Recent Top Quark Measurements From ATLAS

HQL 2021

Sahibjeet Singh[1] on behalf of the ATLAS collaboration

[1]University of Toronto

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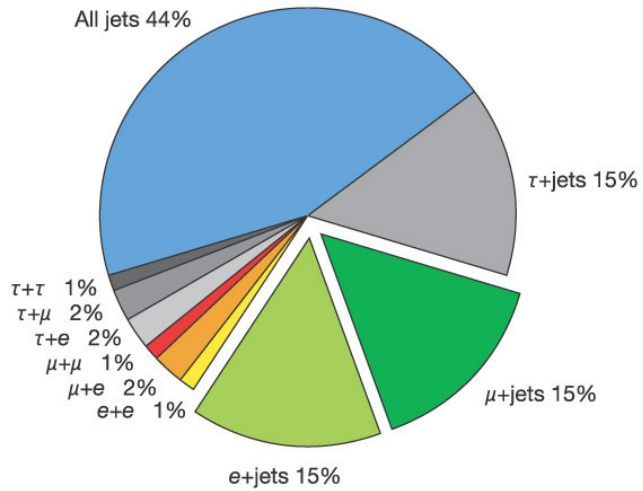
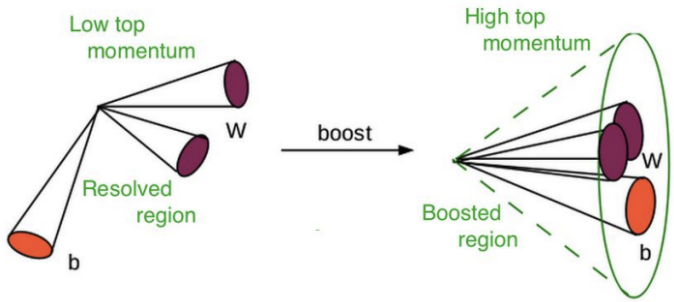
Outline

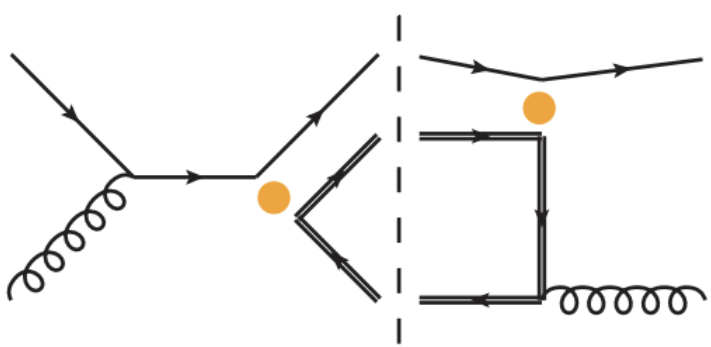
- Measurement of energy asymmetry in $t\bar{t} + j$ events
  - ATLAS-TOPQ-2019-08-002
- Differential cross-section measurement with boosted top-quark pairs in a lepton+jets final state
  - ATLAS-CONF-2021-031
- Differential cross-section measurement with boosted top quarks in an all-hadronic final state
  - ATLAS-TOPQ-2018-11-001

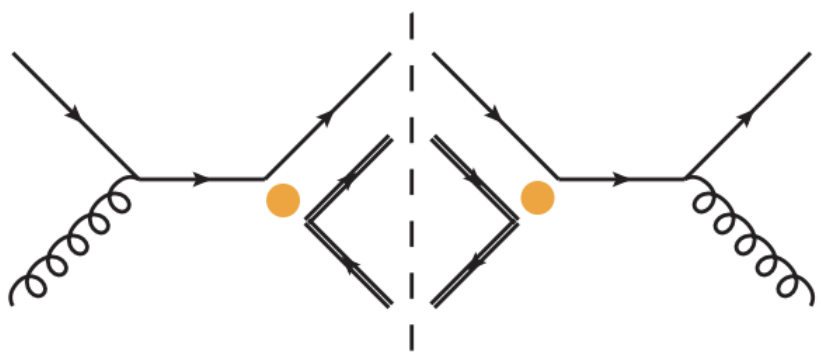




Energy Asymmetry - Overview

- Charge asymmetry in $t\bar{t}$ events can be measured with $t\bar{t}$ pairs produced with an extra high p_T jet JHEP **07** (2013) 179
  - Sensitive to charge asymmetry in a **different** phase space than rapidity asymmetry
  - Sensitive to four quark EFT operators and BSM physics
- 1 e or μ with $p_T > 27$ GeV, MET > 20 GeV, MET + MTW > 30 GeV
- 1 top-tagged large-R $= 1.0$ jet with $p_T > 350$ GeV
- ≥ 1 b-tagged small-R $= 0.4$ jet + 1 small-R $= 0.4$ jet with $p_T > 100$ GeV





