Studies of $t\bar{t}$ production with additional heavy flavour jets in p-p collisions with the ATLAS detector

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für Bildung
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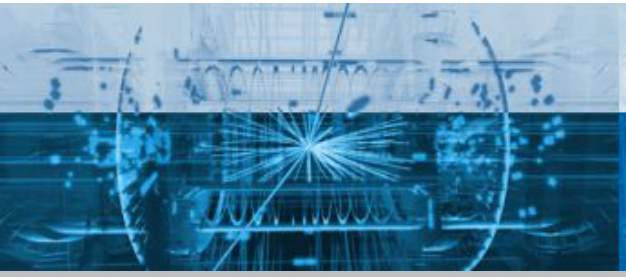

BMBF-ErUM-Forschungsschwerpunkt
ATLAS-EXPERIMENT
Ausbau von ATLAS am LHC: Physik mit dem ATLAS-Experiment
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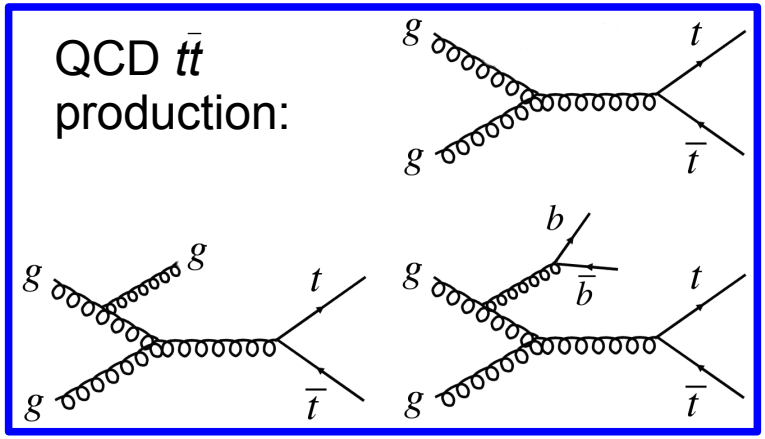
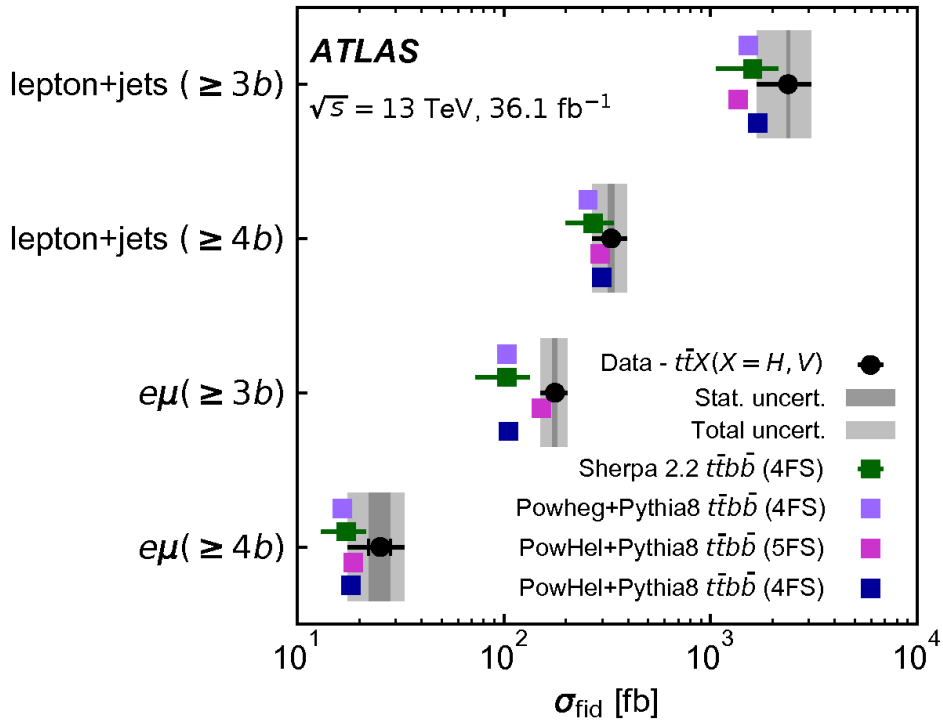
Motivation

- Differential cross section measurements provide tests of perturbative QCD at higher orders
- Measurement of QCD radiation jets produced with $t\bar{t}$ is crucial for tuning MC generator parameters
- $t\bar{t}$ + jets is an interesting background to rare SM processes (e.g. *ttH*, 4-tops) as well as beyond the standard model
- Improve 13 TeV measurements with fullRun-2 data and with more detailed exploration of the observables in a broader phase space



(JHEP 04 (2019) 046)



Measured cross sections are higher than NLO ME+PS $t\bar{t}b\bar{b}$ predictions but still consistent within uncertainties

Introduction

Measurement of:

- Differential distributions in $t\bar{t}$+*b*-jets fiducial phase space
- In *eμ* channel, opposite sign (OS)
  - Relatively smaller ambiguity in *b*-jets from top and additional jets

Challenging background:

- Mis-tagged $t\bar{t}$+light-jets and $t\bar{t}$+*c*-jets estimated using data-driven technique

Additional *b*-jets identification

- Full reconstruction of tops is difficult in dilepton channel
- Use kinematic variables to separate additional *b*-jets

Interesting observables:

- Jet and *b*-jet multiplicity
- p_T spectra of leading *b*-jet from top and leading additional *b*-jet

Object and Event Selection

Lepton:

|η|	*e*: |η| ≤ 2.47 *μ*: |η| ≤ 2.5
p_T-Cut:	$p_T \geq 25$ GeV

Jet:

|η|	|η| ≤ 2.5
p_T-Cut:	$p_T \geq 25$ GeV
b-Tagging:	DL1r @77% Working point (WP)

