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ATLAS RPC certification with cosmic rays

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ABSTRACT

Almost one-third of the 1116 resistive plate chamber (RPC) units installed in the ATLAS experiment was tested and certified at the Lecce Cosmic Ray Testing Facility. About half of these units belong to the same chamber typology named barrel outer small (BOS).

This large and nearly homogeneous sample allowed to perform an extensive study of the detector behavior and characteristics. The intrinsic spread of the chamber parameters was extracted after correction for known pressure and temperature effects. A residual dependence on pressure and temperature has been found and empirically corrected.

The distribution of gas gap and panel efficiencies, cluster sizes (CSs), single rates and dark currents versus the applied threshold and high voltage was measured. An optimal working point was defined for each gas volume and the distribution of all relevant parameters was studied at the average working point for different voltage threshold. This work shows that the single unit BOS ATLAS RPC meets the experiment requirements.

1. Cosmic ray facility in Lecce and software tools

The ATLAS experiment at the LHC accelerator uses as muon trigger detector the resistive plate chambers (RPC) [1]. The life time of the experiment is expected to be about 10 years and for this reason each RPC unit was accurately tested before the installation on the experimental apparatus. This process is denominated in the following quality assurance (Q.A.). The tests involved all the principal RPC components and was focused on many aspects as electrical tests, gas tightness tests, efficiency, noise, cluster size (CS) and gap dark current measurements. The units which did not ensure an adequate performance were repaired and the defective parts eventually substituted. For this purpose a cosmic rays telescope was built and setup in Lecce [2] in order to certify all ATLAS RPC barrel outer small (BOS) units [3], having same length but different width.

The Lecce RPC cosmic ray testing facility consisted of several subsystems: gas system, power system (for low and high voltage distribution), data acquisition system (DAQ), detector control system (DCS), trigger system and tracking system, each one with a specific task. The Lecce RPC cosmic ray testing facility is described in detail in Ref. [2]. The mechanical structure allowed to house four RPC units acting as a trigger and tracking chambers two on the top and two on the bottom, the latter with about 10 cm of iron absorber interleaved, for acting as a filter of low energy and high multiple scattered particle. The setup can host up to eight ATLAS RPC units to be tested. Custom made DAQ, DCS, software tools and programs were developed to allow easy monitoring, data analysis and display of events and results on easily accessible dynamic web pages.

2. Performed test

The Q.A. of an RPC module was certified with a series of accurate measurements and tests intended to verify the correctness of the assembly and detector performance. The results of this procedure were stored in an on-line database. These tests represented the very first full chamber characterization and allowed to extract important information and monitor the assembly line, giving useful feed-back for possible improvements. In addition, in case of chamber malfunctioning or bad detector performance, the module was repaired and, if necessary, defective parts substituted.

The Q.A. procedure consisted of main certification tests and subsidiary control tests. The first test performed was the measurement of the current–voltage characteristic ($I-V$ curve). For each gas volume the current flowing inside the gap (dark current) and the current supplied by the corresponding high voltage channel were measured by ADCs. The $I-V$ curve data

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points were interpolated by the following function:

$$I_{gap} = \frac{V}{R_{gap}} + I_0\, e^{(V/V_0)} \tag{1}$$

where the fit parameters R_{gap} and I_0 can be, respectively, interpreted as the gap volume ohmic resistance and the average primary current emitted from the cathode, while the fit parameter V_0 is related to the effective gas amplification. The same equation was used to fit the value of the current distributed by the power supply, in order to check possible difference between the two values (gas volume leakage currents). After that cosmic ray runs dedicated to measure the readout plane and gas volume detection efficiencies were performed for high voltage values ranging from 8850 to 10 500 V and for different front-end voltage threshold ranging from 800 to 1200 mV. The obtained average efficiency was interpolated by the curve:

$$\varepsilon = \frac{\varepsilon_0}{1 + 81^{(V_{50}-V)/\Delta_{10}^{90}}} \tag{2}$$

where ε_0 is the efficiency reachable for infinite values of the high voltage V, V_{50} is the high voltage value at which the detector reaches half of maximum efficiency and Δ_{10}^{90} measure the HV difference between the values at 90% efficiency and 10% half efficiency.

At the same time the size of clusters (group of adjacent strips hit) associated to real tracks were evaluated for different high voltage values and front-end thresholds. The average CS data point CS was interpolated by the curve:

$$CS = CS_0 + CS_1 \times e^{V/CS_2} \tag{3}$$

where CS_0, CS_1 and CS_2 were the fit parameters.

