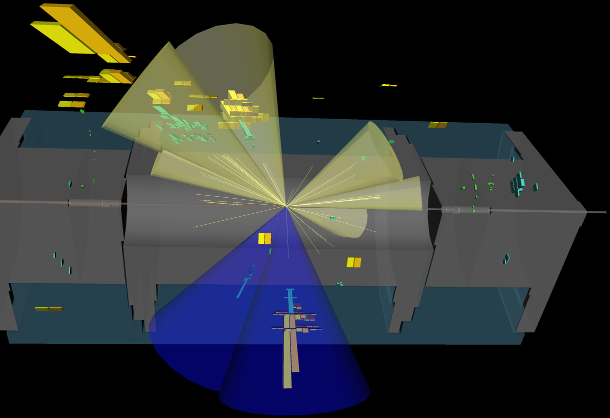
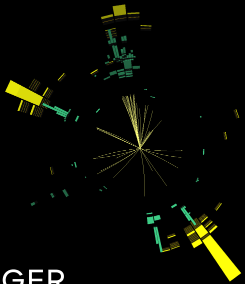
Measurement of Higgs boson production cross sections in the di-τ decay channel with the ATLAS detector and the combination with other decay channels





FRANK SAUERBURGER

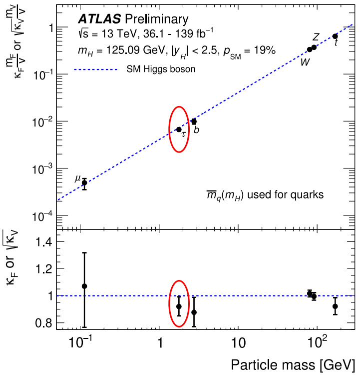
November 23, 2021

Run: 299584
Event: 901388344
2016-05-20 17:40:04 CEST

ATLAS EXPERIMENT

Supervisors: Karsten Köneke, Christopher Young, Karl Jakobs

Motivation

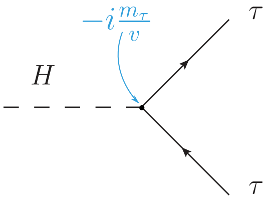


[ATLAS-CONF-2021-053]

Spontaneous symmetry breaking and Yukawa interaction

$$\mathscr{L} \subset -\frac{\sqrt{2}m_\tau}{v}\left[(\bar{\nu}_\tau\,\bar{\tau})_L\,\phi\,\tau_R + \bar{\tau}_R\,\phi\,(\nu_\tau\,\tau)_L\right]$$

$$\to \mathscr{L} \subset -m_\tau\bar{\tau}\tau - \frac{m_\tau}{v}\bar{\tau}\tau h$$



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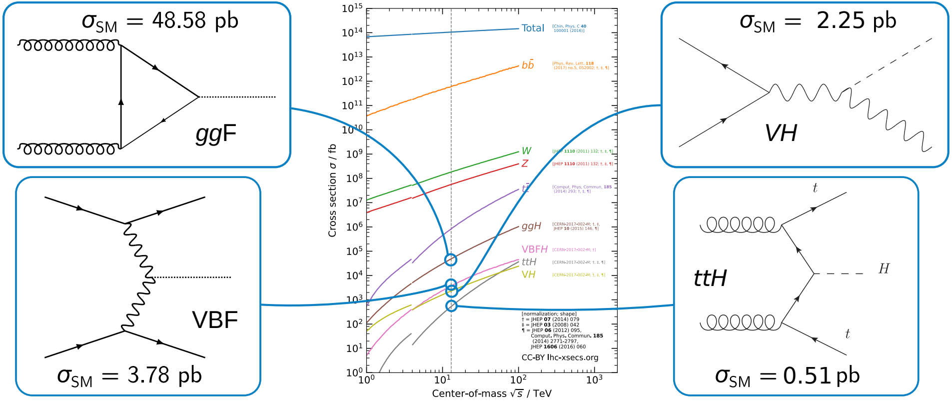
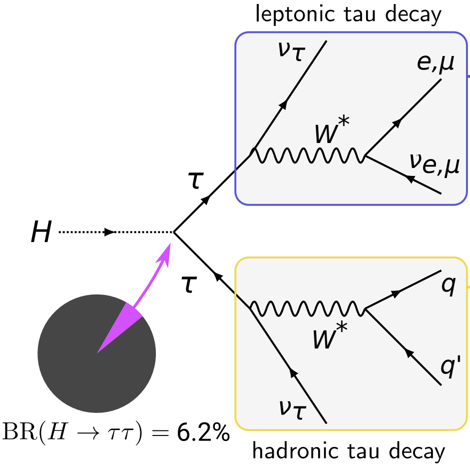
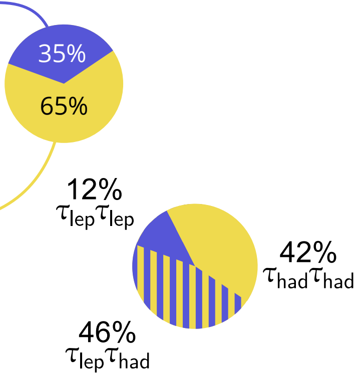
Production modes



