Journal of Physics: Conference Series **219** (2010) 022028 doi:10.1088/1742-6596/219/2/022028

The ATLAS MDT Remote Calibration Centers

T. Dai[1], A. De Salvo[2], E. Diehl[1], A. Di Mattia[3], J. Kennedy[4] S. McKee[1], D. Orestano[6,7], E. Pasqualucci[2], F. Petrucci[6,7], F. Rauscher[5], C. Serfon[5] and W. Vandelli[8]

[1]The University of Michigan, Department of Physics, 2477 Randall Laboratory, 500 East University, Ann Arbor, MI 48109-1120, United States of America
[2]INFN Roma, Piazzale A. Moro 2, IT- 00185 Roma, Italy
[3]Michigan State University, High Energy Physics Group, Department of Physics and Astronomy, East Lansing, MI 48824-2320, United States of America
[4]Rechenzentrum Garching der Max-Planck-Gesellschaft, Boltzmannstr. 2, DE - 85748 Garching, Germany
[6]Università di Roma Tre, Dipartimento di Fisica, via della Vasca Navale 84, IT-00146 Roma, Italy
[7]INFN Roma Tre, via della Vasca Navale 84, IT-00146 Roma, Italy
[5]Fakultät für Physik der Ludwig-Maximilians-Universität München, Am Coulombwall 1, DE - 85748 Garching, Germany
[8]CERN, CH-1211 Geneve 23, Switzerland

E-mail: `Alessandro.DeSalvo@roma1.infn.it`

Abstract. The precision chambers of the ATLAS Muon Spectrometer are built with Monitored Drift Tubes (MDT). The requirement of high accuracy and low systematic error, to achieve a transverse momentum resolution of 10% at 1 TeV, can only be accomplished if the calibrations are known with an accuracy of 20 μm. The relation between the drift path and the measured time (the socalled r-t relation) depends on many parameters (temperature T, hit rate, gas composition, thresholds,...) subject to time variations. The r-t relation has to be measured from the data without the use of an external detector, using the autocalibration technique. This method relies on an iterative procedure applied to the same data sample, starting from a preliminary set of constants. The required precision can be achieved using a large (few thousand) number of non-parallel tracks crossing a region, called calibration region, i.e. the region of the MDT chamber sharing the same r-t relation.

1. Introduction

The Muon Spectrometer [1] of the ATLAS experiment has been designed to provide a precise muon momentum measurement, with a resolution of 10% resolution at 1 TeV/c, and a fast trigger on high transverse momentum muons ($p_T \geq$ 6 GeV/c). Resistive Plate Chambers (RPC) are used as trigger devices in the barrel region (with pseudo-rapidity $|\eta| < 1$) while Thin Gap Chambers (TGC) are installed in the endcap regions ($1 < |\eta| < 2.4$).

For the precision measurement in the bending plane Monitored Drift Tubes (MDT) are used both in the barrel and in the endcap, except for the innermost layer in the region ($|\eta| > 2$), where Cathode Strip Chambers (CSC) are employed. Up to about 100 GeV/c the transverse momentum resolution is dominated by the multiple scattering in the muon spectrometer, but above this value single hit resolution is the most important factor. The target resolution can be achieved provided the single hit chamber resolution is kept near the 80 μm of the intrinsic resolution. The alignment and calibration should then be known with an overall accuracy better than 30 μm.

MDT chambers are built as arrays of drift tubes, organized in two multilayers of 3 or 4 layers each. The tubes are operated with the highly non-linear gas mixture (93% Ar, 7% CO_2) at 3 bar. An accurate correction to the drift velocity is needed to follow variations in operating conditions and to keep systematic effects from spoiling the resolution. The on-chamber front-end electronics consists of “mezzanine cards”, each of which handles signals from 24 MDT tubes. These cards have three 8-channel amplifier, shaper, discriminator (ASD) chips which feed one ATLAS MDT TDC (AMT) chip which digitizes time and charge measurements.

This paper describes the remote Calibration Centers and the hardware and software framework needed for MDT calibration. In section 2 a general description of the MDT calibration is given. In section 3 the procedure to collect the data used for calibration is addressed while in section 4 the architecture of the Remote Calibration Centers is detailed. In section 5 some results on the extraction of the calibration stream extraction processing performance of the Calibration Centers are given using simulated data and data taken with cosmic rays.

