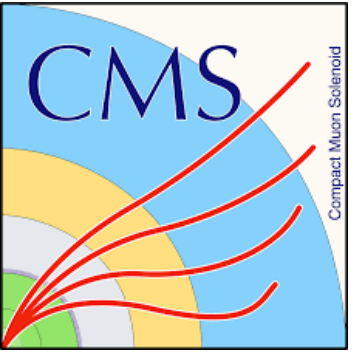
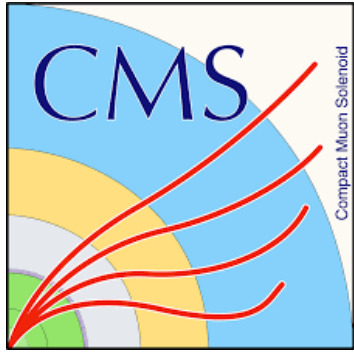




CMS measurements of $t\bar{t} + X$ and $t + X$ production (incl. EFT searches)

The 11th Annual Conference on Large Hadron Collider Physics, May 2023, Serbia

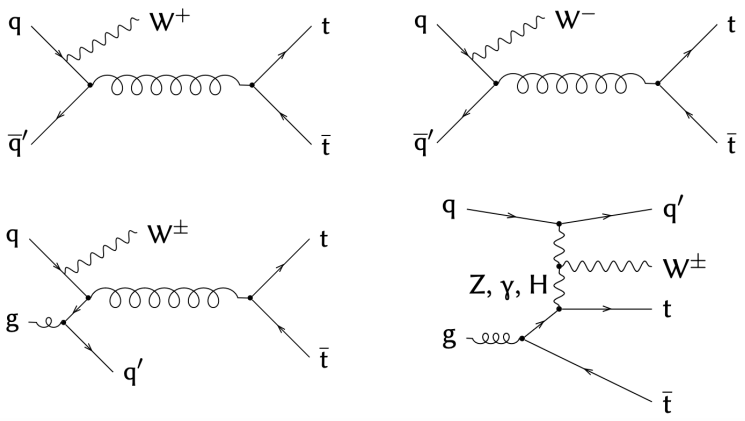
Kathryn Coldham, on behalf of the CMS Collaboration

kathryn.coldham@cern.ch

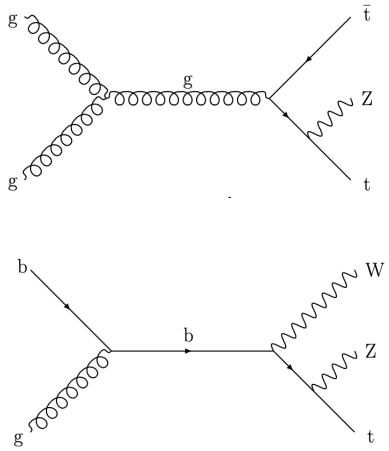
$t\bar{t} + X$

* I will talk about these

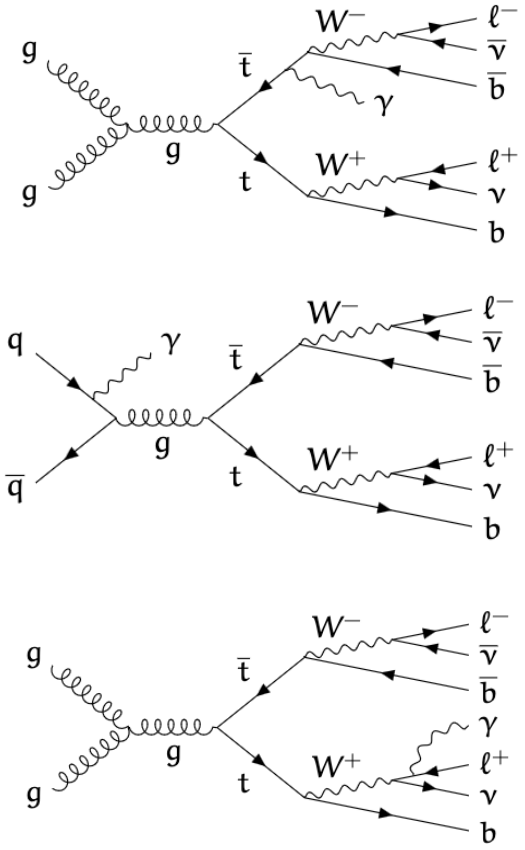
$t\bar{t}W$ [1] *



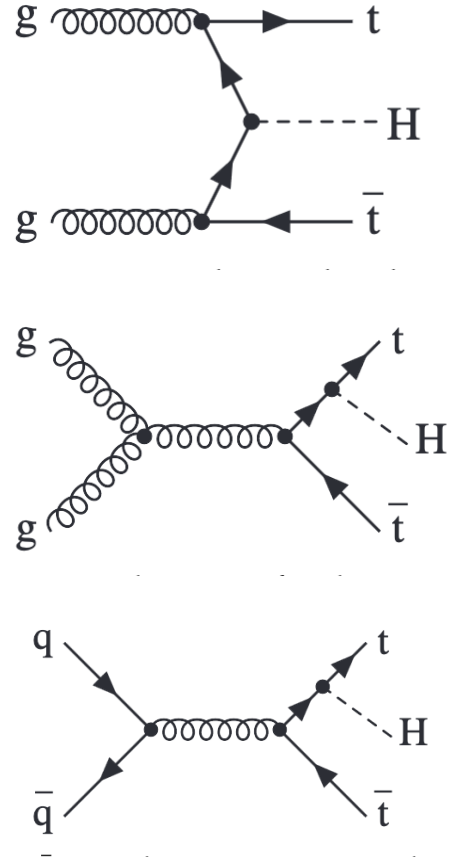
$t\bar{t}Z$ [2] *



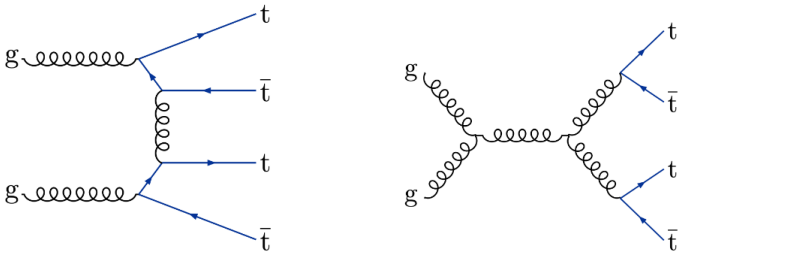
$t\bar{t}\gamma$ [3] *



$t\bar{t}H$ [4] *



$t\bar{t}t\bar{t}$ [5]

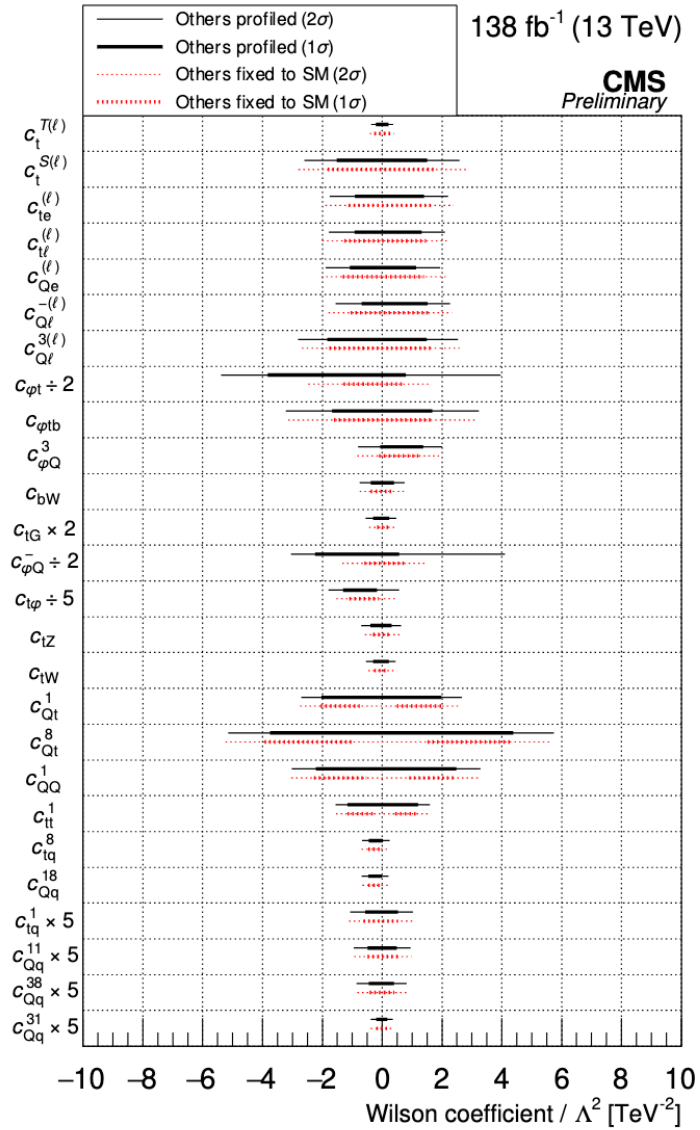


[1] https://arxiv.org/abs/2208.06485
[2] https://arxiv.org/abs/2107.13896
[3] https://arxiv.org/abs/2201.07301
[4] https://arxiv.org/abs/1804.02610
[5] https://arxiv.org/abs/2303.03864

$t\bar{t} + X$: EFT models using tt+X (multi-lepton final states)

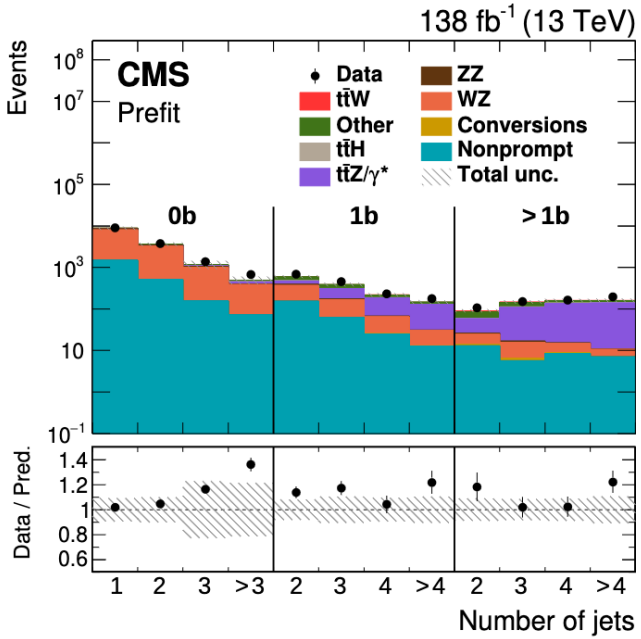
- 2l SS, 3l and 4l
- Includes events with and without on-shell Z decays
- Targets $t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq and $t\bar{t}t\bar{t}$
- Reducible and irreducible backgrounds considered.
- CRs: 2l SS (1 medium b-jet), 3l (0 medium b-tags, fewer jets).
- NPL estimation (fake factor method).

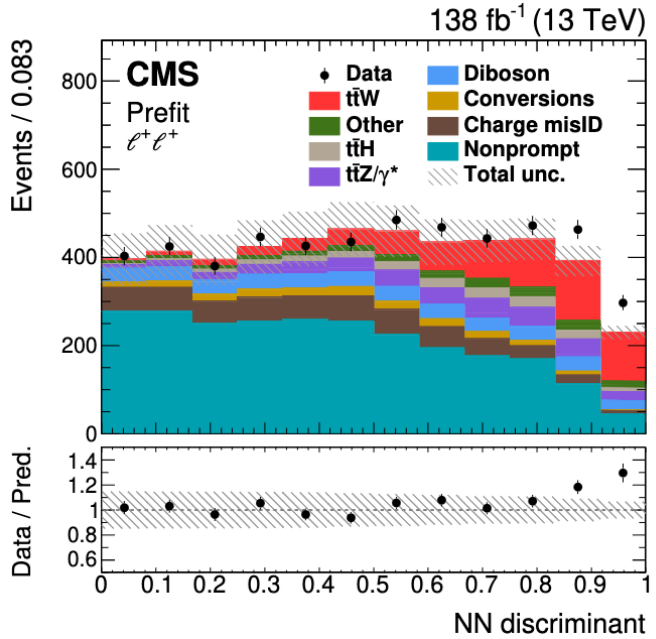
- Likelihood fit for signal extraction.
- 26 WCs ⇒ 26-dimensional quartic function described by 378 structure constants.
- Negative log-likelihood fits to either Asimov or real data (1D scans).

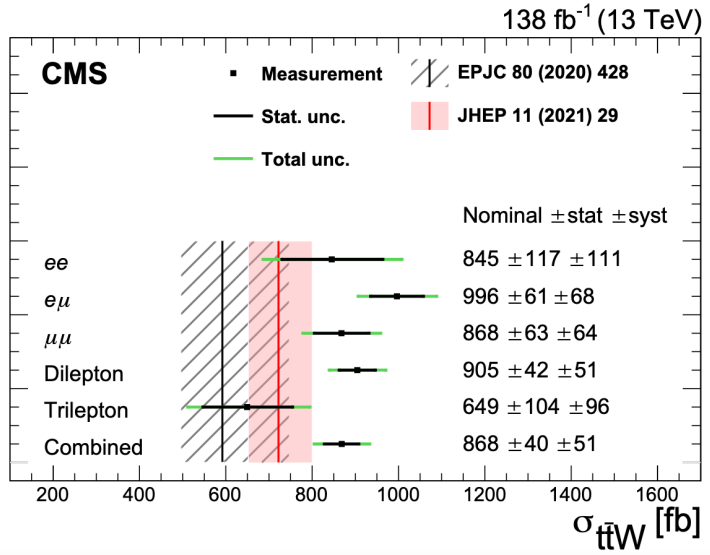


[6] CMS-PAS-TOP-22-006

$t\bar{t}$ + X: Measurement of inclusive ttW cross section







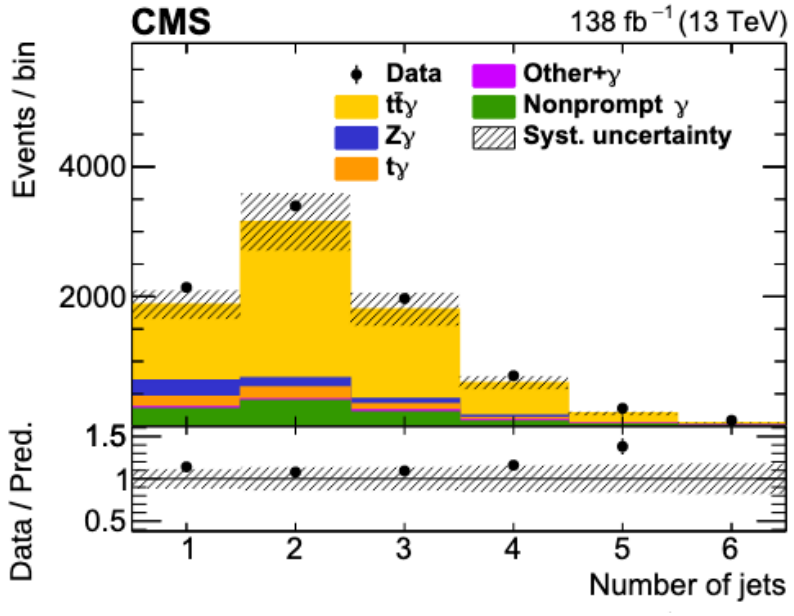
- 2 same-sign or 3 charged leptons. $W \rightarrow l\bar{\nu}$
- Dominant backgrounds: NPL, $t\bar{t}Z, t\bar{t}H, WZ$.
- NPL data estimation using tight-to-loose ratio method.

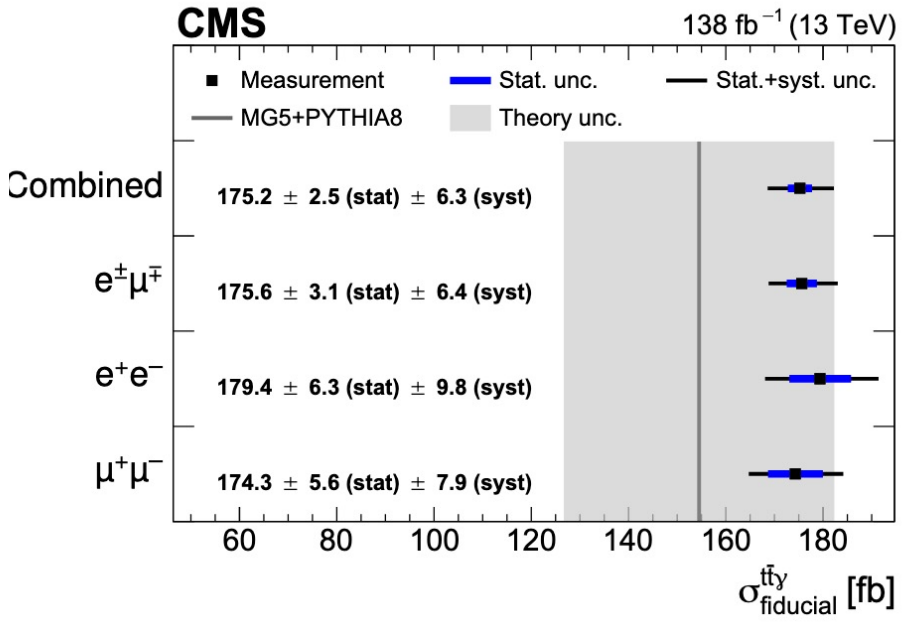
- MVA techniques to suppress background events.
- Dilepton channel: multiclass NN to improve separation of signal and background processes.
- Trilepton: m_{inv} of 3l discriminating variable.

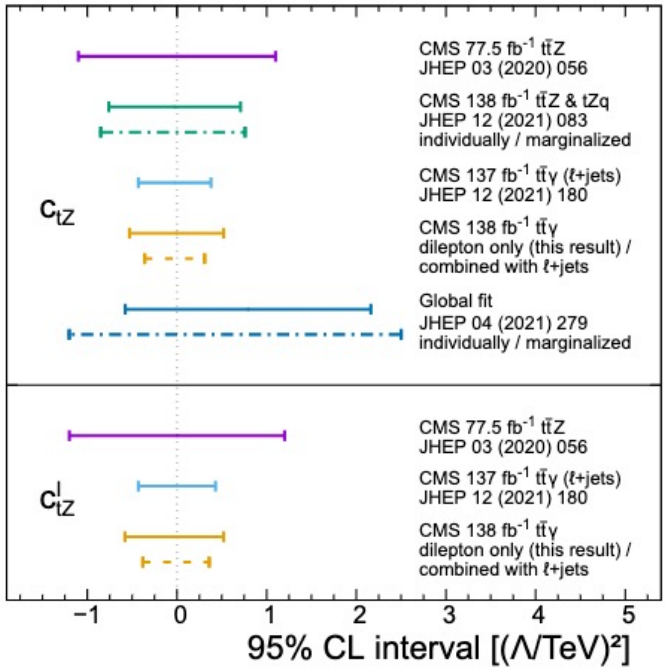
- Binned profile likelihood fit for cross section extraction.
- $\sigma_{t\bar{t}W}$ (full phase space) = 868 ± 40 (stat) ± 51 (syst) fb
- $\sigma_{ttW^+}/\sigma_{ttW^-} =$ $1.61 \pm 0.15(stat)^{+0.07}_{-0.05}$ (syst)

[1] https://arxiv.org/abs/2208.06485

$t\bar{t} + X$: Inclusive and differential $t\bar{t}\gamma$ dilepton







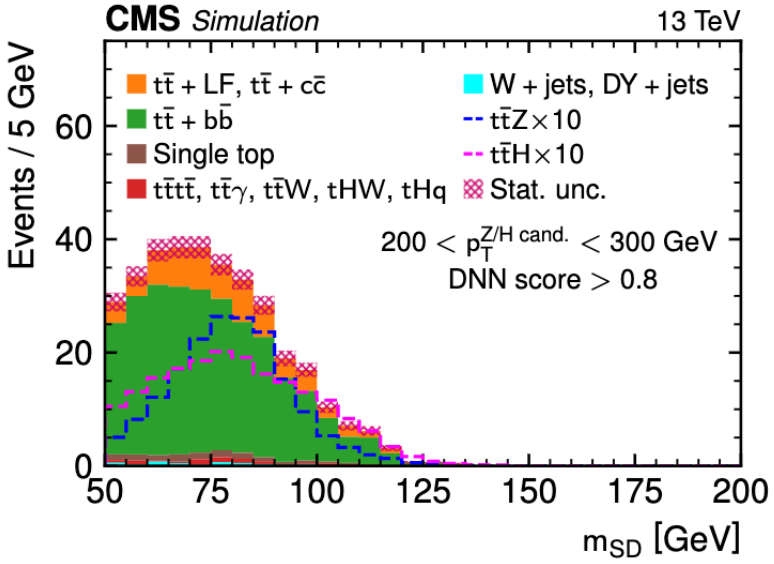
- 2 oppositely-charged leptons, 1 isolated photon and at least 1 jet.
- $Z\gamma$ CR
- Dominant backgrounds: Z+jets and t+γ

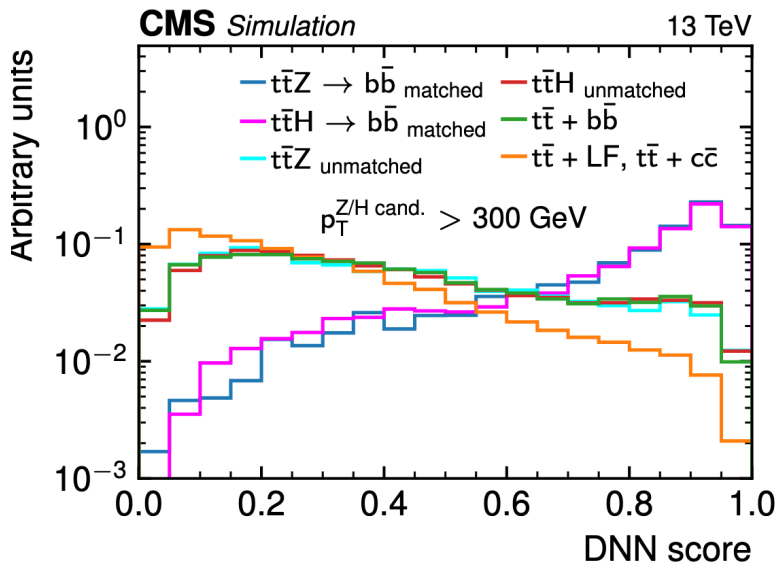
- Inclusive cross section: profile likelihood fit to the reco p_T distribution.
- Differential cross section in fiducial phase space as functions of 12 observables.

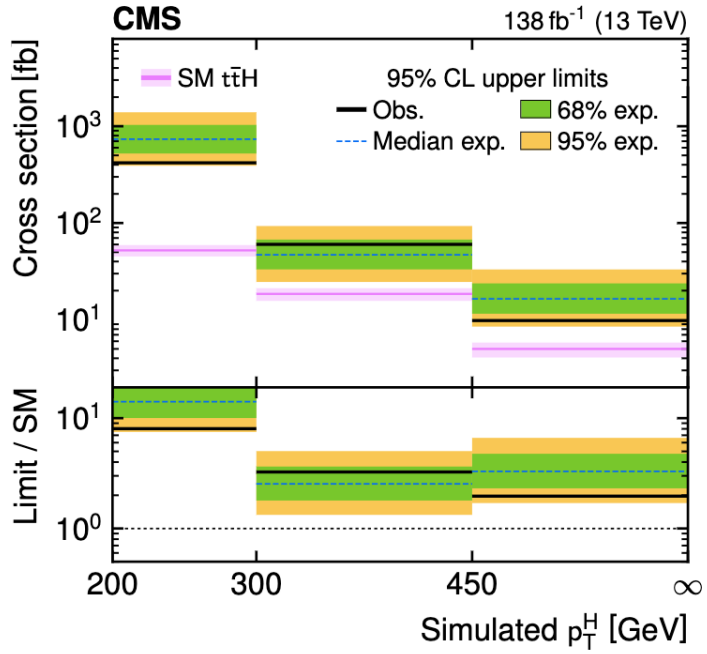
- SMEFT approach – characterizes quantum loop corrections.
- Profile likelihood fit for constraints on Wilson coefficients.

[3] https://arxiv.org/abs/2201.07301

$t\bar{t} + X$: Probing EFT using tt production associated with a boosted Z or Higgs boson







- 1 e^- *or* μ^-, $P_{T_{miss}} > 20\ GeV$
- 5 or more AK4 jets ($\geq$ 2 b-tagged)
- Z or H candidate AK8 jet
- $t\bar{t}$ dominant background

- 3 discriminating variables: p_T and m_{SD} of reco Z or H candidate AK8 jet and a global event NN score.
- Regions enriched in ttZ or ttH events.

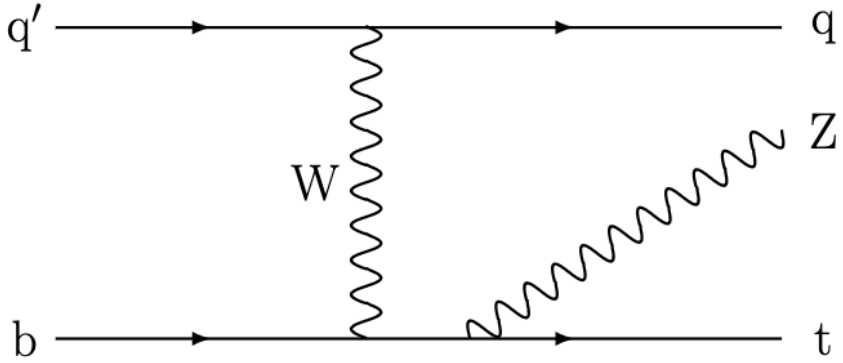
- Observed and expected 95% CL upper limits on the ttZ (left) and ttH (right) differential cross sections.
- Cross sections as functions of the simulated Z and Higgs boson p_T.

