New Facilities for the Production of 1 mm gap Resistive Plate Chambers for the Upgrade of the ATLAS Muon Spectrometer

Francesco Fallavollita on behalf of the ATLAS Muon Collaboration

XVII international Conference on
Resistive Plate Chambers and Related Detectors

Santiago de Compostela - 9th to 13th September

ATLAS EXPERIMENT

MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

RPC 2024 Santiago de Compostela (Spain)

Establishing a new gas gap RPC manufacturer

- ~240/1000 thin-gap RPCs for the ATLAS Muon Spectrometer upgrade project will be produced by the Max-Planck Institute for Physics in cooperation with industrial partners.
- Technology transfer to industry to establish a large-scale RPC production compliant with ATLAS standards.
- The ATLAS group at the MPI for Physics has therefore started to establish two additional manufacturers:

MIRION TECHNOLOGIES — Website: https://www.mirion.com/

PTS Maschinenbau — Website: https://www.ptsmaschinenbau.com/

- PHASE-0: Optimization of the production steps in interaction with companies. ✓
- PHASE-1: Qualification of companies with test-sample prototypes. ✓
- PHASE-2: Qualification of companies with both small- and real-scale prototypes. ← we are HERE!

- A new facility for the production and certification of gas gaps has been established at MPI.
- The series production is planned to start for early 2025.

Final certification phase: Longevity Studies

➢ Overview of Qualification Phase:

- **Objective:** Certify PTS and MIRION companies for large-scale RPC production by conducting comprehensive longevity studies on small- and full-scale RPC detector prototypes at the CERN GIF++ facility.

➢ Small-Scale RPC Detector Prototype Status:

- **Production & Qualification:** Completed at both PTS & MIRION companies.
- **Configuration:** Integrated with pick-up strips and Cardarelli front-end electronics, housed within Faraday cages.
- **Performance Studies:** Undergoing extensive evaluation at CERN GIF++ facility since April 2023 *(see next slide!)*.
- **Longevity Studies:** scheduled for middle of September 2024.

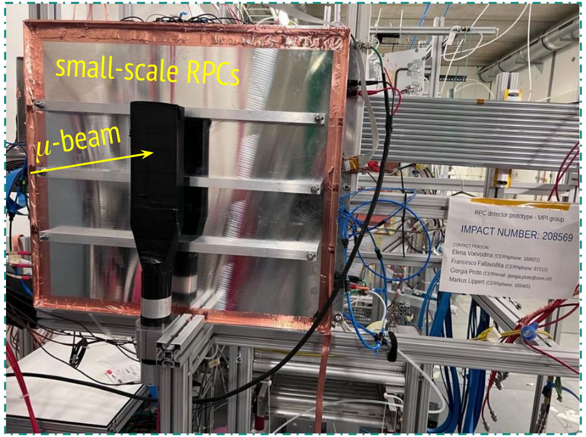
➢ Real-Scale RPC Detector Prototype Status:

- **Production:** Successfully completed at both PTS and MIRION companies.
- **Qualification:** QA/QC protocol evaluation currently in progress at both companies.
- **Longevity Studies:** Transfer to CERN GIF++ facility for longevity studies, scheduled for mid-September 2024.

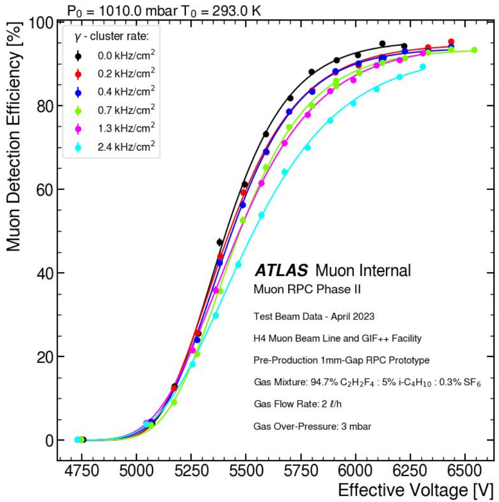
Test beam results for the small-scale RPCs

- 40×50 cm^2 small-scale RPCs were successfully produced at the selected companies: PTS and MIRION.
- Intense test campaign was successfully performed on the gas gaps produced by these companies during the test-beam periods at CERN GIF++ facility in April / August 2023.
  - Performance of test-sample RPCs in presence of a muon beam and γ- background.
  - Test-sample RPCs show very good overall performance, showing their good manufacturing.

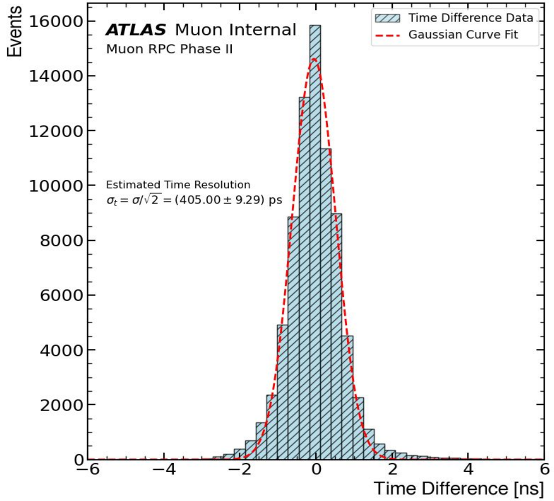
setup installation at CERN GIF++ facility



efficiency vs. γ- background



time resolution



Comprehensive review of the test-beam result in Giorgia Proto's presentation.

