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Jets and charged hadrons in heavy ion collisions with the ATLAS detector *

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Ultrarelativistic heavy ion collisions at the LHC produce the Quark Gluon Plasma. Jets are a useful probe to study this state of matter since they are produced at the early stages of the collisions and are expected to be modified as propagating through the medium. One observable is the energy loss lowering the jet yields at a given transverse momentum. Other observables are the modification of the dijet momentum balance and the modification of fragmentation functions. A phenomenon strictly correlated to the jet energy loss is the modification of the charged-hadron momentum spectrum. The large new Pb+Pb data sample collected by ATLAS in Run 2 allows precision measurements of these observables in a wide transverse momentum range and in different centrality and rapidity intervals.

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1. Introduction

A wide research program is ongoing at the Large Hadron Collider with the aim of studying the properties of QCD matter at extreme temperatures and densities. Jets produced in ultra-relativistic heavy ion collisions constitute a golden probe of such a state of matter. The hard scattered quarks and gluons emerged from these collisions evolve as parton showers that propagate through the hot and dense medium. Constituents of the parton showers emit medium-induced gluon radiation and, as a consequence, the resulting jet loses energy, a phenomenon commonly termed as jet quenching [1]. Jets produced in heavy ion collisions are thus expected to be suppressed at a given p_{T}, relatively to a sample produced in pp collisions. Their internal structure is also expected to be modified. The large acceptance and high granularity of the ATLAS detector [2] is well suited to study these phenomena. Results shown in this conference used data produced in Pb+Pb and pp collisions at the center of mass energies of 2.76 TeV and 5.02 TeV. The

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centrality of the Pb+Pb collisions is estimated using the total transverse energy deposited in the forward calorimeters (FCal, $3.2 \leq |\eta| < 4.9$) and compared to a Glauber Monte Carlo model [3], convoluted with pp data taken at the same beam energy. The $\sum E_T^{\mathrm{FCal}}$ distribution is then divided into percentiles of the total inelastic cross-section for Pb+Pb collisions. Jets are reconstructed using calorimeter "towers" as input signals to the anti-k_t algorithm, with jet radius parameter size $R = 0.4$. The underlying event is estimated and subtracted event-by-event in each calorimeter layer and strip of pseudorapidity after excluding regions subtending jet candidates and corrected for flow modulation.

2. Results

The nuclear modification factor R_{AA}, defined as the ratio of normalized yields in Pb+Pb and pp collision systems, is used to compare the inclusive transverse momentum distributions measured in the two collision systems:

$$R_{\mathrm{AA}} \equiv \frac{(1/N_{\mathrm{evt}})\ \mathrm{d}^2 N_{\mathrm{jet}}^{PbPb}/\mathrm{d}p_{\mathrm{T}}dy\Big|_{\mathrm{cent}}}{\langle T_{\mathrm{AA}}\rangle\ \mathrm{d}^2\sigma_{\mathrm{jet}}^{pp}/\mathrm{d}p_{\mathrm{T}}dy}, \tag{1}$$

where $\langle T_{\mathrm{AA}}\rangle$ stands for the geometric enhancement of per-collision nucleon-nucleon luminosity and N_{evt} is the total number of Pb+Pb collisions within a chosen centrality interval. The jet yields, unfolded for detector resolution, bin-to-bin migration and reconstruction inefficiency, are shown in Fig.1. Jets are suppressed increasingly with collisions centrality, reaching a factor of two in central collisions (0–10%), while showing little dependence on jet transverse momentum and rapidity [4]. These measurements confirm the expectations on the reduction of the jet yields at a given transverse energy due to the interaction of partons in the quark gluon plasma [1].

