

# Instructions for Operation of SEY Test Stand Experiment at MI-10

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## Introduction

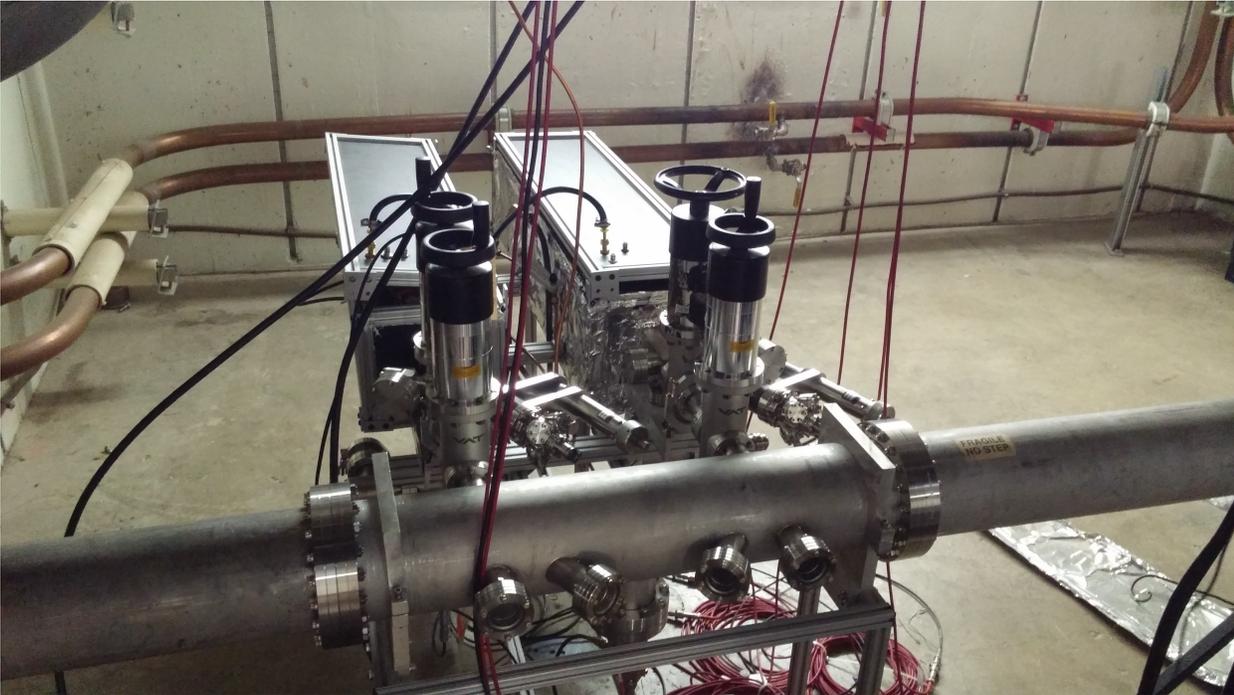


Figure 1: The SEY test stand. Based on this photo, the left arm in this photo is the left hand side and the right is the right hand arm.

Understanding the Secondary Electron Yield (SEY) of the beam chamber material in an accelerator and its evolution is essential to understanding electron cloud build up and electron cloud induced instabilities. SEY is a function of incident energy and incident angle. The SEY curve changes from material to material. Knowing the initial SEY curve for the beam pipe material is not enough, since the electron cloud generated during accelerator operations conditions the beampipe. The SEY measurement test stand located in the MI-10 area is a great tool to measure and understand how SEY develops under the operation of the Main Injector.[2,3,4] The test stand is designed to compare the behavior of two samples of different materials at the same location. Potential coatings or new materials may be directly compared to the stainless steel of the beampipe already in use. The samples are small curved pieces that fit into the vacuum chamber wall. The samples are retracted from the vacuum chamber wall via an electrically isolated arm during measurements and

put back into the beam environment afterward to monitor the continuous conditioning effect.

