The calibration of the resistive plate chambers of ATLAS

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Abstract. Resistive Plate Chambers (RPC) are used in ATLAS to provide the first level muon trigger in the barrel region. The total size of the system is about 16000 m$^2$, readout by about 350000 electronic channels. To reach the needed trigger performance, a precise knowledge of the detector working point (from the point of view of both high and low voltage settings) is necessary and the high number of readout channels calls for severe requirements on the analysis tools. First of all, high-statistics data samples will have to be used as input. Second, the results would be unmanageable without a proper interface to some database technology. Moreover, the CPU power needed for the analysis makes it necessary to use distributed computing resources. A set of analysis tools will be presented, coping with all the critical aspects of this task, ranging from the use of a dedicated data stream (the so-called muon calibration stream), to the automatic job submission on the GRID, to the implementation of an interface to the conditions database of ATLAS. The integration with Detector Control System information and the impact of the calibration on the performance of the reconstruction algorithms will be discussed as well.

1. Introduction
The ATLAS detector [1] is installed at CERN’s Large Hadron Collider (LHC). Its general-purpose design allows it to test the known physics processes at the new energy range accessible at the LHC, while still being an ideal setup for the discovery of new physics processes which may become observable with the new accelerator.

Many of the interesting physics processes are characterized by muonic final states, thus calling for adequate muon identification and measurement. This is provided in ATLAS by a dedicated standalone muon spectrometer.

The muon trigger is provided by Resistive Plate Chambers (RPC) in the barrel region and Thin Gap Chambers in the endcap, while Monitored Drift Tubes (MDT) and Cathod Strip Chambers (CSC) provide a precise position measurement.

The spectrometer is equipped with a standalone toroidal field, providing a bending power up to 7 Tm

2. Constraints and requirements
The challenging LHC environment and the extensive ATLAS physics programme, call for severe requirements on the muon trigger detector:

• Rate capability: 100 Hz/cm$^2$ expected rate including a safety factor of 5.
• The required trigger selectivity leads to the need to have a 2D readout. In particular, precision muon tracking is provided by the dedicated tracking detector only in the bending view: RPCs provide the only source of information along the non-bending view.

• To achieve a robust enough trigger logic, three trigger doublets chambers (6 tracking planes) are used in each projection; the low Pt trigger uses a 3/4 majority, while the 1/2 high Pt trigger decision is made by requiring a 1/2 majority.

• Nanosecond time resolution is needed for a proper bunch-crossing identification.

• To maximize the geometrical coverage, 26 different formats for RPC units had to be built.

The RPC system is thus a 3D tracker with a cm resolution matched with a ns timing. To fully exploit its potentials, such a complex system needs to be fine-tuned, adjusting all operating parameters in order to achieve the best possible (homogeneous) performance over the full barrel region. This leads to the necessity of a dedicated software suite, to extract from all available data sources (detector control system, detector readout, data from other detectors) the required information.

3. Computing challenges
The high number of readout channels (∼350000) calls for severe requirements on the analysis tools. High-statistics data samples will have to be used as input, if a good enough granularity up to the strip level has to be achieved. We estimate about 10 million muon tracks will be needed for a very minimal, rough estimation of performances of the single readout channels. The results would be unmanageable without a proper interface to some database technology. Considering one full calibration per week, we estimate an amount of data of about 1.6GB/year, to be archived in such a way that it can be used to trace back in time the behavior of each readout channel.

The CPU power needed for the analysis makes it necessary to use distributed computing resources. A dedicated farm at Naples has been setup and is being used for the most CPU-intensive tasks.

In addition to the information extracted from the read-out data, detector control system (gas flow, power settings, gap currents,...) and environmental parameters (temperature, pressure,...) must also be taken into account, to provide a complete frame for the RPC calibration.

