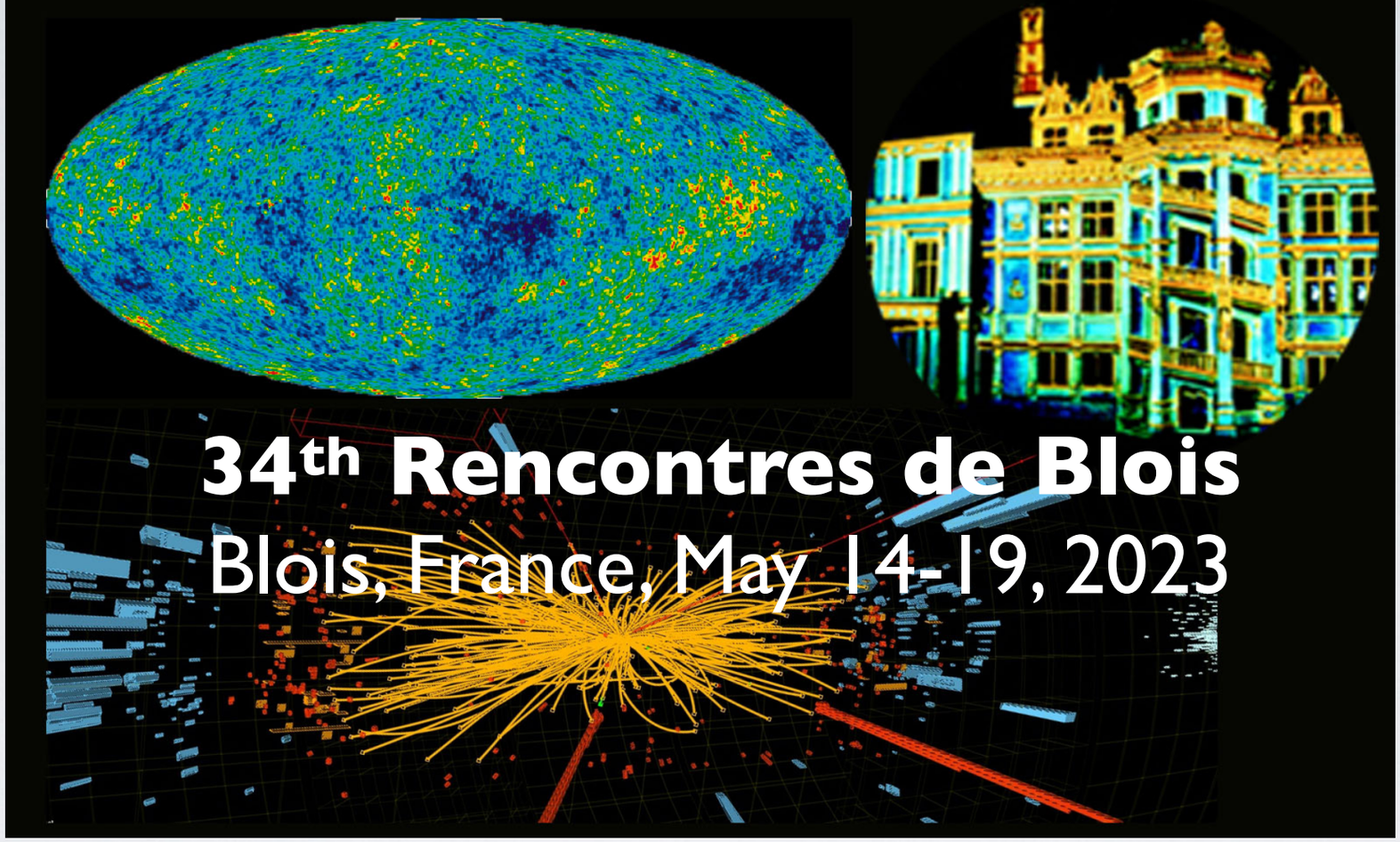


HIGHLIGHTS ON TOP QUARK PHYSICS WITH THE ATLAS EXPERIMENT AT THE LHC

Lucio Cerrito

University and INFN, Roma Tor Vergata

on behalf of the ATLAS Collaboration

PHYSICS OF TOP QUARKS

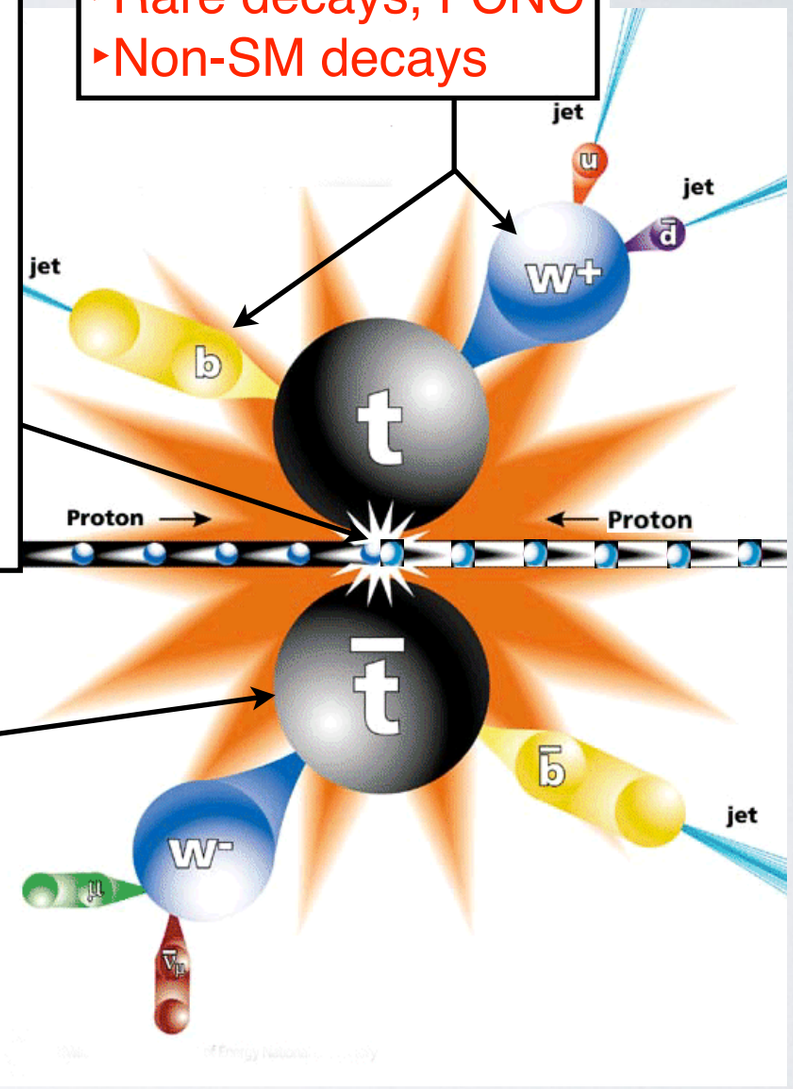
- Test of SM (production, decay, coupling....etc)
- Top quark does not hadronize: momentum and spin transferred to decay products
- Search for processes with similar signature (VLQ, Z'...)
- Natural mass ($y_t \simeq 1$), top quark mass is a fundamental parameter of the SM, and crucial for SM constraints via loop diagrams

Production Rate
- Pair Production cross section
- Single (EWK) production, |Vtb|
- FCNC, anomalous couplings
- Differential cross sections
- Production mechanism (gg,qq)
- Associated production

New Physics in production
- Resonant production
- Heavy Quark production
- ...

Decay
- Branching ratios
- CP asymmetries
- Rare decays, FCNC
- Non-SM decays

Properties
- Top mass
- Top charge
- Top width
- Spin correlation
- Top polarisation
- W helicity
- Charge asymmetry
- Yukawa coupling



RED: new results (since Jan. 2023), discussed in this talk

PART 1: PRODUCTION

- Test of SM (production, decay, coupling....etc)
- Top quark does not hadronize: momentum and spin transferred to decay products
- Search for processes with similar signature (VLQ, Z'...)
- Natural mass ($y_t \simeq 1$), top quark mass is a fundamental parameter of the SM, and crucial for SM constraints via loop diagrams

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New Physics in production
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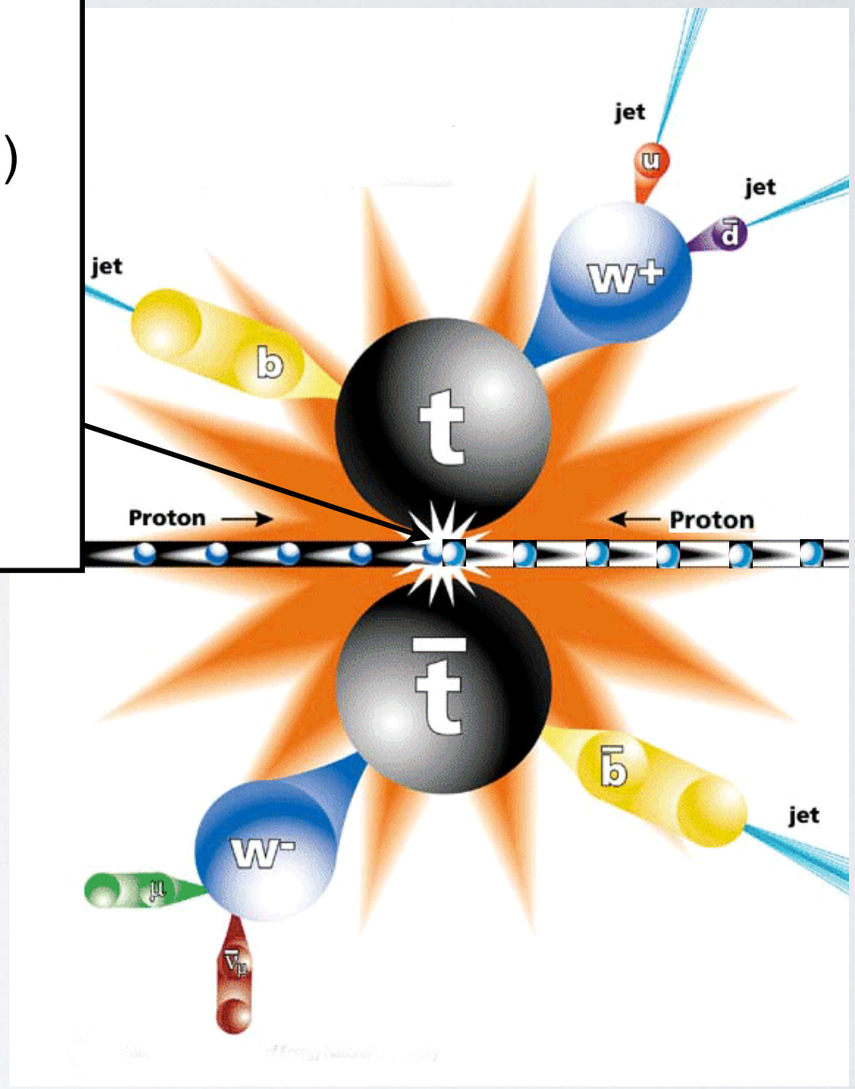


RED: new results (since Jan. 2023), discussed in this talk

Measurement of $t\bar{t}$ and Z-boson cross sections and their ratio using collisions at $\sqrt{s}$=13.6 TeV

- Separate measurements for σ_{tt}, σ^{fid}_{Z} and $R_{tt/Z}$
- First Top measurement with 13.6 TeV collision energy

ATLAS-CONF-2023-006, March 2023.
Follows a previous conf note, 1.2 fb^{-1}

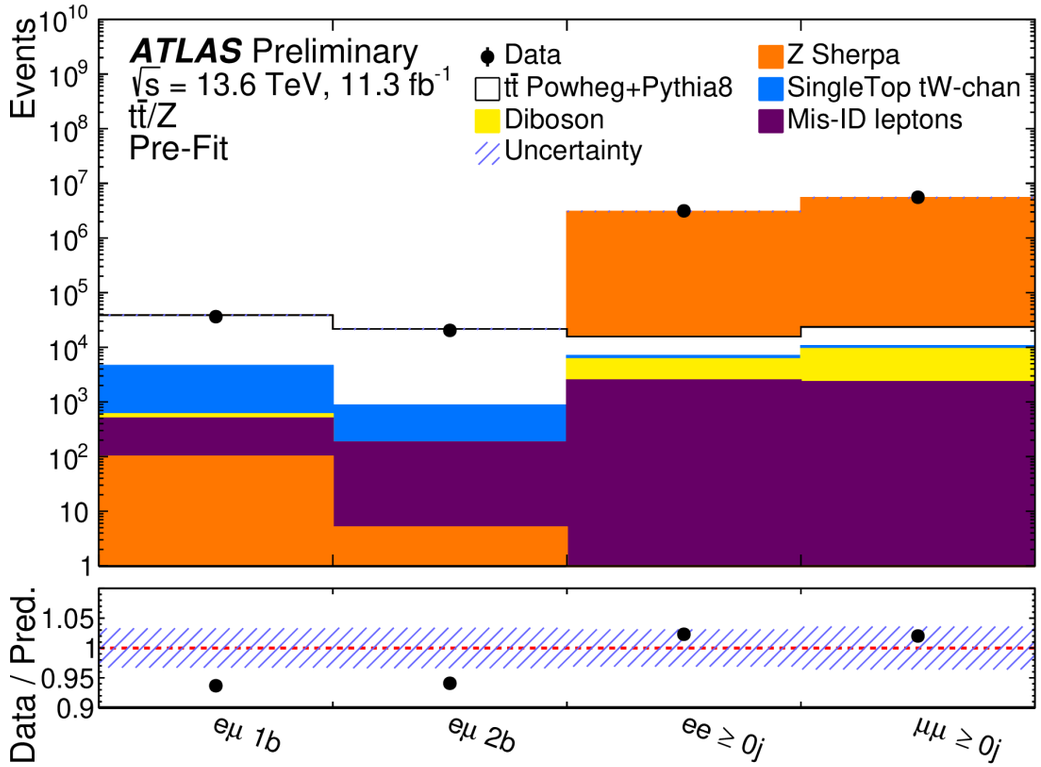
13.6 TeV, 11.3 fb^{-1}

Signature: Electrons and Muons of opposite electric charges: ee, $\mu\mu$, eμ

- Fiducial phase space for Z with leptons p_T>27 GeV, $|\eta|$<2.5 and 66<m_{ll}<116 GeV (on-shell)
- 1 and 2 b-tagged jets for the tt production

Method: Binned profile-likelihood technique, finding the cross sections and the b-tagging ε_b

Pre-fit comparison of data and prediction for the event yields in the three lepton channels



Measurement Results

$$\sigma_{t\bar{t}} = 859 \pm 4(\text{stat.}) \pm 22(\text{syst.}) \pm 19(\text{lumi.})\text{pb},$$
$$\sigma^{\text{fid.}}_{Z\to\ell\ell} = 751 \pm 0.3(\text{stat.}) \pm 15(\text{syst.}) \pm 17(\text{lumi.})\text{pb},$$
$$\epsilon_b = 0.548 \pm 0.002(\text{stat.}) \pm 0.004(\text{syst.}) \pm 0.001(\text{lumi.}).$$

$$R_{t\bar{t}/Z} = 1.144 \pm 0.006(\text{stat.}) \pm 0.022(\text{syst.}) \pm 0.003(\text{lumi.}).$$

