Commissioning the Margherita 2: Bakeout, Tile Sealing, Cesiation, and Plotting Recipes

J. Judge

The University of Chicago

August 17, 2017

Abstract

After the fixture was sealed within the bell jar, the Margherita 2 underwent bakeout and a test seal on a one-inch tile. Following this small success, a larger project of sealing a larger tile during cesiation launched in the final week of the author's summer in the LAPPD Lab. Central to the ability to control these processes is the ability to monitor temperatures, pressures, and RGA plots as well as adjust heating inputs accurately and timely. This report documents the heating procedures, basic sealing cycle, and plotting past events or in real-time with the Margherita 2 infrastructure.

Contents

1 Bakeout

After an RGA singlescan is run as previously documented, contaminant species can be qualitatively assessed and then reduced via a prolonged period of heating over approximately 48 hours. The internal fixture was heated such that the highest reported temperature of the fixture thermocouples stabilized at 355 C. Note that the manifold is much more sensitive to higher heat than is the fixture and bell jar.

1.1 Driving Omega Heaters

Refer to H. Tomlinson and B. Guthrie for Omega heater installation and data acquisition. Omega heaters use Proportional-Integrative-Derivative (PID) calculations on the difference between the goal temperature and the current temperature as measured via the control thermocouple of the heating zone. These calculations serve as feedback to automatically adjust heating power and reach the goal temperature efficiently and without overshooting or undershoot. These Omega heaters are given their goal temperatures via a Python script on pi40 (pi@205.208.20.40). Note that even if the script crashes, the Omega heaters should maintain their most recent temperature settings. Deactivation of the heaters must be done manually–this procedure is included in the following recipe.

1.1.1 Setting the Heater Temperatures with ControlLogger.py

This recipe documents the heater driving for the manifold. It is not strictly relevant to fixture bakeout, but the authors' previous reports neglect to include this recipe.

1. Log in to margherita@psec2 (password "greenpeppers!"). Run the command alias "pi40" to SecureShell into the Raspberry Pi.

2. Navigate to the directory: "cd pi42_5-26-2017/controlLogger." Open the text file "setpoints.txt" with your favorite text editor, e.g. vim or nano.

3. Eighteen numbers in six rows will appear. The first column corresponds to heating zone number. The second column is filled with 0 or 1; 0 indicates a deactivated heater, while 1 sets a heater's status to active. The third column is the temperature in degrees Centigrade. Modify the parameters appropriately. The RGA electronics control unit (ECU) should not exceed 70 C; temperature differences across VAT valves or CF flanges should not exceed 60 C; pressure gauge electronics should not exceed 55 C. Remove ECU's (and insulate their vacancies if on the manifold) before bakeout.

4. Save the modified text file and run the controlLogger script: "python controlLogger.py"

1.1.2 Using the Temperature Ramp Script RampZones.py

When incrementing the setpoint temperature, it is important not to increase rapidly. The script rampzones.py can accomplish this.

1. In the same directory "controlLogger" accessed in the previous recipe on pi40, open the text file "rampParams.txt"

2. The six rows of numbers are parameters meant to be modified. They are in the format <zone>,<ramp or no ramp>,<endpoint>,<temp interval>,<time interval (mins)>. Edit as desired, noting that one or two degrees per minute is an appropriate rate to raise the heater setpoints.

3. Save the text file and run the rampzones script with the .txt file as argument: "python rampzones.py rampParams.txt".

1.2 Variacs and Power Calculations

Three Variacs control the heaters for the RGA, internal fixture, and cesium ampoule holder (J-tube). The RGA and J-tube heaters are external and heat the manifold, as documented by H. Tomlinson. The Ni-Chrome internal heater differs in that it operates in a vacuum, where conduction and convection are minimal. Most of its power is radiated as a blackbody-spectrum that peaks in the infrared range. Stainless steel foil surrounds the fixture to reflect this radiation inward and minimize heat loss to the bell jar.

For the J-tube and RGA Variacs, the knobs are turned over 0-90 V and 0-70 V, respectively, to maintain temperatures 40-250 C. Temperatures are monitored closely via live plots of the thermocouple data.

The internal fixture heater Variac feeds its output into a power distribution box, which has three pairs of sockets. The "hot" and "neutral" provides a multimeter measurement of the voltage output of the Variac. The pairs labeled 1 and 2 measure across 0.1 Ohm resistors that are each in series with the 18.8 Ohm heaters. Measure the voltage in mV across 1 and 2, then multiply by 10 to estimate the currents in mA. Sum these two currents; multiply by the Variac's output voltage in V; then divide by 1000 to estimate the total power delivered to the fixture, in W. Note that this power is delivered to a heat capacity of approximately 10^5 J/K.

