

Search for $t\bar{t}H$ production in multilepton final states using the ATLAS experiment at the LHC

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TEXAS

The University of Texas at Austin

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ATLAS

EXPERIMENT

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Outline

Introduction

Overview of the analysis with 13.2 fb^{-1} of data

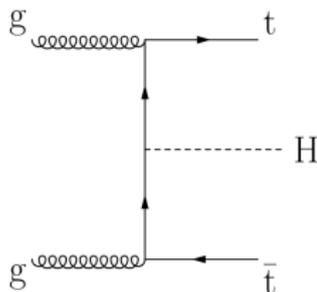
Updates with 36.1 fb^{-1} of data

$3l0\tau$ Channel

Results

Motivation

- ▶ $t\bar{t}H$ production provides a direct measurement of the top Yukawa coupling with the Higgs boson
- ▶ Has potential to identify and disambiguate new physics effects that can modify $t\bar{t}H$ cross section relative to the Standard Model(SM) value.



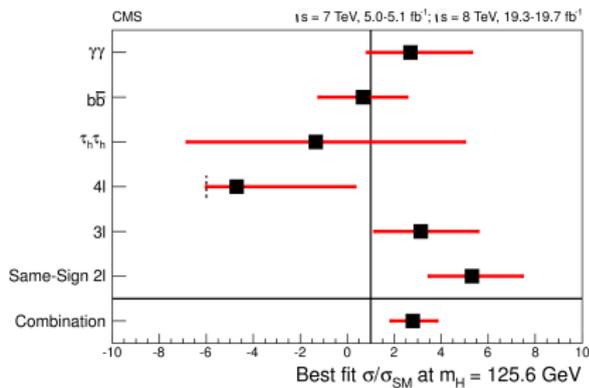
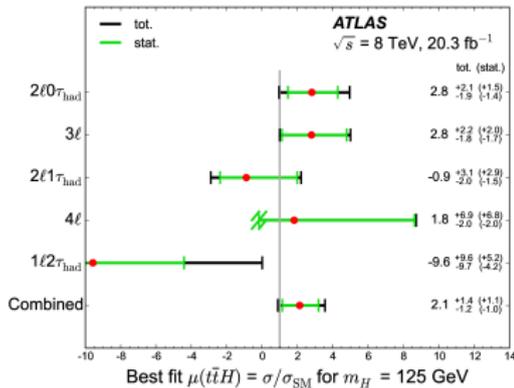
Run-1 and previous measurements

- ▶ Combined measurement of CMS and ATLAS experiments

with Run-1 data : $\mu_{t\bar{t}H} = \frac{\sigma_{t\bar{t}H}}{\sigma_{SM}^{t\bar{t}H}} = 2.3^{+0.7}_{-0.6}$ (JHEP 08 (2016)

045)

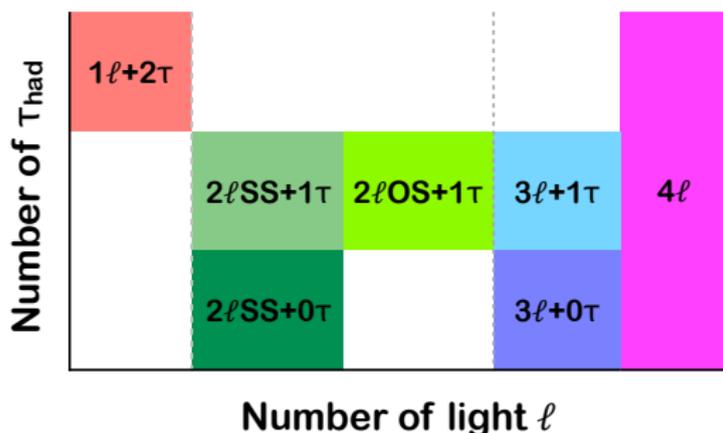
- ▶ The excess over the SM expectation is mainly due to multilepton final states



source : CERN-PH-EP-2015-109 and CMS-HIG-13-029

ttH in multilepton final states

- ▶ Targets mainly $H \rightarrow WW^*$ and $\tau\tau$ decay modes
- ▶ Top quarks almost exclusively decay into a W boson and a b quark
- ▶ Based on decay modes of W bosons and τ leptons, final state will contain multiple number of light leptons and jets
- ▶ ttHML analysis focuses on following 7 different final states



