Observation of single top quark production in association with a W boson in the lepton plus jets channel at √s = 13 TeV

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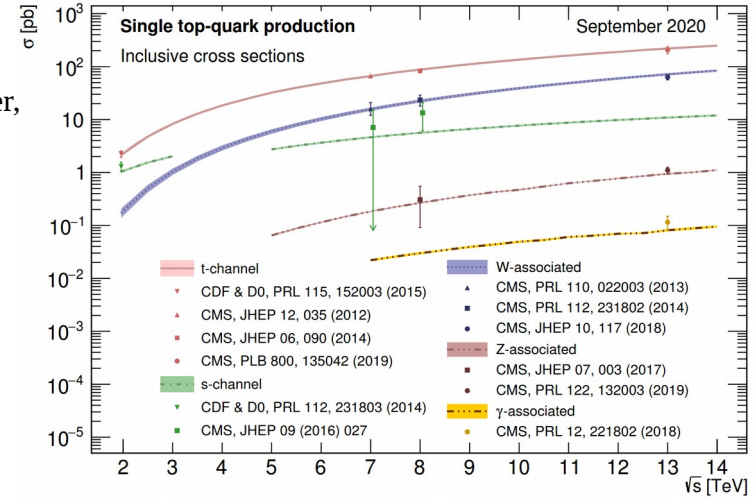
Single top quark production at CMS

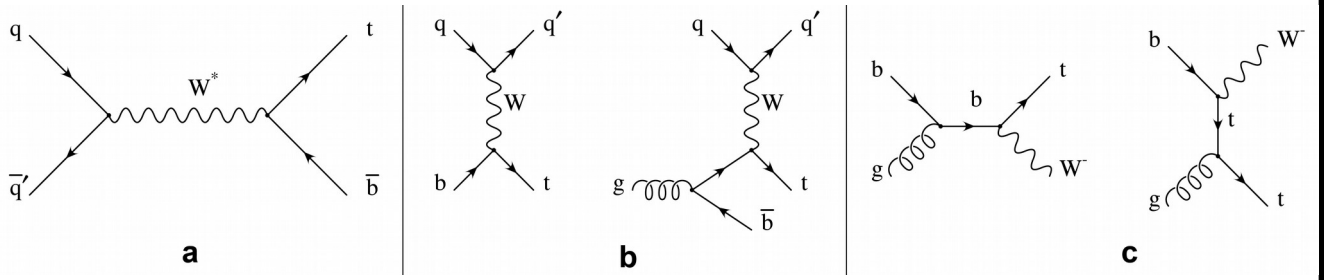
- Top quarks at the LHC are produced predominantly via QCD with $\bar{t}$ partner,
- Can be produced singly via EW interactions.

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.



Single top quark cross sections measured by CMS

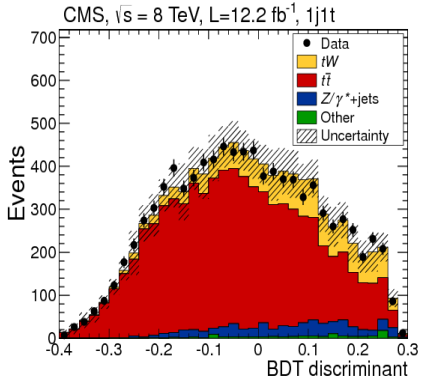


LO Feynman diagrams for the canonical single top production modes; a) s-channel, b) t-channel, c) tW.

tW production at CMS

Associated production of a single top quark with a W boson

Well studied in dilepton channel, including observation.



First observation in dilepton of tW at CMS [1]

tW in the lepton + jets channel

Compared to the dilepton channel:

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

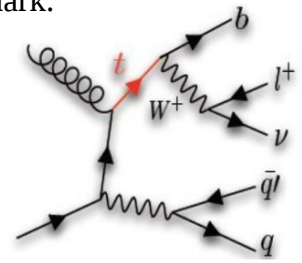
No previous Run II or CMS results.

