Measurements and searches of Higgs boson production involving fermion couplings with the ATLAS detector

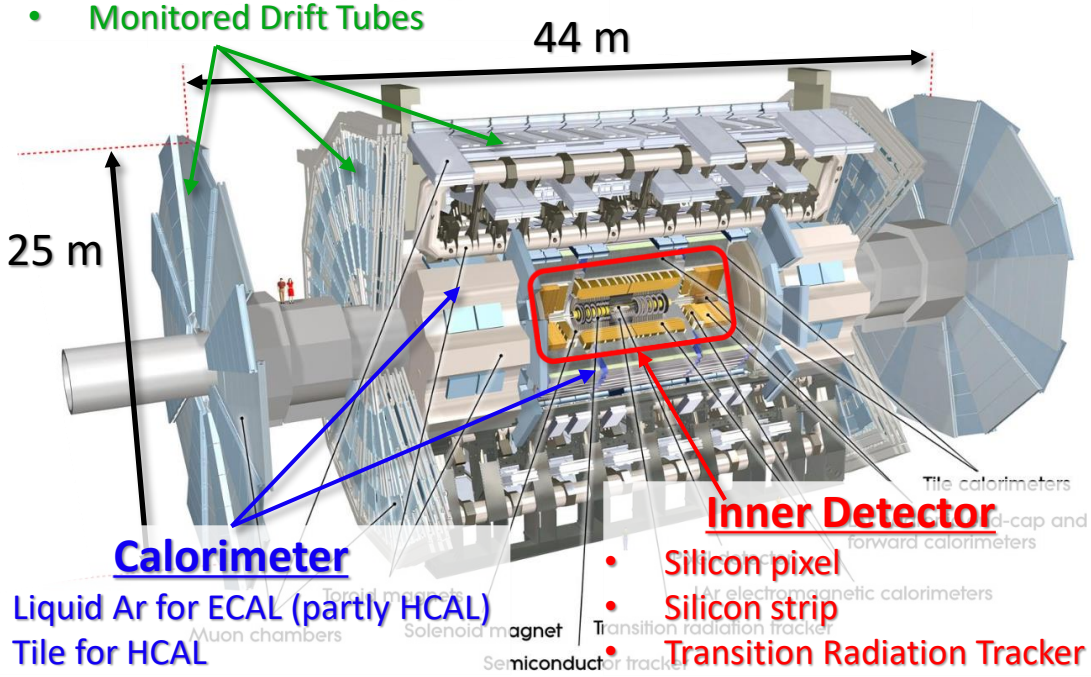
13 April 2021, DIS 2021

Shigeki Hirose (U. Tsukuba)

On behalf of the ATLAS Collaboration

ATLAS experiment

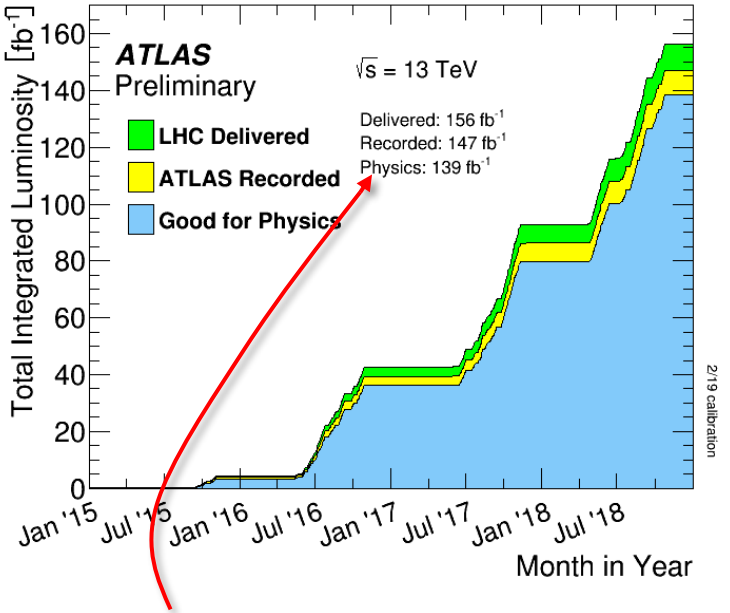
Muon spectrometer
- Resistive Plate Chambers
- Thin Gap Chambers
- Monitored Drift Tubes



Calorimeter
- Liquid Ar for ECAL (partly HCAL)
- Tile for HCAL

Inner Detector
- Silicon pixel
- Silicon strip
- Transition Radiation Tracker

Int. lumi. at Run 2 (2015-18)

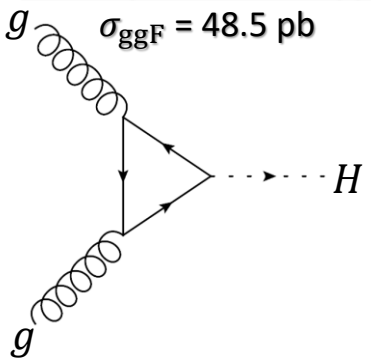


139 fb^{-1} is usable for analyses!
(with >90% efficiency)

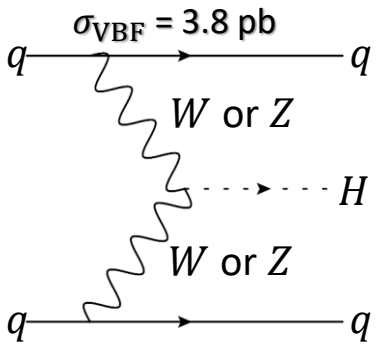
- ATLAS detector: complex of inner tracker, calorimeter and muon spectrometer
- 139 fb^{-1} data were corrected during Run 2 (2015-18) at 13 TeV
  - x5.6 more data than that collected in Run 1 (2011-2012) at 7-8 TeV

Higgs boson productions at LHC

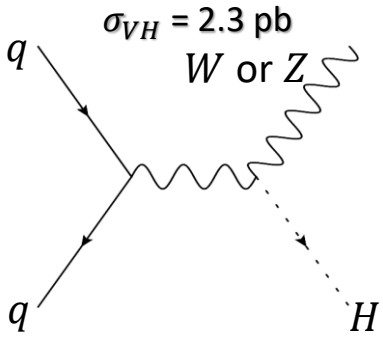
Gluon-gluon fusion (ggF)



