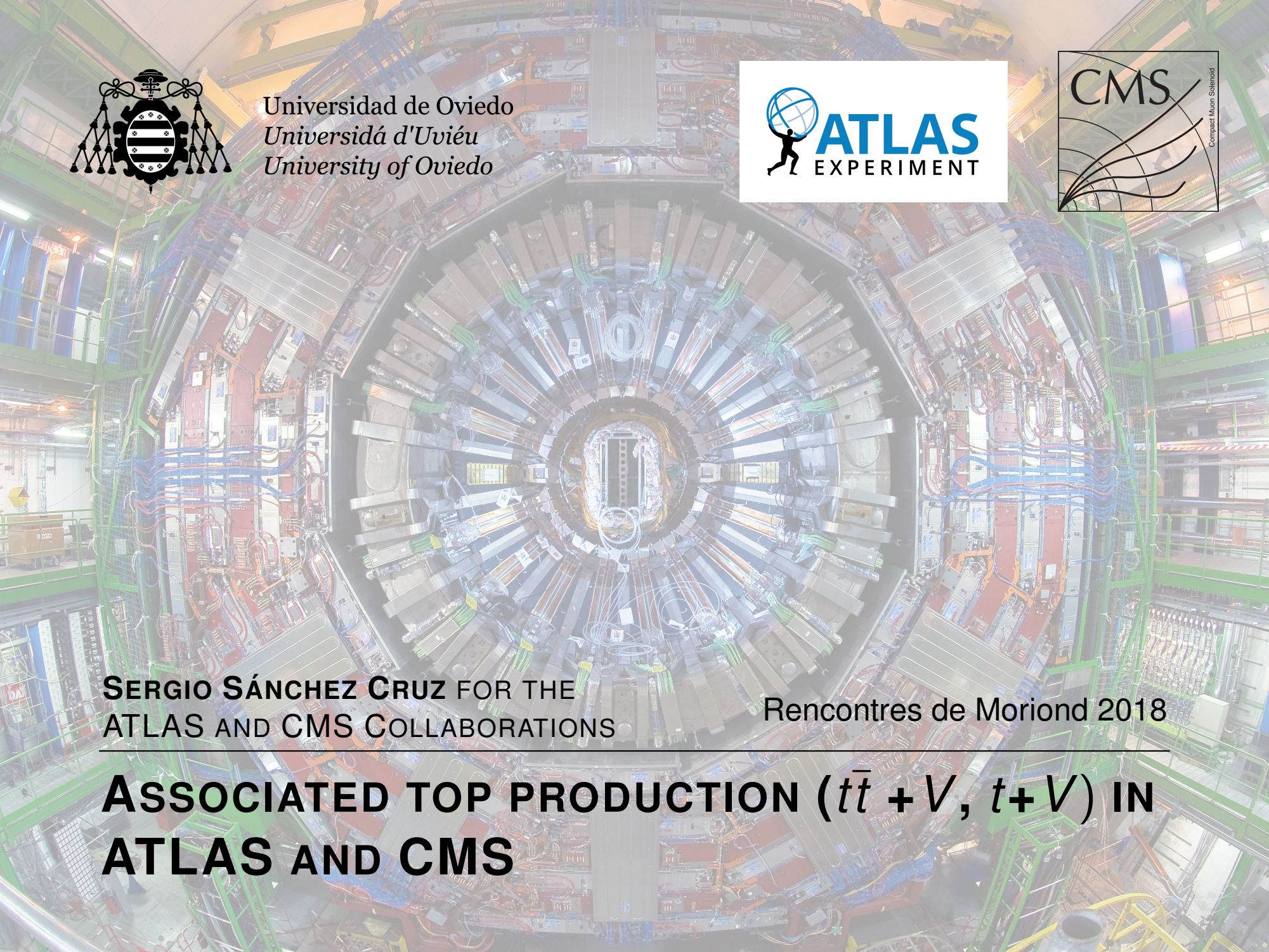
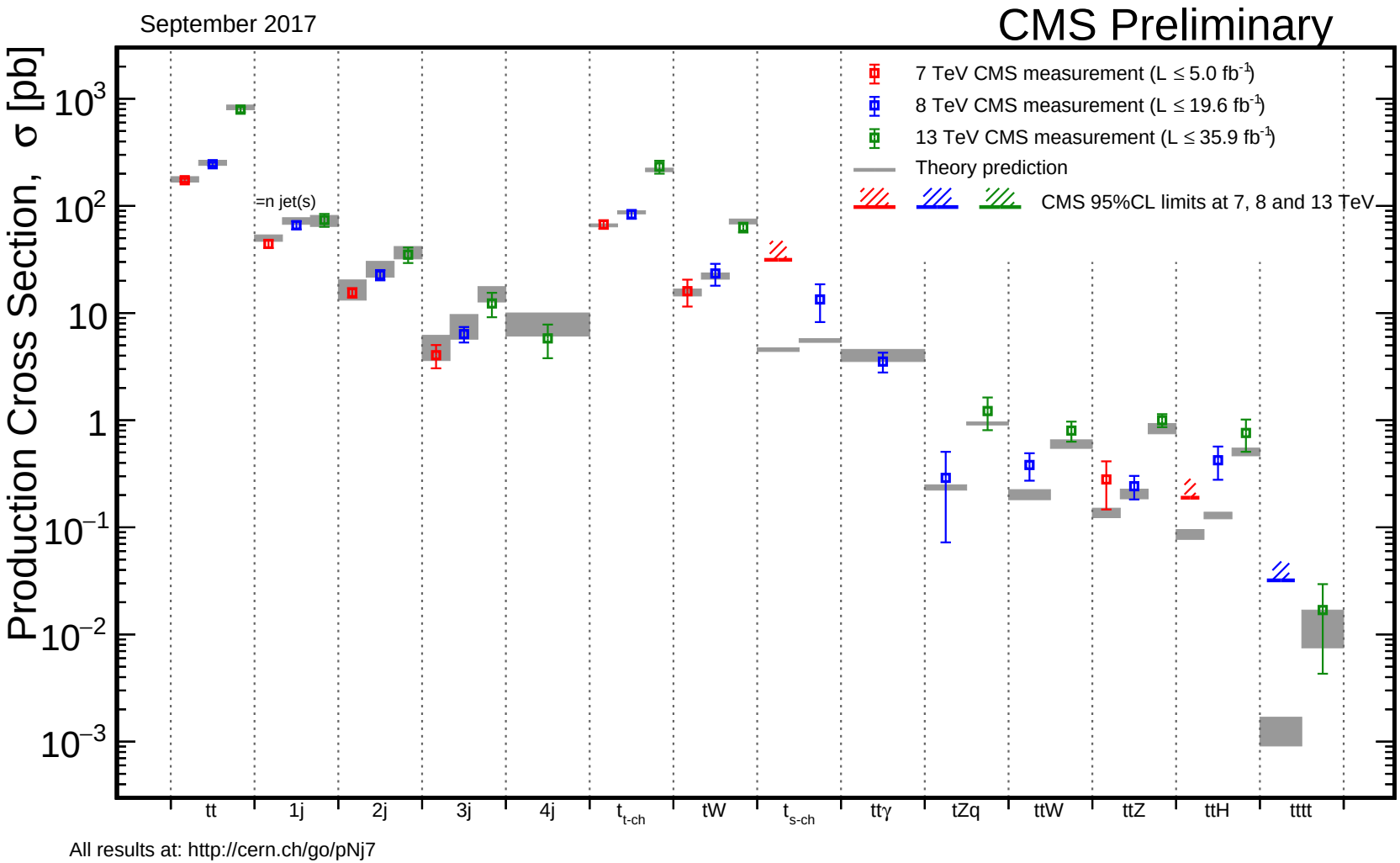


