Recent results on top-quark physics by CMS: cross sections

Javier Fernandez, U. Oviedo-ICTEA (Spain),
on behalf of the CMS collaboration

LHC Days in Split
Hvar, October 2024

Outline

- **Latest (2024) CMS results on top quark "relationships":**

  - CMS-PAS-TOP-23-005 : Measurement of the **inclusive** $t\bar{t}$ cross section in final states with one lepton and additional jets at **5.02 TeV**

    - $t\bar{t}$ @ 5.02 TeV (2017 data), lepton (e/μ) + jets, ∫L = 302 pb^{-1}

  - CMS-PAS-TOP-23-004 : **Inclusive** and **differential** measurement of top quark cross sections in association with a **Z boson**

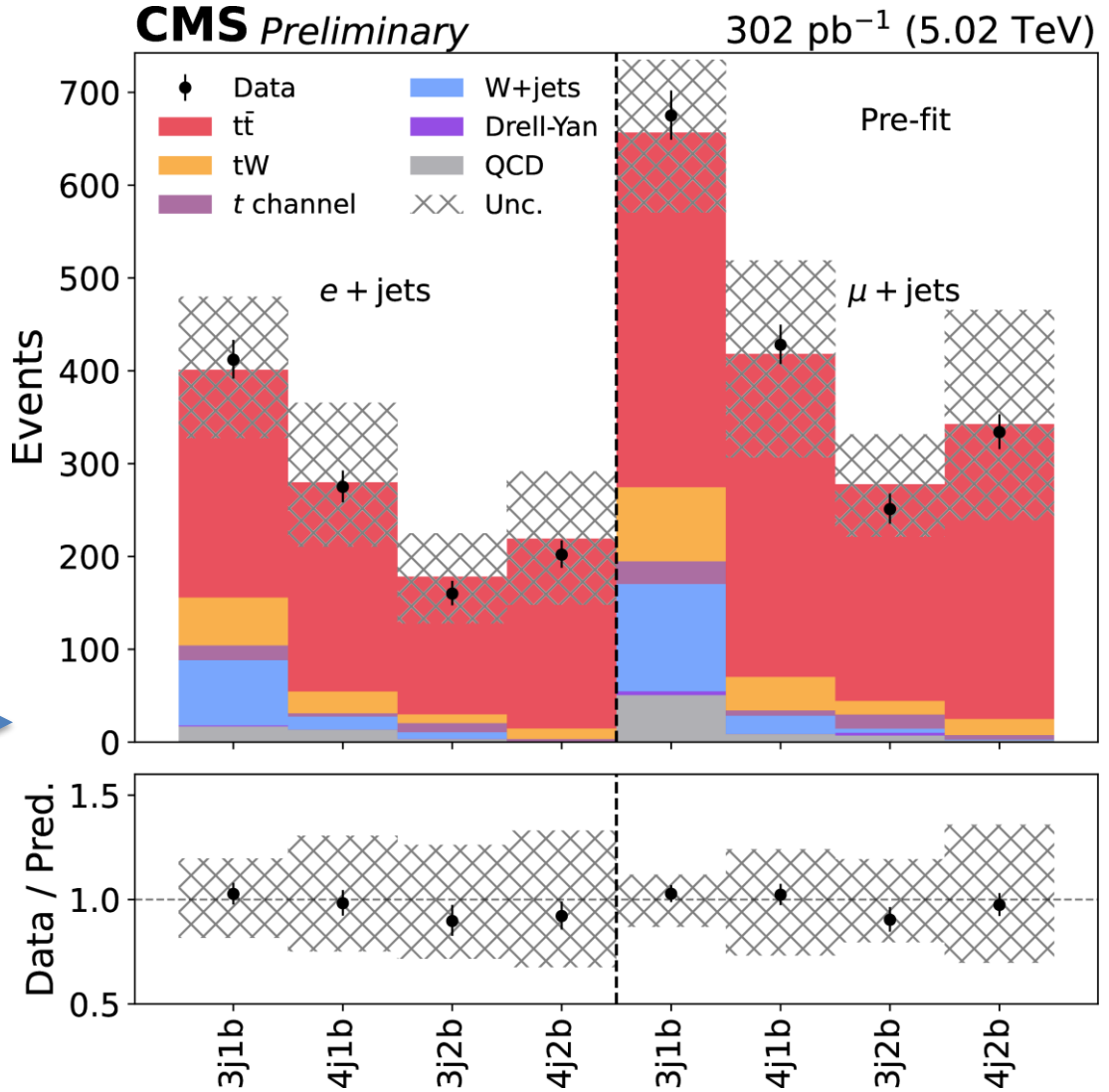
    - $t + Z$ ($t\bar{t}Z$, tZq , tWZ) @ **13TeV**, exactly 3 leptons (e/μ)

  - CMS-PAS-TOP-23-008 : Measurement of **inclusive and differential** cross sections for **single top quark** production in association **with a W** boson in proton-proton collisions at 13.6 TeV (*Submitted to J. High Energy Phys)*
    arXiv:2409.06444

    - tW **@13.6TeV,** 34.7fb^{-1}, 2022 data, dilepton eμ final states

Inclusive $t\bar{t}$ at 5.02 TeV

- e/μ + jets
- dominant backgrounds are W+jets and tW
- QCD multijet events from data
- maximum likelihood fit to **eight event categories** defined in terms of the number of jets and b-tagged jets
- Signal selection with MVA (Random Forest)

