QFTHEP'2017

Highlights of top quark cross-section measurements at ATLAS

Peter Berta
on behalf of the ATLAS Collaboration

Johannes Gutenberg University Mainz

29 Jun 2017

SPONSORED BY THE
Federal Ministry of Education and Research

Introduction

- Millions of top quarks produced at the LHC at various center-of-mass energies: $7\ \mathrm{TeV}$, $8\ \mathrm{TeV}$, and $13\ \mathrm{TeV}$
- Measurements of top production cross-sections:
  - Precision test of the Standard Model
  - Sensitive to new physics beyond the Standard Model
  - Constrain PDF fits
  - Constrain MC generators parameters
  - Estimation of the CKM matrix element V_{tb}
  - Used to extract the top quark pole mass

Top Quark

Production at the LHC:

- Top-antitop pair ($t\bar{t}$) production - probes QCD interactions
- Single top production - probes electro-weak interactions
  - t-channel
  - associated with a W boson
  - s-channel
- $t\bar{t}$ associated with $\gamma/Z/W/H$ (not covered in this talk)

Decay:

- $t \longrightarrow Wb$ in $\sim 100\%$
- Signature depends on the decay mode of the W boson (leptonic or hadronic)

Top cross-section measurement possibilities at ATLAS

- **Inclusive**
  - full phase-space
  - fiducial phase-space
- **Differential** - cross-section as a function of certain observable defined at
  - parton level
    - full phase-space
    - possibility to define in fiducial phase-space (not explored yet)
  - particle level
    - fiducial phase-space

Fiducial phase-space

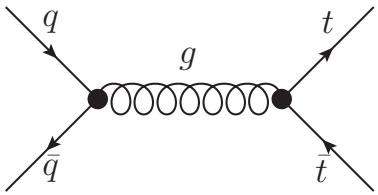
- mostly defined with particle level objects
- typically chosen to be close to the phase space of the selected data

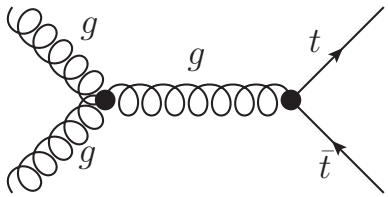
$\Rightarrow$ reduction of systematic uncertainties (mainly signal modeling)

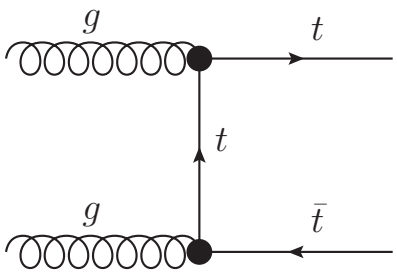
Particle level

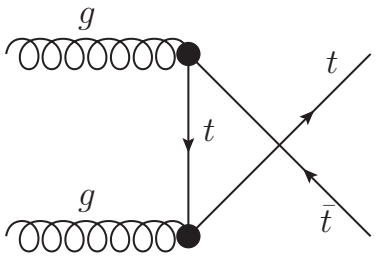
- defined using stable particles ($\tau > 0.3 \cdot 10^{-10}$ s)

$t\bar{t}$ cross-sections



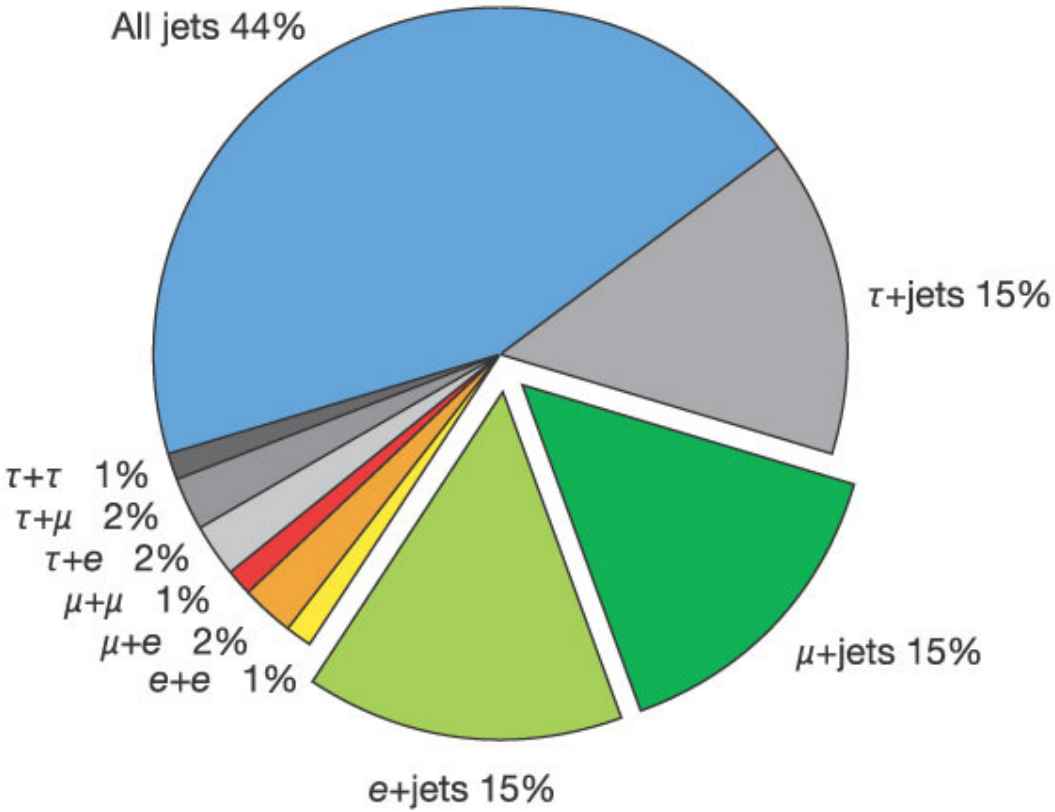






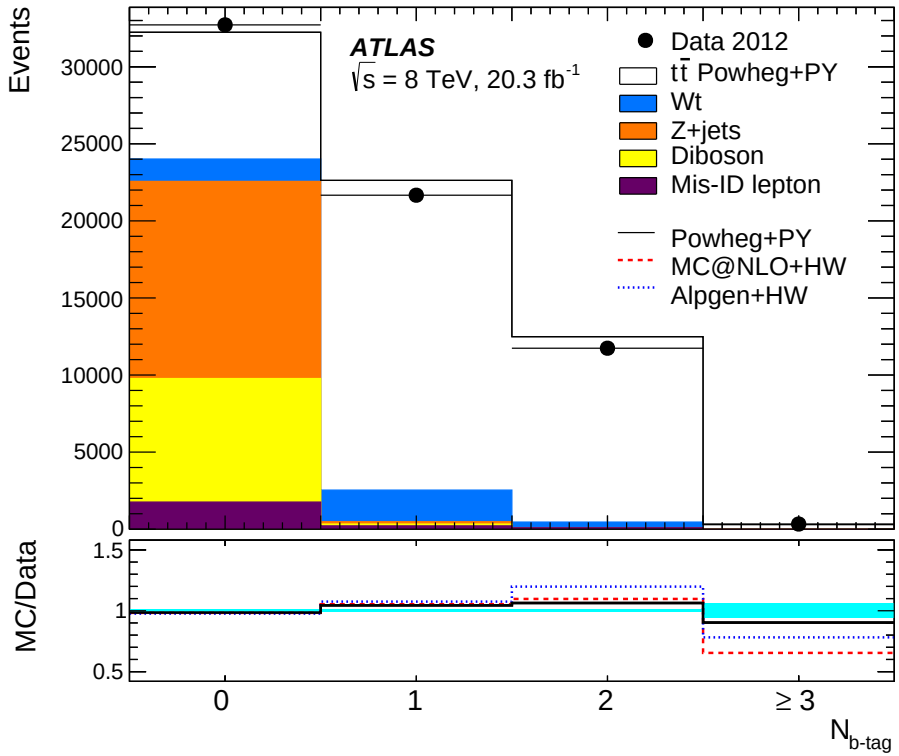
$t\bar{t}$ cross-sections

- Many decay channels with distinguishable signatures
- Main selection regions: dilepton, lepton+jets, all-jets

