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

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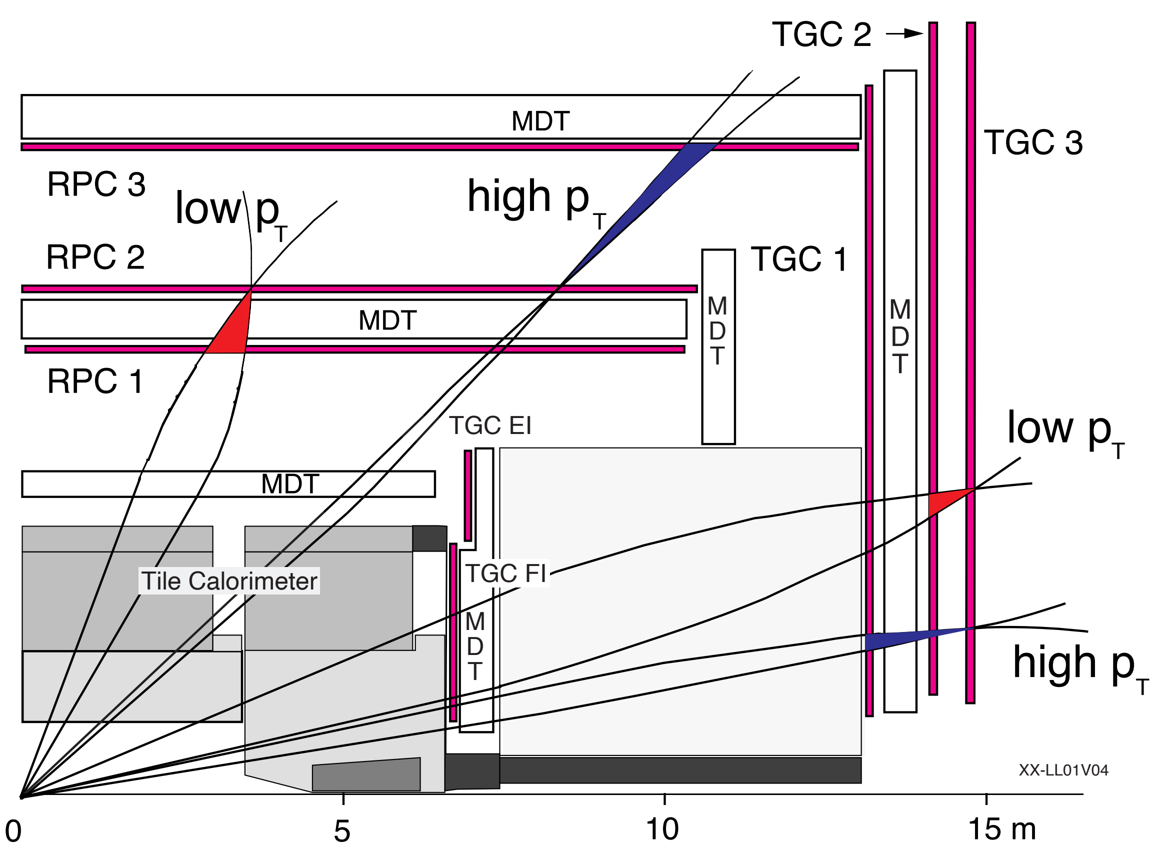
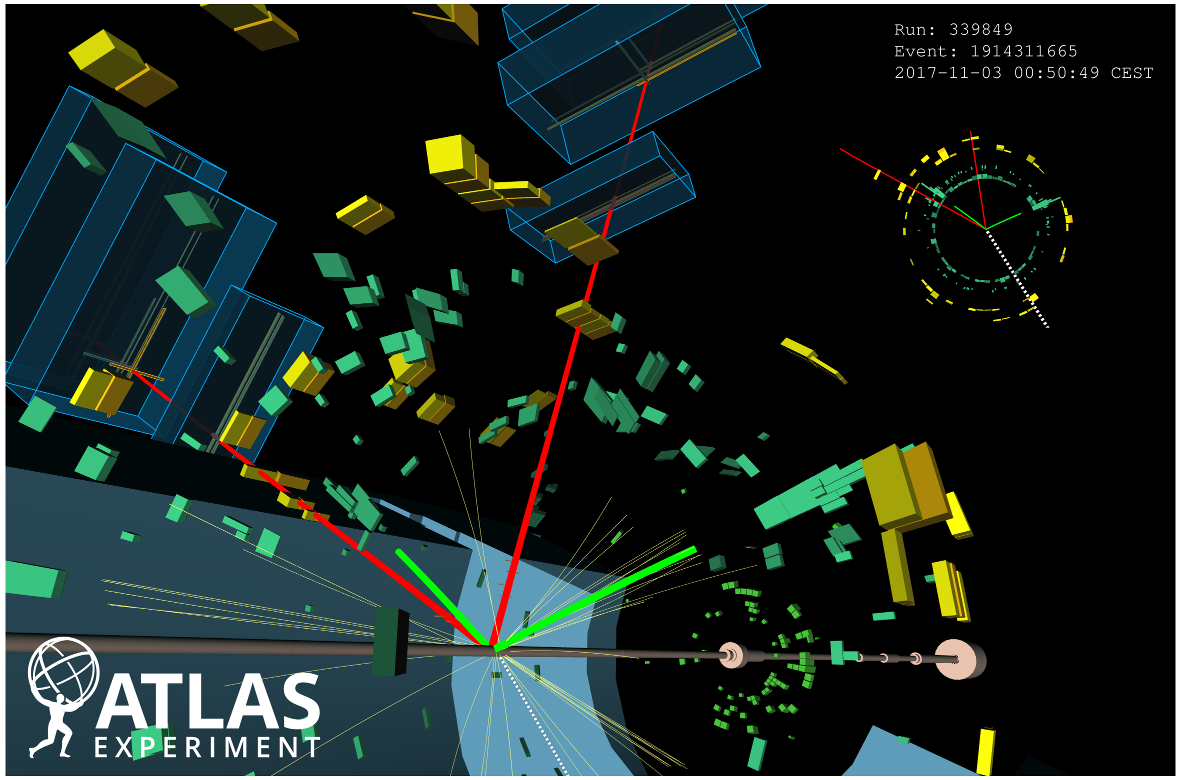
On behalf of the ATLAS Collaboration

Introduction

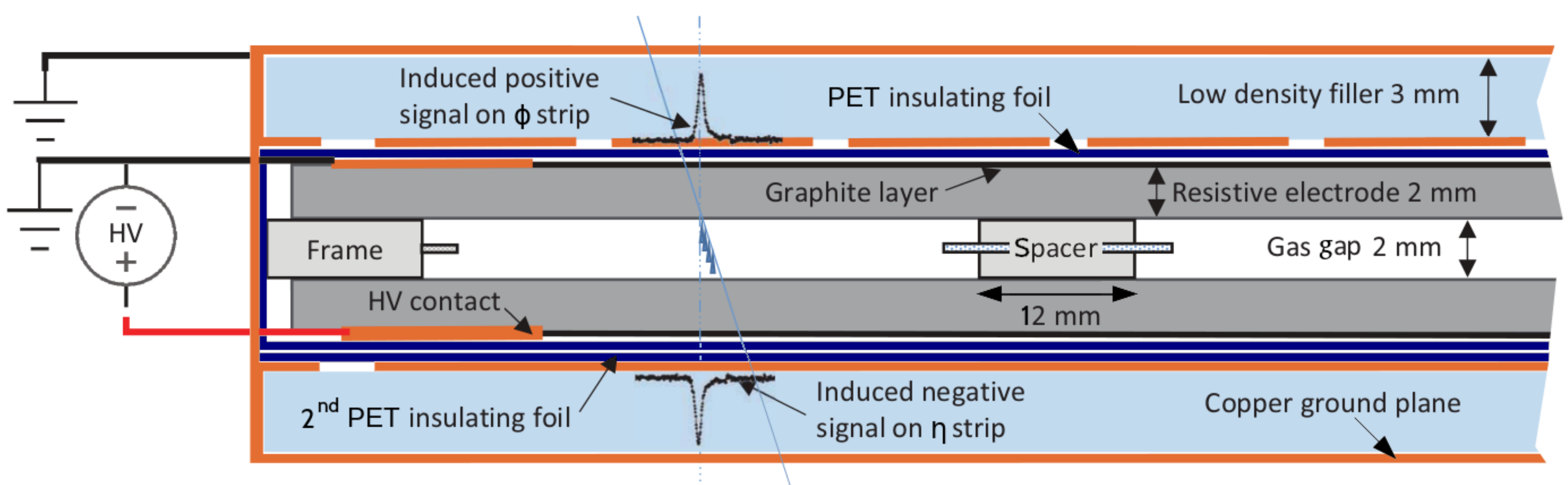
- ATLAS is a general purpose particle detector observing collisions at Large Hadron Collider(LHC) .
- Efficient selection of muons is important for ATLAS physics programme.
- ATLAS Muon barrel detector is equipped with Resistive Plate Chambers (RPC), arranged in 3 concentric doublet layers at radius 7 m, 8 m, and 10 m, operating in a toroidal magnetic field of 0.5 ~ 1.0 Tesla.
- RPC detectors cover the pseudo-rapidity range $|\eta| < 1.05$.
- The Level-1 Muon Barrel trigger uses RPC detectors for selection of events containing muons in the central detector region at 40 MHz.
- Muon candidates are selected using 3 low p_T and 3 high p_T thresholds.





ATLAS Resistive Plate Chambers

- RPCs cover total area of ~ 4000 m^2 with ~ 3700 gas volumes and ~ 380k readout strips.
- Each RPC detector chamber consists of 2 detector layers, each with η and ϕ readout panels.
- RPC gas volumes are made of two parallel resistive (bakelite) plates separated by 2 mm gas gap with insulating spacers.
- Readout is organized by orthogonal η and ϕ strips with 23-35 mm width, with eta strips measuring muon curvature.
- Gas mixture is $C_2H_2F_4$(94.7%), C_4H_{10}(5.0%) and SF_6(0.3%),
- RPC operates in the safe avalanche mode with nominal HV of 9.6 kV.
- The intrinsic time resolution is ~ 1 ns while the time to digital converter have sampling bin of 3.125 ns.



Schematic of the ATLAS RPC single layer

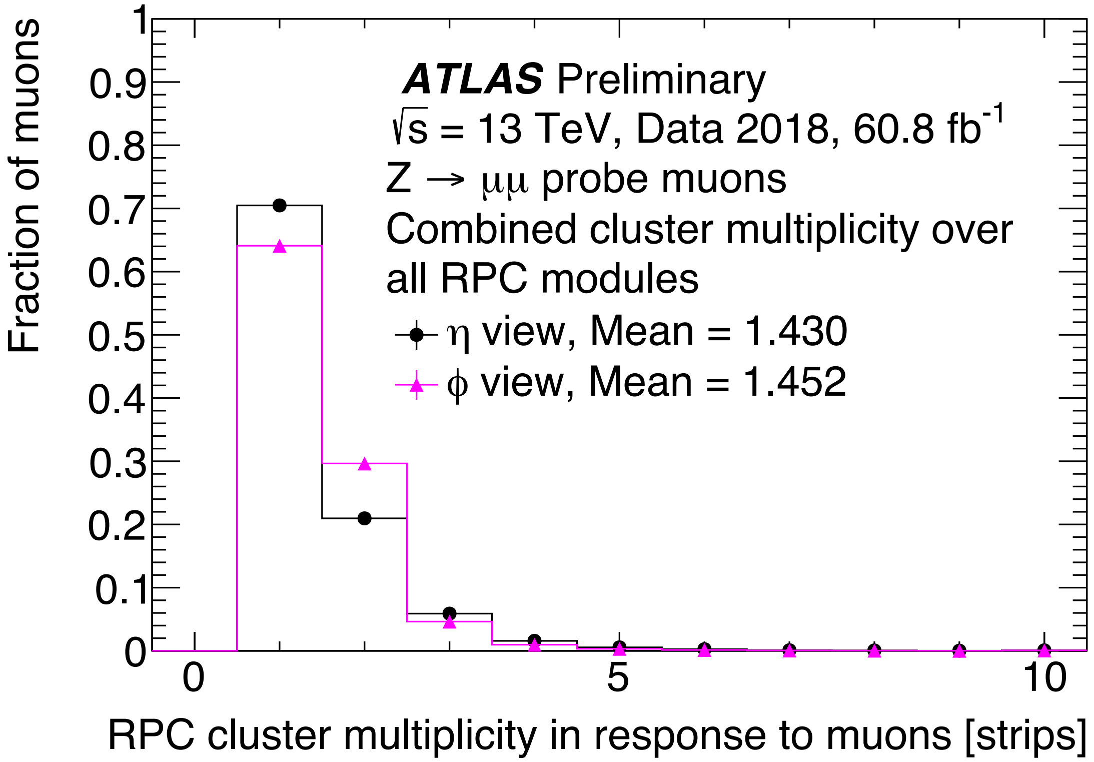
RPC detector performance

https://atlas.web.cern.ch/Atlas/GROUPS/MUON/PLOTS/MDET-2020-01/index.html

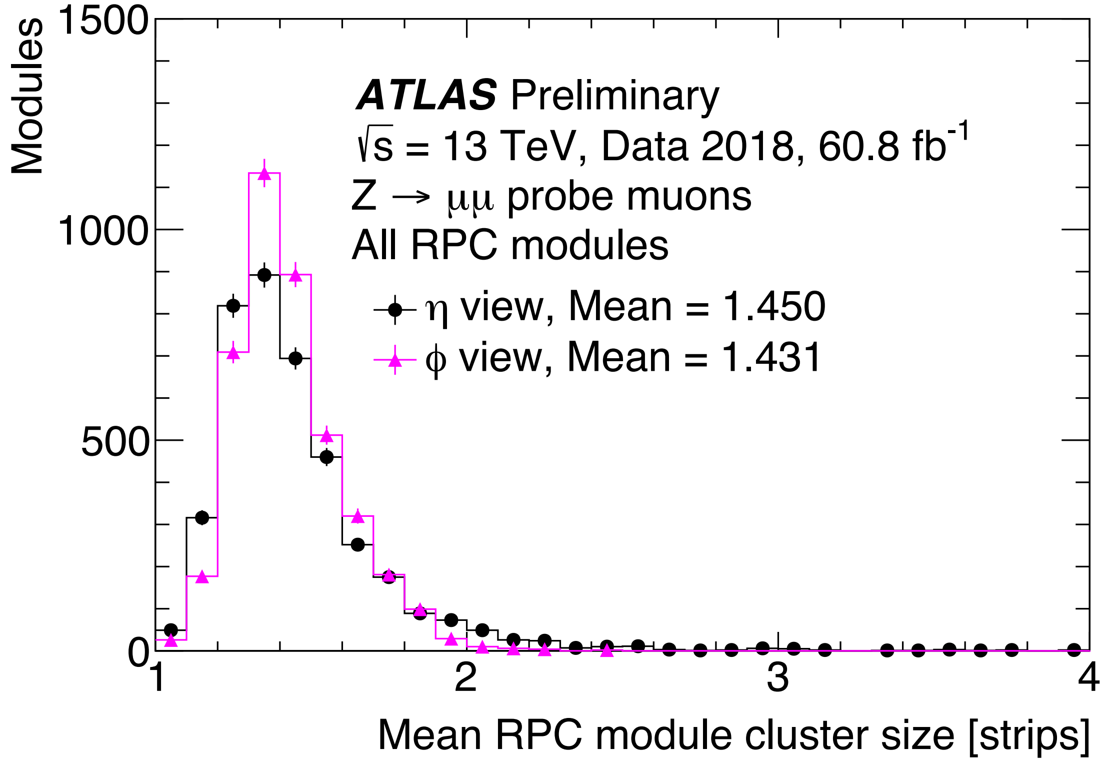
All performance results presented are obtained using the probe muons from Z boson production to avoid bias from muon triggers for events with a single muon.

RPC cluster hit multiplicity and cluster size

RPC cluster hit multiplicity distribution
averaged over all RPC modules



Average cluster size distribution
averaged over all RPC modules

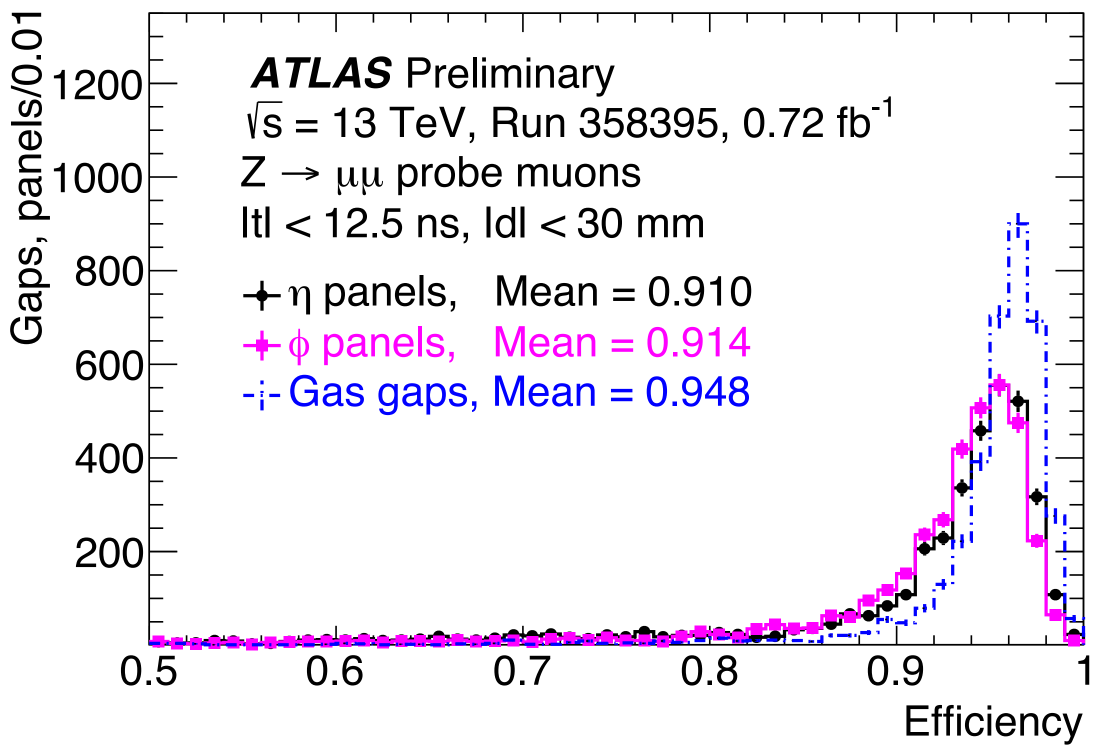


- Typical muons 60% ~ 70% produce clusters with a single cluster hit.
- Small difference between η and ϕ panels due to the different construction: the second PET foil decreases the amount of collected charge in η panels.

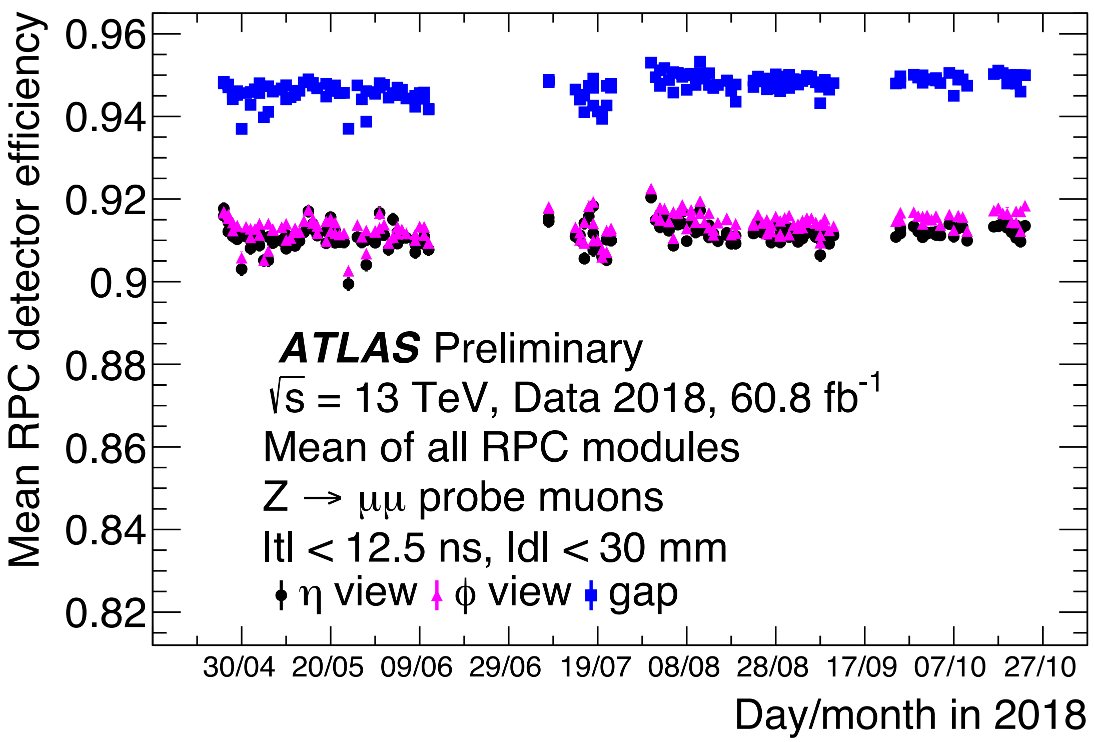
RPC detector efficiency and stability

- RPC detector efficiency is measured using muon hits within ± 12.5 ns time window and within ± 30 mm from the expected muon impact point.
- Detector efficiency is defined as ratio of the number of muons with selected hits over all probe muons
- Gap efficiency, defined by requiring at least one hit in either η or ϕ strip.

Muon detection efficiency distribution for all active RPC modules

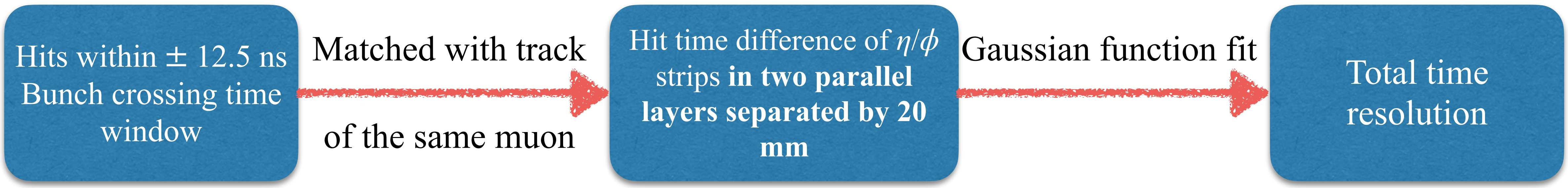


Average muon detection efficiency as function of time



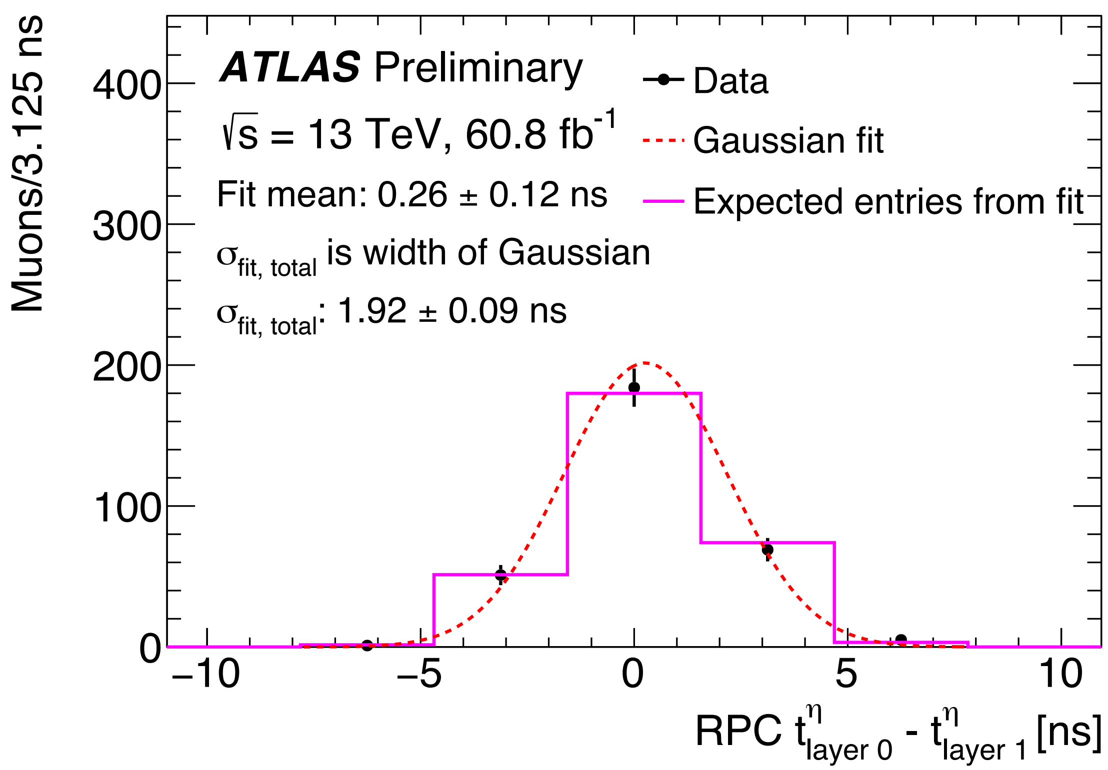
- Most of gas-gaps has very high efficiency ~ 95% and stable during the data-taking in 2018.
- Difference from individual panel efficiency is due to the electronics efficiency.
- The small step in efficiency in August is due to retuning of thresholds.

RPC total time resolution

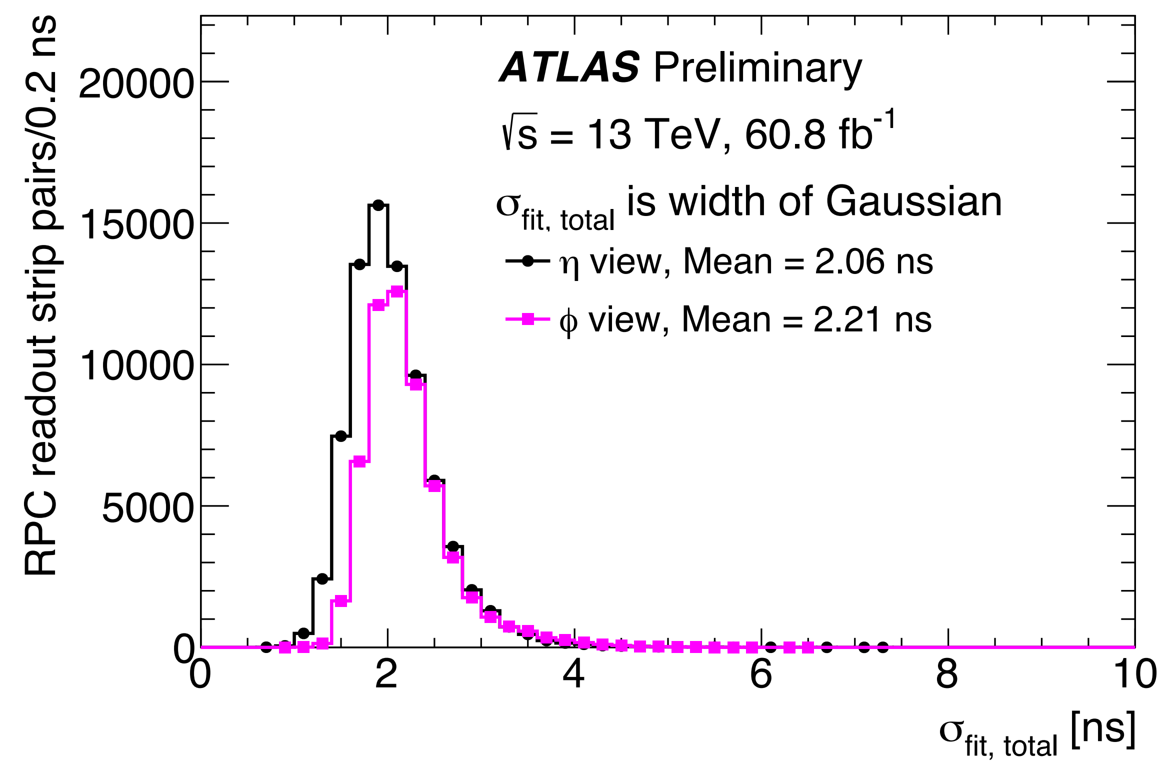


- Time difference plotted with bin width of 3.125 ns sampling time.
- The width of distribution is extracted using a binned maximum likelihood fit of the Gaussian function

Example fit on hit time difference
for one $\eta - \eta$ strip pair



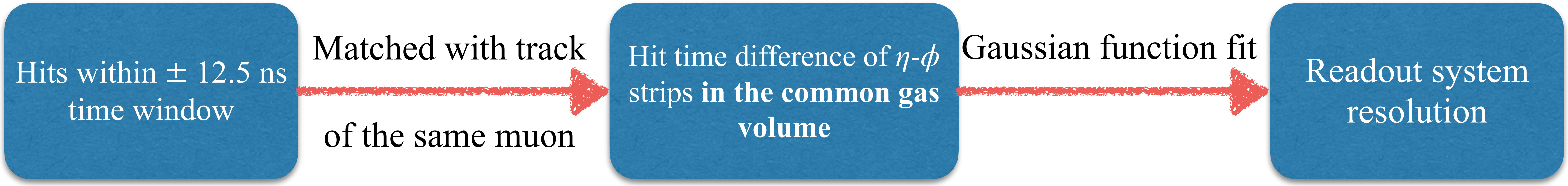
Gaussian width of time difference distribution
for the whole RPC system



- The total time resolution defined as $\sigma_{\text{total}}/\sqrt{2}$ is ~ 1.5 ns
- The difference of total time resolution is due to the the different cluster size composition between η and ϕ panels.

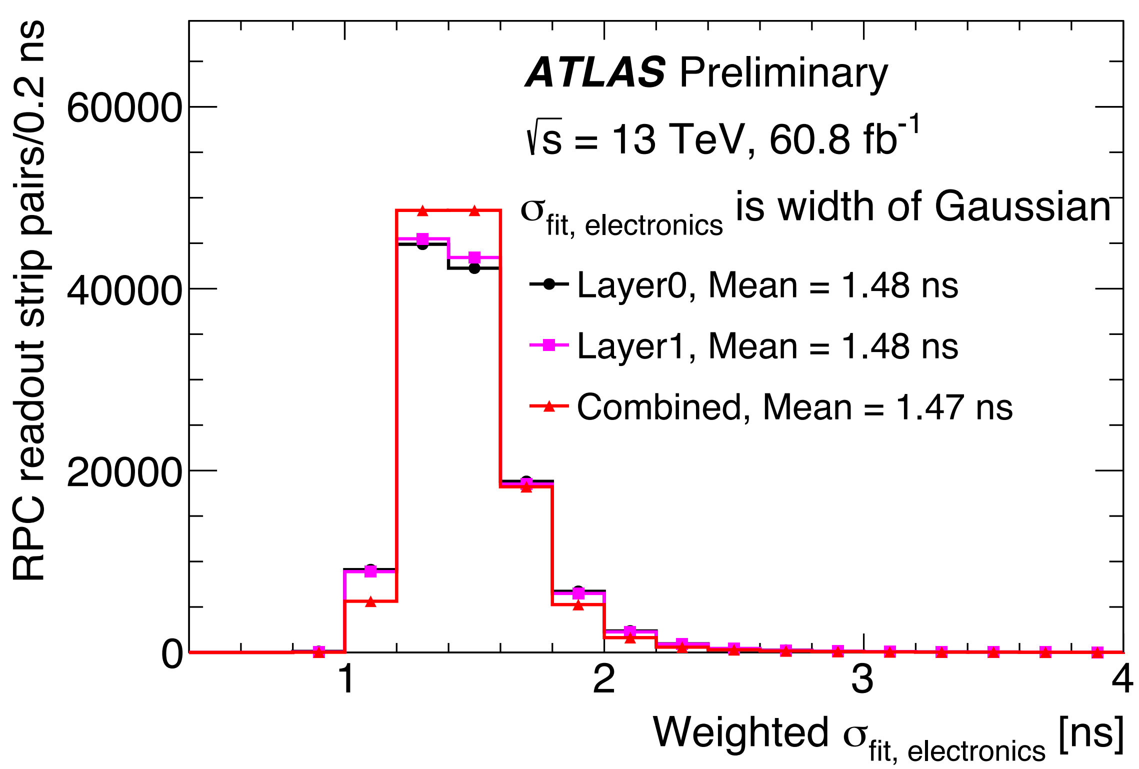
Intrinsic resolution of RPC detector

- RPC total time resolution (σ_{total}) consists of intrinsic detector resolution ($\sigma_{\text{intrinsic}}$) and its readout system resolution ($\sigma_{\text{electronics}}$) by $\sigma^2_{\text{total}} = \sigma^2_{\text{intrinsic}} + \sigma^2_{\text{electronics}}$

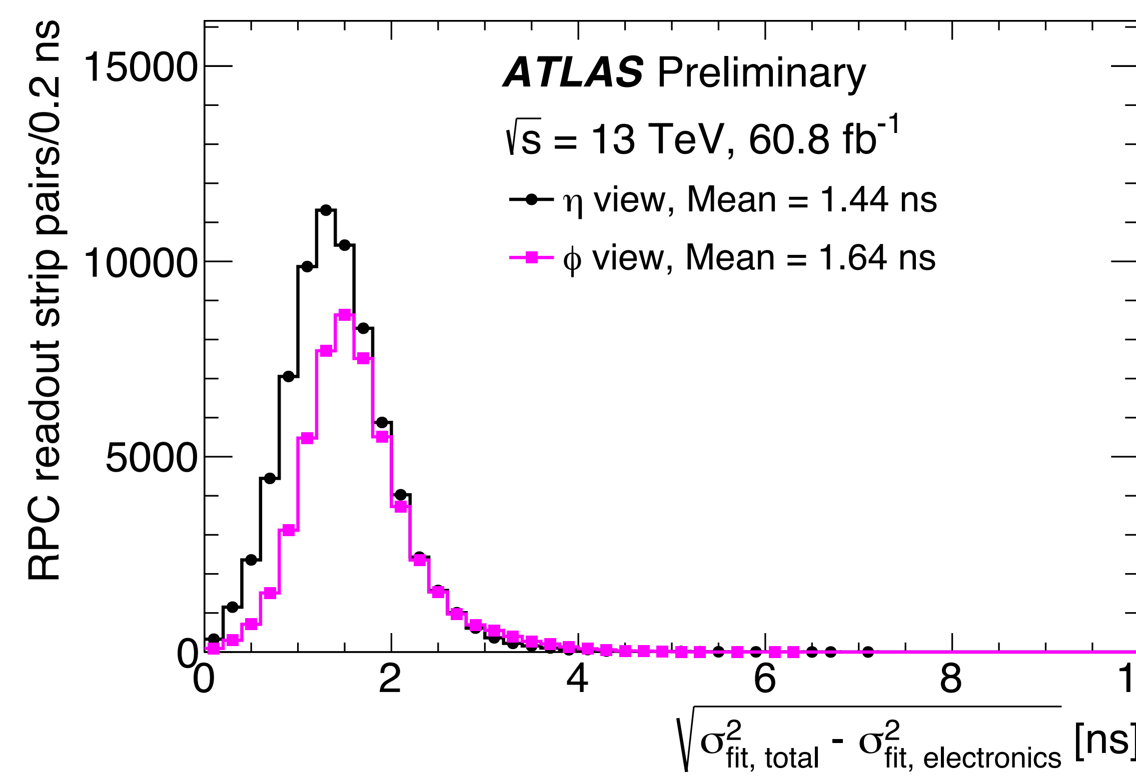


- All possible $\eta - \phi$ pairs considered to compute statistically weighted average values.

Electronic component distribution for the whole RPC system



Intrinsic component distribution for the whole RPC system

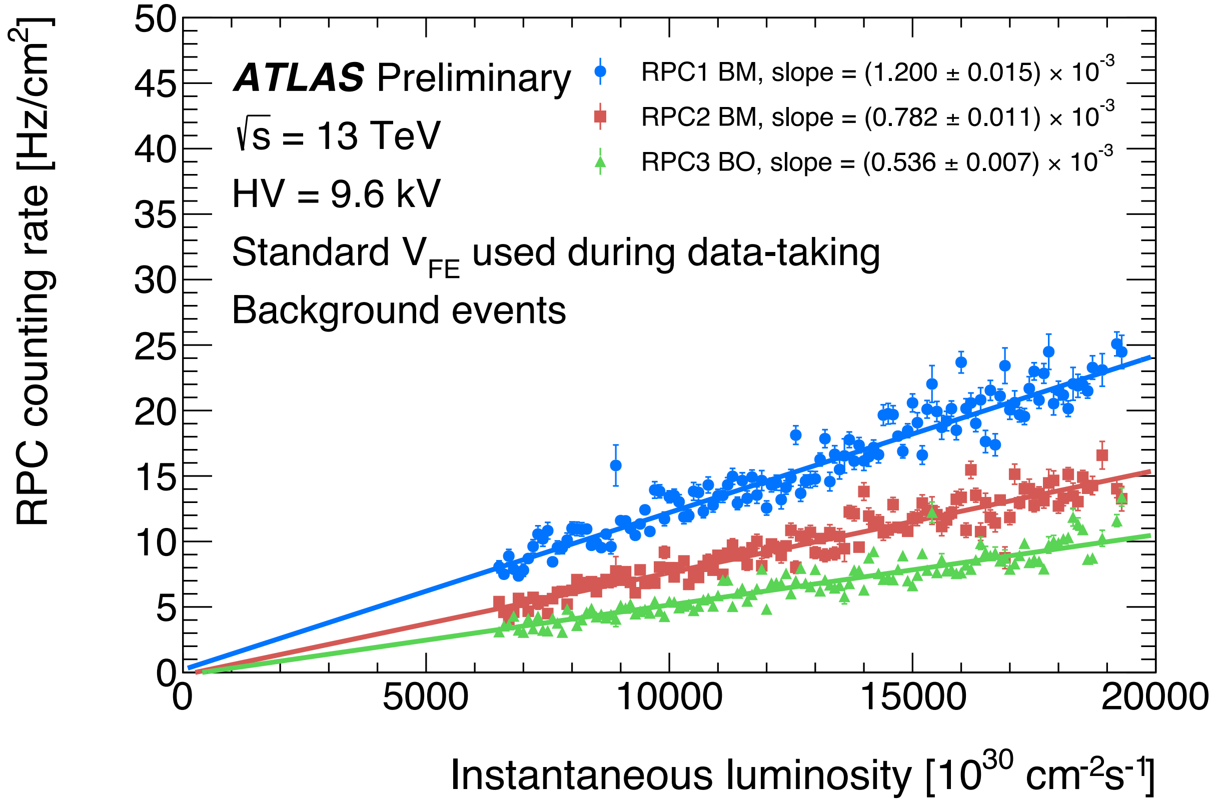


- The intrinsic RPC resolution is estimated as $\sigma_{\text{intrinsic}}/\sqrt{2}$ and is about 1 ns.

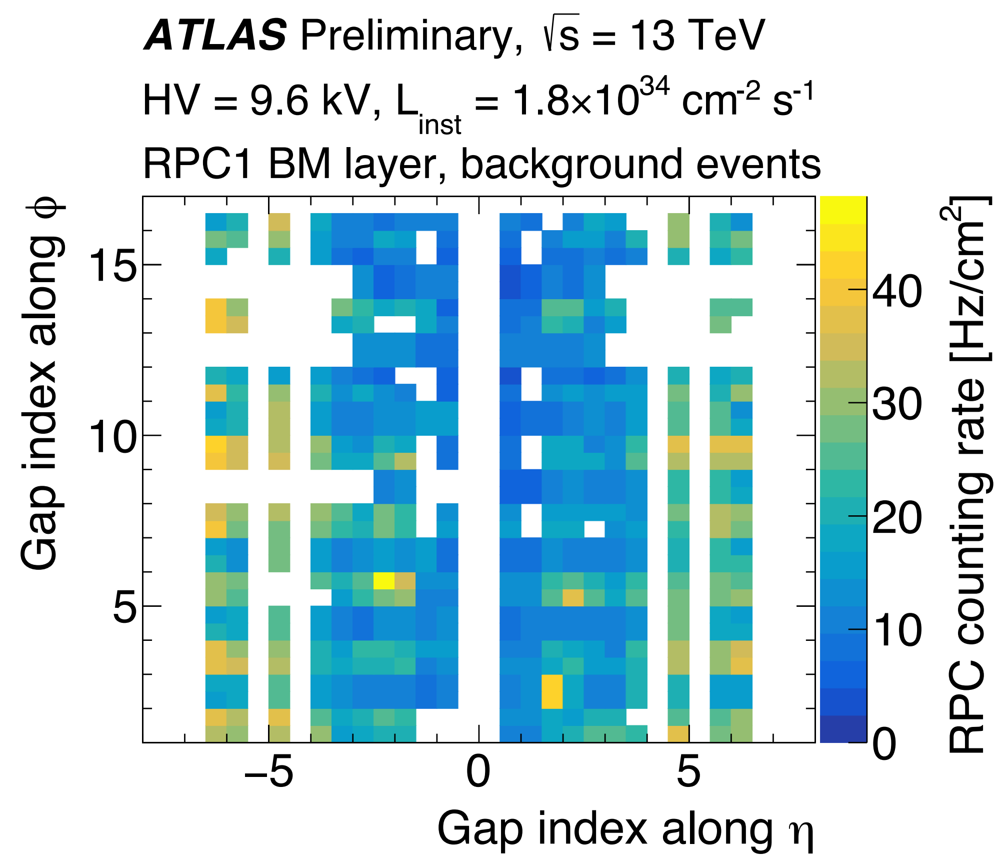
RPC background counting rates

- ATLAS Muon detector background counting rates are dominated by secondary particles, mostly photons and neutrons.
- An unbiased sample of average LHC collisions was selected using the time window preceding the bunch crossing containing triggered muon with $p_T > 26\,\mathrm{GeV}$
- The normalised counting rates are defined as: $\mathrm{Rate} = \dfrac{\mathrm{N_{count}}}{\Delta \mathrm{T} \cdot \mathrm{Area}}$ [Hz/cm²]

RPC counting rate as the function of instantaneous luminosity for RPC panels



RPC counting rate as the function of η and ϕ positions of RPC1 layer.



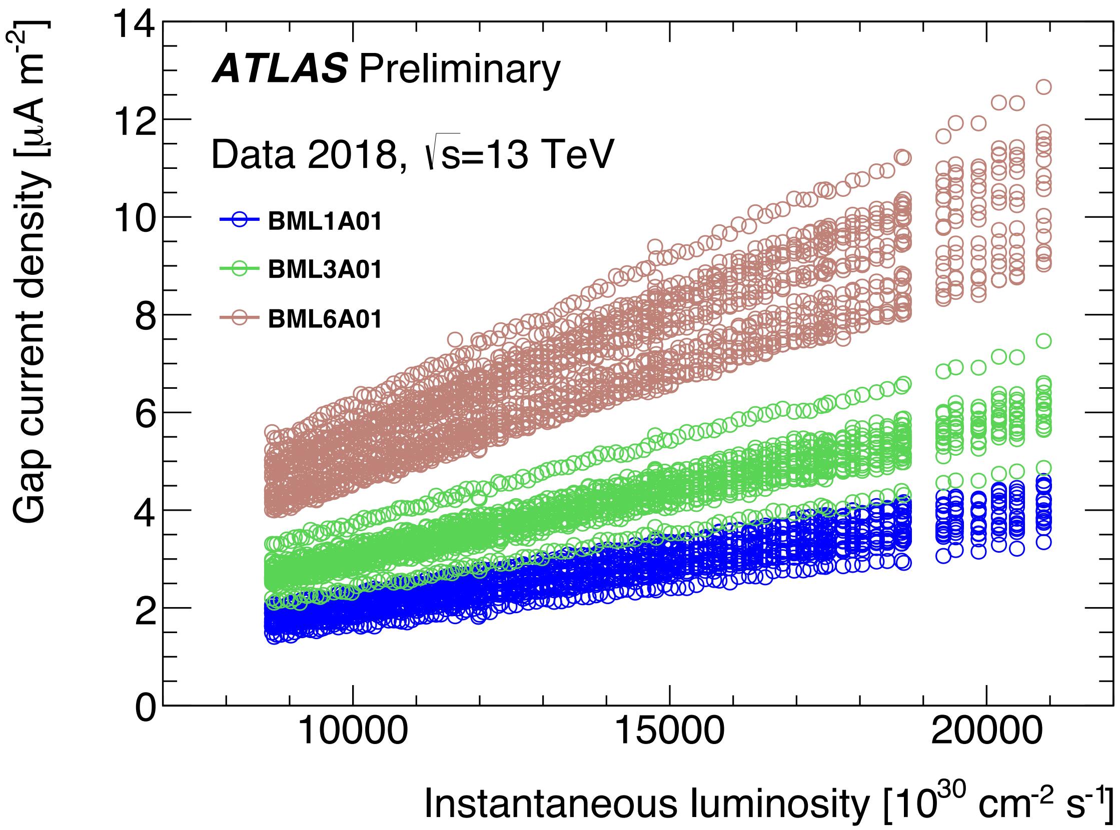
- RPC counting rate is linear dependency of instantaneous luminosity.
- Smaller hit rates in panels located further away from collision points and in the central regions: flux density of ionising particles decrease with the increasing radii values and lower values of $|\eta|$.

RPC current vs. instantaneous luminosity

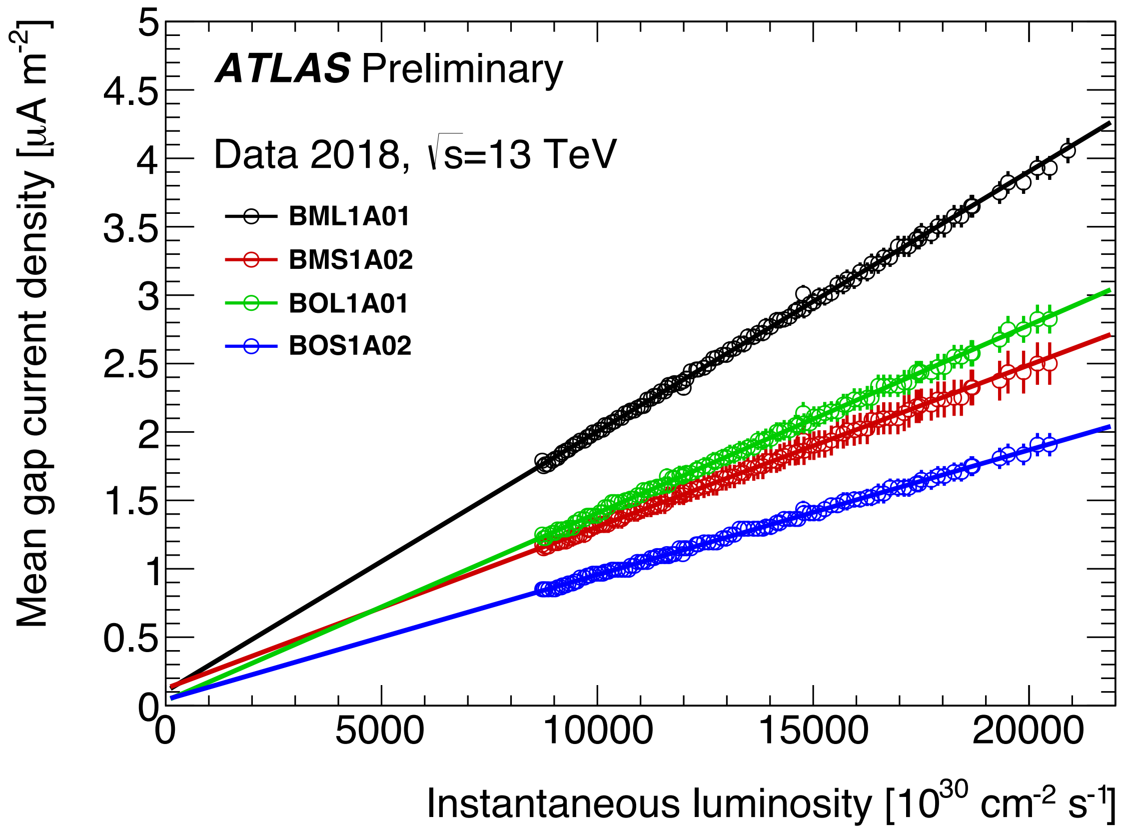
https://atlas.web.cern.ch/Atlas/GROUPS/MUON/PLOTS/MUON-2020-001/

- RPC current densities measured as function of instantaneous luminosity for several representative modules

RPC current density as the function of instantaneous luminosity for RPC modules at different η position



Average RPC current density as the function of instantaneous luminosity for small/large RPC modules at different radii

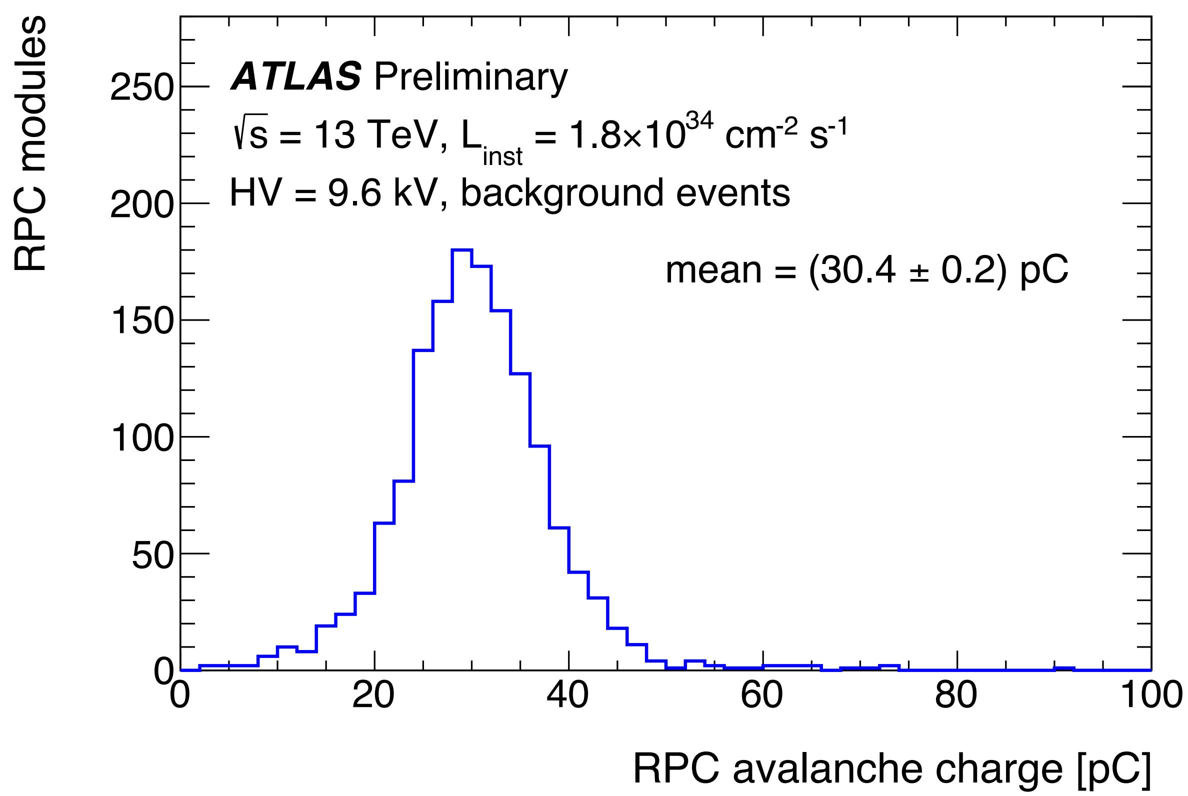


- Linear dependency of currents as a function of instantaneous luminosity is observed
- The current density increases with higher $|\eta|$ values: higher particle fluxes in the gap region due to reduced the shielding material
- Decrease at larger radii due to the reduced particle fluxes.

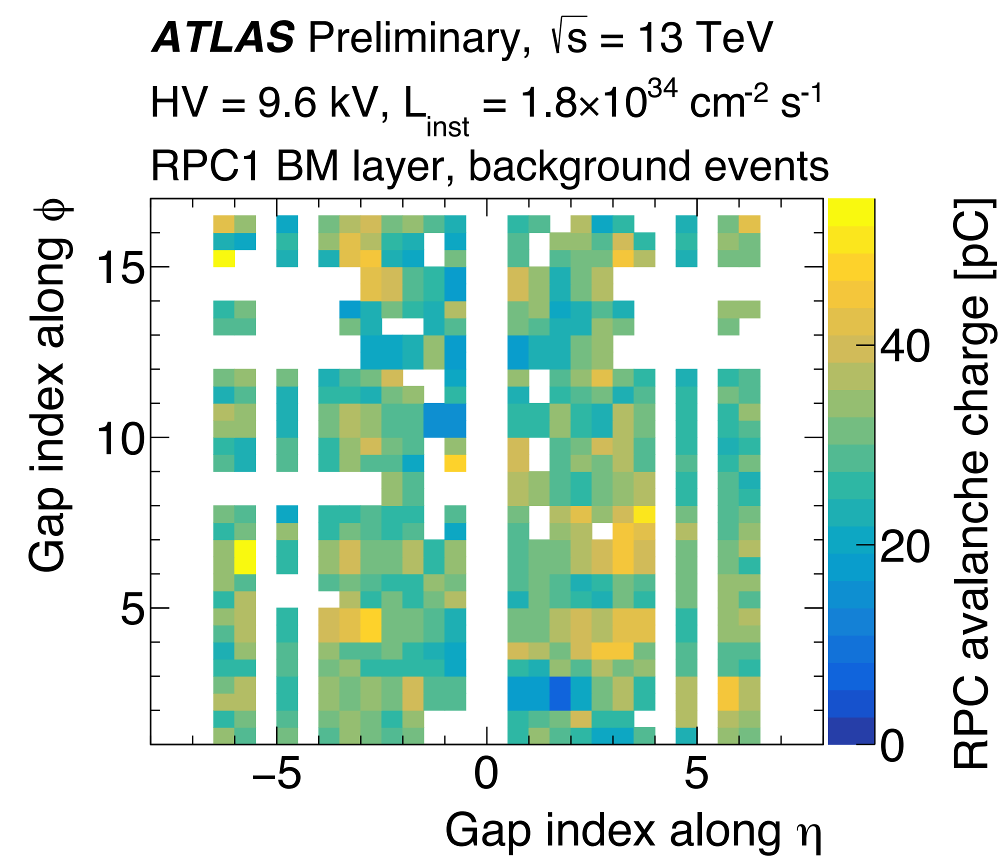
RPC effective avalanche charge measurement

- The avalanche charge produced by the gain of the electron amplification process inside the gas.
- Depends on the electric field across the gas-gap and the gas mixture.
- The avalanche charge of background events is measured by: $Q = \frac{Current}{Rate}$

Averaged RPC avalanche charge distribution per single background hit



RPC avalanche charge as the function of η and ϕ positions of RPC1 layer.



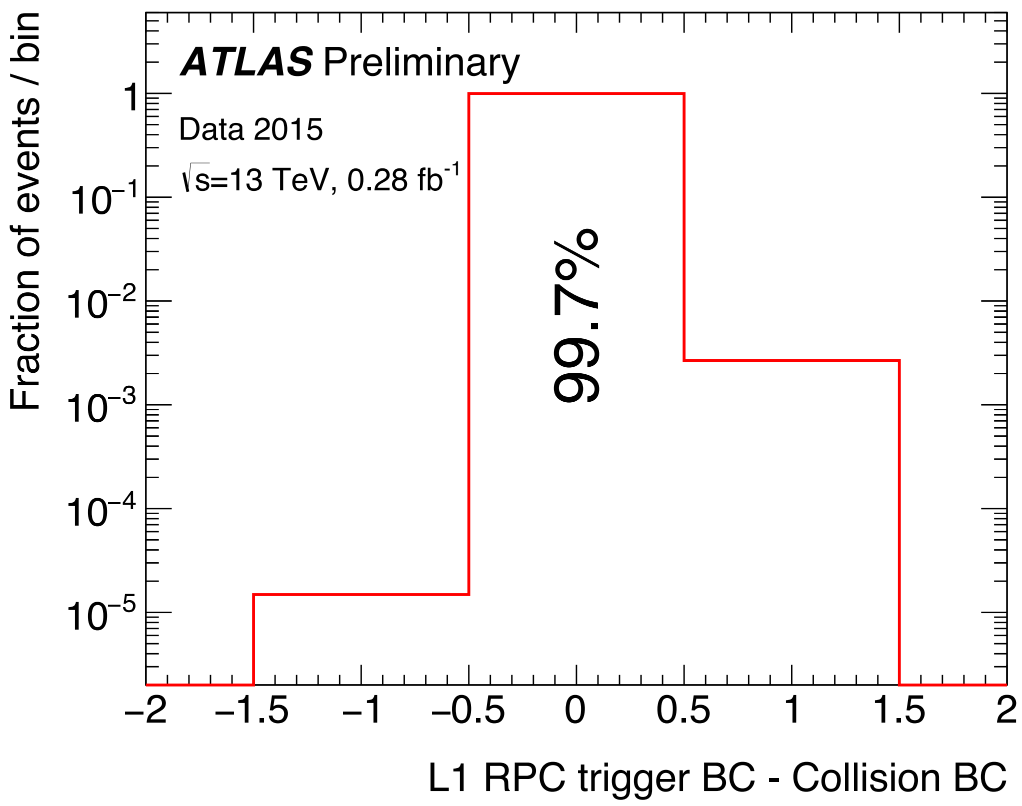
- Results comparable with previous measurement performed using gamma sources in labs or test beam data.

Level-1 Muon Barrel trigger performance

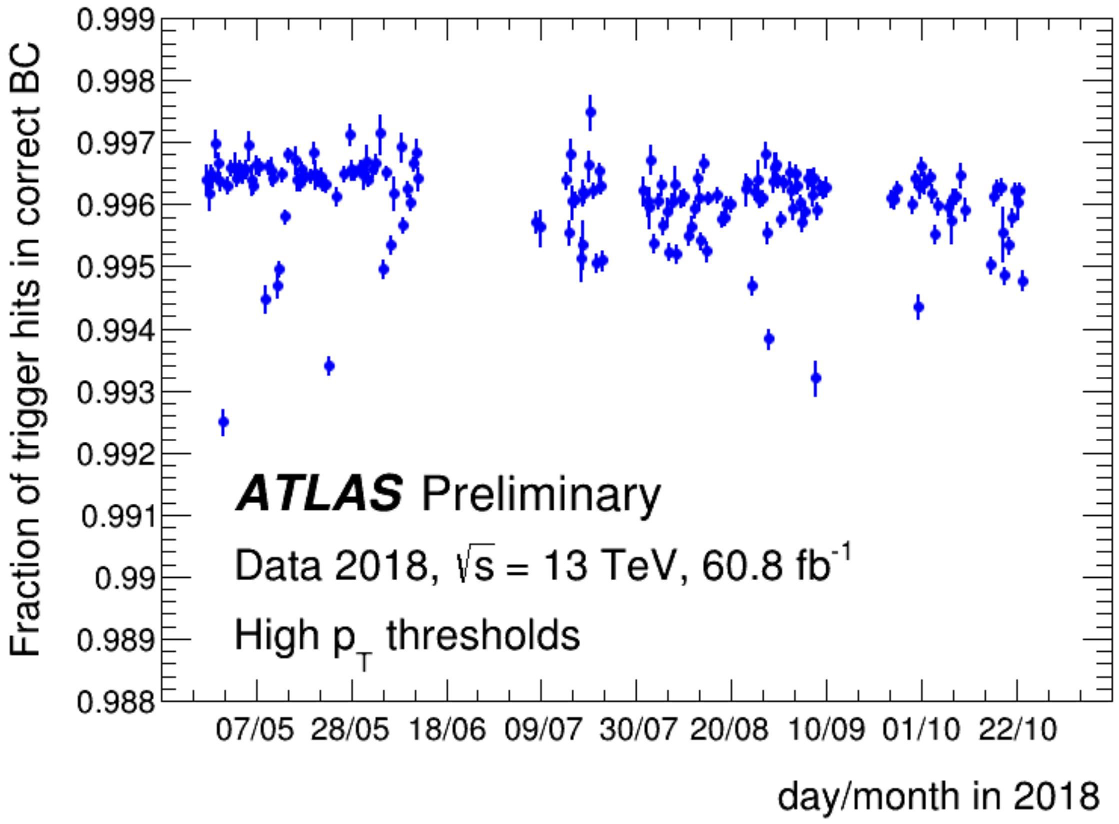
Trigger timing performance

- RPC hits are read out in timing bins of 3.125 ns.
  - Sufficient to identify individual LHC bunch crossing with 25 ns spacing
- ~ 99.7% of muon trigger candidates associated to the correct bunch crossing (BC)
- Excellent stability for correct bunch crossing association during the data taking period.

Global Fraction of trigger hits per BC



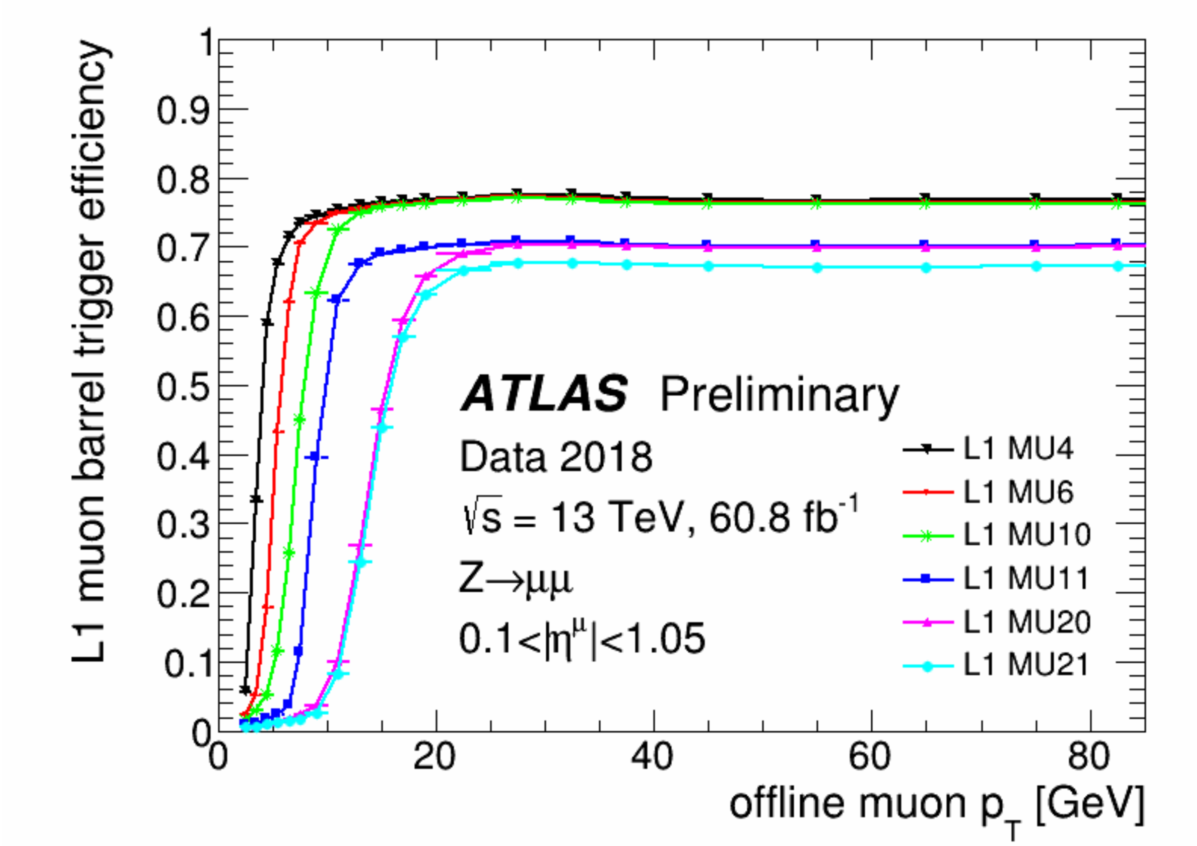
Fraction of trigger hits in corrected BC for each run



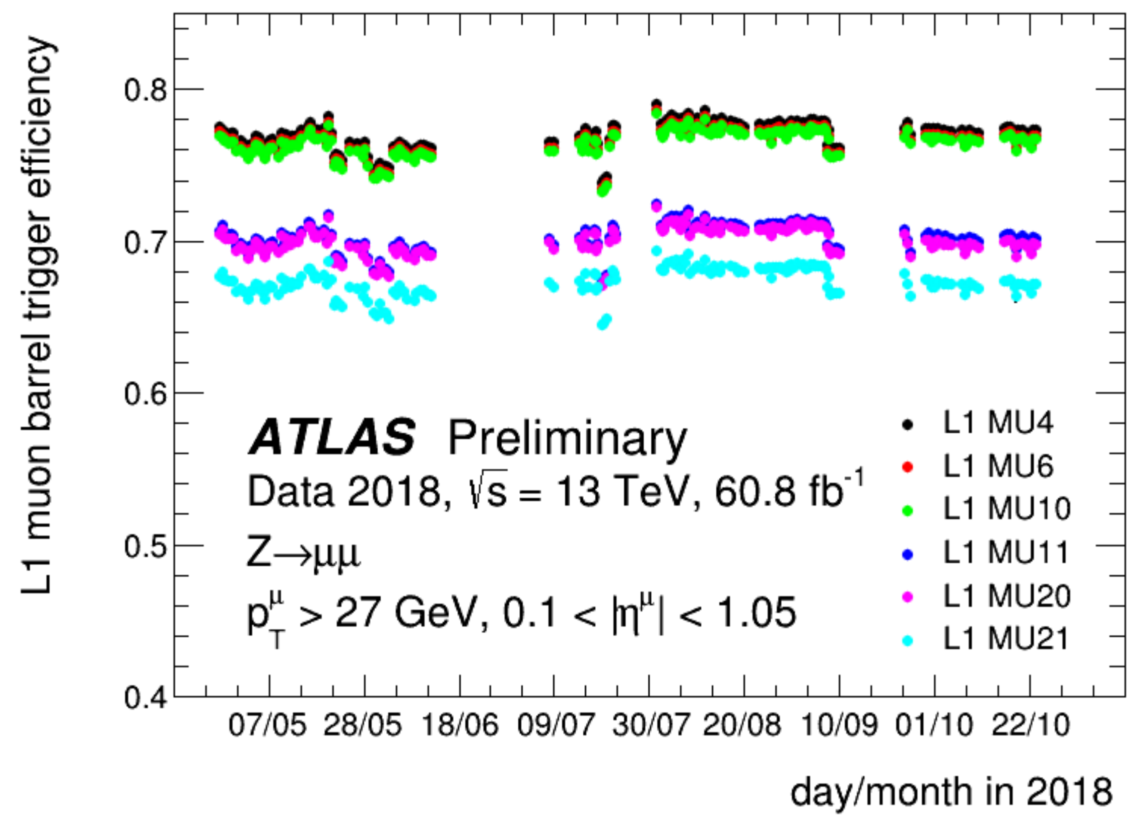
Trigger efficiency of different muon p_{T} thresholds

- The trigger efficiency is measured using unbiased muons from $Z \to \mu^{\pm}\mu^{\mp}$ candidates.
- The efficiency is limited by barrel geometrical acceptance due to detector support structures.

Trigger efficiency of offline muon as the function of transverse momentum



Trigger efficiency plateau value in each run



- Efficiency × acceptance to detect muon candidates with $p_T > 20\,\mathrm{GeV}$ is ~ 76.5% for low p_{T} thresholds and ~ 70% for high p_{T} thresholds with good stability during the data taking.

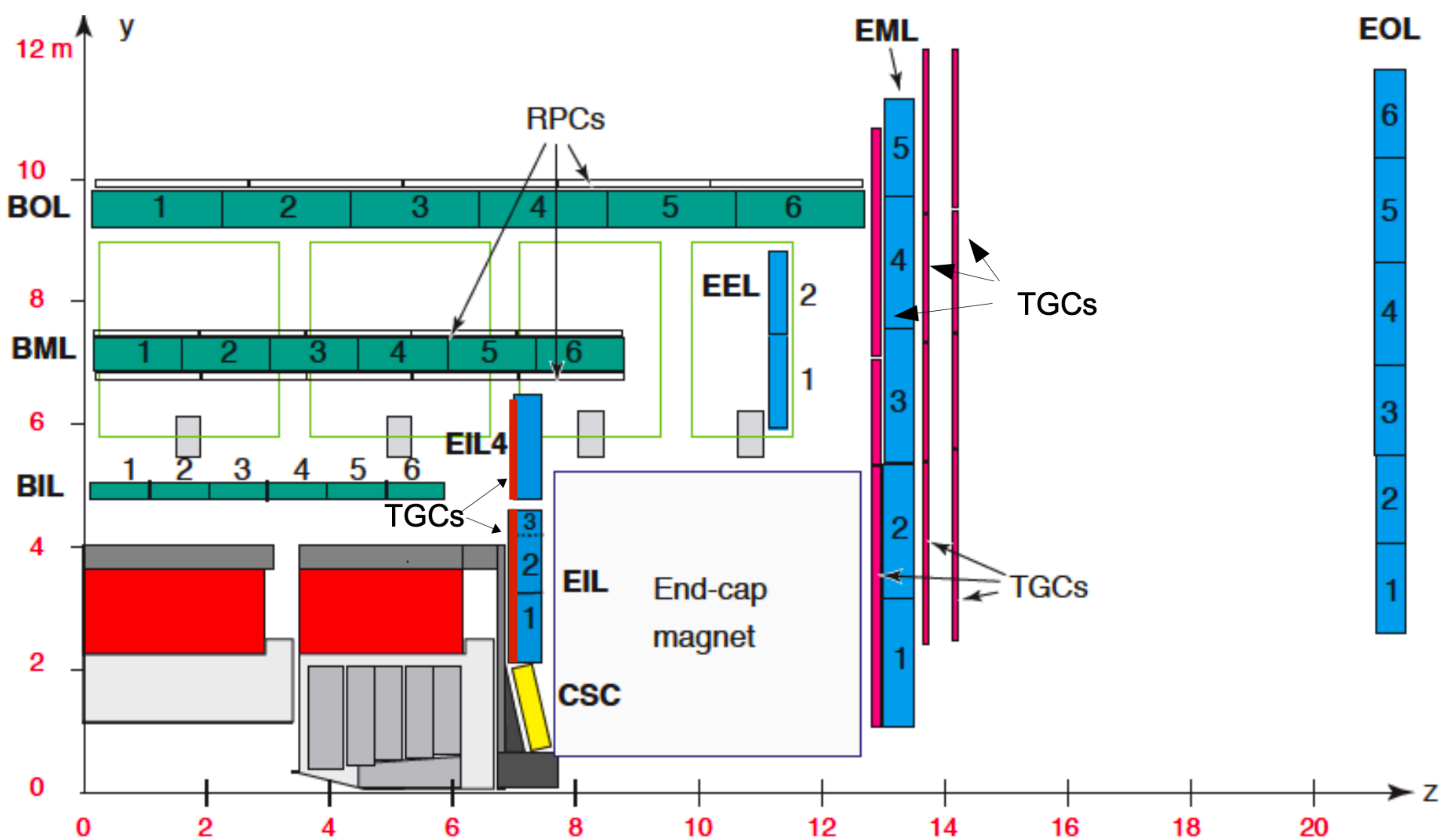
Summary

- Efficient selection of muon candidates are crucial to ATLAS physics programme.
- Presented measurements is obtained using data recorded in 2018 at $\sqrt{s} = 13$ TeV.
- Excellent ATLAS RPC detector and trigger performance since completion in 2008.
  - The average RPC cluster is approximately 1.5 strip wide.
  - Most of RPCs have high efficiency above 90%, with overall efficiency stable with time.
  - The intrinsic time resolution of RPC detector system is ~ 1 ns.
  - RPC background counting rates and currents scale linearly as a function of instantaneous luminosity, up to $2 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$.
  - The RPC avalanche charge for background events is measured to be about 30 pC and in good agreement with previous results.
  - Good performance and stability is observed for Level-1 Muon Barrel trigger efficiency.

Backup

ATLAS muon spectrometer

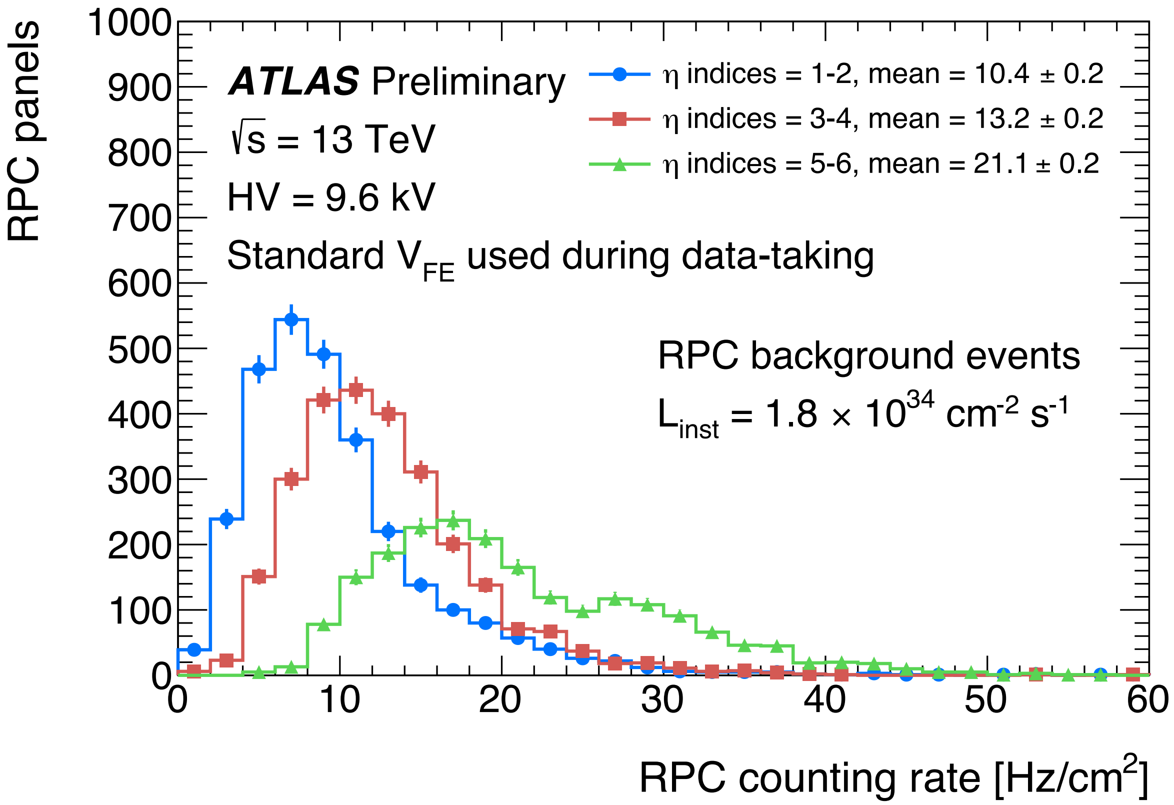
- 2 fast detectors used in L1 trigger system: RPC and TGC
- 2 precision detectors for offline track reconstruction: MDT and CSC

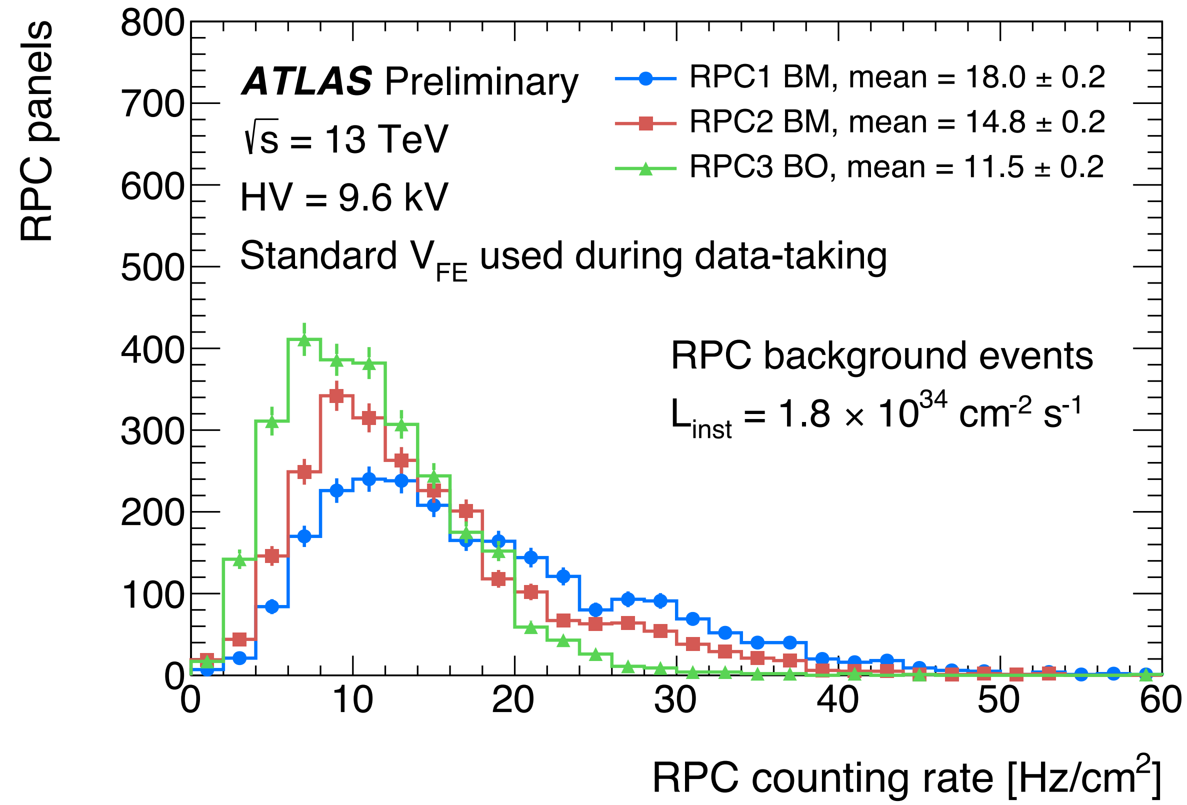


R-Z view of ATLAS muon spectrometer layout

RPC counting rate

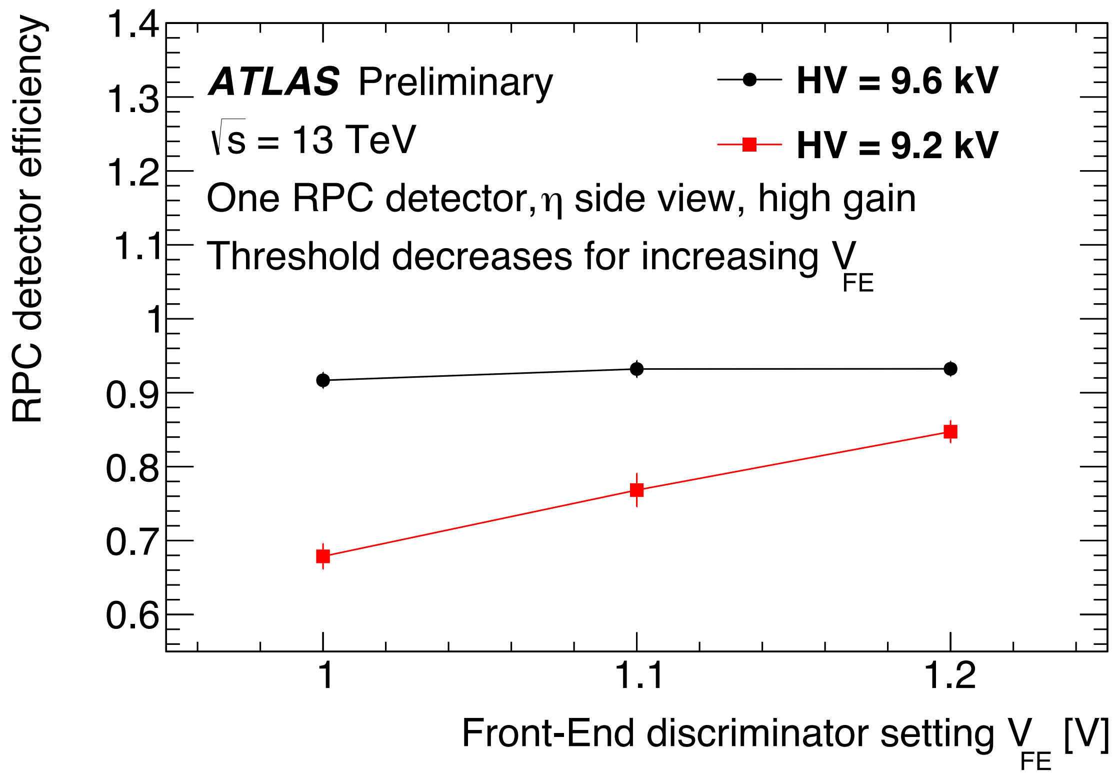
- Higher rates for strip panels located in the forward region.
- Smaller rates for strip panels located further away from collision points, on average.



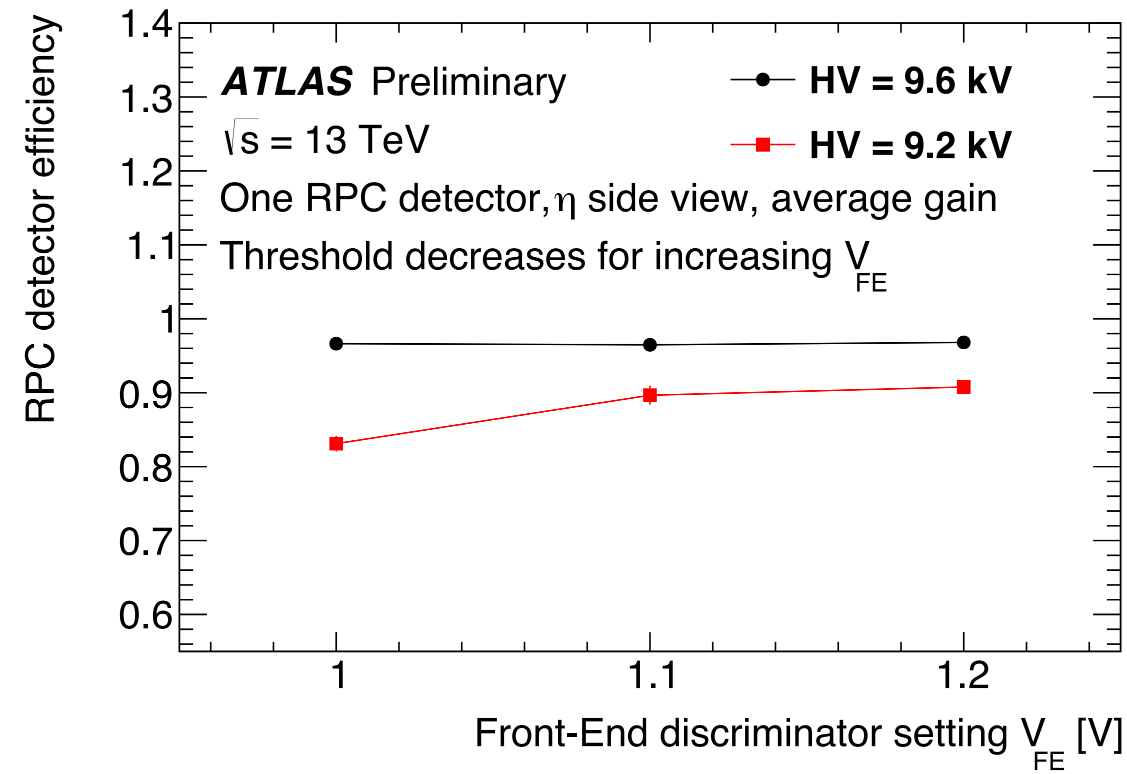


Upgrade studies for HL-LHC

- New RPC chambers will be installed in the innermost layers of barrel region.
- At HL-LHC ($\mathscr{L} \sim 7.5 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$), the integrated charge in the avalanche will be very high to excess RPCs' limit.
- Propose to lower the HV in the RPC gas-gap from 9.6 kV to 9.2 kV at HL-LHC.
- Scan the FE discriminator threshold to detect RPC response with different HV values



High gain: efficiency increasing by ~ 20% at HV = 9.2 kV from V_{FE} = 1.0 V to 1.2 V



Average gain: efficiency increasing by ~ 20% at HV = 9.2 kV from V_{FE} = 1.0 V to 1.2 V