An improved gas distribution system for the ATLAS RPCs

RPC2012

XI Workshop on Resistive Plate Chambers and Related Detectors

INFN - Laboratori Nazionali di Frascati 5-10 February, 2012

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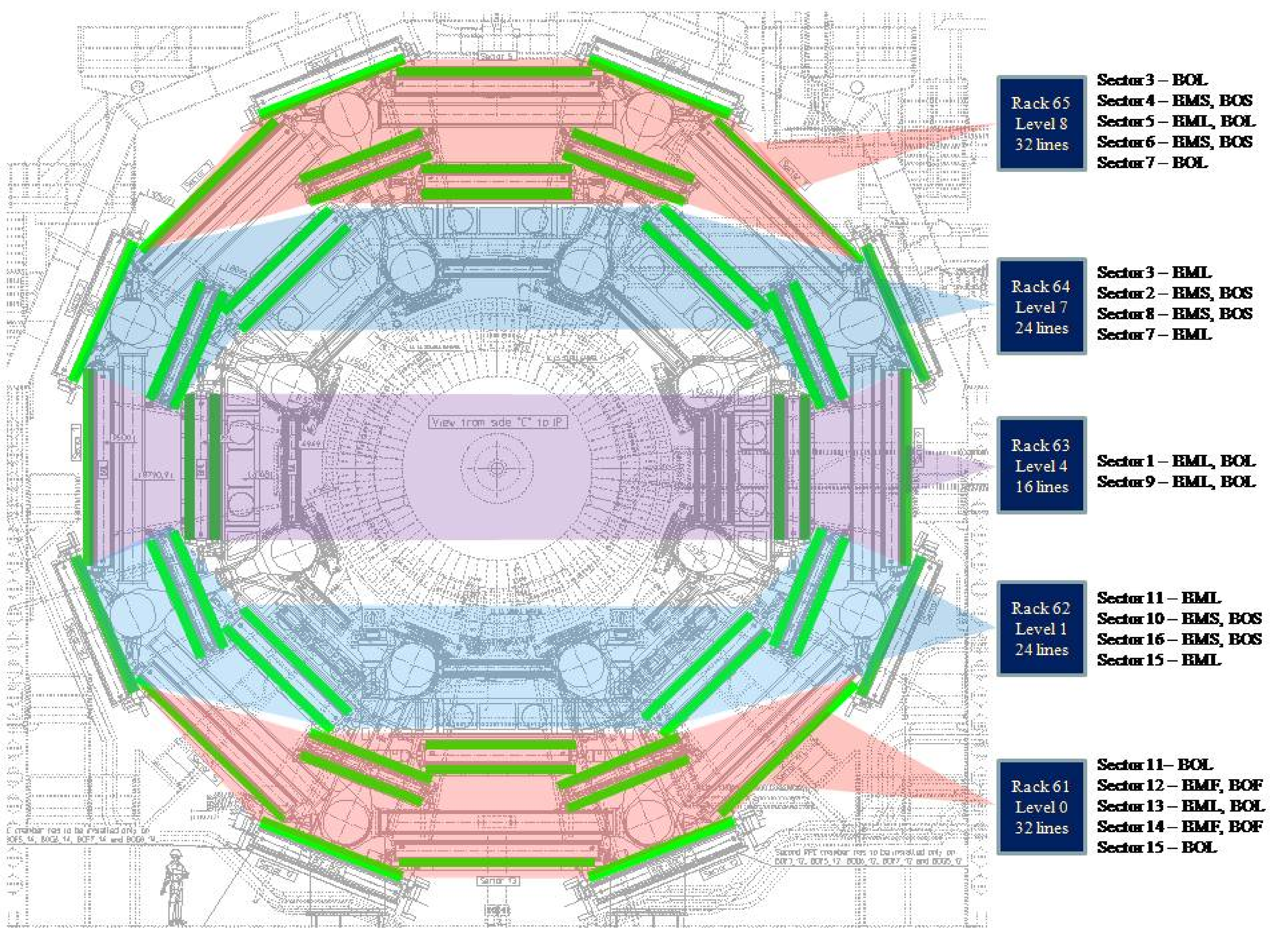
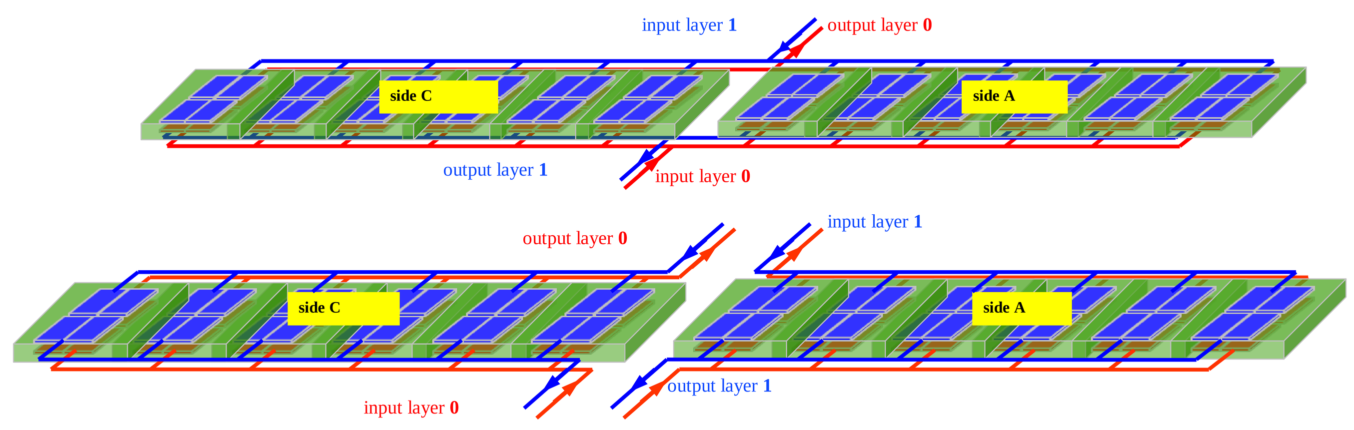
ATLAS RPC Gas System [1]



