Measurement of $R = 0.4$ jet mass in Pb+Pb and $pp$ collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ATLAS detector

The ATLAS Collaboration

The measurement of the jet structure is sensitive to the angular and momentum correlations of the jet constituents. These correlations can be used to study modifications of jets in heavy ion collisions, where they provide complementary information to previously measured jet fragmentation functions. In this note, the mass divided by the transverse momentum of inclusive jets is measured using the ATLAS detector in lead-lead and proton-proton collisions at $\sqrt{s_{NN}} = 5.02$ TeV delivered by the LHC. This quantity is measured for anti-$k_t$, $R = 0.4$ jets in intervals of jet transverse momentum and centrality in Pb+Pb collisions and compared to the same measurements in proton-proton collisions at the same collision energy. The nuclear modification factor, $R_{AA}$, is evaluated. No significant dependence of $R_{AA}$ on the jet mass is observed.

© 2018 CERN for the benefit of the ATLAS Collaboration. Reproduction of this article or parts of it is allowed as specified in the CC-BY-4.0 license.
1 Introduction

Heavy ion collisions at high-energy colliders are used in order to produce and study the quark-gluon plasma (QGP) at high temperatures and densities. Jets measured in these collisions provide a powerful tool to explore properties of the QGP. This is done by measuring the modification of jet rates and their internal structure after the jets have traversed the QGP. The yields of inclusive jets [1–4] as well as the transverse momentum balance in dijet events [5–7] are observed to be modified in a centrality-dependent manner in Pb+Pb collisions with respect to the expectations from measurements in pp collisions at the same centre-of-mass-energy scaled by the nuclear thickness function. The jet internal structure, quantified by measurements of fragmentation functions [8–10] and the angular distribution of tracks around jets [11, 12], is also modified in Pb+Pb collisions.

The mass of jets has been studied in pp collisions [13–16] at the LHC. Measurements of the mass distribution of jets in heavy-ion collisions are also of great interest as a probe of how the jet is modified as it passes through the QGP. If the jet structure is not resolved by the QGP, the entire jet is expected to lose energy coherently [17]. While energy would be lost from the jet, its properties would be unmodified with respect to jets from pp collisions. However, if the QGP resolves the parton branching structure, then parts of the jet would be expected to lose energy incoherently. The ratio of the jet mass, \( m \), and the jet transverse momentum, \( p_T \), is related to the angular width of the jet, thus measurements of \( m/p_T \) are sensitive to coherence effects in the jet quenching processes. Previously, the mass of jets has been measured in Pb+Pb collisions [18, 19]. No significant modification of the jet mass are observed when comparing measurements from Pb+Pb collisions to p+Pb collisions [18] or pp collisions [19]. However, these previous measurements are limited by systematic uncertainties and are not fully corrected for detector effects. It therefore remains of great interest to rigorously test these fundamental questions about the nature of jet quenching.

In this note, a measurement of jet \( m/p_T \) in Pb+Pb and pp collisions with the ATLAS detector at the LHC is presented for jets with \( p_T \) from 126 to 500 GeV in the rapidity range of \(|y| < 2.1\). The observable of interest in this analysis is the distribution of \( m/p_T \), where \( m \) is the norm of the four-momentum of the jet. Instead of \( m \), \( m/p_T \) is presented because it is dimensionless, weakly dependent on \( p_T \), and correlated to the transverse energy profile of jet energy. The jets are reconstructed from massless \( \Delta \eta \times \Delta \phi = 0.1 \times 0.1 \) calorimeter towers using the anti-\( k_T \) algorithm [20] as implemented in the FastJet package [21, 22] with \( R = 0.4 \). The differential cross-section for jet production quantified as a function of \( m/p_T \) is presented as

\[
\frac{d\sigma}{d(m/p_T)} (p_T) = \frac{1}{L_{\text{int}}} \frac{dN_{\text{jet}}^{|y|<2.1}}{d(m/p_T)} (p_T),
\]

where \( N_{\text{jet}}^{|y|<2.1} \) is the number of jets in the range of \(|y| < 2.1\) for a given \((p_T, m/p_T)\) bin and \( L_{\text{int}} \) is the total integrated luminosity.

