The ATLAS RPC system for the LHC Run-3

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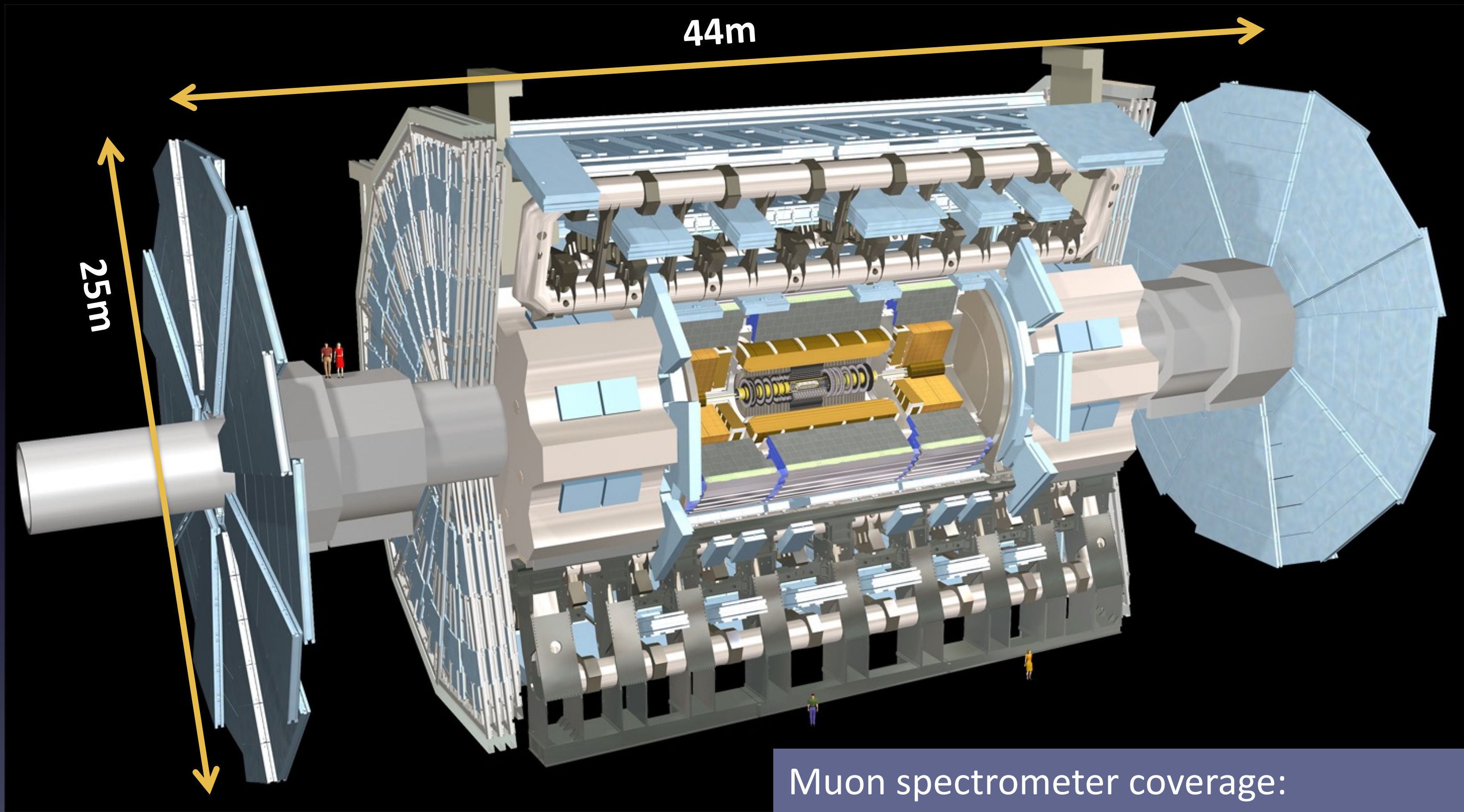
on behalf of the ATLAS Muon Spectrometer Community

Outline:

- *Introduction to the ATLAS RPC system*
- *Overview of LS2 activity*
- *Status of the system at the start of Run-3*

RPC 2022
XVI Workshop on Resistive Plate Chambers and Related Detectors
CERN, 26-30 September 2022

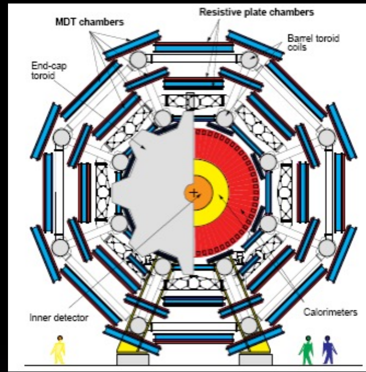
The ATLAS Detector

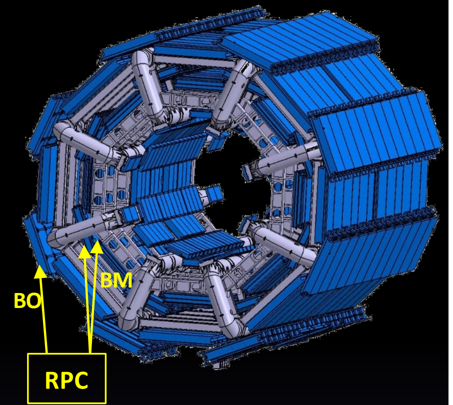


Muon spectrometer coverage:
- barrel $|\eta|<1.05$ ← RPCs are used here
- endcaps $1.05<|\eta|<2.5$

The ATLAS RPC System

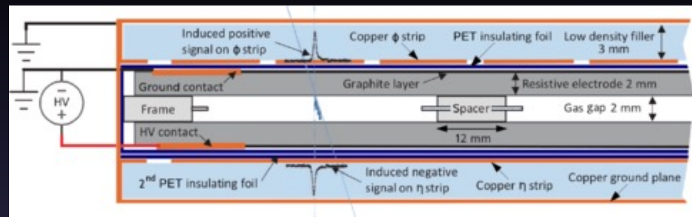
3 concentric double RPC layers in the barrel region at radius ~7m to ~10m, operating in a toroidal magnetic field of approximately 0.5 T and providing 6 independent 2-coordinate measurements





Main detector features:

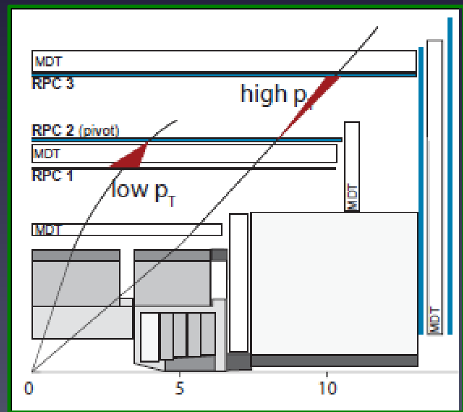
- 2mm gaps with bakelite electrodes
  using a gas mixture of $\mathbf{C_2H_2F_4 : i\text{-}C_4H_{10} : SF_6}$ (94.7 : 5.0 : 0.3)%
  operated in avalanche mode at 4.8 kV/mm with automatic T,p correction
- readout panels with strips 2.3-3.5 cm wide



3714 gas volumes in total, covering an area of 3650m^2,
with ~380k readout channels
Both polar (η) and azimuthal (ϕ) coordinates are measured from each gap

Exclusive level-1 trigger for muons in the barrel region
and measurement of the track coordinate in the non-bending plane
Trigger algorithm based on RPC hit coincidence:

- **Low-p_T** trigger (p_T<10GeV) requiring 3/4 hits in the two BM chambers
- **High-p_T** trigger (p_T>10GeV) requiring in addition 1/2 hits in the BO chamber



Strategy of interventions during LS2

- Maintenance and consolidation work
  - tackle the well-known main source of problems, i.e. gas leaks
  - mitigate effect from possible detector failures
- Prevent the occurrence of new failures
  - develop a technique for increasing robustness and gas tightness of the detector corners
- Upgrade work
  - instrument the barrel-endcap transition region to reduce fake triggers
  - preparation work for LHC phase-2

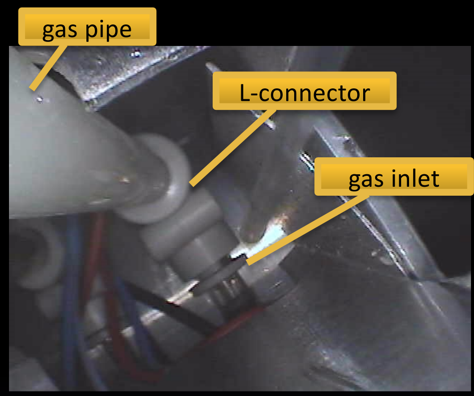
Gas leaks

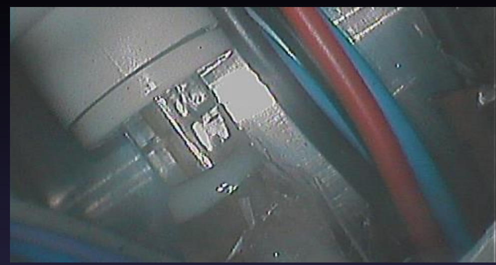
Long standing issue with several negative effects
- performance: air in-take preventing gap operation
- environment: gas with a very high GWP (~1400) released to atmosphere
- cost and procurement: $C_2H_2F_4$ increasingly expensive and being phased out

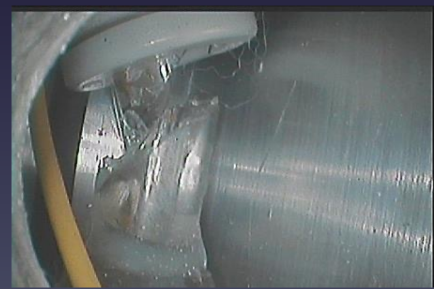
Leaks originate in the gas inlets which tend to crack due to inborn fragility, aggravated by mechanical+chemical stress, pump vibrations, pressure spikes
Cracks develope slowly (months) until reaching a breaking point
  - 8000 inlets in total, located in couples in 4000 boxes on chamber corners, often with difficult access

	RUN1 LS1	RUN2				LS2			
	2009-2014	2015	2016	2017	2018	2019	2020	2021	2022
Total known leaks at the beginning of each year →					166	229	350	300	280
Gas layer repairs done →	***251***	***18***	***55***	***127***	***102***	***270***	***94***	***231***	***148***

- total repairs → 1296 layers; known active leaks 240
- 10% of repaired leaks crack again (old repairs in particular)
- cracking rate accelerating in time (reaching the peak?)




incomplete crack


complete breakdown

RPC interventions in LS2

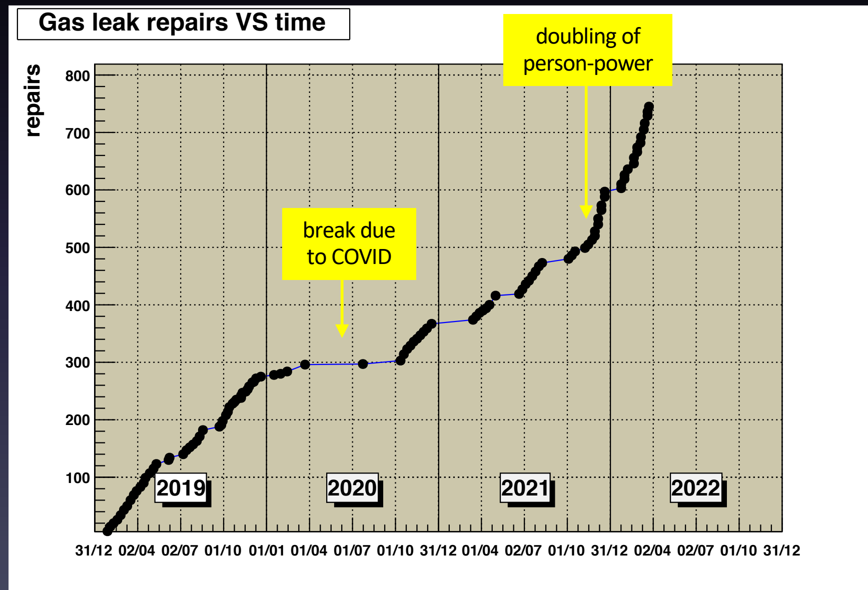
Leak repair

Gas leak repair campaign

- needed to keep under control the continuously developing leaks
- task is very difficult due to problematic access
- endoscope driven operations: spraying glue and/or insertion of a new inlet
- intensive effort by our Dubna colleagues, with long interruptions due to COVID

