Recent highlights of top-quark physics with the ATLAS Experiment

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on behalf of the ATLAS collaboration

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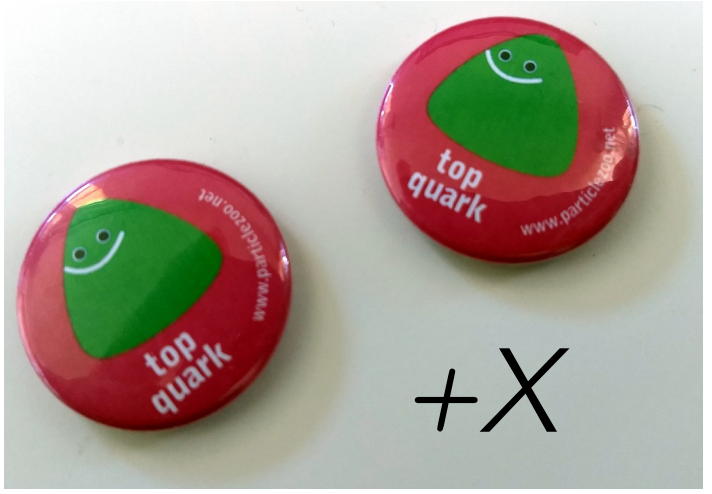


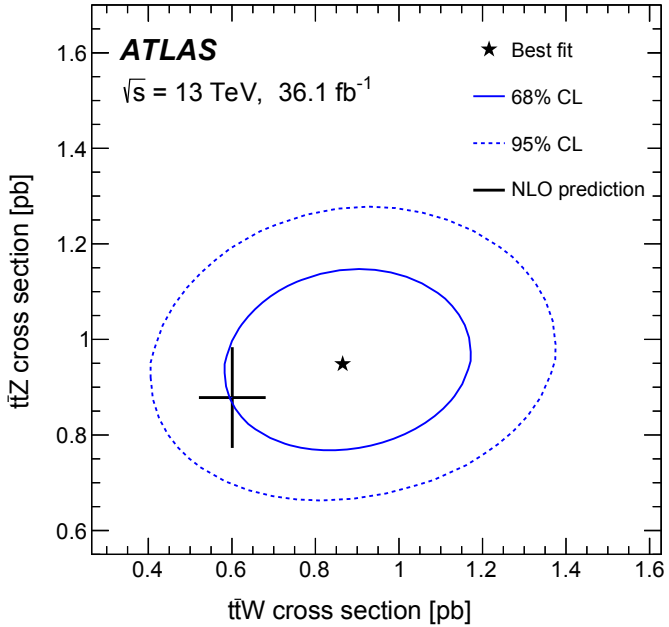
Overview

I Recap *on $t\bar{t}X$ analysis at* 36.1fb^{-1}
- $t\bar{t}Z$ *(+* $t\bar{t}W$*) inclusive cross-section*
- $t\bar{t}t\bar{t}$ upper limit on cross-section in 1L and 2OSL final states

II Brand new $t\bar{t}X$ results 139fb^{-1}
- $t\bar{t}\gamma$ inclusive and differential cross-section in $e\mu$ final
- $t\bar{t}t\bar{t}$ evidence in 2SSL and ML final states

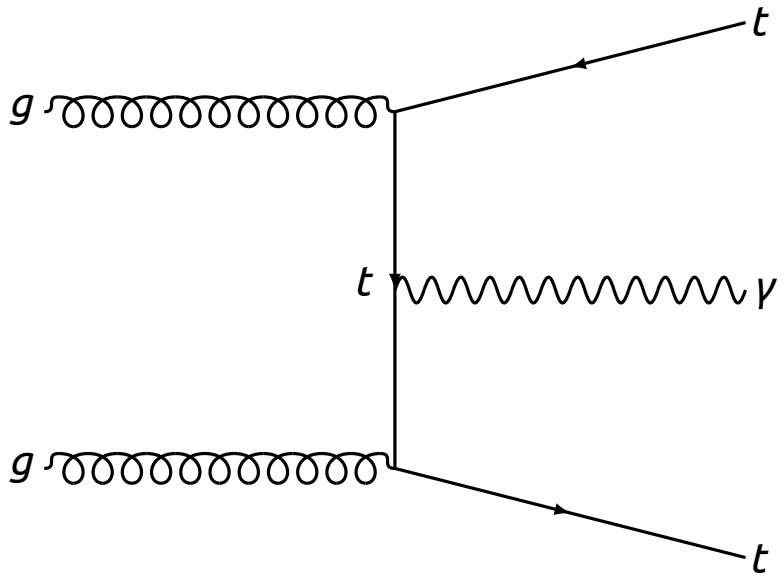
$t\bar{t}Z$ inclusive cross-section with 36.1fb^{-1}

- Combined analysis for $t\bar{t}Z$ and $t\bar{t}W$
- Goal:
  - Inclusive cross-section measurement and SMEFT interpretation
- Motivation:
  - Important Background to searches
  - Access to weak couplings of top quark
- 2 OS, 3 and 4 lepton selections for $t\bar{t}Z$
- Signal Extraction:
  - Dedicated BDT in each SR
- Result:
  - Constraint on Wilson coefficients involving top quark and Z boson
  - $\sigma(t\,t\bar{Z}) = 0.9 \pm 0.3$ pb



