TeVPA 2021

Measurement of top-quark cross sections and properties with the ATLAS detector at the LHC

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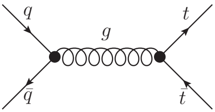
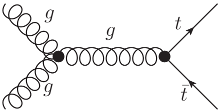
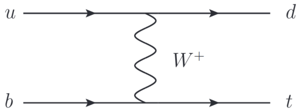
Top quark production at LHC

- Millions of top quarks produced at LHC
- Two main production modes:
  - **pair production** - mainly via strong interaction
  - **single top** - electroweak interactions
- Measurements of cross section and properties important for many reasons:
  - Precision test of the Standard Model
  - Sensitivity to new physics beyond the Standard Model
    - Parameters of Standard Model Effective Field Theory (SMEFT)
  - PDF fits
  - Parameters of MC generators
    - Important for many searches since top quark production is background for them







Recent top-quark measurements in ATLAS

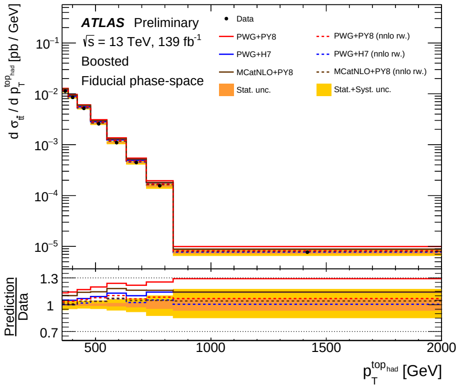
- $t\bar{t}$ **differential cross sections in boosted topology**:
  - lepton+jets selection: ATLAS-CONF-2021-031
  - all-hadronic selection: ATLAS-CONF-2021-050
- **Top-quark properties**
  - $t\bar{t}$ charge asymmetry: ATLAS-CONF-2019-026
  - $t\bar{t}+\mathrm{jet}$ energy asymmetry: arXiv:2110.05453
  - Polarization in single-top production: ATLAS-CONF-2021-027

- All these measurements use proton-proton collisions from full Run2
  - 13 TeV, 139 fb^{-1}

$t\bar{t}$ differential cross sections lepton+jets

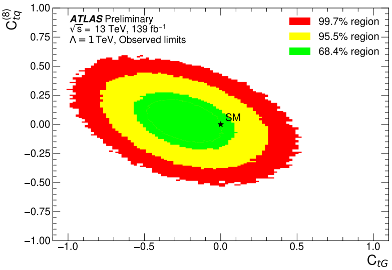
$t\bar{t}$ differential cross sections, lepton+jets

- ATLAS-CONF-2021-031
- Single and double-differential cross sections as a function of:
  - top-quark observables: $p_{\mathrm{T}}^{t\bar{t}}$, $p_{\mathrm{T}}^{\mathrm{top}}$, $m^{t\bar{t}}$,...
  - number of additional jets
- Boosted top quark identified in large-radius jets
- Unfolded to particle level using iterative Bayesian unfolding
- Main uncertainty: Signal modeling



$t\bar{t}$ differential cross sections, SMEFT interpretation

- The measurement is consistent with most predictions based on SM
- SMEFT interpretation to constrain Wilson coefficients C_{tG} and $C_{tq}^{(8)}$:
  - using hadronic top p_{T}
- Tested the impact of Wilson coefficients on the unfolding
  - found negligible impact on unfolded results
- Obtained more stringent limits on $C_{tq}^{(8)}$ than in the recent global fit arXiv:2105.00006

