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Detectors for alpha particles and X-rays operating in ambient air in pulse counting mode or/and with gas amplification

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ABSTRACT: Ionization chambers working in ambient air in current detection mode are attractive due to their simplicity and low cost and are widely used in several applications such as smoke detection, dosimetry, therapeutic beam monitoring and so on. The aim of this work was to investigate if gaseous detectors can operate in ambient air in pulse counting mode as well as with gas amplification which potentially offers the highest possible sensitivity in applications like alpha particle detection or high energy X-ray photon or electron detection.
To investigate the feasibility of this method two types of open-end gaseous detectors were build and successfully tested. The first one was a single wire or multiwire cylindrical geometry detector operating in pulse mode at a gas gain of one (pulse ionization chamber). This detector was readout by a custom made wide -band charge sensitive amplifier able to deal with slow induced signals generated by slow motion of negative and positive ions. The multiwire detector was able to detect alpha particles with an efficiency close to 22%. The second type of an alpha detector was an innovative GEM-like detector with resistive electrodes operating in air in avalanche mode at high gas gains (up to 10^4). This detector can also operate in a cascaded mode or being combined with other detectors, for example with MICROMEGAS. This detector was readout by a conventional charge -sensitive amplifier and was able to detect alpha particles with 100% efficiency. This detector could also detect X-ray photons or fast electrons. A detailed comparison between these two detectors is given as well as a comparison with commercially available alpha detectors. The main advantages of gaseous detectors operating in air in a pulse detection mode are their simplicity, low cost and high sensitivity. One of the possible applications of these new detectors is alpha particle background monitors which, due to their low cost can find wide application not only in houses, but in public areas: airports, railway station and so on.

KEYWORDS: Gaseous detectors; Electron multipliers (gas); Dosimetry concepts and apparatus.

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1. Introduction

In some applications, like dosimetry (see for example [1]) or therapeutic beam monitoring (see for example [2]) it is very attractive to use gaseous detectors operating in air. Indeed, various designs of ionization chambers operating in air were already developed, built and nowadays are successfully used not only in research laboratories but also in many practical applications (see for example [3]).

The aim of this work is to investigate if for some applications, for example for alpha particle detection or X-ray detection one can use gaseous detectors operating in ambient air in pulse counting mode, such detecting an alpha particle or an X-ray photon by its individual charge pulse. In contrast to traditional air filled ionization chambers which measure and averaged ionization current, this approach offers higher sensitivity as well as a capability of evaluating the pulse- height spectrum of the radiation.

Of course, operating an air filled chamber in pulse mode is difficult because one has to deal with slow signals induced by slowly moving negative and positive ions and this imposes special requirements to the detectors geometry and to the front-end electronics.

To investigate the feasibility of this method, two types of open-end gaseous detectors were built and successfully tested. The first one was an open-end single wire or multiwire cylindrical geometry detector operating in pulse mode at a gas gain of one (pulse ionization chamber).

The second type alpha detector was an innovative GEM-like detector with resistive electrodes operating in air in avalanche mode at high gas gains (up to 10^3). This detector can also operate in a cascaded mode or be combined with other detectors, for example with MICROMEGAS.

As will be shown below the second type has much better signal to noise ratio and as a result-higher sensitivity. This allowed us to detect not only individual alpha particles, but also single high energy X-ray photons.

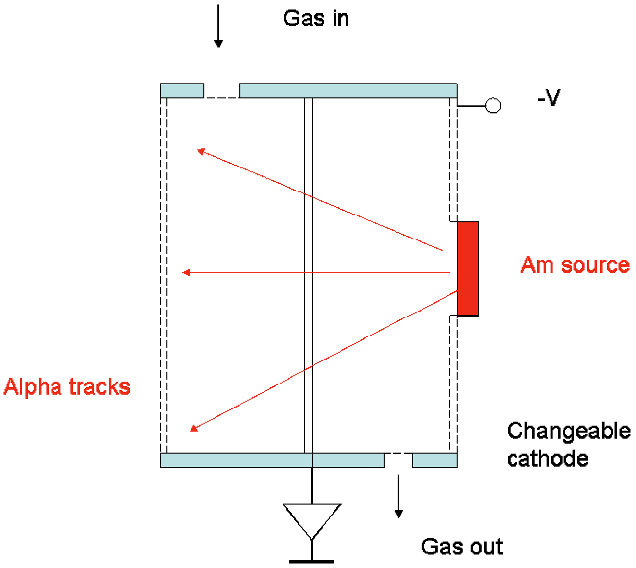

Figure 1. A schematic drawing of the single-wire pulse ionization chamber.

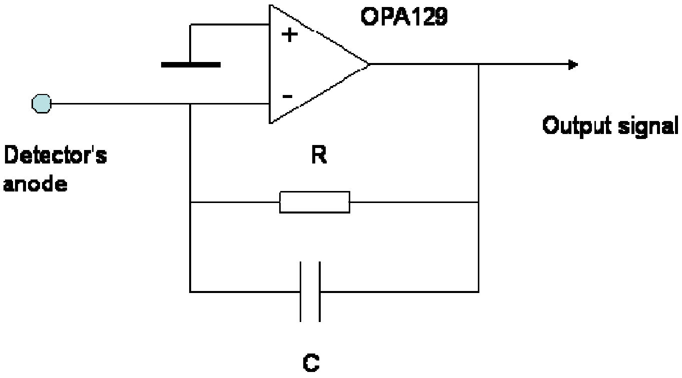

Figure 2. A schema of the custom made amplifier.

We will report below our experience in developing and testing of such detectors.

2. Pulsed ionization chamber

2.1 Design and experimental set up

Our first attempt was to develop a very simple gaseous detector for alpha particles operating in air in pulse counting mode at a gain of one and study its advantages and disadvantages. As was mentioned above, for this particular application operation in pulse counting mode should ensure high sensitivity compared to the conventional ionization chamber operating in current mode. For these studies we have developed and tested two designs of detectors: a single-wire and a multiwire detector. The schematic drawing of the single –wire detector is shown in figure 1. It was a coaxial chamber with a positively biased anode wire of 0.2-2 mm in diameter and with an exchangeable cathode cylinder with diameters ranging from 14 to 120 mm. All outer cylinders had holes along the surfaces covered with 3 μm thick Mylar films to which an ^{241}Am alpha source could be attached. The inner wire was connected to the custom made charge-sensitive amplifier (see figure 2) and the high-voltage (HV) was applied to the outer cylinder. The signals

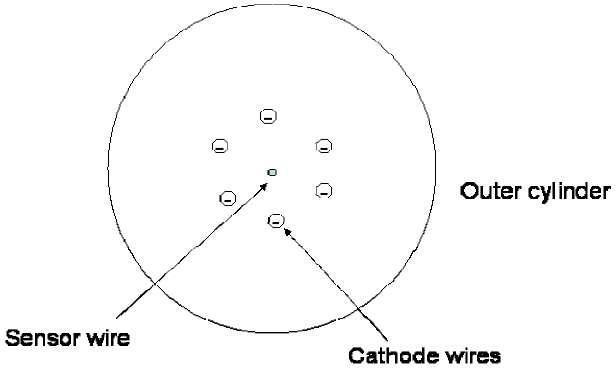

Figure 3. A schematic drawing of the multiwire pulse ionization chamber. For simplicity only one section of wires arranged in an hexagonal order is shown.

from the amplifier were sent to a personal computer where they were treated and viewed using a LabView program. One could monitor at the same time the analog signals from the detector, the counting rate and the pulse-height spectra of the pulses. The program allowed also to reject pulses with very small and very high amplitudes and pulses with "untypical" shape, for example very narrow signals or those which do not reach maximum at one third of the pulse duration.