$t\bar{t}\gamma$ inclusive and differential cross-section with 139fb^{-1}

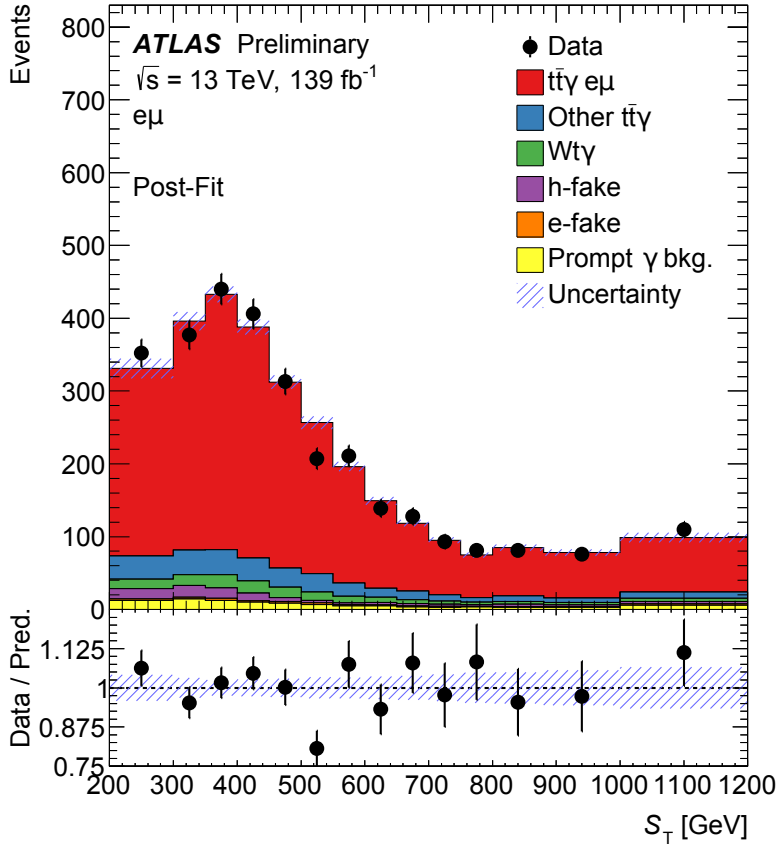
- Inclusive and Differential cross-section measurement in fiducial space
- Selection:
  - 1 photon, 1 OS $e\mu$ pair, ≥ 2 jets, ≥ 1 b-tagged jets
  - Very low background contributions
- Motivation:
  - Comparison to state-of-the-art NLO prediction
  - Access to $t\gamma$ coupling
  - New physics through anomalous dipole moment of the top quark



$t\bar{t}\gamma$ inclusive cross-section

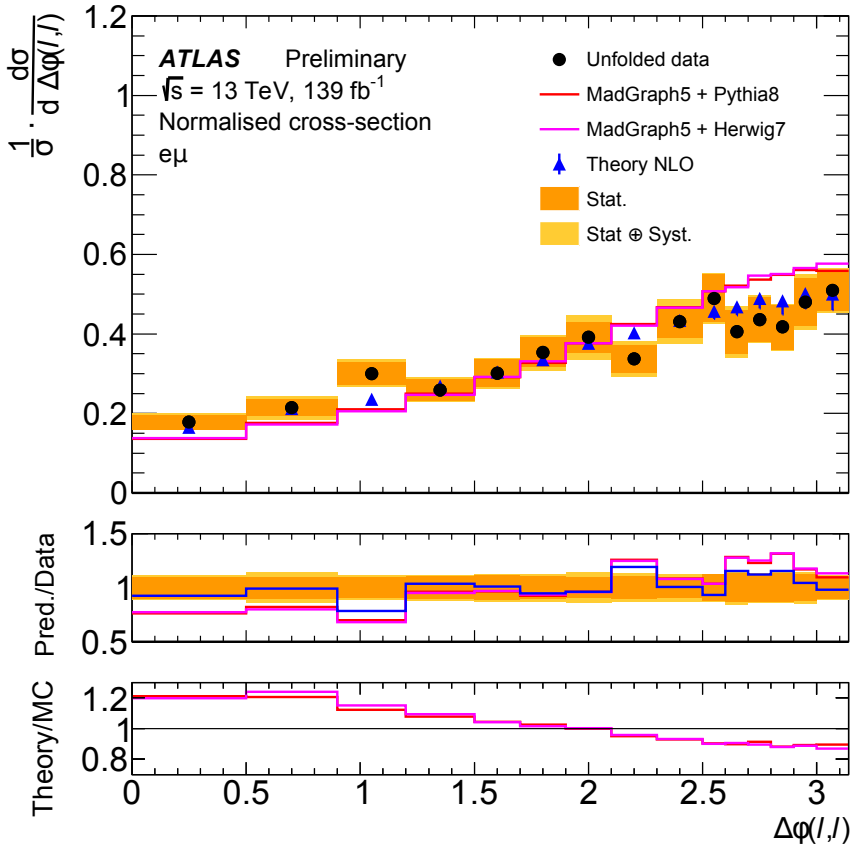
- Likelihood fit to S_T
- Extrapolation to fiducial region with correction factor C
  - $C = \frac{N_{\text{reco}}}{N^{\text{fid}}_{\text{MC}}} = 0.393 \pm 0.013$
  - Determined using LO in QCD signal MC
    MadGraph5_aMC@NLO with NNPDF2.3LO PDF and
    Pythia 8 with A14 tune

