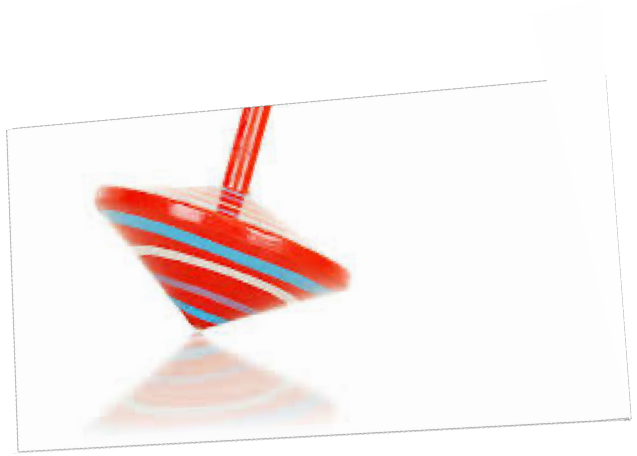
# LOW ENERGY TOP QUARKS SEEN BY THE ATLAS DETECTOR AT THE LHC

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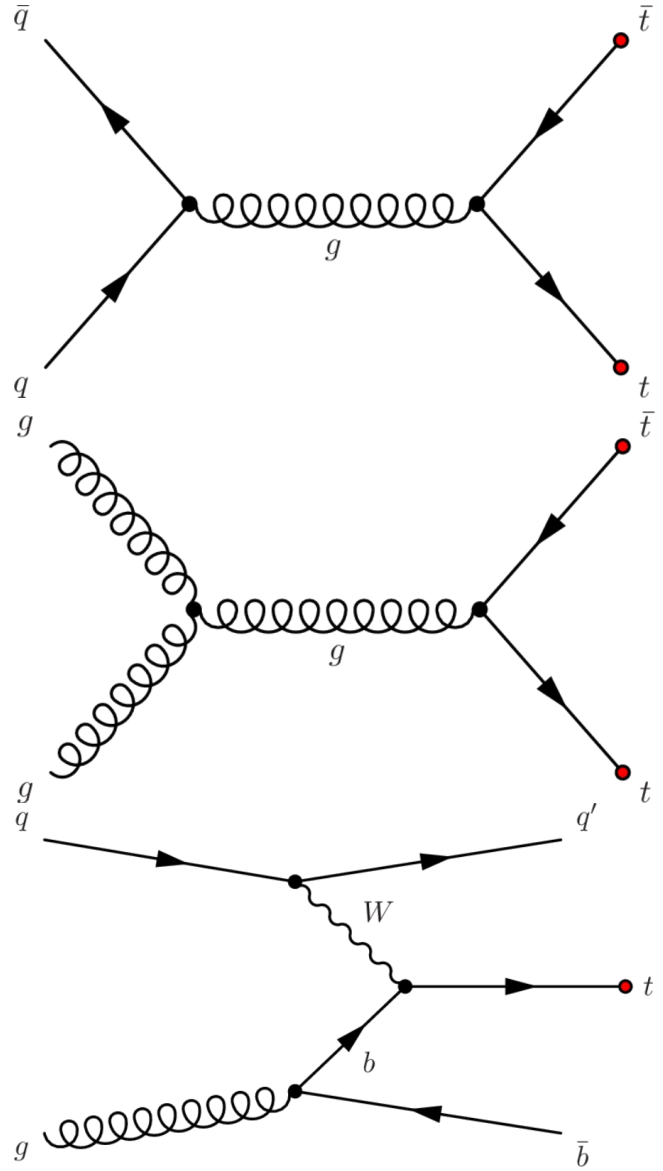
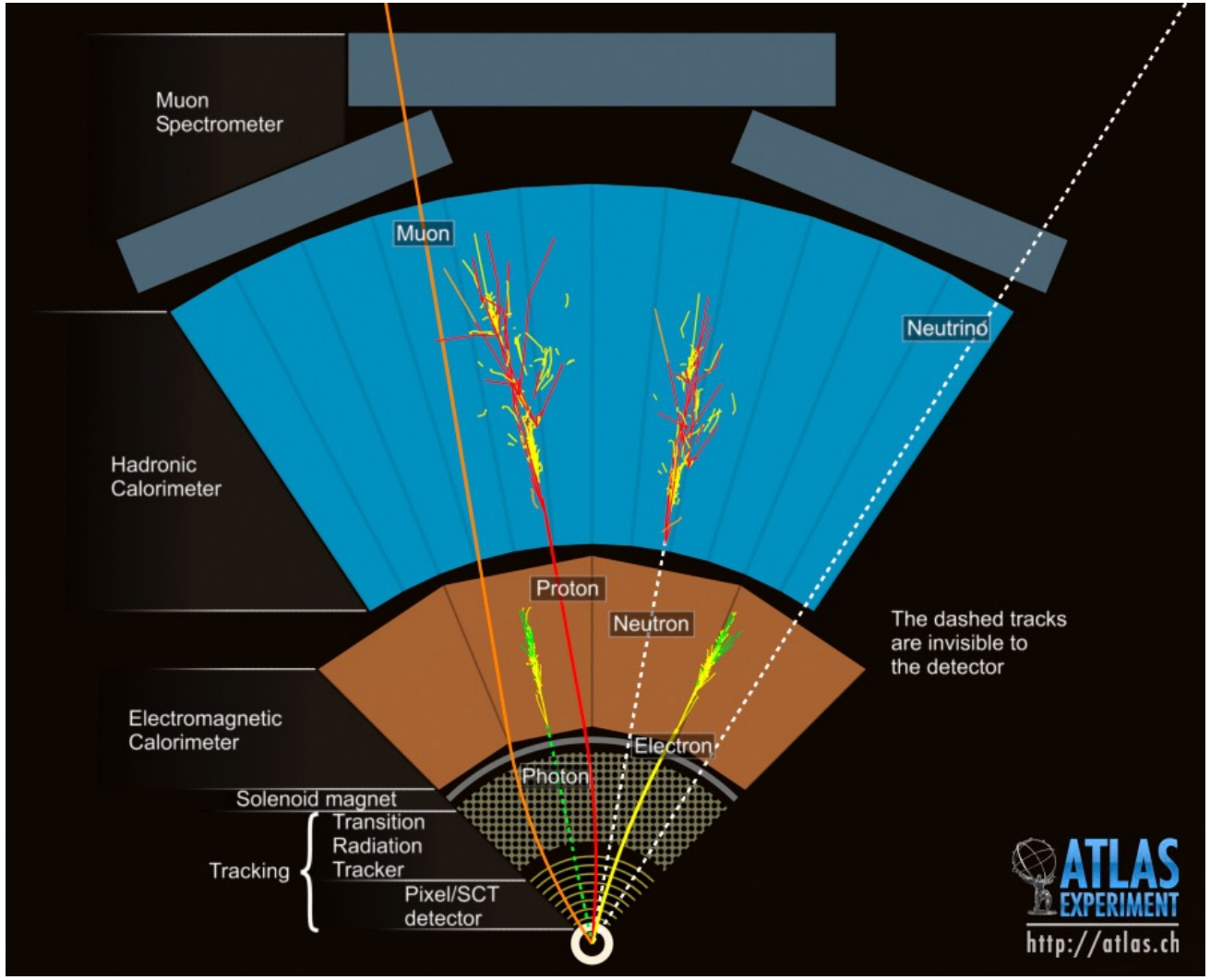
# OVERVIEW OF TOP QUARK PRODUCTION

