Search for resonances decaying into top quark pairs with ATLAS

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Abstract. Some models, including the so-called Randall-Sundrum model, predict the existence of heavy Kaluza-Klein resonances decaying mainly into top quarks. The prospects to discover those resonances in the ATLAS experiment at the LHC are discussed. Special emphasis is given to the techniques used to identify and reconstruct top quarks at high-p_T.

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INTRODUCTION

The top quark could be one of the most important handles in searches for new physics at the LHC. The top quark may couple to new particles (Z', g*, $H^{\pm}$, and $\hat{t}$) in many extensions of the standard model [1, 2, 3]. In the Randall-Sundrum warped extra dimension model, Kaluza-Klein resonances are expected to exist. The Kaluza Klein excitation of the gluon is predicted to couple strongly to heavy quarks (Br($g^* \rightarrow t\bar{t}$) = 92.3 % in [4]).

The reconstruction of the decay of a heavy resonance is an experimental challenge. The decay products from the highly boosted top quark are collimated in a narrow cone. Standard jet reconstruction algorithms will fail to resolve the partons from hadronically decaying tops. Merging of jets will thus limit the performance of the traditional approach towards top reconstruction and a new paradigm is required to explore resonances with very high mass. In this contribution the ATLAS discovery potential for heavy $t\bar{t}$ resonances is discussed, as well as the first attempts to establish a new technique for the identification of high-p_T top quarks.

At Tevatron experiments, a search for a narrow-width heavy resonance decaying into top quark pairs $X \rightarrow t\bar{t}$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV has been performed [5]. D0 reports the search for such resonances in the lepton plus jets channel, and there is no evidence for a narrow resonance of Z' decaying to $t\bar{t}$ up to 700 GeV/c^2 [6].

HIGH MASS GAUGE BOSON SEARCH IN TOP QUARK PAIR EVENTS

ATLAS estimated the discovery potential of the ATLAS detector for a generic narrow Z' boson in a model independent way [7]. For this estimation, the production cross-section, couplings with top, and mass of the Z' are free parameters, while its intrinsic width is required to be small compared to its reconstructed width. To obtain a very pure $t\bar{t}$

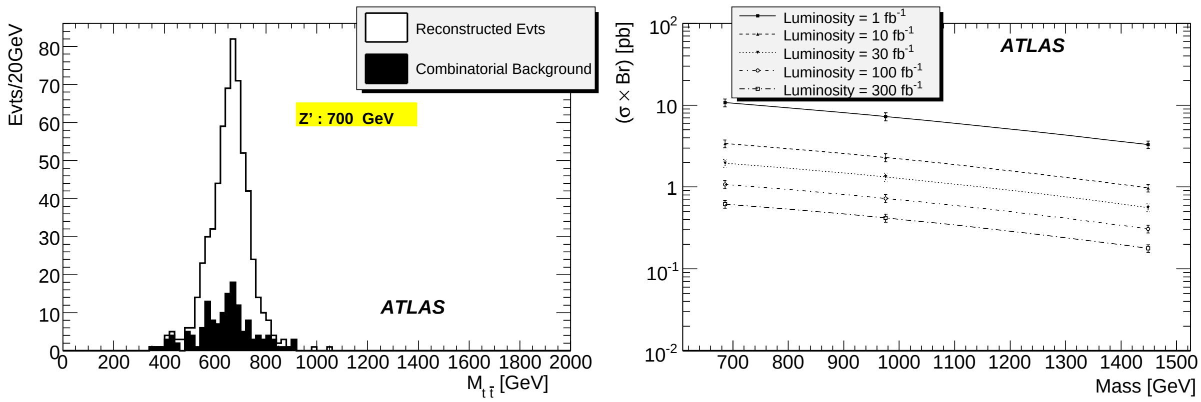

FIGURE 1. Reconstructed $t\bar{t}$ invariant mass spectra for a 700 GeV/c^2 Z'$\rightarrow t\bar{t}$ process (left). Discovery potential of a generic narrow $t\bar{t}$ resonance for different integrated luminosity scenario (right).

