Search for Scalar Top- Quark Production in the all Hadronic Channel at 13 TeV

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Abstract

A search for supersymmetry in all-hadronic events with missing transverse momentum is presented. The data were collected in proton-proton collisions at a center- of-mass energy of 13 TeV with the CMS detector at the LHC and correspond to an integrated luminosity of 2.3 fb^{-1}. Search regions are defined using the properties of reconstructed jets, the presence of b quark and top quark candidates, and miss- ing transverse momentum. No statistically significant excess of events above the expected contribution from standard model processes is observed. Exclusion limits are set on the masses of potential new particles in the context of simplified models of direct and gluino-mediated top squark production.

1 Introduction

A direct top squark production search is described in this document and refers to the HETT portion of Ref. [3] where the results are summarized here. The 'T2tt' and 'T2tb' models are looked at and illustrated in Fig. 1. In the T2tt model the stop decays to a top and neutolino. In the T2tb model the stop decays to a b quark and a neutolino.

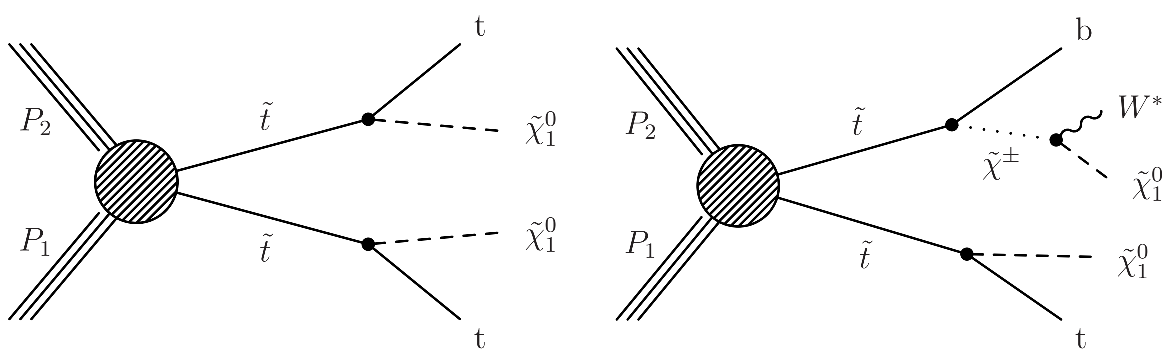

Figure 1: The top squark pair production with the top squark decaying into a top quark and neutralino or into a bottom quark and chargino.

2 CMS Detector

The detector used is the Compact Muon Solenoid (CMS) and is a multi-purpose detector of cylindrical design. More details of the main features of the detector can be found in Ref. [1]. For a jet to be considered a b-quark jet (b-tagged) it has to pass the medium working point requirements of the 'Combined Secondary Vertex' (CSV) method [2] and have $p_T > 30$ GeV and be within $|\eta| < 2.4$. The efficiency to identify the b-quarks is 67% overall. The probability of a jet originating from a light quark or gluon to be mis-identified as a b-quark jet is 1.4%, averaged over p_T in $\mathrm{t\bar{t}}$ events [2].

3 Search Strategy

Top tagging in this analysis is done using all AK4 jets that satisfy $p_T > 30$ GeV and $|\eta| < 5$. There are three categories in this algorithm for these jets: trijet, dijet, and monojet candidates. To deal with the trijet category we require the jets to lie within a cone of radius 1.5 in (η, ϕ) space. Within this cone they are subject to a set of conditions that are kinematically consistent with a top quark decay, more details are available in Refs. [3, 4]. Next the dijets category where one jet originates from the decay products of a W boson (W jet) that is merged, the mass is required to be between 70–110 GeV. Also the ratio of the Wjet and dijet masses are set to be between the ratio of the W boson and the top quark masses. Last but not least is the monojet category for this we have a single jet which we require to have a jet mass between 110–220 GeV. After all the categories are looked at and all the top candidates are found the final step is to require that there be one b jet and that the mass of the candidates be within this range 100–250 GeV. If these candidates pass these requirements they are considered a top jet Ref. [3].

In this analysis the 37 search regions are defined in terms of $\not\!\!E_{\mathrm{T}}$, M_{T2}, and the number of b-tagged jets and top-tagged objects which is shown in Fig. 3. Fig. 2 demonstrates the background composition following the pre-selection cuts for $\mathrm{N_t}$, and $\not\!\!E_{\mathrm{T}}$.

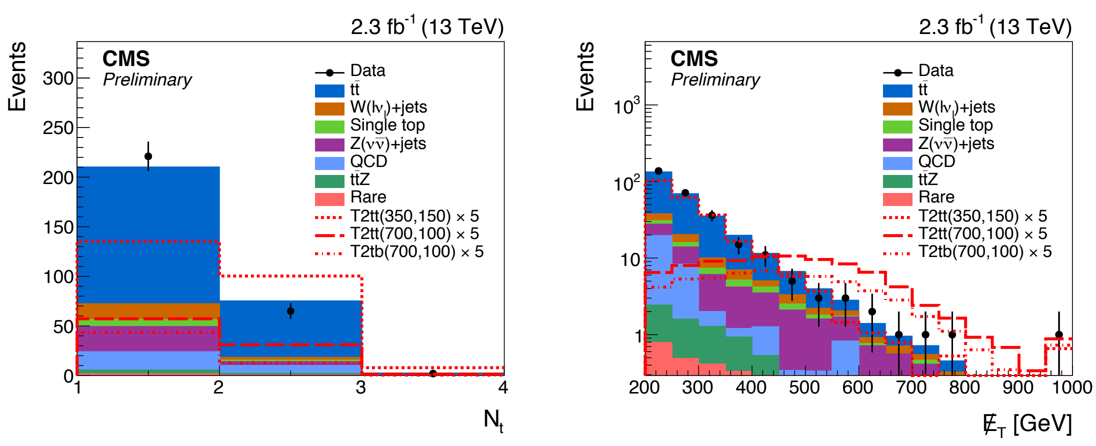

Figure 2: Background composition as a function of $\mathrm{N_t}$, and $\not\!\!E_{\mathrm{T}}$ between SM backgrounds (filled histograms) and several example T2tt signal models (dashed lines) and one T2tb model.

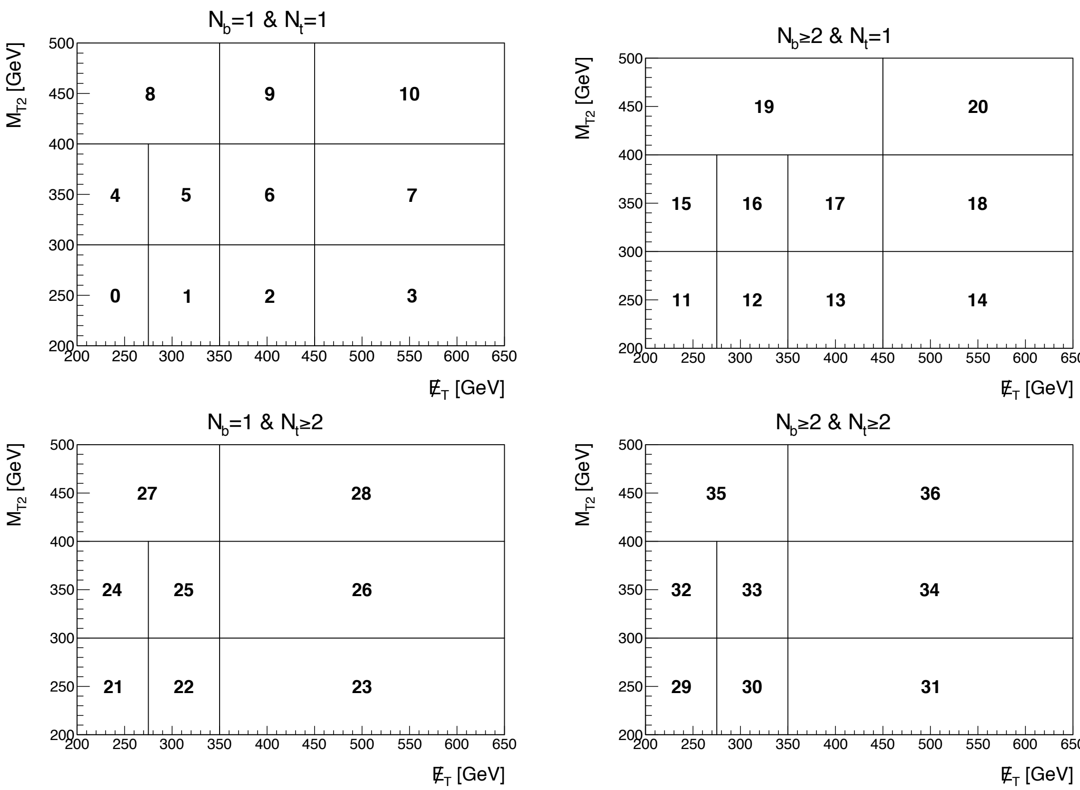

Figure 3: Search bin definitions. The highest $\not\!\!E_{\mathrm{T}}$ and M_{T2} bins are open-ended. An example of this is in bin 10 which requires $\not\!\!E_{\mathrm{T}}$> 450 GeV and M_{T2}> 400 GeV.

4 Backgrounds

4.1 Estimation of the Z$\rightarrow \nu\nu$ background

For the Z $\rightarrow \nu\nu$ background the Z $\rightarrow \nu\nu$ simulation is used in the interpret of this background. Corrections have been applied for the difference between simulation and data. Two scale factors are applied to simulated events. These factors are R_{norm} and $S_{\text{DY}}(N_{\text{j}})$, and they correct the normalization of the simulation and the shape of the simulated N_{j} distribution. To calculate the factors a dimuon control region is used.

The R_{norm} scale factor, is derived in data using the same selection as the search region pre-selection, apart from the muon requirement and the requirement on the b-tagged jets. The expected yield in the DY simulation in this region is compared to the observed event yield in data after subtraction of the other SM processes for the scale factor calculation.

The factor, S_{DY}, depends on the number of jets (N_{j}) in the event and is derived in a loose dimuon control region in which the signal region requirement on H_{T} is relaxed to $\text{H}_{\text{T}} > 200$ GeV and the requirements on $\not{E}_{\text{T}}$, N_{t} and M_{T2} are removed. This scale factor is derived for each N_{j} bin as the ratio between the data, with non-DY backgrounds subtracted, and the DY simulation.

4.2 Estimation of the QCD multijet background

In order to predict the QCD multijet background a QCD multijet-rich data control region with minimum signal is achieved by inverting the pre-selection requirements on $\Delta\phi(\not{E}_{\text{T}}, j_{1,2,3})$. A little of the other SM backgrounds remain, such as $\text{t}\bar{\text{t}}$, W+jets, and Z+jets so they are subtracted out. The method used for lost leptons and hadronic τ's in this analysis are also used to subtract out those backgrounds in this region. For Z $\rightarrow \nu\nu$ simulation is used because the contribution is so small. The number of QCD multijet events is measured in the data control region and a translation factor is applied to predict the amount of the QCD multijet background in each search bin. The translation factor is calculated in data and partly by simulation. It is computed as a simulated ratio between the signal region and the inverted-$\Delta\phi$ control region, in bins of $\not{E}_{\text{T}}$ and M_{T2} where the bin boundaries follow those of the signal bins. The overall shape of this translation factor is kept from simulation. The value is normalized to data. Where the data measurement is in a sideband of the pre-selection region and is defined by the requirement $175 < \not{E}_{\text{T}} < 200$ GeV, where the amount of data is sufficiently large to make an accurate measurement.

