Top-quark pair production cross-section measurements with the ATLAS detector

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Introduction

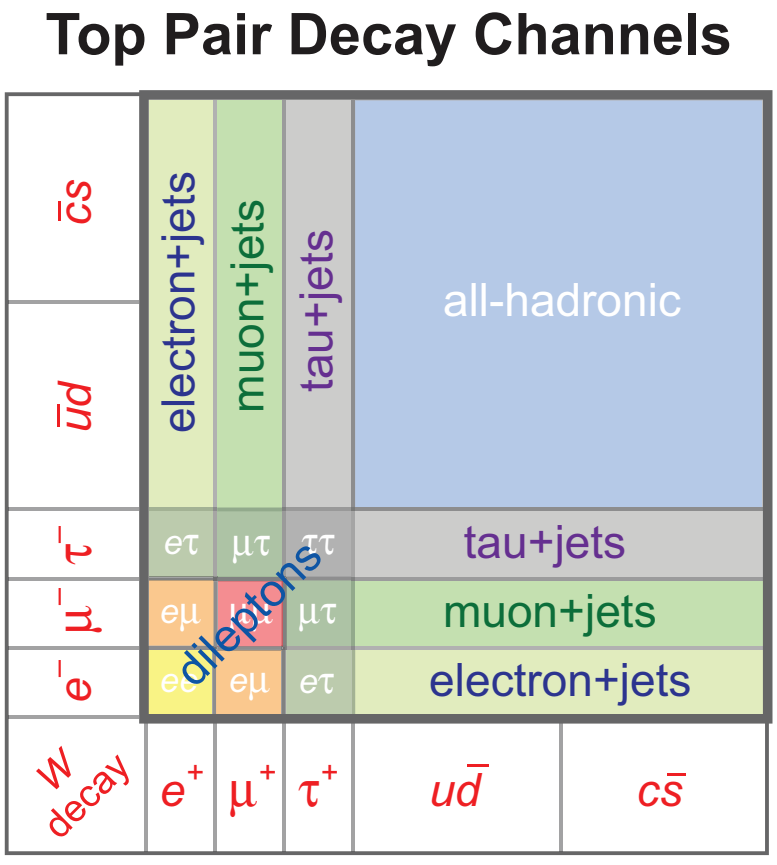
- The top quark is the **heaviest** known fundamental particle. Could it play a special role in **electroweak symmetry breaking?**
- The top quark has a **very short lifetime** and is the only quark that decays before forming **hadronic bound states**
- This leads to many interesting, **measurable properties** that we can test
- Understanding $t\bar{t}$ production is crucial for many searches for rare SM processes and physics **beyond the SM**

Introduction

- The LHC is a **top factory**. We can go beyond inclusive $t\bar{t}$ cross-section measurements and measure **differential** $t\bar{t}$ cross-sections.
- In this talk, I will focus on measurements of $t\bar{t}$ production with **additional jets** using data collected in 2015 / 2016 at $\sqrt{s} = 13$ TeV.
- A good description of $t\bar{t}$ with additional jets is vital for many searches for new physics

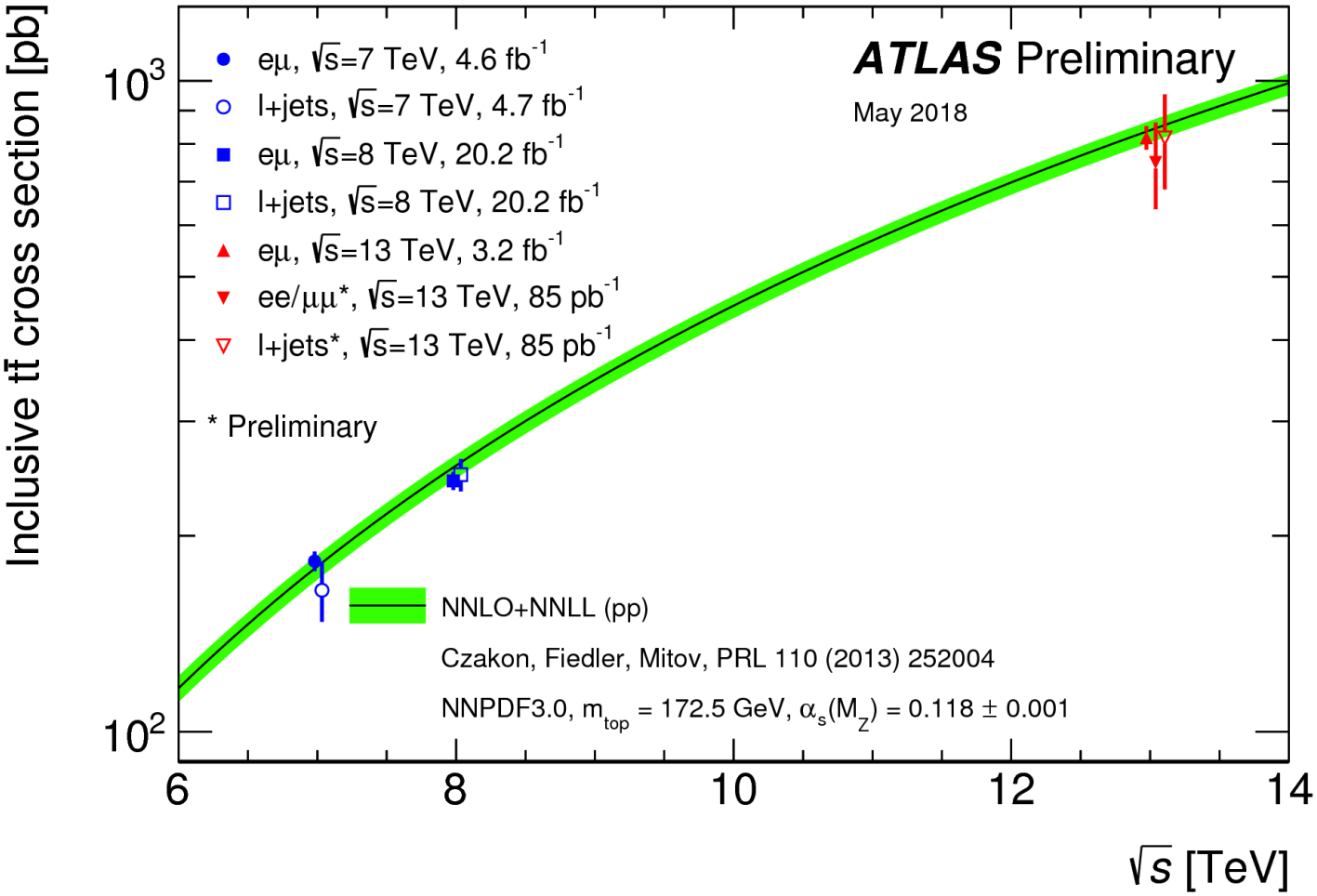
Top quark decay

- The $t \to Wb$ branching ratio is close to 1
- Therefore $t\bar{t}$ event are categorized based on how the two W bosons decay
- The ℓ+jets channel was long considered the "golden channel" due to a balance of statistics and purity
- The large LHC dataset allows the $e\mu$ channel to make the most precise cross-section measurements