The schematic drawing of the multiwire detector is shown in figure 3. It was a metallic cylinder with a diameter of 120 mm. Inside this cylinder wires with a diameter of 0.25 mm (sensor wires) and 2 mm (HV wires) were stretched in a hexagonal order The sensor wires were connected to the charge- sensitive amplifier, whereas the HV wires were connecter to the HV power supply.

Because our amplifier was optimized for slow induced signals, it had a rather high sensitivity to various vibrations including acoustic noise, which affects the signal to noise ratio. To solve the acoustic problem the chamber was suspended inside the metallic shielding box on rubber strings (see figure 4).

Both detectors can operate in open air or, if necessary flushed with gas, such as Ar. The gas-flushed detectors were used for evaluating their efficiency with no trapping of the alpha-particle-produced primary electrons by oxygen or other electronegative molecules.

Due to the high drift velocity of primary electrons in Ar the signals produced by alpha particles were easy to detect not only with our custom made preamplifier, but even with a commercial charge-sensitive amplifier from CAEN. After amplification by a research amplifier and discrimination the pulses were counted by a scaler.

2.2 Test with alpha particles

2.2.1 Single-wire detector

The activity of the ^{241}Am source coated with a 3 μm Mylar film was measured with a custom made dosimeter consisting of a BaF_2 scintillator attached to an EMI-9426 UV- sensitive photomultiplier (PM). The pulses from the PM were amplified, discriminated and counted by a scaler. One should note that the BaF_2 scintillator has a noticeable background counting rate N_b due to the radioactive contaminations inside the crystal. Thus the number of counts/s produced by the alpha source should be calculated taking into account this background counting rate;

$$N_{alph} = N_m - N_b, \tag{2.1}$$

where N_m is actual counting rate measured by the PM when the alpha source was attached to the BaF_2 surface.

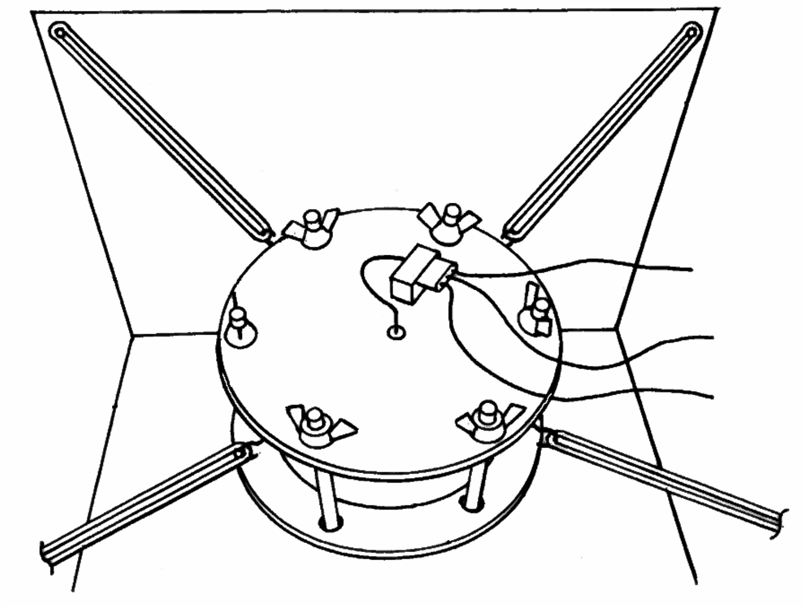

Figure 4. A schematic drawing of the pulsed ionization chamber suspended by rubber strings.

In such measurements it was very important to correctly adjust the electronic threshold to avoid extra counting caused by 60 keV photons emitted by ^{241}Am. For this in the first set of measurements we coated the alpha source with an Al foil, thus fully stopping the alpha particles, and detecting only the BaF_2 background pulses and the pulses produced by 60 keV X-rays. This allowed us to set the threshold of the counting electronics to a level where the counting rate due to the 60keV photons was fully suppressed. After this electronic adjustment the Al foil was removed and we measured the counting rate produced by BaF_2 radioactive background and by alpha particles N_m.

These measurements revealed that our alpha source produced a count rate of N_{alph} = 132 counts/s.

Since this number was very important for all further calculations we also measured independently the activity of the Am source using the commercial alpha detector Automess 6150 AD-k. This detector measured ~ 120 counts*/s*- close enough to the BaF_2 data.

The final set of calibration measurements was performed with a single-wire detector using a cathode of diameter 120 mm. The chamber was flushed with Ar. The alpha source was attached to one of its Mylar windows. The short-duration signals produced by alpha particles in Ar were detected with the commercial CAEN charge-sensitive amplifier. After amplification by a research amplifier and discrimination the pulses were counted by a scaler. The counting rate produced by alpha particles and by the natural radioactive background was 145 counts/s and the background counting rate (the alpha source was covered by an Al foil) was 3counts/s. This allowed us to conclude that the alpha particles counting rate was N_{Ar} ~ 140counts/s.

This value is even slightly higher than the one measured by the BaF_2 scintillator and by the Automess dosimeter. Therefore we assumed that after flushing our detector with Ar it has 100% detection efficiency for alpha particles. This higher sensitivity can be explained by the fact that, in contrast to the BaF_2–based detector or to the Automess 6150 AD-k, the gaseous detector is more sensitive to alpha particles which are emitted at smaller angles relative to the surface of the Am-source.

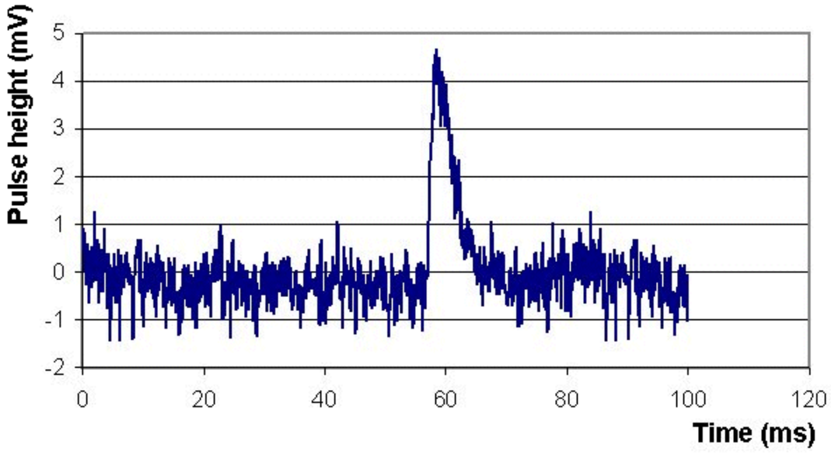

Figure 5. A pulse from the custom-made preamplifier produced by an alpha particle.

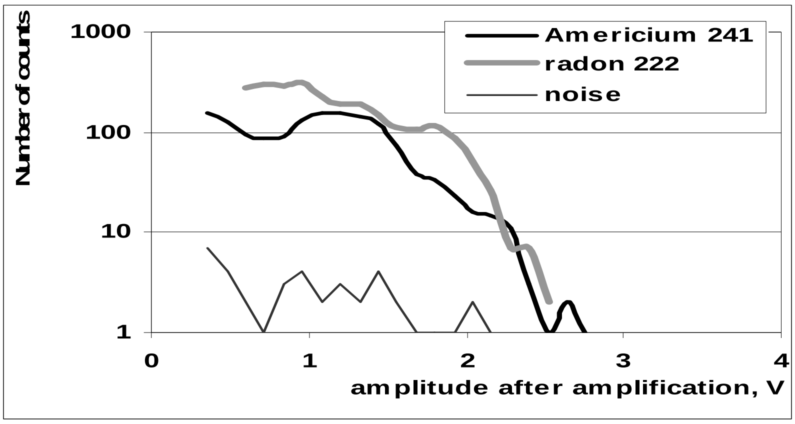

Figure 6. Pulse-height spectra measured with the single-wire pulse ionization chamber operated in air.

After these calibrations we performed measurements with single-wire detectors using cathodes of various diameters D and all filled with ambient air. Of course, in the case of the air filled detector the “fast” preamplifier becomes insensitive to slow signals on anode wires induced by negative and positive ions, so all further measurements were performed with the “slow” custom made charge-sensitive preamplifier. As an example, figure 5 shows the alpha particle signal detected by this amplifier at the condition of an exceptionally low level of acoustic noise and figure 6 shows the pulse-height spectra.

The efficiency of the pulse ionization chamber to alpha particles can be defined by the following relation:

$$\xi = \{N_{air}(D)-N_n(D)\}/N_{Ar}, \qquad (2.2)$$

where $N_{air}(D)$ is the counting rate measured with the single-wire counter using a cathode of diameter D. $N_n(D)$ is the counting rate with the Am-source covered by an Al foil.

The measurements were performed at two different conditions:

a) At a constant voltage V = const = -6kV applied the cathode cylinder

b) At constant electric field near the anode wire (E = const, corresponding to -6kV applied voltage at D = 20mm; at large diameters the applied voltage was logarithmically increased with D).

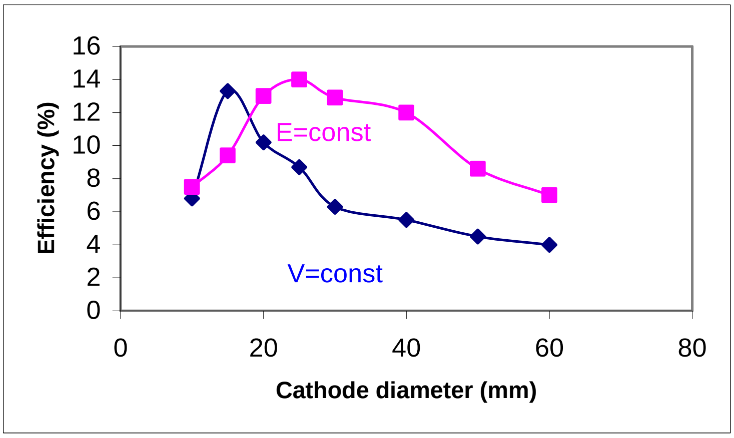

Figure 7. Efficiency of the single-wire ionization chamber as a function of the cathode diameter D measured with ^{241}Am source. The anode diameter was 0.25mm.

The results of the measurements are presented in figure 7. One can see that the maximum achievable efficiency for alpha particle detection in air is around 13-14.5 % and the efficiency curve remains higher at larger cathode diameters for the case of a constant electric near the anode wire. The drop of the efficiency towards higher D can be attributed to the increased electron recombination in the region of weak electric field near the cathode and the smaller contribution of the positive ions to the pulse shape formation. Due to the programmed pulse-shape rejection algorithm and the very small signal to noise ratio the counting rate measured by the LabView program is therefore reduced for events, where the alpha particle originates from areas close to the cathode. However, for the case of alpha particles which are uniformly created in the gas volume (which is for example the case for radon detection in air) the efficiency curve will depend much less on D. Therefore, in this case it will be more favorable for obtaining a high radon detection sensitivity to use detectors with large cathode diameters of up to 120 mm, and apply rather high voltages of the order of 8 kV.

One should note that for the case of thin anode wires (<0.25 mm) and at V>4 kV the signal (and thus the signal to noise ratio) began rapidly to increase with the voltage due to the appearance of gas multiplication.

2.2.2 Multiwire detector

Based on the results presented in figure 7 it is clear that the single-wire detector reaches the efficiency of ~15% for alpha particle detection only at rather high voltages applied to the exchangeable cathode cylinders. In the case of the multiwire detector the effective diameter of the cathode (formed by hexagonally arranged cathode wires) was ~30 mm. However, the anode wires used had rather small diameters (0.25 mm). Therefore, to avoid discharges during the efficiency measurements, they were performed at 4.5kV. In these measurements one or several anode wires were connected to the charge-sensitive amplifier. The results are presented in figure 8. One can see that the efficiency first increased with the number of wires connected, reached the maximum at three wires and then started to decline. This drop of the efficiency was obviously due to the increase of the detector capacity; indeed we observed that the signal amplitude started dropping when more than 3-4 wires were connected to the charge-sensitive amplifier whereas the acoustic noise strongly increased. Probably better results can be obtained if several amplifiers are used simultaneously, each one connected to only a few or even a single wire.

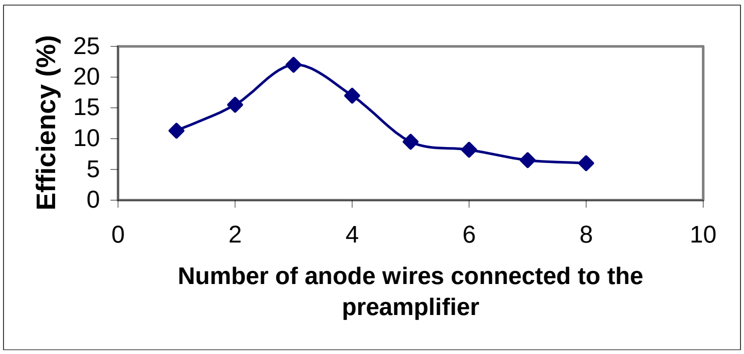

Figure 8. Efficiency of multiwire ionization chamber measured with ^{241}Am alpha source.

However, the maximum efficiency obtained (22 %) may be sufficient for some applications where the cost and complication of the detector is unnecessarily increased with the number of amplifiers used. Certainly the detector design can be further optimized to satisfy the demands of a particular application.

3. Operation in air in avalanche mode

As is evident from the results presented above, the efficiency of the alpha particle detection by the pulse ionization chamber is below 100% due to the low signal-to-noise ratio.

The detector requires very good isolation measures against vibration and acoustic noise. Such protective measures were successfully developed and implemented [4], but make the detector rather bulky and fragile and restrict its applications outside the Laboratory.

To increase the signal to noise ratio we tried to exploit the effect of gas multiplication in air. One should note that the avalanche development in air was carefully studied before (see for example [5]). It was discovered that operation in air is not very stable and initial avalanches may easily transit to discharges via a photon feedback mechanism. Probably for this reason the multiplication in air was not exploited so far in any practical device. Indeed, our own tests with single-wire chambers operating in air with gas gain reveal that gains close to 10^3 can be achieved with gamma radiation (^{60}Co was used); however the operation at this gas gain was unstable.

Recent developments of hole-type multiplication structures [6]-[8] open new possibilities; indeed in these detectors, due to their geometric features, the photon feedback is strongly suppressed. This is why our further experiments and developments were focused on hole- type multiplication structures.

