PROCEEDINGS OF SCIENCE

Search for the $t\bar{t}H$ production in high-p_T regimes with the ATLAS detector

Silvia Biondi*
University "Alma Mater Studiorum" & INFN - Bologna, Italy
E-mail: silvia.biondi@cern.ch

The associated production of the Higgs boson with a pair of top/anti-top quarks ($t\bar{t}H$) is the only process providing a direct access to the measurement of the Yukawa coupling between the Higgs boson and the top quark. The presented results exploit the data collected during 2015 and 2016 by the ATLAS experiment during LHC collisions at a center-of-mass energy of 13 TeV with an integrated luminosity of 13.2 fb^{-1}. The improvement of the analysis includes the use of multivariate techniques in order to discriminate between signal and background events, dominated by the $t\bar{t}$ production. Moreover, due to the very high p_T of the produced particles, the jets have been reconstructed with a specific designed algorithms ("boosted techniques") that take advantages of their peculiar substructure.

EPS-HEP 2017, European Physical Society conference on High Energy Physics
5-12 July 2017
Venice, Italy

*on behalf of the ATLAS Collaboration

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1. Introduction

In this document a new analysis strategy is presented to improve the high-p_T spectrum regimes in an already existing $t\bar{t}H$ production mode analysis. The aim is the measurement of the signal strength of the process.

The importance of this measurement resides in the associated Higgs production with a top quark: up to now only indirect constrains on the Top-Higgs Yukawa coupling have been possible, from the gluon-gluon fusion production, followed by $H \to \gamma\gamma$ decay, since this process involves a top quark loop. Instead, the $t\bar{t}H$ production allows a direct access to the Top-Higgs Yukawa coupling, giving the possibility to put a direct constrain on it. Moreover, the considered production mode has the highest cross section increase as a function of the energy with respect to the other production modes.

Since the results obtained by the previous data-taking have not the necessary statistical significance to confirm the existence of the $t\bar{t}H$ production, for the first time a selection of the high p_T top and Higgs production (boosted category) has been studied in the $t\bar{t}H$ channel.

2. Boosted topology and tecniques

During the Run-2, LHC is exploring a completely new physics regime where the available center-of-mass energy far exceeds the masses of known standard model particles. At such energies, heavy particles such as W, Z and H bosons and top quarks are often produced with large transverse momentum (boosted particles) that implies large Lorentz boost for their decay products. The property of boosted object decays is that they are collimated around the momentum direction of the boosted original particle in the detector rest frame, Fig. 1.

As a consequence, the traditional reconstruction algorithms loose significantly in efficiency, due to the overlapping of the jets coming from an hadronic decay of a mother particle. In the 2015 and 2016 data analysis, the large integrated luminosity collected at $\sqrt{s}$ = 13 TeV (36.1 fb^{-1}) allows to explore the high-p_T region with unprecedent sensitivity. Consequently, at high p_T, the decay products of a hadronically decaying object merge into a single, energetic and large radius jet (large-R jet) with a characteristic substructure different from those initiated by a single parton.

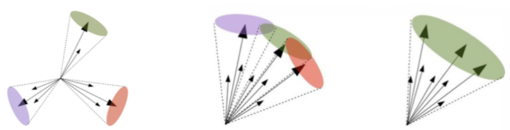

Figure 1: Graphical representation of the jet produced in top quark hadronic decays, in case of low (left) and high (center) values of top p_T. The picture on the right show the same high top p_T configuration as before using a large-R jet reconstruction.

Both large-R jets (tagging top quark and Higgs boson) and re-clustering techniques [1] have been tested for the boosted $t\bar{t}H$ analysis, trying to detect the most optimal reconstruction technique and to improve the significance of the analysis.

Many studies have been performed leading to the decision to use the *re-clustering* technique: this is an innovative way to reconstruct the jets into the events. The clustering algorithms use

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sequential recombination. Given distance metrics d_{ij} (between energy deposit 4-vectors) and d_{iB} (between energy deposit and beam 4-vectors), these algorithms recursively combine proto-jets, adding all p_T ordered deposits until there are none left, as shown in Fig 2.

Traditionally only a few choices of radius parameter R are used for all the analyses in LHC, because every jet configuration must be calibrated to account unmeasured energy deposits and other experimental effects. A solution to this tight limit is to introduce a new angular scale $r < R$, such that jets of radius r can be used to build large radius R jets. If chosen appropriately, the fully calibrated small R jets can make the calibration of the re-clustered large R jets automatic. Furthermore, with no additional calibration needed, any large radius R, any clustering algorithm, and many grooming strategies can be used.