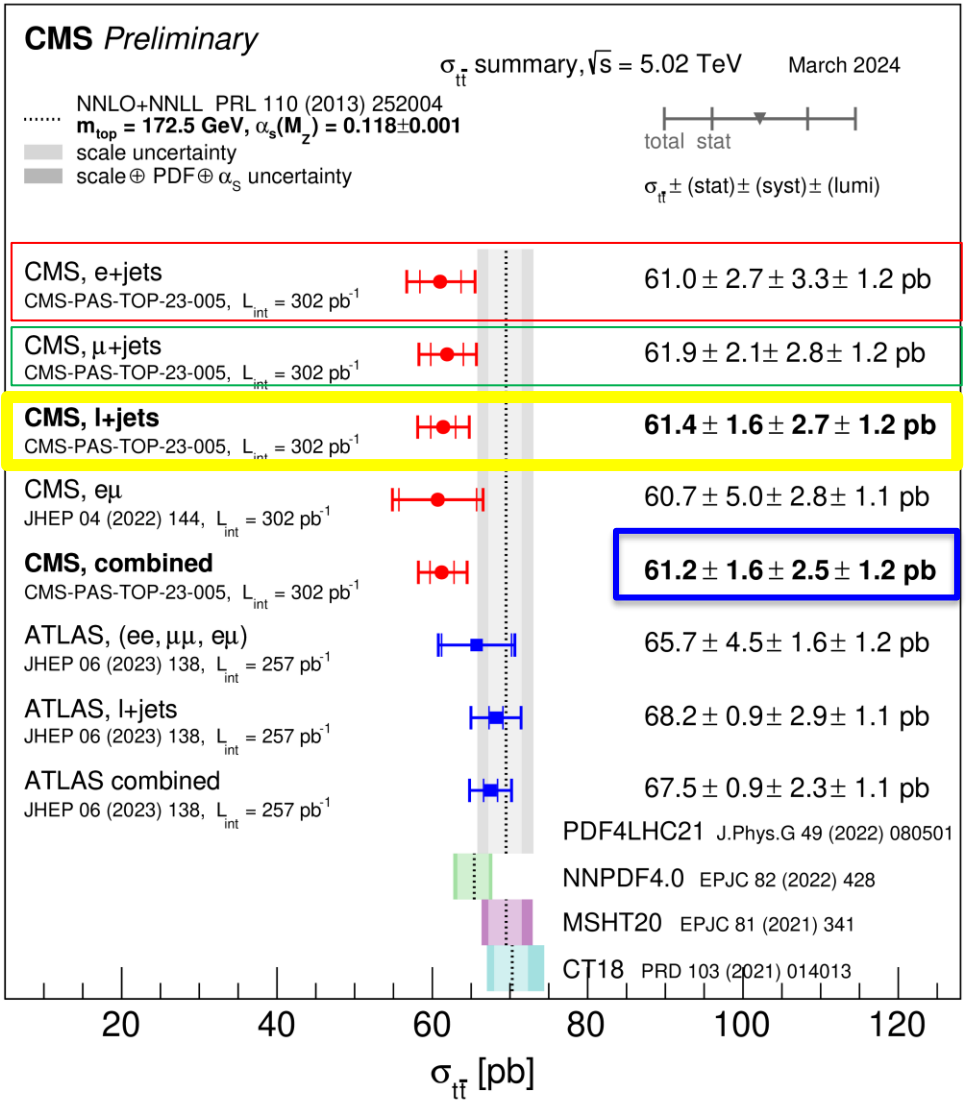


CMS-PAS-TOP-23-005

Inclusive $t\bar{t}$ at 5.02 TeV

CMS-PAS-TOP-23-005

- Dominant uncertainties are those associated with the **luminosity** and with the **b tagging** scale factors for heavy flavours
- This measurement is **combined** with the result obtained in the dilepton channel, based on the same data set
- In **agreement** with the SM prediction: 69.5 +2.9 −3.1pb (at NNLO in QCD)
- And with **previous** measurements from CMS and ATLAS



Inclusive $t\bar{t}$ at 5.02 TeV

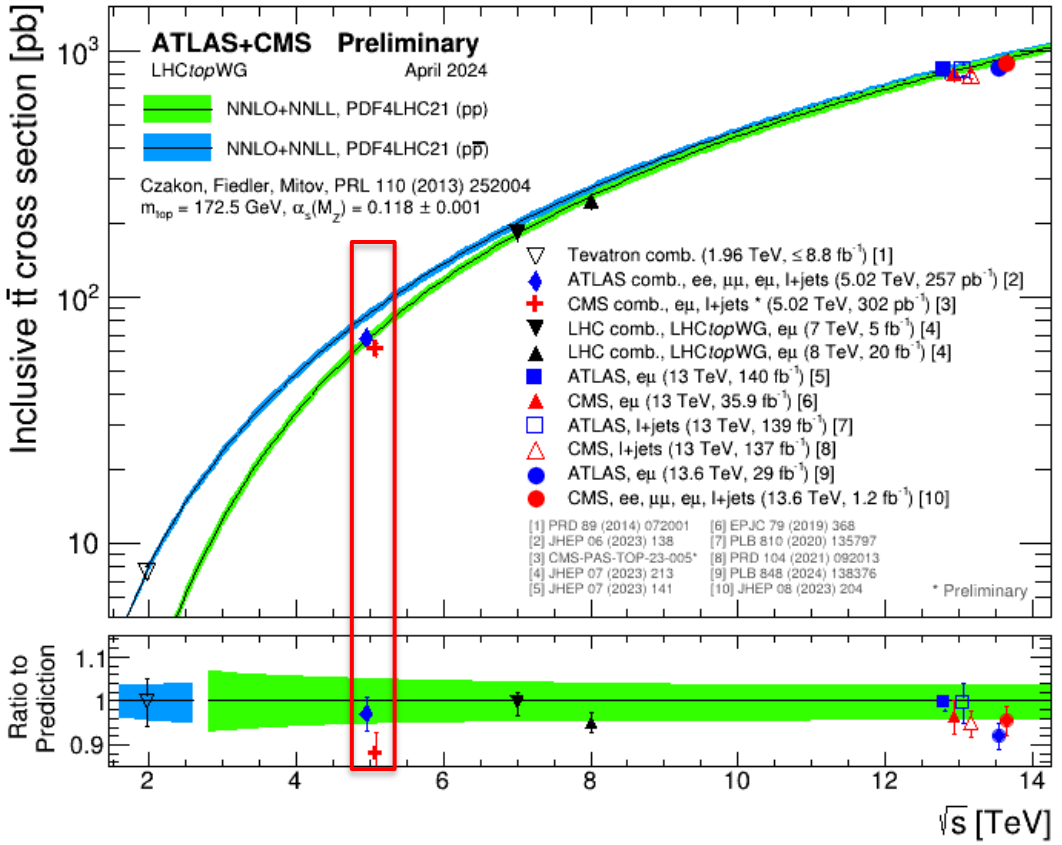
- Dominant uncertainties are those associated with the **luminosity** and with the **b tagging** scale factors for heavy flavours

