# Top physics in ATLAS

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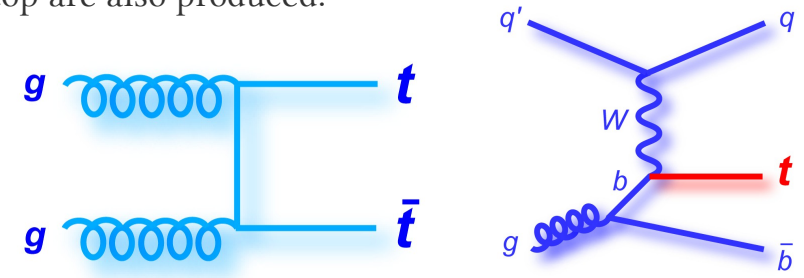
# Overview

- Introduction: Top Quark
- Production
- Mass
- Properties and Searches
- Summary

# LHC: Top quark factory

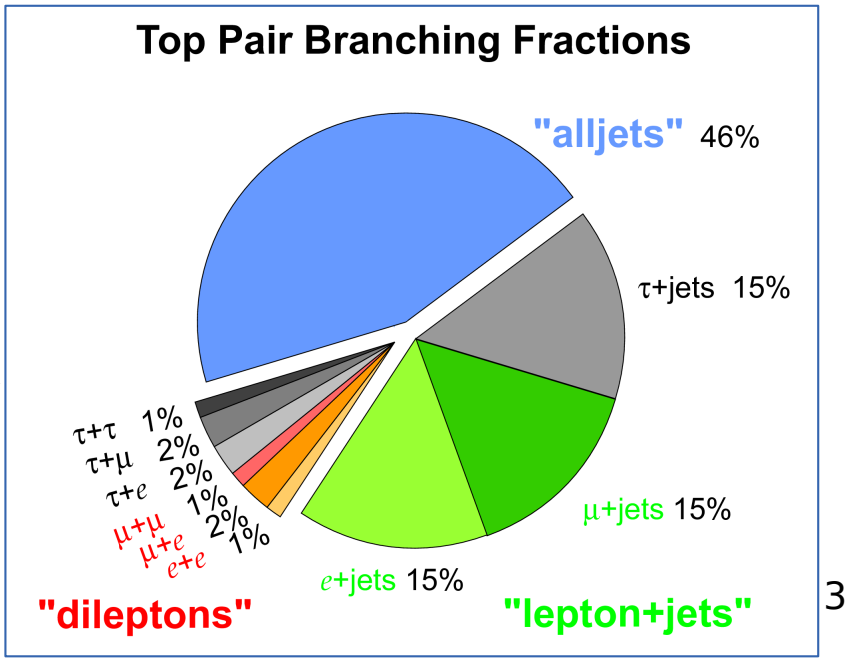
- Heaviest particle of the standard model
  - Life-time shorter than hadronization time
- Privileged window to search for new physics.
- The LHC is a top quark factory.
  - More than 12M tops have been produced.
- The large number of top events allow the study of its properties.

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.

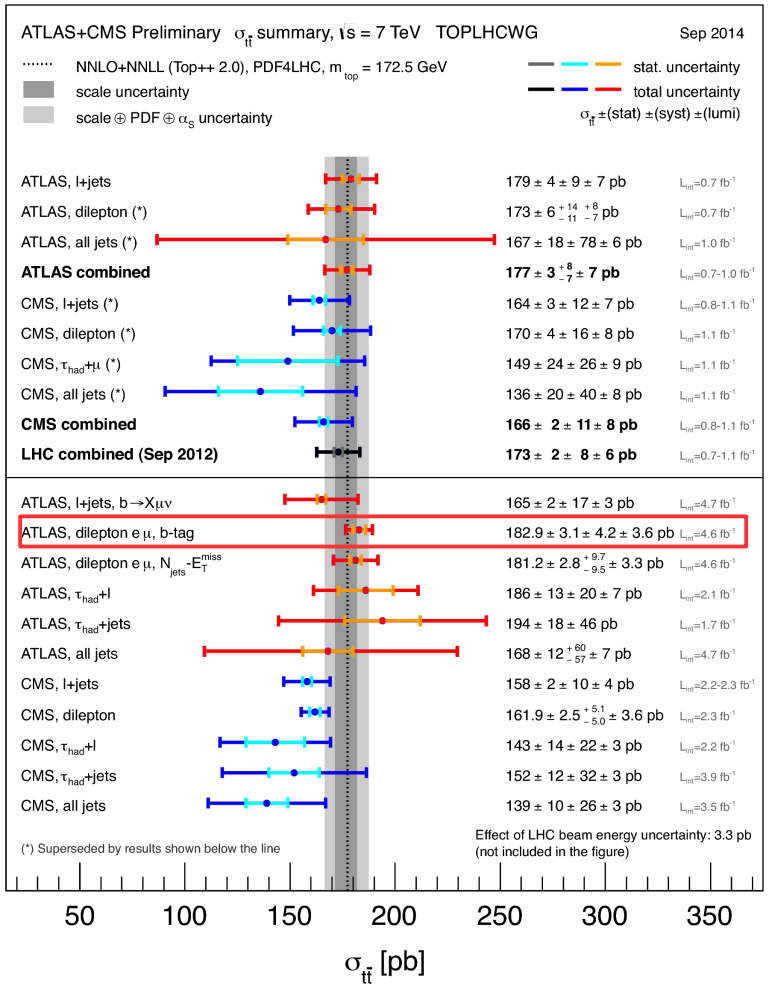


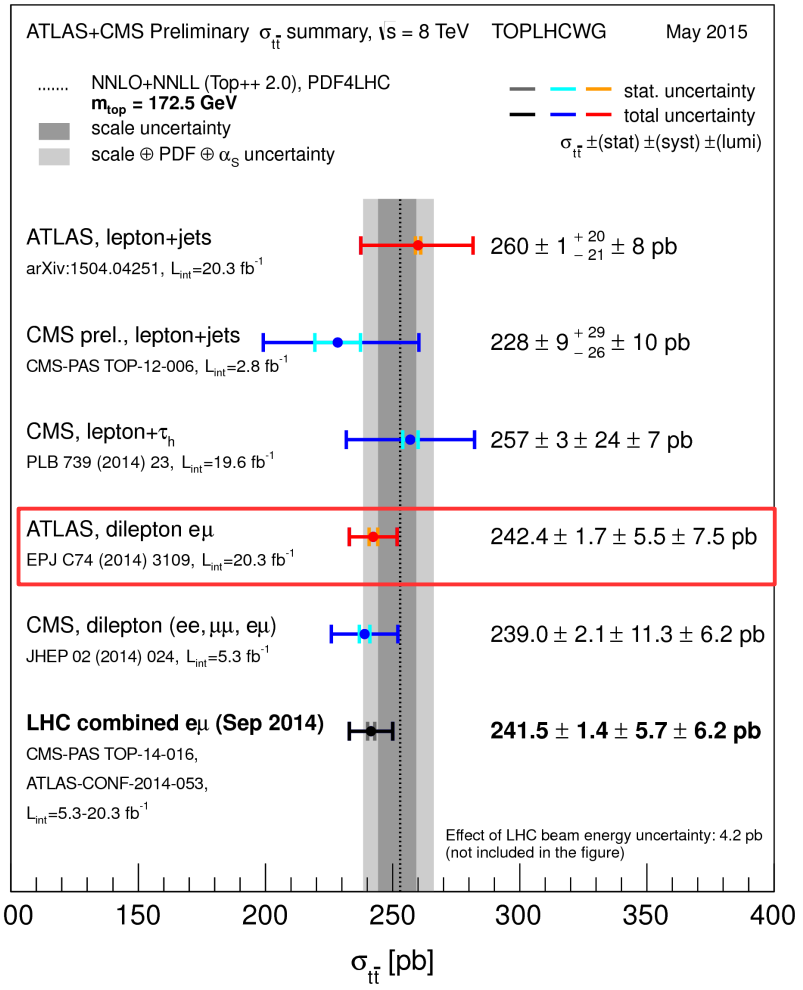
# Top Quark Production

# Inclusive top pair 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

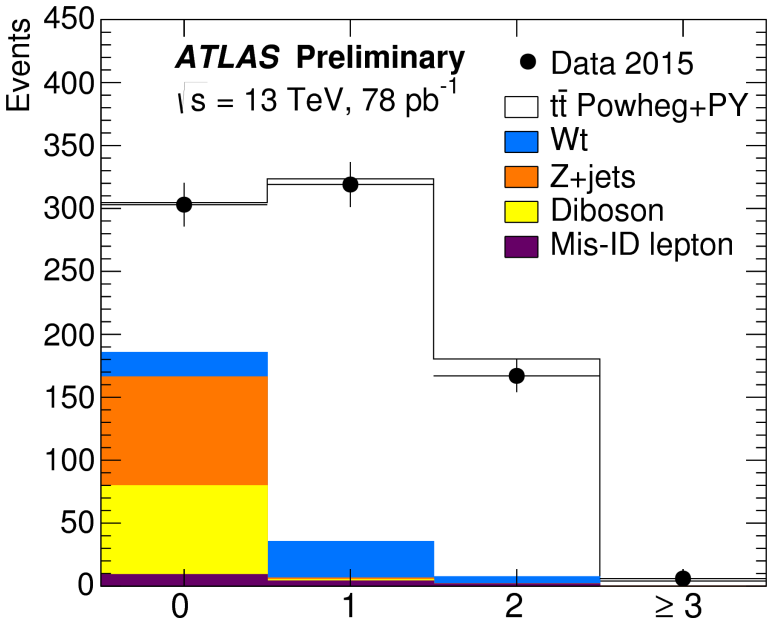
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/TOP/