2 Commissioning the Margherita 2

Despite an increasingly clean hard vacuum profile and support from a large body of experience with the Margherita 1, the Margherita 2 needed field testing to determine its fitness for LAPPD production. This process of commissioning began with the simple but nontrivial indium-solder sealing of the small window of a one-inch glass-base tile. After this basic text, the LAPPD lab undertook commissioning the manifold cesium transport system in addition to the Margherita's ability to seal more difficult tiles.

2.1 Test Cycle of Margherita 2: Sealing a One-Inch Tile

Before the Margherita 2 can attempt the ambitious ceramic base seals or large-area tile seals, it should be proven to be capable of sealing one-inch glass-base tiles. One-inch tiles are placed in aluminum boxes and are then heated for 16 hours at 280 C under vacuum in the fixture. The indium solder melts at 157 C and seals the window if heated properly.

1. Follow the cleaning procedures with the ultrasonic bath to clean the materials that will be placed inside the Margherita 2.

2. Wearing gloves, place the one-inch glass tile inside the bottom half of the aluminum box-like structure. Bolt the top half on gently, tightening only by hand, if at all.

3. Follow the bell jar removal recipe after spinning down the pump and venting. Remove the stainless steel foil insulation and place the tile(s) in the center of the fixture, on the surface on which dummy tiles support the press bars. Replace the bell jar and seal its bottom flange.

4. Calculate the power necessary for heating to 100C, 200 C, and to 280 C. Based on Fig. 4, 310 W (about 54 V output for the Variac) resulted in a stable 280 C for the median-temperature thermocouple. Based on the power-temperature law, which is

$P = \sigma T^4$ where σ is a constant, we find that the necessary power P to achieve stable temperature T can be estimated by:

$P = T^4 \times (310W/((280 + 273)^4)$, or $P = 3.3148293 \times 10^{-9} T^4$ where T is in Kelvin.

5. Follow the heating recipe to bring the fixture to 100 C, then 200 C in about 5 hours. Then aim to reach 280 C at the 7-hour mark (2 h later).

6. Keep the temperature stable at 280 C for 16 hours. Set a timer relay to shut the power to the Variac off at 16 hours (23-h mark from heating start).

7. After the bell jar has reached room temperature, spin down the pump and vent (the VCR valves to the outer manifold should be closed). Follow the bell jar removal procedure, and retrieve the one-inch sample seals.

8. Attach the one-inch tile fitting to the Leak Detector, as shown in Fig. 1 and Fig. 2.

9.The cylindrical end presses against a black rubber O-ring and is clamped onto the leak detector port. Tighten the wingnut by hand, then leak-check this connection by spraying it with helium after the Leak Detector has calibrated, roughed, and achieved vacuum. If you hear

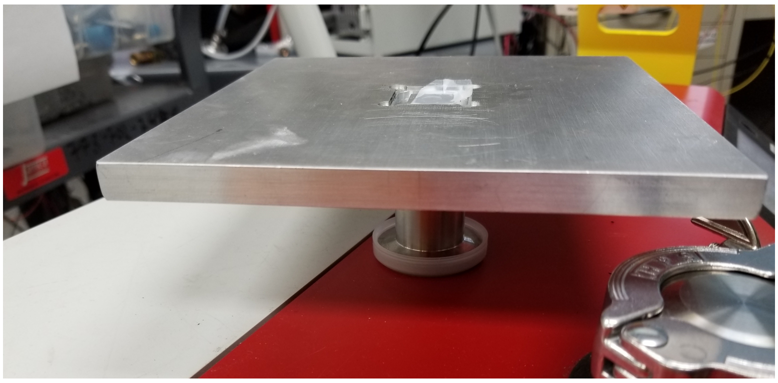

Figure 1: One-inch tile fitting. The cylindrical end presses against a black rubber O-ring and is clamped onto the leak detector port. Tighten the wingnut by hand, then leak-check this connection by spraying it with helium after the Leak Detector has calibrated, roughed, and achieved vacuum. If you hear a hiss, there is a macroscopic-sized leak; put the leak detector in Stand-by mode and close any large leaks. Refer to recipe on Pump Operation.

a hiss, there is a macroscopic-sized leak; put the leak detector in Stand-by mode and close any large leaks. Refer to recipe on Pump Operation.

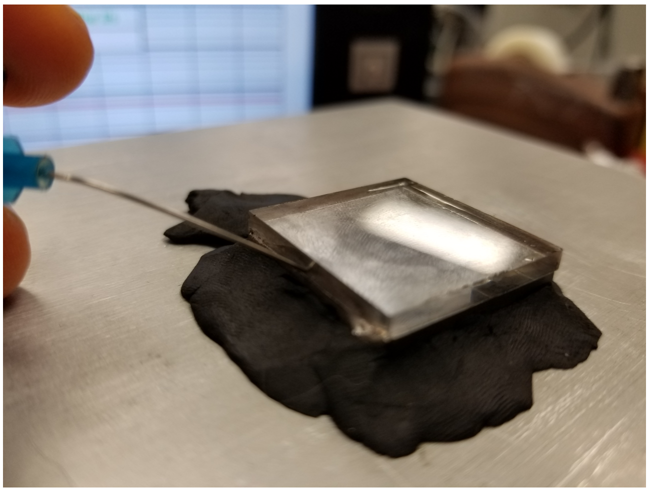

Figure 2: Connection between the one-inch tile and its vacuum fitting. The O-ring under the tile was made in-house with an O-ring kit. This kit has instructions, but creating a truly leak-tight O-ring requires extreme precision. As of this writing, the author has only made a few O-rings that have microscopic leaks, so as seen in the figure, Apiezon Wax was used to seal around the bottom of the tile, leaving the window exposed. As the helium flow rate background level dropped, the tile seal could be sprayed with helium while watching for the leak detector's mass spectrometer readings on helium leak rate. Here, the tile is shown to be leak-tight against a background of $5 \times 10^{-12} mbar L/s He$

2.2 Commissioning the Outer Manifold Cesiation System

The next Margherita 2 capabilities to test in August 2017 include cesiation and sealing a full-sized ceramic base tile. An attempt will be made to seal and cesiate a metallized Abrisa[1] dummy tile.

The Margherita 2 feedthrough to the small tube manifold will feed long, replacable copper tubes to the tile from the small tube manifold, for cesium transport. These two tubes, for this test trial, will terminate in a U-bend inside the Margherita 2 chamber, and not actually feed into the dummy tile. The cesium glass ampoule will be broken inside the cesium ampoule holder. Cesium will condense at the bottom of the J-tube, whose temperature will be manipulated to control the vapor pressure of cesium. Valve C (the middle Swagelok Valve) will remain closed so that cesium vapor will flow into the Margherita 2 chamber before exiting through the large tube manifold, getting pumped out into the atmosphere. In a real photo-detector tile production, the copper tubes will attach to the tile tubes and will transport cesium from the outer manifold for Atomic Layer Deposition (ALD) onto the window, forming the photocathode. Moreover, this process of cesiation will take place under ultra-high vacuum so that a vacuum is sealed, more-or-less permanently, between the base and the window. Keeping a clean inside of the tile is important so that the Micro-channel Plates (MCP) maintain sufficiently pure magnesium oxide to properly multiply electrons.

In addition, a mock-up test will confirm the second pin connection to the spacer shim. The left pin protruding from the tile connects to ground. The plan for the other pin is to connect it to the surface of the top MCP, which has a conductive coating. A conducting pad will be held in place under of the the 1/4" spacer buttons, which is firmly held in place by atmospheric pressure. A 40mm copper wire will connect the pad to the stainless steel pin. The mock-up pin for the commissioning of Margherita 2 will be constructed of a stainless steel tube of inner diameter 42mm; a simple hand crimp will secure it to the copper wire. The distance from the

[1]http://abrisatechnologies.com/

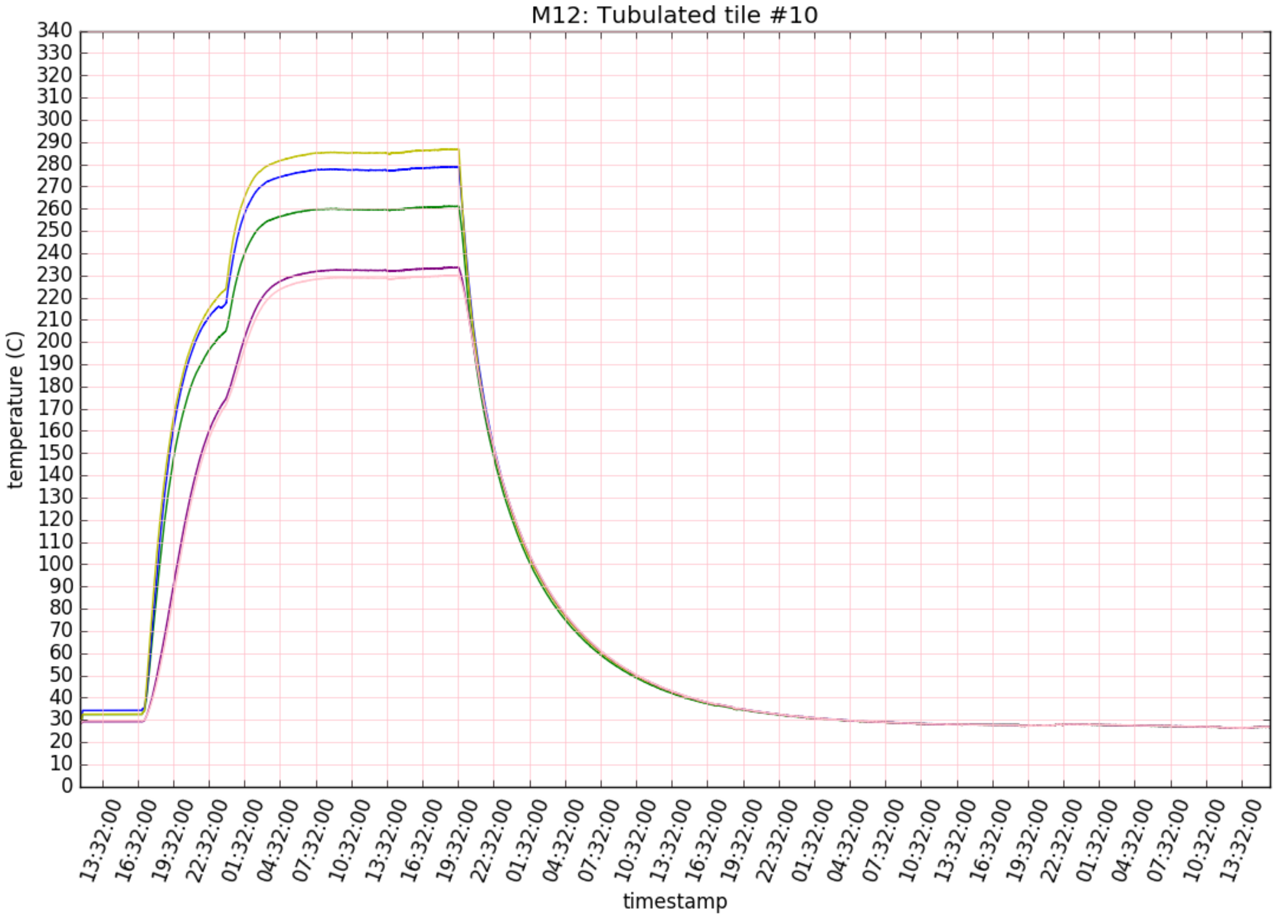

Figure 3: Sample temperature profile for a one-inch tile seal completed in the first Margherita's history. The Margherita's first sealing cycle was based on this temperature profile as well as the recipe recorded in the Margherita 1 Volume III Log Book in December 2016. Here, the temperature was ramped up from room temperature to 280 C over 8 hours, then maintained at that temperature for just over 16 hours, resulting in a successful, leak-tight indium seal.

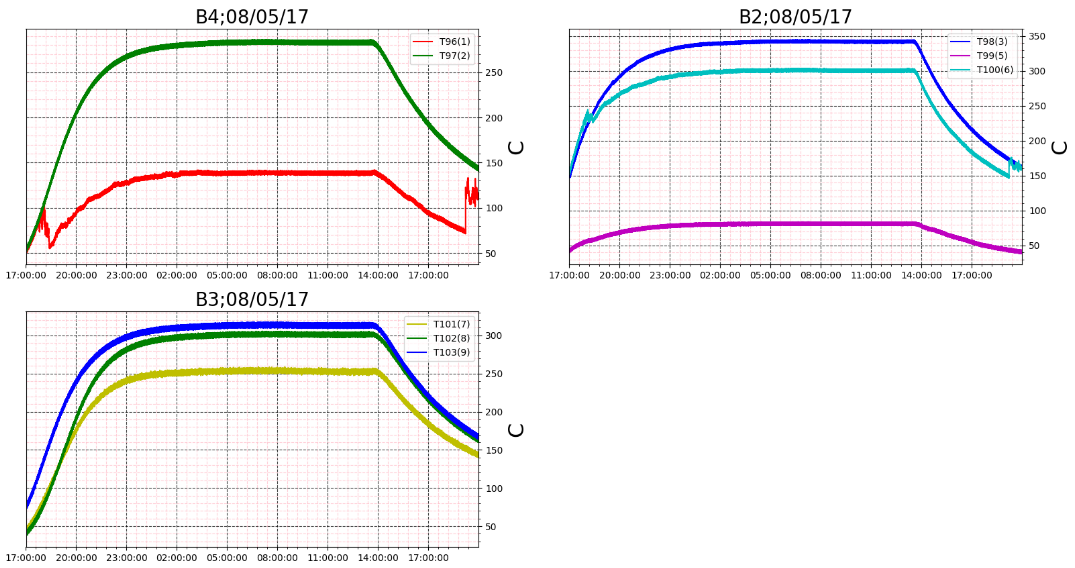

Figure 4: Temperature profile over the duration of the heating period to seal the sample one-inch glass-base tile. Based on the measurement of the power output of the internal heaters (see recipe on Variac-based heaters), the power delivered over this period was 310 W. Afterwards, the two tiles were helium leak-checked with the Leak Detecter and found to be leak-tight to $5 \times 10^{-12} mbar L/s$.

sidewall pin to the nearest button is approximately two inches, and from the sidewall to the MCP surface lies a perpendicular distance of 1/8". The buttons each have a diameter of 3/8".

1. Close valves B and D to valve off the outer manifold. Spin down the Turbo Pump so that the bell jar can be removed. Keep the outer manifold under vacuum.[2]

2. Cover the fixture in aluminum foil as the copper tube system is constructed. Make the appropriate digital-caliper measurements to design, cut, and bend a copper U-bend tube with parallel out-connections that will connect via Swagelok-to-VCR to the feedthrough from the small tube manifold. Use the blue tube-cutting tool to slowly rotate and subsequently tighten to carefully cut the tubes, and use the cylindrical blue tube-deburring tool to smooth the inner diameter of the copper tube. When using a tube bender, brace one end of the tube with a screw-on circular clamp; otherwise the tube will slip and be kinked or ripped open. Periodically let the bender's grip on the tube slacken so that the jaws can slip into a new position farther down the tube, helping to avoid pulling the tube into a kink.

3. Choose a dummy tile[3] Clean the copper tubes and the Swagelok-to-VCR adapters, following the ultrasonic bath cleaner recipe. With solvents, clean the ends of necessary wrenches and other tools for installation.

[2]As of August 2017, the B and D Swagelok valves on the small tube manifold permit leaks between the external and internal vacuums even when the valves are tightly shut. Thus, August 2017 maintenance is following a different procedure to replace the valves–the auxiliary port behind Valve E, which is planned to be used for using other vapors beside cesium to form photocathodes–will be salvaged. Thus, much of the recipe given here is based on the lab's ever-changing plans for the near future, and has not been tested by the author.

[3]August 2017 Margherita 2 commissioning is using an 8" metallized ceramic-base tie from Abrisa Technologies (http://abrisatechnologies.com/). If applicable, install the aforementioned mock-up second pin connection to the MCP at the base of a spacer button. This step is included in our plans for a Margherita 2 commissioning, but mostly for the verification that such a connection is feasible; this step has limited importance in verifying the Margherita 2's operation itself.

4. Install the dummy tile under the press bars. Install the copper tubing for cesium transport within the Margherita 2 chamber. The VCR-to-Swagelok connections need 1.25 wrench turns past finger-tightness (unlike Swagelok which only needs 1/8 turn past finger-tightness. Replace the bell jar and seal the Margherita.

5. Follow the heating cycle in the one-inch tile seal recipe. The eight-inch tile seals with the same temperature and duration used to seal the one-inch tile.

6. Cesiate. Crush the glass cesium ampoule inside the cesium ampoule holder, and follow a recipe for using temperature to control the cesium vapor pressure.

