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“Mini” Electron Gun Report

Purpose:

To test electron guns in the "Elephant" vacuum chamber so that we as a team may obtain a means of testing our particle detectors used for the Cascades 2 project. The following is a recount of my personal efforts in finding a stable source of 0.0016pA of current, a full write-up on how to use the guns involved, as well as any useful data and information I have associated with them.

History and Efforts:

The point at which it all started was to test ten electron guns built during a physics lab for students here at Dartmouth College about a decade ago, chosen for this project due to their ease of testing and availability. Throughout testing on the bench (using a portable vacuum pump, vacuum tubing, and the same power supply that is currently used to power the guns inside the chamber, all borrowed from Ralph) I supplied 100V for the accelerating voltage, approximately 6V for the filament voltage, and ran at various pressures below 100 microns. After finding eight working guns from the group, a week or two went by before testing them inside the chamber. At that point I was unable to get a single gun to work at all; the filaments would get a little red in color, but would not emit a detectable amount of current, let alone the blue glow displayed on the lab test bench from earlier. Both filament and accelerating voltage inside the chamber were kept at the same values as on the bench, with pressures varying between 30-60 microns. Efforts were made to increase voltages by varying amounts, resulting in nothing more than blown filaments.

Following the chamber testing, those guns which were not used in the chamber (since the glass tubings, items necessary for testing with the portable vacuum pump, were removed for

chamber use) were tested on the lab bench, confirming that the guns themselves were no longer working and that the chamber was not necessarily the cause of failure in the guns. The next step was to try "fresh" guns directly in the chamber; guns that were not yet tested by myself personally, only by those students taking the lab from ten-plus years ago. These guns also failed to work.

Up until this point in the testing, all guns tested on the bench have had their glass tubings fully attached and intact. The guns tested in the chamber had this tubing removed for the sake of electrons being able to hit copper detection plates placed in front of the guns to detect current. With this in mind, the next step was to test a "naked" gun, one without its glass tubing, versus a gun with the entirety of its glass tubing still on. After two trials, the gun with tubing consistently worked, and the naked gun consistently failed. However, when trying the guns the next day, the gun with tubing would be much less potent when powered by the same voltages under the same pressure.

Next, Ralph helped by cutting the ends off of some of the glass tubes with a wet saw from the Chemistry building next door so that we may be able to test the benefits of having glass around the guns, but still be able to shoot electrons at the previously-mentioned copper detection plates. I then had two different lengths of hollow, cylindrical glass to attach to my guns. After testing in the chamber, I confirmed a direct correlation between the length of glass attached to the gun and the amount of current detected by both the copper plate that hung down below the guns as well and the deflection plate. The deflection plate was not used for deflection, since the goal is to get a beam, or spread, of electrons that we can reliably aim. Instead, I hooked up the Keithley source meter to it and measured current from it, so that I could have a source of current to measure without the distance of the copper plates. Testing the following day provided a strange, yet similar, hiccup: The gun with the long tube was barely able to fire a detectable amount of current while the gun with the shorter tube seemed completely dead.

This led us to believe that the glass enables a higher level of conductivity, but we still do not know precisely why it helps so much. Kevin had a theory that it was the moisture from the air trapped on the glass that helps the conductivity and that with the tubes being in the chamber overnight, they lost that moisture. To test this theory the door was opened up, used to waft the air a little, and then the chamber was pumped down again. Results were similar to those from the

beginning of the day: The longer gun had a very small current emitting, and the shorter gun had none at all. I also tried wrapping the outsides of the tubes with aluminum foil, but testing was inconclusive. Recently the idea of the glass getting a charge built, or somehow stabilizing floating charges up has been thrown around.

