Searching for ttH(bb) production with the ATLAS detector at √s = 13 TeV

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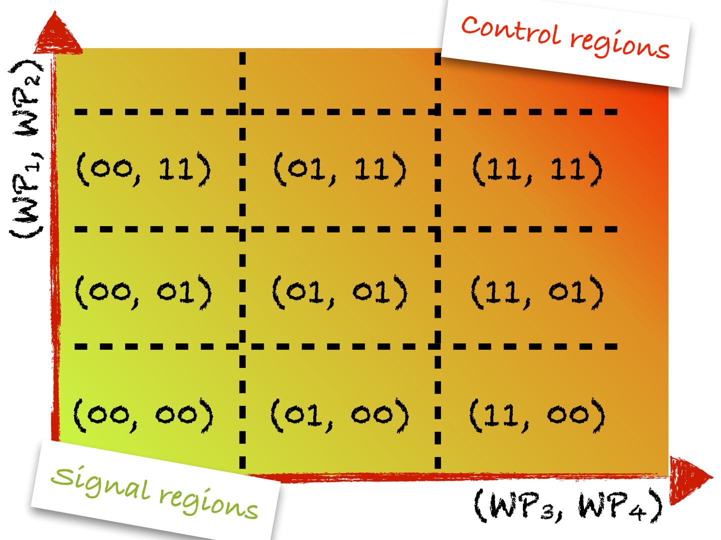
Introduction

The measurement of ttH production will provide a method through which to probe the presence of New Physics.

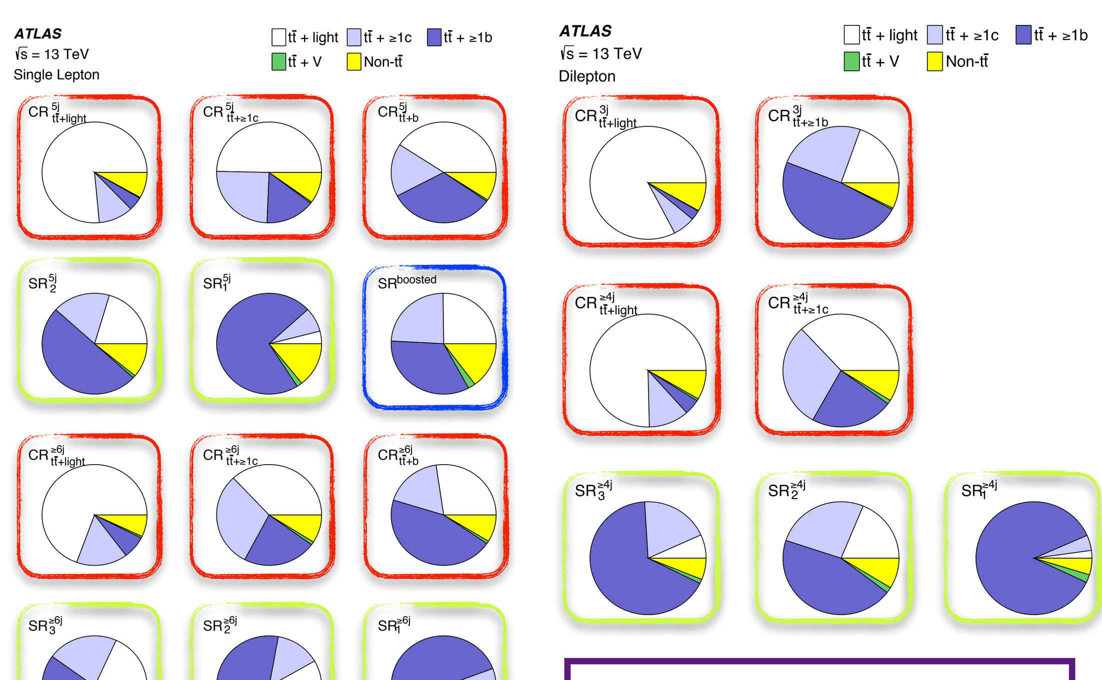
Data collected by the ATLAS Experiment in 2015 and 2016 has been analysed in order to search for the **ttH(bb) final state** and attempt to measure any deviation away from the Standard Model prediction.