- $\sigma(t\bar{t}\,\gamma)_{\text{fid}} = 44.2 \pm 0.9\,(stat)\,^{+2.6}_{-2.4}\,(syst)$ fb $= 44.2 \pm 2.6$ fb
- Compared to
  - $\sigma(t\bar{t}\,\gamma)^{\text{fid}}_{\text{NLO QCD}} = 39.50^{+0.56}_{-2.18}\,(\text{scale})^{+1.04}_{-1.18}\,(\text{PDF})$ fb [JHEP 10(2018)158]



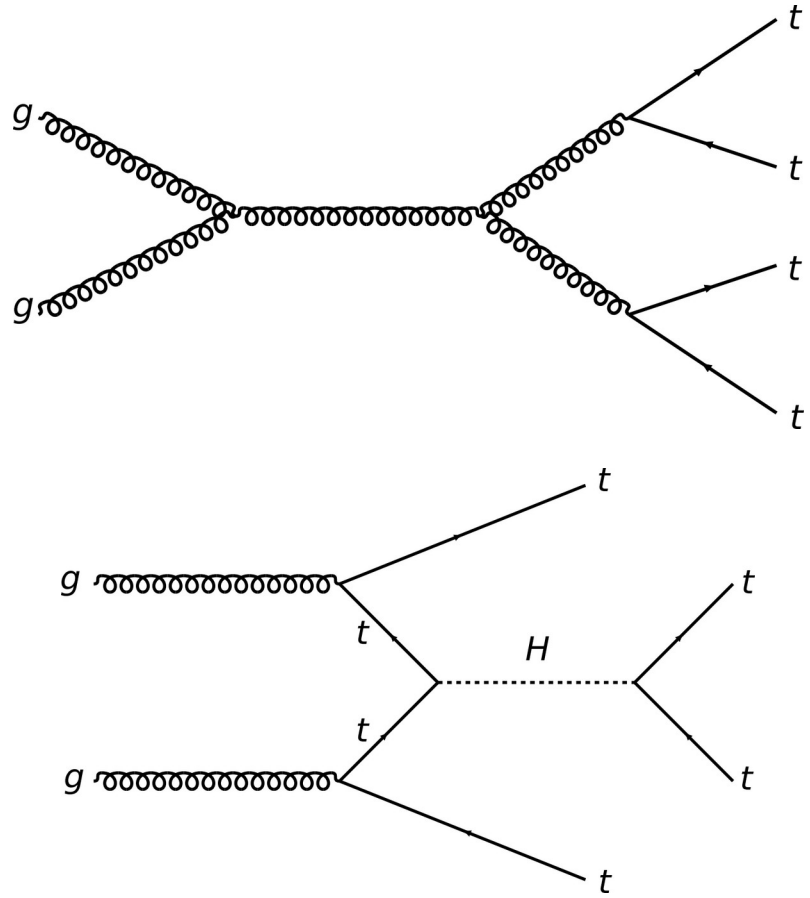
$t\bar{t}\gamma$ differential cross-section

- Unfolding achieved using iterative Bayesian approach with two iterations
  - Migration matrix, signal efficiency and outside-migration fraction determined with the signal MC
- Results:
  - Differential cross-section for:
    - $\Delta R(l,\gamma)_{\text{min}}$: sensitive to $t\gamma$ coupling
    - $\Delta\Phi(l,l)$ and $\Delta\eta(l,l)$: sensitive to $t\bar{t}$ spin-correlations
    - p_{T}^{γ}, $|\eta^{\gamma}|$: important kin. variables
  - Generators agree well with the measurement, except for $\Delta\Phi(l,l)$, where NLO is better

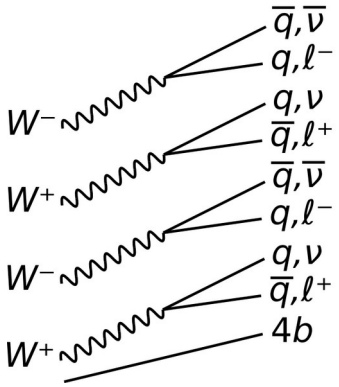


Search for $t\bar{t}t\bar{t}$ production

- Search for rare process in 1L + 2 OSL and 2 SSL+ ML final states
  - $\sigma(t\bar{t}\,t\bar{t})_{\mathrm{NLO}} = 11.97\,^{+15\%}_{-21\%}$ fb [JHEP 02 (2018) 031]
- Goal:
  - Evidence for $t\bar{t}t\bar{t}$ production
  - Inclusive cross-section measurement
- Motivation:
  - Handle on y_t *without* Γ_H
  - Very energetic process and good probe for series of BSM models

