Highlights of the ATLAS Top Quark Precision Measurements

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7th September, 2022

ICNFP, Crete

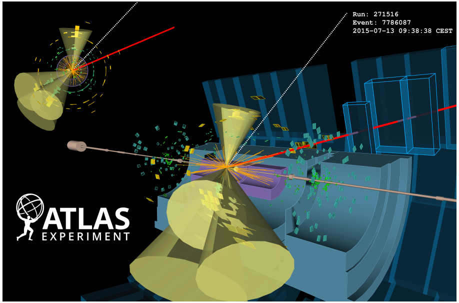
Why do top physics?

- The top quark is the most massive in the SM:
  - Largest Higgs coupling
  - Top processes are important for many searches for rare processes and BSM physics
  - The top decays before hadronisation, so may be studied as a bare quark
- The LHC provides abundant top production
- Top processes are sensitive to many QCD parameters
- Many properties of the top quark are input as important parameters in the SM

ATLAS EXPERIMENT

Top quark precision measurements

- Can probe SM with precision greater than NLO calculations
- Precision measurements of top processes allow for tests of Effective Field Theory interpretations
- Compare data agreement across generators $\Rightarrow$ test SM, EFT interpretation, MC tuning
- Can search for rare processes and probe extreme phase space

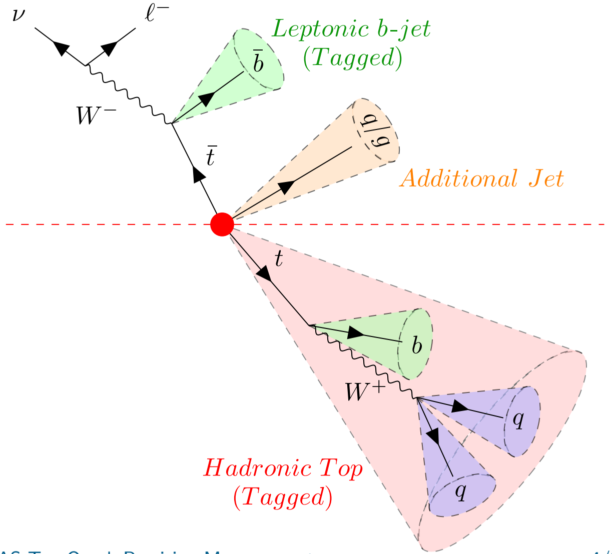


Measurement of the energy asymmetry in $t\bar{t}j$ production at 13 TeV with the ATLAS experiment and interpretation in the SMEFT framework

arXiv:2110.05453

Energy Asymmetry in $t\bar{t}j$: Introduction

- Charge asymmetry in top pair production particularly sensitive to new physics
- Can measure the charge asymmetry as an energy asymmetry when top pairs are produced in association with a high-p_{T} additional jet



Energy Asymmetry in $t\bar{t}j$: Overview and Selection

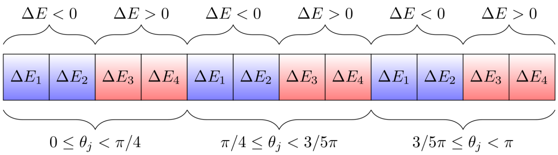
- Analysis performed with full ATLAS Run 2 dataset - 139 fb^{-1} at 13 TeV
- Performed in lepton+jets channel of boosted $t\bar{t}$
- Data unfolded to particle level and results used to obtain EFT limits
- New physics can significantly alter the energy asymmetry
- Event selection:

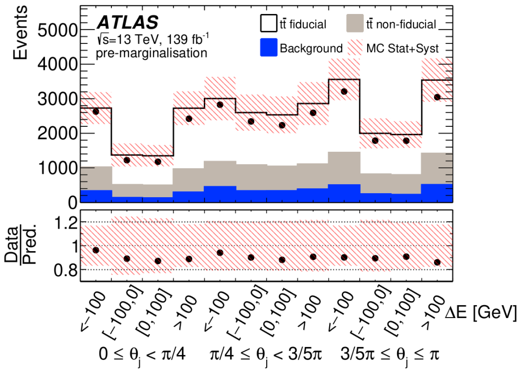
1 lepton (e, μ) l	$p_T > 27$ GeV, no other leptons with $p_T > 25$ GeV
1 neutrino ν,	$E_T^{miss} > 20$ GeV, $E_T^{miss} + \text{MWT} > 30$ GeV
1 anti-kt R=1.0 jet lj	$p_T > 350$ GeV, $\Delta\Phi(lj, l) > 1.0$, top-tagged
1 anti-kt R=0.4 jet sj	$p_T > 25$ GeV, $\Delta R(sj, l) < 2.0$, $\Delta R(sj, lj) > 1.5$ prefer highest p_T b-tagged
1 anti-kt R=0.4 jet aj	highest p_T jet with $p_T > 100$ GeV $\Delta R(aj, lj) > 1.5$, $\Delta R(aj, \{l, sj\}) > 0.4$
≥ 1 b-tagged jet	either sj or lj, no other b-tagged jets

- Define asymmetry observable

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

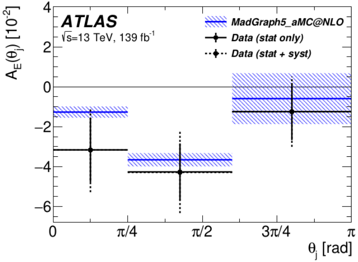
where $\Delta E = E_t - E_{\bar{t}}$ is measured in bins of θ_j, the angle of the additional jet relative to the beamline.

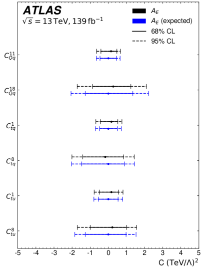




Energy Asymmetry in $t\bar{t}j$: Results

Constraints on Wilson coefficients from energy asymmetry complementary to those from other top observables such as rapidity asymmetry





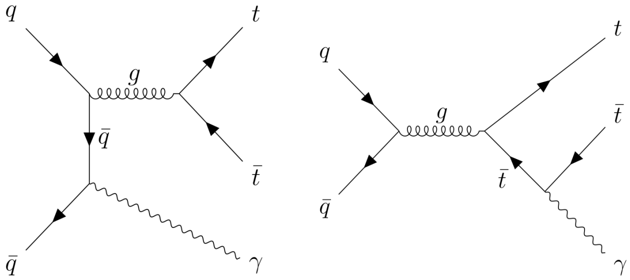
Scenario	$A_E \pm \Delta A_E$ $[10^{-2}]$ $0 \leq \theta_j \leq \frac{\pi}{4}$	$\frac{\pi}{4} \leq \theta_j \leq \frac{3\pi}{5}$	$\frac{3\pi}{5} \leq \theta_j \leq \pi$
Data	-3.2 ± 2.1	-4.3 ± 2.0	-1.3 ± 1.8
SM prediction (MadGraph5_aMC@NLO)	-1.3 ± 0.3	-3.7 ± 0.3	-0.6 ± 1.3
SM expectation	-1.3 ± 2.1	-3.7 ± 2.0	-0.6 ± 1.6

Measurement of the charge asymmetry in top quark pair production in association with a photon with the ATLAS experiment

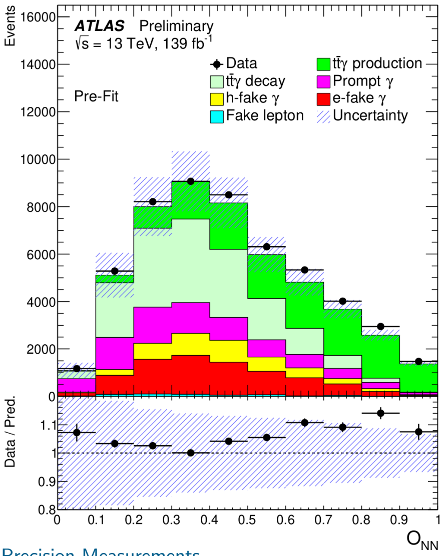
ATLAS-CONF-2022-049

Charge Asymmetry in $t\bar{t} + \gamma$: Introduction

- Analysis performed with full ATLAS Run 2 dataset - 139 fb^{-1} at 13 TeV
- Measuring charge asymmetry in associated production of $t\bar{t}$ with a photon
- Majority of $t\bar{t}$ gluon initiated, which results in charge symmetry
- Expect asymmetry arises from $q\bar{q}$ and gq interference
- $t\bar{t} + \gamma$ ideal for measuring this asymmetry due to greater $q\bar{q}$ initiated production $\Rightarrow$ signal is $t\bar{t} + \gamma$ production

