METHODS OF MULTIPLICITY RECONSTRUCTION IN HEAVY ION COLLISIONS IN THE ATLAS EXPERIMENT*

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The Large Hadron Collider accelerates and collides both proton beams and lead beams to the highest energies available in the laboratory. One of the most important global characteristics of such collisions is the multiplicity of produced particles. The ATLAS detector registers passage of charged particles using silicon detectors over a pseudorapidity range of about 5 pseudorapidity units. Several methods of reconstruction of the charged particle multiplicity and angular distribution were developed. These methods range from the full reconstruction of particles and their momenta to an estimate of the number of charged particles based on counting hits registered in a single layer of the Pixel detector. First results obtained from experimental data for $p+p$ interactions and performance studies for heavy ion collisions based on Monte Carlo simulations are discussed.

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1. Introduction

Since the end of 2009 the Large Hadron Collider at CERN has delivered interactions of protons at the three energies, at first $\sqrt{s} = 900$ GeV, then $\sqrt{s} = 2.36$ TeV and finally $\sqrt{s} = 7$ TeV. In November 2010 also beams of heavy ions were collided at an unprecedented energy $\sqrt{s_{NN}} = 2.76$ TeV (in the nucleon–nucleon centre of mass system), about 14 times larger than previously obtained at the Relativistic Heavy Ion Collider at BNL.

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The analysis of proton+proton interactions is already well advanced and global characteristics of the events are presented in this work. Multiplicity studies of the Pb+Pb collisions have started only recently, thus only the performance results based on Monte Carlo simulations are available. Several methods used to measure charged particle multiplicities for heavy ion collisions are presented. The standard method (track method) uses information on fully reconstructed tracks. The pixel track method is based on simplified reconstruction using hits registered only in the subdetector closest to the primary interaction point. For events with high multiplicities a tracklet method and pixel hit counting method can be successfully used. The first two methods enable more efficient rejection of false track candidates, but lose some fraction of charged particles, especially with low transverse momenta. The two other methods have much higher efficiency at the expense of larger background from secondary particles.

2. The ATLAS detector

The ATLAS detector [1] is one of four main detectors at the Large Hadron Collider [2]. In a general view of the ATLAS detector the largest system is the muon spectrometer, then electromagnetic and hadronic calorimeters. The Minimum Bias Trigger Scintillators (MBTS) [3] are used to obtain the inclusive sample of $p+p$ interactions. They also play an important role in triggering for heavy ion collisions. For measuring charged particle multiplicites the Inner Detector [1] is used. It is shown in more detail in Fig. 1. It comprises the Pixel detector with three layers of silicon sensors, Semiconductor Tracker (SCT) and the Transition Radiation Tracker (TRT). All elements of the Inner Detector are included in the standard track reconstruction. Other methods are based on the information from the Pixel detector and in the pixel hit counting method only the closest to the beam Layer-0 of the Pixel detector is usually used.

3. Tracking results

In this method tracks reconstructed by a pattern recognition procedure are used. Currently two versions of the pattern recognition procedure are deployed. The main procedure is *inside–out* track reconstruction and after it the *outside–in* [4] tracking is performed. A track candidate should have at least one hit in the Pixel detector and five hits in the SCT. Later a momentum fit and quality checks are done. Tracks can be reconstructed in the range of pseudorapidity between -2.5 and 2.5 and unbiased reconstruction of charged particles with $p_{\mathrm{T}} > 500$ MeV is possible. The efficiency of track reconstruction strongly depends on the particle transverse momentum, for $p_{\mathrm{T}} > 100$ MeV at $\eta = 0$ it is of the order of 80% [5].

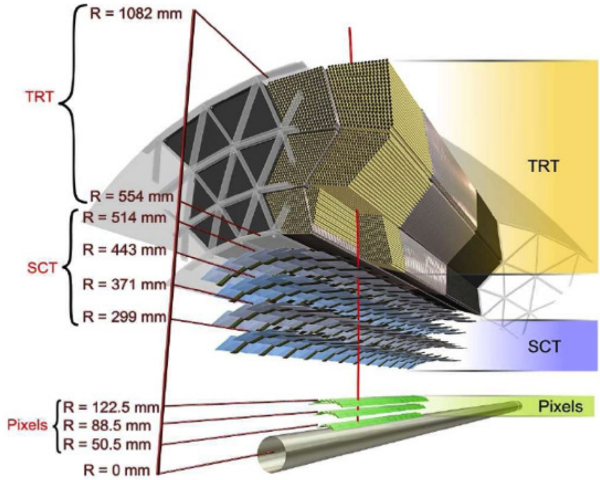


Fig. 1. The Inner Detector of the ATLAS experiment. Starting from the bottom there are: the beam pipe, three layers of the Pixel detector, four layers of the Semiconductor Tracker (SCT) and the Transition Radiation Tracker (TRT). For clarity the detector elements in a limited range of azimuthal angle are shown, in reality these detectors have full azimuthal coverage. R denotes a distance from the beam. The Inner Detector works in a 2T magnetic field with the direction along the beam.

