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Validation and Certification of the RPC-BI chambers for the ATLAS Muon Spectrometer Phase-II upgrade(*)

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Summary. — The ATLAS experiment has started the construction of a layer of Resistive Plate Chambers (RPC) to be installed during the long shutdown LS3 (2026-2029), above the MDT tracking chambers of the innermost layer of the barrel muon spectrometer. These new detectors will participate, along with the other RPC chambers already present in the spectrometer, in the very rapid selection (trigger) of charged particles in small momentum intervals. The RPC chambers will consist of a triple layer of detectors that, at the luminosity of High Luminosity LHC, will have a detection efficiency of 80% per single layer (99.2% per chamber), a time resolution better than 400 ps, and a spatial resolution better than 6 mm in the η direction and 15 mm in the ϕ direction. The construction of the RPC detectors in the Large sectors (RPC-BIL), a joint effort by the INFN groups in Rome1, Rome2, Bologna and Cosenza, began in June 2023 and will continue until the start of LS3, scheduled for 2026. The assembly of the 130 RPC-BIL chambers will be carried out at the CERN laboratories. Each assembly phase is followed by quality tests. Specifically, the individual detectors of each chamber (singlets) are qualified into a cosmic ray tracking test station. The station allows for a complete measurement of detection efficiency and the percentage of streamers as a function of the operating voltage. The trigger chambers of the station are the ATLAS RPC detectors. Therefore the test stand integrates both the existing ATLAS system and the Phase-II detectors; as such it serves as a validation system for the individual detectors and complete chambers and as a study system for the integration of the two technologies. This work presents the first results and the potential of this test system.

(*) IFAE 2024 - "Poster" session

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. The muon trigger requires significant upgrades to maintain the same trigger momentum thresholds while keeping the trigger rates at a manageable level even with high pile-up and high background rates. 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 a new layer of RPC in the inner region of the barrel (BI) of the Muon Spectrometer (see fig. 1), the replacement of some existing chambers, and the replacement of a large part of the front-end, trigger and readout electronics based on FPGAs.

2. – RPC chambers

The present RPCs in the Middle and Outer region (BM abd BO) will have to be operated at reduced voltage with respect to the original design limits on currents and integrated charge to ensure their continued operation at the HL-LHC. The single hit efficiencies at this working voltage will be reduced to about 65%. Despite the reduced single hit efficiencies, the overall trigger efficiency can exceed 98% by requiring the coincidence of RPC-BI with at least two of RPC-BM1, RPC-BM2 and RPC-BO. The installation

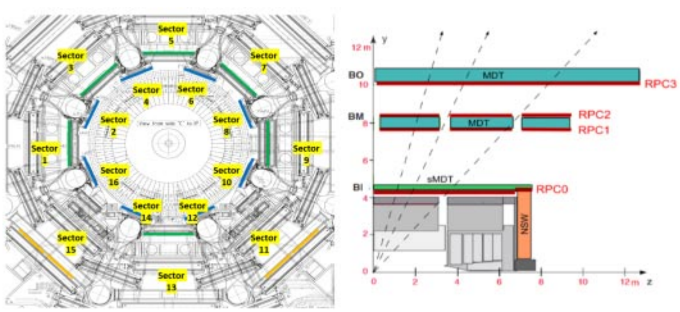

Fig. 1. – Left: x-y view of the MS layout with in green and blue the new RPC chambers which have two types: Small (blue) and Large (green). In grey the present RPC chambers and in orange the BOM/BOL: RPC in the outer region that will be mounted to better cover the region with the bearing structure of 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].

of the RPC-BI will also cover most of the acceptance holes of the current barrel muon trigger, achieving 96% coverage. In total more than 250 new chambers will be built. This new RPC has 1.5 mm thin bakelite electrodes 1 mm apart (fig. 2 (left)). 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 (fig. 2 (right)) and the coordinate along the strip is measured by the difference in the time of arrival of the signal to the electronics [2], differently from the previous RPC-BM/BO where both the η and ϕ coordinates were directly measured with orthogonal strips. 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 structure which comprises one gas gap with two readout panels is called singlet; three of these singlets form a triplet that is placed in an aluminium box, whose base and cover are pre-bent aluminium sheets.

