Measurement of boosted $H \to \tau\tau$

arXiv:2607.22193

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LAPP

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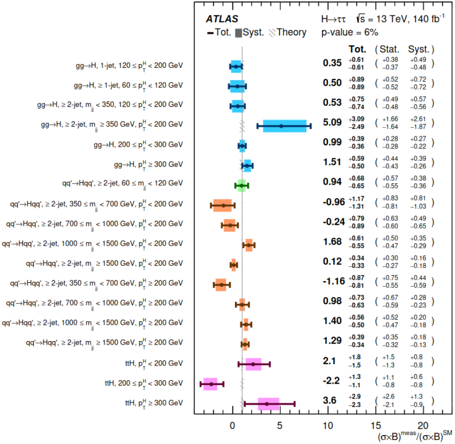
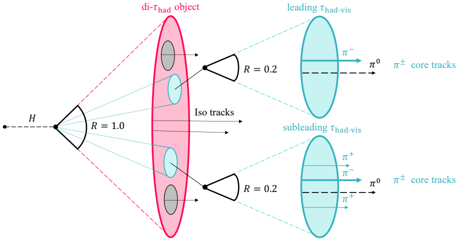
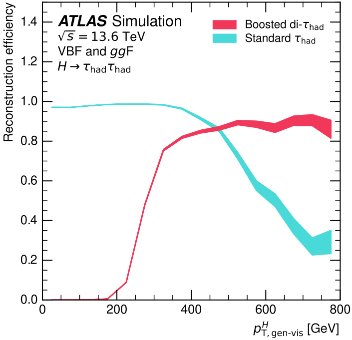
- Measure $H \to \tau_{had}\tau_{had}$ in the boosted regime
- Use Run2 and partial (22-24) Run3 data ($302\,\text{fb}^{-1}$)
- Main sensitivity from ggH and VBF in p_T^H regime above 300 GeV
- Complementary to resolved measurement
- Perform inclusive, STXS and a differential measurement



Di-tau reconstruction

- Target boosted $H \rightarrow \tau_{had}\tau_{had}$ object
- Use dedicated reconstruction of boosted di-tau object

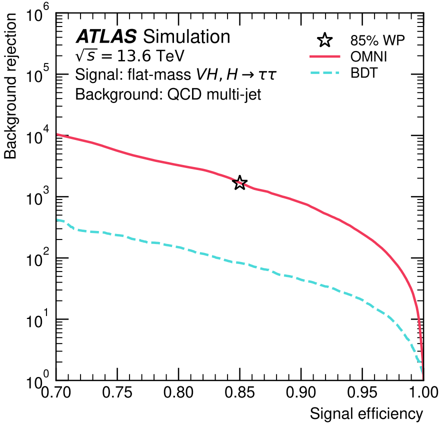




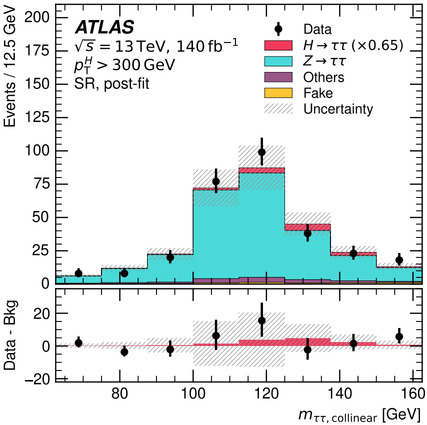
- Big advantage wrt flavour tagging approach: information on subjets (charge, prongness, p_T)

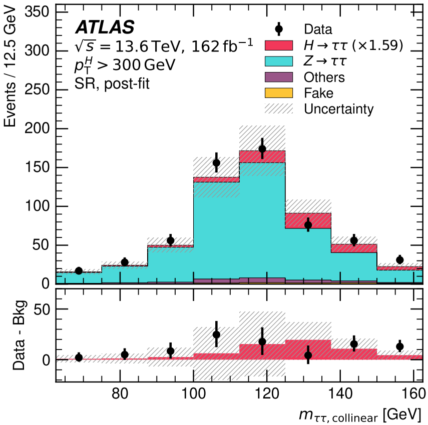
Di-tau identification

- Use dedicated OMNI tagger to reject fake (multi-jet) background
- Use Point-Edge Transformer (PET) architecture



