Study of the MDT drift properties under different gas conditions.

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1 Introduction.

In the summer 2002 six MDT (Monitored Drift Tubes) chambers of the Atlas Barrel muon spectrometer have been exposed to a muon test beam in the H8 area at CERN. The aim was to perform a systematic study of the MDT drift properties respect to variations of gas temperature, gas mixture (percentages of Ar and CO_2) and water content. Moreover we studied the drift properties as a function of the gas flow and the configuration of the gas distribution in the chambers. The results are expressed using the maximum drift time as an overall figure of the drift properties.

The experimental results are compared with the predictions of an accurate simulation of the drift properties based on the Garfield-Magboltz Montecarlo program [4].

2 Experimental Set-Up.

The 2002 MDT test-beam set-up aimed to test a complete barrel and end-cap sector of the ATLAS muon spectrometer. In this note we concentrate on the barrel chamber results. Six barrel chambers have been mounted on the beam line, according to the lay-out shown in Fig.1 [2]. The relative positions of the chambers mimic a standard ATLAS sector of the barrel part of the muon spectrometer. The chambers were two BIL (chambers 1 built in Rome and 2 built in Pavia), two BML (chambers 3 and 4 built in Frascati) and two BOL (chambers 5 and 6 built in NIKHEF). All chambers have been equipped with standard hedgehogs and mezzanine cards with AMT1 TDC chips, and read-out through CSMs (CSM-0). They were operated at a voltage of 3080 V corresponding to a gas gain of about 2×10^4. The threshold at the output of the amplifier was set at 60 mV, roughly corresponding to the 20th electron [1].

The total number of read-out channels was 768, corresponding to a fraction of 38% of the 2016 tubes in the six chambers. The instrumented part of the chambers was chosen in such a way to cover the central part of the full sector. In the baseline running configuration the gas mixture was 93% Ar 7% CO_2 at 3 bar absolute. The precision on the mixture setting is about 0.2%, that on the pressure measurement is at the level of few 10^{-4}. Each chamber was connected in parallel to the gas system. The overall gas flow could be set in a range 100÷ 1400 Nl/h; the flow on the individual chambers could be set and measured at the chamber input by rotameters. The standard gas flow in Atlas (1 volume change per day) was used. Each chamber was fluxed in a serial 3 tubes configuration as shown in Fig.2 with the exception of the second multilayer of one BML chamber (chamber 4) that was completely parallel. This multilayer was used to compare the effects of the serial connections to a completely parallel one. The gas temperature was monitored by means of the DCS system in several positions of the chamber. Typical temperature excursions due to external daily temperature variations were up to 5° C as shown in Fig.3. Temperature studies have been done using these temperature excursions. Dedicated set of runs with small temperature variations have been done to study gas mixture variations and water vapour contamination.

Data have been taken in the period between August 8th and September 10th. Two triggers have been used: one based on 10×10 cm^2 scintillators (10×10 in the following) and another based on a scintillator hodoscope approximately

