Measurement of $tt\gamma$ production in the $e+\mu$ final state at 13 TeV with the ATLAS detector

ATLAS-CONF-2019-042

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on behalf of the ATLAS Collaboration

12th International Workshop on Top Quark Physics, Beijing

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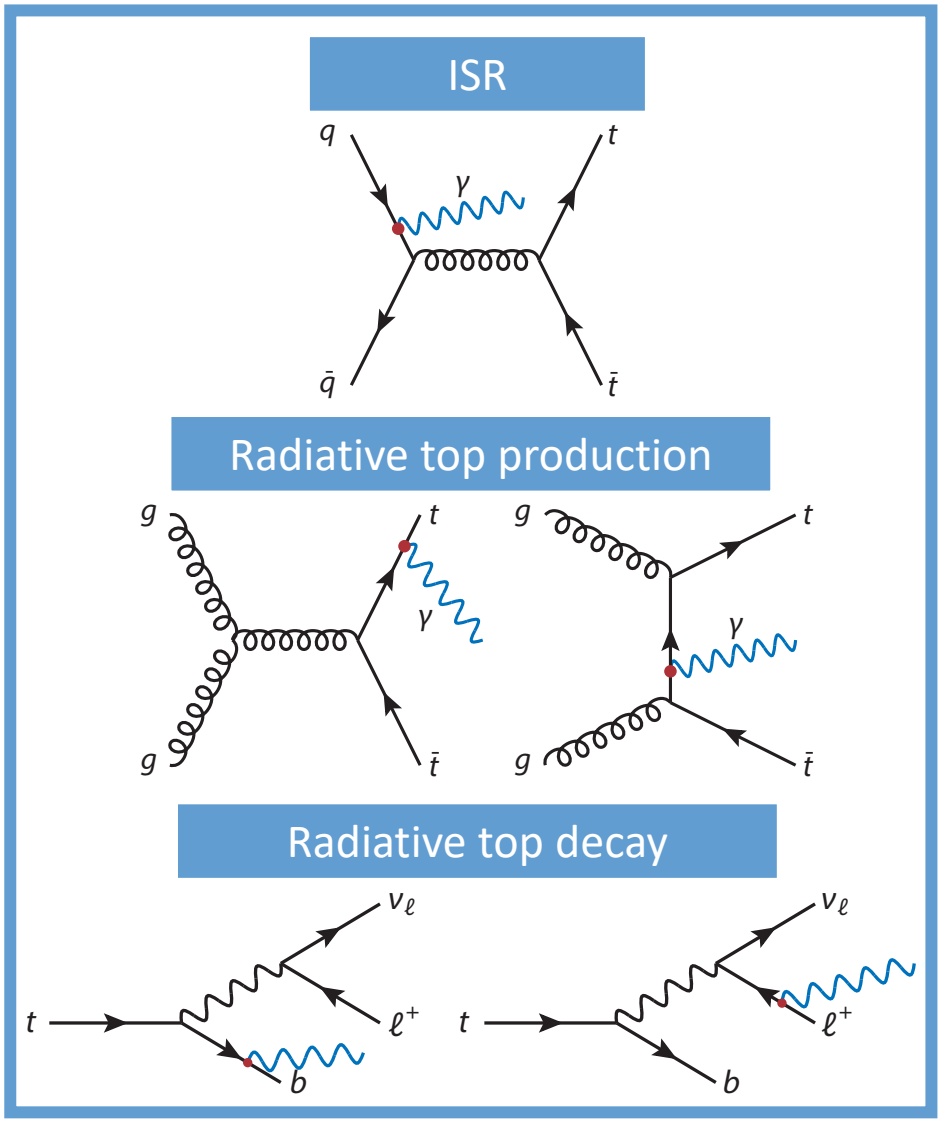
ATLAS EXPERIMENT

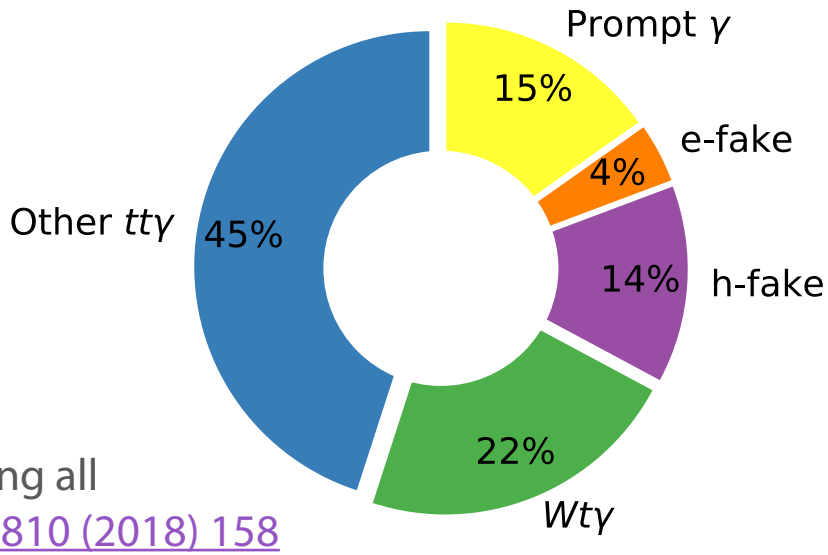
GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Why measure *tty*?

- Photons from various sources
- If from top: probing the *tγ* EM coupling (→ top-quark charge)
- Initiated through gg fusion or $q\bar{q}$ annihilation → charge asymmetry enhanced w.r.t. $t\bar{t}$
- Interpreted in EFT, coupling sensitive to many BSM theories → possibility to constrain Wilson coefficients (e.g. for operators $O_{uB\phi}^{33}$ and O_{uW}^{33})