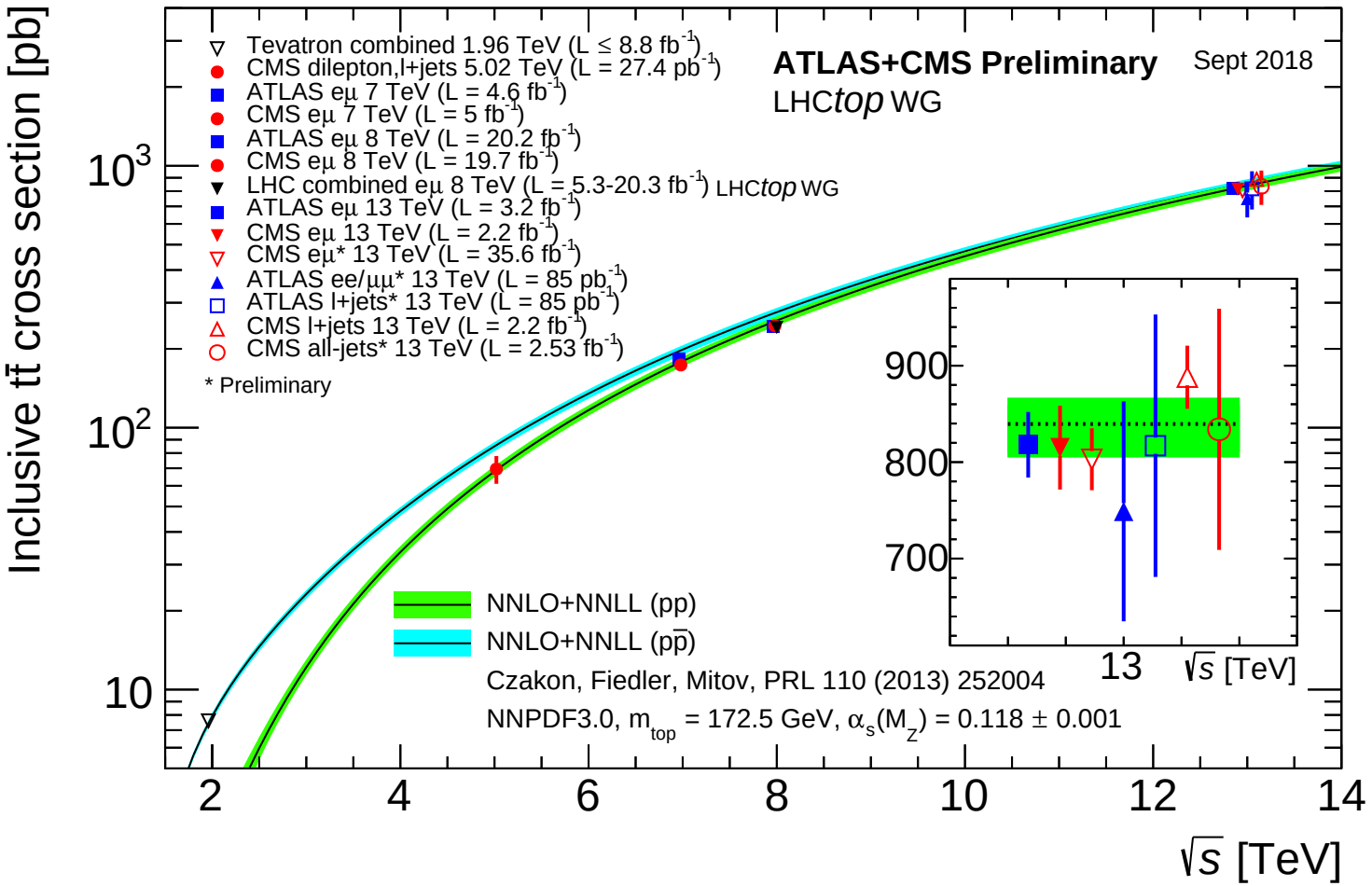
The (inclusive) $t\bar{t}$ cross-section

$t\bar{t}$ cross-section: ATLAS



ATLAS has measured the $t\bar{t}$ cross-section at **three** center-of-mass energies, $\sqrt{s} = 7, 8$ and 13 TeV

$t\bar{t}$ cross-section: all



The $t\bar{t}$ cross-section has been measured over nearly **an order of magnitude**

$t\bar{t}$ with additional jets

$e\mu$+jets

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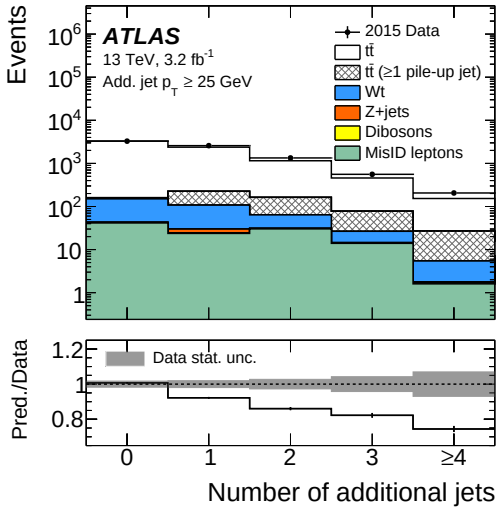
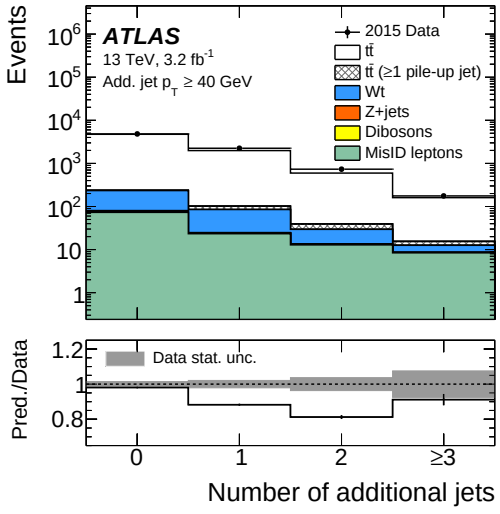
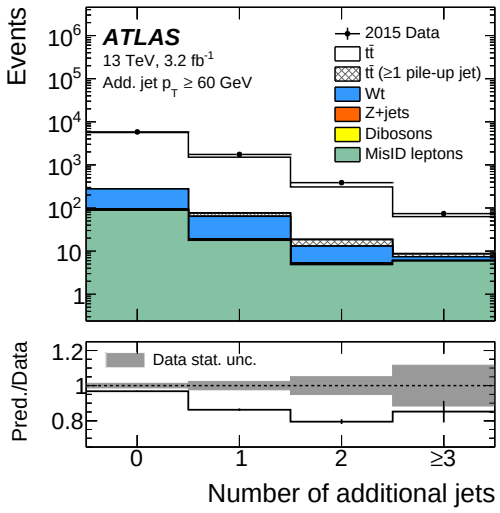
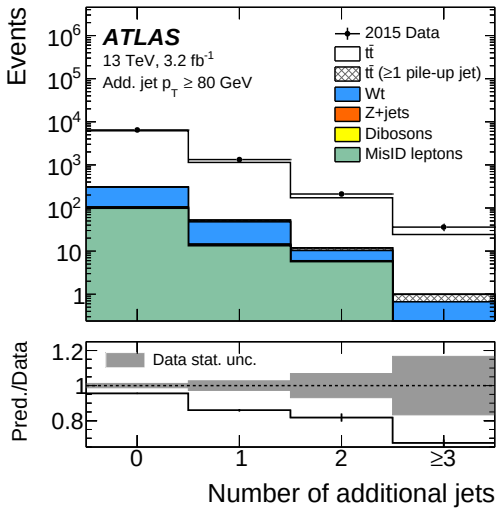
- Analysis performed using the $e\mu$ channel, requiring two *b*-tagged jets (very pure sample of $t\bar{t}$ events)
- A general trend of more additional jets in data than predicted (from POWHEG+PYTHIA6)
- Data are unfolded and compare with more predictions