Measurements of readout panel single counting rates were performed for different high voltage and front-end thresholds by use of random trigger runs. The average noise rates were extracted and interpolated by a curve similar to Eq. (3). Finally, in order to spot local inefficiency, high statistics cosmic ray runs (about two million events) were taken in full efficiency conditions to measure a fine grained bi-dimensional efficiency (radiography) for each gas volume.

The Q.A. procedure required more than 300 automatic fits per each single unit which were stored in a dedicated MySQL networked database. During the whole data taking more than 310 000 records with about 750 entries each where stored. The database allowed an extensive statistical analysis of the results that are discussed in the next paragraph. To allow an easy consultation of the results all histograms and plots produced during the analysis can be queried by a simple web site based on php code.

An ATLAS RPC unit was accepted only if the plateau efficiency exceeds 96% for all readout panels and 96.5% for all gas volumes and requiring at most one dead channel per readout panel. In addition, at the nominal working point (see next paragraph), the dark current of all gaps had to be smaller than 4 μA/m^2 and the average readout panel single rate smaller than 2 Hz/cm^2. Finally, local inefficiency should not be present in any of the gas volumes.

3. ATLAS RPC performance characterization

3.1. Pressure and temperature normalization

The applied high voltage during the tests was not corrected for environmental temperature T and pressure P changes during the runs. The correction was applied at posteriori during the data analysis using the following standard formula [5]:

$$V_{eff} = V_{app}\frac{T}{T_0}\frac{P_0}{P} \approx V_{app}\left(1+\frac{\Delta T}{T_0}\right)\left(1-\frac{\Delta P}{P_0}\right) \tag{4}$$

where V_{eff} and V_{app} are, respectively, the effective and the applied high voltage, $T_0 = 20\,^\circ$C and $P_0 = 1013$ mbar the standard chosen environmental condition. This formula makes the obvious gas density correction derived from the ideal gas equation. Nevertheless, a systematic study of the main RPC parameters showed that a residual effect with respect to temperature and pressure was still present. In order to remove this residual dependence of the environmental conditions from our data the following "empirical" formula:

$$V_{eff} = V_{app}\left(1+0.5\frac{\Delta T}{T_0}\right)\left(1-0.71\frac{\Delta P}{P_0}\right) \tag{5}$$

was extracted from a subset of data acquired at constant temperature and pressure. No explanation of this result has been found up to now and further investigations are under way. After this correction no residual dependence on pressure and temperature was found in our sample.

3.2. Gas volume and readout panel efficiency

A gas volume (gas gap) is declared efficient if in correspondence of an extrapolated track on the active volume, at least one strip in η or ϕ view produces a signal above threshold. Such a definition remove most of the readout panel electronic inefficiency for a small enough value of the physical thresholds V_{ph} because the η and ϕ readout panel signals are correlated to the same electronic avalanche. This also allows to measure the efficiency of the front-end electronics. The physical threshold is set by applying on the front-end comparator a negative voltage $-V_{th}$, ranging from -0.8 to -1.2 V, according to the formula:

$$V_{ph} = -V_{th} - \frac{V_{ee}}{3} \tag{6}$$

where V_{ee} is the supply voltage which was set to -5.2 V.

The front-end electronic efficiency increased rapidly for V_{th} below 1000 mV and reached a plateau afterward, where its average value is very close to one if dead channels are excluded.[1]

In Fig. 1 the measured gap efficiency as a function of the external threshold V_{th} and as a function of the high voltage values is shown. It is possible to notice that for high voltages above 9800 V and V_{th} above 1000 mV a plateau is reached.

The readout panel efficiency, which is the product between gas volume efficiency and electronic front-end efficiency, showed no difference between η and ϕ view readout panels after reaching the plateau.

3.3. CS and noise rate

The *CS* and *noise rate* (or single counting rate) are relevant parameters for RPC operation. Due to the inductive charge sharing phenomena and, eventually, cross-talk, a single avalanche developing inside a gas volume can induce a charge in more than one strip (cluster).

From the ATLAS requirements, the average CS, should be lower than 1.5 [4]. The CS is strongly dependent on the applied high

[1] One single dead front-end channel contribute to ~3% for η readout panel and to ~1.5% for ϕ readout panel.