CMS Internal Note

The content of this note is intended for CMS internal use and distribution only

1 Nov 2006

Mass Reconstruction and Missing E_T Studies on MSSM A/H $\rightarrow \tau^+\tau^-$ Leptonic Decay

F. Duru, U. Akgun, S. Kunori, Y. Onel

University Of Iowa, Iowa City, IA 52242, USA

University of Maryland, College Park, MD 20742, USA

Abstract

$Hbb \rightarrow \tau^+\tau^-$ can be considered one of the signature channels of the MSSM. Due to the fact that the final state neutrinos are very close to the ”sister” leptons, it is possible to identify the direction of missing neutrinos. Thus it will be possible to reconstruct Higgs mass efficiently. This paper summarizes the studies done on mass reconstruction using the Missing Transverse Energy (MET) and jet correction types in ExRoot.

1 Introduction

The Minimal Supersymmetric Standard Model (MSSM) is the supersymmetric extension of the Standard Model (SM) with the minimal particle content. For each particle, there is a superpartner with the same internal quantum numbers, but with spin that differs by half a unit. The introduction of supersymmetric partners cancels the quadratic divergence in the Higgs boson mass. MSSM requires two Higgs doublets in order to preserve symmetry. There are 5 elementary Higgs particles in MSSM: Three neutral ones (H,h, A) and two charged ones (H^{+-}).

One of the goals of LHC is to cover the entire m_A - tanβ plane in order to discover or exclude the existence of the MSSM Higgs sector. In the MSSM, almost the entire Higgs sector can be covered with $30fb^{-1}$ by the LHC experiment. Among several MSSM decay modes, the two channels having τ lepton final states are of great importance [1].

$H \rightarrow \gamma\gamma$ and $H/A \rightarrow tt-bar$ are the most promising channels in the search of neutral heavy Higgs bosons, and it is particularly significant at high $tan\beta$. The $Hbb \rightarrow \tau^+\tau^-$(see Fig:1) can be the signature of MSSM, since for $tan\beta$=30 and m_A=300GeV, the ratio of the MSSM cross-section to the SM cross-section is around 5000. In this decay, there are two b-quarks along with the Higgs boson which decays to two taus. Both taus decay leptonically resulting in two leptons (any combination of electrons and muons) and four neutrinos in the final state.

We studied this decay channel with three different samples with 140 GeV, 200 GeV and 250 GeV Higgs' mass. The events are obtained from DC04 data sets and all digitized events are processed with ORCA8-7-4. ExRoot. We are going to report the results from 140 GeV higgs mass sample.

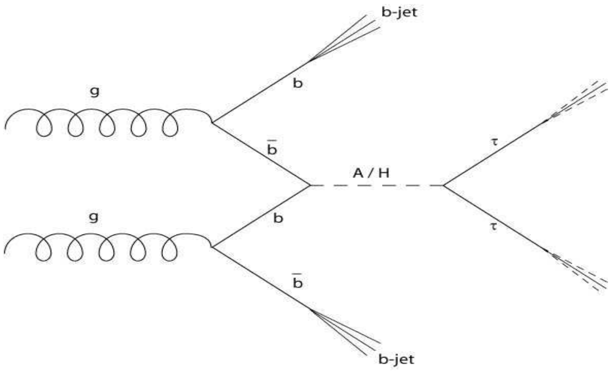

Figure 1: The diagram of $Hbb \rightarrow \tau^+\tau^-$

2 $Hbb \rightarrow \tau^+\tau^-$ Kinematic Properties

In order to study the Missing Transverse Energy (MET) and Jet Correction effects, it is necessary to understand the properties of the channel. The most important characteristic of $Hbb \rightarrow \tau^+\tau^- \rightarrow (l^+\nu\nu_\tau)(l^-\nu\nu_\tau)$ channel is that the "sister" neutrinos are very close to the "sister" leptons. When we plot the angle separation between the lepton and its sister neutrinos at the generator level, the mean is seen to be 2.1 degrees (see Fig.2). So, the direction of the neutrinos, thus the direction of the MET is known allowing to reconstruct the Higgs' invariant mass. Moreover, the final state leptons and neutrinos are in the central region.

