

Performance of the ATLAS Resistive Plate Chamber System during LHC Operations

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on behalf of the ATLAS Muon Community

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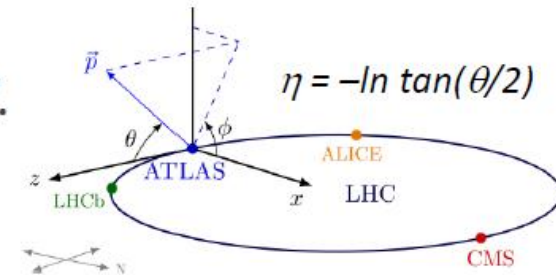
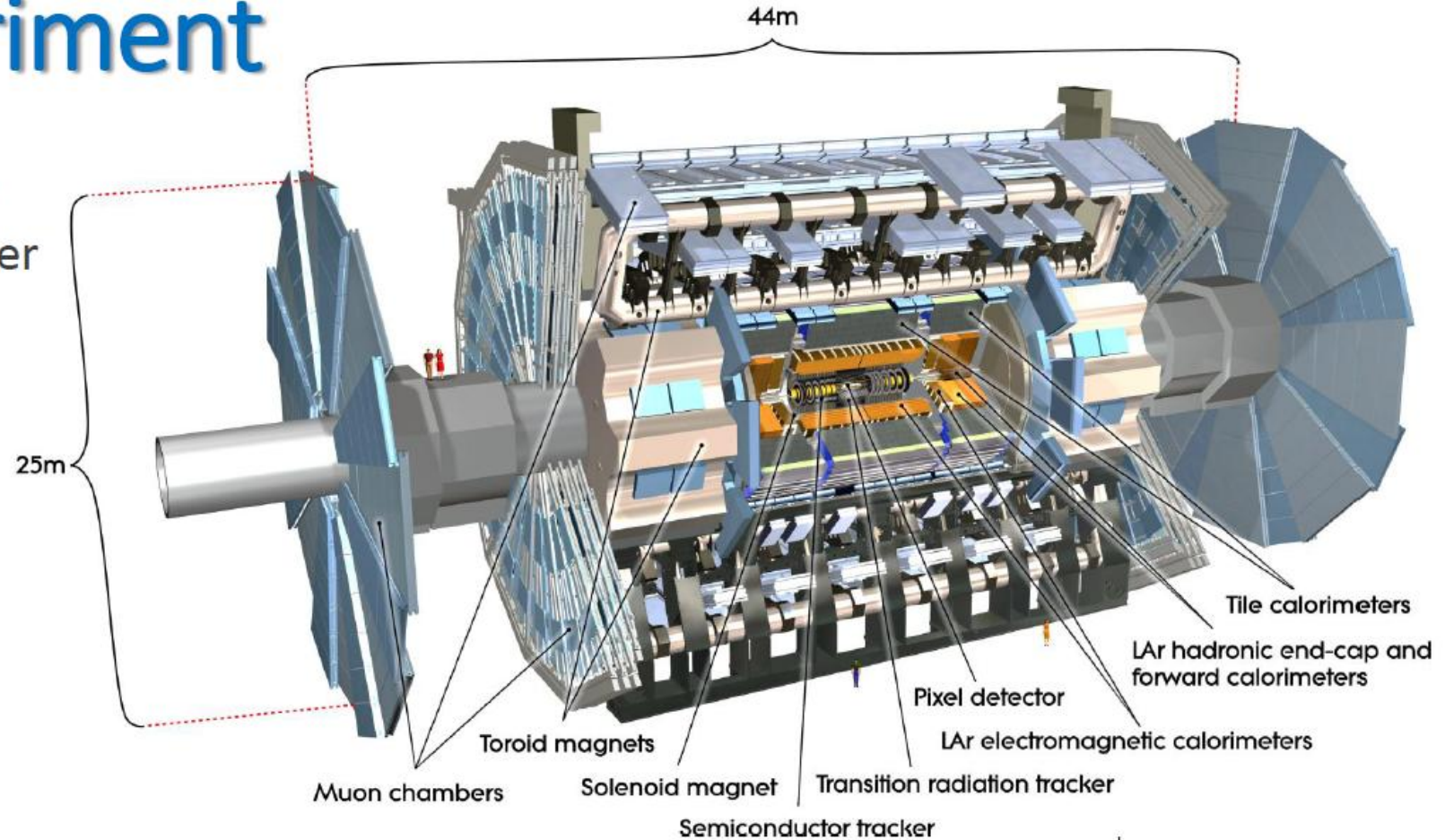
Outlook

- Introduction
- Recent performance of the ATLAS «legacy» RPC and L1 muon barrel trigger system
- Facing the gas-leak problem (see also S. Simsek's talk)
- Conclusion

The ATLAS experiment

ATLAS is a **multi-purpose detector** running at the Large Hadron Collider (**LHC**) for high-precision Standard Model (SM) measurements and beyond SM searches.

- **Tracking system** in $|\eta| < 2.5$ with silicon pixels/strips and TR tracker.
- **Electromagnetic** (liquid Ar) and **hadronic** (scintillating tiles) **calorimeters** covering $|\eta| < 4.9$.
- **Muon spectrometer (MS)** for identifying muons with $\Delta p_T/p_T < 10\%$ up to 1 TeV.
- **Two magnet systems** (toroidal and solenoidal).

