ATLAS EXPERIMENT

BERGISCHE UNIVERSITÄT WUPPERTAL

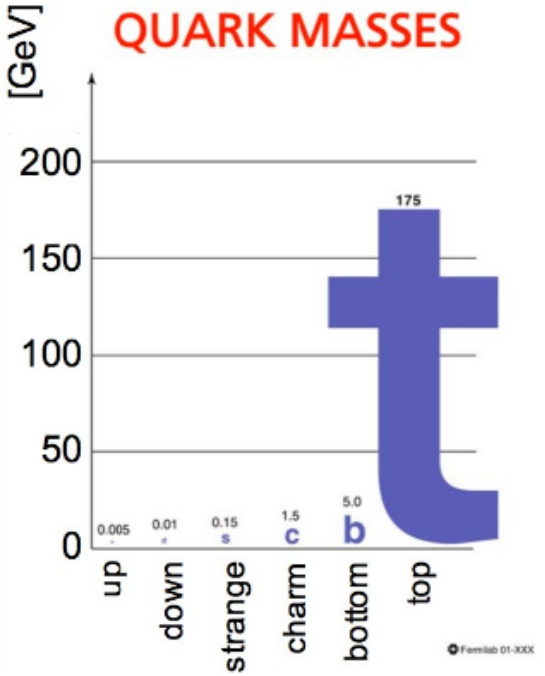
Recent highlights of top-quark cross section and properties measurements with the ATLAS detector at the LHC

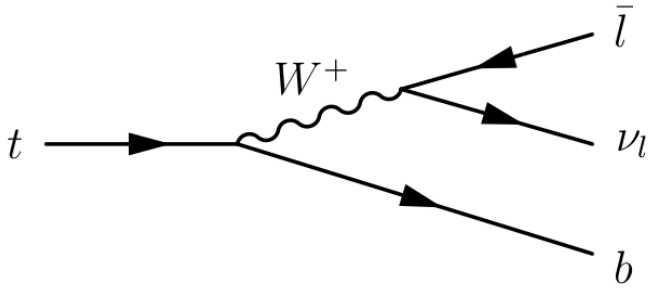
ICNFP2023 - Joshua Reidelstürz - 13.07.2023

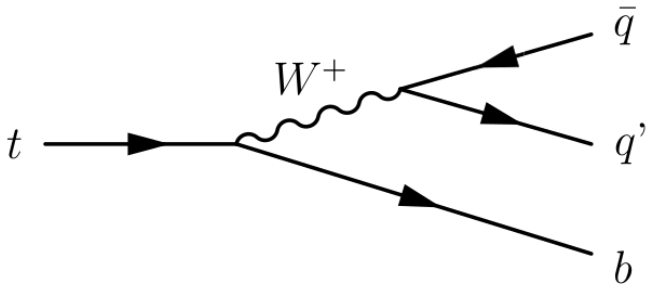
The top quark

- Mass: $m_t = 172.7 \pm 0.3\,\text{GeV}$
- Smallest lifetime of quarks
- Decays before it can form any bound states with other quarks

→ More sensitive to the hard scattering process itself





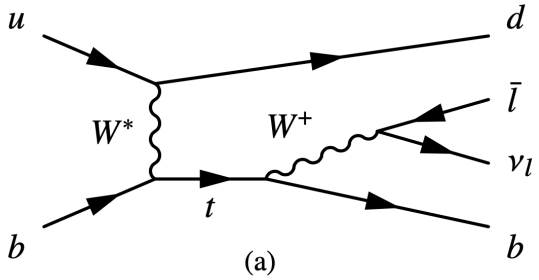


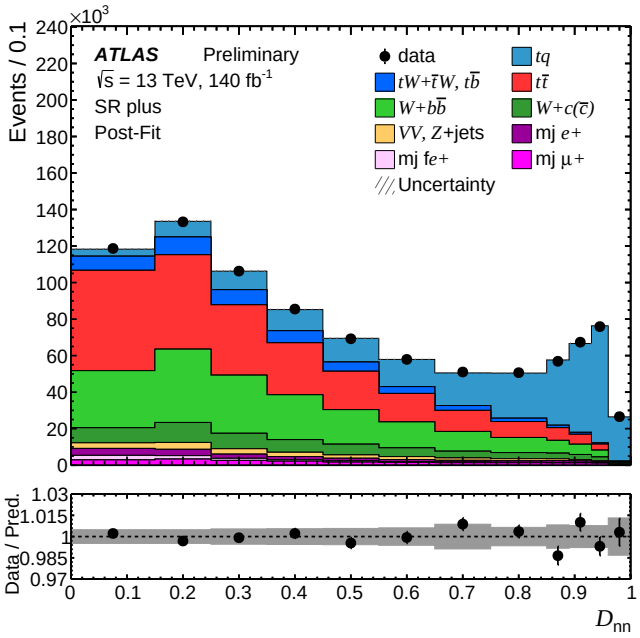
- Almost always decays to b quark (and a W boson)
- Many new top quark physics results obtained in the last year

13 TeV t-channel single top quark production

Measurement of the inclusive t-channel top quark and top anti-quark cross section and their ratio $R_t = \sigma_{tq}/\sigma_{\bar{t}q}$

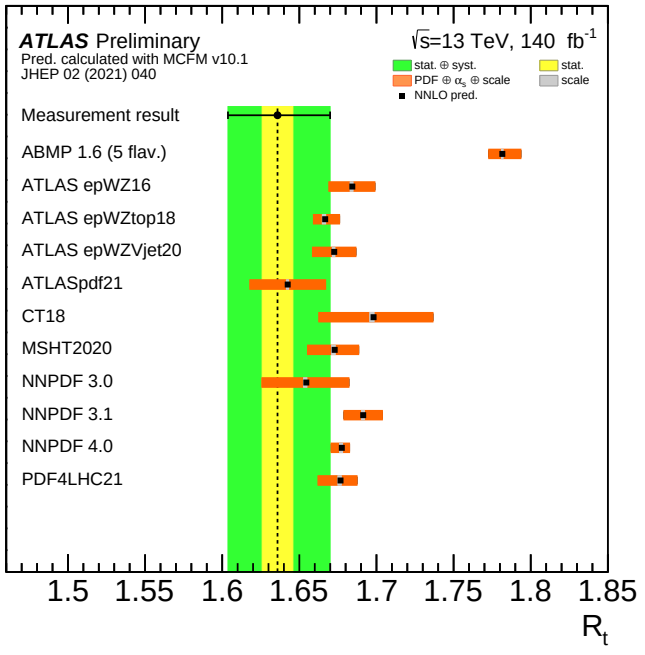
- Precision measurement of the largest single top production channel
- First full Run 2 t-channel measurement
- Neural network used to separate signal from background
- Binned profile maximum likelihood fit





Results

- Testing pdfs (particularly using R_t)
- Sensitive to new physics
- Effective field theory interpretation:
  - $-0.25 < C_{qQ}^{(1,3)} < 0.12$
- Directly constrain $|V_{tx}|$ CKM matrix elements:
  - $|f_{LV} \cdot V_{tb}| = 1.016 \pm 0.031$
  - $|V_{tb}| > 0.95$ at the 95% CL



