Measurement of the top quark pair-production in association with a W or Z boson in pp collisions at 13 TeV with full 2016 dataset at CMS

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Les Rencontres de Physique de la Vallee d'Aoste 2018

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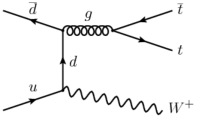
Strategy and event selection



$t\bar{t}W \to (bjj)(bjj)(jj)$
$t\bar{t}W \to (bjj)(bjj)(l\nu)$
$t\bar{t}W \to (bl\nu)(bjj)(l\nu)$
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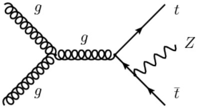


$t\bar{t}Z \to (bjj)(bjj)(jj)$
$t\bar{t}Z \to (bjj)(bjj)(ll)$
$t\bar{t}Z \to (bl\nu)(bjj)(ll)$
$t\bar{t}Z \to (bl\nu)(bl\nu)(ll)$

- The observed yields and measured cross-sections could be altered by new physics, the main background for $t\bar{t}H$ and for BSM processes
- Strength of the electromagnetic coupling of top quark and Z boson can be probed

$t\bar{t}W$, SS2ℓ

- $p_T > 40, 25(27)\text{GeV}$
- at least 2 jets, 1 b-tag jet

$t\bar{t}Z$, 3ℓ

- $p_T >$ 40, 20, 10 GeV
- at least 2 jets
- $|m_{\ell\ell} - M_Z| <$ 10 GeV

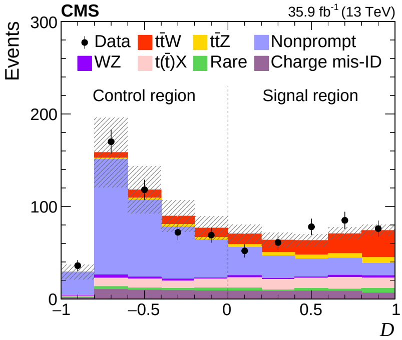
$t\bar{t}Z$, 4ℓ

- $p_T >$ 40 and 10 GeV for others
- at least 2 jets
- $|m_{\ell\ell} - M_Z| <$ 20 GeV

- The number of jets and b-tagged jets are used to form signal regions

$t\bar{t}W$ in SS 2ℓ

- For $t\bar{t}W$ the MVA analysis a Boost Decision Tree (BDT) classifier was developed
- BDT input:
  - Number of jets; number of medium b-tagged jets; the sum of p_T of the jets
  - Leading and trailing lepton p_T, transverse invariant mass of both leptons
  - Leading and subleading jet p_T, missing transverse energy
  - ΔR between the trailing lepton and the nearest selected jet



Event selection and categorisation

- BDT > 0
- Further split in number of jets, b-tag jets
- Split in $++$ and $--$

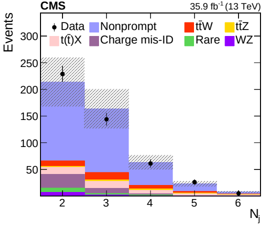
Backgrounds

- misidentified leptons, $t\bar{t}$
- $t\bar{t}Z$ and $t\bar{t}H$

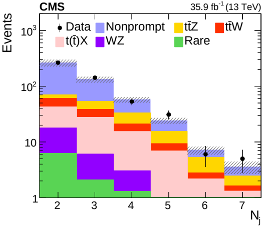
Nonprompt lepton background

- Nonprompt leptons are expected to come mostly from $t\bar{t}$ and Drell-Yan production: an additional nonprompt lepton from the semi-leptonic decay of a b-hadron, additional jets misidentified as leptons, etc.
- The probability of a loosely identified lepton to pass the full set of identification/isolation requirements is calculated in respective enriched region and validated in Monte-Carlo simulation and data:
  - 2ℓ: D $<$ 0
  - 3ℓ: absence of an same flavour opposite-charge lepton pair or invariant mass of 2 leptons is far from Z boson mass

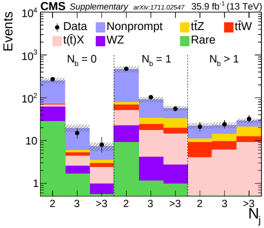
2ℓ



3ℓ



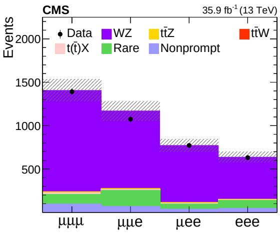
3ℓ



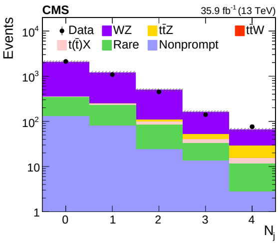
WZ and ZZ background

- Main backgrounds for $t\bar{t}Z$ in 3ℓ and 4ℓ final states
- We rely on MC simulation for yield estimation and validate in enriched control regions:
  - 3 leptons(4 leptons), 2 of the form an (2)SFOC pair close to Z peak mass
  - in 3ℓ the cut that excludes b-tag jets is used

