HARD PROBES IN PB-PB COLLISIONS AT ATLAS

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This document discusses the measurements from the lead-lead run at $\sqrt{s_{NN}} = 2.76$ TeV based on a minimum bias data sample of $5-7\ \mu b^{-1}$ collected by the ATLAS experiment at the LHC. In particular, the results on jet quenching and W production are reviewed. Jet yields are found to be suppressed by a factor of two in the most central collisions showing no modification to the jet internal structure in 10% most central events comparing to the 40-80% centrality bin. The W boson yield is proportional to the number of binary collisions.

1 Introduction

Collisions between lead ions at the Large Hadron Collider (LHC) are thought a way 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 the nuclear collisions, and penetrating such a medium, are supposed to lose energy in the QGP. Both RHIC and LHC experiments have reported a suppression of charged hadron yields 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 forces, provide the means to investigate a 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, W at the LHC energy [6,7,8]. In this context measurements of hard probes at the LHC are very important as they may become a valuable source of information on the matter produced in the ultra-relativistic lead-lead collisions.

The LHC commenced a HI program in two lead-lead 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 jet and W boson measurements based on a minimum bias sample of $5-7\ \mu b^{-1}$ from the ATLAS experiment will be given. These results give some more insight into behavior of jets in the QGP and also establish a first evidence of W boson production with rates which 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*. Jet quenching 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. This can occur through stimulated emission of gluon bremsstrahlung, collisional energy loss due to elastic scattering, or a variety of other processes [9,10].

The modification of the dijet asymmetry distribution reported in the first ATLAS Pb-Pb jet paper [11] strongly suggests, but does not yet prove, quenching of jets in the hot medium produced in the collisions. The dijet asymmetry analysis demonstrated that transverse energies (E_T) of pairs of jets produced in the back-to-back configuration had a significant E_T imbalance in central events. That imbalance can arise from jet quenching if one of the jets travels a longer path in the medium than the other. However, an intrinsic limitation of the dijet asymmetry observable is that it is less sensitive to events where each jet in a dijet pair loses a comparable amount of energy i.e. where each jet from both jets is comparably quenched. In this document proceeding the measurements on inclusive jets will be reported [12].

In ATLAS jets are reconstructed using the anti-kt algorithm with the jet size chosen to be $R = 0.2$ and $R = 0.4$. The jet reconstruction is based on "towers" composed of calorimeter cells integrated over regions of size $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$. The underlying-event background is removed at the cell level. An iterative procedure is applied to remove any residual effect of the jets on the background subtraction. The final jets are corrected for the energy scale and resolution based on PYTHIA jets embedded into HIJING. The analysis of jets is restricted to $|\eta| < 2.8$, to stay within the barrel and endcap regions of the calorimeter.

2.1 Central-to-peripheral ratio for jets

Experimentally, the most direct way to measure modifications in the yield of jets at a given E_T value is to compare Pb-Pb jet measurement results to similar measurements in p-p collisions. A correction for the expected enhancement in the jet rate increase due to nuclear geometry also needs to be taken into account. A parameter which is responsible for the geometric factor is the number of binary collisions between the nucleons of the colliding nuclei which is termed as N_{coll}. Unfortunately the 2.76 TeV sample of p-p collisions obtained by the ATLAS experiment in 2011 has not been fully analyzed yet. In the absence of p-p one can use "peripheral" HI collisions for normalization. Jet quenching effects are expected to be minimal in peripheral collisions in which there is only a small overlap between the incoming nuclei and therefore only a small volume of hot medium created. Such peripheral collisions can provide a baseline for the jet spectrum at 2.76 TeV against which the jet yield in more central collisions can be compared. For this purpose, an observable called *central-to-peripheral ratio*, R_{cp} has been defined as a ratio of the jet yield in a given centrality bin to the jet yield in the reference peripheral centrality bin [3].

