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Measurement of the Jet Mass Scale and Resolution for Large Radius Jets at $\sqrt{(s)} = 8$ TeV using the ATLAS Detector

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A measurement of the jet mass scale and jet mass resolution uncertainty for large radius jets using the full $\sqrt{(s)} = 8$ TeV dataset from the ATLAS experiment is presented. Large radius jets are calibrated so that on average the reconstructed jet transverse momentum is the same as the corresponding particle level jet transverse momentum in simulation. The ratio of the reconstructed jet mass to the particle level jet mass is defined as the jet mass response. The mean response is the jet mass scale and the standard deviation of the jet mass response distribution is the jet mass resolution. In this study the uncertainty on these quantities is measured by fitting the W boson resonant peak in the large radius jet mass spectrum from lepton plus jets $t\bar{t}$ events in both data and Monte Carlo. Large radius jets with $p_T > 200$ GeV and $|\eta| < 2.0$ are used in this study. Two fitting procedures are used and give comparable results. For the more precise method, the ratio between the data and the Monte Carlo simulation is $1.001 \pm 0.004(stat) \pm 0.024(syst)$ for the jet mass scale and $0.96 \pm 0.05(stat) \pm 0.18(syst)$ for the jet mass resolution.

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1. Introduction

This study presents a measurement of the relative difference between data and Monte Carlo simulation of both the jet mass scale and jet mass resolution using a fit to the W boson resonance peak in a sample enriched in lepton+jets $t\bar{t}$ events [1]. Two methods (subtraction and forward folding) are presented to fit the mass spectrum. In both cases, a template is extracted for the particle-level mass spectrum and then a fit is performed to determine the jet mass scale and jet mass resolution that best reproduces the reconstructed jet mass spectrum. This same procedure is applied to both data and Monte Carlo simulation. The difference in the jet mass scale and the jet mass resolution between data and the simulation as well as the uncertainty on these quantities are the main results.

The complete 2012 dataset recorded during the pp collisions at $\sqrt(s) = 8$ TeV by the ATLAS experiment [2], corresponding to an integrated luminosity of $L = 20.3 \pm 0.3$ fb^{-1}, was considered. Simulated Monte Carlo samples are used to model all the Standard Model backgrounds. $t\bar{t}$ and single-top events are produced with the POWHEG generator with parton showering from PYTHIA. The $W+$ jets and $Z+$ jets samples have been produced using the ALPGEN generator with parton showering from PYTHIA. Diboson samples are produced using the SHERPA generator. In order to simulate the pile-up conditions, multiple minimum-bias events which are generated with PYTHIA 8 are overlaid with hard scattering events. The resulting sample is then weighted to reflect the distribution of the average number of pp interactions per bunch crossing μ in the 2012 data. Finally the response of the ATLAS detector to particles is simulated using the GEANT software. The object and event selection is largely based on the single lepton plus jet searches described here [3]. The large-R jets used are calibrated, trimmed anti$-k_t, R = 1.0$ jets, with p_T >200 GeV and $|\eta| < 2.0$.

2. Extracting the jet mass scale and resolution

Two different methods (subtraction and forward folding) are employed to extract the jet mass scale and resolution. The main difference being that the subtraction method is a parametric procedure whereas the forward folding method is nonparametric. Furthermore, the interpretation of the extracted jet mass scale and jet mass resolution are different. The parameters of the assumed jet mass response function in the subtraction method provide a direct measurement of the average and standard deviation of the jet mass response distribution, that may be compared between data and MC simulation, but which are dependent upon the parametric model. The scale factors measured by the forward folding method only provide a measure of the relative difference between data and simulation.

2.1 Subtraction Method

Events where the selected jet does not fully contain the hadronically decaying W boson decay products are subtracted before fitting the data and simulation to the parameteric forms. As a first step, a Breit-Wigner distribution is used to estimate the particle-level distribution. Next, the response function is parameterized as a Gaussian with mean μ and standard deviation σ , The response distribution is convolved with the Breit-Wigner from the previous step and the fit is performed in the mass range 70-100 GeV as shown in Figure 1. The values of μ and σ are chosen

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to minimize the χ^2 per degrees of freedom between the convolved Breit-Wigner and Gaussian and reconstructed jet mass distribution.

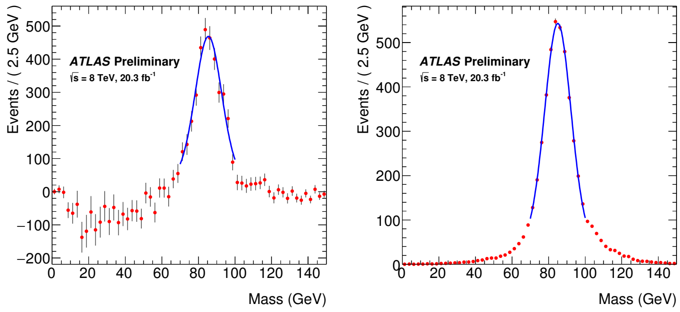

Figure 1: The fit (blue line) of the convolved Gaussian and Breit-Wigner to the subtracted data (left) and the simulation (right) (shown as points) considering only events where the selected jet fully contains the hadronically decaying W boson decay products [1].

