tW in the lepton + jets channel

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What is tW?

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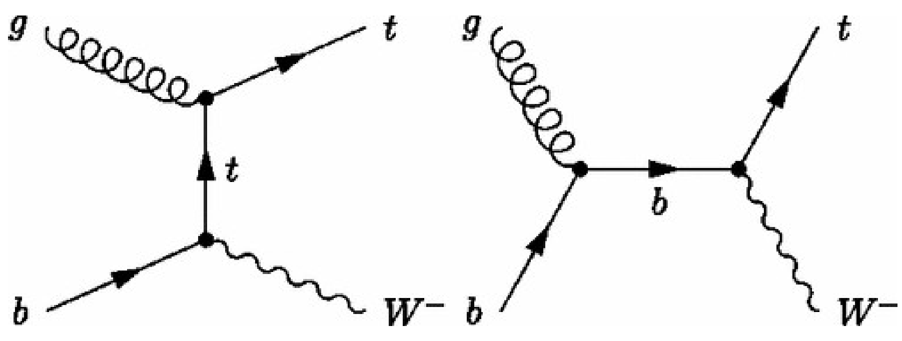
- The associated production of a single top quark with a W boson



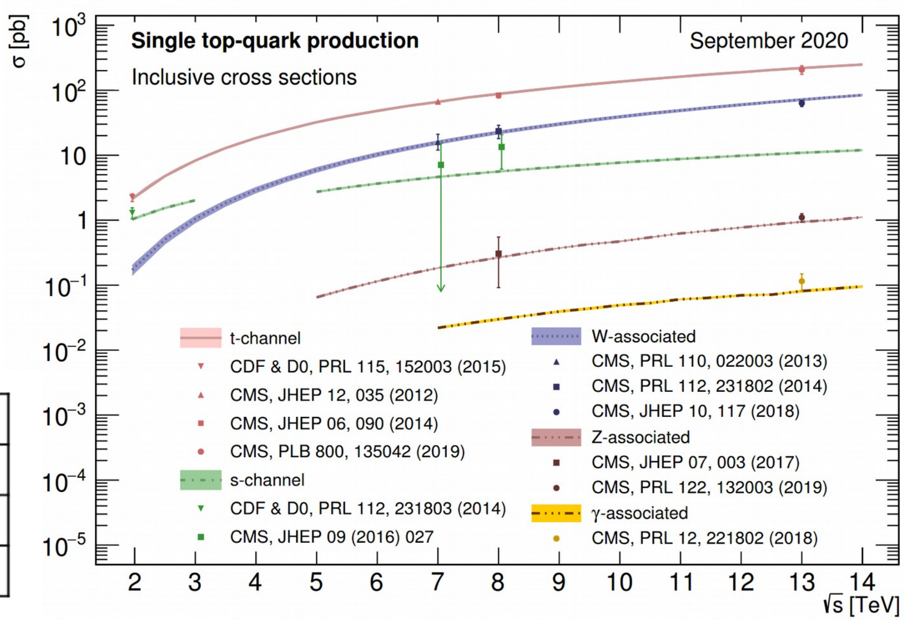
LO diagrams

Why do we study it?

- Direct probe of V_{tb}
- Sensitive to new physics
- Background to dilepton searches (e.g. H->WW)
- Provides additional measurements of top properties

In comparison to the other single top channels, tW has scaled very favourably to the main $t\bar{t}$ background

σ [pb]	ttbar	t-channel	tW	s-channel
LHC @ 8TeV	252.89	84.69	22.2	5.24
LHC @ 13TeV	831.76	216.99	71.2	10.32
From 8 to 13TeV	**3.3**	2.6	**3.2**	1.9



