中国科学院高能物理研究所
Institute of High Energy Physics
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TOP2021 - Young Scientist Forum

Observation of tW in the lepton + jets channel

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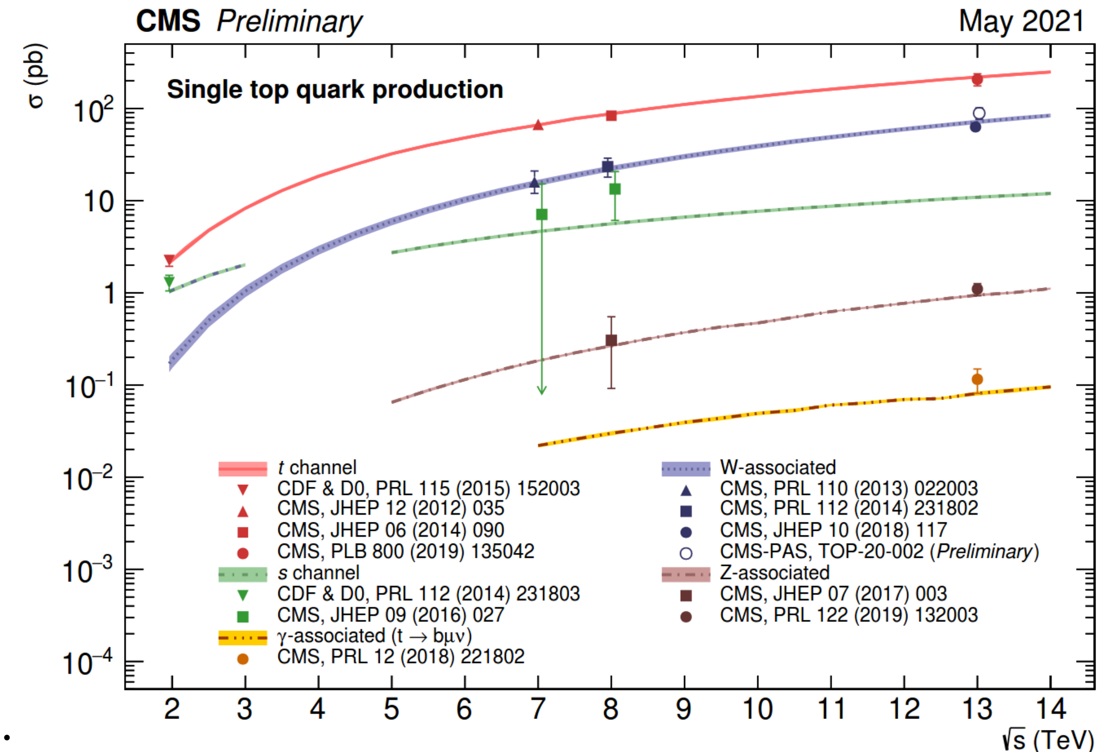
What is tW production?

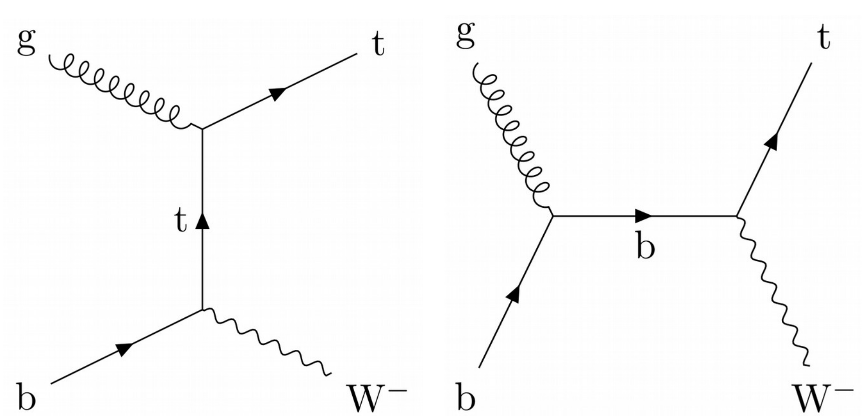
What is tW production?

