I. TRACK-CORRECTED MET

The measurement of MET in CMS suffers from the large material budget of the tracking system, the non-linear response of the calorimeter, and the strong (3.8 T) magnetic field that encompasses the two systems. Although the size of the former is now a constant outside of our control, any correction for $\not\!\!E_T$ must try to overcome the latter two. A method has been developed that to improve the measurement of MET by taking advantage of the CMS tracker. At the scale of interest (1 GeV), the tracker has excellent resolution compared to the calorimeter. The proposal is to correct the $\not\!\!E_T$ by replacing, for all well reconstructed tracks, the average (or expected) energy deposition in the calorimeter by the measured momentum in the tracker.

The foundation of any attempt to correct MET for charged particles is a response function. The goal is to create a fixed lookup table that allows for a simple determination of the expected detector response based only on track kinematics. Starting with a single particle gun, the track and calorimeter information for each pion is extracted and passed through a set of filters. These pions are used to characterize the detector response, E/p, as a function of measured track parameters.

Generally, detector response varies significantly with η and p_T, improving either increases. The trend in p_T is expected. Improved performance in η is a result of both relatively higher energy, $E = E_T \cosh\eta$, and larger tower size. To account for both trends, the response function is constructed with variable bin sizes. This allows for greater sensitivity to both physics and detector properties - i.e. tracks with 2-5 GeV p_T are expected to exhibit greater variation in response that tracks with 52-55 GeV p_T. The response function was derived from the RelVal single π^+ sample generated with release 167. More details can be found in (reference our CMS note).

Track-corrected MET (tcMET) is calculated for an event using the caloMET, muons, electrons, tracks, and the response function. The RF provides a fixed lookup table of detector response for charged hadrons. Leptons, muons and electrons, behave uniquely in the detector and thus need to be treated separately. To account for this, tracks matched to leptons are removed from the set of correctable tracks. Muon corrections have been discussed elsewhere (reference). Electron-like objects deposit most of their energy in the ECAL. The energy of these objects is already well-measured and does not need correction here.

The remaining tracks are passed through a set of filters cutting on kinematic quantities as track variables, similar to those used in the derivation of the response function. The subset of tracks that survive form the array of good tracks for which $\not\!\!E_T$ is corrected. The actual correction is implemented by removing the expected energy deposited by each good track in the calorimeter, determined using the response function, and replacing it with the track momentum at the vertex.

$$\text{tcMET} = \text{baseline MET} + \sum_{\text{good tracks}} \langle \vec{E}_T \rangle - \sum_{\text{good tracks}} \vec{p}_T, \tag{1}$$

where baseline MET is caloMET corrected for any muons in the event.

It is important to note that the correction for each good track involves two sets of coordinates. The expected energy deposition for each track is removed from the calorimeter. This location is determined using the vertex track as a seed to the analytical propagator, as was done in the derivation of the response function. The track momentum that replaces it is taken at the vertex. To be explicit, the correction for a single component of MET takes the form:

$$(\text{tcMET}_x) = (\text{baseline MET}_x) + \sum_{\text{good tracks}} \langle E \rangle \sin\theta_c \cos\phi_c - \sum_{\text{good tracks}} p_T \cos\phi_v, \qquad (2)$$

where θ_c, ϕ_c are the polar and azimuthal position coordinates of the particle at the calorimeter face and ϕ_v is the azimuthal angle of the track at the vertex.

In addition, badly measured tracks can generate fake $\not\!\!E_T$ and correcting for such a track can make things worse. Consider a track that, due to a pattern recognition problem in a noisy environment, has a very large estimated momentum. The amount of this over-estimate will translate directly into excess MET if the track is passed to the response function. Consequently, a set of kinematic and quality cuts is used to filter these mis-measurements from the track collection and avoid generating fake $\not\!\!E_T$. The interested reader can find further details in (reference our CMS note).

The goal at the outset was to reduce the sizable tails of the Drell-Yan MET distribution. The correction was tested on a CSA07 Drell-Yan sample ($m_{ll} > 40$) with the metric being the number of events with MET > 30. In addition, the response function was also used to correct a sample of CSA07 W leptonic decays. The use of a sample with real $\not\!\!E_T$ is an important control. Correcting the Drell-Yan tails with a naive additive or multiplicative factor will eliminate events with high MET, but will also do so for events with real $\not\!\!E_T$. Thus, it is necessary check that any attempt to correct for mis-measured MET does not significantly impact the ability to identify those events for which $\not\!\!E_T$ is an important and real signature.

