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Studies of Cross Talk Between Ion Chambers

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Abstract

Bench tests conducted on ion chambers exposed to radioactive sources are presented. Studies are performed to identify potential sources of cross talk between several parallel plate ion chambers (PPICs) mounted inside a single gas volume. Such features should be avoided in any design of muon and hadron monitor design condsidered for NuMI.

1 Introduction

The present note summarizes several studies of ionization chambers [1] to be used in the NuMI beam line as part of the neutrino beam monitoring system. The effect of cross talk between chambers mounted in large arrays within a single gas volume would be problematic during NuMI beam operation, given that the signal from each pixel will be interpreted as part of the lateral distribution of particles in the NuMI beam.

In this note, we define 'cross talk' to mean any signal from a parallel plate ionization chamber which is not due to ionization which occurs in the gas gap between the chamber plates. Such effects could arise from pick-up between chambers in the gas volume, or could arise from the beam ionizing the gas throughout the volume if such ionization outside the chamber gaps is somehow allowed to reach the chamber electrodes or the lines which bring the signals out of the gas volume.

In this note, the effect of stray ionization is studied. Bench tests of several ion chambers exposed to alpha sources in a single gas volume are described. We investigate chamber design features of chamber signal routing which can enhance stray ionization.

2 Bench Test Setup

These studies have been conducted in the laboratory using Am^{241} alpha ($E_\alpha = 5.4$ MeV) sources. The basic test set-up is shown in Figure 1. Three parallel plate ion chambers are mounted inside a vacuum bell jar on an aluminum 'trellace' which electrostatically screens each chamber from the other two. The bottom, middle, and top chambers have sources mounted on them of 20, 0, and 40 μCi, respectively (see Figure 2). Signal and HV lines are fed

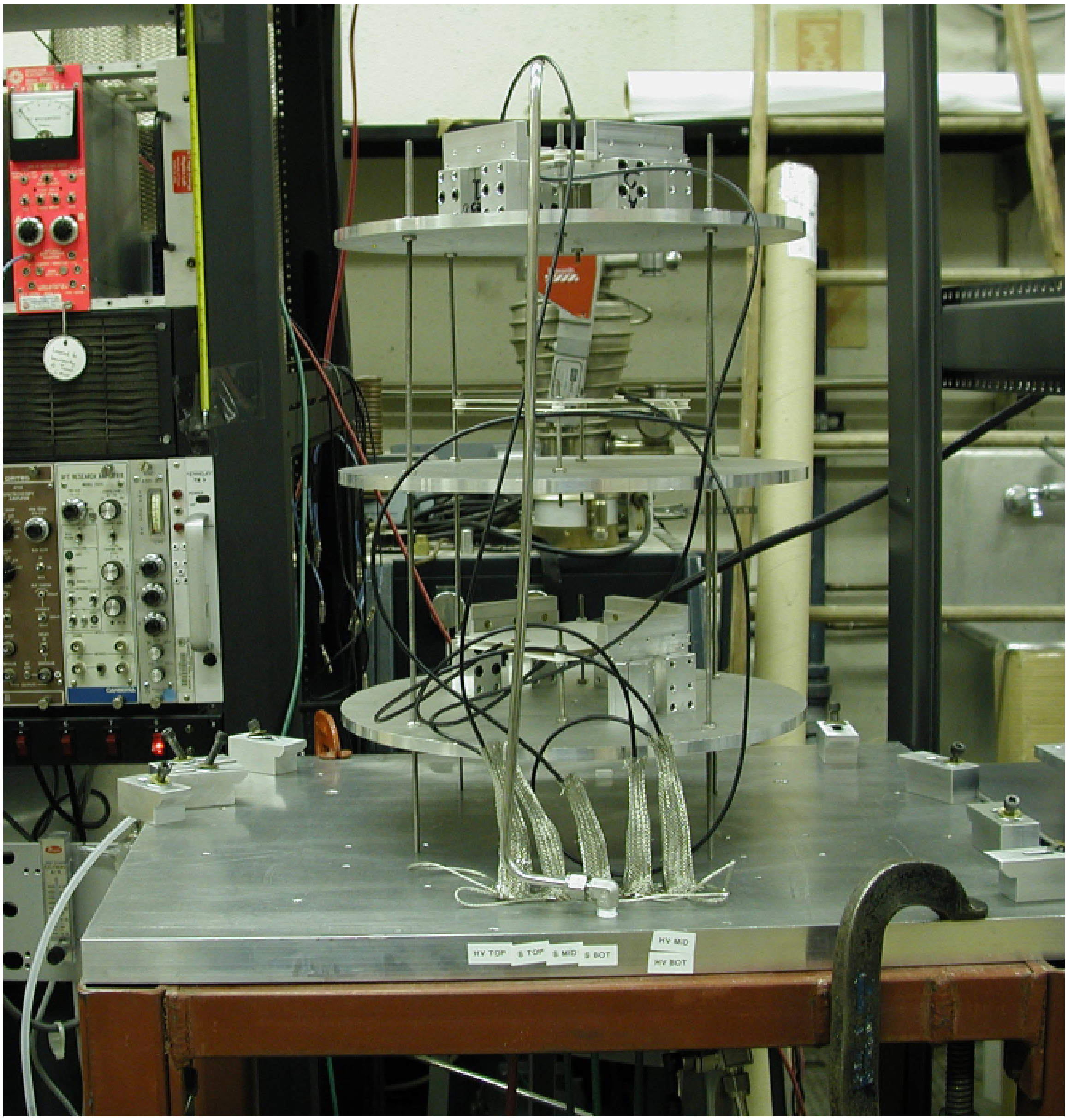


Figure 1: Experimental setup for the test of three ion chambers exposed to α sources in a single gas volume. Each chamber is shielded from the others by an aluminum trellace over which the bell jar fits. RG174 shielded cables deliver signals/HV to/from the chambers to feedthroughs in the base plate. Helium gas enters the bell jar at its top through a stainless line routed from the base plate to the chamber ceiling, and exits the bell jar through feedthrough in the base plate.

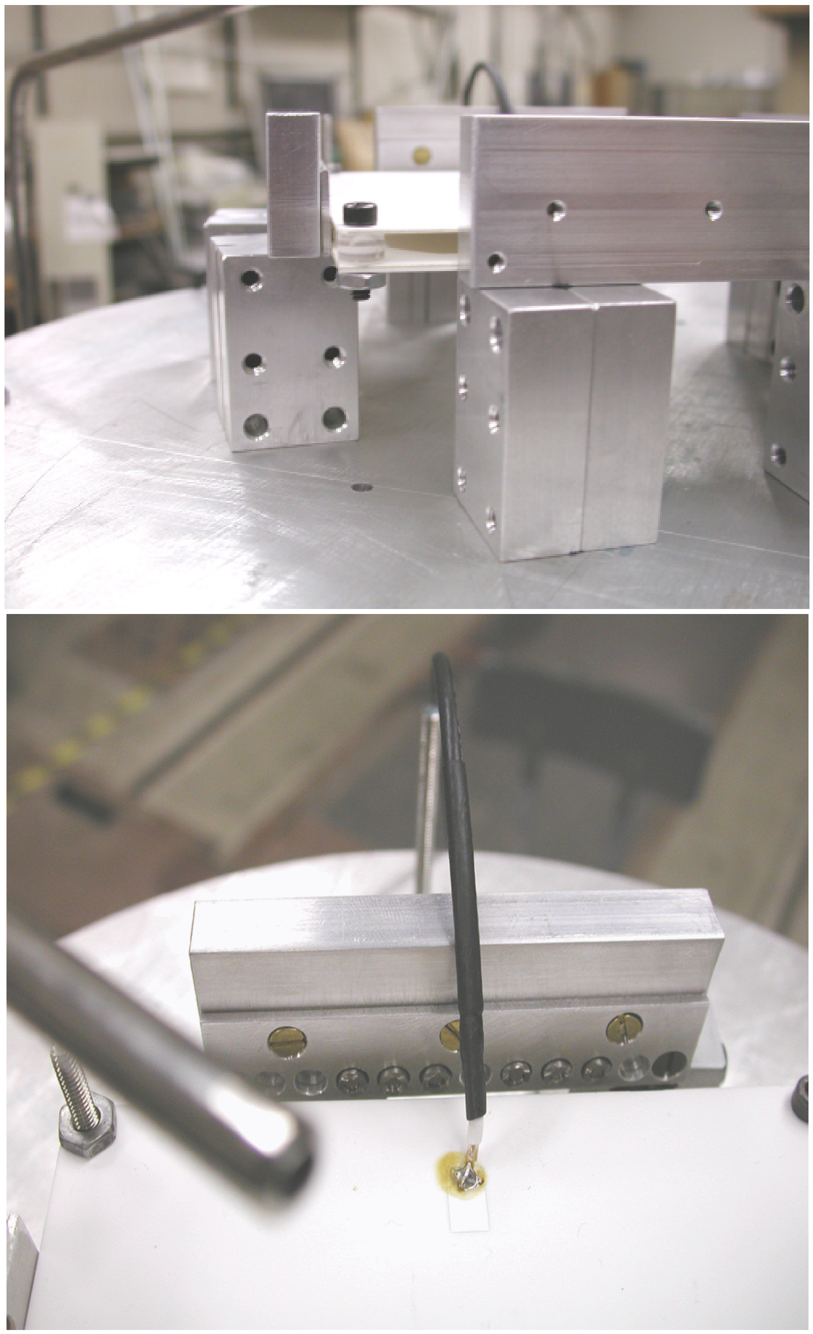


Figure 2: (top) Photo of the top ion chamber, showing two of the holders containing alpha sources. (bottom) Photo of the inside of one of the source holders, with several alpha sources mounted inside facing the ion chamber gap.

through the chamber base plate through BNC or SHV panel mount connectors potted leak-tight in the plate. Electrical connections to the ion chambers from these feedthrough connectors is made via shielded coaxial cable, RG174. The electrical feedthroughs are wrapped in kapton tape and then shielded by a ground braid soldered around them.

Gas is delivered to the bell jar from 'Ultra-High Purity' (UHP) grade bottled Helium, which is 99.999% pure, and no more than 2ppm of the 10ppm impurities is supposed to be Oxygen or water vapor. The exhausted gas passes through an Illinois Instruments model 2550 oxygen analyzer, and then into a long coil followed by a mineral oil bubbler. The oxygen analyzer has minimum sensitivity of 0.01 ppm O_2.

The signals from the ion chambers are read out by three individual Keithley model 480 picoammeters, one connected to each ion chamber. The picoammeters are *relatively* calibrated to one another to within 5%. By averaging multiple readings of the digital picoammeters at a given chamber operating point, the signal repeatability is observed to be 0.4 pA.

3 Plateau Curves

Each chamber is first run through a series of voltages and the ionization current measured. The chamber with zero sources mounted on it showed exactly zero picoamps ionization current at all voltages. The ionization current from the top and bottom chambers are shown in Figure 3. The ionization current observed on plateau in Helium is approximately 2 pA per μCi of source exposure, in approximate agreement with crude calculations. Plateau is achieved at 2-3 Volts, provided sufficient gas purity of < 2 ppm is achieved, and gas amplification is evident at approximately 600 Volts.

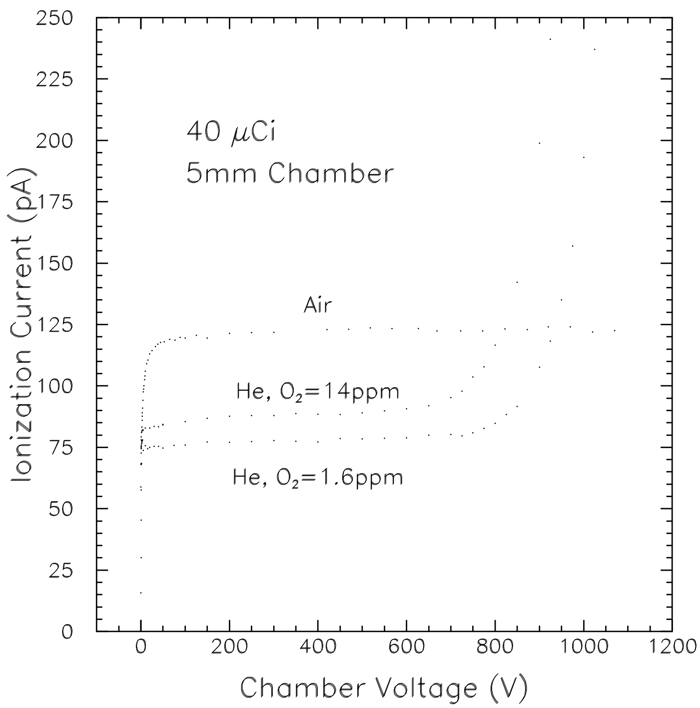
In air, no amplification is observed, and full ionization 'plateau' (full efficiency for collecting all the ionized charge without recombination in the gas) is not reached before 80-100 Volts.