Major Background processes

Backgrounds with prompt leptons : $t\bar{t}Z$, Diboson, Triboson, tH , tWH and others

Non-prompt lepton backgrounds: $t\bar{t}$, $t\bar{t}\gamma$

- ▶ Source of non-prompt or “Fake” leptons
 - ▶ Real leptons from hadron decays in jets
 - ▶ Jets that punch through calorimeter to get through the muon chambers
 - ▶ Jets that are reconstructed as electrons
 - ▶ Electrons from Photon conversions
- ▶ For example, $t\bar{t}$ + jets can contain only up to two opposite-sign prompt leptons. It will contribute to $t\bar{t}H \rightarrow 3l$ signal region, because of fake leptons.

Introduction

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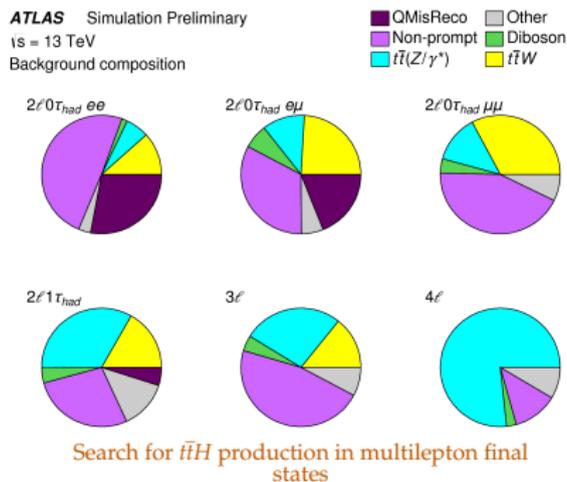
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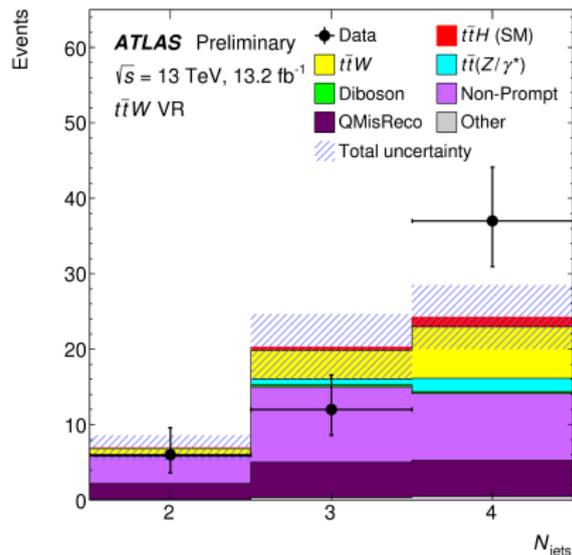
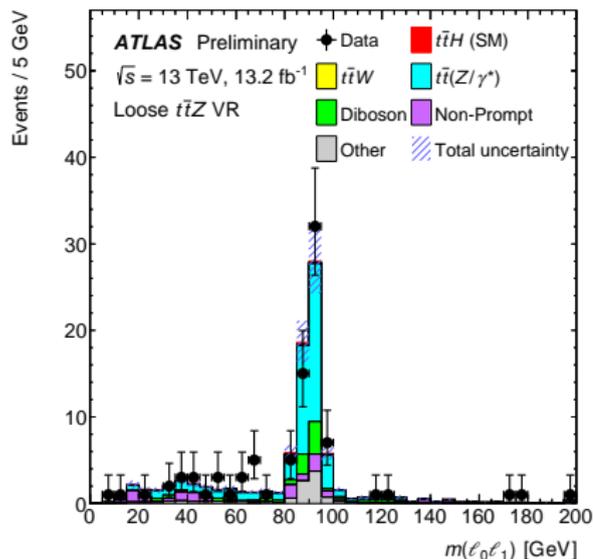
Overview of the previous ttHML analysis with 13.2 fb⁻¹ of data