Dilepton channel:

- Exactly one electron and one muon with OS
- Leptons must satisfy single lepton trigger thresholds (25/27/28/28 GeV for 15/16/17/18)

Invariant Mass:

- Electron and muon pair invariant mass > 15 GeV

Jet Selection:

- At least 3 jets and 2 b-tagged jets

Background estimation

Signal:

- $t\bar{t}$, QCD

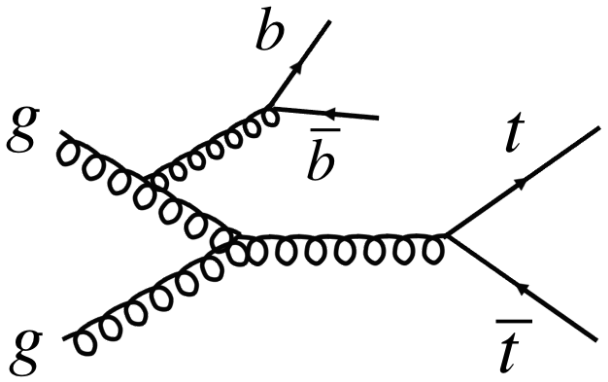
MC based estimation:

- $t\bar{t}H$
- $t\bar{t}V$
- Single top *tW*
- Diboson
- *Z+jets*
- *Others (tZ, tWZ(Z→ll), tWH, tHjb, 4 tops)*

Data-driven correction:

- Fake and non-prompt
- Mis-tagged $t\bar{t}$+light-jets and $t\bar{t}$+*c*-jets

QCD $t\bar{t}b\bar{b}$ production:

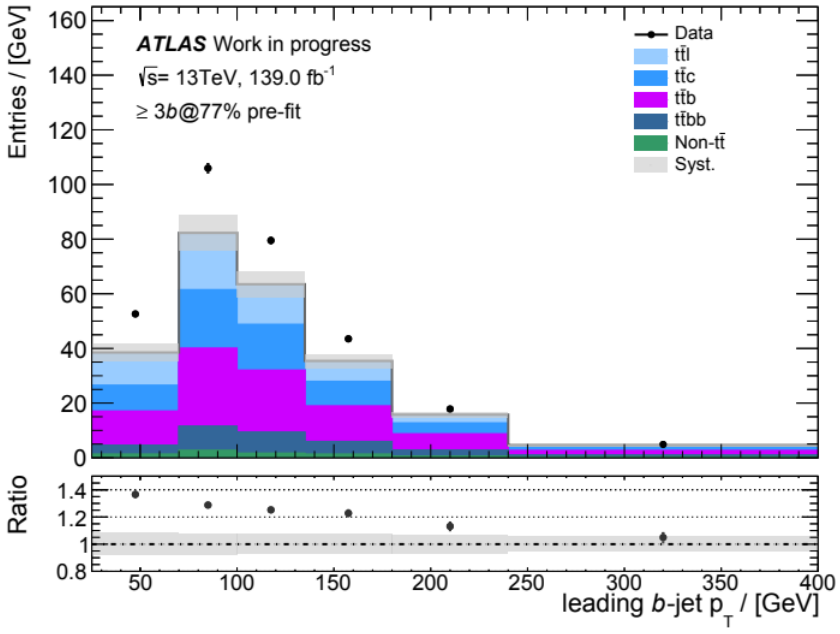


$t\bar{t}$+lights and $t\bar{t}$+*c* jets background estimation

- Contribution of the mistagged jets coming from $t\bar{t}$+light-jets and $t\bar{t}$+*c*-jets is significant background of $t\bar{t}$+*b*-jets measurement
- **≥3*b*-tagged jets at 77% WP**: Only about 50% of events selected at detector level have at least three b-jets at particle level
  - Other events have at least one *c*-jet or light-flavour jet which is misidentified as a *b*-jet
  - Rejection rate:
    - *c*-jets: 5
    - light-jets: 170
- Lack of precise measurements of $t\bar{t}$+light-jets and $t\bar{t}$+*c*-jets

→ Template fits to data are performed in control regions to estimate the normalisation of $t\bar{t}$+light-jet and $t\bar{t}$+*c*-jet backgrounds