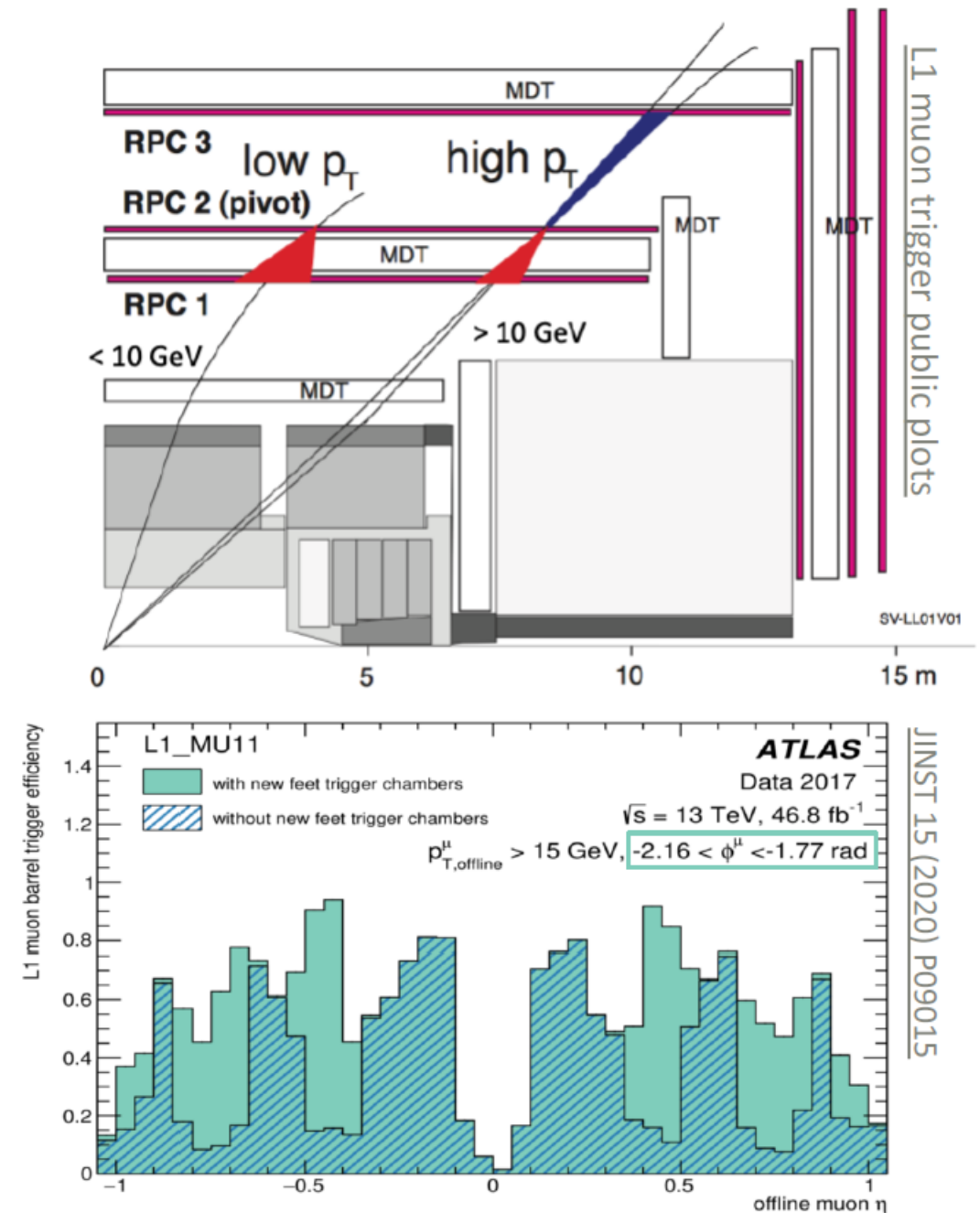


L1 Muon Barrel

RPCs arranged in the MS central detector region ("barrel"): $|\eta| < 1.05$, in three concentric doublet layers at radius 7 m, 8 m and 10 m, operating in a toroidal magnetic field (from 0.5 to 1.0 Tesla).

RPC coincidence requirements applied to define a total of 3 **low- p_T** and 3 **high- p_T** thresholds.

- Since Run 2, ~4% acceptance increase by installing additional chambers in **support structures**.
