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Tau energy calibration in the ATLAS experiment

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We describe the energy scale calibration of hadronic τ decays and the associated uncertainty using 4.5 fb^{-1} of data at $\sqrt{s}$ = 8 TeV recorded in 2012 with the ATLAS detector at the LHC. The calibration is based on simulated τ decays, while the systematic uncertainty includes contributions from the single particle response measurements, pile-up and material modeling. The systematic uncertainty on the hadronic τ energy scale for $p_{\mathrm{T}}^{\tau} > 20$ GeV and $|\eta^{\tau}| < 2.5$ is found to be $\leq 3\%$ for the hadronic decay modes with exactly one reconstructed track, and $\leq 4\%$ for the hadronic decay modes with at least two reconstructed tracks. The systematic uncertainty is obtained with a deconvolution method, and is checked using an in-situ analysis of the visible mass of reconstructed Z boson decays into one leptonically and one hadronically decaying τ. These two methods yield results that are compatible within the calculated uncertainties.

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Understanding the decay of tau leptons is important in Large Hadron Collider (LHC) physics; they are relevant for the phenomenology of the Higgs boson, and in searches for physics beyond the Standard Model, including those searches performed at the ATLAS experiment [1]. Tau leptons decay hadronically 65% of the time, predominantly to one or three charged pions (1-prong and multi-prong taus, respectively), a neutrino, and often additional neutral pions. The energies of these pions are calibrated using the jet energy scale, however this hadronic pre-calibration does *not* account for energy lost before the calorimeters and other effects, and the average difference between the reconstructed and true hadronic tau ($\tau_{\rm had}$) energies can remain as large as 15% at low $p_{\rm T}^{\tau}$ [2]. This indicates the need for an additional correction to the calibration of the visible energy.

The calibrated momentum $p_{\rm cal}^{\tau}$ is defined as

$$p_{\rm cal}^{\tau} = \frac{p_{\rm LC}^{\tau}}{R(p_{\rm LC}^{\tau}, |\eta_{\rm reco}^{\tau}|, n_p)} \; , \tag{1}$$

where $p_{\rm LC}^{\tau}$ is the reconstructed $\tau_{\rm had}$ momentum at the Local Hadron Calibration (LC) scale, $\eta_{\rm reco}^{\tau}$ is the reconstructed $\tau_{\rm had}$ pseudorapidity, n_p is the number of reconstructed tracks and R is the additional calibration term, termed the *response*. R is defined as the ratio of $p_{\rm LC}^{\tau}$ to the true $\tau_{\rm had-vis}$ momentum ($p_{\rm vis}^{\tau-{\rm true}}$), as a function of $p_{\rm vis}^{\tau-{\rm true}}$, $|\eta_{\rm reco}^{\tau}|$ and n_p. The response curves are shown in Fig. 1 as a function of the reconstructed $\tau_{\rm had}$ momentum at the LC scale for $\tau_{1-{\rm prong}}$ (left) and $\tau_{\rm multi-prong}$ (right). These response curves represent a measure of the average $p_{\rm T}^{\rm reco}/p_{\rm T}^{\rm truth}$ *before* the calibration is applied.

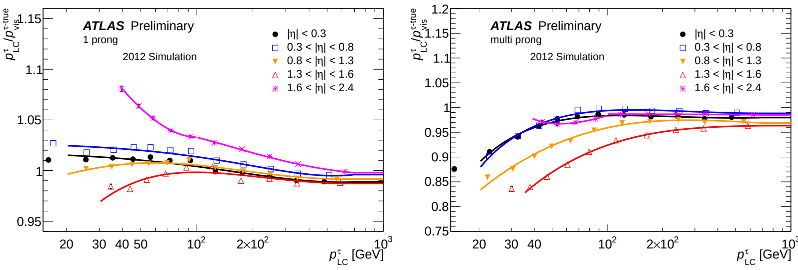

Figure 1: Response curves as a function of the reconstructed $\tau_{\rm had}$ momentum at LC scale for $\tau_{1-{\rm prong}}$ (left) and $\tau_{\rm multi-prong}$ (right) for different ranges of $|\eta_{\rm reco}^{\tau}|$ values [2]. Uncertainties (smaller than the shown markers in most bins) are statistical only.