Among three principal jet algorithms -the iterative cone, the midpoint cone and the inclusive kT jet algorithm- we used the iterative cone algorithm with $\Delta R < 0.5$ to reconstruct the jets. This algorithm searches the maximum transverse energy object and throws a cone around its direction. Any object within that cone will be merged to form a jet [3]. The constituents are then removed from the list of objects, and the procedure is repeated until no objects are left in the list. For a reconstructed jet to be considered as a b-jet we required the separation between the jet and the quark to be less than 0.4 ($\Delta R < 0.4$). Splitted ECAL and HCAL towers are taken into account in this process. It is seen that only 12 percent of the events have two matching jets and around 40 percent of the events have at least one matching jet. The existence of many non-matching jets can be related to the shortcomings of the jet reconstruction algorithms. The jets we are dealing with have low transverse energy and jet reconstruction algorithms are not very efficient in the low E_T region. For highest E_T jets the average transverse energy is 47 GeV and for second highest E_T jets it is 20 GeV. These values are significantly higher than generated level b-quark information. The possible reason for this is again the lack of sensitivity of the jet algorithms and the calorimeters. The pseudorapidity distribution of the generator level jets, suggest that the two b-jets are more likely to have

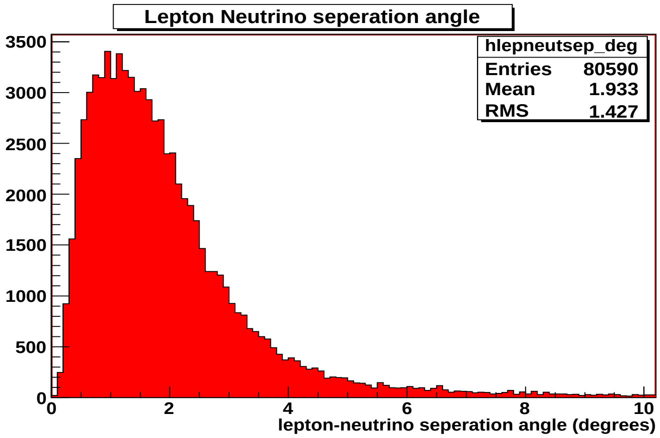

Figure 2: The separation between the leptons and the ”sister” neutrinos.

opposite eta signs. Jets have low transverse momentum and they are mostly central.

The main background channels for our signal decay are $Z\gamma^* \rightarrow \tau\tau$, t t-bar production with real and fake τ's and top production Wt. Since this analysis is focussed on mass reconstruction, MEt and Jet corrections it does not cover all background channels. We have produced 250000 $Z\gamma^* \rightarrow \tau\tau$ events with mass 80-100 GeV and 250000 events with Z mass higher than 100 GeV. These samples are used as a model backgound to cross-check the effects of the techniques used on background events.

3 Higgs Invariant Mass Reconstruction

Our final goal is to reconstruct the mass of the Higgs using the information about the missing transverse energy, (MET). The formal collinear approximation method to reconstruct mass is given in the reference [2]. Knowing the mass of the final state leptons and what fraction of tau's momentum is carried by the neutrinos, we can calculate the mass of the Higgs. The formula is given by :

$$M_H = \frac{M_{ll}}{\sqrt{X1 \times X2}}$$

where M_H is the Higgs' mass, M_{ll} is the mass of the final stage leptons, and X1 and X2 are the fractions of the tau's momentum carried by the first and second neutrino respectively.

