



LHCP2017

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$t\bar{t} + X$ in ATLAS

Jörgen Sjölin

Stockholm University

on behalf of the ATLAS Collaboration



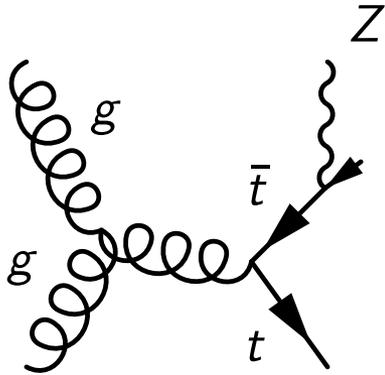
Introduction

- The top quark interactions are of central interest at LHC since many new physics scenarios involve top quarks, for example those that address the Higgs hierarchy problem.
- Effective field theory (EFT) provides one framework towards model independence if new physics resides at high energy.
- Top quark pair production with an additional vector gauge boson is sensitive to most of the leading EFT operators that preserve charge-parity and flavour in neutral-currents.
- This is one of the main reasons for this talk, and why we look at the associated production in the ATLAS detector of:

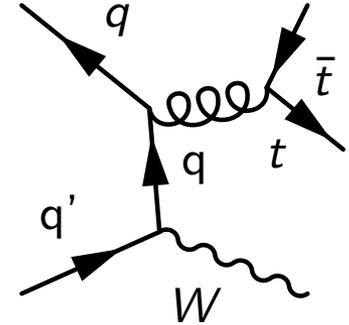
$$t\bar{t} + Z / W / \gamma$$

($t\bar{t}+g/q/H$ are also interesting in this context but covered in other talks)

$t\bar{t} + Z / W$



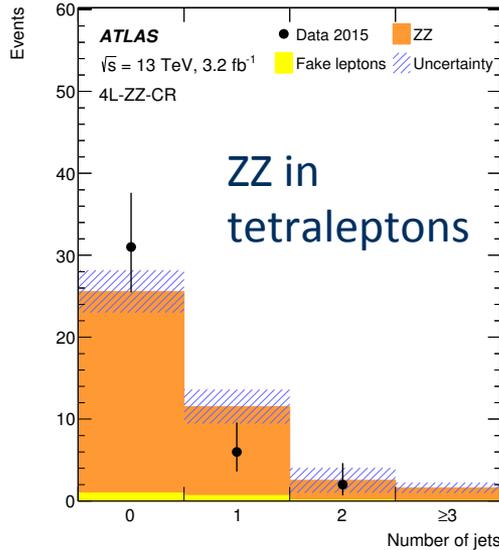
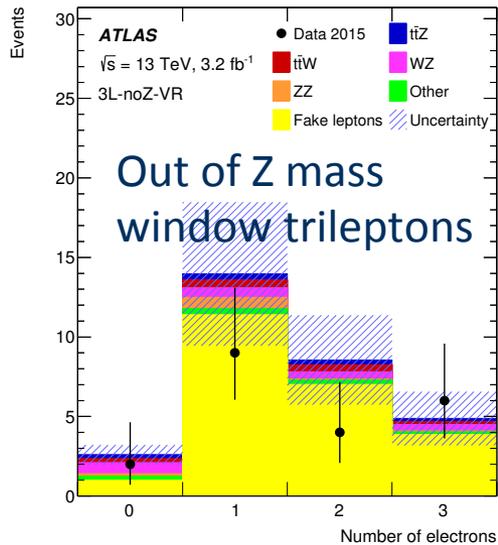
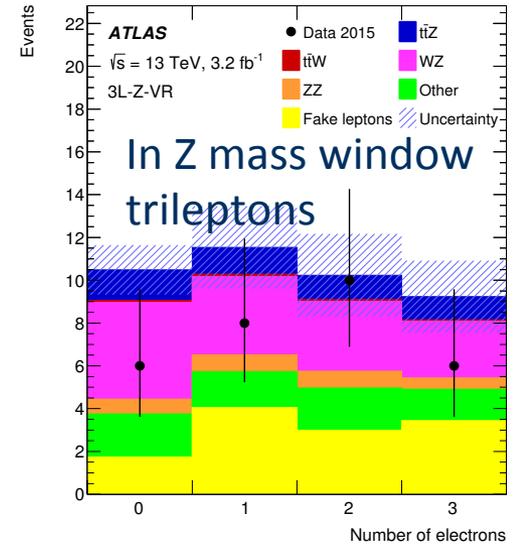
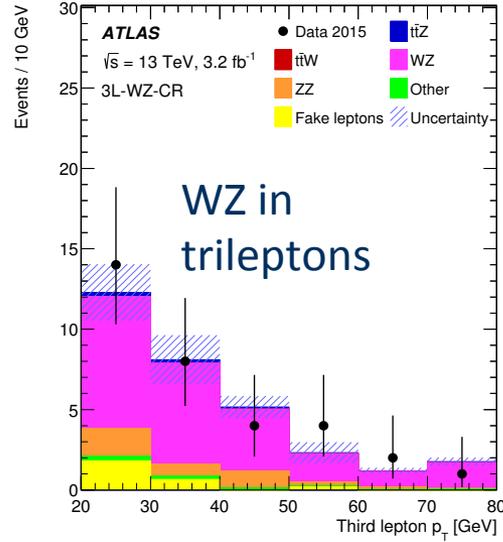
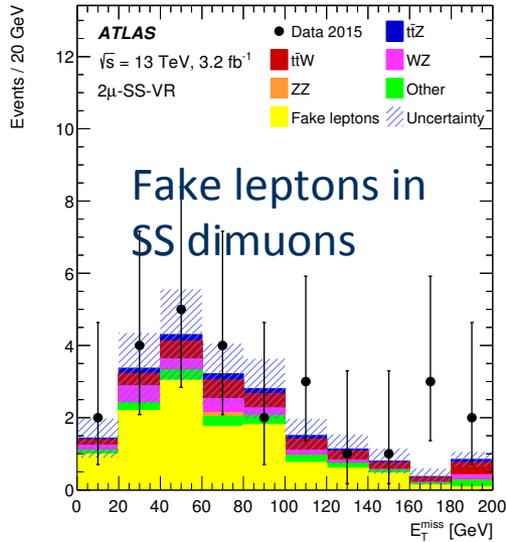
Process	$t\bar{t}$ decay	Boson decay	Channel
$t\bar{t}W^\pm$	$(\mu^\pm\nu b)(q\bar{q}b)$	$\mu^\pm\nu$	SS dimuon
	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$\ell^\pm\nu$	Trilepton
$t\bar{t}Z$	$(\ell^\pm\nu b)(q\bar{q}b)$	$\ell^+\ell^-$	Trilepton
	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$\ell^+\ell^-$	Tetralepton