4. Input data and analysis strategy
ATLAS data are divided into different streams. They can correspond, for example, to different trigger menus (calorimeter trigger, muon trigger, minimum bias trigger, etc). An express stream is also foreseen, including the most promising topologies for discovery channels, which will have the highest priority in the data processing. All these streams contain full events, and can be used, to some extent, to estimate the detector behavior by means of Data Quality (DQ) applications. However, in order to achieve a detailed and reliable measurement of the detector response up to the level of the individual strips, a significant number of muon tracks must be analyzed, which is not achievable in a reasonable time with the normal data streams. A dedicated stream has been foreseen to answer to this kind of necessities, called muon calibration stream. It contains the output of the Level 2 muon trigger, hence it comes at a much higher rate than the events selected by the full trigger chain. Each event contains only hits from the muon spectrometer, in a region where a muon trigger occurred, i.e. a two-muons event would be split in two calibration stream events.

The main advantage of the calibration stream is its high statistics. Its simplified event format, which contains only muon hits in only one part of the spectrometer, allows a relatively easy and fast reconstruction of the muon tracks. This is very useful given the high number of events to be processed. On the other hand, the fact that it does not contain full events, means that it
cannot be used in a straightforward way for a reliable measurement of the noise rate.

From the point of view of the analysis algorithms, there are two main issues in our case: first, RPCs are actually providing the muon trigger and, second, RPCs are also used in reconstruction; in particular, as already mentioned, they are the only source of space measurements in the non-bending direction. Both these effects tend to introduce a bias on efficiency measurements if not adequately treated.

As far as the reconstruction bias is concerned, one simply has to exclude from pattern recognition and track fitting one given layer, whose efficiency can thus be measured with no bias at all. On the other hand, removing the trigger bias is less trivial. Knowing the trigger configuration (in particular its majority) one can extract from the data an unbiased sample for a given layer. For example if the trigger is requiring a coincidence of at least 3 RPC layers out of the 4 in the inner station one can have an unbiased efficiency measurement for layer 1, by using only events where layers 2, 3 and 4 had a hit. This approach is particularly good for monitoring during normal data taking, and has been already implemented in the analysis. One could also run with dedicated trigger configurations where a given layer is excluded from the trigger decision. This second possibility is a better choice in dedicated calibration runs, since higher statistics can be achieved.

To ensure redundancy and robustness, a two-fold strategy is used for RPC detector studies:

- **Exploiting the precision of the muon tracking detector.** The main advantages of this approach is that tracking and extrapolation to RPC layers takes into account materials and magnetic field. Moreover, a precise extrapolation allows to determine the spatial resolution and to study small local effects. Its main drawbacks are that it is applicable only to runs where tracking chambers are on, and that presently all RPC hits are used in the reconstruction, hence a bias is introduced in the efficiency measurement. This will be fixed in a more refined version of the analysis which is in preparation.

- **Using stand alone, RPC-only tracking.** This method does not depend on the tracking detector at all, and its dedicated dedicated tracking algorithm avoids a reconstruction bias on the efficiency measurement by not using hits of the layer under study. On the other hand, interoperability with other reconstruction tools is missing, magnetic field and material effects are not implemented yet and the extrapolation precision is limited by the granularity of the RPC.

The baseline strategy is to exploit the possibilities given by both our analysis techniques and both the data sources:

- Data Quality applications, running on the full streams, measure all relevant quantities using standalone RPC tracking. This is done mainly at the computing facility of CERN.
- Different analysis jobs perform high statistics analysis on the calibration stream, using the full tracking capabilities of the muon spectrometer. A computing farm has been foreseen at Naples for this kind of studies, where calibration stream data is replicated.

Other possibilities are of course available (running DQ-like analysis at Naples on the calibration stream or running precise tracking on the full streams) and, even though they would not add any new information to what already obtained by the previous ones, they play an important role as a fall-back solution in the case any of the baseline measurement fail.

5. Calibration output

The aim of the RPC calibration is to measure with enough precision all the quantities sensitive to the working point. This includes for example the panel efficiencies and the gap efficiencies. A good estimation of the latter is already achievable by looking at the efficiency of any of the two readout panels corresponding to a given gap.
The average size of RPC clusters (i.e. two or more adjacent strips with hits in time coincidence) is also a very important parameter, being very sensitive for example to front-end threshold settings, in particular when measured at the working point. Moreover, one characteristic of RPCs is that a cluster with size 2 is more precise than a cluster with size 1, being the former in general only possible when a particle crosses a small region between two neighboring strips. This means that, when using a precise enough tracking detector, one can measure the different space resolution for clusters of size 1 and 2, and give this information back to the reconstruction algorithms for a proper error handling.