To be able to use this formula, it is necessary to know X1 and X2. There are two different approaches to obtain X1 and X2. For the ”Method 1” approach, the components of MET in the direction of taus are calculated in the transverse plane. Then, it is assumed that the same ratio will be valid for the z-components. In the ”Method 2” approach, all MET is added to one of the taus in the transverse plane. Then, the cross product with the remaining tau is taken. It is assumed that the ratio of the cross products before and after MET addition, is X1 and X2.

To test the validity of these two methods, we used the generator level information. Using the generator level lepton masses and MET, we reconstructed the Higgs mass for 140 GeV sample. The results are shown in Figure 3. The yellow area is for ”Method 1” and blue thick line is for ”Method 2” approach. ”Method 1” collinear approximation, has a tail on mass distribution, but yields almost 2 times more events than Method 2 both for the signal and background. It is not possible to interprete this ratio as efficiency since it is kept same for the background events as well. Method 2 collinear approximation, yields a little sharper mass signal. Both of them give close results to the desired mass (see Fig 3).

4 MET and Jet Corrections

4.1 MET Types on Exroot and Effects on Mass

MET and jet reconstruction is a very complicated process. ORCA implements multiple algorithms for the jet finder, MET reconstruction and several scenarios of JetMET analysis. Correction and calibration is a very important

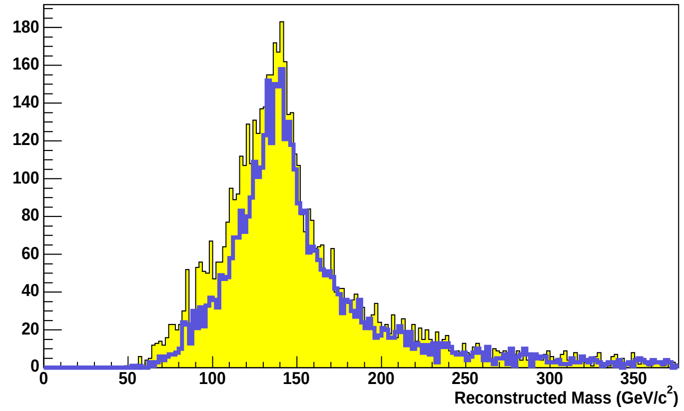

Figure 3: Reconstrcuted higgs mass with two types of collinear approximation methods.

aspect in Jet and MET reconstruction. Jet and MET algorithms are sensitive to the final states accompanied with the pileup, multiple-scattering, underlying-events, and detector performance, -mainly calorimetry. However, the good forward coverage of CMS, the good cell segmentation and hermeticity make the MET measurement easier [4].

MET is the crucial element in the determination of the Higgs' mass. MET can be obtained from Calorimeter Hits, Calorimeter towers and from jets (Kt and iterative cone algorithm). In this note we report the result with MET from calorimeter hits. We used METs from calorimeter towers as well, the results are very similar. The first correction applied to the MET from calorimeter hits (CH) was the subtraction of the muon effect. We know that only a small portion of the muon energy is deposited in the calorimeters. The remaining part adds to the MET. Thus, missing transverse energy has contributions from the neutrinos as well as muons. In order to obtain the energies of neutrinos, we subtracted a given amount of energy, which is thought to be due to the muons, from MET every time we had muons in the final state. Then, we applied the jet corrections. Type 1 jet correction is used with different processes which are explained in the next section.