Analysis targets four H production modes



Both taus decay independetly
➡ Three analysis channels



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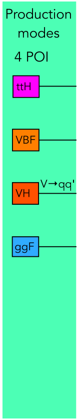
Analysis categories



[ATLAS-CONF-2021-044]

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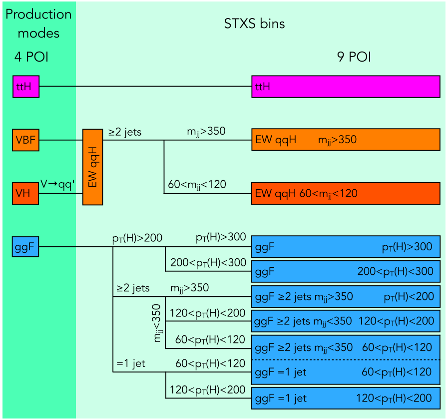
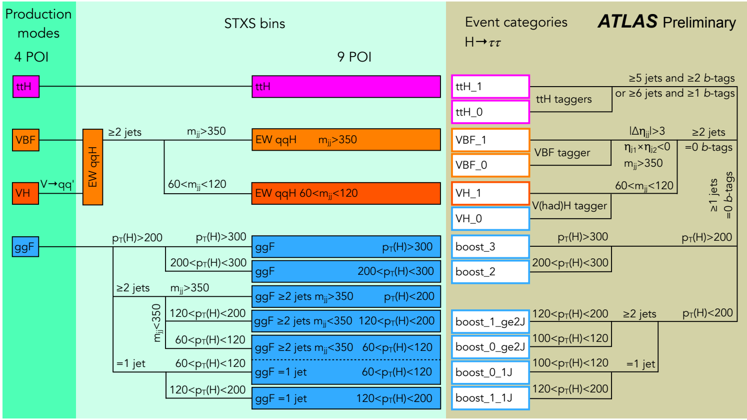
Analysis categories



[ATLAS-CONF-2021-044]

Analysis categories



[ATLAS-CONF-2021-044]

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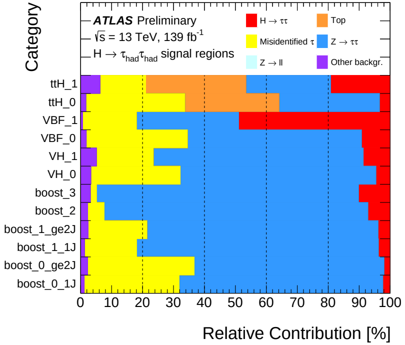
Background composition

Dominant backgrounds

- $Z \to \tau\tau$
  - Monte Carlo simulation
  - 70% overall, up to 90% in boosted
  - Normalization from dedicated, embedded Control Regions
- Misidentified τ
  - Data-driven estimation
- Top
  - Monte Carlo simulation
  - Dedicated Control Regions



Signal region composition with $100\,\text{GeV} < m_{\tau\tau}^{\text{MMC}} < 150\,\text{GeV}$

[ATLAS-CONF-2021-044]