The analysis of the multiplicity of charged particles was performed for events with a well defined primary vertex. Events with a second vertex with more than 3 tracks associated were rejected in order to remove pileup interactions. The applied selection criteria ensure that the fraction of beam background events or the probability of the second interaction in the same bunch crossing are both below 0.1%. For details on event selection see [7,8]. The final charged particle density $dN_{\rm ch}/d\eta$ at $\eta = 0$ for tracks with $p_{\rm T} > 100$ MeV obtained from the Track Method is 3.483 ± 0.009 (stat.) $\pm\, 0.106$ (syst.) for $\sqrt{s} = 0.9$ TeV and 5.630 ± 0.003 (stat.) $\pm\, 0.169$ (syst.) for $\sqrt{s} = 7$ TeV. If the particles with higher momenta are selected, $p_{\rm T} > 500$ MeV, lower particle density (see Fig. 2) is obtained 1.343 ± 0.004 (stat.) $\pm\, 0.027$ (syst.) for $\sqrt{s} = 0.9$ TeV and 2.423 ± 0.001 (stat.) $\pm\, 0.050$ (syst.) for $\sqrt{s} = 7$ TeV [7].

4. Pixel track method

The method which accepts track candidates with less restrictive criteria and allows for reconstructing particles with lower transverse momenta is the pixel track method. It is based on the same inside–out track reconstruction algorithm, but restricted to hits from the Pixel detector. This

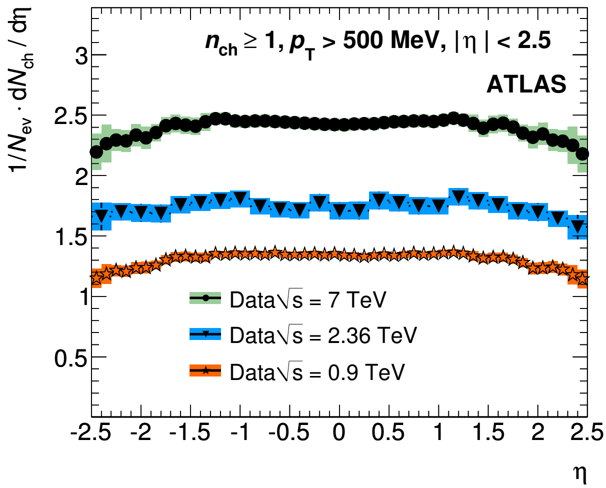


Fig. 2. Charged particle multiplicities as a function of pseudorapidity for particles with $p_{\mathrm{T}} > 500$ MeV emitted in the $|\eta| < 2.5$ range at energies $\sqrt{s} = 7$ TeV, $\sqrt{s} = 2.36$ TeV and $\sqrt{s} = 0.9$ TeV. The results for energy 2.36 TeV were obtained using the pixel track method [7,8].

method was applied for the 2.36 TeV data. During the data taking, the SCT was in standby mode, and thus operated with reduced efficiency. An average charged particle density at $\eta = 0$ for tracks with $p_{\mathrm{T}} > 500$ MeV is 1.739 ± 0.019 (stat.) $\pm\, 0.058$ (syst.) [9]. A direct comparison of results of the pixel track method and the standard track method is shown in Fig. 3. These results were obtained for $\sqrt{s} = 2.36$ TeV and agree within systematic errors [9].

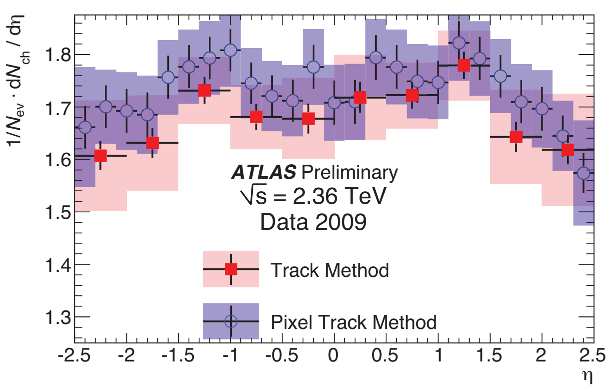


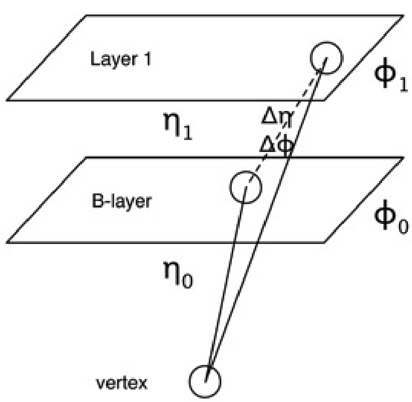
Fig. 3. Charged particle multiplicities as a function of pseudorapidity at $\sqrt{s} = 2.36$ TeV obtained using the pixel track method and the standard track method.

