Measurements of $t\bar{t}$ production cross sections with the ATLAS detector at the LHC

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On behalf of the ATLAS Collaboration
EPS-HEP2021, Virtual Edition

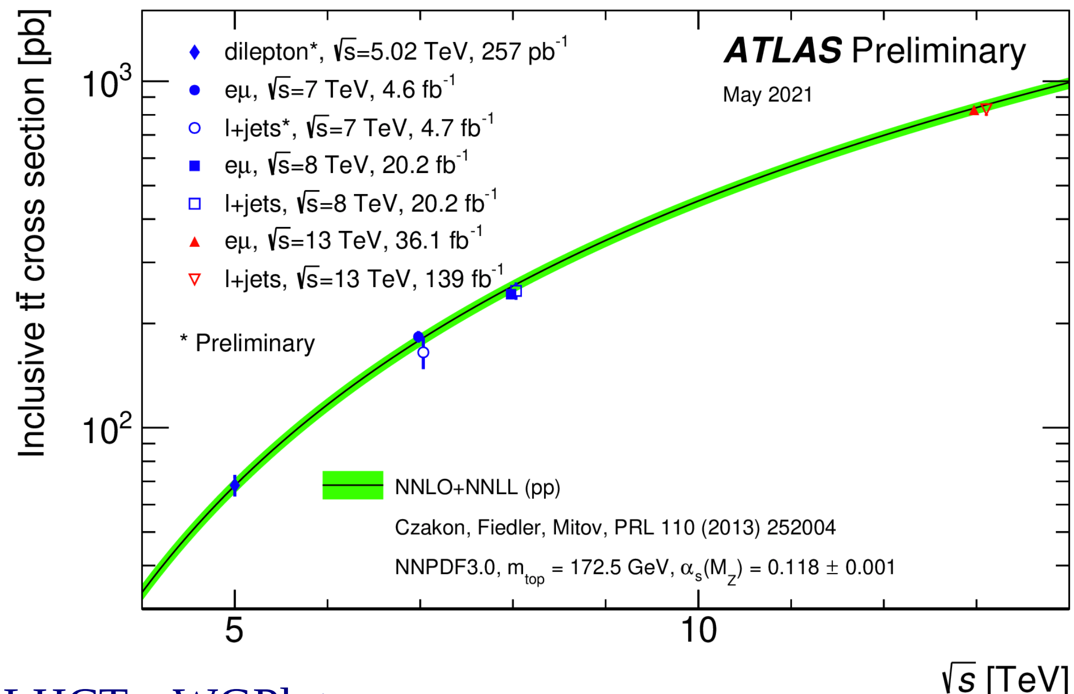
Why are we still measuring $t\bar{t}$?

Recently, several measurements of differential and inclusive tt cross sections have been performed in ATLAS:

Including challenging final state (all-hadronic)

Exploiting new datasets (5 TeV measurements)

Reaching new level of precision (l+jets boosted, dilepton)



LHCTopWGPlots

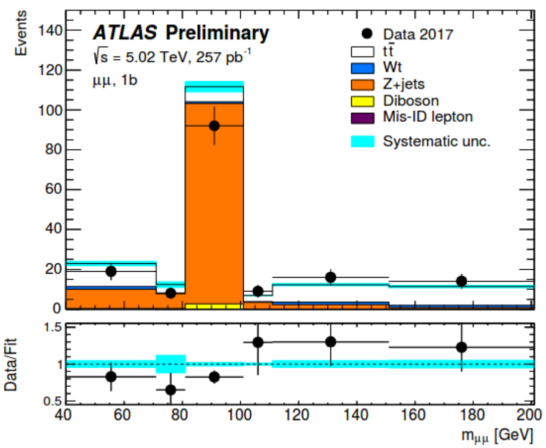
These measurements can be used to:

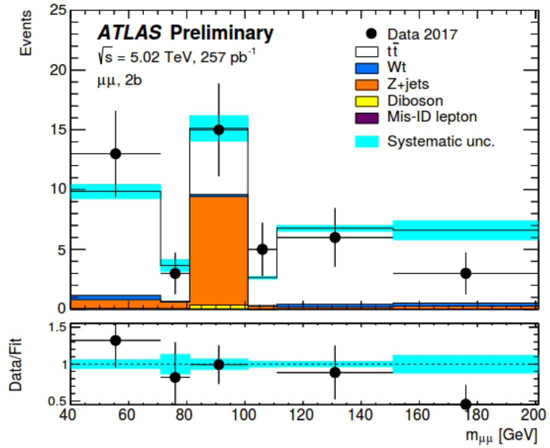
- Assess current level of understanding of the SM
- Perform studies to improve MC tuning and systematic uncertainty definitions
- Provide inputs to the gluon PDF
- Extract m_t or/and α_S
- Set limits on the existence of new physics.

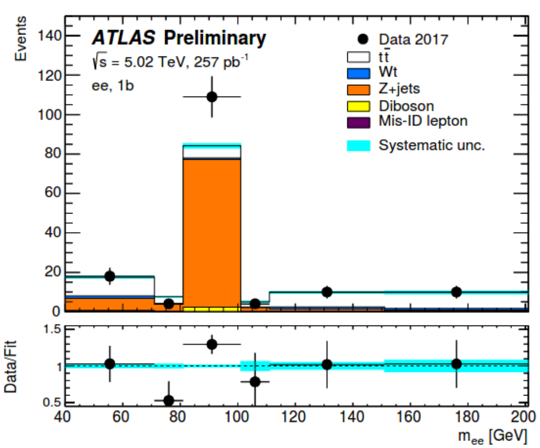
Inclusive measurements of $\sigma(t\bar{t})$:

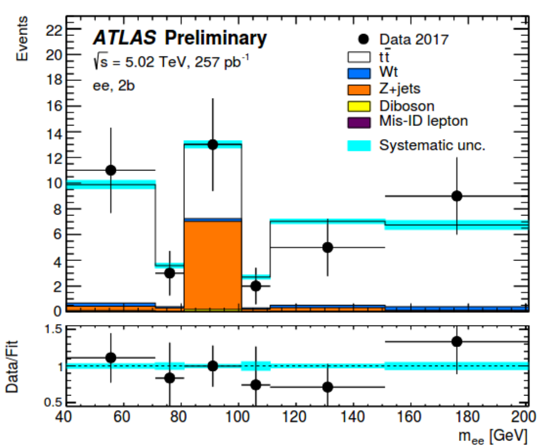
- 5 TeV dilepton measurement: ATLAS-CONF-2021-003
- l+jets inclusive measurement: Phys. Lett. B 810 (2020) 135797

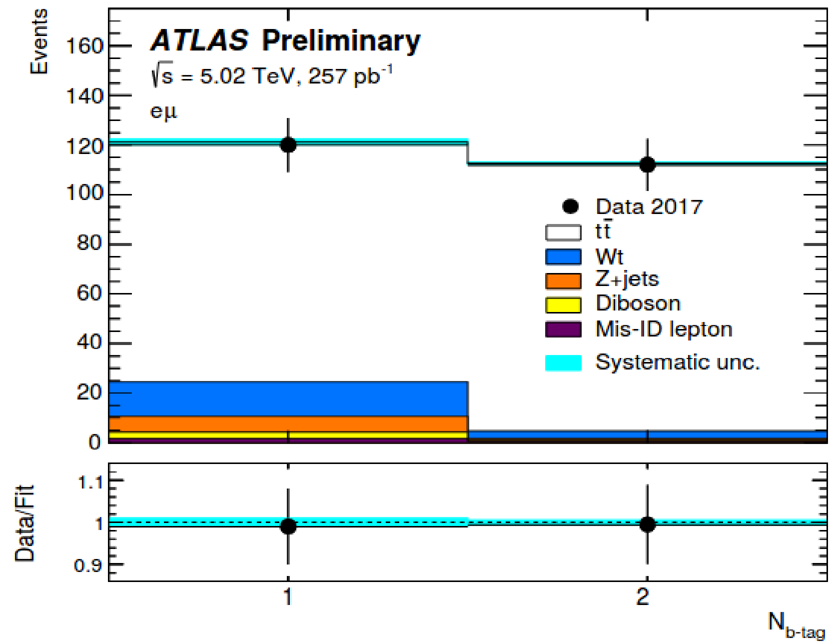
- σ extracted using events in μμ, ee and eμ channels
- Fit performed on the N-btag distribution for the eμ channel
- Fit including also m_{ll} information for μμ, ee channels, to constrain also Z+jets background.











