Status of the present ATLAS RPC system and overview towards HL-LHC

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Abstract

The Resistive Plate Chamber (RPC) system covers the barrel region of the ATLAS muon spectrometer [1] in the pseudo-rapidity range $|\eta| < 1.05$, with six independent detector layers exclusively providing the first level trigger signal and the track coordinate in the non-bending plane of the muon candidates. The system is designed to operate up to the nominal Large Hadron Collider luminosity ($\mathcal{L} = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$) which has been already exceeded thanks to the excellent performance of the collider. The experience in operating the present RPC system, up to the maximum instantaneous luminosity of $2.06 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ reached in 2017, is reported. The performance of the system, in the severe background and pileup conditions of the last data taking period, is presented together with the improved tools implemented in order to have an effective monitoring of the detector status. The plans to successfully operate the present system during the HL-LHC phase are also introduced.

Keywords: Resistive-plate chambers, Muon spectrometers

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1 Introduction

In 2017 the Large Hadron Collider has provided proton-proton collisions at a center of mass energy of 13 TeV with instantaneous luminosities up to $2.06 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, totaling an integrated luminosity of 50.4 fb^{-1} . This document presents the performance and the operational experience of the detector in this period of time and a brief overview of the upgrade activities for the High Luminosity phase of LHC. The document is organized as follows: after a short description of the ATLAS Resistive Plate Chambers (RPCs) in Section 2, the detector status and performance with details of operational experience are presented (Section 3). The improvements and upgrade activities in view of the High-Luminosity LHC phase are described in Section 4, finally some concluding remarks and outlook are given in Section 5.

2 The ATLAS Resistive Plate Chambers

RPCs [2] provide the barrel region of the ATLAS detector [3] with an independent muon trigger and a two-coordinate measurement. The chambers, arranged in three concentric double layers (middle confirm, pivot, outer confirm) are operated in a strong magnetic toroidal field and cover a surface area of about 4000 m^2 . A low p_T ($< 10 \text{ GeV}$) trigger requires a projective coincidence between hits in the pivot and the middle confirm layer while high p_T triggers require an additional hit in the outer confirm layer. An ATLAS RPC chamber is made of two layers, each with two 2 mm thick bakelite laminate plates and providing two η and two ϕ readout strip planes (see Fig.1). Made of phenolic and melaminic resins, the plates are kept apart at 2 mm by insulating spacers, enclosing a gas volume filled with a mixture of $\text{C}_2\text{H}_2\text{F}_4$ (94.7%) - C_4H_{10} (5%) - SF_6 (0.3%). The external surface of the plates is coated with a thin layer of graphite paint to allow a uniform distribution of the high voltage along the plates. The smoothness of the inner

Figure 1: A single gap RPC structure

surfaces is enhanced by means of a thin layer of linseed oil. The high voltage (HV) working point is chosen to be at 9.6 kV at a temperature of 24°C and a pressure of 970 mbar. In these conditions the RPCs work in saturated avalanche mode, inducing, for a minimum ionizing particle, a prompt charge of about 1 pC on the pick-up strips and delivering an average total charge of 30 pC in the gas. The discharge electrons drift in the gas and the signal, induced on pick-up copper strips, is read out via capacitive coupling, and detected by the front-end electronics. Read-out strips have a typical width of ~ 30 mm and are grouped in two (η and ϕ) read-out panels with strips orthogonal to each other. Custom front-end electronics amplifies, discriminates and converts the detector signals to ECL standard. These signals are transmitted to the on-detector trigger electronics [4] which, by requiring appropriate coincidences in the η and ϕ detector layers, provide ATLAS with a Level 1 trigger decision along with the detector data for accepted events.

3 Detector Status and Operation

RPC performance

In 2017 LHC provided proton-proton collisions at center of mass energy $\sqrt{s} = 13$ TeV with 25 ns bunch spacing. The peak instantaneous luminosity was $2.06 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$ and the peak number of collisions per bunch crossing (pile-up) was about 80. The 2017 full dataset is made of a delivered integrated luminosity of 50.4fb^{-1} a recorded integrated luminosity of 46.8fb^{-1} out of which 43.8fb^{-1} were considered good for physics analysis. The 2017 data taking has been very successful for the RPC system which has been running with a fraction of up-time and good data quality efficiency of 97.8%. The number of gas volumes either disconnected or operated not at nominal conditions has been around 6% with 239 total disconnected gaps (out of 3714), out of which 152 were disconnected on chamber, 83 on rack (partially recoverable during Technical Stops) and 4 kept at low voltage for recovery

due to bad gas supply or too high currents. During 2017 three main hardware issues were responsible for the RPC down time: a power crate failure affecting one (out of 100) Caen Easy crate; a Caen Power Supply mainframe failure, stopping one RPC quadrant; some power supply glitches, due to the muon common system infrastructure, causing the main part of the RPC down time.

Detector Control System

ATLAS RPCs are monitored and operated through the Detector Control System (DCS) which is coherently integrated in the muon system so that a single shifter can operate and monitor all the muon sub-detectors. Several automatic monitoring and control tools to simplify the detector operation and optimize the data taking conditions. One important feature is the full automatic control of the HV settings, which are automatically adjusted in order to follow the different LHC beam phases from injection, stable beams, to the final dump; to compensate for the local changes of the environmental conditions (mainly local temperature and atmospheric pressure); to automatically check the individual gas-gaps currents, recalibrate at each end of fill the pedestals and finally to provide an online measurement of the cavern background rates and an instantaneous luminosity. The DCS is in charge of safely operating and monitoring the detector power system including the detector HV and LV supply. In the RPC DCS [5], a large number of settings (DAC ~ 4000) and monitoring (ADC ~ 6500) channels have been integrated into the system in order to optimize the detector performance and allow a fine monitoring at the level of the single individual RPC gas gap (~ 3600). The remaining ADC channels are used to monitor with high granularity the current draw of the front end electronics and RPC gas and environmental sensors (temperature, atmospheric pressure, relative humidity and gas flow). The ability to control by tuning thresholds, and monitoring the current of each RPC gap has shown to be very powerful for the detector operation both for tracing problems and fine tune the detector. This is particularly important as the RPC performance and aging is strongly related to the environmental parameters, namely the temperature (T), the atmospheric pressure (P), and the relative humidity. The gas gain, the noise rate and the dark current of the chamber depend on these parameters following the formula: $V_{\text{appl}} = V_{\text{eff}} \cdot (T_0/T) \cdot (P/P_0)$ where V_{appl} is the applied voltage, T , P are the environment measurements and T_0 , P_0 , V_{eff} are the reference environmental values and HV settings.

Technical Issues

During the years of operation, some gas volume inlets have developed fractures or complete breakups. This issue is currently affecting about 6% of

Figure 2: A partial crack of the gas inlet sealed by sprayed glue

Figure 3: A flowmeter used for single chamber gas output online monitoring

gas gaps and is intensely investigated, as it is responsible for most of the RPCs inefficiency. As most of the volumes can be operated normally, a repair campaign is ongoing. The type of intervention depends on the crack features: if the inlet is completely broken a substitution procedure must be done. On the other hand, if the inlet has developed only a partial fracture, it is possible to intervene by spraying glue on the break, building a sealing membrane (see Fig.2). In the past years many tests both on the procedure for the glue spraying and on the choice of the particular glue to be used have undergone, so that now the procedure is very solid and the results very reliable. In order to provide online monitoring of the gas flow through individual chambers, starting on the end of 2016, 1200 flowmeters (see Fig.3) have been installed at the gas output of the RPCs. The flowmeter readings are fully integrated in the DCS through ADCs (see Fig.4) and are monitored with automatic alarms. It is thus possible to promptly identify the single chamber leaks at a very early stage, allowing a rapid intervention at a time

Figure 4: ADC readings of chamber's output flow through gas flowmeters, each color representing the flow of a single RPC

when the reparation is easier. A good news for the year 2018 comes from the fact that, taking into account the experience from previous years when a large increase of the gas leaks after the system restart (after the winter shutdown) was observed, the decision not to stop the gas system was taken. At the 2018 operation restart no increase in the gas leak was observed (see Fig.5), allowing for the possibility to start the repair campaign from a better portion than last years.

Figure 5: Fresh gas consumption rate since July 2014

Sector	RPC unit Id. along Z direction																					Average
# Id.	-6.2	-6.1	-5.0	-4.0	-3.2	-3.1	-2.2	-2.1	-1.2	-1.1	1.1	1.2	2.1	2.2	3.1	3.2	4.0	5.0	6.1	6.2		
01.01	342	280	301	225	145	114	128	101		61	61	71	113	122	127	136	214	276	269	285	180	
01.02	293	281	303	218	159	133	129	143		76	71	75	127	143	140	148	215	295	278	297	188	
2	168	204	188	138	109	90	77	63	55	56	45	48	61	79	94	104	140	207	196	152	115	
03.01	297	296	281	198	148	128	119	119	68	67	65	71	131	125	114	125	207	329	268	290	177	
03.02	300	243	277	210	151	129	155	122	85	75	75	70	122	127	152	132	207	315	243	299	179	
4	112	166	158	151	101	83	65	77	41	53	46	41	73	68	92	108	160	196	175	112	101	
05.01	171	173	263	138	105	102	140	127	68	60	69	124	177	102	137	185	290	173	171		149	
05.02	227	198	237	158	109	105	136	143	77	61	63	71	111	136	108	141	200	267	255	282	159	
6	175	186	208	163	105	95	90	95	77	59	52	59	84	81	106	124	189	200	227	167	131	
07.01	305	263	288	191	154	129	131	114		76	78		122	139	124	148	185	261	268	305	183	
07.02	327	258	216	203	141	112	129	108		74	77		105	114	112	152	184	278	276	279	175	
8	146	196	195	161	103	85	80	70	50	57	54	54	67	74	85	108	168	196	194	156	118	
09.01	319	246	301	206	155	117	149	119		46	64		106	134	124	135	197	283	262	297	181	
09.02	347	258	287	205	143	95	107	103		58	67		99	112	95	137	188	285	265	292	174	
10	174	201	207	147	99	86	68	71	46	43	41	50	64	69	80	103	148	193	201	170	115	
11.01	308	244	237	157	97	84	81	87		40	43		83	94	92	94	148	227	215	278	132	
11.02	196	193	157	105	78	66	55	57		33	31		50	62	58	71	98	151	160	185	98	
12					80	81	66	51	36	36	51	75	87	80							64	
13.01	291	278	253		140	102	96	84	43	41	47	50	87	95	99	123		249	263	319	149	
13.02	299	264	262		104	97	105	86	49	48	50	56	93	103	97	110		252	227	294	146	
14					142	68	64	52	41	40	49	63	68	136							76	
15.01	196	221	148	113	76	71	67	49		38	36		50	59	86	87	104	156	173	196	104	
15.02	183	159	246	164	116	98	103	75		44	43		75	106	112	107	158	248	159	183	133	
16	173	214	216	173	108	89	54	75	56	59	50	50	77	54	87	103	177	209	208	154	124	
Average	229	223	234	167	118	101	96	88	56	52	51	56	86	97	103	118	171	240	221	221	137	

Figure 6: Averaged RPC hit rates in BM chambers measured in Run1 and extrapolated (including a safety factor of two) to a luminosity of $7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. The plot shows rates in Hz / cm^2 as a function of the ϕ sector (vertical axis) and the station number along Z (horizontal axis). The rates have been derived from detector currents by applying a conversion factor of 30 pC / hit [8]

Figure 7: The region affected by a loss of efficiency in the BML6 and BML6 chambers [8]

4 Overview towards HL-LHC

ATLAS RPCs are certified for 10 years of operation at a luminosity of $10^{34} \text{cm}^{-2} \text{s}^{-1}$ with a rate of 100 Hz cm^{-2} for a total integrated charge of 0.3 C cm^{-2} . The counting rates at the High Luminosity phase of LHC will exceed this limit, for example the rate at $|\eta| = 1$ will be about 300 Hz cm^{-2} (see Fig.6). Moreover the extent of the running time from 10 years to 30 years will bring the integrated charge to 0.48 C cm^{-2} at $|\eta| = 1$ for an integrated luminosity of 4000 fb^{-1} . As a consequence the charge per count of 30 pC / hit must be reduced in order to compensate the increase in the rate (see [8]). This would nonetheless lower the single-gap efficiency of 15% on average and of 35% at large η . The BIS 7/8 upgrade project and the BI upgrade project are presented in [6, 7], so the focus here is on the BO refurbishment project. The basic idea is that the reduction of trigger efficiency at $|\eta| > 0.8$ can be recovered by refurbishing a limited number of BO chambers by replacing the front-end electronics and the readout strip panels, as shown in Fig.7. This can be done during the long shutdown of 2019-2020.

5 Conclusions

The ATLAS RPCs have very successfully operated during 2017, maintaining high efficiency and high data quality over the whole period. A few technical issues have been promptly tackled and absorbed by the system redundancy without considerable effects on the data taking as the RPCs are the only system with trigger capability in the barrel region of the muon spectrometer. The consolidation and upgrade works will ensure the ATLAS RPCs will be able to exploit at best the luminosity delivered by the Large Hadron Collider in the next years.

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