Top physics results with ATLAS

Lorenzo Massa[1]
on behalf of the ATLAS collaboration
University of Bologna and INFN, Italy

This paper contains some of the most recent results on top-quark physics obtained by the ATLAS collaboration from the analysis of pp collisions at $\sqrt{s} = 7$ TeV and 8 TeV at the Large Hadron Collider. Measurement of total and differential top-quark pair ($t\bar{t}$), single top and $t\bar{t} + \gamma$ production cross sections and some top properties like mass, charge asymmetry and spin correlation are presented.

1 Introduction

The top quark, which has been discovered in 1995 by both the CDF [1] and D0 [2] collaborations at the Tevatron collider, is the heaviest known fundamental particle. Its large mass $m_t = 173.34 \pm 0.27 \pm 0.71$ GeV [3] leads to a series of interesting features.

- The top quark is the only quark that decays before the hadronization process, giving the unique possibility to study a "bare" quark.
- The masses of top quark, W boson and Higgs boson are bounded by the radiative corrections to the Higgs boson mass, allowing important consistency tests on the Standard Model.
- The top quark has a large Yukawa coupling with the Higgs boson, playing a special role in the electroweak symmetry breaking and in Beyond the Standard Model physics scenarios.

All these properties make the top quark a privileged window for searches for new physics.

In proton colliders like the Large Hadron Collider, $t\bar{t}$ pairs are produced mainly by gluon fusion (87% at $\sqrt{s} = 7$ TeV) and by quark-antiquark annihilation. Almost every top quark decays into a W boson and a b quark pair, and depending on the decay of the Ws in a lepton-neutrino or a quark-antiquark pair it is possible to determine three different channels: the hadronic channel, the lepton+jets channel and the di-lepton channel.

In this overview some of the most recent measurements of top pair and single top production cross section and other properties (like mass, charge asymmetry and spin correlation), obtained by the ATLAS Collaboration using data collected in 2011 (with an integrated luminosity of $L = 4.6$ fb^{-1} at $\sqrt{s} = 7$ TeV) and in 2012 (with an integrated luminosity of $L = 20.3$ fb^{-1} at $\sqrt{s} = 8$ TeV). The description of the ATLAS detector and its performances can be found in [4].

[1]lorenzo.massa@cern.ch

ATL-PHYS-PROC-2015-130
05/11/2015

2 Measurement of the $t\bar{t}$ inclusive cross section in the $e\mu$ channel

The ATLAS Collaboration performed several measurements of the inclusive cross section, obtaining results which are in good agreement with the Standard Model, with experimental uncertainties smaller than the theoretical ones. The most precise ATLAS single measurement is the one obtained in the final state with oppositely charged $e\mu$ pair [5].

This measurement is performed using the data collected in 2011 with a center of mass energy of 7 TeV and an integrated luminosity of 4.6 fb^{-1}, and the data collected in 2012 with a center of mass energy of 8 TeV and 20.3 fb^{-1}. Counting the number of total events containing exactly one or two b-tagged jets, it has been possible to extract the inclusive cross section $\sigma_{t\bar{t}}$, as well as the b-tagging efficiency, with a significant reduction of the associated systematic uncertainties. The cross section is measured in the fiducial phase space, with one electron and one muon with $p_T > 25$ GeV and $|\eta| < 2.5$, and extrapolated to the total phase space, obtaining:

$$\sigma_{t\bar{t}}^{total}\ (7\ \text{TeV}) = 182.9 \pm 7.1\ \text{pb}, \qquad \sigma_{t\bar{t}}^{total}\ (8\ \text{TeV}) = 242.4 \pm 10.3\ \text{pb}.$$

These results are consistent with what is expected by the theoretical QCD calculations at the NNLO [6]:

$$\sigma_{t\bar{t}}^{th}\ (7\ \text{TeV}) = 177.3^{+4.6}_{-6.0}\ (\text{scale}) \pm 9.0\ (\text{PDF+}\alpha_S)\ \text{pb}, \qquad \sigma_{t\bar{t}}^{th}\ (8\ \text{TeV}) = 252.9^{+6.4}_{-8.6}\ (\text{scale}) \pm 11.7\ (\text{PDF+}\alpha_S)\ \text{pb}.$$

3 $t\bar{t}$ differential cross section measurements

The large integrated luminosity at the LHC allows to perform precision differential cross section measurements, which could unveil unexpected features linked to physics Beyond Standard Model. Depending on the involved energy, there could be two different topologies, leading to different analysis strategies:

- When a top quark has a momentum lower than 300 GeV, its decay products are well separated and can be reconstructed individually. This case is referred as *resolved topology*, and the $t\bar{t}$ system is reconstructed from the resolved decay products.
- For higher momentum top quarks, the decay products tend to become more collimated, and the previous reconstruction technique becomes less efficient. In this case, usually referred as *boosted topology*, the hadronically decaying top quark is reconstructed as a single large radius jet.

Two measurements of the fiducial $t\bar{t}$ differential cross section have been performed by the ATLAS experiment: the $\frac{d\sigma}{dX}$ at 7 TeV as a function of the mass ($m_{t\bar{t}}$) and absolute rapidity ($y_{t\bar{t}}$) of the system and the transverse momentum of the top quark ($p_{T,t}$) with the resolved approach [7], and as a function of the transverse momentum of the top quark ($p_{T,t}$) at 8 TeV with the boosted approach [8]. In both cases, the measurement has been performed through a cut-based analysis in the lepton+jets channel, extracting the reconstructed kinematic distributions and correcting them for detector effects using unfolding techniques.

The results have been compared to next-to-leading-order (NLO) calculations from Monte Carlo generators, and as can be seen in Figure 1 there is a good agreement with the Standard Model expectations. The only exception is the unfolded data distribution for $p_{T,t}$, which appears to be softer than the NLO prediction, especially for $p_{T,t} > 200$ GeV in the resolved topology. The same tendency is confirmed also by the results obtained in the boosted topology.

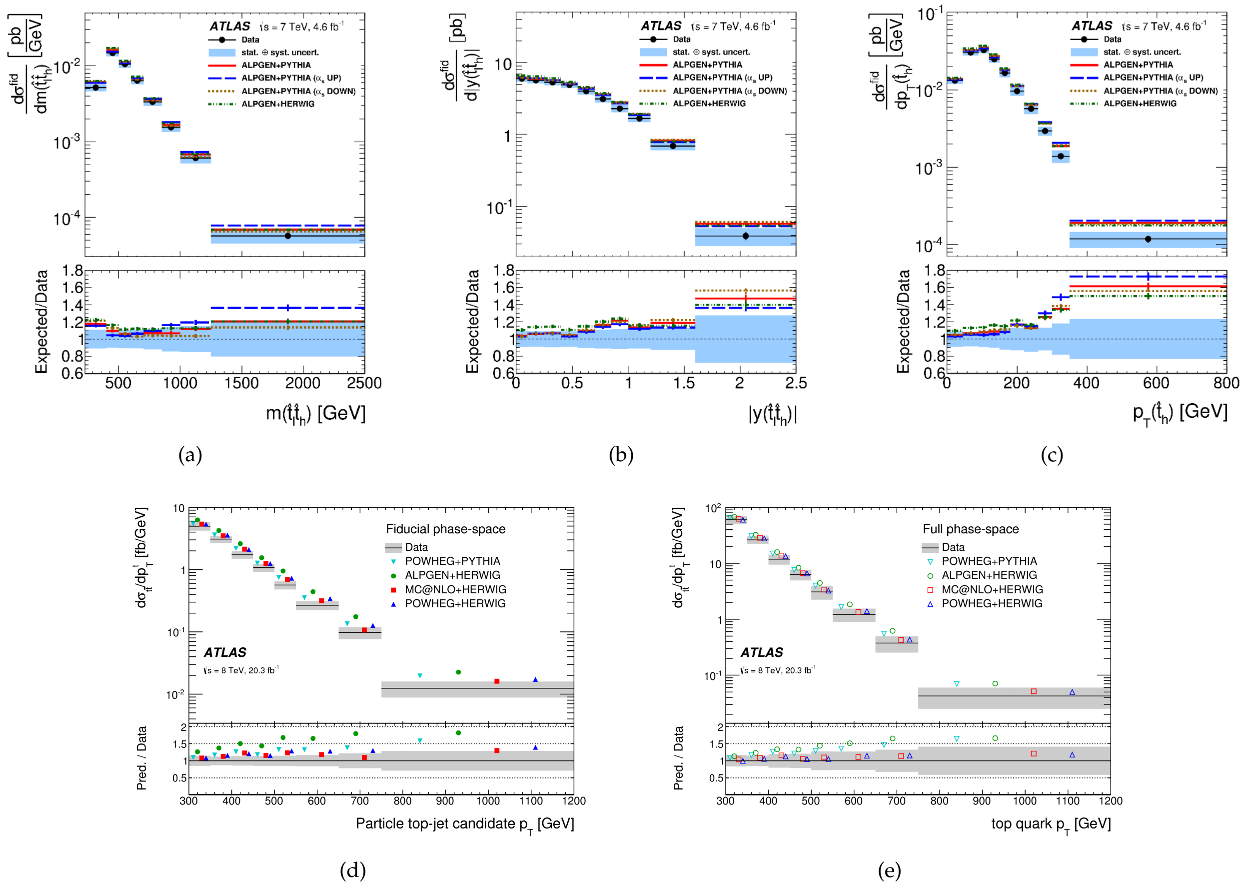

Figure 1: Top: differential $t\bar{t}$ cross section at $\sqrt{s} = 7$ TeV with respect to the mass (a) and the rapidity (b) of the $t\bar{t}$ system and the transverse momentum of the top quark (c), as measured in the resolved topology [7]. Bottom: differential $t\bar{t}$ cross section at $\sqrt{s} = 7$ TeV with respect to the transverse momentum of the top jet candidate at particle (d) and parton level (e), as measured in the boosted topology [8].

4 $t\bar{t} + \gamma$ inclusive cross section measurement

The ATLAS experiment performed the measurement of the cross section of the associated production of photon along with $t\bar{t}$ pairs with a center of mass energy of 7 TeV using the data collected in 2011 [9]. The $t\bar{t} + \gamma$ candidates are selected as $t\bar{t}$ candidates with an additional photon, in the lepton+jets channel. In order to discriminate the signal photons from a background of neutral hadron decays with real or fake photons, the track isolation distribution of the photon candidates is studied. The $t\bar{t}\gamma$ fiducial cross section in the kinematic region of the ATLAS acceptance is extracted through a binned template likelihood fit, where the template is the the track isolation of the photon candidate, used to discriminate the signal photons from a background of neutral hadron decays with real or fake photons.

The resulting fiducial cross section is:

$$\sigma^{fiducial}_{t\bar{t}+\gamma}\ (7\ \text{TeV}) \times BR = 63 \pm 8\ (\text{stat.})^{+17}_{-13}\ (\text{syst.}) \pm 1\ (\text{lumi.})\ \text{fb}.$$

This result is measured with 5 σ of significance and is in good agreement with the theoretical expectation of 48 ± 10 fb.

5 Single top t-channel cross section measurement

The ATLAS experiment measured the single top production cross section in the t-channel and for the first time in Wt associated production channel with more than 5 σ of confidence level, and an upper limit for the s-channel production is set.

In particular, the t-channel single top quark production at $\sqrt{s} = 8$ TeV has been calculated in the lepton+jets topology [10], using a maximum likelihood fit of a multivariate Neural Network discriminant trained with the most sensitive variables.

The resulting fiducial phase space measurement is

$$\sigma_{t-chan}^{fiducial} \text{ (8 TeV)} = 3.37 \pm 0.05 \text{ (stat.)} \pm 0.47 \text{ (syst.)} \pm 0.09 \text{ (lumi.) pb.}$$

which can be extrapolated to the full phase space,

$$\sigma_{t-chan}^{total} \text{ (8 TeV)} = 82.6 \pm 1.2 \text{ (stat.)} \pm 11.4 \text{ (syst.)} \pm 3.1 \text{ (PDF)} \pm 0.09 \text{ (lumi.) pb.}$$

which is obtained using the aMC@NLO generator. The result is in good agreement with the theoretical calculation obtained using an approximated NNLO of $87.8^{+3.4}_{-1.9}$ pb [11].

6 Top mass measurement

The most precise top quark mass measurement performed by the ATLAS experiment has been obtained using 4.7 fb^{-1} of data at $\sqrt{s} = 7$ TeV in both the single lepton and dilepton channels [12]. The top quark mass has been determined through a 3-dimensional template fit, alongside with the global jet energy scale factor and the relative b-jet to lighter jet energy scale factor.

The templates are built by varying the fit parameters in the Monte Carlo simulation, which are the fitted top mass parameter ($m_{t,reco}$), the fitted W mass parameter ($m_{W,reco}$) and the ratio of the sum of the p_T of the b-jets from the top and light jets from the W (R_{bq}^{reco}) for the single lepton channel and the fitted mass of the top using the lepton the b quark ($m_{lb,reco}$) for the dilepton channel. The $t\bar{t}$ kinematics is reconstructed through a maximum likelihood approach, and the signal and background PDFs are used in an unbinned likelihood fit separately for a sample with only one b-tagged jet and a sample with two or more b-tagged jets, giving results which are in good agreement. Eventually, the results of the fit for the single lepton and dilepton channels are combined with the BLUE method [13], obtaining the final measurement of the top quark mass:

$$m_t^{comb} = 172.99 \pm 0.48 \text{ (stat.)} \pm 0.78 \text{ (syst.) GeV}$$

7 $t\bar{t}$ charge asymmetry measurement

The Tevatron experiments measured a discrepancy in the forward backward asymmetry of $t\bar{t}$ with respect to the Standard Model. Unfortunately, because of the different colliding beams and top production mechanism at LHC, it is not possible to measure this kind of asymmetry. Instead, different asymmetries linked to that one can be considered and have been measured with a center of mass energy of 7 TeV.

The charge asymmetry can be expressed as:

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

where $\Delta|y| = |y_t| - |y_{\bar{t}}|$, and ATLAS has performed measurement of this property at $\sqrt{s} = 7$ TeV in the single channel [14], in the dilepton channel [15] and has combined his results with CMS [16].

The dilepton channel is particularly interesting, since it allows the measurement of a lepton-based asymmetry (where $\Delta|y| = |y_{l^+}| - |y_{l^-}|$). This asymmetry is expected to have a smaller effect with respect to the $t\bar{t}$ charge asymmetry, because the leptons do not follow the direction of their parent top quarks, but it can be measured more precisely, since there is no dependence on the algorithm used for top reconstruction.

The reconstructed $\Delta|y|$ spectra are corrected for detector response and acceptance by unfolding procedures, leading to the final results:

$$A_C^{ll} = 0.24 \pm 0.015\ \text{(stat.)} \pm 0.009\ \text{(syst.)}, \qquad A_C^{t\bar{t}} = 0.21 \pm 0.025\ \text{(stat.)} \pm 0.017\ \text{(syst.)},$$

which are in agreement with the Standard Model predictions [17]:

$$A_C^{ll} = 0.0070 \pm 0.0003\ \text{(scale)}, \qquad A_C^{t\bar{t}} = 0.0123 \pm 0.0005\ \text{(scale)}.$$

8 Spin correlation measurements

The spin correlation of top and anti-top provides a precision test of the Standard Model and a window for possible new physics effects. This property is studied by the ATLAS experiment in $t\bar{t}$ events at $\sqrt{s} = 7$ TeV [18] and 8 TeV [19]. The spin correlation is defined as the difference of the number of events where the top and anti-top spins are parallel and antiparallel with respect to the spin quantization axis:

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

The 8 TeV analysis has been done with events in the dilepton channel, extracting the spin correlation through a binned likelihood fit of the distribution of the azimuthal angle $\Delta\phi$ between the charged leptons. The measurement is done on the f_{SM} coefficient, which express the degree of spin correlation with respect to the Standard Model prediction, which is $A^{SM}_{helicity} = 0.318 \pm 0.005$, obtaining

$$f_{SM} = 1.20 \pm 0.05\ \text{(stat.)} \pm 0.13\ \text{(syst.)}.$$

This measurement shows a good agreement with the Standard Model, and confirms the result of the 7 TeV analysis, where the a binned likelihood fit of f_{SM} using $\Delta\phi$ as observable obtained

$$f_{SM} = 1.19 \pm 0.09\ \text{(stat.)} \pm 0.8\ \text{(syst.)}.$$

9 Conclusions

During Run I the ATLAS experiment performed several top quark measurements, in order to make stringent tests on the Standard Model, such like top pair and single top production cross sections, top quark mass, $t\bar{t}$ charge asymmetry and spin correlation.

Most of the measurements are limited by systematic uncertainties and all the results agree with the Standard Model, with small deviations observed in the $t\bar{t}$ differential cross section where the data distribution for $p_{T,t}$ is slightly softer then the theoretical prediction, especially at high p_T.

In Run II, the expected higher statistics will allow to refine all these results with an increased focus on the boosted topologies.

Any additional information, together with the most complete and updated list of the ATLAS results on top physics can be found at the ATLAS top public result webpage [20].

References

[1] F. Abe et al. (CDF Collaboration), Phys. Rev. Lett., 74 (1995) 2626

[2] S. Abachi et al. (D0 Collaboration), Phys. Rev. Lett., 74 (1995) 2632

[3] ATLAS, CDF, CMS, D0 Collaborations, arXiv:1403.4427

[4] ATLAS Collaboration, JINST, 3 (2008) S08003

[5] ATLAS Collaboration, EPJC 74 (2014) 3109

[6] Czakon M. and Mitov A., Comput. Phys. Commun., 185 (2014) 2930

[7] ATLAS Collaboration, JHEP 06 (2015) 100

[8] ATLAS Collaboration, arXiv:1510.03818

[9] ATLAS Collaboration, Phys. Rev. D 91, 072007 (2015)

[10] ATLAS Collaboration, ATLAS-CONF-2014-007

[11] Kidonakis N., Phys. Rev.D, 83 (2011) 091503

[12] ATLAS Collaboration, Eur. Phys. J. C (2015) 75:330

[13] Nisius R., Eur. Phys. J.C, 74 (2014) 3004

[14] ATLAS Collaboration, JHEP 02 (2014) 107

[15] ATLAS Collaboration, JHEP 05 (2015) 061

[16] ATLAS and CMS Collaborations, ATLAS-CONF-2014-012

[17] Bernreuther W. and Si Z.-G., Phys. Rev.D, 86 (2012) 034026

[18] ATLAS Collaboration, Phys. Rev. D. 90, 112016 (2014)

[19] ATLAS Collaboration, Phys. Rev. Lett. 114, 142001 (2015)

[20] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults