Recent Results on Top Physics At ATLAS

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(US LHC Organization Meeting 2012)

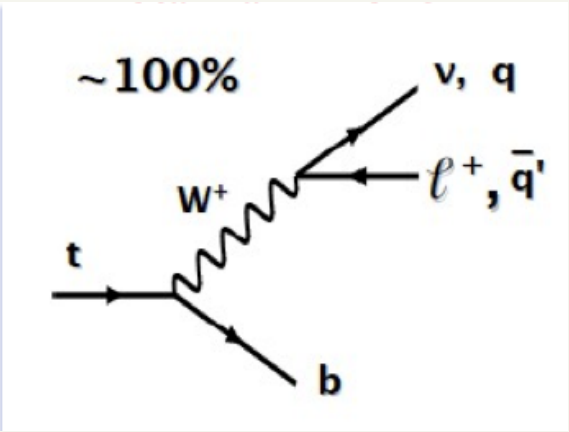
On behalf of the ATLAS Collaboration

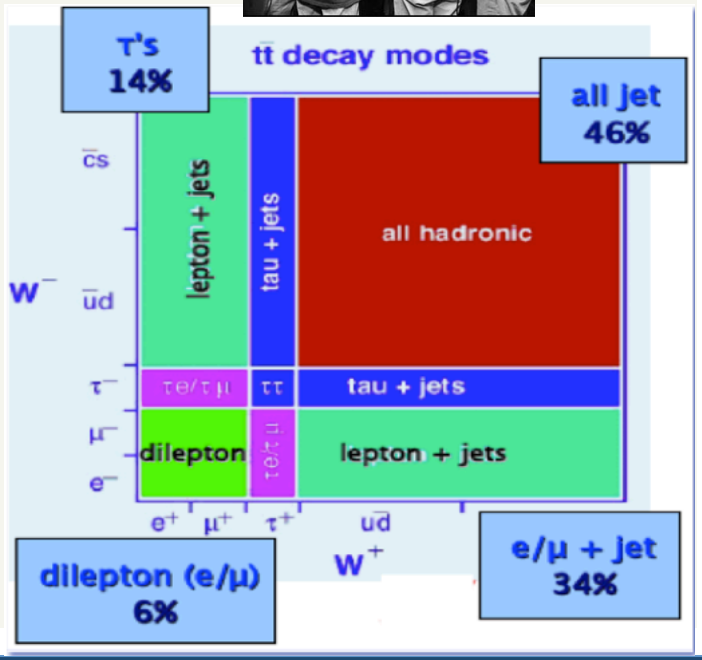
The top quark

Discovered in 1995 at Fermi lab.
Heaviest (up to now...) fundamental particle with unique properties (well defined by SM)

- ✓ Large coupling to the Higgs boson
- ✓ Decays as free quark (before hadronization)
- ✓ New physics might affect its properties
- ✓ Background to Higgs and new physics searches

An interesting hunting place for new physics !



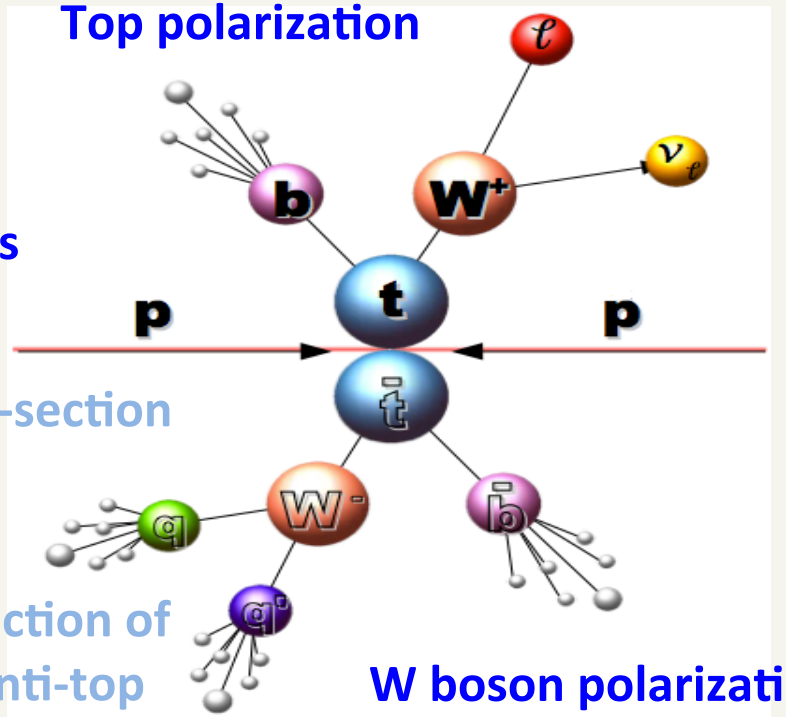


W decay mode defines top pair final state

ATLAS top physics program

Top quark has a rich phenomenology :

Top polarization



production cross-section

Production kinematics

Resonant production

Production mechanism

New particles

Top mass

Single Top cross-section

spin correlations

charge asymmetry

Ratio of cross-section of Single top and anti-top

W boson polarization

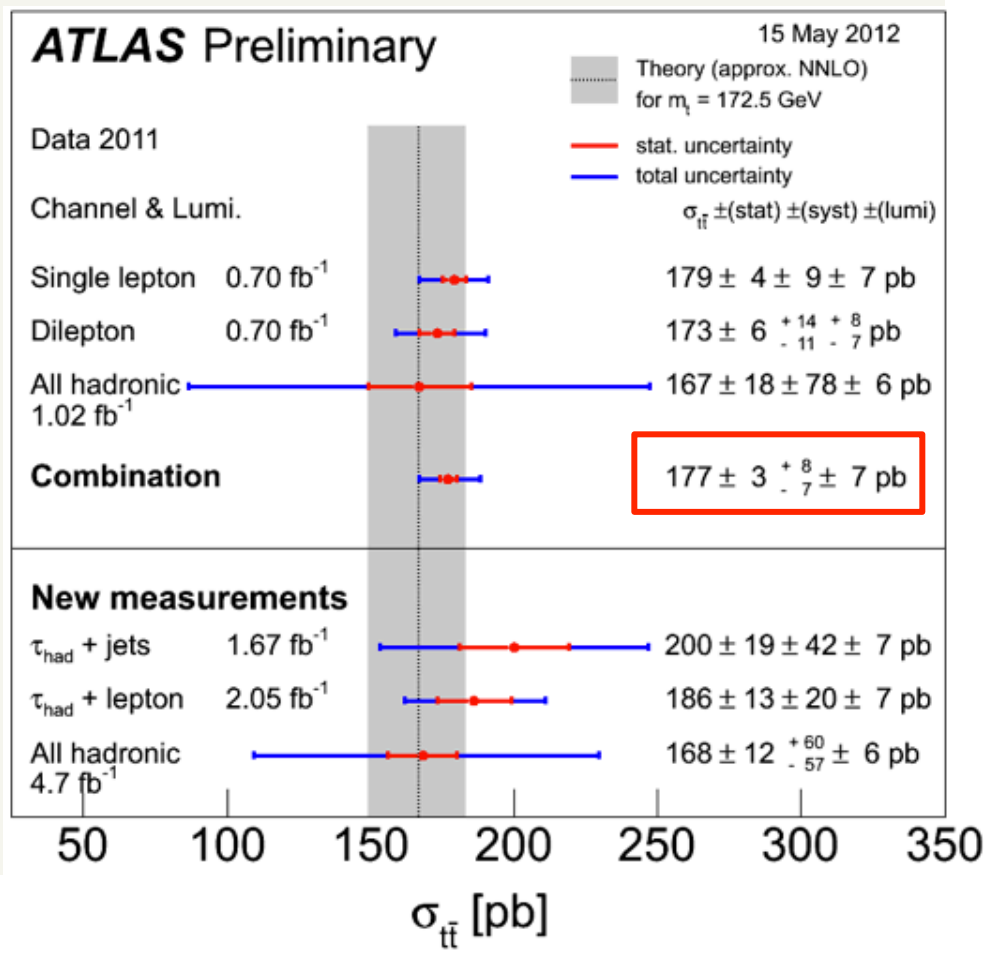
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

ttbar (inclusive) cross section summary

- ✓ Final state lepton+jets with 4.66 fb^{-1}
  ATLAS-CONF-2012-131
- ✓ 2 high p_T-lepton (in final state)
  JHEP 1205 (2012) 059
- ✓ Final state with e/mu and a hadronically decay tau:
  arXiv:1205.2067 [hep-ex] PLB
- ✓ Di-lepton final states:
  Phys. Lett. B707(2012) 459-477
- ✓ Combination :
  ATLAS-CONF-2012-024

For details:
See Jake Searcy's talk on Sat. Oct. 20

pp collisions, $\sqrt{s}$ = 7 TeV ; upto 4.66 fb^{-1}



ttbar + jet cross section

Events selected in lepton (e/μ) + jets channel with additional jet.

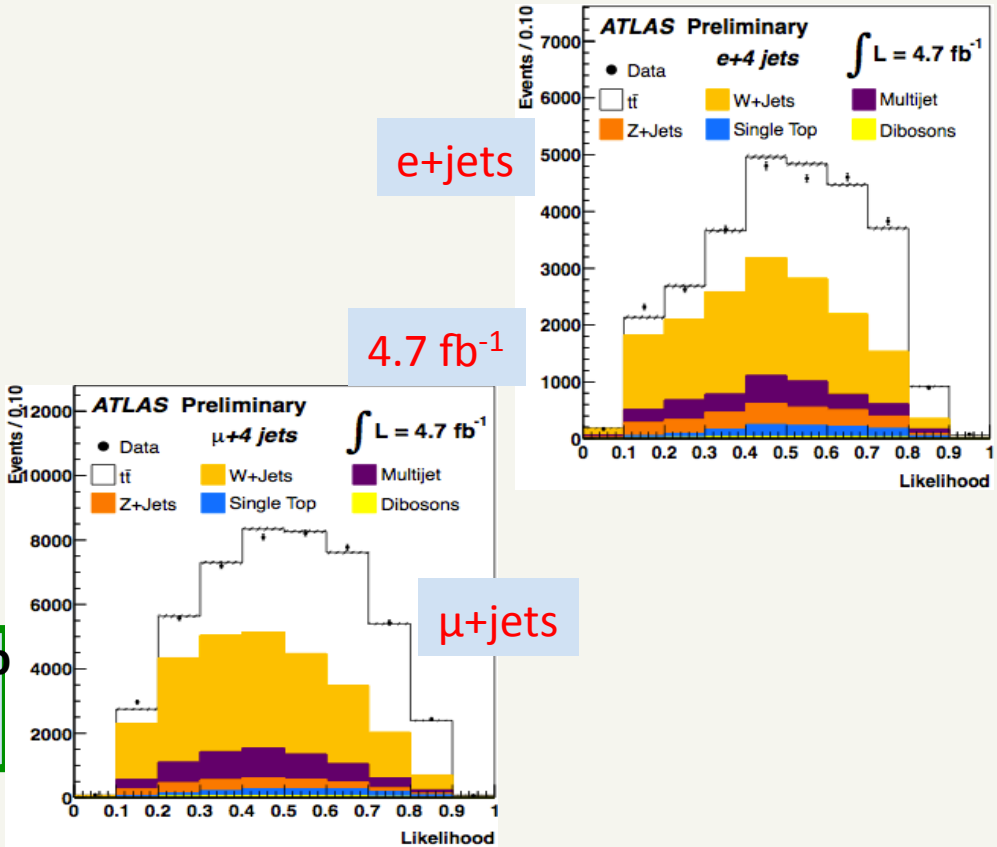
ATLAS-CONF-2012-083

A template fit to data based on the likelihood discriminant constructed from two input variables (charged-lepton pseudo-rapidity, Aplanarity) are used to measure the cross section.

$$\sigma_{ttj} = 102 \pm 2(\text{stat.}) \pm 6(\text{ISR/FSR})\ ^{+22}_{-25}(\textit{syst.})\ \text{pb}$$

$$\sigma_{ttj}/\sigma_{tt} = 0.54 \pm 0.01(\text{stat}) + 0.05\ (\text{syst})\ \text{pb}$$

Dominant systematics are JES & MC generator



Results can be used to test pQCD calculations of jet activity in ttj and improves MC simulations.

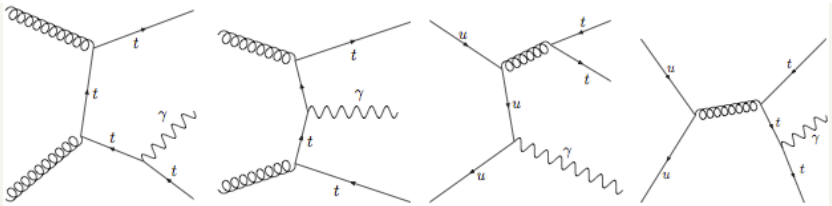
ttbar + γ cross section

Events selected similar to (e/μ) + jets channel with additional γ

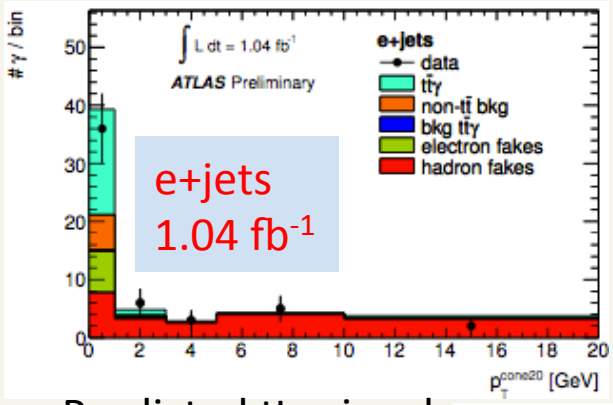
Discriminate prompt γ's from hadron fakes (jet fakes γ) with a template fit method (**ATLAS-CONF-2011-153**)

Data-driven: Signal, hadron fakes (jet faking a γ (π0 conversion)), electron fakes (electrons faking a γ)
MC-driven: W/Z+jets(+γ), VV, QCD + γ, Single-top

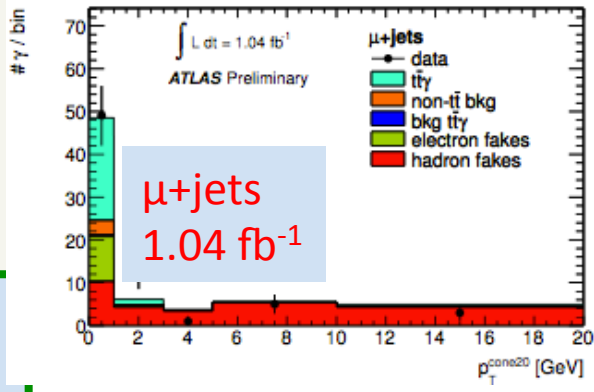
Dominant systematics: Photon ID (0.33 pb), ISR/FSR (0.31 pb), PU (0.28 pb), JES (0.28 pb)



Representative Set of Feynmann diagrams



Predicted ttγ signal on top of different background



$\sigma_{tt\gamma} \times \mathcal{B}(p_T^{Gen}(\gamma) > 8\ GeV) = 2.0 \pm 0.5(stat) \pm 0.7(syst) \pm 0.08(lum)$ pb
.....2.7σ compatible with LO × k-factor prediction.

Gap fraction measurement

Events selected in dilepton channel

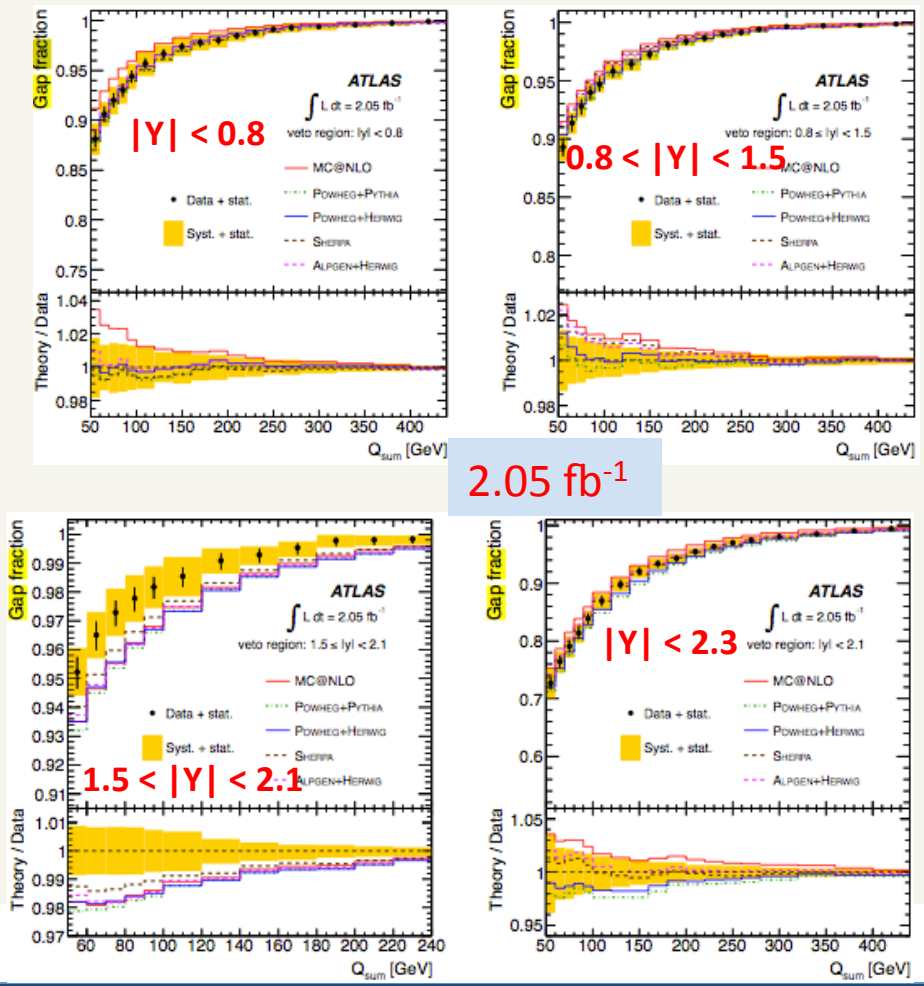
Gap fraction is the ratio between the fiducial cross section and the inclusive top pair cross section, where the fiducial cross section is for the events with no additional jets with $p_T > Q_0$

$f(Q_0) = \sigma(Q_0) / \sigma$

- MC@NLO too little activity in central region
- All four generators produce too large activity in the forward region

- Results can be used to constrain model dependent uncertainties in future measurements

arXiv:1203.5015



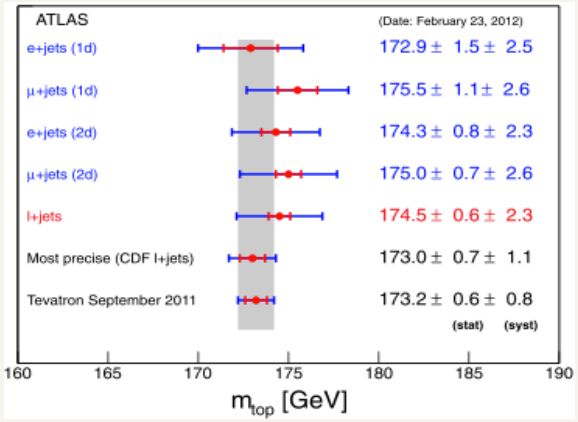
2.05 fb^{-1}

Top mass measurement

Events selected in lepton + jets

Two methods:
1D analysis : reconstruct $R_{32} \cong m_t^{rec}/m_W^{rec}$
2D analysis : simultaneous fit to derive m_{top} and jet energy scale factor(JSF)

....approaching Tevatron sensitivity



Dominant syst. = JES, b-JES, I/FSR
Eur. Phys. J. C (2012) 72:2046

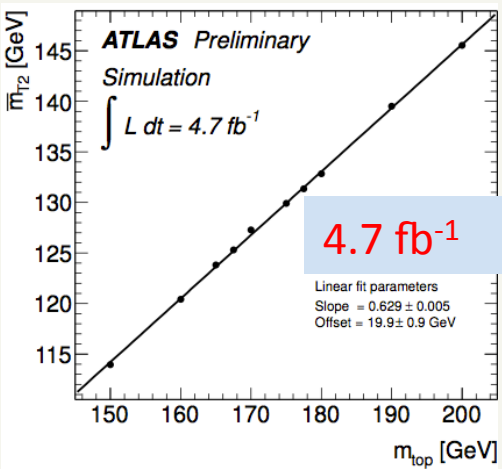
All hadronic Jets: ATLAS-CONF-2012-082

Events selected in di-lepton channel

Low background after selection: define m_{T2} (transverse mass – a lower bound of the parent mass) as:

$$m_{T2}(m_{invis}) = \min_{\vec{p}_T^{(1)},\,\vec{p}_T^{(2)}} \left\{ \max\left[m_T(m_{invis}, \vec{p}_T^{(1)}), m_T(m_{invis}, \vec{p}_T^{(2)}) \right] \right\}$$

$$m_T(m_{invis}, \vec{p}_T^{(i)}) = \sqrt{m_{vis}^2 + m_{invis}^2 + 2(E_T^{vis} E_T^{invis} - \vec{p}_T^{vis} \cdot \vec{p}_T^{(i)})}$$



Calibration of m_{T2} vs m_t to extract the top mass
Average of m_{T2} distribution to obtain m_t
Dominant syst.: JES, b-JES, generator, PS, color connection

M_t=172.5±1.6(stat) $_{-2.8}^{+3.1}$(syst) GeV
ATLAS-CONF-2012-082

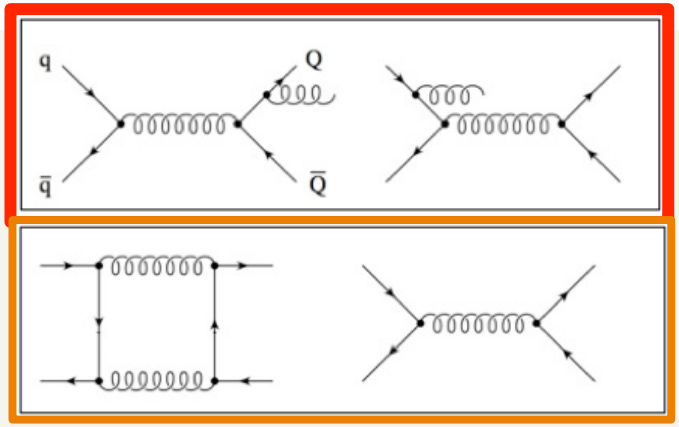
Top charge asymmetry

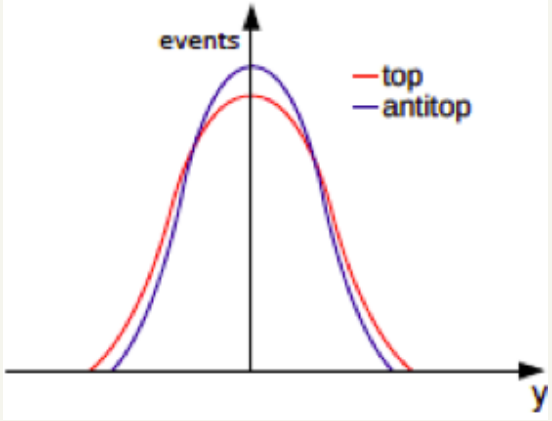
Charge asymmetry can appear in ttbar pair production through qqbar annihilaton at NLO in QCD:

- Interference b/w ISR and FSR
- Interference b/w the Born and Box diagrams.

At Tevatron A_{FB} : top(antitop) produced preferentially in the direction of the incoming proton(antiproton)

-At LHC :No FB asymmetry
Study asymmetry considering that top is produced more broadly than antitop
Select phase space region in order to enhance charge asymmetry: i.e. select high m(ttbar) to reduce gluon fusion and to enhance new bosons contributions





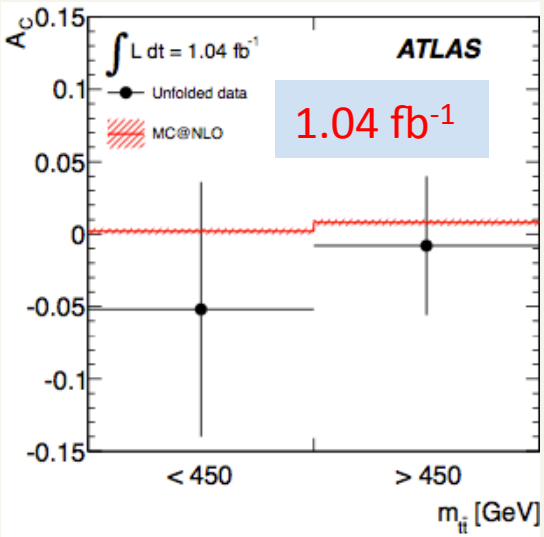
$\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$

Charge of t and tbar is determined by charge of lepton

$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)}$$

Top charge asymmetry

Lepton + jets channel



A_c = -0.008±0.035(stat) ±0.032(syst)
M_{tt} > 450 GeV

In agreement with SM predictions

Eur. Phys. J. C7 (2012) 2039

dilepton channel 4.7 fb^{-1}

1. Lepton charge asymmetry:
(one based on the lepton rapidities)

$A^{\ell\bar{\ell}}_c$ = 0.023±0.012(stat) ±0.008(syst)

2. Top charge asymmetry:
(based on the reconstructed $t\bar{t}$ final state)
$A^{t\bar{t}}_c$ = 0.057±0.024(stat) ±0.015(syst)

Both results are in agreement with SM predictions

ATLAS-CONF-2012-057

Top spin correlations

dilepton events:
Difference in azimuthal angle between the two charged leptons is used to extract the correlation between the top and antitop quark spins [Mahlon, Parke(2010)]

Fit templates of correlated and uncorrelated samples (+bkg templates) to data

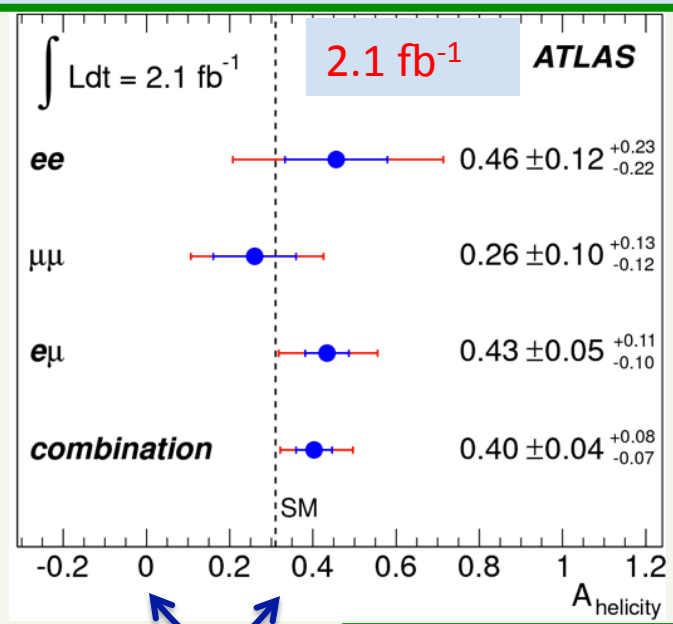
The degree of correlation is fractional difference b/w no. of events:

$$A = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$$

The fit result is converted into a value of A in the helicity and maximal basis

Phys. Rev. Lett 108 (2012) 212001

Dominant Sytematics:
JES, fake background template



$A_{helicity} = 0.40^{+0.09}_{-0.08}$

...Results inconsistent with no correlation at 5σ

Top quark polarization in ttbar events

Lepton + jets events:
Study polar angle of charged lepton in the parent top quark rest frame.

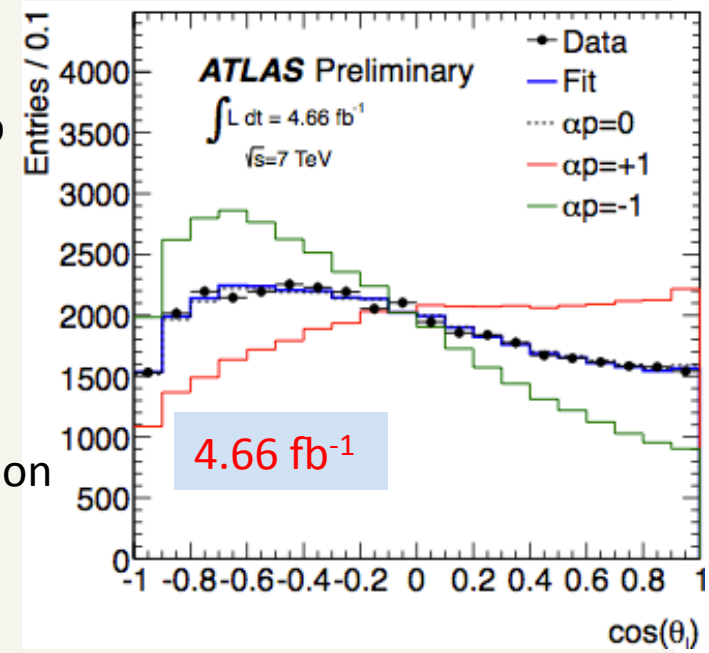
Distribution of the polar angle θ_i :
$W(\cos\theta_i)\ \alpha\ 1 + \alpha_i\, p \cos\theta_i$
P: degree of polarization along axis
α_i: spin analyzing power = 1 (tree level)

Degree of polarization: $\alpha_i\, p = 2f - 1$
f : frac. of positively polarized top quarks

$$f = \frac{1}{2} + \frac{N(\cos\theta_l > 0) - N(\cos\theta_l < 0)}{N(\cos\theta_l > 0) + N(\cos\theta_l < 0)}$$

ATLAS-CONF-2012-133

fits compared to data (in each channel) and to the maximal fit templates ($\alpha p = \pm 1$) and the no polarization expectation



$f = 0.470 \pm 0.009(\text{stat})^{+0.023}_{-0.032}(\text{syst})$

in good agreement with SM predictions f = 0.5

W boson polarization

Lepton+jets and dilepton events

Probes Wtb structure; set a limit on new physics window

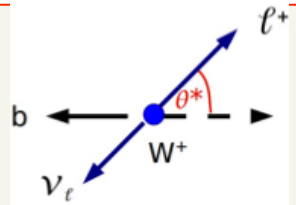
SM predicts helicity fraction of W from top:

$F_L = 0.3$, $F_0 = 0.7$, $F_R = 0$

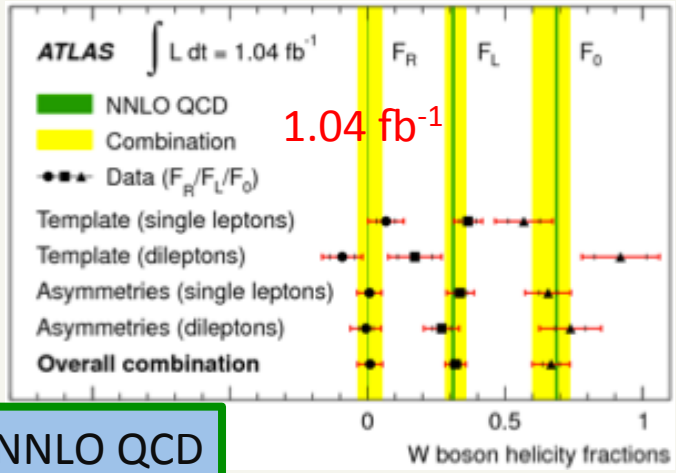
-Compare the observed cos θ* distribution with templates for different W boson helicity states obtained from simulation.

-Extracts angular asymmetries from an unfolded cos θ* spectrum corrected for background contributions.

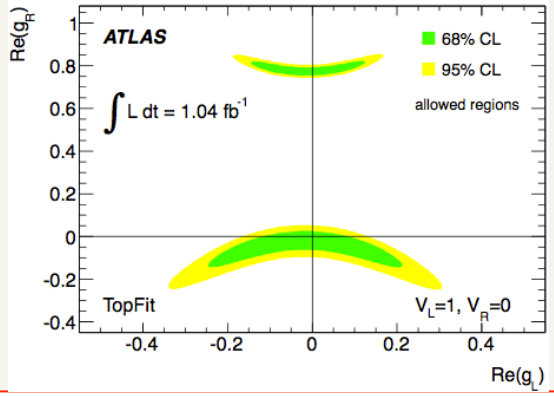
JHEP 1206 (2012) 088



$F_0 = 0.67 \pm 0.07$
$F_L = 0.32 \pm 0.04$
$F_R = 0.01 \pm 0.05$



In agreement with NNLO QCD predictions



Limits on the W tb vertex anomalous couplings were obtained from the combined results on the W boson helicity fractions

Summary

- ✓ **Top quark physics is one of the key elements of the LHC physics program with one of the most enjoyable playground in particle physics**
- ✓ **Large number of top events enable many interesting new analysis – performing precision tests of the SM**
- ✓ **and probing for new physics (on deviation from the SM)**
  - ✓ No evidence of new physics so far but…
  - ✓ Top quark physics approaching an era of new precision measurements
- ✓ **LHC and ATLAS detector performance are excellent**
  - ✓ **Some Results shown are up to 4.7 fb^{-1} of 2011 data, results with 2012 data at 8 TeV C.o.M (still to come)**
- ✓ **ATLAS produced 23 papers on Top physics since 2010**
- ✓ **More results yet to come !**

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

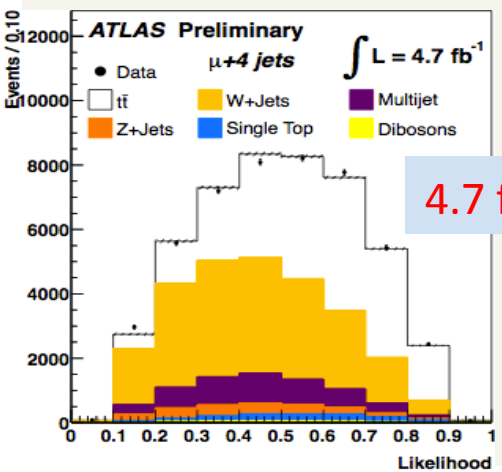
Back-Up

ttbar + jet cross section

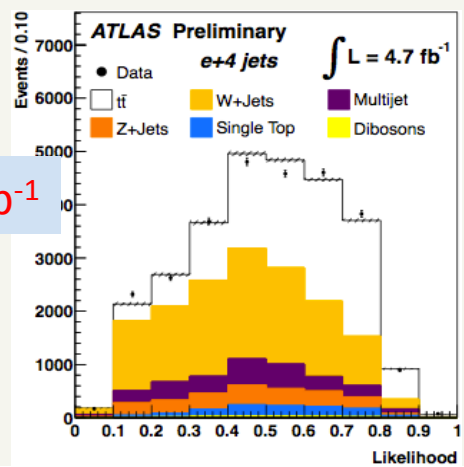
Events selected in lepton (e/μ) + jets channel with additional jet.

ATLAS-CONF-2012-083

1. Jets are considered additional if their ΔR from a parton originating from a top decay is > 0.4
2. An event has additional jets if in the event there are >= 5 jets



4.7 fb^{-1}



A likelihood discriminant function with two discriminating variables is used to extract the signal

measure the number of inclusive ttbar events in each jet multiplicity bin, $N_4^{t\bar{t}}$ and $N_5^{t\bar{t}}$. Finally, calculate the x-sec using:

$$N_4^{t\bar{t}} = \mathcal{L}\sigma_{tt0}\varepsilon_{04} + \mathcal{L}\sigma_{ttj}\varepsilon_{14}$$

$$N_5^{t\bar{t}} = \mathcal{L}\sigma_{tt0}\varepsilon_{05} + \mathcal{L}\sigma_{ttj}\varepsilon_{15}$$

σ_{ttj} = 102 ± 2(stat.) ± 6(ISR/FSR) $^{+22}_{-25}$(*syst.*) pb

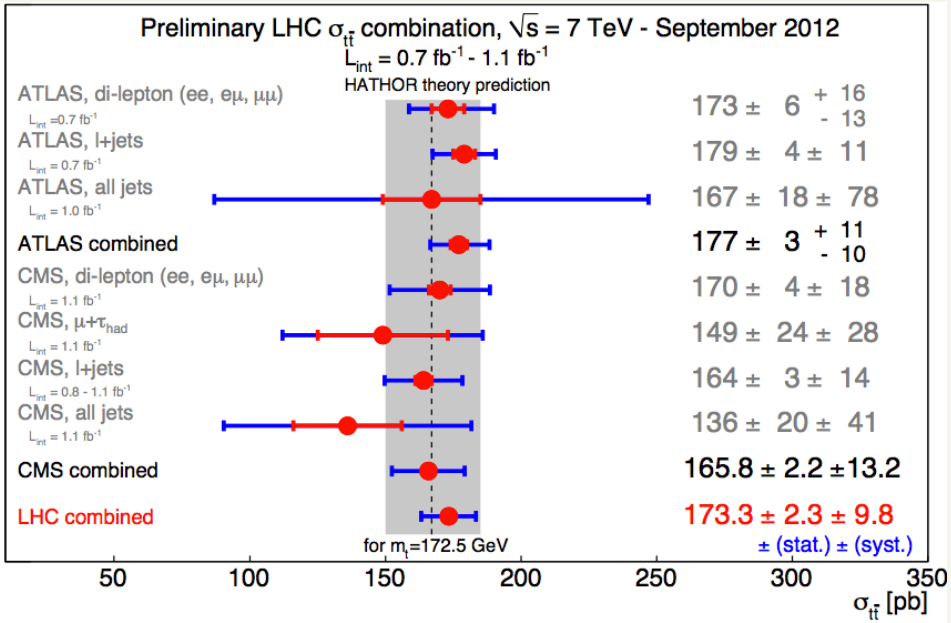
Dominant systematics are JES & MC generator

Results can be used to test pQCD calculations of jet activity in ttj and improves MC simulations.

Top mass combination

ATLAS – CMS Top mass combination:

0.7 – 1.1 fb^{-1}



Dominant syst.

- Detector Modelling
- Signal Modelling
- Luminosity
- JES
- b-JES

ATLAS-CONF-2012-134

CMS-PAS-TOP-12-003

Cross Sections