- Boosted di-tau tagger:
  - very good rejection of fakes
  - no rejection of $Z \to \tau\tau$

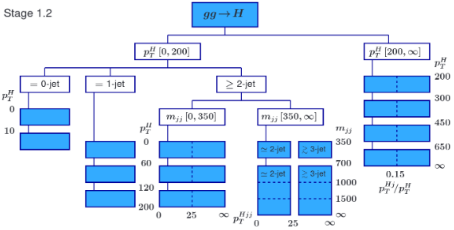


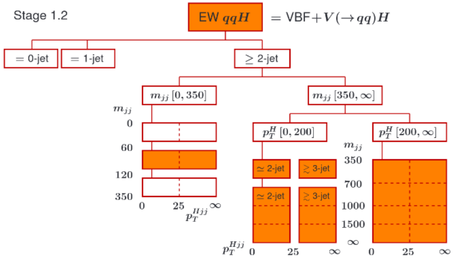


- Dominant background: $Z \to \tau\tau$
- Fakes: data driven estimation (fake factor method)

Region definition

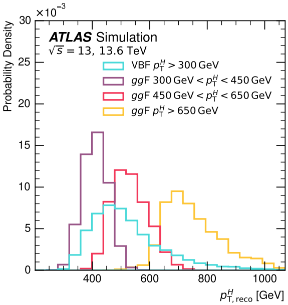
- For STXS measurement: 4 categories
- ggH: $300\,GeV < p_T^H < 450\,GeV$, $450\,GeV < p_T^H < 650\,GeV$, $p_T^H > 650\,GeV$
- qqH: $p_T^H > 300\,GeV$

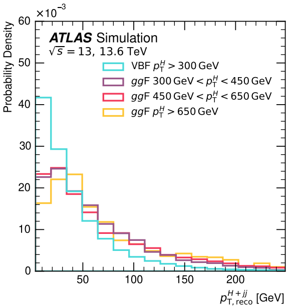


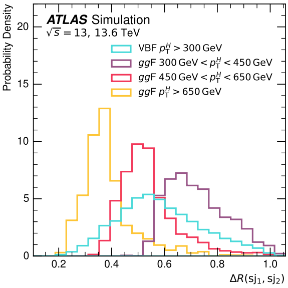


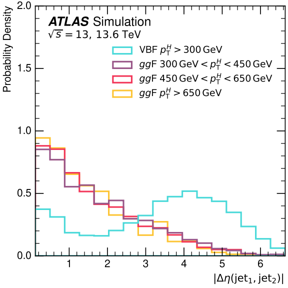
- 4 class BDT to split between VBF and the 3 ggH STXS categories