- large number of leaks → priority in fixing trigger holes

When trigger holes cannot be fixed repairing the gas volumes
→ softened trigger majority (at the cost of higher trigger rates)



cumulative number of repaired chamber-layers

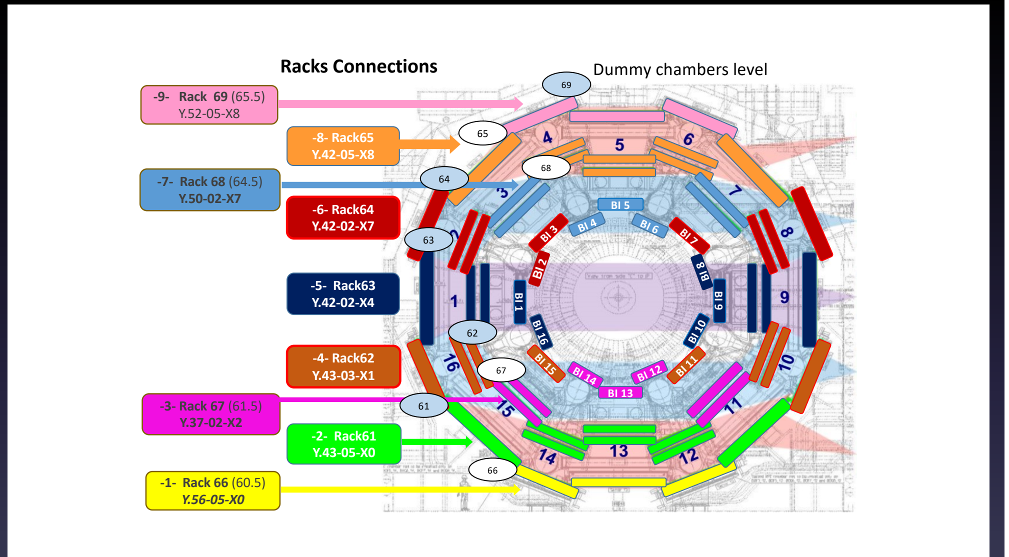
RPC interventions in LS2

Gas distribution upgrade

Intrinsic fragility of the gas inlets → reduce chamber pressure as much as possible (minimal overpressure just to avoid air intake from leaks)

Chambers pressure is adjusted at gas rack level (5 racks up to Run2) and hydrostatic pressure for the RPC mixture is 0.3 mbar/m

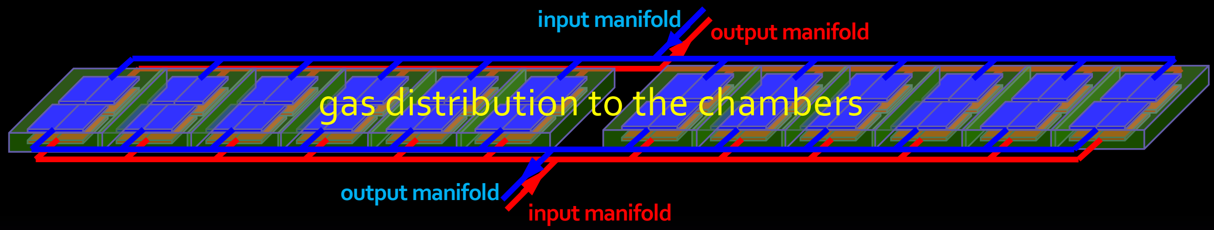
→ increase vertical segmentation, 4 racks added (racks 5 → 9)
Gas lines had to be re-arranged in the racks
Rack re-commissioning took several months in 2021



Fine tuning of chamber pressure while monitoring O_2 content in the gas mixture will be possible
Still ongoing

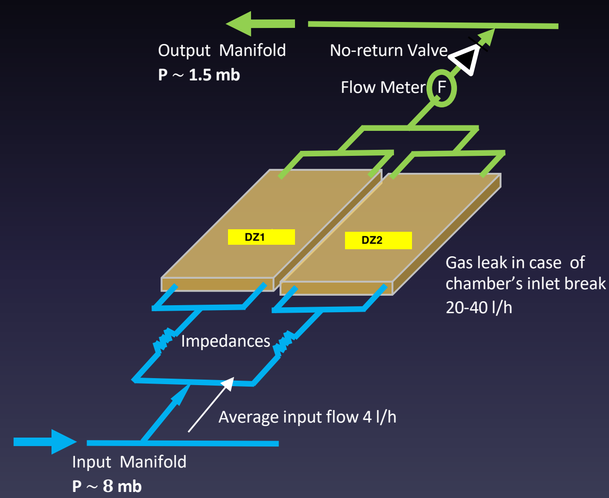
ATLAS RPC gas system

Can leak rate be reduced?



RPC gas distribution description

- 3714 RPC gas gaps are present in ATLAS
- total gas volume is 15 m^3
- gas distributed by 128 input manifold lines (up to 24 RPC layers each) with an overpressure of ~10 mbar falling on input impedances which determine the input flow
- gas recuperated by 128 output manifolds connected to a pump regulating the RPC internal pressure
- recuperated gas is purified and reinjected in the system



- A gas layer is connected through 2 inlets and 2 outlets
- There are 2136 independent gas layers
- Per each 2 gas layers there is an output flow meter
- The RPC gas gap is kept at max 3 mbar above the atmospheric pressure

RPC interventions in LS2

No-return valve installation

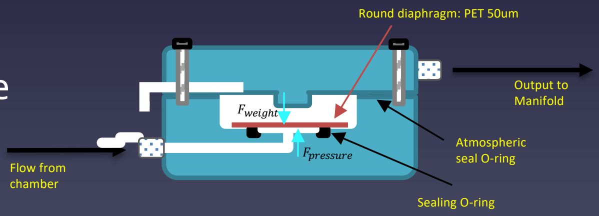
Reduction of gas consumption due to leaks

- gas distribution lines have impedances at the chamber input (needed to optimise the gas flow among the chambers)
- no impedances are present in the output lines (chambers directly connected to the output manifold)
- a newly broken inlets at the chamber output can produce a relevant gas leak (reverse flow from the output manifold)

→ no-return valves installed at the chamber output (1 valve per output line, 1168 in total)
direct flow allowed with ~no impedance, reverse flow is stopped

Valves operating at very small pressure, not available commercially,
produced by an external company based on our design

