Top physics in ATLAS

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Lomonosov Conference 2015. Moscow
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Overview

- Introduction: Top Quark

- Production

- Mass
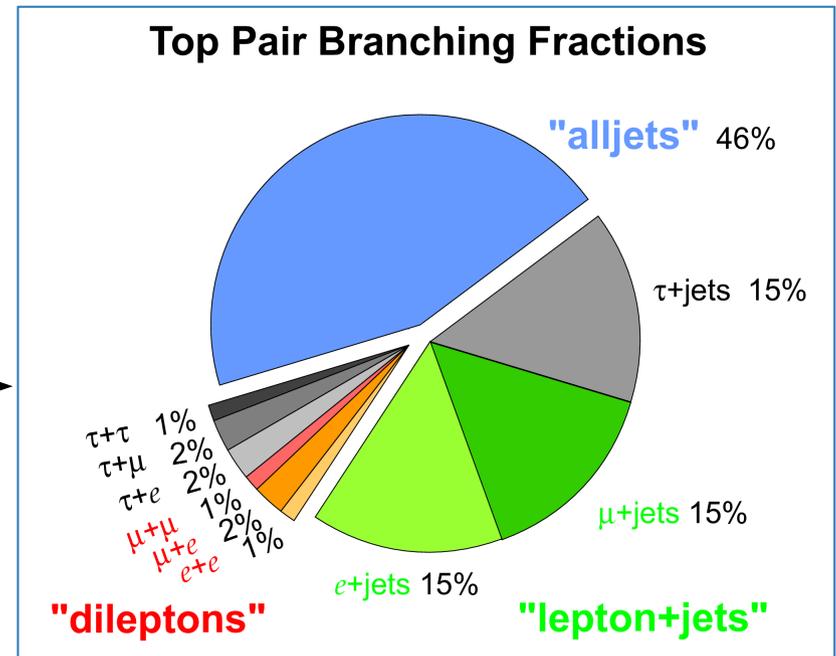
- Properties and Searches

- Summary

LHC: Top quark factory

- Heaviest particle of the standard model
  - Life-time shorter than hadronization time
- Privileged window to search for new physics.
- The LHC is a top quark factory.
  - More than 12M tops have been produced.
- The large number of top events allow the study of its properties.

Top pairs is the dominant produced process, but single top are also produced.
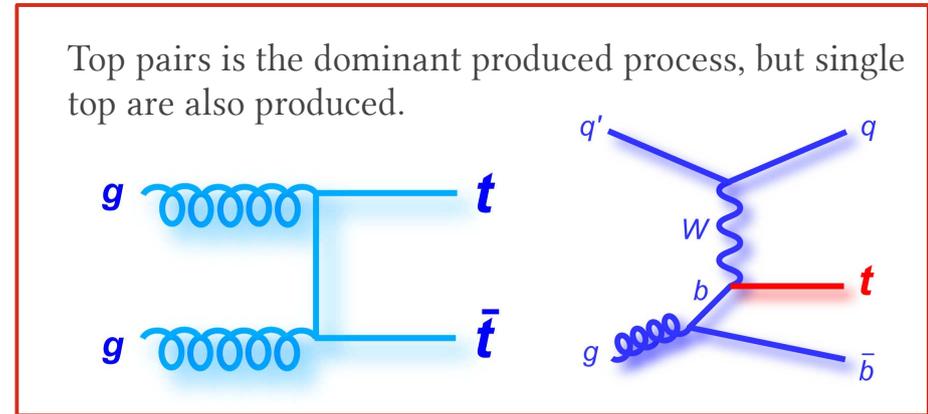
Top quark decays almost 100% of the time in $b+W$.

Top quark events are classified according to the decay of the W bosons.

Top Pair Branching Fractions

"alljets" 46%

τ+jets 15%

τ+τ 1%
τ+μ 2%
τ+e 2%
μ+μ 1%
μ+e 2%
e+e 1%

μ+jets 15%

e+jets 15%

"dileptons"

"lepton+jets"
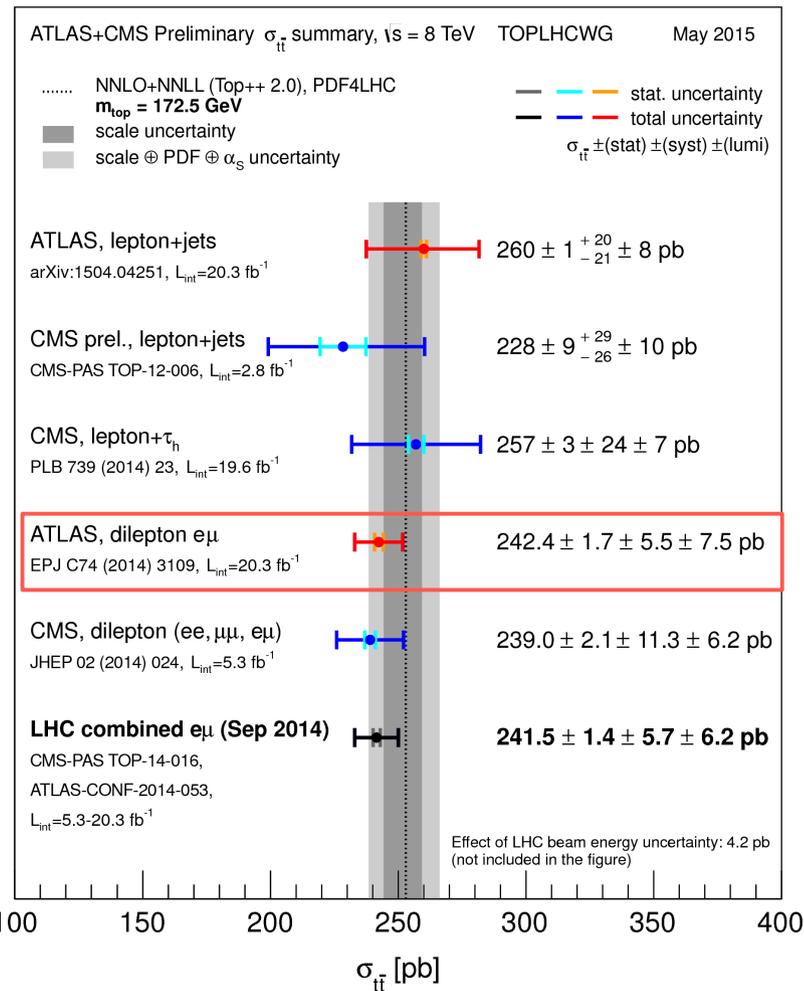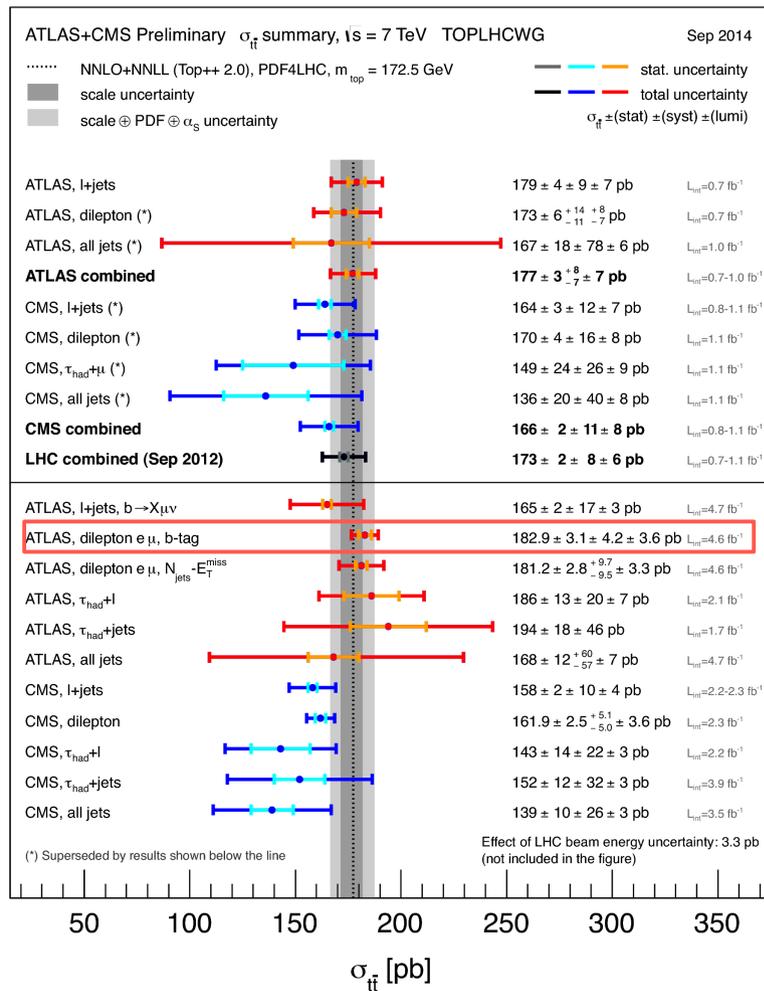
Top Quark Production

7 and 8 TeV

Many measurements of the inclusive cross-section have been performed

Good agreeement of all measurements with SM predictions

Experimental uncertainties smaller than the theoretical ones (~1% more precise)

ATLAS Dilepton emu measurement is the most precise measurement to date

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

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Inclusive top pair production

13 TeV

- First measurement using 13 TeV data.

