STUDY OF HEAVY ION COLLISIONS WITH ATLAS*

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The ATLAS detector was designed primarily for proton–proton collisions but it will also participate in the heavy ion program of the Large Hadron Collider (LHC). The LHC will collide lead ions at the center of mass energy of $\sqrt{s_{NN}} = 5.5$ TeV (with $\sqrt{s_{NN}} = 2.75$ TeV expected in 2010) and thus it will provide crucial information about the hot and dense QCD matter expected to be formed in these collisions. We will take advantage of unprecedented capabilities of the ATLAS detector to measure global observables such as collective flow and particle multiplicities as well as jet quenching and modification of the high p_{T} particle spectra and heavy-quarkonia suppression. Performance of the ATLAS detector to measure these phenomena is presented.

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1. Introduction

The purpose of this contribution is to describe the heavy ion program at the ATLAS detector. ATLAS is primarily designed for $p+p$ collisions at the centre of mass energy 14 TeV with a rich physics program. More information about the ATLAS detector and its expected performance can be found in Ref. [1]. Despite the high particle multiplicities produced in heavy-ion collisions, the ATLAS detector has excellent capabilities for the study of the hot and dense matter expected to be formed in $\mathrm{Pb}+\mathrm{Pb}$ collisions at these high energies.

Experiments at the Relativistic Heavy Ion Collider (RHIC) at BNL with its $\sqrt{s_{NN}} = 200$ GeV observed the production of a new state of matter, the Quark Gluon Plasma (or QGP), which had many unexpected properties.

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The LHC, with almost thirty times higher energy, will provide a new insight into heavy-ion physics and an opportunity to study this hotter, denser and longer-living medium.

The overall properties of the QGP can be studied by the measurement of global observables. For these measurements, we will use the ATLAS Inner Detector (ID), a spectrometer placed in a 2 T field, as well as the ATLAS calorimeter system. Both have large angular coverage, but the calorimeter system covering 10 units of pseudorapidity is an ideal tool to use for studying the production of jets and high energy photons. These observables are important "hard probes" of the properties of the QGP. The ATLAS detector has an extensive system of muon chambers placed inside a 1 T magnetic field for precise measurements of muon momentum. This system will measure quarkonia and Z muon decays. Quarkonia production is strongly influenced by colour screening in the medium, thus it probes the physics of deconfinement in the QGP.

The ATLAS detector is fully operational, with at least 98% of channels in each subdetector fully operational. Millions of cosmic ray events were recorded during 2008 and 2009 for calibration of the detector. The first $p+p$ collisions at 900 GeV were recorded at the end of 2009 when also the energy of 2.36 TeV was reached. The first ATLAS physics results on $p+p$ collision data were published in Ref. [2]. Since March 2010 ATLAS has collected 2.41 nb^{-1} of data from $p+p$ collisions at the centre of mass energy of 7 TeV.

2. Global observables

The first measurements in $\mathrm{Pb}+\mathrm{Pb}$ collisions in ATLAS will be on "global observables", such as charged particle multiplicity, transverse energy and elliptic flow. Global observables are strongly correlated with collision geometry (centrality). An example of such correlation is presented in Fig. 1 which shows a dependence of the total energy E_{Tot} deposited in different parts of calorimeter system on the number of binary collisions, number of participants and the collision impact parameter. These distributions were obtained using the HIJING model [3].

The "day 1" measurement of these quantities can test predictions of theoretical models which differ significantly for LHC energies. One example of such quantities is charged particle density at mid-rapidity. The left panel of Fig. 2 shows predictions of different theoretical models for $dN_{\mathrm{ch}}/d\eta$. It is evident that these predictions differ significantly at LHC energy. The right panel of Fig. 2 shows performance of the $dN_{\mathrm{ch}}/d\eta$ reconstruction with one of our methods based on hit counting in different layers of pixel detector.

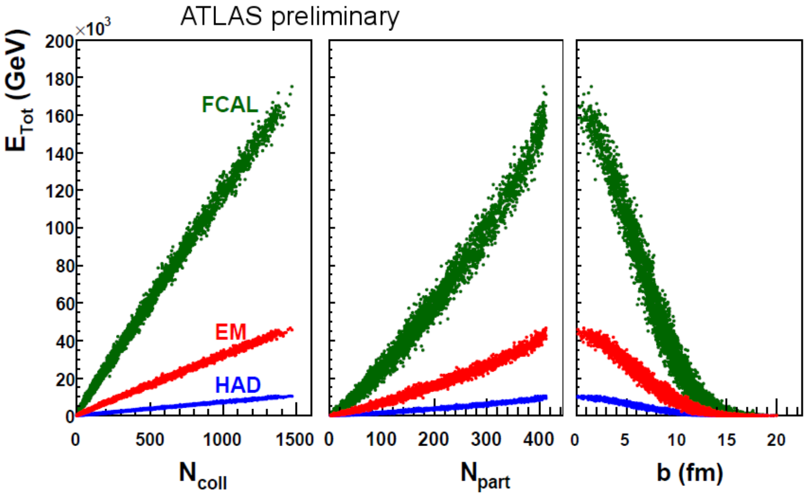

Fig. 1. Dependence of total $E_{\rm Tot}$ in FCAL (forward), EM (electromagnetic) and HAD (hadronic) calorimeter on number of binary collisions (left), number of participants (middle) and impact parameter (right).

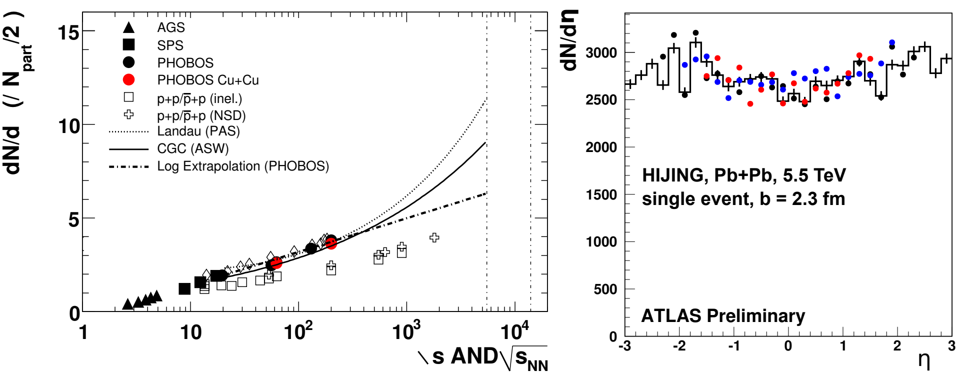

Fig. 2. Left: $dN_{\rm ch}/d\eta$ at mid-rapidity, normalized to the number of participant pairs, as a function of energy for $p+p$ and $A+A$ data compared with three theoretical models [4–6]. Right: Comparison of simulated $dN_{\rm ch}/d\eta$ distribution at particle level (line) and the reconstructed one (marks) in a single central Pb + Pb event. Different colours of marks represent different layers of pixel detector.

Another important observable is the transverse energy. Several methods for $E_{\rm Tot}$ estimation were developed [7]. The left panel of Fig. 3 shows the comparison of $E_{\rm Tot}$ generated and reconstructed distributions. This result is based on HIJING model simulated data. The right panel of Fig. 3 presents the same distribution but it compares first $p+p$ data at 900 GeV with simulations at the detector level. This illustrates that ATLAS has a good understanding of the detector response, even in the early data. We expect similar performance also in Pb + Pb collisions.

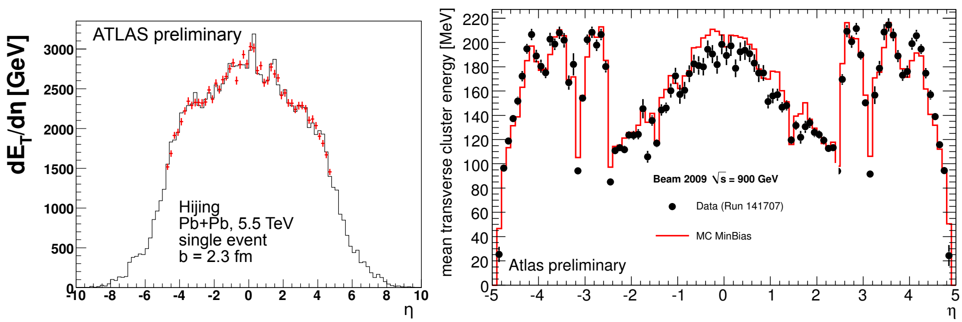

Fig. 3. Left: Comparison of generated (line) and reconstructed (red circles) $dE_{\rm Tot}/d\eta$ distribution in a single central Pb + Pb event. Right: Comparison of mean transverse energy in calorimeter clusters as a function of cluster η for collision data and simulations at the detector level in $p + p$ collisions.