2. MDT calibration

The studies performed on MDT calibration based on data collected in cosmic stands, test beam campaigns and Montecarlo simulations show that the drift parameters should be measured with an high accuracy not to spoil the performance of the Muon Spectrometer. These parameters depend on the operating conditions which can vary with the position (e.g. the magnetic field or the wire sagitta) and/or with time (e.g. the temperature and the gas composition). The MDT calibration aims at providing all the correction parameters, functions, and programs, both for the calibration itself, and for the reconstruction and simulation steps.

The track position in a MDT tube is determined from a function (the r-t relation) which relates the nominal drift time, t, to the impact parameter, r, of the track with respect to the wire center. It is therefore necessary to modify the raw TDC value (tTDC), subtracting the offset t0 and correcting for the local variations of the drift parameters.

Although the r-t relation could be computed from first principles, in practice it will not be accurate enough. A systematic error on the r-t relation better than 20 μm would require an unachievable precision in parameters, like gas composition or electronics. A calibration procedure (autocalibration) has been developed, based on an iterative track fit to minimize track residuals. The procedure makes use only of the data from the MDT chambers themselves and requires some thousands of muon tracks. The r-t relation is modified, until the quality of the track fits is satisfactory. The autocalibration has to be applied to a region of the spectrometer with MDTs operated under similar environmental conditions (gas distribution, temperature, B field, ...), i.e. to a single calibration region.

The resolution, Δr, on the measured drift radius, r, is also required by the reconstruction programs. Since the error on the measured time is not a constant and, moreover, the drift velocity is not constant as a function of the track position in the tube, the resolution is a function of r and therefore of the time t. The methods which compute the the r-t relation measure the resolution as a by-product.

At least 30×10^6 muon tracks are required for a single calibration of the drift parameters in the whole spectrometer. The calibration should be repeated frequently (possibly every day) to follow time variations.

3. Muon calibration stream

It should be noted that the expected maximum rate of muon triggered events on tape is 40 Hz. A dedicated procedure, allowing the extraction of muon triggered events at a higher rate, has been developed in order to achieve enough statistics to be able to follow the possible time variations of the MDT calibrations. We aim at collecting enough statistics to allow a calibration per day with a sample of $\approx 30 \times 10^6$ muon tracks. Accounting for data taking efficiency we require an acquisition rate of $\approx 1\ kHz$. The adopted solution, detailed in reference [2], exploits the extraction of a dedicated data stream (the $Calibration\ stream$) at the second level muon trigger. The muon calibration stream consists of pseudo-events, one for each muon track candidate seen by the level-1 muon trigger (LVL1), collecting both the trigger chamber data accessed by the level-2 trigger algorithm μFast and the MDT hits within the second level pattern recognition road. The pseudo-event header also includes the estimated p_T and the direction of flight. The extracted data size is about 800 bytes per pseudo-event. Data extracted from the level-2 nodes (L2PU) is then concentrated in a Calibration Server and made available to be distributed to calibration farms. Data concentration happens in two steps, sending data to the local file/boot servers in the level-2 racks and, in a second step, to the calibration server.

The general system architecture of the calibration stream is shown in Figure 1. The level-2 trigger algorithms run in a farm of about 500 processors, divided in 20 racks. 25 nodes in a rack are booted from a local disk/file server. Each node runs a level-2 Processing Unit (L2PU) on each of its CPU cores.

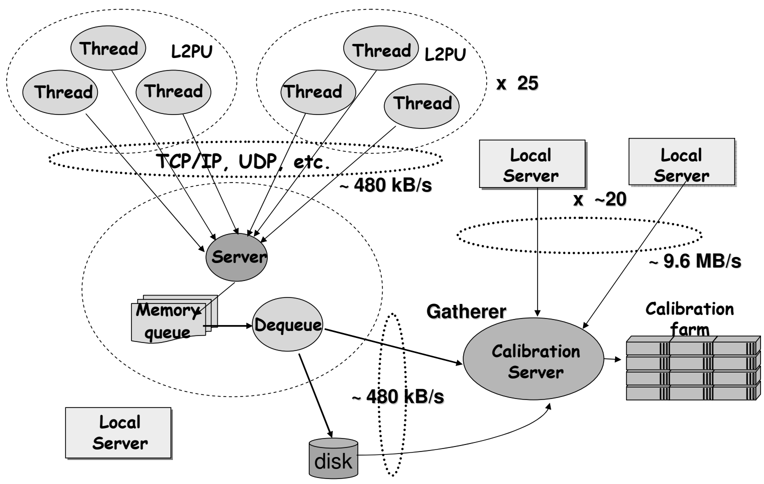

Figure 1. Data extraction and distribution architecture.