# Inclusive top pair production

ATLAS-CONF-2015-033

13 TeV

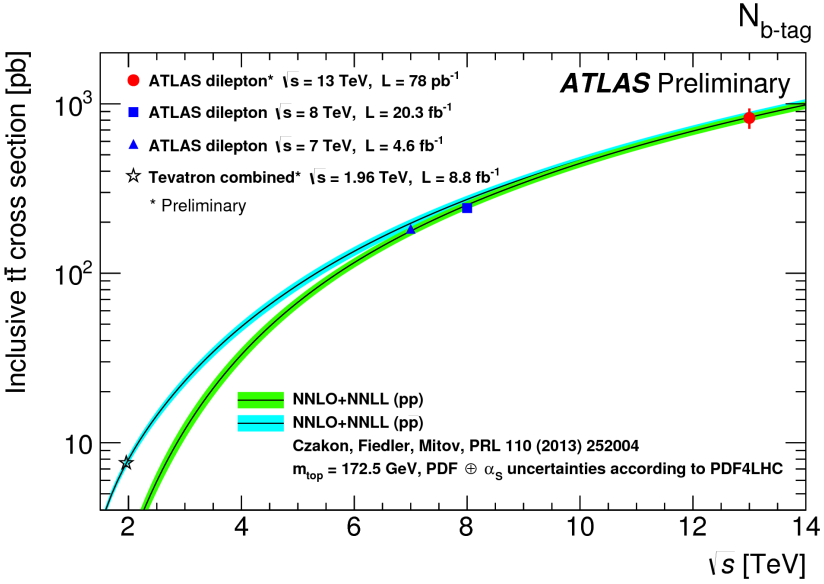
- First measurement using 13 TeV data.
  - Similar method as used for the most precise Run 1 measurement.
    - Simultaneous fit cross section, *b*-jet reconstruction and tagging efficiency.