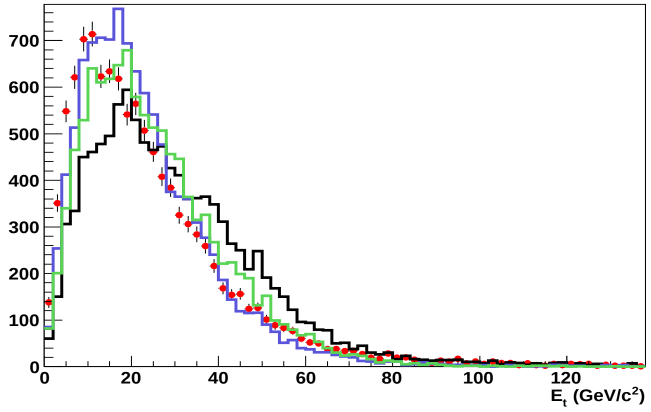

Figure 4: Missing Et from calorimeter hits and V1 jet correction

4.2 Jet Corrections and Effects on MET

To be able to obtain best MET values, we have to work on jet reconstruction and correction methods[5]. Several standard and some ”home-made” jet correction techniques are investigated to achieve the best MET result. Gamma Jet Correction (GJ), Monte Carlo Jet Correction (MC) and V1 Jet Correction are the three standard procedures used. Figures 4, 5 and 6 show the outcomes of the V1, MC and GJ corrections respectively. In all three of these plots, the red line shows the MET distribution obtained using generator level information, the black line is for the plain MET value obtained from calorimeter hits, the blue line gives the MET distribution obtained after muon corrections and