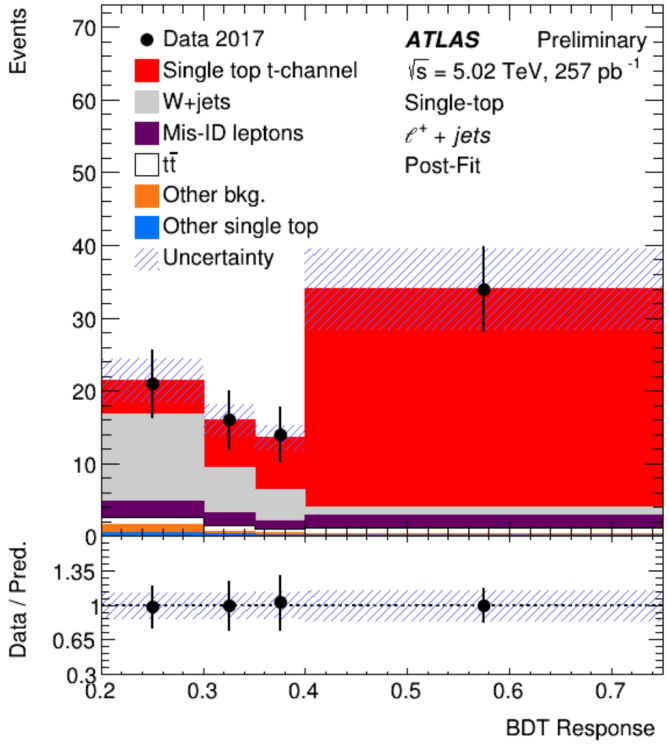
Cross section results:

	σ_t [pb]	$\sigma_{\bar{t}}$ [pb]	σ_{tch} [pb]	R_t
Value	137 ± 8	84^{+6}_{-5}	221 ± 13	$1.636^{+0.036}_{-0.034}$
Relative Uncertainty	$^{+5.9\%}_{-5.5\%}$	$^{+6.6\%}_{-6.2\%}$	$\pm 5.9\%$	$^{+2.2\%}_{-2.1\%}$

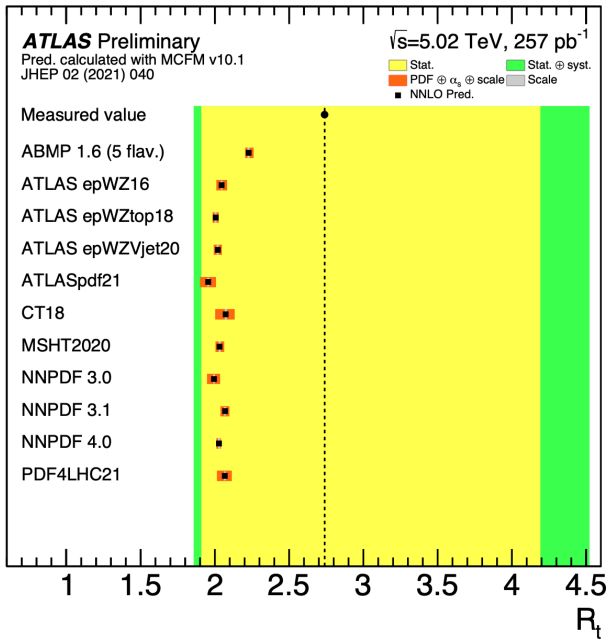
5.02 TeV measurement of single top t-channel cross section

Measurement of the inclusive t-channel top and anti-top cross section and their ratio $R_t = \sigma_{tq}/\sigma_{\bar{t}q}$

- First 5.02 TeV measurement
- using 257 pb^{-1}
- Additional cuts using invariant masses to increase signal fraction
- BDT used to further separate signal from background



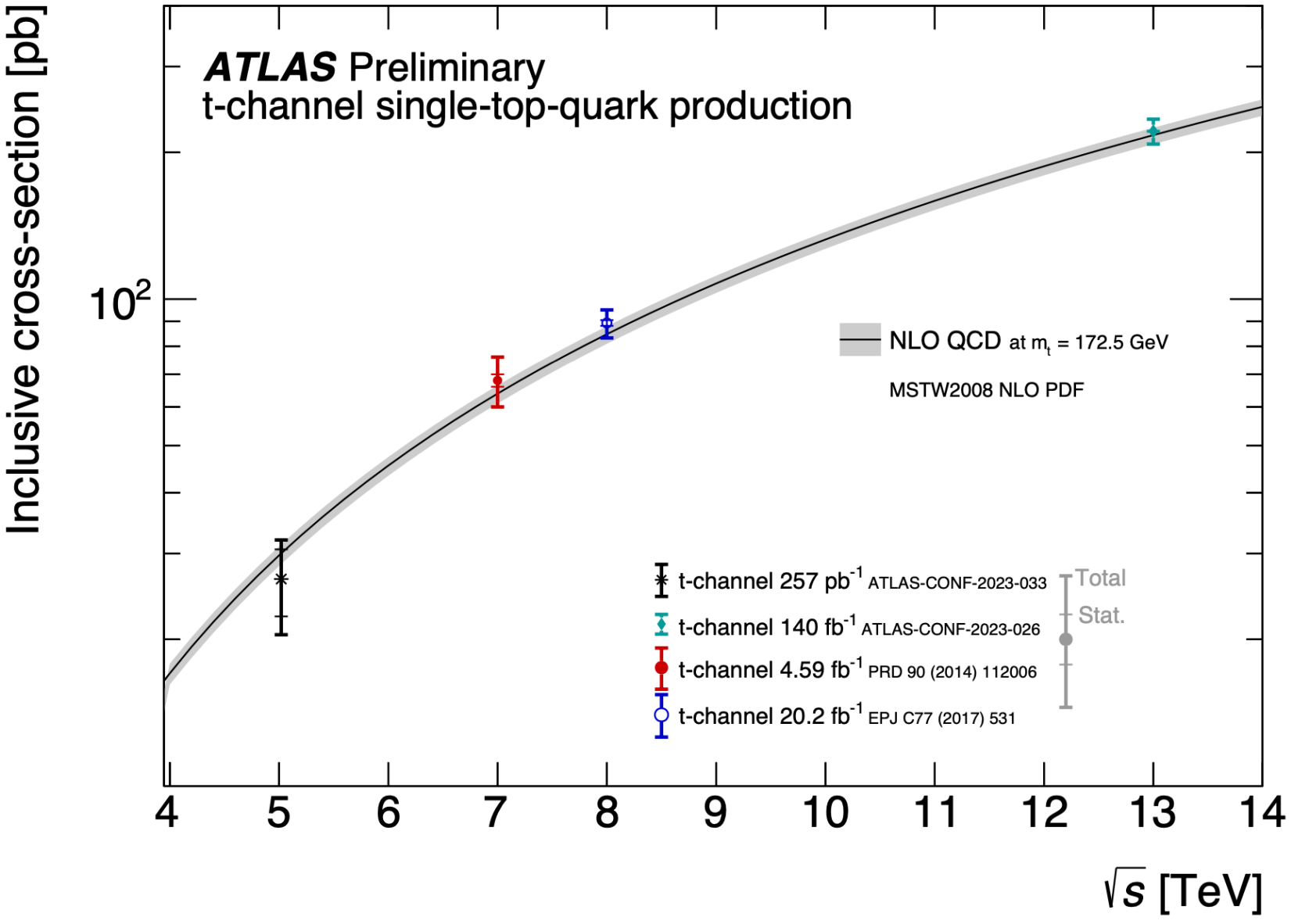
Results



- Significance equivalent to 6.1 standard deviations
- Uncertainties given for systematic & statistical contributions
- Extraction of $|f_{\mathrm{LV}} \cdot V_{tb}| = 0.94^{+0.08}_{-0.07}(\mathrm{stat})^{+0.08}_{-0.06}(\mathrm{syst})$