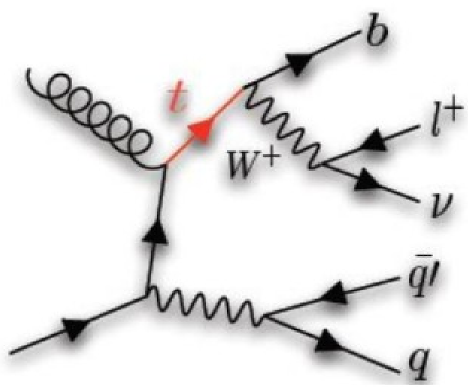
tW in the lepton+jets channel

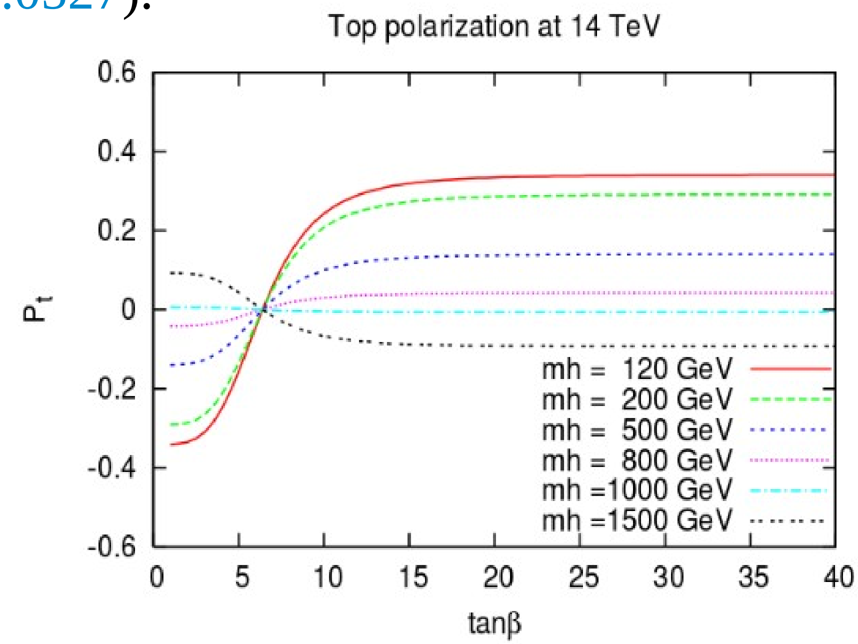
Compared to dilepton channel

- \+ Much larger statistics (*BR*($tW \rightarrow l+j$)~40%), possibility of full reconstruction of the top quark,
- − Worse S/B and additional difficult background processes.

Why study it?

- − No CMS results in this channel, no measurements with Run 2 data,
- − Offers full reconstruction of the top quark system, allowing top property measurements (including polarisation - arxiv.org/abs/1012.0527).