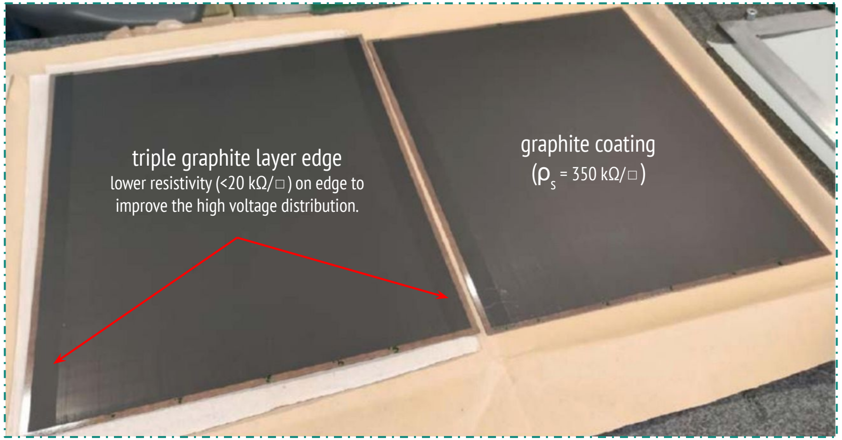
Assembly procedure for the 1mm-gap RPCs

The 1mm-gap RPCs production involve several stages:

➢ Production step 2: HPL electrode production

1. Graphite coating on surface of the the HPL electrodes using a silk-screen technique in industry.
   → Mesh size: 90 threads/cm and graphite coating drying at 105 ◦C for 1h.
   → Varnish provided by the Heysung Trade company and used for CMS RPC mass-production.
2. Installation of the high-voltage and ground contact.
3. Laminating of the insulating Polyethylene Terephthalate (PET) film onto the HPL electrodes.
   → Perfex gloss PET-EVA compound foil (190 µm PET, 80 µm EVA).
   → Lamination of the foil on the electrode under pressure at 105°C with lamination speed of ~3m/min with a roll laminator.

graphite coating of the HPL electrodes



laminating press machine

HPL electrode after lamination

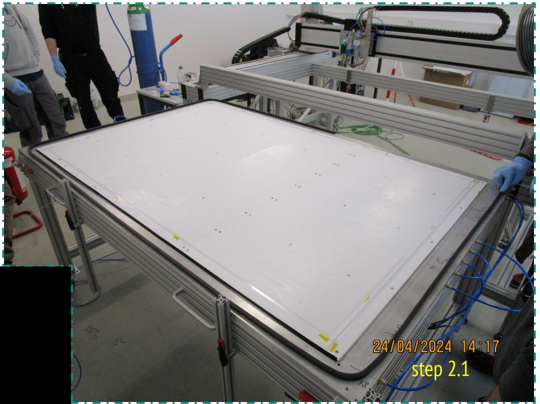
Assembly procedure for the 1mm-gap RPCs

➢ Production step 2: Gas gap production

1. Placing polycarbonate parts (spacers & lateral profiles) in/on the Teflon gluing jig.

→ Polycarbonate components cleaned with isopropanol.

→ Vacuum system to hold the polycarbonate components in position during the glue application.



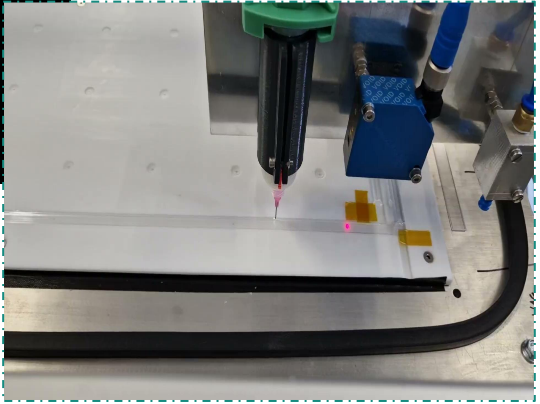
dispensing epoxy glue onto the spacers

2. Applying epoxy glue on polycarbonate parts by using gluing dispenser and X-Y robot.

→ Dynamic glue dispensing parameters to account for the variation in epoxy glue viscosity over time.

→ Room temperature and relative humidity continuously monitored during the gluing phase.

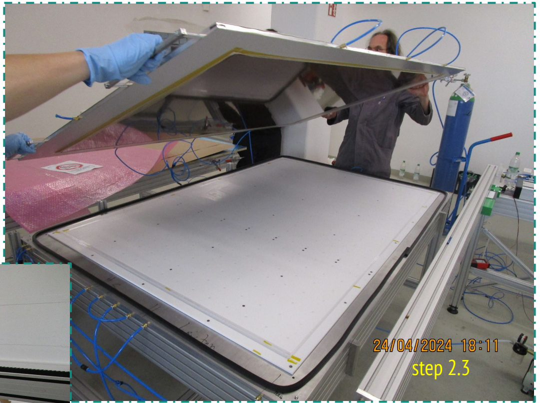
dispensing epoxy glue on the lateral profiles



Assembly procedure for the 1mm-gap RPCs

➢ Production step 2: Gas gap production

3. Placing and aligning the first HPL electrode on the gluing jig with polycarbonate parts and epoxy glue.

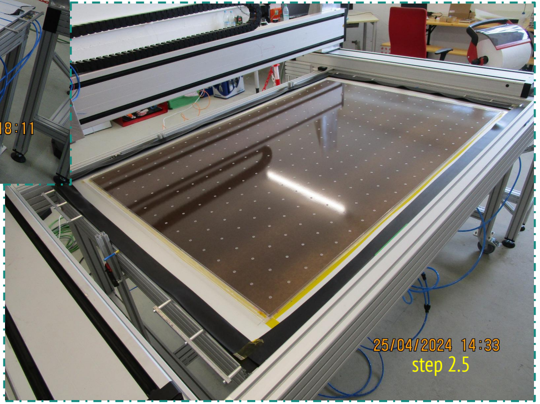


4. Installing the vacuum bagging system for the epoxy glue curing phase.

→ Curing time for the epoxy glue: ~7h at ~20-25 °C.

→ Vacuum level: -200 mbar (i.e. ~ 100 N on each spacer).

5. Removing the first HPL electrode with the glued polycarbonate parts out of the Teflon gluing jig.



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Assembly procedure for the 1mm-gap RPCs

RPC 2024 Santiago de Compostela (Spain)

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➢ Production step 2: Gas gap production

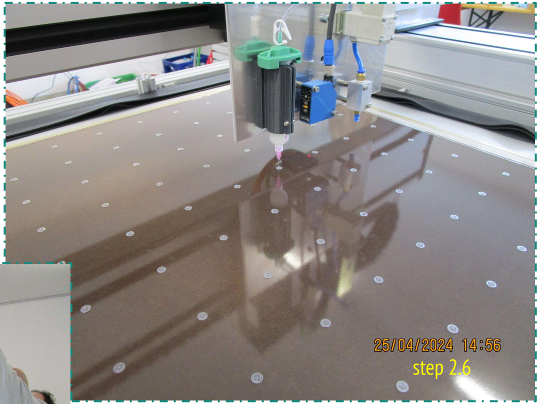
6. Applying epoxy glue on polycarbonate parts glued on the first HPL electrode.