The phenomenon of elliptic flow (the observed anisotropy of particle azimuthal distributions) comes from the initial pressure gradients caused by asymmetric shape of the interaction region. Various methods for flow reconstruction have been developed to have control over non-flow effects. The performance of the elliptic flow reconstruction is shown in Fig. 4, where the

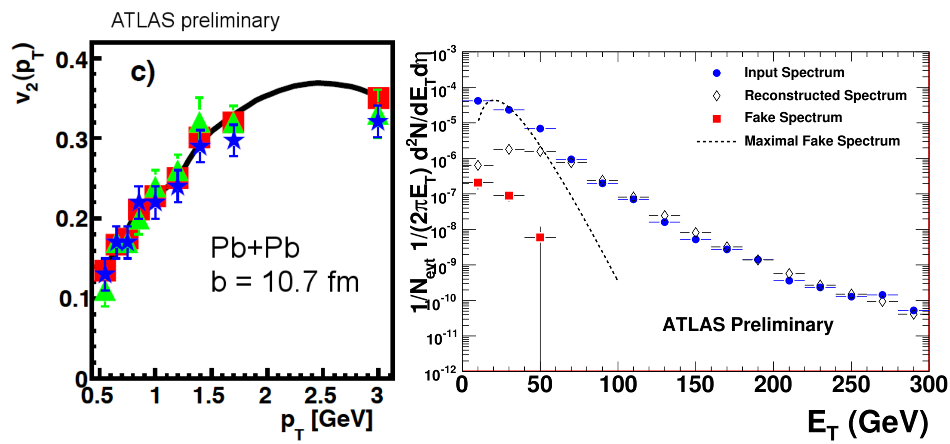

Fig. 4. Left: v_2 as a function of $p_{\rm T}$ reconstructed by three methods: reaction plane method (squares), two-particle correlation method (stars), Lee–Yang zeroes method (triangles) and compared to the generated v_2 (line). Right: Input (circles), reconstructed (diamonds), and fake (squares) spectra for jets reconstructed in central collisions ($b = 2$ fm, $dE_{\rm Tot}/d\eta = 2700$).

magnitude of flow is quantified by parameter v_2, the second Fourier coefficient of the azimuthal distribution. More details about the measurement of global observables can be found in Ref. [7].

3. Jets and photons

The first evidence for jet quenching phenomena in heavy ion collisions was observed by all four RHIC experiments in measurements of high $p_{\rm T}$ particles [10]. The much-higher energy of the LHC, along with the hermetic detectors there, will finally allow full jet reconstruction. However, specific procedures have been developed to deal with the large fluctuations of the underlying event. Details concerning the jet reconstruction can be found in Ref. [8]. Performance of these procedures is presented in the right panel of Fig. 4, where a comparison of the reconstructed, input and fake jet $E_{\rm Tot}$ spectra is shown. The reconstructed spectrum matches the input spectrum quite well above 80 GeV.

The effect of jet quenching and its mechanism can be studied by measurement of quantities describing the jet internal structure such as fragmentation function $D(z) = 1/N_{\rm jet} dN/dz$, where z is the longitudinal momentum fraction of a jet carried by a fragment. The left panel of Fig. 5 shows comparison of simulated and reconstructed fragmentation functions. The right panel of Fig. 5 then compares simulated fragmentation function from PYTHIA (no jet quenching) and PYQUEN (with jet quenching). It is evident that ATLAS is sensitive to quenching effect if it is of the size predicted by PYQUEN. More detailed studies and description of the method used for reconstruction can be found in Ref. [8].

