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Comparison of two approaches to jet reconstruction in proton-lead collisions in ATLAS

Patrycja Potępa[a,b,*] **and on behalf of the ATLAS Collaboration**

[a] *AGH University of Krakow, al. Mickiewicza 30, Kraków, Poland*

[b] *Johannes Gutenberg University Mainz, Saarstr. 21, 55122 Mainz, Germany*

E-mail: patrycja.potepa@cern.ch

Jets are commonly produced in heavy-ion collisions at the LHC energies. Their calibration is essential for precise measurements of various processes, such as top-quark pair production. The report presents the measurement of jet energy scale and resolution in proton-lead collisions collected at 8.16 TeV in 2016 by the ATLAS experiment. The method involving the balance between Z boson and jet transverse momenta is used for jet $p_{\mathrm{T}} > 20$ GeV and $|\eta| < 2.5$ to estimate jet performance in both data and Monte Carlo simulation. The performance of two jet definitions, referred to as PFlow and HI jets, is evaluated and results are compared including systematic uncertainties. The results of these studies are a key input to the ongoing analysis of top-quark pair production in p+Pb collisions [1].

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*Speaker

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1. Jet reconstruction

The baseline jet reconstruction algorithm used in the ATLAS experiment [2] is anti-k_t [3] implemented in the FastJet software package [4]. In this study, jets are clustered within the radius of $R = 0.4$. Two jet definitions, referred to as particle flow (PFlow) and heavy-ion (HI), are considered. The analysis uses $Z \to \ell\ell$ events with $\ell = e^{\pm}, \mu^{\pm}$ in 2016 p+Pb data, corresponding to a total integrated luminosity of 165 nb^{-1}, along with the Monte Carlo (MC) simulation.

PFlow jets [5] are reconstructed by clustering four vectors corresponding to a combination of measurements from the inner detector and calorimeters. Topological clusters with low energies are replaced by track momenta matched to those clusters. A high-pileup jet calibration derived for 13 TeV pp collisions is used.

HI jets [6] are build using massless calorimeter towers with size of $\Delta\eta \times \Delta\phi = 0.1 \times \pi/32$. The background energy originating from the underlying event is subtracted from every tower. A low-pileup jet calibration dedicated for p+Pb collisions is applied.

2. Truth method

Jet performance can be evaluated by comparing reconstructed jets with generated ones, referred to as the truth method [5]. Generated jets, provided in MC simulation, consist of stable final-state particles originating from the primary vertex, excluding muons and neutrinos. Reconstructed and generated jets are geometrically matched by imposing a requirement on the distance, $\Delta R < 0.4$.

The jet p_{T} response, defined as $p_{\mathrm{T}}^{\mathrm{reco}}/p_{\mathrm{T}}^{\mathrm{truth}}$, is studied in multiple jet $p_{\mathrm{T}}^{\mathrm{truth}}$ bins. $p_{\mathrm{T}}^{\mathrm{reco}}$ and $p_{\mathrm{T}}^{\mathrm{truth}}$ denote transverse momenta of the reconstructed and corresponding generated jet, respectively. The mean jet response $\langle p_{\mathrm{T}}^{\mathrm{reco}}/p_{\mathrm{T}}^{\mathrm{truth}} \rangle$ is obtained as the mean of a Gaussian function fitted to the jet p_{T} response distribution. The jet p_{T} resolution is estimated as the ratio of the standard deviation over the mean of the same Gaussian function fit.

Figure 1 shows the mean jet response and p_{T} resolution evaluated in MC simulation for the PFlow and HI jets. The mean jet response is found to be above unity, which originates from a quark-dominated composition of $Z \to \ell\ell$ events. Rising values at low $p_{\mathrm{T}}^{\mathrm{truth}}$ for the PFlow jets come from the underlying event in p+Pb collisions. This effect is not observed for the HI jets, which include the underlying event subtraction. The jet p_{T} resolution determines the amount of fluctuation in the jet energy reconstruction. The resolution improves with rising $p_{\mathrm{T}}^{\mathrm{truth}}$ for both PFlow and HI jets.

3. Z-jet balance method

Another way to estimate jet performance is based on a momentum balance between the Z boson and the jet, called the Z-jet balance method [5]. It utilizes events with a jet recoiling against a Z boson, which further decays to either an electron or muon pair. A pairing criterion of $|\Delta\phi(\mathrm{Z}, \mathrm{jet})| > 2.8$ is imposed to ensure the back-to-back emission of the Z boson and the jet. The advantage of this method is the fact that it can be applied in both data and MC simulation.

In this method, the per-event jet p_{T} response is determined as $p_{\mathrm{T}}^{\mathrm{reco}}/p_{\mathrm{T}}^{\mathrm{ref}}$, where the reference transverse momentum $p_{\mathrm{T}}^{\mathrm{ref}} = p_{\mathrm{T}}^{\mathrm{Z}}|\cos\Delta\phi(\mathrm{Z}, \mathrm{jet})|$ is the projection of the Z boson transverse momentum $p_{\mathrm{T}}^{\mathrm{Z}}$ along the jet axis. The mean jet response $\langle p_{\mathrm{T}}^{\mathrm{reco}}/p_{\mathrm{T}}^{\mathrm{ref}} \rangle$ is defined as the mean of a Gaussian

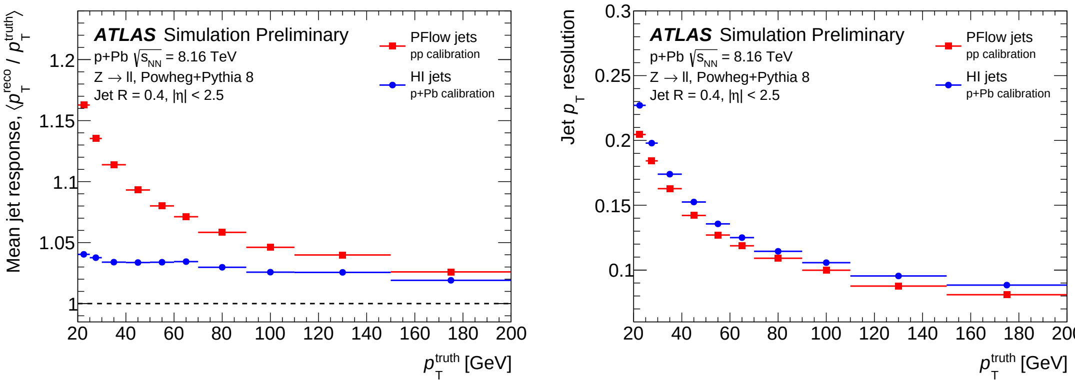

Figure 1: The mean jet response (left) and jet p_T resolution (right) evaluated in 2016 p+Pb simulation as a function of generated jet p_T^{truth} for the PFlow and HI jets [7].

function fitted to the jet p_T response distribution, while the jet p_T resolution is obtained as the ratio of the standard deviation over the mean of the same fit.

Figure 2 presents the mean jet response and p_T resolution in 2016 p+Pb data and MC simulation for the PFlow jets. The mean jet response is below unity and the values at low p_T^{ref} are increased by the underlying event, resulting in a flat p_T^{ref} dependence. The resolution improves with rising p_T^{ref}. The overall jet p_T resolution is higher compared to the generated method due to intrinsic broadening coming from physics of $Z \to \ell\ell$ decays. A good agreement is found between data and MC simulation in the mean jet response, while a small MC non-closure is observed in the jet p_T resolution at jet $p_T > 35$ GeV.