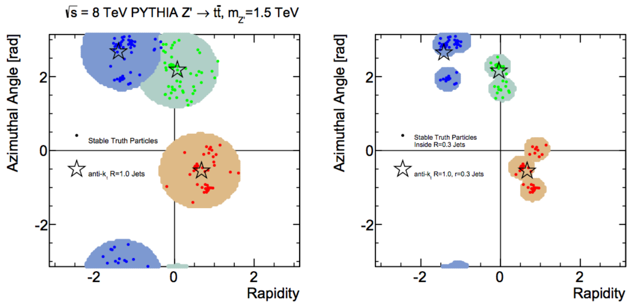

Figure 2: An example event which has been clustered using the anti-k_t $R = 1.0$ (left) and with anti-k_t $R = 1.0$ re-clustered $r = 0.3$ anti-kt jets (right). The shaded regions show the jet area determined by clustering ghost particles. Only large radius jets with $p_T > 50$ GeV are shown and small radius jets are required to have $p_T >$ 15 GeV. [1]

3. Signal region selection and analysis strategy

The analysis described in this document studies the process in Fig. 3, in which the $t\bar{t}$ system decays either semi-leptonically (one top quark decaying leptonically and a top quark decaying hadronically, called *single-lepton* channel) or leptonically (both the top quarks decaying leptonically, called *dilepton* channel). In both the cases the Higgs boson decays in two b quarks ($H \to b\bar{b}$).

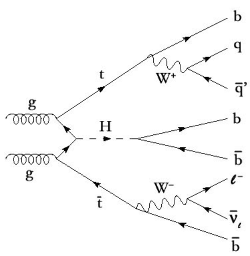

Figure 3: Feynman diagram of the $t\bar{t}H$ process studied in the analysis described in this document.

In the boosted regime of the analysis, the event selection requires:

- exactly one lepton (e or μ with $p_T > 27$ GeV);

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- one Higgs candidate: one re-clustered jet (R = 1.0, $p_T > 200$ GeV) with two associated b-tagged jets;
- one Top candidate: one re-clustered jet (R = 1.0, $p_T > 250$ GeV) with one associated b-tagged jet and one non-b-tagged jet;
- one b-tagged jet outside the two re-clustered jets ($\Delta R > 1.0$).

The analysis strategy consists in the event selection, described above, a signal identification step using a MultiVariate Analysis (MVA, [2]) technique which uses event kinematics and topology and b-tagging information to build a discriminant variable (Boosted Decision Tree, BDT) allowing to identify a very low signal over a very large background. The next step of the analysis is the combination of the boosted regime with the two resolved channels (*single-lepton* and *dilepton*) that use the standard object identification and reconstruction algorithms. The last step is the signal extraction: the BDT distribution is introduced into a combined fit procedure using a Likelihood function to determine the best value of the signal strength ($\mu_{t\bar{t}H} = \frac{\sigma(t\bar{t}H)_{obs}}{\sigma(t\bar{t}H)_{SM}}$). The aim of the analysis is the estimation of the $t\bar{t}H$ signal strength μ and its 95% CL upper limit.

4. Combined results from the resolved and boosted categories

Combined results have been obtained with the 2015 and the early 2016 datasets, corresponding to an integrated luminosity of 13.2 fb^{-1} ($\sqrt{s}$ = 13 TeV), for the resolved analysis. The best fit values of μ and its 95% CL limit are shown in Fig. 4 for each channel and for their combination.

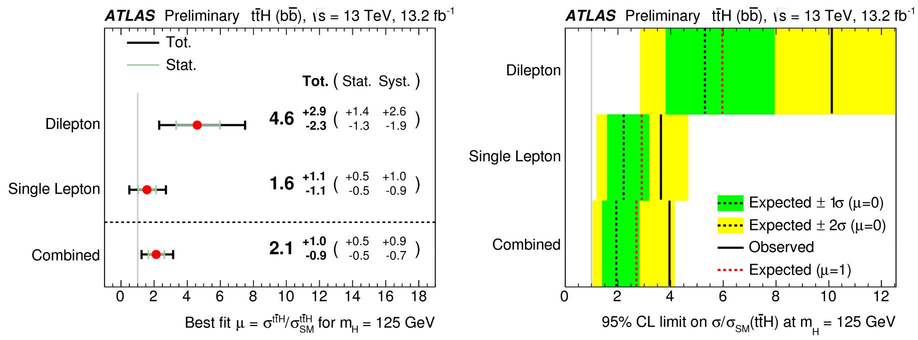

Figure 4: Summary of the signal strength measurements (left) and 95% CL upper limits on $\sigma(t\bar{t}H)$ relative to the SM prediction (right) in the individual channels and for the combination. [3]

With more luminosity, corresponding to 36.1 fb^{-1}, the boosted category will be included into the analysis and will be an interesting addition to these results. The motivations for adding the boosted category to the resolved channels are several: a significant reduction of the combinatorial background and an easier $t\bar{t}H$ system reconstruction. Moreover, it will increase the efficiency in high-p_T phase-space and it has good chances to improve the statistical limit on $\mu_{t\bar{t}H}$.

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References

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[3] The ATLAS Collaboration, *Search for the Standard Model Higgs boson produced in association with top quarks and decaying into a bb pair in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, ATLAS-CONF-2016-080, https://cds.cern.ch/record/2206255.

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