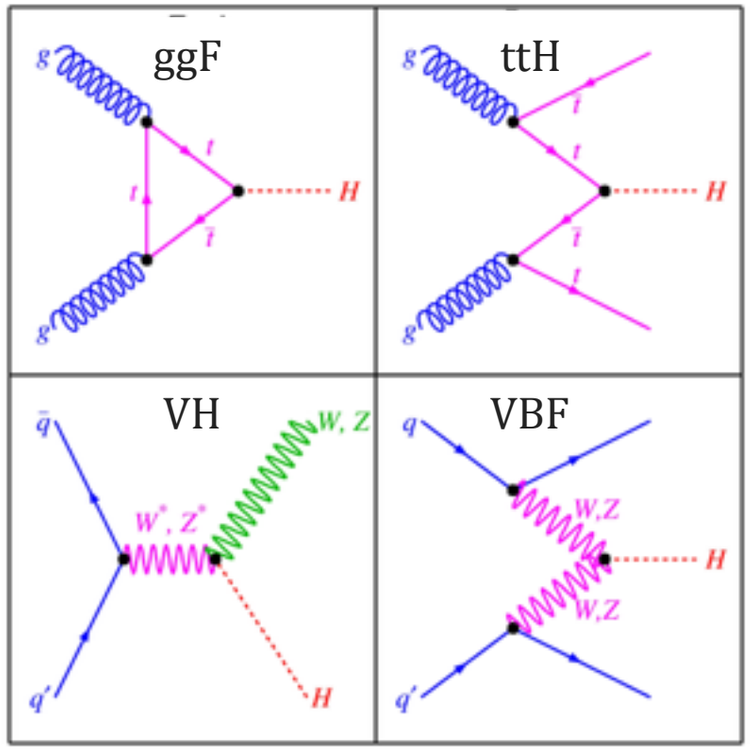
- Higgs Production and decay mechanisms
- Quick Reminder of Run 1 Results
- New Results at 13 TeV!
  - fiducial and total cross sections
  - differential cross sections
  - combinations

And even more covered in Biagio Di Micco's plenary "Higgs Physics in ATLAS"



Phys. Lett. B 716 (2012) 1-29

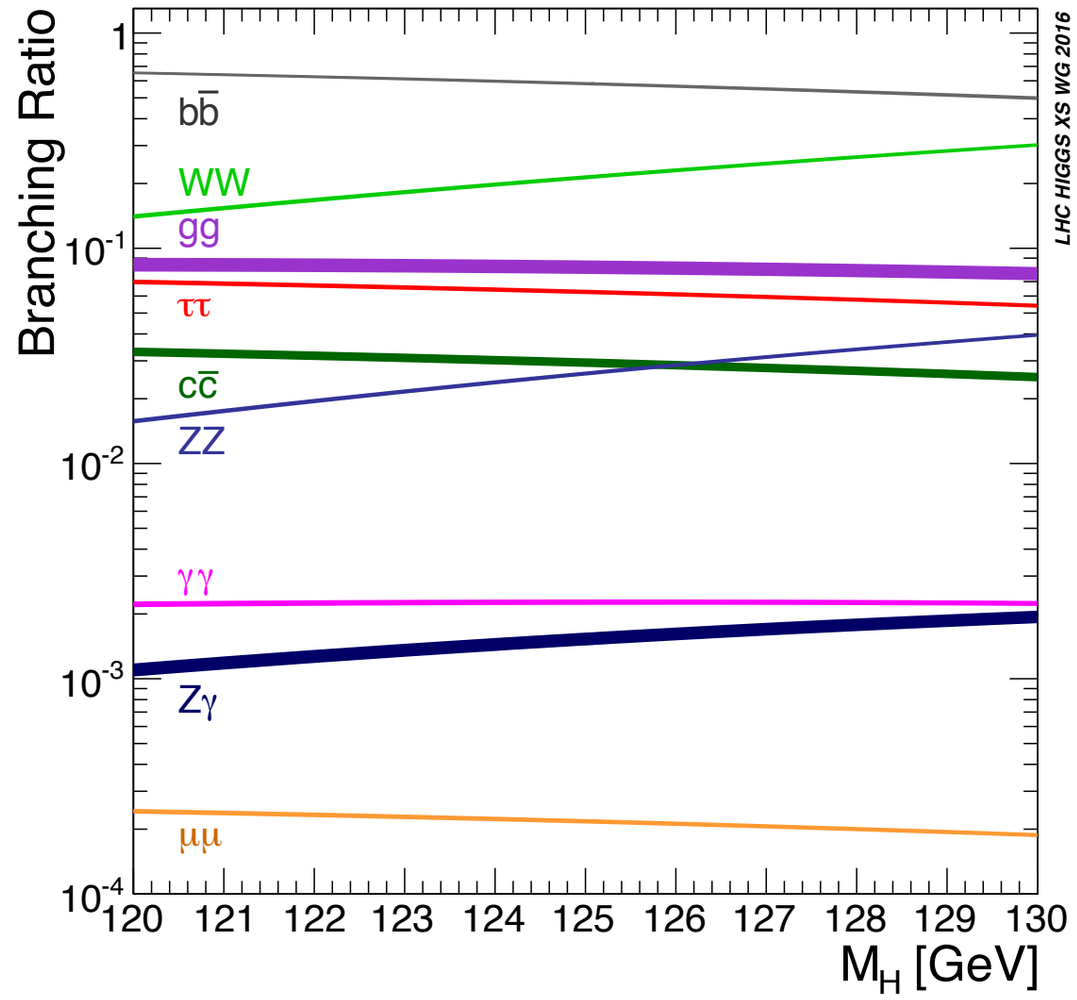
HIGGS PRODUCTION AND DECAYS



- **Production mechanisms @13TeV**
  - **ggF:** dominant production mode (87.3%)
  - **VBF:** H + 2 forward jets (6.8%)
  - **VH:** H + W or Z (4.1%)
  - **ttH/bbH:** H + tt-bar or bb-bar (0.9%/0.9%)

    ~4x increase in ttH production between 8 and 13 TeV

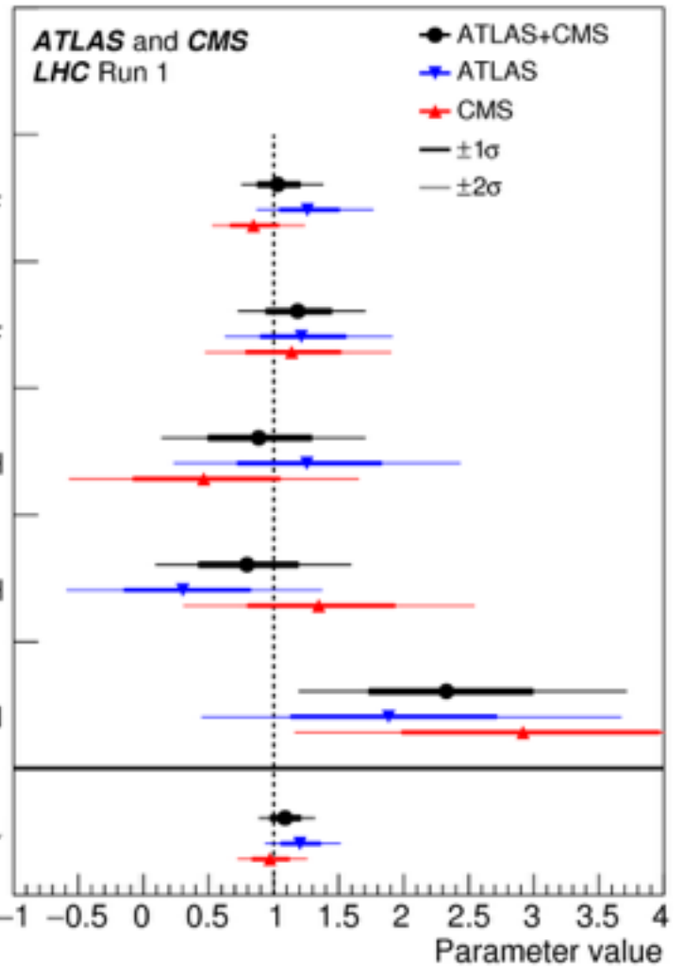
- **Decay modes**
  - **ZZ** and **$\gamma\gamma$:** low stats but clean!
  - **WW:** excellent sensitivity, complicated backgrounds
  - **bb:** largest BR, but huge backgrounds
  - **$\tau\tau$:** only direct observation of H coupling to leptons
  - **Zγ** and **$\mu\mu$:** very small BR



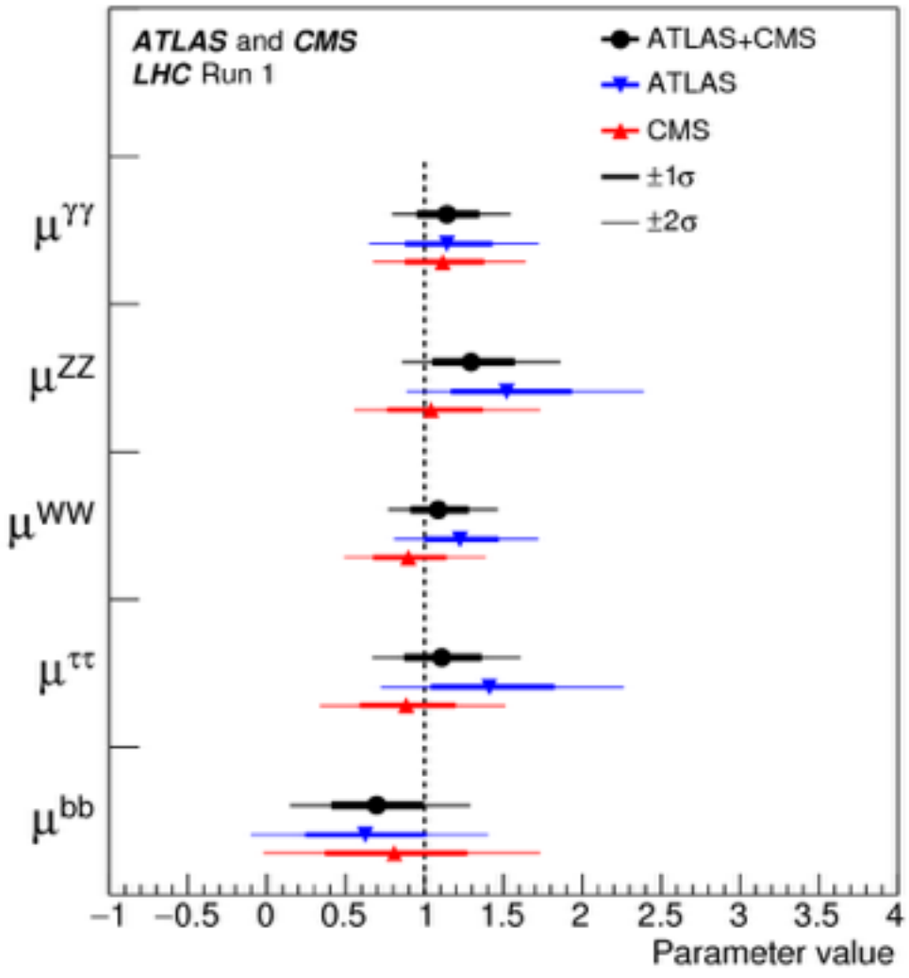
AT THE END OF RUN 1: JHEP 08 (2016) 045

- **Combined ATLAS and CMS measurements with the full Run 1 dataset (5 fb^{-1} at 7 TeV and 20 fb^{-1} at 8 TeV)**
  - Higgs production and decay rates assuming m_H = 125.09 GeV
  - for a production process i, and final state f, define signal strength

$$\mu_i = \frac{\sigma_i}{(\sigma_i)_{\mathrm{SM}}} \quad \text{and} \quad \mu^f = \frac{\mathrm{B}^f}{(\mathrm{B}^f)_{\mathrm{SM}}}$$



slight excess in ttH



slight deficit in $b\bar{b}$

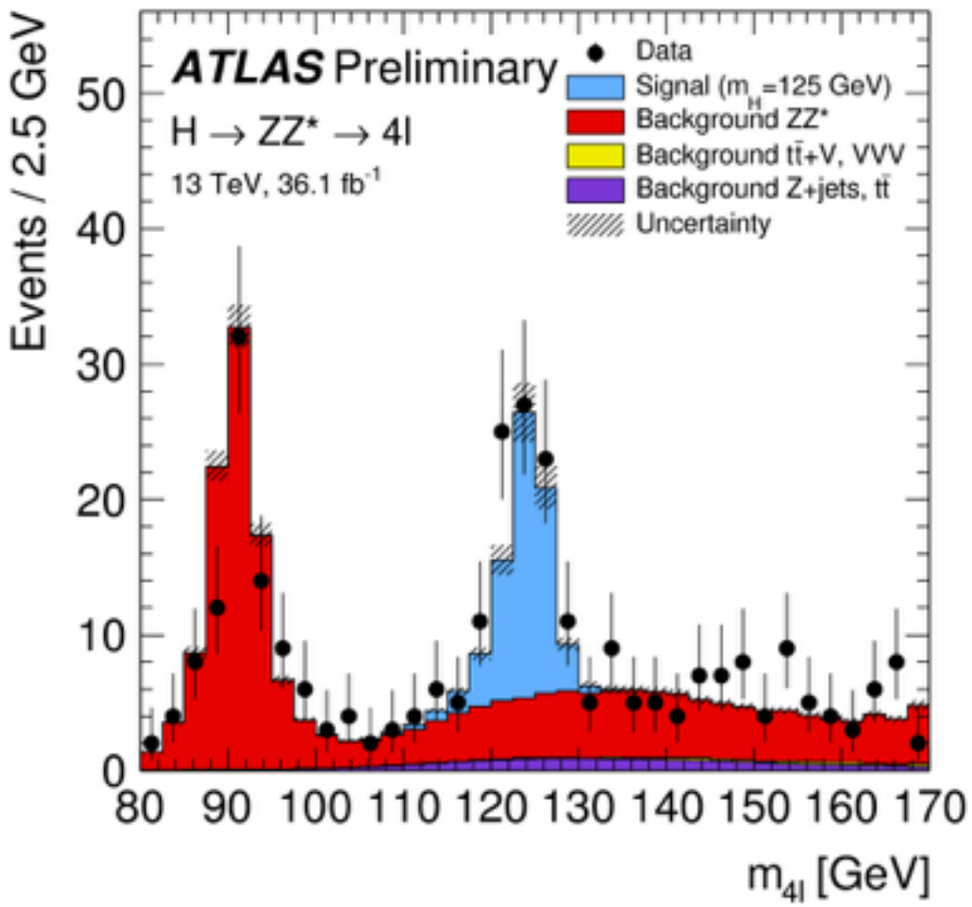
$H \to ZZ^* \to 4\ell$: ATLAS-CONF-2017-032