Event Categorisation

Events have been selected with **1** or **2 leptons** (ℓ) with at least **4 b-jets**. The main challenge in this analysis results from searching for a small signal within a large and poorly modelled top-pair plus heavy flavour background.



To fully exploit the ATLAS data, a ***pseudo-continuous*** categorisation of events was performed using **four calibrated b-tagging working points** for the four leading b-jets. This categorisation enabled the creation of analysis regions which could target particular top processes (e.g. tt̄ + ≥1c, tt̄ + ≥1b).



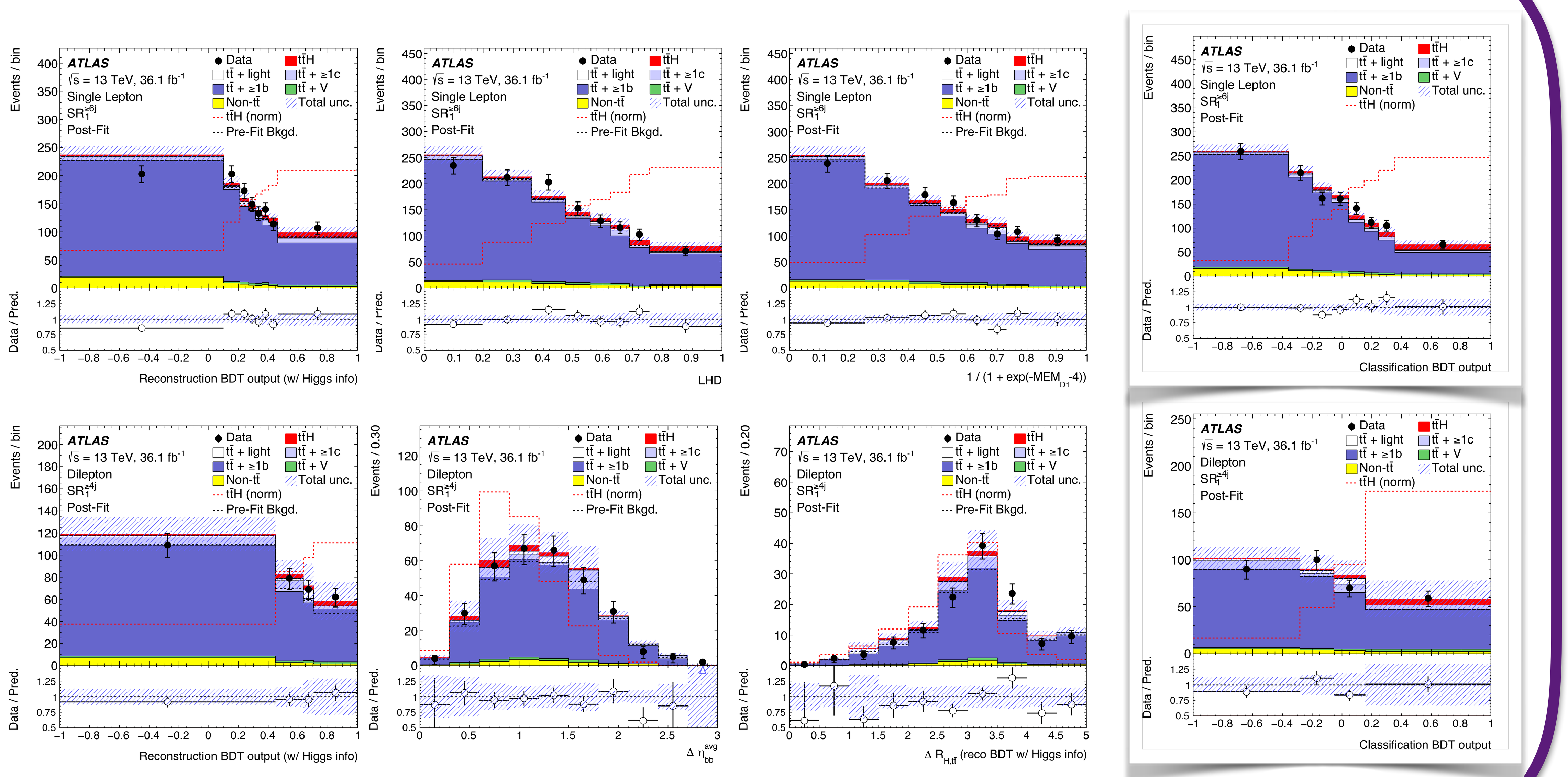
Signal regions typically end up with > 50% of tt̄ + ≥1b and the most sensitive have S/B > 5%.

