Refined reconstruction and calibration of the missing transverse energy in the ATLAS detector

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Abstract. The measurement of the missing transverse energy ($\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$) is fundamental for many analyses at LHC. Good $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ resolution and calibration are essential for searches of new physics as well as precise measurements. We describe a refined reconstruction and calibration of $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ developed by ATLAS and its performances on events containing Z and W bosons. The data sample was collected in proton-proton collisions at a center-of-mass energy of 7 TeV, and corresponds to an integrated luminosity of about 36 pb^{-1}. The determination of the absolute scale of the $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$, fundamental for determining systematic uncertainties in all analysis involving $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ measurements, is also presented.

1 $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction

The $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction includes contributions from energy deposits in the calorimeters and muons reconstructed in the muon spectrometer. The two $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ components are calculated as: $E_{x(y)}^{\mathrm{miss}} = E_{x(y)}^{\mathrm{miss,calo}} + E_{x(y)}^{\mathrm{miss},\mu}$. The $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ calorimeter term $E_{x(y)}^{\mathrm{miss,calo}}$ is reconstructed using calorimeter cells calibrated according to the reconstructed physics object to which they belong. Calorimeter cells are associated with a reconstructed and identified high-p_{T} parent object in a chosen order: electrons, photons, hadronically decaying τ-leptons, jets and muons. Cells not associated with any such objects are also taken into account in the $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ calculation. Their contribution, named $E_{T}^{\mathrm{miss,CellOut}}$ hereafter, is important for the $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ resolution. Once the cells are associated with objects as described above, the $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ calorimeter term is calculated as follows [1]:

$$\begin{aligned} E_{x(y)}^{\mathrm{miss,calo}} &= E_{x(y)}^{\mathrm{miss},e} + E_{x(y)}^{\mathrm{miss},\gamma} + E_{x(y)}^{\mathrm{miss},\tau} + E_{x(y)}^{\mathrm{miss,jets}} \\ &\quad + E_{x(y)}^{\mathrm{miss,softjets}} + E_{x(y)}^{\mathrm{miss,calo},\mu} + E_{x(y)}^{\mathrm{miss,CellOut}} \end{aligned} \quad (1)$$

where each term is calculated from the negative sum of calibrated cell energies inside the corresponding objects, as:

$$E_x^{\mathrm{miss,term}} = -\sum_{i=1}^{N_{\mathrm{cell}}^{\mathrm{term}}} E_i \sin\theta_i \cos\phi_i \quad ,$$

$$E_y^{\mathrm{miss,term}} = -\sum_{i=1}^{N_{\mathrm{cell}}^{\mathrm{term}}} E_i \sin\theta_i \sin\phi_i$$

where E_i, θ_i and ϕ_i are the energy, the polar angle and the azimuthal angle, respectively. The various terms in Equation 1 are described in the following:

- $E_{x(y)}^{\mathrm{miss},e}$, $E_{x(y)}^{\mathrm{miss},\gamma}$, $E_{x(y)}^{\mathrm{miss},\tau}$ are reconstructed from cells in clusters associated to electrons, photons and τ-jets from hadronically decaying τ-leptons, respectively;
- $E_{x(y)}^{\mathrm{miss,jets}}$ is reconstructed from cells in clusters associated to calibrated jets with $p_{\mathrm{T}} > 20$ GeV;
- $E_{x(y)}^{\mathrm{miss,softjets}}$ is reconstructed from cells in clusters associated to jets with 7 GeV < $p_{\mathrm{T}} < 20$ GeV;
- $E_{x(y)}^{\mathrm{miss,calo},\mu}$ is the contribution to $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ originating from the energy lost by muons in the calorimeter
- the $E_{x(y)}^{\mathrm{miss,CellOut}}$ term is calculated from the cells in clusters which are not included in the reconstructed objects. Low-p_{T} tracks are also used to recover low p_{T} particles not reaching the calorimeters. Furthermore the track momentum is used instead of the cluster energy for tracks associated to clusters, thus exploiting the better calibration and resolution of tracks at low momentum compared to clusters

In order to suppress noise contribution, only cells belonging to three-dimensional topological clusters [2] are used. The $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ muon term is calculated from the momenta of muon tracks reconstructed with $|\eta| < 2.7$:

$$E_{x(y)}^{\mathrm{miss},\mu} = -\sum_{\mathrm{muons}} p_{x(y)}^{\mu}$$

where the summation is over selected muons. If the muon is isolated (not nearby a reconstructed jet), the energy lost by the muon in the calorimeters is not added to the calorimeter term to avoid double counting of energy. Otherwise the muon spectrometer measurement of the muon momentum after correcting for energy loss in the calorimeter is used ($E_{x(y)}^{\mathrm{miss,calo},\mu}$ contribution)

2 Study of $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ performance

During 2010 a large number of proton-proton collisions, at a centre-of-mass energy of 7 TeV were recorded. Approximately 600 nb^{-1} for jet events, 0.3 nb^{-1} for minimum bias events and 36 pb^{-1}for $Z \to \ell\ell$ and $W \to \ell\nu$ channels have been used to check both agreements on $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ distributions between data and MonteCarlo (MC) simulation and to study the performances of the $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction in

