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Top Physics with ATLAS

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On behalf of the ATLAS Collaboration

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Outline

Introduction: The Top Quark

Top Quark Production at ATLAS

The Top Quark Mass

Properties of the Top Quark

Summary

The Top Quark

The **heaviest** elementary particle, m_t ~ gold atom.

Free parameter of the Standard Model.

Can test the self consistency of the SM in combination with W mass measurements and Higgs mass measurements.

Large coupling to the Higgs boson. An important role in electroweak symmetry breaking?

The top quark is unique. It is the only quark that **decays before it can hadronise**.

$$\boxed{1/\Gamma_t} < \boxed{1/\Lambda_{\mathrm{QCD}}} < \boxed{m_t/\Lambda^2_{\mathrm{QCD}}}$$

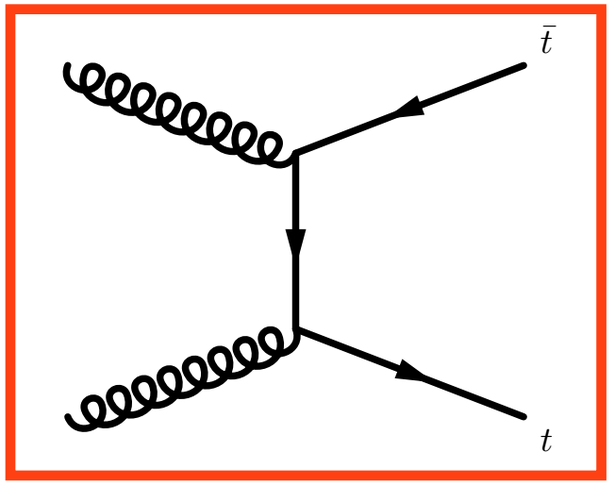
Top quark lifetime

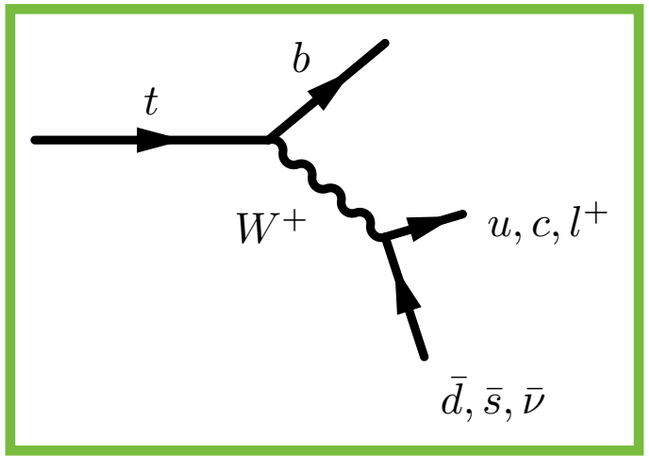
Hadronisation time

Spin decorrelation time

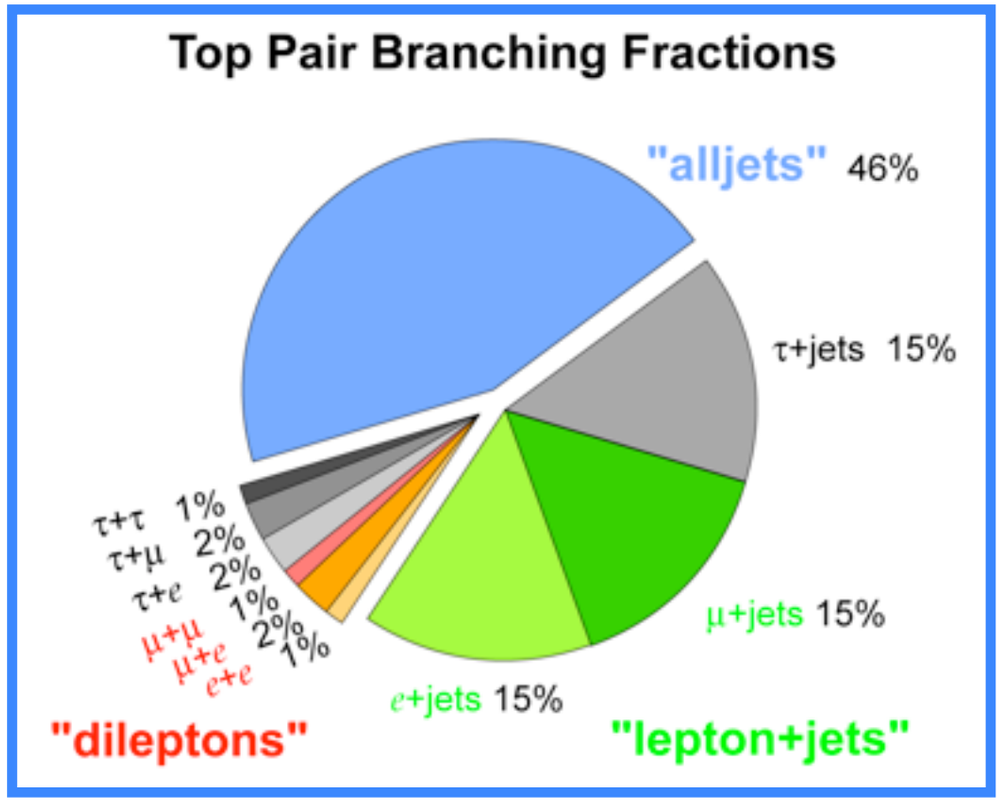
LHC - A Top Quark Factory

- The LHC is a top quark factory.
- Large sample of top events allows for measurements of top quark properties.
- Mostly produced in top anti-top pairs although also produced singularly.

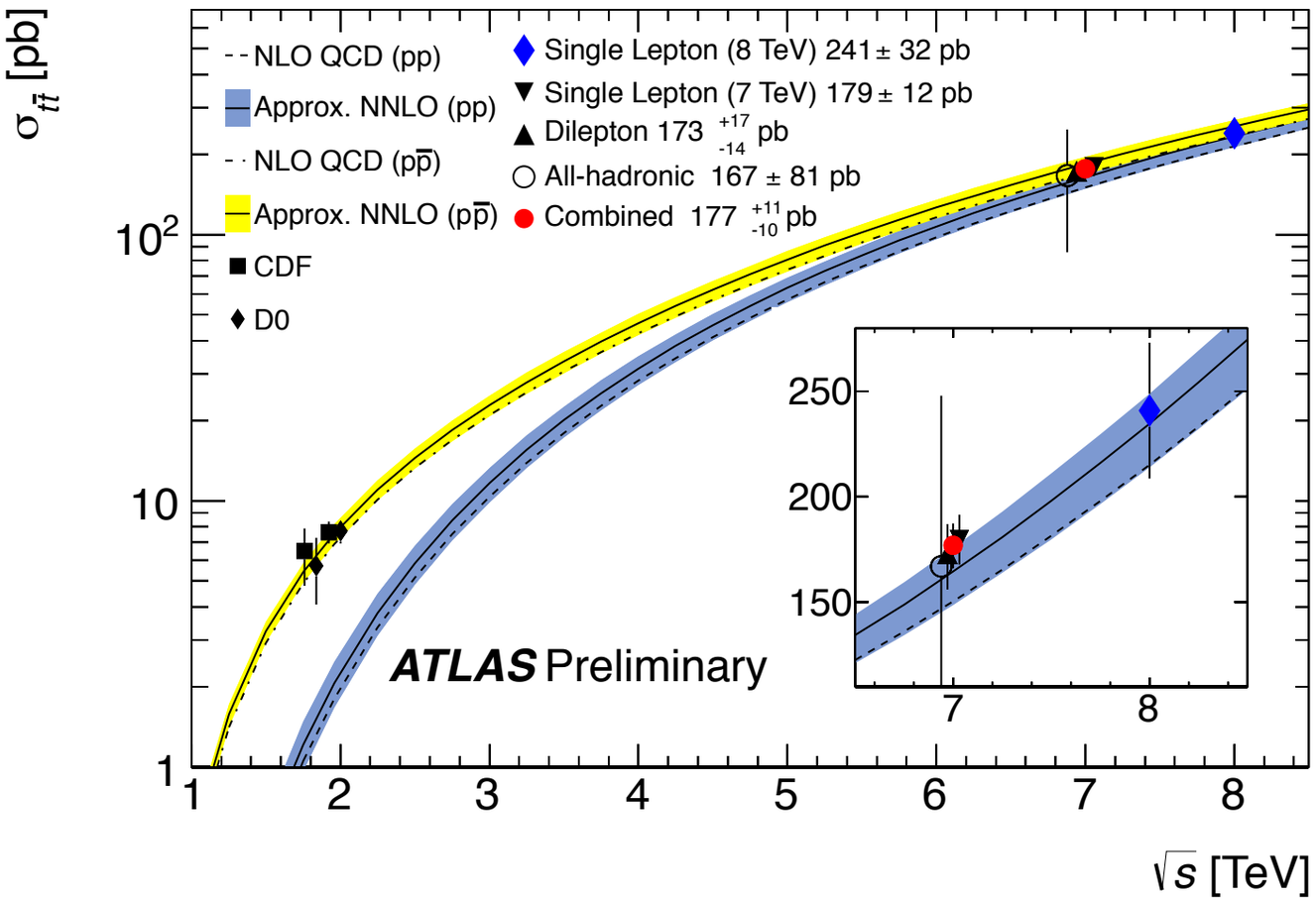




- The top quark decays to Wb ~ 100% of the time.
- Therefore top quark pair events are classified by how each of the two W bosons decay.



Top Production at ATLAS

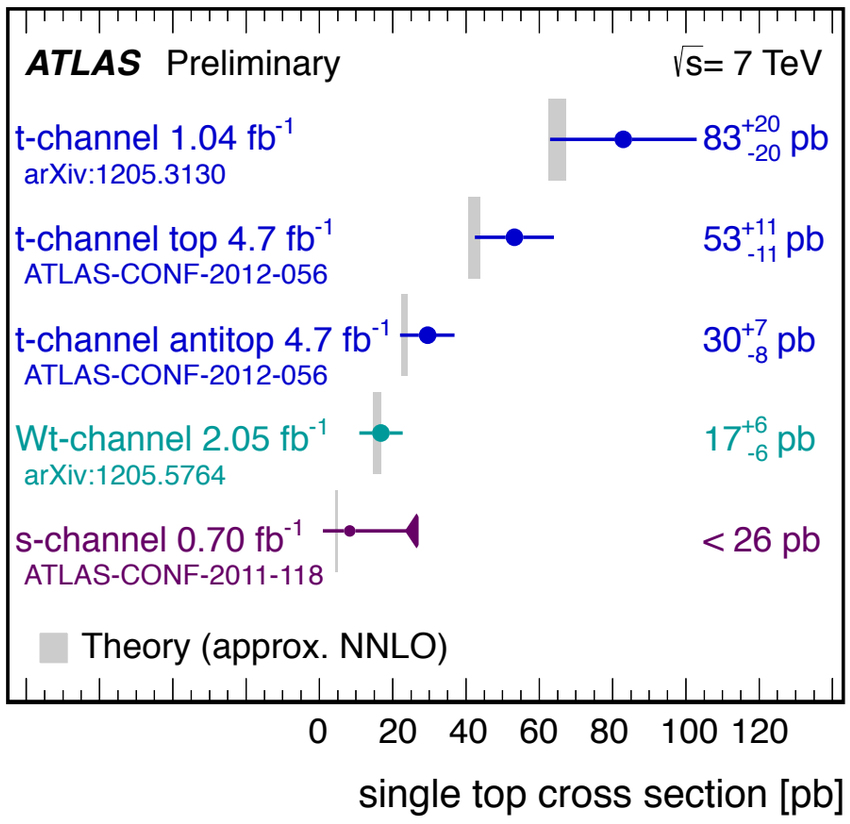


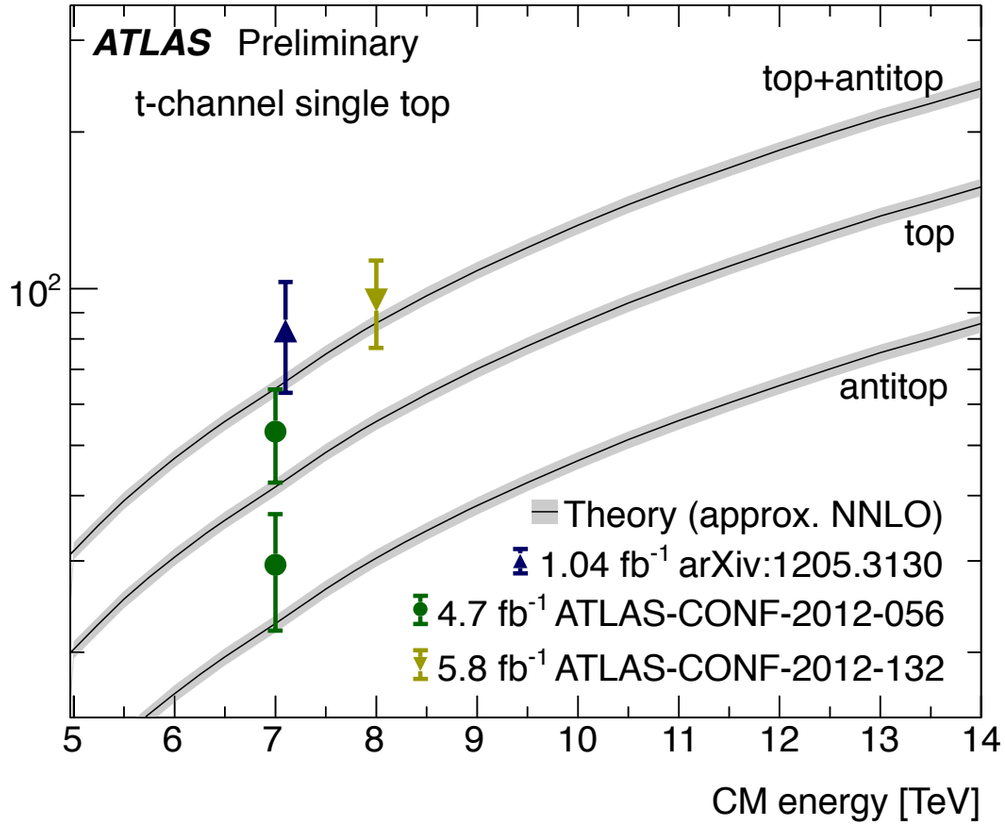
- $t\bar{t}$ production cross-section in good agreement with theory over nearly one order of magnitude in centre of mass energy from 2 - 8 TeV.

- Measure different channels to thoroughly check the SM.
- All channels show consistent results.
- Exact NNLO+NNLL:

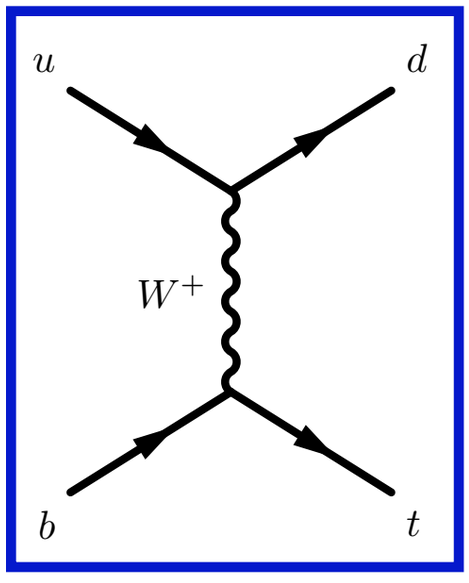
$$177^{+10}_{-11}\ \text{pb}$$ **Top++2.0**

Top Production at ATLAS

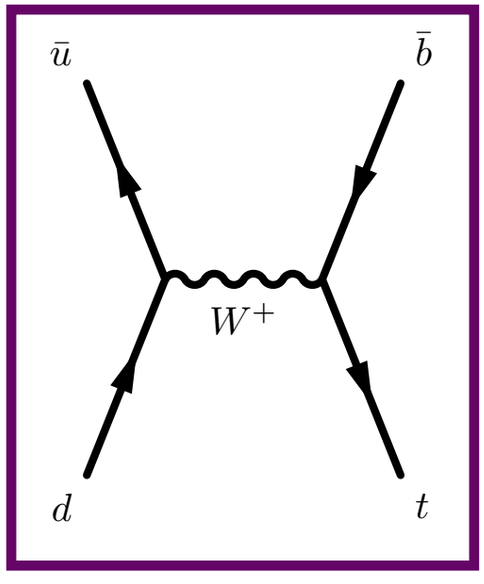




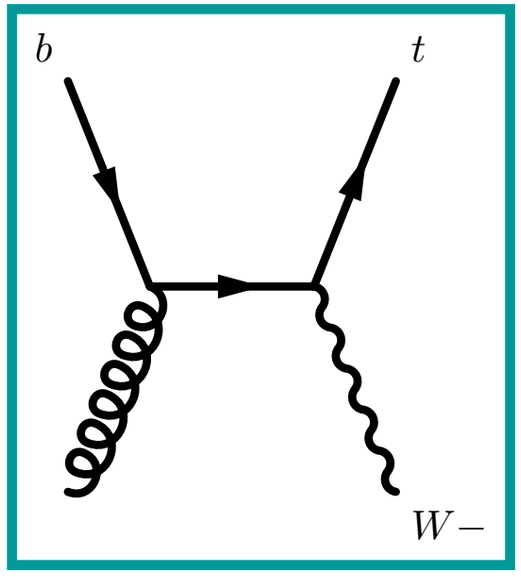
- Single top production cross-section also in good agreement with theory at both 7 & 8 TeV.



t-channel



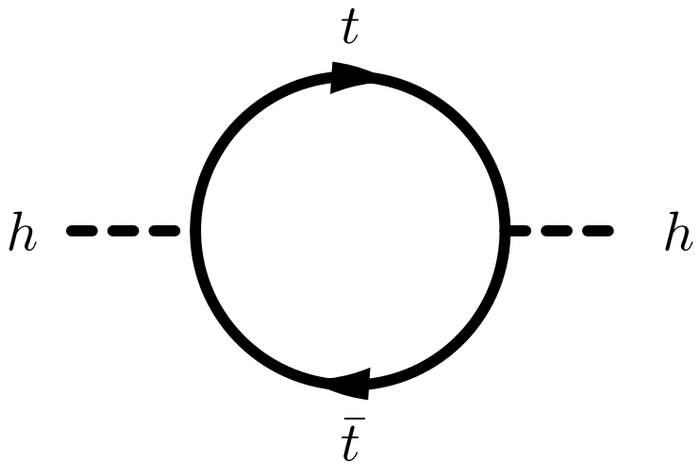
s-channel

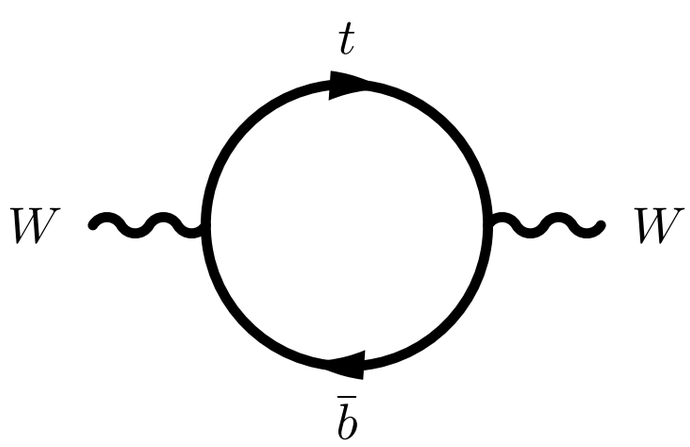


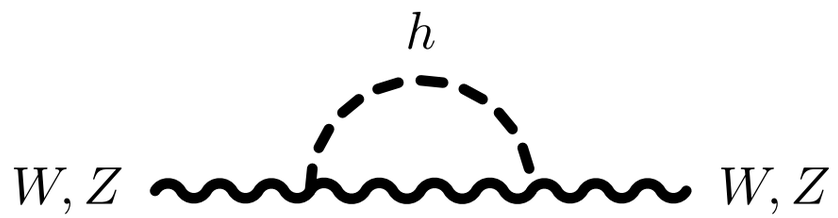
Wt

Top Mass

Production well established at ATLAS to agree with SM.
m_{top} is a free parameter of the SM.
Most massive known particle.
Precise measurement allows to check the consistency of the SM, with the W mass and Higgs mass.