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

Why do we study it?

- Direct probe of V_{tb},
- Sensitive to new physics,
- Background to many searches,
- Interference with ttbar at NLO,
- Additional measurements of top properties.





LO diagrams

tW in the dilepton vs lepton+jet final states

Dilepton

- Clean process with few backgrounds,
- Well studied and understood by CMS and ATLAS.

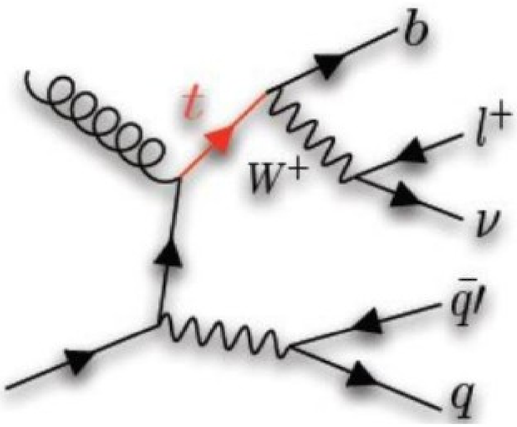
Lepton+jets

- Much larger statistics (*BR*($tW \rightarrow l+j$)~40%),
- Possibility of full reconstruction of the top quark,
- Larger number and more difficult backgrounds.

