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Low gas consumption in tracking detectors for outdoor applications

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Low gas consumption in tracking detectors for outdoor applications

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Abstract.
Gaseous detectors are one of the popular particle tracking technologies in high energy physics, and there are multiple applications where the detectors must tolerate outdoor conditions, e.g. in the emerging field of muography. Gaseous tracking detectors are attractive choices due to their high efficiency, good resolution and large sensitive area at a reasonable cost and low weight, but to achieve these, the gas system is usually not sealed. Continuous gas flow results gas consumption and thus regular gas cylinder replacement which limits applicability. In this paper we present a practical solution to reduce gas flow to a negligible level, keeping the construction cost-efficient and low weight, by a properly chosen buffer tube at the end of the gas line, which makes the system able to withstand large temperature and pressure fluctuations.

1. Introduction

The gaseous tracking technology is one of the main particle detector type, especially for large sensitive area [1]. The great tracking properties are also exploited in outdoor applications, such as muography, where the attenuation of cosmic muon flux is used to map the density of rock layers [2]. On the other hand, field applications present challenges in terms of external conditions and remote operation, so detectors must be robust, portable, low consumption, and practically cost efficient. Gaseous tracking detectors usually operate with a constant gas flow to maintain sufficient gas purity and the contaminated gas is exhausted through an open end. This way the construction is simpler and the weight can be lighter as the detector structure does not have to resist pressure variations. Continuous exhaustion has obvious drawbacks, most importantly the regular maintenance of gas cylinder replacement which reduces applicability. In this paper we summarize a method to drastically reduce the gas flow [3], and show some suggestions for further reduction.

With regard to the detector design concepts mentioned above, the main issues to reduce gas flow are contaminations coming from the outgassing of construction materials, contamination diffusion through walls, diffusion from open end, and air backflow from open end due to temperature drop. The first two are a matter of material choice but detector performance must be checked in ”sealed mode”, and for the latter two issues, the basic idea is a well designed buffer volume.

In this paper a gaseous detector system consisting an improved version of the classical MWPC technology [4] has been used, where the Ar:CO_2 82:18 gas flows serially through eight 120 cm

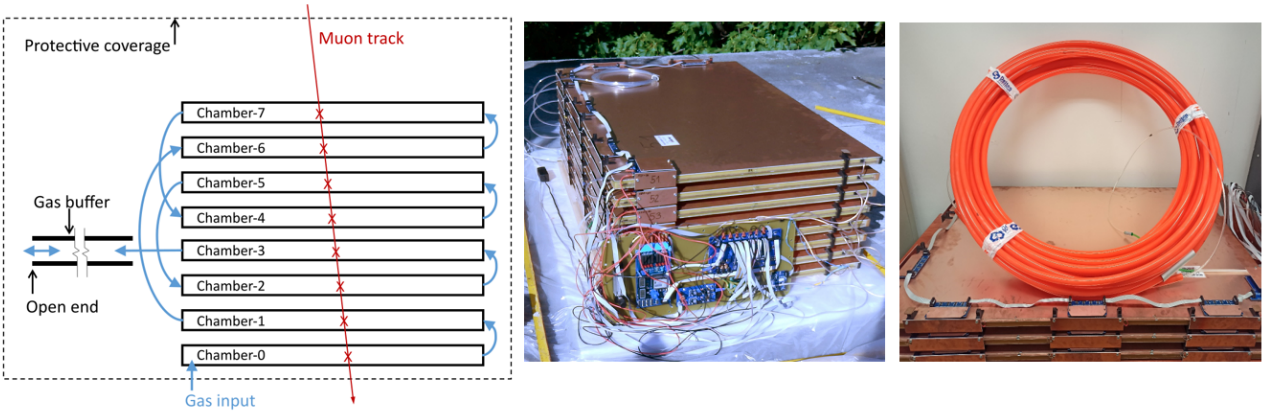

Figure 1. (Left) Scheme showing the detector setup with 8 MWPC chambers. The gas flows serially through the chambers, followed by a buffer tube with open end [3]. (Middle) The measurement setup installed outdoor, with light protective coverage removed. (Right) The buffer tube, attached to the detector setup.

× 80 cm tracking MWPC layers (each layer 11 kg) and a 50 m long 10 l volume PE-RT tube has been attached at the end of the gas line (Fig. 1).