The Calibration Server collects all the pseudo-events coming from all the instances of the level 2 trigger processes. The throughput to each local server is about 480 kB/s and the global throughput is about 9.6 MB/s.

The server also takes care of interfacing the data collection system to the ATLAS Tier-0 Computing Center, implementing the same handshaking protocol used for the other streams and allowing automatic registration of data sets to the data distribution system.

In order to fulfill the requirements, the latency added to the muon level-2 trigger must be negligible with respect to the processing time (< 10 ms), the load on local servers must be negligible and data distribution channels to the farms on the WAN must sustain the data rate.

4. Muon calibration processing

The organization of the ATLAS production requires fast (1 day) availability of the calibration constants, which are used by the reconstruction software. Assuming the present speed of the calibration programme, including data decoding and database access, and the present performance of the computing facilities, these requirements correspond to the availability of few hundred processors, with high reliability.

The muon groups of Ann Arbor[1], MPI Munich[2], LMU[3], Roma "La Sapienza"[4] and Roma Tre[5], have established in Ann Arbor[1)], Munich[2,3)] and Roma "La Sapienza"[4)], three *Calibration Centers*. These farms, which are Tier2s in the ATLAS computing system, have been equipped with the software packages required by the computation (see section 4.2) and have agreed to give high priority to the computation of the calibration constants during data taking periods.

Each Calibration Center performs a fraction of the total computation, with small overlaps for testing and checking purposes. To ensure the necessary redundancy, the Calibration Centers run the same software and are ready to back each other up, in case of failures of the local systems or of the data transmission. In such a case, a larger number of processors will be allocated to the calibration task, to maintain the overall speed.

The computation model foresees that the data are sent to the Calibration Centers synchronously, in blocks of few GB as soon as they are available from the calibration stream. Therefore the local computation (and the data quality check) starts almost immediately after the beginning of the data taking. Only the second part of the computation, which is much faster than the real processing of all the tracks, is performed at the end of the data taking.

At the end of the computation, the results (i.e. the constants, together with the assessment of the quality of the data) are sent back to the central computing facilities at CERN, checked for overlaps, merged and inserted in the ATLAS main reconstruction database.

4.1. Muon Calibration data flow

The calibration datasets collected in the ATLAS Tier-0 are sent to the three remote calibration Tier-2 centers, in order to be analyzed. The calibration datasets are shipped through the standard ATLAS Distributed Data Management system (DDM).

The Calibration Farms in the Tier2 are able to process the files as soon as they are available in the local Storage Elements (SE). Files belonging to an incomplete dataset may be used as soon as they are transferred.

4.2. Architecture of a Calibration Tier2 Center

The Calibration Tier2 have the same components as a standard ATLAS Tier2 [3] with additional job and data management components to control the calibration activity. These components allow for additional services, such as different partitioning and allocation of the resources, the dynamic partitioning of the computing resources for the calibration tasks, the partitioning and reservation of the storage resources for the calibration tasks. A dedicated database (in the present implementation the ORACLE (TM) database) and some network QoS are also required.

The Job Management components include, in addition to the standard Tier2 components, entry points for Grid jobs, which needs a *digital certificate* to operate, and are integrated in a Batch Queue manager. Some of the Tier2 worker nodes (presently about one third of the cores) are dedicated to the calibration activity.

