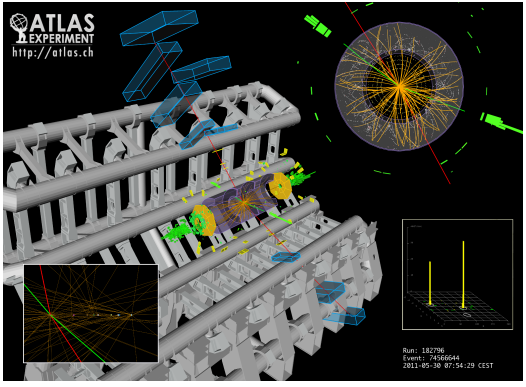
Performance of ATLAS RPC detector and Level 1 muon barrel trigger



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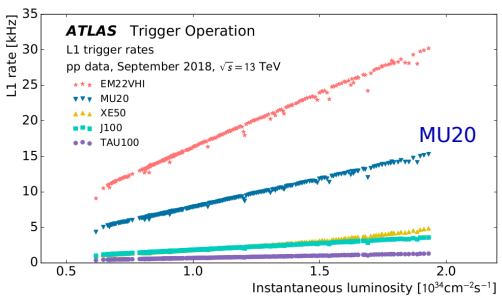
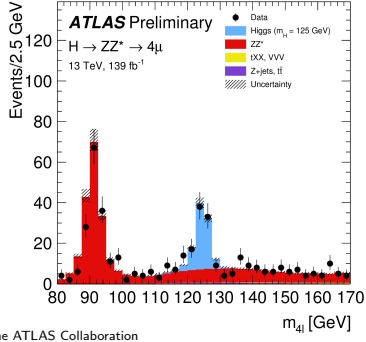
Introduction

- ATLAS is general purpose particle detector observing LHC collisions at 40 MHz rate
- ATLAS muon spectrometer triggers and reconstructs muon candidates
  - Fast detectors operating at 40 MHz for Level 1 hardware trigger (L1)
  - Precision detectors for offline reconstruction
- Muons are important signature for the ATLAS physics programme
  - Muon trigger signatures contribute $\sim$ 10% of 100 kHz Level 1 trigger bandwidth
  - Hundreds of measurements, including Higgs boson measurements, searches for new phenomena...

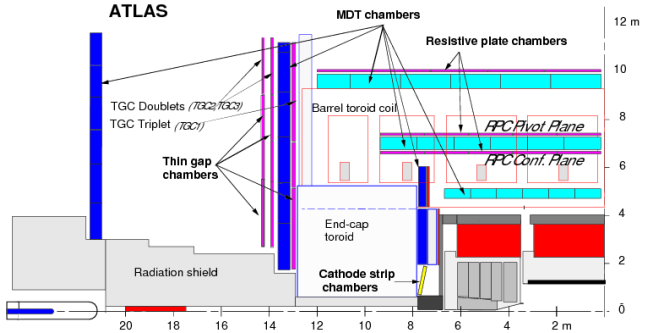
Level 1 trigger rates vs. instantaneous LHC luminosity





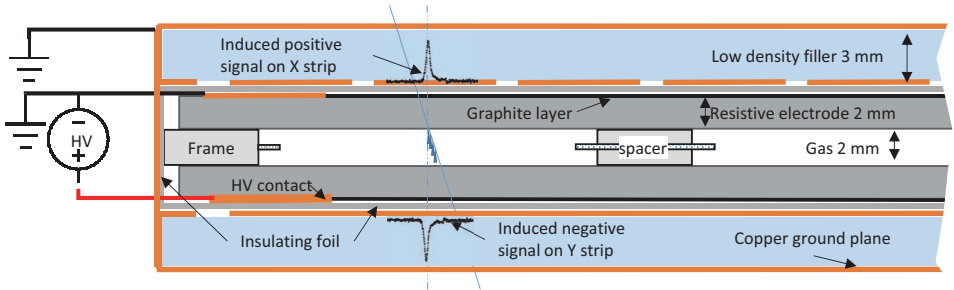
ATLAS muon spectrometer

- 2 fast detectors for L1 trigger with position resolution of ~ 1 *cm*:
  - Resistive Plate Chambers (RPC) for barrel region ($|\eta| < 1.05$) - *subject of this talk*
  - Thin Gap Chambers chambers (TGC) for endcap region ($1.05 < |\eta| < 2.4$)
  - Fast measurement of muon transverse momentum (p_T) within 2.1 μs for L1 trigger
- 2 precision detectors for offline reconstruction with position resolution of ~ 80 μm:
  - Muon Drift Tubes (MDT) for $|\eta| < 2.7$
  - Cathode Strip Chambers (CSC) for $2.0 < |\eta| < 2.7$ for the innermost layer



ATLAS Resistive Plate Chambers

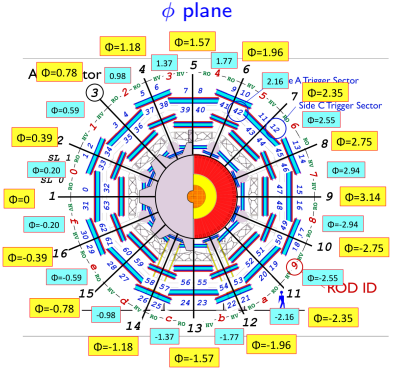
- Parallel 2×10^{10} Ω *cm* resistive (bakelite) plates are separated by 2 mm with insulating spacers
- Non-flammable low cost gas: tetrafluorethane $C_2H_2F_4$(94.7%), iso-butane C_4H_{10}(5%), sulphur hexafluoride SF_6(0.3%)
- Orthogonal η and ϕ readout strips with 23-35 mm pitch
- $\sim$ 2 ns total time resolution $\rightarrow$ designed to identify proton bunches separated by 25 ns
- Operating in avalanche mode at 9.6 kV with $\sim$ 97% muon detection efficiency per layer
- RPC sustained rate is 100 Hz/cm^2 (and capability up to 1000 Hz/cm^2)
- RPC detector chamber is made of two detector layers with 2 η and 2 ϕ readout strip panels

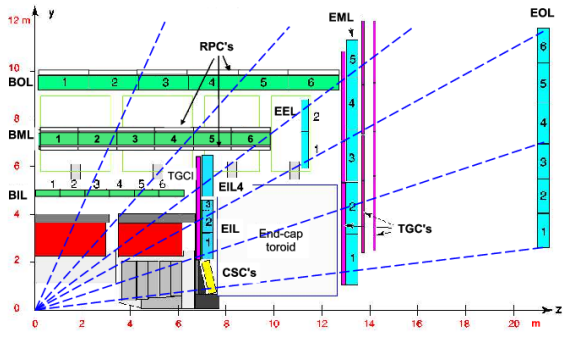


ATLAS RPC detector

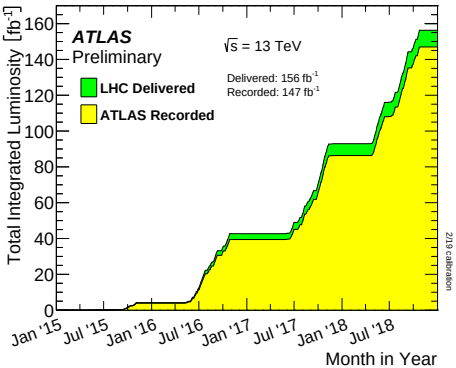
- 3 concentric cylindrical shells of doublet chambers with radius of ~ 7, ~ 8 and 10 meters
- ~ 3600 gas volumes with area of $\sim 4000 m^2$ and ~ 360k readout strips
- Immersed in toroidal magnetic field of 0.5 $\sim$ 1 Tesla
- 6 measurements in bending η plane and 6 measurements in non-bending ϕ plane
- RPC provide ϕ coordinate measurement for offline muon reconstruction

ϕ plane





Performance measurements of RPC detector with proton-proton collision data at 13 TeV

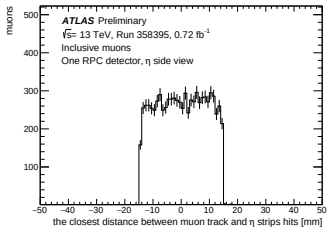


LHC delivered about a half of originally designed integrated luminosity

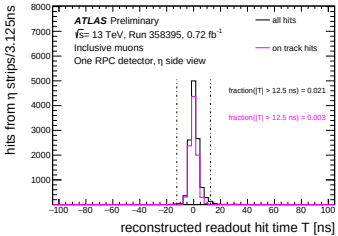
RPC detector response

- Measure RPC detector response with muons produced in pp collisions
  - Muon candidates are reconstructed primarily with MDT detector and independently of RPC η readout
  - Propagate muons through magnetic field and material to RPC surface
  - Muon induced avalanche $\rightarrow$ hit is signal above threshold in one strip
- Measure hit position, time and multiplicity

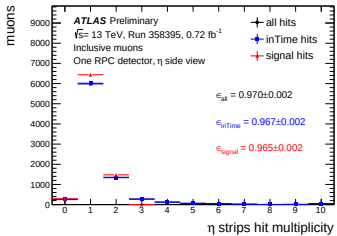
Expected muon η position minus closest hit η position



Calibrated time of strip hit for one example chamber

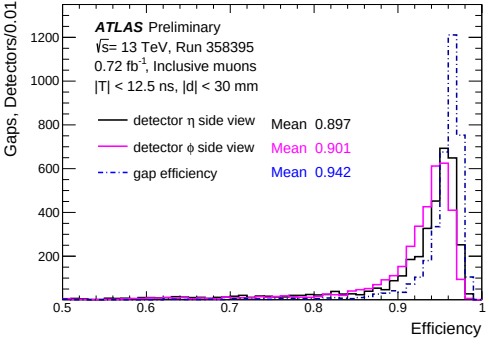


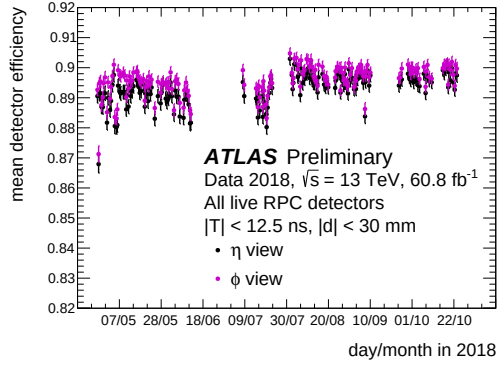
Hit multiplicity in response to muon passage efficiency for one example chamber



RPC detector efficiency

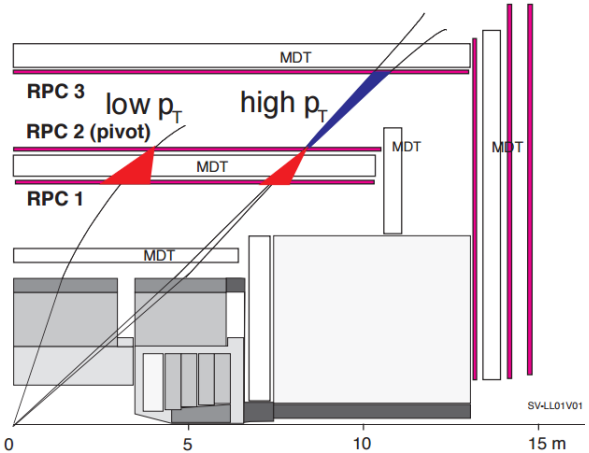
- Average overall efficiency to detect at least one muon hit is $\sim 94\%$
- Excellent detector stability during data taking during 2018 (and since 2008)
- ATLAS RPC detectors are planned to operate until ~ 2040 (after upgrades)





Performance measurements L1 Muon Barrel trigger response

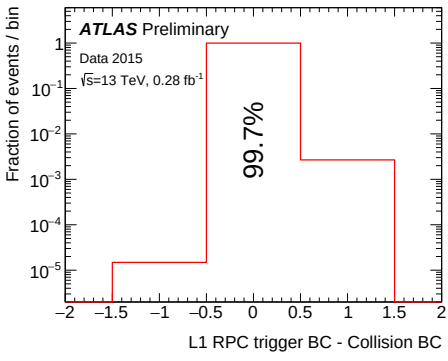
Level 1 Muon Barrel trigger

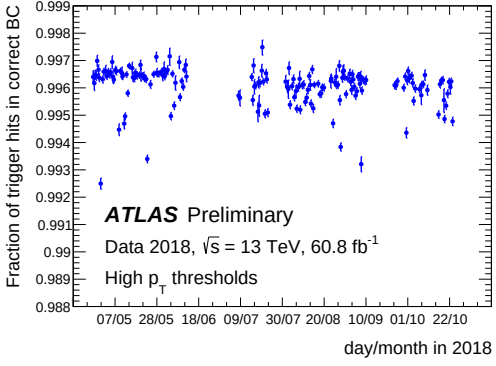


- L1 Muon Barrel trigger uses RPCs to detect muon trigger candidates at 40 MHz rate
  - Custom-built on-detector electronics making decision within 2.1 μs after collision
  - 3328 detector regions of 0.1×0.1 in $\Delta\eta \times \Delta\phi$
- 3 low p_T thresholds:
  - Requires 3/4 coincidence within trigger road in the two inner doublet layers
- 3 high p_T thresholds:
  - Requires low p_T trigger and 1/2 coincidence in the outer doublet layer

Trigger timing calibrations

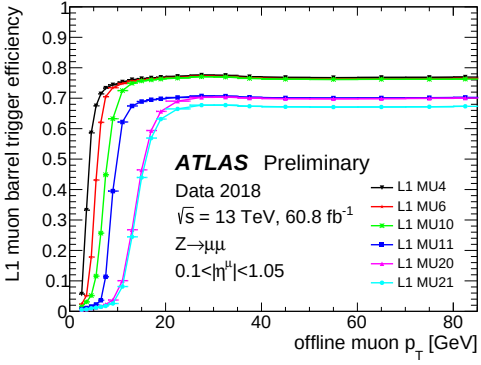
- RPC hits (muon signals) are calibrated online with 3.125 ns step
  - More than sufficient to identify individual LHC bunch crossings with 25 ns spacing
- 99.7% of muon candidates arrive within expected 25 ns time window
- Excellent stability of timing calibrations during data taking period

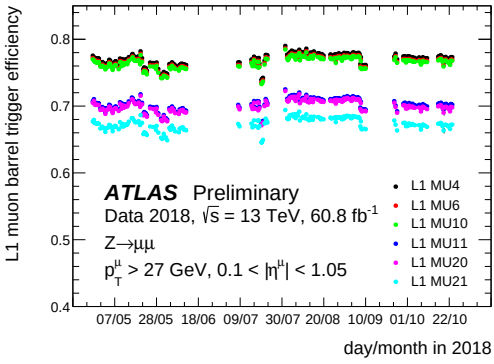




L1 Muon Barrel trigger efficiency

- Measure efficiency to identify L1 muon candidate using $Z \to \mu^{\pm}\mu^{\mp}$ events
- Efficiency×acceptance to detect muon candidates with $p_T > 20$ GeV is $\sim 70\%$
  - Barrel geometrical acceptance is limited by the detector support structures
- Trigger efficiency is stable during data taking period

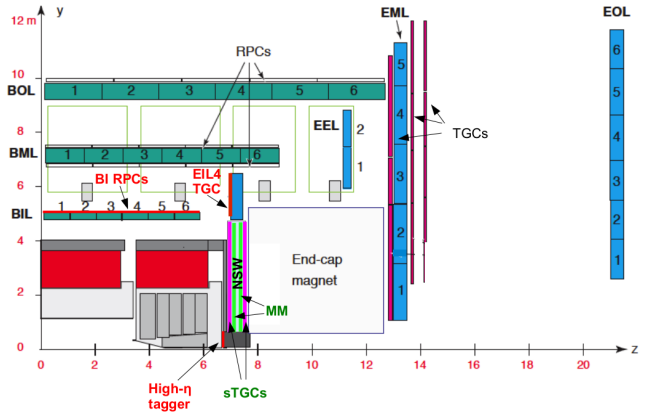




Muon Spectrometer upgrade studies

Muon Spectrometer upgrades for High-Luminosity LHC

- *New Small Wheels* in forward regions and extra RPC chambers (BIS78) - 2019-2020
  - Poster by Salvatore Loffredo: BIS78 Pad trigger board for the Phase-I Upgrade of L1 Muon Trigger
- Install 3 inner RPC layers (BI RPCs) with 470m^2 area - 2024-2025
  - New 1 mm gas gap structure operating at 5.8 kV with better performing front end electronics

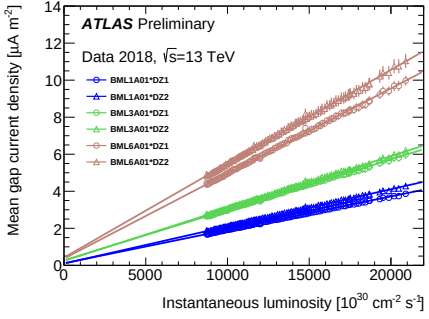


- New readout electronics for existing chambers (keep existing FEBs)
- New off-detector trigger electronics based on FPGAs

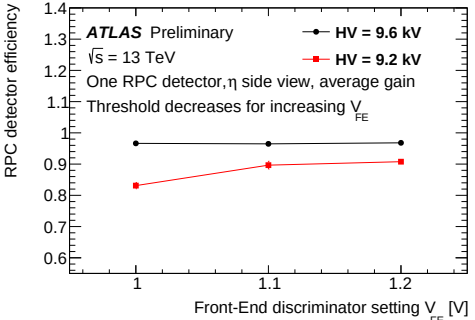
HL-LHC studies

- RPC upper limit on current density is $30\mu A/m^2$ for HL-LHC at $\mathcal{L} = 7.5 \times 10^{34} cm^{-2} s^{-1}$
- Extrapolate current LHC data to high luminosity to study expected performance
  - Chambers with smaller radius and at high $|\eta|$ will exceed these limits
  - Plan to reduce HV to 9.2 kV and decrease front end thresholds to regain $\sim 10\%$ efficiency
- Scan FE discriminator thresholds at 9.6 kV (nominal) and 9.2 kV (proposed for HL-LHC)

RPC detector currents at different $|\eta|$ stations versus instantaneous luminosity



RPC detector efficiency versus discriminator V_{FE}



Summary

- ATLAS RPC detector was completed in 2008 and need to operate until ~ 2040
- Muon barrel RPC trigger selects muon candidates at 40 MHz collision rate
- Excellent detector and trigger performance during data taking since 2008
- Overall probability to detect barrel muon candidates is $\sim 70\%$ for $p_T > 20$ GeV
- Extensive detector upgrades to prepare for High Luminosity LHC
- New RPC inner triplet layer will be installed in 2025-2026
- Preliminary studies indicate that existing RPCs will perform well at higher luminosity

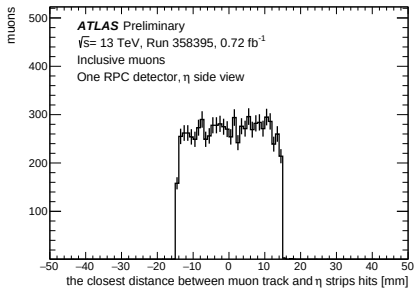
Thank you!

BACKUP

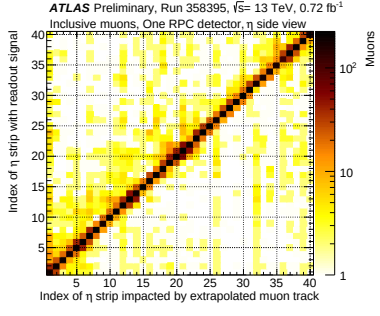
RPC detector response

- Measure RPC detector response with muons produced in pp collisions
  - Offline muon candidates are reconstructed primarily with MDT detector
  - Propagate offline muon candidates through B-field and material to RPC surfaces
  - Muon produce avalanches → hit is signal on one strip above electronics threshold
- Check expected and actual detector response using expected muon hit position

Expected muon η position minus closest hit η position

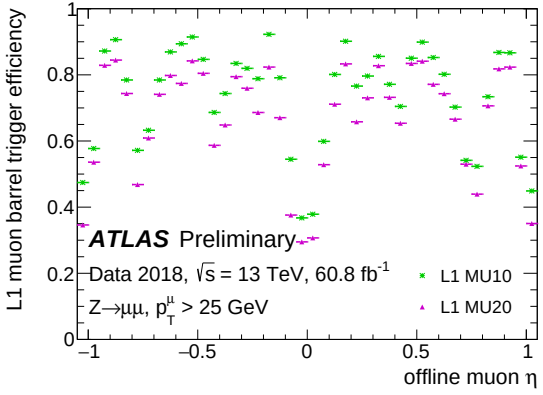


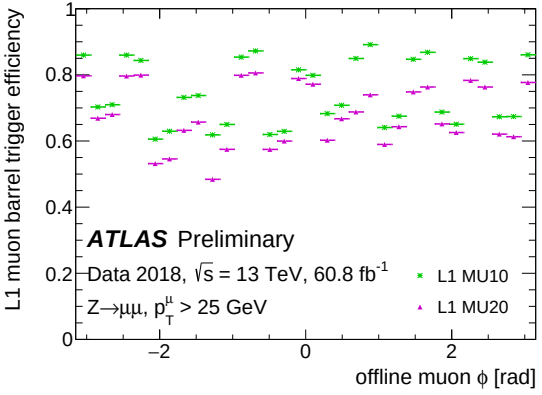
Expected muon η position versus hit η position



L1 Muon Barrel trigger efficiency

- Measure efficiency to detector L1 muon barrel candidate using $Z \to \mu^{\pm}\mu^{\mp}$ events
- Barrel geometrical coverage is reduced by detector support structures

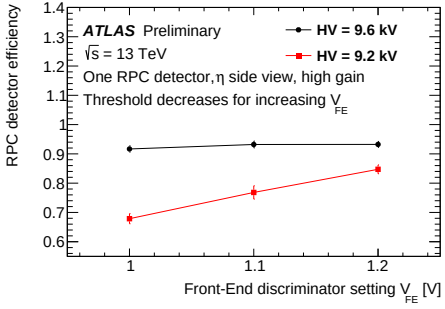




RPC currents versus instantaneous luminosity

- RPC detectors have upper limits on current density
- Extrapolate current LHC data to high luminosity to study expected performance
  - Some chambers at high $|\eta|$ will exceed these limits
  - Plan to reduce operational voltage
  - Plan to also reduce signal thresholds to regain some of lost efficiency

RPC detector currents versus instantaneous luminosity at different radii



RPC detector currents at radius of $\sim$ 8 and 10 meters versus instantaneous luminosity