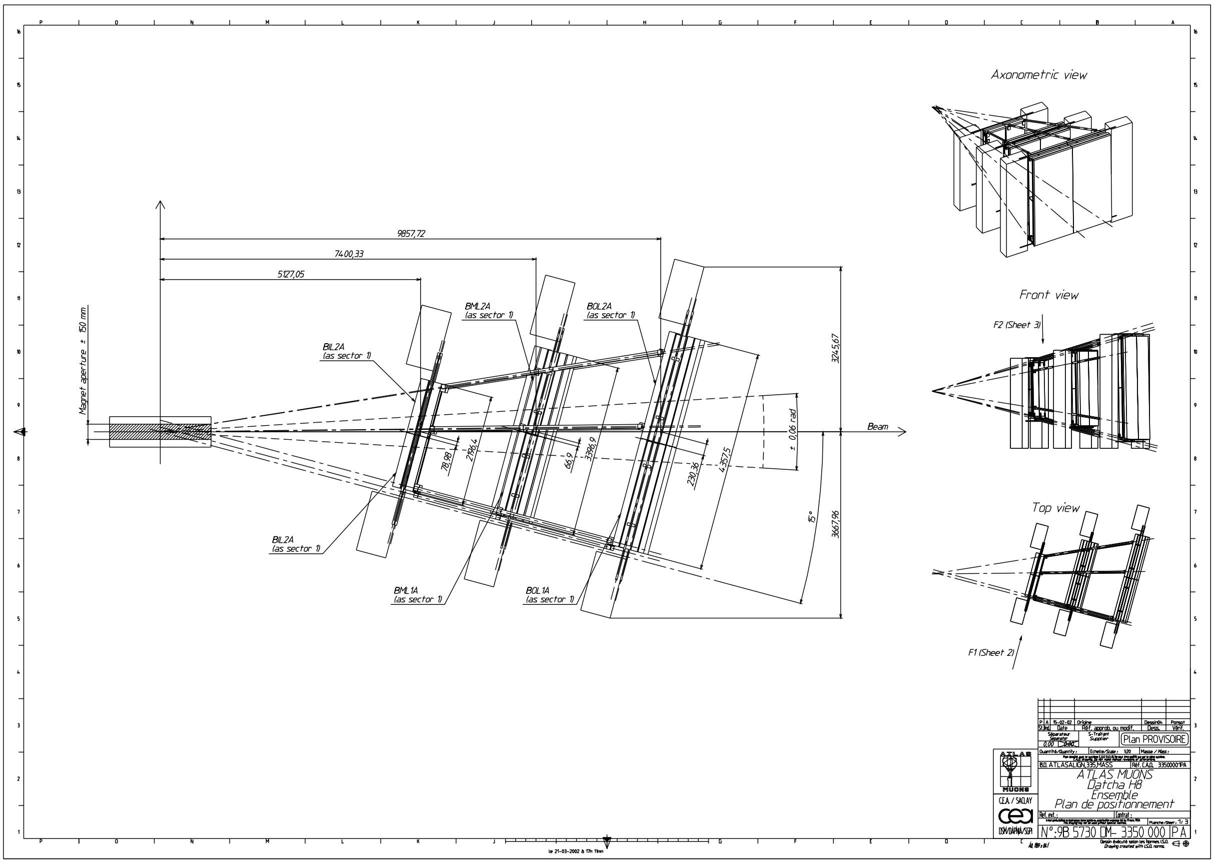


Fig. 1. *Experimental lay-out of the H8 muon barrel test beam 2002.*

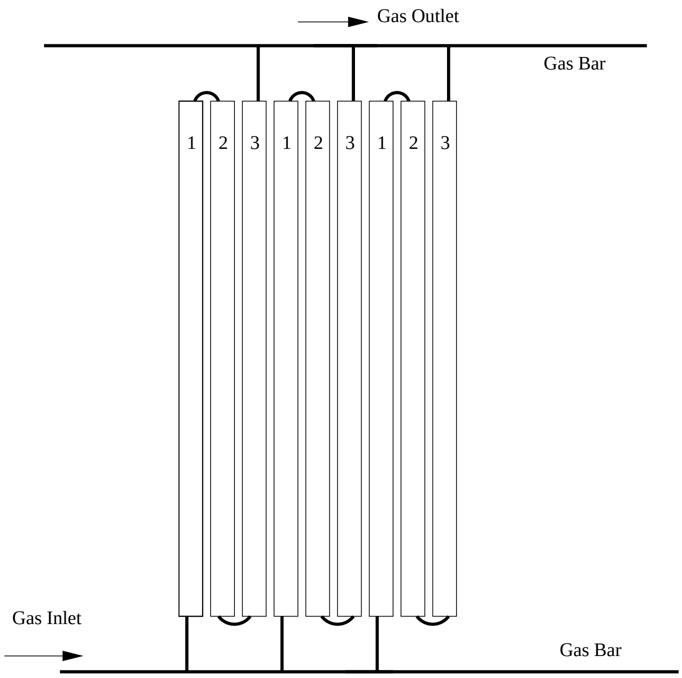
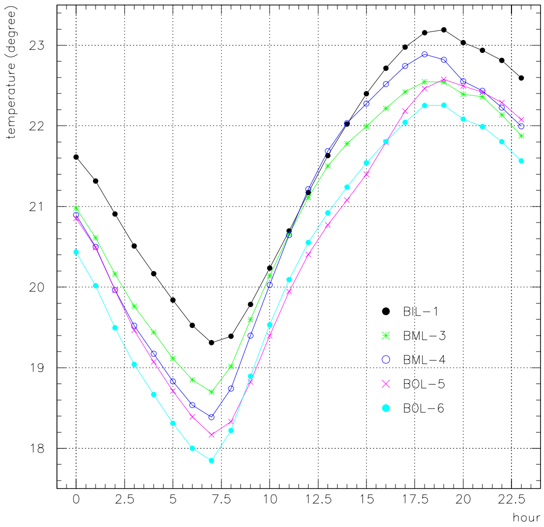


Fig. 2. *Sketch of the serial gas connections. 9 tubes belonging to a layer are shown. The triplet structure is repeated for all the tubes of the layer.*



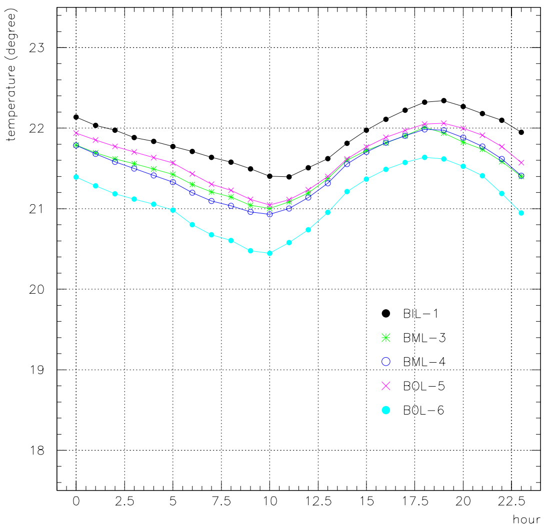


Fig. 3. *Temperature excursions on the chambers during two days with quite different atmospheric situation: 29 August (upper plot) and 2 September (lower plot). The temperature of BIL-2 is not present due to a failure of the sensor.*

100(horizontal)×60(vertical) cm^2 wide (hodoscope trigger in the following). The hodoscope trigger was vetoed by the 10×10 trigger which is centred on the beam spot, to get uniform illumination by the muon halo across most of the chamber area (30 tubes per layer). The 10×10 trigger condition was used to get high event rates shared among few tubes, the hodoscope trigger to get a uniform illumination over larger areas. The data have been recorded with a prototype of the final Atlas data acquisition system "daq-1" [3].