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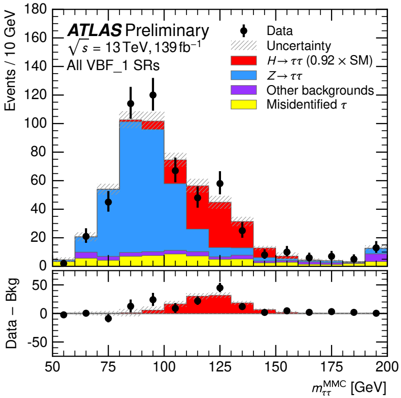
Missing mass calculator

- At least two neutrinos in the final state
- Individual contributions to $E_{\mathrm{T}}^{\mathrm{miss}}$ not measured
- Perform likelihood scan using angles between measured particles and $E_{\mathrm{T}}^{\mathrm{miss}}$
- Find most probable Higgs boson mass m_{MMC}
- Most important discriminant



[ATLAS-CONF-2021-044]

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Machine learning

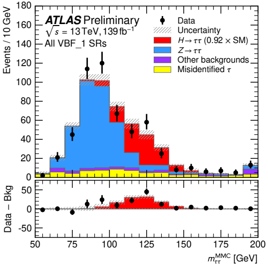
Machine learning

VBF tagger

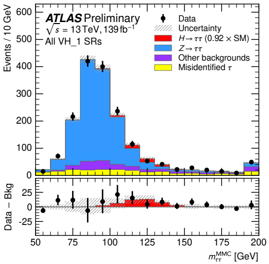
- Targeting VBF topology (two forward jets)
- Rejecting: ggF and $Z \to \tau\tau$
- Trained on jet kinematics

VH tagger

- Reject non-VH production modes
- Trained on jet and Higgs kinematics



[ATLAS-CONF-2021-044]



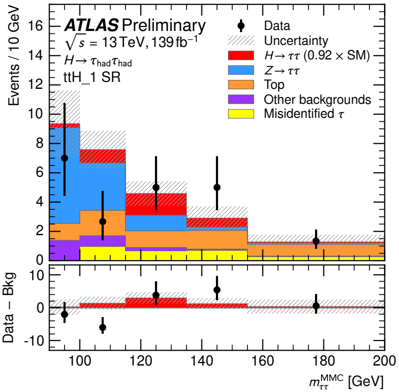
[ATLAS-CONF-2021-044]

Targeted signal frac.: 94% in VBF_1 66% in VH_1

Machine learning

BDTs for ttH

- Employ two BDTs
- Reject tt and $Z \to \tau\tau$ background
- Trained on jet, τ, H and $E_{\mathrm{T}}^{\mathrm{miss}}$ properties
- Define ttH_1 with rectangular cuts
- ttH signal fraction in ttH_1: 92%



[ATLAS-CONF-2021-044]

Results

Measured cross sections

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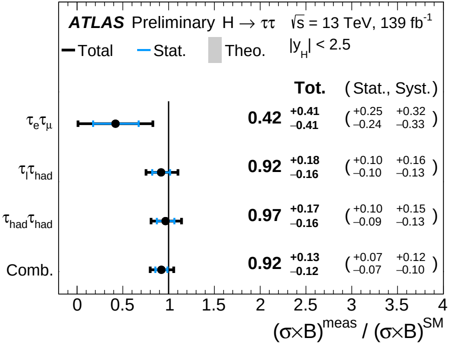
Measurements for different Parameters of Interest (PoI)

1. Total cross section
2. Cross section per production mode
3. 9 bins of STXS stage 1.2

Results are in agreement with the SM



[ATLAS-CONF-2021-044]

Total Cross section

$$(\sigma \times \mathrm{BR})^{\mathrm{obs}} = 2.90 \pm 0.21\,(\mathrm{stat})\,^{+0.37}_{-0.32}\,(\mathrm{syst})\,\mathrm{pb}$$

Measured cross sections

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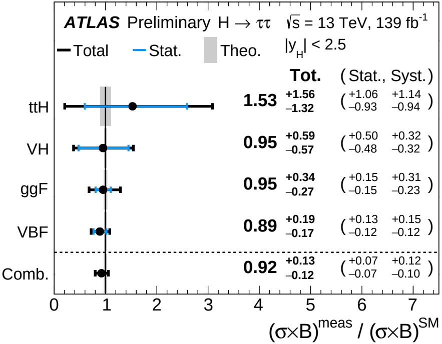
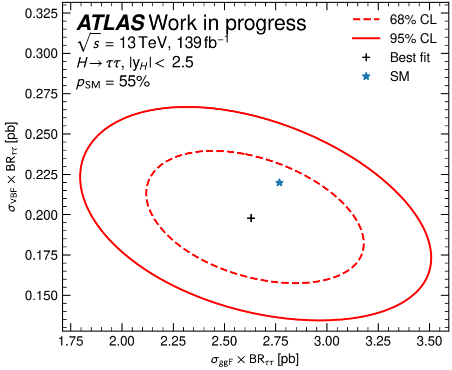


