MITIGATION OF THE ATLAS RPC ENVIRONMENTAL IMPACT

Sinem Simsek on behalf of ATLAS Muon Community

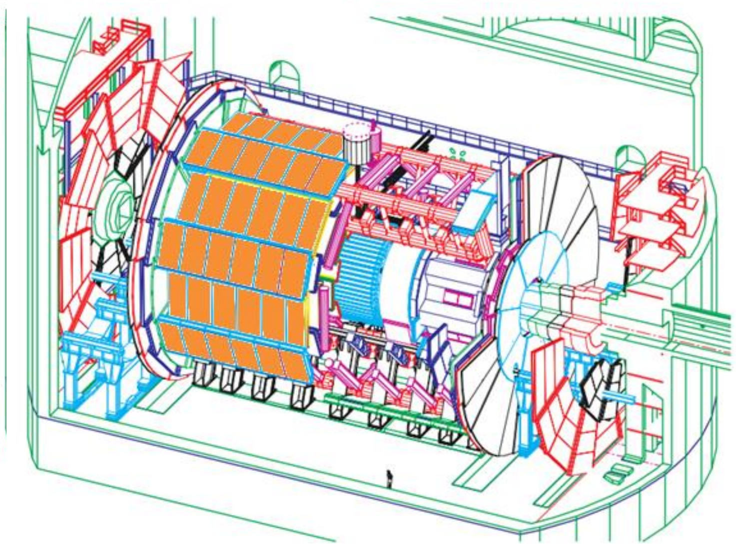
ICHEP 2024

19.07.2024

ATLAS EXPERIMENT

ISU | ISTINYE UNIVERSITY ISTANBUL

ATLAS RPC STRUCTURE IN CAVERN



The Resistive Plate Chambers (RPCs) is a gaseous detector which surround the barrel region of the ATLAS experiment

- **Only muon trigger detector**
- **measurement of the azimuthal coordinate**

CAVERN CHALLENGE

<u>ATLAS RPCs with numbers:</u>

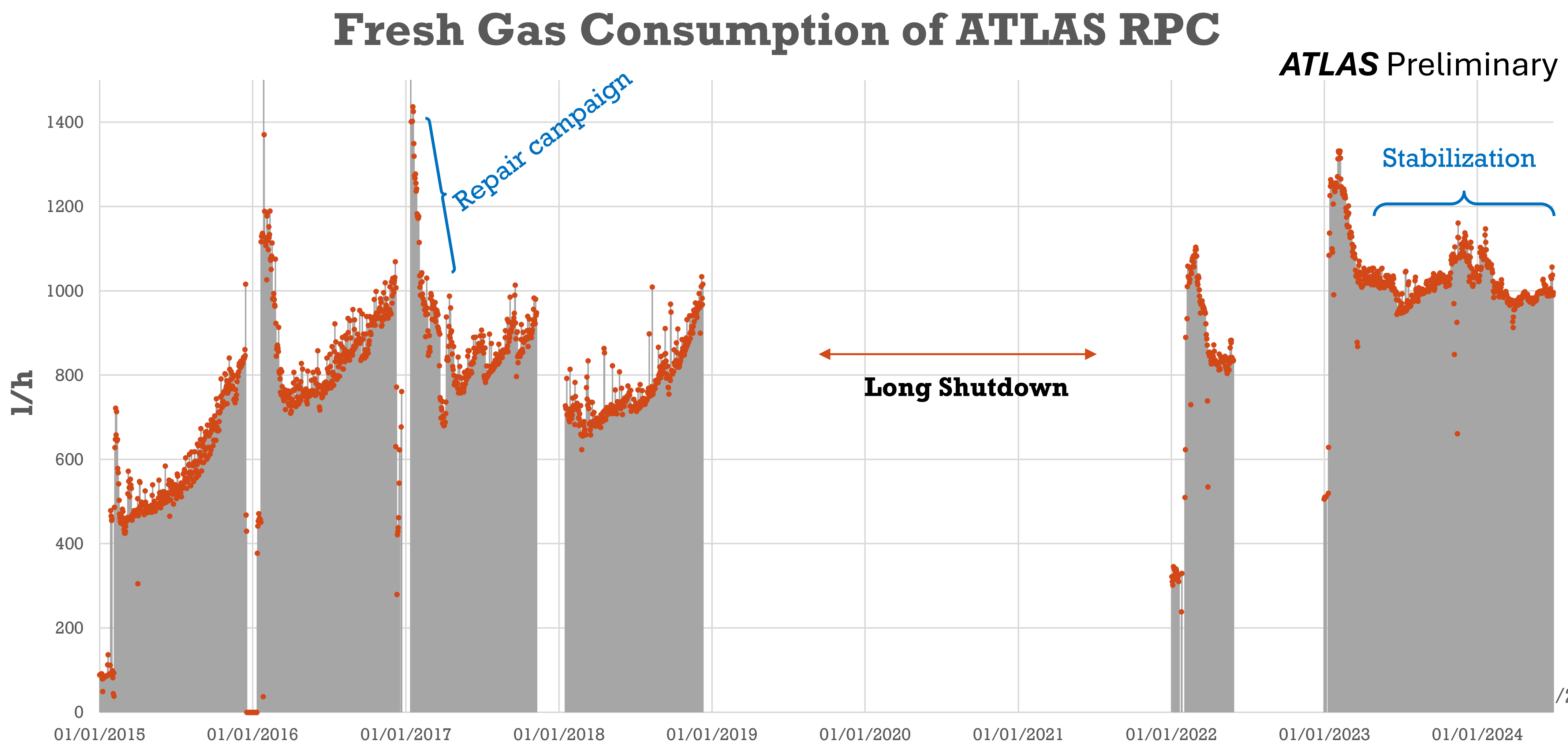
- ~ 3800 RPC gas gaps
- The total gas volume is 15 m^3
- 128 I/O gas manifolds
- Manifolds are connected to chambers through 8000 gas inlets located in 4000 service boxes

Historically, the inlets tend to crack showing leaks!

GAS LEAK ISSUE OF ATLAS RPC

- Fresh gas injection in the last 8 years
- Big increases at each system restart
- Leak rate acceletates during the run
- System stabilized after LS2

Loosing 500-1400 l/h depending of the period of the year



/2024

IMPACT OF THE LEAKS

Consequences of leaks→ There are two factors to be considered:

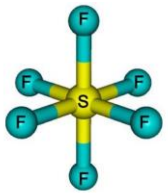
1 – Performance: The chambers can have air intake → it seriously impact the performance of the detector and decrease the trigger performance

2 – Environmental impact: Standard mix is expensive and have high GWP!

- GWP of R134A → 1400!

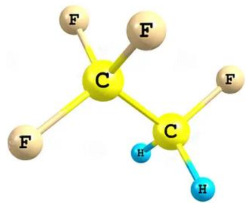
Both points can be addressed by reducing the leaks → see repair & consolidate

The second point can be further addressed by replacing the standard mixture with an alternative one having lower GWP and equivalent performance



The RPC (Atlas case) standard mix is 94.7 % [R134A] 5 % [C4H10] 0.3% SF6

- R134A has high electron density (high primary ionization) and is electronegative to control the avalanche growth;
- C4H10 absorbs photons provoking the degradation of fluorinated gases which byproducts may damage the chamber
- SF6 an electronegative component that helps to prevent the transition to streamer.



Alternative mixtures can be determined according two different strategies → see **test on new mixtures**:

a. Challenging approach (very low GWP but representing a risk for the RPC performance):
   - fully replace the major component R134A with a low GWP substitute, up to now within the family of HFOs, which are fast degrading with UVs. The challenge comes from the high impact of the degradation byproducts on the chamber longevity

b. Conservative approach: partly replace R134A with CO_2 and possibly SF6 as well, substantially conserving the known RPC ageing features of the standard mix

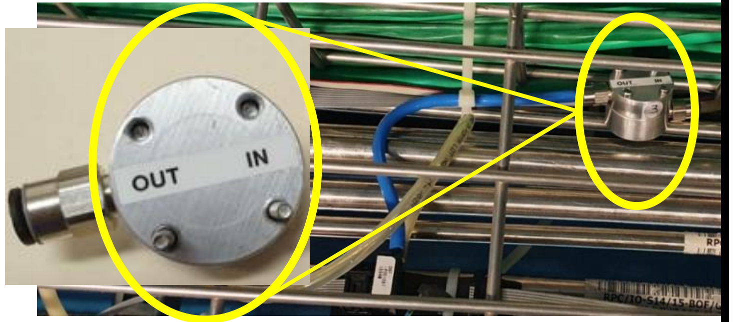
5 REPAIR & CONSOLIDATE

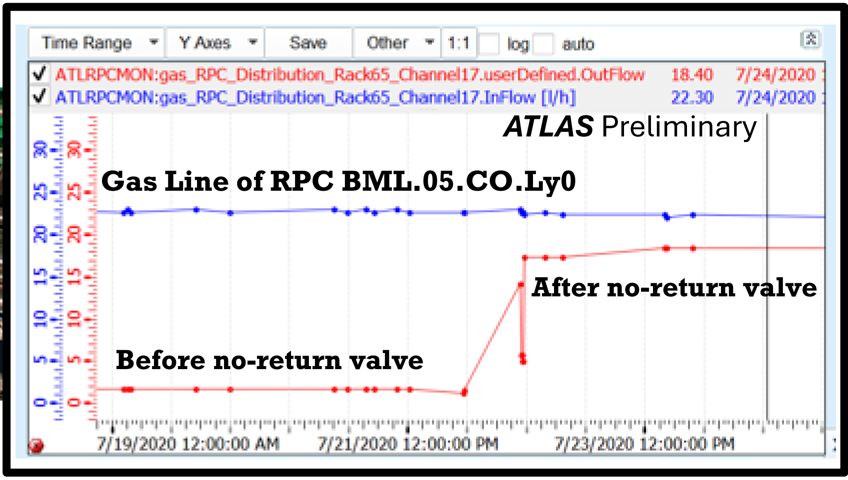
PLAN PROPOSED BEFORE LS2 AND ACTION SUMMARY

➢ Developing different strategies to prevent the lose of fluorinated gases

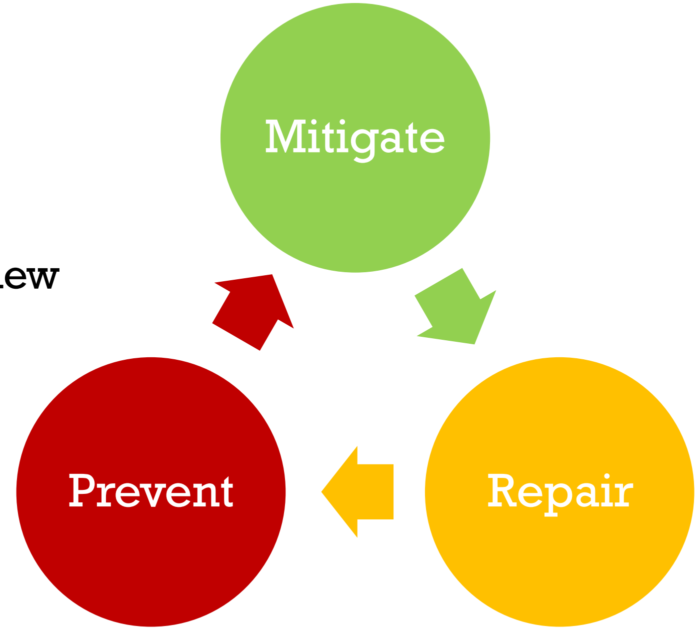
Mitigate

- No return valves → >1100 no-return valves have been installed on chambers, one for each flow meter to prevent the flow inversion and the resulting large gas leak
- Higher distribution rack granularity





Flowmeter Result: it has been possible to save about 20 l/h of gas!



Prevent

- Foam Technique: Introduction of a new consolidation and repair technique

Repair

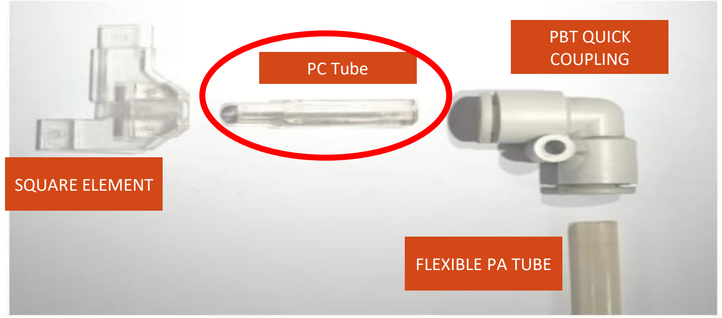
- Standard Technique: The classic glueing technique which is used since 2008

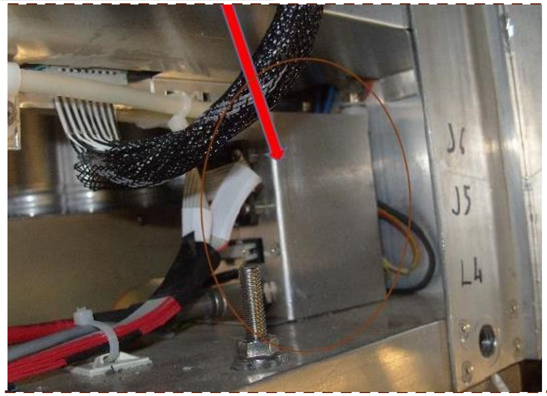
STANDARD VS FOAM TECHNIQUE FOR ATLAS RPC GAS REPARATIONS

Where these gas leaks occur?

This connectors:

- has intrinsic fragility
- are installed inside aluminum boxes which are often hard to reach!

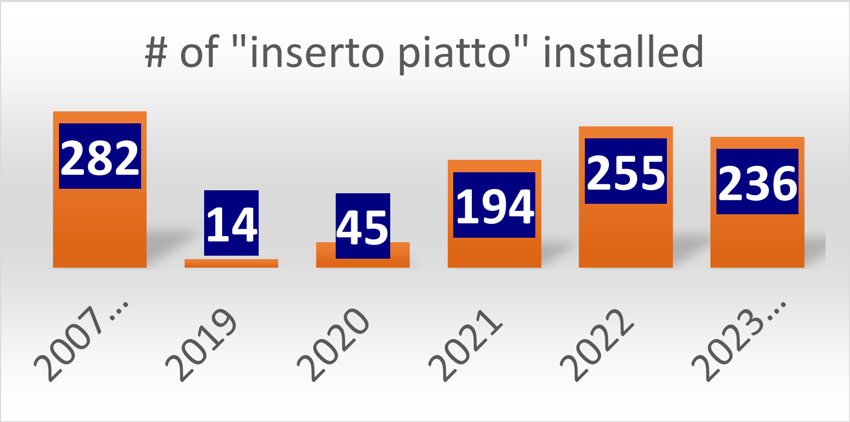




STANDARD TECHNIQUE

A special type of glue which is precisely sprayed with a special tool to surround the leak
Or inserting a new inlet in the cracked hole

- Efficiency improved greatly with time
- Only method available in case of complete inlet cracking



FOAM TECHNIQUE

Polyurethane Foam

- The idea is to fill the boxes with this foam curing small leaks and preventing any future leak

Why developing Foam Technique?

Repairing leaks in a way that is

- easier,
- faster,
- Preventive

But! This method is **not** suitable for big leaks!

8 TEST ON NEW MIXTURES

REPLACING RPC GAS MIXTURE

- Replace a limited fraction of R134a CO_2 (low GWP, non flammable, non toxic, inexpensive, good RPC performance)
- Reduction of SF_6
- Replacement of SF_6 → future CL-HFO

	RPC Standart Gas Mixture				
	Conc. Vol. (%v)	PM	GWP	GWP Weighted	in CO2e
$C_2H_2F_4$ (R-134A)	94.7	102	1430	1382.23	617
I-C_4H_{10}	5	58	0	0	0
SF_6	0.3	146	22800	99.93	45
CO_2	0		1	0	0
	TOTAL:				661

	Current Gas Mix. (30% CO_2 + 1% SF_6)				
	Conc. Vol. (%v)	PM	GWP	GWP Weighted	in CO2e
$C_2H_2F_4$ (R-134A)	64	102	1430	1132.68	420
I-C_4H_{10}	5	58	0	0	0
SF_6	1	146	22800	400.77	149
CO_2	30	44	1	0.1589	0
					569

	Achievable Target (40% CO_2 + 1.0% SF_6)				
	Conc. Vol. (%v)	PM	GWP	GWP Weighted	in CO2e
$C_2H_2F_4$ (R-134A)	54	102	1430	957.06	355
I-C_4H_{10}	5	58	0	0	0
SF_6	1	146	22800	400.77	149
CO_2	40	44	1	0.2118	0
					504

Reached target: 14% GWP reduction for 30% CO_2

.

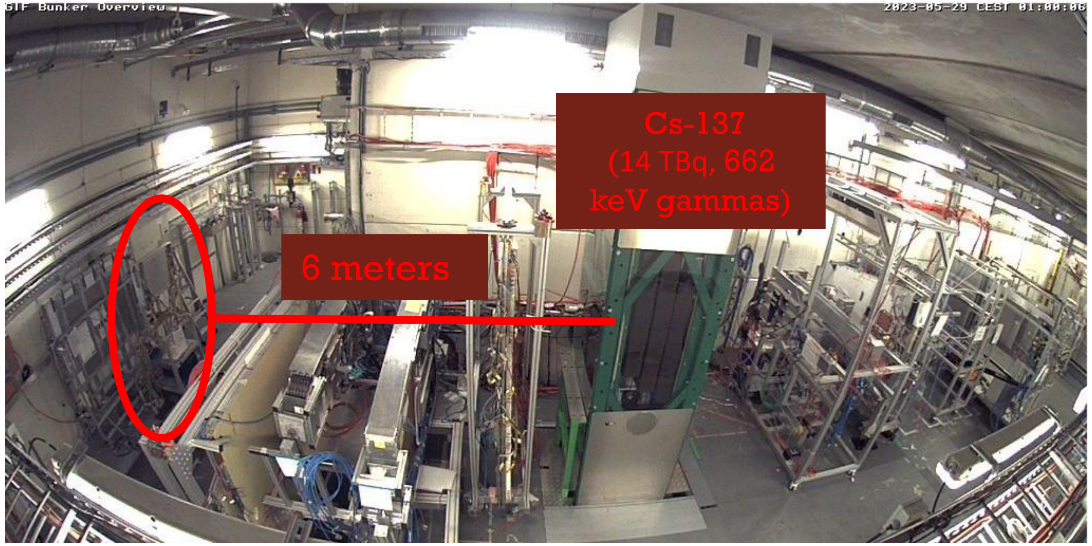
Achievable target: 24% GWP reduction for 40% CO_2

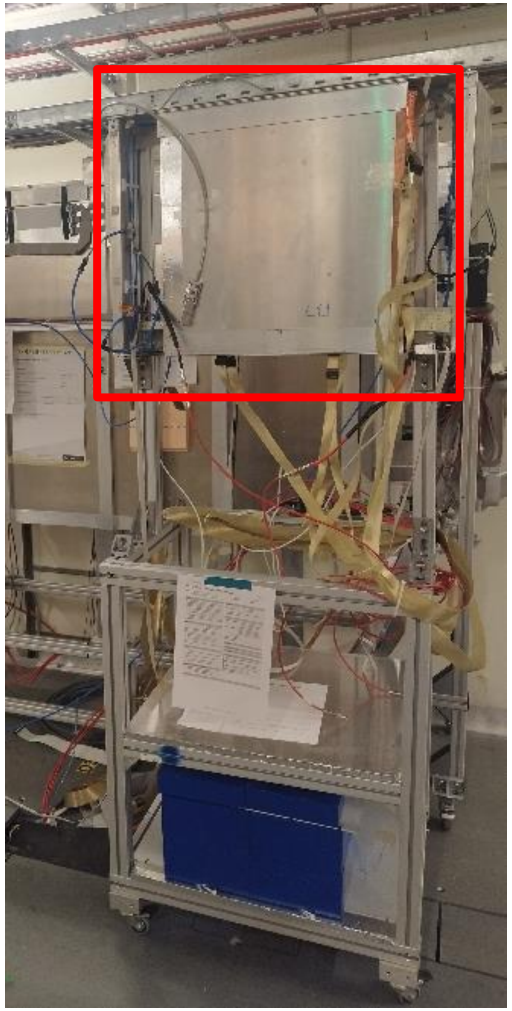
In case a full replacement of SF_6 with CL-HFO → up to 36% reduction → Studies are ongoing

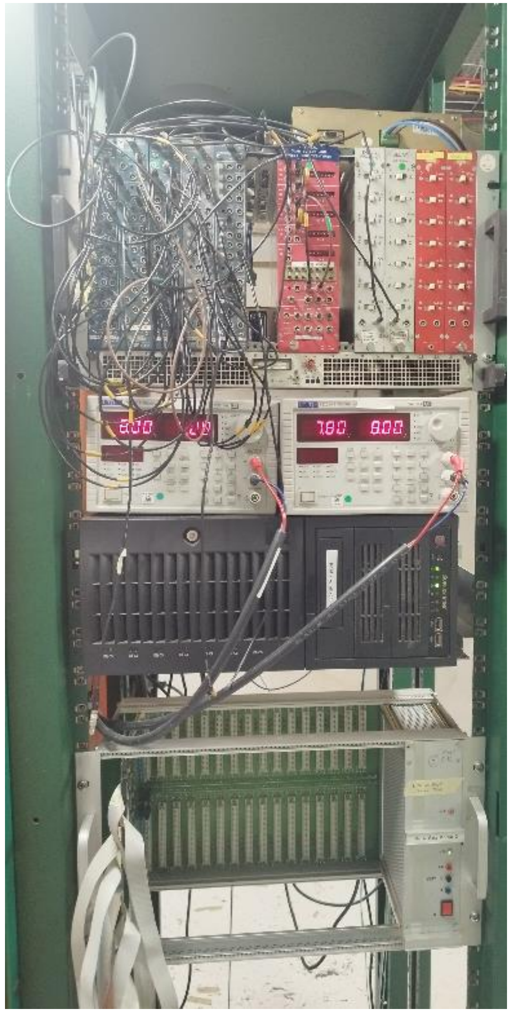
ATLAS RPC-LIKE PERFORMANCE WITH ADDITIONAL CO_2

Test chamber: 50 cm x 50 cm ATLAS RPC-like doublet

Test Area: Gamma Irradiation Facility (GIF++)







Trigger: <u>clean and acceptance effects free</u>

- double coincidence from external scintillators
- One of the layers of the doublet

Test: the other layer of the doublet

OBJECTIVES OF THE TEST

We test the RPC behaviour while exposed to the photon background to simulate HL-LHC conditions.

- **Performance measurements** are done at each available muon beam period
  - Efficiency, current, counts vs. HV, source intensity, gas composition and FE threshold
- **Fluoride concentration measurement**
  - The F- concentration in the output gas is measured as a function of photon background, HV, and gas composition
- **Aging test**
  - Integrate a significant fraction of the equivalent of HL-LHC total work load
  - The acceleration factor 5 is a compromise between realism and test duration
    - The aging is monitored through periodic performance measurements, observing in particular, ohmic current, exponential current, electrode resistivity

This ageing test was the first performed with this mixture, and thanks to that, ATLAS was the first experiment adopting this mixture in July 2023.

PERFORMANCE TESTS OF THE RPC PROTOTYPE WITH CO_2 GAS MIXTURE IN GIF++ TEST BEAMS

The working point anticipation is

~250V for 30% CO_2

~400V for 40% CO_2 gas mixtures

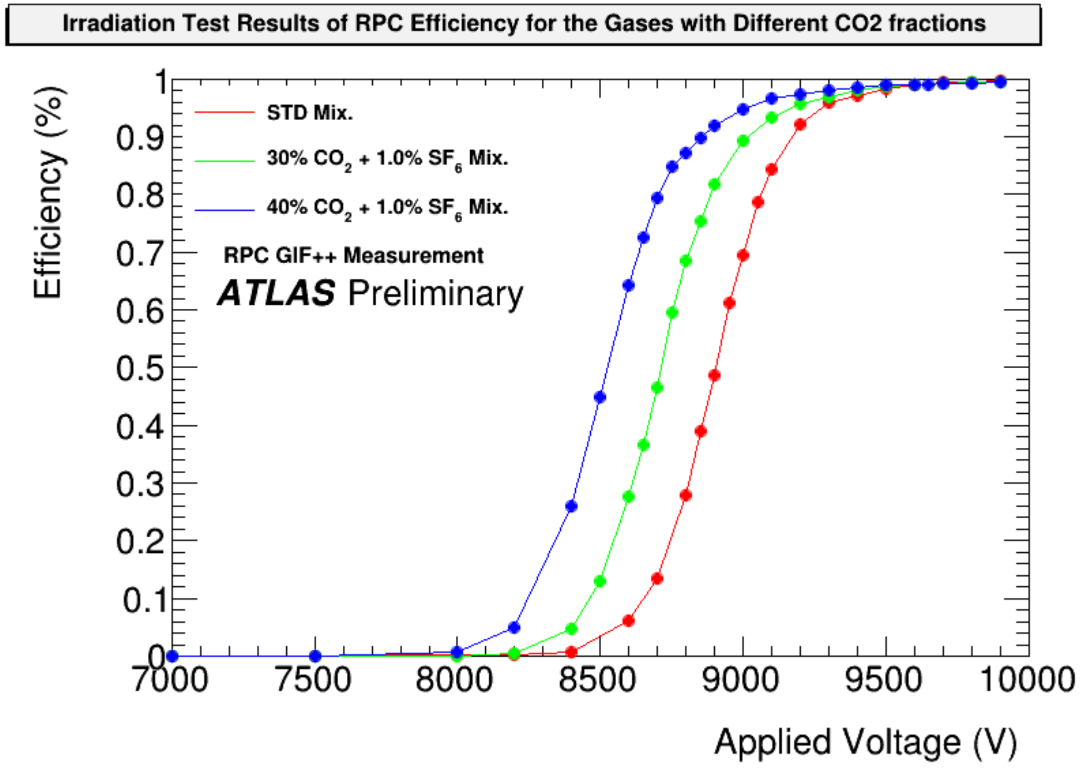
wrt. Standard gas mixture under the same photon flux

