Analysis of $t\bar{t}H(b\bar{b})$ in single lepton channel with run II data

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HiggsTools closing meeting
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Overview

Introduction

ICHEP result for $t\bar{t}H(b\bar{b})$

b-tagging ICHEP and beyond

Conclusion

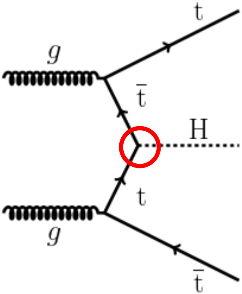
Higgs discovery big success for the Standard Model (SM)

Open question now:

- Is the found boson the SM-Higgs boson?
- How compatible are its features with the SM-Higgs boson?

Stepping stones toward an answer are measurements of:

- spin properties
- *CP*-properties
- coupling to fermions/bosons

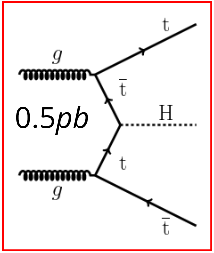


$t\bar{t}H$ provides access to the **top Yukawa coupling Y_t**

Y_t is sensitive to new physics → deviations of SM value might have dramatic consequences for vacuum stability of the universe

Introduction II

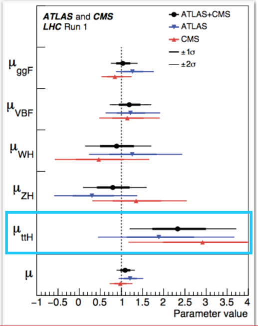
- Measurement of $t\bar{t}H$-signal strength ($\mu_{t\bar{t}H}$) in LHC run I:
  4.4 sigma combined significance, cross-section above SM value but consistent within large uncertainty.
- Why $t\bar{t}H$ in run II?
  → *large increase* of the $t\bar{t}H$ cross-section!
  though backgrounds increase at a comparable rate in the signal regions...



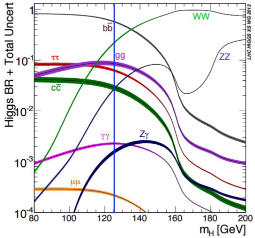
Cross section (fb)

@NLO	$t\bar{t}H$	$t\bar{t}W$	$t\bar{t}Z$	$t\bar{t}$(NNLO)
8 TeV	133	232	206	2,53E+05
13 TeV	507	566	760	8,32E+05
13 TeV / 8TeV	3.8	2.4	3.7	3.3

→ $t\bar{t}H$-production cross-section is < 1% of ggF production x-section



Higgs decay mode	Branching ratio [%]
$H \to bb$	58.1
$H \to WW$	21.5
$H \to \tau\tau$	6.3
$H \to ZZ$	2.6
$H \to \gamma\gamma$	0.23



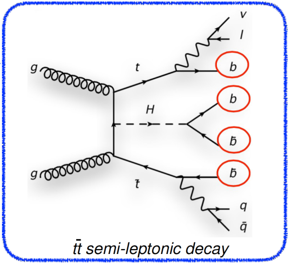
Dedicated analysis for all channels but:

$\to$ focus on $H \to b\bar{b}$ decay!

It has:

- largest branching ratio
- offers sensitivity to bottom Yukawa coupling

tt̄H(bb) Feynman diagram



Goal of this talk: summarize public material by Atlas in $t\bar{t}H(b\bar{b})$, a.k.a. ICHEP result.

Event selection:

Single Lepton

- one electron or muon
- at least 4 jets
- at least 2 b-tagged jets

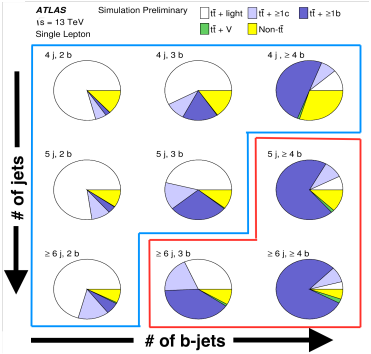
What is a jet in Atlas?

