Synopsis

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- Thesis Title: Unveiling some supersymmetric scenarios using tau-leptons at the Large Hadron Collider.
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The Standard Model (SM) of particle physics is incomplete in various senses. To list a few, the Higgs mass is unstable under the quantum correction, the SM can’t provide a viable dark matter candidate, the observed baryon asymmetry of the Universe remains unexplained and moreover the evidences of non-vanishing neutrino masses and mixing are unexplained. Therefore, there are ample reasons to look for physics beyond the Standard Model.

The Supersymmetric (SUSY) extension of the SM is one of the most popular and theoretically well motivated framework for physics beyond the SM. It not only solves the problem of quadratic divergence appearing in the quantum correction of Higgs mass but also provide a viable candidate for dark matter in terms of the weakly interacting stable massive particle in its $R$-parity conserving form (with $R$-parity defined by $R = (-)^{3B+L+2S}$).

Searches for supersymmetry at the collider experiments and currently at the Large Hadron Collider (LHC) are largely based on signals with missing transverse energy ($\not{E}_T$) due to the pair production of invisible lightest supersymmetric particles (LSP) which go undetected at the collider.

However, $\not{E}_T$ is not a unique signal of SUSY. Scenarios with quasi-stable charged particles are also viable possibilities within SUSY. Such a scenario can arise when the next-to-lightest SUSY particle (NLSP) is a charged particle and the decay of the NLSP to the LSP is suppressed due to very small coupling or when the NLSP and LSP are degenerate in masses. For example, one can have a gravitino LSP in a supergravity (SUGRA) model. They can be envisioned in gauge-mediated SUSY breaking theories as well. In the MSSM, too, one can have the so-called co-annihilation region of dark matter, where a stau and the neutralino LSP are closely degenerate, leading to a quasi-stable character of the former. One
can also have a scenario, the one we have worked with, in which the minimal supersymmetric standard model (MSSM) is augmented with a right-chiral neutrino superfield for each generation, motivated by the non-vanishing neutrino masses and mixing. The essence of SUSY signal lies not in $E_T$ but in charged tracks due to massive particles, seen in the muon chambers. From the kinematics of these charged particles and a detailed study of the momenta of the final state particles, which often include tau produced in association with charged tracks, one is able to reconstruct the masses of various superparticle.

The thesis aims at looking at the possibilities of reconstructing the masses of various superparticles in such scenarios. We have suggested some techniques for reconstruction of the masses of the neutralino, the lightest chargino and the left-chiral tau-sneutrino in this long-lived stau scenario.

- To reconstruct the neutralino we have considered pair production of neutralinos in SUSY cascades. It further decays into a $\tilde{\tau}\tilde{\tau}$ pair. The final state consists of $2\tau_j + 2\tilde{\tau} + E_T + X$, where $X$ comprises of all the hard jets arising from SUSY cascades. Reconstruction of the neutralino requires the knowledge of four-momenta of tau as well as stau. We first reconstruct the two taus in the final state from the knowledge of total $E_T$ of that event. The four momenta of the stau (which shows up as a charged track in the muon chamber) are not completely known. From the bending of the track only its three momenta can be measured. To measure the mass of the particle (lighter stau) associated with the charged track we have prescribed a method of extracting it on an event-by-event basis. Then the mass of the neutralino can be obtained from the invariant mass distribution of the $\tilde{\tau}\tilde{\tau}$ pair.

- The chargino has been reconstructed considering the associated production of it with the neutralinos in SUSY cascades. The chargino further decays into a $\tilde{\tau}\nu_\tau$ pair and the neutralino on the other side decays into a $\tilde{\tau}\tau$ pair. The final state in this case consists of $\tau_j + 2\tilde{\tau} + E_T + X$. However, this final state can be faked by other SUSY processes. We have suggested a way of reducing these SUSY backgrounds imposing various cuts. The chargino mass, can then be found from the transverse mass distribution of the $\tilde{\tau}\nu_\tau$ pair, where we have also prescribed a way to find the transverse component of the four-momenta of the neutrino out of a chargino decay.

- The left-chiral tau sneutrino ($\tilde{\nu}_\tau$) has been reconstructed in a way similar to
that for the chargino. \( \tilde{\nu}_\tau \) is predominantly produced in SUSY cascade via the decay of second lightest neutralino or the chargino and it further decays into a \( \tau W \) pair. Therefore, we have an additional \( W \) in the final state in addition to that considered for chargino case, namely, \( \tau j + W + 2\tilde{\tau} + E_T + X \). We have suggested two different methods for reconstructing the mass of the left-chiral tau sneutrino. One of them is independent of the mass of the other SUSY particles whereas, the other one is more model dependent but has better signal to background ratio.

In each of the above cases, we have also addressed the possible SM backgrounds and suggested various cuts for their elimination. The method of reconstruction that we have suggested is not limited to the scenario with right-handed sneutrino LSP alone. In fact it can be applied to all those cases where the stau is long-lived.

The thesis also focuses on aspects of theories with non-universal Higgs mass (NUHM). One of the most striking feature of this theory is that the lighter stau mass eigenstate is dominated by the left-chiral stau component owing to the large negative value of \( m_{H_u}^2 - m_{H_d}^2 \) where, \( m_{H_u}^2 \) and \( m_{H_d}^2 \) are the mass squared value of the Higgs doublets which give masses to the up-type and down-type quarks respectively. This is rather difficult to obtain in an mSUGRA scenario where, the lighter stau mass eigenstate is dominantly right-chiral. Hence, the tau produced in the SUSY cascade in such a scenario will be left polarised as long as the lighter chargino and first and second neutralino are gaugino-like. We have shown that studying the polarisation of the tau, it is possible to distinguish the NUHM scenario from mSUGRA in the same sign di-tau channel at the LHC for a substantial region in the \( m_0 - m_{1/2} \) plane. In addition, we have studied a charge asymmetry in the jet-lepton invariant mass distribution, arising from decay chains of squarks leading to leptons of the first two families. Using these two types of discriminators, we conclude that it is indeed possible to identify NUHM scenario at the LHC.