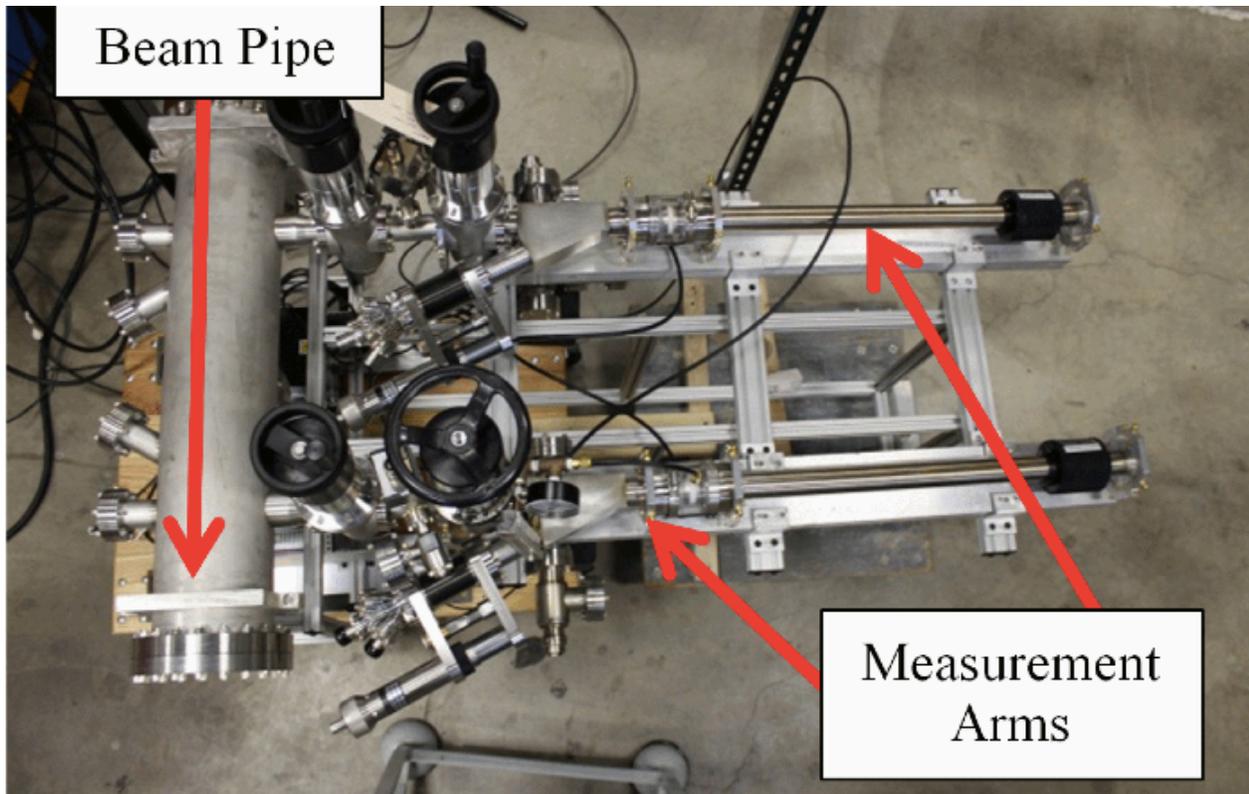


Figure 2: The test stand before installation. The measurement arm is electrically isolated from the rest of the test stand with a ceramic. During measurements, the arms and the samples are biased while the rest of the test stand is grounded.

### Measurement overview

The test stand measures the SEY by shooting an electron beam at the sample and then measuring the current. Two Kimball Physics ELG-02 electron guns were installed and are directed towards the sample at a  $15^\circ$  angle, which will increase the measured SEY by 1% compared to normal incidence, according to the Furman-Pivi probabilistic model[1]. Two currents are measured by the Keithley 6487 pico-Ammeter.

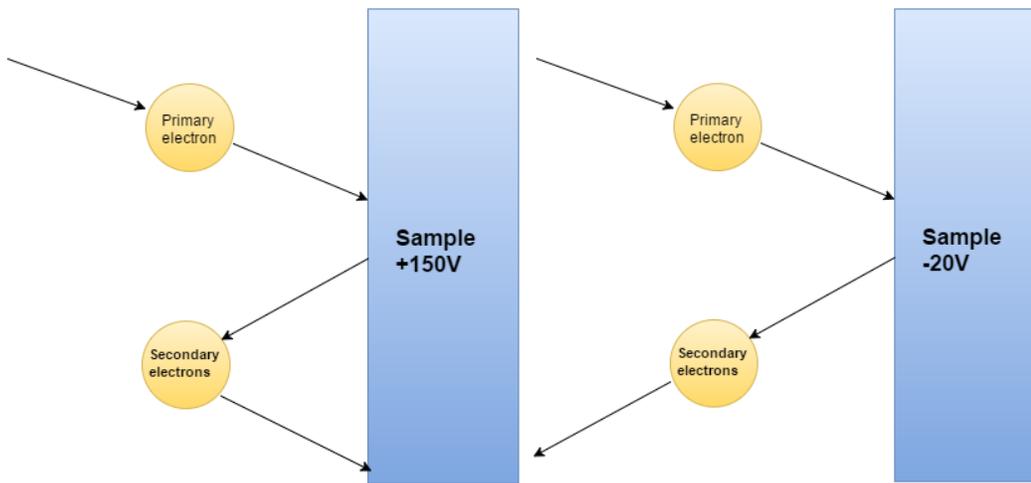


Figure 3: In the left subfigure, the primary current is measured by applying a +150 V bias voltage that recaptures all secondary electrons. In the right subfigure, the total current is measured by applying -20 V that repels all secondary electrons.

The primary current  $I_p$  is measured by applying a +150 V bias voltage that recaptures all secondary electrons. The total current  $I_t$  is measured by applying -20 V that repels all secondary electrons.

The Keithley 6487 built in voltage source is used to provide the bias voltage.

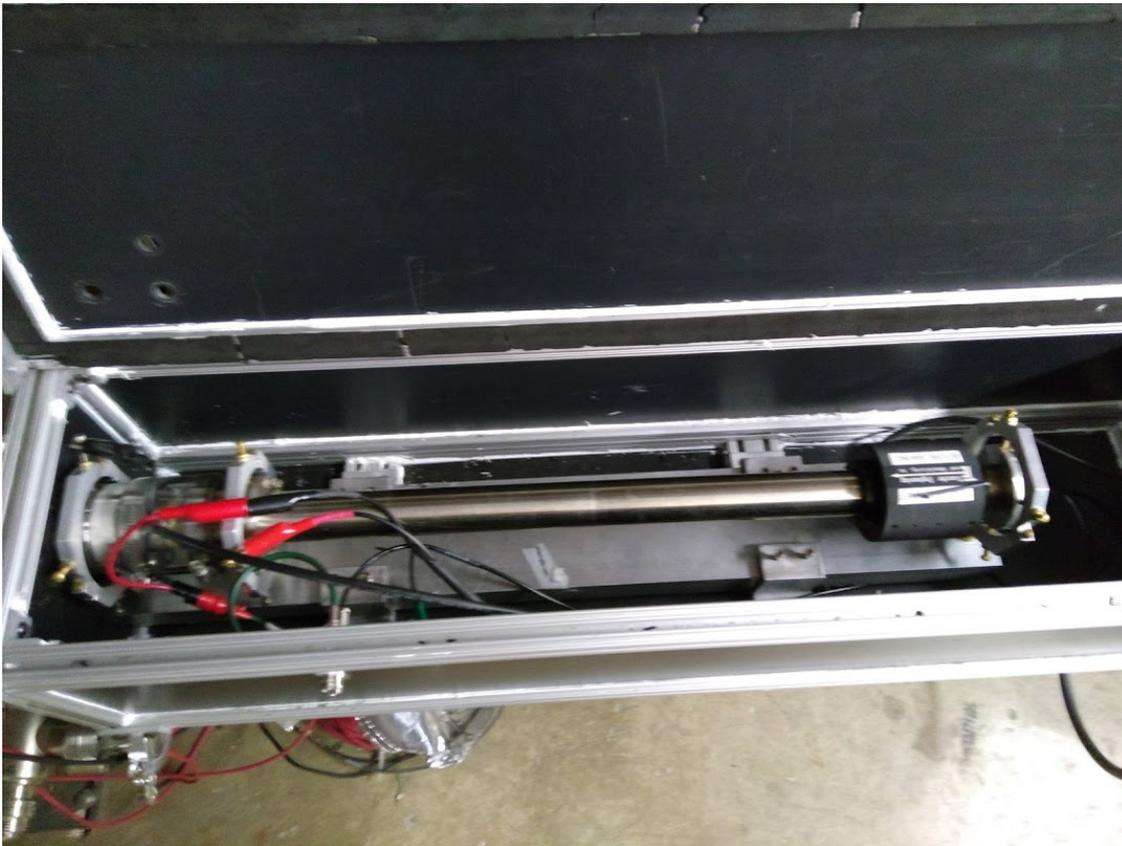


Figure 4: View inside the measurement arm protection box. The pico-ammeter is

connected between the arm and the ground. There are two BNC cables from the pico-ammeter with alligator clips, a duel-ax cable for the bias voltage and a triax cable for the current measurement.



