Performance of the ATLAS Resistive Plate Chambers

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Abstract

An overview and results of the effort to monitor and measure the relevant quantities of the Resistive Plate Chamber detectors are presented, addressing in particular three aspects. First, the full exploitation of the high-precision tracking provided by ATLAS Monitored Drift Tubes when measuring the performance of the RPCs. Second, the use of a dedicated data stream to achieve the required statistics. Last, the central role of GRID facilities in providing the necessary computing resources.

Keywords:
RPC, ATLAS, calibration, performance

1. The Resistive Plate Chambers of the ATLAS experiment

The Resistive Plate Chambers (RPCs) \cite{1, 2} provide the muon trigger in the barrel region of the Muon Spectrometer of the ATLAS experiment \cite{3} and are also used to measure the coordinate along the MDT\textsuperscript{2} tubes in the non-bending plane\textsuperscript{3}.

The RPCs are located in between the eight coils of the superconducting barrel toroid magnet. The $\phi$ symmetry of the toroid is reflected in the symmetric structure of the muon chamber system, consisting of eight octants. Each octant is subdivided in the azimuthal direction in two sectors with slightly different lateral extensions, a large (L) and a small (S) sector, resulting in a region of overlap in $\phi$ (Fig. 1). The muon chambers are arranged in three concentric cylindrical shells around the beam axis at radii of approximately 5 m, 7.5 m and 10 m and the RPC chambers cover a pseudorapidity range $|\eta| < 1.05$.

The RPCs are assembled together with a MDT of equal dimensions in a common mechanical support structure. In order to provide the first-level muon trigger two RPC chambers are installed together in the barrel middle station (BM) which provide the low-$p_T$ trigger information. The high-$p_T$ trigger makes use of the RPC modules installed on the outer barrel chambers (BO) combined with the trigger result form the low-$p_T$ system. Each chamber consists of two independent detector layers, each measuring $\eta$ and $\phi$ coordinates via two orthogonal sets of read-out strips.

The RPCs used in the ATLAS experiment will be described in the following. Fig. 2 shows a sketch of the structure of a typical RPC chamber. The electrodes are 2 mm thick plastic laminate plates made of phenolic and melaminic resins, whose volume resistivity is $2 \div 5 \times 10^{10} \Omega \cdot \text{cm}$. The plates are kept apart at 2 mm by insulating spacers, enclosing a gas volume filled with an appropriate gas mixture: $C_2H_2F_4$ 94.7\% - $C_4H_{10}$ 5\% - $SF_6$ 0.3\%. The spacers are cylindrical with 12 mm diameter and are placed one every $\sim 10$ cm in both perpendicular directions. The plate external surface is coated by a thin layer of graphite painting. The graphite has a surface resistivity of $\sim 100 \Omega / \square$, thus allowing uniform distribution of the high voltage along the plates. The working point is chosen at 9.6 kV and is normalized at 22 $^\circ$C and 970 mbar. The presence of such high electric field requires an extreme smoothness of the inner surfaces of the resistive plates, which is obtained by means of a thin layer of linseed oil. In these conditions the RPCs work in saturated

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\textsuperscript{2}MDT, Monitored Drift Tube chambers are part of the ATLAS Muon Spectrometer and provide the precision measurement of the muon momentum in the bending plane of the magnetic field.

\textsuperscript{3}The bending plane is parallel to the beam axis and is called $\eta$ view. The plane perpendicular to the beam axis is the non-bending plane and is called $\phi$ view.
avalanche mode which induces, for a mip, a prompt charge of ∼ 1 pC on the pick-up strips and delivers in the gas an average total charge of 30 pC [4].

The discharge electrons drift in the gas and the signal, induced on pick-up copper strips, is read out via capacitive coupling, and detected by the front-end electronics. Read-out strips have a typical width of ∼ 30 mm and are grouped in two (η and φ) read-out panels with strips orthogonal to each other.