sample, top quark pairs in the "lepton+jets" channel are selected, where lepton is either a muon or an electron. In order to reproduce trigger cuts, and to reduce the backgrounds, such as multi-jets, W+jets, Z+jets, dibosons and single-top production, the following criteria are required for event selection. Standard offline selection cuts are applied to the events satisfying a high-p_T isolated lepton trigger. The standard offline selection cuts consist of exactly one isolated lepton ($p_T^l > 40$ GeV/c, $|\eta_l| < 2.5$), high missing transverse energy ($\not{E}_T > 20$ GeV), at least four jets ($p_{jetT} > 40$ GeV/c, $|\eta_{\rm jet}| < 2.5$) on which exactly two b-tagged jets. Then, the kinematics of the event is reconstructed as follows: the "hadronic top quark" is reconstructed combining the nearest b-tagged jet to the hadronic W, which is reconstructed from the two light (non b-tagged) jets which are closest in the $\eta \times \phi$ (smallest ΔR). Two leptonic W boson candidates are formed because of the two-fold ambiguity in the reconstructed longitudinal neutrino momentum (p_z^ν). The one providing the leptonic top mass closest to the mean value of the hadronic top mass is chosen. In the leftmost panel of Fig. 1 the reconstructed $t\bar{t}$ mass distribution is shown for a 700 GeV/c^2 Z'$\rightarrow t\bar{t}$ process. The reconstructed Z' mass resolution is 40 GeV/c^2 for 700 GeV/c^2 Z'. The level of SM backgrounds can be reduced by applying cuts on the reconstructed hadronic W and both top masses. The level of instrumental and physical SM backgrounds is estimated to be small: (SM $t\bar{t}$)/(SM background) $\sim$ 70. The reconstructed top quark pairs includes the combinatorial background, which is due to the $t\bar{t}$ events with a wrong b-jet, light jet or p_z^ν assignment and is also important for the background estimation.

The discovery potential is determined from the $t\bar{t}$ reconstructed $m_{t\bar{t}}$ spectrum. The counting method is used with a sliding window technique to detect any excess of event in a mass window. The window width is optimized for narrow resonance searches ($\Gamma_{Z'} < 50$ GeV/c^2). Right panel of Fig. 1 shows the discovery potential of a generic narrow $t\bar{t}$ resonance for different integrated luminosity scenario. The resulting sensitivity shows that a 700 GeV Z' resonance produced with a cross-section of σ(pp$\rightarrow$Z')$\cdot$Br(Z'$\rightarrow t\bar{t}$) $>$ 11 pb should produce an excess of selected events S/$\sqrt{\rm B}$ greater than 5 σ (statistics and systematics combined) with 1 fb^{-1} of $\sqrt{s} = 14$ TeV data.

The sensitivity in the high mass region is limited by the efficiency for the reconstruction of high-p_T top quarks. A different approach is necessary for the reconstruction of high-p_T top quarks of $p_T > 500$ GeV/c.

RECONSTRUCTION OF BOOSTED TOP QUARK

The identification of highly boosted tops is an experimental challenge. For hadronic decay of the W (nearly 70 % of cases) from a top quark, three jets are produced in a narrow cone. For large top quark p_T, the separation between the three jets becomes so small that the individual decay products can no longer be distinguished by the standard jet reconstruction algorithms. At higher-p_T, top quark are thus increasingly reconstructed as a single jet, which is a so-called "mono-jet".

One of the approaches for the reconstruction of such boosted hadronically decaying top quarks is the reconstruction of sub-jets within high-p_T jets [8]. The idea for the reconstruction of underlying sub-jets is to use the kT clustering jet algorithm. It fulfils the theoretical requirements on jet algorithms, and tends to reconstruct the sub-jets in a jet, due to fragmentation and radiation effects. The characteristic scale of the sub-jets splitting is logarithmically below the jet scale in the case of QCD jets, since in the region around the jet strongly-ordered DGLAP-like QCD evolution dominates. ATLAS examined the discrimination of signal hadronic top quarks and jets originating from a single hard parton using sub-jets technique with requiring a further advanced selection procedure [9]. At first, high-p_T kT jets are considered ($p_T^{jet} > 300$ GeV/c). Then, a multivariate sequential selection is used, with several discriminant variables: the mass of the jet and the energy scale values at which the mono-jet splits into two, three and four jets. The mass of a kT jet is defined as the invariant mass of all the jet's constituents, which are the calorimeter cells. The left panel of Fig. 2 shows the selection efficiency for the signal and the QCD background. The selection efficiency increases with p_T^{top}. A high efficiency is achieved for top mono-jets while keeping the light jet efficiency below 25 %.