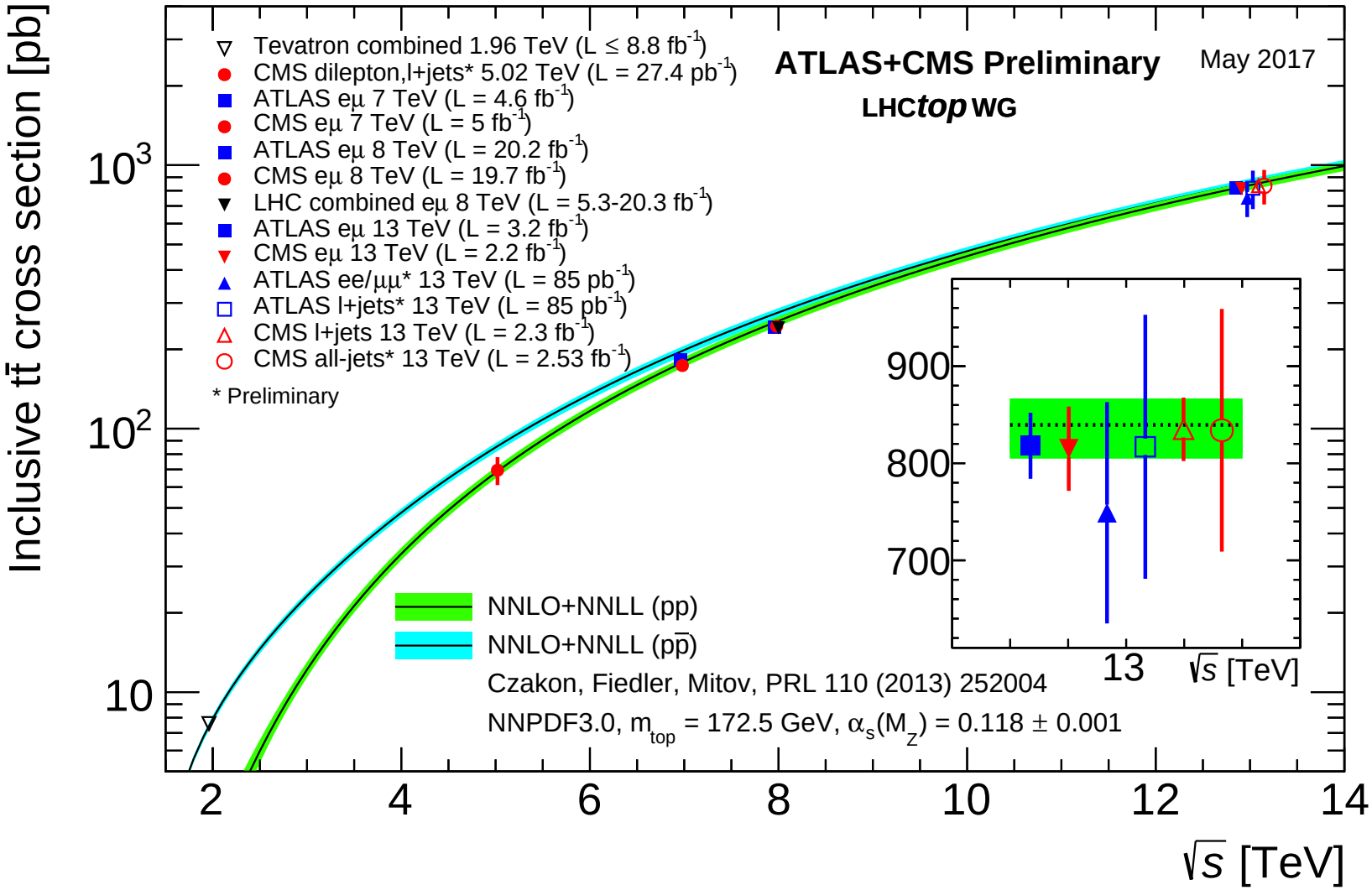


$t\bar{t}$ inclusive cross-sections

- 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 μ
- Requiring 1 and 2 b-tag jets
  - direct determination of b-tagging efficiency
- Main systematic uncertainties: luminosity, LHC beam energy, signal modeling
- Total uncertainty $\sim 4\%$
- Measurements consistent with SM



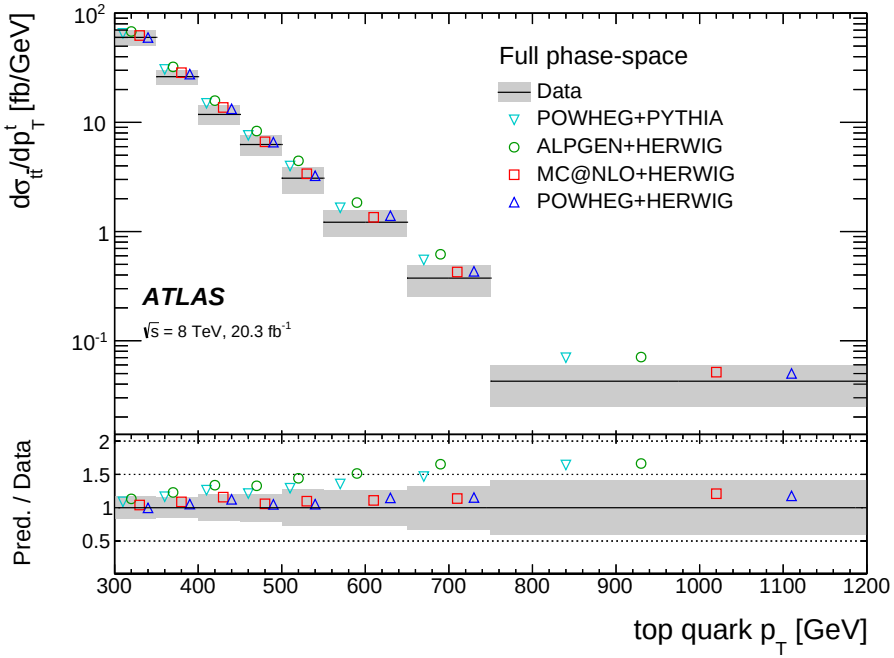
$t\bar{t}$ inclusive cross-sections - summary



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

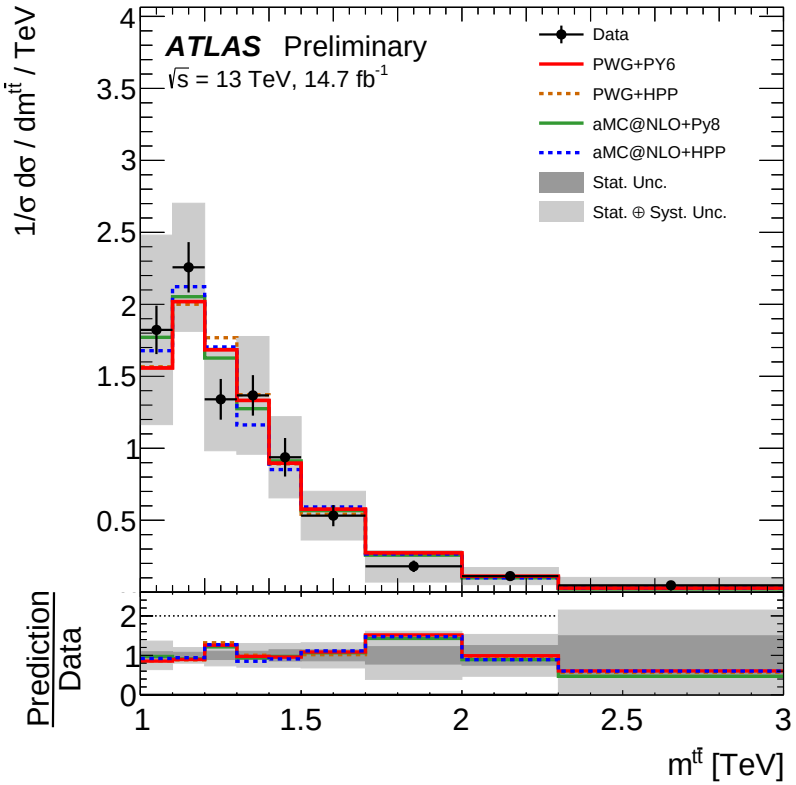
$t\bar{t}$ differential cross-sections - lepton+jets selection

- Measured at all c.m.s. energies
- Presenting 8 TeV results - two topologies for hadronic top quark:
  - Resolved - the three jets are well separated
    Eur. Phys. J. C76 (2016) 538
  - Boosted - the three jets are contained in a large-R jet
    Phys. Rev. D93 (2016) 032009
- Unfolding to particle and parton levels
- Main uncertainties: signal modelling, JES