Signal region	Main cuts	Main background	Background treatment
SS dimuons	≥ 2 b-tags	Fake leptons	Matrix method
Trileptons	≥ 3 jets, ≥ 1 b-tag	Fake leptons, WZ	Matrix method, Fit WZ in CR
Tetraleptons	≥ 1 b-tag	ZZ	Fit ZZ in CR

Theory: $\sigma_{t\bar{t}Z} = 0.84$ pb and $\sigma_{t\bar{t}W} = 0.60$ pb
(12% uncertainty)

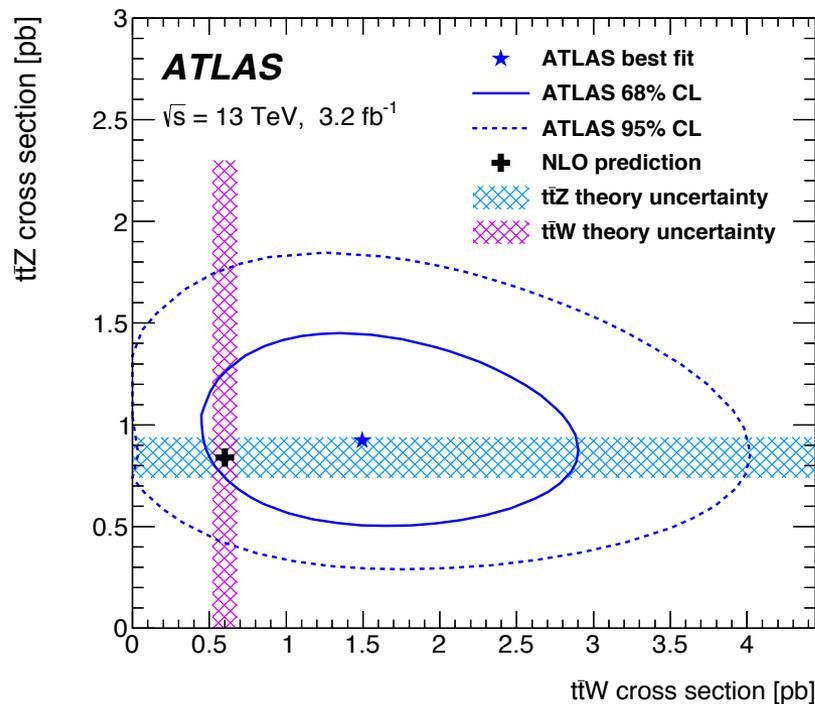
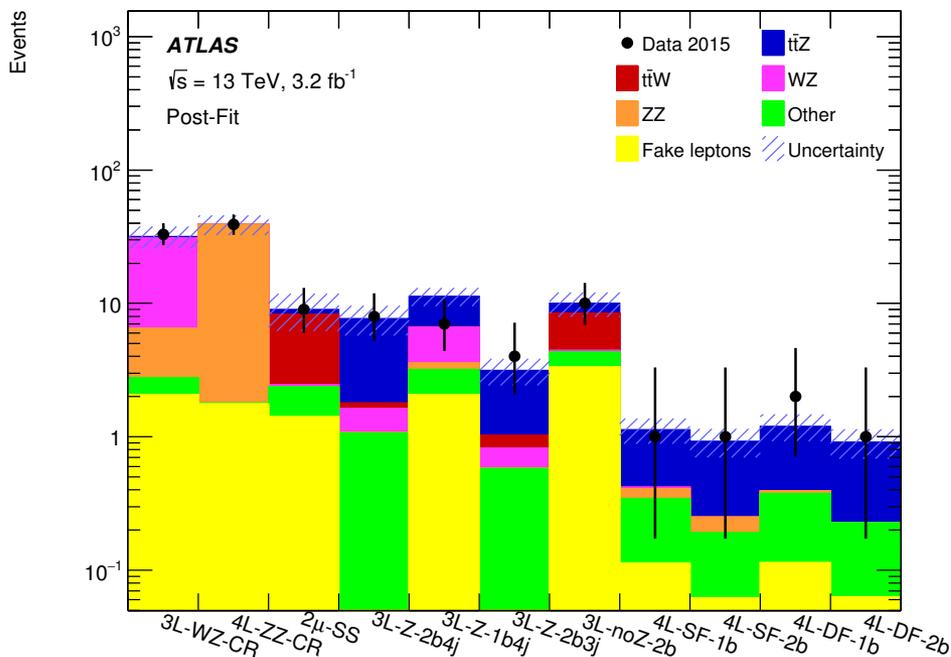
$t\bar{t} + Z / W$