  - Similar method as used for the most precise Run 1 measurement.

    - Simultaneous fit cross section, b-jet reconstruction and tagging efficiency.

- Dominating systs: integrated lumi, top pair modelling

$$\sigma_{t\bar{t}} = 825 \pm 49 \ (stat) \pm 60(syst) \pm 83(lumi) \ pb$$

- Consistent with QCD NNLO predictions


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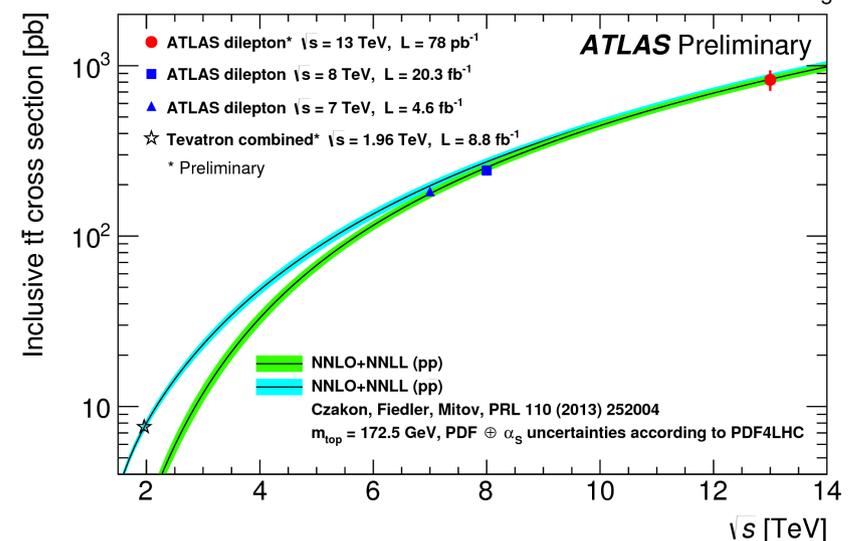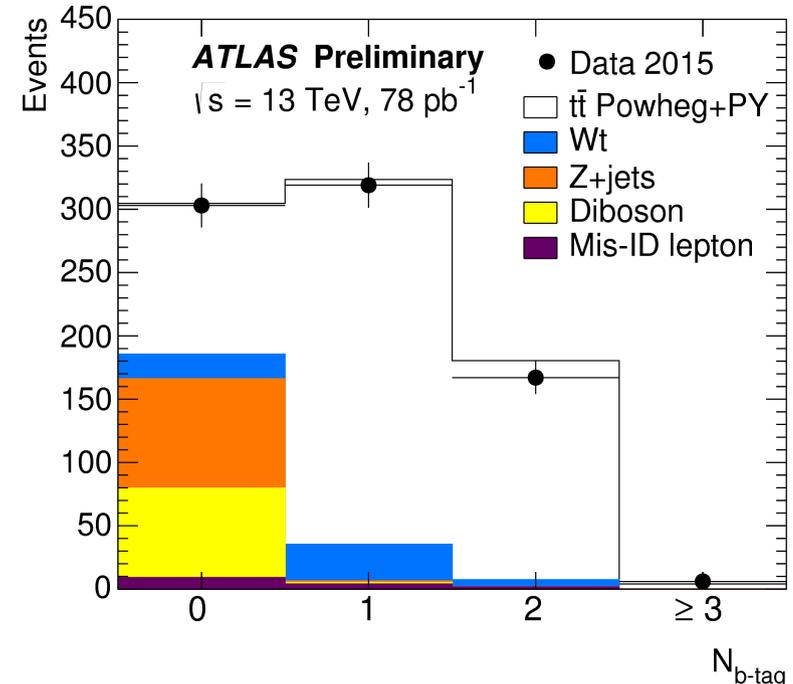
Differential top pair production

8 TeV

- Total cross-section measurements show very good agreement with the SM
  - New physics could still affect the shape
- Measurements performed in two topologies

|	Resolved Topology	Boosted Topology
Top p_T	< 300 GeV	> 300 GeV
Decay products	Well separated and can be reconstructed individually	Not well separated
Reconstruction	Top reconstructed from the decay products	Top reconstructed in a single large radius jet
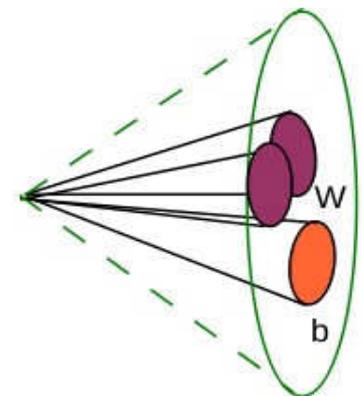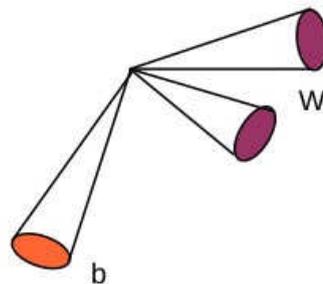
Differential top pair production

- Top-antitop differential cross section as a function of the mass, p_T, rapidity of the top pair system.
  - Measurement performed in a fiducial region
  - Using particle level tops observables
- Analysis performed in the lepton+jet channel
- Data softer than MC, observed as well in the parton level analysis
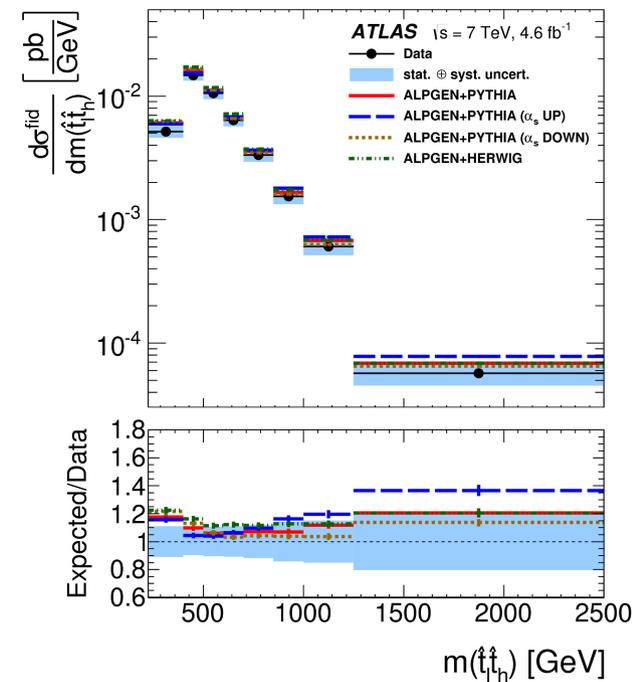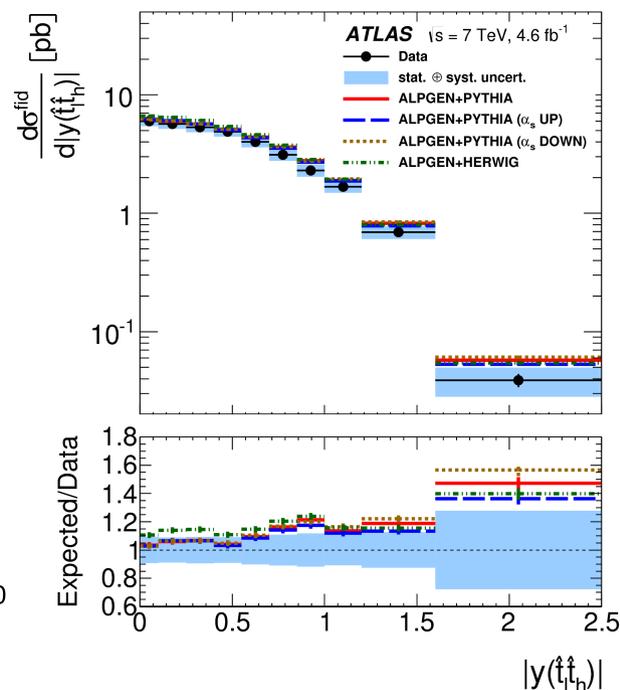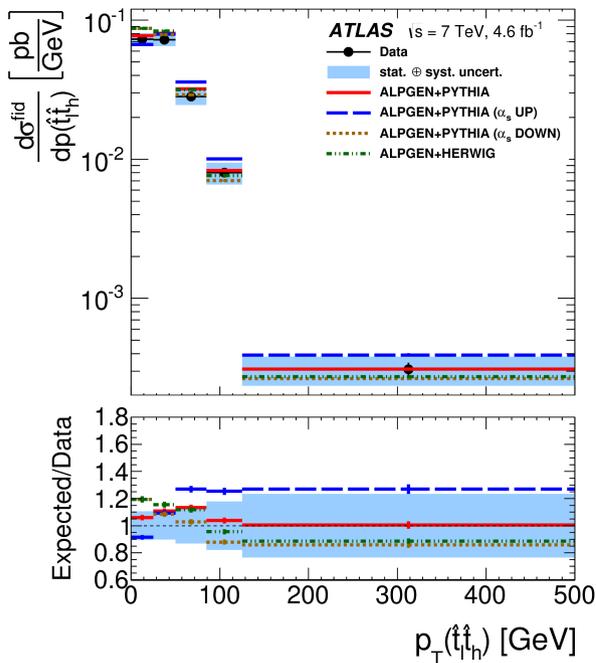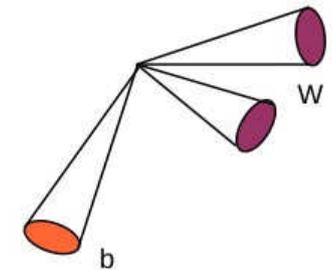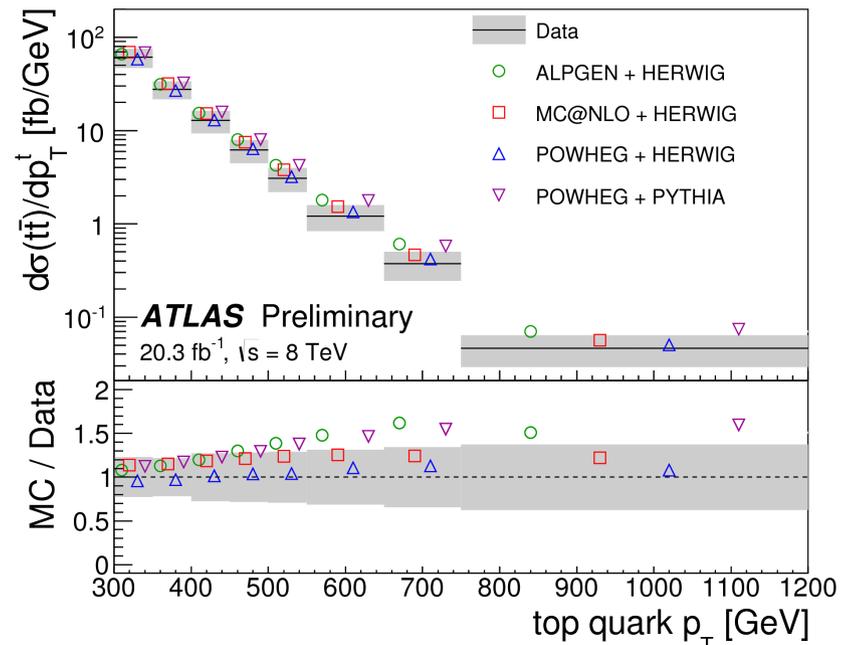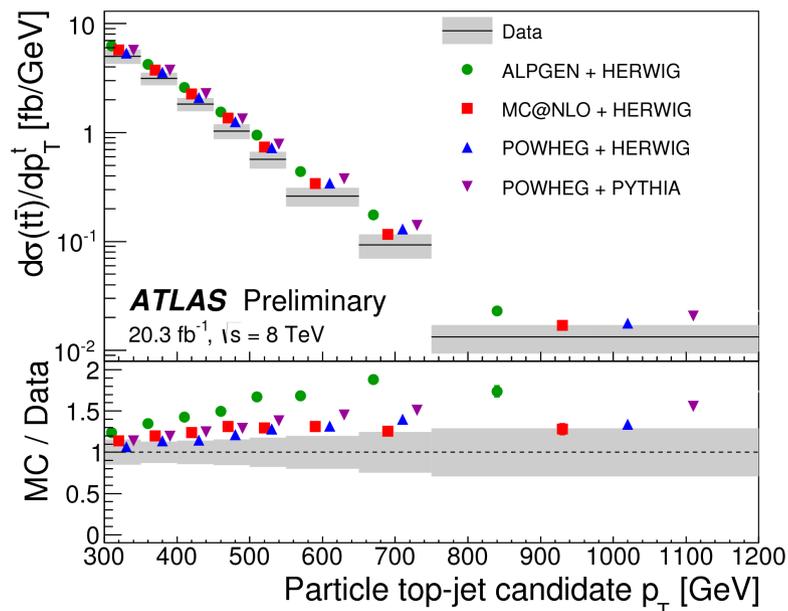
Differential top pair production