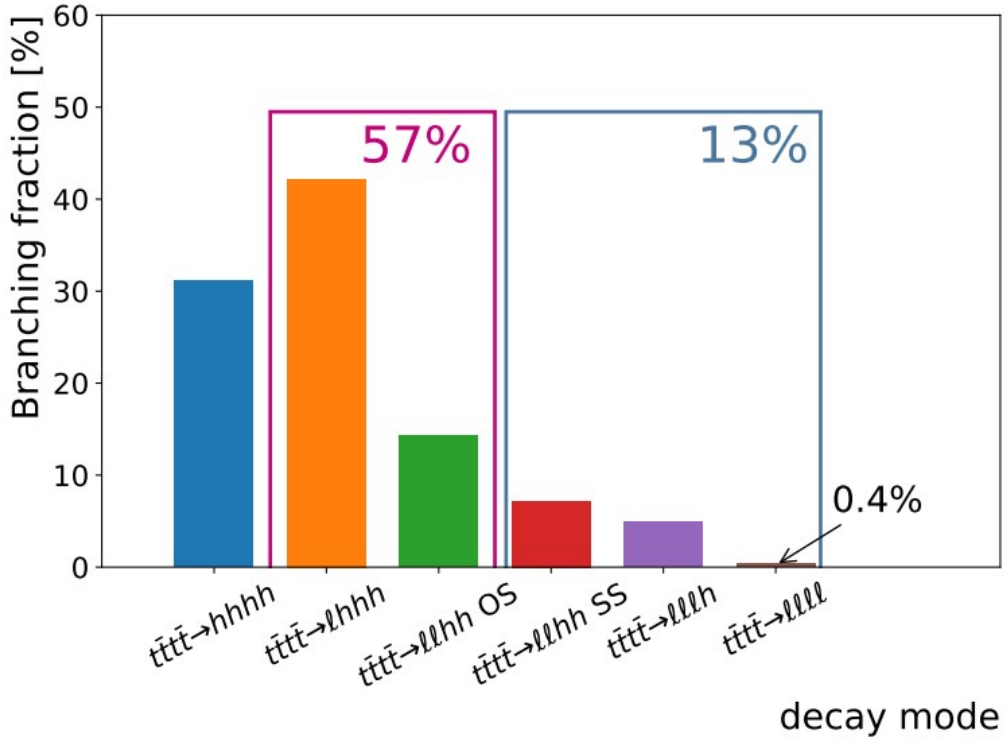


Analysis channels



- 1 lepton and 2 opposite-sign leptons final states: 36.1fb^{-1}
- 2 same-sign leptons, 3 (or 4) leptons: 139fb^{-1}

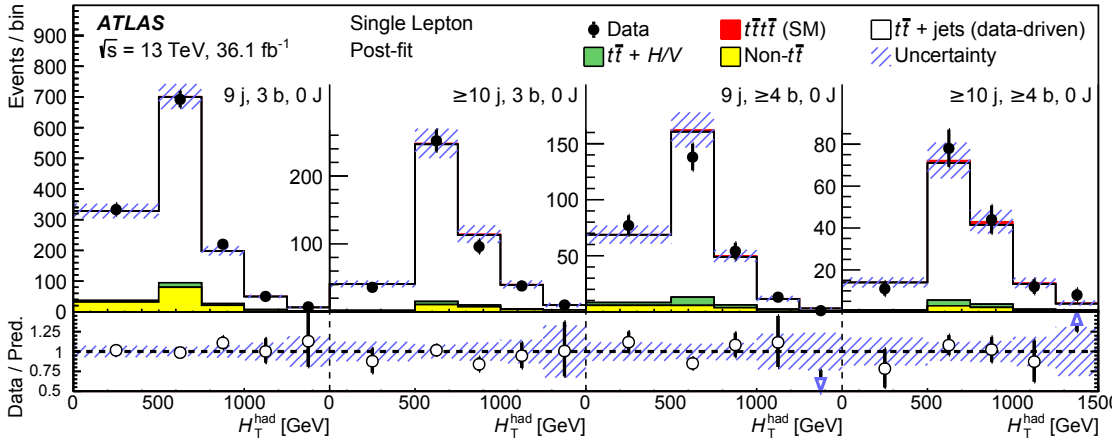
First presented at LHCP on 26.05.2020 -> Brand new!



1L and 2OSL final states

- 36.1fb^{-1} analysis assuming $\sigma(t\bar{t}t\bar{t})_{\mathrm{NLO\,QCD}} = 9.2 \pm 30\,\%(\mathrm{scale}) \pm 6\,\%(\mathrm{PDF})\,\mathrm{fb}$

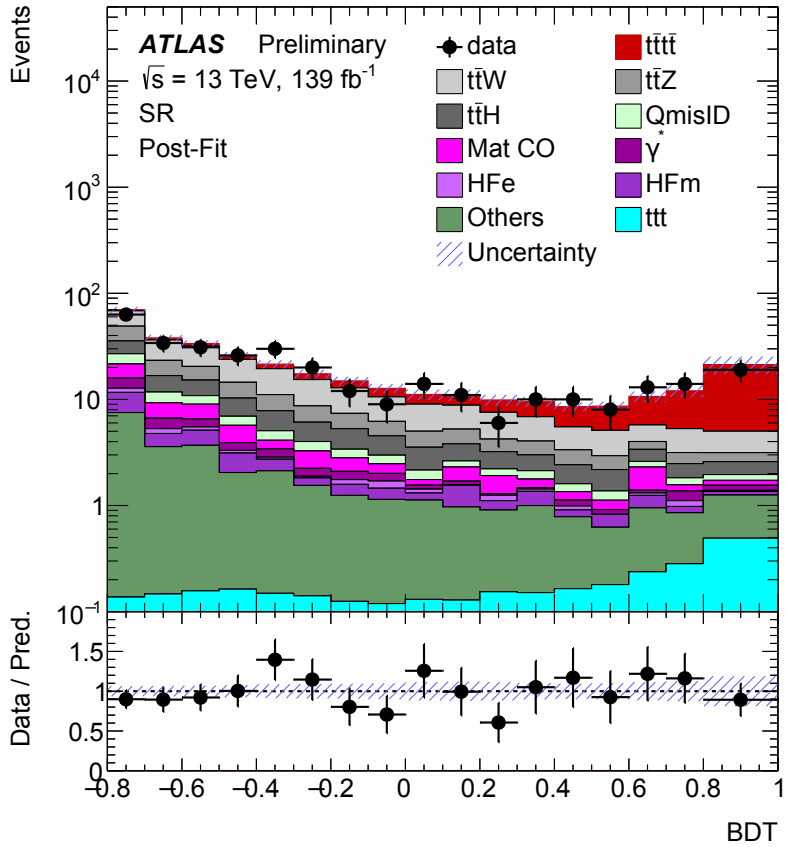
- SRs based on (*b*-tagged) jet and RCLR jet multiplicities
  - Likelihood fit of $H_{\mathrm{T}}^{\mathrm{had}}$
- Results:
  - 47fb (33fb) observed (expected) 95% C.L upper limit on cross-section (CL_s method)
  - EFT interpretation