Soon after this test I enlisted the help of Professor Emeritus William Doyle, whose office is on the second floor. He was recommended to me by Professor Kristina Lynch as an aid and a great experimentalist, and I soon learned why. He was of great help and was the one to suggest that we stop trying to use the thorium and thorium oxide-coated tungsten and start using pure tungsten filaments. After some research, I found that the reason for the Thorium coating on the tungsten filaments was to increase current production, especially at low voltages and temperatures. While this is great for a lab where students want to see a blue glow without much hassle, this is bad for our goal in two ways: First, the filaments are so old that the coating is now flaky and unstable. I believe this provides some explanation as to why the guns would work for what seemed like only a single day of testing. (Some papers provided by Kevin Rhoads also offer one possible/additional explanation as to how these filaments could be poisoned: Emissions of any oxide-coated cathode depends on the maintenance of a certain barium reserve. If more barium is produced by electrolysis and by reduction than is lost by evaporation and gas-poisoning, the emission remains stable. If the two latter influences dominate, the emission drops. We also know that the barium production is greatly enhanced with increasing temperature, and therefore AC voltage.) The second reason this coating is bad for our project's guns is that we need a specific, constant, and quite small current of 0.0016pA to hit our detectors so that we may avoid both (the problems of) not being able to detect anything and oversaturation.

To test the new approach of pure tungsten filaments, I looked to the filaments found in incandescent light bulbs found in Ralph's supply room. It took a couple of tries, but after wrapping the bulbs in tape and breaking the glass with a hammer hitting a knife pressed against the bulb, I was able to salvage a very thin and fragile tungsten filament. I then proceeded to make a "homemade" gun using the base of the bulb which holds the tungsten and various spare parts from old electron guns. Testing in the chamber proved successful; the current emitted from the homemade gun was controllable at various levels below about $0.15\mu\text{A}$. Before much more

testing could be completed, the filament burnt out. These results inspired me to build another homemade, pure tungsten electron gun.

For this, two different metals in the form of wire were used: tungsten and molybdenum. I cut them out in about 1" pieces, and bent them to a similar 'U' shape as those filaments found in the premade electron guns. I then crimped them into the guns already made, replacing the thorium-coated directly with these pure metals. Testing in the chamber provided the data I was looking for: Under the correct conditions these guns were able to run 0.0016pA at various distances from the copper detection plate.

Gun Characteristics:

Thorium-Oxide-coated Tungsten Filaments: These guns were very difficult to deal with and measure at a stable value of current. Typically I would run them at 100V for accelerating voltage, about 6V for the filament voltage, and would get anywhere from 0.001 μ A to 20 μ A, depending mostly on how much filament voltage I supplied. Accelerating voltage also caused a gain or loss, but the reaction was not nearly as large. When the guns were tested, how fresh they were (to me) would change the attributes of the guns greatly. When "fresh," (in the beginning of testing, either on the bench or in the chamber) the guns would dive and rise dramatically at any sort of change in filament voltage. Typically, if they increased in current value, they would display a constant rise in current. When they would get to be a little used, they would be easier to control, showing lower values to the same inputs I would have supplied only minutes before. It seemed like they were always depreciating in potency, where eventually every gun would die. If left at a constant setting, they would slowly decrease emitted current. I never ran them long enough to watch it go all the way to zero, only after a day would I be able to come back and see nothing being emitted.

Pure Tungsten Filaments: These filaments have performed much better, exhibiting easily controlled values of emitted current, ranging from nothing to a couple of Amperes. There seems to be little to none of the aging/poisoning effects the thorium coated filaments had; guns that have been tested over the period of weeks feel just as good and responsive and powerful as they were on day one, all using the same inputs as before.

Gun Elements:

The final electron guns I have are very similar to those found for the old lab. Said guns consist of:

- 1 eight-pin vacuum tube header
- 1 glass tube
- 2 deflection plates
- 1 anode cap
- 1 filament
- 2 filament support tubes

As stated before, the guns I have been using with success replace the glass tube with one having its end cut off so as to let electrons pass unobstructed and replace the regular thorium coated tungsten filament with a pure tungsten or molybdenum filament. This list along with information on how to manufacture and run these guns is described in detail in “Experiment Six: Construction of an Electron Gun” on page 303 of the old physics lab book.