The obtained R_{cp} values as a function of centrality for fixed E_T values are shown in Fig. 1 for $R = 0.2$ and $R = 0.4$ jets. A suppression of the jet yield of approximately a factor of two in central Pb-Pb collisions for both $R = 0.4$ and $R = 0.2$ jets is observed. Within the errors no deviation from an E_T-independent R_{cp} for $R = 0.2$ jets with $E_T > 50\,GeV$ and for $R = 0.4$ jets with $E_T > 100\,GeV$ is seen. The suppression strength is comparable for two jet sizes.

2.2 Jet fragmentation functions

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 gluon radiation inside the medium. To quantify the effect of the jet modification the jet fragmentation functions have been measured as a function of j_T - the transverse momentum of charged particles with respect to the jet axis, and z - the longitudinal fraction of the jet momentum carried by the charged particles. The j_T distribution has a soft core governed by non-perturbative physics and a power law tail resulting from hard radiation of the parton shower. In-medium jet energy loss is expected to modify the distribution of hard particles associated

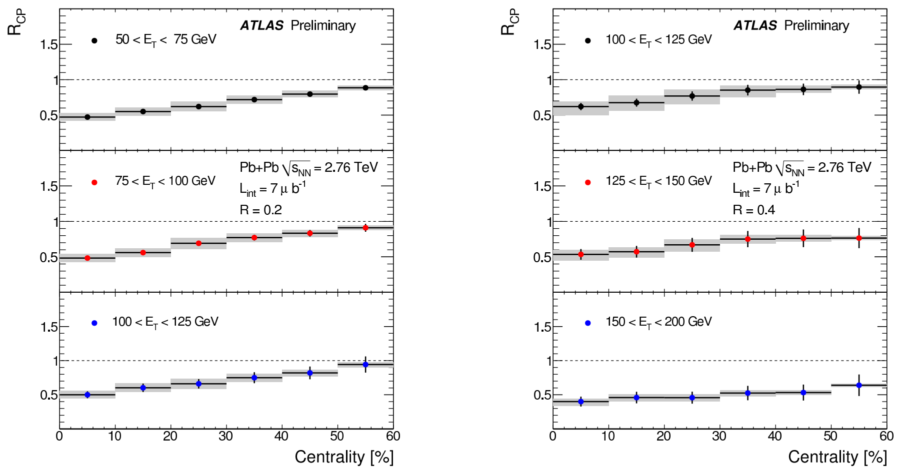

Figure 1: R_{CP} for $R = 0.2$ (left) and $R = 0.4$ (right) jets as a function of centrality for three E_T intervals. Error bars on the data points indicate statistical uncertainties, shaded errors represent combined systematic uncertainties.

with the jet and can be detected as a modification of the j_T distribution. Also the interaction of the jet with the medium may lead to a softening of the fragmentation function by reducing the number of charged particles at large z values and increasing the number of charged particles at small z. Direct measurements of the transverse and longitudinal fragmentation functions for tracks with $p_T > 2$ GeV in the ATLAS experiment, shown in the left and right panels respectively of Fig. 2, confirm that no substantial modification of the fragmentation function can be observed when comparing peripheral and central events. In other words, the suppression of the jet rates is not accompanied by any evident modification of the jets themselves.

