TEST OF THE ATLAS INNER DETECTOR RECONSTRUCTION SOFTWARE USING COMBINED TEST BEAM DATA

W. Liebig, M.J. Costa, CERN, Geneva, Switzerland*
on behalf of the ATLAS Inner Detector Software project†

Abstract

The Athena software framework for event reconstruction in ATLAS is employed to analyse the data from the 2004 Combined Test Beam. In this test beam, a slice of the ATLAS detector is operated and read out under conditions similar to future LHC running, thus providing a test-bed for the complete reconstruction chain. First results for the ATLAS Inner Detector are presented.

In particular the reading of the ByteStream data inside Athena, the monitoring tasks, the alignment techniques and all the different online and offline reconstruction algorithms have been fully tested with real data. Their performance is studied and results compared to simulated data, which has been made specifically for the test beam layout.

INTRODUCTION

The ATLAS collaboration conducts in summer 2004 a so-called Combined Test Beam (CTB) [1]. This means that a primary accelerator (SPS) beam is sent through a “slice” of ATLAS, ressembling a region of interest at a polar angle of 90^o. Electron, muon, pion and proton beams from the SPS at energies ranging from 1 to 350 GeV, a 1.4 T magnetic field around the precision detectors and a dedicated run with a 25ns bunched beam provide experimental conditions as close as possible to the future ATLAS experiment at LHC. The Inner Detector [2] is fully participating in this test beam. It consists of 6 Pixel modules in 3 layers, 8 double-sided SemiConductor Tracker (SCT) silicon strip modules in 4 layers and 2 Transition Radiation Tracker (TRT) phi sectors. The TRT is an assembly of 3×30 layers of drift tubes intersperced by a radiator medium. It provides trajectory information as well as electron identification. Fig. 1 illustrates the configuration of Pixel, SCT and TRT along the beam line.

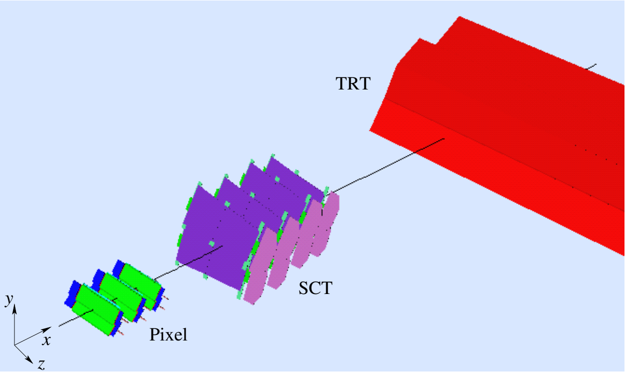

Figure 1: Layout of the Inner Detector in the test beam.

The Combined Test Beam serves as an integration test of the entire ATLAS data acquisition and reconstruction chain. Prototypes of the final read-out and trigger electronics are used while the detector control system and online monitoring checks are run. The ATLAS offline software is employed for the whole reconstruction chain from data-decoding via calibration and alignment up to track fitting. The idea behind this test is to spot possible obstacles or problems now and not when the LHC starts to deliver physics collisions. With a large set of real data to be analysed, experience with the latest offline reconstruction software can be gained and the generator and detector description models for the simulation verified.

During August and September 2004, the Inner Detector has been integrated gradually into the test beam. First the TRT started taking data on August 9th together with the calorimeters and the muon spectrometer, a few days later the Pixels joined with first 2 modules and later all 6. By end of September the Pixel layers were moved from their service position upstream by 4 m into the magnet, and the field has been switched on. Finally on Oct 2nd, after CHEP ’04, the SCT has been integrated into the combined read-out.

THE INNER DETECTOR OFFLINE RECONSTRUCTION

The current ATLAS offline reconstruction chain was redesigned in its entirety in summer 2003 and has been implemented in the months after [3]. This new design has

---

* Wolfgang.Liebig@cern.ch, Maria.Jose.Costa@cern.ch

† A. Ahmad (Academia Sinica, Beijing), T. Atkinson, G. Moorhead (University of Melbourne) J. Baines, D. Emeliyanov (Rutherford Appleton Laboratory, Didcot) P. Bell, M.J. Costa, M. Elsing, R. Hawkings, W. Liebig, E. Moyse, R. Petti, A. Poppleton, S. Roe (CERN, Geneva) J. Bernabeu, C. Escobar, S. Gonzalez, S.M. Garcia (IFIC, Universidad de Valencia) M. Brinet (University of Geneva) Z. Broklova, P. Kodys (Charles University, Prague) M. Cobal, L. Santi (Università degli studi di Udine) T. Cornelissen, G. Gorfine (NIKHEF, Amsterdam) S. Correard, A. Rozanov, J. de Vivie (Centre de Physique des Particules de Marseille) Davide Costanzo (Lawrence Berkeley National Laboratory, Berkeley) M. Dam, P. Hansen, T. Kittelman, R. Mackeprang (Niels Bohr Institute, Copenhagen) G. Gagliardi, C. Schiavi, F. Parodi (INFN, sezione di Genova) I. Gavrilenko (P.N. Lebedev Institute of Physics, Moscow) P. Keener (University of Pennsylvania, Philadelphia) A. Khomich (Universität Mannheim) N. Konstantinidis (University College London) T. Lari (Università degli studi di Milano) A. Lipniacka (University of Bergen) F. Luehring (Indiana University) P. Nevski (Brookhaven National Laboratory, Upton) A. Salzburger (Leopold-Franzens-Universität Innsbruck) S. Smirnov (Moscow Physical Engineering Institute) A. Zalite, Y. Zalite (Petersburg Nuclear Physics Institute)

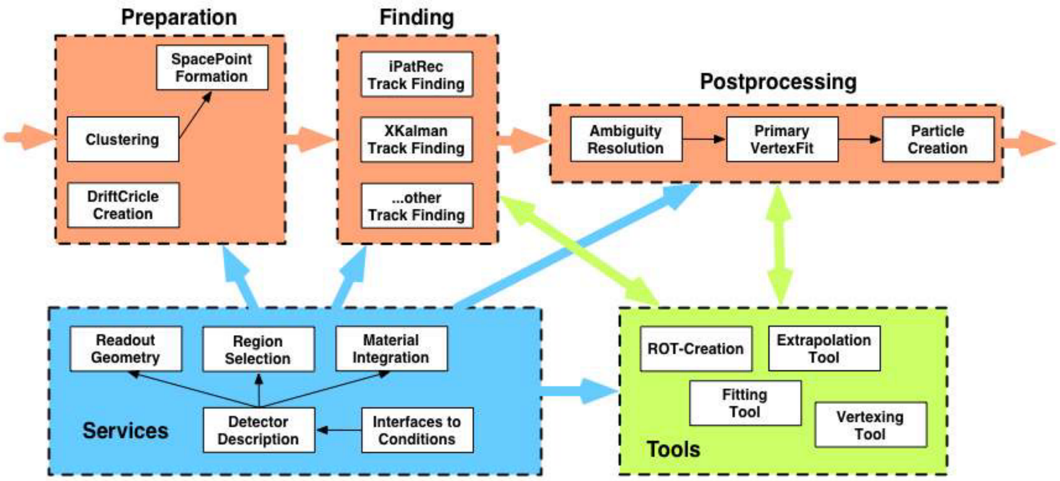

Figure 2: ATLAS offline reconstruction chain.

been co-authored by the High-Level Trigger (HLT) community and follows the paradigms of the Athena software framework [4], namely the separation into event data, tools, services and algorithms. A high level of modularity and a common data model are its key characteristics which were chosen to ensure maintainability as well as the possibility to involve many (new) developers in parallel, aiming at an improved physics performance.

Fig. 2 gives a schematic overview on the new reconstruction. The data flow is divided into four stages: the decoding of raw ByteStream data (or digitisation of simulated data), the preparation of measured hits (TRT drift circles and silicon clusters), the track finding and finally post-processing such as ambiguity resolving and vertex fitting. Helper services such as detector description, calibration or track extrapolation are set up as independent libraries with a common interface for all detector technologies. For the CTB, the Inner Detector makes full use of this design, and has given feed-back to the fine-tuning of its implementation.

