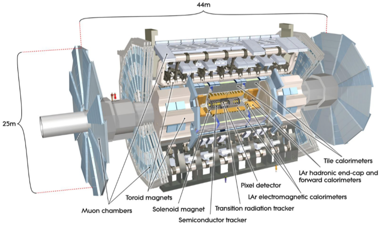
National Technical University of Athens
Department of Physics
Laboratory of Experimental High Energy Physics

Gas Leak Test System for the Micromegas Detectors Validation for the New Small Wheel Upgrade Project of ATLAS Experiment

T. Alexopoulos, A. Koulouris, S. Maltezos, D. Matakias, P. Tzanis

Recent Developments in High Energy Physics and Cosmology
Athens 30th March, 2018

ATLAS Experiment

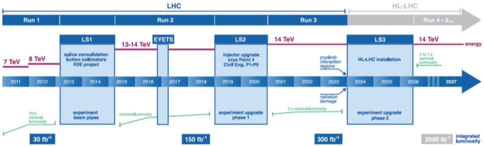


The main subsystems of ATLAS are:

- Magnet System
- Inner Detector
- Calorimeters
- Muon Spectometer

High Luminosity LHC

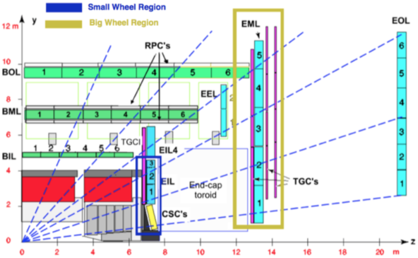
The transition from the LHC to HL-LHC will take place during LS3, with more than $3000\,\mathrm{fb}^{-1}$ of data expected to be delivered during Run-3. The harsh HL-LHC environment will be extremely challenging for the experiments with expected maximum peak luminosisities of the order of $\mathcal{L} = 7 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for the ATLAS experiment. In order to maintain its current excellent performance and to cope with the corresponding increase in the particle rate that is expected, the ATLAS detector will be upgraded in two steps: Phase-I in the LHC shutdown 2018/19 and Phase-2 in 2023-2025.

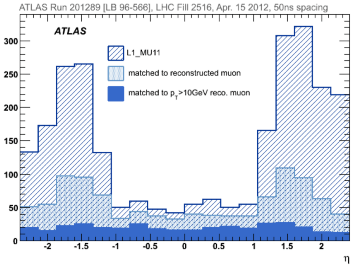


Motivation for the Small Wheel Upgrade

The largest of the ATLAS Phase-1 upgrades focuses on the inner end-cap region of the muon spectometer, the so-called Small Wheel that is composed of CSC, MDT & TGC detectors. At the high luminosity foreseen after LS2 the following two points are of particular importance for the ATLAS muon system:

- The performance of the muon tracking chambers (MDT & CSC), efficiency and spatial resolution, significantly degrades with the expected increase of cavern background rate.
- The Level-1 muon trigger in the end-cap region is eight to nine times higher that in the barrel region due to low energy particles generated between the SW and the EM station.

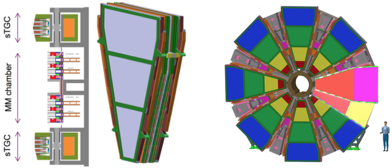




Detector Technologies

The NSW system will combine two detector technologies:

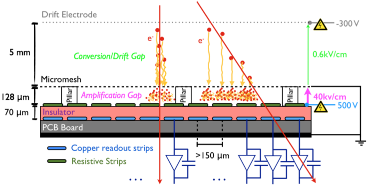
- small-strip Thin Gap Chamber
- Micromegas



8 MM and 8 sTGC layers per NSW sector

Micromegas Detector

A Micro-Pattern Gaseous Detector with 2 asymmetric E-field regions, separated by a metallic micromesh.