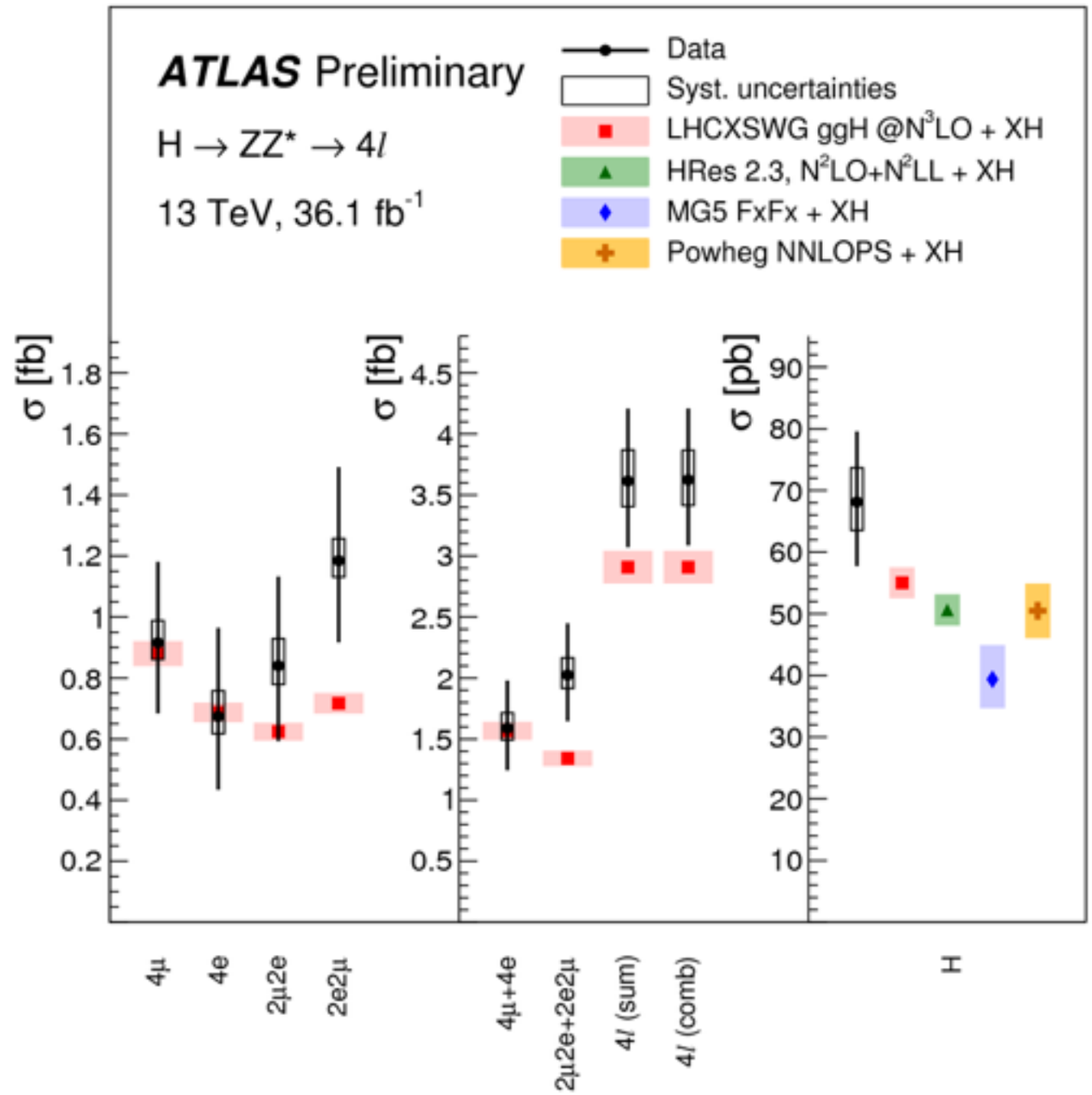
- **New 13 TeV result with 36.1 fb^{-1}!**
  - extremely clean channel with best S/B, >2
  - select 2 SFOS lepton pairs, from common vertex
  - inclusive fiducial cross sections

    $\sigma_{4\ell}$ [fb] = $3.62\ ^{+0.53\ +0.25}_{-0.50\ -0.20}$

    σ_{SM}[fb] = 2.91 ± 0.13
  - extrapolation to total SM Higgs XS

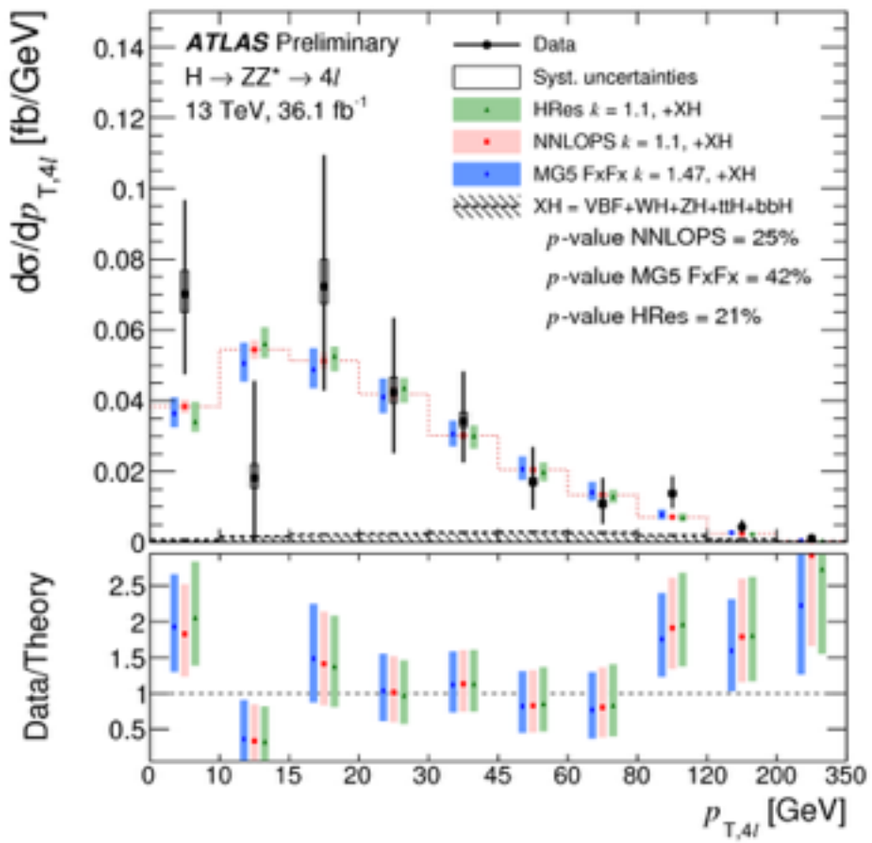
    σ_{Tot}[pb] = $69\ ^{+10}_{-9} \pm 5$

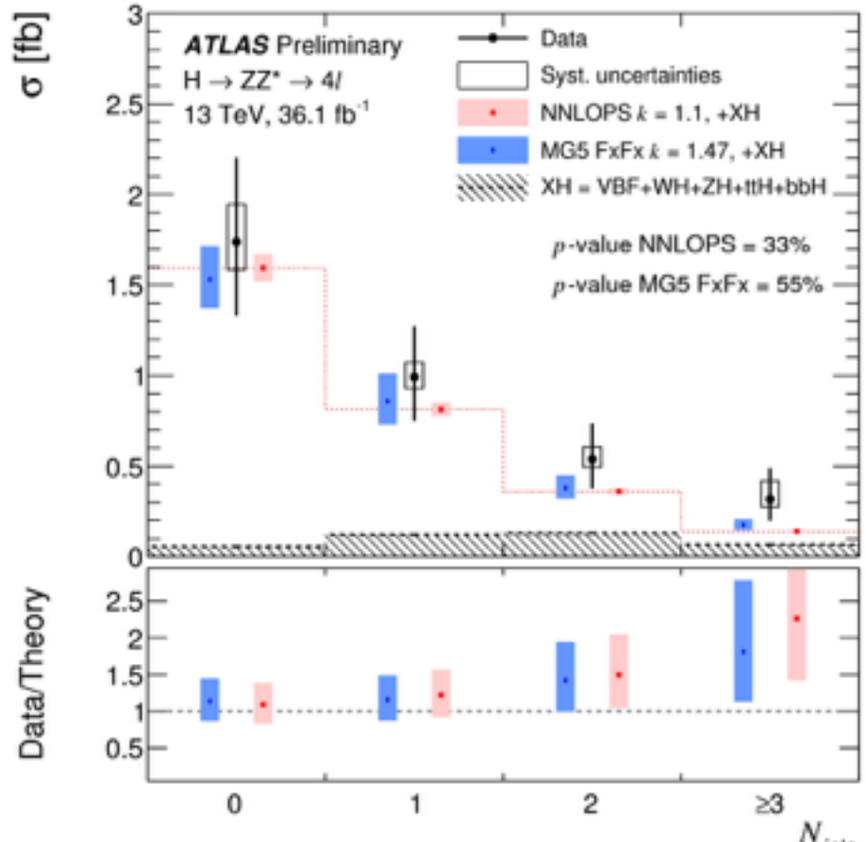


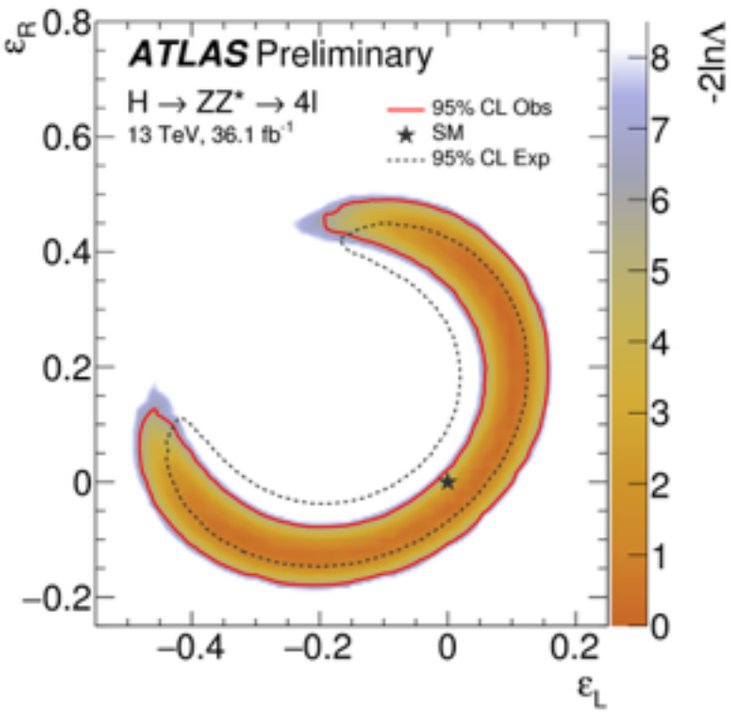


$H \to ZZ^* \to 4\ell$: ATLAS-CONF-2017-032

- **New 13 TeV result with 36.1 fb^{-1}!**
  - measurement of differential cross sections sensitive to production and decay
  - used to set constraints on anomalous Higgs interactions
  - ε_L and ε_R, modify contact terms between Higgs boson and left- and right-handed leptons







$H \rightarrow \gamma\gamma$: ATLAS-CONF-2016-067

- **Using 13.3 fb^{-1} of 13 TeV data**
  - clean signature with good mass resolution
  - selecting two isolated photons with p_T (γ)> 35%, 25% of $m_{\gamma\gamma}$ in $|\eta|<2.37$, excluding $1.37<|\eta|<1.52$
  - background parameterization from simulation fit to data
  - fiducial, total, and differential cross sections

$$\sigma_{\text{fid}} = 43.2 \pm 14.9\,(\text{stat.}) \pm 4.9\,(\text{syst.})\ \text{fb}$$

$$\sigma_{\text{SM}} = 62.8\,^{+3.4}_{-4.4}\ \text{fb}$$

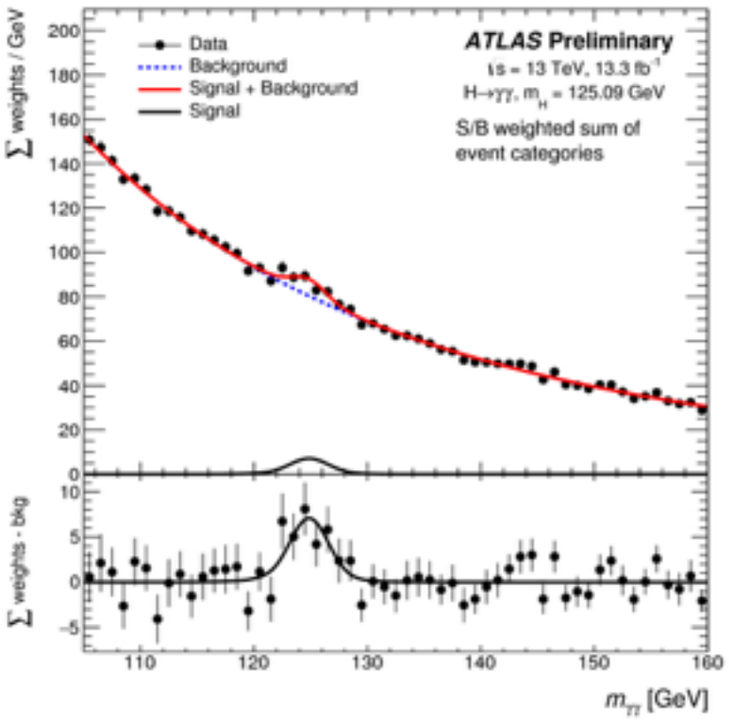
Total Production Mode Cross Sections for m_H = 125.09 ± 0.24 GeV