PET foil used as membrane

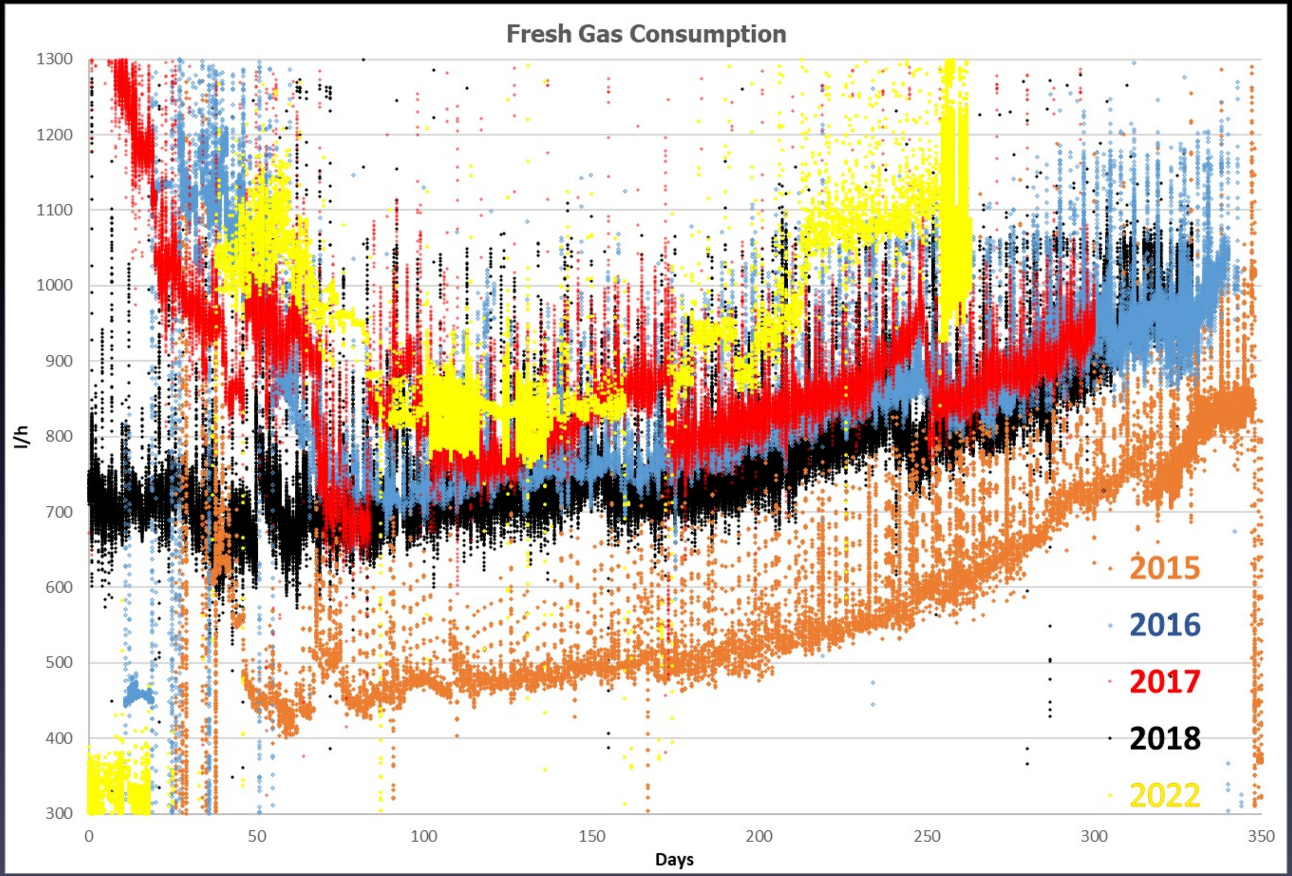


RPC fresh gas consumption

Time evolution of fresh gas consumption per year

In 2022 the situation still looks hectic because of the many interventions

In the long term the rising trend should be less visible thanks to the non-return valves



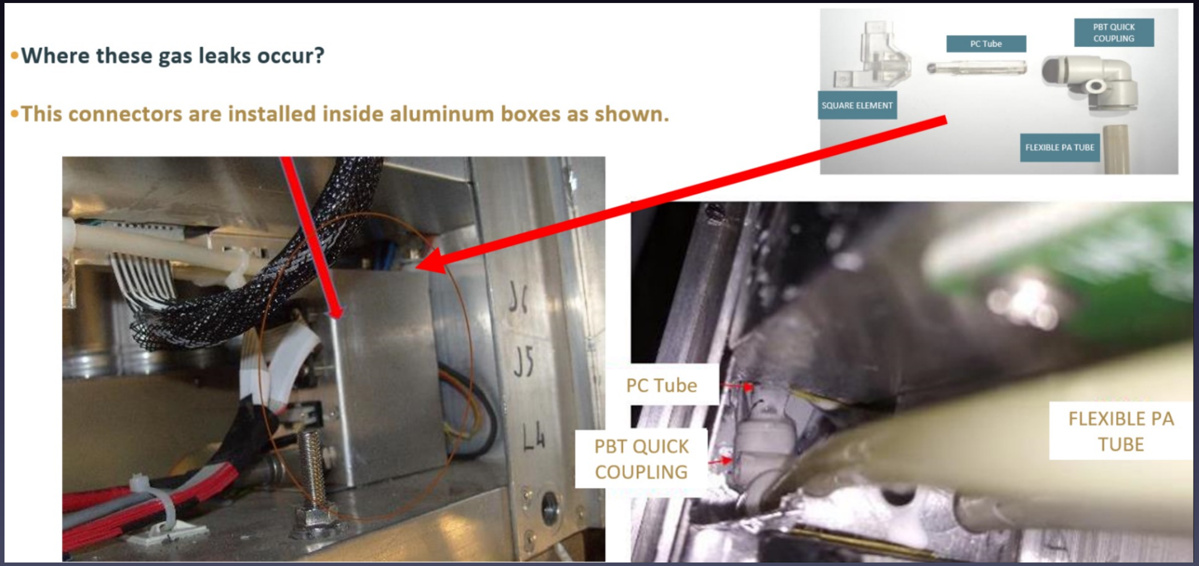
Developing a new repair technique

Need for a new technique

With the current glueing technique:
- need to operate on inlets with a precision of <1mm
  → difficult and time consuming
- leaks are fixed, but they can occur again

Requirements for the new technique:
- fixing and preventing leaks
- easier/faster application

R&D ongoing since almost 2 years
by our Boğaziçi colleagues



RPC interventions in LS2

New leak repair technique

Proposal is to use an expansive resin to fill the service boxes hosting the gas inlets in order to form gas-tight rigid blocks

Products with needed properties have been searched for

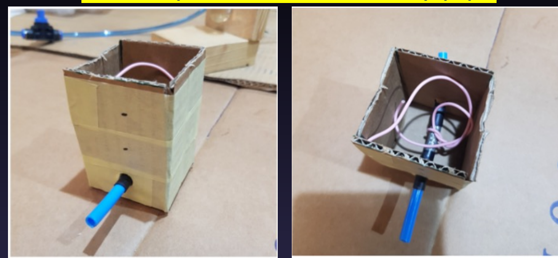
- high adhesion to surfaces
- mechanical and chemical resistant
- radiation hard
- not flammable

Several products tested, two candidates found,
both based on 2-component polyurethane resin
Submitted to many extensive lab tests