2SSL and ML final states

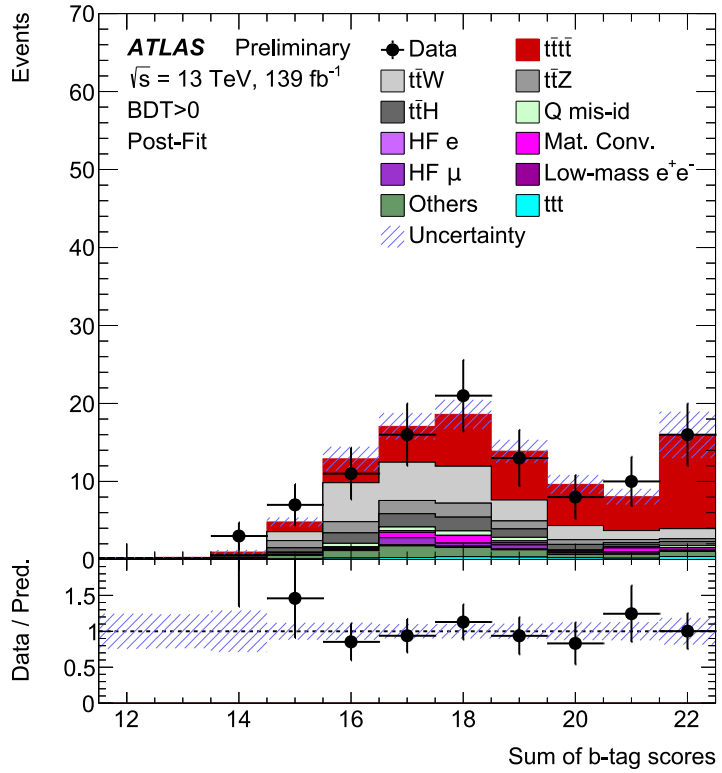
Brand New!

- 139fb^{-1} analysis assuming $\sigma(t\bar{t}t\bar{t})_{\mathrm{NLO}} = 11.97\,^{+15\%}_{-21\%}$ fb [JHEP 02(2018)031]
- Background Estimation
  - Electron charge mis-reconstruction
    - Data-driven method using *Z* boson enriched regions
  - Other instrumental backgrounds and $t\bar{t}W$
    - Normalisation from fit to data in dedicated regions, shape from MC
- Signal Extraction
  - BDT, sum of pseudo-continous *b*-tagging weights most important, $\mathrm{AUC} = 0.853 \pm 0.006$
- Results:
  - $\mu_{t\bar{t}t\bar{t}} = \frac{\sigma_{obs}}{\sigma_{NLO}} = 2.0^{+0.4}_{-0.4}(stat)^{+0.7}_{-0.5}(syst) = 2.0^{+0.8}_{-0.6}$
    - Consistent with SM within 1.7 standard deviations
  - Observed (expected) significance: 4.3 (2.4) standard deviations. ***Evidence!***
  - $\sigma(t\bar{t}t\bar{t}) = 24^{+5}_{-5}(stat)^{+5}_{-4}(syst)\,\mathrm{fb} = 24^{+7}_{-6}\,\mathrm{fb}$



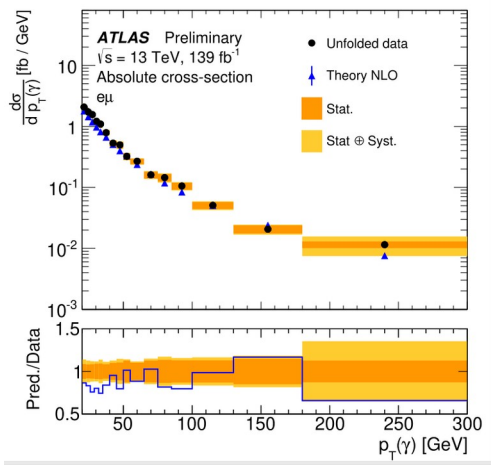
Conclusion

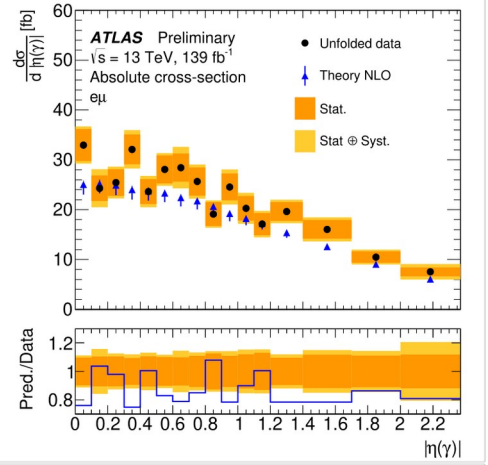
- Two exciting new results:
  - $t\bar{t}\gamma$ inclusive and differential cross-section
  - Evidence for $t\bar{t}t\bar{t}$ production