To quantify the modifications of jet yields in heavy ion collisions with respect to pp collisions, the nuclear

---

1 ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the center of the LHC ring, and the y axis points upward. Cylindrical coordinates \((r, \phi)\) are used in the transverse plane, \( \phi \) being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle \( \theta \) as \( \eta = -\ln \tan(\theta/2) \). The rapidity is defined as \( y = 0.5 \ln \frac{E+p_z}{E-p_z} \), where \( E \) and \( p_z \) are the energy and the component of the momentum along the beam direction.
A modification factor is presented:

\[
R_{AA}(m/p_T, p_T) = \frac{1}{N_{\text{evt}}} \frac{dN_{\text{jet}}^{\text{Pb+Pb}}}{d(m/p_T)} \frac{dN_{\text{jet}}^{\text{cent}}}{d(m/p_T)}
\]

(2)

where \(N_{\text{evt}}\) is the total number of hadronic collisions in each centrality interval and \(\langle T_{AA} \rangle\) is the mean of the nuclear thickness function obtained from a Glauber model MC simulation [23].

2 Experimental setup

The measurements presented in this paper were performed using the ATLAS inner-detector, calorimeter, trigger and data acquisition systems [24].

The calorimeter system consists of a sampling liquid argon (LAr) electromagnetic (EM) calorimeter covering \(|\eta| < 3.2\), a steel–scintillator sampling hadronic calorimeter covering \(|\eta| < 1.7\), LAr hadronic calorimeters covering \(1.5 < |\eta| < 3.2\), and two LAr forward calorimeters (FCal) covering \(3.1 < |\eta| < 4.9\) [24]. The EM and hadronic calorimeters are segmented longitudinally in shower depth into three layers each, with an additional EM pre-sampler layer covering \(|\eta| < 1.8\). The EM calorimeters have a granularity that varies with layer and pseudorapidity, but which is generally much finer than that of the hadronic calorimeter.

The inner detector measures charged particles within the pseudorapidity interval \(|\eta| < 2.5\) using a combination of silicon pixel detectors, silicon microstrip detectors (SCT), and a straw-tube transition radiation tracker (TRT) covering \(|\eta| < 2.0\), all immersed in a 2 T axial magnetic field [24]. Each of the three detectors is composed of a barrel and two symmetric end-cap sections.

The zero-degree calorimeters (ZDCs) are located symmetrically at \(z = \pm 140\) m and cover \(|\eta| > 8.3\). They are constructed from tungsten absorber plates, while Čerenkov light is transmitted via quartz fibers. In Pb+Pb collisions the ZDCs primarily measure “spectator” neutrons, that is neutrons that do not interact hadronically when the incident nuclei collide. A ZDC coincidence trigger is implemented by requiring the pulse height from each ZDC to be above a threshold set to accept the single-neutron peak. The minimum-bias trigger scintillators (MBTS) detect charged particles over \(2.1 < |\eta| < 3.9\) using two segmented counters placed at a distance from the detector center of \(\pm 3.6\) m. Each counter provides measurements of both the pulse heights and arrival times of ionization energy deposits.

A two-level trigger system is used to select the Pb+Pb and pp collisions. The first, a hardware-based trigger stage named Level-1, is implemented with custom electronics. The next level is the software-based High Level Trigger (HLT), which is used to further reduce the accepted event rate. Minimum-bias events are recorded using a trigger defined by a logical OR of the following two triggers: 1) total energy Level-1 trigger; 2) veto of the previous trigger, plus requirements of a ZDC coincidence trigger at Level-1 and at least one track in the HLT. The total-energy trigger requires the total transverse energy measured in the calorimeter system to be greater than 50 GeV. Jet events are selected by the HLT, after requiring the identification of a jet by the Level-1 jet trigger in pp collisions or the total energy trigger in Pb+Pb collisions. The Level-1 jet trigger utilized in pp collisions requires a jet with transverse momentum greater than 20 GeV. The HLT jet trigger uses a jet reconstruction algorithm similar to that used in the
offline analysis (the offline jet reconstruction is discussed in Sec. 4), selecting events containing jets with transverse energy of at least 75 GeV in Pb+Pb collisions and at least 85 GeV in pp collisions. Both jet triggers sample the full delivered luminosity. The measurement is performed in the jet transverse momentum region where the triggers are fully efficient.