- σ extracted at the same time with a parameter sensitive to the b-tagging efficiency
  - Limit the impact of the related uncertainty (0.2%)
- No requirements applied on the number of jets
  - Very small related uncertainties (0.03%)

ATLAS-CONF-2021-003

$\sigma(t\bar{t})$: dilepton @5 TeV

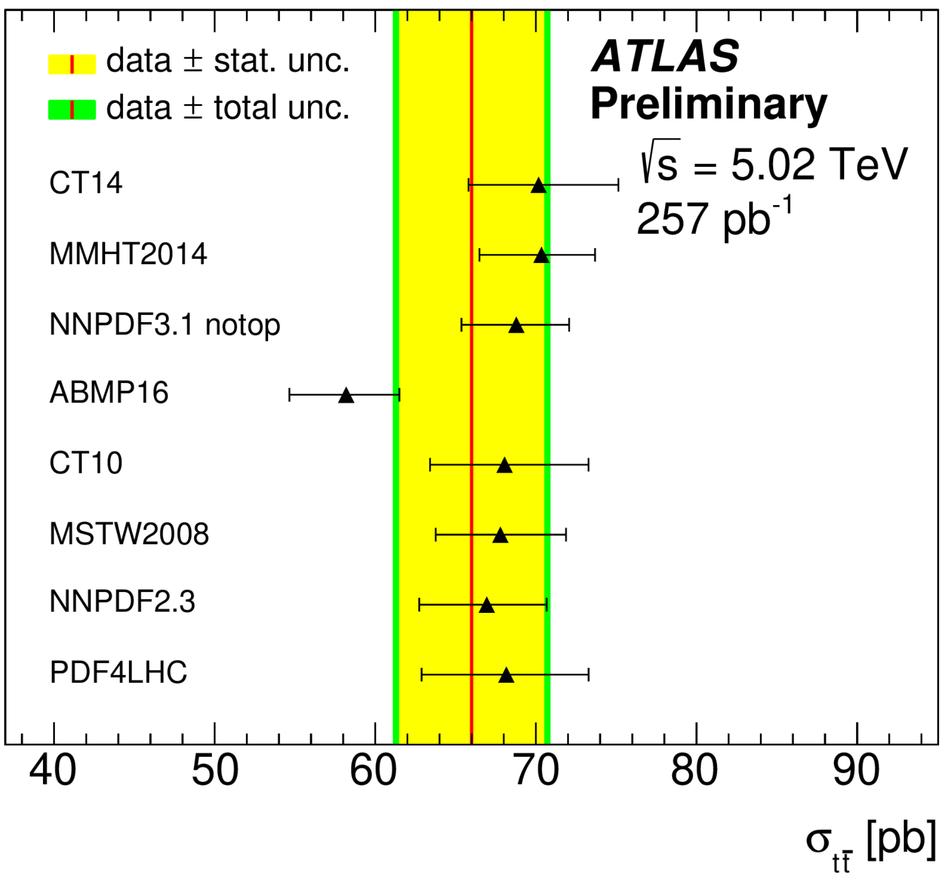
Result:

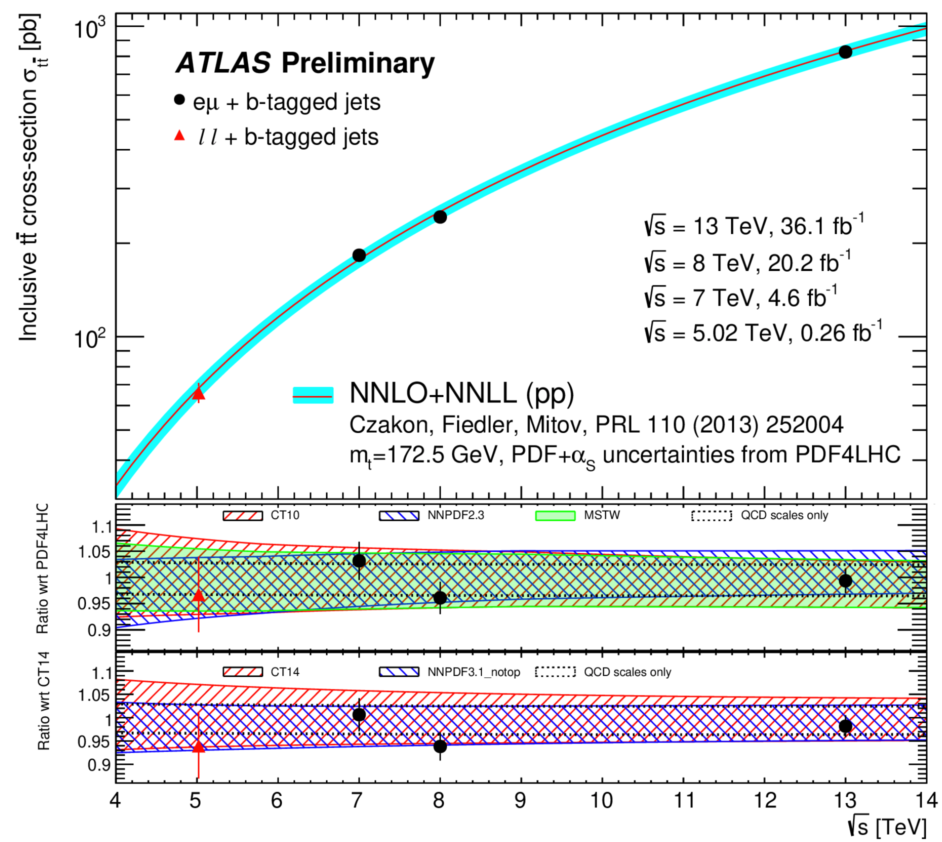
$\sigma(t\bar{t})$=66.0±4.5(stat.)±1.6(syst.)±1.2(lumi.)±0.2(beam)pb (7.5%)

Dominant components from modeling uncertainties of the signal and background (single top)

SM:

$\sigma_{NNLO}(t\bar{t})$ = 68.2±5.32 pb (7.8%)





ATLAS-CONF-2021-003

σ($t\bar{t}$): l+jets @13 TeV

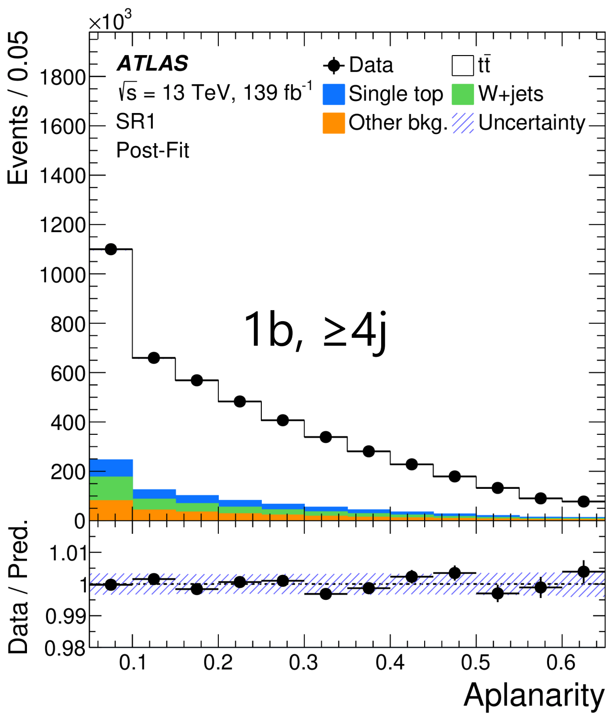
Profile likelihood fit to 3 distributions in 3 SR categorized based on the number of jets and b-jets.