3. – Cosmic Rays Test Stand

The RPC-BI chambers under construction are composed of three gas volumes, each enclosed between two strip planes for reading signals produced in the gas by the passage of an ionizing particle from cosmic rays. This structure is called a triplet, and each gas volume is called a singlet. The data from the detector are handled and transmitted through the Data Collector and Transmitter (DCT) board which differs between BI and BM/BO chambers. The test system built at the CERN laboratories in Geneva aims to certify all triplets that make up the RPC chambers produced by the Italian community for the Phase-II upgrade. This includes approximately 100 triplets for the RPC-BI and 40 triplets for the RPC-BOM/BOR. The tests involve measuring detection efficiency, the voltage-current curve, the streamer rate, and the tomography of the singlet/chamber. The test tower has six shelves to accommodate singlets and two for complete chambers. The trigger consists of four RPC-BO type Large (BOL) singlets, the same ones installed in ATLAS. The test tower (fig. 3) will also allow the integration testing of the new readout electronics (DCT) with the BM/BO RPC chambers already present in ATLAS. The system will therefore include 3 DCT-BI for reading 6 singlets and 3 RPC-BI triplets, and 1 DCT-BM/BO for reading the four RPC-BOL trigger chambers.

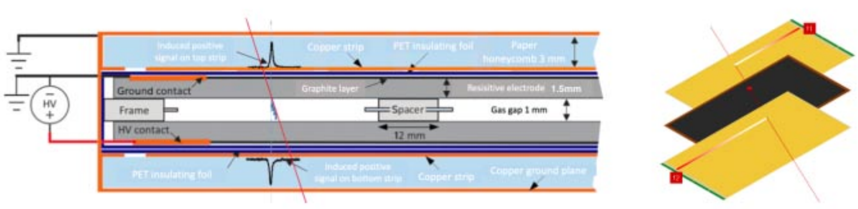

Fig. 2. – Left: Cross-section of a singlet. The ionization electrons, under the influence of the electric field present in the gap, trigger avalanche multiplications. These charges induce charges of opposite sign on the conductors facing them, and with them electrical signals in the circuits connected 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.

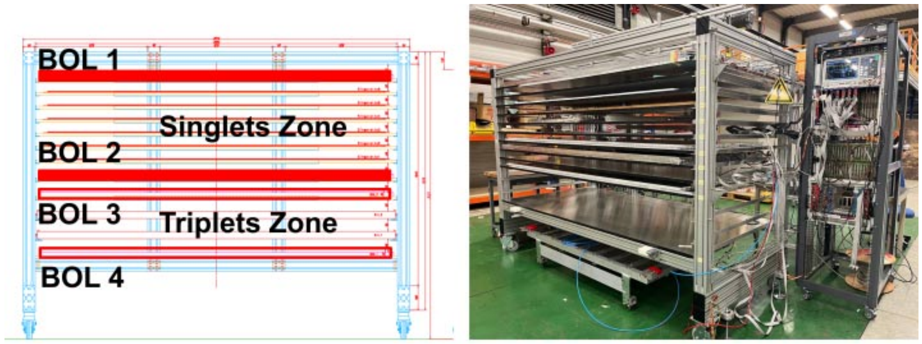

Fig. 3. – Left: schematics of the structure with the four BOL highlighted. On the top the singlets test zone and in the bottom the triplets zone. Right: Cosmic rays test stand fully assembled at CERN.

4. – Structure and Trigger Logic

Each of the four RPC-BOL provides the point P(x, y) where a charged particle from a cosmic ray passed through it. Trigger events are those with four aligned points within a time window of a few tens of nanoseconds. On the long side of the chamber, there are 10 front-end (FE) electronics boards to read 80 strips, while on the short side there are 4 FE boards to read 24 strips. The output signals from the RPC-BOL FEs are sent to a TTL receiver and then passed to the discriminator. The discriminated signal is sent to the inputs of a CAEN Trigger Logic Unit, which, thanks to the built-in FPGA, allows for the creation of up to 130 topological trigger configurations. The trigger signal is obtained from the coincidence (logical AND) between the BOL chambers: for each chamber, a logical AND is performed between the logical ORs of the 4 FEs on the short side and the ORs of the 10 FEs on the long side; the result of this operation is ANDed with that of the other chambers. The trigger scheme (fig. 4) foresees the integration of the new RPC electronics while the TDAQ system has been developed using a RPC-BI triplet.

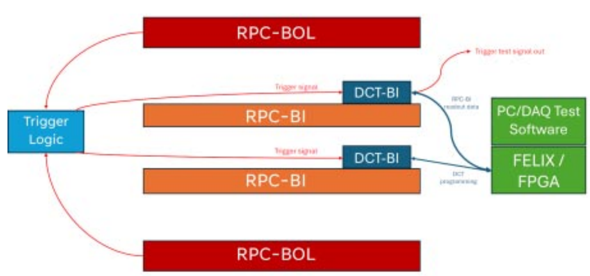

Fig. 4. – Schematics of the trigger logic. The trigger signal from the logic AND of the four BOL will be sent to the DCT-BI to acquire the signal from the RPC-BI chamber under test (Trigger test signal out). The programming and data reading from the DCT-BI will then be handled by the DAQ system.