→reconstructed objects from

- calorimeter hits
- anti-k_t algorithm with $r = 0.4$

After calibration jets are required to have:

- $p_T > 25$Gev
- $\eta < 2.5$



Signal region

Control region

→ Categorize according to nb. of jets and nb. of b-jets

- $t\bar{t} + \geq 1b$, $t\bar{t} + \geq 1c$, $t\bar{t}$+light are main backgrounds
- target different background composition in fit to reduce uncertainties

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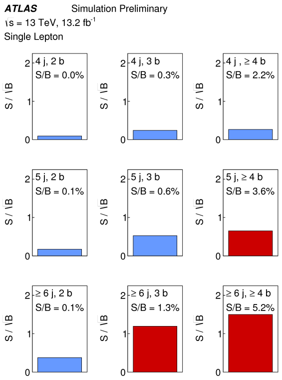

Signal region
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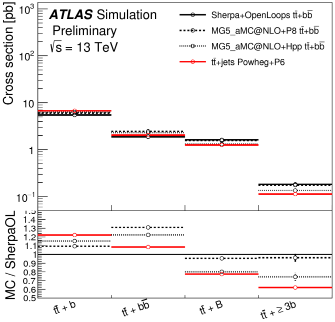
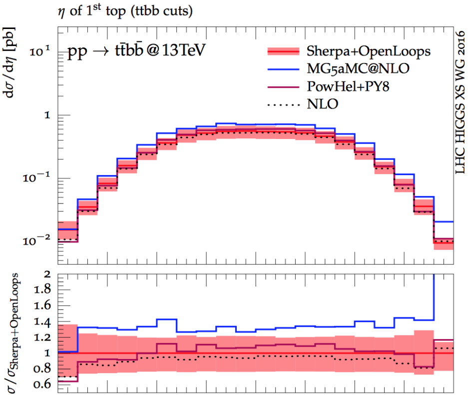
MC modeling of backgrounds

- Using MC prediction for $t\bar{t}$+jets from Powheg+Pythia6 at NLO
- Correcting top and $t\bar{t}$-p_T to NNLO calculation
- Reweight the $t\bar{t}+\geq 1b$-category in PP6 to 4-flavor Sherpa+OpenLoops calculation
- Systematic uncertainties of different kinds considered, e.g. generator, parton shower, PDF, ...



Uncertainty source	$\Delta\mu$	
$t\bar{t}+\geq 1b$ modelling	+0.53	−0.53
Jet flavour tagging	+0.26	−0.26
$t\bar{t}H$ modelling	+0.32	−0.20
Background model statistics	+0.25	−0.25
$t\bar{t}+\geq 1c$ modelling	+0.24	−0.23
Jet energy scale and resolution	+0.19	−0.19
$t\bar{t}$+light modelling	+0.19	−0.18
Other background modelling	+0.18	−0.18
Jet-vertex association, pileup modelling	+0.12	−0.12
Luminosity	+0.12	−0.12
$t\bar{t}Z$ modelling	+0.06	−0.06
Light lepton (e,μ) ID, isolation, trigger	+0.05	−0.05
Total systematic uncertainty	+0.90	−0.75
$t\bar{t}+\geq 1b$ normalisation	+0.34	−0.34
$t\bar{t}+\geq 1c$ normalisation	+0.14	−0.14
Statistical uncertainty	+0.49	−0.49
Total uncertainty	+1.02	−0.89

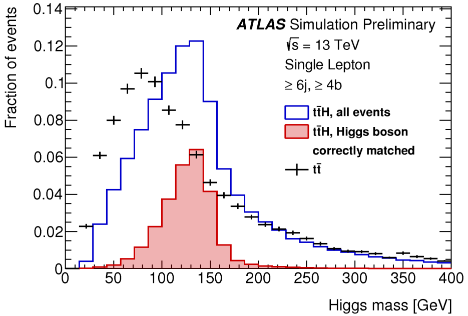
- study of different generators for prediction of the irreducible background $t\bar{t}b\bar{b}$ in LHC yellow report 4 arXiv:1610.07922v1



→ ongoing discussion how to treat $t\bar{t}b\bar{b}$
→ bottleneck for measurement of $t\bar{t}H$, theo. uncertainty $\mathcal{O}$**(40%) at NLO**
Multiscale problem: What scale to use in simulation?

