Highlights on top quark physics with the ATLAS experiment at the LHC

Miguel Príncipe on behalf of ATLAS Collaboration

Universidad Autónoma de Madrid

November 8th 2024
SILAFAE 2024, Ciudad de México

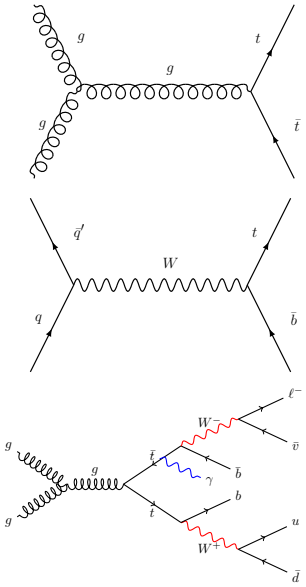
Introduction

The top quark is the heaviest elementary particle of the Standard Model.

In hadron colliders, top quarks are predominantly produced in pairs. Other modes are single-top and top quarks in association with other particles.

The dominant decay mode for top quarks in the SM is $t \to Wb$, with the W boson decaying either hadronically or leptonically.

Top-quarks physics provides tests of the SM and a window to BSM physics.



$t\bar{t}$ and $t\bar{t}$+jets production in ℓ+jets final state (JHEP 08 (2024) 182)

Overview:

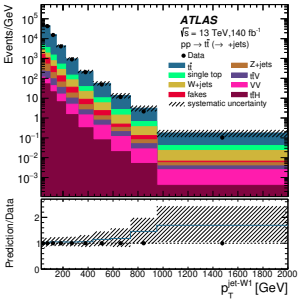
- $\mathcal{L} = 140$ fb^{-1} at $\sqrt{s} = 13$ TeV.
- pp collisions.
- single-lepton channel (e or μ), ≥ 4 jets (2 of them b-tagged).

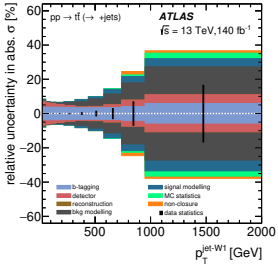
Motivation:

- Test of pQCD theory.
- Characterization of the kinematics and topology of the $t\bar{t}$ system.
- Characterization of the kinematics, dynamics and topology of the two hardest QCD emissions.

Precision and uncertainties:

- At low p_{T}, the b-tagging efficiency is the dominant source of uncertainty.
- In the high p_{T} region, background modelling becomes the dominant systematic.

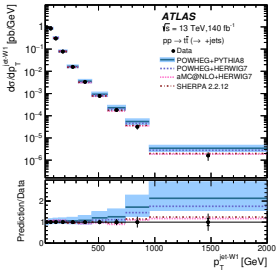


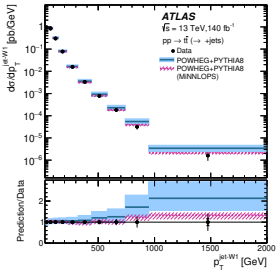


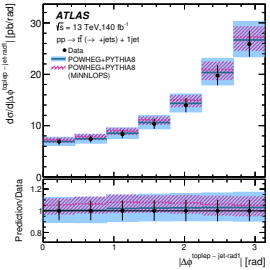
$t\bar{t}$ and $t\bar{t}$+jets production in ℓ+jets final state (JHEP 08 (2024) 182)

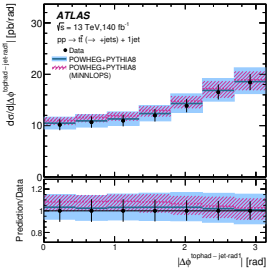
Differential cross sections at particle level for $t\bar{t}$ production are measured.

- 20 novel jet observables including p_{T}, rapidities, angular correlations and invariant masses from jets in $t\bar{t}$ system or arising from hard QCD radiation.
- NLO and NNLO predictions are compared to the measurements.
- The NNLO predictions computed using the MINNLOPS scheme give an improved description for p_{T} and invariant masses.









