Missing Transverse Energy in Events with Taus at CMS

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Outline

- Physics motivation for looking at Missing Transverse Energy (MET)
- MET reconstruction
- Contributions to MET scale and resolution
- Current status of MET scale and resolution at CMS
- Define an “ideal” correction for the MET using Particle Flow
- Basics of Particle Flow (PF)
- Define a “minimal” correction for MET
- MET scale and resolution with PF based corrections
- MET corrections for Underlying Events (UE) and Pile-Up (PU)
- MET scale and resolution with PF based corrections and UE/PU corrections
**MET: Physics Motivation**

- In most extensions of the Standard Model, the Higgs is a good target for most "New Physics" searches at the LHC
  - High production rate, especially at high $\tan\beta$
  - For Higgs masses of ~ 100 – 150 GeV, the $H\rightarrow\tau\tau$ branching can be the second highest branching ratio (highest: $b's$)
  - $H \rightarrow \tau\tau$: Because the taus will decay to neutrinos (Missing Energy), in order to make a “Full Mass Reconstruction”, one needs to project the MET back on to the direction of the taus (this method is very sensitive to the MET measurement)

- MET is a main discriminator for SUSY searches
  - “Small” missing energy from neutrinos in the SM, but “Large” missing energy from SUSY
τ MET Corrections

- At the detector level, we can calculate the MET at different levels:
  - Calorimeter towers, jets, electrons, muons, etc., or any combination of objects
- Currently, the MET is usually calculated using ECAL and HCAL towers that are above a certain $E_T$ threshold:
  \[
  \vec{E} = - \sum_{i=1}^{\text{towers}} \vec{E}_i, \quad MET = \sqrt{E_x^2 + E_y^2}
  \]

- Contributions to MET scale and resolution
  - $\tau$ $P_T$ mismeasurements
    - non-compensating calorimeter, B-field
  - QCD Jets
    - non–compensating calorimeter, B-field
  - Underlying Events (UE)
    - soft particles from other interactions that fall inside jet or tau cone
  - Pile-Up (PU)
    - particles from multiple pp interactions
τ MET Corrections

Event Selection:

- Used CMS detector simulator CMSSW version 1_6_0
- Fast Simulation: $W \rightarrow \tau \nu$ (120k events)
- The first goal is to isolate the effects to MET due to $\tau$

$P_T$ mismeasurements

- In order to remove effects due to PU, sample was generated without PU
- $P_T > 15$ GeV, $|\eta| < 2.5$ for Monte Carlo hadronic $\tau$
- $N_{jets}(QCD) = 0$ with $P_T(\text{raw}) > 5$ GeV - to isolate effects due to QCD jets
τ MET Corrections

- Current MET tools:
  - Reconstructed from Calorimeter Towers
  - Type-1 MET corrections
    \[ M\tilde{E}_{\text{corrected}} = M\tilde{E}_{\text{uncorrected}} - (\tilde{E}_\tau^{\text{corrected}} - \tilde{E}_\tau^{\text{raw}}) \]
  - Corrections based on jet response
    (RecoJet ET / GenJet ET) as a function of \( \eta \) and \( E_T \)

- MET tools NOT applicable for taus:
  - MET scale is off without MET correction
  - Type-1 Jet MET corrections sets scale completely off and has worse resolution

- Cause - mismeasurements in τ energy:
  - Type-1: over-correction of \( P_T \) and worse resolution
  - No Correction: under-correction of \( P_T \)
Correcting the MET scale & resolution

- Ideally, one would like to define a region in the calorimeter that is large enough to include all decay products of the $\tau$ and calculate the correction as follows:

$$\Delta \vec{E}_T = \sum_{reg} \vec{E}_T^{cal} - \vec{E}_T^\tau - \sum_{reg} \vec{E}_T^{UE} - \sum_{reg} \vec{E}_T^{PU}$$

- 1st term: energy deposition in the calorimeter region around the $\tau$
- 2nd term: ‘TRUE’ visible $\tau$ transverse energy
- 3rd term: energy deposition of particles from underlying events in the calorimeter region around the $\tau$
- 4th term: energy deposition of particles from pile-up in the calorimeter region around the $\tau$

*We need to choose a specific $\tau$ algorithm that calculates the $\tau$ energy as best as possible. This measurement will define our 2nd term.*
Currently, different sub-detectors are treated separately

- Jets/Taus are 1st reconstructed using calorimeter tower information

*Particle Flow combines the information from the sub-detectors!*
**Basics of Particle Flow**