3 Data sets and event selection

The Pb+Pb and pp data used in this analysis were recorded in 2015. The data samples consist of 25 pb^{-1} of $\sqrt{s} = 5.02$ TeV pp data and 0.49 nb^{-1} of $\sqrt{s_{NN}} = 5.02$ TeV Pb+Pb data. In both Pb+Pb and pp collisions, events are required to have a reconstructed vertex within 150 mm of the nominal interaction point along the beam axis. Only events taken during stable beam conditions and satisfying detector and data quality requirements, which include the calorimeters and inner tracking detectors being operating nominally, are considered.

In addition to the jet-triggered sample, a separate Pb+Pb data sample was used to produce Monte Carlo (MC) samples with conditions that match the data. The sample was recorded with the minimum-bias triggers and two total transverse-energy triggers requiring 1.5 TeV and 6.5 TeV, which are used to enhance the rate of more central Pb+Pb events.

A sample of $1.8 \times 10^7$ simulated 5.02 TeV Powheg+Pythia8 [25, 26] pp hard-scattering events, generated using the A14 tune [27] and the NNPDF23LO parton distribution function (PDF) set [28], is used to evaluate the detector performance in pp data. The detector performance in Pb+Pb collisions is evaluated using the same sample of $1.8 \times 10^7$ simulated 5.02 TeV hard-scattering pp events generated with Powheg+Pythia8 overlaid with Pb+Pb data collected using the above minimum-bias and transverse energy triggers. For both samples, the detector response is simulated using Geant4 [29, 30], and the for the Pb+Pb overlay sample the simulated hits are combined with those from the data event. The MC samples are then reconstructed in the same manner as the Pb+Pb data.

In Pb+Pb collisions, the event centrality reflects the overlap area of the two colliding nuclei and is characterized by $\Sigma E_{T}^{FCal}$, the total transverse energy deposited in the FCal [31]. The centrality intervals used in this analysis are defined according to successive percentiles of the $\Sigma E_{T}^{FCal}$ distribution obtained in minimum-bias collisions ordered from the most central (highest $\Sigma E_{T}^{FCal}$) to the most peripheral collisions (lowest $\Sigma E_{T}^{FCal}$): 0–10%, 10–20%, 20–30%, 30–40%, 40–60%, 60–80%. A weight is assigned to each MC event to match the centrality distribution observed in the data.

4 Jet selection

The jet reconstruction procedures closely follow those used by ATLAS for jet measurements in pp and Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [2]. First, the anti-$k_t$ algorithm is run in four-momentum recombination mode, with inputs of $\Delta \eta \times \Delta \phi = 0.1 \times 0.1$ calorimeter towers, with the distance parameter of $R = 0.4$. The energies in the towers are obtained by summing the energies of calorimeter cells at the electromagnetic energy scale within the tower boundaries. Then, an iterative procedure is used to estimate the $\eta$-dependent transverse energy density of the underlying event (UE), while excluding the regions populated by jets. The estimate of the UE contribution is performed on an event-by-event basis. Furthermore, the background is modulated to account for the presence of the azimuthal anisotropy of
particle production [32]. The modulation accounts for the contribution of the second, third, and fourth order azimuthal anisotropy harmonics. Higher order harmonics introduce a negligible variation of the mean reconstructed jet energy and are thus neglected. The UE transverse energy is subtracted from each calorimeter tower included in the reconstructed jet, and the four-momentum of the jet is updated accordingly. Then, a jet $\eta$- and $p_T$-dependent simulation-derived correction factor is applied to the jet energy to correct for the calorimeter energy response [33]. An additional correction based on in situ studies of jets recoiling against photons, $Z$ bosons, and jets in other regions of the calorimeter is applied [34, 35]. The same jet reconstruction procedure without the azimuthal modulation of the UE is also applied to $pp$ collisions.