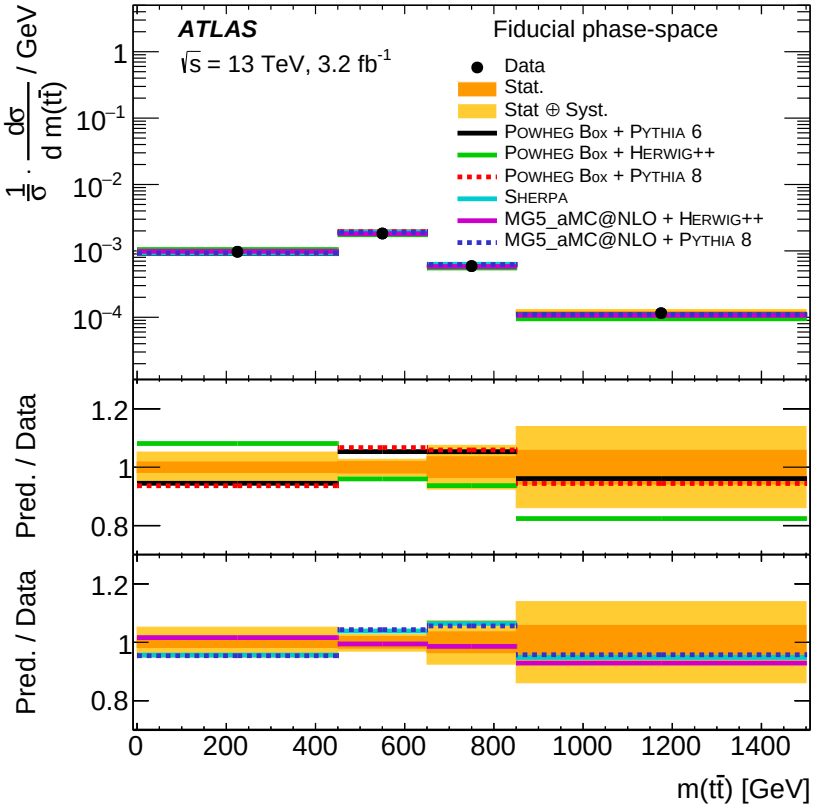
$t\bar{t}$ differential cross-sections - all-jets selection

- Preliminary 13 TeV results: ATLAS-CONF-2016-100
- Observables: top p_{T}, top $|y|$, $t\bar{t}$ mass, $t\bar{t}$ p_{T}, $t\bar{t}$ $|y|$, ...
- Boosted topology selection:
  - 2 large-R jets
    - jet substructure
  - no leptons
  - b-tag jet near each large-R jet
- Main background: QCD jet production
  - Data-driven estimation
- Unfolding to particle level
- Main uncertainties: signal modelling, JES of large-R jets



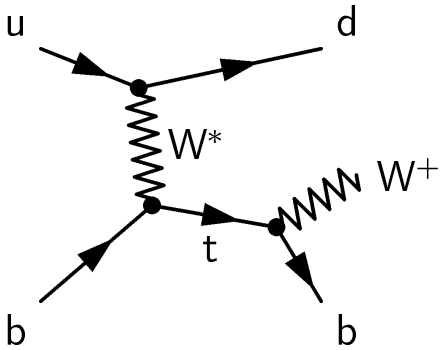
$t\bar{t}$ differential cross-sections - dilepton selection

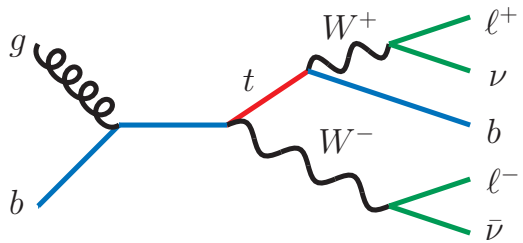
- Measured at all c.m.s. energies
- Presenting 13 TeV results: Eur. Phys. J. C77 (2017) 299
- Observables: top p_{T}, top $|y|$, $t\bar{t}$ mass, $t\bar{t}$ p_{T}, $t\bar{t}$ $|y|$
- Selection:
  - two jets (at least 1 b-tag jet)
  - opposite sign e and μ
    $\Rightarrow$ low background
- Unfolding to particle level
- Main uncertainties: signal modelling (PS), b-tagging

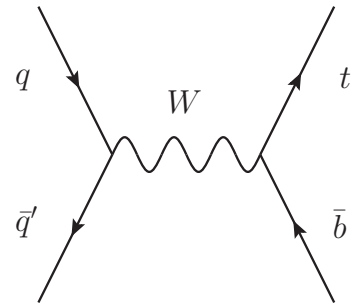


Measurement consistent with MC predictions (NLO QCD + PS) except Powheg Box + Herwig++

Single top cross-sections







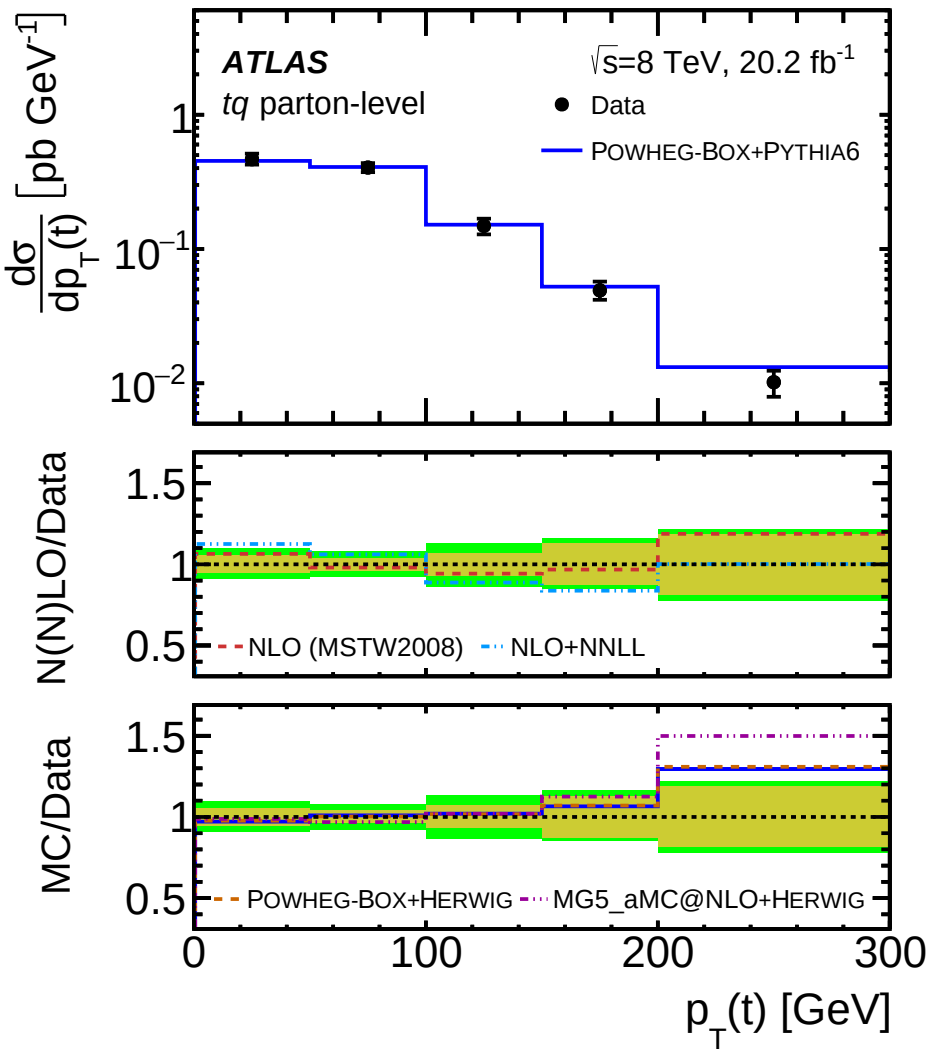
Single top cross-section measurements at ATLAS

- Selections focusing on leptonic decay of W bosons

Process	t-channel	Wt	s-channel
Selection	1 lepton, $E_{\mathrm{T}}^{\mathrm{miss}}$, 2 jets (1 b-tag)	2 leptons, 1 b-tag jet	1 lepton, $E_{\mathrm{T}}^{\mathrm{miss}}$, 2 b-tag jets
Main background	$t\bar{t}$, W+jets	$t\bar{t}$	$t\bar{t}$, W+jets, single top t-channel
Main uncertainty	JES, background modeling	JES, signal modeling	data statistics

