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Search for new resonances with top quark

Min Suk Kim*
Department of Physics, Kyungpook National University, Daegu, South-Korea
E-mail: minsuk@cern.ch

Many models of physics beyond the Standard Model predict new gauge bosons that decay to a top quark pair or a top quark and a bottom quark. The most recent results from new resonance searches for $\mathrm{Z}' \rightarrow \mathrm{t\bar{t}} \rightarrow \mathrm{W^+bW^-\bar{b}}$ and $\mathrm{W}' \rightarrow \mathrm{tb} \rightarrow \mathrm{Wbb}$ are presented using the proton-proton collision data at a centre-of-mass energy of 8 TeV. The searches are performed with the ATLAS and CMS experiments at the LHC using an integrated luminosity of 20.3 fb^{-1} and 19.7 fb^{-1}, respectively. The analyses are done in the leptonic and hadronic decay modes of the top quark. No evidence for new resonances with top quark is observed and 95% confidence level (CL) limits on the production rate are determined for massive states in theories beyond the Standard Model.

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*Speaker.

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1. Introduction

Many models beyond the Standard Model predict the existence of new massive gauge bosons, including Z′ and W′, that preferentially couple to the third generation and in particular to the top quark. Top quarks emerging from the decay of heavy resonances in $Z' \rightarrow t\bar{t}$ and $W' \rightarrow tb$ have large transverse momenta (p_T). The decay products of highly boosted top quarks are collimated and can be reconstructed as a single jet in the ATLAS [1] and CMS [2] detectors at the LHC. Jet substructure methods are applied to separate contributions of different particle decays to one jet with top flavour. This allows for a search for high-mass bosons in the range up to 3.0 TeV.

2. Search for $t\bar{t}$ resonances

The search in the lepton+jets channel performed with the ATLAS experiment [3] considers events with one isolated lepton (e or μ), missing transverse energy and hadronic jets, of which at least one jet is identified to originate from a b-quark. To improve the sensitivity to the production of any new particle, two separate samples are explored by a top event topology: boosted and resolved.

Events to be considered for the boosted topology must have at least one large-radius jet and at least one small-radius jet, while events for the resolved topology have at least four small-radius jets. Jets are reconstructed using the anti-k_T algorithm [4] applied to clusters of calorimeter cells. Small-radius jets with a distance parameter of $R = 0.4$ are required to have $p_T > 25$ GeV and $|\eta| < 2.5$, while large-radius jets ($R = 1.0$) have $p_T > 300$ GeV and $|\eta| < 2.0$. For both the boosted- and resolved-topology selections, three categories of b-tagged events are used: those in which both top quark candidates have a matching b-jet and those in which either the hadronically or leptonically decaying top quark candidate has a matching b-jet. In the boosted-topology selection the match is defined as either the selected jet or a small-radius jet within the large-radius jet as being a b-tagged jet, while in the resolved-topology selection the matching is determined by the χ^2 algorithm.

No excess is observed and limits on the production cross section are determined for massive states in the following benchmark models: new particles with spin 0 (scalar resonance), 1 (Z′ and Kaluza-Klein gluons, g_{KK}) and 2 (KK Gravitons) and masses from 0.4 to 3.0 TeV. The width relative to the mass varies from 1% to 15%. Figure 1 shows good agreement between the data and the total expected background, and the limits for two of the four signal hypotheses. A narrow Z′ of width 1.2% with standard model couplings is excluded with masses below 1.8 TeV (2.0 TeV expected). The limits are stronger with a 3% width, excluding up to 2.3 TeV (2.5 TeV expected). A broad g_{KK} of width 15.3% due to an enhanced coupling is excluded for masses less than 2.2 TeV (2.3 TeV expected). The limit dependence on the width is explored for the Randall-Sundrum g_{KK} model up to a 40% width. No mass range is excluded in the benchmark models with spin 0 and 2.

In the CMS experiment the search is performed on the final states with two, one, or zero leptons (e or μ) [5]. Since the top-quark decay products can be collimated at high values of $M_{Z'}$, no isolation requirement is applied to the leptons. Particle-flow candidates are clustered into jets and charged hadrons that are not associated to a primary vertex are removed prior to jet clustering. All jets are required to have $|\eta| < 2.4$. The dilepton and lepton+jets analyses use jets reconstructed using the anti-k_T algorithm with $R = 0.5$. The all-hadronic analyses use the the Cambridge-Aachen jet-clustering algorithm [6] with $R = 0.8$ (CA8) and 1.5 (CA15) respectively for high and low

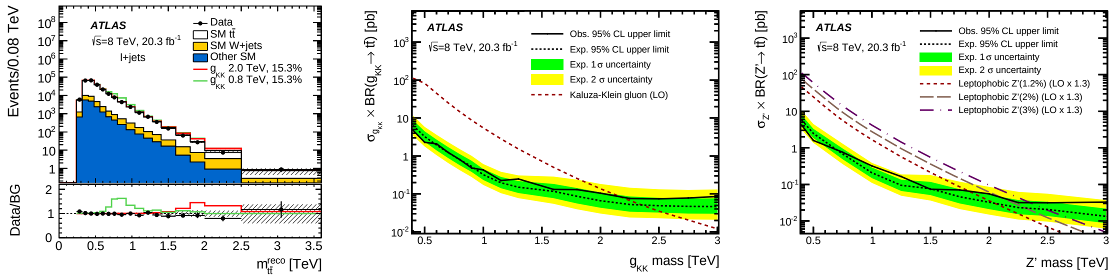

Figure 1: The $M_{t\bar{t}}$ distribution for all selections (left). The shaded areas indicate the total systematic uncertainties. The red (green) line shows the expected distribution for a broad g_{KK} of mass 2.0 (0.8) TeV with the boosted (resolved) selection. Upper limits at 95% CL on the production cross section times branching fraction to $t\bar{t}$ final states as a function of the mass of g_{KK} (middle) and Z′ boson (right). Taken from Ref. [3].

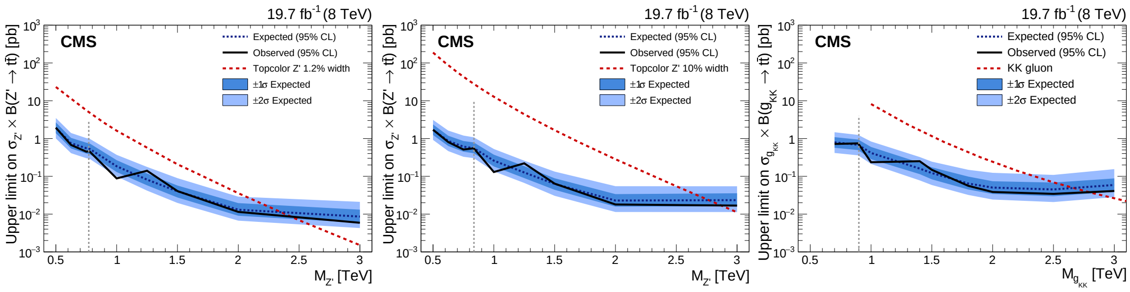

Figure 2: Upper limits at 95% CL for a Z′ with narrow (left) and wide (middle) width, and a g_{KK} (right). The vertical dashed line indicates the transition in the results between the resolved and boosted channels [5].

values of $M_{t\bar{t}}$ to decompose highly boosted top jets into subjet components and examine kinematics of these subjets.

For the dilepton channel, events are selected from the sample that contains two leptons with high transverse momentum, at least two jets from the fragmentation of b-quarks, and missing transverse energy. At high $M_{Z'}$ with the boosted topology, special selection criteria are used to preserve high efficiency for non-isolated leptons. For the lepton+jets channel, events with one high-p_T lepton, at least two jets with at least one b-tagged jet, and missing transverse energy are selected. Like the analysis in dilepton channel, special selection criteria are used to identify non-isolated leptons at high $M_{Z'}$. A top-tagging algorithm is applied to identify hadronically decaying top merged into one single jet and is utilized to enhance the sensitivity at high masses by 30–40%. For the all-hadronic channel, events with a dijet topology is considered and divided into two regions by Z′ mass: below 1 TeV using CA15 jets and above 1 TeV using CA8 jets. Two distinct top-tagging algorithms are used for the analyses in two regions. In both regions one identified subjet in each of two top quark candidates to be consistent with the fragmentation of a b-quark or c-quark is required so that the dominant background from non-top multijet production can be reduced.

In all three channels the dominant irreducible background is the standard model $t\bar{t}$ production. No evidence is found for a resonance beyond the $t\bar{t}$ continuum production, and a limit is extracted by performing a template-based statistical evaluation of the $M_{t\bar{t}}$ distributions of all channels. Figure 2 shows the results for each of the three signal hypotheses with all channels combined. The observed limit for a narrow Z′ of width 1.2% with standard model couplings corresponds to 2.4 TeV (2.4 TeV expected). For a Z′ with a 10% width, the observed and expected limits are 2.9 and 2.8 TeV. Randall-Sundrum KK gluons are excluded for masses less than 2.8 TeV (2.7 TeV expected).

3. Search for W′ → tb

Models potentially inaccessible to $W' \to \ell\nu$ searches are explored by the search for a $W' \to tb$ with right-handed (W'_R) and left-handed couplings (W'_L). Their couplings to fermions are assumed to be same as for the standard model W boson. The latest searches from CDF are shown in Ref. [7].

