



Associated top-quark productions and measurement of production asymmetries with the ATLAS experiment

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Top quark measurements with ATLAS

- * LHC is a top quark factory
- Large Run 2 dataset (139 fb⁻¹) enables precise measurement of many processes in top-sector
 - eg. observation of charge asymmetry in *tt* production
- * Also allows probing very rare processes, eg.
 - **observation of 4-top production**,
 (New! reference to arXiv will be available tomorrow)
 - observation of *tqγ* production
- Full list of the ATLAS measurements can be found <u>here</u>





Associated productions of top quark involving EW vertices



Direct experimental access to electroweak couplings of top quark



Observation of tqy production arXiv:2302.01283

- * Rare SM process, sensitive to $top-\gamma/W^{\pm}$ interaction
- * CMS reported evidence of $t + \gamma$ with 36 fb^{-1} data $(\sqrt{s} = 13 \text{ TeV})$
- * Focuses on the dominant t-channel production
 - * Events with photon radiated from the decay of top is not considered as signal
- * **2 SRs**, requiring the presence of 1 photon, 1 e/μ , 1 b-jet and 1 or **0** forward jet
- * CRs to control $t\bar{t}\gamma$ and $W\gamma$
- * Neural Network used to distinguish $tq\gamma$ from backgrounds

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 e, μ $u_e,
u_\mu$

Observation of tqy production arXiv:2302.01283

- Simultaneous profile likelihood fit performed using NN output in SRs and CRs
- Observed significance of *tqy* process: 9.3σ (6.8 σ expected):

Parton level

 $\sigma_{tq\gamma}^{fid} = 688 \pm 23(\text{stat})^{+75}_{-71}(\text{syst}) \text{ fb}$ $\sigma_{tq\gamma}^{fid,SM} = 515^{+36}_{-42} \text{ fb} (@ \text{NLO in QCD})$

- * ~30% higher cross-section than SM prediction (compatible within 2.0 σ), consistent with CMS
- Dominant systematic uncertainties:
 - * $t\bar{t}\gamma$, $tq\gamma$, $t\bar{t}$ modelling, limited MC statistics for minor SM backgrounds







- Probes top- γ coupling, sensitive to new physics through anomalous dipole moment of the top-quark also in the context of EFT
- Inclusive and differential cross-section measurement of combined $t\bar{t}\gamma + tW\gamma$ production

- Targets *eµ* channel (clean channel)
- Inclusive and differential cross-section measured in a fiducial phase space at **parton** level
 - * Incl. cross-section measured by profile likelihood fit to S_T distribution
 - * Diff. cross-section measured using iterative **Bayesian unfolding**





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Fiducial cross-section:

* $\sigma_{t\bar{t}\gamma}^{fid} = 39.6 \pm 0.8(stat.)^{+2.6}_{-2.2}(syst)$ fb

* $\sigma_{t\bar{t}\gamma}^{SM,fid} = 38.50^{+0.56}_{-2.18}(scale)^{+1.04}_{-1.18}(PDF)$ fb (@ NLO QCD)



300

arXiv:1809.08562 Theory pred.: **Parton level**









- Probes top-Z coupling
- Any deviation from SM would imply existence of new effects in EWSB mechanism
- Important irreducible background to many BSM searches and SM measurements
- * Measurement targets **31** and **41** final states
 - * **Two 3l regions** split by (b-)jet multiplicity
 - Four 4l regions based on same / different flavour non-Z pair, b-jet multiplicity
- * CRs to control WZ(31) and ZZ(41)
- * Inclusive cross-section extracted by performing simultaneous profile likelihood fit to all SRs, CRs









10.00 A 10.00 A 10.00

200

100

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0.5

Parton-level p_T^Z [GeV]

400

300



- Differential cross-section in 10 observables in **particle** and parton level in a fiducial phase space
- All measurements in agreement with SM
- Dominant uncertainties: $t\bar{t}Z$ parton shower, modelling of tWZ





