Evidence for the associated production of a single top quark and W boson with the CMS detector

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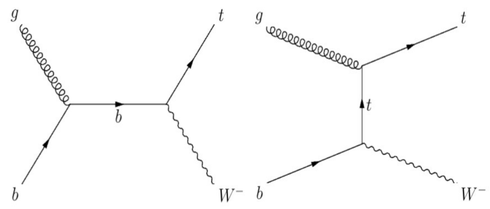
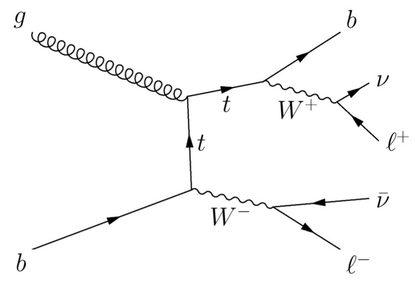
INTRODUCTION

Production of a single top quark allows for probing electroweak physics with top quarks. This analysis searched for the production of a single top quark in association with a W boson (tW channel).



Leading order Feynman diagrams for tW channel production of a single top quark



tW dilepton Feynman diagram

Top quarks decay almost exclusively to a b quark and a W boson. In the dilepton final state, both W bosons will further decay into a lepton and a neutrino. The event signature for tW production decaying to the dilepton final state will be two oppositely charged isolated leptons (eμ, μμ, and ee), a jet originating from a b quark, and missing transverse energy (E^T_{miss}) from the neutrinos.

Analysis is based on 4.9 fb^{-1} of pp collisions with the CMS detector[1]. At a center of mass energy of 7 TeV, the Standard Model predicts a cross section of:

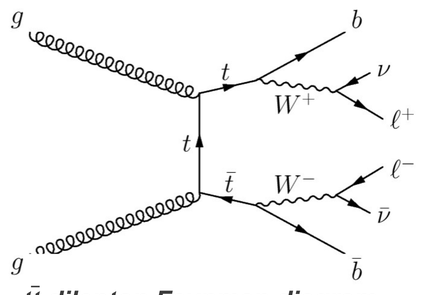
$$\sigma_{tW} = 15.6 \pm 0.4^{+1.0}_{-1.2}\,\text{pb}^{[2]}$$

BACKGROUNDS

Numerous processes provide similar event signatures, but with much larger cross sections. In order of importance they are:

- $t\bar{t}$: σ = 163 pb (NNLO)[3]
- Z+jets: σ = 3048 pb (NNLO)[4]
- WW/WZ/ZZ: σ = 42.9/18.3/7.67 pb (NLO)[4]

The most significant background is by far $t\bar{t}$, the difference is only a matter of one b-jet at LO



$t\bar{t}$ dilepton Feynman diagram

EVENT SELECTION

Lepton Selection:

- Transverse momentum p_T > 20 GeV
- Pseudorapidity |η| < 2.4 (2.5) for muons (electrons)
- Isolated from other particles
- Oppositely Charged

Jet Selection:

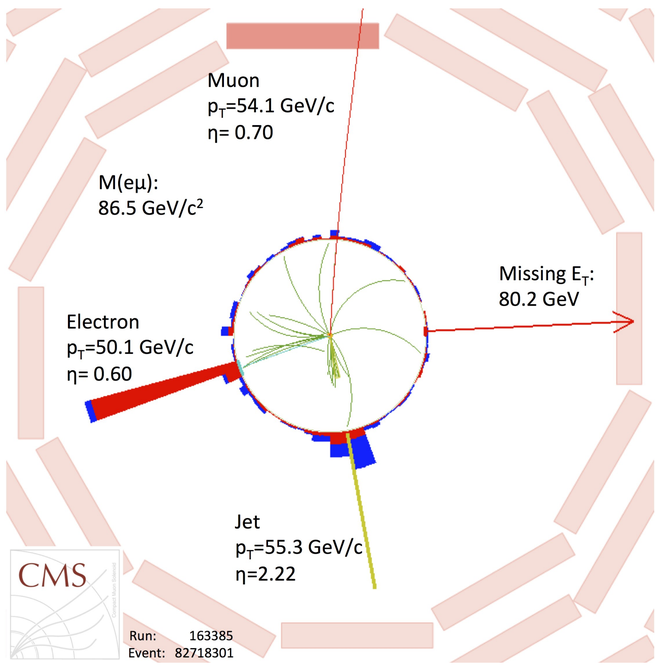
- Transverse momentum p_T > 30 GeV
- Pseudorapidity |η| < 2.4
- Tagged as coming from a b quark (b-tagged) based on displaced secondary vertex