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 $t\bar{t}$ 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

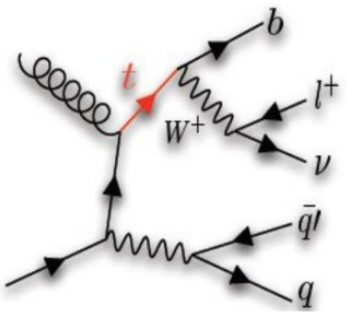
Event yields per process after event selections

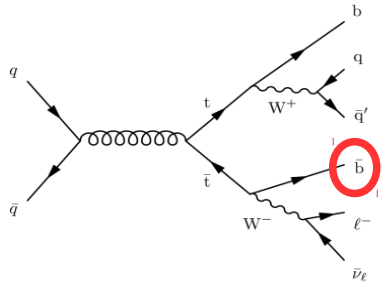
Sample	Muon channel 3j	2j	4j
tW	26091 ± 62	29772 ± 66	10580 ± 40
$t\bar{t}$	272590 ± 360	196690 ± 300	184500 ± 300
W+jets	79800 ± 1200	332300 ± 3300	12000 ± 330
QCD multijet	67470 ± 320	275130 ± 700	10440 ± 140
Single top	15786 ± 55	54930 ± 100	4105 ± 28
Z+jets	7410 ± 500	26450 ± 970	2070 ± 240
VV	2850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

Sample	Electron channel 3j	2j	4j
tW	15725 ± 35	17453 ± 37	6578 ± 23
$t\bar{t}$	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 $t\bar{t}$

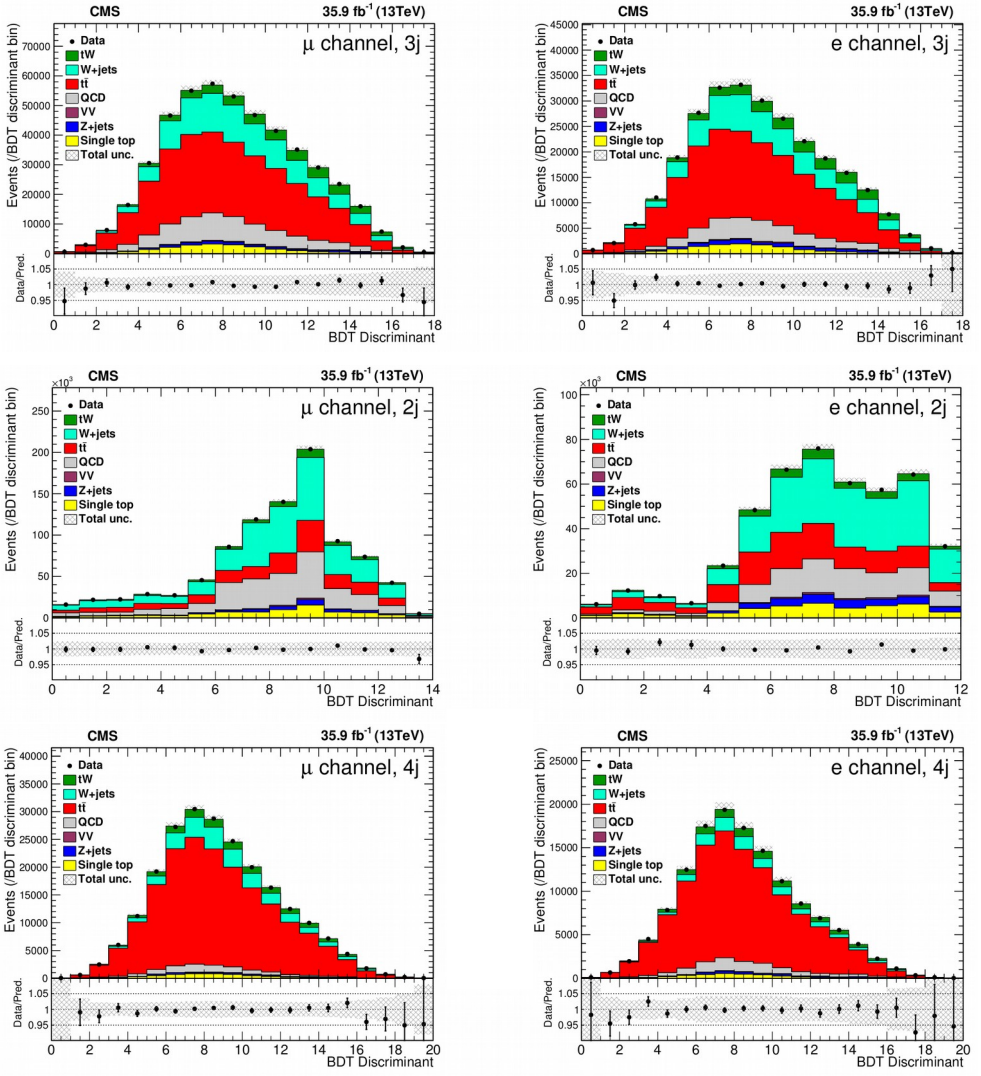
A BDT is trained to discriminate between signal and leading tt background based on the kinematic differences between the two processes.

