1 Introduction

For the last few decades, the standard model (SM) of particle physics has served physicists well as a means of understanding the world around us. However, as the scope of experimental observation and data expand to otherwise previously untouched realms of physics, there are a growing number of observations that suggest that the SM is incomplete. The motivation for physics beyond the SM (BSM) range from astrophysical evidence of dark matter (DM) to theoretical issues associated with the observation of certain particle mass heirarchies. The Large Hadron Collider (LHC) is expected to probe physics models which extend the SM. The analysis presented here focuses on a search for ~~physics beyond the SM~~ using data samples of proton–proton collisions at a center-of-mass energy of 7 TeV and with integrated luminosities of 4.6 fb^{-1} collected by the CMS detector at the LHC at CERN.

Supersymmetry (SUSY) is favored as a leading candidate for physics beyond the SM because it ~~allows for the unification of gauge couplings~~ while ~~also~~ naturally providing ~~a DM candidate in the form of~~ the lightest SUSY particle (LSP). SUSY models predict a spectrum of new particles similar to those of the SM but with spins that differ by one-half from their respective SM partners. In the case of supergravity (~~or~~ CSSM) models [1–5] the lightest neutralino ($\tilde{\chi}_1^0$) is the stable LSP which would escape the detector and be a good cold dark matter candidate. Colored SUSY particles can be copiously pair-produced at the LHC and will very often decay into color singlet states that ultimately decay into an LSP. Therefore a typical SUSY signature at the LHC would consist of a high multiplicity of highly energetic jets and a large momemtum imbalance in the detector. Also, in the case of large values of tanβ (the ratio of vacuum expectation values of two Higgs doublets), ~~tau~~ leptons as well as third generation squarks become lighter ~~and are enhanced~~. For example, the stau-neutralino $\tilde{\tau}_1$–$\tilde{\chi}_1^0$ co-annihilation region [6] is consistent with the amount of dark matter relic density observed by the Wilkinson Microwave Anisotropy Probe (WMAP) [7]. Another example is the ~~G~~auge-mediated supersymmetry breaking model [8–10] where the $\tilde{\tau}_1$ is the NLSP.

The stau-neutralino coannihilation region is particularly difficult to identify using τ leptons due to the production of very low energy taus from $\tilde{\tau}_1 \rightarrow \tau\tilde{\chi}_1^0$ ($M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0} \sim 10GeV/c^2$). Therefore the stau-neutralino coannihilation region provides a very good benchmark scenario for designing a search for BSM physics processes with highly energetic jets, large momentum imbalance, and tau leptons.

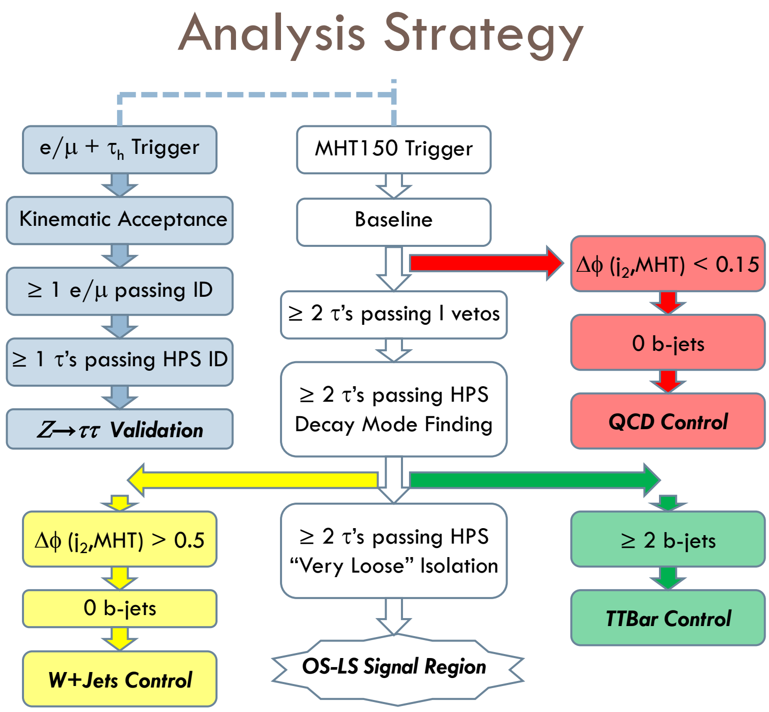
The analysis presented is not limited to a particular BSM theory. However, to illustrate the sensitivity of a search for BSM processes, the mSUGRA or CSSM model and a few simplified models are chosen as benchmarks.

2 Analysis Strategy

Because squark ($\tilde{q}$) and gluino ($\tilde{g}$) pairs is the dominant SUSY production mechanism at the LHC, the presence of SUSY will most likely reveal itself in final states with high p_T jets due to the heavy nature of $\tilde{q}$ or $\tilde{g}$ ($M_{\tilde{q},\tilde{g}}$ at TeV scale), followed by their cascade decays (e.g. $\tilde{q} \rightarrow q\tilde{\chi}_2^0$).

Certain regions of SUSY parameter space (e.g. mSUGRA at high tanβ) can give rise to $\tilde{\chi}_2^0 \rightarrow \tau\tilde{\tau} \rightarrow \tau\tau\tilde{\chi}_1^0$ decays that have a branching ratio close to 100%. In these regions, the presence of SUSY and the co-annihilation region vital to the connection to cosmology can be discovered in final states containing a pair of tau leptons. Taus from $\tilde{\tau}_1 \rightarrow \tau\tilde{\chi}_1^0$ decays are expected to have low energy due to the near mass degeneracy between the $\tilde{\tau}$ and $\tilde{\chi}_1^0$ and these events would be characterized by a pair of tau leptons in the final state, one of which is a low p_T tau. Hence, in this analysis, we look for events with at least two energetic jets, large momentum imbalance and τ pairs.

We follow the analysis strategy described in CMS AN-11-164 [11]. An important aspect of the analysis consists of obtaining a clean sample of $Z \rightarrow \tau\tau$ events to be used for the validation of tau identification and to ensure the robustness of the tau selections. Obtaining a clean sample of $Z \rightarrow \tau\tau$ events is not possible in the double hadronic tau final state due to the large background contamination from QCD dijet events. However, one can obtain relatively clean samples of $Z \rightarrow \tau\tau$ events in the $\mu\tau_h$ and $e\tau_h$ final states where the presence of the light lepton significantly reduces the QCD background. If a control sample of $Z \rightarrow \tau\tau$ events is achieved in both the $e\tau_h$ and $\mu\tau_h$ final states with consistency in shapes and event rates between data and MC, then this gives us confidence that the tau ~~tagging~~ criteria is robust and that the proper scale factors have been applied. In order to ensure robustness of the analysis and our confidence in the results, whenever possible we rely on the data itself to understand and validate the efficiency of reconstruction methods as well as the estimation of the background contributions. For that purpose we define control regions with most of the selections similar to what we use in our main search but enriched with events from background processes. Once a background enhanced region is created, we measure selection efficiencies in those regions and extrapolate to the region where we expect to observe our signal. In cases where a complete data–driven method is not possible we make use of scale factors, ratio between observed data events and expected MC events in the background enhanced region to estimate the background contribution in the signal region.



(a)

Figure 1: Depiction of the analysis strategy in the $\tau_h\tau_h$ + Jets + $\not{H}_T$ final state.