Measurement of tW production (Phys. Rev. D 110 (2024) 072010)

Overview:

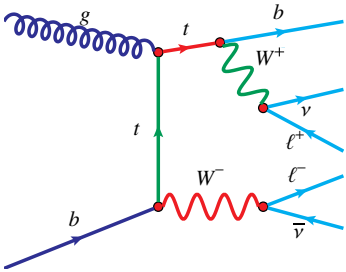
- $\mathcal{L} = 140$ fb^{-1} at $\sqrt{s} = 13$ TeV.
- pp collisions.
- $e\mu$ channel with OS leptons and 1 b-jet.

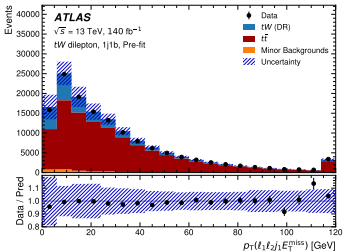
Motivation:

- Test of the CKM $|V_{tb}|^2$ vertex.
- Search for BSM physics in the Wtb vertex.
- A better understanding will improve measurements and searches in which tW is a main background.

Precision and uncertainties:

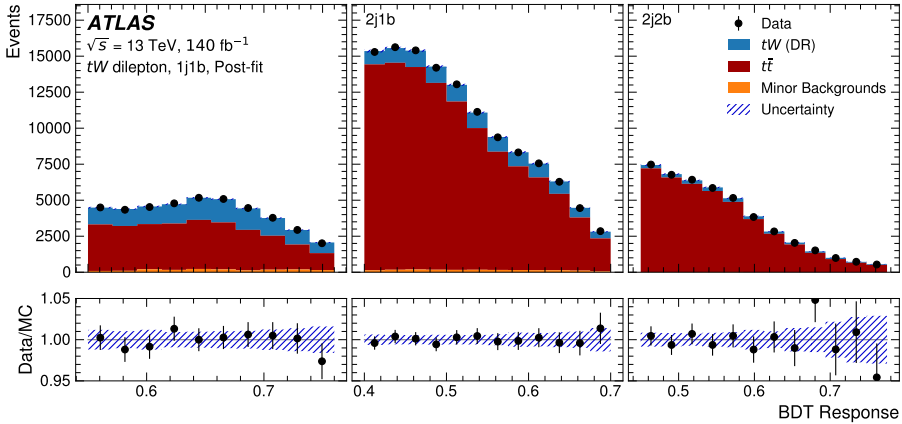
- Similar signature than $t\bar{t}$ (main background).
- Uncertainties are reduced by restricting the fitting region.
- Main sources: Jet energy scale/resolution (JES/JER) and diagram reduction/subtraction (DR/DS) modelling.





Measurement of tW production (Phys. Rev. D 110 (2024) 072010)

The ***tW* cross section** is measured and a value for $|f_{\mathrm{LV}} V_{tb}|$ is extracted.



$\sigma_{tW} = 75 \pm 1\ (\mathrm{stat.})^{+15}_{-14}\ (\mathrm{syst.}) \pm 1\ (\mathrm{lumi.})\ \mathrm{pb}$ (20% of uncertainty).

$\sigma^{\mathrm{NLO+NNLL}}_{tW} = 79.3^{+1.9}_{-1.8}\ (\mathrm{scale}) \pm 2.2\ (\mathrm{PDF})\ \mathrm{pb}$.

$|f_{\mathrm{LV}} V_{tb}| = 0.97 \pm 0.10$

Measurement of $t\bar{t}\gamma$ production (JHEP 10 (2024) 191)

Overview:

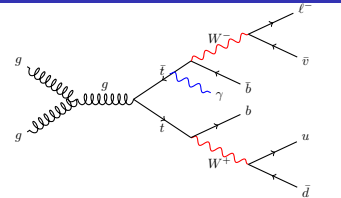
- $\mathcal{L} = 140$ fb^{-1} at $\sqrt{s} = 13$ TeV.
- pp collisions.
- single-lepton (4 jets) and dilepton (2 jets) channels with 1 b-jet.

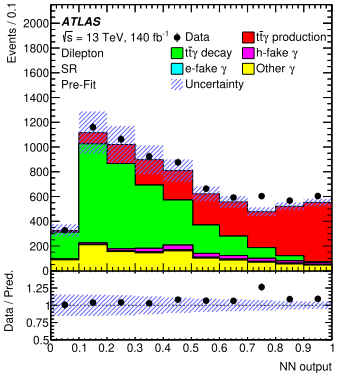
Motivation:

- Provide information about the top-photon electroweak coupling.
- Search for BSM physics through anomalous dipole moments.

Precision and uncertainties:

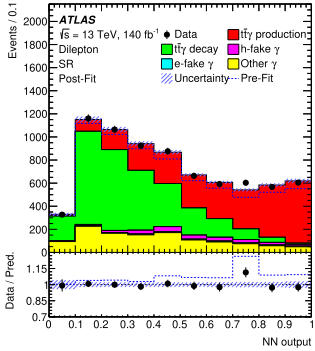
- Main sources: b-tagging, JES/JER and signal modelling.
- At high p_{T}^{γ}, statistical uncertainty becomes dominant.





Measurement of $t\bar{t}\gamma$ production (JHEP 10 (2024) 191)

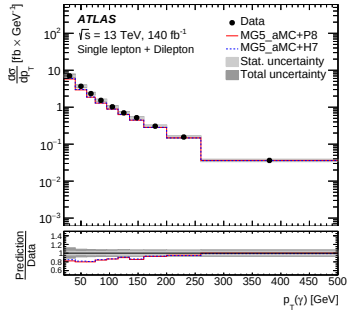
The **fiducial and differential cross sections** of $t\bar{t}\gamma$ production are measured.

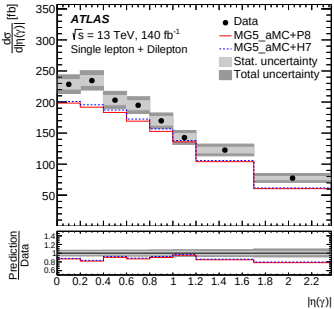


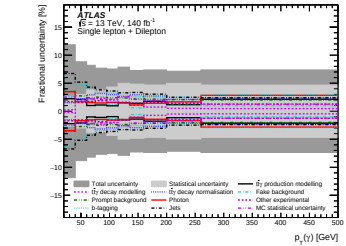
$\sigma_{t\bar{t}\gamma} = 322 \pm 5\,(\text{stat.}) \pm 15\,(\text{syst.})$ fb.

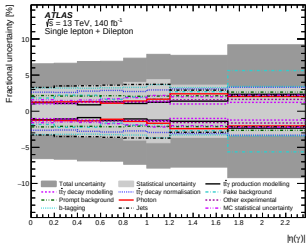
Relative uncertainty of 5%.

$\sigma^{\text{NLO}}_{t\bar{t}\gamma} = 299^{+29}_{-30}\,(\text{scale})^{+7}_{-4}\,(\text{PDF})$ fb.







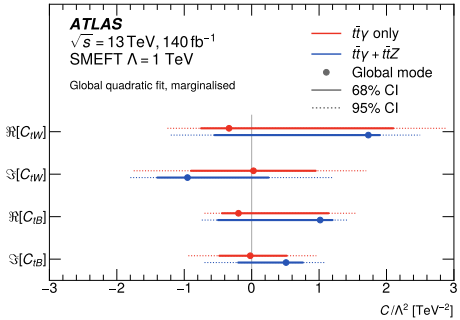


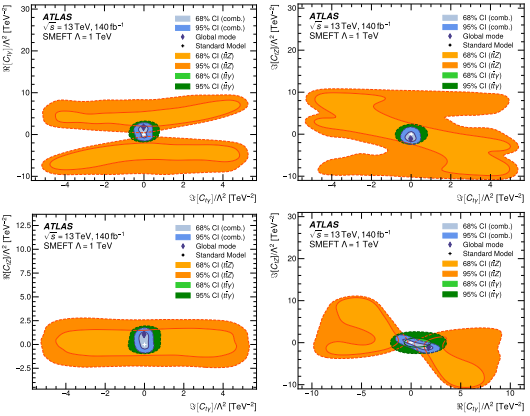
Measurement of $t\bar{t}\gamma$ production (JHEP 10 (2024) 191)

SMEFT is used to model the deviations from SM, considering C_{tW} and C_{tB} Wilson coefficients.

$$\mathcal{L}_{\text{EFT}} = \mathcal{L}_{\text{SM}} + \sum \frac{c_i^D}{\Lambda^{D-4}} \mathcal{O}_i^D$$

The results are in **agreement with the SM**.





