PROCEEDINGS OF SCIENCE

ATLAS Results on Pb+Pb Collisions

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A wide research program provided by heavy ion collisions is ongoing at the Large Hadron Collider with the aim of studying the properties of QCD matter at extreme temperatures and densities. The large acceptance and high granularity of the ATLAS Detector is well suited to perform detailed analyses on bulk phenomena, jets and leptonic probes. Measurements of these observables provided by the 9 μb^{-1} of Pb+Pb collision data collected during the Fall 2010 Pb+Pb run at the nucleon-nucleon center of mass energy of 2.76 TeV are presented.

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1. Heavy Ions with the ATLAS Detector

Evidence from SPS/CERN and RHIC/BNL data suggest that in extreme conditions of temperature and density, as those provided by ultra-relativistic Pb+Pb collisions, matter undergoes a phase transition from ordinary hadronic matter to a plasma of quarks and gluons, the QGP. Later, under its own pressure, the QGP expands and cools recombining the quarks and gluons into hadrons that carry information about the deconfined phase. Pb+Pb collisions at the LHC are expected to produce a QGP with energy densities at least 3 times larger than at RHIC, with higher initial temperatures and longer lifetimes.

After one year of smooth running with p+p collisions, the LHC switched to lead beams in order to carry out the Heavy Ion Program. The first Pb+Pb collisions, at the center of mass energy of 2.76 TeV, took place in November 2010. ATLAS [1] has shown an excellent performance. The full detector was operational and the fraction of data passing quality criteria in each sub-detector was almost 100%. A total integrated luminosity of 9 μb^{-1}, which corresponds to more than 95% of the luminosity provided by the LHC, has been recorded. The collision centrality, characterized by the impact parameter of two colliding nuclei, has been estimated using the total transverse energy deposited in the forward calorimeters (FCal, $3.2 < |\eta| < 4.9$) and compared to a Glauber Monte Carlo model [2], convoluted with p+p data taken at the same beam energy. The fraction of the total inelastic cross section measured after all trigger and selection cuts, is $f = 98 \pm 2\%$. Using this fraction events are categorized into centrality classes and the numbers of binary collisions and nucleon participants N_{part} are calculated for these classes using the same Glauber MC model.

2. Global Observables

The charged particle multiplicity density is one of the most basic characteristics of the HI collisions. The top plot of Figure 1 shows the multiplicty density measured at midrapidity in the most central collisions and divided by colliding nucleon pair, $dN_{ch}/d\eta/\langle N_{part}/2\rangle$, averaged over $|\eta| < 0.5$, for several colliding systems: AGS, SPS, RHIC and LHC. In order to minimize the losses from the bending of low momentum particles, the solenoid field of ATLAS has been turned off. The multiplicity at ATLAS/LHC in central collisions $(0-5\%)$ is significantly higher than at RHIC, in well agreement with the ALICE and CMS results. They follow a power law fit and do not confirm the predictions of the Landau hydrodynamical model [3], neither the logarithmic scaling motivated by previous SPS and RHIC results. The bottom panel shows the same observable but as a function of the number of participants, N_{part}. A monotonic increase of particle production up to the most central collisions is observed. The results from ALICE and RHIC are also shown. The later was scaled by the observed factor of 2.15 and presents a similar centrality dependence, although has been measured at a much lower collision energy. Details of this analysis can be found in [4].