Calculations:

1. Velocity of Emitted Electrons

$$eV = \frac{1}{2} mV^2$$

$$(50 \text{ V}) (1.602\text{E-}19 \text{ C}) = (\frac{1}{2}) (9.109\text{E-}31 \text{ kg}) (V_{50})^2$$

$$(100 \text{ V}) (1.602\text{E-}19 \text{ C}) = (\frac{1}{2}) (9.109\text{E-}31 \text{ kg}) (V_{100})^2$$

$$(150 \text{ V}) (1.602\text{E-}19 \text{ C}) = (\frac{1}{2}) (9.109\text{E-}31 \text{ kg}) (V_{150})^2$$

$$\underline{V_{50} = 4.19\text{E}8 \text{ cm/s} = 4.19\text{E}6 \text{ m/s}}$$

$$\underline{V_{100} = 5.93\text{E}8 \text{ cm/s} = 5.93\text{E}6 \text{ m/s}}$$

$$\underline{V_{150} = 1.87E9 \text{ cm/s} = 1.87E7 \text{ m/s}}$$

2. Radius of curvature

$$R = V / \omega = mV / qB$$

$$R_{50} = (9.109E-31 \text{ kg}) (4.19E6 \text{ m/s}) / (1.602E-19 \text{ C}) (5E-4 \text{ T})$$

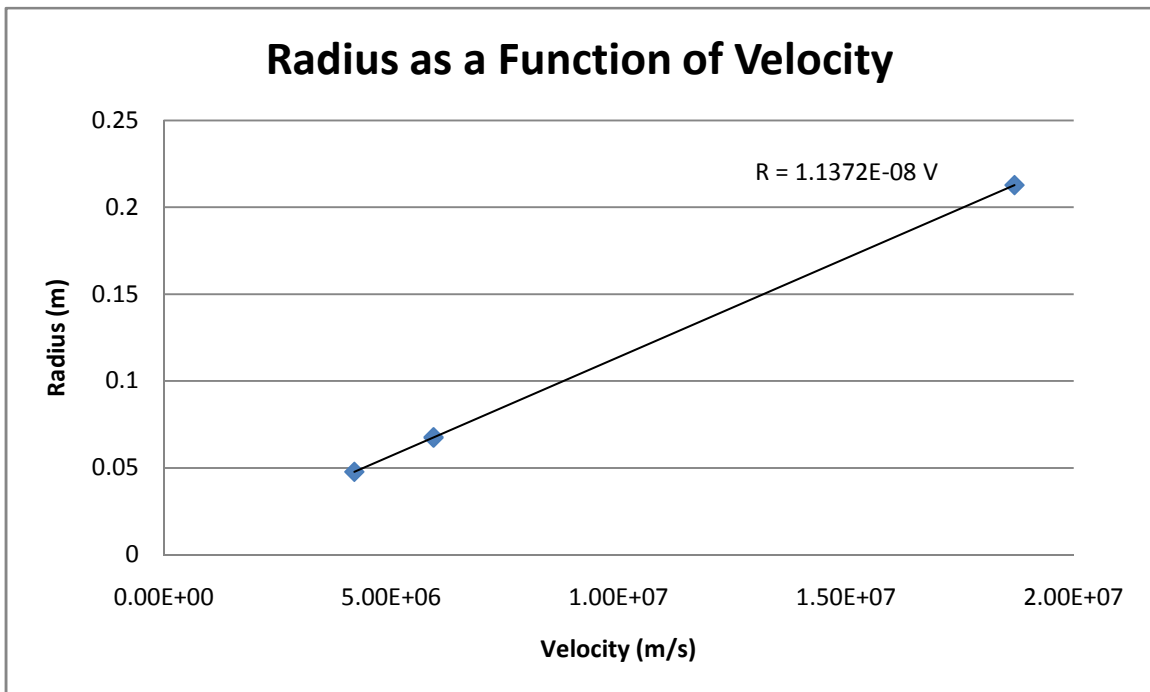
$$R_{100} = (9.109E-31 \text{ kg}) (5.93E6 \text{ m/s}) / (1.602E-19 \text{ C}) (5E-4 \text{ T})$$

$$R_{150} = (9.109E-31 \text{ kg}) (1.87E7 \text{ m/s}) / (1.602E-19 \text{ C}) (5E-4 \text{ T})$$