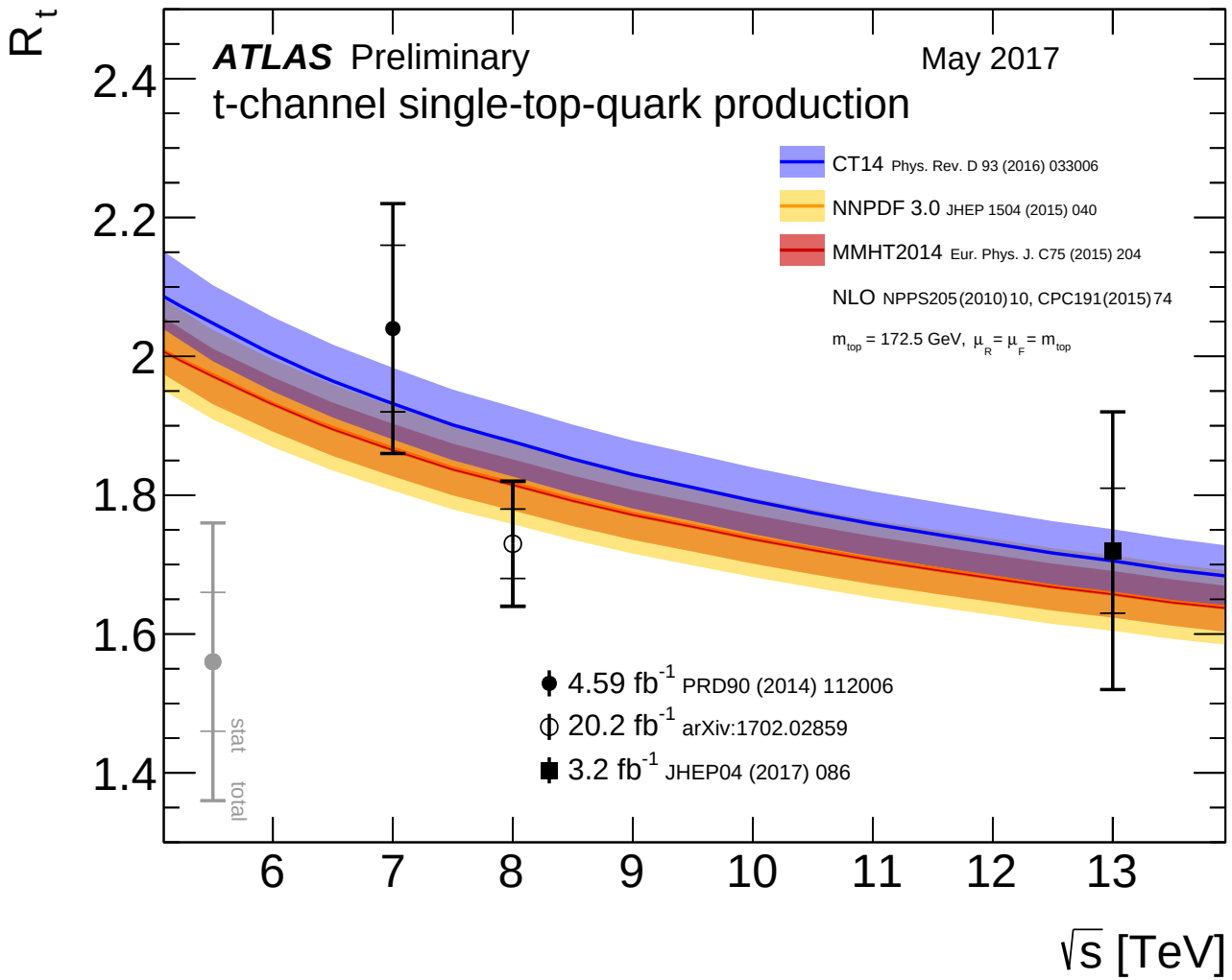
Single top t-channel

- Detailed measurement at 8 TeV: arXiv:1702.02859
- Top and antitop quark production measured separately
- Inclusive in full and fiducial phase-space
- Differential cross-sections at particle and parton levels
- Neural network to separate signal from background
- Inclusive fiducial cross-section measured with a precision of 5.8% (top quark) and 7.8% (antitop)



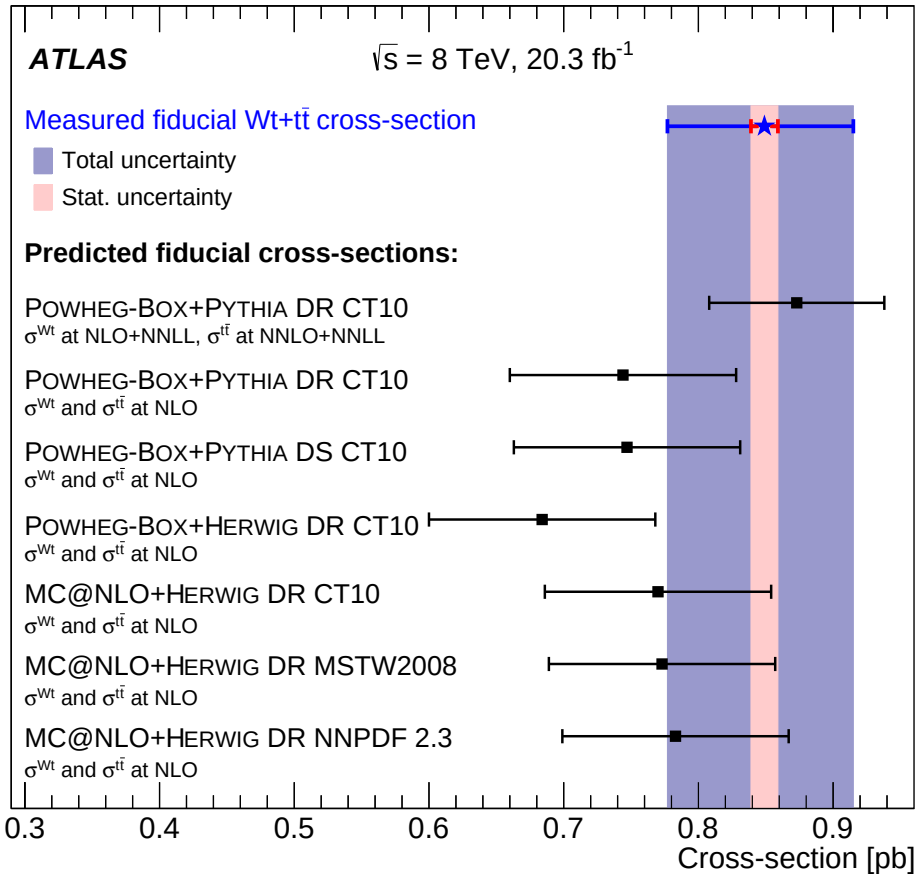
Single top t-channel - R_t

- R_t = ratio between top and antitop production
  - sensitive to d/u-quark ratio



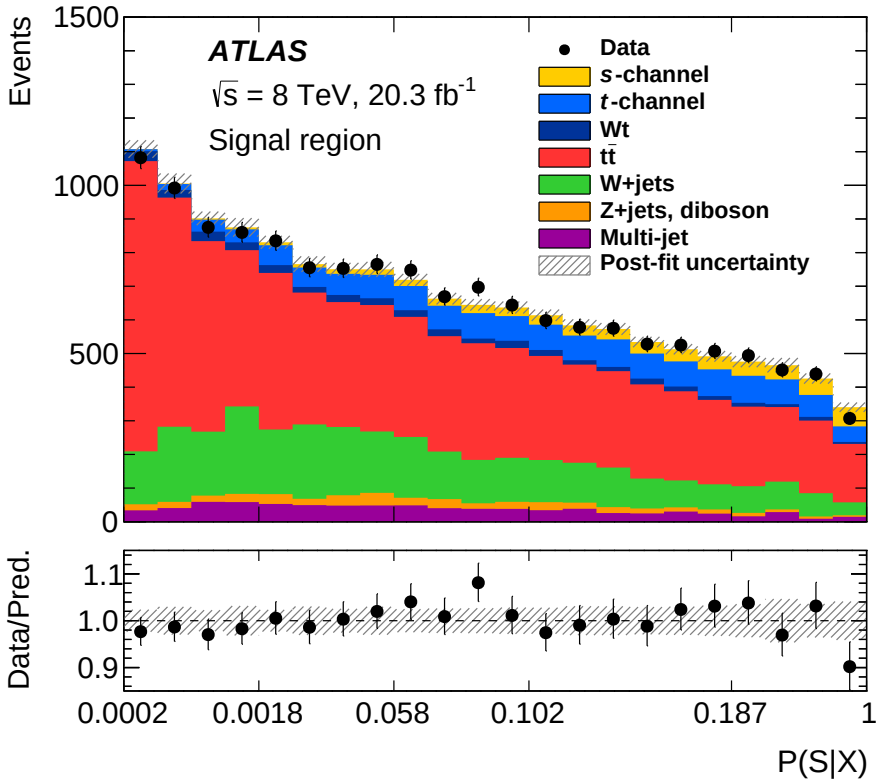
Single top Wt

- Difficult due to low cross-section and large background
- Selections based on boosted decision trees
- Lowest uncertainty so far $\sim 20\%$ in the 8 TeV measurement: JHEP 01 (2016) 064
- Measured cross-section in a fiducial phase space for the $t\bar{t}$ + Wt process
  - Reduced uncertainty wrt inclusive measurement
  - Consistent with various MC generators (QCD NLO + PS)