Another observable that gives insight into the earliest phase of the collisions is the elliptic flow, which arises when two colliding nuclei do not overlap completely. In such a case the initial spatial anisotropy leads to a final state elliptical asymmetry in the momentum space with respect to the reaction plane defined by the impact parameter and the beam axis. In ATLAS this plane is estimated using the FCal. The "elliptic flow" parameter v_2 is the second Fourier coefficient. Higher

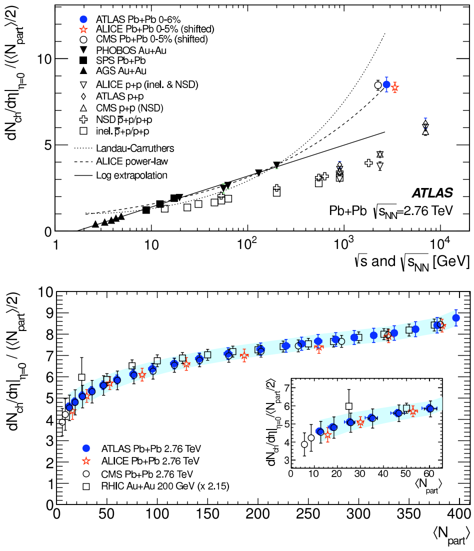

Figure 1: (Top) Collision energy dependence of $dN/d\eta$ per participant pair from a variety of measurements in p+p and central nuclear collisions including the 0-6% reported here for $|\eta| < 0.5$ and the previous $0-5\%$ ALICE and CMS measurements (points shifted horizontally for clearness). (Bottom) $dN/d\eta/(N_{part}/2)$ evaluated over $|\eta| < 0.5$ vs $\langle N_{part} \rangle$. Error bars represent combined statistical and systematic uncertainties, the shaded band represents the total systematic uncertainty including N_{part} uncertainties.

order components of the Fourier decomposition are expected to be induced by initial event-by-event fluctuations. The different v_n parameters are measured using tracks in the Inner Detector (ID, $|\eta| < 2.5$). "Non-flow" contributions are minimized by maximizing the gap between the track and the reaction plane, that is, by using the reaction plane estimated in the opposite FCal hemisphere relative to the measured track. Figure 2 shows $v_2 - v_6$ Fourier coefficients as a function of the collision centrality and transverse momentum [5]. All harmonics up to v_6 are positive and show similar p_T dependence, i.e., they first increase with p_T to about 3-4 GeV, and then decrease. The v_2 magnitude has the strongest variation with centrality. The overall magnitude of each v_n generally decreases for larger n, except in the most central events where v_3 is the largest.

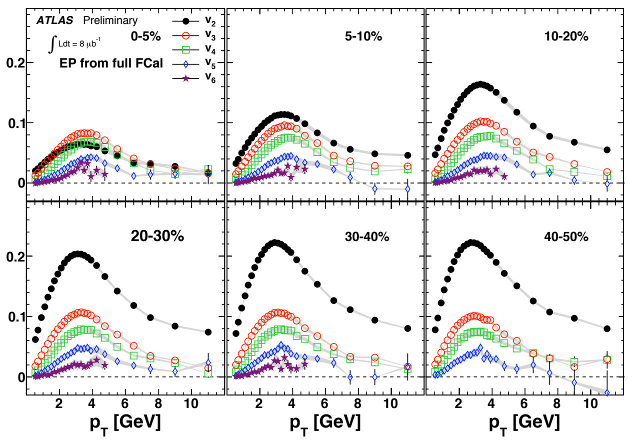

Figure 2: v_n as a function of p_T for several centrality classes. The shaded bands indicate the systematic uncertainties.

3. Hard Probes

Measurements of the W boson production as a function of the collisions centrality have been performed. Since vector bosons are produced in the primary nucleon-nucleon collisions and do not interact with the colour medium, they provide a reference for jets and quarkonia production which are known to be suppressed [6, 10]. The left panel of Figure 3 shows the inclusive muon p_T spectrum [7]. Dimuons originated likely from Z and Drell-Yan are vetoed. The W yields is obtained by fitting a template using simulations of W decaying in a muon plus a neutrino in p+p collisions and using a functional form to describe the background. The right plot shows the ratio of W productions in a given centrality interval and the most central one, scaled by the respective number of binary nucleon-nucleon collisions (N_{coll}), R_{pc}. Within the current statistical accuracy of the measurement the W boson is found to be not suppressed as it is expected for a weakly interacting particle.