Main characteristics:

- Drift Gap (5 mm), $E_{\mathrm{drift}} \simeq 0.6\,\mathrm{kV/cm}$
- Amplification Gap (128 μm), $E_{\mathrm{amp}} \simeq 39\,\mathrm{kV/cm}$
- Spatial resolution: $\sim 60\,\mu m$
- Gas mixture: Ar : CO_2(93 : 7), gain $\sim 10^4$

- e^- drifts towards the mesh (95% transparent) in $\sim$ 100 ns
- Avalanche formation in the amplification region (1 ns) with fast ion evacuation ($\sim$ 200 ns)

2 NSW $\Rightarrow$ 2$\times$16 Sector$\Rightarrow$2$\times$16$\times$2 MM QPs $\Rightarrow$ 64 MM QPs (LM1,LM2,SM1,SM2)

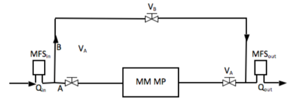
According to the ideal gas law ($pV = nRT$), in the gases as compressible fluids, their volume is related to the pressure for constant temperature and quantity of substance n. Definition of gas leak is based on the mass flow expressed as:

$$Q_L = \frac{\mathrm{d}(pV)}{\mathrm{d}t} = p\frac{\mathrm{d}V}{\mathrm{d}t} + V\frac{\mathrm{d}p}{\mathrm{d}t} = RT\frac{\mathrm{d}n}{\mathrm{d}t}$$

Flow Rate Loss (FRL) - (p constant)

Gas leak expressed by flow rate loss in L/h:

$$Q_L = p_0\frac{\mathrm{d}V}{\mathrm{d}t}$$



The obtained leak rate loss is:

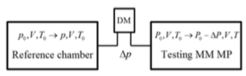
$$Q_L = \frac{1}{b}\left(\Delta V_0^A - \Delta V_0^B\right)$$

Direct differential measurement

Pressure Drop Rate (PDR) (V and T constant)

Gas leak expressed by pressure drop rate:

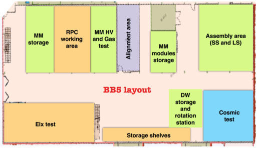
$$Q_L = \frac{\Delta P \cdot V}{t}$$



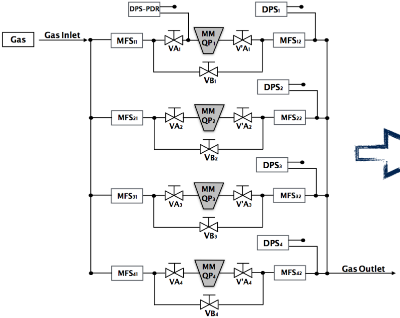
Cons:

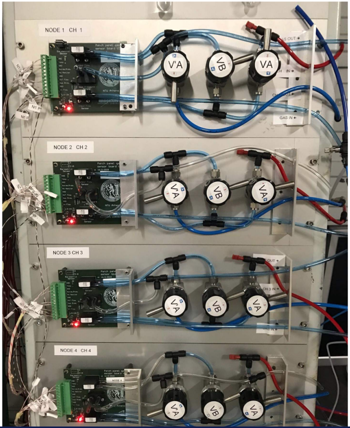
- Model uncertainty
- Temperature compensation
- Volume compliance

The need to control the tightness of MM QPs prior to installation in NSW led to the development of the 4MM QPs composite experimental setup.



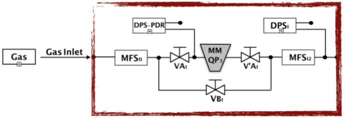
Setup overview (M4 Patch panel setup in parallel configuration for the gas leak measurements)

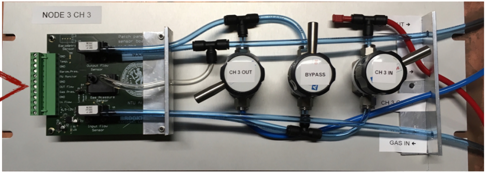


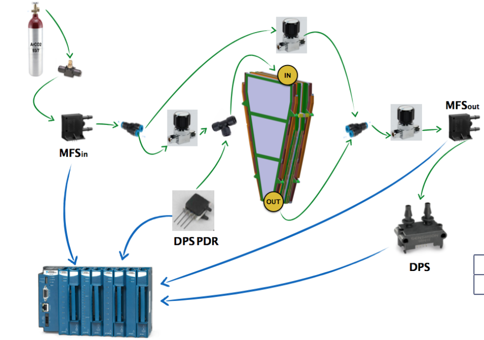


GTS Node

Patch panel with gas sensor board has been constructed per node/chamber.