Observation of $t\bar{t}$ production in pPb (arXiv: 2405.05078)

Overview:

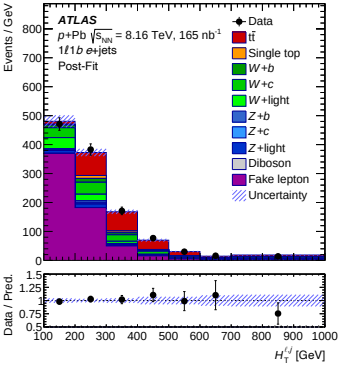
- $\mathcal{L} = 165$ nb^{-1} at $\sqrt{s} = 8.16$ TeV.
- pPb collisions.
- single-lepton (4 jets) and dilepton (2 jets) channels with 1 b-jet.

Motivation:

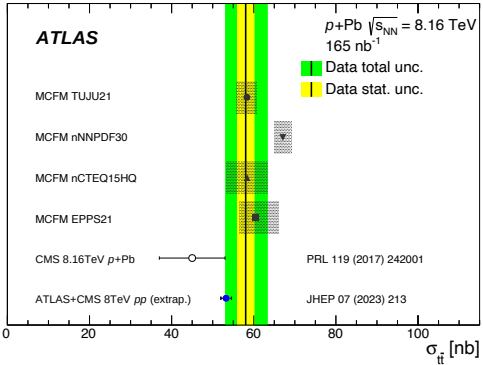
- Probes of nuclear-PDFs.
- Important for future studies of quark-gluon plasma.
- Observation of the dilepton channel.

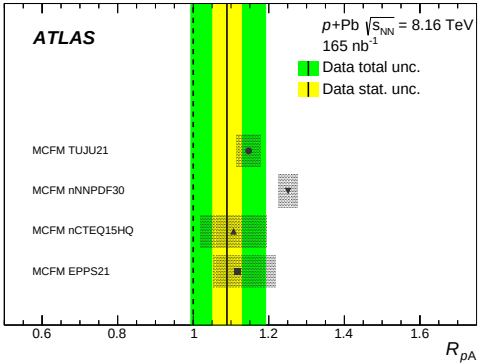
Precision and uncertainties:

- Main sources: JES and signal modelling.
- The background-only hypothesis is rejected with a significance of more than five standard deviations individually for ℓ+jets and dilepton.



Observation of $t\bar{t}$ production in pPb (arXiv: 2405.05078)





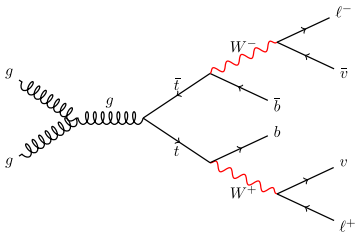
Measured cross section: $\sigma = 58.1 \pm 2.0\ (\text{stat.})^{+4.8}_{-4.4}$ (syst.) nb.
Relative unc: 9%. Measurement limited by systemactics.

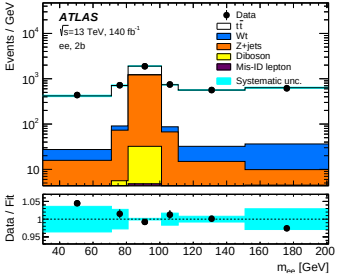
Measured nuclear modification factor: $R_{p\text{A}} = \frac{\sigma_{p\text{Pb}}}{A \cdot \sigma_{pp}} = 1.090 \pm 0.039\ (\text{stat.})^{+0.094}_{-0.087}$ (syst.).

Lepton flavour universality (Eur. Phys. J. C 84 (2024) 993)

Overview:

- $\mathcal{L} = 140$ fb^{-1} at $\sqrt{s} = 13$ TeV.
- pp collisions.
- dilepton channel with 1 b-jet.