[ATLAS-CONF-2021-044]

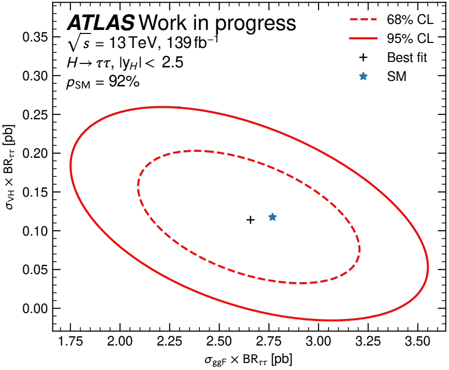
- Strong constraints on VBF cross-section
- Observation of VBF process at 5.3σ

2D Scans

ggF vs. VBFH



ggF vs. VH



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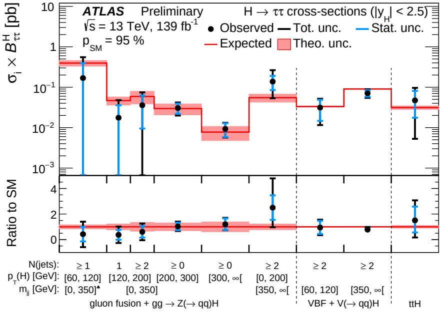
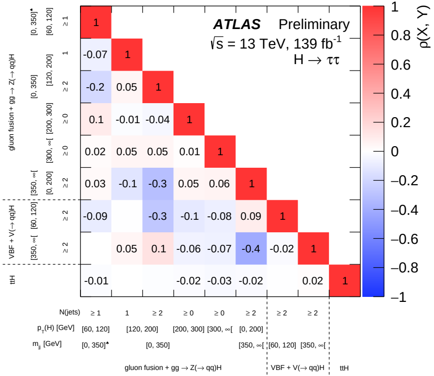
Measured cross sections

STXS measurement

Measurement in 9 bins of STXS stage 1.2



[ATLAS-CONF-2021-044]



[ATLAS-CONF-2021-044]

Combination

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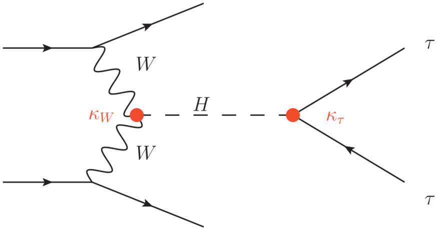
κ framework

- Zero-width assumption, decompose production and decay
- Scale coupling strengths with κ modifiers

$$\sigma_j \to \kappa_j^2 \sigma_j^{\mathrm{SM}} \quad \Gamma_j \to \kappa_j^2 \Gamma^{\mathrm{SM}}$$

- For Standard Model, all $\kappa_j = 1$



VBF with coupling modifiers

κ Combination

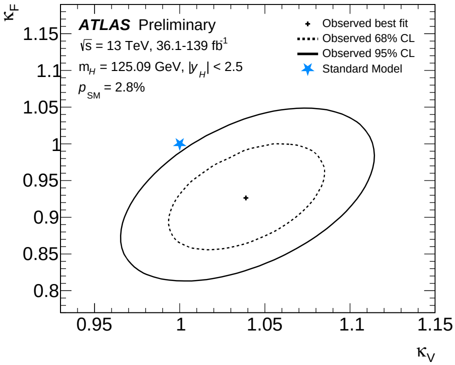
Model 1: Fermion and gauge boson couplings