7. Placing and aligning the second HPL electrode on the first HPL electrode.

8. Installing the vacuum bagging system for the epoxy glue curing phase.

→ Curing time for the epoxy glue: ~7h at ~20-25 °C.

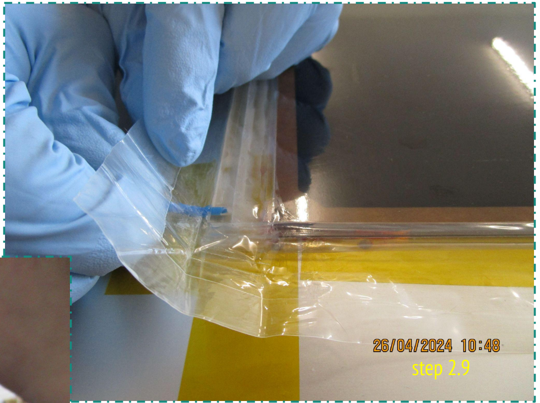
→ Vacuum level: -200 mbar (i.e. ~ 100 N on each spacer).



Assembly procedure for the 1mm-gap RPCs

➢ Production step 2: Gas gap production

9. Installing and gluing the gas pipes into a hole in the lateral profile.

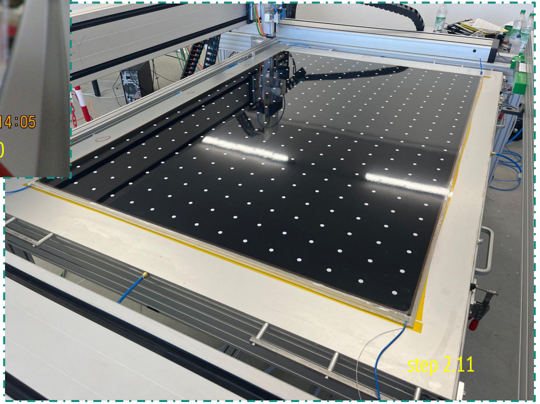


10. Filling and sealing of the long edges of the RPC structure with EVA hot-melt glue.

11. Installation of the spacer indicators on both surfaces of the gas gap.

→ 0.10 mm thick paper stickers, serving as an additional marker of the spacer position.

→ Fully automated stickers application process.



Assembly procedure for the 1mm-gap RPCs

➢ Production s[redacted]

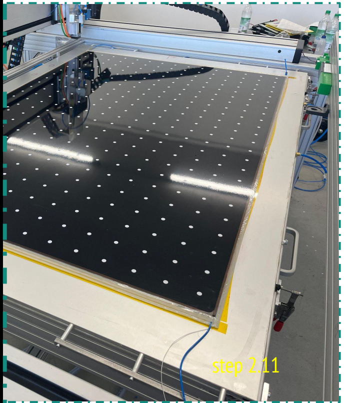
9. Installing and [redacted]
lateral profile[redacted]

10. Filling and se[redacted]
structure with [redacted]

11. Installation of [redacted]
of the gas gap [redacted]

→ 0.10 mm thick [redacted]
marker of the sp[redacted]

→ Fully automated [redacted]

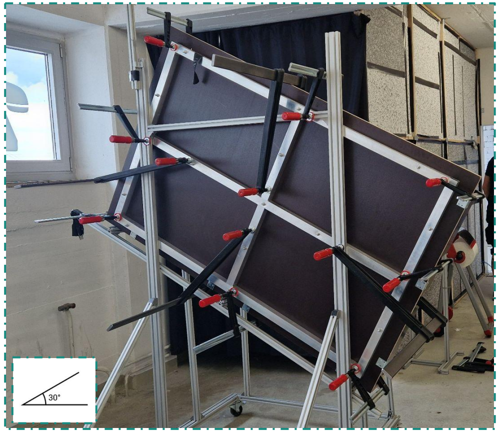


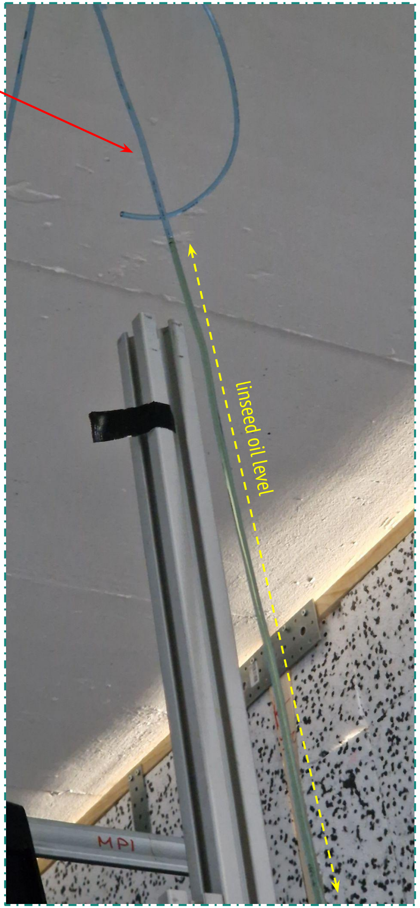
Assembly procedure for the 1mm-gap RPCs

➢ Production step 3: Linseed oil surface treatment

→ The gas gap is filled with a mixture of 30% linseed oil and 70% heptane, introduced through the gas connections from a supply bottle in a temperature-controlled room set at 30°C.

→ The gas seal is compressed between two plates to prevent blowout under oil pressure and is inclined at a 30° angle.





→ The linseed oil is drained slowly (at a rate of less than 1 m/h) while lowering the bottle to ensure an even and smooth coating.

→ Filtered air is circulated through the gas gap for two weeks to ensure the linseed oil fully polymerizes.

Factory Acceptance Tests

An extensive Quality Assurance and Quality Control (QA/QC) program has been established to guarantee high quality and reliability of the gas volume production:

QA/QC step 1: HPL production test

- ➢ Visual inspection of surface, volume resistivity meas., thickness meas.