5. – Test on BIS Chamber

The RPC-BI Small (BIS) have a 1 mm gap, and the signal is read from the two short sides of the chamber, referred as the HV side and the I side (fig. 5) for the sake of the test. The coordinate measured in this way is the η coordinate, while the ϕ coordinate is obtained from the time difference of the signal arriving at the electronics on the two opposite sides. Using two BOL chambers for the trigger, the signals of each strip were acquired from the two FEs at the center of the BIS directly through the TDC.

6. – Tracking and Data analysis

A total of two million events of cosmic rays was acquired with the test stand. This acquisition allowed the development of the first programs for tracking and data analysis. Only "golden" events were selected, defined as events with exactly 4 signals, one for each trigger coordinate on two chambers. Only straight tracks in the trigger coordinate ϕ were selected. The reconstructed coordinate ϕ on the BIS chamber, corresponding to the coordinate X in the reference system of the stand, is related to the length of the chamber L_{BI} and to the position with respect to the reference of the tower L_{offset} by the relation

$$X = \frac{v}{2}(t_1 - t_2) + \frac{L_{BI}}{2} + L_{offset} \tag{1}$$

It is possible to extrapolate the velocity v of the signal propagation by measuring its arrival time difference (Δtime) between the two sides of the BIS chamber as a function of the reconstructed coordinate ϕ (fig. 6).

From the fit parameter p_1 of the distribution we obtain the signal propagation velocity along the BIS strips as:

$$v = \frac{2}{p_1} = 0.24\frac{mm}{ps} \tag{2}$$

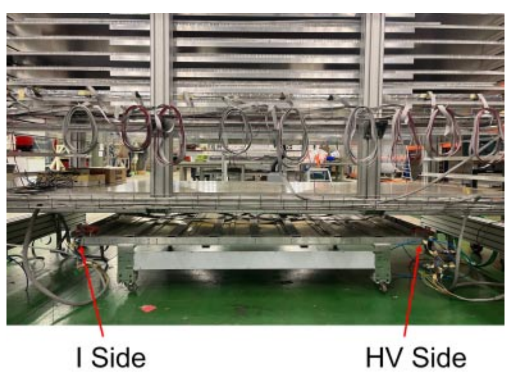

Fig. 5. – The BIS chamber mounted and cabled beneath the cosmic stand. With respect to the reference point inside the tower, we identify and label each side in order to match the signals coming from the front-end boards.

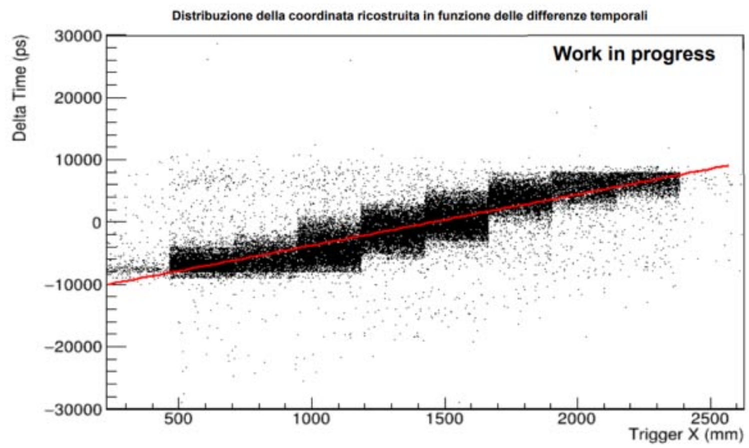

Fig. 6. – Distribution of Δtime expressed in picoseconds as a function of the ϕ reconstructed position coordinate (Trigger X expressed in mm). The linear fit to extrapolate the signal propagation velocity is shown in red.

7. – Conclusions

The test station is fully operational for conducting tests on the RPC-BI chambers and is now completed with the last two RPC-BOL chambers for a triple and a quadruple coincidence. We have developed a robust framework and dedicated software for performing the tests and analyzing the related data. The station is ready to conduct the integration test of the new DCT electronics on the RPC chambers. The station provides the entire collaboration with a configurable trigger test area to meet any requirements.

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