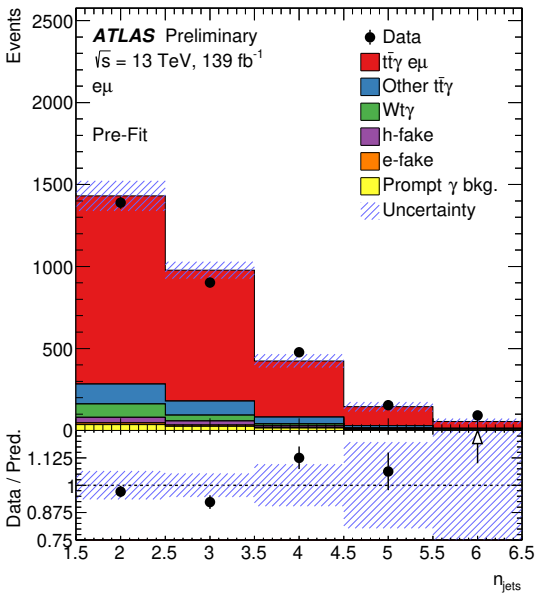
Analysis prerequisites

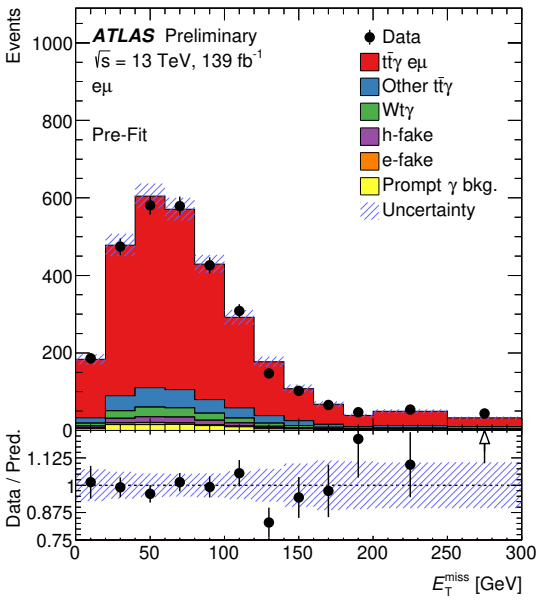


- Analysis of full Run 2 data, 139/fb
- Focus on the *e*+*μ* final state:
  - Clean channel with S : B at about 4 : 1
  - Full fixed-order NLO calculation including all off-shell contributions available: JHEP 1810 (2018) 158
- Signal only direct *e*+*μ* decays → via tau decay etc. treated as *"Other ttγ"*
- Major background processes:
  - For preliminary results: *Wtγ* (however, included in NLO calculation)
  - h-fake photons: (1) hadr. activity faking photons, (2) non-prompt photons (π^0)
  - e-fake photons: electrons faking photons
  - Background processes with prompt photons (e.g. *VVγ*, *Zγ*+jets)
  - Fake-lepton background: included in other categories

Event selection

	e+μ signal region
Trigger	Single-*e*/single-*μ* trigger
Leptons	1 electron, p_T > 25 GeV
	1 muon, p_T > 25 GeV
	opposite sign
	M_{ll} > 15 GeV
Jets	2 or more (*R*=0.4)
b-tags	1 or more (85% efficiency)
Photons	1 photon, p_T > 20 GeV





Major uncertainties considered:

- *ttγ*/*Wtγ* modelling uncertainties: alternative showering, μ_R/μ_F scale, ISR/FSR variation
- Conservative rate uncertainty of 50% for categories: h-fake, e-fake and prompt *γ* bkg.
- ATLAS luminosity uncertainty of ±1.7%

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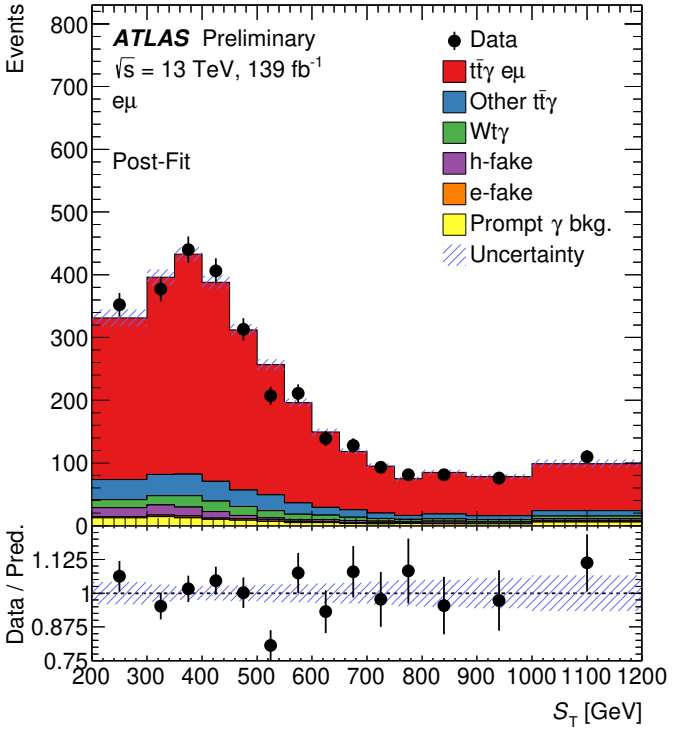
Fiducial measurement

- Inclusive cross-section measured in fiducial phase-space volume → aligned with NLO theory calculation
- Collaboration with M. Worek et al.
- Binned profile likelihood fit of S_T (scalar sum of all transv. momenta, incl. E_T^{miss})
- Measured fiducial cross-section:
  $44.2 \pm 0.9\ (\text{stat.})\ ^{+2.6}_{-2.4}\ (\text{syst.})$ fb
  corresponding to 6.0% rel. uncertainty
- Dedicated theory calculation (with *Wty*):
  $39.50^{+0.56}_{-2.18}\ (\text{scale})\ ^{+1.04}_{-1.18}\ (\text{PDF})$ fb

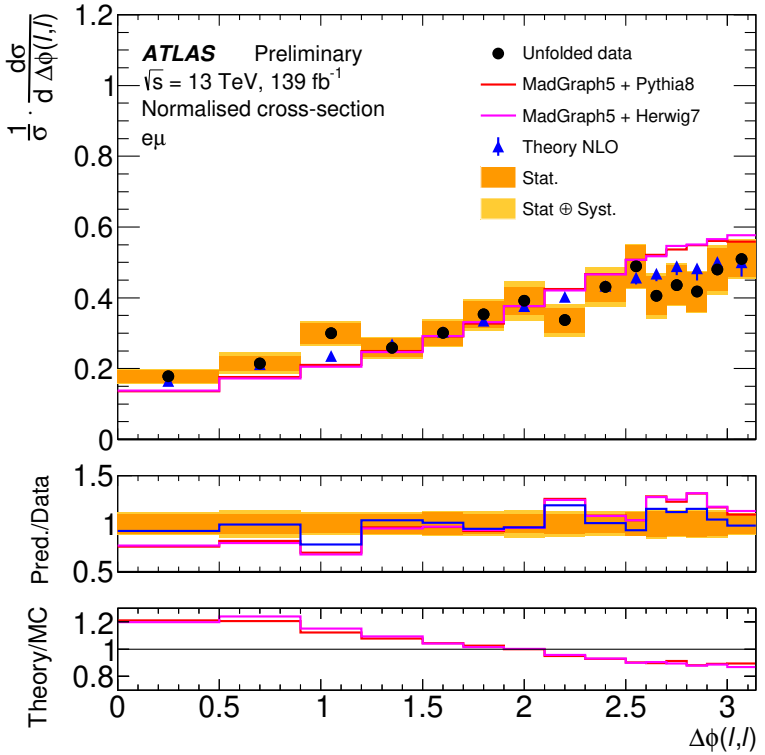


Category	Uncertainty
Signal modelling	3.4%
Background modelling	2.2%
Photons	2.0%
Luminosity	1.9%
Jets	1.8%
Flavour-tagging	1.1%
MC statistics	0.5%
Others	1.7%
Total syst.	5.5%

Summary & Outlook

- Dedicated measurement of *ttγ* in *e+μ* final state with full Run 2 ATLAS data
- Fiducial inclusive cross-section:
  - Measured with 6.0% precision
  - Dominated by signal & bkg. modelling, photon and luminosity uncertainties
  - Fixed-order NLO slightly below, but compatible with data
- Differential measurements:
  - Unfolded ATLAS data to parton level
  - Direct rate/shape comparison with NLO
  - More details: Friday's plenary talk by Y. Li
- Reference: ATLAS-CONF-2019-042

Preview of Friday's talk



	χ^2/ndf	p-value
MG5 + Pythia8	35.2/14	< 0.01
MG5 + Herwig7	36.8/14	< 0.01
Fixed-order NLO	12.0/14	0.61

