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Response of Muon Drift Tubes to Radioactive Sources

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Abstract

We report on qualitative tests performed on muon drift tubes produced for the construction of a 2.2 m × 2 m prototype ATLAS muon chamber. The intent was to check whether the tubes functioned properly, prior to being assembled into modules. Based on an initial lot of about 260 tubes, we found a rejection rate of less than 2 %. A more detailed study of the performance of the chamber is planned in a forthcoming run at a test beam at CERN.

1 Introduction

Aluminum drift tubes, 3 cm in diameter, 2.2 m long, and 0.4 mm thick, are presently being prepared at the Institute for use in the construction of a prototype muon tracking chamber for ATLAS. Each tube contains a centered anode wire kept in position and under tension by endplugs located at the ends of the tube. Each endplug has a groove for crimping the tube into proper position, and a channel for an O-ring that provides a gas seal. Further details on the mechanical features of the tubes can be found elsewhere [1].

After a tube is completed, it is checked for gas tightness, and then tested for its response to a radioactive source. These tests consist of simply measuring the counting rate when a drift tube is exposed to a ^{90}Sr β source, and comparing that with the counting rate without source (background from cosmic rays, noise, etc).

In this note we discuss the results of such tests performed on tubes that were crimped mechanically onto both Type-A and Type-B endplugs [1]. We also present more detailed measurements on one, randomly-selected, drift tube. This was for the purpose of tracing out its response to different parameters of the testing procedure.

2 Setup

The test had to be performed on all 512 drift tubes needed for the construction of the prototype chamber. A schematic of the setup used to check the response of each tube is shown in Fig. 1.

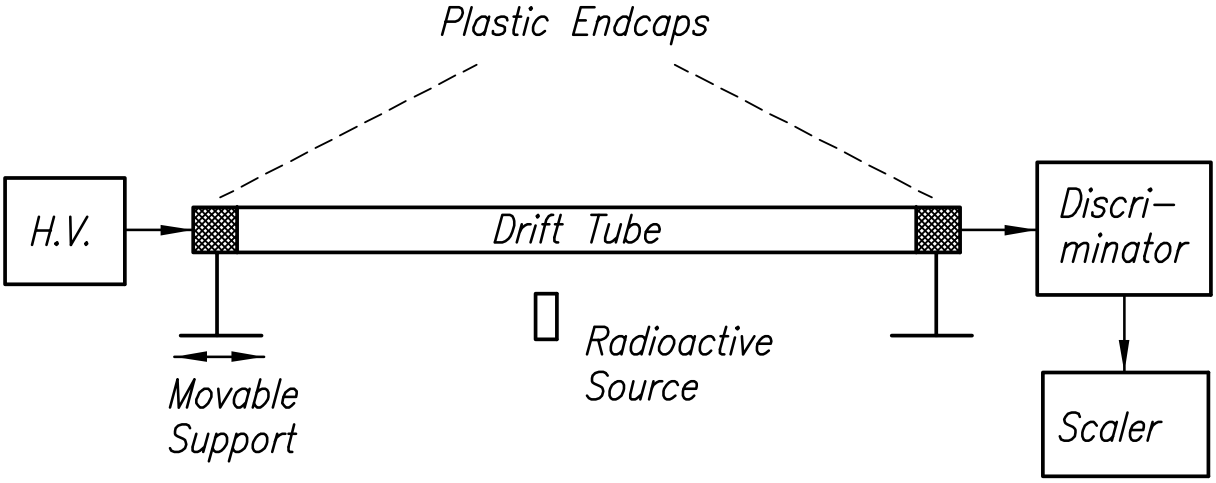

Figure 1: Setup used to check the response of each tube to a radioactive source.