- 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

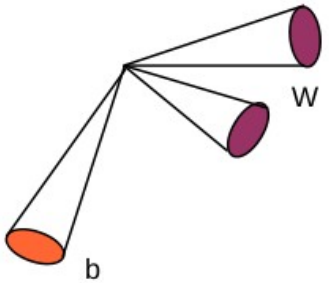


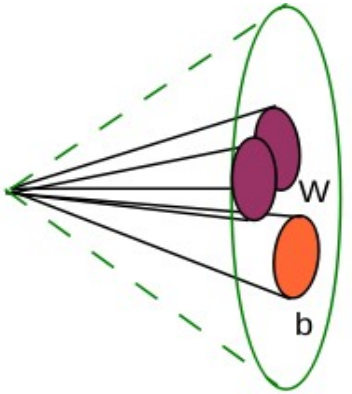
# Differential top pair production

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 |



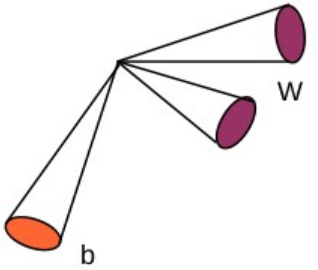



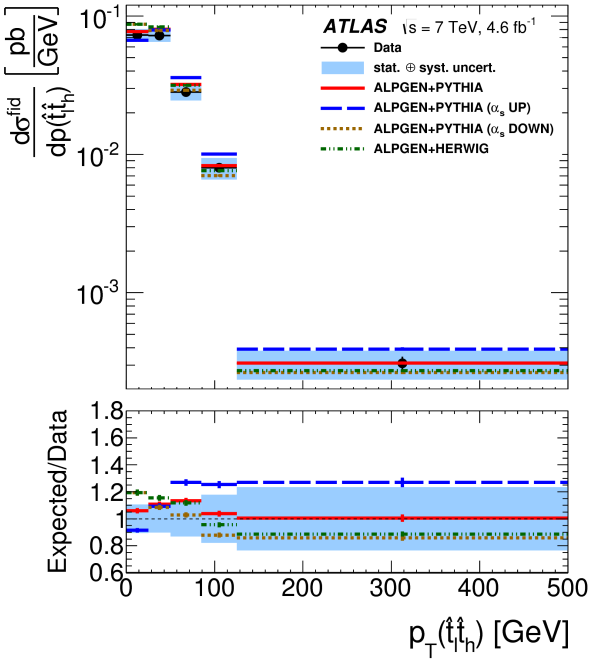
# Differential top pair production

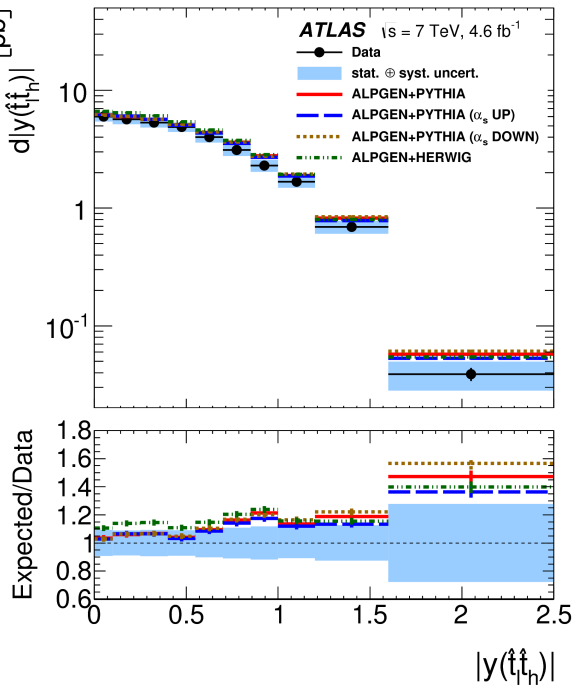
7 TeV

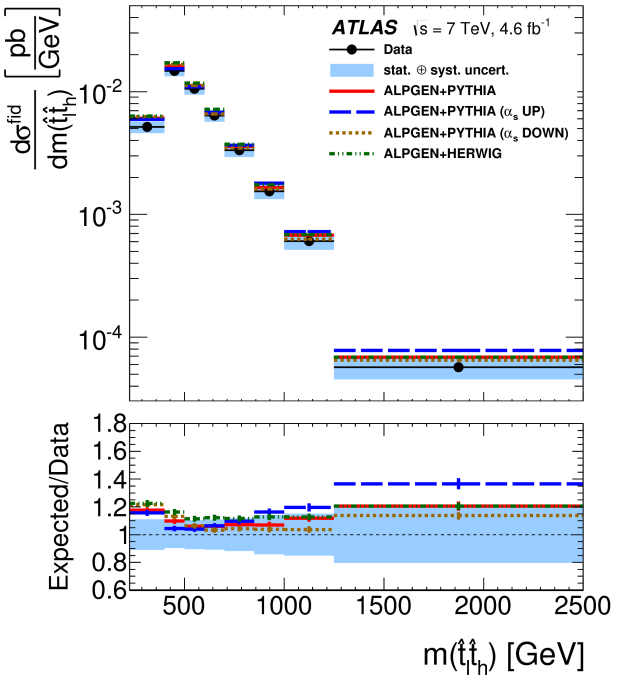
JHEP 06 (2015) 100

- 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



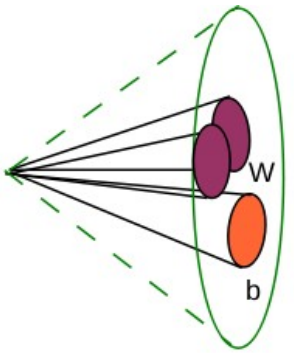



# Differential top pair production

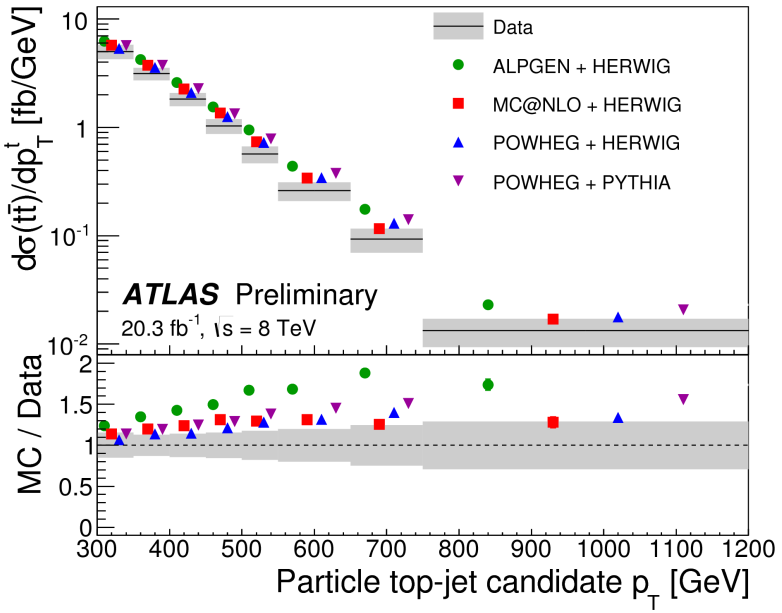
8 TeV

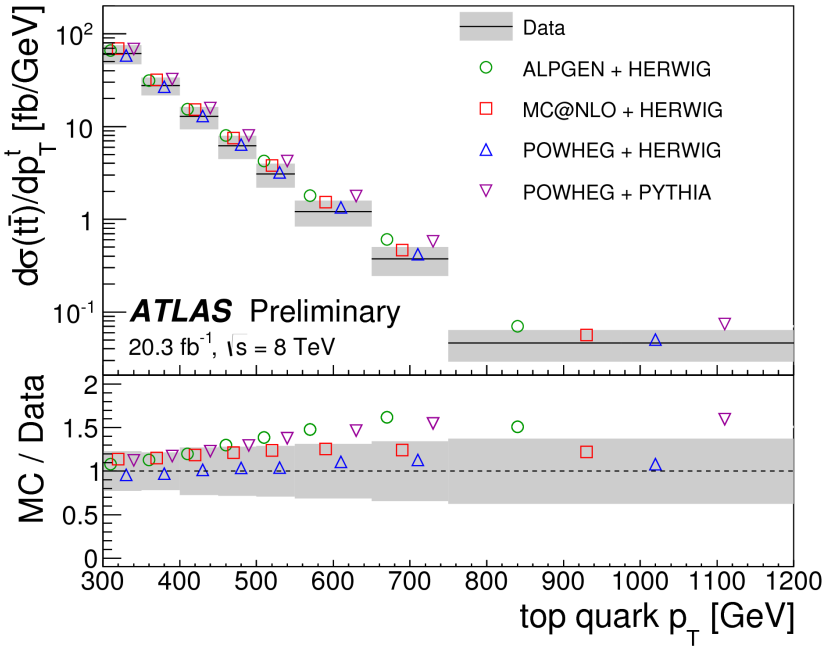
ATLAS-CONF-2014-057

- 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



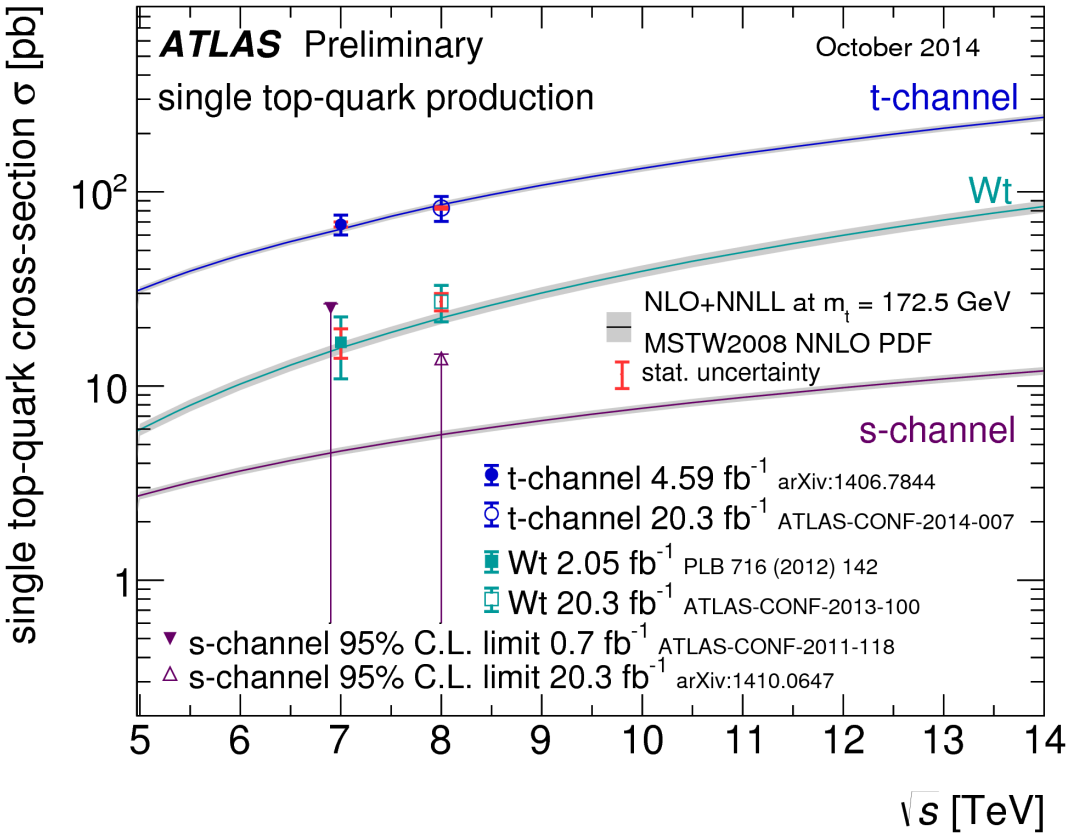



# Single top production

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

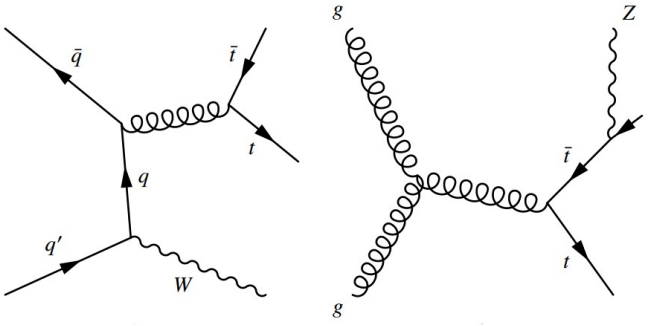