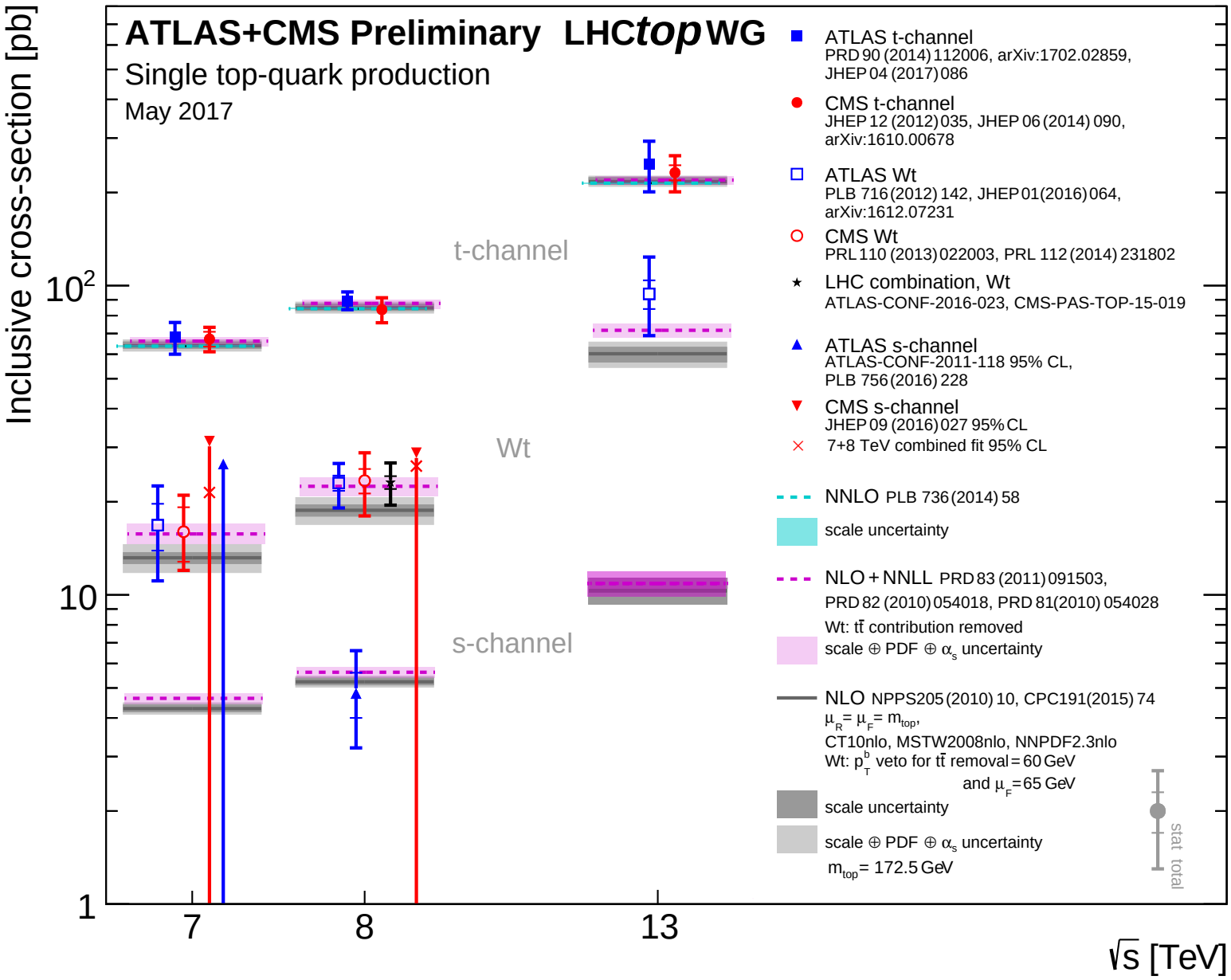


Single top s-channel

- Very challenging due to low cross-section and large background
- Evidence for the first time at ATLAS:
  Phys. Lett. B 756 (2016) 228-246
- Observed significance:
  3.2 standard deviations
- Measured cross-section consistent with SM
- Matrix element method
  - event-by-event discriminant based on matrix elements of signal and background processes