Figure 5: The red clip of the duel-ax should be connected to the black clip of the triax (left), leaving the green of the triax hanging around (right).

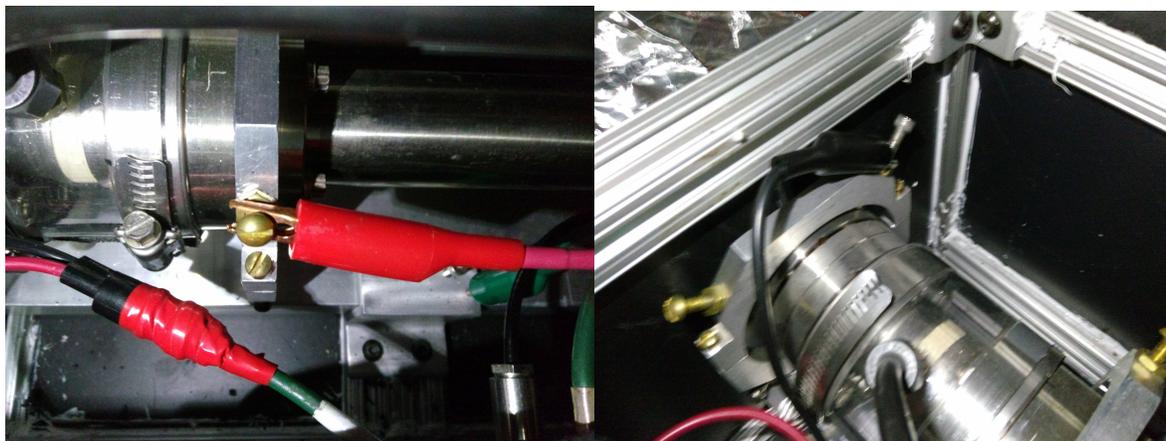


Figure 6: Connect the red of the triax to the arm (left) and the black duel-ax to ground (right).

The secondary emission current is given by  $I_{SEY} = I_t - I_p$ . The SEY can be calculated by the following equation.

$$SEY = \frac{I_t - I_p}{I_p}$$

The bias voltage induced leakage current can cause very high background signals during

measurements compared to the low signal current. The leakage current can reach as high as tens of nano-Amperes while the signal current is typically on the order of hundreds pico-Amperes. So the leakage current must be compensated for during later data analysis to extract the SEY.

Furthermore, the leakage current can be unstable over the course of a measurement. There is a dedicated paragraph discussing how to compensate for it.

### **Nitrogen Gas Flow\***

The process of flowing nitrogen gas to the system's isolating ceramic helps reduce error. The leakage current is the largest source of error in this set up and the humidity isolating ceramic is a major source of the leakage current. Using nitrogen gas to dry the ceramic greatly reduces the leakage current, yielding better measurements. Generally, during short machine shut downs, the humidity in the accelerator is well controlled and the nitrogen gas flow is not crucial.

Measurements without nitrogen gas flow can yield good results, but nitrogen gas flow is still recommended. However, during the long annual shut downs, the humidity in the tunnel is generally not under control, and the isolating ceramic has to be dried with nitrogen gas.

**I.** It takes time for the nitrogen gas flow to dry the ceramic. One needs to flow Nitrogen gas to the SEY test stand for about 24 hours before making a SEY measurement.. The pressurized Nitrogen gas cylinders are located in the MI-10 service building. The valve on one of the cylinders and the corresponding interconnect valve should be turned left. The left pressure gauge on the interconnect should read less than 5 psi. The fine adjustment valve and gauge above the interconnect should be set to 4 inH2O.

**A.** If the pressure cannot reach the desired value, it may mean that the Nitrogen gas cylinder is empty. If both Nitrogen gas cylinders are empty, full Nitrogen gas cylinders are located on a rack on the front of the building and can be swapped out. If all cylinders out on the rack are empty, contact the store room for more cylinders. The 'Pressure Safety Orientation' training is required before disconnecting or transporting cylinders. Stop all pressure flow before disconnected the gas hose from the cylinder. A 1&1/8 inch wrench will be needed to disconnect the gas hose from the cylinder. Use a cylinder cap before transporting the cylinder in the cart. Secure the cylinder with a chain or strap at all times when it is not manually being kept steady. Do not transport the cylinder with an unauthorized vehicle.

Whenever possible, carefully label cylinders to indicate empty or full.

**II.** After completing the SEY Test stand measurement, turn off the gas flow by turning the valves on the interconnect and the cylinder all the way to the right.

### **Access Procedure**

**I\*.** Verify the vacuum pressure at MI-10 is better than  $10^{-5}$  torr if there is a possibility that the MI-10 region could be up to atmosphere. You can check the pressure in the MI using the I55 page on an ACNET console. Setting the page to “Global” and clicking 'Plot' will suffice.

**A.** Before breaking beampipe vacuum at MI-10, the SEY test stand isolation valves should be closed to protect the conditioned samples. Note the isolating valves need to be opened before exposing the samples to the beam again. A vacuum tech might be required for these operations.

*This is very important, because running the setup under higher pressure could damage the electron gun.*

**II.** Take the measurement cart at MI-60 down the into the tunnel through the service elevator and to the SEY test stand setup at MI-10.

**III.** Plug in the power cord at the outlet to the right of MI-10 recess.

**IV.** Turn on the computer, currently the Dell Precision T3400.

**A.** The password for this computer is fermilab@789 (the username is automatically set to APC109230\localadmin )

**B.** The monitor must be plugged in before the computer is started. If you have to plug in the monitor afterward then restart the computer.

