Top-quark physics highlights from ATLAS

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For the ATLAS Collaboration

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Recent results shown today

Cross section measurements

- **Measurement of single top-quark production in association with a W boson in pp collisions at $\sqrt{s}=13$TeV with the ATLAS detector** - Aad, Georges *et al* - ***Phys.Rev.D*** **110 (2024) 7, 072010**
  CERN-EP-2024-168

- **Measurement of $t\bar{t}$ production in association with additional b-jets in the $e\mu$ final state in proton-proton collisions at $\sqrt{s}=13$TeV with the ATLAS detector** - Aad, Georges *et al* - **arXiv:2407.13473 - CERN-EP-2024-191 (Submitted to JHEP)**

- **Measurements of differential cross-sections in top-quark pair events with a high transverse momentum top quark and limits on beyond the Standard Model contributions to top-quark pair production with the ATLAS detector at $\sqrt{s}=13$TeV** - Aad, Georges *et al* - **JHEP 2206 (2022) 063 - CERN-EP-2022-003**

- **Measurement of differential cross-sections in $t\bar{t}$ and $t\bar{t}$+jets production in the lepton+jets final state in pp collisions at $\sqrt{s}=13$TeV using 140 fb^{-1} of ATLAS data** - Aad, Georges *et al* - ***JHEP*** **2408 (2024) 182** - CERN-EP-2024-163

- **Measurements of inclusive and differential cross-sections of $t\bar{t}\gamma$ production in pp collisions at $\sqrt{s}=13$*TeV* with the ATLAS detector** - Aad, Georges *et al* - ***JHEP*** **10 (2024) 191** - CERN-EP-2024-052

Recent results shown today

Searches for new Physics

- Search for flavour-changing neutral-current couplings between the top quark and the Higgs boson in multi-lepton final states in 13 TeV pp collisions with the ATLAS detector - Aad, Georges *et al* - ***Eur. Phys. J. C*** **84 (2024) 757** - CERN-EP-2024-070
- Search for heavy right-handed Majorana neutrinos in the decay of top quarks produced in proton-proton collisions at $\sqrt{s} = 13$TeV with the ATLAS detector - Aad, Georges *et al* - ***Phys. Rev. D*** **110 (2024) 112004 - CERN-EP-2024-154**
- Search for same-charge top-quark pair production in pp collisions at $\sqrt{s} = 13$TeV with the ATLAS detector - Aad, Georges et al - **arXiv:2409.14982 - CERN-EP-2024-226 (submitted to JHEP)**
- A search for $tW \rightarrow tW$ scattering in the multi-leptonic final state $t\bar{t}Wj$ at $\sqrt{s} = 13$TeV with the ATLAS detector with bounds on Effective Field Theory operators - **ANA-TOPQ-2019-18**

Quantum Effects and Novel Observations

- Observation of quantum entanglement with top quarks at the ATLAS detector - Aad, Georges *et al* - ***Nature*** **633 (2024) 542** - CERN-EP-2023-230

Recent results shown today

Higgs Boson and Top Quark Properties

- **Constraint on the total width of the Higgs boson from Higgs boson and four-top-quark measurements in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector** - Aad, Georges *et al* - arXiv:2407.10631 - CERN-EP-2024-190 **(Submitted to Phys. Lett. B)**

Tests of Universality

- **Test of lepton flavour universality in W-boson decays into electrons and -leptons using pp collisions at $\sqrt{s} = 13$TeV with the ATLAS detector** - Aad, Georges *et al* - CERN-EP-2024-315 **(Submitted to JHEP)**
- **Precise test of lepton flavour universality in W-boson decays into muons and electrons in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector** - Aad, Georges *et al* - ***Eur. Phys. J. C* 84 (2024) 993**- CERN-EP-2024-063

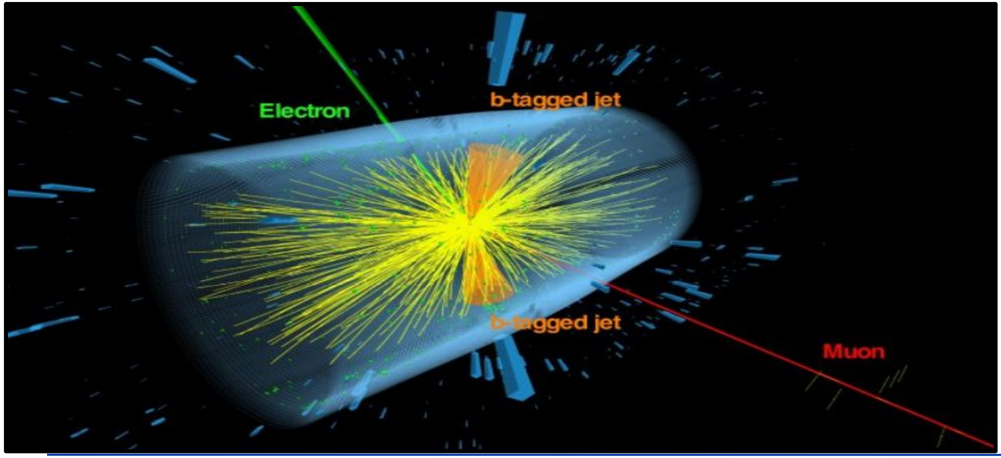
Heavy ion measurement

- **Observation of $t\bar{t}$ production in the lepton+jets and dilepton channels in p+Pb collisions $\sqrt{s_{NN}} = 8.16$ TeV with the ATLAS detector** - Aad, Georges *et al* - ***JHEP* 2411 (2024) 101** - CERN-EP-2024-097

Top quark physics: State of art

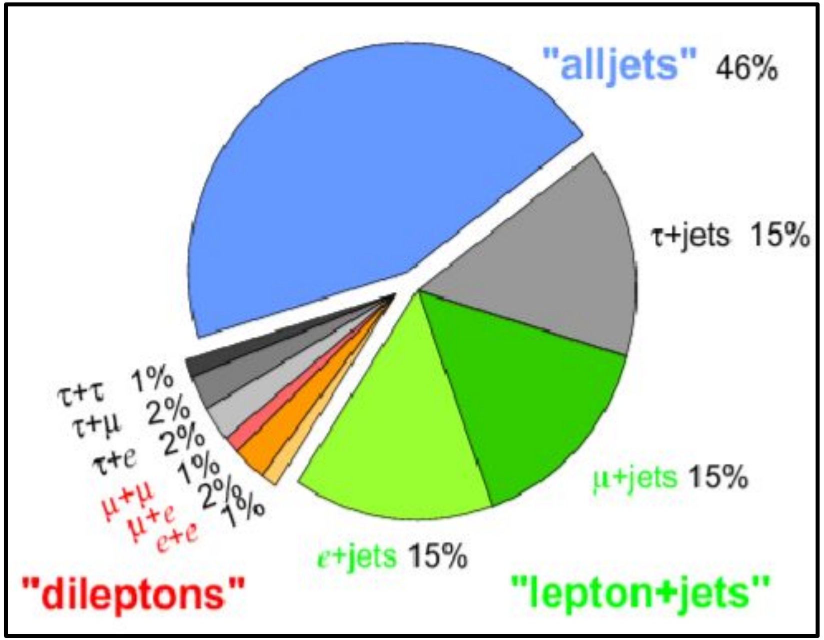
- Is the most massive of all known elementary particles, with a mass of approximately 173 GeV/c^2 and carries an electric charge of $+\frac{2}{3}e$.

- Its discovery in 1995 by the CDF and DØ collaborations at Fermilab completed the quark sector of the SM.



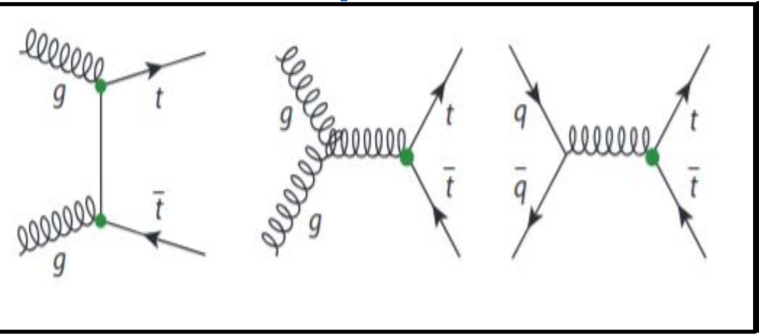
- Decay Characteristics: It decays predominantly into a W boson and a bottom quark (b), with a mean lifetime of about 5×10^{-25} seconds, decaying before it can hadronize.

Branching ratio of top decay

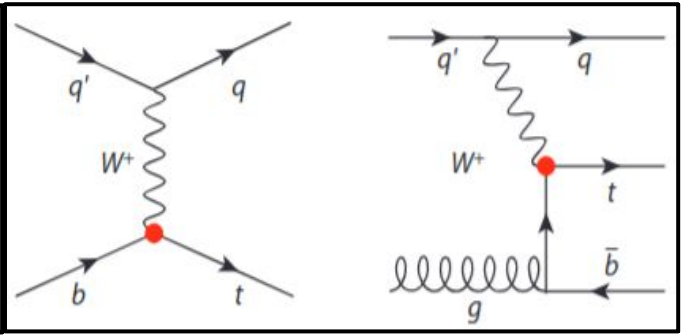


Top quark physics: State of art

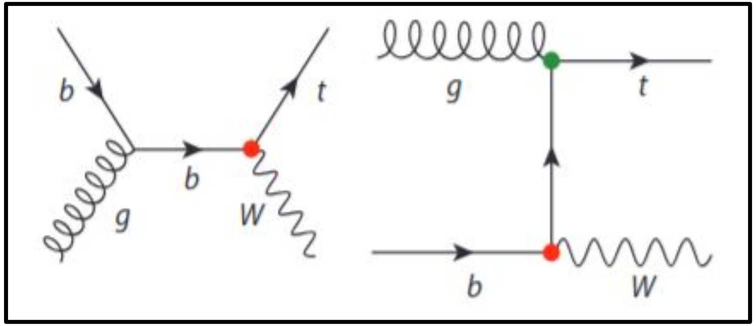
Pair production



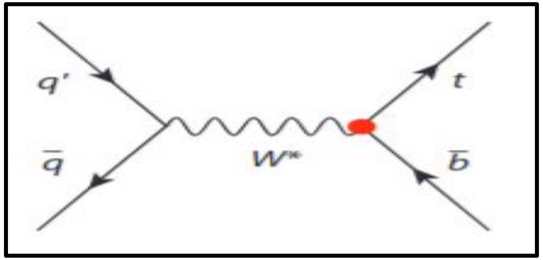
t-channel



W-associated production



s-channel



- Given the actual center-of-mass energy of the LHC, gluons dominate the PDFs of the colliding protons;
- tt production is the dominant top quark production;
- The inclusive tt cross section allows to test QCD predictions and constraining parameters;
- The final state topology is given in term of W-boson decay mode;

$W \rightarrow l\nu$ (~ 30%) / qq' (~ 70%)

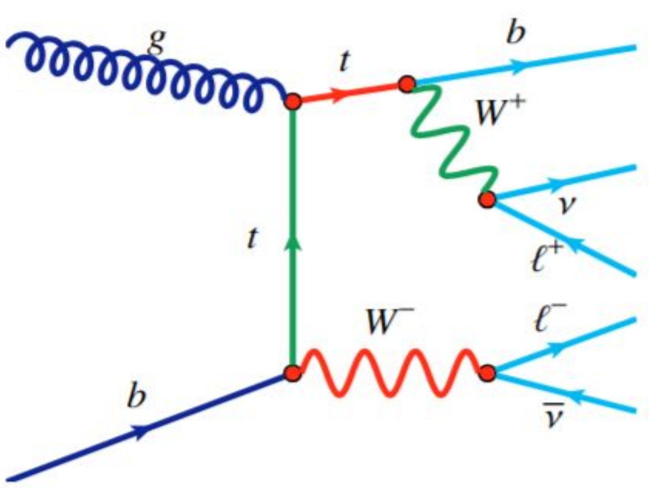
Measurement of single top-quark production in association with a W boson in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