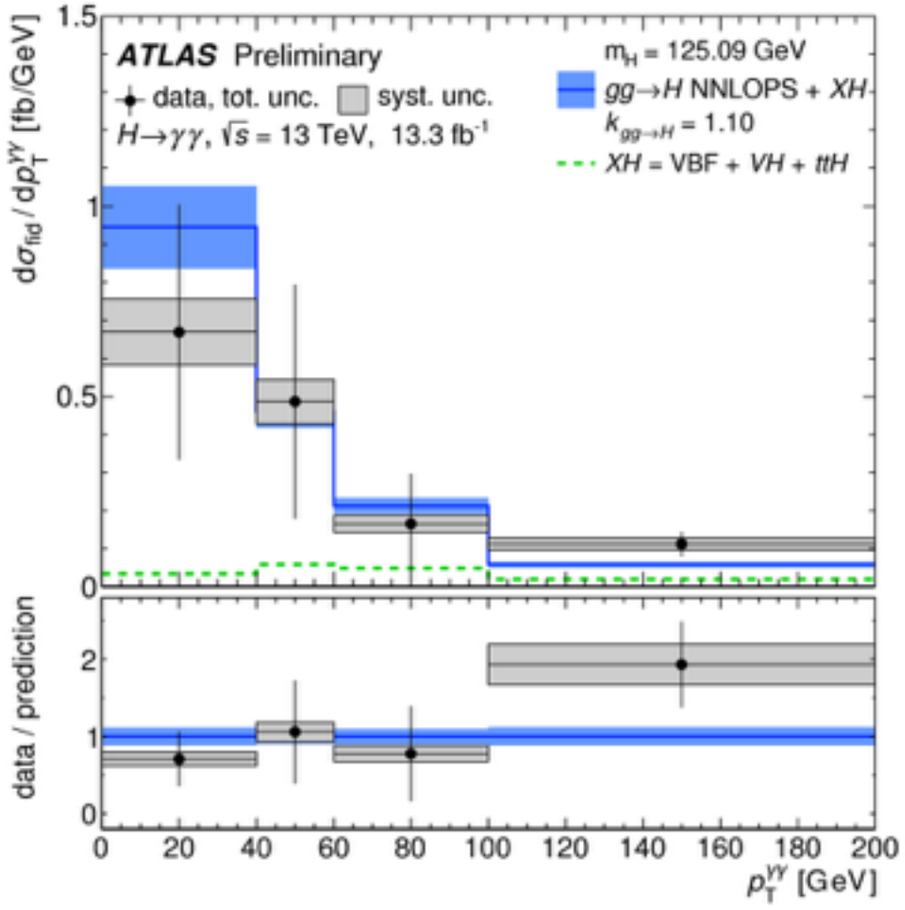
$$\sigma_{ggH} \times \mathcal{B}(H \rightarrow \gamma\gamma) = 65\,^{+32}_{-31}\ \text{fb}$$

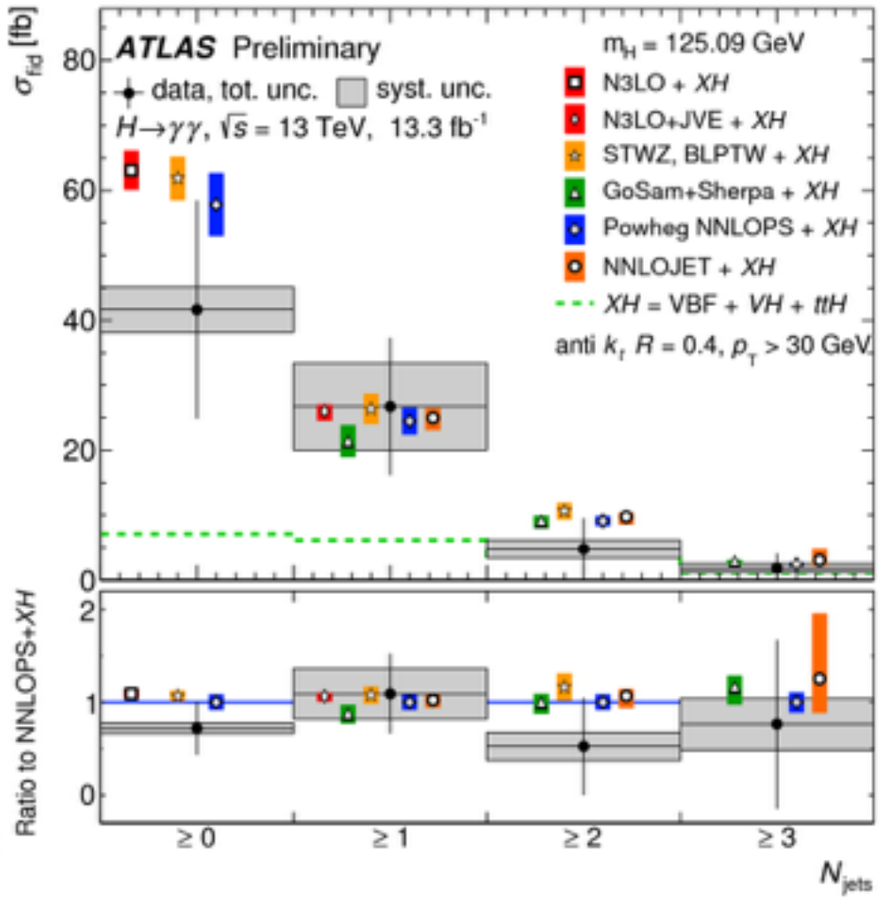
$$\sigma_{\text{VBF}} \times \mathcal{B}(H \rightarrow \gamma\gamma) = 19.2\,^{+6.8}_{-6.1}\ \text{fb}$$

$$\sigma_{VH} \times \mathcal{B}(H \rightarrow \gamma\gamma) = 1.2\,^{+6.5}_{-5.4}\ \text{fb}$$

$$\sigma_{t\bar{t}H} \times \mathcal{B}(H \rightarrow \gamma\gamma) = -0.3\,^{+1.4}_{-1.1}\ \text{fb}$$



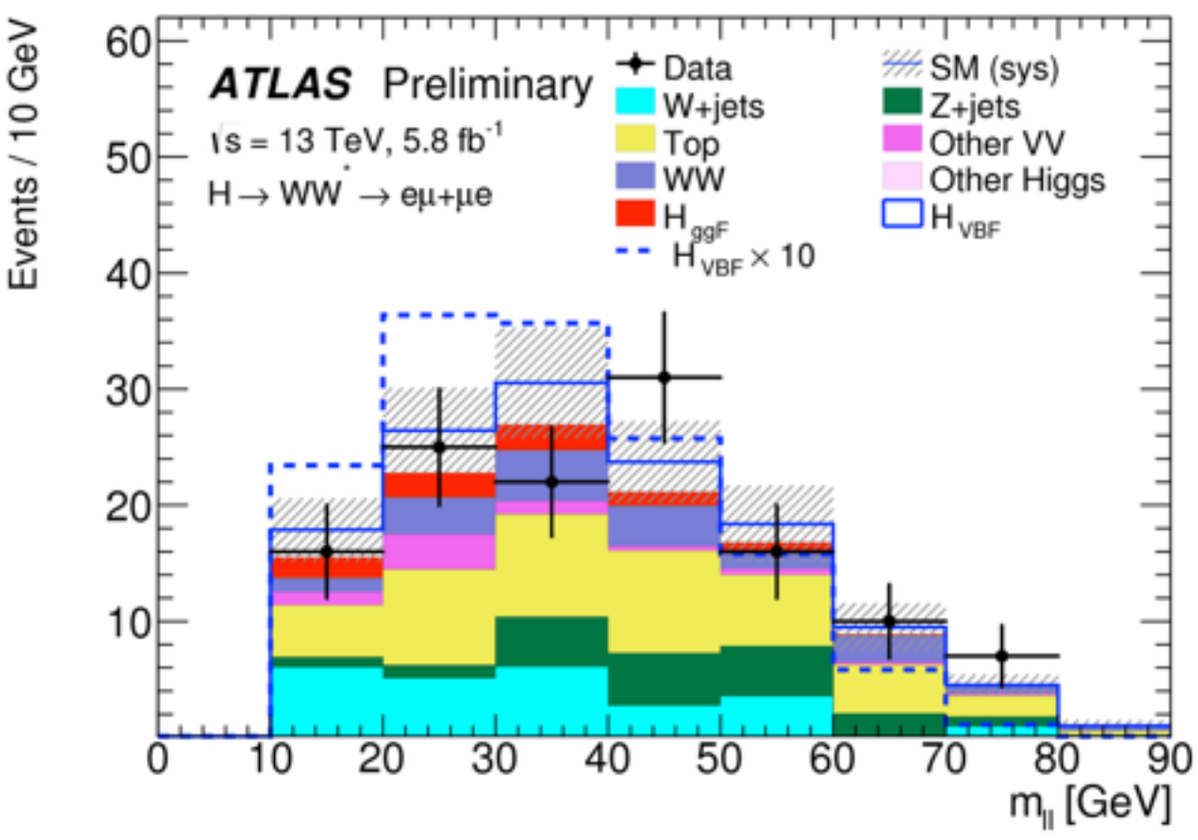


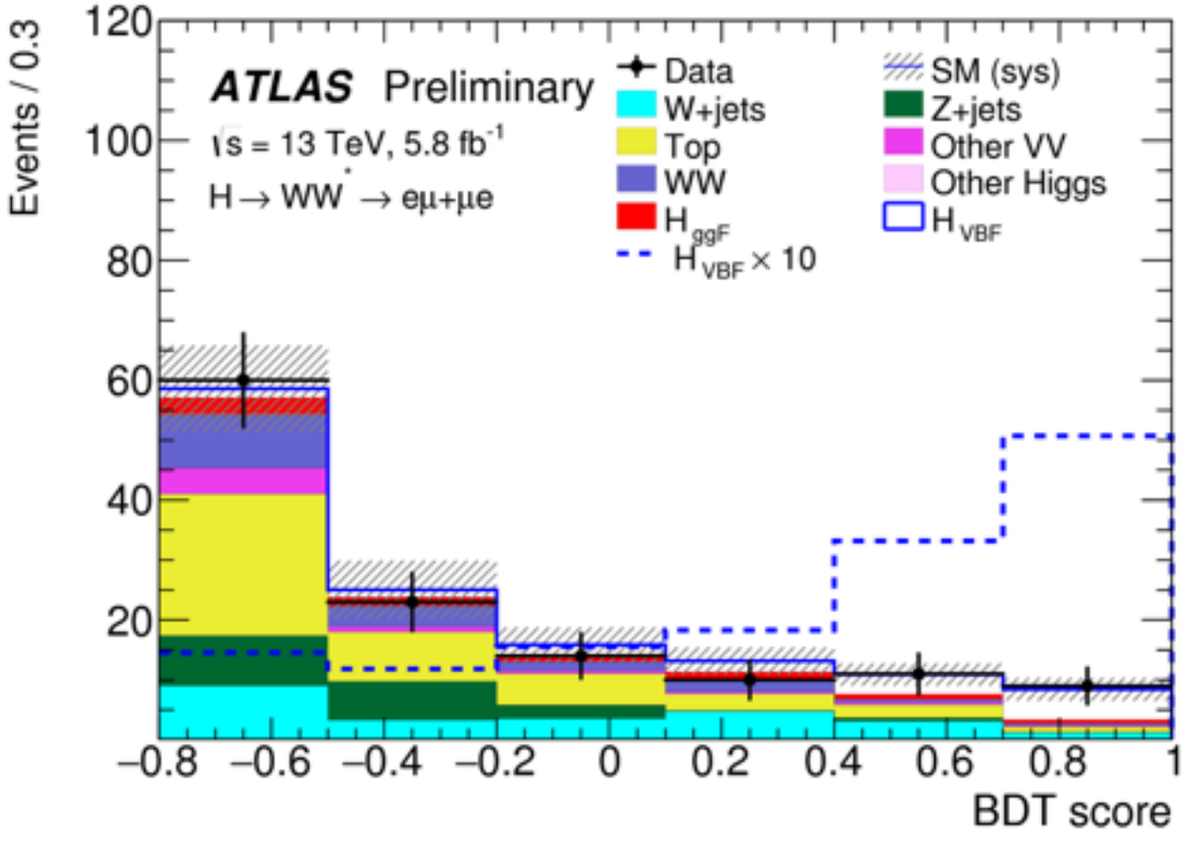


$H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$: ATLAS-CONF-2016-112

- **Cross sections for VBF and WH productions modes using 5.8 fb^{-1}**

- **VBF:**
  - eμ/μe channels in addition to 2 forward jets
  - Boosted Decision Tree (BDT) is used to select characteristic VBF signature
  - Control Regions for normalization of Top and $Z \rightarrow \tau\tau$