3.1 Experimental set up and the detector's design

Our experimental set up is shown in figure 9. It contains a gas chamber where various hole - type multiplication structures can be installed and tested. The distance between the drift mesh and the hole-type multiplier can be varied from 1 to 4cm. The gas chamber can be flushed with various gas mixtures or filled with ambient air.

The ionization inside the chamber was produced by an ^{241}Am or by a ^{55}Fe source (one should note that the Am source used in these measurements was not the same as the one used before with the pulsed ionization chamber). Each of the sources could be closed by special shutters, which allowed us to verify that observed signals were caused by these sources and not by spurious pulses. Because the signals from the hole-type multiplication structures had high amplitudes and were rather fast (in Ar and Ar-based mixtures) conventional Ortec or CAEN

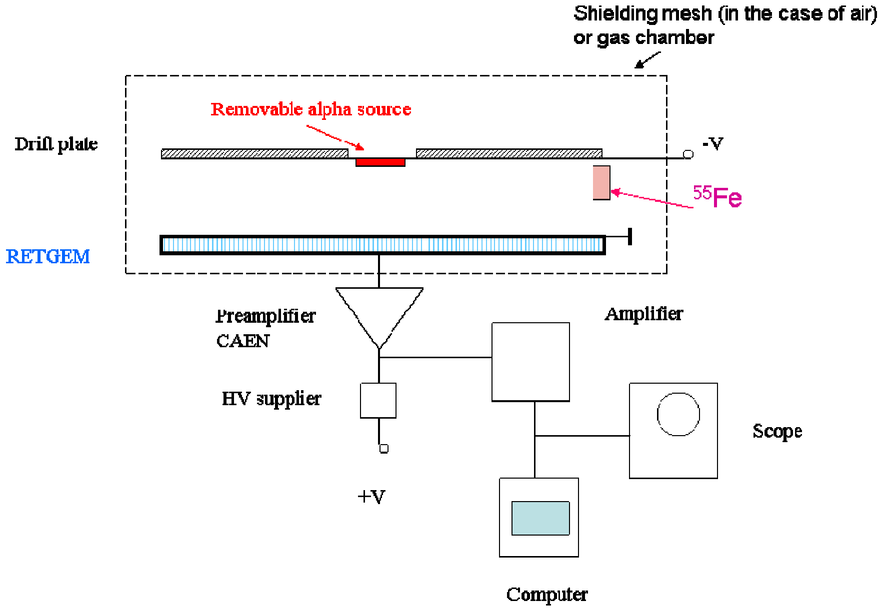

Figure 9. A schematic view of the experimental set up used for studies of the Resistive Electrode Thick Gas Electron Multiplier (RETGEM) operation in air. Typically the upper electrode of the RETGEM was grounded and a positive voltage was applied to its bottom electrode.

charge- sensitive amplifier were used for their detection. The pulses, after the amplification by a research amplifier, were then sent to a personal computer where they were treated and viewed using a LabView program.

Our first attempts to achieve multiplication in air were done with a GEM [8] and also with so called “optimized” or “thick” GEM (TGEMs) [9], however, both of these detectors, especially the GEM, were not able to operate with sufficient stability for an extended period in ordinary, ambient air containing dust particles. To solve this problem we invested quite a lot of efforts to develop more robust versions of TGEM, using Cr electrodes coated with thin high-resistivity CrO layers (see figure 10) [10]. The important feature of this detector were dielectric rims around the holes, 0.1-0.2 mm thick and manufactured by photolithographic technology. We called this detector Resistive Electrode TGEM or RETGEM. High resistivity coating together with dielectric rims made this detector extremely robust, enabling it to operate in air containing dust.[1] RETGEMs with the following geometrical characteristics were used in this work: thickness 0.5 -1mm, diameter of holes 0.3-0.5 mm, pitch 0.6-0.8 mm.

The experiments and tests described below demonstrated that an air filled detector based on RETGEM (single RETGEM or two RETGEMs operating in cascade- see below) are very promising devices allowing to detect not only alpha particles in air with 100% efficiency, but also soft X-rays, for example 60 keV X-ray from ^{241}Am. Moreover, RETGEM can be used in combination with other detectors, for example MICROMEGAS and this double multiplication structure also can operate stable in ambient air.

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[1] Although dust particles on the dielectric rims cause field line concentration on their sharp surfaces due to their polarization, this does not provoke discharges since there is no low-conductivity path for a large discharge current.

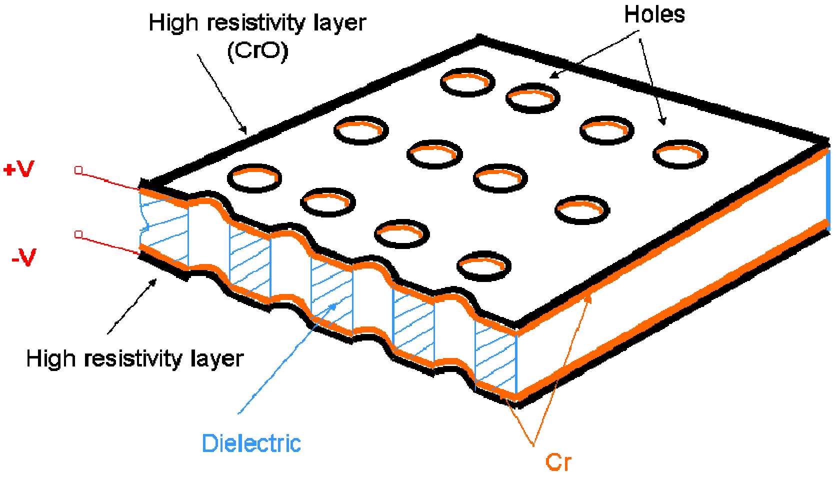

Figure 10. A schematic drawing of a RETGEM with double layer Cr/CrO electrodes.

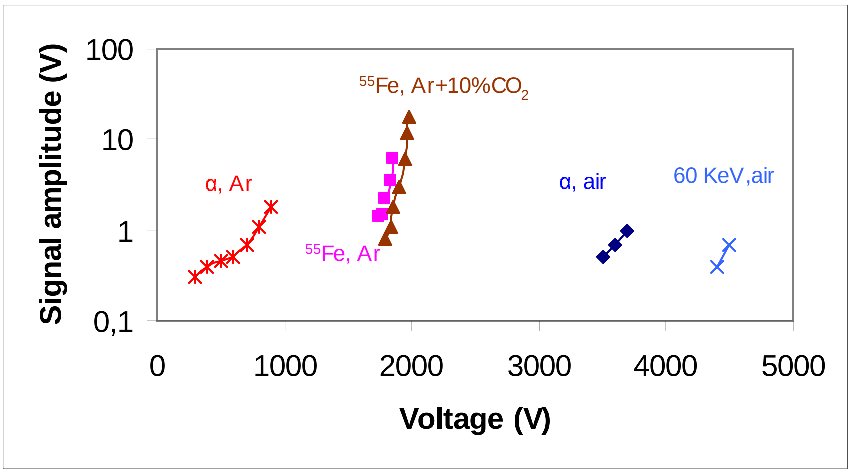

Figure 11. Signal amplitude vs. voltage measured with a RETGEM (holes 0.3 mm) in Ar (alpha particles and 6 keV photons, labeled “^{55}Fe”), Ar+10%CO_2 (6 keV photons) and in air (alpha particles and 60 keV photons).