Existing tW results

Run 1 CMS paper

- Phys. Rev. Lett. 112, 231802
- First observation of the process

Run 2 CMS paper

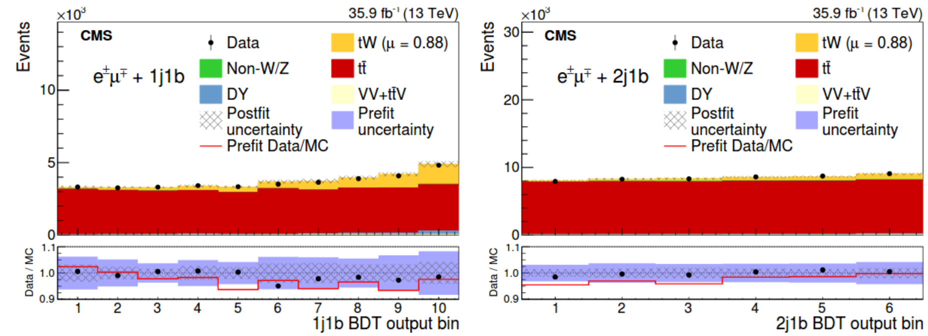
- JHEP10(2018)117

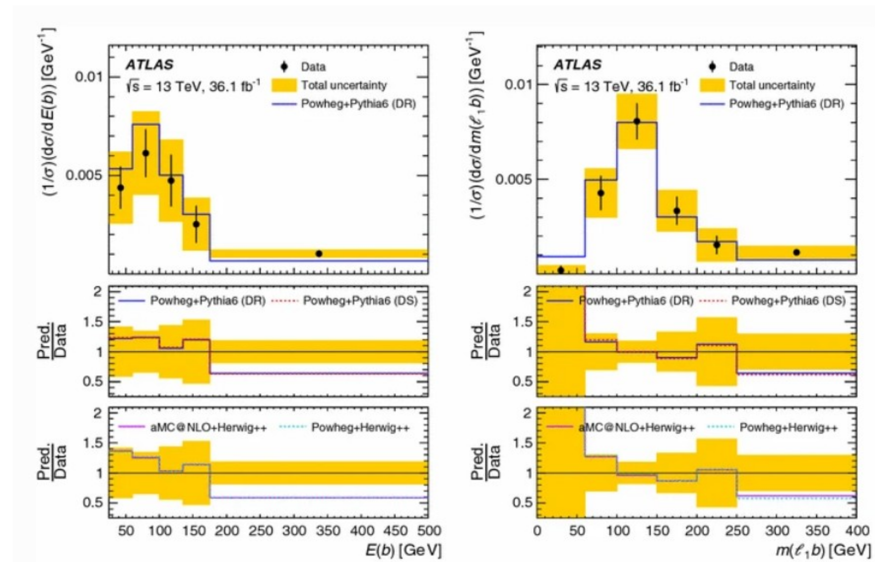
Run 2 ATLAS measurement

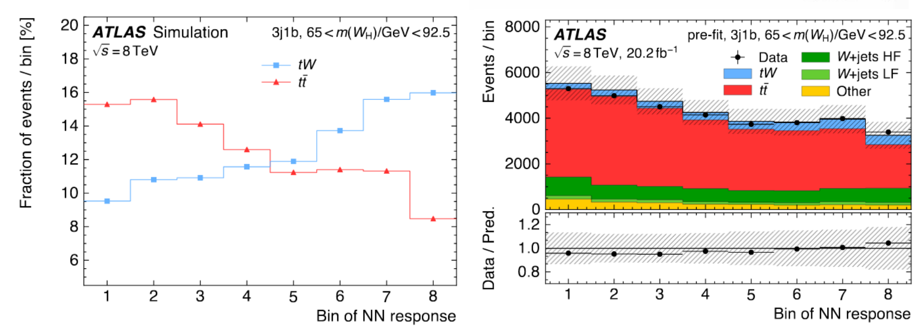
- Eur. Phys. J. C 78, 186
- First differential measurements in tW

Lepton+jets measurement at 8 TeV ATLAS

- Eur. Phys. J. C 81 (2021) 720
- First measurement in l+jets channel







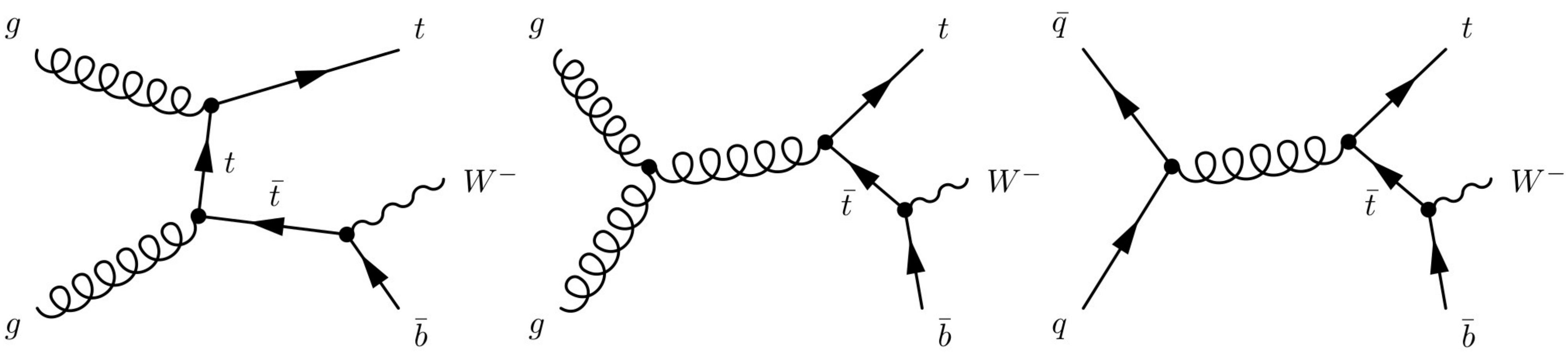
Treatment of tW and $t\bar{t}$ interference

tW signal interferes with $t\bar{t}$ at NLO, causing conceptual and computational problems in signal definition.

Two schemes used to mitigate issue in tW samples:

- Diagram Removal (DR) – remove doubly resonant diagrams from signal definition,
- Diagram Subtraction (DS) – subtract gauge-invariant term to cancel interference.

DR is used as the default in the analysis, with DS included as a systematic.

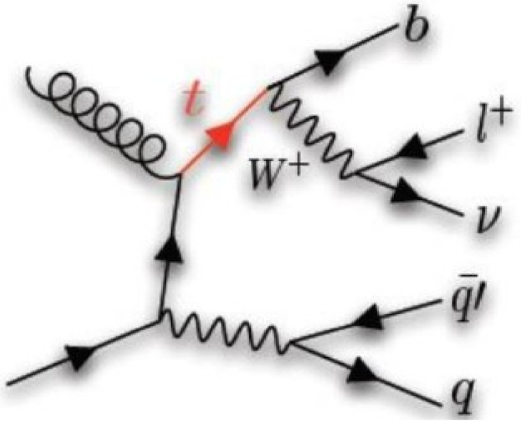


Alternate method: Unified WWbb sample that incorporates both processes

Signature and backgrounds

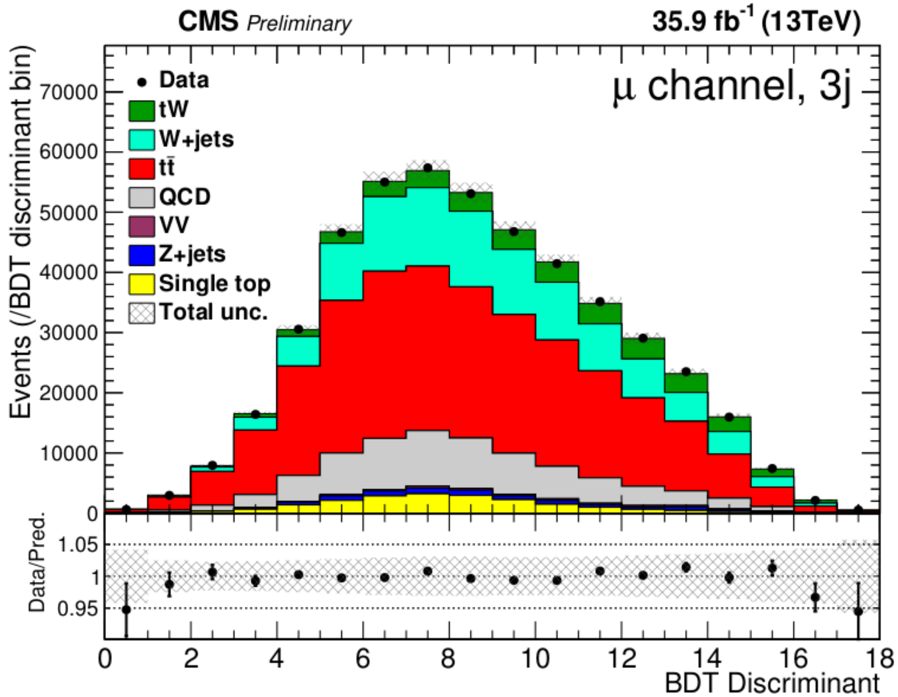
Signal definition

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



Major backgrounds

- $t\bar{t}$ – indistinguishable at NLO,
- W+jets and QCD with fake b-tags,
- Small contributions from DY and other single top processes.



This result is based on 36 fb^{-1} pp collisions collected in 2016 by CMS at $\sqrt{s}$ = 13 TeV

PAS available on CDS: CMS-PAS-TOP-20-002

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 templates are data-driven;

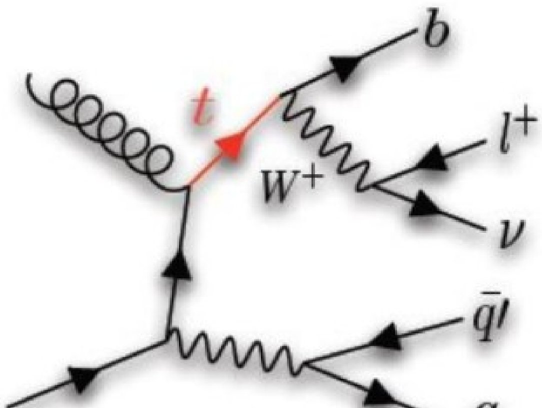
- Shape taken from inverted isolation requirement on lepton,
- Normalisation estimated from a 0t control region.

Table 1: The total number of events passing event selection in each defined jet topology region for the analysis and their associated statistical uncertainties. The event yields are given for the tW signal and all major backgrounds for both the muon (upper) and electron (lower) channels. The estimations of QCD multijet and W+jets backgrounds include data-based estimates.

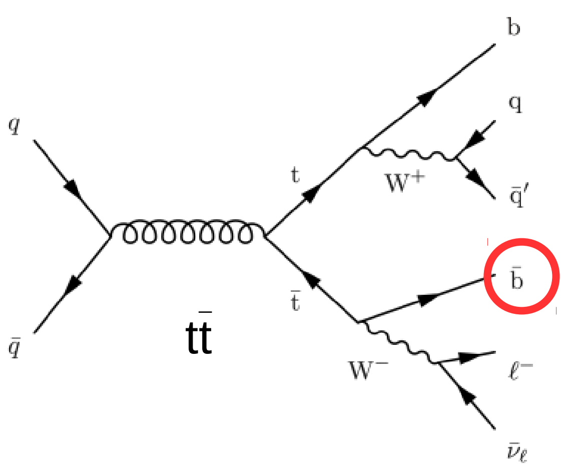
Sample	Muon channel 3j	2j	4j
tW	26091 ± 62	29772 ± 66	10580 ± 40
$t\bar{t}$	272590 ± 360	196690 ± 300	184500 ± 300
W+jets	79800 ± 1200	332300 ± 3300	12000 ± 330
QCD multijet	67470 ± 320	275130 ± 700	10440 ± 140
Single top	15786 ± 55	54930 ± 100	4105 ± 28
Z+jets	7410 ± 500	26450 ± 970	2070 ± 240
VV	2850 ± 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

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



tW



Difference between tW and $t\bar{t}$ at LO is one b quark

In order to discriminate tW from leading ttbar background, a BDT is used.