Here we will consider Drell-Yan events with two electrons in the final state having $p_T >$ 20 GeV and W events with at least one electron matching the same criteria. The results, in the figure below, show that the MET distribution for W events changes by less than 5% while the tail of the Drell-Yan distribution is reduced by a factor of 2.7 for a cut at 30 GeV. A tighter cut of 50 GeV reduces the tail by more than a factor of 3.

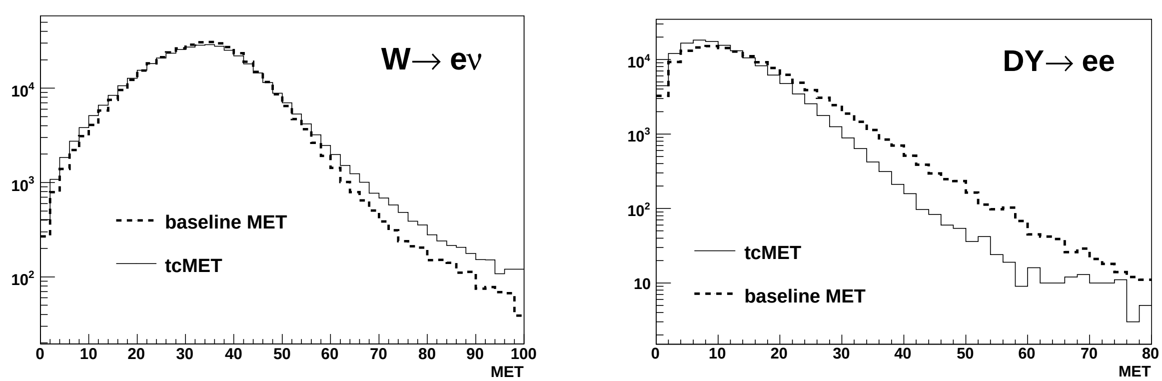

FIG. 1: For W events in the plot on the left, the shift of events between the body and distribution is less than 5%. On the right is the same distribution for Drell-Yan events with fake $\not\!\!E_T$. The number of events with MET$>$ 30 GeV is reduced by a factor of 2.7. A tighter cut at 50 GeV sees further reduction, the number of events in the tail decreasing by more than a factor of 3.

It is also useful to break these results down into n-jet bins. Here, the jet counting parameters are $E_T > 15$ GeV, $|\eta| < 3$. Changes in the W sample are less than 5% in any n-jet bin. The table below shows the breakdown for Drell-Yan. Each entry shows the approximate fraction of events with MET > 30 in raw numbers and as a percentage. The final row shows the factor of improvement for tcMET over baseline.

TABLE I: Performance of tcMET

Case	0 jets	1 jet	2 jets	3+ jets
baseline	3%	16%	27%	40%
tcMET	1%	5%	10%	20%
improvement	2.2	3.1	2.8	2.0

The majority of Drell-Yan events fall into the 0-jet bin. These events are the target of the correction and reduction of the tail by a factor of 2.2 is reason for optimism. Although this correction wasnt conceived with jets in mind, the large number of tracks in these events gives reason to expect similar reductions and the results do not disappoint. The improvement in the 2-jet bin is commensurate with that seen in events with no jets. The 1-jet bin shows even better pruning. This is not entirely unexpected. These events contain one sizable jet which provides additional tracks for correction. The presence of a single large jet that is typically under-measured produces significant asymmetry, providing excellent conditions for correction. The observation of a smaller improvement in the 2-jet bin is also reconciled in this view as the two jets typically have some spatial separation which results in corrections for tracks in one jet partially canceling out corrections for tracks in the other jet. This cancellation becomes more evident in those events with more than 2 jets.

It is also interesting to consider the effect a track-based correction has on QCD samples. These events are expected to contain little real MET and thus serve as a good platform for comparison. Here, inclusive qcd samples over several p_T were tested. In all cases, tcMET is seen to improve both the tails and the resolution of the MET distribution. This improvement increases with increasing p_T up to several hundred GeV.

The track-based correction shown above is quite effective at reducing the tail of the MET distribution in Drell-Yan. However, no effort was made to try to improve resolution. Although reducing the tails is a desirable goal, tcMET may be of limited utility if it significantly worsens the MET resolution. A crosscheck was performed by fitting the distribution of each component of missing ET with a Gaussian from which the resolution was determined according to (reference last year's MET note).The figure below show the distributions of the y-component of two MET determinations with Gaussian fits overlaid. The table shows the width of each component and the MET resolution calculated from these values.

MET resolution gets better after applying the track-based correction! The resolution improves by $\sim$15%. This is an unintended bonus - we set out to reduce the tail and along the way also improved the resolution. The presence of this enhancement validates the procedure and indicates that the algorithm developed is reasonable.