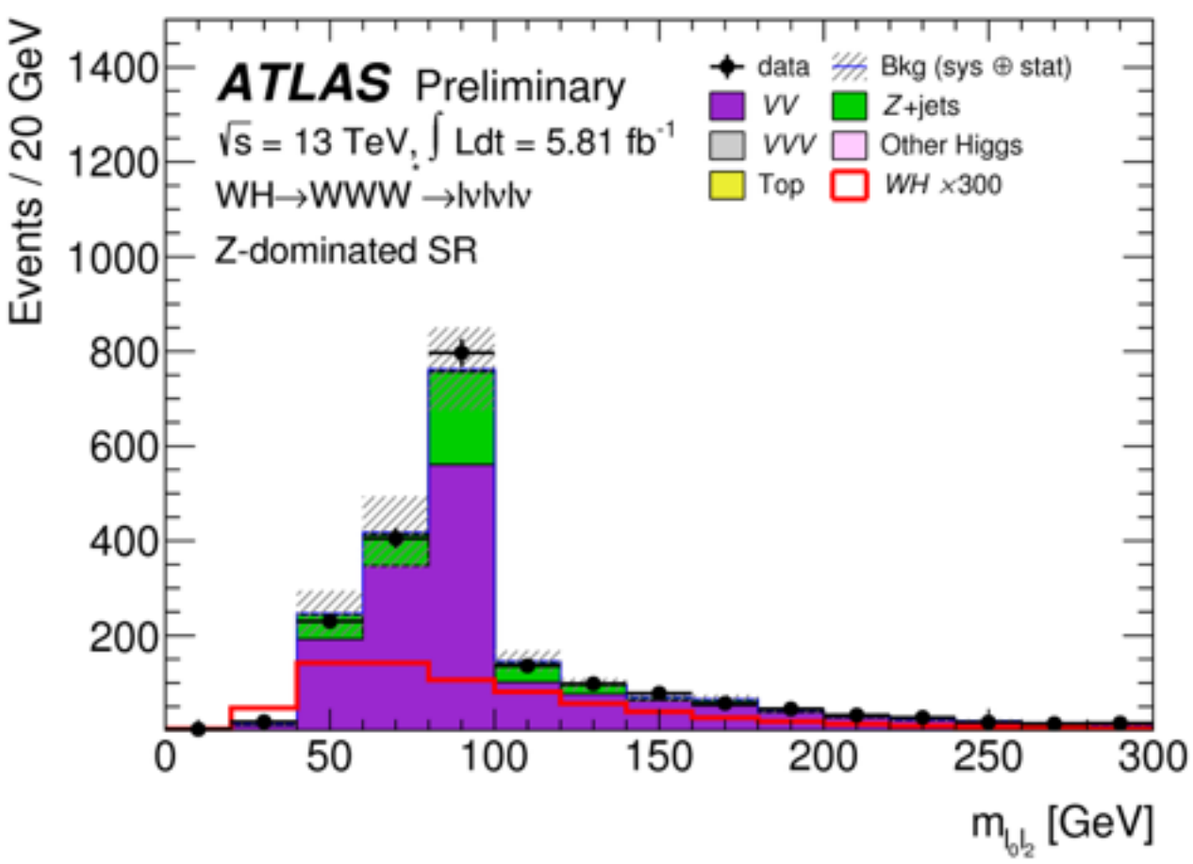


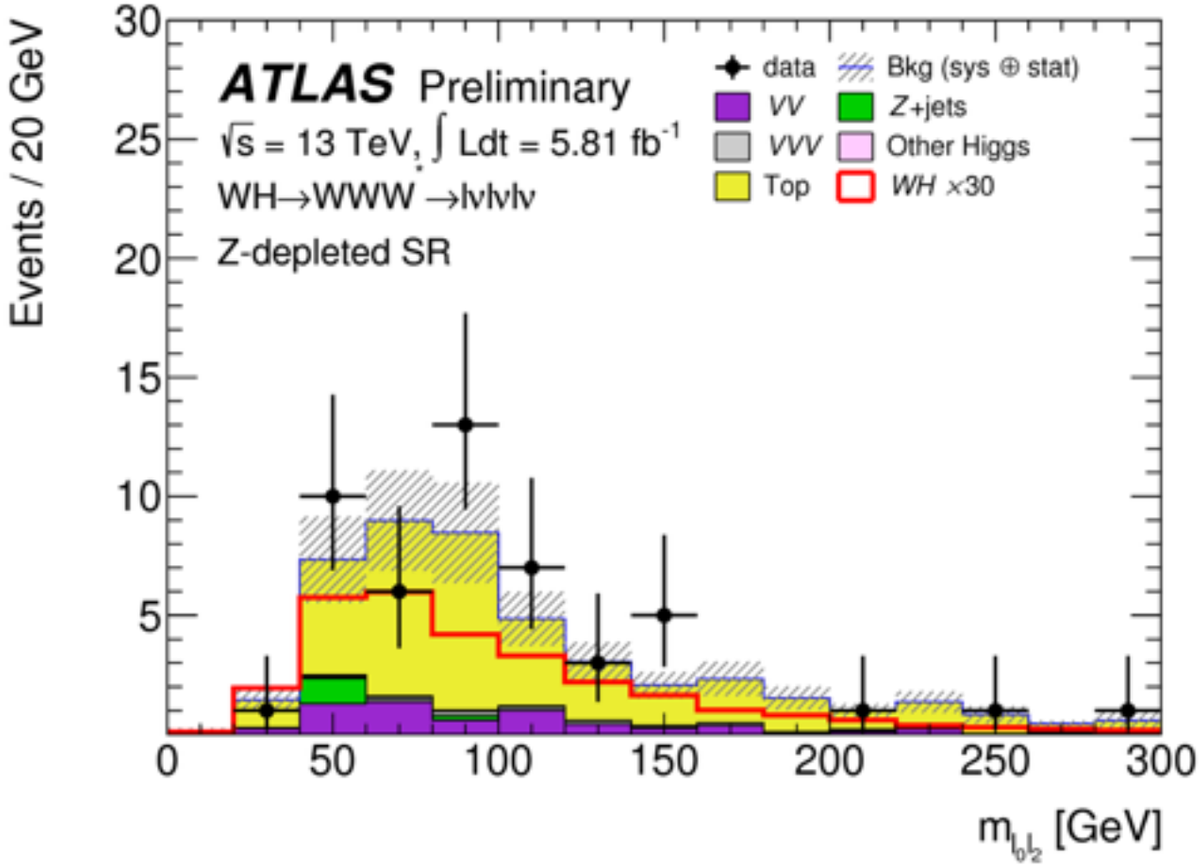


$H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$: ATLAS-CONF-2016-112

- **Cross sections for VBF and WH productions modes using 5.8 fb^{-1}**

- **WH:**
  - 3 leptons, total electric charge of ±e
  - l_0: lepton with unique charge, l_1: lepton closest to l_0, l_2: remaining
  - Z-dominated and Z-depleted regions separated by #SFOS lepton pairs
  - WZ/Wγ*, Zγ, Z+jets, and top-quark Control Regions



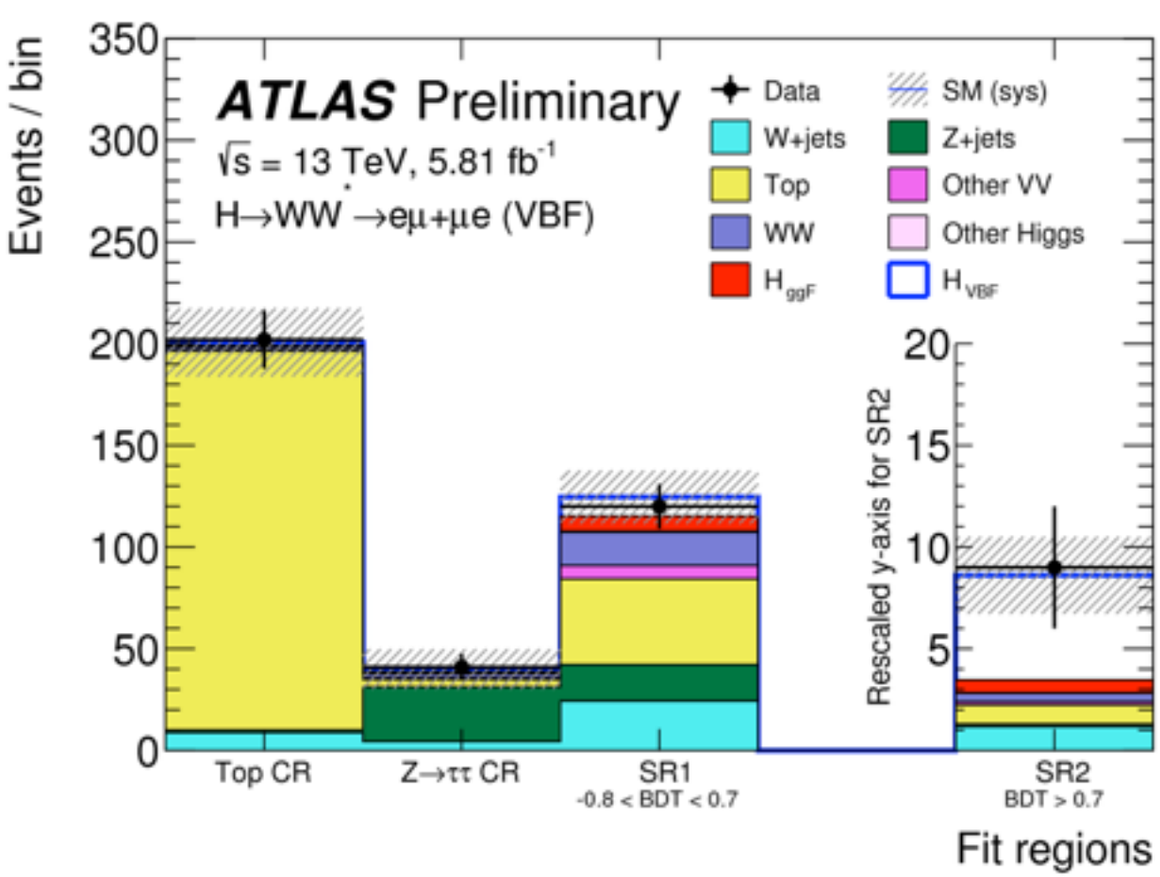


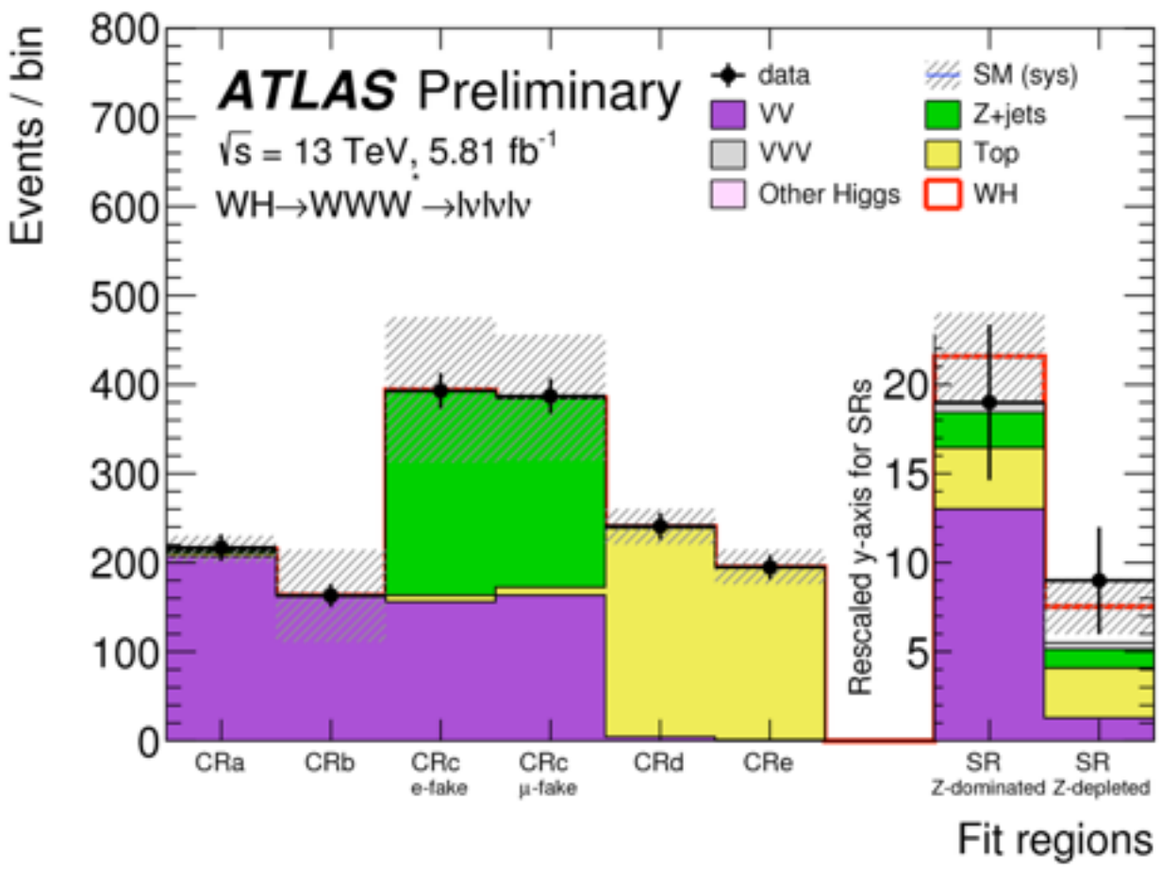
$H \to WW^* \to \ell\nu\ell\nu$: ATLAS-CONF-2016-112

- **Cross sections for VBF and WH productions modes using 5.8 fb^{-1}**
  - Both production modes are still statistically limited, 60% (120%) for VBF (WH)
  - Dominating systematic uncertainty for VBF - W+jets/fake estimation
  - Higher pileup in full 2015/2016 dataset will a challenge for all production modes

$$\sigma_{\text{VBF}} \cdot \mathcal{B}_{H\to WW^*} = 1.4^{+0.9}_{-0.7}\ \text{pb} \qquad \mu_{\text{VBF}} = 1.7^{+1.1}_{-0.9}$$
$$\sigma_{WH} \cdot \mathcal{B}_{H\to WW^*} = 0.9^{+1.3}_{-1.2}\ \text{pb} \qquad \mu_{WH} = 3.2^{+4.4}_{-4.2}$$

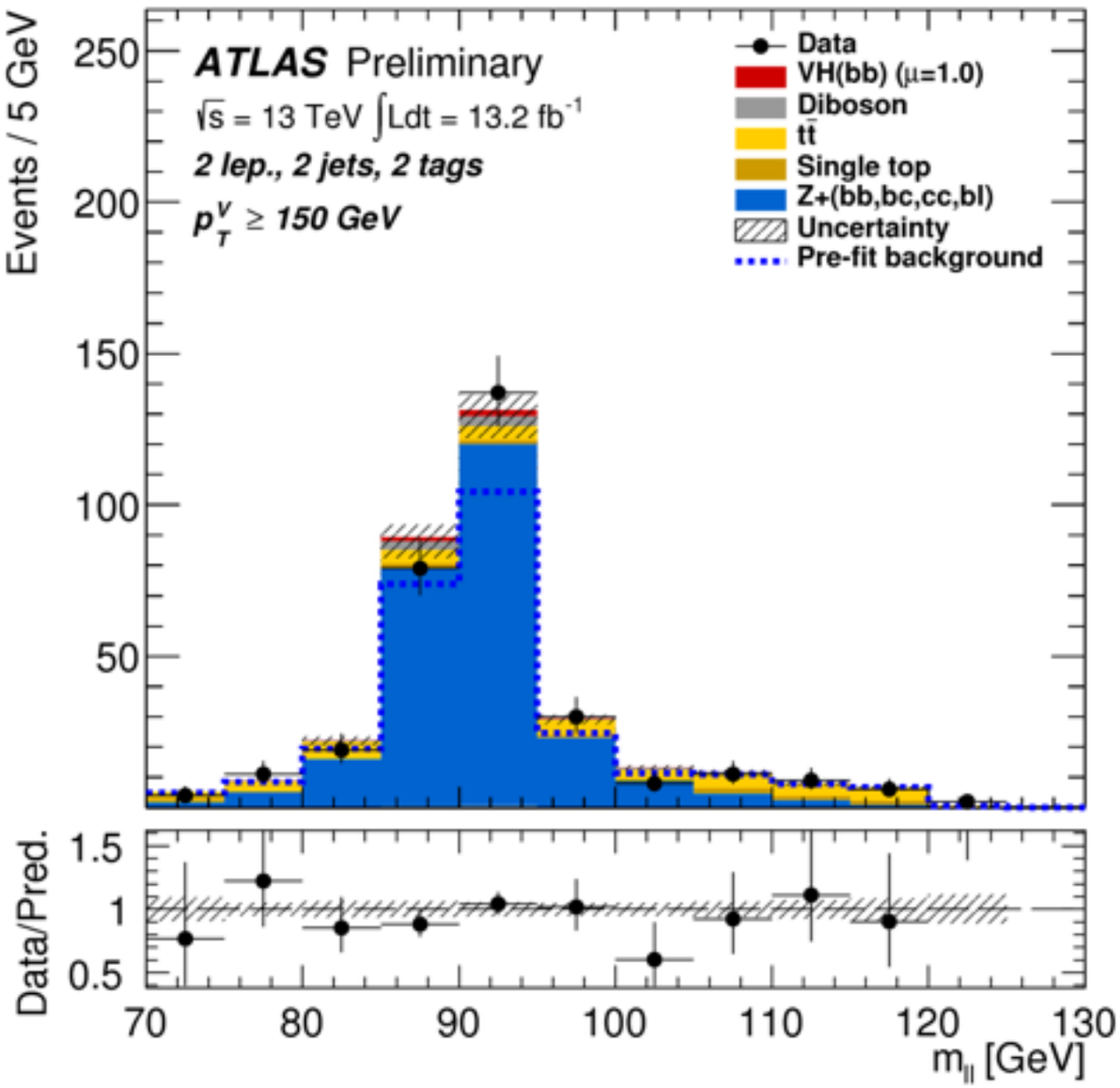
Observed (expected) signal significance
- VBF : 1.9σ (1.2σ)
- WH: 0.77σ (0.24σ)