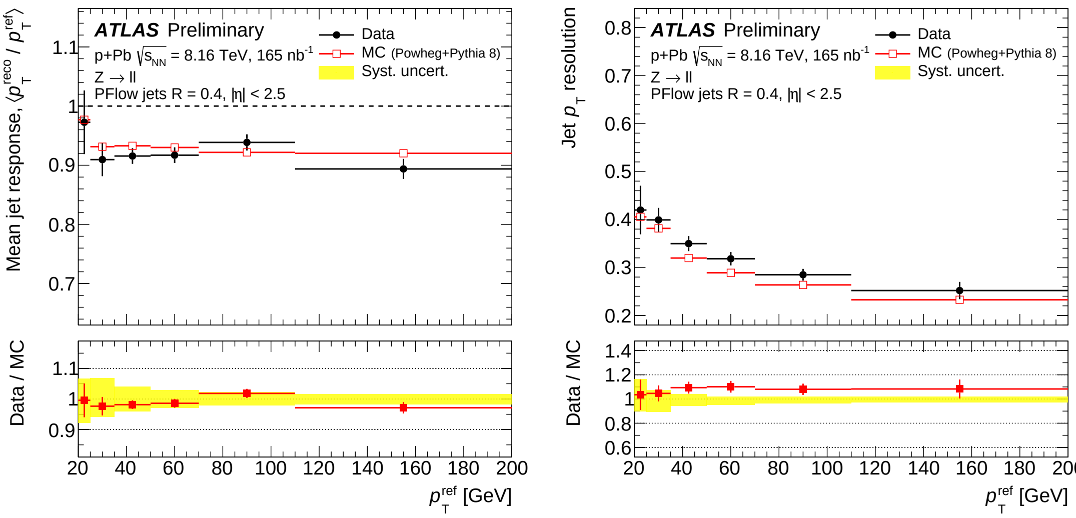

Figure 2: The mean jet response (left) and jet p_T resolution (right) evaluated in 2016 p+Pb data and simulation as a function of reference jet p_T^{ref} for the PFlow jets. The bottom panel shows the data-to-MC ratio with error bars and yellow boxes representing statistical and systematic uncertainties, respectively [7].

The mean jet response and p_T resolution in 2016 p+Pb data and MC simulation for the HI jets is shown in Figure 3. The mean jet response is below unity and rises with p_T^{ref} as expected. The resolution at low $p_{\mathrm{T}}^{\mathrm{ref}}$ is worse compared to the PFlow jets. The mean jet response in data and MC simulation is consistent within uncertainties, while a small MC non-closure is found in the jet p_{T} resolution at jet $p_{\mathrm{T}} > 50$ GeV.

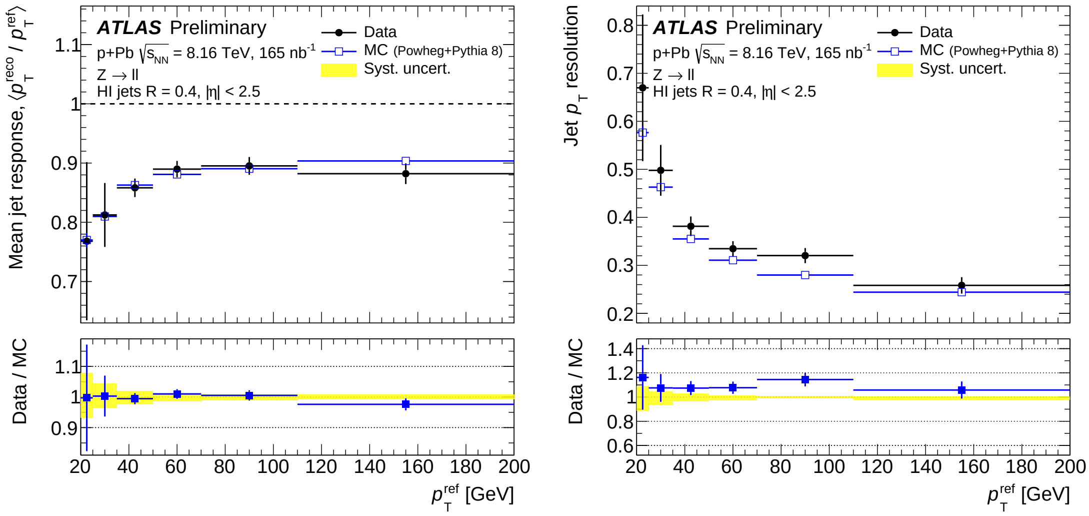

Figure 3: The mean jet response (left) and jet p_{T} resolution (right) evaluated in 2016 p+Pb data and simulation as a function of reference jet $p_{\mathrm{T}}^{\mathrm{ref}}$ for the HI jets. The bottom panel shows the data-to-MC ratio with error bars and yellow boxes representing statistical and systematic uncertainties, respectively [7].

4. Conclusions

Jet performance has been evaluated in 2016 p+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV collected by the ATLAS experiment at the LHC. The data set corresponds to a total integrated luminosity of 165 nb^{-1}. Two jet definitions, PFlow and HI, have been studied using two alternative approaches, the truth and Z-jet balance methods. The mean jet response and p_{T} resolution have been estimated using both methods for the PFlow and HI jets.

The mean jet response obtained from the truth method is above unity due to the quark-dominated composition of $Z \to \ell\ell$ events. The rising mean jet response at low jet p_{T} for the PFlow jets originates from the underlying event in p+Pb collisions.

The resolution improves with increasing jet p_{T} for both jet definitions. Higher resolution estimated using the Z-jet balance method compared to the truth one comes from intrinsic broadening from physics of $Z \to \ell\ell$ decays.

The results obtained in data and MC simulation using the Z-jet balance method have been compared. A good agreement is observed in the mean jet response for both jet definitions. A small MC non-closure is found in the jet p_{T} resolution at higher jet p_{T} values.

5. Acknowledgements

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