QA/QC step 2: Electrode production test

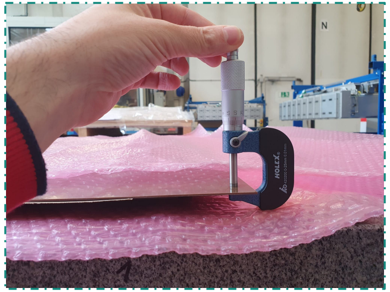
- ➢ Visual inspection and surface resistivity meas. of the graphite coating.
- ➢ Test of absence of bubbles between the insulating PET foil and the graphite coating.

QA/QC step 3: Gas gap production test

- ➢ *... see next slides!*


visual inspection


volume resistivity meas.

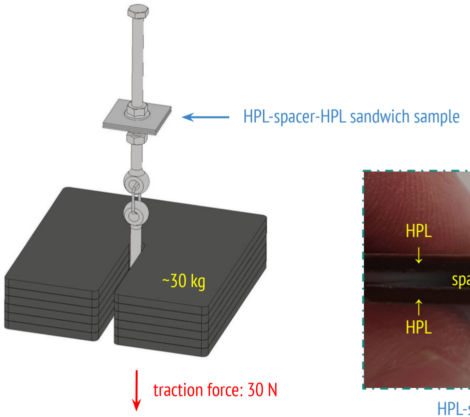

thickness meas.

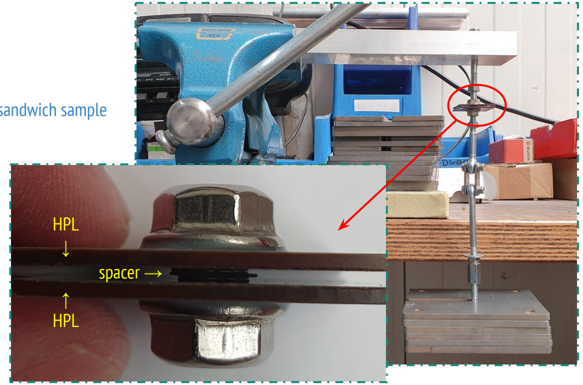
Spacer traction test & Spacer height measurement

Objective:
Ensure the reliability of glued pillars on HPL plates for assembled gas volume.

Methodology:
- ➢ For each gas volume, a 3×3 cm^2 HPL-spacer-HPL sandwich sample is prepared at the end of each gluing phases.
- ➢ A traction force of 30 N is applied to each sample to ensure that no disconnection occurs.
- ➢ If no disconnection occurs at 30 N, the applied force is gradually increased until the pillar breaks.

Analysis:
The breaking point occurs at a traction force $\gtrsim$ 100 N.



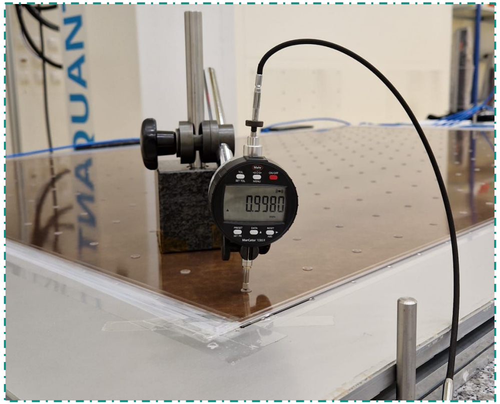


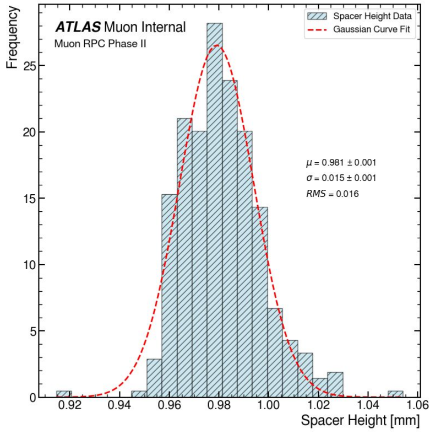
HPL-spacer-HPL sandwich sample

Objective:
Ensure precise compliance with spacer height during the gas gap gluing phase, serving as an indirect verification of accurate gas gap dimensions.

Methodology:
Following the initial gluing step, the spacers remain accessible, allowing for precise measurement of their heights relative to the HPL plate using a digital drop indicator.

Analysis:
All spacer heights are within the 1 mm gas gap specification, with a spread well below 20 µm.





Gas gap mechanical rigidity test

Objective:

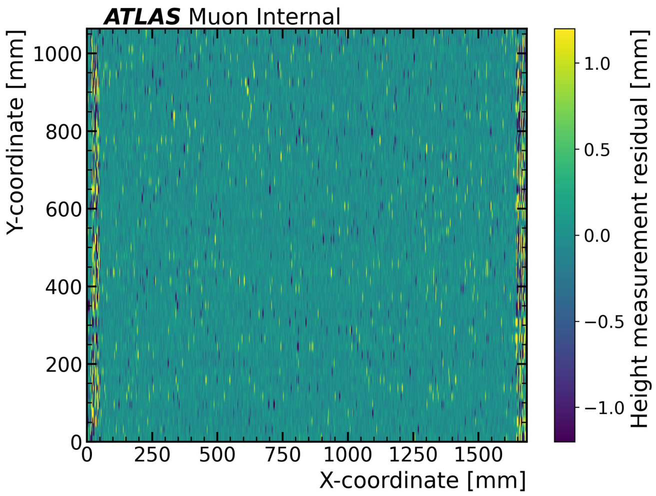
To ensure the integrity of each completely assembled gas volume, it is crucial to detect any popped-up spacers, which may occur due to insufficient adhesive bonding or improper handling during fabrication process.

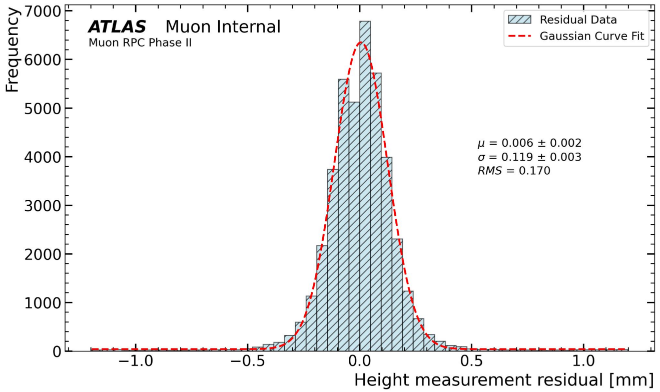
Methodology:

- ➢ **Initial Test** (Atmospheric Pressure): A laser scan planarity test is conducted to assess the flatness of the gas volume at atmospheric pressure.
- ➢ **Pressurized Test** (3 mbar Above Atmospheric Pressure): The gas volume is then pressurized to approximately 3 mbar above atmospheric pressure, and the laser scan is repeated.