A complementary observable to jet production is the measurement of charged particle spectra, as these contribute to the understanding of jet energy loss mechanisms. Tracks are reconstructed using the ATLAS inner detector system in the pseudorapidity range $|\eta| < 2.5$ and over the full azimuthal acceptance. Corrections to measured p_{T} spectra, like fake tracks, bin-to-bin migration, and reconstruction inefficiency are estimated from Monte Carlo simulations. The charged hadron R_{AA} as a function of p_{T} is shown in Fig.2. A characteristic p_{T} shape, which becomes more pronounced with increasing centrality, is observed. The R_{AA} distributions first increase reaching a local maximum at $p_{\mathrm{T}} < 2$ GeV, a feature commonly associated with the Cronin effect [5], i.e. hardening of the p_{T} spectrum in heavy ion collisions relative to pp collisions, often understood to be due to multiple scattering of partons. At higher p_{T} the R_{AA} decreases reaching a minimum

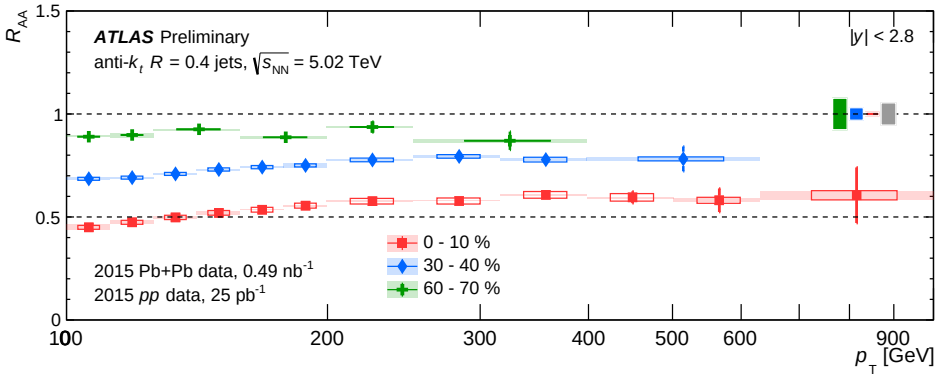

Fig. 1. The R_{AA} as a function of jet p_{T} for jets with $|y| < 2.8$ for three centrality bins. The error bars represent statistical uncertainties, the shaded boxes around the data points represent correlated systematic uncertainties, open boxes represent uncorrelated systematic uncertainties. The colored shaded boxes at unity represent $\langle T_{\mathrm{AA}} \rangle$ uncertainties and the gray shaded box represents the uncertainty on pp luminosity. The horizontal width on the shaded boxes represents the width of the p_{T} interval and the horizontal widths on the open boxes are arbitrary for better visibility [4].

at $p_{\mathrm{T}} = 7$ GeV. The rate of charged particles is noticeably suppressed even in the 60–80% centrality interval but the suppression is strongest in the most central 0–5% collisions. Above 7 GeV, the R_{AA} generally increase with increasing p_{T} up to 60 GeV, after which the slope changes. Details of this analysis can be found in [6].

Jet fragmentation functions are measured aiming a deeper understanding of the jet energy loss nature and constraining jet quenching models. The jet structure is probed in the p_{T} range from 100 to 398 GeV, using tracks with $p_{\mathrm{T}} > 1$ GeV. The fragmentation functions, defined as $D[z(p_{\mathrm{T}})] = (1/N_{\mathrm{jet}})dN_{\mathrm{ch}}/dz(p_{\mathrm{T}})$, are studied as a function of the longitudinal momentum fraction, $z = {p_{\mathrm{T}}}^{ch}/{p_{\mathrm{T}}}^{jet}\cos\Delta R$, and track p_{T}, where ${p_{\mathrm{T}}}^{ch}$ stands for the transverse momentum of a charged particle and ΔR is the distance between the charged particle and the jet axis. The $D(z)$ and $D(p_{\mathrm{T}})$ distributions are background subtracted, corrected for reconstruction inefficiency and unfolded with a 2D Bayesian method. Figure 3 shows the modification of the fragmentation functions, assessed with $R_{D(z)} = D(z)|_{\mathrm{Pb+Pb}}/D(z)|_{\mathrm{pp}}$ in different ranges of rapidity. An enhancement at low z, up to 0.03, and at z larger than 0.2, mainly at mid-rapidity, is observed in central collisions. The range $0.03 < z < 0.2$ shows a clear depletion. The enhancement of fragment yields at low z is consistent with an interpretation in which the energy lost