Backup

Generalised *tty* interaction

- As taken from Nucl.Phys. B812 (2009) 181-204

$$\mathcal{L}_{\gamma tt} = -eQ_t\bar{t}\,\gamma^\mu t\;A_\mu - e\bar{t}\,\frac{i\sigma^{\mu\nu}q_\nu}{m_t}\left(d_V^\gamma + id_A^\gamma\gamma_5\right)t\;A_\mu$$

$$\delta d_V^\gamma = \frac{\sqrt{2}}{e}\,\mathrm{Re}\left[c_W C_{uB\phi}^{33} + s_W C_{uW}^{33}\right]\frac{vm_t}{\Lambda^2}$$

$$\delta d_A^\gamma = \frac{\sqrt{2}}{e}\,\mathrm{Im}\left[c_W C_{uB\phi}^{33} + s_W C_{uW}^{33}\right]\frac{vm_t}{\Lambda^2}$$

$$O_{uB\phi}^{ij} = (\bar{q}_{Li}\sigma^{\mu\nu}u_{Rj})\tilde{\phi}\,B_{\mu\nu}$$

$$O_{uW}^{ij} = (\bar{q}_{Li}\sigma^{\mu\nu}\tau^I u_{Rj})\tilde{\phi}\,W_{\mu\nu}^I$$

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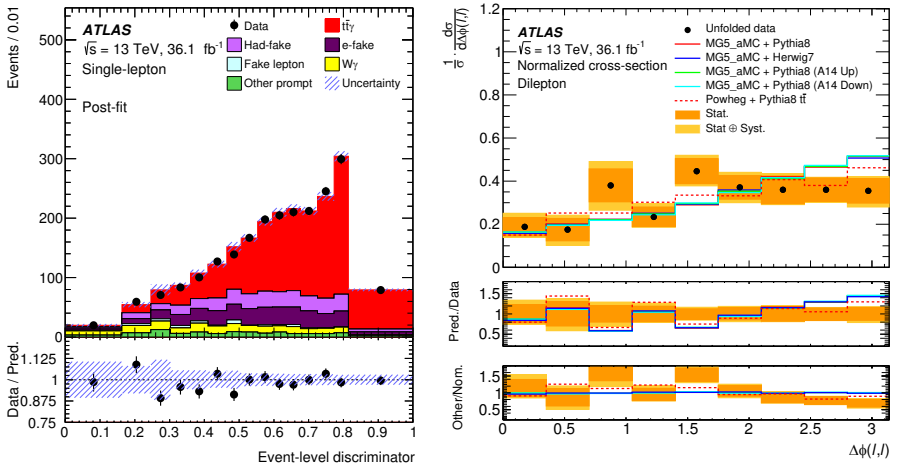
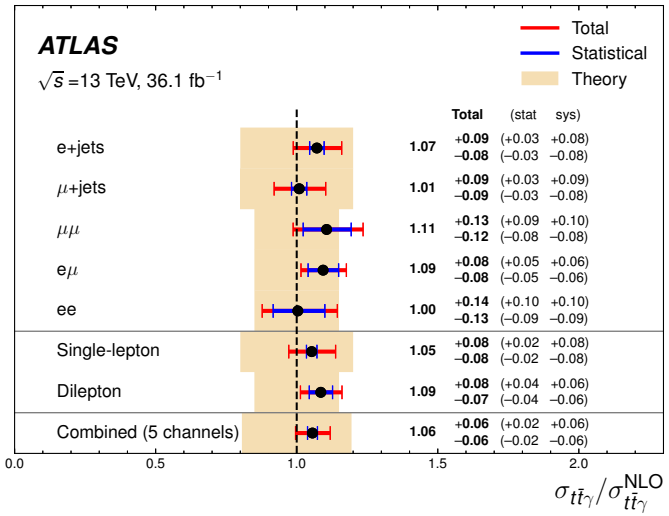
Previous results at 13 TeV

- 2015/16 data, approx. 36.1/fb
- Eur. Phys. J. C 79 (2019) 382
- Combination of single-lepton and dilepton channels
- Inclusive and differential cross-sections (unfolded to particle level)
- Multiple neural nets used:
  - Prompt/fake discrimination
  - S/B separation in both single-lepton and dilepton channels