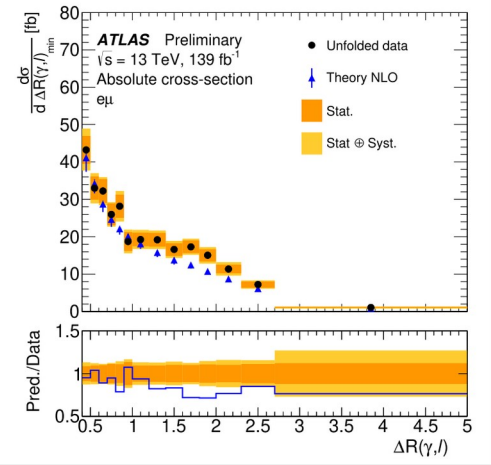


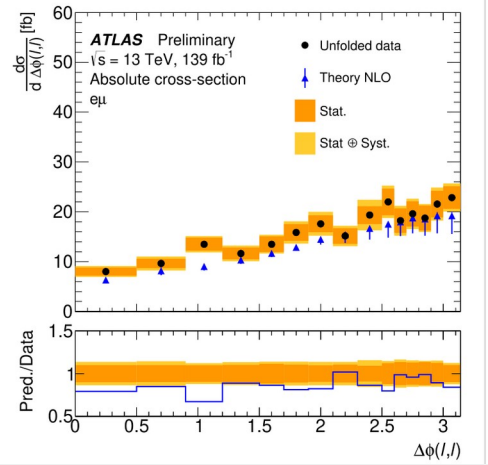
Additional Material

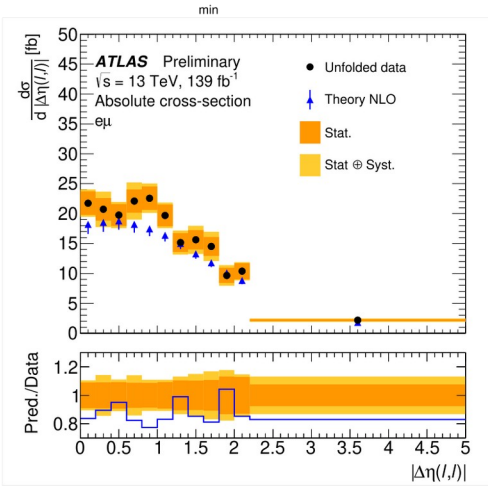
$t\bar{t}\gamma$ differential cross-section





