Search for physics beyond the Standard Model with top quarks at ATLAS

Philippe Calfayan[1] on behalf of the ATLAS Collaboration

[1]Ludwig-Maximilians-Universität, Munich, Germany

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This document reports on recent searches for new physics involving top quarks in proton-proton collisions at the center-of-mass energy $\sqrt{s} = 7$ TeV. Analyses using data samples with integrated luminosities up to 2 fb^{-1} recorded with the ATLAS detector are presented.

1 Introduction

With a mass close to the scale of the electroweak symmetry breaking, the top quark plays a special role in some models of new physics by coupling to new particles.

The $t\bar{t}$ forward-backward asymmetry (A_{FB}) has recently been measured at the Tevatron [1, 2] and was found to be significantly larger than the prediction from the SM, which further motivates the search for physics beyond the Standard Model (SM) with top quarks.

Using data sets of proton-proton collisions collected by the ATLAS detector [3] at the Large Hadron Collider (LHC), we present searches for resonances decaying to opposite or same-sign top-quark pairs, or top-quark partners with decay products resulting in an excess of missing transverse momentum ($\not{E}_T$).

2 Top pairs and top quark decays

As predicted in the SM, the top quark decays to a W boson and a b quark, and may lead to a leptonic or hadronic final state, according to the subsequent decay of the W boson.

As a consequence, the $t\bar{t}$ decays are characterized by the di-lepton, lepton plus jets, and all jets signatures. While the di-lepton final state has the cleanest topology and a low branching ratio, the all jet signature is produced with a large branching ratio and suffers from a significant background contamination. The lepton plus jet final state thus constitutes a compromise in terms of branching ratio and associated background.

3 Searches for $t\bar{t}$ resonances

3.1 The di-lepton final state

The search for $t\bar{t}$ resonances in the di-lepton final state has been carried out using a data sample of 1.04 fb^{-1} [4]. Three final state topologies have been considered: di-electron, di-muon, and electron-muon. The signal is interpreted in terms of the production of top pairs via a Kaluza-Klein gluon (KK-gluon) in the Randall-Sundrum (RS) Model [5].

The main background is the SM production of top pairs, while the second largest one originates from Drell-Yan processes and is estimated by normalizing simulation to data in the mass window of the Z boson. The scalar sum $H_T + \not{E}_T$ is used as the main discriminant between signal and background due to the presence of two neutrinos, with H_T defined as the scalar sum of the transverse momenta of the two final state leptons and of all the jets in the event above a given momentum threshold.

Upper limits on the signal production cross section times branching ratio are derived as function of the KK-gluon mass, using bins of the $H_T + \not{E}_T$ variable. As shown in Figure 1, these experimental limits are compared to the theoretical production cross sections and interpreted as lower bounds on the mass of the KK gluon. Four different values for the coupling of light quarks to the KK gluon are considered by scaling the strong coupling parameter $g_{qqg_{KK}}/g_s$ from 0.2 to 0.35. Observed lower bounds on the KK-gluon mass from 0.8 to 1.02 TeV are found. All limits reported in this proceedings are at 95% confidence level.

3.2 The lepton plus jets final state

The search for $t\bar{t}$ resonances in the electron plus jets and in the muon plus jets final states has been performed with a data sample corresponding to 2.05 fb^{-1} [6]. The signal is assumed to originate from the resonance of a leptophobic $Z^{'}$ [7] or a KK-gluon.

The main irreducible background from the SM is the $t\bar{t}$ production. The background consisting of the W boson production in association with jets is modeled using simulation and data-driven corrections. The multi-jet background, which contains fake leptons, is estimated with data-driven templates. The selection of candidate events requires at least one b-tagged jet, and a minimal requirement on the number of jets that depends on whether the event contains a jet with a large mass. The reconstructed $t\bar{t}$ invariant mass is used to distinguish between signal and background, and its shape is taken into account to derive upper limits on the signal production cross section times branching ratio. The limits are compared to the theory.

Leptophobic $Z^{'}$ with masses between 500 and 860 GeV are excluded, as illustrated in Figure 2. In the case of standard RS couplings between the KK-gluon and quarks, KK-gluon with masses between 500 and 1025 GeV are discarded.

4 Search for new phenomena in the $t\bar{t}$ plus $\not{E}_T$ final state

A search for new phenomena in events consisting of $t\bar{t}$ pairs and large $\not{E}_T$ has been published [8] using 1.04 fb^{-1} of data. The analysis investigates the pair production of fourth generation spin-$\frac{1}{2}$ quarks (T) which would decay to a SM top quark and stable, neutral, and weakly-interacting new particle (A_0) [9]. $T\bar{T}$ pairs are assumed to only decay to the final state $t\bar{t}A_0A_0$, and the search is performed in the case where the $t\bar{t}$ pair decays to a lepton plus jets.

The main background arises from SM $t\bar{t}$ di-lepton events where one lepton is not reconstructed, is outside the detector acceptance, or is a tau lepton decaying hadronically. The second largest background is due to W+jets and semi-leptonic $t\bar{t}$ decays, for which the normalization and shape are extracted from the data. To isolate the signal, events with an additional lepton or isolated track are excluded. The track veto reduces single prong hadronic tau decays in $t\bar{t}$ events.

Figure 3 represents the region of excluded signal as function of the masses of the new particles T and A_0. The mass of T is excluded up to 420 GeV assuming that the mass of A_0 is less than 10 GeV. In the case where the mass of A_0 does not exceed 140 GeV, masses of T between 330 and 390 GeV are ruled out. Currently, this analysis is not sensitive to scalar T quarks due to their smaller production cross section.