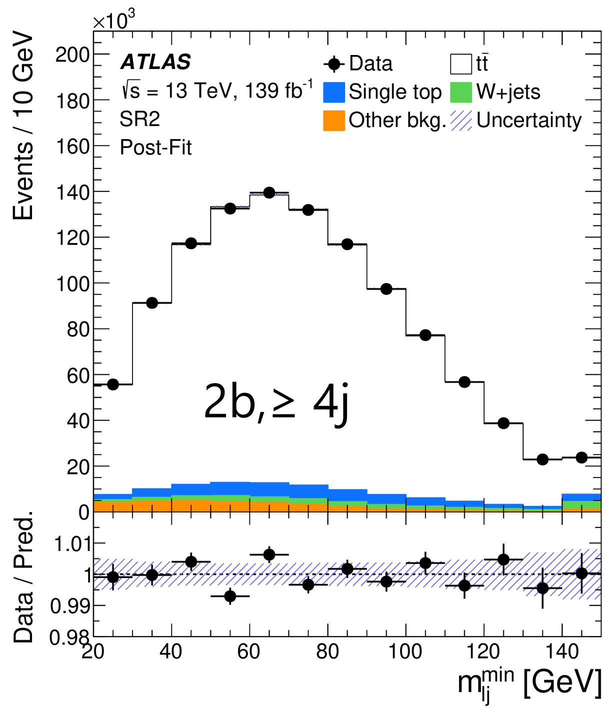
σ($t\bar{t}$)=830±0.4(stat.)±36(syst.)±14(lumi.)pb (4.6%)

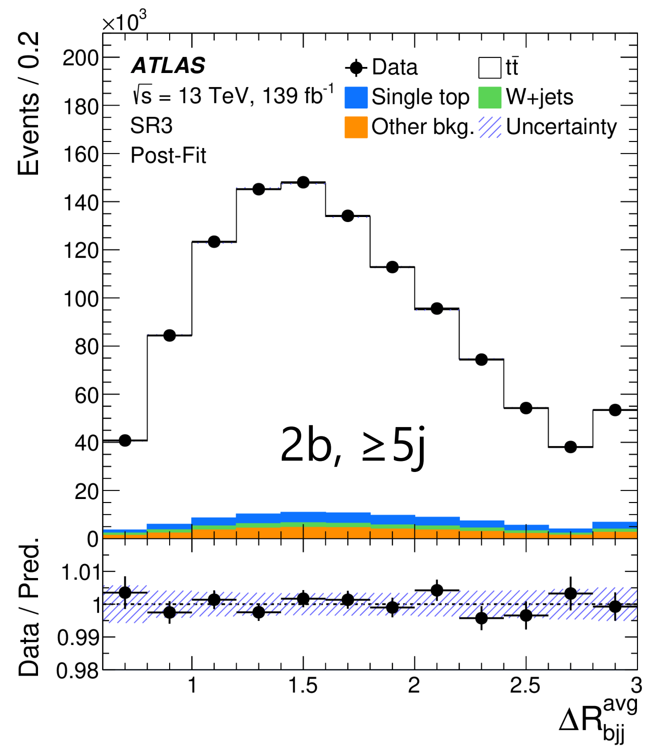
SM: $\sigma_{NNLO}(t\bar{t})$ = 832±40.3 pb (5.4%)

- The dominant backgrounds are single top, W+jets and multijet
- Dominant systematic uncertainties: hadronization/showering of the signal and jet reconstruction uncertainties.

Excellent agreement with NNLO+NNLL prediction and with the ATLAS dilepton measurement @13 TeV







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Differential measurements of $\sigma(t\bar{t})$:

- All hadronic measurement @13 TeV: JHEP 01 (2021) 033
- l+jets measurement @13 TeV (resolved + boosted):Eur. Phys. J. C 79 (2019) 1028
- Dilepton measurement @13 TeV: Eur. Phys. J. C 80 (2020) 528
- NEW!! l+jets boosted measurement @13 TeV: ATLAS-CONF-2021-031

dσ(tt̄): all-hadronic @13 TeV

Event selection:
- At least 6 jets (==2 b-jets)
- Exactly 0 lepton
- Kinematic requirements on system reconstruction

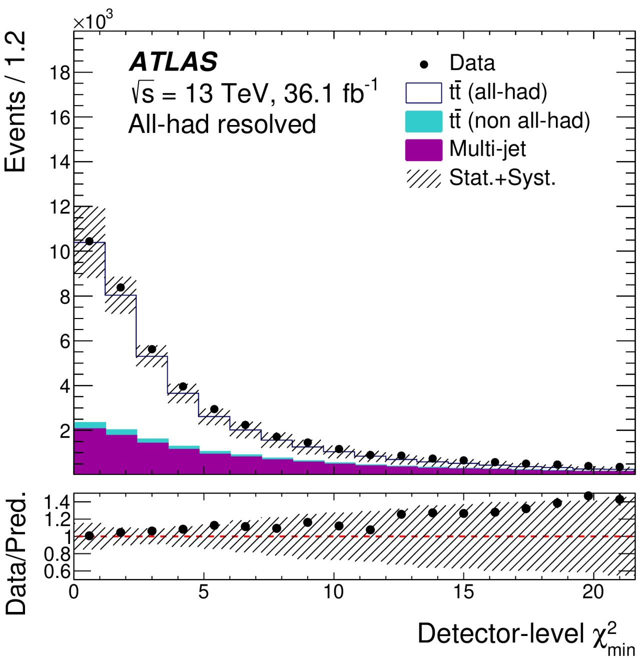
Reconstruct the tt̄ system minimising of the χ^2:

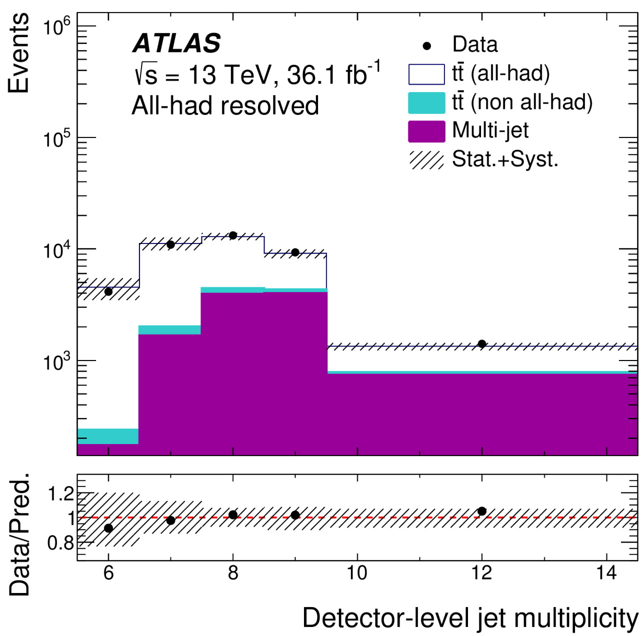
$$\chi^2 = \frac{(m_{b_1 j_1 j_2} - m_{b_2 j_3 j_4})^2}{\sigma_t^2} + \frac{(m_{j_1 j_2} - m_W)^2}{\sigma_W^2} + \frac{(m_{j_3 j_4} - m_W)^2}{\sigma_W^2}$$

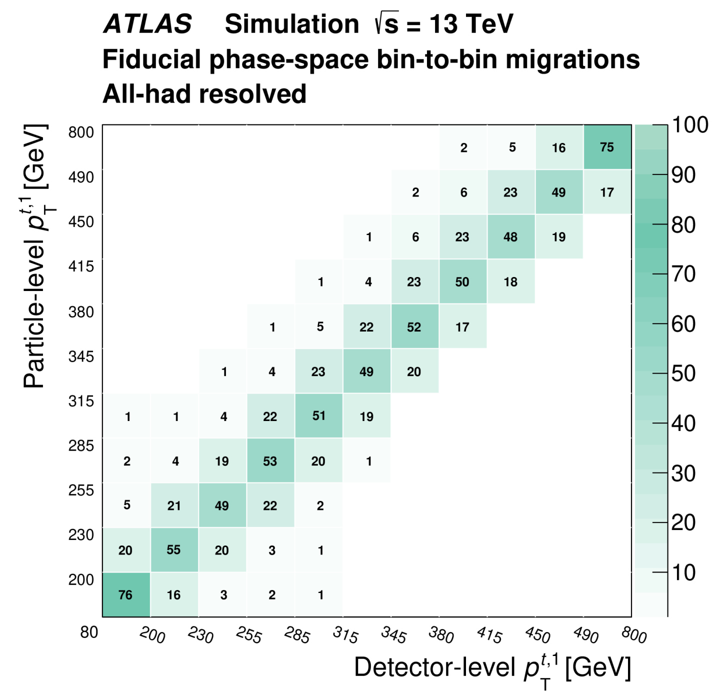
- A key aspect of the analysis is the separation of the signal and the multi-jet background.
  - Employed a data-driven method
  - Cut on the χ^2 result

dσ(tt̄) measurement:

Unfolding to the particle and parton level





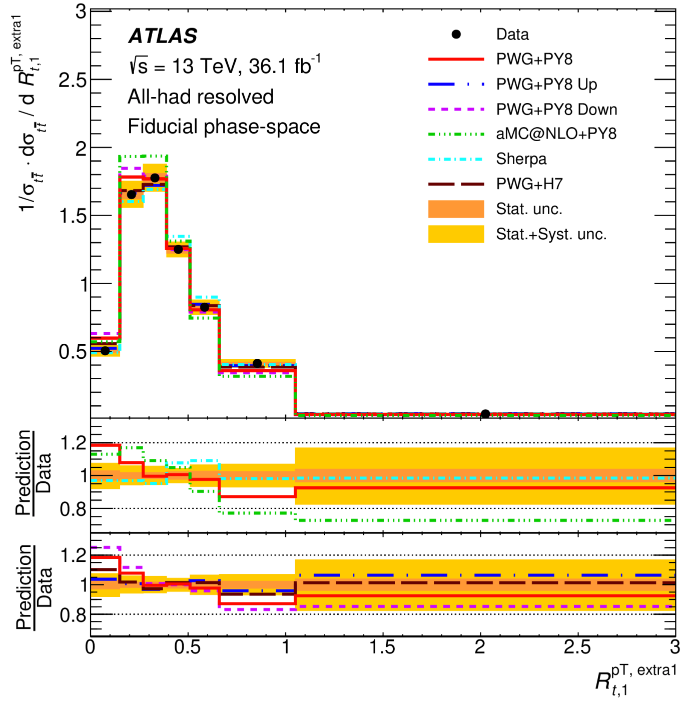


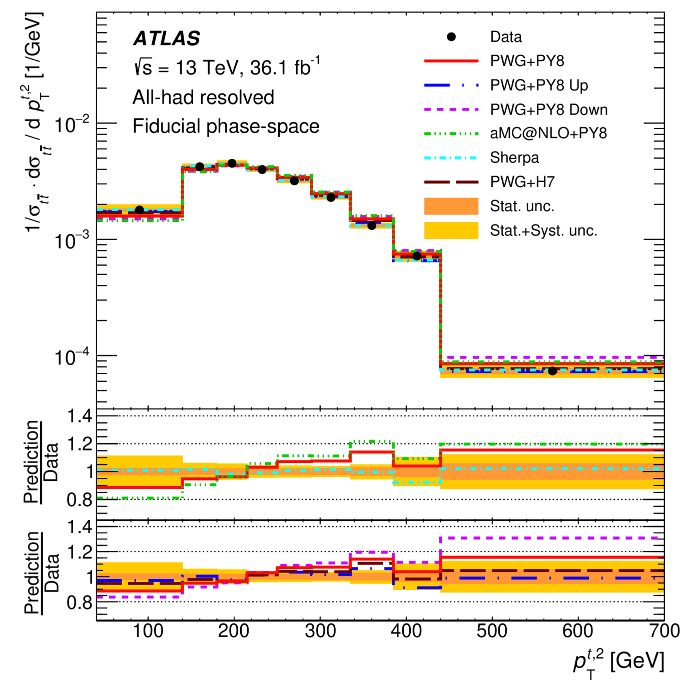
JHEP 01 (2021) 033

dσ(tt̄): all-hadronic @13 TeV

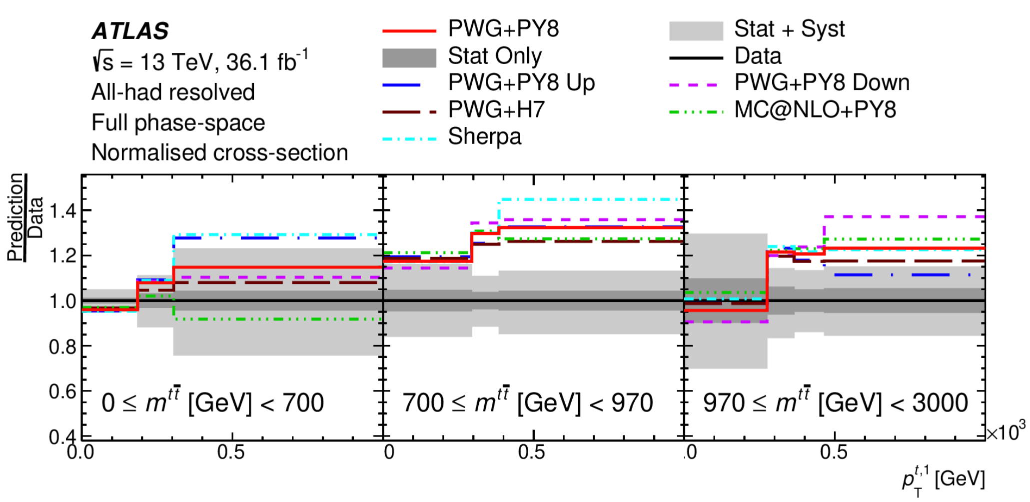
- dσ(tt̄) as a function of the top quarks and tt̄ system kinematic
- Included many variables sensitive to additional radiations
- Including double differential spectra

Particle level



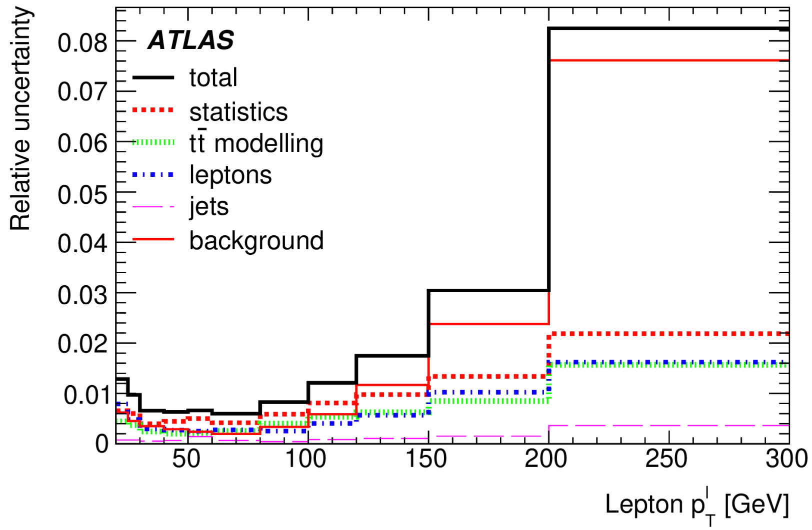


Parton level



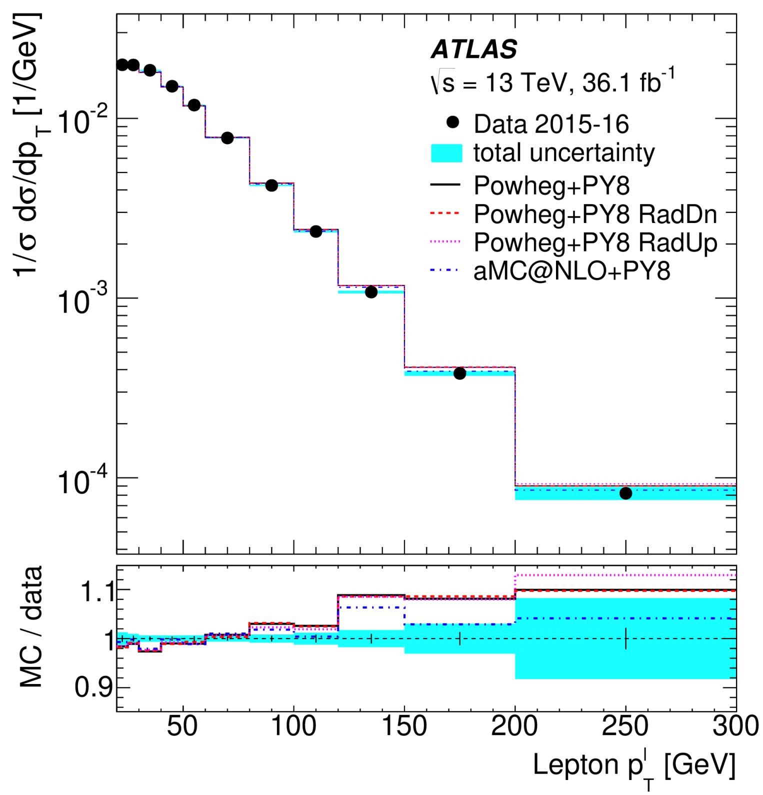
- Dominant uncertainties from signal showering modeling, multijet background estimate and jet reconstruction.
- Good agreement with NLO+PS generator on angular variables, p_T of the leading top quark and tt̄ system.