- $\kappa_V := \kappa_W = \kappa_Z$
- $\kappa_F := \kappa_t = \kappa_b = \kappa_\tau = \kappa_\mu$
- Best-fit:

$$\kappa_V = 1.039^{+0.031}_{-0.030}$$
$$\kappa_F = 0.93 \pm 0.05$$

- Low p-value attributed to:

$$(\sigma \times \mathrm{BR})_{ttH+tH\,bb} = 0.35^{+0.34}_{-0.33}$$
$$(\sigma \times \mathrm{BR})_{ggH\,\tau\tau} = 0.87^{+0.23}_{-0.25}$$

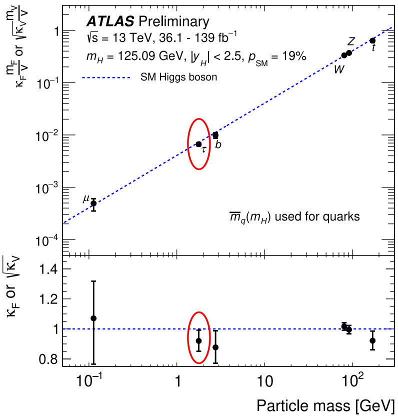


[ATLAS-CONF-2021-053]

κ Combination

Model 2: Generic without BSM

- Generic "tree-level" model
- Loops assumed to be SM-like
- No invisible/undetected decays
- Measure $\kappa_W, \kappa_Z, \kappa_t, \kappa_b, \kappa_\tau$ and κ_μ



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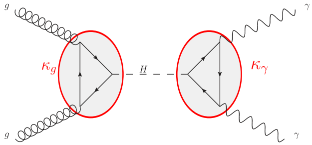
κ Combination

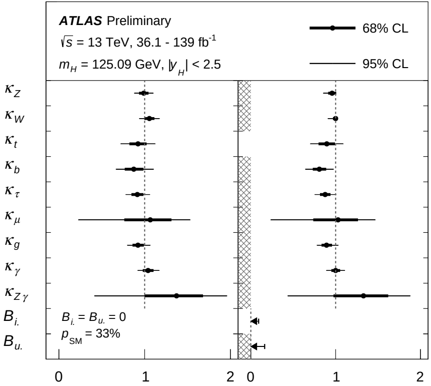
Model 3: Tree-level plus BSM in loops

- Higgs mechanism: coupling $\propto$ mass
- Heavy BSM particles contributing to loops?
- Measure tree-level modifiers: $\kappa_W, \kappa_Z, \kappa_t, \kappa_b, \kappa_\tau$ and κ_μ
- Measure loop modifiers: κ_g, κ_γ, $\kappa_{\gamma Z}$
- Limits on invisible BSM decays



$\rightarrow$ No sign of BSM

$B_{i.} < 0.09$ and $B_{u.} < 0.16$ at 95% CL



[ATLAS-CONF-2021-053]

Conclusion

Conclusion

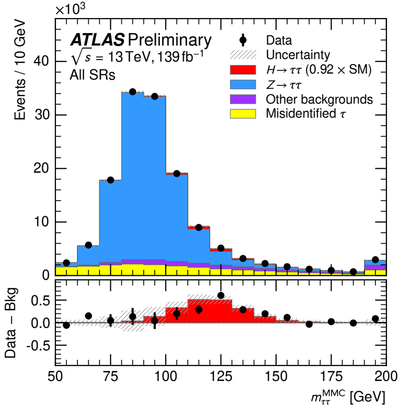
- Total measured $H \to \tau\tau$ cross section

$$2.90 \pm 0.21\,(\text{stat})\,^{+0.37}_{-0.32}\,(\text{syst})\,\text{pb}$$

- STXS measurements in 9 bins
- Observation of VBF $H \to \tau\tau$ at 5.3 σ
- Improved precision† from 27% to 14%
- Combination with other Higgs decay channels

→ More precise measurements in future with refined analysis techniques and Run 3 dataset

† wrt. Phys. Rev. D **99**,072001 (2019)



[ATLAS-CONF-2021-044]

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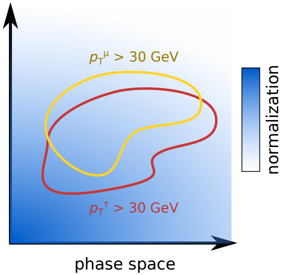
Backup

Simplified embedding procedure

UNI FREIBURG

Motivation

Phase space mismatch between SR ($Z \to \tau\tau$) and CR ($Z \to \ell\ell$)



$\to$ How to define matching CR?

Procedure

In control region

1. Select $Z \to \ell\ell$ events
2. Unfold ℓ reconstruction, identification and isolation effects
3. Scale p_ℓ by parametrized τ decay effects
4. Reweight to account for efficiencies

Data-driven estimation of misidentified τ

lep had and $\tau_{\text{had}}\tau_{\text{had}}$

- Jets misidentified as τ_{had}
- Background estimated with **fake factor** method

$$N_{\text{fake}}^{\text{SR}} = (N_{\text{Data}}^{\text{anti-}\tau} - N_{\text{MC, no jet}}^{\text{anti-}\tau}) \times \mathscr{F}$$

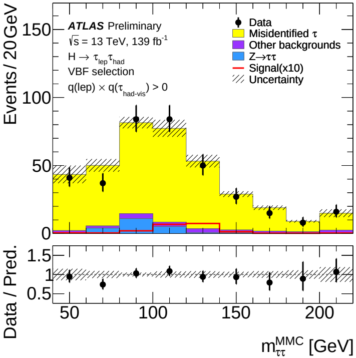
$\tau_e\tau_\mu$

- Misidentified leptons
- Data-driven **matrix method**

$$\left(N_{\text{tight/loose}}\right) = \left[\text{eff. matrix}\right]\left(N_{\text{real/fake}}\right)$$

For all channels

Assign uncertainties $O(5-30\%)$



[ATLAS-CONF-2021-044]

Uncertainties

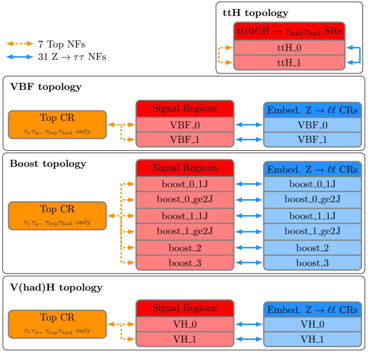
- Limited by systematic uncertainties
- Large theory uncertainties
- Largest exp. uncertainties from Jet/MET

Source of uncertainty	Impact on $\Delta\sigma/\sigma(pp \to H \to \tau\tau)$ [%] Observed	Expected
Theoretical uncertainty in signal	8.1	8.6
Jet and $E_{\mathrm{T}}^{\mathrm{miss}}$	4.2	4.1
Background sample size	3.7	3.4
Hadronic τ decays	2.0	2.1
Misidentified τ	1.9	1.8
Luminosity	1.7	1.8
Theoretical uncertainty in Top processes	1.4	1.2
Theoretical uncertainty in Z+jets processes	1.1	1.1
Flavor tagging	0.5	0.5
Electrons and muons	0.4	0.3
Total systematic uncertainty	11.1	11.0
Data sample size	6.6	6.3
Total	12.8	12.5

[ATLAS-CONF-2021-044]

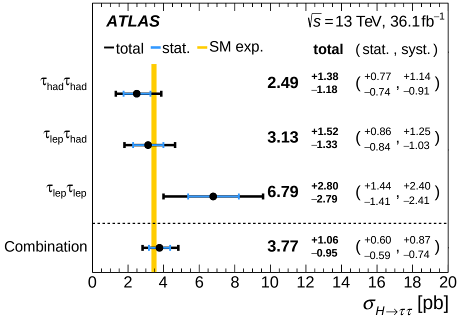
Fit structure

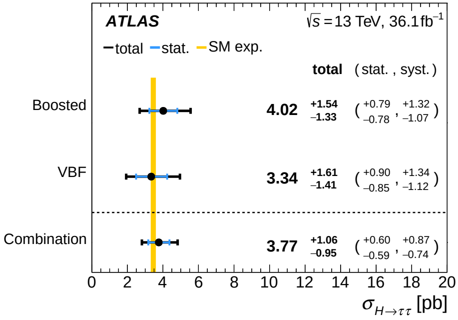
- Normalization of Top background from Top control regions
- Normalization of $Z \to \tau\tau$ from kinematically embedded $Z \to \ell\ell$



[ATLAS-CONF-2021-044]

Partial Run 2 dataset





[Phys. Rev. D **99**, 072001 (2019)]