- Inclusive cross sections extracted using profiled likelihood fit to 10 signal regions and 2 control regions.
- Statistics dominates the uncertainties.

Uncertainty	$\sigma_{t\bar{t}Z}$	$\sigma_{t\bar{t}W}$
Luminosity	2.6%	3.1%
Reconstructed objects	8.3%	9.3%
Backgrounds from simulation	5.3%	3.1%
Fake leptons and charge misID	3.0%	19%
Signal modelling	2.3%	4.2%
Total systematic	11%	22%
Statistical	31%	48%
Total	32%	53%

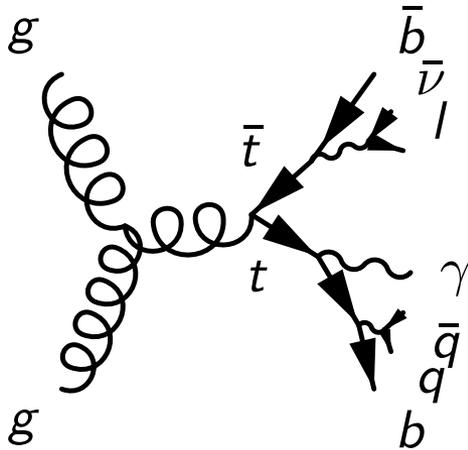
* Previously in 8 TeV: JHEP11 (2015) 172



$$\sigma_{t\bar{t}Z} = 0.9 \pm 0.3 \text{ pb and } \sigma_{t\bar{t}W} = 1.5 \pm 0.8 \text{ pb}$$

Relative uncertainty $t\bar{t}Z$: 30% (* in 8 TeV it was 30%),
 relative uncertainty $t\bar{t}W$: 50% (* in 8 TeV it was 30%)

$t\bar{t} + \gamma$



- Measurement performed in a fiducial volume, $E_T(\gamma) > 20$ GeV using the lepton+jets decays channel of the top pair.
- Main backgrounds are prompt and non-prompt photon contributions. Determined using data-driven template fit to track isolation.