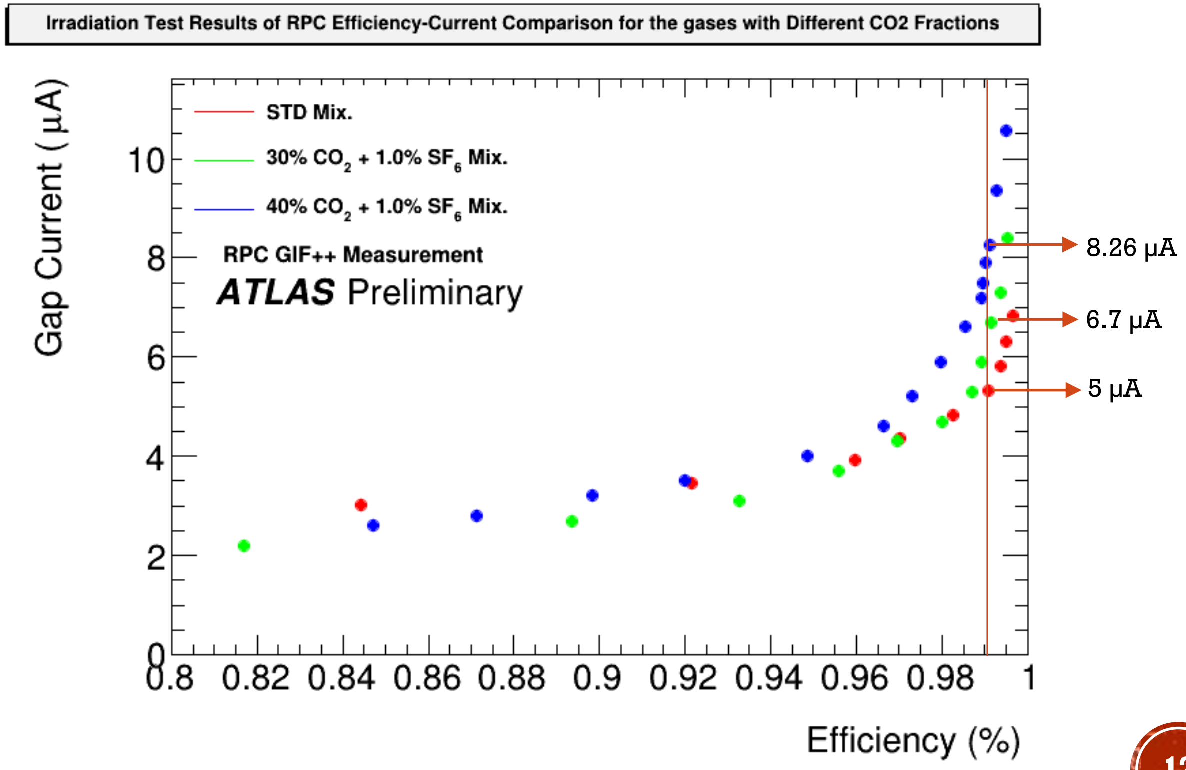
The current increase is

18% - 20% for 30% CO2

40% - 45% for 40% CO2 gas mixtures

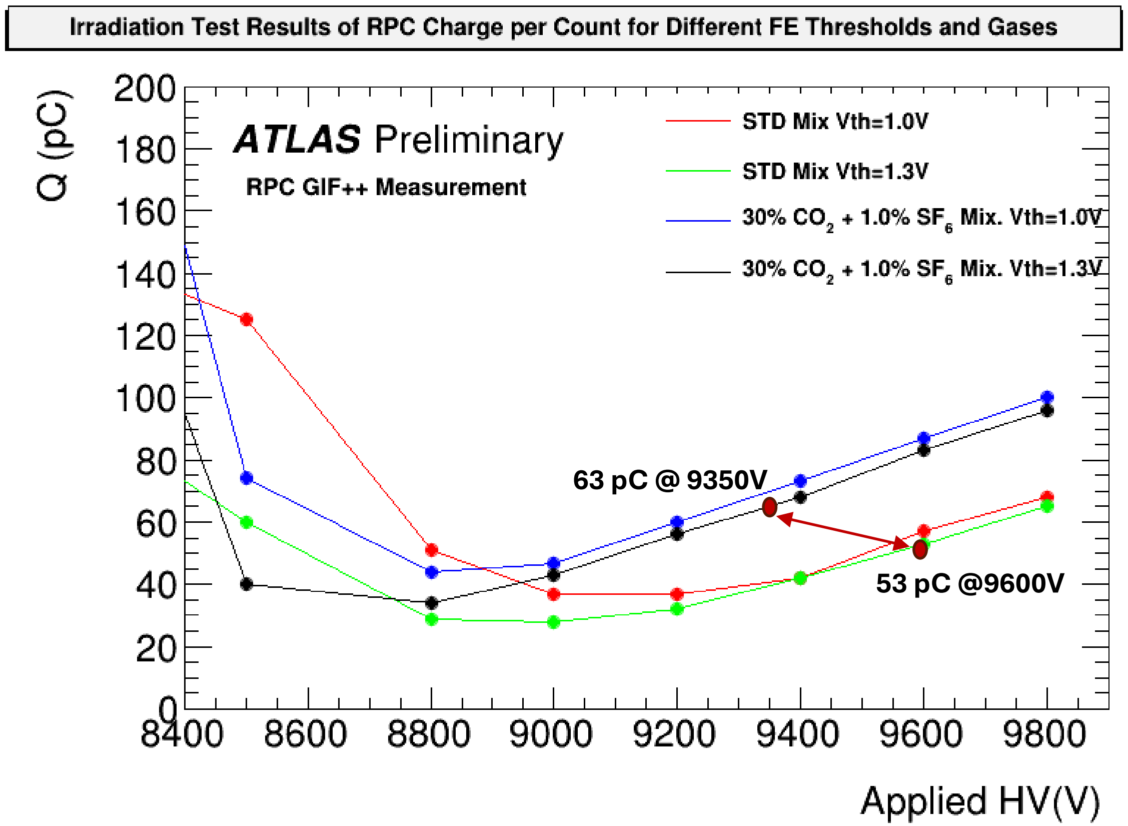
wrt. Standard gas mixture under the same photon flux