Cross section measurements

Phys.Rev.D 110 (2024) 7, 072010

- ***Data Sample***: **140 fb^{-1}** @ √s = 13 TeV (2015-2018);
- ***Event Selection***: Focused on events with two charged oppositely leptons with lower pT threshold of
- **Electron: 24 GeV (26 GeV);**
- **Muons: 20 GeV (26 GeV) ;**
- at least one jet identified as originating from a b-quark;
- ***Analysis Technique***: Multivariate discriminant to distinguish the **tW** signal from the dominant tt̄ background;
- **Final states:** events with exactly one selected jet that is also b-tagged (denoted **1j1b**), events with exactly two selected jets one of which is b-tagged (**2j1b**), and events with exactly two jets where each are b-tagged (**2j2b**);
- MC simulation for signal and background;

tt̄ and tW modelling: PowHegBoxv2@NLO



	1j1b	2j1b	2j2b
Pre-fit tW	13 000 ± 1400	11 900 ± 1200	2000 ± 400
Pre-fit $t\bar{t}$	28 000 ± 4000	112 000 ± 8000	43 000 ± 4000
Pre-fit Z+jets	1130 ± 160	750 ± 100	38 ± 12
Pre-fit diboson	380 ± 80	570 ± 130	8.5 ± 1.3
Pre-fit non-prompt	140 ± 70	450 ± 220	54 ± 27
Pre-fit total prediction	43 000 ± 5000	126 000 ± 8000	45 000 ± 4000
Post-fit tW	12 500 ± 2000	11 400 ± 2200	2000 ± 400
Post-fit $t\bar{t}$	27 400 ± 2000	110 300 ± 2200	42 100 ± 500
Post-fit Z+jets	1100 ± 120	750 ± 80	38 ± 6
Post-fit diboson	380 ± 80	570 ± 120	8.6 ± 1.1
Post-fit non-prompt	140 ± 70	450 ± 220	53 ± 27
Post-fit total prediction	41 600 ± 210	123 500 ± 400	44 150 ± 210
Data	41 591	123 531	44 149

BDTs : separate the signal from the dominant tt background.

Region	Learning rate	Number of leaves	Minimum data in a leaf	Maximum depth
1j1b	0.2	20	50	4
2j1b	0.1	20	120	7
2j2b	0.2	20	50	4

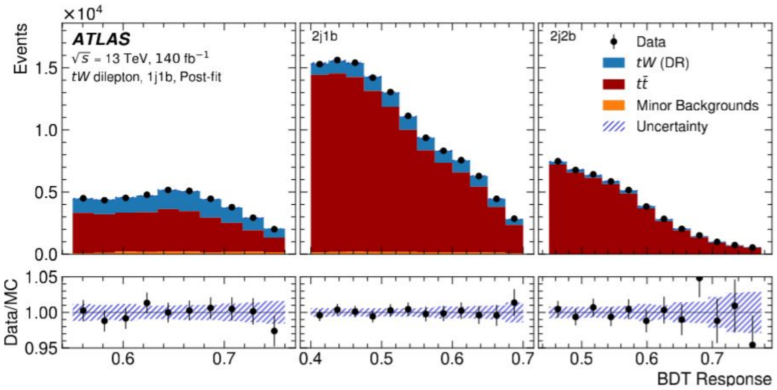
Results:

Inclusive cross-section for tW production

$\mu_{tW} = 0.95^{+0.19}_{-0.18}$ $\mu_{t\bar{t}} = 0.99^{+0.07}_{-0.06}$

$$\sigma_{tW} = 75^{+15}_{-14}\ \text{pb} = 75 \pm 1\ (\text{stat.})^{+15}_{-14}\ (\text{syst.}) \pm 1\ (\text{lumi.})\ \text{pb}$$

BDT Response



- **Wtb Vertex Constraint:** left-handed form factor at the Wtb vertex times CKM matrix element **$|f_{LV}V_{tb}| = 0.97 \pm 0.10$;**
- This **precise measurement enhances our understanding of electroweak interactions** involving the top quark and provides stringent tests of the SM.

Measurement of $t\bar{t}$ production in association with additional b-jets in the $e\mu$ final state in proton–proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

Cross section measurements

arXiv:2407.13473

- ***Data Sample***: Utilized 140 fb^{-1}@ $\sqrt{s}$ = 13 (2015-2018);

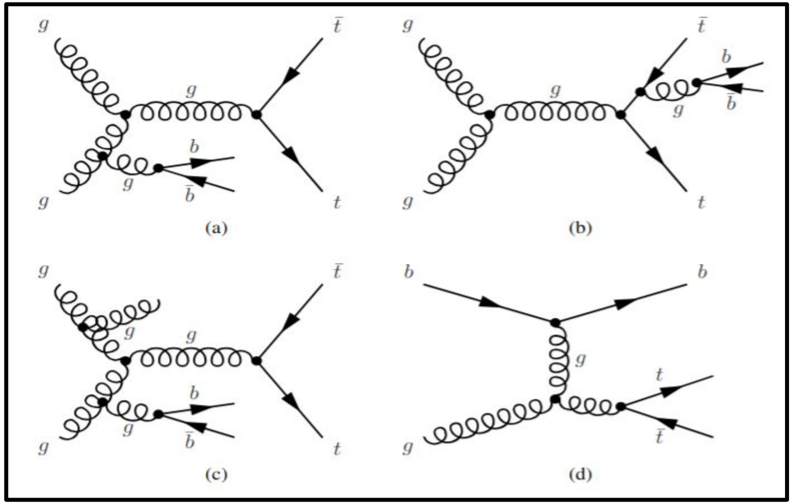
- ***Event Selection***:
  - For electrons: pT = **26, 60** and **140 GeV**;
  - For muons the thresholds were $\boldsymbol{p}$**T = 26** and **50 GeV**
  - Isolation requirements.

- **Final states:** $t\bar{t}$+b-jets: fiducial cross-sections;

- **tt event production**: PowhegBox v2 heavy-quark (hvq) at NLO with NNPDF3.0NLO;

- **Backgrounds:** $t\bar{t}Z$, $t\bar{t}W$,$t\bar{t}H$ (prompt leptons), tWZ, tWH, $tHb\ j$, tZ and $t\bar{t}t\bar{t}$ (rare SM processes). To assess the interference between tW and $t\bar{t}$ production, the diagram removal scheme is applied;

W bosons decay leptonically



tt+b-jets final state

- two oppositely charged leptons ($e^{\pm}\ \mu^{\mp}$);

- At least 3 or 4 b-jets;

Extraction of fiducial cross sections

- Data-driven correction factors for flavour composition of additional jets in $t\bar{t}$ events: mis-tagged jets in $t\bar{t}c$ and $t\bar{t}l$ events contribute as significant background to the $t\bar{t}+b$-jets process.

Process	$\geq 2j, 2b$@77%	$\geq 3j, 3b$@77%	$\geq 4j, \geq 4b$@77%
$t\bar{t}+b$-jets	4100 ± 790	3550 ± 650	474 ± 99
$t\bar{t}c$	11600 ± 2200	2190 ± 430	57 ± 15
$t\bar{t}l$	263000 ± 33000	2080 ± 440	25 ± 15
Wt	9100 ± 1800	227 ± 94	14 ± 11
$t\bar{t}V$	740 ± 230	94 ± 30	16.3 ± 5.1
$t\bar{t}H$	180 ± 22	108 ± 13	37.2 ± 5.3
Non-prompt lepton	340 ± 210	37 ± 20	10.9 ± 6.1
Z/γ^*+jets	96 ± 38	3.4 ± 1.4	0.15 ± 0.09
Diboson	85 ± 43	3.0 ± 1.5	0.11 ± 0.07
Others	41 ± 20	16.4 ± 8.2	6.4 ± 2.9
Total predicted	290000 ± 35000	8300 ± 1300	640 ± 120
Observed	281213	10235	798

	Inclusive region *Global* approach	Regions in terms of jet multiplicity and third-highest-p_T jet-p_T *Kinematic-dependent* approach					
	(nominal)	(systematic)					
Category	$\geq 3j \geq 2b$@77%	$3j \geq 2b$@77%			$\geq 4j \geq 2b$@77%		
	≥ 25 GeV	25–35 GeV	35–50 GeV	≥ 50 GeV	25–50 GeV	50–75 GeV	≥ 75 GeV
$t\bar{t}b$	≥3 b-jets	≥3 b-jets			–		
$t\bar{t}b_{ex}$	–	–			exactly 3 b-jets		
$t\bar{t}b\bar{b}$	–	–			≥4 b-jets		
$t\bar{t}c$	< 3 b-jets and ≥ 1 c-jet	< 3 b-jets and ≥ 1 c-jet			< 3 b-jets and ≥ 1 c-jet		
$t\bar{t}l$	events that do not meet above criteria	events that do not meet above criteria			events that do not meet above criteria		

Best-fit values of the $t\bar{t}b$, $t\bar{t}b_{ex}$, $t\bar{t}b\bar{b}$, $t\bar{t}c$

Regions	Fitted values of scale factors α_b^s	α_{bex}^s	α_{bb}^s	α_c^s	α_l^s	Type
$\geq 3j \geq 2b$; ≥ 25 GeV	1.20 ± 0.03	–	–	1.62 ± 0.09	0.92 ± 0.04	*Global*
$3j \geq 2b$; (25–35) GeV	1.40 ± 0.15	–	–	1.99 ± 0.42	0.98 ± 0.08	*Kinematic-dependent*
$3j \geq 2b$; (35–50) GeV	1.30 ± 0.11	–	–	1.74 ± 0.27	0.77 ± 0.11	
$3j \geq 2b$; ≥ 50 GeV	1.26 ± 0.12	–	–	1.05 ± 0.27	1.09 ± 0.15	
$\geq 4j \geq 2b$; (25–50) GeV	–	1.31 ± 0.10	1.15 ± 0.14	1.93 ± 0.11	0.92 ± 0.01	
$\geq 4j \geq 2b$; (50–75) GeV	–	1.10 ± 0.09	1.20 ± 0.10	1.64 ± 0.09	0.86 ± 0.01	
$\geq 4j \geq 2b$; ≥ 75 GeV	–	1.10 ± 0.10	1.09 ± 0.10	1.25 ± 0.10	0.83 ± 0.02	

Fiducial phase space	Fiducial cross-sections [fb] $\geq 3b$	$\geq 3b \geq 1l/c$	$\geq 4b$	$\geq 4b \geq 1l/c$
Measured	143 ±1 (stat) ±12 (syst)	87 ±1 (stat) ±8 (syst)	22 ±1 (stat) ±3 (syst)	14 ±1 (stat) ±2 (syst)
Powheg+Pythia 8 $t\bar{t}b\bar{b}$ (4FS)	132	78	23	14
Powheg+Pythia 8 $t\bar{t}b\bar{b}$ h_{bzd} (4FS)	129	74	21	13
Powheg+Pythia 8 $t\bar{t}b\bar{b}$ dipole (4FS)	128	71	22	13
Powheg+Pythia 8 $t\bar{t}b\bar{b}$ p_T^{hard} (4FS)	129	68	21	12
Powheg+Herwig 7 $t\bar{t}b\bar{b}$ (4FS)	130	77	22	14
Sherpa $t\bar{t}b\bar{b}$ (4FS)	135	90	21	15
Helac-NLO (off-shell) $e\mu+4b$	–	–	20	–
Powheg+Pythia 8 $t\bar{t}$ (5FS)	120	74	18	11
Powheg+Herwig 7 $t\bar{t}$ (5FS)	128	75	18	11
MG5_aMC@NLO+Pythia8 $t\bar{t}$ (5FS)	122	72	18	11
MadGraph5_aMC@NLO+Herwig 7 $t\bar{t}$ (5FS)	110	66	13	8
Sherpa 2.2.12 $t\bar{t}$ (5FS)	124	73	16	10