Latest published results from ATLAS use 7 TeV and 4.6/fb of data

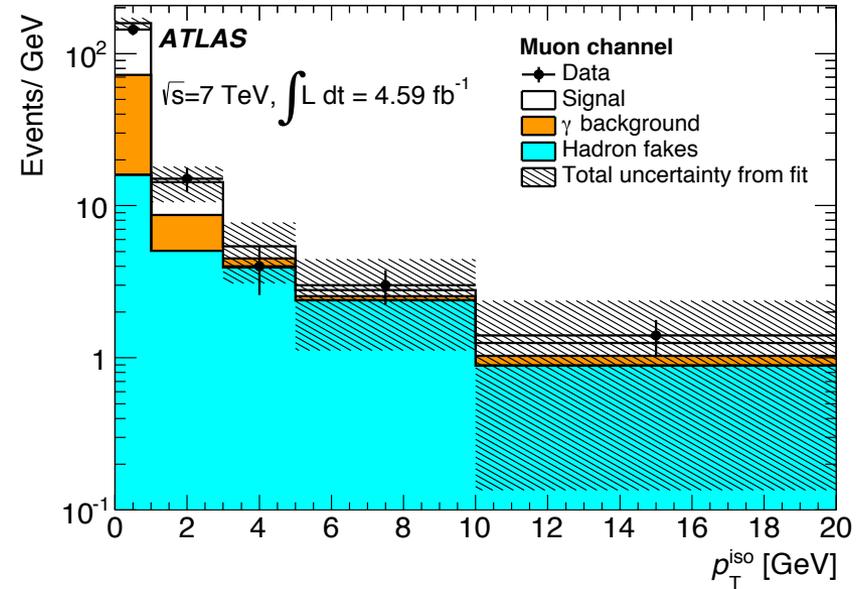
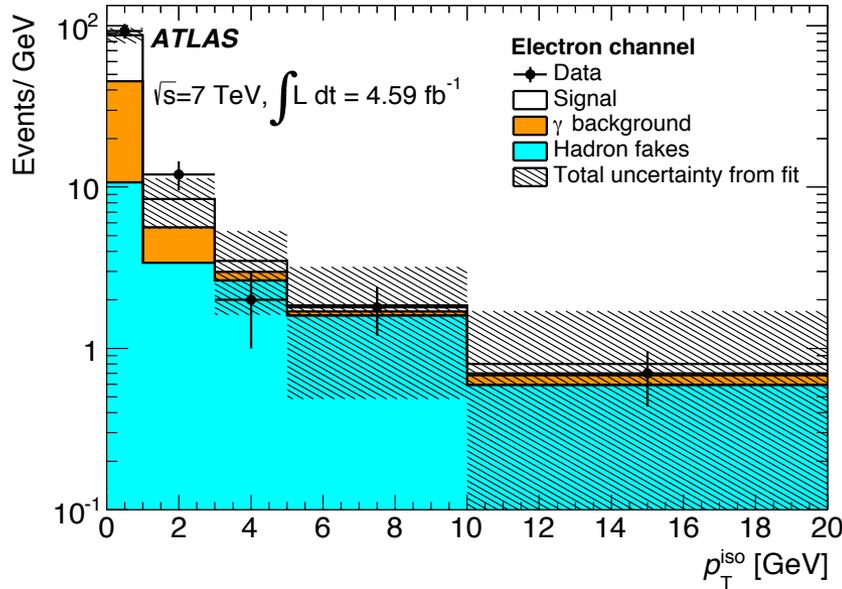
PHYSICAL REVIEW D **91**, 072007 (2015)

** Also new preliminary results at the end of the talk **

Yields and systematics

Contribution	Electron chan.	Muon chan.	Total
Signal	52 ± 14	100 ± 28	152 ± 31
Hadrons	38 ± 26	55 ± 38	93 ± 46
Prompt photons	41 ± 5	65 ± 9	106 ± 10
Total background	79 ± 26	120 ± 39	199 ± 47
Total	131 ± 30	220 ± 48	351 ± 59
Data candidates	140	222	362

Uncertainty source	Uncertainty [%]
Background template shapes	3.7
Signal template shapes	6.6
Signal modeling	8.4
Photon modeling	8.8
Lepton modeling	2.5
Jet modeling	16.6
b -tagging	8.2
E_T^{miss} modeling	0.9
Luminosity	1.8
Background contributions	7.7



$$\sigma_{t\bar{t}\gamma}^{\text{fid}} \times \text{BR} = 63 \pm 8(\text{stat})_{-13}^{+17}(\text{syst}) \pm 1(\text{lumi}) \text{ fb per lepton flavor}$$

