Top quark pair differential cross-section measurements in pp collisions in the ℓ+jets channel at $\sqrt{s}$=13 TeV with the ATLAS Detector

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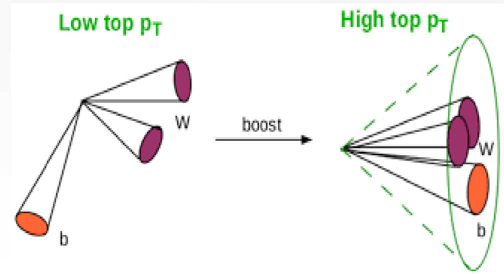
On behalf of the ATLAS Collaboration

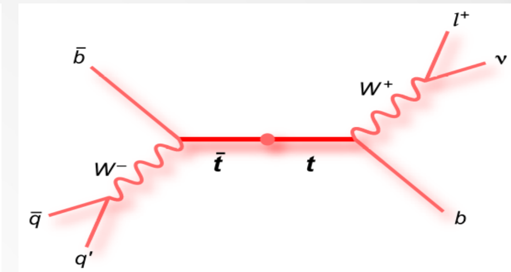
– Bad Neuenhar – 16-21 September 2018

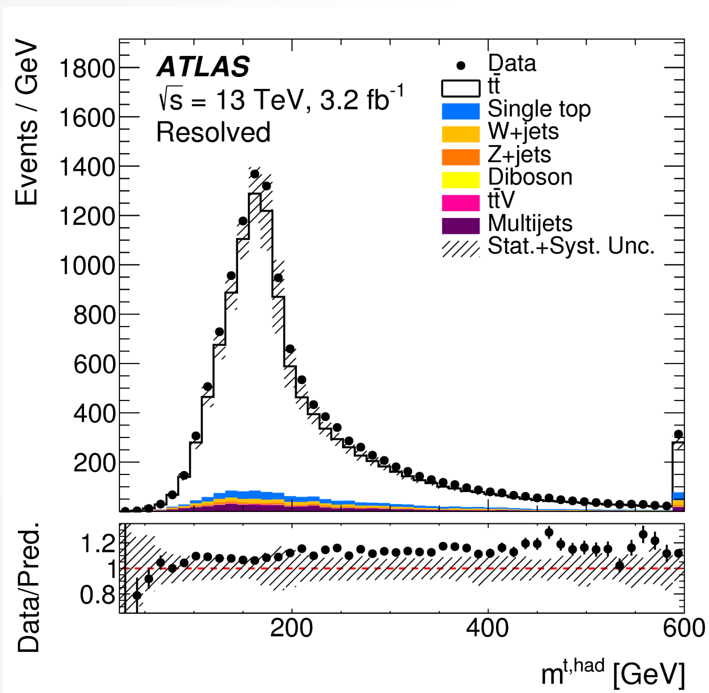
Due to time constraints, I will focus on presenting a selection of results, more detail in the *paper*
The analysis has already been introduced in Matteo Negrini's talk

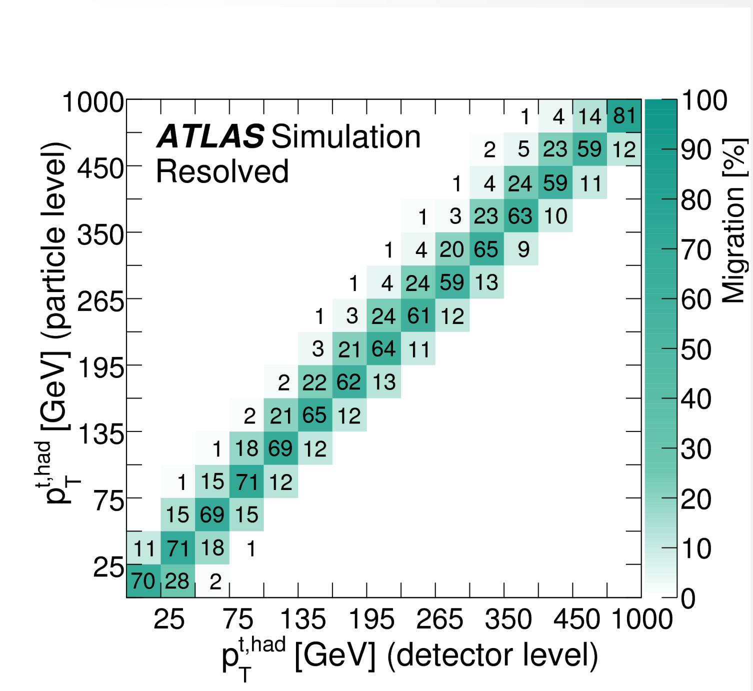
Analysis strategy

- Resolved topology
  - Top decay products are well separated in space
  - One lepton, four small-R jets, two b-tagged jets
  - $t\bar{t}$ system reconstructed with the PseudoTop algorithm







