Project Report
CERN Summer Student Programme 2004

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1 Introduction

In summer 2004 a combined test beam of the ATLAS detector was conducted. Therefore a "slice" of the planned ATLAS experiment with all its sub-detectors was set up in the H8 beamline at the SPS accelerator, which shoots a beam of varying particle types and energies through this slice. It should allow to test the whole analysis chain from low level triggering to track reconstruction. In ATLAS the so called Inner Detector — consisting of a Pixel detector, a silicon strip detector (SCT) and a Transition Radiation Tracker (TRT) — is essential for track finding. One of the aims for the test beam was to check how different track fitters perform in a real environment.

This project should use the data from the test beam and from Monte Carlo simulations to test different steps of reconstruction. Due to several delays in the hardware setup real data could only be used in the last weeks.

2 Aim of the project

In general the aim of this project was to investigate data reconstruction with the ATHENA framework of ATLAS. The specific aims changed in between the project, because they were strongly dependent on the development of the test beam. The first part of the project was focused on the level of detector hits and the second part on track fitting in the Inner Detector.

3 Project description

All the work was done in two different programming environments. On the one hand code was written for ATHENA, the ATLAS offline software, to extract reconstructed data into ROOT ntuples. On the other hand these ntuples were used by ROOT macros to make histograms and analyse the data. For the combined test beam a class of algorithms (in InDetTestBeamCBNT) was created in ATHENA before to collect all the code used for this purpose.

In ATHENA raw data is first imported by byte stream converters and stored as so called Raw Data Objects (RDOs) [1]. On the level of RDOs coordinates of detector hits are available in their natural frame, i.e. columns and rows for Pixel and strip numbers for SCT. As a first test this data for Pixels was written into the combined ntuple and hitmaps for the six Pixel modules of the test beam created. These were used later on in offline analysis to check whether all modules are operating in a certain run. An example is shown in figure 1.

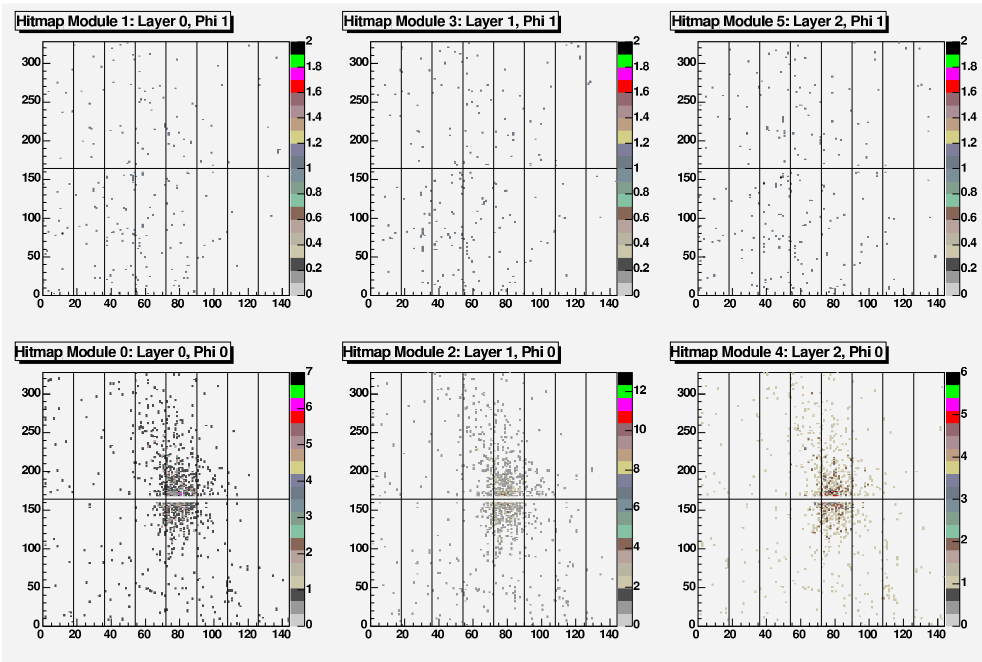

Figure 1: Hitmap of the Pixel detector for the first test beam run with all modules working. Lines are indicating the chip borders.

Correlations between different Pixel layers were investigated next for the two modules operating at first in the test beam. Figure 2 shows these correlation plots, once with all combinatorics of hits per event and once with only one hit in each layer per event. In the latter case hits with the maximum time over threshold, which is an indicator for the deposed energy, was chosen to reduce fake combinations. These plots showed some kind of "steps" in column direction and revealed an error in the Pixel byte stream converter. Column numbers were decoded incorrectly because of a wrong detector description.

