ICHEP 2018

# Top-quark pair production cross-section measurements with the ATLAS detector


Peter Berta

on behalf of the ATLAS Collaboration

Johannes Gutenberg University Mainz


5 Jul 2018

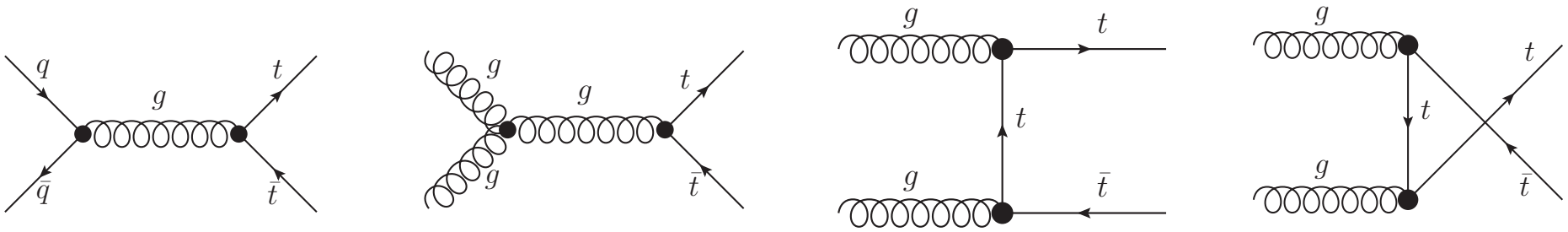

SPONSORED BY THE

Federal Ministry of Education and Research




# Top Quark Production at the ATLAS experiment

- Top-quark pair ($t\bar{t}$) production - probes QCD interactions



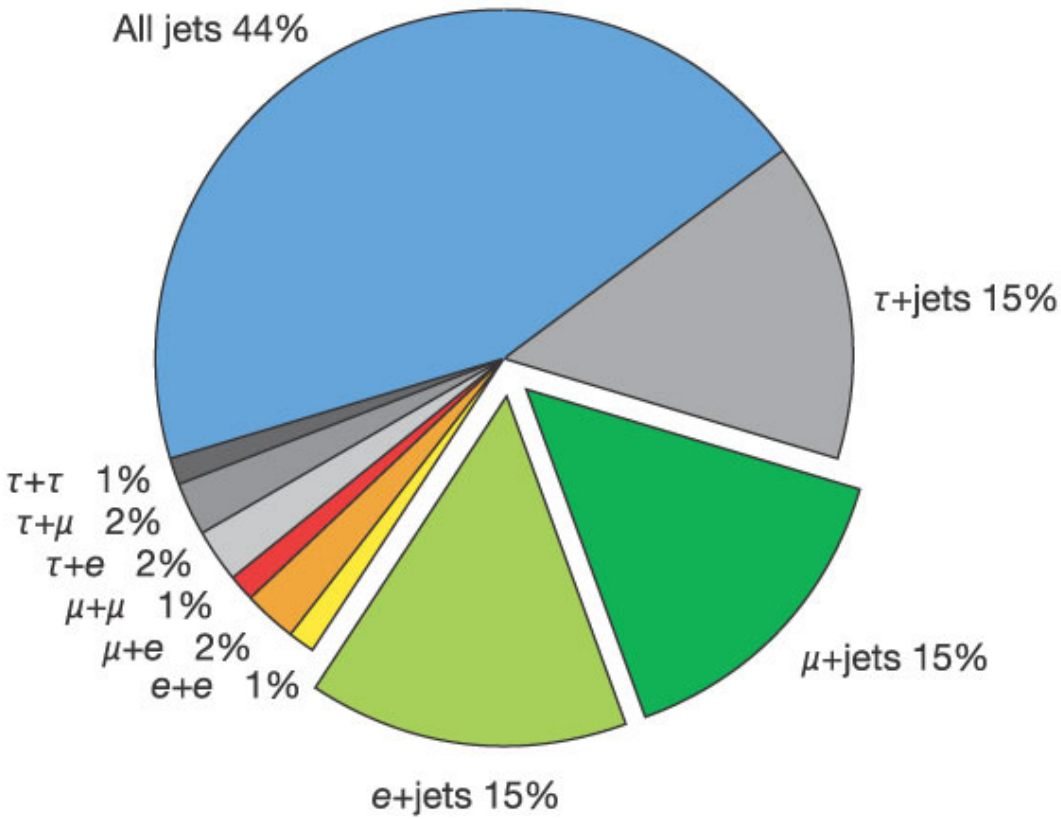

- Single top production - probes electro-weak interactions
  - covered in ATLAS talk from Marcel Vreeswijk, 5 Jul 2018, 10:00
- Associated with $\gamma/Z/W/b$-quarks
  - covered in ATLAS talk from Marisa Sandhoff, 5 Jul 2018, 11:15

# $t\bar{t}$ cross sections

- Large recorded luminosity allows for high-precision measurements
- Motivations:
  - Precision test of the Standard Model (SM)
  - Sensitivity to new physics beyond the SM
  - Constrain PDF fits
  - Constrain MC generator parameters
    - Important for many searches since top quark production is background for them
  - Extraction of the top quark pole mass

# $t\bar{t}$ decay channels

- Decay $t \longrightarrow Wb$ in $\sim 100\%$
  - Signature depends on the decay mode of the $W$ boson (leptonic or hadronic)
- Main selection regions for $t\bar{t}$: dilepton, lepton+jets, all-jets



# Type of measurements in ATLAS

- **Inclusive**
  - full phase space
  - fiducial phase space
- **Differential** - cross section as a function of certain observable defined at
  - parton level
    - full phase space
    - fiducial phase space
  - particle level
    - fiducial phase space