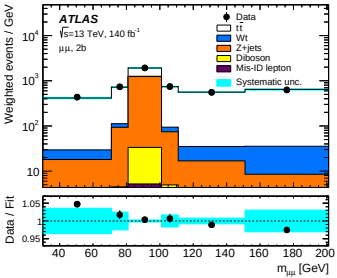


Motivation:

- Test a key axiom of the SM as lepton universality.
- Deviations would imply BSM physics.

Precision and uncertainties:

- Main sources: lepton misidentification and PDFs.
- Reduced uncertainty by measuring $R_{WZ}^{\mu/e} = \dfrac{R_W^{\mu/e}}{\sqrt{R_Z^{\mu\mu/ee}}}$.



Lepton flavour universality (Eur. Phys. J. C 84 (2024) 993)

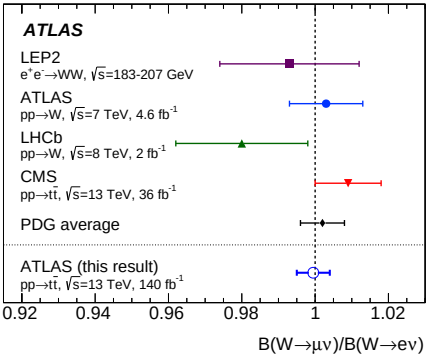
The **ratio of branching ratios** $\boldsymbol{R_W^{\mu/e} = \mathcal{B}(W \to \mu\nu)/\mathcal{B}(W \to e\nu)}$ is determined.

A measurement of $R_W^{\mu/e}$ and $R_Z^{\mu\mu/ee}$ is performed to compute $R_{WZ}^{\mu/e}$.

The precise measurement by LEP+SLD of:

$$R_Z^{\mu\mu/ee} = 1.0009 \pm 0.0028,$$

is used to extract $R_W^{\mu/e}$.



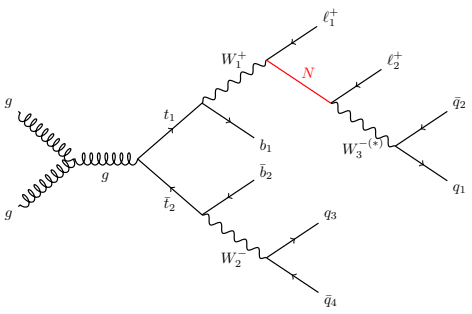
The resulting value of $R_W^{\mu/e} = 0.9995 \pm 0.0045$ (0.5% of uncertainty) is **consistent with the assumption of lepton flavour universality**.

This is the most precise measurement of $R_W^{\mu/e}$ to date, with a smaller uncertainty than the previous world average.

Search for heavy right-handed Majorana neutrinos (arXiv: 2408.05000)

Overview:

- $\mathcal{L} = 140$ fb^{-1} at $\sqrt{s} = 13$ TeV.
- *pp* collisions.
- dilepton channel with SS leptons, ≥ 2 *b*-tagged jets and ≥ 4 non *b*-tagged jets.

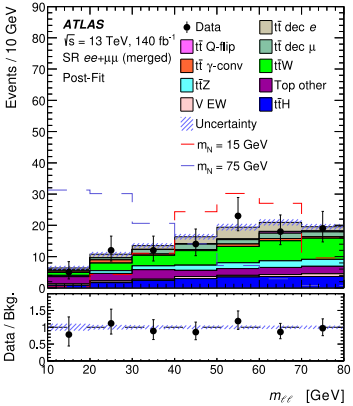


Motivation:

- Search for new BSM particles.

Precision and uncertainties:

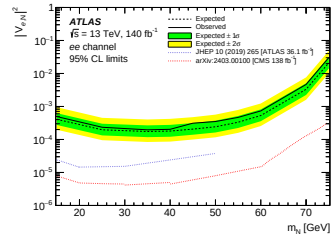
- Main sources: lepton efficiency.