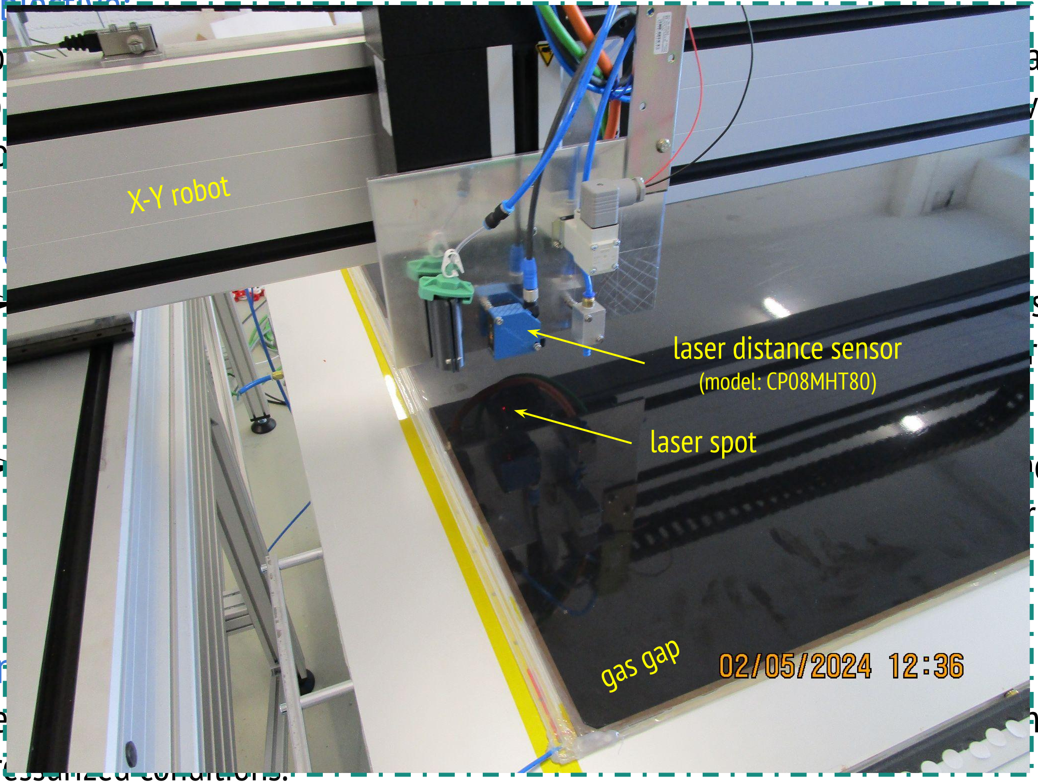
Analysis:

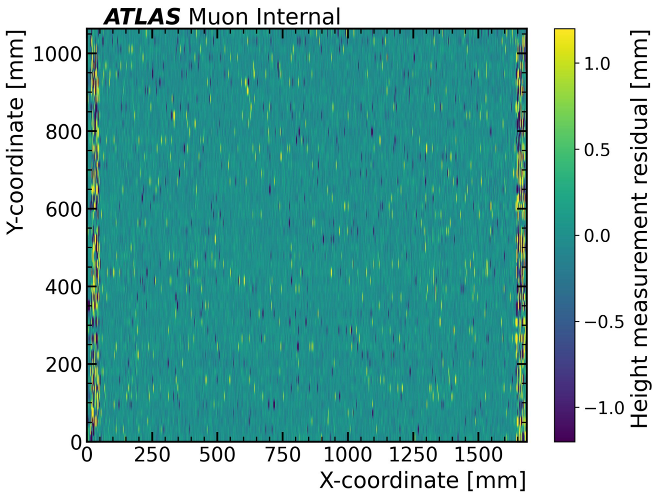
Residuals are calculated by comparing the laser scans at atmospheric and pressurized conditions.