Signature and backgrounds

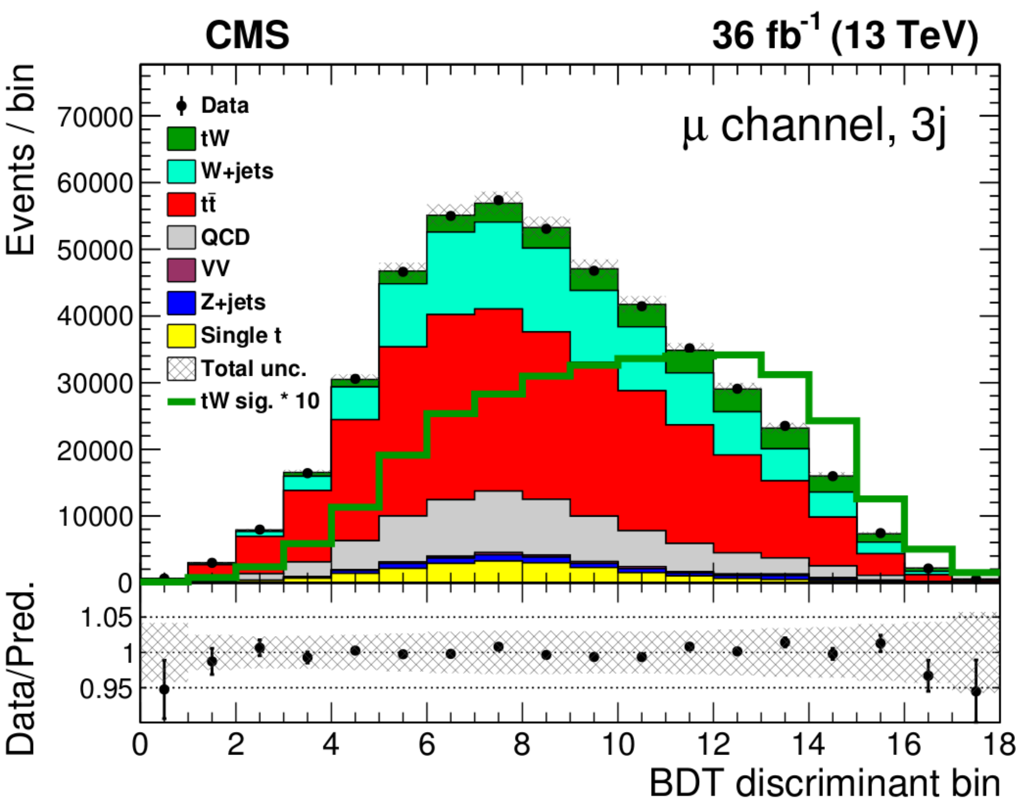
Signal definition

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



Major backgrounds

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



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

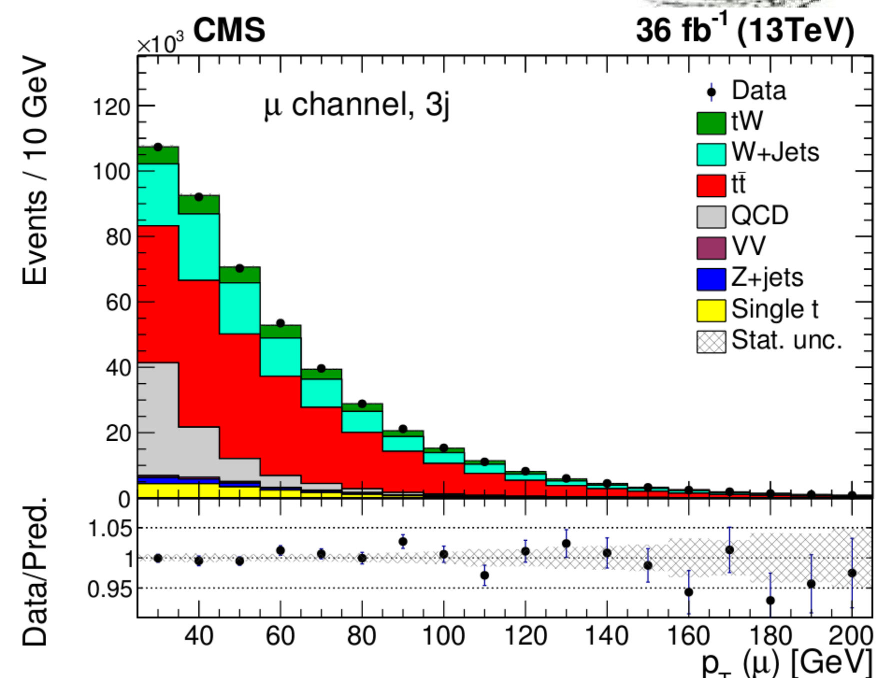
One jet must pass b tagging

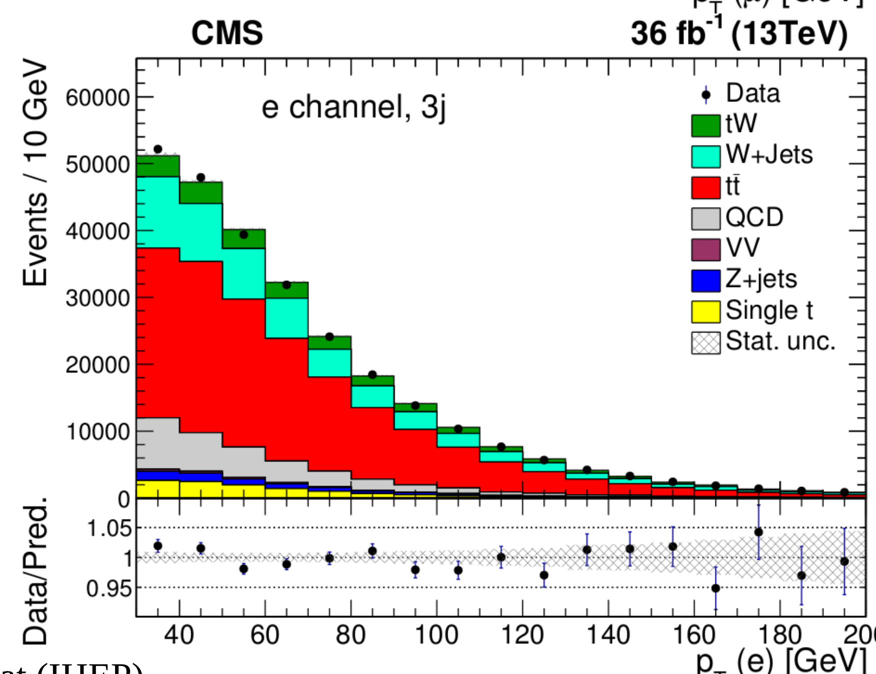
No requirements are made on p_T^{miss} or m_T^W