- For Run 3, improved sector logic and optimized thresholds to reinforce fake muon rejection.



The effective operational voltage correction

- ❑ The effective operational voltage V_{eff} is corrected for local changes in **environmental pressure p** and **temperature T** at the **chamber** level by the HV correction factor $\rho(p, T)$
- ❑ The applied operational voltage V_{app} is therefore given by

$$V_{app} = V_{eff} \rho(p, T)$$

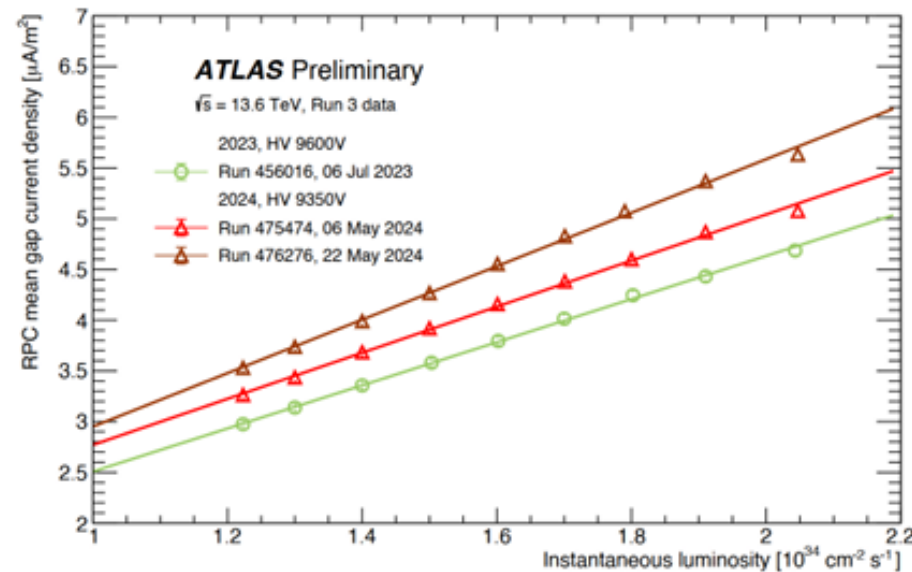
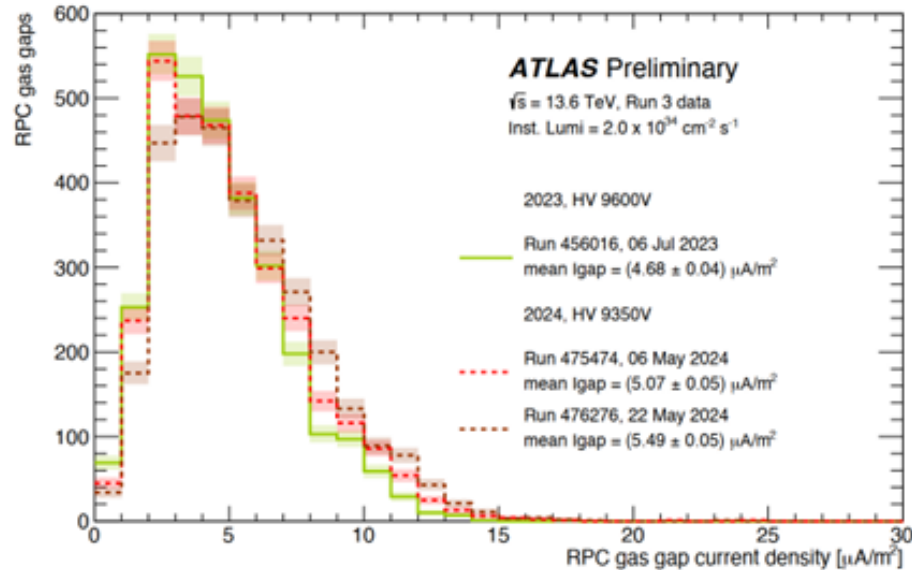
where