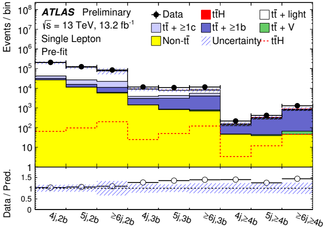
2-step BDT approach (boosted decision tree)

- ambiguities in the assignment of b-jets to Higgs or top
- target to overcome this ambiguity with a BDT
- "signal" in training step is the correct combination and background the rest

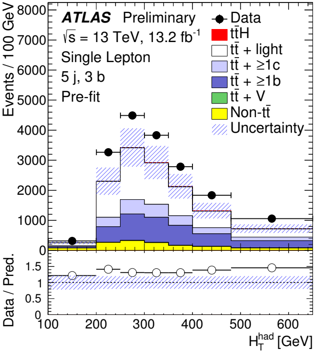


12% correctly assigned jets
8% without Higgs information

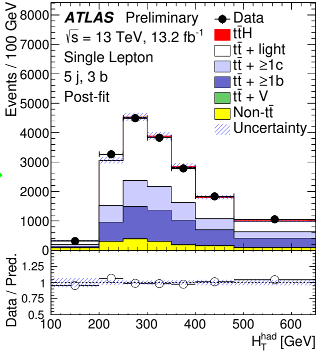
Fit model

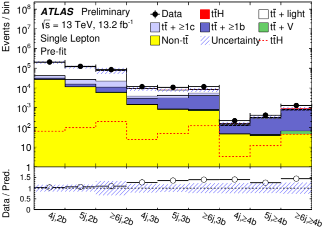


- fit in 14 regions
- $t\bar{t} + \geq 1b$ and $t\bar{t} + \geq 1c$ normalisation taken as free parameters from the fit
- variable in SR: BDT
- variable in CR: H_T (scalar sum of all jets)



Fit →





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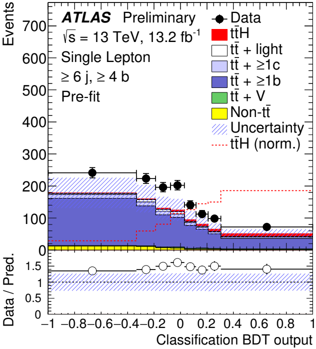
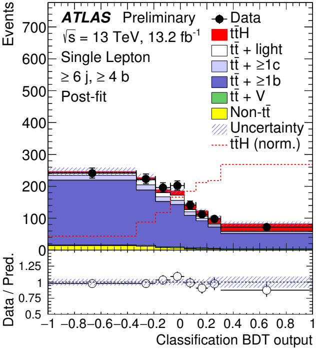


Fit →



Fit result in single lepton

$$\mu_{t\bar{t}H} = 1.6^{+1.1}_{-1.1} (\text{ stat.}^{+0.5}_{-0.5} \text{ sys.}^{+1.0}_{-0.9})$$

result is:

- compatible with SM expectation
- systematically dominated
  $\rightarrow t\bar{t} + \geq 1b$ and $t\bar{t} + \geq 1c$ normalisation and modeling are main systematics

$\rightarrow$ adding just more data does not help

more accurate and precise description of phase $t\bar{t}H(b\bar{b})$-phase space is needed, especially for main backgrounds points to improve on

theory:

- more accurate $t\bar{t}b\bar{b}$-prediction, better $t\bar{t}$+jets modeling
- clear(er) prescription how to use 4-flavor prediction in experiment
- in general: how to construct a better $t\bar{t}$-model for that specific phase space

experiment:

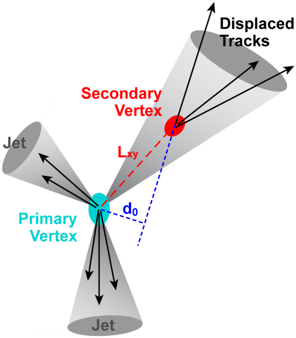
- regions (more) enriched in $t\bar{t} + \geq 1b$, $t\bar{t} + \geq 1c$ and $t\bar{t}H$ $\rightarrow$ more accurate measurement of normalisation factors
- better b-tagging performance

b-tagging in Atlas

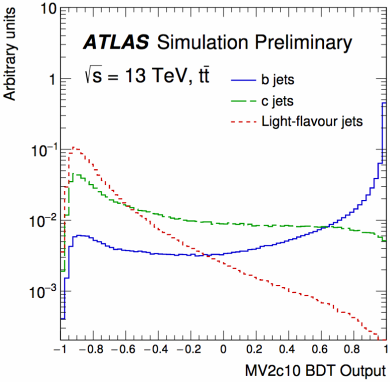
b-tagging: identification of jets originating from b-quarks

Mainly 3 different ideas:

1. Secondary vertices
2. Impact parameter of tracks
3. Decay chain of a B-hadron



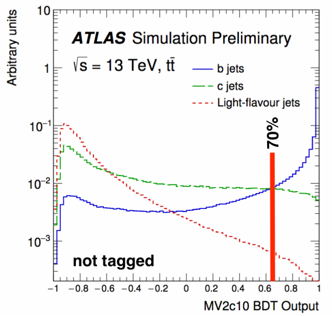
Main algorithm
(combination of these ideas):

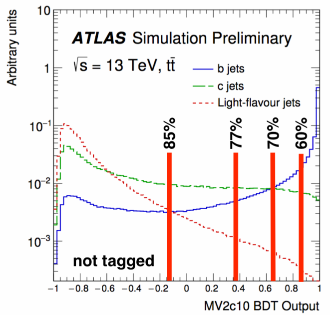


→ Result is a powerful variable to separate b-jets from other jets

Improvements in b-tagging

Traditional b-tagging vs continuous b-tagging





Traditional b-tagging: uses 2 bins of the distribution

Continuous b-tagging: attempt to use more bins and gain more information

- Need to convert fixed-cut calibration into (pseudo-)continuous calibration
- Underlying calibrations need to be present

Conclusion

result is compatible with SM expectation

$t\bar{t}H(b\bar{b})$-ICHEP analysis is *systematics* dominated

$\rightarrow$ The time for improvements of the analysis is now

Complicated analysis with many different objects

possible improvements in:

- MC prediction for $t\bar{t}+\geq 1b$-backgrounds
- b-tagging
- analysis strategy which exploits improvements in b-tagging

Stay tuned for more news!

Hopefully really, really soon...

BACKUP

MC details

Simulation of $t\bar{t}$+jets:

ME gen. PS/UE gen.	Powheg-Box Pythia 6.428	Powheg-Box Herwig++ 2.7.1	MG5_aMC Herwig++ 2.7.1	Powheg-Box Pythia 6.428	Powheg-Box Pythia 6.428
Ren. scale	$\sqrt{m_t^2 + p_{\mathrm{T},t}^2}$	$\sqrt{m_t^2 + p_{\mathrm{T},t}^2}$	$\sqrt{m_t^2 + \frac{1}{2}(p_{\mathrm{T},t}^2 + p_{\mathrm{T},\bar{t}}^2)}$	$\frac{1}{2} \cdot \sqrt{m_t^2 + p_{\mathrm{T},t}^2}$	$2 \cdot \sqrt{m_t^2 + p_{\mathrm{T},t}^2}$
Fact. scale	$\sqrt{m_t^2 + p_{\mathrm{T},t}^2}$	$\sqrt{m_t^2 + p_{\mathrm{T},t}^2}$	$\sqrt{m_t^2 + \frac{1}{2}(p_{\mathrm{T},t}^2 + p_{\mathrm{T},\bar{t}}^2)}$	$\frac{1}{2} \cdot \sqrt{m_t^2 + p_{\mathrm{T},t}^2}$	$2 \cdot \sqrt{m_t^2 + p_{\mathrm{T},t}^2}$
hdamp	m_t	m_t	–	$2 \cdot m_t$	m_t
ME PDF	CT10	CT10	CT10	CT10	CT10
PS/UE PDF	CTEQ6L1	CTEQ6L1	CTEQ6L1	CTEQ6L1	CTEQ6L1
Tune	P2012	UE-EE5	UE-EE5	P2012 radHi	P2012 radLo

Simulation details for $t\bar{t}b\bar{b}$:

ME gen. PS/UE gen.	MG5_aMC Herwig++ 2.7.1	MG5_aMC Pythia 8.210	SherpaOL Sherpa
Renorm. scale	μ_{CMMPS}	μ_{CMMPS}	μ_{CMMPS}
Fact. scale	$H_{\mathrm{T}}/2$	$H_{\mathrm{T}}/2$	$H_{\mathrm{T}}/2$
Resumm. scale	$f_{\mathrm{Q}}\sqrt{\hat{s}}$	$f_{\mathrm{Q}}\sqrt{\hat{s}}$	$H_{\mathrm{T}}/2$
ME PDF	NNPDF3.0 4F	NNPDF3.0 4F	CT10 4F
PS/UE PDF	CTEQ6L1	NNPDF2.3	
Tune	UE-EE-5	A14	Author's tune

Reco BDT details single lepton

Variable	≥6j, ≥4b	≥6j, =3b	=5j, ≥4b
Topological information from $t\bar{t}$:			
t_{lep} mass	✓	✓	✓
t_{had} mass	✓	✓	–
Incomplete t_{had} mass	–	–	✓
W_{had} mass	✓	✓	–
Mass of W_{had} and b from t_{lep}	✓	✓	–
Mass of q from W_{had} and b from t_{lep}	–	–	✓
Mass of W_{lep} and b from t_{had}	✓	✓	✓
$\Delta R(W_{\mathrm{had}}$, b from $t_{\mathrm{had}})$	✓	✓	–
$\Delta R(q$ from W_{had}, b from $t_{\mathrm{had}})$	–	–	✓
$\Delta R(W_{\mathrm{had}}$, b from $t_{\mathrm{lep}})$	✓	✓	–
$\Delta R(q$ from W_{had}, b from $t_{\mathrm{lep}})$	–	–	✓
$\Delta R(\mathrm{lep}$, b from $t_{\mathrm{lep}})$	✓	✓	✓
$\Delta R(\mathrm{lep}$, b from $t_{\mathrm{had}})$	✓	✓	✓
$\Delta R(b$ from t_{lep}, b from $t_{\mathrm{had}})$	✓	✓	✓
$\Delta R(q_1$ from W_{had}, q_2 from $W_{\mathrm{had}})$	✓	✓	–
$\Delta R(b$ from t_{had}, q_1 from $W_{\mathrm{had}})$	✓	✓	–
$\Delta R(b$ from t_{had}, q_2 from $W_{\mathrm{had}})$	✓	✓	–
min. $\Delta R(b$ from t_{had}, q from $W_{\mathrm{had}})$	✓	✓	–
$\Delta R(\mathrm{lep}$, b from $t_{\mathrm{lep}})$ - min. $\Delta R(b$ from t_{had}, q from $W_{\mathrm{had}})$	✓	✓	–
$\Delta R(\mathrm{lep}$, b from $t_{\mathrm{lep}})$ - $\Delta R(b$ from t_{had}, q from $W_{\mathrm{had}})$	–	–	✓
Topological information from Higgs :			
Higgs mass	✓	✓	✓
Mass of Higgs and q_1 from W_{had}	✓	✓	✓
$\Delta R(b_1$ from Higgs, b_2 from Higgs$)$	✓	✓	✓
$\Delta R(b_1$ from Higgs, lep$)$	✓	✓	✓
$\Delta R(b_1$ from Higgs, b from $t_{\mathrm{lep}})$	–	✓	✓
$\Delta R(b_1$ from Higgs, b from $t_{\mathrm{had}})$	–	✓	✓

Classification BDT details single lepton

Variable	Definition	Region		
		$\geq$ 4j, $\geq$ 4b	$\geq$ 4j, 3b	3j, 3b
General kinematic variables				
$\Delta\eta_{bb}^{\text{avg}}$	Average $\lvert\Delta\eta\rvert$ among pairs of b-jets	✓	–	–
$\Delta\eta_{\text{bb}}^{\text{max}}$	Maximum $\Delta\eta$ between any two b-jets	–	✓	✓
$\Delta\eta_{\text{jj}}^{\text{avg}}$	Average $\Delta\eta$ among jet pairs	–	✓	–
$\Delta R_{bb}^{\text{max}\ p_T}$	ΔR between the two b-tagged jets with the largest vector sum p_{T}	✓	✓	✓
$\Delta R_{\text{bb}}^{\text{Higgs}}$	ΔR between the two b-tagged jets with mass closest to the Higgs boson mass	✓	–	–
$\Delta R_{\text{bb}}^{\text{max m}}$	ΔR between the two b-jets with the largest invariant mass	✓	✓	✓
$m_{\text{bb}}^{\text{max}\ p_T}$	Mass of the two b-tagged jets with the largest vector sum p_{T}	–	–	✓
$m_{\text{bb}}^{\text{Higgs}}$	Mass of the two b-tagged jets closest to the Higgs boson mass	✓	✓	✓
$m_{\text{bb}}^{\text{min}}$	Minimum mass of two b-tagged jets	–	–	✓
$m_{\text{bb}}^{\text{min}\ \Delta R}$	Mass of the combination of the two b-tagged jets with the smallest ΔR	✓	✓	✓
$p_{\text{T},b}^{\text{min}}$	Minimum b-tagged jet p_{T}	–	–	✓
$H_{\text{T}}^{\text{all}}$	Scalar p_{T} sum of all leptons and jets	–	✓	✓
$\text{N}_{\text{bb}}^{\text{Higgs 30}}$	Number of b-jet pairs with invariant mass within 30 GeV of the Higgs boson mass	✓	–	✓
$\text{N}_{\text{jj}}^{\text{Higgs 30}}$	Number of jet pairs with invariant mass within 30 GeV of the Higgs boson mass	–	✓	–
Aplanarity	$1.5\lambda_2$, where λ_2 is the second eigenvalue of the momentum tensor [42] built with all jets	✓	✓	✓
Centrality	Sum of the p_{T} divided by sum of the E for all jets and both leptons	✓	–	✓
$H2_{\text{jets}}$	Third Fox–Wolfram moment computed using all jets	–	✓	–
$H4_{\text{all}}$	Fifth Fox–Wolfram moment computed using all jets and leptons	–	–	✓
Variables from reconstruction BDT output				
BDT output		✓*	✓*	–
m_{H}	Higgs boson mass	✓(*)	✓(*)	–
$\Delta\eta_{\text{H},l}^{\text{min}}$	Minimum $\Delta\eta$ between the Higgs boson and a lepton	✓*	✓	–
$\Delta\eta_{\text{H},l}^{\text{max}}$	Maximum $\Delta\eta$ between the Higgs boson and a lepton	✓*	✓	–
$\Delta\eta_{\text{H,b}}^{\text{min}}$	Minimum $\Delta\eta$ between the Higgs boson and a b-jet	✓*	–	–