Performance of the ATLAS RPC detector and Level-1 muon barrel trigger at $\sqrt{s} = 13$ TeV

RPC2020 Workshop - Rome

Heng Li
on behalf of the ATLAS Collaboration

University of Science and Technology of China

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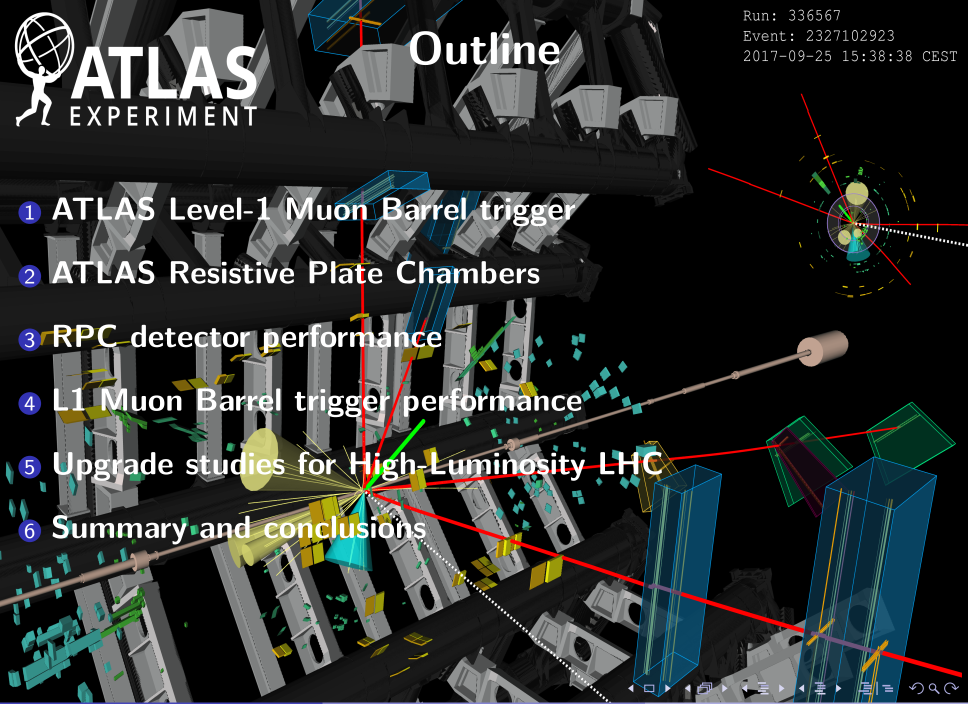
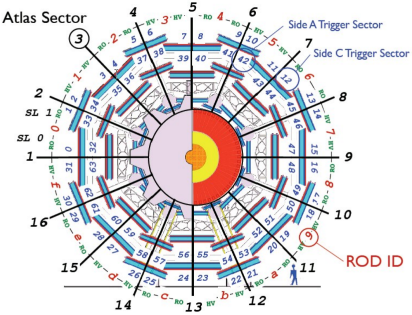


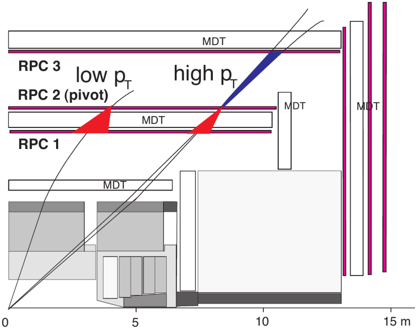
Outline

1. ATLAS Level-1 Muon Barrel trigger
2. ATLAS Resistive Plate Chambers
3. RPC detector performance
4. L1 Muon Barrel trigger performance
5. Upgrade studies for High-Luminosity LHC
6. Summary and conclusions

ATLAS Level-1 Muon Barrel trigger

- ATLAS is a general purpose particle detector observing collisions at Large Hadron Collider(LHC) at 40 MHz rate
- The Level-1 Muon Barrel trigger is one of the main elements of the online event selection of the ATLAS experiment
- It exploits the Resistive Plate Chambers (RPC) detectors to generate the trigger signals
- The RPCs are placed in the barrel region of the ATLAS experiment: arranged in three concentric doublet layers at radius 7 m, 8 m and 10 m, operating in a toroidal magnetic field of 0.5 $\sim$ 1 Tesla
- The Level-1 Muon Barrel trigger allows to select muon candidates according to their transverse momentum $\rightarrow$ 3 low p_T thresholds and 3 high p_T thresholds

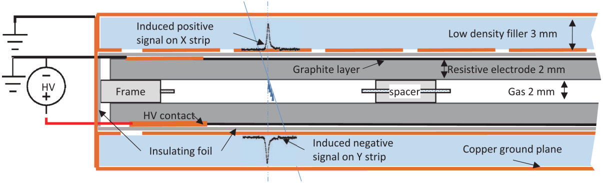




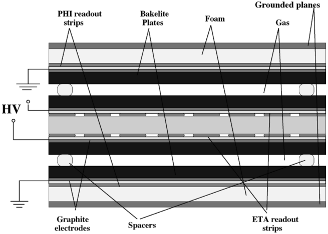
ATLAS Resistive Plate Chambers

- Parallel resistive (bakelite) plates are separated by 2 mm gas gap with insulating spacers
- Gas mixture of $C_2H_2F_4$(94.7%, ionization gas), C_4H_{10}(5.0%, quencher gas) and SF_6(0.3%, electronegative gas) operated in safe avalanche mode applying a nominal HV of 9.6 kV
- Orthogonal η and ϕ readout strips with 23-35 mm pitch
- $\sim 1\ ns$ intrinsic time resolution → designed to identify proton bunches separated by 25 ns
- RPC detector chamber consists of 2 detector layers with 2 η and 2 ϕ readout panels
- RPC detectors cover the pseudo-rapidity range $|\eta|$<1.05 ($\theta <$ 38°) for a total surface of about 4000 m^2 and $\sim$ 3600 gas volumes (with 380k readout channels)

RPC detector single layer



RPC detector doublet layer

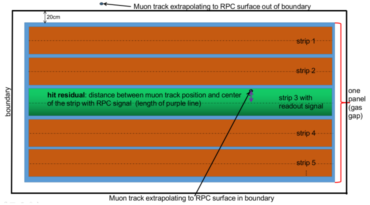


RPC detector performance

RPC detector response

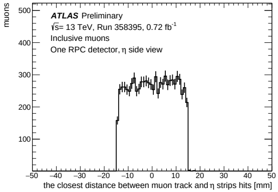
- Measure RPC detector response with muons produced in pp collisions
  - Muon candidates are reconstructed primarily with MDT detector and RPC ϕ coordinate readout
  - Extrapolate muon tracks from MDT through magnetic field and material to RPC surface
  - Muon induced ionization and avalanche $\rightarrow$ induced signal in RPC readout strips $\rightarrow$ hit is signal above readout threshold in one strip

Schematic view of the muon extrapolation to RPC surface

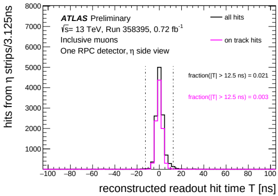


- Measure hit position, time and multiplicity

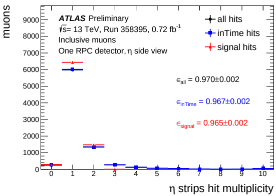
Expected muon η position minus the closest η hit position



Online calibrated time of strip hit for one example panel



Hit multiplicity in response to muon passage for one example panel

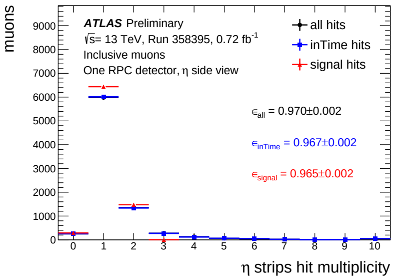


- Most of the panels perform properly with uniform position residual distribution in the width of a strip, negligible fraction of hits with time out of 1 BC and getting 1 or 2 hits in response to muon passage

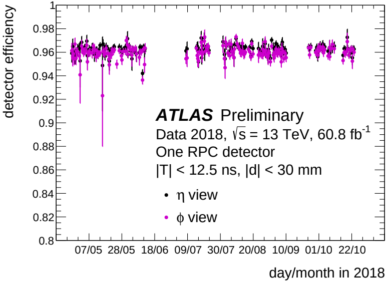
RPC detector efficiency - single chamber

- RPC detector efficiency is computed as the fraction of muons which are with hits associated to the extrapolated muon track in RPC surface within a distance of 30 mm from the centre of the strip and within 12.5 ns from the triggered bunch crossing (BC0)

Detector efficiency measured with the hit multiplicity for one example panel in one ATLAS run in 2018



Detector efficiency for η and ϕ views, for each ATLAS run recorded in 2018 $\rightarrow$ stable performance during the year

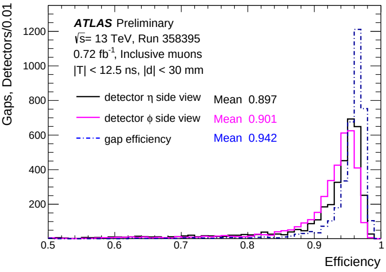


- The efficiency is over 96% in this panel with quite stable performance during the year

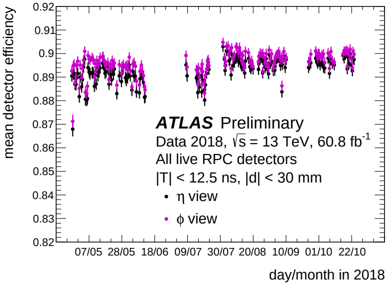
RPC detector efficiency - overall system

- Most of chambers work with high efficiency
- Gap efficiency, defined by hits registered for at least one of η and ϕ coordinates overall is $\sim$ 94% on average
- The detector efficiency is stable around 90% during data taking in 2018 monitored using 60.8 fb^{-1} data

Distribution of the panel and gap efficiencies for all alive panels in one ATLAS run in 2018



Mean detector efficiency for all alive RPC panels in each run recorded in 2018 $\rightarrow$ stable overall performance during the year

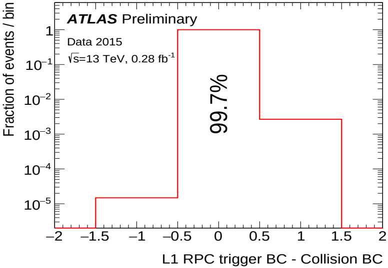


L1 Muon Barrel trigger performance

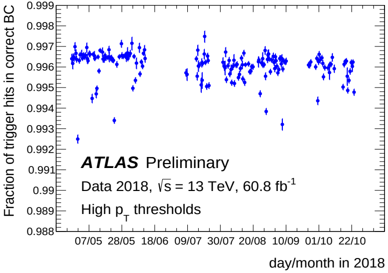
Trigger timing performance

- The RPC hits (muon signals) "online" calibration is performed using programmable delays in steps of 3.125 ns (1/8 BC)
- 99.6% - 99.7% of the Level-1 Muon barrel trigger hits are associated to the correct bunch crossing with good stability during data taking period except a few outliers due to a trigger tower losing synchronization during a run
- Correct bunch crossing (BC) association is one of the main requirements of the Level-1 Muon Barrel trigger and the RPC trigger is capable of satisfying the requirement

Global fraction of trigger hits per BC



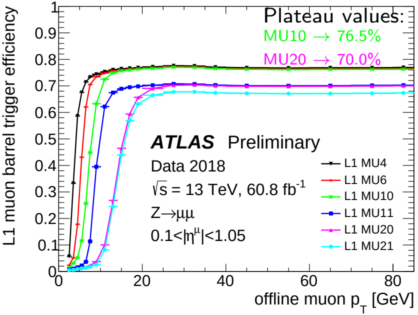
Fraction of trigger hits in correct BC for each run



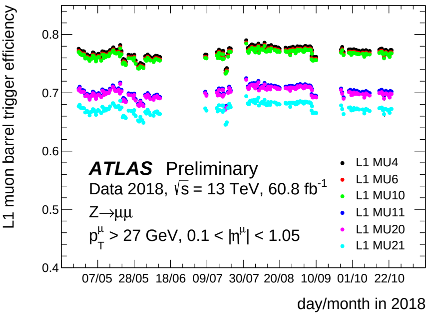
Trigger efficiency

- Trigger efficiency is one of the key parameters of the Level-1 Muon Barrel trigger
- It is measured using unbiased muons from Z→ $\mu^{\pm}\mu^{\mp}$ candidates in each run
- Efficiency is limited in the barrel region by acceptance due to toroid support structures and ATLAS "feet" supports;

Trigger efficiency for offline muons as a function of their transverse momentum



Plateau value of the trigger efficiency in each run recorded in 2018



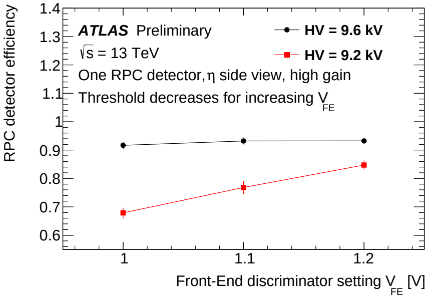
- Efficiency × acceptance to detect muon candidates with $p_T > 20$ GeV is $\sim$ 76.5% for low p_T thresholds and $\sim$ 70.0% for high p_T thresholds with very good stability during the year

Upgrade studies for High-Luminosity LHC

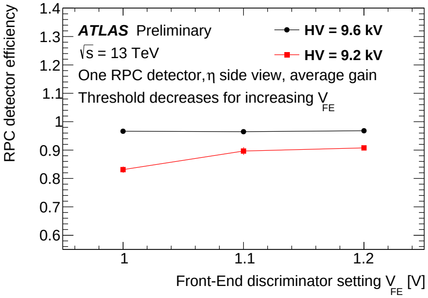
Front End discriminator thresholds scan

- ATLAS RPC detectors are planned to operate until $\sim$ 2040
- At HL-LHC ($\mathcal{L} \sim 7.5 \times 10^{34} cm^{-2} s^{-1}$) the integrated charge collected in the avalanche will be enough high to limit the detector lifetime
- It is proposed to lower the HV in the RPC gas-gaps (9.6 kV $\rightarrow$ 9.2 kV). At the same time, new RPCs will be installed in the innermost layer of the Muon Barrel Spectrometer to increase the redundancy of the trigger system and the trigger efficiency
- Study response of few RPC detectors at nominal and lower HV with different FE thresholds

high gain $\rightarrow$ efficiency increasing by $\sim$ 20% at HV = 9.2 kV from V_{FE} = 1.0 V to 1.2 V



average gain $\rightarrow$ efficiency increasing by $\sim$ 10% at HV = 9.2 kV from V_{FE} = 1.0 V to 1.2 V



- Part of the efficiency lost by reducing the HV on RPC gas-gaps can be recovered by lowering the thresholds of the FE discriminator (10% on average)

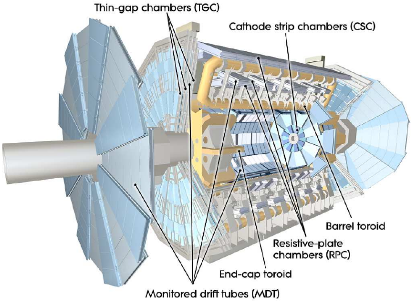
Summary and conclusions

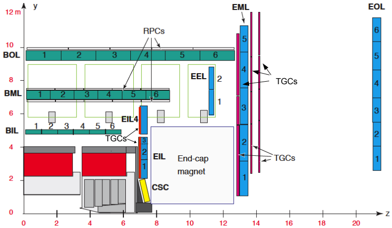
- Muon barrel RPC triggers selecting muon candidates at 40 MHz collision rate are of crucial importance for the ATLAS experiment
- Many studies has been done to monitor the RPC performance continuously during the year
- ATLAS RPCs have been working with excellent performance (both detector and trigger) since the completion of the system in 2008 even working at a instantaneous luminosity of a factor of 2 larger than the designed
- Preliminary studies indicate that existing ATLAS RPCs will perform well at higher instantaneous luminosity
- Extra RPC chambers (BIS7/8) to install for Run 3 → See talk from Lorenzo Massa and extensive detector upgrades to prepare for High Luminosity LHC including new RPC inner triplet layer and new readout electronics → See talk from Yongjie Sun

back up

ATLAS Muon spectrometer

- 3D scheme of ATLAS Muon spectrometer
- R-Z view of the present (Run 1/2) ATLAS muon spectrometer layout. The green (blue) chambers labelled BIS/BIL, BMS/BML, BOS/BOL, BEE (EIS/EIL, EES/EEL, EMS/EML, EOS/EOL) are MDT chambers in the barrel (endcap) regions of the spectrometer. The TGCs, RPCs, and CSCs are shown in red, white, and yellow, respectively. Top: One of the azimuthal sectors that contain the barrel toroid coils (small sector)



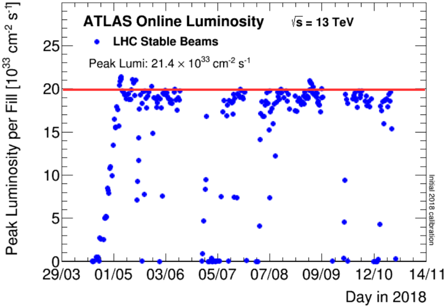


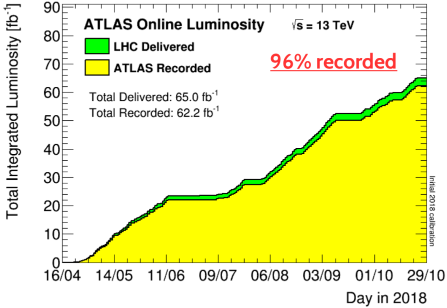
ATLAS RPC parameters and performance

Table 6.10: RPC parameters and performance.

Parameter	**Design value**
E-field in gap	4.9 kV/mm
Gas gap	2 mm
Gas mixture	$C_2H_2F_4$/Iso-C_4H_{10}/SF_6 (94.7/5/0.3)
Readout pitch of η and ϕ-strips	23–35 mm
Detection efficiency per layer	$\geq$98.5%
Efficiency including spacers and frames	$\geq$97%
Intrinsic time jitter	$\leq$1.5 ns
Jitter including strip propagation time	$\leq$10 ns
Local rate capability	$\sim$1 kHz/cm^2
Streamer probability	$\leq$1%

ATLAS data-taking performance during 2018

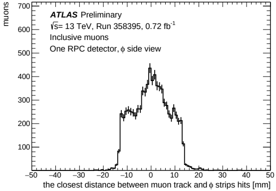




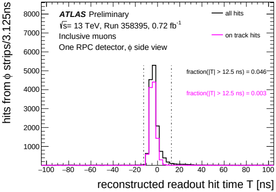
RPC detector response in one example ϕ panel

⊛ peak in the hit position plot is due to the bias from muon track ϕ coordinates measured from RPC

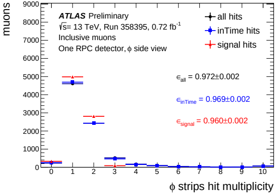
Expected muon ϕ position minus the closest ϕ hit position



Online calibrated time of strip hit for one example panel



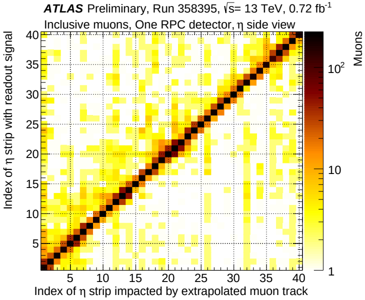
Hit multiplicity in response to muon passage for one example panel

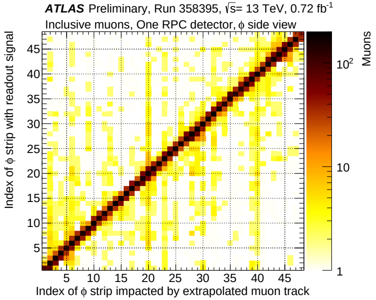


⊛ Most of the panels perform properly with uniform position residual distribution in the width of a strip, negligible fraction of hits with time out of 1 BC and getting 1 or 2 hits in response to muon passage

Hit position reconstruction

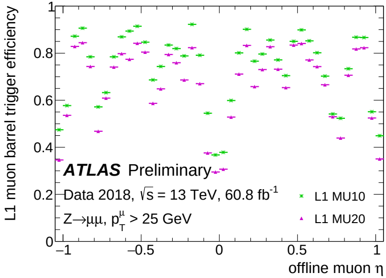
- Detector alignment and correct cabling are investigated using the correlation between the expected and measured muon positions

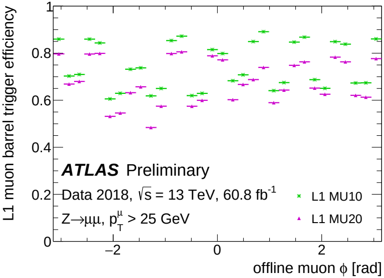




Trigger efficiency

- Trigger efficiency is measured using unbiased muons from Z boson decays(Z→ $\mu\mu$ Tag&Probe)
- Efficiency limited in the barrel region by toroid support structures and ATLAS "feet" supports
- Further reduction due to gas-gaps disconnected from HV (gas leaks) → mostly located on the external layer (BO chambers)





Gas gap current measurement

- RPC upper limit on gap current density is $30\mu A \cdot m^{-2}$ for HL-LHC
- Gas gap current (normalized to the gap area) as a function of instantaneous luminosity
- Aim to predict safe operating HV settings for each gas gap for HL-LHC
- Current proportional to the luminosity $\rightarrow$ this shows that the present RPC system is in a very good status