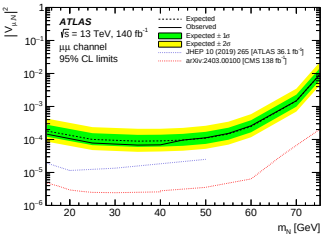


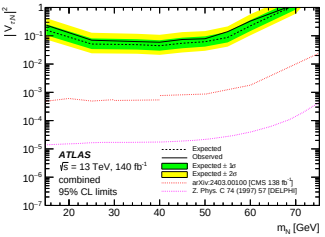
Search for heavy right-handed Majorana neutrinos (arXiv: 2408.05000)

Heavy neutral leptons in $t\bar{t}$ events with dileptonic final states are searched for.

Observations are **consistent with the Standard Model** predictions.







Upper limits obtained in this analysis:

$$|V_{e,\mathrm{N}}|^2 < 2.0 \times 10^{-4} \qquad |V_{\mu,\mathrm{N}}|^2 < 6.8 \times 10^{-5} \qquad |V_{\tau,\mathrm{N}}|^2 < 5.9 \times 10^{-2}$$

The search region reaches up to 75 GeV (previous ATLAS search: up to 50 GeV).

Search for same-charge top-quark pairs (arXiv: 2409.14982)

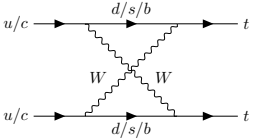
Overview:

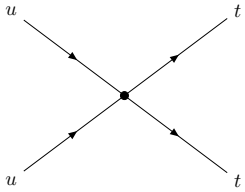
- $\mathcal{L} = 140$ fb^{-1} at $\sqrt{s} = 13$ TeV.
- pp collisions.
- dilepton channel with SS leptons, ≥ 2 jets (1 of them b-tagged).

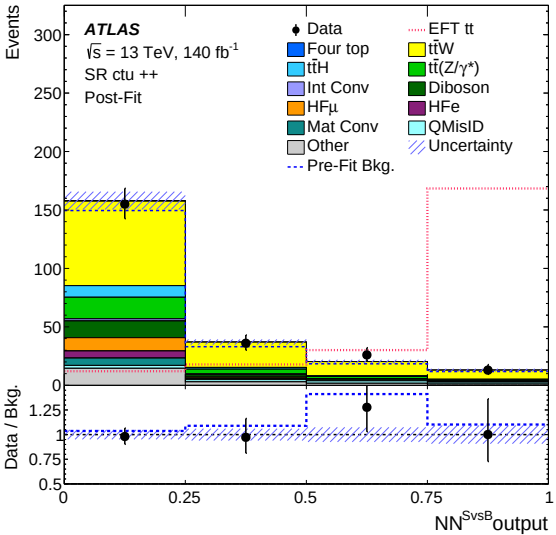
Motivation:

- Search for deviations from SM.

$\sigma_{\text{SM}} \approx 4 \cdot 10^{-15}$ pb.







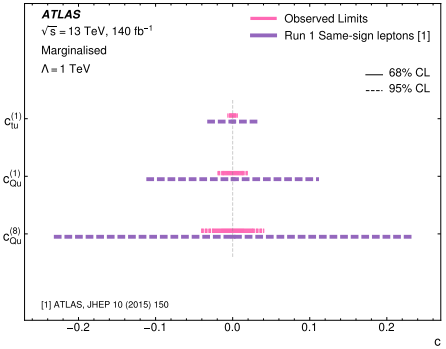
Search for same-charge top-quark pairs (arXiv: 2409.14982)

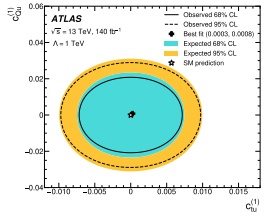
Top-quark pairs with the same electric charge are searched for.

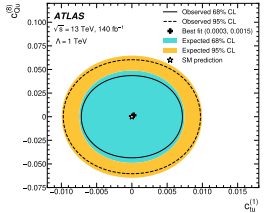
SMEFT is used to model the signal process, considering $c_{tu}^{(1)}$, $c_{Qu}^{(1)}$ and $c_{Qu}^{(8)}$ Wilson coefficients.