3.2 Results obtained with RETGEMs

3.2.1 Single RETGEM

Because the oxide- coated RETGEM is a novel device, we made careful studies of its operation. First tests were made in gases and gas mixtures in which ordinary GEM and RETGEM were studied earlier. These comparative studies allowed for a better understanding of the properties of the RETGEM. The final tests of course were done in ambient air. Some of our results are presented in figure 11 and figure 12, showing the signal amplitude (raw data) from the research amplifier vs. the voltage applied to the RETGEM electrodes in various gases: Ar and Ar+10%CO_2. Figure 11 corresonds to the RETGEM 1mm thick with holes diameter of 0.3 mm whereas figure 12 shows the data obtained with the RETGEM having 0.5mm holes. Our charge -sensitive amplifier was calibrated by the charge injection method [10] so from the amplitudes of the signals in Ar and Ar+ CO_2 one can calculate the gas gain. For example, in the case of the ^{55}Fe a 10 V signal corresponded to a gain of ~10^4. Independently, this calibration was verified from the data obtained with alpha particles. As one can see from figure 11 in Ar at applied

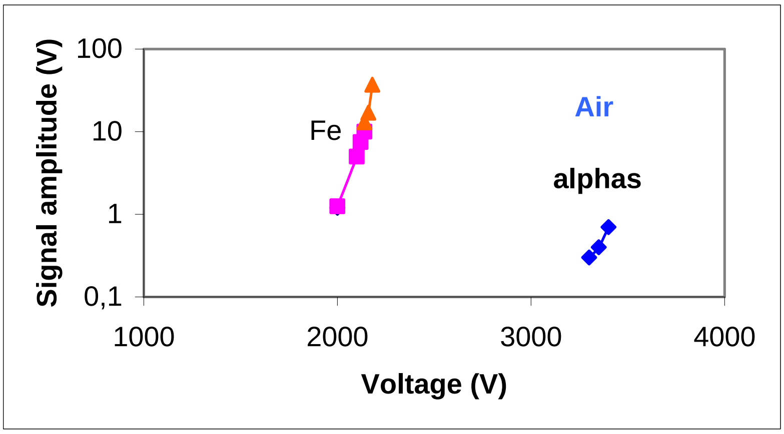

Figure 12. Signal amplitude vs. voltage measured with RETGEM (holes 0.5 mm) in Ar (rose) and in Ar+10%CO_2 (orange) with 6 keV photons and in air (blue) with alpha particles.

voltages to the RETGEM electrodes of 450- 600V the alpha signals could easily be detected at a gain of one (a plateau in the signal curve); the avalanche multiplication only began at voltages of more than 600V. The number of primary electrons in the collection mode (in the voltage interval of 450-660V) could be rather precisely calculated which gave a reliable calibration cross-check.[2] Note that signals produced by ^{55}Fe appeared at much higher voltages than signals produced by alpha particles because the primary ionization induced by the 6 keV photons is much smaller than for the alpha particles. Therefore, to achieve the same signal amplitudes for 6 keV photons and alpha particles higher gains are required for the photons.

From the figure 11 and figure 12 one can see that signal amplitudes of 0.5 -1 V were measured with alpha particles in air at voltages applied to RETGEMs more than 3200V. However, the gas gain in air could not be calculated easily. It is known that for electronegative gases [11], including air, mainly negative ions reach the hole- type structure (most of primary electrons created by alpha particles are captured by oxygen molecules). However, in the strong electric field inside the holes some of these electronegative ions loose the attached electrons (by the so-called electron detachment effect [12] and these free electrons trigger Townsend avalanches. A priory the fraction of detached electrons is not known precisely, so one cannot calculate the gas gain simply from the measured signal amplitude as it was possible for Ar and Ar+CO_2. For estimation of the gain in air we used results of measurements performed in current mode –see [13] for more details. The conclusion was that in the voltage interval of 3500-4500V the gains were 10^2-10^3 respectively. In this work, however we were mostly focused on determination the detector efficiency for alpha particles in air as it is the most important property for a practical detector. As in the case of the pulse ionization chamber described above, we determined the efficiency as a ratio of alpha counting rate, measured with the RETGEM in air and in Ar;

$$\xi_{RETGEM} = \{N_{air}-N_{nair}\}/N_{Ar} \qquad (3.1)$$

where N_{nair} is the counting rate in air when the alpha particles were shielded by an Al foil.

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[2] We also measured the alphas signals vs. applied voltages to the drift electrode when the top and the bottom RETGEM electrodes were interconnected and their combined signal was fed to the charge-sensitive amplifier. The signal amplitudes increased with voltage up to a 200 V and saturated above that level. The mean value of the signal amplitude in the saturation region was 0.5 V-almost the same as in figure 11 in the plateau's region.

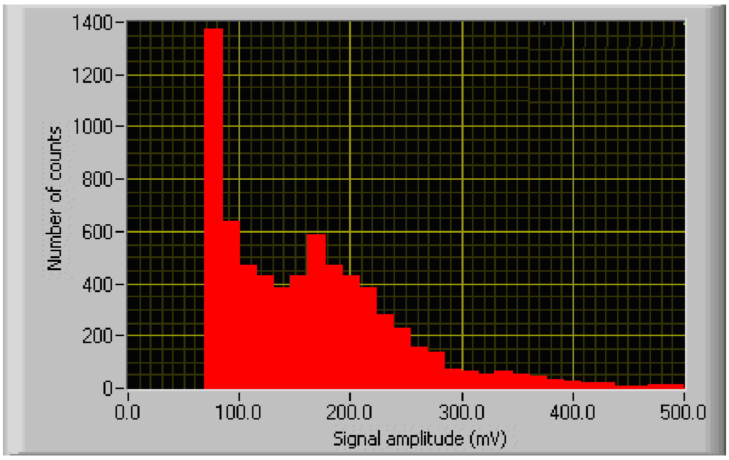

Figure 13. A print of the LabView screen showing a pulse-height spectrum of alpha particles measured with a single stage RETGEM operating in Ar at a pressure of 1 atm.

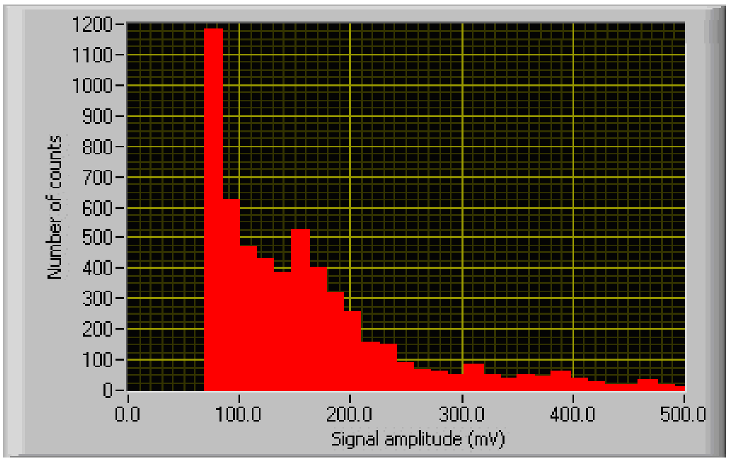

Figure 14. Pulse-height spectrum of alpha particles measured with a single stage RETGEM operating in air. The voltage across the RETGEM was 3200 V, the thickness of the drift gap 2 cm.

Figure 13 and figure 14 show pulse-height spectra produced by alpha particles in Ar and air respectively.