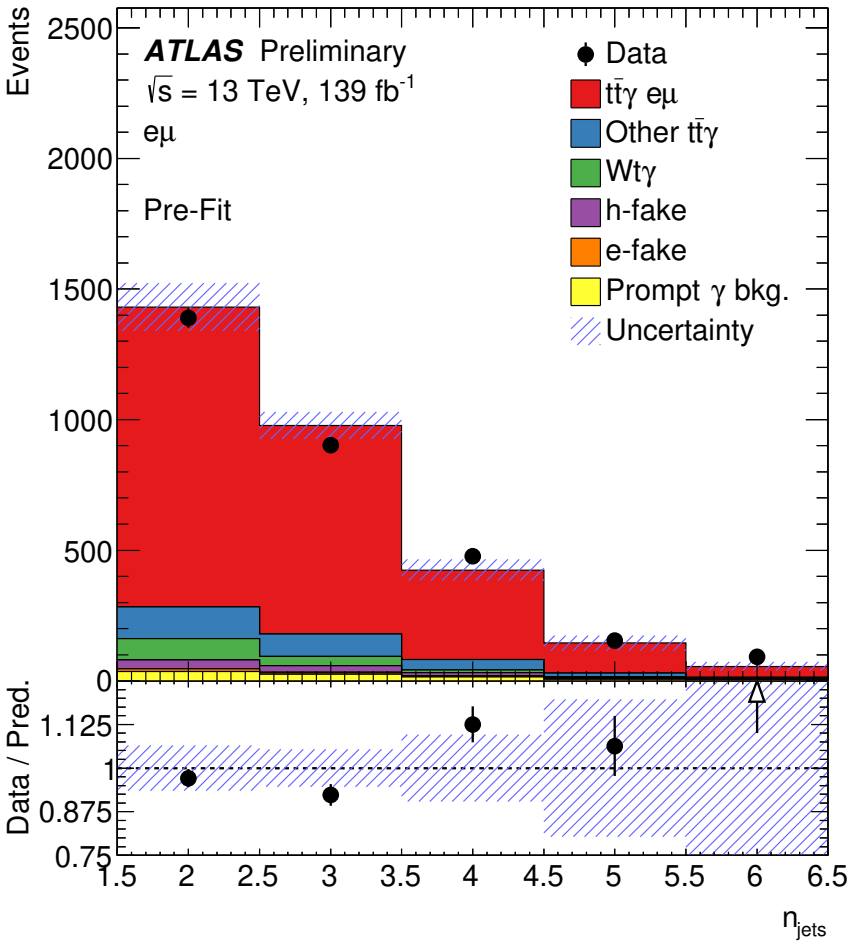


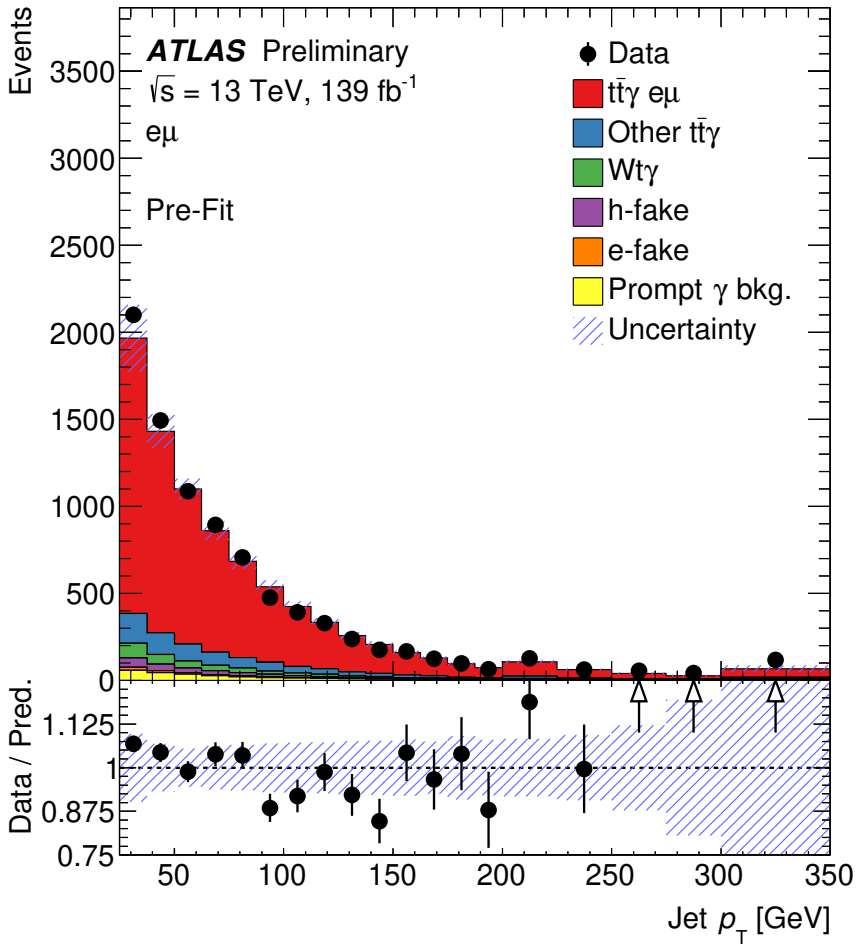
Pre-fit event yields

Table 1: The data and expected event yields before the likelihood fit for the signal and background processes after the full selection for the different data-taking periods and the full data set. All categories are estimated based on MC simulation including correction factors for detector effects as described in Section 6. The quoted uncertainties correspond to the total statistical and systematic uncertainties (cf. Section 6) added in quadrature.

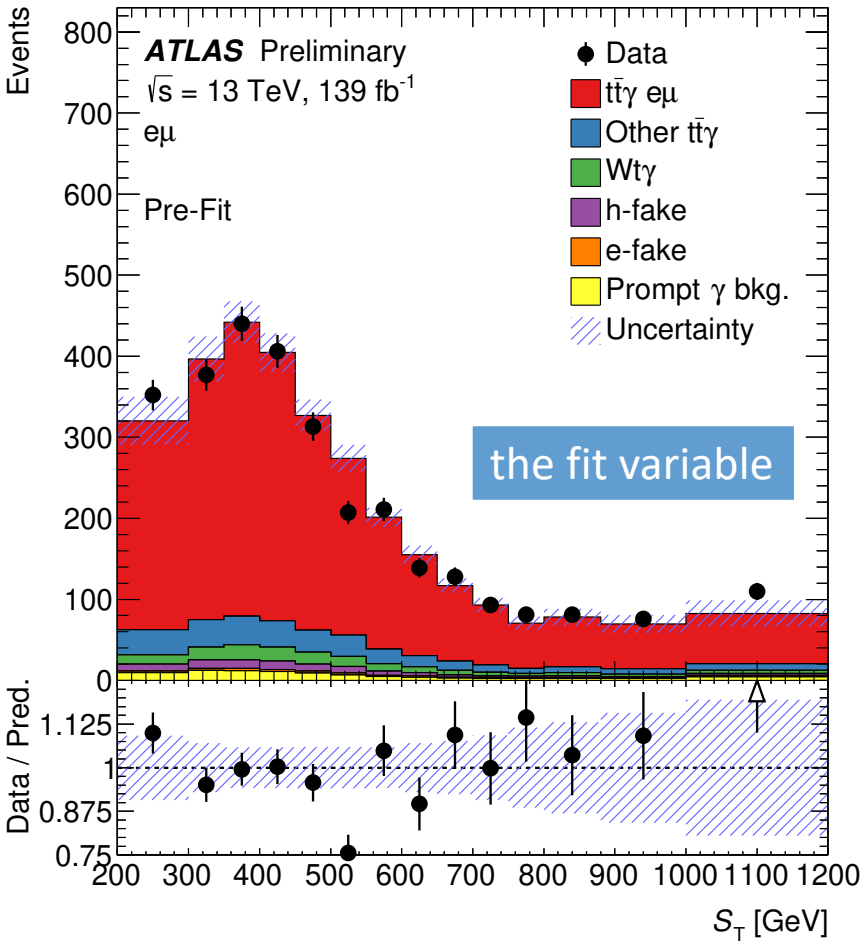
	2015/16	2017	2018	full data set
$t\bar{t}\gamma$ $e\mu$	682 ± 33	760 ± 40	1010 ± 50	2450 ± 120
Other $t\bar{t}\gamma$	75 ± 4	82 ± 5	110 ± 6	266 ± 13
$Wt\gamma$	37 ± 6	41 ± 7	54 ± 9	131 ± 22
h-fake	23 ± 12	23 ± 12	32 ± 16	80 ± 40
e-fake	6 ± 3	7 ± 4	11 ± 6	24 ± 12
Prompt γ bkg.	19 ± 10	30 ± 15	38 ± 19	90 ± 40
Total	840 ± 40	940 ± 50	1250 ± 60	3030 ± 150
Data	809	958	1247	3014

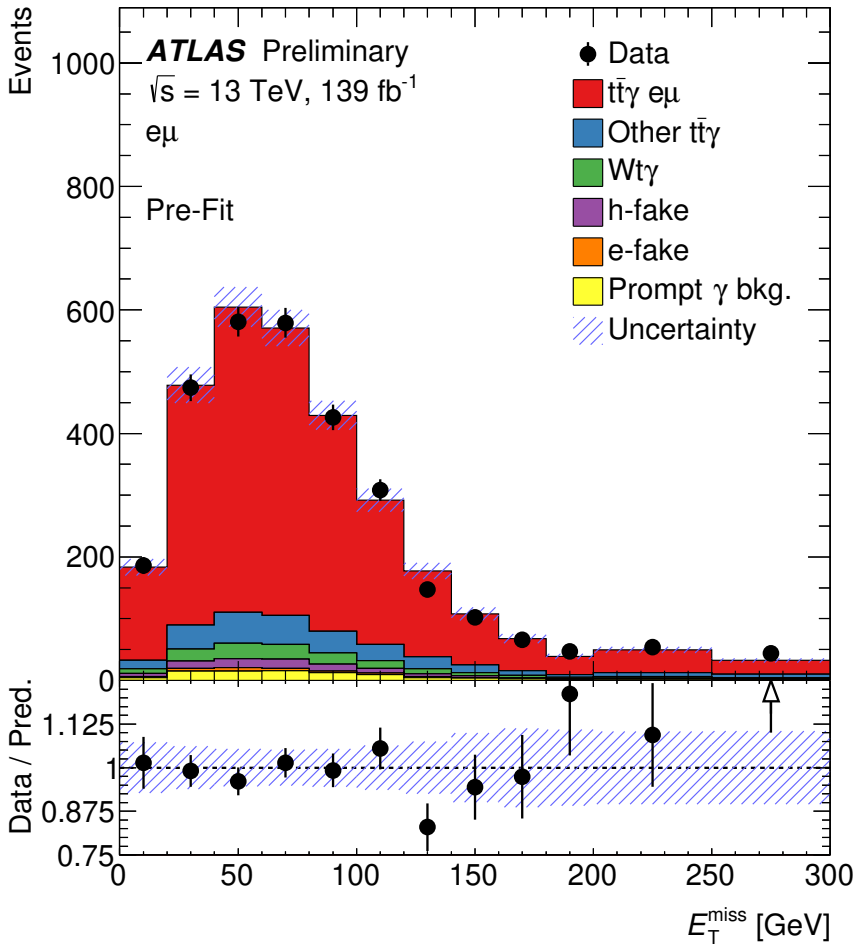
Data/MC control plots (1)