- One BDT is trained in the signal region (3j) per channel,
- Weights applied to all three analysis regions,
- A subset of the signal and $t\bar{t}$ 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 $p_{\mathrm{T}}^{\mathrm{miss}}$



BDT discriminant for all analysis regions

Result

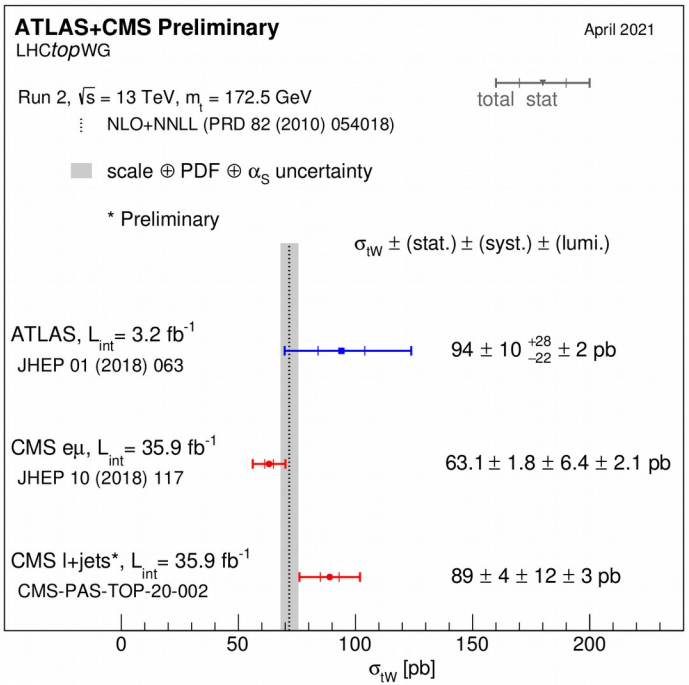
Measured cross section:

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



Systematic uncertainties

Included as nuisance parameters on rate and/or shape of BDT discriminant templates.

15% total uncertainty on measurement

- 17% expected uncertainty based on asimov dataset

Dominant uncertainties;

- Data-driven background estimations,
- JES,
- $t\bar{t}$ modelling

Relative contribution of each systematic source

Source	Relative uncertainty (%)
QCD normalization	7
W+jets normalization	6
Z+jets normalization	3
Single top normalization	1
$t\bar{t}$ normalization	1
VV normalization	< 1
JES	6
b-tagging	4
Luminosity	3
LES	2
Trigger	1
JER	1
Mistag	< 1
Unclustered MET	< 1
Pileup	< 1
h_{damp}	4
DR/DS	3
MC tune	3
Colour reconnection	1
PDF	1
ME/PS matching	1
Final state radiation	< 1
Initial state radiation	< 1
Total systematic uncertainty	14
Statistical uncertainty	5
Total uncertainty	15

[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
[3] Measurement of tW production in the semileptonic channel, CMS collaboration, https://cds.cern.ch/record/2759300