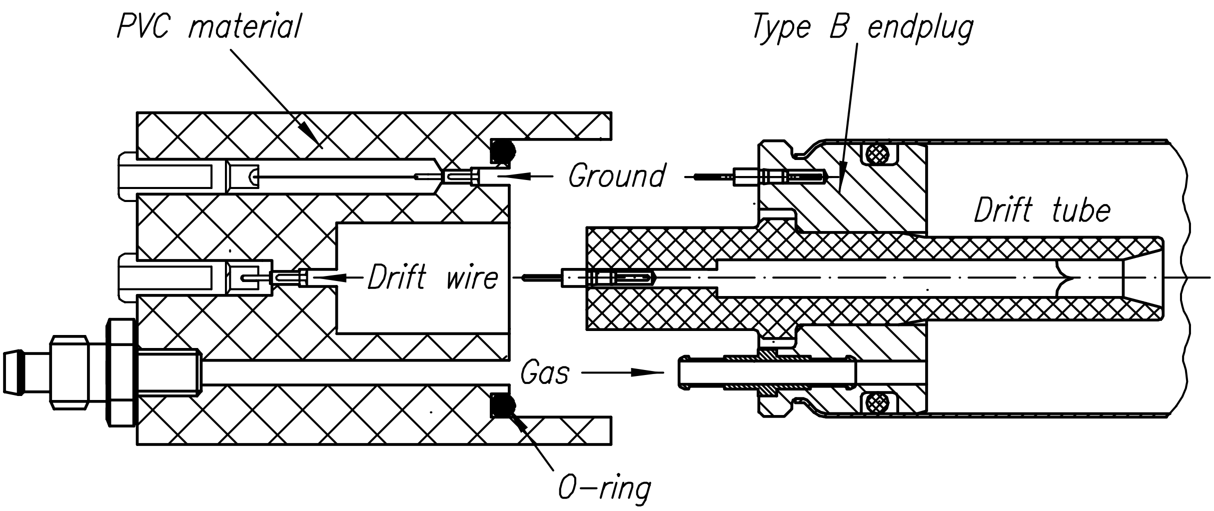

Figure 2: Plastic endcaps used to connect and disconnect drift tubes to the gas line, the read-out electronics and the high-voltage connections. The same endcaps were used for Type-A and Type-B endplugs [2].

A relatively quick connect and disconnect system was designed to accommodate the input gas line, the preamplifier read-out electronics, and the high-voltage (HV) connections.[2] The system consisted of two plastic endcaps (having the shape of cylindrical cups) that were attached to a large aluminum bar. The inner diameter of the endcaps matched the outside diameter of the endplugs of the drift-tube. An O-ring in the cap provided gas tightness. The details are shown in Fig. 2.

The signal was amplified using an L3 pre-amplifier [3], and the output of the preamplifier was connected to a LeCroy 620 discriminator that triggered a CAEN N145 scaler. The preamplifier was housed within an aluminum box, and was connected to the pin of the drift wire via a pin connector that penetrated the plastic endcap. A similar connection was used for applying the HV on the other end of the drift tube. After inserting the tube into the endcap containing the preamplifier, the end with the HV connection was moved toward the drift tube to provide a gas seal and good electrical contact.

For convenience, we used a gas mixture of Ar (90 %) and CH_4 (10 %) for our tests. The gas pressure was usually set at 3 bar (absolute), and monitored to a precision of about 1 %.

3 Choosing an Operating Point for the Test

In order to choose a reasonable working point for checking the response of the drift tubes, we used one randomly-selected tube (Tube #601) to measure the dependence of the signal on various parameters.

In Fig. 3 we show the counting rate versus high-voltage setting when the drift tube was irradiated with a ^{90}Sr β source, and when the source was removed. The results are given for different gas pressures, and for measurement times of 10 seconds. The radioactive source was located at a distance of $\sim$2 cm from the middle of the tube. A slit collimator, 1 cm long and 100 μm wide, was used to reduce the source activity, which was 20 MBq. We estimate an effective activity of about 8000/sec at the tube. The background measurements were performed by just removing the source from the tube, and capping it in its own lead container. The output signal from the L3 preamplifier had a typical amplitude of 600 mV, and the electronic noise was about 50 mV rms. We used a discriminator threshold of 200 mV for these studies.

For a given HV, the observed counting rate decreases with increasing gas pressure, and there is no substantial difference between the dependence on pressure with or without the radioactive source. This can also be seen in Fig. 3, where the quality factor, defined as the ratio in percent of the counting rates without and with the radioactive source, is plotted versus the HV for different gas pressures. The distribution of the measured quality factors has a mean value of 4.4 %, with a standard deviation of 0.98 %, the latter being somewhat larger than expected from purely statistical uncertainty (see below).

The main result of these preliminary measurements is that the quality factors obtained at different values of HV and gas pressure can be used to extract the same qualitative information on the response of the MDT. This is important for our test, where variations in measurement conditions can occur during the checkout of all the tubes over a period of weeks or months.

