HARD PROBES WITH ATLAS

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An overview of the latest results on high-transverse momentum particle production in lead-lead collisions at a center-of-mass energy $\sqrt{s_{NN}} = 2.76$ TeV obtained with the ATLAS detector is presented. Updated jet quenching measurements are discussed including inclusive jet suppression as a function of jet radius and a modification of jet fragmentation functions. Results on Z boson and isolated direct photon production are shown, also in conjunction with jets, which reveal a transverse momentum imbalance of the system. These results bring some further insight into parton shower modifications due to interactions with the medium. A majority of measurements use the entire statistics of the 2011 lead-lead run.

1 Introduction

Collisions between lead (Pb) ions at the Large Hadron Collider (LHC) are thought to create strongly interacting matter at temperatures well above the QCD critical temperature. The Relativistic Heavy Ion Collider (RHIC) has established [1] that at such temperatures, strongly interacting matter is expected to take the form of quark-gluon plasma (QGP). The energetic color charge carriers generated in hard-scattering processes during the initial stages of nuclear collisions are expected to lose energy in the QGP. Both RHIC and LHC experiments have reported a suppression of charged hadron yields by a factor of two at high transverse momenta in heavy-ion (HI) collisions [2,3,4]. On the other hand particles which are created in hard scatterings and whose products do not interact via the strong force, provide an alternative means to investigate the phenomenon of energy loss in the QGP. The PHENIX experiment at RHIC measured the properties of highly energetic photons [5] while the ATLAS and CMS experiments at the LHC provided in addition the first measurements of Z and W bosons decaying leptonically at the LHC energy [6,7,8,9]. In this context measurements of hard probes at the LHC are important as they are a valuable source of information on the matter produced in the ultra-relativistic Pb-Pb collisions.

The LHC commenced a HI program in two Pb-Pb runs which took place in 2010 and 2011 at $\sqrt{s_{NN}} = 2.76$ TeV per colliding nucleon pair. In this document a report on inclusive jet and electroweak boson measurements based on the entire data sample of 2011 from the ATLAS experiment will be given. These results give additional insight into behavior of jets in the QGP and confirm that electroweak boson production rates follow the scaling with a number of binary collisions.

2 Inclusive jets

Jets are considered to be one of the most direct probes to study hot matter through the process of *jet quenching*, which generally refers to the phenomenon by which a quark or a gluon can lose energy and/or have its parton shower modified in a medium of high color-charge density [10,11]. The ATLAS experiment has established a direct evidence of jet quenching, reporting on the modification of the dijet asymmetry distribution as a function of centrality in the early Pb-Pb data [12]. More recently the inclusive jet measurements have been released [13]. Jets were reconstructed in the calorimeter over the pseudorapidity interval $|\eta| < 2.1$ and over the transverse momentum range $38 < p_T < 210$ GeV using the anti-k_t algorithm with values for the distance parameter that determines the nominal jet radius of $R = 0.2$, 0.3, 0.4 and 0.5. The centrality dependence of the jet yield is characterized by the jet *central-to-peripheral ratio*, $R_{\rm cp}$, which is defined as a ratio of the central to peripheral events scaled by the number of binary nucleon-nucleon collisions, $N_{\rm coll}$. Jet production is found to be suppressed by approximately a factor of two in the 10% most central collisions relative to peripheral collisions as shown in the left panel of Fig. 1. The observed suppression is only weakly dependent on jet radius that is nonetheless significant when taking into account the correlations in the uncertainties between the different R values.