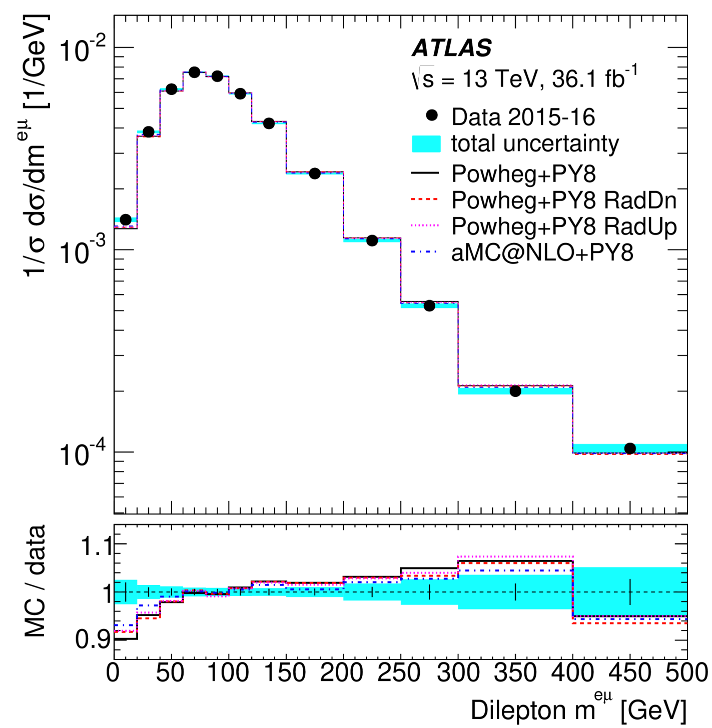
dσ($t\bar{t}$): dilepton @13 TeV



- Measured events in the eμ channel
  - Similar to the 5 TeV strategy, performing the fit in every bin
- Both inclusive and differential measurements performed:
  - Most precise inclusive measurement (2.4%)
  - dσ($t\bar{t}$) measured as a function of the several kinematic distributions of the leptons

- NLO+PS predictions give a good dscription of several observables
- Predictions using POWHEG predict a harder spectrum for lepton p_T



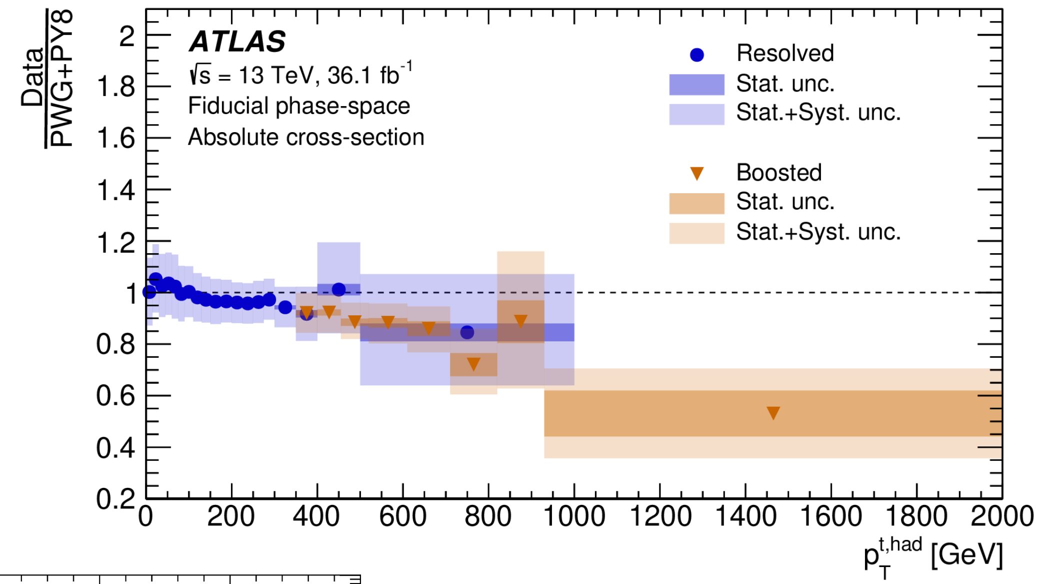


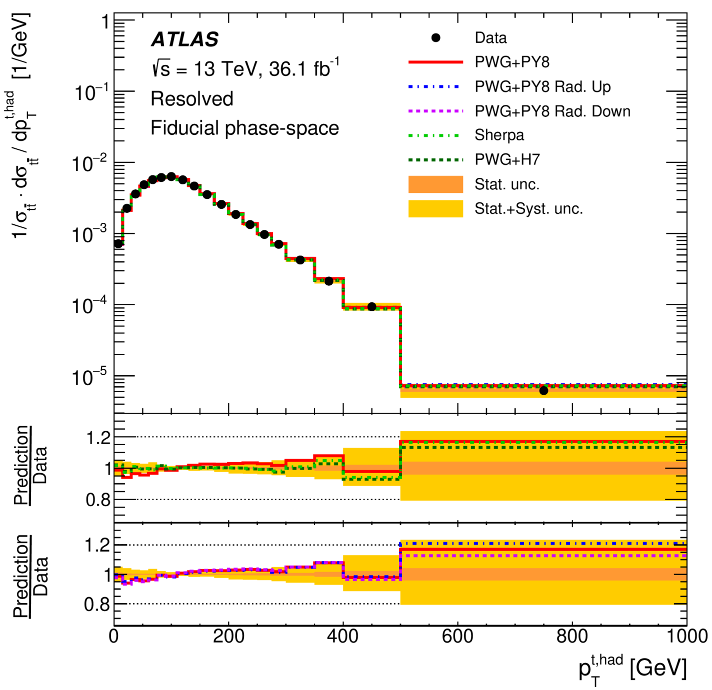
Eur. Phys. J. C 80 (2020) 528

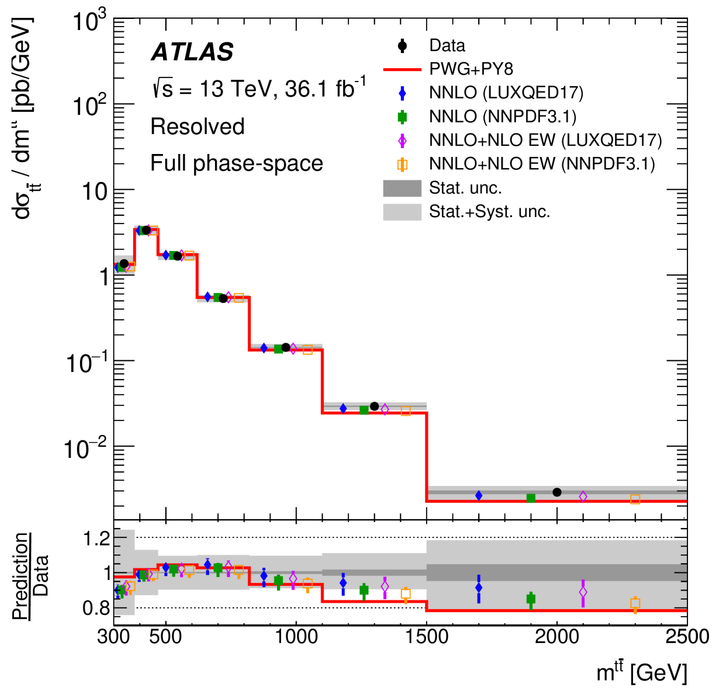
dσ(tt̄): l+jets @13 TeV (resolved)

Event selection:
- At least 4j (>= 2b)
- Exactly 1 lepton (e/mu)

Analysis strategy:
- Reconstruction of the tt̄ system
- Unfolding to parton and particle level
- Avoiding overlap with the boosted topology







Source	Uncertainty[%]	
	Particle level	
	Resolved	Boosted
Flavour Tagging	7.1	2.1
JES/JER	4.9	4.1
Lepton, E_T^{miss}	0.9	1.1
Backgrounds	2.5	3.9
Generator	3.1	0.9
Hadronisation	1.1	4.3
Rad., PDF, MC Stat.	0.5	0.7
Stat. Unc.	0.1	0.5
Stat+Syst Unc.	9.8	7.9

Good agreement between several predictions and NLO+PS generators prediction, especially on single differential measurements.