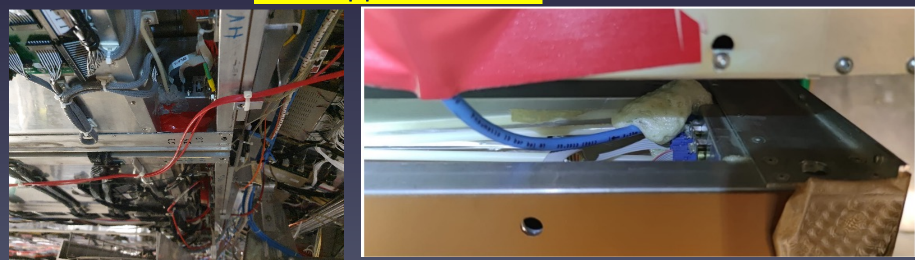
Technique tested in ATLAS on 100 boxes for validation
Results are very promising

sample boxes for irradiation

mockup boxes with a leaky pipe



resin applied in ATLAS



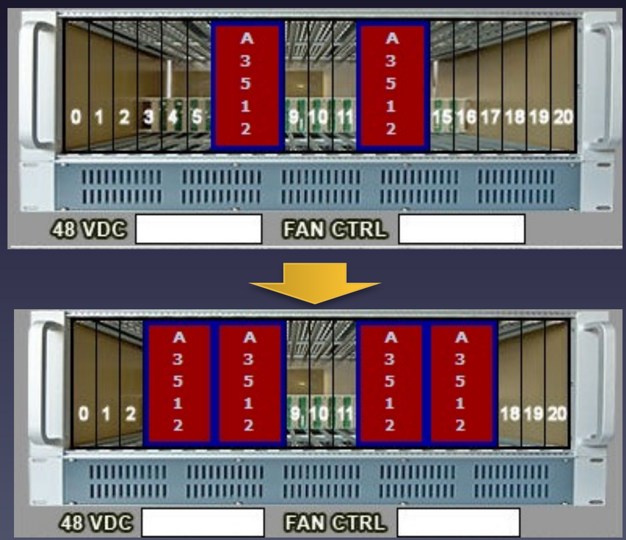
RPC interventions in LS2

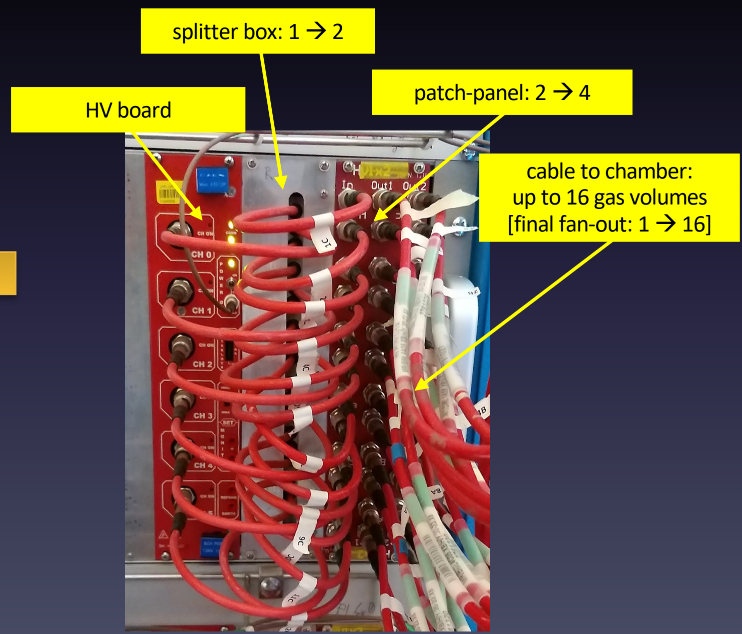
Upgrade of HV channels

- Mitigate effect of failures at channel or chamber level (without entering the cavern)
- Current fan-out factor 1 x 16 (initial request was 1x8, downscoped at funding level)

→ doubling of HV channels for BO chambers (funding limited to 1/3 of the channels)

- 16 additional HV boards installed
- cabling modified accordingly
- DCS mapping updated



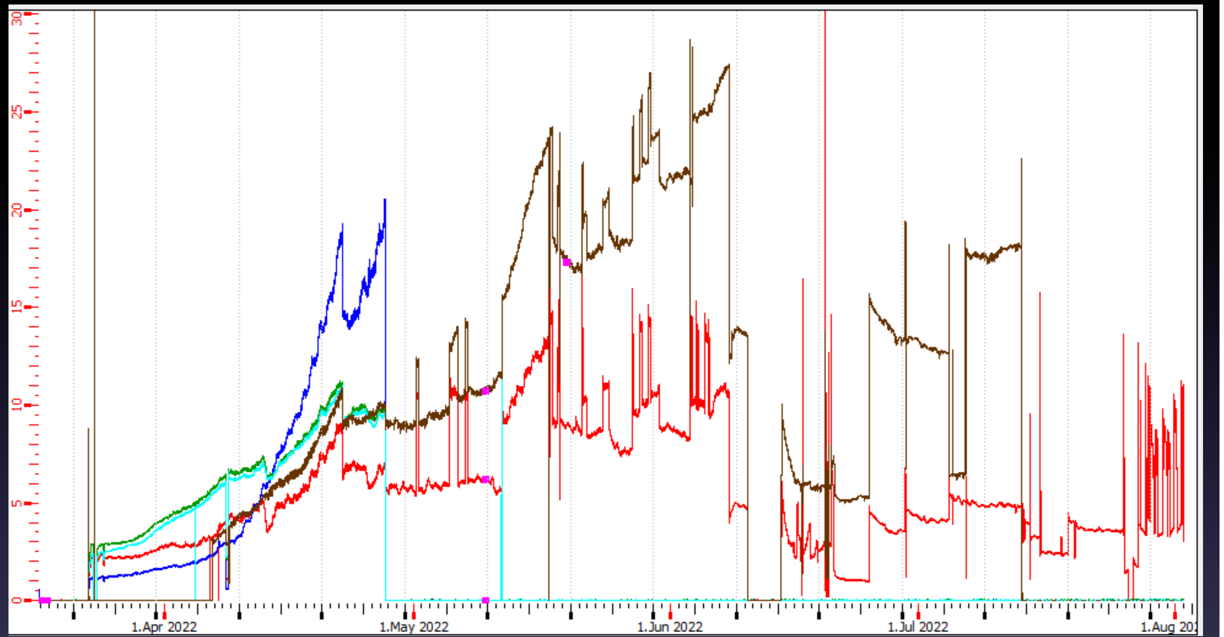


HV restart at end of LS2

At end of March after repair campaign and gas distribution upgrade the HV system was restarted to perform long cosmic runs

Several gas gaps belonging to different gas and HV layers showed currents drifting up