The used gas mixture is $C_2H_2F_4$(94.7%) : iso-C_4H_{10} (5%) : SF_6 (0.3%)
The gas circulates in a closed loop, and purifiers are used to preserve the gas quality. A small fraction of fresh gas is injected into the loop to compensate for leaks.
The total gas flow is distributed by 5 gas racks in 128 manifolds (8 for each sector).
In each Rack a manometer sets the input pressure of the manifolds.

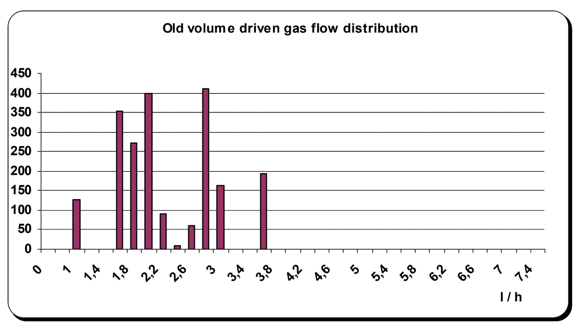
128 Input lines (manifolds)
128 Output lines
Total Gas Volume of the whole detector: 13490.3 l
Number of gas layers: 2080 (one or two gas-volume cascade connections)
Number of Gas Volumes: 3592
Total Gas Flow: 5000 l/h
(Now 3 *volume exchanges per hour* down to 1 *volume exchange per hour* at full operation)

