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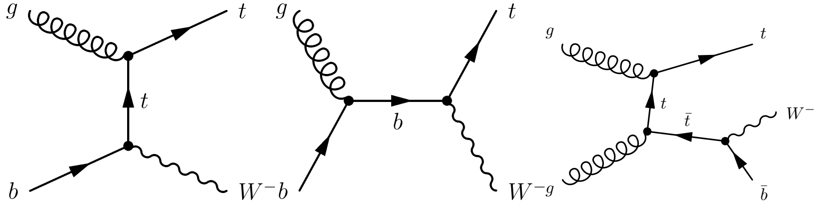
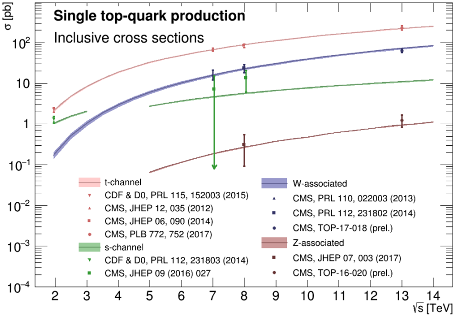
Comparison of ATLAS and CMS tW results at 13 TeV

- It is an excellent probe of the V_{tb} matrix element
- It can be sensitive to the b pdfs
- It is the main background in $t\bar{t}$ precision measurements
- Its production interferes with $t\bar{t}$ production at NLO
  - Two configurations to subtract overlaping diagrams: diagram subtraction and removal



Historical aspects of tW production



- Both collaborations have performed measurements of the tW cross-section at 7, 8 and 13 TeV
- In this presentation I will focus on the latest results by CMS and ATLAS at 13 TeV
- These results correspond to
  - CMS-PAS-TOP-17-018
  - ATLAS arXiv:1612.07231

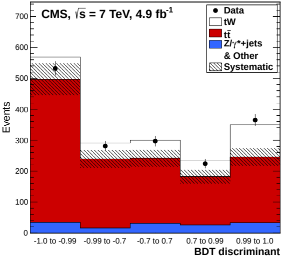
Run I results: tW at 7 and 8 TeV

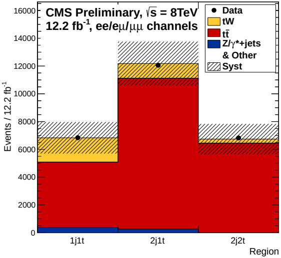
CMS measurement at 7 and 8 TeV

- Event selection:
  - Two opposite-charge leptons
  - Analysis regions defined: 1j1b, 2j1b and 2j2b
- Signal extracted with ML fit to each (ee, $\mu\mu$ and eμ) channels
- BDT trained to discriminate signal from background
- Results:
  - 7 TeV: 4.0σ, $\sigma_{tW} = 16 \pm 5$ pb
  - 8 TeV: 6.1σ, $\sigma_{tW} = 23.4 \pm 5.4$ pb

PRL 110 (2013) 022003

PRL 112 (2014) 231802





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RUN I RESULTS: TW AT 7 AND 8 TEV

ATLAS measurement at 7 TeV

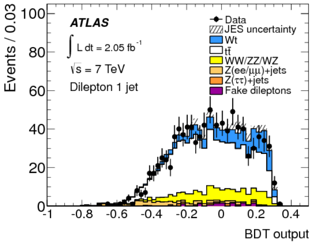
- Analysis regions defined: 1-jet, 2-jet, $\geq$3-jets
- 3 BDTs trained to discriminate signal from background

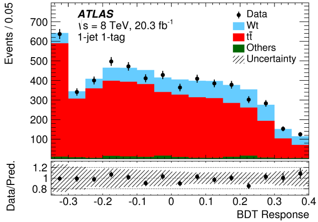
ATLAS measurement at 8 TeV

- Analysis regions defined: 1j1b, 2j1b, 2j2b
- 3 BDTs trained to discriminate signal from background
- Results:
  - 7 TeV: 3.3σ, $\sigma_{tW} = 16.8 \pm 2.9 \pm 4.9$ pb
  - 8 TeV: 7.7σ, $\sigma_{tW} = 23.0 \pm 1.3 \pm 3.5 \pm 1.1$ pb

Phys. Lett. B716 (2012) 142-159

JHEP 01 (2016) 064





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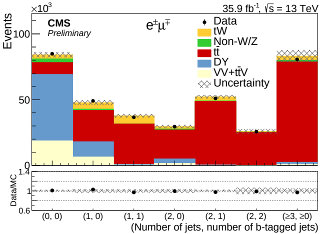
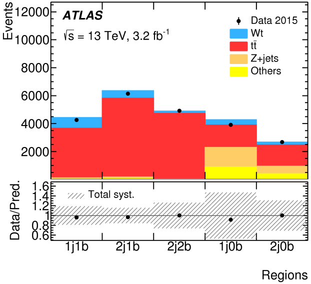
Overview of the ATLAS and CMS analyses at $\sqrt{s} = 13$ TeV



- Both analyses focus in the dilepton channel
- $t\bar{t}$ is the main background $\Rightarrow$ both analyses utilize differences in the (n_j, n_b) spectrum
- Further discrimination is obtained by exploiting dedicated BDTs
- Signal is extracted by performing a likelihood fit
- ATLAS uses 2015 (3.2 fb^{-1}) dataset in ee, $\mu\mu$ and eμ channels
- CMS analysis is performed in the 2016 dataset (35.9 fb^{-1}) in the eμ channel (ten times the luminosity)



Object Selection

- Both analyses use a similar object selection
- However, minor differences are present

CMS

Triggers

- Single and double lepton paths

Lepton selection

- Leading lepton $p_T > 25$ GeV
- Sub-leading lepton $p_T > 20$ GeV
- No veto on events with a third lepton

Jet selection

- Using jets with $p_T > 30$ GeV

ATLAS

Triggers

- Single lepton paths

Lepton selection

- Leading lepton $p_T > 25$ GeV
- Sub-leading lepton $p_T > 20$ GeV
- Reject events with third lepton with $p_T > 20$ GeV

Jet selection

- Using jets with $p_T > 25$ GeV

Event selection

- There are some differences in the event selection of both analyses

CMS

- Events with an electron and a muon ($m_{e\mu} > 20$ GeV)
- Three regions defined: 1j1b, 2j1b, 2j2b
- No additional cuts are applied on top of the definition of the signal / control regions

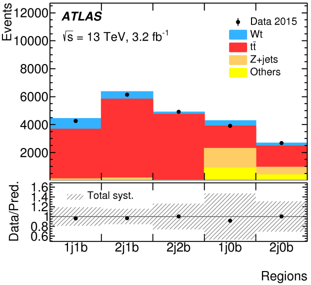
ATLAS

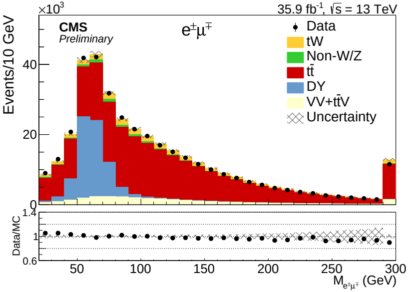
- Events with two leptons (signal extracted without splitting in channels)
- Three regions defined: 1j1b, 2j1b, 2j2b
- E_T^{miss} and $m_{\ell\ell}$ cuts for Drell-Yan rejection