$e\mu$+jets

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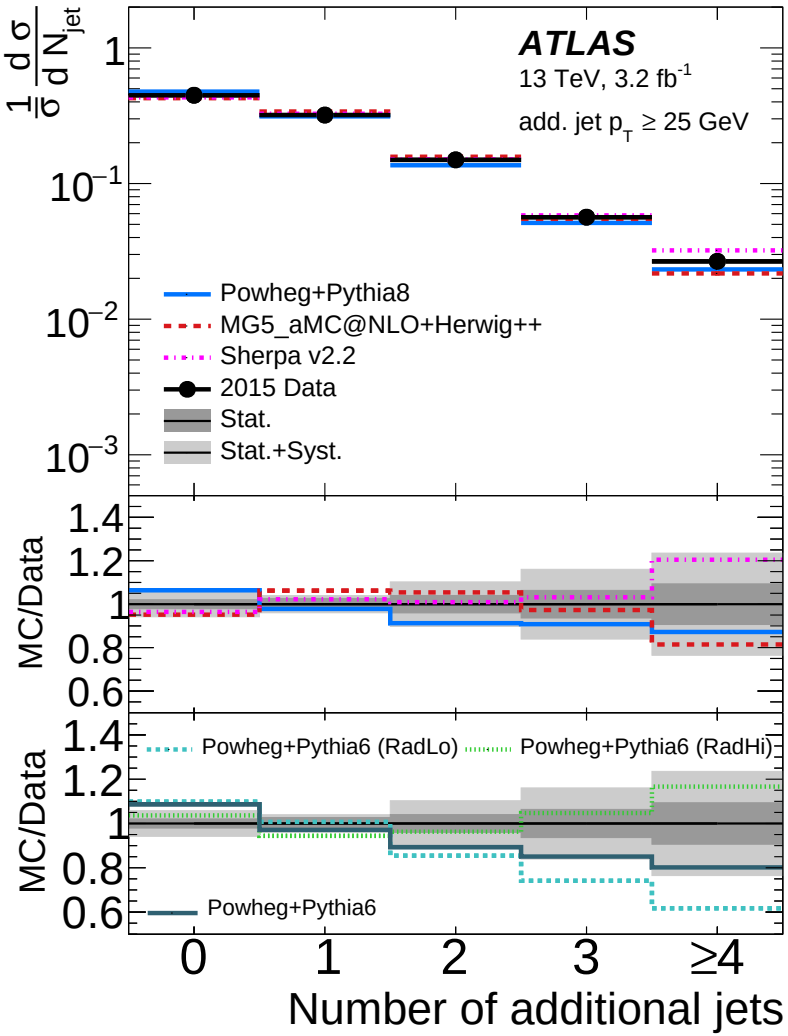
- POWHEG+PYTHIA8 (now used as the default $t\bar{t}$ sample in ATLAS) performs slightly better than POWHEG+PYTHIA6.
- Other generators also provide a reasonable description.



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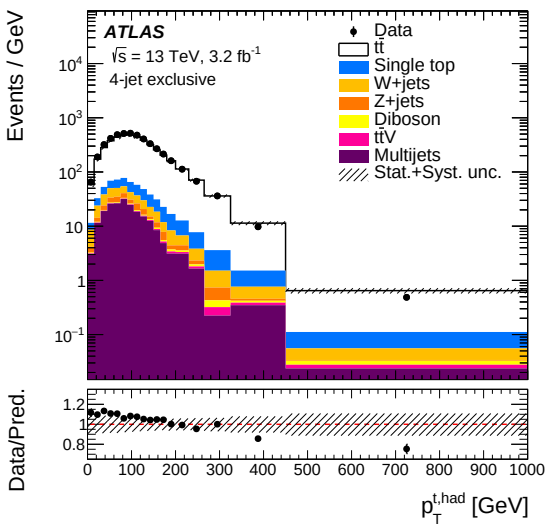
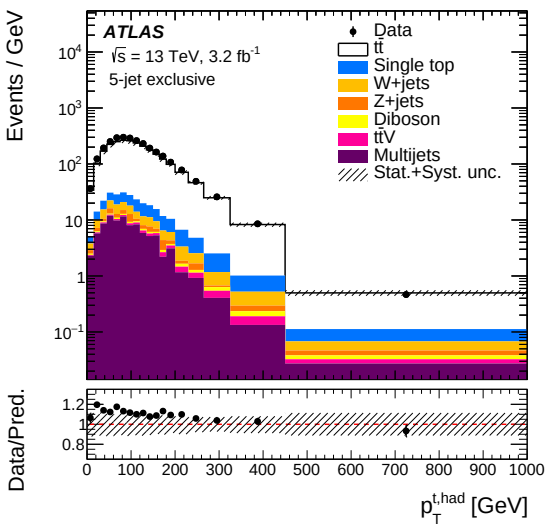
- In addition to measuring the number of jets, we can also look at properties of the top quark in events with a certain number of jets.
- Analysis in the ℓ+jets channel.
- Slope in top-quark p_{T} with respect to prediction (POWHEG+PYTHIA6)



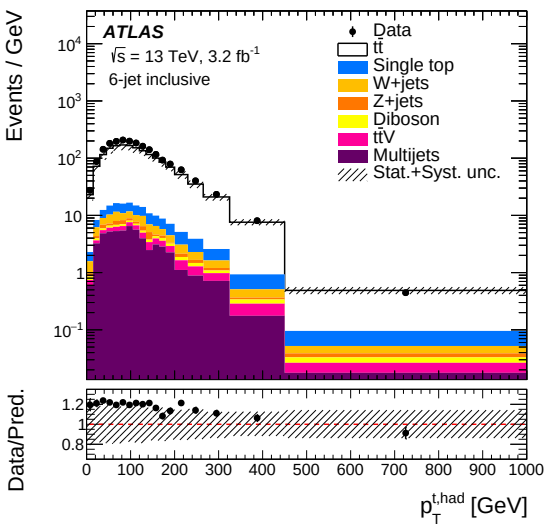
$= 4$ jets

$(+0$ jets$)$



$= 5$ jets

$(+1$ jets$)$



≥ 6 jets

$(+\geq 2$ jets$)$

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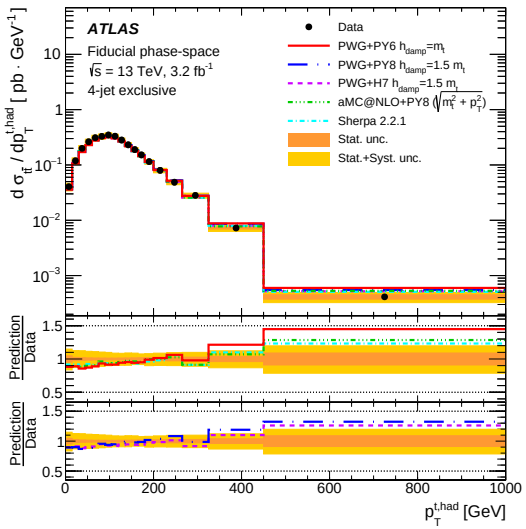
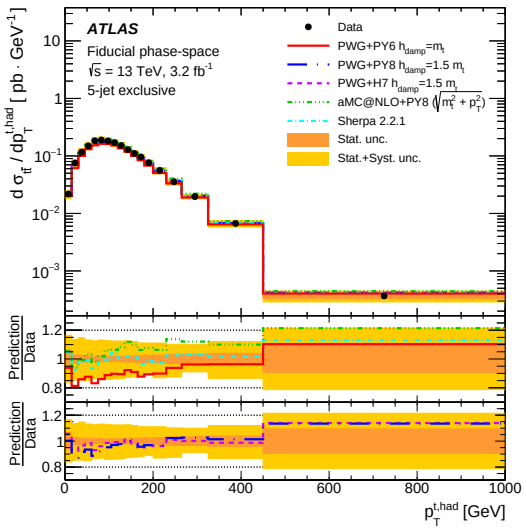
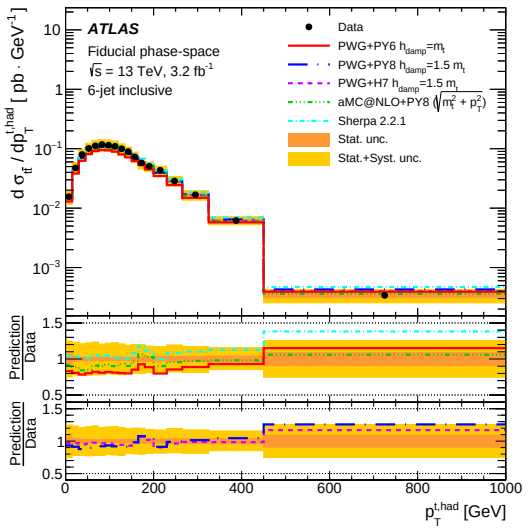
- Data are unfolded and compared to multiple predictions
- Slope most evident in $= 4$ jet events
- As in the $e\mu$ channel, the POWHEG+PYTHIA8 prediction is generally better than the POWHEG+PYTHIA6 prediction