ByteStream converters

In the CTB, prototype hardware for the final ATLAS read-out system collects the raw data from every subdetector. The measured data is written to ByteStream, a format organised hierarchically in headers and fragments. Whenever a raw data object is requested in Athena that is not yet instantiated, the matching raw data is decoded by means of ByteStream converters, which encapsulate detector-specific knowledge of the data format and the cabling map. The full decoding sequence can be used in the level-2 trigger, the event builder as well as the offline reconstruction and has therefore been designed mainly to meet HLT performance requirements. Not all of its speed-related features have been exercised in the CTB because of its limited size compared to the full ATLAS detector.

For the Pixel, SCT and TRT ByteStream converters new versions have been written both because of a test-beam specific hardware setup and because for some detectors it was the first use of the prototype read-out with real beam data. All three converters have been ready in time to be able to analyse the first CTB data offline within Athena. The offline tools for data quality monitoring and event display have then been successfully used to validate the converters: An accidental swap of the TRT ϕ sectors and a wrong assumption about the Pixel layer 0 modules could be found quickly.

Detector description and simulation

The service to provide detector geometry information in the new reconstruction design is called GeoModel. In the CTB (as well as full ATLAS simulation) it is successfully used by all stages: simulation, digitisation, reconstruction and visualisation. Technically GeoModel currently stores its geometry constants in NOVA (a MySQL database; however, to have additional features like automatic versioning a migration to Oracle has started). Alignment adjustments to the detector positions can be made, and the neccessary parameters are retrieved via connection to the ATLAS conditions database [5], which handles all kinds of run and calibration data in large quantities.

The CTB set-up has been simulated using Geant4 and the GeoModel detector description. Simulated data for the entire CTB and for only the Inner Detector set-up have been available five months before data-taking, thus giving time to validate the offline software. Hereby different particles and energies have been studied. During the preparation and running phase the simulation had to be re-done several times to include evolutions or corrections in the real test beam setup.

Data quality monitoring

In the same way that the future ATLAS data quality will have to be monitored directly while it is being taken, a monitoring has been created for the CTB. Basically two approaches are followed: an ntuple based interactive validation and an automated monitor that is running in the online event filter. The interactive approach runs the offline reconstruction on a part of a completed run, so that an ntuple is filled with observables from all detectors and all stages of the reconstruction. This allows to scrutinise possible problems in a flexible way and to visualise also more sophisticated correlations. Regular checks can be done by analysing the ntuple through a set of root macros. They are structured as a top-level menu to select the sub-detector or kind of study and a specific choice of histograms for each point. The histograms include for example hit maps, time-over-threshold distributions, channel and global position correlations between different detectors, and finally information about tracks.

Together with knowledge from previous standalone test beam runs, experience from the ntuple monitoring is transferred to the online event filter monitor, which is running synchronously with the data acquisition and checked regularly by the test beam shift personnel. Both techniques have their specific strenghts: the ntuple monitoring has proved to be essential for removing both possible hard-ware related effects (wrong configuration, desynchronisation) and mistakes in the software right at the start of the detector integration, when it had been fully available. When the data are taken more copiously and the correct functioning has been assured, the online monitoring is neccessary to keep the quality stable while minimising the effort in human expert time.

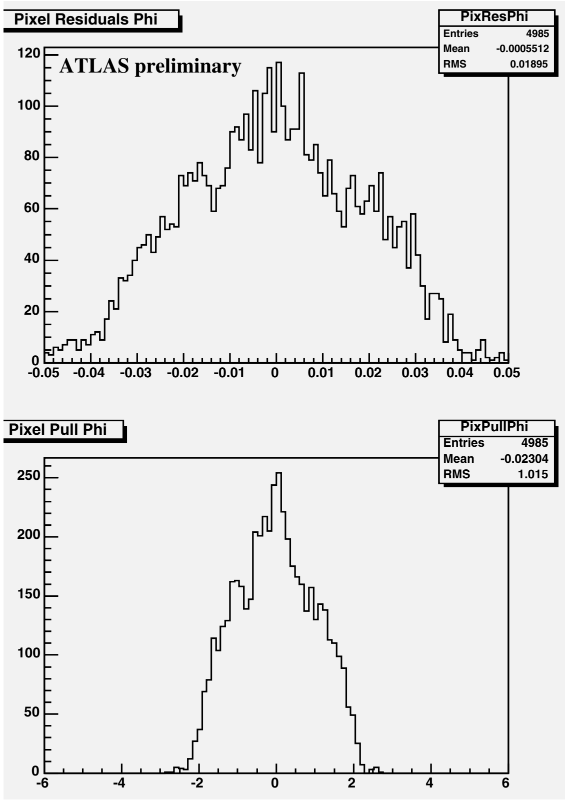

Figure 3: Preliminary residual and pull distributions found in the Pixel layers for straight line tracks fitted through measurements in the Pixel and TRT detectors. The distributions are integrated over all 6 modules.

Track reconstruction

For the task of track finding and fitting in the Inner Detector, different packages are available: after some adaptations to the code, the large ATLAS reconstruction packages (iPatRec and xKalman) are both able to reconstruct tracks in the full Pixel + SCT + TRT test beam setup with and without field. xKalman can also cope with the initial setups of only TRT and TRT+pixel. Also standalone pattern recognition packages from the HLT software for either the TRT or the silicon detectors have been adapted for and tested with CTB data. Finally an Inner Detector straight line fitter has been developed specifically for the CTB, which can be configured to apply only loose constraints so that data with unaligned detectors and a reduced number of precision measurements can still be analysed. If desired, any trajectory can be re-fitted by two different Kalman-filter track fitting packages, which have been developed recently to make seamless use of the new reconstruction chain.

All of the above algorithms produce as output a new common track class. It is therefore easy to interchange the active reconstruction algorithm e.g. for the purpose of debugging or reacting to a change in the Inner Detector CTB setup. A number of clients are already profiting from this situation, namely the monitoring discussed in the previous section, the detector alignment, a drift time calibration which is under development and finally the post-processing chain which stores the fitted tracks together with other information in event summary data files.

As an example the residuals between the hits in the Pixel modules and the thereof unbiased track prediction are shown together with the pull distribution in Fig. 3, for 180 GeV pion tracks without magnetic field. The r.m.s of the pull distribution is compatible with 1, thus validating fit and error estimation.

The tracks observed in the Inner Detector are compared to those from the Muon Spectrometer. The latter provides in the test beam only measurements in the z coordinate. Comparisons between the Pixel and Muon show a clear correlation in both z coordinate, e.g. Fig. 4, and the gradient dz/dx. A strategy to merge the two track segments taking into account also material effects and bremsstrahlung is under development.

Alignment and calibration

The alignment technique needs tracks in order to minimise residuals like those in Fig. 3 as a function of linear or rotational shifts to detector modules or entire support boxes. Track fit constraints have to be relaxed in order to be efficient on unaligned detectors. The resulting align-