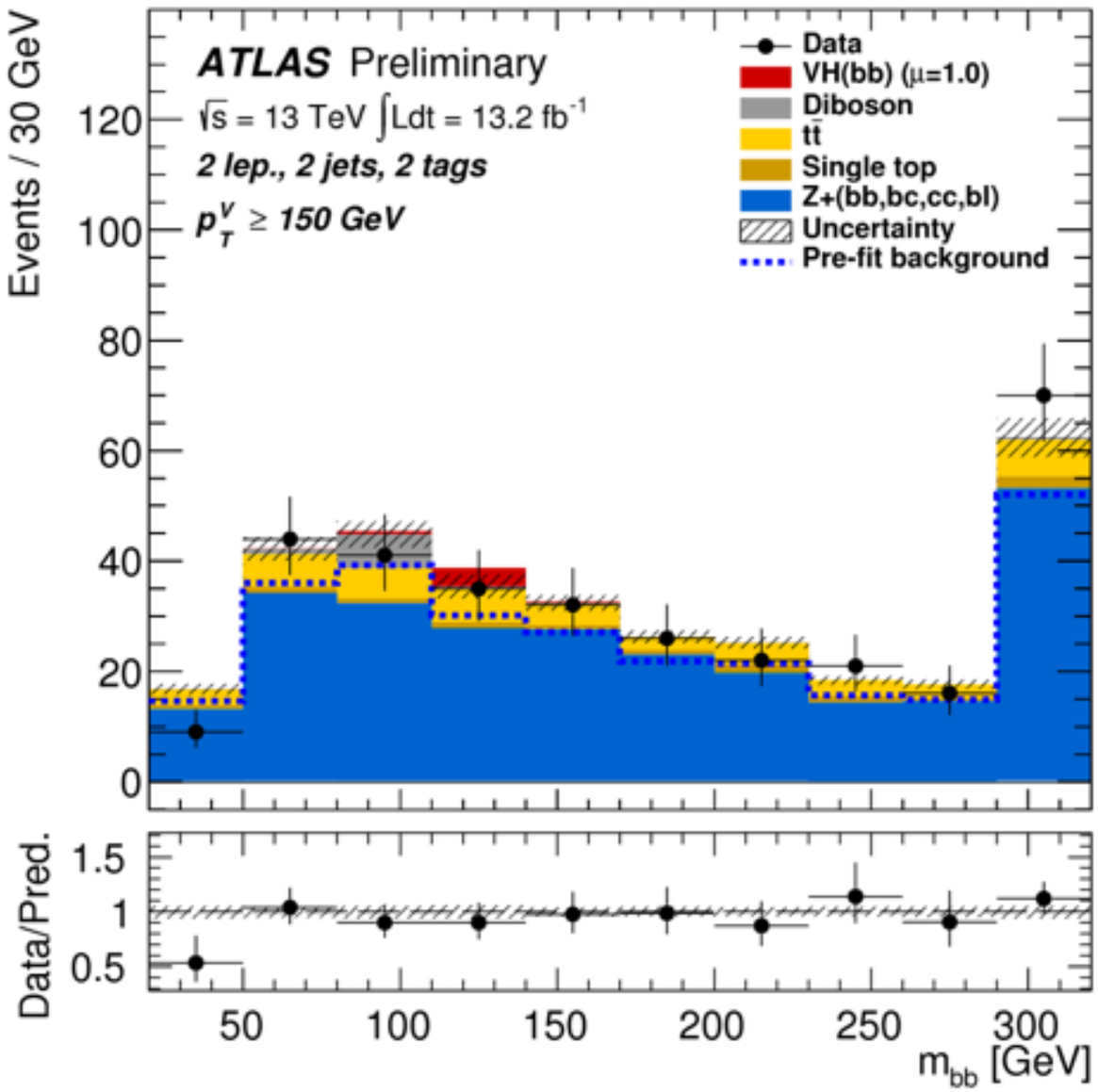




$H \to b\bar{b}$: ATLAS-CONF-2016-091

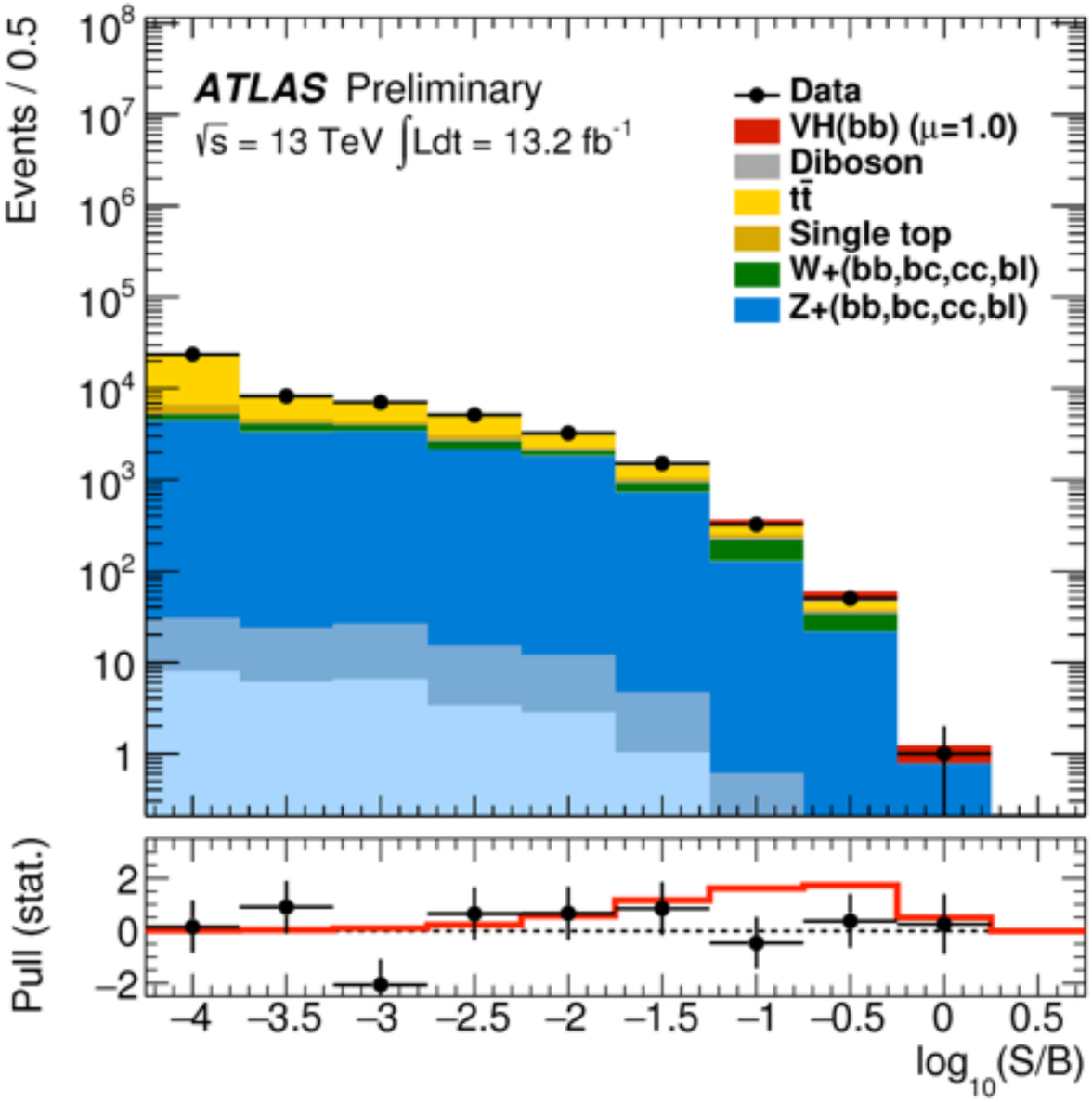
- **Search for ZH and WH production using 13.2 fb^{-1}**
  - VH leptonic decays provide a nice handle on challenging backgrounds
  - Select for 2 high p_T b-jets along with 0, 1, or 2 charged leptons (e,μ) targeting $Z \to \nu\nu$, $W \to \ell\nu$, and $Z \to \ell\ell$

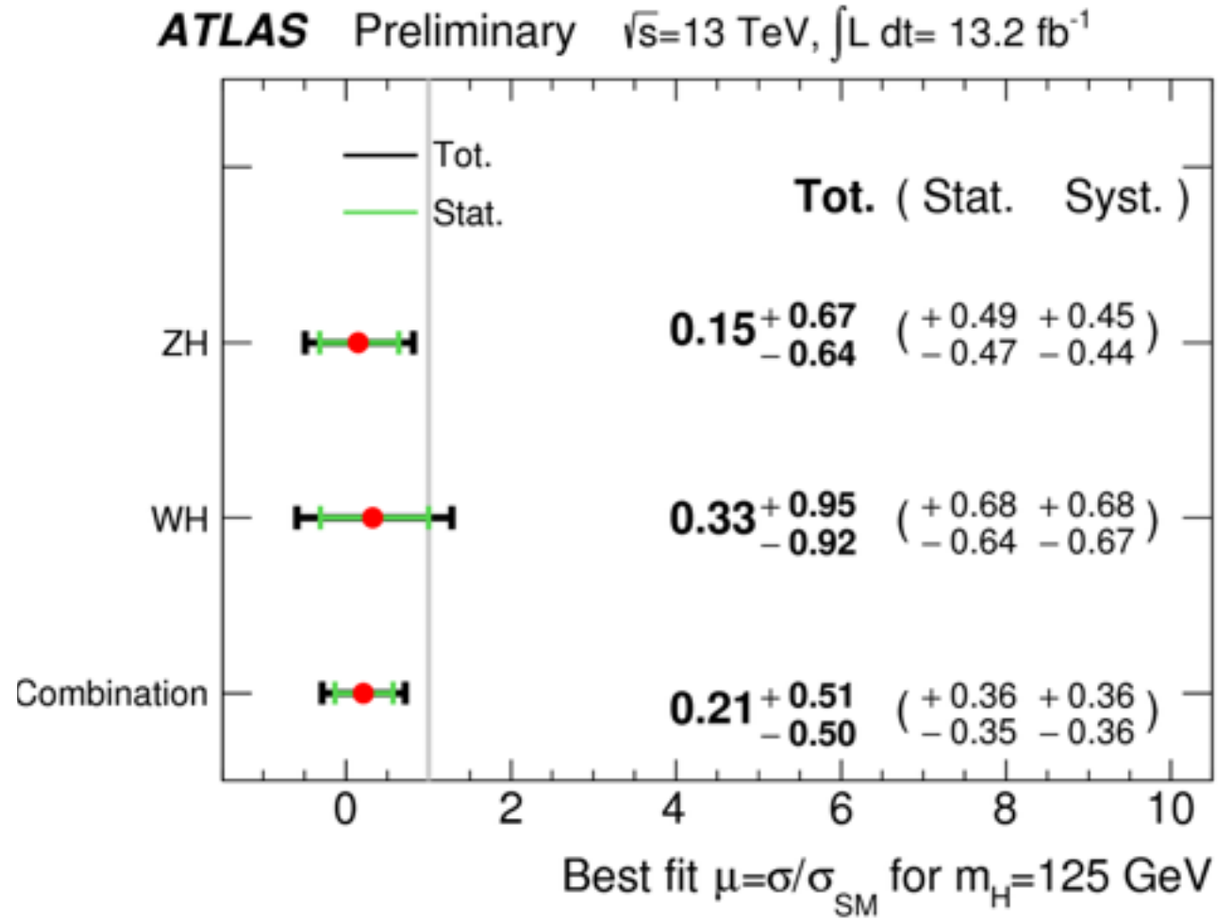




$H \to b\bar{b}$: ATLAS-CONF-2016-091

- **Search for ZH and WH production using 13.2 fb^{-1}**
  - Categorizing events using N_{jets} and $p_T(V)$
  - Simultaneous fit to boosted decision tree (BDT) distributions
  - Validate analysis procedure by measuring $VZ(\to b\bar{b})$

