Commissioning a Test Stand for Secondary Electron Yield Studies

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Abstract

As particle accelerators continue to explore the intensity frontier, the problem of electron cloud formation is becoming an increasingly serious problem in hadron colliders. The formation of an electron cloud results in beam instabilities which are very difficult to predict and correct. Thus, it is necessary to investigate methods of preventing electron cloud build up. In hadron colliders, the cloud is seeded primarily with electrons from residual gas ionization. These electrons collide with the beam pipe and produce a shower of secondary electrons. At certain energies, this can lead to a rapid multiplication of electron numbers. A test stand was commissioned to test the secondary electron yield of various materials at energies ranging from 50 eV to 2000 eV.

1 Introduction

From the earliest days of accelerator science, the formation of free electrons has caused instabilities. One of the first recorded examples of the electron cloud effect was in a proton storage ring at INP Novosibirsk in 1967. The instability appeared at a threshold of only 1.2E11 protons [1] [1]. As hadron colliders reach unprecedented intensities, the formation of an electron cloud has become a significant concern because the resulting instabilities become very difficult to manage.

[1] For a brief overview of historical electron cloud instabilities, see [2]

When discussing the formation of the electron cloud, electrons are placed into one of two categories. They may either be *primary* electrons or *secondary* electrons. Primary electrons are usually produced in three ways: photoelectric effect, beam loss and residual gas ionization. In hadron colliders, the main method of primary production is residual gas ionization. For electron/positron machines, intense synchrotron radiation results in a large number of primary electrons from the photoelectric effect. Beam loss can also produce primary electrons as the beam particles strike the beam pipe or components.

For the accelerators at Fermilab, only residual gas ionization and beam loss make a significant contribution to the number of primary electrons. The number of primaries from residual gas ionization can be readily estimated from the gas density. Similarly, the number of primaries from beam loss can be calculated. An example of these calculations for Fermilab's Main Injector can be seen in [3].

These primary electrons then strike the beam pipe or components and eject secondary electrons. Depending upon the material, several seocndaries may be released when a single primary strikes the pipe, resulting in a net amplification of free electrons in the beam line. These secondary electrons can be further classified into three "types": reflected secondaries, rediffused secondaries, and true secondaries. These components have different energy spectra; reflected secondaries typically have the greatest energy. This is an important consideration when making secondary electron yield (SEY) measurements where SEY is understood to be the ratio of secondary current over primary current.

The SEY is energy dependent and can be expressed as a function of E_0, the incident or primary electron energy, and θ_0, the incident angle. In this study, the dependence upon angle was not considered although it should be possible to examine this dependence with the current set-up. Generally, the SEY for typical materials falls off quickly at low energies, reaches a maximum around 300-600 eV and slowly drops off for higher energies. A detailed examination of secondary electron yield can be seen in [4] and [5].

2 Method

A test stand was commissioned to test the secondary electron yield of various samples. As proof of concept, initial measurements were all done on a sample of copper. A Kimball Physics electron gun was used as the source of primary electrons. The energy of the primary electrons was stepped from 50 eV to 500 eV in 10 eV steps, from 520 to 820 eV in 20 eV steps and finally from 850 eV to 2000 eV in 50 eV steps[2]. Two measurements were needed to determine the SEY: primary current and sample current. The primary current is simply the beam current; it is the total current incident on the sample. The sample current is the current flowing into (or out of) of the sample. The SEY current is then given as the difference between these two measurements.

The beam current was measured by biasing the sample at +500 volts. The large positive bias was chosen to insure the capture of all secondaries including reflected secondaries, which typically have a higher energy spectrum. Thus the current measured at a +500 V bias is expected to be very nearly the entire beam current. The sample current was then measured by biasing the sample to -50 volts in order to avoid recapturing low-energy secondaries. These two currents are subtracted to arrive at the SEY current and the SEY current is divided by the beam current to find the SEY. More concisely:

$$SEY = \frac{(I_{-50V} - I_{+500V})}{I_{+500V}}$$

The SEY values may then plotted as a function of beam energy. The beam energy is the energy indicated on the power supply minus the 50 volt bias. All of the current measurements were made with a Keithley Picoammeter, model number 6487. This model has an integrated voltage source which may be used to bias the sample. A cartoon of the setup is shown in Fig. 1.