The mass of a jet is reconstructed from the calorimeter towers. The energy density of the UE is determined as described above and subtracted tower-by-tower. The norm of the total four-momentum is calculated as:

$$m = \sqrt{(\sum_{i \in J} E_i)^2 - (\sum_{i \in J} \vec{p}_i)^2}$$

(3)

where $E_i$ and $\vec{p}_i$ represent the energy and momentum vector for $i^{th}$ constituent in jet $J$ after background subtraction. Due to resolution effects, some jets can have $E < |\vec{p}|$ for which $m^2$ is negative. For those jets, a negative mass value was assigned in the reconstruction level as:

$$m = -\sqrt{-(\sum_{i \in J} E_i)^2 + (\sum_{i \in J} \vec{p}_i)^2}$$

(4)

The fraction of such jets are 0.2% in $pp$ collisions, a similar value in 60–80% Pb+Pb collisions, and 3.2% in 0–10% central Pb+Pb collisions. These effects are observed in both the data and MC samples and the negative mass values are corrected by the unfolding (discussed below). The $m/p_T$ distributions are not calibrated to put the mass scale at unity; the impact of this choice is included in the uncertainties discussed in Sec. 6. The generator-level mass is constructed using primary particles.$^2$

To evaluate the precision of the $m/p_T$ measurement, the jet mass scale (JMS) and resolution (JMR) are evaluated. The distributions of $(m/p_T)^2_{\text{Reco}}$ are fit to Gaussian functions, and the means and the widths of these fits are used to quantify the jet mass response as shown in Figure 1 as a function of $(m/p_T)^2_{\text{Truth}}$. This quantity is evaluated separately for each centrality interval in Pb+Pb collisions and $pp$ collisions. The mean values of the jet mass response are very similar for $pp$ collisions and 0–10% central Pb+Pb collisions, while the resolution is worse for Pb+Pb collisions than $pp$ collisions due to the large UE in central Pb+Pb collisions.

5 Analysis procedure

The measurement is performed for jets in the $p_T$ range 126–500 GeV and with rapidity $|y| < 2.1$. Six $p_T$ ranges are used in the measurement: 126–158, 158–200, 200–251, 251–316, 316–398 and 398–500 GeV.

In order to make a direct comparison between Pb+Pb and $pp$ collisions, the measurement is corrected for detector effects using a two-dimensional unfolding in $p_T$ and $m/p_T$. The unfolding procedure uses a

$^2$ Primary particles are defined as particles with a mean lifetime $\tau > 0.3 \times 10^{-10}$s either directly produced in $pp$ interactions or from subsequent decays of particles with a shorter lifetime. All other particles are considered to be secondary.
Figure 1: The mean (top) and the resolution (bottom) of $m^2/p_T^2$ for $pp$ collisions (left) and 0–10% Pb+Pb collisions (right).

Bayesian method [36] from the RooUnfold software package [37]. This procedure removes the effects of bin migrations due to the jet energy resolution, the jet mass resolution, and the jet mass scale. The response matrices are made separately for $pp$ collisions and for each centrality bin in Pb+Pb collisions. In order to better match the data, the MC is reweighted so that its prior has a similar shape to the data. The number of iterations in the unfolding is chosen to minimize the amplification of statistical fluctuations and minimize the bias due to the choice of the prior in the unfolded distribution. For both $pp$ and Pb+Pb collisions, six iterations is found to be optimal. Figure 2 shows, as examples, the $m/p_T$ distribution before and after unfolding for $pp$ and 0–10% central Pb+Pb events.
6 Systematic uncertainties

The systematic uncertainties on the measurement are described below, and include: jet energy scale (JES), jet energy resolution (JER), jet mass scale (JMS), jet mass resolution (JMR), and the unfolding procedure. The systematic uncertainties have been evaluated separately for the differential cross-section in Pb+Pb and pp collisions, as a function of jet $p_T$ and $m/p_T$. For each systematic variation, the entire unfolding procedure is repeated. All sources of systematic uncertainties were combined in quadrature to obtain the total systematic uncertainty.