**C.** If the computer boots with an error message describing a memory crash or does not boot at all, it may be that the RAM memory was shaken out of place in transport. Opening the case, removing the RAM and putting it back into place generally solves the problem.

### **Test Stand Setup**

**I.** Locate the large metallic electron gun power supply connectors on the SEY test stand arm (outside of the box, near the beampipe). Thumb screw the threaded standoffs on these connectors all the way towards the beampipe. This will provide clearance for the sample to be retracted.

**II.** Open the black box at the SEY test stand (the box for the arm that you are using for the

measurement). Retract the sample using the allen wrench in the box.

**A.** The sample is on a black magnet connected to the metallic arm and is held in place with a black clamp on either side. The 'exposed' position for the sample is on the beampipe end of the arm and the 'retracted' position is on the opposite end of the arm.

**B.** Move the sample from the exposed position to the retracted position by following these steps: Detach the outer clamp with the Allen wrench. Push the sample all the way out (as far from the beampipe as it will go). Reattach the clamp to the arm on the inner side, securing the sample in place.

**C.** DO NOT move the clamp at the end of the measurement arm, as it indicates the measurement position. Moving it will cause the electron beam to not be focused on the correct spot on the samples.

**III.** Plug in the two BNC cables to the connectors attached to the black box. These cables take the current on the sample to the picoammeter for read out, and provide the bias voltage. One cable has two notches and the other has three notches to match their respective connectors to prevent error, so they cannot be connected incorrectly.

**IV.** There are two big black cables with metallic connectors and one thin black cable. The big black cables are high-voltage cables for the electron gun and the thin black cable is voltage for the electron gun acceleration grid. Locate the large metallic connectors on the SEY test stand arm (outside of the box, near the beampipe). Thumb screw the threaded standoffs on these metallic connectors to allow the connectors to have clearance from the beampipe. When the clearance is sufficient, connect the cables to the electron gun; the angled cable connector attaches on the left and the straight cable connector attaches on the right. The connectors are different to prevent connection error, do not attempt to force cables as that may damage the pins. Keep the left threaded standoffs all the way in (away from the beampipe) and adjust the right threaded standoffs so the outer edge (towards the stand) matches up with the red mark.

### **Computer Setup**

**I.** Turn Keithley picoammeter on. On the Kimball electron gun power supply, flip the on switch and then the HV power switch.

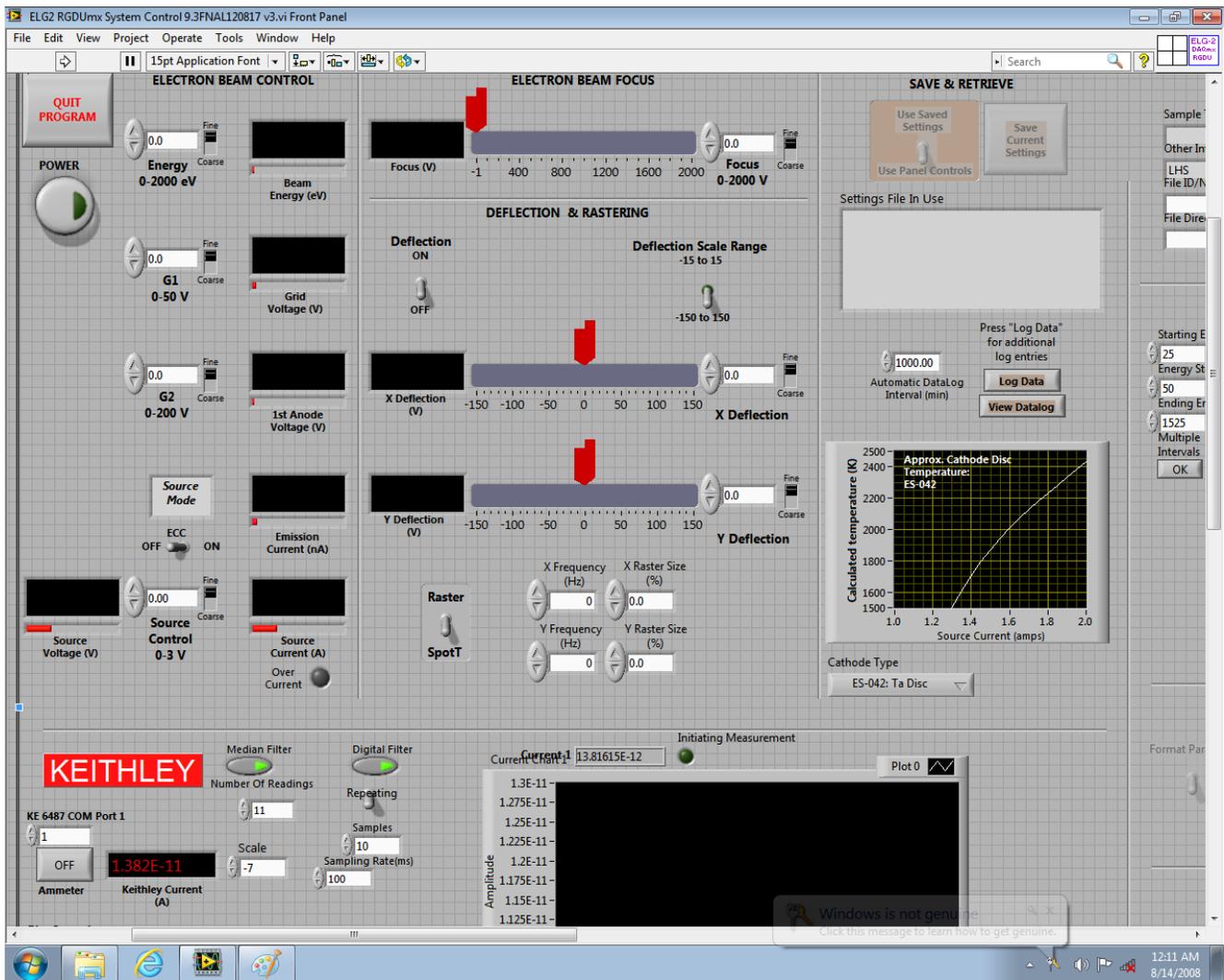


Figure 5: The start up page of the SEY measurement program. Hit the run button to start the program

II. Open Labview using the Desktop icon labeled SEY Scan. Click 'Launch LabVIEW'. Under the menu bar heading 'Operate'; click 'Run'. Then click the power button on the virtual control panel.