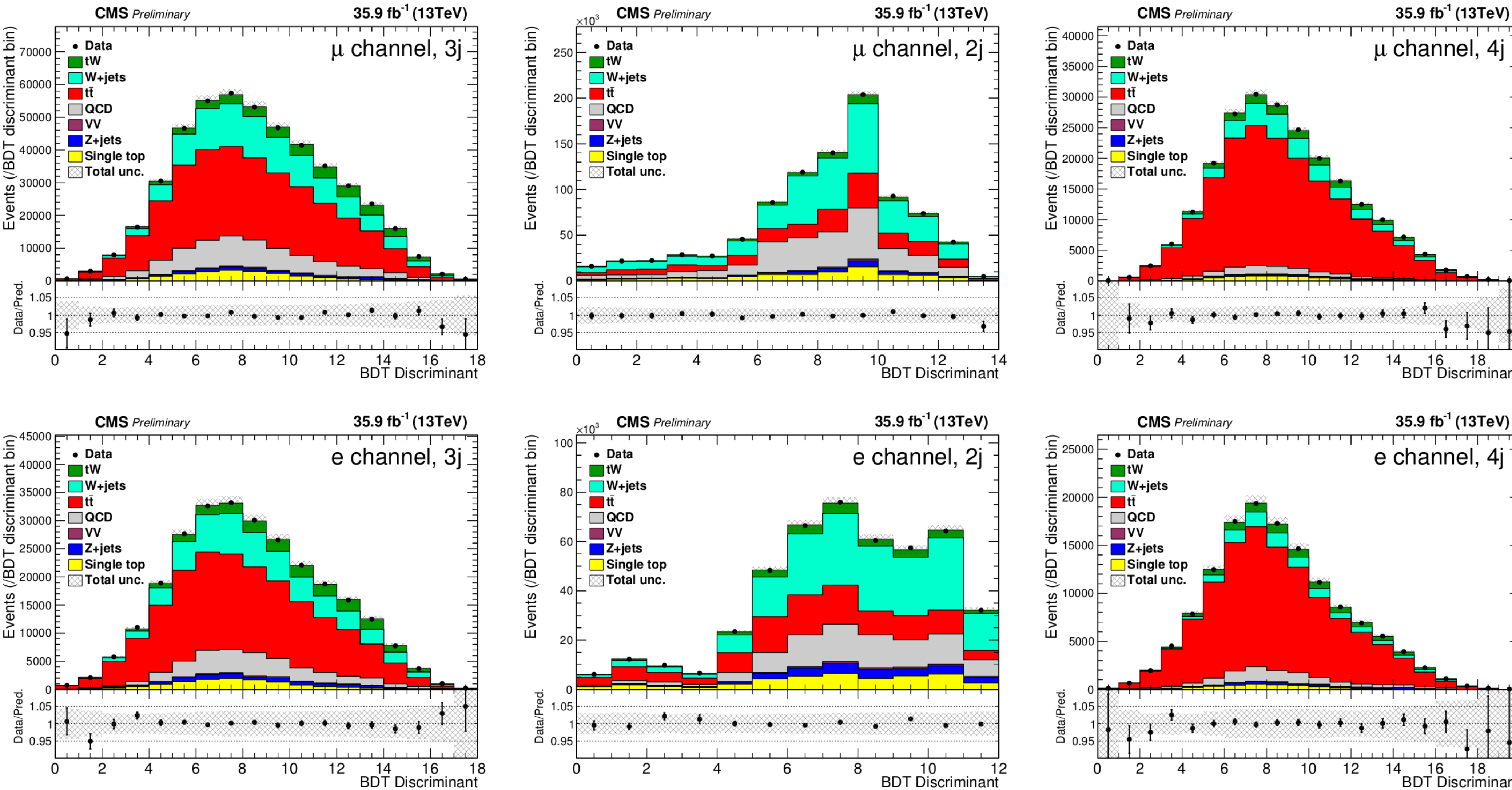
- One BDT is trained in the signal region (3j) per channel,
- Weights applied to all three analysis regions,
- A subset of the signal and $t\bar{t}$ events are used for the training.

Table 2: Descriptions of the variables used to train and evaluate the BDT, ranked in order of importance in the final result. The same variables are used in both muon and electron channels.

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 $p_{\mathrm{T}}^{\mathrm{miss}}$

Variables chosen to exploit the kinematic differences caused by the loss of one jet.

BDT distributions for each region



BDT discriminant distributions for each analysis region scaled to the result of the likelihood fit.

Likelihood fit and results

Binned likelihood fit of BDT discriminant;

- Assuming Poisson distributions in each bin,
- Systematic uncertainties included as nuisance parameters affecting rate and/or shapes of input templates.

