Observation of single top quark production in association with a W boson in the lepton plus jets channel at $\sqrt{s} = 13$ TeV

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Single top quark production at CMS

- Top guarks at the LHC are produced _ predominantly via QCD with t partner,
- Can be produced singly via EW interactions.

Why do we study them?

- Direct probes of V_{tb} and therefore _ sensitive to new physics,
- Background to many searches,
- Can constrain PDFs,
- Provides measurements of top quark properties.







First observation in dilepton of tW at CMS [1]

tW in the lepton + jets channel

Compared to the dilepton channel:

- Much larger branching ratio $(BR(tW \rightarrow l+j) \sim 40\%),$
- Wider range of more difficult backgrounds.

No previous Run II or CMS results.



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Analysis outline

- − 36 fb⁻¹ pp collision data collected in 2016 by CMS at \sqrt{s} = 13 TeV,
- Data-driven estimation used for QCD background,
- BDT to discriminate between tW and tt background,
- Binned likelihood fit on BDT output to extract tW production cross section.

Signal definition

- One lepton (muon or electron),
- Missing energy from associated neutrino,
- Three jets, one originating from a b quark.



LO diagram of tW in lepton +jets channel

Event selections

All events require exactly 1 well isolated lepton (muon/electron)

Analysis regions based on jet topology:

- 3j – Signal region

- 2j W+jets and QCD enriched region
- $4j t\bar{t}$ enriched region

One jet must pass b-tagging. No requirements are made on p^{T}_{miss} or $m_{T,W}$.

QCD multijet background estimated using data-driven techniques

 Inverted isolation requirement on selected lepton Event yields per process after event selections

Sample	3j	Muon channel 2j	4j
tW	26091 ± 62	29772 ± 66	10580 ± 40
tī	272590 ± 360	196690 ± 300	184500 ± 300
W+jets	79800 ± 1200	332300 ± 3300	12000 ± 330
QCD multijet	67470 ± 320	275130 ± 700	10440 ± 140
Single top	15786 ± 55	54930 ± 100	4105 ± 28
Z+jets	7410 ± 500	26450 ± 970	2070 ± 240
VV	2850 ± 160	7450 ± 250	731 ± 81
Total prediction Data	$\begin{array}{c} 472000 \pm 2700 \\ 472540 \end{array}$	$\begin{array}{c} 922700 \pm 5700 \\ 923880 \end{array}$	$\begin{array}{c} 224400 \pm 1200 \\ 223720 \end{array}$

Sampla	Electron channel			
Sample	Зј	2j	4j	
tW	15725 ± 35	17453 ± 37	6578 ± 23	
tī	157780 ± 200	111030 ± 160	109259 ± 160	
W+jets	63400 ± 850	191000 ± 1800	9610 ± 250	
QCD multijet	15370 ± 180	85080 ± 410	5960 ± 100	
Single top	8939 ± 30	30223 ± 54	2375 ± 15	
Z+jets	7080 ± 300	23830 ± 590	1800 ± 140	
VV	1645 ± 85	4010 ± 130	461 ± 44	
Total prediction	269900 ± 1700	462600 ± 3200	136000 ± 740	
Data	270330	462930	136190	

Major backgrounds

- $t\bar{t}$ at LO differs by only one b jet,
- W+jets and QCD with fake b-tags,
- Small contributions from **DY** and other single top processes.



Difference between tW and tt at LO is one b quark

Discriminating between tW and $\ensuremath{t\bar{t}}$

A BDT is trained to discriminate between signal and leading tt background based on the kinematic differences between the two processes.

- One BDT is trained in the signal region (3j) per channel,
- Weights applied to all three analysis regions,
- A subset of the signal and tt events are used for the training.
- BDT discriminants for all regions used as templates in binned likelihood fit to extract tW signal strength.

Selected BDT input distributions

Variable Description

Mass of the reconstructed W boson decaying hadronically Invariant mass of the b-tagged jet and sub-leading non b-tagged jet

Angular separation between the two non b-tagged jets

Angular separation between the reconstructed leptonic W boson and leading non b-tagged jet

Transverse momentum of the selected lepton

Energy of the two non b-tagged jets system

- Angular separation between the b-tagged jet and the selected lepton
- Transverse momentum of the system made of the three jets, lepton and $p_{\rm T}^{\rm miss}$





BDT discriminant for all analysis regions

Result

Measured cross section:

89 ± 4 (stat) ± 12 (syst) pb

SM prediction (NNLO):

71.7 ± 1.8 (scale) ± 3.4 (PDF) pb [2]

First observation of tW in the l+jets channel

ATLAS+CMS Preliminary LHCtopWG	April 2021
Run 2, √s = 13 TeV, m _t = 172.5 Ge\ ∷ NLO+NNLL (PRD 82 (201	v total stat 0) 054018)
scale \oplus PDF $\oplus \alpha_S$ unc	ertainty
* Preliminary	$\sigma_{tW} \pm (\text{stat.}) \pm (\text{syst.}) \pm (\text{lumi.})$
ATLAS, L _{int} = 3.2 fb ⁻¹ JHEP 01 (2018) 063	+ ■ + 94 ± 10 ⁺²⁸ ₋₂₂ ± 2 pb
CMS еµ, L _{int} = 35.9 fb ⁻¹ JHEP 10 (2018) 117	63.1±1.8±6.4±2.1 pb
CMS I+jets*, L _{int} = 35.9 fb ⁻¹ CMS-PAS-TOP-20-002 0 50	89 ± 4 ± 12 ± 3 pb 100 150 200
0 50	100 150 200 σ _{tW} [pb]

Systematic uncertaintiesSourceRelative uncertainty (% QCD normalizationuncertaintiesQCD normalization7 W+jets normalizationIncluded as nuisance parameters on rateZ+jets normalization3 Single top normalizationand/or shape of BDT discriminant templates.VV normalization1 VV normalization15% total uncertainty on measurementJES6 b-tagging-17% expected uncertainty based on asimov datasetMistag<1 Unclustered MET-Data-driven background estimations, h_{damp} 4 DR/DS-Data-driven background estimations,MC tune3 Colour reconnection-JES, Total systematic uncertainty14 Statistical uncertainty15		Relative contribution of each systematic source		
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[1] Observation of associated production of a single top quark and a W boson, *CMS Collaboration*, arXiv:1401.2942v2

[2] Theoretical results for electroweak-boson and single-top production, N. Kidonakis, arXiv:1506.04072

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