4 Cross Talk Studies

Cross talk is studied first with the (well-shielded) setup of the previous Section 3. In successive subsections, we remove one shielding feature at a time to investigate what effect this has on cross talk. To better isolate the source of the ion current, the cross talk in air and in pure Helium gas is measured (presumably charges drift over longer distances in Helium).

In several sections which follow, we shall also place 'stray' sources over various signal lines, HV lines, feedthroughs, *etc.* This is to simulate the fact that the NuMI beam is quite broad and that ionization will occur throughout the gas volume, not just in the gas gap of a PPIC. Having 'signal' and 'stray' sources separately moveable allows us to identify when an observed ionization current is due to ionization in the chamber gas gap ('signal') or somewhere else in the gas volume ('stray' or 'cross talk' current)

It should be noted that these tests are all performed with comparatively weak radioactive sources, and that the ionization measured here are $10^6 - 10^9$ times weaker than the NuMI



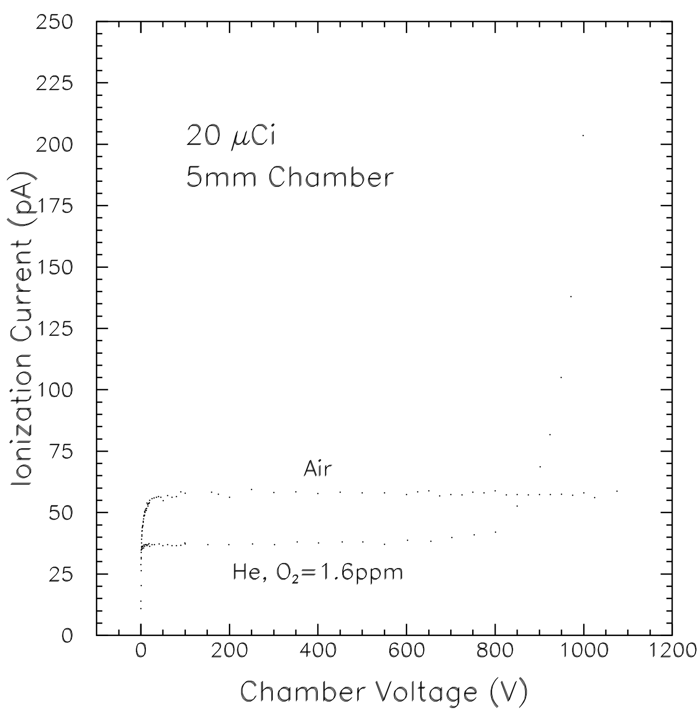


Figure 3: Curves of ionization current as a function of chamber voltage for air and Helium gas filling for the chambers in the optimally shielded configuration. (top) top chamber, which has 40 μCi mounted to it (bottom) bottom chamber, which has 20 μCi mounted to it.

beam. However, this is not as important for our purposes as the fact that the *relative* source strength on the chambers is comparable, and that the ionization from 'stray' regions in the gas volume is comparable to the gas gap ionization ('signal').

4.1 Cross Talk with Ideal Shielding

We first tried to produce any evidence of cross talk or stray signals using the setup of Section 3. Some studies performed:

1. Take a plateau curve of the top chamber with the bottom chambers set to 0 V. Repeat with the bottom chambers set to 1000 V.
2. Place stray sources over the RG174 signal lines of the chambers.
3. Place stray sources over the feedthroughs.

None of these tests produced any measureable effect on the plateau of either the top or bottom chamber, and all of these tests failed to produce a 'phantom' signal on the middle chamber (which had zero sources). We thus conclude that this configuration is quite well-shielded.

4.2 No Shielding on Signal, HV, or Feedthroughs

In the first study, the chambers are removed from the trellace which electrostatically shields them from one another. Two chambers are placed side by side, approximately 1" apart on the base plate of the bell jar in the arrangement shown in Figure 4. "Chamber 1" has 30μCi of sources aimed directly at its plate gap, while "Chamber 2" has no sources aimed at its gas gap. The two chambers are placed at different heights off the base plate so that the alpha particles passing through Chamber 1 should not enter Chamber 2, and indeed no signal is initially seen on Chamber 2.

The two chambers are connected to the bell jar feedthroughs using bare wire for both the signal lines and also the high voltage connections. From the BNC and SHV feedthroughs in the base plate, the bare wires are run along a 8" path to a breadboard placed in between the two chambers. The breadboard is used to solder cables that run to the chambers. Note that an extra signal line, labelled "3" runs to the breadboard but is not connected to a chamber.

On occaision a set of 'stray' sources (10μCi total activity) illuminate these bare signal and HV wires. The 'stray' sources are suspended approximately 2" over the bare wires using a machinist's dial indicator base, as shown in the photograph.