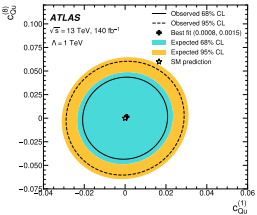
$$\mathcal{L}_{\text{EFT}} = \mathcal{L}_{\text{SM}} + \sum \frac{c_i^D}{\Lambda^{D-4}} \mathcal{O}_i^D$$

The results are in **agreement with the SM**, with no significant signal detected.









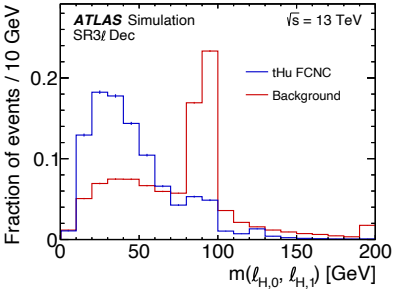
Search for FCNC *tHu* and *tHc* couplings (Eur. Phys. J. C 84 (2024) 757)

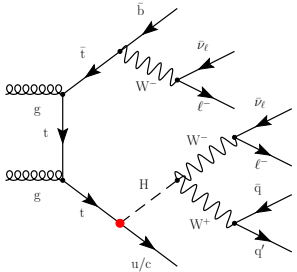
Overview:

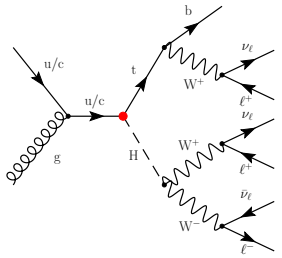
- $\mathcal{L} = 140$ fb^{-1} at $\sqrt{s} = 13$ TeV.
- *pp* collisions.
- 2ℓSS and 3ℓ with 1 *b*-jet.

Motivation:

- Search for FCNC interactions as a BSM signal.

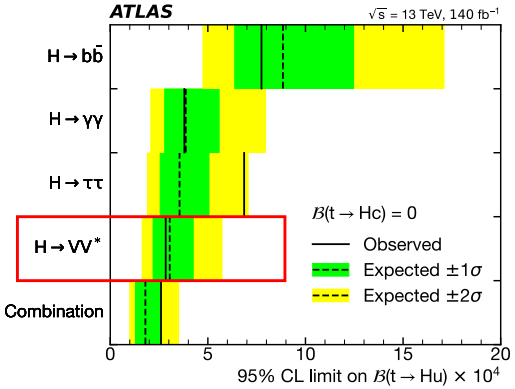


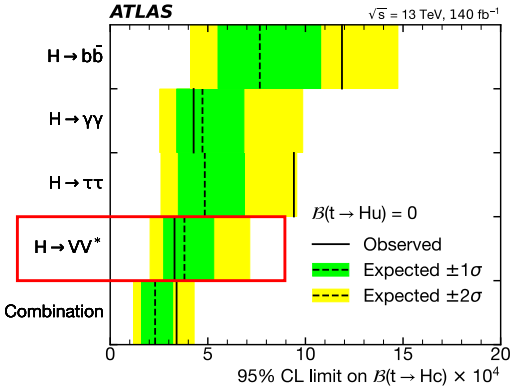




Search for FCNC *tHu* and *tHc* couplings (Eur. Phys. J. C 84 (2024) 757)

FCNC couplings between the top quark, the Higgs boson and a second up-type quark are searched for.
The results are **compatible with the SM** and no evidence of FCNC couplings is observed.





Summary and conclusions

The ATLAS collaboration exploits fully the potential of the LHC as a top quark factory, producing a wide range of results, including:

- Measurements of cross-sections and comparisons with NLO and NNLO predictions for:
  - top-quark pairs.
  - single top.
  - top quark in association with photons.

  In general, good agreement between predictions and data.
- Observation of $t\bar{t}$ production in pPb collisions.
- Test of lepton flavour universality with good agreement with the SM prediction.
- Searches for new physics such as:
  - Heavy right-handed Majorana neutrinos.
  - Same-charge top-quark pairs.
  - FCNC tHu and tHc couplings.

  No significant deviations from the SM were observed and limits were set.