5. Tracklet method

This method was developed specially for heavy ion collisions. Tracklets are constructed from the reconstructed vertex and 2 hits from different layers of the Pixel detector. For each pair of two hits we take their η and ϕ values and calculate the differences. For a tracklet $\Delta\eta$ and $\Delta\phi$ have to be smaller than η_c and ϕ_c. The η_c and ϕ_c values were selected on the basis of Monte Carlo studies and are about 0.01 and 0.08 respectively. The basic steps of the algorithm of this method are the following:

- search for tracklets in first two layers: Layer-0 and Layer-1, clusters belonging to accepted tracklets are removed from the search;
- looking for tracklets in Layer-0 and Layer-2, again used clusters are removed;
- repeat search for tracklets in Layer-1 and Layer-2;
- finally duplicated tracklets due to overlaps of sensors and ganged pixels are removed.

Figure 4 presents how the tracklet method works. The distribution of the values of particle density $dN_{\mathrm{ch}}/d\eta$ at $\eta = 0$ for primary charged particles and those obtained from the tracklet method agree well even before applying final corrections. Performance of this method is presented in figure 5. The efficiency of reconstruction for the tracklets method is close to



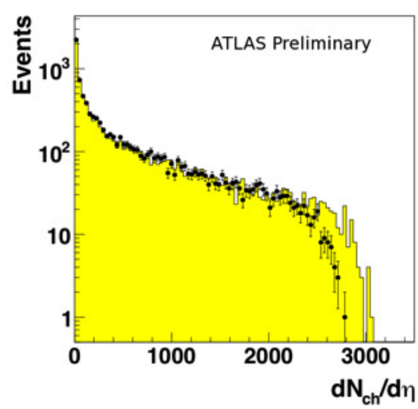


Fig. 4. Multiplicity reconstruction in the tracklet method. Left: Schematic drawing explaining the formation of tracklets. Right: Comparison of the results of reconstruction for the Monte Carlo simulations of Pb+Pb collisions from Hijing generator. Light grey (yellow) histogram presents $dN_{\mathrm{ch}}/d\eta$ of the primary charged particles, points represents reconstruction results (without corrections).

90%. The systematic error on the reconstructed multiplicity in the η range from -1 to 1 is about 2% for events with charged particle density $dN_{\mathrm{ch}}/d\eta$ larger than about 500. These results were obtained using Hijing [10] fully simulated lead–lead collisions at $\sqrt{s_{NN}} = 5.5$ TeV.

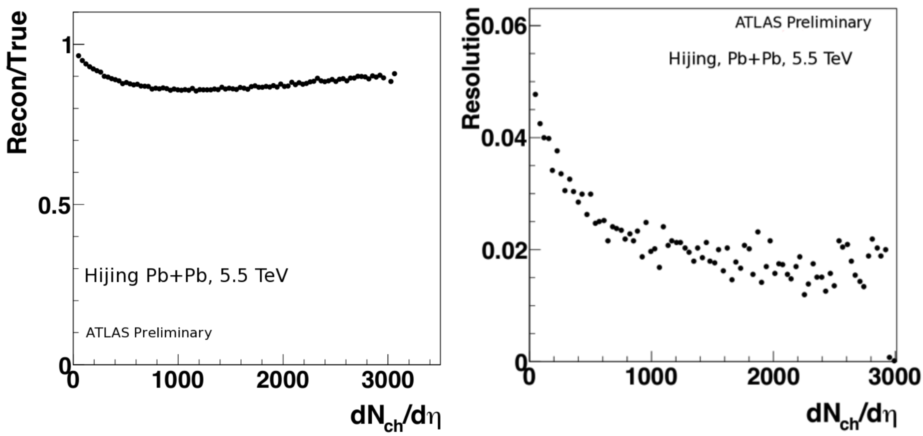


Fig. 5. Efficiency of track reconstruction for the tracklet method (left) and the resolution of reconstructed charged particle multiplicities (right).