- Major source of production is via pair production
- Single top quarks produced through three mechanisms and t-channel has the largest cross-section of the three
  - $\sigma_{t-chan} \propto V_{tb}$ term of the CKM matrix
- ATLAS collected $257$ pb$^{-1}$ worth of data at $\sqrt{s} = 5.02$ TeV in 2017
  - $t\bar{t}$ cross-section measurement published last year - JHEP 06 (2023) 138
  - t-channel production is just about to be published - ATLAS-CONF-2023-033
- Measurement at $\sqrt{s} = 5.02$ TeV allows for a test of the SM and possible constraints on PDFs



# ATLAS DETECTOR

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# MEASURED PAIR PRODUCTION CROSS SECTION

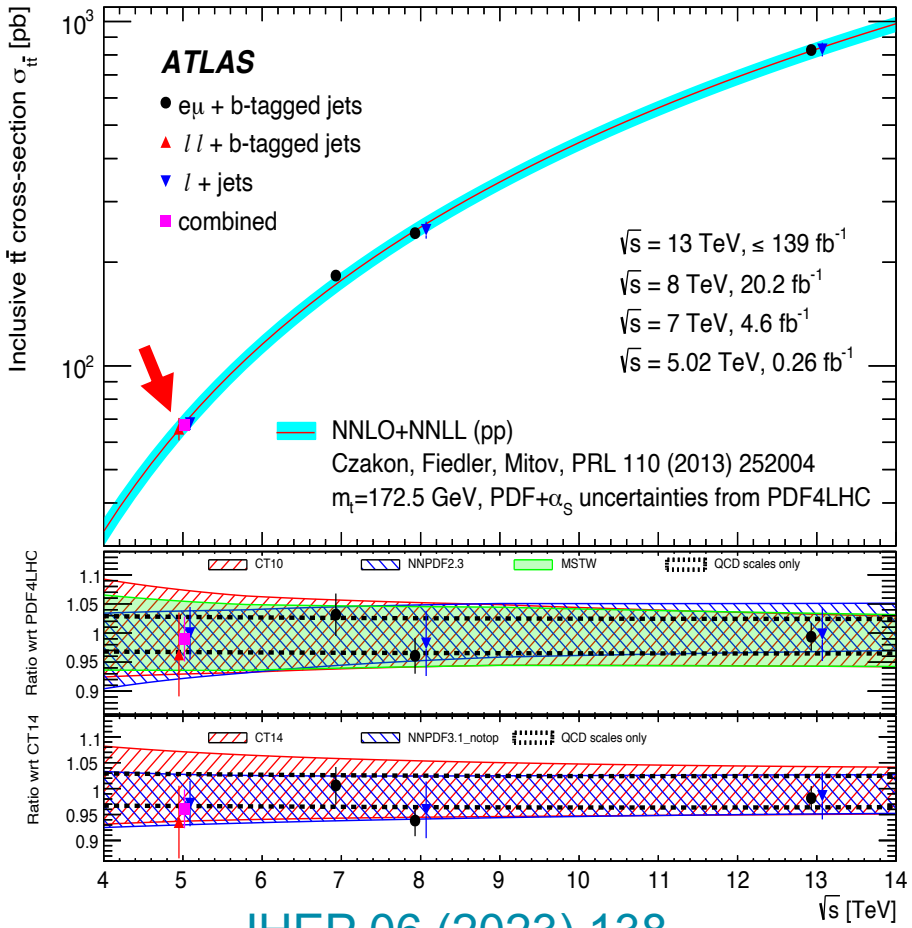
- Fitted Boosted Decision Tree (BDT) distribution in single lepton (SL) and cut and count for dilepton (DL) regions
- Measurements:

SL: $68.2 \pm 0.9(\text{stat.}) \pm 2.9(\text{syst.}) \pm 1.1(\text{lumi.}) \pm 0.2(\text{beam})$ pb

DL: $65.7 \pm 4.5(\text{stat.}) \pm 1.6(\text{syst.}) \pm 1.2(\text{lumi.}) \pm 0.2(\text{beam})$ pb

Comb: $67.5 \pm 0.9(\text{stat.}) \pm 2.3(\text{syst.}) \pm 1.1(\text{lumi.}) \pm 0.2(\text{beam})$ pb

- SM predicts $\sigma_{t\bar{t}} = 68.2^{+5.2}_{-5.3}$ pb
- Most precise (4.5%) $\sigma_{t\bar{t}}$ measurement in the SL channel by ATLAS!
- 3.9% overall uncertainty in the combined result of the two channels

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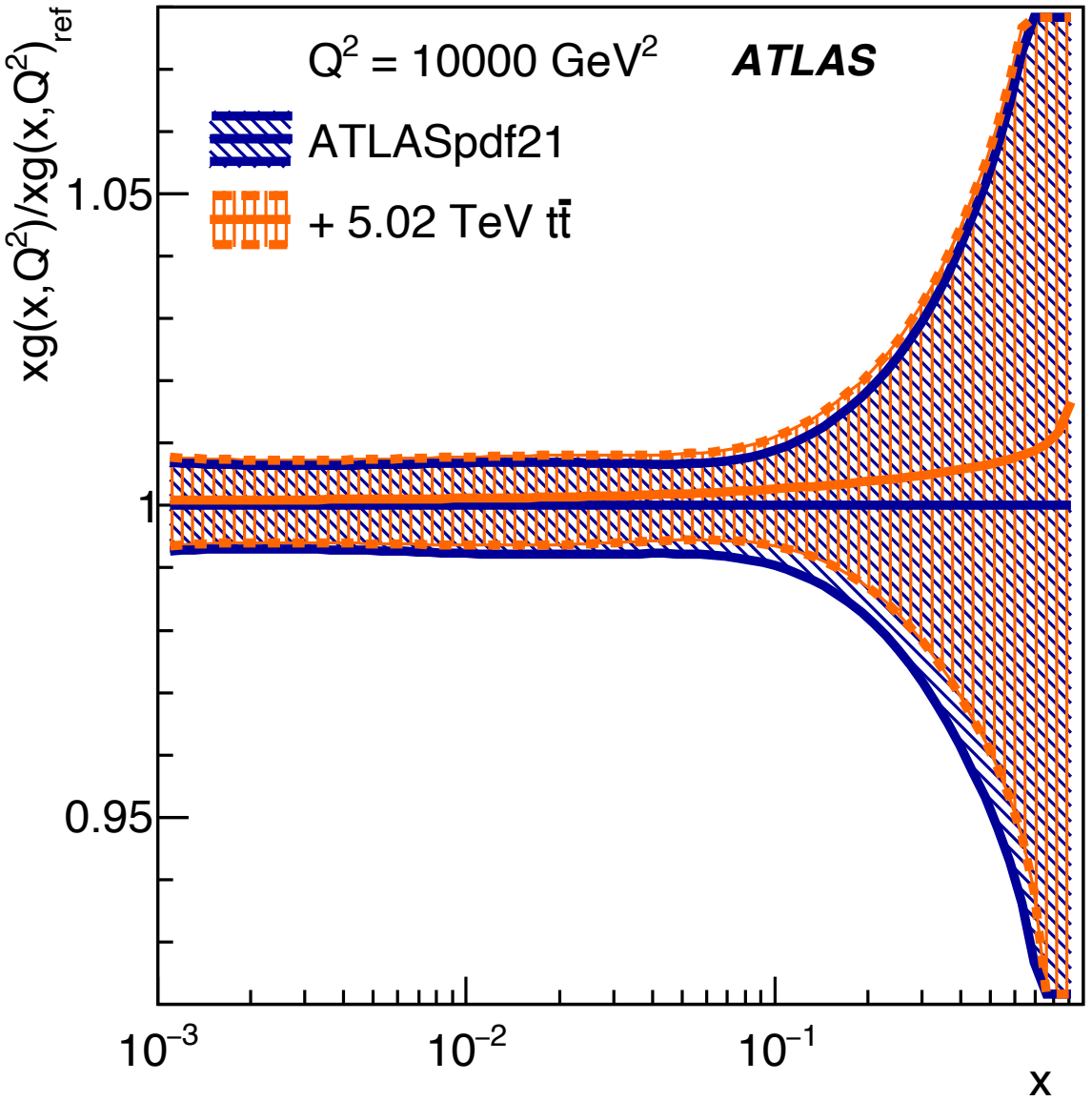
# EFFECT ON THE GLUON PDF

- Including the combined $\sigma_{t\bar{t}}$ measurement to the ATLASPDF21 fit
- ~1% increase in the gluon PDF at high $x$
- ATLASPDF21 also contains multiple top quark measurements from 8 and 13 TeV
  - The effect of these measurements at high $x$ is O(1%) as well
  - One measurement at 5.02 TeV gives a 1% change in a fit with ~1500 degrees of freedom

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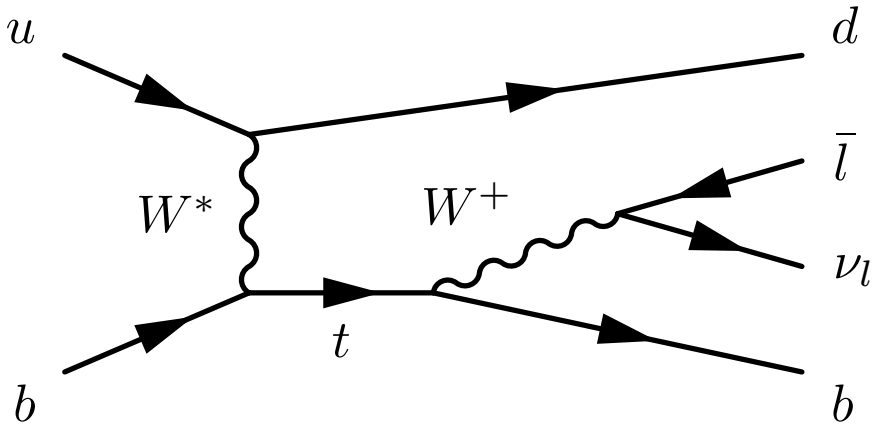
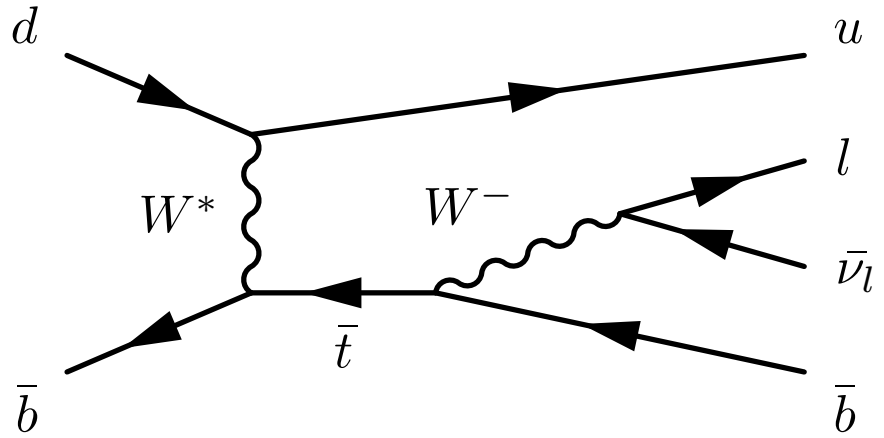
# SINGLE TOP ANALYSIS STRATEGY

See also Laura's talk!

- There is an additional spectator jet produced with the top quark
  - This forward jet is typically produced in the high $|\eta|$ region
  - Optimized selection for maximum S/sqrt(S+B)
- Use the leptonic decay of the top quark to trigger on events
- Require one b-tagged jet with $|\eta| < 2.5$ and one "untagged" jet with $|\eta| < 4.0$
- At 5.02 TeV the t-channel cross section is predicted at NNLO to be 30.3 pb
  - $\sigma_t = 20.3$ pb and $\sigma_{\bar{t}} = 10$ pb



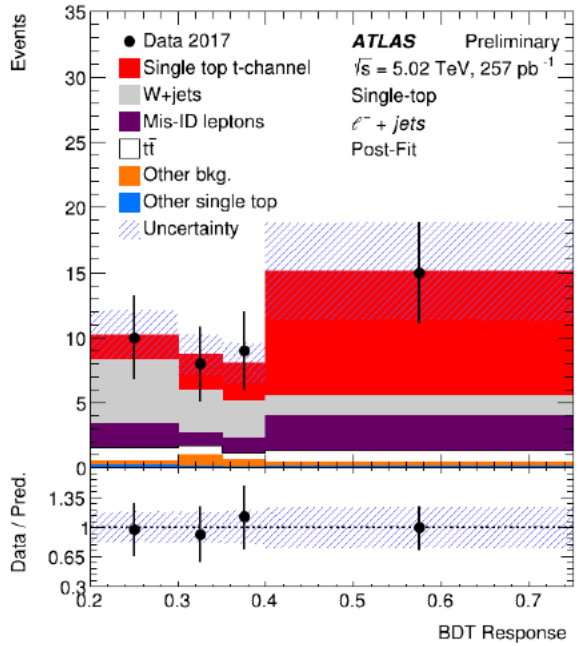



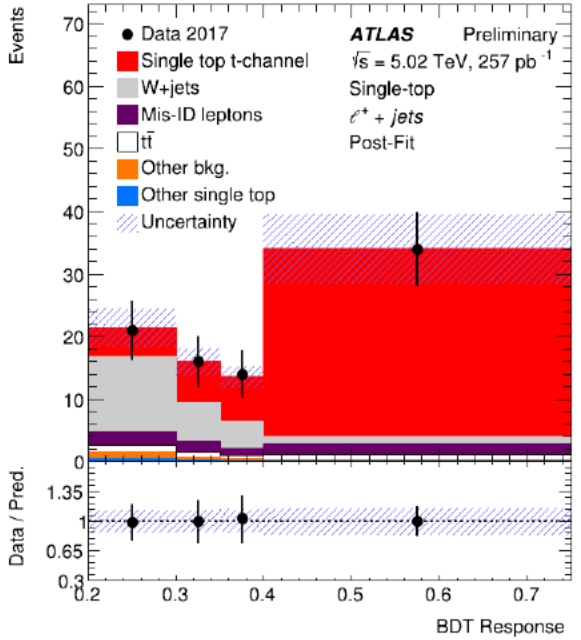
# BDT IMPLEMENTATION AND RESULTS

- Train a BDT to separate signal from background
- Apply it to a positive lepton and negative lepton regions
  - Used to select for top quark or antitop quark production
- Extract $\sigma_{t-chan}$ and $R_t$ (ratio of individual cross sections) from a fit to data
  - Calculate $\sigma_t, \sigma_{\bar{t}}$, and $V_{tb}$

| Variable | Predicted | Measured |
|---|---|---|
| $\sigma_{t\text{-chan}}$ | $30.3^{+0.7}_{-0.5}$ pb | $26.6^{+4.3}_{-4.0}$ (Stat.) $^{+4.4}_{-3.6}$ (Syst.) pb |
| $R_t$ | $2.03^{+0.06}_{-0.07}$ | $2.74^{+1.44}_{-0.83}$ (Stat.) $^{+1.04}_{-0.29}$ (Syst.) |
| $\sigma_t$ | $20.3^{+0.5}_{-0.4}$ pb | $19.5^{+3.8}_{-3.1}$ (Stat.) $^{+2.9}_{-2.2}$ (Syst.) pb |
| $\sigma_{\bar{t}}$ | $10.0^{+0.2}_{-0.3}$ pb | $7.1^{+3.2}_{-2.1}$ (Stat.) $^{+2.8}_{-1.5}$ (Syst.) pb |
| $\lvert f_{LV} \cdot V_{tb} \rvert$ | – | $0.94^{+0.08}_{-0.07}$ (Stat.) $^{+0.08}_{-0.06}$ (Syst.) |

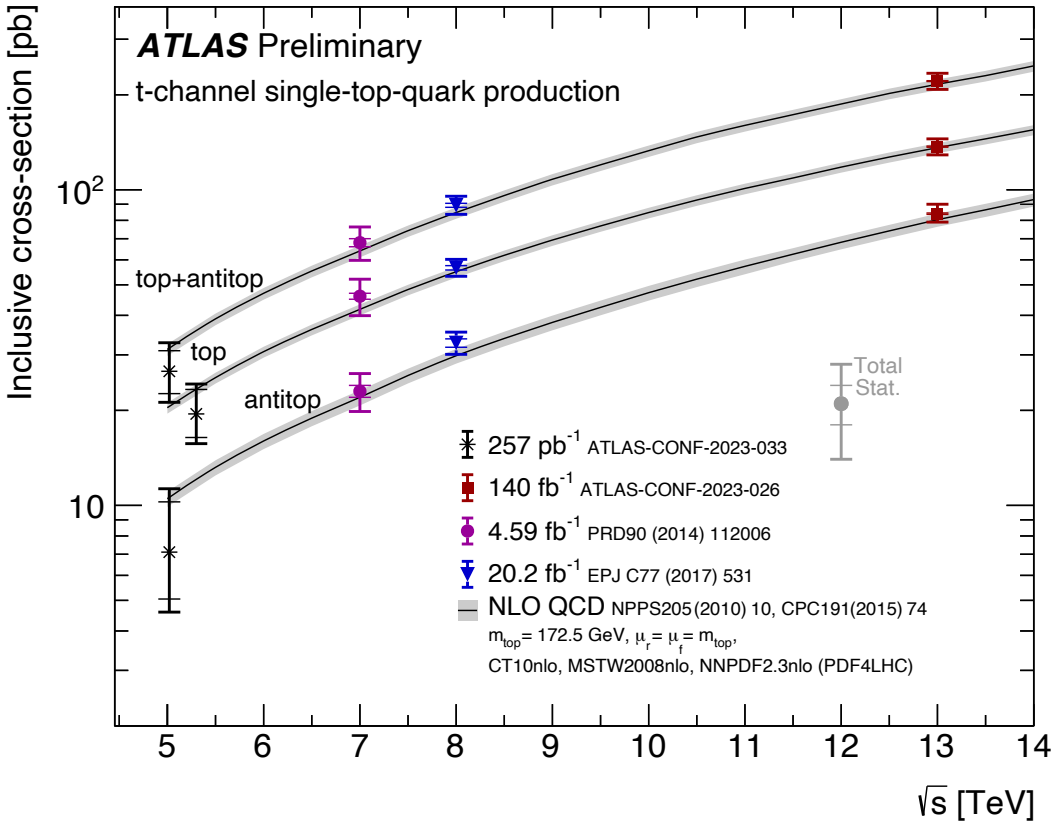
ATLAS-CONF-2023-033

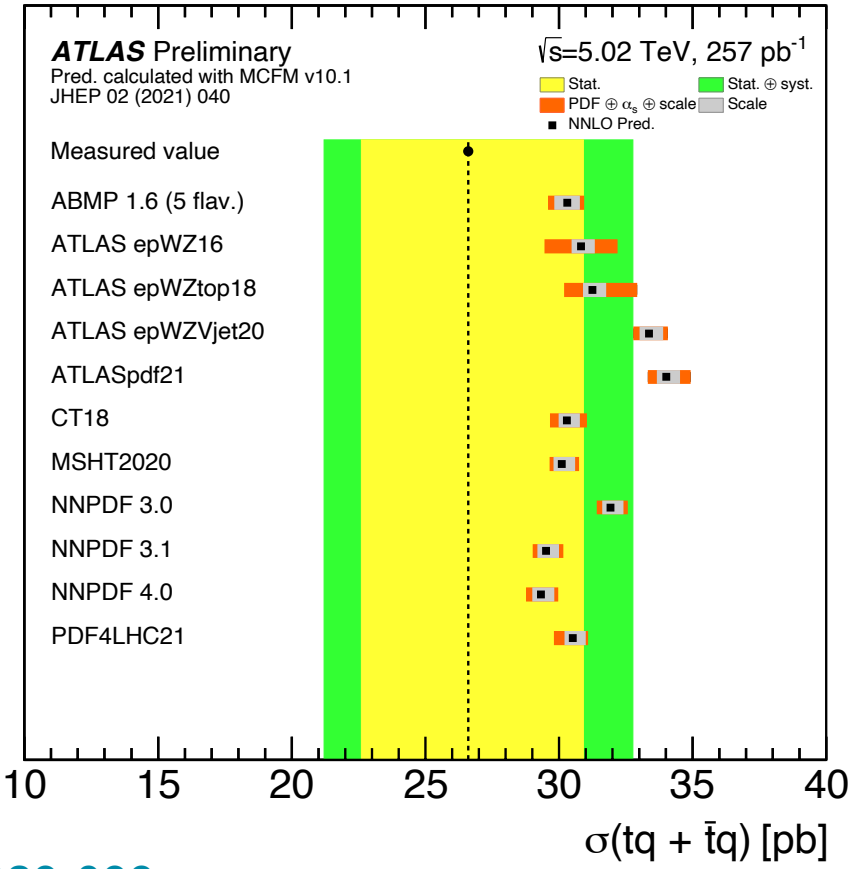


# SINGLE TOP QUARK PRODUCTION AT 5.02 TEV

- Observed single top t-channel production with a significance of $6.1\sigma$
- Statistics limited due to small dataset




ATLAS-CONF-2023-033