Combination of all regions gives measured cross section:

$\boxed{89 \pm 4\ (\mathrm{stat}) \pm 12\ (\mathrm{syst})\ \mathrm{pb}}$

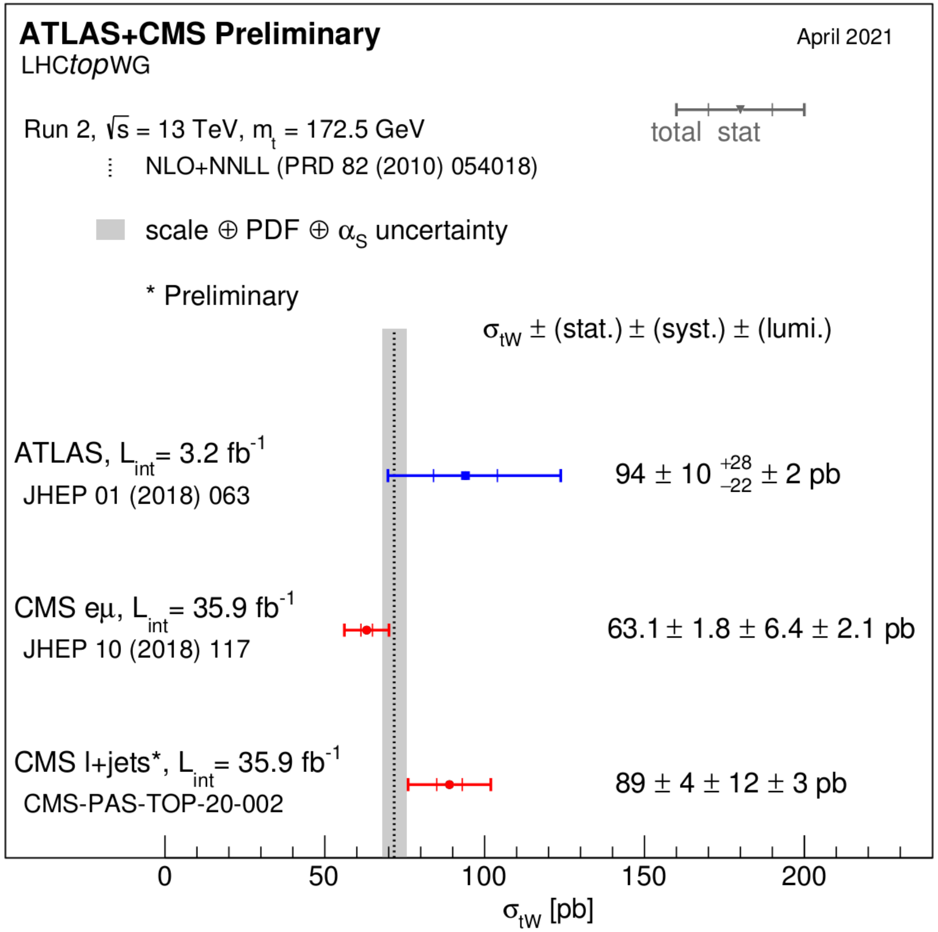
15% uncertainty, compared to an expected uncertainty of 17% based on the Asimov dataset.

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

Summary

First observation of the tW process in the lepton+jets channel is presented,

- Using 36 fb^{-1} pp collision data collected in 2016 by CMS at $\sqrt{s}$ = 13 TeV,
- QCD background templates assembled using data-driven control region,
- BDT used to separate tW signal from leading ttbar background,
- Systematics and major backgrounds are controlled via two control regions,
- Likelihood fit used to extract signal strength of signal tW.



Measured cross section: 89 ± 4 (stat) ± 12 (syst) pb

Standard model prediction: 71.7 ± 1.8 ± 3.4 pb at NNLO [Kidonakis, arXiv:1506.04072]

Result was originally present at Moriond QCD 2021.
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