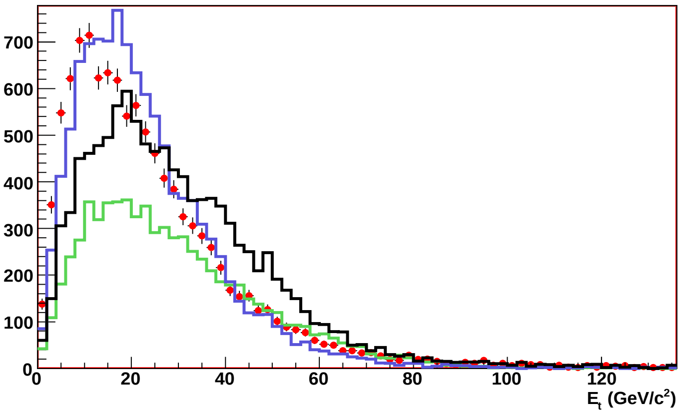

Figure 5: Missing Et from calorimeter hits and MC jet correction

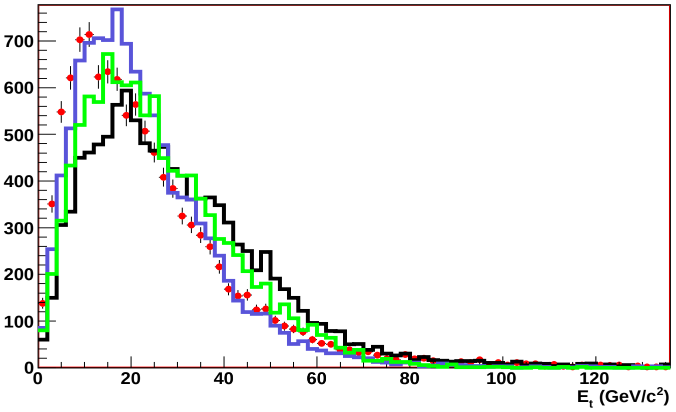

Figure 6: Missing Et from calorimeter hits and GJ jet correction

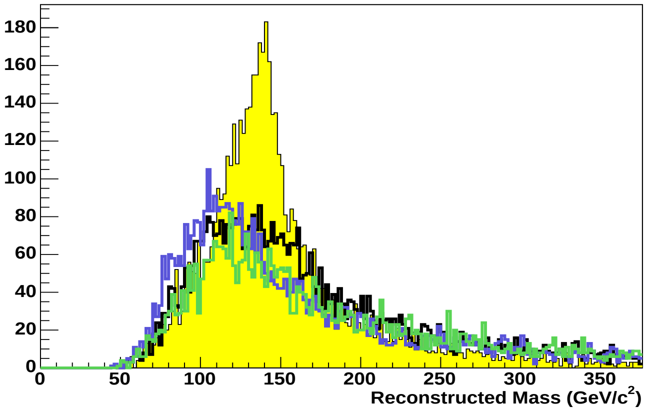

Figure 7: Reconstructed Mass with Method 1 and V1 jet correction

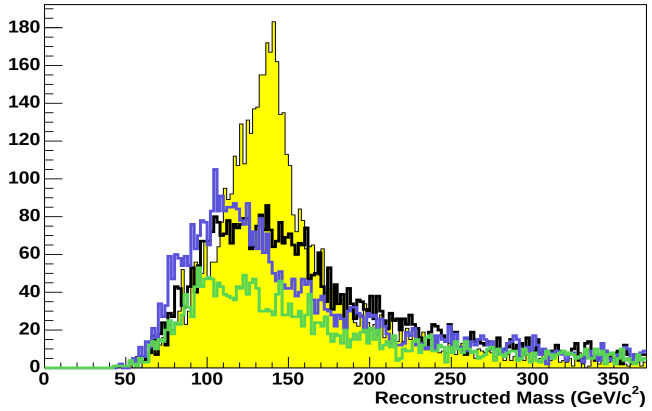

Figure 8: Reconstructed Mass with Method 1 and MC jet correction

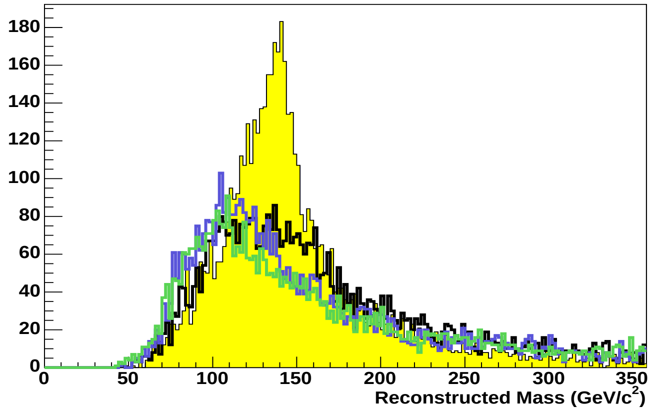

Figure 9: Reconstructed Mass with Method 1 and Gamma jet correction

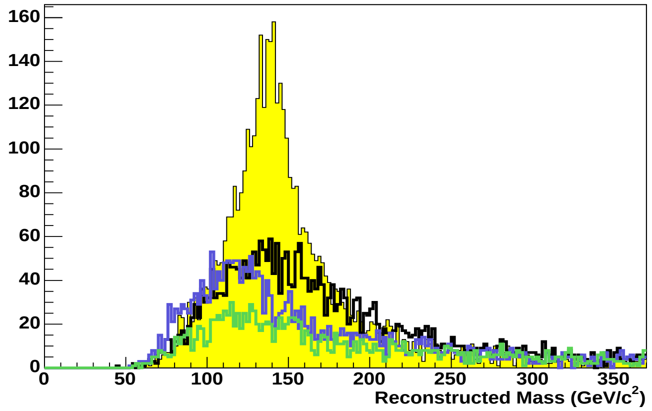

Figure 10: Reconstructed Mass with Method 2 and V1 jet correction

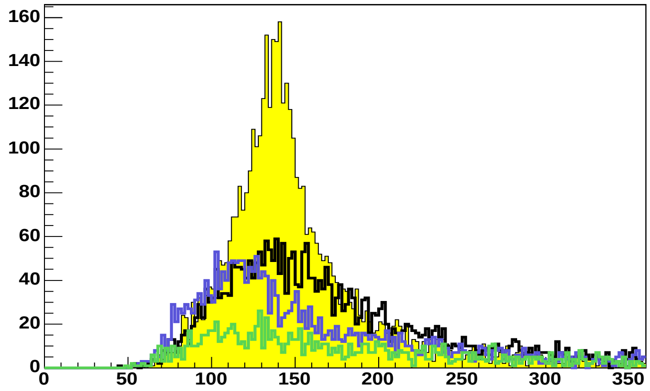

Figure 11: Reconstructed Mass with Method 2 and MC jet correction

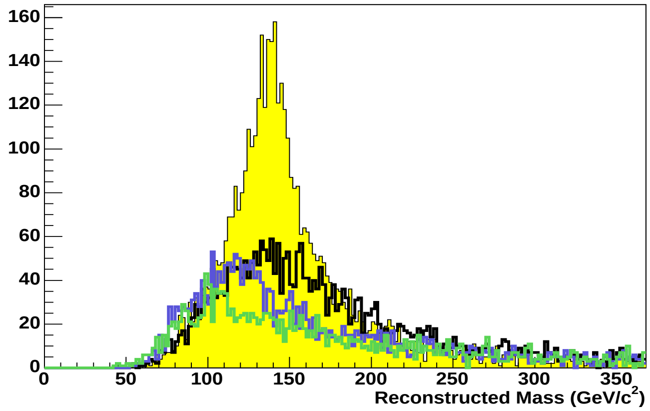

Figure 12: Reconstructed Mass with Method 2 and Gamma jet correction

finally the green line shows MET obtained after (type1) jet corrections. Similarly, the results of the ”Method 1” mass reconstruction are shown in Figures 7 (for V1), 8 (for MC) and 9 (for GJ). Finally, Figures 10, 11 and 12 display the ”Method 2” mass reconstruction results. In all of these plots, the yellow area shows the distribution obtained by the generator level information. The black, blue and green lines are for MET obtained from calorimeter hits (CH), MET we got after muon corrections, and MET obtained after muon plus jet corrections respectively. As can be seen, the V1 corrections give slightly better results. However, none of the corrections yield close enough results to the generator level missing transverse energy. In the case of the ”Method 1” mass reconstruction, the jet correction methods lead to a shift in the peak in the wrong direction.

We deduced that Standard CMS jet correction methods do not improve the mass resolution. We created jet corrections specific to this channel by comparing the generated jet E_Ts to reconstructed jet E_Ts in small η regions. But with the low statistics from DC04 sample we did not get significant improvement on MET distributions.