[7] https://arxiv.org/abs/2208.12837

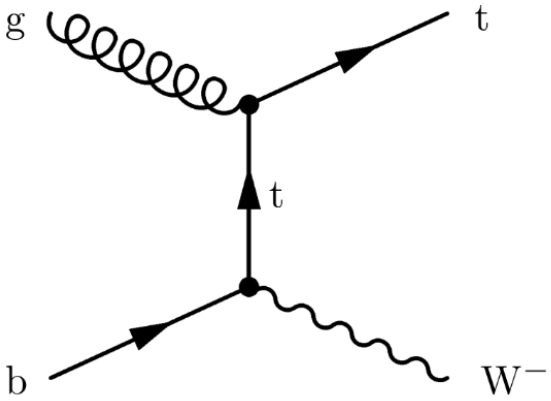
$t + X$

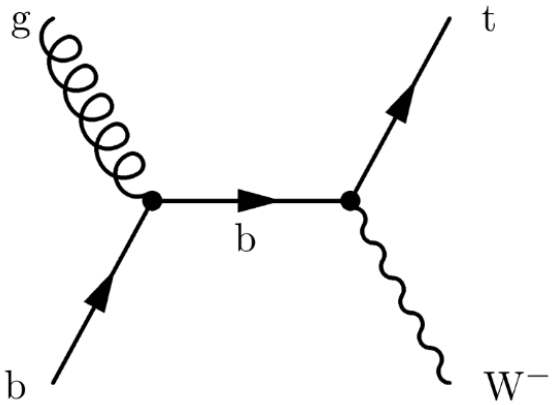
* I will talk about these

tZq [8]

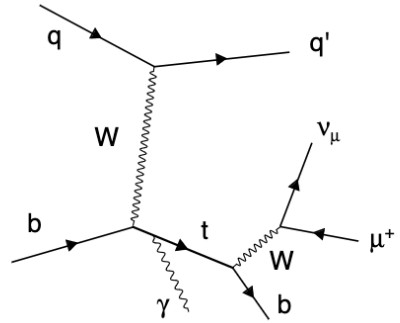


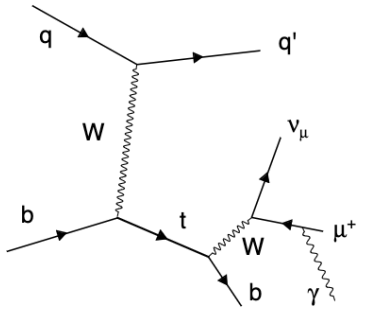
tW [9] *

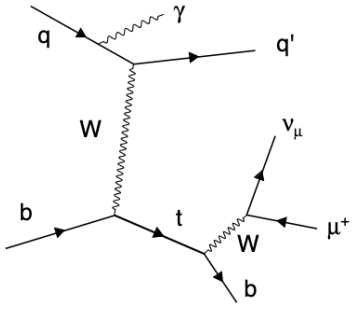




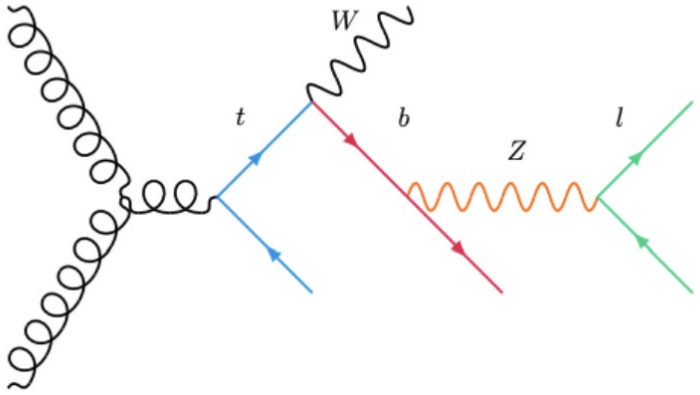
tγ [10]