In order to get reasonably accurate values, the beam current measurements and sample current measurements were made consecutively. This was done to reduce the impact of current drift, which is a significant problem. At large beam currents where the gun is stable, the sample is conditioned while the measurements are made. Instead, small currents must be used to minimize the self-conditioning problem. On the other hand, at low currents the gun exhibits some instability in current. Even taking precautions, the current continued to oscillate about an average value for each setting. Measurements were made by randomly recording one of these values. For this reason, statistical errors may be apparent in the data. This could be corrected by taking more samples (with an automated system).

[2] As indicated by the EG power supply. The actual energy of the electrons depends upon both the indicated energy and the bias on the sample.

The Setup

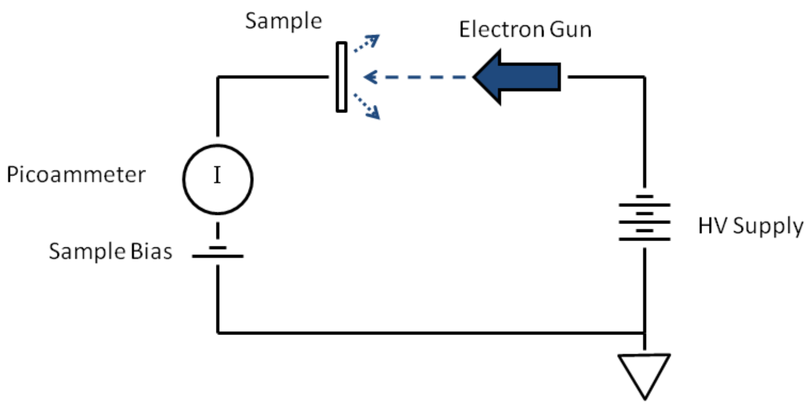

Figure 1: A schematic of the setup

Convention suggests the use of a negative 20 volt bias, instead of the 50 volt bias described here. This choice was made after making a qualitative assessment of the SEY curves produced by several different biases. A few of these curves are shown on the same plot in Fig. 2. At greater than 50 volts bias, the curves converged nicely. At smaller biases, the low energy measurements were spotty. The exact cause of this irregular behavior was unknown so the decision to use 50 volts was really an aesthetic decision.

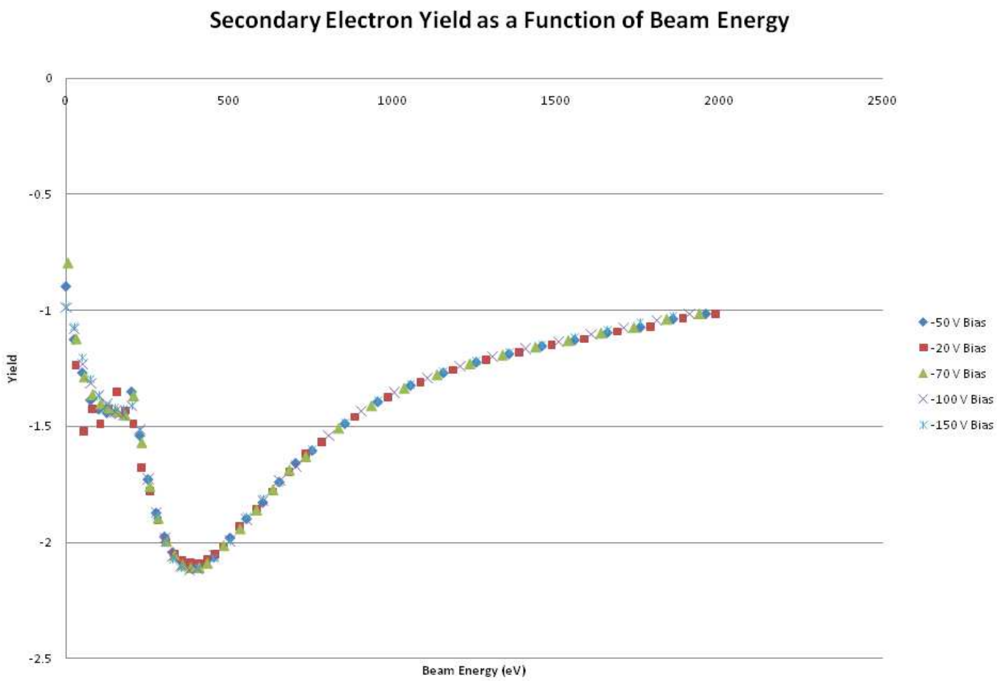

Figure 2: SEY curves for several different bias voltages

The whole apparatus consisted of a test stand made from stainless steel tubing. The main beam line was a horizontal tube with the electron gun mounted on a CF flange. Above the gun body a T with a KF flange was welded in place. This was fitted with another T to form the upper section. This upper section consisted of a valve for the pumping station and an inverted magnetron gauge. Roughly 1.5 cm down stream from the gun tip is a cross. One side port was eventually mounted with a mechanical feedthrough and the other had an electrical feedthrough onto which the copper sample was mounted. Thus the sample was stationary and electrically isolated. The other end of the tube was eventually fitted with an ion pump to improve the vacuum.

Apart from actual SEY measurements, there was also interest in the effect of conditioning on the SEY of a sample. After making several measurements of the SEY, the beam current was increased to the maximum value of roughly 30.99 μA. The sample was then left to "cook" for several hours with no bias. After allowing some time to elapse, the beam current is reduced and another set of SEY measurements made.

After noting some discrepancies in the data, the need for a better understanding of the beam characteristic became obvious. It was decided that an aperture on a mechanical feedthrough with a vernier should be installed in order to take some basic spot size measurements. The aperture consisted of a single jaw (edge) and a slit. Basic extinction measurements were made with the single jaw while the slit was used to plot the current as a function of position.

The single jaw extinction technique required that an initial current be measured with the aperture completely withdrawn. Then, the aperture is extended into the beam. When the beam current drops to 99% of the unobstructed current, the position was recorded. The aperture was then extended further until the beam current dropped to 1% of the original value, at which the point the position was again recorded. The displacement of the aperture was then understood to be the size of the beam spot.

The double sided aperture or slit technique consisted of taking readings of beam current at regular intervals as the slit was moved forward and backward. In this way, the current distribution as a function of location could be determined. It should be noted that both of these measurements were made with a negative 20 volt bias on the sample. The current measured was thus positive from secondary emission. The reason the sample was maintained at a negative bias during these studies was to prevent false current readings caused by secondaries from the aperture.

3 Results

The initial SEY curve for a copper sample is shown in Fig. 3. Qualitatively, the results were reasonable and encouraging. It was decided that the sample should be conditioned and another SEY measurement made. Fig. 4 shows the SEY curve for an unconditioned sample and the SEY curves after two conditioning periods. These results were unexpected and it was noted that the shape of the curve, especially after conditioning, was very sensitive to beam parameters. These results are presented here to aid in the understanding of the effect that beam parameters can have on the measured SEY. However, these results show a clear effect of conditioning.