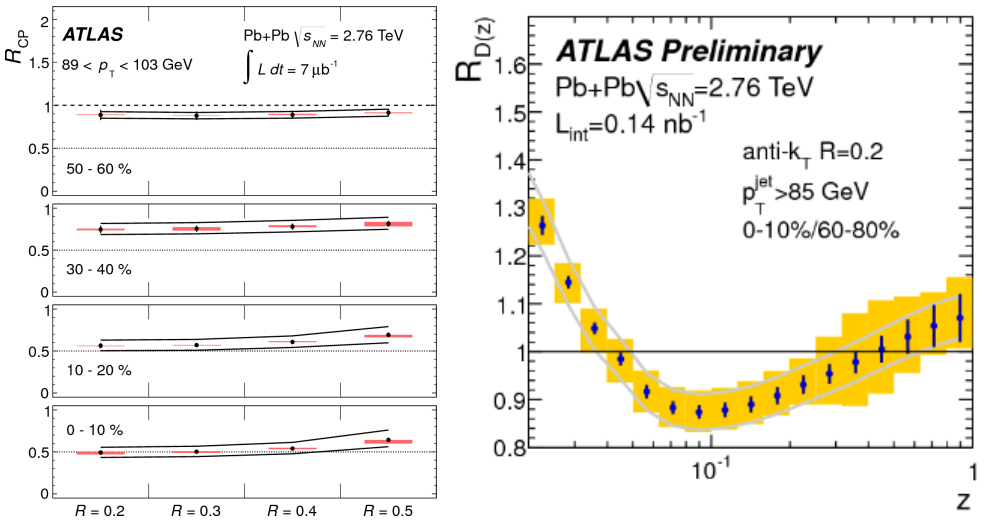

Figure 1: (left) $R_{\rm cp}$ as a function of jet radius for four centrality bins for jets with $89 < p_T < 103$ GeV [13]. (right) Ratios of the longitudinal fragmentation function, $D(z)$ for central (0-10%) collisions to those in peripheral (60-80%) collisions for $R = 0.2$ jets [14].

Different models of jet quenching predict different levels of modification of the jet internal structure. Both transverse and longitudinal structure of the jet are expected to be modified due to the medium-induced radiation. To quantify the effect of the jet modification the jet fragmentation functions have been measured as a function of z - the longitudinal fraction of the jet momentum carried by the charged particles [14]. The right panel of Fig. 1 shows a ratio of the longitudinal fragmentation functions, $D(z)$ for jets in the 0-10% centrality class to jets from the 60-80% centrality class. One can see an enhanced yield of low-z fragments and a suppressed yield of fragments at intermediate z values in more central collisions relative to the peripheral ones. The size of these observed modications was also found to decrease gradually with centrality between central and peripheral collisions.

3 Photon-jet Momentum Imbalance

Photons are hard probes which do not carry a color charge and as such they are expected not to interact with the QGP. Therefore, studying photon-jet pairs produced in hard scattering

processes offers the possibility of calibrating the energy of the initial jet. Recently ATLAS has reported on a measurement of production rates of isolated direct photons with transverse momenta $45 < p_T^{\gamma} < 200$ GeV and $|\eta^{\gamma}| < 1.3$ in Pb-Pb collisions [15]. It was found that photon production yields exhibit a linear scaling with the number of binary collisions.

More recently, a measurement of the correlation of back-to-back isolated prompt photons with jets as a function of transverse momentum and centrality has been done [16]. The left panel of Fig. 2 shows the energy fraction $x_{J\gamma} = p_T^{\rm jet}/p_T^{\gamma}$ for data and PYTHIA+Data [a] MC as a function of centrality represented by a number of participants, $N_{\rm part}$. In the peripheral centrality interval, $\langle x_{J\gamma} \rangle$ is just below what is obtained using the truth jet and true photon energies in the MC. As the centrality increases, the $\langle x_{J\gamma} \rangle$ systematically decreases, although quite slowly. However, the most central value is significantly different than the PYTHIA+Data prediction. The right panel of Fig. 2 shows an integrated yield of jets per photon, $R_{J\gamma}$ as a function of $N_{\rm part}$ in comparison to the PYTHIA+Data MC. As the centrality increases $R_{J\gamma}$ decreases significantly deviating from the MC.

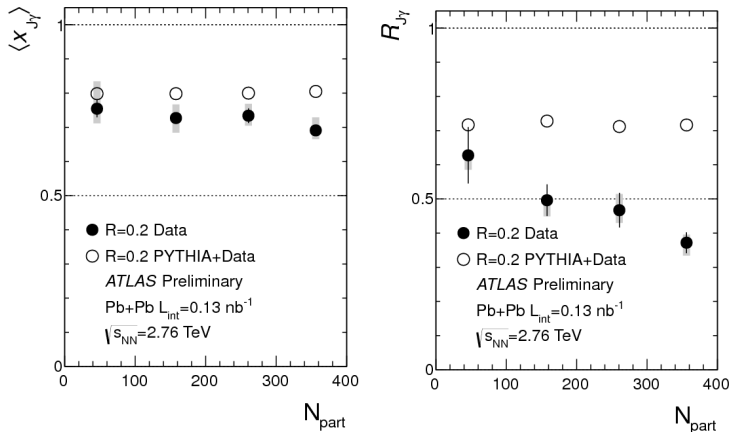

Figure 2: (left) The mean energy fraction $\langle x_{J\gamma} \rangle$ from fully corrected and unfolded distributions for $R = 0.2$ jets calculated as a function of $N_{\rm part}$ [16]. (right) The integrated yield of $R = 0.2$ jets per photon $R_{J\gamma}$ calculated as a function of $N_{\rm part}$ [16].