$= 4$ jets
$(+0$ jets$)$



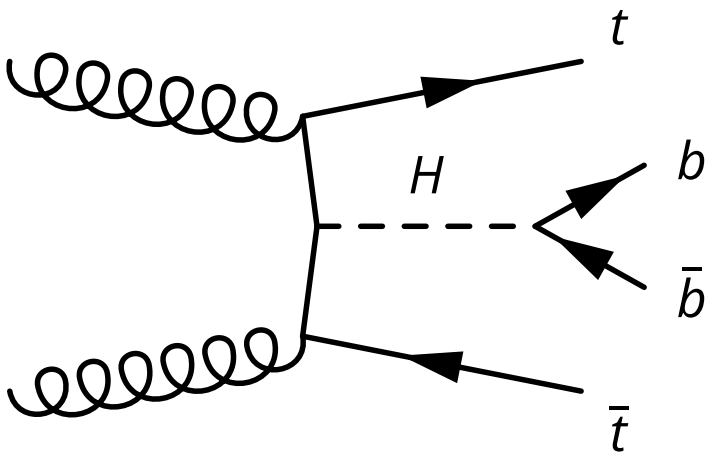
$= 5$ jets
$(+1$ jets$)$

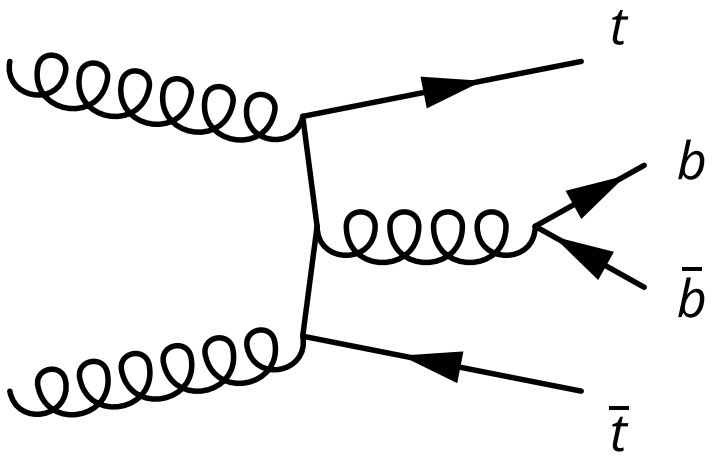


≥ 6 jets
$(+ \geq 2$ jets$)$

$t\bar{t}$ with additional b-jets

$t\bar{t}b\bar{b}$: $t\bar{t}H$





- $t\bar{t} + b\bar{b}$ is an interesting process because of $t\bar{t}H(H \to b\bar{b})$
- $H \to b\bar{b}$ is the dominant decay of the Higgs

- However, $t\bar{t}H(H \to b\bar{b})$ measurements are limited by our knowledge of the QCD $t\bar{t}b\bar{b}$ background

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

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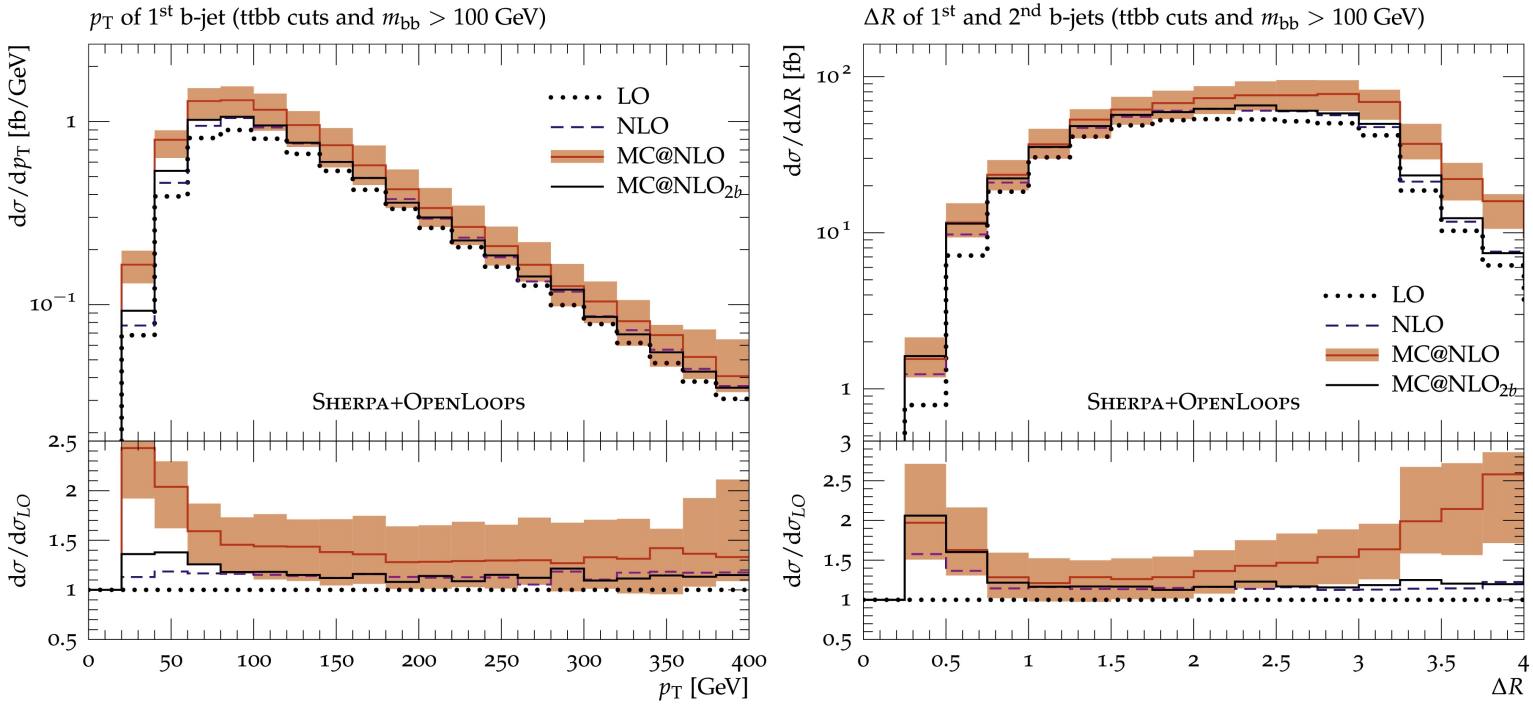
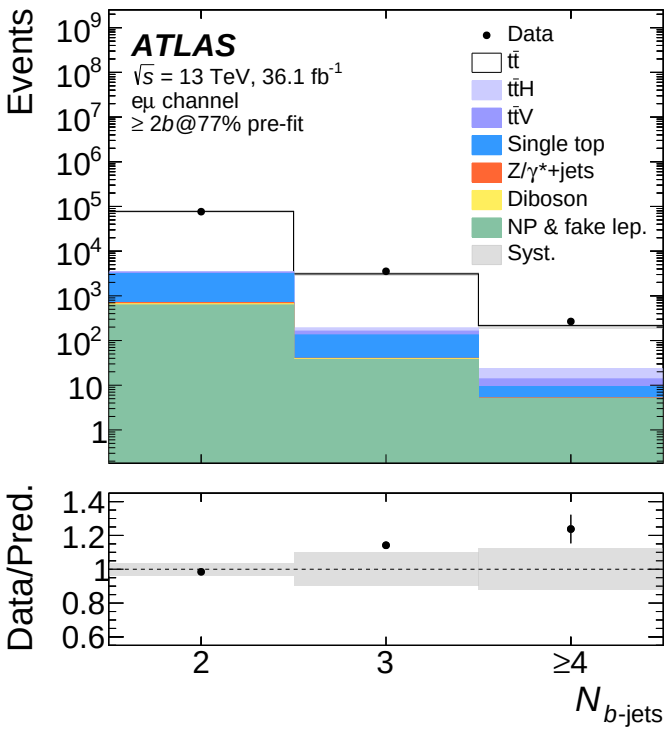
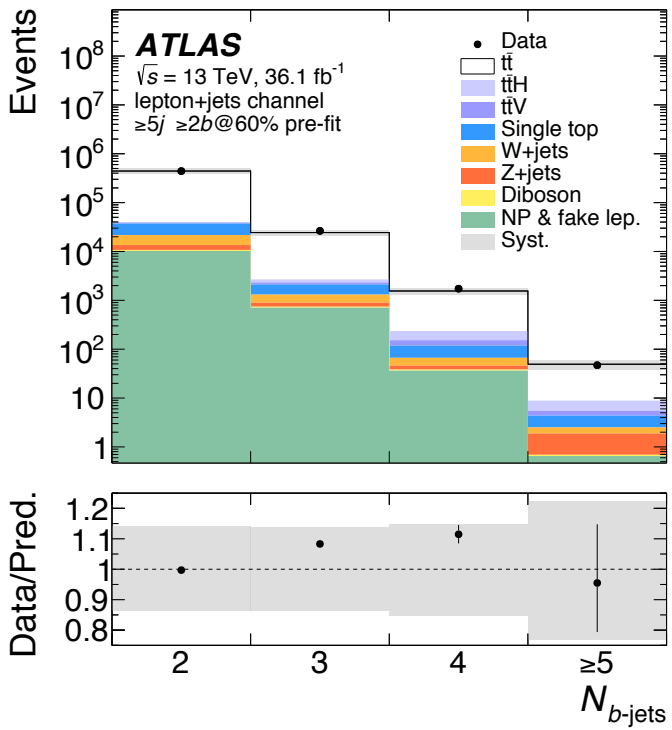