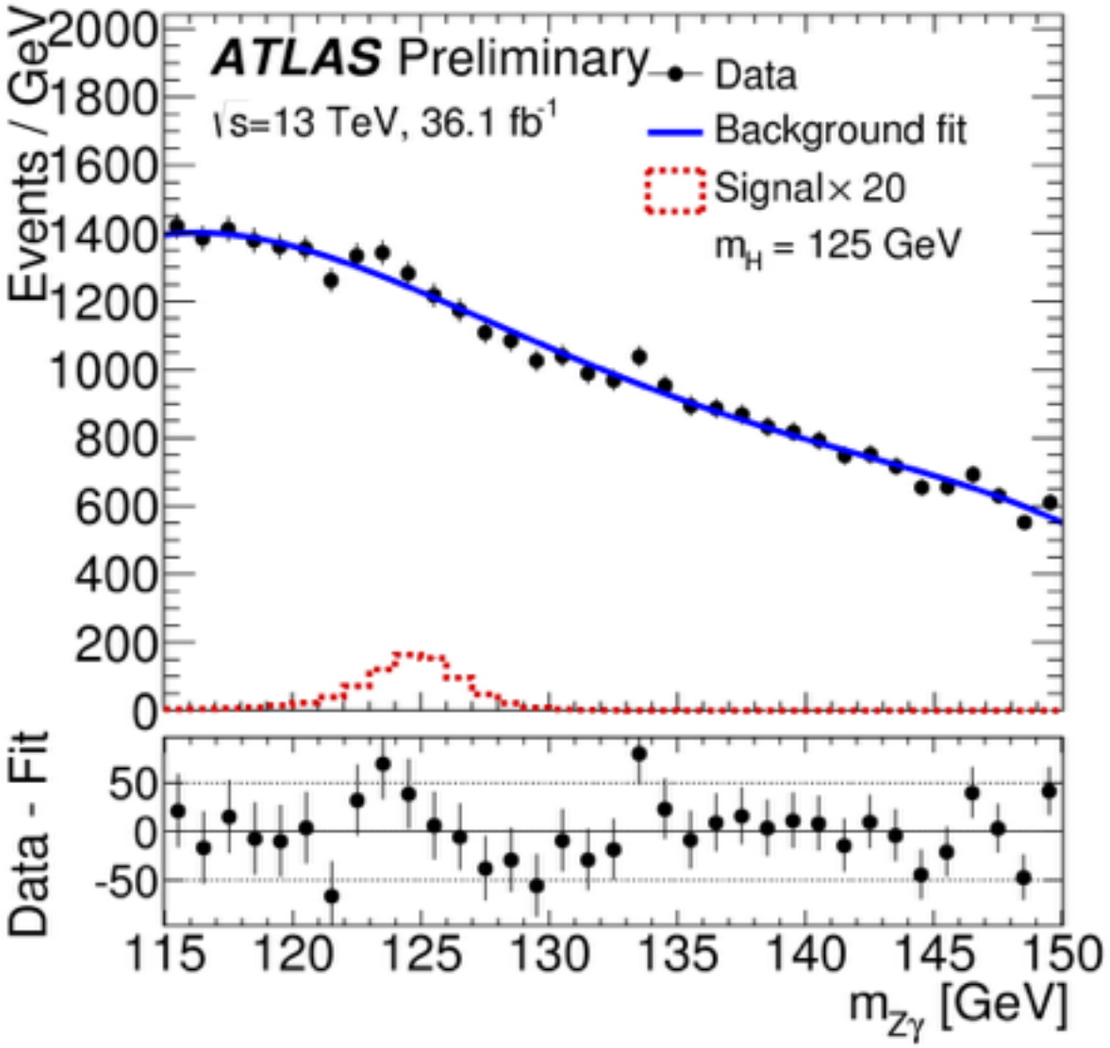


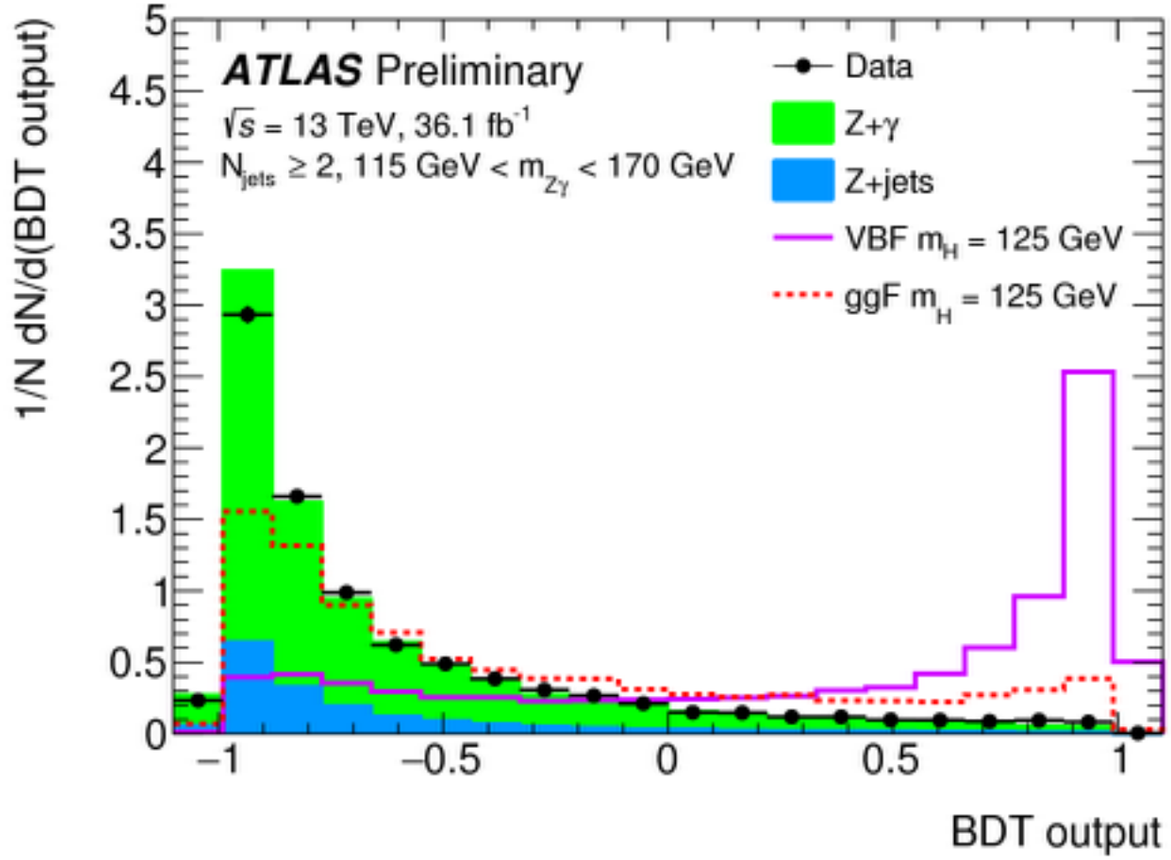


- **Observed (expected) signal significance**
  - Run 1: 1.4σ (2.6σ)
  - Run 2: 0.4σ (1.9σ)

H → Zγ: HIGG-2016-14

- **Search for Higgs decaying to a Z boson and photon using 36.1 fb^{-1}**
  - another rare Higgs decay, probing the same loop as gamma gamma
  - select 1 SFOS lepton pair, consistent with the Z mass, and a photon with pT > 15 GeV
  - 6 categories, based on lepton flavor, transverse thrust of Zγ, and VBF topology
  - background: Bernstein polynomial functions fit to data
  - Local significance: 1.0σ (0.5σ) observed (expected) at 125.09 GeV
  - Upper limit on BR: 6.6x (5.2x) SM predicted observed (expected)

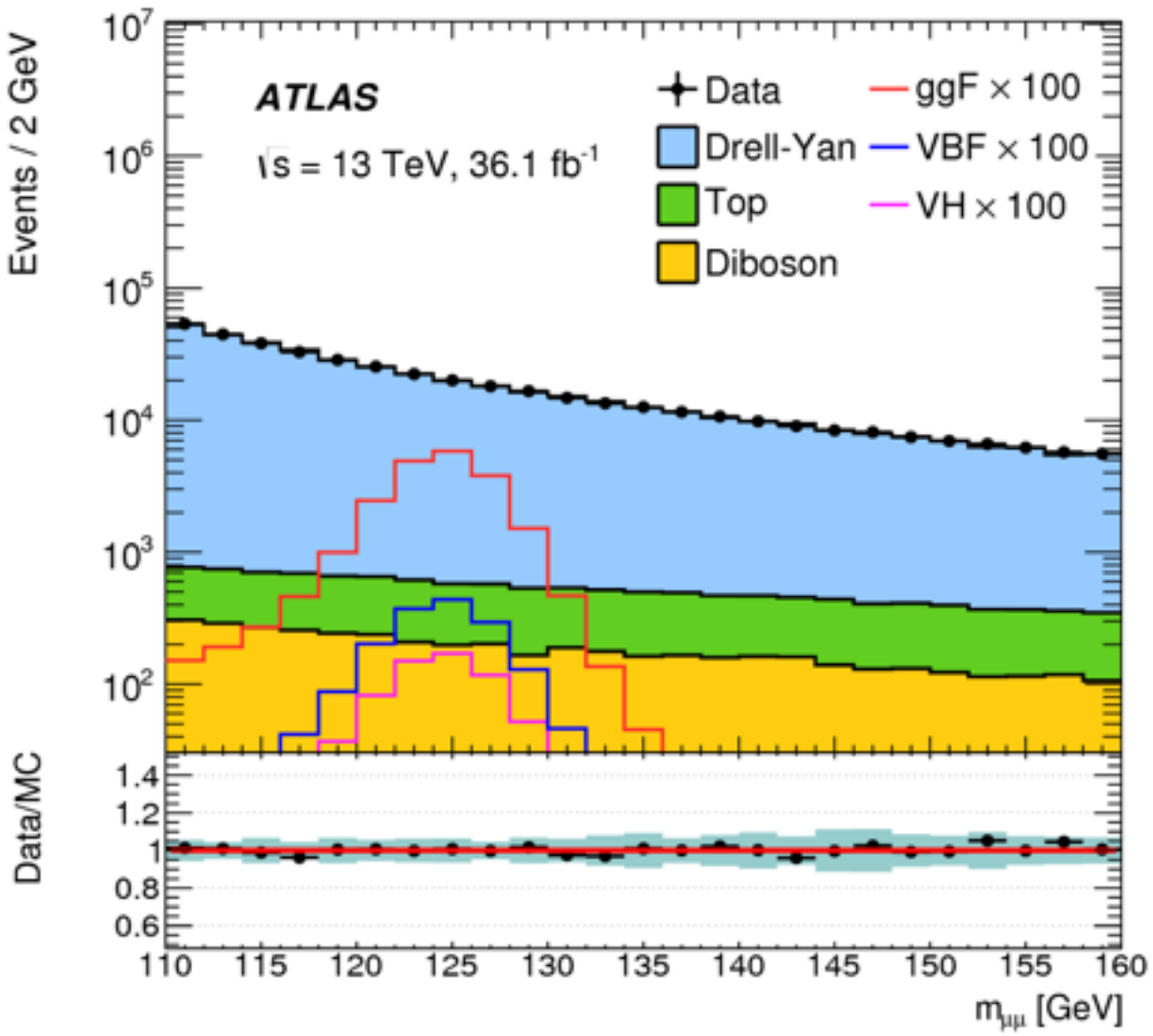


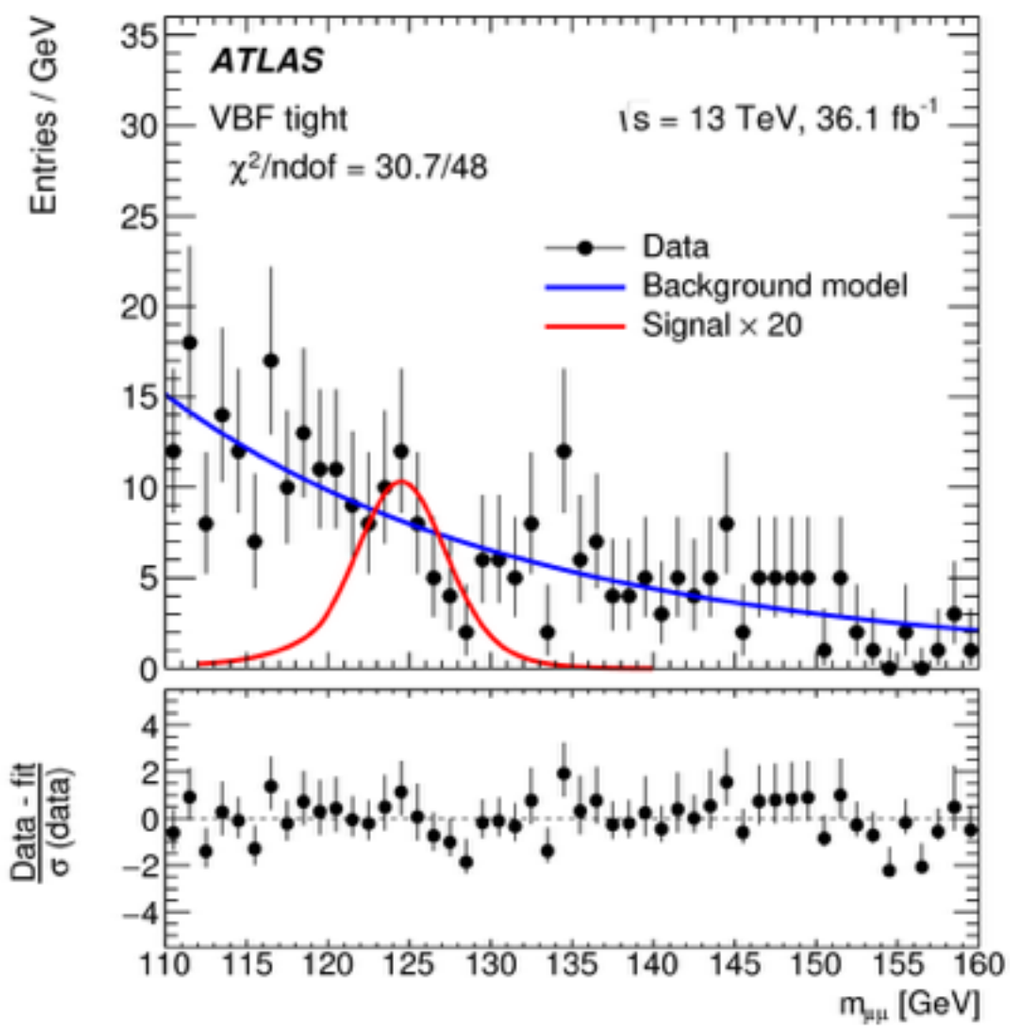


H → μμ: arXiv.705.04582

- **Search for Higgs di-muon decay using 36.1 fb^{-1}**
  - clean experimental signature, but small BR
  - probing the Higgs coupling to second generation fermions
  - background parameterization from simulation fit to data
  - categories for $p_T(\mu\mu)$, $|\eta(\mu)|$ and VBF topology
  - invariant mass fit in $m_{\mu\mu}$ = 110-160 GeV

- **Measured signal strength**
  - $\mu = -0.1 \pm 1.5$
- **Observed (expected) upper limit on signal strength**
  - 3.0x (3.1x) SM prediction
- **Run 1+2 combined upper limit**
  - 2.8x (2.9x) SM prediction