Leading *b*-jet p_T

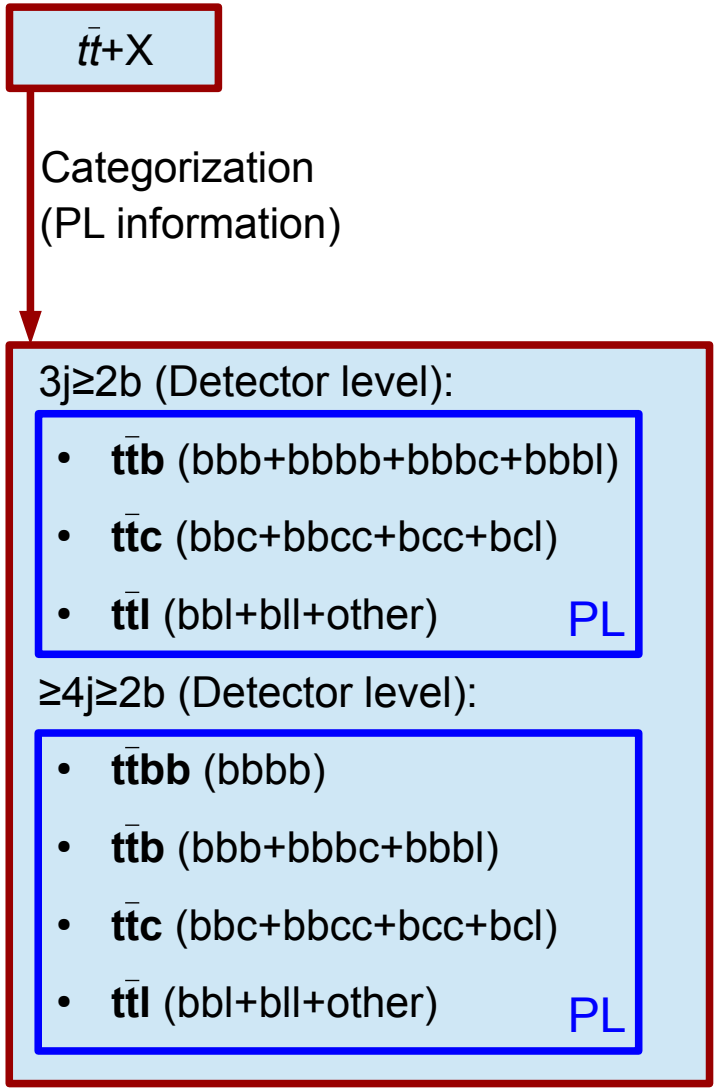


Flavour fit: Categorization

Categorization:

- Two control regions:
  - exactly 3 jets and ≥ 2 *b*-tagged jets
  - ≥ 4 jets and ≥ 2 *b*-tagged jets
- Split into categories using number of *b*-, *c*- and light-jets at particle level (PL):
  - **$t\bar{t}b$**
  - **$t\bar{t}bb$**
  - **$t\bar{t}c$**
  - **$t\bar{t}$+light (= $t\bar{t}l$)**

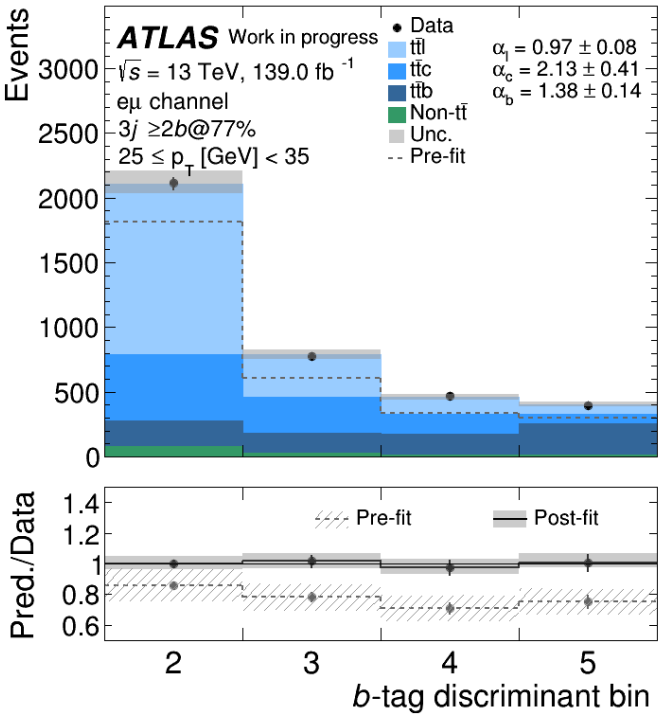
Templates are obtained from $t\bar{t}$, $t\bar{t}H$ and $t\bar{t}V$ MC



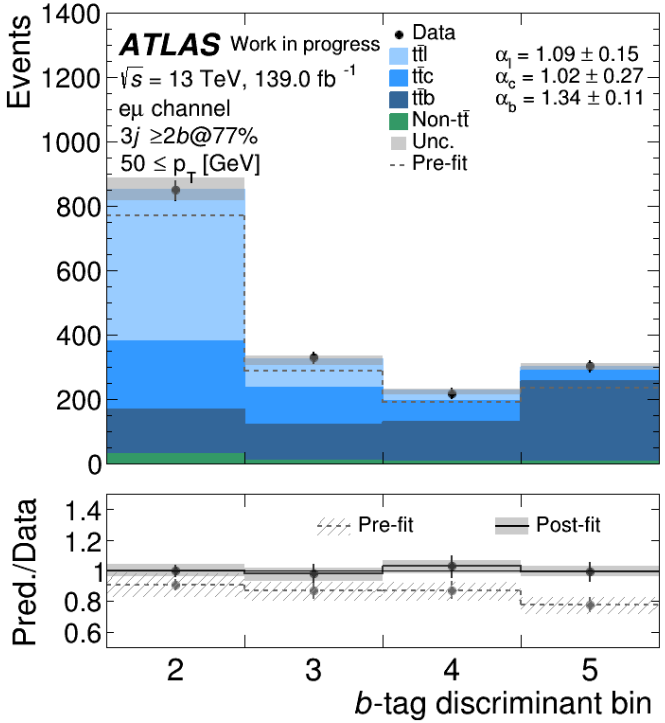
Flavour fits in p_T regions

- **3j≥2b region**
- Jets sorted according to the b-tagging efficiency (b-tagging discriminant, DL1r):
  - Using 3rd *b*-tag discriminant ranked jet as a variable seperating ***ttb***, ***ttc*** and ***ttl*** (also a proxy for 1st additional jet)
- **3rd leading Reco jet p_T dependent slices**