$$\underline{R_{50} = 4.765 \text{ cm} = 4.765E-2 \text{ m}}$$

$$\underline{R_{100} = 6.744 \text{ cm} = 6.744E-2 \text{ m}}$$

$$\underline{R_{150} = 21.266 \text{ cm} = 0.21266 \text{ m}}$$



3. Area Ratios

Area Ratio = Square Area / Round Area Spread of Beam

$$\text{Area Ratio} = (1 \text{ cm}) (1 \text{ cm}) / (\pi) (R)^2$$

Area Ratios for Various Lengths		
Distance Shot	90° Angle of e⁻ Beam Spread	45° Angle of e⁻ Beam Spread
1.0 m	3.1831E-5	1.8554E-4
0.5 m	1.2732E-4	7.4208E-4
0.1m	3.1830E-3	1.8550E-2

4. Thorium-Coated Tungsten Electron Current

$$I = 0.2\text{A} = (0.2 \text{ C/s}) (1 \text{ e}^- / 1.602\text{E-}19 \text{ C})$$

$$I = 1.2484\text{E}18 \text{ e}^-/\text{s}$$

5. Expected Target Current for Particle Detectors

$$I_{\text{TARGET}} = 10\text{kHz} = 10,000 \text{ Hz} = 10,000 \text{ e}^- / \text{s}$$

$$(10,000 \text{ e}^-/\text{s}) (1.602\text{E-}19 \text{ C/e}^-) = 1.602\text{E-}15 \text{ C/s}$$

$$Q = It$$

$$I_{\text{TARGET}} = 1.602\text{E-}15 \text{ A} (1\text{E}12 \text{ pA} / 1\text{A})$$

$$\underline{I_{\text{TARGET}} = 1.602\text{E-}3 \text{ pA}}$$

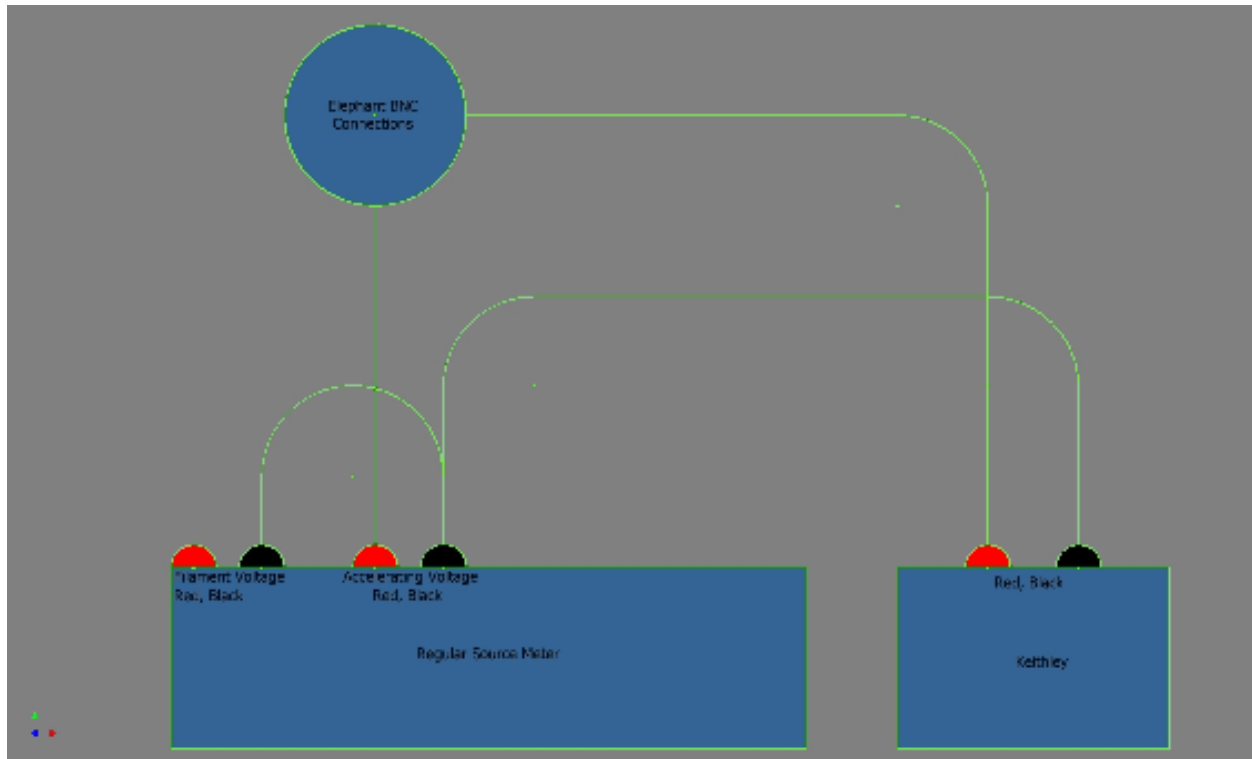
How to Run the Guns:

1. **Wire the guns inside the chamber.** When the tank is open, have two wires lead to the ends of the filament, one to the deflector plate so as to measure current, one to the accelerator plate, and one to a copper detection plate underneath at some distance. Make sure to wear gloves when handling anything going into the chamber.

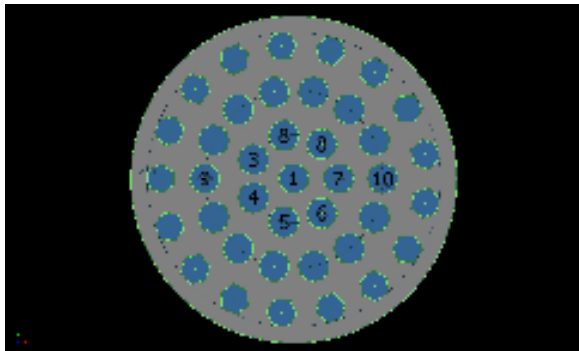
2. **Position the guns.** Earth's magnetic field inside the Elephant's room is nearly vertical (it is easily measured with a magnetic rod). In order to decrease the amount of curve the electron beam follows, position and aim the guns to fire with the magnetic field line. Position the copper plate below the gun at some measured distance.
3. **Pump down.** Close the door and green knob, and pump down to about 50 micron.
4. **Wire the equipment.** Have the two wires of the filament voltage supply go to the two BNC connectors for whichever gun's filament you are using. Wire the Keithley to either the copper detection plate or the deflector plate. Wire the source meter's accelerating voltage red cable to the accelerator plate. Ground all connections properly, as shown below. As of August 22, 2008, the guns are wired as:

Electron Gun Connections		
Outside Wiring Position	Gun Type	Function Connected
1	Tungsten	Filament
2	Molybdenum	Filament
3	Molybdenum	Filament
4	Tungsten	Filament
5	Molybdenum	Deflector Plate
6	Molybdenum	Accelerator Plate
7	Molybdenum	Copper Detection Plate
8	Tungsten	Copper Detection Plate
9	Tungsten	Deflector Plate
10	Tungsten	Accelerator Plate

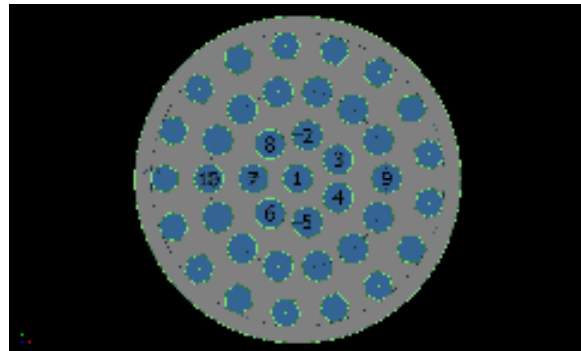
Wiring Schematic



BNC Connections Inside the Chamber



BNC Connections Outside the Chamber



5. **Turn on the equipment.** Flip the switch on the back of the regular source meter (dim lights will come on), make sure the knobs on front are at zero positions, and flip the accelerator voltage switch to on (another dim light turns on). Turn the voltage supply on. Turn the Keithley on.
6. **Adjust values.** Slowly increase acceleration voltage to 100V. Very slowly twist the knob on the filament voltage supply to 10V. Past that, you will feel a slight resistance in your fingers as you increase the value to 15V or so, which is the maximum value I've run

these guns at. Adjusting the filament voltage gets the biggest reaction, but changing the accelerating voltage not only affects the electron flux, but also the speed at which the electrons travel.

Typical Chamber Use:

The following is directly out of Kristen's thesis (Section B.5, page 8), and is what I have referred to this entire summer. They are directions for using the roughing pump with the main chamber. I have never used the cryogenic pump, but the directions for that are continued on the next page of the thesis.

- **Preliminaries**

1. Check oil in big and small rough pumps
2. Check cryogenic compressor static pressure
3. Turn on convection gauges
4. Activate Control Power switch

- **Rough Main Chamber**

1. Activate **Up-to-Air Rough** switch to seal roughing line
2. Activate **Big Rough Pump** Switch to pump out roughing line
3. If chamber is at atmosphere, proceed. Else, wait ~5 minutes
4. Activate **Small Gate Valve** switch to isolate chamber
5. Deactivate **Big Rough Pump** to turn off pump
6. Deactivate **Up-to-Air Rough** to backfill roughing line with air

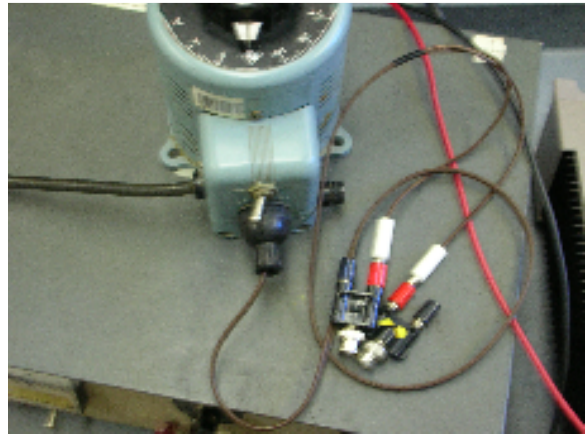
- **A couple of things the above directions lack:**

1. There is a green valve knob on the opposite side of the tank from the wire outputs for gun testing. Twist to open this to let air into the chamber; it takes about 30-40 minutes for the chamber to get to 1atm. Close it when pumping down.
2. When letting air into the chamber, twist the knob holding the main door closed to a more open position so that the door does not get stuck. The door will naturally open about ½” when it comes to 1atm of pressure.
3. The directions state to avoid taking the pressure of the tank beyond 50 microns. I personally pumped it to as low as 30 microns, however one should consult Kristina before doing this. There may be a very good reason for not taking it below that pressure, including the possibility of oil getting into the tank at very low pressures.
4. As of August 20, 2008, the large roughing pump has a brand new filter in its smoke eliminator. This filter costs about \$112 from Oerlikon Leybold Vacuum, product number 99-171-130. This part needs replacement for when whichever of the following occurs first:
 - i. If oil leaks out of it and forms a puddle on the ground underneath
 - ii. If excessive smoke is visible when the pump is in use
 - iii. Every few years

Pictures:



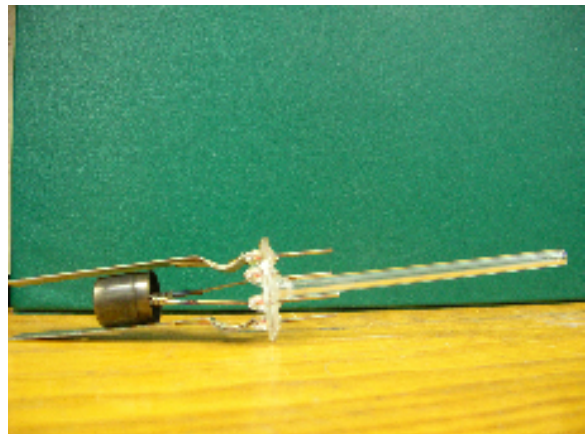
Regular Source Meter used in chamber to apply accelerator voltage and accept ground from the Ketihley.