- This measurement is **combined** with the result obtained in the dilepton channel, based on the same data set

- In **agreement** with the SM prediction of 69.5 +2.9−3.1pb (at NNLO in QCD)

- And with **previous** measurements from CMS and ATLAS

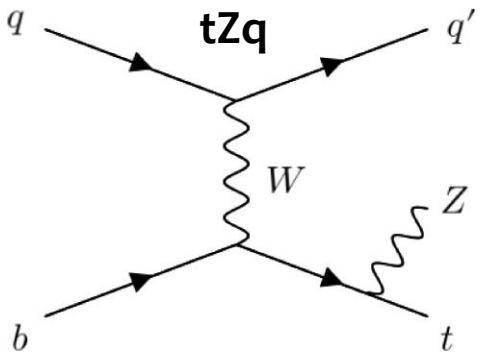
CMS-PAS-TOP-23-005

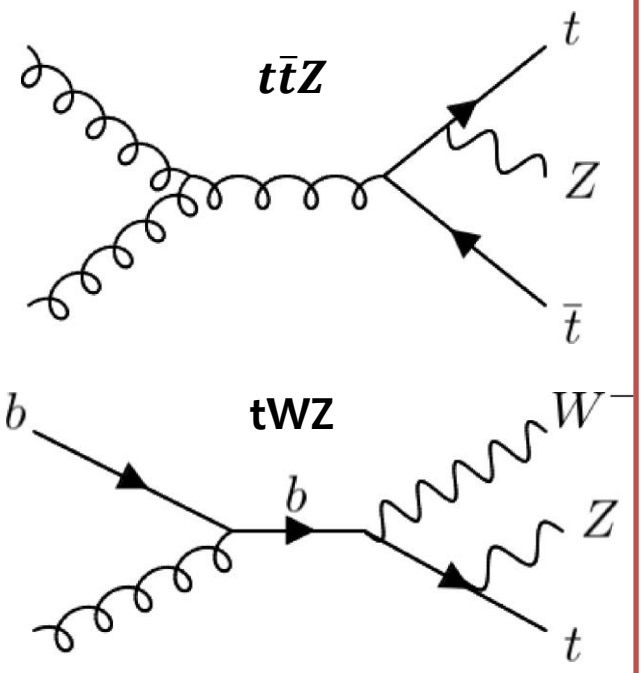


Inclusive and differential $t + Z$ at 13 TeV

CMS-PAS-TOP-23-004

First measurement doing **simultaneously** $t\bar{t}\,Z + tWZ + tZq$:





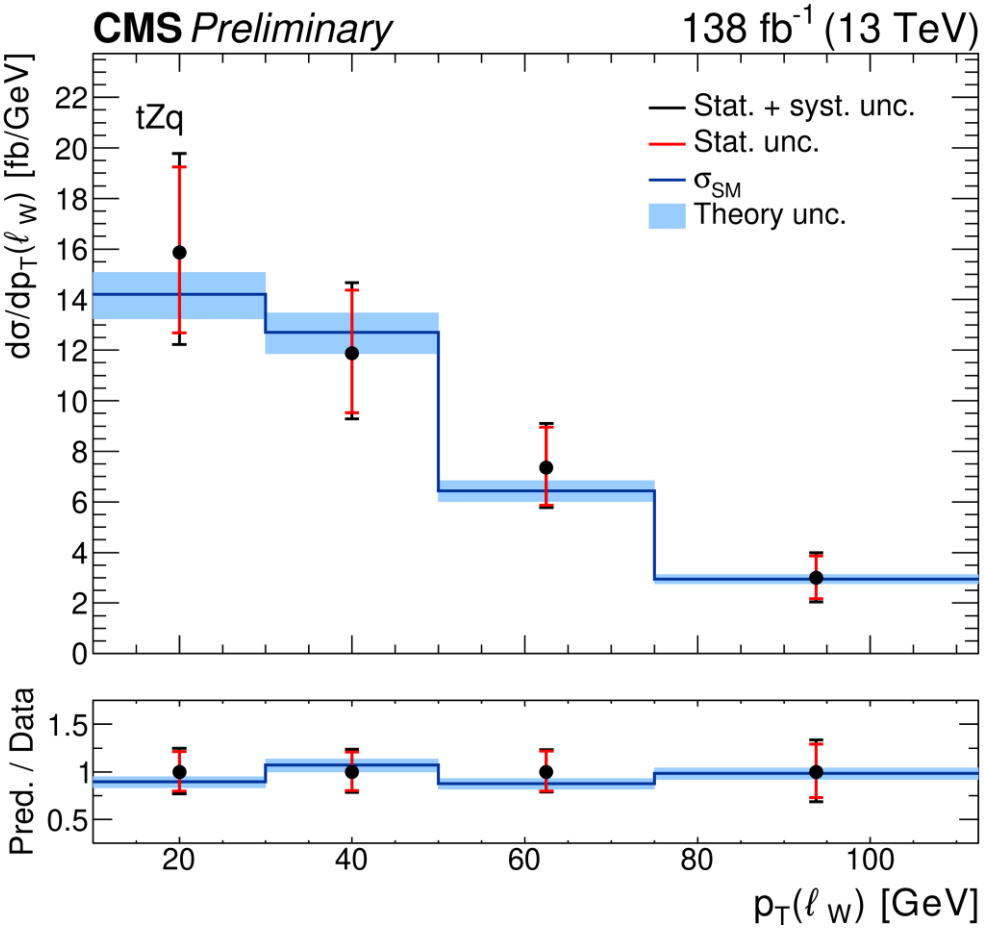
$t\bar{t}Z$ and **tWZ** measured together due to their similar experimental signature and significant interference beyond LO

Exactly 3 leptons (e/μ)

- **DNN** trained to separate the signal processes and the backgrounds
- A **combined profile likelihood** approach is used to unfold the differential cross sections, to account for systematic uncertainties, and to determine the correlations between the two signal categories in one global fit
- Inclusive cross sections for a **dilepton invariant mass within 70 and 110 GeV**

Inclusive and differential $t + Z$ at 13 TeV

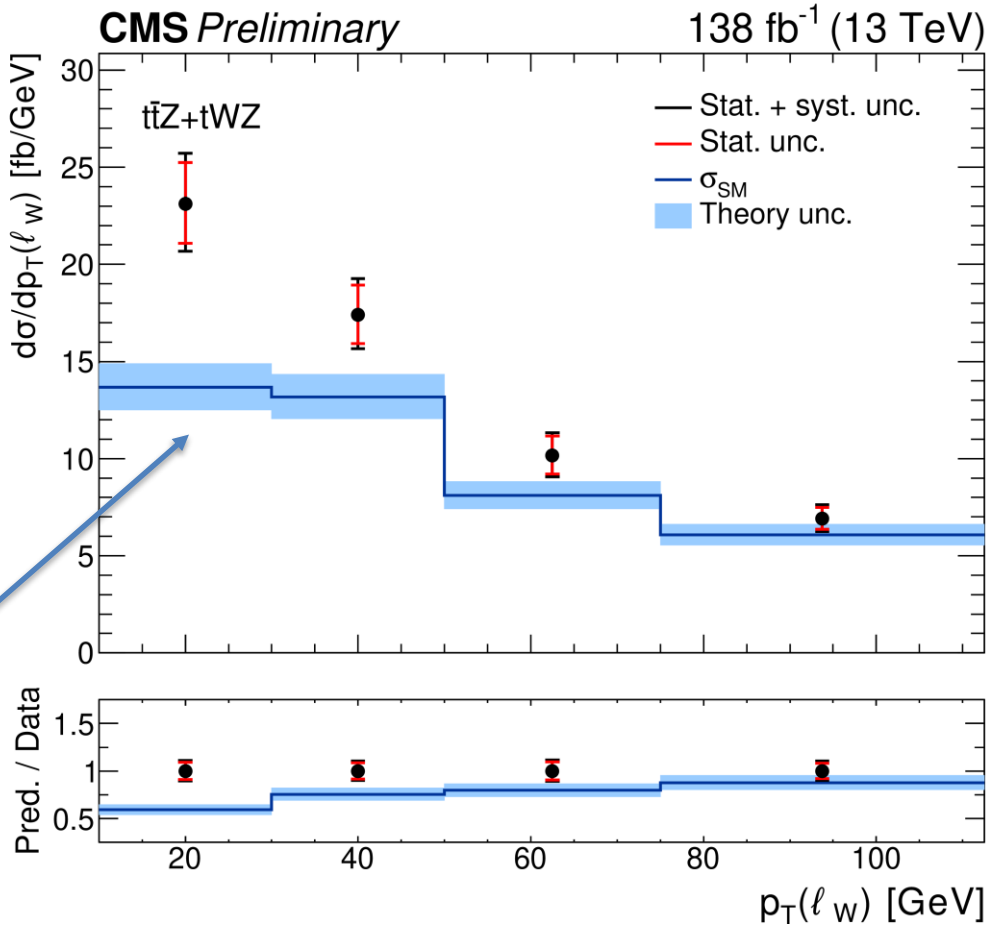
- The cross sections are measured differentially as functions of **several observables:** $p_T(Z)$, $\Delta\phi(l,l)$, $\Delta R(Z,t)$, $\cos(\theta^*_Z)$
- In general good agreement is found for the $\boldsymbol{tZq}$ **process** $\sigma(\boldsymbol{tZq})$ = 0.81 ± 0.10 pb
- While for $\boldsymbol{t\bar{t}Z + tWZ}$, a clear trend is observed as a function of the transverse momentum p_T of the lepton originating from the top quark, leading to a significant excess of the data over expectation at low values of p_T



