Observation of t-channel Single-top-quark Production at $\sqrt{s} = 5.02$ TeV with the ATLAS Detector

ATLAS-CONF-2023-033

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Motivation

- **SM** predicts **single-top-quark production** in the t-channel
- Previous t-channel single-top-quark cross-section measurement by ATLAS at $\sqrt{s} = 7$ TeV, 8 TeV, 13 TeV:

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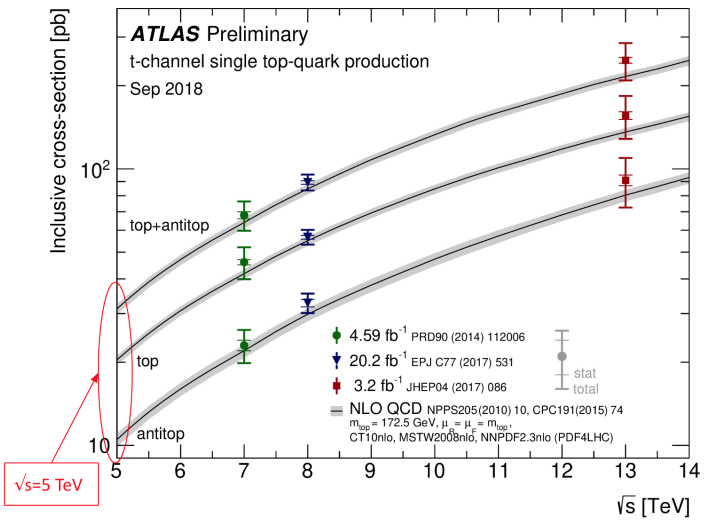
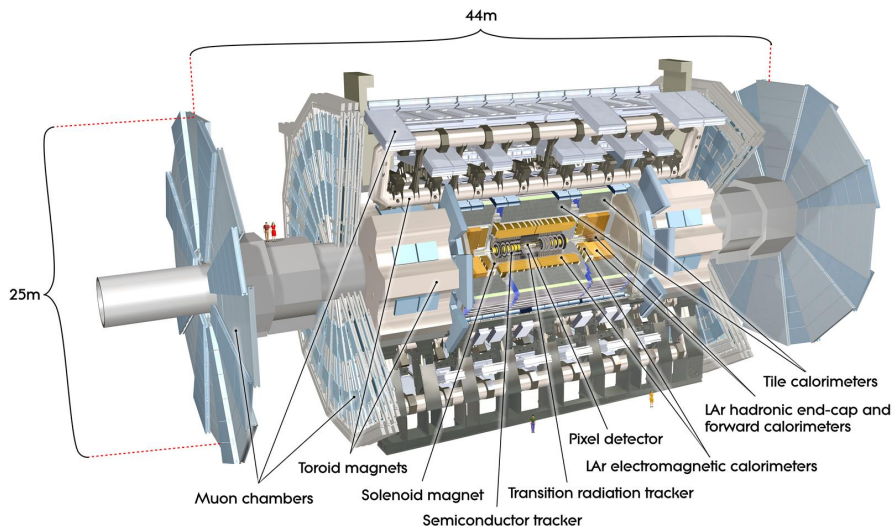