Universidad de Oviedo
Universidá d'Uviéu
University of Oviedo

SERGIO SÁNCHEZ CRUZ FOR THE
ATLAS AND CMS COLLABORATIONS

Rencontres de Moriond 2018

ASSOCIATED TOP PRODUCTION ($t\bar{t}+V$, $t+V$) IN ATLAS AND CMS

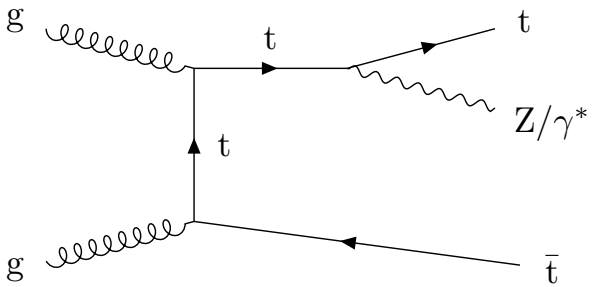


- Will cover several channels of associated $t\bar{t}$ production
- Low cross-section processes but crucial for understanding of EWK symmetry breaking
- Also background for many searches and SM measurements

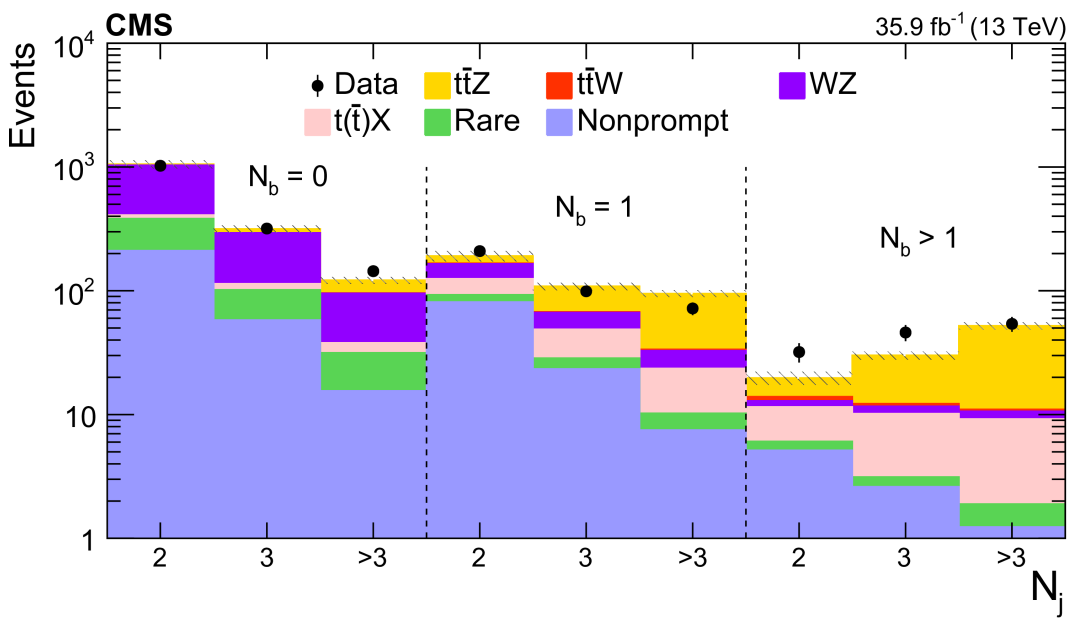
$t\bar{t}+Z$ PRODUCTION IN CMS

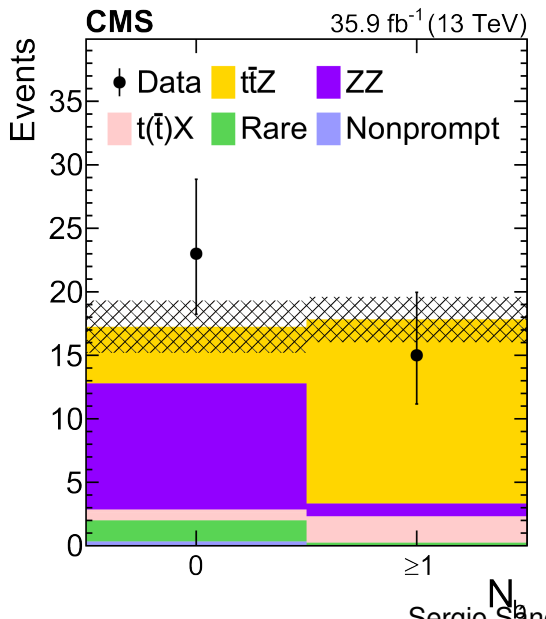
arXiv:1711.02547

- Sensitive to Z boson coupling to top quarks
- Measurement of $t\bar{t}+Z$ in 3l and 4l regions
- Classes depending on the number of jets and *b*-jets in 3l
- WZ processes estimated and validated in control regions
- Signal extracted by performing a ML fit



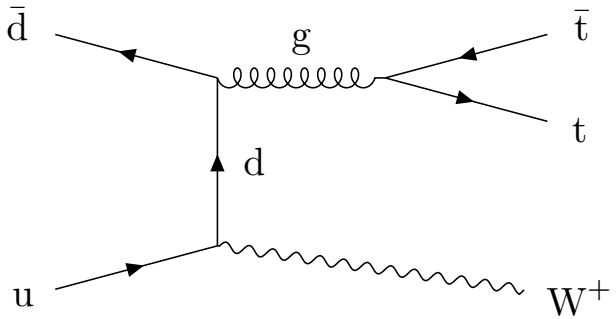
$$\sigma^{SM} = 0.839 \pm 0.101 \text{ pb}$$