5 Conclusion

The $bbH \rightarrow \tau^+\tau^-$ is a very important channel to understand MSSM. The main characteristic of the channel is known neutrino directions, with this distinct kinematics it serves as a benchmark to tune our reconstruction tools, as well. In this note we demonstrated two different approach to invariant mass reconstruction using collinear approximation. For this channel the missing transverse energy is very low, and to reconstruct the Higgs mass efficiently, it is important to improve MET using adequate jet reconstruction algorithms. The methods known and used so far, do not work very efficiently. Standard CMS jet correction methods do not give satisfying answers. Some of them help to improve the mass reconstruction a little; With V1 jet correction method, it is possible to achieve slightly better distributions. However, some of the algortihms shift the mass peak in the wrong direction. It is important to realize the ”error” and find methods which work better. This study as been performed on 140 GeV, 200 GeV and 250 GeV samples from DC04 using ExRoot. Only 140 GeV sample has been reported in this note due to its higher statistics, the other samples yield similar results. We are studying to produce, and test the same channel with CMSSW, and contribute to improvement of CMS reconstruction software.

References

[1] R. Kinnunen et al., *”Measurement of the H/A $\rightarrow \tau\tau$ cross section and possible constraints on $tan\beta$”*, **CMS Note 2004/027.**

[2] T. Plehn, D. L. Rainwater, D. Zeppenfeld, *A Method for identifying $H \rightarrow \tau\tau \rightarrow e^{+-}\mu^{-+}P_t$ at the CERN LHC.*, **Phys. Rev. D 61, 093005, 2000.**

[3] A. Heister et al., *”Measurement of jets with the CMS detector at the LHC*, **CMS Note 2006/036.**

[4] H. Pi et al., *”Measurement of missing transverse energy with the CMS detector at the LHC”*, **CMS Note 2006/035.**

[5] A. Nikitenko et al., *”Missing transverse energy measurement with jet energy corrections”*, **CMS Note 2001/040.**