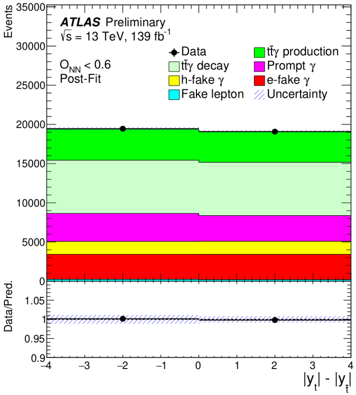


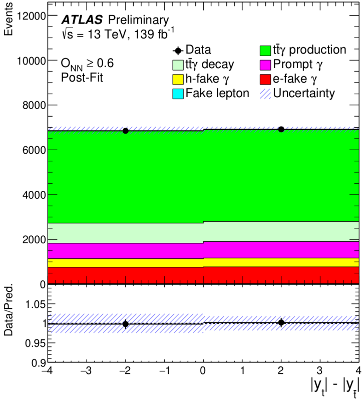
- Event selection:
  - Exactly one trigger-matched e/μ
  - Exactly one photon with $\Delta R(\ell,\gamma) > 0.4$
  - $m_{e\gamma}$ outside Z mass window
  - At least four jets
  - At least one b-jet
- Neural Network used to separate signal and background.
- Main backgrounds come from $t\bar{t}\gamma$ decay and prompt γ
- Also backgrounds arising from electron faking photons, hadronic decays faking photons, and fake leptons.



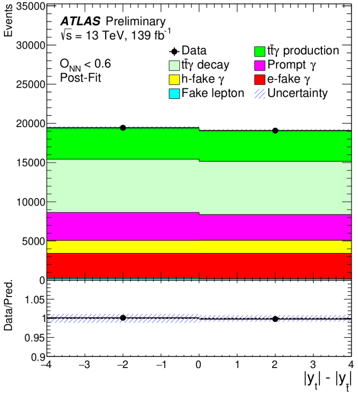
Charge Asymmetry in $t\bar{t}+\gamma$: Measurement

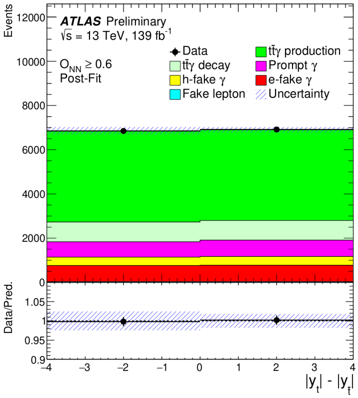
- Charge asymmetry defined: $A_C = \frac{N(|y_t|>|y_{\bar{t}}|)-N(|y_t|<|y_{\bar{t}}|)}{N(|y_t|>|y_{\bar{t}}|)+N(|y_t|<|y_{\bar{t}}|)}$
- Extracted by maximum likelihood unfolding simultaneously to $|y_t| - |y_{\bar{t}}|$ distributions in regions defined by NN





- $A_C = -0.006 \pm 0.030 = -0.006 \pm 0.024(\text{stat}) \pm 0.018(\text{syst})$
- Statistically limited
- Consistent with SM prediction of $A_C = -0.014 \pm 0.001(\text{scale})$