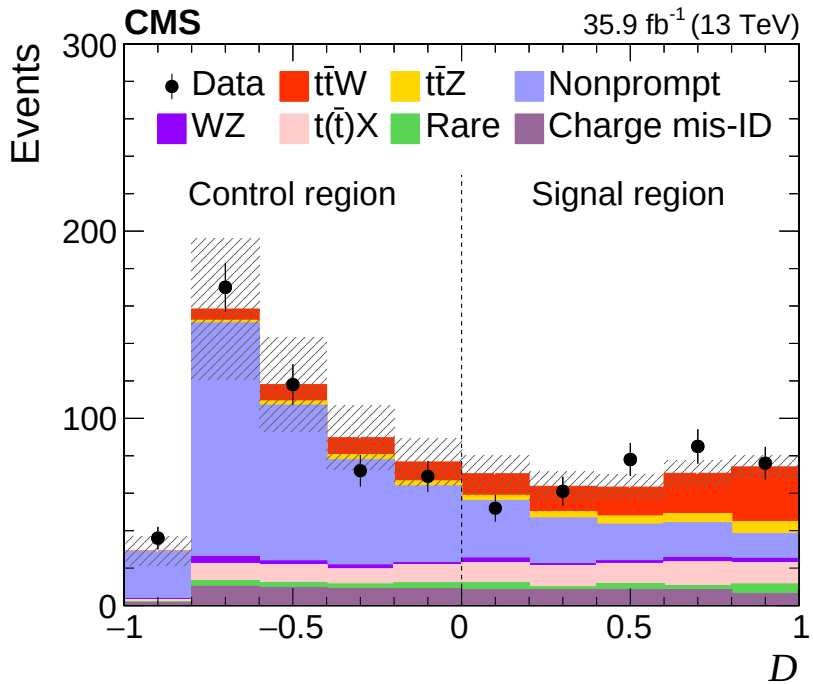
$t\bar{t}+W$ PRODUCTION IN CMS

arXiv:1711.02547



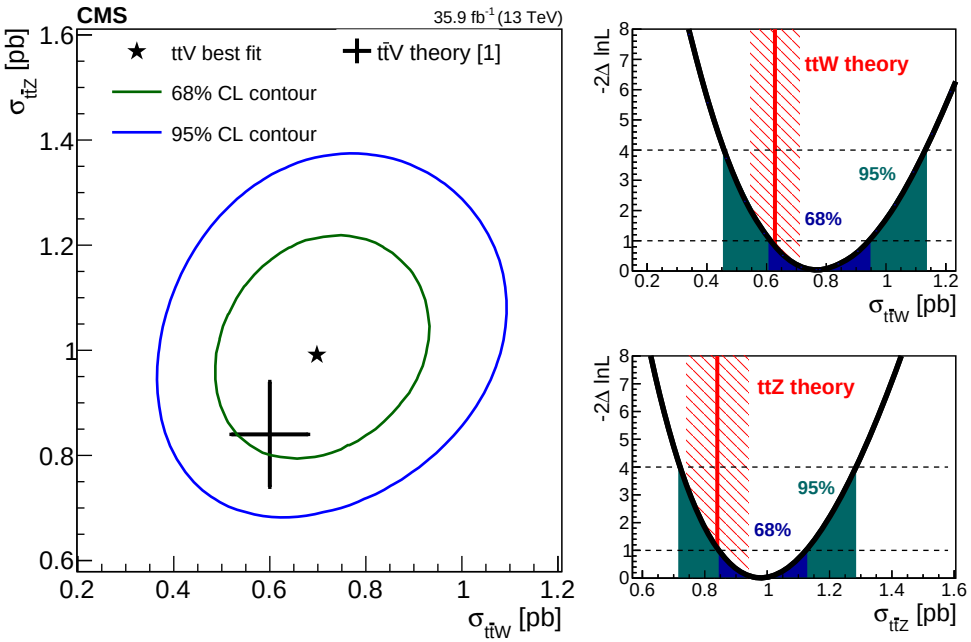
$\sigma^{SM} = 0.628 \pm 0.082$ pb

- Measurement of $t\bar{t}+W$ in the 2lss channel
- BDT trained to discriminate signal from all the backgrounds using kinematic variables
- Data-driven estimation of main background: non-prompt leptons
- 20 independent measurement regions
- Signal extracted by performing a ML fit



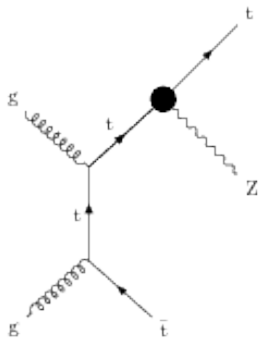
Results and EFT interpretations

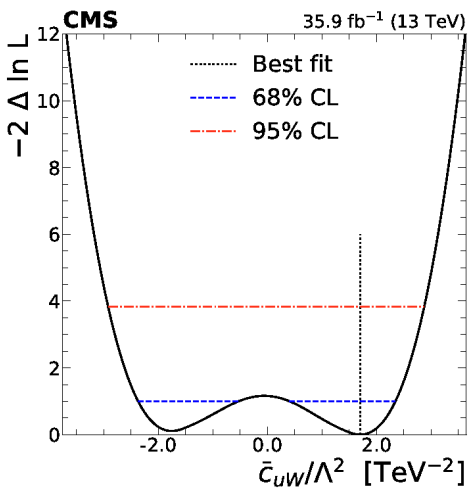
arXiv:1711.02547

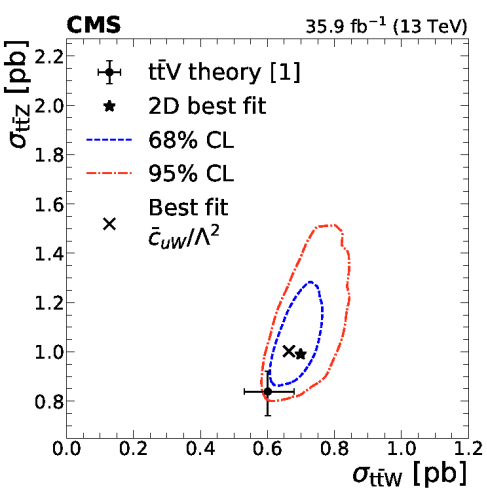


- Observations consistent with SM expectations within 1 sigma
- Above 5 observed standard deviations for all processes
- Sensitivity for $t\bar{t}\,W^+$ and $t\bar{t}\,W^-$

- New physics can affect $t\bar{t}+W$ and $t\bar{t}+Z$ cross-sections
- Constrains on Wilson coefficients for 8 dimension 6 operators