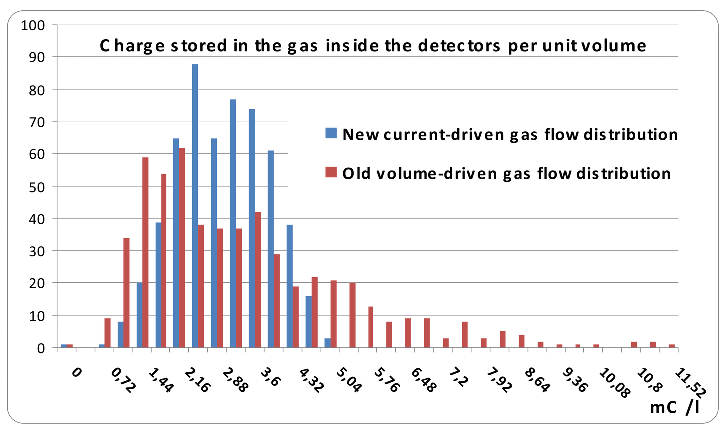
1 gas line / layer in the BM stations
(same pipe from side A to side C)
4 Layers→ 4 gas lines per sector
2 gas lines / layer in the BO stations
(Two different pipes for each side)
2 Layers→ 4 gas lines per sector

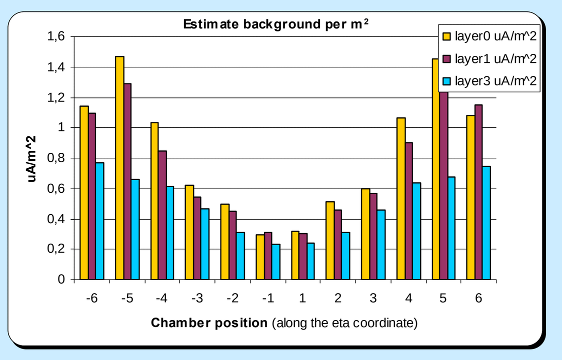


Gas-flow equalization

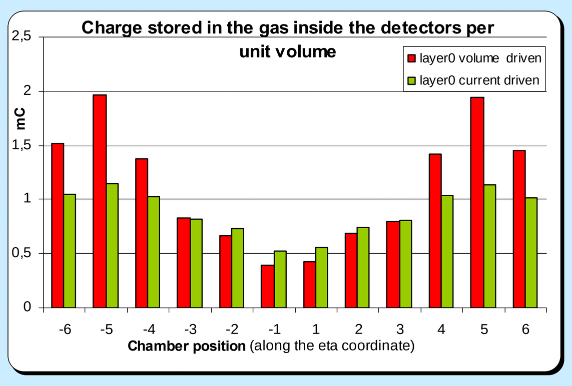
In the 2080 gas units with volume ranging from 1.36 l to 10.77 l the first parameter for the gas-flow equalization is the number of volume exchanges. This parameter has driven the project of the existing gas-distribution system that was planned for increasing the total flow with the rise of the LHC background. At the moment as a consequence of some gas leaks the gas-flow increment is practically impossible, therefore almost all the gas-gap problems noticed until now are related to insufficient gas flow. We also realized that almost all the gas leaks found are greater than expected due to misbehaving of the gas distribution at the existing gas-flow rate. For this reason and with a better understanding of the actual ATLAS background we considered the possibility to replace the old gas-distribution system.





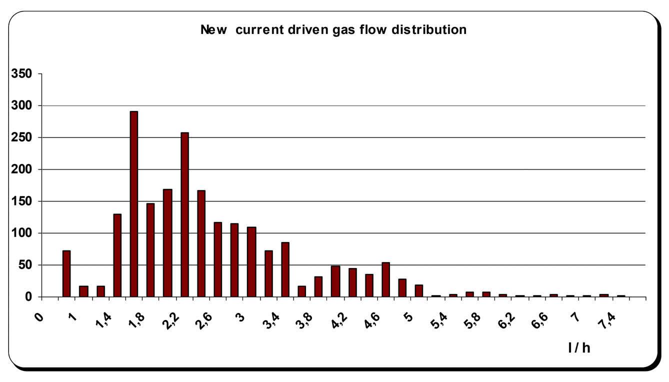


The estimate background was obtained from the current difference measured in each detector with and without the beams interaction, integrated over the all sectors (phi coordinate). Note the excess on the chamber number 5 in both side.