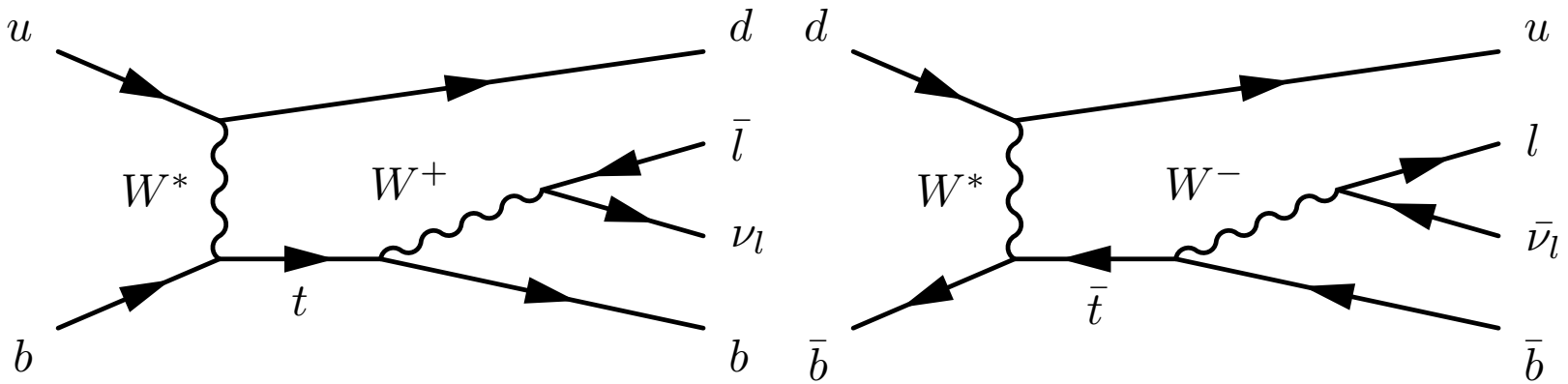


- 257 pb^{-1} of data collected by ATLAS in 2017 with $\sqrt{s} = 5.02$ TeV
  - Allows for a cross-section measurement with a lower number of average interactions per crossing
- Additional test of SM and **possible constraints on proton PDFs**

Objective

Single top-quark production in t-channel

- Expected NNLO cross-section $\sigma_{\mathrm{SM}} = 30.3$ pb at 5 TeV
  - $\sigma_t = 20.3$ pb for top-quark
  - $\sigma_{\bar{t}} = 10.0$ pb for antitop-quark
  - $R_t = 2.03$ for ratio between cross-section of top and antitop
- **t-channel is largest process**; Wt associated production and s-channel are much smaller



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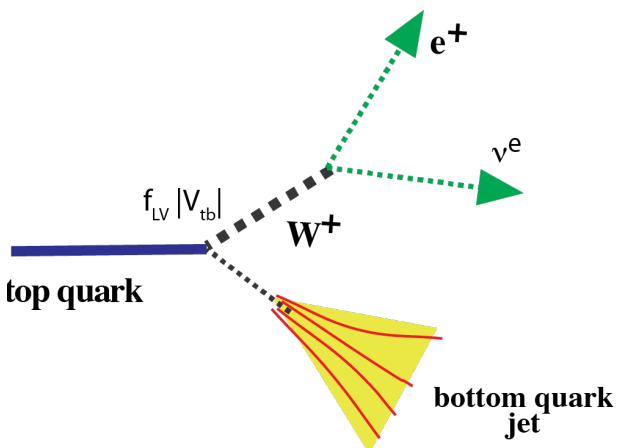
Analysis Strategy

1. Select for t-channel single-top-quark events
   - Include forward jets
2. Train a Boosted Decision Tree (BDT) to enhance signal vs background separation
3. Use a binned-profile likelihood fit of BDT output distribution to extract:
   - Total single top (top and antitop) cross-section ($\sigma_{t\text{-chan.}}$)
   - Ratio between top/antitop (R_t)

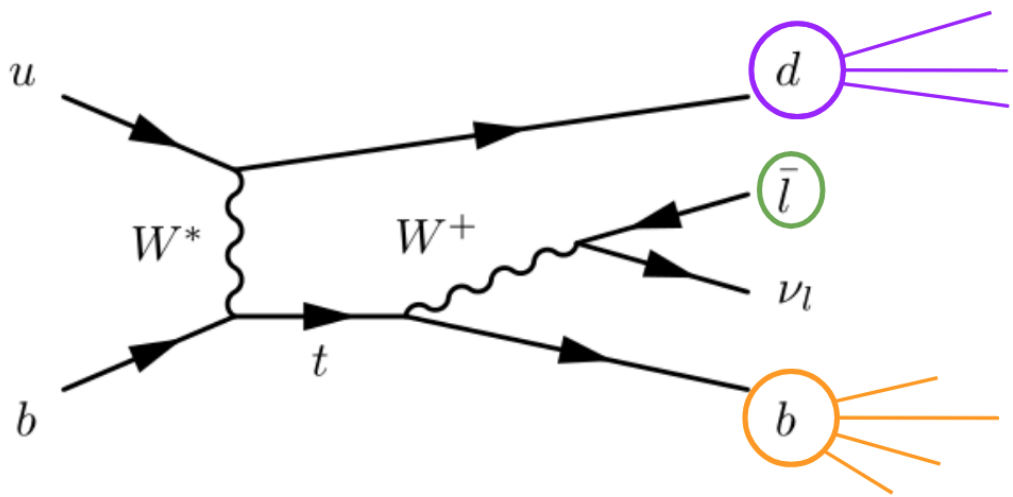
Use $\sigma_{t\text{-chan.}}$ and R_t to calculate:

- Single top only cross-section (σ_t)
- Single antitop only cross-section ($\sigma_{\bar{t}}$)
- Product of the left-handed form factor and CKM matrix element V_{tb} ($f_{LV} \cdot |V_{tb}|$)



Event Selection Requirements

- Semi-leptonic decay: 1 lepton, exactly 2 jets
  - 1 untagged jet (originating from the light quark)
  - 1 b-tagged jet (originating from b hadrons)
- $1.5 < |\eta| < 4.0$ for untagged jet to characterize forward jet
- Various optimized kinematic requirements
  - Reduce contribution from W+jets, $t\bar{t}$ process and mis-ID leptons
  - Increase purity of signal events



H_{T} Distribution

- $H_{\mathrm{T}} = p_{\mathrm{T,lep}} + \sum p_{\mathrm{T,jet}} + E_{\mathrm{T}}^{\mathrm{miss}}$

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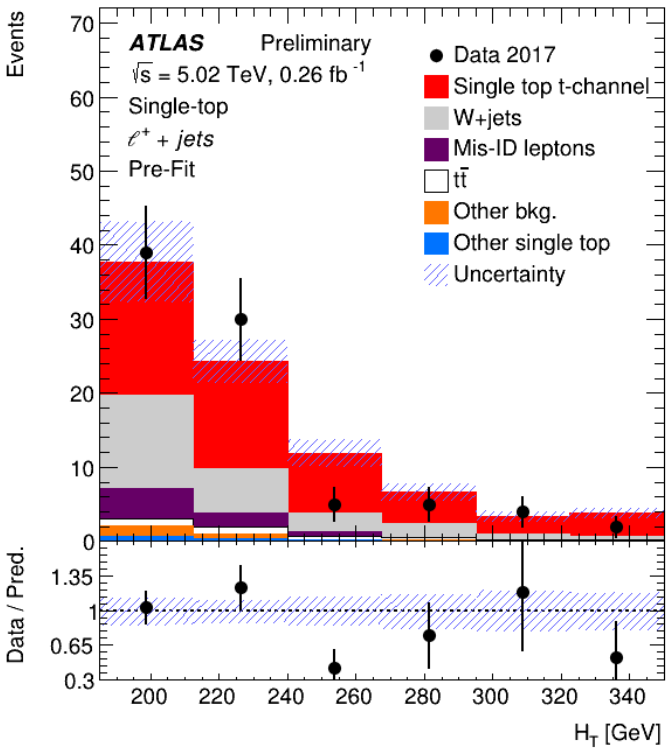
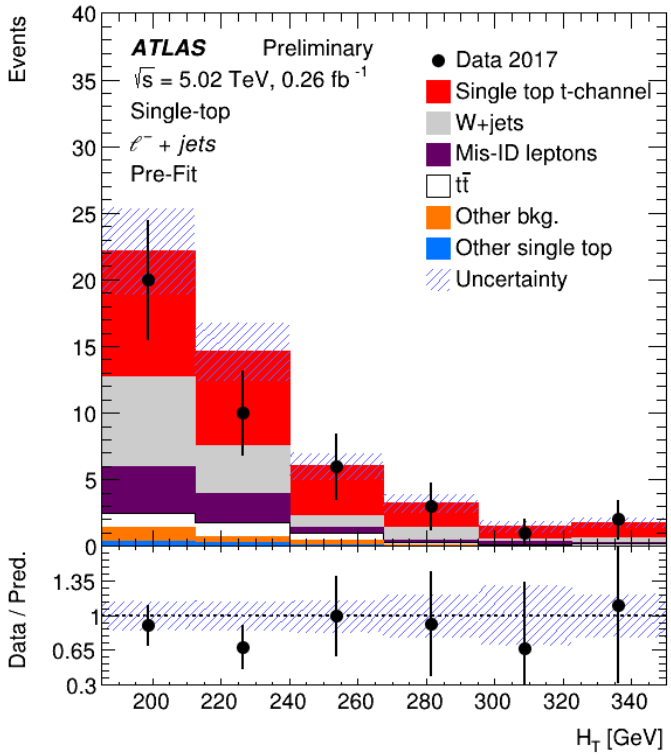