Single top inclusive cross-sections - summary

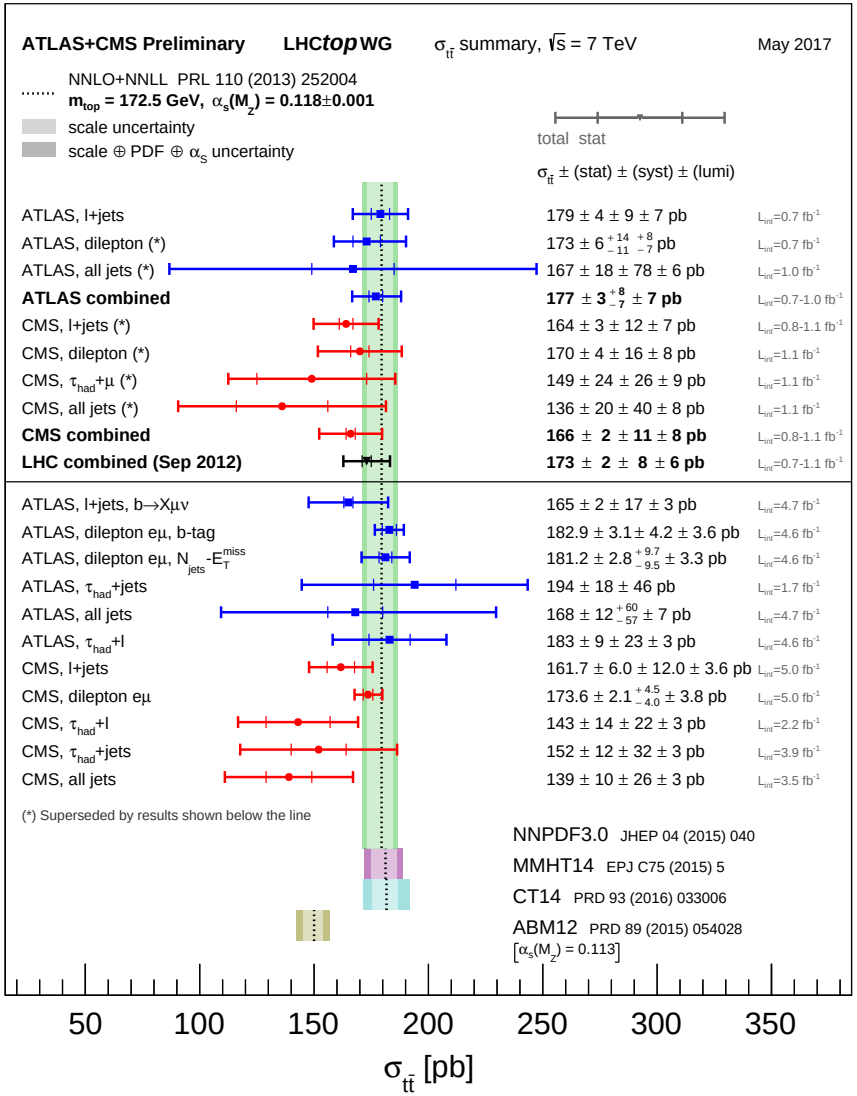


Summary

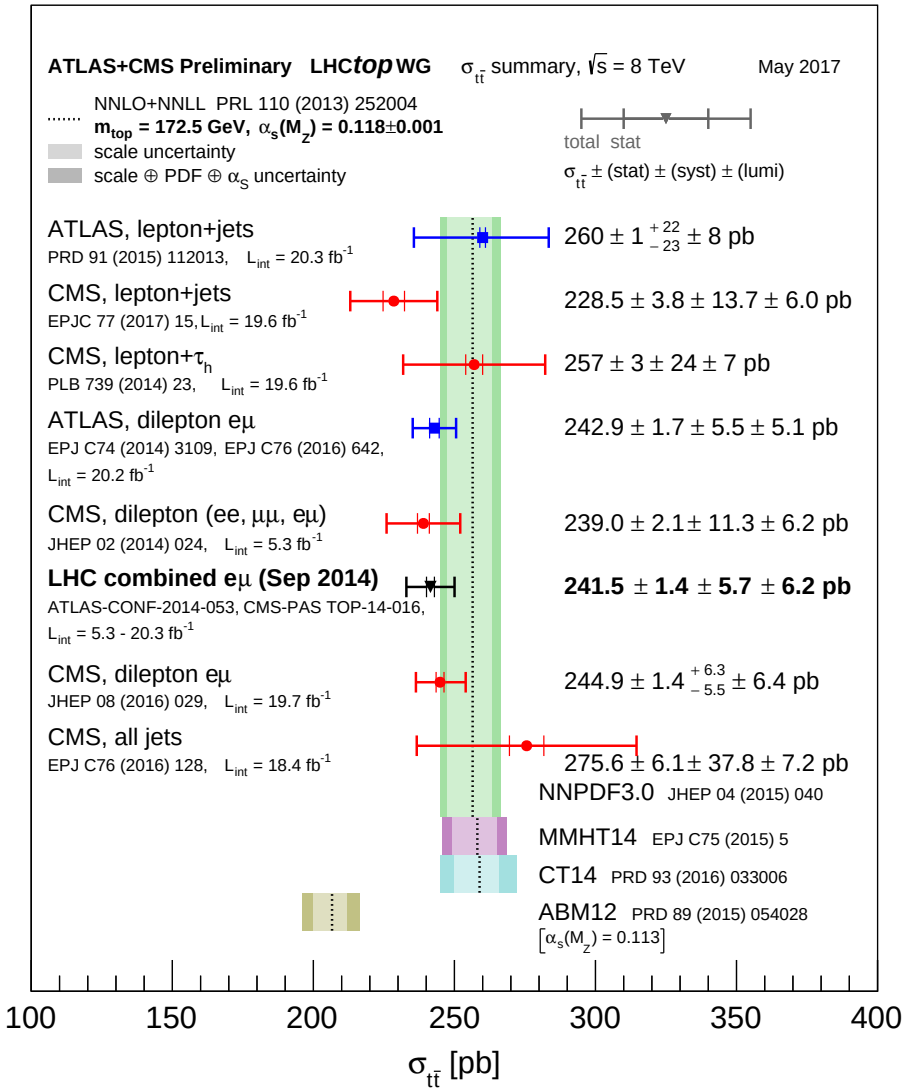
- The ATLAS experiment has an extensive program of inclusive and differential top cross-section measurements
- Measurements consistent with the Standard Model predictions
- $t\bar{t}$ production
  - Uncertainties of inclusive cross-sections are up to a few percent
  - Differential cross-section measurements probe the TeV scale
    - Main uncertainties: signal modeling and JES
- Single top production
  - Available differential measurements for the t-channel
  - Explored matrix element method for the s-channel
  - Main uncertainties: data statistics, JES and MC modeling

