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Heavy ion collisions with the ATLAS detector

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Abstract. The ATLAS detector is designed to study high-p_T physics in proton-proton collisions at the LHC design luminosity. The detector capabilities for heavy-ion physics are now being evaluated. This paper reports on a preliminary assessment of the baseline ATLAS detector potential for heavy-ion physics. The ATLAS sensitivity to some of the expected signatures from the quark-gluon plasma (e.g. jet quenching, Υ suppression) is discussed.

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1 Introduction

At the LHC, a single ultra-relativistic heavy ion central collision will produce an enormous number of virtual partons, dominated by gluons. These partons should often form a quark-gluon plasma characterised by quark deconfinement and restoration of approximate chiral symmetry.

One of the key observables is the measurement of parton probes of the plasma medium via their induced gluon radiation, often referred to as jet quenching [1]-[3]. Recent results from RHIC already suggest that, during hadronisation, partons may radiate gluons in the dense matter formed in heavy ion collisions [4].

The parton energy loss is directly related to the initial gluon density of the system, which is expected to be over a factor of ten higher at the LHC than at RHIC. At the LHC beam energy, jets will therefore serve as powerful probes of the hot QCD matter created after the nuclei collide.

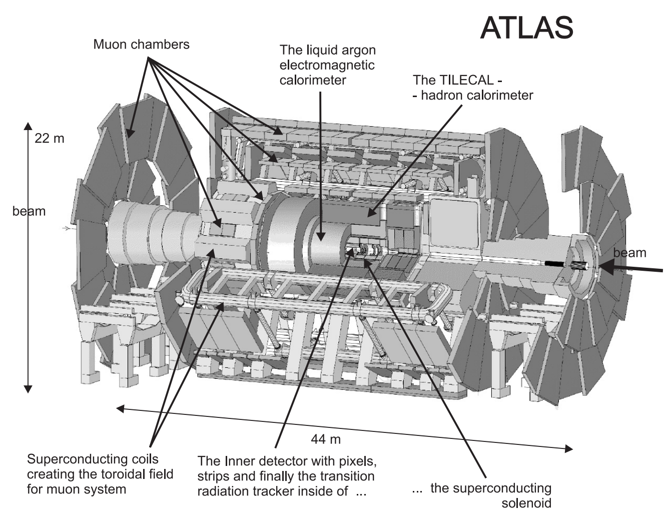

Fig. 1. View of the ATLAS detector

2 Simulation tools

The ATLAS detector will contain a precise tracking system (Inner Detector) for charged particle measurements, a hermetic calorimeter system (full azimuthal coverage for pseudorapidities below 4.9) and a stand-alone muon system [5]. Most of the detector subsystems will be operational for the study of heavy-ion collisions. A view of the detector is shown in Fig. 1.

The ATLAS detector performance in these conditions has been studied using GEANT3-based detector simulations and a detailed description of the signal processing electronics validated by an extensive programme of test-beam measurements.

The Pb-Pb collisions were simulated using HIJING1.38 [6], which predicts an avarage particle density $dN_{ch}/d\eta$ of ~ 3200 charged particles at $\eta \sim 0$. This is significantly higher than the direct extrapolation from the RHIC data [7], which yields an everage expected density $dN_{ch}/d\eta \sim 1300$ at mid-rapidity. One can therefore assume that HIJING provides a conservative scenario for heavy-ion collisions at the LHC.

The simulated rapidity range was limited to $|\eta| < 3.2$. As a result the simulation of a single central collision takes approximately 6-8h of a 1 GHz CPU. The simulations described here have thus left over the forward calorimeters.

To reconstruct simulated events we used the standard ATLAS reconstruction software most of which is able to handle heavy ion events. Modifications were introduced only at selection (filtering) stage as this was necessary for the jet reconstruction and tracking.

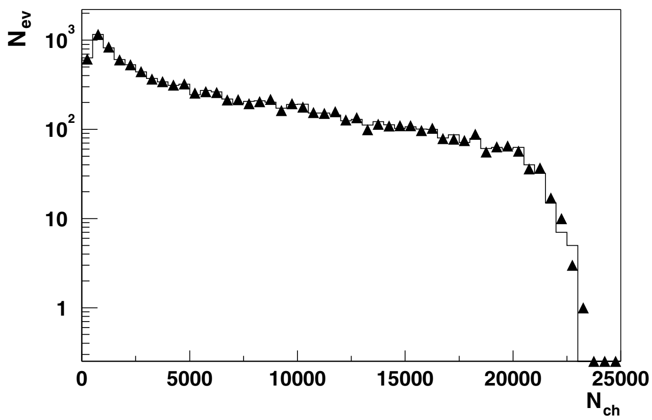

Fig. 2. Comparison of the reconstructed (*triangles*) and simulated (*histogram*) charged particle multiplicity distributions

3 Inner detector performance

The ATLAS inner detector has been designed to have good tracking efficiency in this momentum range over the pseudo-rapidity range $|\eta| \leq 2.5$.