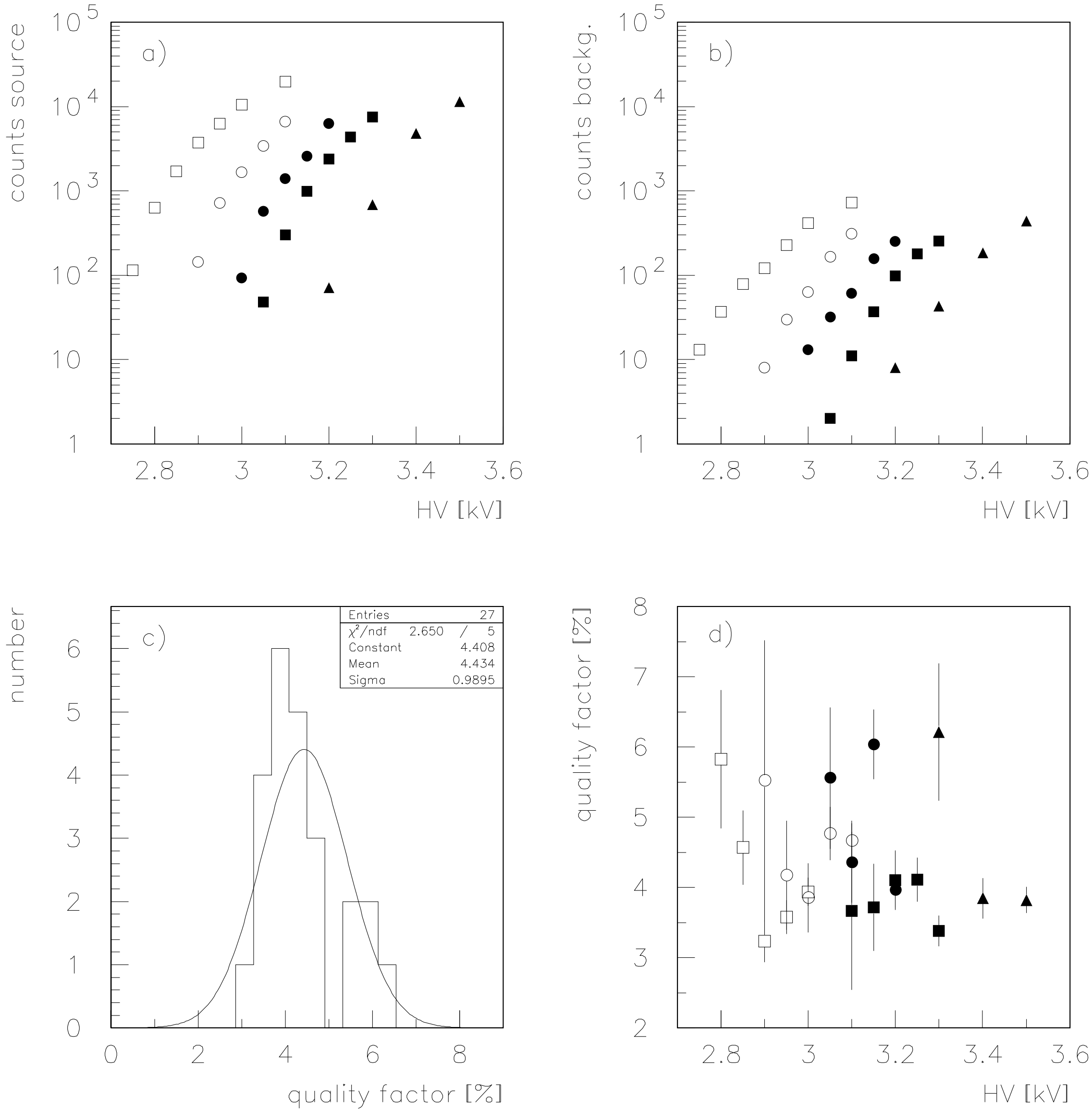

Figure 3: Counting rate versus HV obtained from irradiating Tube #601 with a ^{90}Sr β source at different gas pressures; open squares correspond to 2.5 bar absolute gas pressure, open circles to 2.8 bar, solid circles to 3 bar, solid squares to 3.2 bar and solid triangles to 3.5 bar. The measurement times were 10 seconds, and the discriminator threshold was set at 200 mV. *a*) Counting rate with the source, *b*) without source, *c*) distribution in quality factors, and *d*) quality factors with their associated statistical errors. The background was measured in the same manner as in the quality tests of tubes with Type-A endplugs.

4 Measured Response of the Tubes

The quality tests were performed at a gas pressure of 3 bar, using a HV setting of 3.1 kV, and a discriminator threshold of 200 mV. As for the measurements discussed in the previous section, the ^{90}Sr β source was located at a distance of ~ 2 cm from the middle of the tube.

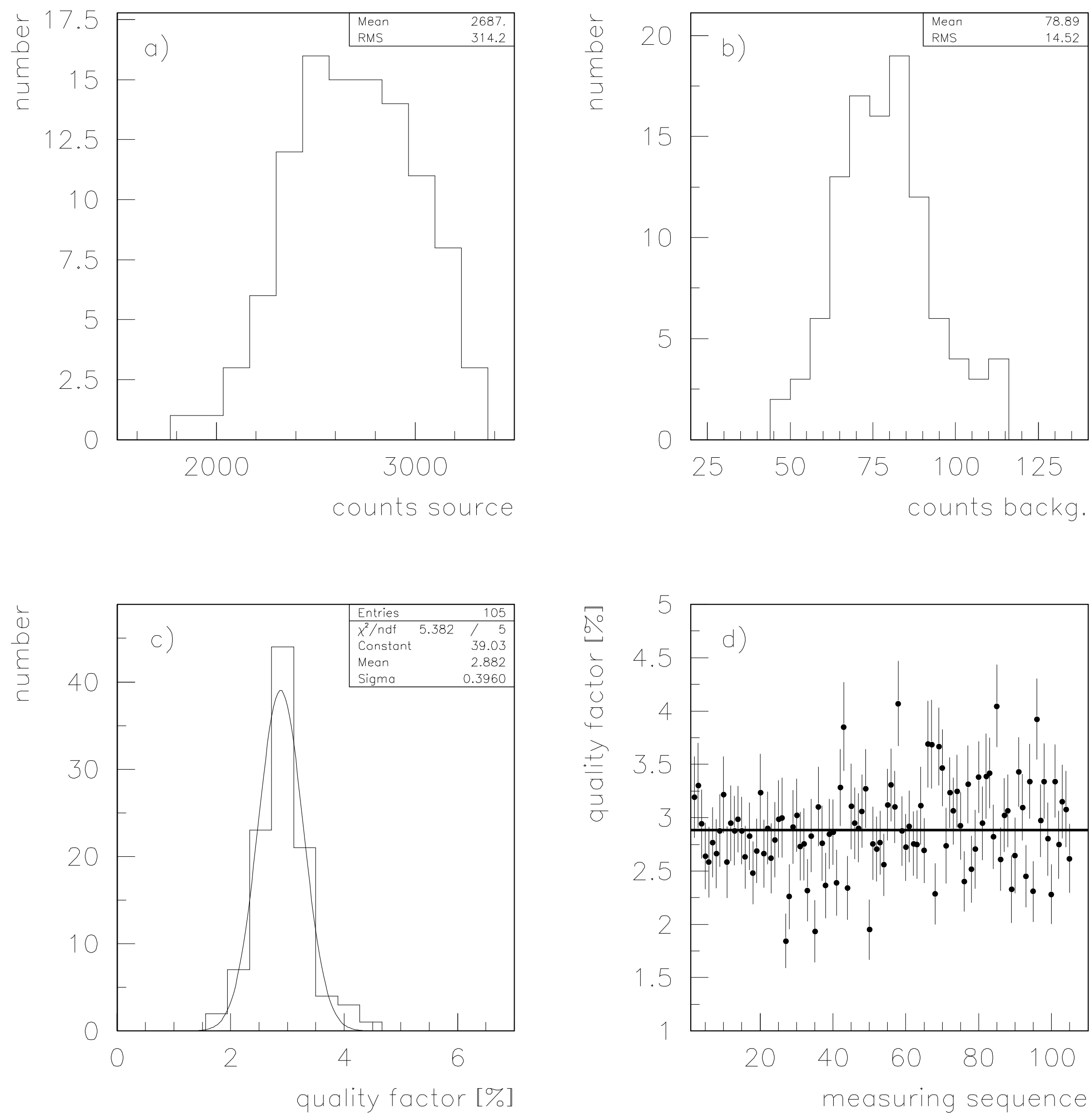

Figure 4: Quality test of 105 tubes with Type-B endplugs. The counts were taken over measurement times of 20 seconds, at a gas pressure of 3 bar, high-voltage of 3.1 kV, and a discriminator threshold of 200 mV. *a*) Counting rate with the source, *b*) without source, *c*) distribution in quality factors, and *d*) quality factors with their associated statistical uncertainties versus measuring sequence.

Before measuring the counting rate, the tube was flushed with gas for about 30 seconds. During this time, the HV was increased from zero to the nominal value. After flushing, we waited another minute for the gas pressure to stabilize. Once we obtained a stable pressure of 3 bar, we measured the background rate for 20 seconds, and subsequently the counting rate due to the radioactive source for another 20 seconds. In this way, the two measurements were taken at essentially identical operating conditions. The source was always placed in the same position and, due to the small size of the collimator, the counting rate was relatively insensitive to the fine tuning of that position. The background measurements were performed with the source removed, and placed in a well-shielded lead enclosure.

The distributions in counting rate obtained with and without the radioactive source, the measured quality factors, and the associated statistical errors, are plotted in Fig. 4 for 105 tubes with Type-B endplugs. The distribution in the counting rate with source is centered around 2700 counts, while the background distribution has a mean value of about 4 counts/s. When the distribution in the quality factor is fitted to a Gaussian, it has a mean value of 2.88 % and a standard deviation of 0.39 %. The dispersion in the quality factor values is almost entirely due to the expected statistical error as shown in Fig. 4d, where the quality factors are plotted with their associated statistical errors.

Before performing the above tests, we tested the quality of the first 128 Type-A drift tubes, but used slightly different measurement procedures. We had shorter measuring times of 10 seconds, and the background was measured with the source contained only within its own lead cage at a distance of ~ 30 cm from the tube. This was the same method that we used to obtain the operating settings for our tests (see previous section, and the results given in Fig. 3). Unfortunately, after most of the Type-A tubes were measured, we realized that the lead receptacle for the source was not providing sufficient shielding, and that our background counting rate was affected by a systematic increase from the soft radiation emanating from the contained source. (This is, in fact, why we changed our procedure.) The distributions in the counting rate and in the quality factors for the Type-A tubes are plotted in Fig. 5. The background counting rate is centered around 5 counts/s, and is ~ 1.3 times higher than the one measured with the source properly shielded (Fig. 4). Despite the difference in background, the distribution in the quality factor can still be fitted with a Gaussian. The distribution for these tests has a mean value of 4 %, and a standard deviation of 0.84 %. The dispersion is somewhat larger than for the case of Type-B tubes, but is still dominated by statistical error, as shown in Fig. 5d, where, again, the quality factors are plotted with their associated statistical errors. We attribute this increase in dispersion to the systematic error introduced in the background measurement. (In addition, we found that the background rate depended somewhat on the orientation of the slit on the source relative to the drift tube, which would also widen the distribution in quality factors.)

Occasionally, during background measurements with both Type-A and Type-B tubes, we also noticed sudden jumps in the counting rate due to electronic pickup (e.g., from switching lights on and off), which produced bursts in counting rate. This was because the tubes behaved as 2 meter-long antennas. Since our tests were designed just to provide a qualitative check of the tubes in a minimum time, it was not deemed important to shield the system more effectively. Consequently, when we noticed large anomalies in counting rates without source, we repeated those measurements.

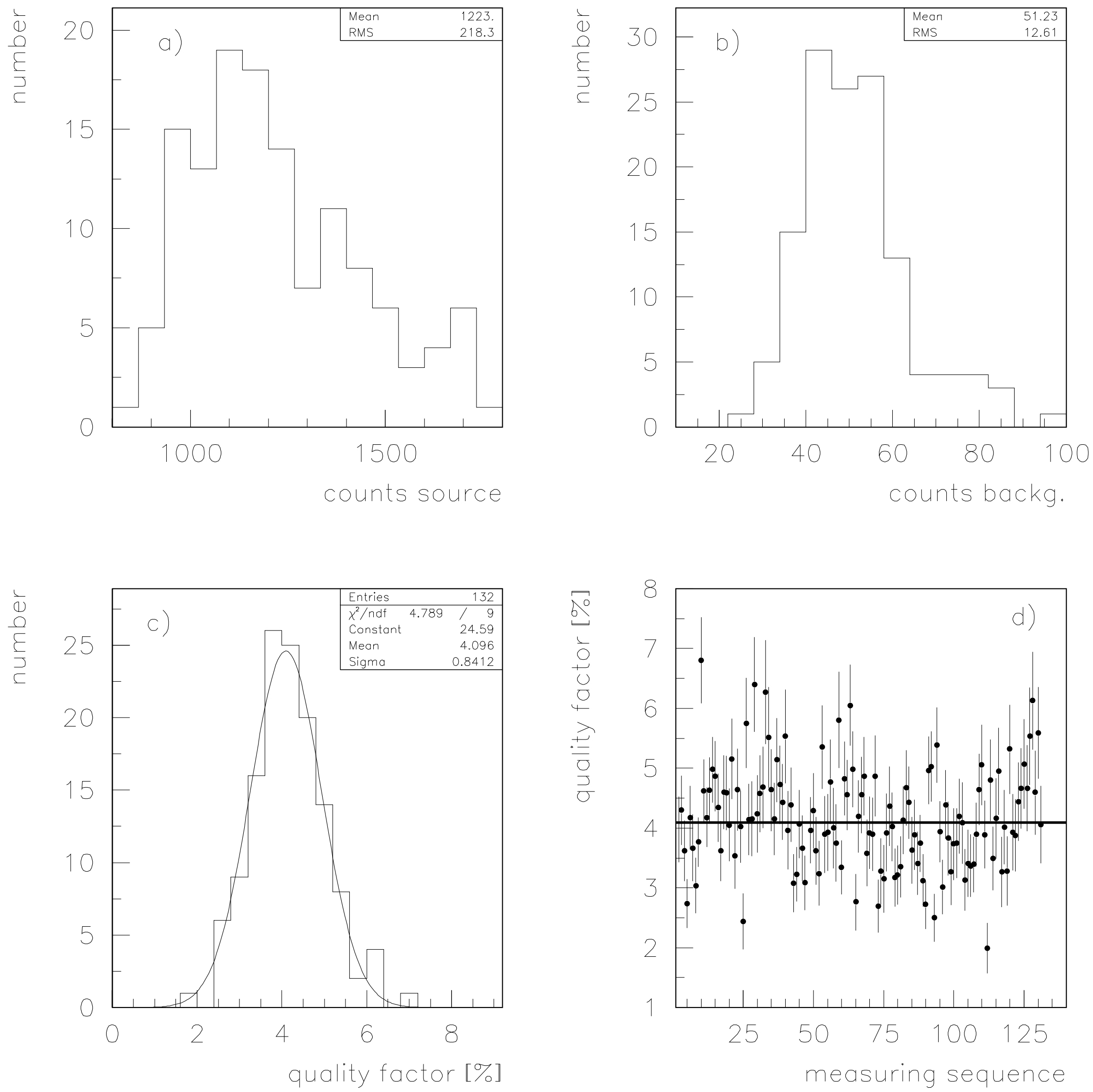

Figure 5: Quality test of 132 tubes with Type-A endplugs. The counts were taken over measurement times of 10 seconds with the same gas pressure, high voltage and discriminator threshold used in the quality tests of Type-B tubes. *a*) Counting rate with the source, *b*) without source, *c*) distribution in quality factor, and *d*) the quality factors with their associated statistical uncertainties versus measuring sequence. The background measurements were slightly different than for the case of Type-B tubes, as discussed in Sec. 4.

5 Other Measurements

The background measurements discussed in this section were performed with the radioactive source removed and properly shielded, as was the case for the quality checks of Type-B drift tubes (Sec. 4).

In Fig. 6 we show the response of Tube #601 to irradiation with the ^{90}Sr β source at a gas pressure of 3 bar and at a discriminator threshold of 200 mV. The source was positioned as described in Sec. 4, and the data correspond to the mean values of four measurements of 20 seconds each.

In Fig. 7 we show the counting rate versus high voltage obtained by irradiation from a ^{55}Fe γ source at a gas pressure of 3 bar, but using a smaller threshold of 100 mV. The data correspond to the mean values of four sets of measurements, each of 10 seconds in duration. The measurements with the γ source were performed with the source in contact with the tube wall at the middle of the drift tube. The γ source activity is 1.8×10^6 photons/second/steradian and the number of X-rays penetrating the 400 μm thick Al wall is $\sim 4.7 \times 10^{-6}$ of the initial intensity. Almost all the γ rays interact within the gas [4]. Because the source was in contact with the Al tube, the solid angle was close to be 2π, and we expected ~ 50 interactions per second, which is in approximate agreement with observation. Although the discriminator threshold was lower, the background counting rate for the γ measurements is comparable to that for the case of β source. Thus the contribution from electronic noise does not appear to be a major problem. (The background rate for the X-ray measurements is about 40 % of the counting rate with source in position.)

It is interesting to note that, despite the fact that the measurements were done without requiring coincidence triggers, there is an indication of a plateau in the counting rates between 3.2 and 3.4 kV, for both source and background. For the case of the background, the counting rate in the plateau corresponds roughly to the rate expected from the cosmic ray flux [5].

We have also performed a qualitative measurement of the current flowing into the anode wire during irradiation. In order to increase the signal rate, we used the ^{90}Sr source in contact with the tube wall, without the additional collimator. The measured current was $\sim 1.5\,\mu$A at 3.5 kV, which is consistent with the expected value for a gas amplification factor of $\sim 10^4$.

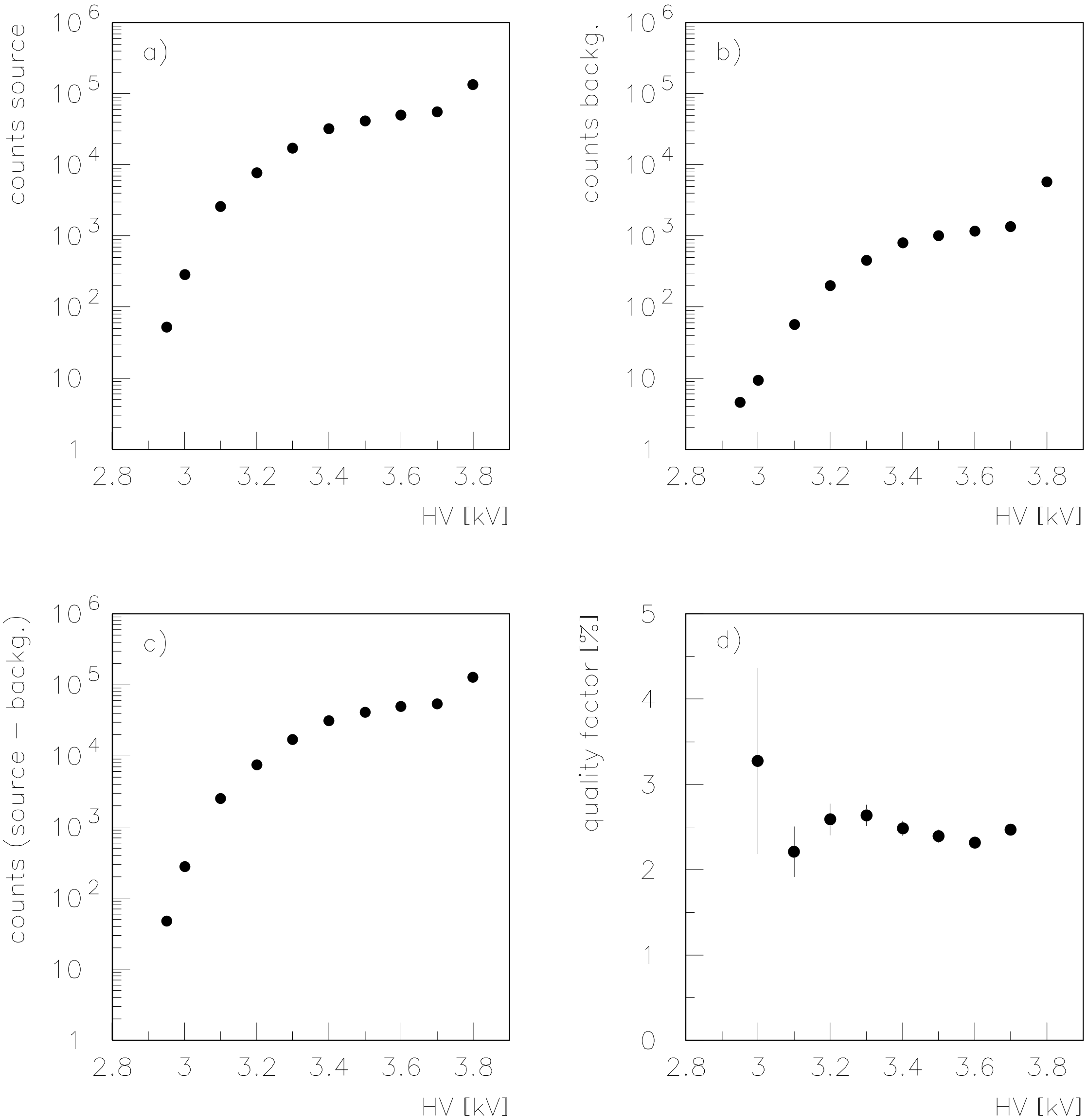

Figure 6: Irradiation with ^{90}Sr of Tube #601 at a gas pressure of 3 bar and discriminator threshold of 200 mV. The β source was located in the same position as used for the quality tests, and the data correspond to mean values of four measurements of 20 seconds each. *a*) Counting rate with the source, *b*) without source, *c*) counting rate with the source after subtracting the background and *d*) the quality factors with their associated statistical errors.

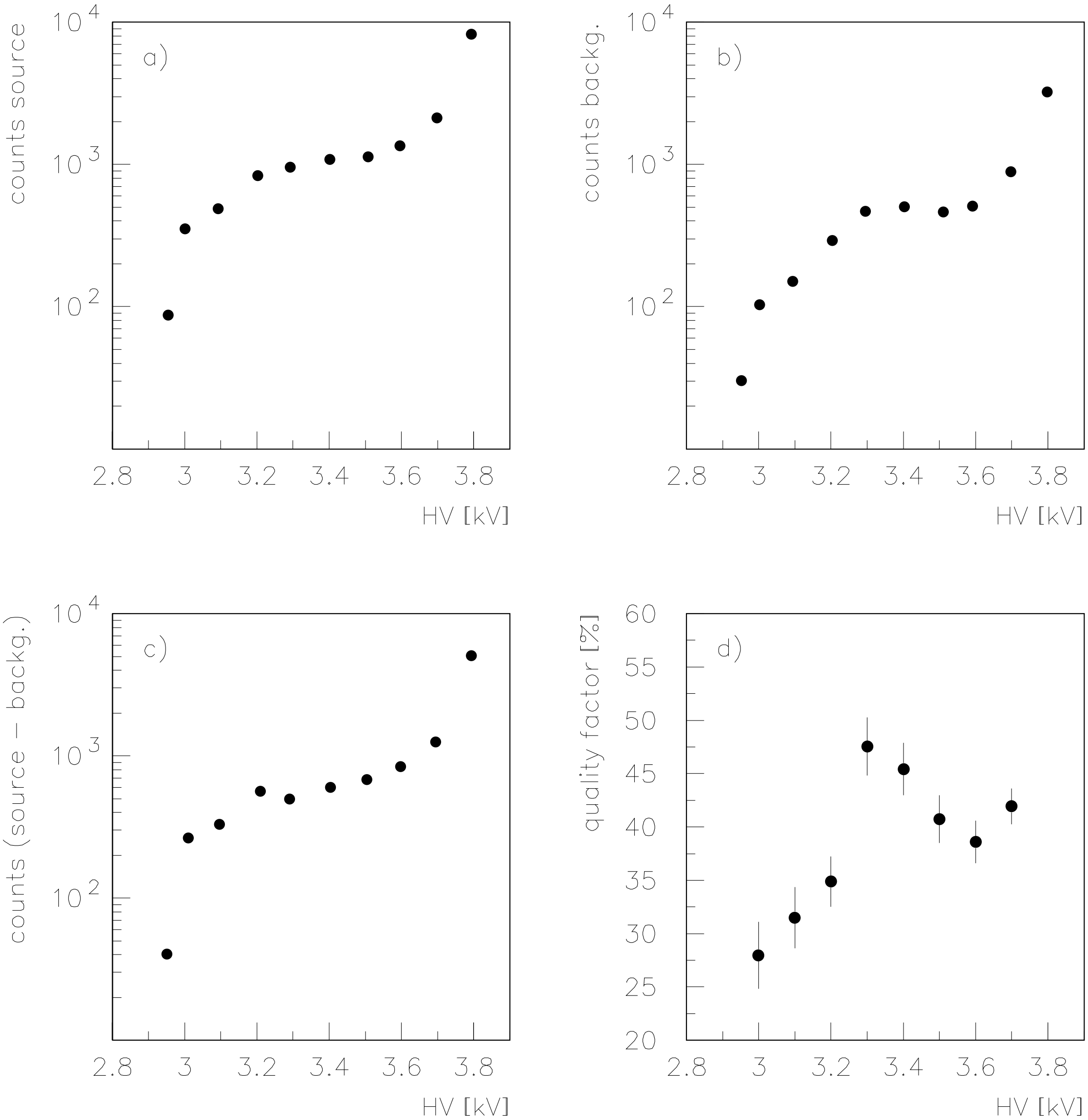

Figure 7: Irradiation with ^{55}Fe of Tube #601 at a gas pressure of 3 bar and discriminator threshold of 100 mV. The γ source was in contact with the Al tube at the middle of the drift tube. The data correspond to mean values of four measurements of 10 seconds each. *a*) Counting rate with the source, *b*) without source, *c*) counting rate with the source after subtracting the background and *d*) the quality factors with their associated statistical errors.

6 Conclusions

Only four tubes out of the 256 that we checked had background counting rates that differed significantly from the norm. In several other instances, the quality factor for a tube improved with time, and these were marked as acceptable, as were several that had high, but not exceptionally large quality factors. The four exceptional tubes were excluded from inclusion in the prototype chamber. We could find no clear correlation between the observed quality factor and any parameters such as gas tightness of the tube, the resistance of the anode wire, or the resistance between the ground pin and the outer aluminum wall. It will be interesting to see if the response in the test team will reveal some reason for the variation in quality factors.

Quantitative differences aside, the distributions for the two sets of drift tubes indicate that both Type-A and Type-B functioned adequately.

Acknowledgement

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References

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