- ▶ Previous analysis with 13.2 fb⁻¹ of data collected in 2015 and early 2016 is documented here: [ATLAS-CONF-2016-058](#)
- ▶ Analysis was carried out in four channels: 2lSS + 0τ, 2lSS + 1τ, 3l, 4l
- ▶ **cut and count analysis was performed in all channels**



Background validations

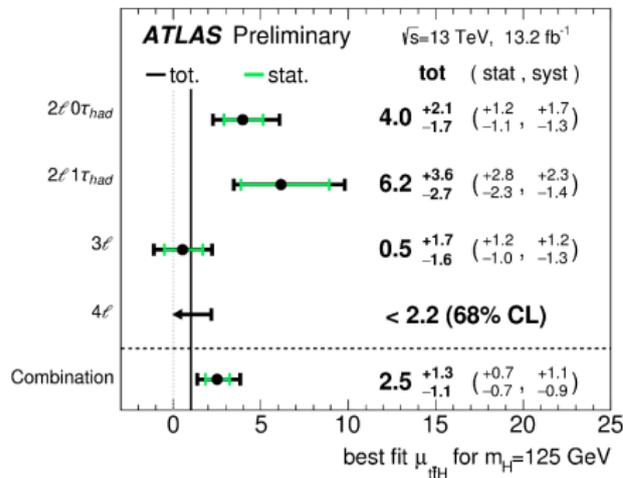
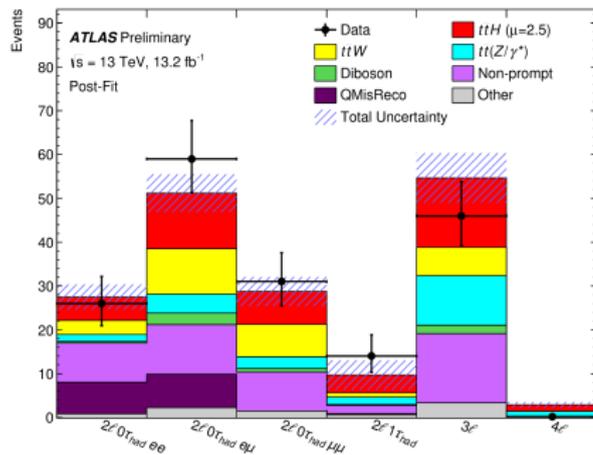
- ▶ Monte Carlo simulations have been validated in $t\bar{t}Z$ and $t\bar{t}W$ enriched regions with 13.2 fb^{-1} of data. They are in good agreement with the data



Source: ATLAS-CONF-2016-058

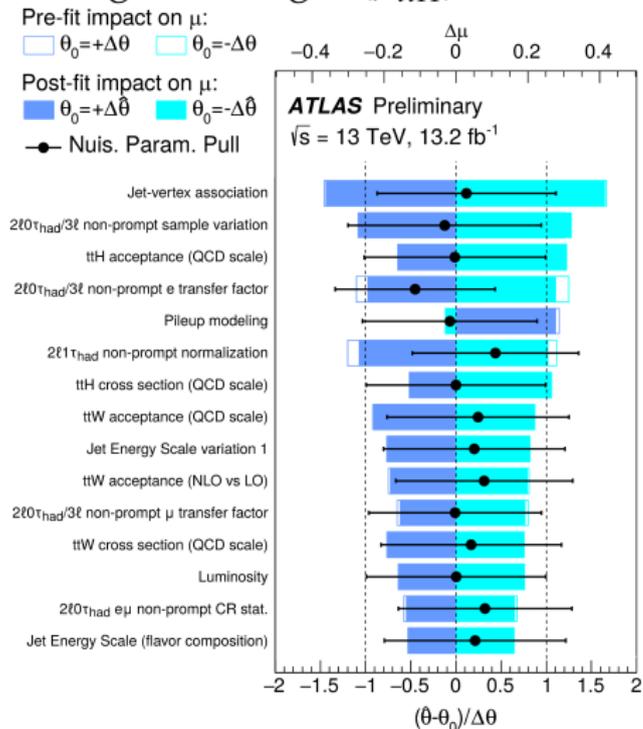
Results with 13.2 fb^{-1} of data

Best fit value of $t\bar{t}H$ multileptons combined signal strength = $2.5^{+1.3}_{-1.1}$



