Methods used for Gas Tightness Test and percent Oxygen Monitoring of the NSW Micromegas Detectors of LHC-ATLAS Experiment

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Outline

- **ATLAS Upgrade NSW - Gas system for Micromegas Wedges**
- Baseline gas tightness method and validation stages
- Overall results of the Micromegas Quads
- Oxygen impact and percent oxygen monitoring
- Conclusions
ATLAS UPGRADE NSW
GAS SYSTEM FOR MICROMEGAS WEDGES
Overview of gas system of NSW at Lab in B.191

Gas supply: Argon + 7% CO₂
Nominal flow rate per gas channel: 20.8 L/h
Flow rate at “Operation”: 20-25 L/h
Flow rate at “Standby”: 10-15 L/h
Average static pressure in the MM: 3 mbar
Nominal pressure in the MM input: >10 mbar
Nominal pressure in the MM output: <5 mbar
Maximum input pressure in the Mixer: 1.5 bar
Maximum level at input safety bubbler: 55 cm
Maximum level at output safety bubbler: 6.3 cm
Level at exhaust bubbler: 3.8 cm
Impedances in Small Wedges: ZSM-370-10800
Impedances in Large Wedges: ZLM-420-12000
Impedances in the “TM”: 2xZTM13 + 1xZTM13

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Gas system of the NSW Micromegas wedges

- 16 gas channels of mixture Ar+7% CO₂ are used for each NSW
- Each channel provides gas either for two LM wedges or for two SM wedges
- The gas inlet comes from the outer rim and the gas outlet goes to the inner rim.

Reference
ATL-COM-MUON-2015-043
BASELINE GAS TIGHTNESS METHOD AND VALIDATION STAGES
The basics of the Flow Rate Loss (FRL) method

- Based on mass concentration principle along a gas leaking branch:

\[ \dot{m}_1 = \dot{m}_2 + \dot{m}_L \Rightarrow \rho Q_1 = \rho Q_2 + \rho_o Q_L \]

\[ Q_L = \frac{\rho}{\rho_o} (Q_1 - Q_2) = Q_{1,0} - Q_{2,0} = c \Delta V_L^{\text{net}} \text{ [mL/h]} \]

where \( \Delta V_L^{\text{net}} \text{ [mV]} \), \( c \approx 3.4 \text{ mL h}^{-1} \cdot \text{mV}^{-1} \) at NC: 25 °C, P=1.013 bar

- No need to know the volume under test (spacer frame, MM quads or wedges)

- Insensitive to temperature variations

- Advantage in the analysis: the measuring quantity is a constant differential signal, not a rate, as in the pressure decay method.

References

- ATL-COM-MUON-2017-054
- ATL-COM-MUON-2017-004
- ATL-COM-MUON-2018-094
In all the stages below, the baseline gas leak test method is the Flow Rate Loss (FRL), introduced by our HEP team since 2015. In total 9 equipments have been assembled and used in different setup variants.

- **0\(^{th}\) stage**: gas leak test of the piping of the Spacer Frames.
- **1\(^{st}\) stage**: gas leak test of the received MM Quads with air – up to 4 Quads at the same time.
- **2\(^{nd}\) stage**: gas leak validation of the integrated single or double wedges with Ar+7%CO\(_2\).
- **3\(^{rd}\) stage**: gas tightness validation of wedges in NSW (B. 191) with Ar+7%CO\(_2\). (is done by the same method to the installed Wedges in each side IP and HO)
The instrument is a “briefcase” portable setup GLT operating at higher pressures with air, providing a sensitivity corresponding to about 1/500 of the nominal tightness of a Quad.

- Maximum regulated gauge pressure: \( p = 150 \text{ mbar} \)
- Testing time: \( \sim 15 \text{ min} \)
By the Gas Tightness Station 4 Micromegas Quads can be tested at the same time. The monitoring is performed by using Arduino + 16-Bit ADC recorded by WinCC-OA by using a dedicated software control panel.
Obtained leak rate of LM2-M38: $Q_L = 40.3 \pm 0.5$ (stat.) $\pm 2$ (syst.) mL/h (x1.10 ATLAS limit)

In case of very low $Q_L$ (close to the theoretically feasible limit) the two Gaussians should be overlapped.
2nd STAGE: gas tightness of integrated wedges

- We use either a “briefcase” portable setup + WinCC monitoring or compact multifunction SA-GLT instruments (Arduino+16-Bit ADC+LCD display+specific code).