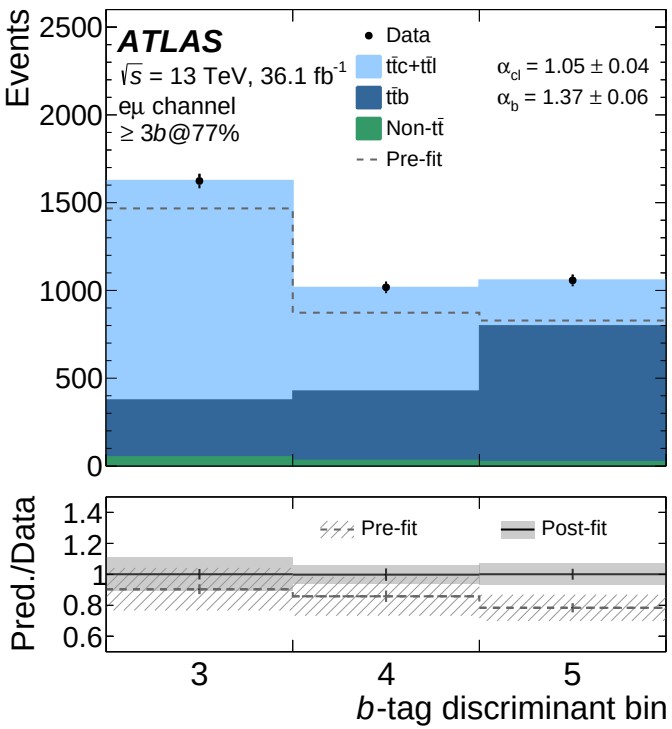
- $t\bar{t}b\bar{b}$ is also an interesting process to study in it's own right. Four quark final state with very different scales $m_t \gg m_b$.
- Recent NLO QCD calculations of the $t\bar{t}b\bar{b}$ process show some unexpected features
- Significant contributions from double collinear $g \to b\bar{b}$ splittings
- Uncertainties range from 20 to 40 % depending on the phase space

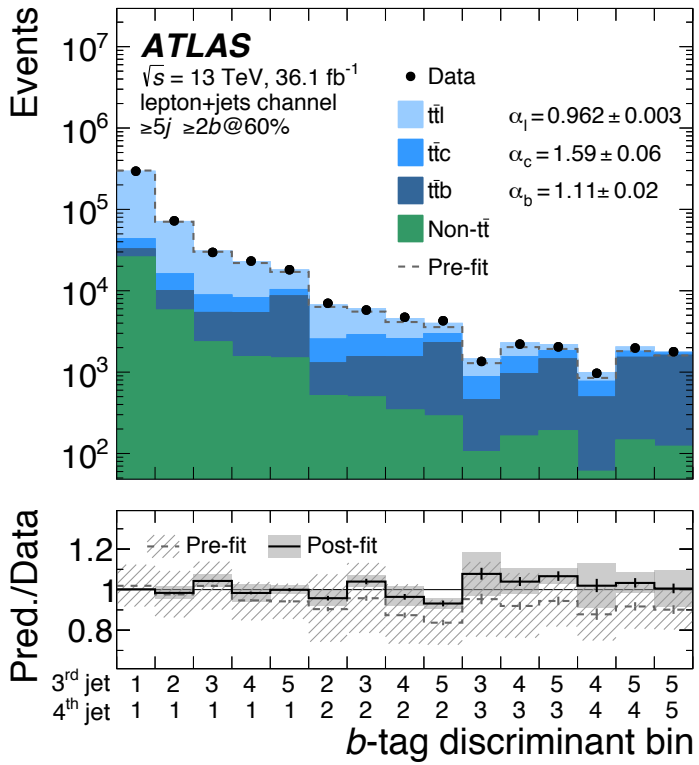
- ATLAS has now measured the $t\bar{t}$ cross-section with additional b-jets with 36 fb^{-1} of $\sqrt{s} = 13$ TeV data in both the ℓ+jets and $e\mu$ channels.
- Begin by selecting an inclusive sample of $t\bar{t}$ events





- Events are categorized based on the flavors of additional jets in the MC simulation
- A fit is then performed based on the *b*-tagging discriminant to correct for flavour mismodelling in the MC prediction.





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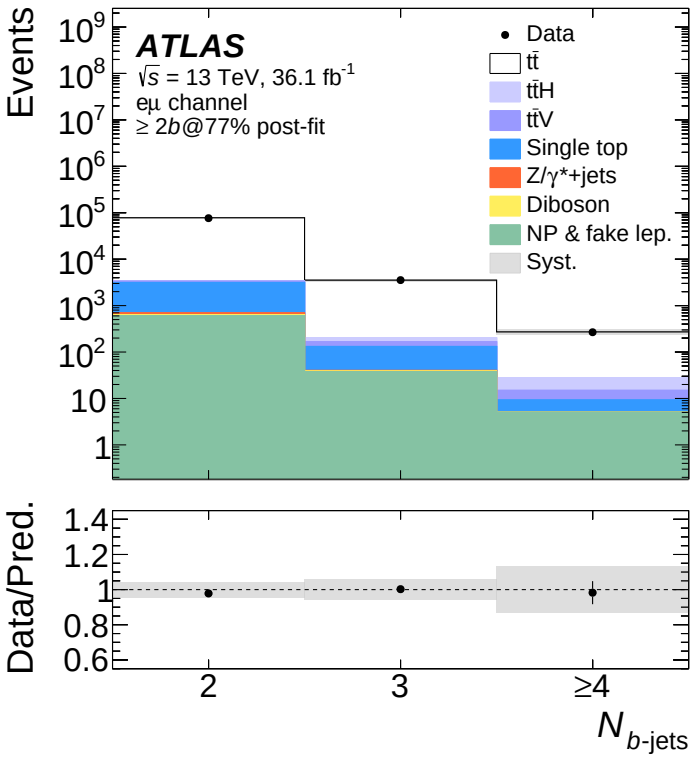