Additional Cuts

- Invariant Mass of leptons, $m_{\ell\ell}$ > 20 GeV
- Veto event 81 < $m_{\ell\ell}$ < 101 GeV in μμ and ee channels
- E^T_{miss} > 30 GeV in μμ and ee channels

Signal / Control Regions

- Signal and control regions based on jet and b-tagged jet multiplicity
- Signal region:
  - One jet, which is b-tagged (one jet – one tag : 1j1t)
- Control regions:
  - Two jets, one is b-tagged (two jet – one tag : 2j1t)
  - Two jets, both are b-tagged (two jet – two tags : 2j2t)



Event display of candidate tW event in the eμ channel

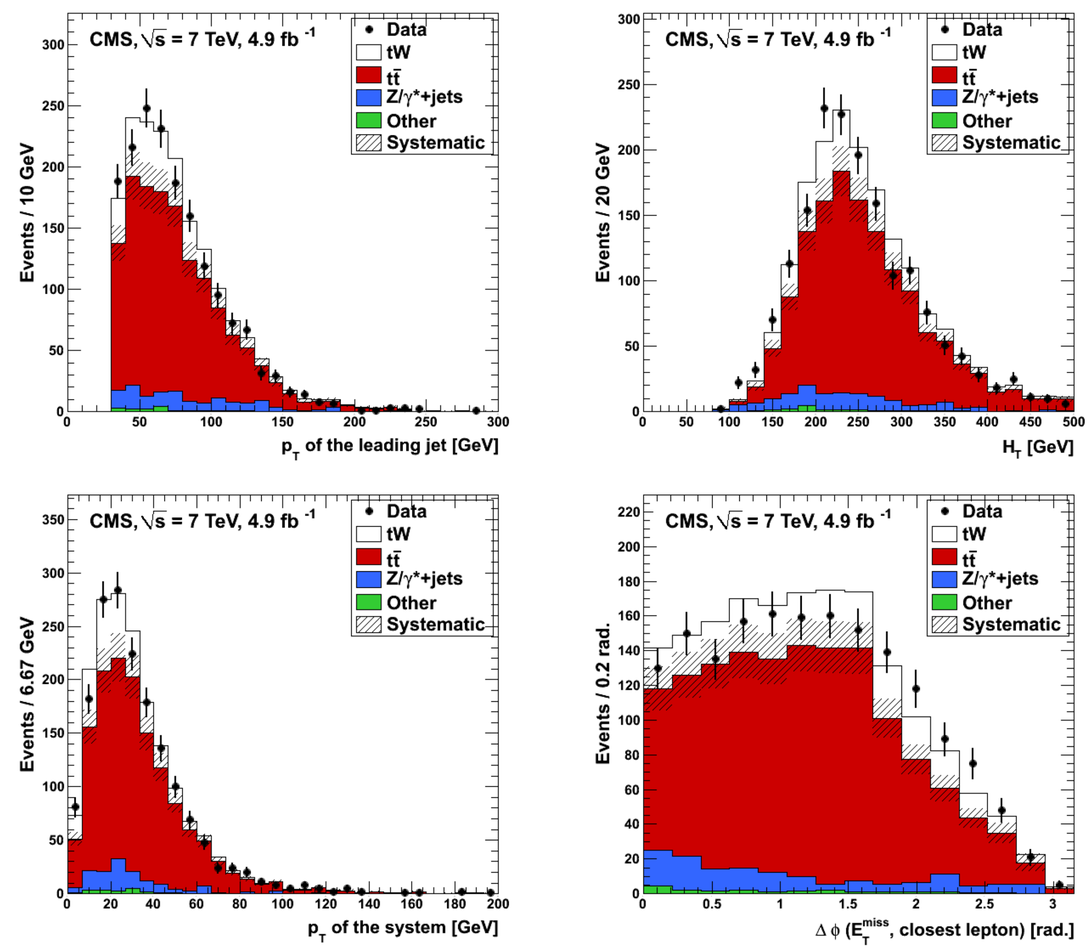
	1j1t	2j1t	2j2t
tW	336 ± 5 ± 16	180 ± 3 ± 16	45 ± 1 ± 6
$t\bar{t}$	1263 ± 19 ± 138	2775 ± 28 ± 205	1488 ± 21 ± 222
Z/γ^* + jets	128 ± 12 ± 28	113 ± 10 ± 22	8.5 ± 1.8 ± 1.8
Other	19 ± 3	8.8 ± 0.7 ± 0.2	4 ± 3
Total estimated	1746 ± 23 ± 141	3077 ± 30 ± 207	1546 ± 21 ± 222
Total data	1699	2878	1507