# SUMMARY

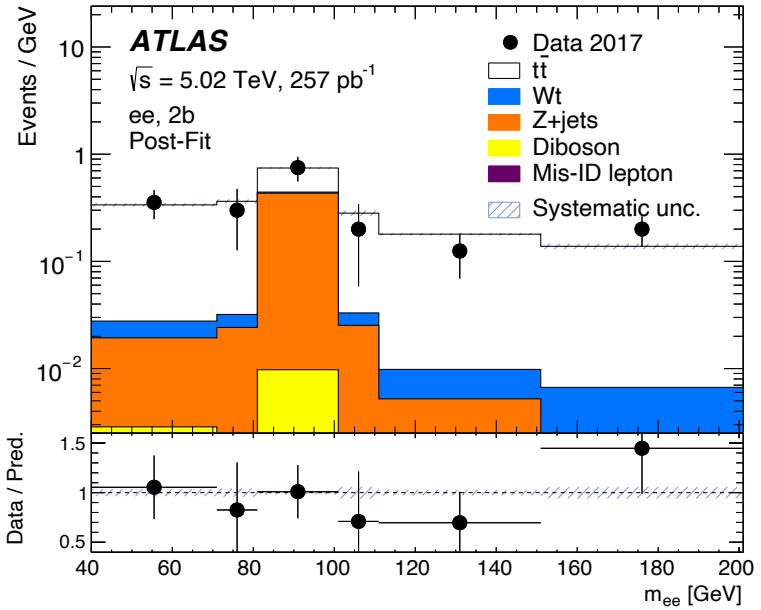
- The LHC has provided an abundance of interesting data to study
- Can continue to learn more about top quarks with LHC data
- LHC started off as a search machine but has transitioned to a precision measurement machine – even with small datasets!
- Unique LHC runs such as the 5.02 TeV run can give interesting physics results!

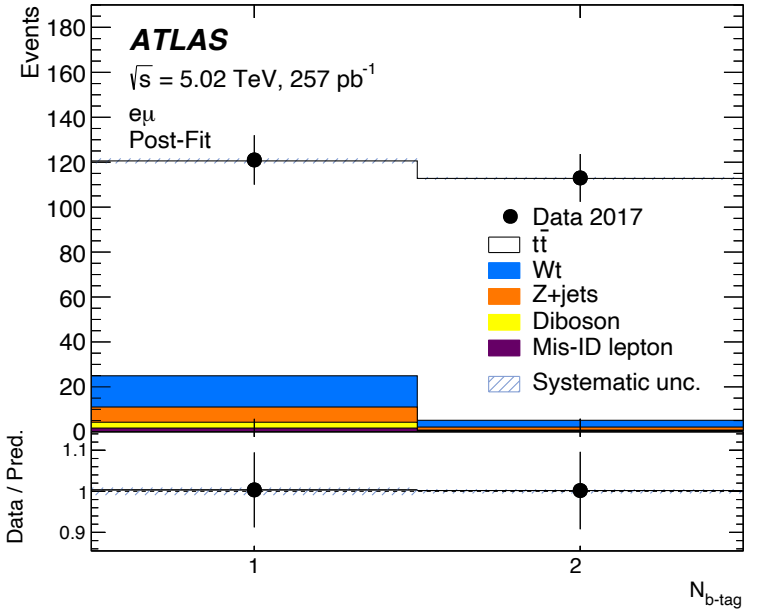
**More LHC data is on its way**

# BACKUP

# THE DILEPTON CHANNEL

- First time using both same flavour $(ee, \mu\mu)$ and opposite flavour $(e\mu)$ dilepton events
- Good purity but low statistics
- Single lepton trigger
  - Require 2 opposite sign leptons to be reconstructed
- Lepton $p_T > 18$ GeV and $|\eta| < 2.5$
  - Trigger is fully efficient
- Jet $p_T > 25$ GeV, $|\eta| < 2.5$, and one or two b-tagged jets
- $\eta \equiv -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$