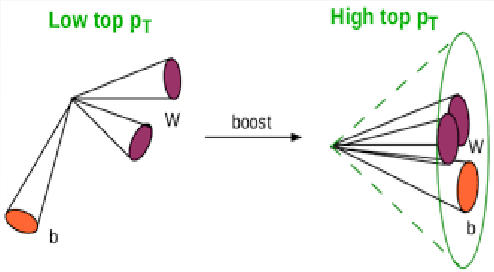


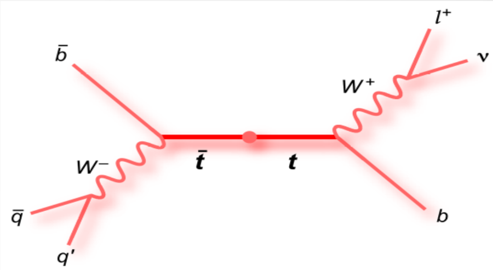
- Reconstructed top invariant mass exibits a narrow peak at top mass value
  - m_{top}^{PDG}=173.21±0.51±0.71 GeV

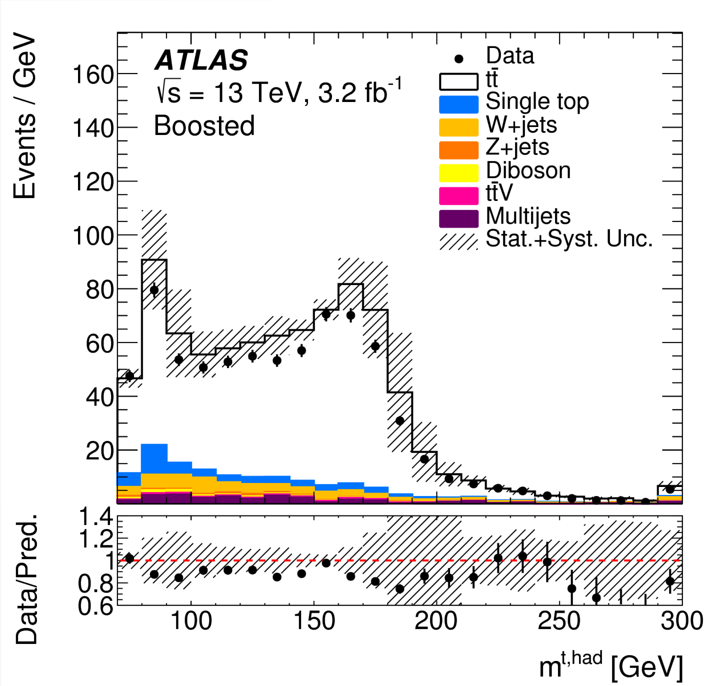
- Binning chosen such that migration matrices have more than 55% of events staying on the diagonal

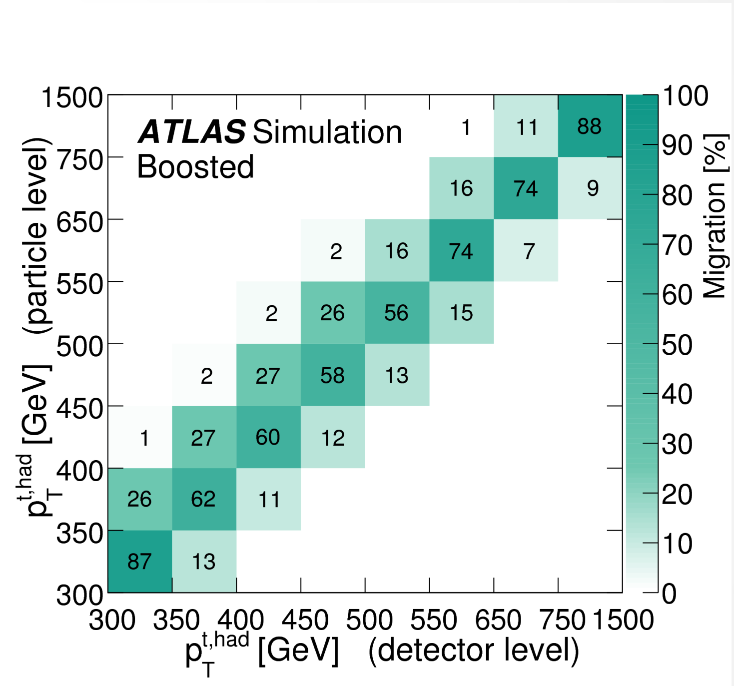
Analysis strategy

- Boosted topology (non-exclusive)
  - Hadronic top decay products are contained in a single large-R (R=1.0) jet
  - One lepton, one top-tagged large-R jet, one small-R jet
  - B-tagged small-R jet or b-tagged large-R subjet
  - Hadronic top is the large-R jet, identified with a top-tagger algorithm (80% WP)