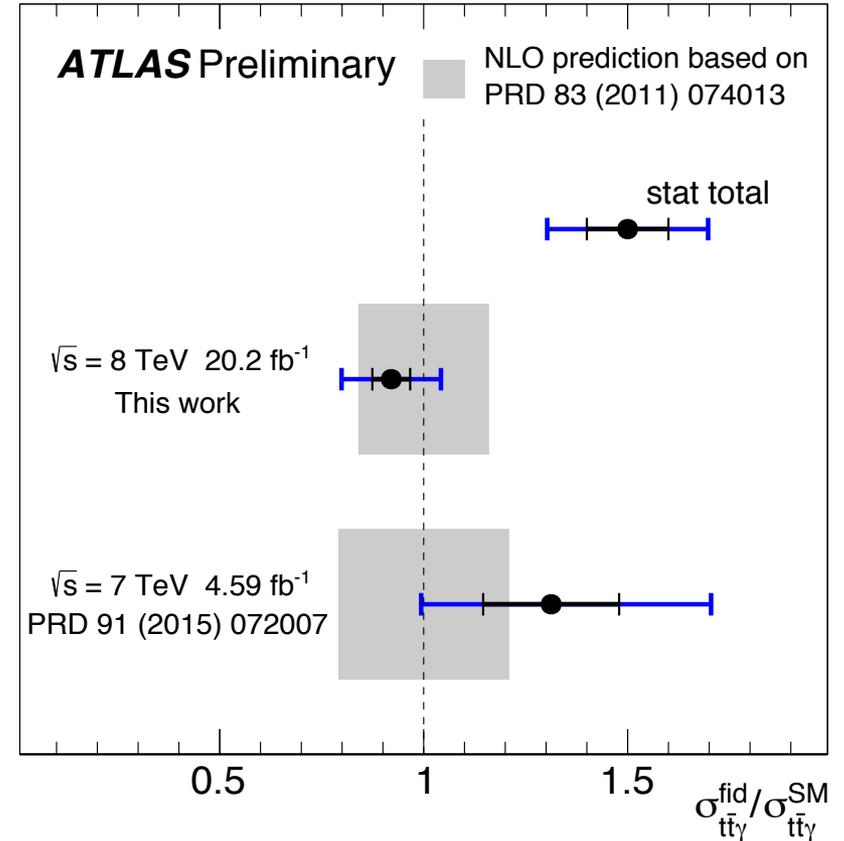
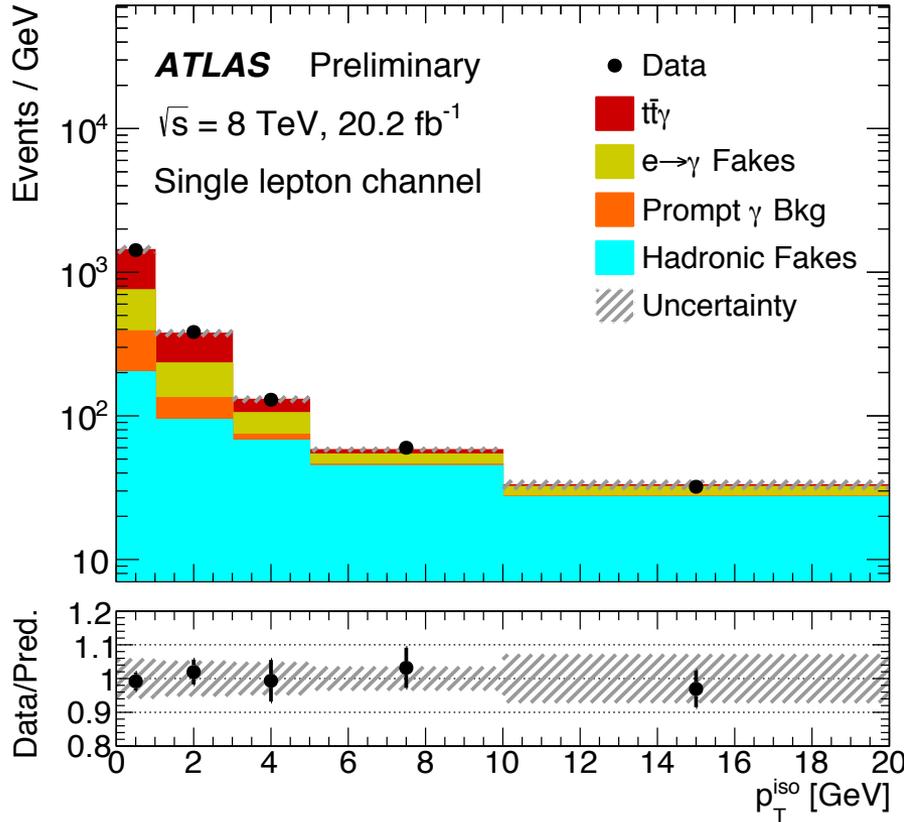
In agreement with NLO predictions: 48 ± 10 fb.

Background hypothesis excluded with 5.3σ (first observation).