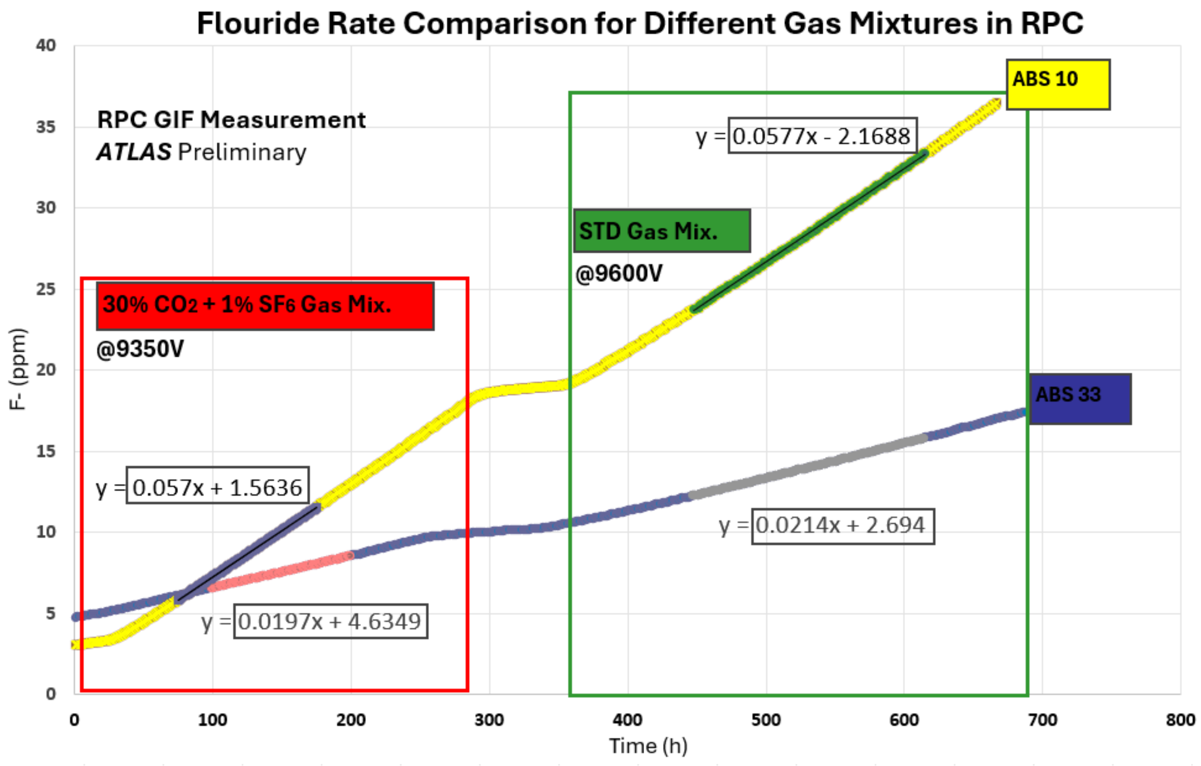




- Efficiency is > 98% for each gas mixture

CHARGE PER COUNT & FLOURIDE MEASUREMENT





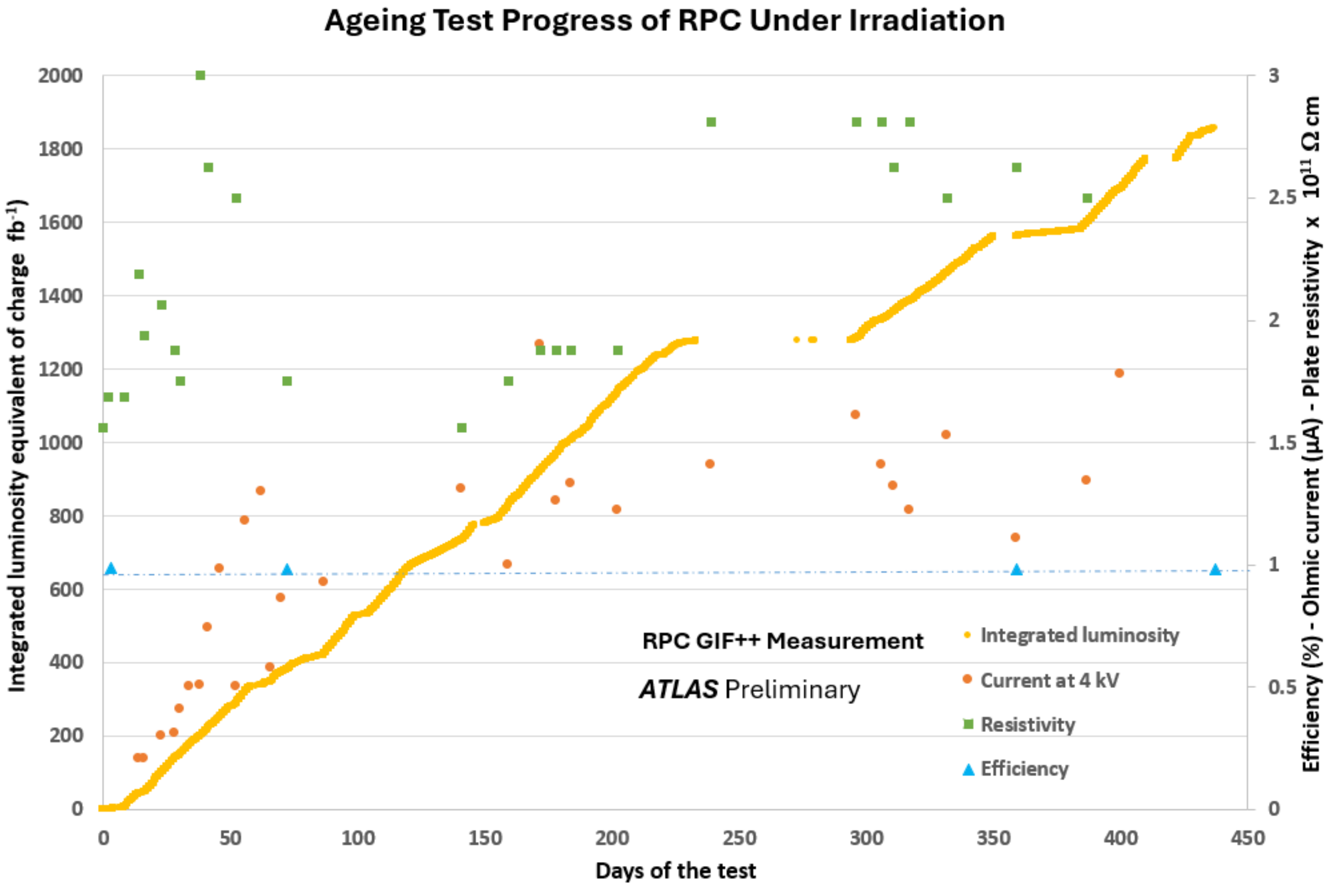
- For 30% CO_2, the charge per count is ~19% higher
  - This is due to the presence of an higher amount of undetected photons (less counts).

The current is not ALL.....

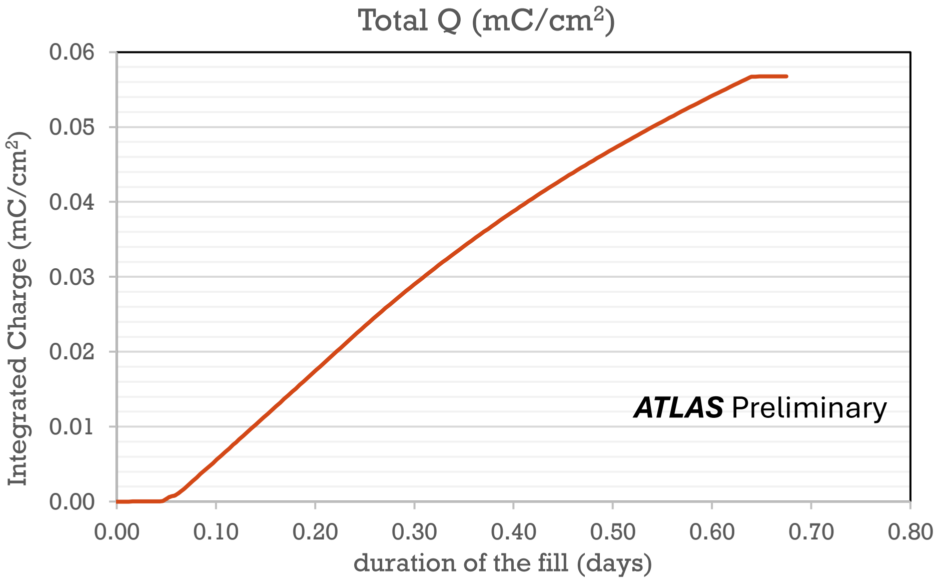
Method: Using an Ion Selective Electrode (ISE) station
Starting with 30% CO_2 gas mixture for 2.5h
Switching the gas and waiting for the gas flush for 1h
Continuing with Standard Gas Mixture for 2.5h
To eliminate the systematic and environmental effects!

Comparison STD vs 30% CO_2 mixtures:
For the same efficiency we have the similar amount (or slightly less) of fluoride production!

AGEING STUDY WITH 30% CO_2 + 1% SF6



High background ref. chamber
(BML6A13.CO.Ly0 in ATLAS cavern)