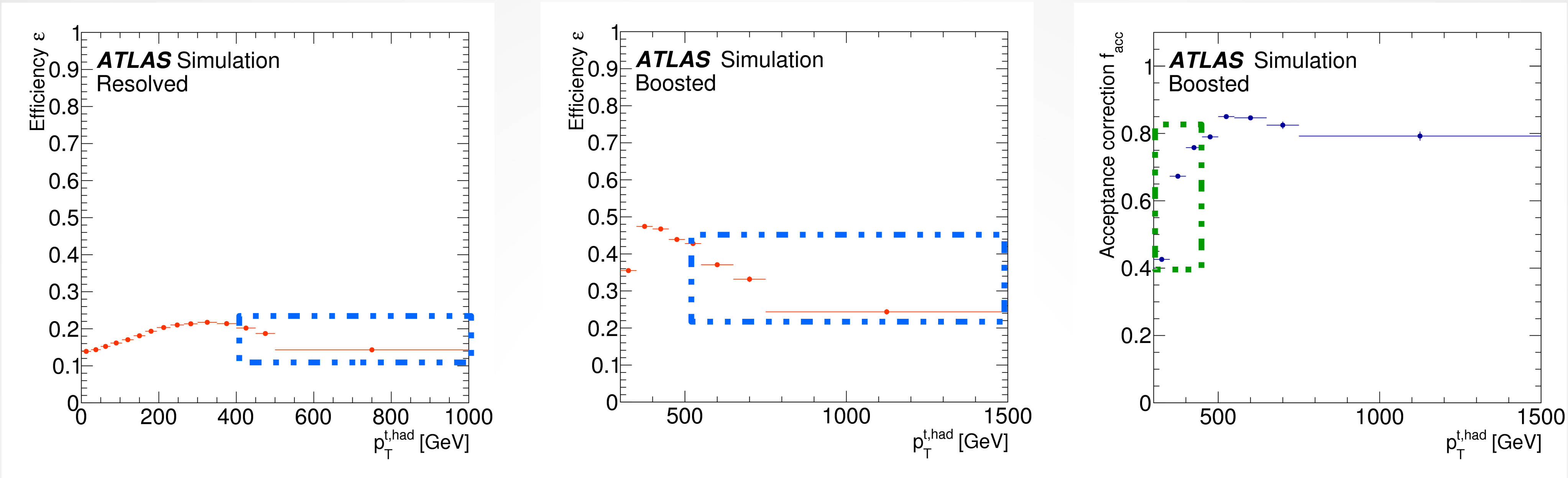




- Reconstructed top invariant mass has a peak at W boson mass value
  - The top decay products are not always contained in the large-R jet

- Although the top mass is better reconstructed in the resolved topology, migration matrices are very diagonal due to binning optimization

Unfolding to particle level

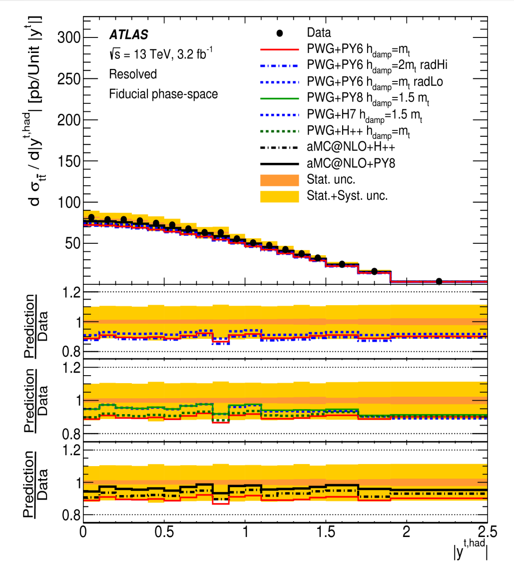


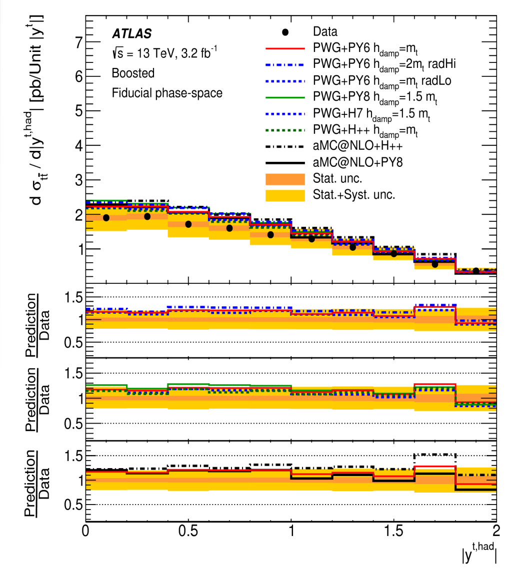
Increasing fraction of non-isolated leptons and drop in b-tagging efficiency

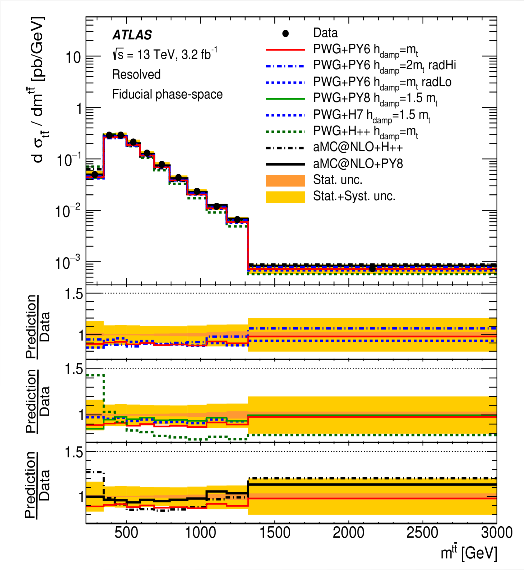
p_T and mass dependancy of the top-tagging algorithm at detector-level