The systematic uncertainty due to the JES is composed of two parts: a centrality-independent baseline and a centrality-dependent component. The centrality-independent baseline is applied to both pp and Pb+Pb collisions, while the centrality-dependent component is only applied to Pb+Pb collisions. The baseline uncertainty is determined from in situ studies of the calorimeter response [38–40], and from studies of the relative energy scale difference between the jet reconstruction procedure in this measurement [39] and the procedure used in pp collisions in Ref. [41]. The centrality-dependent uncertainty reflects a modification of parton showers by the Pb+Pb environment, and it is evaluated by comparing calorimeter $p_T$ and the sum of $p_T$ of tracks within the jet in data and MC. The size of the centrality-dependent uncertainty on the JES reaches 0.5% in the most central collisions. Each component that contributes to the JES uncertainty is varied separately by ±1 standard deviation for each interval in $p_T$, and the response matrix is recomputed accordingly. The data are unfolded with these modified matrices.

The uncertainty on the $m/p_T$ distributions due to the JER is also evaluated by then repeating the unfolding procedure with modified response matrices, where an additional contribution is added to the resolution of the reconstructed $p_T$ using a Gaussian smearing procedure. The smearing factor is evaluated using an in situ technique in 13 TeV pp data involving studies of dijet energy balance [42, 43]. An additional uncertainty is included to account for differences between the jet reconstruction procedure in this measurement and
that used in \( pp \) data in Ref. [41]. The resulting uncertainty from the JER is symmetrized to account for reductions in the JER.

The systematic uncertainty on the JMS is evaluated by comparing the jet mass measured using calorimeter towers (the default measurement) to \( m_{\text{trk}} \), the jet mass measured using tracks matched to the jet (\( \Delta R < 0.4 \)). A ratio of these observables is calculated:

\[
\frac{m_{\text{trk}}}{m_{\text{cal}}},
\]

where all tracks with a transverse momentum \( p_T^{\text{trk}} > 1 \text{ GeV} \) and which are associated with the jet are used to construct \( m_{\text{trk}} \). The UE contribution to \( m_{\text{trk}} \) is subtracted in Pb+Pb collisions using the random cone method [10, 44]. The distribution of \( r_{\text{trk}}^m \) is expected to be well described in the MC samples. The uncertainty is then quantified by a data-to-MC ratio of \( r_{\text{trk}}^m \) defined as

\[
R^m = \left( \frac{\langle r_{\text{trk}}^m \rangle_{\text{data}}}{\langle r_{\text{trk}}^m \rangle_{\text{MC}}} \right),
\]

where \( \langle r_{\text{trk}}^m \rangle \) denotes the peak position of the \( r_{\text{trk}}^m \) distribution. A Landau function is used to determine the peak position. \( R^m \) is found to vary with \( m/p_T \), \( p_T \), and event centrality by as much as 4%. These differences can be due to the increased JER and JMR as well as the modified fragmentation in Pb+Pb collisions [10]. In order to propagate the systematic uncertainties to the results, the jet mass in MC samples was scaled by \( R^m \) in constructing the response matrix. This uncertainty is taken to be uncorrelated between Pb+Pb and \( pp \) collisions.

One assumption of this approach is that the JMS of track-jets is the same for MC and data, thus their effects are canceled in the double ratio. To assess the sensitivity to the track reconstruction performance, the uncertainties on the tracking efficiency, residual misalignment of the tracking detectors, and the fake rate [45, 46] are accounted for in the estimate of \( R^m \). The change in \( R^m \) is less than 1.4% in all kinematic selections in both \( pp \) and Pb+Pb collisions. The uncertainty is taken to be a uniform 1.4% on the \( m/p_T \) distributions and is applied symmetrically around the central value. The uncertainty on correcting for the \( m/p_T \) scale in the unfolding is assessed by evaluating the JMS and applying the calibration to both data and MC events and repeating the unfolding of the data with the modified response matrices.

The systematic uncertainty due to the JMR is evaluated by adding an additional resolution source to the reconstructed jet mass in the MC samples and repeating the unfolding procedure with modified response matrices. The smearing factor has two contributions: a baseline uncertainty of 20% derived in \( pp \) collisions and an additional uncertainty originating from differences in the mass resolution of jets built using topological cell clusters [47] and calorimetric towers. The size of the additional uncertainty varies from 6–15% depending on \( p_T \). These uncertainties are added and the resulting final JMR uncertainty is 26–35% for \( pp \) collisions. Additionally, a centrality dependent JMR uncertainty of up to 21% is applied to Pb+Pb events, which is based on the additional smearing present in Pb+Pb overlay MC samples compared to \( pp \) MC samples.