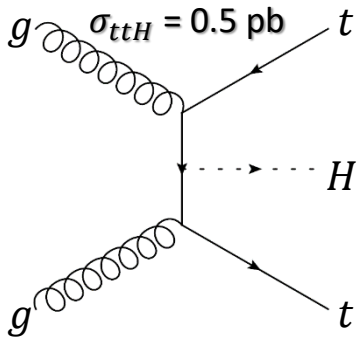
Vector boson fusion (VBF)



Vector-boson association (VH)



ttH process (ttH)



σ_{total} = **55 pb** @ 13 TeV

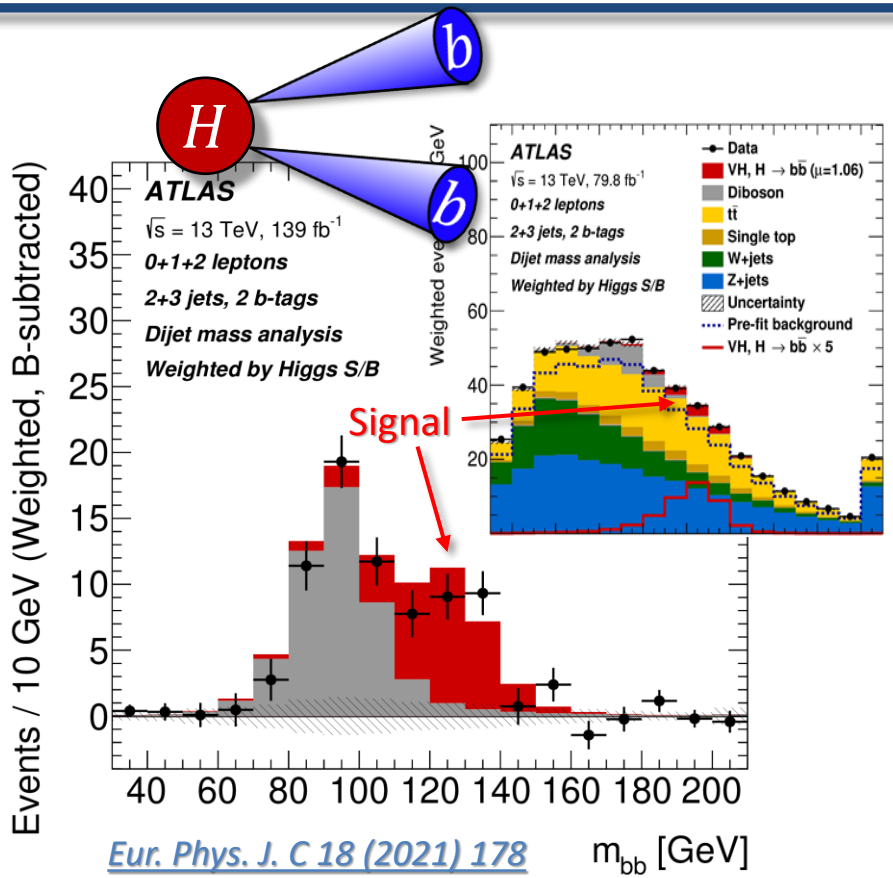
- ATLAS Run-2 data contains ~80M Higgs bosons!
  - The large statistics allows us to attempt to measure
    - Kinematics of Higgs productions: Simplified Template Cross Section (STXS)
      → Pre-defined binning based on kinematics such as p_{T}^{H}, N_{jets} etc.
    - More challenging or rare processes

Topics of this talk

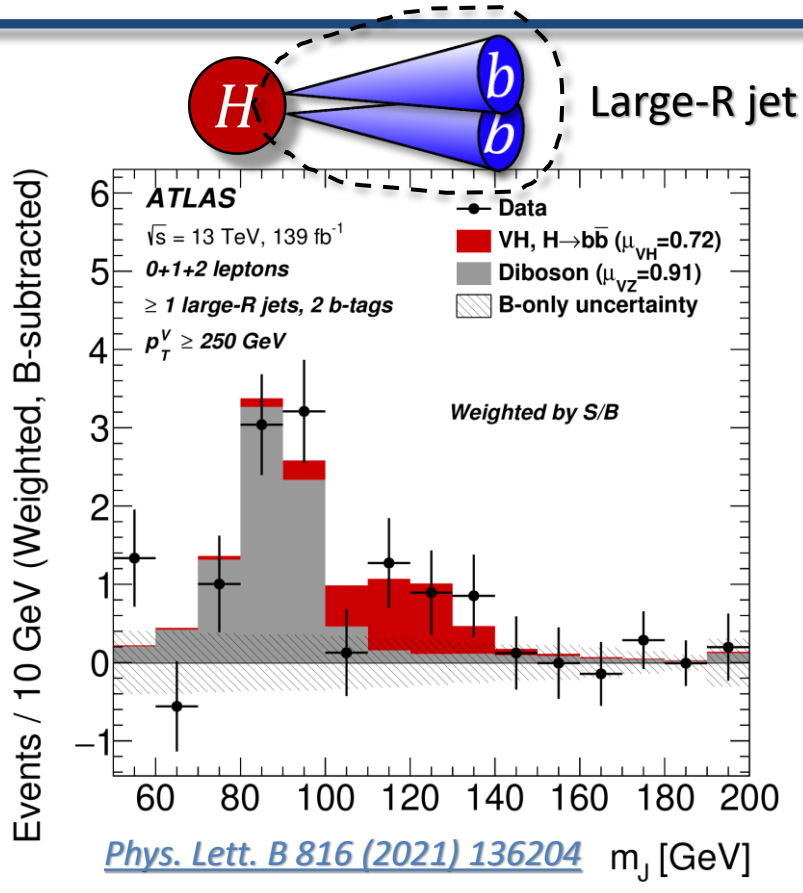
$H \to bb$ related topics
- VBF production
- Inclusive boosted Higgs
- ttH process using $H \to bb$