In the next step of data reconstruction for Pixels and SCT in ATHENA RDOs are combined to Clusters. In these PrepRawData objects the position is still stored in local coordinates. To check the process of clusterisation, correlation plots between cluster and hit positions were created. Also another speciality of clusterisation was investigated. In the region where two Pixel chips abut no readout electronics is placed. To avoid dead area these pixels are "ganged" with other pixels to the same readout channel. At clusterisation hits in the ganged region are doubled to both positions of the ganged pixels. Therefore the

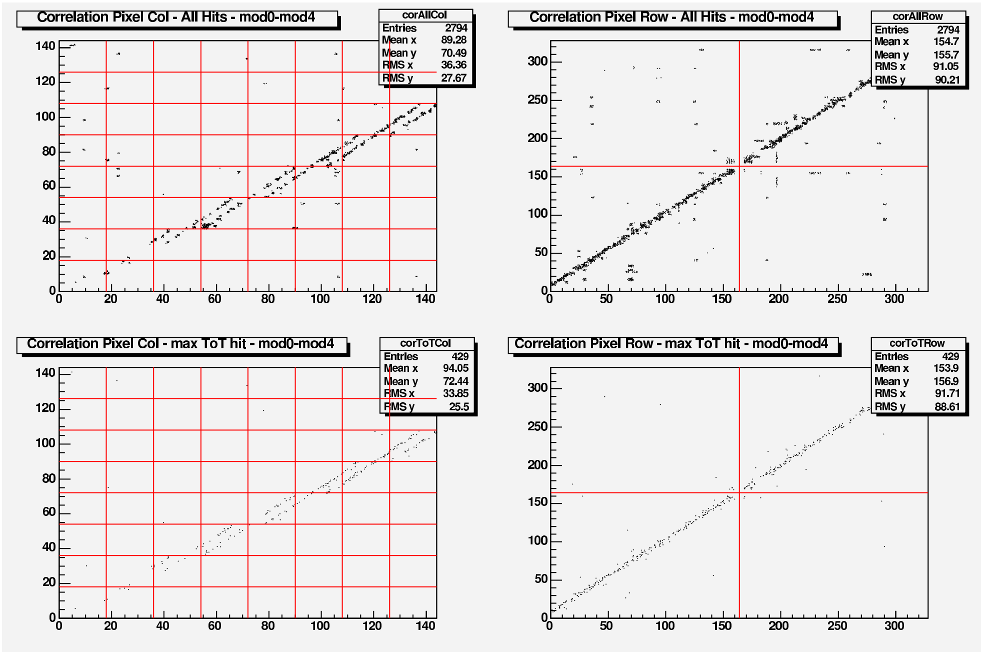

Figure 2: Correlations between different Pixel layers: Shown are correlations between column numbers (left) and row numbers (right) for hits in layer 0 and layer 2. The steps were produced by an error in the Pixel byte stream converter. Above: all combinatorics, below: only one hit per event, chosen by maximum time over threshold. Lines indicate chip borders.

cluster density is increased at the chip borders. This process was checked by deactivating the ganged pixel correction.

After clusterisation is carried out the cluster positions can be translated into global coordinates. This information is in ATHENA available on the level of so called SpacePoints. For SpacePoints different correlations were tested.

The second part of the project investigated the performance of track fitters for the test beam. Most of the work had to be done with simulated data, because only in the last week test beam data with three layers of Pixel detectors was available which is needed for confident track finding. At first an ATHENA class was written which calculates the residuals for each hit in Pixels, SCT and TRT. For the Pixel detector these residuals where calculated 2-dimensional in the Pixel plane, for SCT and TRT perpendicular to strip and straw direction respectively. For the SCT this involves a rotation from the local coordinate frame to the strip's frame since the SCT modules for the ATLAS end-cap have a radial orientation. To check the error estimation also the pulls, i.e. residual over track and hit error, were calculated.