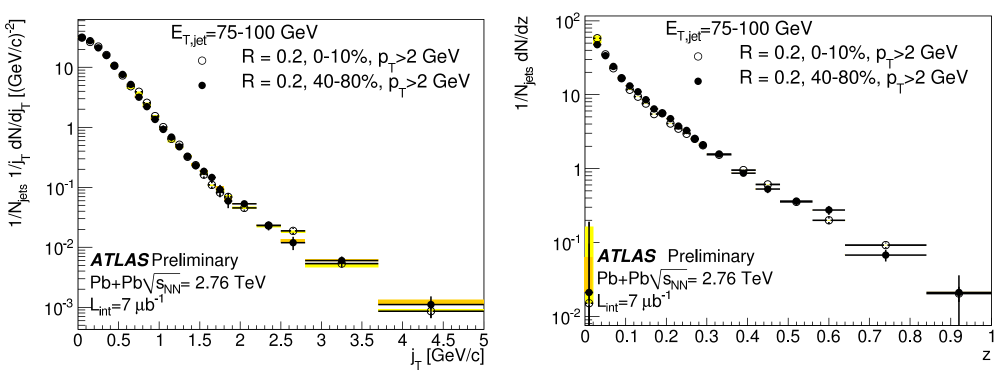

Figure 2: (left) Transverse fragmentation function for $R = 0.2$ anti-kt jets, comparing central 0-10% events with peripheral 40-80%. (right) The similar comparison for the longitudinal fragmentation function.

3 W bosons

The ATLAS experiment has performed a measurement of W boson production as a function of the collisions centrality [13]. Since vector bosons are produced in the nucleon-nucleon collisions and along with their decay products they do not interact with the color medium, they provide a reference for jets and quarkonia production which are known to be suppressed [6]. The left panel of Fig. 3 shows the inclusive muon p_T spectrum. The W yields are obtained by fitting a template using simulations of W decaying into a muon plus a neutrino in p-p collisions and using a functional form to describe the background. A sample of approximately 400 W bosons has been extracted. The binary scaling of the measured yields is studied using the variable R_{pc}, defined as the ratio of yields measured in different centrality classes to the yield measured in the

10% most central events, with all yields scaled by the corresponding number of binary nucleon-nucleon collisions. The right panel of Fig. 3 shows R_{pc} as a function of centrality. Using a fit to a constant value, giving $R_{pc} = 0.99 \pm 0.10$ with a $\chi^2 = 3.02$ for 3 degrees of freedom, a significant consistency with binary scaling is observed. Therefore this observation is an indication that W bosons are indeed produced at the initial phase of the collisions and neither $W's$ nor their decay products interact with the medium.

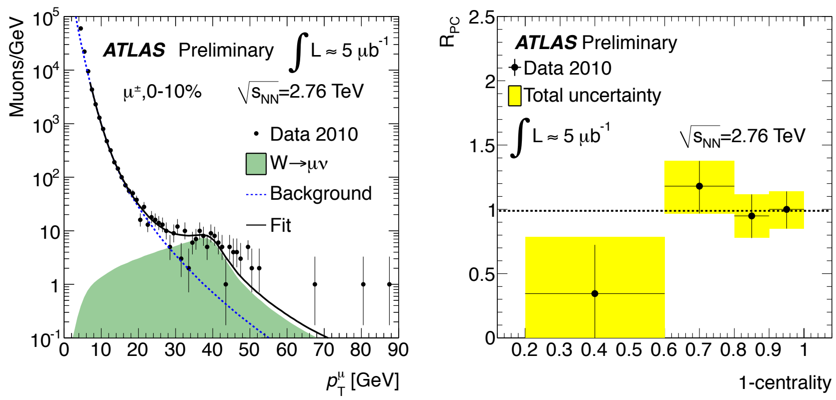

Figure 3: (left) Single muon spectrum measured for the 0-10% most central events. The templates for W bosons and heavy flavor (indicated as "Background") are also shown to illustrate the yield extraction procedure. (right) R_{pc} for W bosons as a function of centrality, showing consistency with binary collision scaling. The dotted line is a fit to a constant.

4 Summary

Results from the ATLAS detector based on lead-lead collisions from the 2010 LHC heavy-ion run have been presented. Jets are found to be suppressed in central events by a factor of two relative to peripheral events, with no significant dependence on the jet transverse energy. At the same time jet fragmentation functions are also found to be consistent in central and peripheral events. Single muons at high transverse momentum are used to extract the yields of W bosons as a function of centrality, which are found to be consistent with the binary collision scaling.

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