The front-end electronics [5] performing the ATLAS RPCs readout is a full custom 8 channels GaAs circuit, which integrates in a single die both the analog and digital signal processing. Its function is to amplify, discriminate and convert the detector signals to ECL standard. The front-end electronics was conceived to guarantee good time performances with high counting rate, adequate immunity with respect to the noise and radiation hardness. The chip is based on a three stage wide band voltage amplifier and on a variable threshold comparator.

2. Resistive Plate Chambers calibration

After the installation of the RPC system in the cavern, the main activity was the study of its performance. Using cosmic ray tracks reconstructed by MDTs (for another technique, cfr. [6]), the performance of the detectors have been verified as by design, after the integration of the chambers in the full apparatus [7, 8]. Results shown in the following section are from data recorded over the full Muon Spectrometer ( ∼ 8000 RPC read-out panels ).

The goal of these studies is the optimization of the working parameters of the detector. A detailed and reliable measurement of the detector response, up to the level of the individual strip, needs a significant number of muon tracks to be analyzed. For such purpose a dedicated stream has been foreseen, called muon calibration stream. It contains the output of the Level 1 muon trigger (before any Level 2 selection) and has the advantage to come at a much higher rate (∼ 1 kHz) than the events selected by the full trigger chain (∼ 100 Hz). Each muon calibration stream event contains only hits from the muon spectrometer, in a region where a muon trigger occurred. It is possible to use also the normal physics dataset, the full stream, as a backup solution or for specific studies.

The complete analysis is splitted in two separate steps:

• creation of dedicated RPC calibration ntuples;
• processing of the ntuples to obtain calibration results.

In order to gain time, both steps need to be performed in parallel. Ntuple production is performed via the GRID. The tools used to launch jobs on the GRID allow their automatic splitting: for example, one job per input file. Once the ntuples are produced and registered on the GRID in a dataset for later access one can launch the analysis consistent in a ROOT [9] macro: the input is one or more file from datasets obtained in previous steps and the results are simple text files in a custom format with a summary of all relevant information. The output from several jobs can be easily merged. The merging step is where one can choose how many runs to group together, e.g. runs taken in the same detector conditions.

The diagram in Fig. 3 shows the RPCs performance analysis flow from detector raw data to the final results, which include several detector-related quantities:

• efficiency
• cluster size
• space residuals

The granularity is up to the strip level, but averages per panel are provided as well.

3. RPCs performance

One of the first quantity measured to monitor the status of the detector is the mean cluster size of each RPC read-out panel, that is the number of strips fired by a single muon track crossing the read-out panel. In Fig. 4 the distributions for BM and BO chambers are shown. The working parameters of each gas gap were set up at the default chosen value of 9600 V for the high voltage (HV) and of 1 V for the variable threshold voltage (Vth). The peak and FWHM values of each distribution are reported on the respective plot.

The best way to appreciate the effect of different thresholds on cluster size is to fix the high voltage at a value below the plateau, e.g. in the middle of the plateau rising, and choosing two extreme values for the threshold, i.e. 1.05 and 0.8 V. In this way one expects to see the biggest effect, if any. As Fig. 5 shows, the average cluster size has a very low dependency
from threshold. The effective discriminating signal threshold is obtained from the following formula\(^4\):

\[
V_{th}^{eff} = -|V_{th}| + |V_{ee}|/3
\]

were \(V_{th}\) is the variable threshold voltage to which has been referred above and \(V_{ee}\) is the voltage supplied to front-end electronics (6 V). According to the above relationship higher values of \(V_{th}\) correspond to effective lower threshold [5].

\(^4\)To obtain the equivalent physical threshold the \(V_{th}^{eff}\) value should be divided by the amplification factor of \(\sim 1000\)

In Fig. 6 the cluster size is evaluated fixing the threshold to 1 V and changing the high voltage to 9000 V and 9600 V. The variation of cluster size with the high voltage is clearly visible.

Figure 4: Mean cluster size for BM (up) and BO (down) chambers.

Figure 5: Distribution of the average cluster size for RPC panels at an high voltage value of 9000 V. The two histograms are referred to two different threshold values. The histograms are normalized to unity.

Figure 6: Distribution of average cluster size for RPC panels for different high voltage and at a fixed threshold value of 1000 mV. The histograms are normalized to unity.