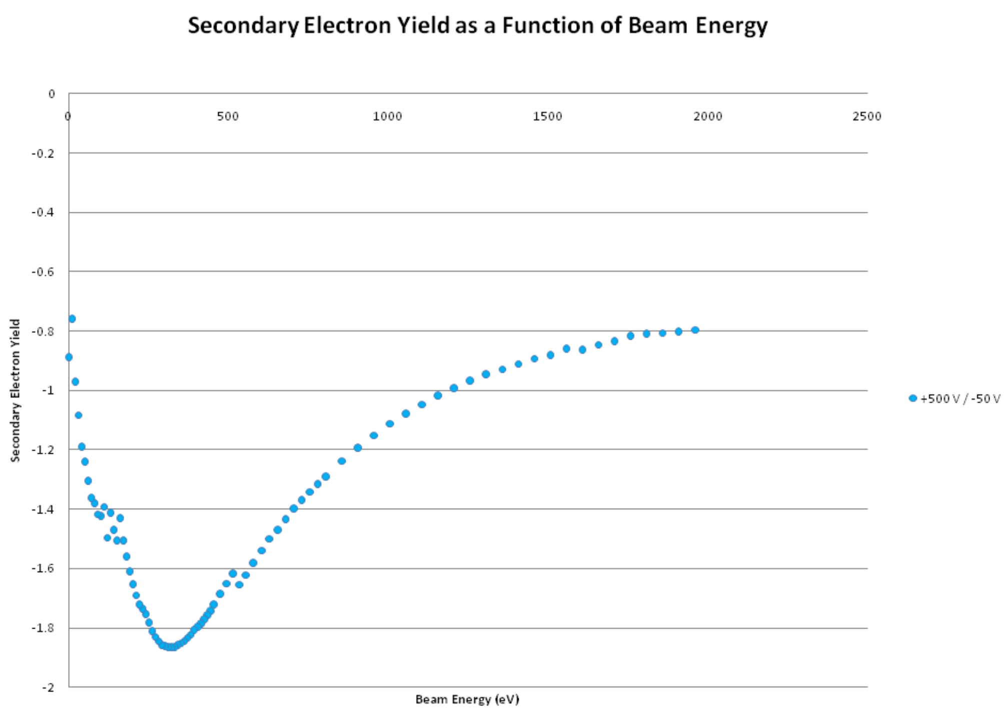

Figure 3: Showing the initial SEY curve for a copper sample. Note the "hiccups".

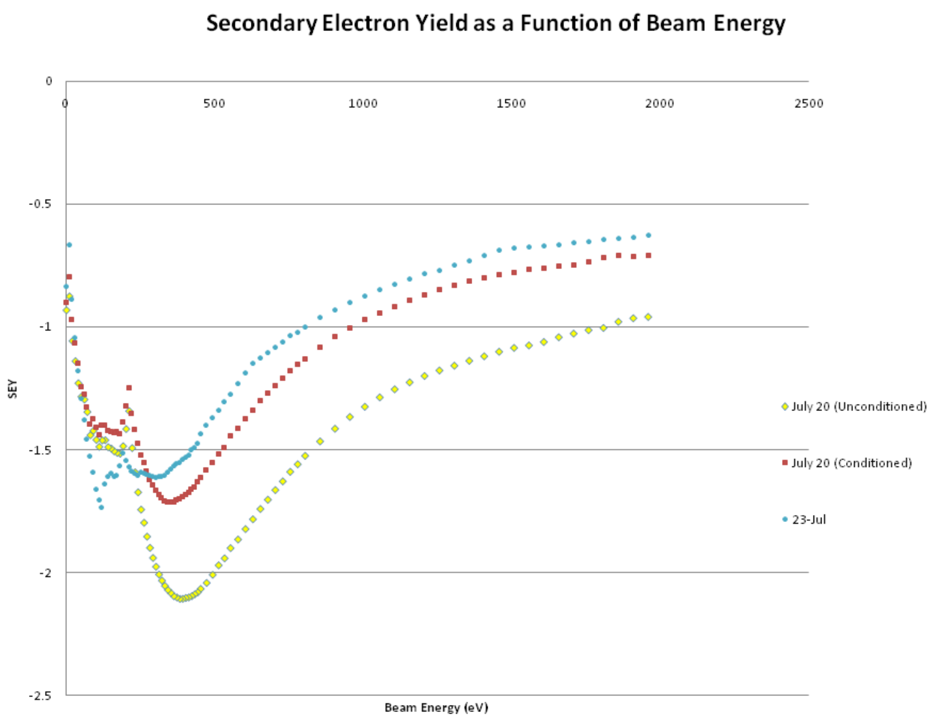

Figure 4: Showing the effect of conditioning. Also note the peculiar shape at low energies.

Several changes were made to the setup to improve the quality of the data. Among these changes was the installation of an aperture to better understand the effect of gun parameters on spot size. See the Discussion section for more details. Presented here are the first set of measurements made with the new setup (Fig. 5), including some measurements which show a dramatic effect of choosing bad gun parameters (Fig. 6. Again, this is discussed in detail later. Finally, a good SEY curve for copper is shown in Fig. 7.