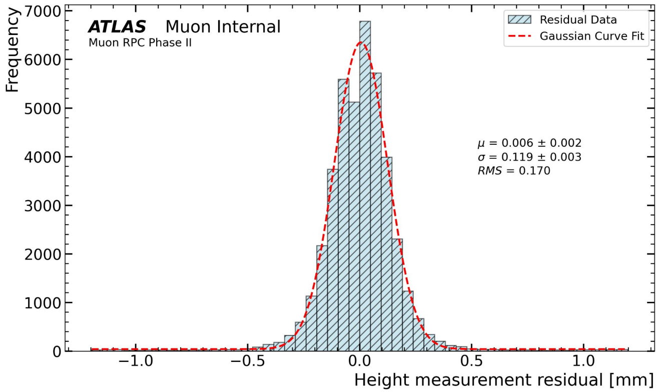




Gas gap mechanical rigidity test







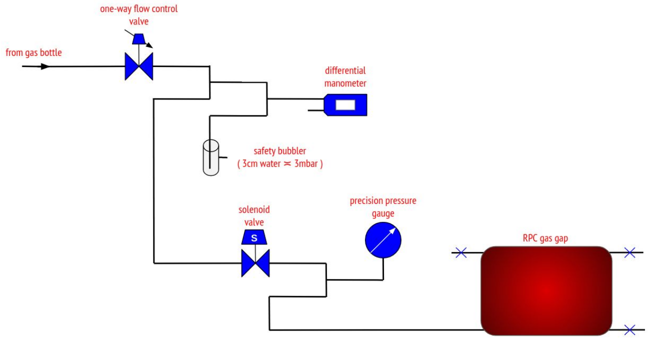
Gas tightness measurement

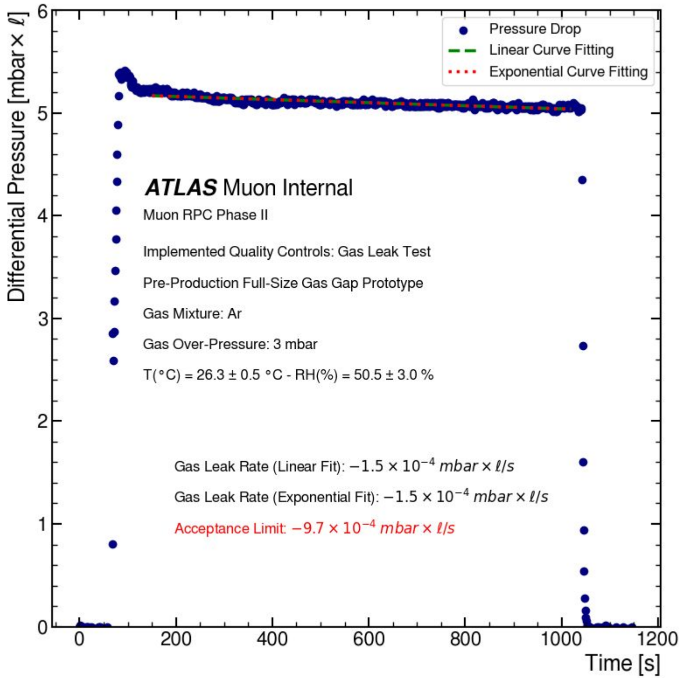
Objective:

Identify the gas leak rate of the gas gap by monitoring the drop of the internal over-pressure as a function of time and check the gas tightness

Methodology:

- ➢ The internal pressure of the gas volume is increased by up to 3 mbar above atmospheric pressure using a controlled gas supply.
- ➢ The internal pressure is monitored for 15 min. after closing the gas volume.





Analysis:

- ➢ The experimental data are modeled using both linear and exponential fits to determine the gas leak rate of the gas volume
- ➢ The gas volume passes the gas tightness test if the gas leak rate of the gas gap + gas system does not exceed: $- 9.7 \times 10^{-4}$ mbar × l / s.

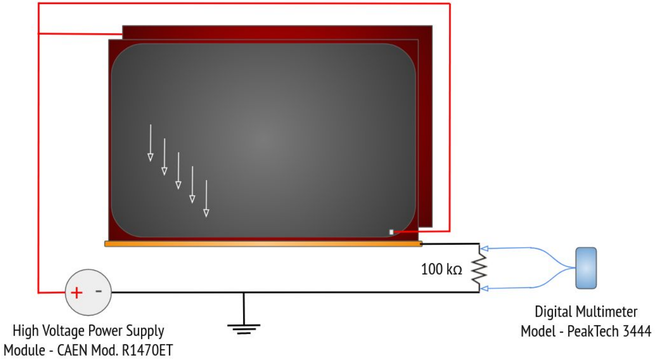
Leakage current measurement

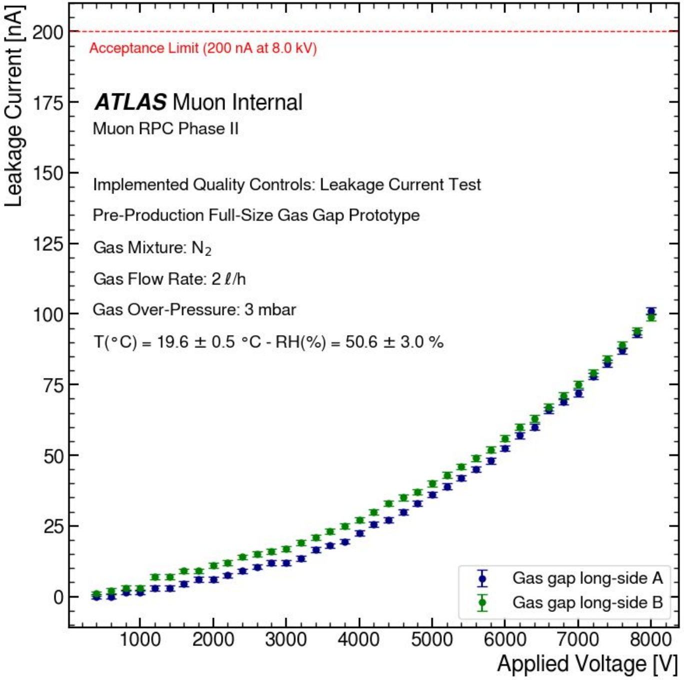
Objective:

Measure the leakage current within the HPL electrodes of the gas volume to ensure proper insulation and minimal leakage.

Methodology:

- ➢ The HPL electrodes are subjected to the same voltage as the HV power supply.
- ➢ A copper-coated aluminum bar, grounded through a 100 kΩ resistor, is brought into contact with the long side of the gas gap under test.
- ➢ The leakage current flow to ground is measured using a digital multimeter, by monitoring the voltage drop across the resistor.





Analysis:

The gas volume passes the leakage current test if the leakage current not exceed 200nA at the maximum applied voltage of 8 kV on both HPL electrode.

Volt-Amperometric characteristic test

Objective:

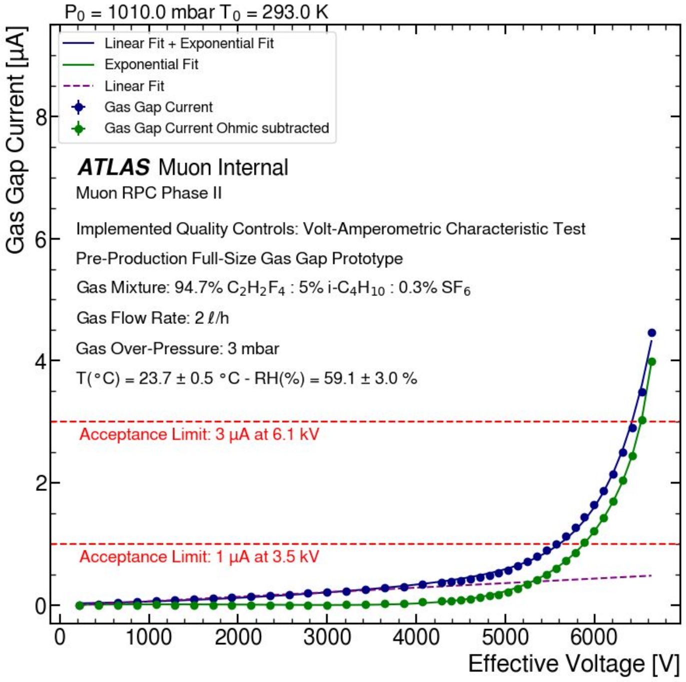
Characterize the gas volume by evaluating the current flow through the gas gap under different voltage conditions with the standard ATLAS gas mixture (94.7% $C_2H_2F_4$: 5% i-C_4H_{10} : 0.3% SF_6).