Number of events passing event selection for simulation and data for all three dilepton channels combined. Statistical (first) and systematic (second) uncertainties are quoted for simulation estimates

MULTIVARIATE ANALYSIS

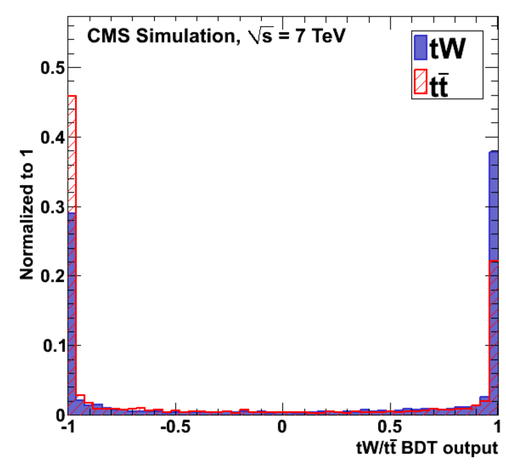
A Boosted Decision Tree (BDT) was trained to discriminate between the tW signal and $t\bar{t}$ background. Input variables:

- p_T of leading jet
- p_T of the system: Vector sum of transverse momentum of leptons, jet and missing energy
- H_T: Scalar sum of transverse momentum of leptons, jet, and missing energy
- Δϕ(E^T_{miss}, closest lepton): Difference in ϕ between E^T_{miss} and closest lepton

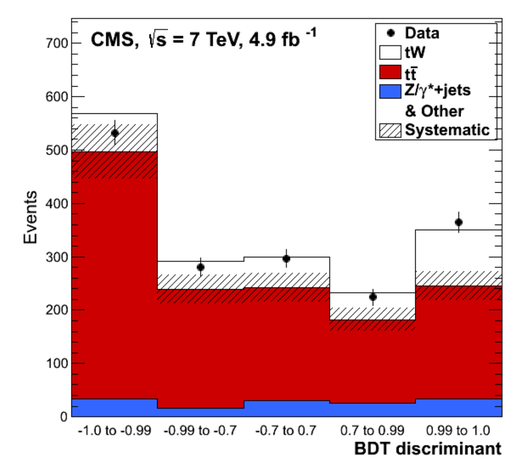


Distributions of input variables in 1j1t signal region

The BDT returns a single discriminant for each event ranging from -1 (background-like) to +1 (signal-like).



Normalized shape of BDT in tW and $t\bar{t}$ simulation in 1j1t signal region



BDT discriminant distribution in data and simulation in 1j1t signal region

STATISTICAL EVALUATION

A binned likelihood fit to the shape of the BDT discriminant is performed. The fit is performed simultaneously across the three channels in all three regions. Templates for the shapes of signal and background are taken from simulation.

Systematic uncertainties are taken into account by applying ±1σ systematic shifts to the templates and adding them as nuisance parameters to the fit.

RESULTS

An excess over the expected background-only hypothesis is observed with a significance of 4.0σ, compatible with the expected value based on simulation of $3.6^{+0.8}_{-0.9}\sigma$

Cross section is measured to be $\sigma = 16^{+5}_{-4}$ pb, in agreement with the standard model prediction of $\sigma = 15.6 \pm 0.4^{+1.0}_{-1.2}\,\text{pb}^{[2]}$

An estimate of the CKM matrix element, $|V_{tb}|$, is extracted under the assumption that $|V_{tb}|$ is much larger than $|V_{td}|$ and $|V_{ts}|$:

$$|V_{tb}| = \sqrt{\frac{\sigma_{tW}}{\sigma_{tW}^{th.}}} = 1.01^{+0.16}_{-0.13}(\text{exp.})^{+0.03}_{-0.04}(\text{th.})$$

References: [1] CMS Collaboration, *JINST* 3 (2008) S08004
[2] N. Kidonakis, *Phys. Rev. D* 82 (2010) 054018
[3] N. Kidonakis, *Phys. Rev. D* 82 (2010) 114030
[4] R. Gavin, Y Li., F. Petriello et al., *Comput. Phys. Commun.* 182 (2011) 2388

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