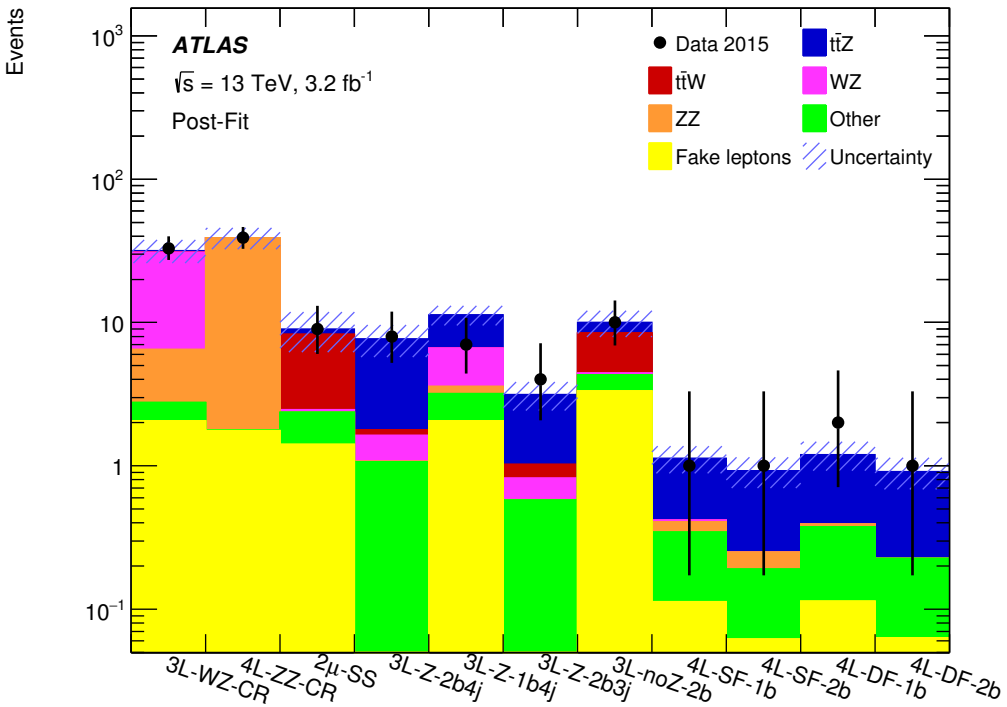






$t\bar{t}+V$ PRODUCTION IN ATLAS

Eur. Phys. J. C77 (2017) 40

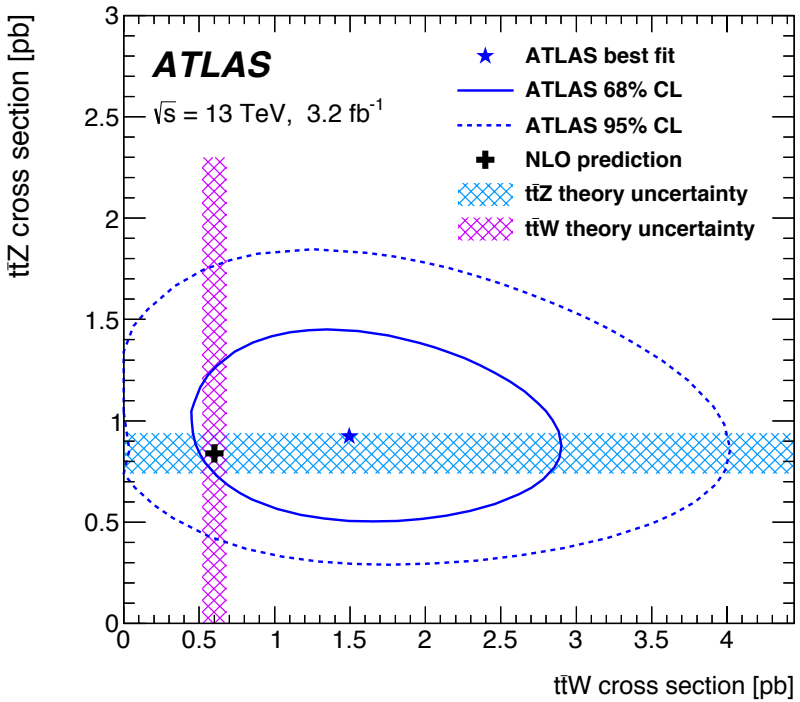


- $t\bar{t}+W$ measurement in $\mu^{\pm}\mu^{\pm}$ and 3l regions:
- $t\bar{t}+Z$ measurement in 3ℓ and 4ℓ

- Data-driven approach to estimate fake leptons / simulation corrected by data
- WZ production estimated through simulations evaluated in data

ATLAS RESULTS

Eur. Phys. J. C77 (2017) 40

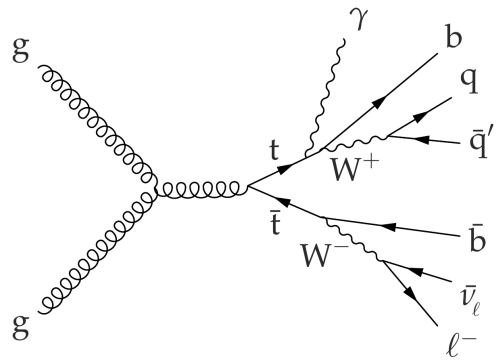


- Simultaneous fit to signal and control regions
- Results compatible with Standard Model expectation
- 3.9 (3.4) σ expected (observed) in $t\bar{t}+Z$
- 2.2 (1.0) σ expected (observed) in $t\bar{t}+W$

- Uncertainties dominated by statistical uncertainties

TTγ PRODUCTION

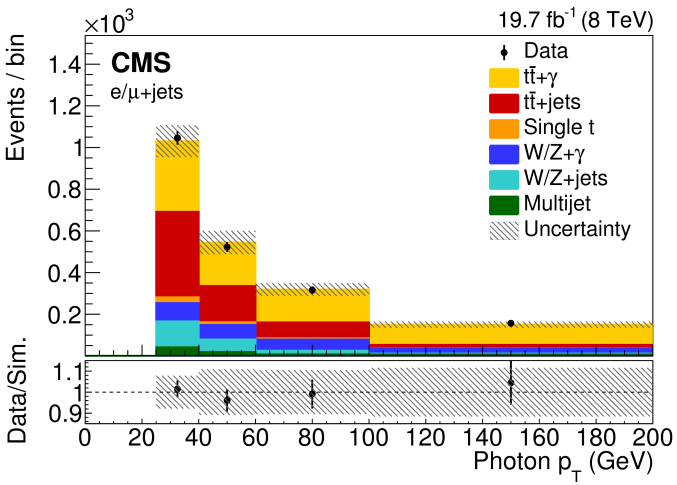
- Measurements of the fiducial $t\bar{t}$ +γ cross-section
- Events are required to have at least 1 lepton, jets and one photon
- Backgrounds are
  - $t\bar{t}$ events with a non-prompt photon
  - Non $t\bar{t}$ events with a prompt photon



CMS

JHEP 10 (2017) 006

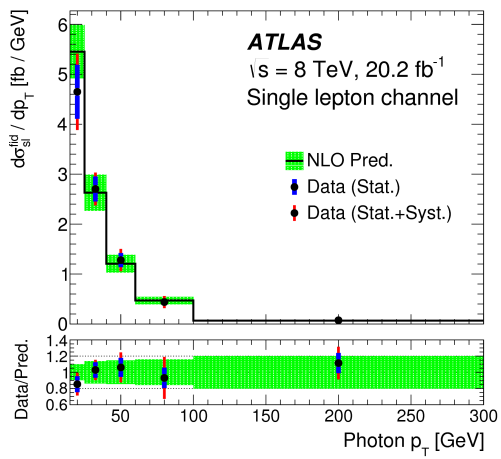
- $\sigma^{fid}_{tt+\gamma}$ = 127 $\pm$ 27 fb
- $R = (5.2 \pm 1.1) \times 10^{-4}$



ATLAS

JHEP 11 (2017) 086

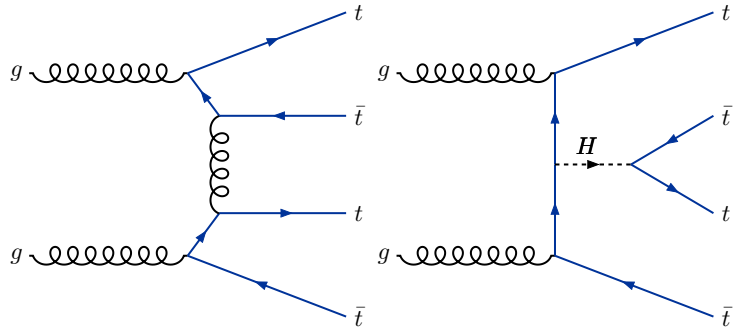
- $\sigma^{fid} = 139 \pm 18$ fb
- Differential cross-section unfolded to particle level



- Results compatible with SM expectation

Four tops production

Eur. Phys. J. C 78 (2018) 140
ATLAS-CONF-2016-020

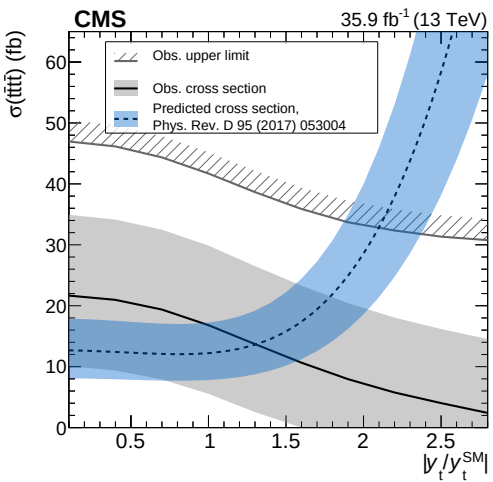


- Process sensitive to y_t coupling

$$\sigma^{SM} = 9.2^{+2.9}_{-2.4}\ \text{fb}$$

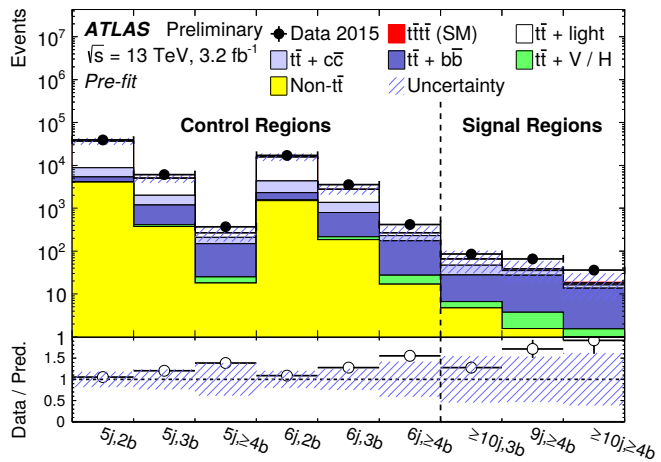
CMS

- Events with at least a same-sign dilepton pair and hadronic activity
- $\sigma = 16.9^{+13.8}_{-11.4}$ fb
- Significance: 1.6 σ (1.0 σ)
- Upper limit on $|y_t/y_t^{SM}| < 2.1$