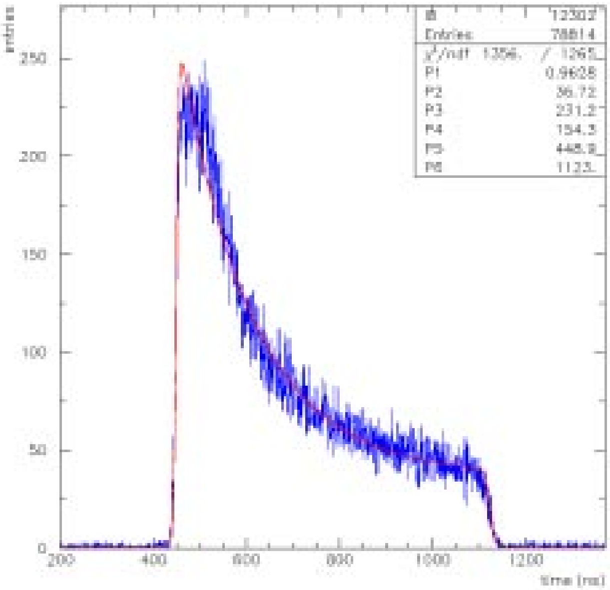


Fig. 4. *Example of raw time spectrum with the fit superimposed. Parameters p5 and p6 are* t_0 *and* t_f *respectively.*

3 Analysis method.

The drift properties of a tube in any given gas configuration determine the so called "r-t relation", *i.e.* the drift time for a given radial position of the track respect to the wire. The measurement of the maximum drift time is an integral figure of the r-t relation, since it corresponds to the time required to drift from the internal tube wall up to the wire. So it is a simple and robust figure of the gas drift properties, provided that the particle illumination is uniform over the tube diameter and the efficiency is constant. On the other hand this quantity doesn't give any information on the resolution and the efficiency of the system.

The measurement of the maximum drift time is obtained starting from the raw time spectrum of each tube. No selection is applied to get the spectrum so that no bias is introduced. Each spectrum is fitted (as shown in Fig.4) with a 5 parameters function describing the shape of the signal distribution plus a constant describing an out of time background. Two out of the six total parameters account for the rise time t_0 and the fall time t_f. The difference $t_{tot} = t_f - t_0$ is the maximum drift time. The uncertainty on t_{tot} is dominated by the uncertainty on t_f that is larger than the one on t_0 due to the lower statistics in that region of the spectrum. In a typical 5×10^5 events run (about 30 minutes in hodoscope trigger for fully efficient beam) we obtain more than 10^4 events per tube and the statistical uncertainty on t_{tot} is of the order or below 1 ns.

4 Simulation of the gas properties.

The experimental results have been extensively compared with the results of a Montecarlo simulation. The Garfield program was used for simulating the response of an MDT tube to charged particle tracks. The program calculates field maps, electron and ion drift lines, drift time tables and arrival time distributions, signals induced on the wires by ions and electrons. Garfield provides also an interface for the computation of electron transport properties in different gas mixtures, and an interface with the Heed program to simulate ionization of gas molecules by particles traversing the tube. The standard MDT operating point and different temperature and gas mixture conditions have been simulated. The gas average gain is held fixed to 2×10^4.

The standard conditions and the corresponding variations are:

- mixture: Ar/CO_2 93/7 (91/9 $\div$ 95/5);
- temperature: 20 ° (17° $\div$ 23°);
- pressure: 3 bar absolute;
- high voltage: 3080 V corresponding to a gain of $G = 2 \times 10^4$;
- no impurities (water vapour $0 \div 1000ppm$; air $0 \div 1000ppm$)

A time spectrum for uniform illumination of the tube along the radial distance is shown in Fig.5 where it is also compared with a data spectrum. The slight discrepancy in shape can be attributed to a different effective gas mixture, resulting in a different drift velocity dependence on the drift distance. The Garfield computed r-t relation is shown in Fig.6 and is compared to the one found from the data.

5 Results.

5.1 Temperature dependence.

In our experimental set up the gas pressure is kept fixed at 3 bar absolute within some 10^{-4}, therefore changes of the gas temperature reflect in density variations which in turn modify the drift velocity according to $v_{drift} \sim E/\rho$ with E the electric field. The maximum drift time has been measured for runs at different temperature taken at different times along the day. Each run was about 10 minutes long and was taken with the 10×10 trigger to get high

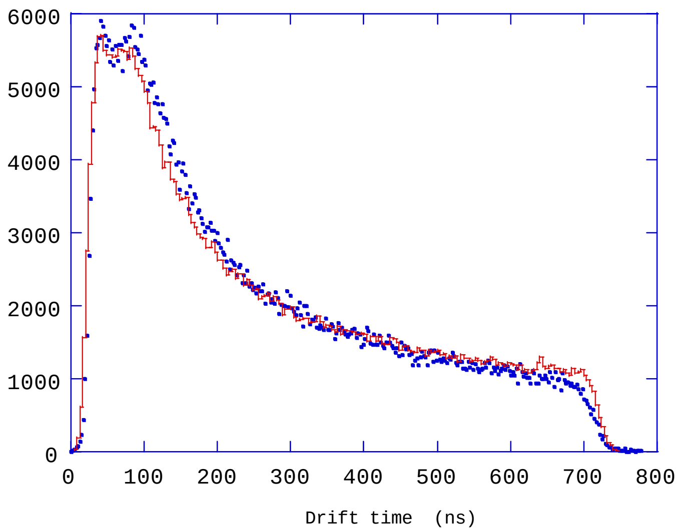


Fig. 5. *Raw time spectrum simulated by Garfield (histogram) compared with a data spectrum (points). The two spectra are normalized to the same number of events.*