Used to apply filament voltage, shown here with its banana plugs into BNC adapters.



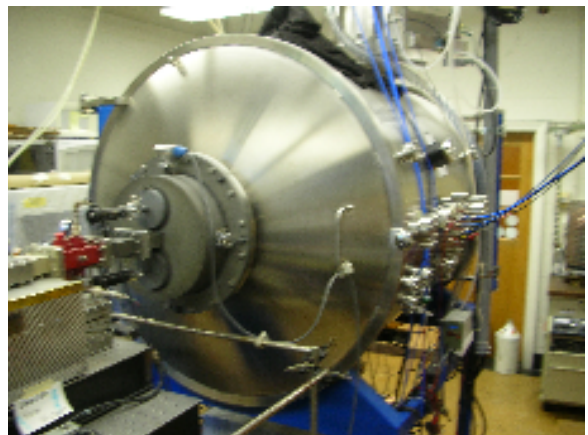
Homemade electron gun using the tungsten filament from an incandescent light bulb.



Electron gun innards.



Front of the "Elephant" Vacuum Chamber.



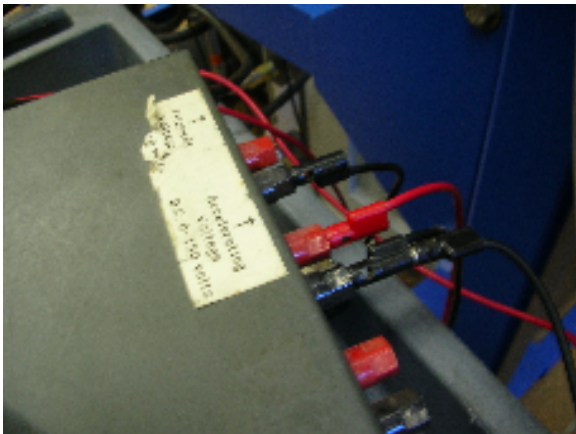
Back of the "Elephant" Vacuum Chamber.



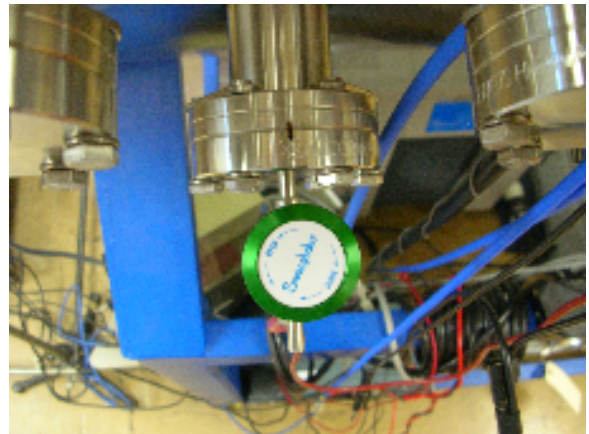
Old thorium-coated electron gun filament.



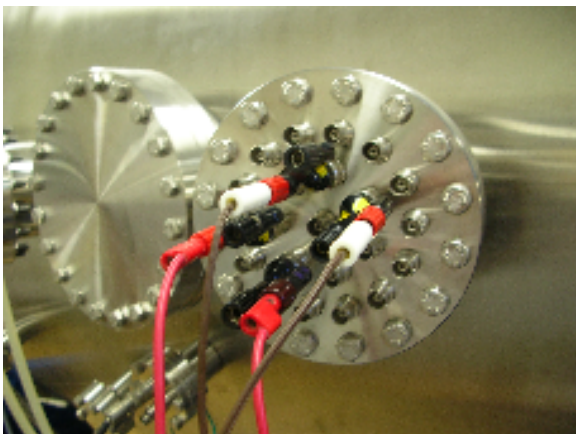
Keithley source meter, set up to measure current from a voltage source.



Connections used for the regular source meter.



Green knob used to let air into the chamber.



Connections for gun filament, copper detection plate, and accelerator plate.



Oerlikon Leybold rotary vane roughing pump with smoke eliminator.