The nominal ε_b =0.545

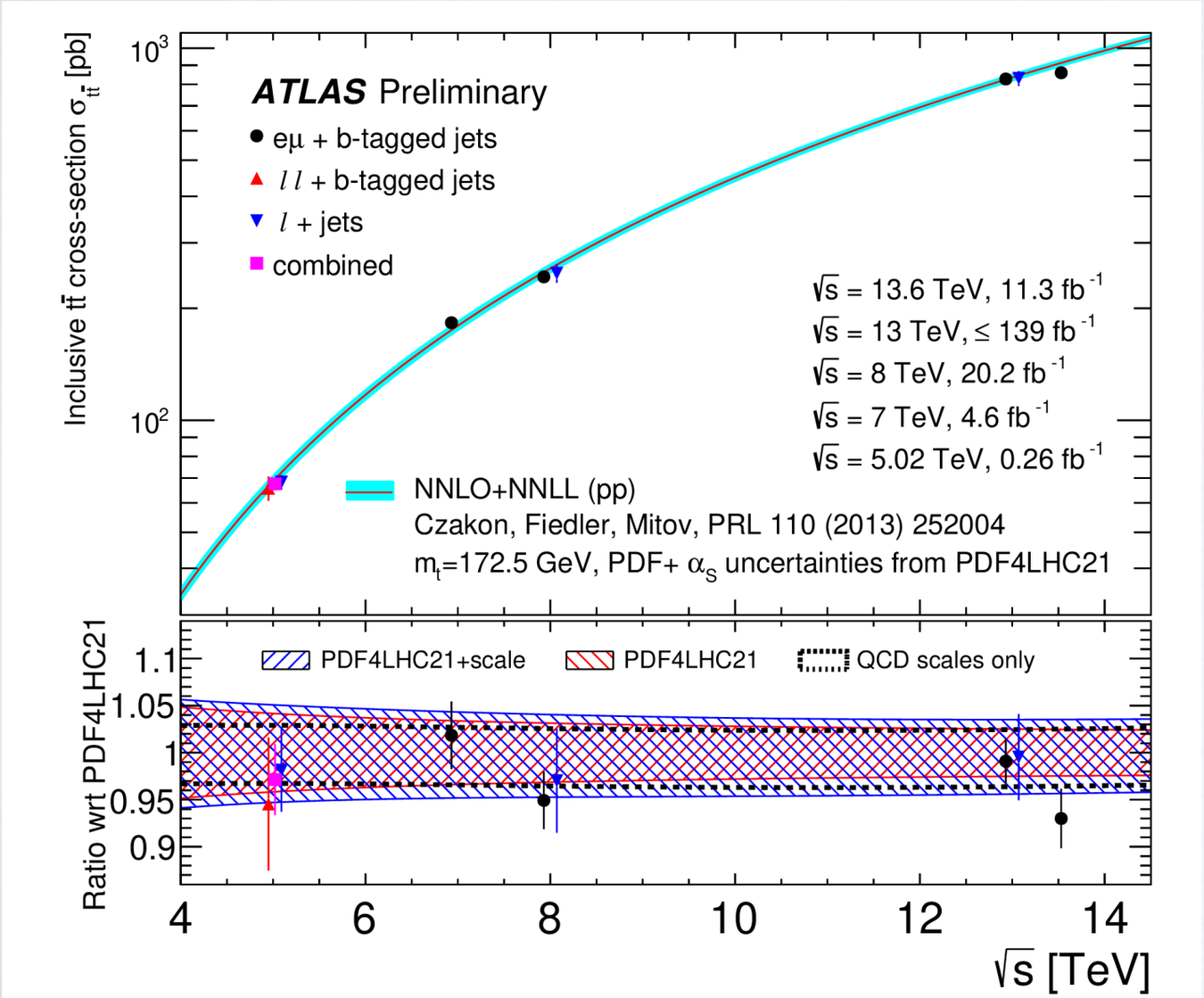
Measurement of $t\bar{t}$ and Z-boson cross sections and their ratio at $\sqrt{s}$=13.6 TeV

ATLAS-CONF-2023-006

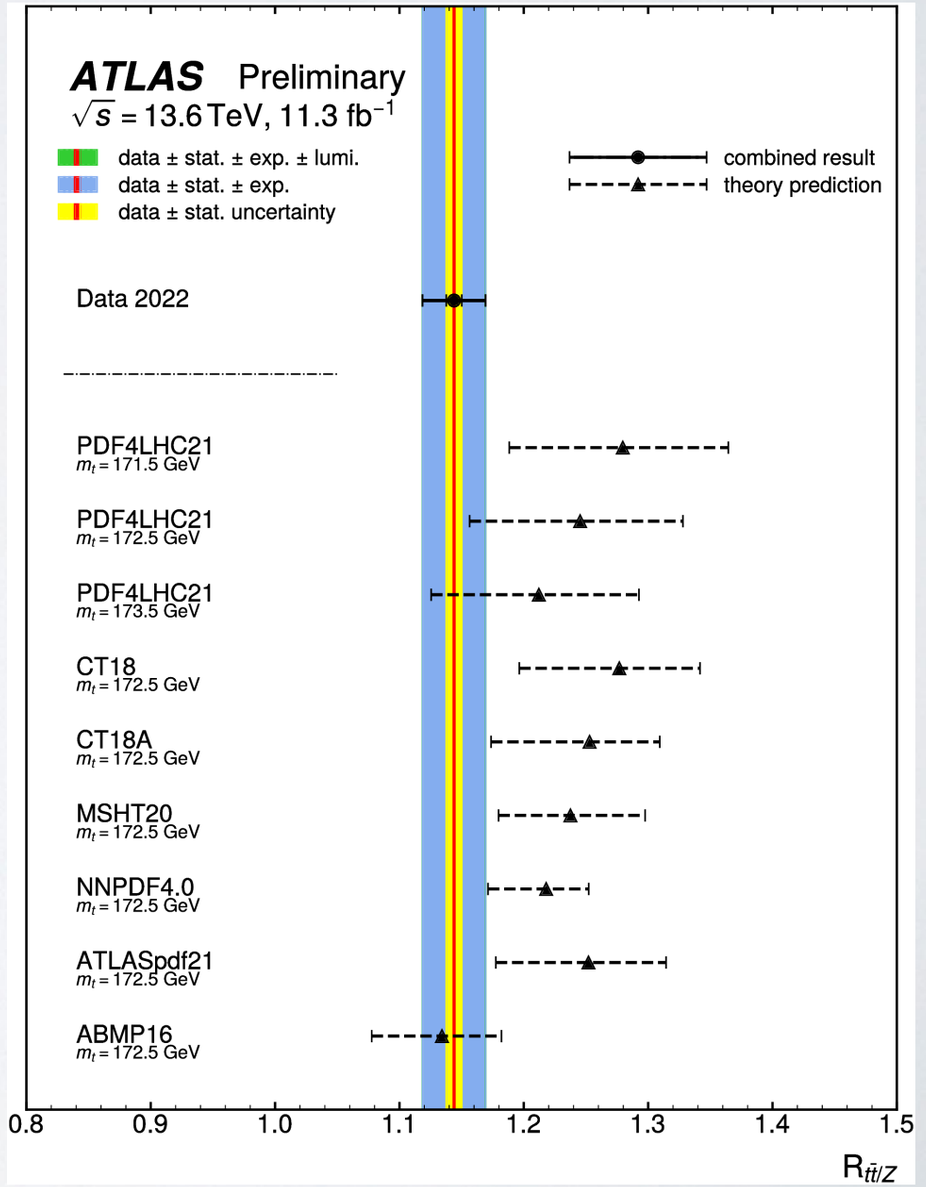
13.6 TeV, 11.3 fb^{-1}

- Comparison of the measured $t\bar{t}$ cross-sections at various centre-of-mass energies and the theory predictions using the PDF4LHC21 PDF set
- For the PDF4LHC21 PDF set, predictions for different assumptions about the top-quark mass are also displayed.

Measured and predicted $t\bar{t}$ cross section vs collision energy



Ratio $t\bar{t}/Z$ production compared to PDF predictions



Inclusive and differential cross-sections for dilepton $t\bar{t}$ production measured in $\sqrt{s}$=13 TeV

- Top dilepton analysis both inclusive and 8-kinematic variables differential distributions, with **wider** range and **finer** granularity
- 4 double-differential distributions
- Uses a revised luminosity uncertainty of only ±0.83%

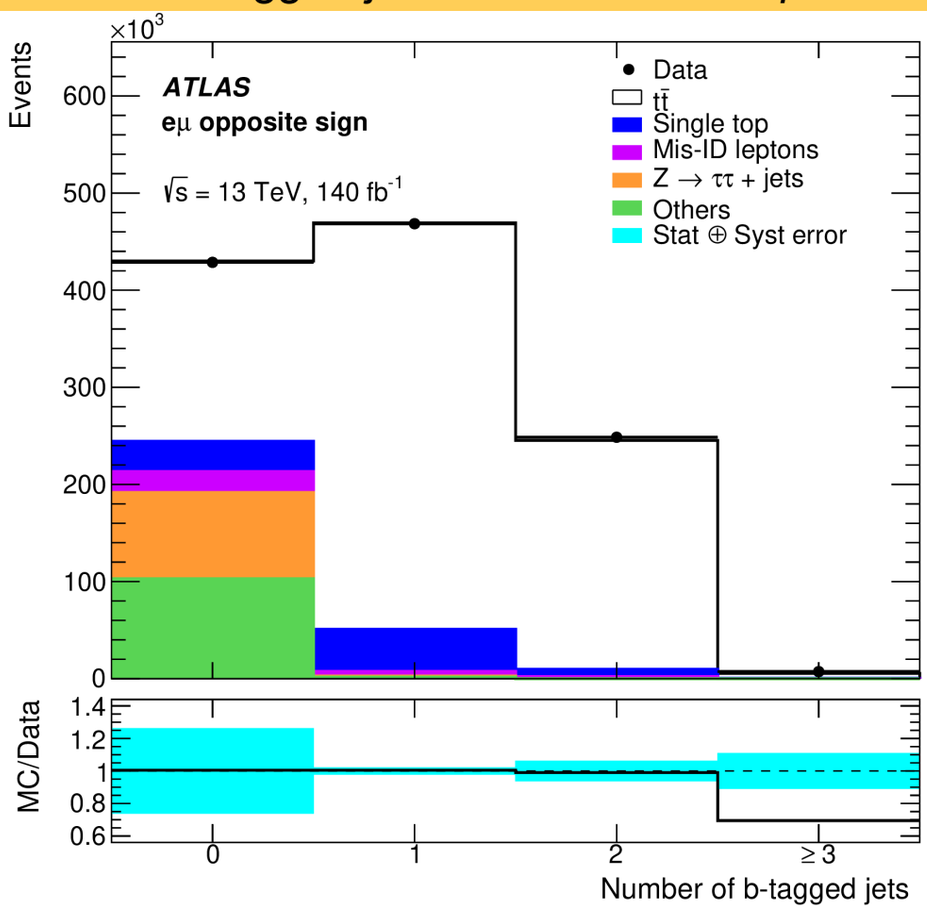
hep-ex arXiv:2303.15340
submitted to JHEP, Mar. 2023
Updates a previous result with 36 fb^{-1}

13 TeV, 140 fb^{-1}

Signature: Oppositely charged $e\mu$ pairs. Full and fiducial phase space at particle level with p_T^{ℓ} > 27 (25) GeV and $|\eta^{\ell}|$<2.5; Exactly 1 or 2 *b*-tagged jets. The B.R. to signature is 3.26±0.06%

Method: Log-likelihood fit for cross-section and *b*-tagging efficiencies

Number of *b*-tagged jets in selected OS $e\mu$ events



Selected data events with 1- and 2-*b* jets

$$N_1^i = \mathcal{L}\sigma_{t\bar{t}}^i G_{e\mu}^i 2\epsilon_b^i(1-\epsilon_b^i C_b^i) + N_{1,\mathrm{bkg}}^i$$
$$N_2^i = \mathcal{L}\sigma_{t\bar{t}}^i G_{e\mu}^i (\epsilon_b^i)^2 C_b^i + N_{2,\mathrm{bkg}}^i$$

Total inclusive cross-section

$$\sigma_{t\bar{t}} = 829 \pm 1\ (\mathrm{stat}) \pm 13\ (\mathrm{syst}) \pm 8\ (\mathrm{lumi}) \pm 2\ (\mathrm{beam})\ \mathrm{pb}$$

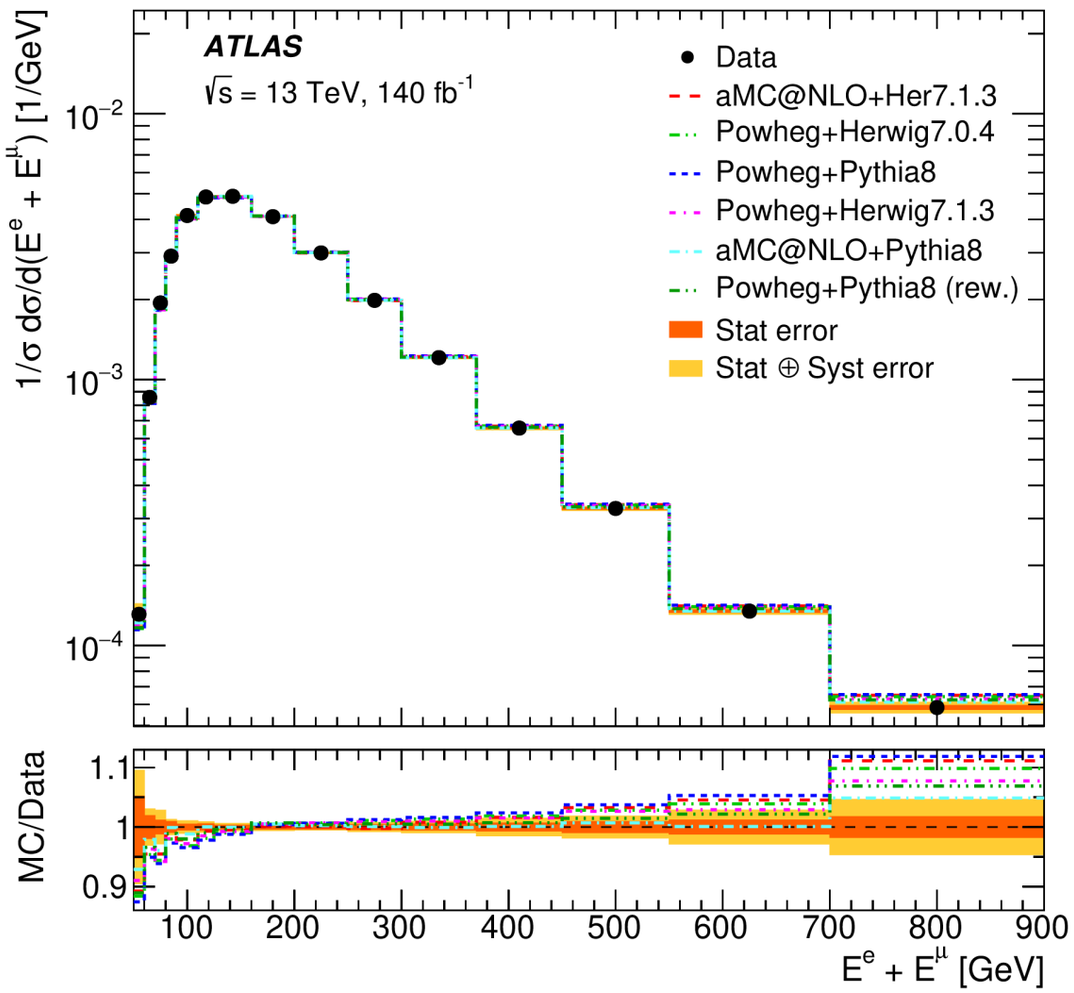
- Most precise measurement of σ_{tt} (±1.8%)
- Dominant uncertainties from: luminosity (0.9%), modelling of top boost (0.6%), *Wt* background (0.5%), Electron ID (0.5%)

Inclusive and differential cross-sections for dilepton $t\bar{t}$ production in $\sqrt{s}$=13 TeV

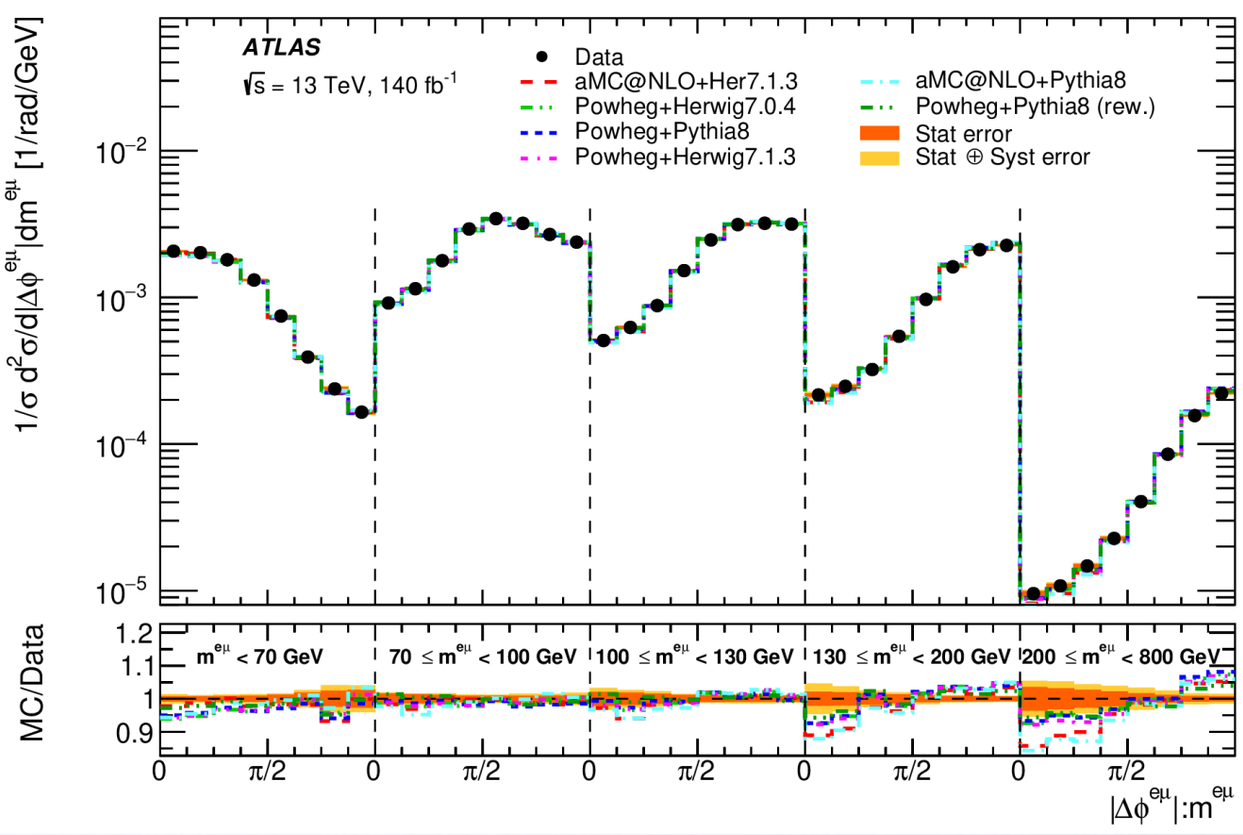
hep-ex arXiv:2303.15340

13 TeV, 140 fb^{-1}

Normalised differential cross-section as a function of E^e+E^μ



Normalised double-differential cross-sections as a function of $|\Delta\varphi^{e\mu}|$ in bins of $m^{e\mu}$



- The results are compared with the predictions from different Monte Carlo NLO generators normalised to the NNLO (Top++) prediction
- No model can describe **all** measured distributions within their uncertainties.

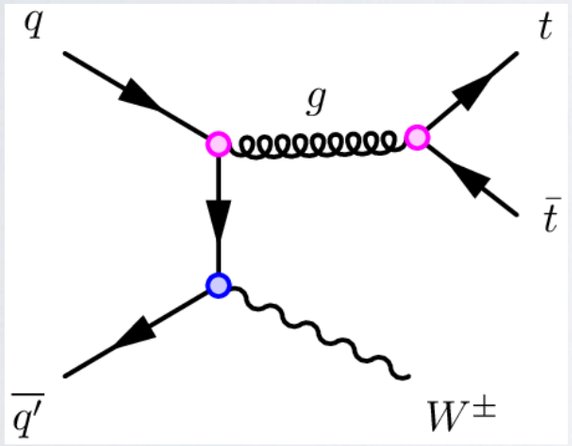
Measurement of total and differential cross-sections of $t\bar{t}W$ production

ATLAS-CONF-2023-019, March 2023
Updates earlier measurements with 3.2 fb^{-1} and 36.1 fb^{-1}

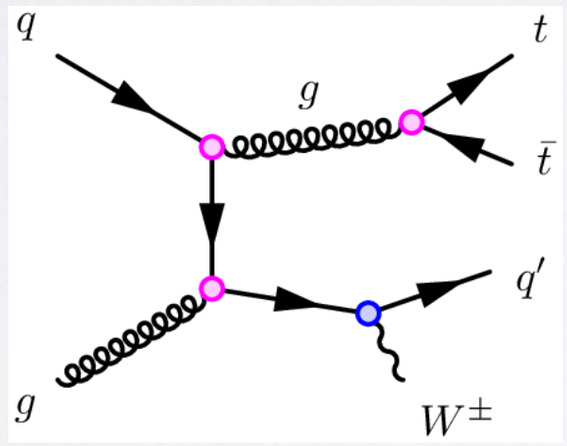
13 TeV, 140 fb^{-1}

- Very rare process, $\mathcal{O}$(1 pb), accessible with Run 2 data, and important background to rare *4-top* and $t\bar{t}H$ processes
- Recent measurements suggested $t\bar{t}W$ production yields slightly higher than SM (e.g. CMS: JHEP **08** (2018) 011)
- Rich phenomenology from charge-asymmetric production and QCD and EWK corrections

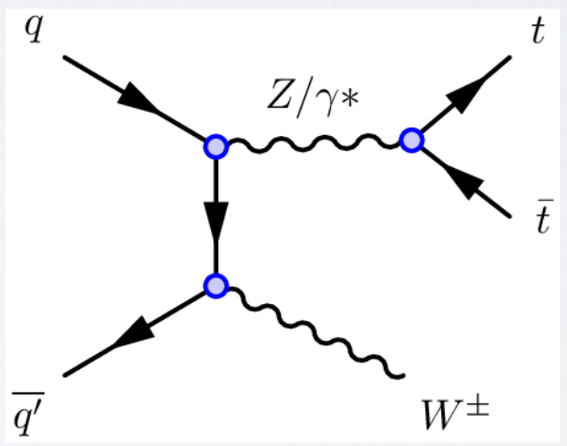
LO contribution ($\alpha_S{}^2$)



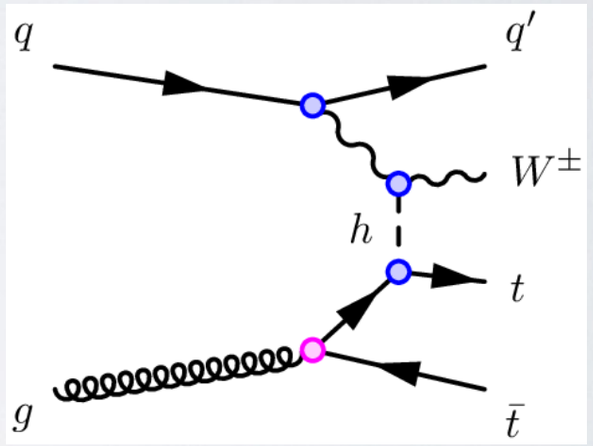
Real emission diagram NLO QCD contribution ($\alpha_S{}^3$)



Tree-level EWK contribution



Representative diagram of combined NLO QCD and EWK contributions (α_S)



- We measure the inclusive and differential cross sections, and relative charge asymmetry
- Theoretical prediction of $\sigma(t\bar{t}W) = 722^{+70}_{-78}$(scale) ± 7 (PDF) fb [JHEP **11** (2021) 029]

Measurement of total and differential cross-sections of $t\bar{t}W$ production

ATLAS-CONF-2023-019

13 TeV, 140 fb^{-1}

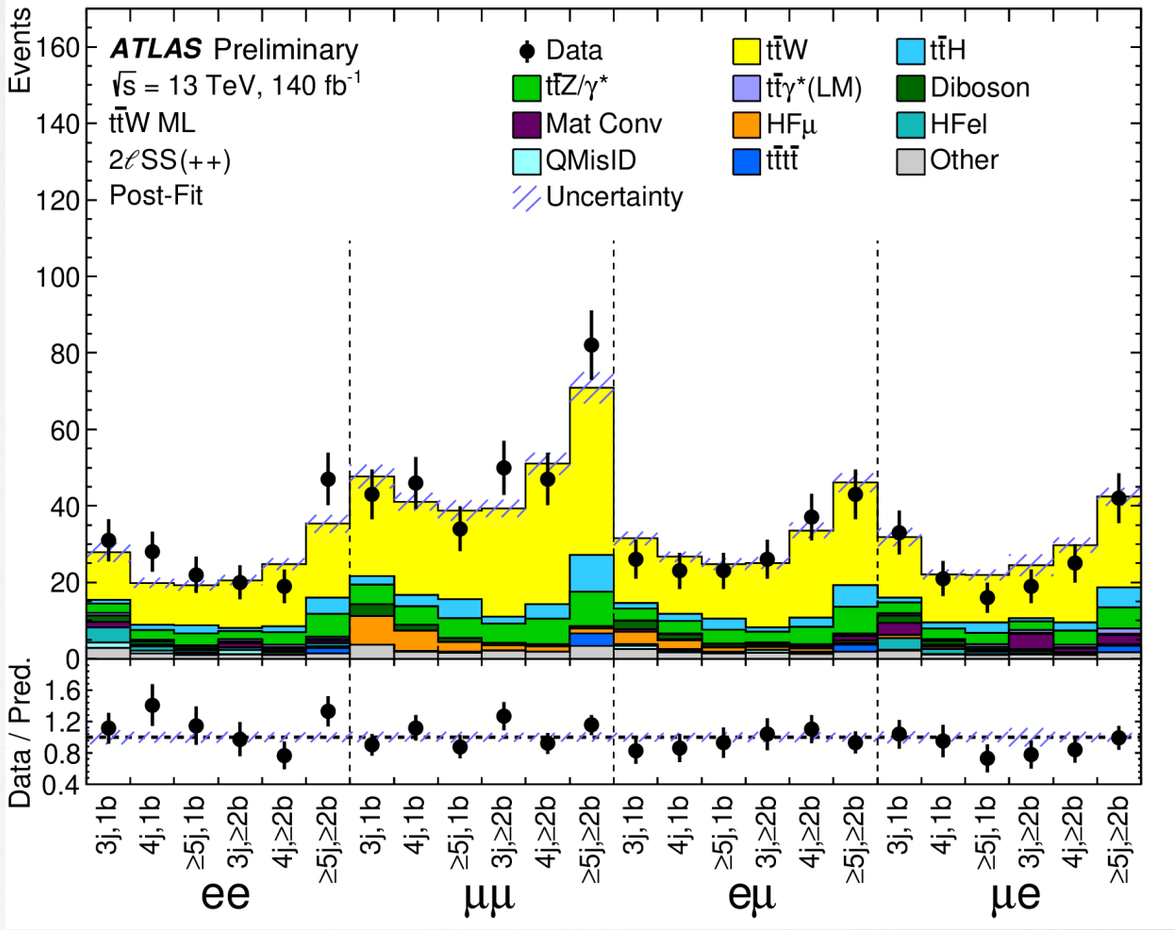
Signature: Two same-sign lepton (2ℓSS) or three lepton (3ℓ) final states

Method: Several Control (CR) and Signal Regions (SR); inclusive cross section measured in full phase space and in fiducial region. Combined likelihood fit to data under the signal plus background hypothesis

Summary of observed and predicted yields in the four signal region categories

	$\ell^-\ell^-$ SR	$\ell^+\ell^+$ SR	$\ell^+\ell^-\ell^-$ SR	$\ell^-\ell^+\ell^+$ SR
$t\bar{t}W$	261 ± 20	472 ± 30	64 ± 6	116 ± 10
$t\bar{t}H$	66 ± 9	66 ± 9	29 ± 4	28 ± 4
$t\bar{t}Z/\gamma^*$	95 ± 9	100 ± 10	69 ± 8	72 ± 8
$t\bar{t}\gamma^*$(LM)	9 ± 5	9 ± 5	2.6 ± 1.5	2.6 ± 1.5
Diboson	16 ± 5	22 ± 6	9.0 ± 2.7	12 ± 4
Mat Conv	11.1 ± 3.3	19 ± 5	2.5 ± 0.8	3.9 ± 1.1
HFμ	35 ± 11	30 ± 10	6.2 ± 2.6	6.6 ± 2.6
HFel	14 ± 6	15 ± 6	2.9 ± 1.3	2.0 ± 0.8
QMisID	8.2 ± 2.7	8.2 ± 2.7	0.69 ± 0.15	0.66 ± 0.13
$t\bar{t}t\bar{t}$	9 ± 7	9 ± 7	4.0 ± 3.2	4.2 ± 3.3
Other	32 ± 5	42 ± 6	18.6 ± 3.1	25.0 ± 3.3
Total	557 ± 16	790 ± 24	208 ± 7	273 ± 9
Data	546	803	225	269

Comparison between data and background prediction for the event yields in the 24 2ℓSS++ SR categories



Measurement of total and differential cross-sections of $t\bar{t}W$ production

ATLAS-CONF-2023-019

13 TeV, 140 fb^{-1}

Measurement Results

$$\sigma(t\bar{t}W) = 890 \pm 50\ (\text{stat.}) \pm 70\ (\text{syst.}) = 890 \pm 80\ (\text{tot.})\ \text{fb}$$

$$\sigma_{\text{fid}}(t\bar{t}W) = 21.7\ ^{+1.1}_{-1.1}\ (\text{stat.})\ ^{+2.1}_{-1.9}\ (\text{syst.}) = 21.7\ ^{+2.4}_{-2.2}\ (\text{tot.})\ \text{fb}$$

$$\sigma(t\bar{t}W^+) = 585\ ^{+35}_{-34}\ (\text{stat.})\ ^{+47}_{-44}\ (\text{syst.}) = 585\ ^{+58}_{-55}\ (\text{tot.})\ \text{fb}$$
$$\sigma(t\bar{t}W^-) = 301\ ^{+28}_{-27}\ (\text{stat.})\ ^{+35}_{-31}\ (\text{syst.}) = 301\ ^{+45}_{-41}\ (\text{tot.})\ \text{fb}$$

With leading systematics from $t\bar{t}W$ ME and PS modelling

In agreement (1.5σ) with NNLO prediction [arxiv 2108:07826]:

$$\sigma(t\bar{t}W) = 722\ ^{+70}_{-78}\ (\text{scale})\ \pm 7\ (\text{PDF})\ \text{fb}$$

$$A_{\text{C}}^{\text{rel}} = \frac{\sigma(t\bar{t}W^+) - \sigma(t\bar{t}W^-)}{\sigma(t\bar{t}W^+) + \sigma(t\bar{t}W^-)}.$$

