IL NUOVO CIMENTO **47 C** (2024) 117
DOI 10.1393/ncc/i2024-24117-9

Colloquia: IFAE 2023

Results on pre-series production and QA/QC tests of the double-ends readout panels of the new layer of trigger chambers for the ATLAS muon spectrometer phase 2 upgrade(*)

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received 13 February 2024

Summary. — In view of High Luminosity LHC upgrade, the ATLAS experiment will add a new layer of Resistive Plate Chambers (RPC) trigger chambers into the barrel muon spectrometer. These next-generation RPC chambers will use a 1 mm gap and a single type of readout strips coupled to front-end electronics capable of providing both coordinates in the detector plane. The procedures for assembling the readout panels and the results of Quality Assurance and Quality Control (QA/QC) tests on the pre-series panels is reported here.

1. – Introduction

The High-Luminosity upgrade of the LHC (HL-LHC) will provide pp collisions at a center-of-mass energy of $\sqrt{s} = 14$ TeV with luminosities up to $7{\cdot}10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ and a total integrated luminosity of $3000\,\mathrm{fb}^{-1}$. The ATLAS detector [1] will undergo a second and last upgrade before the start of HL-LHC physics runs: the Phase-II upgrade during LS3 (2024–2026). The challenge for the muon spectrometer (MS) is to preserve its muon identification and tracking performance in much harsher conditions in terms of particle rates, radiation, and number of inelastic pp interactions per bunch crossing. In particular the muon trigger has to become more selective, so that the low p_T thresholds required for many physics studies and searches result in an acceptable trigger rate, and acceptance should possibly overcome the present geometrical limitations. To achieve this performance, a new layer of Resistive Plate Chambers (RPC) will be mounted in the inner region of the barrel Muon Spectrometer (BI).

(*) IFAE 2023 - "Poster" session

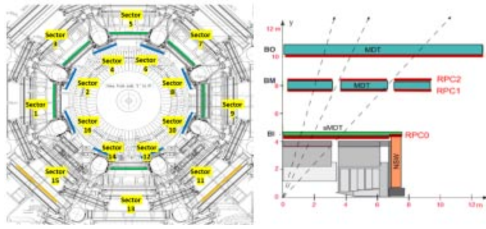

Fig. 1. – Left: x-y view of the MS layout with in green and blue the new RPC chambers which have two types: Small (blue) and Large (green). In grey the present RPC chambers and in orange the BOM/BOL: RPC in the outer region that will be mounted to better cover the region with the bearing structure of the experiment [2]. Right: R-z view of a quarter of the longitudinal cross-section of ATLAS small sector, showing the New Small Wheel (NSW) of the Phase-I ATLAS upgrade (orange), installed during the long shutdown LS2, and the new RPC0 layer to be installed during Phase-II upgrades [2]. On top of the NSW structure the are the BIS78 chambers made of sMDT and RPC, installed during LS2.

2. – The Muon Spectrometer

The ATLAS muon spectrometer (MS) [3] consists of three large air-core superconducting toroidal magnets (two endcaps and one barrel) providing a magnetic field up to 3.5 T. The deflection of the muon trajectories in the bending plane orthogonal to the magnetic field is measured via hits in three layers of monitored drift tube (MDT) chambers covering the region in pseudo-rapidity $|\eta| < 2.7$. The innermost forward wheels, Small Wheels (SW), of the MS [4], have been replaced during the Phase-I ATLAS update with New Small Wheels (NSW) using TGC (sTGC) and micro-mesh Gaseous Structure (MM) chambers for both triggering than precision tracking. The locations of the new Phase-I upgrade detectors are shown in fig. 1 (right). The present hardware trigger level is based on hit coincidences between different RPC or TGC detector layers inside programmed geometrical windows which define the muon p_T. The maximum rate and latency of this first-level trigger are 100 kHz and 2.5 μs , respectively. The high-level trigger level performs a full track reconstruction and a refined p_T measurement by using also precision chamber hits.

3. – Muon spectrometer Phase-II upgrade

The reconstruction efficiency and momentum resolution of the MDT system will be robust against high pile-up and high background rates and the muon identification and reconstruction performance will not be degraded by the higher particle rates and backgrounds of the HL-LHC. The muon trigger requires instead significant upgrades to maintain the same trigger momentum thresholds while keeping the trigger rates at a manageable level. The efficiency of the trigger is high in the endcap regions, but is limited in the barrel region by the geometrical acceptance of the RPC system, which is below 80% for tracks detected in three RPC chambers. The Phase-II upgrade of the MS [2] comprises the installation of new chambers, the replacement of some existing chambers, and the replacement of a large part of the front-end, trigger and readout electronics. Indeed, the electronics currently mounted in the ATLAS Muon Spectrometer cannot be used for a L0 trigger able to handle a 1 MHz frequency. Programmable external FPGAs will be used to make coincidences, instead of the present custom ASICs on detectors, making