Cuts in ATLAS analysis		
Different flavor	$E_T^{miss} > 50$ GeV	if $m_{\ell\ell} < 80$ GeV
	$E_T^{miss} > 20$ GeV	if $m_{\ell\ell} > 80$ GeV
Same flavor	$E_T^{miss} > 40$ GeV	always
	veto	if $m_{\ell\ell} < 40$ GeV
	$4E_T^{miss} > 5m_{\ell\ell}$	if 40 GeV $< m_{\ell\ell} <$ 81 GeV
	veto	if 81 GeV $< m_{\ell\ell} <$ 101 GeV
	$2E_T^{miss} + E_T^{miss} >$300 GeV	if $m_{\ell\ell} > 101$ GeV

Background estimation

- Both analyses predict backgrounds using MC simulations
- Both use POWHEG-BOX for tW (v1) and $t\bar{t}$ (v2)
- Parton showers are modelled with Pythia8 in CMS analysis, Pythia 6 is used by ATLAS
- CMS assesses systematic uncertainties of DY and fake estimation through data-driven techniques
- ATLAS validates their modeling in 1j0b and 2j0b regions





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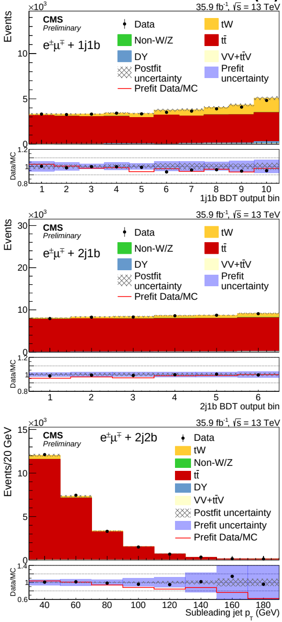
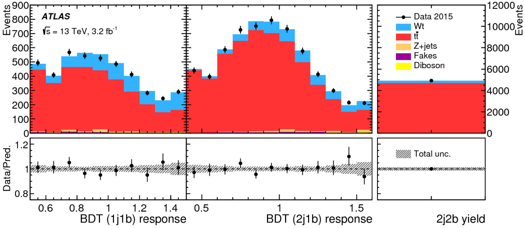
SIGNAL EXTRACTION (I)



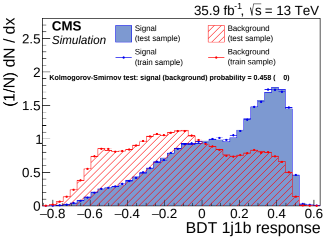


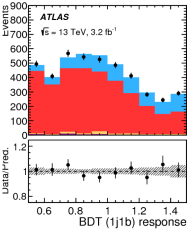
- Signal extraction is performed using a maximum likelihood fit to 1j1b, 2j1b and 2j2b regions
- Both analyses exploit BDTs in 2j1b and 1j1b regions to discriminate signal from background
- Both use the 2j2b region to constrain $t\bar{t}$
- CMS additionally uses the subleading jet p_T distribution in the 2j2b region to further constrain systematic uncertainties

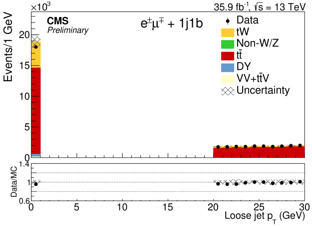
SIGNAL EXTRACTION (II)

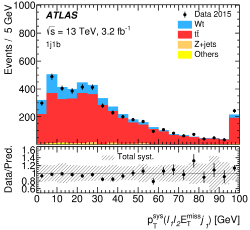
1J1B REGION

- Even in the 1j1b region $t\bar{t}$ contribution is still large
- Both analyses employ dedicated BDTs to discriminate signal from $t\bar{t}$
- Discriminating BDT in the 1j1b is fed with kinematic variables
- CMS additionally looks for additional low momentum ($p_T > 20$ GeV) jets