$$\rho(p, T) = \left[1 + \alpha_p \left(\frac{p}{p_0} - 1 \right) \right] \left[1 + \alpha_T \left(\frac{T_0 - 273.15}{T - 273.15} - 1 \right) \right]$$

In the formula,

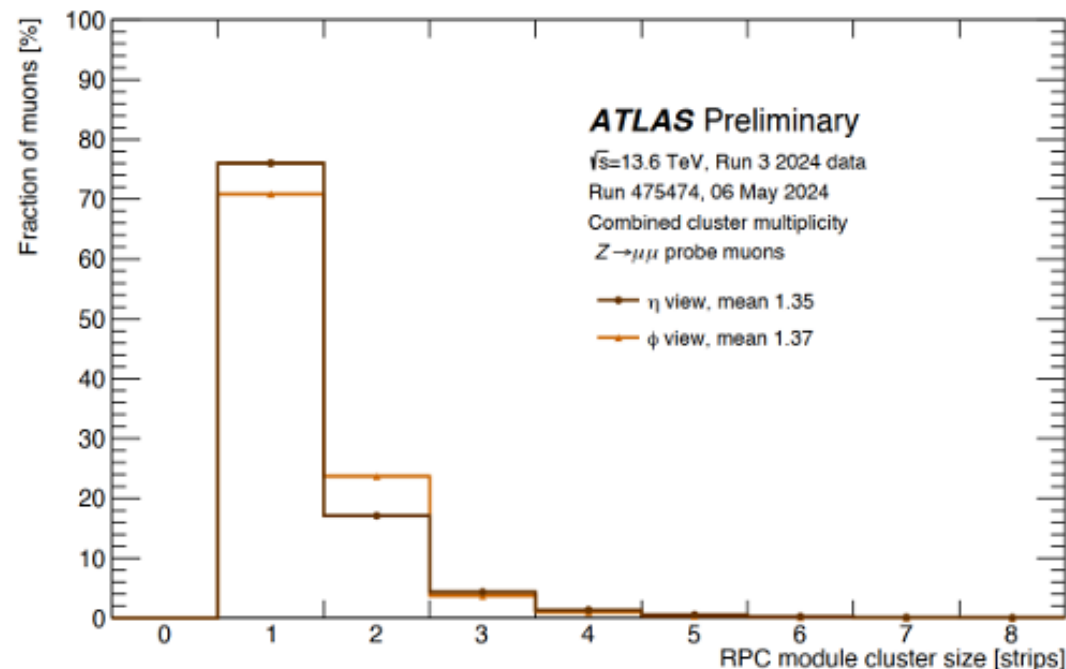
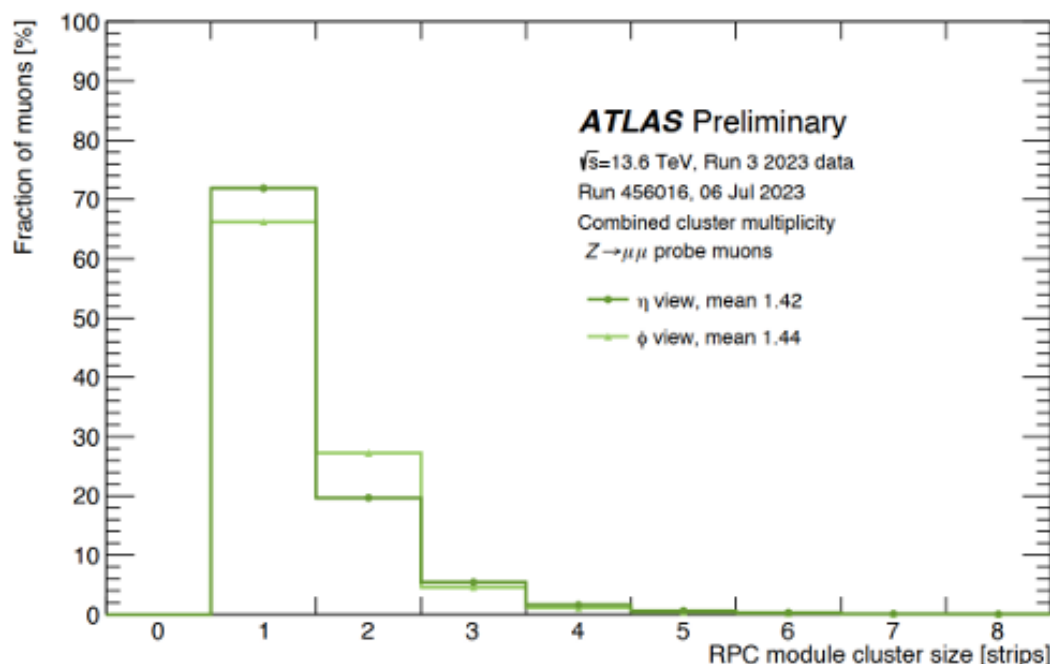
- $\alpha_p = 0.8, \alpha_T = 0.5, p_0 = 9.6 \cdot 10^4 \text{ Pa}, T_0 = 294.15 \text{ K}, V_{eff} = 9350 \text{ V}$
 - p is the atmospheric pressure from a probe in ATLAS experimental cavern (UX15)
 - T is the temperature from sensors installed onto every chamber
 - $0.98 \leq \rho(p, T) \leq 1.02$
- ❑ The final HV correction factor $\rho(p, T)$ was updated to take into account a **new pressure probe** and **local changes of pressure and temperature for the BO chambers** whose segmentation for the HV channels has been doubled
 - ❑ The updated HV correction factor led to a **change between ~30 V and ~150 V** for some of the RPC chambers, resulting in an **increase of the mean gas gap current density** and **improving the stability of the RPC trigger efficiency**