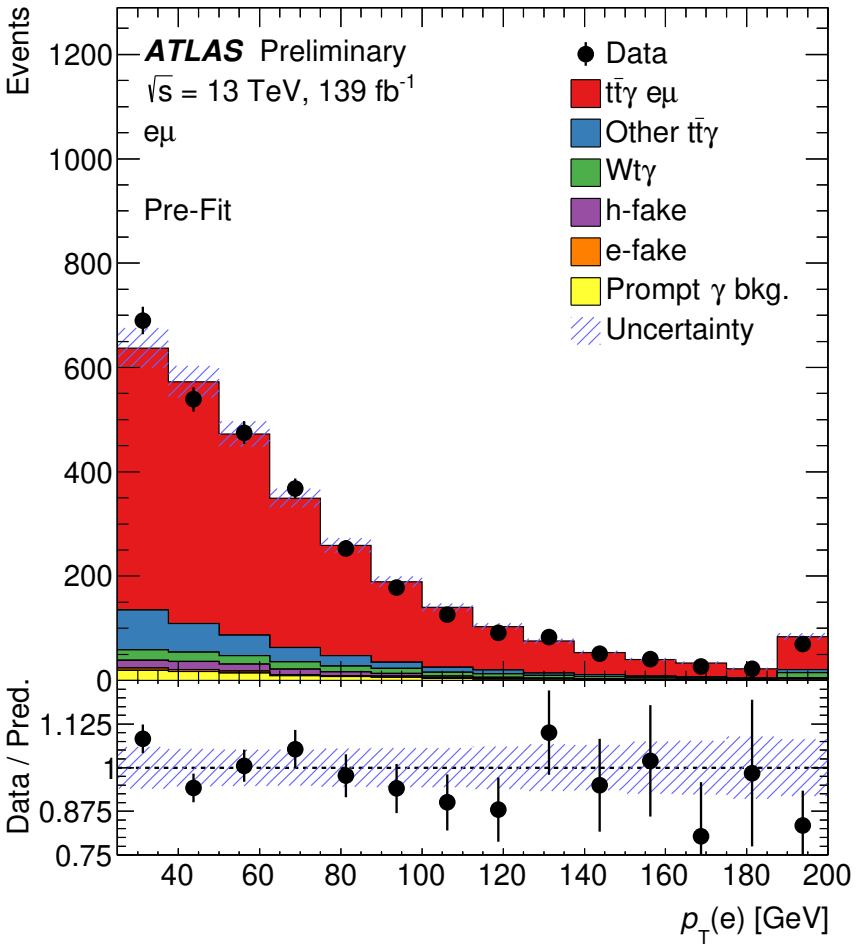


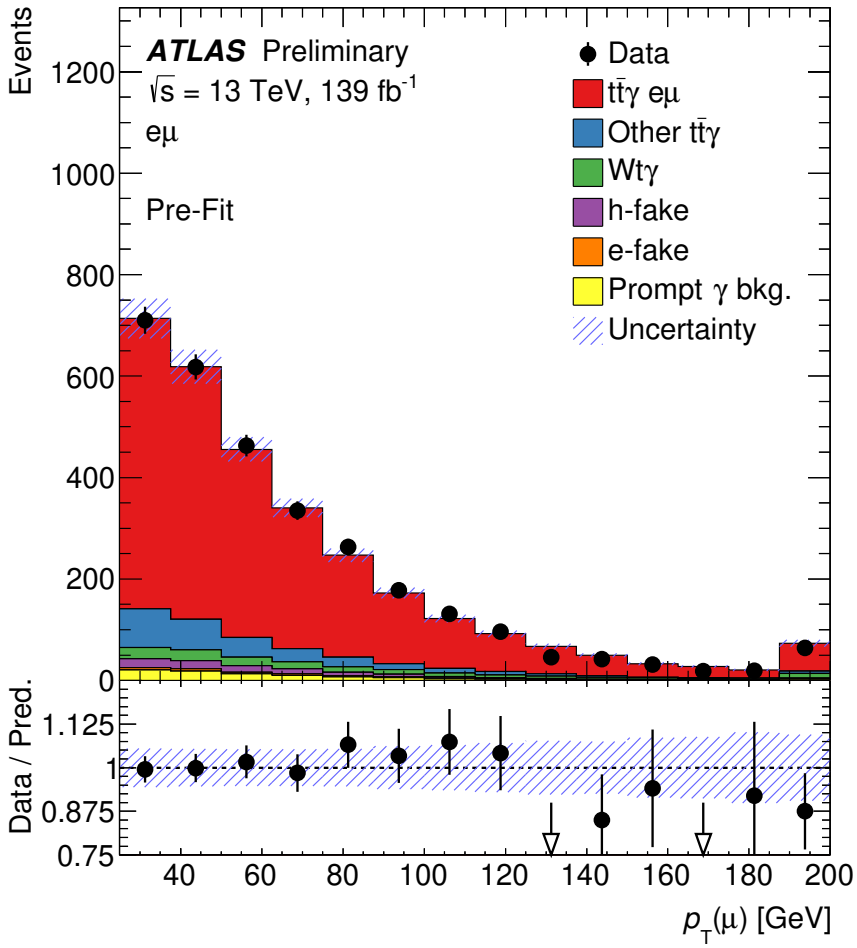
Data/MC control plots (2)