Our signal region consists of events with 2 or more highly energetic jets, 2 or more hadronic tau jets, and large momentum imbalance. A search for excess of events in the high $\not{H}_T$ region is performed. However, the presence of a possible excess in the high $\not{H}_T$ region does not immediately determine the connection to a particular SUSY model, region of parameter space, SUSY masses, or cosmology. To establish such a connection, a search for an excess of opposite-sign minus like-sign $(OS - LS)$ $\tau_h\tau_h$ pairs is also performed following the prescription outlined in [6]. The $OS - LS$ method [6] makes use of the idea that most jet based background processes that remain after requiring the presence of high p_T non-tau jets, two hadronically decaying taus, and large $\not\!\!E_{\mathrm{T}}$ can be removed on a statistical basis because the fragmentation of the quarks and gluons produce charge blind ditau pairs.

If an excess remains in $OS - LS$ $\tau_h\tau_h$ pairs in the high $\not\!\!H_{\mathrm{T}}$ region, then we proceed to quantify the significance of the excess for potential discovery. If no excess exists, then we proceed to set a 95% C.L. upper limit on the cross section using the CMS recommended CL_s method [12].

It is important to note that the analysis has been designed with two goals in mind: (1) provide a general search for BSM processes such as SUSY; (2) if a possible excess or discovery is observed, make precision measurements of the kinematic endpoints and attempt to extract SUSY masses and model parameters. This note focuses on goal (1) ~~and~~ Figure 1 shows the overall analysis strategy ranging from the definition of the signal region to the determination of control regions.

3 Backgrounds and Samples

3.1 Backgrounds

W + jets and $t\bar{t}$ are the dominant backgrounds for this analysis. W + jets background becomes a dominant process because the decay of the W boson creates a very clean prompt tau that passes all the tau related requirements at the same rate as signal events. Moreover, jets from quarks and gluons can be identified as tau candidates. W + jets also becomes a background when the W decays to $q\bar{q}$ giving rise to tau fakes or high p_T jets if the W boson is significantly boosted. However, because W + jets events mostly contain only one tau lepton from the W boson decay, $\tau\tau$ pairs are charge blind due to the presence of at least one jet that fakes a hadronically decaying tau. Therefore, any W + jets contamination that remains after requiring the presence of 2 high p_T jets, 2 τ_h's, and large $\not\!\!E_{\mathrm{T}}$ can be removed on a statistical basis using the OS-LS subtraction technique that will be discussed in the sections that follow.

Events containing $t\bar{t}$ contribute to the expected background due to the production of real taus from one of the W boson decays ($t \to bW \to b\tau\nu$) and/or jet fakes from the second W boson decay. Additionally, events can have high p_T b-jets from the top quark decays and large $\not\!\!E_{\mathrm{T}}$ from the leptonic decays of the W bosons which give rise to energetic neutrinos. In many $\tau\tau$ related searches, $t\bar{t}$ is minimized by requiring events with zero jets tagged as b-jets. However, this is not possible for this analysis because SUSY production often occurs via stop ($\tilde{t}$) and sbottom ($\tilde{b}$) pairs that can give rise to b-jets via e.g. $\tilde{t} \to \tilde{\chi}^{\pm}_{1,2}b$ or $\tilde{t} \to \tilde{\chi}^{0}_{1,2}t \to \tilde{\chi}^{0}_{1,2}bW$. However, we do make use of b-tagging to provide a data-driven background extraction method for $t\bar{t}$ (section 8.1).

QCD dijet events are expected to be a very small contribution to the signal region due to the requirement of 4 jet-like objects (2 non-tau jets and 2 tau jets) and large $\not\!\!E_{\mathrm{T}}$. This process can only become a background if one of the jets is badly mismeasured, giving rise to large $\not\!\!E_{\mathrm{T}}$, and additional jets from initial state or final state radiation provide fake $\tau\tau$ pairs. However, these cases can also be removed on a statistical basis using the OS-LS subtraction technique. As the QCD contribution is expected to be small, we measure a scale factor from a QCD enriched sample to correct the MC prediction in the signal region and validate that QCD is indeed a small contribution.

$Z \to \nu\nu$ + jets is the only other important background of interest. This background does have