A. During this process a window should pop up and ask for 'Operator Initials', 'Sample Type', and 'Other Information'. It's important to specify whether the measurement is for the sample in the "left-hand side arm" or the "right-hand side arm". The orientation is assigned by standing at the MI-10 entrance side of the beampipe and facing the test-stand.

**The above graphic is not needed**

III. Look at the part of the control panel under the 'Keithley' heading, and look at the plot. The y-

axis is the current in amps and the x-axis is time.

A. If it's blank, click the ammeters on/off button on the virtual control panel (under the Keithley heading, above the Bias Control button).

B. If the plot is flat, or if the plot is reading values on the order of amps instead of  $10^{-12}$  amps, then double-click the ammeter on/off button on the virtual control panel to turn the plot off and then back on again.

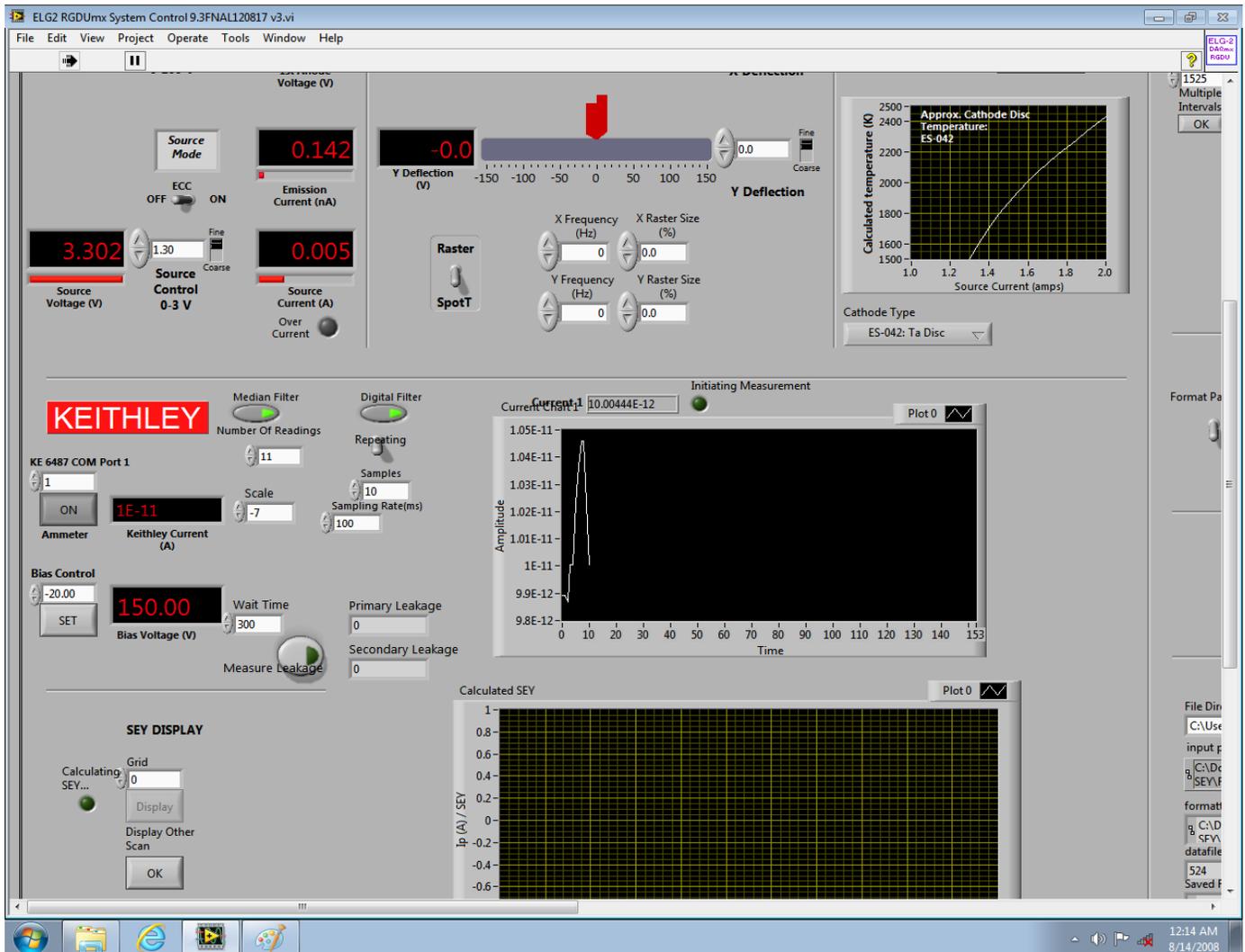


Figure 6: The pico-ammeter control and read out. The measurement can be monitored and quick leakage current measurements can be performed here.

IV. Look at the top-left part of the panel with the heading 'Electron Beam Control' and enter the following values:

A. 'Energy' should be 300

- B. 'G1' should be 25
- C. 'G2' should be 95
- D. 'Source Current' should be 1.3

### **Warmup Period**

- I. After connecting the cables, turning on the electronics, and setting the 'Electron Beam Control' parameters (in that order), the warm-up period begins. The warm-up time is 2 hours.
- II. There is no way to verify that the electron gun is sufficiently warmed up, without engaging in a test which would condition the sample and thereby ruin the measurement. Therefore 2 hours (or any amount longer) is protocol.
- III. A Leakage Current Measurement can be made while the electron gun is warming up, but it is important to make a Leakage Current Measurement with the SEY Test Stand Measurement.