Ranking of systematic uncertainties

Most important systematic uncertainties and their impact on the signal strength ($\mu_{t\bar{t}H}$) measurement is shown here.



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New techniques developed for 36.1 fb^{-1} data analysis

- ▶ **Non-prompt lepton MVA :**
 - ▶ Systematic uncertainties related to non-prompt backgrounds are leading in the 13.2 fb^{-1} analysis
 - ▶ To reduce these backgrounds, a lepton MVA analysis has been developed for discriminating between prompt and non-prompt leptons
- ▶ **Event MVA techniques :**
 - ▶ MVA techniques have been developed for all channels except $3l + 1\tau_{had}$ channel
 - ▶ Based on the output of the MVA, each event will be categorized either as signal or as background

Non-prompt lepton MVA

- ▶ A lepton Multivariate Analysis (MVA) technique has been developed to reject non-prompt lepton backgrounds
- ▶ 8 input variables related to lepton isolation and b-tagging likelihood for track jets close to leptons are used as input variables for MVA training

Variable	Description
N_{track} in track jet	Number of tracks collected by the track jet
$\text{IP2 } \log(P_b/P_{\text{light}})$	Log-likelihood ratio between the b and light jet hypotheses with the IP2D algorithm
$\text{IP3 } \log(P_b/P_{\text{light}})$	Log-likelihood ratio between the b and light jet hypotheses with the IP3D algorithm
$N_{\text{TkAtVtx}} \text{ SV} + \text{JF}$	Number of tracks used in the secondary vertex found by the SV1 algorithm in addition to the number of tracks from secondary vertices found by the JetFitter algorithm with at least two tracks
$p_{\tau}^{\text{lepton}} / p_{\tau}^{\text{track jet}}$	The ratio of the lepton p_{τ} and the track jet p_{τ}
$\Delta R(\text{lepton, track jet})$	ΔR between the lepton and the track jet axis
$p_{\tau} \text{VarCone30} / p_{\tau}$	Lepton track isolation, with track collecting radius of $\Delta R < 0.3$
$E_{\tau} \text{TopoCone30} / p_{\tau}$	Lepton calorimeter isolation, with topological cluster collecting radius of $\Delta R < 0.3$

Analysis Strategy

- ▶ Event MVA techniques have been developed for all channels except $3l + 1\tau_{had}$ channel because of low statistics
- ▶ These techniques rely on shapes from MC for training except for backgrounds with fake leptons
- ▶ kinematic and topological aspects of the event are given as inputs for each channel
- ▶ In $2lSS + 0\tau$ and $3l0\tau$ channels, Event MVAs have been cross-checked with cut-based approaches

Channel	Event MVA	Cut-based analysis
$1l + 2\tau$	✓	
$2lSS + 0\tau$	✓	✓
$2lSS + 1\tau$	✓	
$2lOS + 1\tau$	✓	
$3l0 + \tau$	✓	✓
$3l + 1\tau$		✓
$4l$	✓	

- ▶ We are currently in the process of finalizing results of the analysis

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3l0 τ channel Optimization

In the next few slides, I will focus on the cut-based categorization analysis in the 3l0 τ channel.

