Search for heavy narrow $t\bar{t}$ Resonances in Muon-plus-Jets final States with the CMS Detector

Thomas Peiffer[1]

on behalf of the CMS Collaboration

[1] Institut für Experimentelle Kernphysik, KIT

Wolfgang-Gaede-Straße 1, 76131 Karlsruhe, Germany

Many physics models beyond the Standard Model predict heavy new particles preferentially decaying to top pairs. Such new particles are searched for in proton-proton collisions at a centre-of-mass-energy of 10 TeV with the CMS detector as resonances in the top pair mass spectrum. New methods are presented for the selection and analysis of these events with two highly-boosted top quarks decaying into a final state with jets and a muon.

1 Introduction

The top quark, discovered in 1995 by the Tevatron experiments [1, 2], is the heaviest known elementary particle. Because its mass is of the order of the electroweak symmetry breaking scale, the top quark plays a special role in many theories beyond the Standard Model (SM). Many of those models predict new gauge bosons, for instance heavy gluons, axigluons, Z'-bosons, or gravitons, which couple strongly to top quarks [3]. In all these cases, the production of top pairs at hadron colliders through beyond SM mechanisms leads to resonances in the top pair invariant mass ($M_{t\bar{t}}$) spectrum. Because the centre-of-mass energy at the proton-proton collider LHC will be a factor 5–7 larger than at the Tevatron, the search for heavy resonances decaying into top quark pairs will be soon more effective than at the Tevatron.

In the analysis presented here [4] the experimental sensitivity to a narrow resonance in the $M_{t\bar{t}}$ distribution was studied, assuming an integrated luminosity of 200 pb^{-1} expected to be collected with the CMS detector [5] within the first year of operation at a centre-of-mass energy of 10 TeV. This study focuses on the search for new heavy particles with a mass above 1 TeV/c^2, which decay to top pairs, where one top quark decays leptonically into a muon, a neutrino and a b-quark, and the other hadronically. The branching ratio of this muon+jets channel is about 15%.

2 Event selection and reconstruction

In case of a high mass resonance which decays into a top pair, the event kinematic differs from the event topology of a $t\bar{t}$ event produced in a Standard Model process. In SM top-pair production the decay products of the top quarks are distributed isotropically since the top quarks are mainly produced with low transverse momenta. For the muon+jets decay channel one would therefore expect to observe one isolated muon and four jets, where two of the jets are b-jets, which might be identified by a b-tagger. If the top quarks originate from the decay of a heavy particle, the top and the anti-top quarks are highly boosted. Their momenta are mostly in a back-to-back topology and the decay products of each top quark merge together. The hadronically decaying top quark will therefore often ends up in only one big jet instead of three well separated jets. The muon from the top quark which is assumed to decay leptonically will no longer be isolated, since it will be close to the b-jet from the top decay. Also the b-tagging requirements will work less optimal, due to decreasing b-tagging efficiency in case of highly boosted jets, for which it is more difficult to find secondary vertices, the main identification criterion for b-jets.

The event selection is therefore as follows: Only events accepted by a single-muon trigger are selected. At least one muon candidate is required to be reconstructed with a p_{T} larger than 15 GeV/c. Two jets are required to be reconstructed with a p_{T} larger than 50 GeV/c. The leading jet, possibly arising from the merging of the three quark jets from the hadronic top decay, is required to have a p_{T} above 260 GeV/c. No cut on the energy deposits in the calorimeters in a cone around the muon trajectory is applied, because the muon and the jet from the leptonic top decay might overlap for energetic top quarks. In place of this cut, events with $\Delta R_{\mathrm{min}} <0.4$ and $p_{\mathrm{T}}^{\mathrm{rel}} <35$ GeV/c are vetoed to strongly reduce the QCD multi-jet background, where ΔR_{min} indicates the minimum distance between the candidate muon and any reconstructed jet with $p_{\mathrm{T}} >30$ GeV/c and $p_{\mathrm{T}}^{\mathrm{rel}}$ is the transverse momentum of the muon relative to the direction of the closest jet with $p_{\mathrm{T}} >30$ GeV/c. For further background suppression, $H_{\mathrm{T}}^{\mathrm{lep}}$, defined as the sum of missing transverse energy and the transverse energy of the leading muon, has to exceed 200 GeV.

The invariant mass of the top pair is computed by reconstructing the four-vectors of the top quarks from the final state products: jets, muon and missing transverse energy due to the neutrino. The reconstruction method is adjusted to account for the special event kinematic of boosted top quark events. Particularly, the small angular separation of the decay products of the leptonically decaying top quark and the large separation of the two top quarks in a resonant decay are exploited. Details of the reconstruction are given in [4]. The result of event selection and reconstruction for backgrounds and signal is shown in Fig. 1. As signal, a Z' with masses of 1, 2 and 3 TeV/c^2 decaying to $\mathrm{t\bar{t}}$ is presented for an assumed scenario of 200 pb^{-1} integrated luminosity at $\sqrt{s}$=10 TeV of CMS data. The Z' cross section is assumed to be topcolor like [6].

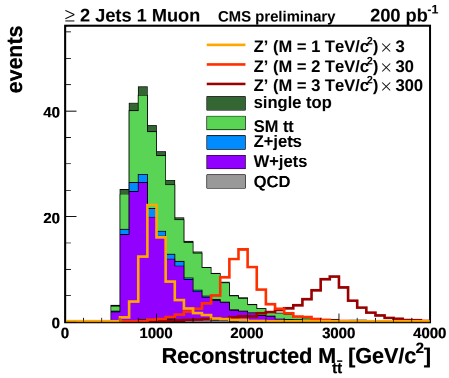

Figure 1: Distribution of reconstructed $M_{\mathrm{t\bar{t}}}$ with superimposed Z' signals. The Z' cross sections used for this illustration purpose are given in multiples of the topcolor Z' cross section [6].

3 Statistical analysis

The extraction of the signal cross section is done by performing a likelihood fit of the $M_{\mathrm{t\bar{t}}}$ distribution. As this distribution cannot separate different background processes well, a simultaneous fit to data is performed in a background enriched sideband. In the fit the rates for W+jets and QCD multi-jet backgrounds are kept as free parameters, while the rate of the

SM top pair background is constrained to the anticipated measured value within an statistical uncertainty of 20%.

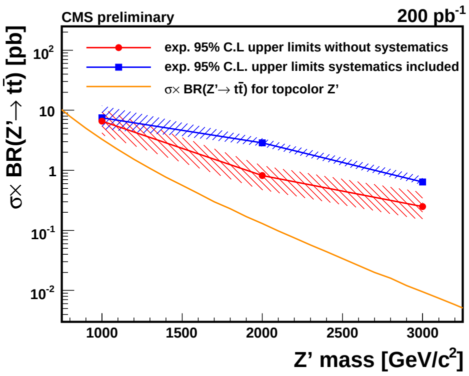

Figure 2: Expected limits on a narrow $t\bar{t}$ resonance with and without systematic uncertainties incorporated into the fit.

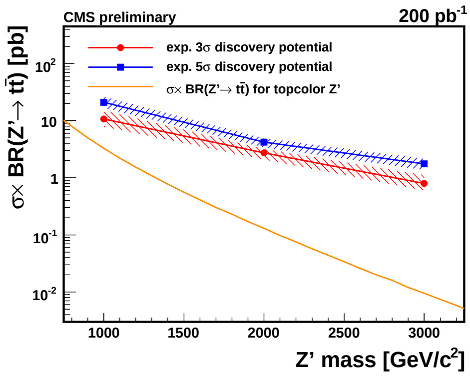

Figure 3: Expected cross sections of a $t\bar{t}$ resonance needed to claim a significance of 3 respectively 5σ with systematic uncertainties included.

Two physics aspects are exploited with the likelihood fit: A possible 95% C. L. exclusion limit on the cross section of a narrow resonance decaying to $t\bar{t}$ and the cross section, which would be required to claim a 3σ evidence or a 5σ discovery of such a signal (see Figures 2 and 3). Systematic uncertainties are incorporated into the fit and it has been found out, that the dominant systematic uncertainty is the uncertainty on the jet energy scale.

4 Conclusion

Assuming a scenario of 200 pb^{-1} collected at $\sqrt{s}$=10 TeV limits on heavy resonances decaying to top pairs in the multi-TeV range will be feasible for the first time. The cross section limits in reach are at the level of a few picobarn. While the obtained limits are not sufficient to exclude a topcolor Z', it is expected to set more stringent mass limits on models with heavy gluons or axigluons decaying to top pairs.

References

[1] F. Abe et al. Observation of top quark production in $\bar{p}p$ collisions. *Phys. Rev. Lett.*, 74:2626–2631, 1995.

[2] S. Abachi et al. Observation of the top quark. *Phys. Rev. Lett.*, 74:2632–2637, 1995.

[3] Rikkert Frederix and Fabio Maltoni. Top pair invariant mass distribution: a window on new physics. *JHEP*, 01:047, 2009.

[4] The CMS Collaboration. Search for heavy narrow $t\bar{t}$ resonances in muon-plus-jets final states with the CMS detector. CMS PAS EXO-09-008, 2009.

[5] R. Adolphi et al. The CMS experiment at the CERN LHC. *JINST*, 0803:S08004, 2008.

[6] Robert M. Harris, Christopher T. Hill, and Stephen J. Parke. Cross section for topcolor Z'(t) decaying to t anti-t. 1999.