PROCEEDINGS OF SCIENCE

The ATLAS RPC Phase II upgrade for High Luminosity LHC era

Eric Ballabene,[a,b,*] **Alessandro Rocchi**[c,d] **and Marco Sessa**[c,d]
on behalf of the ATLAS Collaboration

[a] *Department of Physics and Astronomy A. Righi, University of Bologna*
[b] *INFN, Sezione di Bologna,*
Viale Carlo Berti Pichat, 6/2, Bologna, Italy

[c] *Department of Physics, University of Rome Tor Vergata*
[d] *INFN, Sezione di Roma Tor Vergata,*
Via della Ricerca Scientifica, 1, Rome, Italy

E-mail: eric.ballabene@cern.ch, alessandro.rocchi@cern.ch, marco.sessa@cern.ch

Resistive Plate Chamber (RPC) detectors play a crucial role in triggering events with muons in the ATLAS central region; it is facing a significant upgrade in the view of the HL-LHC program. In the next few years, 306 triplets of new generation RPCs with a 1 mm gas gap (instead of 2 mm) will be installed in the innermost region of the ATLAS Muon Barrel Spectrometer, increasing the number of tracking layers from 6 to 9, doubling the trigger lever arm and increasing the coverage. Innovative front-end electronics will allow to operate the RPCs with an order of magnitude less of average charge. Both sides of RPCs are read out by strip panels and the second coordinate is reconstructed from the time difference of signal drift at opposite detector ends. The expected time resolution is approximately 300 ps; the possibility of a stand-alone Time of Flight measurement will have a huge impact on ATLAS searches for long-lived particles. An overview and the present status of the ATLAS RPC Phase II project is presented.

42nd International Conference on High Energy Physics (ICHEP2024)
18-24 July 2024
Prague, Czech Republic

[*] Speaker

 https://pos.sissa.it/

PoS(ICHEP2024)873

1. The Phase II Muon Trigger upgrade

The ATLAS Muon Trigger system needs major upgrades in view of the HL-LHC, where a luminosity increase up to 7×10^{34} cm^{-2}s^{-1} at $\sqrt{s}$ = 14 TeV pp collisions with $\langle \mu \rangle = 200$ is expected [1, 2]. The RPC system will be upgraded by adding about 300 new generation RPC detectors with 10 kHz/cm^2 rate capability in the Barrel Inner (BI) and replacing the old on-detector trigger boards with new boards. The foreseen improvements are the increase of trigger redundancy from 6 to 9 layers, the increase of the trigger acceptance from 78% to 92% with 96% acceptance for Barrel Outer (BO) coincidence with BI, the increase of the spectrometer lever arm from 2.3 m to 4.5 m, a time resolution for triggering muons of 0.4 ns for BI-RPCs due to new thinner gas gaps and new readout electronics and an improvement of the time resolution from 2 ns to 1.1 ns for Legacy RPCs due to new readout electronics.

2. The RPC Phase II upgrade

The RPC Phase II upgrade will consist of the installation of a BI layer of RPC triplets, BI-RPC, with new Front-End (FE) ASICs to increase trigger acceptance, the replacement of the on-detector trigger boxes with new trigger boards, the installation of new on-detector trigger boards for BI-RPC and the replacement of the RPC Power System. The BI-RPCs consist of chambers made up of three singlets, where each singlet contains a gas volume. A gas volume comprises a gas gap closed by two High-Pressure Laminate (HPL) bakelite plates. The outer faces of the HPL plates are coated with a graphite layer. The gas volume thickness is about 4.5 mm.

3. The BI-RPC gas volumes

The new BI-RPC gas volumes have been developed with many improvements compared to the ATLAS RPC Legacy ones. The gas gap thickness has been reduced from 2 mm to 1 mm to improve the time resolution and the gas distribution has been redesigned with four holes for connecting the gas pipes placed on each corner of the detector and drilled in solid profile. The profile closes the internal gas distributor channel along the short side of the gas volume. The HV cable connection has been moved to the gas volume side to eliminate conflicts with the readout panels, 6 mm diameter gas pipes have been replaced with 3 mm diameter ones, graphite layer resistivity has been reduced from 500 k$\Omega/\square$ to 320 k$\Omega/\square$ and footprint redesigned to reduce current leaks, electrodes thickness has been reduced from 1.8 mm to 1.4 mm. The production of the gas gaps is ongoing over 2 years (2023-2025) in Italy by General Tecnica Engineering (GTE). Two other producers, Munich (Max Planck Institute, MPI) and Hefei China (University of Science and Technology of China, USTC), could construct a fraction of gas volumes and they are in the phase of qualification.

The qualification of the gas volumes is performed with measurements for both the bakelite plates and the gas volumes. The qualification of the HPL plates is carried out by INFN at GTE and involves sample measurements of the resistivity of the sheets (maximum $10^{11}\Omega$cm), sample measurements of the plate thickness and the visual inspection for the detection of any macroscopic defects. The qualification of assembled gas volumes is carried out at GTE and starts with ten tests that are under the responsibility of the manufacturer. Additionally, three tests are under CERN-INFN responsibility: current-voltage (I-V) characterization, gas tightness test (Δp < 0.1 mbar after 3 minutes) and current leak test. Finally, conditioning is carried out at the Gamma Irradiation Facility (GIF++) with measurements of the I-V before and after gamma irradiation of the gas volumes.

In particular, according to the tender, volumes are accepted if they show a total current of less than 1 μA at 3.5 kV and a current after subtracting the ohmic component less than 3 μA at 6.1 kV. The ohmic component is estimated by performing a linear fit in the [0-3] kV range. All volumes undergo an I-V characterization before invoicing. Figure 1 shows the total current (left) and the current recalculated after subtracting the ohmic component (right) as a function of the voltage for an entire production batch of BI Large (BIL) gas volumes. The tested batch meets the production requirements.

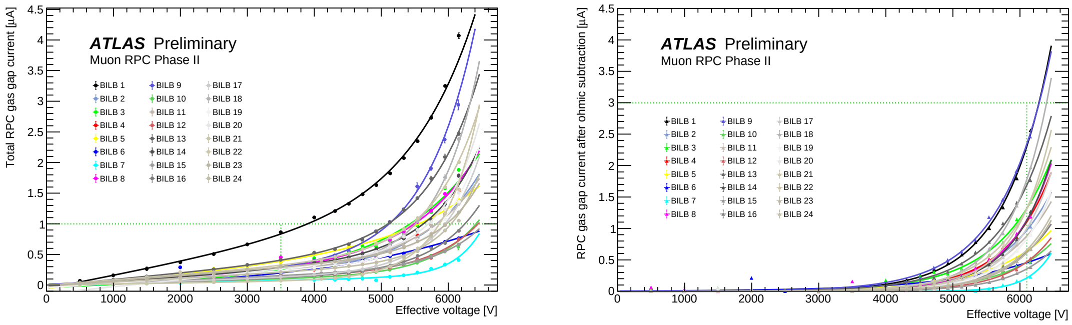

Figure 1: Total current (left) and current recalculated after subtracting the ohmic component (right) as a function of the effective voltage for an entire production batch.

Stress tests are carried out performing thermal cycles in the climatic chamber of the ATLAS laboratories at INFN Frascati for BIL gas volumes and at Cambridge University for BI Small (BIS) gas volumes. Different cycles ranging from +30°C to -20°C have been performed. Gas volumes have been flushed in parallel with low dew point dry air and a 1.8 mbar overpressure at the gas inlet during thermal cycles. Two temperature sensors are inserted into the gas gaps to evaluate the delay in temperature variation and the attenuation of the cycle range. At the end of each cycle, a waiting time of 15 minutes was allowed to reach the thermal equilibrium. Mechanical strength and gas tightness have been monitored during cycles.

4. The BI-RPC singlets

The gas volume is contained between two readout panels with η-oriented strips (along the long side of the chamber) forming a singlet. The singlet is enclosed in a Faraday cage consisting of the outer faces made of copper material and connected by conductive copper tape on the edges. The singlet thickness is about 13 mm. New readout panels consisting of three layers have been developed, each made of one layer of aramid paper honeycomb 3 mm thick and two layers of copper-plated 0.4 mm thick laminates on which readout strips are produced through a photoengraving process. Panel thickness and materials are selected to optimize the impedance of the strips and the weight of the detector. A termination resistor is welded to the ends of each strip and guard wire.

The construction of the readout panels is divided between INFN Cosenza for BIL and Hefei China for BIS. The qualification of the readout panels involves measurements of the thickness of the laminates, of the aramid paper honeycomb, of the assembled panel surface, of length and width of the assembled panel, of the strip width and electrical continuity measurements for strips and guard wires. Figure 2 shows an apparatus used for several measurements (left) and the distribution of the measured thickness for the readout panels (right), where each reported measurement corresponds to the mean of thickness measurements taken on a 7 cm x 7 cm matrix on the panel surface.

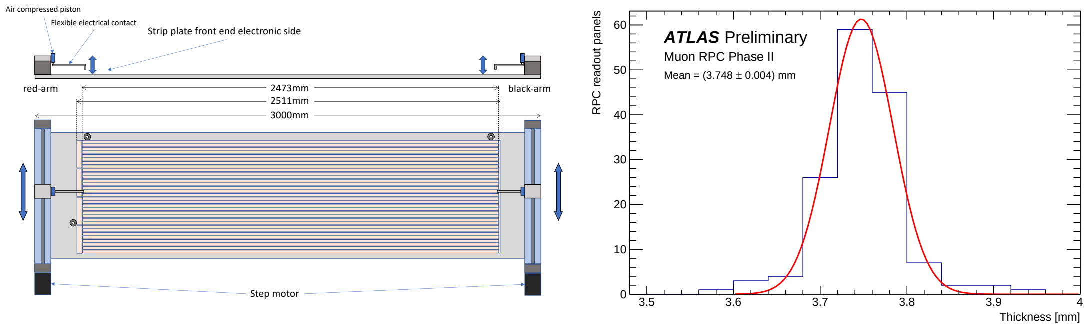

Figure 2: Motorized apparatus for geometrical measurements (left) and thickness measurements of the RPC readout panels (right).

For BI-RPC, an ASIC chip has been developed by INFN Rome Tor Vergata integrating a preamplifier, a discriminator and a Time-to-Digital Converter (TDC). The BI-RPC provides for an improvement in stability and sensitivity compared to the FE of ATLAS BIS-78 prototypes and allows the ϕ coordinate reconstruction. In particular, it can detect signals of only 1-2 fC with a minimum discrimination threshold of 0.3 mV. It implements a Voltage Controlled Oscillator (VCO) defining the TDC time resolution driving the scaler (50-150 ps rms) and uses the Manchester code for the data encoding. Each ASIC chip has 8 channels, each channel has its serial transmission line. Ten ASIC chips were irradiated with a neutron flux of $10^{13} n_{\mathrm{eq}}/\mathrm{cm}^2$ at the China Spallation Neutron Source (Dongguan) to check the chip radiation hardness: no changes in the discriminator and in the VCO response was observed after the irradiation.