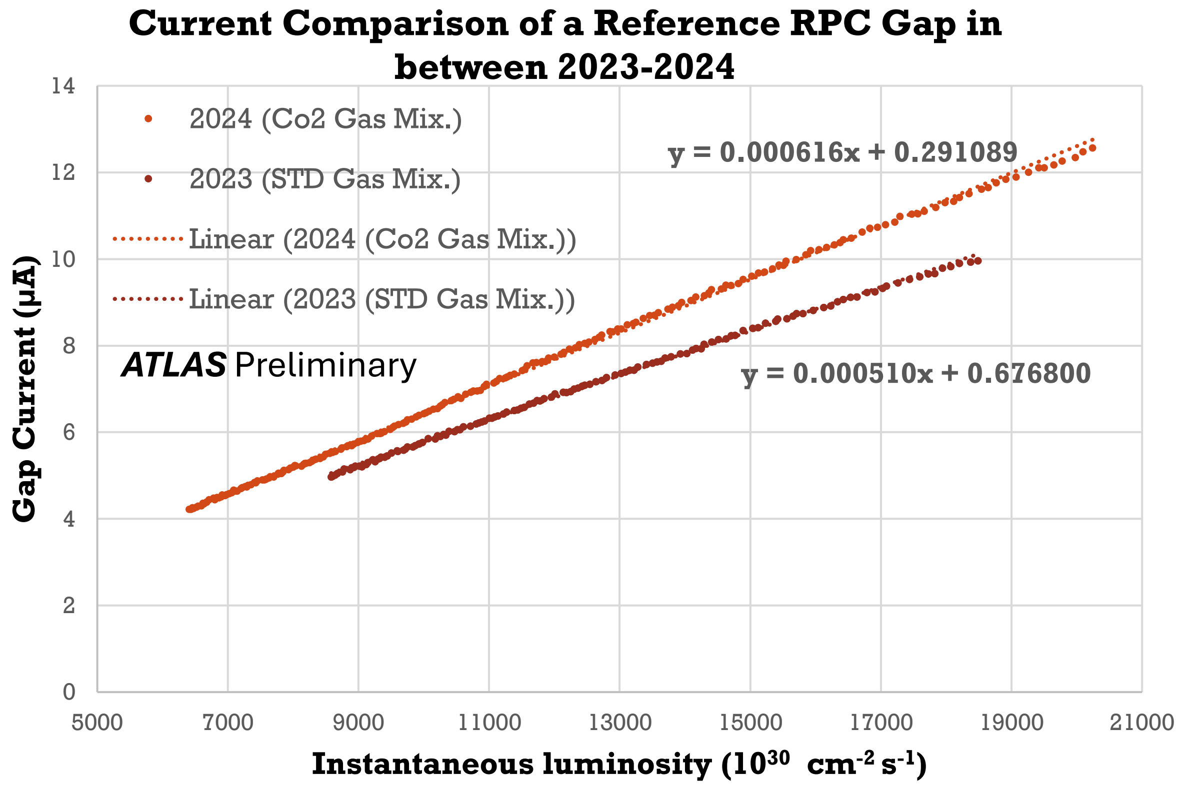


Calibration Q vs. Lumi

fill lumi	0.821fb^{-1}
int. charge	0.05677mC/cm^2
conversion factor	0.069145mC/cm^2 · fb

- Target →Full HL-LHC program corresponds to ~ 3000 fb^{-1}
- We are in more than half of the target corresponding to ~1900 fb^{-1}
- Ohmic current is very good! It increased slightly due probably the accelerated ageing at the beginning
- Electrode resistance started very high and is not changing much
- Efficiency is not changing after 1.5 years!

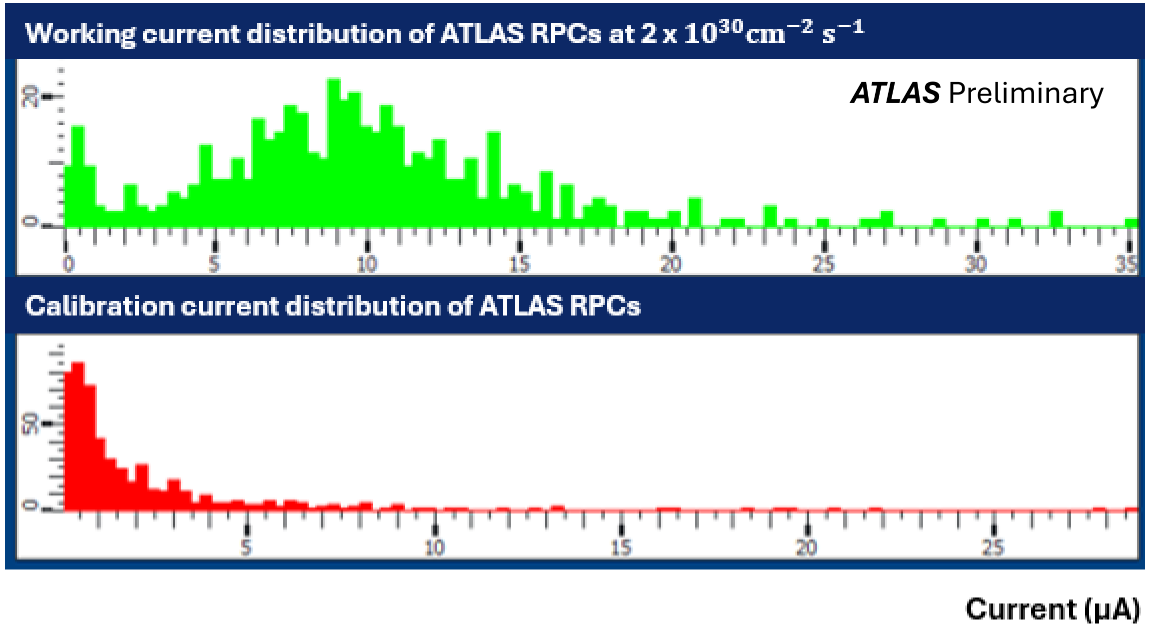
ATLAS RPC IN CAVERN:
COMPARISON OF THE CURRENT AFTER THE GAS MIXTURE CHANGE



The ratio between gas gap current and Inst. Lumi which proportional to the **charge/count** is increasing ~ **17%**

See also Eric Ballabene's the talk: Performance of ATLAS RPC detectors and L1 Muon Barrel Trigger with a new CO2 based gas mixture

Current Distribution of RPC Gas Gaps Operated with CO_2 Gas Mixture



The top plot: The working current of the chambers (at 9350V) with beam → good performance with CO_2 except for tails indicating problematic, potentially leaky chambers

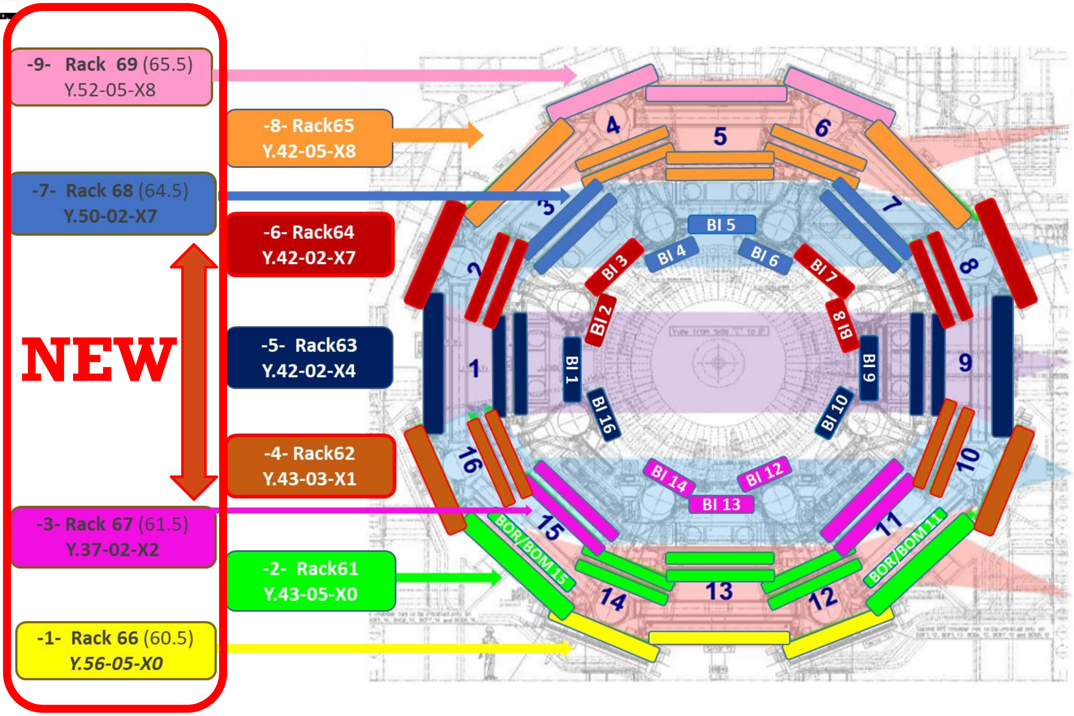
The bottom plot: the calibration current distribution (at 9350V) without beam → the intrinsic behavior of the gas gaps has not deteriorated after switching to the new gas mixture with CO_2

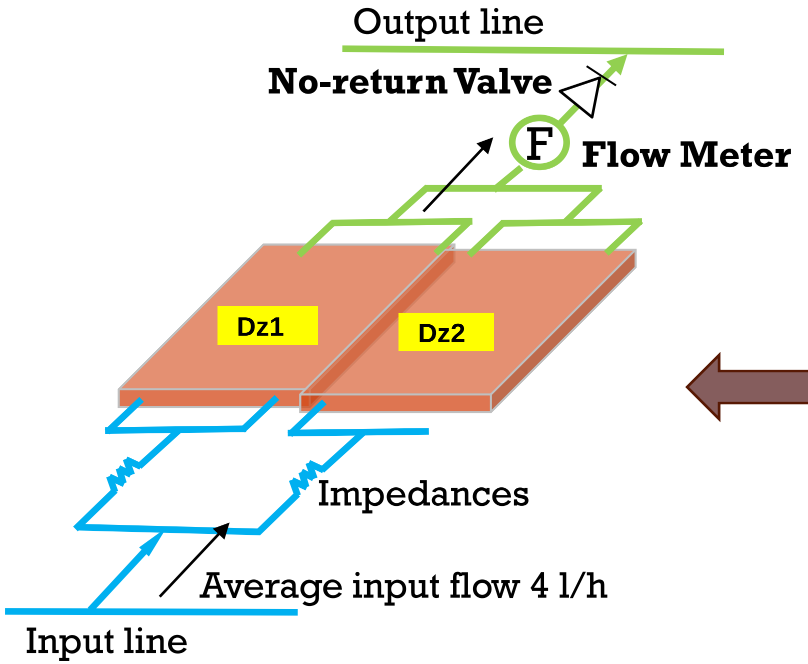
CONCLUSION

- The only important issue found on ATLAS are the gas leaks
- The ATLAS RPC community is putting in place all the necessary measures to secure the system for the next decades operation and drastically reduce the GWP.
- A major R&D is in progress
- A huge person power and technical effort is put in place to fix and secure the leaks.
- We are performing longevity and performance studies with alternative gas mixtures with a lower GWP
  - We aim reduce the emissions up to 36% with respect to the Standard gas mixture
  - No hint of worry for chamber longevity emerged for 30% CO_2 based gas mixture
- The new Phase-2 upgrade RPCs must be leak free working with lower GWP mixtures