In the search performed by the ATLAS collaboration [8, 9], the mass of the right-handed neutrino is assumed to be larger than the mass of the W' boson. Thus only hadronic decays of the W'_R are allowed. For the analysis in the leptonic decay mode of the top quark, events are required to have exactly one lepton, two or three jets with exactly two of them identified as originating from a b-quark, and the sum of the W boson transverse mass and missing transverse energy more than 60 GeV. In the case of a W'_L, leptonic decays are allowed and, since the W'_L signal is same as for the single top quark production in the s-channel, an interference term between two processes is taken into account. For a W'_R (W'_L without and with interference), the observed mass limit is 1.92 (1.80, 1.70) TeV, while the expected limit is 1.75 (1.57, 1.54) TeV. For the analysis in the hadronic decay mode of the top quark, two radius parameters are used for jet reconstruction: a small-R of 0.4 and a large-R of 1.0. The W' top-tagging algorithm uses different large-R jet substructure properties developed to efficiently select large-R jets from W' signal events over the dominant background from multijet production. Candidate events must have exactly one large-R W' top-tagged jet and one small-R b-tagged jet, each with $p_T > 350$ GeV and an angular separation in the η-ϕ plane between them larger than 2.0. The events are divided into two categories: 1 and 2 b-tagged jets. For the two b-tagged jets, an additional small-R b-tagged jet with $p_T > 25$ GeV should be present within the large-R jet as the top candidate. The observed and expected limits are 1.76 and 1.85 TeV (1.68 and 1.63 TeV) in the W'_R (W'_L). Figure 3 shows the cross section limits obtained by W' searches in the two decay modes of the top quark. For both decay modes, limits on the ratio of couplings to quarks as a function of the $M_{W'}$ is also derived from the limits on the W' cross section.

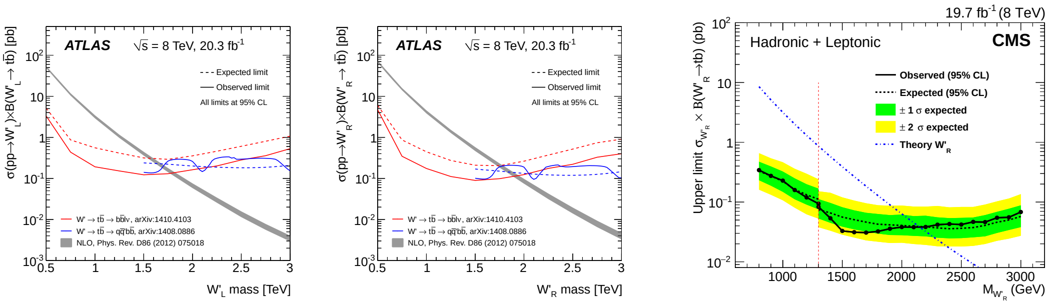

Figure 3: ATLAS W'_L (left) and W'_R limits (middle) for the leptonic and hadronic channels. CMS W'_R limits (right) for the combined channels. The region to the left of the vertical line shows the leptonic channel only.

Searches for $W' \to tb$ performed by the CMS collaboration [10] make no assumptions regarding the mass of the right-handed neutrino and are thus complementary to searches in the $W' \to \ell\nu$. The analysis in the $W' \to tb \to \ell\nu bb$ considers events with a high-p_T isolated lepton, missing transverse energy, and at least one of the two leading jets with $p_T > 120$ and 40 GeV, respectively, to be tagged as a b-jet. For W' bosons with purely right-handed couplings if M_{ν_R} is larger than a few GeV, and for those with left-handed couplings assuming no interference with the standard model, there is no practical difference for search between W'_R and W'_L, and the lower mass limit is 2.05 TeV (2.02 TeV expected). Assuming heavy ν_R ($M_{\nu_R} > M_{W'}$), the limit is 2.13 TeV (2.12 TeV expected). For a W′ boson with only left-handed couplings, with interference effects, the limit is 1.84 TeV (1.84 TeV expected). When the W′ decays to hadrons ($W' \to tb \to qqbb$) [11], the top quark can be detected as three jets. The CMS top-tagging algorithm discriminates signal from background by reclustering the CA jet until finding anywhere from 1 to 4 subjets. Candidate events must have one jet with $p_T > 450$ GeV identified with the combined top tagger with subjet b tagging, one b-tagged jet with $p_T > 370$ GeV, and those two jets in $|\Delta\phi| > \pi/2$ and $|\Delta y| < 1.6$. A W'_R is excluded with a mass less than 2.02 TeV (2.02 TeV expected). Because the left-handed and mixed-coupling samples cannot be separated from single top quark production, limits are set on both couplings. As mentioned above, the leptonic channel excludes a W′ mass below 2.05 TeV. Because the hadronic and leptonic channels have similar sensitivity in the high $M_{W'}$ regime, the combination of these two channels makes it possible to extend this limit to 2.15 TeV (2.15 TeV expected), shown in Figure 3.

4. Conclusions

Results are presented from searches for the production of heavy gauge bosons, performed with the ATLAS and CMS detectors at the LHC, in proton-proton collisions at $\sqrt{s} = 8$ TeV, using data corresponding to an integrated luminosity of 20.3 fb^{-1} and 19.7 fb^{-1}, respectively. The analyses are done in the top-quark decay modes. No evidence for new resonances with top quark is found and 95% CL upper limits on the production cross section times branching fraction are obtained.

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