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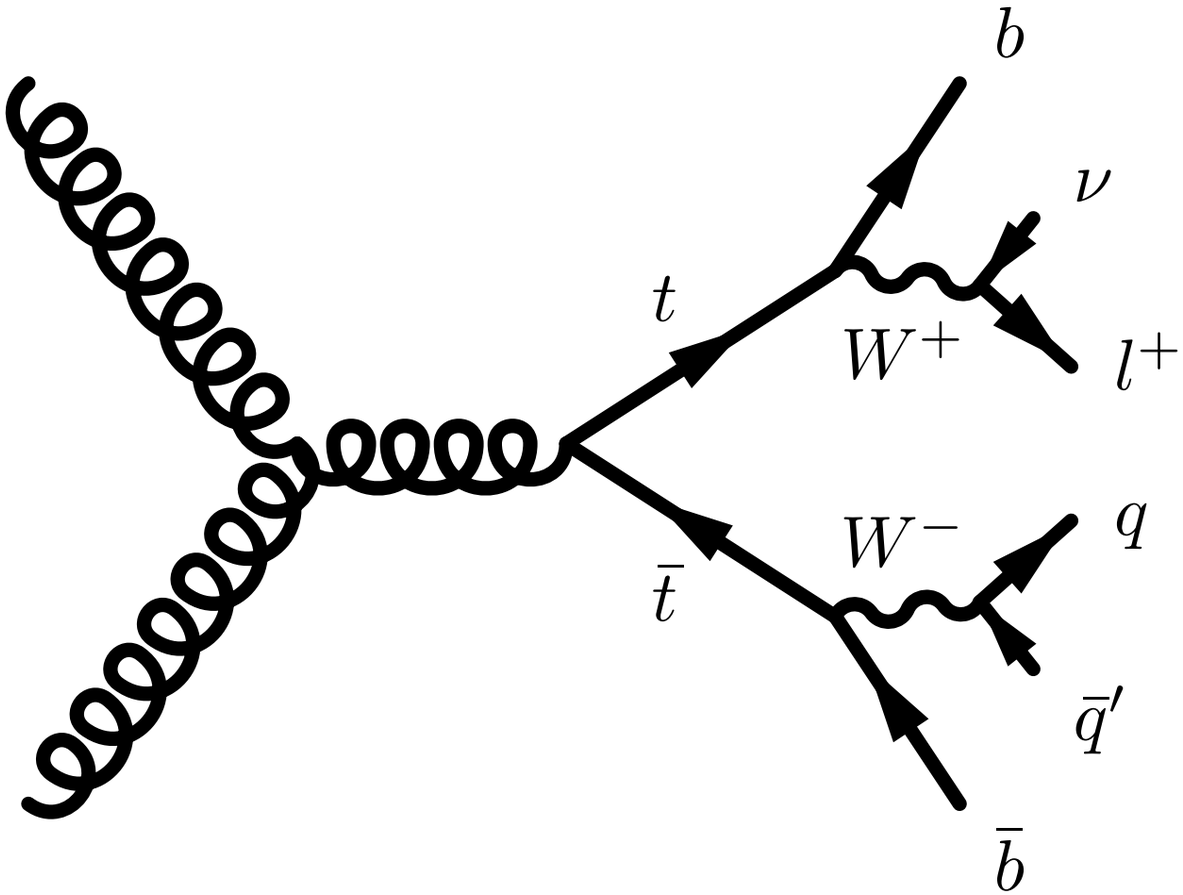
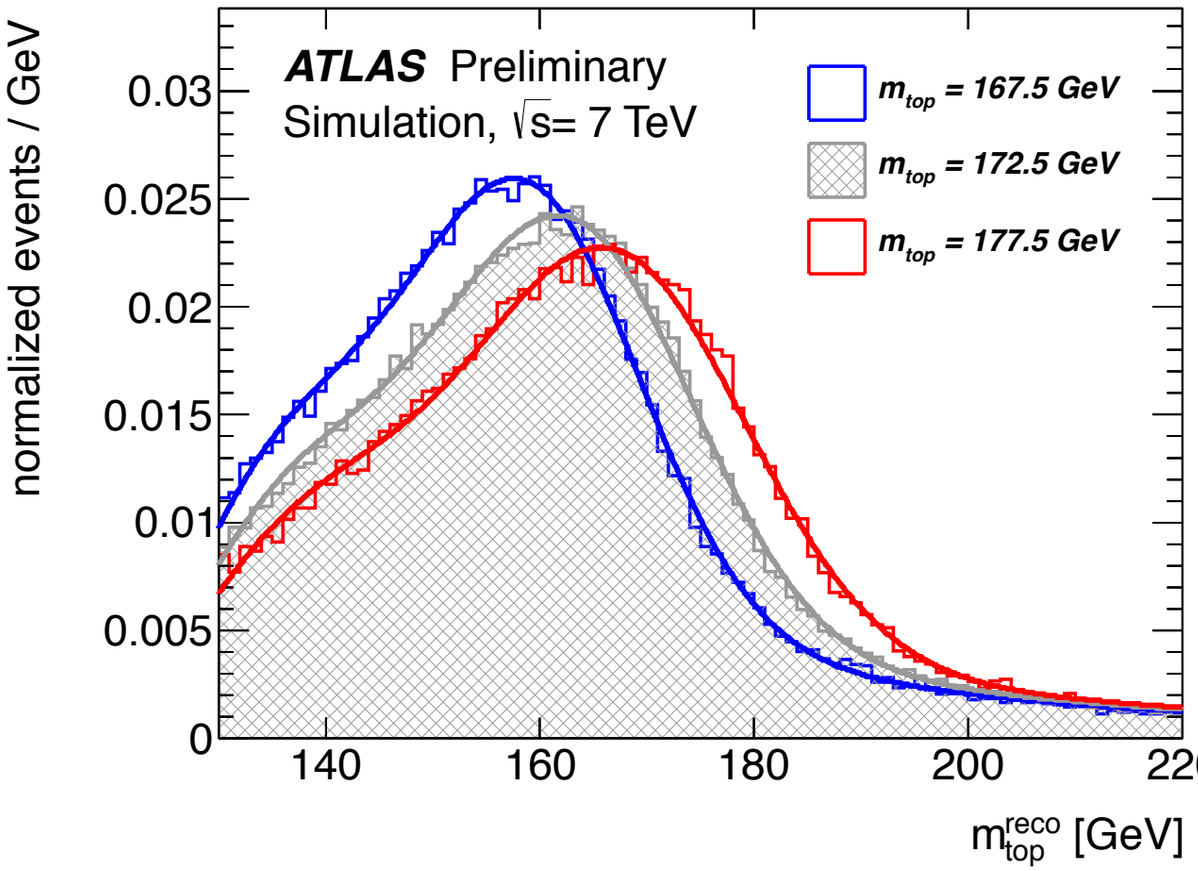
4.7fb^{-1} 7TeV

m_{top} - Lepton + Jets Channel





Reconstruct each event using a kinematic likelihood method.

Create templates of reconstructed top mass with different values of input MC top mass.

Reconstructed top mass is sensitive to different input mass in the MC but also to the **jet energy scale.**

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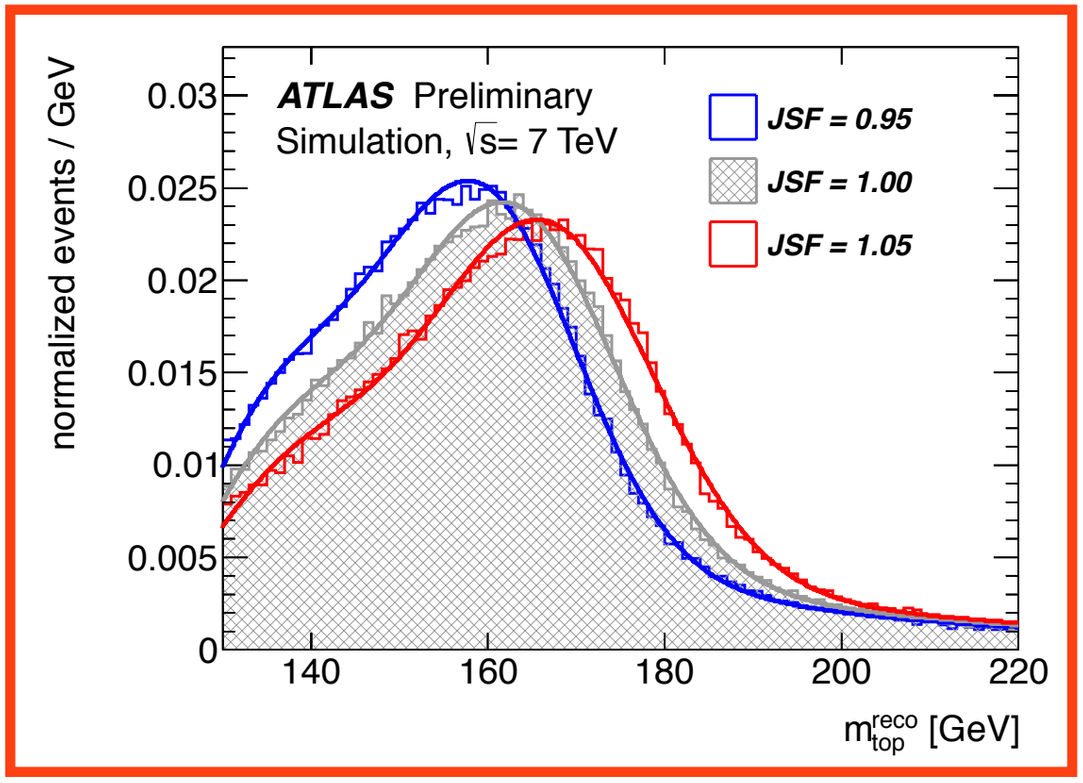
Jet Energy Scale (JES)

$4.7fb^{-1}$ 7TeV



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m_{top} - Lepton + Jets Channel

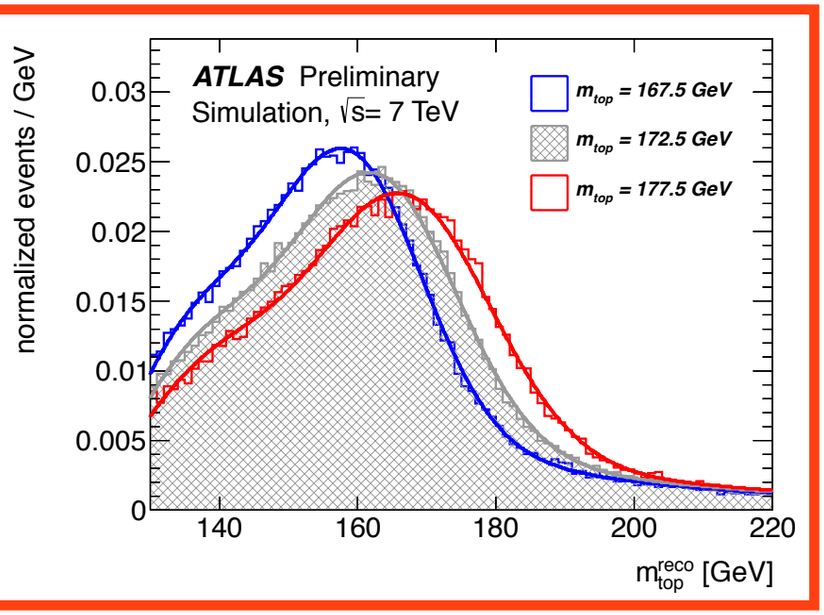
$4.7fb^{-1}$ 7TeV

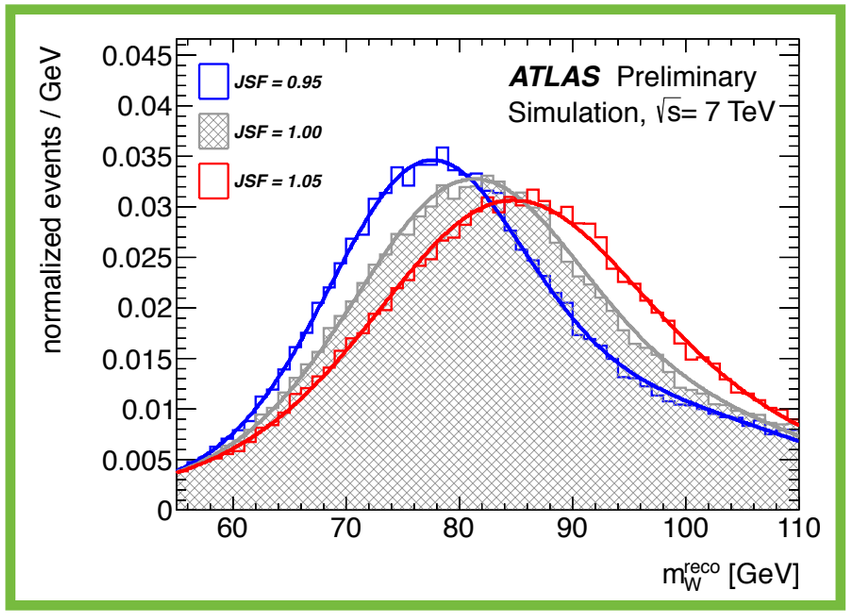
2010 data: **1D** fit of **m_{top}**. Large systematics from **JES**.

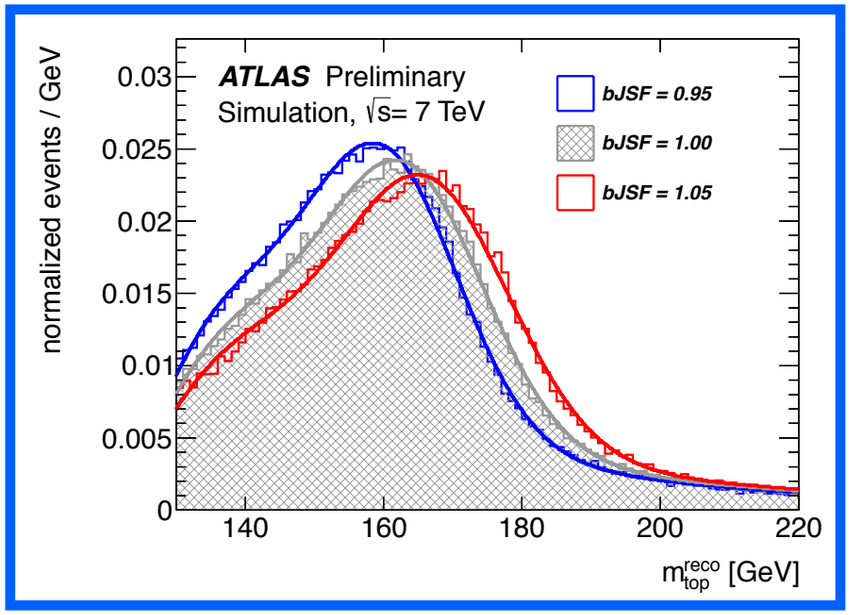
early 2011 data: **2D** fit of **m_{top}** & **Jet Scale Factor (JSF) using m_W**. Largest systematic is **bJES**.

full 2011 data: **3D** fit of **m_{top}**, **JSF** and **bJSF**.

Large dataset makes such a measurement possible. (**$4.7fb^{-1}$**)







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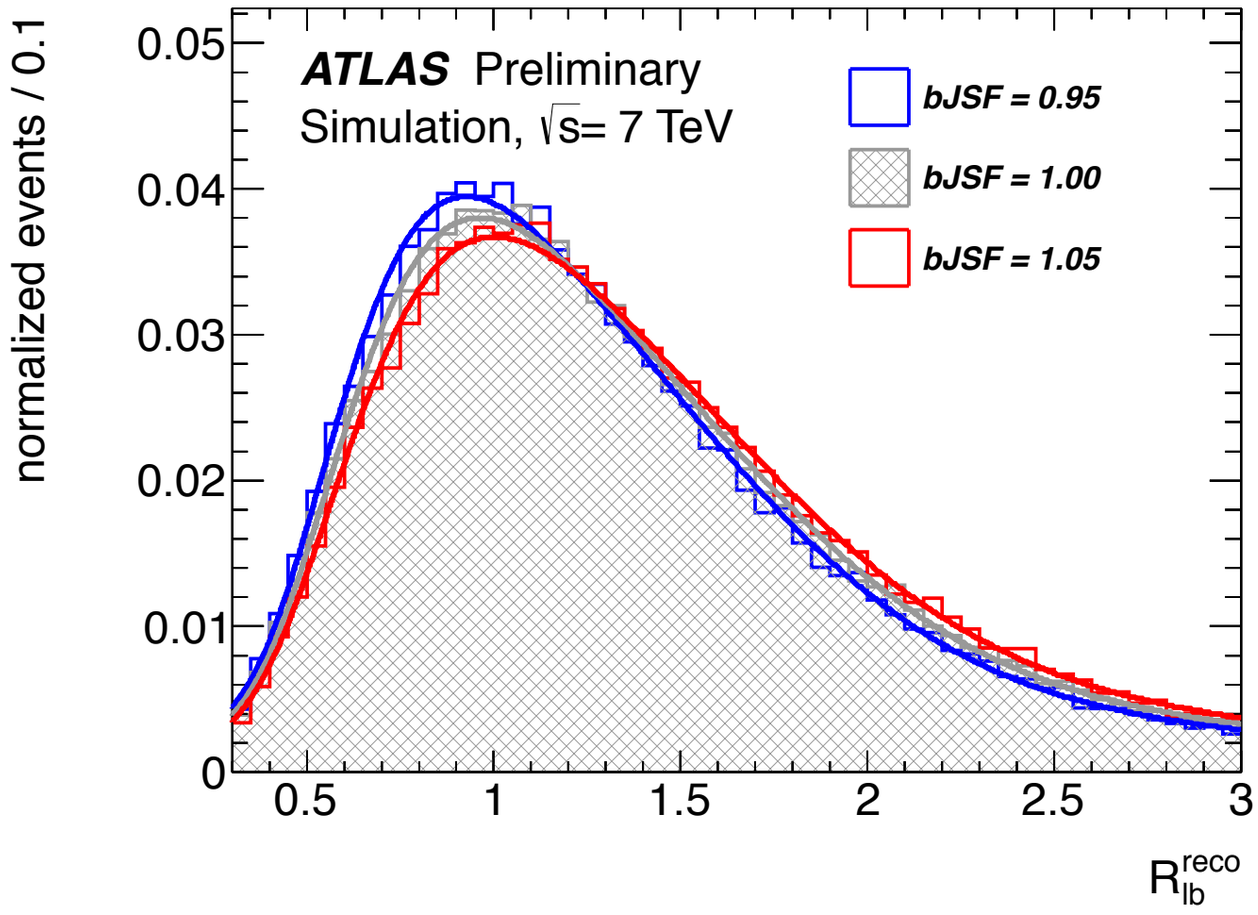
The 3rd dimension

4.7fb^{-1} 7TeV

- Use m_W to fit the JSF, but how do we fit bJSF?