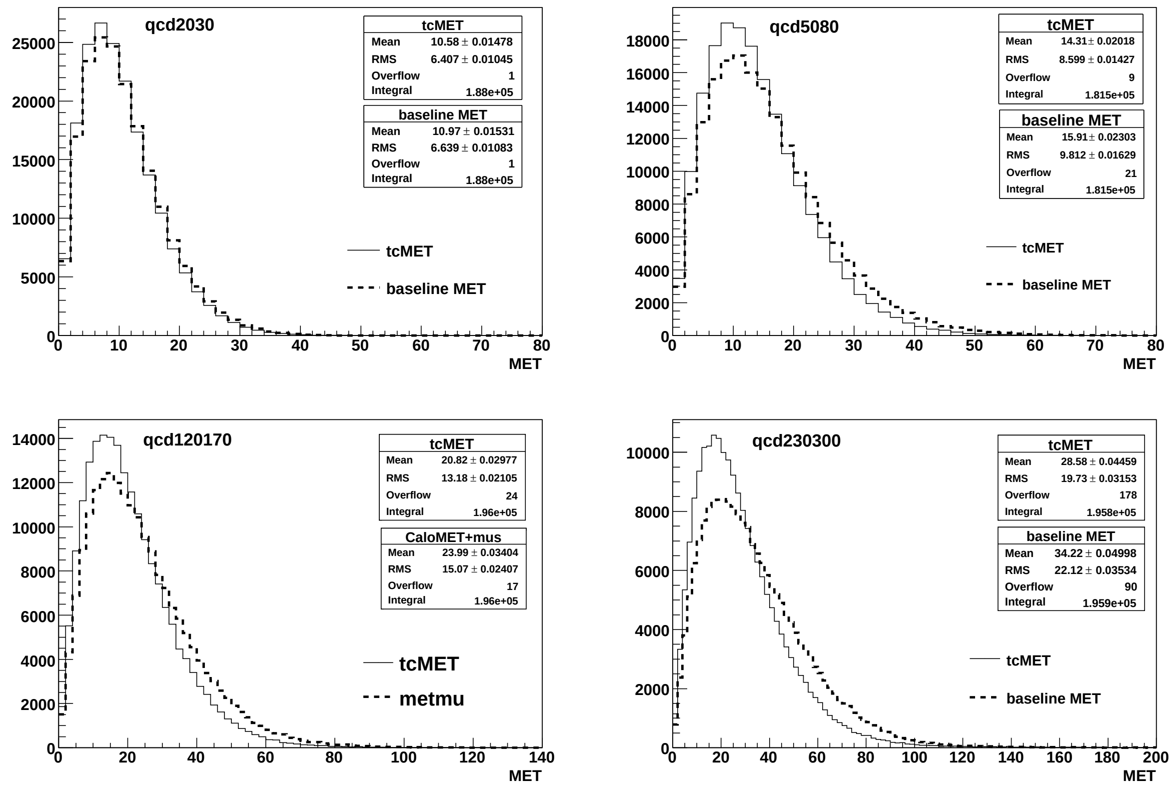

FIG. 2: The figures above compare tcMET to baseline MET defined to be caloMET corrected for muons. Four different p_T ranges are shown, where qcdXY refers to the lower value, X, and upper value, Y, of the p_T bin used. In all cases, tcMET improves both the tail and resolution of the MET distribution with the degree of improvement increasing with p_T. All plots were made from CSA07 inclusive QCD samples.

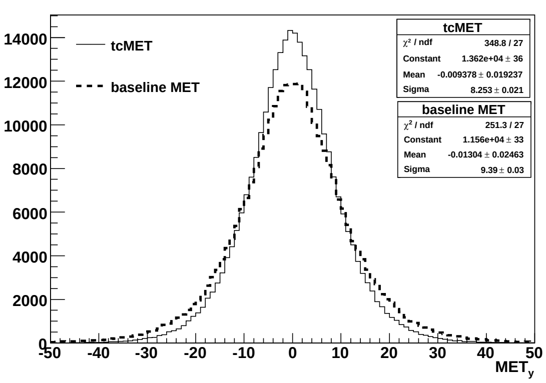

TABLE II: tcMET Resolution

Case	σ_x	σ_y	σ_{MET}
baseline	9.43	9.49	6.2
tcMET	8.29	8.32	5.4

FIG. 3: The plot on the left shows distributions for the y-component of MET for the DY→ee final state. Gaussian fits are overlayed. The table on the right shows the widths of the component distributions for the two cases and the MET resolution calculated from the components. Resolution is improved by $\sim 15\%$ for tcMET compared to the baseline.