Eur. Phys. J. C 80 (2020) 528

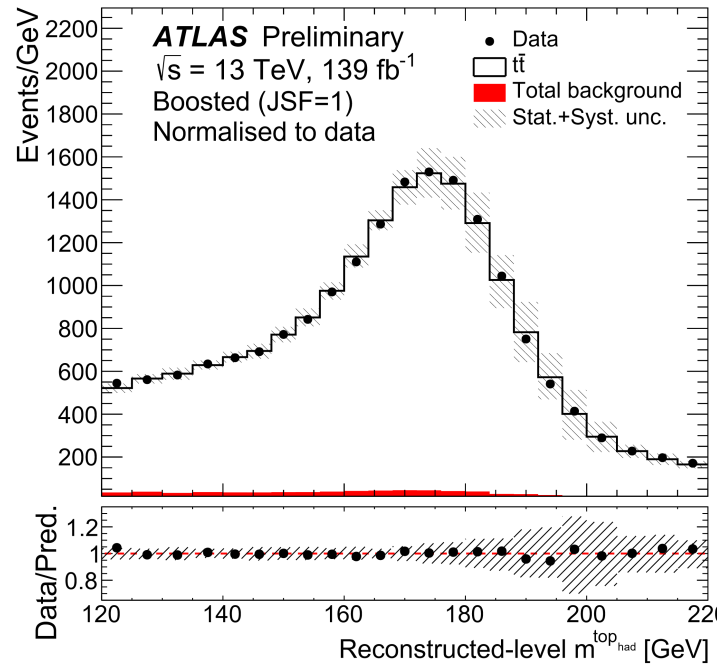
dσ(tt̄): l+jets @13 TeV (boosted)

Event selection

- At least 1 lepton (e/μ)
- At least 1 reclustered(R=1.0) jet (p_T > 355 GeV)

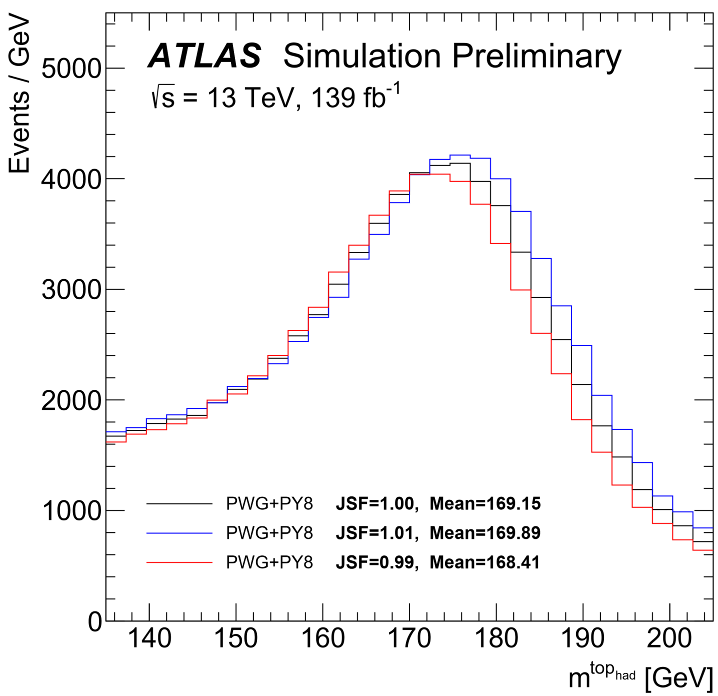
  Top jet mass $= \sum_i (E_i)^2 - (p_i)^2$ (i = jets R=0.4)
- At least 2 b-jets, cut on m(lb) and E_T^{miss}

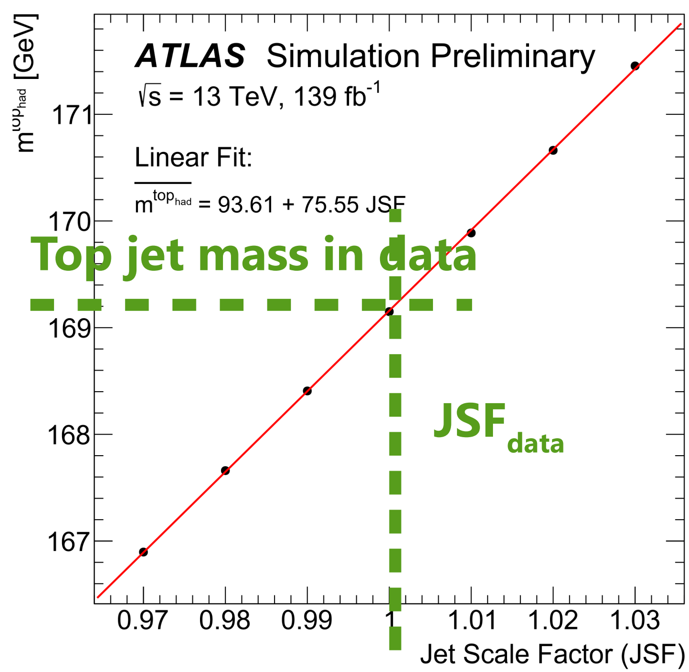
NEW!!



Analysis strategy:

- Employ a parameter sensitive to the top mass to reduce the JET uncertainties (JSF)
- Assume the data and MC top jet mass differs due to the a multiplicative difference on the energy of R=0.4 jets.





- Calibration line obtained by shifting JSF and register the effect on jet mass
- Excellent agreement observed between MC and data