## Parton level

- defined using particles before hadronization

## Particle level

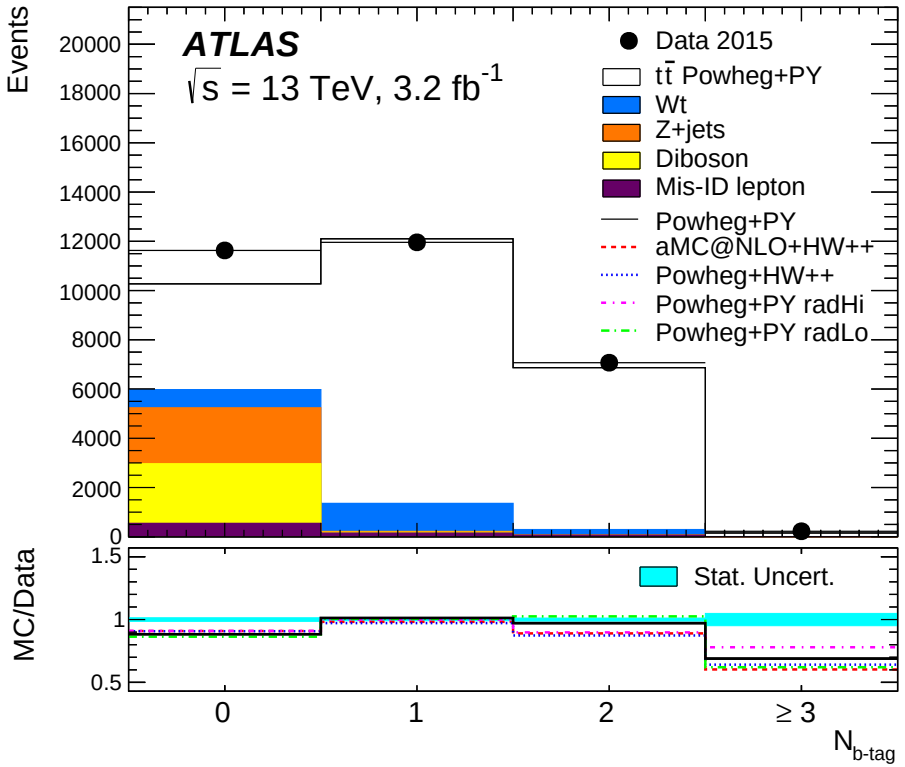
- defined using stable particles after hadronization ($c\tau > 1$ cm)
$\Rightarrow$ reduction of signal modeling uncertainties

## Fiducial phase space

- typically chosen to be close to the phase space of the selected data
- can use parton or particle level observables

# $t\bar{t}$ inclusive cross sections

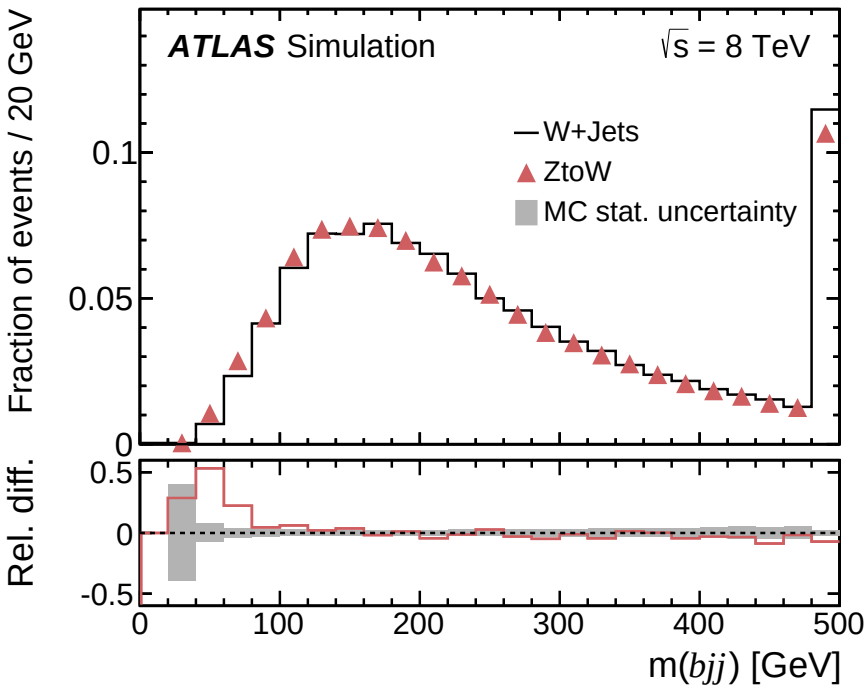
- Most precise measurements in dilepton selection at:
  - 7 TeV and 8 TeV:
    Eur. Phys. J. C74 (2014) 3109
  - 13 TeV:
    Phys. Lett. B761 (2016) 136
- Requiring opposite sign $e$ and $\mu$
- Requiring 1 and 2 $b$-tag jets
  - direct determination of $b$-tagging efficiency
- Main uncertainties: luminosity, LHC beam energy, signal modeling
- Total uncertainty $\sim 4\%$
- Full and fiducial phase-space measurements
- Results consistent with SM




Phys. Lett. B761 (2016) 136

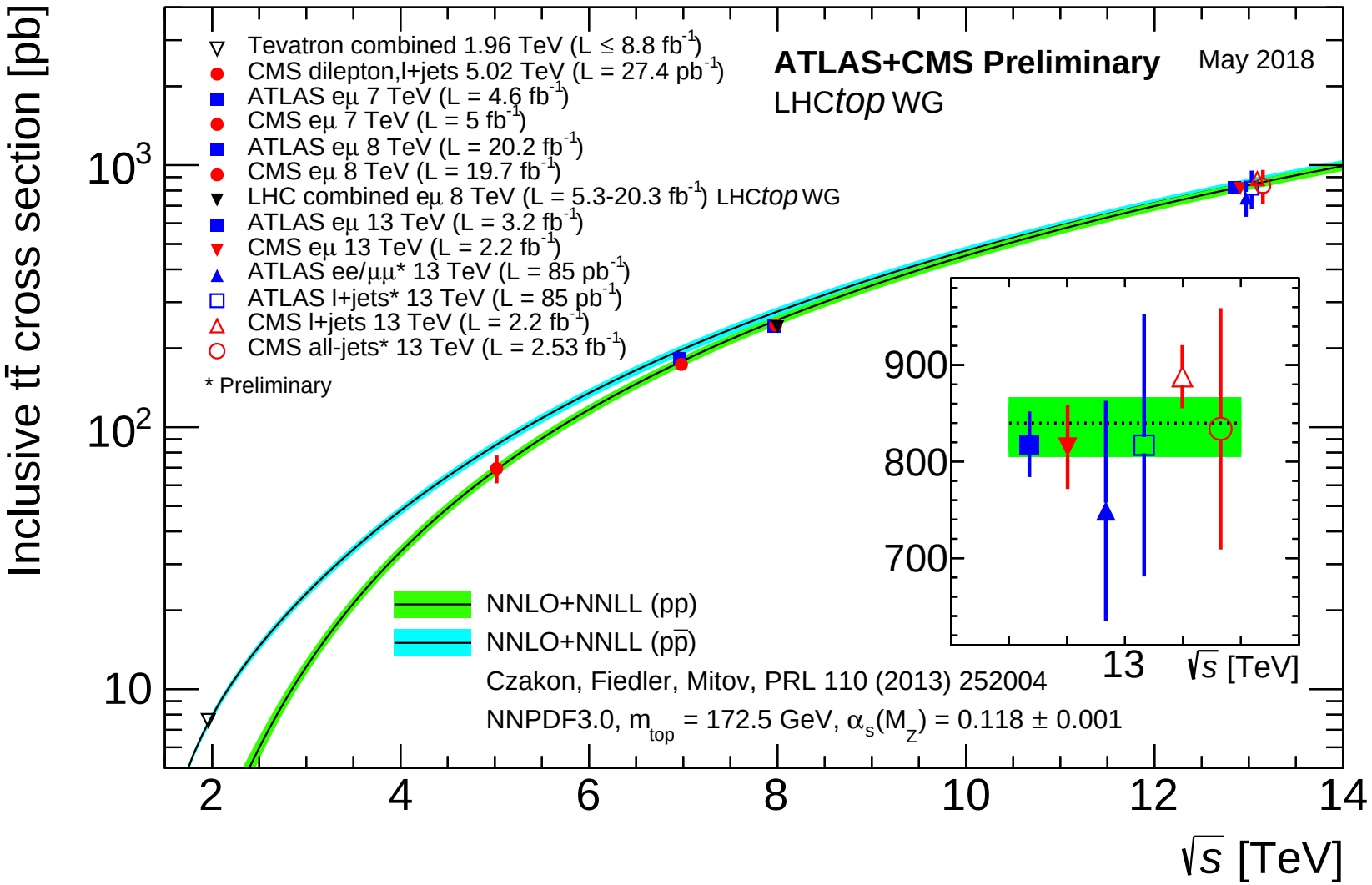
# $t\bar{t}$ inclusive cross sections

- Recently measured in lepton+jets selection
  - Eur. Phys. J. C 78 (2017) 487
- Reduction of systematic uncertainty for the estimate of $W$+jets background
  - data-based approach using $Z$+jets candidate events
- Uncertainty of $\sim 6\%$, main source: signal modeling, luminosity
- Full and fiducial phase-space measurements
- Results consistent with SM




Validation of the method to estimate $W$+jets background

# $t\bar{t}$ inclusive cross sections - summary



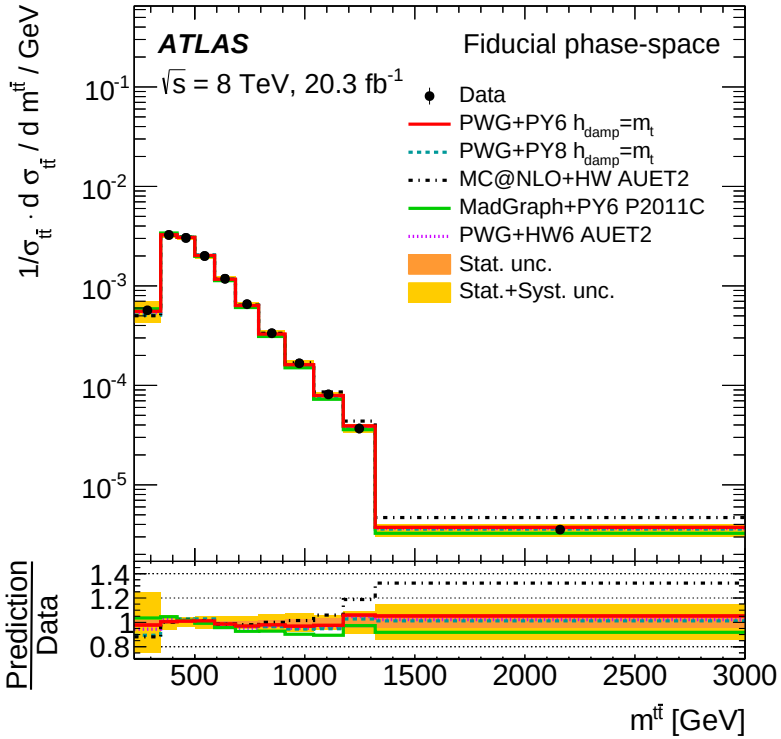

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/TOP/

# $t\bar{t}$ differential cross sections at 8 TeV and 13 TeV

Measured in various selection regions:

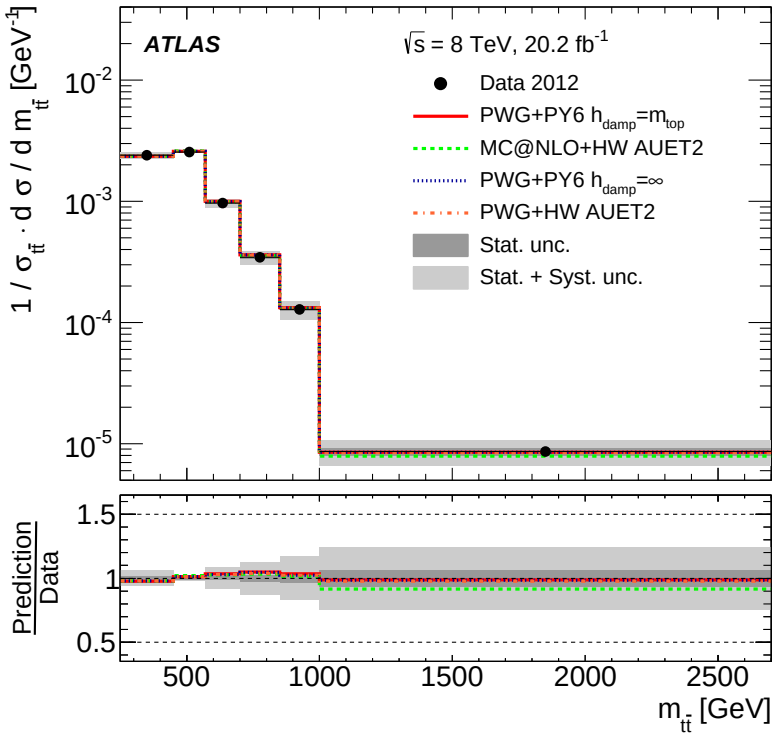
- All-jets (boosted): arXiv:1801.02052
  - no leptons
  - two large-R jets
    - jet substructure
  - $b$-tag jet within each large-R jet
- Lepton+jets (resolved): JHEP 11 (2017) 191, Eur. Phys. J. C76 (2016) 538, arXiv:1802.06572 ($t\bar{t}$+jets)
  - one lepton
  - at least four jets (at least one $b$-tag jet)
- Lepton+jets (boosted): JHEP 11 (2017) 191, Phys. Rev. D93 (2016) 032009
  - one lepton
  - one large-R jet
    - jet substructure
  - $b$-tag jet near lepton
- Dilepton: Eur. Phys. J. C77 (2017) 292, Phys. Rev. D94 (2016) 092003
  - opposite sign $e$ and $\mu$
  - two jets (at least one $b$-tag jet)

# $t\bar{t}$ differential cross sections at 8 TeV - $t\bar{t}$ mass




lepton+jets

Eur. Phys. J. C76 (2016) 538

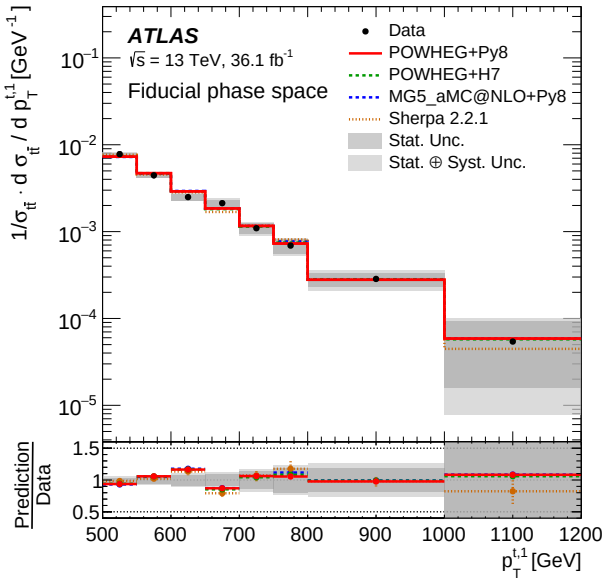



dilepton

Phys. Rev. D94 (2016) 092003

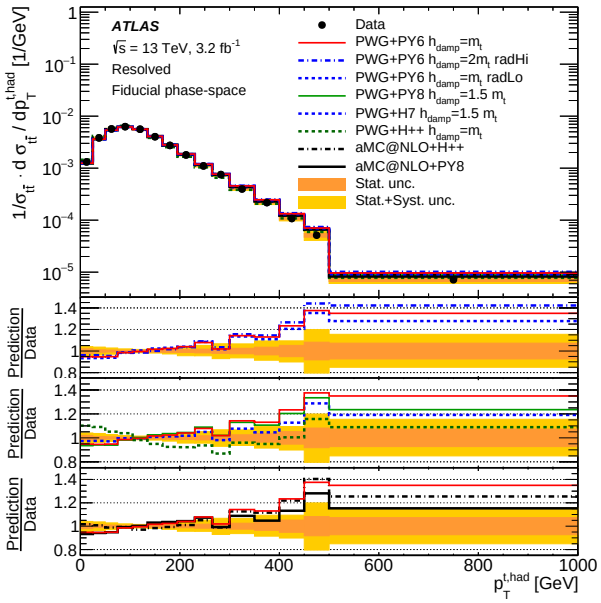
- Main uncertainties: signal modeling, JES, $b$-tagging
- Most SM predictions (NLO QCD + parton shower) are consistent with data