BI-RPC detectors have only η-oriented readout strips, which are equipped with FE-electronics with a 100 ps TDC temporal resolution at the opposite ends. The reconstruction of the ϕ coordinate is obtained from the propagation time of the signals on the strips and the velocity. The signal propagation velocity on the strip can be estimated by measuring the time difference on opposite readout strip ends. Measurements have been performed by placing 2 cm narrow trigger scintillators in different positions orthogonal to the strips of a BIL-RPC equipped with a BIS-78 like FE-board, as shown in Figure 3 (left). A signal propagation velocity of 20 cm/ns is measured from the fit of the time difference at opposite readout strip ends as a function of the trigger scintillator position, as shown in Figure 3 (right). A spatial resolution of about 2 cm was obtained for the reconstructed ϕ coordinate, driven by trigger geometry. The spatial resolution on the η coordinate depends instead on the cluster size of the event.

5. The BI-RPC chambers

Three singlets, that is a triplet, are inserted inside the containment mechanics to form the BI chamber. BIL-RPC will be installed in the Large sector while BIS-RPC will be installed in the

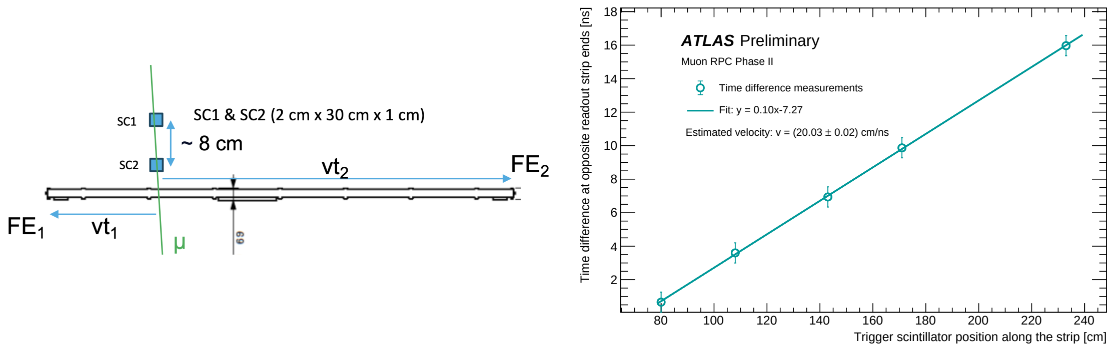

Figure 3: Experimental apparatus for reconstructing the ϕ coordinate (left) and measured time difference as a function of the trigger scintillator position (right).

Short sectors. The BI-RPC chamber thickness is about 65 mm. The design of the containment mechanics has been defined for all the main chambers. There are four BIL types (BIL 680S, BIL 680L, BIL 620S, BIL 520S) covering 75% of BIL sectors, two BIS types (BIS1 and BIS from 2 to 6) covering all the BIS sectors involved in Phase-II upgrade and other special cases. Additional chambers will be installed in the feet sectors (S11 and S15) of the BO: 80 identical non-overlapping RPC triplets of BIS-like size. On the containment mechanics, a Data Collector and Transmitter (DCT) board is installed. The DCT connects detector FE with Barrel Sector Logic (SL), where trigger logic operations are performed. Two kinds of DCTs are developed: the BMBO-DCT for the Legacy RPC system of the Barrel Medium (BM) and BO, and the BI-DCT for BI-RPC. The main difference for the DCT is that a TDC is in the BI-RPC FE but not in the RPC Legacy FE. The BMBO-DCT receives hit analog pulses from FE, measures arrival time with FPGA-TDC and sends timing data to the SL. The BI-DCT receives the hit time digital data from FE-TDC, decodes and sends timing data to the SL, and reconstructs the ϕ coordinate from the time difference of two η-η readouts. The first hardware and software prototype of BMBO-DCT has been extensively tested for both the communication with SL and its readout with a RPC chamber. A 0.8 ns time resolution on time of flight is measured for cosmic muons between two RPCs and a 0.24 ns TDC time resolution is measured for η-ϕ panels facing the same gap. A second BMBO-DCT prototype is under test. A first BI-DCT prototype has been submitted and the FE-DCT communication test is in progress. 1208 BMBO-DCT and 338 BI-DCT are foreseen to be installed.