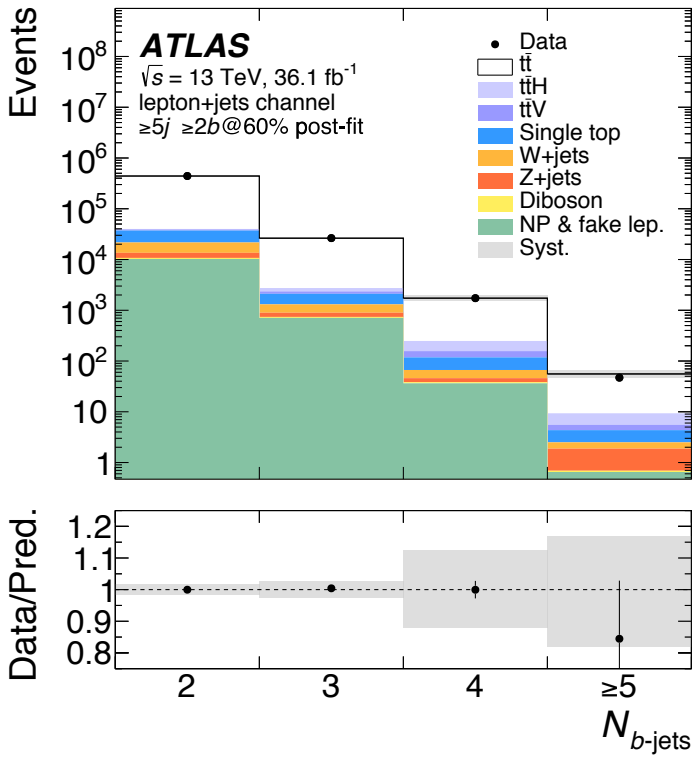

$t\bar{t}b\bar{b}$: Fiducial cross-section results

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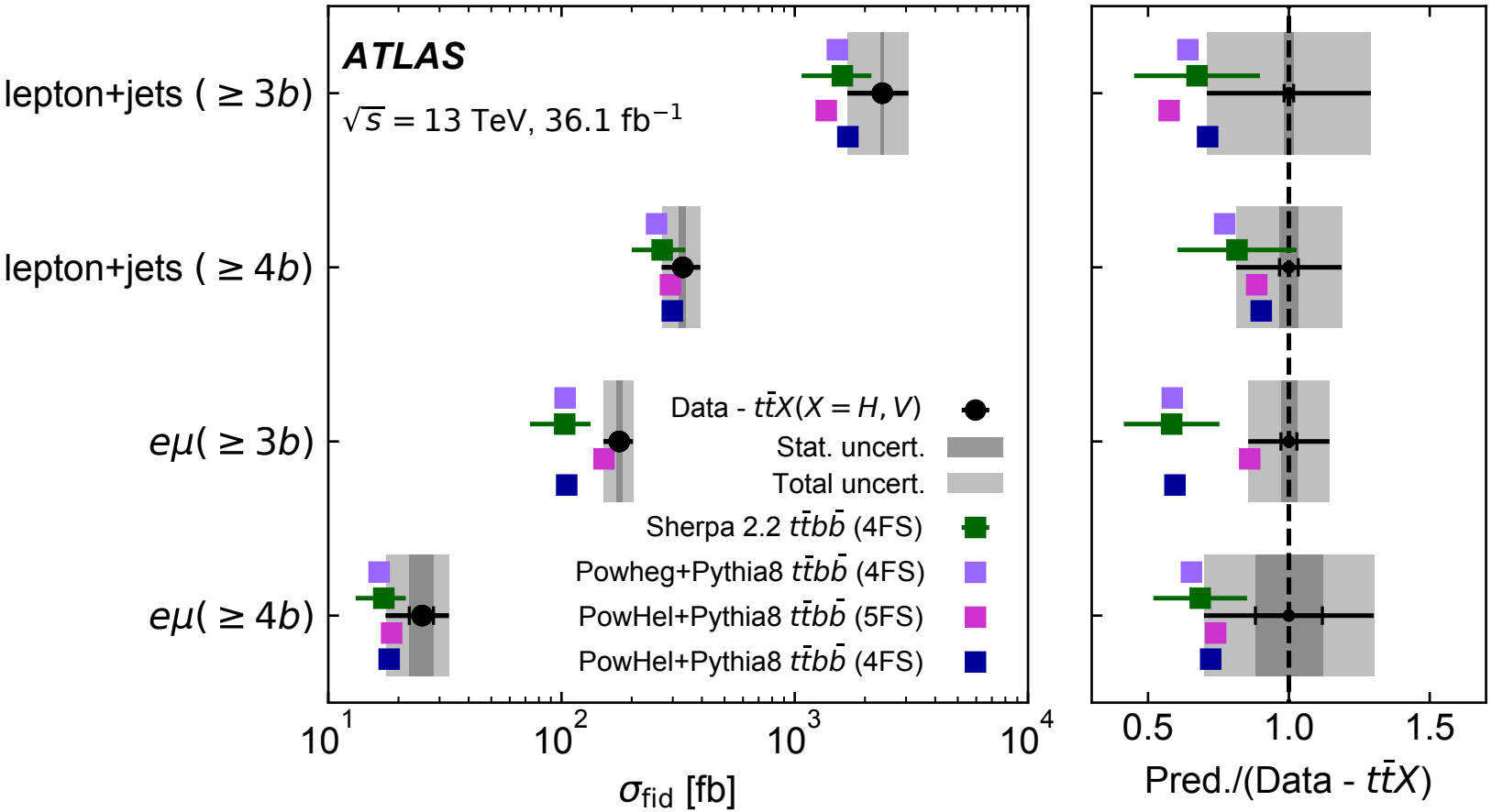