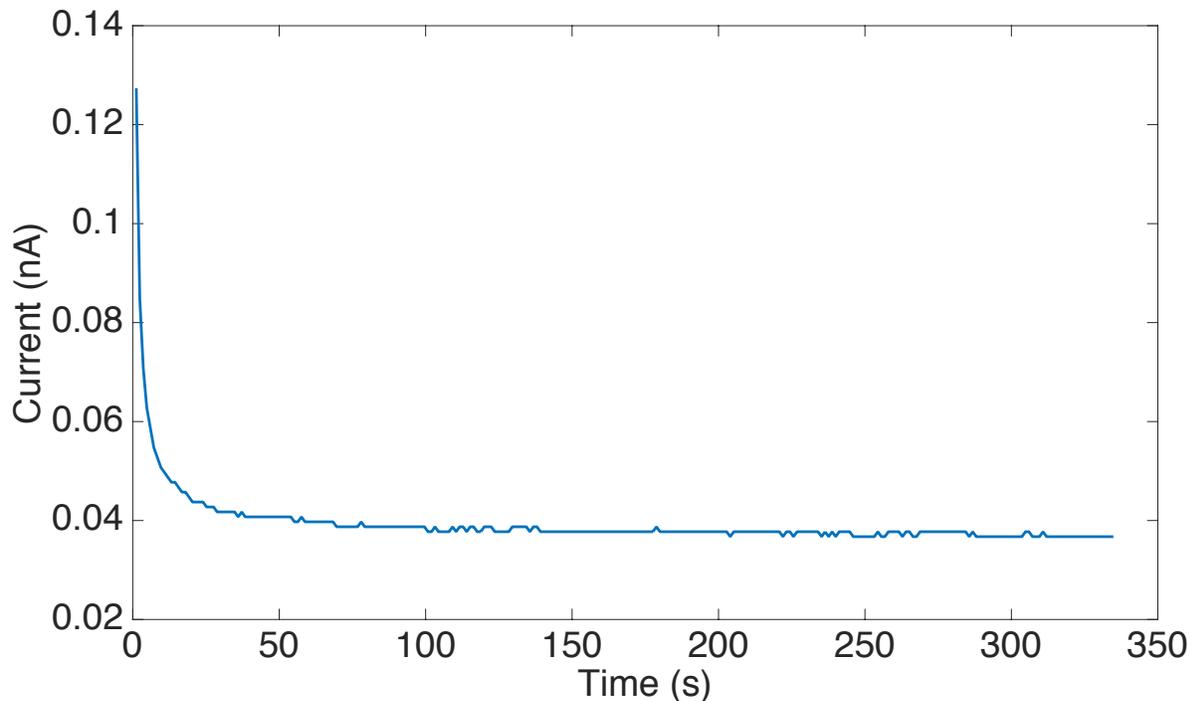


Figure 7: Typical leakage current for 150V bias voltage. The measurement should be performed after the exponential drop

### **Leakage Current Measurement & SEY Measurement**

- I. The SEY Test Stand measurement takes place after the Test Stand Setup, the Computer Setup,

and the Warm-up Period have all been completed.

**II.** Make sure the 'Wait time for Ip to SEY (ms)' entry is set to 180000, the 'Starting Energy' entry is set to 0 and the 'Energy step Size' entry is set to 25.

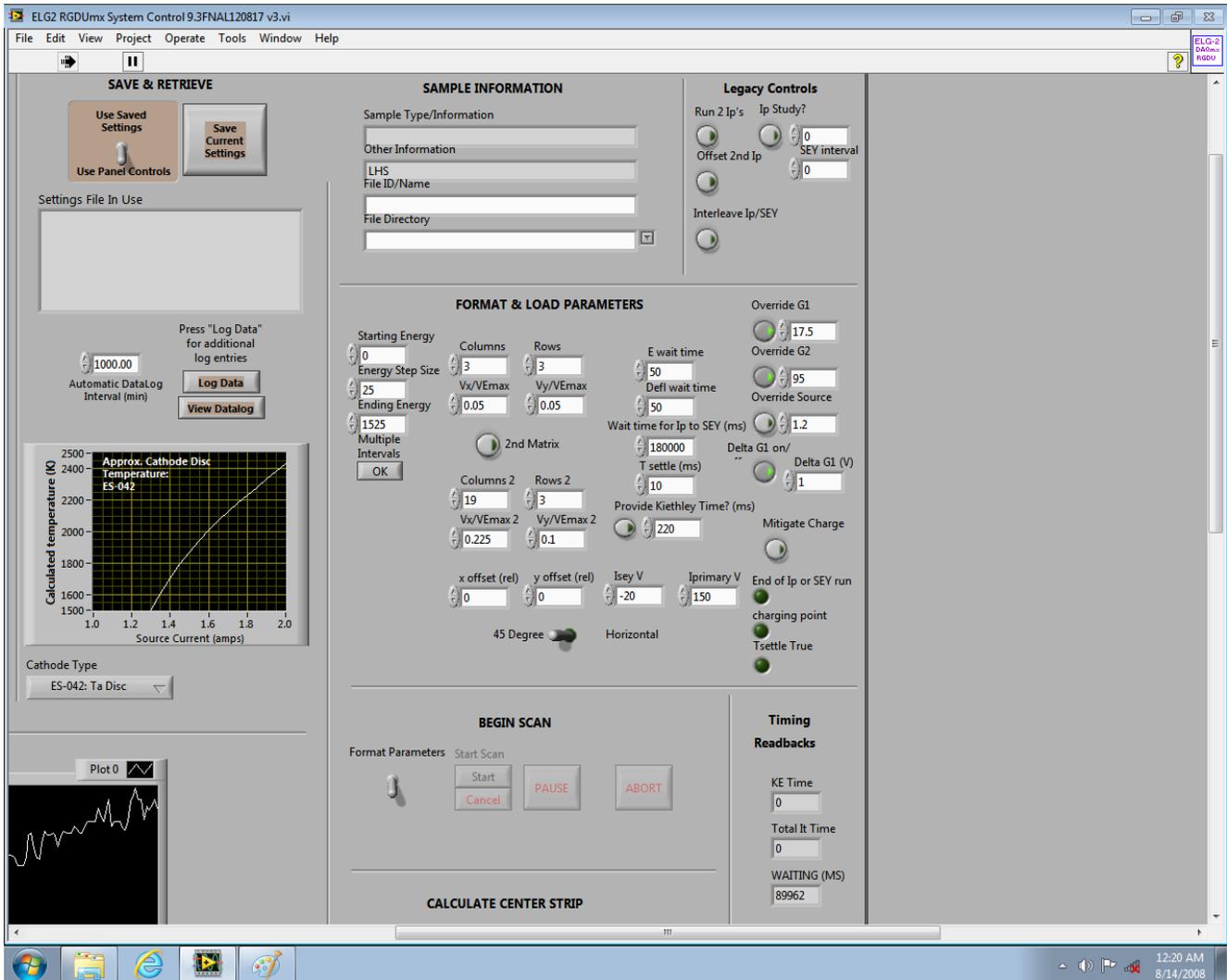


Figure 8: The measurement parameters. These parameters are default setting for Right Hand Side measurement. The 'Override G1' value should be determined every time based on leakage current. Change the 'Vx/VEmax' and 'Vy/VEmax' should be changed to 0.3 for Left Hand Side measurement.