The systematic uncertainties considered are shown in Fig. 2. The single particle response is derived from the calorimeter uncertainty, and includes contributions from the combined test-beam (CTB) data [3], $\langle E/p \rangle$ in-situ measurements [4], and the EM energy response. Together, the systematic uncertainty, across most $|\eta_{\tau}|$ and $p_{\rm T}$ bins, is between 2-3% ($\tau_{1-{\rm prong}}$) and 2-3.5% ($\tau_{\rm multi-prong}$) for taus passing the *medium* identification criteria, and between 2-4% ($\tau_{1-{\rm prong}}$) and 2.5-4% ($\tau_{\rm multi-prong}$) for taus passing the *tight* identification criteria[1] [2]. The maximum uncertainties are on multi-prong taus in the region $1.3 < |\eta^{\tau}| < 1.6$, in the lowest $p_{\rm T}$ bin.

An in-situ cross-check is performed using the visible mass peak of the $Z \to \tau\tau \to \mu\tau_{\rm had}$ final state to measure the TES and associated uncertainty, in particular to verify our procedure in the region $|\eta^{\tau}| > 0.8$ where there is no CTB data available. Small shifts in the Z visible mass are

[1] See Ref. [5] for a description of the use of a Boosted Decision Tree algorithm to define these identification criteria.

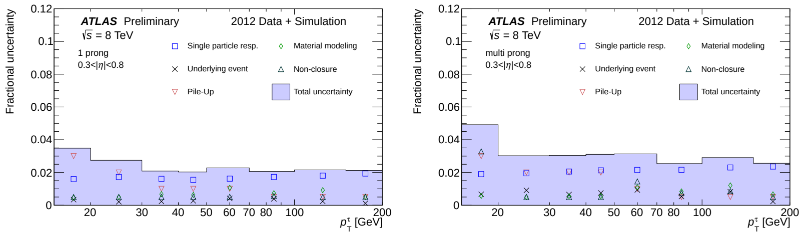

Figure 2: TES uncertainty for $\tau_{1-\mathrm{prong}}$ (left) and $\tau_{\mathrm{multi-prong}}$ (right) for $0.8 < |\eta^\tau| < 1.3$ [2]. The individual contributions are shown as points and the combined uncertainty is shown as a filled band. Bins in p_T^τ with equal uncertainties are grouped.

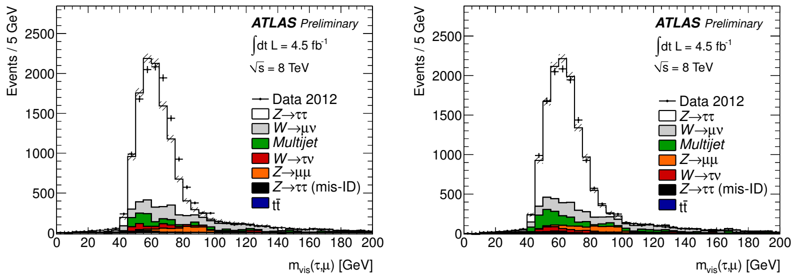

Figure 3: Templates for $0.8 < |\eta^\tau| < 2.5$ for values of α of -10% (left), and the best match with the data (right) [2].

proportional to shifts in the tau transverse momentum, p_{T}^{τ}, so we can shift p_{T}^{τ} in simulation according to $p\prime_{\mathrm{T}}^{\tau} = (1+\alpha)p_{\mathrm{T}}^{\tau}$, and compare the position of the visible mass peak to that in data. Fig. 3 shows the visible mass peak of the Z in the region $0.8 < |\eta^\tau| < 2.5$ for α = -10% (left), and for the optimal value of α = -1.6% (right). In the low $|\eta^\tau|$ region, α is calculated to be -3.0%, and so the difference between the two regions is $(1.4 \pm 3.6)\%$ [2], with the systematic uncertainties calculated by varying each source of uncertainty of uncertainty and recalculating the TES. This is interpreted as indicating no significant difference between the two $|\eta^\tau|$ regions.

References

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[3] E. Khramov et al., *Study of the Response of the Hadronic Barrel Calorimeter in the ATLAS Combined Test-beam to Pions of Energies from 20 to 350 GeV for Beam Impact Points from 0.2 to 0.65*, ATL-TILECAL-PUB-2009-007

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