- additional current mostly ohmic → no substantial alteration of the gas mixture or working point
- good gas flow (neighbour chambers sharing same distribution behaving well)



time evolution of current for a few gas volumes

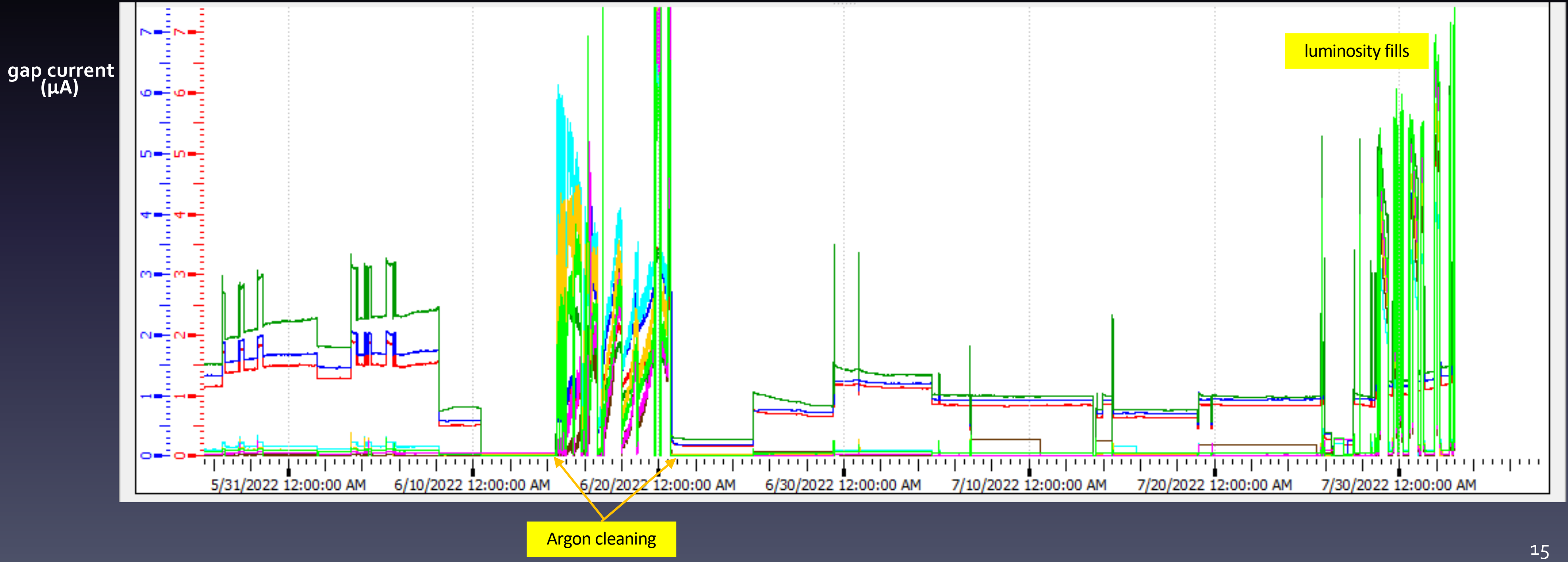
Initially HV channels lowered to preserve the gas gaps,
then gaps disconnected from HV to recover trigger coverage → ~80 gas volumes currently disconnected

Gas volumes with high current /1

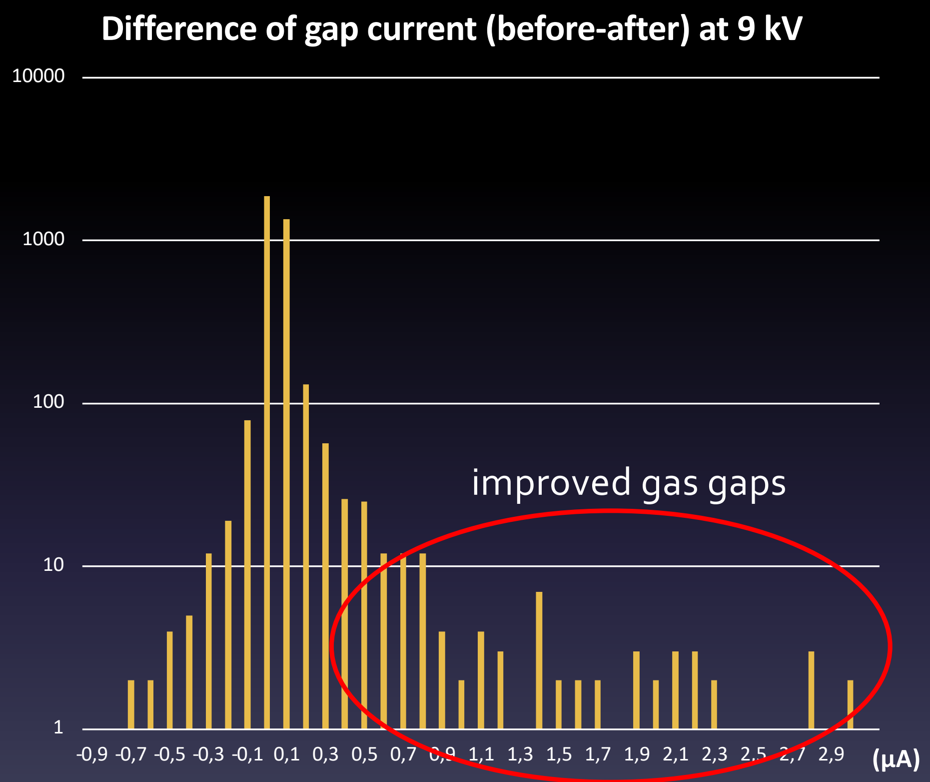
First contribution considered: the missing Argon cleaning, usually done every year (last time was in 2018)

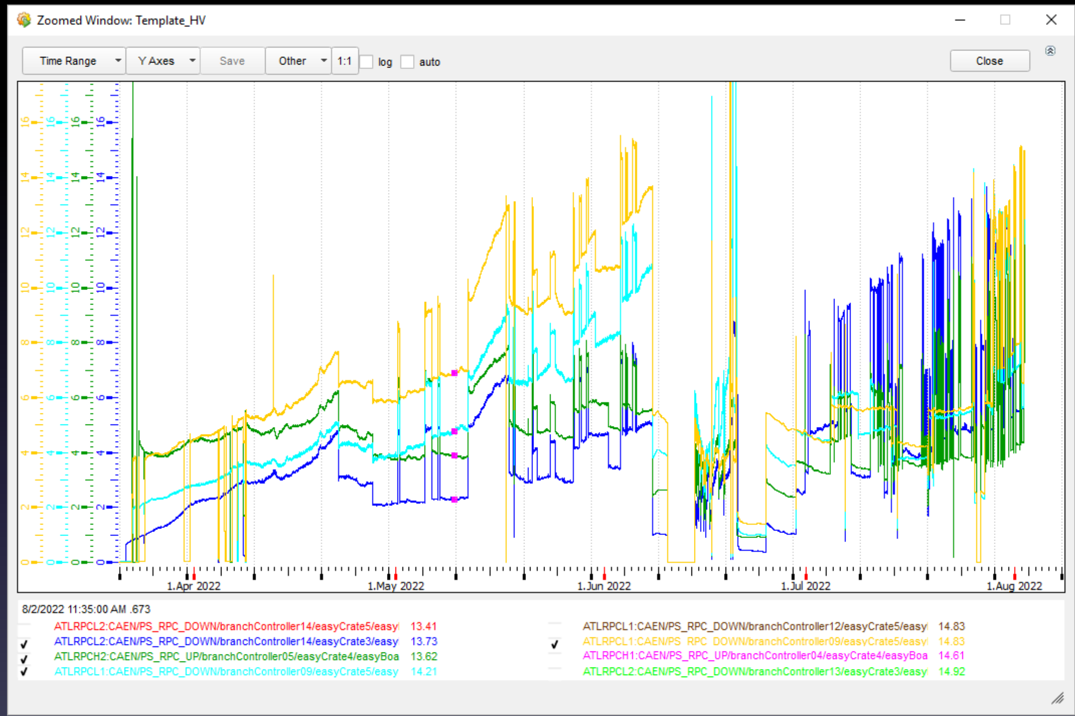
Procedure attempted with the aim to remove any internal deposit (typically HF compounds) producing an increase of the ohmic current

Short time left before luminosity, cleaning applied for less than a week



Effect of Argon cleaning





Improvement observed. A few gaps with current still drifting up.
However, time with Argon was short. Further conditioning to be planned for next YETS

Gas volumes with high current /2

Second contribution is the high O_2 content in the mixture which could damage the detector surface

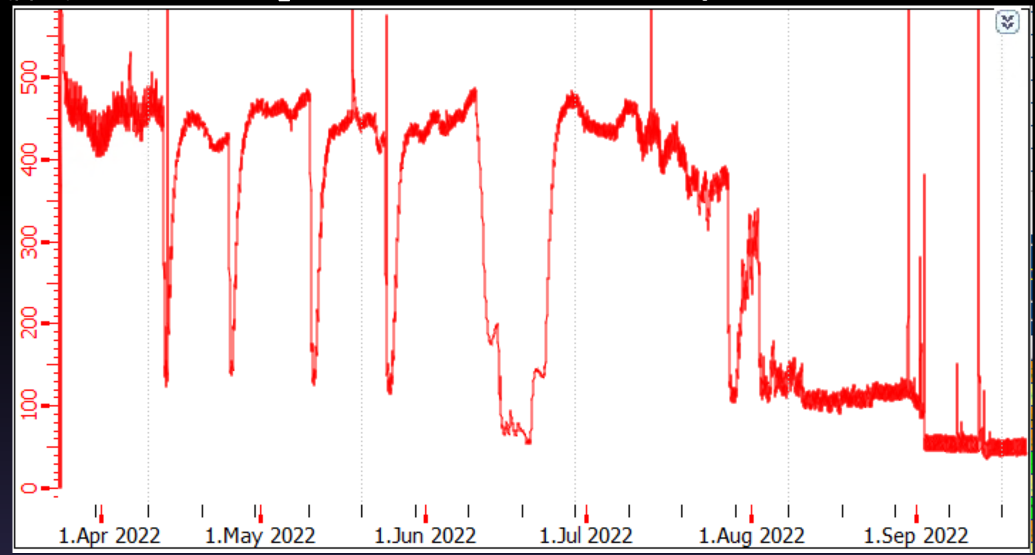
At beginning of this year the Oxygen level was ~400 ppm to be compared with ~20 ppm in Run2

Oxygen can enter through the leaks if chambers and lines are not over pressured

Pressure tuning was not optimal
(gas system operated at half flow wrt design value and regulation valves at their range limit)

Furthermore, purifier was saturating too fast…

O_2 content at chamber output

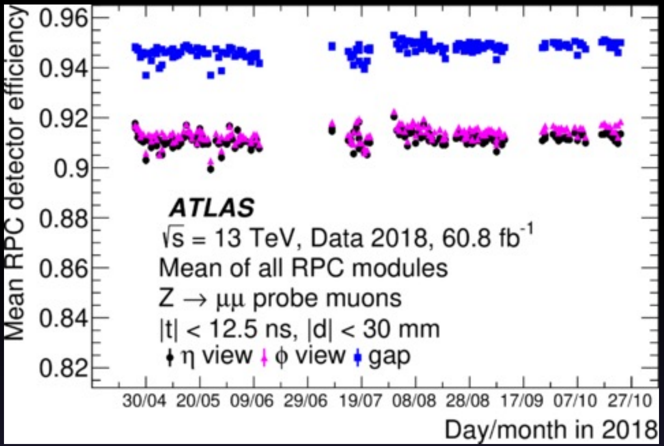


Now the gas system is operated in a better regime, after further leak reduction and flow increase (by-passing the chambers) and the situation is much improved → O_2 content at ~40 ppm, similar to Run2

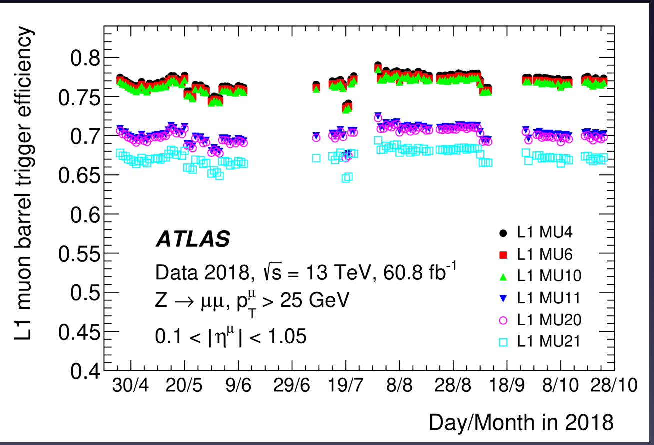
Recall from Run2

RPCs have completed Run2 data taking with excellent performance

High and stable hit efficiency throughout the year (2018)…



… and analogously for the trigger efficiency ⊗ acceptance



Plenty of results can be found in:
[*JINST 16 (2021) P07029*]
Performance of the ATLAS RPC detector and Level-1 muon barrel trigger at √s=13 TeV

Looking at first Run3 data

All the above problems (gas leaks and high currents) lead to the disconnection of several gas volumes, partially recovered with interventions on chambers to reduce the effect of the fan-out in the HV distribution