Rare processes with leptons
- $H \to \mu\mu$
- $H \to \ell\ell\gamma$

$H \to bb$ measurement



Eur. Phys. J. C 18 (2021) 178

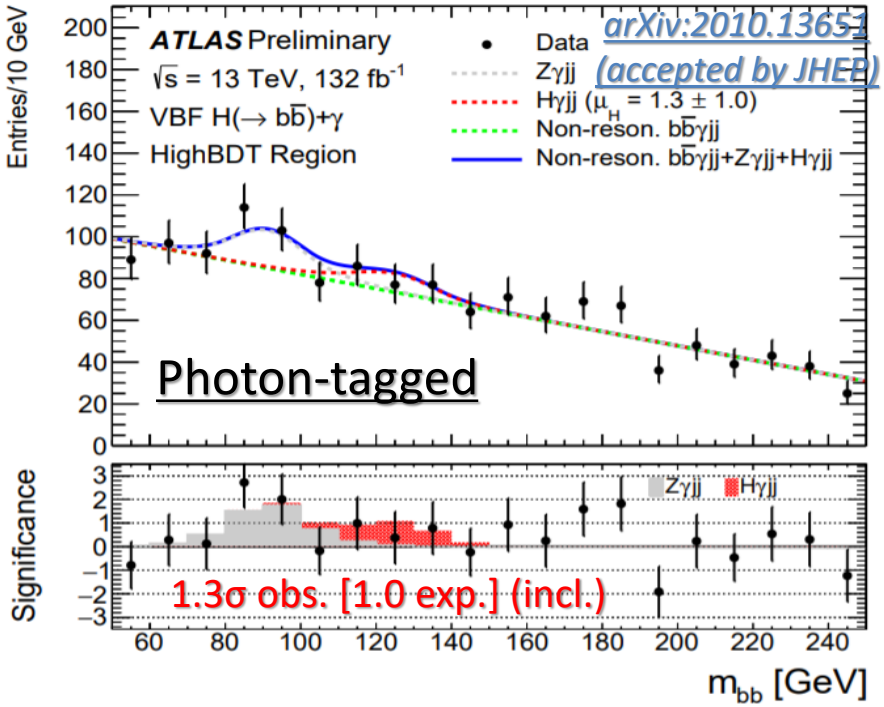


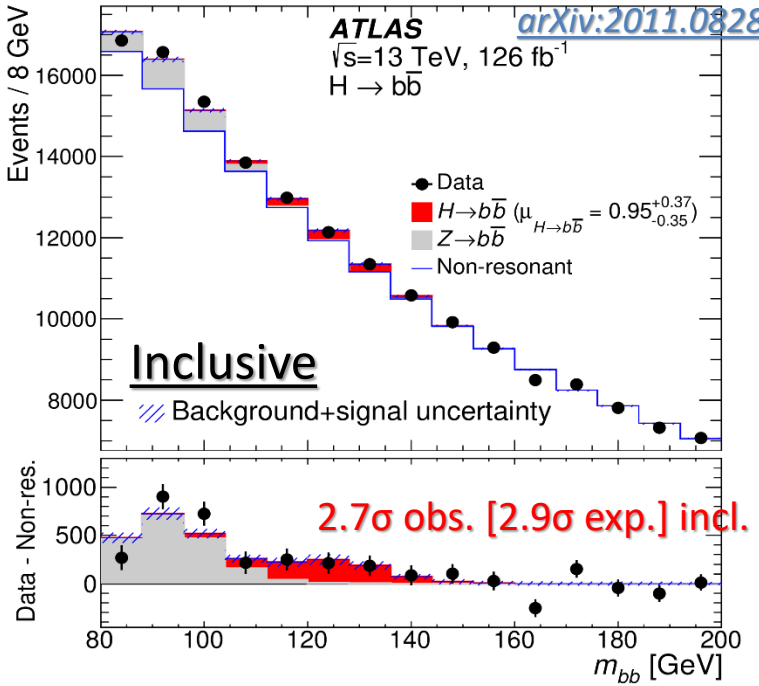
Phys. Lett. B 816 (2021) 136204

- VH process: $Z \to \ell\ell, \nu\nu$ or $W \to \ell\nu$ helps to reduce background
  - Already well-established channel with ~7σ significance
  - STXS measurement achieved for several bins in p_T^V
- Next steps: attempts to access different phase spaces

$H \to bb$ with VBF process

- Two orthogonal analyses targeting VBF production
  - Photon-tagged: VBF topology with a photon
    - High-E γ + 4 jets (VBF + Higgs decay products) are used for the trigger
  - Inclusive: VBF topo. targeting boosted Higgs: p_{T} > 150 GeV
    - High-E γ is vetoed to assure an orthogonality to the photon-tagged method





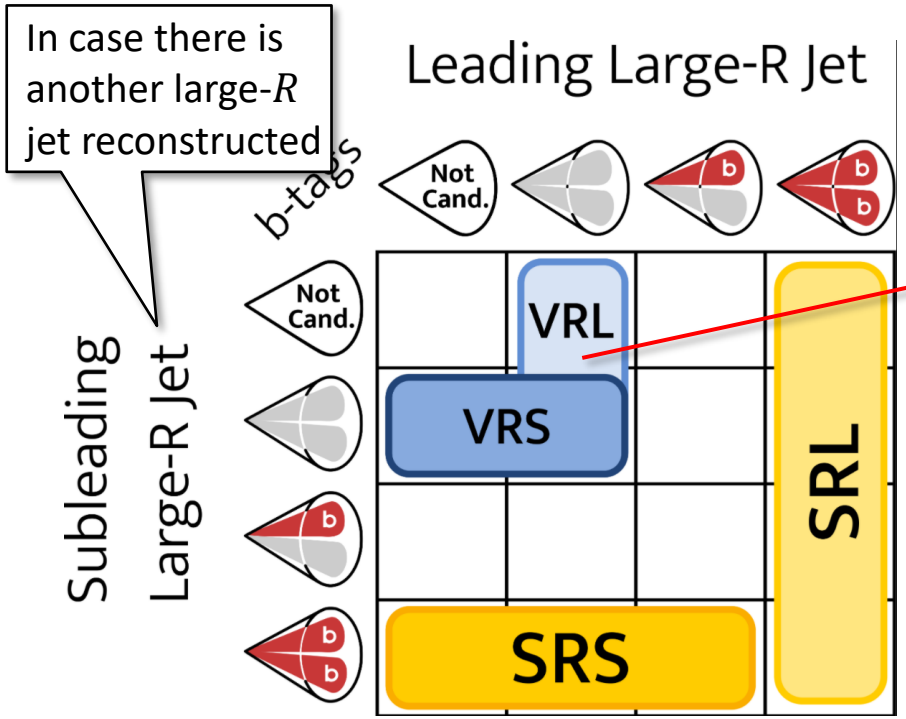
# of observed signals to SM expectation ← $\mu_{\mathrm{VBF}} = 0.99 \pm 0.30\ (\mathrm{stat.})\ ^{+0.18}_{-0.16}\ (\mathrm{syst.})$

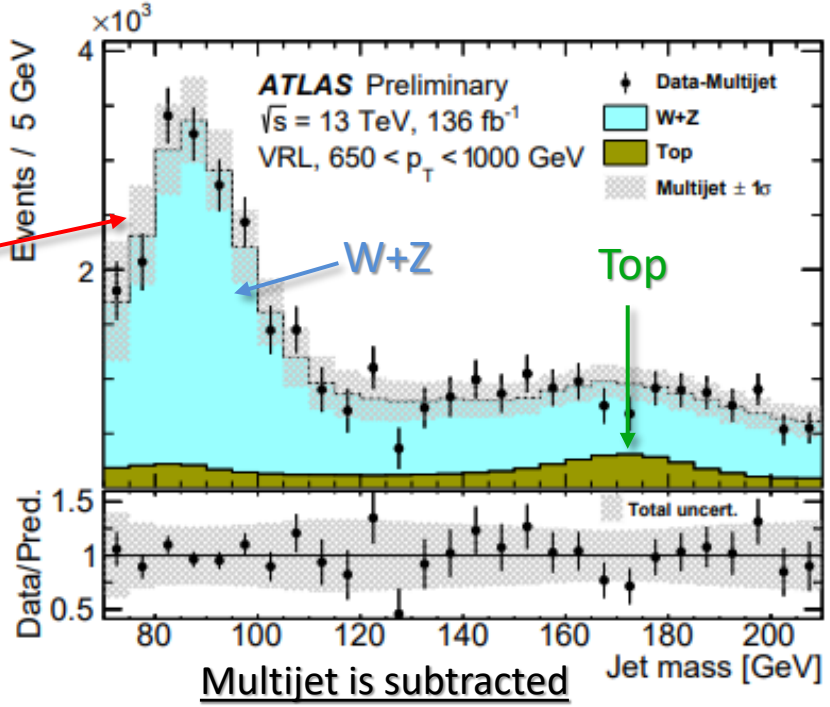
(Observed significance of **2.9**σ)

Inclusive boosted $H \to bb$ New!

ATLAS-CONF-2021-010

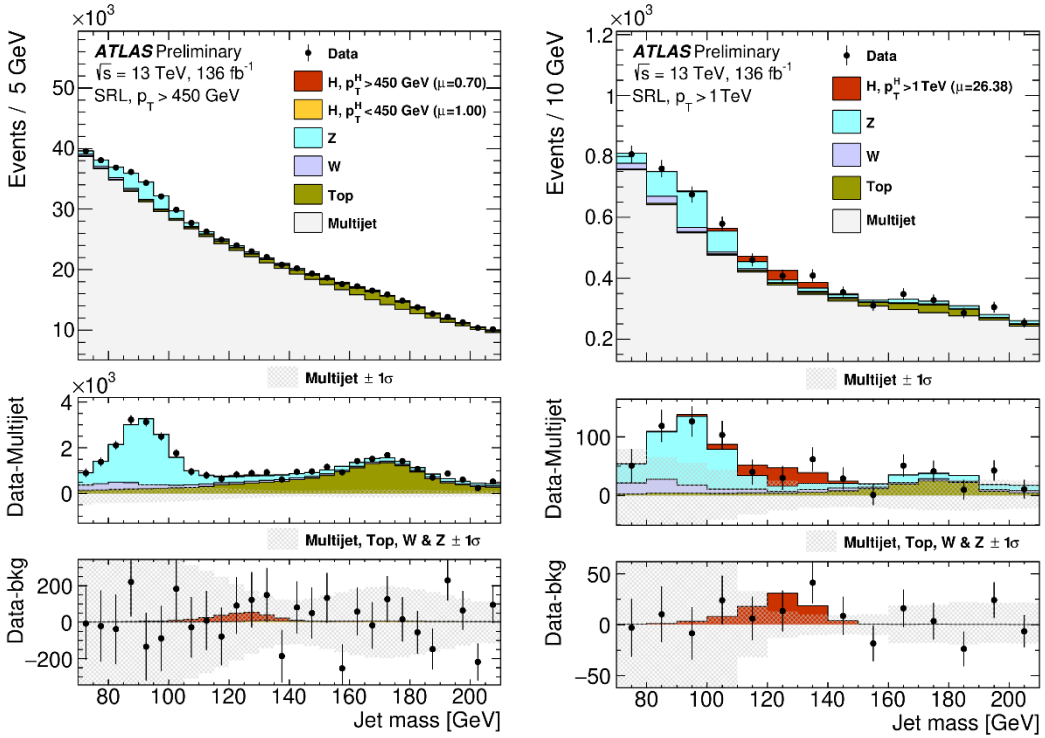
- Target very high-p_{T} Higgs production
  - Choose at least one large-R jet with two b-tagged subjets
- Multi-jet is a dominant BG, so its shape is checked in VR
- Jet mass reconstruction is validated using V and t resonances