2. Outgassing and diffusions

We quantify gas quality by measuring the gain (detector signal amplitude) loss caused by any contamination. The contamination due to outgassing, the diffusion through tubing walls (hereinafter called radial diffusion), and the diffusion from the open end (named axial diffusion) can be examined separately [3]. The first one has been measured in a sealed mode, meaning that the gas flow was zero during the gain measurement, and has been stopped long before air could reach the detector from the open end. The gain loss is linear with the contamination concentration inside the detector, and less than 0.3 %/day gain loss has been determined. For this type of MWPC, even 30% gain loss do not cause tracking performance loss due to the short ($\sim$1 cm) drift length, so the detector gas volume needs to be replaced at least in 100 days. The radial diffusion can be examined by attaching the examined tube between two chambers, and the relative gain loss found to be negligible if proper materials are used for tubing, e.g. copper, stainless steel, PU (polyurethane), PA (polyamide), or PE (polyethylene).

The third limiting factor, axial diffusion has been investigated by measuring the diffusion coefficient. For this, a test tube of variable length was attached to the exhaust of the last chamber in the gas chain, and at $t = 0$ the gas input of this single chamber was closed. Due to diffusion, the gas in the exhaust tube starts to be contaminated with air, which at some point reaches the detector. Then air diffuses into the sensitive volume, leading to decrease in the gain which can be translated to air concentration, shown in Fig. 2. The best fit of diffusion constant to the measurements is $D = 20.1 \pm 0.7$ mm^2/s, and due to Fick's laws this means that after 24 (6) hours the air contamination in a tube, originally filled with pure gas, is around 1250 ppm at a distance of 6 (3) m from the open end.

3. Breathing effect

This section is about the air backflow from open end due to temperature drop, called breathing effect. Assuming that the pressure and temperature inside the chambers follow the external

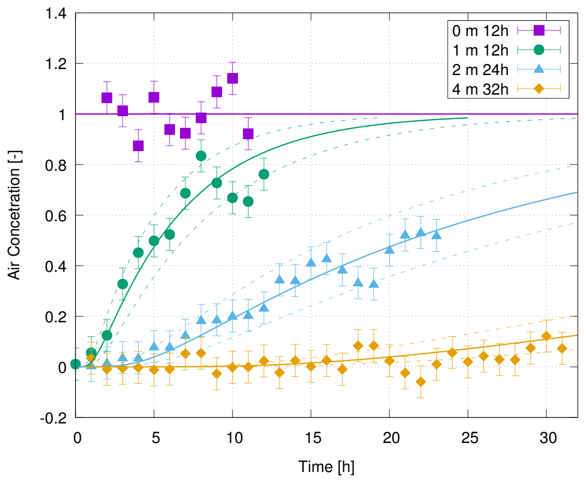

Figure 2. Air concentration at the detector end of the variable length exhaust tubes, obtained from the gain change rate. Continuous lines show simulations with a $D \pm 30\%$ bracket [3].

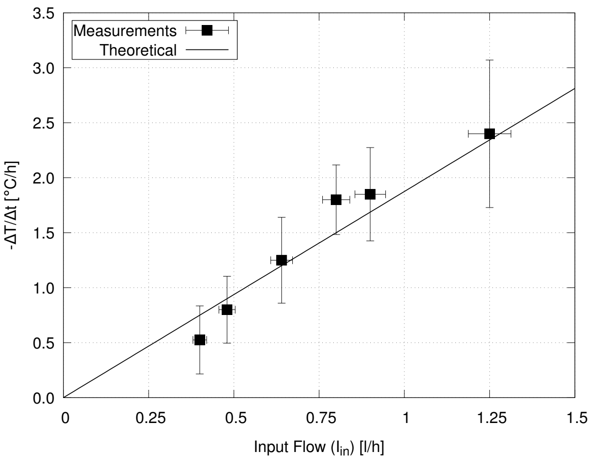

Figure 3. The critical temperature reduction rates at different flow values, where a sharp gain drop was observed due to air ingestion, in case of a 160 l total volume detector system [3].

conditions, the total mass of working gas stored varies strongly, following the gas laws. In field applications the daily temperature cycle is a major issue at low input flow: if the input does not feed sufficient working gas, external air may be drawn in through the exhaust. A series of measurements was performed to check the theoretical backflow phase boundary which is shown in Fig. 3, attempting to observe the gain drop when backflow occurs, and determine the corresponding critical temperature drop rate for various flow values. The required buffer volume can be derived from the gas laws in the following form: $V_{buffer} = V_0 \cdot (T'_{max} - T'_{min})$ [3].