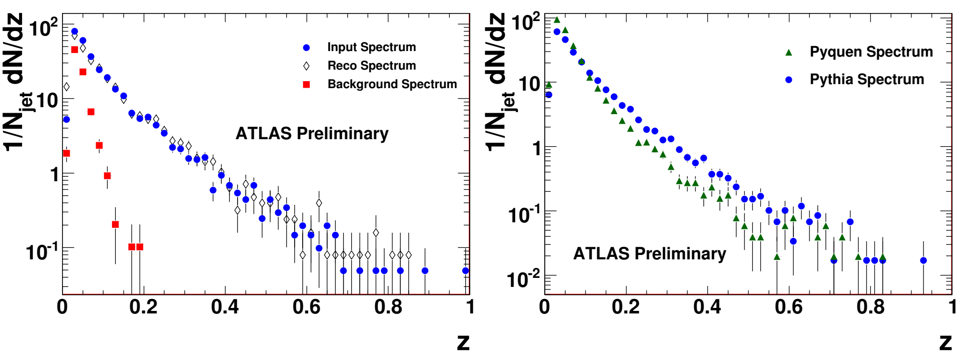

Fig. 5. Left: Comparison of jet fragmentation function in central collisions after background subtraction (diamonds) with the truth fragmentation function (blue circles). Background spectrum is also shown. Right: Fragmentation function for reconstructed PYTHIA (blue circles) and PYQUEN (green triangles) events.

The ATLAS calorimeter, especially first layer of electromagnetic calorimeter, has an unprecedented capability for photon measurements. Study of direct photons is very useful since the medium is transparent for them. Measurement of γ in γ–jet events thus should be able to calibrate the energy of individual partons in the medium. ATLAS performance for photon reconstruction after applying isolation cuts and shower pattern recognition [9] is presented in the left panel of Fig. 6. The cuts suppress the yield of neutral hadrons (background) below the direct photon yield for photons with E_{Tot} above 60 GeV.

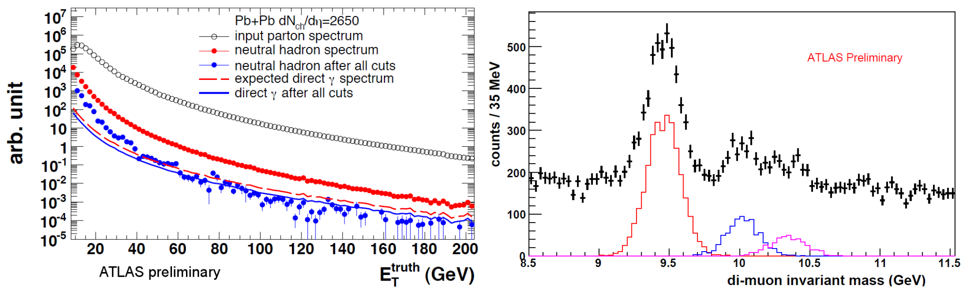

Fig. 6. Left: The spectra for input jets (open circles), input $\pi^0 + \eta$ (red/light grey solid circles), remaining $\pi^0 + \eta$ (blue/dark grey solid circles), expected direct γ (dashed line) and direct γ surviving all cuts (solid line). Right: Di-muon invariant mass distribution in barrel $|\eta| < 1.0$ taking into account acceptance and efficiency. Solid colour histograms represent expected yields from the three Υ states. Black crosses show the sum of signal and background.

4. Quarkonia

The details of deconfinement can be studied by the suppression pattern of different quarkonia states. Different quarkonia states dissociate at different plasma temperatures and thus we may be able to use them as a "thermometer" of the QGP. The right panel of Fig. 6 shows spectrum of Υ family as it is expected in one month of standard Pb + Pb run (0.5 nb^{-1}). The mass resolution of 120 MeV is more than sufficient for separation of the Υ and Υ' states.

5. Summary

Monte Carlo studies show that ATLAS has excellent capabilities to study heavy-ion physics, especially due to the fine granularity of the calorimeter and large coverage of the all detector subsystems. ATLAS is fully operational and MC simulations of the detector response are in good agreement with first $p + p$ data, which are being used for testing and calibration of the methods developed for the analysis of heavy-ion collision data. We expect first results shortly after the start of the Pb + Pb run, but we expect a rich physics program in the coming years. Overall we expect that ATLAS will provide an important contribution to heavy ion physics.

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