	σ_t [pb]	$\sigma_{\bar{t}}$ [pb]	σ_{tch} [pb]	R_t
Value	$19.5^{+3.8+2.9}_{-3.1-2.2}$	$7.1^{+3.2+2.8}_{-2.1-1.5}$	$26.6^{+4.3+4.4}_{-4.0-3.6}$	$2.74^{+1.44+1.04}_{-0.83-0.29}$
Rel. Unc.	$^{+25\%}_{-19\%}$	$^{+60\%}_{-36\%}$	$^{+23\%}_{-20\%}$	$^{+65\%}_{-32\%}$

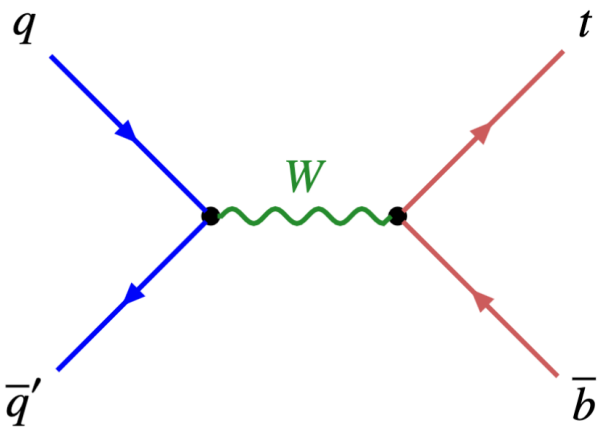
t-channel summary



JHEP06(2023)191

13 TeV measurement of single top-quark production in the s-channel

- First $\sqrt{s} = 13\,\text{TeV}$ s-channel measurement
- s-channel plays an important role in searches for new phenomena
- SR event selection: exactly one lepton, two b-tagged jets



- Using Matrix element method for signal separation

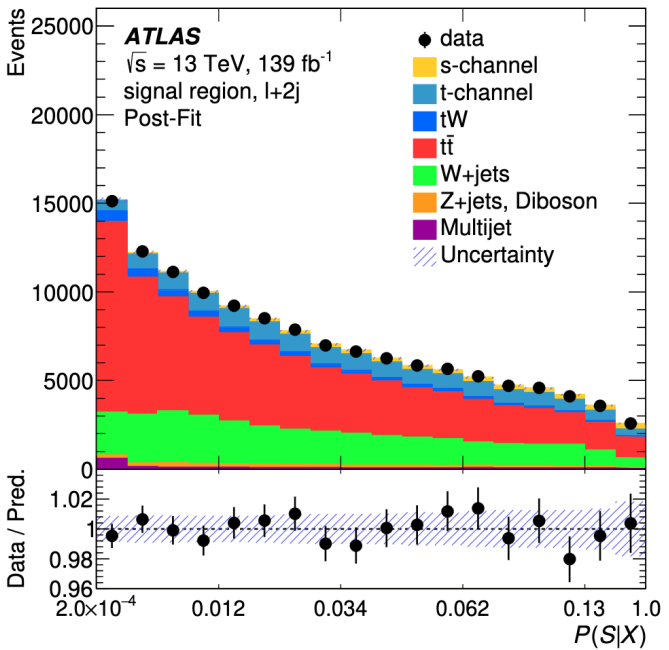
Observed (expected) signal significance: 3.3 (3.9)

Measured cross section:

$\sigma = 8.2^{+3.5}_{-2.9}\,\text{pb}$

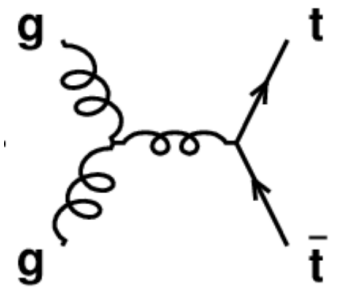
Compatible with SM prediction:

$\sigma_{\text{SM}} = 10.32^{+0.40}_{-0.36}\,\text{pb}$

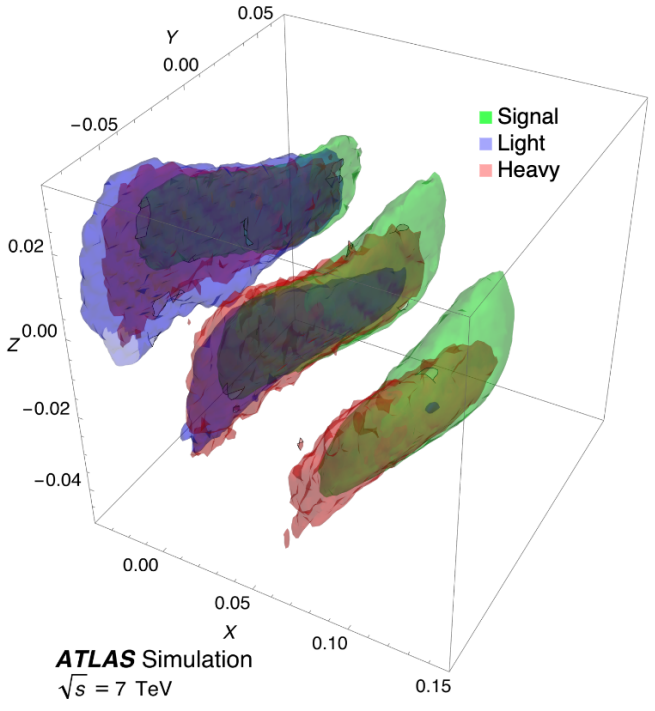


arXiv:2212.00571

7 TeV inclusive $t\bar{t}$ production cross section at 7 TeV



- Single charged lepton plus jets channel
- Full 7 TeV dataset
- Novel technique:
  - Use three different support vector machines (SMVs) to incorporate more information about events
- Multi-class event discriminator:
  - Signal, light background and heavy background
- 3D profile likelihood fit



Result:

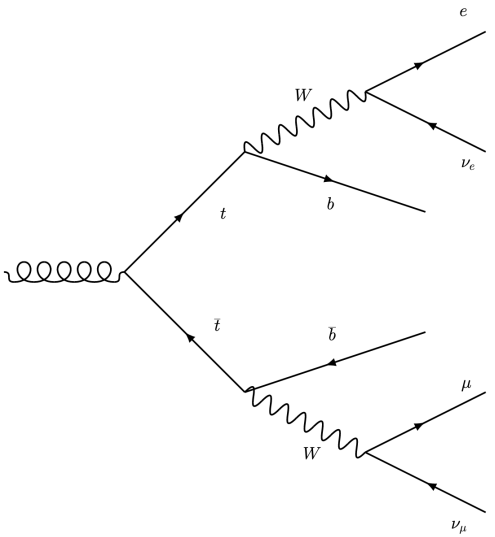
$\sigma_{t\bar{t}} = 168.5 \pm 0.7(\text{stat.})^{+6.2}_{-5.9}(\text{syst.})^{+3.4}_{-3.2}$ pb