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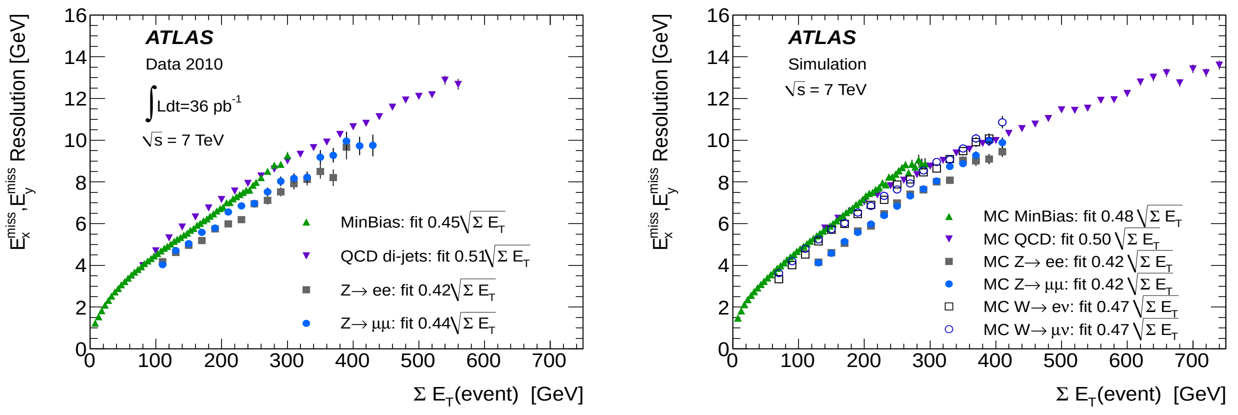

Fig. 1. $E_x^{\rm miss}$ and $E_y^{\rm miss}$ resolution as a function of the total transverse energy in the event calculated by summing the $p_{\rm T}$ of muons and the total transverse energy in the calorimeter in data at $\sqrt{s} = 7$ TeV (left) and MC (right).

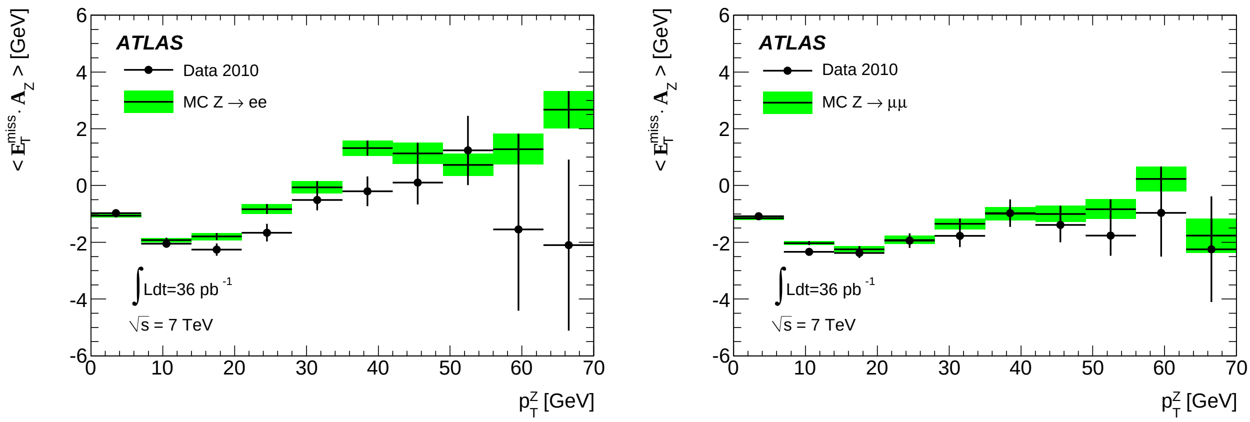

Fig. 2. Mean values of $E_{\rm T,Z}^{\rm miss}$ as a function of $p_{\rm T}^{Z}$ in $Z \rightarrow ee$ (left) and $Z \rightarrow \mu\mu$ (right) events

terms of resolution and scale. Details on this study can be found in Ref. [1]. In particular in minimum bias, di-jet and $Z \rightarrow \ell\ell$ events no true $\boldsymbol{E}_{\rm T}^{\rm miss}$ is expected and resolution can be estimated as the width of distribution of $E_x^{\rm miss}$ and $E_y^{\rm miss}$. In Figure 1 (left) the resolution from data at $\sqrt{s} = 7$ TeV is shown for $Z \rightarrow \ell\ell$ events, minimum bias and di-jet events as a function of the total transverse energy in the event, obtained by summing the $p_{\rm T}$ of muons and the $\sum E_{\rm T}$ in calorimeters. In Figure 1 (right) the $\boldsymbol{E}_{\rm T}^{\rm miss}$ resolution is shown for MC events also for $W \rightarrow \ell\nu$ MC events. The resolution of the two $\boldsymbol{E}_{\rm T}^{\rm miss}$ components is fitted with a function $\sigma = k \cdot \sqrt{\Sigma E_{\rm T}}$. A good agreement in the resolution is found between data and MonteCarlo simulation. In order to study the $\boldsymbol{E}_{\rm T}^{\rm miss}$scale it's useful to consider the component of $\boldsymbol{E}_{\rm T}^{\rm miss}$ along the Z direction ($E_{\rm T,Z}^{\rm miss}$) which is sensitive to the balance between the leptons and the hadronic recoil. Figure 2 shows the mean value of $E_{\rm T,Z}^{\rm miss}$ as a function of $p_{\rm T}^{Z}$. The negative bias for low values of $p_{\rm T}^{Z}$ is due to the underestimation of magnitude of the hadronic recoil dominated by $E_{\rm T}^{\rm miss,CellOut}$ and by softjets.