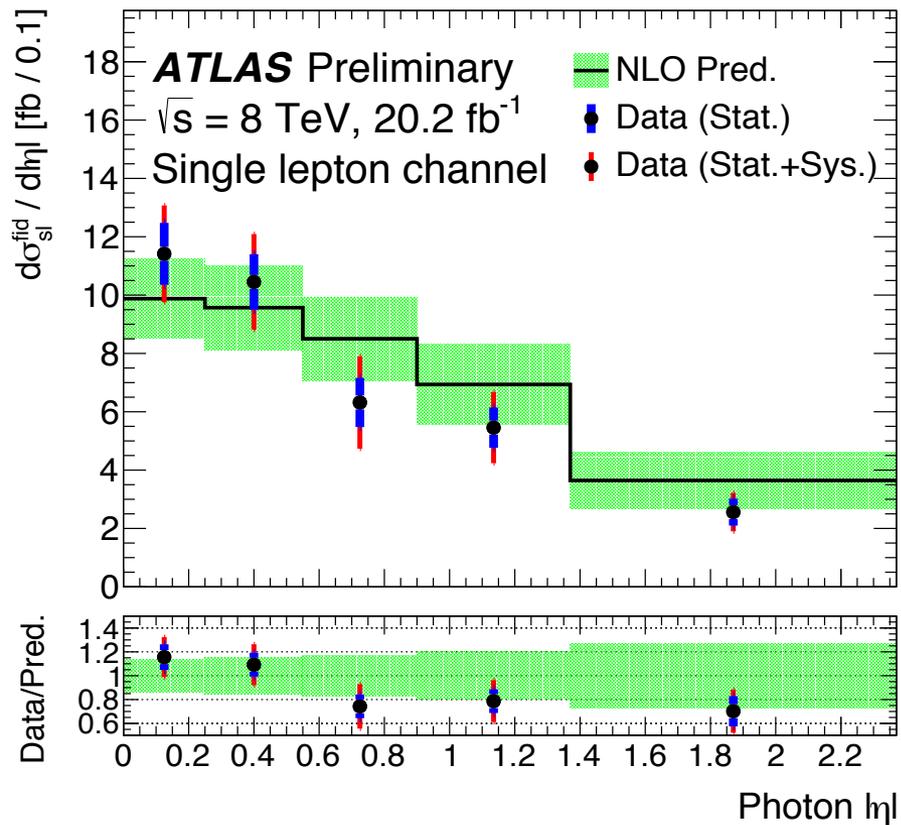
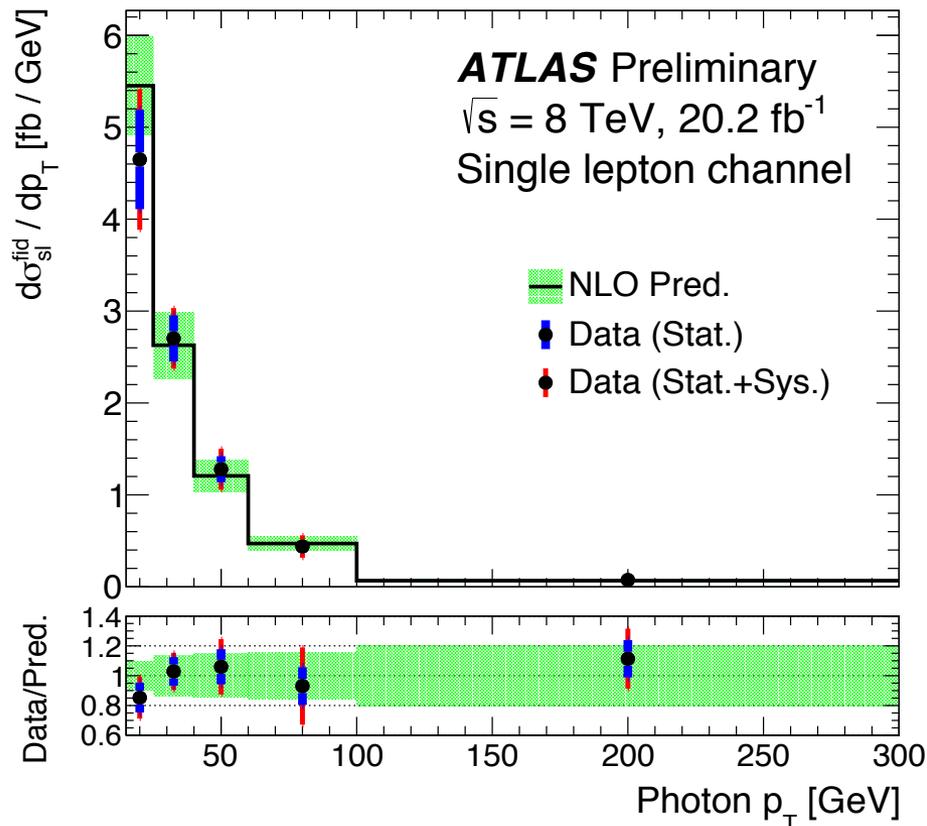
$$t\bar{t} + \gamma$$