Figure 5 shows the plateau curve for Chamber 1 which has 30μCi on the chamber. In air, with no 'stray' sources over the wires (closed circles), the plateau curve is as expected, and is independent of whether or not the other chamber, Chamber 2, is turned on or off. However, as the stray sources are placed over the signal wires (open diamonds), Chamber 1's signal increases from 60 pA to 100 pA on plateau. Thus it appears that ionization collects

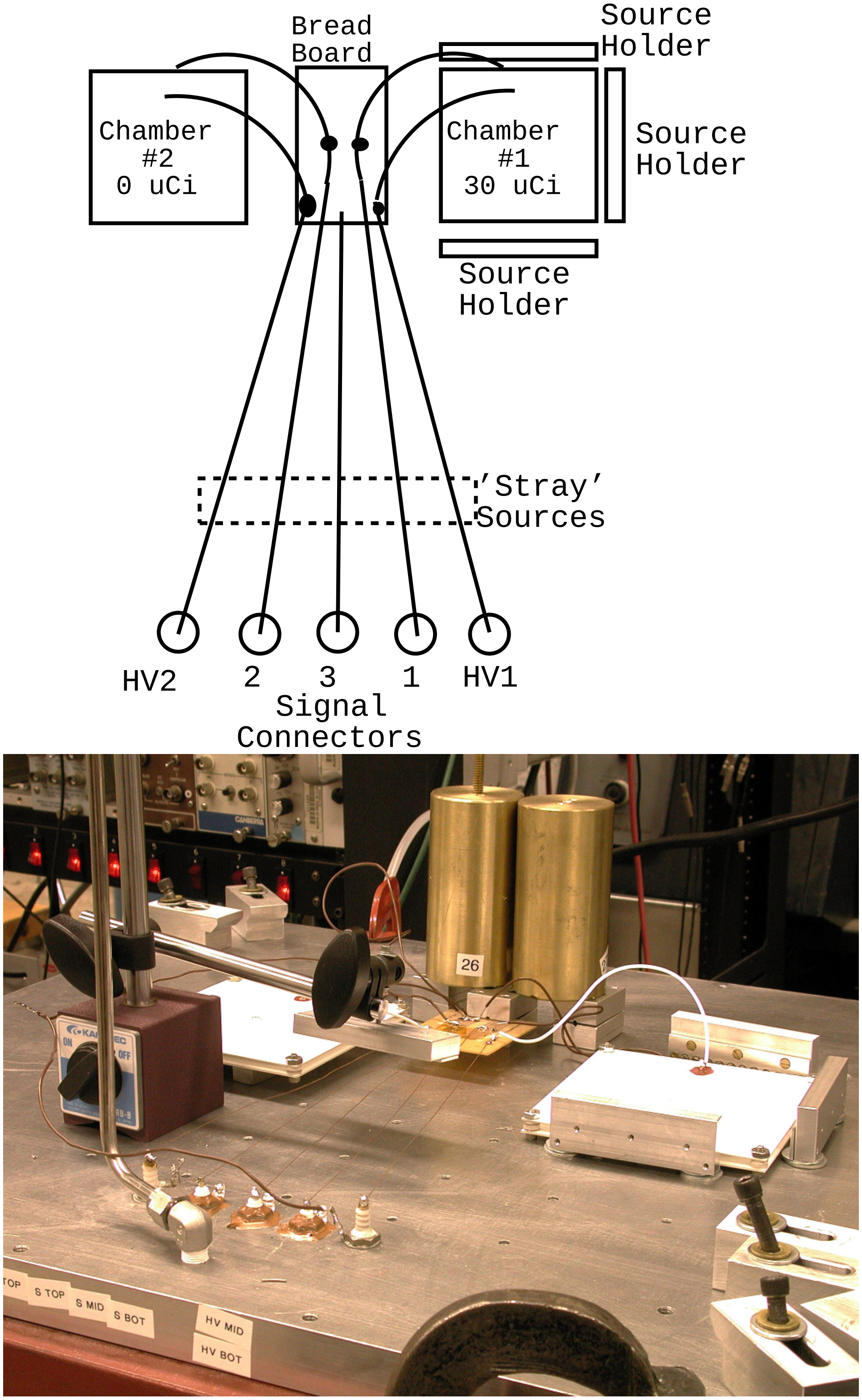
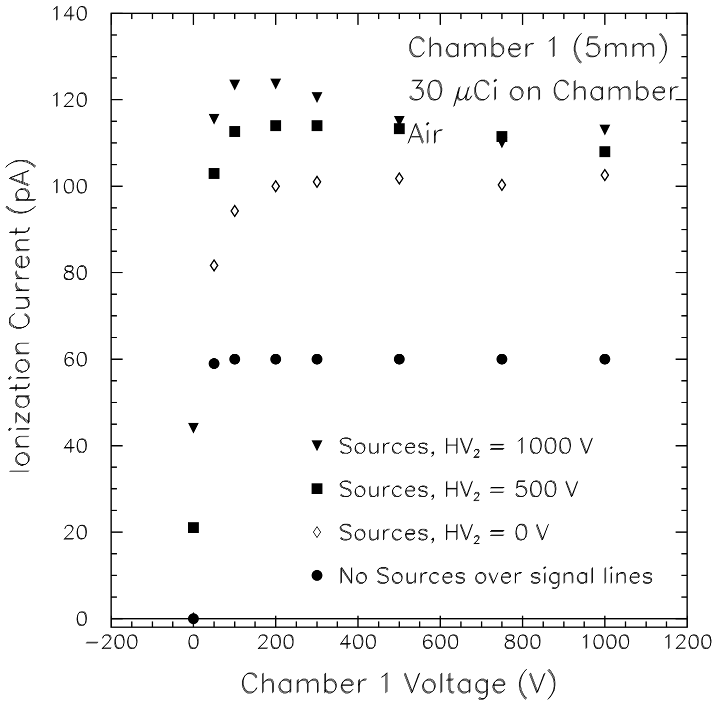


Figure 4: (above) Configuration of Section 4.2, in which two of the chambers are placed side by side on the floor of the bell jar. Sources are aimed at Chamber 1, but not at Chamber 2. 'Stray' sources suspended over the signal lines to investigate signal contamination. See text for details. (below) Photograph of this configuration. The BNC feedthroughs are visible in the foreground, with the breadboard towards the rear (held in place by two brass weights). The machinist's dial indicator base holds the 'stray' sources over the bare signal lines.



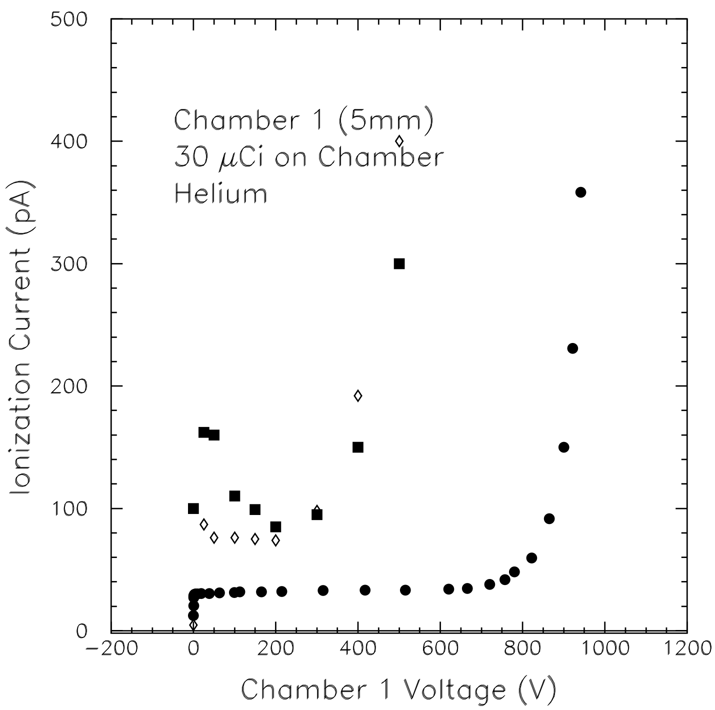


Figure 5: (above) Signal observed on Chamber 1 when operated in air in the configuration of Section 4.2. Shown is the bias curve when no stray sources are placed over the signal lines, when stray sources are in place but Chamber 2 is turned off, and when Chamber 2 is set to either 500 V or 1000 V. The chambers are in air. (below) Same, but with the bell jar filled with He gas, O_2 impurities less than 2 ppm.

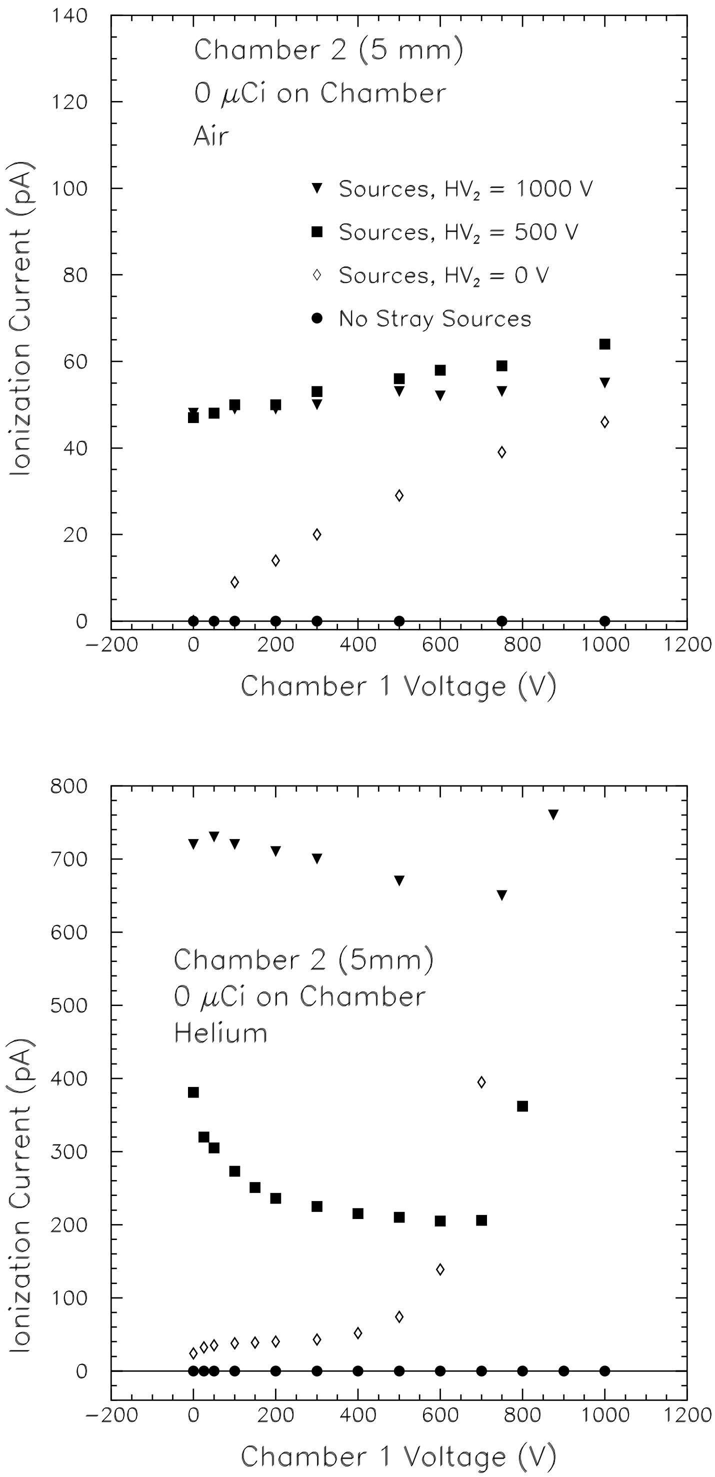


Figure 6: (above) Signal observed on Chamber 2 when operated in air in the configuration of Section 4.2. Shown is the bias curve when no stray sources are placed over the signal lines, when stray sources are in place but Chamber 2 is turned off, and when Chamber 2 is set to 500 V or 1000 V. The chambers are in air. (below) Same, but with the bell jar filled with He gas, O_2 impurities less than 2 ppm.

on the signal wire for Chamber 1. As Chamber 2 is turned on to either 500 V or 1000 V, the extra ionization on Chamber 1 increases further (closed squares and triangles).

In Helium (lower plot of figure), the modification to Chamber 1's signal is also observed, although the effect is larger, and it is clear that gain is occuring on the bare wires, because the gain rise in signal now occurs at $\approx$400 V, rather than at 600 V.

Figure 6 shows the signals observed on Chamber 2 during these tests. This chamber has no signal sources aimed at its gas gap, so any signal observed is a 'phantom' signal caused by the stray ionization occuring in the rest of the bell jar, not in Chamber 2's gas gap.