Note that alpha particle and 60keV photons produced a bunch of small pulses which were “smeared” by the amplifier and counted by the computer as a single pulse. The longest pulse duration was in air, the scaler however still counted this “integrated” pulse as one event. The average alpha counting rate in Ar was $N_{Ar} = 120$ counts/s whereas the average counting rate of the RETGEM operating in air was $N_{air} = 95$, thus the detection efficiency in air was 80% - almost 4 time higher than in the measurements with the pulse ionization chamber (N_{nair} and N_{nAr} were ~0).

Note that the RETGEM-based detector was not very sensitive to vibrations and thus can be used in harsher conditions than the pulsed ionization chamber.

During the long term tests of the RETGEM operation in air it was observed that during those days where the humidity of the ambient air was high (>30%), spurious pulses appeared. These pulses disappeared when the gas chamber was flushed with dry air. To suppress this undesired effect we modified our device by adding a second RETGEM operating in tandem with the first RETGEM.

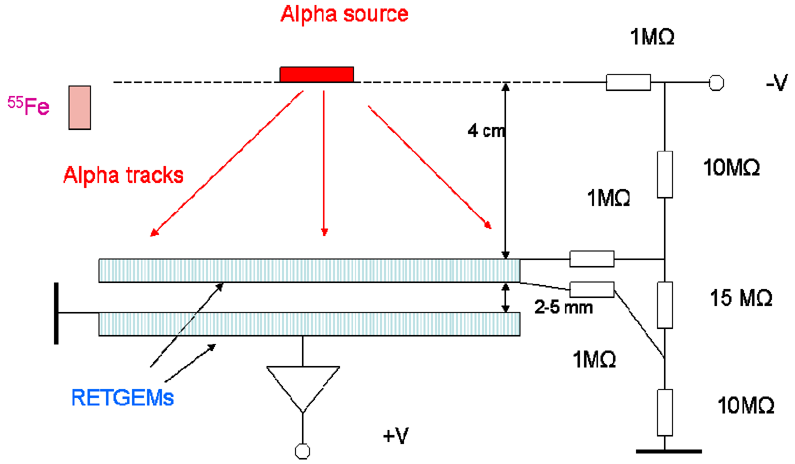

Figure 15. A schematic view of the double RETGEM feed with voltages via a resistive divider chain.

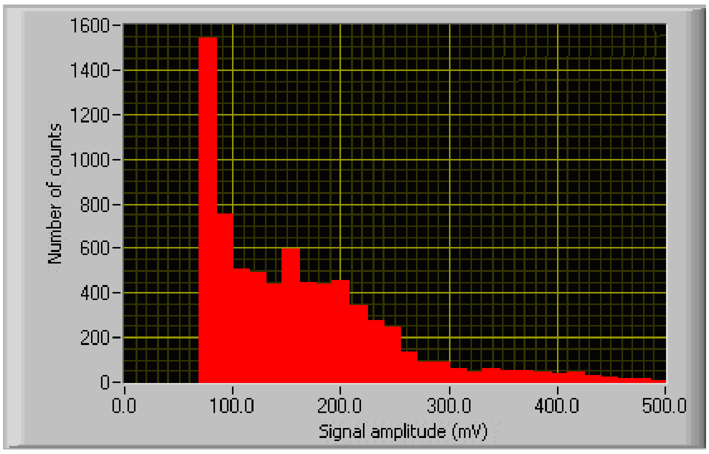

Figure 16. Pulse height spectrum obtained with a two- stage RETGEM detecting alpha particles in Ar. Detection efficiency for alpha particles was 100%.

3.2.2 Double -stage RETGEMs

The schematic drawing of the double RETGEM is shown on figure 15. The HV to the detector's electrodes were applied using a resistive divider. Systematic tests of this detector showed that in contrast to the single RETGEM, the double RETGEM could operate in ambient air at much higher stability - even at a humidity level close to 70%. Presumably this is due to the lower voltage across each RETGEM in a two-stage configuration than in the case of the single RETGEM detector. Thus the charge leaks due to the humidity were smaller. In addition, if necessary, a higher amplitude of the output signal could be achieved before the sparking appeared. Thus we consider double RETGEM as being more suitable for a practical alpha detector operating in air.

For curiosity we also flushed our detector with air of 100% humidity. In this case a leak current appeared between the detector electrodes, however, 10 min after the flushing with humid air was stopped the detector returned to normal operation.

Figure 16 and figure 17 show the pulse-height spectrum corresponding to the measurements with the double RETGEM in Ar and air respectively. By comparing the spectra presented in figure 13 and figure 14 with those in figure 16 and figure 17 one concludes that the energy resolution degraded in the case of the double-stage RETGEM. This is well known also for double-stage GEM-like detectors (see for example [14]).

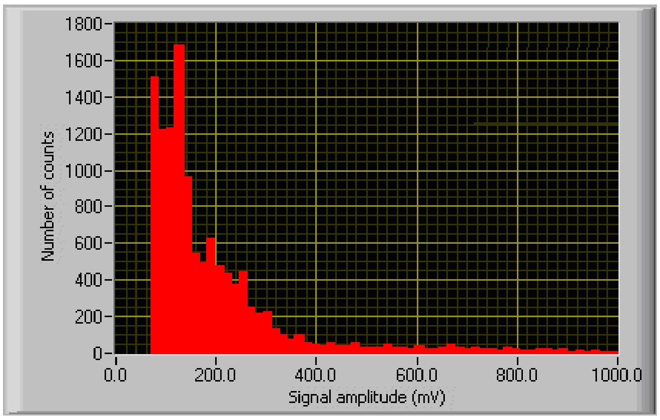

Figure 17. Pulse-height spectrum of alpha particles in air measured with double RETGEM. The voltage on the resistive divider was -6kV, the voltage across the bottom RETGEM was 3.6kV.From the counting rate value one can see that efficiency of alpha particles detection was 100%.

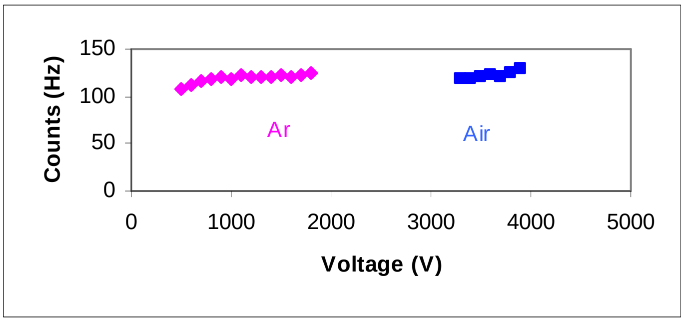

Figure 18. Counting rate vs. voltage applied across the bottom RETGEM measured in Ar and air.

By comparing the measured counting rates in Ar and air we conclude from eq. (3.1) that with the cascaded RETGEM an efficiency of ~100 % was achieved in air.

The results of the detection efficiency measurements vs. the applied voltages are shown in figure 18. One can see that a very good counting-rate plateau was achieved.

In another set of measurements we tried to determine whether the higher efficiency (~100%) is due to the fact that alpha particles hit directly the top electrode of the RETGEM and thus the RETGEM might have detected only those electrons and negative ions which were created close to its holes. To verify this we changed the position of the source as shown on figure 19: the alpha source was placed 2 cm above the top RETGEM and its active part faced the drift mesh. In this geometry alpha particles could not hit the RETGEM surface. The detector efficiency measured in this condition in air was also 90%. This measurement clearly indicated that electronegative ions could drift a distance of more than 2 cm before entering the holes of the RETGEMs where the electron detachments and avalanche development occurred.