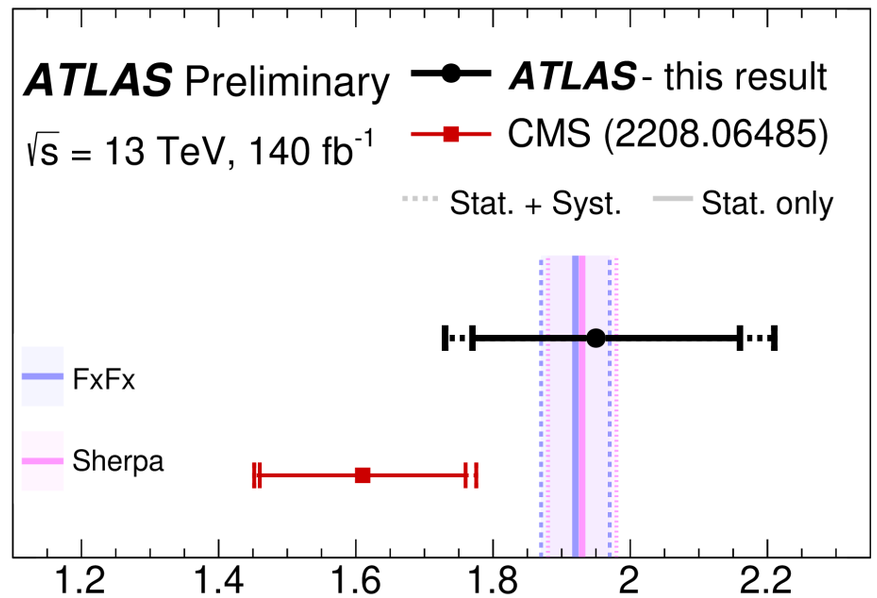
$$A_{\text{C}}^{\text{rel}} = 0.32 \pm 0.05\ (\text{stat.}) \pm 0.03\ (\text{syst.}) = 0.32 \pm 0.06\ (\text{tot.})$$

In agreement with Sherpa prediction:

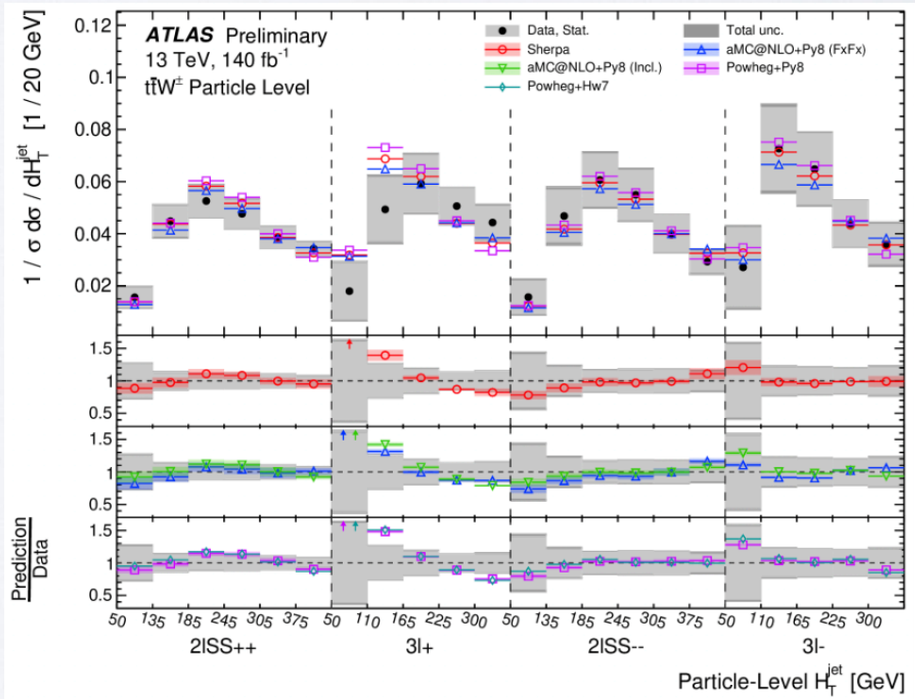
$$A_C^{\text{rel}} = 0.322 \pm 0.003(\text{scale}) \pm 0.007(\text{PDF})$$

First differential distributions, 7 variables; in good agreement

Comparison of the measured ttW^+/ttW^- cross section ratio to the theoretical predictions



Unfolded distributions of the lepton charge-split normalised cross section as a function of $H_{T,\text{jets}}$



Observation of four-top-quark production in the multilepton final state

- Process sensitive to top-Higgs Yukawa coupling and its CP properties
- Sensitive to BSM, including gluino pair, scalar-gluon, heavy-scalar or pseudoscalar bosons in 2HDM or top compositeness
- Predicted NLO QCD+EW @ $\sqrt{s}$=13 TeV is σ=12 fb with ±20% (scale) [JHEP 02 (2018) 031]

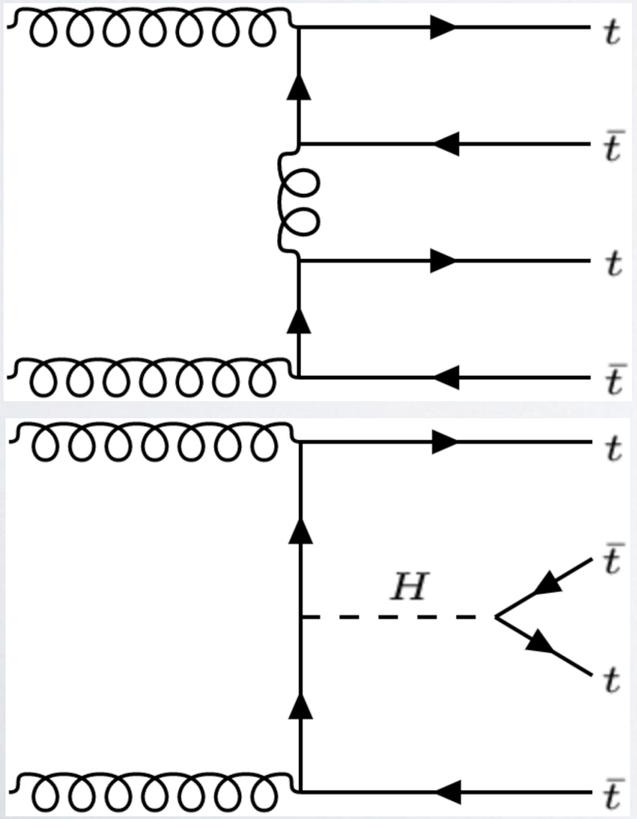
hep-ex arXiv:2303.15061
accepted by EPJC, March 2023
Supersedes and improves a previous result with same dataset

13 TeV, 140 fb^{-1}

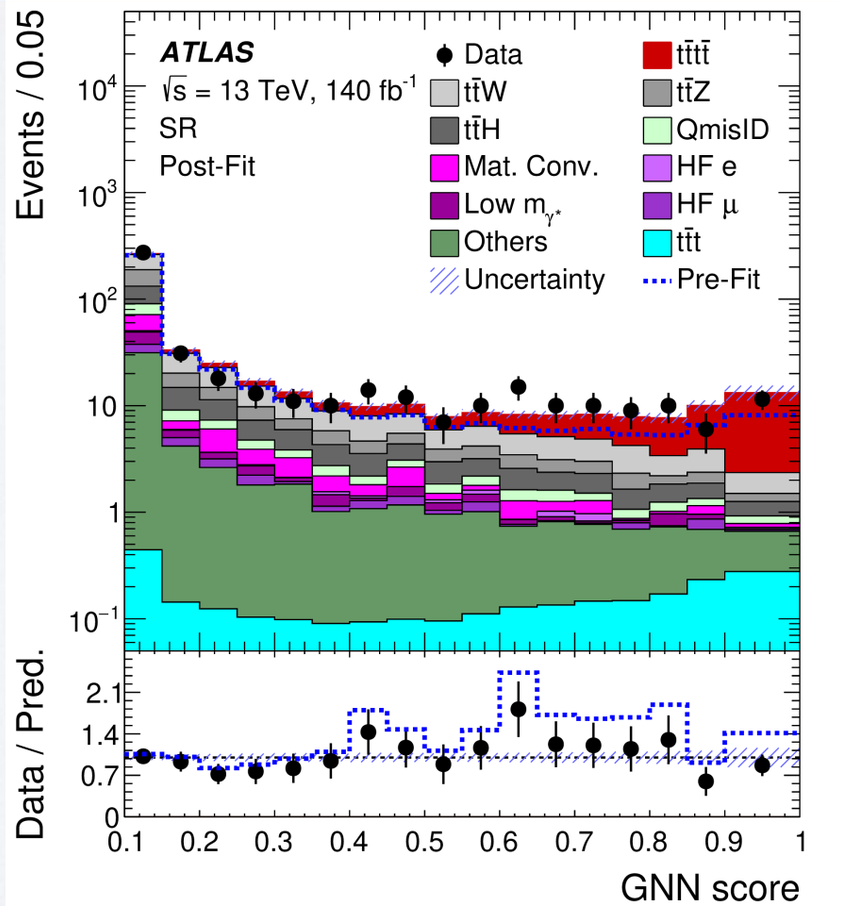
Signature: Two leptons with same electric charge (2LSS) or ≥3 leptons (e or μ, 3L) with high light-jet and *b*-jet multiplicity and high overall event energy

Method: Multivariate discriminant (Graph Neural Network) to separate signal and background

Tree-level Feynman diagrams for the SM $t\bar{t}t\bar{t}$ signal. The mediator connecting two top quarks can be a gluon, a neutral electroweak gauge boson (γ or Z), or a Higgs boson



Comparison between data and the predictions after a fit to data for the GNN distribution in the SR



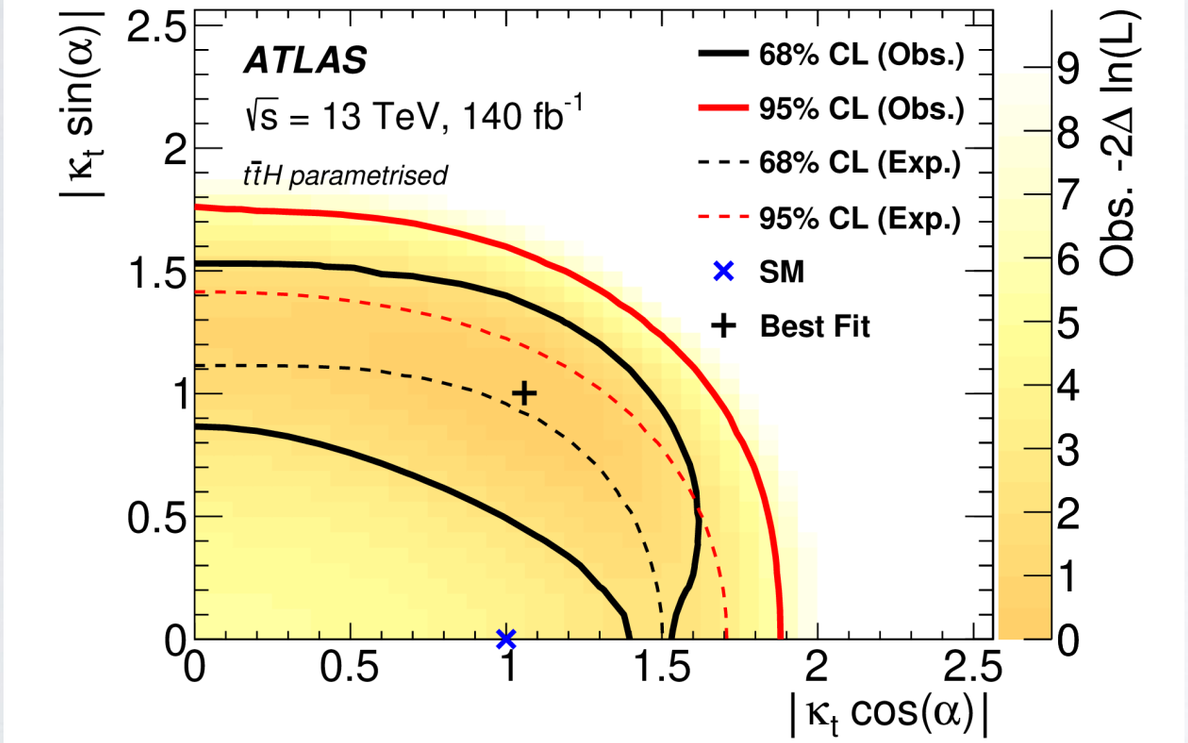
Observation of four-top-quark production in the multilepton final state

hep-ex arXiv:2303.15061

13 TeV, 140 fb^{-1}

Binned likelihood fit to the discriminant score for: σ_{tttt}, normalisation of backgrounds and $t\bar{t}W$

Likelihood contours for the top-Higgs Yukawa coupling strength and CP-even/odd mixing angle



Measured $t\bar{t}t\bar{t}$ cross section:

$$\sigma_{t\bar{t}t\bar{t}} = 22.5^{+4.7}_{-4.3}\,(\text{stat})\,^{+4.6}_{-3.4}\,(\text{syst})\ \text{fb} = 22.5\,^{+6.6}_{-5.5}\ \text{fb}.$$

consistent (1.7σ) with the new calculation QCD+EW NLO prediction, incl. NLL threshold resummation [arXiv: 2212.03259 [hep-ph]]:

$$\sigma_{t\bar{t}t\bar{t}} = 13.4^{+1.0}_{-1.8}\ \text{fb}$$

Largest systematic uncertainties from signal modelling (MC generator and PS and Hadronisation) and $t\bar{t}W$ background

Observation of single-top-quark production in association with a photon

- Probes non-resonant contributions from BSM physics
- Measurement in fiducial phase space at parton level with γ radiated from the top quark, and a fiducial cross section at particle level.

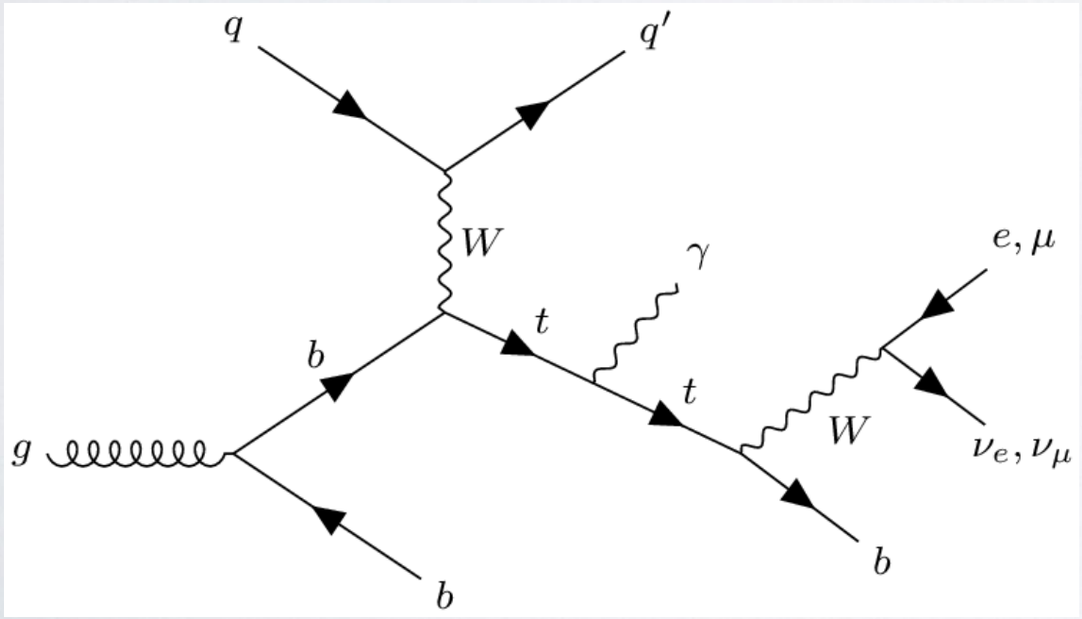
hep-ex arXiv:2302.01283
submitted to PRL, Feb. 2023
First ATLAS observation of this process

13 TeV, 139 fb^{-1}

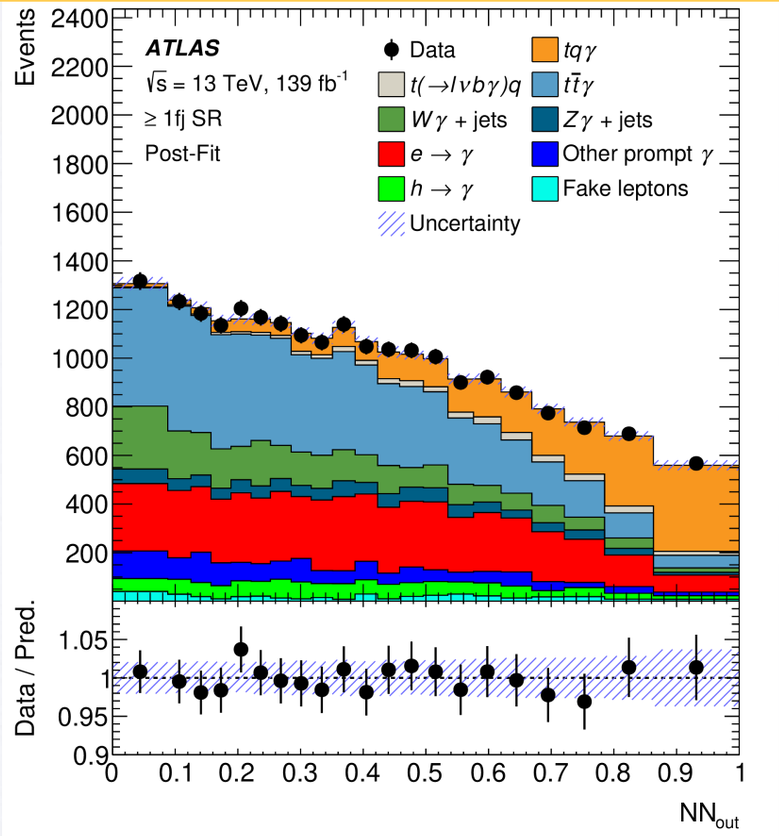
Signature: 1 γ, 1 e or μ, large MET, 1 b-jet, 1 forward jet identification, characteristic of t-channel. Two Signal Regions (SR) based on the presence or not of a forward jet.