The charge stored in the gas flowing through the detectors decreases significantly with the new current-driven gas distribution especially in the peak on the chambers 5.

With the data collected in more than 1 year at luminosity up to $3x10^{33}$ cm^{-2} s^{-1} which is about 1/3 of the LHC project value, and with a better knowledge of the LHC-induced background, it is possible to choose a better gas equalization taking into account the detector functionality [2].
The flow needed in each gap is proportional to the prompt charge rate in the gas, which is in turn proportional to the total current measured in each RPC gap.
In any case for safe detector operation a minimum gas flow is required. This minimum was set at 1.5 *volume exchanges per hour.*
Taking into account these two constraints, we have re-equalized the gas flow available at the price of a wider dynamic but with a reduced value of the charge stored in the gas flowing through the detectors.
This is one of the most important parameters driving the RPCs to malfunctionings and faster ageing.



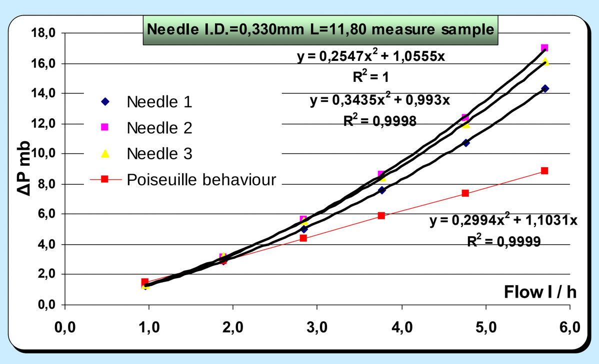
Impedance system for the gas distribution

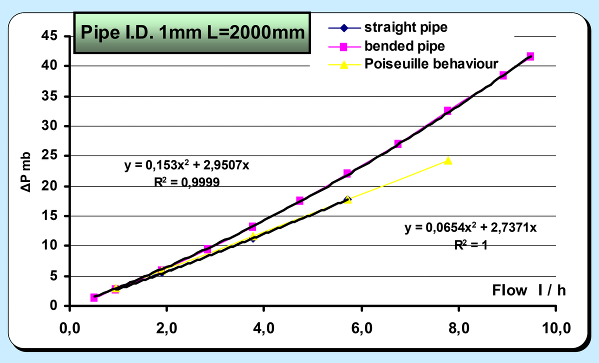
The starting point in the project of the gas-flow distribution system is the Hagen–Poiseuille law

$$\Delta P = \frac{8\mu L}{\pi r^4}\Phi$$

μ is the dynamic viscosity of the gas

The equation gives the pressure drop in a fluid flowing through a long cylindrical pipe with the assumptions that the flow is laminar, viscous and incompressible (in our case is true because ΔP << Atmospheric pressure) and the flow is through a constant circular cross-section that is substantially longer than its diameter. The fluid flow will be turbulent for velocities above a threshold (Reynolds number greater than 2000), leading to larger pressure drops than would be expected according to the Hagen–Poiseuille equation.
Poiseuille's law corresponds to Ohm's law for electrical circuits, where the pressure drop is analogous to the voltage and the volumetric flow rate is analogous to the current because both illustrate transport phenomena. In an electrical circuit starting with a fixed input voltage, it is possible to drive the same current in different loads by connecting a resistance of appropriate value in series, with the assumption that the voltage drop in each resistance will be greater than the voltage drop in each load (ideal current generator limit).
In the same way, starting from a common pressure rail for a proper flow distribution, a gas impedance delivers a certain flow depending only on its value if the pressure drop in each gas layer will be negligible compared to the pressure drop on the impedance.
We have set the pressure drop in each impedance to 6 mbar.
This value is greater than the pressure drop in each gas layer plus the return manifold pressure, it is well in the range of the setting possibility of the gas racks and is not so high as to reach unsafe conditions in case of blocked outputs in some detectors. Furthermore we are planning to remove the flow-line screw regulation in the gas racks because the smallest pressure drop in each regulator does not permit an adequate adjustment in the flow distribution, a task which is already carried out well by the gas *impedances.*





All measurements were done with pure TFE (μ very closed to the actual ATLAS gas mixture) and temperature in the range: 19°C - 22°C.
The first graph shows the measures on a sample of needles of the same type.
The second graph shows the measures on the same capillary straight and bended.

The wide gas flow spread needed in the system requires the same spread in the impedance value.
For the construction of the wide set of impedances, a set of commercial dosage needles with a very strict tolerance of the inner diameter was chosen (the gas impedance depends on the fourth power of the inner diameter).
The impedance was built by jamming the needle inside a PU plastic gas pipe (2x4 mm).
A sample of each type of needles has been tested with an accurate differential electronic manometer and with a gas flow meter after accurate calibration.
The test result differs from the Poiseuille law for the presence of a quadratic term. This term is due to the sharp change in the gas velocity, as it happens in a bent pipe or in an abrupt change of the pipe diameter.

This Table shows (in green) the Reynolds numbers that lead to laminar flow for each needle.

Gas Flow l/h	Reynolds numbers													
3	1289	1289	1074	992	992	992	992	807	807	807	807	645	645	645
4	1719	1719	1432	1323	1323	1323	1323	1076	1076	1076	1076	860	860	860
5	2149	2149	1790	1654	1654	1654	1654	1344	1344	1344	1344	1075	1075	1075
6	2579	2579	2148	1985	1985	1985	1985	1613	1613	1613	1613	1289	1289	1289
7	3009	3009	2506	2316	2316	2316	2316	1882	1882	1882	1882	1504	1504	1504
8	3439	3439	2864	2647	2647	2647	2647	2151	2151	2151	2151	1719	1719	1719
9	3868	3868	3221	2977	2977	2977	2977	2420	2420	2420	2420	1934	1934	1934
10	4298	4298	3579	3308	3308	3308	3308	2689	2689	2689	2689	2149	2149	2149
12	5158	5158	4295	3970	3970	3970	3970	3227	3227	3227	3227	2579	2579	2579
14	6017	6017	5011	4632	4632	4632	4632	3765	3765	3765	3765	3009	3009	3009
18	7737	7737	6443	5955	5955	5955	5955	4840	4840	4840	4840	3868	3868	3868
22	9456	9456	7875	7278	7278	7278	7278	5916	5916	5916	5916	4728	4728	4728
25	10745	10745	8949	8271	8271	8271	8271	6722	6722	6722	6722	5373	5373	5373
30	12894	12894	10738	9925	9925	9925	9925	8067	8067	8067	8067	6447	6447	6447

This Table shows the linear and quadratic terms measured for a sample of each type of needles.

Needle Type	1	2	5	6	7	8	9	10	11	12	13	15	16	17
DI (mm)	0.254	0.254	0.305	0.33	0.33	0.33	0.33	0.406	0.406	0.406	0.406	0.508	0.508	0.508
Length (mm)	11.80	18.20	19.20	11.80	18.20	30.80	43.10	11.80	18.20	30.80	43.10	11.80	18.20	30.80
ImpTeor	4.41	6.80	3.45	1.55	2.39	4.04	5.65	0.68	1.04	1.76	2.47	0.28	0.42	0.72
Quadratic term	0.802	1.083	0.676	0.299	0.332	0.342	0.486	0.1290	0.120	0.164	0.169	0.060	0.064	0.0638
Linear term	2.920	4.073	2.731	1.051	1.813	2.570	4.120	0.6490	0.775	1.325	1.868	0.291	0.368	0.6097