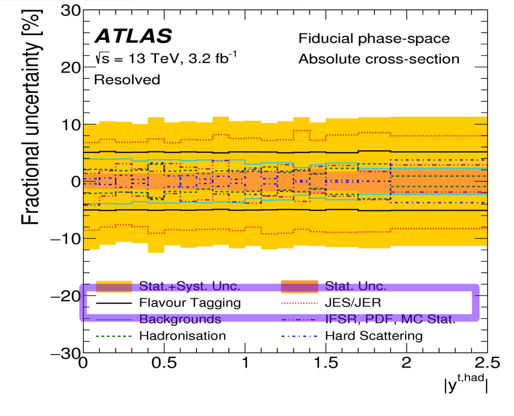
- Results are unfolded to particle level using an iterative D'Agostini technique
  - Particle level is defined from stable particles (τ>3 ns) in a fiducial region close to the detector-level one
  - Particle level is useful for MC comparisons since less affected by detector and modeling effects
    - $$\frac{d\sigma^{fid}}{dX^i} \equiv \frac{1}{\mathcal{L}\cdot\Delta X^i}\cdot\frac{1}{\epsilon^i}\cdot\sum_j \mathcal{M}_{ij}^{-1}\cdot f_{match}^j\cdot f_{acc}^j\cdot\left(N_{reco}^j - N_{bg}^j\right)$$ Matching correction in resolved regime only