The systematic uncertainty on the unfolding procedure come from the sensitivity of the unfolding to the choice of the prior. The default version of the unfolding uses the MC reweighted such that the reconstructed MC is matched to the reconstructed data in both \( p_T \) and \( m/p_T \). The systematic uncertainty on the reweighting procedure is evaluated by changing the shape of the reweighting function, \( w(m/p_T, p_T) \), by scaling the deviation of \( w(m/p_T, p_T) \) from unity, \( w(m/p_T, p_T) - 1 \), up and down by 50% of the nominal values. The MC is reweighted the MC by these new reweighting functions and the unfolding procedure is repeated.
To assess the sensitivity of the measurement to the MC modeling response, the default response matrices generated with POWHEG+PYTHIA8 MC samples are used to unfold the Herwig++ MC events. The deviation from the Herwig++ truth is added to the uncertainties for both pp and Pb+Pb collisions.

The uncertainty on $\langle T_{AA} \rangle$ originates from geometric modeling uncertainties (nucleon-nucleon inelastic cross-section, Woods-Saxon parameterization of the nucleon positions) and the uncertainty on the fraction of selected inelastic Pb+Pb collisions.

The pp components of the JES and the JER uncertainties are taken as correlated between Pb+Pb and pp collisions. The remaining systematic uncertainties are taken as uncorrelated between Pb+Pb and pp collisions. The total uncertainties and their compositions are shown in Figures 3 through 5 for pp collisions, Pb+Pb collisions in 0–10%, 30–40% and 60–80% intervals of centrality, and for $R_{AA}$.

![Figure 3: Systematic uncertainties for pp collisions (top row), 0–10% Pb+Pb collisions (middle row), and $R_{AA}$ (bottom row) as a function of $m/p_T$ for the $p_T$ intervals used in this analysis. The uncertainties are: JMR (dashed red), JMS (dashed brown), JER (dark blue), JES (green), unfolding (magenta), and total (black).](image)

7 Results

The differential cross-section for pp collisions is shown along with the cross-section from POWHEG+PYTHIA8 in Figure 6. The POWHEG+PYTHIA8 distributions are normalized to have the same integral as data to allow for a comparison of shapes. The MC-to-data ratios are consistent with unity within the combined statistical and systematic uncertainties. However, they exhibit a trend of increased (decreased) jet yield with small (large) $m/p_T$ in MC compared to data.

Figure 7 shows the yields normalized by the number of events in Pb+Pb collisions for the 0–10%, 30–40% and 60–80% centrality intervals. The $R_{AA}$ values in the same centrality selections are shown in Figure 8.
Figure 4: Systematic uncertainties for 30–40% Pb+Pb collisions (top row), and $R_{AA}$ (bottom row) as a function of $m/p_T$ for the $p_T$ intervals used in this analysis. The uncertainties are: JMR (dashed red), JMS (dashed brown), JER (dark blue), JES (green), unfolding (magenta), and total (black).