Region definition

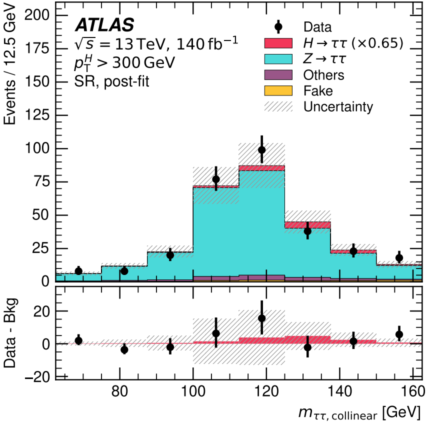


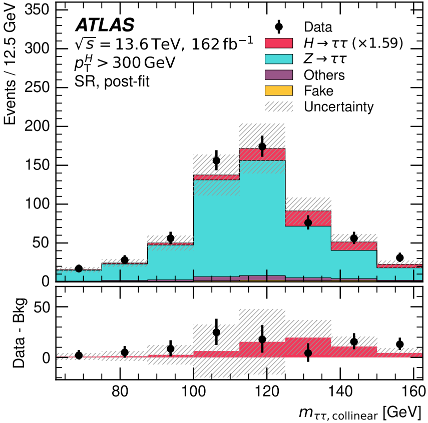






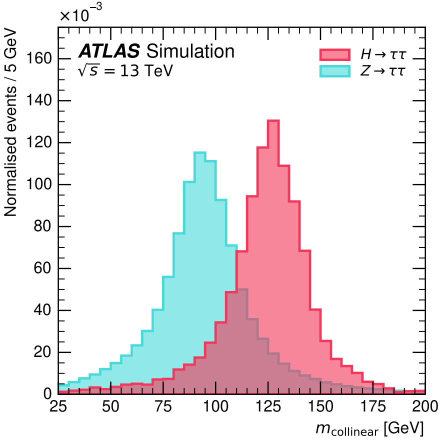
- 2 class BDT to separate signal and background
- SRs: BDT output score above 0.2

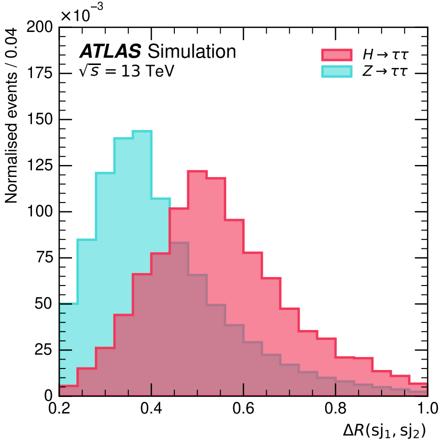




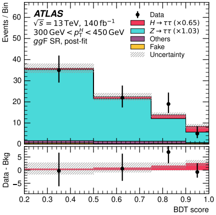
- SRs binned in BDT output score

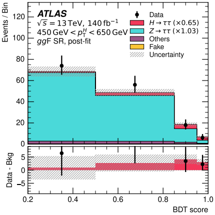
Region definition

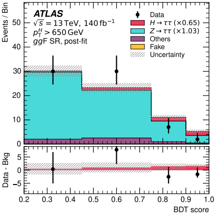


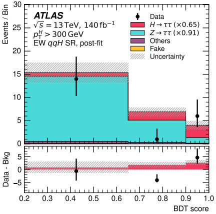


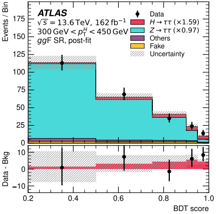
Signal regions

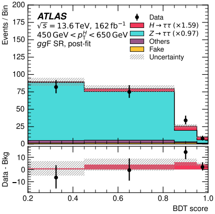


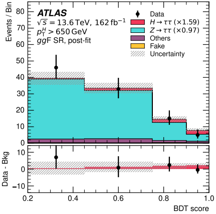


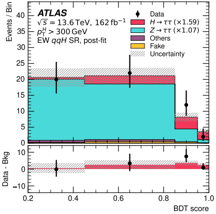




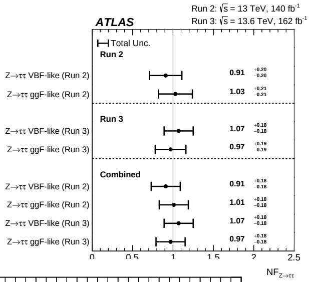


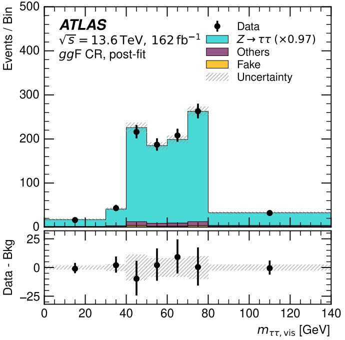


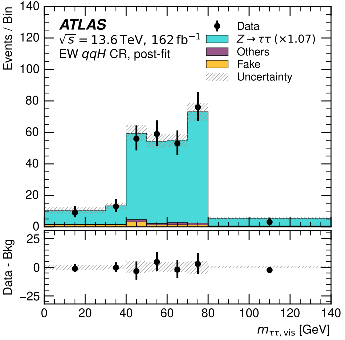




- Define $Z \to \tau\tau$ CRs with cut on S/B BDT
- Free floating $Z \to \tau\tau$ NFs
- Binning in visible mass used for TES calibration