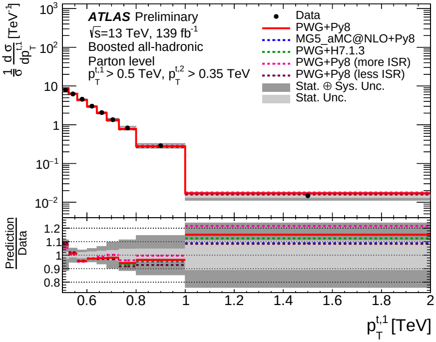


Wilson coefficient	Marginalised 95% intervals		Individual 95% intervals		
	Expected	Observed	Expected	Observed	Global fit [101]
C_{tG}	[-0.44, 0.44]	[-0.68, 0.21]	[-0.41, 0.42]	[-0.63, 0.20]	[0.007, 0.111]
$C_{tq}^{(8)}$	[-0.35, 0.35]	[-0.30, 0.36]	[-0.35, 0.36]	[-0.34, 0.27]	[-0.40, 0.61]

$t\bar{t}$ differential cross sections all-hadronic

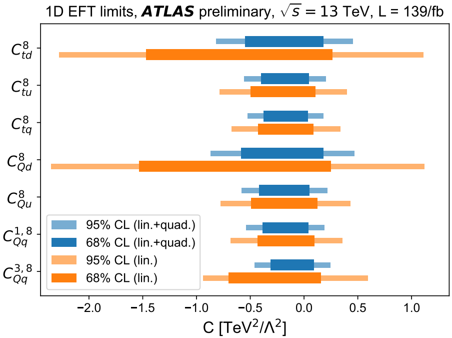
$t\bar{t}$ differential cross sections, all-hadronic

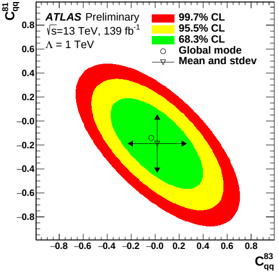
- ATLAS-CONF-2021-050
- All-hadronic
  - both top quarks boosted
- Boosted top quark identified in large-R jets
- Unfolded to parton and particle levels using iterative Bayesian unfolding
- Single-, double-, and triple-differential cross sections
- Main uncertainties: Data statistics, JES, top-tagging
- Measurement consistent with the SM prediction



$t\bar{t}$ differential cross sections, all-hadronic, SMEFT interpretation

- The measurement is consistent with the SM prediction
- SMEFT interpretation to constrain 7 Wilson coefficients
- Using hadronic top p_{T}
- The coefficients are constrained one at a time in the right plot

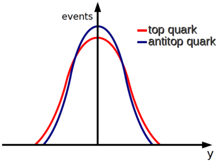




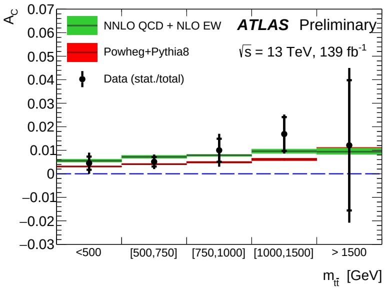
$t\bar{t}$ charge asymmetry

$t\bar{t}$ charge asymmetry

- ATLAS-CONF-2019-026
- Evidence for charge asymmetry
- Lepton+jets selection
- Boosted top quark identified in large-R jets
- Inclusive and differential as a function of $m_{t\bar{t}}$ and longitudinal boost of $t\bar{t}$ system
- Unfolded to parton level using Fully Bayesian Unfolding
- Main uncertainties: Data statistics, signal and background modelling



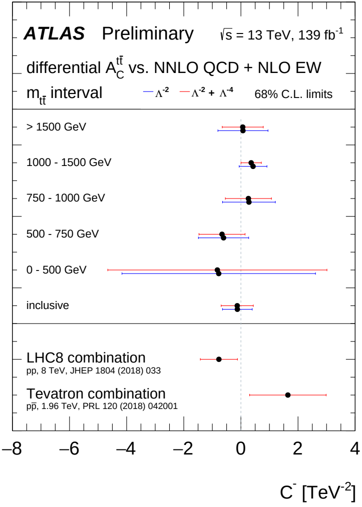
$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$