- Gas mixture Ar : CO_2 (93 : 7)
- 3 high-tightness on-off valves
- 2 Mass flow sensors
- 2 Differential pressure sensors
- 1 Temperature sensor
- 1 16-bit ADC

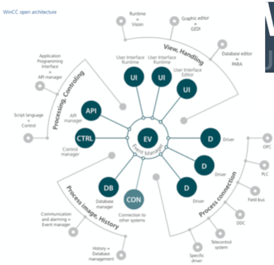
MFS	DPS	TS(REF)	DPS(REF)	Total
$8(2 \times 4)$	$4(1 \times 4)$	1	1	14

Supports gas leak measurement of 4 MM QPs simultaneously using FRL and PDR.

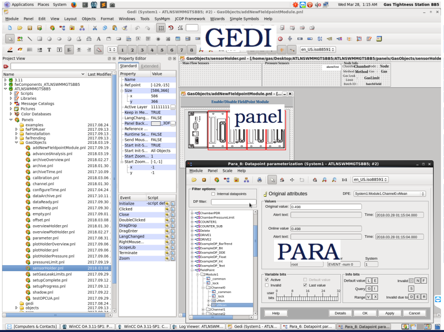
WinCC-OA

GTS developed by Siemens WinCC-OA SCADA software.
Main features:

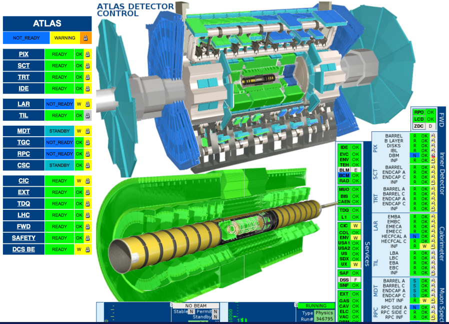
- Scalability (distributed system)
- Hardware connection (OPC, Modbus, etc)
- Operating Systems (Windows, Linux)
- User interface design (GEDI, PARA)
- Manager CTRL (C) and API
- Archive and database managers