ℓ^++jets



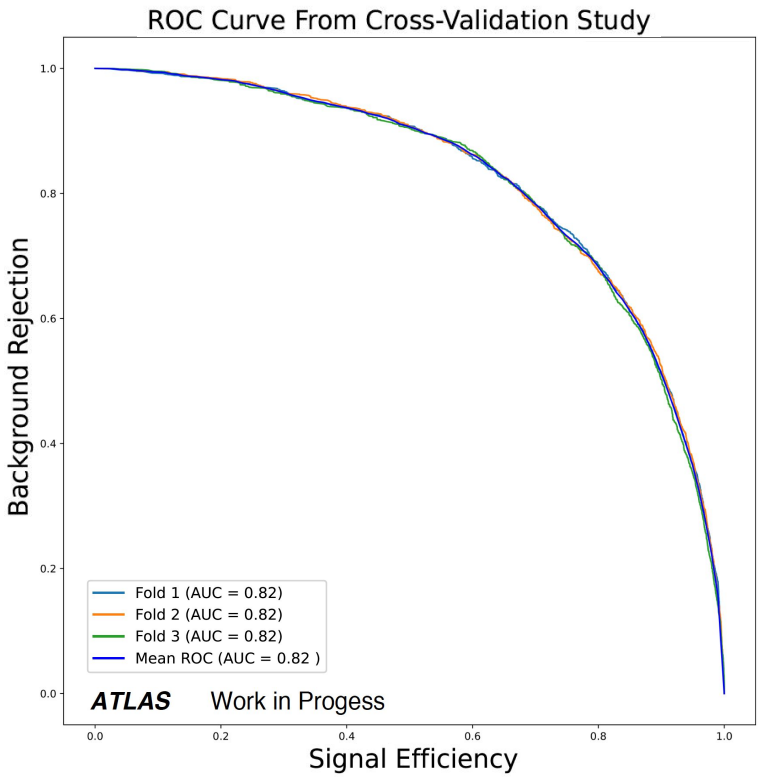
ℓ^-+jets

- Split into:
  - ℓ^++jets region $\rightarrow$ single top events
  - ℓ^-+jets region $\rightarrow$ single antitop events

BDT Implementation

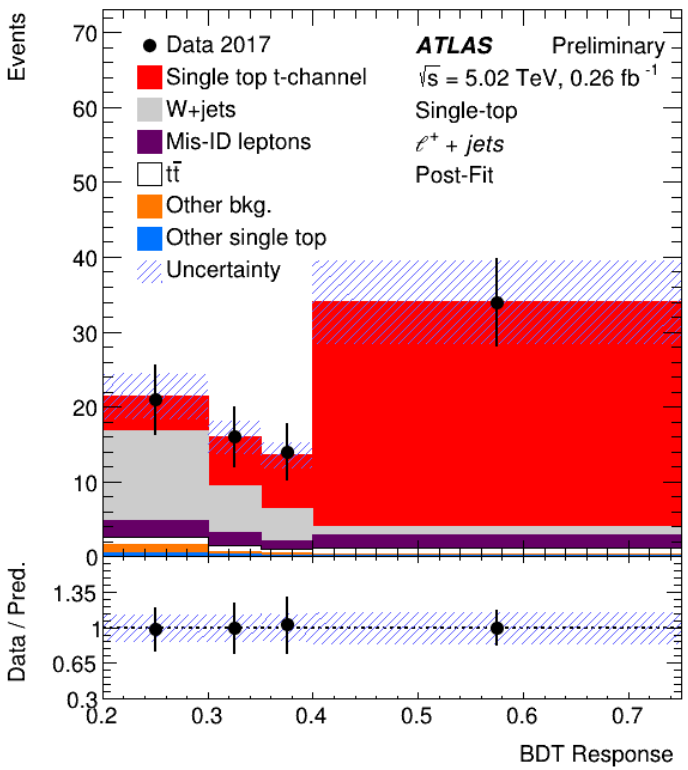
Using BDT to optimize Signal vs Background separation