Multivariate Techniques for ttH(bb)

Events in the signal regions are passed through a series of multivariate classifiers to improve the separation between signal and background processes.

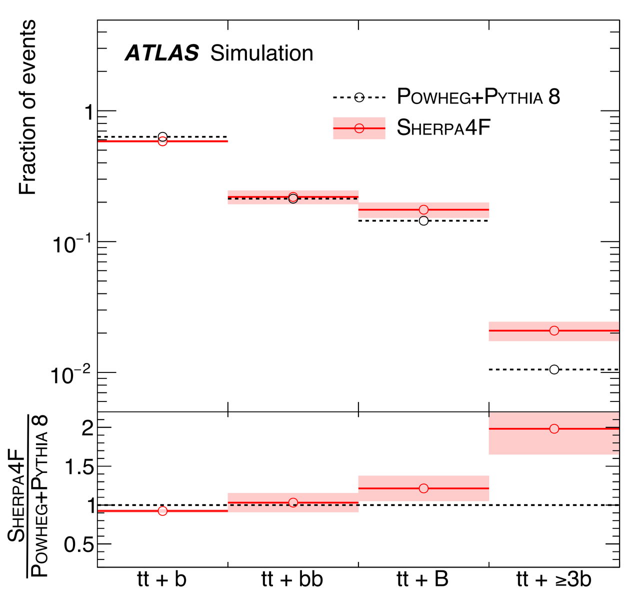
- **Reconstruction BDT** [1ℓ, 2ℓ] (identify the best jet-parton hypothesis)
- **Likelihood discriminant** [1ℓ] (combine signal and background probabilities for all jet-parton combinations)
- **Matrix element method** [1ℓ] (exploit the full matrix element calculation to separate signal and background)

The output of these MVAs are passed into a final **classification BDT** combined with additional variables to provide optimal signal/background separation.



Top three variables entering the classification BDT in single-lepton and dilepton channels.

Modelling and Uncertainties for tt̄+jets



The dominant background process is tt̄+jets, which is modelled using Powheg+Pythia8 and split into three categories: **tt̄ + ≥1b**, **tt̄ + ≥1c**, **tt̄ + light**.

The **relative fractions of tt̄ + ≥1b**, based on the number of particle b-jets, are corrected to a Sherpa prediction at NLO in a four-flavour scheme.

Uncertainties are applied independently to each category, using the most precise predictions available. A total cross-section uncertainty is correlated across all three.

Group	Systematic source	Description	$t\bar{t}$ categories
Normalisation	$t\bar{t}$ cross-section	Up or down by 6%	All, correlated
	$k(t\bar{t}+\geq 1c)$	Free-floating $t\bar{t}+\geq 1c$ normalization	$t\bar{t}+\geq 1c$
	$k(t\bar{t}+\geq 1b)$	Free-floating $t\bar{t}+\geq 1b$ normalization	$t\bar{t}+\geq 1b$
Modelling	SHERPA5F vs. nominal	Related to the choice of NLO event generator	All, uncorrelated
	PS & hadronization	POWHEG+HERWIG 7 vs. POWHEG+PYTHIA 8	All, uncorrelated
	ISR / FSR	Variations of μ_R, μ_F, h_{damp} and A14 Var3c parameters	All, uncorrelated
	$t\bar{t}+\geq 1c$ ME vs. inclusive	MG5_aMC@NLO+HERWIG++: ME prediction (3F) vs. incl. (5F)	$t\bar{t}+\geq 1c$
	$t\bar{t}+\geq 1b$ SHERPA4F vs. nominal	Comparison of $t\bar{t}+b\bar{b}$ NLO (4F) vs. POWHEG+PYTHIA 8 (5F)	$t\bar{t}+\geq 1b$
Theoretical	$t\bar{t}+\geq 1b$ renorm. scale	Up or down by a factor of two	$t\bar{t}+\geq 1b$
	$t\bar{t}+\geq 1b$ resumm. scale	Vary μ_Q from $H_T/2$ to μ_{CMMPS}	$t\bar{t}+\geq 1b$
	$t\bar{t}+\geq 1b$ global scales	Set μ_Q, μ_R, and μ_F to μ_{CMMPS}	$t\bar{t}+\geq 1b$
	$t\bar{t}+\geq 1b$ shower recoil scheme	Alternative model scheme	$t\bar{t}+\geq 1b$
	$t\bar{t}+\geq 1b$ PDF (MSTW)	MSTW vs. CT10	$t\bar{t}+\geq 1b$
	$t\bar{t}+\geq 1b$ PDF (NNPDF)	NNPDF vs. CT10	$t\bar{t}+\geq 1b$
	$t\bar{t}+\geq 1b$ UE	Alternative set of tuned parameters for the underlying event	$t\bar{t}+\geq 1b$
	$t\bar{t}+\geq 1b$ MPI	Up or down by 50%	$t\bar{t}+\geq 1b$
	$t\bar{t}+\geq 3b$ normalization	Up or down by 50%	$t\bar{t}+\geq 1b$