$t\bar{t}$ charge asymmetry, SMEFT interpretation

- Measurement consistent with SM prediction
- 68% CL on SMEFT parameter C^-/Λ^2
  - linear combination of seven 4-fermion operators in the Warsaw basis

$$C_u^1 = C_{qq}^{(8,1)} + C_{qq}^{(8,3)} + C_{ut}^{(8)}$$
$$C_u^2 = C_{qu}^{(1)} + C_{qt}^{(1)}$$
$$C_d^1 = C_{qq}^{(8,1)} - C_{qq}^{(8,3)} + C_{dt}^{(8)}$$
$$C_d^2 = C_{qd}^{(1)} + C_{qt}^{(1)}$$
$$C_u^1 = C_d^1 = C^1$$
$$C^- = C^1 - C^2$$



$t\bar{t}+\mathrm{jet}$ **energy asymmetry**

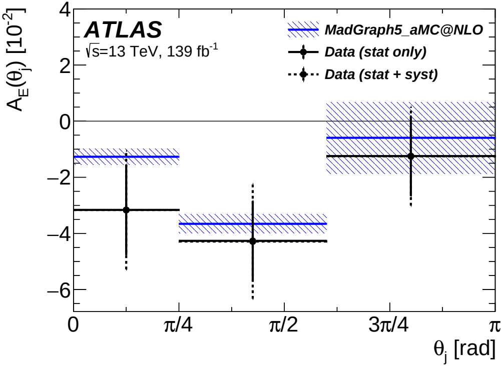
$t\bar{t}$+jet energy asymmetry

- arXiv:2110.05453
- Energy asymmetry A_E:
  - Similar observable as the charge asymmetry
  - Optimized for $t\bar{t}$ production in association with a jet
  - Measured as a function of θ_j
    - θ_j - angle between the additional jet and the z-axis in the $t\bar{t}$+jet system
- Lepton+jets selection
  - hadronic top quark boosted
- Main uncertainties: Data statistics

$$A_E(\theta_j) \equiv \frac{\sigma^{\text{opt}}(\theta_j|\Delta E > 0) - \sigma^{\text{opt}}(\theta_j|\Delta E < 0)}{\sigma^{\text{opt}}(\theta_j|\Delta E > 0) + \sigma^{\text{opt}}(\theta_j|\Delta E < 0)}$$

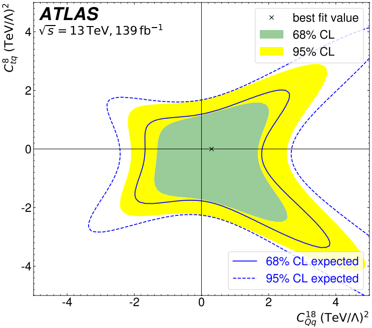
$$\sigma^{\text{opt}}(\theta_j) = \sigma(\theta_j|y_{t\bar{t}j} > 0) + \sigma(\pi - \theta_j|y_{t\bar{t}j} < 0)$$

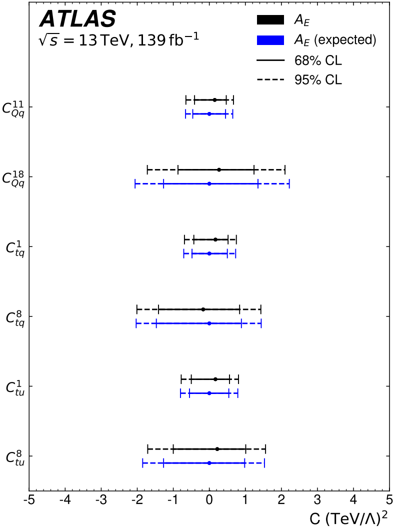
$$\Delta E = E_t - E_{\bar{t}}$$



$t\bar{t}$+jet energy asymmetry, SMEFT interpretation

- Measurement consistent with the SM prediction
- SMEFT interpretation to constrain 6 Wilson coefficients