**** New preliminary results ****
TOPQ-2015-21

Inclusive fiducial cross section measurement



Differential cross section measurement



Conclusions

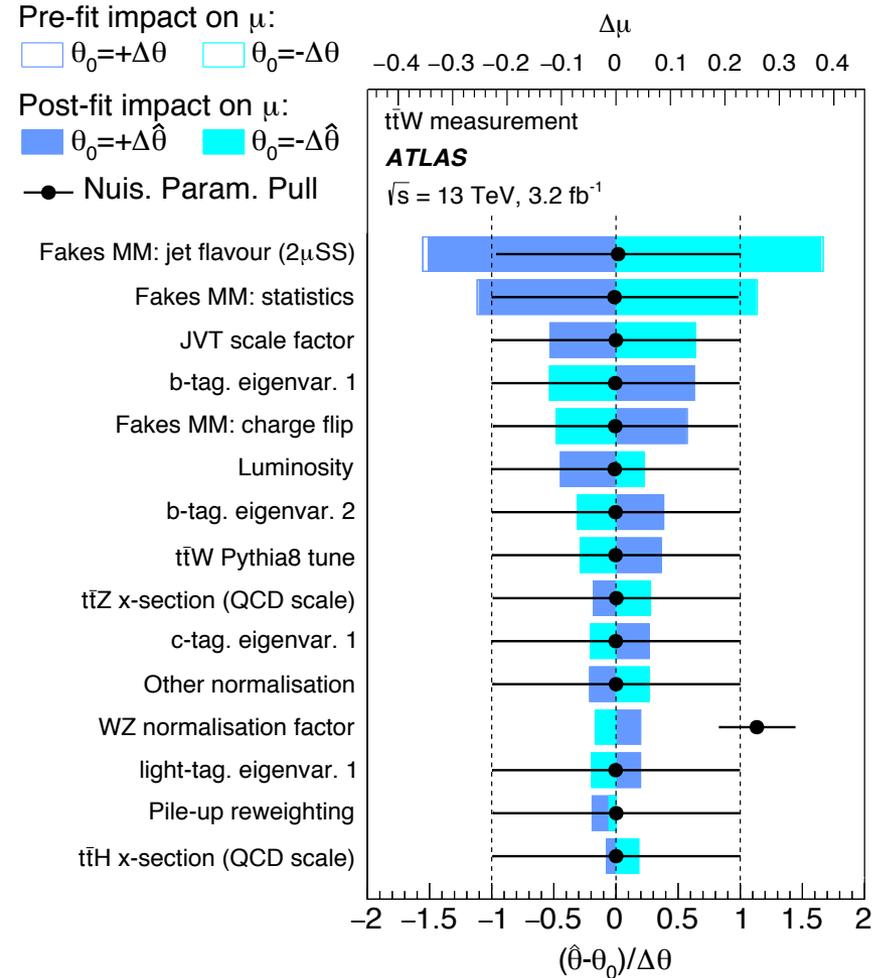
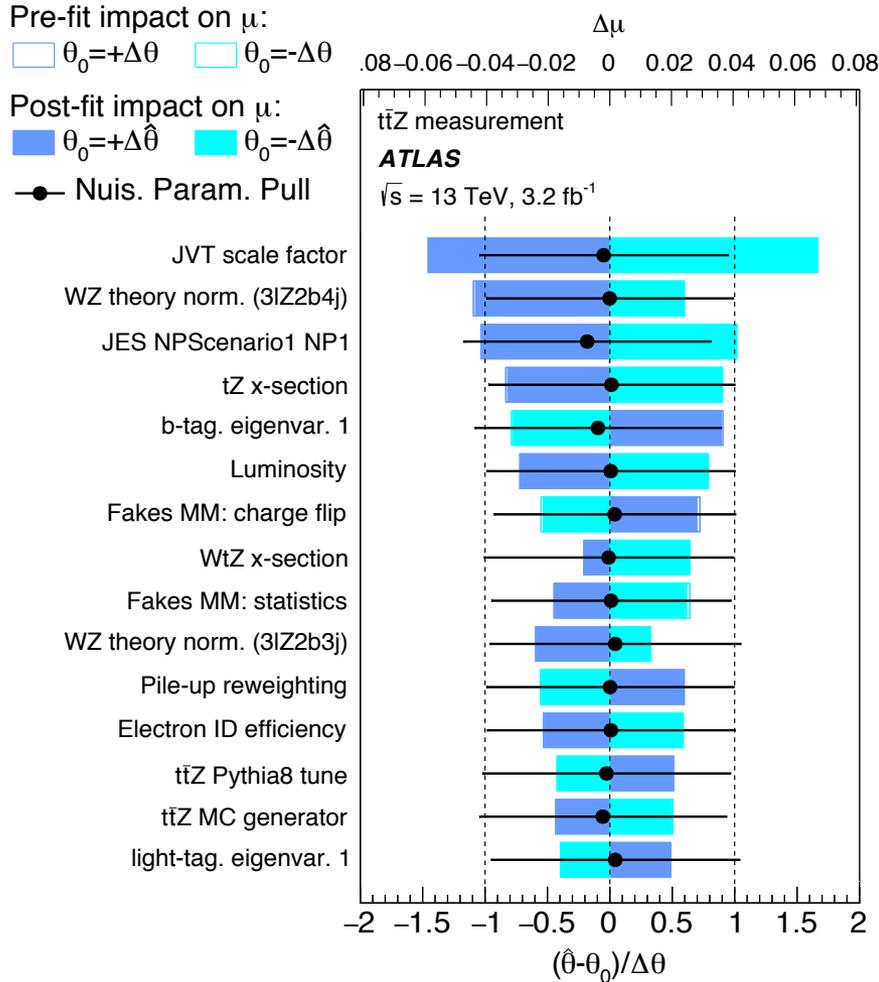
- The production of top pairs with associated bosons is a very active research field at the LHC.
- Activity mainly prompted by the strong ability to constrain EFT operators in the top sector.
- Focus towards making measurements less model dependent (using well defined fiducial volume) and stronger (unfolded differential).
- New preliminary results shown for a top quark pair + photon.
- The name of the game is precision, so this kind of physics will become more and more important in future high statistics LHC data samples.

