Mass Asymmetry on Chargino Decay to $\tau\tau HH$ with Missing Transverse Energy

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ABSTRACT

This research investigates the reconstruction of chargino pair with RPV decay to $\tau\tau HH$ with special consideration on missing transverse energy. The leptonic-tau pair case is considered mainly. Since tau decay releases at least one neutrino (invisible to the detector) and all neutrinos released are in the same direction of the visible part, missing transverse energy (mET) can be used to improve the reconstruction of two tau cases. The mET vector is decomposed into the directions of the visible parts (leptons/hadronic tau jets) on the transverse plane and is then projected onto the real directions. An improvement of about 20% is achieved across energy levels from 250GeV to 1500GeV on truth level, and the reconstructed chargino mass peaks closer to the expected mass. This method also improves chargino mass distribution on reconstructed level, but the extra noise in reconstructed level may reduce the effectiveness.

BACKGROUND: Beyond the Standard Model

The Standard Model provides a rather successful description of presently known particles and interactions but is still a "work in progress" as there are many hints for "new physics", such as the "hierarchy problem". The Higgs boson with a mass of 125 GeV implies that, assuming the Standard Model is correct as an effective field theory, then the quantum correction to the Higgs is some 30 orders of magnitude larger than the required value. Such enormous contribution and cancellation leads to the idea of a new symmetry — Supersymmetry.[1]

The Supersymmetry model introduces superpartners to all existing particles in the Standard Model, the spin of which differs by a half-integer. For example, electron, a Fermion with Spin ½, has a superpartner called selectron, a Boson wit Spin 0. And the charginos (C1, C2 or $\mathrm{X}_1, \mathrm{X}_2$), with Spin ½, are superpartners of charged Higgs boson and W boson.

There are a variety of Supersymmetric extensions of the Standard Model. Specifically, the model investigated in this research allows R-parity violation. R-parity is also known as "matter parity", which has a value of +1 for Standard Model particles and -1 for their superpartners. Conservation of R-parity prevents proton and the lightest superpartner from decaying, while extending the Standard Model with a new gauge symmetry with charge (B-L) can also suppress unwanted decays (such as proton decay) and would allow the lightest superpartner to decay.[2]

METHOD & RESULTS: Truth Level

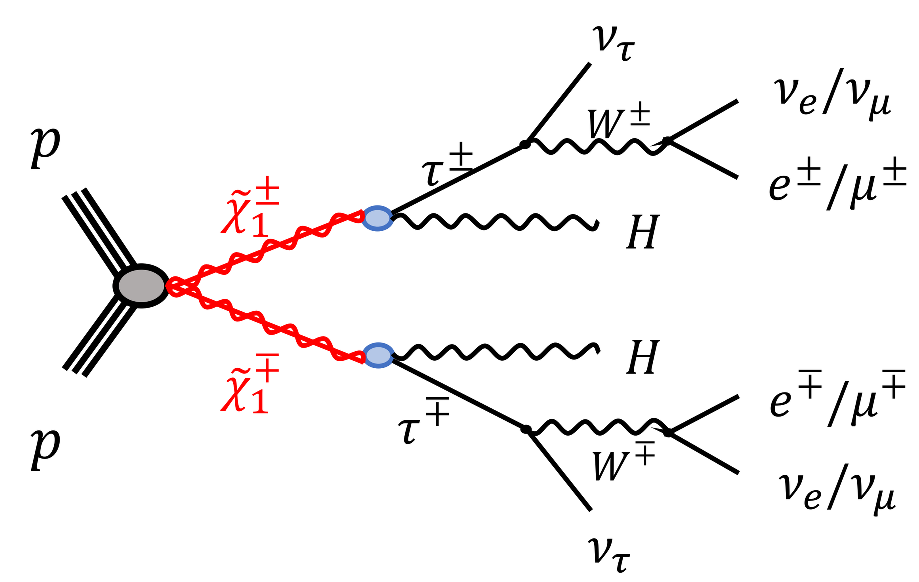

Figure 1: $C_1C_1 \rightarrow \tau\tau HH$ with $\tau \rightarrow \nu_\tau + l + \nu_l$ (antineutrino not specified)

Figure 1 illustrates the decay pattern that is investigated in this research. Two protons collide and create a pair of charginos which both decay to a tau and a Higgs. The taus then decay leptonically into a tau neutrino, an electron or a muon, and a corresponding lepton neutrino.

Neutrinos hardly interact with other particles, which means they are invisible to the detector. However, they do carry some momentum (energy) from the system. They hold the missing energy of the system, which can be calculated on the transverse (vertical) plane. In most realistic simulations (and real collisions), only the transverse part of the missing energy is accessible and affected by noise.

Assuming the noise does not affect mET much, it is possible to decompose the vector into the directions of the leptons on the transverse plane (see Figure 2), which is then added to the 4-vector of the leptons to "reconstruct" the 4-vector of the taus.

After augmenting the leptons with mET, the method of mass asymmetry is used to find the correct pairing of leptons and Higgs. The pairing with smaller mass difference (mass asymmetry) is considered the accepted pairing. On truth level (simulation data where everything is accessible), the rate of correct pairing is 85.1% at 800 GeV, while without augmentation, it is only 65.2%. Also, the mass distribution is narrower and the peak is closer to the expected mass. See Figure 3 for augmented case and Figure 4 for un-augmented case.

An average improvement of about 20% is achieved with mET augmentation on different energy levels (see Figure 5). Overall, this augmenting method has shown to be helpful on truth-level studies.

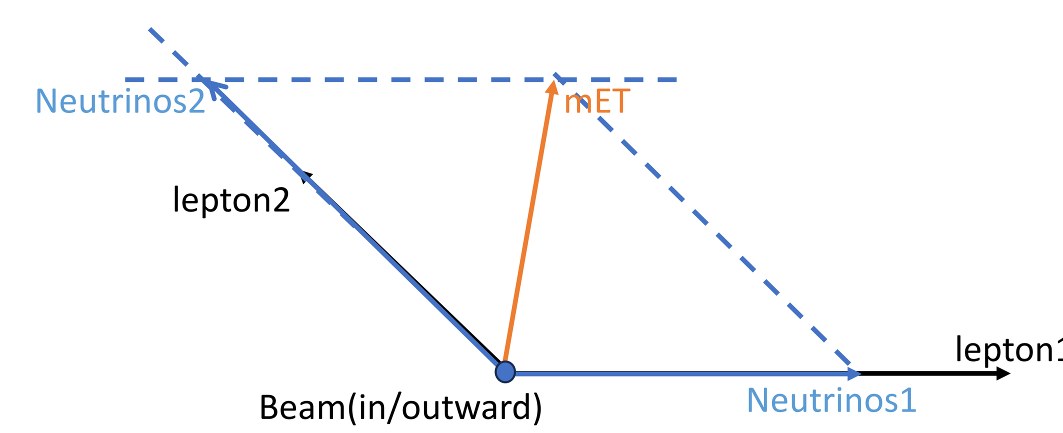

Figure 2: mET decomposition on transverse plane

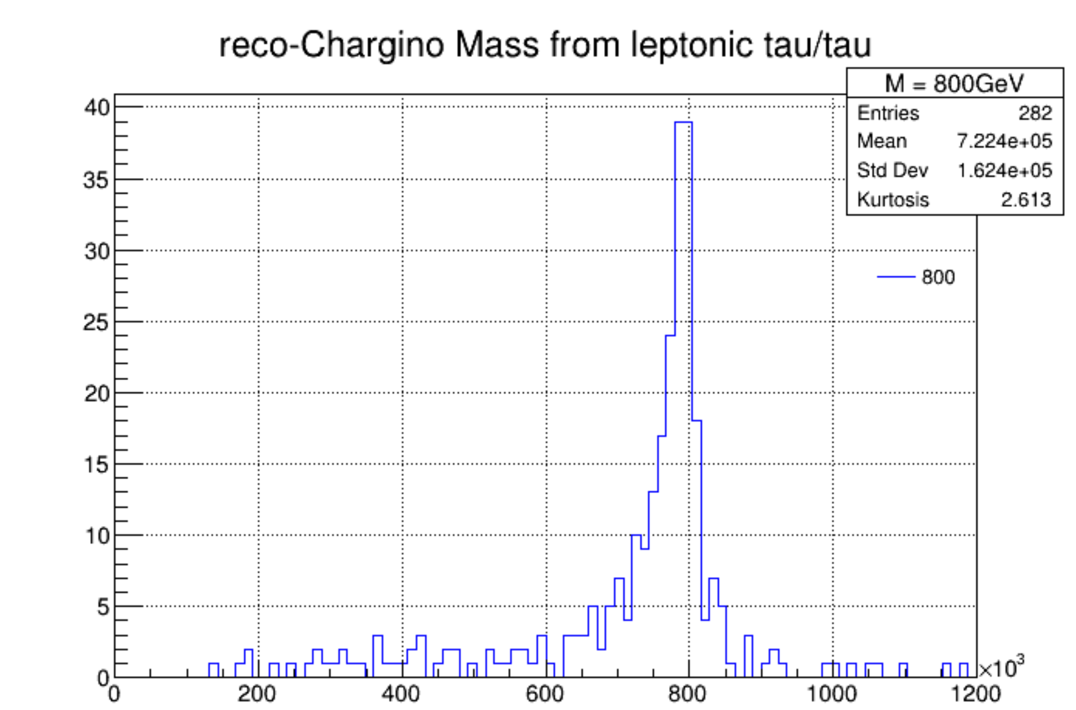

Figure 3: augmented reconstructed chargino mass (800 GeV)