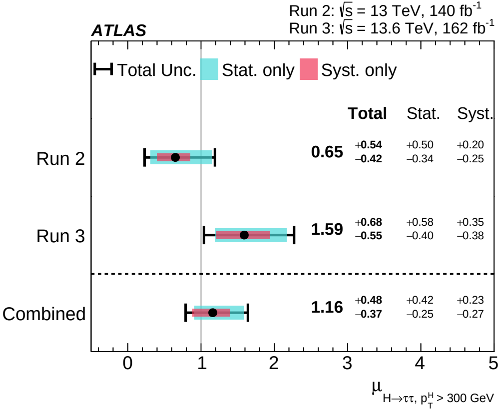






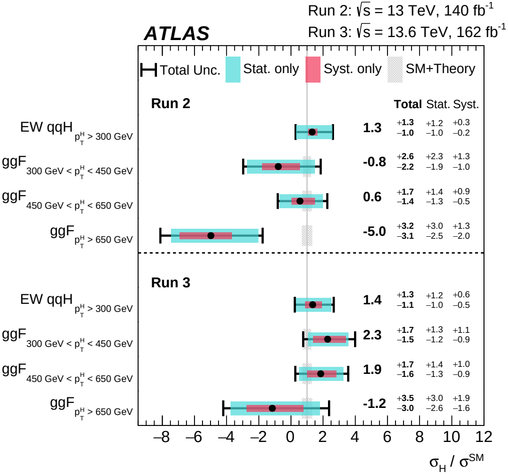
Inclusive fit

- Measure Higgs production with Higgs $p_T > 300\text{GeV}$
- Significance of 3.8σ (3.3σ expected)
- 69% compatibility with SM expectation
- Results statistics dominated



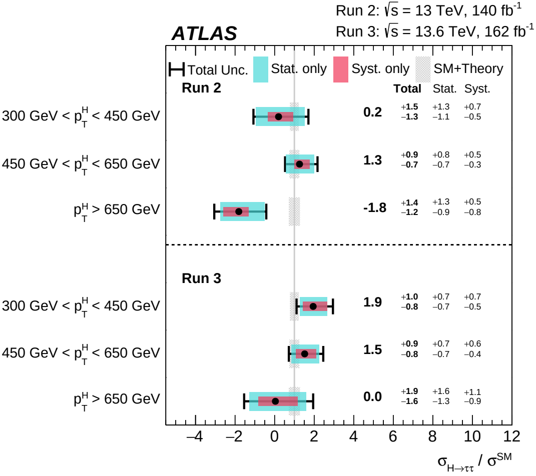
STXS fit

- 52% for Run2 and 70% for Run3 compatibility with SM expectation

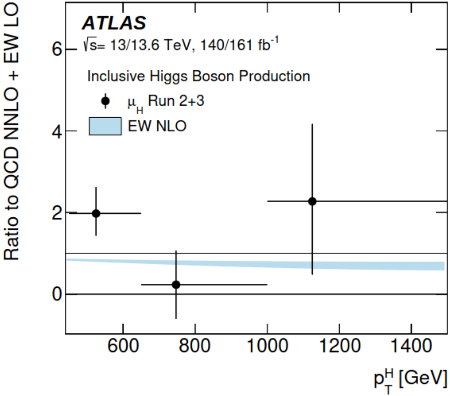


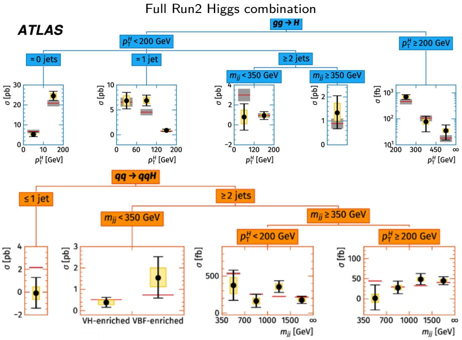
- For Run2 ggF events with $p_T^H > 650$GeV: upper limit of 4.5 times SM (6.5 expected)

- Merge production modes
- Introduces slighlty larger correlations through VBF



- General effort to measure Higgs in boosted regime
- Increasing statistics and new taggers give access to this new phase-space
- ATLAS $H \to bb$ measurement arXiv:2603.19369



