Top Production at ATLAS

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on behalf of the
ATLAS collaboration

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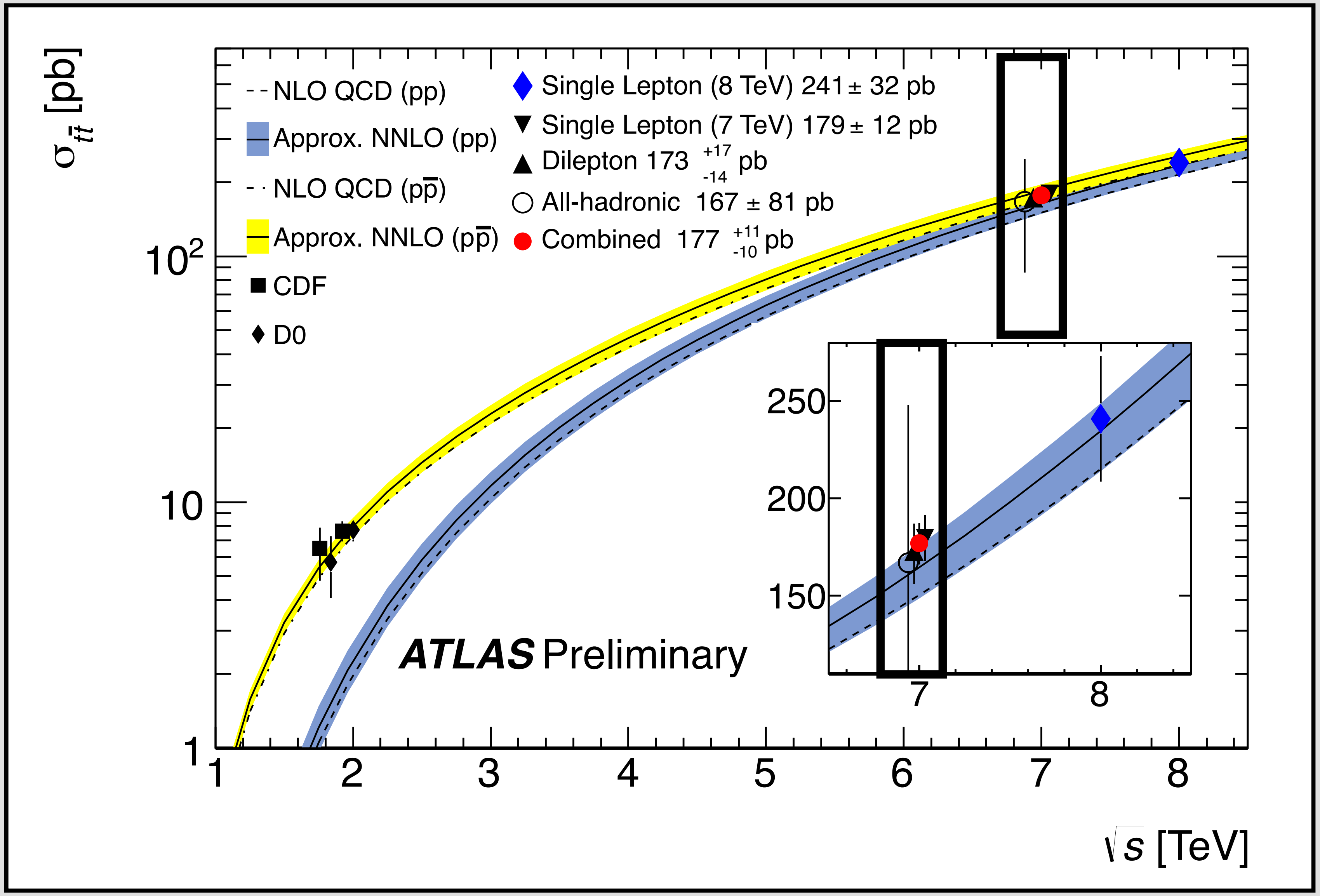
The Top Quark at the LHC

- Why study the top quark?
  - *Precision test* of the Standard Model (QCD) - Can also be used to constrain our simulation/generator models
  - Many new physics models would predict enhancements in the top production rates
- The LHC era signals a *new paradigm* for top quarks
  - From its *discovery* at the Tevatron, the top quark is now becoming a SM '*candle*' for LHC physics
  - It is also a sizable *background* to many new physics searches! Crucial that we understand this process!

Over 25 papers and over 50 preliminary notes produced on top physics at ATLAS!

The Top Quark at 7 TeV - 2011 Run

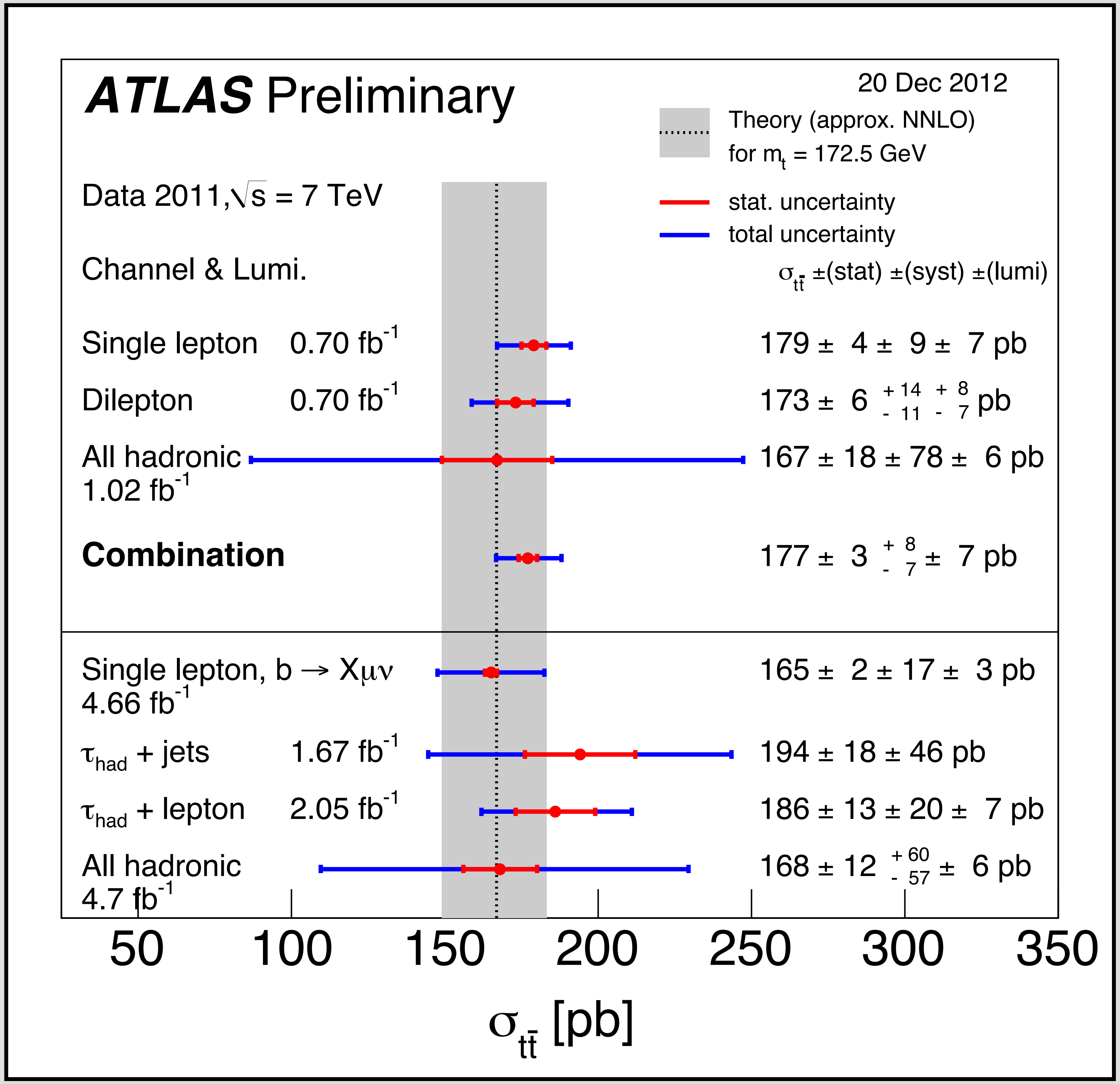


A wealth of top quark measurements were performed with the 2011 dataset, many of which were finalized recently!

Will focus on the most recent results...

Almost 1 million top quark pair events produced in 2011 across all channels!

Top Quark Pair Cross-Section



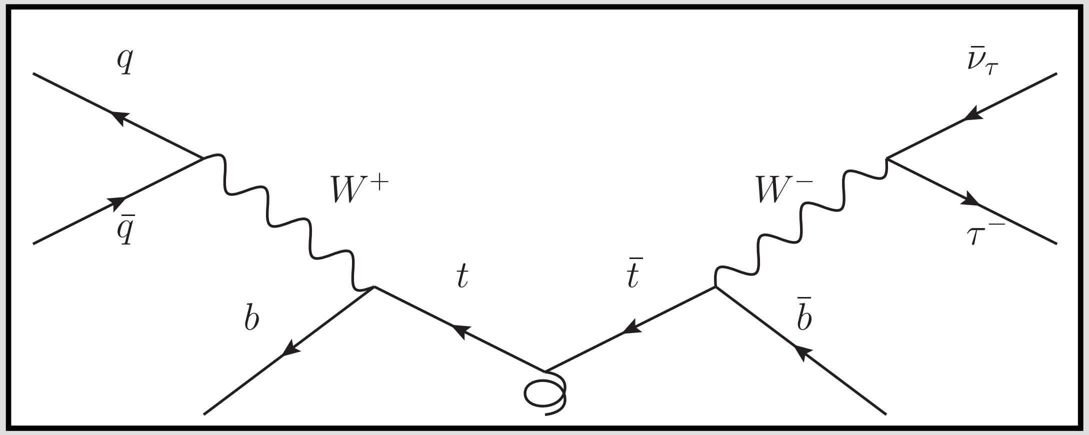
Combination is driven by the high-precision channels with electrons and muons in the final state

Systematic uncertainties drive the precision of most measurements...

Cross-section in the τ_{had} + jets channel

ATLAS-CONF-2012-032
arXiv:1211.7205
(Submitted to EPJC)

- First measurement in this channel at the LHC!
- Difficult final state to reconstruct, with very large backgrounds!



