Studies of gas gaps current density in the ATLAS RPC detector during 2018 data taking at Large Hadron Collider

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Z(\mu\mu)H -> Z(\mu\mu)Z(\text{ee}) candidate

RPC successfully contributes to ATLAS Level 1 trigger since first collisions at LHC in 2009.
The RPCs are placed in the barrel region of the ATLAS experiment: they are arranged in three concentric double layers at radius 7 m and 10 m, operating in a toroidal magnetic field \( \sim 0.5 \, \text{T} \).

RPC detectors cover the pseudo-rapidity range \( |\eta| < 1.05 \) for a total surface of about 4000 m\(^2\) and \( \sim 3700 \) gas volumes: 16 sectors in \( \phi \) direction and 12 stations in \( \eta \) directions.

The ATLAS RPCs have been certified to operate up to an integrated charge of 0.3 C/cm\(^2\). This corresponds to ten years of LHC operation at a counting rate of 100 Hz/cm\(^2\).

*More details in Heng’s talk and also in backup.*
Each RPV detector is made of two bakelite gas volumes with a 2 mm gap, operated in avalanche mode at 4.8 kV/mm with automatic correction for temperature and pressure variations with respect to the reference values of 24°C and 970 mbar.

Gas mixture: tetrafluoroethane, iso-butane, sulphur hexafluoride - 94.7 : 5.0 : 0.3 %.

Detector operates in saturated avalanche mode at 9.6 kV (standby mode – 9.0 kV).

All gas volumes have individual readout, measurements are available through ATLAS Detector Data Control System (DCS).
Gas gap current studies: motivation

- Confirm expected linear increase of gas volumes current up to the highest instantaneous luminosities – crucial feature for stable RPC performance;
- Understand gas volume current density at different voltages during data taking in 2018 and make extrapolations for future (High Luminosity LHC regime);
- Check the status of RPC gas volumes: gas purity, surface issues.
Studies with the collisions
Gas volume current measurements

- Current in gas volumes at nominal voltage but without collisions (calibration current) was subtracted.
- Gas volumes currents are normalized to gap area.

Time intervals during beam positions adjustment are excluded from the study.
Representative collection of highly performing gas volumes are selected.

Expected linear increase was confirmed up to the highest instantaneous luminosity during the 2\textsuperscript{nd} data taking period for various RPC gas volumes.
HV scans

Procedure:
- 5 scans (~ 5 min each) at the beginning of physics runs with HV=9.1/9.2/9.3/9.4/9.5 kV – range is chosen to address future possible RPC working conditions;
- two standard working points: HV=9.0/9.6 kV;
- luminosities are corrected to \( L = 1.8 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \) (largest correction 3%);
- HV values are corrected for temperature and pressure effects;
- data extraction was performed 2 times to estimate systematic uncertainty.

\[
\Delta I = \frac{I_{\text{max}} - I_{\text{min}}}{2}
\]

Gas volume currents summed across one HV channel [\( \mu \text{A/m}^2 \)]
ATLAS Instantaneous luminosity \([10^{33} \text{ cm}^{-2} \text{ s}^{-1}]\)
RPC Voltage [V]
Gas volumes currents do not exceed 12 μA/m² at HV=9.6 kV and instantaneous luminosity $1.8\times10^{34}$ cm$^{-2}$ s$^{-1}$ during data taking in 2018.

Gas volumes current density dependence from HV at beam conditions can be linearly described at V=9-9.6 kV.
Scale factors are derived from the linear fit of gas volume current density as function of voltage:

- Global SF = 2.13 is based on the most common linear fit parameters along all gas volumes;
- Individual SFs are derived per gas volume.

SFs from linear approximation can be used to obtain gas volume current densities within HV = 9 - 9.6 kV. Scaling per gas volume is more precise.
Current vs HV and extrapolation at HL-LHC

**Luminosity scaling:**
Gas volume current linearly depends on instantaneous luminosity => scale factor=7.5/1.8

**Safe threshold for current:** $30 \ \mu A/m^2$
based on results reported in Muon Phase II upgrade report ATLAS-TDR-026, i.e. RPC integrated charge is less than 30 mC/cm$^2$ per year (assuming LHC run 33% of time).

In some gas volumes current exceed safe threshold at $V=9.6$ kV and $L=7.5\times10^{34} \ \text{cm}^{-2}\text{s}^{-1}$.
It can be solved by lowering HV from 9.6 to 9.2 kV, but reducing efficiency.
Current vs HV, HL LHC

Safe thresholds are shown by pink circles, rate map includes additional safety factor of 2

- 2D $\phi$-$\eta$ map confirms that lowering HV to 9.2 kV helps to address the issue with overcurrent in affected gas volumes at HL LHC conditions.
- Right plots show some increase of gas volume current density as function of $\phi$ index, which is consistent with the temperature increase gradient in ATLAS cavern (please see next slide).
Temperature studies

RPCs at $\varphi$ sectors 3 and 7 (in the top half of ATLAS) have higher temperature than sectors 11 and 15 placed symmetrically on bottom of the detector.

- Consistent increase of gas volume current density with temperature across the whole RPC was observed ($\sim 6 \mu\text{A/m}^2$ per $10^\circ\text{C}$).
- Gas volume current density increases from upper (3,7) to lower (11,15) $\varphi$ sectors, confirming the previous statement.
Studies without the collisions
Gas volumes current dependence from HV at beam conditions can be linearly described up to HV=6 kV (Ohm’s law), then current density starts to increase exponentially with voltage. Right plot shows same curves after subtraction of Ohmic current contribution:

Discrepancies between these two curves indicate difference in operation mode of this gas. For instance generally discrepancies in linear slopes are connected to a different level of cleanliness or deposition on frame and spacer surfaces. *Studies are ongoing.*
Through the entire detector a mean of gas volumes current density distribution increase by 15% from HV=9.2 kV to HV=9.6 kV, where 5% increase comes from the Ohmic contribution and the rest is from the avalanche growth. This result confirms good quality of gaps.
RPC gas volumes currents were studied as a function of instantaneous luminosity, voltage and temperature for the condition with and without pp collisions.

Studies at various luminosity and voltage showed:
- expected linear increase of gas volume current was confirmed up to the highest instantaneous luminosity during the 2^{nd} data taking period of LHC for various RPCs;
- gas volumes current dependence from voltage at beam conditions can be linearly described at V=9-9.6 kV. Therefore gas volume currents can be scaled in a straightforward way between different voltages.

Studies of gas volume current density extrapolations to HL LHC conditions showed:
- lowering HV to 9.2 kV helps to address the overcurrent in affected gas volumes at HL LHC conditions, however with some drop of efficiency;
- consistent increase of gas volume current density with temperature across the whole RPC was observed (\sim 6 \mu A/m^2 per 10^\circ C).

Curves of gas volumes current as function of HV (without collisions condition) are efficient instrument to monitor gaps state.

The end, thank you.
ATLAS RPC details view
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 0.1x0.1 in ΔηΔφ

- 3 low pT thresholds:
  - Requires 3/4 coincidence within trigger road in the two inner doublet layers

- 3 high pT thresholds:
  - Requires low pT trigger and 1/2 coincidence in the outer doublet layer
Efficiency vs HV vs high gain threshold

**ATLAS Preliminary**

\( \text{\( s = 13 \) TeV} \)

One RPC detector, \( \eta \) side view, high gain
Threshold decreases for increasing \( V_{FE} \)

*nominal*

**ATLAS Preliminary**

\( \text{\( s = 13 \) TeV} \)

One RPC detector, \( \eta \) side view, average gain
Threshold decreases for increasing \( V_{FE} \)