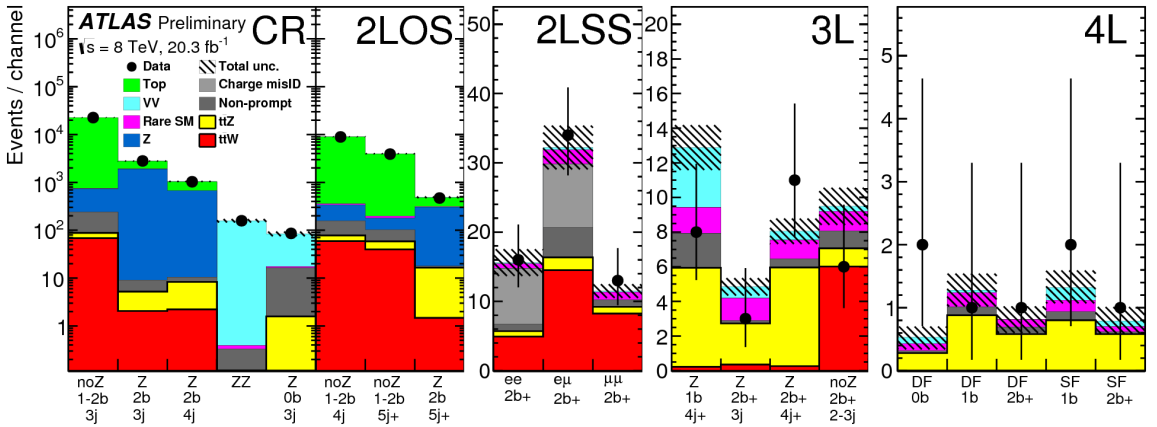

Results are compatible with NLO+ NNLL predictions

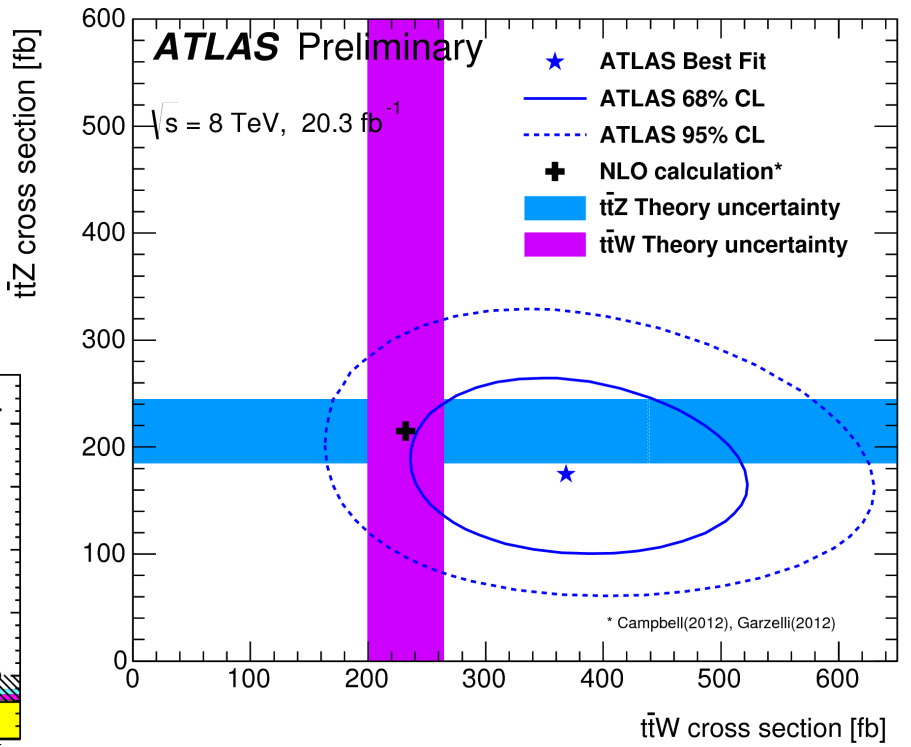
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/TOP/

# $t\bar{t}W$ and $t\bar{t}Z$ 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



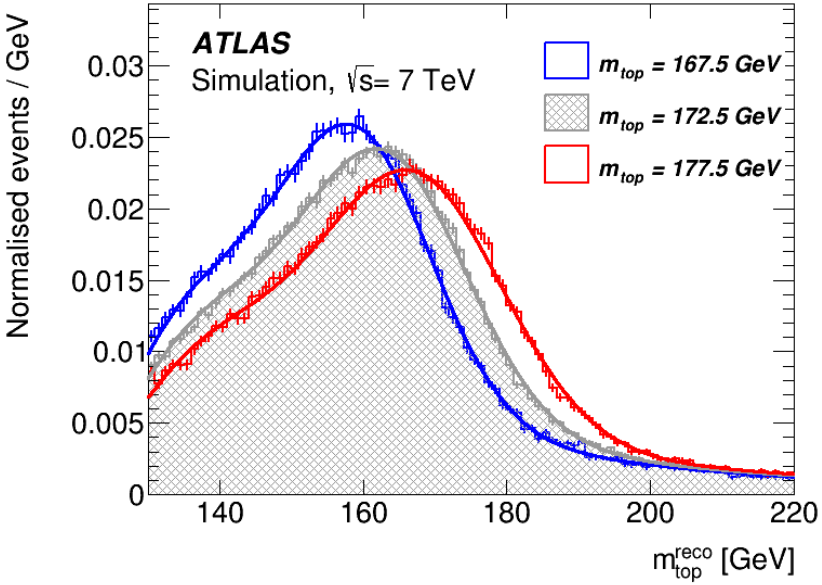




ATLAS-CONF-2015-012

# 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

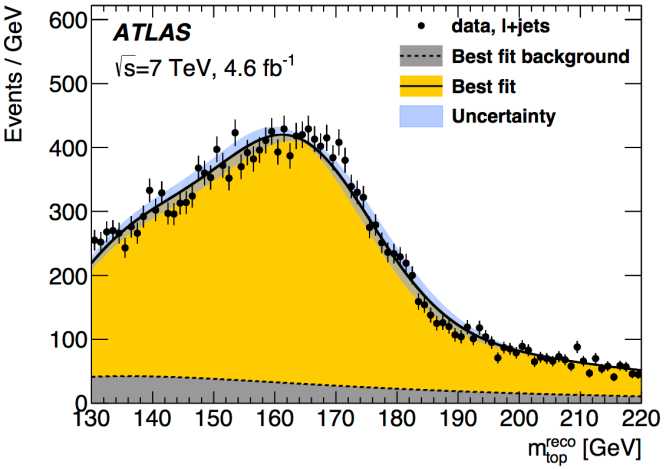


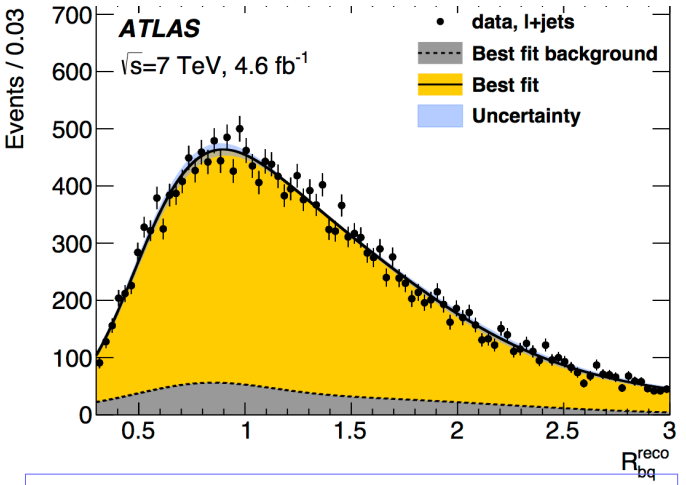
# Mass measurements

$t\bar{t} \rightarrow l$+jets and $t\bar{t} \rightarrow$ 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

$$m_{top} = 172.99 \pm 0.48(\text{stat}) \pm 0.78(\text{syst})$$




Main uncertainties

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

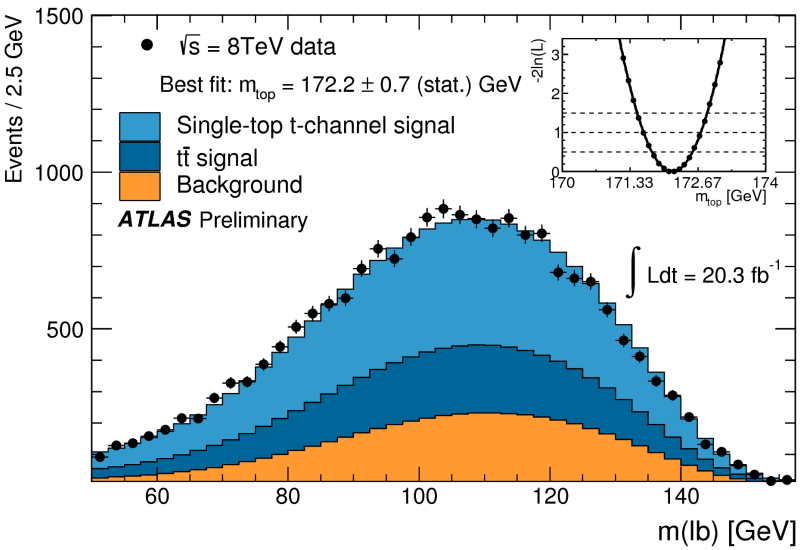
arXiv:1503.05427 submitted to EPJC

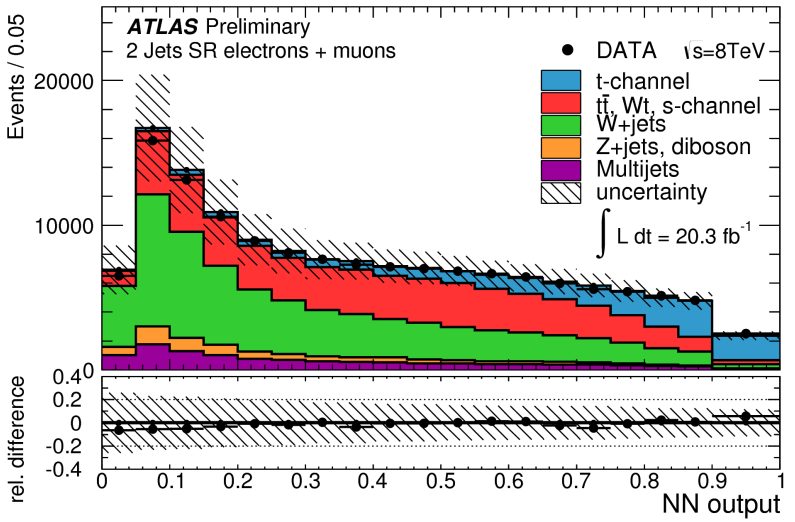
# Mass measurement in single-top

8 TeV

- 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.

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




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

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

- Unfold R + extract the pole mass using NLO calculation

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

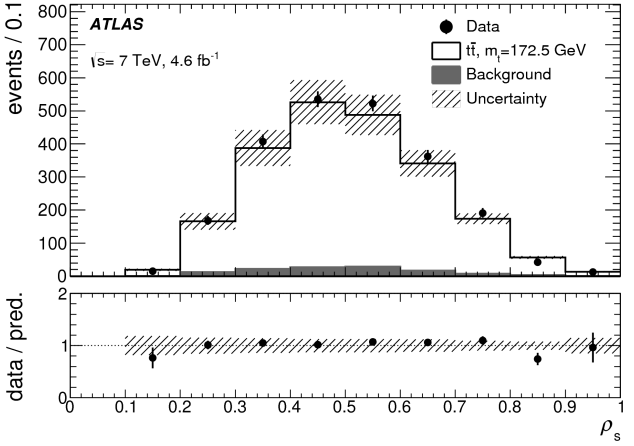
- Extra jet is required to have a $p_T$ > 50 GeV

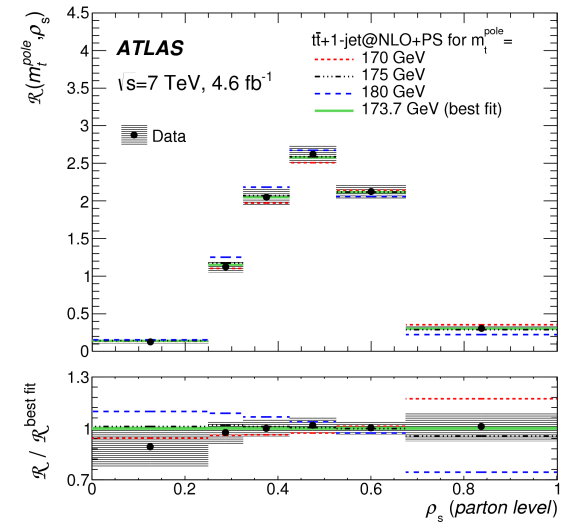
$$m_t^{\text{pole}} = 173.7 \pm 1.5\,(\text{stat}) \pm 1.4\,(\text{syst})^{+1.0}_{-0.5}(\text{theory})\ \text{GeV}$$

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.