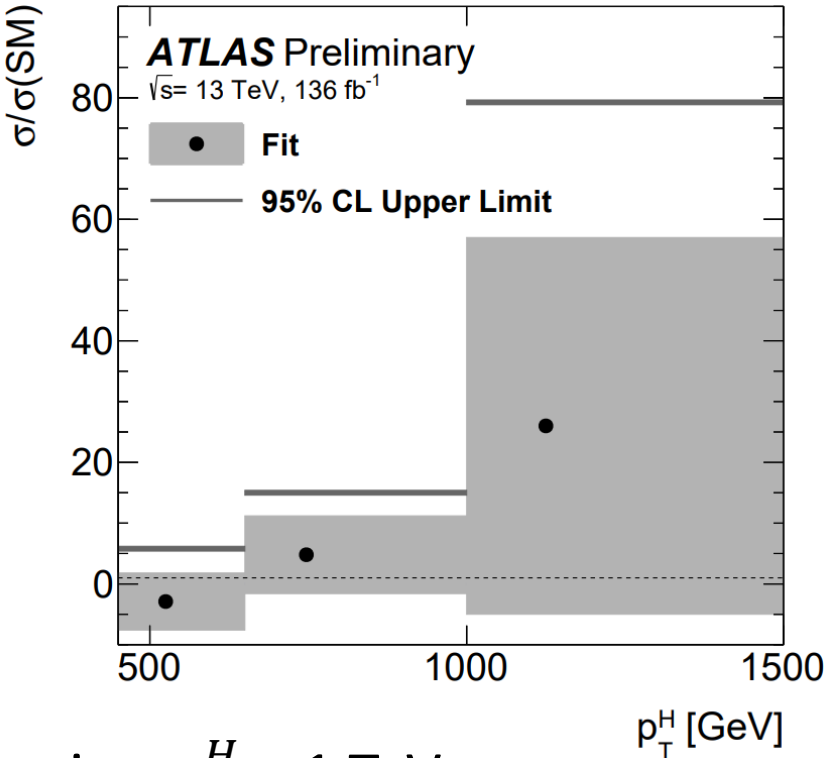




Inclusive boosted $H \to bb$ New!

ATLAS-CONF-2021-010





- Cross section measured up to the region $p_{\mathrm{T}}^{H} \sim 1$ TeV

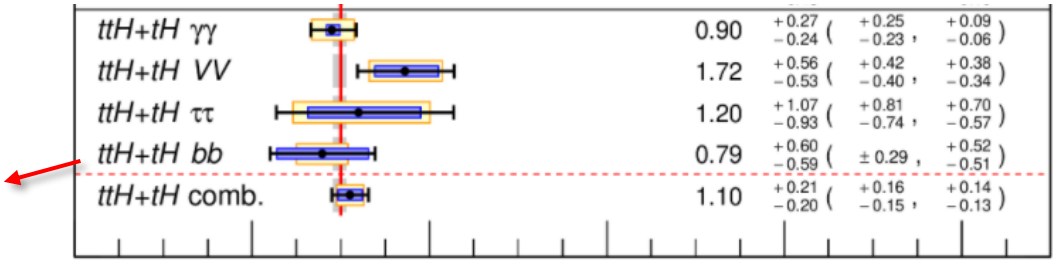
  $\sigma_H(p_{\mathrm{T}}^{H} > 450\ \mathrm{GeV}) = 13 \pm 52\ (\mathrm{stat.}) \pm 32\ (\mathrm{syst.}) \pm 3\ (\mathrm{theo.})\ \mathrm{fb}$

- Main experimental systematics arise from estimation on jet mass resolution

$ttH, H \to bb$

ATLAS-CONF-2020-058

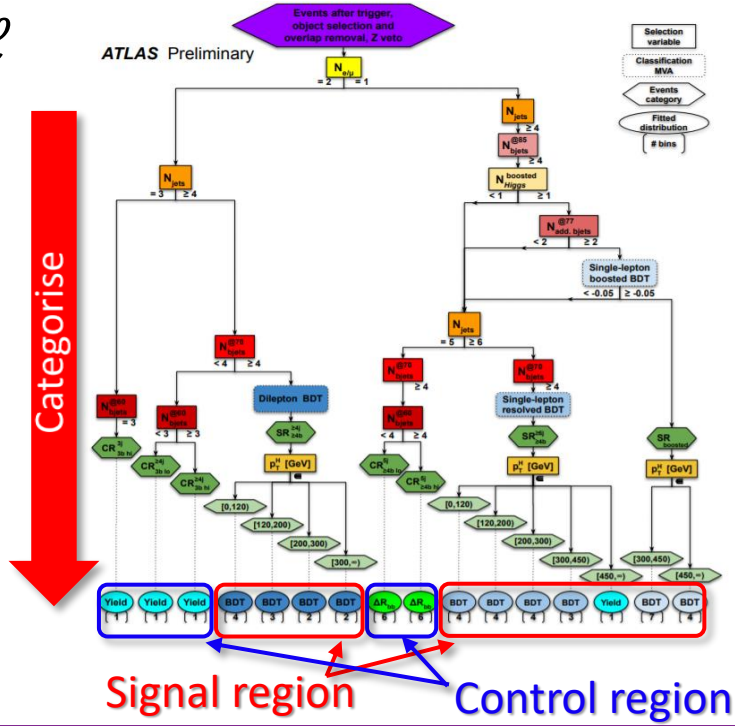
- ttH process has been measured with various final states



Update with full Run-2 dataset (x3.9 more data)