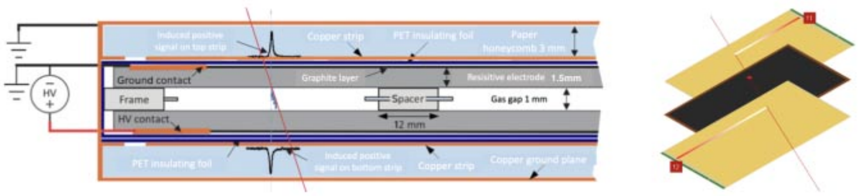

Fig. 2. – Left: Cross-section of a singlet. The ionization electrons, under the influence of the electric field present in the gap, trigger avalanche multiplications. These charges induce charges of opposite sign on the conductors facing them, and with them electrical signals in the circuits connected to these conductors. Right: 3D view of a singlet highlighting the strips hit by a particle and the two arrival times used to calculate the coordinate along the strips.

the new trigger more robust, simple and flexible. The readout electronics on detectors will be replaced by data multiplexers and high bandwidth optical links to send out hit information from the detectors to the L0 trigger logic.

3˙1. *RPC chambers.* – To maintain high trigger efficiency, new RPC chambers will be installed. Due to the very limited space for small sectors, MDT chambers will be replaced with others having smaller diameter drift tubes (sMDT). The present RPCs, to ensure their continued operation at the HL-LHC, will have to be operated at reduced voltage to respect the original design limits on currents and integrated charge. The single hit efficiencies at this working voltage will be reduced to about 65%. Despite the reduced single hit efficiencies, the trigger efficiency can exceed 98% by requiring the coincidence of RPC0 with at least two of RPC1, RPC2 and RPC3. The installation of these chambers will also cover most of the acceptance holes of the current barrel muon trigger, achieving 96% coverage. In total more than 250 new RPC chambers will be built. Similar chambers are currently being built for the BIS78 project. This new RPC has 1.5 mm thin bakelite electrodes 1 mm apart (fig. 2). On both sides of the gas gap there are two planes with the strips oriented in the same direction. The signal is read from one end of the upper strips and from the opposite end of the lower strips and the coordinate along the strip is measured by the difference in the time of arrival of the signal to the electronics [2]. The chamber consists of three layers with single gap efficiency greater than 95%. The rate capability can reach 9 kHz with efficiency greater than 80%, 400 ps time resolution and 1-2 mm spatial resolution at 5.6 kV operating voltage [5]. The layers of RPC took place in an aluminium box, which base and cover are pre-bent aluminium sheets.

3˙2. *BIL Strip panel assembly.* – The strip panels are made of aramid paper honeycomb (3 mm thick) with two halogen-free copper-clad halogen-free FR4 (0.4 mm thin) plates, one acting as a ground plate and the second photoengraved to form parallel strips. These three elements are glued all together with Araldite 2011. The assembly site dedicated to the production of the RPC-BI type Small (RPC-BIS) will be the University of Science and Technology of China (USTC) while the RPC-BI type Large (RPC-BIL) will be produced at the Laboratorio Alte Energie of Università della Calabria in Cosenza; the laboratory has produced some prototypes of these panels, proving to be able to build them with the required accuracy and on schedule. A precise template is used to align the FR4 sheets with respect to each other during gluing, and an accurate Quality Assurance and Quality Control (QA/QC) procedure is applied to both the FR4 plates, honeycomb

Fig. 3. – Left: the stand table used to measure the lateral dimension of the panel. Right: ten analog linear probes measure the thickness of the panel with respect the granite table with a granularity 70x70 mm and a precision of 10 μm.

foils and the assembled panels to verify dimensions and thickness of the assembled panel that must not exceed the nominal values of ±0.25 mm and ±0.1, respectively. Figure 3 (left) shows the support for measuring width and length. On the upper part of the table three non-aligned washers are screwed and the panel is firmly pressed against them. Two digital micrometers measure the size against the calibrated bars. The panel is turned over and the measurement is repeated. Finally, the panel is rotated 180 degrees with respect to a vertical axis, and the measurement is repeated again. With these 6 measures, two are redundant, it is possible to reconstruct the geometric shape of the panel and its lateral dimensions. Figure 3 (right) shows the system used to measure the thickness of the panel. The assembly site also takes care of the soldering of the termination resistors (3 SMD resistors per strip) and the taping of the edges of the panel with copper adhesive tape. Finally, the site should check for electrical shorting between adjacent strips and for interruption of electrical continuity along each strip. The site in Cosenza is able to produce two complete strip panels per day.

4. – Conclusions

Paper honeycomb structure and photoengraved plates will be used in the readout panel for ATLAS Phase-II RPC upgrade, leading to better mechanical and electrical performances and stability in prevision of High Luminosity LHC. Some prototypes have been successfully built. In total, ∼600 BIS read-out panels will be produced and qualified in USTC, ∼700 BIL read-out panels will be produced and qualified in Cosenza. Finally, the RPC chambers assembly and commissioning will mostly be performed at CERN.

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