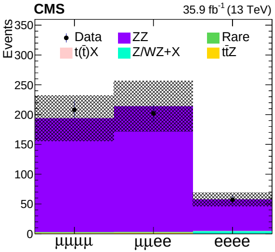
3ℓ



3ℓ



4ℓ

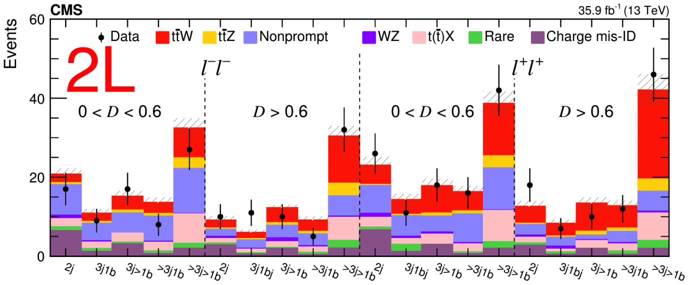


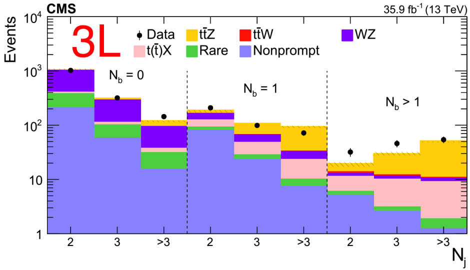
ttV: systematic uncertainties

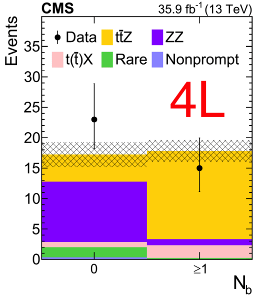
Source	Uncertainty range	Impact on ttW cross-section	Impact on ttZ cross-section
Luminosity	2.5%	4%	3%
Jet Energy Scale/Resolution	2-5%	3%	3%
Trigger	2-4%	4-5%	5%
B tagging	1-5%	2-5%	4-5%
PU modeling	1%	1%	1%
Lepton ID, efficiency	2-7%	3%	6-7%
μ_R/μ_F scale choice	1%	<1%	1%
PDF choice	1%	<1%	1%
Nonprompt background	30%	4%	< 2%
WZ cross section	10-20%	<1%	2%
ZZ cross section	20%	-	1%
Charge misidentification	20%	3%	-
Rare SM background	50%	2%	2%
ttX background	10-15%	4%	3%
Stat. unc. for nonprompt	5-50%	4%	2%
Stat. unc. rare SM processes	20-100%	1%	< 1%
Total systematic	-	14%	12%

- Uncertainties on the lepton reconstruction, b tagging and trigger efficiency have the greatest effect both on the $t\bar{t}W$ and $t\bar{t}Z$ cross-section measurement.
- The uncertainty on nonprompt background gives a significant contribution to the systematic uncertainty of $t\bar{t}W$ cross section measurement.
- The systematic uncertainty for $t\bar{t}W$ and $t\bar{t}Z$ becomes dominant!

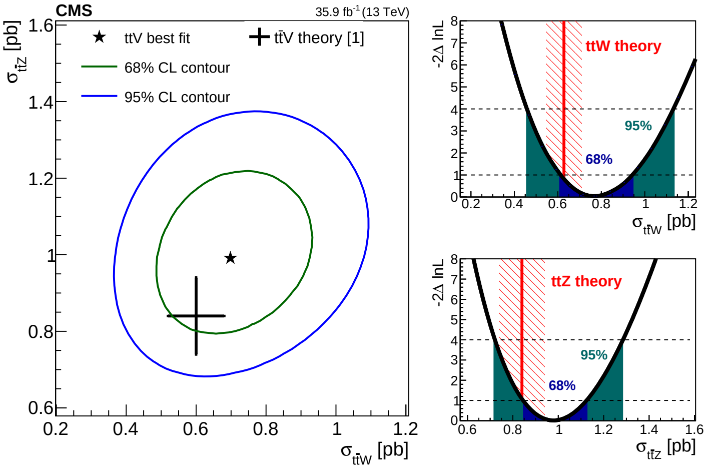
$t\bar{t}V$ results







$t\bar{t}V$ results



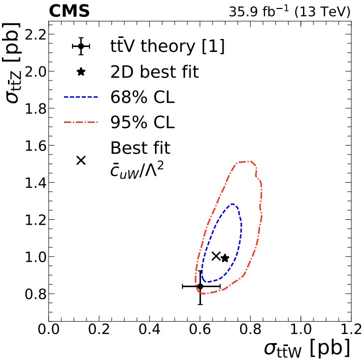
⇒ First time a single experiment achieves $> 5\sigma$ for both processes simultaneously at 13 TeV