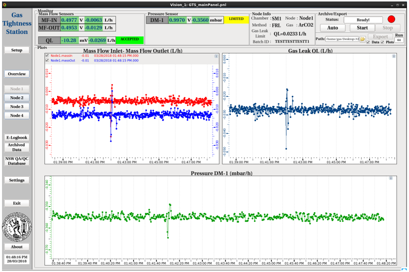
Panel connection with DPEs

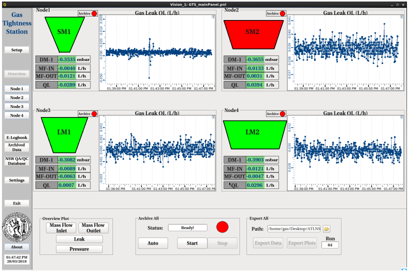


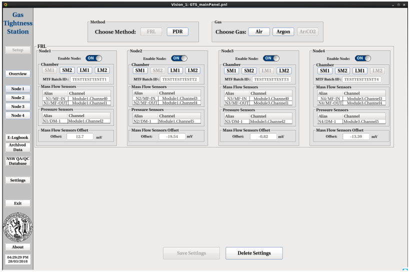
ATLAS Detector Control System



GTS Software



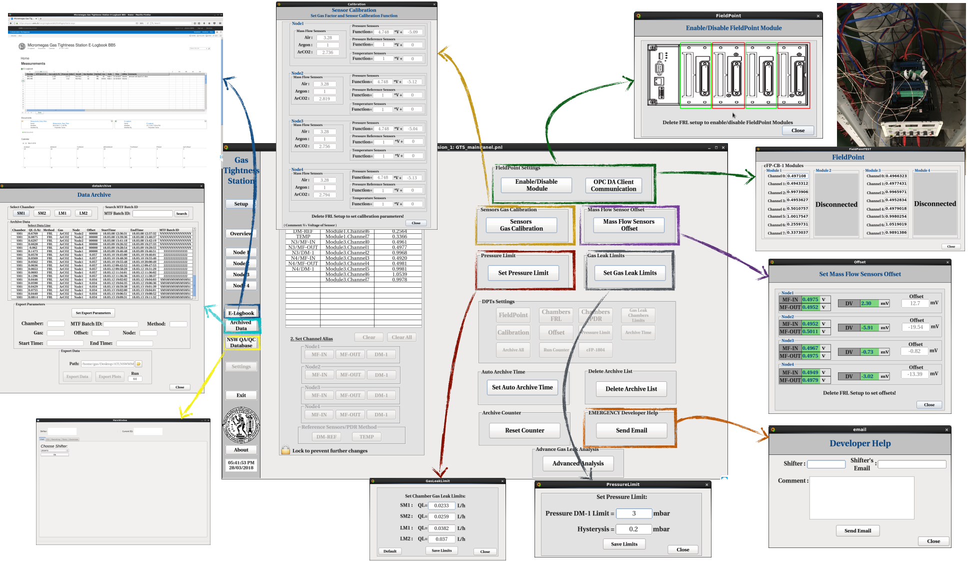




Supports:

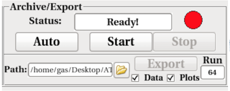
- FRL/PDR methods for Air/Ar:CO2
- Monitor and trending (1&4)
- Alarm handling (gas leak & pressure)
- Archive/Export of sensor's data (1&4)
- Archived data DB (local & online)
- NSW Oracle DB access
- Settings (calibration, offset, limits etc.)
- Automatic advanced analysis using ROOT Data Analysis Framework

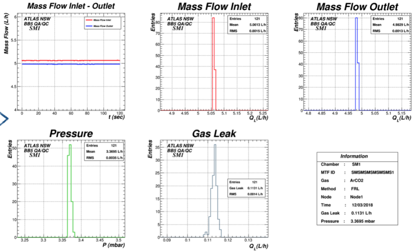
GTS Settings



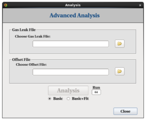
GTS Analysis techniques

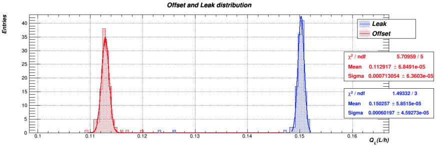
Quick analysis plots





Advanced analysis



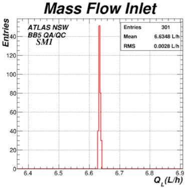


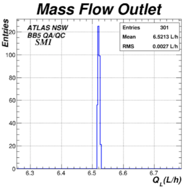
Results

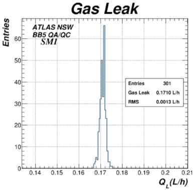
Chamber : SM1
MTF ID : SMSMSMSMSMSMS1
Gas : ArCO2
Method : FRL
Node : Node1
Time : 13/03/2018
Gas Leak : 0.0373 L/h
Statistical Error : 0.0001 L/h
Systematic Error : 0.0019 L/h
Pressure : 3.062 mbar

GTS detection limit

Checking the flow rate distribution in by-pass mode (zero leakage).





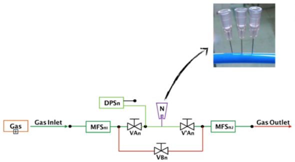


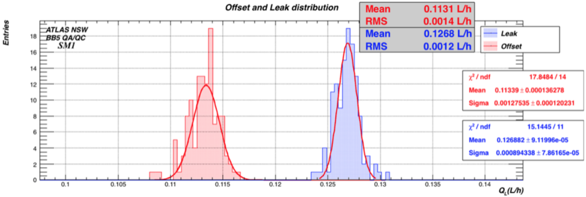
- Fluctuations represent the MFS's repeatability
- $RMS_{in} = 2.8\,\mathrm{mL/h}$, $RMS_{out} = 2.7\,\mathrm{mL/h}$

$RMS_{gl} = 1.3\,\mathrm{mL/h} \Rightarrow FWHM = 3\,\mathrm{mL/h} \Rightarrow$ setup detection limit

GTS calibration

Hypodermic needles to create gas leakage (e.g. 32G $D = 105\,\mu$m)



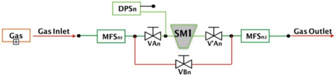


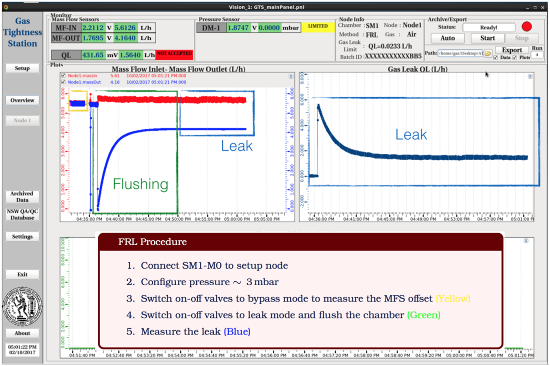
$\Rightarrow$Automatic advanced analysis with double Gaussian fittings