SM pred.: $\sigma_{t\bar{t}} = 177^{+10}_{-11}$ pb

arXiv:2303.15340

13 TeV inclusive and differential cross-sections for dilepton $t\bar{t}$ production

- Inclusive and differential distributions
- Oppositely charged $e\mu$ pair and b-tagged jets
- First ATLAS measurement of this channel using full Run 2 data sample at $\sqrt{s} = 13\,\text{TeV}$
- Channel is only minimally affected by QCD modelling uncertainties



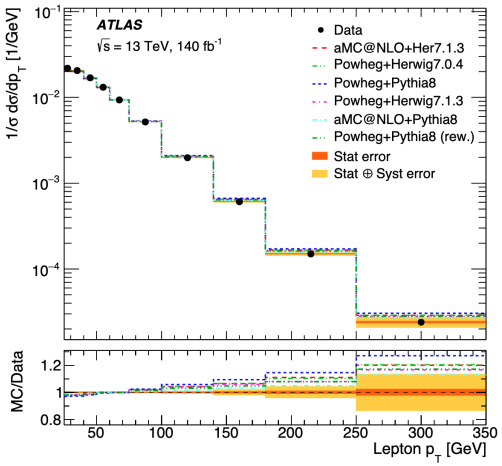
Simultaneous determination of the cross-section and the combined jet selection and b-tagging efficiency
$\rightarrow$ reduce jet and b-tagging systematics

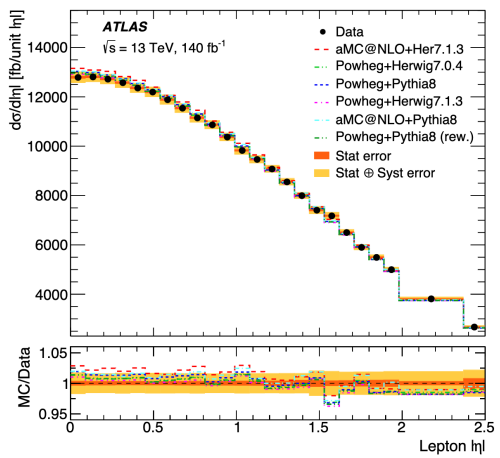
arXiv:2303.15340

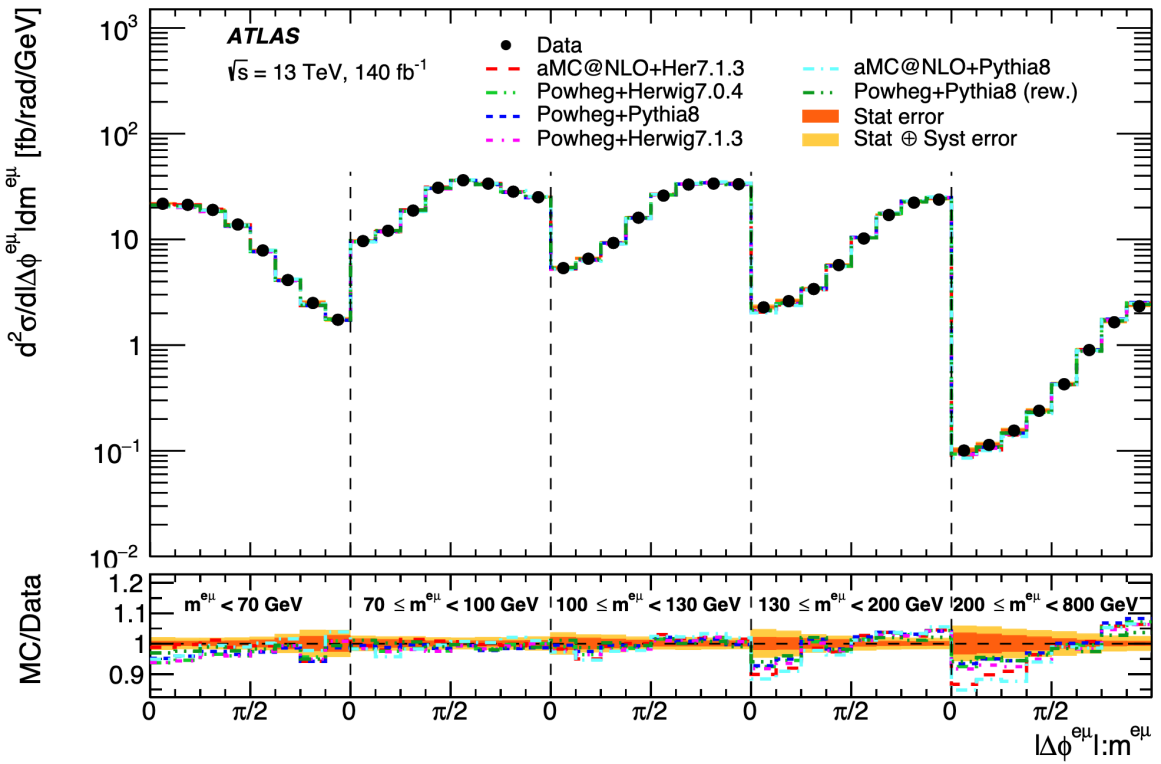
13 TeV inclusive and differential cross-sections for dilepton $t\bar{t}$ production

$$\sigma_{t\bar{t}} = 829 \pm 1(\text{stat}) \pm 13(\text{syst}) \pm 8(\text{lumi}) \pm 2(\text{beam})\,\text{pb}$$

SM pred.: $\sigma_{t\bar{t}} = 832^{+20}_{-29}(\text{scale})^{+23}_{-23}(m_t)^{+35}_{-35}(\text{PDF}+\alpha_s)\,\text{pb}$

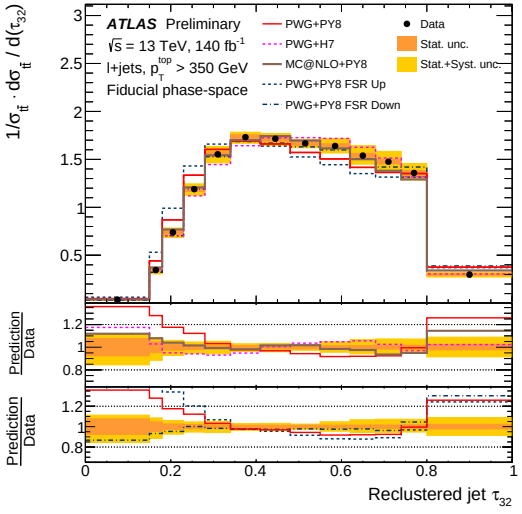


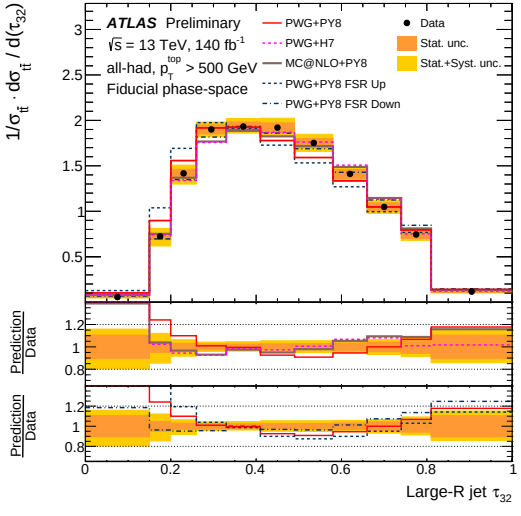




13 TeV measurement of jet substructure in boosted $t\bar{t}$ events

- Study of top-quark decay and the resulting parton-showering and hadronization effects
- Poor modelling of jet substructure in data by current MC generators
- Using full Run 2 data sample
- $t\bar{t}$ lepton+jets and allhadronic channels
- Measurement of jet substructure observed in high transverse-momentum
- 8 substructure variables