CMS-PAS-TOP-23-004

Inclusive and differential $t\bar{t}Z$ at 13 TeV

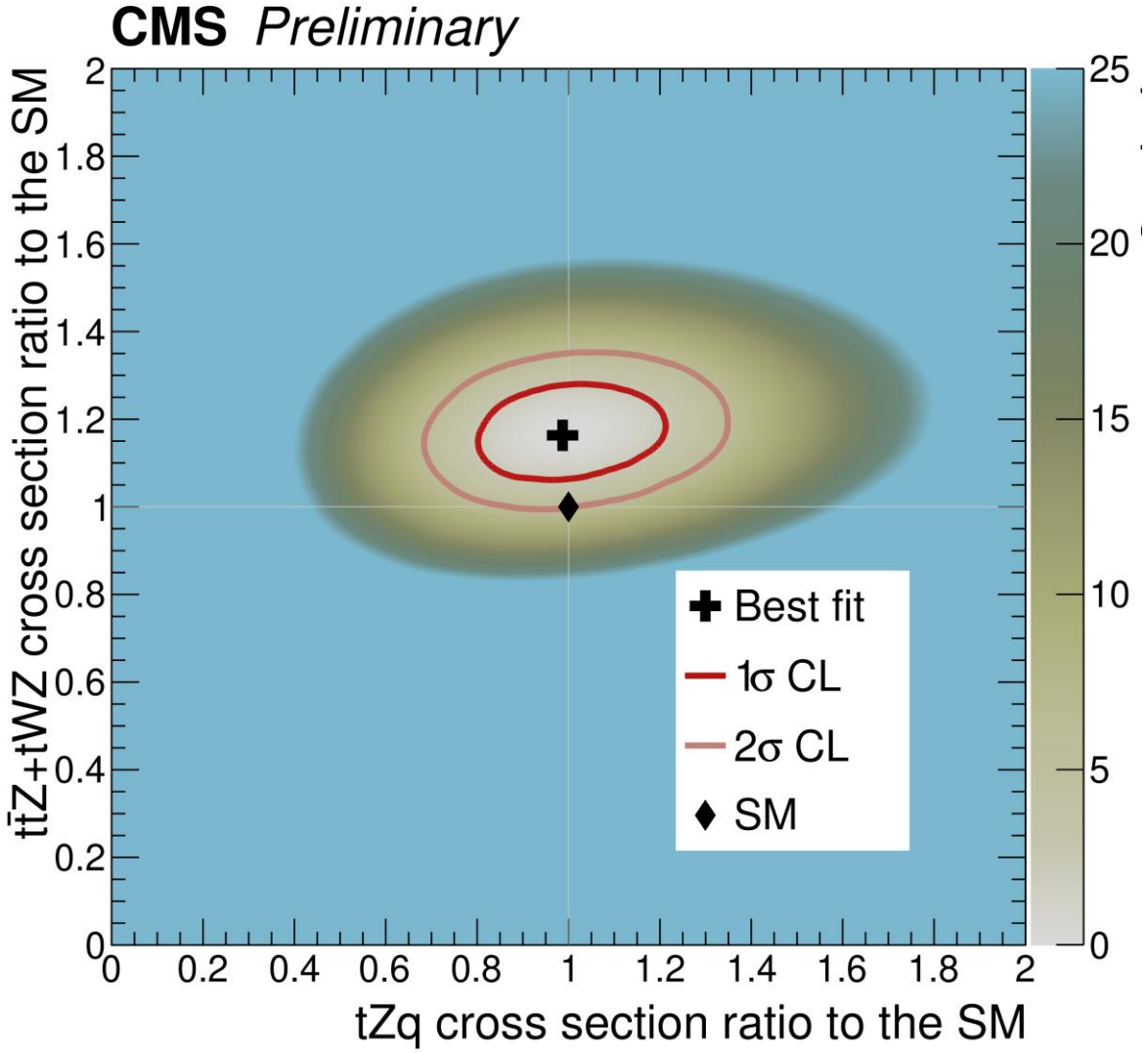
- The cross sections are measured differentially as functions of **several observables:** $p_T(Z)$, $\Delta\phi(l,l)$, $\Delta R(Z,t)$, $\cos(\theta^*_Z)$
- In general good agreement is found for the $\boldsymbol{tZq}$ **process** $\sigma(tZq) = 0.81 \pm 0.10$ pb
- While for $\boldsymbol{t\bar{t}Z + tWZ}$, a clear trend is observed as a function of the transverse momentum p_T of the lepton originating from the top quark, leading to a significant excess of the data over expectation at low values of p_T



CMS-PAS-TOP-23-004

Inclusive and differential $t + Z$ at 13 TeV

CMS-PAS-TOP-23-004



Likelihood scan of the two measured inclusive cross sections normalized to the SM prediction.