2.2 Forward-folding Method

In this method the jet mass resolution function is shifted and stretched so that the modified simulation best matches the data. A non-parametric form is used for the resolution function, which can in general depend on mass and p_T. Let $R(m_{true}, p_T^{reco})$ be a random variable describing jet mass response for given values of the particle-level jet mass m_{true} and the reconstructed jet transverse momentum p_T^{reco}. Given parameters r and s, define the *folded jet mass*, $m_{folded}(r,s)$, as follows:

$$m_{folded}(r,s) = [sR(m_{true}, p_T^{reco}) + (R(m_{true}, p_T^{reco}) - \langle R(m_{true}, p_T^{reco})\rangle (r-s) m_{true})].$$

The jet mass scale and the jet mass resolution of the folded jet mass are given by:

$$\langle m_{folded}(r,s)/m_{true}\rangle = s\langle R(m_{true}, p_T^{reco})\rangle$$
$$\sigma(m_{folded}(r,s)/m_{true}) = r\sigma(R(m_{true}, p_T^{reco})),$$

where $\sigma(X)$ is the standard deviation of the random variable X. By construction, s is a shift in the average response and r is a shift in the standard deviation. The values s and r are chosen to minimize the χ^2 per degrees of freedom between the distribution of $m_{folded}(r,s)$ and reconstructed jet mass distribution over the mass range $50-120$ GeV. At the minimum (r', s'), the folded distribution is called the fitted mass distribution, $m_{fitted} = m_{folded}(r', s')$. A comparison between the template from simulation with the fitted parameters and the data is shown in Figure 2(left plot). The final result, one and two σ uncertainty ellipses around the jet mass scale and resolution are also shown in Figure 2 (right plot).

3. Conclusions

The relative jet mass scale and jet mass resolution derived from both methods are compatible with unity within the statistical uncertainties that range from 0.3% for the jet mass scale to 5-8% for the jet mass resolution. The forward folding method has a significantly lower systematic uncertainty for both the jet mass scale (2.4%versus 3.6%) and the jet mass resolution (18%versus

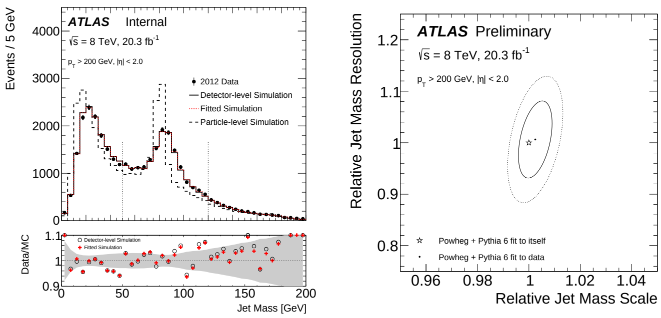

Figure 2: (left plot)A comparison between the post- and pre-fit simulation and the data. The dashed line is the particle-level jet mass spectrum before any detector simulation. The solid line is the detector-level simulation without any fit ($m_{\text{folded}}(r = s = 1)$). The solid line shows the detector-simulation before fitting the relative jet mass scale and resolution and the dotted red line shows the post-fit distribution. In the ratio plot, the band is the statistical uncertainty from the data while the black and red points are the pre- and post-fit ratios of the simulation with the data. The vertical dotted lines indicate the fit range, (right plot)The one (solid) and two (dashed) σ uncertainty ellipses for the relative jet mass scale and the relative jet mass resolution. The circular marker indicates the fit of the relative jet mass scale and jet mass resolution from templates using the simulation with $t\bar{t}$ modeled by Powheg+Pythia 6 to the data while the star indicates the result of fitting the simulation to itself. The later is by construction at the point (1,1) [1].

Table 1: A summary of the measured relative jet mass scale and jet mass resolution using both the subtraction and the forward folding methods. Uncertainties are given as a fraction of the nominal. The jet energy scale, ISR/FSR, and non-$t\bar{t}$ background uncertainties are treated as asymmetric but the maximum of the two variations are reported. The uncertainties not applicable to the either method are denoted by "–". The systematic uncertainties are added in quadrature to produce the total [1].

Source of Uncertainty	Relative Jet Mass Scale		Relative Jet Mass Resolution	
	Subtraction	Forward fold	Subtraction	Forward fold
ME Generator	0.027	0.017	0.11	0.08
Fragmentation Model	0.022	0.018	0.01	0.05
ISR/FSR	0.009	0.004	0.17	0.15
Jet Energy Scale	0.001	0.002	0.11	0.03
Jet Energy Resolution	0.001	0.001	0.02	0.03
b-tagging	< 0.001	< 0.001	0.02	0.01
categories	0.001	–	0.02	–
MC Normalization	0.002	0.001	0.08	0.01
Total Systematic Uncertainty	0.036	0.024	0.24	0.18
Data Statistical Uncertainty	0.003	0.004	0.08	0.05
Value	1.005	1.001	1.00	0.96

24%). The subtraction method provides an advantage over the forward folding method by allowing a measurement of the absolute jet mass scale.

References

[1] ATLAS Collaboration, *Measurement of the Jet Mass Scale and Resolution for Large Radius Jets at $\sqrt(s) = 8$ TeV using the ATLAS Detector*, ATLAS-CONF-2016-008

[2] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*. *JINST* **3** (2008) S08003

[3] ATLAS Collaboration, *A search for $t\bar{t}$ resonances using lepton-plus-jets events in proton-proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, *JHEP* **08** (2015)148.