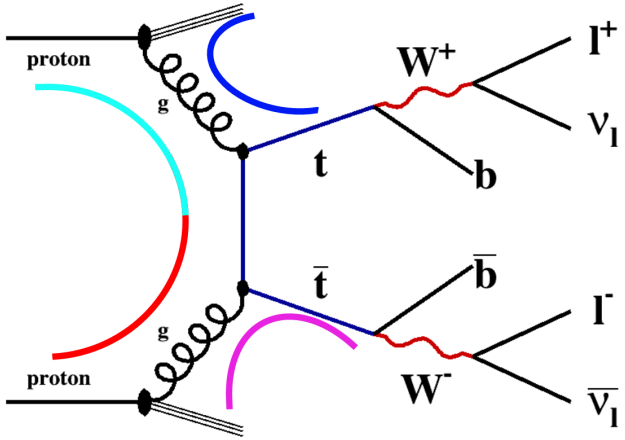


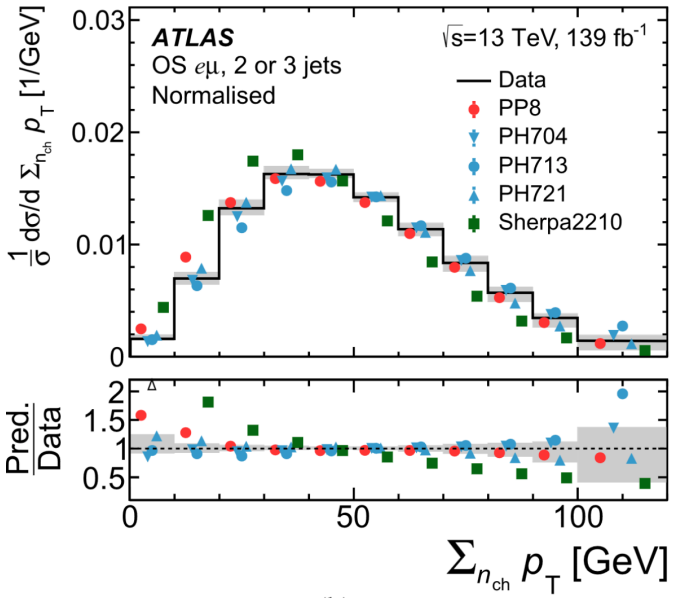


EPJ C 83, 518 (2023)

13 TeV measurements of observables sensitive to color reconnection

- Modelling of colour reconnection in MC is not well understood
- Models are non derived from first principles of QCD
- Data is needed to exclude models
- Sensitive observables at particle level and detector level
- $t\bar{t}$ dilepton channel
- Compared with different colour reconnection models in Monte Carlo generators





JHEP06(2023)019

13 TeV top-quark mass measurement using a leptonic invariant mass

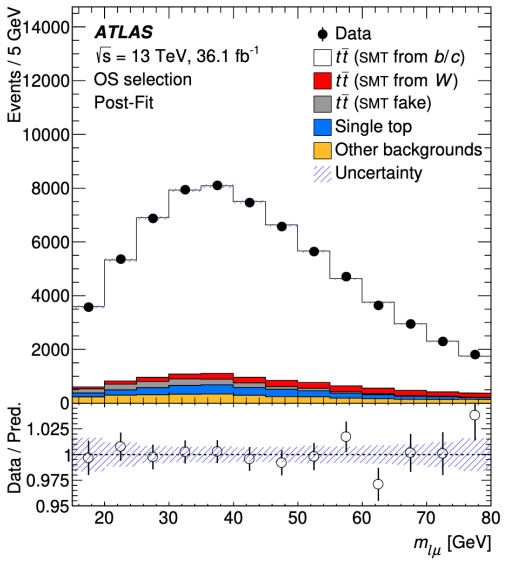
- Direct measurement of the top-quark mass
- ℓ+jets channel with semileptonic B decays
- Reconstructing $m_{\ell\mu}$

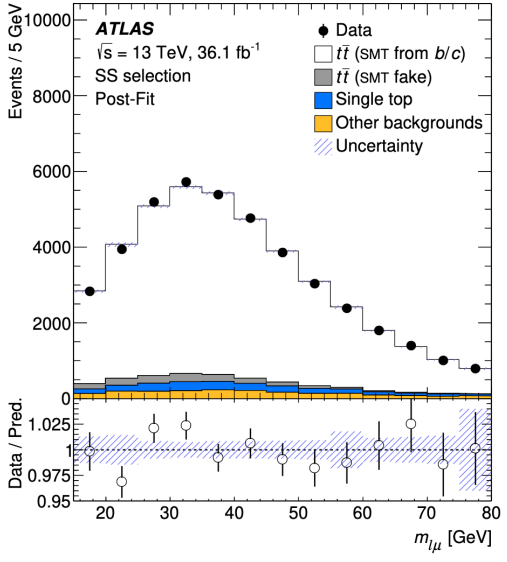
→ less sensitivity to top-quark production modelling

- Sensitive to the modelling of the B-hadron fragmentation

→ used to improve modelling by LEP data

- Distribution of $m_{\ell\mu}$ is used to determine m_t
- Binned-template profile likelihood fit



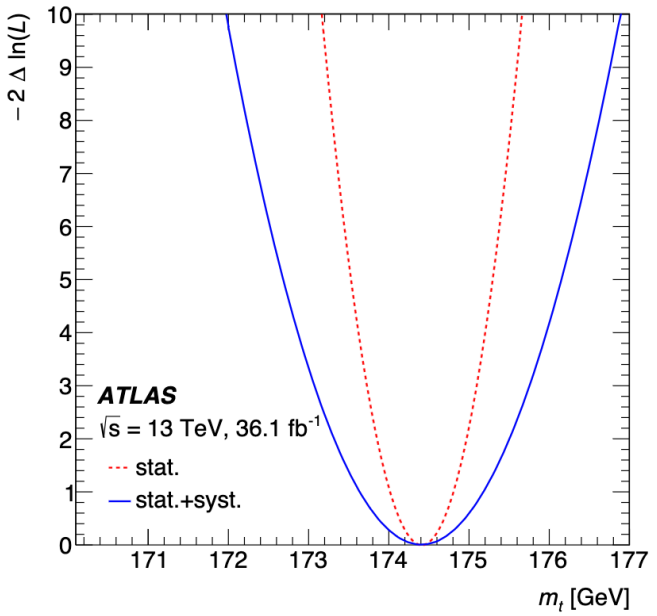


JHEP06(2023)019

13 TeV top-quark mass measurement using a leptonic invariant mass

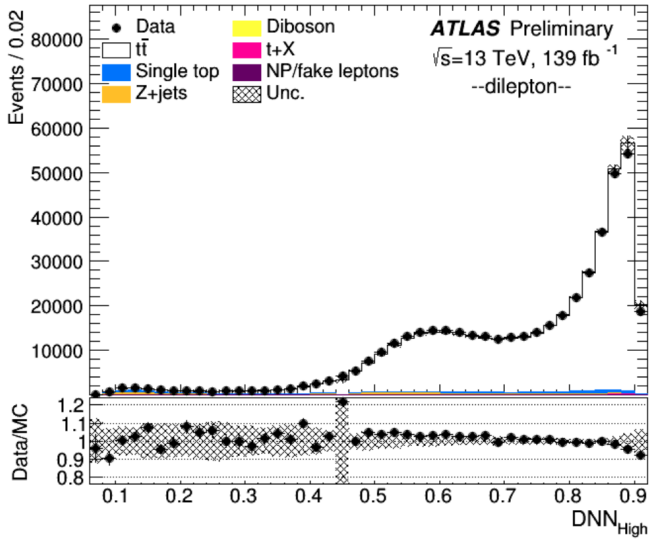
- $m_t = 174.41 \pm 0.39(\text{stat.}) \pm 0.66(\text{syst.}) \pm 0.25(\text{recoil})$ GeV