3.2.3 RETGEM+MICROMEGAS

As was mentioned above, the main reason why the hole- type detector can operate with good stability in air is because in this geometry the photon feedback from the cathode is strongly suppressed. On the other hands, our earlier studies showed that the ratio of the number of emitted photons from the Townsend avalanche relatively to the avalanche electrons drops when the electric field is increased [15]. This suggests that in detectors with higher electric field in the amplification gap the light emission from a given electron avalanche will be relatively lower.

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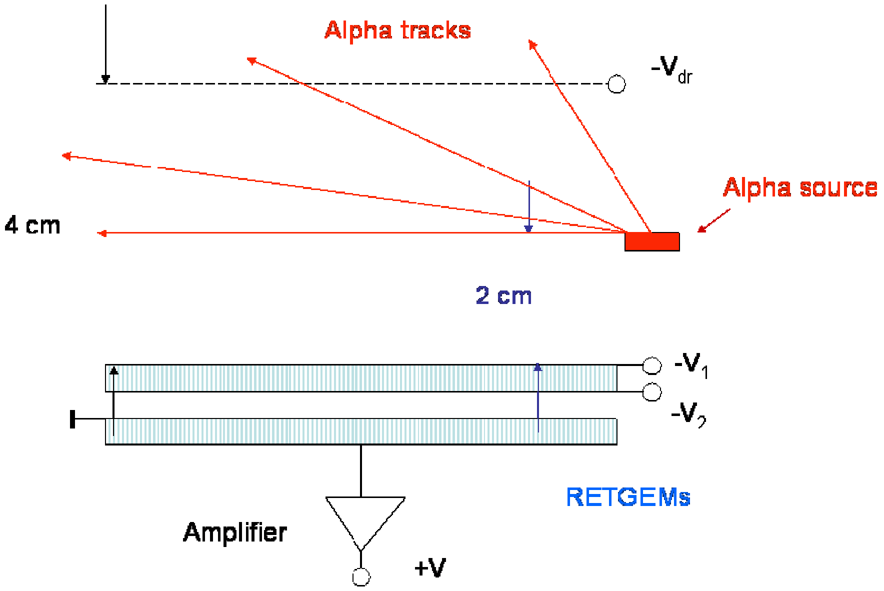

Figure 19. A schematic drawing of the measurements with the alpha source facing the drift mesh. An efficiency of 90% was achieved in this geometry. Thus electronegative ions can be drifted at least 2 cm in air and then trigger avalanches in the RETGEM holes.

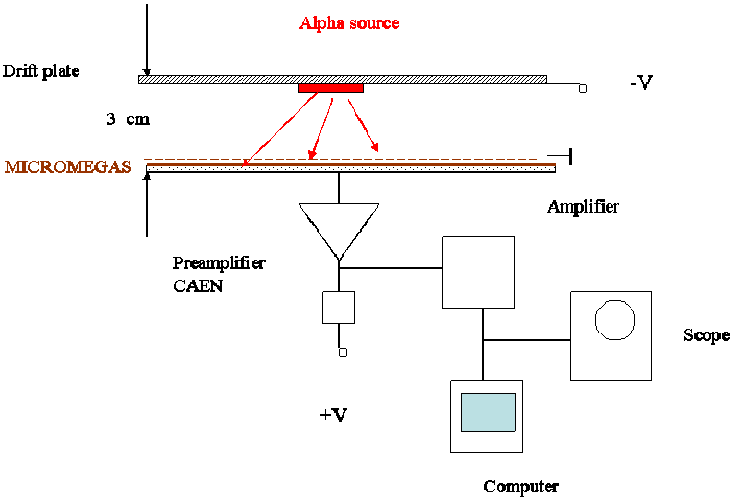

Figure 20. A schematic drawing of the experimental set up for test of MICROMEGAS operation in air.

An example of such an amplification element could be MICROMEGAS [16] which has a very strong electric field in the multiplication gap. So it was interesting to check whether with MICROMEGAS one can achieve higher multiplication in air compared to single -wire counters or ordinary parallel-plate chambers. To answer this question we installed MICROMEGAS in our gas chamber (see figure 20) and performed measurements with alpha particles in various gases including ambient air. Some results are shown in figure 21. One can see that signal amplitudes in the interval 0.5-1 V were observed in air with MICROMEGAS.

Unfortunately the MICROMEGAS operation in ambient air was unstable; large amplitude spurious pulses appeared quite often and triggered discharges in the MICROMEGAS. We attributed this unstable operation to the charge leaks across the MICROMEGAS spacers caused by humidity. Indeed in dry air the MICROMEGAS operation was much more stable.

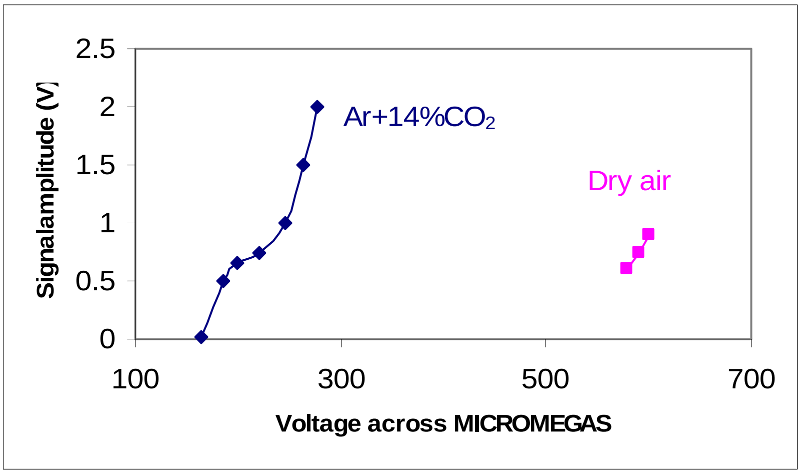

Figure 21. Signal amplitude vs. voltage applied across MICROMEGAS measured in Ar+14%CO_2 and in dry air.

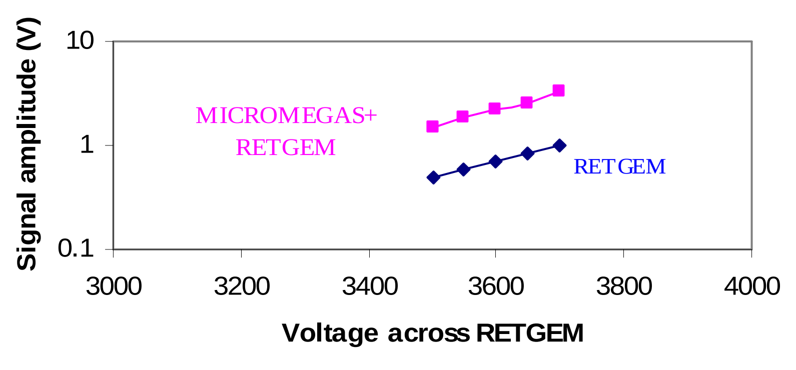

Figure 22. Amplitude of the alpha signal vs. the voltage applied across the single RETGEM (blue) and for the case of the same RETGEM operating in cascade with MICROMEGAS (rose).

To solve this problem of unstable operation we assembled and tested MICROMEGAS operating in cascade mode with the RETGEM placed a few mm above the MICROMEGAS and used it as a gas gain booster. Indeed, in this detector configuration a stable operation was achieved. In figure 22 signal amplitude curves for single RETGEM and RETGEM combined with MICROMEGAS are shown, from which one can conclude that MICROMEGAS allowed to boost the overall gain by a factor of 5. An important advantage of this approach is that the overall voltage applied to such two-stage detector is lower than for double RETGEMs. This lower operation voltage can be attractive in practical applications.

