The ATLAS RPC upgrade project for the High Luminosity LHC program

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Abstract

The present ATLAS RPC system is a 3D+time tracking detector providing the first level trigger in the ATLAS barrel. It is constituted by 6 concentric cylindrical layers providing independent space-time measurements along the track, with 1 ns x 1 cm resolution. This system will undergo a major upgrade for the HL-LHC program, consisting in three additional full coverage layers of new generation RPCs, to be installed in the inner barrel region. The new system will extend from about 70% to about 96% the trigger acceptance; add redundancy to the legacy RPC; increase the trigger selectivity and bring the resolution on the particle velocity up to 0.5%, thanks to the increased time resolution and lever arm. The new RPCs are an evolution of the BIS78 RPCs, an ATLAS pilot project installed for the LHC Run3, designed for working at a rate, compatible with Eco-friendly gas mixtures. One sensible feature is the front-end electronics rad-hard chip, based on IHP SiGe BiCMOS technology, and integrating a 100 ps sharp discriminator, 70 ps TDC and 4 GBPS serial encoder, all working at 150 ns of fixed latency compatibly with the fastest ATLAS muon trigger. The project is in advanced design phase aiming to build final prototypes, to start the construction in 2022. In the present contribution the detailed project design, features, along with the first results of the official prototypes will be illustrated.

Keywords: Muon Spectrometer, ATLAS-RPC Upgrade, RPC Phase-2 Project

1. Introduction

The High Luminosity Large Hadron Collider (HL-LHC) is an upgraded version of the LHC, with an integrated luminosity larger than the LHC's design value by a factor of 10. The instantaneous luminosity will increase up to 5-7 x 10^{34} cm^{2} s^{-1} (nominal LHC luminosity: 10^{34} cm^{2} s^{-1}), and the expected integrated luminosity will be 4000 fb^{-1}. Such significant increase in luminosity will make it possible to generate more data in the detectors and therefore to probe beyond the Standard Model physics such as observation of rare processes, search for supersymmetric particles, dark matter and the electroweak symmetry breaking. The ATLAS upgrade takes shape in two phases: Phase-1 in Long Shutdown-2 (LS2) that is planned to be finalized in 2022, and Phase-2 in LS3, which is expected in 2026. Although most of the existing components of the ATLAS [1] will remain in place, ATLAS Muon upgrade program in view of HL-LHC will imply a substantial upgrade of the muon trigger system in order to maintain high efficiency and selectivity for the muons with $p_T > 20$ GeV and to keep the rate of fake triggers under control.

An upgrade plan, which consists of 2 projects, has been proposed for the ATLAS Resistive Plate Chambers (ATLAS-RPC), the trigger detectors of the ATLAS barrel. While the BIS78 Project in Phase-1 is staged in a smaller pilot upgrade, the BI Project in Phase-2 will target the whole inner barrel. The proposed upgrade will increase the muon trigger barrel acceptance from 70% to about 96%, and its redundancy by adding 3 new independent tracking layers in the inner barrel [2]. This will increase the overall reliability of the RPC system which design was not taking into account the HL-LHC program.

2. Phase-1 BIS78 Project

The primary goal of the Phase-1 upgrade is the replacement of the first endcap station of the Muon Spectrometer with the new small wheel (NSW) detectors composed of Micromegas (MM) and small-strip Thin Gap Chambers (sTGC) [3]. In addition, each legacy Monitoring Drift Tube chamber (MDT) is replaced with the small-diameter tube MDT chamber (sMDT) to recuperate a space for a thin-gap RPC (BIS7 and BIS8) in the barrel inner region.

The BIS78 project, which is considered as a pilot project of the Phase-2 BI upgrade [4], uses a new generation of RPC installed in the edges of the ATLAS muon inner barrel, covering the region of $1.0 < \eta < 1.3$, which is outside of the coverage of the NSW, in order to reduce the fake muon rate. It is important to stress that even though the chambers are installed in the barrel region, they are projective to the endcap trigger chambers and included in the endcap trigger chain.

ATLAS legacy RPCs are certified to operate up to an integrated charge of 0.3 C/cm^2, which corresponds to ten years LHC operation at a counting rate of 100 Hz/cm^2 [5], while the rates expected for HL-LHC can exceed 300 Hz/cm^2, leading to an integrated dose over 30 years ten times higher than the design specification. In order to maintain the RPCs in good working condition, their current should be limited by reducing the

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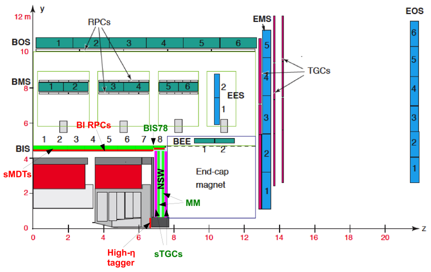
Figure 1: ATLAS-RPC upgrade projects for HL-LHC.



working point, and lowering the single-hit efficiency of about 15% up to 35%.

In 2021, the BIS78 project installed a bunch of 16 innovative RPC triplets coupled with sMDT chambers, using new generation gas gaps and a front-end amplifier [6] and discriminator [7]. The discriminator threshold of 0.3 mV that results in a detectable signal of 1-2 fC, allows to reducing the operating high voltage and the average charge produced inside the gas gap by about an order of magnitude, hence increases the rate capability of the detector as well as improving its lifetime.

Three independent RPC singlets fully enclosed in its Faraday cage also containing the front-end electronics compose a triplet. Each singlet is composed of a 1 mm gas gap with 1.2 mm thick electrodes, that almost halves the current applied voltage and improves the time resolution to 0.4 ns. In addition, thinner electrodes lead to a reduced total thickness and weight. The BIS78 RPC detector integrate a fast (100 ps peaking time) and sensitive (as small as 100 μV threshold) Front-End electronics (FE) with a very large size detector structure.

Table 1: Comparison of the parameters of the legacy RPC and BIS78 RPC [8].

	Standard RPC	**BIS78 RPC**
Effective Threshold	1 mV	0.3 mV
Power Consumption	30 mW	6 mW
Technology	GaAs	BJT Si + SiGe
Gap Width	2 mm	1 mm
Operating Voltage	9600 V	5800 V
Charge x Hit	30 pC	5-7 down to 3 pC
Electrode Thickness	1.8 mm	1.2 mm
Time Resolution	1 ns	0.4 ns
Gaps per Chamber	2	3

The performance of the BIS78 chambers was tested with cosmic muons and the results show that the noise rate is about 0.1 Hz /cm^2, single-gap efficiency is better than 95%, space resolution reaches 1 mm at operating voltage and the time resolution reaches 0.35 ns with the time walk correction [7].

3. Phase-2 BI Project

The Phase-2 BI project [4] consists of the extension of the RPC chambers to the whole ATLAS inner barrel to maximize

Table 2: The parameters of the new amplifier and discriminator of the new generation RPCs [9].

Amplifier in Silicon	
Gain	0.2-0.4 mV/fC
Power Consumption	3-5 V, 1-2 mA
Band Width	100 MHz
Discriminator in SiGe	
Threshold	0.5 mV
Power Consumption	2-3 V, 4-5 mA
Band Width	100 MHz

Figure 2: Noise rate distribution of the BIS78 RPC [10].

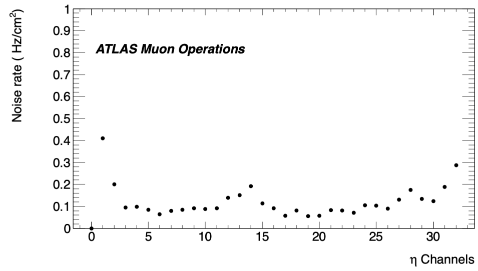


Figure 3: Single gap efficiency of the BIS78 RPC [10].

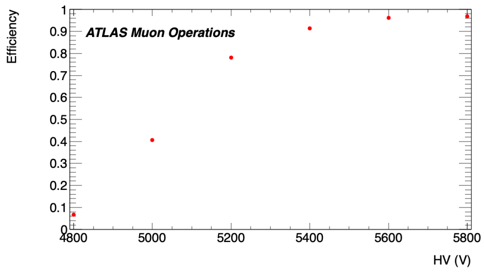
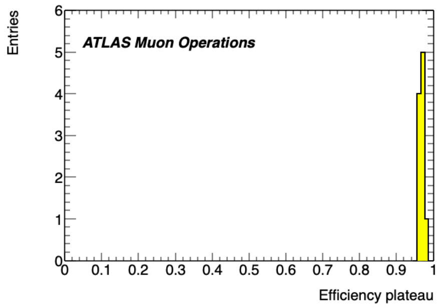


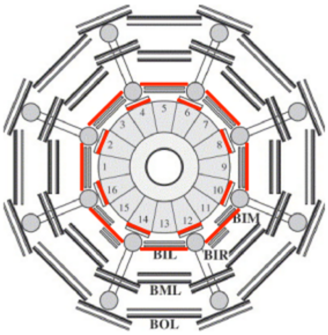
Figure 4: η OR ϕ efficiency of a sample of 10 gas gaps of the BIS78 RPC.



the coverage and increase the trigger redundancy to ensure high performance selectivity and Time of Flight performance thanks to an excellent time resolution of 0.4 ns, hence a long term operation for barrel muon trigger. This project is considered as a solution for the ATLAS barrel, and will inherit most of the BIS78 technology.

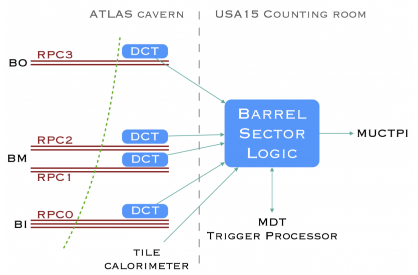
The total High-p_T trigger acceptance is just about 70% in AT-

Figure 5: New generation BI RPC detectors for the Phase-2 upgrade.



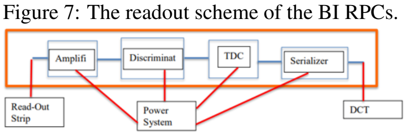
LAS barrel; this limitation is due to the partially instrumented areas such as the ATLAS toroid magnet and services that are mostly affecting the middle and outer barrel, where the RPCs are present. Moreover, the present trigger is composed of 4+2 layers of RPC chambers in ATLAS barrel. This limited redundancy could be a problem for the ageing of the detectors. To overcome these limitations, an additional layer of 300 new generation of RPC triplets will be installed in the inner-barrel layer, and they will be increasing the acceptance up to 96% while lowering the demand on the legacy RPC by using nine measurement layers instead of six.

Figure 6: Scheme of the readout and the trigger logic of ATLAS barrel region.



The most relevant innovation of the BI RPCs will be a new front-end chip designed to exploit the features of the new RPCs. It is based on IHP SiGe BiCMOS technology, and will be integrated with 100 ps rise time discriminator, 70 ps TDC and 4GBPS serializer, working at 150 ns of fixed latency. The new chip provides both leading and trailing edges of the pulse allowing a good estimation of the pulse width. This is useful both to improve time and space precision and to monitor the detector physics.

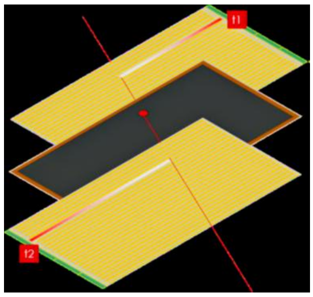
Figure 7: The readout scheme of the BI RPCs.



Besides the FE improvement, the filler material Forex (BIS78) for the strip panels will be replaced with paper honeycomb, which provides a better panel rigidity and saves a significant amount of weight. Furhermore, the input and output gas distribution manifolds embedded in the gas gap are redesigned to improve the uniformity of the gas change inside the gas gap, and the connection point of the HV will be moved from the top to one side of the chamber in order to have a flat surface.

The BI readout logic represents another important innovation: the FE of the two panels will read out the signals of the new RPCs, both in the η direction, obtaining the ϕ coordinate from time difference of the signals at the 2 opposite side of the chamber to determine the incident position. This approach allows a better usage of the limited available space, with a reduced dead area of the detector and a lower number of readout channels. Moreover, the high resolution of the TDC allows 1 cm precision on the second coordinate measurement.

Figure 8: The new readout method of the BI RPCs.



4. Summary

The steps of the ATLAS RPC upgrade towards the HL-LHC have been well defined for the production of the new generation RPCs. As a pilot project, the BIS78 ATLAS Side-A production for Phase-I was completed and the chambers were integrated into the ATLAS detector in 2021. In addition, there are ongoing studies for the commissioning of the BIS78 chambers in the ATLAS cavern. Phase-2 BI chamber pre-production is ongoing in all the aspects.

References

[1] A. Collaboration, The Atlas Collaboration, JINST 3 (2008) S08003.

[2] A. Collaboration, Technical Design Report for the Phase-1 Upgrade of the ATLAS TDAQ System, Tech. Rep. CERN-LHCC-2013-018. URL `https://cds.cern.ch/record/1602235`

[3] A. Collaboration, New Small Wheel Technical Design Report, Tech. Rep. CERN-LHCC-2013-006. URL `http://cdsweb.cern.ch/record/1552862`

[4] A. Collaboration, Technical Design Report for the for the Phase-2 Upgrade of the ATLAS Muon Spectrometer, Tech. Rep. CERN-LHCC-2017-017. URL `https://cds.cern.ch/record/2285580`

[5] G. Aielli, New results on ATLAS RPC's aging at CERN's GIF, IEEE Trans. Nucl. Sci. 53 (2) (2006) 567–571.

[6] R. C. et al., Performance of RPCs and diamond detectors using a new very fast low noise preamplifier, JINST 8 (01) (2013) P01003.

[7] L. P. et al., Development of a new front end electronics in Si and SiGe technology for the Resistive Plate Chamber detector for high rate experiments, JINST 14 (10) (2019) C10010.

[8] A. Collaboration, Performance of the BIS78 RPC detectors: a new conceptof electronics and detector integration for high-rate andfast timing large size RPCs, ATL-MUON-PROC-2020-012.
URL `https://cds.cern.ch/record/2720934`

[9] L. Massa, The BIS78 Resistive Plate Chambers upgrade of the ATLAS Muon Spectrometer for the LHC Run-3, JINST 15 (2020) C10026.

[10] A. Collaboration, Certification of a new generation of Resistive Plate Chambers for the Phase-1 BIS78 upgrade of the ATLAS Muon Spectrometer, ATL-MUON-PROC-2021-002.
URL `https://cds.cern.ch/record/2774103`