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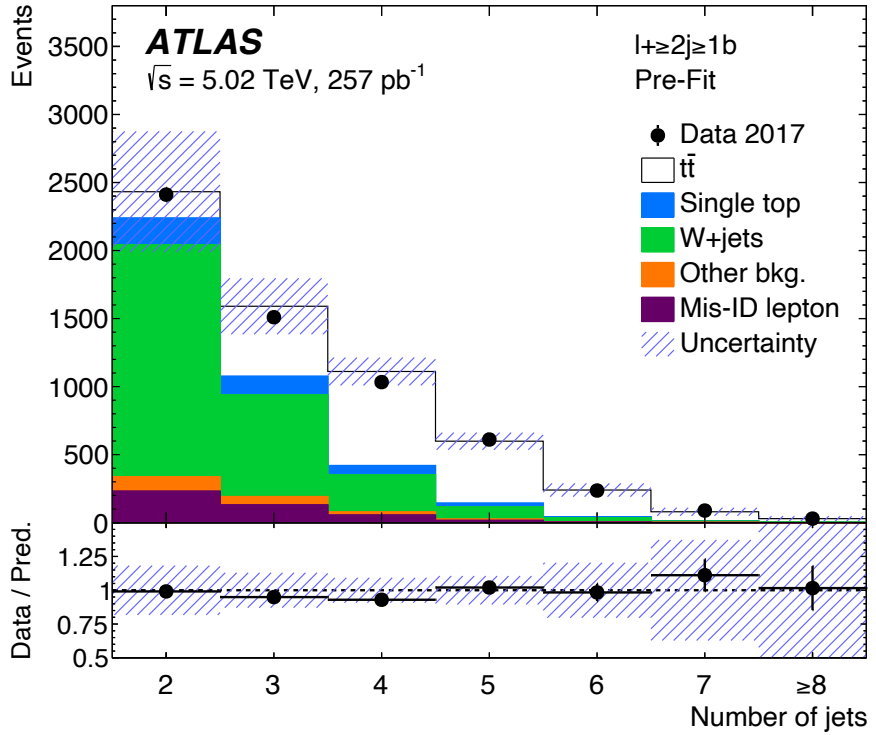
# LEPTON+JETS CHANNEL

- More statistics but more background
- Exactly one electron or muon candidate that was triggered on
- Lepton $p_T > 25$ GeV
  - Reject "soft" mis-identified leptons
- Two or more jets with $p_T > 25$ GeV and $|\eta| < 2.5$
- Events classified into 6 regions based on number of jets and b-tagged jets
- Boosted Decision Tree (BDT) trained to separate signal from background

| Region name | Jet multiplicity | $b$-jet multiplicity |
|---|---|---|
| $\ell$+2j≥1b | 2 | ≥ 1 |
| $\ell$+3j 1b | 3 | 1 |
| $\ell$+3j 2b | 3 | 2 |
| $\ell$+≥4j 1b | ≥ 4 | 1 |
| $\ell$+4j 2b | 4 | 2 |
| $\ell$+≥5j 2b | ≥ 5 | 2 |