  $JSF_{data} = 1.00035 \pm 0.00087$

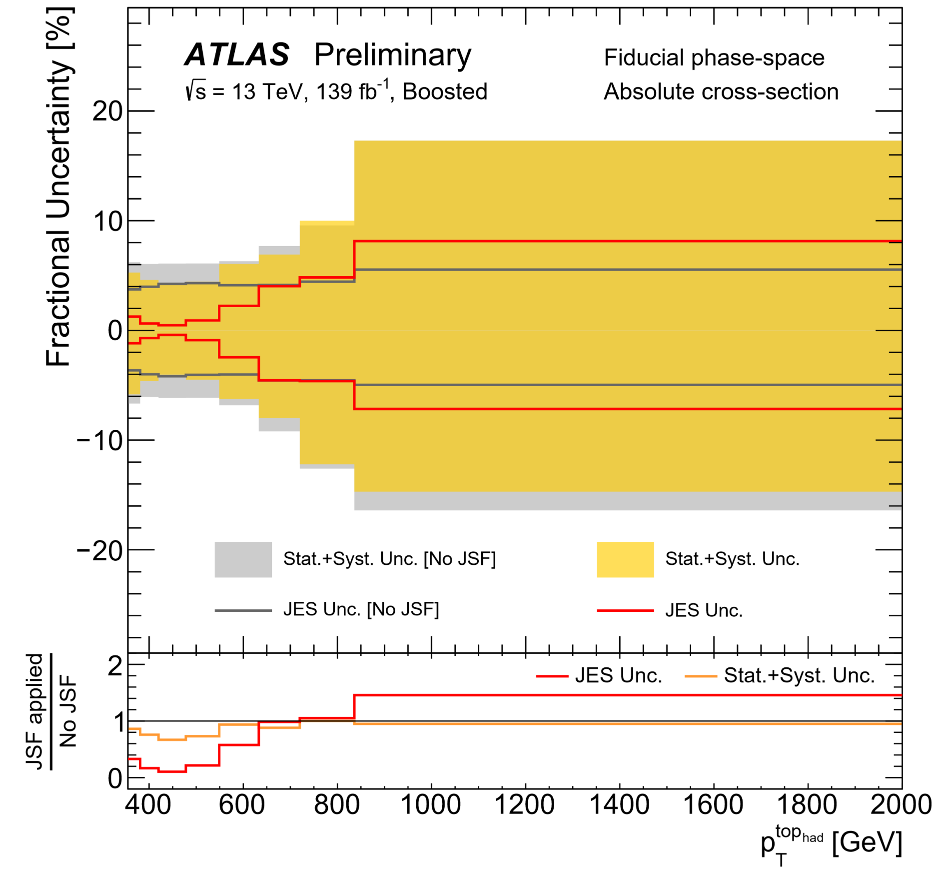
ATLAS-CONF-2021-031

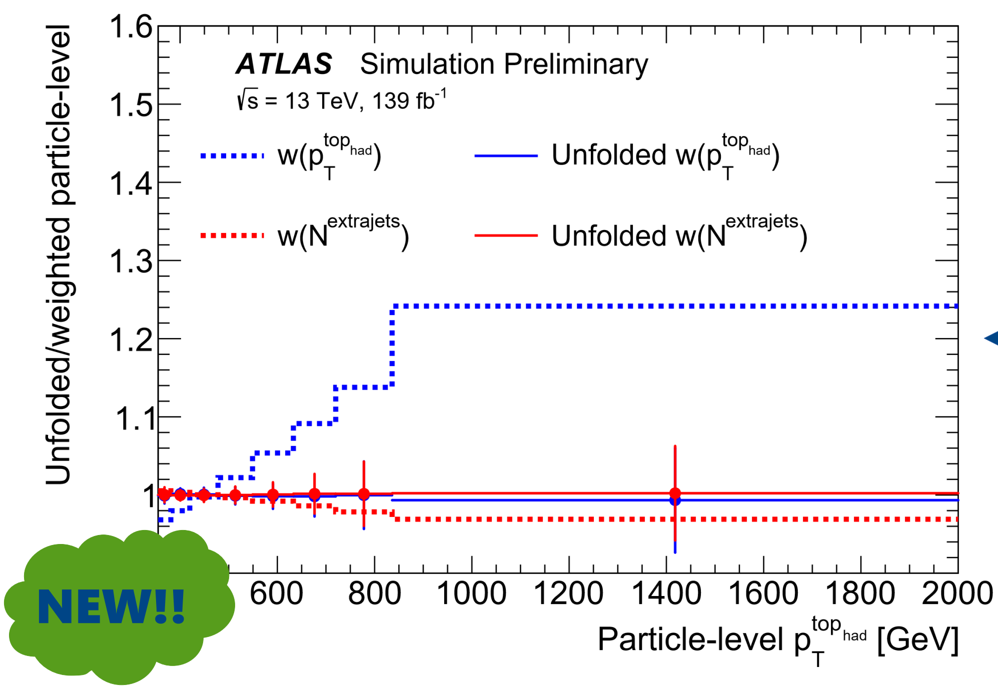
dσ($t\bar{t}$): l+jets @13 TeV (boosted)

Systematic uncertainty evaluation:

The JSF technique brings a significant improvement on the total uncertainty: **from 6% to 4.3% on the inclusive measurement**.

- Only Jet related uncertainties significantly reduced
  - 4.2% → 0.67%
- Modelling uncertainties slightly affected
- Pileup uncertainty increased
- Lumi, bkg and other detector unc unchanged
- Include an uncertainty on top jet mass (1%)
- Include the statistical uncertainty on JSF



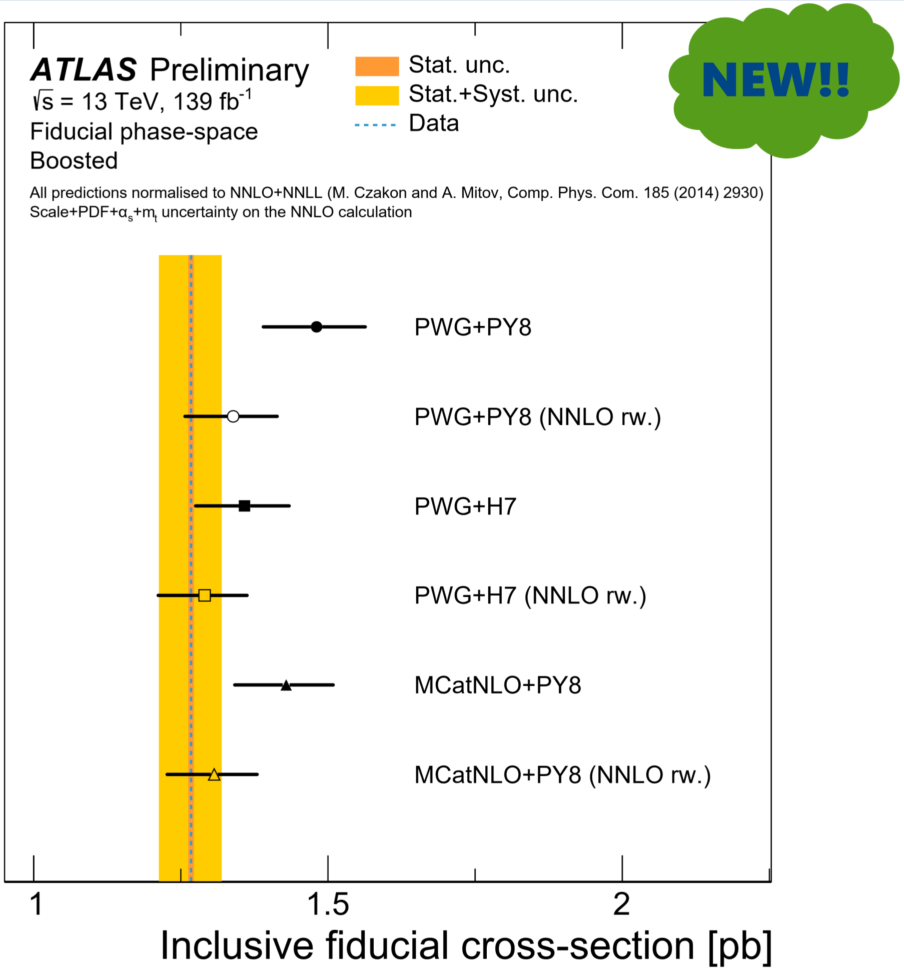


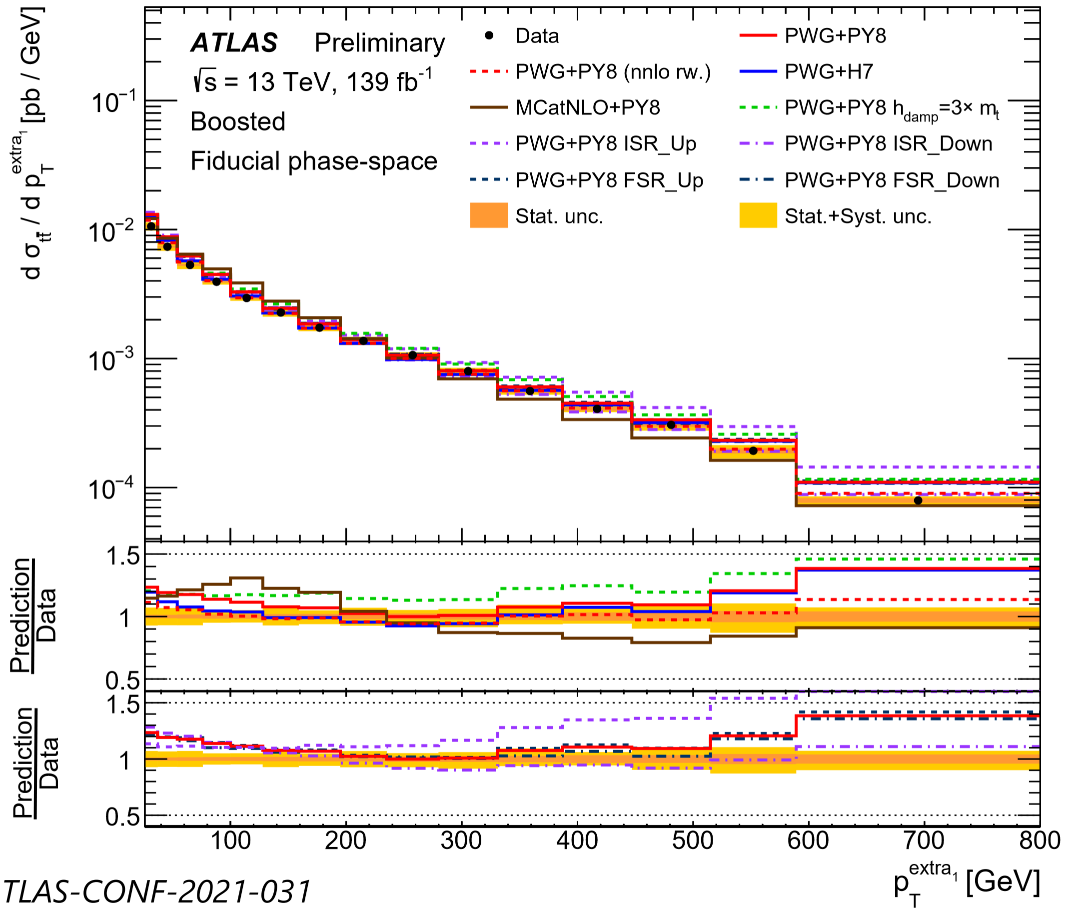
- Result unfolded to particle level
  - Several checks on the validity of the unfolding technique
- System reconstructed with the pseudo-top algorithm
- Measured kinematic observables of the top quark, $t\bar{t}$ system and additional radiation