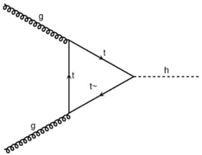


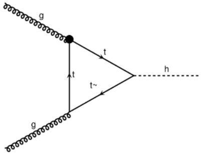
- Probe slightly higher p_T^H regime
- Can also access higher p_T^H regime in $H \to \tau\tau$ through $\tau_{lep}\tau_{had}$

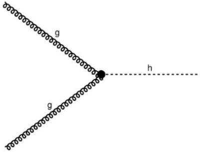
High-luminosity projections and EFT interpretation

- Constrain ggF and VBF related EFT operators in boosted regime
- EFT interpretation at event level
- Energy growth in EFT operator impact
- ggH: SMEFTatNLO

$$\mathcal{M} = \mathcal{M}^{SM}_{loop} + \mathcal{M}^{EFT}_{loop} + \mathcal{M}^{EFT}_{tree}$$



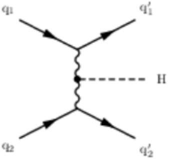




$$|\mathcal{M}|^2 = \left|\mathcal{M}^{SM}_{loop}\right|^2 + \left|\mathcal{M}^{EFT}_{loop}\right|^2 + 2Re\left(\mathcal{M}^{SM}_{loop}\mathcal{M}^{*EFT}_{loop}\right) + \left|\mathcal{M}^{EFT}_{tree}\right|^2 + 2Re\left(\mathcal{M}^{SM}_{loop}\mathcal{M}^{*EFT}_{tree}\right) + 2Re\left(\mathcal{M}^{EFT}_{loop}\mathcal{M}^{*EFT}_{tree}\right)$$

C. Knight

- VBF: SMEFTsim



Expected EFT results

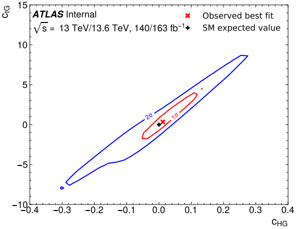
- First EFT results (work in progress)
- For VBF: significant EFT impact through effects on Higgs width

WC	linear+quadratic	linear
c_{HG}	$[-0.018, +0.014]$	$[-0.012, +0.018]$
c_{tG}	$[-0.52, +0.79]$	$[-0.69, +0.45]$
c_{tH}	$[-7.44, +8.20]$	$[-9.53, +6.03]$

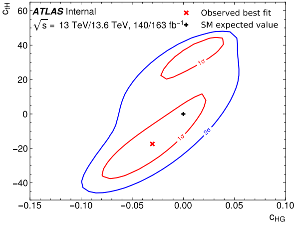
WC	lin+quad (wo Γ_H)	lin+quad(w Γ_H)	lin (wo Γ_H)	lin (w Γ_H)
c_{HW}	$[-0.69, +0.47]$	$[-0.80, +0.48]$	$[-1.22, 1.46]$	$[-1.10, 1.12]$
c_{HB}	$[-2.01, +2.01]$	$[-0.71, +0.78]$	$[-642, 748]$	$[-7.63, 3.78]$
c_{HWB}	$[-2.20, +1.93]$	$[-1.58, +1.46]$	$[-13.26, 15.85]$	$[-5.87, 19.27]$

Likelihood scans

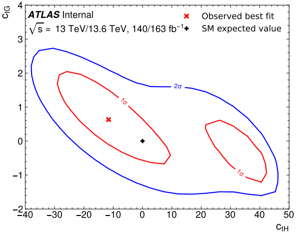
c_{HG}: $[-0.03, 0.09]$, c_{tG}: $[-1.08, 3.09]$



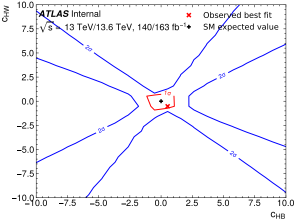
c_{HG}: $[-0.07, 0.002]$, c_{tH}: $[-32.13, -0.31]$



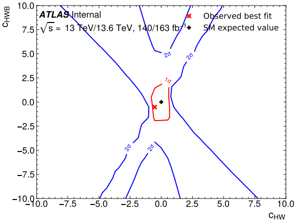
c_{tH}: $[-23.86, 1.32]$, c_{tG}: $[-0.17, 1.65]$



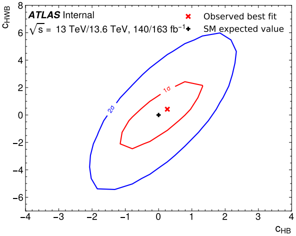
c_{HB}: $[-0.69, 0.59]$, c_{HW}: $[-0.65, 0.56]$



c_{HW}: $[-0.73, 0.61]$, c_{HWB}: $[-1.23, 1.38]$



c_{HB}: $[-0.85, 0.90]$, c_{HWB}: $[-1.69, 1.65]$



High-lumi projections of EFT results

- Consider different projection sceanrios:
  - Scenario1: lumi scaling, MC stats scaling by 0.22
  - Scenario2: additional experimental syst scaling, MC stats put to 0
  - Scenario3: additional theory syst scaling

WC	Run2+3	Scenario1	Scenario2	Scenario3
c_{HG}	$[-0.018, +0.014]$	$[-0.009, +0.009]$	$[-0.007, +0.008]$	$[-0.006, +0.005]$
c_{tG}	$[-0.52, +0.79]$	$[-0.35, +0.34]$	$[-0.29, +0.26]$	$[-0.21, +0.22]$
c_{tH}	$[-7.44, +8.20]$	$[-4.63, +4.03]$	$[-4.04, +3.32]$	$[-2.82, +2.84]$
c_{HW}	$[-0.80, +0.48]$	$[-0.59, +0.27]$	$[-0.55, +0.24]$	$[-0.54, +0.23]$
c_{HWB}	$[-1.58, +1.46]$	$[-0.96, +0.83]$	$[-0.87, +0.75]$	$[-0.80, +0.67]$
c_{HB}	$[-0.71, +0.78]$	$[-0.42, +0.49]$	$[-0.38, +0.45]$	$[-0.34, +0.41]$

Conclusion

- Published a first boosted $H \to \tau\tau$ measurement in ATLAS for LHCP
- Observe $H \to \tau\tau$ with $p_T^H > 300$GeV with significance of 3.8σ
- Provide STXS and differential fit
- Good sensitivity in $300\text{GeV} < p_T^H < 450\text{GeV}$
- Analysis still heavily statistics dominated
- Complementary phase space to boosted $H \to bb$
- EFT interpretation and high-luminosity projections are work in progress
- Preliminary results show comparable sensitivity to $H \to 4\ell$ EFT limits

Backup

Event selection

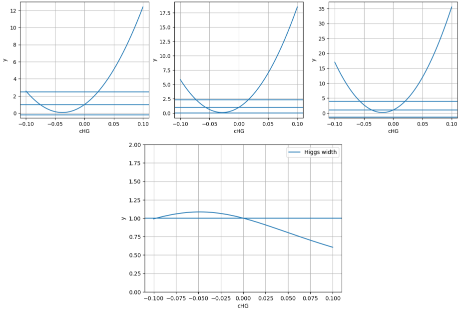
Object	Signal region	Control region
Di-τ_{had}	Pass 85% OMNI WP	Fail 85% OMNI WP
	$N_{\text{subjets}} \geq 2$	
	$\Delta R(\text{di-}\tau_{\text{had}}, \text{lead jet}) > 0.4$	
	$N_{b\text{-jets}} = 0$	
Subjets	$N_{\text{tracks}}^{\text{sj}_1,\text{sj}_2} \in \{1, 3\}$	
	$p_{\text{T}}^{\text{sj}_1} > 50$ GeV	
	$p_{\text{T}}^{\text{sj}_2} > 15$ GeV	
	$q_{\text{sj}_1} * q_{\text{sj}_2} = -1$	
$E_{\text{T}}^{\text{miss}}$	$E_{\text{T}}^{\text{miss}} > 60$ GeV	
Combined	$E_{\text{vis},i}/E_{\tau,i} > 0$	
	$N_{\text{tracks}}^{\text{di-}\tau_{\text{had}}} - N_{\text{tracks}}^{\text{sj}_1} - N_{\text{tracks}}^{\text{sj}_2} = 0$	
	$\lvert\Delta\phi(E_{\text{T}}^{\text{miss}}, \text{sj}_1 + \text{sj}_2)\rvert < 1.3$	