ATLAS-CONF-2014-057

- First cross section measurement as a function of top p_T (boosted)

- Semi-leptonic channel with p_T of the hadronic top > 300 GeV

- Boosted hadronic top defined as a single large-R jet

- Fiducial (particle level tops) and total (parton tops) phase space measurements are performed

- Measured cross section in general lower than predictions, same behavior observed in the resolved analysis
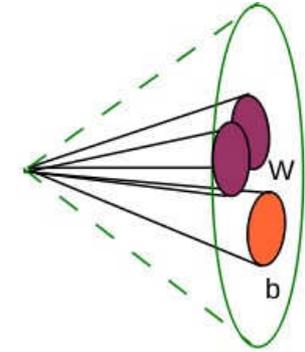
Main uncertainties:
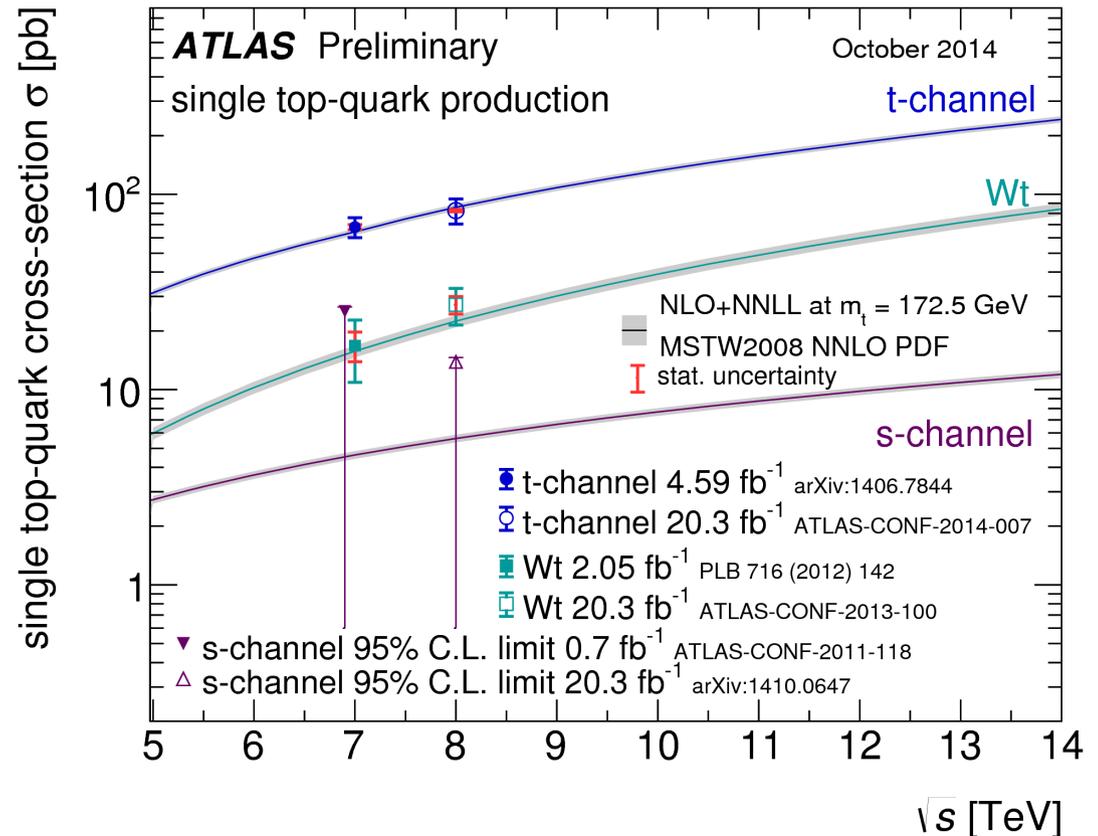large-R jet energy scale

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Single top production

7 and 8 TeV

Several measurements at 7 and 8 TeV have been performed

- Cross section for t and *Wt* channels

- Differential cross-section in the t channel

- Upper limit for the s channel

- Top/antitop t-channel ratio

Results are compatible with NLO+ NNLL predictions

# t̄tW and t̄tZ production cross sections

- Final states with two, three or four leptons are considered
  - Simultaneous fit performed in 20 signal and control regions

- The background-only hypothesis with neither $t\bar{t}W$ nor $t\bar{t}Z$ production excluded at 7.1σ