Measurements of differential cross-sections in top-quark pair events with a high transverse momentum top quark and limits on beyond the Standard Model contributions to top-quark pair production with the ATLAS detector at $\sqrt{s}$ = 13 TeV

Cross section measurements

JHEP 2206 (2022) 063 - CERN-EP-2022-003

- ***Data Sample***: **139 fb^{-1}** @ $\sqrt{s}$ = 13 TeV;
- ***Event Selection***:

- **PV with at least two** associated tracks with pT>0.5 GeV;
- **Electrons**: ET > 27GeV and pass the 'Tight' likelihood-based requirement with |η|<2.47 outside (1.37<|η|< 1.52).
- **Muons:** pT > 27 GeV and |η|<2.5,'Medium' identification requirements and 'Tight' isolation requirements;

- **Final states:** one selected lepton, at least one top-tagged jet and at least two b-tagged jets;

- **$t\bar{t}$ event production**: top-quark pair production where the hadronically decaying top quark has transverse momentum greater than 355 GeV and the other top quark decays into *lvb*;

- ***Background estimate***

- **Most dangerous:** tW single top quark production and W+jets production

- **Least important:** **($t\bar{t}V$,$t\bar{t}H$, Z+jets, diboson production);**

- Cross-section is measured differentially as a function of variables characterising the $t\bar{t}$ system and additional radiation in the events. Comparison with MC, also at parton-level calculation at NNLO;

- Fiducial requirements:
Electrons, muons and neutrinos not originating, either directly or through a τ -lepton decay-> prompt;
Particle-level: small-R jets with |η|<4.5 with pT > 26 GeV *and* |η|<2.5, large-R jets pT > 355 GeV and |η|<2.0 in high pT order;

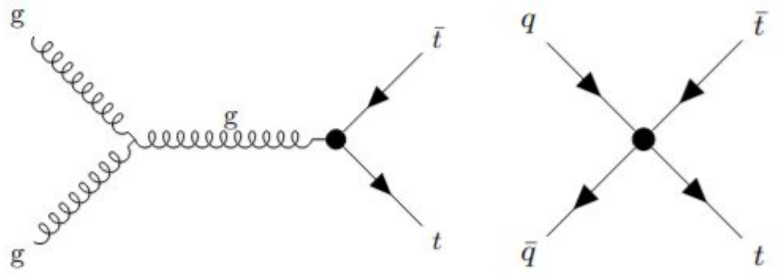
- Observables:
m($t\bar{t}$),y($t\bar{t}$),m(t),y(t), $\Delta\phi(b_l,t_h)$

- **Fiducial cross section**
σ = 1.267 ± 0.005 ± 0.053 pb

Limits on EFT operators

Differential cross section - Second degree - 2 Wilson Coeff.

$$\sigma^j(C_{tG},C_{tq}^{(8)}) = p_0^j + p_1^j \cdot C_{tG} + p_2^j \cdot C_{tq}^{(8)} + p_3^j \cdot (C_{tG})^2 + p_4^j \cdot (C_{tq}^{(8)})^2 + p_5^j \cdot C_{tG} \cdot C_{tq}^{(8)}$$



Model	$C_i\ (\Lambda/\text{TeV})^2$	Marginalised 95% intervals		Individual 95% intervals		Global fit 95% limits [111]
		Expected	Observed	Expected	Observed	
Λ^{-4}	C_{tG}	[−0.44, 0.35]	[−0.53, 0.21]	[−0.44, 0.28]	[−0.52, 0.15]	[0.006, 0.107]
	$C_{tq}^{(8)}$	[−0.57, 0.17]	[−0.60, 0.13]	[−0.57, 0.18]	[−0.64, 0.12]	[−0.48, 0.39]
Λ^{-2}	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]

Measurement of differential cross-sections in $t\bar{t}$ and $t\bar{t}$+jets production in the lepton+jets final state in pp collisions at $\sqrt{s}$ = 13 TeV using 140 fb^{-1} of ATLAS data

- *Data Sample*: 140 fb^{-1} @ √s = 13 TeV;
- *Event Selection*:
  - PV(>=two associated tracks with pT>0.5 GeV, $|z_0 \sin\theta|$ < 0.5 mm and $|d_0|/\sigma(d_0)$ < 5);
  - Electrons: pT>27GeV with |η|<2.47 outside (1.37<|η|< 1.52);
  - Muons: pT > 27 GeV and |η|<2.5;
- Final states: e+jets, μ + jets.
- *Background estimate:*
  - Single top in t- and s- channel with a W boson(POWHEG-BOX v2 @ NNPDF3.0NLO PDF - Pythia 8.230 - A14 tune)
  - W +jets and Z+jets @ NNLO
  - Diboson production: (WW,ZZ,WZ) - (had + lep) decay;
- Unfolding method: RooUnfold - Repeated applications of the Bayes' theorem are used to invert the unfolding matrix;

Cross section measurements

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Observables

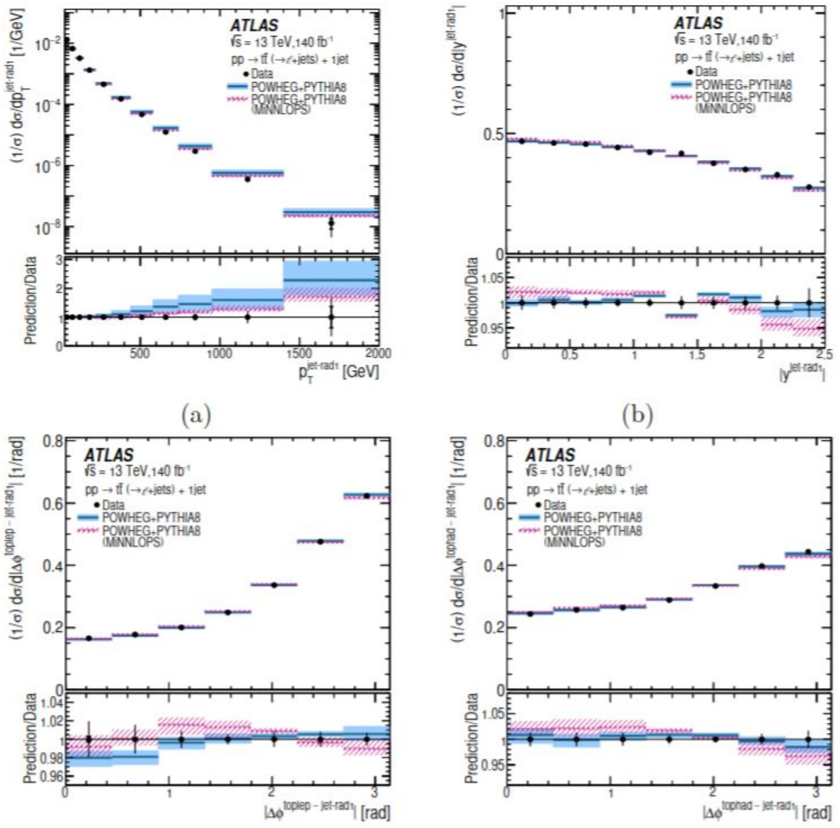
$t\bar{t}$:pT(jet-W1), pT(jet-W2), jet-rad1(highest pT jet outside the ttbar system);

$t\bar{t}$+1jet:pT(jet-rad1),Δϕ(jet-W1-jet-rad1), m($t\bar{t}$-jet-rad1);

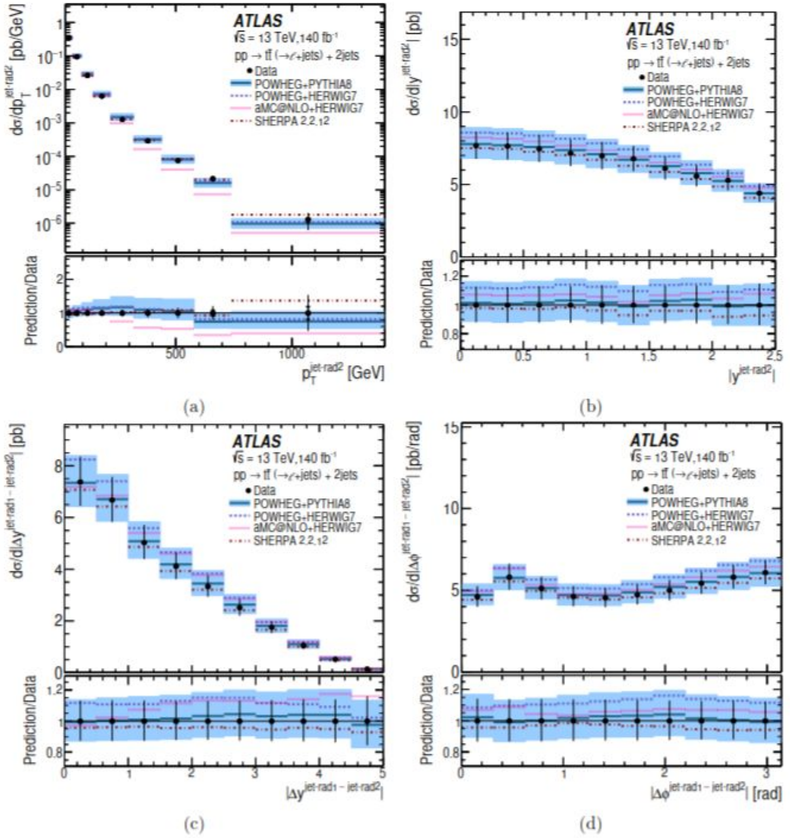
$t\bar{t}$+2jets: Δϕ(jet-W1-jet-rad2)

Process	Yield for channel: $t\bar{t}$ inclusive	$t\bar{t}$+1jet	$t\bar{t}$+2jets
$t\bar{t}$	4 120 000 ± 690 000	2 110 000 ± 420 000	860 000 ± 240 000
single-top quark	194 000 ± 33 000	82 000 ± 19 000	28 900 ± 8 300
W+jets	103 000 ± 53 000	44 000 ± 23 000	17 200 ± 8 900
fakes	66 000 ± 33 000	30 000 ± 15 000	12 000 ± 6 000
Z+jets	37 000 ± 19 000	14 600 ± 7 600	5 400 ± 2 800
$t\bar{t}V$	13 100 ± 1 100	10 300 ± 900	6 470 ± 660
diboson	6 000 ± 600	2 820 ± 350	1 220 ± 180
$t\bar{t}H$	5 460 ± 320	4 710 ± 310	3 260 ± 270
Total SM prediction	4 540 000 ± 710 000	2 300 000 ± 440 000	940 000 ± 240 000
Data	4 445 113	2 248 410	924 751

$t\bar{t}$+1jet

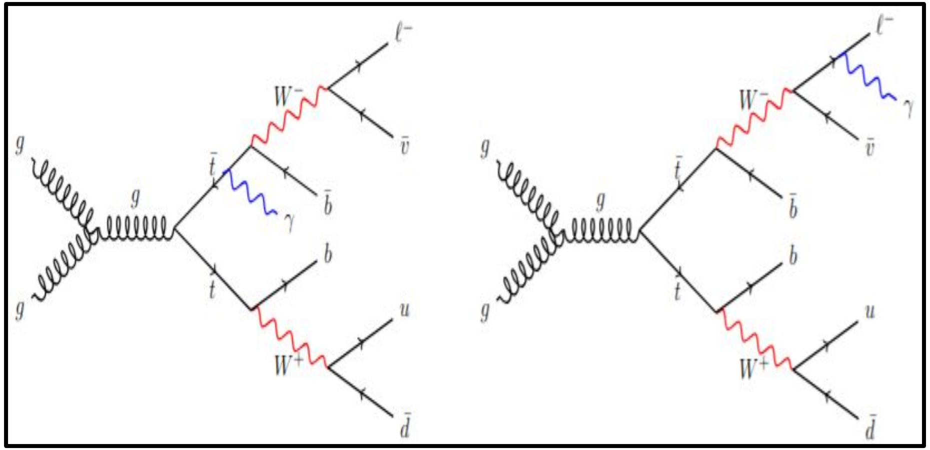


$t\bar{t}$+2jet



Measurements of inclusive and differential cross-sections of $t\bar{t}\gamma$ production in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

JHEP 10 (2024) 191 - CERN-EP-2024-052



- Measurements of the associated production of a top quark pair and a photon ($t\bar{t}\gamma$) in proton-proton collisions at a center-of-mass energy of 13 TeV with 140 fb^{-1};

Cross section measurements

- The inclusive fiducial cross-section for the $t\bar{t}\gamma$ production process;
- Differential cross-sections are measured for various kinematic variables in both single-lepton and dilepton decay channels.
- The measurements are interpreted in the context of the Standard Model Effective Field Theory (SMEFT), setting limits on parameters related to the electroweak dipole moments of the top quark.
- The measured cross-sections and differential distributions are compared with predictions from NLO simulations using MadGraph5_aMC@NLO interfaced with Pythia 8 and Herwig 7.

Single-Lepton Channel Selection

- Exactly **one photon**, **exactly one isolated lepton** (electron or muon) with **pT > 25 GeV** and at least four jets, with at least one jet identified as a b-jet (b-tagged);
- Jets with **pT > 25 GeV** with **anti-kt** algorithm (ΔR = 0.4); One b-jet with **W.P. 70%**;
- Events are rejected if there are additional lepton candidates with **pT > 7 GeV**;
- Invariant mass of the lepton and photon must be outside a **±5 GeV** window around Z mass;
- **Photon:** E_T > 20 GeV, pseudorapidity range $|\eta|$ < 2.37, excluding the transition region between the barrel and endcap calorimeters (1.37 < $|\eta|$ < 1.52);
- **Method:** multi-class NN is used to separate the $\bar{t}t\gamma$ production signal from the background;

Category	Single-lepton channel	Dilepton channel
$t\bar{t}\gamma$ production	12450 ± 740	2400 ± 99
$t\bar{t}\gamma$ decay	13400 ± 3100	3100 ± 640
h-fake	3600 ± 1200	220 ± 82
e-fake	6900 ± 980	57.9 ± 7.0
$W\gamma$	2700 ± 1400	–
$tW\gamma$	1180 ± 580	290 ± 150
Other prompt γ	2500 ± 600	820 ± 170
Lepton fake	640 ± 110	–
Total	43900 ± 4600	6900 ± 710
Data	47767	7379

Fiducial $t\bar{t}\gamma$ cross-section

$$\sigma^{\text{Single lepton}}_{t\bar{t}\gamma\text{ production}} = 288^{+21}_{-19}\text{ fb} = 288 \pm 5(\text{stat})^{+20}_{-19}(\text{syst})\text{ fb.}$$

Fiducial $t\bar{t}\gamma$ cross-section- All decay modes

$$\sigma^{\text{Single lepton}}_{t\bar{t}\gamma} = 704^{+49}_{-46}\text{ fb} = 704 \pm 5\ (\text{stat})\ ^{+49}_{-46}\ (\text{syst})\text{ fb}$$

Dilepton Channel Selection

- Exactly **one photon**, exactly **two isolated oppositely charged leptons** (electron or muon) with **pT > 25 GeV**, with at least **two jets** identified as a b-jet (b-tagged);
- Jets with **pT > 25 GeV** with anti-kt algorithm ($\Delta R = 0.4$); One b-jet with **W.P. 70%**;
- Invariant mass of the lepton pair smaller than 15 GeV are rejected to suppress contributions from low-mass Drell-Yan processes;
- **MET > 30 GeV**;
- **Photon:** E_T **> 20 GeV**, pseudorapidity range $|\eta|$ **< 2.37**, excluding the transition region between the barrel and endcap calorimeters **(1.37 < $|\eta|$ < 1.52)**;
- **Method**: multi-class NN is used to separate the $t\bar{t}\gamma$ production signal from all backgrounds;

Fiducial $t\bar{t}\gamma$ cross-section

$$\sigma^{\text{Dilepton}}_{t\bar{t}\gamma\text{ production}} = 45.7^{+3.3}_{-3.1}\text{ fb} = 45.7^{+1.4}_{-1.3}(\text{stat})^{+3.0}_{-2.8}(\text{syst})\text{ fb}$$

Combined results - Single Lepton

$$\sigma_{t\bar{t}\gamma\text{ production}} = 319 \pm 15\text{ fb} = 319 \pm 4\,(\text{stat})\,^{+15}_{-14}(\text{syst})\text{ fb}$$

Fiducial $t\bar{t}\gamma$ cross-section - All decay modes

$$\sigma^{\text{Dilepton}}_{t\bar{t}\gamma} = 116.1^{+8.2}_{-7.7}\text{ fb} = 116.1 \pm 1.7\,(\text{stat})\,^{+8.0}_{-7.6}\,(\text{syst})\text{ fb}$$

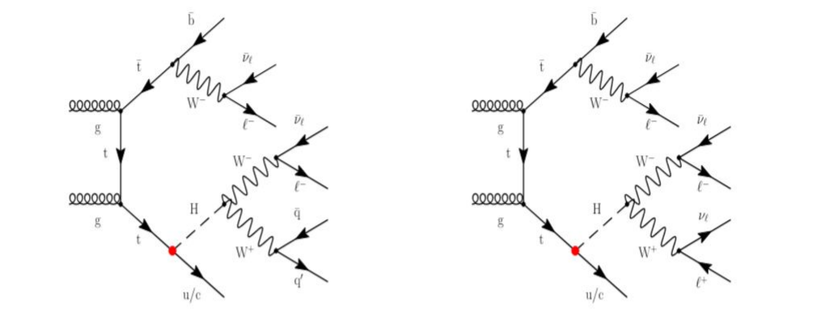
Combined results - Dilepton

$$\sigma_{t\bar{t}\gamma} = 788^{+38}_{-37}\text{ fb} = 788 \pm 5\,(\text{stat})\,^{+38}_{-37}\,(\text{syst})\text{ fb}$$

Search for flavour-changing neutral-current couplings between the top quark and the Higgs boson in multi-lepton final states in 13 TeV pp collisions with the ATLAS detector

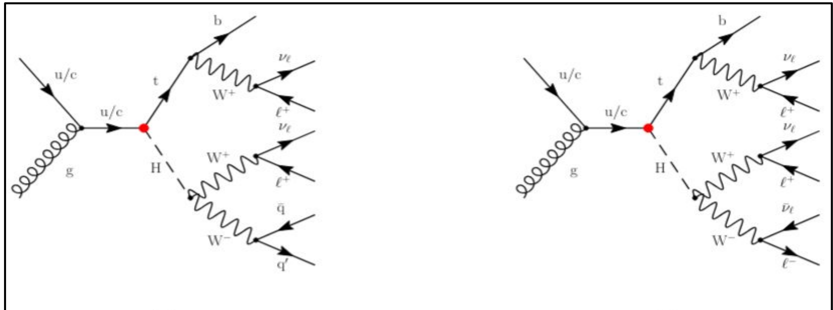
Searches for new Physics

2ℓSS $t\bar{t}(t \to Hq)$ **3ℓ**



(a) (b)

$$gq \to Ht$$



(a) (b)

- Following the discovery of the Higgs boson at the LHC in 2012, various properties of the Higgs have been studied, including potential flavor-changing neutral currents (**FCNC**) involving top quarks;
- This analysis aims to investigate the **FCNC processes in Higgs production**, specifically targeting the **tHq** interactions,Data sample: (2015-2018) with an integrated luminosity of **140.1 fb^{-1}**;
- Event Selection: at least one vertex with two tracks with pT > 0.5 GeV;
- At least one lepton with **pT>28 GeV**;

- **Electrons: pT>10 GeV and |η|<2.47(*);**
- **Muons: pT>10 GeV and |η|<2.5;**
- **Jets: pT>20 GeV and |η|<2.5**

Signal region

SR2lDec: $N_{jets} \geq 4$ (exactly 1 ***b-tag***)

SR2lProd: $N_{jets} \leq 3$ (exactly 1 ***b-tag***)

	SR2ℓDec	SR2ℓProd	SR3ℓDec	SR3ℓProd
N_{jets}	≥ 4	≤ 3	≥ 3	≤ 2
$N_{b\text{-tags}}$	$= 1$	$= 1$	$= 1$	$= 1$
$p_T(\ell_1)$	≥ 12 GeV	≥ 16 GeV	≥ 20 GeV	≥ 20 GeV
$p_T(\ell_2)$	–	–	≥ 16 GeV	≥ 16 GeV
$\lvert m(e,e) - m_Z \rvert$	≥ 10 GeV	≥ 10 GeV	–	–

Background region

	CR2ℓHFe	CR2ℓHFμ	CR3ℓHFe	CR3ℓHFμ
N_{jets}	≤ 3	≤ 3	≥ 1	≥ 1
$N_{b\text{-tags}}$	≥ 1	≥ 1	$= 1$	$= 1$
ℓ_0 flavour	μ	μ	–	–
ℓ_1 flavour	e	μ	–	–
$p_T(\ell_1)$	< 16 GeV	< 16 GeV	≥ 20 GeV	≥ 20 GeV
ℓ_2 flavour	–	–	e	μ
$p_T(\ell_2)$	–	–	< 16 GeV	< 16 GeV

- No significant evidence for FCNC couplings was observed, indicating results are compatible with the SM;

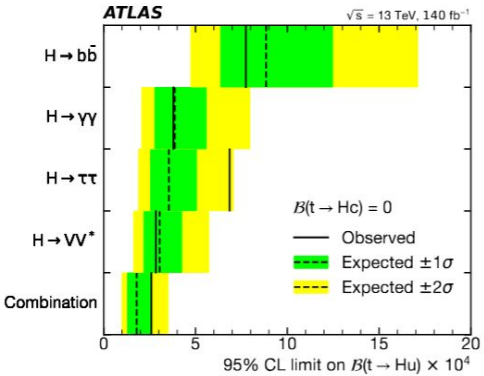
Upper limits at 95% Confidence Level (CL) were established on the branching ratios

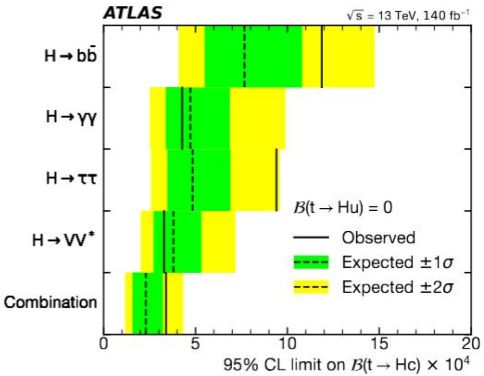
- **B(t → Hu) < 2.8 × 10⁻⁴** (observed), **3.0 × 10⁻⁴** (expected)
- **B(t → Hc) < 3.3 × 10⁻⁴** (observed), **3.8 × 10⁻⁴** (expected)

Limits on the absolute value of the dimension-6 Wilson coefficients

- |Cuϕ| < 0.78 (observed), 0.64 (expected)

Results combined with other ATLAS searches: $H \rightarrow \tau\tau, bb, \gamma\gamma$;



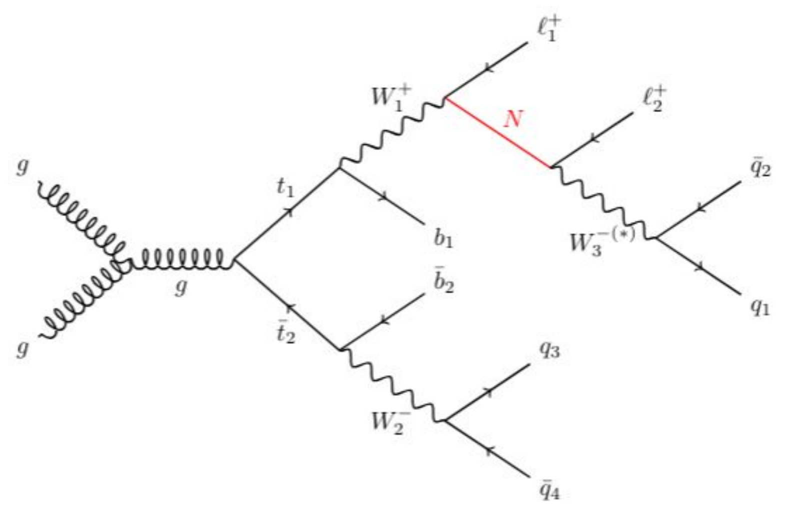


Search for heavy right-handed Majorana neutrinos in the decay of top quarks produced in proton–proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

Searches for new Physics

- Search for heavy neutral leptons(**HNL**) in the mass window **15-75 GeV** for **140 fb^{-1}** in $t\bar{t}$ production;
- HNL is identified through its decay into another lepton and a W boson, resulting in a final state with two same-charge, same-flavor leptons;
- Multivariate approach to distinguish between signal and background events, focusing on final states with two same-charge leptons;
- Type-I seesaw model, translating cross-section limits into upper limits on the mixing parameters of the HNL with Standard Model neutrinos;

HNL signal

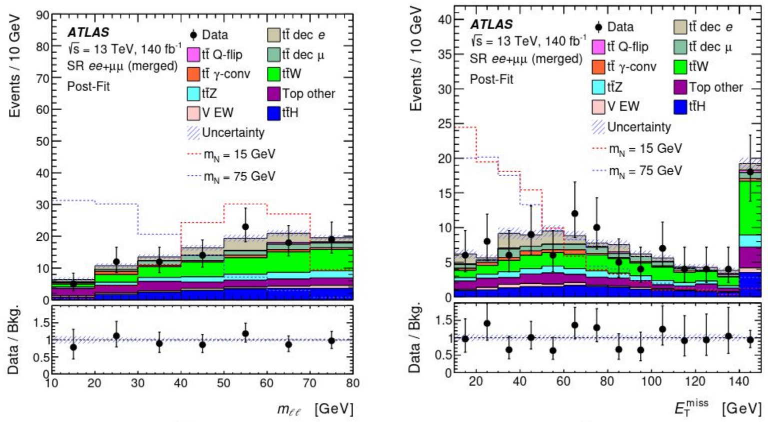


Event selection: two light leptons (electrons or muons) of the same charge and flavor;
Trigger Criteria: The leading lepton must have a transverse momentum (pT) greater than 27 GeV;
Jet Requirements: At least two b-tagged jets and at least four non-b-tagged jets are required;
Invariant Mass: invariant mass of the lepton pair must higher than 12 GeV (background from Drell-Yan);

Signal and Control Regions

- **Signal Regions (SR)**: Defined for both ee and μμ channels, with tighter isolation criteria and invariant mass requirements to minimize background contamination.
- **Control Regions (CR)**: Established to study specific background processes, ensuring less than 1% signal contamination.
- **Multivariate Analysis**: BDTs is performed to enhance the separation between signal and background events. Key input variables include the **invariant mass** of the lepton pair and missing **transverse momentum.**

m_N [GeV]	15	25	35	40	45	50	55	60	70	75
Exp. $\sigma_{e,N}$ [fb]	21	9.8	7.3	6.9	6.9	6.7	7.2	8.5	18	36
Obs. $\sigma_{e,N}$ [fb]	26	12	8.2	7.8	10	9.7	10	12	26	52
Exp. $\sigma_{\mu,N}$ [fb]	9.3	5.0	3.7	3.5	3.2	3.1	3.2	4.0	8.2	15
Obs. $\sigma_{\mu,N}$ [fb]	7.5	3.9	2.8	2.6	3.2	3.1	3.3	4.2	8.3	15
Exp. $\sigma_{\tau,N}$ [pb]	8.9	2.6	2.1	1.7	1.8	1.8	2.0	3.7	7.0	19
Obs. $\sigma_{\tau,N}$ [pb]	13	3.6	2.7	2.3	2.5	2.2	3.2	5.5	7.3	20



(a) (b)

No Significant Excess: of events above the expected background. The presence of HNLs in the studied mass range is not supported by the data.

Upper limits obtained in this analysis are about one order of magnitude weaker than those from previous ATLAS searches for HNLs in W boson decays.

This study extends the search region for the first two generations of leptons beyond 50 GeV, probing HNL masses up to 75 GeV.

Search for same-charge top-quark pair production in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

Searches for new Physics

- Data: The analysis utilized 140 fb^{-1} of proton-proton collision data at a center-of-mass energy of 13 TeV;

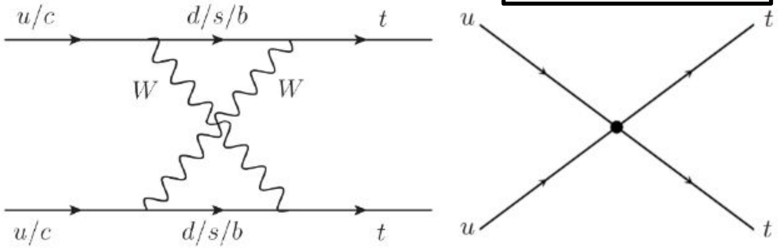
- Study focused on events compatible with the production of two top quarks with the same electric charge, specifically -dilepton final state characterized by two same-sign leptons, two b-hadrons, and missing transverse momentum.

- Signal and Background Modeling: The signal samples were simulated using effective field theory (EFT) with three Wilson coefficients associated with operators O(1)□u and O(1)□u, and O(8)□u.

\- The dominant background processes included **t̄tW, t̄tZ, and t̄tH**, with normalization constrained through likelihood fits to data.

SM

Pointlike (EFT) four-fermion interaction



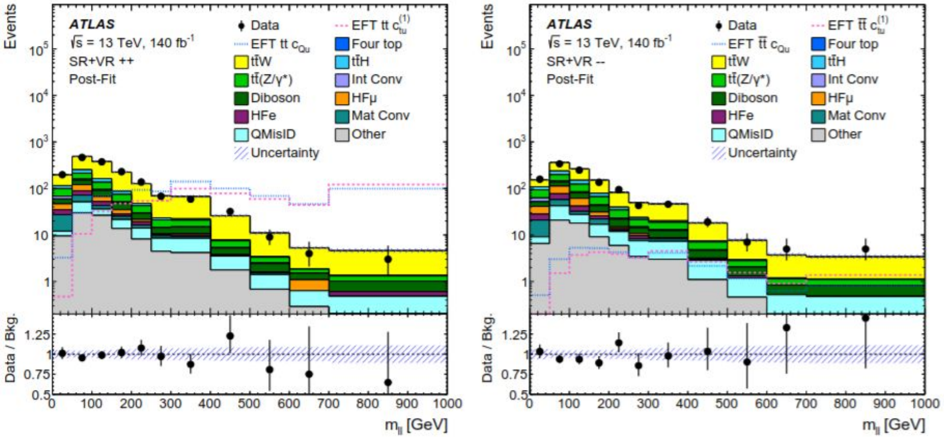
(a) (b)

$$\mathcal{L}_{\mathrm{D=6}}^{qq\to tt} = \frac{1}{\Lambda^2}\left(c_{tu}^{(1)}O_{tu}^{(1)} + c_{Qu}^{(1)}O_{Qu}^{(1)} + c_{Qu}^{(8)}O_{Qu}^{(8)}\right) + h.c.$$

$$O_{tu}^{(1)} = [\bar{t}_{\mathrm{R}}\gamma^{\mu}u_{\mathrm{R}}][\bar{t}_{\mathrm{R}}\gamma_{\mu}u_{\mathrm{R}}],$$
$$O_{Qq}^{(1)} = [\overline{Q}_{\mathrm{L}}\gamma^{\mu}q_{\mathrm{L}}][\overline{Q}_{\mathrm{L}}\gamma_{\mu}q_{\mathrm{L}}],$$
$$O_{Qq}^{(3)} = [\overline{Q}_{\mathrm{L}}\gamma^{\mu}\sigma^{a}q_{\mathrm{L}}][\overline{Q}_{\mathrm{L}}\gamma_{\mu}\sigma^{a}q_{\mathrm{L}}],$$
$$O_{Qu}^{(1)} = [\overline{Q}_{\mathrm{L}}\gamma^{\mu}q_{\mathrm{L}}][\bar{t}_{\mathrm{R}}\gamma_{\mu}u_{\mathrm{R}}],$$
$$O_{Qu}^{(8)} = [\overline{Q}_{\mathrm{L}}\gamma^{\mu}T^{A}q_{\mathrm{L}}][\bar{t}_{\mathrm{R}}\gamma_{\mu}T^{A}u_{\mathrm{R}}].$$

Same-charge dilepton events e±μ±,e±e±,μ±μ±

- Require **two same-charge leptons** (ee or μμ) with high transverse momentum (pT). Isolation criteria helps reduce contamination from non-prompt leptons.
- Multiple jets: at least one b-tagged jet, to identify top-quark decays.
- A threshold is imposed on MET(for neutrinos);
- Fake Lepton Backgrounds: Suppressed using isolation and impact parameter cuts.
- Charge Misidentification: Mitigated using charge-flip probabilities, especially in ee events.
- SM Processes: Dominant contributions (e.g., ttW) modeled using MC simulations.
- NN is trained to optimize signal-to-background separation: multivariate correlations between observables: pT, jet and b-jet mult. and MET



- No Significant Signal Observed - No evidence of same-charge top-quark pair production.
- Upper Limit on Cross Section
    - **σ(tt/t̄t̄) < 1.6 fb** (95% CL).
- Limits on Wilson Coefficients (SMEFT):
    - Operators: O(1)tu, O(1)Qu, O(8)Qu.
    - Tightened constraints on BSM couplings.
- No deviations from SM observed.
- Strong constraints on models predicting enhanced same-charge top-quark production.

A search for $tW \to tW$ scattering in the multi-leptonic $t\bar{t}Wj$ final state at $\sqrt{s} = 13$ TeV with the ATLAS detector with bounds on Effective Field Theory operators

Searches for new Physics

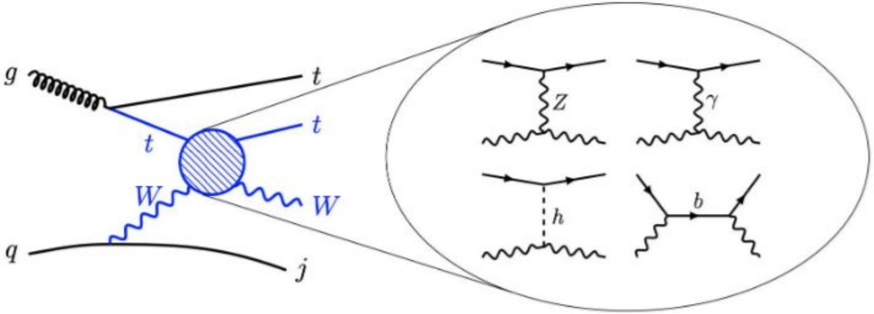
- The search uses same-sign pairs of electrons and muons together with jets, out of which at least one is b-tagged;
- Dataset: Full Run 2 (2015-2018) with 140 fb−1;

Signal region

	Preselection	Signal Region
Leptons	2 same-sign leptons	2 same-sign leptons
$p_T(l_0)$	> 28 GeV	> 80 GeV
$p_T(l_1)$	> 20 GeV	> 40 GeV
$\eta(e)$	<2.0	<2.0
$\eta(\mu)$	<2.5	<2.5
N (jets)	>=3	>=4
N (b-jets)	>=1	>=1
$p_T(j_0)$	> 60 GeV	> 60 GeV
m_{ll}	>30 GeV	>125 GeV
Z veto (ee)	Applied	Applied
$\Delta\eta_j$	—	>2.0
$\sum p_T(j)$	—	>250 GeV
Conversion radius	—	>50 mm

ttWj signature at the LHC

- 2 same-sign leptons and high jet multiplicity;
- Strong dependence in cross section in the presence of EFT coupling;



First attempt to measure this process

$$\Delta\mathcal{L}_t = \frac{i\bar{c}_L^{(1)}}{v^2} H^\dagger \overleftrightarrow{D}_\mu H \bar{q}_L \gamma^\mu q_L + \frac{i\bar{c}_L^{(3)}}{v^2} H^\dagger \sigma^a \overleftrightarrow{D}_\mu H \bar{q}_L \gamma^\mu \sigma^a q_L + \boxed{\frac{i\bar{c}_R}{v^2} H^\dagger \overleftrightarrow{D}_\mu H \bar{t}_R \gamma^\mu t_R} + \frac{i\bar{c}_R^b}{v^2} H^\dagger \overleftrightarrow{D}_\mu H \bar{b}_R \gamma^\mu b_R + \left(\frac{i\bar{c}_R^{tb}}{v^2} \tilde{H}^\dagger \overleftrightarrow{D}_\mu H \bar{t}_R \gamma^\mu b_R + \text{h.c.} \right) + \frac{\bar{c}_u y_t}{v^2} H^\dagger H \bar{q}_L \tilde{H} t_R + \text{h.c.} \,,$$

$$\boxed{\bar{c}_R = \frac{v^2}{\Lambda^2} c_{\varphi u}^{(33)} = \frac{v^2}{\Lambda^2} c_{\varphi t}}$$

Backgrounds:

- **ttW QCD and tt + fake leptons**: estimated via data-driven technique;

Control Regions	3J-CR	4J-lo$\Delta\eta$-CR	4J-hi$\Delta\eta$-CR	Conv-CR	CF-CR	3L-CR (ttZ)	3L-CR
Leptons	2 same-sign	2 same-sign	2 same-sign	2 same-sign (ee or $e\mu$)	2 same-sign ee	3 leptons	3 leptons
$p_T(\ell_0)$	> 28 GeV	> 28 GeV	> 28 GeV	> 28 GeV	> 50 GeV	> 28 GeV	> 28 GeV
$p_T(\ell_1)$	> 20 GeV	> 20 GeV	> 20 GeV	> 20 GeV	> 30 GeV	> 20 GeV	> 20 GeV
$p_T(\ell_2)$	—	—	—	—	—	> 20 GeV	> 20 GeV
N(jets)	== 3	>= 4	>= 4	>= 4	>=3	>= 4	==3
N(b-jets)	>= 1	>= 1	>= 1	>= 1	>=1	>= 2	==1
$p_T(j_0)$	—	>60 GeV	>60 GeV	>60 GeV	>60 GeV	>60 GeV	—
m_{ll}	> 160 GeV	> 30 GeV	> 30 GeV	> 30 GeV		OS AND > 81.1 GeV AND < 101.1 GeV	
m_{ee}	< 81.1 GeV OR > 101.1 GeV	< 81.1 GeV OR > 101.1 GeV.	< 81.1 GeV OR > 101.1 GeV	> 81.1 GeV AND < 101.1 GeV	> 81.1 GeV AND < 101.1 GeV	—	
SR-like cuts							
- $\Delta\eta_j$		$\Delta\eta_j$ <2.0	$\Delta\eta_j$ >2.0 AND NOT	$\Delta\eta_j$ < 2.0			
- $\sum p_T(j)$			($\sum p_T(j)$ > 250 GeV AND	OR $\sum p_T(j)$ <250 GeV			
- $p_T(\ell_0)$			$p_T(\ell_0)$ > 80 GeV AND				
- $p_T(\ell_1)$			$p_T(\ell_1)$ > 40 GeV AND				
- mll			m_{ll} > 125)				
$\lvert$Conversion radius (e)$\rvert$	—	>=50 mm	>=50 mm	<50 mm	>=50 mm	—	—
Conv. invariant mass	—	—	—	<0.5GeV	—	—	—
E_T^{miss}	—	—	—	—	< 100 GeV	—	—

- Seven control regions;
- Fake leptons estimation via matrix method;

- SM signal process has a very low cross section compared to dominant QCD contribution;
- SM cross section: 47.7 fb

Upper limits at 95% C.L.

$$\mu_{t\bar{t}Wj_{EW}} < 4.555$$

$$\sigma_{t\bar{t}Wj_{EW}} < 217.27 \text{ fb}$$

- Set constraints in the couplings that would increase this cross section;
- Next step: Compare the EFT limits in this work with the existent limits on ttZ and ttW cross sections;

Observation of quantum entanglement with top quarks at the ATLAS detector

Quantum Effects and Novel Observations

- The **spin correlation between the top quark and antitop quark** is used to probe the effects of quantum entanglement, in proton-proton (pp) collision events recorded with the ATLAS detector at a center-of-mass energy of 13 TeV;
- If two particles are entangled, the **quantum state of one particle cannot be described independently**;
- Quantum entanglement is a key test of the SM and probe for BSM physics;
- Data: **140 fb^{-1} @ 13 TeV**;
- Event selection: **e±μ±,e±e±,μ±μ±**
  - Two high-pT leptons;
  - 2 b-jets;
  - High missing transverse energy;

Two-qubit system whose spin quantum state is described by the spin density matrix ρ

$$\rho = \frac{1}{4}\left[I_4 + \sum_i \left(B_i^+ \sigma^i \otimes I_2 + B_i^- I_2 \otimes \sigma^i \right) + \sum_{i,j} C_{ij} \sigma^i \otimes \sigma^j \right]$$

Angular direction of each of these leptons is correlated with the direction of the spin

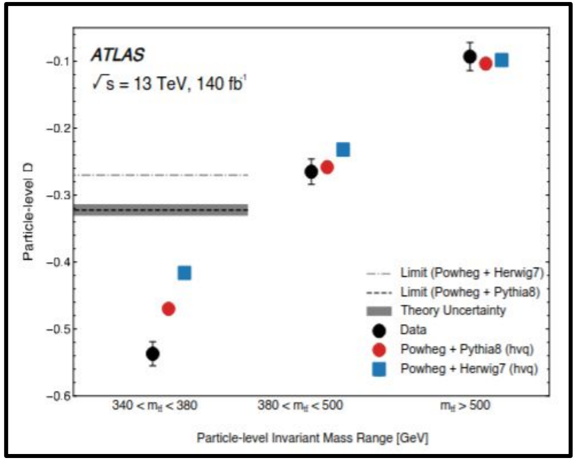
$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega_+ d\Omega_-} = \frac{1 + \mathbf{B}^+ \cdot \hat{\mathbf{q}}_+ - \mathbf{B}^- \cdot \hat{\mathbf{q}}_- - \hat{\mathbf{q}}_+ \cdot \mathbf{C} \cdot \hat{\mathbf{q}}_-}{(4\pi)^2}$$

Entanglement marker - Experimental approach

$$D = -3 \cdot \langle \cos\varphi \rangle$$

Measurement of Entanglement Observable (D)

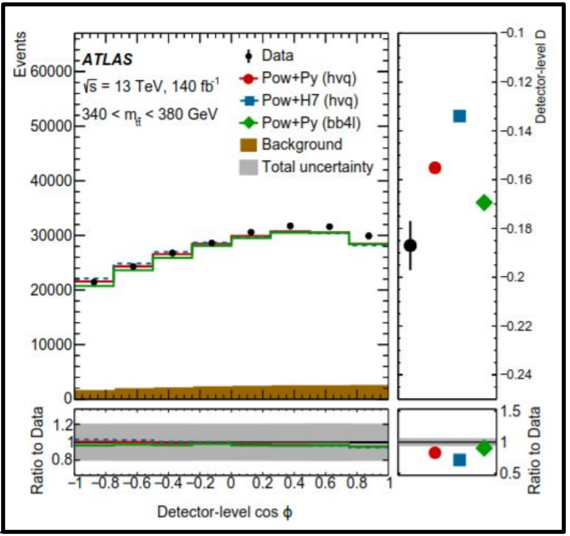
- The study measures the observable D, inferred from the angle between charged leptons in the rest frames of their parent top and antitop quarks.



For 340 < m($t\bar{t}$) < 380 GeV

$$D = -0.537 \pm 0.002\ [\text{stat.}] \pm 0.019\ [\text{syst.}]\ (-0.470 \pm 0.002\ [\text{stat.}] \pm 0.017\ [\text{syst.}])$$

This result deviates from the **non-entanglement scenario by more than five standard deviations**, providing strong evidence for entanglement.



For 380 < m($t\bar{t}$) < 500 GeV

$$D = -0.265 \pm 0.001\ [\text{stat.}] \pm 0.019\ [\text{syst.}]\ (-0.258 \pm 0.001\ [\text{stat.}] \pm 0.019\ [\text{syst.}])$$

For m($t\bar{t}$) > 500 GeV

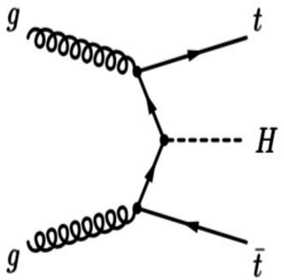
$$D = -0.093 \pm 0.001\ [\text{stat.}] \pm 0.021\ [\text{syst.}]\ (-0.103 \pm 0.001\ [\text{stat.}] \pm 0.021\ [\text{syst.}])$$

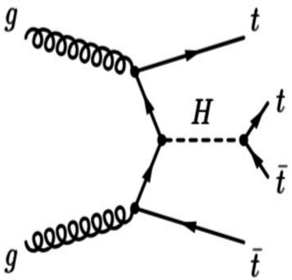
Constraint on the total width of the Higgs boson from Higgs boson and four-top-quark measurements in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

Higgs Boson and Top Quark Properties

- Production of four top quarks in multi-lepton final states using data from the LHC Run 2;
- Measure the cross-section of the $t\bar{t}t\bar{t}$ signal and compare it with SM predictions;

- Multi-lepton final states:
- **Two leptons** of the same electric charge or **at least three leptons** (electrons or muons).
- At least **two b-tagged jets**.
- Most dangerous backgrounds: **$t\bar{t}W$, $t\bar{t}Z$,** and **$t\bar{t}H$**.
- Data-driven is employed to estimate and correct for fake/non-prompt lepton backgrounds and charge mis-assignment.
- Graph Neural Network (GNN) classifier implemented to enhance signal-background separation.





- Observed significance of the $t\bar{t}t\bar{t}$ signal: 6.1 σ, with an expected significance of 4.3σ;

- Measured $t\bar{t}t\bar{t}$ production cross-section: 22.5 fb, consistent with the SM prediction of 12.0 ± 2.4 fb within 1.8σ.

On-shell and off-shell measurements used as input for the total width measurement

Target processes	
Off-shell measurement	
$pp \rightarrow t\bar{t}t\bar{t}$	
On-shell measurement	
Production	Decay
ggF, VBF, WH, ZH, $t\bar{t}H$, tH	$H \rightarrow \gamma\gamma$
$t\bar{t}H + tH$	$H \rightarrow b\bar{b}$
WH, ZH	$H \rightarrow b\bar{b}$
VBF	$H \rightarrow b\bar{b}$
ggF, VBF, $WH + ZH$, $t\bar{t}H + tH$	$H \rightarrow ZZ$
ggF, VBF	$H \rightarrow WW$
WH, ZH	$H \rightarrow WW$
ggF, VBF, $WH + ZH$, $t\bar{t}H + tH$	$H \rightarrow \tau\tau$
ggF+ $t\bar{t}H + tH$, VBF+ $WH + ZH$	$H \rightarrow \mu\mu$
Inclusive	$H \rightarrow Z\gamma$

- The observed **95% confidence level (CL)** upper limit on the total width of the **Higgs boson is 450 MeV**, which is approximately 110 times the Standard Model (SM) prediction of 4.1 MeV;
- The **expected upper limit is 75 MeV**, corresponding to about 18 times the SM prediction;
- When considering constraints on the Higgs-top Yukawa coupling from loop-induced processes, the observed upper limit on Γ_H decreases to 160 MeV, while the expected limit becomes 55 MeV.
- The **best-fit value for the total width is reported as Γ_H = 86 ($^{+110}_{-49}$) MeV**, which is 2.0σ away from the SM expectation. This discrepancy is primarily driven by a 1.8σ difference between the data and the SM prediction in the four-top-quark measurement.
- Strong channel to investigate **potential BSM physics**;

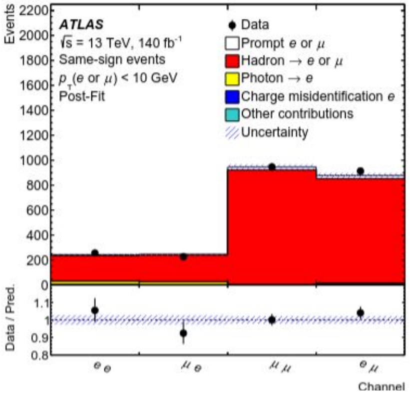
Test of lepton flavour universality in W-boson decays into electrons and τ-leptons using pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

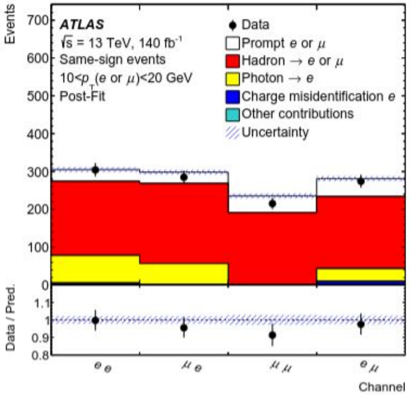
- Measure the lepton flavor universality (LFU) by analyzing the ratio of branching fractions $R\tau/e=B(W\to\tau\nu\tau)/B(W\to e\nu e)$;
- Investigate potential deviations from the SM that could indicate new physics;

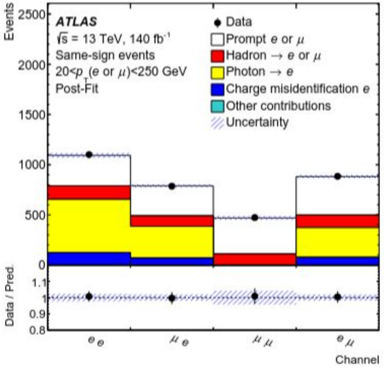
Event selection

- One tagged lepton (muon or electron) and one probe electron with opposite charges;
- At least two *b*-tagged jets to enhance signal purity.
- Application of a jet vertex tagger (JVT) to mitigate pile-up effects;
- Exclusion of events with invariant mass close to the Z to reduce background from Drell-Yan *Z* production;

Number of same-sign events in the ee, μe, $e\mu$ and $\mu\mu$ channels where the first lepton is the tag lepton and the second is the probe lepton







Number of events for μe channel

	μe $7 < p_T < 10$ GeV	μe $10 < p_T < 20$ GeV	μe $20 < p_T < 250$ GeV
Prompt $e(t\bar{t})$	1278 ± 28	13370 ± 150	178000 ± 1000
e from τ ($t\bar{t}$)	1092 ± 32	4490 ± 100	11670 ± 290
Prompt $e(Wt)$	34 ± 6	340 ± 60	5300 ± 900
e from τ (Wt)	28.0 ± 2.5	119 ± 16	380 ± 110
Prompt e (not from $t\bar{t}$ or Wt)	5.2 ± 1.5	23 ± 7	180 ± 50
e from $Z \rightarrow \tau^+\tau^-$	19.9 ± 0.4	85.4 ± 1.4	132.9 ± 2.2
Fake e	317 ± 22	380 ± 33	840 ± 60
Total predicted	2770 ± 40	18880 ± 120	196500 ± 400
Data	2768	18783	196552

Number of events for ee channel

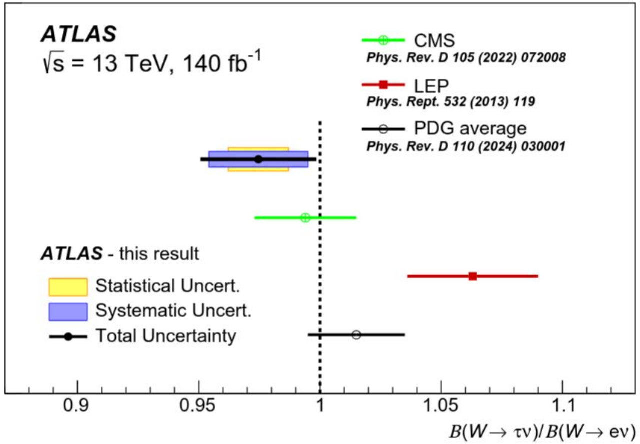
	ee $7 < p_T < 10$ GeV	ee $10 < p_T < 20$ GeV	ee $20 < p_T < 250$ GeV
Prompt $e(t\bar{t})$	1238 ± 35	12210 ± 130	160300 ± 900
e from τ ($t\bar{t}$)	1051 ± 30	4060 ± 100	10490 ± 260
Prompt $e(Wt)$	35 ± 7	320 ± 50	5000 ± 700
e from τ (Wt)	30 ± 4	116 ± 13	340 ± 100
e from $Z \rightarrow e^+e^-$	240 ± 50	1770 ± 120	12380 ± 200
Prompt e (not from $t\bar{t}$ or Wt)	11.7 ± 3.5	59 ± 17	560 ± 170
e from $Z \rightarrow \tau^+\tau^-$	19.7 ± 0.4	69.7 ± 0.9	105.3 ± 1.3
Fake e	302 ± 20	374 ± 32	810 ± 50
Total predicted	2930 ± 50	18970 ± 120	190000 ± 400
Data	2928	19047	189945

- The measured value of **$R_{\tau/e}$** was found to be consistent with the predictions of the SM, with a **global fit p-value of 87%**;

$$R_{\tau/e} = 0.975 \pm 0.012\,(\text{stat.}) \pm 0.020\,(\text{syst.})$$

For different pT bins

p_T bin	$R_{\tau/e}$
$7 < p_T < 10$ GeV	1.13 ± 0.11 (stat) ± 0.07 (syst)
$10 < p_T < 20$ GeV	0.93 ± 0.04 (stat) ± 0.02 (syst)
$20 < p_T < 250$ GeV	0.98 ± 0.04 (stat) ± 0.02 (syst)



Precise test of lepton flavour universality in W-boson decays into muons and electrons in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

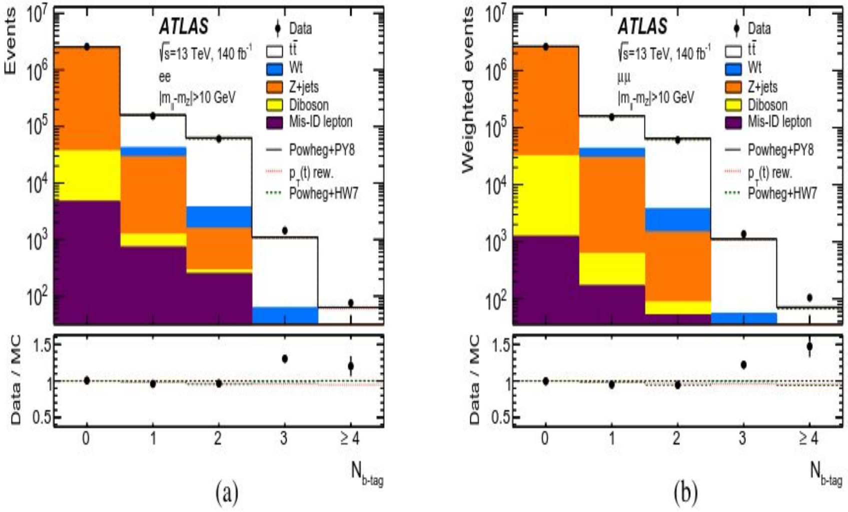
- Testing the assumption of lepton flavour universality in the SM by analyzing the ratios of decay widths of particles into electrons, muons, and taus;
- Measure the inclusive top quark pair production cross-section and the Z boson decay to leptons;

Event selection

- Exactly two leptons (electrons or muons) of opposite charges, with at least one lepton matched to a trigger.

- **Electrons**: p_T > 27.3 GeV, $|\eta|$ < 1.37 or 1.52 < $|\eta|$ < 2.47;
- **Muons**: p_T > 27.3 GeV, $|\eta|$ < 2.5
- Events categorized into top quark pair production (t t) and Z boson decay ($Z \rightarrow \ell\ell$) based on dilepton invariant mass and b-tagged jet multiplicity.

Object selection		
Electrons	$p_T > 27.3$ GeV, $\lvert\eta\rvert < 1.37$ or $1.52 < \lvert\eta\rvert < 2.47$	
Muons	$p_T > 27.3$ GeV, $\lvert\eta\rvert < 2.5$	
b-tagged jets	$p_T > 30.0$ GeV, $\lvert\eta\rvert < 2.5$, b-tagging DL1r 70%	
Event selection	$t\bar{t} \rightarrow \ell\ell b\bar{b}\nu\bar{\nu}$	$Z \rightarrow \ell\ell$
Dilepton flavour ($\ell^+\ell^-$)	ee, $e\mu$, $\mu\mu$	ee, $\mu\mu$
Dilepton invariant mass	$m_{\ell\ell} > 30$ GeV	66 GeV $< m_{\ell\ell} <$ 116 GeV
b-tagged jet multiplicity	1 or 2	–



Results

- Fit the number of selected events to predictions based on the assumed cross-sections and efficiencies. Use a maximum likelihood fit to extract parameters of interest(cross-sections and background contributions).

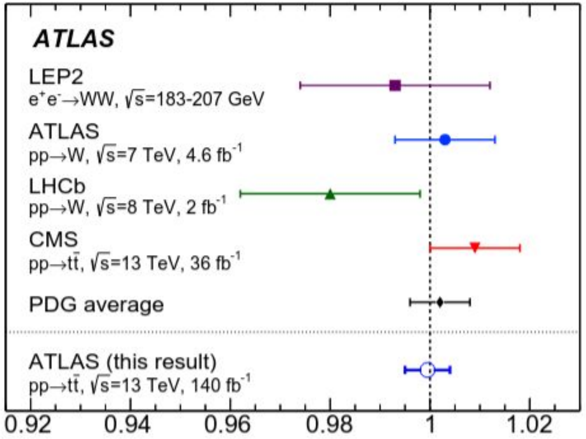
Fitted distributions

Event selection	Variable	Bins	Event count
$e\mu$+1 or 2 b-tagged jets	$N_{b\text{-tag}}$	2	$N_1^{e\mu}$, $N_2^{e\mu}$
ee+1 b-tagged jet	$m_{\ell\ell}$	6	$N_{1,m}^{ee}$
ee+2 b-tagged jets	$m_{\ell\ell}$	6	$N_{2,m}^{ee}$
$\mu\mu$+1 b-tagged jet	$m_{\ell\ell}$	6	$N_{1,m}^{\mu\mu}$
$\mu\mu$+2 b-tagged jets	$m_{\ell\ell}$	6	$N_{2,m}^{\mu\mu}$
$Z \to ee$ or $\mu\mu$	channel	2	N_Z^{ee}, $N_Z^{\mu\mu}$

$$\sigma_{t\bar{t}} = 809.5 \pm 1.1 \pm 20.1 \pm 7.5 \pm 1.9\,\text{pb}$$
$$\sigma_{Z\to\ell\ell} = 2019.4 \pm 0.2 \pm 20.7 \pm 16.8 \pm 1.8\,\text{pb}$$