[1] The University of Michigan, Ann Arbor, USA
[2] Max-Planck-Institut für Physik, München, Germany
[3] Fakultät für Physik der Ludwig-Maximilians-Universität München, Garching, Germany
[4] INFN Roma and Università La Sapienza, Dipartimento di Fisica, Italy
[5] INFN Roma Tre and Università di Roma Tre, Dipartimento di Fisica, Roma, Italy

The storage management requires the support of the GSIFTP transfer protocol, the access to CASTOR, DPM, and dCache [4, 5]. All the current Centers already have these facilities (EGEE SRM SEs in Rome and Munich, supporting DQ2, OSG SE in Michigan, supporting DQ2 (GSIFTP) through the UltraLight network facility [4, 5]). The storage space in local Tier2, dedicated for calibration tasks amounts to about 5 TB of disk space. As mentioned above, the ORACLE database is used to store the final calibration constants and to maintain the bookkeeping of the operations.

During the ATLAS data-taking periods, the nodes performing calibration tasks should be mainly dedicated to this activity and excluded from Grid access, although they should be instrumented with all the Grid facilities to access the data. This could be done by creating a separate partition within the Tier2 infrastructure and reconfiguring the underlying Batch Queue system by adding a calibration queue/share ("static" reservation of working nodes). Although this method is not very efficient, it guarantees the required performance. In future a more sophisticated system will be implemented, based on dynamical farm partitioning and shares (guaranteed share of resources, reserved for calibration purposes, plus a pool of additional resources with higher priority for calibration tasks).

When the resources from the pool are not needed, they may be used for normal Tier2 tasks (mainly simulation and analysis). No check-pointing is currently possible, which means that it is not possible to temporarily suspend a job giving priority to another one, thus the higher priority for the calibration tasks can only be used at the scheduling level.

In addition, a dedicated node in the Tier2 is dedicated to calibration data preparation and cleanup, as a local Calibration Data Splitter.

4.3. The LCDS architecture

The local Calibration Data Splitter permanently watches for incoming data. As soon as the first data arrive, this node starts its operations, splitting the input data files in separate output streams according to a predefined scheme (e.g. different angular regions of the ATLAS muon spectrometer) and submitting a set of jobs to the calibration batch queue. This allows for the creation of the output ROOT files [6] in parallel.

Partial checks of the data integrity and quality are performed as soon as the data are available, to allow for fast recognition of possible hardware or DAQ failures on the high statistics sample of the calibration stream.

When sufficient data have been processed, or at the end of data-taking, either a local operator or an automatic procedure starts the final phase of data processing, which includes the checks of the data quality and calculation of the calibration constants.

The monitoring of the calibration is performed by a monitoring client, integrated in the calibration application and in the splitter agent. The calibration status of each Center will be published in a central server visible to the full ATLAS collaboration.

At the end of the calibration, when all the relevant data have been properly stored, the operators should tag a calibration as *done*. Then, the data could be in principle released (*unsubscribed*), and deleted from the Tier2 storage (at the moment this process is manual). In case there is a need of reprocessing, the data have to be re-subscribed from the Tier1, although a manual option exists to keep the data for a longer period in the Tier2 storage. A "garbage collection" process will also be provided, to put a limit on the maximum amount of local Tier2 storage that can be used for calibration data.

The quality and stability of the individual tube parameters, as well as of the $r - t$ relation, must be continuously monitored. In addition to the limited number of calibration parameters to be used by the reconstruction the processing described in previous sections produces a sizable amount of information (50 MB/day) essential to evaluate the quality of the calibrations.

A dedicated MDT database (Calibration Database) [7, 8] is thus being implemented to store the complete calibration information. Validation procedures make use of the additional information, to ensure that the calibration constants have been correctly computed. Also, the newly produced constants will be compared to those from the previous data taking to decide whether the Conditions Database must be updated. The full information produced at every stage is stored in local ORACLE Calibration Databases that is replicated via ORACLE streams to a central database located at CERN: this allows each Calibration Center to access the data produced by the others and to eventually provide back-up should one site become unavailable for any reason.

The validated calibration constants are extracted from the CERN Calibration Database and stored into the ATLAS Conditions Database for subsequent use in reconstruction and data analysis. This data management model has the major advantage that the Calibration Database is completely decoupled from the clients of the calibration and thus it can be modified without affecting the reconstruction; moreover, while the Conditions Database is optimized for reconstruction access, the Calibration Database is optimized for access by calibration and validation programs.