⇒ First time ttV reaches $> 5\sigma$ at 13 TeV

EFT Lagrangian:

$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda}\sum_i c_i \mathcal{O}_i + \frac{1}{\Lambda^2}\sum_j c_j \mathcal{O}_j + \cdots$

- $\mathcal{M} = \mathcal{M}_0 + \sum c_j \mathcal{M}_j$, consider one operator at a time
- Do not consider all NP couplings to the first two generations, as well operators which caused significant cross section scaling for $t\bar{t}$, inclusive Higgs, WW or WZ
- Considered NP effects on $t\bar{t}H$ as well as $t\bar{t}W$ and $t\bar{t}Z$
- Construct a profile likelihood test statistic $q(c_j)$, maximize to find the asymptotic best-fit c_j



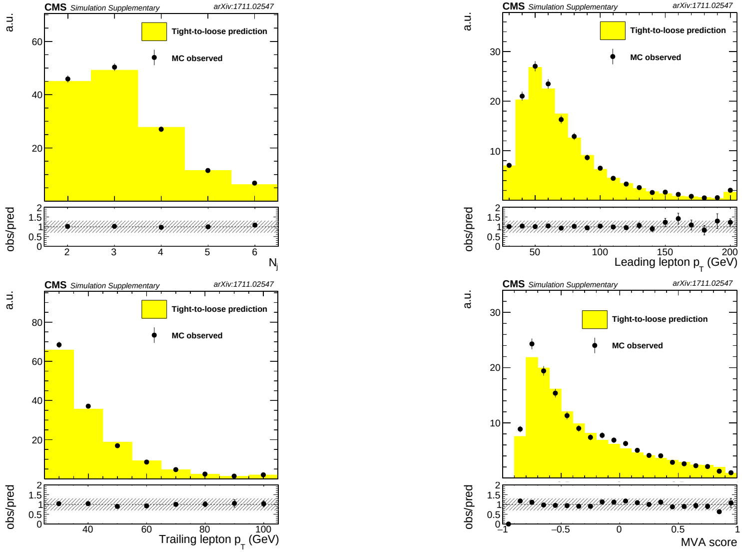
Wilson coefficient	Best fit $[\text{TeV}^{-2}]$	68% CL $[\text{TeV}^{-2}]$	95% CL $[\text{TeV}^{-2}]$
$\bar{c}_{uW}/\Lambda^2$	1.7	$[-2.4,-0.5]$ and $[0.4,2.4]$	$[-2.9,2.9]$
$\lvert\bar{c}_H/\Lambda^2 - 16.8\ \text{TeV}^{-2}\rvert$	15.6	$[0,23.0]$	$[0,28.5]$
$\lvert\widetilde{c}_{3G}/\Lambda^2\rvert$	0.5	$[0,0.7]$	$[0,0.9]$
$\bar{c}_{3G}/\Lambda^2$	-0.4	$[-0.6,0.1]$ and $[0.4,0.7]$	$[-0.7,1.0]$
$\bar{c}_{uG}/\Lambda^2$	0.2	$[0,0.3]$	$[-1.0,-0.9]$ and $[-0.3,0.4]$
$\lvert\bar{c}_{uB}/\Lambda^2\rvert$	1.6	$[0,2.2]$	$[0,2.7]$
$\bar{c}_{Hu}/\Lambda^2$	-9.3	$[-10.3,-8.0]$ and $[0,2.1]$	$[-11.1,-6.5]$ and $[-1.6,3.0]$
$\bar{c}_{2G}/\Lambda^2$	0.4	$[-0.9,-0.3]$ and $[-0.1,0.6]$	$[-1.1,0.8]$

