The top quark pair production cross-section with ATLAS

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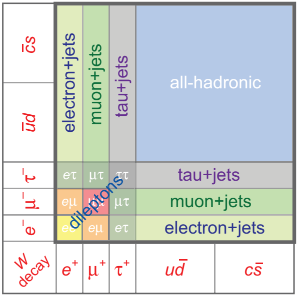
Outline

Introduction

Motivations and theoretical predictions of $t\bar{t}$ production

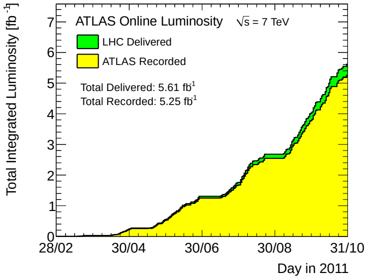
- The LHC is the world's first "top factory", producing of order one million top quark pairs during the full 2011 run.
- For pp collisions at $\sqrt{s} = 7$ TeV: $\sigma_{t\bar{t}} = 167^{+17}_{-18}$ pb at approximate NNLO - **M. Aliev et al., HATHOR**.
- Deviations from the Standard Model could indicate the presence of new physics.
- Top quarks decay almost exclusively to a W-boson and a b-quark.
- The ATLAS experiment has measured the $t\bar{t}$ cross-section in most decay topologies.
- Jet activity in association with $t\bar{t}$ production has also been measured.

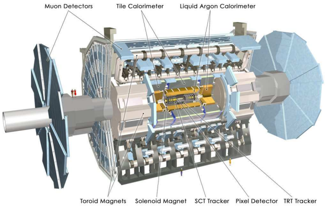
Top Pair Decay Channels



The LHC and the ATLAS detector

- The Large Hadron Collider (LHC) is a 27 km in circumference proton-proton collider located at CERN near Geneva, Switzerland.
- Delivered over 5 fb^{-1} of $\sqrt{s} = 7$ TeV collisions during the 2011 run.





- ATLAS (**A** **T**oroidal **LHC** **A**pparatu**S**) is a general purpose detector.
- Combination of precision and straw tube trackers immersed in 2 T magnetic field.
- High granularity liquid-argon sampling calorimeters, plus scintillator tile for additional hadronic calorimetry.
- Muon spectrometer with air-core toroidal magnet system providing strong bending power.

Di-lepton channels

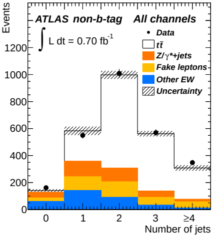
arXiv:1202.4892

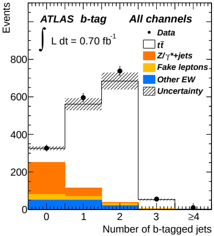
Several complementary analyses performed on 0.7 fb^{-1} of the 2011 run:

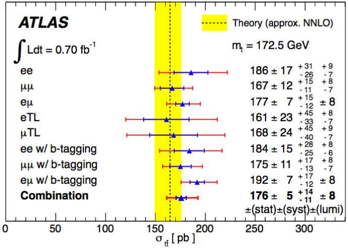
- Search for:
  - Exactly 2 isolated high p_{T} leptons.
  - $E_{\mathrm{T}}^{\mathrm{miss}} > 60$ GeV (*ee* and $\mu\mu$).
  - $m_{\ell\ell} > 15$ GeV (*ee* and $\mu\mu$).
  - $m_{\ell\ell} < 81$ GeV or $m_{\ell\ell} > 101$ GeV (*ee* and $\mu\mu$).
  - $H_{\mathrm{T}} > 130$ GeV ($e\mu$).
  - At least two jets with $p_{\mathrm{T}} > 25$ GeV.
- Both with and without *b*-tagging.
- Track lepton (TL) analysis recovers some of the ID efficiency loss.

$$\sigma_{t\bar{t}} = 176 \pm 5(\mathrm{stat})^{+14}_{-11}(\mathrm{syst}) \pm 8(\mathrm{lumi})\ \mathrm{pb}$$

Largest uncertainties: Generator, Statistics, and Jet/$E_{\mathrm{T}}^{\mathrm{miss}}$ uncertainties.





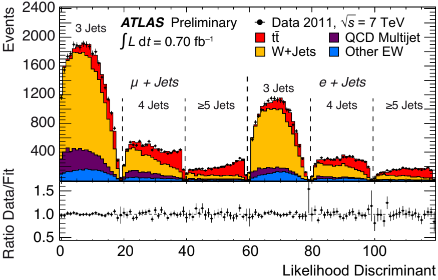


Single lepton channels

ATLAS-CONF-2011-121

For 0.7 fb^{-1} of 2011 data:

- A single high p_{T} lepton.
- e+jets: $E_{\mathrm{T}}^{\mathrm{miss}} > 35$ GeV and $m_{\mathrm{T}}(W) > 25$ GeV.
- μ+jets: $E_{\mathrm{T}}^{\mathrm{miss}} + m_{\mathrm{T}}(W) > 60$ GeV.
- At least 3 jets with $p_{\mathrm{T}} > 25$ GeV.



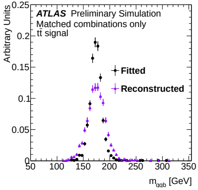
- Use kinematic information instead of b-tagging to separate $t\bar{t}$ from W+jets background (NOTE: W+jets shape uncertainty 0.9%).
- Kinematic likelihood variables: lepton η, aplanarity, leading jet p_{T}, and $H_{\mathrm{T},3p} = \sum_{i=3}^{i=N_{\mathrm{jets}}} p_{T,i} / \sum_{i=1}^{i=N_{\mathrm{jets}}} |p_{z,i}|$

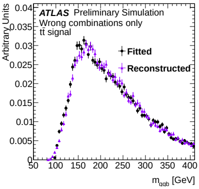
$$\sigma_{t\bar{t}} = 179 \pm 4(\mathrm{stat}) \pm 9(\mathrm{syst}) \pm 7(\mathrm{lumi})\ \mathrm{pb}$$

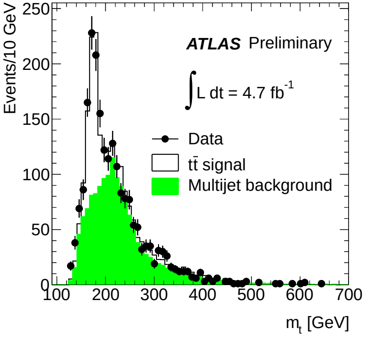
Cross-section from a maximum likelihood fit. Largest uncertainties: Luminosity (±3.7%), Generator (±3.0%), Muon (±2.3%), and Jets (+1.8/ − 2.3%).

All hadronic channel *NEW*

ATLAS-CONF-2012-031







- $4.7\ \mathrm{fb}^{-1}$ dataset. Selections:
  - No isolated leptons.
  - ≥ 5 jets with $p_{\mathrm{T}} > 55$ GeV (2 b-tagged).
  - 1 additional jet with $p_{\mathrm{T}} > 30$ GeV.
  - $dR(b_1, b_2) > 1.2$ for b-jets.
  - $dR(j_i, j_k) > 0.6$ for others.
  - $S_T = E_{\mathrm{T}}^{\mathrm{miss}}/(0.5\sqrt{H_{\mathrm{T}}}) < 6$.
- Perform a kinematic likelihood (KL) fit to optimize the top mass reconstruction.
- Additional requirements on top masses, fit probability, and χ^2 from reconstructed masses.
- Non-top multi-jet background from untagged sample (corrections derived from MC).

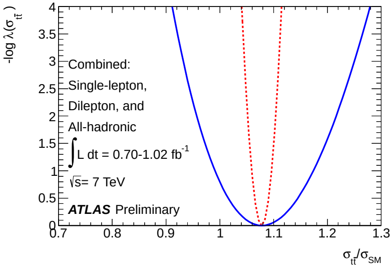
$$\sigma_{t\bar{t}} = 168 \pm 12(\mathrm{stat})^{+60}_{-57}(\mathrm{syst}) \pm 7(\mathrm{lumi})\mathrm{pb}$$

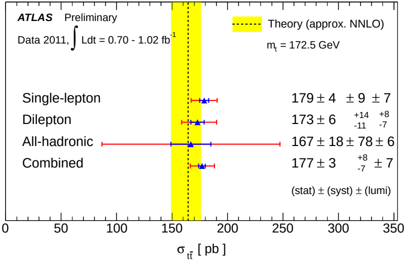
Extracted from unbinned likelihood fit.
Dominant uncertainties are the jet energy scale (JES, $+20/-11\%$), b-tagging efficiency ($\pm17\%$), I/FSR ($\pm17\%$), Parton Shower model ($\pm13\%$).

Statistical combination *NEW*

ATLAS-CONF-2012-024

- Combine results from 0.7 fb^{-1} single and di-lepton analyses and earlier (1.02 fb^{-1}) all hadronic analysis.
- Define the profile likelihood ratio $\lambda(\sigma_{t\bar{t}}) = \frac{L(\sigma_{t\bar{t}}, \hat{\hat{\mathcal{L}}}, \hat{\hat{\alpha}}_j)}{L(\hat{\sigma}_{t\bar{t}}, \hat{\mathcal{L}}, \hat{\alpha}_j)}$,
- Consistent treatment of the shared sources of systematic uncertainties.
- Use $\lambda(\sigma_{t\bar{t}})$ to find best fit and define a 68% confidence interval $(-\log(\lambda) < \frac{1}{2})$.
- Precision of the combined measurement: $+6.2/-5.8\%$.





τ+jets analysis *NEW*

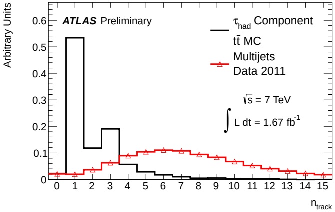
ATLAS-CONF-2012-032

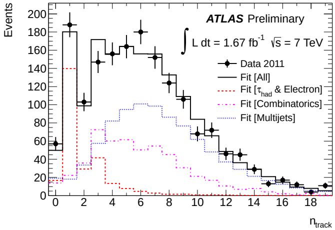
Performed on 1.67 fb^{-1}:

- Require 5 jets with $p_T > 20$ GeV
- Veto on any identified leptons.
- Require at least two *b*-tagged jets.
- Require $S_T = E_{\mathrm{T}}^{\mathrm{miss}}/(0.5\sqrt{H_{\mathrm{T}}}) > 8$

Analysis:

- Select 3 jets with highest p_{T} sum. Remaining untagged highest p_{T} jet $\rightarrow \tau_{\mathrm{had}}$ candidate.
- Fit to the n_{track} distribution of the τ_{had}.
- Multi-jet template from a low S_T sample.
- Combinatoric template from μ+jets $t\bar{t}$ data sample with two *b*-tagged jets.





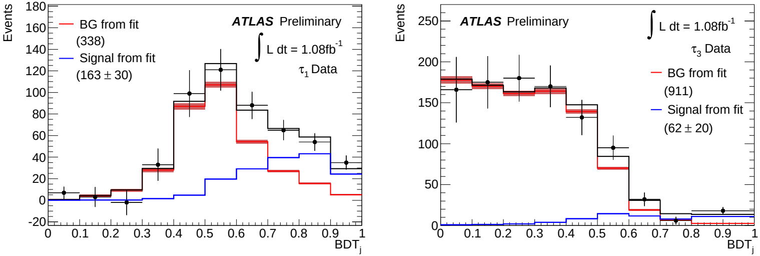
$\sigma_{t\bar{t}} = 200 \pm 19(\mathrm{stat}) \pm 43(\mathrm{syst})$ pb

Extended bin likelihood fit. Largest uncertainties: I/FSR, *b*-tagging, hadronization model, and JES.

$\mu+\tau$ analysis

ATLAS-CONF-2011-119

- Analysis on 1.08 fb^{-1}. Selections:
  - One isolated high p_T muon.
  - At least one loose τ candidate
  - At least two $p_T > 25$ GeV jets (at least one b-tagged).
  - $E_T^{miss} > 30$ GeV and $H_T > 200$ GeV.
- Same-sign sample used for fake studies. Multi-jets modeled from non-isolated muons (normalized to low m_T region).



$$\sigma_{t\bar{t}} = 142 \pm 19(\text{stat}) \pm 43(\text{syst})\ \text{pb}$$

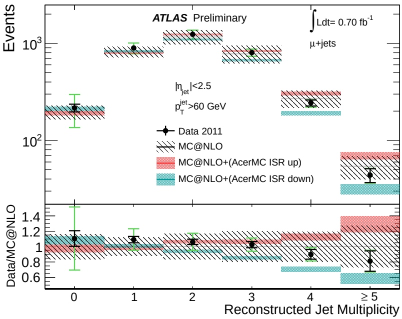
Fit templates to τ ID Boosted Decision Tree (BDT) discriminant distributions. Largest uncertainties: τ ID BDT, b-tagging, and I/FSR.

Reconstructed jet multiplicities

ATLAS-CONF-2011-142

Single lepton analysis on 0.7 fb^{-1} of 2011 data.

- Exactly one high p_T lepton.
- e+jets: $E_{\mathrm{T}}^{\mathrm{miss}} > 35$ GeV and $m_{\mathrm{T}}(W) > 25$ GeV
- μ+jets: $E_{\mathrm{T}}^{\mathrm{miss}} + m_{\mathrm{T}}(W) > 60$ GeV
- At least 4 jets with $p_{\mathrm{T}} > 25$ GeV (1 b-tagged).



Perform the measurement for several jet p_{T} thresholds.

- Compare to nominal MC@NLO, as well as ISR variations derived from AcerMC samples.

Results consistent with theory within the systematics

Jet Energy Scale uncertainty dominates higher multiplicity bins.

Central jet veto analysis *NEW*

arXiv:1203.5015

2.05 fb^{-1} analysis. Selection similar to di-lepton inclusive cross-section except:

- 2 *b*-tagged jets.
- $E_T^{\text{miss}} > 40$ GeV (*ee* and $\mu\mu$ channels).

Consider jets with $p_T > 25$ GeV.

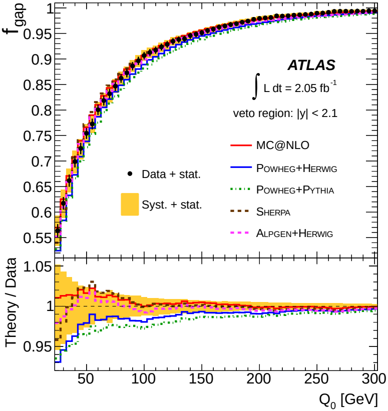
Define gap fraction $f(Q_0) = n(Q_0)/N$:

- N - number of events passing all selections.
- $n(Q_0)$ - passes a veto on additional jets in some rapidity region with $p_T > Q_0$.

Compare to generator predictions.

Ratio decreases sensitivity to systematics.

Most generators resonably describe the data in the rapidity region $|y| < 2.1$.



Central jet veto analysis *NEW*

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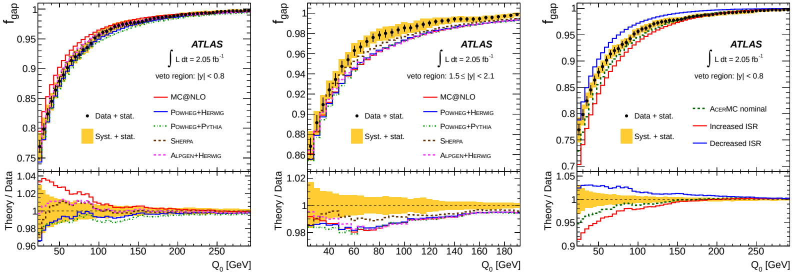
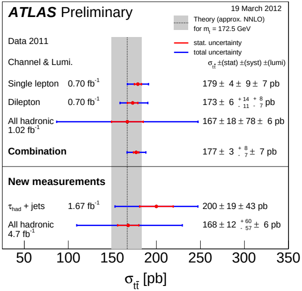


- Gap fraction too large in $|y| < 0.8$ region for MC@NLO (left).
- All generators poorly describe $1.5 < |y| < 2.1$ region (center).
- Can use thes results to constrain the ACERMC ISR variations (right).
- Also measured $f(Q_{\mathrm{sum}})$ with veto on the scalar sum of jet transverse momenta (similar levels of agreement).

Summary

- Top quark pair production cross-section measured in several decay modes with the ATLAS detector.
- Combined results from several channels also presented.
- All results are in agreement with the approximate NNLO predictions.
- Experimental uncertainties have better precision (6.2% for the combination) than the theoretical predictions.



- Additionally, analyses measuring jet activity in $t\bar{t}$ events see reasonable agreement with the theoretical predictions.
- Can use the results of these analyses for constraints on additional radiation.

Monte Carlo samples

COLUMBIA UNIVERSITY

Except where specified, all analyses use for the nominal estimates:

- MC@NLO for $t\bar{t}$ and single top samples with CTEQ6.6 parton distribution functions (PDFs).
- ALPGEN with CTEQ6L1 PDFs for W+jets, Z+jets, and di-boson samples.

All samples were showered with HERWIG supplemented by JIMMY for the underlying event, both tuned to ATLAS data.

Normalized to the NNLO predictions (except the di-boson samples which were normalized to the NLO).

Processed using the GEANT4 simulation of the ATLAS detector.

Monte Carlo samples (systematics)

- $t\bar{t}$ efficiency estimation uncertainties for all analyses:
  - Generator - Compare the results from the nominal MC@NLO to those of POWHEG showered with HERWIG.
  - Parton Shower - Compare the results from POWHEG showered with HERWIG to POWHEG showered with PYTHIA.
  - I/FSR - Compare results derived with ACERMC variations tuned for more/less radiation to the nominal ACERMC sample.
- W+jets shape for the single-lepton analysis:
  - Modify the ALPGEN parameters defining parton-jet matching, factorization scale, etc.
- ACERMC ISR variations:

ACERMC sample	PARP(67)	PARP(64
central	4	1
ISR down	1	4
ISR up	6	0.25

$e\mu$ Event Display

Event display of a top pair e-mu dilepton candidate with two b-tagged jets. The electron is shown by the green track and calorimeter cluster in the 3D view, and the muon by the long red track intersecting the muon chambers. The two b-tagged jets are shown by the purple cones, whose sizes are proportional to the jet energies. The inset shows the XY view of the vertex region, with the secondary vertices of the two b-tagged jets indicated by the orange ellipses.