Measured cross-sections generally slightly higher than predicted

$t\bar{t}b\bar{b}$: Differential cross-section results

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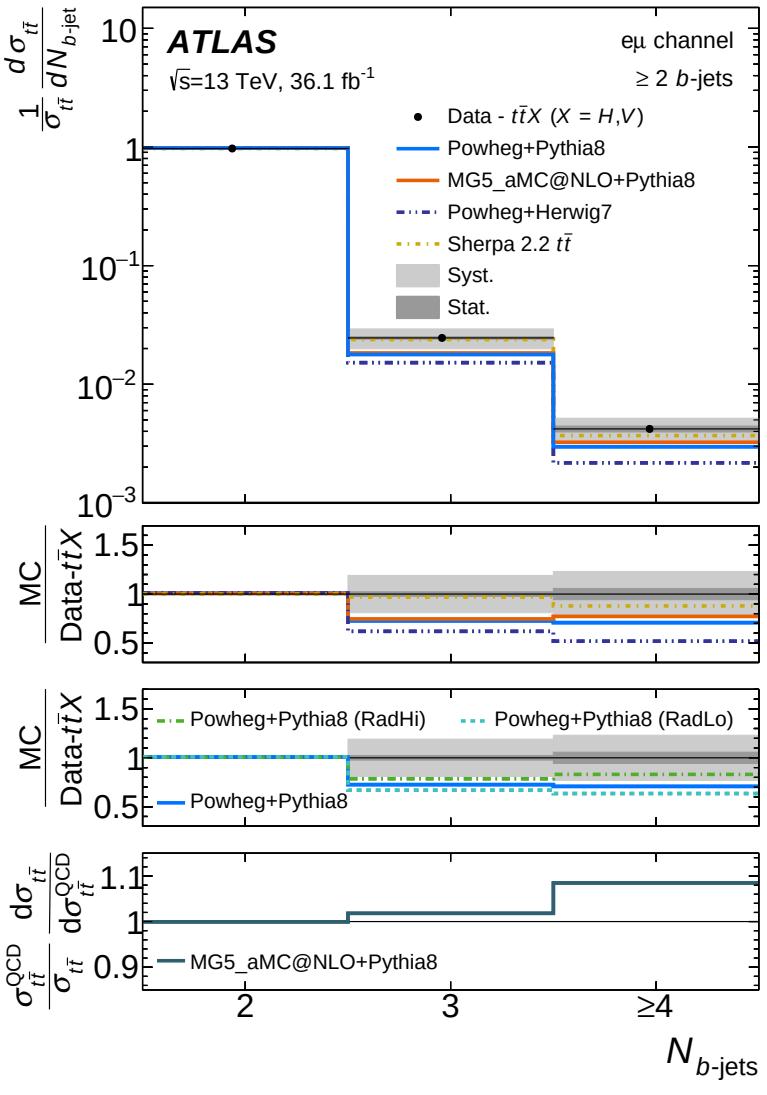
- We also present differential cross-sections.
- The variables investigated are:
  - Number of b-jets ($e\mu$ channel)
  - H_{T}, $H_{\mathrm{T}}^{\mathrm{had}}$
  - p_{T} of leading three (or four) b-jets
  - p_{T}, m and ΔR of the leading two b-jets
  - p_{T}, m and ΔR of the closest (smallest ΔR) two b-jets



$t\bar{t}b\bar{b}$: Differential cross-section results

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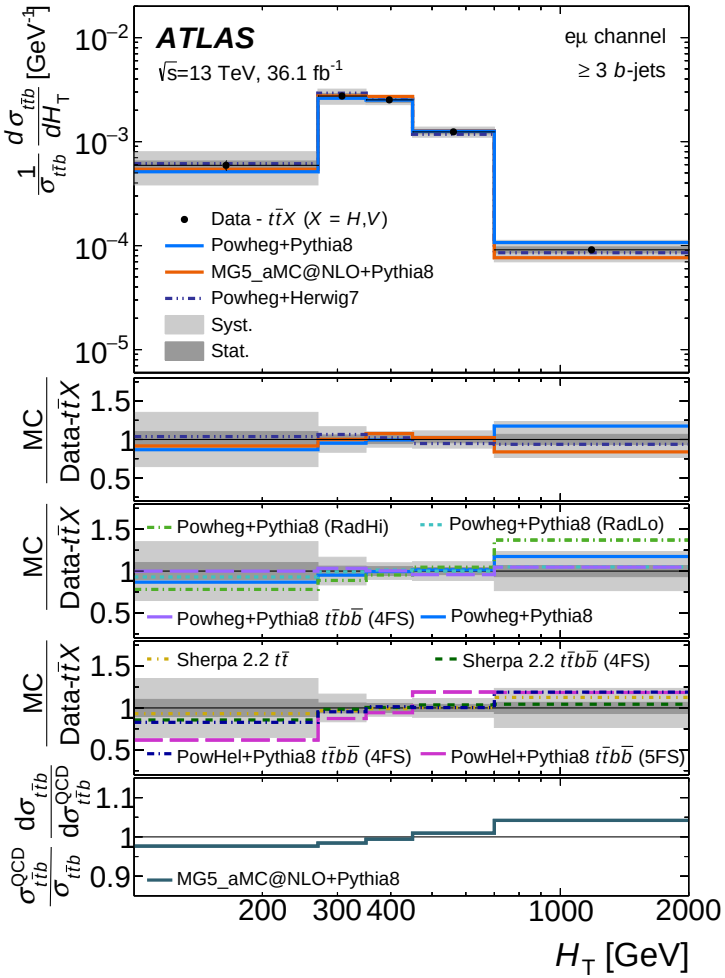
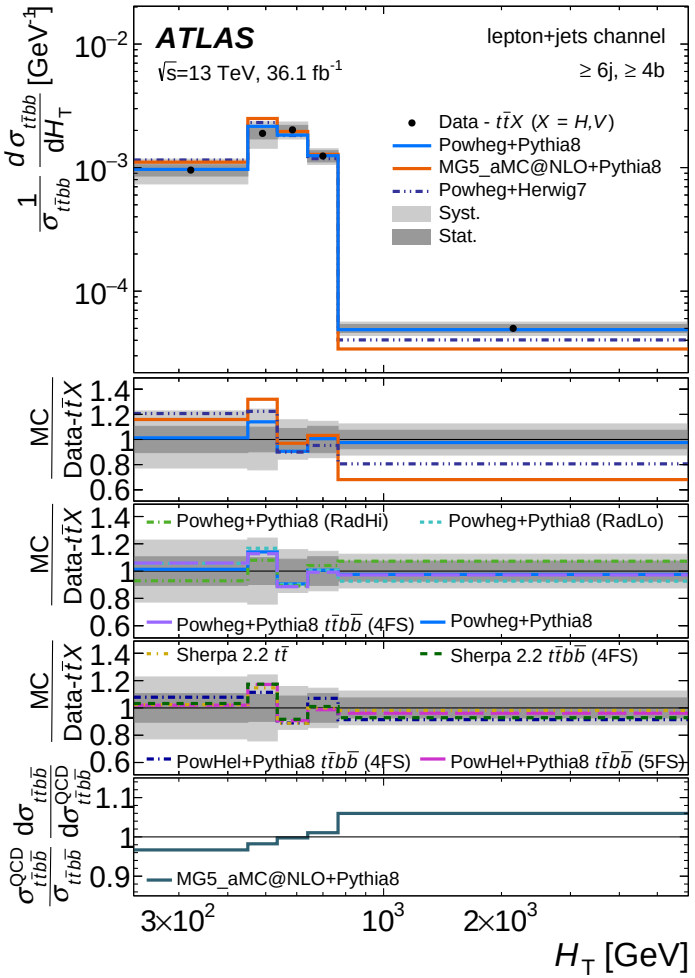




