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STUDY ON THE DISCOVERY POTENTIAL OF ALL-HADRONIC SEARCHES FOR TTBAR RESONANCES AT FUTURE COLLIDERS

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Introduction and Aim. The discovery of the top quark in 1995 by the CDF and D0 experiments at Fermilab marked the beginning of a new era of particle physics, and throughout the more than two decades since its discovery the top quark has provided remarkable insight and motivation for much of the physics studied today.[1, 2] Understanding the role of the top quark is especially important when taken in context with the discovery of a 125 GeV scalar boson at the Large Hadron Collider (LHC) with the ATLAS and CMS experiments.[3, 4] More specifically, the top quark's high mass implies the strongest coupling of any known particle to the 125 GeV scalar boson, currently believed to be the source of electro-weak symmetry breaking (EWSB). Furthermore, since the top is heavier than the flavor-changing weak bosons, it decays before it hadronizes and provides a unique avenue through which to study the dynamics of bare quarks.

Although all observations in previous experiments confirm the success of the Standard Model, we also know that the theory is incomplete since it lacks an explanation of the various energy hierarchies, as well as suffers from a quadratically diverging bare mass for the scalar boson responsible for EWSB. Various explanations exist attempting to correct the problems in the Standard Model, including Little Higgs, Kaluza-Klein and Randall-Sundrum models.[5, 6, 7] Each of these Standard Model extensions predict additional symmetries that are broken at higher energies, as well as the existence of new, heavy particles which can couple to top quarks through resonant production of a ttbar pair.

Context and Past Searches. Top-antitop resonance searches have been flagship analyses at the LHC, providing stringent limits on the existence of possible new particles predicted by extensions of the Standard Model. Since the top quark has various complementary decay channels, these can be combined to make efficient use of our data. For this Letter of Interest we focus on motivating the fully hadronic channel, as this top quark final state has the largest branching fraction and is the expertise of the authors.

The current limits set by CMS depend heavily on the specific parameters of the hypothesized mediator particles, in particular the width of the resonance as illustrated by the plots in Figure 1. For results using 36 fb^{-1} of data, the exclusions measured by CMS range between $3.8 - 6.65$ TeV for widths of 1-30% with respect to the mass of the new

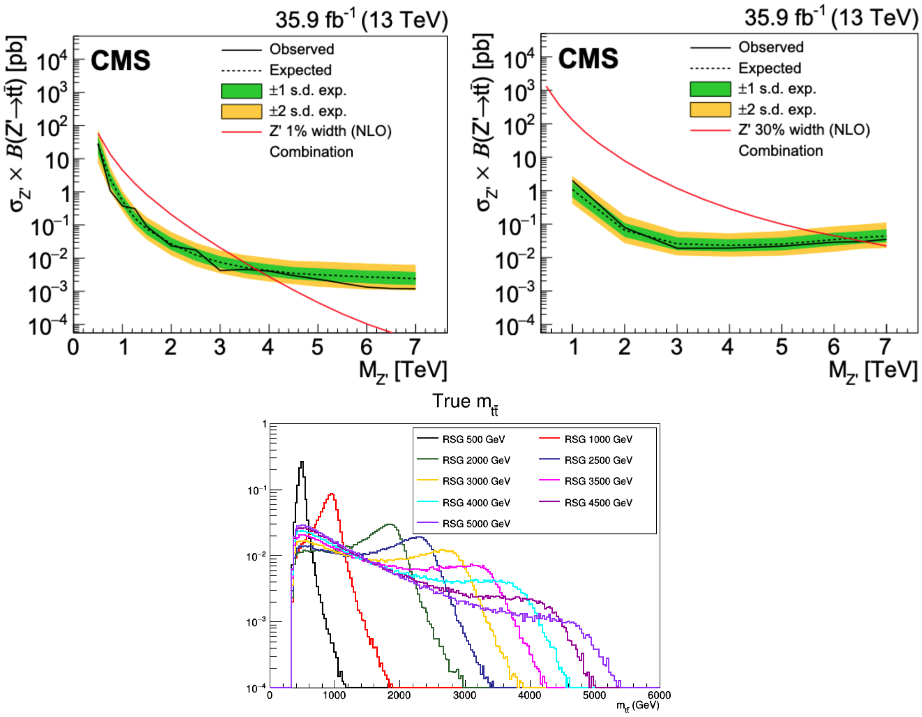

FIGURE 1. Observed mass exclusion limits at 95% confidence level for Z' signal hypotheses with 1% (top-left) and 30% (top-right) widths with respect to the mediator mass. The bottom plot shows the width-smearing effect of high mass RSG signals due to the momentum fraction carried by the incoming partons.[8]

mediator.[8] ATLAS has performed complementary analyses of ttbar resonances with up to $137 fb^{-1}$ of data, establishing limits on dark matter mediators up to 2.2 TeV and of 3% width Z' bosons up to 4.4 TeV.[9, 10, 11] Furthermore, the parton momentum distribution within protons in LHC conditions presents an additional complication of resonant Randall-Sundrum Gravitons (RSG) being harder to produce at high masses and thus smearing the width of the signal over a large mass range.

Looking Forward to Future Colliders. The future of the energy frontier will bring higher luminosities to LHC energies and with it more data, but more exciting still are the possibilities of higher energy colliders such as the Super Proton Proton Collider (SPPC) and Future Circular Collider (FCC). With the increase in beam energies comes shifts in the parton momenta which impact the production of ttbar resonances. We would like to study the discovery potential of all-hadronic searches for ttbar resonances at various center-of-mass energies of future colliders, as well as deepen our understanding of the challenges to come with these new machines in detecting the production of heavy resonances.

Study Strategy and Resources Needed. To evaluate the reach of future colliders, we propose first to extrapolate current analysis methods to HL-LHC conditions and expected data. Then we will contrast the discovery potential of ttbar resonance searches at the various FCC and SPPC energy benchmarks. With each study we wish to evaluate the performance of several substructure-based top-tagging methods. By studying the above, we can obtain information on baseline improvements due to the different colliding environments, as well as illustrate the potential gains that can be achieved by investing in novel analysis algorithm development. Since some of the authors of this Letter are developers of the Boosted Event Shape Tagger algorithm, we would like to include it in our evaluation of jet-substructure methods for top-tagging.[12]

In order to perform the study, we will need to generate MC samples of Z', Kaluza-Klein Graviton, and Randall-Sundrum Graviton benchmarks ($\sim 2 - 10\ TeV$) and the typical background processes at a hadron collider for ttbar resonance searches (W+jets, ttbar, ttH, high-pt QCD). In order to train a Machine Learning (ML) based tagger for the study, we would need additional, independent simulations of processes enriched in the boosted-objects tagged: X→bb/tt/WW/ZZ, high-pt QCD. For the training, the production mechanism is of secondary importance; what is crucial is that there are enough statistics to fit a robust ML model (∼1M jets with p_T of $2 - 10\ TeV$ per object type would be ideal) and that the sample is independent of the background and signal used in the analysis. In terms of the event information needed, we ask to have jets and their constituent information (Particle-Flow candidates, or truth particle ID + eta/phi/pt), as well as secondary-vertex information of the jet constituents for b-hadron tagging.

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