- Construct R_{lb}, the ratio of the scalar sum of the pT of b-jets over light jets:

$$R_{lb}^{reco,2b} = \frac{p_{\mathrm{T}}^{b_{\mathrm{had}}} + p_{\mathrm{T}}^{b_{\mathrm{lep}}}}{p_{\mathrm{T}}^{W_{\mathrm{jet_1}}} + p_{\mathrm{T}}^{W_{\mathrm{jet_2}}}}$$



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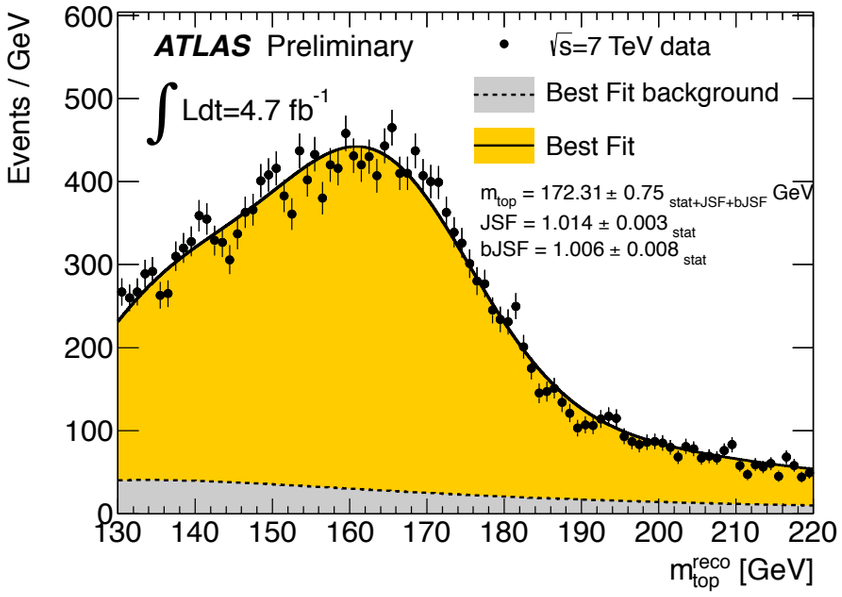
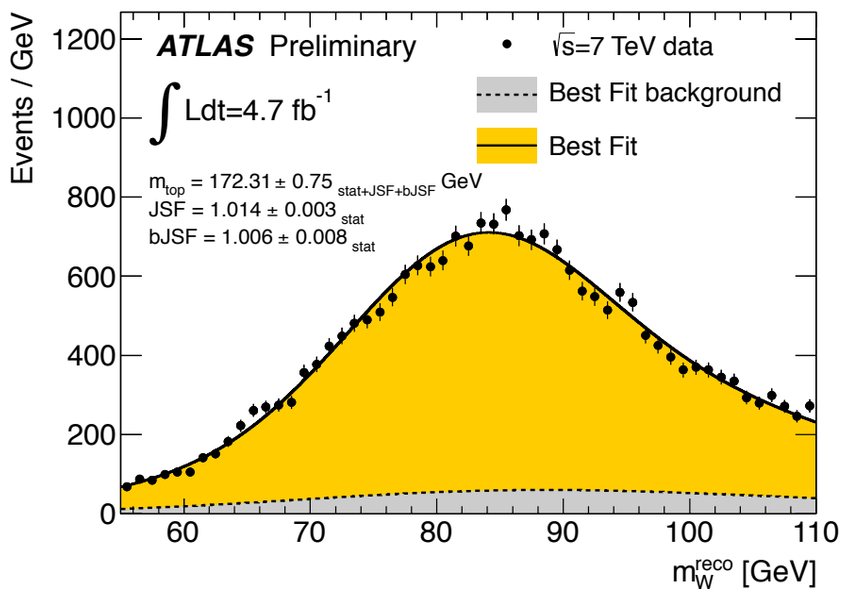
$4.7fb^{-1}$ 7TeV

Fit Results

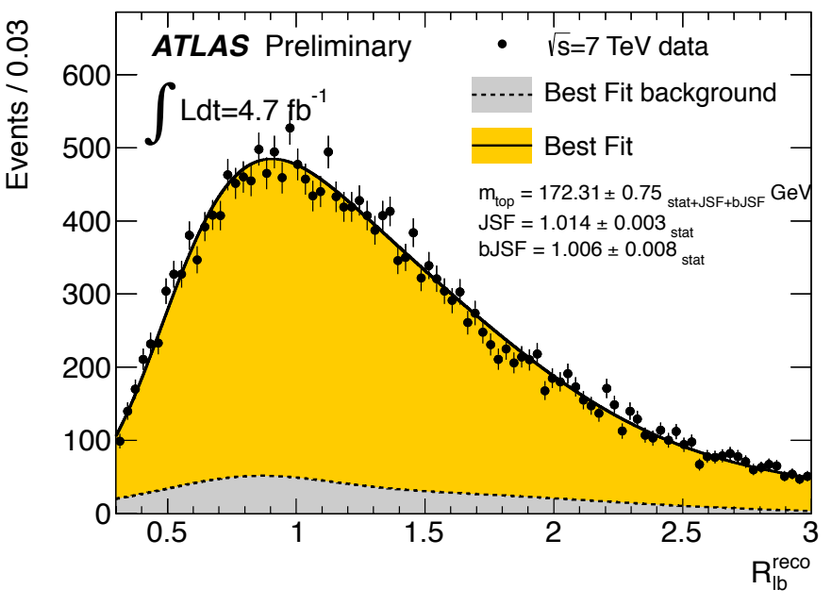
- 3 variables with sensitivity to m_{top}, JSF, bJSF. A 3-dimensional fit is performed to find the best fit values.



m_{top}



m_W



R_{lb}

Fit Result:

m_{top} = 172.31 ± 0.75 (stat+JSF+bJSF) ± 1.35 (syst) GeV

Largest systematics from JES and b-tagging efficiency/mistag rate.

Top Mass - dilepton channel

$4.7fb^{-1}$ 7TeV

- Select events with 2 leptons, 2 b-jets and missing transverse energy (from 2 neutrinos).

- Events are essentially background free and fewer lepton+b-jet pairings than in the lepton+jets channel.

- Use m_{lb}, the lowest average mass of the two lepton+b-jet permutations to measure m_{top}:

$$m_{lb} = \frac{1}{2}\min(m_{l_1 b_1} + m_{l_2 b_2}, m_{l_1 b_2} + m_{l_2 b_1})$$

- No need to fully reconstruct the top quarks in the event.

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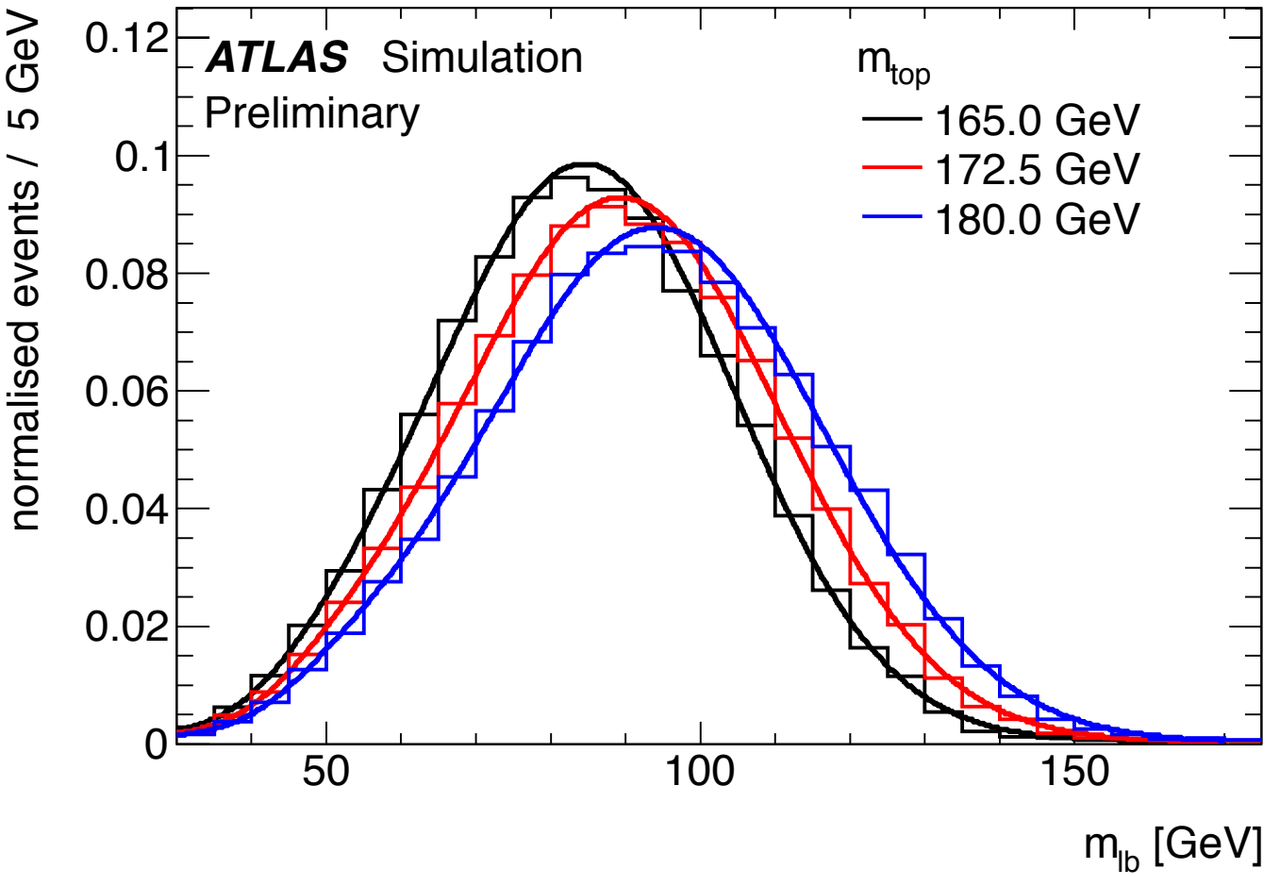
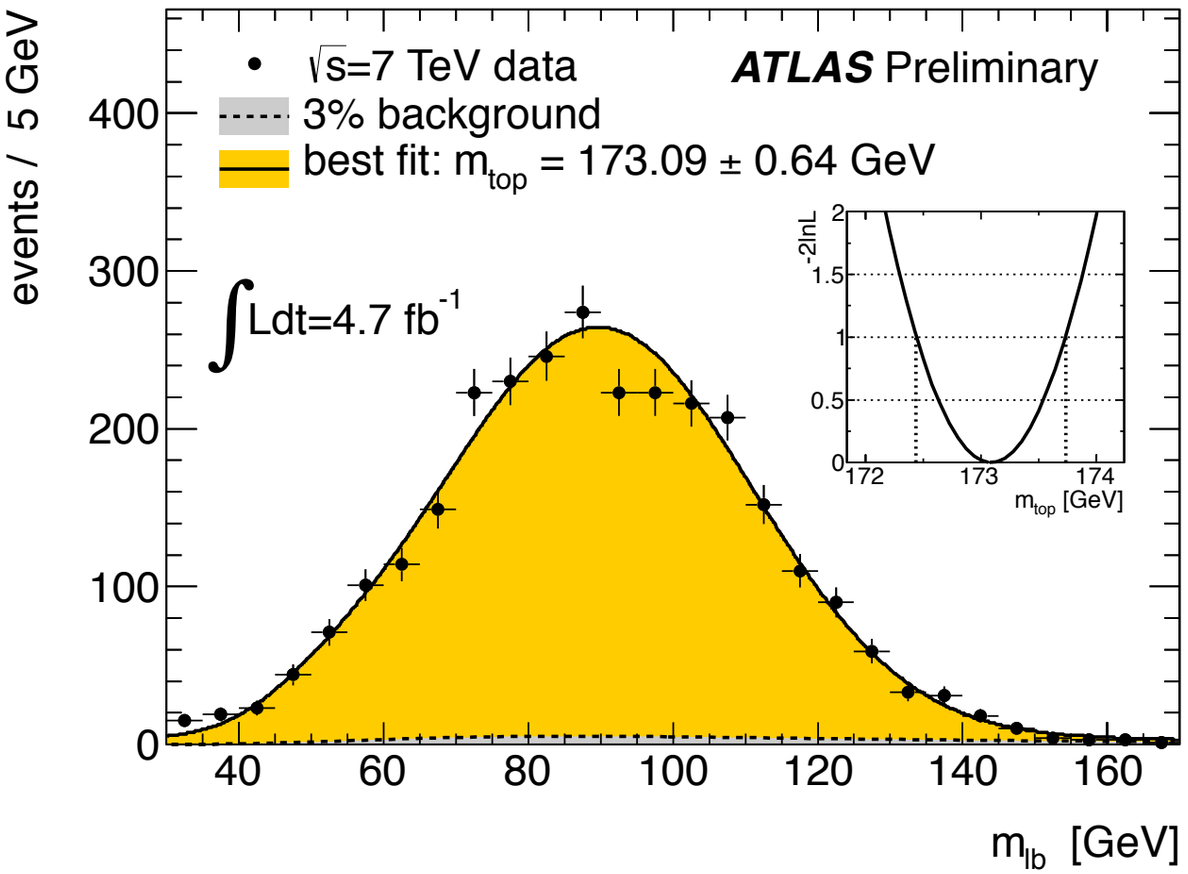
$4.7fb^{-1}$ 7TeV

m_{lb}





Extremely pure sample of $t\bar{t}$ events after event selection. Background is almost completely (Wt) single top events and therefore has top mass dependence.

Sensitive to different generated values of m_{top}.

m_{top} = 173.09 ± 0.64 (stat) ± 1.50 (syst) GeV

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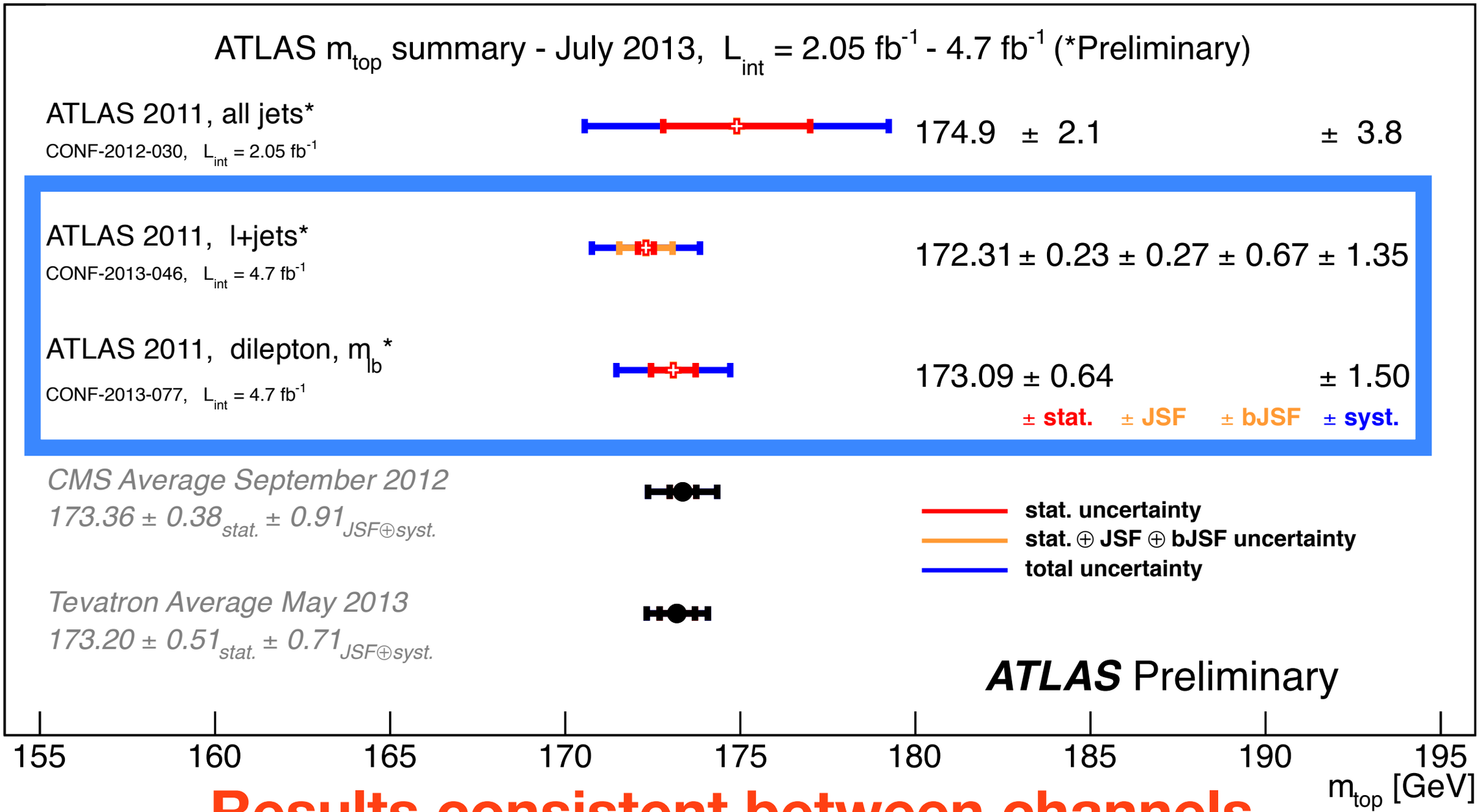
Top Mass Results

4.7fb^{-1} 7TeV



Results consistent between channels, experiments and colliders!

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Properties Of The Top Quark

Does the top quark we have observed have the same properties as that predicted by the SM?
e.g. Is the top quark polarised when pair produced?
e.g What charge does it have?

Large sample of top events allows for precision measurement of the top quark's properties.

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Top Quark Charge Asymmetry

4.7fb^{-1} 7TeV

- Interest in charge asymmetry measurement has intensified since the Tevatron measurements of forward-backward asymmetry observed a deviation from the SM.

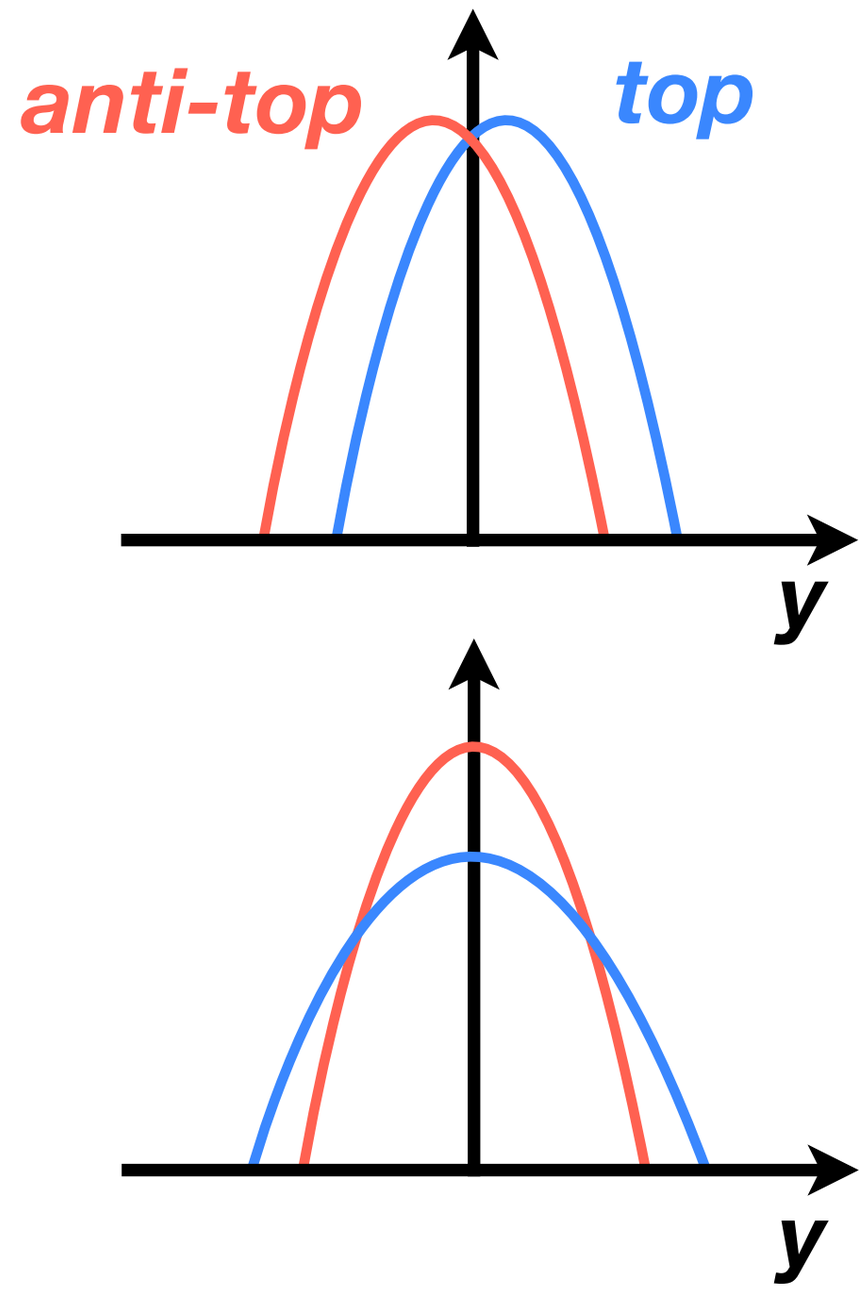
$$A_{\mathrm{FB}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

- As the LHC is a proton-proton collider A_{FB} is no longer a useful observable. Instead use A_C as top antiquarks are expected to be produced more centrally than top quarks.