# $t\bar{t}$ differential cross sections at 13 TeV - top $p_{\mathrm{T}}$



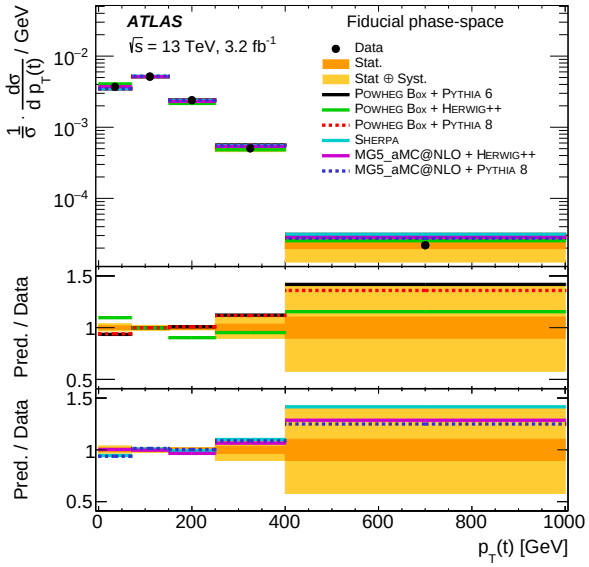

all-jets

arXiv:1801.02052




lepton+jets

JHEP 11 (2017) 191

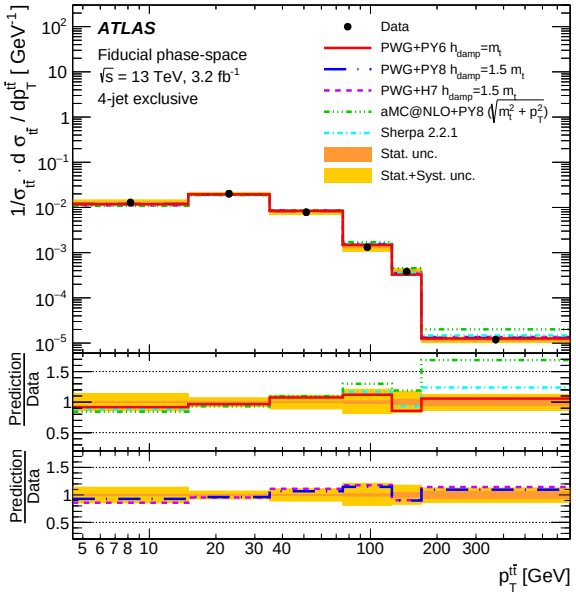



dilepton

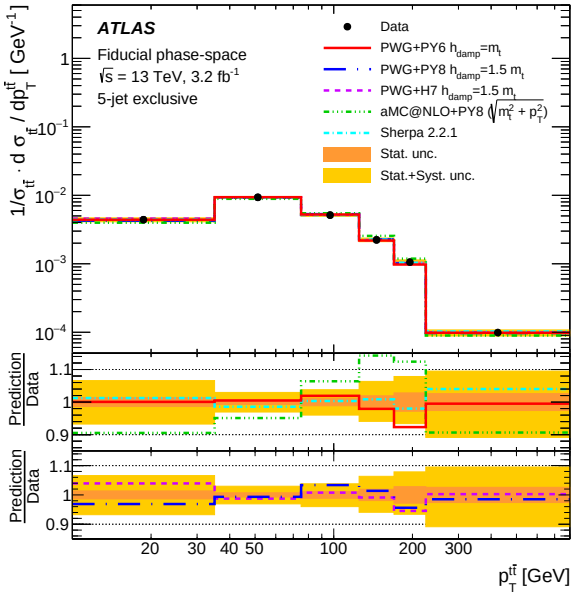
Eur. Phys. J. C77 (2017) 292

- Main uncertainties: JES, $b$-tagging, signal modeling
  - Signal modeling lower than at $8\ \mathrm{TeV}$ (improved signal modeling based on the $8\ \mathrm{TeV}$ measurements)
- Most SM predictions (NLO QCD + parton shower) are consistent with data
- These measurements allow to tune MC generators for the future

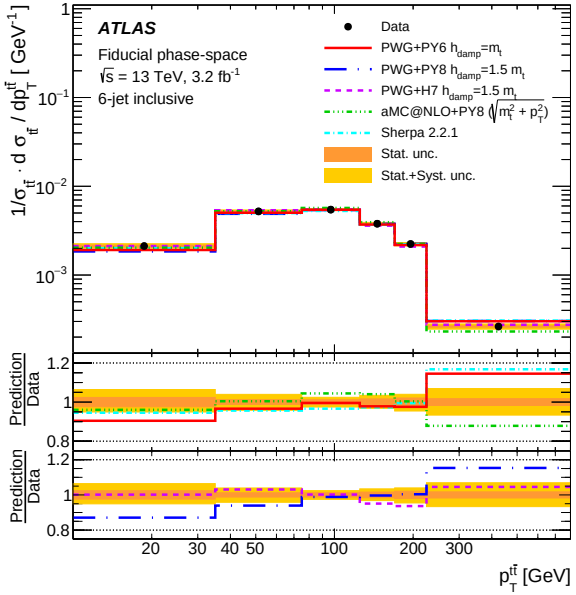
# $t\bar{t}$+jets differential cross sections at 13 TeV - $p_{\mathrm{T}}^{t\bar{t}}$