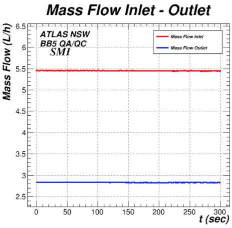
$\boxed{Leak\ rate\ Q_L = 13.7 \pm 0.2(stat) \pm 0.07(syst)\,\mathrm{mL/h}} \sim 1/2\ limit\ of\ SM\ QPs$

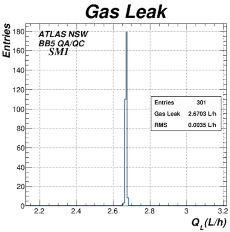
(MM QPs limits: $SM1 = 0.0233\,\mathrm{L/h}$, $SM2 = 0.0259\,\mathrm{L/h}$, $LM1 = 0.0384\,\mathrm{L/h}$, $LM2 = 0.0370\,\mathrm{L/h}$)

SM1-M0 gas leak measurement









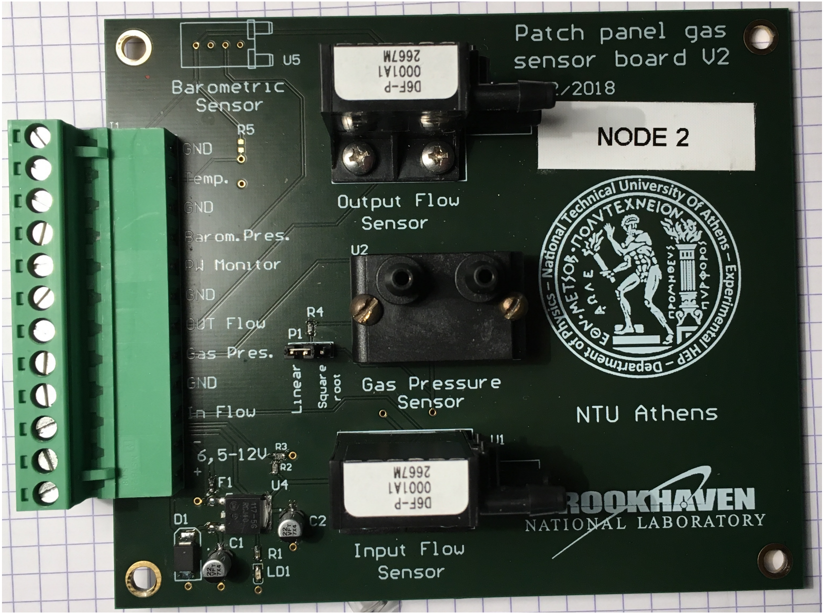
$$\boxed{Q_L = 2.580 \pm 0.003\,\mathrm{L/h}}$$

$\sim$ 10$\times$ SM1's limit

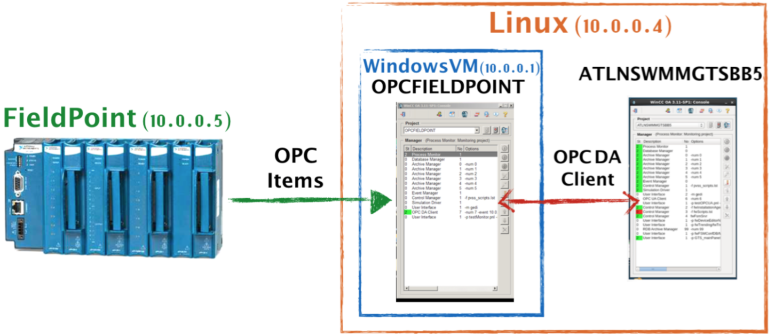
(Not Pass QA/QC)