Event Selection

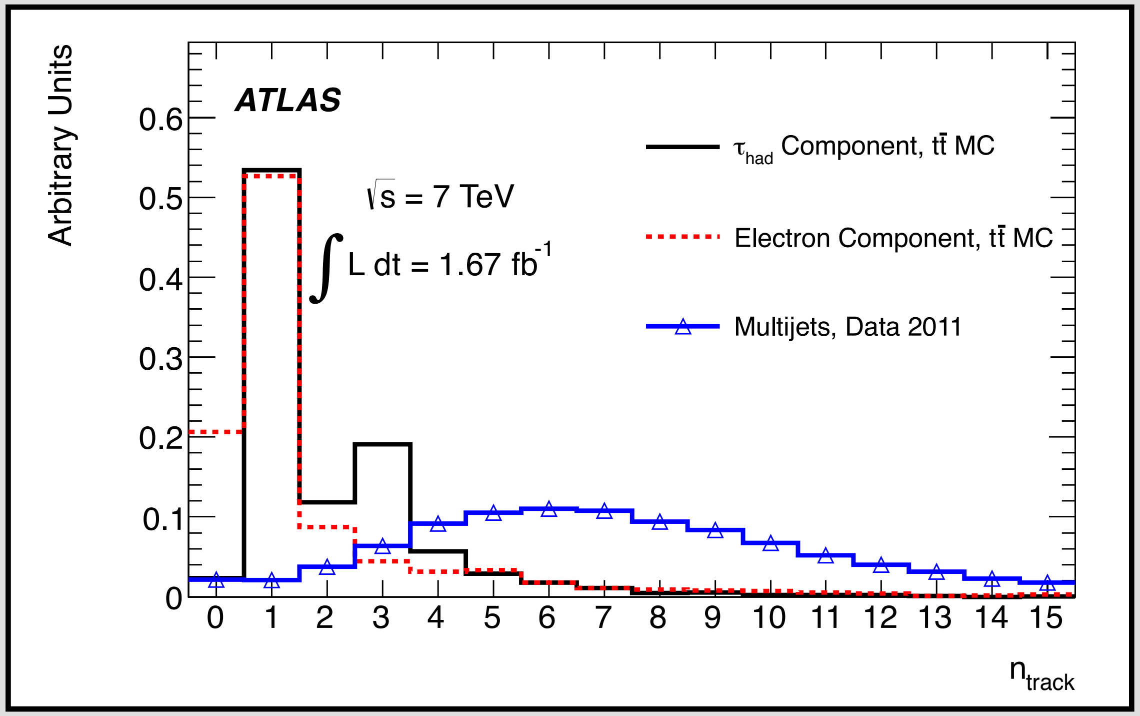
Trigger on 4 jets (p_T > 10 GeV),
of which 2 are b-tagged *at trigger level*

5 jets with p_T > 20 GeV and $|\eta|$ < 2.5,
of which 2 are b-tagged
Veto reconstructed electrons/muons
τ_{had} p_T > 40 GeV
E_T^{miss} / [0.5 sqrt(ΣE_T)] > 8
(E_T^{miss} significance)

First use of a dedicated b-jet trigger in an ATLAS measurement!

Methodology

Use a Template Fit: Number of tracks associated with tau candidate is ideal (very well modeled)
Background templates are data-driven
Signal template taken from simulation



Cross-section in the τ_{had} + jets channel

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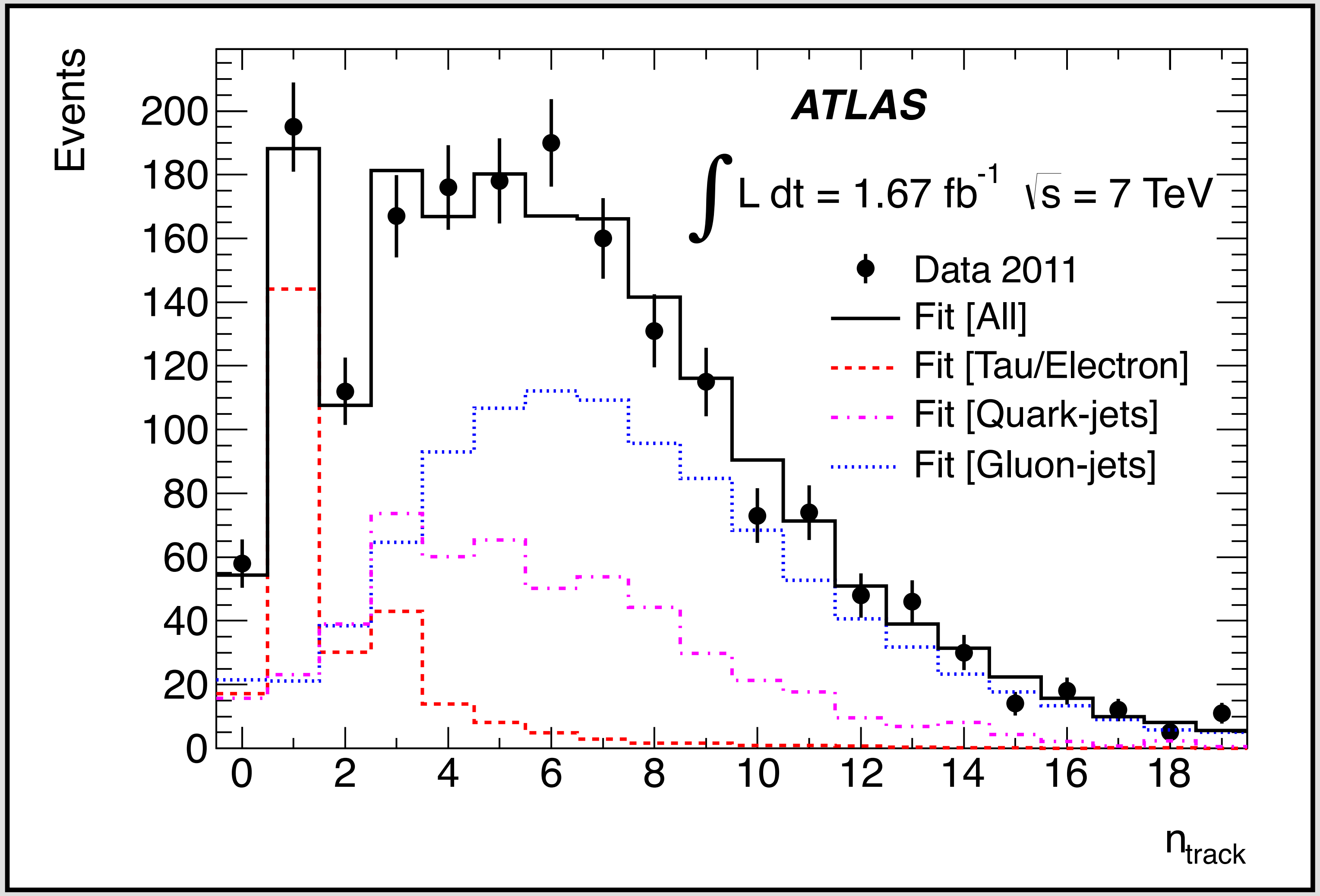


Source	Number of events
tau/electron	
$t\bar{t}$ (τ_{had})	170 ± 40
$t\bar{t}$ (electrons)	47 ± 11
Single top	12 ± 2
W+jets	9 ± 5
Total expected	240 ± 50
Fit result	270 ± 24 (stat.) ± 11 (syst.)
quark-jet	
$t\bar{t}$ (jets)	540 ± 160
Single top	24 ± 4
W+jets	21 ± 12
Total expected	580 ± 160
Fit result	520 ± 97 (stat.) ± 78 (syst.)
gluon-jet	
Fit result	960 ± 77 (stat.) ± 74 (syst.)

$$\sigma_{t\bar{t}} = 194 \pm 18\ (\text{stat.}) \pm 46\ (\text{sys.})$$

Uncertainties are dominated by the generator modeling of the signal acceptance, and the b-tagging efficiency

Top pair events 'only' high statistics SM source of high p_T τ_{had} (p_T > 40 GeV)
Possible future use for performance studies?

Cross-section in the lepton + jets channel with a semi-leptonic b-decay

ATLAS-CONF-2012-131

- Uncertainty on the performance of 'lifetime-based' b-taggers is typically a driving systematic for top-pair cross-section measurements
- Using a different method for identifying b-jets gives a measurement driven by a separate set of systematics

Event Selection

'Standard' lepton + jets selection except using:

Soft Muon Tagger

Exploits the $b \to \mu X$ decay (20% B.R.)

Standard muon cuts and:

$\Delta R(\mu, \text{jet}) < 0.5$

$|d_0| < 3$ mm

$|z_0 \sin\theta| < 3$ mm

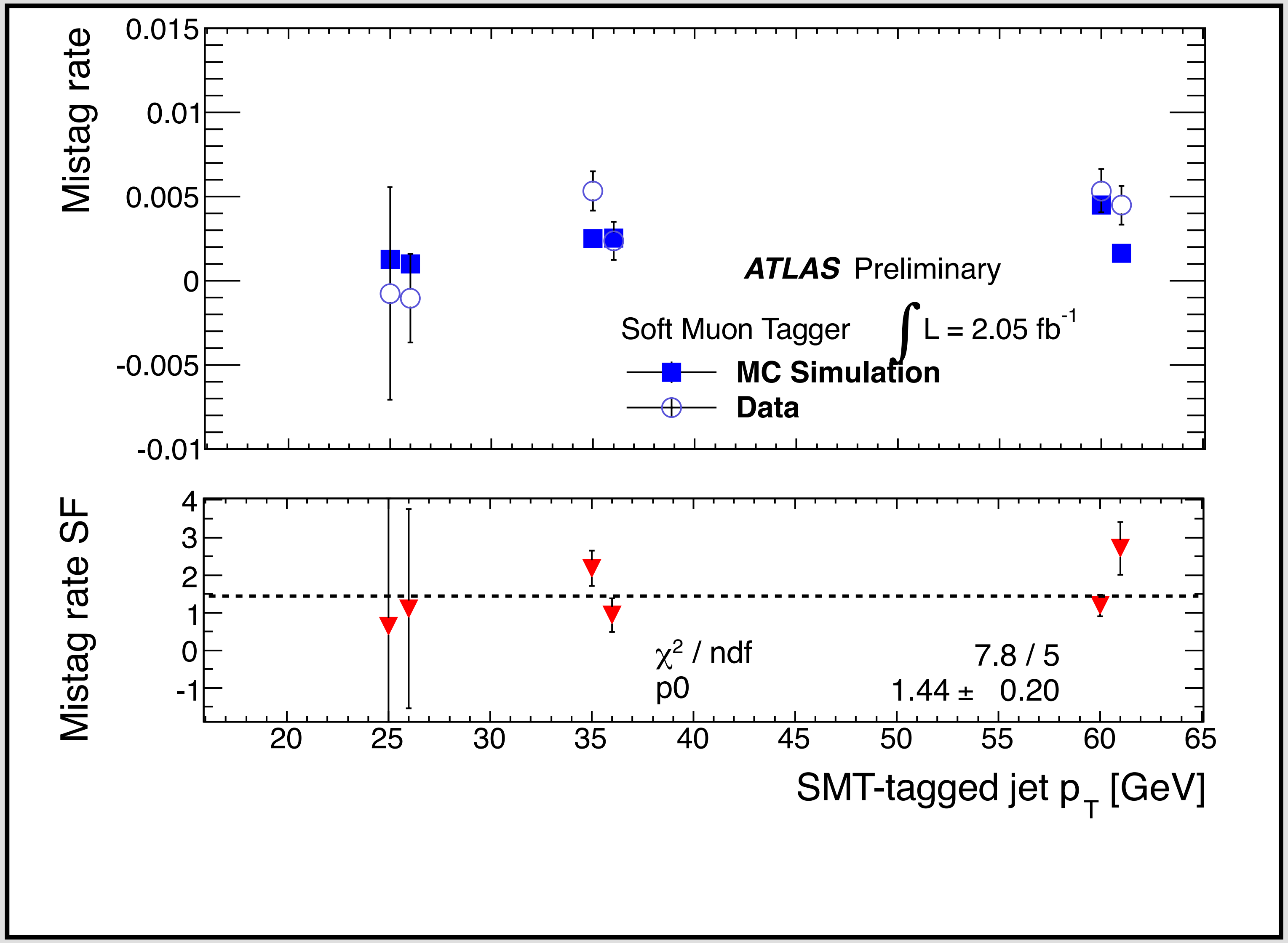
$p_T > 4$ GeV

$\Delta R(\mu_W, \mu_{SMT}) > 0.01$

$\eta < 2.5$

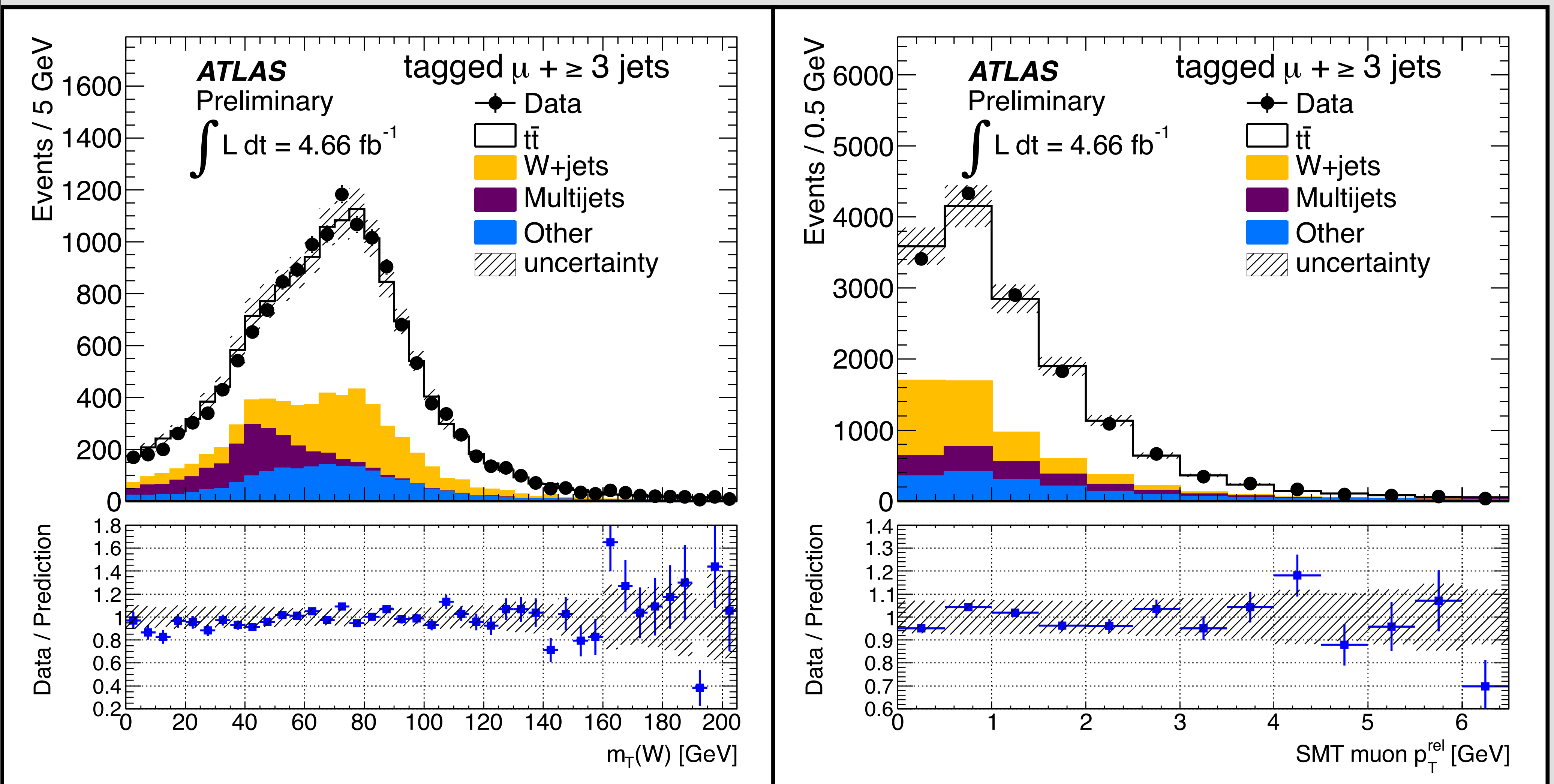
Jet track multiplicity > 3, or Jet EM Fraction < 0.8

$\chi^2_{match} < 3.2$



Cross-section in the lepton + jets channel with a semi-leptonic b-decay

ATLAS-CONF-2012-131



W+Jets and multijets are data-driven (charge asymmetry and matrix method, respectively)

Other backgrounds taken from simulation

Main contribution to systematics from background normalizations, generator uncertainties, jet energy scale and lepton identification

$$\sigma_{t\bar{t}} = 165 \pm 2\ (\text{stat.}) \pm 17\ (\text{sys.}) \pm 3\ (\text{lumi.})$$

See ATLAS-CONF-2012-097 for an in-situ measurement of the b-tagging efficiency using top-pair events

Resulting uncertainty due to the tagging efficiency is only at the ~ 1-2% level! The uncertainty due to the b branching ratio is however at the 3% level...

Jet Multiplicity in Top Pair Events

ATLAS-CONF-2012-155

- By measuring the cross-section as a function of the number of jets in an event, constraints can be placed on various ISR/FSR models, and generator configurations

<u>Event Selection</u>

'Standard' lepton + jets selection

<u>Strategy</u>

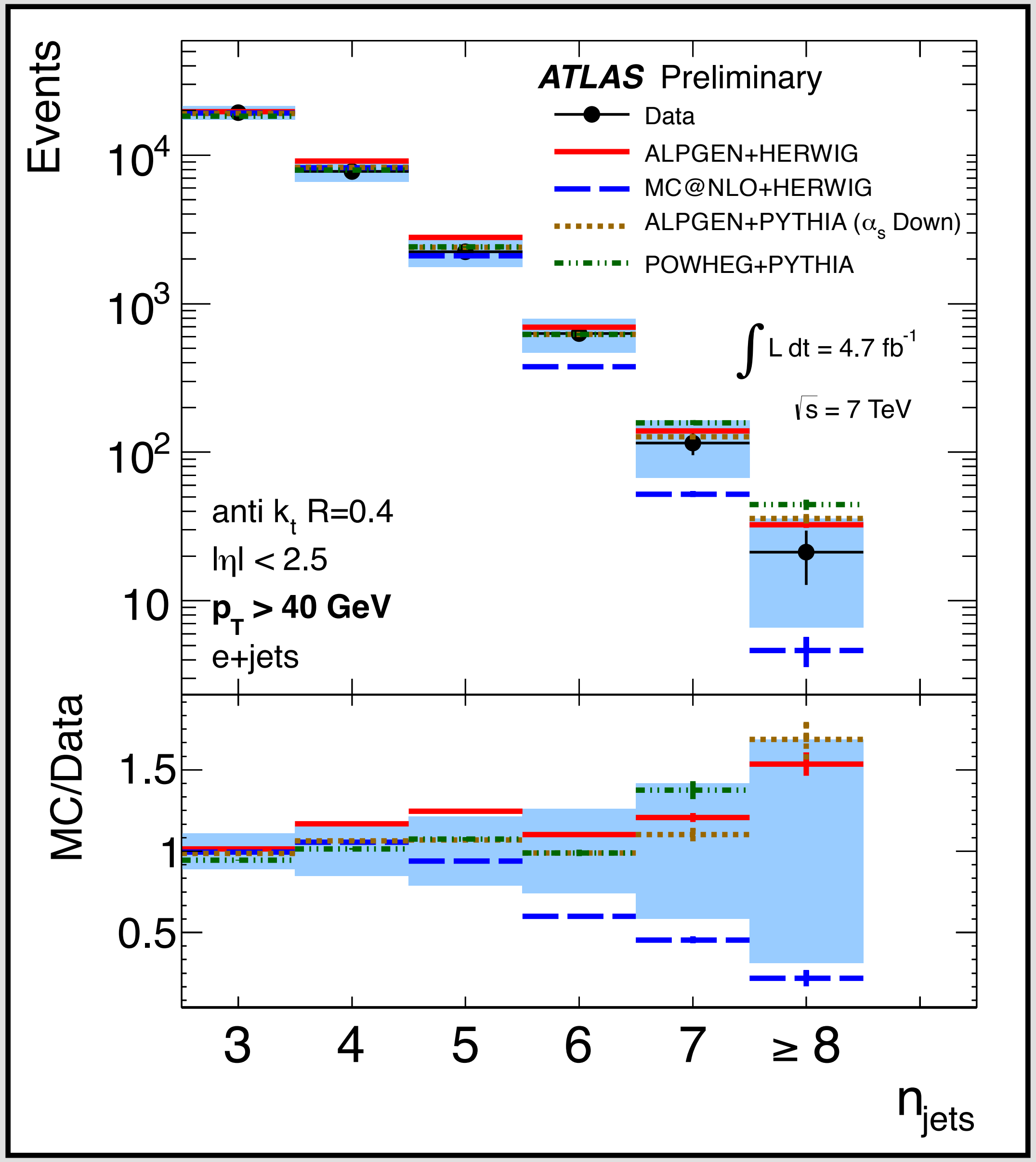
Count the number of jets produced in the events for 4 different thresholds:

p_T > 25, 40, 60, 80 GeV

To be able to perform precise comparisons to Monte Carlo, the distributions are then 'unfolded' to truth 'particle-level'

Compare data to 4 different models
ALPGEN+HERWIG
MC@NLO+HERWIG
ALPGEN+PYTHIA (with as variations)
POWHEG+PYTHIA

After unfolding



Proper understanding of the agreement between the various models and the data can lead to reduced uncertainties in future top measurements!