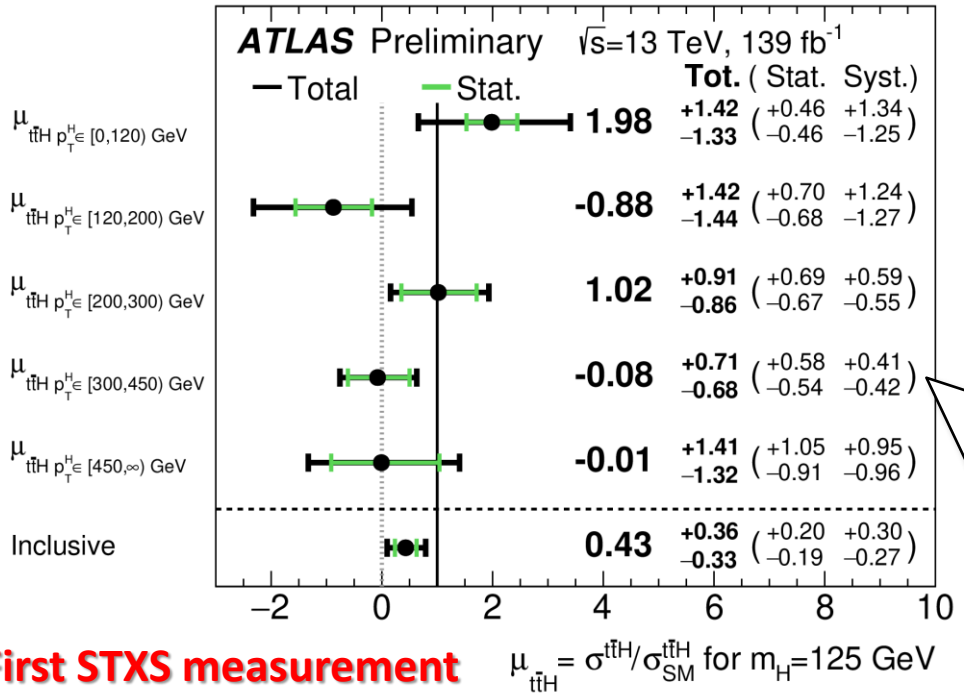
ATLAS-CONF-2020-027

- $ttH, H \to bb$ measurement with $\geq 1\ell$
  - Very challenging mode with a final state containing many jets
  - Already systematically limited
    → Background Modelling with t is a key of this analysis
- Many signal/control regions to better to control background
  - Also targets STXS measurements

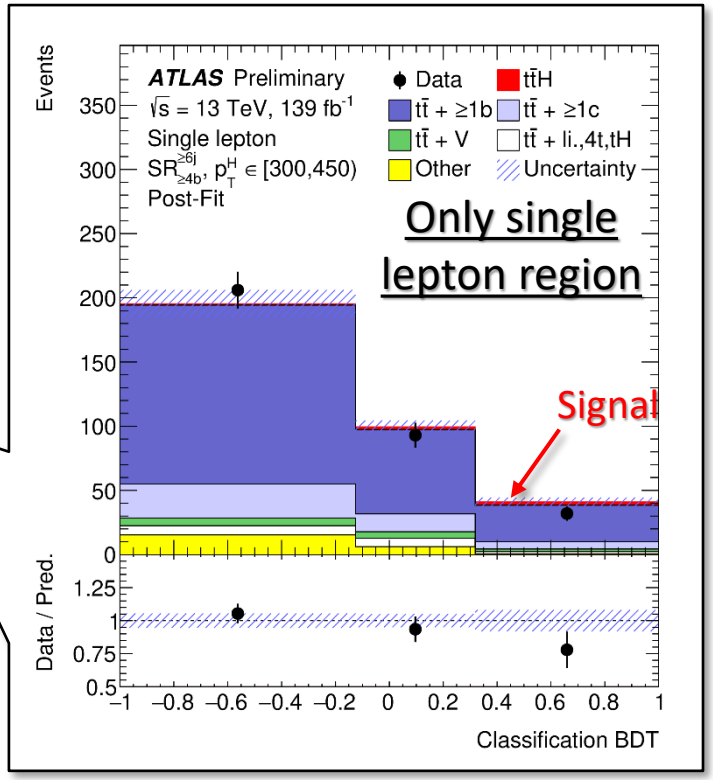


$ttH, H \to bb$

ATLAS-CONF-2020-058



First STXS measurement



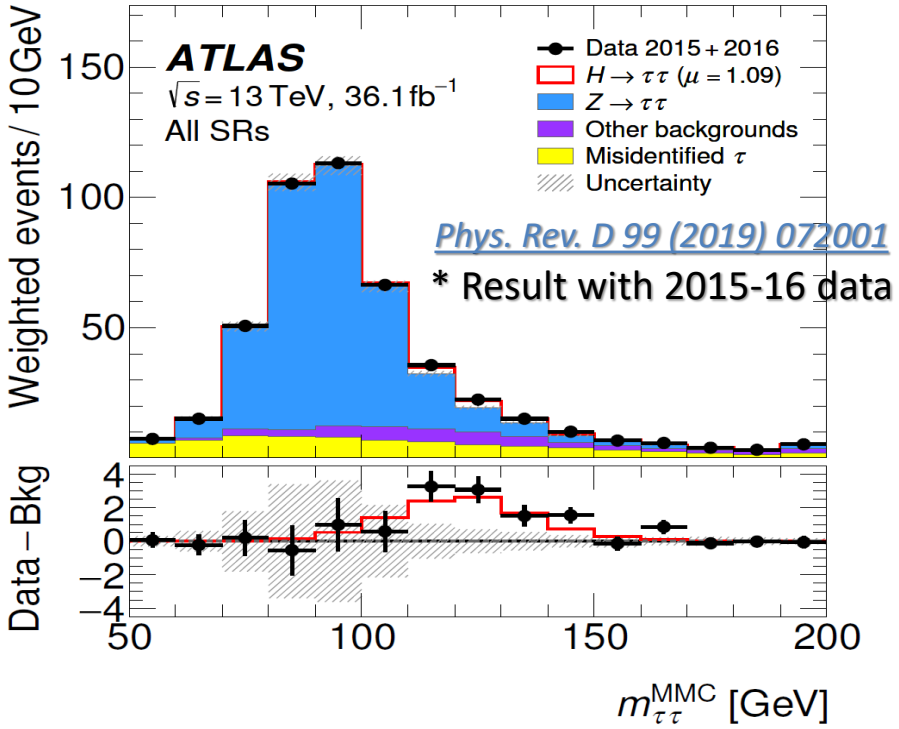
- Inclusive result is

$$\mu = 0.43\ ^{+0.20}_{-0.19}(\text{stat.})\ ^{+0.30}_{-0.27}(\text{syst.})$$

(Observed significance of **1.3**σ; while 3.0σ was expected)