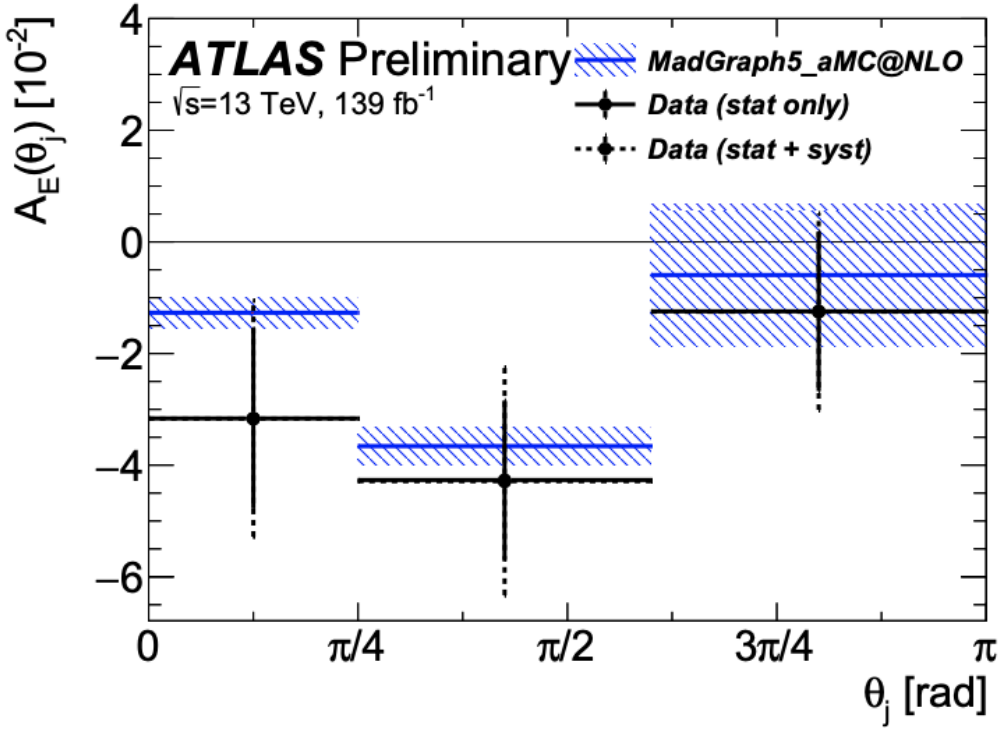
Energy Asymmetry - Formulation

$$A_E(\theta_j) \equiv \frac{\sigma^{\text{opt}}(\theta_j|\Delta E > 0) - \sigma^{\text{opt}}(\theta_j|\Delta E < 0)}{\sigma^{\text{opt}}(\theta_j|\Delta E > 0) + \sigma^{\text{opt}}(\theta_j|\Delta E < 0)} \quad \Delta E = E_t - E_{\bar{t}}$$

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

- Both ΔE and θ_j are defined in $t\bar{t}j$ rest frame
- θ_j is the angle between the jet and the positive z-axis
- Results unfolded to particle level in bins of θ_j and ΔE using fully Bayesian unfolding
- σ^{opt} is optimized for statistical sensitivity Phys Rev. D **95** 2017

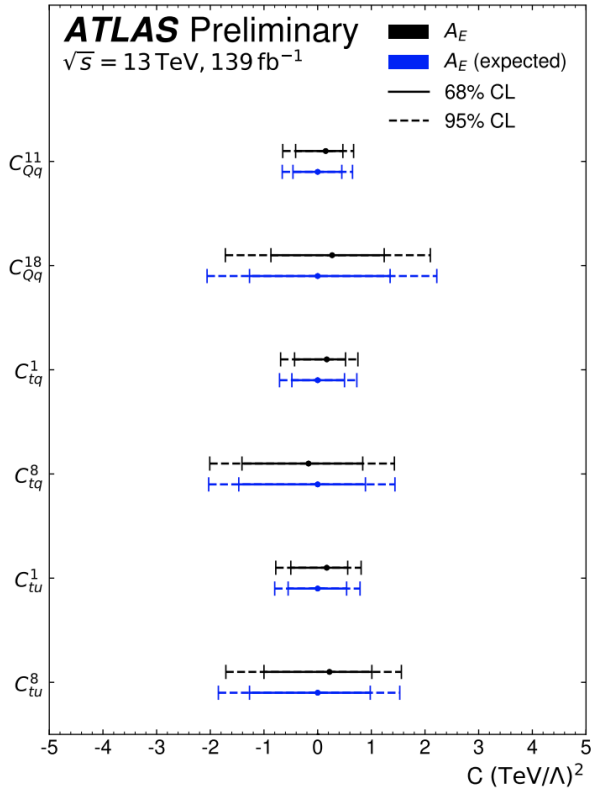
Energy Asymmetry - Results



- Inclusive energy asymmetry $A_e^2 = -0.043 \pm 0.020$ agrees with SM prediction of -0.037 ± 0.003
- Energy asymmetry shows good agreement with SM
- Dominant source of uncertainty is data statistics followed by $t\bar{t}$ modelling uncertainties