The modification of the plateau curve on Chamber 1 and the creation of a phantom signal on Chamber 2 indicate that ionization outside the chamber gas gap is occuring.

4.3 Shielded HV, Exposed Signal Lines

Clearly, the bare HV and signal lines of the previous section cannot be allowed for any chamber array design. In this section, we replace the bare conductor HV wire with shielded RG174 again. In this way we investigate how much stray signal is induced just from ionization collecting on the signal wires (with no acceleration there by the HV wires).

Figure 7 shows what happens to Chamber 1's signal. Again, in air and in Helium, if no stray sources are present then no modification to the plateau curve is observed, and this observation is true for any voltage (0, 500, 1000 V) on Chamber 2. Again, if stray sources are placed over the signal lines, then the ionization plateau on Chamber 1 is increased by $\sim$10% in air and 40% in Helium. What is interesting here and different from the previous section is that this stray ionization current induced on Chamber 1 is more or less independent of the Chamber 2. Thus, this is some form of 'self-induced' stray signal. It suggests that the long bare signal line running from Chamber 1 to the feedthrough builds up some small potential as a result of the current running through it that comes from the signal sources on that chamber. Indeed, only a small fraction of a volt would be required to produce this extra ionization signal.

This observation of a self-induced stray ionization current on the bare signal wire is quite important, and recalls some observations made on the early designs of the SIC chambers. This self-induced stray signal appears as a larger than expected plateau, and furthermore creates a small slope to Chamber 1's plateau with respect to voltage. This is quite consistent with observations made with the SIC's at the Fermilab Cs^{137} γ source, and was traced to inadequate shielding of the signal pin on the outside of the SIC. Thus, even a single chamber mounted inside the gas volume can contaminate its own signal if its connections are not properly shielded from stray ionization in the gas volume.

Figure 8 shows the phantom signal induced on Chamber 2 during this round of tests. Again, with no stray sources, this chamber sees small ionization currents, but with the stray sources illuminating its signal wire, the phantom signal increases.

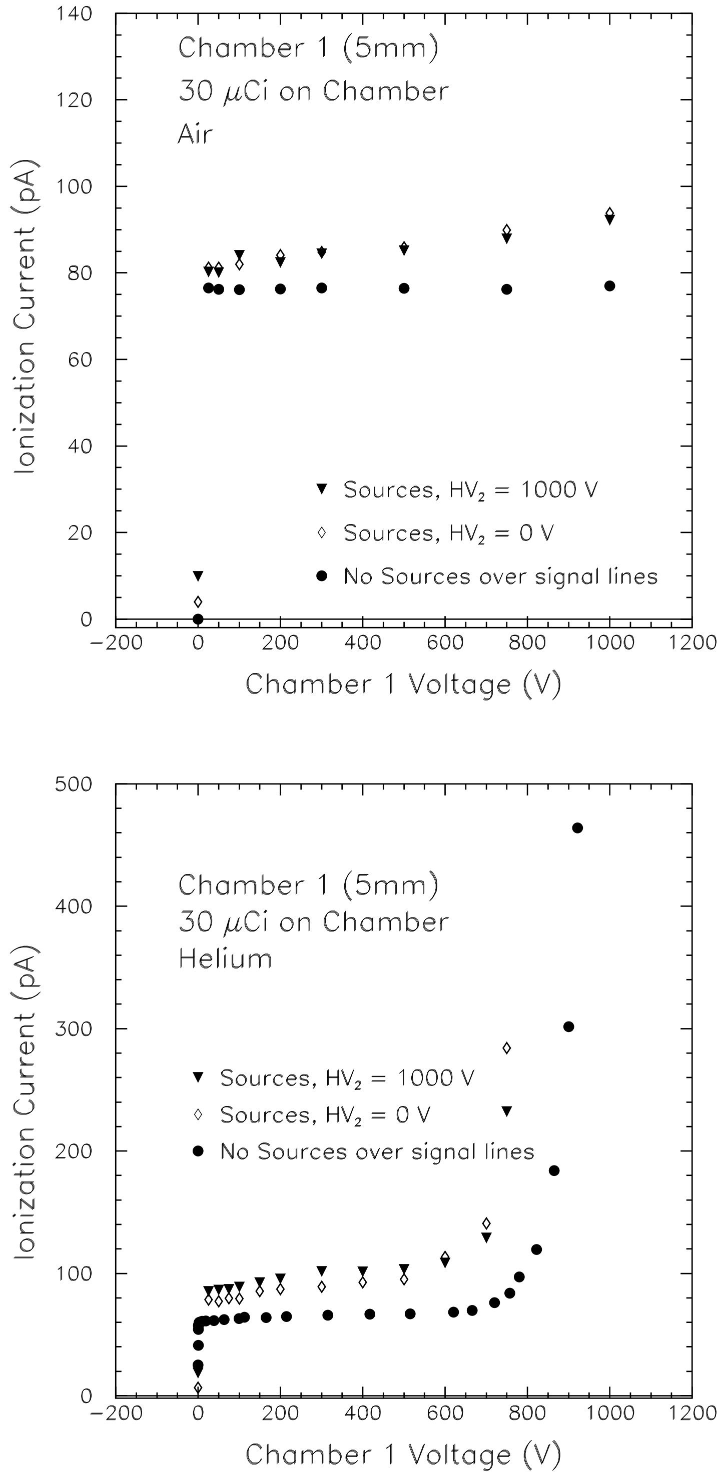


Figure 7: (above) Signal observed on Chamber 1 when operated in air in the configuration of Section 4.3. Shown is the bias curve when no stray sources are placed over the signal lines, when stray sources are in place but Chamber 2 is turned off, and when Chamber 2 is set to 500 V or 1000 V. The chambers are in air. (below) Same, but with the bell jar filled with He gas, O_2 impurities less than 2 ppm.