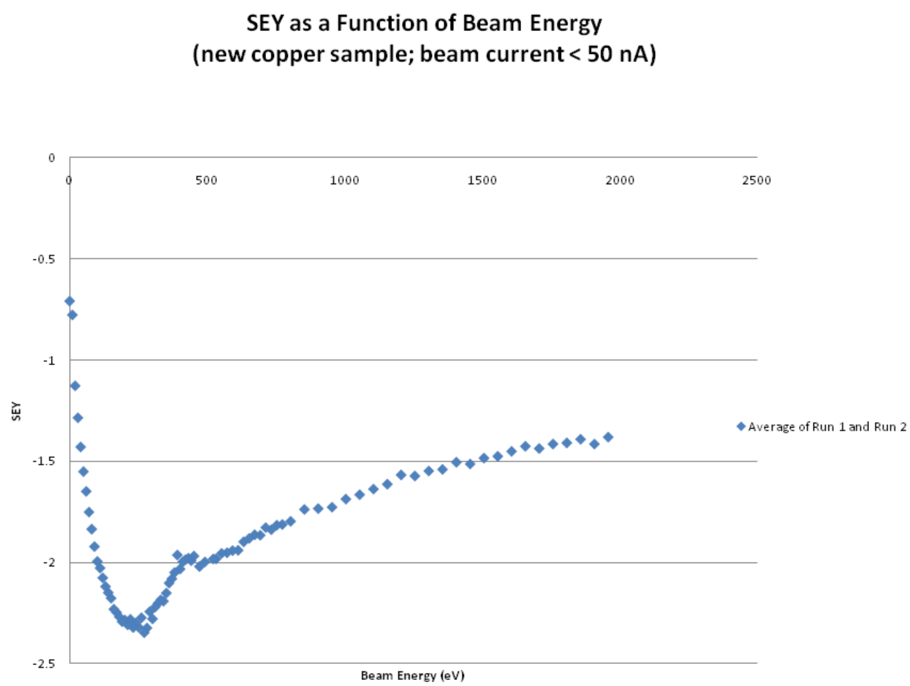

Figure 5: First SEY curve with the new setup. A qualitative assessment suggests that this data is reasonable although there is some question regarding the kink around 500 eV.

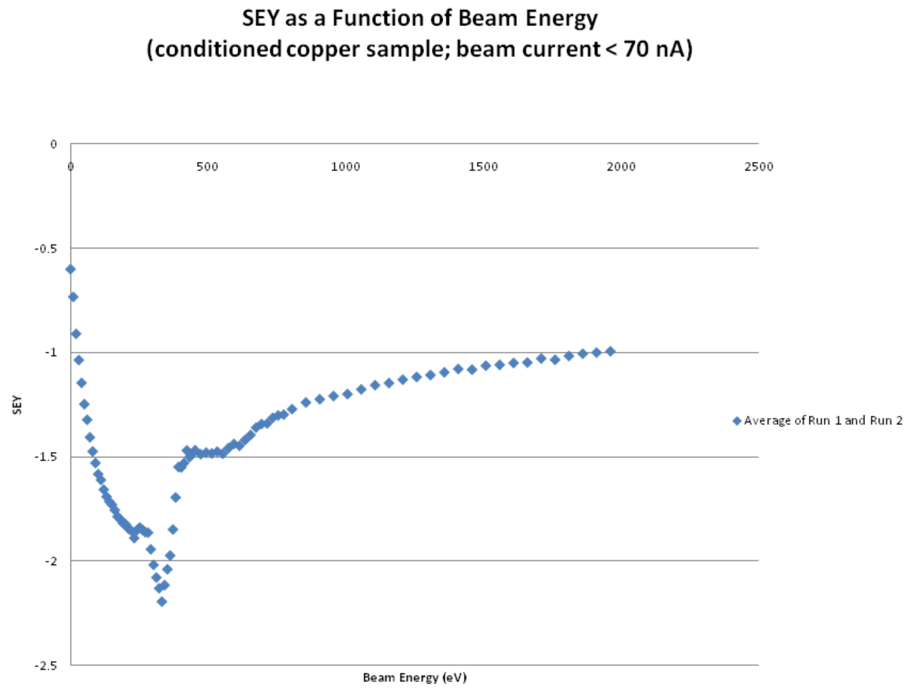

Figure 6: Showing the effect of conditioning. Note the dramatic results of a poorly chosen spot size.