4 jets exclusive




5 jets exclusive




6 jets inclusive

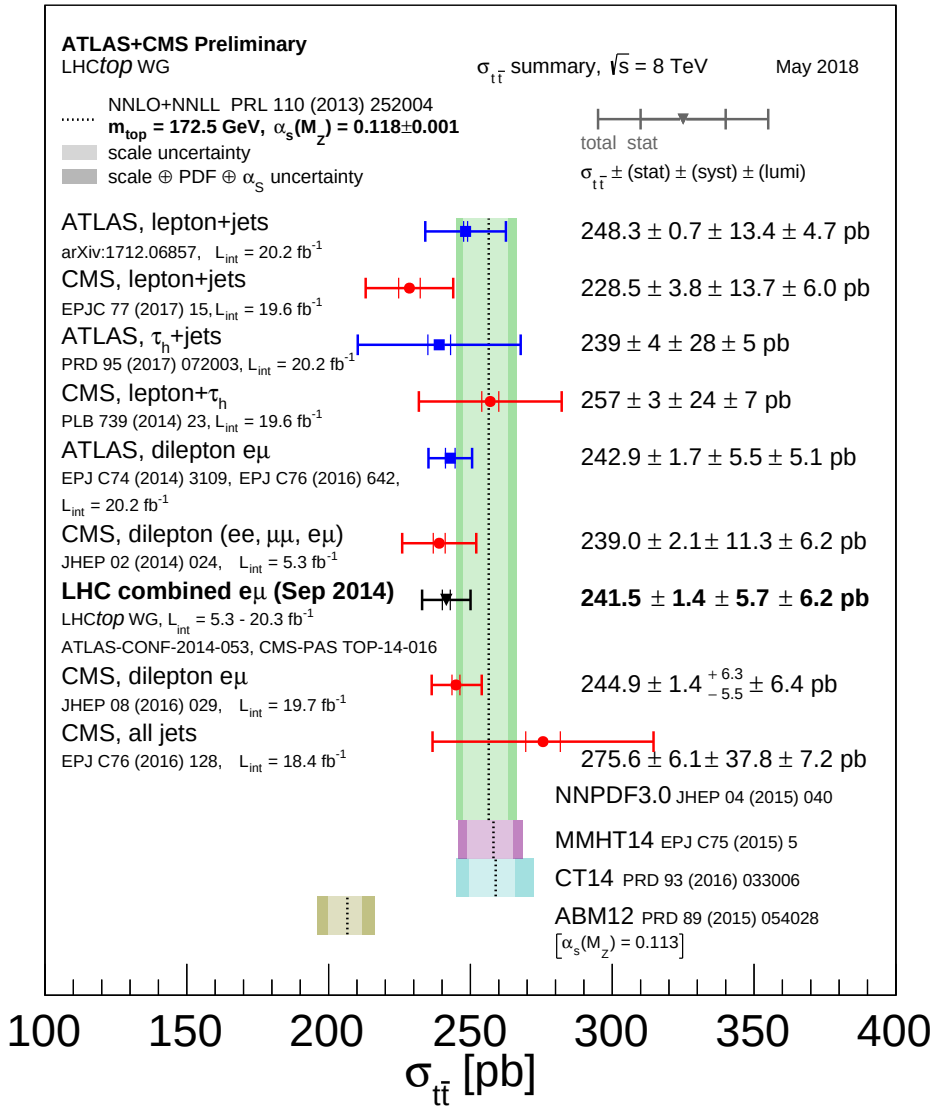
- arXiv:1802.06572
- Lepton+jets (resolved)
- Main uncertainties: JES, $b$-tagging, signal modeling
- Several tested MC configurations are disfavored
- Large potential to improve the MC configurations for the future

# Summary

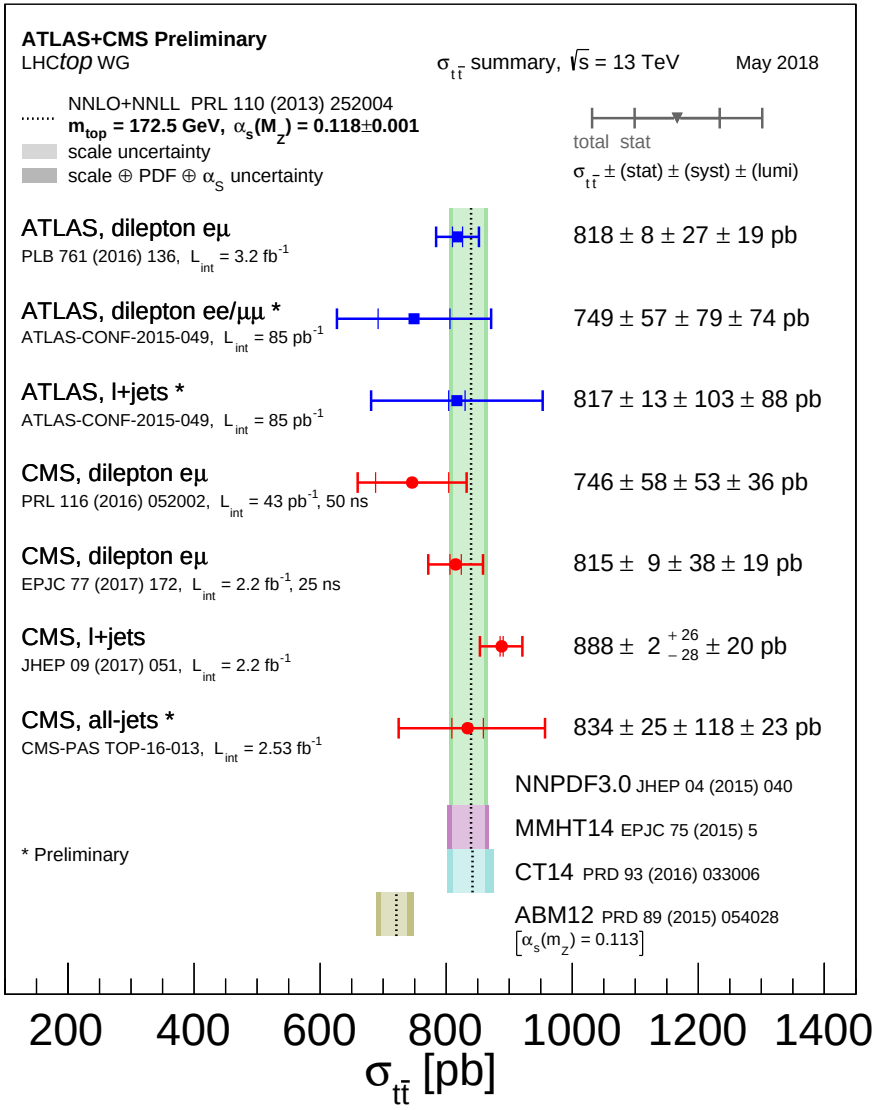
- The ATLAS experiment has an extensive program of inclusive and differential top pair cross-section measurements
- All measurements consistent with the Standard Model predictions
- Uncertainties of inclusive cross sections are up to a few percent
- Differential cross-section measurements probe the TeV scale
- $13\ \mathrm{TeV}$ measurements benefit from better signal modeling based on the $8\ \mathrm{TeV}$ measurements
  - expecting further reduction of signal modeling uncertainties in the future

