PROCEEDINGS OF SCIENCE

Performance of the ATLAS RPC detector and L1 Muon Barrel trigger at 13 TeV

Marco Sessa, on behalf of the ATLAS Muon Collaboration

Università degli Studi Roma Tre & INFN Sezione di Roma Tre,
Via della Vasca Navale 84, Rome, Italy

E-mail: marco.sessa@cern.ch

Resistive Plate Chambers (RPCs) are fast gaseous detectors that are employed by the Level-1 muon trigger system in the barrel region of the ATLAS muon spectrometer. The Level-1 muon trigger system selects muon candidates produced in proton-proton collisions at the Large Hadron Collider (LHC). Muon candidates are associated by the Level-1 system with the correct LHC bunch crossing and assigned to one of the six transverse momentum thresholds. The RPCs are arranged in three concentric double layers and consist of approximately 3700 gas volumes, with a total surface of more than 4000 m^2. They operate in a toroidal magnetic field of approximately 0.5 T and provide up to 6 position measurements along the muon trajectory, with a space-time resolution of about 2 cm $\times$ 2 ns. This contribution will discuss performance of the RPC detector and Level-1 muon barrel trigger system measured using proton-proton collision data at a centre-of-mass energy of 13 TeV. New measurements of RPC cluster size, detector efficiency and time resolution will be presented. Trigger efficiency, measured using Z boson decays to a muon pair, and trigger rate measurements will be summarised, as well as the composition of the accepted RPC muon candidates. Measurements of RPC currents as a function of the voltage and of the environmental parameters will be also presented, both with and without beams in the LHC. Similarly, RPC background counting rates are measured as a function of the instantaneous luminosity up to 2×10^{34} cm^{-2} s^{-1}. Measurements of the average avalanche charge for background events will be also presented. Finally, results of the extrapolations of the RPC detector response to the expected luminosity of the High Luminosity LHC will be shown.

ATL-MUON-PROC-2021-004
20 September 2021

PoS(EPS-HEP2021)750

**** The European Physical Society Conference on High Energy Physics (EPS-HEP2021), ****
**** 26-30 July 2021 ****
**** Online conference, jointly organized by Universität Hamburg and the research center DESY ****

1. The ATLAS RPCs and the Level-1 Muon Barrel Trigger System

The barrel region of the Muon Spectrometer (MS) of the ATLAS experiment [1] at the Large Hadron Collider (LHC) covers a pseudo-rapidity [1] range up to $|\eta| < 1.05$ and it employs Resistive Plate Chambers (RPCs) [2] for triggering events containing muons.

RPCs cover a surface area of about 4000 m^2; they are arranged in three concentric layers and are divided in 16 sectors (organized in 8 small and 8 large sectors) along the azimuthal coordinate. The innermost stations, RPC1 and RPC2, are located in the Medium Layer of the MS, while the third station, RPC3, is located in the Outer Layer. Each RPC detector consists of two gas gaps (2 mm width), read out by two orthogonal planes of strips, called panels, in η and ϕ views, with a pitch of $23 - 35$ mm. The RPCs are continuously flushed with a gas mixture of $C_2H_2F_4$(94.7%)–C_4H_{10}(5%)–SF_6(0.3%). This mixture includes a quencher component (C_4H_{10}) that helps to avoid propagation of the discharge and an electronegative component (SF_6) that helps to limit the growth of avalanches.

The Level-1 (L1) muon barrel trigger algorithm is based on the coincidence of hits in the three concentric RPC stations (both in η and ϕ projections). Two different trigger regimes exist:

- the **low-p_T trigger** requires a coincidence between the innermost two RPC stations (RPC1 and RPC2). It is used to select muons with p_T above the three thresholds of 4 GeV, 6 GeV and 10 GeV (called MU4, MU6 and MU10 respectively);
- the **high-p_T trigger** requires an additional confirmation on the third external station (RPC3) and selects muons with p_T above the thresholds of 10 GeV (called MU11, to be distinguished from MU10) and 20 GeV (MU20). A third high-p_T threshold, MU21, is defined in such a way the muon transverse momentum requirement is the same of MU20 but the trigger signals from some RPC chambers, located in sectors 12 and 14 (two small sectors located in the bottom region of the ATLAS detector), are not taken into account [2].

2. RPC detector performance

The detector response of ATLAS RPCs is studied using offline muon tracks, reconstructed by the ATLAS software and extrapolated to the surface of each RPC detector with the goal to compute the expected muon position on the read-out strip panels, both in η and ϕ views.

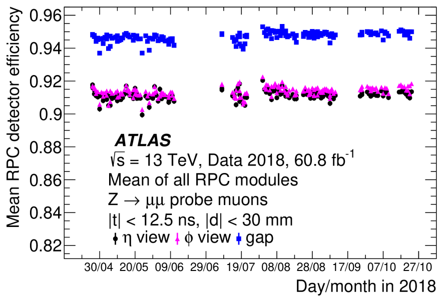
The RPC detector efficiency is defined for each read-out strip panel as the ratio between the number of hits associated to a muon track and all the reconstructed muon tracks passing through that panel. It is measured in each ATLAS run in 2018 and found to be stable across the whole year. The average panel efficiency is measured to be approximately 91%, for both η and ϕ strip panels, as shown in Figure 1a. The gas gap efficiency is computed by requiring at least one hit either in η or ϕ strips belonging to the same RPC module and it is measured to be about 94%.

The time resolution of the RPC detector is measured to be approximately 1.5 ns, as shown in Figure 1b, where the mean value of the distribution of the widths of the Gaussian fits to the total

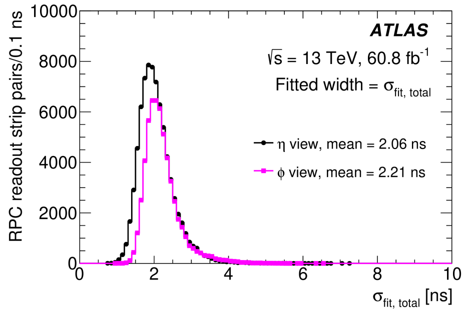
[1]ATLAS experiment uses a right-handed coordinate system. The origin of the system is in the nominal proton-proton interaction point, set in the center of the ATLAS detector. The z-axis is along the beam line, while the xy plane is the plane perpendicular with respect to the beam line. The positive x-axis is defined as pointing from the interaction point to the centre of the LHC ring and the positive y-axis is defined as pointing upwards.

PoS(EPS-HEP2021)750

time difference distributions of all selected RPC strip pairs, belonging to two different modules, has to be divided by $\sqrt{2}$ to get the time resolution of one single RPC module. The intrinsic time resolution and the time resolution of RPC electronics are also evaluated separately and measured to be approximately 1.1 ns each. The fast response and the good time resolution make the RPC technology suitable for the muon trigger of the ATLAS experiment.



(a)



(b)

Figure 1: (a) Muon detection efficiency for η and ϕ strip panels, averaged over all active RPC modules plotted as a function of time [2]. (b) Distribution of the widths of the Gaussian fits to the total time difference distributions of all selected RPC strip pairs. The RPC total time resolution is obtained dividing the mean value of the time difference distribution by $\sqrt{2}$ [2].

3. Measurements of RPC currents and counting rates

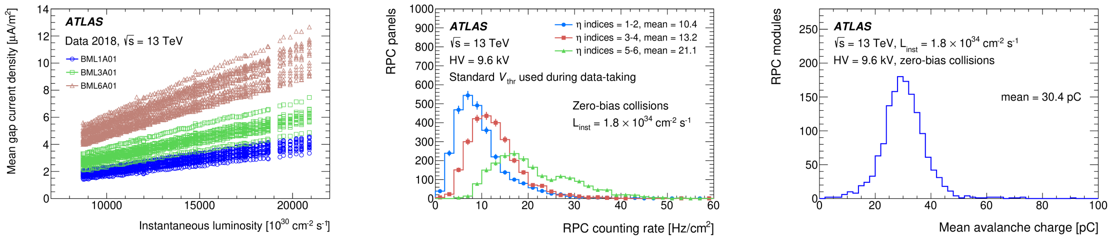
RPC current density is used to check the stability of the detector as function of the instantaneous luminosity. An expected linear increase of gap current densities is observed up to $2.1{\times}10^{34}$ cm^{-2} s^{-1}, with RPCs working smoothly, as shown in Figure 2a.

The distributions of RPC counting rates at an instantaneous luminosity of 1.8×10^{34} cm^{-2} s^{-1} are presented in Figure 2b, where RPC panels in each station are separated into three sets of chambers in different η ranges. Because the flux of ionising particles increases at higher η values, panels located in the more forward regions of the MS measure higher counting rates.

Mean avalanche charge per single hit is also measured for all RPC modules by the ratio between the current and the counting rate. Its value is found to be approximately 30 pC, as shown in Figure 2c.

4. L1 muon barrel trigger performance

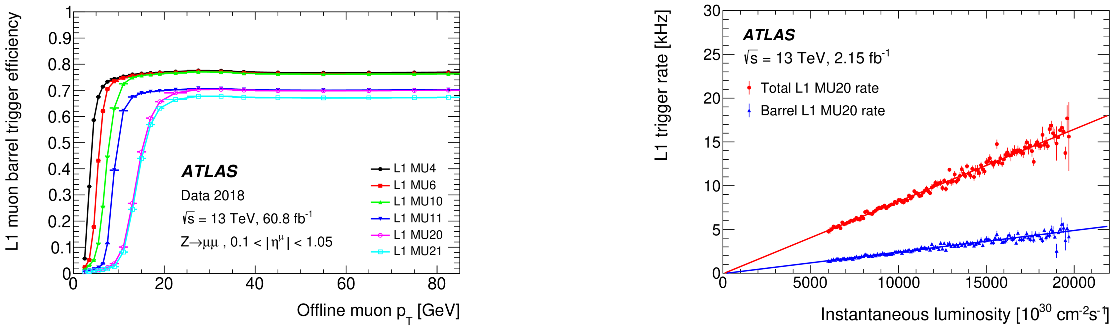
Trigger efficiency is one of the key parameters to evaluate the performance of the L1 muon barrel trigger and for this purpose it has been monitored continuously during the data-taking. Unbiased muons from Z boson decays are used to compute the trigger efficiency using the *Tag&Probe* [3] method. Figure 3a shows the muon barrel trigger efficiency as a function of the probe muon transverse momentum, for six trigger thresholds: three for low transverse momentum muons, which require a coincidence of hits between the two inner RPC stations, and three for high transverse momentum muons, with a further coincidence on the outer RPC station. The trigger efficiency is measured to be approximately 77% for L1 MU10 and 70% for L1 MU20 trigger thresholds, where the main limitation comes from the detector services and detector support structures



(a) (b) (c)

Figure 2: (a) RPC current density shown as a function of instantaneous luminosity for several representative modules [2]. (b) Distribution of the RPC counting rates per unit surface area for all RPC panels, separated into three sets of chambers in different pseudo-rapidity regions at 1.8×10^{34} cm^{-2} s^{-1} [2]. (c) Distribution of the mean avalanche charge of the ATLAS RPC detector [2].

The L1 muon trigger rates are measured as a function of the LHC instantaneous luminosity, as shown in Figure 3b. L1 MU20 trigger rate contributes with approximately 15% to the 100 kHz Level 1 trigger bandwidth at the highest luminosity value of Run 2. At the highest luminosity value reached in Run 2, the L1 MU20 trigger rate from the barrel region only is found to be approximately 5 kHz.



(a) (b)

Figure 3: (a) L1 muon barrel trigger efficiency as a function of the probe muon transverse momentum [2]. (b) Rates of MU20 L1 triggers as a function of the instantaneous luminosity [2].

References

[1] ATLAS collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, Journal of Instrumentation 3 (2008) S08003 - DOI:10.1088/1748-0221/3/08/S08003

[2] ATLAS collaboration, Performance of the ATLAS RPC detector and Level-1 muon barrel trigger at $\sqrt{s}$ = 13 TeV, JINST 16 (2021) P07029, DOI:10.1088/1748-0221/16/07/P07029

[3] ATLAS collaboration, Muon reconstruction performance of the ATLAS detector in proton–proton collision data at $\sqrt{s}$ = 13 TeV, Eur. Phys. J. C 76 (2016) 292 - DOI:10.1140/epjc/s10052-016-4120-y