Backup

$t\bar{t} + Z / W$ Prefit yields

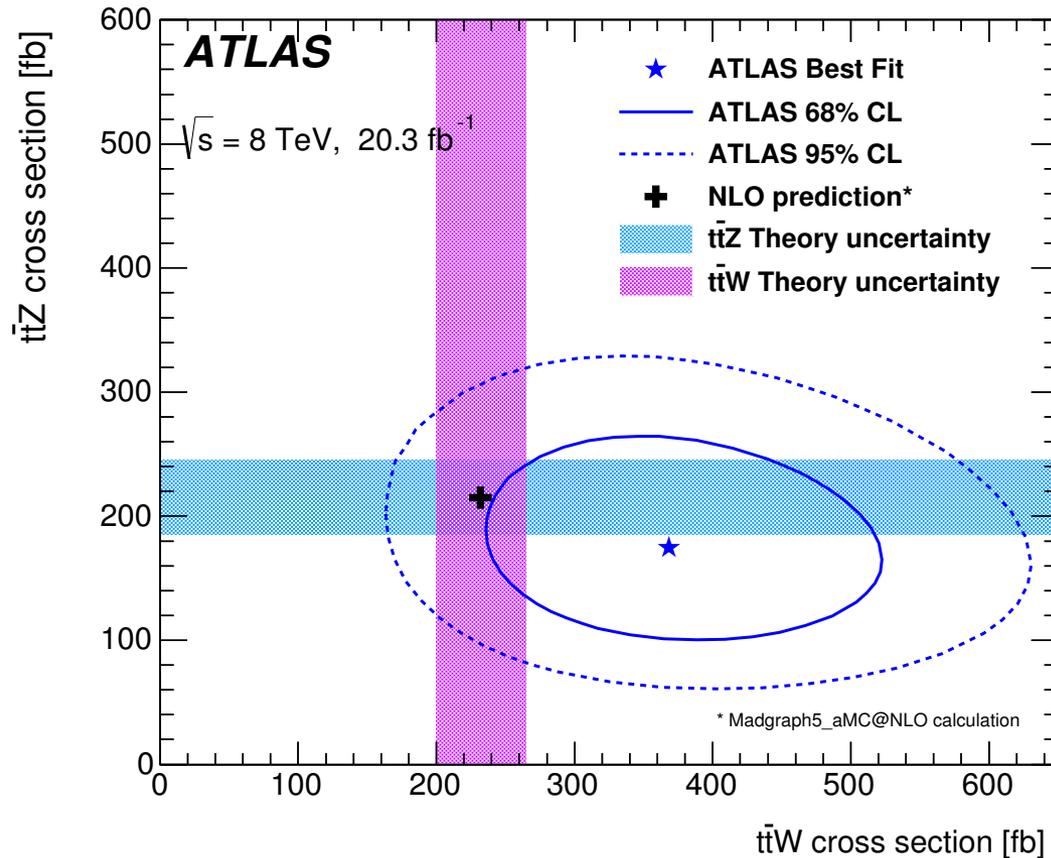
Region	$t + X$	Bosons	Fake leptons	Total bkg.	$t\bar{t}W$	$t\bar{t}Z$	Data
3 ℓ -WZ-CR	0.52 ± 0.13	26.9 ± 2.2	2.2 ± 1.8	29.5 ± 2.8	0.015 ± 0.004	0.80 ± 0.13	33
4 ℓ -ZZ-CR	< 0.001	39.5 ± 2.6	1.8 ± 0.6	41.2 ± 2.7	< 0.001	0.026 ± 0.007	39
2 μ -SS	0.94 ± 0.08	0.12 ± 0.05	1.5 ± 1.3	2.5 ± 1.3	2.32 ± 0.33	0.70 ± 0.10	9
3 ℓ -Z-2b4j	1.08 ± 0.25	0.5 ± 0.4	< 0.001	1.6 ± 0.5	0.065 ± 0.013	5.5 ± 0.7	8
3 ℓ -Z-1b4j	1.14 ± 0.24	3.3 ± 2.2	2.2 ± 1.7	6.7 ± 2.8	0.036 ± 0.011	4.3 ± 0.6	7
3 ℓ -Z-2b3j	0.58 ± 0.19	0.22 ± 0.18	< 0.001	0.80 ± 0.26	0.083 ± 0.014	1.93 ± 0.28	4
3 ℓ -noZ-2b	0.95 ± 0.11	0.14 ± 0.12	3.6 ± 2.2	4.7 ± 2.2	1.59 ± 0.28	1.45 ± 0.20	10
4 ℓ -SF-1b	0.212 ± 0.032	0.09 ± 0.07	0.113 ± 0.022	0.42 ± 0.08	< 0.001	0.66 ± 0.09	1
4 ℓ -SF-2b	0.121 ± 0.021	0.07 ± 0.06	0.062 ± 0.012	0.25 ± 0.07	< 0.001	0.63 ± 0.09	1
4 ℓ -DF-1b	0.25 ± 0.04	0.0131 ± 0.0032	0.114 ± 0.019	0.37 ± 0.04	< 0.001	0.75 ± 0.10	2
4 ℓ -DF-2b	0.16 ± 0.05	< 0.001	0.063 ± 0.013	0.23 ± 0.05	< 0.001	0.64 ± 0.09	1

$t\bar{t} + Z / W$ Detailed systematics



$t\bar{t} + Z / W$ Previous 8 TeV results

JHEP11 (2015) 172



$t\bar{t} + \gamma$ Template shapes

TOPQ-2015-21