**III.** You need to first try to control the leakage current then measure the exact leakage current.

**A.** Look at the 'Keithley' heading and find the 'Bias Control'. Enter 150 as the 'Bias Control' value and then click 'Set'. Wait for the leakage current to decay for 15 to 30 seconds and read the value. Ideally, the leakage current should be as low as possible. If the leakage current exceeds 1nA, the measurement will be very noisy. If the leakage current is high fiddle with

the cables inside the black box to reduce it. No cable should touch the silver metallic arm. Use cardboard to isolate them if necessary. When installing cardboard, make sure the cardboard does not connect the silver metallic arm with the box. If the leakage current is controlled to be under 300 pA, perform one leakage current measurement (this is an SEY measurement without the electron beam) and an SEY measurement. Otherwise, perform at least 2 SEY measurements and 3 leakage current measurements.

**B.** On the left of the virtual panel under the 'Format & Load Parameter' heading setting the 'G1' value to 25 will prevent the electron beam from leaving the electron gun. Then perform the SEY measurement procedure described in **VI.** below.

**IV.** Enter 0 as the 'Bias Control' value and then click 'Set'. Decrease 'G1' until the current reads 1.2 nA. Copy this value of G1 to the value for 'Override G1' under the 'Format & Load Parameter' heading. Other values are preset and should be kept the same.

**V.** Look at the  $V_x/V_{x\max}$  and the  $V_y/V_{y\max}$  parameters. The most significant digit should be a 5. When performing the “left-hand side” measurement, change the most significant digit to 3. Otherwise, leave the most significant digit as a 5. This parameter sets the grid spacing for the points measured on the sample and the change is needed to compensate for a slight difference in gun-to-sample distance between the left and right arms.

**VI.** SEY Measurement:

**A.** Look at the 'Begin Scan' heading. Click the 'Format Parameter' switch and then click 'Start'. When the SEY Measurement is done the 'Format Parameter' switch will toggle back. This process should take 17 minutes.

**B.** Carry out 'Format Parameter' scans through every energy step and make measurements for both  $I_p$  and  $I_t$ . The leakage current measurement is performed separately, but is integrated into the control system to run automatically. The save files are stored automatically, using the identifying information supplied when initially running LabVIEW.

### **End of Measurement**

**I.** Set 'Energy', 'G1', 'G2', and 'Source Current' (under the 'Electron Beam Control' heading) each to zero. Wait for the readbacks for each of these values to reach zero.

**II.** Hit the power button at the top-left corner of the virtual control panel. Quit the program using the LabVIEW menu bar at the top of the window and close out the LabVIEW program.

- III.** Turn off the Picoammeter Power, the Kimball electron gun power supply HV power, and the Kimbal electron gun power supply on/off.
- IV.** Unplug the high-voltage cables from the electron gun and the BNC cables from the black box. Thumb-screw the threaded standoffs so that the electron gun connectors are all the way out (towards the beampipe).
- V.** Retrieve the piece of cardboard. Return the sample to the exposed position by deataching the metallic clamp, pushing the sample all the way towards the beampipe, and reapplying the metallic clamp. Replace the lid of the box.
- VI.\*** Look into the straight viewport and shine a light through the angled viewport. Verify that the sample is exposed and centered - the circular hole should be filled with the metallic circular sample.

### **Second Arm Measurement**

- I.** Follow the End of Measurement section for the first arm.
  - A.** Make sure you close out of the LabVIEW program.
  - B.** One does not need to turn off the picoammeter if one sets the grid voltage to 0.
  - C.** One does not need to turn off the electron gun power supply as long as the parameters are all set to zero.
- II.** Follow the procedures in the 'Test Stand Setup' section and the 'Computer Setup' section for the second arm.
- III.** Another 2 hour Warm-up Period is necessary.
- IV.** Follow the procedure in the 'Leakage Current Measurement' and 'SEY Measurement' sections.
- V.** When the measurement is complete, follow the procedure in the 'End of Measurement' section for the second arm.

### **Closing Procedure**

- I.** Make sure you have completed the 'End of Measurement' steps for both arms. MAKE SURE the arms are in Exposing Position again.
- II.** Shutdown the computer. After the computer is shutdown, unplug the power cord.
- III.** Ensure all of the SEY test stand cables are clear from the tunnel walkway and clear from the magnet buses.

IV. Ensure all the cables on the cart are secured and return the cart to MI-60 using the service elevator.

### **Result Data Format**

The measurement results will be automatically saved as *TXT* files under the *FileDirectory* folder. This folder can be found under the *SEY* short cut on the desktop of the measurement computer. Here is a full set of files of the measurement result.