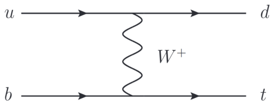




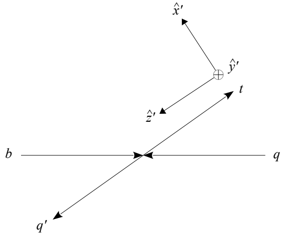
Polarization in single-top production

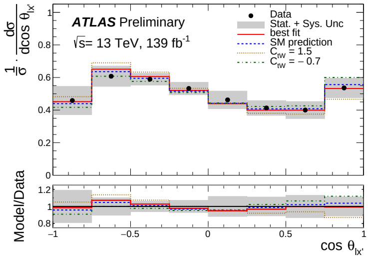
Polarization in single-top t-channel production

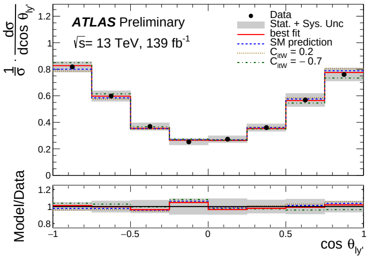
- ATLAS-CONF-2021-027
- t-channel production
  - targetting leptonic decay of W



- Measuring angle θ of the lepton in the reference frame $\{x', y', z'\}$
  - z' in the direction of the spectator quark
  - top-quark rest frame

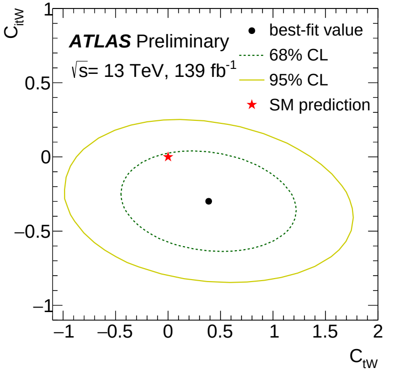






Polarization in single-top production, SMEFT interpretation

- Measurement consistent with the SM prediction
- SMEFT interpretation to constrain O_{tW} dipole operator



	C_{tW}		C_{itW}	
	68% CL	**95% CL**	**68% CL**	**95% CL**
All terms	[-0.2, 0.9]	[-0.7, 1.5]	[-0.5, -0.1]	[-0.7, 0.2]
Order $1/\Lambda^4$	[-0.2, 0.9]	[-0.7, 1.5]	[-0.5, -0.1]	[-0.7, 0.2]
Order $1/\Lambda^2$	[-0.2, 1.0]	[-0.7, 1.7]	[-0.5, -0.1]	[-0.8, 0.2]

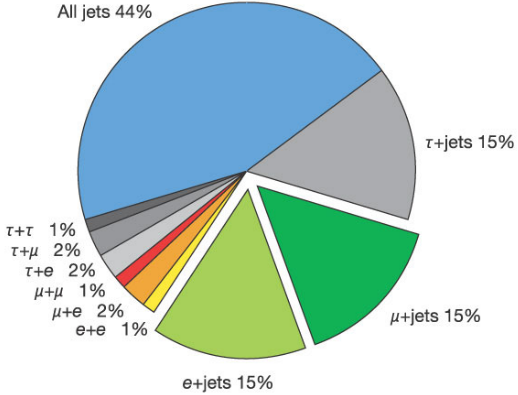
Summary

- The ATLAS experiment has an extensive program of top-quark measurements
- Measurements consistent with the Standard Model predictions
- Large potential to improve the MC configurations for the future
- Differential cross-section measurements probe the TeV scale
- Valuable inputs for the global EFT fits

Backup

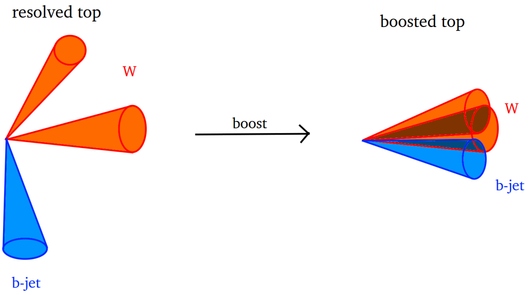
$t\bar{t}$ decay channels

- Decay $t \longrightarrow Wb$ in $\sim$100%
  - Signature depends on the decay mode of the W boson (leptonic or hadronic)
- Main selection regions for $t\bar{t}$: dilepton, lepton+jets, all-jets