Pre-Selection for 3l0 τ channel:

- ▶ Exactly 3 leptons with $|\sum q| == 1$ and 0 hadronic taus in the event
- ▶ Trigger matched lepton(s) (Single lepton and dilepton triggers used)
- ▶ $p_T > 15$ GeV for same sign leptons & $p_T > 10$ GeV for opposite sign lepton
- ▶ Same sign leptons must pass Non-prompt lepton MVA selection
- ▶ Z-veto on 3-lepton invariant mass
- ▶ at least 3 jets with at least 1 b-tagged jet

Cut-based cross-check for $3l0\tau$ channel

- ▶ $3l0\tau$ signal region has been divided into 12 categories based on following variables

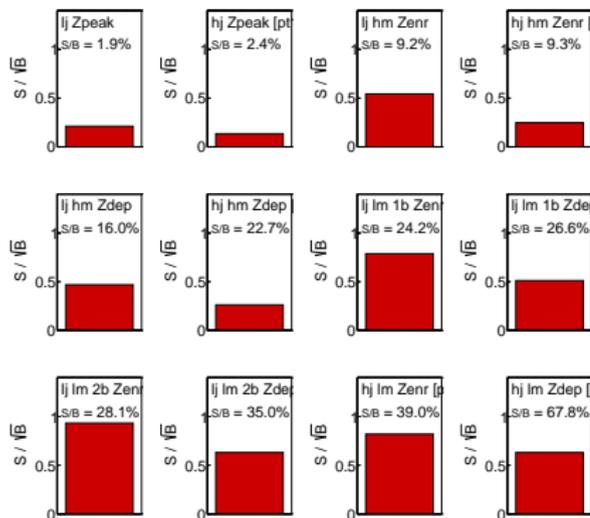
Variable	Reduced background	Regions
Number of jets	$t\bar{t}, WZ$	less than 6 or ≥ 6 jets
Number of b-jets	$t\bar{t}, WZ$	1b-jet or > 1 b-jets
Number of Opposite Sign Same Flavor lepton pairs	$t\bar{t}Z, WZ$	zero or ≥ 1 with no Z candidate or at least one Z candidate
Invariant mass of opposite sign leptons with smallest angular separation	$t\bar{t}W, t\bar{t}Z$	above or below 70e3

Expected signal & background distributions

- ▶ S/B and S/\sqrt{B} values for each region are shown here
- ▶ Regions with low S/B values act as control regions

$\sqrt{s} = 13 \text{ TeV}$, 36.1 fb^{-1}
v29SystPlots

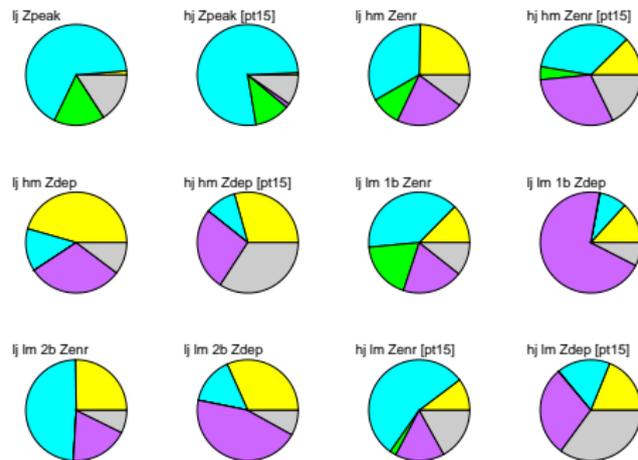
ATLAS Simulation Work in Progress



$\sqrt{s} = 13 \text{ TeV}$
v29SystPlots

ATLAS Simulation Work in Progress

Other (grey), Diboson (green), $t\bar{t}$ (cyan), Fakes (purple), $t\bar{t}W$ (yellow)



Results & Summary

- ▶ Best fit value of the $t\bar{t}H$ multileptons combined signal strength with 13.2 fb^{-1} data is $= 2.5^{+1.3}_{-1.1}$ which corresponds to 1.3σ
- ▶ **Work in Progress: Results with the full 2015 and 2016 dataset**
- ▶ Uncertainties on the $t\bar{t}H$ measurement will be decreased significantly with the expected 100 fb^{-1} of data by end of Run-2