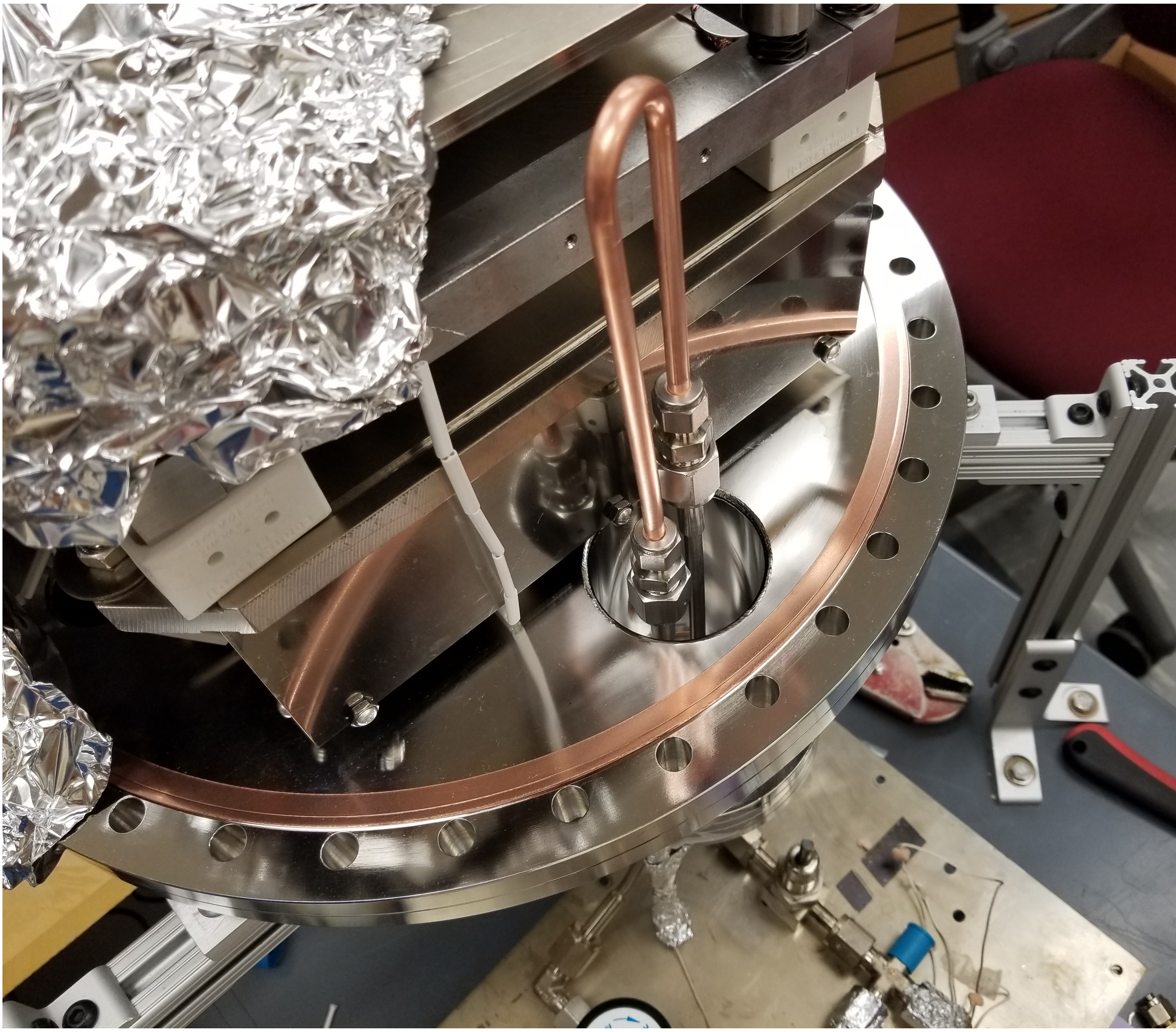

Figure 5: Mock-up copper tube U-bend connection from the small tube manifold to the tile, allowing for cesium Atomic Layer Deposition (ALD) onto the window under ultra-high vacuum to form the tile's photocathode. In this August 2017 commissioning trial, the copper tube does not feed into the tile, but simply lead back to the outer manifold. The purpose is simply to show that the cesium vapor pressure can be controlled for future use in building photocathodes.

3 Construction and Calibration of Attenuator for Diode Box

The diode box provides a light of precise intensity and wavelength, which is delivered to the Margherita's tile via fiber optics cables and a motor[4]. This light is controlled via function generator. Both the input and output are fed into a lock-in amplifier[5] to determine the quantum efficiency, the fraction of light that is detected, of the photon detector tile. The LED box connection to the lock-in amplifier is moderated with through an calibrated attenuator built out of optical fibers and ThorLabs[6] optics structures–three 30mm Cage Plates and a cylindrical empty spacer were fixed onto rods. The attenuator height is fixed at the height of four 30mm ThorLabs Cage Plates and implements a neutral density filter[7]. An orange 400μm optical fiber cable[8] connects the LED box to the attenuator. A 1.5mm, 1.5 meter long, 0.5 NA black fiber connects the attenuator to the lock-in amplifier. The attenuator is updated when the properties of the tile mandate changes to the input signal.

1. Check the attenuation of the current attenuator configuration. Connect the LED to the attenuator input and the power meter readout to its output. Set the intensity of the LED box to zero (the dial settings are in 1/1000 graduations of full intensity) and record the power in Watts. Repeat this for the full range of intensities at convenient intervals.