statistics spectra in a small amount of time on few tubes. Moreover these data have been taken at high gas flow in order to minimise other effects like water contamination (see sect.5.3). More than 2×10^4 events were collected for the tubes illuminated by the trigger. Fig.7 shows the observed dependence of t_{tot} on the temperature for some tubes from the different chambers. We observe a decrease of the drift time with the temperature. The average slope is -2.67±0.10 ns/K. No significant differences among the 6 chambers have been observed as shown in Fig.8a, where the average slopes per chamber are compared. The observed slope is roughly in agreement with the one measured in the 2001 test-beam -2.3 ± 0.1 ns/K [5] and is also in agreement with the predicted value of -2.61±0.03 ns/K from the Garfield simulation.

It is interesting to notice that the rise time t_0 of the spectrum is also weakly dependent on the temperature. The slope is small but significantly different from zero: -0.22±0.03 ns /K. On the contrary Garfield predicts a slightly positive slope 0.06±0.02 ns /K. The effect on the t_0 for the six chambers is

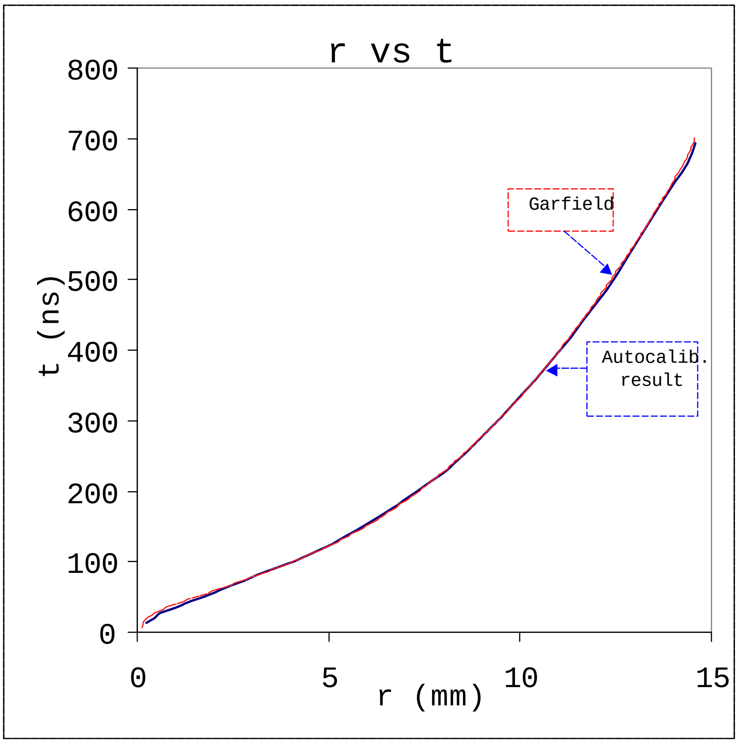


Fig. 6. *Space-Time relation as evaluated by the Garfield simulation (red curve) compared to one obtained applying the autocalibration procedure on a data sample (blue). The high non-linearity of the gas mixtures can be noticed.*

shown in Fig.8b. A decrease of the gas density due to a temperature increase other than change the drift velocity, affects the time at which the threshold is crossed and hence the t_0, in two opposite ways: (i) the specific ionization gets lower, hence the threshold is reached later on average; (ii) the gas gain increases (according to the Diethorn formula see [6]) hence the threshold is reached before. In the simulation the gain is held fixed hence effect (ii) is not taken into account. This can explain the discrepancy. A dedicated study of this effect can be done directly evaluating the r-t relation profile as a function of the temperature [7].

Fig.8c shows the maximum drift time at a given temperature (namely 20°) for the six chambers. Again, no significant differences among the chambers are observed. This is a test of the equality of the gas mixture among the chambers

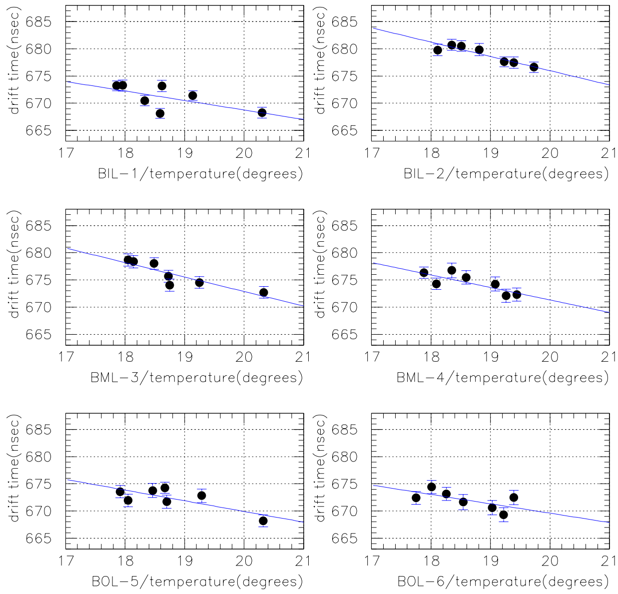


Fig. 7. t_{tot} *as a function of temperature for one tube per chamber. Linear fits are shown giving the slope and the* t_{tot} *at the reference temperature of 20°.*

when operated at high flow, once the dependence on the temperature has been properly removed.