Uncertainty source	$\Delta\mu$	
$t\bar{t}+\geq 1b$ modeling	+0.46	−0.46
Background-model stat. unc.	+0.29	−0.31
b-tagging efficiency and mis-tag rates	+0.16	−0.16
Jet energy scale and resolution	+0.14	−0.14
$t\bar{t}H$ modeling	+0.22	−0.05
$t\bar{t}+\geq 1c$ modeling	+0.09	−0.11
JVT, pileup modeling	+0.03	−0.05
Other background modeling	+0.08	−0.08
$t\bar{t}$ + light modeling	+0.06	−0.03
Luminosity	+0.03	−0.02
Light lepton (e, μ) id., isolation, trigger	+0.03	−0.04
Total systematic uncertainty	+0.57	−0.54
$t\bar{t}+\geq 1b$ normalization	+0.09	−0.10
$t\bar{t}+\geq 1c$ normalization	+0.02	−0.03
Intrinsic statistical uncertainty	+0.21	−0.20
Total statistical uncertainty	+0.29	−0.29
Total uncertainty	+0.64	−0.61

The analysis is limited by the uncertainties related to tt̄ + ≥1b modelling and the statistical uncertainties on MC events.

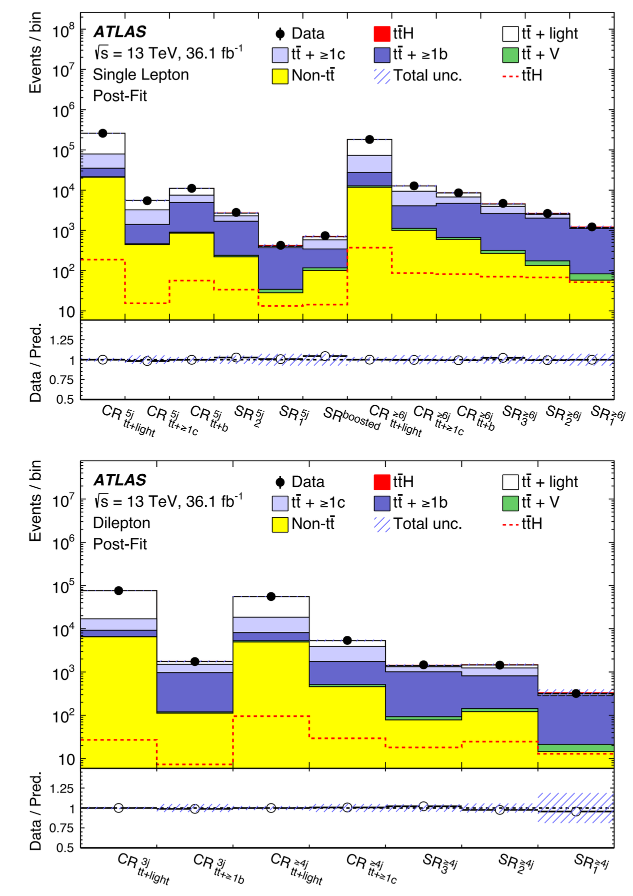
To improve upon this for a future analysis, improvements will be needed in understanding this dominant background from the theoretical community, further measurements and novel data-driven techniques.

Fitting

A profiled likelihood fit is performed over all signal and control regions. In the signal regions, the **classification BDT** is fitted to data. The combined fit provides the ability to constrain the background and reduce the impact of some uncertainties.

