Nuclear Instruments and Methods in Physics Research A 1068 (2024) 169749

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

The ATLAS RPC Phase-II upgrade for High Luminosity LHC era

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ARTICLE INFO

Keywords:
ATLAS
Muon spectrometer
Upgrade

ABSTRACT

Resistive Plate Chambers (RPC) detectors play a crucial role in triggering events containing muons in the central region of ATLAS. In view of the High Luminosity-LHC program, the existing RPC system, consisting of six independent cylindrical detector layers each providing a full space time localization of hits, is currently undergoing a significant upgrade. In the next few years, 306 triplets of new generation RPCs will be installed in the innermost region of the ATLAS Muon Barrel Spectrometer, increasing from 6 to 9 the number of tracking layers, doubling the trigger lever arm. This allows a substantial enhancement of the present trigger redundancy, increasing the coverage from 76% to approximately 96%. Fitting new chambers in the narrow space left in ATLAS inner barrel was a challenge, achieved by optimizing RPC materials and thickness, featuring a 1 mm gas gap (instead of 2 mm), and 1.4 mm resistive electrodes (instead of 1.8 mm) while reaching an high rate capability. To achieve such results, a 100 ps precise Time-to-Digital Converter (TDC) has been integrated in the front-end electronics ASIC. The expected time resolution of a single 1 mm RPC gas gap is approximately 300 ps, and the possibility of a stand-alone Time of Flight measurement will have a huge impact on ATLAS searches for massive long-lived particles. An overview and the present status of the ATLAS RPC Phase-II project will be presented.

1. Muon spectrometer phase-II upgrade and the RPC-BI chambers

The Phase-II upgrade of the Muon spectrometer [1] foresees the installation of a new layer of triplet Resistive Plate Chambers (RPC) with increased rate capability [2] in the barrel inner (BI) region, enhancing the geometrical acceptance. These new chambers will have a gas gap of 1 mm of thickness and 1.4 mm resistive electrodes. The new chamber design is based on a very efficient integration of an innovative front-end electronics within the detector Faraday cage, reducing the impedance and thus the noise and allowing to operate the RPCs with an order of magnitude less of average charge per count, correspondingly increasing rate capability and longevity [3]. Both sides of RPCs are readout by strip panels oriented to measure the bending coordinate of the Muon Spectrometer, while the second coordinate is reconstructed from the time difference of signal drift at opposite detector's ends. In the case of reduced efficiencies in the legacy chambers, maintaining high trigger efficiency and purity will be feasible by relaxing hit coincidence requirements in old chambers while introducing coincidences with new RPC-BI chambers. Adding new RPC in the barrel poses challenges in terms of space and installation logistics as shown in Fig. 1. In total 130 RPCs Barrel Inner Large (BIL) and 96 Barrel Inner Small (BIS) will be installed. In the lower sectors, because of ATLAS rails supporting the calorimeters the space is lacking, and thus the installation of 80 special triplets with the same technology of the BI in the outer region (BOM/BOR) is planned.

2. Trigger logic and upgrade

All hits from RPC detectors contribute to generating barrel trigger candidates. The new RPC trigger will utilize nine measurement planes (instead of six) from four layers of RPCs: one BI triplet (RPC0), two Barrel Medium BM doublets (RPC1 and RPC2) and one Barrel Outer BO doublet (RPC3) as shown in Fig. 2 (left). The trigger algorithm that has been developed uses these four RPC layers to perform coincidences, following specific logic schemes based on requirements across the layers:

- 3/3 chambers: Hits in at least three out of four planes of RPC1+RPC2 chambers and in at least one out of two planes of RPC3, equivalent to the present high-pt trigger.
- 3/4 chambers: Previous requirement combined with hits in at least two planes out of three in RPC0 and at least three planes out of six in RPC1+RPC2+RPC3, accepting all combinations of three-chamber coincidences.

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https://doi.org/10.1016/j.nima.2024.169749
Received 5 July 2024; Received in revised form 5 August 2024; Accepted 18 August 2024
Available online 19 August 2024
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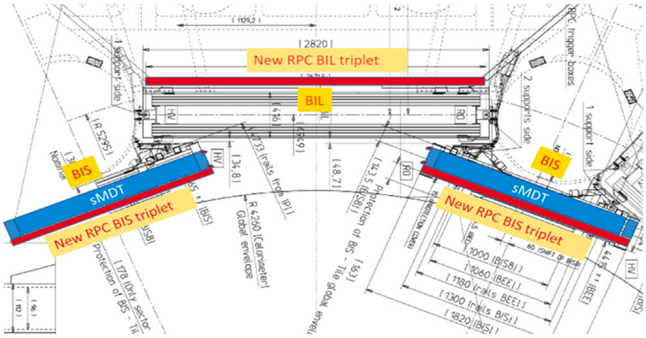

Fig. 1. Schematics of the new RPC-BI layout: large sector layout in the middle on top of the Monitored Drift Tubes (MDT), while on the edges there are the small sectors with RPC-BI and new small MDT chambers to cope with the lack of space.

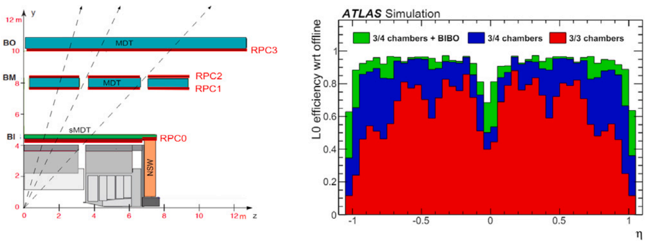

Fig. 2. Left: ATLAS section with three possible muon trajectory: the first has 4 hits (one hit per RPC layer), the second has 3 hits and the last has two hits. Right: Trigger efficiency as a function of the pseudorapidity for the three possible schemes.

- 3/4 chambers + BI-BO: Previous requirement combined with at least two hits in RPC0 and at least one hit in RPC3, enhancing trigger coverage in regions without BM RPCs.

The trigger efficiency for these three schemes is compared, as shown in Fig. 2 (right), and it is higher for the 3/4+BI-BO scheme on a much wider range of pseudorapidity.

The ATLAS Trigger and Data Acquisition system [4] features a two-level trigger system: a first-level trigger (L0) hardware-based that utilizes muon and calorimeter data. L0 muon trigger candidates will be sent to the ATLAS L0 global trigger within a latency of approximately 5 μs, with readout buffers accommodating a maximum latency of 10 μs. This extended latency allows for more complex trigger algorithms compared to the current Run 3 setup. Ultimately a high-level trigger, which is software-based, receives from the L0 trigger and processes events with a rate of 1 MHz.

3. Readout electronics

The Data Collector and Transmitter (DCT) board interfaces with RPC Front-End boards and is based on FPGA [5]. It receives trigger, timing, and control signals from barrel Sector Logic board through optical fiber and transmits zero-suppressed detector hit data to Sector Logic via a different optical fiber. A total of 1096 DCT boards will be installed in the barrel as follows: 272 for BI, 424 for BM and 400 for BO connected to 32 off-detector Sector Logic boards. There will be two types of DCT: the DCT-BM/BO will substitute the present on-detector trigger and readout electronics which is not compatible with Phase-II requirements. The DCT-BI has an FPGA that decodes TDC input data before performing zero-suppression logic. The output data format remains consistent with BM/BO but the new BI front-end electronics feature internal TDC embedded in Front-End ASIC with 100 ps time resolution.

4. Power system

MDT, RPC, and Thin Gap Chambers detectors are equipped with low-voltage (LV) and high-voltage (HV) power systems from the EASY 3000 family by CAEN. These systems were tested up to accumulated radiation doses equivalent to 1500 fb^{-1}, approximately half the expected total dose at the HL-LHC. Combination of ageing, irradiation, and component obsolescence will pose significant challenges for maintenance up to 2035–2040 and thus it is foreseen a complete replacement of the Muon Power System during Long Shutdown 3, with new EASY Crate and new branch controller to communicate also with the new LV modules for the RPC-BI electronics.

5. Conclusions

Upgrades to the Muon Spectrometer are crucial for maintaining performance under the high-rate, high-luminosity conditions of the HL-LHC. Trigger systems are being upgraded to cope with increased luminosity and maintain low trigger thresholds using evolutionary schemes with two-level triggers for improved performance and adaptability. Also replacement of on-detector trigger and readout electronics is essential for compatibility with Phase-II requirements and the upgrade to the original power system will address the challenges of ageing, irradiation, and component obsolescence.

Declaration of competing interest

No author associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Gregorio Falsetti reports financial support was provided by National Institute of Nuclear Physics. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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