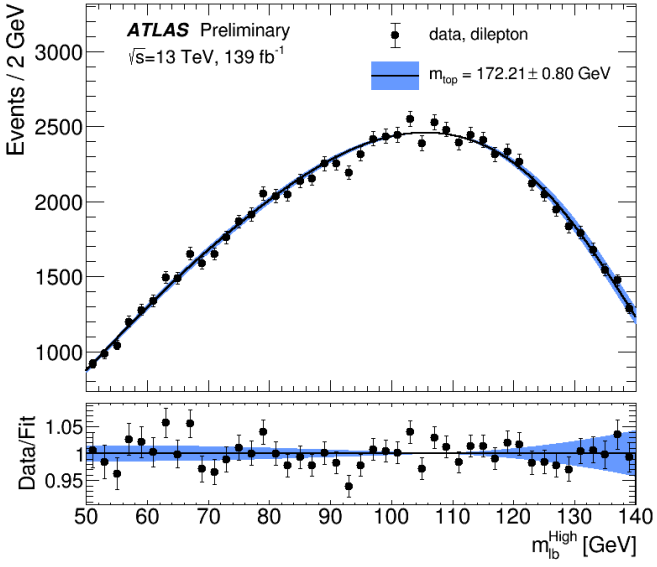
- Using new recoil uncertainty
  - Describes how secondary and additional gluons are radiated from the b-quark
- Consistent at 2σ with the current ATLAS combination from the reconstruction of the top-quark decay



13 TeV measurement of the top-quark mass in $t\bar{t}$ dilepton events

- Full Run 2 data sample at $\sqrt{s} = 13\,\text{TeV}$
- Using the template method
- Reconstructing $m_{\ell b}$
- DNN used to select the best ℓb-pairing and improve signal purity
- $m_t = 172.21 \pm 0.20(\text{stat.}) \pm 0.67(\text{syst.}) \pm 0.39(\text{recoil})\,\text{GeV}$
- Also using new recoil uncertainty

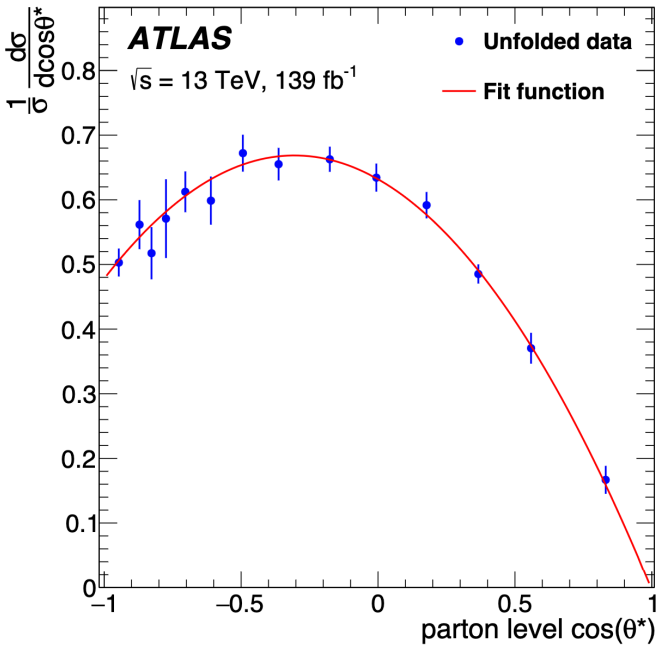




Phys. Lett. B 843 (2023) 137829

13 TeV measurement of polarisation of W bosons in top-quark decays using dilepton events

- Fractions of longitudinal (f_0), left-handed (f_L) and right-handed (f_R) polarised W bosons
- Probe possible new physics processes
- Especially sensitive to the C_{tW} Wilson coefficient
- Expected value of f_R is very small making it particularly sensitive

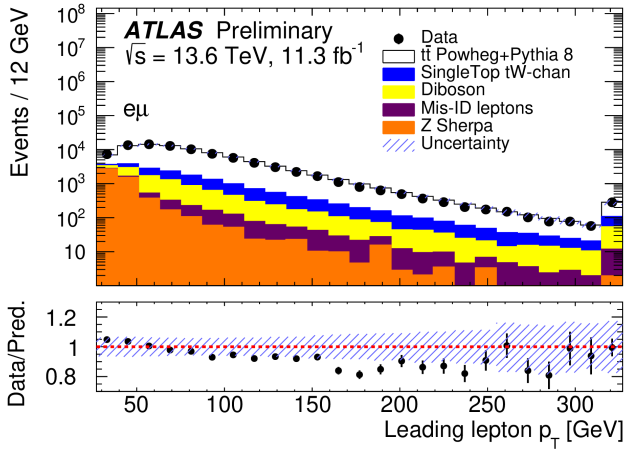


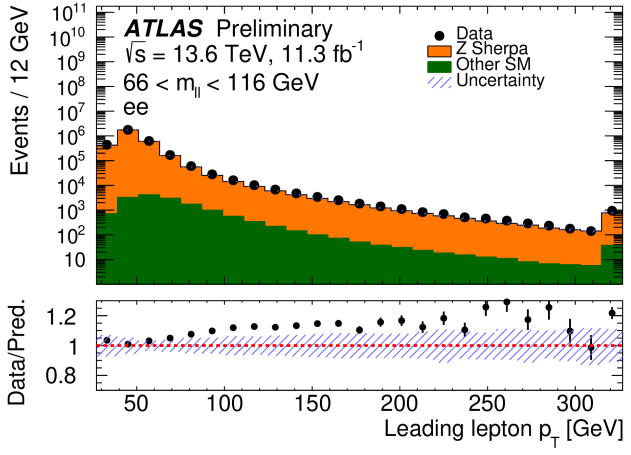
$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)f_0 + \frac{3}{8}(1-\cos\theta^*)^2 f_L + \frac{3}{8}(1+\cos\theta^*)^2 f_R$$

$$f_0 = 0.684 \pm 0.005(\text{stat}) \pm 0.014(\text{syst}) \qquad f_0^{\text{SM}} = 0.687 \pm 0.005$$
$$f_L = 0.318 \pm 0.003(\text{stat}) \pm 0.008(\text{syst}) \qquad f_L^{\text{SM}} = 0.311 \pm 0.005$$
$$f_R = -0.002 \pm 0.002(\text{stat}) \pm 0.014(\text{syst}) \qquad f_R^{\text{SM}} = 0.0017 \pm 0.0001$$