- Measurement dominated by statistical uncertainties

ATLAS-CONF-2015-012
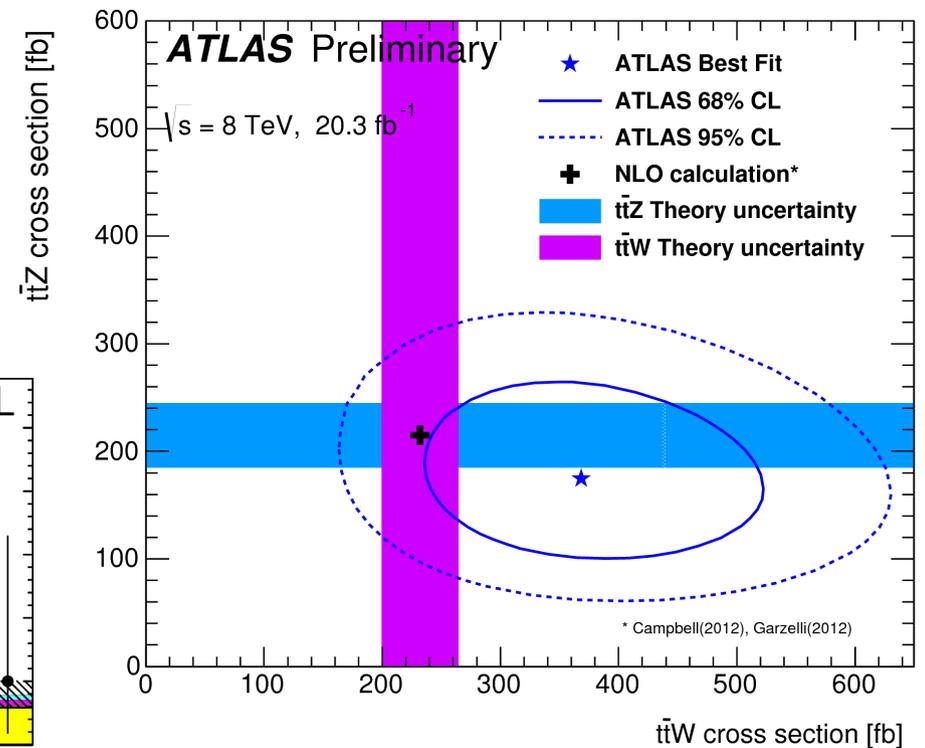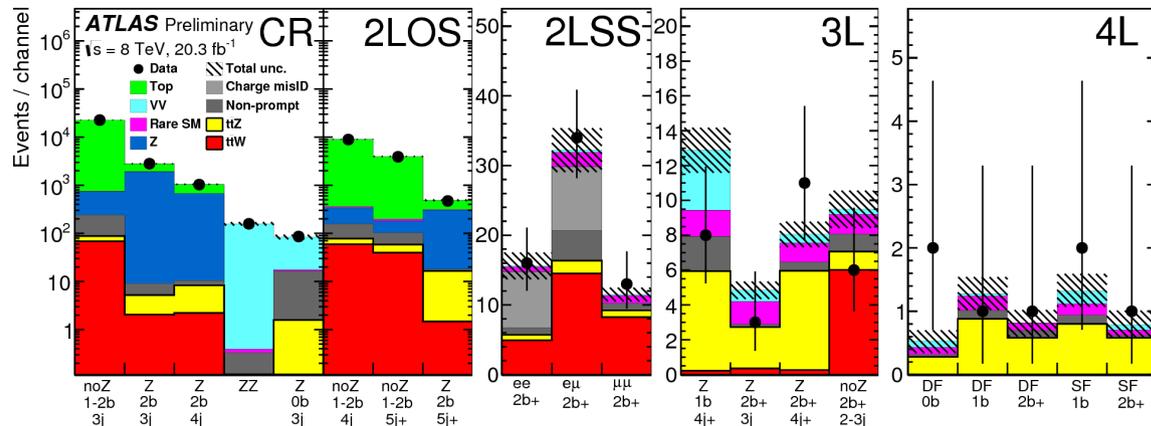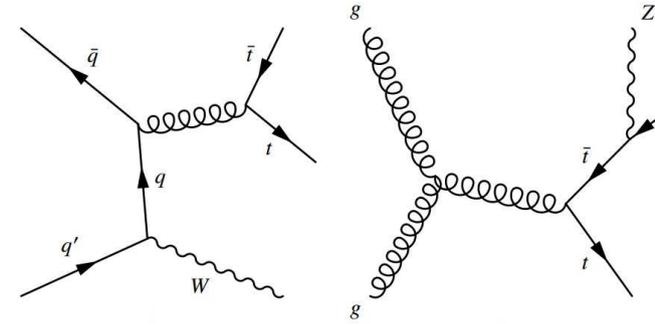
Top Mass Measurements

Mass measurements

- Mass of the top is a free parameter of the SM
- Typically the mass is measured in top pair events
  - Dilepton and lepton+jet channels
- Possible to use other topologies
  - Single top in t channel
- The measurements can be done using
  - Template Fit
    - Extract the MC mass
    - Multidimensional fit reduces the JES related uncertainties

  - Normalized differential cross section of $t\bar{t} + 1$ jet to extract the pole mass.
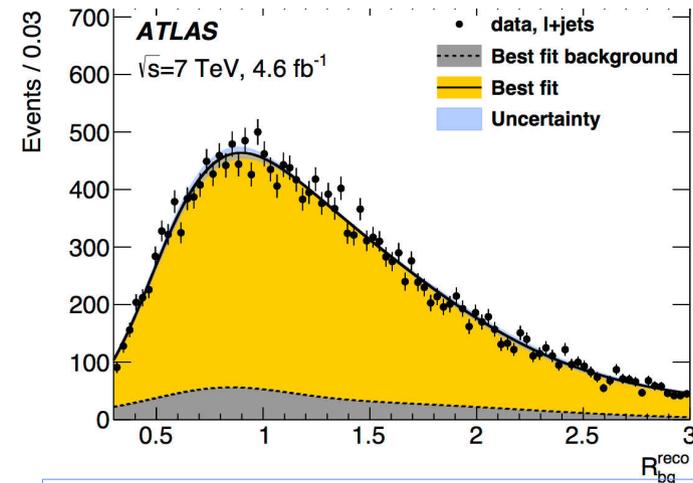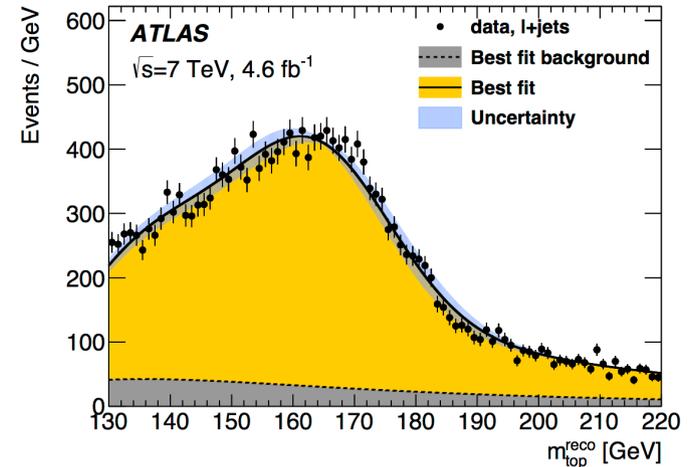   - The "pole" in the top quark propagator
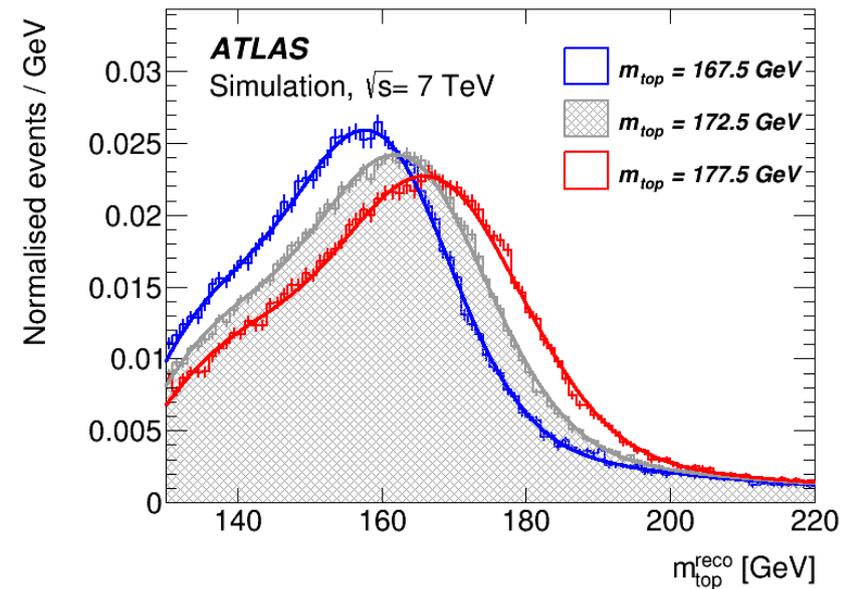
Mass measurements

$t\bar{t} \to l+$jets and $t\bar{t} \to$ dilepton   7 TeV

- Lepton + jets channel uses a three-dimensional template

  – Determines the top quark mass, JSF and bJSF

  – ATLAS's most precise measurement

- Dilepton channel uses a one dimensional fit

- The l+jets and dilepton results are combined

$$m_{\mathrm{t}op} = 172.99 \pm 0.48(\mathrm{stat}) \pm 0.78(\mathrm{syst})$$

Main uncertainties

lepton+jets: JES, b-tagging
Dilepton: JES, b-quark JES

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arXiv:1503.05427 submitted to EPJC

Mass measurement in single-top

- First measurement of top mass in single top decays
- Template method using the invariant mass of the lepton and b-jet
  - Reduce systematic uncertainties
- Using neural network to optimize the purity ~50%
- Main uncertainties: JES, Hadronisation, W+jets bgr.