1st: Sub-Detectors are linked to each other

Finally, PF “particles” are created!

$$\chi^2 = \left( \frac{\Delta \phi}{\sigma_\phi} \right)^2 + \left( \frac{\Delta \eta}{\sigma_\eta} \right)^2$$

$$\sigma_\eta^2 = \sigma_\eta^2(\text{ECAL}) + \sigma_\eta^2(\text{HCAL})$$

$$\sigma_\phi^2 = \sigma_\phi^2(\text{ECAL}) + \sigma_\phi^2(\text{HCAL})$$

*Neutral hadron*

$$E_{\text{rec}}(\text{ECAL, HCAL}) > E_{\text{tracks}} + 3\sigma_{E_{\text{rec}}}$$
Use Particle Flow to measure the $\tau$ $P_T$

- Taus are tagged using a “Cone Isolation” algorithm (NO PF particles in the isolation region with $P_T > 1$ GeV)

PF provides the “best” available measurement of the $\tau$ $P_T$

- Relative $\Delta P_T$ distribution for PF is peaked at 0 and the resolution has improved
- Tails in the PF distribution are due to double counting of energy
  - Expect improvements once the problem is fixed
τ MET Corrections

- Correcting the MET scale & resolution
  - Ideal Correction: \[ \Delta \vec{E}_T = \sum_{\text{reg}} \vec{E}^{\text{cal}}_{T_{\text{reg}}} - \vec{E}^{\tau}_{T_{\text{reg}}} - \sum_{\text{reg}} \vec{E}^{\text{UE}}_{T_{\text{reg}}} - \sum_{\text{reg}} \vec{E}^{\text{PU}}_{T_{\text{reg}}} \]
  - Above correction assumes that corrections for UE/PU are applied everywhere
    - Not a typical assumption
  - Instead we define a ‘minimal’ correction that excludes corrections due to UE/PU:
    \[ \Delta \vec{E}_T = \sum_{\text{calojet, } R=0.5} \vec{E}^{\text{calojet, } R=0.5}_{T_{\text{reg}}} - \vec{E}^{PF(\tau)}_{T_{\text{reg}}} \]
    - Accurate for the low luminosity regime, where UE/PU effects are small
    - Calorimeter jet energy approximates the 1st term in our ideal correction
  - Improved MET scale and resolution!
  - Absence of visible offset confirms that effects due to UE are small
Corrections to MET for UE/PU

• The problem with the previous definition for the MET correction is that jets are usually reconstructed using towers above a certain $E_T$ threshold (~ 0.5 GeV). MET is reconstructed using towers above a different threshold (usually ~ 0 GeV).

• Furthermore, the previous definition does NOT account for UE/PU (UE effects might only be a few GeV, but PU effects are luminosity dependent).

• We define a “full-scale” MET correction as follows:

$$
\Delta \vec{E}_T = \left[ \sum_{i=1}^{\text{towers}} \vec{E}_{calo, R<0.5} - \sum_{i=1}^{\text{towers}} \vec{E}_{calo, R<0.5} \right] - \left[ \vec{E}_{PF} - \sum_{i=1}^{PF \text{Candidates}} \vec{E}_{i, R<0.5} \right]
$$

• 1st term: energy of towers (with $E_T>0$ GeV) within $\Delta R=0.5$ around the PF $\tau$

• 2nd term: energy of towers (with $E_T>0$ GeV) within $\Delta R=0.5$ around a random direction in $\eta$–$\phi$ space (NOTE: random direction must satisfy PF isolation requirement in order to be consistent with the PF tau tagging algorithm)

• 3rd term: Particle Flow $\tau$ energy

• 4th term: energy of PF “particles” (with $E_T>0$ GeV) within $\Delta R=0.5$ around a random direction in $\eta$–$\phi$ space
Let’s compare the MET scale/resolution using both corrections …

Even with NO Pile-Up, we can see an improvement in MET scale and resolution!

“minimal” correction

“full-scale” correction
Summary

- Current MET tools are not applicable for taus
  - Cause: mismeasurements in \( \tau \) energy
- Particle Flow provides better \( P_T \) resolution
- Defining a minimal definition for the MET correction and using Particle Flow to measure the \( \tau \) \( P_T \) improves the MET scale and resolution
  - Although the scale and resolution has improved, more improvement is expected once the double counting of energy is fixed (double counting of energy is the cause of the tails in the PF distributions)
- Defining a “full-scale” correction that includes UE and PU corrections improves the MET scale and resolution.