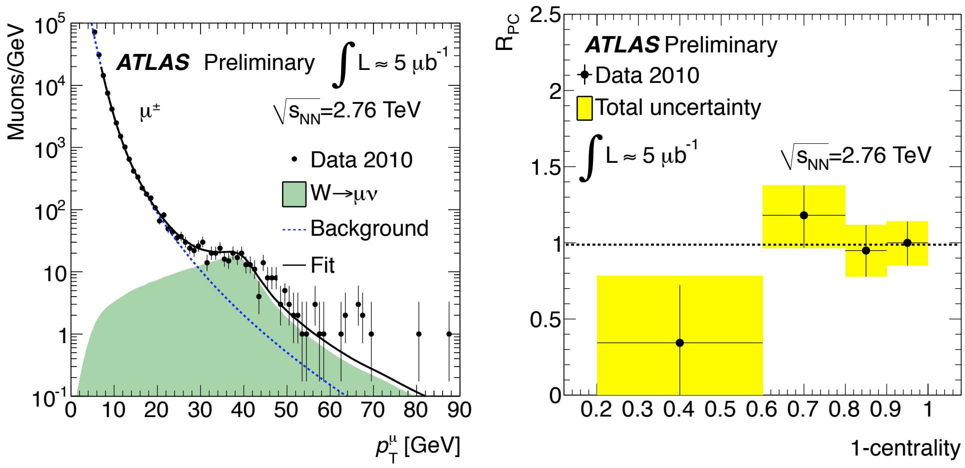

Figure 3: (Left) Uncorrected inclusive muon p_T spectrum fitted (solid line) with two components: signal $W \rightarrow \mu\nu$ (shaded area) simulated with PYTHIA in p+p collisions and a background parameterization (dashed line). (Right) R_{pc} for W bosons as a function of centrality. Error bars are statistical and fit method uncertainties. Yellow bands include uncertainties on the number of nucleon-nucleon collisions estimates.

Jet production is one of the hot topics of the heavy ion program. The interaction of the parton in the medium is expected to reduce the jet yields at a given transverse energy [8], as well as to modify the fragmentation functions [9]. The first indication of jet quenching was given by the observation of large asymmetrical dijet events [10]. Later on ATLAS performed measurements of the inclusive jet production as a function of the collisions centrality and jet transverse energy aiming for a deeper understanding of the jet energy loss. Jets are reconstructed using calorimeter "towers" as input signals for the anti-k_t algorithm. The underlying event is estimated on an event-by-event basis in each calorimeter layer and η intervals, after excluding regions subtending jets and corrected for flow modulation. The E_T spectra of $R = 0.4$ jets, corrected for jet energy scale and resolution and scaled by the number of binary nucleon-nucleon collisions, N_{coll}, are shown on the left panel of Figure 4. The main source of systematic uncertainty on jet E_T and centrality is the jet energy resolution. The N_{coll} estimation also contributes varying with centrality and reaching 8% in the most central collisions. The centrality independent 22% systematic error on the normalizations due to 4% uncertainty in the jet energy scale is not shown. The right panel shows the R_{cp} (similar to the previous R_{pc} definition, but using the peripheral collisions interval as the reference). A suppression of the jet yields of approximately a factor of two in central collisions is observed [11]. Although not presented here, the results of jets with smaller radius, $R = 0.2$, show the same behaviour contradicting the theoretical expectations of medium-induced energy loss due to the radiation falling outside the angular coverage associated to the jet definition [8].