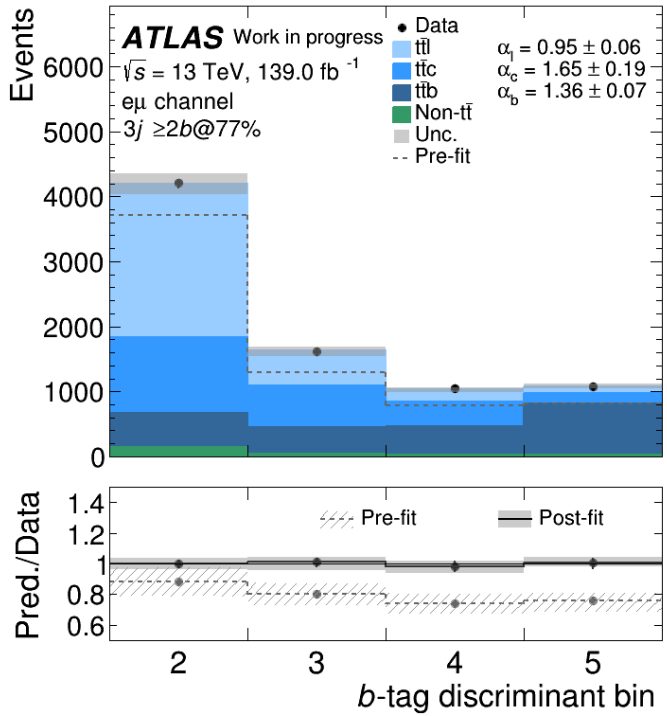
25 – 35 GeV:



≥ 50 GeV:



jet p_T inclusive:

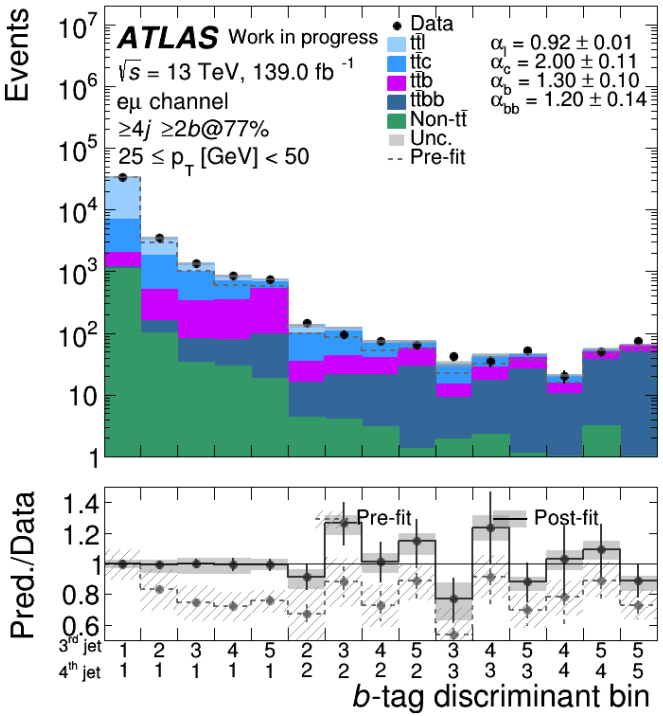


B-tag eff. borders	100-85%	85-77%	77-70%	70-60%	60-0%
B-tag discr.	1	2	3	4	5

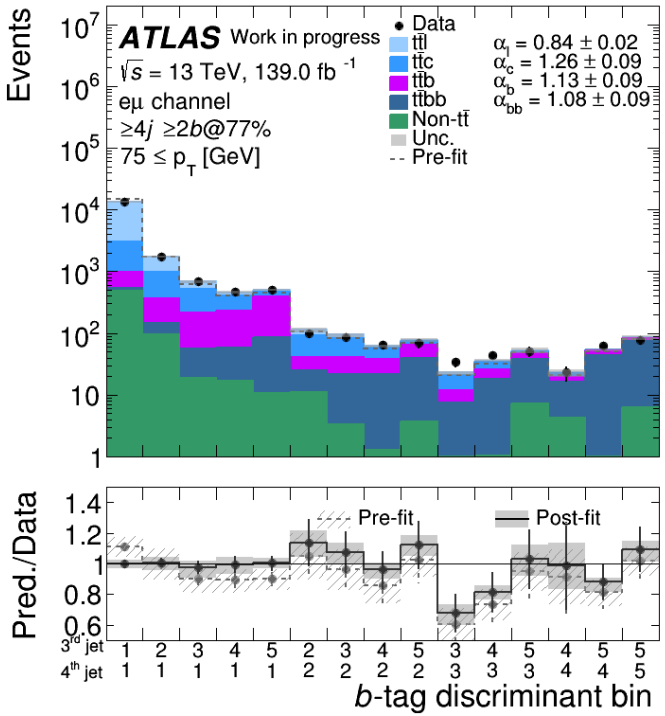
Flavour fits in p_T regions

- **≥4j≥2b region**
- Jets sorted according to the b-tagging efficiency (b-tagging discriminant, DL1r):
  - Using 3rd and 4th *b*-tag discriminant ranked jet as a variable seperating ***ttbb***, ***ttb***, ***ttc*** and ***ttl*** (also a proxy for 1st and 2nd additional jet)
- **3rd leading Reco jet p_T dependent slices**

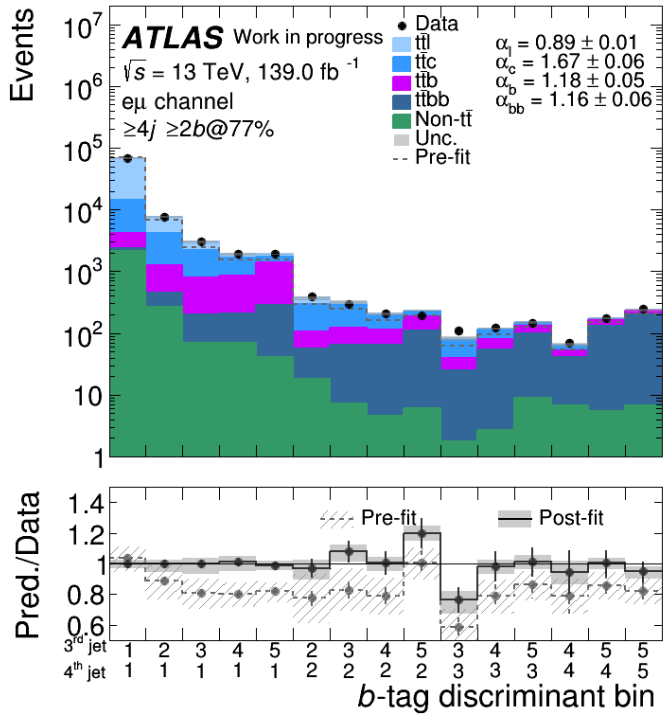
25 – 50 GeV:



≥ 75 GeV:



jet p_T inclusive:



B-tag eff. borders	100-85%	85-77%	77-70%	70-60%	60-0%
B-tag discr.	1	2	3	4	5

Post-fit Data/MC comparison

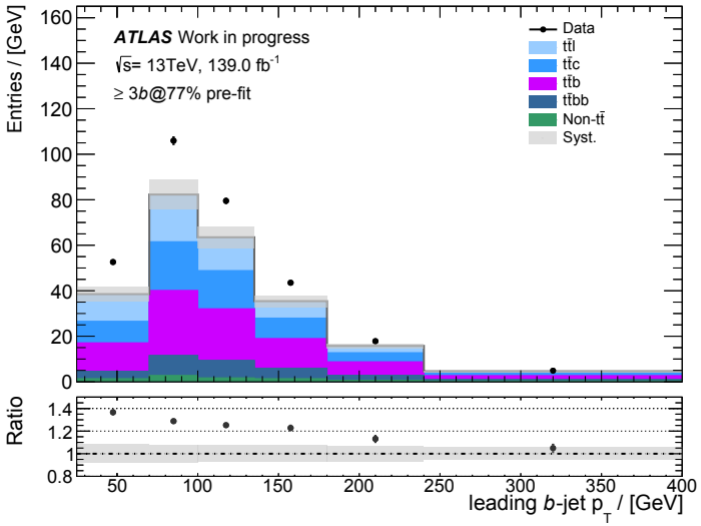
Leading *b*-jet p_T

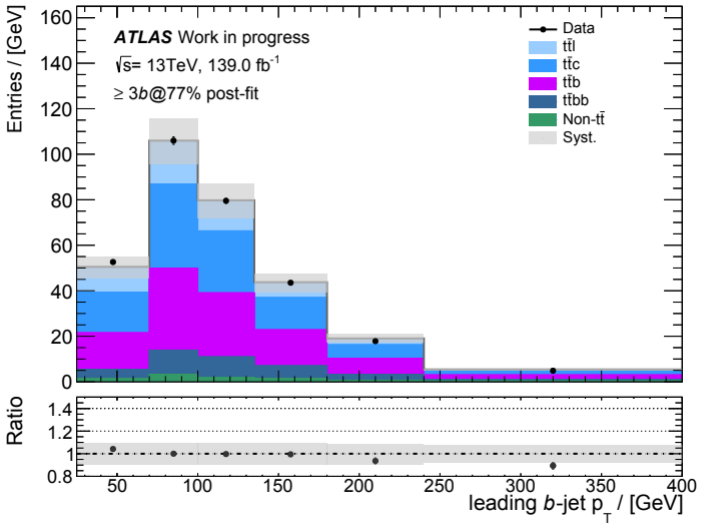
- lepton $p_T \geq 25$GeV
- jet $p_T \geq 25$ GeV
- $e\mu$, OS

Pre-fit:

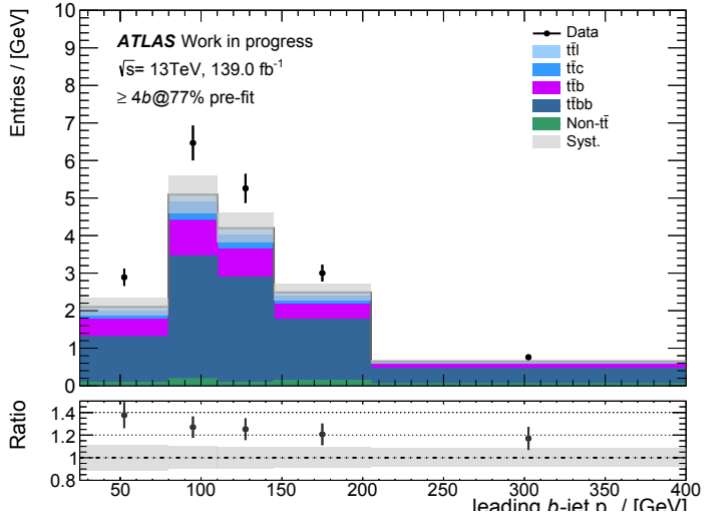
Post-fit:

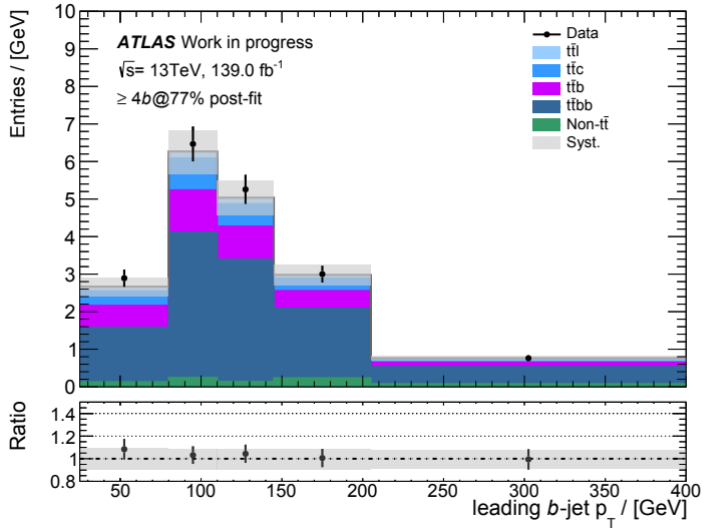
≥ 3 *b*-tagged jets:





≥ 4 *b*-tagged jets:





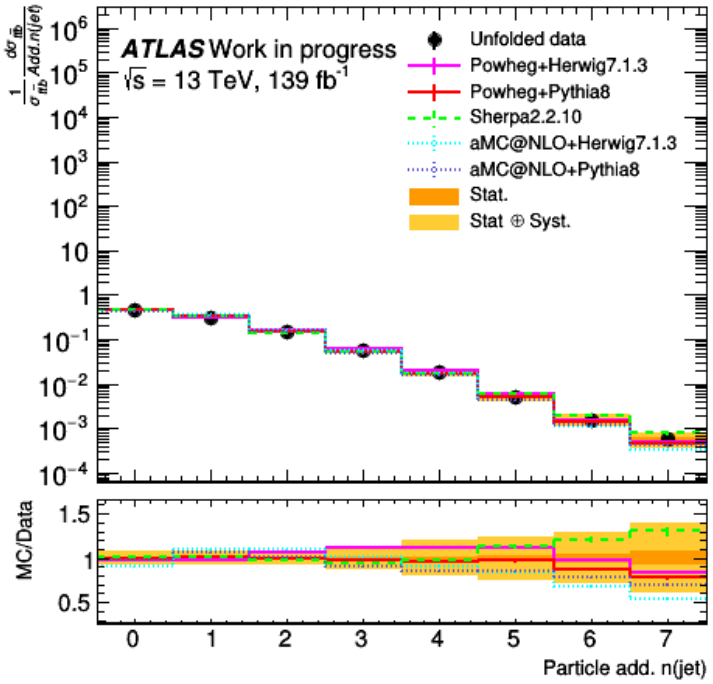
Unfolded Distributions

Jet multiplicity

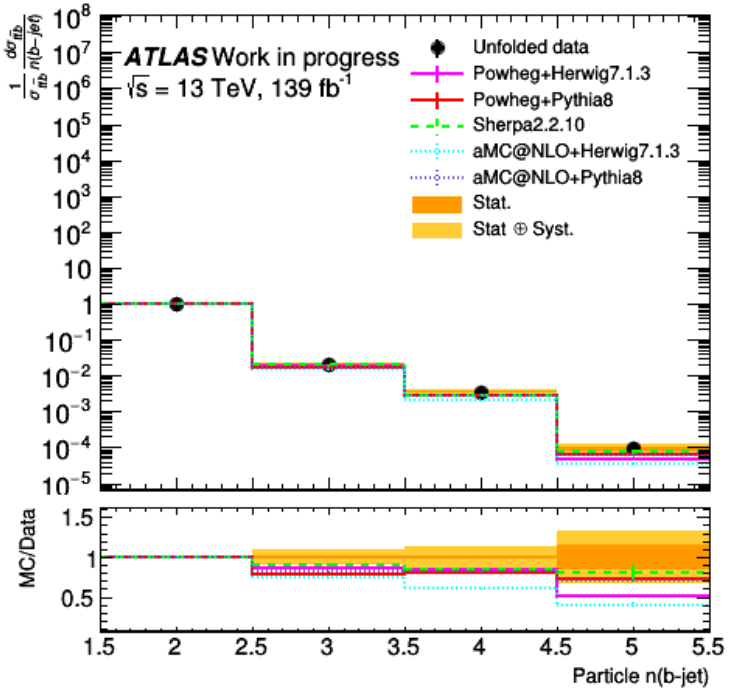
Fiducial definiton:
- lepton $p_T \geq 25$ GeV, jet $p_T \geq 25$ GeV
- *eμ*, OS, **≥ 2 *b*-jets**

Main systematic uncertainties are included

Add. jet multiplicity:



b-jet multiplicity:



Fiducial cross-section:

Preliminary results:
- **≥ 3 *b*-jets:** 169±2(stat)±19(syst) fb
- **≥ 4 *b*-jets:** 24±1(stat)± 4(syst) fb

Existing measurements (JHEP 04 (2019) 046):
- **≥ 3 *b*-jets:** 181±5(stat)±24(syst) fb
- **≥ 4 *b*-jets:** 27±3(stat)± 7(syst) fb

Additional *b*-jet classification

2*b*-jets are assigned to top based on the highest event weights computed from all possible sets (b_1, b_2, b_3, b_4):

from top

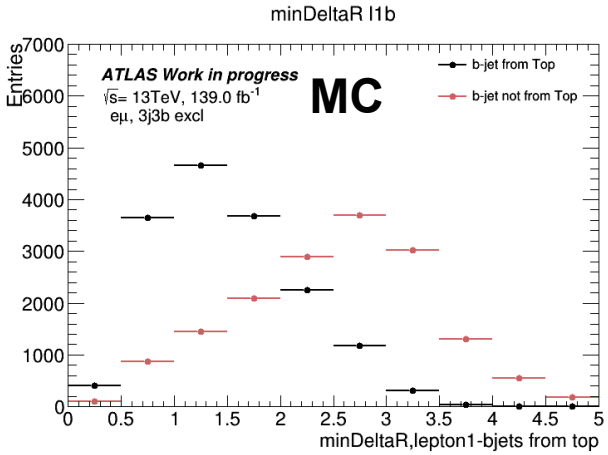
(b_1, b_2, b_3, b_4)