2.1 Evaluation of the systematic uncertainty on the $\boldsymbol{E}_{\rm T}^{\rm miss}$ scale

The knowledge of the systematic uncertainty on the $E_{\rm T}^{\rm miss}$ scale is fundamental for any analysis involving $\boldsymbol{E}_{\rm T}^{\rm miss}$ measurements. The overall systematic uncertainty on the $E_{\rm T}^{\rm miss}$ scale can be calculated from the uncertainty on each high $p_{\rm T}$ reconstructed object and from the uncertainty on soft-jets and CellOut term (Equation 1) , which are evaluated to be 13% and 10 % respectively. In $W \rightarrow \ell\nu$ events the overall $\boldsymbol{E}_{\rm T}^{\rm miss}$ systematics uncertainty is on average 2.6% for both electron and muon channel.

3 Determination of the $\boldsymbol{E}_{\rm T}^{\rm miss}$ scale from $\boldsymbol{W} \rightarrow \ell\nu$ events

The determination of the absolute $E_{\rm T}^{\rm miss}$ scale is important in a range of analyses involving $E_{\rm T}^{\rm miss}$ measurements, ranging from precision measurements to searches for new physics. $E_{\rm T}^{\rm miss}$ scale has been determined from data with two methods [1]. The first uses a fit to the distribution of transverse mass, mT, of the lepton $\boldsymbol{E}_{\rm T}^{\rm miss}$ system (Figure 3, left). The second uses the dependence between the neutrino and lepton momenta (Figure 3, right). Both methods

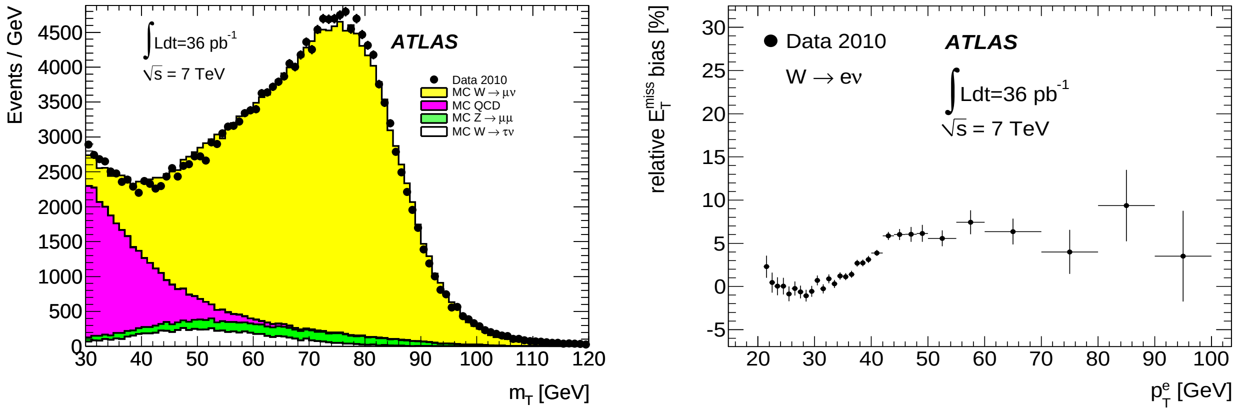

Fig. 3. Left: Fit to m_T distribution for $W \to \mu\nu$ events. Right: Relative bias, $(\langle E_{\mathrm{T}}^{\mathrm{miss}}\rangle - \langle E_{\mathrm{T}}^{\mathrm{miss,True}}\rangle)/\langle E_{\mathrm{T}}^{\mathrm{miss,True}}\rangle$, in the reconstructed $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ as a function of the p_T^e of the electron for $W \to e\nu$ events.

have consistent results and find good agreement between data and MC simulation for the $E_{\mathrm{T}}^{\mathrm{miss}}$ scale. The uncertainty on the scale is about 2% with 36 pb^{-1}.

References

1. ATLAS Collaboration, "Performance of missing transverse momentum reconstruction in proton-proton collisions at 7 TeV with ATLAS", EPJC 72 (2012), arXiv:1108.5602 [hep-ex]
2. W. Lampl and others, "Calorimeter clustering algorithms: Description and performance", ATL-LARG-PUB-2008-002