Systematics impact

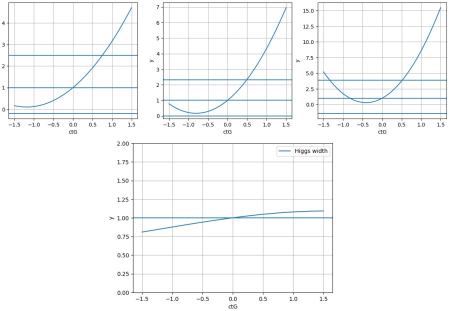
Source of uncertainty	Impact on the signal strength Observed	Expected
Theoretical scale/phase space uncertainty on signal	0.15	0.13
Di-τ_{had} energy scale acceptance, Run 2	0.12	0.08
Misidentified τ_{had}, Run 3	0.10	0.08
Background sample size	0.07	0.06
Jet and E_T^{miss}	0.07	0.06
Di-τ_{had} identification	0.04	0.03
Parton shower and PDF uncertainty on signal, Run 2	0.04	0.03
Parton shower and PDF uncertainty on signal, Run 3	0.02	0.02
Di-τ_{had} energy scale acceptance, Run 3	0.02	0.03
Theoretical uncertainty in Z + jets processes	0.01	0.02
Misidentified τ_{had}, Run 2	0.01	0.04
Di-τ_{had} energy scale MC-MC calibration	0.01	0.01
Luminosity Run2	0.01	0.01
Luminosity Run3	0.01	0.01
Total systematic uncertainty	0.25	0.21

EFT parametrisation: p_T^H dependence

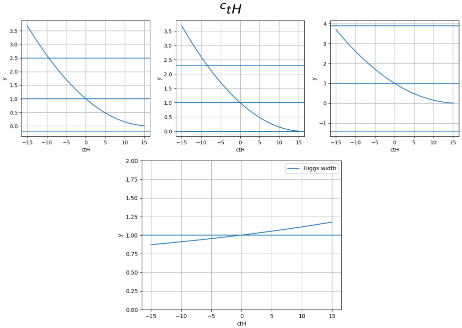
c_{HG}



c_{tG}

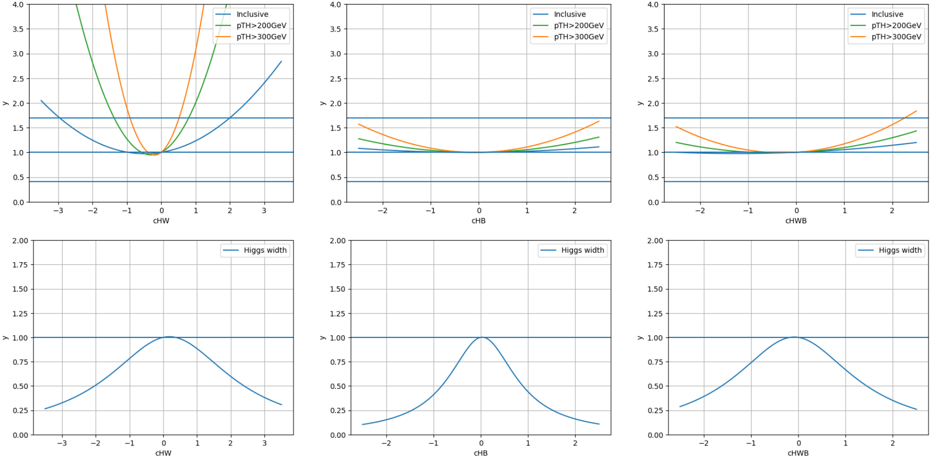


- Observe strong energy growth $\rightarrow$ gain from boosted topology



- Only normalisation effect $\rightarrow$ limits not expected to be competitive here

EFT parametrisation: p_T^H dependence



- Gain sensitivity from the 300GeV cut (STXS v1.3: additional cut at 450GeV)
- Strong impact on total Higgs width $\rightarrow$ need to constrain it through other operators