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Search for supersymmetry in events with two leptons including a tau

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Abstract. Searches for new physics in events with hadronic jets, missing transverse energy, and two leptons of which at least one is a hadronically decaying tau are presented. The result is based on a data sample corresponding to an integrated luminosity of 1 fb^{-1} at a center-of-mass energy of 7 TeV collected by the CMS experiment at the LHC. No significant excess with respect to the standard model predictions is found.

1 Introduction

This article summarizes searches for physics beyond the Standard Model (BSM), analyzing $\int Ldt \approx 1\text{fb}^{-1}$ of data recorded by the Compact Muon Solenoid Experiment (CMS). Proton-proton collisions where provided by the LHC at center of mass energies of $\sqrt{s} = 7\text{TeV}$ in 2011 .

CMS conducted several searches for BSM in finale states characterized by large missing transverse energy (E_T^{miss}) and hadronic activity. On the one hand, the high E_T^{miss} signature occurs in models with weakly interacting particles that escape detection, which are favored by cosmological measurements. On the other hand, hadronic activity accours naturally in colored particle interactions dominating BSM cross sections in proton-proton collisions. In this article we focus on finale states containing a combination of two leptons, at least one of which is required to be a hadronically decaying tau (eτ_h, $\mu\tau_h$, or $\tau_h\tau_h$). The charges of these two leptons can be either of same sign [1] or opposite sign [2], leading to different selection and background estimation strategies. The study concerning same and opposite sign finale are described in sections 3 and 4, respectively.

In both cases hadronic jets and $E_T^{miss}$are reconstructed using the particle flow technique [3] and jets are clustered using the anti-kt algorithm [4]. The amount of hadronic activity in the event is measured by the quantity $H_T = \sum p_T^{jet}$ and the requirement of two or more jets per event. Hadronically decaying tau leptons (τ_h) are identified using the HPS algorithm [5]. To suppress multi-jet QCD backgrounds all leptons are required to be isolated.

2 The CMS Detector

The central feature of the Compact Muon Solenoid (CMS) apparatus is a superconducting solenoid, of 6 m internal diameter, providing a field of 3.8 T. Within the solenoids volume are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter (ECAL) and the brass/scintillator hadron calorimeter (HCAL). Muons are measured in gas-ionization detectors embedded in the steel return yoke. In addition to the barrel and endcap detectors, CMS has extensive forward calorimetry. A much more detailed description of CMS can be found elsewhere [6].

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3 Same Sign Search

Finale states with two leptons of the same charge are rare in the Standard Model (SM). Thus, the main backgrounds for this search are quark or gluon jets misidentified as a τ_h (e.g. in W+jets events) and events where the charge of one of the leptons is misidentified (e.g. in dileptonic $t\bar{t}$ events). Both backgrounds are estimated directly from data as described in sections 3.2 and 3.3. The influence of light leptons not produced in the hard scattering (e.g. from heavy flavor decays) is small compared to that of misidentified τ_h due to the abundance of hadronic jets in the region of interest. Contributions from rare same sign SM processes such as diboson production, double W strahlung, or double parton scattering are small and estimated using simulation.

3.1 Event Selection

The same sign search region is selected requioring $H_T > 350$ GeV and $E_T^{miss} > 80$ GeV. For the requirement of two or more jets and in calculating H_T jets with transverse momenta $p_T > 40$ GeV are considered. Leptons are required to be in $|\eta| < 2.4$ and have transverse momenta of $p_T^e > 10\,GeV, p_T^{\mu} > 5\,GeV, p_T^{\tau_h} > 15\,GeV$, to ensure efficient trigger selection.

3.2 Estimating Misidentified Jet Contribution

The HPS τ_h identification algorithm distinguishes hadronic jets created in the decay of a τ lepton from those created in the hadronisation of a quark or gluon by means of isolation and reconstructed particle content. Nonetheless, the selection of hadronically decaying τ leptons always includes a remaining contamination by misidentified quark or gluon jets.

In order to estimate this contamination we employ the tight-to-loose method (TL). First, we define a loose τ_h selection by relaxing the isolation requirement, in addition to

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Table 1. Predicted backgrounds and observed event yields in the search region (H_T > 350 GeV and E_T^{miss} > 80 GeV). Statistical and systematic errors have been added in quadrature. The upper limit is set using the CL_Smethod.

	$e\tau_h$	$\mu\tau_h$	$\tau_h\tau_h$	Total	95% CL UL yield
Predicted background	1.1 ± 0.4	1.8 ± 1.4	0.0 ± 0.2	2.9 ± 1.7	
Observed	1	2	0	3	5.8

the tight τ_h selection used in the analysis. Second, we measure the fraction f_{TL} of loose candidates, which pass the tight criteria in a sample containing predominately quark and gluon jets. Finally, we extrapolate the expected number of misidentified tight τ_h candidates from the number of observed loose candidates in the signal region.

The tight-to-loose ratio f_{TL} mainly depends on the transverse momentum and pseudorapidity of a given τ_h candidate and is measured in bins of those variables. The difference in H_T of the region where f_{TL} is measured and the search regions are minimised in the definition of the loose selection. The results of this procedure have been shown to be in good agreement with background simulation.

3.3 Estimating Misidentified Charge Contribution

Backgrounds due to charge misidentification arise from the relative abundance of SM processes with two leptons of opposite charge, at least one of which is an electron or hadronically decaying τ. The contribution of muons with misidentified charge is found to be negligible. The misreconstruction of Electron charge occurs due to energy loss in the tracking volume. Furthermore, τ_h charge misidentification occurs in three prong τ_h decays, when a track form the background is wrongly associated with the τ_h object.

To estimate the impact of these effects, we compare the number of opposite- and same sign dilepton pairs near the Z resonance. The Drell-Yan (DY) signal is fitted in the dilepton invariant mass spectrum alongside backgrounds form misidentified leptons and other SM processes. We identify the probability f_q^ℓ of lepton charge misidentification as the ratio of dilepton pairs recontructed with the same sign to those reconstructed with opposite sign.

For electrons we measure $f_q^e = 2 \cdot 10^{-4}$ $(3 \cdot 10^{-3})$ in the ECAL barrel (endcap). Differences arise due to differences in the amount of tracker material in front of the ECAL crystals.

For three prong τ_h decays we measure $f_q^{\tau_h} = 7.1 \pm 1.0_{stat.} \pm 2.5_{syst.}\%$.

Again results from this data driven background estimation are in agreement with background simulation.

3.4 Results

A summary of the predicted background and the observed yield in the search region is given in table 1. We do not observe evidence of an event yield in excess of the SM based predictions and set 95% CL upper limits (UL) on the number of observed BSM events. The hybrid frequentist-baysian CL_Smethod [7] is applied, including nuisance parameters and the signal strength maximizing the ratio of the signal with background and background only likelihoods.

Table 2. Predicted backgrounds and observed event yields in the high E_T^{miss}(H_T > 300 GeV and E_T^{miss} > 200 GeV) region for the opposite sign $e\tau_h$and $\mu\tau_h$ channels and for the $\tau_h\tau_h$ search region (≥ two jets with p_T^{jet} > 100 GeV and H_T^{miss} > 200 GeV). Errors are separated in statistical and then systematic uncertainty.

	$e\tau_h + \mu\tau_h$	$\tau_h\tau_h$
$p_T(\ell\ell)$ Prediction	5.9 ± 1.5 ± 1.9	—
TL Prediction	1.6 ± 0.6 ± 0.2	—
QCD	—	0.58 ± 0.02 ± 0.41
W+Jets	—	0.00 ± 1.20 ± 0.10
$t\bar{t}$	—	2.18 ± 2.18 ± 0.35
$Z \to \nu\bar{\nu} + Jets$	—	0.00 ± 0.16 ± 0.02
$\sum$ Prediction from data	7.5 ± 1.6 ± 1.9	2.76 ± 2.50 ± 0.55
$\sum SM$ simulation	9.6 ± 4.2 ± 3.1	4.56 ± 1.08 ± 0.91
Data	8	3

4 Opposite Sign Search

In contrast to the same sign search there are several SM processes, such as DY and $t\bar{t}$ decays, with finale states containing two leptons of oposite charge. The background from DY processes can be sufficiently suppressed by the choice of search region. However, contributions from $t\bar{t}$ decays remain. For the channels $e\tau_h$ and $\mu\tau_h$ those are estimated from data as described in section 4.2. Naturally backgrounds due to misidentified quark and gluon jets remain and are estimated as described in section 3.2. Furthermore, the fully hadronic finale state $\tau_h\tau_h$ is treated differently than the other finale states: Here we define background enriched sideband regions for each considered background. In this instance f_{TL}^{bkg} is taken from simulation. Backgrounds are predicted extrapolating from the number of loose candidates in a background enriched sideband to the search region.

4.1 Event Selection

For the finale states containing a light lepton ($e\tau_h$ and $\mu\tau_h$) two search regions are defined (Fig. 1). For brevity we focus on the high E_T^{miss} region (H_T > 300 GeV and E_T^{miss} > 200 GeV). Jets with transverse momenta p_T > 30 GeV are considered in H_T and the two jet requiroment. All leptons are selected to have $|\eta| < 2.1$ and $p_T^\ell > 20$ GeV.

For the $\tau_h\tau_h$ finale state two jets of transverse momenta p_T > 100 GeV are required and instead of E_T^{miss} the correlated variable $H_T^{miss} = |\sum \mathbf{p}_T^{jet}| > 200$ GeV is used, for jets satisfying $p_T^{jet} > 30$ GeV. This is done to minimize turn-on effects due to the trigger selection. Als the HPS τ_h identification and transverse momentum requirement ($p_T^{\tau_h}$ > 15 GeV) are relaxed, in order to maximize the statistical significance of the result.

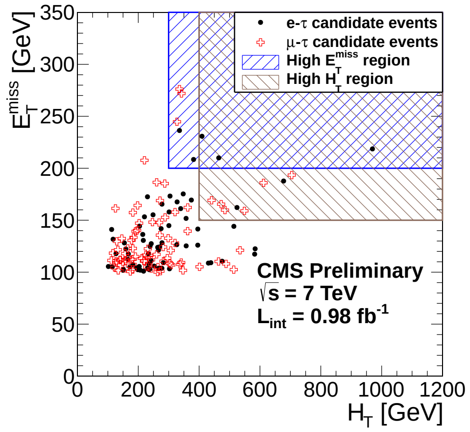

Fig. 1. Distributions of E_T^{miss}vs. H_T for data. The high E_T^{miss}(high H_T) search region is indicated with the blue forward hatched (brown backward hatched) region.

4.2 Estimating Dileptonic $t\bar{t}$ Contribution

We use the dilepton transverse momentum ($p_T(\ell\ell)$) method to estimate the contribution of dileptonic $t\bar{t}$ events in the signal region of opposite sign $e\tau_h$ and $\mu\tau_h$ events. We estimate the contribution of $t\bar{t}$ events to the corresponding light lepton channels (ee, eμ, and $\mu\mu$), following the idea [8] that the variable $p_T(\ell\ell)$ can be used to model $E_T^{miss} = p_T(\nu\nu)$ [9].

Here, we exploit the fact that in dileptonic $t\bar{t}$ decays the p_T distributions of the leptons are related to those of the neutrinos via the common boosts from the intermediate top and W decays. This relation is governed by the well understood W polarization, which can be reliably accounted for.

Contamination by events which stem from Z decays is first reduced by a $76 < m_{\ell\ell} < 106$ GeV and a $E_T^{miss} > 50$ GeV requirement. The remaining contribution is then predicted and subtracted using the same procedure as in Ref. [10]. The bias of the $p_T(\ell\ell)$ distribution due to the E_T^{miss} requirement is measured and accounted for.

Finally, lepton universality allows us to extrapolate from the light lepton channels to the τ_h channels in question. In this, τ_h reconstruction efficiency, acceptance, and branching ratios are taken from simulation.

4.3 Results

A summary of the observed event yields and the data driven background predictions in the search regions is given in table 2. We observe no excess of events over the SM predictions. Also these predictions are shown to be in agreement with SM expectations from simulation.

We procede to evaluate three benchmark scenarios, referred to as LM1, LM2 and LM13, of the minimal supersymmetric extension of the standard model (cMSSM) [11]. The parameter values for [LM1, LM2, LM13] are m_0 = [60, 185, 270], $m_{1/2}$ = [250, 350, 218], $\tan\beta$ = [10, 35, 40], A_0 = [0, 0, −553], and $\mu > 0$ [12]. We place 95% confidence level upper limits on the cross section of those scenarios using again the CL_S method (Table 3). The combination of the three channels takes differences in search regions and correlations of the uncertainties into account.

Table 3. Summary of model cross sections as well as expected and measured 95% upper limits as derived through the CL_Smethod.

Model	σ^{NLO}_{model} [pb]	UL $\sigma^{CL_S^{95\%}}_{expected}$ [pb]	UL $\sigma^{CL_S^{95\%}}_{measured}$ [pb]
LM1	6.6	2.4 ± 1.4	2.8
LM2	0.8	0.6 ± 0.3	0.6
LM13	9.8	1.2 ± 1.0	1.5

All three scenarios are ruled out by the presented results. Furthermore we publish [2] additional information to allow testing of specific BSM models against these results.

5 Conclusion

Searches for physics beyond the standard model with τ_h final states using $\approx 1 fb^{-1}$ of integrated luminosity are summarized. Dominant backgrounds are estimated from the data taking the challenges of the hadronic τ finale state into account. No deviation from the SM is found and 95% CL upper limits are computed.

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