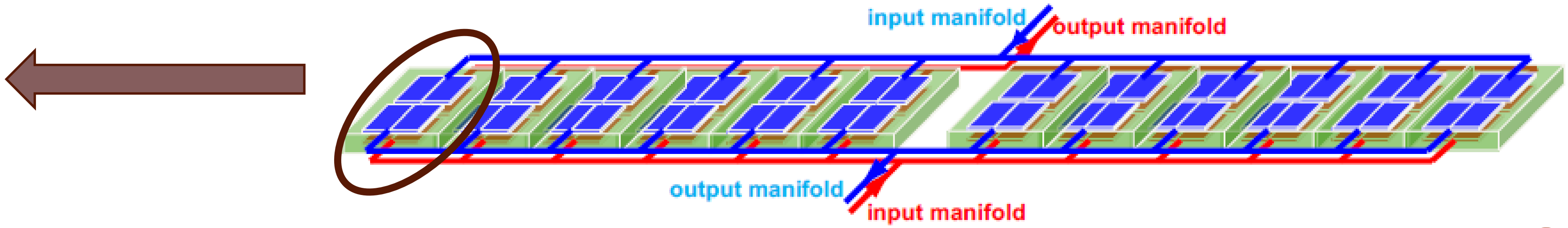
BACKUP: PRESENT GAS SYSTEM

- There are 128 I/O gas manifolds
- A pump regulates the RPC internal pressure at about 1 mbar
- Manifolds are connected to chambers through 8000 gas inlets located in 4000 service boxes
- Historically, the inlets tend to crack showing leaks





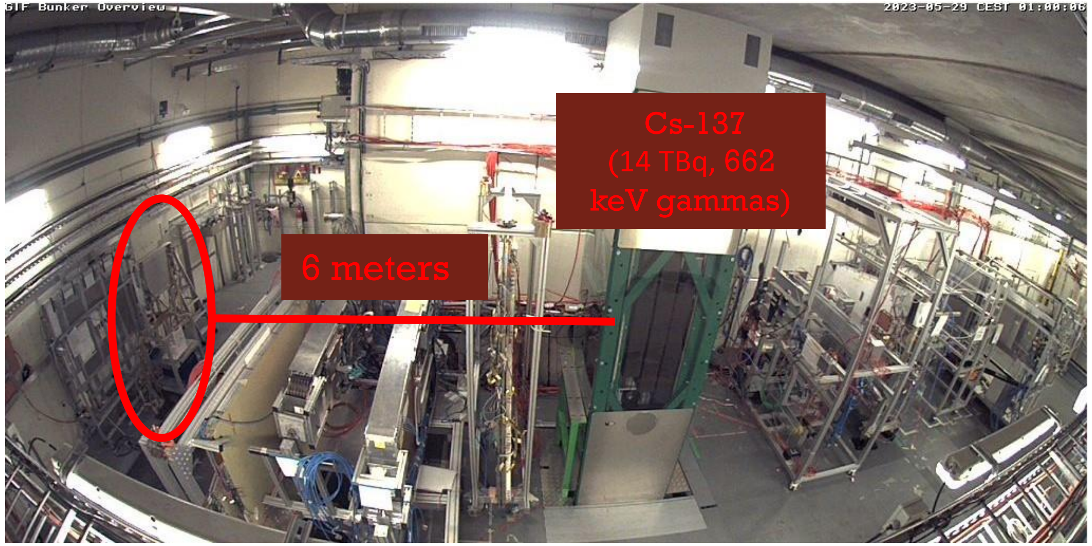
No-return valve: To prevent the massive leak
Flowmeter: To have a granular monitor

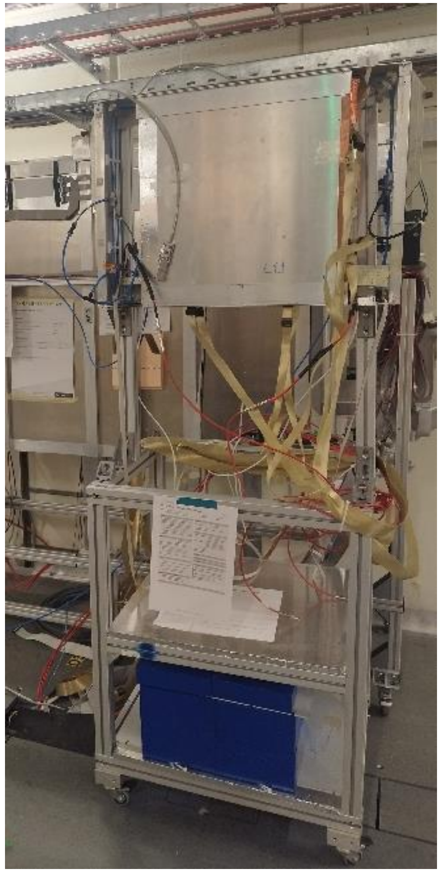


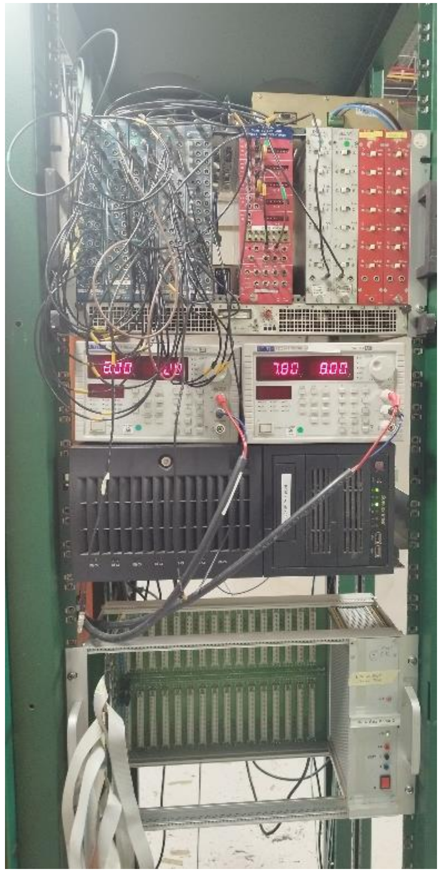
ATLAS RPC-LIKE PERFORMANCE WITH ADDITIONAL CO_2

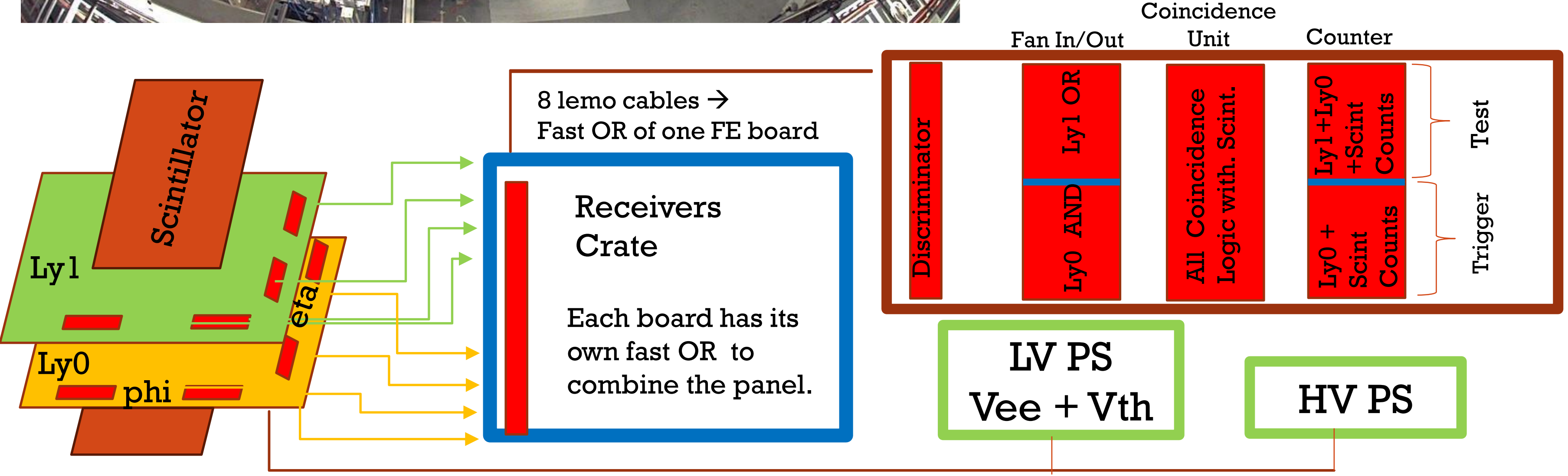
Test chamber: 50 cm x 50 cm ATLAS–RPC doublet

Test Area: Gamma Irradiation Facility (GIF++)









Double layers of the scintillator and one of the layers (Ly0) was defined as the <u>trigger to have tighter selection and to eliminate any acceptance effect.</u>

Ly1 was defined as the <u>Test</u> Layer to measure the efficiency.