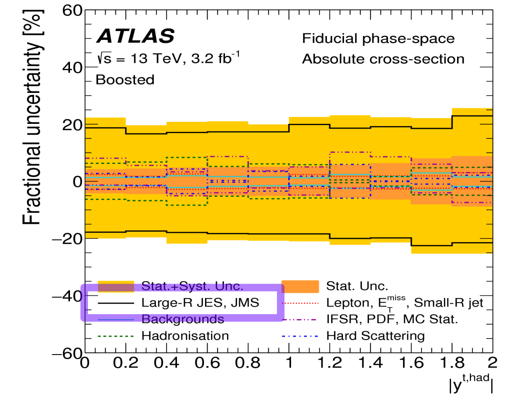
Results

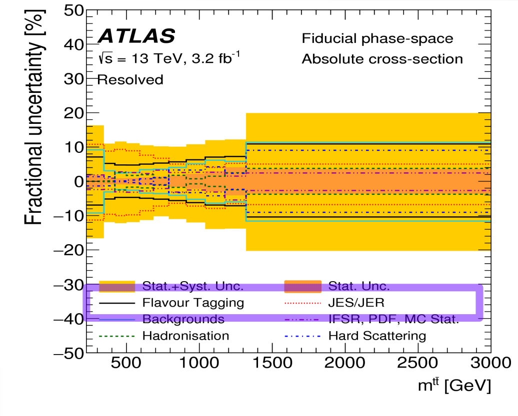








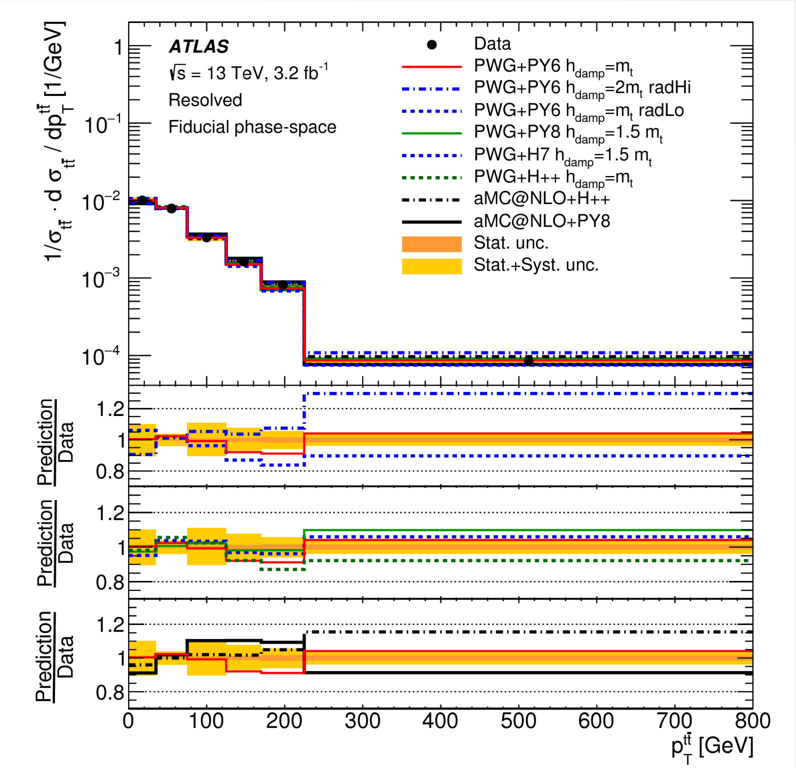


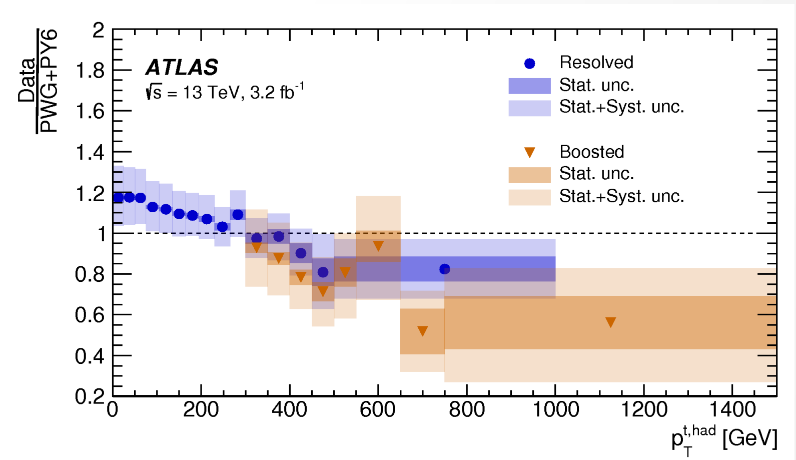


- Resolved total uncertainties at 15-20% level, 20-50% level for the boosted topology
- First ATLAS measurement of the rapidity of the hadronic top in the boosted regime
  - Very good agreement with data in both regimes

Conclusions

- Measurements of differential cross sections in the ℓ+jets channel using data from 13 TeV p–p collisions collected by the ATLAS detector during 2015 ($\mathcal{L}$=3.2 fb^{-1}) have been presented
- A general good agreement between data and MC in a wide kinematic region is observed
  - In the resolved topology, the $p_T^{t\bar{t}}$ spectrum has a good discriminating power between several predictions
    - Possible improvement to MC parameters
- The largest disagreement is observed in the hadronic top p_T spectrum
  - Behaviour consistent both in the resolved and boosted regime
  - Same behaviour observed in previous measurement at lower √s and in other channels





Backup

Montecarlo samples

Physics process	Event generator	Cross-section normalisation	PDF set for hard process	Parton shower	Tune
$t\bar{t}$ Nominal	POWHEG-BOX v2	NNLO+NNLL	CT10	PYTHIA 6.428	Perugia2012
$t\bar{t}$ PS syst.	POWHEG-BOX v2	NNLO+NNLL	CT10	HERWIG++ v2.7.1	UE-EE-5
$t\bar{t}$ ME syst.	MADGRAPH5_ aMC@NLO	NNLO+NNLL	CT10	HERWIG++ v2.7.1	UE-EE-5
$t\bar{t}$ rad. syst.	POWHEG-BOX v2	NNLO+NNLL	CT10	PYTHIA 6.428	'radHi/Lo'
Extra $t\bar{t}$ model	POWHEG-BOX v2	NNLO+NNLL	NNPDF3.0NLO	PYTHIA 8.210	A14
Extra $t\bar{t}$ model	POWHEG-BOX v2	NNLO+NNLL	NNPDF3.0NLO	HERWIG v7.0.1	H7-UE-MMHT
Extra $t\bar{t}$ model	MADGRAPH5_ aMC@NLO	NNLO+NNLL	NNPDF3.0NLO	PYTHIA 8.210	A14
Single top t-channel	POWHEG-BOX v1	NLO	CT10f4	PYTHIA 6.428	Perugia2012
Single top s-channel	POWHEG-BOX v2	NLO	CT10	PYTHIA 6.428	Perugia2012
Single top Wt-channel	POWHEG-BOX v2	NLO+NNLL	CT10	PYTHIA 6.428	Perugia2012
$W(\to \ell\nu)$+ jets	SHERPA v2.1.1	NNLO	CT10	SHERPA	SHERPA
$Z(\to \ell\bar{\ell})$+ jets	SHERPA v2.1.1	NNLO	CT10	SHERPA	SHERPA
WW, WZ, ZZ	SHERPA v2.1.1	NLO	CT10	SHERPA	SHERPA
$t\bar{t}$+$W/Z/WW$	MADGRAPH5_ aMC@NLO	NLO	NNPDF2.3LO	PYTHIA 8.186	A14