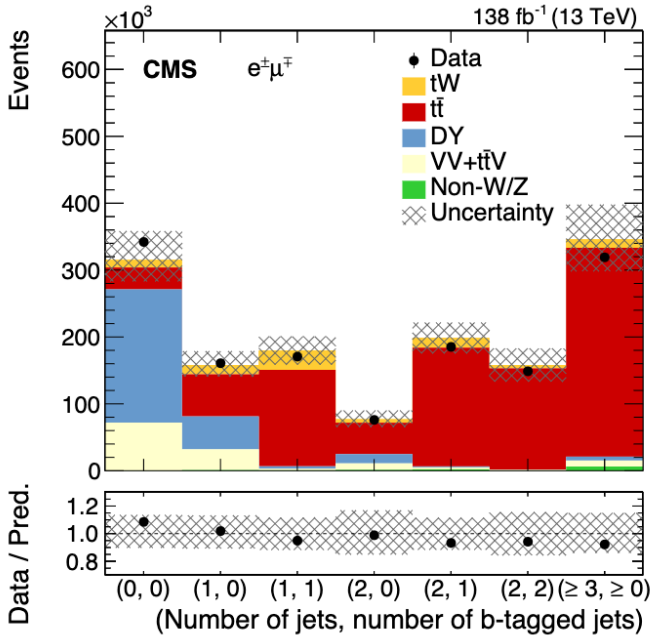


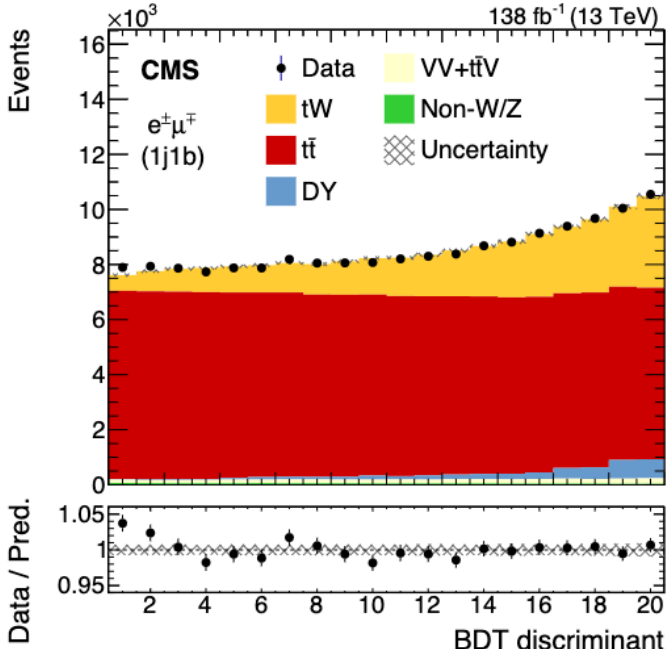
tWZ [11] *

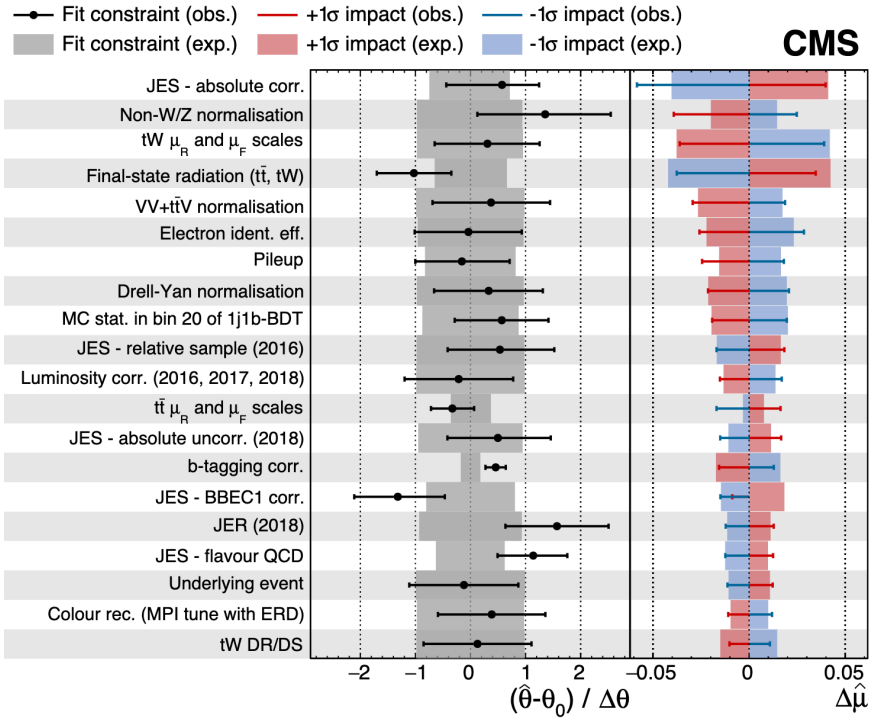


[8] https://arxiv.org/abs/2111.02860
[9] https://arxiv.org/abs/2208.00924
[10] https://arxiv.org/abs/1808.02913
[11] CMS-PAS-TOP-22-008

$t + X$: Inclusive and differential tW with dileptonic events







- $e^{\pm}\mu^{\mp}$ final state.
- 2 different flavour leptons, opposite charge.
- 1 jet, 2 neutrinos.

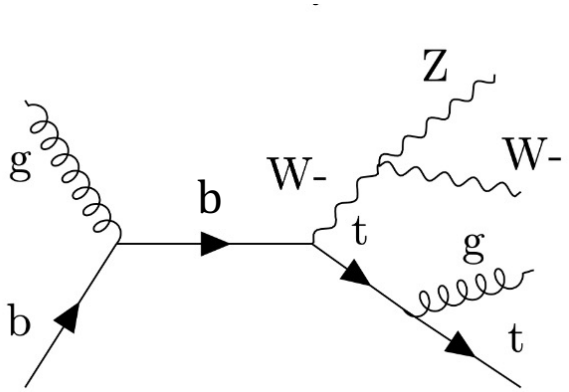
- 1j1b region most signal-enriched, used for differential measurement.
- Inclusive measurement: 1j2b, 2j1b and 2j2b regions used.

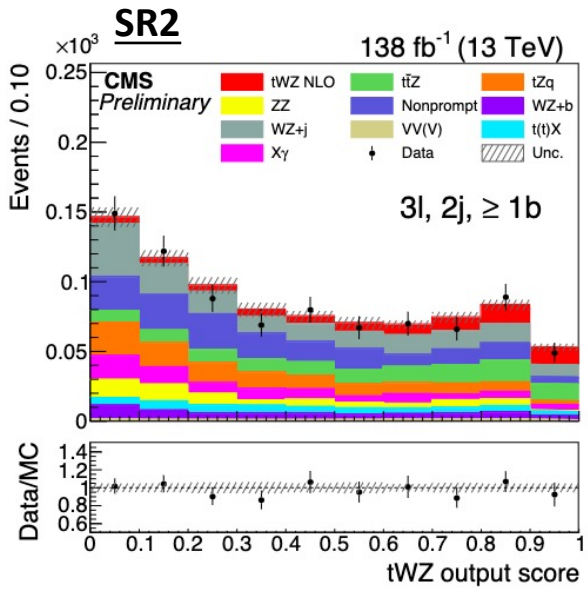
- Cross section: $79.2 \pm 0.9(\text{stat})^{+7.7}_{-8.0}$ (syst) ± 1.2 (lumi) pb

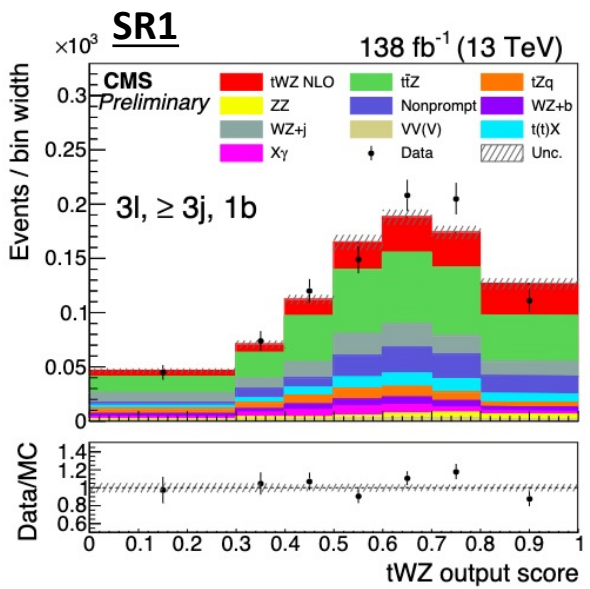
[9] https://arxiv.org/abs/2208.00924

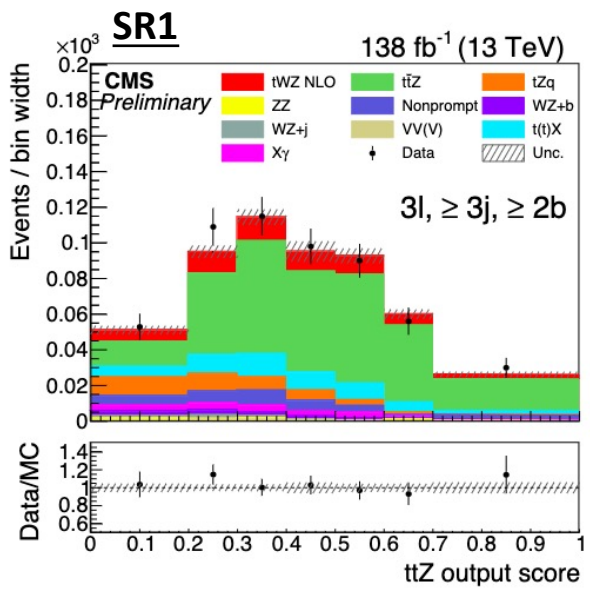
$t + X$: SM tWZ (multi-lepton final states)

Check out the CMS physics briefing!









- $\geq$ 3l, Z→2l (l = e^-/μ^-)
- Main background: $t\bar{t}Z$
- NPL estimation (DY, dileptonic $t\bar{t}$ events)
- 3 SRs and a boosted SR
- ZZ and WZ CR

- DNN to improve discrimination power between the tWZ and $t\bar{t}Z$ processes.
- Two DNNs trained for SR1 (multiclass classifier) and SR2 (binary classifier).

- Binned maximum likelihood fit using DNN output scores.
- First evidence at 3.5σ!
- Inclusive cross section: 0.37 ± 0.05 (stat) ± 0.10 (syst) pb

[11] CMS-PAS-TOP-22-008

Summary

The most recent CMS results for $t\bar{t} + X$ and $t + X$ production (including EFT) have been presented.

Also see CMS TOP talks by Nicholas Chanon, Federica Colombina, Ashley Parker and Melissa Quinnan, and posters!

$t\bar{t} + X$:

- EFT models using tt+X
- inclusive $t\bar{t}W$
- inclusive and differential $t\bar{t}\gamma$ dilepton
- $t\bar{t}$ + boosted Z or H

$t + X$:

- inclusive and differential tW with dileptonic events
- SM tWZ (multilepton final states)

Thank you – any questions?

Follow the CMS Experiment on social media!

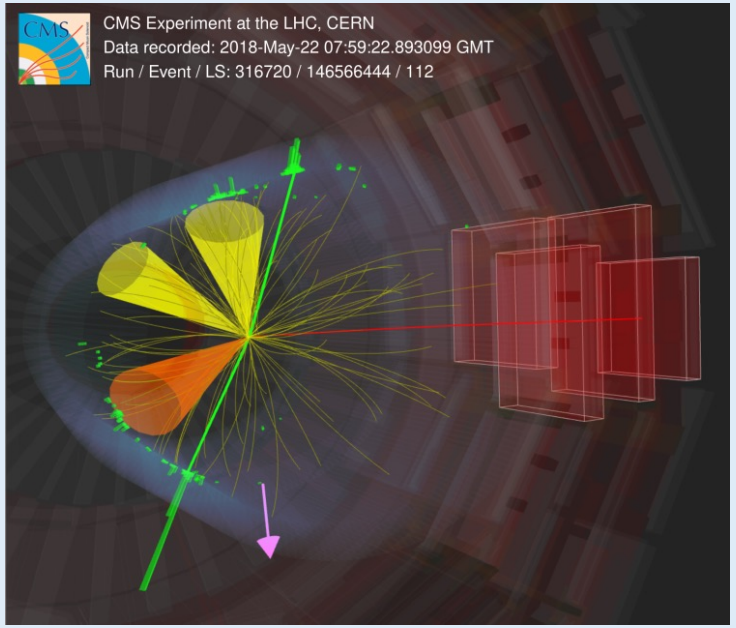
https://twitter.com/CMSExperiment

https://www.linkedin.com/company/cmscollaboration

https://www.facebook.com/CMSexperiment/

https://www.instagram.com/cmsexperiment/

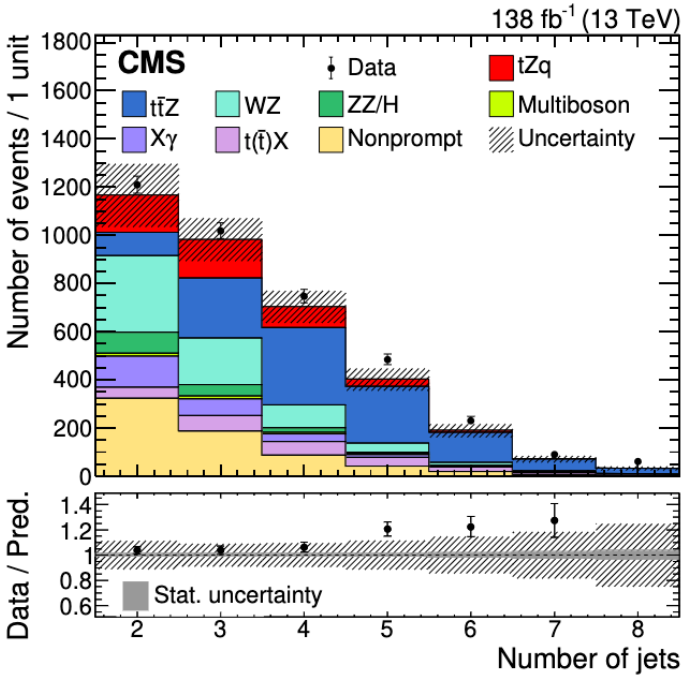
Check out CMS physics briefings!

