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The ATLAS Muon Spectrometer Upgrade for HL-LHC

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Summary. — The ATLAS Muon Spectrometer will be heavily modified during the operation shutdown forseen in 2024–2026, for the high-luminosity program of LHC. The trigger and data acquisition system will be completely redesigned, to cope with a level-0 trigger frequency of 1 MHz, and all the readout electronics will be replaced. New generation RPCs and MDTs will be installed in the inner barrel layer, while new TGC triplets will be installed in the transition region ($1 < |\eta| < 1.3$). A major upgrade of the power system is also foreseen. This upgrade will complete the spectrometer adjustment to the increasing performances of LHC, started with the New Small Wheel project.

1. – The HL-LHC program

During the HL-LHC program forseen to start in 2026, LHC will have a maximum luminosity $L = 7.5 \cdot 10^{34}\text{cm}^{-2}\text{s}^{-1}$, and a maximum pile-up $\mu = 200$, with the aim of recording between 3000 and 4000 fb^{-1}. During this new phase, it will be possible to make precision measurements of the Higgs boson properties, in all its production and decay channels, as well as to study rare processes and search for Beyond Standard Model phenomena. To record a large statistics of such rare events, it is fundamental to trigger muons with a momentum of 20 GeV, making a level-0 trigger with a frequency of 1 MHz necessary, while the current system would be able to trigger only muons with a momentum greater than 50 GeV at the HL-LHC conditions.

Hence, an upgrade of the ATLAS Muon Spectrometer [1] is needed. Before the HL-LHC program, two other improvements are already forseen between 2019 and 2020: the trigger and tracking systems will be upgraded in the $|\eta| > 1.3$ region by replacing the inner layer of the End Cap with the New Small Wheel [2], and in the transition region ($1 < |\eta| < 1.3$) by adding new RPC triplets in the inner layer of the barrel, for the BIS78 project [3]. However, other important changes are still necessary [4].

2. – Upgrade of the ATLAS Muon Spectrometer

It is not possible to have a level-0 trigger that handles a 1 MHz frequency, using the electronics currently mounted in ATLAS; hence, the DAQ and readout electronics will be replaced in all the detectors. The new trigger is designed to be more robust, simple and flexible, calculating coincidences with programmable external FPGAs instead of custom ASICs on detectors. Finally, the information from the precision chambers will be added to the new trigger, making it more redundant and sharpening the momentum threshold efficiency.

To ensure the aimed performances, new detectors also need to be installed. New generation RPC triplets will be installed in the inner barrel (BI) region, to enlarge the acceptance and the efficiency of the trigger. In the same region, to make space for the new RPCs, the MDTs built on top of the toroid will be replaced by thinner-diameter MDTs. In the transition region new triplets of TGCs will replace the present doublets, to reduce the fake trigger rate. It is also possible that a new high-η tagger will be added in the $2.7 < |\eta| < 4.0$ region. Finally, the entire power system for low and high voltages will be replaced.

3. – RPC BI project

Among the projects which are forseen by the upgrade program, the one involving the RPCs is particularly complex. During the HL-LHC program, the present ATLAS RPCs will have to work beyond their safety limits of integrated charge. In order to be operative even at a higher-luminosity regime, these RPCs will have to work at lower tensions, with a resulting efficiency to 80%. To recover this loss and to increase the trigger selectivity, the BI region will be covered by 272 triplets of new-generation RPCs. In the transition region, 32 new triplets will be already installed in 2019 for the BIS78 project. This addition will increase the redundancy (passing from 6 to 9 layers of detectors), the lever-arm (passing from 2.3 m to 4.5 m) and the geometrical acceptance (passing from 80% to 96%) of the system. The resulting trigger will look for coincidences of 3 chambers out of 4 (instead of 3 out of 3) being fully efficient at the luminosities forseen for HL-LHC, even using the present RPCs at 70–80% efficiency.

3˙1. *The new generation of RPCs.* – A new generation of RPCs has been developed and will be used to make the BI triplets. The new gas gaps and the electrodes will be both 1 mm thick (instead of 2 mm gas gaps and 1.8 mm electrodes for the present RPCs), leading to several improvements. First of all, the detector efficiency is reached with a lower applied high voltage (5.4 kV instead of 9.6 kV), as can be seen in fig. 1 (left) [4]. In addition, the time resolution is improved, passing from 1 ns to less then 0.4 ns. Finally, these new dimensions lead to other important improvements in terms of weight and size of the detector, signal collection efficiency and charge distribution.

The Front End electronics of the new generation of RPCs will be developed in SiGe BiCMOS technology, leading to several advantages with respect to the present RPCs: better aging, radiation hardness and space-time resolution, and low consumption with high performances, allowing low-noise operations even if the electronics is mounted on the detector. The final goal will be to integrate all the Front End electronics components (amplifier, discriminator, TDC and serializer) into one single ASIC.

A prototype of a new TDC together with a serializer, with a time resolution of 100 ps, has been developed, to enhance the features of the new RPCs allowing charge

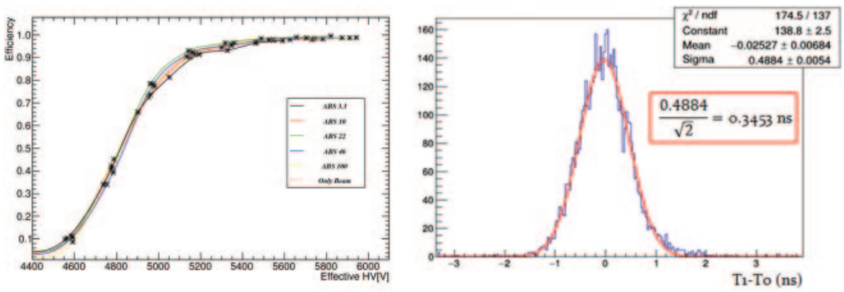

Fig. 1. – Left: the efficiency plateau for a 1 mm gap RPC irradiated at the CERN GIF++ with different intensities [4]. Right: time resolution obtained with a 1 mm gap RPC and the new discriminator [6].

measurements through the Time-Over-Threshold method. The intrinsic jitter of the prototye has been measured to be $\sigma_{VCO} = \frac{\sigma}{\sqrt{2}} = 10.77$ ps [5].

A prototype of the new discriminator in SiGe BiCMOS technology has been already produced and tested with a test beam at CERN in October 2017, obtaining a time resolution of 0.35 ns once the time-walk corrections are applied, which is the best result ever obtained with a 1 mm gap RPC [6] (fig. 1 (right)).

4. – Conclusions

In order to guarantee suitable performances in the HL-LHC phase, many upgrades of the Muon Spectrometer are forseen, completing what is already in development with the New Small Wheel and the BIS78 installation.

In order to improve the trigger selectivity 272 triplets of new generation of RPC will be added in the inner layer of the barrel.

Research has developed new detectors having high efficiency already at 5.4 kV of applied high voltage and a time resolution of some hundreds of ps, establishing new standards for RPCs in hadron colliders.

Any additional information can be found in the Technical Design Report [4].

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