- Systematic uncertainties dominated by modelling of $t\bar{t}$+b background ($^{+0.25}_{-0.24}$)

Leptonic final states

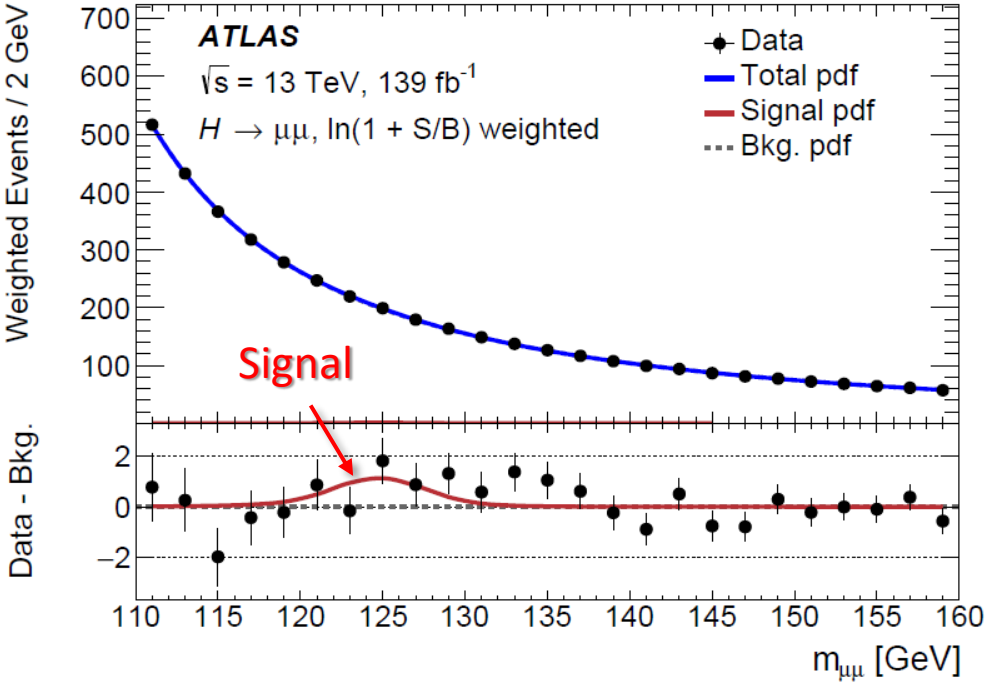


- Cleaner signature compared with hadronic final states
  - $H \to \tau\tau$ is well established with ~20% uncertainty
- Towards rare processes with light leptons such as $H \to \mu\mu$
  - Although very small BRs, very clean final state may realise observing those processes

$H \to \mu\mu$

Phys. Lett. B (2121) 135980

- Interesting channel to investigate Yukawa coupling in 2-gen
- Clean final state, but need to handle overwhelming background from $Z/\gamma^* \to \mu\mu$
  - Improve $m_{\mu\mu}$ with recovering an FSR γ from μ
  - Event categorisations with BDT; 20 signal regions



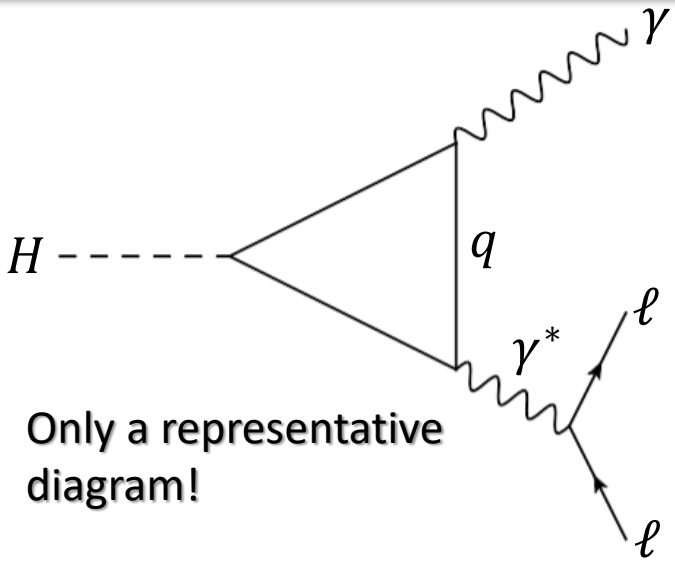
$\mu = 1.2 \pm 0.6\ (\text{stat.})\ ^{+0.2}_{-0.1}\ (\text{syst.})$

(**2.0**σ observed [1.7σ expected])

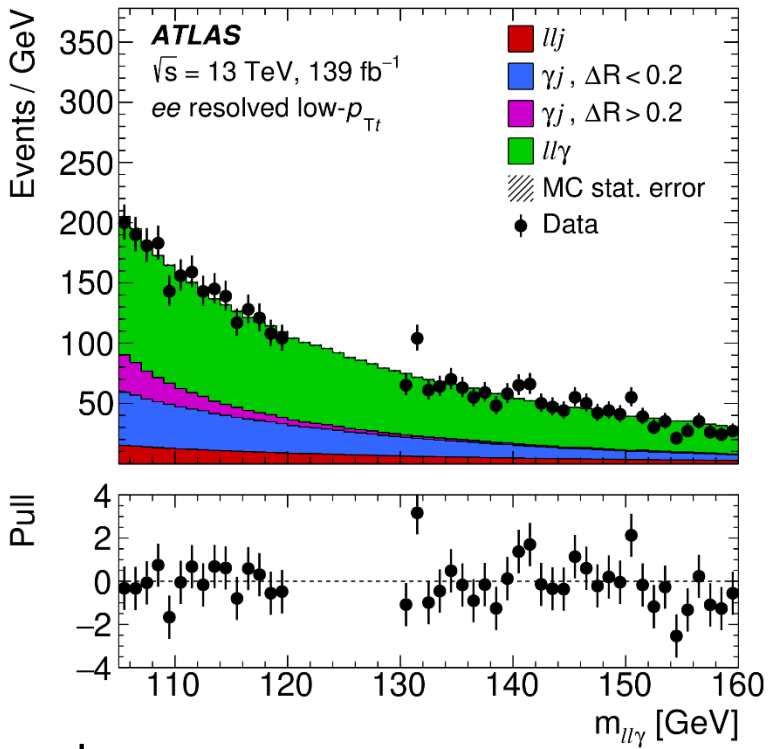
Together with CMS, an evidence of $H \to \mu\mu$ was observed for the first time!