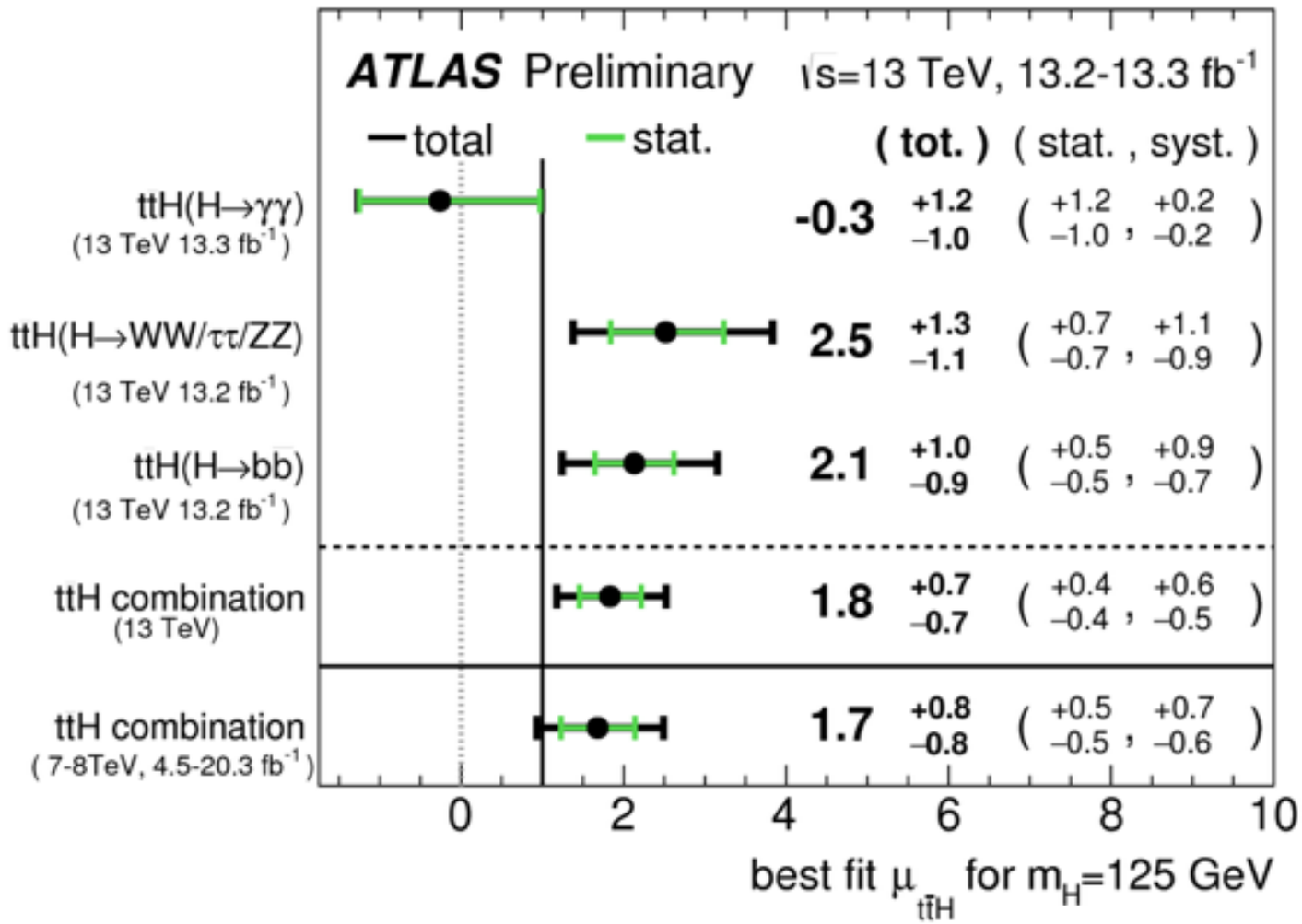




$t\bar{t}H$ COMBINATION: ATLAS-CONF-2016-068

- **Combination of searches for $t\bar{t}H$ production in $\gamma\gamma$, multi-lepton, and $b\bar{b}$ final states with 13.2-13.3 fb^{-1}**
  - Improvement in sensitivity with respect to Run 1 analysis
  - Observed (expected) significance
    - Run 2: 2.8σ (1.8σ)
    - Run 1: 2.3σ (1.5σ)

Covered in Biagio's Talk!



SUMMARY & CONCLUSIONS

- **Large variety of Higgs measurements and searches in Run 2**
  - fiducial and total cross sections
  - differential distributions
  - combinations
  - limits on anomalous couplings

- **Data described well by Standard Model so far**
  - ttH production rate is slightly higher than expected
  - many measurements, and differential distributions are still statistically limited

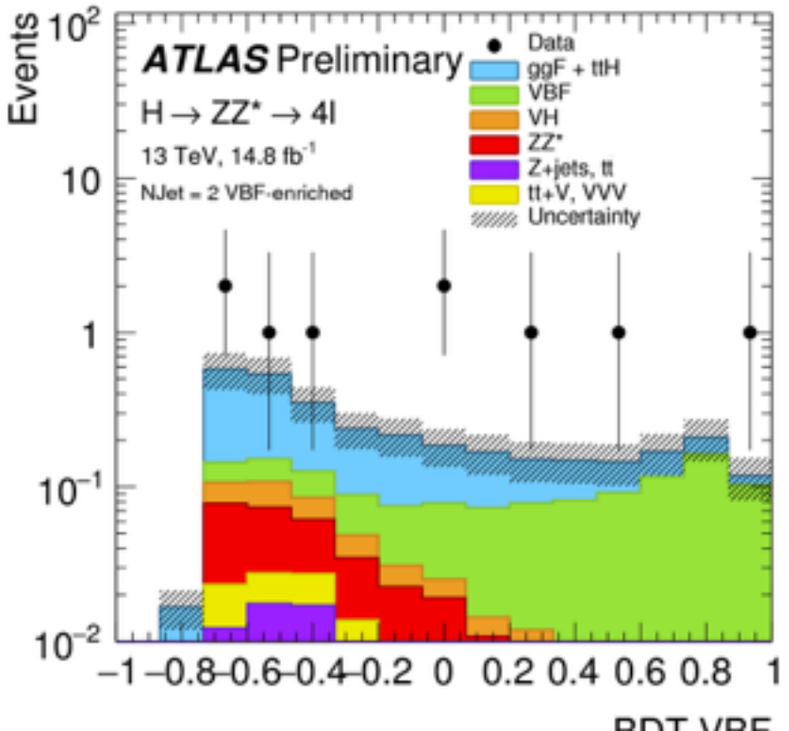
- **Looking forward to a few more results with 2015+2016 dataset**
  - most stringent tests will come with full Run 2 dataset, 100 fb^{-1}

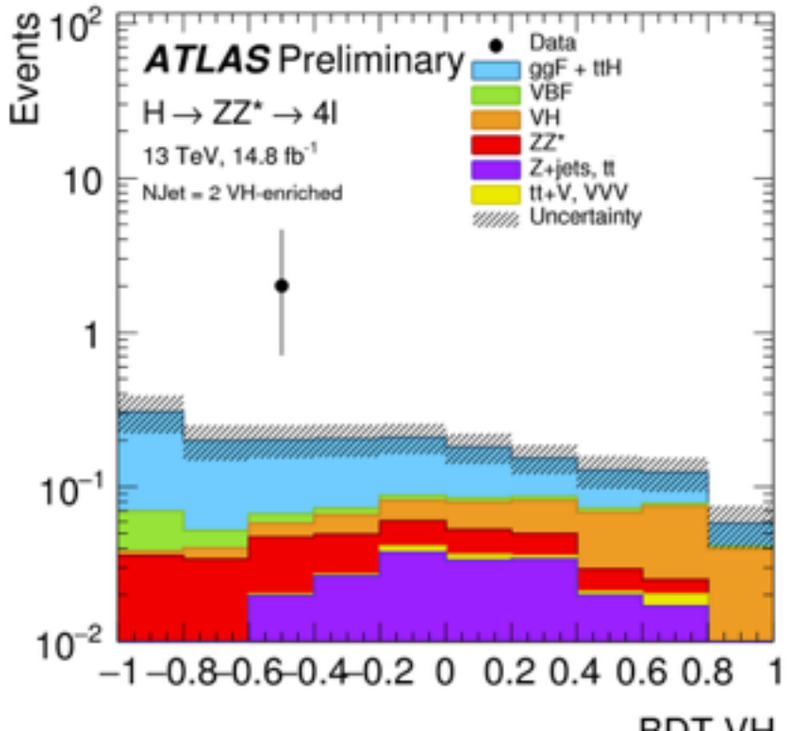
BACKUP

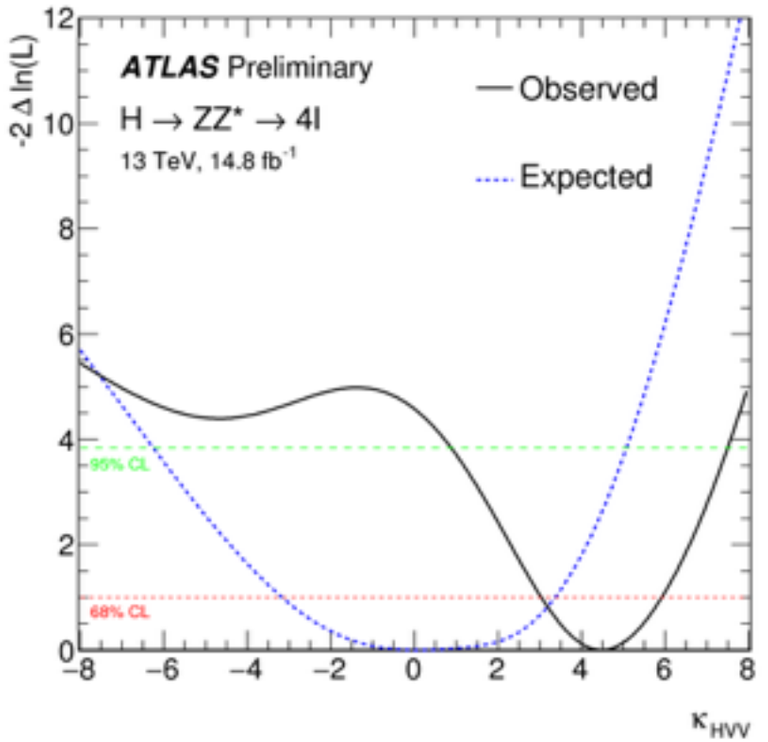
$H \to ZZ^* \to 4\ell$: ATLAS-CONF-2016-079

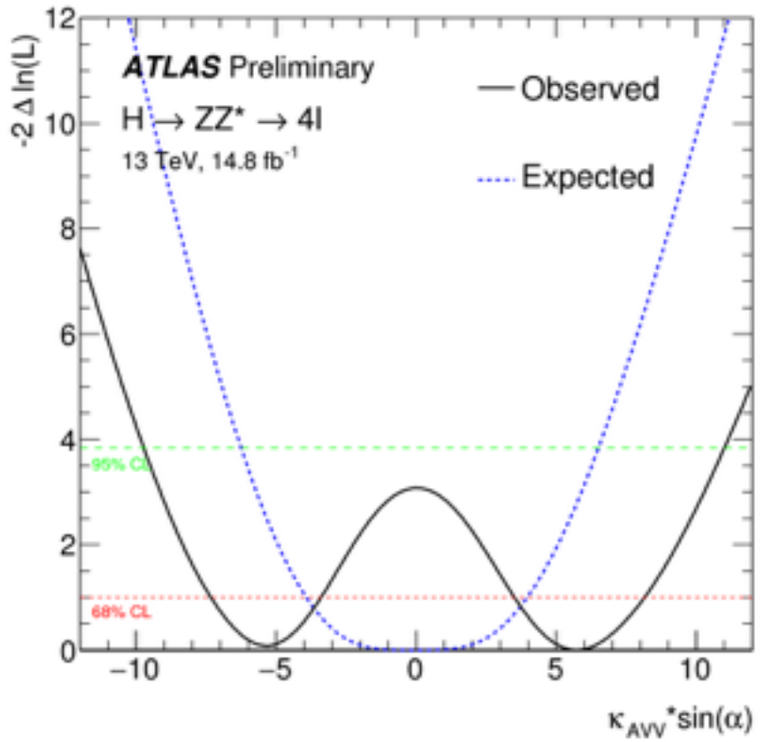
- **Using 14.8 fb^{-1} of 13 TeV data**
  - targets different production modes using BDTs
  - tests BSM interactions using an effective Lagrangian approach

$\sigma(gg \to H)$ pb
48.5 ± 2.4
$\sigma(qq' \to Hqq')$ pb
3.78 ± 0.08
$\sigma(q\bar{q}' \to WH)$ pb
1.369 ± 0.028
$\sigma(q\bar{q}' \to WH)$ pb
1.369 ± 0.028