$$A_{\mathrm{C}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

where :

$$\Delta|y| \equiv |y_t| - |y_{\bar{t}}|$$



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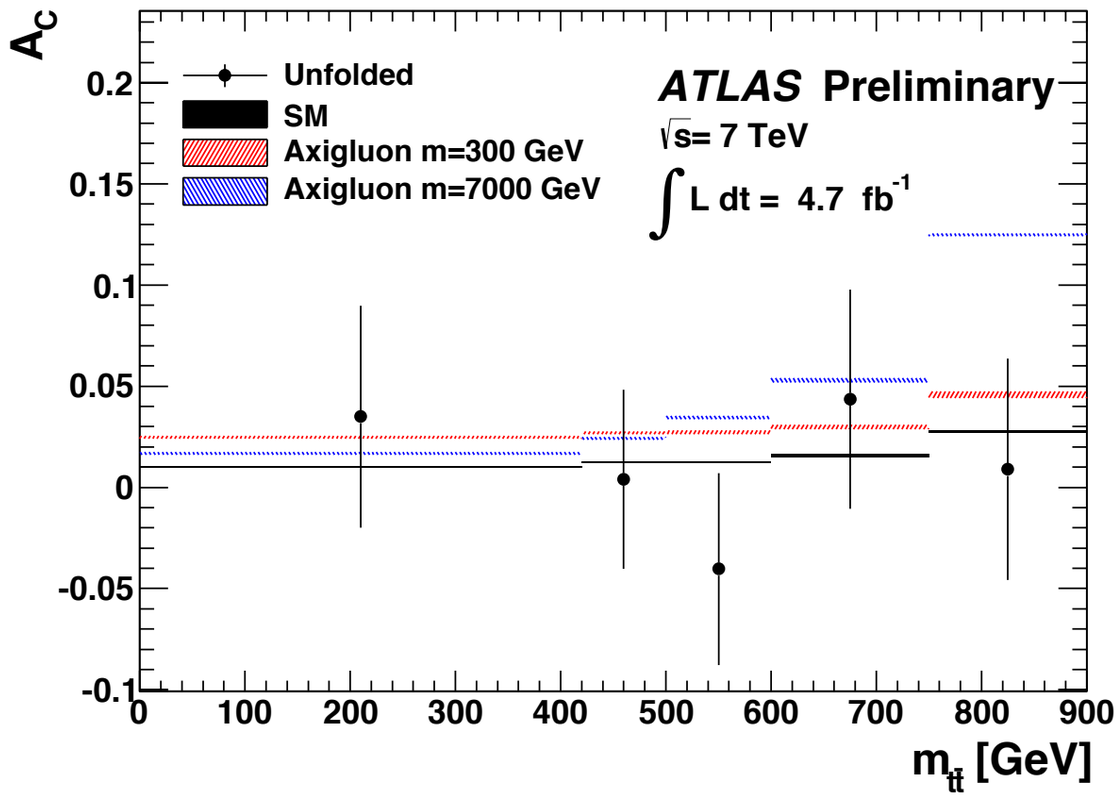
Top Quark Charge Asymmetry

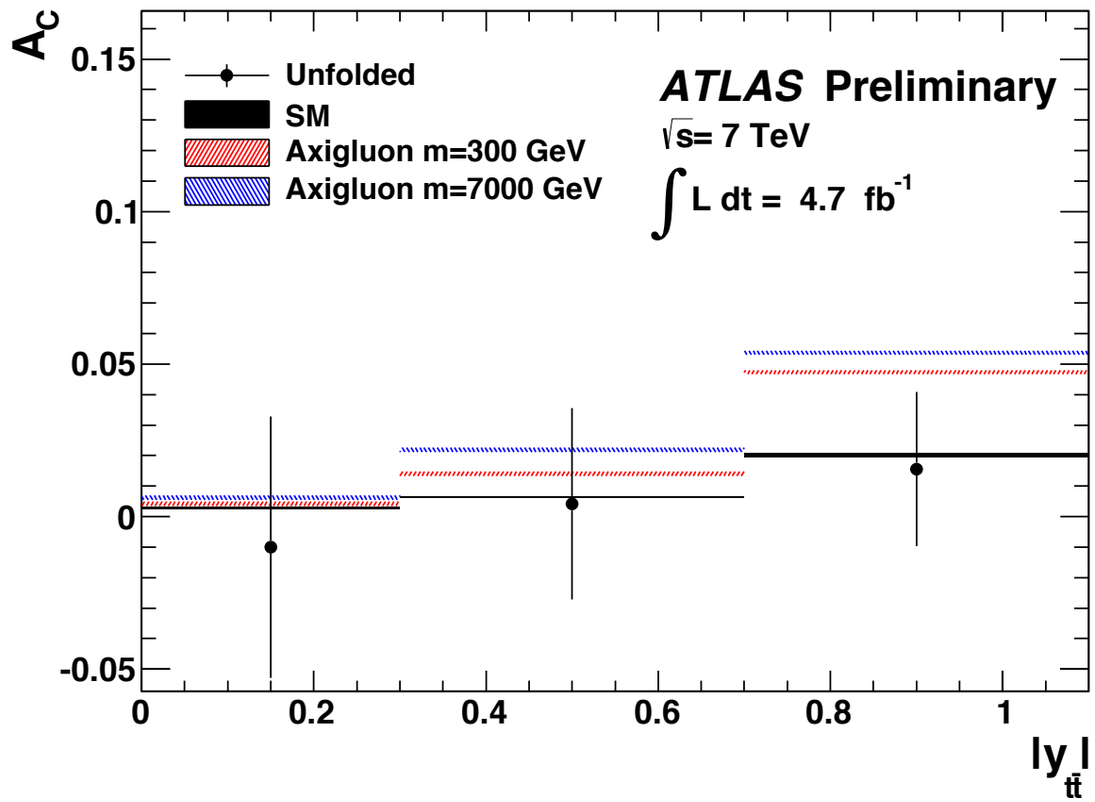
$4.7 fb^{-1}$ 7TeV

A_C predicted to be very small in the SM but can be large in BSM models such as an Axigluon, particularly at high $t\bar{t}$ mass.

Unfold A_C in bins of the invariant mass, rapidity and the transverse momentum of the $t\bar{t}$ system.

Unfolded data consistent with SM prediction.





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$4.7fb^{-1}$ 7TeV

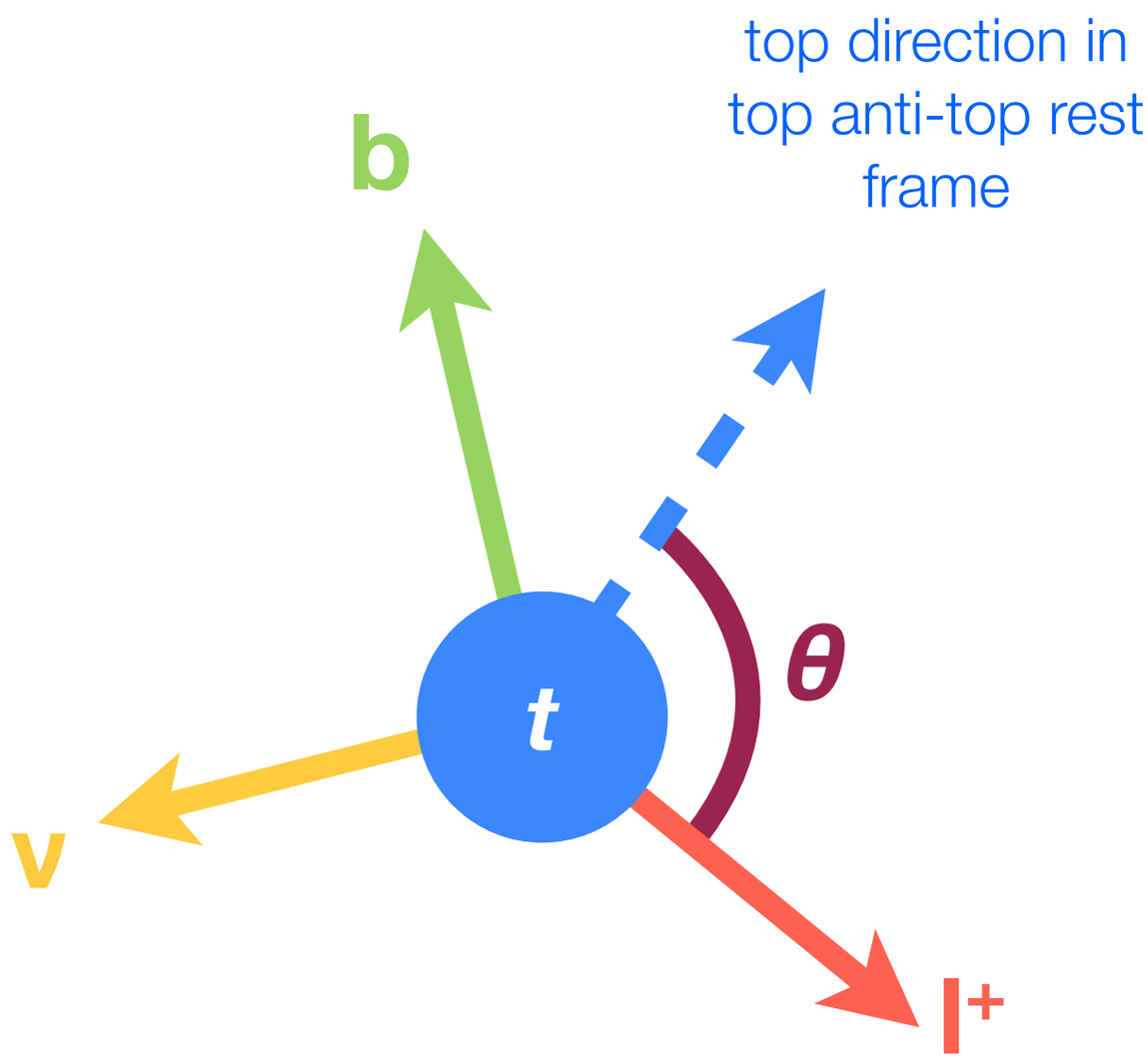
Top Quark Polarisation

- In the SM pair produced (anti) top quarks are expected to have **negligible** (0.003) polarisation.

- Measure angle between top quark direction of flight in $t\bar{t}$ rest frame and lepton direction of flight in top rest frame.

- Two angles per dilepton event but fewer events than the lepton + jets channel.

- Many models that try to explain Tevatron A_{FB} measurements also affect polarisation.



arXiv:1307.6511

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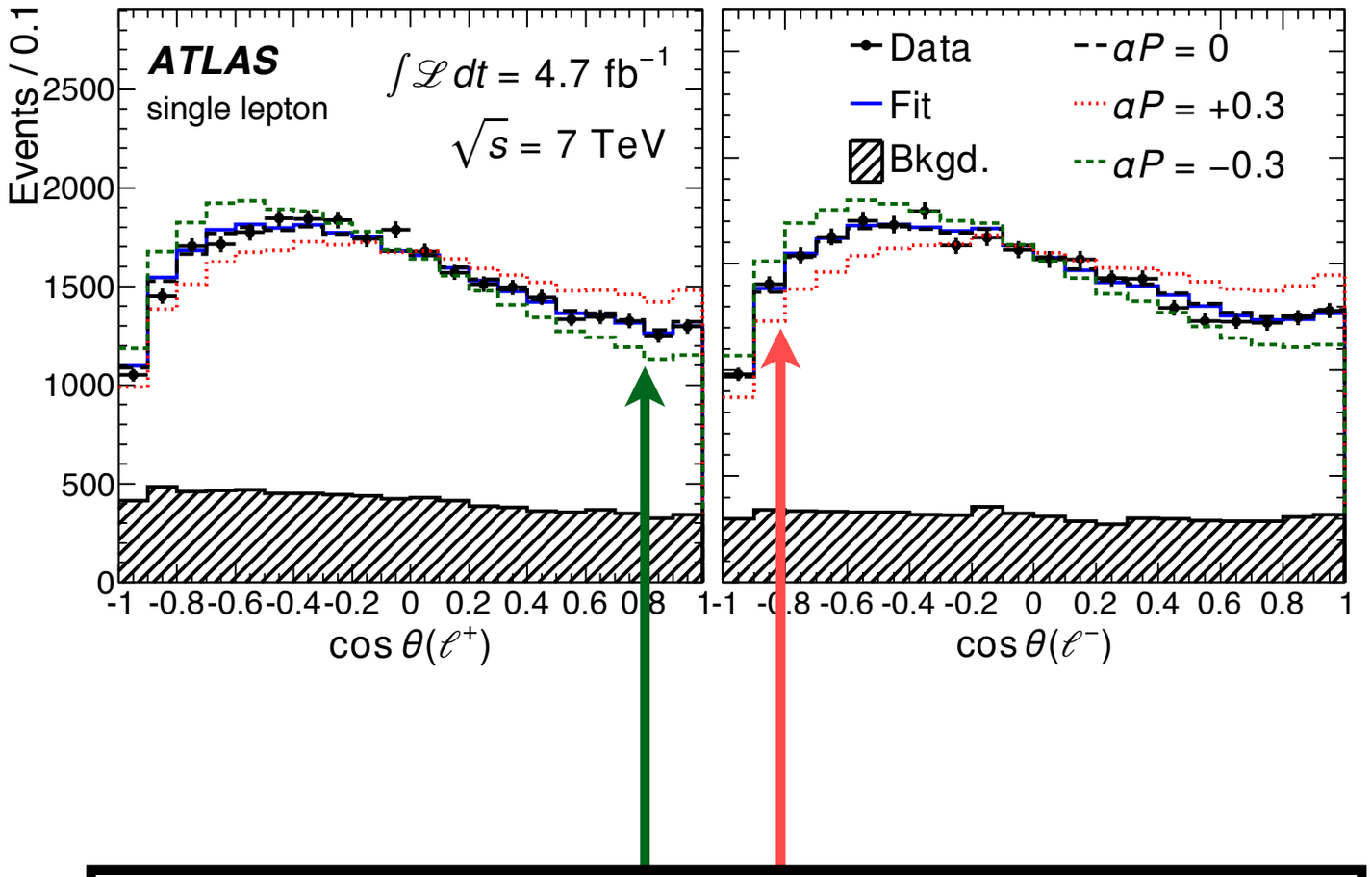
$4.7fb^{-1}$ 7TeV

Top Quark Polarisation

- Templates are fitted to the data in individual channels and combined for both CP violating and conserving hypotheses.
- Results agree with the SM prediction of negligible polarisation.
- Largest systematic from JES.



- Introducing polarisation changes the cosθ distribution.
- Shape from event selection.

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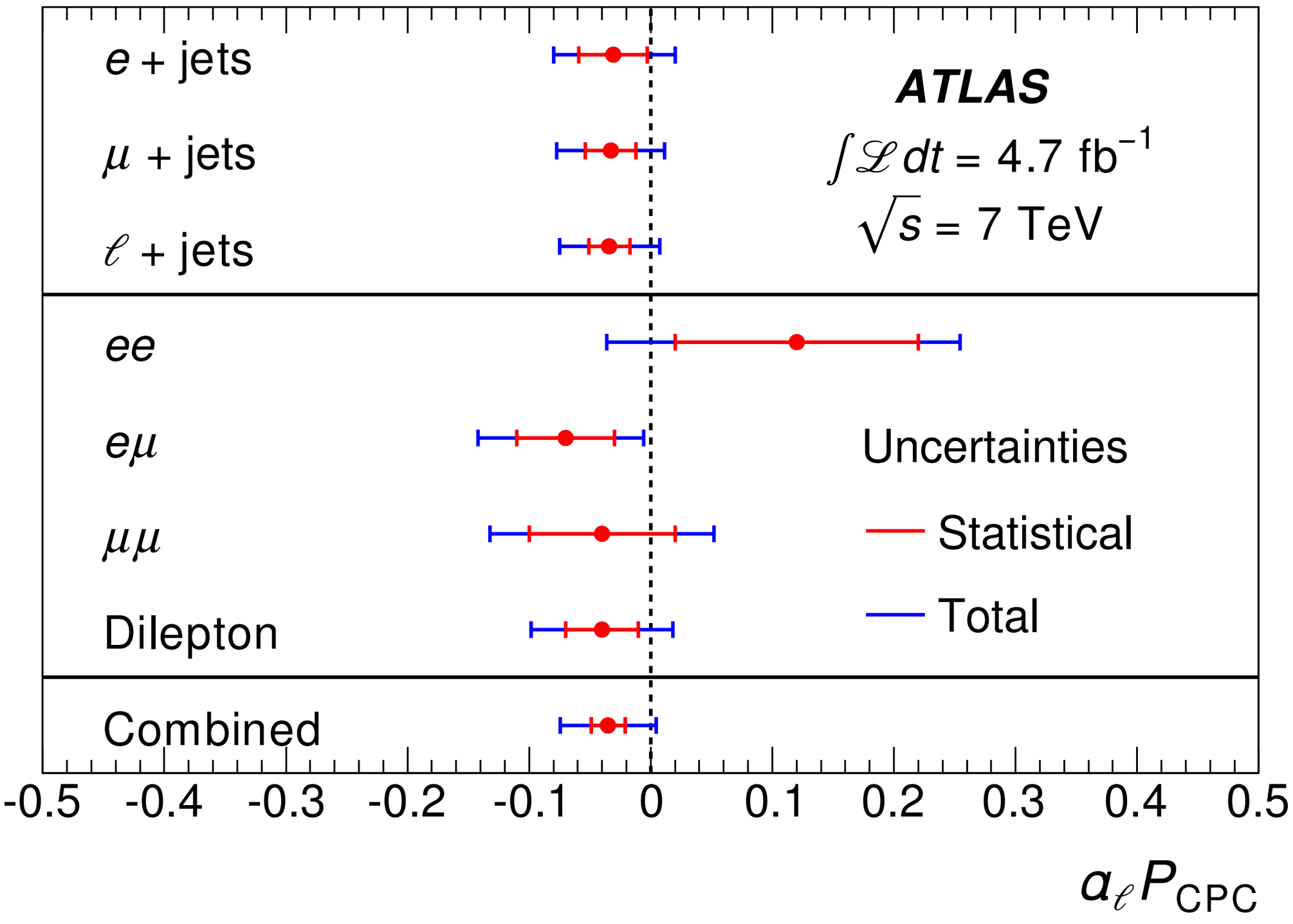
Top Quark Polarisation

4.7fb^{-1} 7TeV



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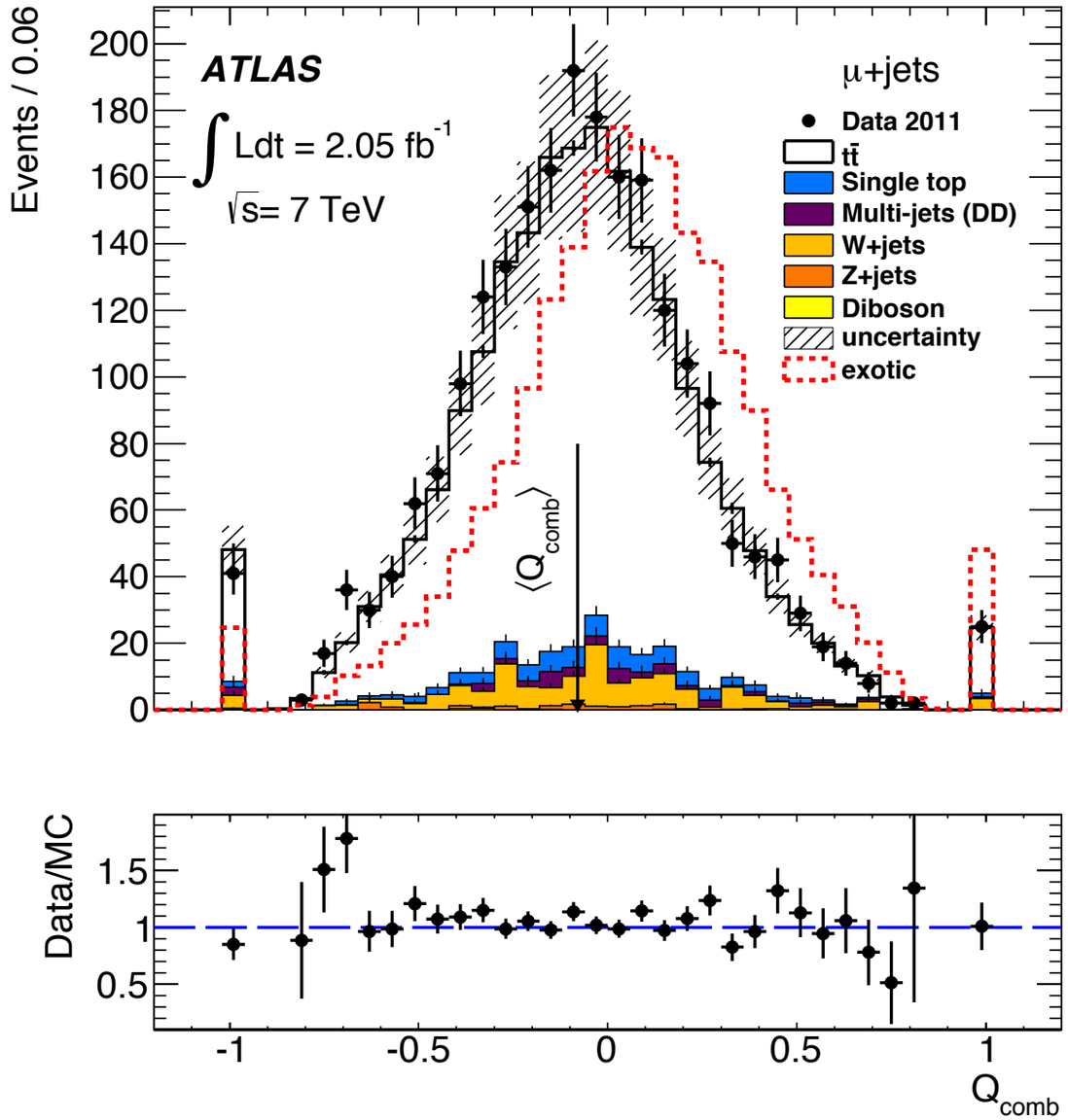
Top Quark Charge

2.05fb^{-1} 7TeV

- Top quark charge measured in lepton+jets channel.
- Measure the lepton charge and the b-jet charge using tracks in jet.

$$Q_{\text{comb}} = Q_l \times \frac{\sum_i Q_i |\vec{j} \cdot \vec{p}_i|^{\frac{1}{2}}}{\sum_i |\vec{j} \cdot \vec{p}_i|^{\frac{1}{2}}}$$

$$Q_{top} = 1 + Q_{comb} \times C_b$$



- C_b is the b-jet charge calibration calculated using MC.
- Top quark charge measured to be:
  Q_{top} = 0.64 ± 0.02 (stat) ± 0.08 (syst)
- **Exotic top** with charge -4/3 excluded to greater than 8σ.

arXiv:1307.4568

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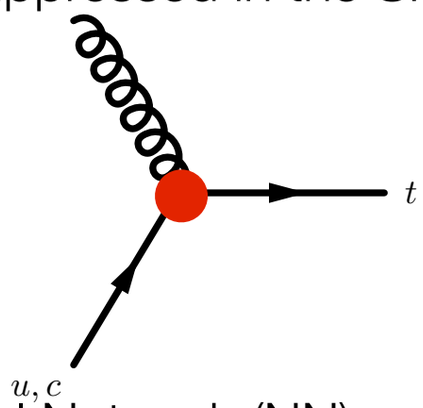
FCNC in Single Top Production

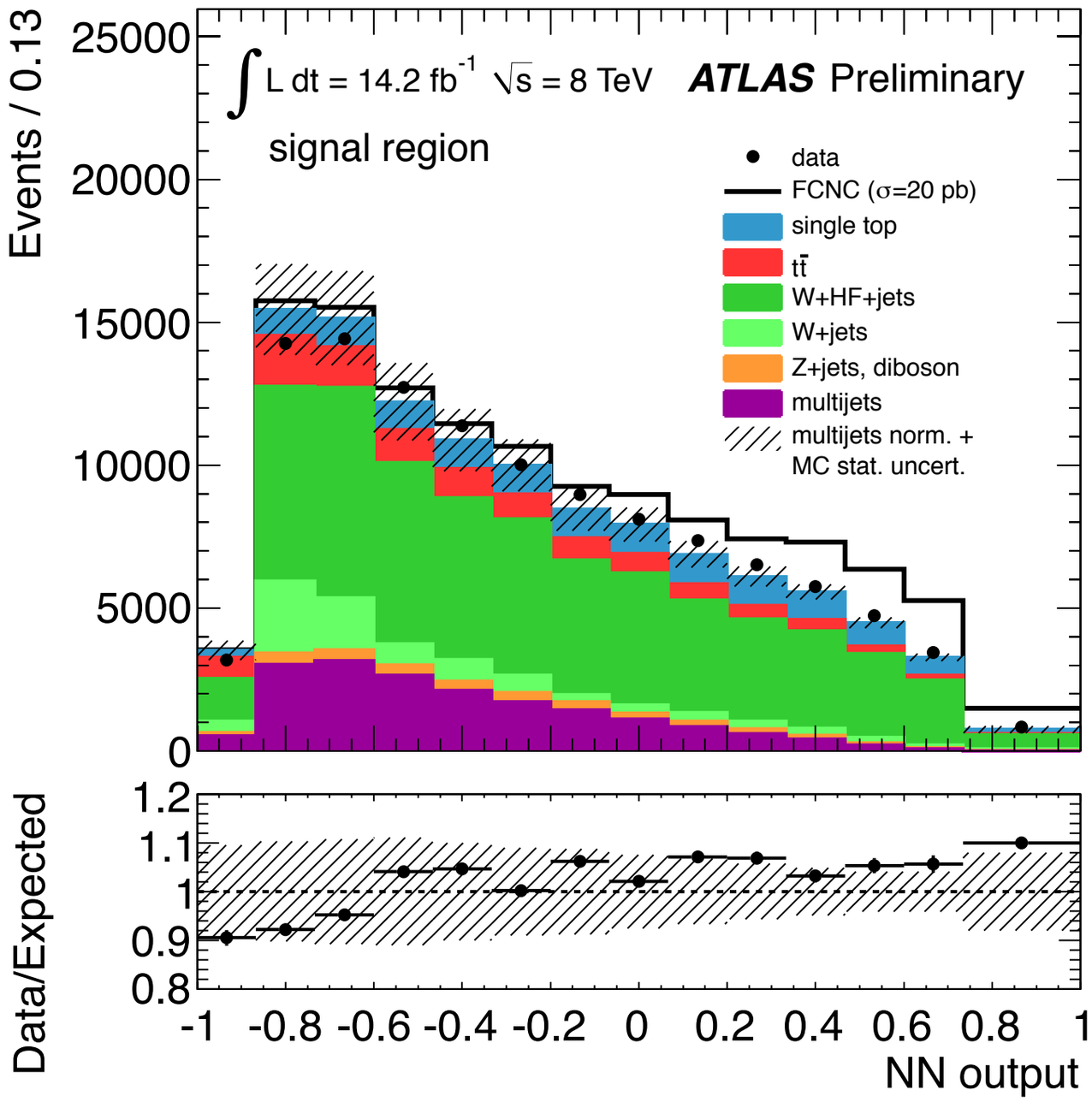
14.2fb^{-1} 8TeV

- Search for single top quark production via a flavour changing neutral current (FCNC). Strongly suppressed in the SM.



- Neural Network (NN) used to distinguish between FCNC and background.

- Set limit on $\sigma_{qg\to t} \times B(t\to Wb)$ and can convert into limits on coupling constants and branching fractions ($t\to qg$, q=u,c). Most stringent direct limits.



ATLAS-CONF-2013-063

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Summary

- LHC is a top factory producing more top quarks than ever before allowing us to make high precision measurements of its properties.

- New ATLAS measurements of the top quark mass in both the lepton+jets and dilepton channels, using the full 2011 7TeV dataset.

- Measurements of top quark properties show good agreement with the SM.

- Many properties sensitive to physics beyond the SM. No hint of new physics so far.

- Many more ATLAS top results: **https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults**

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Back-up

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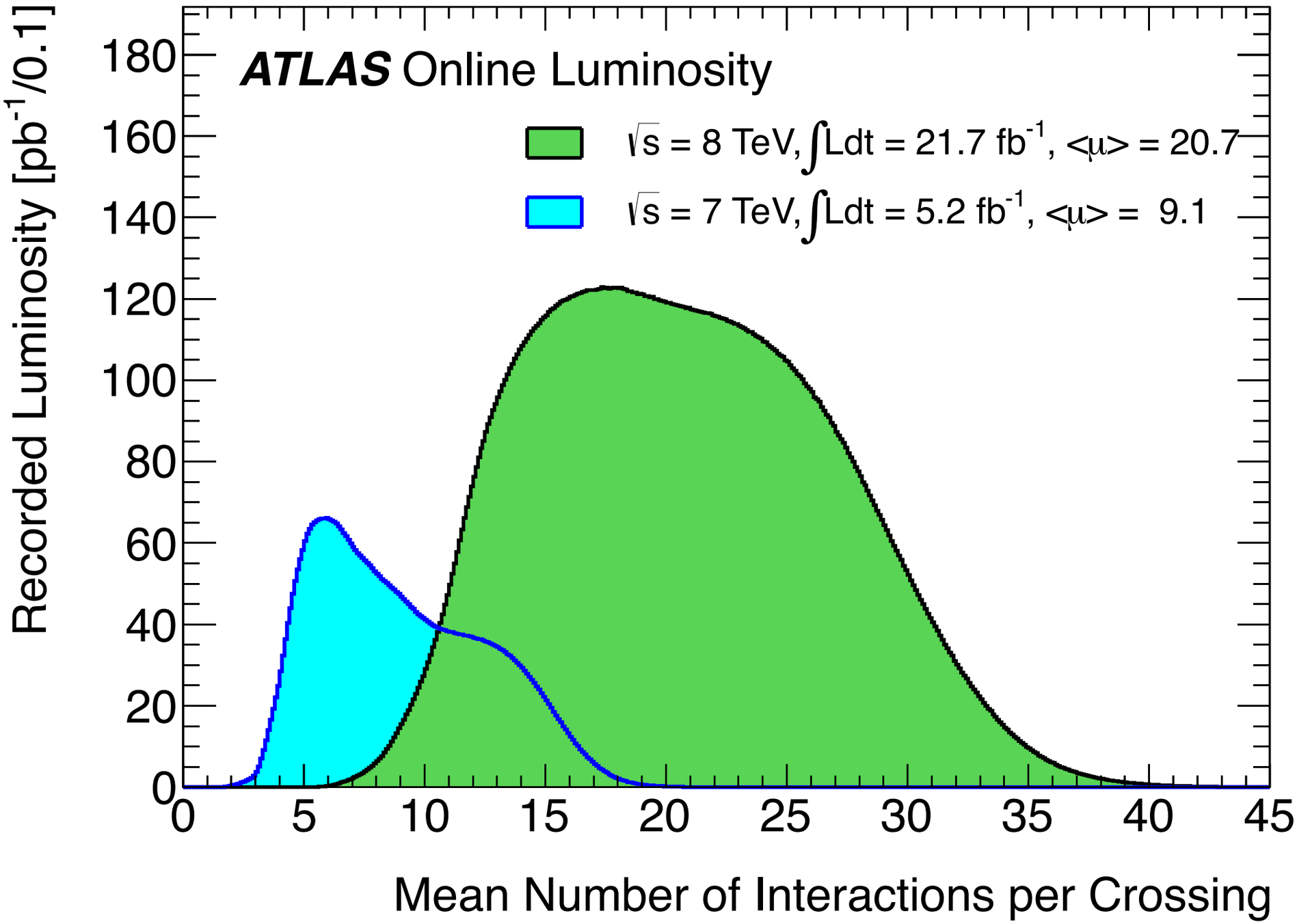
Pile-up

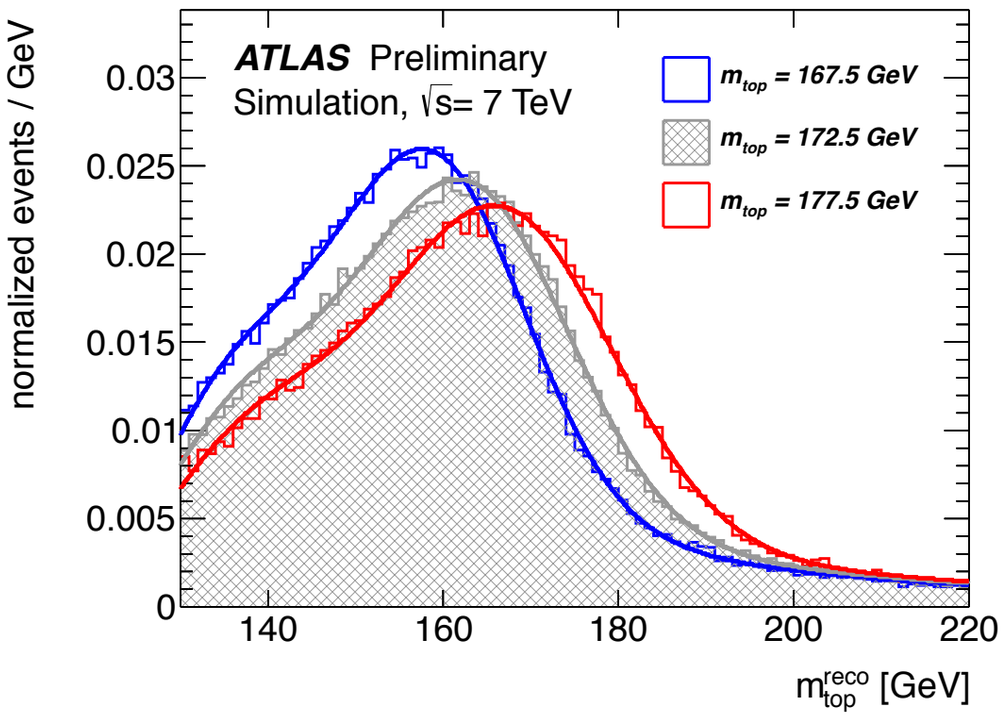


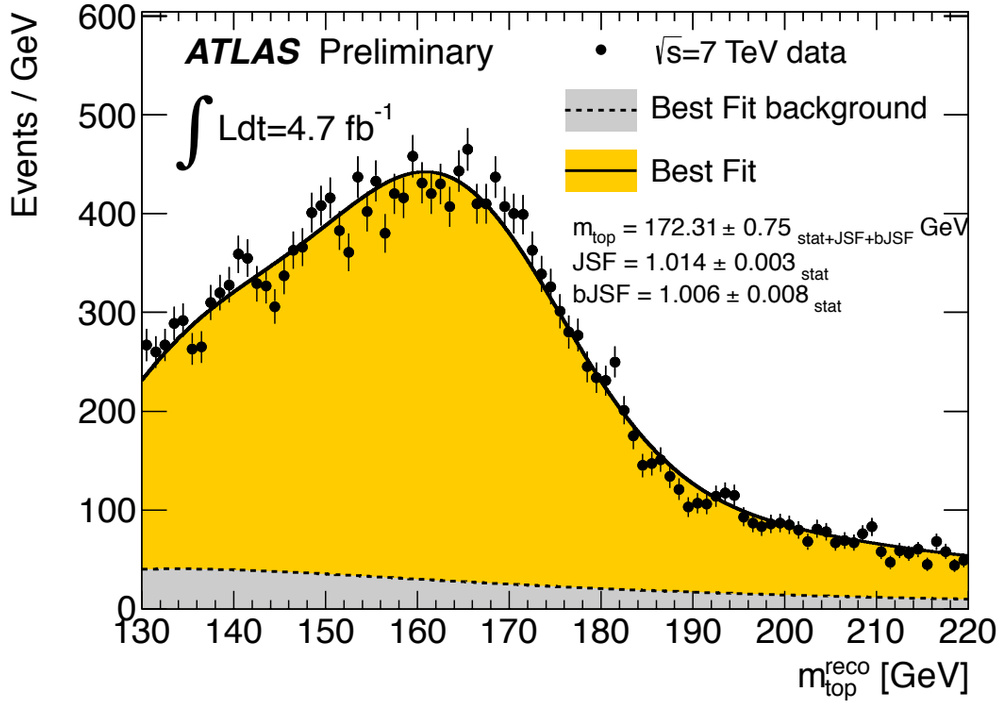
The Template Method

1. Generate templates by varying one or more parameters in monte carlo.

2. Interpolate between templates to create a probability density function (PDF) that depends on the parameter(s) of interest.

3. Find the best fit value of the parameter by fitting the PDF to the data.





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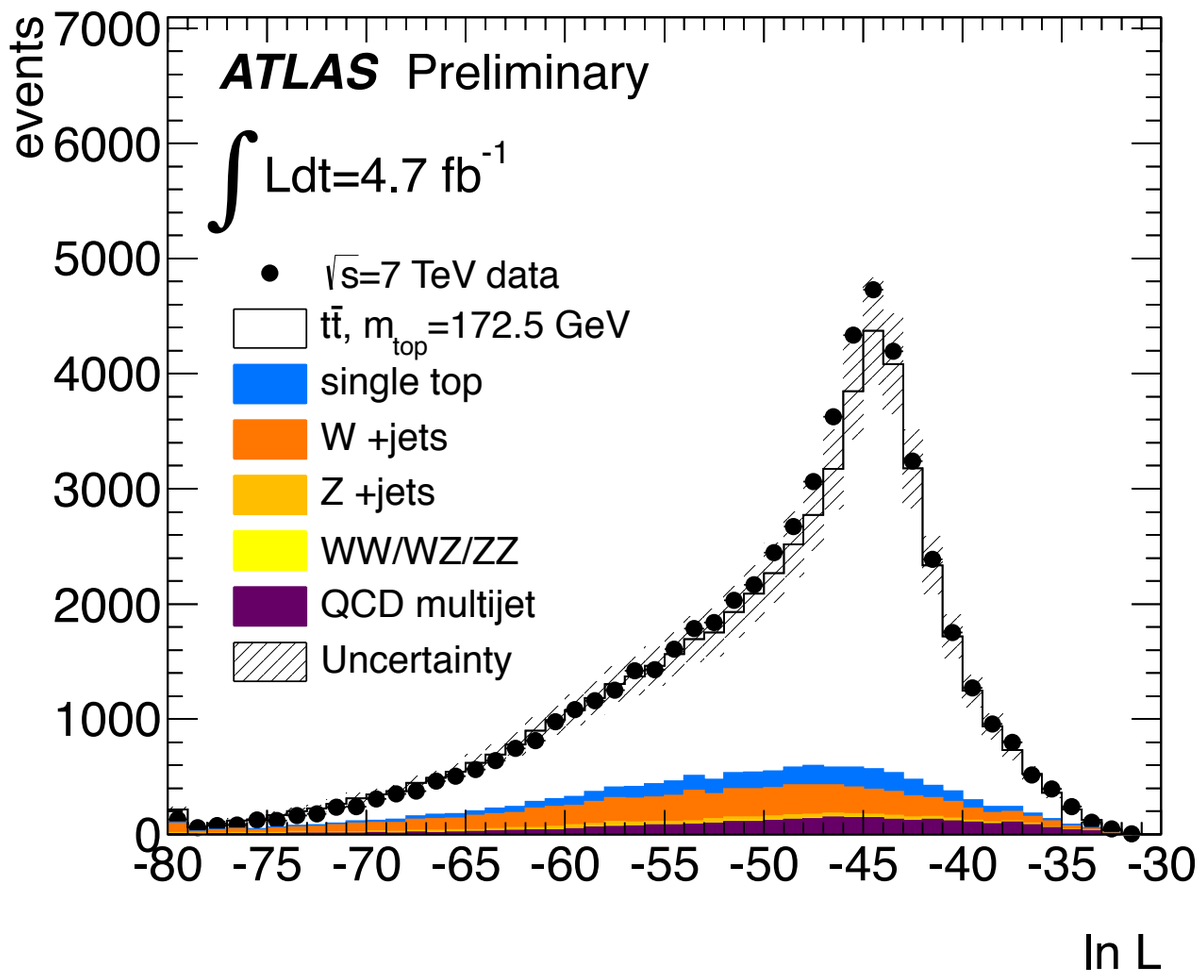
4.7fb^{-1} 7TeV

Reconstruction

- Reconstruct events using a (LO) kinematic likelihood fit.
- Assign reconstructed objects to partons. The missing ET is used as the pT of the neutrino.
- 4 reconstructed jets are used in the likelihood fit. The leading 2 (1) b-tagged jets and the leading 2 (3) light jets. B-tagging information is used to correctly assign b-jets to the b quarks.
- Transfer functions correct measured energies back to the parton level.
- The mass of the hadronicly decaying top (W) and leptonically decaying top (W) are constrained to be equal in the kinematic fit.
- The fit results in a value for m_{top}, m_W and tells us the partons each jet us assigned to.



lnL

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$4.7fb^{-1}$ 7TeV

IMPORTANT: “Consequently, the top quark mass determined this way from data corresponds to the mass definition used in the Monte Carlo. It is expected that the difference between this mass definition and the pole mass is of order 1 GeV [*].”