In addition to the jet substructure, the long lifetime of the B-hadron embedded in the top mono-jet is expected to be useful signature to identify top-jets. Tagging of b-jets has proven to be a very powerful tool. The ATLAS collaboration has developed a suite of b-tagging algorithms based on the precise reconstruction of charged tracks in the inner detector. In reference [10] the IP3D+SV1 algorithm, that combines impact parameter and secondary vertex information to construct a b-tag likelihood, was applied to top mono-jets. In the rightmost panel of Fig. 2 the signed impact parameter significance distribution for light jets (continuous line), b-jets (dashed line) and top mono-jets (dotted line). The tail towards positive values in the significance distribution for b-jets is due to the large lifetime of B-hadrons. The distribution for top mono-jets is much more symmetric than that for b-jets due to the large uncertainty on the B-hadron flight path. While the tagging performance is degraded with respect to b-jets of the same transverse momentum, the lifetime signature remains a powerful tool to distinguish top mono-jets from jets originating in light quarks or gluons. For jets with a transverse energy of 1 TeV, the light jet rejection power is a factor 6 for a top mono-jet tagging efficiency of 60 %.

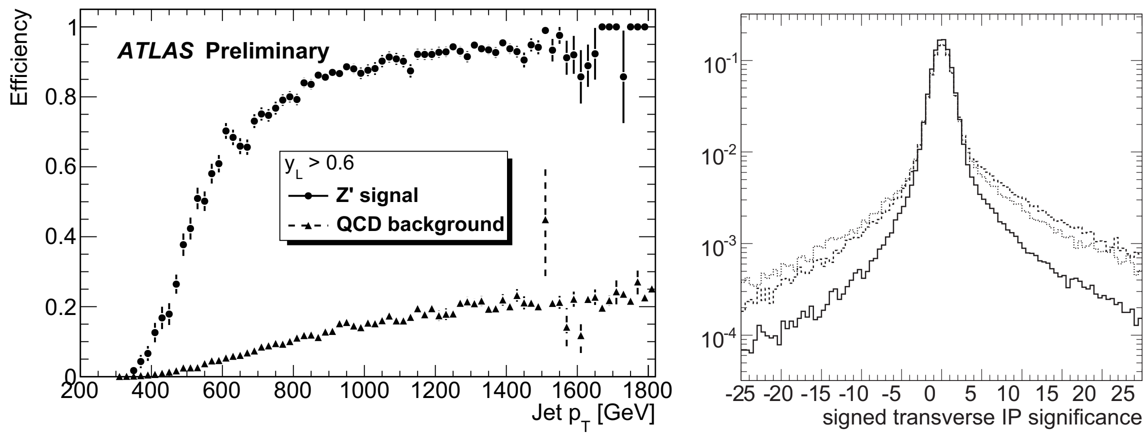

FIGURE 2. Left figure shows the selection efficiency for jets coming from the hadronic top quark (circle) and coming from hard light partons (triangle). y_L stands for the likelihood variable defined in [9]. Right figure shows the signed impact parameter significance of all tracks inside light jets (continuous line), b-jets (dashed line) and hadronic top mono-jets (dotted line).

SUMMARY

ATLAS estimated the discovery potential for the Z' narrow resonance decaying into top quark pairs in the lepton+jets channel. In order to reconstruct the boosted top quarks from heavy $t\bar{t}$ resonances with a high efficiency, ATLAS developed kinematic variables and selection criteria. Especially, jet mass information, sub-structure of jets and b-tagging technique are useful for the high-p_T top mono-jets reconstruction.

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