Energy Asymmetry - EFT Results

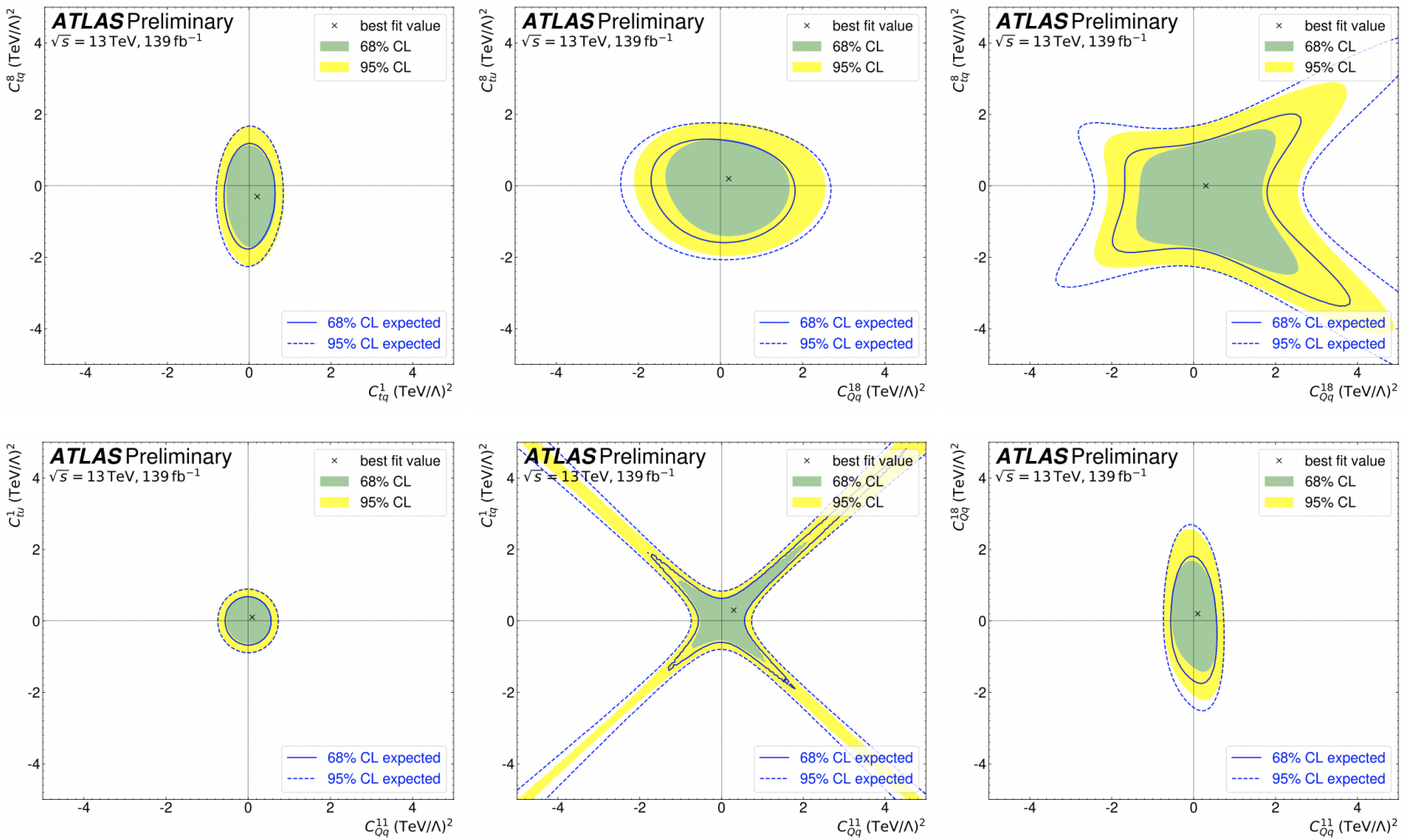
- $\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2}\sum_i C_i \mathcal{O}_i^{(6)} + \mathcal{O}(\frac{1}{\lambda^4})$
- Six four-quark operators studied in the context of EFT
- Model independent method to search for new physics
- No deviations from SM



C (TeV/Λ)^2	A_E (Λ^{-4})		A_E (Λ^{-2})	
	68% CL	95% CL	68% CL	95% CL
C_{Qq}^{11}	$[-0.41, 0.47]$	$[-0.65, 0.67]$	$[-0.68, 4.06]$	$[-3.36, 6.16]$
C_{Qq}^{18}	$[-0.87, 1.24]$	$[-1.72, 2.10]$	$[-1.26, 4.76]$	$[-3.24, 9.64]$
C_{tq}^{1}	$[-0.43, 0.52]$	$[-0.69, 0.75]$	$[-0.60, 5.76]$	$[-3.42, 9.36]$
C_{tq}^{8}	$[-1.41, 0.84]$	$[-2.01, 1.43]$	$[-1.86, 1.70]$	$[-3.30, 3.98]$
C_{tu}^{1}	$[-0.50, 0.56]$	$[-0.78, 0.81]$	$[-0.96, 5.82]$	$[-4.72, 8.88]$
C_{tu}^{8}	$[-1.00, 1.01]$	$[-1.71, 1.56]$	$[-1.30, 2.52]$	$[-3.02, 4.66]$

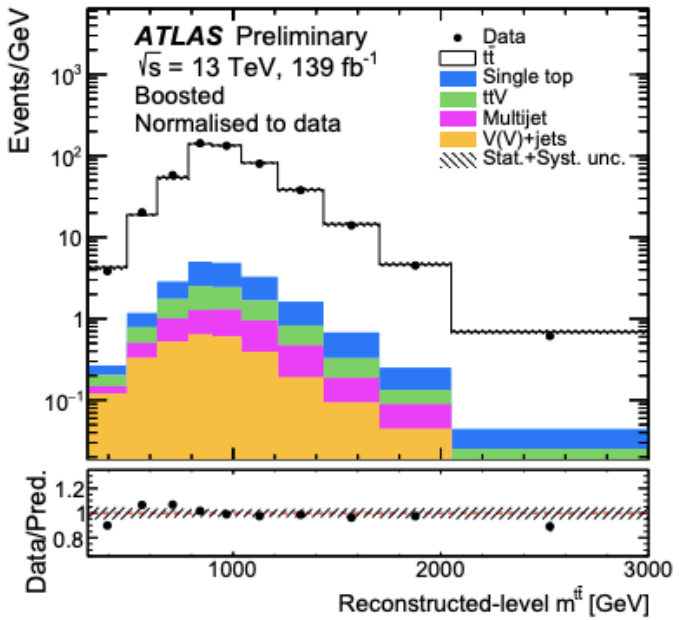
Energy Asymmetry - EFT Results

- Probes new direction in parameter space of Wilson coefficients



l+jets Differential Cross-Section - Overview

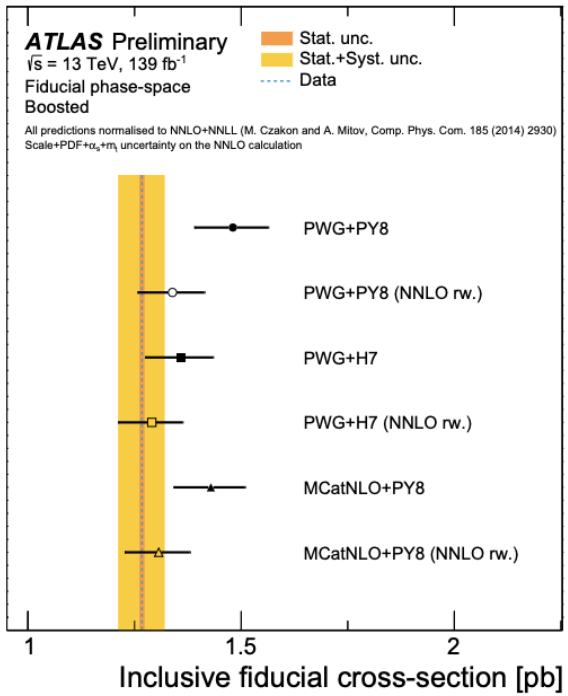
- BSM physics expected to couple to top quarks at high p_T
- Requires precise measurements in the boosted $t\bar{t}$ phase space
- 1 e or μ with $p_T > 27$ GeV, MET > 20 GeV, $m_{(l,b)} < 180$ GeV
- 1 large-R = 1.0 high p_T jet, $120 < M < 255$ GeV,
- ≥ 1 b-tagged subjet matched to large-R jet
- Iterative Bayesian Unfolding (IBU) used to unfold to fiducial phase space

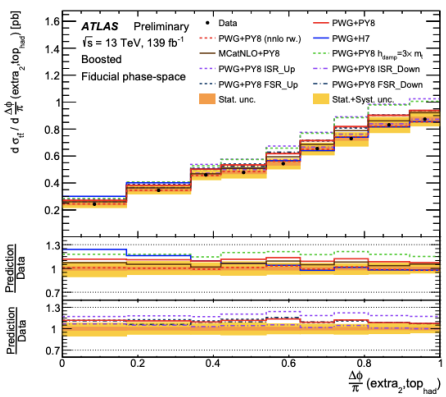


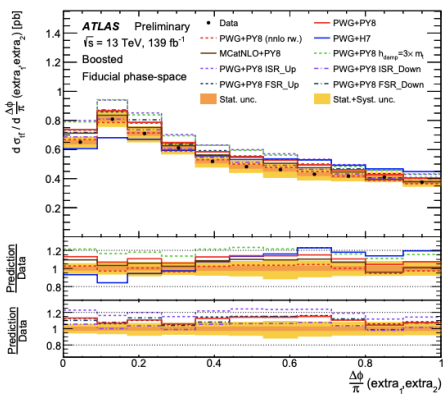
$$\frac{d\sigma^{\text{fid}}}{dX^i} \equiv \frac{1}{\mathcal{L} \cdot \Delta X^i} \cdot \frac{1}{\epsilon^i_{\text{eff}}} \cdot \sum_j \mathcal{M}^{-1}_{ij} \cdot f^j_{\text{acc}} \cdot \left(N^j_{\text{reco}} - N^j_{\text{bg}} \right)$$

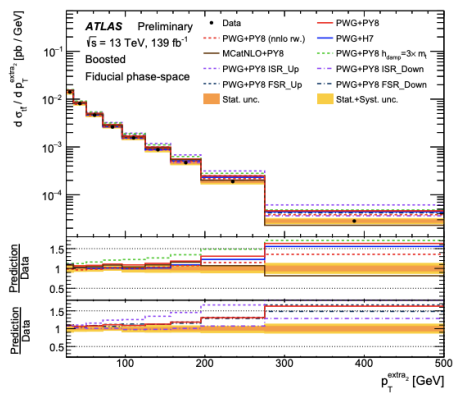
l+jets Differential Cross-Section - Results

- $\sigma_{t\bar{t}}^{fid} = 1.267 \pm 0.005 \pm 0.053$ pb
  - Precision (4.2%) comparable to inclusive l+jets (4.3%)
  - Systematic uncertainty dominated by $t\bar{t}$ modelling and luminosity
- Modelling of additional jets probed by $\Delta\phi(\text{extra}_2, \text{top}_{had})$, $\Delta\phi(\text{extra}_1, \text{extra}_2)$, $p_T^{\text{extra}_2}$
  - $\text{extra}_1, \text{extra}_2$ are the two leading additional jets
- None of the models tested provide a good match to data with additional jets



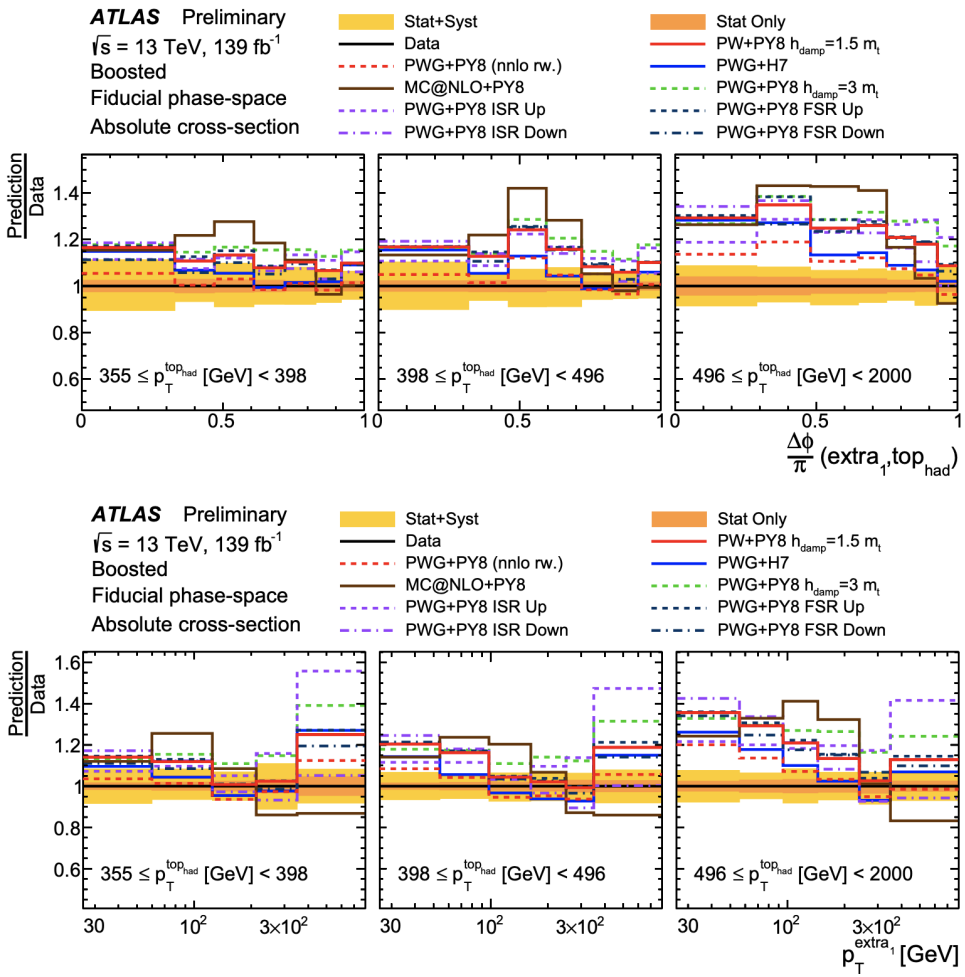






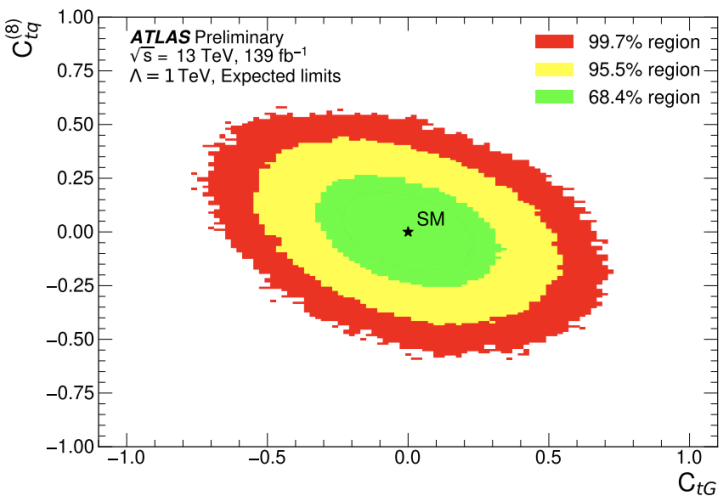
l+jets Differential Cross-Section - Results