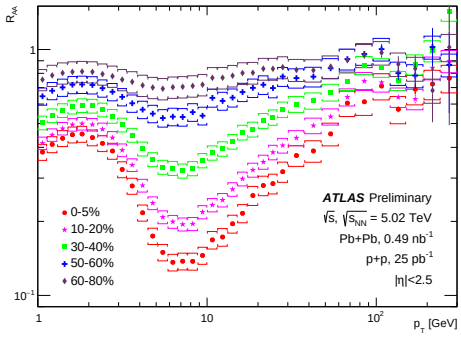

Fig. 2. Nuclear modification factor R_{AA} as a function of p_{T} for charged hadrons measured in Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV for five centrality intervals: 0-5%, 10-20%, 30-40%, 50-60% and 60-80%. Bars represent the statistical uncertainties and brackets represent the systematic uncertainties [6].

by partons is transferred predominantly to soft particles [7]. Details on this analysis can be found in [8].

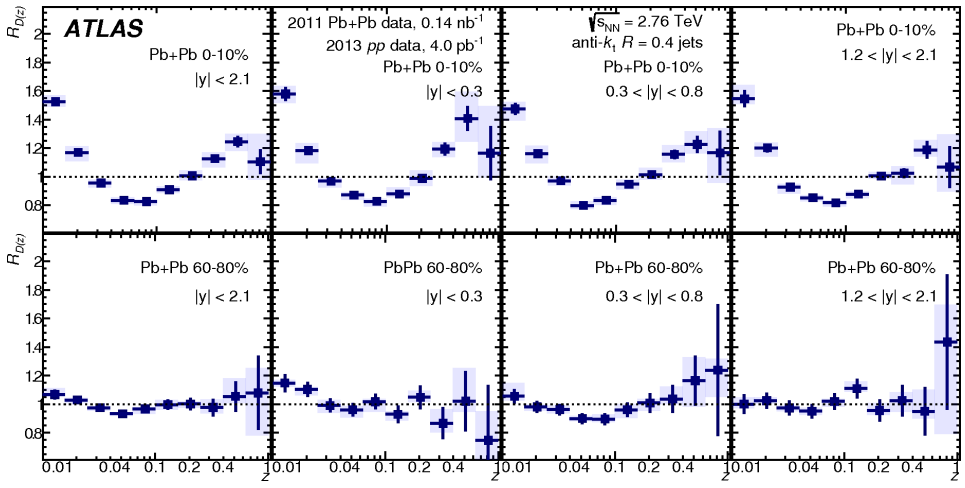

Fig. 3. The ratio $R_{\mathrm{D(z)}}$ of unfolded $D(z)$ distributions measured in heavy-ion collisions to unfolded $D(z)$ distributions measured in pp collisions. The $R_{\mathrm{D(z)}}$ distributions shown here are evaluated in two different centrality bins (rows) and four different selections in jet rapidity (columns). The error bars on the data points indicate statistical uncertainties while the shaded bands indicate systematic uncertainties [8].

The first indication of jet quenching was given by the observation of

large asymmetrical dijet events [9]. Dijets probe differences in the two parton showers since in most of the cases the interaction of the two outgoing partons in the quark gluon plasma is not identical. A new analysis has been performed using 140 μb^{-1} of Pb+Pb data taken at $\sqrt{s_{NN}}$=2.76 TeV and benefiting from a deeper understanding of the underlying event and analysis conditions. Figure 4 shows the distribution of dijets produced in Pb+Pb and *pp* collisions as a function of x_J, the ratio between the transverse momenta of the two leading jets. The measured distributions are unfolded to account for the effects of experimental resolution and inefficiencies on the two-dimensional (p_{T_1}, p_{T_2}) distributions and then projected into bins of fixed ratio $x_J = p_{T_1}/p_{T_2}$. The observation of large asymmetric dijets in central collisions is striking. The distributions in the two colliding systems become increasingly similar with decreasing centrality. Interesting is the study of the variation of the dijet asymmetry with the p_T of the leading jet. A modification in the asymmetry in Pb+Pb collisions as the p_T of the leading jet increases is observed, indicating that higher transverse momentum jets lose less energy and so tend to be more balanced. This feature is particularly evident for transverse momentum greater than 200 GeV. Details on this analysis can be found in [10].