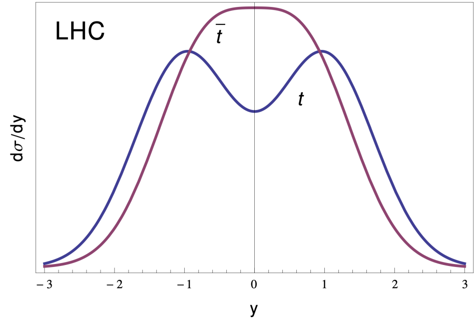


Evidence for the charge asymmetry in $pp \to t\bar{t}$ production at $\sqrt{s} = 13$ TeV with the ATLAS detector

arXiv:2208.12095

- Analysis performed with full ATLAS Run 2 dataset - 139 fb^{-1} at 13 TeV
- Aim to measure $A_C^{t\bar{t}}$ and $A_C^{\ell\bar{\ell}}$ in $t\bar{t}$ events for in lepton+jets (resolved and boosted) and dilepton (resolved) channels
- Asymmetry arises from $q\bar{q}$ and qg initial states $\Rightarrow$ at LHC diluted by charge-symmetric $gg \to t\bar{t}$ process
- Asymmetries sensitive to many BSM effects
- Previous measurements statistically limited and consistent with SM

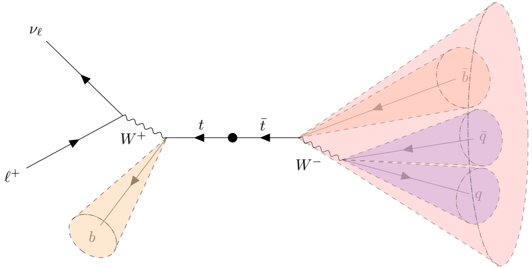
- $A_C^{t\bar{t}}$ and $A_C^{\ell\bar{\ell}}$ measured differentially as function of $m_{t\bar{t}}/m_{\ell\bar{\ell}}$, $p_{\mathrm{T},t\bar{t}}/p_{\mathrm{T},\ell\bar{\ell}}$, $\beta_{z,t\bar{t}}/\beta_{z,\ell\bar{\ell}}$
- EFT interpretation to place limits on Wilson coefficients of operators affecting top production



Charge Asymmetry in $t\bar{t}$: Measurement

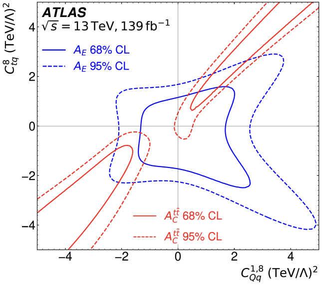
- Lepton + jets resolved channel uses a BDT combining kinematics, *b*-tagging, KLFitter, to output a discriminant for signal selection
- Boosted lepton + jets channel requires top-tagged large-*R* jet
- Dilepton topology requires two opposite charge leptons, at least one *b*-jet, $\mid m_{\ell\bar{\ell}} - m_Z \mid > 10$ GeV
- Fully Bayesian Unfolding used to correct rapidity distributions for detector effects

- $A_C^{t\bar{t}}/A_C^{\ell\bar{\ell}}$ inferred from posterior $\mid \Delta y_{t\bar{t}} \mid / \mid \Delta \eta_{\ell\bar{\ell}} \mid$ distribution resulting from the unfolding procedure

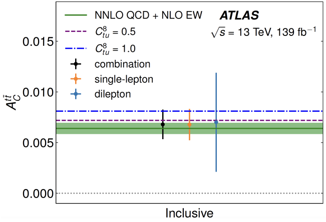


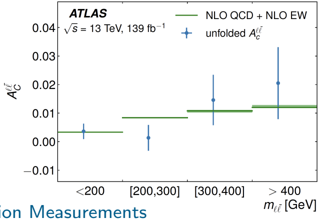
Charge Asymmetry in $t\bar{t}$: Results

- SM prediction gives $A_C^{t\bar{t}} = 0.0064^{+0.0005}_{-0.0006}$, measured to be $A_C^{t\bar{t}} = 0.0068 \pm 0.0015$, so compatible and 4.7σ from zero.
- Improved bounds on Wilson coefficients, complementary to constraints from $t\bar{t}j$ energy asymmetry measurement



- SM prediction gives $A_C^{\ell\bar{\ell}} = 0.0040^{+0.0002}_{-0.0001}$, measured to be $A_C^{\ell\bar{\ell}} = 0.0054 \pm 0.0026$, compatible.