ATLAS

- Events with one lepton and large jet multiplicity



- Upper limit on $t\bar{t}\ t\bar{t}$ production: 21 (16) $\times \sigma_{t\bar{t}\ t\bar{t}}{}^{SM}$

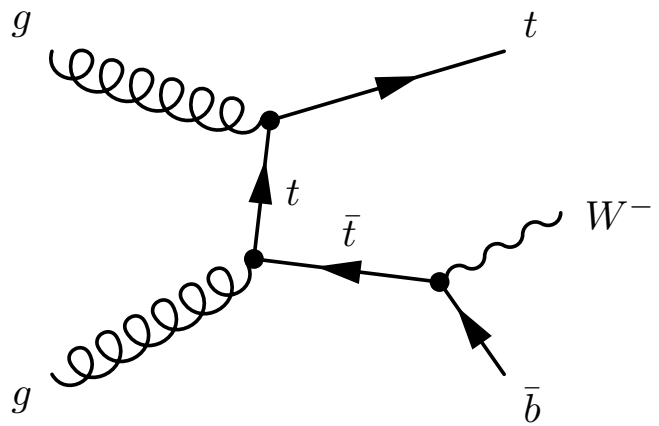
tW-CHANNEL

CMS ANALYSIS

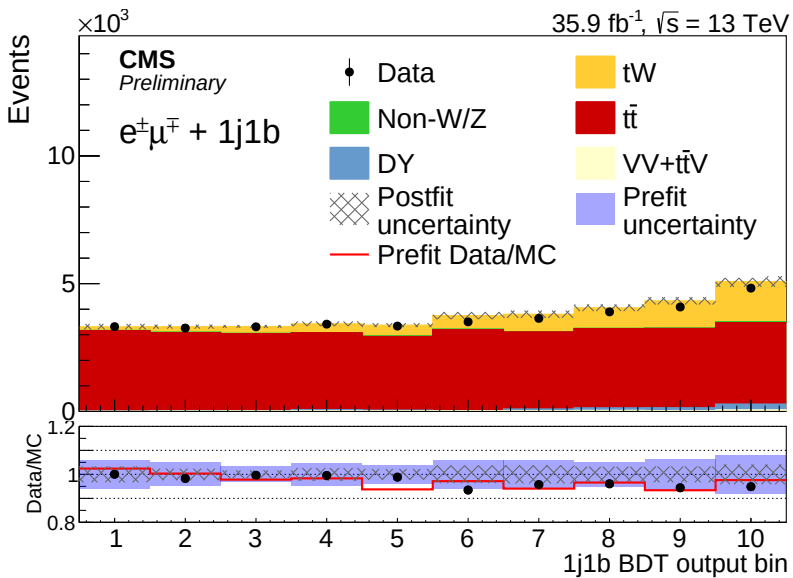
CMS-PAS-TOP-17-018

- Sensitive to b pdfs
- Interference with $t\bar{t}$ at NLO
- Background for $t\bar{t}$ production

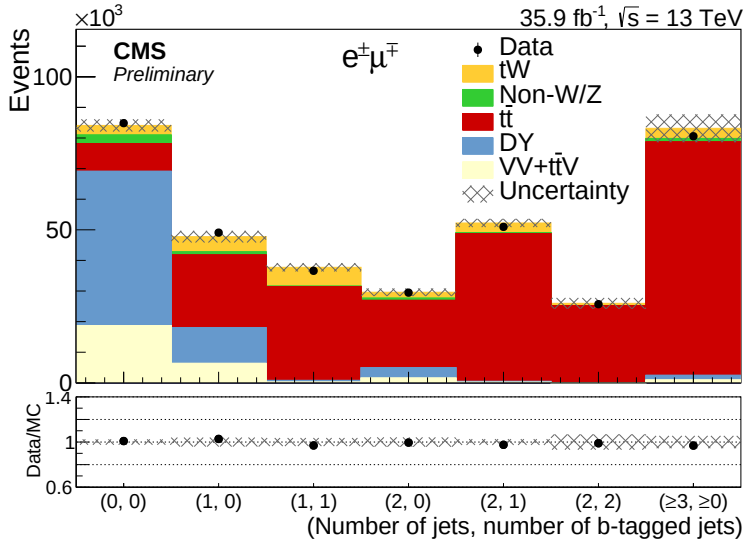
- Measurement in the e+μ channel
- Challenging due to overwhelming presence of $t\bar{t}$
- BDT trained in the 1j1b and 2j1b regions
- BDTs and subleading jet p_T in the 2j2b region used to extract signal in a ML fit



$$\sigma^{SM} = 71.7 \pm 1.8 \pm 3.4 \text{ pb}$$



tW INCLUSIVE RESULTS

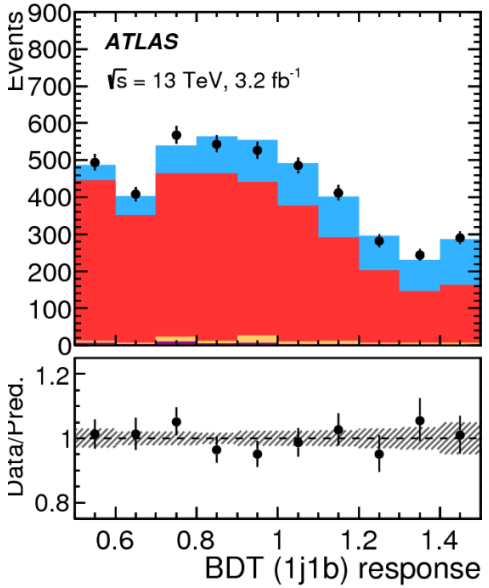


CMS **CMS-PAS-TOP-17-018**

- $63.1 \pm 3\%$ (stat.) $\pm 9\%$ (syst.) $\pm 3\%$ (lumi) pb
- Determination with 10% uncertainty