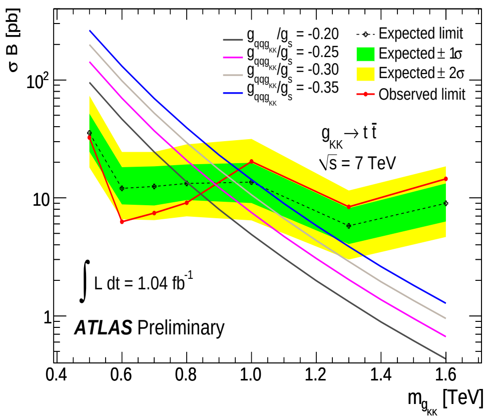

Figure 1: Search for $t\bar{t}$ resonance in the di-lepton final state [4]. Expected and observed upper limits on the signal cross section times branching ratio are compared to the theory in the case of a KK-gluon (g_{KK}) mediator.

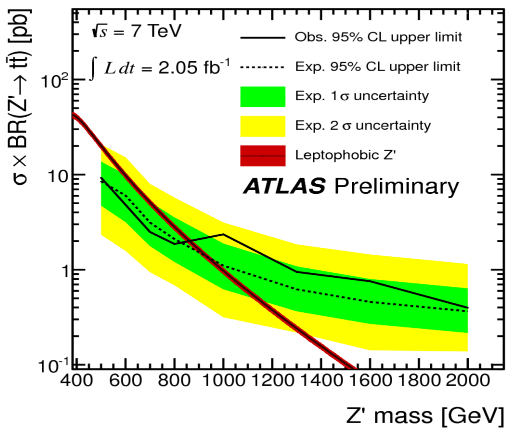

Figure 2: Search for $t\bar{t}$ resonance in the lepton plus jets final state [6]. Expected and observed upper limits on the signal cross section times branching ratio are compared to the theoretical prediction in the case of a a leptophobic $Z^{'}$ mediator.

5 Search for same-sign top-quark production

A search for same-sign top-quark (tt) production based on 1.04 fb^{-1} of data has recently been published [10]. Various generic heavy vector bosons and scalars are considered as mediators. Both top quarks are assumed to decay leptonically, which results in a final state consisting of two same-sign leptons. The di-electron and di-muon channels are explored.

The main background from the SM is due to the associated production of W and Z bosons. The contribution of events with fake leptons from hardonic decays or photon conversions is estimated from the data. Another source of background is the misidentification of the lepton charge, which is accounted for using a data-driven approach. The event selection includes a requirement on the variable H_T depending on the mass of the assumed mediator.

The production of tt pairs via a flavour-changing $Z^{'}$ [11] could explain the $t\bar{t}$ A_{FB} measured at the Tevatron. Upper limits on the tt production cross section from 1.4 to 2.0 pb are obtained, depending on the mass of the assumed mediator. Figure 4 provides the Tevatron measurements of A_{FB}, together with the tt production cross section for different masses of $Z^{'}$ as function of A_{FB} [12], and with the associated upper limit measured at ATLAS. As shown, a flavour-changing $Z^{'}$ is excluded as the source of the large A_{FB} asymmetry observed at the Tevatron.

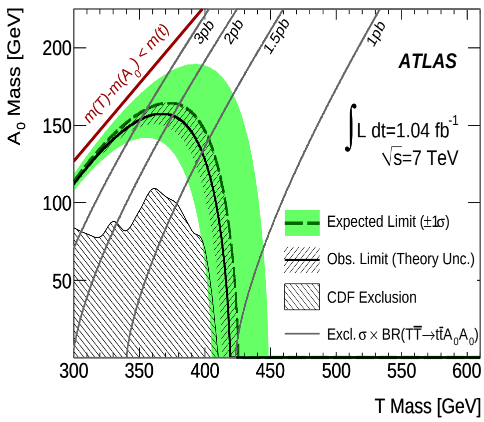

Figure 3: Search for new phenomena in the $t\bar{t}$ plus $\not{E}_T$ final state [8]. The mass exclusion region is parametrized as function of the masses of the hypothetic particles T and A_0.

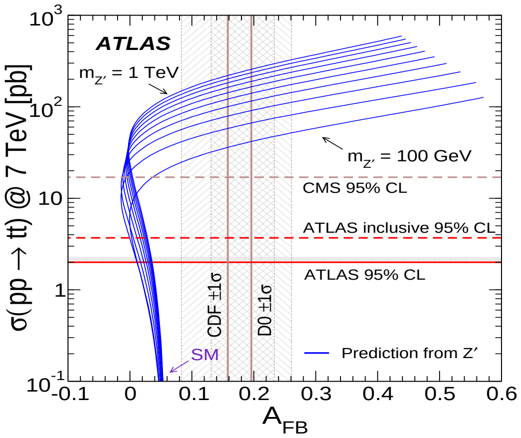

Figure 4: Search for same-sign top-quark production (1.04 fb^{-1}) [10]. Allowed regions for new physics contributions to inclusive $t\bar{t}$ A_{FB}, and contribution from Z' exchange versus tt production cross section at the LHC [12].

6 Conclusions and perspectives

The ATLAS experiment carried out seaches for physics beyond the SM with top quarks using data samples of proton-proton collision at $\sqrt{s} = 7$ TeV with integrated luminosities up to 2 fb^{-1}. Diverse final states have been explored but no evidence of new phenomena has been observed. Limits on production cross section and mass of new particles and mediators have however significantly been improved. Results are to be revised using the complete 2011 data set of 5 fb^{-1}, yet updates are expected based on the large data sets the LHC is planned to collect at $\sqrt{s} = 8$ TeV in 2012.

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