4.3 Estimation of the τ background

The biggest contribution to the SM background comes from $\text{t}\bar{\text{t}}$ and W+jets events with leptonic W decays. In one case a τ lepton decays hadronically from the W boson which is reconstructed as a jet in this case the lepton would pass all of our veto requirements, this we call the hadronic τ background. In the other case where the W boson decays to an electron or muon, than the veto on leptons are satisfied unless the lepton is 'lost'. By 'lost' we mean not isolated, not identified/reconstructed, or out of the acceptance region.

To model these lost leptons (LL) a weighted data sample that consists mainly of $\text{t}\bar{\text{t}}$ events is used. The search trigger and the pre-selection are the same in this region but the muon veto is replaced requiring there be exactly one isolated muon with $p_T > 10$ GeV and $|\eta| < 2.4$, where the isolated track veto is removed. Also required is that the $M_T < 100$ GeV this is used to reduce any signal contamination. The M_T is reconstructed from the muon p_T. and is defined as $M_T = \sqrt{2p_{\text{T}}^{\mu}\not{E}_{\text{T}}(1-\cos(\Delta\phi))}$, where $\Delta\phi$ is the distance in ϕ between the muon and the $\not{E}_{\text{T}}$ vector.

The weight factor is defined as taking into account acceptance, reconstruction and identification, and isolation efficiencies multiplied by a factor that accounts for dilepton events where both leptons are lost is applied to the sum over the events in the single-muon control region, where this includes events with lost leptons from $t\bar{t}$, W+jets, and single-top processes. A further correction is applied in order to take into account the efficiency of the $M_T < 100$ GeV requirement. The final correction that is applied is to take into account the isolated track veto efficiency.

The estimate of the remaining hadronic τ's background is calculated by taking the signal region after applying the isolated track veto and is based on a control sample of $\mu+$jets events selected from data using a muon and $\mathrm{H_T}$-based trigger, and requiring exactly one muon with $p_T^{\mu} > 20$ GeV and $|\eta| < 2.4$. A cut on the transverse mass of the W boson, $M_T < 100$ GeV, is required to select events containing a $\mathrm{W} \to \mu\nu$ decay and to suppress potential signal events from being present in the $\mu+$jets sample.

The muon p_T is smeared by response template distributions derived for a hadronically-decaying τ lepton to correct the leptonic part of the event. The response templates are derived using $t\bar{t}$and W+jetsMC by comparing the true τ lepton p_T with the reconstructed hadronic τ's jet p_T. The kinematic variables of the event are recalculated with this hadronic τ's jet, and the search selections are applied. The probability to mistag a hadronic τ's jet as a b jet is significant and affects the $\mathrm{N_b}$distribution of hadronic τ's background events. This effect is taken into account in the same way as in Ref. [3].

The hadronic τ's background prediction is calculated as a sum over all events in the $\mu+$jets control sample weighted by the τ_h response. Additional corrections are applied. A few corrections are the muon acceptance, the M_T selection efficiency, the contamination in the control sample from muons from τ decays, the isolated track veto efficiency,

5 Results

In Fig. 4 the number of events observed in data and the SM background predictions for the search region defined above are shown. In general the most significant background across the search regions comes from the SM $t\bar{t}$ production or W-boson production and the lepton is not detected or where the W boson decays hadronically. The next largest contribution is $\mathrm{Z} \to \nu\nu$ production in association with jets, which also including heavy-flavor jets, where the neutrino pair gives large $\not\!\!E_\mathrm{T}$ and the top quark conditions are satisfied by a combination of jets accidentally. The rest of the backgrounds are small contributions.