ATLAS **JHEP 01 (2018) 63**

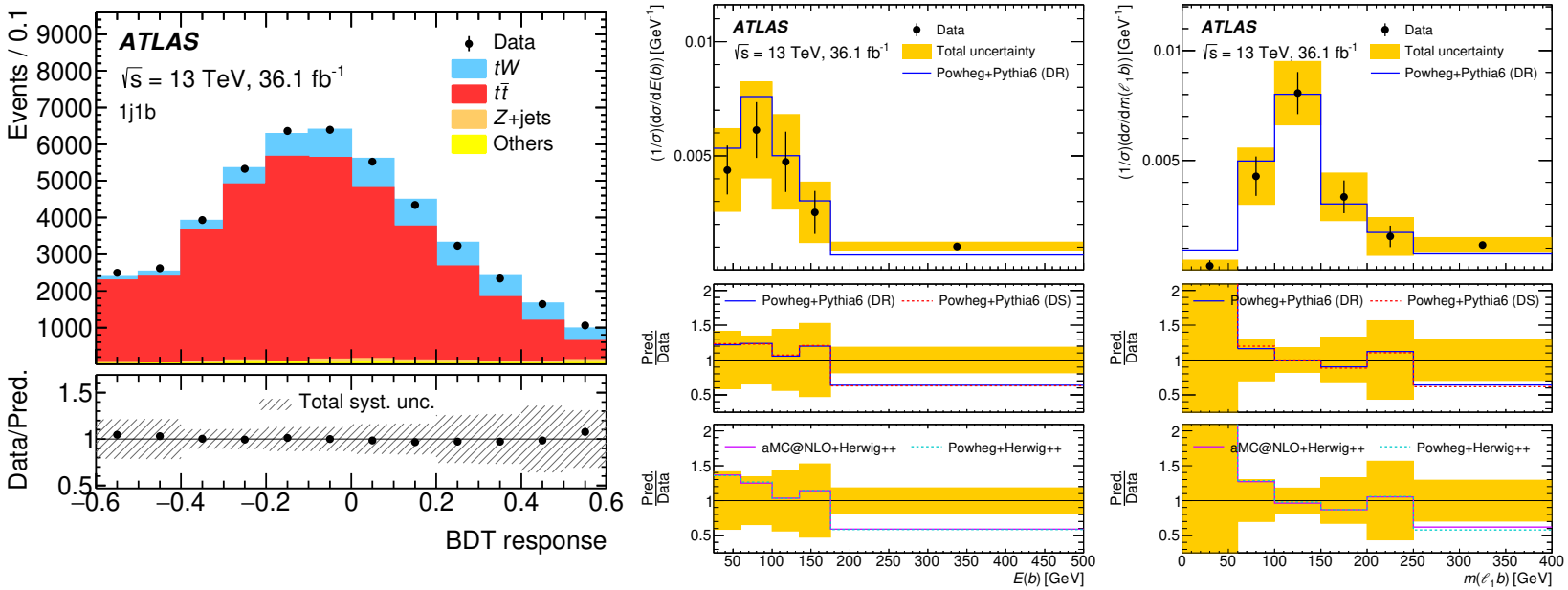
- Similar methodology used by ATLAS (smaller dataset)
- $\sigma_{tW} = 94 \pm 10(\text{stat.})\ ^{+28}_{-22}$ (syst.) ± 2 (lumi.) pb
- Uncertainty of the order of 30%



Both measurements consistent with SM expectation
$\sigma_{tW}^{\text{SM}} = 71.7 \pm 1.8$ (scale) ± 3.4 (pdf) pb

DIFFERENTIAL *tW* MEASUREMENT

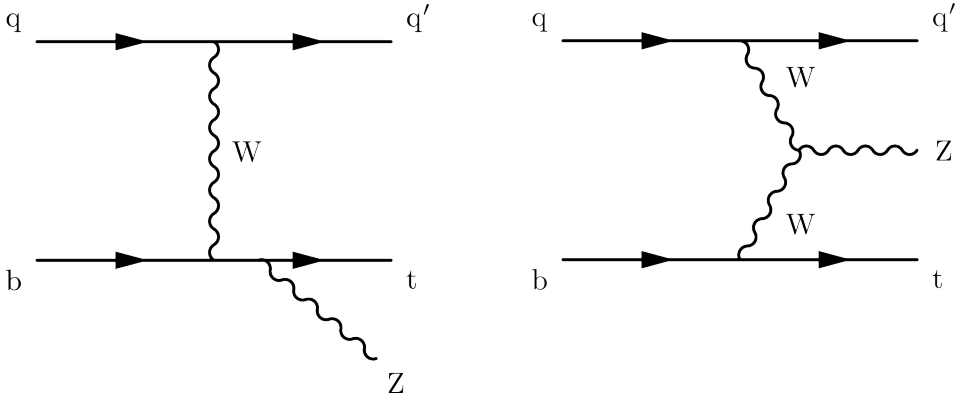
arXiv:1712.01602



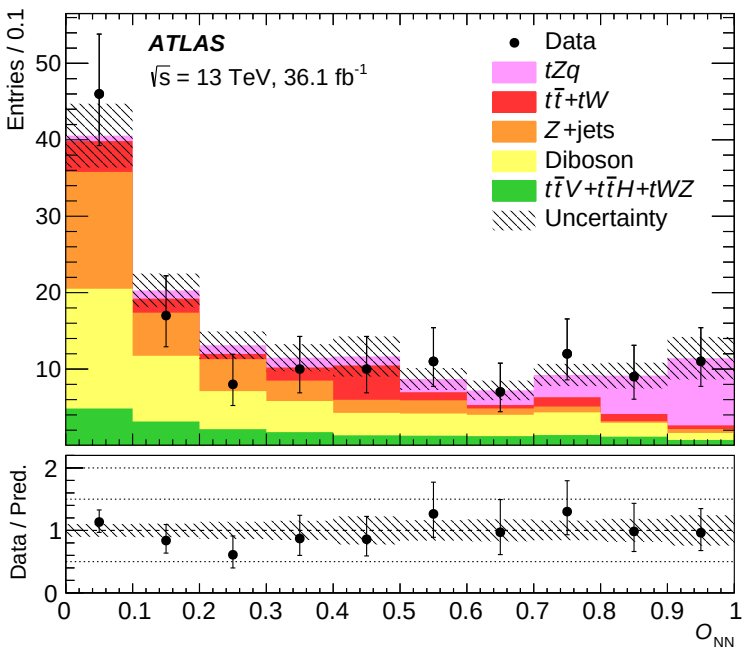
- Differential measurement performed on a signal enhanced region defined by the BDT used in the inclusive measurement
- Distributions unfolded to particle level
- Allows to compare diagram subtraction and removal prescriptions
  - Both prescriptions are compatible with data

tZq PRODUCTION IN ATLAS

arXiv:1710.03659



$\sigma^{SM}(tZq) = 820$ fb [Z $\rightarrow$ anything]



- Direct probe of top coupling to Z
- Sensitive to WWZ coupling

- Measurement in events with 3l
- Fakes from DY+fake using a data-driven method
- Fakes from $t\bar{t}$ using simulations and corrected in CR
- ANN trained to discriminate signal from backgrounds but $t\bar{t}$