Counting rates per panel and per gap are also crucial in understanding the evolution of the status of the detector in time.

All these quantities, with granularity up to the strip level, are presently stored in a dedicated structure in a database (ATLAS Conditions DB, [2]). In addition to this, a separate structure keeps track of all the detector control system and environmental parameters. Two more structures are presently used by the DQ applications (online and offline) to store their results. For performance reasons, however, reconstruction algorithms will need to access only one, smaller structure, with reduced granularity. This will be created by a dedicated algorithm (still to be prepared), which will extract relevant information from the other structures and merge them into a table to be exposed to reconstruction clients. Figure 1 shows a schematical view of the handling of RPC calibration output.

**Figure 1.** Schematical representation of the handling of the RPC calibration output. Several sources of information fill dedicated tables in the Conditions DataBase. A merger job takes care of generating a summary table to be exposed to reconstruction clients.
6. Calibration dataflow
Figure 2 shows the structure of the calibration procedure, using the muon calibration input stream and exploiting a precise muon tracking.

![Diagram of calibration dataflow]

**Figure 2.** Schematical representation of the data flow in an RPC calibration job.

The muon calibration stream will be copied at calibration center with high priority data transfers, thus allowing to process obtain analysis outputs in a relatively short timescale. Job submission will be triggered by data arrival, and the ganga [3] tool will be used for actual job launching and monitoring. In a second phase, the output from single subjobs will be merged. Depending on the granularity (i.e. the statistics) one wants to achieve, it will be possible to tune the merger process, for example to group together results from different runs. The merged results will be available in several formats (ASCII file, sqlite DataBase file, ROOT file) and, in particular in the early phases of data taking, it will be crucial to closely inspect and validate them before committing them to the Conditions DataBase. All steps described are presently working, but automation (in particular the job submitter) still has to be implemented.

7. Example results
Some example results are shown here. They must be treated as very preliminary, and not representing the general status of the RPC detector in ATLAS. They are reported here just to give a clearer understanding of the kind of results the RPC calibration software can produce. Figure 3 shows the distribution of the average efficiency for RPC BM panels in run 91060. The reconstructed track is extrapolated to the RPC plane, and a panel is defined to be efficient if it shows a hit within a ±70 mm window. The tail at lower efficiencies is due to known problems,
which were mostly fixed in subsequent runs. Several dedicated runs were taken to determine the optimum working condition of the chambers from the point of view of the high voltage setting. Figure 4 summarizes such measurements showing, for each panel, the variation in efficiency observed between two different high voltage values. It can be easily seen that at 9.6 kV, almost all panels reach a plateau in the efficiency. One can also evaluate the residual effect of trigger bias after the offline removal described above, by studying different trigger sources: figure 5 shows the efficiency distribution similar to figure 3, compared to the same distribution obtained with a different trigger source. Finally, figure 6 shows the spatial resolutions as measured on \( \eta \) panels (i.e. those measuring the position in the bending direction), for clusters of size 1 and 2. The residual distributions are fitted with a gaussian function, and the resulting standard deviation is divided by the strip pitch, to allow comparison between the different panels. As expected, clusters of size 2 give an improved spatial resolution.

**Figure 3.** The distribution of the average efficiency for RPC BM panels in run 91060.

**Figure 4.** Differences in RPC panel efficiencies at different values of the high voltage. Each distribution refers to the variation in efficiency between two high voltage values, as specified in the legend. As shown, the efficiency plateau is already reached at 9.6 kV.

**References**

[1] The ATLAS Experiment at the CERN Large Hadron Collider, ATLAS collaboration, 2008 JINST 3 S08003

[2] Computing Technical Design Report, ATLAS collaboration, CERN-LHCC-2005-022

[3] Ganga: a tool for computational-task management and easy access to Grid resources, F. Brochu et al., arXiv:0902.2685v1
Figure 5. The distribution of the average efficiency for RPC BM panels for two different trigger sources. The integrals of the histograms are normalized to unity.

Figure 6. The distribution of the spatial resolution for $\eta$ RPC panels. Only BM chambers are shown. Spatial resolution is divided by the strip pitch, and the integrals of the histograms are normalized to unity.