For the very central collisions ($b = 0 - 1fm$) the simulated occupancy for the Pixel detector are close to 1% with relatively large fluctuations. In the Semiconductor Tracker occupancies are varying from 20% at innermost radius to below 10% at outermost radius. The occupancy of Transition Radiation Tracker make it unusable for nucleus-nucleus studies. Thus the Inner Detector will provide track information of at least 11 measured points on a track.

Already cluster counting in the Pixel Detector and Semiconductor Tracker can be used to reconstruct the charged particle multiplicity (N_{ch}) and their rapidity dependence ($dN_{ch}/d\eta$) at the very beginning of the LHC Pb-Pb running. This dependence can be calibrated in *pp* collisions and used to reconstruct charge particle multiplicity at $Pb - Pb$ collisions. This will allow to reconstruct the charged particle multiplicity N_{ch}^{rec}, on an event-by-event basis, using the total number of registered signals.

Figure 2 demonstrates the reconstructed multiplicity distribution dN_{ev}/dN_{ch} compared to the input HIJING distribution. For central Pb-Pb collisions a statistical accuracy of about 2% can be achieved using such technique, For most peripheral interactions the accuracy rapidly deteriorates to a value of about 10%.

Particle tracks from HIJING events were reconstructed using *xkalman*, the ATLAS package for global pattern recognition and track fitting [9]. In case of Heavy Ion collision this package use the fact that most of the tracks originate from the same vertex. Track reconstruction efficiency and fake tracks are shown in Fig. 3. As it can be seen from the plot, tracking can be done with a reasonable efficiency even in this highly complicate environment. At p_T higher than 15 GeV combinatorial background give rise to a relatively high number of fake tracks. Most of them can probably be rejected using the calorimeter information, but this work still has to be done in the future.

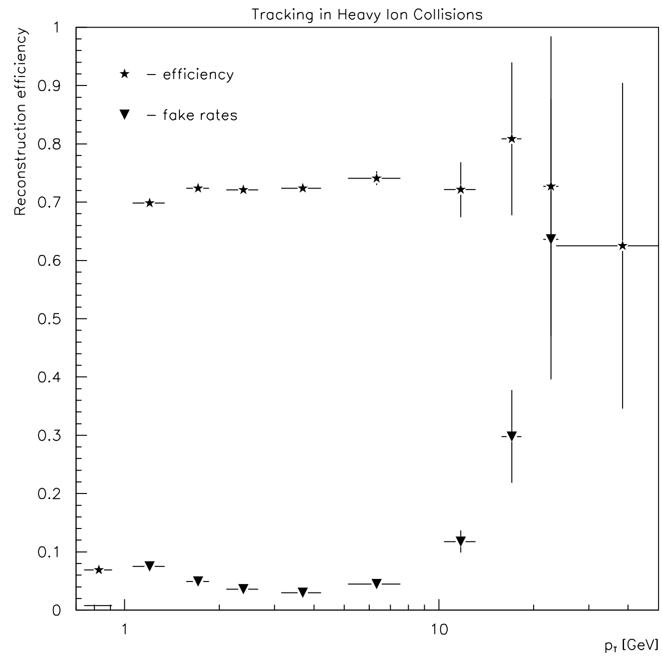

Fig. 3. Reconstruction efficiency and percentage of fake tracks as function of reconstructed particle p_T

4 Jets reconstruction

One of the highlights of the ATLAS detector is its calorimeter subsystem with a large rapidity coverage ($|\eta| < 4.9$). Both the electromagnetic and hadronic compartments are finely segmented and well suited for jet quenching studies. ATLAS calorimeter has the best granularity and hadronic energy resolution compared to other LHC detectors with good energy and timing resolution. This will provide the optimal opportunity for measuring jets using detailed shape information.

In central Pb-Pb events most of the calorimeter towers will have signals. The HIJING events deposit most of the energy in the electromagnetic section of the calorimeter. Our simulations show that the amount of energy deposited in a typical $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ tower will be close to 2 GeV in the electromagnetic calorimeter and less the 0.5 GeV in the hadronic calorimeter systems. The distribution of energy within the EM calorimeter indicate that most of the energy is deposited in the first layer of the calorimeter.

For the whole calorimeter system the average background is approximately $\sim 20GeV$ for a window of 0.4, which translates into a worsening of the jet energy resolution. In first approximation the fluctuations are the same for all jets, and this should translate into a larger constant term.

To study the ability to reconstruct jets in the heavy ion environment Pythia jets were overlapped on a HIJING event. Pythia jets and those overlapped to the background events were reconstructed using the algorithm described below. The energy of the jet at the level of the event generator is used as a reference.

