PROCEEDINGS OF SCIENCE

Search for the electroweak production of charginos in final states with two τ's in pp collisions at $\sqrt{s} = 8$ TeV using 2012 CMS experiment data

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The results of the search for electroweak production of supersymmetric particles with two tau leptons in the final state are presented. The data of proton-proton collisions at $\sqrt{s} = 8$ TeV collected with the CMS detector corresponding to 18.1 to 19.6 fb^{-1} is used for this analysis. The observed events are found to be consistent with the standard model prediction. The results are interpreted to set upper limits on the masses of the lightest chargino and the lightest neutralino.

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1. Introduction

Supersymmetry (SUSY) [1] is one of the most promising extensions of the standard model (SM) of elementary particles. It addresses most of the SM shortcomings by introducing new particles with the same properties as SM particles but differing in spin by half a unit. Extensive searches at the CERN LHC have excluded the existence of colored sparticles with masses below a few hundred GeV to about 1 TeV, for different production and decay scenarios [2, 3, 4, 5, 6, 7, 8, 9].

Several searches for the electroweak production of SUSY have been performed by the CMS and ATLAS collaborations and are documented in Refs. [10, 11, 12, 13, 14]. In various SUSY models, the lightest SUSY partners of SM fermions are those from the third generation, resulting in enhanced branching fractions for final states with taus [15]. In this report, a search for charginos using events with two opposite-sign τ leptons and missing transverse momentum ($p_{\mathrm{T}}^{\mathrm{miss}}$), assuming the masses of the third-generation sleptons are between those of the chargino and the lightest neutralino is described [16]. Two τ leptons can be generated in the decay chain of $\widetilde{\tau}$ or charginos ($\widetilde{\chi}_1^+$) as shown in Fig. 1.

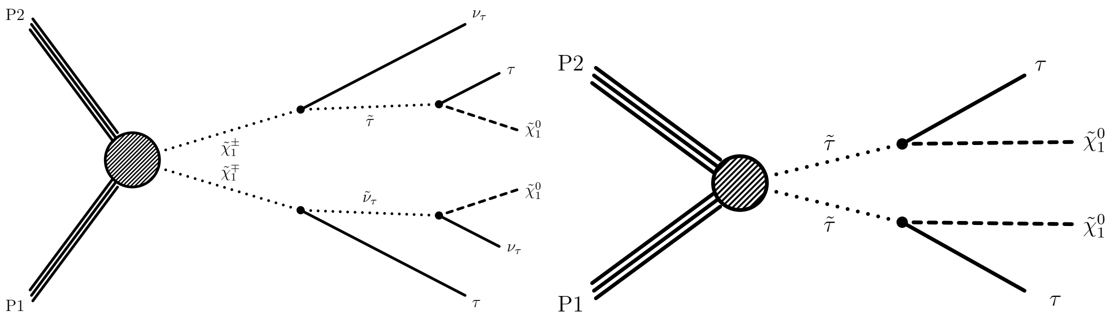

Figure 1: Schematic production of double τ from chargino pair and stau pair.

2. Event reconstruction and selection

64% of τ leptons decay hadronically and the rest decay either into an electron or μ. This analysis is designed to include events with at least one hadronic decay of the τ lepton (τ_{h}). Due to different background compositions, the $\tau_{\mathrm{h}}\tau_{\mathrm{h}}$ and $\ell\tau_{\mathrm{h}}$ selections are optimized separately.

In CMS, hadronically-decaying τ leptons, are reconstructed using the hadron-plus-strips algorithm [17]. The constituents of the reconstructed jets are used to identify individual tau decay modes with one charged hadron and up to two neutral pions, or three charged hadrons. Additional discriminators are used to separate τ_{h} from electrons and muons. Prompt τ leptons are expected to be isolated in the detector. To discriminate them from QCD jets, we use a measure of isolation based on the charged hadrons and photons falling within a cone around the tau momentum direction after correcting for the effect of pileup. A similar isolation algorithm is used in this analysis to separate leptons (e or μ) from tau decays from those arising from hadron decays within jets.

In addition, in order to separate backgrounds, the transverse mass (m_{T}) and its extension M_{T2} [18, 19] are used.

2.1 Event selection for the $\tau_{\mathrm{h}}\tau_{\mathrm{h}}$ channel

Events which fire the di-τ_{h} trigger [20] which requires the existence of two loosely identified, isolated τ_{h} candidates with $p_{\mathrm{T}} > 35\,\mathrm{GeV}$ and $|\eta| < 2.1$ are used for this channel.