5.2 Gas Mixture dependence.

The dependence of the maximum drift time on the gas mixture (namely on the Ar fraction) is shown in Fig.9. A linear behaviour in the Ar fraction between 92 and 94% is observed with a negative slope of -69.6±0.7 ns/%. As expected, the higher is the amount of Ar the faster is the gas (a maximum drift time of 1.6 μs was observed for the Ar-CO_2 80-20% mixture employed in the 1997 test beam [8]). The data used are from the gas mixture scan done with high gas flow and with hodoscope trigger. For each gas mixture configuration we have taken data after several gas volume exchanges. The value obtained is qualitatively in agreement with the value predicted by Garfield -84.19±0.02 ns/%.

5.3 Dependence on water content.

In order to have a controlled amount of H_2O in the chambers, part of the gas was flown through a vessel containing water at a given temperature. The level of water vapour contained in the humid flow was set by the temperature of

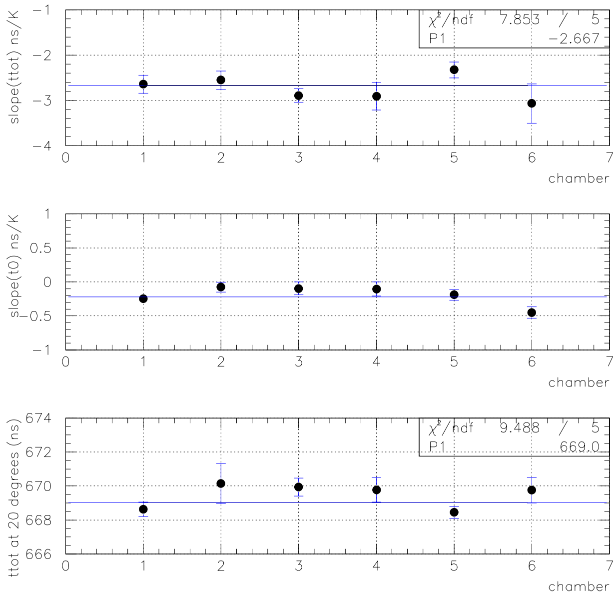


Fig. 8. *Results of the temperature study for the six chambers: (a) average* t_{tot} *- temperature slopes, (b) average* t_0 *- temperature slopes and (c) average* t_{tot} *at 20°. The values given are averages among the tubes with sufficiently high statistics and the lines are weighted averages. Data are taken at high gas flow.*

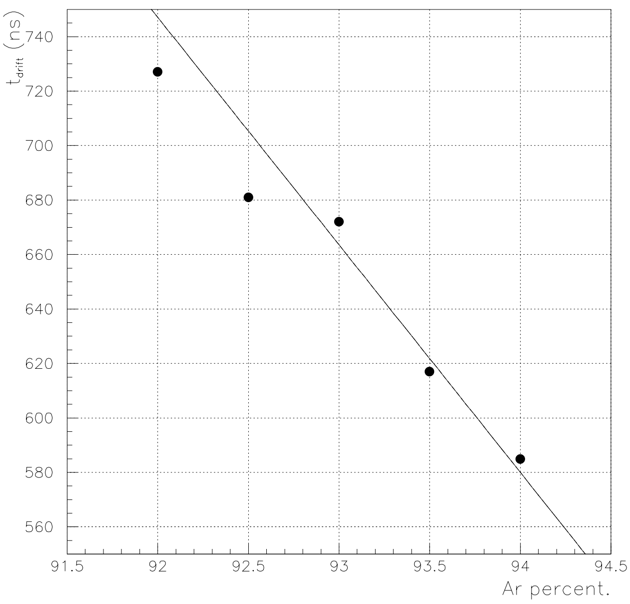


Fig. 9. t_{tot} *as a function of the Ar content in the mixture. Data (points) are compared with the slope predicted by the Garfield program(line).*

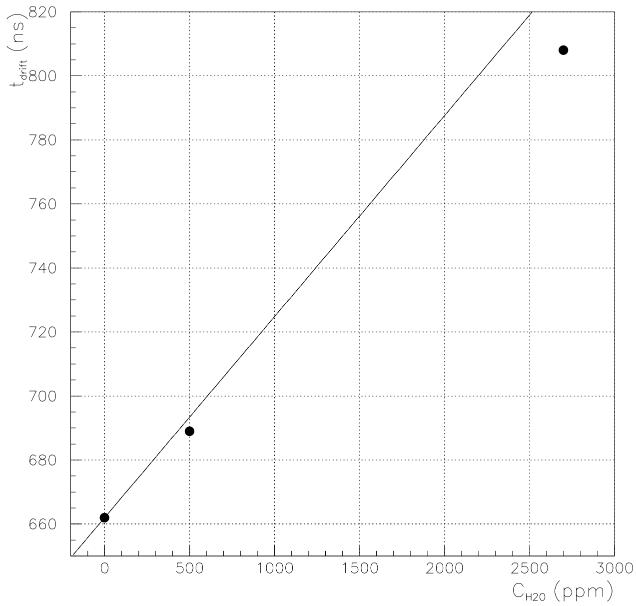


Fig. 10. t_{tot} *increase with the* H_2O *content. Data (points) compared with the Garfield predictions (line). The point at 0 ppm assumes that no water contamination is present in standard operation at high flow.*

the vessel while the overall water vapour partial pressure was set by the ratio of the humid to the dry flow. We have taken two sets of data at high gas flow and with two different ratios of humid to dry flow, corresponding to water contents of 520 and 2700 ppm respectively. We have observed an increase of t_{tot} of 28 and 147 ns in the two cases giving an average slope of 5.50±0.05 ns / 100 ppm of H_2O (the error quoted does not include possible uncertainties on the water content values). The results are shown and compared to the Garfield simulation in Fig.10. The slope predicted by Garfield is significantly larger than the one found in the data, 6.37± 0.03 ns / 100 ppm.