	dP(mB)														
Flow(6mB)	6	1.47	1.13	1.58	3.05	2.32	1.87	1.27	4.75	4.54	3.23	2.60	7.84	7.24	6.03
Flow(12mB)	12	2.45	1.94	2.65	4.82	3.87	3.26	2.29	7.45	7.28	5.42	4.55	11.89	11.15	9.74
Flow(18mB)	18	3.25	2.61	3.52	6.20	5.12	4.41	3.18	9.56	9.44	7.19	6.18	15.02	14.18	12.68
Flow(12mB)/Flow(6mB)		1.7	1.7	1.7	1.6	1.7	1.7	1.8	1.6	1.6	1.7	1.7	1.5	1.5	1.6
Flow(18mB)/Flow(6mB)		2.2	2.3	2.2	2.0	2.2	2.4	2.5	2.0	2.1	2.2	2.4	1.9	2.0	2.1

This Table shows the flow driven for each needle at different starting-point pressure (6mb is the design pressure). We obtain that, by doubling the pressure, the flow is increased only by a factor 1.6. This limit is almost insurmountable and is caused by the quadratic term in the ΔP vs Flow relation (see the figure with measured straight and bent pipe). To overcome this problem we are studying a different type of gas impedance made of many pipes mounted in a parallel configuration but we are also confident that with this new gas equalization a good detector operation at the full-project ATLAS background will be possible without increasing the total gas flow more than a factor two.

This table shows the 18 combinations of one or two needles in series used for assembling the 2080 impedances needed. For each impedance, the linear and quadratic term of both needles and the flow obtained with input pressure of 6 mb are shown.

Impedance type	Needle 1	Needle 2	a1	b1	a2	b2	a-tot	b-tot	Flow l / h	Number needed
1	1	2	0.80	2.92	1.08	4.07	1.89	6.99	0.72	72
2	5	8	0.68	2.73	0.34	2.57	1.02	5.30	0.96	16
3	5	7	0.68	2.73	0.33	1.81	1.01	4.54	1.07	12
4	9		0.49	4.12	0.00	0.00	0.49	4.12	1.27	40
5	7	13	0.33	1.81	0.17	1.87	0.50	3.68	1.37	194
6	5		0.68	2.73	0.00	0.00	0.68	2.73	1.58	264
7	8		0.34	2.57	0.00	0.00	0.34	2.57	1.87	290
8	6	11	0.30	1.05	0.12	0.78	0.42	1.83	2.19	252
9	7		0.33	1.81	0.00	0.00	0.33	1.81	2.32	160
10	13		0.17	1.87	0.00	0.00	0.17	1.87	2.60	202
11	6		0.30	1.05	0.00	0.00	0.30	1.05	3.05	158
12	12		0.16	1.33	0.00	0.00	0.16	1.33	3.23	100
13	17	17	0.06	0.61	0.06	0.61	0.13	1.22	3.58	48
14	16	17	0.06	0.37	0.06	0.61	0.13	0.98	4.03	110
15	11		0.12	0.78	0.00	0.00	0.12	0.78	4.54	100
16	18		0.09	0.73	0.00	0.00	0.09	0.73	5.07	30
17	17		0.06	0.61	0.00	0.00	0.06	0.61	6.03	22
18	16		0.06	0.37	0.00	0.00	0.06	0.37	7.24	10
									TOT	2080

First check of the system on gas rack 63 and conclusion

A sample of the new gas impedances was installed in the entire gas rack 63 and has been working since the end of November. The gas pressure in the rack inlet has increased as expected to 7.5 mb (on the impedance the ΔP is about 6 mb as designed but more than 1 mb is lost on the rack screw for line regulation)
No problem was shown by the chambers connected to rack 63. Furthermore, a leak test was made by disconnecting the gas inputs in two chambers: the lost flow was compatible with the value of the installed impedance. Given the positive results achieved we are installing the new gas impedances in all ATLAS RPCs

References and Further Information

[1] *De Asmundis, R ATL-MUON-SLIDE-2009-372*
[2] *Aielli, G Cavern background measurement with the ATLAS RPC system RPC2012 Frascati*