$H \to \ell\ell\gamma$ New!

arXiv:2103.10322



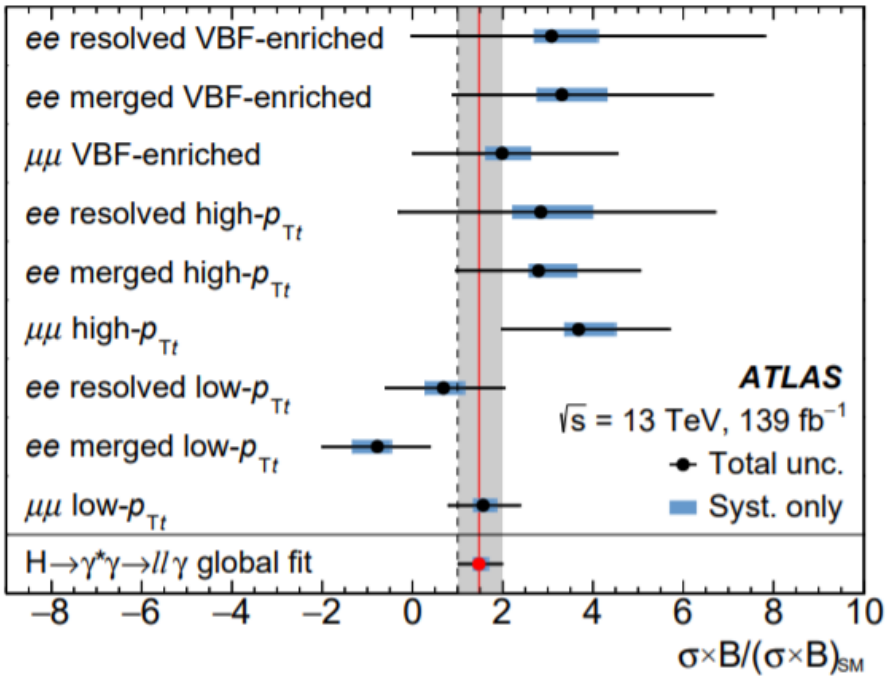
Only a representative diagram!

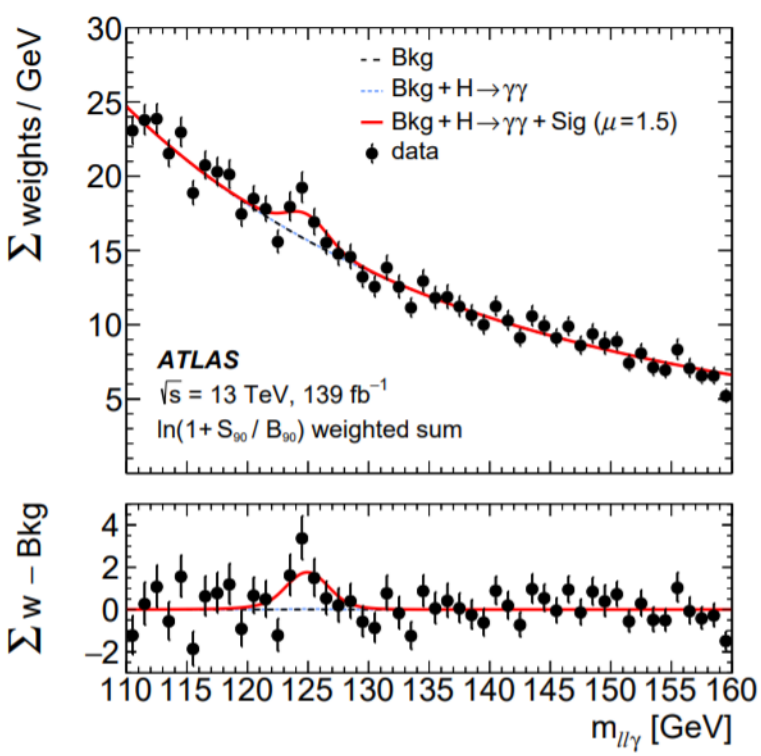


- Search for $H \to \ell\ell\gamma$ with $m_{\ell\ell} < 30$ GeV
  - In this $m_{\ell\ell}$ region, $\gamma^* \to \ell\ell$ is dominant
    → Probing couplings between H and intermediate particles in the loop
  - [ee(resolved, merged), $\mu\mu$] ⊗ [VBF, non-VBF(high-p_T, low-p_T)]
    → 9 signal regions in total
- Main background: non-resonant $\ell\ell\gamma$
  - Normalisation determined in the fit

$H \to \ell\ell\gamma$ New!

arXiv:2103.10322





- A small bump in the signal region

$$\mu = 1.5 \pm 0.5\ (\text{stat.})\ ^{+0.2}_{-0.1}\ (\text{syst.})$$

(Observed significance of **3.2**σ)

- First evidence of $H \to (\gamma^* \to \ell\ell)\gamma$

Summary

- Many analyses using full dataset of Run 2 were complete
  - Thanks to the large statistics, precision measurements for the Yukawa couplings in the 3-gen fermions became possible
  - Results are getting more important in the STXS measurements
  - Rare decays such as $H \to \mu\mu$ and $H \to \ell\ell\gamma$ became accessible

- A few more interesting analyses are ongoing
  - $H \to cc$, $H \to \tau\tau$, LFV decays, ...
  - Combinations of all STXS / coupling measurements based on full Run-2 dataset

- LHC Run-3 operation will start in 2022
  - The data size will be twice larger than what we have

    → Good opportunity to more precisely understand Higgs properties