5.4 Effect of serial connection of drift tubes.

One problem that could arise connecting serially the tubes along the gas line, is the possible appearance of dependencies of the gas drift properties on the tube position along the gas line. This possibility has been studied previously with measurements and simulations with different gases [9], [10]. We have investigated this possibility looking at the chambers with serial connections (see Fig.2) compared to the only multilayer (multilayer 2 of chamber 4) that was completely parallel. We have looked at the maximum drift times of tubes in position 1, 2 and 3 starting from the gas entrance.

We have observed a significant difference of t_{tot} as a function of the tube position in the serial gas distribution in all the serial chambers and not in the parallel one, with the following main features:

- the effect depends on the gas flow, increasing the flow the effect is clearly reduced: at the Atlas nominal flows it is still significant (of order 1% on the total drift time);
- the effect is chamber dependent, we have observed the maximum effect in the BIL and the minimum in the BOL; but can be different for chambers with the same tube length (there is a factor two difference between BIL 1 and BIL 2);
- whatever the initial gas condition is (high flux or no flux at all), the effect appears with a time scale given by the flow itself (about 1 day at the standard Atlas flow); once the flow is closed the effect remains for a much longer time (probably related to the diffusion time between the tubes);

Figs.11 and 12 show the effect for a multilayer of a BIL chamber after one week at the Atlas nominal gas flow [1] . The maximum drift time is characterised by a clear pattern as a function of the tube number. Grouping the tubes according to their positions along the gas flow, we obtain the three distributions of Fig.12 where we see the clear separation among the three populations. We remind that position 1 is the one closer to the gas entrance. The fully parallel multilayer doesn't show a similar pattern but only random fluctuations with a rms of about 2 ns around an average t_{tot} close to the one of position 1 in the serial connected tubes.

With larger gas flow the effect is reduced. Since we had not the possibility to measure gas flows larger than 40 (for BIL chambers) or 80 l/h (for BML and BOL chambers) per chamber (maximum for our flowmeters) we cannot give a quantitative figure of this dependence.

The effect has been systematically studied flowing all the chambers in stable conditions for a period of 8 days looking at the time evolution of the effect (see also Ref.[11]). In the first 4 days the flow was 20 l/h at 3 bar for all the chambers. Then it has been moved to the standard Atlas flow different for each chamber. Fig.13 shows for the six chambers the time evolution of the quantity Δt_{tot}, defined as the difference between the maximum drift time of the tube in position 3 minus that of the tube in position 1. For the BIL chambers we observe a transition from a high flux status (small effect) to a ATLAS flow status (big effect). For BML and BOL chambers, that had been closed for a quite long period, the Δt_{tot} starts from high values and decreases with time, with a sharp slope in the first few days (corresponding to the time for a full change at this flow that is between 1 and 3 days depending on

[1] For BIL chambers, since V= 530 l, one volume change per day means a flow of 22 l/h at 3 bar. For BML it is 35 l/h and for BOL is 63 l/h.

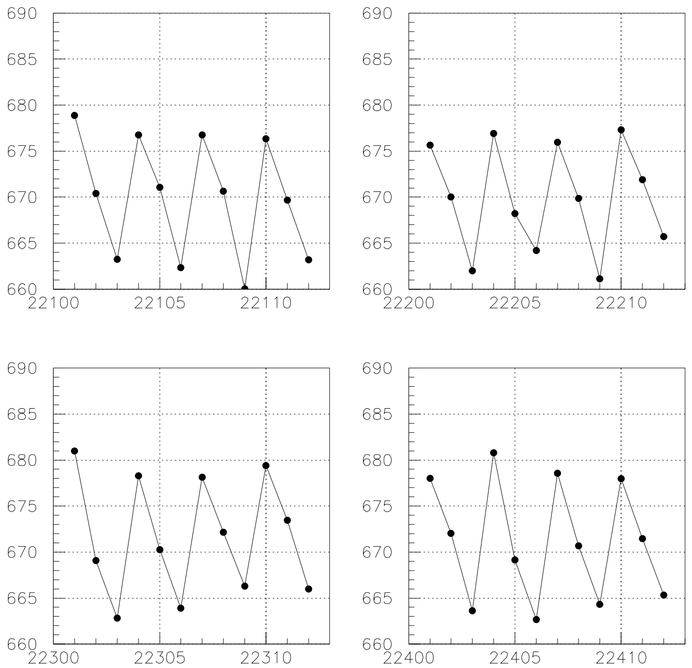


Fig. 11. t_{tot} *(ns) vs tube code for the 4 layers of the second multilayer of BIL-2 The gas inlets correspond to the tubes with the lower* t_{tot}*, the outlets to those with higher* t_{tot}*. The tube code is: chamber / multi-layer / layer / tube. The run was taken after 8 days of standard Atlas gas flow.*

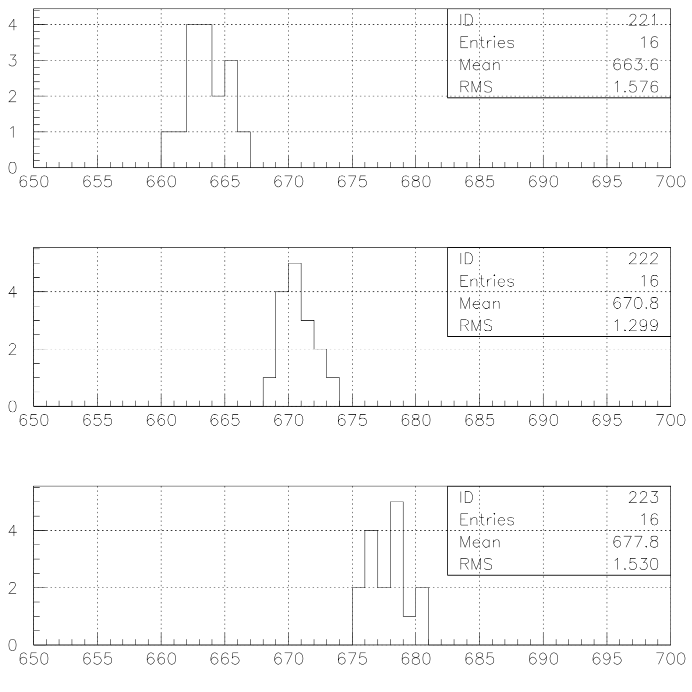


Fig. 12. *Distributions of* t_{tot} *(in ns) for tubes in position 1, 2 and 3 respectively in the gas sequence for BIL-2.*

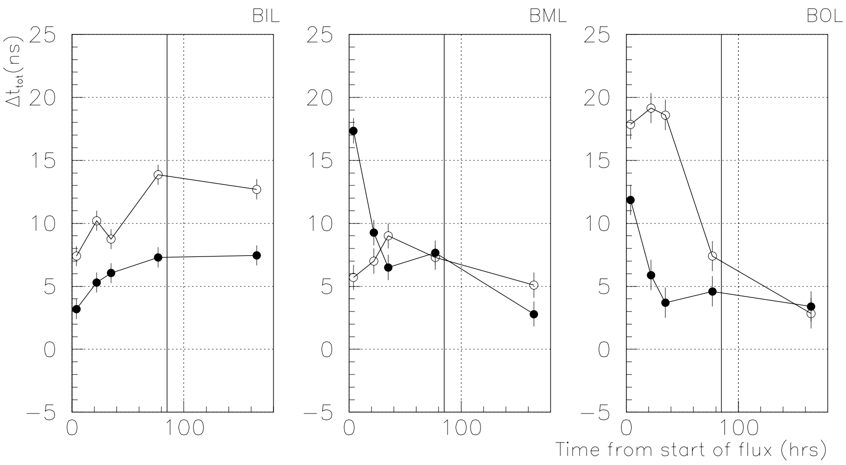


Fig. 13. *Average Δt_{tot} as a function of time for BIL chambers (full circles BIL-1 and open circles BIL-2) BML (full circles BML-3 and open circles BML-4 without the fully-parallel multi-layer) and BOL (full circles BOL-5 and open circles BOL-6). The vertical line indicates the time at which the flow has been moved to the standard Atlas flow.*

the chamber volume). During the transient period, the pattern of the t_{tot} of the tubes is changing as shown in Fig.14 for one layer of BML3. The history plot shows that the flux act before on tubes in position 1 and with a longer time scale on tubes in position 3 (the first of the triplet). Fig.15 gives the summary of Δt_{tot} after 77 and 165 hours. Each point is the average effect on all the instrumented tubes of each chamber. Only the tubes of the fully parallel multilayer have been taken out from chamber 4 (multilayer 2).

It has been proposed that the effect could be due to water contamination accumulated during the gas flowing in the chambers. If water enters in the connections between tubes, a water content is accumulated in such a way that the first tube has less water content than the second and so on. An estimate of the effect can be given using the result given above, namely

$$\Delta t_{tot}(\text{ns}) = 5.50 \times C_{H_2O}(\text{ppm})/100$$

where C_{H_2O}(ppm) in ppm is the water content. C_{H_2O} has been measured for BIL 1 and 2 before the inlet of the chambers and after the outlet and the result of the measurement is shown in Fig.16. This measurement shows clearly that during the passage through the tubes, water contaminates the gas. The predicted effect on Δt_{tot} for BIL-1 and BIL-2 is:

$$\Delta t_{tot}(BIL-1) = 5.5\text{ns}$$

$$\Delta t_{tot}(BIL-2) = 11\text{ns}$$

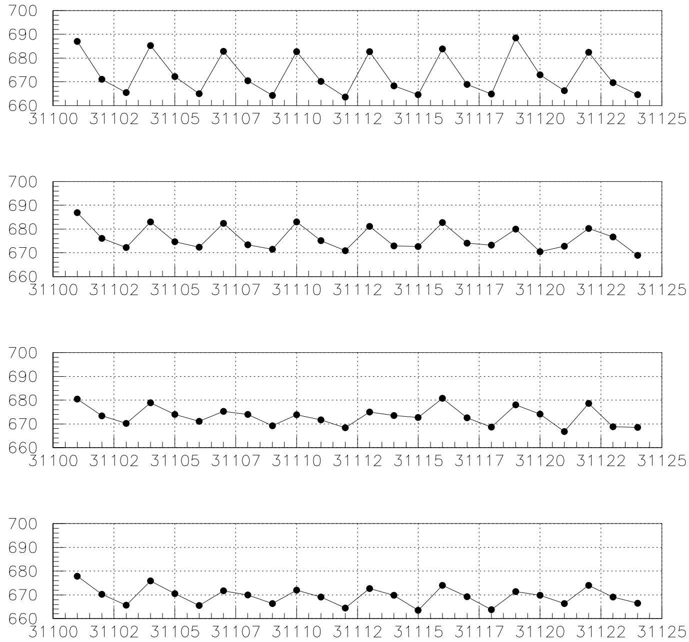


Fig. 14. t_{tot} *(ns) pattern for one layer of chamber 3 at 4 different times after the start of the gas flow at 20 l/h: after 4h, 22h, 35h and 77h.*

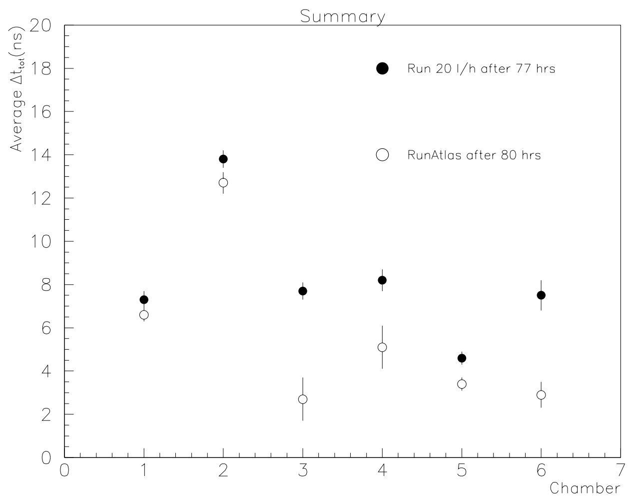


Fig. 15. *Average* Δt_{tot} *for the 6 chambers: (full circles) after about 4 days of flowing at 20 l/h; (open circles) after 8 days of flowing, the first 4 days at 20 l/h and the following 4 days at the standard Atlas flow.*

in acceptable agreement with the measured effect for the two chambers.

Attempts to understand the source of water contamination have not given positive results. In particular it is not clear why chambers that are identical in principle (like BIL-1 and BIL-2) show such a different water content and also why tests done in apparently similar conditions do not reproduce the same

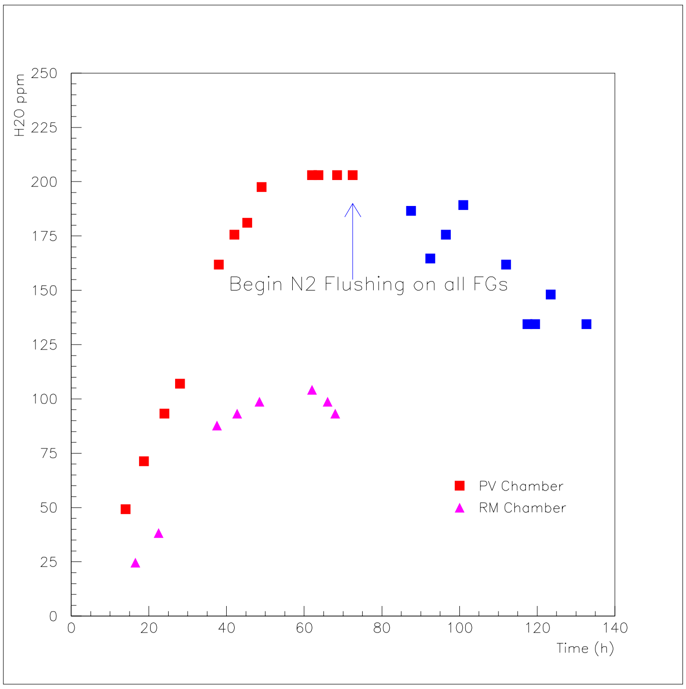


Fig. 16. *Water content measured at the exit of the 2 BIL chambers (RM chamber is BIL-1 and PV chamber is BIL-2) as a function of the time from the start of gas flowing. After 80 hours of Atlas flow, N_2 has been flushed on the Faraday cages of the BIL-2 chamber. The observed reduction of the water content can be due to the decrease of the water content in the atmosphere of the Faraday cages.*

Table 1
Summary of the slopes of t_{tot} for the considered gas parameters. The last column shows the variation of the parameter which corresponds to a 2 ns change in t_{tot}.

Parameter	slope (data)	slope (Garfield)	Maximal variation
temperature (ns/K)	-2.67±0.10	-2.61±0.03	0.7°
Ar percentage (ns/% (Ar))	-69.6±0.7	-84.19±0.02	3×10^{-4}
H_2O content (ns / 100 ppm (H_2O))	5.50±0.05	6.37±0.03	40 ppm

effect. So work is in progress to address the problem.

6 Summary

We summarise the dependencies of the maximum drift time t_{tot} on the considered gas parameters in Tab.1. The values of the slopes are given with the statistical uncertainty only. In the table we have indicated also the variation of the parameter corresponding to a change of t_{tot} of 2 ns that in turn corresponds to a systematic of about $20\mu m$ on the position determination, once the r-t relation change has not been taken into account. If the variations of the parameters exceed the indicated levels, a new calibration is required to avoid a systematic uncertainty exceeding the 20 μm level.

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