Number of disconnected gas volumes:

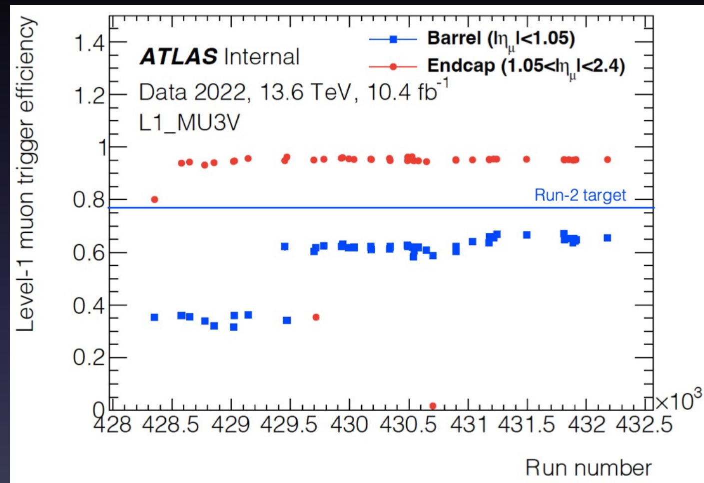
606 → 486 → 439 [out of 3714]

end of LS2 — before last LHC break — after last LHC break

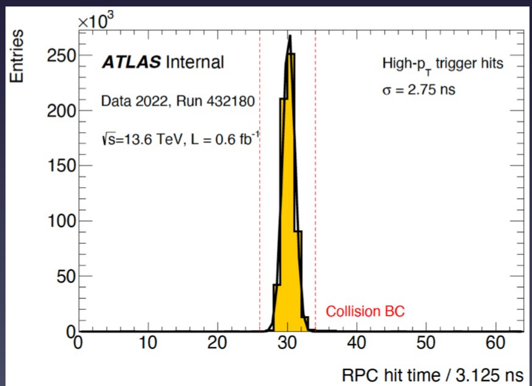
Muon trigger in Run3 data

- the Level-1 muon barrel trigger efficiency ⊗ acceptance is being recovered and before the LHC break was about 15% lower wrt the Run2 value

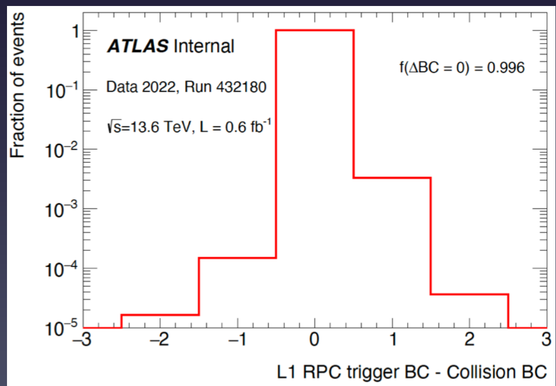
- RPC trigger signals have been synchronized with ATLAS/LHC



benefits from interventions after last LHC break not yet included



RPC trigger hit distribution is within the collision BC



99.6% of the L1 barrel events with the correct BC number

Upgrade programmes

New detectors for Run3

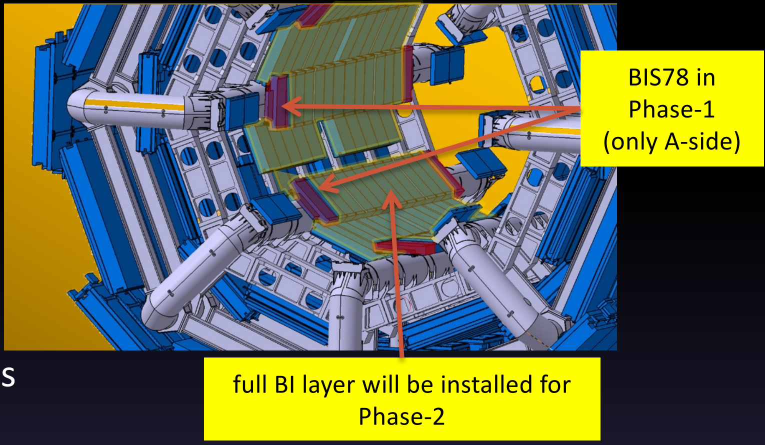
Barrel-endcap transition region not fully covered

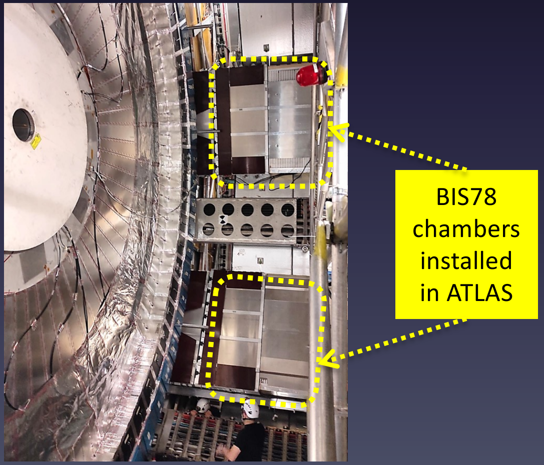
16 triplet RPC chambers (**BIS78**)
installed to reduce the fake trigger rate in 1.0<η<1.3
RPCs with gas volumes of bakelite electrodes separated by a 1mm gap, equipped with copper strips readout by high-amplification low-noise electronics
Coverage of -1.3<η<-1.0 postponed to LS3

Also a **pilot project for the HL-LHC upgrade of the RPC** having to provide very similar performance

In LS3 an additional **triple RPC layer (BI)** will be installed in the inner part of the barrel spectrometer and it will provide larger acceptance, increased selectivity, redundancy

See presentations of S.Simsek (for BIS78) and L.Pizzimento (for BI)





Conclusions

After a very successful data taking in Run2 with fundamental contributions to the ATLAS physics measurements, during LS2 RPCs have undergone an intense period of activity with the aim of maintaining and consolidating the system

Gas leaks remain the main issue for ATLAS RPCs
An intense repair campaign has been carried out with some delays due to COVID
However, the rate of new leaks is such that a complete recovery of leaky volumes was not possible
A new repair technique, also focusing on prevention, has to be pursued to overcome this source of failure

Unexpected high gap current has shown up in a number of gas volumes
The origin of the problem is likely due to the high O_2 level in the gas mixture at the restart, now much reduced

Activities to restore the RPC trigger performance have been carried out and interventions are being planned for further improvements during next YETS:

- resume the gas leak repair campaign
- re-condition the gaps with high current
- progress with and apply the new promising repair technique