- ❑ After a successful data taking period in Run 2, the detector has undergone an **intense maintenance** to ensure an efficient data taking during Run 3.
- ❑ Several interventions have been carried out on the detector, mainly covering the **gas distribution** with the aim of
 - stabilizing the system
 - reducing the amount of gas released in the atmosphere
- ❑ The main interventions were:
 - New gas distribution racks have been added to increase the vertical segmentation and in view of the installation of new Phase-II chambers;
 - Non-return valves have been installed on the chamber outputs to avoid reverse flow with large leaks;
 - A massive gas leak repair campaign has been done for fixing the continuously developing leaks;
 - A new technique to repair and prevent new leaks has been tested;
 - **The segmentation of the HV channels has been doubled in a third of the spectrometer to mitigate the effect of detector failures;**
 - **Change of gas mixture adding a 30% CO₂ gas fraction.** (see S. Simsek's talk)



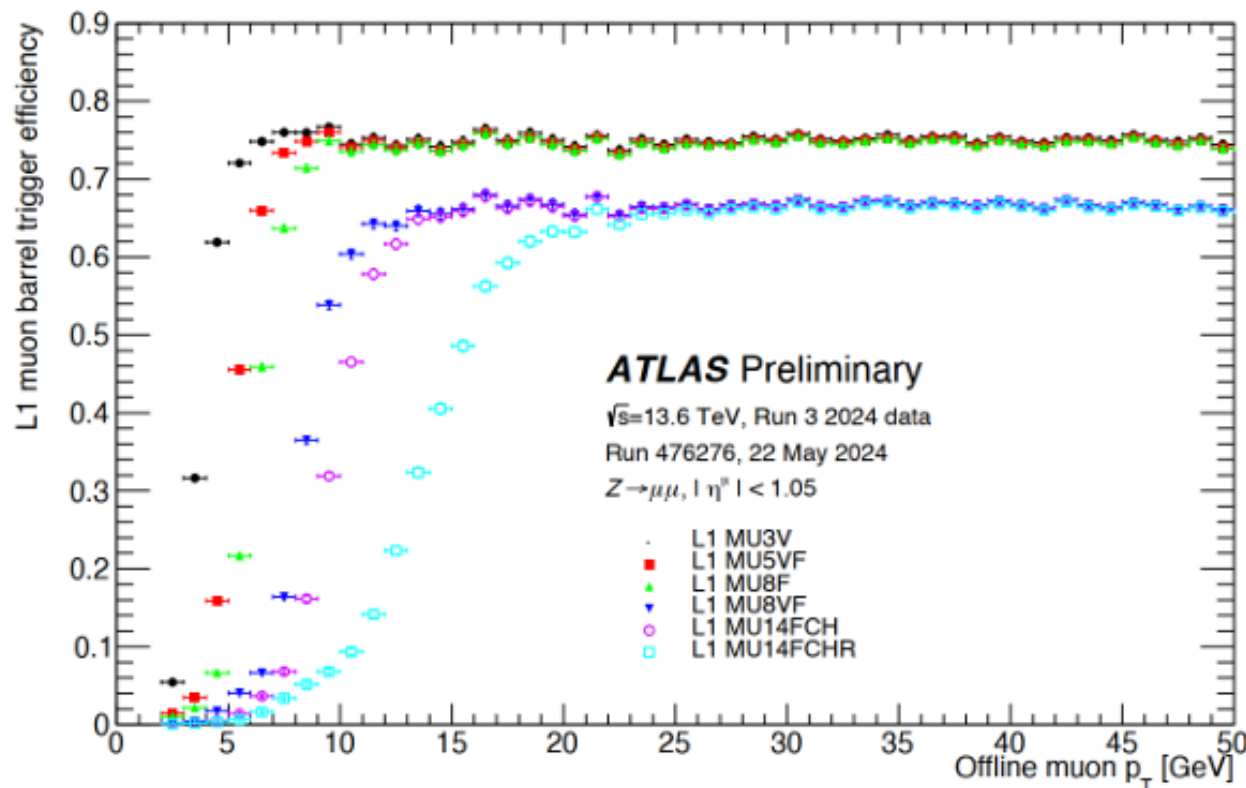
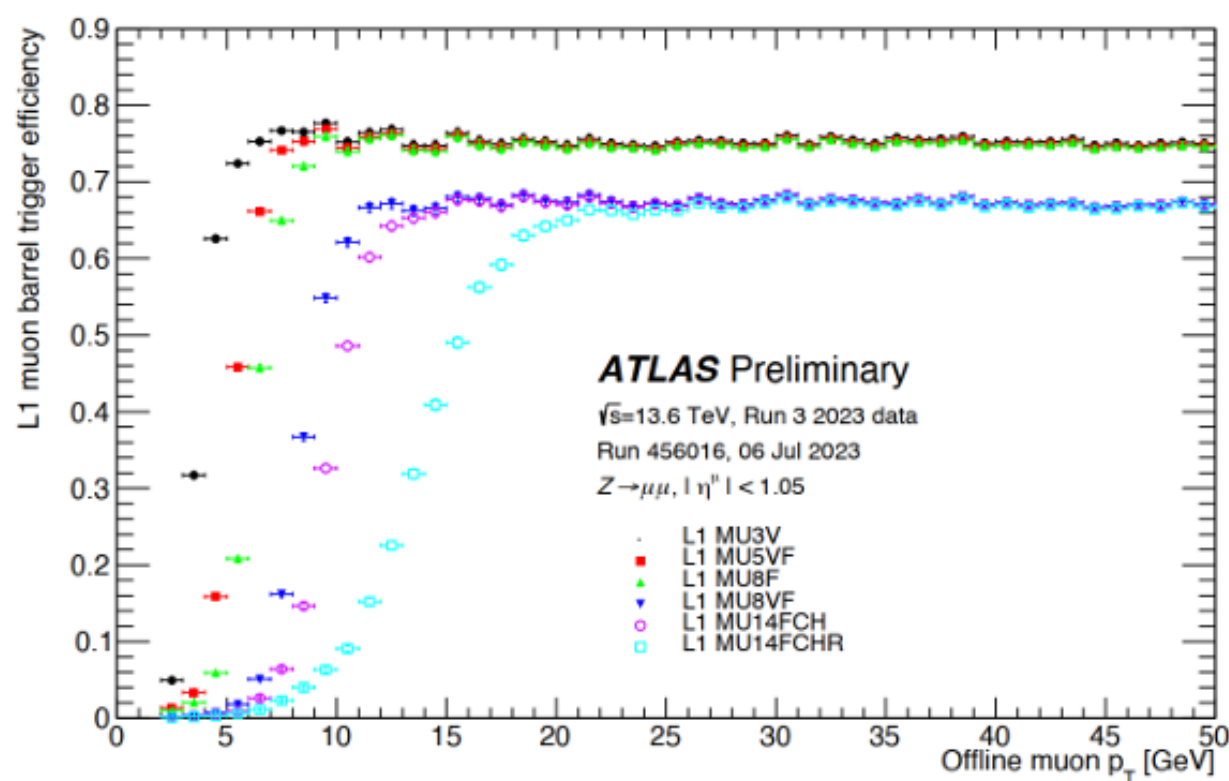
- ❑ **Up:** distributions of the measured current density for all the RPC gas gaps at the instantaneous luminosity of $2.0 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- ❑ **Bottom:** measured current density for all the RPC gas gaps as a function of the instantaneous luminosity
 - **Linear** increase of the RPC mean gap current density as a function of the instantaneous luminosity
- ❑ **Three runs**
 - Run 45016 (2023)
 - Run 475474 (2024 before the updated HV correction factor)
 - Run 476276 (2024 after the updated HV correction factor)
- ❑ The addition of the CO_2 leads to an increase of the current density of the gas gaps of around **~17%** in agreement with prototype results, even if the operational voltage has been lowered with the new gas mixture, **without decreasing the muon detection performance** (see S. Simsek's talk)