*6-29-2016 LHS Calculated SEY 419.txt*

*6-29-2016 LHS DataLog 419.txt*

*6-29-2016 LHS Iprimary 419.txt*

*6-29-2016 LHS Embedded Ip 1 419.txt*

*6-29-2016 LHS Control Parameters 419.txt*

*6-29-2016 LHS Front Panel Controls 419.txt*

The field name starts with the date (*6-29-2016*), followed by the comments you typed during the startup (*LHS*). To change the comment, one needs to restart the Labview program. Each measurement will have a 3 digit ID (*419*). The system's embedded SEY analysis tool was buggy and not reliable. The *Calculated SEY* file can be disregarded. The *Control Parameters* file stores the operating parameters, and the *Front Panel Controls* file stores the initial setups. These files are used for debugging and can be generally ignored when processing measurement results. Both *Embedded Ip* and *Iprimary* files contain the  $I_p$  measurement. The *Embedded Ip* includes more detail about each data point while the *Iprimary* extracts only the incident electron energy  $E$  and the primary current  $I_p$ . One can use the *Iprimary* to extract  $I_p$ . The *Iprimary* file has a minor bug, the 1<sup>st</sup> 2<sup>nd</sup> 4<sup>th</sup> and 5<sup>th</sup> row are always 0, the first data point is stored in the 3<sup>rd</sup> row and the rest are in the 6<sup>th</sup> row and after. The *DataLog* file contains the  $I_t$  measurement. The *DataLog* file has the same format as the *Embedded Ip* file, except the headers of each column are disregarded. For data analysis, one can directly use the 20<sup>th</sup> column in the *DataLog* file as the total current  $I_t$ . For the case of the leakage current measurement result, the  $I_p$  and  $I_t$  data are the leakage current for each data point. For each energy step, the system measures one  $I_p$  value and nine  $I_t$  values at different locations. The  $I_t$  values are stored sequentially, the system always measures the 9 different locations in the same order. Every set of nine  $I_t$  data points consists of one time step. Details about the energy step and locations can be found the in *DataLog* file.

## **Data analysis procedure**

When calculating the SEY, compensation for the leakage current must be done. Check the level first, this can be done by checking the  $0-eV$ -data-point. The  $0-eV$ -data-point always serves as a quick leakage current measurement. If the leakage current level is low enough, less than 10% of the average  $I_p$ , one can directly use the  $0-eV$ -data-point to compensate the leakage current, by subtracting the  $0-eV$ -data-point from all other data points. If the leakage current is not low enough, one needs to use a set of leakage current data to compensate. The leakage current changes during the measurement, so a fit of the leakage current must be performed for a better result.

Because of the bias voltage applied, the incident energy needs to be modified. The primary current  $I_p$  is only dependent on the electron gun; the incident energy of  $I_p$  will not be changed by the 150V bias. However, the -20V bias voltage will decrease the incident energy by 20eV for secondary emission. So, the SEY measured for each data point is 20eV lower.

## **Conclusion**

The SEY measured from this set-up has been compared to Furman-Pivi model (see Fig. 9), and the data is a good match to the model. The leakage current was initially not considered a major issue during the design of the SEY test stand. Since it has not be negligible, more shielding could be done to reduce the leakage current.

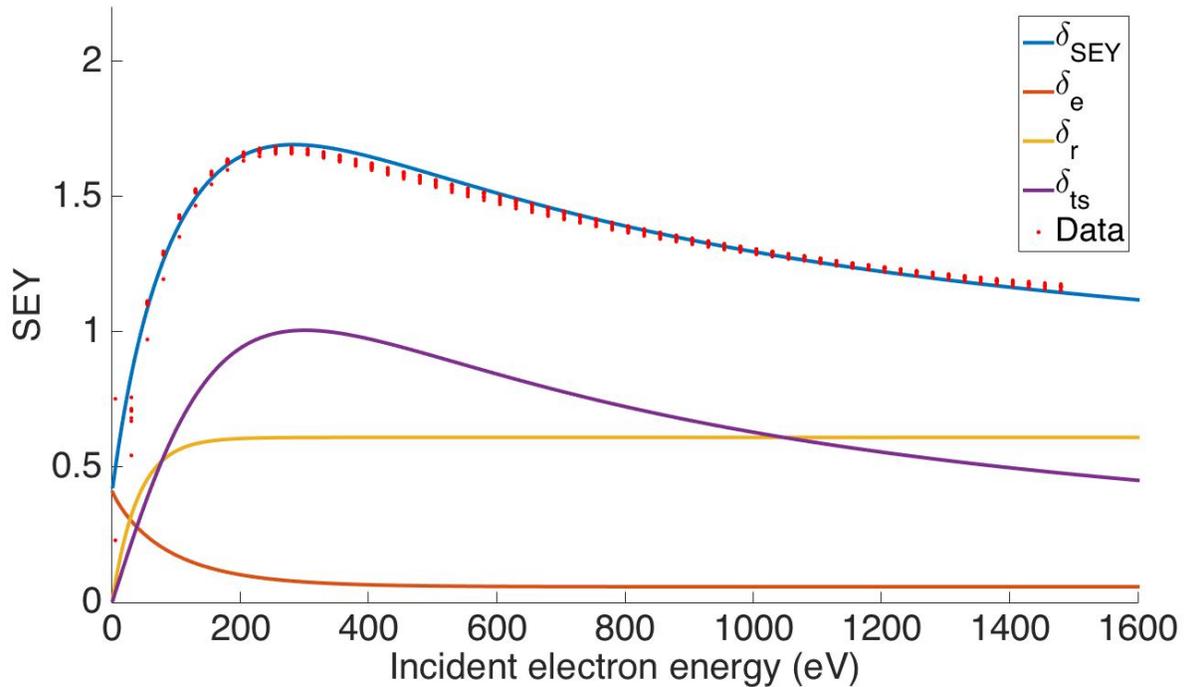


Figure 9: Typical SEY curve of stainless steel from a measurement compared to the Furman-Pivi model. The solid lines show each Furman-Pivi model component. The blue curve is the total modeled SEY, the others are the elastic electrons (red curve), rediffused electrons (yellow curve) and true secondary electrons (purple curve) (not the exact physical process, just part of the model). The red dots are data from the test stand measurement.

### **List of special equipment**

Ammeter: Keithley 6487 pico-Ammeter

Electron Gun: Kimball Physics ELG-02 with costumed length and power supply

DAQ card: NI PCI-6221, M Series DAQ (16 Analog Inputs, 24 Digital I/O, 2 Analog Outputs) with NI-DAQmx driver software.

Control card: NI PCI-6703 Analog Output Board and NI DAQ Software.

### Reference

[1] M. A. Furman and M. T. F. Pivi SLAC-PUB-9912, LBNL-49771, CBP Note-415.

[2] Y. Ji, L. Spentzouris, R. M. Zwaska, Proc. of NAPAC16 THPOA45

[3] Y. Ji, L. Spentzouris, R. Zwaska. Proc. of IPAC15 MOPMA039

[4] D. J. Scott, D. Capista, K. L. Duel, R. M. Zwaska et al. FERMILAB-CONF-12-196-AD