# Backup

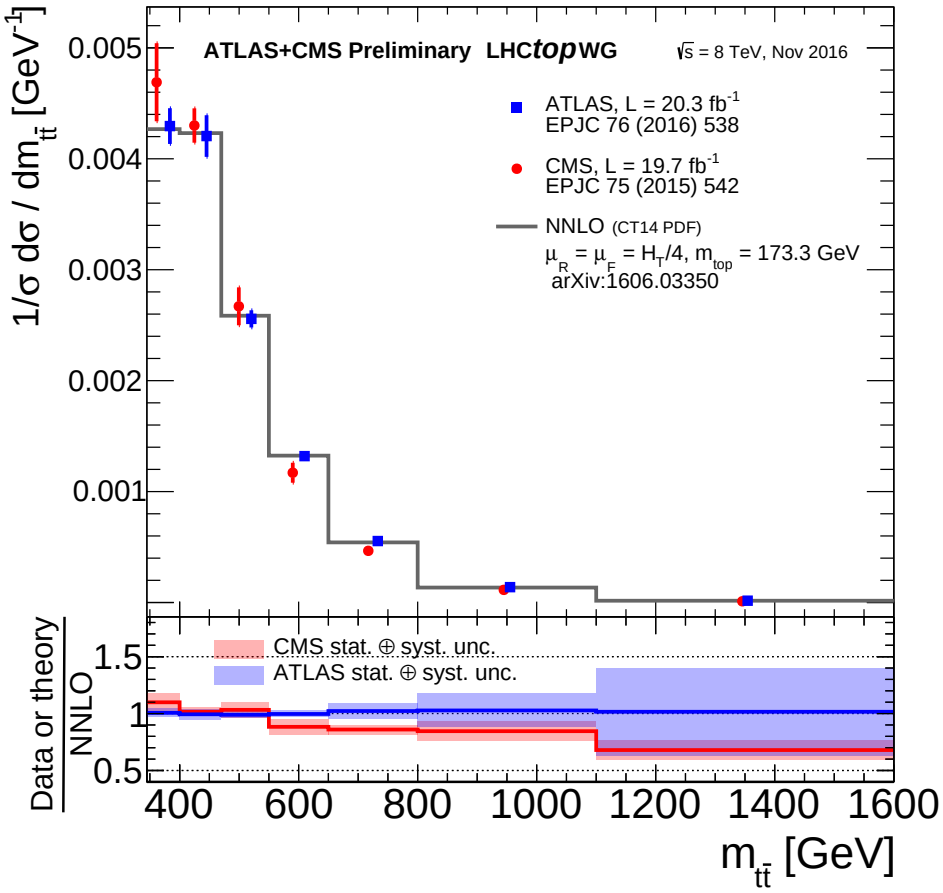
# $t\bar{t}$ total cross sections - 8 TeV

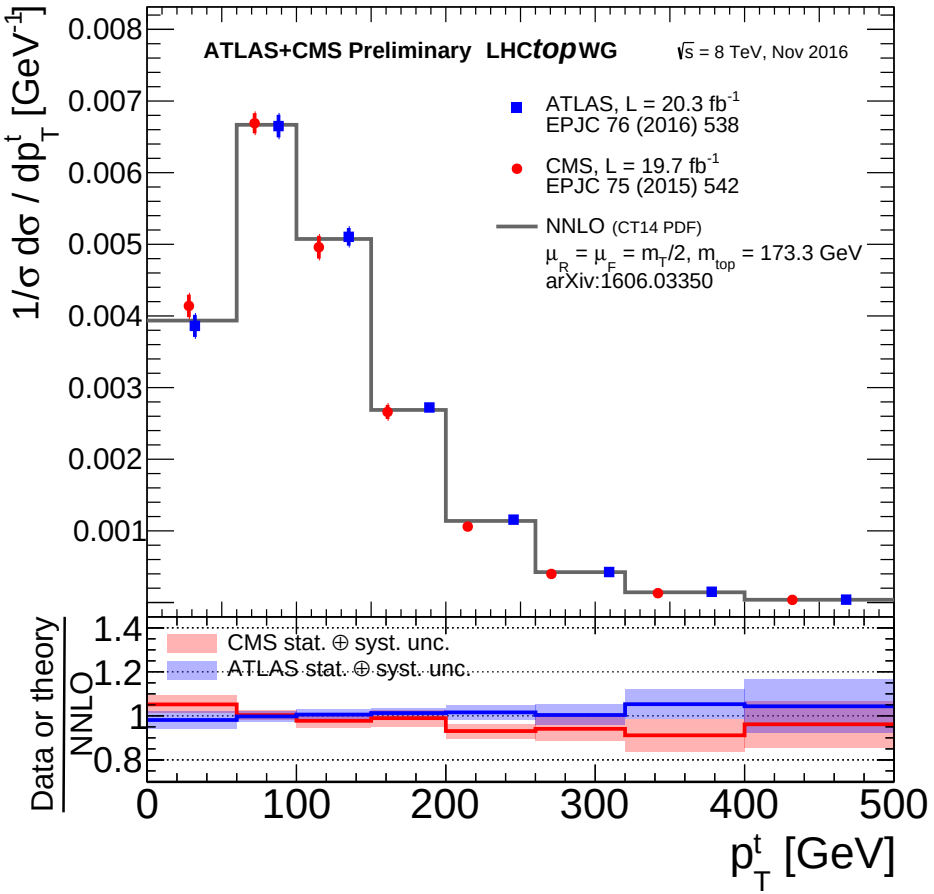


# $t\bar{t}$ total cross sections - 13 TeV



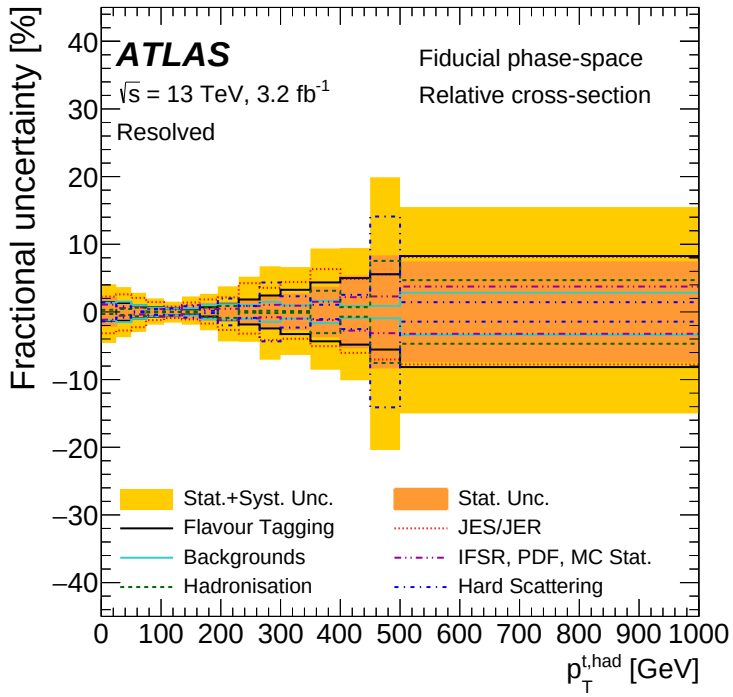
# $t\bar{t}$ differential cross sections - comparison with NNLO QCD