[*] A. Buckley et al., General-purpose event generators for LHC physics, Phys. Rept. 504 (2011) 145.

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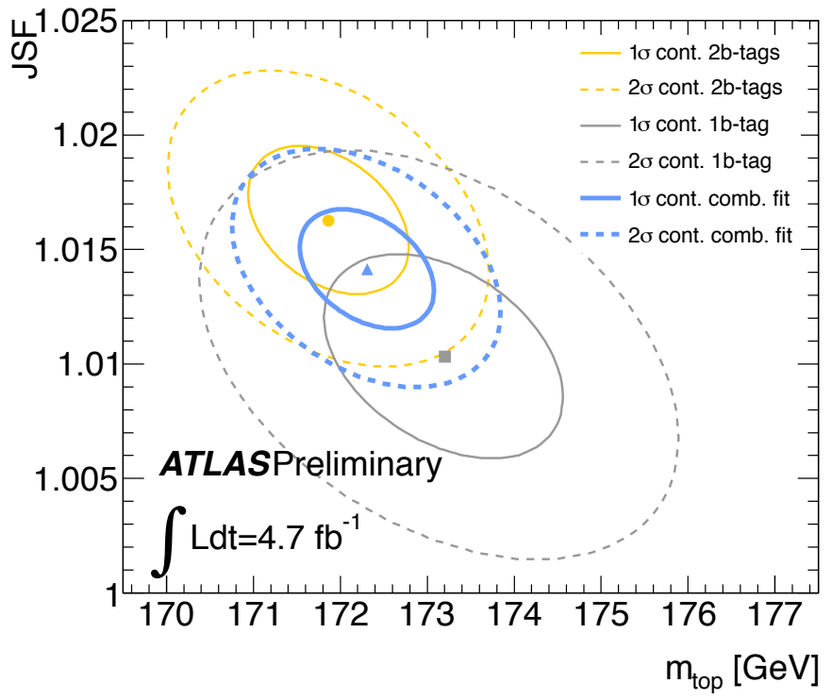
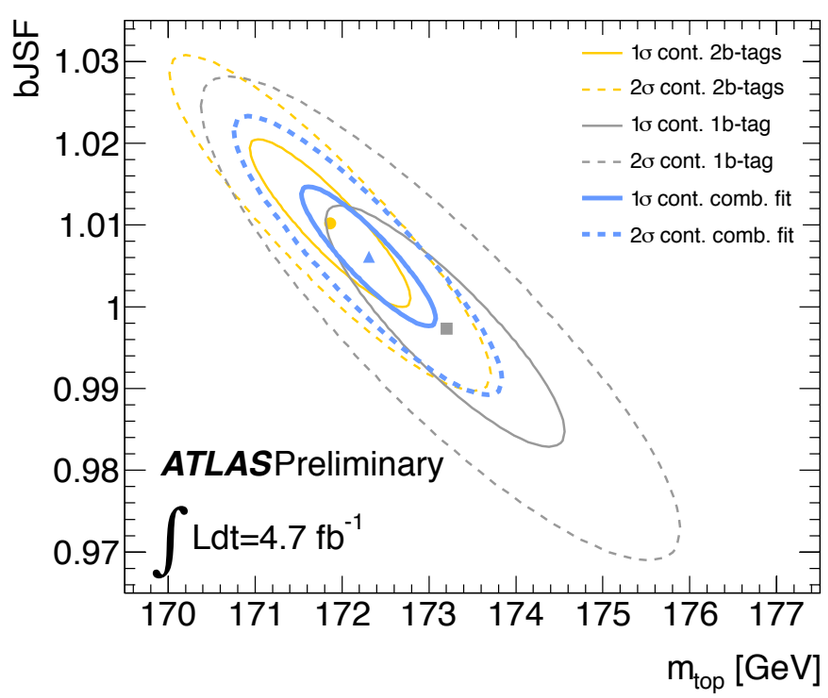
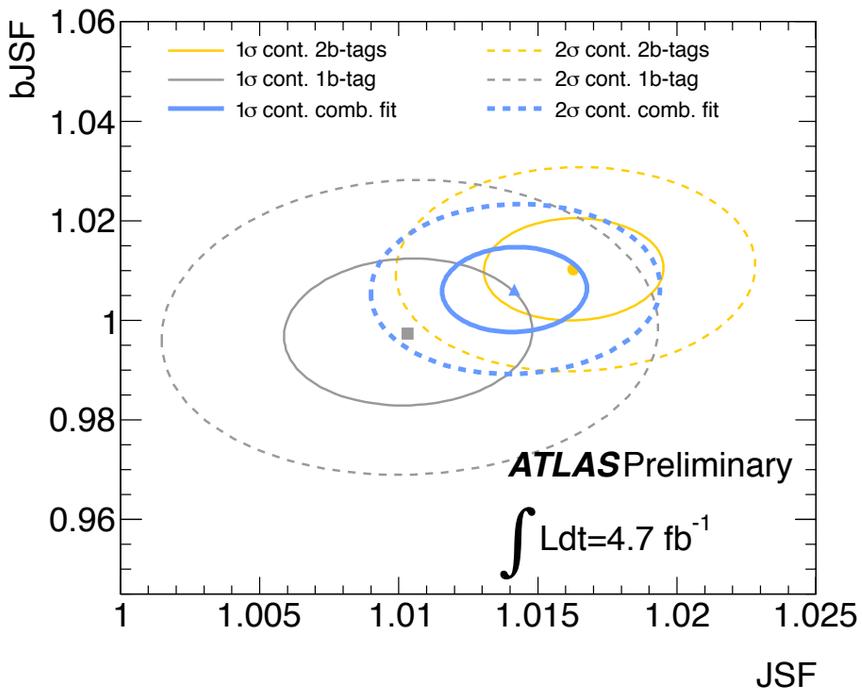
L+Jets mass : Fit Results

4.7fb^{-1} 7TeV







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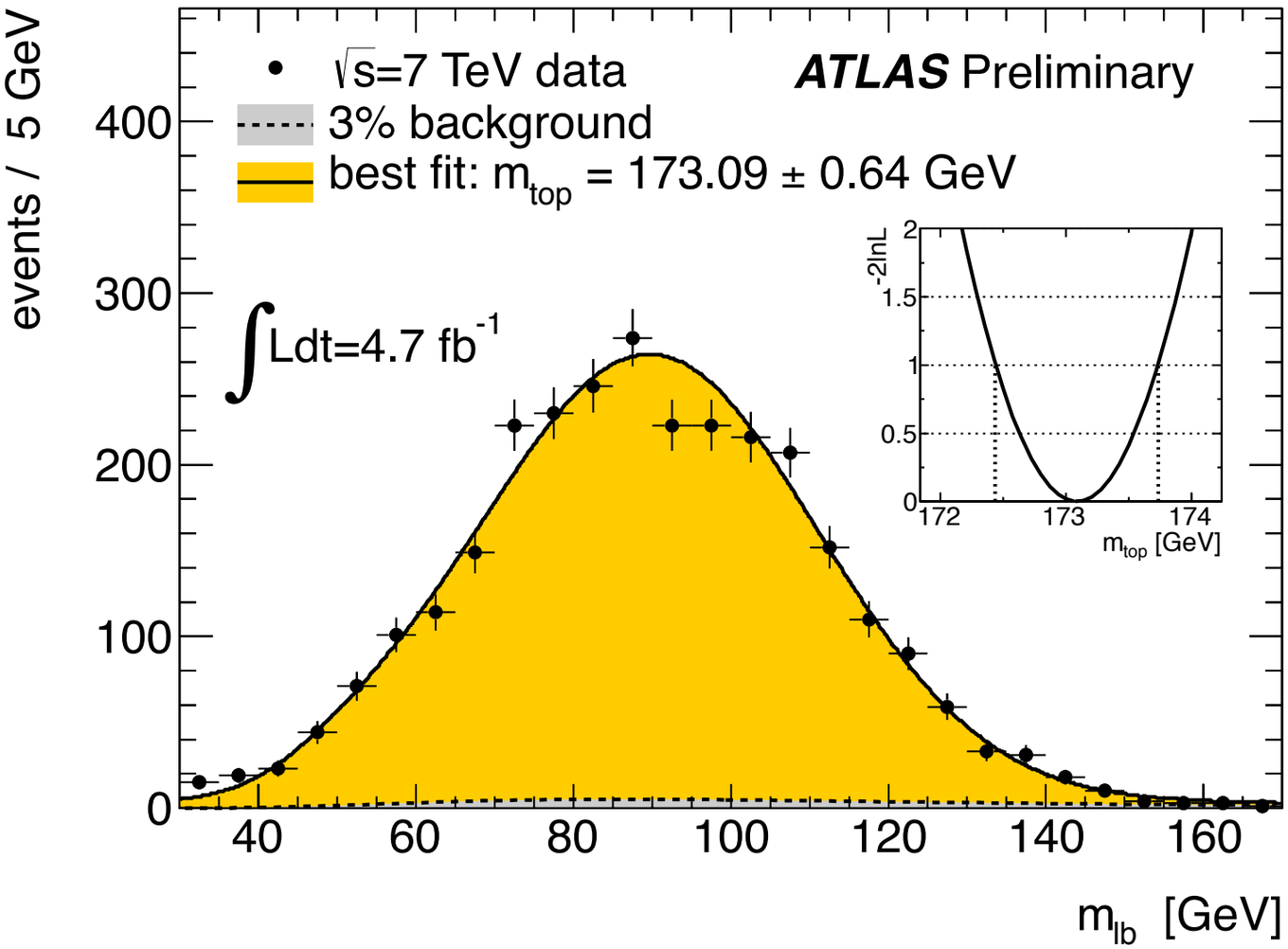
$4.7fb^{-1}$ 7TeV

Dilepton m_{top} - fit

- The signal template is parameterised using a sum of a Gaussian and a Landau function.
- The background template is parameterised using a Landau function.
- Fit the signal and background templates to the data.
- Pseudo-experiments show a good linearity between the input top mass and the measured top mass.



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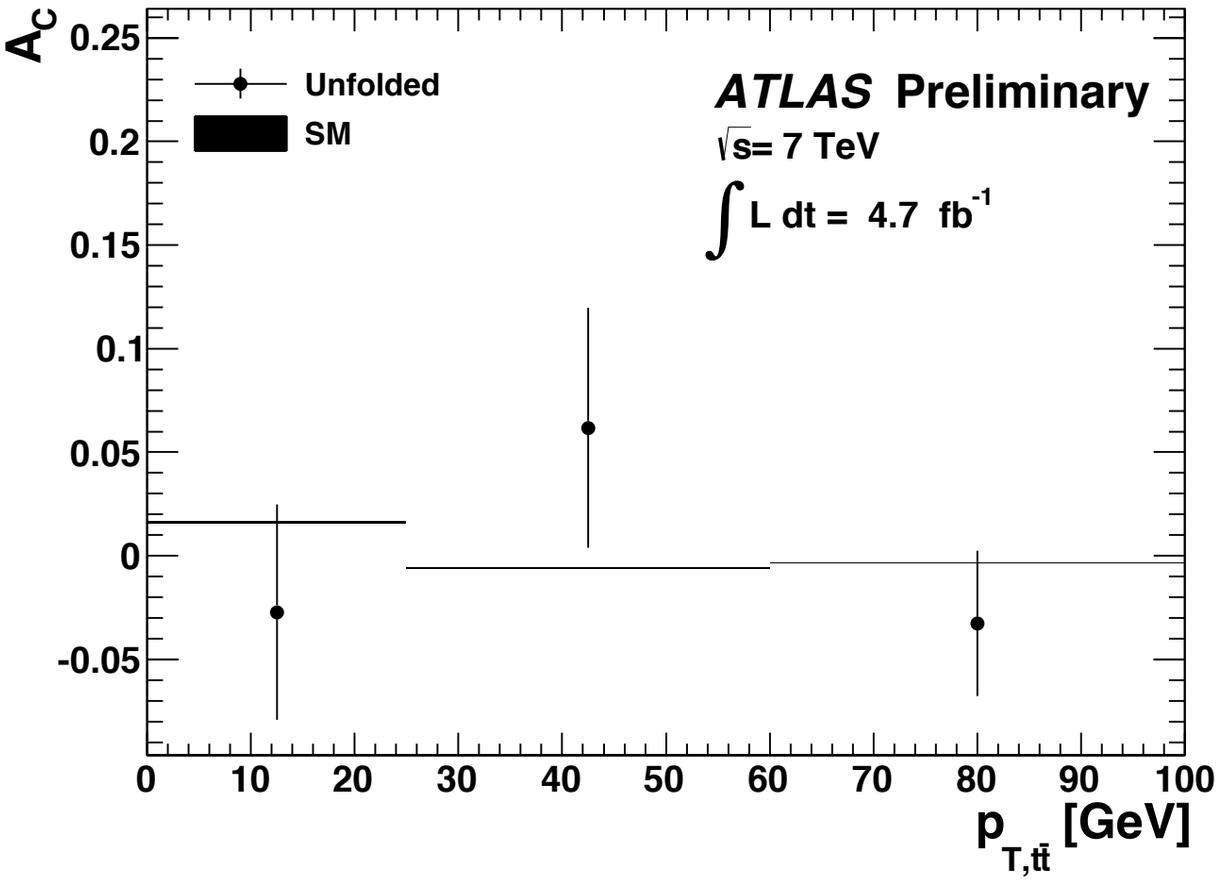
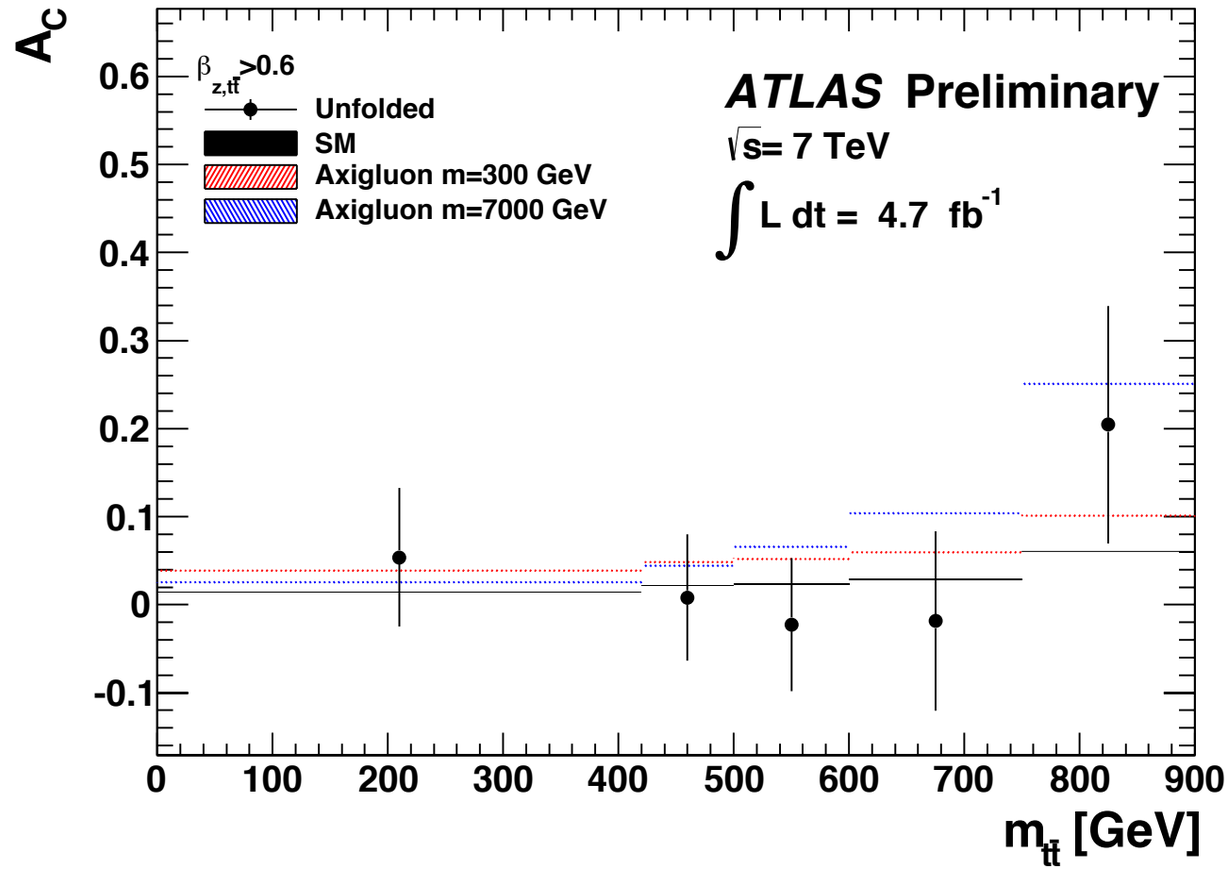
Top Charge Asymmetry

$4.7fb^{-1}$ 7TeV

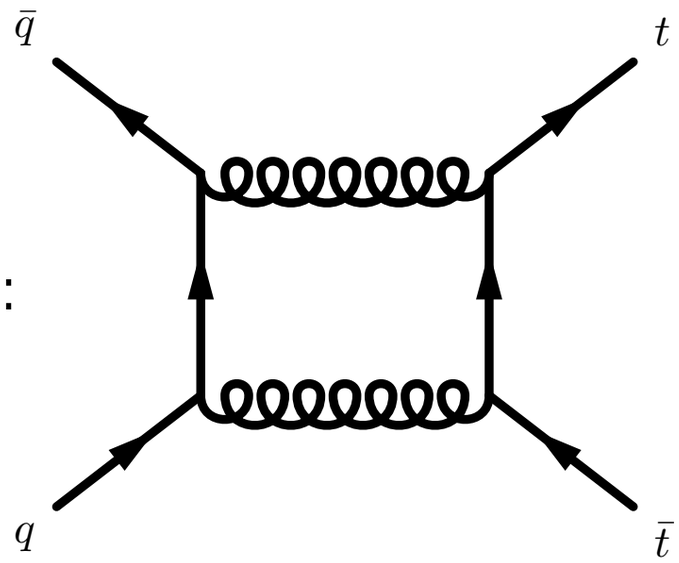




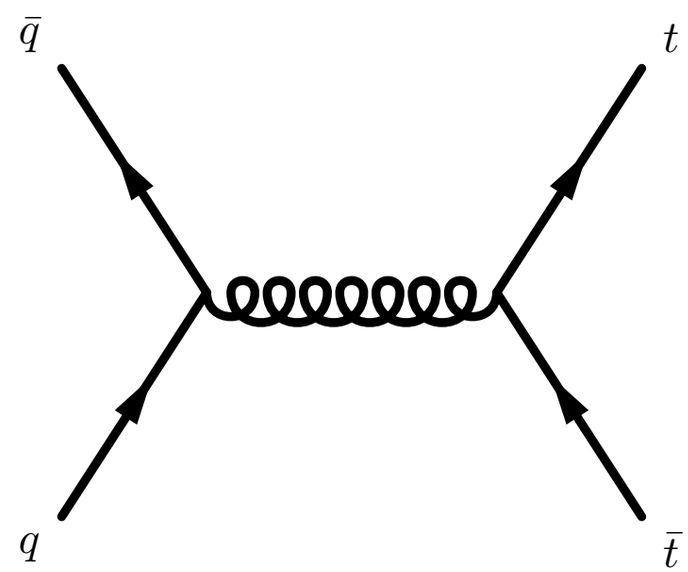
Top Charge Asymmetry

asymmetry at NLO QCD

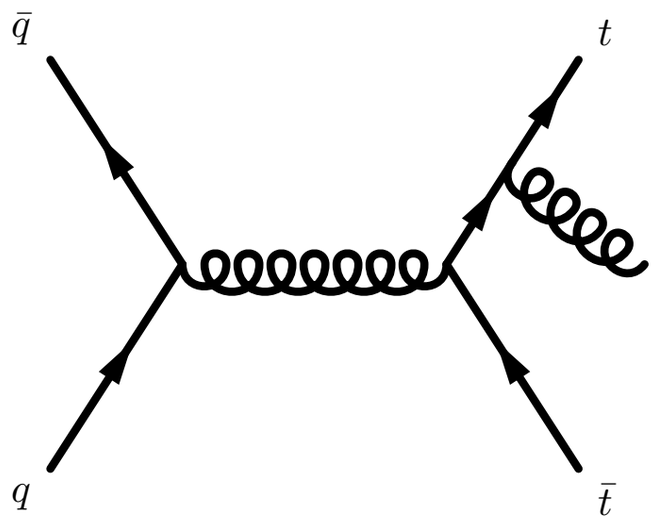
interference between:



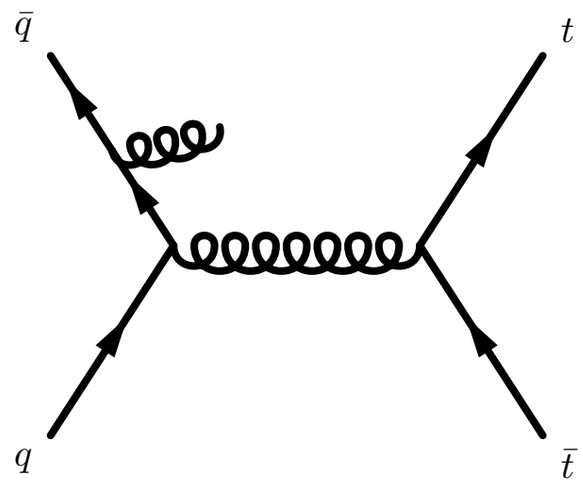
and



interference between:



and



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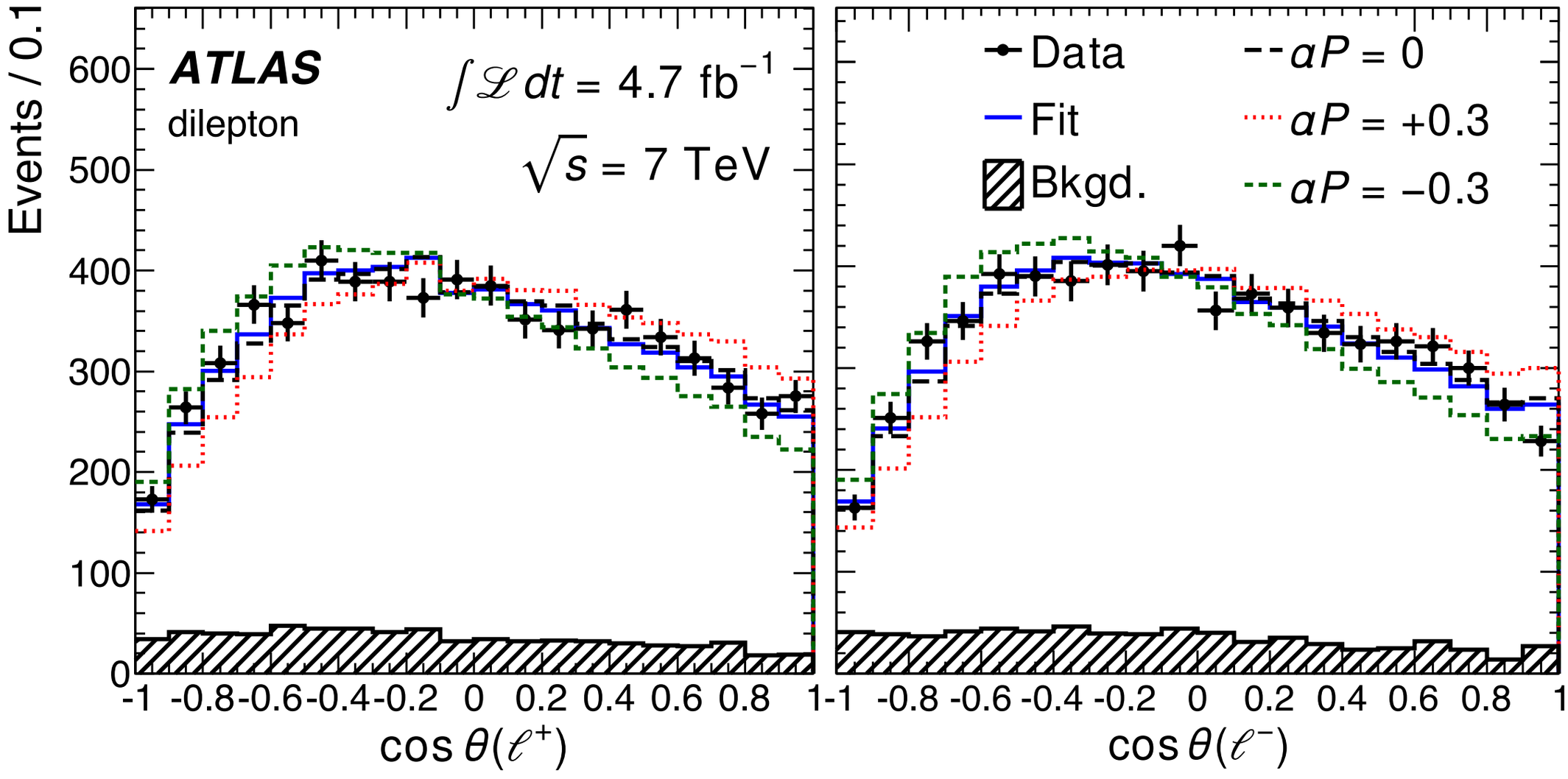
Polarisation CPC Dilepton

4.7fb^{-1} 7TeV



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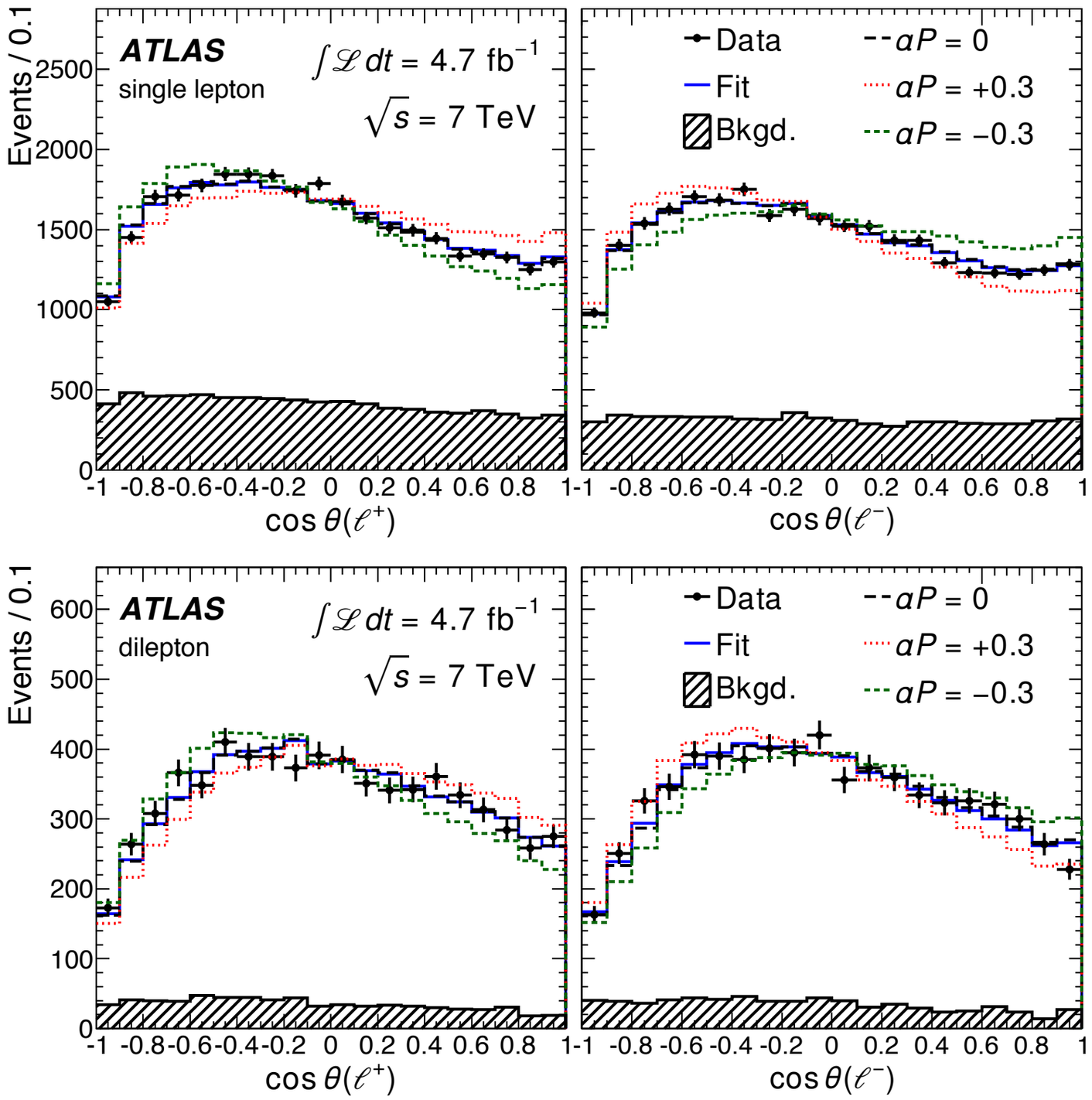
Top Quark Polarisation - CPV

4.7fb^{-1} 7TeV



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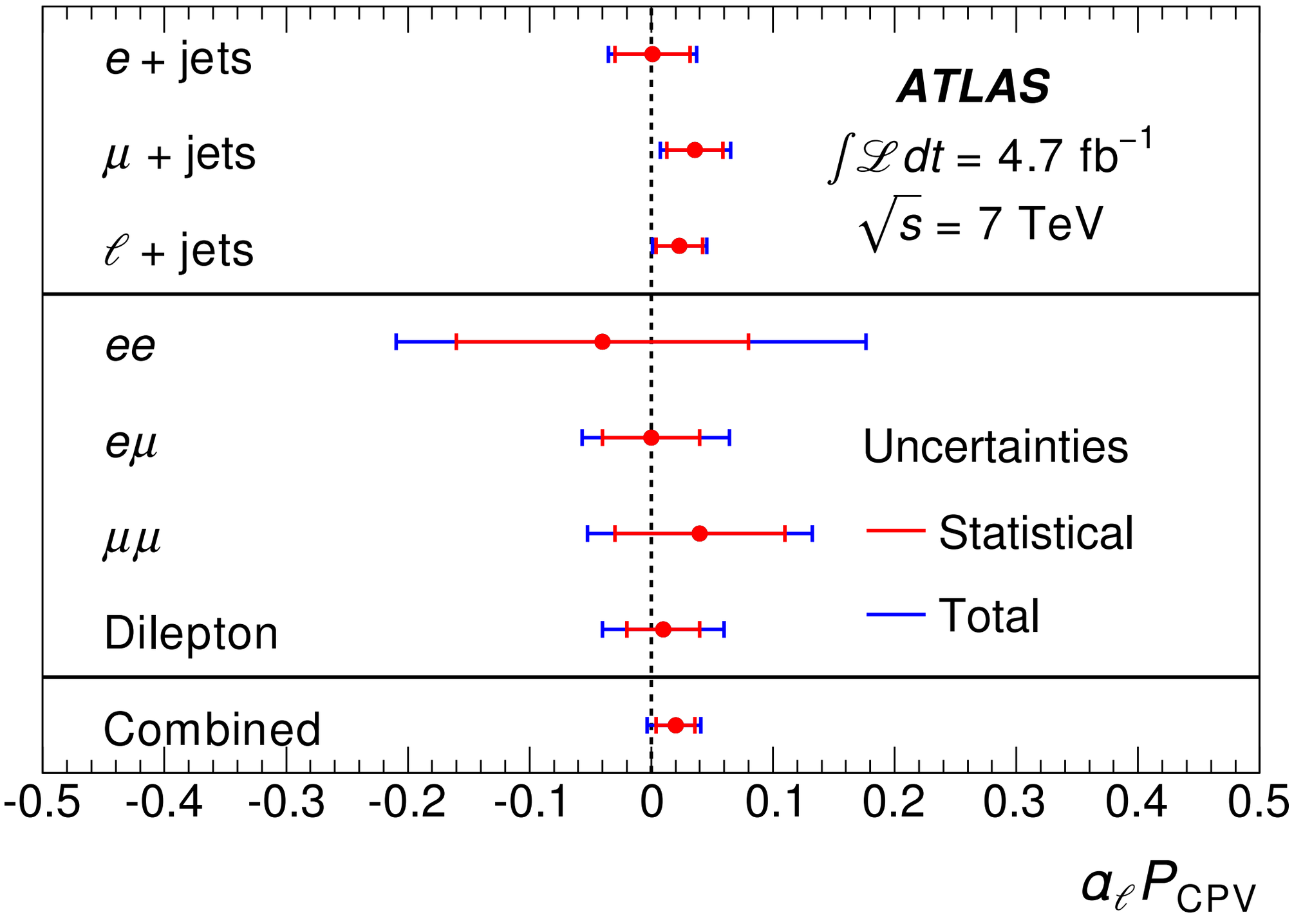
Top Quark Polarisation - CPV

$4.7fb^{-1}$ 7TeV



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Top Quark Charge

2.05fb^{-1} 7TeV

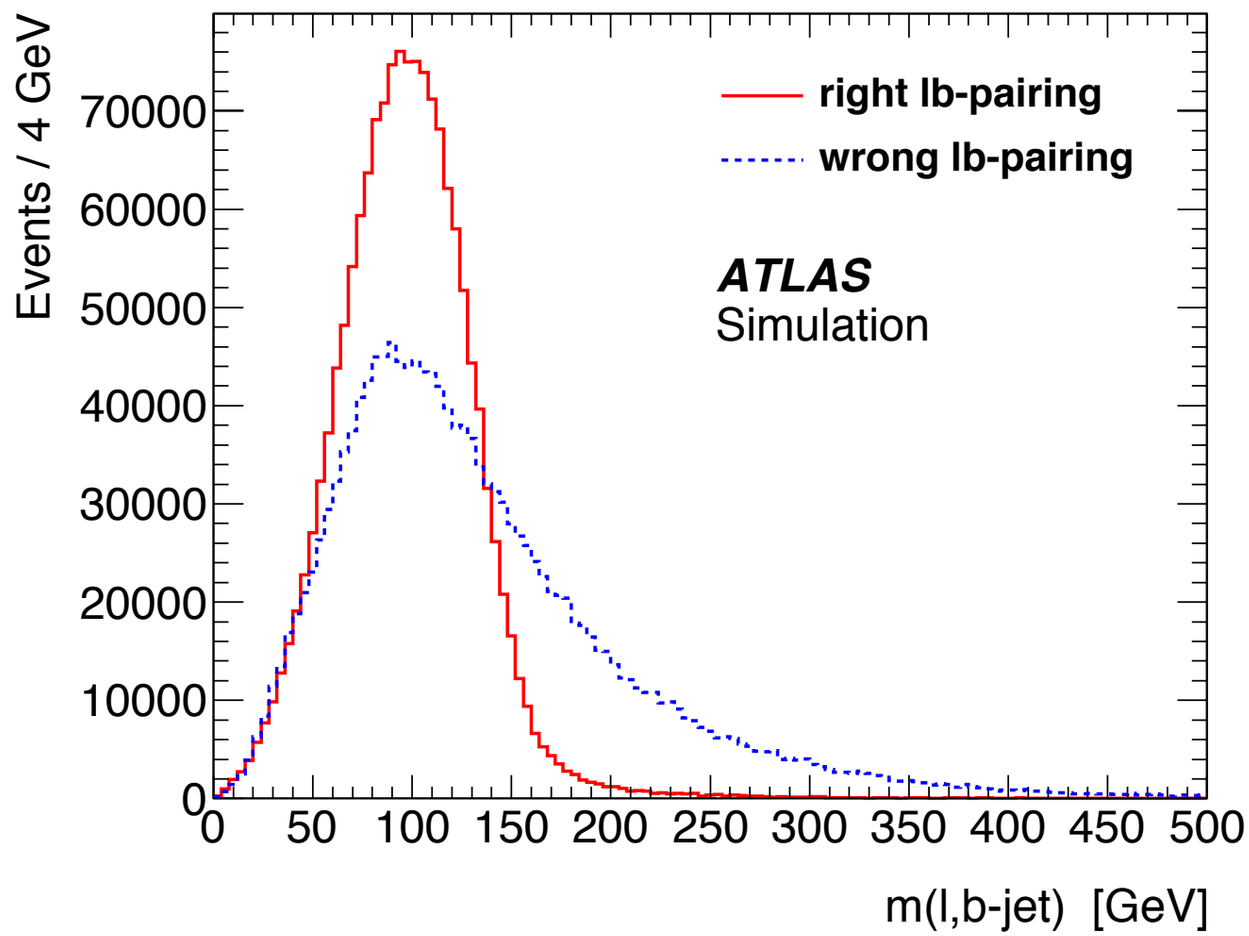
- Choose the correct b-jet lepton pairing by requiring two b-tags and a condition that:

m(l, b1) < 155 GeV **and** *m(l, b2)* > 155 GeV

or

m(l, b2) < 155 GeV **and** *m(l, b1)* > 155 GeV

- Method has low efficiency (28%) but a high purity (87%).



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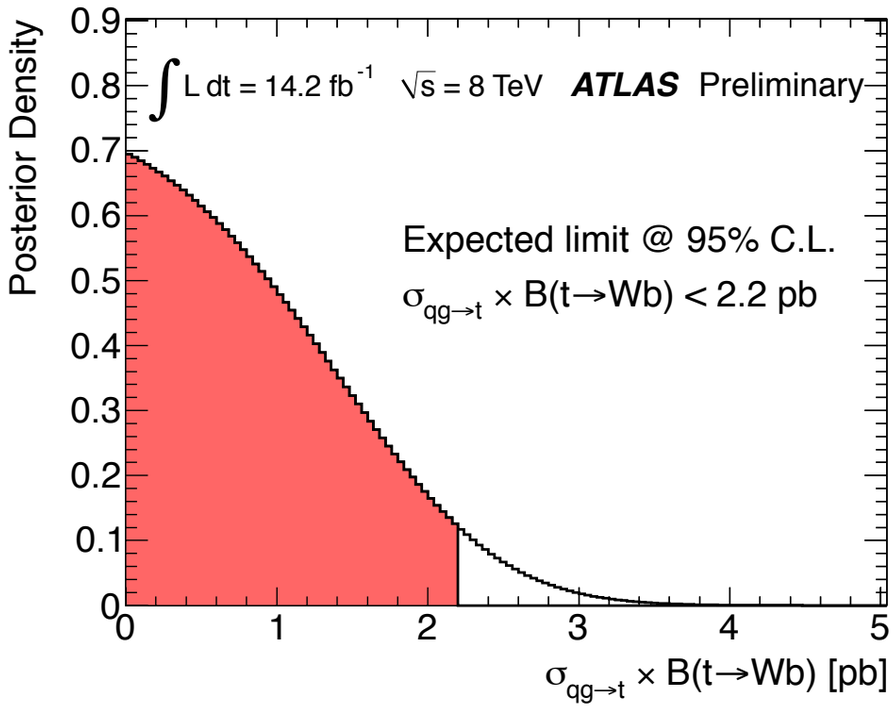
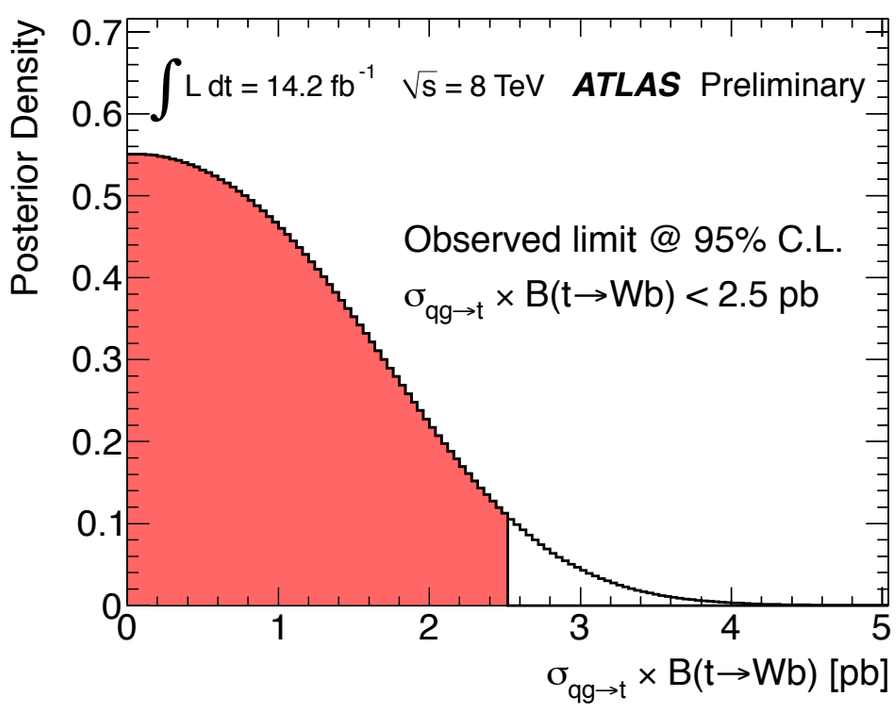
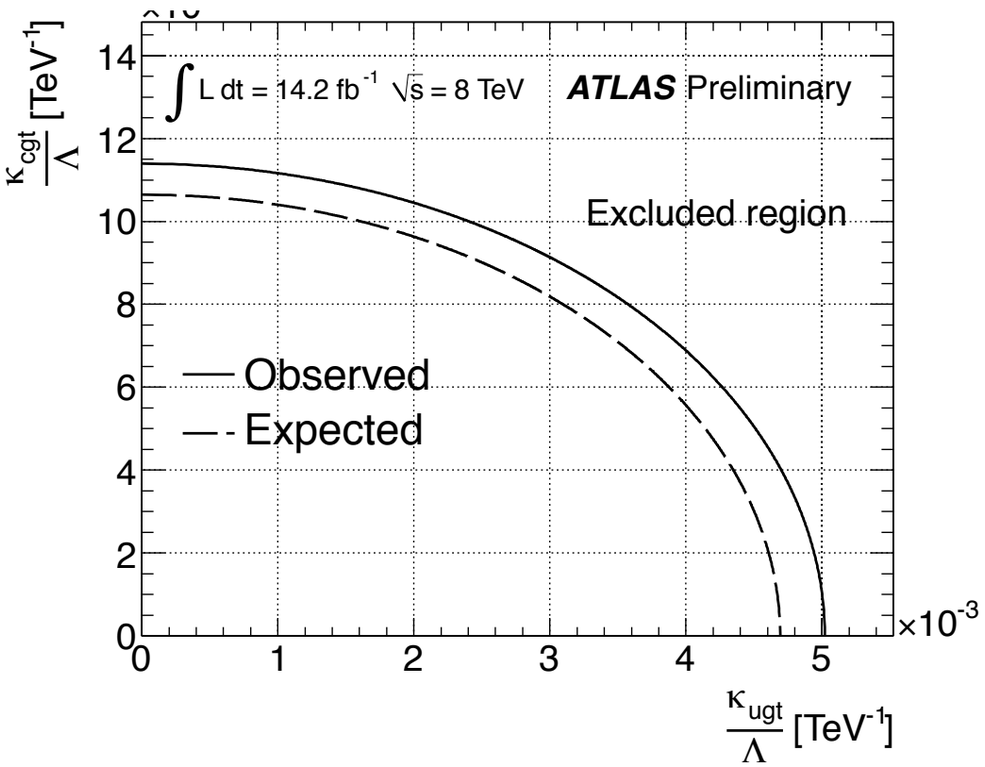
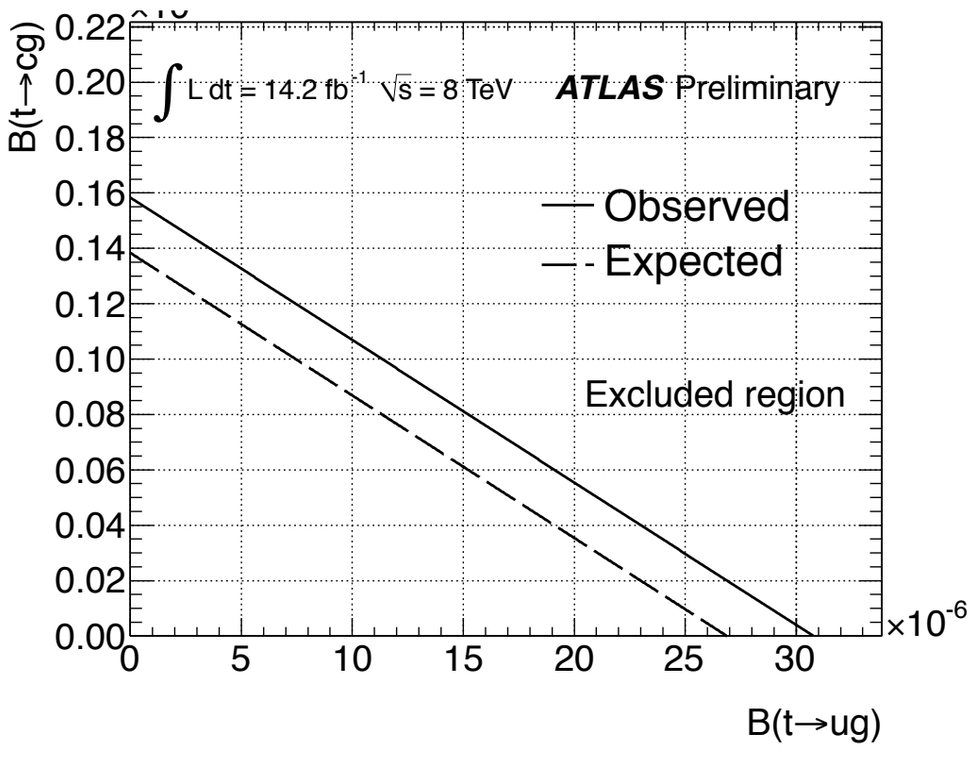
FCNC in Single Top Production

$14.2fb^{-1}$ 8TeV









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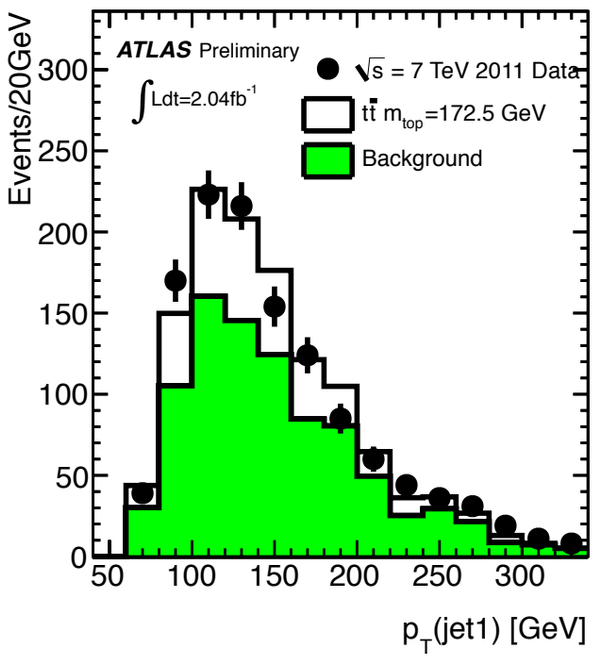
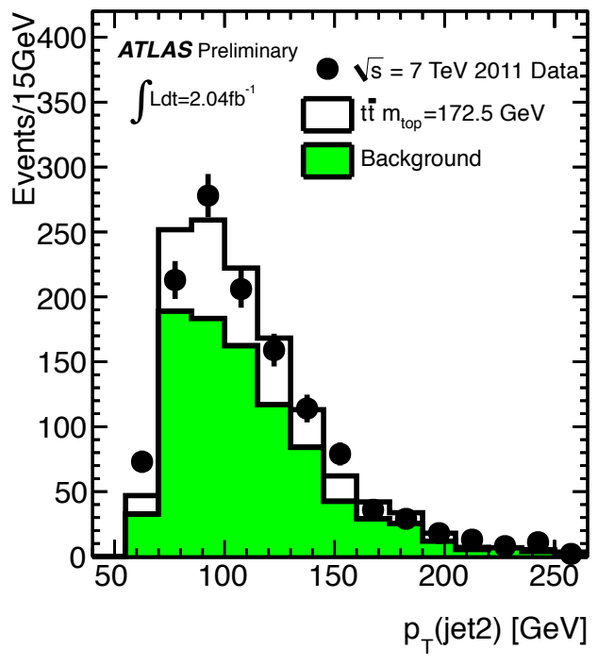
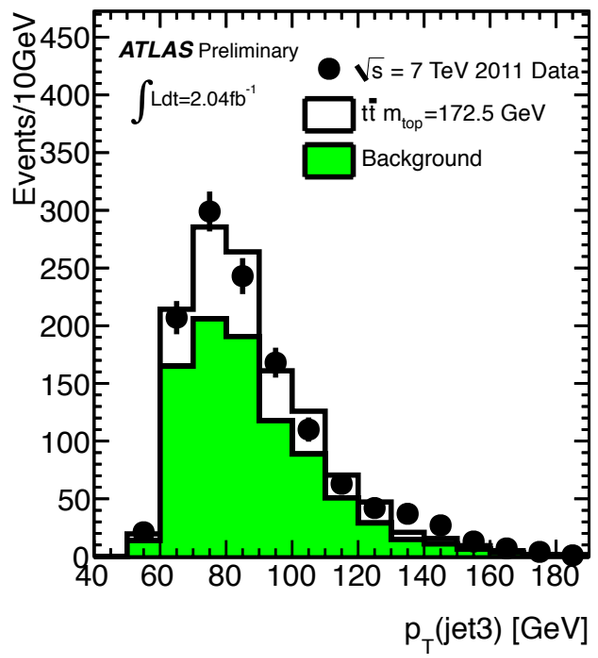
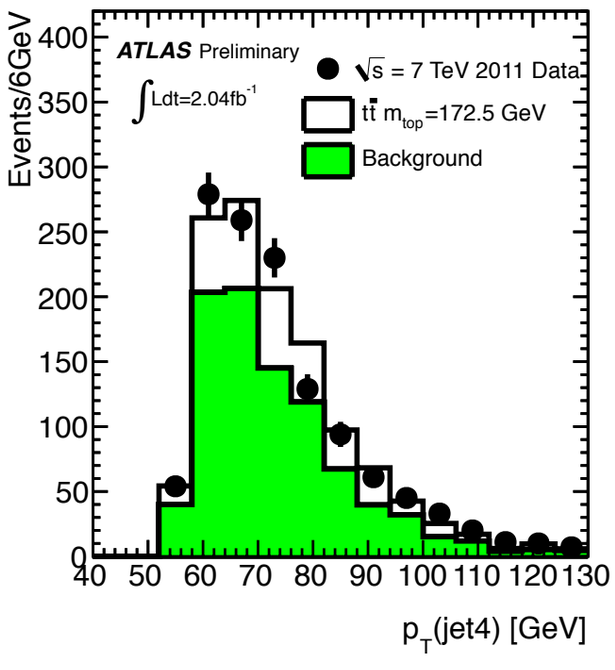
Top Mass - All Hadronic

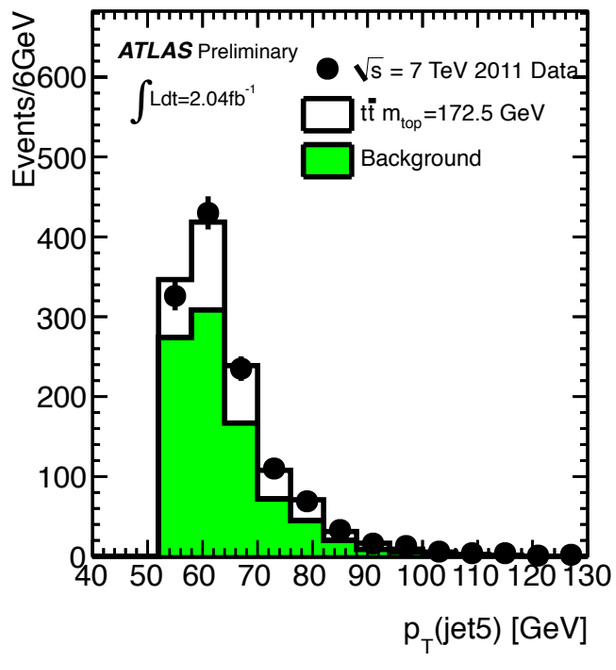
$2.04fb^{-1}$ 7TeV

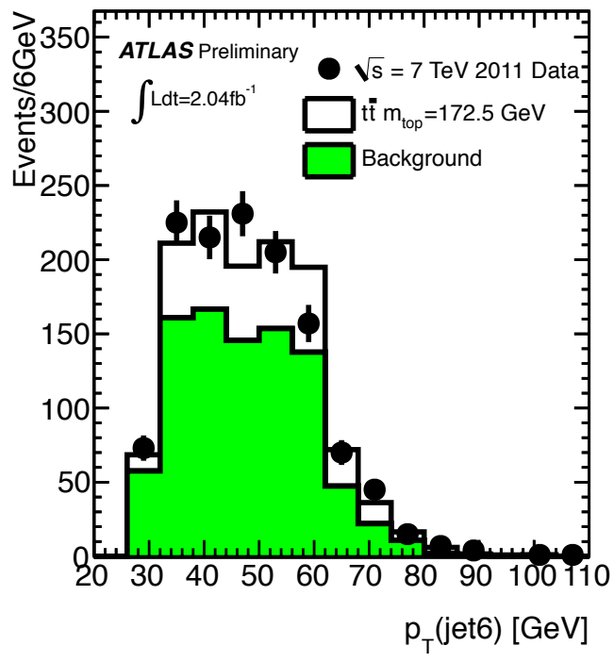












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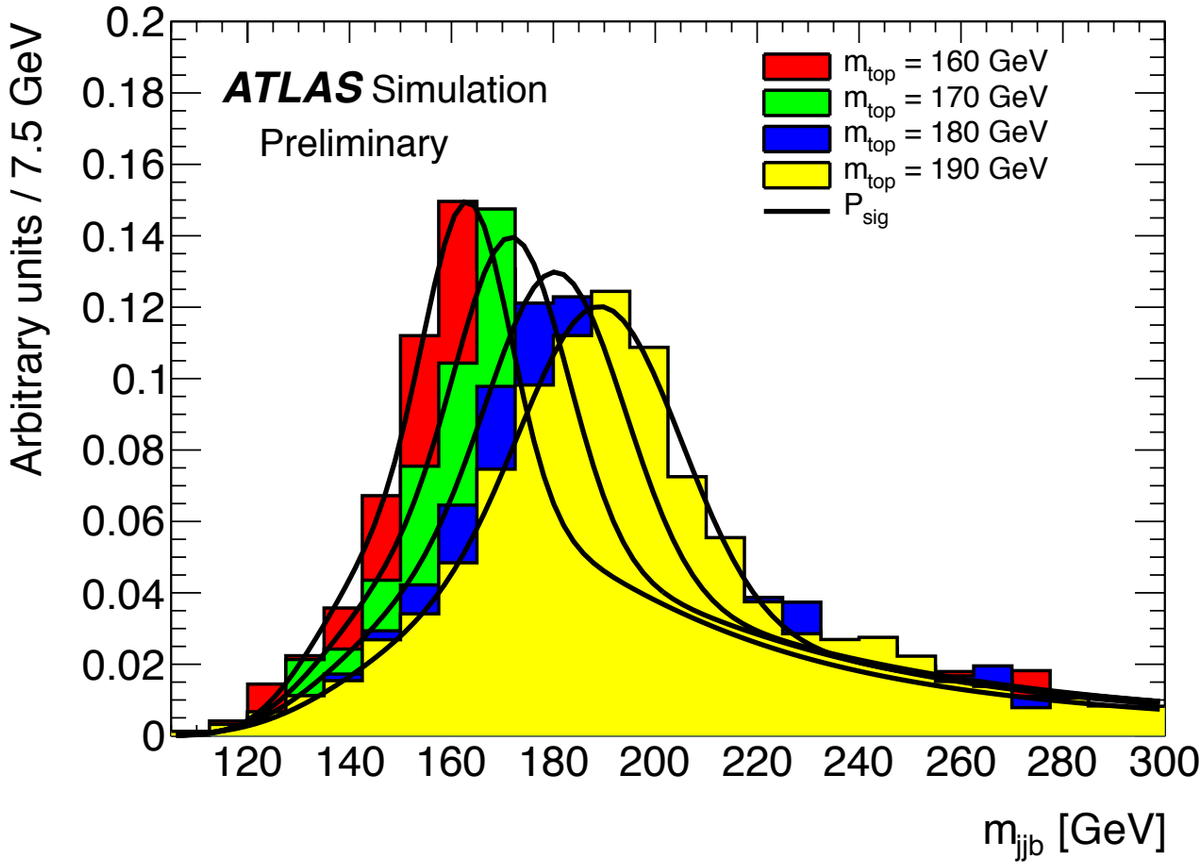
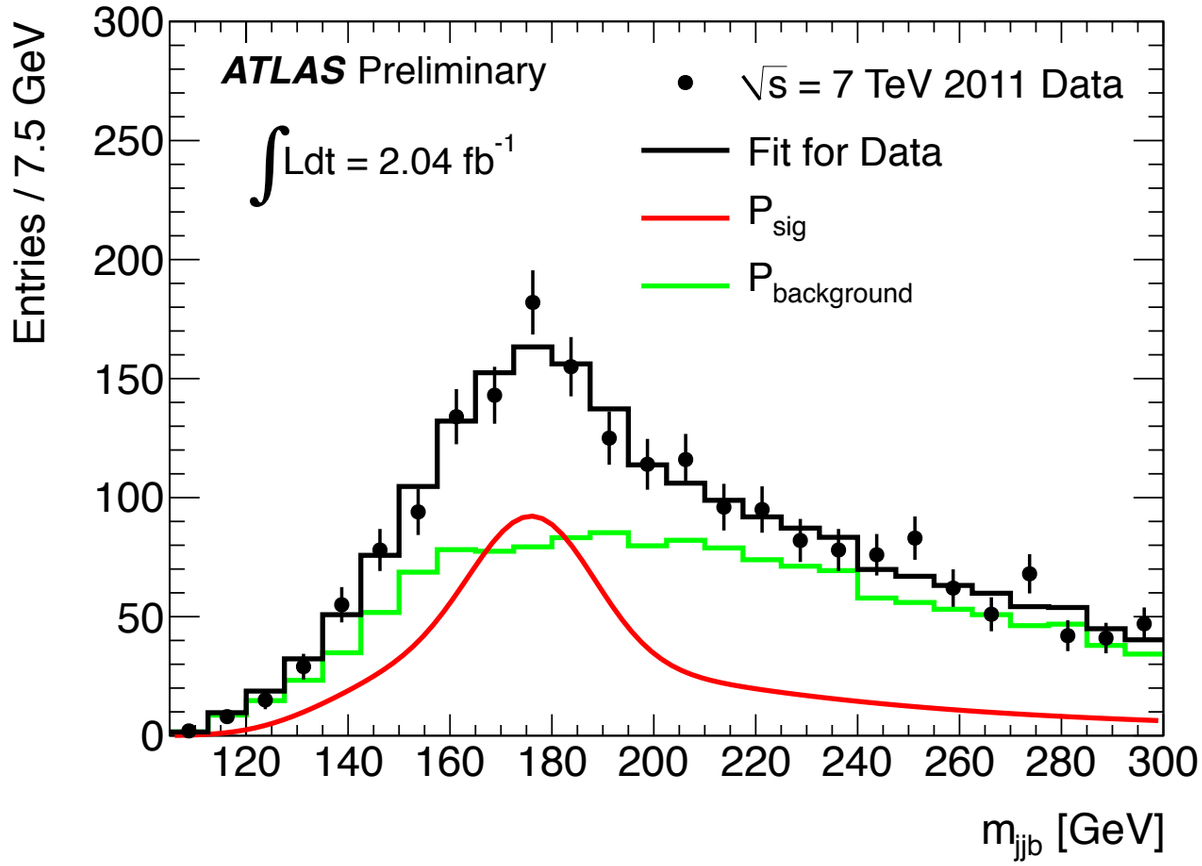
Top Mass - All Hadronic

2.04fb^{-1} 7TeV





m_{top} = 174.9 ± 2.1(stat) ± 3.8 (syst) GeV

(b)JES
I/FSR

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The ATLAS Detector