ATLAS-CONF-2021-031

dσ(t$\bar{t}$): l+jets @13 TeV (boosted)

- Inclusive fiducial xs overestimated by several NLO+PS predictions, as observed also in previous boosted measurements from ATLAS and CMS
- Fiducial xs agrees significantly better with NLO+PS prediction reweighted to NNLO(QCD)+NLO(EW) @ parton-level





ATLAS-CONF-2021-031

- Good agreement in shape observed between single differential distributions and several NLO+PS predictions
- Measurement used to extract limit on EFT coupling (see P. Berta talk)
- More details in J. Jamieson Poster!!

Conclusions

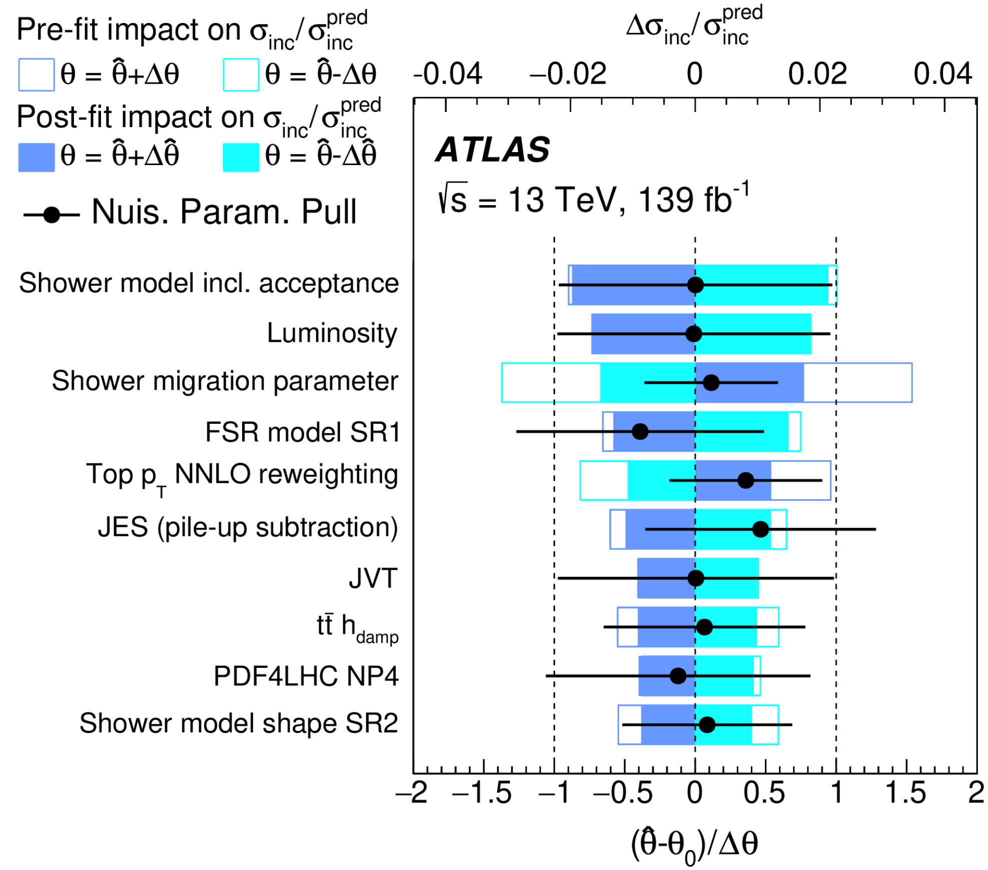
- Presented most recent inclusive and differential measurements of $t\bar{t}$ production performed by ATLAS :
  - **Differential measurements performed in all channels** l+jets (resolved and boosted topologies), all-hadronic and dilepton.
  - As a **function of many observables** of $t\bar{t}$, jets and leptons kinematics, including double differential distributions, at particle and parton level.
  - Presented the **first ATLAS measurement at 5 TeV.**
  - Showed new **techniques that can really improve the precision of the measurements**, with the **boosted topology reaching the resolved one**.
  - No significant differences with the SM have been observed
    - **Some tension observed with the NLO predictions**, in particular on double-differential distributions and variables related to the top p_T.

- Differential and Inclusive measurements are used to extract limits on new physics (P. Berta)

Thank you for your attention!

$\sigma(t\bar{t})$: l+jets @13 TeV, systematic

Category	$\frac{\Delta\sigma_{\text{fid}}}{\sigma_{\text{fid}}}$ [%]	$\frac{\Delta\sigma_{\text{inc}}}{\sigma_{\text{inc}}}$ [%]
Signal modelling		
$t\bar{t}$ shower/hadronisation	±2.8	±2.9
$t\bar{t}$ scale variations	±1.4	±2.0
Top p_{T} NNLO reweighting	±0.4	±1.1
$t\bar{t}$ h_{damp}	±1.5	±1.4
$t\bar{t}$ PDF	±1.4	±1.5
Background modelling		
MC background modelling	±1.8	±2.0
Multijet background	±0.8	±0.6
Detector modelling		
Jet reconstruction	±2.5	±2.6
Luminosity	±1.7	±1.7
Flavour tagging	±1.2	±1.3
$E_{\text{T}}^{\text{miss}}$ + pile-up	±0.3	±0.3
Muon reconstruction	±0.6	±0.5
Electron reconstruction	±0.7	±0.6
Simulation stat. uncertainty	±0.6	±0.7
Total systematic uncertainty	±4.3	±4.6
Data statistical uncertainty	±0.05	±0.05
Total uncertainty	±4.3	±4.6



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$\sigma(t\bar{t})$: l+jets boosted @13 TeV, systematic

Source	Uncertainty [%]	Uncertainty [%] (no JSF)
Statistical (data)	±0.4	±0.4
JSF statistical (data)	±0.4	—
Statistical (MC)	±0.2	±0.1
Hard scatter	±0.5	±0.8
Hadronisation	±2.0	±1.8
Radiation (IFSR + h_{damp})	$^{+1.0}_{-1.6}$	$^{+1.4}_{-2.3}$
PDF	±0.1	±0.1
Top-quark mass	$^{+0.8}_{-1.1}$	±0.1
Jets	±0.7	±4.2
b-tagging	±2.4	±2.4
Leptons	±0.8	±0.8
E_T^{miss}	±0.1	±0.1
Pileup	±0.4	±0.0
Luminosity	±1.8	±1.8
Backgrounds	±0.7	±0.6
Total systematics	$^{+4.1}_{-4.3}$	$^{+5.8}_{-6.0}$
Total	$^{+4.1}_{-4.3}$	$^{+5.8}_{-6.0}$