$$m_{\rm top} = 172.2 \pm 0.7(\text{stat.}) \pm 2.0(\text{syst.})\text{GeV}$$

ATLAS-CONF-2014-055
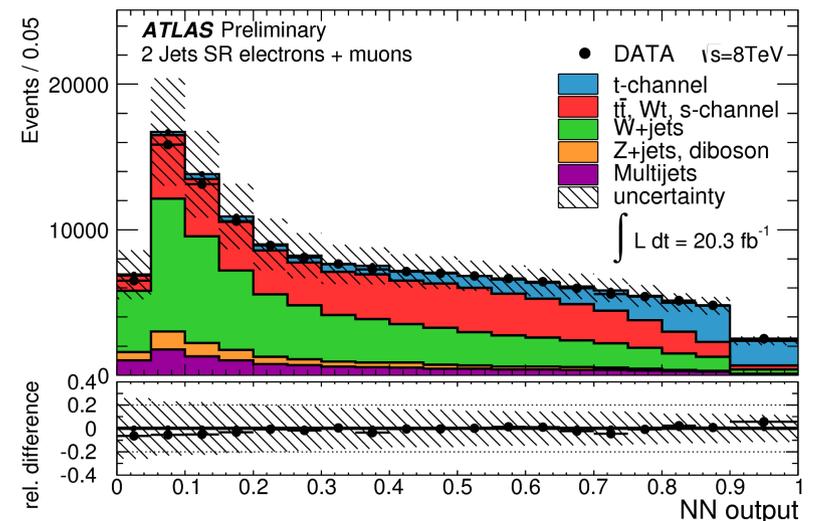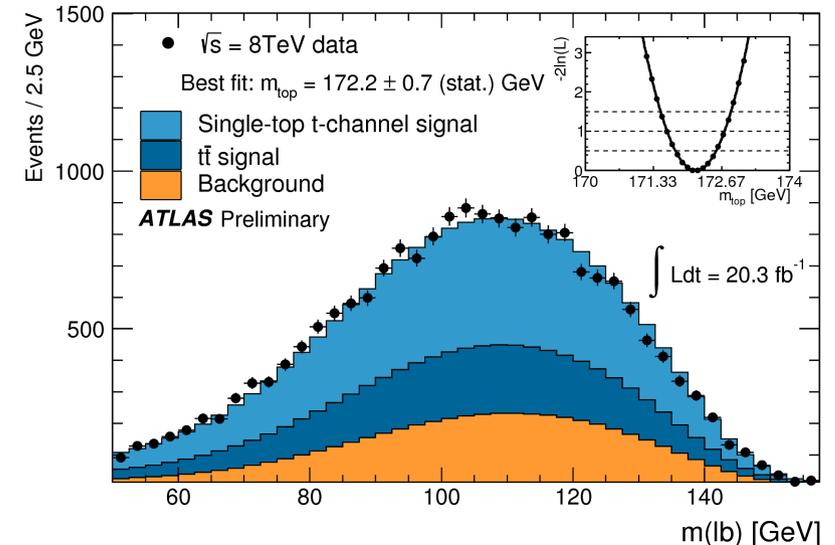
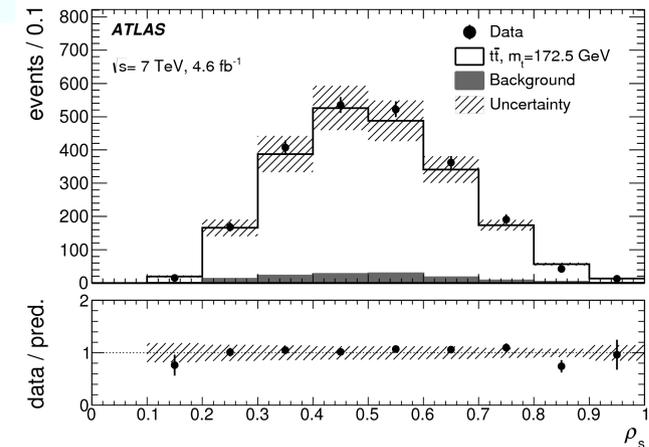# Pole mass measurement in $t\bar{t}$+jets

7 TeV

- Hard gluon radiation of top quark depends on mass of the top

$$\mathcal{R}(m_t^{\text{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s}(m_t^{\text{pole}}, \rho_s), \qquad \rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}+1\text{-jet}}}},$$

- Unfold R + extract the pole mass using NLO calculation

- $t\bar{t}$ system is reconstructed by chi2 minimization

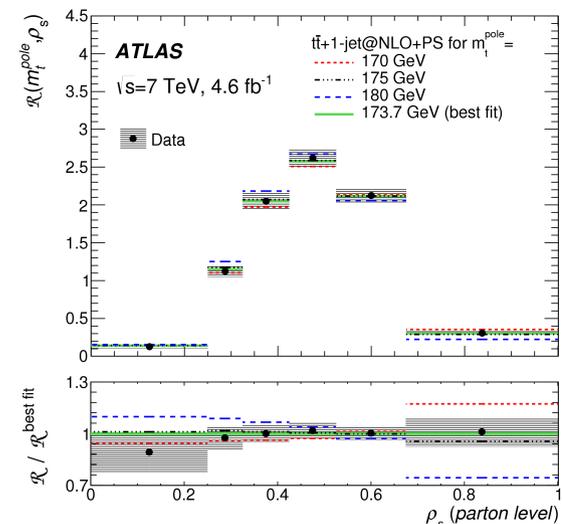- Extra jet is required to have a $p_T > 50$ GeV

$$m_t^{\text{pole}} = 173.7 \pm 1.5\,(\text{stat}) \pm 1.4\,(\text{syst})^{+1.0}_{-0.5}(\text{theory})\,\text{GeV}$$

Main systematic uncertainties:
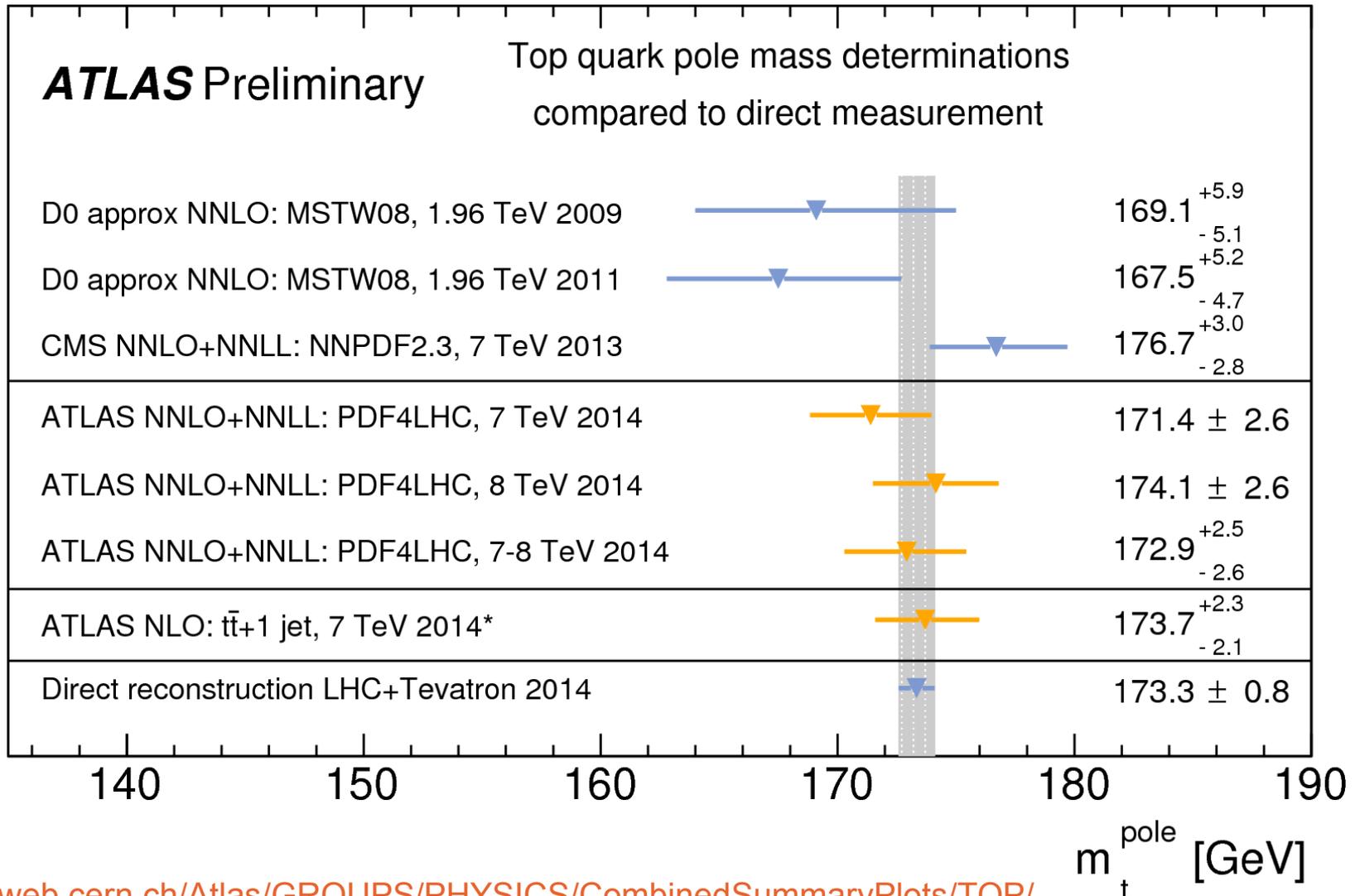
- JES + b-quark JES
- ISR/FSR
- PDF
- Theory Uncertainties

This result represents the most precise measurement of the top-quark pole mass to date.