Backup

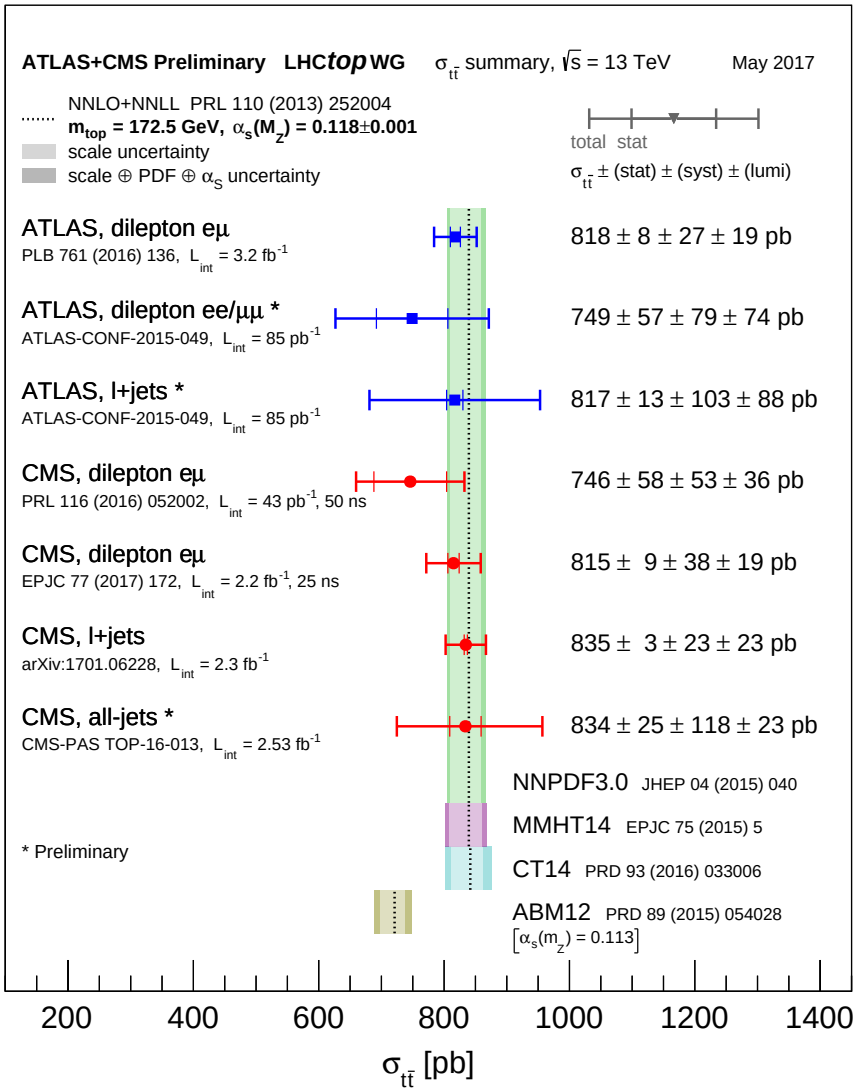
$t\bar{t}$ total cross sections - 7 TeV



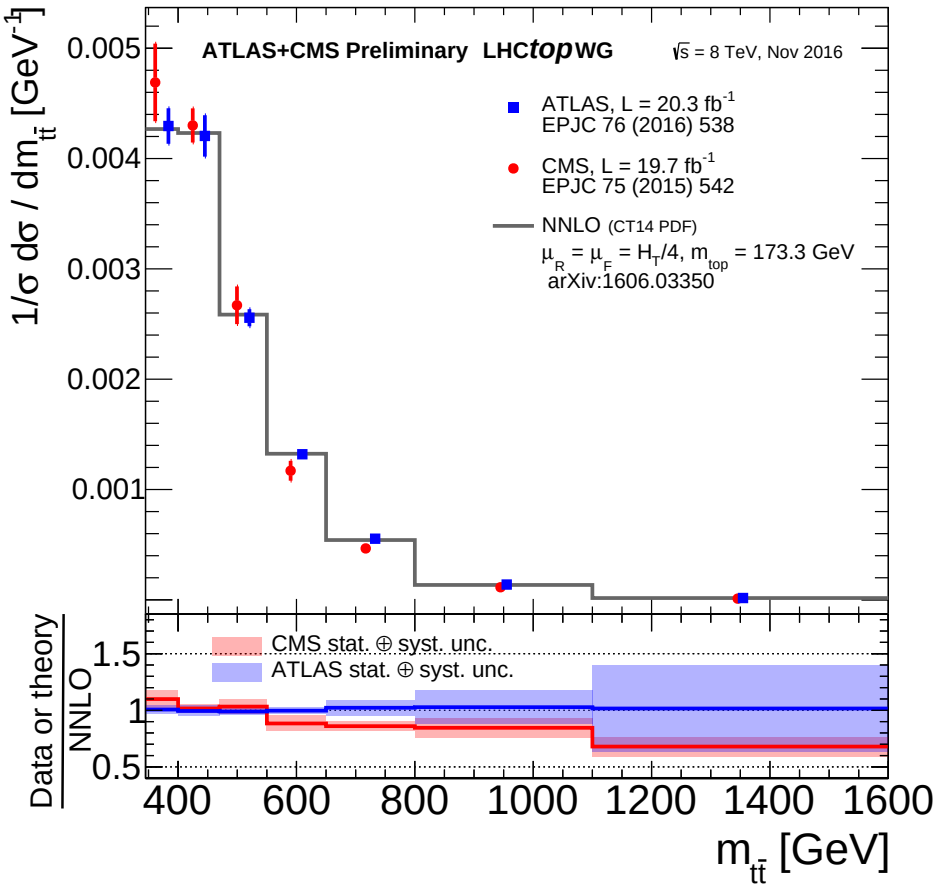
$t\bar{t}$ total cross sections - 8 TeV

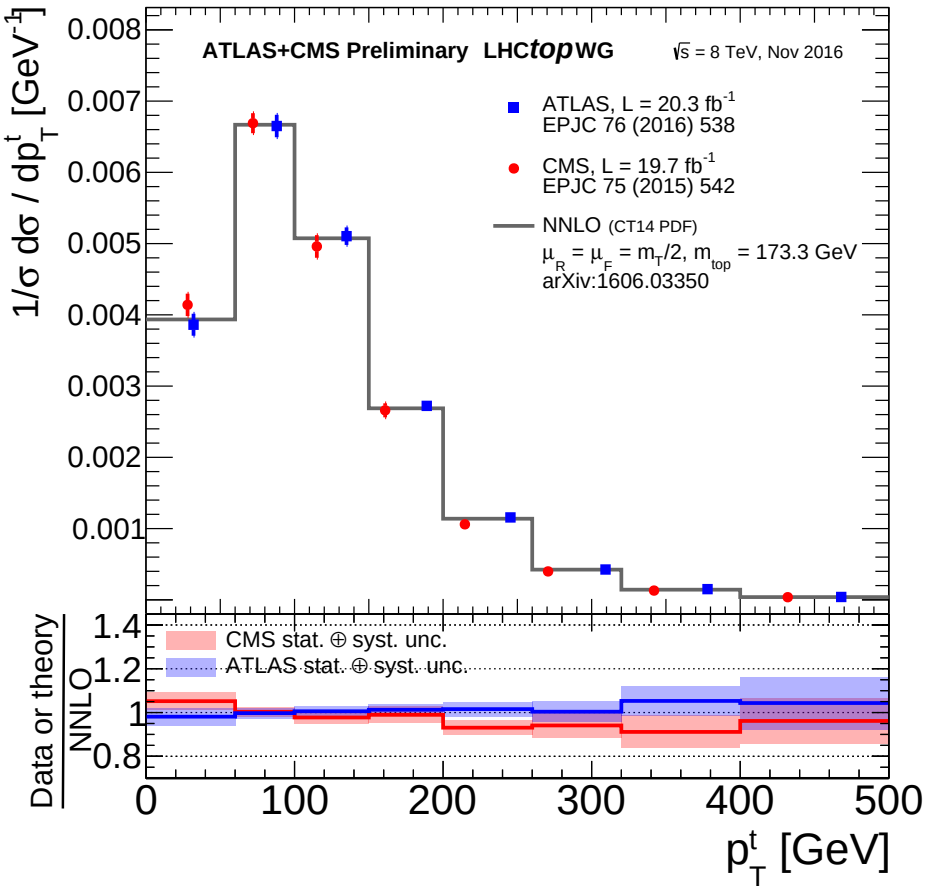


$t\bar{t}$ total cross sections - 13 TeV

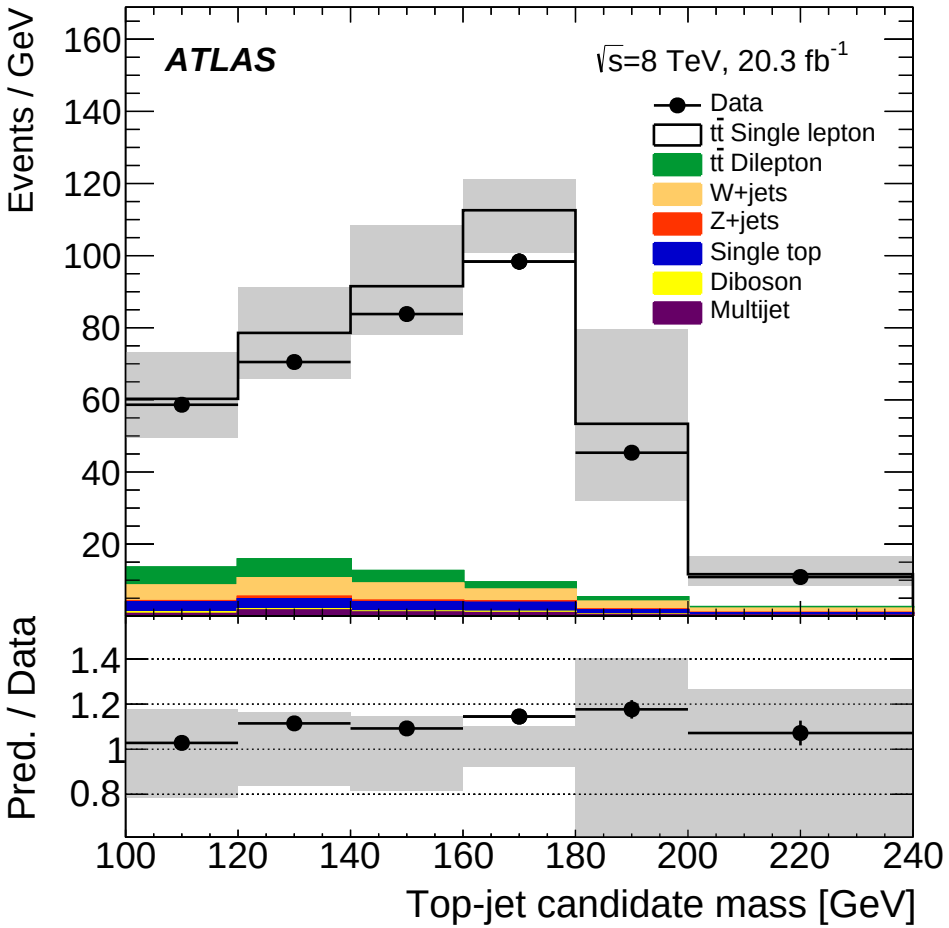


$t\bar{t}$ differential cross sections - comparison with NNLO QCD



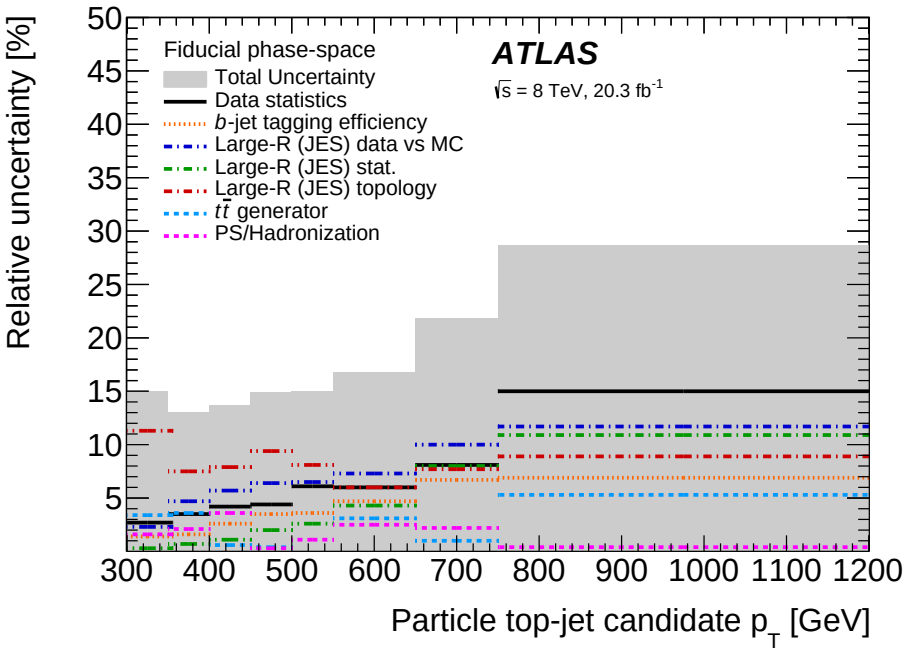