Cluster size distributions for Run 456016 (2023, left) and for Run 475474 (2024, right)

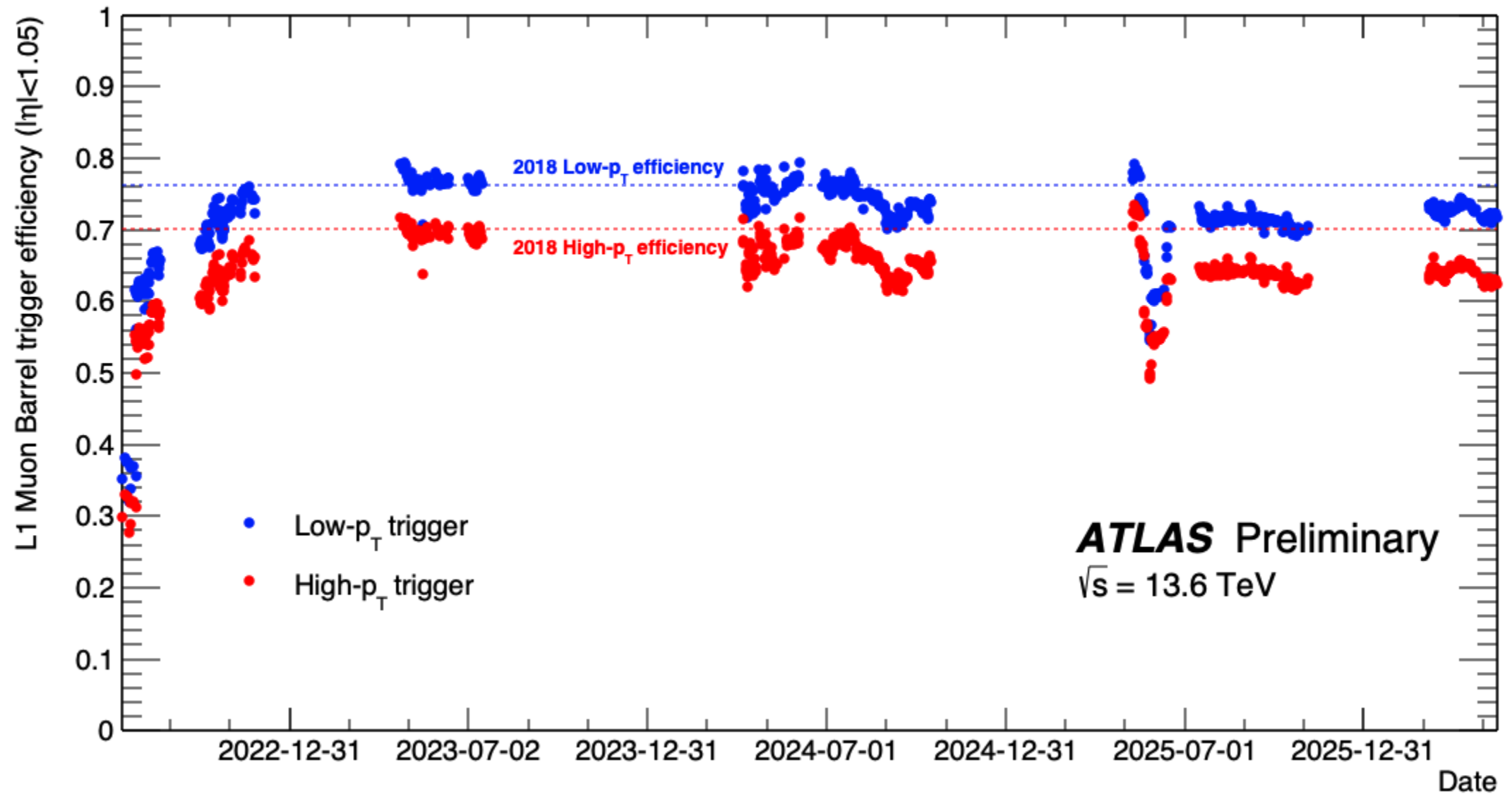


- ❑ The addition of CO_2 would increase the cluster size but the increased SF_6 component in the gas mixture limits the dimension of the avalanche
- ❑ The combined effect yields a similar cluster size between 2023 and 2024, smaller in 2024 than in 2023.
- ❑ No signs of detector ageing effects yet

L1 muon barrel trigger efficiency as a function of the offline muon p_T for Run 456016 (2023, left) and for Run 476276 (2024, right) for different L1 triggers used in Run 3



Constant trigger performance between 2023 and 2024 for the different Run3 L1 trigger thresholds



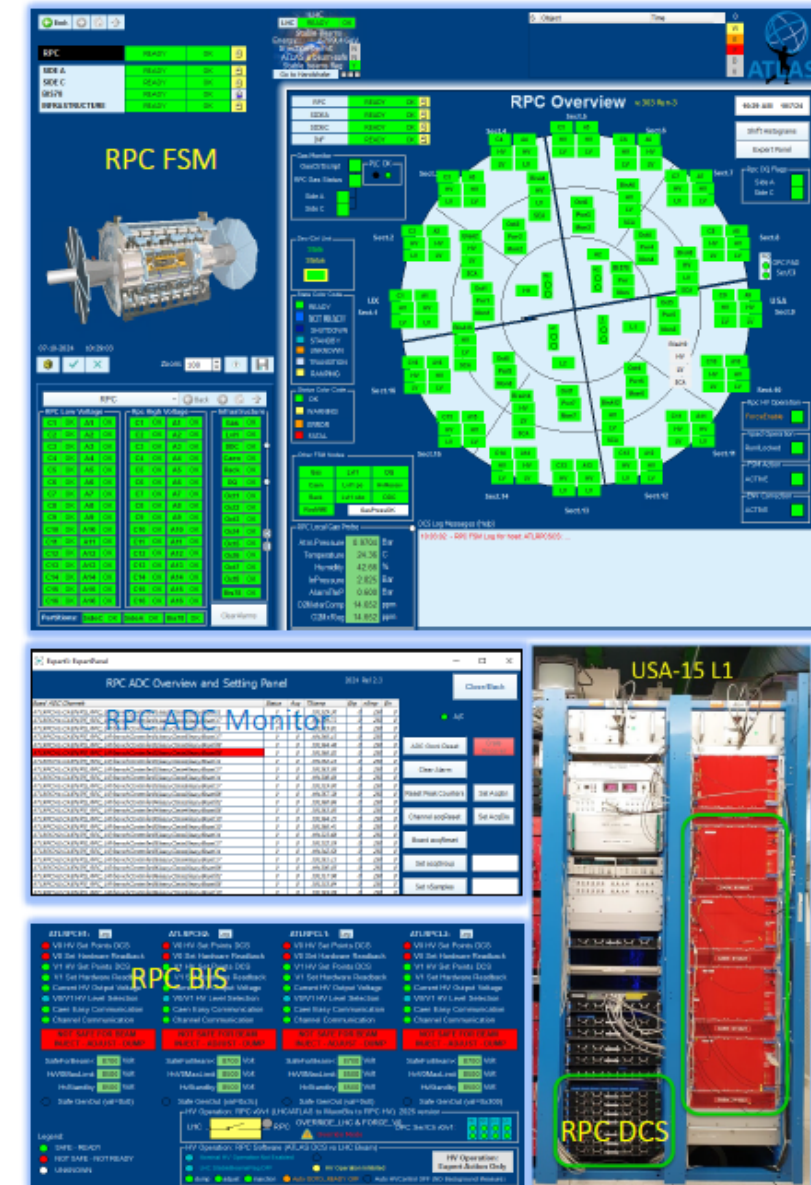
RPC DCS: Operations

DCS Operations:

- RPC DCS in general very stable and very smooth operation
- RPC handling stably both RPCs and BIS-78
- Detector alerts kept to a minimum. They mainly required the standard maintenance follow-up in the cavern.

Plans in coming months:

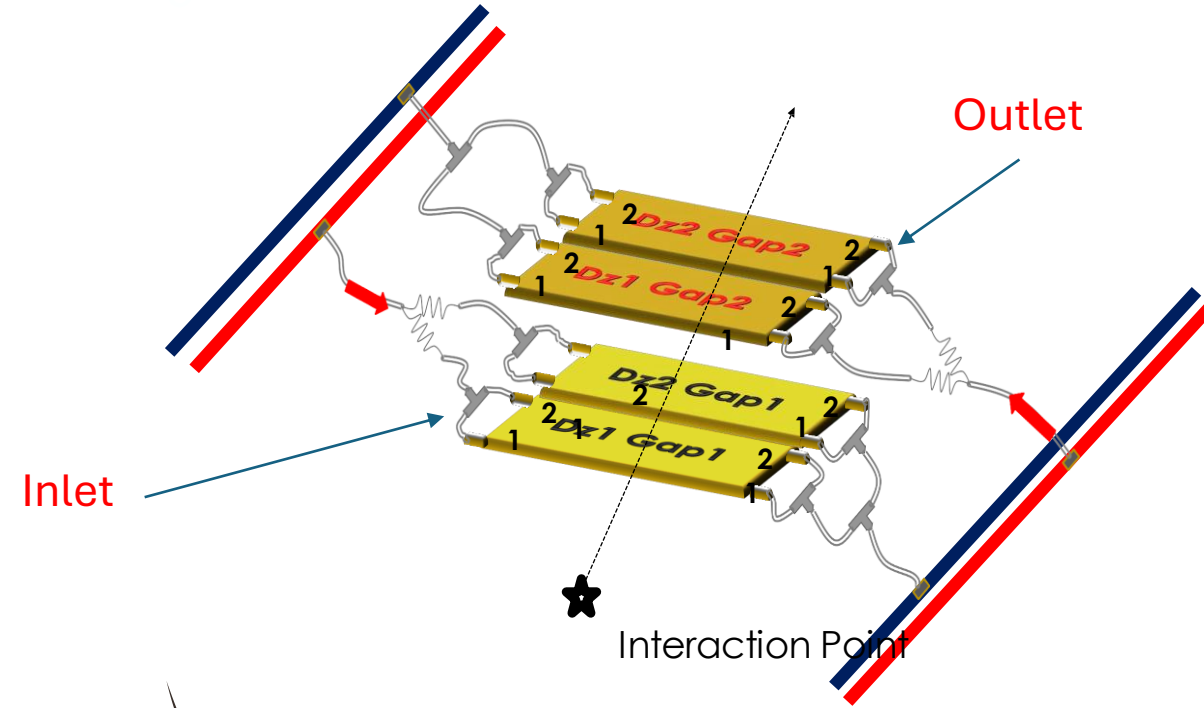
- Keep DCS up and running (WinCC servers and possibly ENV/Gas monitoring) as required by maintenance
- Develop software and familiarize with new HW needed for RPC BI.
- Reviews of relevant modules took place in April; at the moment only very few prototypes available and framework in preparation within Muon and CERN.
- Work the extension of DCS to include the new RPC BI detector (installation is in mid 2027). Baseline architecture and rack allocation ready.
- Ideal activity for new person-power and the experts for tomorrow.



Causes of the leak in ATLAS RPC system

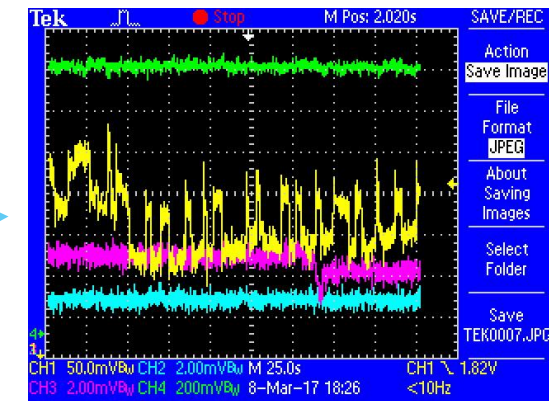
The ATLAS RPC leaks are **concentrated in the gas inlets and outlets.**

Typical new cracked inlet



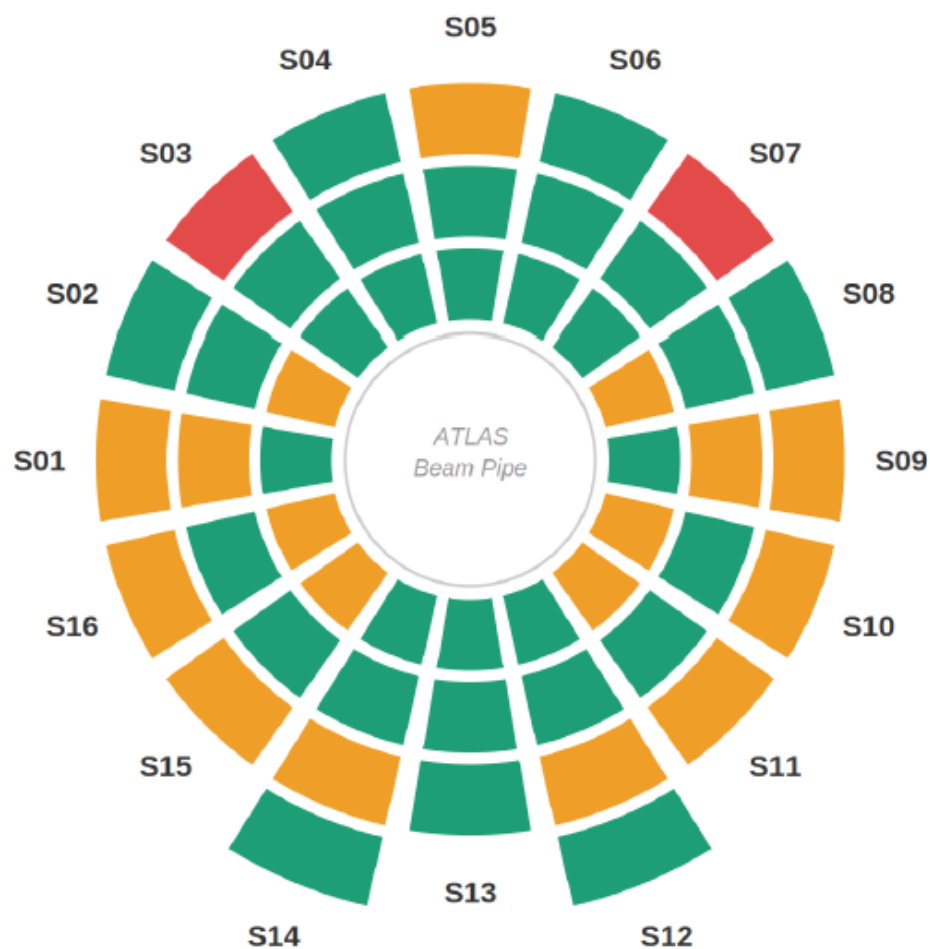
The following main causes were found:

- A **lower-than-expected quality in the original polycarbonate** moulded inlet and outlet production: this material becomes very fragile after few years
- A stress applied to the gas inlets through the gas pipes
- The gas system is generating a constant stress in the form of **fast propagating flow changes (about 1-2 %)**
- The **former purge procedure** (happening at each YETS) was **producing a very large shock** with a consequent extensive system damage.
- However, it is crucial to stress that the inner serial gas connections between gas volumes inside the same chamber never got broken, showing that the leak problem related to the outer gas connectors is specific.