6. The QC of BI-RPC singlets and chambers

The final QC for BI-RPC singlets and chambers is performed using a cosmic ray test stand in BB5 at CERN. There are two trigger sectors available for QC tests, the upper sector is used to certify up to six BIL singles while the lower sector is used to certify up to two BIL chambers (triplets). The cosmic ray test stand employs four RPC Legacy detectors as triggers, with one on the top, two in the middle and one on the bottom. The height of the trigger detectors can be adjusted to optimize certification during production, e.g. according to the number of detectors under test. All the four RPC gas volumes and the eight read-out panels have been refurbished and the trigger detectors have been assembled and installed at CERN.

A measurement of the trigger time resolution for the cosmic ray test stand has been performed after the installation of two trigger detectors. The trigger logic has been implemented on an open FPGA module with up to 196 input-output channels interface. A coincidence of four read-out planes has been required using two RPCs with η and ϕ readouts. 40 trigger regions were defined in the FPGA to perform an online trigger tracking system and were acquired with a TDC. The time of flight is estimated by selecting tracks with hits in each of the four panels. Time resolutions of 2.25 ns and 2.00 ns were measured for ϕ and η panels, respectively, as shown in Figure 4. The rate produced by the FPGA trigger logic has also been compared with an equivalent NIM one.

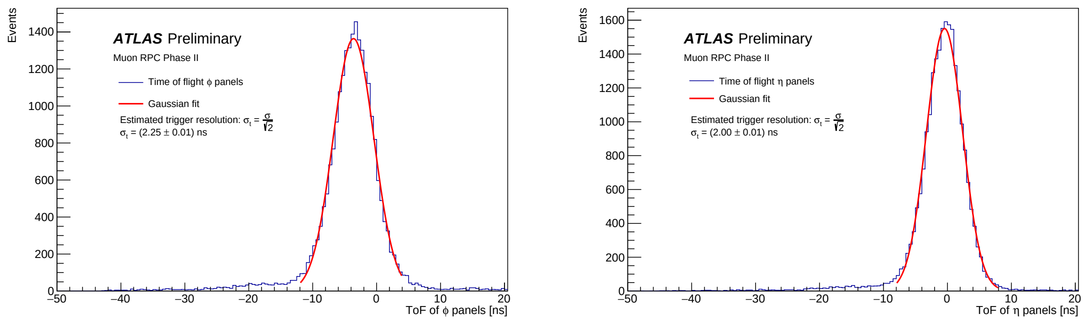

Figure 4: Trigger time resolution of ϕ (left) and η (right) panels for the cosmic ray test stand at BB5.

7. Conclusions

New state-of-the-art RPC detectors have been developed for the Phase-II upgrade of the Muon Trigger System. Among the most important features, the new gas volumes have a gas gap thickness reduced to 1 mm with improvements in gas and high voltage distributions. The readout panels contain new FEs consisting of Si technology preamplifier and SiGe-HBT ASIC with discriminator and TDC embedded. The new FEs have a sensitivity to signals of 1-2 fC and a TDC time resolution of around 100 ps, allowing the reconstruction of the second coordinate through the difference of signal propagation times along the strip. New on-detector DCT boards have been developed with about 250 ps time resolution. The new BI-RPC have an improved rate capability up to 10 kHz/cm^2 to withstand the HL-LHC conditions. The production of detector components has started. The gas gap production is in progress at GTE in Italy while two additional producers are under qualification. The readout panels assembly is ongoing in INFN Cosenza and Hefei China. The FE electronics is close to completing the integration tests with the ASICs already produced. A first prototype of BI-DCT is close to production while a second prototype of BMBO-DCT is under validation.

References

[1] The ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.

[2] The ATLAS Collaboration, *Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer*, *CERN-LHCC-2017-017; ATLAS-TDR-026*.