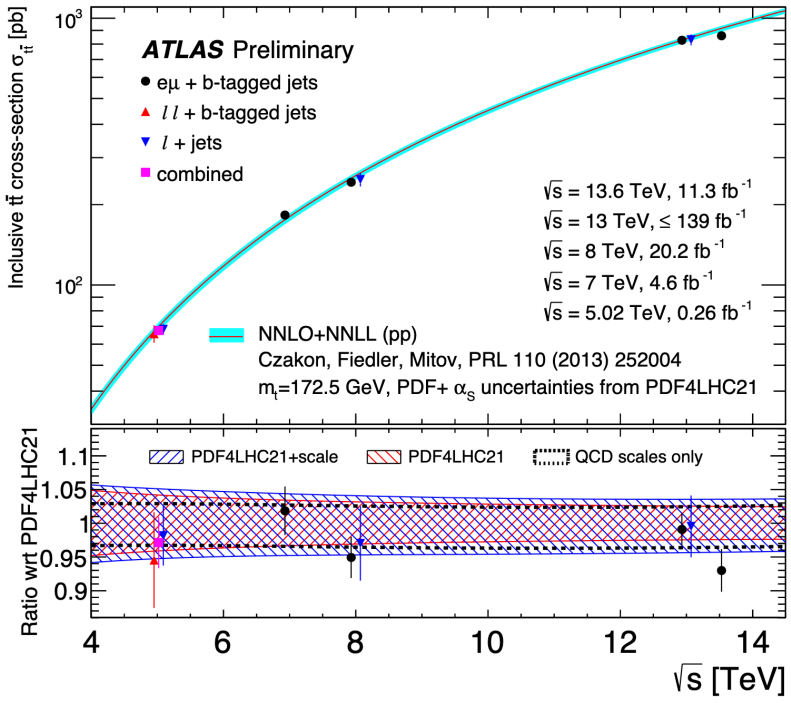
13.6 TeV measurement of $t\bar{t}$ cross section and $t\bar{t}/Z$ cross section ratio using Run 3 data

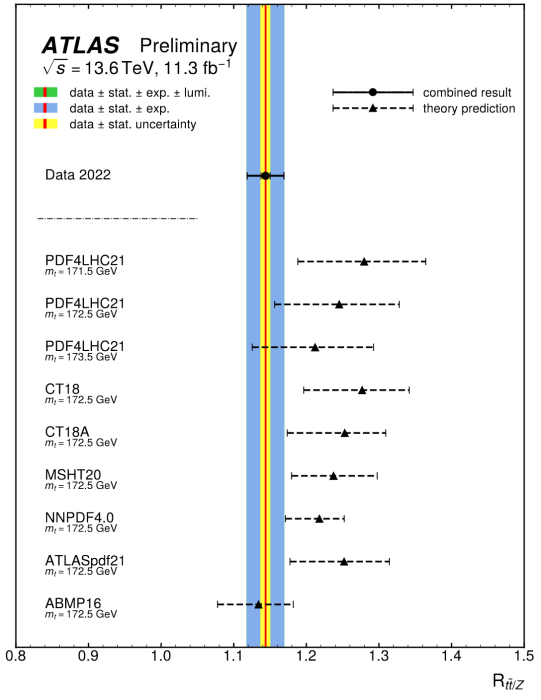
- Quick measurement after the successful start of Run 3 in 2022
- At $\sqrt{s} = 13.6\,\text{TeV}$ using $11.3\,\text{fb}^{-1}$
- Measurement $t\bar{t}$ cross section and $t\bar{t}/Z$ cross section ratio
- Essential tests of quantum chromodynamics (QCD) and electroweak (EW) processes





$t\bar{t}$ cross section and $t\bar{t}/Z$ cross section ratio using Run 3 data





Results:

$\sigma_{t\bar{t}} = 859 \pm 4(\text{stat}) \pm 22(\text{syst}) \pm 19(\text{lumi})\,\text{pb}$

$\sigma^{\text{fid}}_{Z\to\ell\ell} = 751 \pm 0.3(\text{stat}) \pm 15(\text{syst}) \pm 17(\text{lumi})\,\text{pb}$

$R_{t\bar{t}/Z\to\ell\ell} = 1.144 \pm 0.006(\text{stat}) \pm 0.022(\text{syst}) \pm 0.003(\text{lumi})\,\text{pb}$

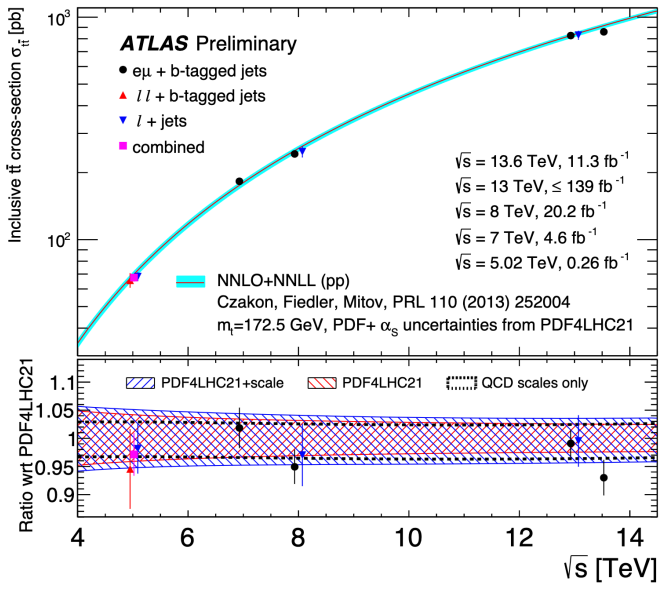
SM prediction:

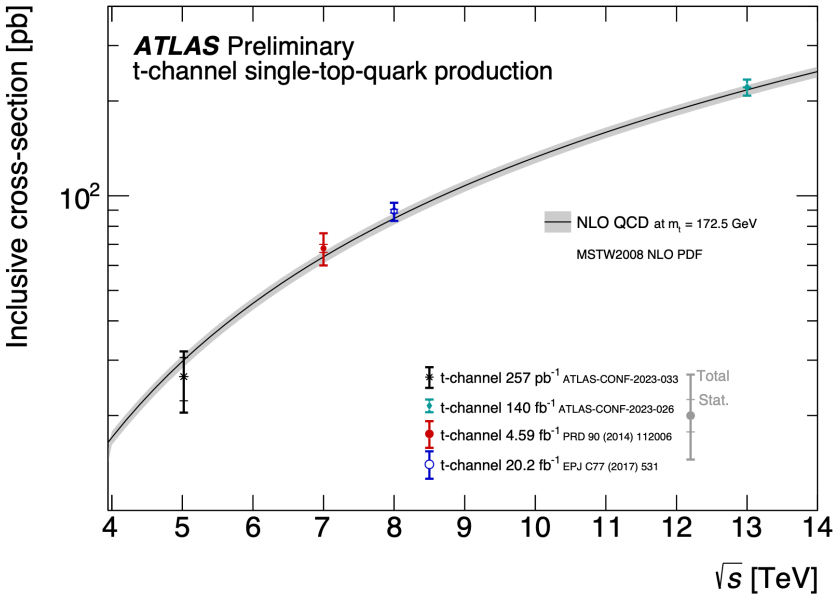
$\sigma_{t\bar{t}} = 924^{+32}_{-40}(\text{scale+PDF})\,\text{pb}$