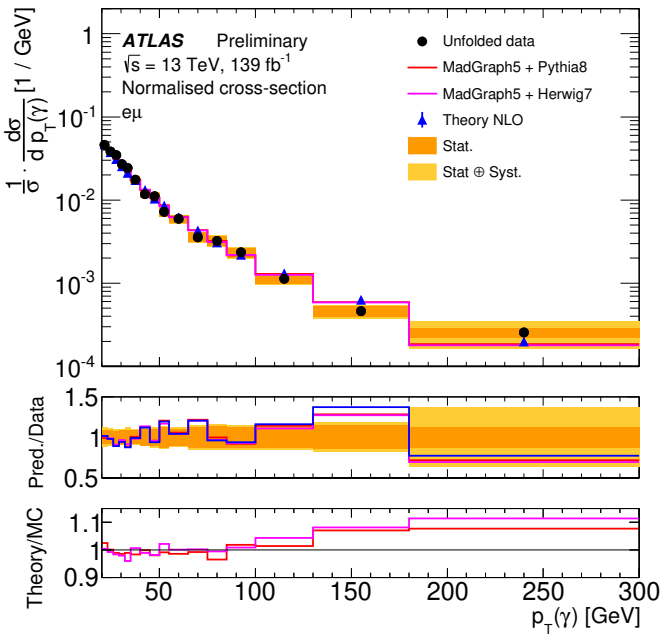


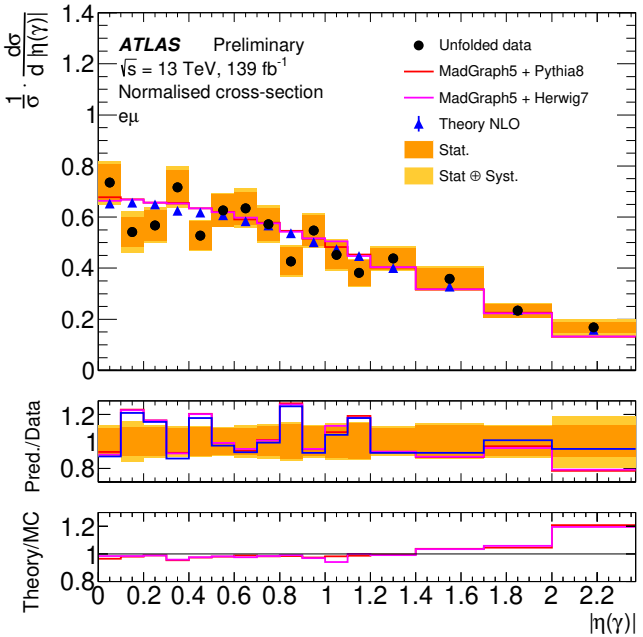
Data/MC control plots (3)

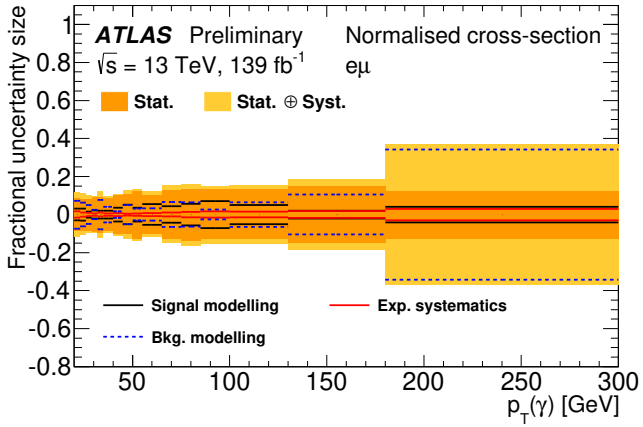


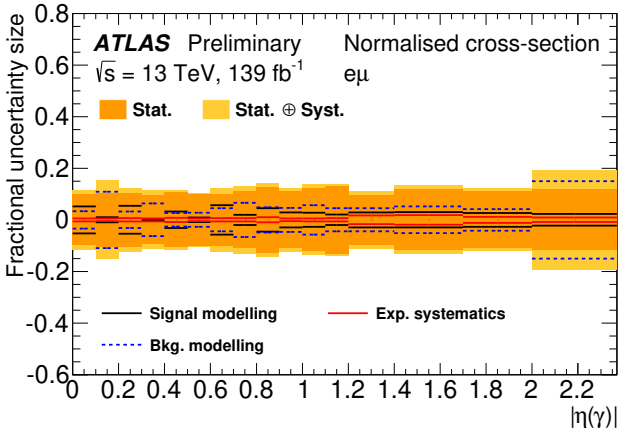


Photon kinematics (normalised)

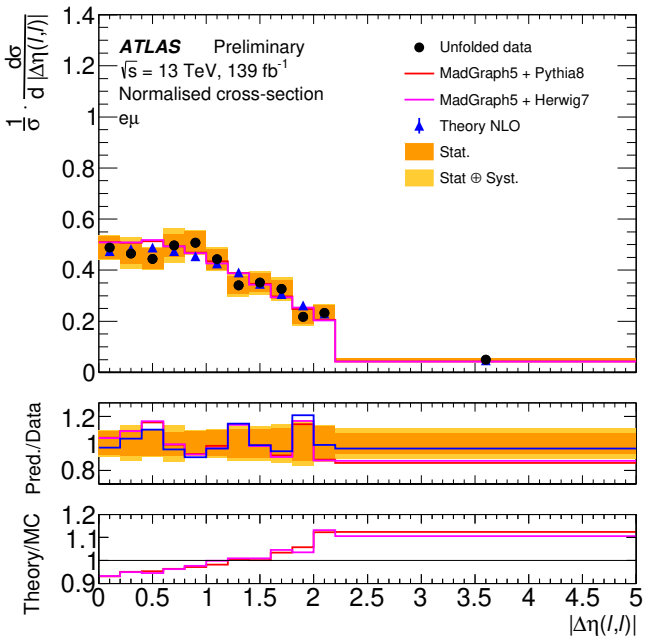


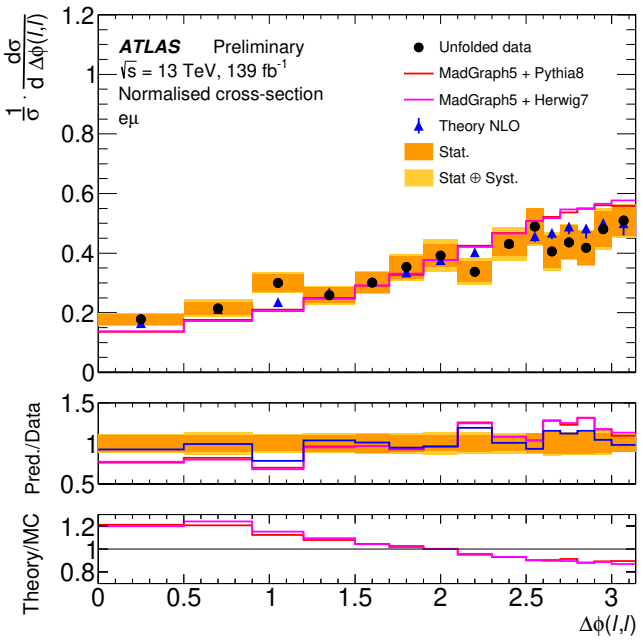


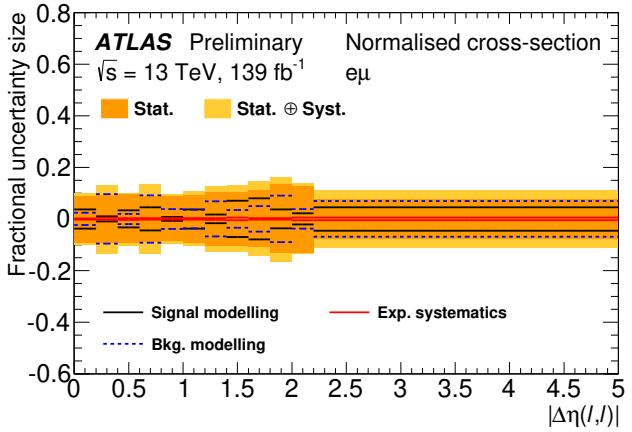


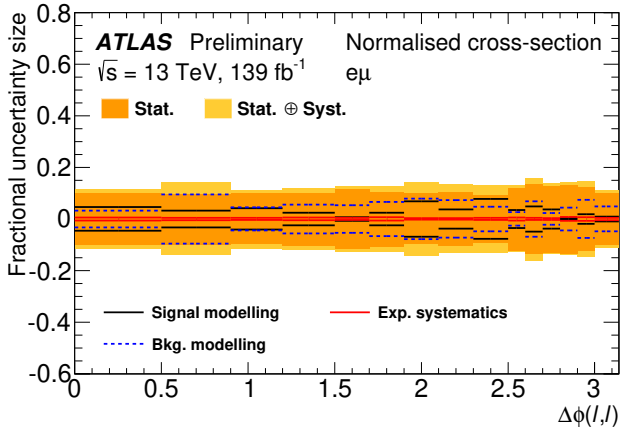


Lepton kinematics (normalised)