Event selection

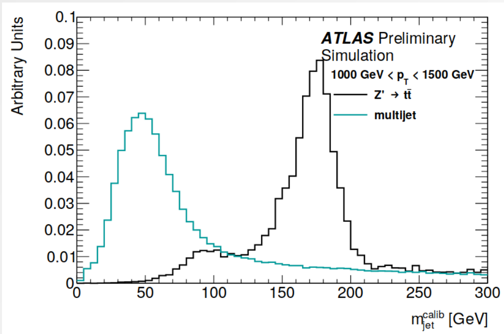
Level	Detector		Particle
Topology	Resolved	Boosted	
Leptons	$\|d_0\|/\sigma(d_0) < 5$ and $\|z_0 \sin\theta\| < 0.5$ mm Track and calorimeter isolation $\|\eta\| < 1.37$ or $1.52 < \|\eta\| < 2.47$ (e), $\|\eta\| < 2.5$ (μ) E_T (e), p_T (μ) > 25 GeV		$\|\eta\| < 2.5$ $p_T > 25$ GeV
Small-R jets	$\|\eta\| < 2.5$ $p_T > 25$ GeV JVT cut (if $p_T < 60$ GeV and $\|\eta\| < 2.4$)		$\|\eta\| < 2.5$ $p_T > 25$ GeV
Num. of small-R jets	≥ 4 jets	≥ 1 jet	Same as detector level
E_T^{miss}, m_T^W		$E_T^{miss} > 20$ GeV, $E_T^{miss} + m_T^W > 60$ GeV	Same as detector level
Leptonic top	Kinematic top-quark reconstruction for detector and particle level	At least one small-R jet with $\Delta R(\ell$, small-R jet$) < 2.0$	
Hadronic top	Kinematic top-quark reconstruction for detector and particle level	The leading-p_T trimmed large-R jet has: $\|\eta\| < 2.0$, 300 GeV $< p_T <$ 1500 GeV, $m > 50$ GeV, Top-tagging at 80% efficiency ΔR(large-R jet, small-R jet associated with lepton) > 1.5, $\Delta\phi(\ell$, large-R jet$) > 1.0$	**Boosted:** $\|\eta\| < 2.0$ $300 < p_T < 1500$ GeV Top-tagging: $m > 100$ GeV, $\tau_{32} < 0.75$
b-tagging	At least 2 b-tagged jets	At least one of: 1) the leading-p_T small-R jet with $\Delta R(\ell$, small-R jet$) < 2.0$ is b-tagged 2) at least one small-R jet with ΔR(large-R jet, small-R jet$) < 1.0$ is b-tagged	Ghost-matched b-hadron

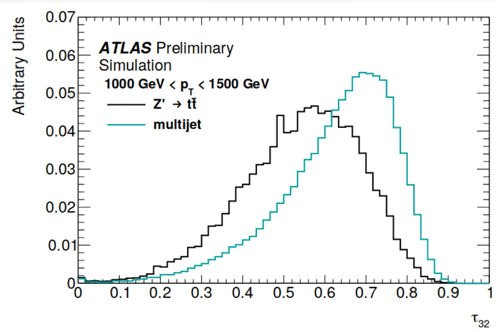
Background estimation

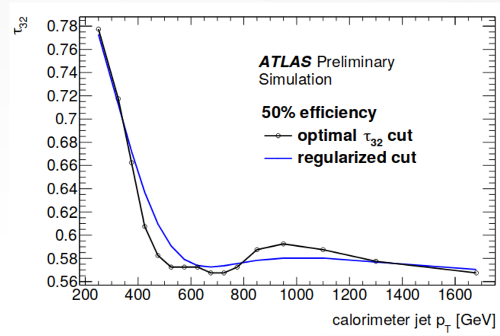
- Single-top is the largest background
  - 35% of total background, MC estimated
- Multi-jet background estimated from data using a matrix-method
  - Efficiency factors are applied to events passing tight and loose lepton requirements
  - Fake-leptons efficiency evaluated in control regions from data subtracted from real-leptons contribution using MC simulations
  - Real-leptons efficiency from tag-and-probe technique using leptons from Z decays
- The W+jets background is the second-leading (20%-31% of total background) and it is estimated from a combination of MC and real data
  - Shapes are from MC, total normalization and heavy-flavour fraction for this process are from data
- Z+jets, $t\bar{t}V$ and dibosons from MC simulations

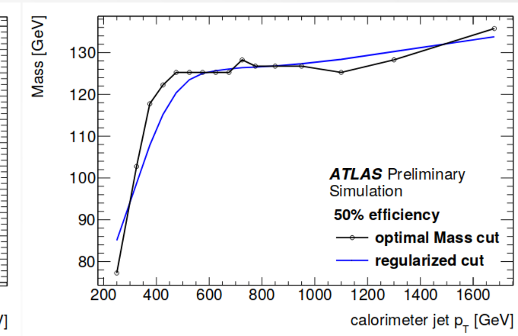
Process	Expected events	
	Resolved	Boosted
$t\bar{t}$	123800 ± 10600	7000 ± 1100
Single top	6300 ± 800	500 ± 80
Multijets	5700 ± 3000	300 ± 80
W+jets	$3600\ ^{+2000}_{-2400}$	500 ± 200
Z+jets	1300 ± 700	60 ± 40
$t\bar{t}V$	400 ± 100	70 ± 10
Diboson	300 ± 200	60 ± 10
Total prediction	$142000\ ^{+11000}_{-12000}$	8300 ± 1300
Data	155593	7368