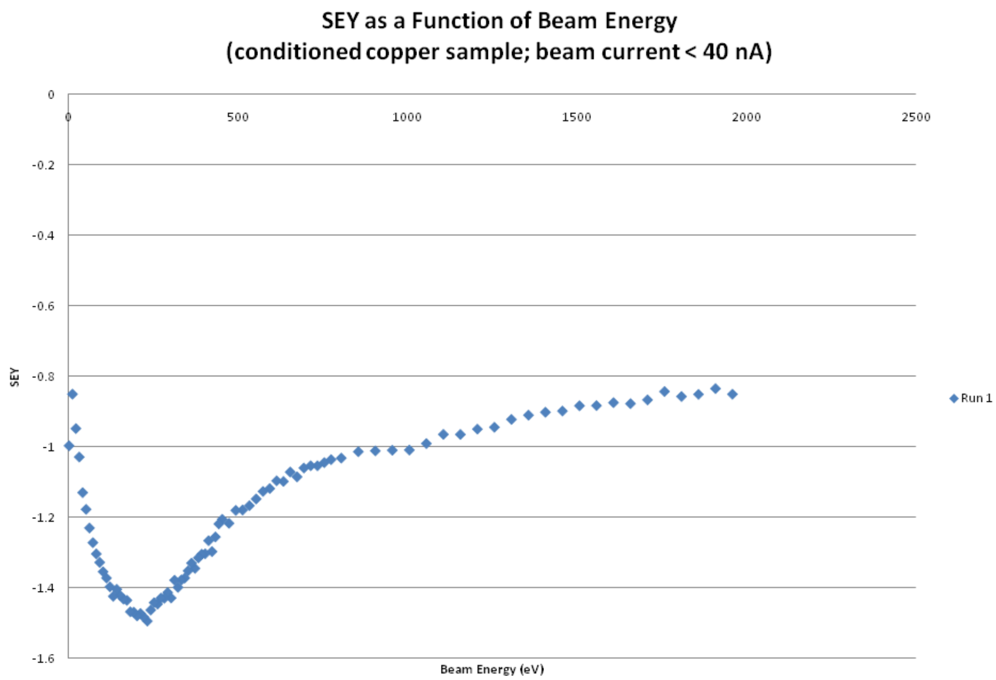

Figure 7: SEY measurement after choosing good gun parameters. The slight "wobble" is a statistical error resulting from the random sampling of the current readings

4 Discussion

Initially, there were some concerns at low electron energies. The use of a magnetron gauge and ion pump generated magnetic fields in the range of 20-30 gauss that had to be accounted for. Initially, it was believed that these fields could be causing the strange effects in the SEY curves at low energies. These fields were partially reduced through the use of mu-metal magnetic shielding. It was also found that the threaded rods which supported the test stand had become magnetized during machining. A simple “degauser” [3] was built to correct the problem. The degaussing procedure reduced the magnetic field from 42 gauss to roughly 1.2 gauss. After correcting for magnetic fields, the maximum measured field inside of the test stand was on the order of 1 gauss. These efforts significantly improved low energy measurements but a dramatic spike in SEY for a select range was observed after conditioning.

This effect was due to a poor understanding of the beam characteristics. One of the biggest challenges in taking good SEY measurements was developing a good set of parameters for each energy step to insure a relatively uniform spot size throughout the sweep. Also, the beam loss should be minimized. Ideally, the SEY measurements should be made with as small of a beam current as possible to prevent conditioning. However, some conditioning will likely take place. If the spot size varies in size or shape, the resulting SEY curves will be ”jittery” in appearance. This is due to the local variations as the beam illuminates an area that was previously unilluminated or vice versa. Also ideally, the beam loss would be minimized. The current that is lost eventually collides with other material in the test stand. This could be the stainless steel beam pipe or individual components of the gun itself. In these cases, the material will generate secondaries which may be collected by the sample when the sample has a positive bias, thus inflating the actual beam current.

The importance of beam size is extremely important when conditioning. If the test beam is larger in diameter than the conditioning beam for certain settings, an artificially high SEY will be recorded for that setting. From about 280 eV to 470 eV, the gun parameters chosen resulted in a spot size that was not only larger than the conditioning beam but was also off-center from the conditioned spot. This means that the majority of the current was

[3] The degauser consisted of a half-torroid ferrite core wound with 16 gauge wire. It was driven with a variac. The part to be degaussed was brought into contact with the core and the voltage ramped up and then down

landing on an area that was unconditioned where, for the other measurements, the majority of the current was landing on a conditioned area. In the ideal case, the conditioned spot size is uniform and much larger than the measurement beam spot size. Also, the measurement beam should be a stable, low current, tight beam centered on the conditioned spot.