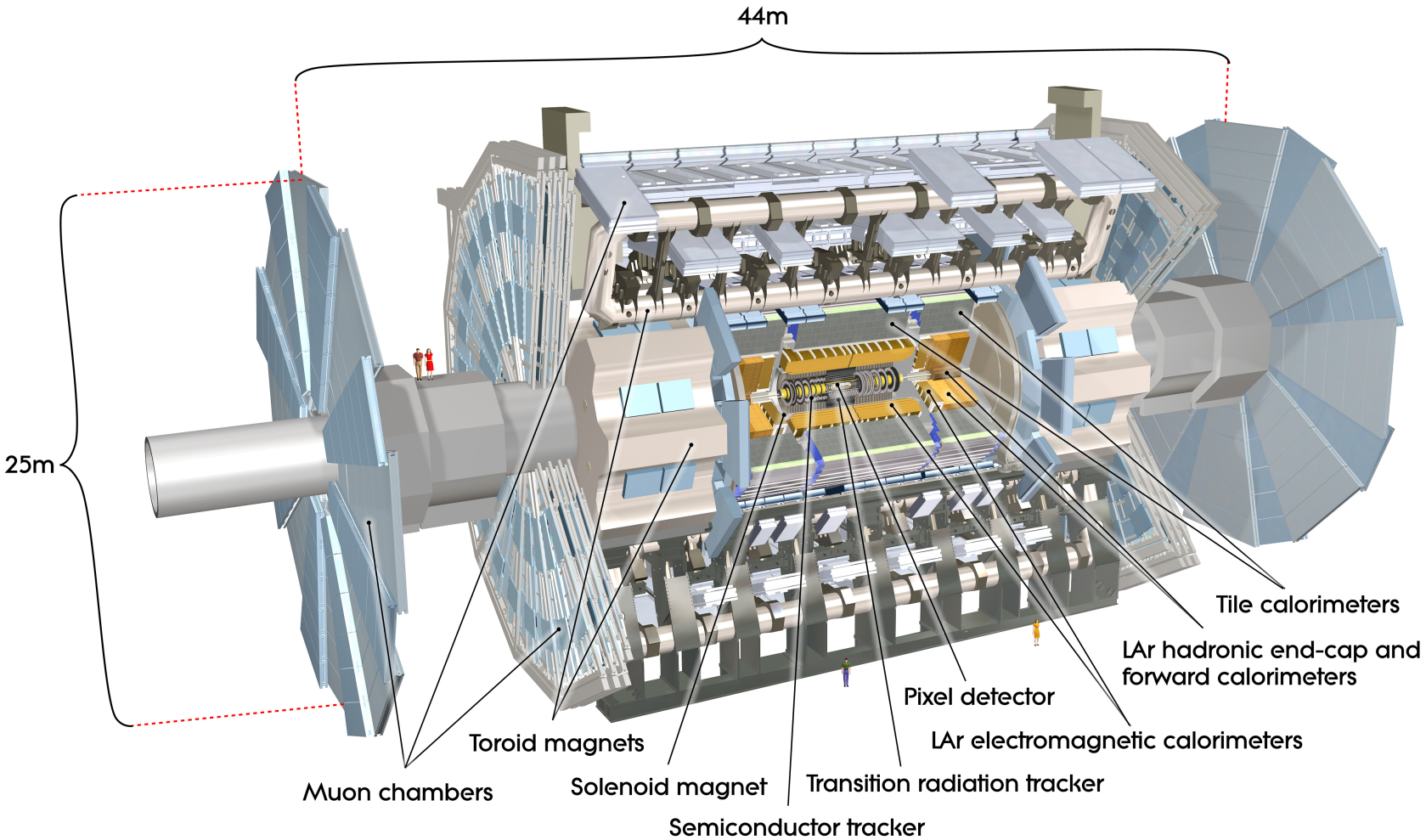
The shapes of distributions are generally well described

Summary

- The LHC is a **top factory**.
- We can go beyond inclusive $t\bar{t}$ cross-section measurements and measure **differential** $t\bar{t}$ cross-sections.
- A good description of $t\bar{t}$ with additional jets is vital for many searches for new physics
- ATLAS has studied $t\bar{t}$ production with additional jets, including b-jets, using data collected in 2015 and 2016.
- Another two years of data on disk, more results to come!

Back-up

The ATLAS detector



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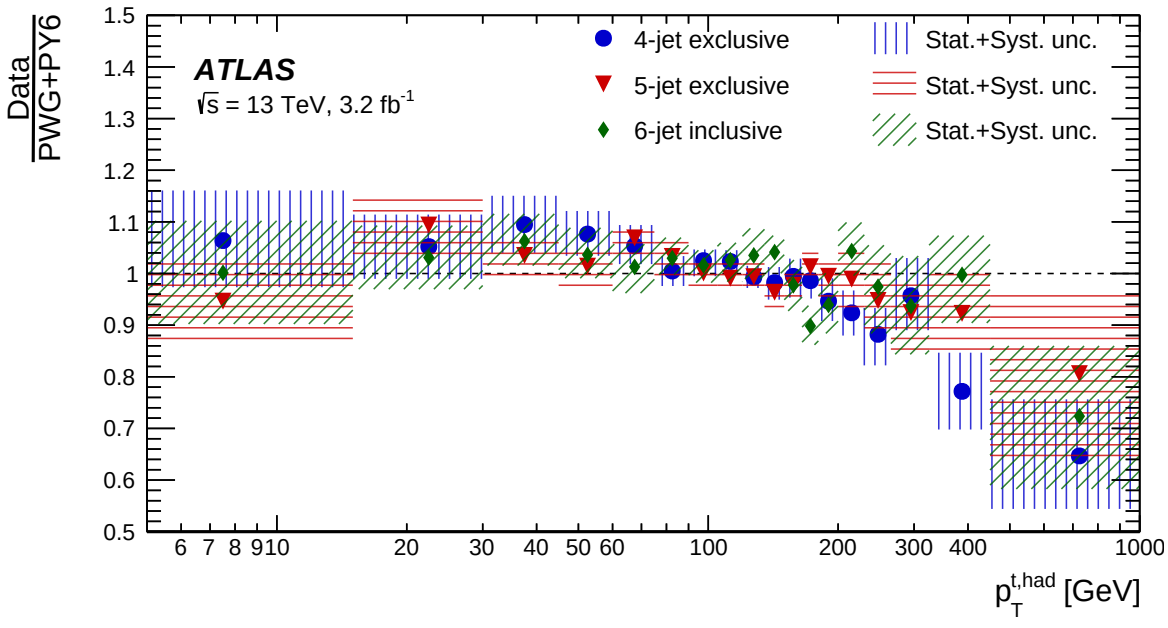
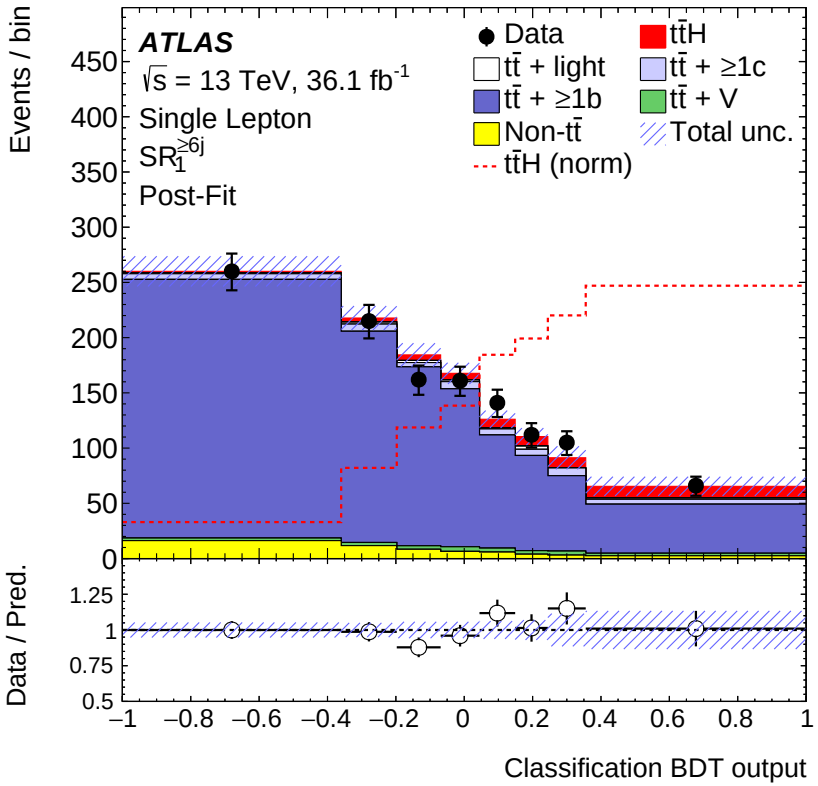


The ratio of unfolded data to POWHEG+PYTHIA6 in $= 4$, $= 5$ and ≥ 6 jet regions

$t\bar{t}H(H \to b\bar{b})$

Phys. Rev. D 97 (2018) 072016



- $t\bar{t}H(H \to b\bar{b})$ searches dominated by QCD $t\bar{t}b\bar{b}$ background and it's uncertainties

Outline

- $t\bar{t}$ production
- TOPQ-2015-17: $e\mu + \text{jets}$
- TOPQ-2017-01: $t\bar{t}(+\text{jets})$
- TOPQ-2017-12: $t\bar{t}b\bar{b}$

▸ Eur. Phys. J. C77 (2017) 220

▸ JHEP 10 (2018) 159

▸ JHEP 04 (2019) 046