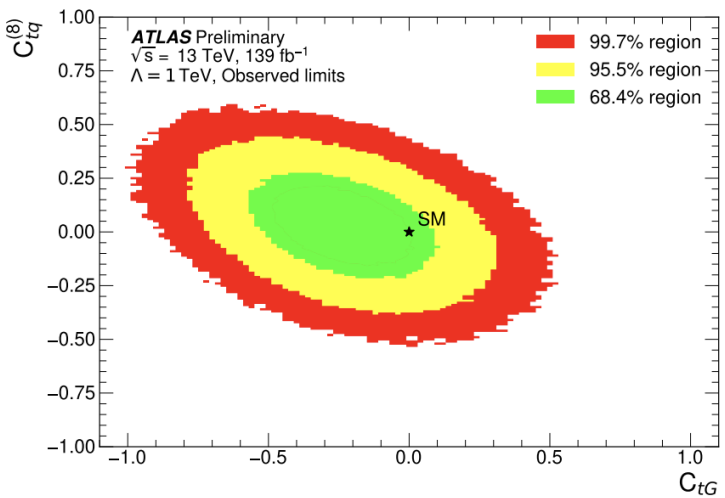
- Double differential cross-sections of $\Delta\phi(\text{extra}_1, \text{top}_{had})$ and $p_T^{extra_1}$ with $p_T^{top}{}_{had}$ disagree with data for large $p_T^{top}{}_{had}$
- Best agreement given by NNLO reweighted PP8



l+jets Differential Cross-Section - EFT Results

- C_{tG} and $C_{tq}^{(8)}$ Wilson coefficients found to be consistent with SM
  - $C_{tG} = -0.24$, $C_{tq}^{(8)} = 0.03$
- Limits placed on 95% confidence intervals for both C_{tG} and $C_{tq}^{(8)}$
  - $C_{tq}^{(8)}$ limits stronger than recent global EFT fit arXiv: 2105.00006





Wilson coefficient	Marginalised 95% intervals		Individual 95% intervals		
	Expected	Observed	Expected	Observed	Global fit [99]
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]

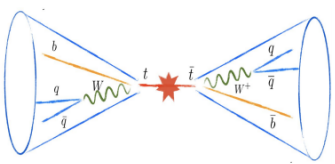
All-Hadronic Differential Cross-Section - Overview

- Measurements of 1, 2, and 3D differential cross-sections of boosted top quarks in an all-hadronic final state
- Select two high p_T large R = 1.0 jets with a DNN based top tagger and b-tagger
- Data driven estimate used to calculate the multijet background
- Unfolding performed using four iterations of IBU

Particle level fiducial phase space definition:

Truth trimmed jets R=1.0

$p_{T,J1} > 500$ GeV
$|m_{J1}-m_{Top}| < 50$ GeV
$|\eta_{J1}| < 2$

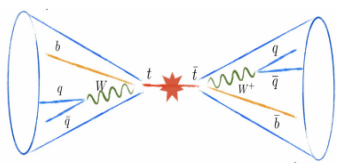


$p_{T,J2} > 350$ GeV
$|m_{J2}-m_{Top}| < 50$ GeV
$|\eta_{J2}| < 2$

+ both matched with B-hadron
• Top-tagging not applied

Parton level limited phase space definition:

$p_{T,top1} > 500$ GeV

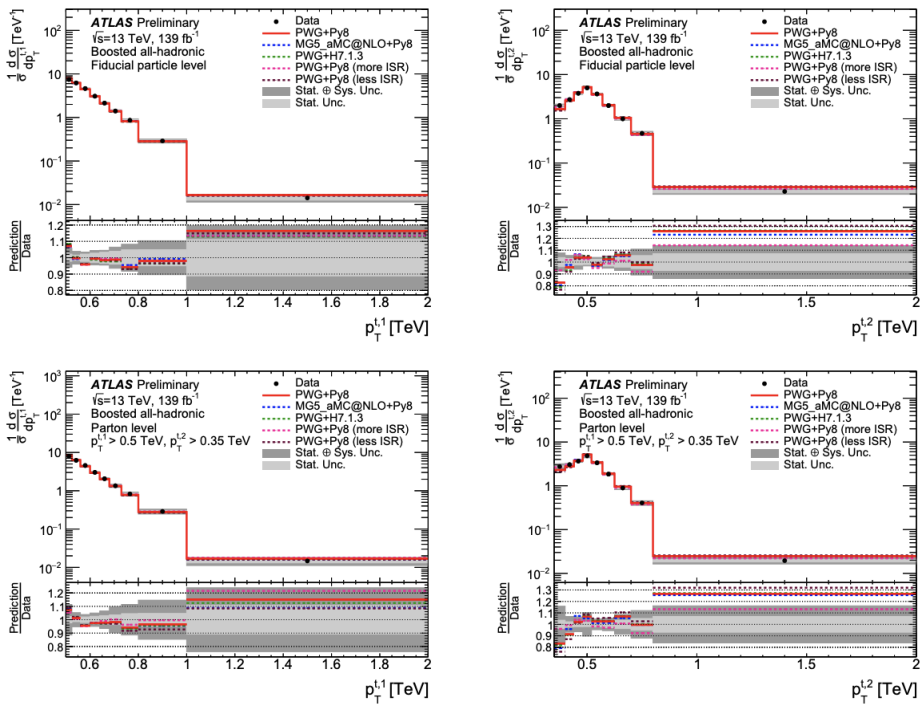


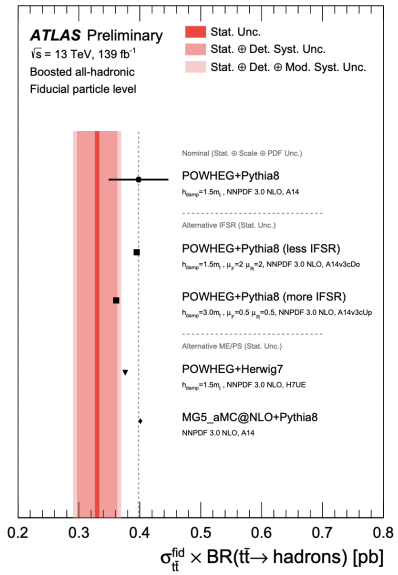
$p_{T,top2} > 350$ GeV

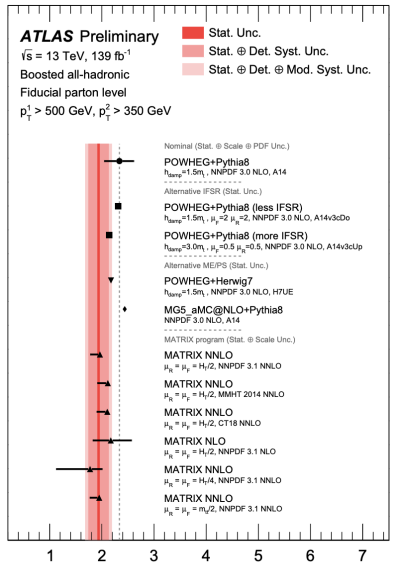
• last top in chain in MC (after radiation)

All-Hadronic Differential Cross-Section - Results

- Particle level $\sigma_{t\bar{t}}^{fid} = 0.330 \pm 0.003 \pm 0.038$ pb
- Parton level $\sigma_{t\bar{t}}^{fid} = 1.940 \pm 0.002 \pm 0.025$ pb
- Top-tagging related uncertainties are the largest
- Good agreement between data and prediction for both particle and parton level