Data-driven methods used for QCD and W+jet backgrounds

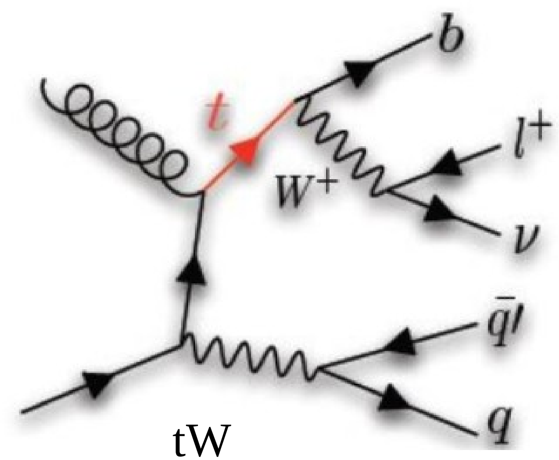
- QCD templates taken from an inverted isolation requirement on lepton,
- Corrections to W+jets and QCD normalisations are estimated from a fit on m_T^W in a 0t control region.

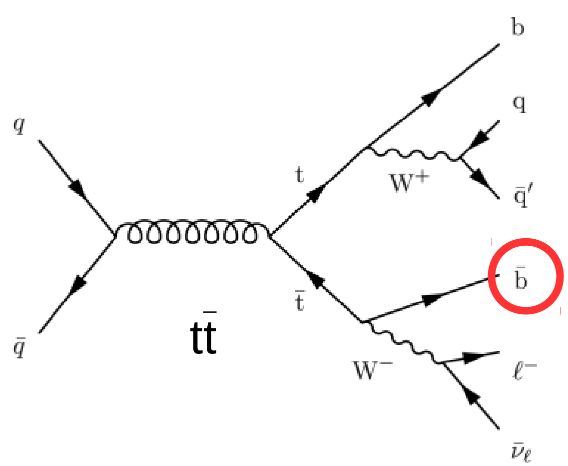
$$m_T^W = \sqrt{2 p_T^{miss} p_T^{\ell} \left(1 - \cos[\phi^{\vec{p}_T^{miss}} - \phi^{\ell}]\right)},$$





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





Difference between tW and $t\bar{t}$ final states 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.

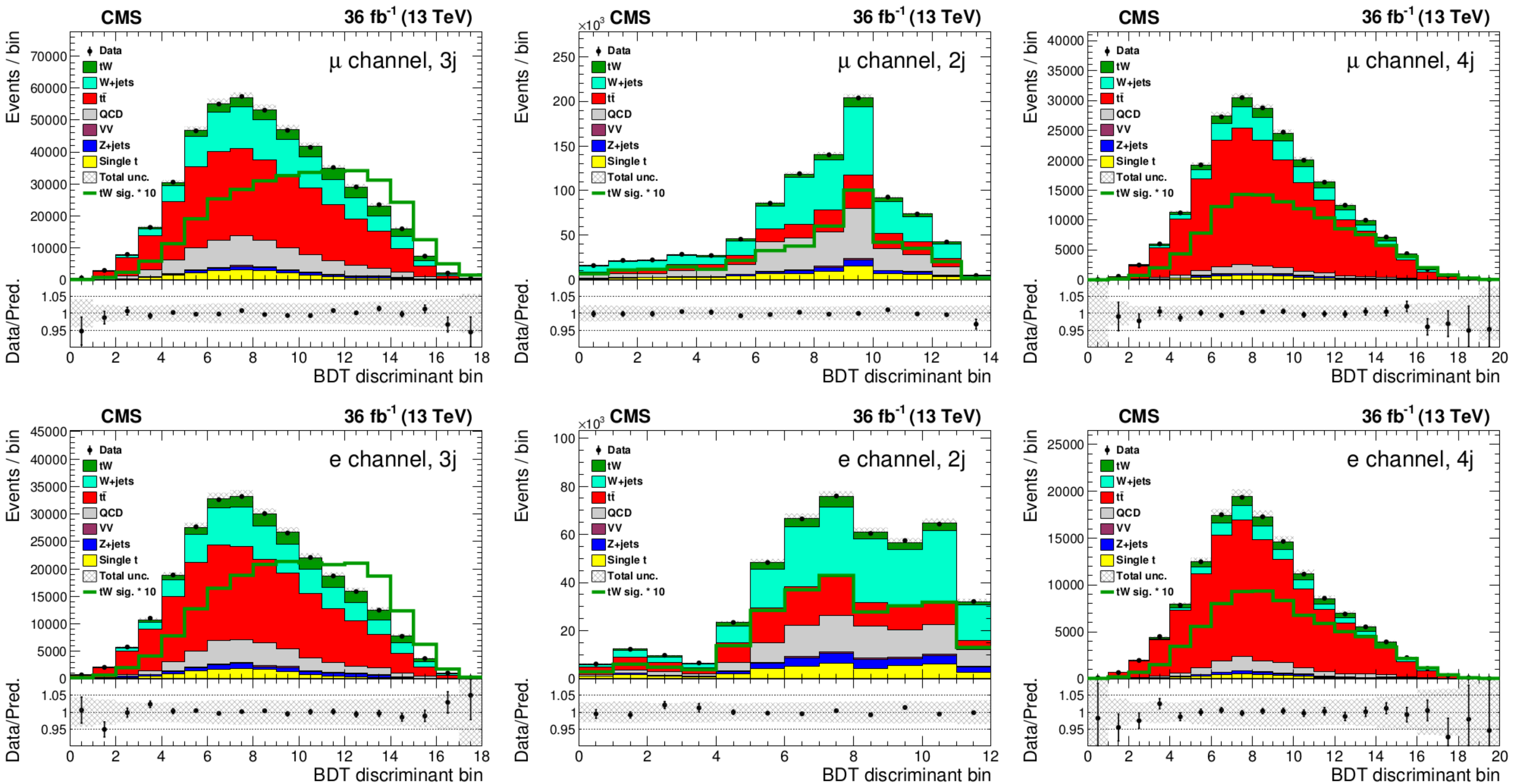
Table 2: Descriptions of the variables used to train and evaluate the BDT, ranked in order of importance in the final result. The same variables are used in both muon and electron channels.

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_T^{miss}

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

BDT discriminant in each region

BDT discriminants from all regions are fit simultaneously to extract the signal cross section



BDT discriminants for all regions 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:

89 ± 4 (stat) ± 12 (syst) pb

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

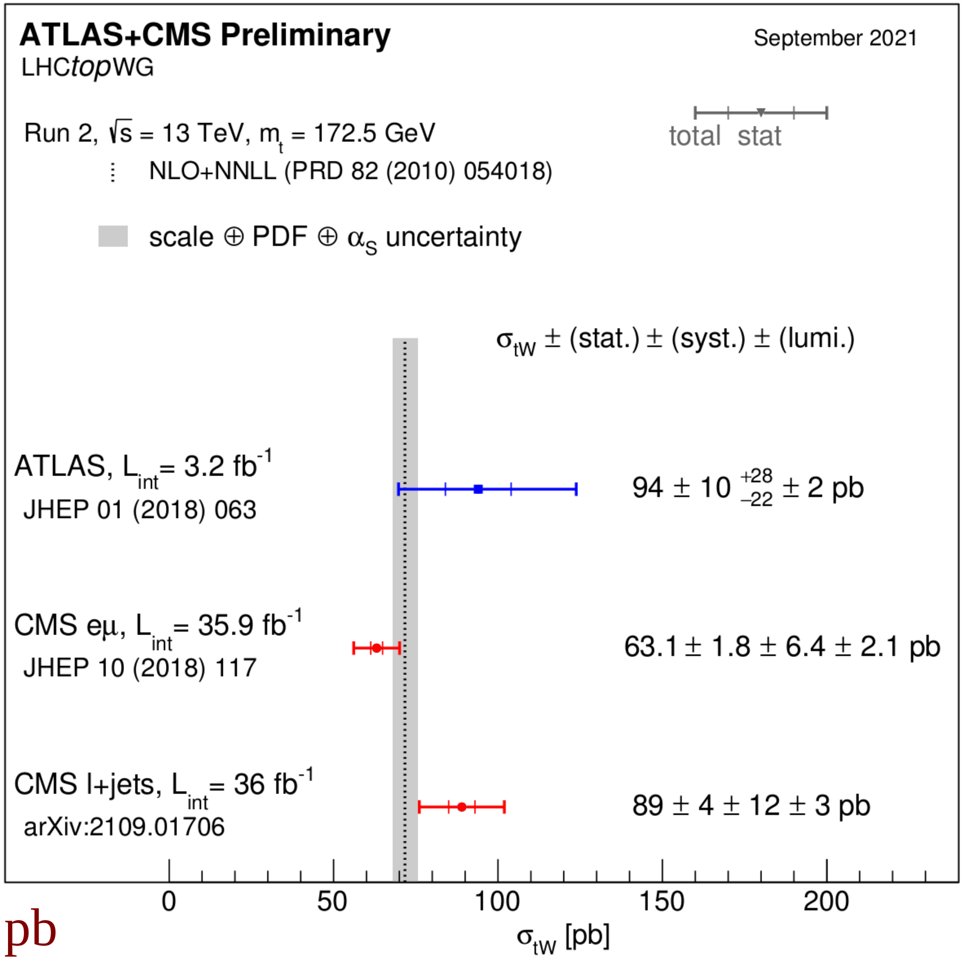
Source	Relative uncertainty (%)
Experimental	
Jet energy scale	6
b tagging efficiency	4
Luminosity	3
Lepton energy scale	2
Trigger efficiency	1
Jet energy resolution	1
b tagging misidentification rate	<1
Unclustered energy	<1
Pileup	<1
Normalization	
QCD multijet normalization	7
W+jets normalization	6
Z+jets normalization	3
Single t normalization	1
$t\bar{t}$ normalization	1
VV normalization	<1
Theoretical	
h_{damp}	4
Diagram removal/diagram subtraction	3
Underlying event tune	3
Colour reconnection model	1
Parton distribution function	1
Matrix element/parton shower matching	1
Final-state radiation	<1
Initial-state radiation	<1
Total systematic uncertainty	14
Statistical uncertainty	5
Total uncertainty	15

Data-driven background uncertainties

Summary

First observation of tW production in the lepton+jets final state is presented,

- 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

SM prediction: 71.7 ± 1.8 (scale) ± 3.4 (PDF) pb at NNLO [Kidonakis, arXiv:1506.04072]
$79.5^{+1.9}_{-1.8}$ (scale) $^{+2.0}_{-1.4}$ (PDF) pb at aN3LO [Kidonakis, Yamanaka, arXiv:2102.11300]

Result available on arXiv (arXiv:2109.01706) and submitted to JHEP