4 Z Boson Production

Like photons, weak bosons do not interact via strong forces, therefore they are supposed not to lose energy in the QGP. As such they are a perfect tool to calibrate energies of jets. The ATLAS experiment has performed a measurement of Z boson production decaying to di-muon and di-electron final states [18]. A left panel of Fig. 3 shows the invariant mass of selected electron and muon opposite signed signal pairs together with estimated combinatorial backgrounds from same sign pairs compared with the simulation normalized to the number of pairs in the region $66 < m_{ll} < 102$ GeV ($l = e, \mu$). The background contamination is less than 3% which makes this measurement very clean in particular in the context of Z+jet correlation studies [19]. The per-event yields of Z bosons have been extracted from the mass peak. These yields where scaled by the number of binary collisions, $N_{\rm coll}$, and are shown as a function of centrality represented by $N_{\rm part}$ for several Z boson transverse momentum intervals. Within the statistical significance of the data sample, the Z boson per-event yield obeys the binary collision scaling with centrality.

5 Summary

The updated results on high-transverse momenta particles from the ATLAS experiment based on Pb-Pb collisions from the 2010-11 LHC heavy-ion runs have been presented. Inclusive jets are found to be suppressed in central events by a factor of two relative to peripheral events,

[a] A hard process is generated by PYTHIA and embedded into a minimum-bias event from real data. The in-medium energy loss is not modelled.

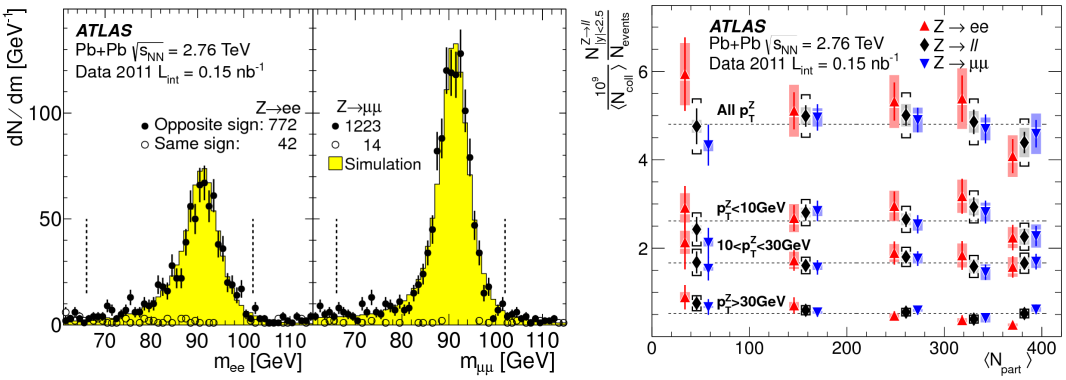

Figure 3: (left) The invariant mass distributions of $Z \to ee$ and $Z \to \mu\mu$ candidates, integrated over momentum, rapidity, and centrality [18]. (right) Centrality dependence of Z boson yields for di-electron, di-muon and combined data divided by $\langle N_{\rm coll} \rangle$ and a total number of minimum bias events $N_{\rm events}$ [18].

with no significant dependence on the jet size. At the same time jet fragmentation functions are found to be enhanced for fragments at low-z values followed by a suppression of intermediate-z fragments in the most central collisions relative to 60-80% centralities. Di-electron and di-muon pairs have been used to measure Z boson production yields which are found to scale linearly with a number of binary collisions. Events with photon-jet pairs have been analyzed to measure a transverse momentum imbalance. Both the mean energy fraction and the yield of jets per photon are found to be significantly reduced in the most central collisions. All these results may provide more insight into our understanding of the jet quenching phenomenon.

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