Method: Trained Neutral Networks to separate signal from the background with 12 or 15 input variables, with top-mass the variable giving the largest S:B separation. Profile likelihood fit simultaneous in the CRs and SRs.

Representative Feynman diagram at LO in α_s for $tq\gamma$ production with semileptonic top-quark decay.



NN output in the SR with at least 1 forward jet, in data and the expected contribution of the signal and background processes



Observation of single-top-quark production in association with a photon

hep-ex arXiv:2302.01283

13 TeV, 139 fb^{-1}

Measured fiducial **parton**-level cross section:

$$\sigma_{tq\gamma} \times \mathcal{B}\,(t \to \ell\nu b) = 688 \pm 23\,(\text{stat.})\,^{+75}_{-71}\,(\text{syst.})\ \text{fb}$$

One photon with p_T > 20 GeV and $|\eta|$ < 2.37, isolated

[Phys. Lett. B 429 (1998) 369] with ΔR<0.2

consistent (2.1σ) with the QCD + EW NLO prediction, arXiv: 2106.02059 [hep-ph]

$$\sigma_{tq\gamma} \times \mathcal{B}\,(t \to \ell\nu b) = 515\,^{+36}_{-42}\ \text{fb}$$

Measured fiducial **particle**-level cross section (see definition in the paper):

$$\sigma_{tq\gamma} \times \mathcal{B}\,(t \to \ell\nu b) + \sigma_{t(\to\ell\nu b\gamma)q} = 303 \pm 9\,(\text{stat.})\,^{+33}_{-32}\,(\text{syst.})\ \text{fb}$$

consistent (2.0 σ) with the QCD + EW NLO prediction using the signal samples:

$$\sigma_{tq\gamma} \times \mathcal{B}\,(t \to \ell\nu b) + \sigma_{t(\to\ell\nu b\gamma)q} = 217\,^{+27}_{-15}\ \text{fb}$$

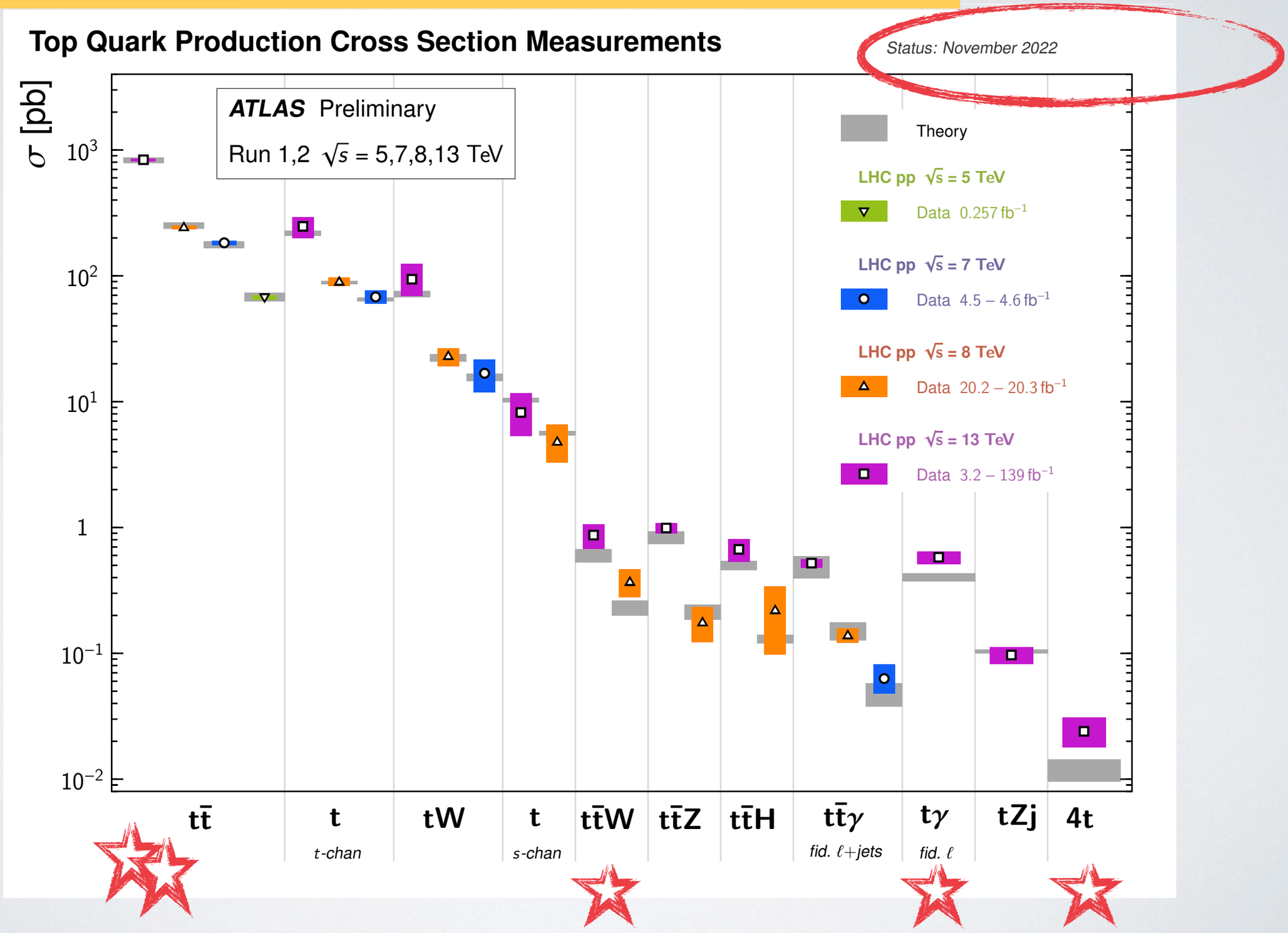
Impact of systematic uncertainties by category in the **parton**-level measurement

Uncertainty	$\Delta\sigma/\sigma$
$t\bar{t}\gamma$ modeling	±5.5%
Background MC statistics	±3.5%
$tq\gamma$ MC statistics	±3.3%
$t\bar{t}$ modeling	±2.4%
$tq\gamma$ modeling	±2.0%
$t\,(\to \ell\nu b\gamma)\,q$ modeling	±1.9%
Additional background uncertainties	±1.9%
$t\,(\to \ell\nu b\gamma)\,q$ MC statistics	±0.3%
$h \to \gamma$ photon fakes	±2.0%
Lepton fakes	±1.9%
$e \to \gamma$ photon fakes	±0.6%
Luminosity	±2.2%
Pileup	±1.2%
Jets and E_T^{miss}	±3.6%
Photons	±2.5%
Leptons	±0.9%
b-tagging	±0.9%
Total systematic uncertainty	±10.6%

Summary of Top Quark Production Measurements

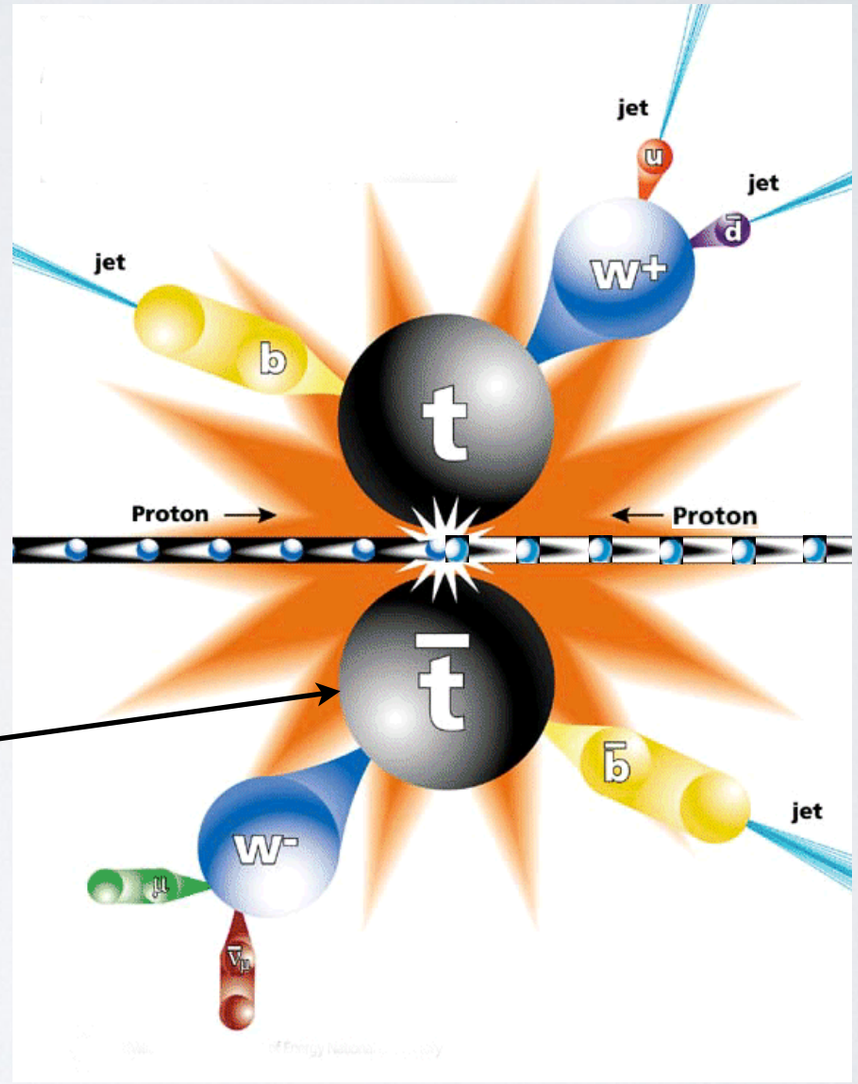
Summary of several top-quark related production cross-section measurements, compared to the corresponding theoretical expectations. All theoretical expectations were calculated at NLO or higher. **ATL-PHYS-PUB-2022-051**

: new, shown today



PART 2: PROPERTIES

- Test of SM (production, decay, coupling....etc)
- Top quark does not hadronize: momentum and spin transferred to decay products
- Search for processes with similar signature (VLQ, Z'...)
- Natural mass ($y_t \simeq 1$), top quark mass is a fundamental parameter of the SM, and crucial for SM constraints via loop diagrams



Properties
- Top mass
- Top charge
- Top width
- Spin correlation
- Top polarisation
- W helicity
- Charge asymmetry
- Yukawa coupling

RED: new results (since Jan. 2023), discussed in this talk

Search for leptonic charge asymmetry in $t\bar{t}W$ production in final states with 3 leptons

- Rare SM process with large perturbative corrections and BSM sensitivity.
- Relative dominance of qq^{-}' initial state in $t\bar{t}W$ enhances the rapidity charge asymmetry wrt standard tt events. Measurements oriented to the **leptonic** charge asymmetry:

$$A_{\mathrm{c}}^{\ell} = \frac{N\left(\Delta\eta^{\ell} > 0\right) - N\left(\Delta\eta^{\ell} < 0\right)}{N\left(\Delta\eta^{\ell} > 0\right) + N\left(\Delta\eta^{\ell} < 0\right)},$$

hep-ex arXiv:2301.04245
submitted to JHEP, Jan. 2023
First measurement for $t\bar{t}W$

13 TeV, 139 fb^{-1}

Signature: Exactly 3 charged light-leptons (e or μ) in the final state. Requirements on the number of jets and *b*-tagged jets, are imposed to define 4 Signal Regions

Method: Profile likelihood fit to the event yields in pseudorapidities of the charged leptons from top and anti-top quark. BDT classifier for the lepton-top association, with ~71% efficiency

Measured leptonic charge asymmetry:

$$A_{\mathrm{c}}^{\ell}(t\bar{t}W) = -0.123 \pm 0.136\,(\mathrm{stat.}) \pm 0.051\,(\mathrm{syst.})$$

Consistent with the SM expectation of:

$$A_{\mathrm{c}}^{\ell}(t\bar{t}W)_{\mathrm{SM}} = -0.084\,^{+0.005}_{-0.003}\,(\mathrm{scale}) \pm 0.006\,(\mathrm{MC\ stat.})$$

Measured $A_C{}^{\ell}$ at Particle Level:

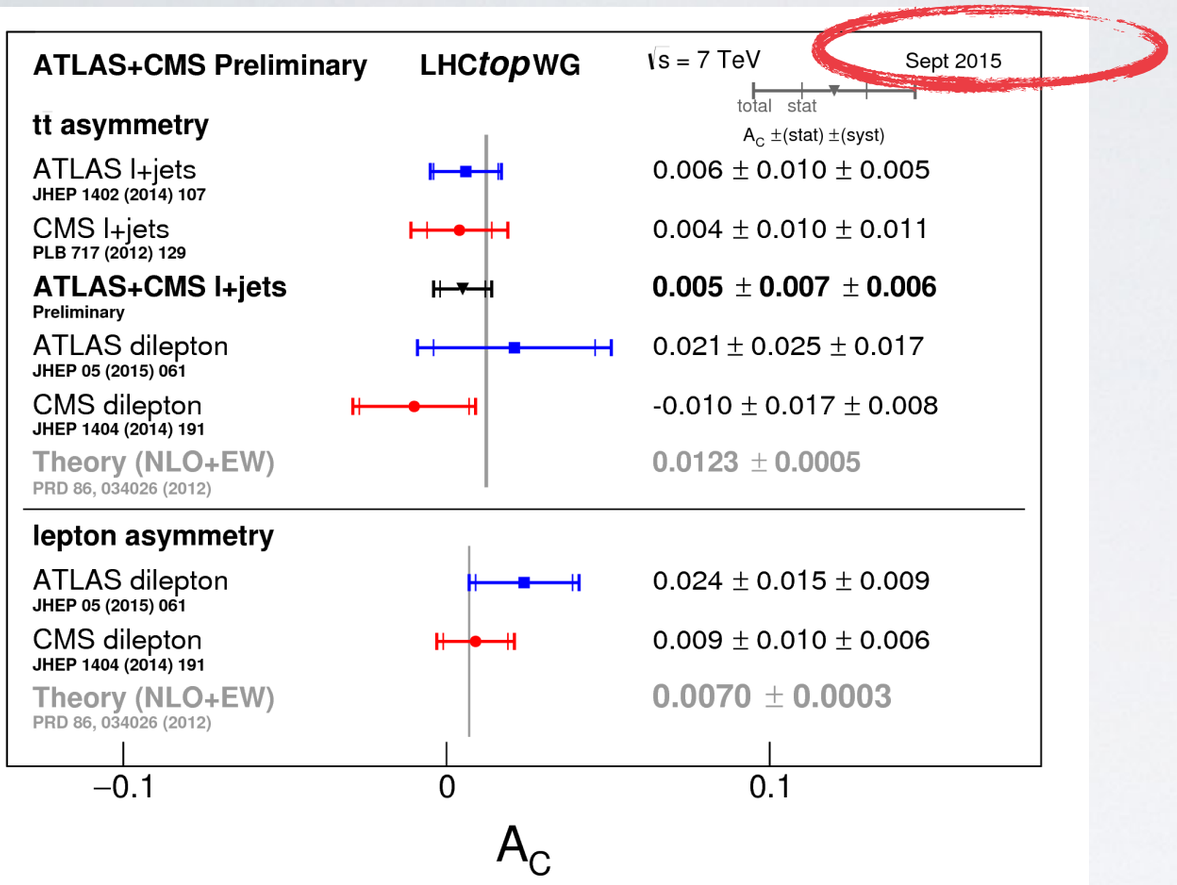
$$A_{\mathrm{c}}^{\ell}(t\bar{t}W)^{\mathrm{PL}} = -0.112 \pm 0.170\,(\mathrm{stat.}) \pm 0.054\,(\mathrm{syst.})$$