- In the photo, the IP side of an integrated MM double wedge is under test by using the SA-GLT-1 equipment.
SA-GLT-1 & 2 are prototype instruments designed in NTUA

The functional drawing of a Stand-Alone and Multifunction Gas Leak Tester based on FRL method.
More details regarding the SA-GLT configuration

The stand alone - multifunction high accuracy device based on Arduino microcontroller with 4 channels 16-bit ADC and LCD display (providing 4 2/3 displayable significant digits).
OVERALL RESULTS OF THE MICROMEGAS QUADS
In total, 137 Micromegas Quads have been tested and validated since January 2019.
The theoretical – feasible limit was determined before the production started and was: $x (0.11 \pm 0.03)$ A.L.
Individual distributions

LM1 - construction site in France

SM1 - construction site in Italy

LM2 - constr. site in Greece, Russia, CERN

SM2 - construction site in Germany

| Class   | Frequency | Mean (A.L) | RMS (A.L) |
|---------|-----------|------------|-----------|
| LM1     |           | 3.3        | 3.09      |
| SM1     |           | 1.55       | 1.33      |
| LM2     |           | 1.29       | 1.02      |
| SM2     |           | 1.64       | 1.24      |
Interpretation of the obtained distribution

- The Gamma distribution has been “tuned” to the calculated overall mean and variance of $Q_L$.
- Moreover, it is the “maximum entropy probability distribution” with minimum information (if nothing is known about the distribution under study).
- Median=$x_{1.3}$ A.L.
- Probability to obtain $Q_L < x_{1}$ A.L. = 41.8%

* Histogram of the residuals using the Gamma distribution. For the “$\chi^2$ goodness of the fit” we have obtained, $\chi^2/\nu=0.68$, where the extreme data point at bin 14 was excluded as an “outliner”. It concerns a potentially defective Quad.

Parameterized “Gamma” distribution by setting shape=0.914, scale=2.13
OXYGEN IMPACT AND
PERCENT OXYGEN MONITORING
The impact of oxygen contamination in MM Detectors

• Because the oxygen is an electronegative gas, its contamination in the gas mixture Ar+7% CO₂ causes a drop-off of the Mesh transparency and the gas amplification of a Micromegas layer.

• A detailed simulation has been performed by the well-known and widely used tool-kit for the simulation of particle detectors which is the Garfield++.

• The program is interfaced to applications like, ``ElmerFEM'' for the precise calculation of the electric fields, ``Magboltz'' for the definition of the electron transport parameters and the ``gmsh'' for describing the geometry of the detector.
This technique is based on low cost Oxygen Probe Analyzer (from AMI) operating at continuous gas flow. A custom made configuration at low full scale (1% in our case) is a great advantage.
Indirect calibration of OPA sensor

Trapped air (2.0 mL)

Ar+air

Trapped air (2.0 mL)

Argon

V_A

V_A'

V_B

QPA#1
• The voltage output pulse constitutes a Transient State Flow (TSF) signal when the 2 mL air volume passes through the OPA. By integrating this signal pulse we can calibrate its sensor.

• A Steady State Flow (SSF) signal can be recorded by using a constant flow of gas under study. A direct calibration of an OPA was performed by using a bottle containing Ar+1%O₂.

\[ V_x = \int_0^{t_s} x_n(t)Q \, dt = Q \int_0^{t_s} x_n(t) \, dt = QI \]

The pulse can be fitted by a semi-gaussian function (n=3 is optimal)

\[ v(t) = At^n e^{-t/\tau} \]

\[ I = An!\tau^{n+1} = A\Gamma(n+1)\tau^{n+1} \]
Percent oxygen monitoring at CERN using OPA

**OPA-1 (B. 191 - NSW).**
- Preliminary value obtained for a S. Wedge:
  - Percent Oxygen = 0.278%
  - Percent air = 1.337%
  - Renewals = 0.24 d⁻¹

**OPA-2 (GIF++ - SPS).**
- Preliminary value obtained for a Quad:
  - Percent Oxygen = 0.134%
  - Percent air = 0.640%
  - Renewals = 0.91 d⁻¹

**OPA-3 (BB5 - CRS).**
- Preliminary value obtained for a D. Wedge:
  - Percent Oxygen = 0.182%
  - Percent air = 0.869%
  - Renewals = 0.33 d⁻¹

The voltage output is recorded by 16-bit ADC and Arduino Mega 2560, converted to percent oxygen taking into account the offset of the sensor in Ar+CO₂ or pure argon.
Preliminary prediction model

\[ y = 0.432 e^{-1.286x} \]

Percentage oxygen \( x \) [%]

Renewals \( R [h^{-1}] \)
Impact of the air (oxygen) to the “mesh transparency”

The mesh transparency plot was produced by simulations using “Garfield++” and assuming detector gas the Argon+7%CO$_2$ mixture [C. Kitsaki, Dipl. Thesis in NTUA]
Conclusions

- Several projects regarding the Micromegas New Small Wheels and the Wedges gas system, we have developed during last 6 years.

- For the gas tightness of the Micromegas Quads and Wedges, we have introduced novel methods and instruments and we have performed the required validation tests during the integration and commissioning.

- The overall-final statistical distribution of the Micromegas Quad leak rate shows a Gamma distribution shape.

- By a precise and low cost percent oxygen monitoring technique can conclude regarding the drop-off level of the performance of the Micromegas Wedges.