Shown below are a few plots which illustrate this point. First, the single jaw extinction technique was used to measure the spot size for several points. A comparison between the spot size of good measurements and the spot size of bad measurements is given in Fig. 8. The bad measurements correspond to one of two beam types: a tight, displaced beam or a large, centered beam. Fig 8 shows a tight, displaced beam.

Figure 8: A comparison of spot size for good SEY measurements and spot size for bad SEY measurements

In order to resolve the spot size mismatch, both the measurement and conditioning beams had to be investigated. In order to understand conditioning, the beam current and size were measured. Fig. 10 shows the size of the conditioning beam. With the old parameters, the conditioning beam was approximately 1.5mm in diameter. With the new parameters, the FWHM estimate is about 3mm. Fig. 9 shows a plot of the conditioning current. The estimated total dose was 0.041 coulomb per square millimeter.

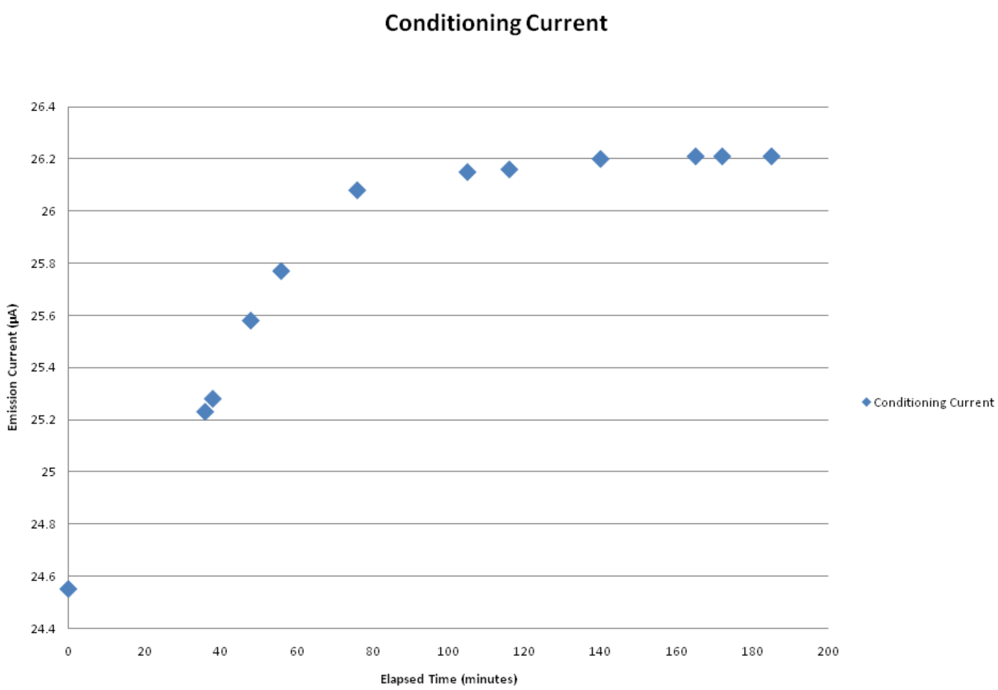

Figure 9: Rough plot of conditioning current as a function of time

With a baseline understanding of the spot size, a new set of gun parameters could be chosen to operate the test stand in the ideal case. Shown in Fig 11 are two plots. One shows a bad SEY measurement beam plot superimposed on a conditioning beam plot. The other shows a good SEY measurement beam plot superimposed on a conditioning beam plot. Note that the plots have not been normalized, so the relative heights of the distri-