Scale factors are fitted for ttH, tt̄ + ≥1b and tt̄ + ≥1c.

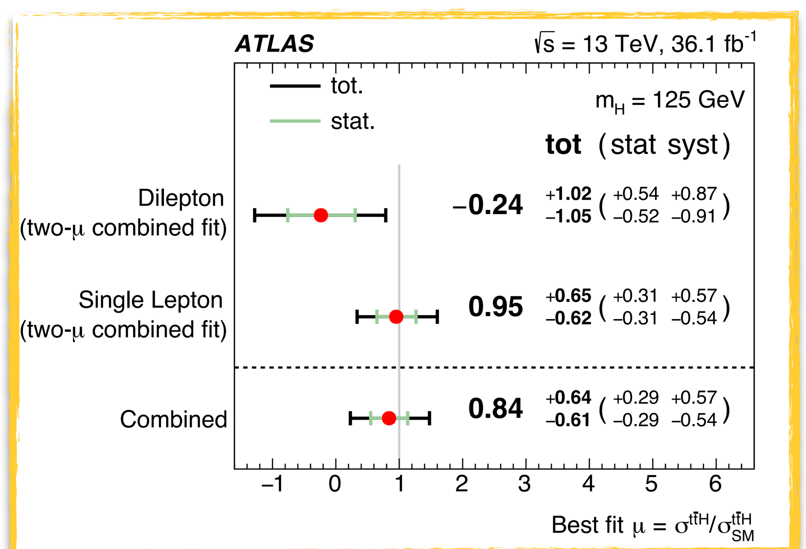
***μ*(tt̄ + ≥1b)**	**1.24 ± 0.10**
***μ*(tt̄ + ≥1c)**	**1.63 ± 0.23**

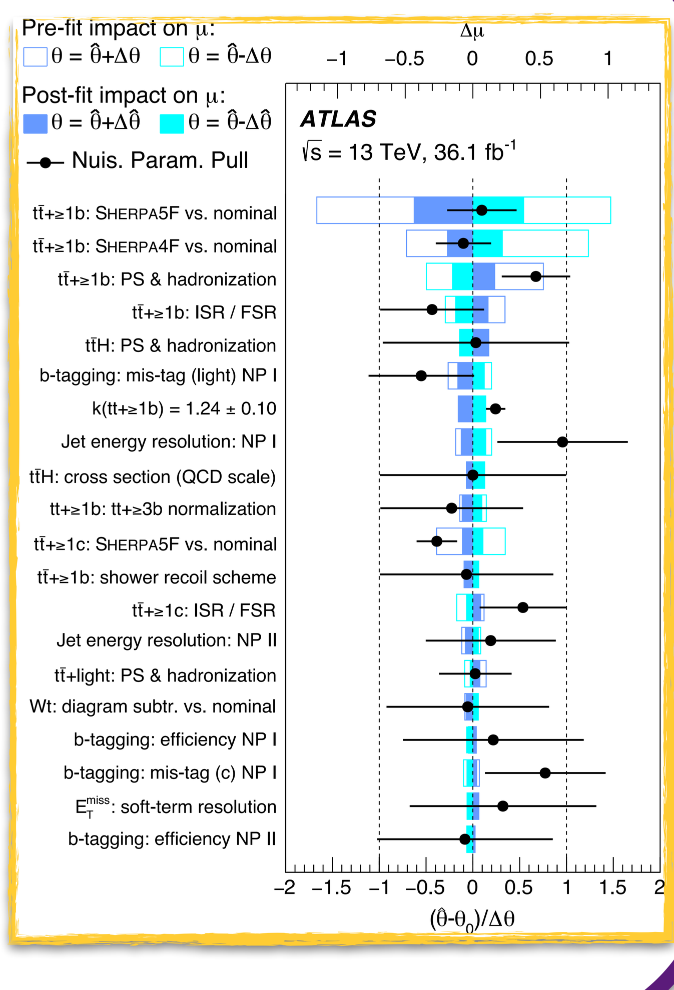


Results

The signal-strength, ***μ*(ttH)**, has been extracted using 36.1 fb^{-1} of 13 TeV data. Pseudo-data created from an alternative model found no strong bias in the signal extraction.

An excess of **1.4σ** is observed, with 1.6σ expected for a SM Higgs boson.





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