SM expectation from *ttW* Sherpa:

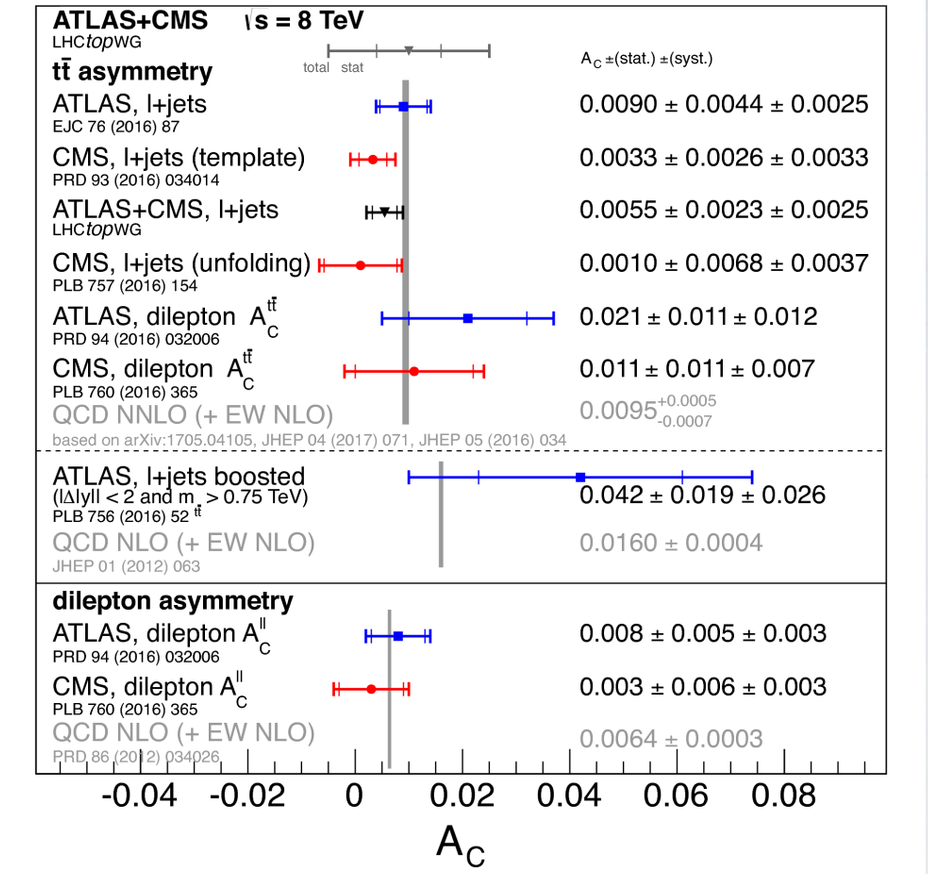
$$A_{\mathrm{c}}^{\ell}(t\bar{t}W)^{\mathrm{PL}}_{\mathrm{SM}} = -0.063\,^{+0.007}_{-0.004}\,(\mathrm{scale}) \pm 0.004\,(\mathrm{MC\ stat.})$$

Summary of Other Charge Asymmetry Measurements

Summary of the charge asymmetry measurements on ATLAS and CMS at **7 TeV** showing both the ttbar-based and lepton-based asymmetry measurements



Summary of the charge asymmetry measurements on ATLAS and CMS at **8 TeV** showing both inclusive measurements and the measurement using boosted events (2017)



Combination of inclusive and differential $t\bar{t}$ CA measurements, ATLAS and CMS at $\sqrt{s}$ = 7 and 8 TeV:

A_C^{LHC7} = 0.005 ± 0.007 (stat) ±0.006 (syst) at 7 TeV and
A_C^{LHC8} = 0.0055 ± 0.0023 (stat) ± 0.0025 (syst) at 8 TeV.

JHEP **04** (2018) 033, arXiv: 1709.05327 [hep-ex].

Evidence for charge asymmetry in $t\bar{t}$ production (13 TeV):

$$A_C^{t\bar{t}} = 0.0068 \pm 0.0015$$

[hep-ex] arXiv:2208.12095 accepted by JHEP, Aug. 2022

Charge asymmetry in $t\bar{t}\gamma$ (13 TeV):

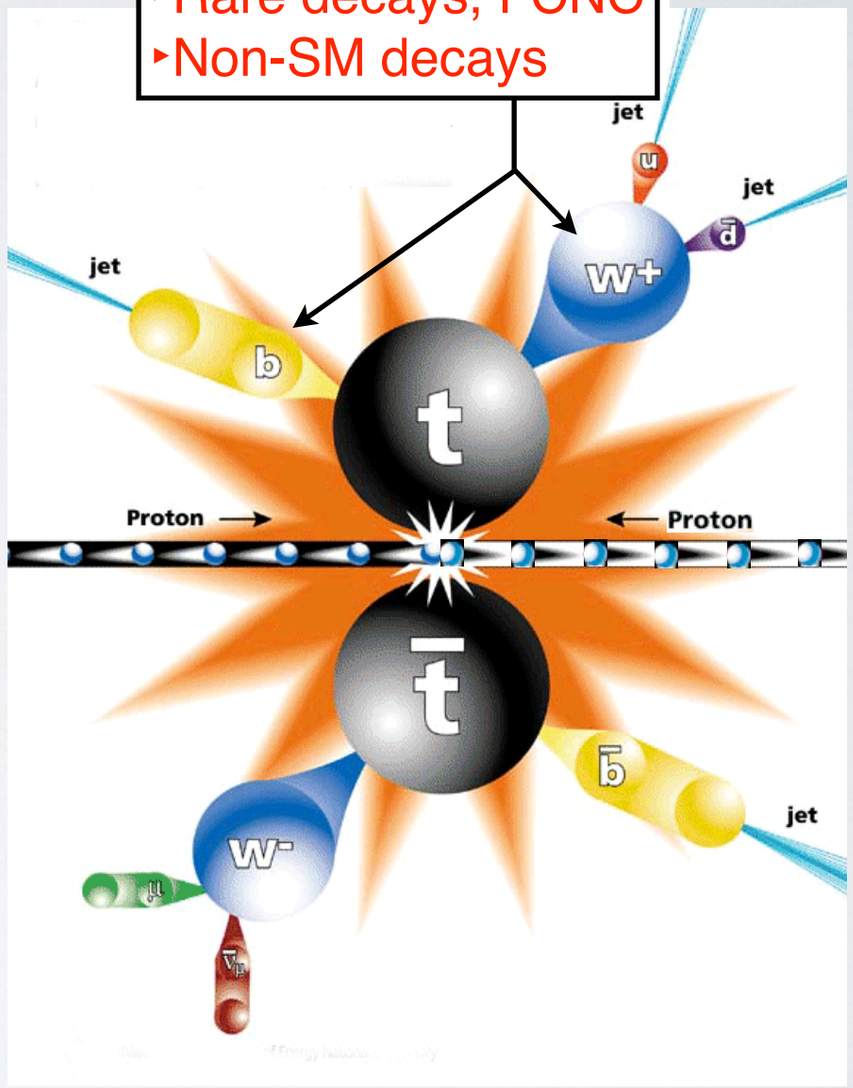
$$A_C = -0.003 \pm 0.029 = -0.003 \pm 0.024(\text{stat}) \pm 0.017(\text{syst})$$

[hep-ex] arXiv:2212.10552 accepted by Phys. Lett. B, Dec. 2022

PART 3: DECAY

- Test of SM (production, decay, coupling....etc)
- Top quark does not hadronize: momentum and spin transferred to decay products
- Search for processes with similar signature (VLQ, Z'...)
- Natural mass ($y_t \simeq 1$), top quark mass is a fundamental parameter of the SM, and crucial for SM constraints via loop diagrams

Decay
- Branching ratios
- CP asymmetries
- Rare decays, FCNC
- Non-SM decays



RED: new results (since Jan. 2023), discussed in this talk

Search for flavour-changing neutral-current couplings between the top quark and the Z boson

hep-ex arXiv:2301.11605
submitted to Phys. Rev. D, Jan. 2023
Supersedes previous analysis with 36.1 fb^{-1}

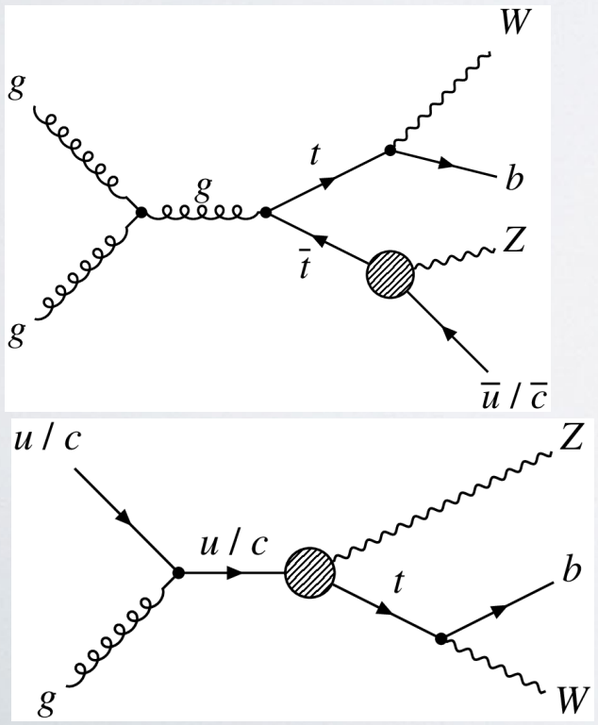
13 TeV, 139 fb^{-1}

- FCNC tZq forbidden at tree-level in SM, suppressed at higher orders, leading to BR of top FCNC decay $\mathcal{O}$ (10^{-14})
- Several SM extensions enhance BR up to 10^{-4}—10^{-7}
- Search for FCNC in both production ($gq \to tZ$) and decay of tops ($t \to Zq$), with sensitivity to tZu and tZc

Signature: Trileptonic final state, a b-tagged jet, possible additional jets and MET

Method: Multivariate technique (Gradient Boosted Decision Tree) to improve the separation Signal vs Background and binned profile likelihood fit to data. Two different optimised Signal Regions

Examples of the lowest-order Feynman diagrams for FCNC decay and production



Overview of the requirements applied to select the events in the signal regions

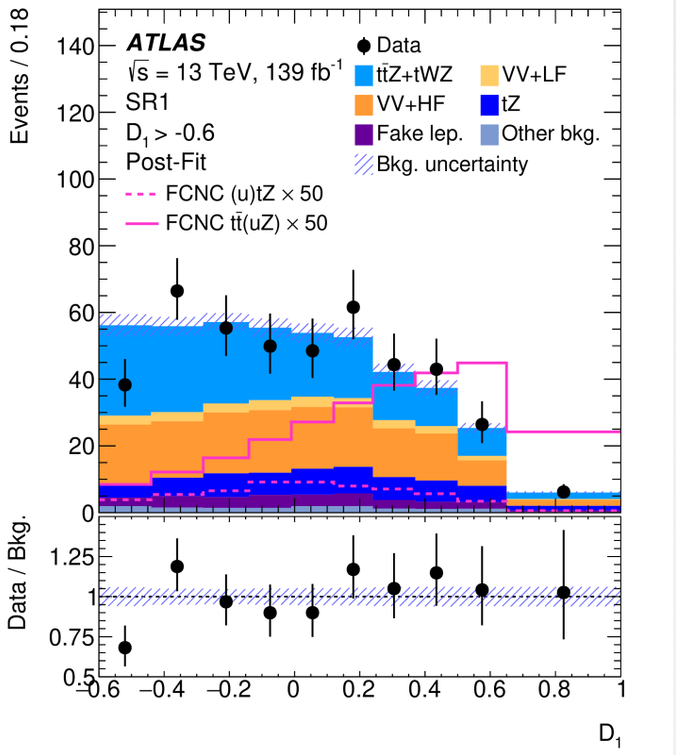
Common selections		
Exactly 3 leptons with $p_{\mathrm{T}}(\ell_1) > 27\,\mathrm{GeV}$ ≥ 1 OSSF pair, with $\lvert m_{\ell\ell} - m_Z \rvert < 15\,\mathrm{GeV}$		
SR1	SR2	
≥ 2 jets	1 jet	2 jets
1 b-jet	1 b-jet	1 b-jet
–	$m_{\mathrm{T}}(\ell_W, \nu) > 40\,\mathrm{GeV}$	$m_{\mathrm{T}}(\ell_W, \nu) > 40\,\mathrm{GeV}$
$\lvert m^{\mathrm{reco}}_{j_a \ell\ell} - m_t \rvert < 2\sigma_{t_{\mathrm{FCNC}}}$	–	$\lvert m^{\mathrm{reco}}_{j_a \ell\ell} - m_t \rvert > 2\sigma_{t_{\mathrm{FCNC}}}$
–	$\lvert m^{\mathrm{reco}}_{j_b \ell_W \nu} - m_t \rvert < 2\sigma_{t_{\mathrm{SM}}}$	$\lvert m^{\mathrm{reco}}_{j_b \ell_W \nu} - m_t \rvert < 2\sigma_{t_{\mathrm{SM}}}$

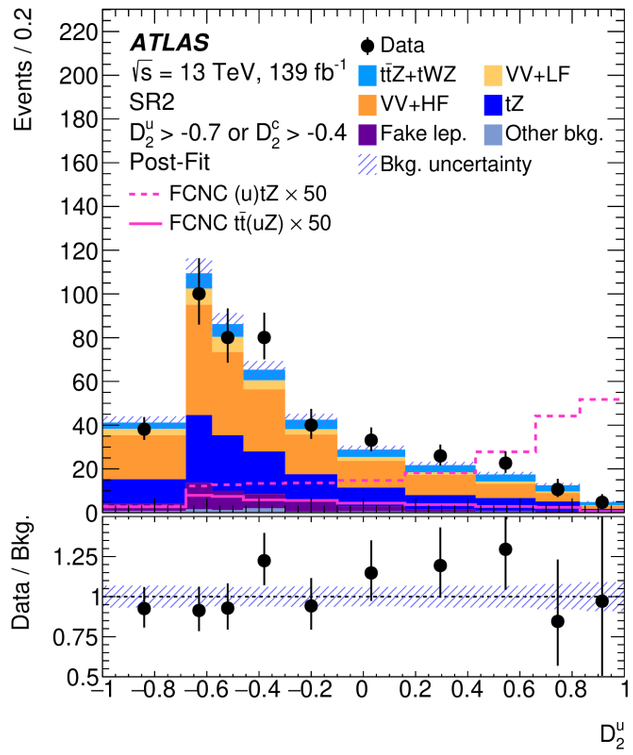
Search for FCNC couplings between the top quark and the Z boson

hep-ex arXiv:2301.11605

13 TeV, 139 fb^{-1}

Comparison between data and background prediction after the fit to data (Post-Fit) for the FCNC *tZu* LH coupling extraction for the fitted distributions in the SRs





Observed and expected 95% CL limits on FCNC $t\to Zq$ branching ratios and the effective coupling strengths for different vertices and couplings (top eight rows).