4. Low flow outdoor test

Putting all together the information from the previous sections, a long term outdoor test was performed on low flow operation instead of the previously used 1-2 l/h. The detector setup was 160 l, thus due to outgassing, the 100 days replacement criterion puts a lower limit of 0.07 l/h, but we chose 0.12 l/h for margin of safety. The required minimal buffer volume derives from the breathing effect, so if an upper estimation of daily temperature change is 15 °K, it means a ∼5% gas volume change (8 l) in the detector setup, and an additional minimum 5 m length needed to restrain axial diffusion. Our design choice was a 10 l 50 m long PE-RT tube for gas buffer, and it was tested in a 50 days long outdoor measurement where there was no decrease in tracking efficiency [3].

5. Implementation examples

Practical implementation of the proposed structure is relevant e.g. at the Sakurajima Muography Observatory (SMO)[5]. Currently there are 11 MWPC-based modules, similar to the setup outlined in this paper. One year data showed that temperature gradient never goes below -1.6 °C/h, thus flow could safely be reduced from 2 l/h to 1 l/h based on Fig. 3, and ever since gain data show no significant drop. To further reduce gas flow, outgassing must be checked, as described in Sec. 2.

Another important application would be in underground muography (e.g. mining, speleology, archaeology), where remote operation and easy maintenance is crucial, because low flow operation would exempt maintenance from cylinder replacement. Technical implementation

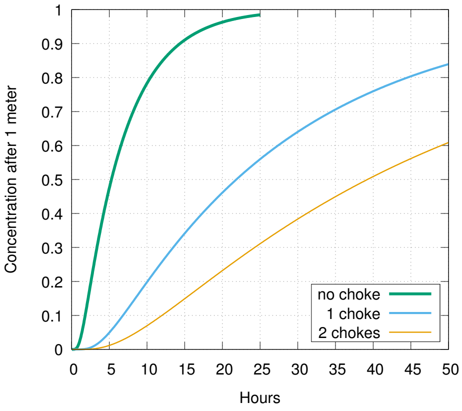

Figure 4. Simulations of air concentration if 4 mm diameter choke elements applied in a 1 m buffer tube. No choke element is the same as the 1 m case in Fig. 2.

of low flow can be achieved by precision flowmeters, simple needle valve with a calibrated permeation, or timed gas injections with electronic valve.

6. Conclusions and outlook

Gaseous detector technology in outdoor muography applications has a lot of advantages but an important issue is the continuous gas consumption. In this paper a summary of a method has been shown to reduce gas flow from 1–2 l/h to 0.12 l/h using the improved MWPC (MultiWire Proportional Chamber) detectors. The limiting factors are the contamination outgassing from the materials, diffusion of air through walls, diffusion from the open end, as well as the air backflow from open end due to temperature drop. The first two are a matter of material choice and must be checked in "sealed mode", the latter two limiting factor can be eliminated with a properly chosen buffer tube. The length and the diameter of the tube depends on the detector total volume and the applied gas flow.

Suggestions for further reducing the flow:

- Axial diffusion can be minimized with choke elements in the buffer tube (Fig. 4)
- Detector materials and construction revision to minimize outgassing
- If the intrinsic degradation of the gas is high, recirculation and absorbers can be used to maintain high intrinsic gas velocity and purity at low input flow [6]
- Fully sealed mode, if higher weight is allowed [7].

Acknowledgments

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References

[1] F. Sauli, *Gaseous Radiation Detectors*, Cambridge University Press (2014)
[2] H. K. M. Tanaka, and L. Oláh, Philos. Trans. R. Soc. A 377 20180143 (2018)
[3] G. Nyitrai, G. Hamar, and D. Varga, J. Appl. Phys. 129 244901 (2021)
[4] D. Varga, G. Nyitrai, G. Hamar, and L. Oláh, Adv. High Energy Phys. 2016 1962317 (2016)
[5] L. Oláh et al., Nucl. Instrum. Methods Phys. Res. A 936 57-58 (2019)
[6] S. Procureur et al., Nucl. Instrum. Methods Phys. Res. A 955 163290 (2020)
[7] S. Wuyckens, A. Giammanco, E. Cortina Gil, and P. Demin, Phil. Trans. R. Soc. A. 377 20180139 (2018)