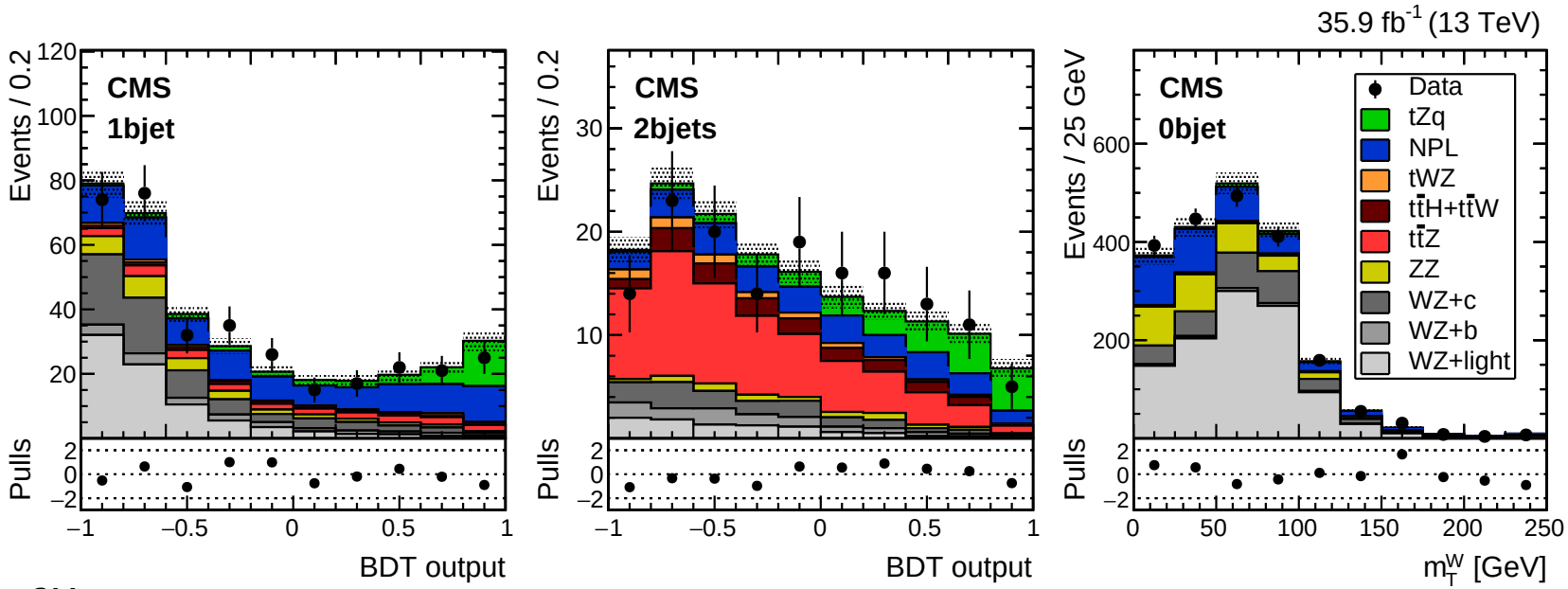
- Signal extracted by performing a ML fit to ANN distribution

tZq PRODUCTION IN CMS

Phys. Lett. B 779 (2018) 358

- 3ℓ with a Z candidate
- Three regions of interest:
  - 1 *b*-jet (signal enriched region)
  - 2 *b*-jet ($t\bar{t}$ +*Z* enriched region)
  - 0 *b*-tagged (non-prompt lepton enriched)

- BDT trained against WZ, $t\bar{t}$ +*V* and ZZ using top and *Z* reconstruction
  - MEM weights added to increase BDT performance
- Three regions of interest included in the fit

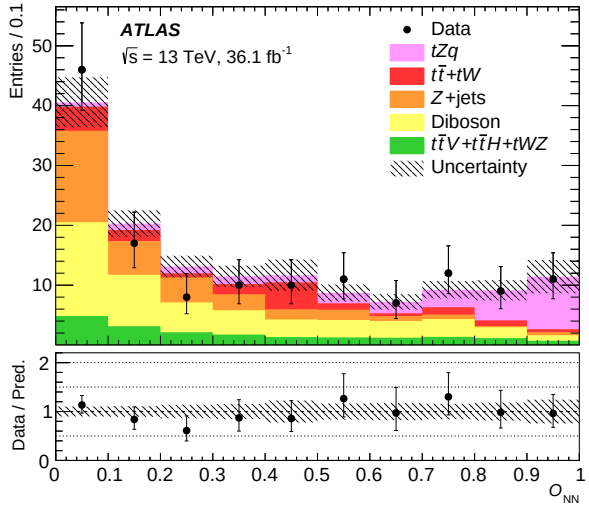


$\sigma^{SM}(t\ell\ell q) = 94$ fb [$\ell = e, \mu, \tau$]

RESULTS *tZq*

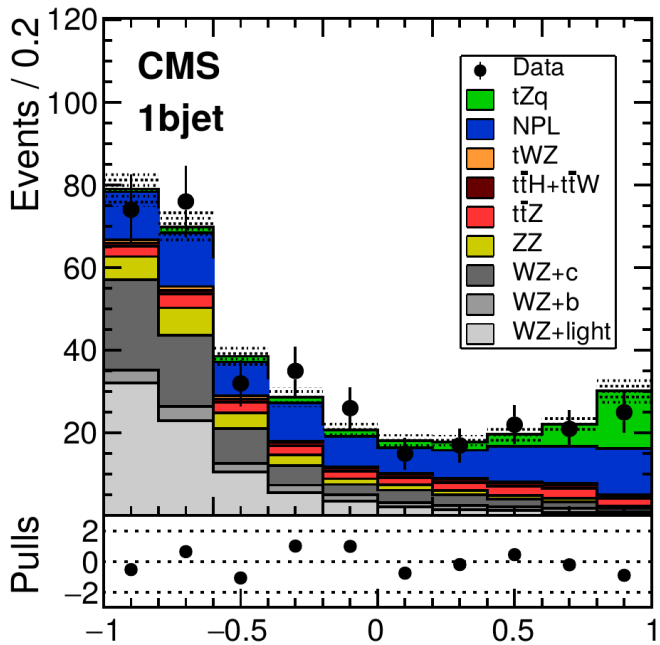
ATLAS

- $\mu = 0.75 \pm 0.21(\text{stat}) \pm 0.17(\text{syst}) \pm 0.05(\text{th})$
- $\sigma(t(Z \rightarrow \text{ anything})q) =$
  $600 \pm 170(\text{stat.}) \pm 140(\text{syst.})$ fb
- Significance obs (exp): 4.2 (5.4) σ
- Evidence for tZq production



CMS

- $\mu = 1.31\ ^{+0.35}_{-0.33}(\text{stat})^{+0.31}_{-0.25}(\text{syst})$
- $\sigma(t\ell\ell q) = 123\ ^{+33}_{-31}(\text{stat})^{+29}_{-23}(\text{syst})$ fb
- Significance obs (exp): 3.7 (3.1) σ
- Evidence for tZq production



- Different modeling of signal and different treatment of fakes

CONCLUSIONS

- Review of experimental results on associated top production
- Experiments are consolidating observations of $t\bar{t}+Z$ and $t\bar{t}+W$ production
  - Interpretation of the results in terms of EFTs
- Starting to have sensitivity to $t\bar{t}\,t\bar{t}$ production
- Evidence for tZq production for the first time
- Already hitting the precision frontier in measurements of tW production
- Keep tuned for more interesting results!