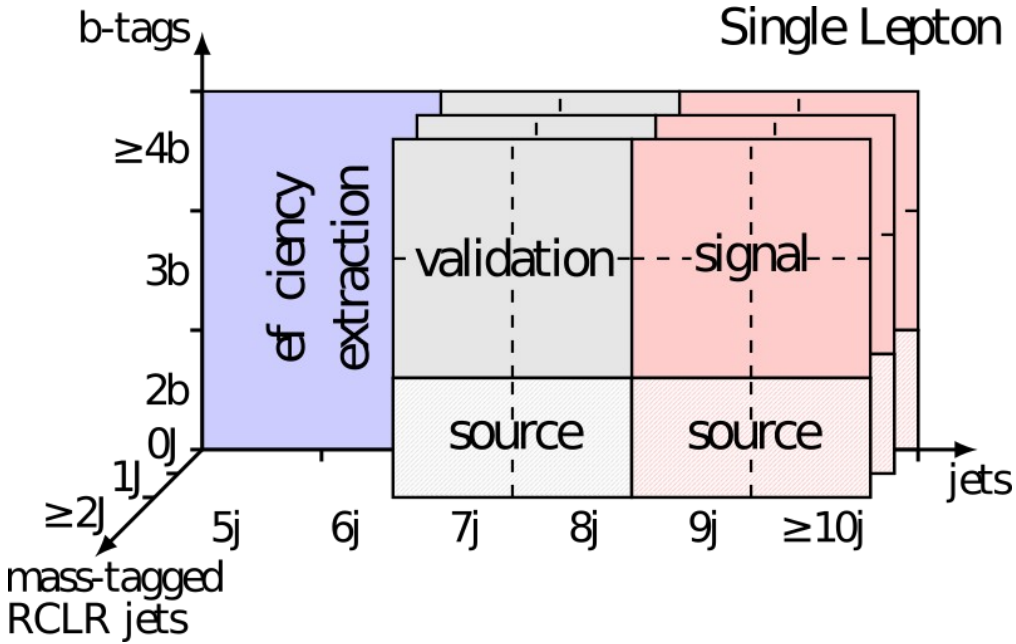






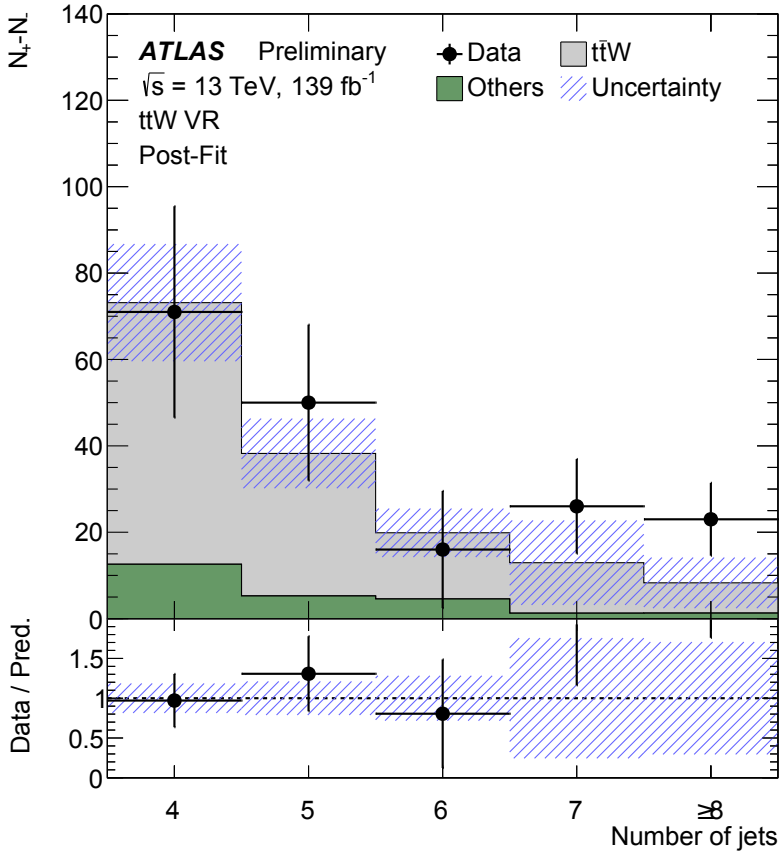
1LOS Data-Driven Background

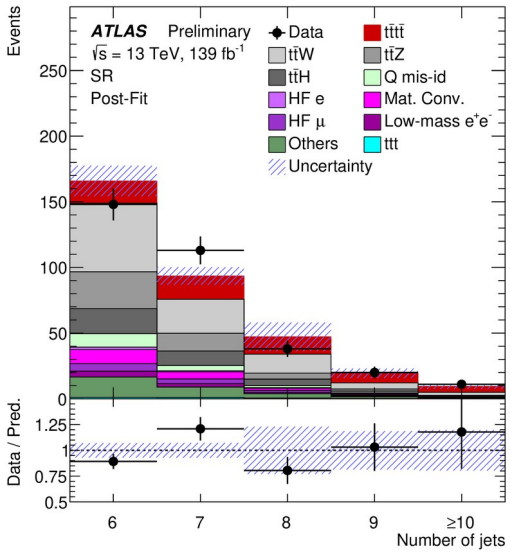
- $t\bar{t}$ modelling difficult for high (*b*-tagged) jet multiplicities → $t\bar{t}$ tag rate function data-driven background estimation
  - Assumption: Probability to tag an additional jet as a *b* jet is the same for any number of additional jets
    - Calculate this probability in low N_j
    - Apply in SRs

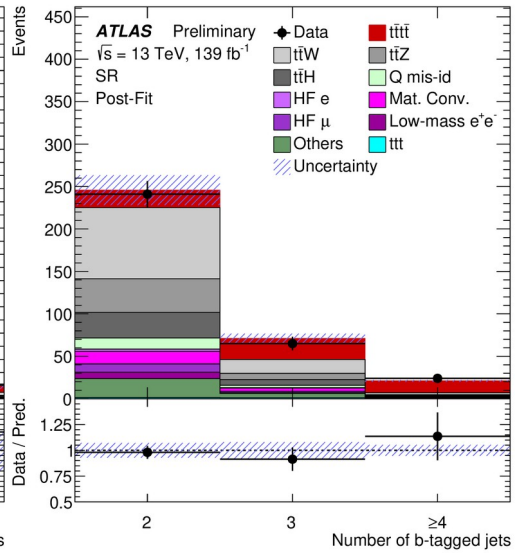


$t\bar{t}W$ normalisation and uncertainties

- $t\bar{t}W$ scaled by 1.6
  - Agrees well with $t\bar{t}H$ to ML search
  - Very high N_j multiplicity
  - Trigger for new NLO in QCD computation [arxiv:2005.09427]
- Systematic uncertainties:
  - 125% on $t\bar{t}W$ $7j$
  - 300% on $t\bar{t}W \geq 8j$
  - 50% $t\bar{t}W$ $3b$ and $t\bar{t}W \geq 4b$
  - *100% on ttt*
  - *50% on ttt+b*




ATLAS Preliminary
√s = 13 TeV, 139 fb-1
SR
Post-Fit
Data
tt̄W
tt̄H
HF e
HF μ
Others
Uncertainty
tt̄tt̄
tt̄Z
Q mis-id
Mat. Conv.
Low-mass e+e-
ttt
Events
Data / Pred.
Number of jets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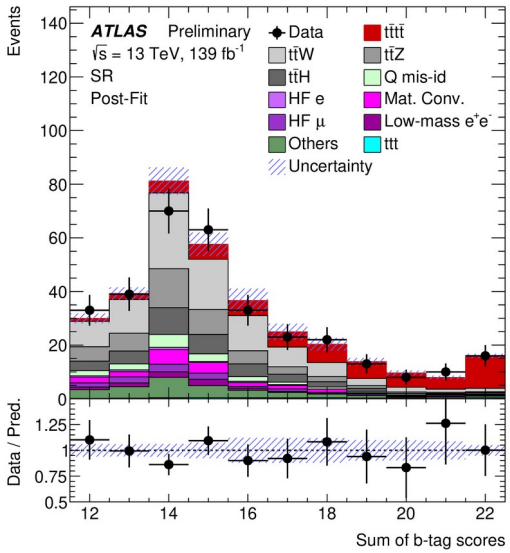
tt̄Z
Q mis-id
Mat. Conv.
Low-mass e+e-
ttt
Events
Data / Pred.
Number of b-tagged jets