The spatial resolution is related to the clusters size. A muon crossing the detector near the center of a read-out strip, will in general produce a cluster of size one, while clusters of size two are only observed when muons hit a narrow region at the boundary between two strips. The actual sizes of the regions corresponding to clusters of size one and two depends on the detector operating parameters, but it is typically true that the latter is smaller than the former. This implies that the spatial resolution must be smaller when measured on a subset of data with only clusters of size two. The spatial resolutions of \(\eta\) strips was determined selecting muon tracks reconstructed by the MDTs as explained above. For each RPC read-out plane, the distribution of the distance from the extrapolated track was obtained separately for clusters of size one and two and then was fitted with a Gaussian. The RMS widths of the fit were divided by the strip pitch to allow for comparison between different RPCs and are shown in Figure 7. This technique has been used only for the \(\eta\) panels since the MDTs are measuring only in the bending plane. On average, clusters of size two give a spatial resolution about half as for clusters of size one.

In order to determine the RPC efficiency two main issues have to be taken into account. The first one is due to the fact that the RPCs are actually providing the muon trigger, thus resulting in a trigger bias on the efficiency calculation. The effect of the trigger bias has been removed from the efficiency measurement.
of an RPC plane by selecting all the events in which the other three planes (in the case of a middle station) were producing hits, since the trigger requirement is a 3 over 4 planes majority. The second one is caused by the fact that the RPC hits are also used in the track reconstruction; in particular, they measure the coordinate in the non-bending, $\phi$ projection. The second effect has negligible contribution if the efficiency is measured for the $\eta$ read-out panels, since in this projection the track reconstruction is driven by the MDTs. For the efficiency measurement, MDT tracks were extrapolated to the RPC planes and the layer was counted as efficient if at least one $\eta$ hit was found with a distance of less than 7 cm from the extrapolation. Fig. 8 shows RPC efficiency as a function of the 16 ATLAS sectors. Corrections of the high voltage for temperature and pressure variations [10, 11] are not applied. All chambers are at 9600 V (red and blue), except ones in sectors 4, 5, 6 which are at 9400 V (yellow). The blue distribution shows panels with a mean panel hit time less than 25 ns (1 bunch crossing), i.e. close to the border of the time acceptance window. This causes loss of hits and time alignment (hit time centered in the read-out window) is required in order to eliminate this effect.

The mean value of the residual distribution of each $\eta$ panel is plotted for different sectors in Fig. 10. Displacement of RPC panels with respect to MDT chambers up to fraction of millime-

<table>
<thead>
<tr>
<th>Sector</th>
<th>Residual Mean (mm)</th>
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<tbody>
<tr>
<td>0</td>
<td>-0.4</td>
</tr>
<tr>
<td>2</td>
<td>-0.2</td>
</tr>
<tr>
<td>4</td>
<td>-0.0</td>
</tr>
<tr>
<td>6</td>
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<tr>
<td>10</td>
<td>0.6</td>
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<tr>
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<td>0.8</td>
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<tr>
<td>14</td>
<td>1.0</td>
</tr>
<tr>
<td>16</td>
<td>1.2</td>
</tr>
<tr>
<td>18</td>
<td>1.4</td>
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The efficiency as a function of cluster size is shown in Fig. 9 for BO chambers and the dependence is as expected.

The efficiency as a function of the 16 ATLAS sectors. Only panels with $V_{th} = 1$ V are selected.

The mean value of the residual distribution for $\eta$ panels as a function of sectors.

4. Conclusions

The ATLAS RPC system is a very complex setup. The collection of several millions of cosmic ray events allowed to perform large scale studies of the detector performance with unprecedented sensitivity. The preliminary results shown here are in agreement with expectations from early data/operations. This first attempt of the evaluation of RPC performance allowed also to test the analysis tools: they have shown their readiness to take advantage of muons from collisions, when enough statistics is collected.

References

[6] A. Guida, Offline monitoring and data quality of the ATLAS Resistive Plate Chambers at CERN Tier0 facility, these proceedings.