While good agreement with SM prediction is found for the tZq process

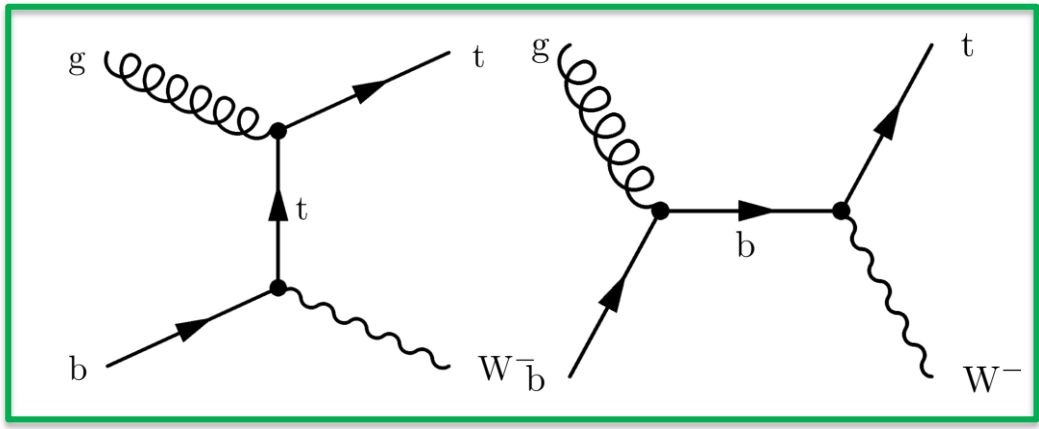
$\mu = 0.99 \pm 0.13$ (NLO, QCD+EW),

for $t\bar{t}Z + tWZ$ measurement has a ratio to the central value of the prediction of **1.17 ± 0.07**

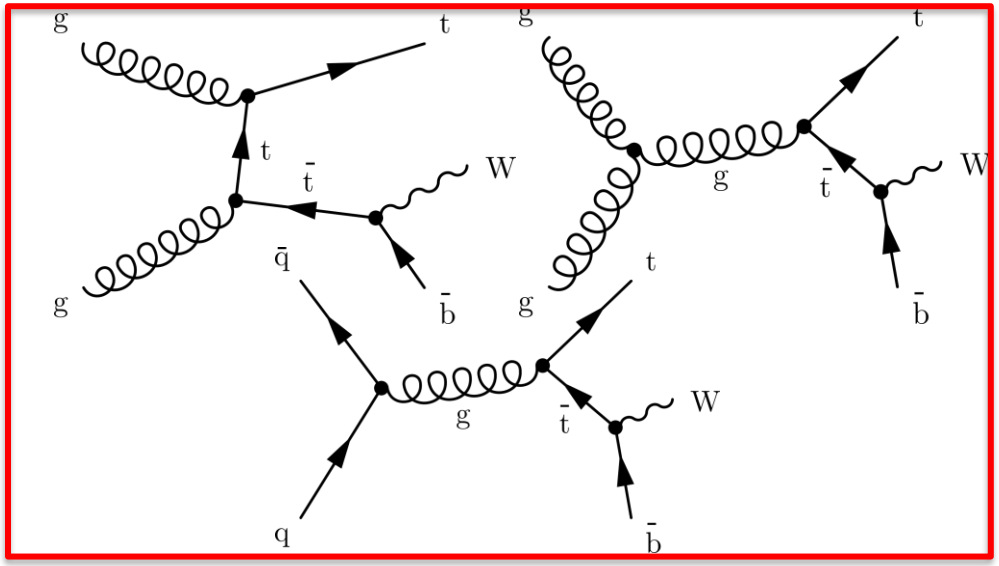
Inclusive and differential tW at 13.6 TeV

- First measurement of the inclusive and normalised differential tW cross sections at 13.6TeV, eμ channel
- For the **inclusive** measurement, multivariate discriminants exploiting the kinematic properties of the events are used to separate the signal from the dominant $t\bar{t}$ production
- A fiducial region is defined according to the detector acceptance to perform the **differential** measurements. The resulting differential distributions are unfolded to particle level and show good agreement with the predictions at NLO