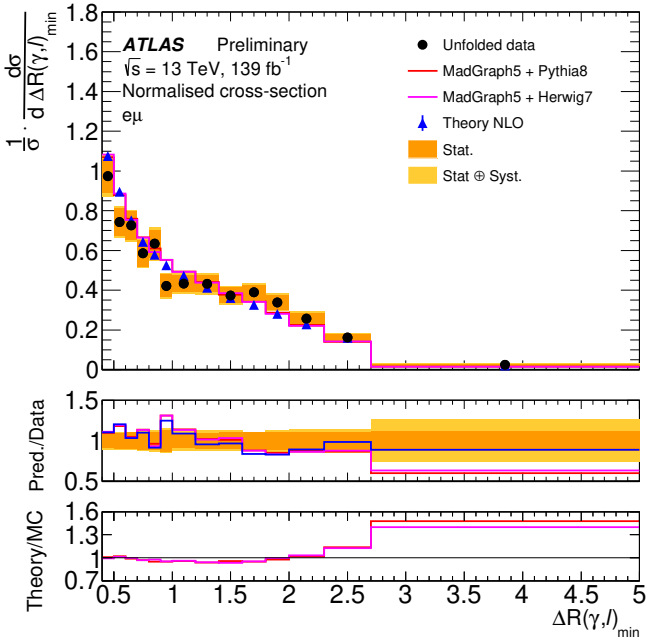


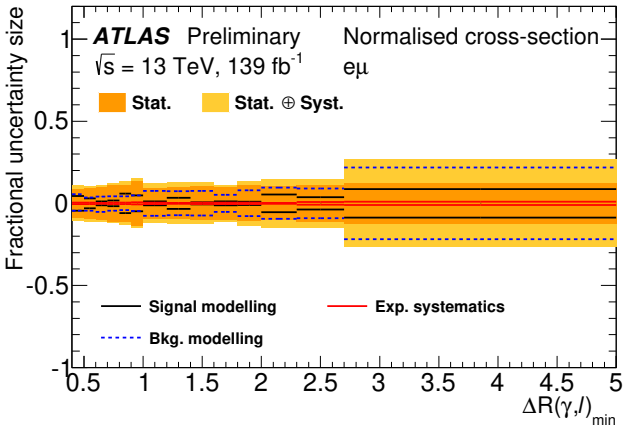




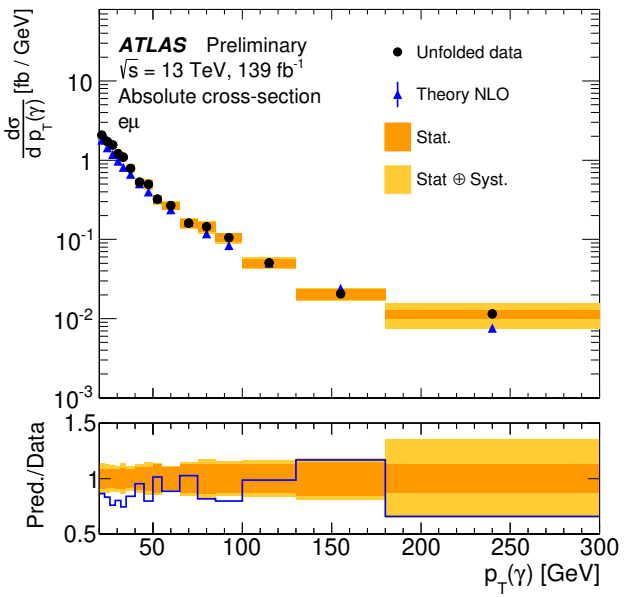


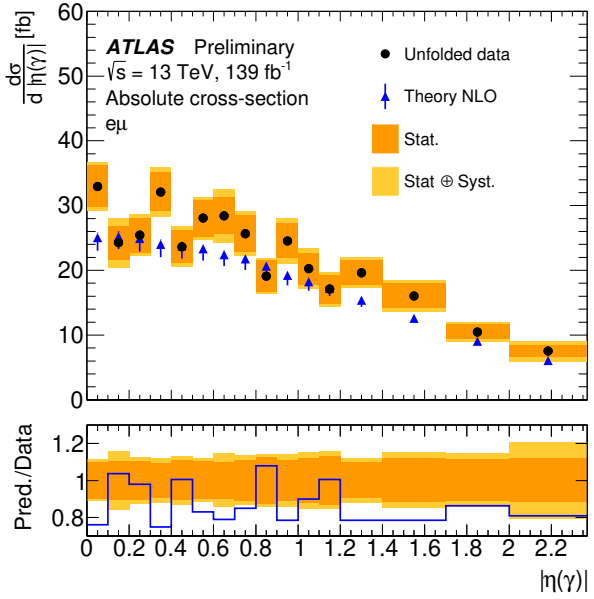
ΔR(l, γ) (normalised)

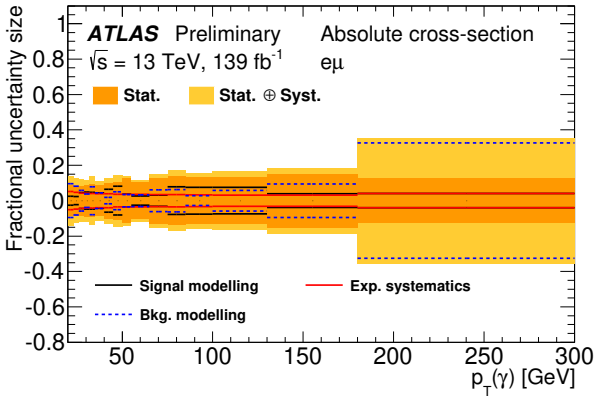


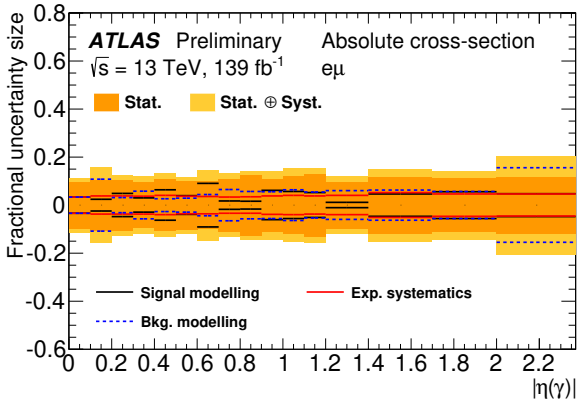


Photon kinematics (absolute)