- likelihood fit to all SRs and CRs
- consistent with CMS



ttW: Differential cross-section ATLAS-CONF-2023-019

- * Absolute and normalised differential cross-section measured in a fid. phase space at particle level
- * Measurements agree good with SM (slight tension in some bins)
- * Dominant uncertainties: modelling of $t\bar{t}H, t\bar{t}W$





tt charge asymmetry

- * $t\bar{t}$ charge asymmetry (CA) arises in $q\bar{q}$ initial state from interference between: born & 1-loop, ISR & FSR
- * CA experimentally accessible via observables:

*
$$A_c^{t\bar{t}} = \frac{N(\Delta |y| > 0) - N(\Delta |y| < 0)}{N(\Delta |y| > 0) + N(\Delta |y| < 0)}$$
 Rapidity
where $\Delta |y| = |y_t| - |y_{\bar{t}}|$

*
$$A_{c}^{ll} = \frac{N(\Delta |\eta_{ll}| > 0) - N(\Delta |\eta_{ll}| < 0)}{N(\Delta |\eta_{ll}| > 0) + N(\Delta |\eta_{ll}| < 0)}$$
 Leptonic a where $\Delta |\eta_{ll}| = |\eta_{l-}| - |\eta_{l+}|$

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asymmetry

asymmetry



Observation of *tt* charge asymmetry arXiv:2208.12095

- * SM $A_c^{t\bar{t}}$ expectation depends on kinematics, e.g. longitudinal boosts ($\beta_{t\bar{t}}^z$) of $t\bar{t}$ system
- BSM scenarios also predict A_c^{tt} dependence on kinematics *
- * $A_c^{t\bar{t}}$ sensitive to SMEFT operators encoding colour/chirality structures $O_{tu}^8 = (\bar{t}\gamma_\mu T^A t)(\bar{u}_i\gamma^\mu T^A u_i)$

- * l+jets & dilepton, resolved and boosted topologies
- * Inclusive and differential measurements of $A_c^{t\bar{t}}$ and A_c^{ll}
- Asymmetries extracted at particle level vs $p_{t\bar{t}}^T$, $\beta_{t\bar{t}}^z$ and $m_{t\bar{t}}$ after unfolding









- * Incl. and diff. A_c^{tt} results used to constrain SMEFT coefficients individually and in pairs
- Results generally consistent with SM expectation
- Complementarity of energy and rapidity asymmetries made explicit 2-D constraints



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- * $t\bar{t}\gamma$ has enhanced contribution from $q\bar{q}$ initial state
- * Dominant effects from diagrams with ISR/FSR photon
 - * Leading to negative asymmetry
- * l+jet channel, neural network discriminator to maximise S/B
- * Kinematic reconstruction to estimate $y_t, y_{\bar{t}}$
- * $A_c^{t,\bar{t}}$ extracted at particle level after unfolding procedure
- * Result:
 - * $A_c = -0.003 \pm 0.029 = -0.003 \pm 0.024(stat) \pm 0.017(syst)$
 - * $A_c^{SM} = -0.014 \pm 0.001(scale)$ (@NLO in QCD)
 - Limited by statistical uncertainty





ttW charge asymmetry arXiv:2301.04245

- * $t\bar{t}W$ production involves $q\bar{q}'$ and qg initial states
- * A_c^l in $t\bar{t}W$ measured in 31 final states
- Simultaneous profile likelihood fit to multiple ** regions
- * A_c^l measured at reconstruction and particle level (PL) consistent with expectation
 - * $A_c(t\bar{t}W)^{PL} = -0.112 \pm 0.170(\text{stat}) \pm 0.054(\text{syst})$
 - * $A_c(t\bar{t}W)_{SM}^{PL} = -0.063^{+0.007}_{-0.004}$ (scale) ± 0.004 (MC stat) (@ NLO QCD + NLO EW)
- Dominant uncertainties: limited statistics in data, modelling of $t\bar{t}W$ and $t\bar{t}Z$







- * Presented highlights of ATLAS measurements of associated top quark production in pp collision at 13 TeV
- * Results consistent with SM expectations
- * All the ATLAS measurements can be found here

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Thank you for your attention!