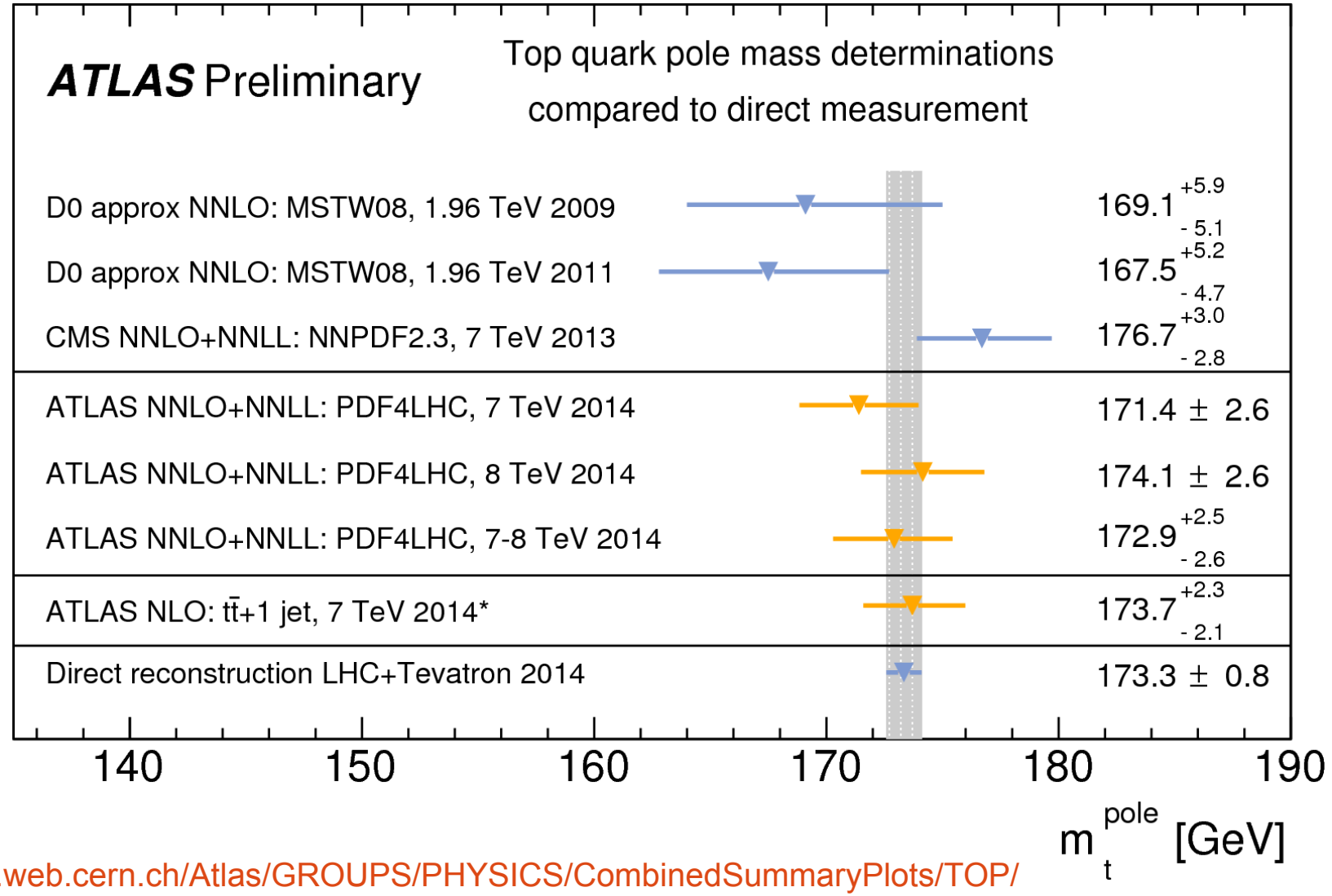






arXiv:1507.01769, subm. to JHEP

# 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

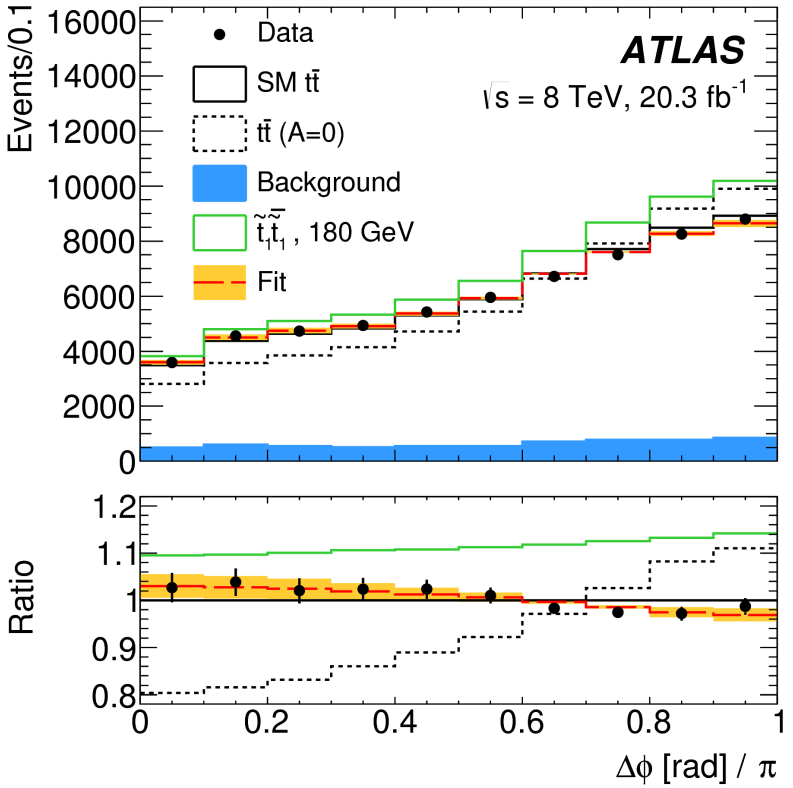
# Spin Correlation

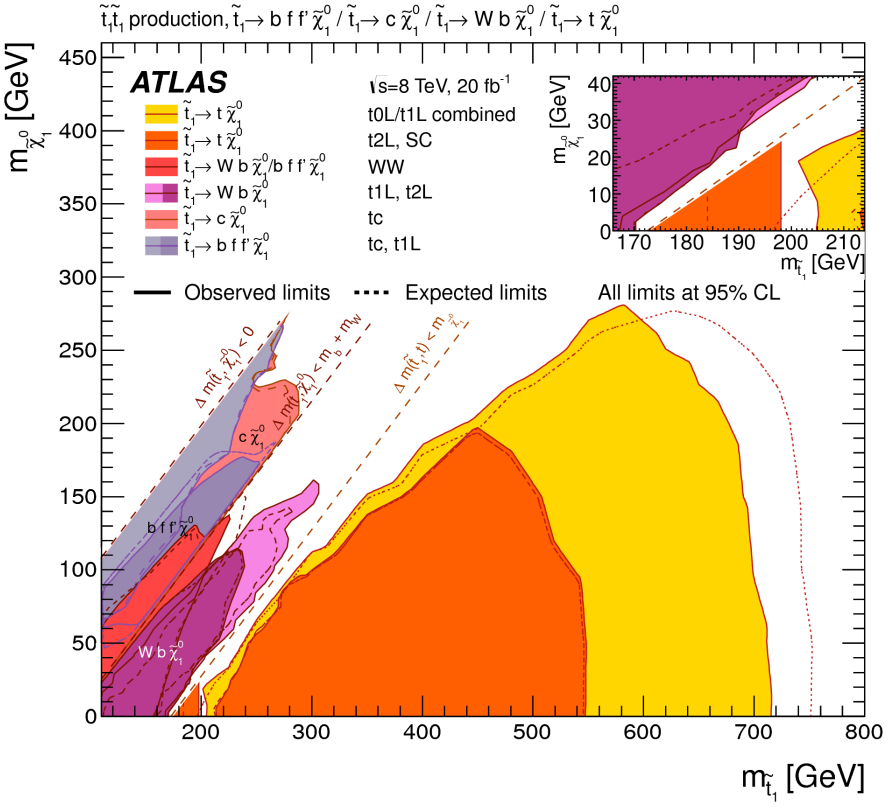
Phys. Rev. Lett. 114, 142001 (2015)