2. Construct the attenuator with an attempt at the desired changed features (e.g. new filter, different spacing), using the 0.050" and 5/64" hex keys to fix the ThorLabs Cage Plates to the metal rods. Note that the attenuator box may have to be taken apart and reconstructed, whether immediately to correct attenuation or in the unforeseeable future to update the attenuator. Thus, the design should feature accessibility.

3. Check for the reduction factor relative to the original attenuation. Connect the LED to the attenuator input and the power meter readout to its output. With the intensity reduction factor in mind, set the intensity of the LED box to zero (the dial settings are in 1/1000 graduations of full intensity) and record the power in Watts. Repeat this for the full range of intensities, and compute the average reduction factor compared to the original attenuation factor. If the new attenuation is not within the desired range, return to step 2.

4. Now calibrate the new attenuator at the available wavelengths of the LED box at full intensity. For each of the wavelengths 365nm, 405nm, 450nm, 500nm, and 535nm, record the power readout in μW.

5. Next, open a terminal on margherita@psec2. Navigate to the directory that contains the calibrate information for the attenuator, which is named "motorplotters." This directory contains text files with all past attenuator calibrations. As of August 2017, the current calibration is stored in "attenuatorCalibrations2.txt." Open up the most recent calibration text file. The first line ends in an ascending sequence of integers starting at 0, separated by commas. Append the next integer to this list. The next five lines correspond to each of the wavelengths 365nm, 405nm, 450nm, 500nm, and 535nm; at the end of each of these lines, add a comma followed by the power readout at full intensity of that wavelength, in microWatts (these were recorded in step 4). Save the text file, and write an entry in the log book recording the changes made.

[4] A future improvement will likely replace the use of motors with multiple cables.

[5] A lock-in amplifier "locks in" to a known wavelength and extracts the intensity-modulated signal at that wavelength from the noisy background.

[6] ThorLabs Cage Systems, https://www.thorlabs.com

[7] 25.0nm Absorptive Neutral Density Filter TP00661929; the second-lightest filter of the set was used to produce our attenuator. The addition of this ND filter to the previously empty attenuator reduced the intensity by a factor of 6.35 at 405nm.

[8] M28L02 - Ø400 μm, 0.39 NA, SMA-SMA Fiber Patch Cable, Low OH, 2 Meters from ThorLabs: https://www.thorlabs.com/thorproduct.cfm?partnumber=M28L02