Top tagging algorithm

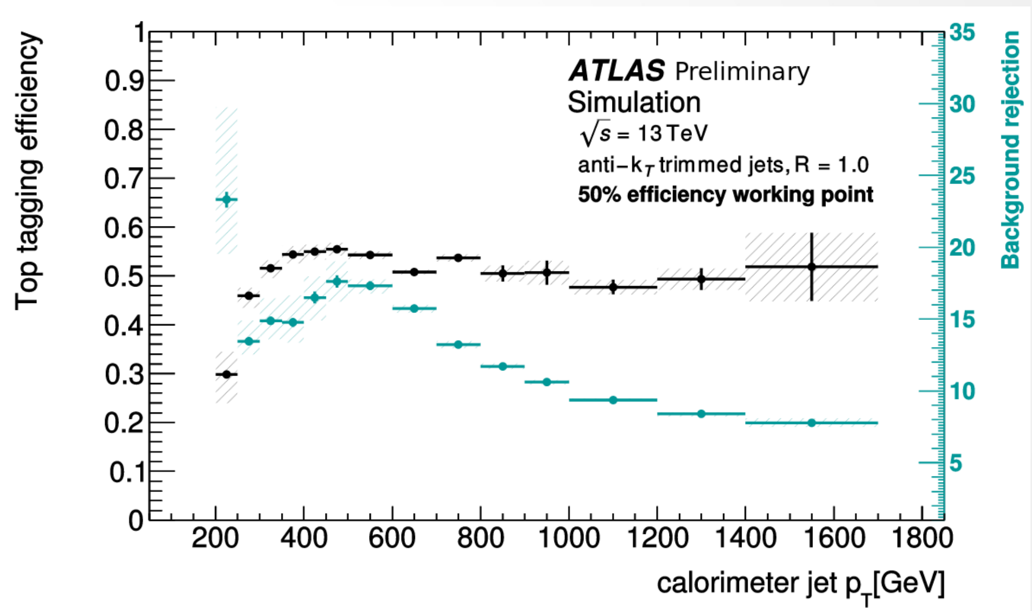








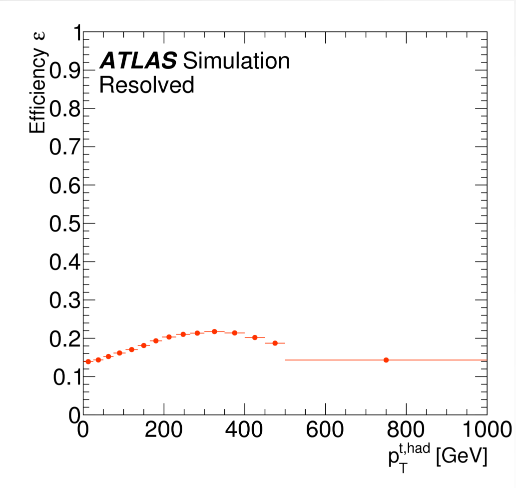
- The top-tagging algorithm uses 2 substructure variables
  - Calibrated jet mass
  - N-subjettiness ratio $\tau_{32}=\tau_3/\tau_2$
    - Calculated from the N-subjettiness τ_N, based on reconstructing exactly N subjets with the k_t algorithm from the jet constituents
    - $$\tau_N = \frac{1}{d_0}\sum_k p_{Tk} \times \min(\delta R_{1k}, \delta R_{2k}, \ldots, \delta R_{Nk})$$