Methodology:

- ➢ The voltage scan is conducted by gradually increasing the applied voltage in 200 V increments up to 4 kV, followed by 100 V increments up to 6.2 kV.
- ➢ The current flowing through the gas gap is measured via a 100 kΩ resistor connected in series with the device.
- ➢ The applied voltage V_{app} is rescaled to calculate the effective voltage V_{eff} using the equation: $V_{eff} = V_{app} \times (P_0 / P) \times (T / T_0)$, where P_0=1010 mbar and T_0=293 K.

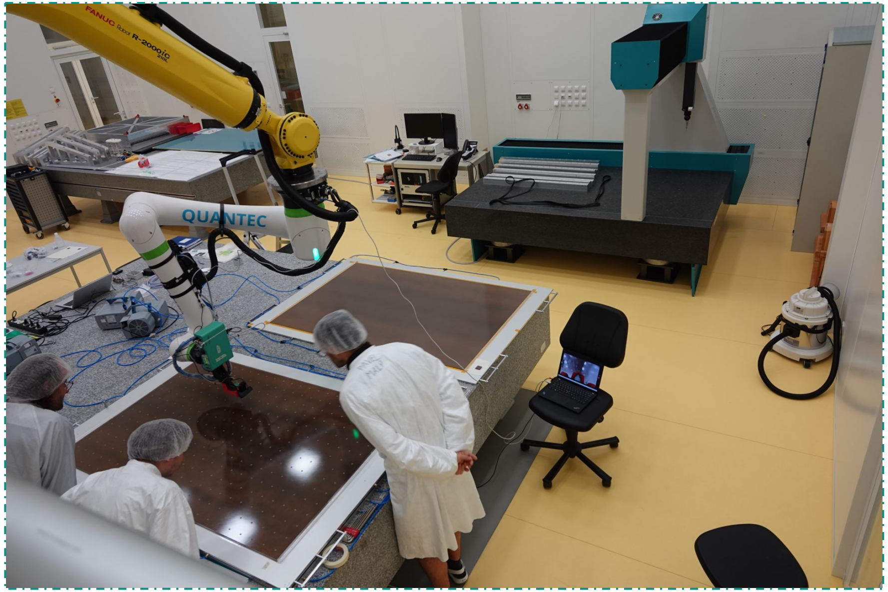
Analysis:

- ➢ Acceptance Limits:
  - ○ Maximum current of 3 μA at 6.1 kV after subtracting ohmic contribution.
  - ○ Maximum current of 1 μA at 3.5 kV.
- ➢ Ohmic contribution is determined using a linear fit in the range [0, 3] kV.



RPC gas gap production facility at MPI

- The gas gap production facility is in full operation in the new clean room of the new MPI building (Garching Research Center).
- The innovative COBOT system permit to automatize the gluing and spacer placement phases during the gas gap assembly.
- The clean room environment is essential for maintaining the high standards of precision and cleanliness required for gas gap assembly.



Conclusion

- ➢ Industrializable manufacturing procedures have been developed for large-scale production of 1mm-gap RPCs for the ATLAS muon spectrometer upgrade.
- ➢ Certification of the new manufactures has been successfully carried out with the production of small-scale prototype using procedures scalable to standard full-size prototypes.
- ➢ To date, five large-scale RPC detector prototypes have been successfully assembled and certified: two at MIRION, two at PTS, and one at MPI.
- ➢ Small-sample RPCs from two German companies successfully meet the stringent ATLAS requirements after extensive performance studies with muon beams and γ - background.
- ➢ A longevity test campaign at CERN GIF++ facility is planned on both small- and real-scale RPC detector prototype to qualify the German companies for final large-scale production.
- ➢ Large-scale production of RPC gas gaps is scheduled to begin in early 2025.
- ➢ Our new RPC production and certification facilities will not only support the ATLAS upgrade but also provide capabilities for future applications leveraging RPC detector technology.