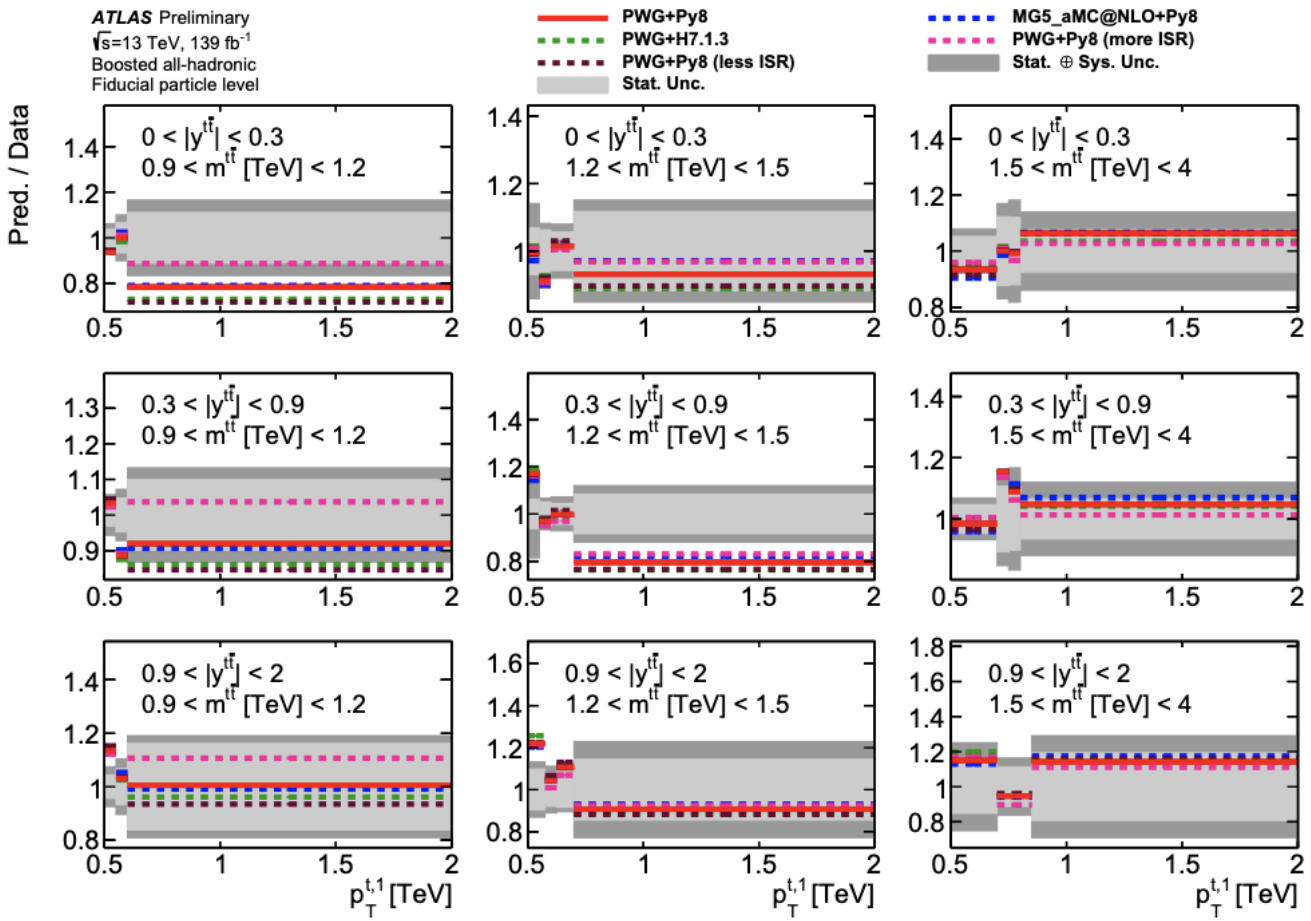






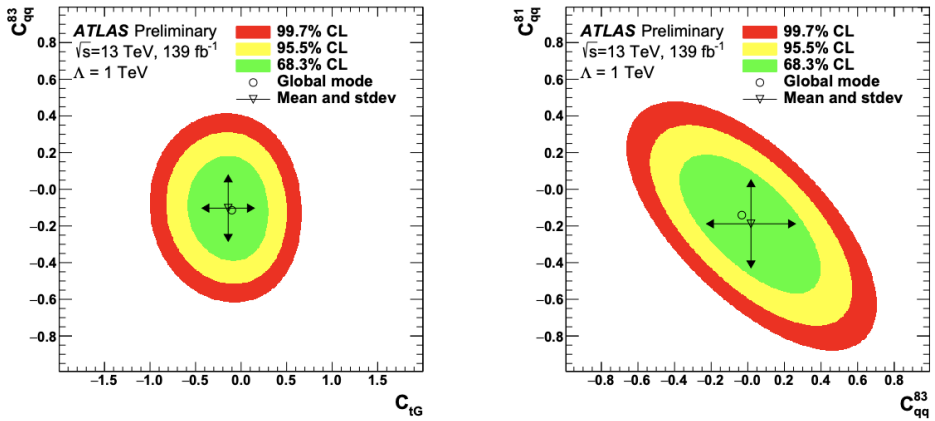
All-Hadronic Differential Cross-Section - Results

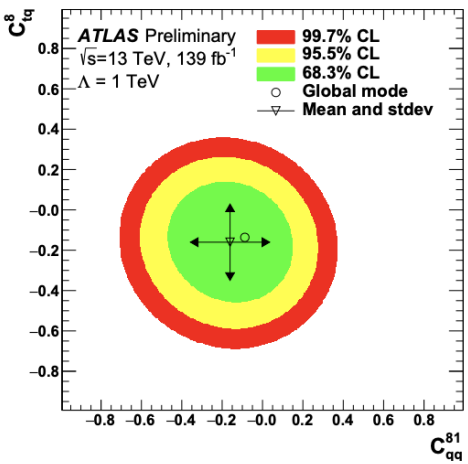
- Triple differential cross-sction of the leading top quark p_T ($p_T^{t,1}$), rapidity ($|y^{t\bar{t}}|$), and mass of the $t\bar{t}$ system ($m^{t\bar{t}}$) at parton level shows overall good agreement with data

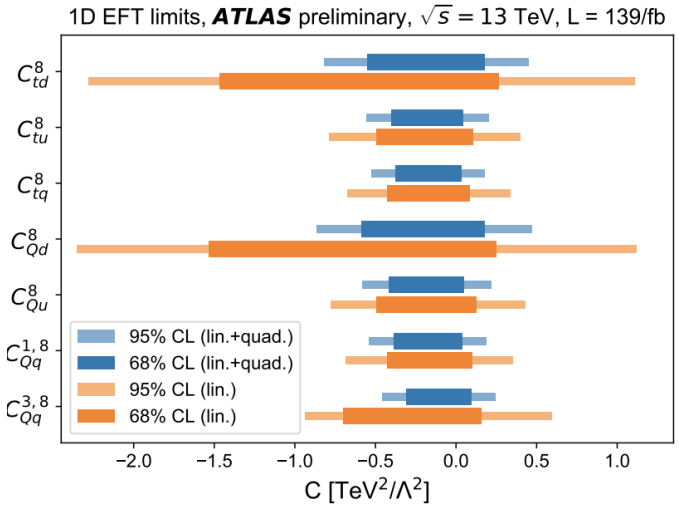


All-Hadronic Differential Cross-Section - EFT Fits

- 1D and 2D limits set on sensitive Wilson coefficients
- No significant deviation from SM







Conclusions

- Various new results from ATLAS using full Run 2 data
- Measurement of energy asymmetry shows no deviations from SM
  - Allows further constrains to four-quark Wilson coefficients
- Differential cross-sections measured in two of the three $t\bar{t}$ decay modes
  - Fits to sensitive Wilson coefficients in the context of EFT performed as well
  - All EFT fits show agreement with SM
- Differential measurements overall show agreement with SM predictions
- Further interesting results from ATLAS + CMS on top quark mass and properties is given by Baptiste Ravina yesterday!

Backup