3. Conclusions

Inclusive jets yields are found to be suppressed with collisions centrality, reaching a factor of two in central collisions, while showing little dependence on jet transverse momentum and rapidity. In contrast, the nuclear modification factor of charged hadrons shows a striking non-flat p_T shape which becomes more pronounced with increasing centrality. The jet structure is modified: in central collisions there is an enhancement of particles at low and high z, while a suppression at intermediate z is observed. The p_T balance of dijets produced in Pb+Pb collisions is increasingly asymmetric when compared to the *pp* results as the centrality of the collisions increases. At larger values of $p_{T_1}$the x_J distributions are observed to narrow and the differences between the distributions in central Pb+Pb and *pp* collisions become much smaller.

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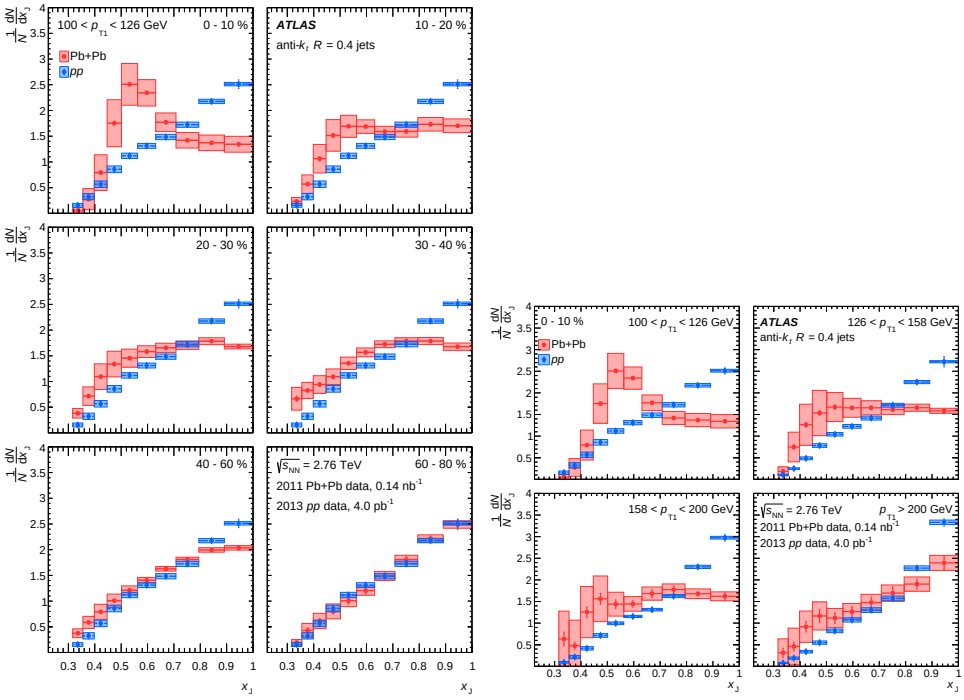

Fig. 4. Left: The $(1/N)\mathrm{d}N/\mathrm{d}x_\mathrm{J}$ distributions for jet pairs with $100 < p_{\mathrm{T}_1} < 126$ GeV for different collision centralities and for R=0.4 jets. The Pb+Pb data are shown in red circles, while the *pp* distribution is shown for comparison in blue diamonds and is the same in all panels. Right: The $(1/N)\mathrm{d}N/\mathrm{d}x_\mathrm{J}$ distributions with different selections on p_{T_1}, shown for the 0–10% centrality interval (red circles) and for *pp* (blue diamonds). In both panels the statistical uncertainties are indicated by the error bars while systematic uncertainties are shown with shaded boxes [10].

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