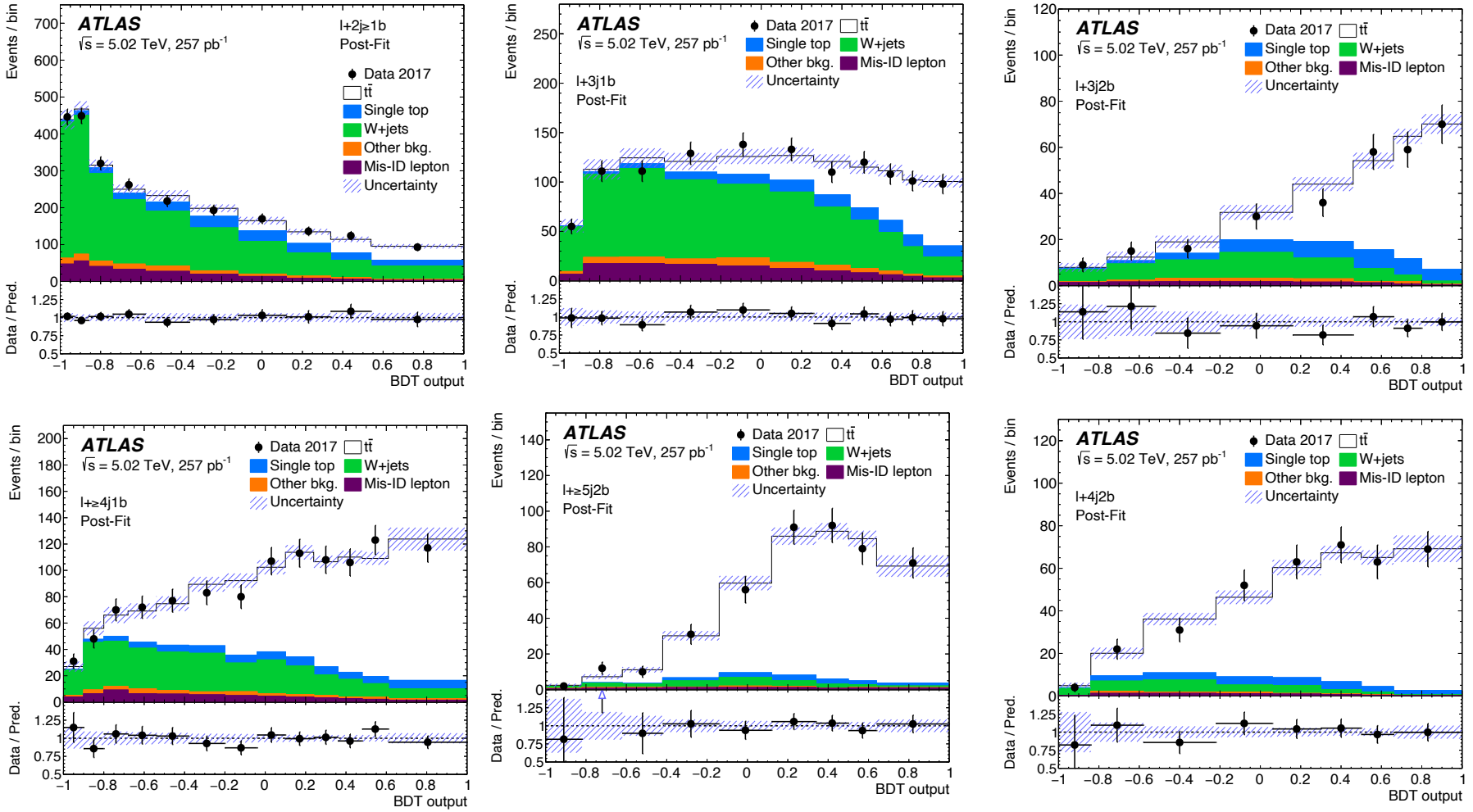


# LEPTON+JETS BDT INPUT VARIABLES

| VARIABLE | DEFINITION | $\ell$ + (2, 3)j, (1, 2)b | $\ell$ + (4, ≥ 5)j, (1, 2)b |
|---|---|---|---|
| $H_{\mathrm{T}}^{\mathrm{had}}$ | Scalar sum of all jet transverse momenta | ✓ | ✓ |
| FW2 (l+j) | Second Fox-Wolfram moment computed using all jets and the lepton | ✓ | ✓ |
| Lepton $\eta$ | Lepton pseudorapidity | ✓ | ✓ |
| $\Delta R_{bl}$ (med.) | Median $\Delta R$ between the lepton and $b$-jets | ✓ | ✓ |
| $\Delta R_{jj}$ (med.) | Median $\Delta R$ between any two jets | ✓ | – |
| $\mathrm{m(jj)}^{\mathrm{min.}\Delta R}$ | Mass of the combination of any two jets with the smallest $\Delta R$ | ✓ | – |
| $\Delta R_{uu}$ (med.) | Median $\Delta R$ between any two untagged jets | – | ✓ |
| $\mathrm{m(uu)}^{\mathrm{min.}\Delta R}$ | Mass of the combination of any two untagged jets with the smallest $\Delta R$ | – | ✓ |

# LEPTON+JETS CHANNEL BDT

- BDT response distributions in the six regions



# T-CHANNEL SELECTION

**Topology requirements**

- Exactly 1 lepton
  - Electron $|\eta_{\text{cl}}| \leq 2.47$ + exclude crack region
  - Muon $|\eta| \leq 2.5$
- Exactly 2 jets
  - 1 untagged jet $1.5 \leq |\eta| \leq 4.0$
  - 1 b-tagged jet $|\eta| \leq 2.5$ and DL1R 60% WP
  - $\Delta\eta$ between jets $\geq 1.5$

**Kinematic requirements**

- Lepton $p_T \geq 18$ GeV
- Both jets $p_T \geq 23$ GeV
- $E_T^{\text{miss}} \geq 15$ GeV
- $m_T^W \geq 35$ GeV
- Triangular $(m_T^W + E_T^{\text{miss}}) \geq 70$ GeV
- $H_T \geq 185$ GeV
- Mass of the lepton and b-tagged jet $m_{lb} \leq 165$ GeV
- $m_W \leq 102$ GeV and $140$ GeV $\leq m_{\text{top}} \leq 225$ GeV

# T-CHANNEL BDT INPUT VARIABLES

| Variable | Definition |
|---|---|
| $m_{lb}$ | Invariant mass of the lepton ($l$) and the tagged jet ($b$) |
| $H_T(l, \text{jets}, E_T^{miss})$ | Scalar sum of transverse momentum of the charged lepton, the jets, and $E_T^{miss}$ |
| $\lvert\eta(u)\rvert$ | Absolute value of the pseudorapidity of the light quark (untagged) jet ($u$) |
| $\lvert\Delta p_T(W, ub)\rvert$ | Absolute value of the scalar difference in transverse momentum between the reconstructed $W$-boson and the jet pair |
| $\lvert\Delta\eta(b, l)\rvert$ | Absolute value of the difference in pseudorapidity between the charge lepton and the tagged jet ($b$) |
| $\lvert\Delta\eta(u, l)\rvert$ | Absolute value of the difference in pseudorapidity between the charge lepton and the untagged jet ($u$) |
| $\lvert\eta(l)\rvert$ | Absolute value of pseudorapidity of the charged lepton |
| $m(lvb)$ | Invariant mass of the reconstructed top-quark |
| Transverse sphericity | $\frac{2\lambda_2}{\lambda_1+\lambda_2}$ where $\lambda_1 \geq \lambda_2 \geq \lambda_3$ and $\lambda_1, \lambda_2, \lambda_3$ are eigenvalues of $S^{ab} = \frac{\sum_i p_i^a p_i^b}{\sum_i p_i^2}$; $a, b = x, y, z$; $i$ = jet index. |