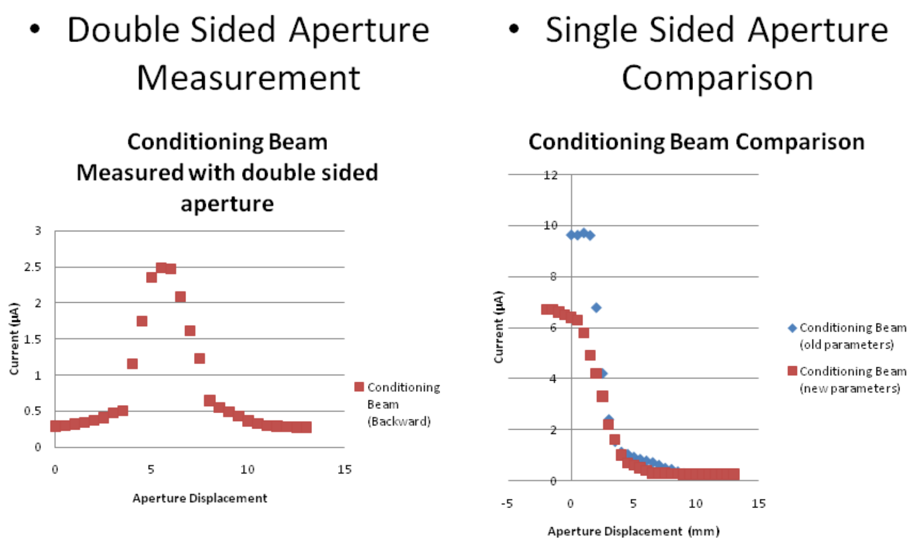

Figure 10: Note the difference between the conditioning beam with the old parameters and the new parameters

butions is meaningless. However, the qualitative shape and location of the distributions is important. The bad SEY measurement beam was roughly the same size as the conditioning spot but it is shifted; the peak of the measurement beam distribution occurs over the tail of the conditioning beam distribution. With the new parameters, the peaks are centered and the measurement beam is much smaller than the conditioning beam. This is the ideal case and yielded the most accurate results (see Fig. 7).

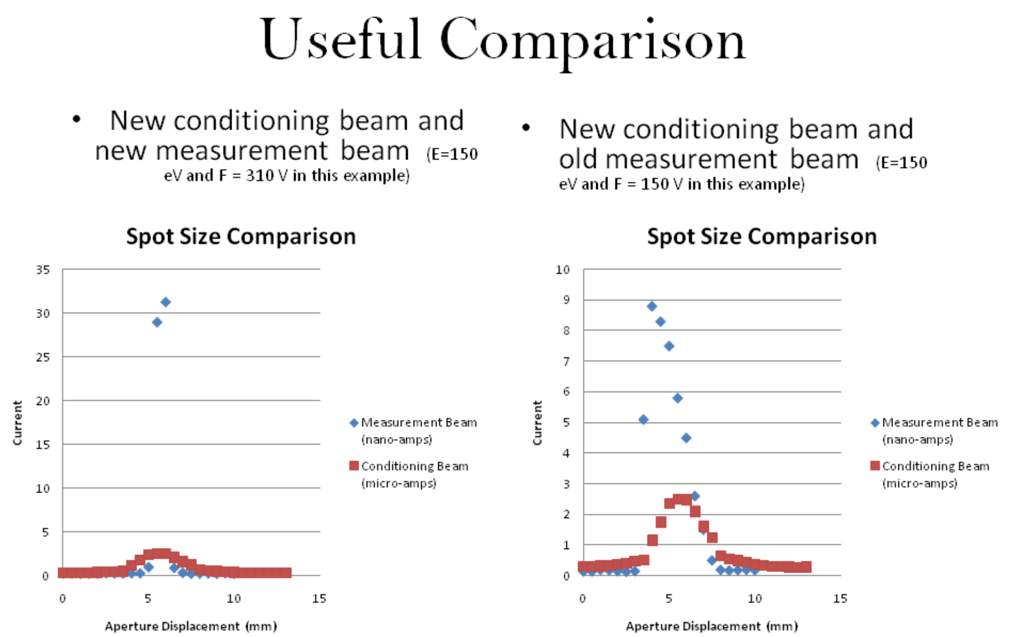

Figure 11: Spot size of measuring beams and conditioning beams

5 Conclusion

The ability to measure the SEY of various materials as an explicit function of primary energy and the ability to measure the effect of conditioning on SEY were both successfully demonstrated. Further work is needed to develop a solid set of gun parameters that will optimize the beam size based on the criteria discussed above. Future work should also include a detailed study of conditioning and how the energy of the conditioning beam effects the conditioning rate and final SEY.

6 Acknowledgements

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