Conclusions

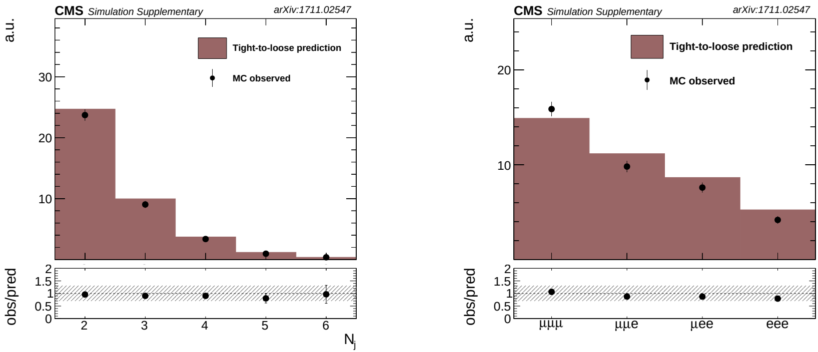
- The measurement of $t\bar{t} + V$ cross-section is done at 13 TeV with statistical uncertainty O(15%) and systematic uncertainty O(15%)
- Next step is to measure differential cross-section for $t\bar{t}Z$ and the tZ coupling
- We are excited to have more data already in 2017-2018!

Back-up

$t\bar{t}$ MC closure test

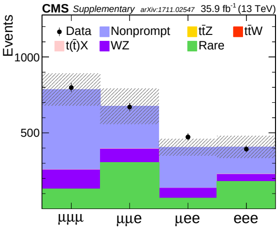


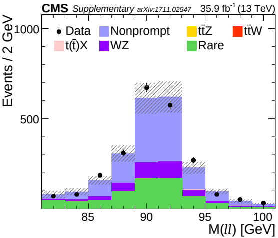
DY MC closure test

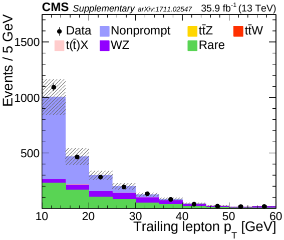


DY control region in data

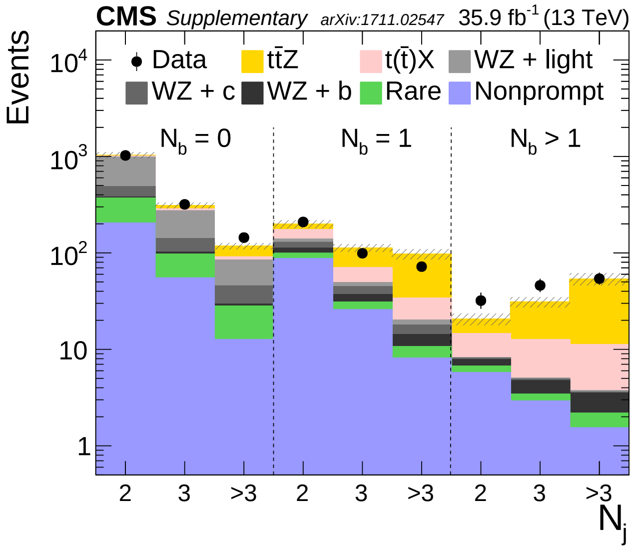
3ℓ channel, OSSF pair, 0-1 jets, 0 b jets, $E_T^{miss} < 30$ GeV





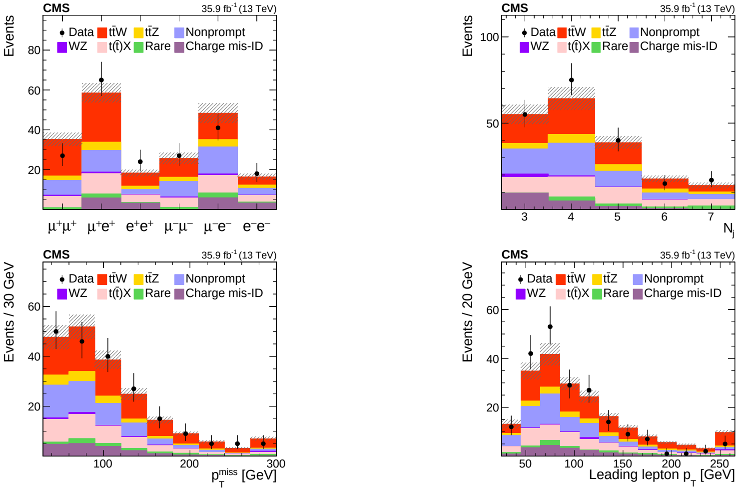


WZ+jets split in flavour



$t\bar{t}W$ in same-sign 2ℓ

same-sign 2ℓ channel in enriched $t\bar{t}W$ region: ≥ 3 jets, ≥ 2 b jet



3ℓ channel in enriched $t\bar{t}Z$ region: ≥ 3 jets, ≥ 1 b jet