After the full reconstruction, the two τ_h candidates are required to pass the medium working point [17] of τ isolation discriminator, fulfill $p_T > 45$ GeV and $|\eta| < 2.1$, and be of opposite charge.In events with more than one $\tau_h\tau_h$ pair, we only consider the pair with the most isolated τ_h objects. Events with isolated extra electrons or muons are rejected to suppress backgrounds from diboson decays. The background from $Z \to \tau_h\tau_h$ events is discarded by rejecting events where the visible di-τ_h invariant mass is between 55 and 85 GeV (Z veto). Furthermore, contributions from low-mass Drell-Yan and QCD multijet production are reduced by requiring the invariant mass to be greater than 15 GeV. To suppress more $Z \to \tau_h\tau_h$ and QCD multijet contributions, $p_T^{miss} > 30$ GeV and $M_{T2} > 40$ GeV are required. The minimum angle $\Delta\phi$ in the transverse plane between the $\vec{p}_T^{miss}$ and any of the τ_h and jets, including b-tagged jets, must be greater than 1. This requirement reduces backgrounds from QCD multijet events and W+jets events.

After applying the pre-selection described above, additional requirements are introduced to define two search regions (SR). The first search region (SR1) which includes events with $M_{T2} >$ 90 GeV, targets the models with large mass difference (Δm) between charginos and neutralinos. The second search region (SR2) is dedicated to models with small Δm. Events with $M_{T2} < 90$ GeV fall in this SR. To provide additional discrimination between signal and SM background processes, the sum of the two transverse mass values, $\Sigma m_T^{\tau_i} = m_T(\tau_h^1, p_T^{miss}) + m_T(\tau_h^2, p_T^{miss})$, is requested to be greater than 250 GeV. To discard $t\bar{t}$ events, b-tagged jets are also vetoed.

2.2 Event selection for the $\ell\tau_h$ channel

Events in the $\ell\tau_h$ final states ($e\tau_h$ and $\mu\tau_h$) were collected with triggers that require a loosely isolated τ_h with $p_T > 20$ GeV and $|\eta| < 2.3$ as well as an isolated electron or muon with $|\eta| < 2.1$. The minimum p_T requirement for the electron (muon) was increased during the data taking from 20 to 22 GeV (17 to 18 GeV) due to the increase in instantaneous luminosity.

In the offline analysis, the electron, muon, and τ_h objects are required to have $p_T > 25$, 20, and 25 GeV, respectively, while tightening the corresponding identification and isolation requirements. In events with more than one opposite-sign $\ell\tau_h$ pair, we only consider the pair that maximizes the scalar sum of τ_h and electron or muon transverse momenta. Events with an additional loosely isolated lepton with $p_T > 10$ GeV are rejected to suppress backgrounds from Z boson decays.

Just like for the $\tau_h\tau_h$ channel, we apply preselection requirements to suppress QCD multijet, $t\bar{t}$, $Z \to \tau\tau$, and low mass resonance events. These requirements are: $M_{T2} > 40$ GeV, $p_T^{miss} >$ 30 GeV, $\ell\tau_h$ invariant mass between 15 and 45 GeV or > 75 GeV, $\Delta\phi > 1$. We reject events with b-tagged jets. The final signal region requirements are $M_{T2} > 90$ GeV and $m_T^{\tau_h} > 200$ GeV. The latter requirement provides discrimination against the W+jets background. Unlike the $\tau_h\tau_h$ channel, events with $M_{T2} < 90$ GeV are not used because of the higher level of background.

3. Backgrounds

In the $\tau_h\tau_h$ channel, backgrounds with real τ_h's including $t\bar{t}$ and Z+jets backgrounds are estimated using MC simulation, after verifying in dedicated control regions. To estimate the contribution of W+jets events, the efficiency of the M_{T2} and $\Sigma m_T^{\tau_i}$ cuts are measured in an enriched control region which can be obtained by loosening other cuts. Considering correlations, the cut efficiencies are obtained in the simulation and are verified in a W+jets enriched control sample of data.

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Table 1: The estimated QCD multijet background event yields in the $\tau_h\tau_h$ channel. The first two uncertainties are statistical and systematic uncertainties of the method, the last uncertainty is the extra systematic uncertainty due to correlation assumptions.

Signal Region	QCD Estimation
$\tau_h\tau_h$ SR1	0.13 ± 0.06(stat) $\pm$ 0.18(sys) $\pm$ 0.10(fit)
$\tau_h\tau_h$ SR2	1.15 ± 0.39(stat) $\pm$ 0.70(sys) $\pm$ 0.25(fit)

To estimate the contribution of QCD multi-jet background in the $\tau_h\tau_h$ channel, the so-called ABCD method has been exploited. To make a QCD dominated control-region, τ_h isolation cut is reversed and same-charge events are selected. The ratio of QCD events in signal region and control region is determined in low M_{T2} and low $\Sigma m_T^{\tau_i}$ regions by subtracting the contribution of other backgrounds taken from simulation from data. The correlation of the M_{T2} and $\Sigma m_T^{\tau_i}$ cuts on the ratio is considered and the QCD contamination in the signal region is obtained and reported in Table 1. For the $\ell\tau_h$ channels, the main background is due to the misidentification of τ_h. This contribution is estimated using a method that takes into account the probability that a loosely isolated misidentified or real τ_h, passes the tight isolation. If the signal selection is done using the τ_h objects which pass the "loose" isolation instead of "tight", the number of loose τ_h objects (N_{Loose}) is:

$$N_{Loose} = N_{Real} + N_{Fake} \tag{3.1}$$

where N_{Real} is the number of real τ_h objects and N_{Fake} is the number of misidentified τ_h objects. If the selection is tightened, the number of tight τ_h objects (N_{Tight}) is

$$N_{Tight} = r_{Real} \times N_{Real} + r_{Fake} \times N_{Fake} \tag{3.2}$$

where r_{Real} (r_{Fake}) is the real (fake) rate, the probability that a loosely selected real (misidentified) τ_h object passes the tight selection. Knowing r_{Real} and r_{Fake} one can obtain $r_{Fake} \times N_{Fake}$ which is the contamination of misidentified τ_h objects to the signal region.

The fake rate is measured in a sample which is dominated by misidentified τ_h objects and is found to be 0.54 ± 0.01. The real rate (r_{Real}) is measured in simulated DY events, and it is found to be $r_{Real} = 0.766 \pm 0.003$. A conservative relative systematic uncertainty of 5% is assigned to the central value of r_{Real} and r_{Real} to cover their fluctuations in different values of M_{T2}. The uncertainties on the fake rate and the real rate are negligible compared to the statistical uncertainties associated with the sidebands.

The estimates of the misidentified τ_h contamination in the two $\ell\tau_h$ channels are summarized in Table 2. The relative statistic and systematic uncertainties are reported separately.

4. Systematic uncertainties

Systematic uncertainties can affect the shape or normalization of the backgrounds estimated from simulation ($t\bar{t}$, Z+jets, dibosons and Higgs boson), as well as the signal acceptance.

Systematic uncertainties due to τ_h energy scale, τ_h and lepton id and trigger efficiencies, simulation of the initial state radiation in the signal events and its effect on the b-tagged jet veto and

Table 2: Estimation of the misidentified τ_h contribution in the signal region of the $\ell\tau_h$ channels. The total systematic is the quadrature sum of the fractional systematics. All uncertainties are relative. r_{Fake} (r_{Real}) is shorthand for fake (real) rate.

Channel	Total Fake	stat	r_{Fake} sys	r_{Real} sys	Total Unc
$\mu\tau_h$	8.15	56%	18%	5%	59%
$e\tau_h$	3.30	101%	17%	2%	102%

Table 3: Summary of systematic uncertainties that affect the signal event selection efficiency and the background normalization and their shape.

	Background			Signal		
Systematic uncertainty source	$\ell\tau_h$	$\tau_h\tau_h$ SR1	$\tau_h\tau_h$ SR2	$\ell\tau_h$	$\tau_h\tau_h$ SR1	$\tau_h\tau_h$ SR2
Total shape-altering sys.	11%	16%	16%	6-13%	7-16%	
Total non-shape-altering sys.	9%	16%	16%	14%	20%	21%
Total Systematic	14%	22%	22%	15-19%	21-25%	22-26%
Monte Carlo Statistic	22%	13%	70%		3-15%	
Total	26%	26%	73%	15-24%	21-29%	22-30%
Low rate backgrounds		50%			-	

p_T^{miss} have been estimated. The main sources of uncertainty are found to be the τ_h energy scale and the lack of Monte Carlo statistics.

The uncertainties are summarized in Table 3. The results are categorized in shape-altering and non-shape-altering categories. The shape-altering sources are considered correlated between two signal regions of $\tau_h\tau_h$ in the final statistical combination.

5. Results and interpretation

The observed data and predicted background yields for the four signal regions are summarized in Table 4. In all signal regions the observed data are consistent with the predicted SM values within the uncertainties.

The results are interpreted in the context of a simplified model of chargino pair production and decay which corresponds to the left diagram in Fig. 1. A modified frequentist approach, known as the CLs method [21], is used to set limits on cross sections at 95% confidence level. Combining all four signal regions, the observed limits rule out $\widetilde{\chi}_1^{\pm}$ masses up to 417 GeV for a massless $\widetilde{\chi}_1^0$. The results on excluded regions are shown in Fig. 2(Left).

The results of the $\tau_h\tau_h$ channels are also interpreted to set limit on the $\widetilde{\tau}\,\widetilde{\tau}$ production, which corresponds to the right diagram in Fig. 1. Figure 2(Right) represents the ratio of the obtained upper limit on the cross section and the cross section expected from SUSY (signal strength) vs. the mass of the $\widetilde{\tau}$ particle, when $\widetilde{\chi}_1^0$ mass is 1 GeV. The observed ratio is within one standard deviation of the expected ratio.

Table 4: Data yields and background predictions with uncertainties in the four signal regions of the search. The uncertainties are reported in two parts, which are statistics and systematic uncertainty, respectively. The main backgrounds (W+jets and QCD multijet) are derived from data as described in Section 3. "VV" is a shorthand for diboson events.

	$e\tau_h$	$\mu\tau_h$	$\tau_h\tau_h$ SR1	$\tau_h\tau_h$ SR2
Z+jets	0.19 ± 0.04 ± 0.03	0.25 ± 0.06 ± 0.04	0.56 ± 0.07 ± 0.12	0.81 ± 0.56 ± 0.18
$t\bar{t}$, VV, Higgs	0.03 ± 0.03 ± 0.02	0.19 ± 0.09 ± 0.09	0.19 ± 0.03 ± 0.09	0.75 ± 0.35 ± 0.38
W+jets	3.30 ± 3.35 ± 0.56	8.15 ± 4.59 ± 1.53	0.72 ± 0.11 ± 0.57	2.58 ± 0.35 ± 1.25
QCD multijet	-	-	0.13 ± 0.06 ± 0.21	1.15 ± 0.39 ± 0.74
SM Total	3.52 ± 3.35 ± 0.56	8.59 ± 4.59 ± 1.53	1.60 ± 0.15 ± 0.62	5.29 ± 0.70 ±1.51
Observed	3	5	1	2

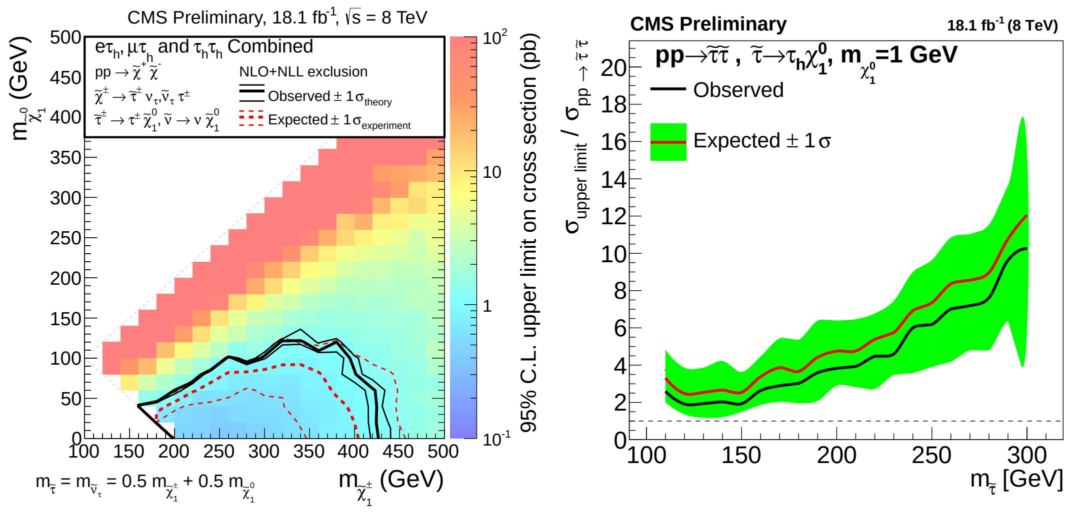

Figure 2: Left : Expected and observed exclusion regions in terms of Simplified Models of chargino pair production with the total dataset of 2012. The bottom-left triangle was excluded by LEP $\widetilde{\tau}$ searches. The diagonal line denotes the boundary for $m_{\widetilde{\chi}_1^{\pm}} = m_\tau + m_{\widetilde{\chi}_1^0}$. The $\pm$ 1 standard deviations of the expected (observed) exclusions introduced by the experimental (theoretical) uncertainties are also shown. Right : Upper limits on $\widetilde{\tau}\,\widetilde{\tau}$ production cross section in $\tau_h\tau_h$ channel. The mass of $\widetilde{\chi}_1^0$ is 1 GeV.

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