Back-up

DIFFERENCES IN tZQ BETWEEN ATLAS AND CMS

- Signal modeled with LO normalized to NLO, while CMS uses NLO taking
  - Different modeling of jet multiplicity
  - LO signal more prone to populate regions with higher signal/background
- Different *b*-tagging performance in the two detectors
- Different approach in the estimation of fake leptons
- CMS not training BDT against the fakes

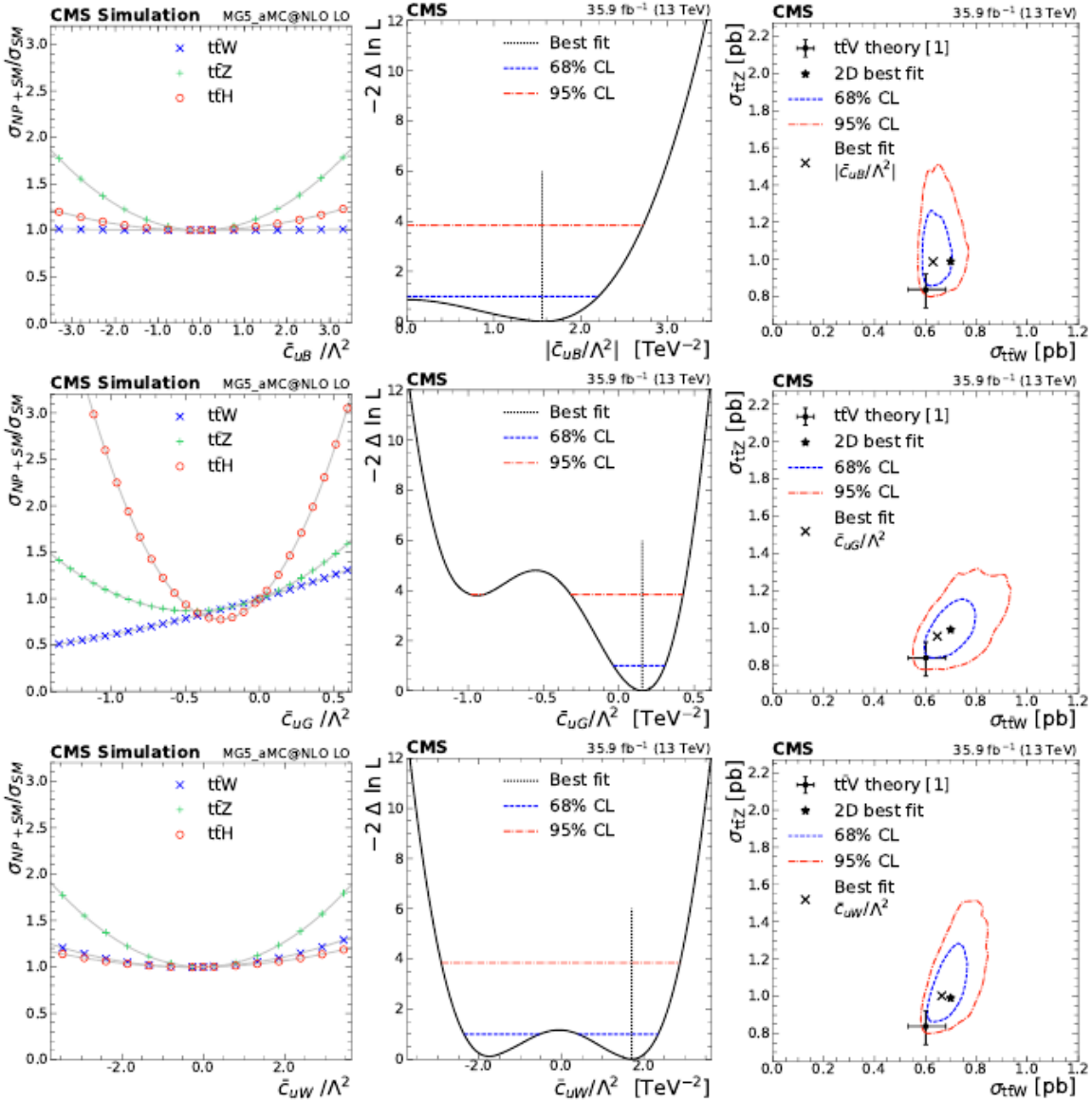
TTV EXTRA PLOTS

Channel	Expected significance	Observed significance
SS dilepton $\ell^-\ell^-$ ($t\bar{t}W^-$)	2.4	2.3
SS dilepton $\ell^+\ell^+$($t\bar{t}W^+$)	4.2	5.5
SS dilepton $\ell^\pm\ell^\pm$ ($t\bar{t}W^\pm$)	4.5	5.3
Three-lepton ($t\bar{t}Z$)	>5.0	>5.0
Four-lepton ($t\bar{t}Z$)	4.7	4.5
Three- and four-lepton combined ($t\bar{t}Z$)	>5.0	>5.0

$$\sigma(pp \to t\bar{t}W^+) = 0.58 \pm 0.09\,(\text{stat})^{+0.09}_{-0.08}\,(\text{syst})\,\text{pb},$$

$$\sigma(pp \to t\bar{t}W^-) = 0.19 \pm 0.07\,(\text{stat}) \pm 0.06\,(\text{syst})\,\text{pb}.$$

ttV Wilson coefficients



ttV Wilson coefficients

Wilson coefficient	Best fit [TeV^{-2}]	68% CL [TeV^{-2}]	95% CL [TeV^{-2}]
$\bar{c}_{uW}/\Lambda^2$	1.7	$[-2.4,-0.5]$ and $[0.4,2.4]$	$[-2.9,2.9]$
$\lvert\bar{c}_{H}/\Lambda^2 - 16.8\ \text{TeV}^{-2}\rvert$	15.6	$[0,23.0]$	$[0,28.5]$
$\lvert\widetilde{c}_{3G}/\Lambda^2\rvert$	0.5	$[0,0.7]$	$[0,0.9]$
$\bar{c}_{3G}/\Lambda^2$	-0.4	$[-0.6,0.1]$ and $[0.4,0.7]$	$[-0.7,1.0]$
$\bar{c}_{uG}/\Lambda^2$	0.2	$[0,0.3]$	$[-1.0,-0.9]$ and $[-0.3,0.4]$
$\lvert\bar{c}_{uB}/\Lambda^2\rvert$	1.6	$[0,2.2]$	$[0,2.7]$
$\bar{c}_{Hu}/\Lambda^2$	-9.3	$[-10.3,-8.0]$ and $[0,2.1]$	$[-11.1,-6.5]$ and $[-1.6,3.0]$
$\bar{c}_{2G}/\Lambda^2$	0.4	$[-0.9,-0.3]$ and $[-0.1,0.6]$	$[-1.1,0.8]$

TTV SYSTEMATICS

Source	Uncertainty from each source (%)	Impact on the measured $t\bar{t}W$ cross section (%)	Impact on the measured $t\bar{t}Z$ cross section (%)
Integrated luminosity	2.5	4	3
Jet energy scale and resolution	2–5	3	3
Trigger	2–4	4–5	5
B tagging	1–5	2–5	4–5
PU modeling	1	1	1
Lepton ID efficiency	2–7	3	6–7
Choice in μ_R and μ_F	1	<1	1
PDF	1	<1	1
Nonprompt background	30	4	<2
WZ cross section	10–20	<1	2
ZZ cross section	20	—	1
Charge misidentification	20	3	—
Rare SM background	50	2	2
$t(\bar{t})X$ background	10–15	4	3
Stat. unc. in nonprompt background	5–50	4	2
Stat. unc. in rare SM backgrounds	20–100	1	<1
Total systematic uncertainty	—	14	12

tW-CHANNEL SYSTEMATICS

Source	Uncertainty (%)
Trigger efficiencies	2.7
Muon efficiencies	3.1
Electron efficiencies	3.2
Jet energy scale	3.2
Jet energy resolution	1.8
b tagging efficiency	1.4
Mistagging rate	0.2
Pileup	3.3
$t\bar{t}$ μ_R and μ_F scale	2.5
tW μ_R and μ_F scale	0.9
Underlying event	0.4
ME/PS matching	1.8
Initial state radiation	0.8
Final state radiation	0.8
Color reconnection	2.0
PDF	1.5
DR-DS	1.3
VV normalization	0.4
Drell–Yan normalization	1.1
Non-W/Z leptons normalization	1.6
$t\bar{t}V$ normalization	0.1
MC statistics	1.6
Full phase space extrapolation	2.9
Total systematic (excluding integrated luminosity)	9.5
Integrated luminosity	3.3
Statistical	2.8
Total	10.5