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arXiv:1507.01769, subm. to JHEP

Pole mass measurement in $t\bar{t}$+jets

7 TeV and 8 TeV

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

Top Properties and Searches

Spin Correlation

8 TeV

- Top pairs produced via the strong interaction are produced almost unpolarised
  - Spins are correlated and information transferred to decay products.
- The correlation is extracted from dilepton events
  - Difference in the azimuthal angle of the two leptons
  - Used to probe BSM
- Top squarks with masses between the top quark mass and 191 GeV are excluded at the 95% confidence level


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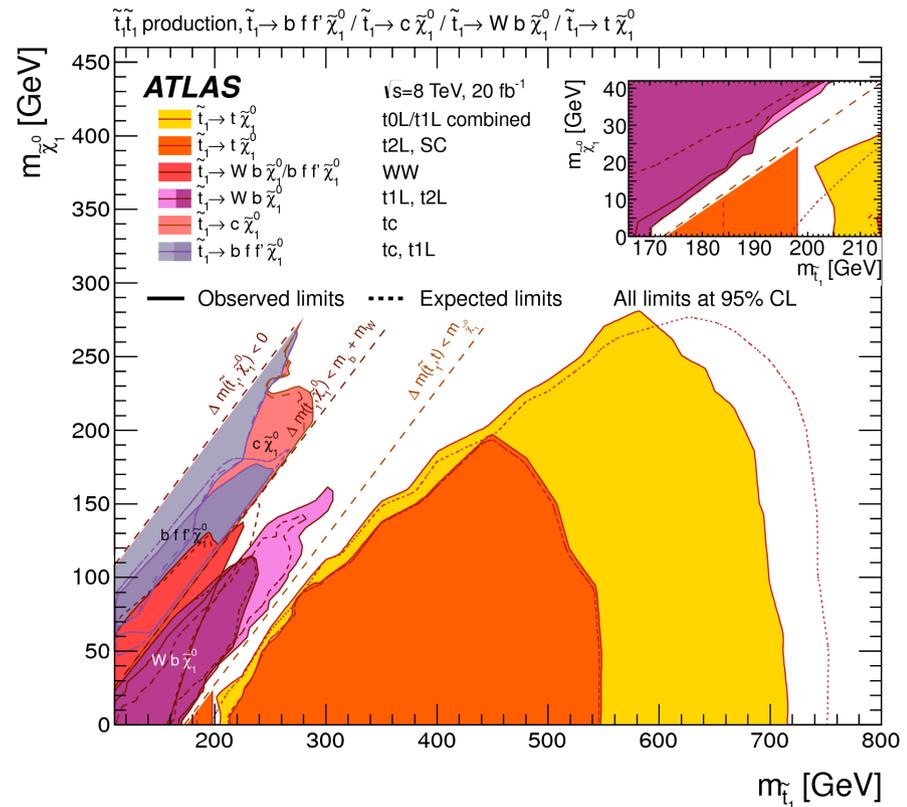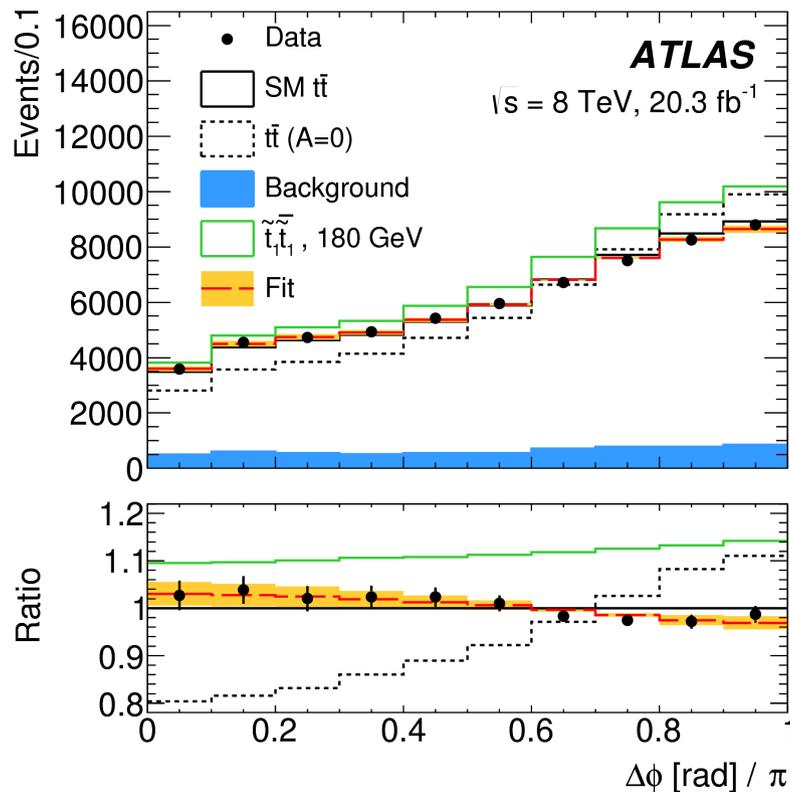
FCNC in the trilepton channel

- Flavor changing neutral currents are predicted by the SM
  - Highly suppressed by the GIM mechanism

- Looking for tt events with one top quark $t \to qZ$ and the other $t \to bW$ with both bosons decaying leptonically

- Chi2 minimization is used for kinematic reconstruction and to discriminate signal and background

- No evidence of FCNC is found

- Observed upper limit on $t \to qZ$ branching ratio is established at 7×10^{-4}

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To be submitted
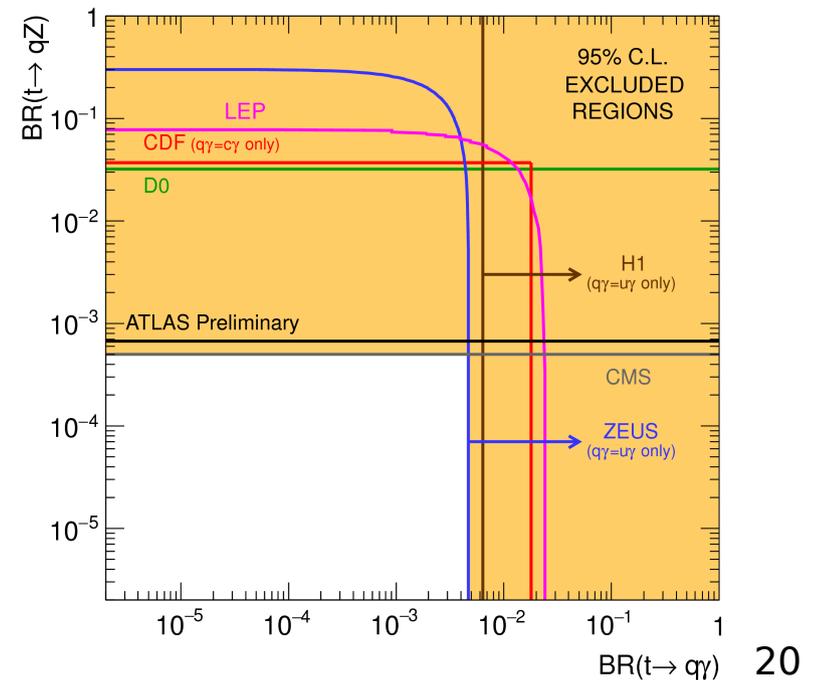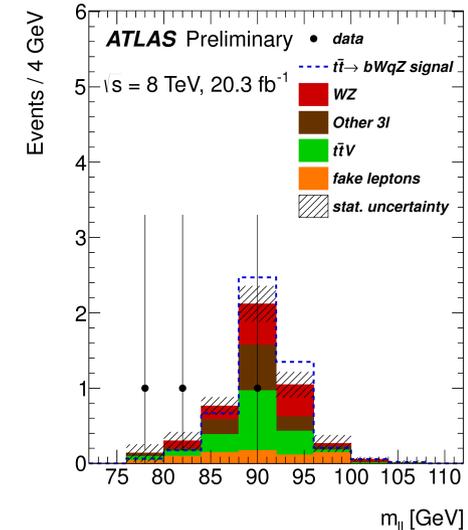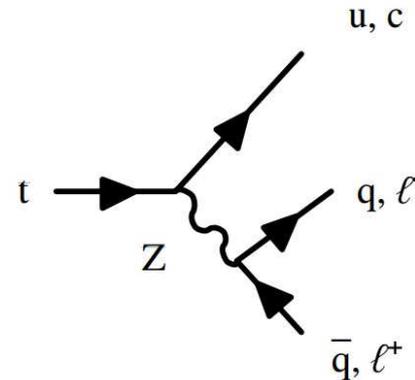
Single top production via FCNC

- Search for single top production via $gu/c \to t$
- Only leptonic decay channel is considered
- NN used to discrimate signal and background
- Upper limit are established on
  – The cross section times branching ratio
  – The coupling constants