Boosted top quark production

- Hadronically decaying boosted top quarks
  - $p_{\mathrm{T}} \gtrsim 300$ GeV
  - Decay products start to overlap - different identification methods are needed
- New physics can alter top quark production especially in the boosted phase space
- Boosted top quarks identified within large-R jets
  - Reduced combinatorics
  - Possibility to use large-R jet triggers



Type of measurements in ATLAS

- **Inclusive**
  - full phase space
  - fiducial phase space
- **Differential** - cross section as a function of certain observable defined at
  - parton level
    - full phase space
    - fiducial phase space
  - particle level
    - fiducial phase space

Parton level

- defined using particles before hadronization

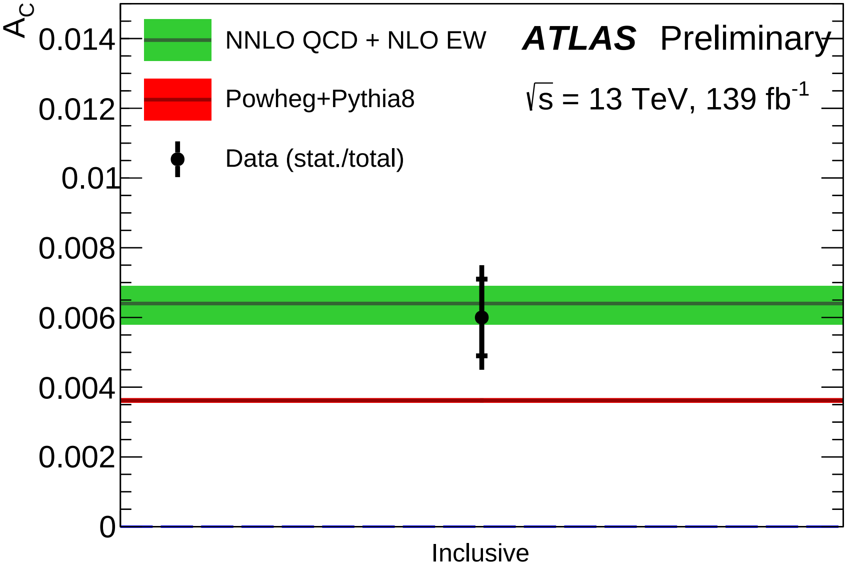
Particle level

- defined using stable particles after hadronization ($c\tau > 1$ cm)
$\Rightarrow$ reduction of signal modeling uncertainties

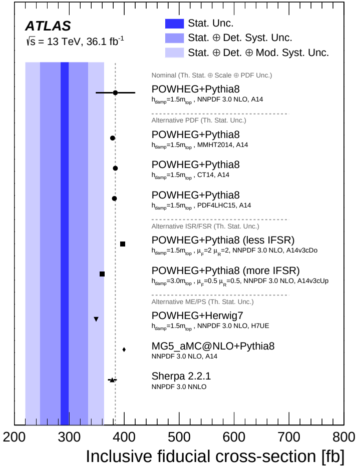
Fiducial phase space

- typically chosen to be close to the phase space of the selected data
- can use parton or particle level observables

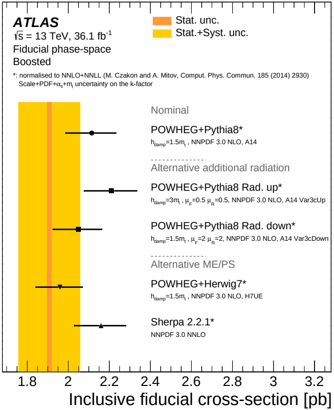
Inclusive charge asymmetry



Inclusive $t\bar{t}$ differential cross section in fid. region, all-hadronic



Inclusive $t\bar{t}$ differential cross section in fid. region, lepton+jets



Inclusive $t\bar{t}$ differential cross section in fid. region, lepton+jets, NEW