For all centrality bins, these values have no significant dependence on $m/p_T$. They are also observed to be consistent with the inclusive jet $R_{AA}$ measured in Ref. [48]. The $R_{AA}$ values evaluated as a function of $p_T$ in intervals of $m/p_T$ are presented in Figure 9 in 0–10%, 30–40%, and 60–80% centrality bins. The dependence on $p_T$ is the same in all $m/p_T$ intervals within the statistical and systematical uncertainty.
Figure 5: Systematic uncertainties for 60–80% Pb+Pb collisions (top row), and $R_{AA}$ (bottom row) as a function of $m/p_T$ for the $p_T$ intervals used in this analysis. The uncertainties are: JMR (dashed red), JMS (dashed brown), JER (dark blue), JES (green), unfolding (magenta), and total (black). The highest two $p_T$ intervals were merged.
Figure 6: (Left) Differential cross sections as a function of $m/p_T$ in $pp$ collisions and in Powheg+Pythia8 MC simulation. The distribution from Powheg+Pythia8 MC sample is normalized to have the same integral as the data. (Right) The ratio of differential cross sections in Powheg+Pythia8 to those in $pp$ collisions. The boxes indicate systematic uncertainties, vertical error bars represent statistical uncertainties.
Figure 7: Jet yields in Pb+Pb collisions as a function of $m/p_T$ measured in 0–10%, 30–40%, and 60–80% centrality intervals for different intervals of jet $p_T$. The boxes indicate systematic uncertainties, vertical error bars represent statistical uncertainties.
Figure 8: $R_{AA}$ as a function of $m/p_T$ measured in 0–10%, 30–40%, and 60–80% centrality bins for different interval of $p_T$. The black boxes centered at one represent the fractional uncertainty on $pp$ luminosity (5.4%) and on $\langle T_{AA} \rangle$. The yellow boxes indicate systematic uncertainties, vertical error bars represent statistical uncertainties.
Figure 9: $R_{AA}$ as a function of $p_T$ measured in 0–10%, 30–40%, and 60–80% centrality bins for different interval of $m/p_T$. The black boxes centered at one represent the fractional uncertainty on $pp$ luminosity (5.4%) and on $\langle T_{AA} \rangle$. The yellow boxes indicate systematic uncertainties, vertical error bars represent statistical uncertainties.
8 Summary

This note presents a measurement of the jet cross-section in \textit{pp} collisions, and jet yields in Pb+Pb collisions evaluated as a function of \( m/p_T \). These distributions are used to calculate the jet nuclear modification factor, \( R_{AA} \). The distributions are reported for \( R = 0.4 \) anti-\( k_t \) jets with \( |y| < 2.1 \) and with \( p_T \) measured in the range of 126–500 GeV in Pb+Pb and \textit{pp} collisions at \( \sqrt{s_{NN}} = 5.02 \) TeV with calorimeter towers used as the jet constituents. The measurement is performed as a function of jet \( p_T \) and event centrality in Pb+Pb collisions. The measured distributions are fully corrected for jet response. The \( R_{AA} \) values show a suppression of jets that becomes stronger for more central collisions, without significant dependence on \( m/p_T \).
References

[1] ALICE collaboration, 
*Measurement of charged jet suppression in Pb-Pb collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \),* 

[2] ATLAS Collaboration, 
*Measurements of the Nuclear Modification Factor for Jets in Pb+Pb Collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \) with the ATLAS Detector,* 

[3] CMS Collaboration, 
*Charged-particle nuclear modification factors in PbPb and pPb collisions at \( \sqrt{s_{NN}} = 5.02 \text{ TeV} \),* 

[4] ALICE Collaboration, 
*Measurement of jet suppression in central Pb-Pb collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \),* 

[5] ATLAS Collaboration, 
*Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at \( \sqrt{s_{NN}} = 2.77 \text{ TeV} \) with the ATLAS Detector at the LHC,* 

[6] CMS Collaboration, 
*Observation and studies of jet quenching in PbPb collisions at nucleon-nucleon center-of-mass energy = 2.76 TeV,* 

[7] ATLAS Collaboration, 
*Measurement of jet \( p_T \) correlations in Pb+Pb and pp collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \) with the ATLAS detector,* 

[8] ATLAS Collaboration, 
*Measurement of inclusive jet charged-particle fragmentation functions in Pb+Pb collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \) with the ATLAS detector,* 

[9] CMS Collaboration, 
*Measurement of jet fragmentation in PbPb and pp collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \),* 

[10] ATLAS Collaboration, 
*Measurement of jet fragmentation in Pb+Pb and pp collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \) with the ATLAS detector,* 

[11] CMS Collaboration, 
*Correlations between jets and charged particles in PbPb and pp collisions at \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \),* 

[12] CMS Collaboration, 
*Jet properties in PbPb and pp collisions at \( \sqrt{s_{NN}} = 5.02 \text{ TeV} \),* (2018), 

[13] ATLAS Collaboration, 
*Jet mass and substructure of inclusive jets in \( \sqrt{s} = 7 \text{ TeV} \) pp collisions with the ATLAS experiment,* 

[14] ATLAS Collaboration, 
*ATLAS Measurements of the Properties of Jets for Boosted Particle Searches,* 