The jet reconstruction used in this study is the standard ATLAS sliding window algorithm. Prior to the re-

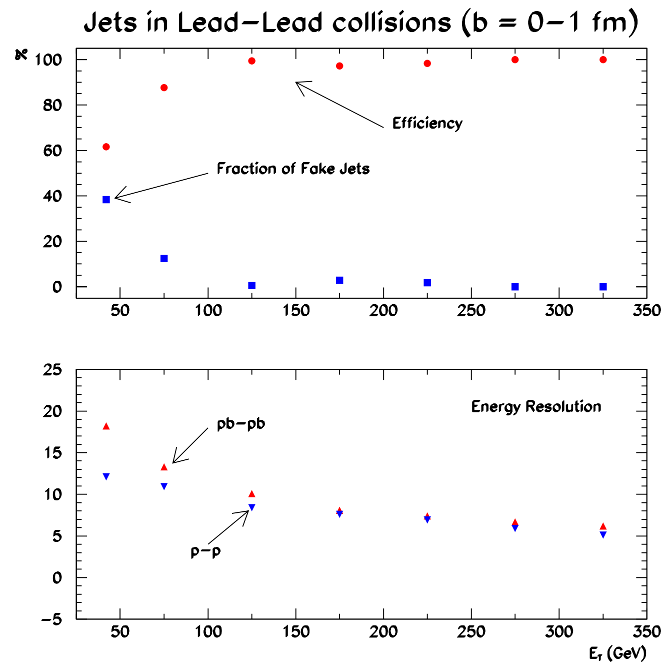

Fig. 4. jet reconstruction efficiency

construction the average background energy is subtracted from each tower. The background is calculated using towers of energy below a threshold. Another tool that is under further investigation is to remove layers of the calorimeter for jet finding.

The efficiency plot is shown in Fig. 4. For jet $E_T > 75GeV$ the efficiency is close to 100%. Below that energy the efficiency drops to approximately 60% for $E_T = 40GeV$.

We are also investigating the possibility of finding and reconstructing jets using the track informations, which should be feasible taking into account that a track reconstruction efficiency of $\sim$ 85% can be reached. This could provide an extra handle for the rejection of fake jets and improve the jet reconstruction efficiency at low jet E_T.

5 Muon system

The muon spectrometer in heavy ion collisions is more quiet than in proton-proton collisions at high LHC luminosity and can be used for an efficient muon identification and b-jet tagging using soft decay muons.

For p_T larger than 40 GeV, we expect of the order of 500 $Z^0 \to \mu^+\mu^-$ events for one month-run. Recent theoretical investigations [8] have indicated that charm and bottom quarks propagating through a dense partonic medium will have a suppressed gluon radiation.

Tagging of b-jets by the associated muon is possible in the proton-proton environment [5]. We are currently studying the possibility of tagging b-jets by matching a measured muon in the muon spectrometer to the jet measured by the calorimeter system in the heavy ion environment. Thus the possibility of measuring b-jets in ATLAS would give an important comparison measurement to the

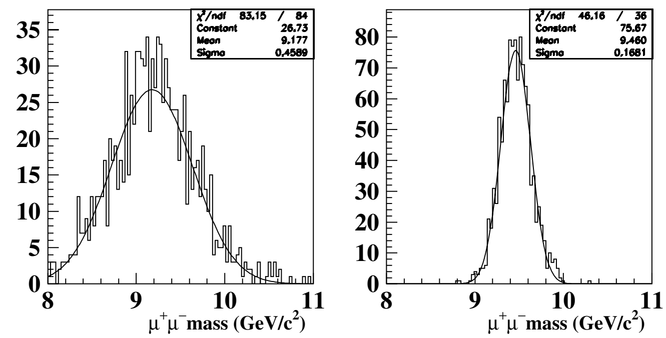

Fig. 5. Upsilon mass resolution with the Muon Spectrometer alone (*left*) and with muon track propagated in the Inner Detector (*right*)

light quark and gluon jets and would have an important implication on gluon shadowing and saturation models.

We studied the ATLAS capability to identify Υ states. Upsilons where generated according to the phase space and overlayed on top of the HIJING events. The initial evaluation is that the stand-alone muon system will provide marginal resolution for a clear separation of the three states. However, extrapolating muon trajectory and finding it in the Inner Detector significantly improve the mass resolution (Fig. 5).

6 Conclusion

The first glance on the ATLAS detector performance in Heavy Ion collisions is promising. The inner Detector can not only be used to provide the global properties of the system created in heavy ion collisions, but will be capable to provide a reasonable tracking capability. Jet reconstruction in the heavy ion environment seems feasible with ATLAS for jets with energies above 50 GeV.

Altogether the ATLAS detector provides and unprecedent opportunity to study nucleus-nucleus, proton-nucleus and light nucleus-nucleus collisions in a detector with both large acceptance and nearly complete coverage for the various final states that can result from perturbative QCD processes.

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