Observable	Vertex	Coupling	Observed	Expected
	SRs+CRs			
$\mathcal{B}(t \to Zq)$	tZu	LH	6.2×10^{-5}	$4.9\,^{+2.1}_{-1.4}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZu	RH	6.6×10^{-5}	$5.1\,^{+2.1}_{-1.4}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZc	LH	13×10^{-5}	$11\,^{+5}_{-3}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZc	RH	12×10^{-5}	$10\,^{+4}_{-3}\times10^{-5}$
$\lvert C_{uW}^{(13)*}\rvert$ and $\lvert C_{uB}^{(13)*}\rvert$	tZu	LH	0.15	$0.13\,^{+0.03}_{-0.02}$
$\lvert C_{uW}^{(31)}\rvert$ and $\lvert C_{uB}^{(31)}\rvert$	tZu	RH	0.16	$0.14\,^{+0.03}_{-0.02}$
$\lvert C_{uW}^{(23)*}\rvert$ and $\lvert C_{uB}^{(23)*}\rvert$	tZc	LH	0.22	$0.20\,^{+0.04}_{-0.03}$
$\lvert C_{uW}^{(32)}\rvert$ and $\lvert C_{uB}^{(32)}\rvert$	tZc	RH	0.21	$0.19\,^{+0.04}_{-0.03}$
	SR1+CRs			
$\mathcal{B}(t \to Zq)$	tZu	LH	9.7×10^{-5}	$8.6\,^{+3.6}_{-2.4}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZu	RH	9.5×10^{-5}	$8.2\,^{+3.4}_{-2.3}\times10^{-5}$
	SR2+CRs			
$\mathcal{B}(t \to Zq)$	tZu	LH	7.8×10^{-5}	$6.1\,^{+2.7}_{-1.7}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZu	RH	9.0×10^{-5}	$6.6\,^{+2.9}_{-1.8}\times10^{-5}$

Search for a new scalar resonance in FCNC top-quark decays $t \to qX$ ($q=u,c$), with $X \to b\bar{b}$

hep-ex arXiv:2301.03902
accepted by JHEP, Jan. 2023
Extends searches with $H \to bb$

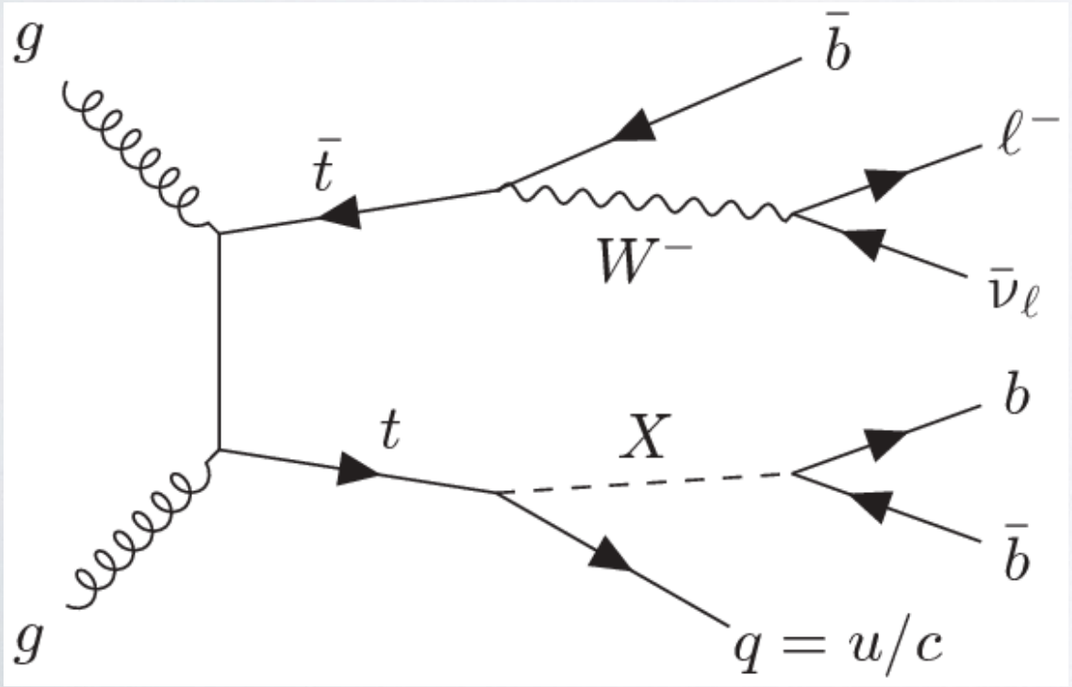
13 TeV, 139 fb^{-1}

- Some BSM models predict the existence of new particles (neutral scalar, a pseudoscalar, or an axion-like particle ALP), which are strongly coupled with third generation quarks
- In Froggatt-Nielsen SM extension mechanism [Nucl. Phys. B. **147** (1979) 277], for example, $X \to b\bar{b}$ is the leading decay

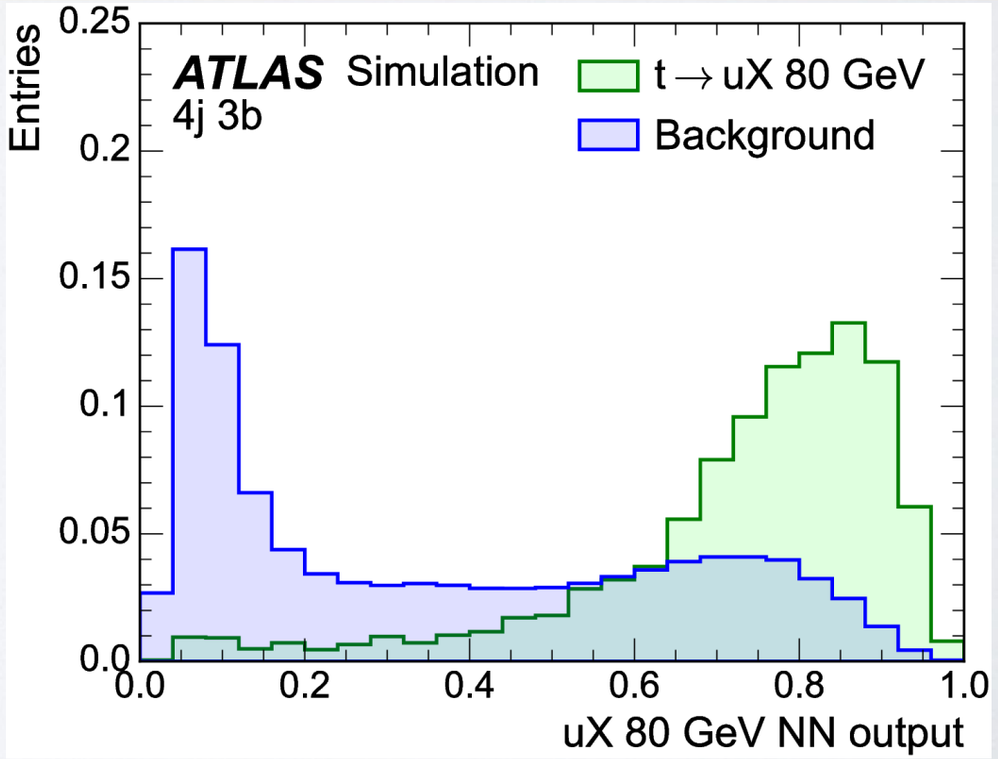
Signature: Leptonic W decay from the SM top decay. Isolated e or μ and ≥ 4 jets (3 b-tagged)

Method: Neural Network discriminant between Signal and Background. 3 Signal Regions.

Leading-order Feynman diagram for the production of a scalar particle X in association with a top quark



NN output distributions in the *4j 3b* signal region for top-quark decays to ***uX*** under the 80 GeV X mass hypothesis.



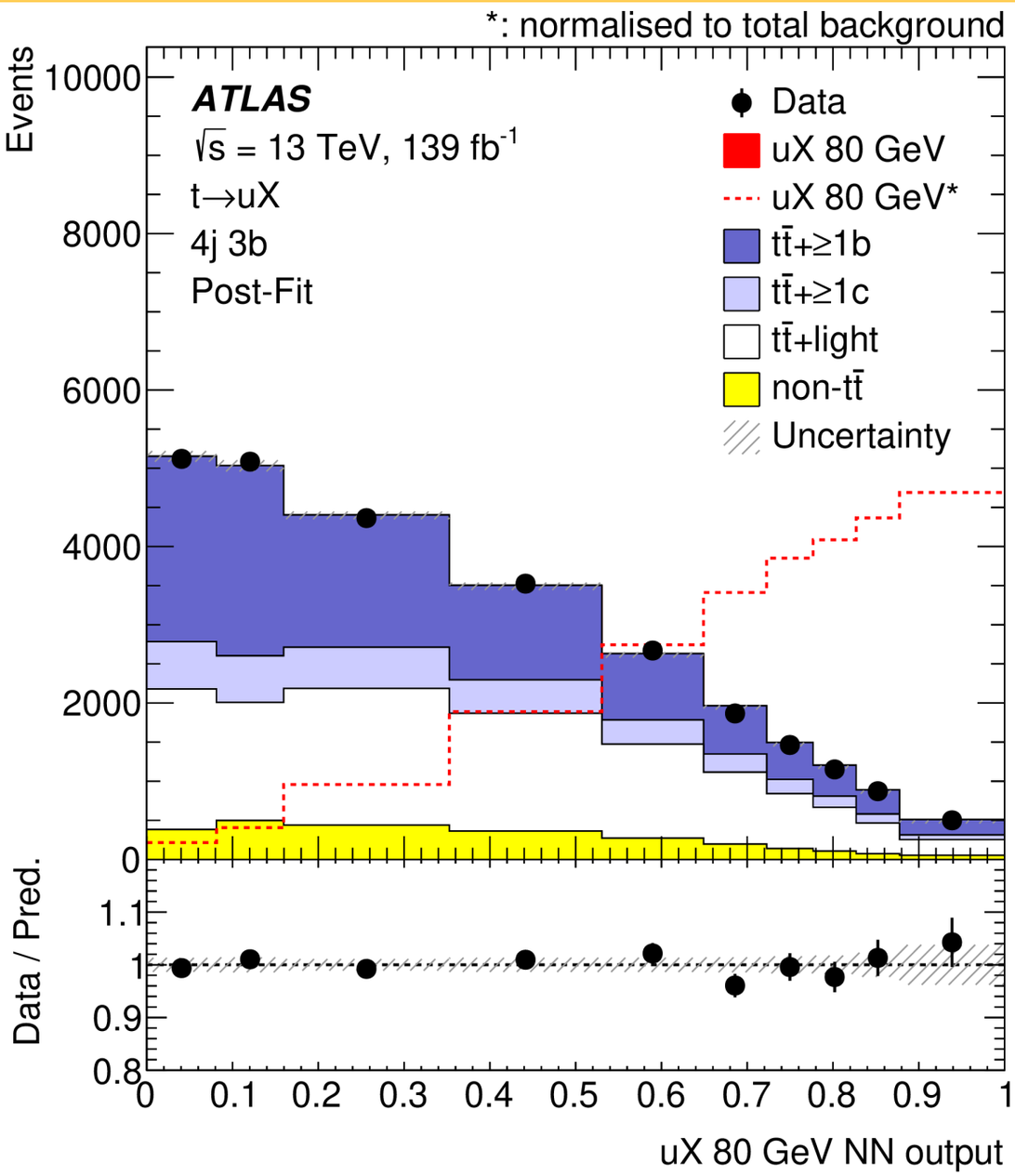
Search for a new scalar resonance in FCNC top-quark decays $t \to qX$ ($q=u,c$), with $X \to b\bar{b}$

arXiv:2301.03902

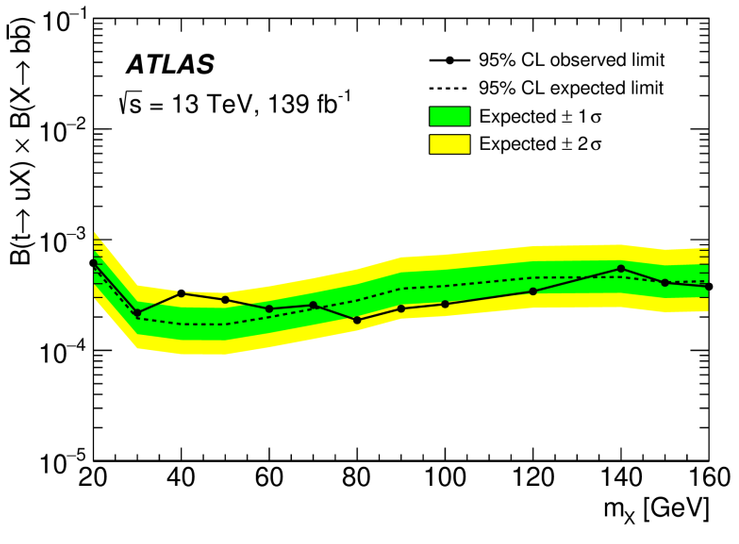
13 TeV, 139 fb^{-1}

Binned maximum-likelihood fit to data for $t \to qX$ and the backgrounds

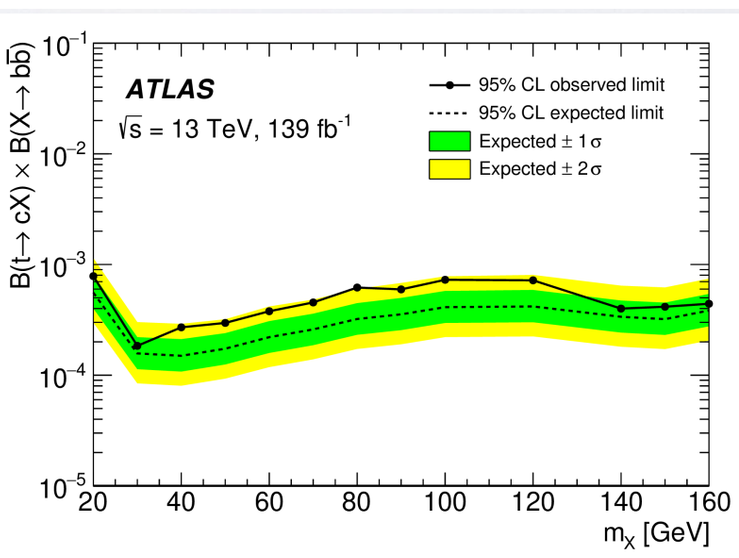
Data and prediction for the NN output in the 4j 3b region for the $t \to uX$ process after the S+B fit to data for the 80 GeV X scalar mass hypothesis.