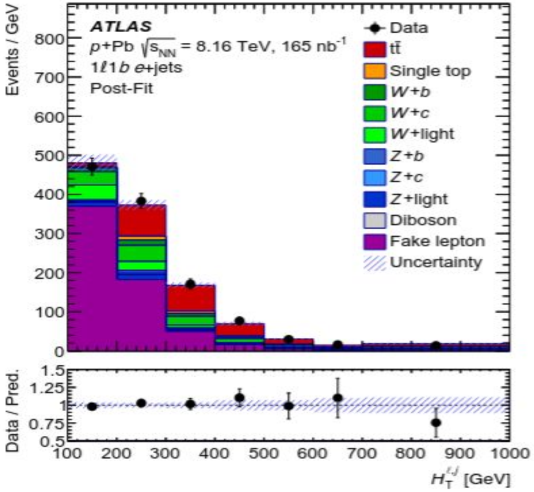
Event counts	$N^{ee}_{1,\text{off}-Z}$	$N^{ee}_{1,\text{on}-Z}$	$N^{e\mu}_{1}$	$N^{\mu\mu}_{1,\text{off}-Z}$	$N^{\mu\mu}_{1,\text{on}-Z}$
Data	222304	442108	405437	223085	448105
$t\bar{t}$	154800 ± 1700	24830 ± 850	361000 ± 4200	152500 ± 1800	24070 ± 860
Wt	17500 ± 1600	2770 ± 240	41500 ± 3800	17800 ± 1700	2730 ± 250
Z+jets	46880 ± 400	410700 ± 2000	859 ± 21	51010 ± 780	418000 ± 2000
Diboson	770 ± 160	3940 ± 840	790 ± 280	770 ± 160	3880 ± 830
Mis-ID leptons	1300 ± 500	360 ± 260	1740 ± 610	390 ± 150	172 ± 87
Total prediction	221280 ± 550	442600 ± 1100	405900 ± 1800	222390 ± 670	448900 ± 1100
Event counts	$N^{ee}_{2,\text{off}-Z}$	$N^{ee}_{2,\text{on}-Z}$	$N^{e\mu}_{2}$	$N^{\mu\mu}_{2,\text{off}-Z}$	$N^{\mu\mu}_{2,\text{on}-Z}$
Data	85936	37704	198502	86169	38512
$t\bar{t}$	79750 ± 920	13340 ± 480	191000 ± 1800	79770 ± 830	13180 ± 450
Wt	2860 ± 760	400 ± 110	6700 ± 1600	2940 ± 740	423 ± 90
Z+jets	2675 ± 68	23610 ± 590	78 ± 2	3095 ± 87	24110 ± 600
Diboson	67 ± 23	550 ± 110	29 ± 8	71 ± 30	570 ± 110
Mis-ID leptons	400 ± 290	96 ± 59	720 ± 520	350 ± 160	104 ± 56
Total prediction	85760 ± 360	38000 ± 190	198510 ± 440	86230 ± 300	38380 ± 210

$$R_W^{\mu/e} = R_{WZ}^{\mu/e}\sqrt{R_{Z-\text{ext}}^{\mu\mu/ee}} = 0.9995 \pm 0.0022\,(\text{stat}) \pm 0.0036\,(\text{syst}) \pm 0.0014\,(\text{ext})$$



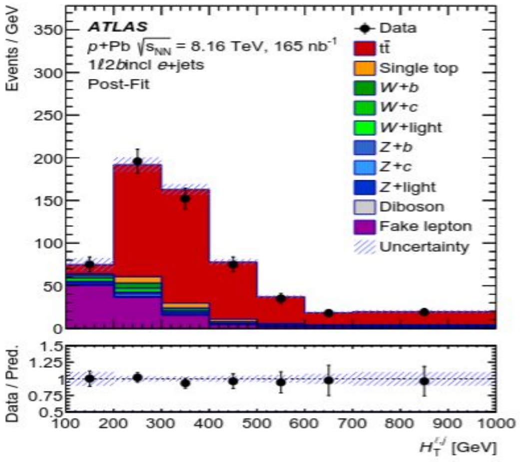
Observation of $t\bar{t}$ production in the lepton+jets and dilepton channels in p+Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV with the ATLAS detector

- Observation of top-quark pair production in proton-lead (p+Pb) collisions at a center-of-mass energy of 8.16 TeV;
- Also includes the measurement of the nuclear modification factor for top-quark pair production in p+Pb collisions;



Single leptonic

- Events with exactly one lepton (electron or muon): single-lepton triggers with a minimum pT threshold of 15 GeV.
- At least four jets;
- At least 1 b-tagged jet;

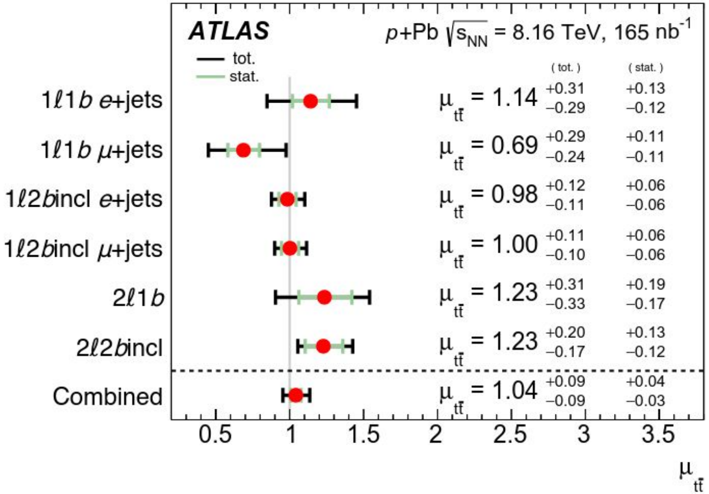


Dileptonic

- Events with two opposite-charge leptons with additional Invariant mass cuts
- at least two jets;

- Top-quark pair production is observed with a significance exceeding five standard deviations in both channels with a total systematic uncertainty of 8%;

$$\sigma_{t\bar{t}} = \mu_{t\bar{t}} \cdot A_{\mathrm{Pb}} \cdot \sigma_{t\bar{t}}^{\mathrm{th}}$$

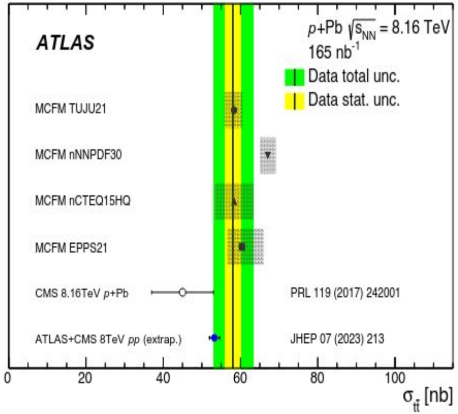


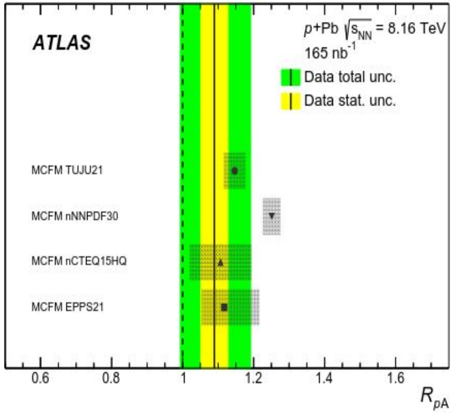
- $\mu_{t\bar{t}}$ values are consistent with the SM predictions;
- This confirmed the observation of $t\bar{t}$ production in p+Pb collisions for the first time at the LHC.

Nuclear modification factor

$$R_{pA} = \frac{\sigma_{t\bar{t}}^{p+\mathrm{Pb}}}{A_{\mathrm{Pb}} \cdot \sigma_{t\bar{t}}^{pp}}$$

$$R_{pA} = 1.090 \pm 0.039\ (\mathrm{stat.})\ {}^{+0.094}_{-0.087}\ (\mathrm{syst.})$$





- The measured value is found to be consistent with unity within the uncertainty.

Conclusions

Precision Cross-Sections

- High-accuracy measurements of tt cross-section for 13 TeV: differential studies exploring top quark kinematics and spin correlations.

Single Top Quark Production

- Detailed studies of electroweak production modes tW,tb,ttZ;
- Observation of rare tWZ production;

Higgs-Top Coupling

- Direct measurements of the Yukawa coupling strength.
- Evidence of top-mediated Higgs production.

New Physics searches

- Strong portal do look for BSM physics

More to come …

- Joint contributions with CMS to (have) refine(d) SM predictions.
- Complementary results enhance understanding of the top quark's role in electroweak symmetry breaking;

Toponium

- A hypothetical bound state of a tt pair analogous to quarkonium predicted in scenarios of strong coupling or near-threshold tt production.

- Sheds light on QCD at high energies and potential new interactions.
- Provides constraints on top quark-antiquark dynamics in the threshold region.

Back-up slides

*Measurement of single top-quark production in association with a W boson in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector - Aad, Georges et al - Phys.Rev.D 110 (2024) 7, 072010 CERN-EP-2024-168

*Measurement of $t\bar{t}$ production in association with additional b-jets in the $e\mu$ final state in proton-proton collisions at $\sqrt{s}$=13 TeV with the ATLAS detector - Aad, Georges et al - arXiv:2407.13473 - CERN-EP-2024-191 (Sent to JHEP)

*Measurements of differential cross-sections in top-quark pair events with a high transverse momentum top quark and limits on beyond the Standard Model contributions to top-quark pair production with the ATLAS detector at $ \sqrt{s} $ = 13 TeV - Aad, Georges et al - JHEP 2206 (2022) 063 - CERN-EP-2022-003

*Search for heavy right-handed Majorana neutrinos in the decay of top quarks produced in proton-proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector - Aad, Georges et al - Phys. Rev. D 110 (2024) 112004 - CERN-EP-2024-154

*Search for same-charge top-quark pair production in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector - Aad, Georges et al - arXiv:2409.14982 - CERN-EP-2024-226 (sent to JHEP)

*Constraint on the total width of the Higgs boson from Higgs boson and four-top-quark measurements in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector - Aad, Georges et al - arXiv:2407.10631 - CERN-EP-2024-190 (Submitted to Phys. Lett. B)

*Test of lepton flavour universality in W-boson decays into electrons and τ-leptons using pp collisions at $\sqrt{s}=13$ TeV with the ATLAS detector - Aad, Georges et al - CERN-EP-2024-315 (Submitted to JHEP)

*Measurement of differential cross-sections in $ t\overline{t} $ and $ t\overline{t} $+jets production in the lepton+jets final state in pp collisions at $ \sqrt{s} $ = 13 TeV using 140 fb$^{−1}$ of ATLAS data - Aad, Georges et al - JHEP 2408 (2024) 182 - CERN-EP-2024-163

*Observation of quantum entanglement with top quarks at the ATLAS detector - Aad, Georges et al - Nature 633 (2024) 542 - CERN-EP-2023-230

*Measurements of inclusive and differential cross-sections of $t\bar{t}\gamma$ production in pp collisions at $sqrt{s} = 13$ TeV with the ATLAS detector - Aad, Georges et al - JHEP 10 (2024) 191 - CERN-EP-2024-052

* Search for flavour-changing neutral-current couplings between the top quark and the Higgs boson in multi-lepton final states in 13 TeV pp collisions with the ATLAS detector - Aad, Georges et al - Eur. Phys. J. C 84 (2024) 757 - CERN-EP-2024-070

*Observation of $t\bar{t}$ production in the lepton+jets and dilepton channels in p+Pb collisions $\sqrt{s_{NN}}$ = 8.16 TeV with the ATLAS detector - Aad, Georges et al - JHEP 2411 (2024) 101 - CERN-EP-2024-097

*Precise test of lepton flavour universality in W-boson decays into muons and electrons in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector - Aad, Georges et al - arXiv:2403.02133 - CERN-EP-2024-063

Search for ttW+jet production A search for $tW \rightarrow \tW$ scattering in the multi-leptonic $t\bar{t}Wj$ final state at $\sqrt{s} = 13$~TeV with the ATLAS detector with bounds on Effective Field Theory operators