6. Pixel hit counting method

This is the simplest method of charged particle multiplicity reconstruction. The number of hits (clusters of pixels with signal) in a selected layer of the Pixel Detector is counted (the most suitable is the Layer-0, closest to the beam). The reconstructed number of primary particles is obtained after applying appropriate corrections. This method is sensitive to particles with very low transverse momenta, which leave only one hit or are deflected too much by the magnetic field to be accepted in other methods. On the other hand, a single hit does not allow precise selection of tracks pointing to the vertex and background from secondary particles can be removed only by applying an overall correction. The correction functions, representing both acceptance effects and contributions from secondary particles, for three different layers are shown in Fig. 6. They were obtained using Monte Carlo simulations. The dependence on simulations and sensitivity to background fluctuations are the main disadvantages of this method. However, when the multiplicity of the event is sufficiently large, results obtained from the pixel hit counting method are quite reasonable. This is confirmed by a comparison of $dN_{\mathrm{ch}}/d\eta$ distributions for primary particles (histogram) and reconstructed values (points) obtained from the pixel hit counting method separately for each of 3 layers of the Pixel detector. The plot in the left panel in Fig. 7

was obtained for one central event, while the plot in the right panel is for one peripheral event. In both cases not only the mean $dN_{\mathrm{ch}}/d\eta$ value is reproduced, but reconstruction reflects also multiplicity fluctuations.

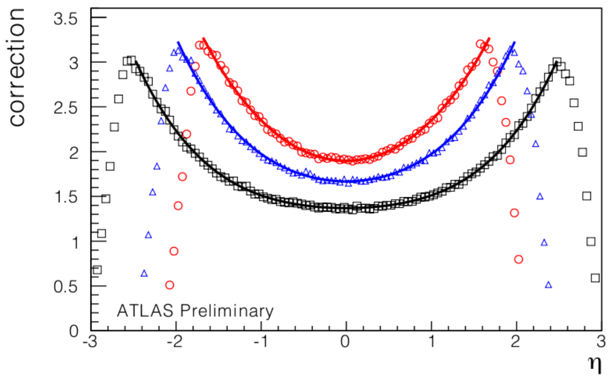


Fig. 6. The correction factor for the pixel hit counting method of multiplicity reconstruction obtained from Monte Carlo simulations of Pb+Pb collisions obtained for three layers of the pixel detector (squares — Layer-0, triangles — Layer-1, circles — Layer-2). The lines represent correct polynomial fits used to smooth the dependence of corrections on pseudorapidity.

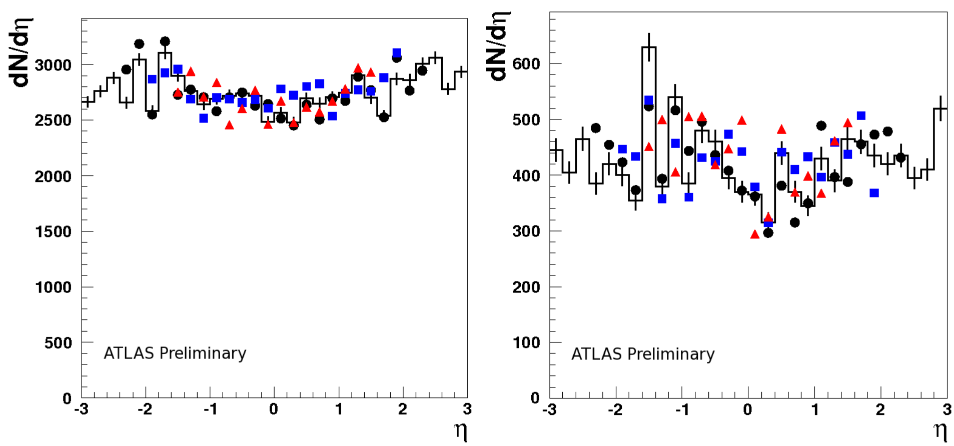


Fig. 7. Example of the pixel hit counting method reconstruction of a single Monte Carlo event from Hijing generator: a central Pb+Pb collision (left) and a peripheral Pb+Pb collision (right) for three layers of the pixel detector (Layer-0 — circle, Layer-1 — square, Layer-2 — triangle).

7. Summary

The Atlas Inner Detector tracking is used for $|\eta| < 2.5$ and $p_{\mathrm{T}} > 100$ MeV. Simplified pixel track and pixel hit counting methods are sensitive to particles with even smaller momenta, but are more appropriate for events with larger multiplicities. The charged particle multiplicity has already been measured at several proton+proton energies and the analysis of the Pb+Pb collisions is ongoing.

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