Expected and observed 95% CL upper limits



CL$_{95}$ B($t \to uH$): 0.077%(0.088%) obs(expc)



CL$_{95}$ B($t \to cH$): 0.12%(0.076%) obs(expc)

Limits improve by a factor of ~3 earlier analysis with 36 fb^{-1} regarding $t \to qH$ ($H \to b\bar{b}$) [JHEP **05** (2019) 123] and similar to $t \to qH$ ($H \to \tau^+\tau^-$) [hep-ex arXiv:2208.11415 (2022)]

Search for charged-lepton-flavour violating $\mu\tau qt$ interactions in top-quark production and decay

- cLFV would provide strong evidence for BSM physics
- Extensions of the SM with leptoquarks, including SUSY and technicolor models provide cLFV with sizeable rates
- Searching for production of a single top quark via $gq_k \to t\ell^{\pm}\ell'^{\mp}$ with $k = \{1, 2\}$ and $\ell\ell' = \{\mu\tau, \tau\mu\}$ and top decay in *tt via* $t \to \ell^{\pm}\ell'^{\mp}q_k$

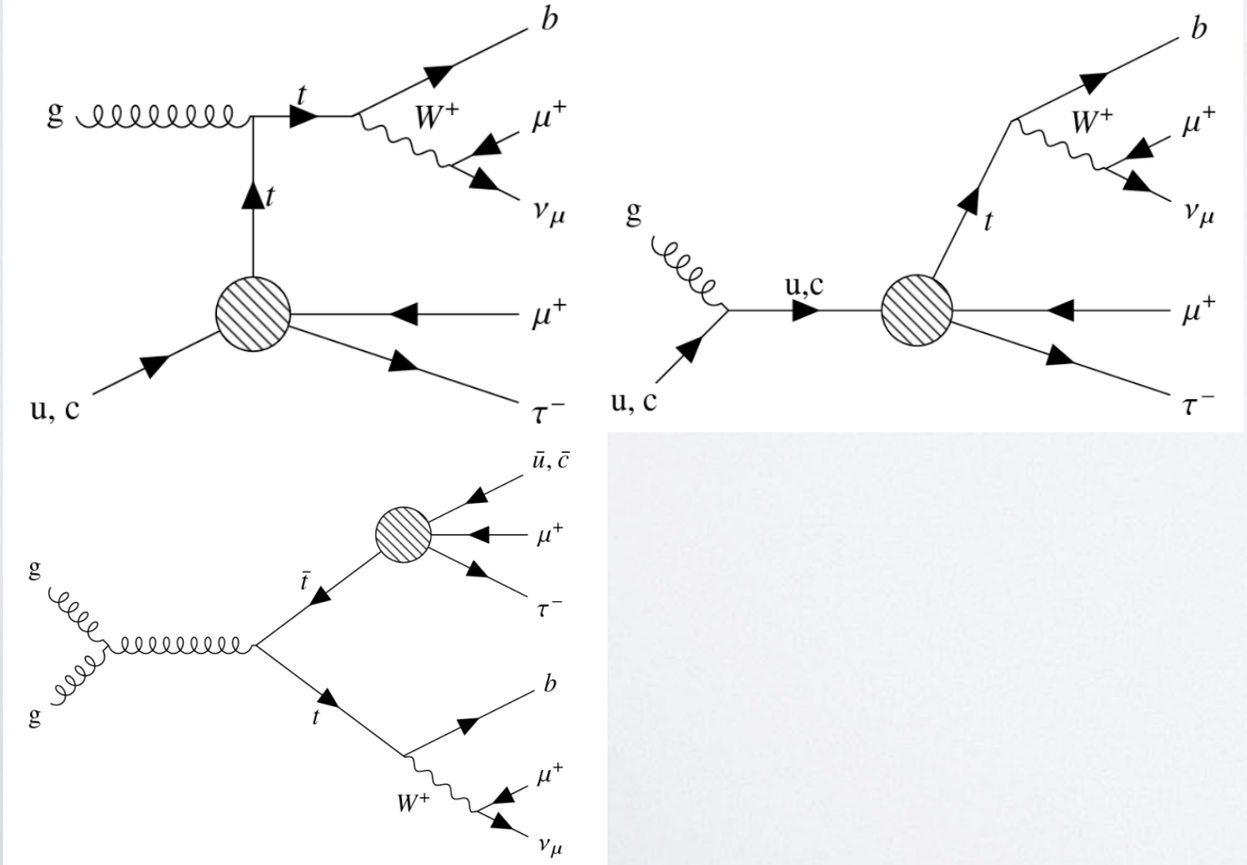
ATLAS-CONF-2023-001, Jan. 2023
Complements earlier constraints on Wilson coefficients from FCNC *tZq*

13 TeV, 139 fb^{-1}

Signature: 2 μ (SS), 1 τ-hadronic, and 1 or more jets one of which *b*-tagged (SR1, SR2)

Method: Binned profile-likelihood fit to event yields. CR$t\bar{t}\mu$ is included in the fit, to determine the normalisation of the non-prompt muon background

Example Feynman diagrams of the process under study, where the hashed circle represents the cLFV vertex



Requirements for each analysis region. The symbol ℓ_3 denotes the lowest p_T lepton.

	SR1	SR2	CRτ	CR$tt\mu$
Lepton flavour	$2\mu 1\tau_{\text{had-vis}}$			$2\mu 1e$ ($\ell_3 = \mu$)
N_{jets}	≥ 2	1	≥ 2	≥ 2
$N_{b-\text{tags}}$	1	1	1	≤ 2
Muon p_T cut	> 15 GeV	> 15 GeV	> 15 GeV	> 10 GeV
Lowest p_T muon selection	*Tight*	*Tight*	*Tight*	*Loose*
Muon charges	SS	SS	OS	-
$\lvert m_{\mu\mu}^{OS} - M_Z \rvert$	-	-	<10 GeV	>10 GeV

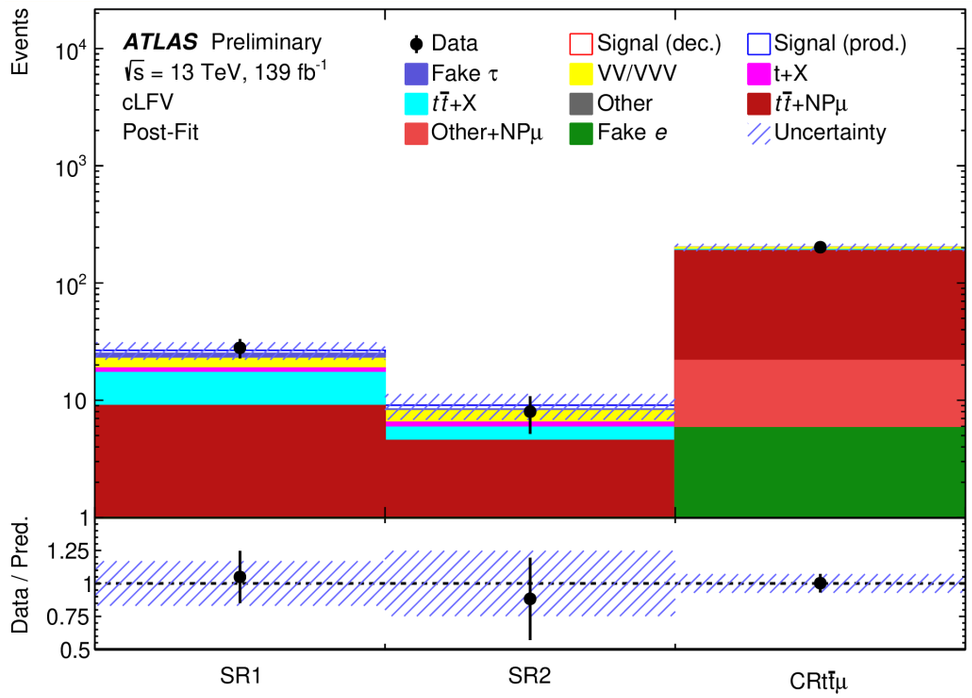
CRτ only used to estimate the fake τ background, not in the fit

Search for cLFV $\mu\tau qt$ interactions in top-quark production and decay

ATLAS-CONF-2023-001

13 TeV, 139 fb^{-1}

Observed event yields in SRs and CRtt̄μ compared to post-fit expectations from Monte Carlo simulations



Expected and observed 95% CL upper limits on Wilson coefficients corresponding to 2Q2L EFT operators which could introduce cLFV top decay in the μτ channel, and existing limits from analysis [22]: arXiv: 1809.09624 [hep-ph]

	95% CL upper limits on Wilson coefficients c/Λ^2 [TeV^{-2}]							
	$c_{lq}^{-(ijk3)}$	$c_{eq}^{(ijk3)}$	$c_{lu}^{(ijk3)}$	$c_{eu}^{(ijk3)}$	$c_{lequ}^{1(ijk3)}$	$c_{lequ}^{1(ij3k)}$	$c_{lequ}^{3(ijk3)}$	$c_{lequ}^{3(ij3k)}$
Previous (u) [22]	12	12	12	12	26	26	3.4	3.4
Expected (u)	0.47	0.44	0.43	0.46	0.49	0.49	0.11	0.11
Observed (u)	0.49	0.47	0.46	0.48	0.51	0.51	0.11	0.11
Previous (c) [22]	14	14	14	14	29	29	3.7	3.7
Expected (c)	1.6	1.6	1.5	1.6	1.8	1.8	0.35	0.35
Observed (c)	1.7	1.6	1.6	1.6	1.9	1.9	0.37	0.37

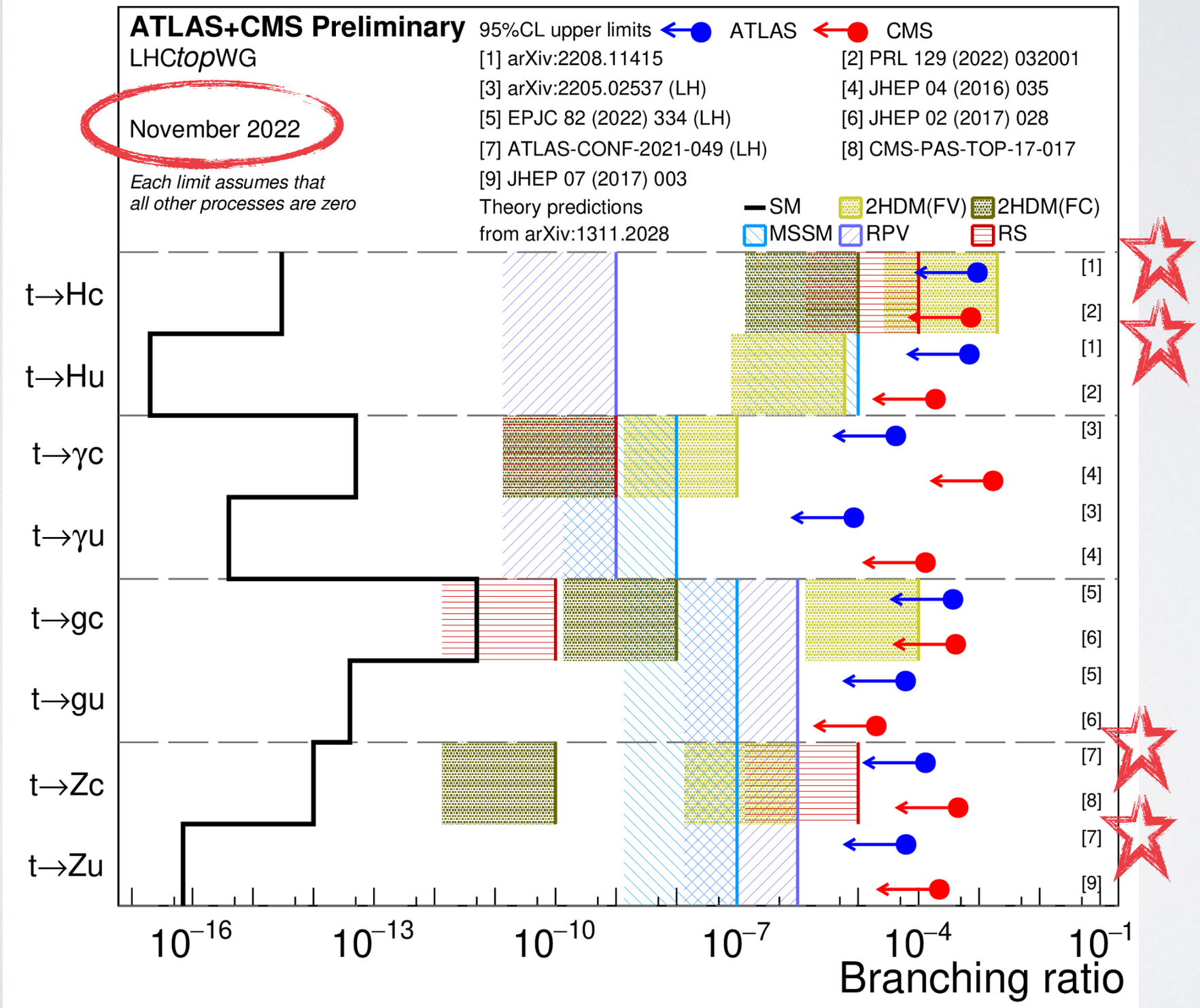
Expected and observed 95% CL upper limits on the inclusive branching ratio corresponding to the decay of a top quark to a muon and a τ lepton through a cLFV process.

	95% CL upper limits on BR($t \to \mu\tau q$)	
	Stat. only	**All systematics**
Expected	8×10^{-7}	10×10^{-7}
Observed	9×10^{-7}	11×10^{-7}

Summary of Other FCNC Measurements

Summary of the current 95% confidence level observed limits on the branching ratios of the top quark decays via flavour changing neutral currents (FCNC) to a quark and a neutral boson t → Xq (X = g, Z, γ or H; q=u or c) **ATL-PHYS-PUB-2022-049**

★ : new, shown today



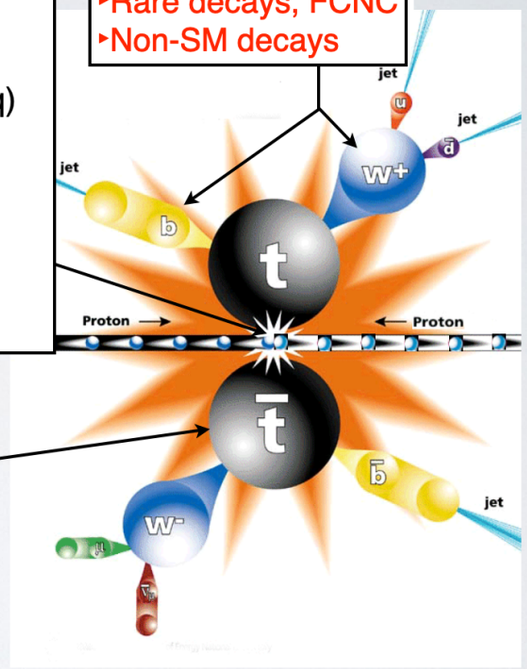
SUMMARY

Production Rate
- Pair Production cross section
- Single (EWK) production, |Vtb|
- FCNC, anomalous couplings
- Differential cross sections
- Production mechanism (gg,qq)
- Associated production

New Physics in production
- Resonant production
- Heavy Quark production
- ...

Decay
- Branching ratios
- CP asymmetries
- Rare decays, FCNC
- Non-SM decays

Properties
- Top mass
- Top charge
- Top width
- Spin correlation
- Top polarisation
- W helicity
- Charge asymmetry
- Yukawa coupling



- I presented 9 new measurements from the last 5 months
- 8 full Run 2 datasets and 1 Run 3
- Chance to study rare top processes
- Several other measurements in 2022, including:

- Measurement of tt production cross section using collisions at √s=5.02 TeV, hep-ex arXiv:2207.01354 (2022) — 5 TeV, 257 pb^{-1}
- Evidence for charge asymmetry in tt production, hep-ex arXiv:2208.12095 (2022) — 13 TeV, 139 fb^{-1}
- Measurement of the polarisation of *W* bosons produced in top-quark decays using dilepton events, hep-ex arXiv:2209.14903 (2022) — 13 TeV, 139 fb^{-1}
- Measurement of the top-quark mass using a leptonic invariant mass, hep-ex arXiv:2209.00583 (2022) — 13 TeV, 36.1 fb^{-1}
- Measurement of the top-quark mass in tt dilepton events, ATLAS-CONF-2022-058 (2022) — 13 TeV, 139 fb^{-1}
- Search for FCNC interactions of the top quark and the Higgs boson in events with a pair of τ-leptons, hep-ex arXiv:2208.11415 (2022) — 13 TeV, 139 fb^{-1}
- Measurement of the charge asymmetry in top-quark pair production with a photon, hep-ex arXiv:2212.10552 (2022) — 13 TeV, 139 fb^{-1}

Find out more at:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults