RPC operation in the ATLAS experiment

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On behalf of the RPC/LVL1 community

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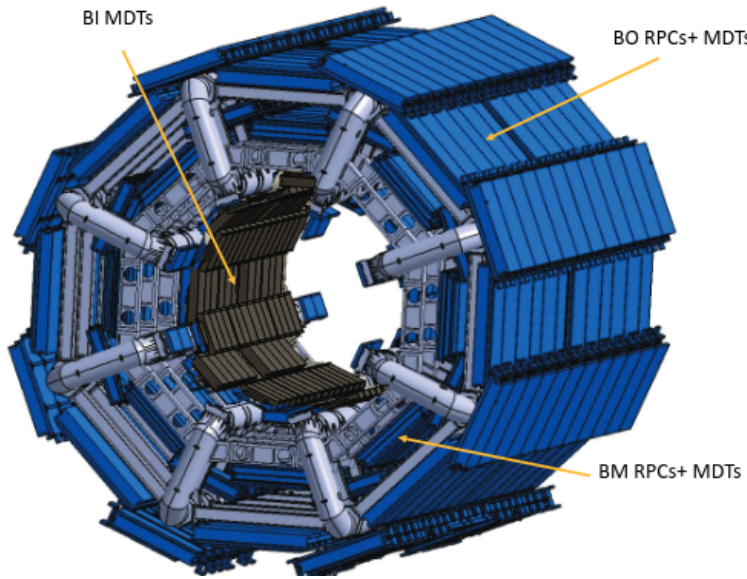
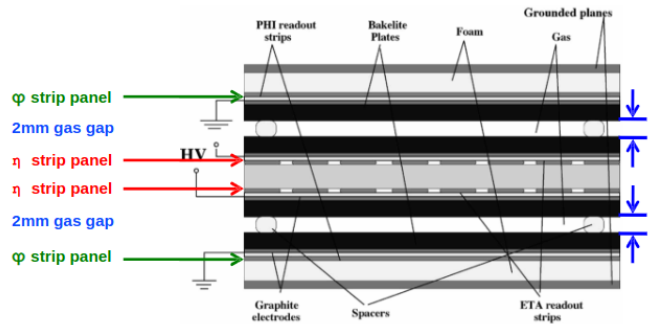
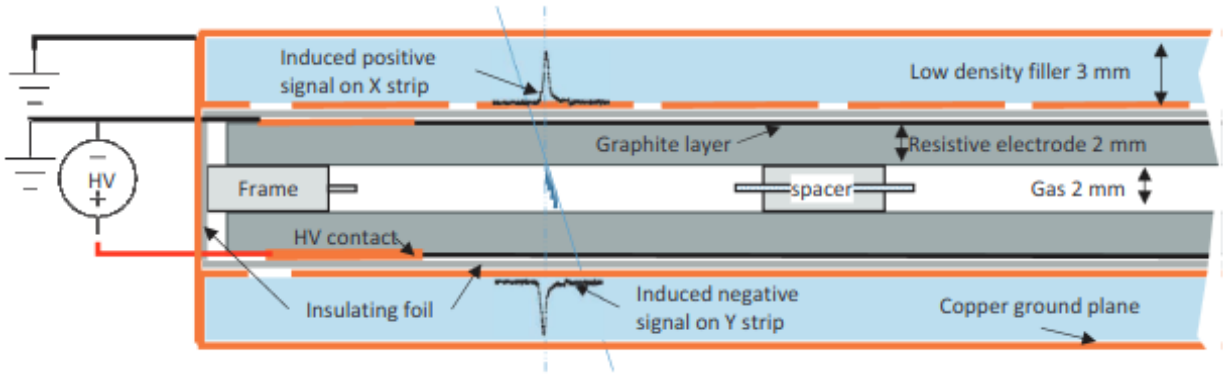
Overview

The ATLAS RPC System

- 3 concentric layers of doublet chambers in the barrel region at radius ∼7m to ∼10m, operating in a toroidal magnetic field of approximately 0.5 T and providing 6 independent 2-coordinate measurements.
- Two doublets on the two sides of the MDT in BM, and the third one to one side of MDT outer layer BO.
- 2 sensitive gas gaps, with read out on both surfaces with orthogonal strips to provide a measurement of the η and ϕ coordinates.
- Used for triggering, muon reconstruction to measure the track positions in the non-bending (ϕ) coordinate, and time measurement to reject cosmic muons and to search for delayed signals from high-mass LLPs.

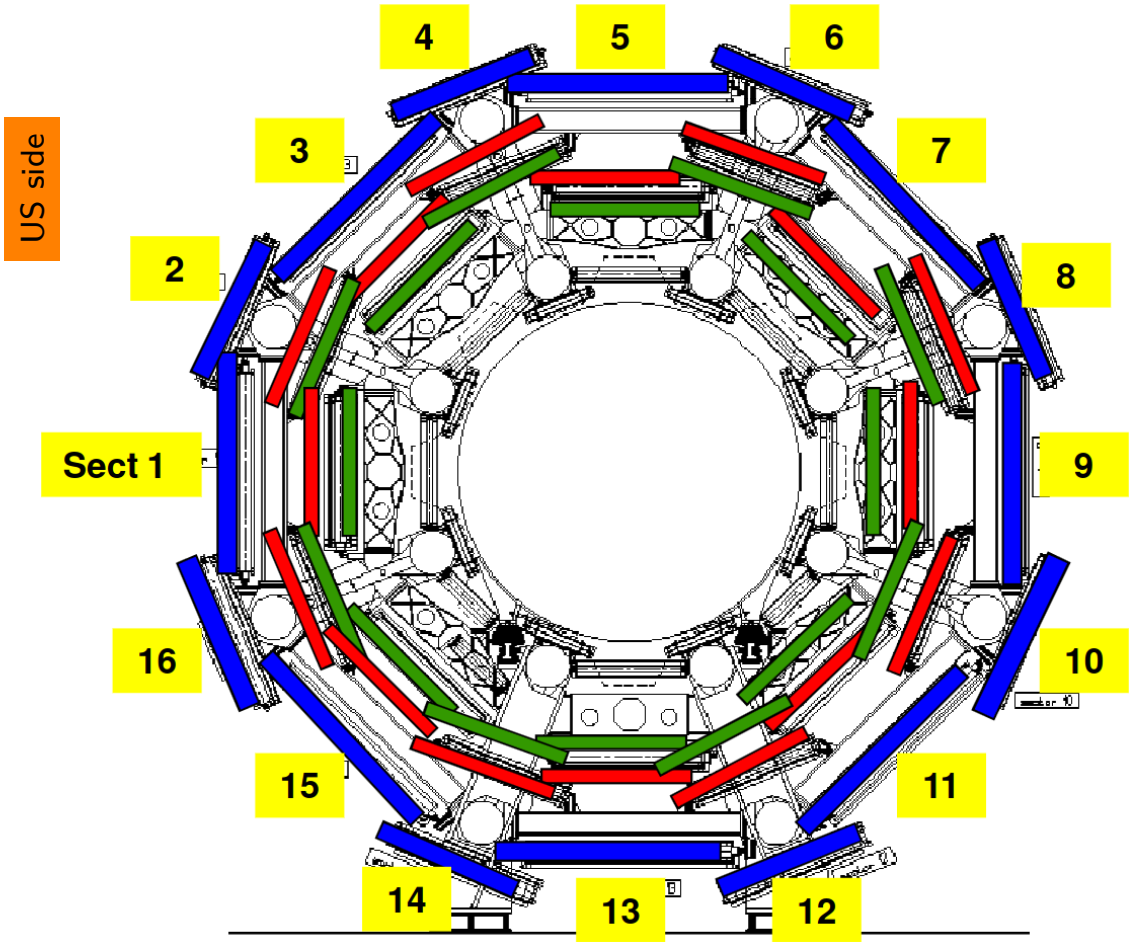


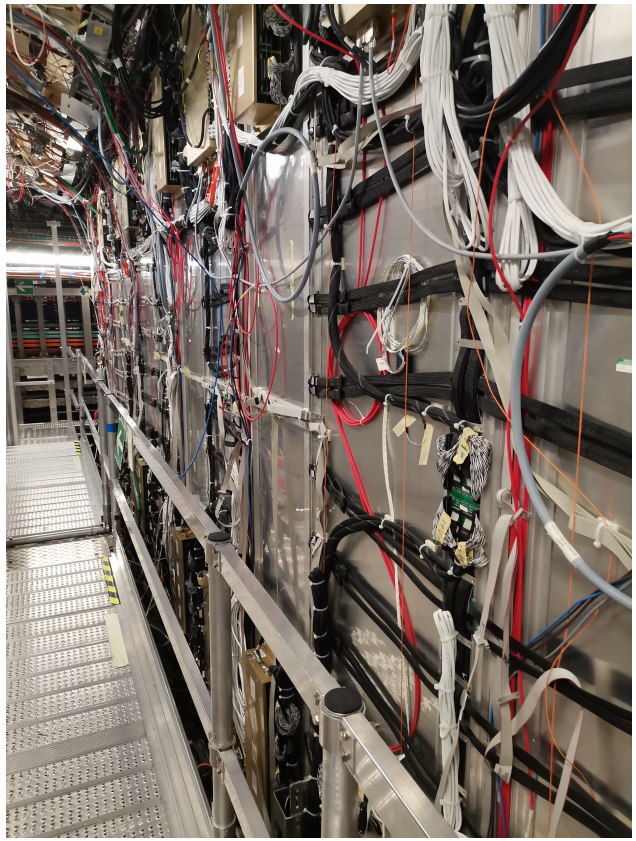




- 2 bakelite electrodes and a gap with gas mixture of $C_2H_2F_4 : i - C_4H_{10} : SF_6$ (94.7 : 5.0 : 0.3)%, operating in avalenche mode at 4.8 kV/mm with automatic T,p corrections.

The ATLAS RPC System





- Layers are arranged in 16 barrel sectors.
  - 2 in BM stations (BM Confirm – BM Pivot)
  - 1 in BO stations (BO Confirm)
- No RPCs in the inner stations.

- ATLAS MS RPCs in z-axis view: BOL.A09.Ly1
- No RPCs in EndCaps.

RPC LVL1 Trigger

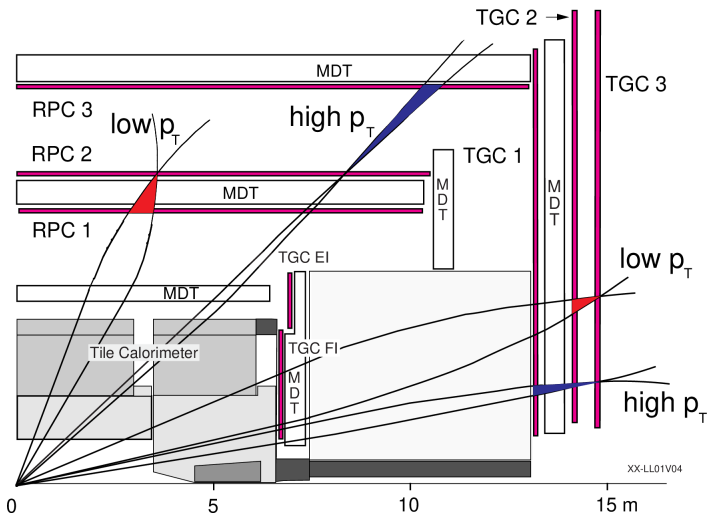
Two trigger algorithms in the B (3 RPC doublets) and EC regions.

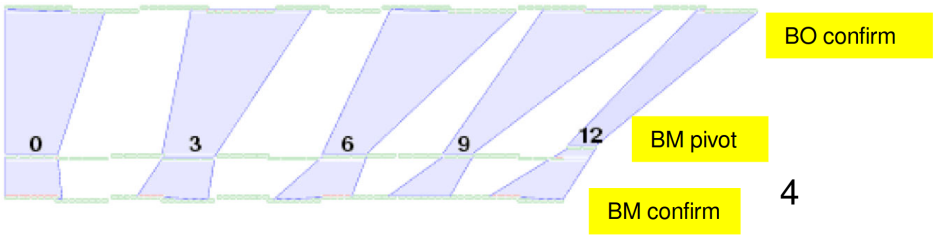
- Low-p_T trigger: RPC2 & RPC1

  At least 3 hits in the 4 inner layers on both η and ϕ views: Hit in station RPC2 (BM pivot) extrapolated to station RPC1 (BM confirm) along a straight line through IP and within a coincidence window.

- High-p_T trigger: Low-p_T & RPC3

  Logical AND of Low PT and at least 1 hit; on both η and ϕ views; on one of the 2 planes in station RPC3 (BO confirm) within a coincidence window.





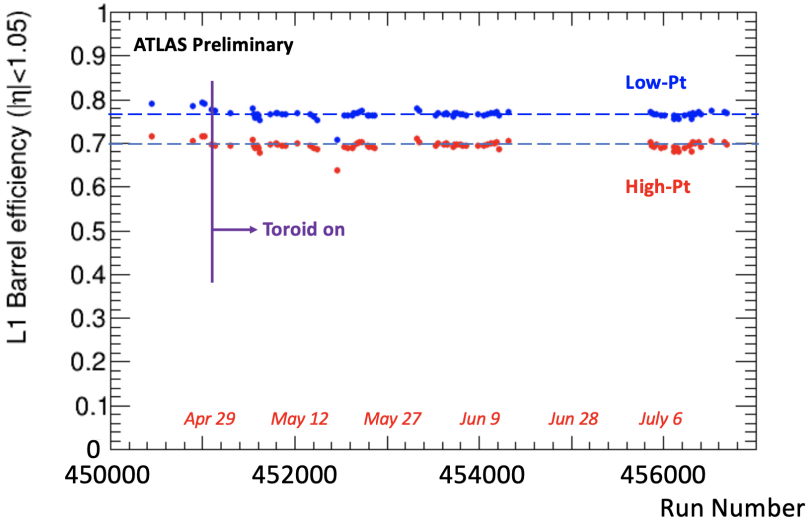
Some trigger road projections for the η-coincidences.

Coincidences are performed in coincidence matrices (CM) hosted inside PAD boxes placed on detector.
Since last year **relaxation of majority conditions** has been introduced to recover trigger efficiency if one layer is off on both RPC1 & RPC2, 3/4 majority gives trigger holes.

- If there is just one layer off out of 4, 3/4 majority gives lower efficiency $\sim 89\%$.
- Majority changed to 2/4 with very modest effects on trigger rates.

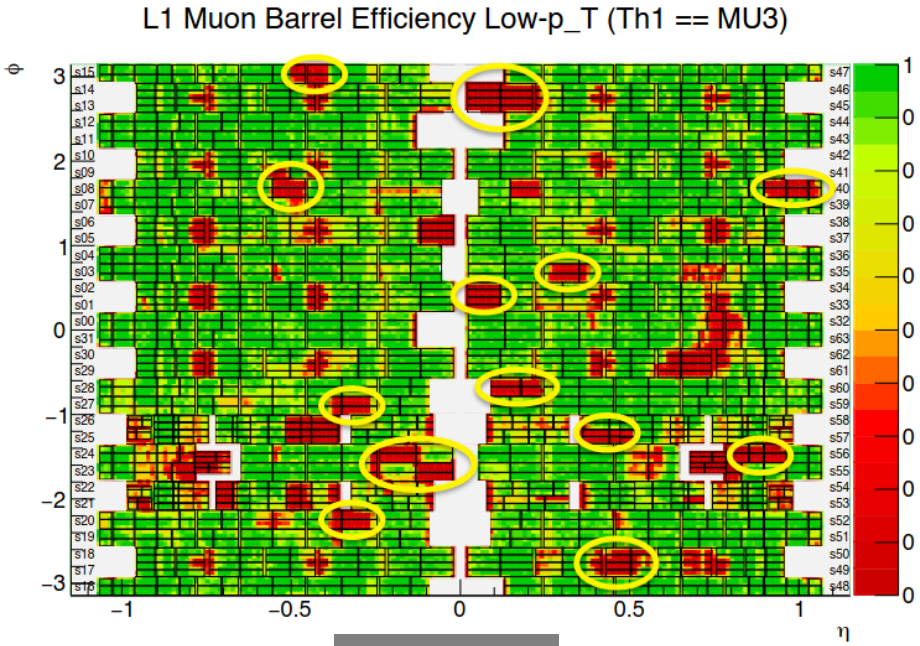
Trigger Efficiency

- In 2023, the trigger efficiency remained stable throughout the entire year, mirroring the performance observed during Run2.
- This is achieved by: • using the majority 2/4 (actually 1/2 AND 1/2), that is our new baseline (contrary to the 3/4 used in Run2) [allows less sensitivity of the trigger to the RPC HV problems] • by recovering HV channels via several disconnections (usually on chamber) of gaps with high current.
- RPC gas leaks repairs successfully remedied a significant portion of the trigger holes observed in 2022.
- New trigger holes are present also in 2023, due to new appeared leaks.



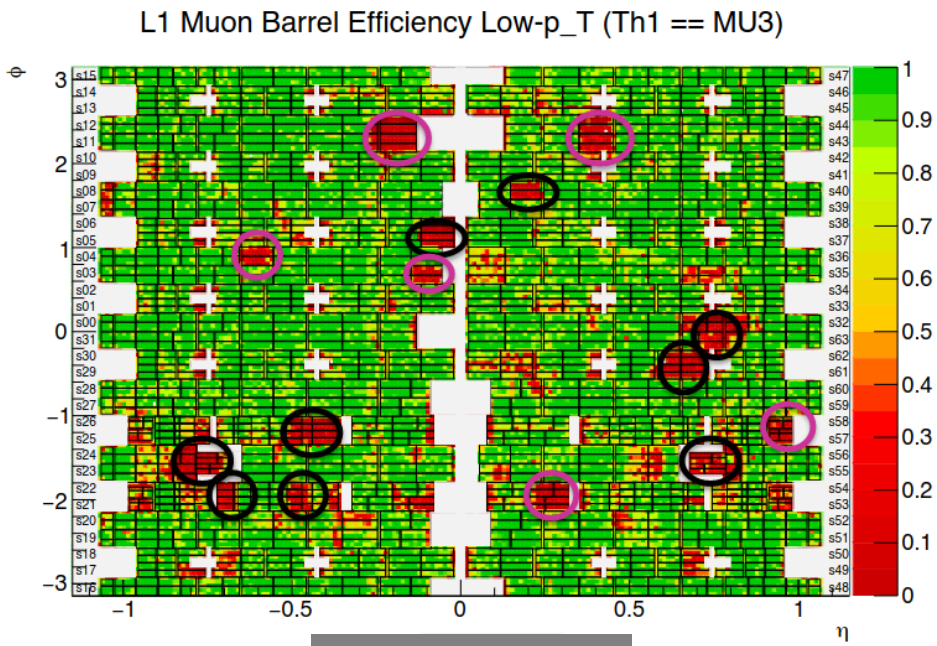
Comparison of trigger efficiency maps

Low-pT **End-of-2022**



Recovered

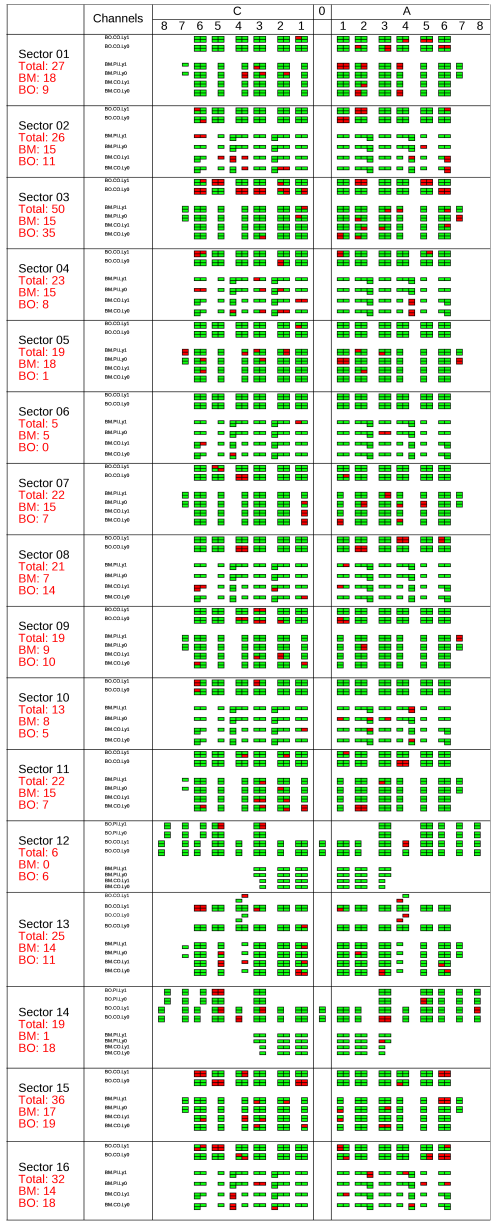
Low-pT **Run 453556 (Jun 02)**



Unfixed New

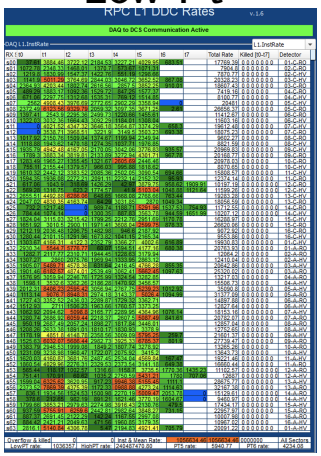
Gap status from DCS

- Total number of gaps is 3714, powered by 380 HV channels.
- End of YETS (Apr 2023): 393 Gas Gaps dead in total, of which:
  - 23 in recovery.
  - 166 disconnected on chamber.
  - 204 disconnected on rack.
- Now (Oct 2023): 360 Gas Gaps dead in total:
  - 23 in recovery.
  - 188 disconnected on chamber.
  - 149 disconnected on rack.
- Thanks to the several shadow accesses, the number of Dead Gas Gaps is maintained stable and slightly improved.



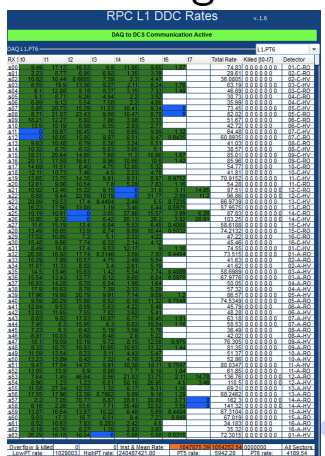
RPC Trigger Hardware Status

Low-Pt



- Green towers: hardware fully working
- Blue towers: trigger holes due to RPC HV missing. [Work ongoing..]

High-Pt



New Readout Window: 8 BC $\rightarrow$ 4 BC

- Since 20th of June, RO Windows changed from 8 BC to 4 BC.
  - $\mapsto$ The goal: reduce the number of rod and tower resynchronizations during a run.

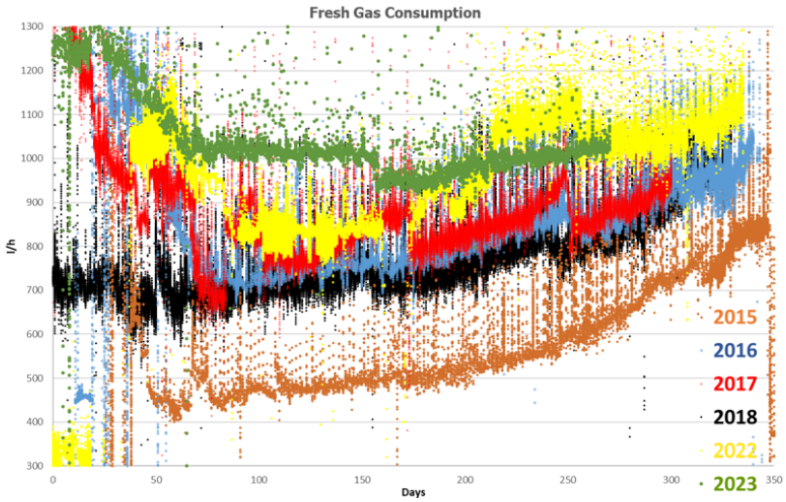
RO wind.	Int. Lumin.	Lumi Blocks	Days	# of resynchs	Resyncs/ fb^{-1}
8 BC	3.9 fb^{-1}	9101	8	117	29.5 +- 2.1
4 BC	3.9 fb^{-1}	8932	4	69	17.7 +- 2.1

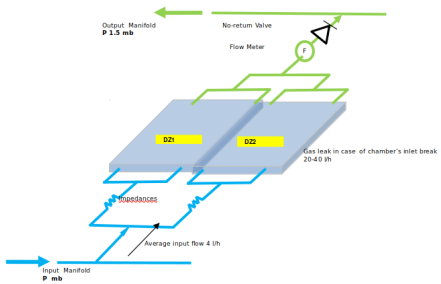
- A clear improvement in the number of resynchs.
- With next year pp collisions at high luminosity, additional studies will be conducted.
- The result in term of efficiency is very similar for the two window choices. i.e.: Run 454222 [8 BC] and Run 456016 [4 BC] efficiencies look very similar.
- The two runs could differ for other things besides the RO window, like HV status, thresholds, etc..., so we do not expect that black and red points lie on top of each other.
- Trigger efficiency is unchanged because we didn't touch the trigger path; it does not depend on the readout window.

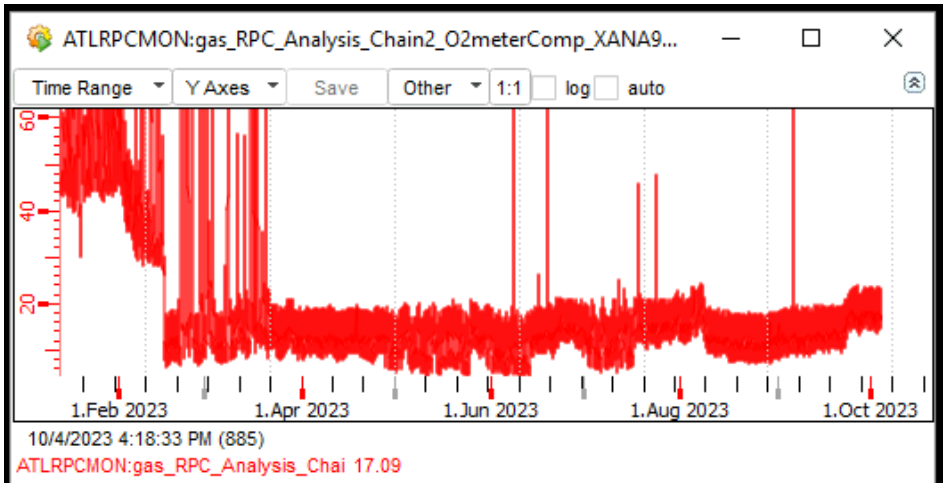
Gas system status

Time evolution of fresh gas consumption per year.

- Flow is stable at 1060 l/h.
- Effect of non-return valves well visible.
- **Since august running with new gas mixture: 30% CO2, 64% C2H2F4, 6% C4H10, 1% SF6.**
- For BM and BO: HV nominal (9.35kV) and standby (8.8kV) values changed accordingly.
- For BME: HV nominal (5.6kV) and standby (4.8kV)
- p-p collisions needed to measure the new trigger efficiency.







Oxygen content in the mixture:

- Running with an O2 content stable at 15 ppm.
- Recently small increase: possible cause is a new air intake probably due to a new leak.

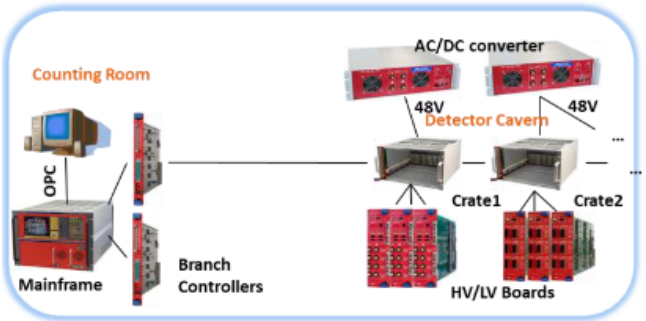
RPC DCS and 2023 Operation

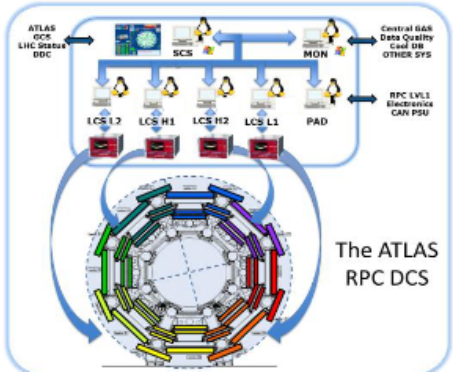
RPC Detector Control System:

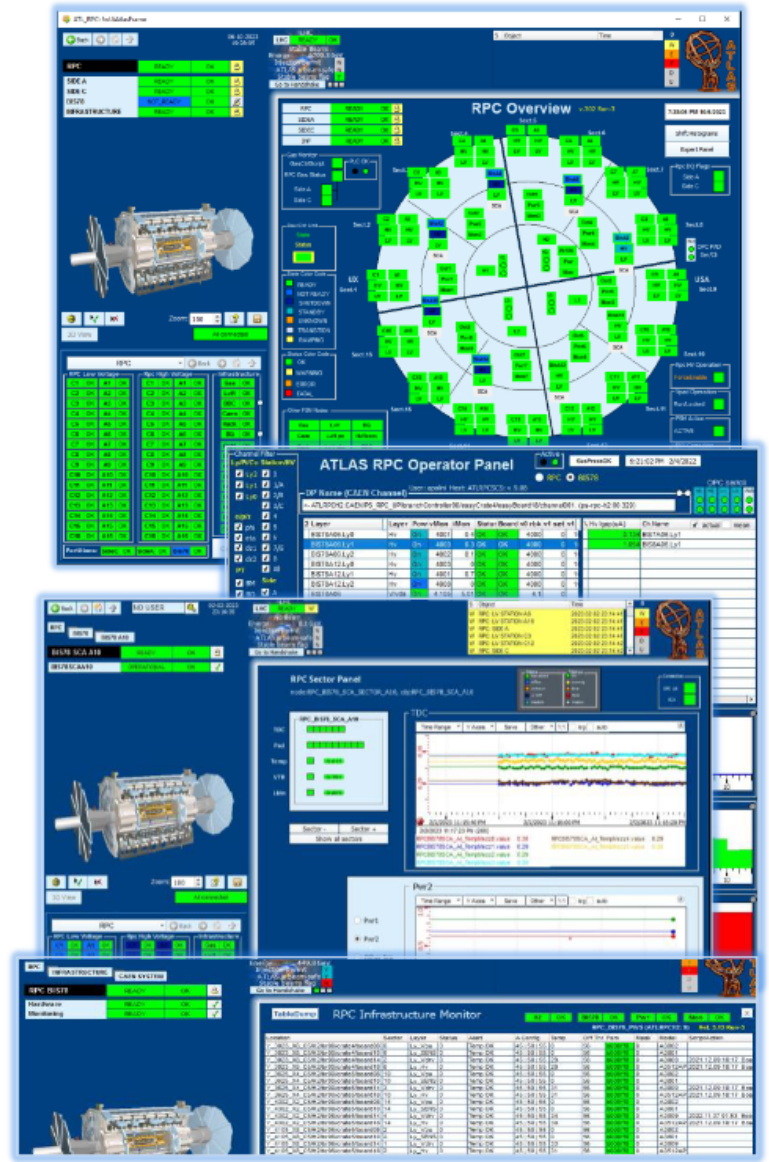
- Distributed System with several PC servers running SCADA Software (WinccOA) connected to several systems including an extended CAEN EASY Power System
- CAEN Power System: 4 mainframes, 17 Branch Controllers, 100 crates, ~400 boards, 20K channels (HV/LV ADC/DAC)

2023 Operations:

- Overall RPC DCS Stable Operation
- The rare stuck communication to CAEN mainframe can be reset remotely without glitches on the HV/LV modules.
- Few boards failing during the full 2023 running.



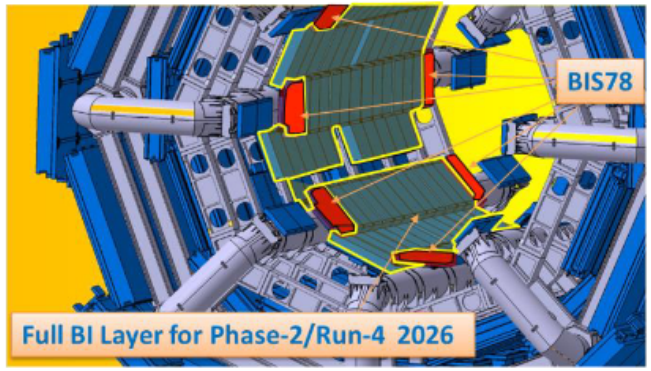




RPC BIS-78 Phase I Upgrade

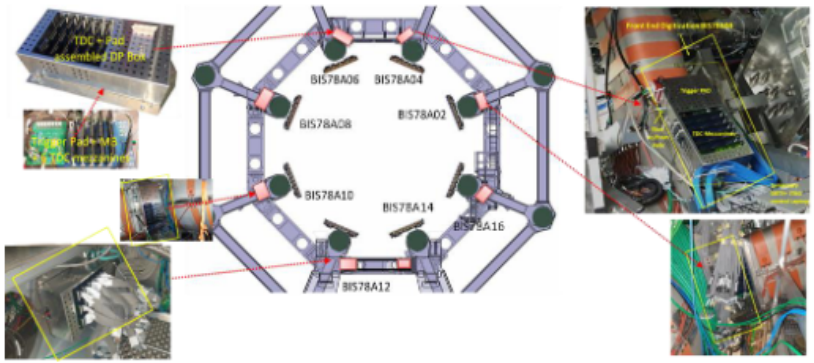
RPC BIS78:

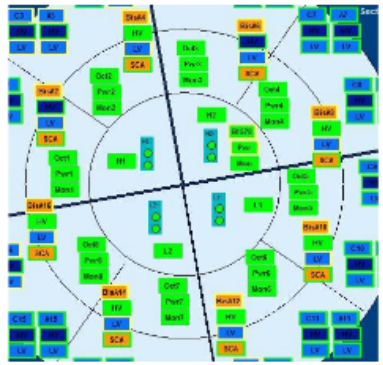
- Pilot project for RPC BI Phase 2 Upgrade (2026-28)
- New RPC triplets, 1mm gas gap in the ATLAS Barrel Inner region.
- Side A installed in LS-2
- Integrated into DCS, CAEN Power System (4 additional crates), additional monitoring through GBTSCA
- New DAQ system (Felix based).

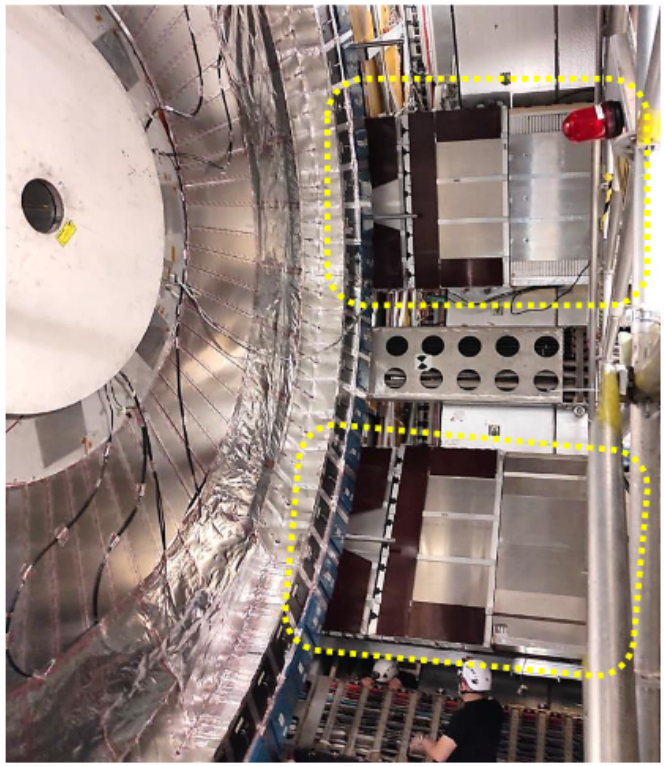


2023 Operation:

- Took mostly standalone data in 2023, integration in ATLAS TDAQ being finalized.
- BIS78 fully integrated in the DCS running with infrastructure monitored and ON, but, to allow for FW development and tests, set not to propagate FSM states and alarms to not disrupt shifter and ATLAS operation

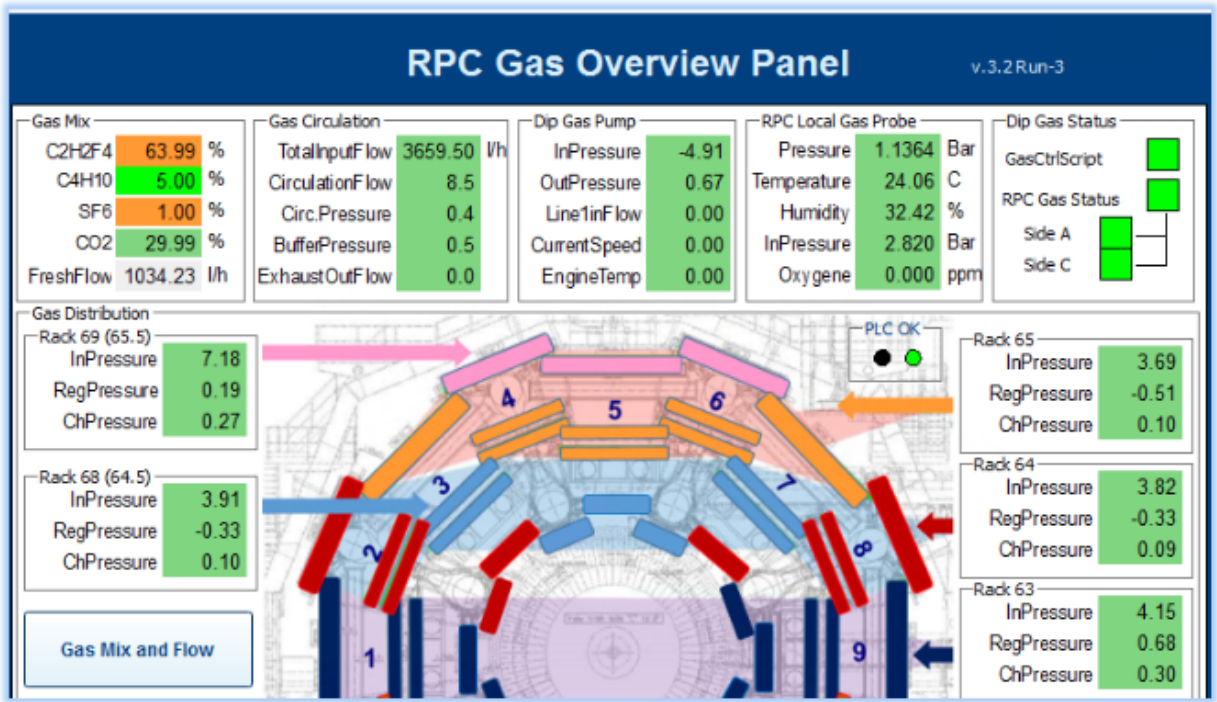


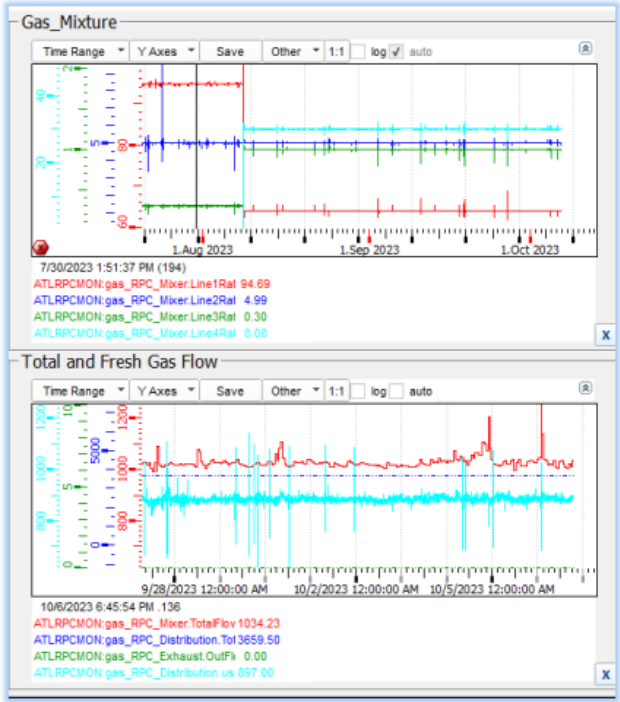




Recent Developments (Gas)

- Development in view of the Gas Mixture change August 8th:
  - From: C2H4F4 94.7%, C4H10 5%, SF6 0.3%
  - To: C2H4F4 64%, C4H10 5%, SF6 1%, CO2 30%





- On WinCC side gas infrastructure updated.
- WinCC Control Managers for LHC interaction, FSM commands and GUI Panels have been correspondingly updated.
- Ready/Nominal voltage for Legacy Chambers 9600 $\mapsto$ 9350 V (T/p corrected).
- Standby: 9000V - 8000V $\mapsto$ 8800V - 8000V
- Smooth operation both DCS, Detector and Gas-wise

Gas leaks repairs technique

Standard technique

Consists of:

- Glueing partially cracked inlets: spray glue.
- Replacing fully cracked inlets with a small pipe: remove the PBT QUICK coupling by small pipe that is thight toward the pipe.

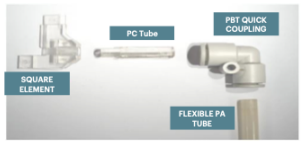
First, priority is given to repairing gaps in order to address trigger holes. Subsequently, large leaky lines are addressed.

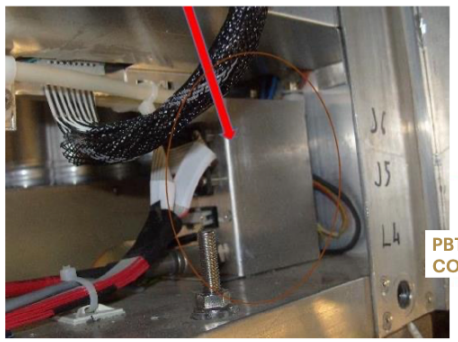
Resin injection technique

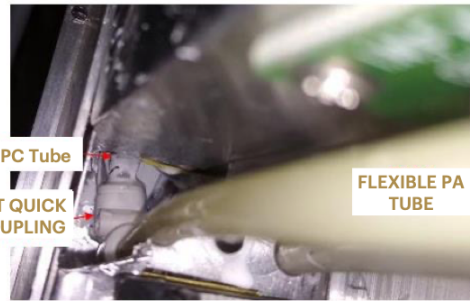
- Fixing of small leaks and prevention of leaks
- Applicable when inlets are not completely cracked
- R&D still ongoing to extend the applicability to all barrel regions (e.g. vertical chambers)

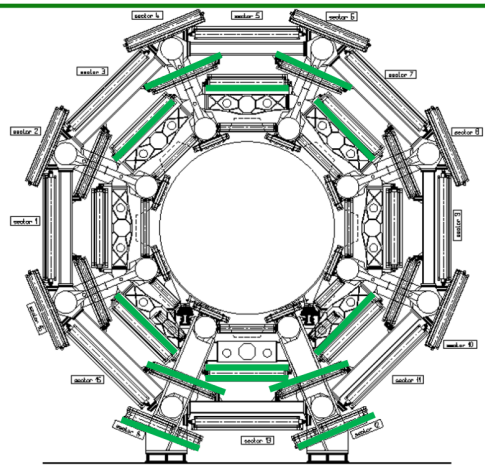
Injected boxes: 435, i.e 870 inlets (~10% of the total)

- **Where these gas leaks occur?**
- **This connectors are installed inside aluminum boxes as shown.**







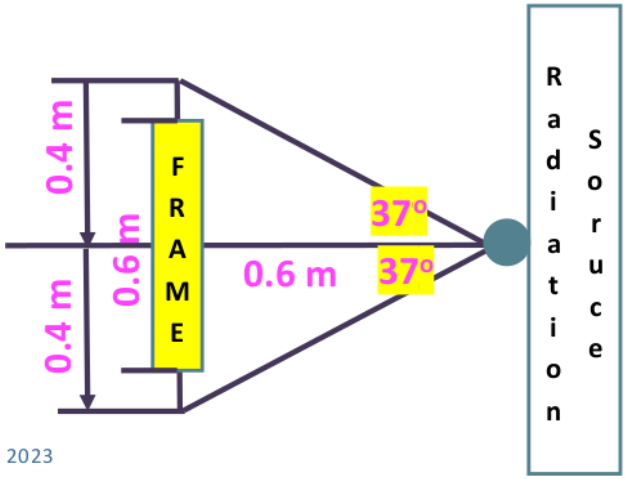


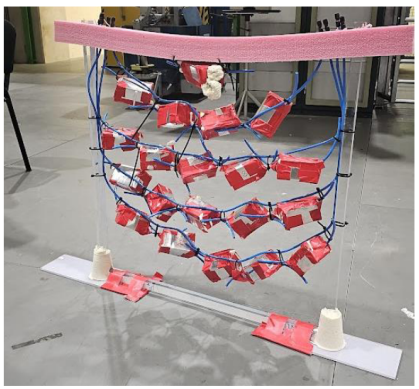
- Repair rate (determined from previous campaign)

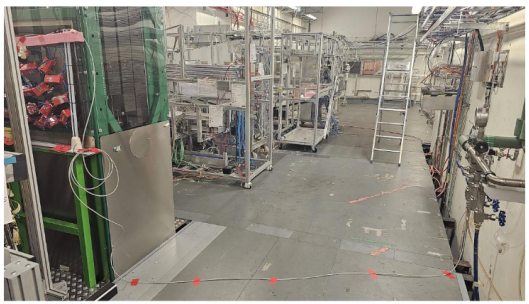
  Resin injection rate: 60 boxes/week, i.e. 120 inlets/week (assuming 4 Istinye + other teams, 8 persons) 600 filled boxes in next YETS
- Applicability of the technique is the limiting factor.

Validation of the non-flammable resin

- Radiation test: the setup is tested at GIF++
  - 0.6 m away from the source has approximately $1 Sv/h$ dose rate from last year's experience.
  - Assuming the yearly absorbed dose as 1 Gy.
  - The setup has been irradiated for 50 hours.
- 20 test boxes filled with the new foam has been used
- Frame with samples has been put on front of the source in GIF++ with a sensor; **the leak test after the irradiation was completely successful.**



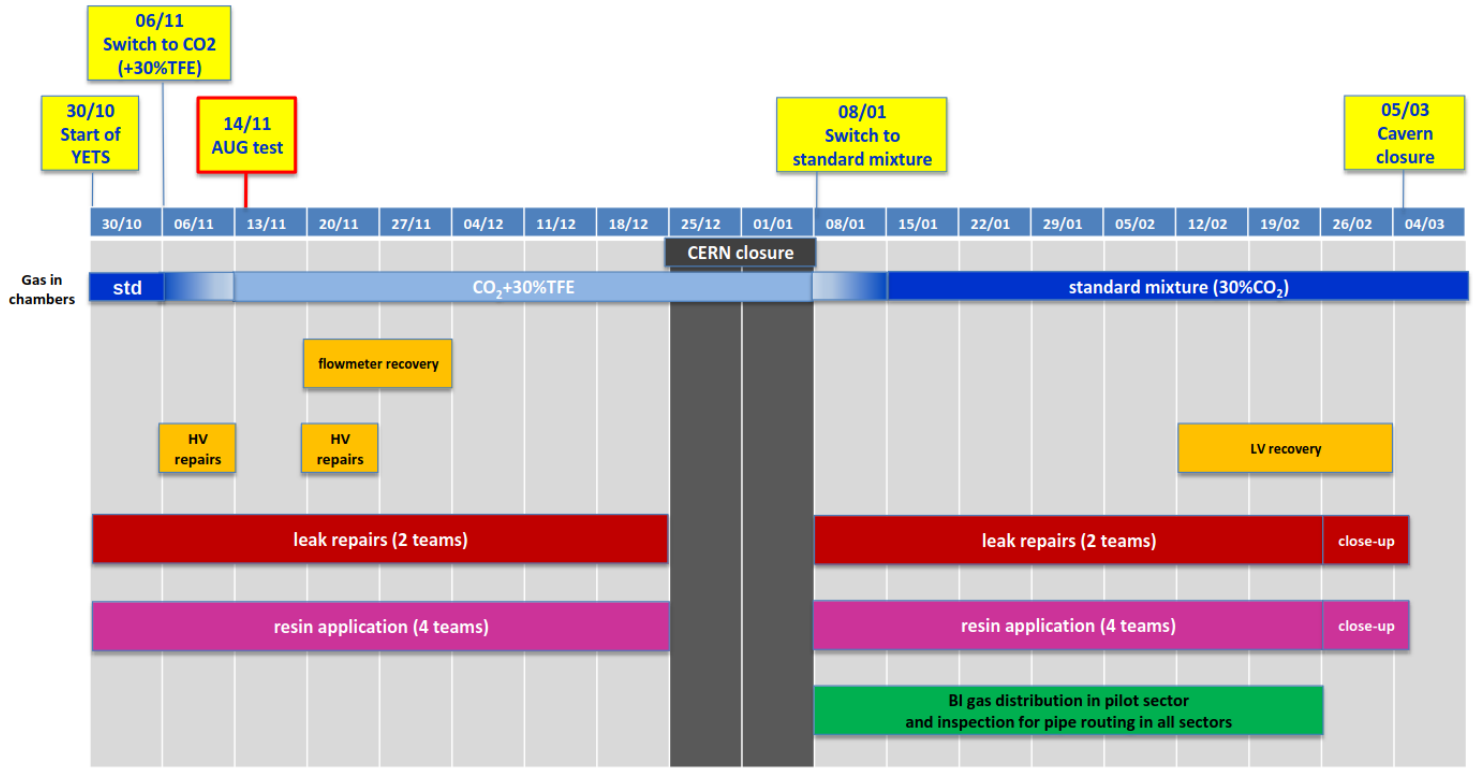




- R&D ongoing for automatising the mixing and injection steps, use of new type of plastic static mixer, and replacing the claying step with a nano-tape baloon.

RPC in YETS-2023

- The gas system will not be stopped during YETS (except for mandatory power cuts like AUG test) in order to minimize the appearance of new leaks.
- The mixture will be changed reducing the TFE content to 30% (enough to discriminate air intake by ramping the HV)
- Several interventions for maintenance of • HV (sparking connectors), • LV (noisy channels) and • trigger (pad failures) will be carried out.
- Two large leak-repair campaigns will take place:
  - Leak repair with standard technique by the DUBNA teams also planning to have training sessions to form new experts due to ending of collaboration agreement with JINR/Russia/Belarus, YETS 2024 could be very problematic
  - Resin injection to extend the number of boxes (i.e. inlets) made safe wrt leak formation Istinye teams should be completed with volunteers from the sustainability-forum applicability limited to not completely broken inlets and to not too vertical chambers (R&D ongoing)
- Competition with Phase-2 activity: • the BI gas system has to progress (not possible to wait for LS3) • sharing of person-power to be taken into account.



Summary

- Smooth operation, with no significant disruptions, is maintained for both the detector and trigger systems.
- Continuous maintenance is performed by capitalizing on the short accesses in LHC breaks.
- Trigger efficiency at the same level of Run-2 since the beginning of 2023 data-taking.
- RO window reduced from 8 to 4 BC to diminish the number of rod and tower resynchronisations.
- Fresh gas consumption currently stable.
- Gas mixture changed: with 30% of CO2: p-p collisions needed to check trigger efficiency.
- The environmental impact of the RPC system is improved. The situation is expected to improve due to leaks maintenance.
- R&D continue for BIS78 and gas leaks repairs.

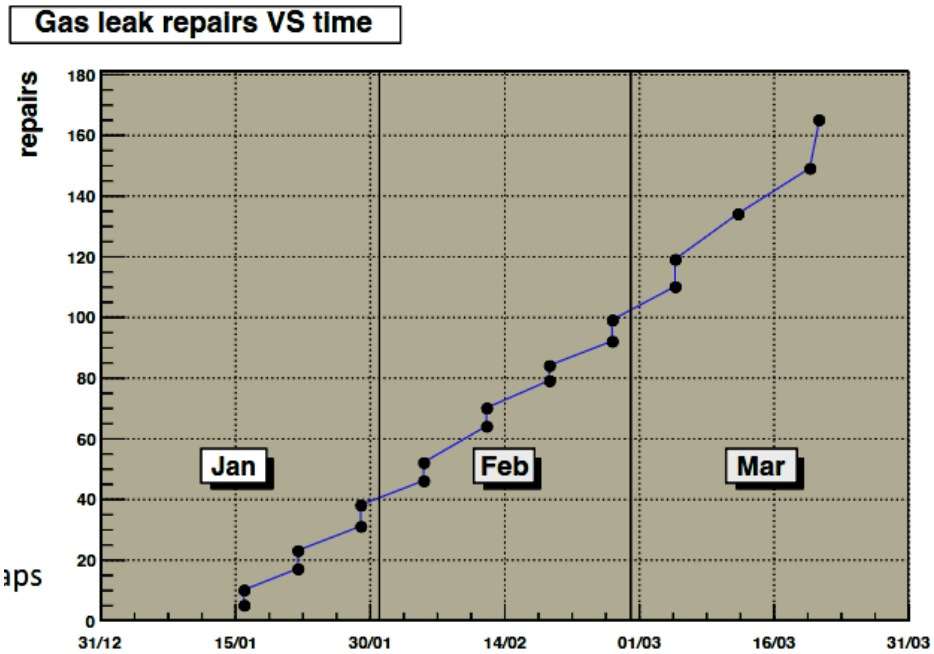
Backup

Gas leak repairs with standard technique: Dubna teams

Consists of:

- Glueing partially cracked inlets: spray glue.
- Replacing fully cracked inlets with a small pipe: remove the PBT QUICK coupling by small pipe that is thight toward the pipe.

First, priority is given to repairing gaps in order to address trigger holes. Subsequently, large leaky lines are addressed.



- During last YETS: 165 repair in total (16.5 repairs/week)
- Non-repairable gaps are disconnected.
- Resin injections technique may be applied.

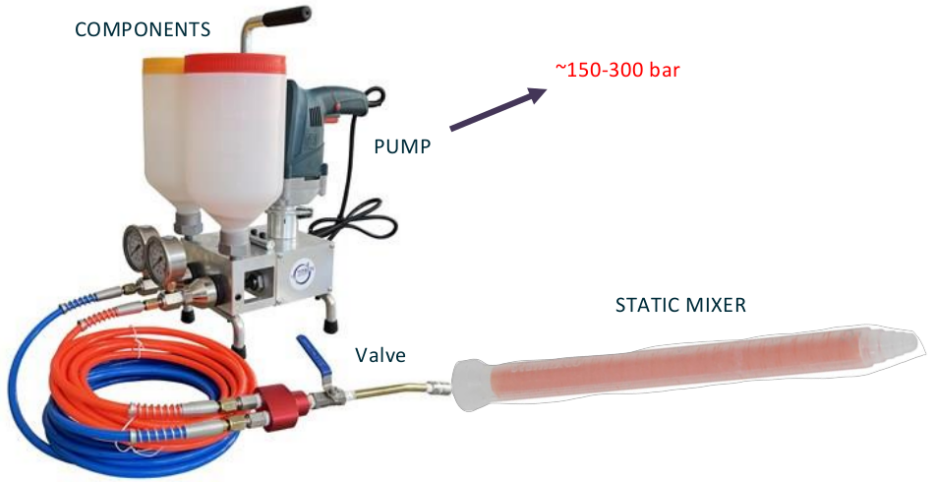
- We expect to have the Dubna teams at CERN for the upcoming YETS.
- Training on this technique will be held by the team.

Gas leak repairs with resin injection strategy:

Two important tasks are ongoing:

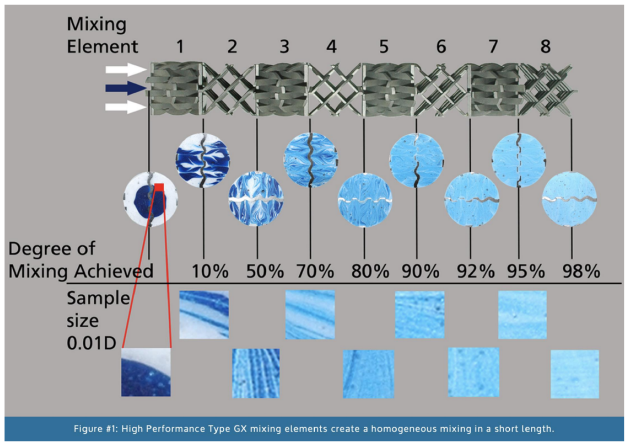
- AUTOMATIZATION OF MIXING AND INJECTION STEPS.

It is important to take caution to avoid damaging the connections: We need to optimize the pressure to 6-7 bar maximum to use it in our case



- A new type of plastic static mixer by StaMixCo:

The plan is to produce these static mixers by 3D printer and test it with the proper pump and dispenser system with the help of Titech Airless Sprey Teknolojileri.



- NEW IDEA: INSTEAD OF CLAY TECHNIQUE NANO-TAPE BALOON (work ongoing)

RPC gas fresh flow per years