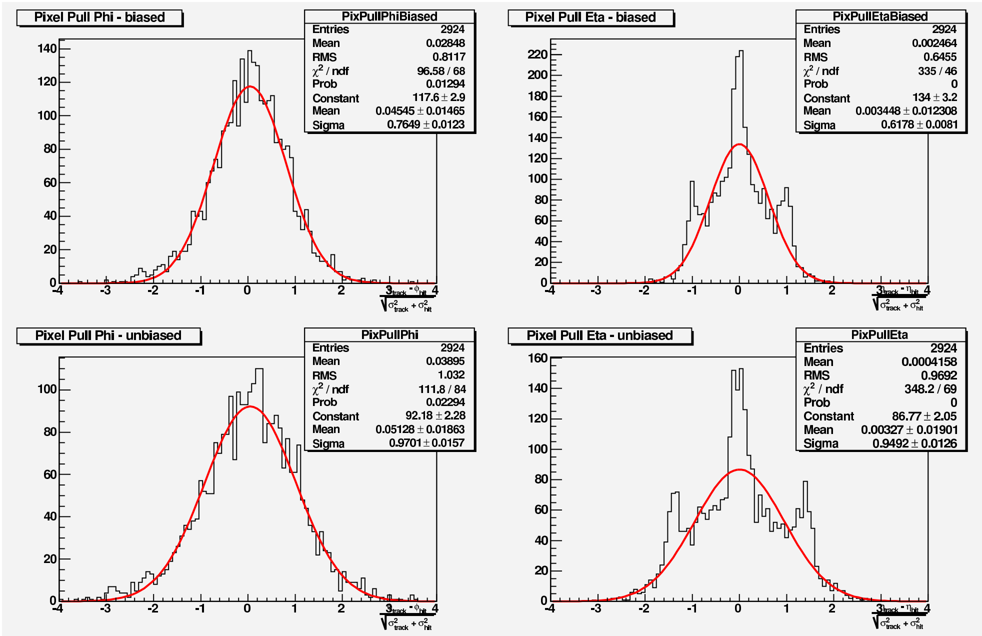

Figure 3: Biased and unbiased pulls for Pixels: above pulls for original track residuals, below with correction by inverse Kalman filtering. Left: phi direction of Pixel chip, right: eta direction. The width of the distribution for corrected pulls agrees much more with the expected value of one. Plots were produced with 1000 events of Monte Carlo data and Kalman refitted tracks.

The distribution of the pulls which was expected to have a root mean square of one was especially for the Pixels too narrow. This effect was assumed to have its origin in a bias of the reconstructed track position at the hit plane. Because trackfitting also takes the hit into account for which the residual is calculated, the track will be shifted to this hit. Reliable residuals can only be extracted with tracks which ignore the current investigated hit. One solution of this problem would be a complete refit of the track without one hit. This procedure has then to be done for each hit and will yield to an extreme increase in computing time.

At this point one could utilise a characteristic of Kalman fitters. Kalman filtering processes tracks in an iterative procedure by adding one hit per step to the trajectory. Afterwards a smoother process in the opposite direction provides track estimations at each measurement surface which are equivalent to a least-squares fit. The Kalman formalism even allows to calculate the unbiased track position directly by taking the measurement covariance matrix negative and effectively removing the hit from the track position [2, p. 447]. This so called "inverse Kalman filtering" was implemented in ATHENA within in the scope of the project. It is clearly superior to a refit for each hit, because only the track estimation and hit position on one surface with their covariance matrices need to be known. Therefore inverse Kalman filtering can be applied even to tracks produced with other kinds of least-squares fitters. Comparison of original residuals and residuals with correction by inverse Kalman filtering show the achievement of the method (figure 3). In this report pulls are only shown for Pixels because due to the high spatial resolution and small number of Pixel hits per track the bias is tallest for the Pixel detector.

In eta direction the distribution of residuals shows two peaks beside the maximum at zero. This effect occurs because in eta direction the reconstructed track is nearly completly determined by Pixel hits. Furthermore the Pixel chips have less resolution in eta than in phi direction. Therefore multiple scattering is small compared to the spatial resolution and the distribution gets discontinous. Some investigations have been done on this subject and first test beam results show exactly the same patterns.

4 Conclusion

This project provided many insights into offline data analysis and track reconstruction. It was well integrated into the tasks of the working group. Different kinds of tests on reconstruction could be implemented and some bugs identified.

Acknowledgements

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References

[1] M. Elsing, *Inner Detector Input Event Data Model*, `http://atlas.web.cern.ch/Atlas/GROUPS/INNER_DETECTOR/SOFTWARE/DoxygenDoc/newDoc/InputEDM.html`

[2] R. Frühwirth, *Application of Kalman Filtering to Track and Vertex Fitting* (Nuclear Instruments and Methods in Physics Research A262, 1987)