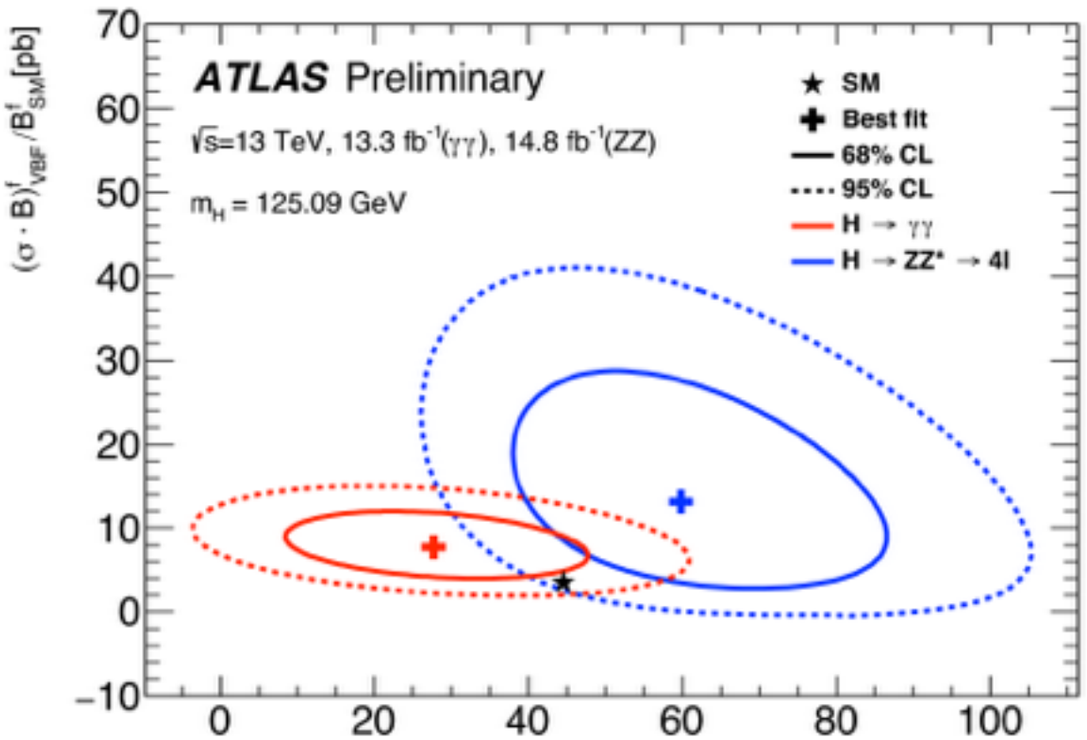


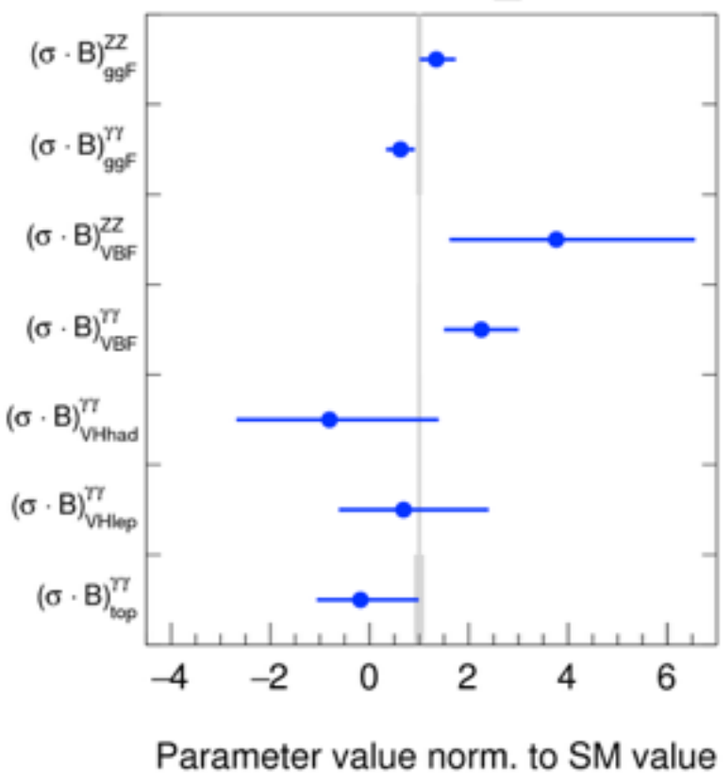


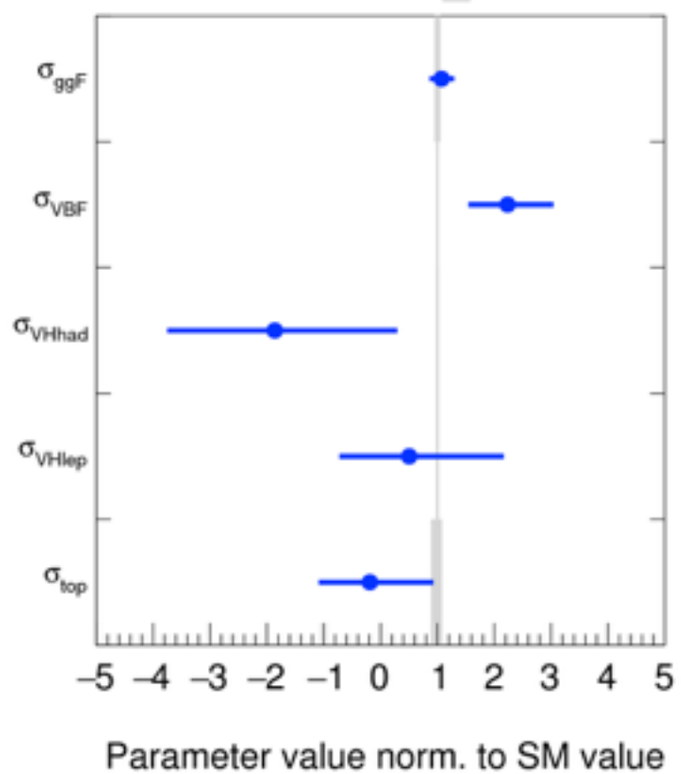
H → ZZ* → 4ℓ AND H → γγ COMBINATION

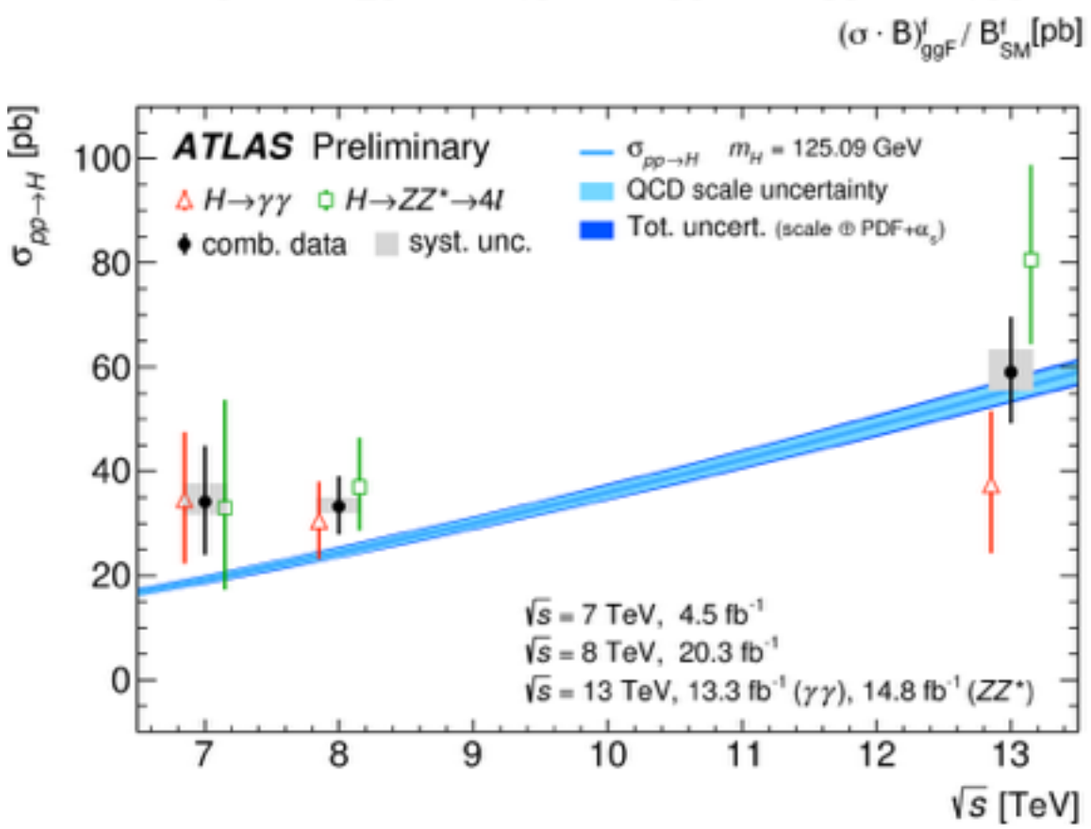
ATLAS-CONF-2016-081

- **Combination using 13.3 fb^{-1} (γγ) and 14.8 fb^{-1} (ZZ) 13 TeV data**
  - "stage-0" simplified cross sections, $\sigma_i \cdot B^f = (\sigma \cdot B)_i^f$
    - production process i for $|y_H| < 2.5$, final state f
  - production cross sections, σ_i, assuming SM BRs
  - total cross sections and μ, extrapolate to full phase space
  - assuming $m_{\gamma\gamma} = 125.09 \pm 0.21(\text{stat}) \pm 0.11$ (sys)
  - theory prediction: N3LO



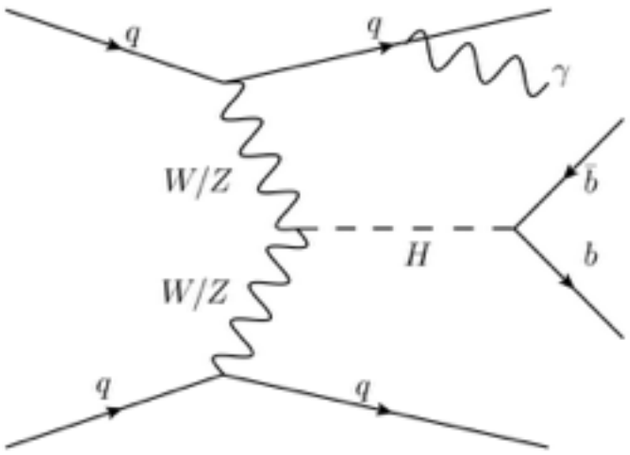




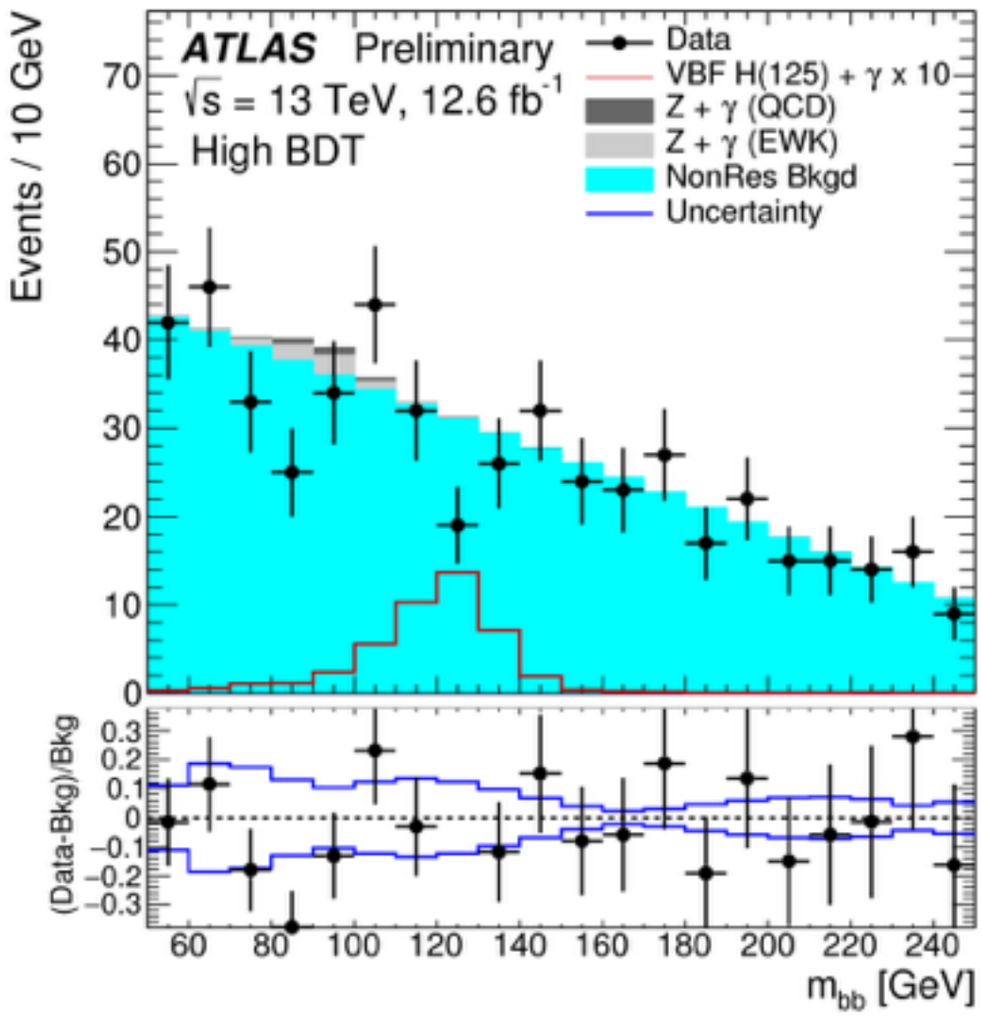


VBF: H → $b\bar{b}$ + γjj: ATLAS-CONF-2016-063

- **Search for VBF production of a Higgs decaying to $b\bar{b}$ with an associated γ using 13.2 fb^{-1}**
  - exploits VBF signature and additional photon to reject non-resonant $b\bar{b}$jj background
  - a boosted decision tree (BDT) is used to separate signal from background
  - analysis procedure validated with Z(→$b\bar{b}$) + γjj
  - observed (expected) upper limit of 4.0x (6.0x) on SM production
    - for comparison: Run-1 VBF H→ $b\bar{b}$ ~5x SM prediction



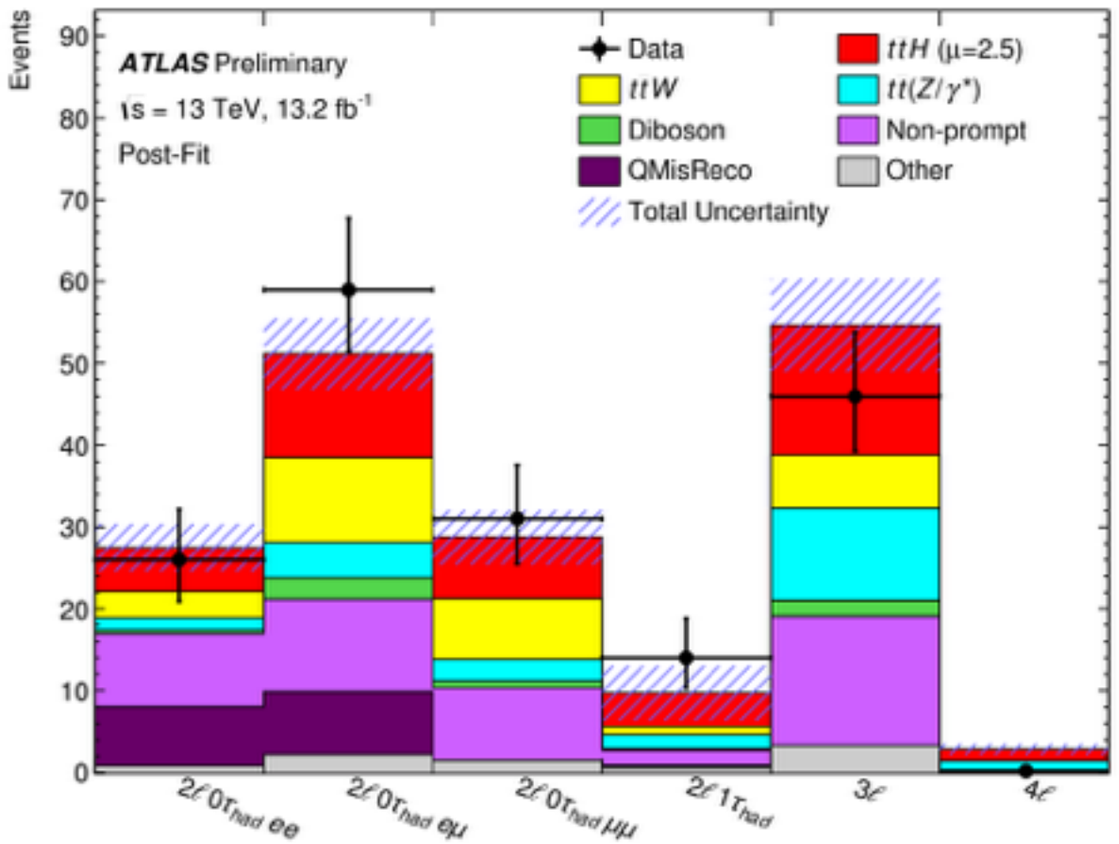
Result	$H(\to b\bar{b})+\gamma jj$	$Z(\to b\bar{b})+\gamma jj$
Expected significance	0.4	1.3
Expected p-value	0.4	0.1
Observed p-value	0.9	0.4
Expected limit	$6.0\ ^{+2.3}_{-1.7}$	$1.8\ ^{+0.7}_{-0.5}$
Observed limit	4.0	2.0
Observed signal strength μ	$-3.9\ ^{+2.8}_{-2.7}$	$0.3\ \pm 0.8$



$t\bar{t}H$ PRODUCTION

- **Probing Higgs coupling to the top quark in $\gamma\gamma$, multi-lepton, and $b\bar{b}$ decay channels with 13.2-13.3 fb^{-1}**
  - $\gamma\gamma$: searching for a narrow peak in di-photon invariant mass spectrum, taking into account hadronic and leptonic top decays
  - multi-lepton: lepton counting experiment with categories to look for WW*, $\tau\tau$, and ZZ*
  - $b\bar{b}$: multivariate technique used to search for a moderate signal in a large background

ttH multi-lepton ATLAS-CONF-2016-058



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