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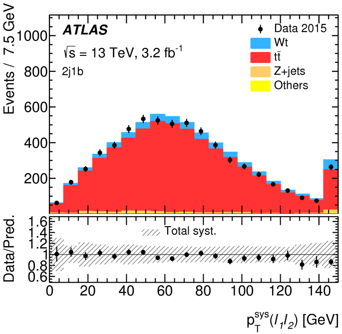
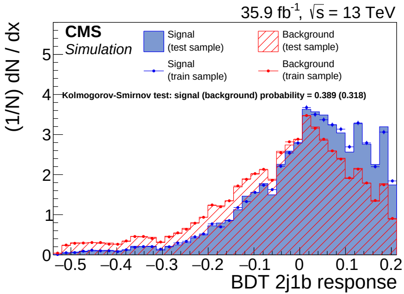
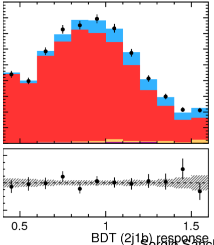
Signal extraction (III)

2j1b region





- BDTs are also utilized in the 2j1b region to distinguish separate signal from background
- CMS exploits angular correlation variables between the leptons, jets and E_T^{miss} as well as the p_T of the subleading jet
- ATLAS additionally uses transverse momenta and masses of systems formed by leptons, jets and E_T^{miss}



SYSTEMATIC UNCERTAINTIES (EXPERIMENTAL)

- Both experiments handle experimental uncertainties in a similar fashion

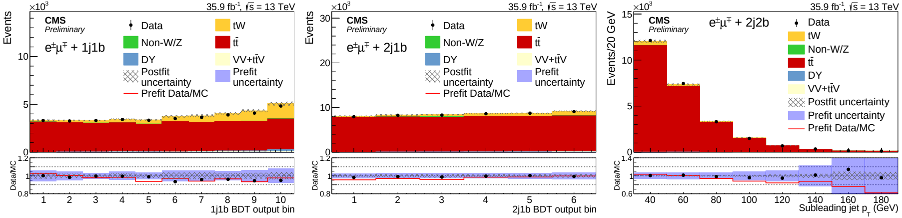
Experimental systematics	
CMS	**ATLAS**
b-tagging efficency Mistagging rate	*b*-tagging
Jet Energy Scale Jet Energy Resolution	Jet Energy Scale Jet Energy Resolution $E_{\mathrm{T}}^{\mathrm{miss}}$ soft terms
Trigger efficiency Muon efficiency Electron efficiency	Lepton efficiency energy and resolution
Pile-up	

Modelling systematics

	CMS	ATLAS
Matrix element	Normalization and factorization scales varied up and down by a factor 2	POWHEG+Pythia vs aMC@NLO + Herwig†
Parton Shower, hadronization, underlying event	UE: variation of Pythia parameters ME/PS matching: variation of h_{damp} Color reconnection	POWHEG+Pythia vs POWHEG+Herwig†
ISR/FSR	PS scale used for ISR/FSR varied up and down by a factor of two	Idem as CMS (tW†) (only one nuisance)
pdf	Root-mean-square of 100 NNPDF3.0 pdfs	Difference between PDF4LHC15 and CT10†
Diagram subtraction and removal	Yes	Yes†
Extrapolation to full phase space	Yes	No

†Comparison performed in fast simulation

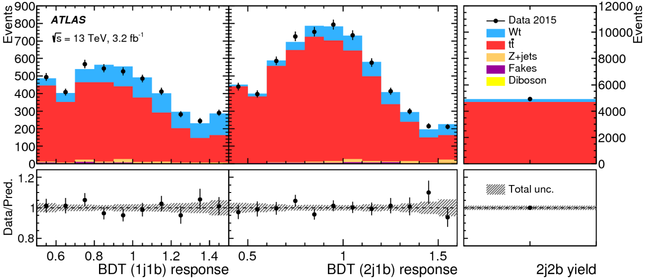
RESULTS
CMS



- $\sigma_{tW} = 63.1 \pm 1.8(\text{stat}) \pm 6.0(\text{syst}) \pm 2.1(\text{lumi})$ pb.
- tW cross-section measured with a precision of the order of 10%
- Measurement consistent with Standard Model expectation
  - $\sigma_{tW}^{SM} = 71.7 \pm 1.8$ (scale) ± 3.4 (pdf) pb