https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/TOP/

# $t\bar{t}$ differential cross sections - uncertainties and $p$-values




| Observable | $p_{\mathrm{T}}^{t,\mathrm{had}}$ | | $\lvert y^{t,\mathrm{had}}\rvert$ | | $m^{t\bar{t}}$ | | $p_{\mathrm{T}}^{t\bar{t}}$ | | $\lvert y^{t\bar{t}}\rvert$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\chi^2$/NDF | $p$-val | $\chi^2$/NDF | $p$-val | $\chi^2$/NDF | $p$-val | $\chi^2$/NDF | $p$-val | $\chi^2$/NDF | $p$-val |
| Powheg+Pythia6 | 23.0/14 | 0.06 | 8.1/17 | 0.96 | 6.3/10 | 0.79 | 7.7/5 | 0.17 | 22.5/17 | 0.17 |
| Powheg+Pythia6 (radHi) | 23.8/14 | 0.05 | 8.5/17 | 0.95 | 7.7/10 | 0.66 | 5.1/5 | 0.41 | 19.3/17 | 0.31 |
| Powheg+Pythia6 (radLo) | 25.9/14 | 0.03 | 7.5/17 | 0.98 | 8.2/10 | 0.61 | 20.4/5 | <0.01 | 28.0/17 | 0.04 |
| MadGraph5_aMC@NLO+Herwig++ | 24.4/14 | 0.04 | 10.8/17 | 0.87 | 23.6/10 | <0.01 | 2.6/5 | 0.76 | 30.0/17 | 0.03 |
| Powheg+Herwig++ | 24.0/14 | 0.05 | 7.4/17 | 0.98 | 37.9/10 | <0.01 | 25.0/5 | <0.01 | 32.8/17 | 0.01 |
| MadGraph5_aMC@NLO+Pythia8 | 21.8/14 | 0.08 | 7.8/17 | 0.97 | 6.8/10 | 0.75 | 3.3/5 | 0.66 | 18.0/17 | 0.39 |
| Powheg+Pythia8 | 21.5/14 | 0.09 | 9.6/17 | 0.92 | 6.5/10 | 0.77 | 1.1/5 | 0.96 | 14.0/17 | 0.67 |
| Powheg+Herwig7 | 15.4/14 | 0.35 | 9.3/17 | 0.93 | 6.7/10 | 0.76 | 5.4/5 | 0.37 | 15.1/17 | 0.59 |

13 TeV, single lepton (resolved), JHEP 11 (2017) 191

# $t\bar{t}$ +jets differential cross sections - $p$-values

| | 4-jet exclusive | | 5-jet exclusive | | 6-jet inclusive | |
|---|---|---|---|---|---|---|
| | $\chi^2$/NDF | $p$-value | $\chi^2$/NDF | $p$-value | $\chi^2$/NDF | $p$-value |
| Powheg+Pythia6 | 4.3/5 | 0.51 | 3.0/5 | 0.70 | 3.9/5 | 0.56 |
| Powheg+Pythia6 (radHi) | 5.2/5 | 0.40 | 6.3/5 | 0.28 | 9.8/5 | 0.08 |
| Powheg+Pythia6 (radLo) | 6.2/5 | 0.29 | 3.5/5 | 0.62 | 5.2/5 | 0.39 |
| Powheg+Pythia8 ($h_{\text{damp}} = m_t$) | 7.6/5 | 0.18 | 4.5/5 | 0.48 | 4.7/5 | 0.46 |
| Powheg+Pythia8 ($h_{\text{damp}} = 1.5\,m_t$) | 5.5/5 | 0.36 | 3.9/5 | 0.57 | 6.2/5 | 0.28 |
| Powheg+Pythia8 (radHi) ($h_{\text{damp}} = 3\,m_t$) | 6.5/5 | 0.26 | 4.0/5 | 0.55 | 10.5/5 | 0.06 |
| Powheg+Pythia8 (radLo) ($h_{\text{damp}} = 1.5\,m_t$) | 5.2/5 | 0.39 | 5.6/5 | 0.35 | 7.6/5 | 0.18 |
| Powheg+Herwig7 | 10.5/5 | 0.06 | 5.1/5 | 0.41 | 3.1/5 | 0.68 |
| Powheg+Herwig++ | 18.6/5 | ¡0.01 | 16.2/5 | ¡0.01 | 19.4/5 | ¡0.01 |
| MadGraph5_aMC@NLO+Herwig++ | 12.8/5 | 0.03 | 10.0/5 | 0.07 | 9.3/5 | 0.10 |
| MadGraph5_aMC@NLO+Pythia8 ($H_{\text{T}}/2$) | 26.8/5 | ¡0.01 | 10.2/5 | 0.07 | 8.2/5 | 0.14 |
| MadGraph5_aMC@NLO+Pythia8 ($\sqrt{m_t^2 + p_{\text{T}}^2}$) | 17.3/5 | ¡0.01 | 10.0/5 | 0.07 | 7.8/5 | 0.17 |
| Sherpa 2.2.1 | 7.5/5 | 0.19 | 1.7/5 | 0.89 | 2.2/5 | 0.82 |

arXiv:1802.06572