Measurement of single top-quark production in the s-channel in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

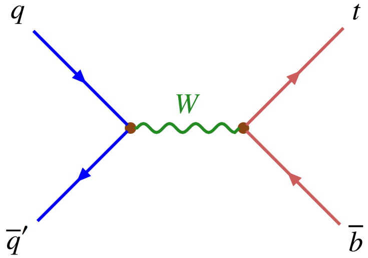
ATLAS-CONF-2022-030

s-Channel Single Top: Overview and Strategy

- Analysis performed with full ATLAS Run 2 dataset - 139 fb^{-1} at 13 TeV
- Aim to measure s-channel single top production, observed to 3.2σ at 8 TeV
- NLO calculation gives cross-section $\sigma^{\mathrm{SM}} = 10.32^{+0.40}_{-0.36}\mathrm{pb}$
- Template fit for cross-section extraction
- Matrix element method for signal discrimination

Select s-channel by requiring:

- exactly 1 lepton $p_{\mathrm{T}} > 30$ GeV
- exactly 2 b-tagged jets



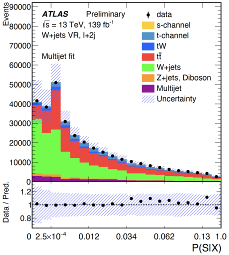
s-Channel Single Top: Measurement

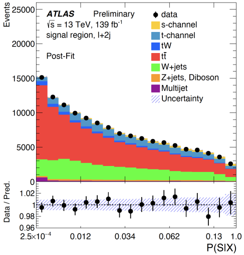
- Matrix element method

$$P(S \mid X) = \frac{\sum_i P(S_i)\mathcal{P}(X \mid S_i)}{\sum_i P(S_i)\mathcal{P}(X \mid S_i) + \sum_j P(B_j)\mathcal{P}(X \mid B_j)}$$

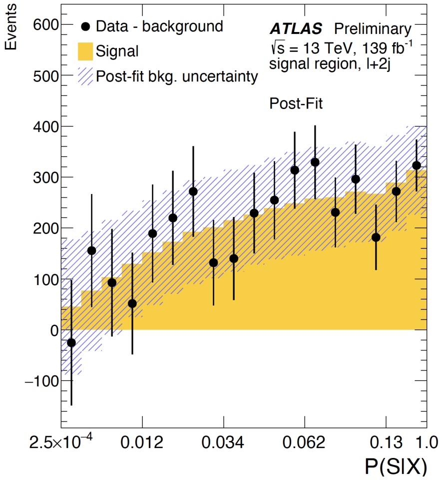
is used to provide per-event signal discriminant - the probability that an event X be a signal event S, with $\mathcal{P}(X \mid H)$ computed as the probability for event X to arise from process H

- Cross-section extracted by binned profile maximum-likelihood fit of the discriminant in the signal region





- s-channel production observed to 3.3σ above background only hypothesis
- Cross-section measured $\sigma = 8.2^{+3.5}_{-2.9}\text{pb}$ - in agreement with SM prediction
- Limited by systematics:
  - $t\bar{t}$ normalisation
  - JES, JER
  - ISR/FSR modelling



Conclusion

- $t\bar{t}+\gamma$ charge asymmetry measurement improves on previous results, agrees with SM prediction, limited by statistical uncertainty
- Strong evidence of charge asymmetry in $t\bar{t}$ (4.7σ), with EFT interpretation producing constraints on Wilson coefficients complementary to energy asymmetry measurement in $t\bar{t}j$
- s-channel single top production observed with significance of 3.3σ, cross-section measured at $\sigma = 8.2^{+3.5}_{-2.9}\mathrm{pb}$, in agreement with SM
- Many more results than the selected highlights covered here - see ATLAS Top Working Group public site for a more comprehensive list
- Constraints on EFT operators in these analyses complement many more from other ATLAS top measurements, shown in the EFT summary plots