The jet R_{cp} agrees very well with the observed suppression in the charged hadron spectra

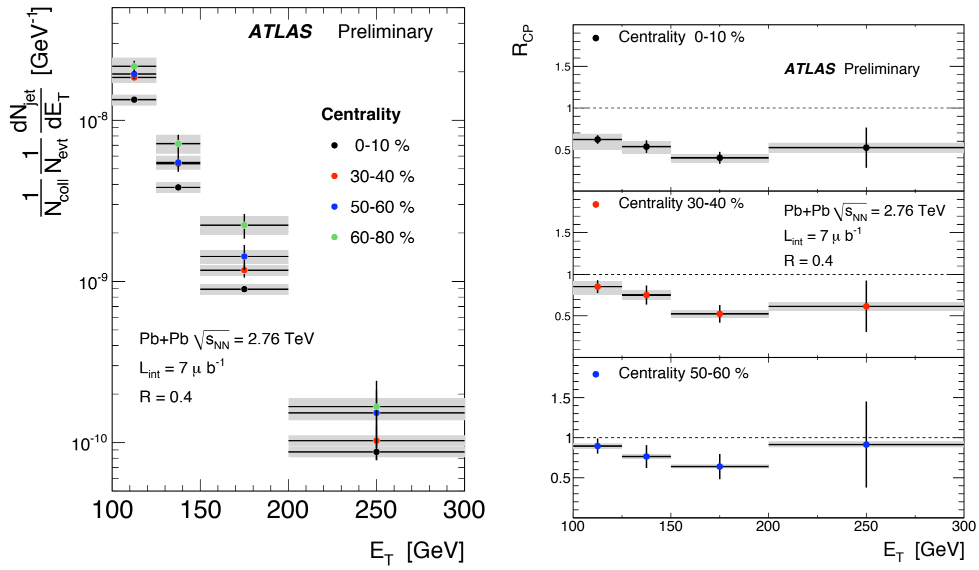

Figure 4: (Left) R=0.4 jet spectra as function of E_T and collisions centrality. Error bars represent statistical errors, the shaded bands represent the total systematic uncertainties with exception of the luminosity one. (Right) Ratio of the jet yields in a given centrality interval and the peripheral collisions one (60-80%), scaled by the respective N_{coll}.

at very central collisions, $\langle N_{part} \rangle = 382$ $(0-5\%)$, which can be seen in Figure 5 for different η ranges. In the global charged hadron analysis [12] tracks have been reconstructed in the full Inner Detector, $|\eta| < 2.5$, and measured out to $< p_T <$30 GeV, with stringent requirements on the number of hits per track in order to suppress fake rates. With these requirements efficiencies are typically $70-80\%$. While fake rates near $|\eta|$=0 are less than a percent, both efficiency and purity are slightly reduced towards larger pseudorapidities.

4. Conclusions

ATLAS results from the 2010 LHC Pb+Pb run have been presented. The charged particle multiplicity produced yields in central collisions $(0-5\%)$ is significantly higher relatively to Au+Au RHIC collisions, but present approximately the same centrality behaviour. $v_2 - v_6$ flow coefficients have be measured as a function of centrality. The p_T dependence of the different v_n is

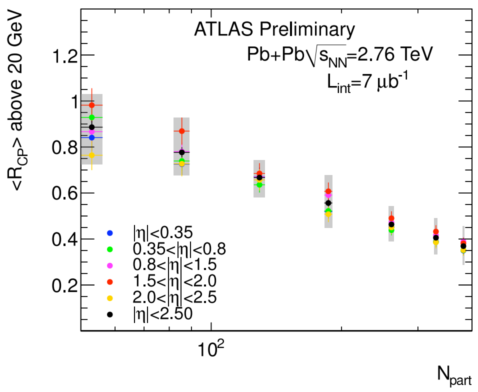

Figure 5: $R_{cp}(\langle N_{part}\rangle)$ for charged hadron spectra averaged over η, and in five $|\eta|$ regions, all integrated above a fixed p_T cut of 20 GeV. Error bars represent statistical errors and the gray boxes represent the systematic uncertainties.

found to be quite similar. W production in heavy ion collisions is found to be consistent with binary collision scaling. On contrary, jets are suppressed by a factor of two when comparing central and peripheral collisions, in well agreement with the observed suppression in the charged hadron p_T spectra.

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