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

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

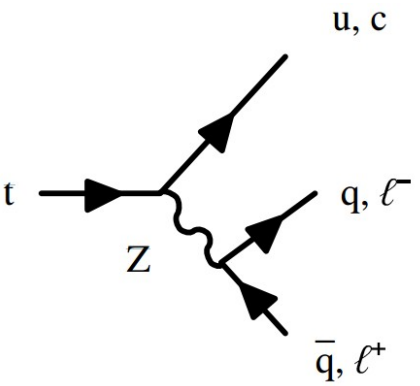


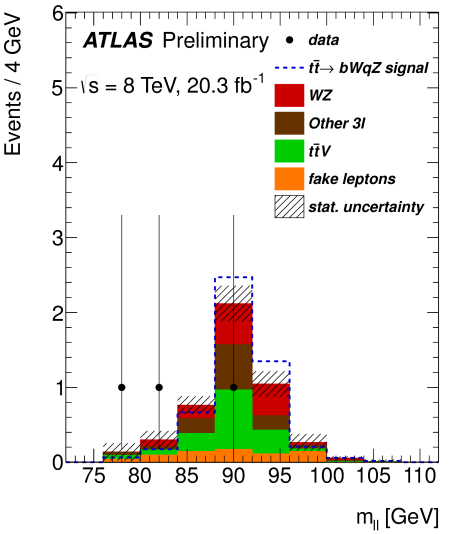



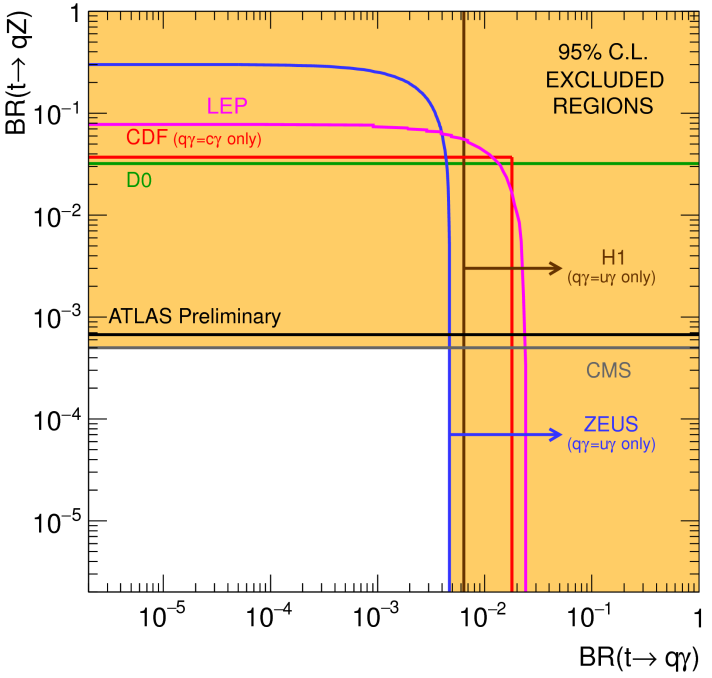
# FCNC in the trilepton channel

8 TeV

- 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 $7 \times 10^{-4}$



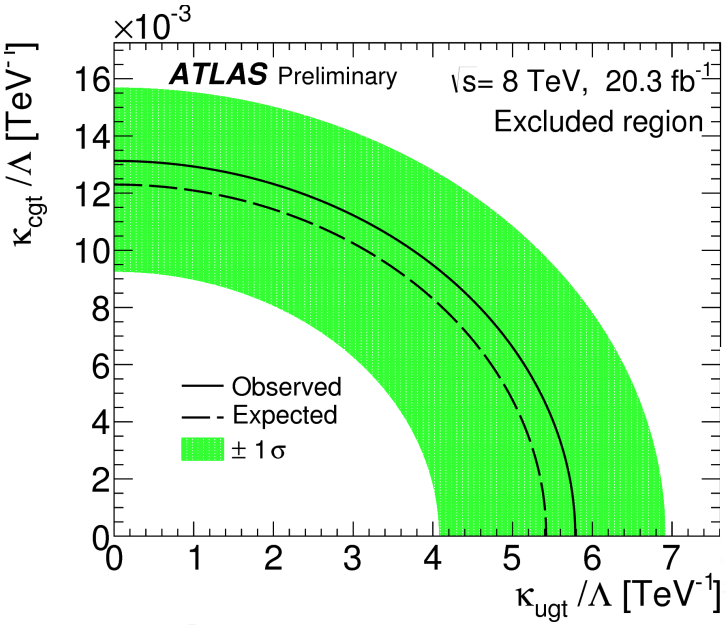



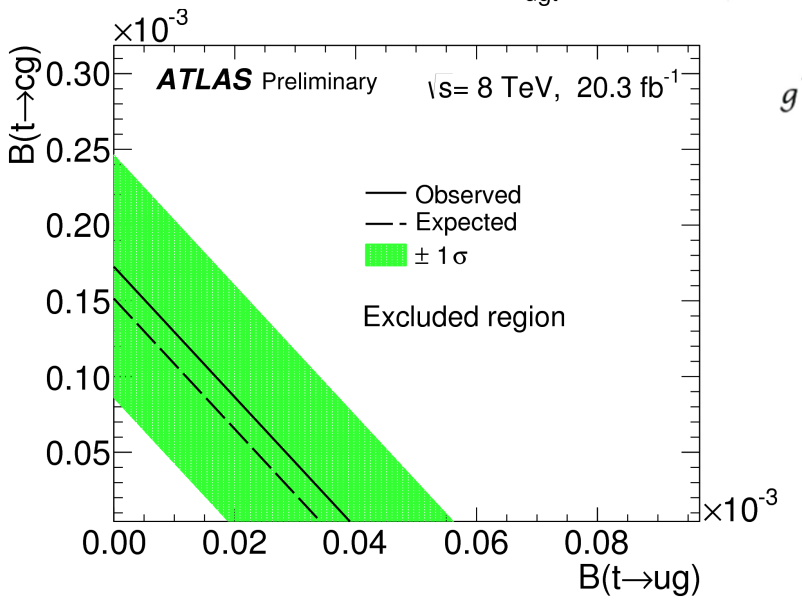



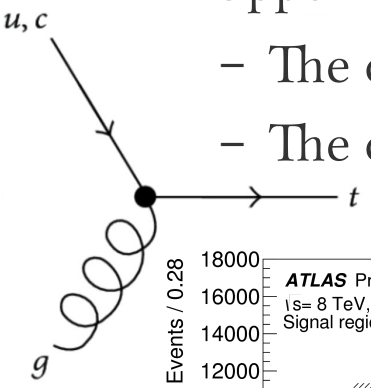

To be submitted

# Single top production via FCNC

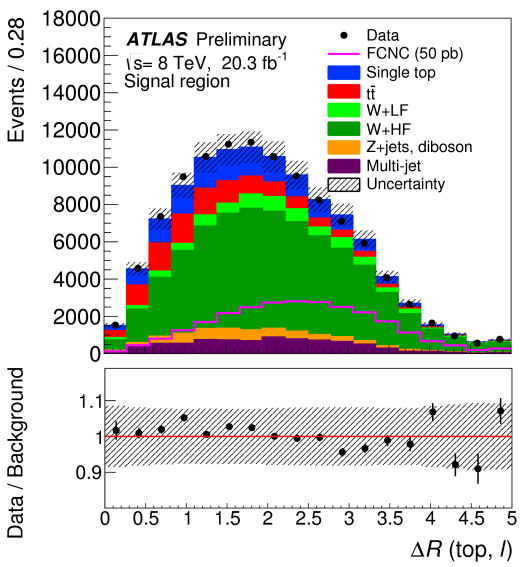
8 TeV

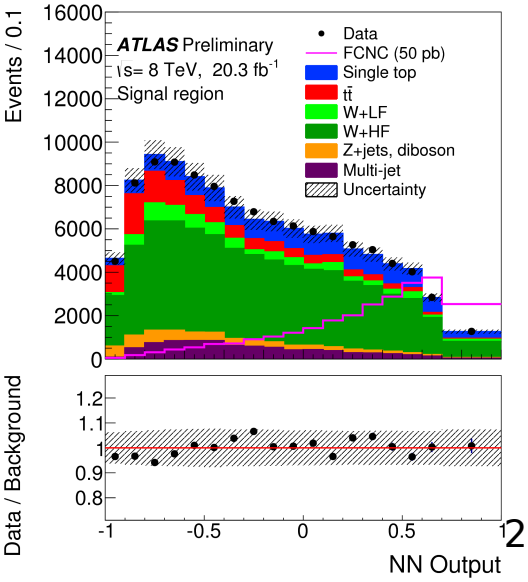



- Search for single top production via $gu/c \to t$
- Only leptonic decay channel is considered
- NN used to discrimate signal and background
- Upper limit are established on
  - The cross section times branching ratio
  - The coupling constants




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!

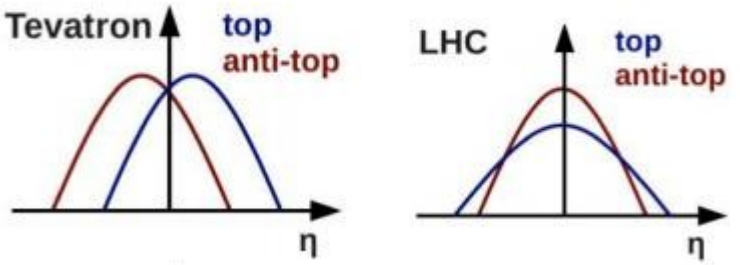
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

# Backup

# Charge Asymmetry Measurement

7 TeV JHEP 05 (2015) 061

- 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

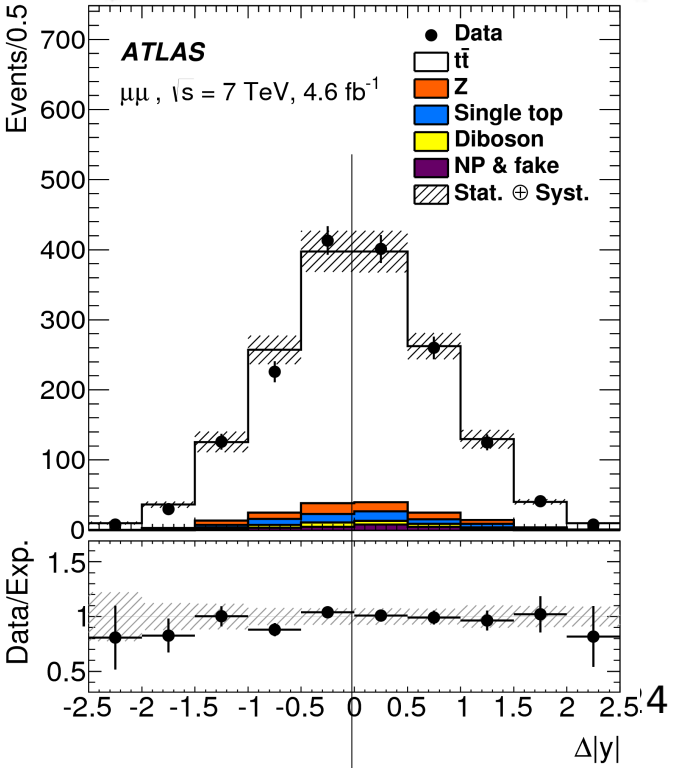
Top based asymmetry

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

Lepton based asymmetry

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

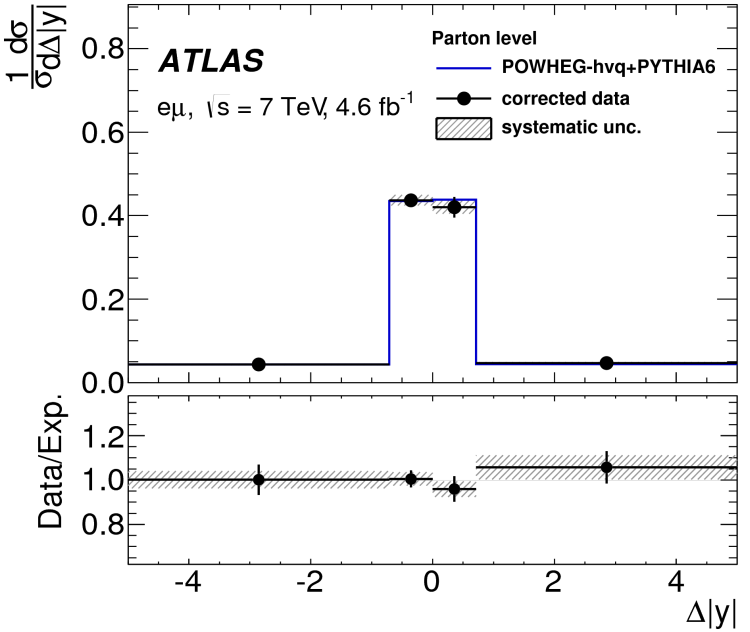
- Latest results in the dilepton channel at 7 TeV
- Kinematic reconstruction is required in order to compute the top based asymmetry