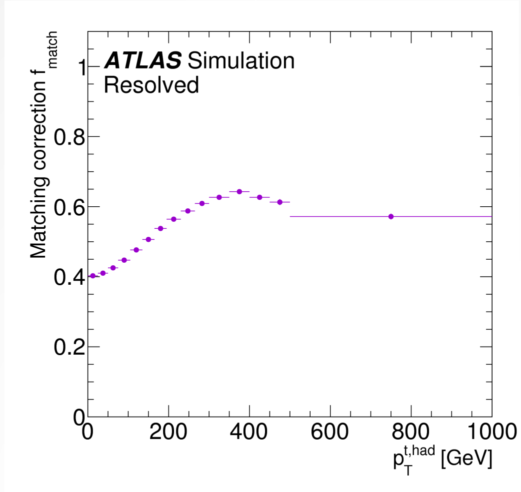


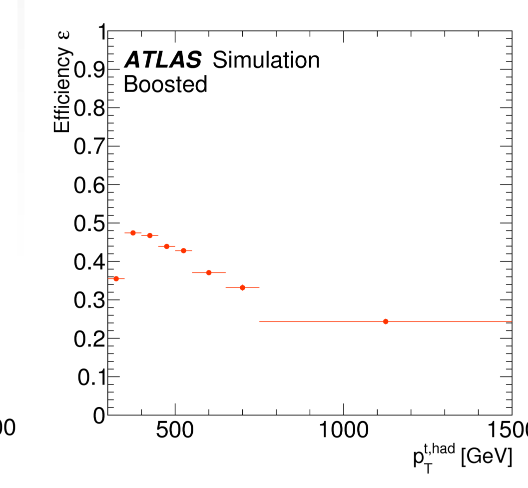
PseudoTop algorithm

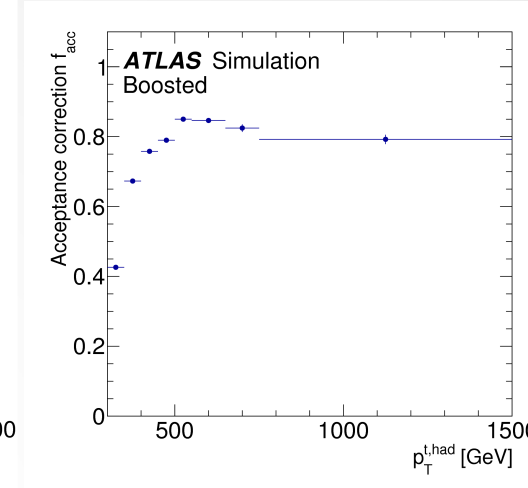
- Kinematic reconstruction of top four-vector from final state objects
- B-tagged jets
  - Select 2 p_T leading b-tagged jets
- Leptonic W
  - Reconstructed from the lepton and the neutrino ν
    - Underconstrained system: the p_x and p_y components of the ν correspond to the E_T^{miss} vector. To evaluate the p_z component of ν four-momentum the mass of the W boson is set to m_W=80.399 GeV and the associated quadratic equation is solved
    - 2 real solutions
      - Solution with smaller $|p_z|$ taken
    - 2 imaginary solutions
      - Imaginary part dropped
        or
      - Netruino four-momentum smeared
- Leptonic top is reconstructed from leptonic W and the closest b-jet (in ΔR)
- Hadronic W
  - Reconstructed from the pair of non b-tagged jets whose invariant mass is closest to the W boson PDG value
- Hadronic top is reconstructed from the non-leptonic b-jet and hadronic W

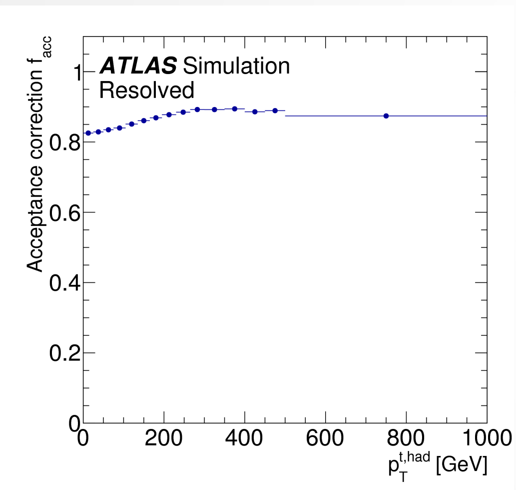
Unfolding to particle level (extended)

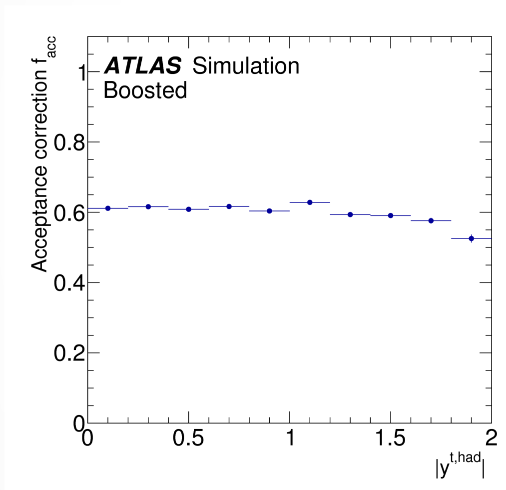


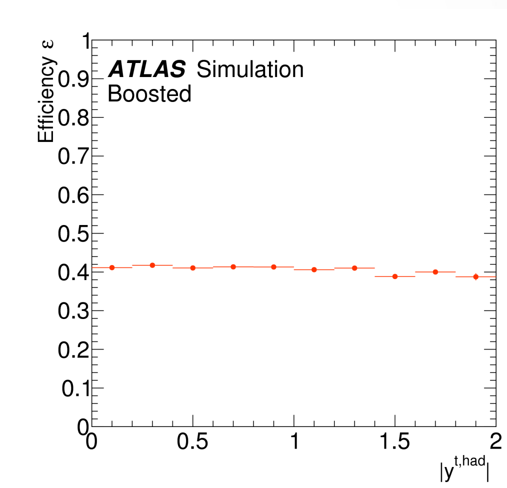












$$\frac{d\sigma^{fid}}{dX^i} \equiv \frac{1}{\mathcal{L}\cdot\Delta X^i}\cdot\frac{1}{\epsilon^i}\cdot\sum_j \mathcal{M}_{ij}^{-1}\cdot f^j_{match}\cdot f^j_{acc}\cdot\left(N^j_{reco}-N^j_{bg}\right)$$

$$f^j_{acc} \equiv \left(\frac{N_{reco\wedge part}}{N_{reco}}\right)^j$$

$$f^j_{match} \equiv \left(\frac{N_{reco\wedge part\wedge matched}}{N_{reco\wedge part}}\right)^j$$

$$\epsilon \equiv \left(\frac{N_{reco\wedge part\wedge matched}}{N_{part}}\right)^i$$

- Spectra are corrected for acceptance effects, efficiency due to events passing the particle level selection but are not reconstructed at detector level and recombinatorial effects by angular matching (resolved topology only)
- Low efficiency at high values of p_T in resolved topology due to increasing fraction of non-isolated leptons and of merged jets and drop in b-tagging efficiency
- High efficiency at large pT observed with the boosted reconstruction. Decreasing efficiency at very high momentum due to too stringent lepton isolation requirement and low b-tagging efficiency at high p_T
- Low acceptance at low momentum in the boosted regime is due to the p_T and mass dependancy of the top-tagging algorithm at detector level