Differential Cross-Section

Eur. Phys. J. C (2013) 73:2261

- Measuring the cross-section as a function of the properties of the top pair system is a stringent test on the Standard Model predictions

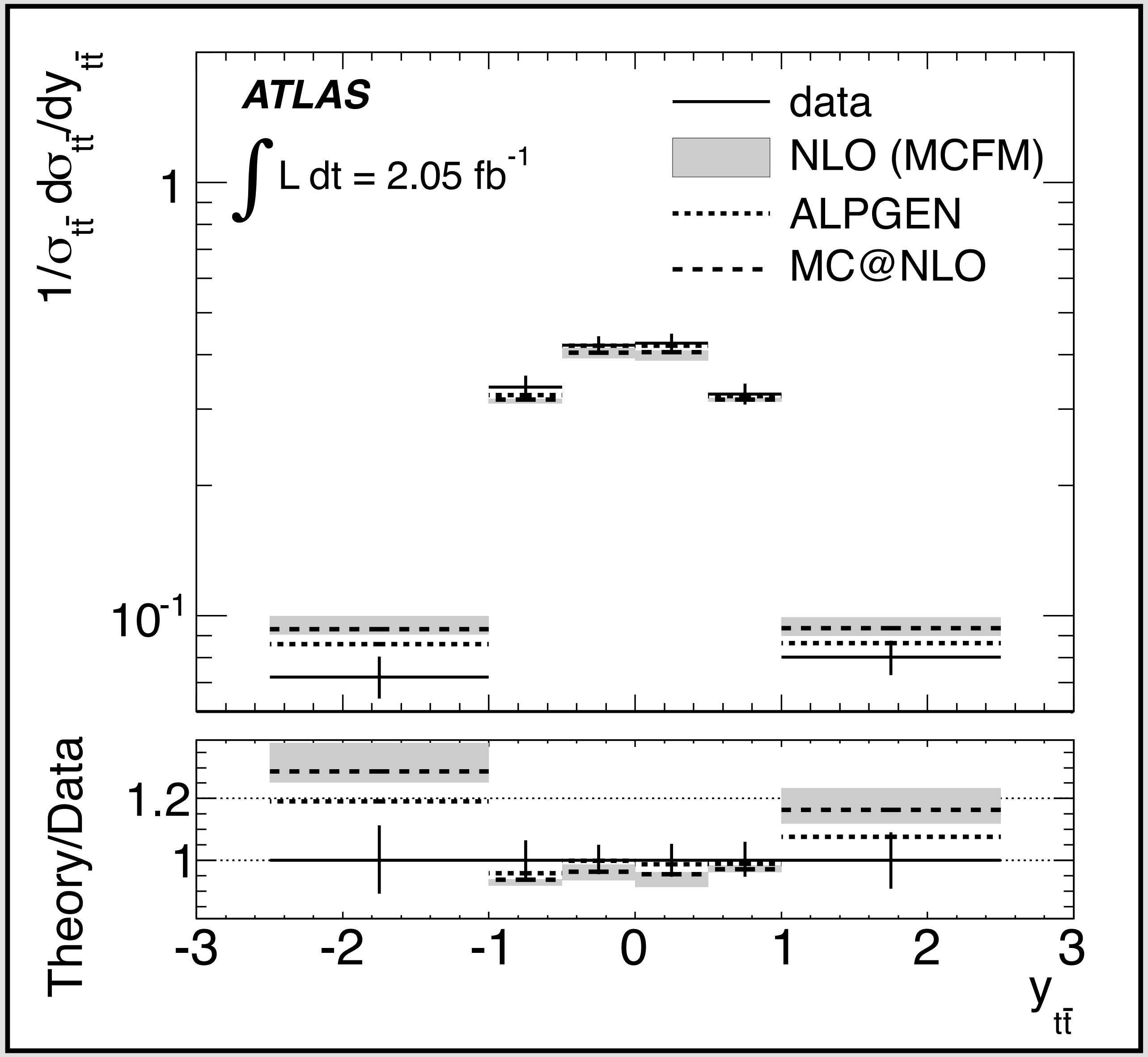
<u>Event Selection</u>

'Standard' lepton + jets selection

<u>Strategy</u>

Maximize a likelihood determinant based on the masses of the particles in the system, the probabilities for the given kinematics, and the b-tagging probability. This allows for a full kinematic reconstruction of the top pair topology.

Use migration matrices to 'unfold' the results to truth 'particle-level'



Cross-section is measured as a function of observables sensitive to QCD predictions: m, p_T, y of $t\bar{t}$ system

Uncertainties are driven by systematics on jet kinematics and generator uncertainties

Search for Top Pair Resonances

ATLAS-CONF-2012-136

- Many *BSM* models predict the existence of new particles that decay primarily to top quark pairs
- Perform a search for resonant production in $\boldsymbol{m_{tt}}$
- Due to the high mass regime being probed, need a dedicated selection to increase acceptance in scenarios where top decay products are boosted

Leptophobic Z', KK gluon, etc.

Event Selection

'Standard' lepton + jets selection except:
Use a shrinking cone for isolation ('mini-isolation') to increase acceptance in due to boosted products

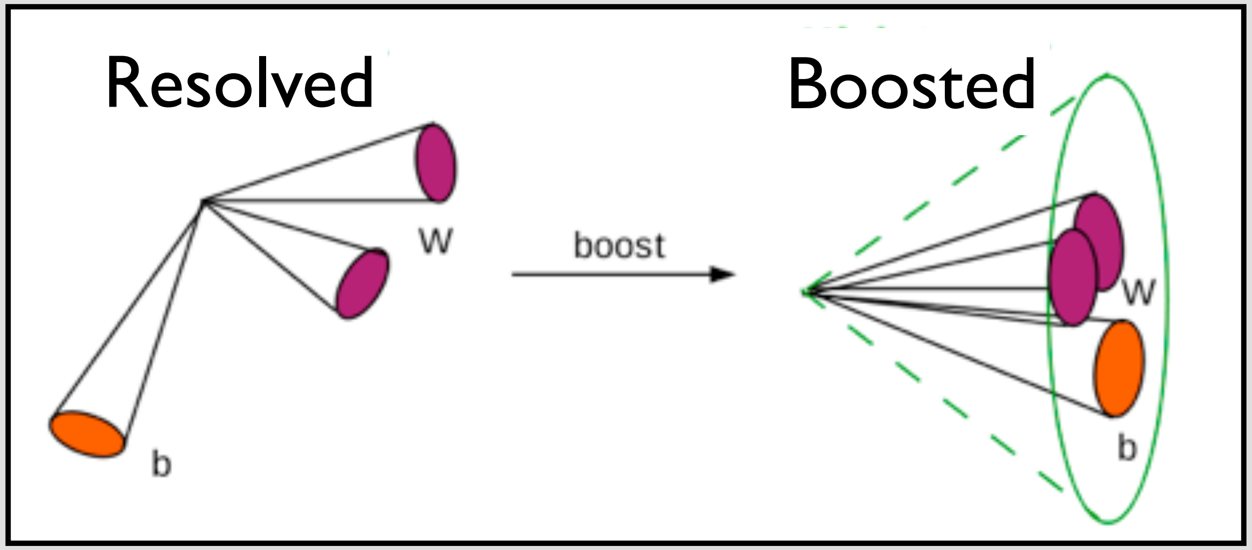
Resolved Scenario

3 or 4 jets 'narrow' (anti-k_T D = 0.4) jet
(if 3, one must have mass > 60 GeV)

Boosted Scenario

1 large jet (anti-k_T D = 1.0, $\sqrt{[k_{12}]}$ > 40 GeV)
and 1 'narrow' jet

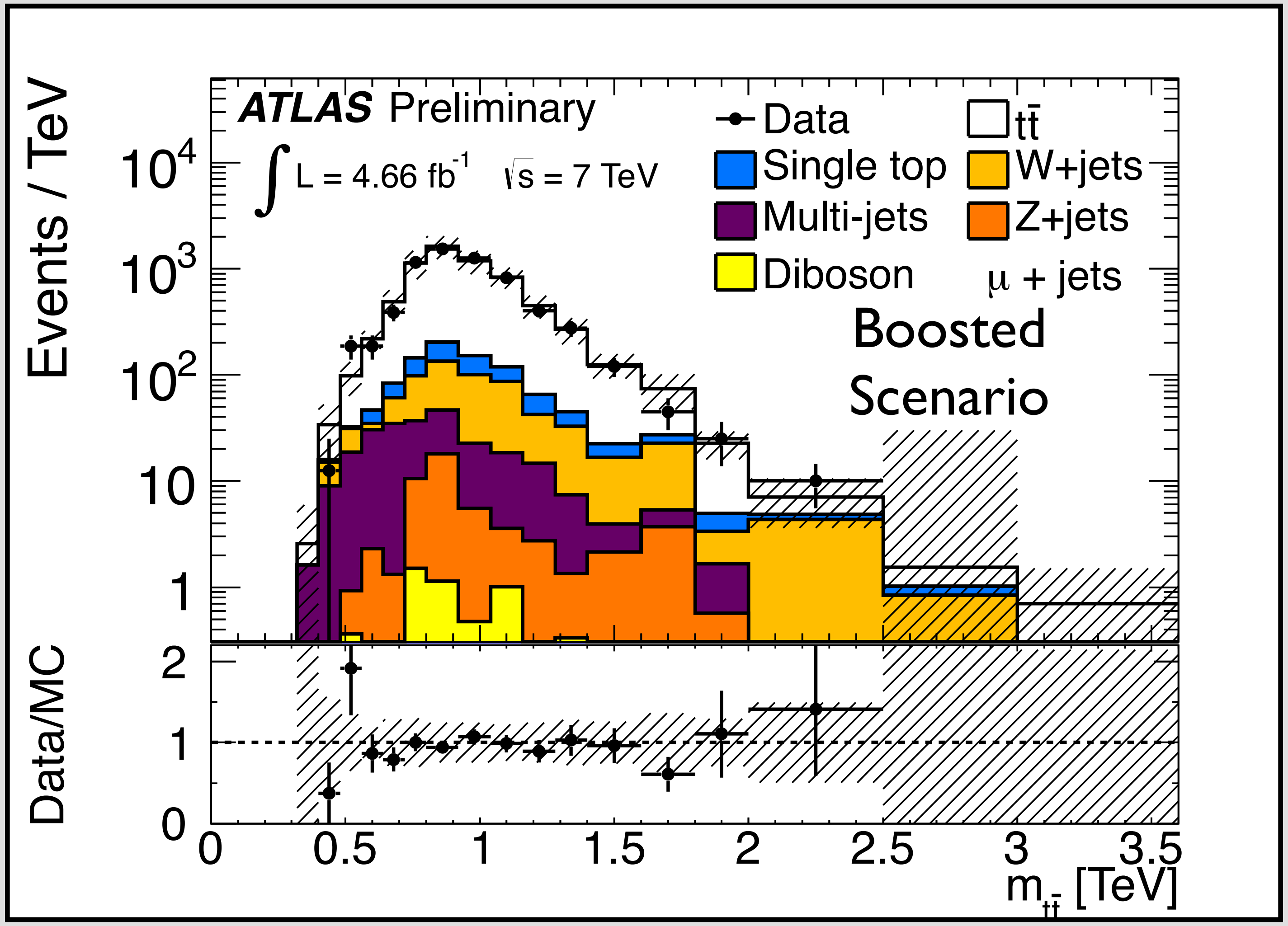
Categorize events in 'resolved' and 'boosted' scenarios



Obtain m_{tt} by solving for mass constraints and taking the E_T^{miss} as the $p_{(x,y)}$ component of the neutrino

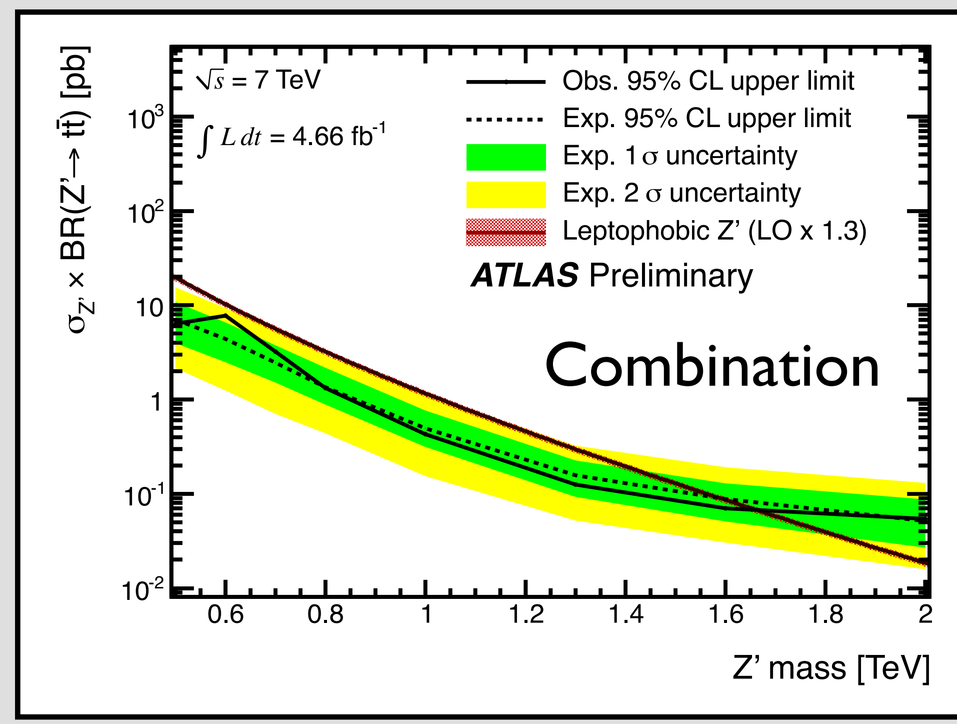
Search for Top Pair Resonances

ATLAS-CONF-2012-136



Type	Resolved selection	Boosted selection
$t\bar{t}$	44 000 ± 4 700	950 ± 100
Single top	3 250 ± 250	49 ± 4
Multi-jets e+jets	2 500 ± 1 500	12 ± 7
Multi-jets μ+jet	1 010 ± 610	20 ± 12
W+jets	6 940 ± 730	82 ± 15
Z+jets	840 ± 410	11 ± 5
Di-bosons	124 ± 43	0.88 ± 0.30
Total	58 700 ± 5 300	1 120 ± 100
Data	61 954	1079

Same background estimation method as p.8
Systematics are driven by JES and $t\bar{t}$ normalization



See also JHEP01(2013)116 *for a measurement with a similar philosophy in the all hadronic channel*

As we probe higher-x regimes in the future, we will encounter more boosted final states which cannot be resolved 'traditionally'
Developing such 'boosted' techniques is crucial for future searches!

Measurement of the Charge Asymmetry

- Top quark pair production has a small asymmetry under charge conjugation predicted by the SM
- BSM physics could lead to an enhancement in this effect

Strategy

This particular analysis uses the dilepton channel
a) Can measure A_{tt} directly, but this requires a strategy to resolve the momentum of the 2 neutrinos
b) Can measure A_{ll} instead which is still sensitive to the same effects

$$A_C^{t\bar{t}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)},$$

$$A_C^{\ell\ell} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| > 0) + N(\Delta|\eta| < 0)},$$

Event Selection

2 opposite sign electrons/muons
with p_T > 25/20 GeV
$|m_{ll} - m_Z|$ > 10 GeV (ee or μμ channel)
E_T^{miss}> 60 GeV (ee or μμ channel)
$\Sigma[p_T^l$ & $E_T^j]$ > 130 GeV (eμ channel)
at least 2 jets with p_T > 25 GeV and $|\eta| < 2.5$

How to resolve the ttbar kinematics?

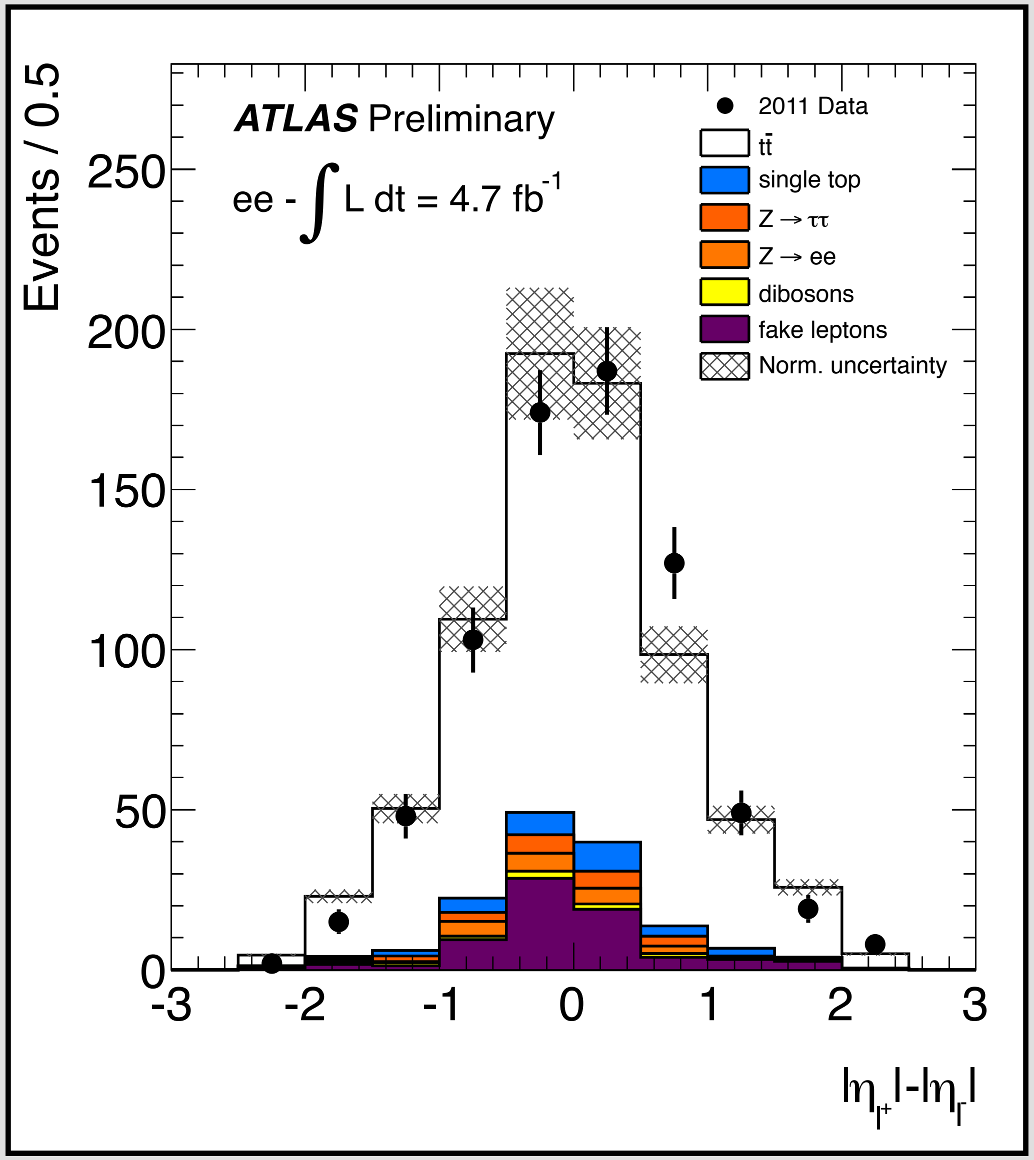
'Matrix-element' method is used
Assuming the kinematics are the same as in the tree-level process, various solutions are found for the unconstrained kinematics
Each solution is weighted to give a final value the chosen observable

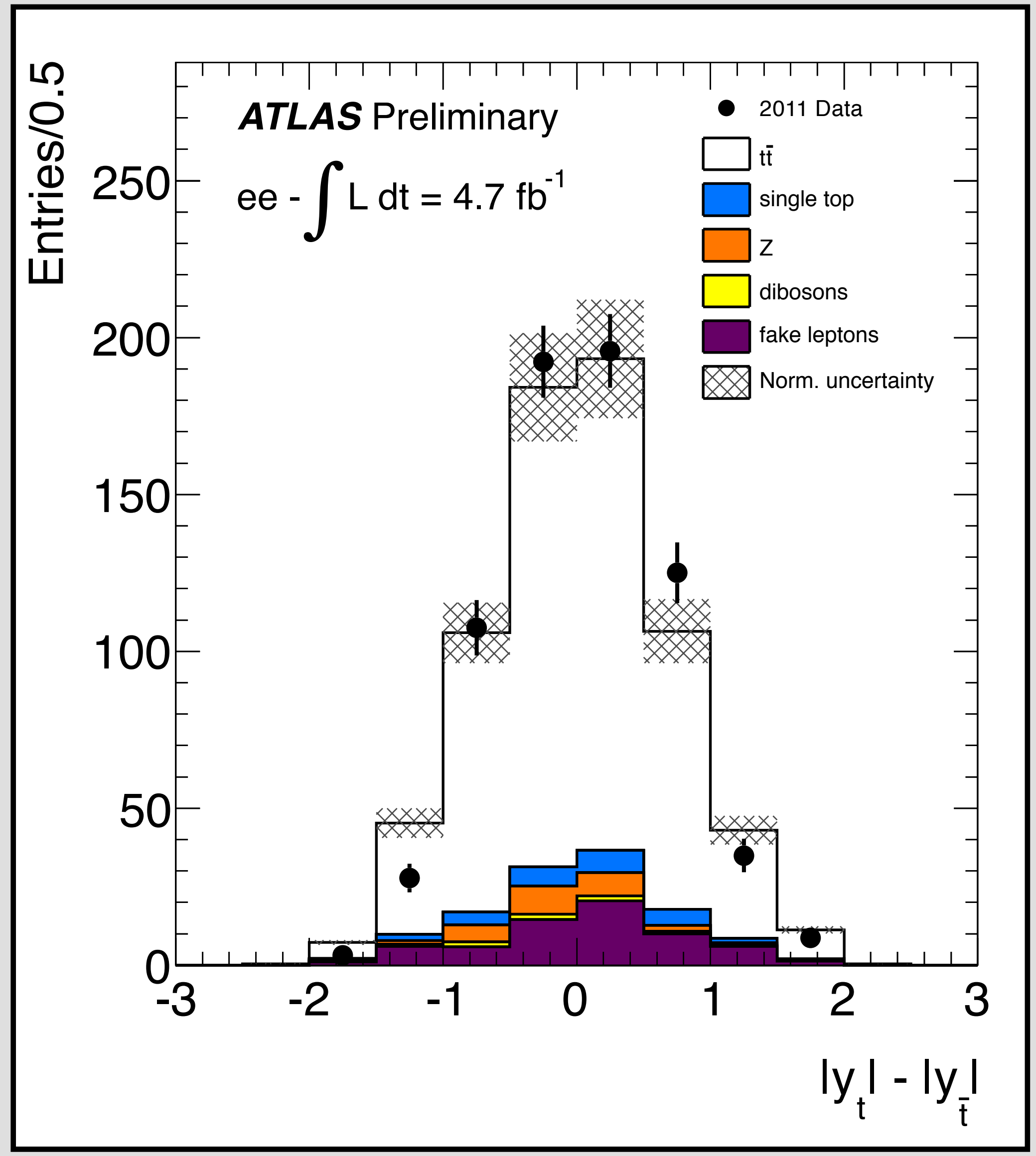
$$\frac{(2\pi)^4}{\varepsilon_1\varepsilon_2 s} d\varepsilon_1 d\varepsilon_2 f_{PDF}(\varepsilon_1) f_{PDF}(\varepsilon_2) |\mathcal{M}(y)|^2 W(x,y) d\Phi_n$$

Measurement of the Charge Asymmetry

ATLAS-CONF-2012-057

see Eur. Phys. J. C (2012) 72:2039 for leptons+jets channel





A_{ll} = 0.023 ± 0.012 (stat.) ± 0.008 (sys.)

SM: A_{ll} = 0.004 ± 0.001

$A_{t\bar{t}}$ = 0.057 ± 0.024 (stat.) ± 0.015 (sys.)

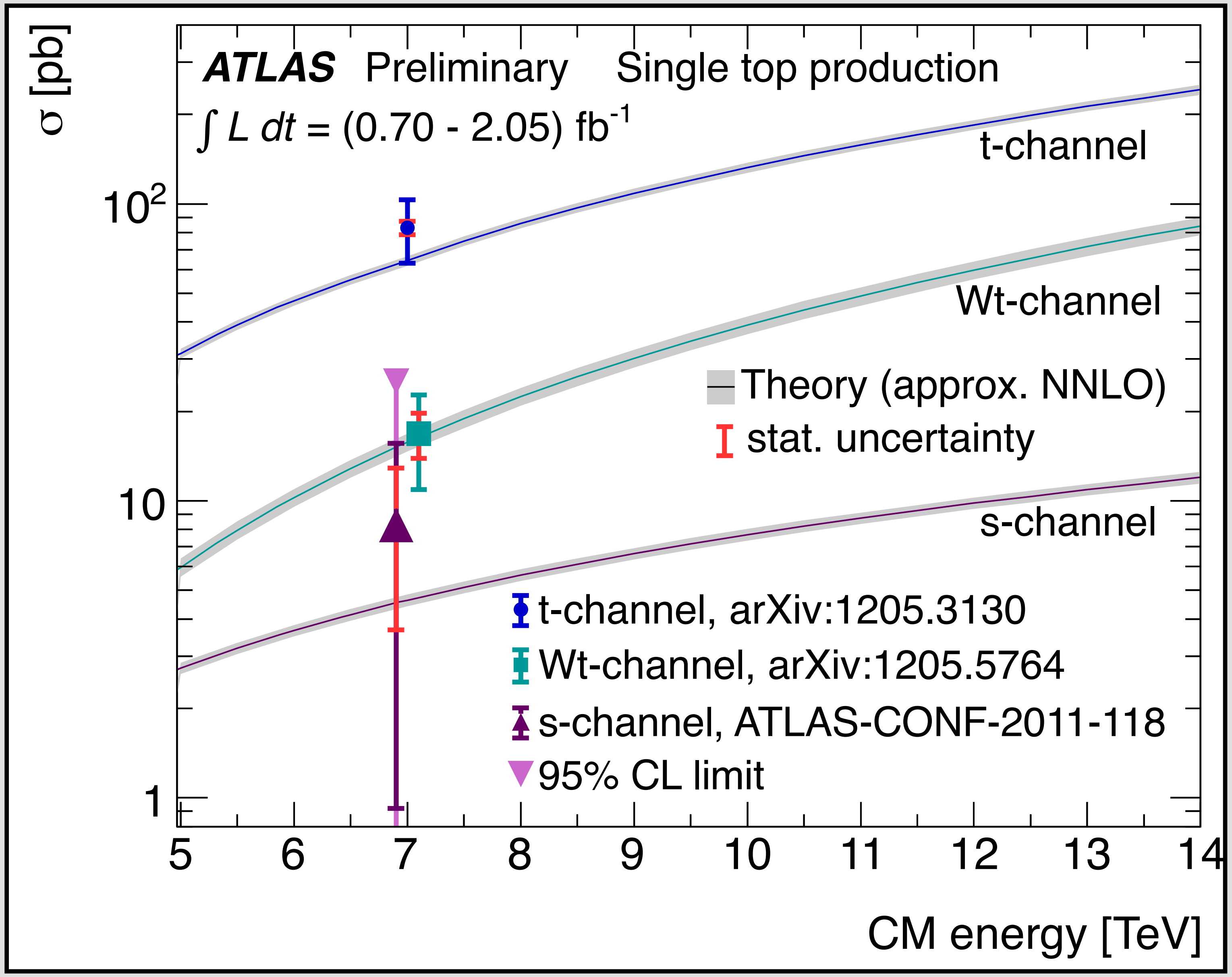
SM: $A_{t\bar{t}}$ = 0.006 ± 0.002

ATLAS Combination with lepton + jets channel:

$A_{t\bar{t}}$ = 0.029 ± 0.018 (stat.) ± 0.014 (sys.)

Measurements are statistics limited, but this will be improved with 2012 data

Single Top Cross-Section



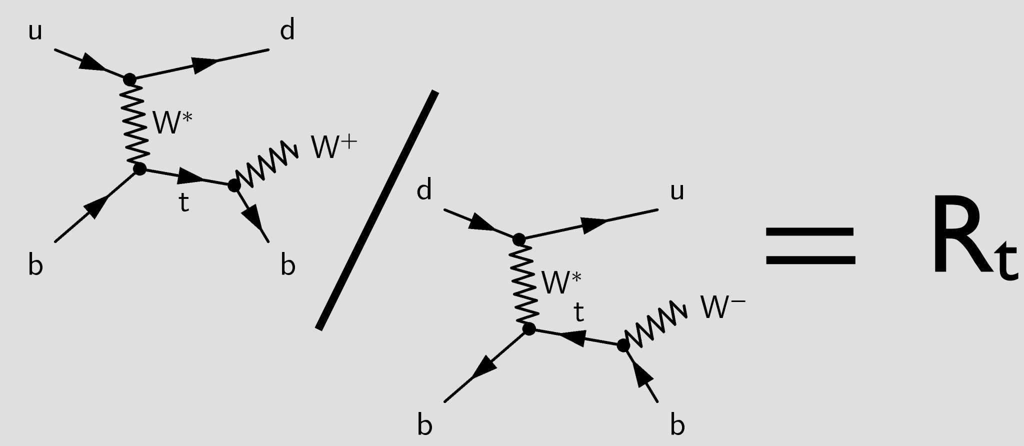
Production of single top occurs in 3 channels

ATLAS has:
Observation in t-channel
Evidence in Wt-channel
Upper Limits in s-channel

Single-Top Cross-Section Ratio

ATLAS-CONF-2012-056

- Two processes contribute to the t-channel single-top cross-section: top and anti-top production (*u* or *d* quark in the initial state)
- Measuring their relative cross-section ratio leads to direct experimental constraints on PDFs! (Regime is ~ $0.02 < x < 0.5$)



Naively $R_t \sim 2$

Event Selection

2 or 3 jets with $p_T > 25$ GeV and $|\eta| < 4.5$ (> 50 GeV if in the endcap), 1 b-tag

exactly 1 isolated electron or muon with $p_T > 25$ GeV and $|\eta| < 2.5$

$E_T^{miss} > 30$ GeV

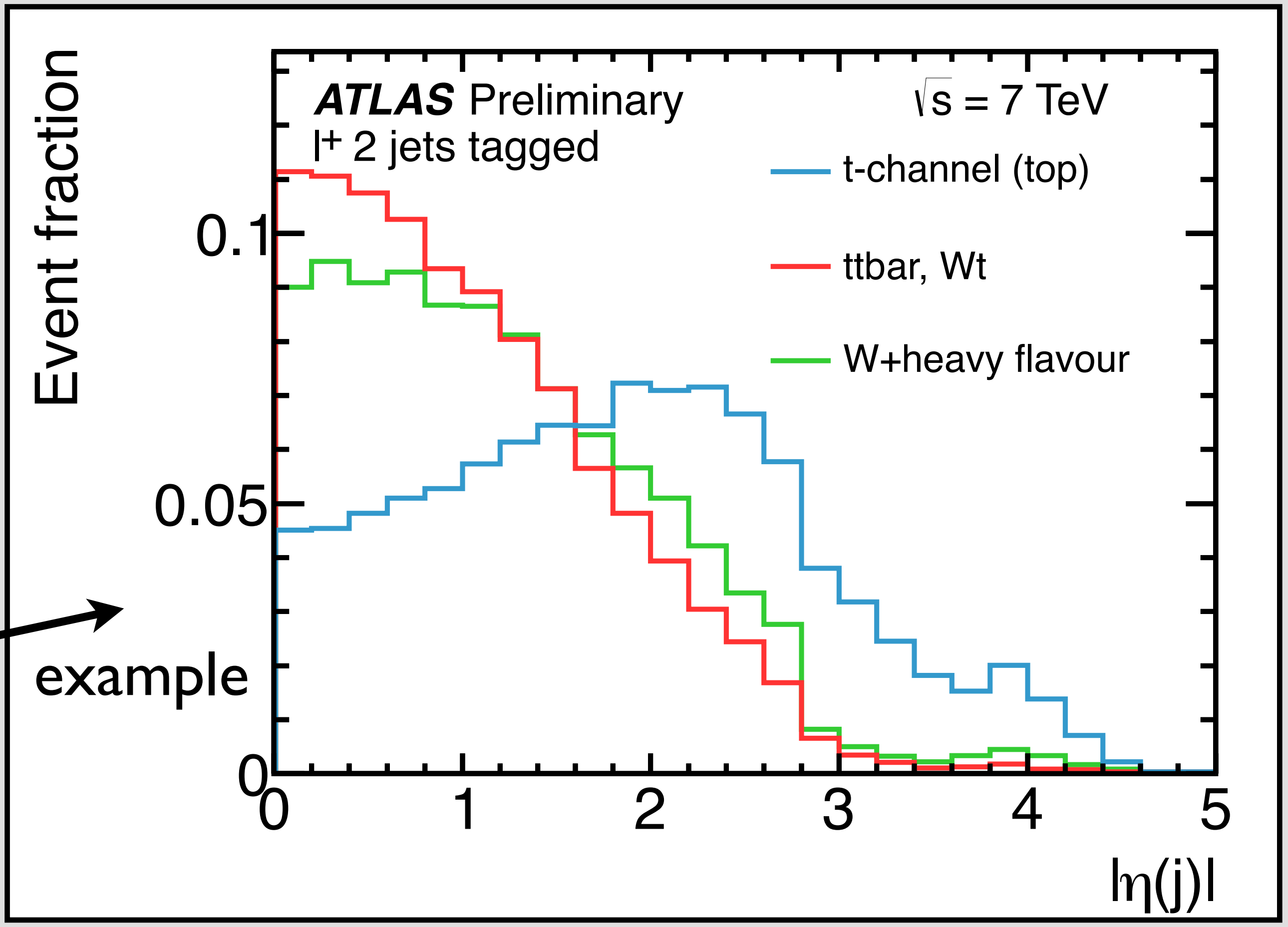
$m_T > 30$ GeV

Strategy

Use a Neural Network discriminant trained with the 15 to 19 most-sensitive variables

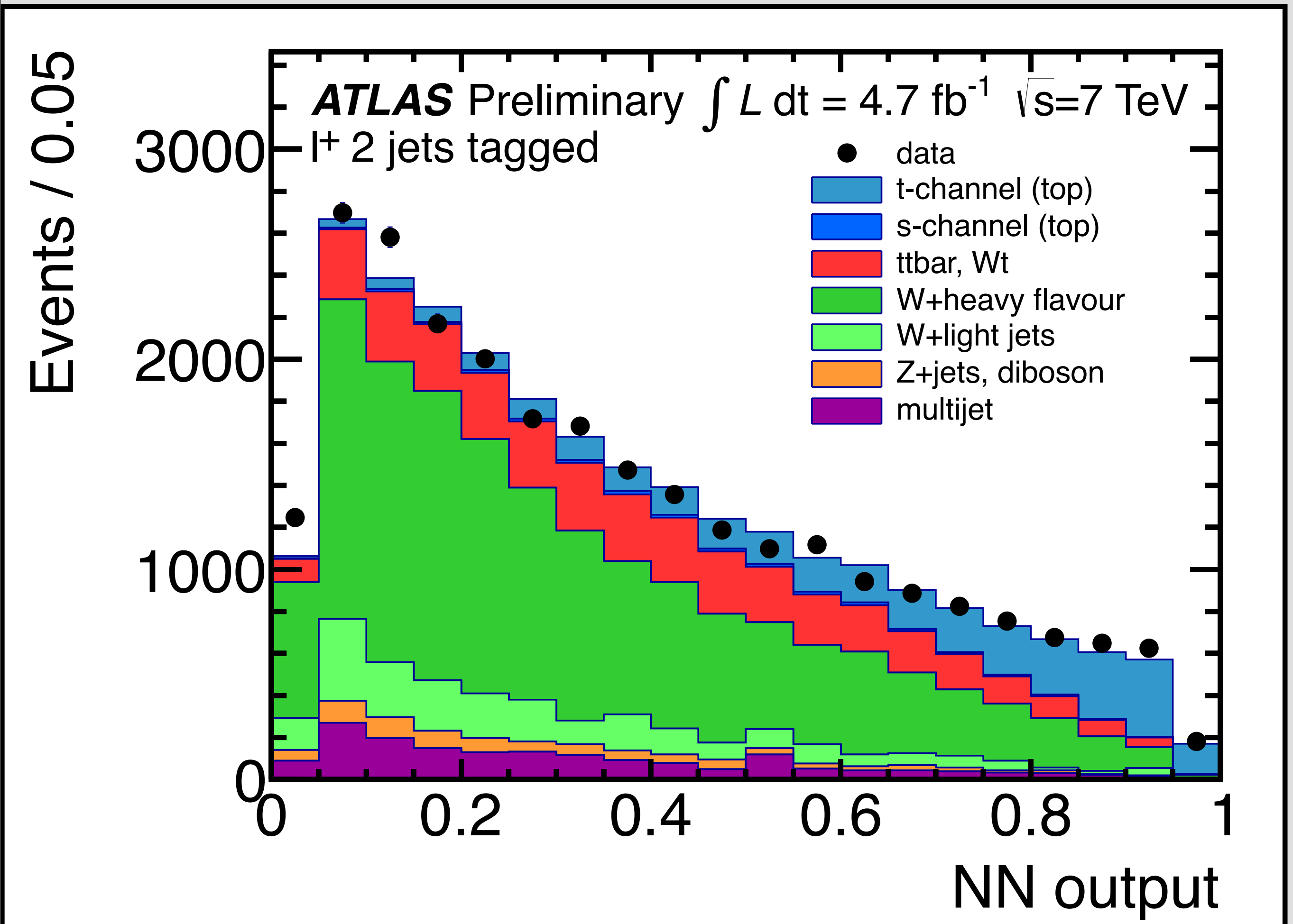
Use simulated templates to fit the contributions from signal and background, using constraints based on their expected normalizations

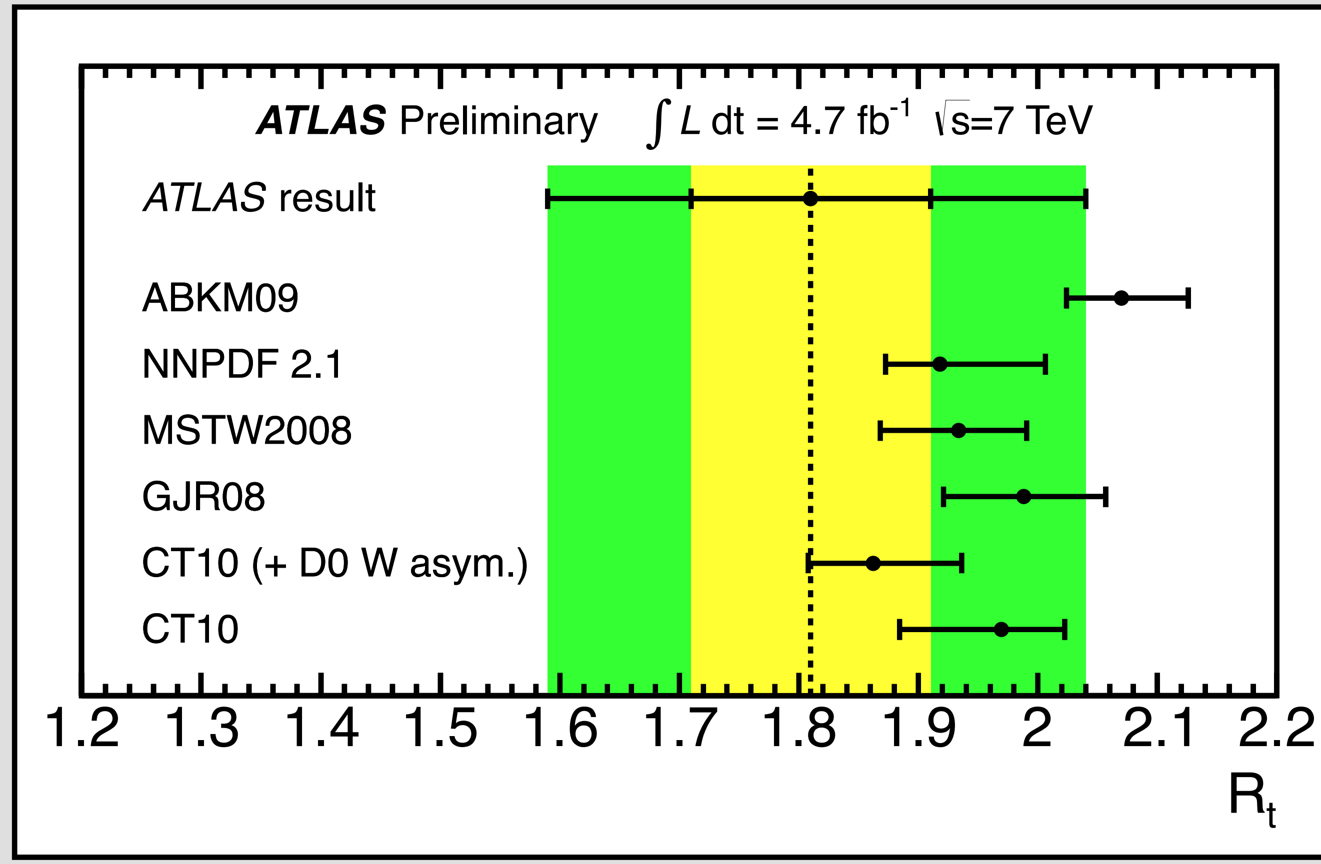
example



Single-Top Cross-Section Ratio

ATLAS-CONF-2012-056





$\sigma_{\text{t-channel}}(t) = 53.2 \pm 1.7\ (\text{stat.}) \pm 10.6\ (\text{sys.})$

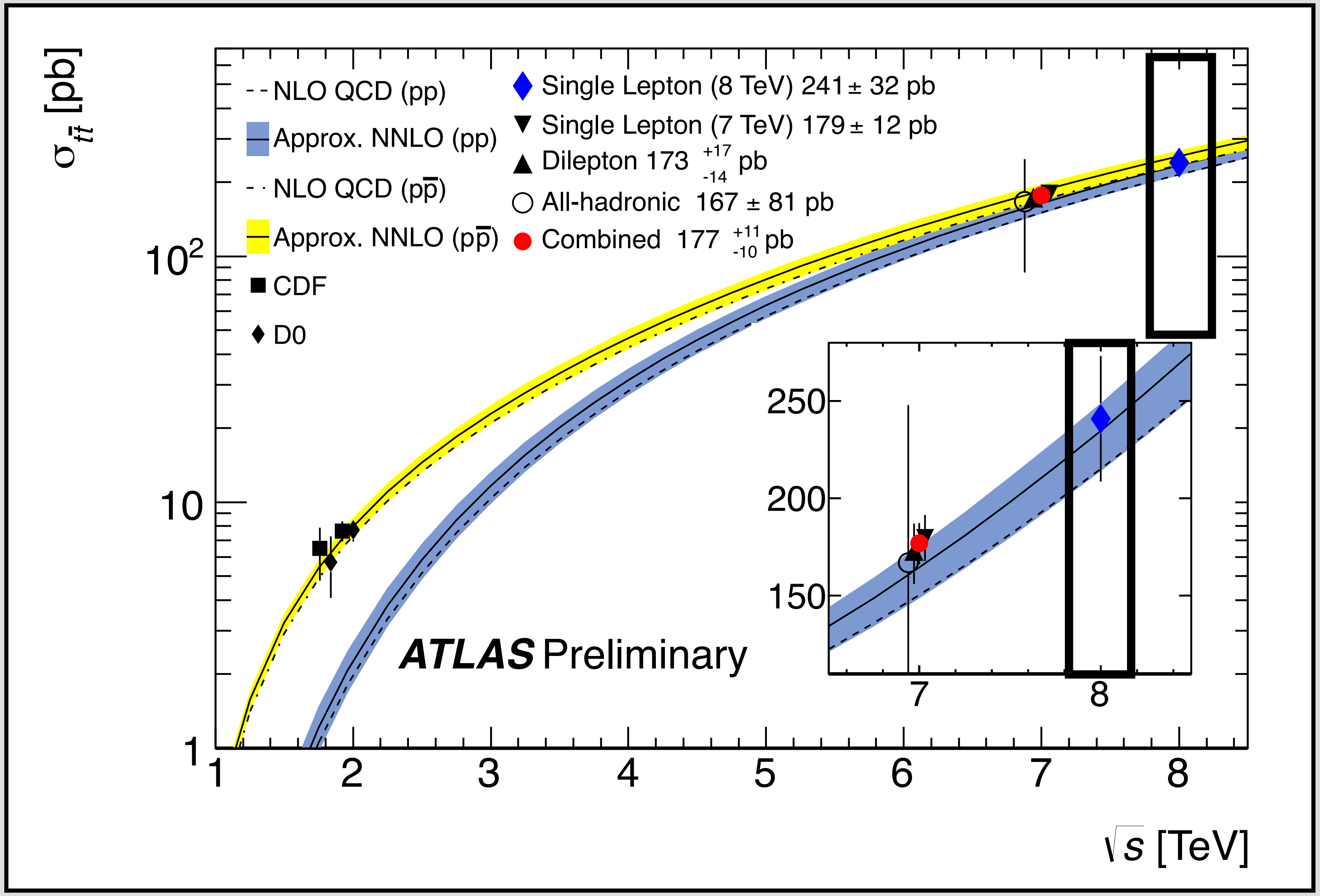
$\sigma_{\text{t-channel}}(\bar{t}) = 29.5 \pm 1.5\ (\text{stat.}) \pm 7.3\ (\text{sys.})$

Systematic uncertainties dominated by the JES, b-tagging efficiency and $t\bar{t}$ normalization

$$\sigma_{\text{t-channel}} = 82.7 \pm 2.3\ (\text{stat.}) \pm 17.9\ (\text{sys.})$$

Constraints are 'soft' at the moment, but with more statistics and a better understanding of the systematics, can strongly constrain existing PDF sets!

The Top Quark at 8 TeV - 2012 Run



The 2012 dataset is still been studied and many more results will soon be forthcoming!

A quick look at the first available measurements!

Over 5 million top quark pair events produced in 2012 across all channels!

Cross-section in the lepton + jets channel

ATLAS-CONF-2012-149

- Same method as for the last public 7 TeV results...
- Template fit, using a likelihood discriminant based on the product of the PDF for 2 variables, taken from simulations of the signal (tt) and background (W+jets)

<u>Event Selection</u>

Use single lepton triggers

At least 3 jets, p_T > 25 GeV and $|\eta|$ < 2.5

p_T (e, μ) > 40 GeV (pile-up robustness)

e-channel:

E_T^{miss} > 30 GeV and m_T > 30 GeV

mu-channel:

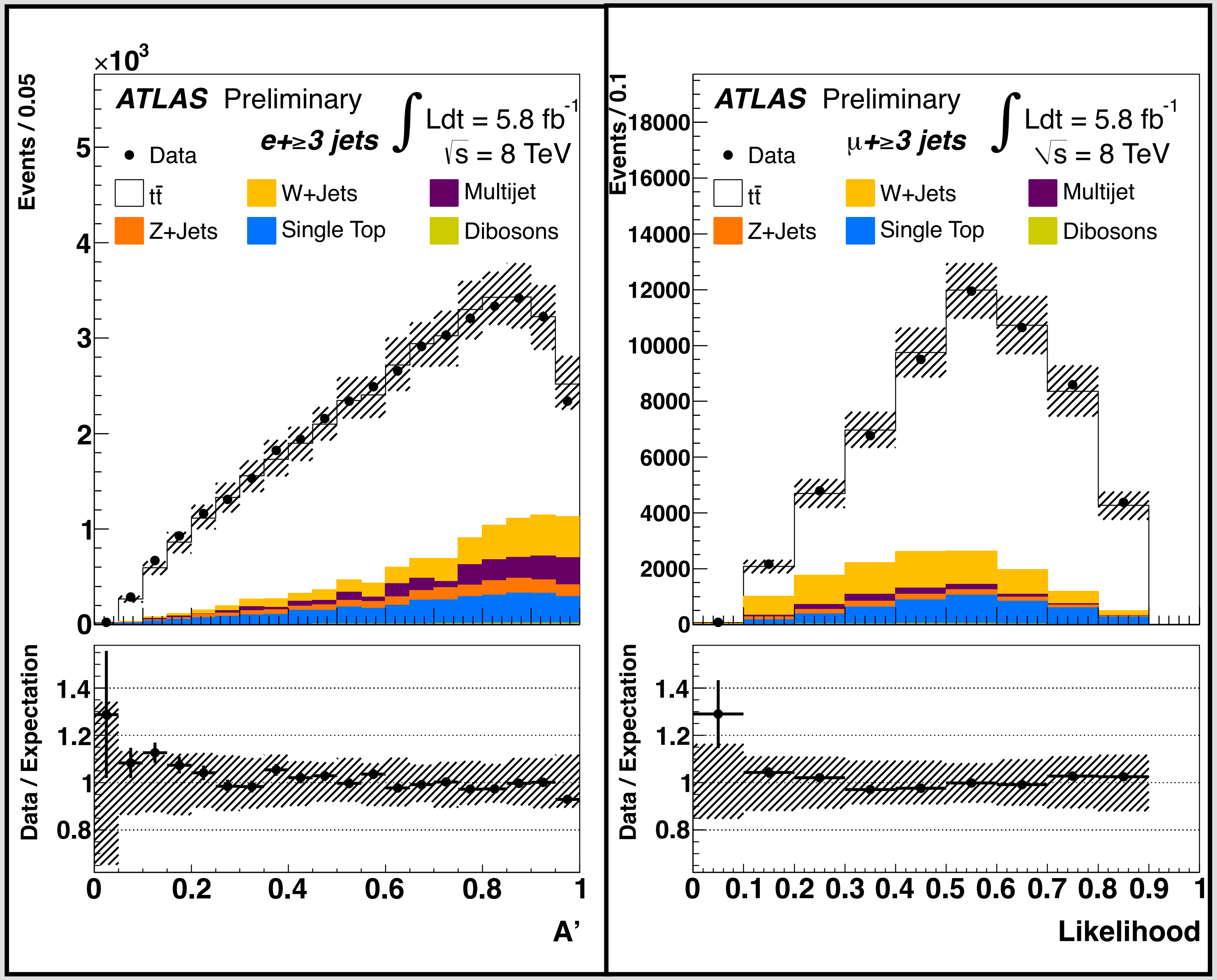
E_T^{miss} > 20 GeV and (E_T^{miss} + m_T) > 60 GeV

<u>Likelihood uses</u>

Event aplanarity A'

Lepton η

Systematics dominated by the modeling of the $t\bar{t}$ acceptance in simulation



$$\sigma_{t\bar{t}} = 241 \pm 2\ (\text{stat.}) \pm 31\ (\text{sys.}) \pm 9\ (\text{lumi.})$$

Single-Top Cross-Section

- Signal extracted using the same method as for the cross-section ratio

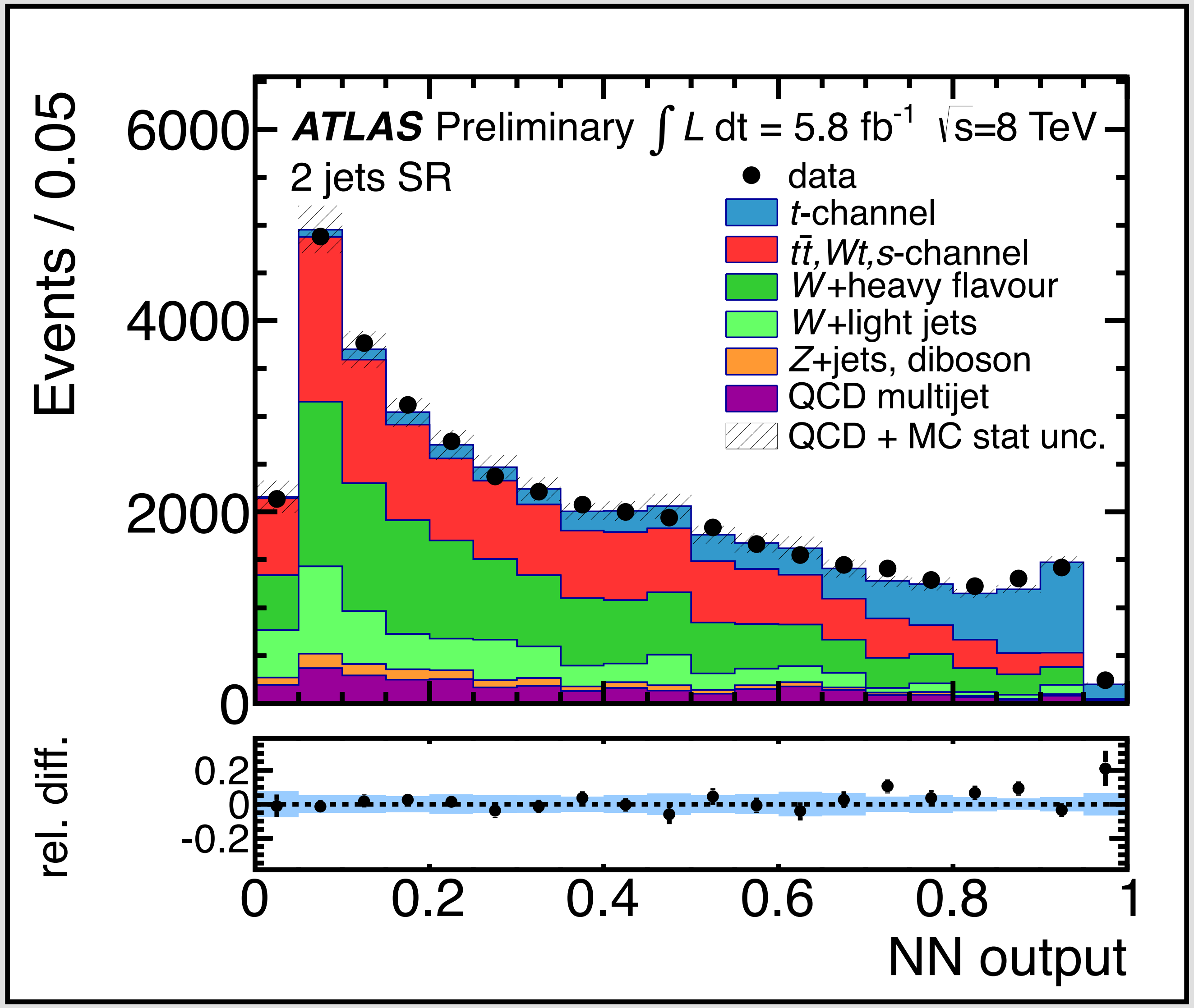
Event Selection

Cuts tightened to deal with pile-up:

jet p_T > 30 GeV (was 25)

m_T > 50 GeV (was 30)

	Signal region	
	2 jets	3 jets
t-channel	5210 ± 210	1959 ± 78
s-channel	343 ± 14	100 ± 4
Wt	1570 ± 110	1363 ± 95
$t\bar{t}$	11700 ± 1200	15300 ± 1500
W+light flavour	5500 ± 1700	1160 ± 350
W+heavy flavour	12000 ± 6000	3900 ± 2000
Z+jets, diboson	1200 ± 720	410 ± 240
QCD multijet	3000 ± 1500	1650 ± 830
Total Expectation	41600 ± 6600	25800 ± 2700
Data	40663	23687



Systematic uncertainties dominated by the JES, b-tagging efficiency and $t\bar{t}$ normalization

$$\sigma_{\text{single-t}} = 82.7 \pm 2.3\ (\text{stat.}) \pm 17.9\ (\text{sys.})$$

Conclusions / Outlook

- Only a quick overview of the recent top results from ATLAS!
- The various properties of the top quark are measured with increasing precision, providing a stringent test of the Standard Model
- But also, various methods have been developed (and are still being developed!), forging the path for future analyses
- Many more results are available! Please visit:

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

- Approximately 20 fb^{-1} of data collected in 2012, being analyzed at the moment - Expect more exciting results soon!

Thanks for your time!