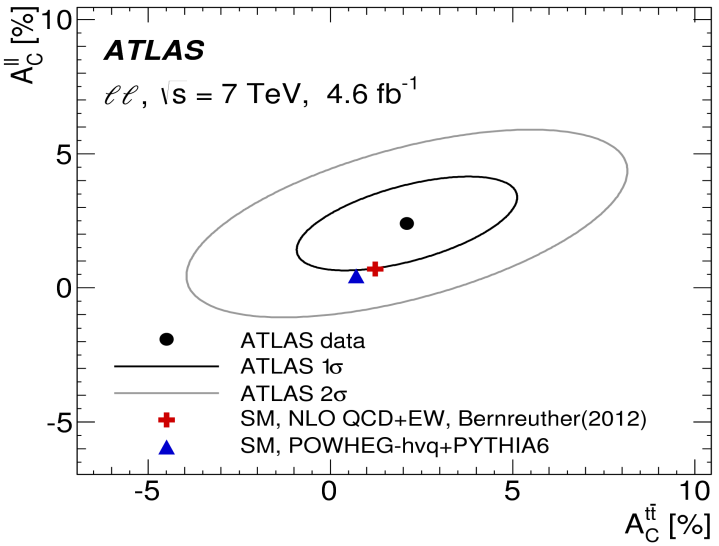


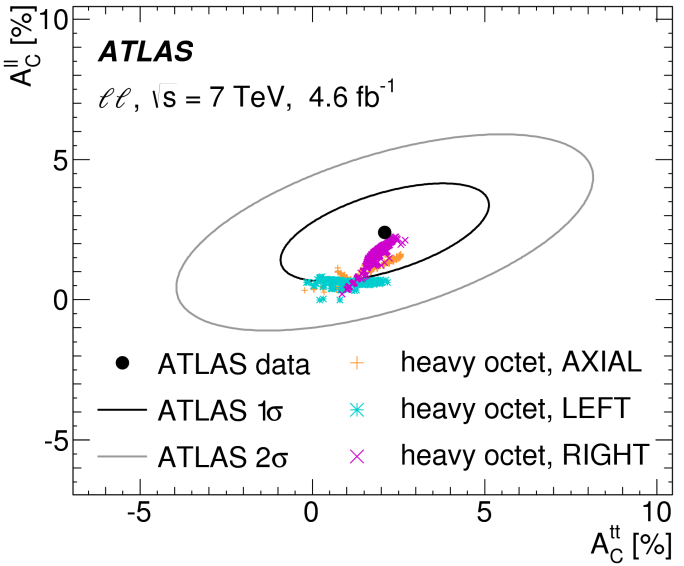
# Charge Asymmetry Measurement

7 TeV JHEP 05 (2015) 061

- 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



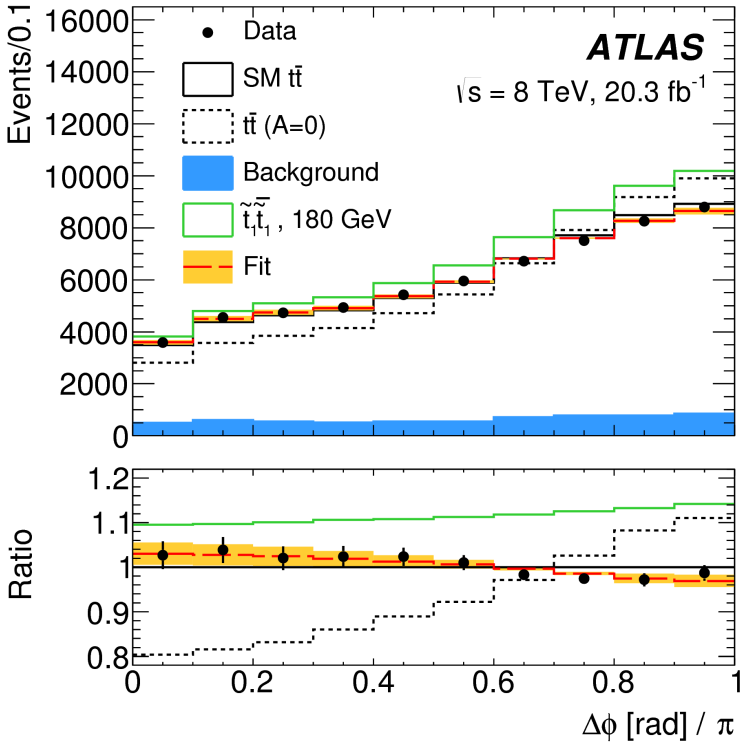



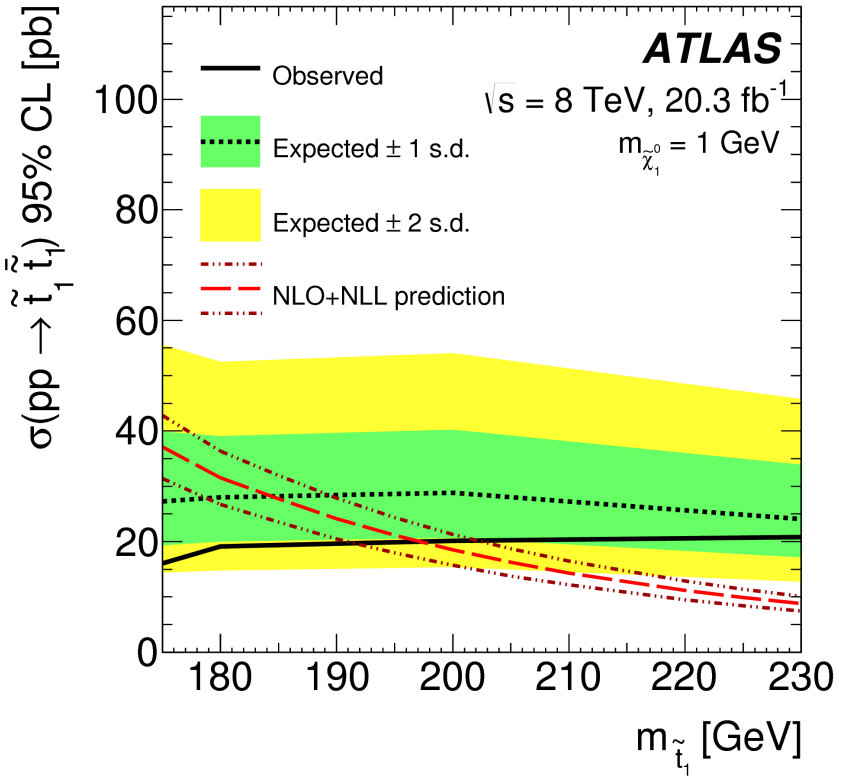
# Spin Correlation

Phys. Rev. Lett. 114, 142001 (2015)

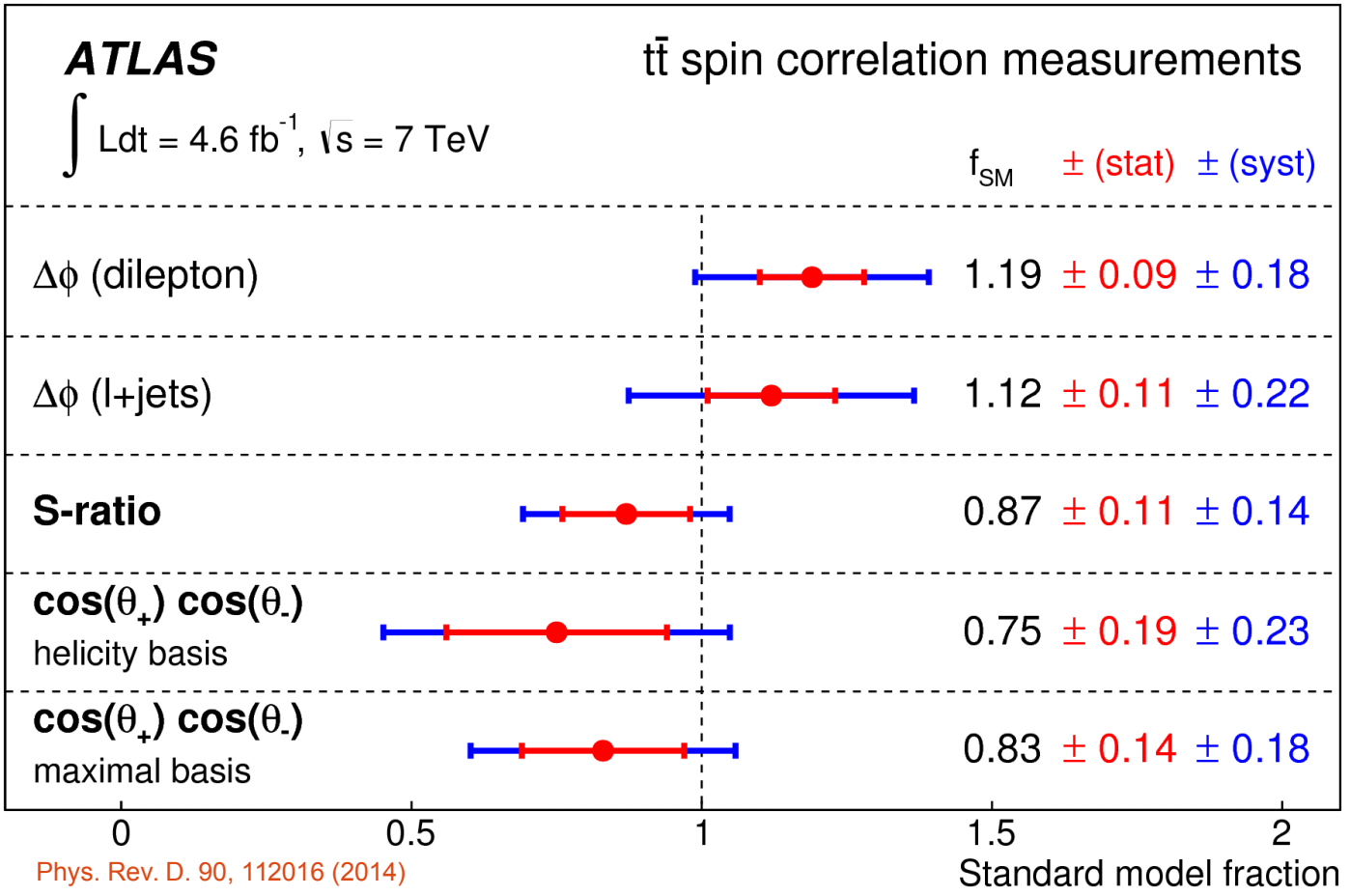
8 TeV

- 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



# Others spin correlation measurements

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