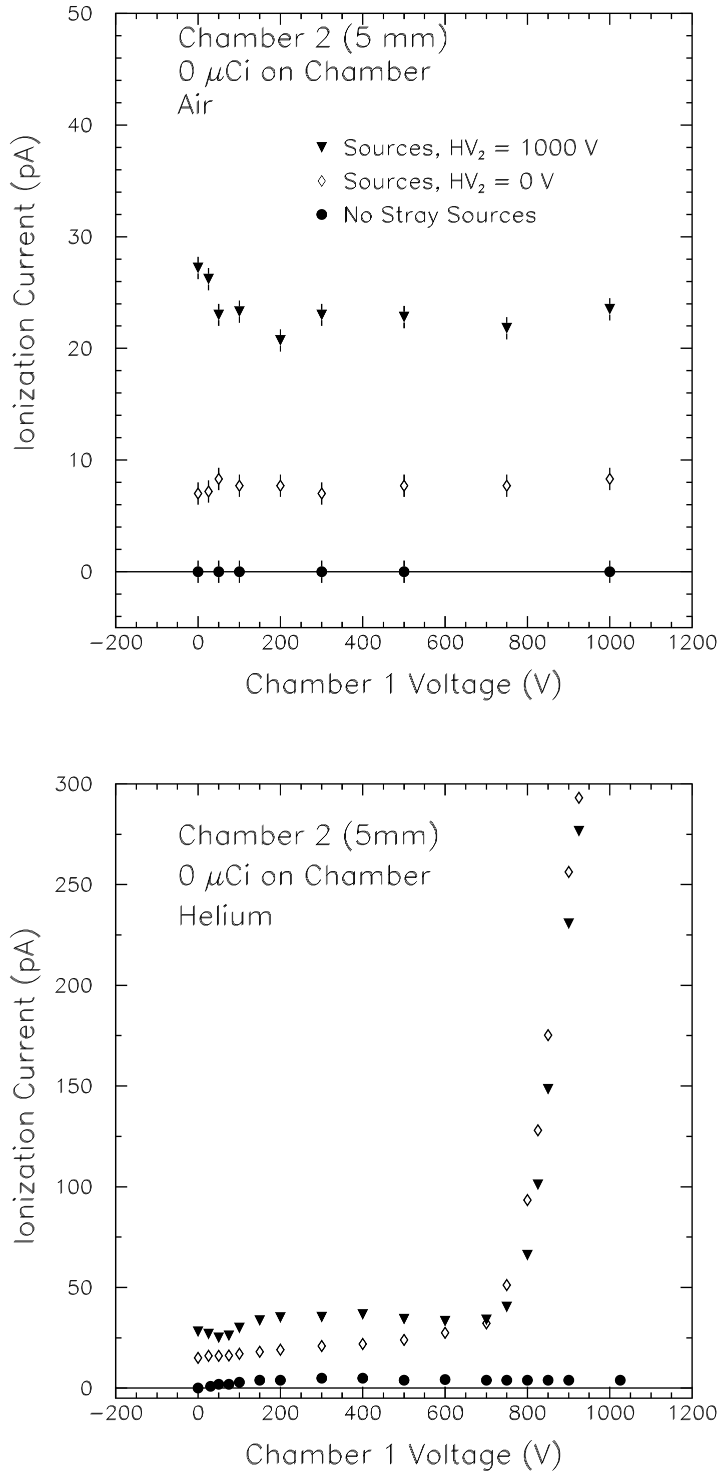


Figure 8: (above) Signal observed on Chamber 2 when operated in air in the configuration of Section 4.3. Shown is the bias curve when no stray sources are placed over the signal lines, when stray sources are in place but Chamber 2 is turned off, and when Chamber 2 is set to 500 V or 1000 V. The chambers are in air. (below) Same, but with the bell jar filled with He gas, O_2 impurities less than 2 ppm.

4.4 Shielded HV, Insulated Signal

In the next study we replaced the bare signal conductor wire above with teflon-coated signal wire. Thus, the signal lines were not shielded with a ground, but they were protected from ions directly reaching the conductors from the gas.

When we ramped the voltages in this configuration, again the signal contamination was zero unless the 'stray' sources were placed over the signal wires. When the stray sources were in place, extra ionization current was again observed of order 100 pA, and what was interesting is that this 100 pA current persisted long after the chamber was turned off! The current could die away after of order 24 hours, but the only way to quickly dissipate it was to rub the teflon wire jacket with an alcohol-soaked wipe. Our interpretation of this observation is that the unshielded signal line is still drawing ionization in the surrounding gas volume toward it, and that these ions collect on the teflon insulator.

Thus, we conclude that it is important that the signal line is protected from this stray ionization by the ground shield, as was the case when RG174 cable is used, and we conclude that little or no gas volume can surround the signal conductor inside the shield, lest that gas volume be ionized by the beam as well. The signal conductor must be in close contact with the insulating jacket, and the insulating jacket must be in close contact with the ground shield.

4.5 Exposed Feedthrough Connectors

The next study involved placing the chambers on the trellace and replacing all the signal and HV wires with shielded RG174. The only difference between this and our original configuration of Section 4.1 is that the feedthroughs in the base plate are no longer kapton-wrapped and surrounded with a ground braid shield (compare Figures 1 and 9). In this study the stray sources illuminate the feedthroughs themselves, not the cables (illuminating the cables showed no effect). Because of geometrical constraints, however, the stray sources could only be placed 3.5" above the feedthroughs, not the 1" in the case of illuminating the wires.

The results are shown in Figure 10. It may seem that the cross talk improved as a result of shielding the cables, but stray ionization at the feedthroughs is still as much as 10% of the signal if the chambers are operated at the upper end of the plateau. From this one concludes that all feedthroughs should be adequately shielded.