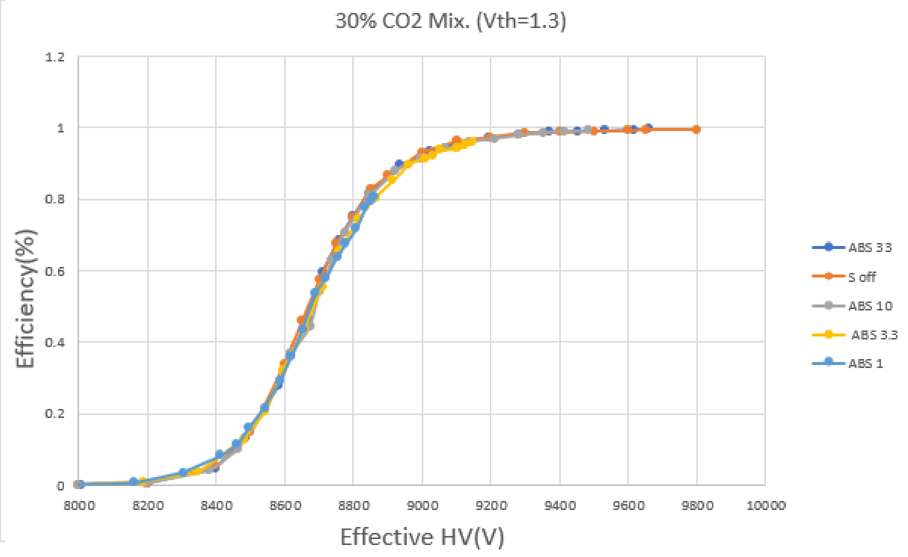
MEASUREMENT OF THE RESISTIVITY

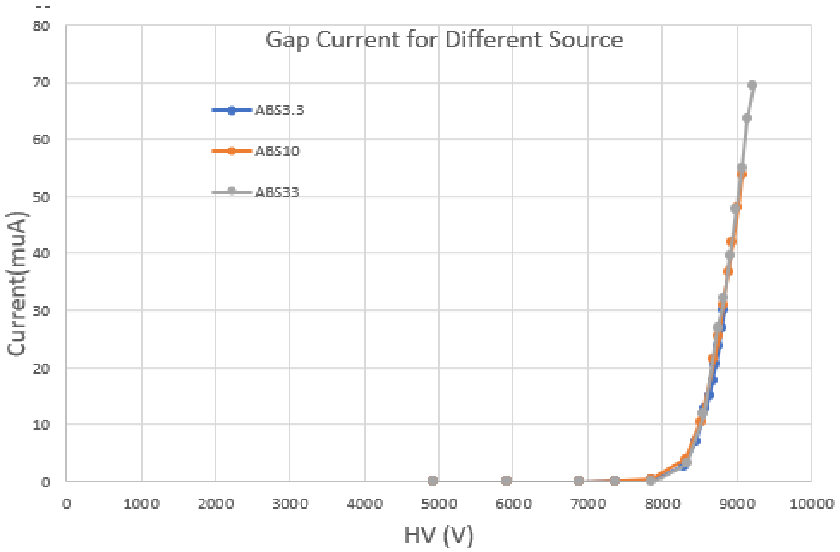
HVeffective = HVapplied – I*R

Resistivity measurement:

- Resistivity is measured through the voltage drop induced by the working current under uniform irradiation
- We observe: efficiency and current as a function of HV
- We find the value of R as the one exactly accounting for the voltage drop

$$R = \frac{\Delta V}{I} \longleftrightarrow R = \frac{\rho * 2\ HPL\ thickness}{Area}$$





30% CO_2 ADD TO THE STANDARD MIXTURE CASE

Legacy RPCs features:

- 2 mm gaseous target → about 7 primary clusters
- Approximately 10% more current (with respect to std.) per count at the standard FE threshold

  Performance:
- Ageing properties comparable to 2002-2004 ageing test, HL-LHC rate for 2/3 of 10 ATLAS years (100 Hz/cm^2)
- Absolute efficiency > 98% thanks to at least 7 primary clusters in the gas

Upgrade RPCs features:

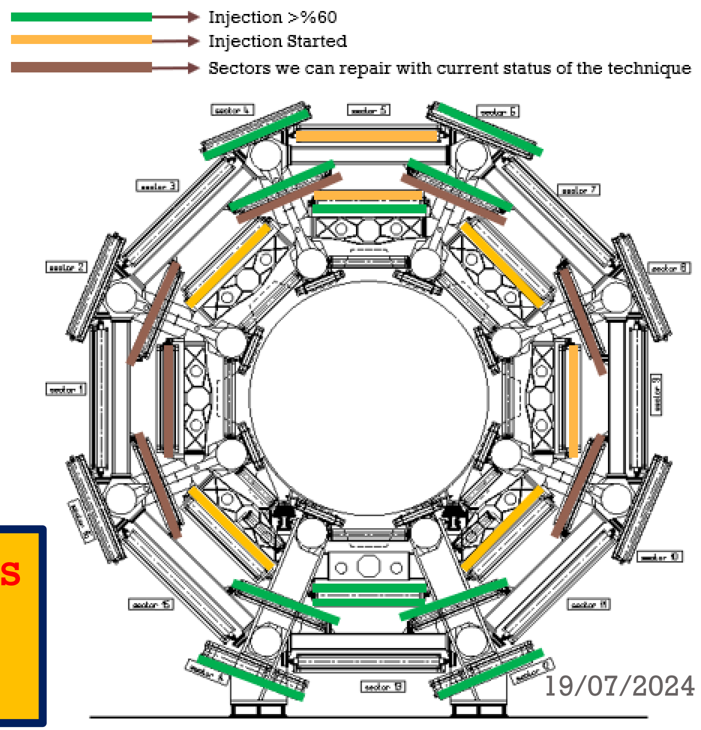
- 1 mm gaseous target → about 4-5 primary clusters
- Average 3 pC per count at the standard FE threshold

  Performance:
- Ageing properties extrapolated from 2002-2004 ageing test, assessing compatibility of RPCs to work at about 10 x HL-LHC rate for 10 ATLAS years
- Absolute efficiency > 97.5% due to at least 3.5 primary clusters in the gas

FOAM TECHNIQUE WHAT HAS DONE UNTIL NOW?

- Due to the inability to apply the Foam Technique on relatively large leaks, we have not been able to cover 100% of the boxes in any sector with foam
- There is a learning curve in order to reach all the possible boxes
  - We started with relatively easy cases and learning how to reach more difficult ones
- Aiming to cover 50% to 70% of the boxes with foam seems to be the most optimal target for now.
- 97 full gas layers foamed on the 4 corners and tested before and after repair showing no leaks.
- Monitored for 1 year through the flowmeters and no new leaks have been detected

Working Period	Total Covered Inlets	Not Fully Repaired Layers
YETS 21/22	200	0
YETS 22/23	554	97
YETS 23/24	448	66
Total	**1202**	**163**



In comparison there were 2100 non treated layers showing "250" leaks in the same period, with an expected value of about "12" new leaks

FOAM TECHNIQUE
WHAT DO WE PLAN FOR FUTURE?

- We created a Research and Development Team to focus on improvement of the technique.
- The studies are ongoing in Istinye, Türkiye.
- 2024 Targets of Research and Development Team?
  - **Make the technique more easily applicable**
    - Design and Production (3D Printer) of Static Mixers for our special requirements.
    - Automation of the Mixing and Injection Steps
  - **Projects on methods to reach difficult-to-access corners**
    - Robot Arm Studies that will help us to close the opening of the boxes we fill.
      - This Robot Arm may help us to inject automaticly
    - Automation of the Mixing and Injection Steps