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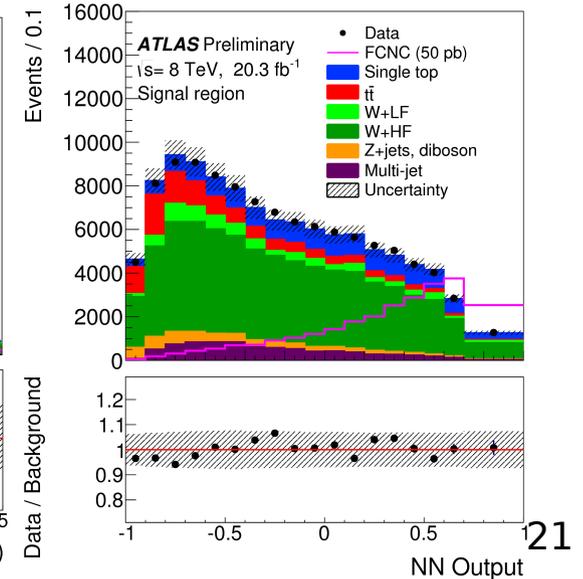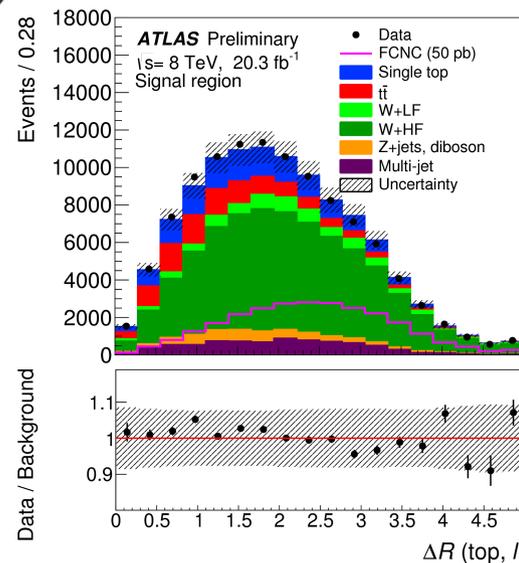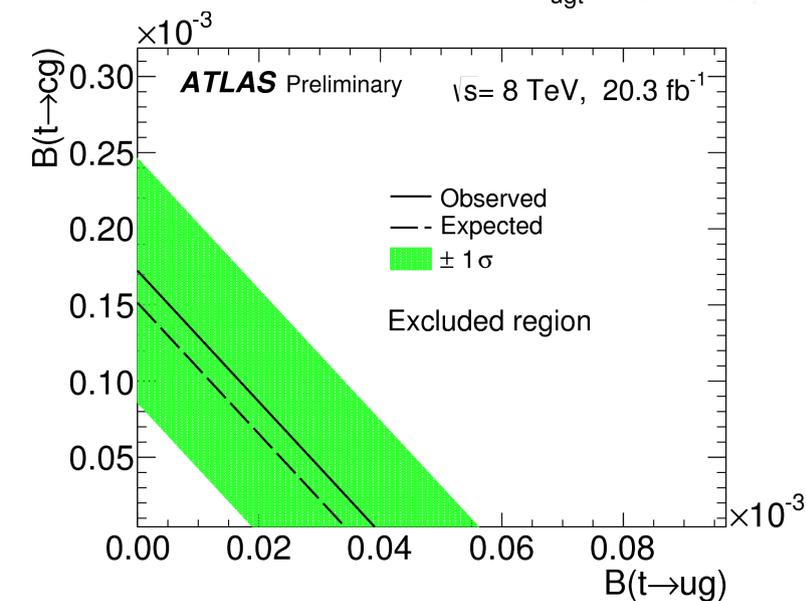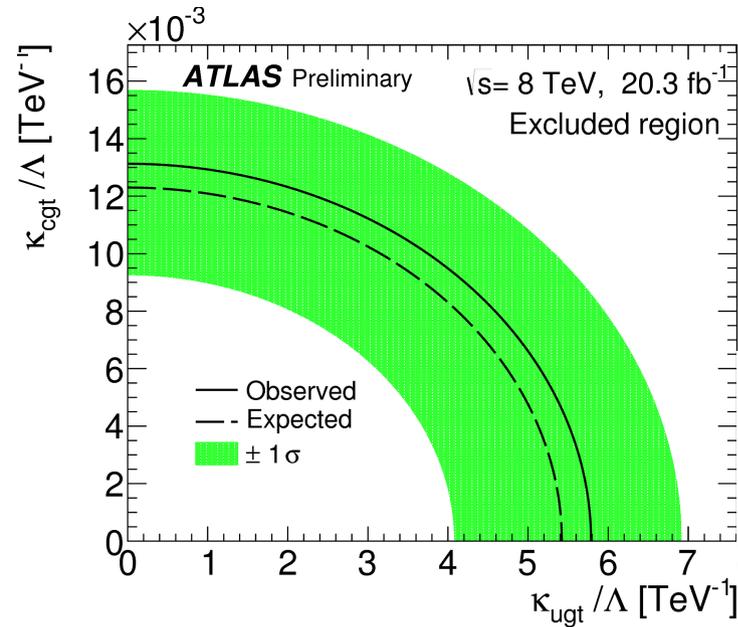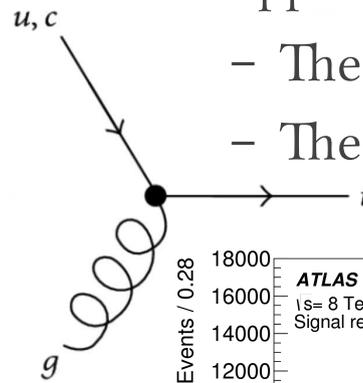
To be submitted

Summary

- ATLAS has performed multiple measurements on Top physics
  - Production, mass and properties
- All the results are in agreement with the SM
- Some properties have been used to exclude BSM models
- More exciting times are coming with 13 TeV
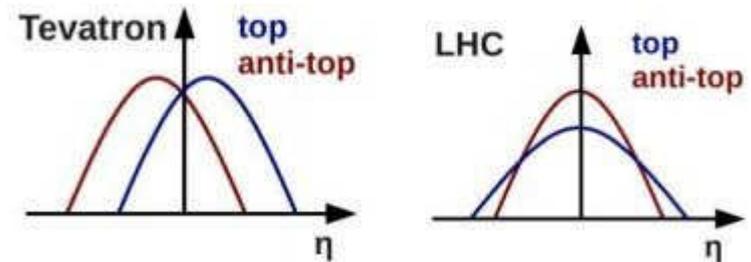- Stay tuned for new results!

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

Backup

Charge Asymmetry Measurement

- At LO the standard model predicts a symmetric top pair production under charge conjugation
- At NLO a non-zero asymmetry is expected
- Effect can be measured in the l+jets or dilepton channel
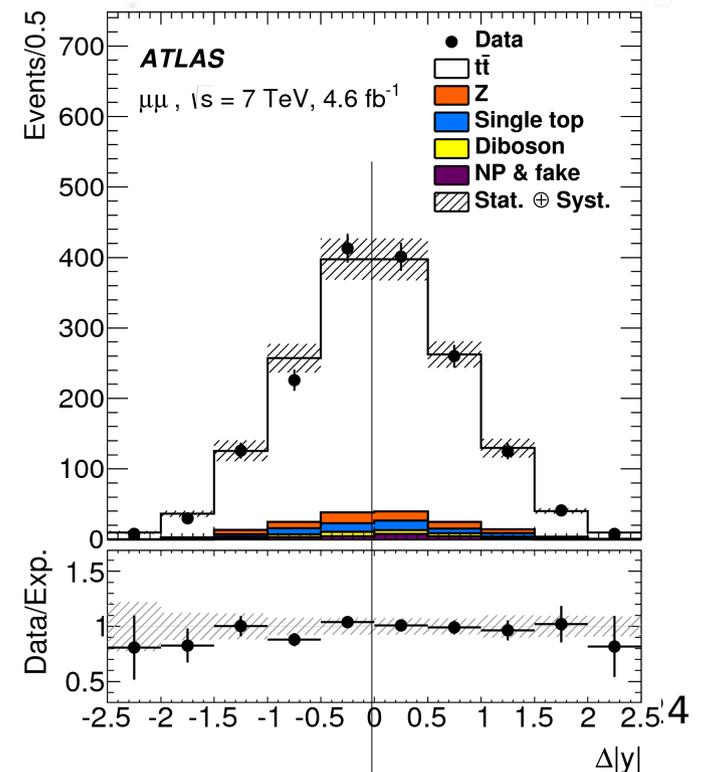
Observables at LHC

Top based asymmetry

$$\Delta|y| = |y_{top}| - |y_{antitop}| \qquad A_c^{t\bar{t}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| < 0) + N(\Delta|y| > 0)}$$

Lepton based asymmetry

$$\Delta|\eta| = |\eta_+^\ell| - |\eta_-^\ell| \qquad A_c^{\ell\ell} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| < 0) + N(\Delta|\eta| > 0)}$$

- Latest results in the dilepton channel at 7 TeV
- Kinematic reconstruction is required in order to compute the top based asymmetry

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Charge Asymmetry Measurement