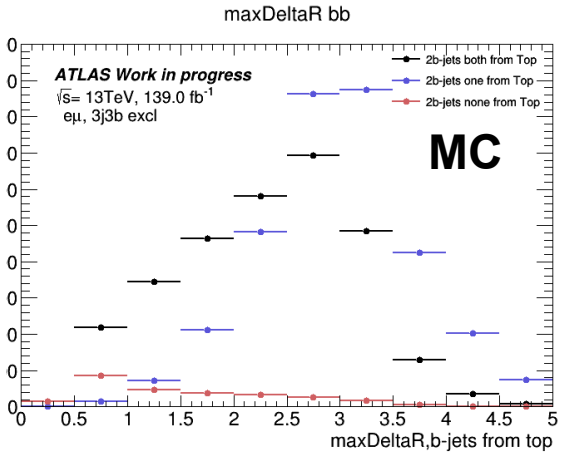
add.

$$w_{3b} = e^{-(\Delta R_{l1b}^{min} - \Delta R_{l1b1})^2} \cdot e^{-(\Delta R_{l2b}^{min} - \Delta R_{l2b2})^2} \cdot e^{-(\Delta R_{bb}^{max} - max(\Delta R_{b1b3}, \Delta R_{b2b3}))^2}$$

$$w_{4b} = e^{-(\Delta R_{l1b}^{min} - \Delta R_{l1b1})^2} \cdot e^{-(\Delta R_{l2b}^{min} - \Delta R_{l2b2})^2} \cdot e^{-(\Delta R_{bb}^{min} - \Delta R_{b3b4})^2}$$

3*b*-jets:





Discrimination variables:

- ΔR_{l1b}^{min}
- ΔR_{l2b}^{min}
- ΔR_{bb}^{min}
- ΔR_{bb}^{max}

Efficiency:

Number of *b*-jets	detector-level efficiency	particle-level efficiency
Simple *b*-jet classifier		
No. of *b*-jets = 3	59(51) %	57(52) %
No. of *b*-jets ≥ 4	56(55) %	56(55) %

Unfolded Distributions

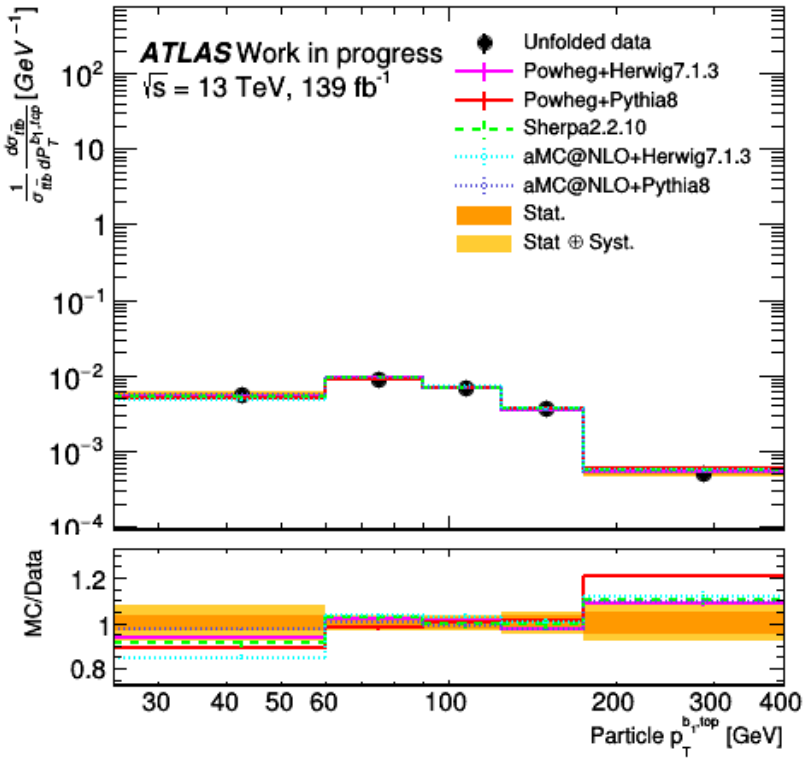
b-jet p_T spectra

- Measured distributions are consistent with various $t\bar{t}$ NLO+PS generator predictions within total uncertainties, but most MC tend to predict slightly harder p_T

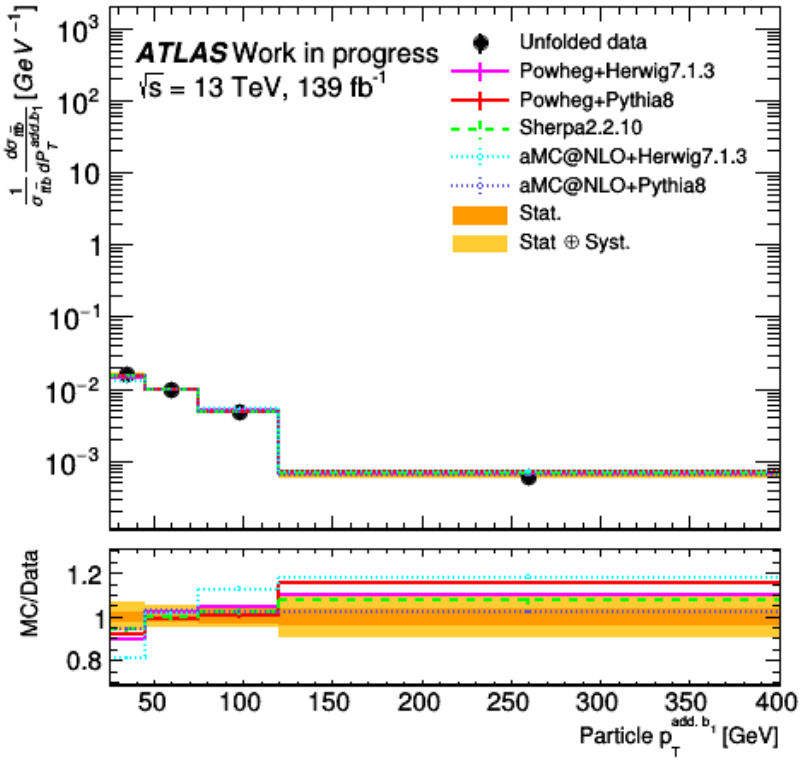
Fiducial definiton:

- lepton $p_T \geq 25$ GeV, jet $p_T \geq 25$ GeV
- $e\mu$, OS, **≥ 3 *b*-jets**

Leading b-jet p_T from top:



Leading add. b-jet p_T:



Main systematic uncertainties are included

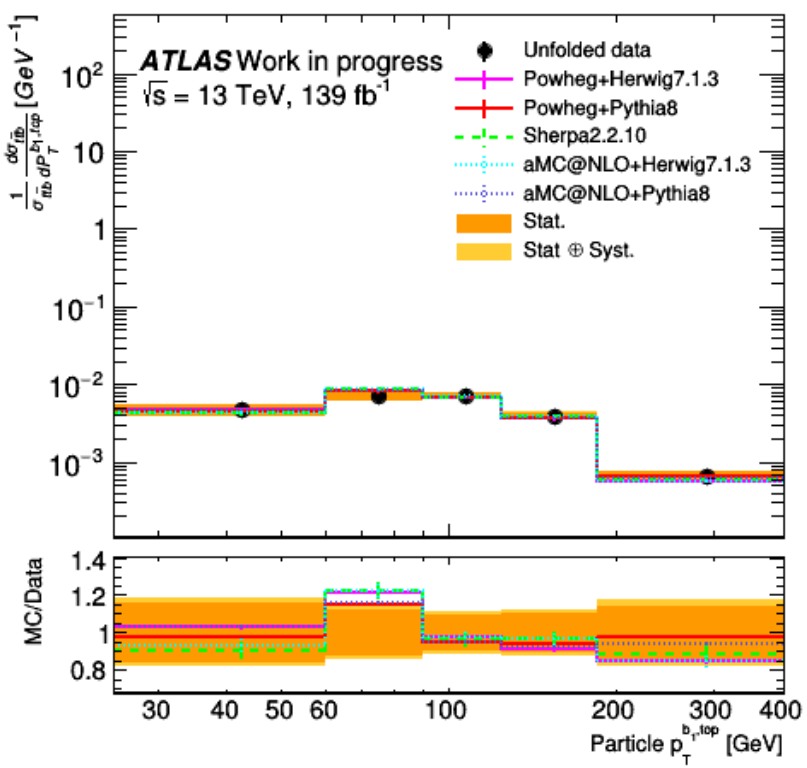
Unfolded Distributions

b-jet p_T spectra

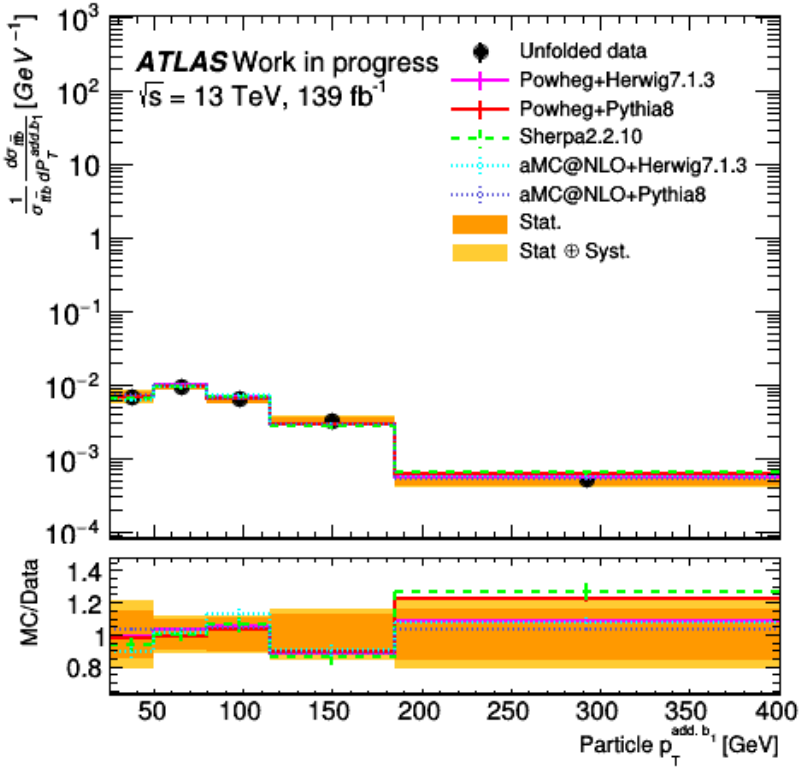
Fiducial definiton:
- lepton $p_T \geq 25$ GeV, jet $p_T \geq 25$ GeV
- $e\mu$, OS, **≥ 4 *b*-jets**

- First time measured in this phase space
- Measured distributions are consistent with various $t\bar{t}$ NLO+PS generator predicitons within large statistical uncertainties

Leading b-jet p_T from top:



Leading add. b-jet p_T:



Main systematic uncertainties are included

Summary

- Preliminary measurements of $t\bar{t}$+*b*-jets in *eμ* channel (OS) at particle-level with 139 fb^{-1} data
  - ≥ 3 *b*-jets and ≥ 4 *b*-jets region
- Challenging background $t\bar{t}$+light and $t\bar{t}$+*c*-jets have been measured using a data-driven estimation
- Improved observables for additional *b*-jets
- New measurements of fiducial cross sections are in agreement with previous measurements at 13 TeV
  - Improvement in statistical precision by a factor of 2 (as expected)