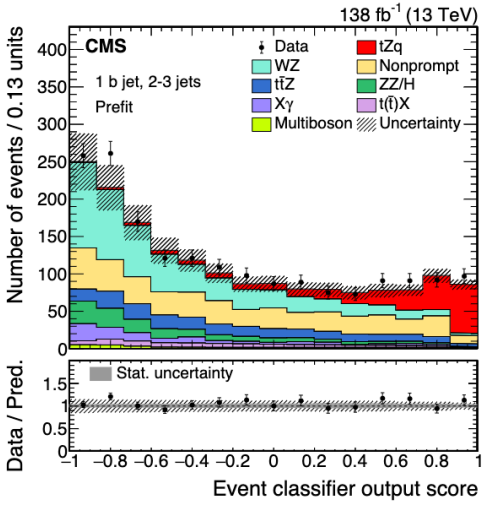


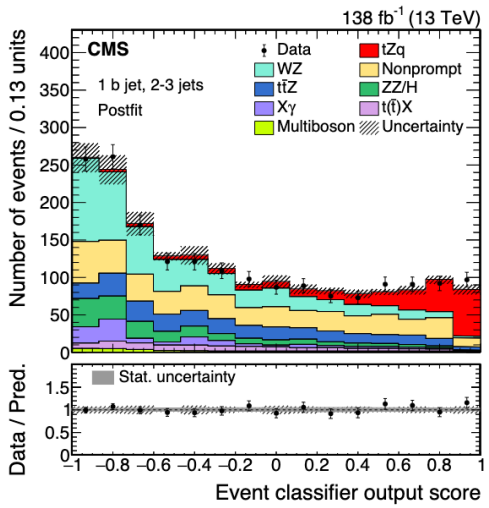
https://cms.cern/tags/physics-briefings

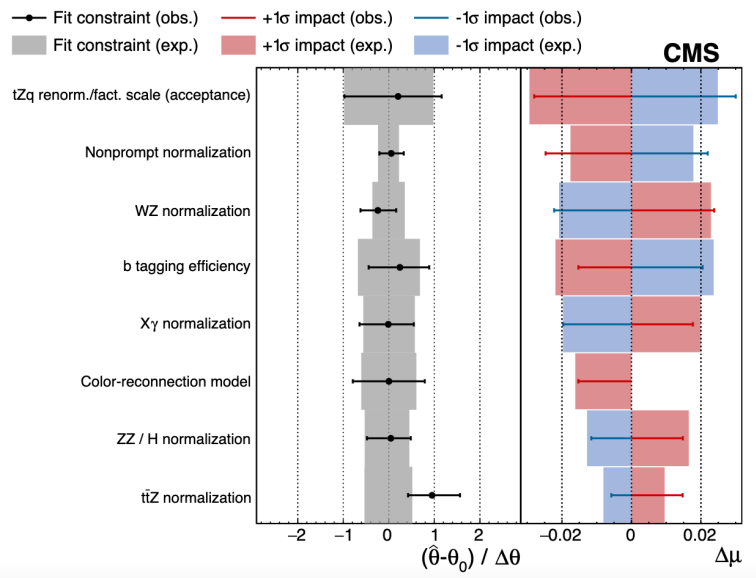
Back up

$t + X$: Inclusive and differential measurement of tZq (3l)









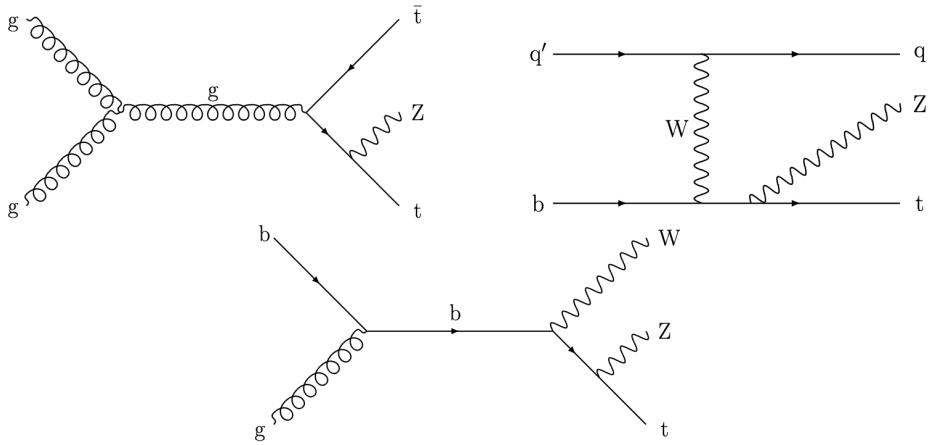
- 3 tight leptons, 2/3 OSSF
- Invariant mass of OSSF $\pm$ 30 GeV of m_Z
- $\geq$ 2 jets, of which $\geq$ 1 b-tagged

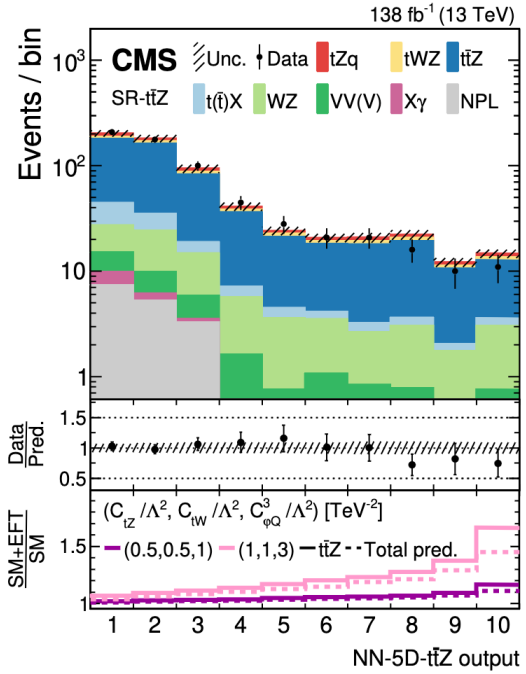
- MVA techniques to discriminate tZq signal and backgrounds.
- Backgrounds divided into two main categories: 1. processes with 3 genuine prompt leptons 2. events with $\geq$ 1 non-prompt lepton.
- WZ and ZZ-enriched CRs.

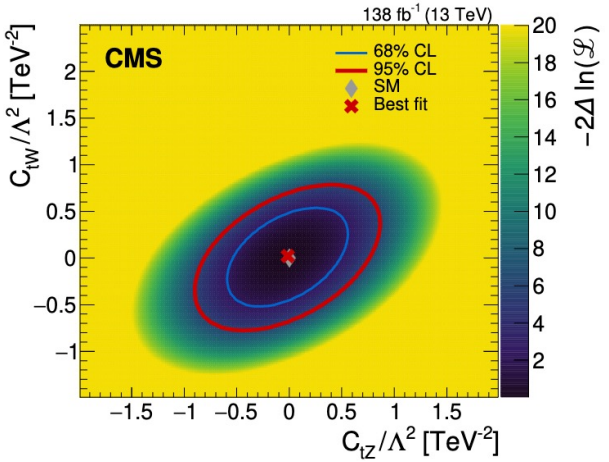
- MVA output score used in maximum likelihood fits
- Inclusive cross section of $87.9^{+7.5}_{-7.3}(\text{stat})^{+7.3}_{-6.0}$ (syst) fb

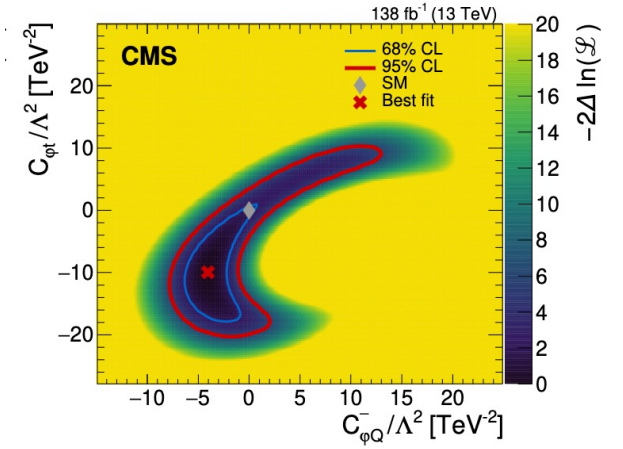
[8] https://arxiv.org/abs/2111.02860

EFT search in 3l using ML techniques









- tZq and t$\bar{t}$Z, Run-2 data
- Multilepton final states (3 or 4l)
- NPLs – misidentification probability method
- CRs: WZ and ZZ

- Neural network – defined 3 subregions enriched in tZq, t$\bar{t}Z$ and background events.
- Additional NNs used to separate SM events from events with non-zero WC values.

- Binned log-likelihood function with model parameter information.
- Simultaneous fit to data in 6 event categories. 2 confidence intervals per WC.

[12] https://arxiv.org/abs/2107.13896