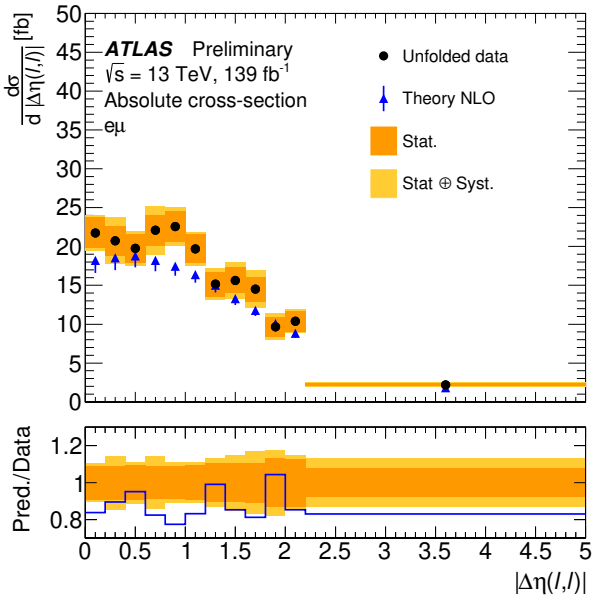


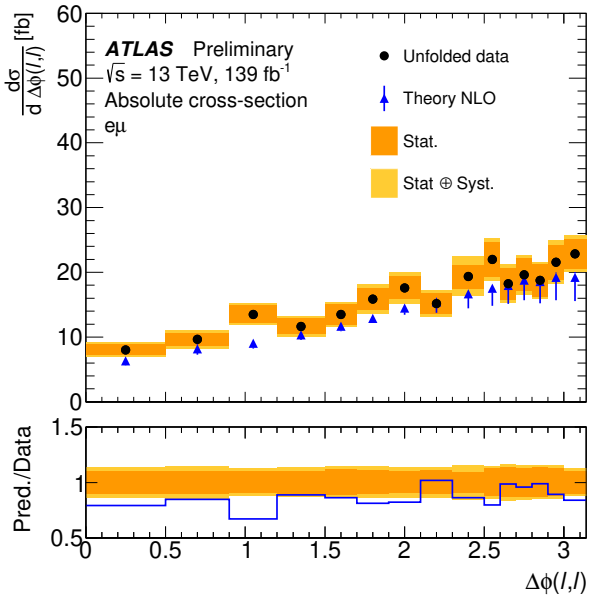


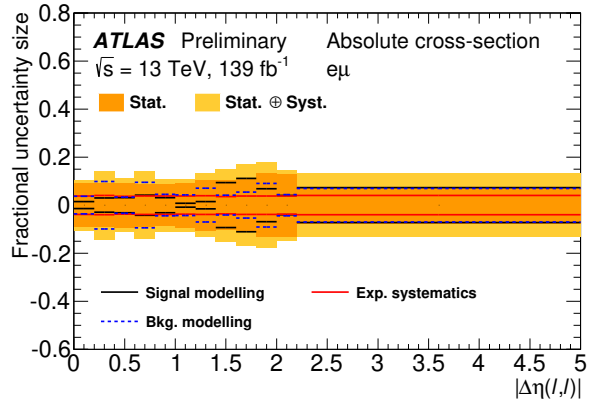


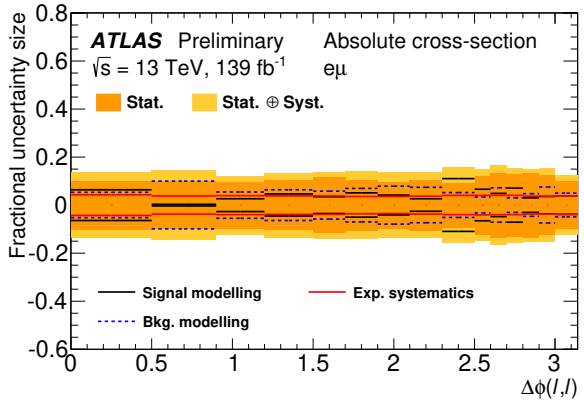


Lepton kinematics (absolute)

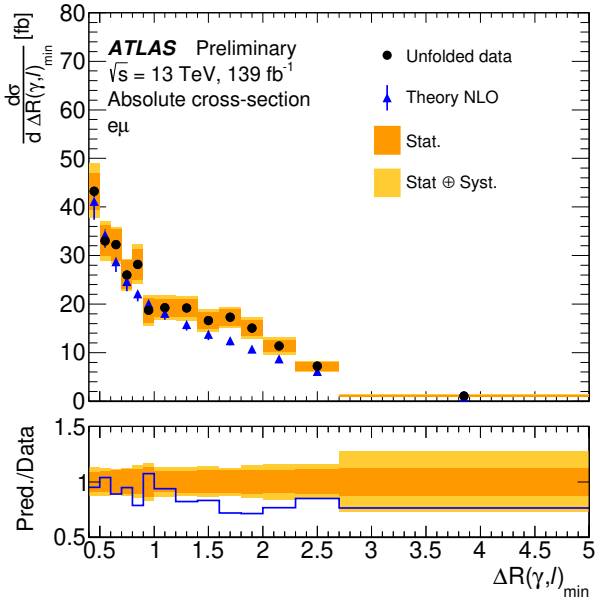


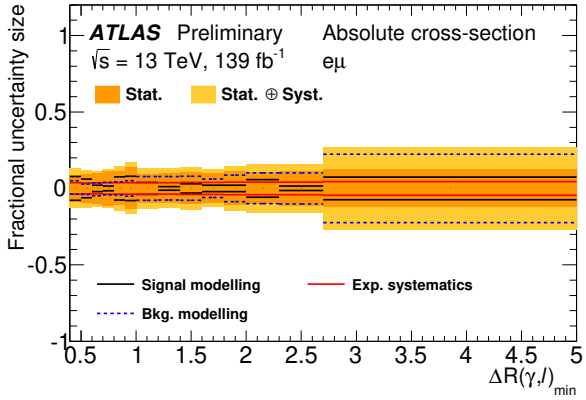






ΔR(l, γ) (absolute)





χ^2/ndf and p-values

Table 3: χ^2/ndf and p-values between the measured normalised cross-sections and various predictions from the MC simulation and the NLO calculation.

Predictions	$p_T(\gamma)$		$\lvert\eta(\gamma)\rvert$		$\Delta R(\gamma,\ell)_{\min}$		$\lvert\Delta\eta(\ell,\ell)\rvert$		$\Delta\phi(\ell,\ell)$	
	χ^2/ndf	p-value	χ^2/ndf	p-value	χ^2/ndf	p-value	χ^2/ndf	p-value	χ^2/ndf	p-value
MadGraph+Pythia8	14.0/15	0.53	20.7/15	0.15	17.3/13	0.19	8.3/11	0.69	35.2/14	<0.01
MadGraph+Herwig7	11.9/15	0.69	20.8/15	0.14	18.5/13	0.14	9.4/11	0.59	36.8/14	<0.01
Theory NLO	16.9/15	0.32	20.1/15	0.17	14.7/13	0.33	7.2/11	0.78	12.0/14	0.61

Table 4: χ^2/ndf and p-values between the measured absolute cross-sections and the NLO calculation.

Predictions	$p_T(\gamma)$		$\lvert\eta(\gamma)\rvert$		$\Delta R(\gamma,\ell)_{\min}$		$\lvert\Delta\eta(\ell,\ell)\rvert$		$\Delta\phi(\ell,\ell)$	
	χ^2/ndf	p-value	χ^2/ndf	p-value	χ^2/ndf	p-value	χ^2/ndf	p-value	χ^2/ndf	p-value
Theory NLO	16.0/16	0.45	20.7/16	0.19	12.8/14	0.54	11.4/12	0.49	16.3/15	0.36

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