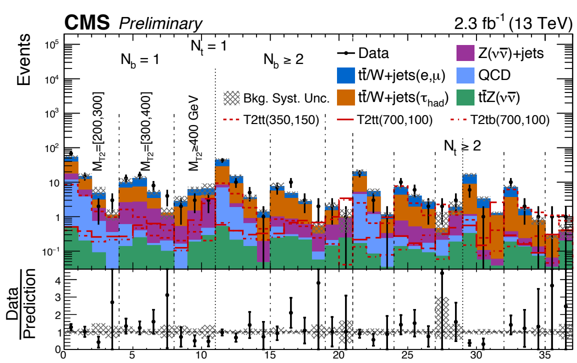

Figure 4: The black points are observed event yields in data and the filled solid areas are the predicted SM backgrounds for the 37 search bins of this analysis. The ratio of data over total background prediction in each search bin is shown in the latter half of the plot. In the ration only statistical uncertainties are propagated.

The binned likelihood fit to the observed data is the statistical interpretation of the results for the exclusion limits for both T2tt and T2tb models. This takes into account the predicted background and expected signal yields with their uncertainties in each bin. Exclusion limits are extracted based on a modified frequentist approach [3] using a profile likelihood ratio as test statistic. If the 95% upper limit on the production cross section falls below the theoretical cross section the signal models are considered to be excluded by the analysis.

Figures 5 show the 95% CL exclusion limits obtained, for both the pure T2tt scenario, and in the mixed T2tb scenario assuming a 50% branching fraction for each of the two decay modes ($\tilde{t} \rightarrow t\tilde{\chi}_1^0/\tilde{t} \rightarrow b\ \tilde{\chi}_1^{\pm}$). In the T2tb model the $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$ have a 5 GeV mass difference this is because there masses are assumed to be nearly degenerate. Using the 2.3 fb^{-1} dataset, for the T2tt model stop masses are up to 780 GeV and LSP masses up to 260 GeV are probed. In the T2tb model, stop masses up to 750 GeV and LSP masses up to 200 GeV are probed. Observed weaker limits than expected for the LSP mass in the T2tb model because the most sensitive bins have a small excess.

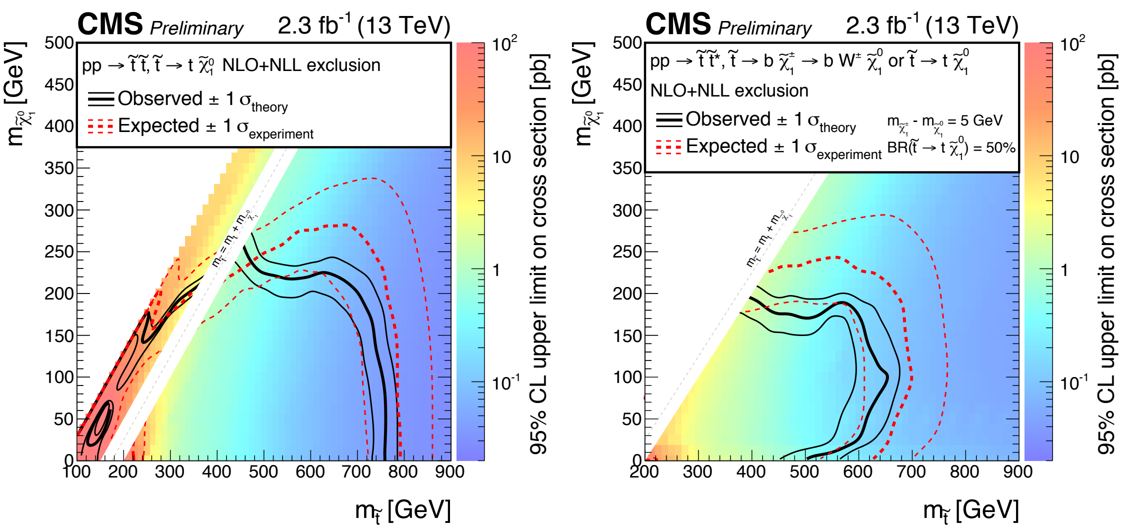

Figure 5: The solid black curves represent the observed exclusion contours and the corresponding ±1 standard deviations. The expected exclusion contour is the dashed red curves and includes a ±1 standard deviations with experimental uncertainties.

References

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