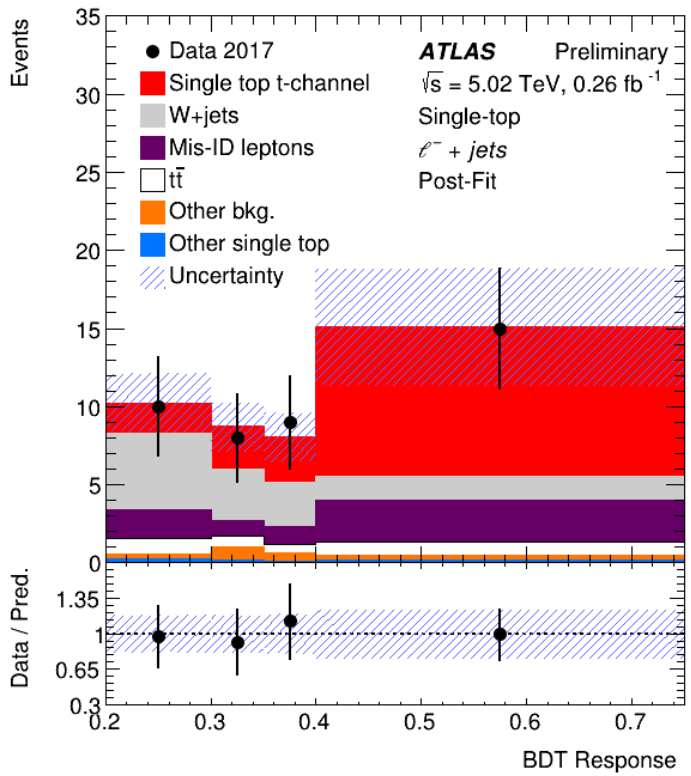
- BDT trained on an **inclusive region** using truth MC info
- **9 input parameters**, most discriminating:
  - H_{T}
  - Magnitude difference in p_{T} between the reconstructed W boson and the jet pair
  - $|\eta|$ of the light quark (untagged) jet



BDT Response Distribution

- Perform a binned profile-likelihood fit of the sum of the BDT response distribution for signal and bkg MC samples to the observed BDT response distribution
- Systematic uncertainties included into fit using nuisance parameters





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Results

- $\sigma_{t\text{-chan.}} = 26.6\ ^{+4.3}_{-4.0}\,(\text{stat.})\ ^{+4.4}_{-3.6}\,(\text{syst.})$ pb
- $R_t = 2.74\ ^{+1.44}_{-0.83}\,(\text{stat.})\ ^{+1.04}_{-0.29}\,(\text{syst.})$

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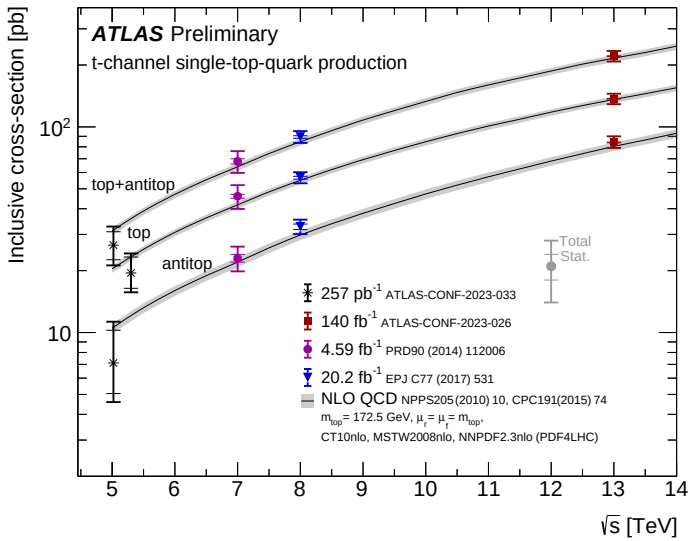
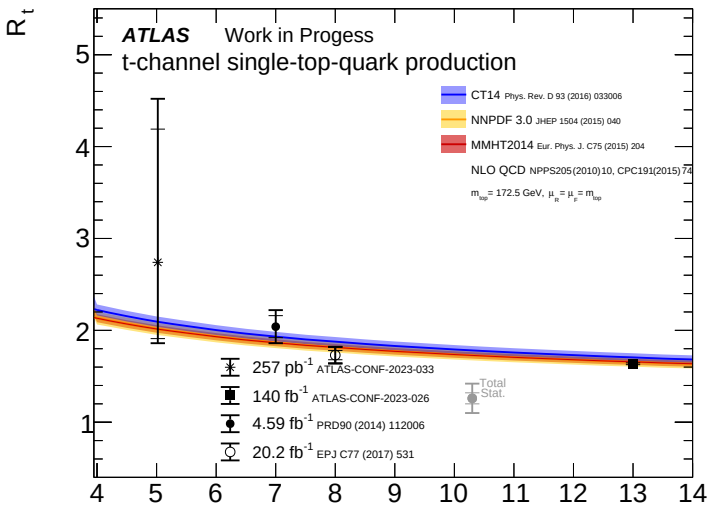
Source	Number of events ℓ^++jets	ℓ^-+jets
$tq + \bar{t}q$	48 ± 9	17 ± 8
W + jets	24 ± 5	13 ± 3
Misidentified leptons	7 ± 3	7 ± 3
$t\bar{t}$	3 ± 0.5	3 ± 0.5
Z + jets and diboson	2 ± 1	2 ± 1
Other single-top-quark production	1 ± 0.2	1 ± 0.5
Total predicted	85 ± 9	42 ± 7
Data	85	42





- Good agreement between data and prediction
- **Significance: 6.1σ observed!**

Conclusion

- Results:

Variable	Predicted	Measured
$\sigma_{t\text{-chan.}}$	30.3 pb	$26.6\ ^{+4.3}_{-4.0}\,(\text{stat.})\ ^{+4.4}_{-3.6}\,(\text{syst.})$ pb
R_t	2.03	$2.74\ ^{+1.44}_{-0.83}\,(\text{stat.})\ ^{+1.04}_{-0.29}\,(\text{syst.})$
σ_t	20.3 pb	$19.5\ ^{+3.8}_{-3.1}\,(\text{stat.})\ ^{+2.9}_{-2.2}\,(\text{syst.})$ pb
$\sigma_{\bar{t}}$	10.0 pb	$7.1\ ^{+3.2}_{-2.1}\,(\text{stat.})\ ^{+2.8}_{-1.5}\,(\text{syst.})$ pb
$f_{LV} \cdot \lvert V_{tb}\rvert$	1.01	$0.94\ ^{+0.08}_{-0.07}\,(\text{stat.})\ ^{+0.08}_{-0.06}\,(\text{syst.})$

- Measurement in **good agreement with SM**
- CONF note released – ATLAS-CONF-2023-033
- The $\sqrt{s} = 5.02$ TeV special run provides unique opportunity to probe interesting physics in the top sector
  - Provides an independent test of the SM predictions
  - Could increase understanding of proton PDFs in the future.

Backup

Event Selection Requirements

- **Topology requirement**
  - Exactly 1 lepton
    - Electron → $|\eta_{cl}| \leq 2.47$ + exclude crack region
    - Muon → $|\eta| \leq 2.5$
  - Exactly 2 jets
    - 1 untagged jet → $1.5 \leq |\eta| \leq 4.0$
    - 1 b-tag jet → $|\eta| \leq 2.5$ and `DL1r` 60% efficiency
    - $\Delta\eta$ between jets > 1.5

Reduce ttbar contribution

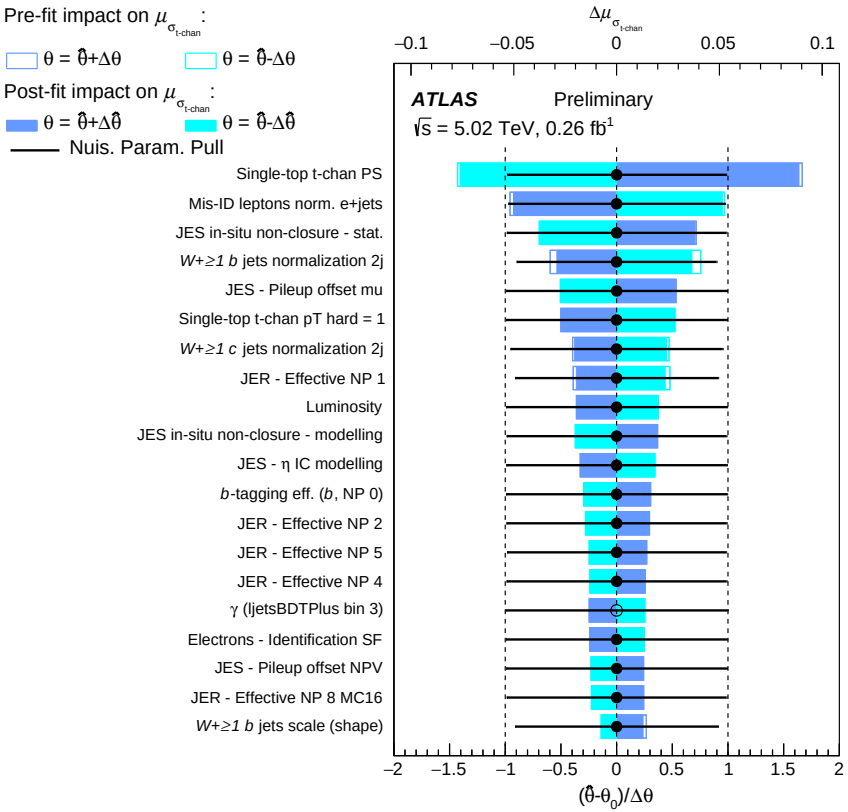
- **Kinematic requirement**
  - Lepton $p_T \geq 18$ GeV
  - Jets $p_T \geq 23$ GeV
  - $E_T^{miss} \geq 15$ GeV
  - $m_T^W \geq 35$ GeV
  - Triangular $(m_T^W + E_T^{miss}) \geq 70$ GeV

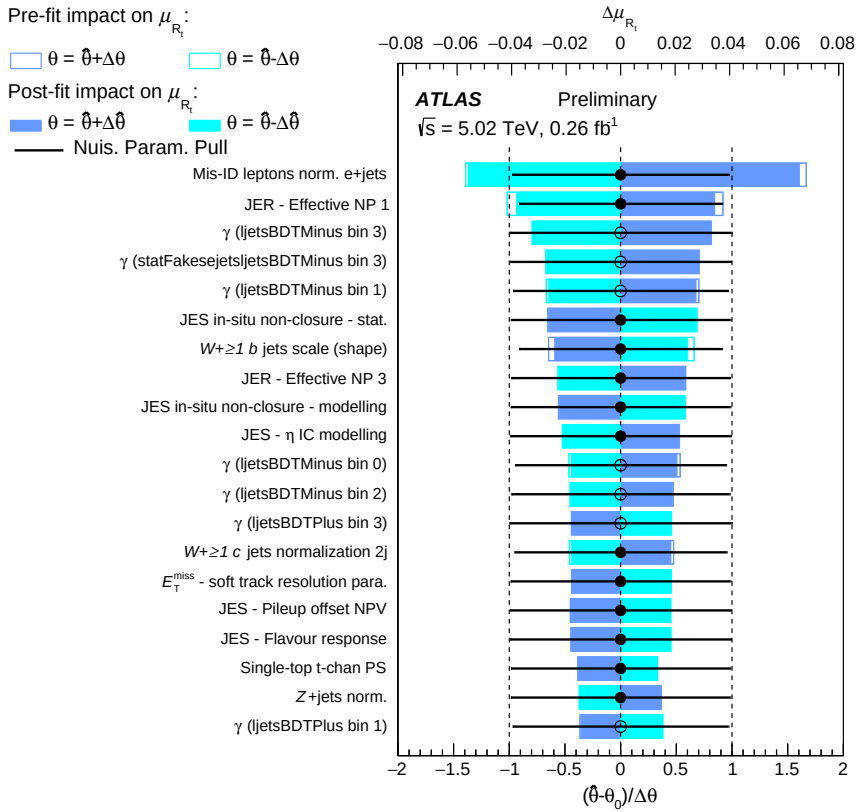
Reduce Mis-ID lepton contribution

  - $HT = (p_{T,lep} + \sum p_{T,jet} + E_T^{miss}) \geq 185$ GeV
  - Lepton and b-tagged jet mass $m_{lb} \leq 165$ GeV
  - $m_W < 102$ GeV
  - 140 GeV $< m_{top} < 225$ GeV

Increase purity of signal events

Systematic Uncertainties Ranking Plots





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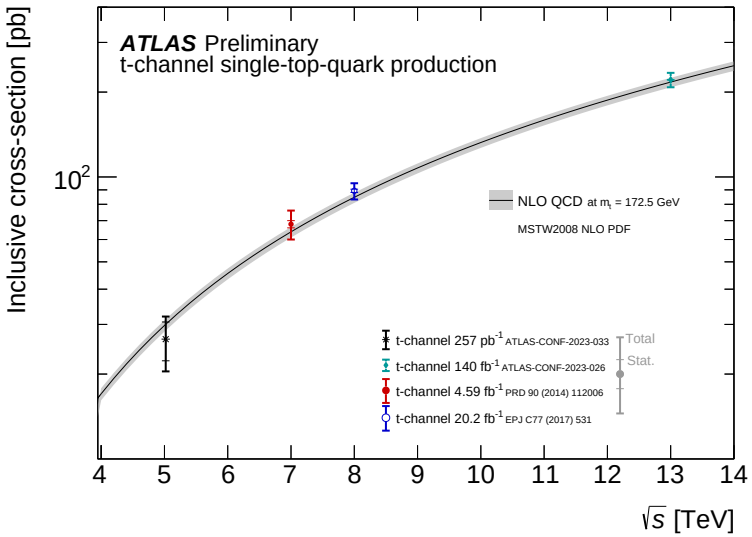
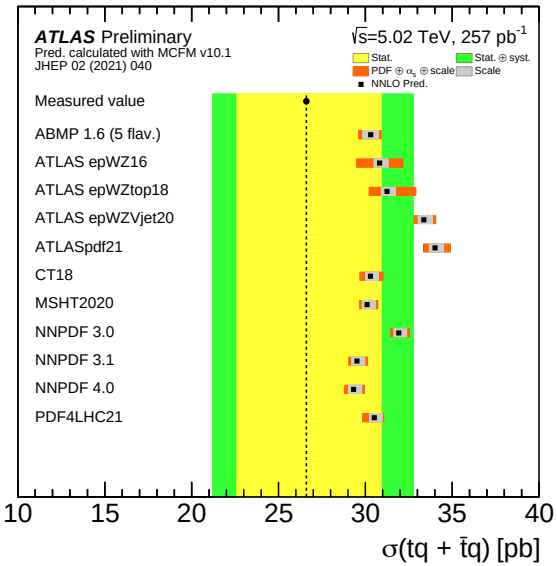
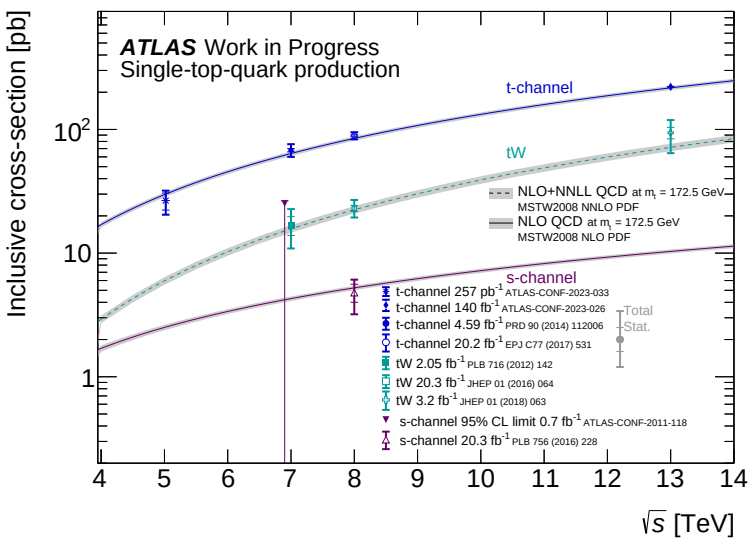
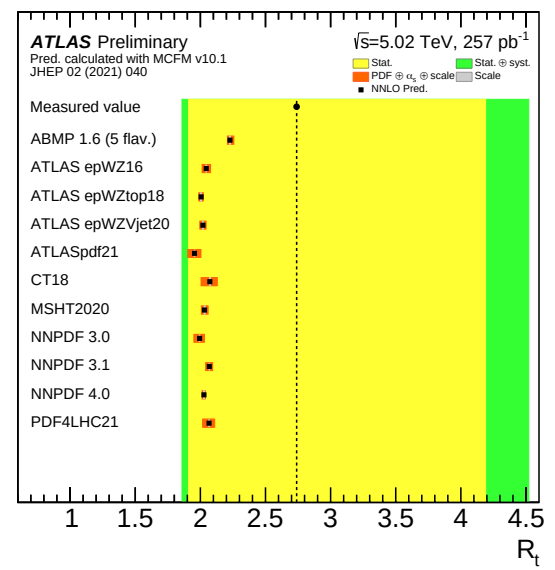
Summary Plots









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