- Analysis use unfolding procedure
  - Correct for reconstruction and detector acceptance.
- Results are compatible with the standard model predictions
- Statistically dominated
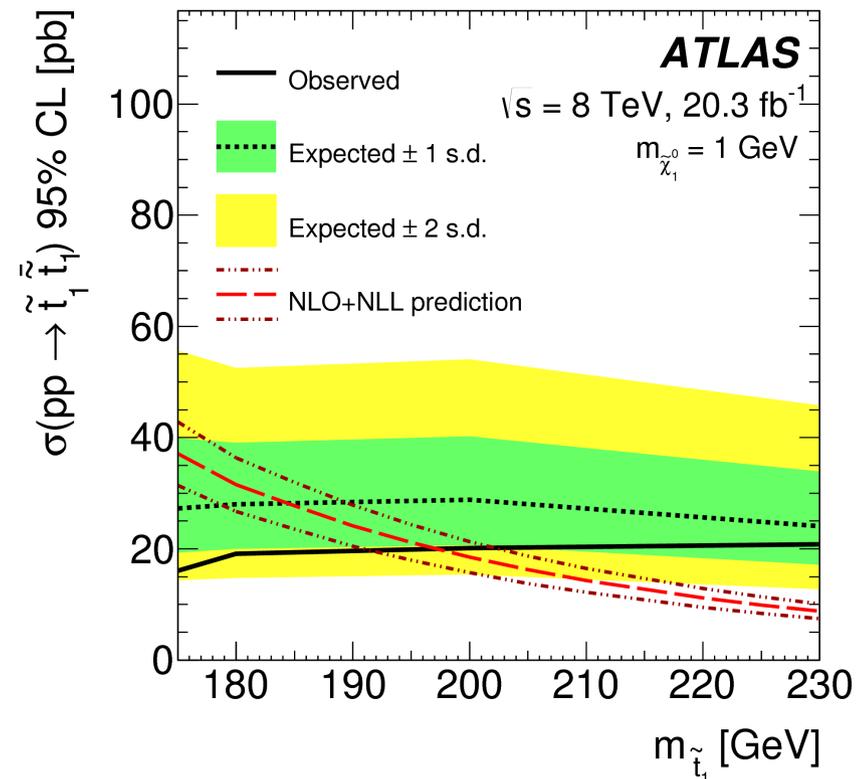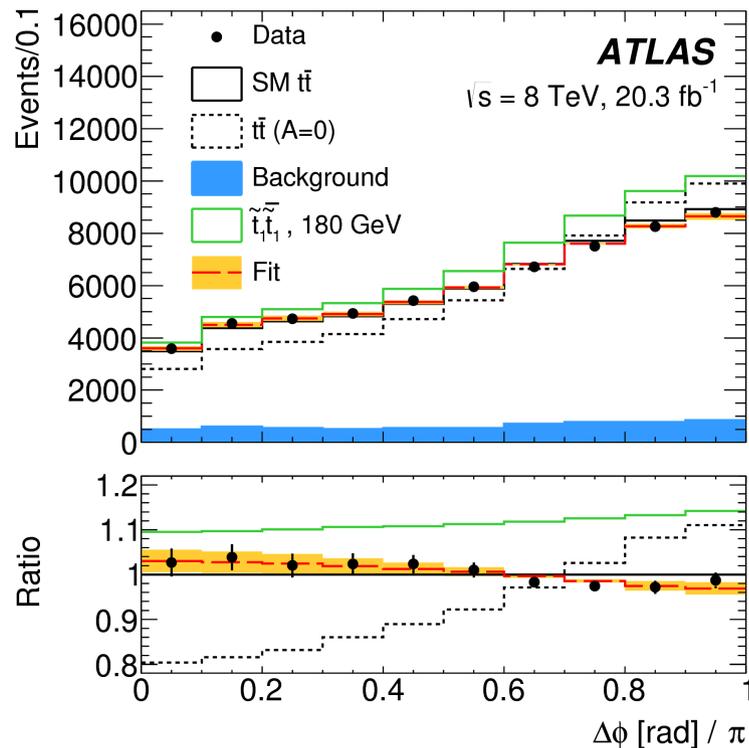 - More statistics will probe new physics models
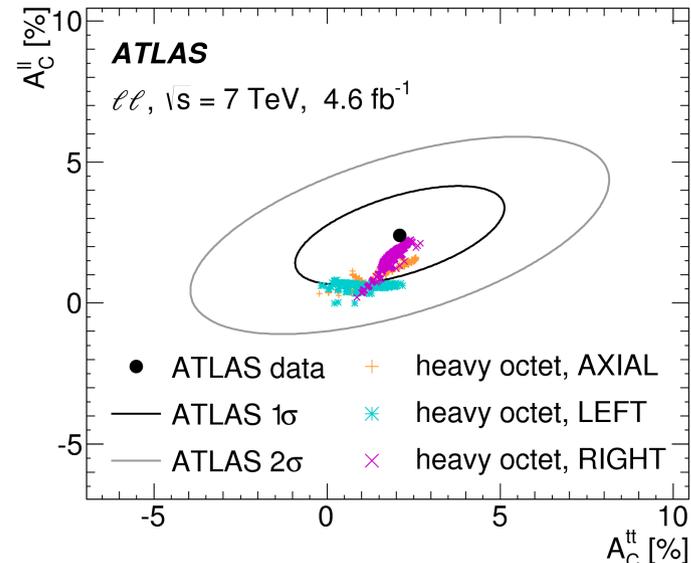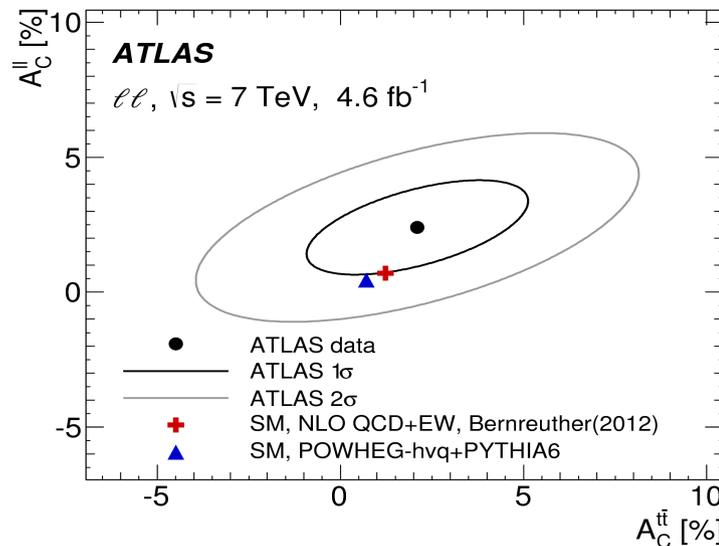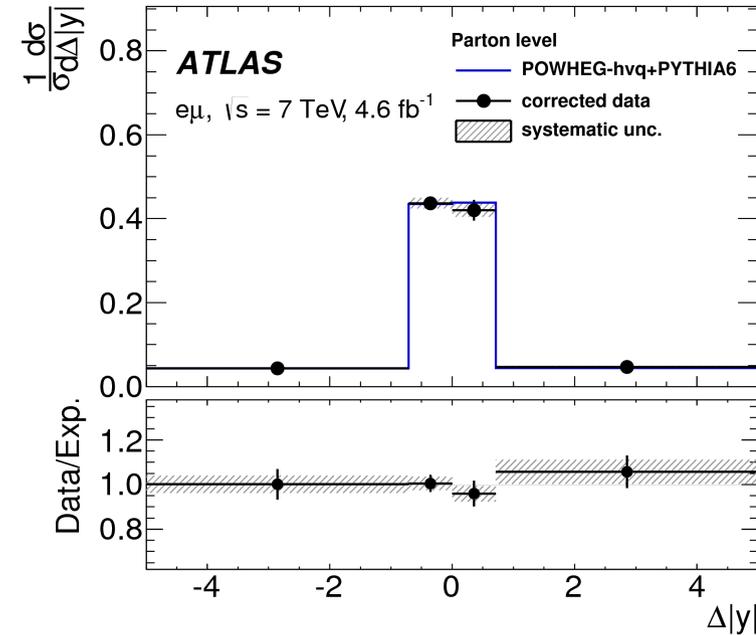
8 TeV

- The measurement of angular distribution is sensitive to supersymmetric top squark (stop) pair production

- Stop decays to a top and a very light neutralino, changing the spin correlation value

ATLAS $t\bar{t}$ spin correlation measurements

$\int$ Ldt = 4.6 fb^{-1}, $\sqrt{s}$ = 7 TeV

	f_{SM}	$\pm$ (stat)	$\pm$ (syst)
$\Delta\phi$ (dilepton)	1.19	$\pm$ 0.09	$\pm$ 0.18
$\Delta\phi$ (l+jets)	1.12	$\pm$ 0.11	$\pm$ 0.22
S-ratio	0.87	$\pm$ 0.11	$\pm$ 0.14
cos(θ_+) cos(θ_-) helicity basis	0.75	$\pm$ 0.19	$\pm$ 0.23
cos(θ_+) cos(θ_-) maximal basis	0.83	$\pm$ 0.14	$\pm$ 0.18

0   0.5   1   1.5   2

Phys. Rev. D. 90, 112016 (2014)   Standard model fraction