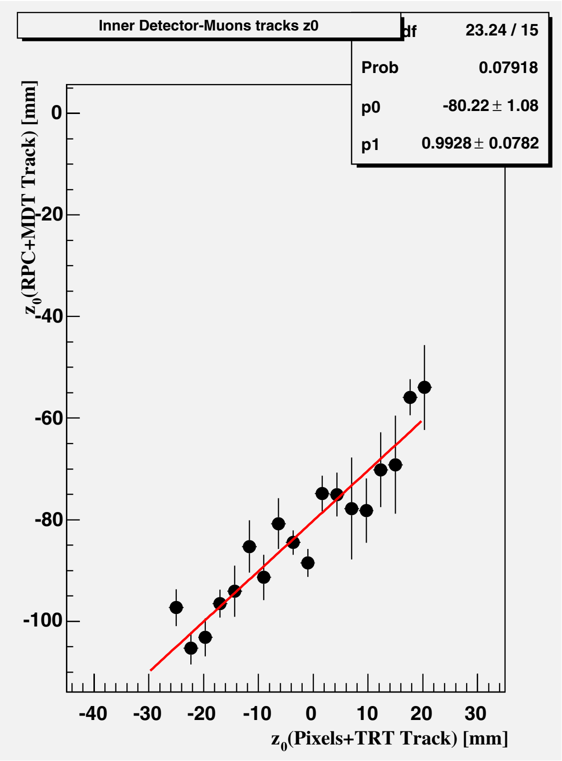

Figure 4: Correlation between tracks reconstructed independently in the Inner Detector and Muon System, as seen in the z coordinate at $x = 0$.

ment parameters are interfaced to the GeoModel description via the conditions database, where they are recorded for a given time period of data-taking. The implementation of this strategy has been prepared on test beam events simulated with intentional misalignment. Additional work was necessary to set up an alignment procedure for the silicon detectors with only the three Pixel layers present. A preliminary alignment has been successful with shifts well below 100 μm to the Pixel modules.

General remark on CTB reconstruction

A couple of effects have raised our attention during the software integration which might be worth mentioning.

- The CTB hardware has been integrated gradually, and therefore the offline software has to deal with several different setups. Already shortly after the CTB start it has become evident that every configuration has to be reflected appropriately by numbers in the conditions database and retrieved automatically for the reconstruction to avoid errors and reduce the need of expert knowledge to run it properly.
- Also from the reconstruction packages themselves flexibility is needed to cope with a “real” detector as opposed to a perfectly simulated one. In the CTB this refers to parallel beam tracks that do not originate from a primary vertex, a set-up without field, or the absence of a sub-detector due to an ongoing integration process or DAQ problems. Also in ATLAS such situations might occur, like in cosmic data-taking or in a physics run with a part of the detector not able to provide data. Such flexibility should be provided deep in the software design and not by a quick fix.
- The CTB has improved significantly the frequent communication between detector and software experts. Vital information about the hardware setup and the correct reconstruction of the data has been passed to the offline software, leading e.g. to functioning ByteStream converters. The conditions database offers the possibility to handle much of this flow of information on a technical level.

CONCLUSIONS

The Inner Detector integration in the Combined Test Beam software has been very successful: read-out, data decoding, cluster respectively drift circle formation and track reconstruction have been operating right from the start of data-taking. More sophisticated techniques such as alignment and calibration, including the connection to the conditions data base, have become available with only a few weeks delay. To achieve this situation, a lot of new code has been added and validated rapidly by a large group of developers: an effort which ows much of its success to the modular design of the new reconstruction chain. Another benefit of this design is the ability to flexibly choose the reconstruction algorithm and as a consequence e.g. speed up debugging and validation significantly.

Rapid and precise feed-back could be given at the same time to the implementation of details and additional features in the new offline chain. From the time of CHEP 2004 on, the CTB programme goes on for another month, and will continue to be an interesting test-bed for ATLAS software integration!

ACKNOWLEDGEMENTS

The authors are greatly indebted to the detector and DAQ collaborators who have made the CTB data-taking possible, and to the software developers who have provided and validated the CTB versions of various ATLAS packages.

REFERENCES

[1] Contribution #275 by A. Farilla to CHEP2004, “Offline Software for the ATLAS CTB”, these proceedings.

[2] The ATLAS Coll., ATLAS Detector and Physics Performance TDR, CERN/LHCC 99-14/15

[3] V. Boisvert et al, “Final Report of the ATLAS RTF”, Atlas note ATL-SOFT-2003-010.

[4] http://atlas.web.cern.ch/Atlas/GROUPS/SOFTWARE/OO/architecture/index.html.

[5] Contribution #262 by D. Klose to CHEP2004, “Addressing the persistency patterns of the time evolving HEP data in the ATLAS/LCG MySQL Conditions Databases”, these proceedings.