4. Summary and outlook

Two types of alpha particle detectors operating in ambient air in pulse counting mode and /or with gas multiplication were developed and tested in this work. The first one is a pulsed ionization chamber able to detect individual pulses produced by Am alpha particles with 15-22% efficiency. This relatively low efficiency was due to the sensitivity of our custom made amplifier to various vibrations and acoustic noise. The single -wire version of this detector was already used for detection of Rn in ambient air. As an example figure 23 shows results of the Rn

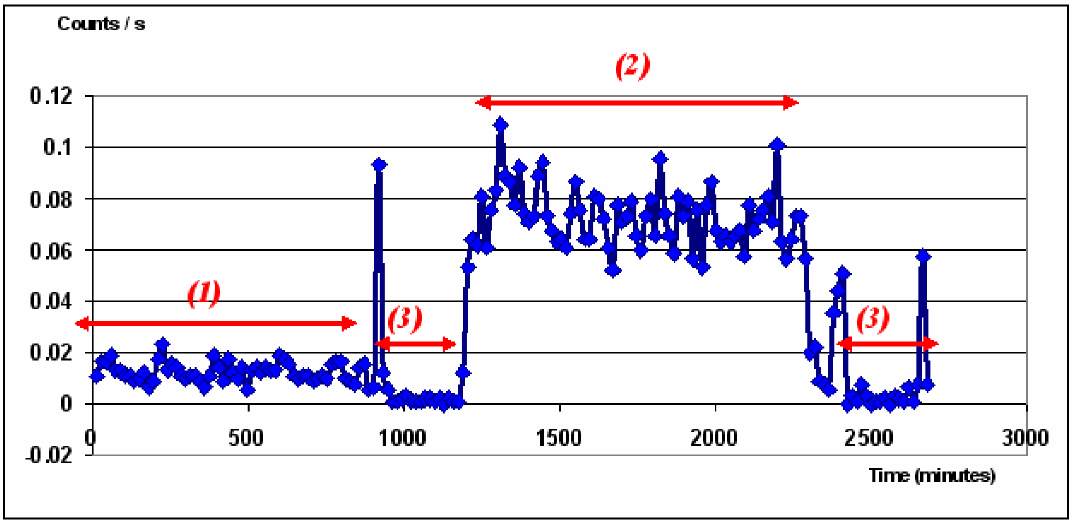

Figure 23. Results of measurements of the Rn background with a single-wire pulsed ionization chamber: 1-Counting rate measured in the laboratory, 2-counting rate measured in the basement, 3-the single wire counter was flushed with fresh air taken from outside the building.

measurements in our laboratory at Ecole des Mines in St. Etienne and in the basement situated just under the Laboratory. One can clearly see the increase of the Rn (and its decay chain daughters) concentration by a factor of five in the basement One should note that in contrast to the Am source, which was attached at a well defined place at the detector cathode cylinder, the Rn alpha tracks are randomly distributed inside the detector volume and in many cases their signals were below the electronic threshold of the counting system, which was set sufficiently high to cut parasitic acoustic noise. As a result the sensitivity of our single -wire detector to Rn was 40 Bq/m^3 for 10 min measurement time and 7 bq/m^3 for 6 hours measurement time which is a factor of three lower than that of some commercial device (see for example specification for ATMOS [17]). The pulse- height spectrum of the alpha particles produced by Rn (and its daughters) is shown in figure 6; as one can see the energy resolution achieved with a single –wire detector is much worse compared to commercial devices (see for example [14]). However, we think that our device can be manufactured at a very low price and thus it still can compete in some applications with high performance, but more expensive commercial devices. Moreover, the multiwire version of this detector has potential for better efficiency and better energy resolution.

However, there is another way to improve the signal to noise ratio by exploiting the gas multiplication mode. This possibility was successfully demonstrated with the second type of the air filled detector - RETGEM. This detector allowed to achieve easily ~100% detection efficiency of Am alpha particles.

We believe that this type of the detector should be useful not only for Rn detection, but also for detection of alpha particles emitted by surfaces (surfaces alpha contamination). Indeed, as it was shown above, with the RETGEM we were able to detect even 60 keV energy deposited in the air volume which is equivalent to detecting only a small fraction of the alpha track. Because the mean free path of alpha particles in air is around 4 cm, one can scan surfaces with this device at a distance of a few cm -see figure 24. Moreover, it was demonstrated that the negative ions can be drifted in air for distances of at least a few cm and this effect can be exploited in practice by building a long -range alpha particle detector. In connection to this one should note that the authors of a recent work [11] succeeded to build a TPC prototype for high

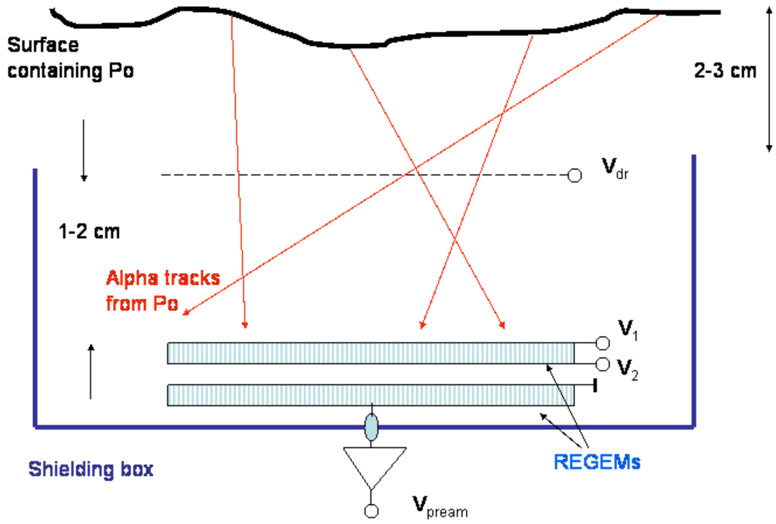

Figure 24. A possible design of the detector for Po monitoring. As follows from our studies for the “short-range” operation mode the voltage applied to the detector electrodes should be: Vdr~ -6 kV, V_1~-4. 3kV, V2~-1.7 kV and the voltage applied via the charge-sensitive amplifier “ V_{pream}”~+3,6 kV. In the case of the “long-range” detection mode all applied voltages should be positive in order to ensure the drift and collection of electronegative ions created in the gap between the investigated surface (grounded) and the drift mesh. Thus the expected voltages are: Vdr=+ 1kV, V_1~+2.7 kV, V_2 ~ 5 kV , the top electrode of the bottom RETGEM should be disconnected from the ground and kept at +6 kV and finally ~9.6 kV should be applied to the bottom electrode of the bottom RETGEM.

energy physics experiments in which electronegative ions were drifted 8 cm before they entered the readout gas amplification structure. These results indicate that in sufficiently clean ambient air (not much dust or aerosols) one also can drift electronegative ions for distances of more than a few cm, which can make a practical device more convenient in exploitation.

Of course, the energy resolution of our present prototype is much inferior to the best commercial devices, but due to its estimated low cost it can be used in mass-applications which require continuous monitoring of alpha particle contamination (for example Po), e.g. at airports, railway stations and so on. In the present version the stationary installed RETGEM can be used in these areas as a “first level” alarm, which is followed by a more refined analysis a few minutes later using a more powerful and expensive portable alpha analyzer.

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