5. MDT calibration test results

5.1. Computing challenge

In June 2008 the Calibration Centers participated in the ATLAS Full Dress Reharsal (FDR) data challenge, exercising over few days the data distribution and processing of a realistic amount of (replicated) simulated calibration stream data, corresponding to an extraction rate of 2kHz. Data were injected at the Calibration Server and followed the regular distribution from there to the Calibration Centers. The Calibration Database and its replication were fully tested for the first time in this context and have been regularly used, though at a lower rate, since then.

5.2. Calibration stream extraction during cosmics data taking

The calibration stream has been regularly extracted in cosmics data taking in all the runs in which the high level trigger was enabled, since Fall 2007. It is automatically distributed to the Calibrations Centers since the FDR.

5.3. Calibration Centers operation during cosmics data taking

The remote calibration centers have been tested with the cosmic data in 2008. Figure 2 shows the amount of data processed per day. Figure 3 shows the dataset splitting latency, i.e. the

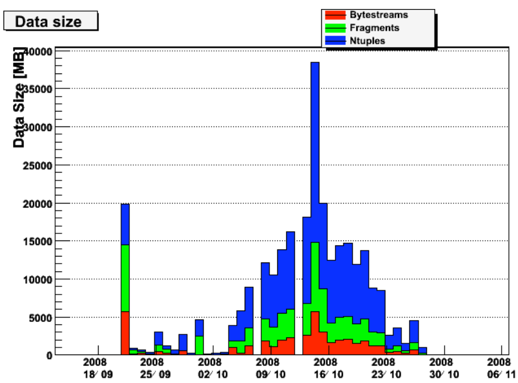

Figure 2. Size of the data processed per day during a cosmic rays data taking period in October 2008.

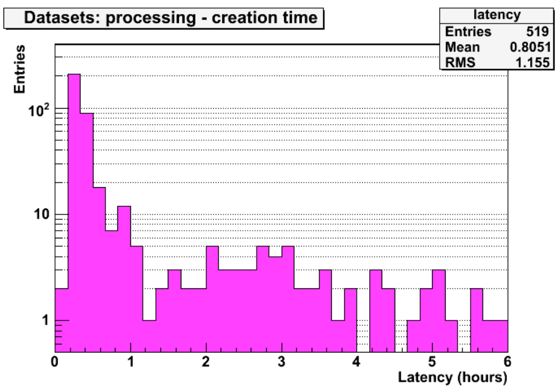

Figure 3. Datasets splitting latency (as described in the text) for the same period.

latency beween the data taking and when the data has been split and is available in the remote calibration centers. The latency is peaked at about 1h, meaning that most of the dataset splitting is completed in the calibration centers about 1h after the data taking. The calibration ntuples are created a few minutes after the data fragments are available in the local Storage Elements.

6. Conclusion

The Remote Centers used for the calibration of the MDT chambers of the ATLAS Muon Spectrometers have been set up and their functionalities have been tested both during a Computing Challenge with simulated data and with real data during cosmic rays data taking periods.

The performance are satisfactory and we are looking forward to face the large amount of data awaited during LHC p-p collisions for the calibration of the whole spectrometer.

References

[1] ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3:S08003,2008.
[2] P.Bagnaia et al., Calibration model for the MDT chambers of the ATLAS muon spectrometer, ATL-MUON-PUB-2008-004, CERN, Geneva
[3] ATLAS Collaboration, ATLAS computing Technical Design Report, (CERN, Geneva, 2005), ISBN 9290832509
[4] Eck, C. *et al* , LHC computing Grid Technical Design Report. Version 1.06 (20 Jun 2005), (CERN, Geneva, 2005), ISBN 9290832533
[5] EU EGEE Project, http://glite.web.cern.ch/glite/documentation/default.asp
[6] Brun, R. and Rademakers, F., ROOT: An object oriented data analysis framework, Nucl. Instrum. Meth. **A389** (1997) 81–86
[7] Cirilli, M. *et al* , Conditions database and calibration software framework for ATLAS monitored drift tube chambers, Nucl. Instrum. Meth. **A572** (2007) 38–39
[8] P. Bagnaia *et al.*, Database Architecture For The Calibration Of Atlas Monitored Drift Tube Chambers, J. Phys. Conf. Ser. **119**, 042003 (2008).