ATLAS Preliminary
√s = 13 TeV, 139 fb-1
SR
Post-Fit
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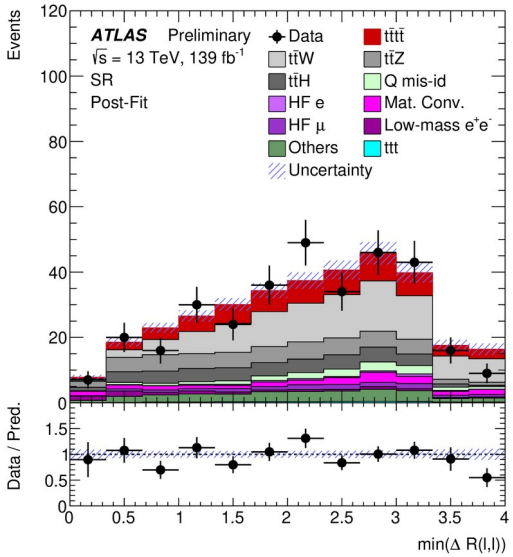
tt̄W
tt̄H
HF e
HF μ
Others
Uncertainty
tt̄tt̄
tt̄Z
Q mis-id
Mat. Conv.
Low-mass e+e-
ttt
Events
Data / Pred.
Sum of b-tag scores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tt̄Z
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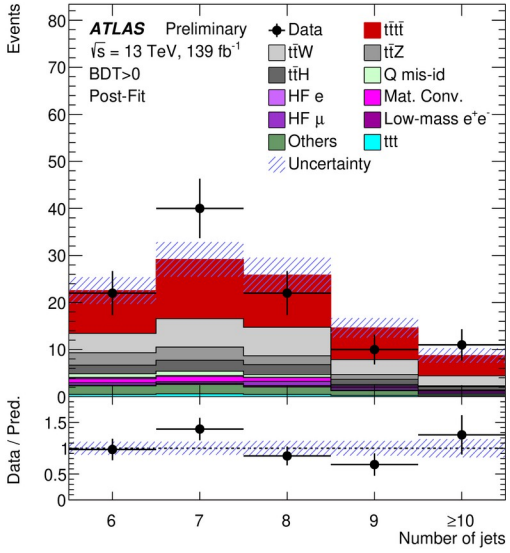
Low-mass e+e-
ttt
Events
Data / Pred.
min(Δ R(l,l))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BDT>0
Post-Fit
Data
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tt̄H
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HF μ
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Uncertainty
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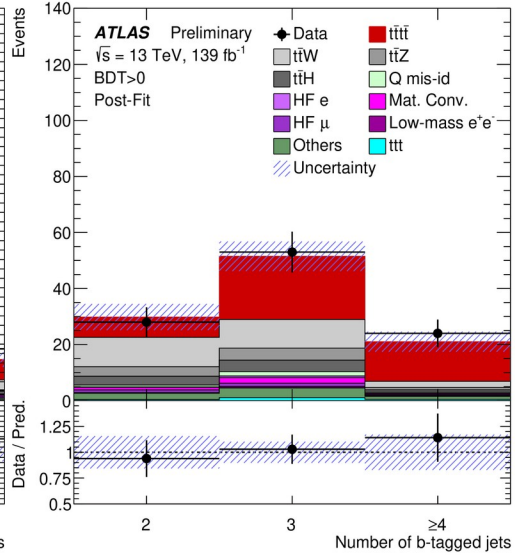
Mat. Conv.
Low-mass e+e-
ttt
Events
Data / Pred.
Number of jets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Uncertainty
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tt̄Z
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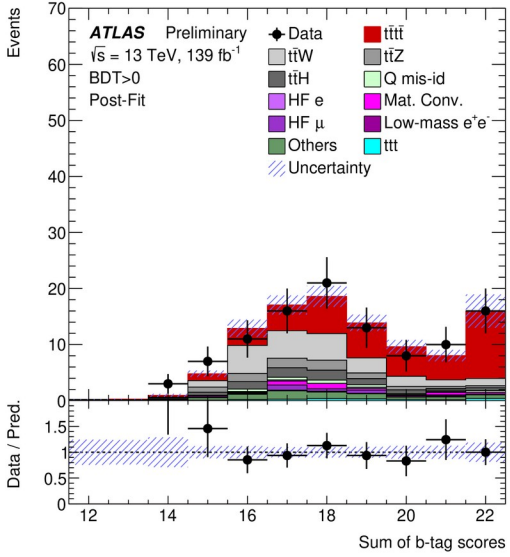
Mat. Conv.
Low-mass e+e-
ttt
Events
Data / Pred.
Number of b-tagged jets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Low-mass e+e-
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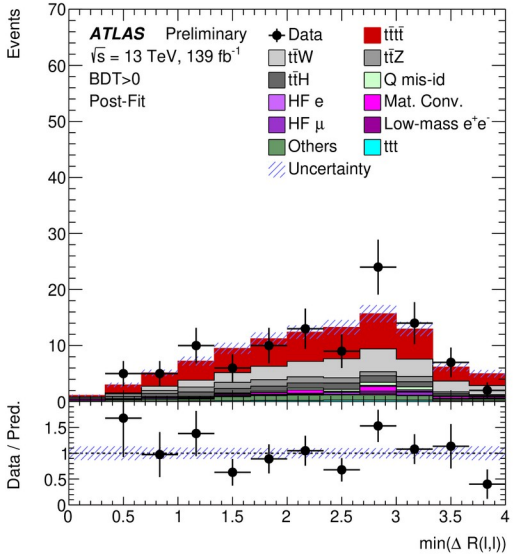
Events
Data / Pred.
Sum of b-tag scores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min(Δ R(l,l))