CMS-PAS-TOP-23-008



tW at NLO removed from the signal definition in the DR scheme

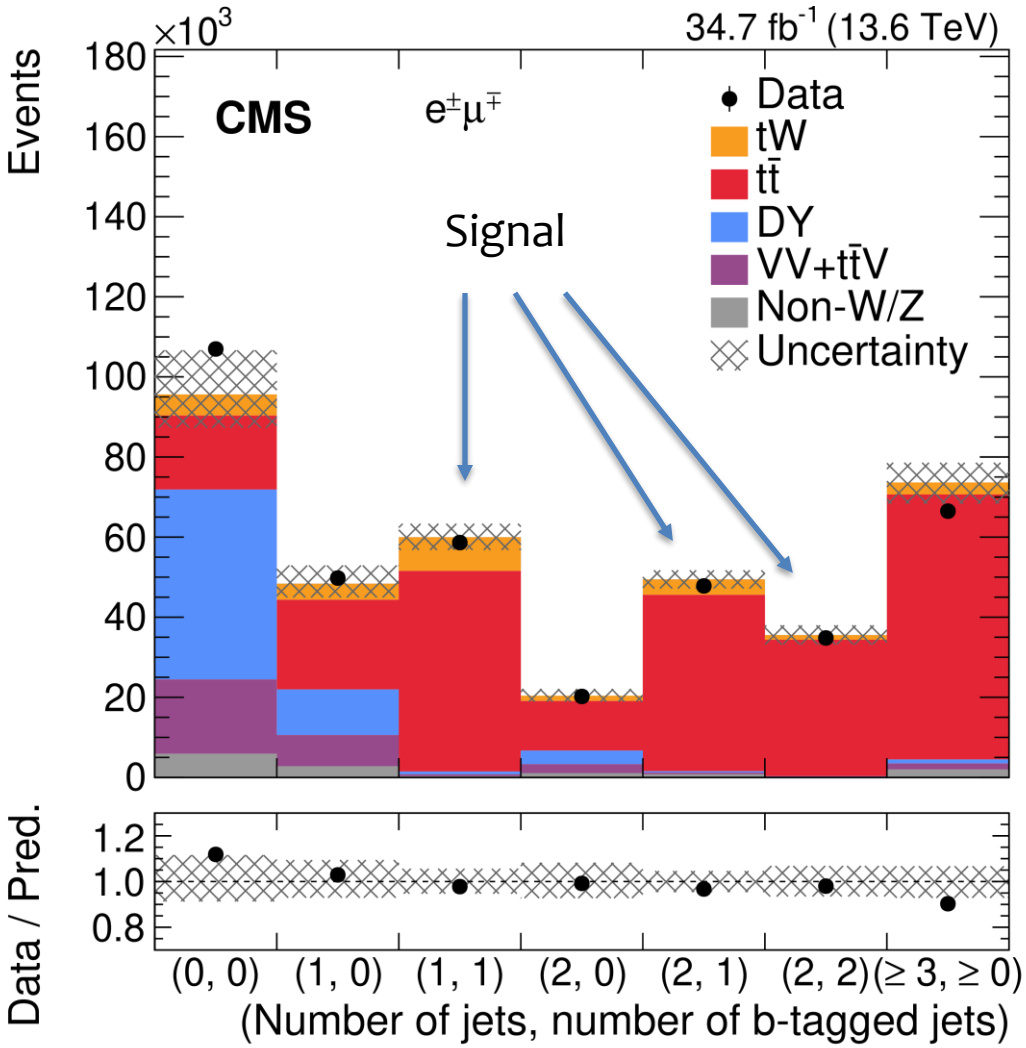


Inclusive and differential tW at 13.6 TeV

- For the **inclusive** measurement, the events have been categorised depending on the number of jets and jets originating from the fragmentation of bottom quarks (b jets)

- The **signal** is measured using a maximum likelihood fit to the distribution of RF discriminants in the regions with **one or two jets** where one of them is a b jet, and to the transverse momentum (p_T) distribution of the second-highest p_T jet in a third category with two jets, both of which are b jets.

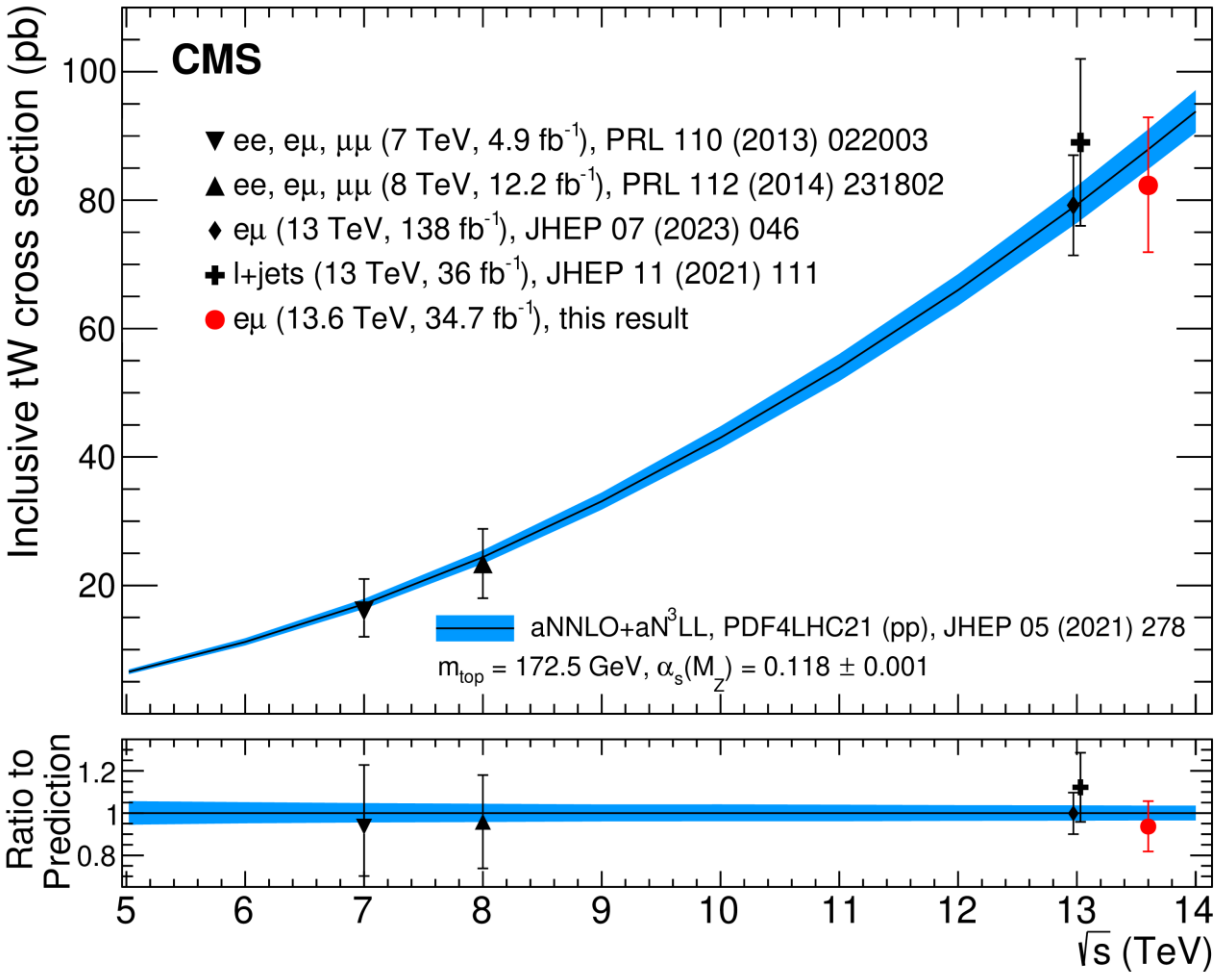
CMS-PAS-TOP-23-008



Inclusive and differential *tW* at 13.6 TeV

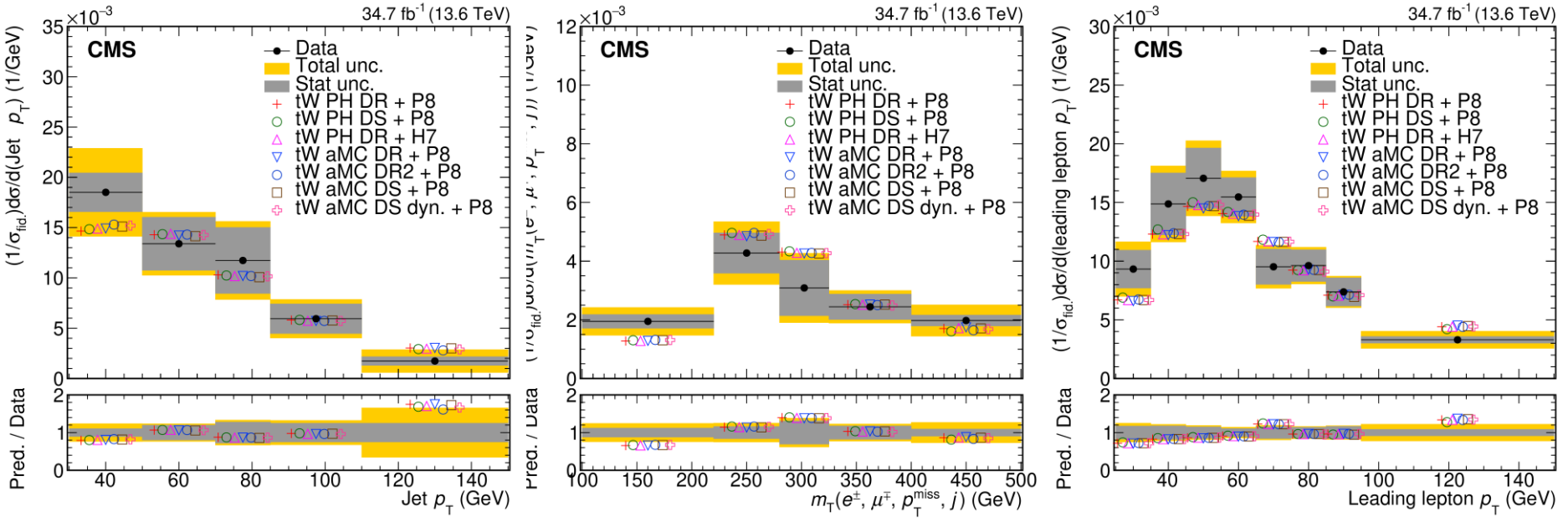
CMS-PAS-TOP-23-008

- A cross section of **82.3 ± 2.1 (stat) +9.9−9.7 (syst) ± 3.3 (lumi) pb** is measured
- Total relative uncertainty of about **13%**
- This measurement is in **agreement** with the latest theoretical prediction at approximate **NNNLO** accuracy and with other measurements



Inclusive and differential tW at 13.6 TeV

CMS-PAS-TOP-23-008



- **Fiducial region selection**:
  - leptons $e^{\pm}/\mu^{\mp} \geq 2$
  - Leading >25GeV
  - m_{ll}> 20GeV
  - 1 jet = 1 bjet

- relative uncertainties in the range of **20-40%**
- uncertainties are mainly **statistical**
- good agreement with predictions
- **different approaches** used to simulate tW events give similar values in all distributions, which points to small effects related to the $tW/t\bar{t}$ interference on these distributions in the defined fiducial region

Summary

- CMS has made **significant progress**

in measuring top quark **cross-sections**

- Precision tests already well established

in Run2, now approaching ultraprecise measurements:

  - **tt** production at **all LHC √s**
  - **tt + boson** combinations at √s=13TeV
  - **tW** for every LHC √s (5.02TeV not yet)
  - Both **inclusive** and **differential**!!!!!

No deviations from SM so far, but MCs >NLO are a need

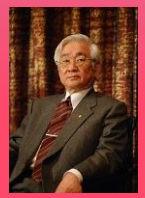
- **More results** to come:
  - Run 3 still ongoing at 13.6TeV
  - Expected $\int L \sim 450\ fb^{-1}$, so far recorded: ~ $170\ fb^{-1}$

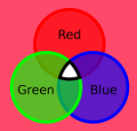
Top quark makes **matches** with most of SM particles (see backup slide for its profile....)

• CMS Top Physics results:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

BACKUP SLIDES

binder profile:

- **Age**: 29 (in theory 51…)
- **Country**: USA (Japanese fathers)
- **Gender**: fermion (s=1/2)
- **Status**: single
- **Weight** : ~172.5GeV
- **Charge**: +2/3 |e|
- **Likes**: strong, EW and gravity forces
- **Favorite colors**: many 

- **Siblings**: a non-identical twin brother

"I am open to new physics discoveries beyond the Standard Model"