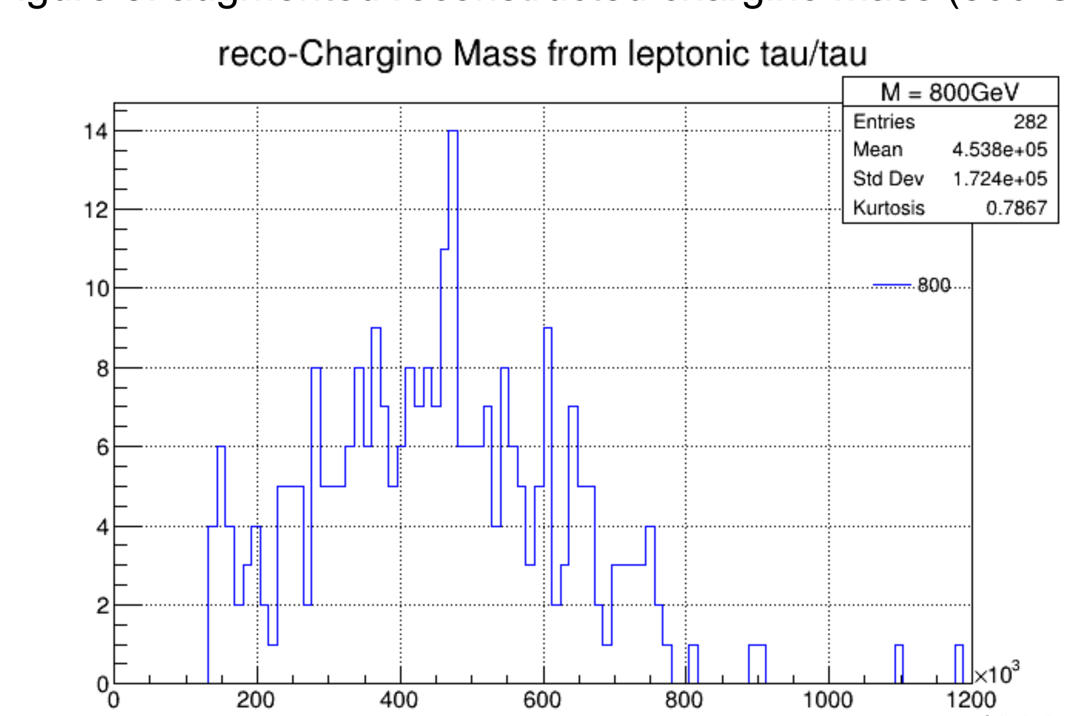

Figure 4: un-augmented reconstructed chargino mass (800 GeV)

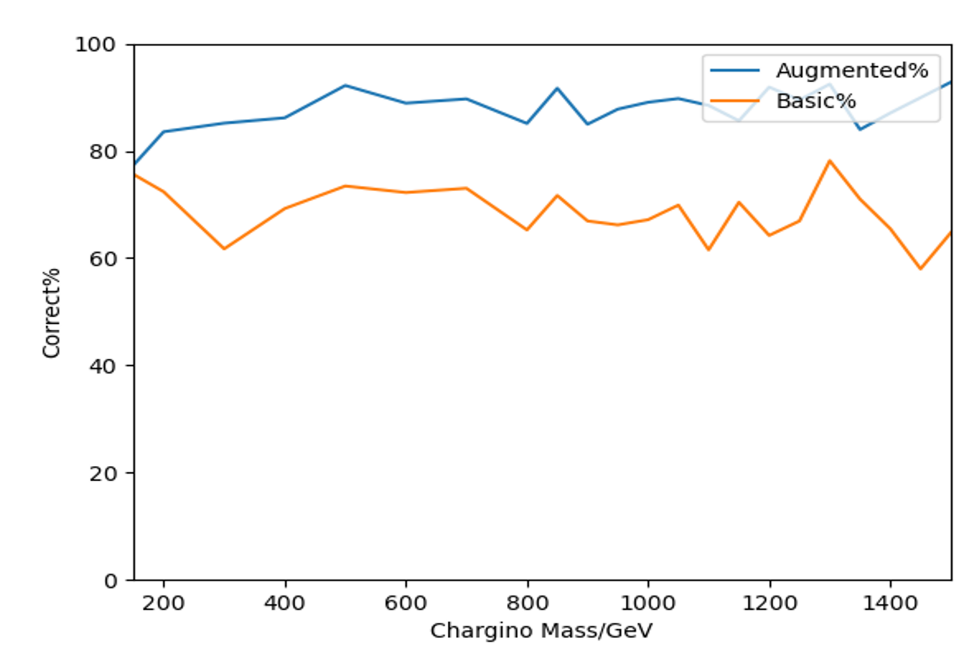

Figure 5: mET augmentation improvement rate

RESULTS: Reconstructed Level

On reconstructed level, simulations are treated and filtered so that only the data expected to be produced by the detector can be accessed. Thus, the improvement rate can no longer be assessed as it is not possible to identify the true pairings. However, applying the augmentation method improves the chargino mass distribution. See Figure 6 a/b.

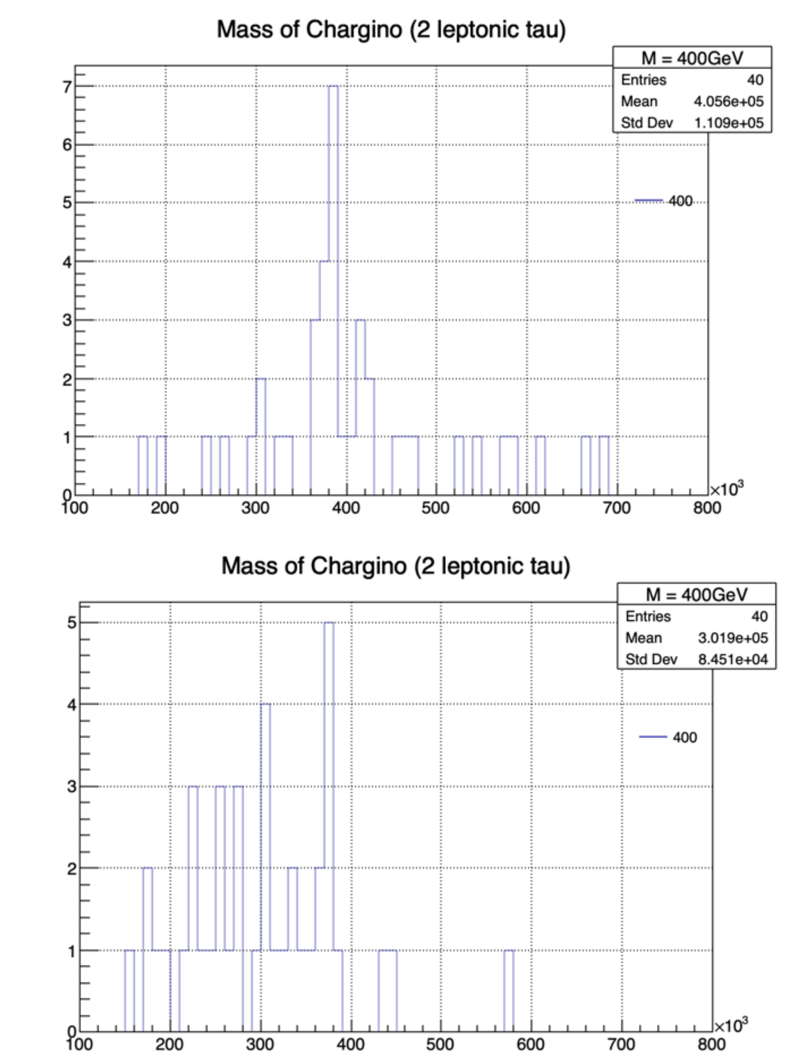

Figure 6 a/b:

The upper figure (a) is the chargino mass distribution at 400 GeV with augmentation and the lower figure (b) is without augmentation.

A clearer peak around 400 GeV is seen with augmentation with more accurate mean value of mass.

This mET augmentation method improves the chargino mass distribution both on truth and reconstructed levels. Further research can examine the interactions between this method and different cuts currently applied to reduce noise, as well as the effectiveness of single leptonic and hadronic tau pair cases.

Reference:

1. Martin, Stephen P. (1997). "A Supersymmetry Primer". Perspectives on Supersymmetry. Advanced Series on Directions in High Energy Physics. Vol. 18. pp. 1–98. arXiv:hep-ph/9709356
2. ATLAS Experiment, CERN (2023). R-parity. ATLAS Experiment at CERN. https://atlas.cern/glossary/r-parity

Acknowledgement:

Special thanks to my primary investigator, Dr. Evelyn Thomson, and my post-doctoral fellow, Michael Hank, for the opportunity to participate in Penn ATLAS research through PennCURF PURM.

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