BACKUP SLIDES

Francesco Fallavollita on behalf of the
ATLAS Muon Collaboration

XVII international Conference on
Resistive Plate Chambers and Related Detectors

Santiago de Compostela - 9th to 13th September

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

MAX-PLANCK-GESELLSCHAFT

Spacer traction test & Spacer height measurement

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Method

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Analysis

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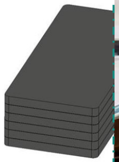
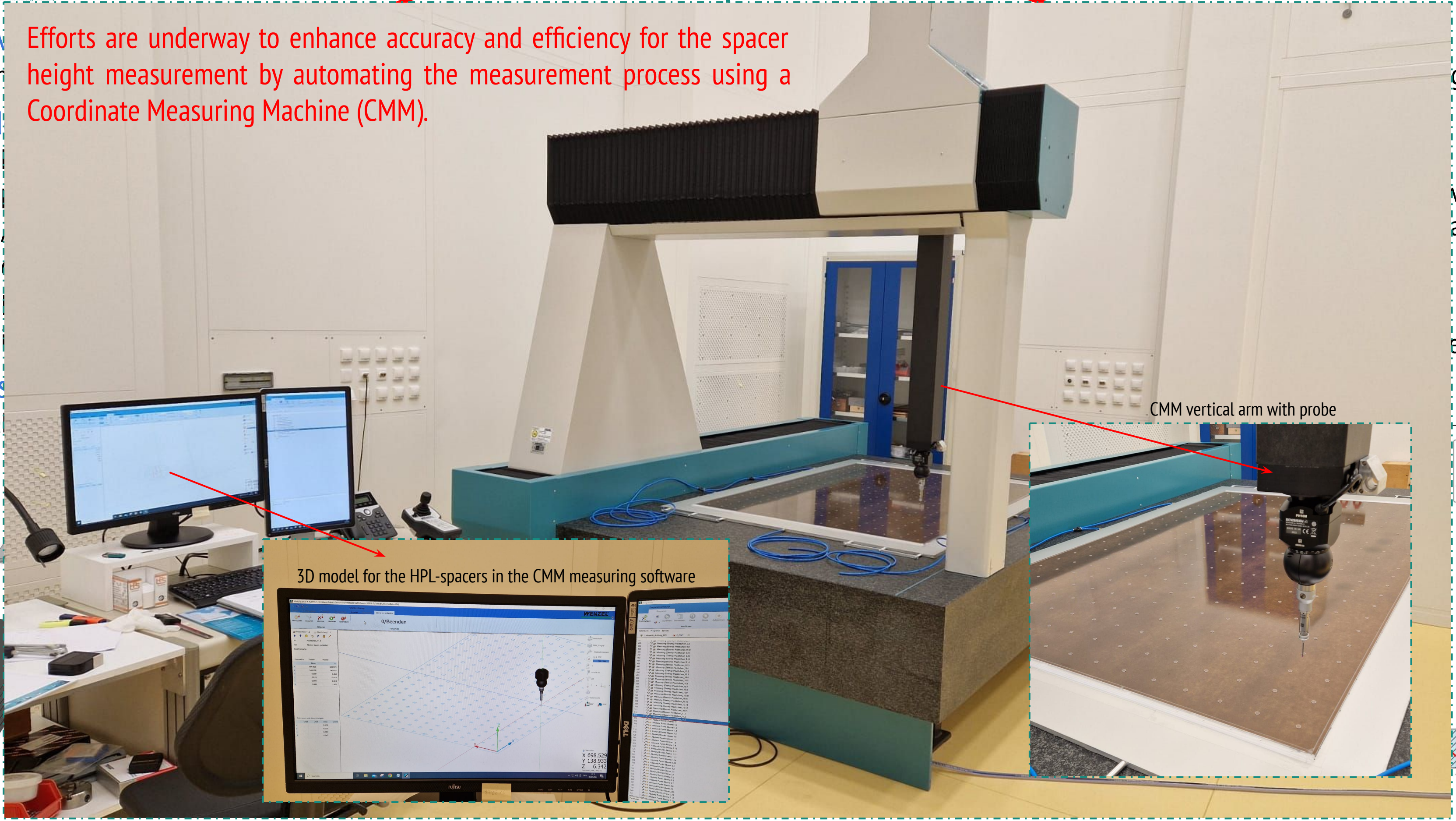
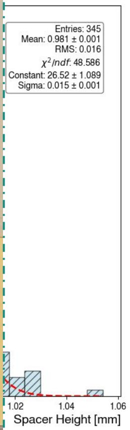


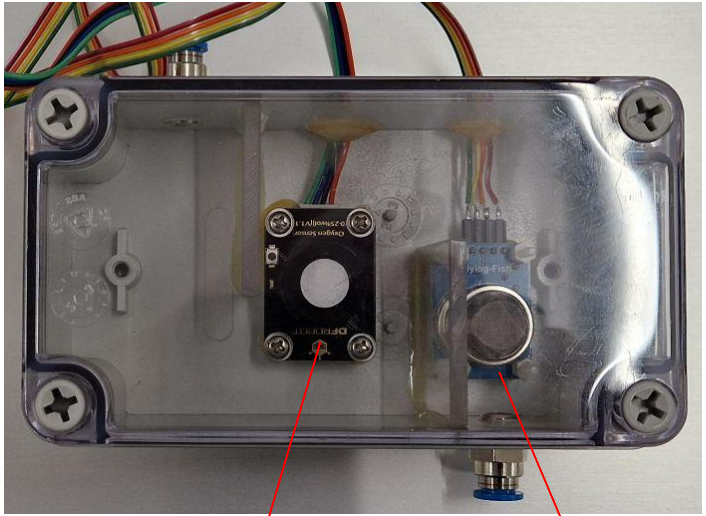




Monitoring of the linseed oil polymerization

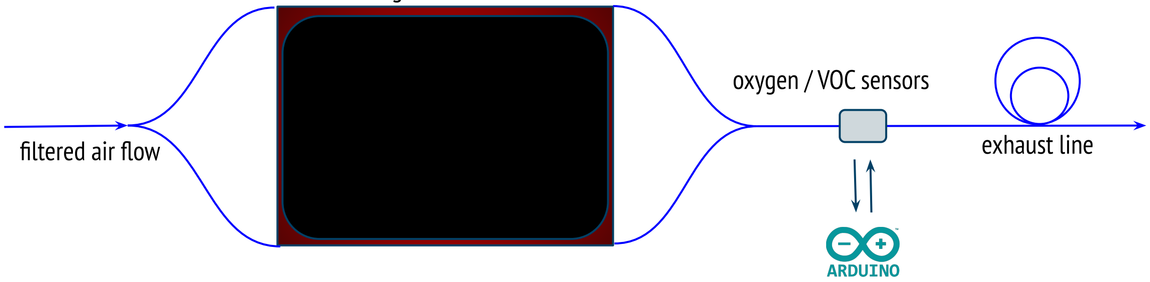
Objective:

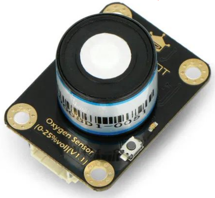
Continuously monitor the polymerization process of linseed oil to ensure optimal curing, while maintaining the highest quality and durability of the linseed oil coating applied to the internal surface of the gas volume.



Methodology:

- An oxygen sensor and VOC (Volatile Organic Compounds) sensor are connected to the exhaust line of the gas volume after the linseed oil treatment to continuously monitor the polymerization status.
- The sensors are monitored through an Arduino interface.





Oxygen sensor
(model: SEN0322)

VOC sensor
(model: MQ-135)

Linseed oil coating test

Objective:

Ensure the high quality and durability of the linseed oil coating applied to the internal surfaces of the gas volume.

Methodology:

- ➢ A small mock-up gas volume is connected to the exhaust line of a randomly selected real-scale gas volume, downstream of the drying air flow, for each oiling batch.
- ➢ The mock-up is subjected to the same oiling and drying procedures as the real-scale gas volume.
- ➢ Post-drying, the mock-up is inspected for scratch resistance using the following procedure:
  - A 10 mm wide blade, held at a 45° angle, is applied to the surface with a 1 N force.
  - The blade must scrape across a 100 mm length of the surface.

Analysis:

The test is considered successful if:

- ➢ No oil residue remains on the blade after scraping.
- ➢ The scraped surface shows no visible marks or damage, indicating effective curing and high-quality oiling.