RESULTS
ATLAS

- Signal is extracted from the ee, $\mu\mu$ and $e\mu$ channels (without splitting in classes)
- $\sigma_{tW} = 94 \pm 10(\text{stat.}) \, ^{+28}_{-22} \, (\text{syst.}) \, \pm 2 \, (\text{lumi.})$ pb
- Uncertainty of the order of 30%
- Measurement consistent with Standard Model expectation
  - $\sigma_{tW}^{\text{SM}} = 71.7 \pm 1.8 \, (\text{scale}) \, \pm 3.4 \, (\text{pdf})$ pb



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COMPARISON OF SYSTEMATIC UNCERTAINTIES

Source	Uncertainty (%)
Trigger efficiencies	2.7
Muon efficiencies	3.1
Electron efficiencies	3.2
Jet energy scale	3.2
Jet energy resolution	1.8
b tagging efficiency	1.4
Mistagging rate	0.2
Pileup	3.3
$t\bar{t}$ μ_R and μ_F scale	2.5
tW μ_R and μ_F scale	0.9
Underlying event	0.4
ME/PS matching	1.8
Initial state radiation	0.8
Final state radiation	0.8
Color reconnection	2.0
PDF	1.5
DR-DS	1.3
VV normalization	0.4
Drell–Yan normalization	1.1
Non-W/Z leptons normalization	1.6
$t\bar{t}$V normalization	0.1
MC statistics	1.6
Full phase space extrapolation	2.9
Total systematic (excluding integrated luminosity)	9.5
Integrated luminosity	3.3
Statistical	2.8
Total	10.5

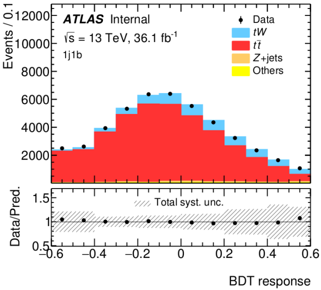
- CMS is dominated by experimental uncertainties: lepton efficiencies, jet energy scale, pile-up
- ATLAS is uncertainty dominated by jet energy scale and matrix element generator

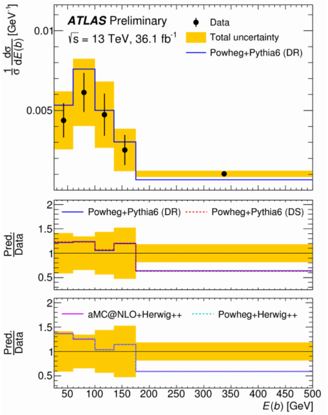
Source	$\Delta\sigma_{Wt}/\sigma_{Wt}$[%]
Jet energy scale	21
Jet energy resolution	8.6
E_T^{miss} soft terms	5.3
b-tagging	4.3
Luminosity	2.3
Lepton efficiency, energy scale and resolution	1.3
NLO matrix element generator	18
Parton shower and hadronisation	7.1
Initial-/final-state radiation	6.4
Diagram removal/subtraction	5.3
Parton distribution function	2.7
Non-$t\bar{t}$ background normalisation	3.7
Total systematic uncertainty	30
Data statistics	10
Total uncertainty	31

DIFFERENTIAL tW CROSS-SECTION

- ATLAS has released a measurement of the differential cross-section
- Same event selection as in the total cross-section analysis
- Using 2016 dataset (36.1 fb^{-1})

- Signal enriched region is constructed in the 1j1b region, using the $BDT > 0.3$ region
- Showing E(b), many other variables available





$$N_i = \frac{N_{\text{fid}}}{N_{\text{fid\&reco}}} \sum_j M_{ij} \frac{N_{fid\&reco}}{N_{fid}} (N_j^{\text{data}} - N_b)$$

CONCLUSIONS

- Both CMS and ATLAS have measured tW production cross-section at $\sqrt{s} = 13$ TeV
- Guiding principle of both analyses is similar: three regions 1j1b, 2j1b and 2j2b
- However many details on the dataset and event selection as well as the BDTs discriminators are different
- Modelling uncertainties are assessed in different ways by the two collaborations

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Thanks for your attention!
Questions?