5 Conclusions

We have investigated several potential design features that can lead to signal cross talk on ion chambers. Signal and HV lines should be shielded, and the electrical feedthroughs through the gas enclosure walls should be well shielded as well. The insulator around the signal conductor must be in close contact so as to permit no gas volume for stray ionization, and

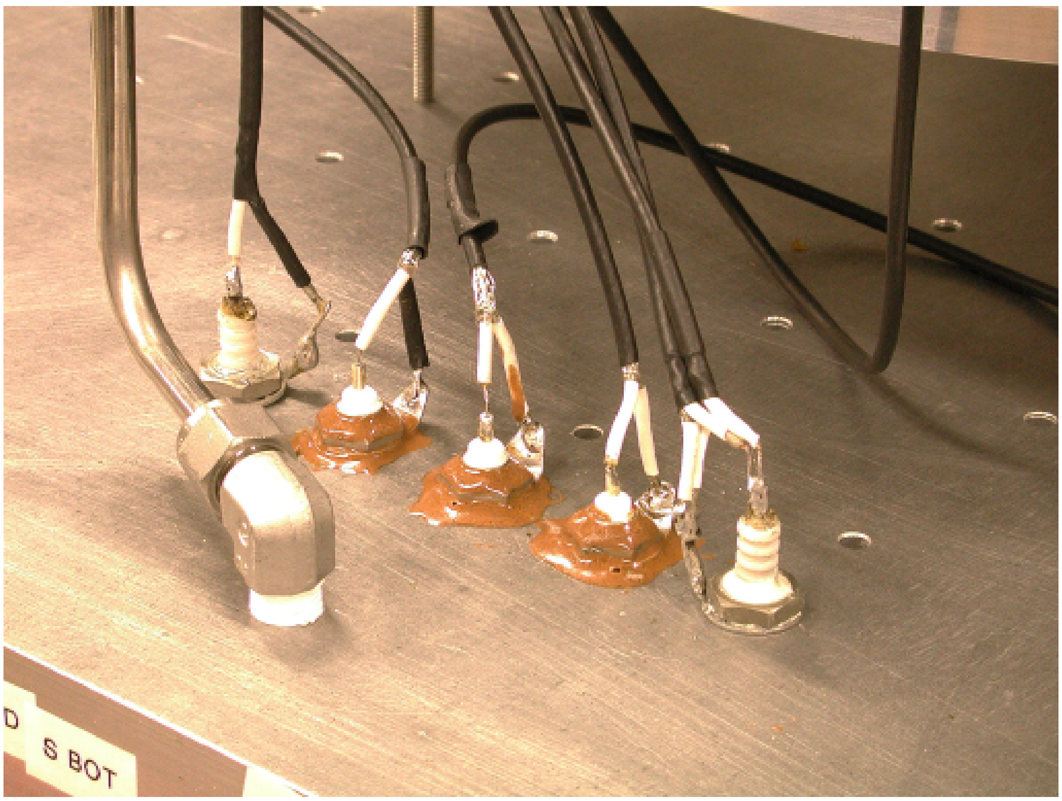
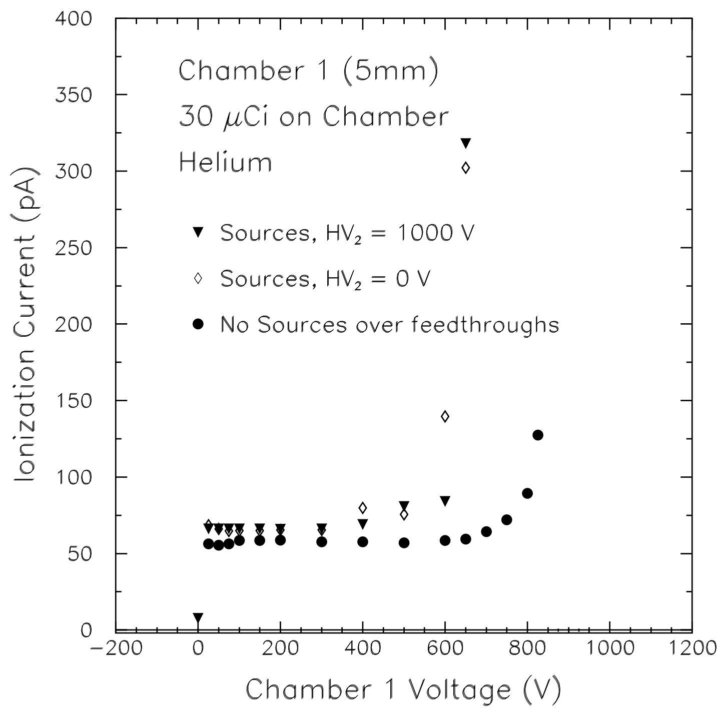


Figure 9: Removal of the shielding around one of the SHV feedthrough connectors in the base plate, as described in Section 4.5. The cable shield is grounded, but the shielding around the signal lines are removed so as to allow stray fields from one chamber's HV to impinge on the other chambers' signal connections.



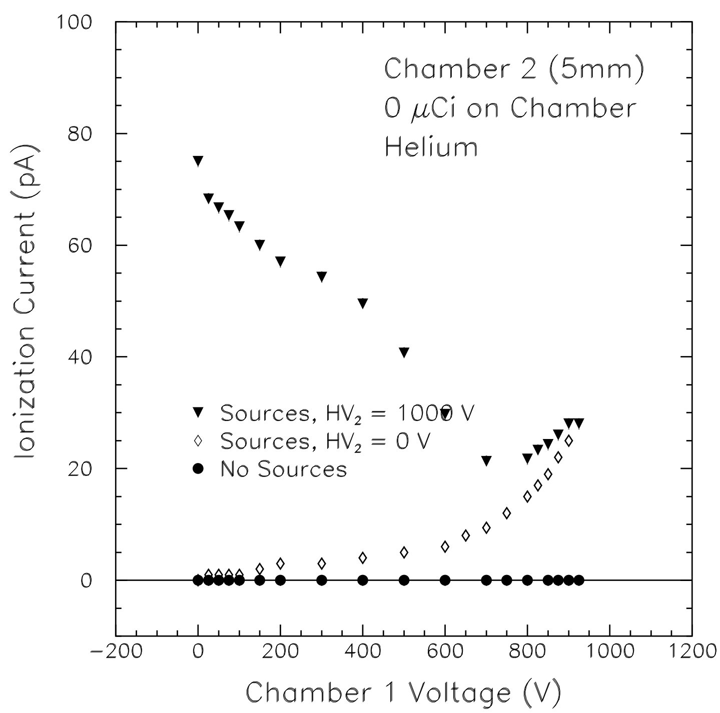


Figure 10: (above) Signal observed on Chamber 1 when operated in air in the configuration of Section 4.5. (below) The signal observed on Chamber 2 during this study.

the ground shield around the insulator must be closely wrapped around the insulator. Furthermore, the individual ion chambers must be electrically shielded from other ion chambers in the volume.

References

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