- Full understanding of the model of gas leakage from the theoretical and experimental study
- Study and development of a prototype setup for the measurement of gas leakage using the FRL method and calibration of sensors using medical needles
- Construction of an experimental setup for the gas tightness of the NSW MM QPs at BB5 laboratory
- Development of the Automated Gas Tightness Station control, monitor and archiving software for the QA/QC tests
- Implementing automatic analysis methods into the GTS software and listing the results in the NSW QA/QC Database
- **Development and construction of a fully operation experimental setup and stable software to measure the gas tightness of various gas detectors using FRL and PDR methods**

Back Up



Patch panel gas sensor board V2
NODE 2
U5
Barometric Sensor
R5
GND
Temp.
GND
Barom.Pres.
PW Monitor
GND
OUT Flow
Gas Pres.
GND
In Flow
6,5-12V
R3
R2
F1
U4
D1
C1
C2
R1
LD1
Output Flow Sensor
U2
R4
P1
Linear
Square root
Gas Pressure Sensor
U1
Input Flow Sensor
NTU Athens
National Technical University Of Athens – Experimental HEP – Department of Physics
NATIONAL LABORATORY


FieldPoint (10.0.0.5)
OPC Items
Linux (10.0.0.4)
WindowsVM (10.0.0.1)
OPCFIELDPOINT
OPC DA Client
ATLNSWMMGTSBB5

Back Up

2.3 “Volume compliance” effect in the PDR method

If a testing chamber has a degree of elasticity, that is after pressurization it appears to have a slight expansion. In this case the PDR method becomes noticeably risking for the measured leak rate. This can be explained based on the Ideal Gas Law:

$$-P_0 Q_L = \frac{\mathrm{d}(pV)}{\mathrm{d}t} = V_0 \frac{\mathrm{d}p}{\mathrm{d}t} + P_0 \frac{\mathrm{d}V}{\mathrm{d}t} \tag{23}$$

In Eq. 1 we can use the quantity “volume compliance” defined as, $c_v = \mathrm{d}V/\mathrm{d}t$. But it should be more practical to normalize it in order to be dimensionless and thus measuring relative quantities. This can be done defining, c, (where $0 \le c \le 1$)in the following way:

$$c = \frac{\mathrm{d}p/P_0}{\mathrm{d}V/V_0} \tag{24}$$

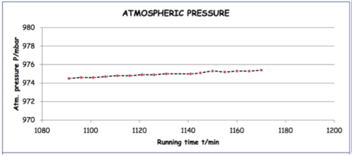
From Eq. (23) and (24) we obtain:

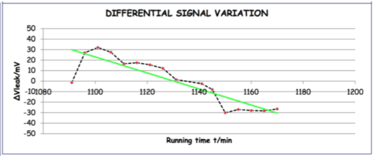
$$-P_0 Q_L = V_0 (1 + c) \frac{\mathrm{d}p}{\mathrm{d}t} \tag{25}$$

or

$$\frac{V_0}{P_0} \frac{\mathrm{d}p}{\mathrm{d}t} = -\frac{Q_L}{(1 + c)} \tag{26}$$

From Eq. (26) we conclude that the pressure drop rate is much lower for a given leak rate by a factor $1/(1 + c)$ which varies in the range $[0, 1)$. Let us now correlate the compliance with the Young’ s modulus, E. According to the definition of c we have, $c = P_0/E$.





Βαθμονόμηση

Για την μέτρηση του ρυθμού διαρροής αερίου με την μέθοδο FRL, αναγκαία είναι η βαθμονόμηση των αισθητήρων ροής μάζας (MFS). Η συνοπτική διαδικασία μέτρησης του παράγοντα $\mathrm{F_{gas}}$ περιλαμβάνει τα εξής βήματα:

- Τοποθέτηση της ιατρικής βελόνας στο κλάδο διαρροής της πειραματικής διάταξης
- Μέτρηση του offset ΔV_{air}^{tare} και της διαρροής ΔV_{air} μέσω των αισθητήρων MFS για αέρα
- Μέτρηση του offset ΔV_{gas}^{tare} και της διαρροής ΔV_{gas} μέσω των αισθητήρων MFS για το αντίστοιχο αέριο
- Υπολογισμός του παράγοντα $\mathrm{F_{gas}}$

$$F_{gas} = R_{gas} \times 0.00328 \times \frac{\Delta V_{air} - \Delta V_{air}^{tare}}{\Delta V_{gas} - \Delta V_{gas}^{tare}} \tag{11}$$