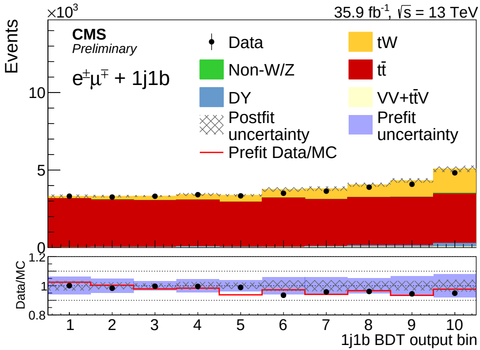
Back-up

- Break-down of systematics table in the 8 TeV CMS analysis

Systematic uncertainty	$\Delta\sigma$ (pb)	$\Delta\sigma/\sigma$	Notes
ME/PS matching thresholds	3.3	14%	Matching threshold $2\times$ and $1/2\times$ nominal 20 GeV value in $t\bar{t}$ simulation
Renormalization/factorization scale	2.9	12%	Scale value $2\times$ and $1/2\times$ nominal value of $m_t^2 + \sum p_T^2$ in $t\bar{t}$ and tW simulation
Top-quark mass	2.2	9%	m_t varied in tW and $t\bar{t}$ simulation by ± 2 GeV
Fit statistical	1.9	8%	Remaining uncertainty in fit when all other systematic uncertainties are removed
Jet energy scale	0.9	4%	Jet energy scale varied up/down
Luminosity	0.7	3%	2.6% uncertainty in the measured luminosity
Z+jets data/simulation scale factor	0.6	3%	Varying scale factors used for correcting Z+jets E_T^{miss} simulation
tW DR/DS scheme	0.5	2%	Difference between DR and DS scheme used for defining tW signal
$t\bar{t}$ cross section	0.4	2%	Uncertainty in the cross section of $t\bar{t}$ production
Lepton identification	0.4	2%	Uncertainty in scale factors for lepton efficiencies between data/simulation
PDF	0.4	2%	From choice of PDF
Jet energy resolution	0.2	1%	Energy resolution for jets varied up/down
b-tagging data/simulation scale factor	0.2	<1%	Variations in scale factors
$t\bar{t}$ spin correlations	0.1	<1%	Difference between $t\bar{t}$ simulation with/without spin correlations
Pileup	0.1	<1%	Varying effect of pileup
Top-quark p_T reweighting	0.1	<1%	Uncertainty due to differences in top quark p_T between data and $t\bar{t}$ simulation
E_T^{miss} modeling	0.1	<1%	Uncertainty in amount of unclustered E_T^{miss}
Lepton energy scale	0.1	<1%	Uncertainty in energy of leptons
Total	5.5	24%	

- Break-down of systematics table in the 8 TeV ATLAS analysis

Uncertainty	Impact on $\hat{\mu}$ [%]
Statistical	± 5.8
Luminosity	± 4.7
Theory modelling	
ISR/FSR	$^{+8.2}_{-9.4}$
Hadronisation	± 1.7
NLO matching method	± 2.5
PDF	± 0.6
DR/DS	$^{+2.2}_{-4.8}$
Detector	
Jet	$^{+9.0}_{-9.9}$
Lepton	± 3.0
$E_{\mathrm{T}}^{\mathrm{miss}}$	± 5.5
b-tag	± 1.0
Background norm.	$^{+2.9}_{-2.6}$
Total	$^{+16}_{-17}$



- Several uncertainties get constrained in the fit: JES, FSR, ISR, pdfs

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