$t\bar{t}$ differential cross section - boosted, 8 TeV

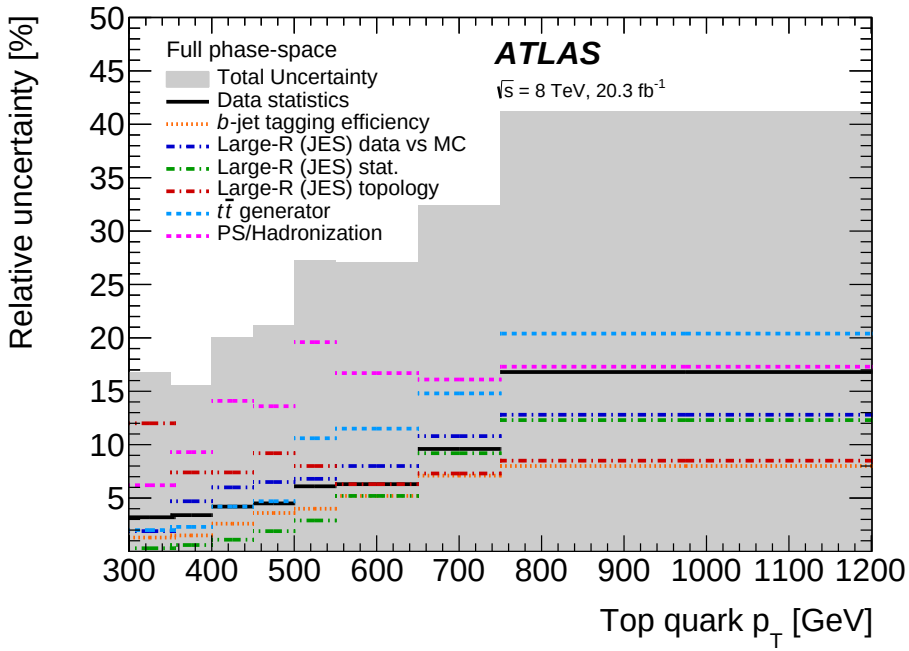


large-R jet mass distribution

$t\bar{t}$ differential cross section - boosted, 8 TeV, uncertainties

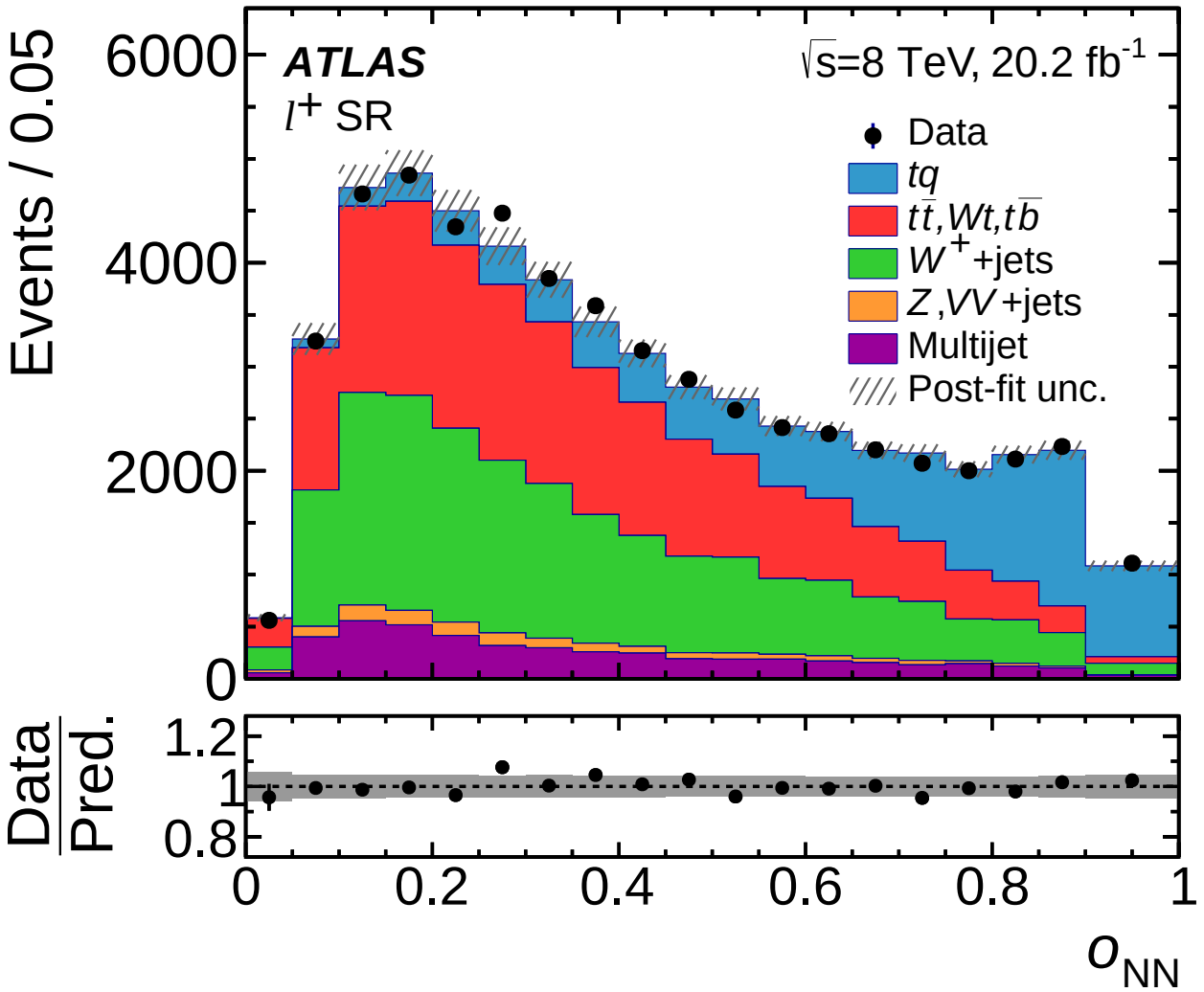


Particle level

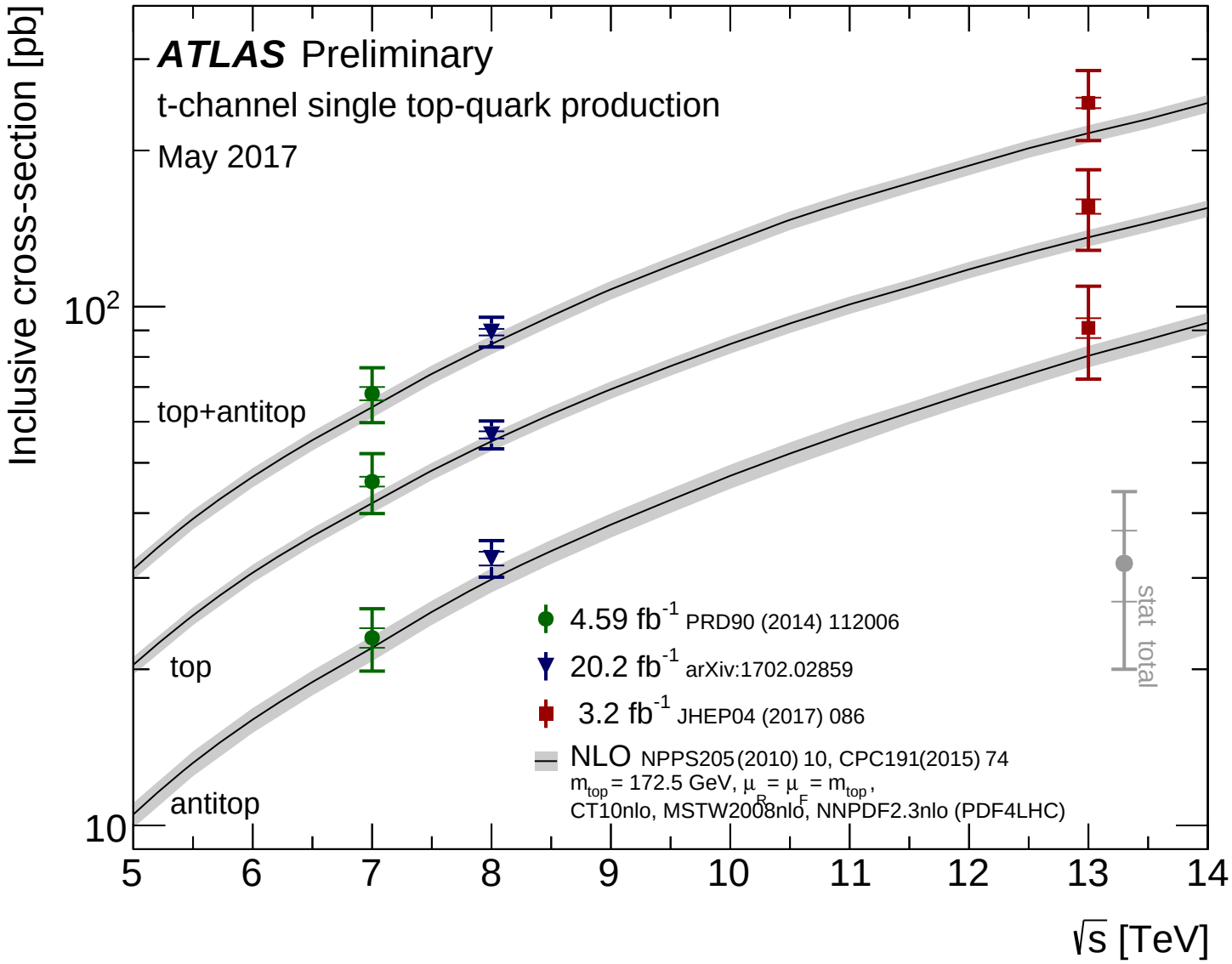


Parton level

Single top t-channel - discriminant



Single top t-channel - top vs antitop



Single top t-channel - R_t, other PDFs