RPC LS3 Repair Capability — First Impressions

Where the two repair techniques (Standard & Foam) can be applied across the barrel RPC system
— and where access is the real constraint to discuss with Technical Coordination.



- Both techniques applicable
- Foam currently hard (standard OK)
- Neither applicable yet

It's more time consuming to implement the "Claying Step" in these sectors without any platforms or ladders.

Access points flagged to TC

- Trigger boxes on RPC short sides — removal improves BO access.
- BO.3 / BO.7 nearly unreachable — relocation worth considering.
- BO.11 / BO.15 need a dedicated platform.
- Sector-by-sector standard-then-foam — full sequence not yet executed end-to-end.

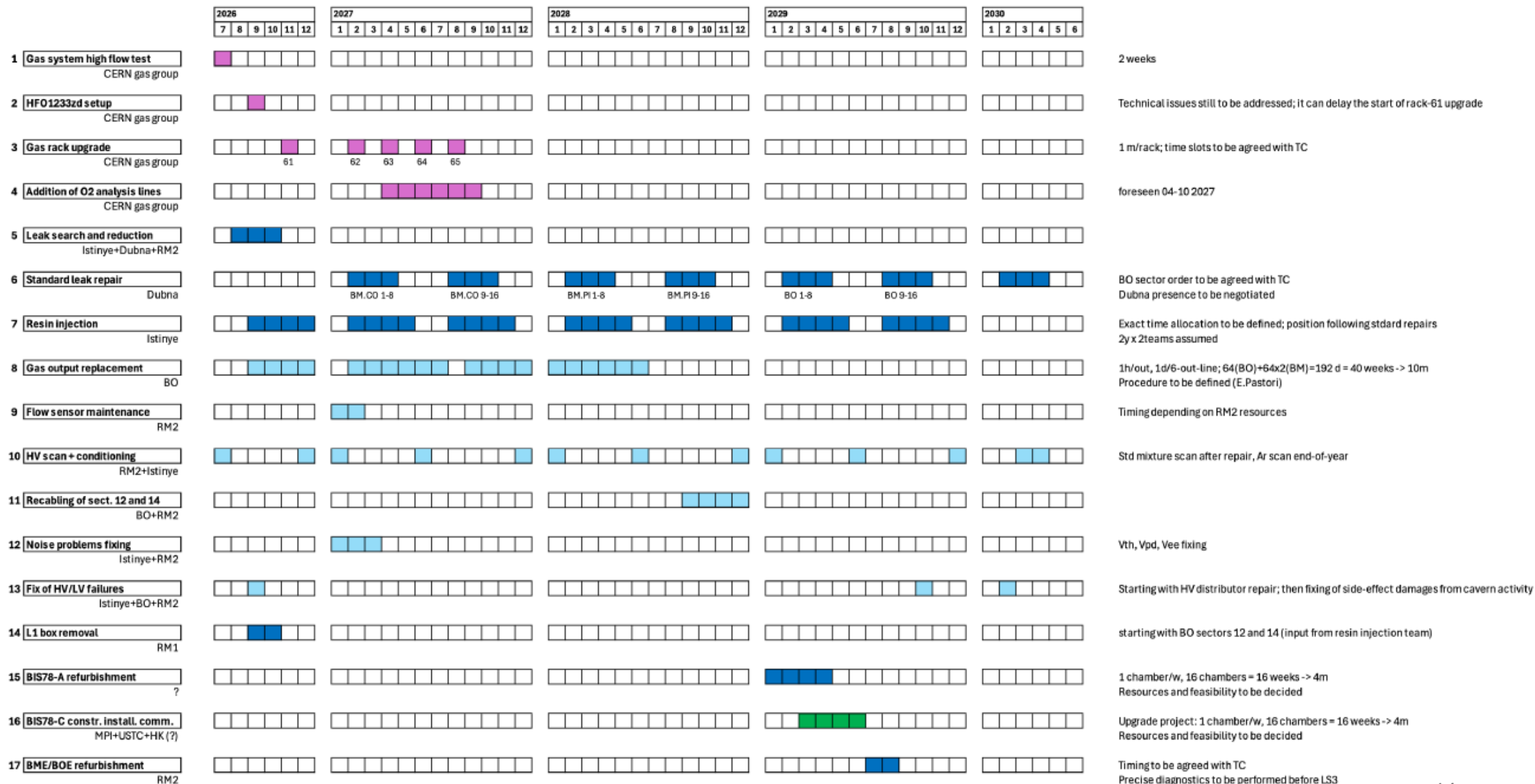
First impression

Most regions are reachable by at least one technique. The open questions cluster in the **BO ring** — where access, not technique, is the limiting factor.

(see S. Simsek's talk
for further details)

RPC LS3 activity timeline — 2026 *Draft plan — consolidating inputs from all sub-task responsables.*

CERN gas group
100%
50%
Upgrade



Summary & outlook

Four messages to take away.

Operations

Detector running stable & smooth

DCS and trigger under control; the one watch-point is readout inefficiency (up to 26 holes) — repair is scheduled.

Gas R&D

Low-GWP gas replacement on track

GIF++ validates SF₆ replacements with no loss of plateau efficiency; HFO-1233zd emerges as the leading candidate.

Reparation

Foam technique cuts leaks ~10×

Approved for LS3 (TR 30 Apr); 0 / 109 intrinsic failures; only 8 of 297 layers remain genuinely unrepairable.

LS3 2026

Minimize F-gas, use it as a diagnostic

Systematic inspection & disconnect-before-reconnect; target fresh-gas consumption < 200 l/h while tracing hidden leaks.