$\sigma^{\text{fid}}_{Z\to\ell\ell} = 741 \pm 15(\text{scale+PDF})\,\text{pb}$

$R_{t\bar{t}/Z\to\ell\ell} = 1.245 \pm 0.076(\text{scale+PDF})\,\text{pb}$

Conclusion





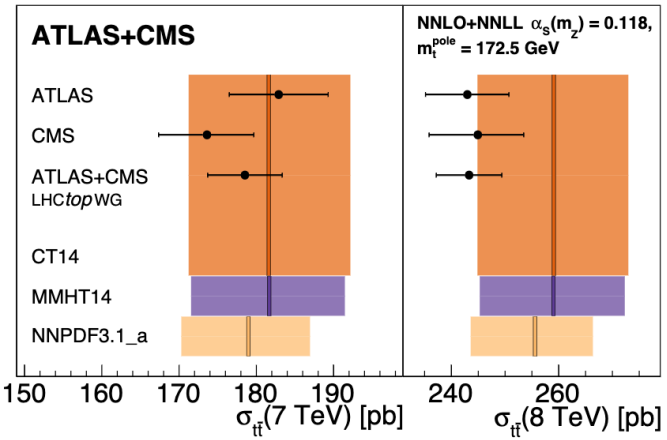
- New precision measurements of top quark cross sections using full Run 2 dataset at $\sqrt{s} = 13\,\text{TeV}$
- New measurements at different $\sqrt{s}$ energies
- New analysis strategies and techniques
- More Run 2 analyses are ongoing
- First Run 3 measurements at $\sqrt{s} = 13.6\,\text{TeV}$

Backup

arXiv:2205.13830

Combination of inclusive top-quark pair production cross-section measurements using ATLAS and CMS data at $\sqrt{s} = 7$ and 8 TeV

- Combination of ATLAS and CMS data at $\sqrt{s} = 7$ and 8 TeV
- Using the most precise measurements: $t\bar{t}$ decays into electron–muon pairs
- Pearson χ^2 minimization accounting for post fit correlations between systematic and correlations between measurements



Improvement of 25% at $\sqrt{s} = 7$ TeV and of 28% at $\sqrt{s} = 8$ TeV

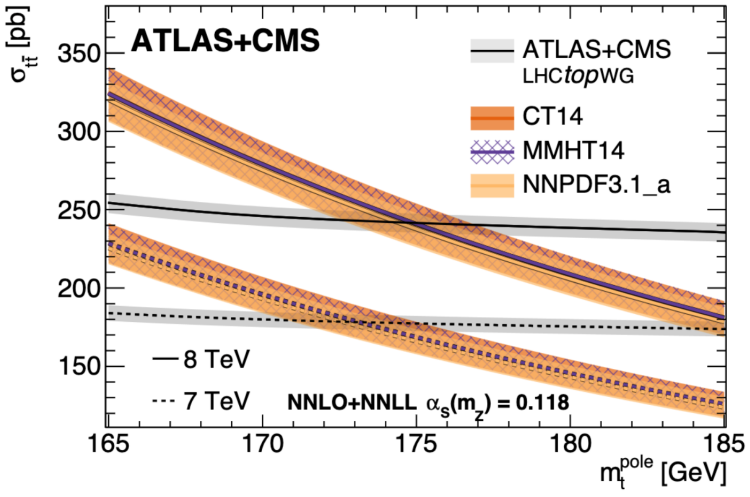
$\sigma_{t\bar{t}}(\sqrt{s} = 7\,\text{TeV}) = 178.5 \pm 4.7$ pb

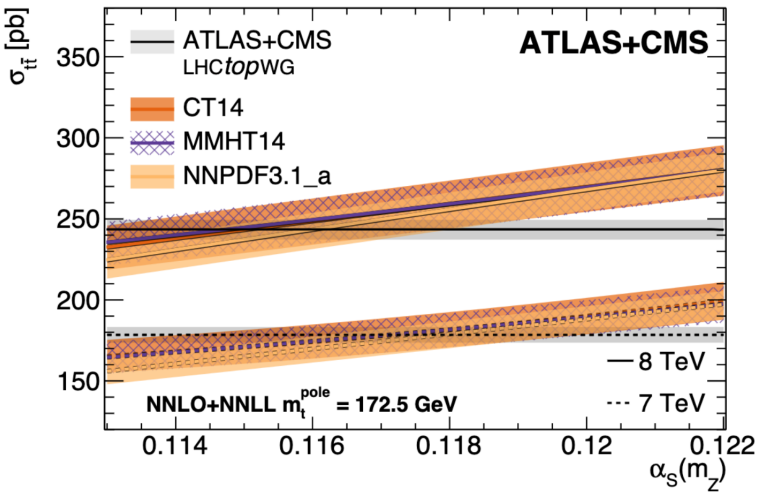
$\sigma_{t\bar{t}}(\sqrt{s} = 8\,\text{TeV}) = 243.3^{+6.0}_{-5.9}$ pb

arXiv:2205.13830

Combination of inclusive top-quark pair production cross-section measurements using ATLAS and CMS data at $\sqrt{s} = 7$ and 8 TeV

- Cross sections depend strongly on top mass and α_s:



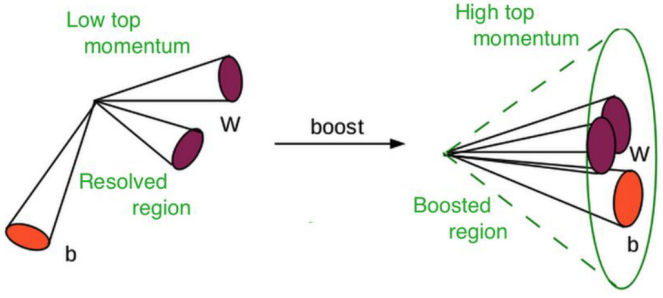


PDF set	m_t^{pole} ($\alpha_s = 0.118 \pm 0.001$)	$\alpha_s(m_Z)$ ($m_t = 172.5 \pm 1.0$ GeV)
CT14	$174.0\ ^{+2.3}_{-2.3}$ GeV	$0.1161\ ^{+0.0030}_{-0.0033}$
MMHT2014	$174.0\ ^{+2.1}_{-2.3}$ GeV	$0.1160\ ^{+0.0031}_{-0.0030}$
NNPDF3.1_a	$173.4\ ^{+1.8}_{-2.0}$ GeV	$0.1170\ ^{+0.0021}_{-0.0018}$

JHEP04(2023)080

13 TeV differential $t\bar{t}$ cross-section using boosted top quarks in the all-hadronic final state

- All hadronic final state
- Single-, double-, and triple-differential cross-sections
- Full LHC Run 2 data sample, $\sqrt{s} = 13\,\text{TeV}$
- Boosted top quarks: $p_\text{T} > 500\,\text{GeV}$
- Unfolded particle-level and parton level distributions
- EFT interpretation



- Fiducial phase space: $p_\text{T}^1 > 500\,\text{GeV}$ and $p_\text{T}^2 > 350\,\text{GeV}$
- $\sigma^\text{fid}_\text{particle} \times B(t\bar{t} \to \text{hadron}) = 331 \pm 3(\text{stat}) \pm 39(\text{syst})\,\text{fb}$
- $\sigma^\text{fid}_\text{parton} = 1.94 \pm 0.02(\text{stat}) \pm 0.25(\text{syst})\,\text{pb}$

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13 TeV differential $t\bar{t}$ cross-section using boosted top quarks in the all-hadronic final state