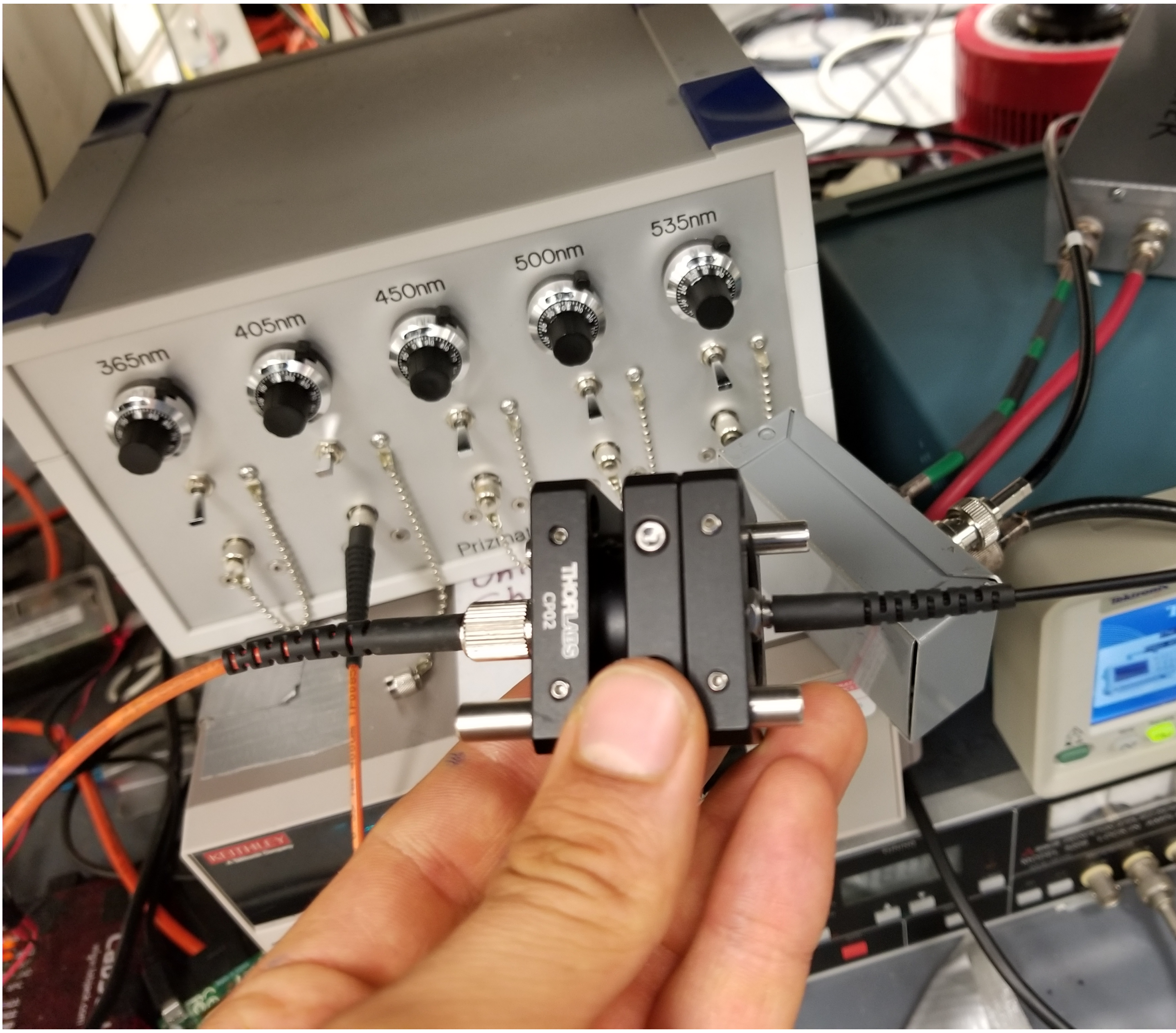

Figure 6: LED box attenuator constructed of ThorLabs cage plates, a cylindrical spacer, a neutral density filter, and optical fibers. This attenuator feeds the input light from the LED box into the lock-in amplifier. Its calibration specifications must be entered into the attenuatorCalibrations2.txt file on the psec2 system to quantify the precise intensity of the LED light at a certain wavelength. By comparing this measurement to the anode readout of the tile that receives the same signal, the quantum efficiency over the areas of the tile can be computed.

4 Creating Plots

On margherita@psec2, run the command alias "runmarg" to navigate to the frequently used directory. Then, follow one of these three recipes:

4.1 Liveplotter

1. "cd run_liveplotter/configFilesMargPlotter"

2. Create a text file with a filename of your choice–note that this will be designated your "config file" to configure your plot. Find out the <directory> where your data is located. Your data should be a series of text files in the format <filetag>y-m-d.txt where y is year, m is month, d is day. The first line of the should follow the format "*../../data/<directory>/<filetag>". This is the directory header. Note the asterisk is a splitting symbol for the code, so it is important that it appears at every header start and nowhere else.

3. The data that you wish to plot will be a series of lines in the format '<value0>,<value1>,<value2>..., where 0,1,2...n are the indices. In the config text file, lines following the directory header should be formatted as follows: "<index>,<two-letter graph label><dataline label>,<name>,<color letter>,<units>". Note that there is no comma between the graph and dataline labels. The graph label letters can control certain settings, e.g. a "P" as the first of the two letters makes the vertical axis logarithmic and appropriate for pressure plots; "L" creates a fixed scale; etc. Color letters include r,b,g,m,c,k,y. The <name> label is largely historical and now serves as a simple documentation tool, much like a commented note. Below is a sample config file, which was used to produced Fig. 4. The first header produces a pressure plot not shown in the figure.

*../../data/pressure_data2/pressureLog
0,PGManifold,Manifold pressure,r,Torr
1,PGInternal,Margherita chamber internal pressure,g,Torr
*../../data/temperature_data2/tcLog
24,B4T96(1),fixture thermocouple level 4 T96,r,C
25,B4T97(2),fixture thermocouple level 4 T97,g,C
26,B2T98(3),fixture thermocouple level 2 T98,b,C
27,B2T99(5),fixture thermocouple level 2 T99,m,C
28,B2T100(6),fixture thermocouple level 2 T100,c,C
29,B3T101(7),fixture thermocouple level 3 T101,y,C
30,B3T102(8),fixture thermocouple level 3 T102,g,C
31,B3T103(9),fixture thermocouple level 3 T103,b,C

4. Include additional directory headers and configuration options on subsequent lines, leaving no blank lines.

5. Save the config file and run "cd .."

6. If the data you are plotting is a new pipeline, modify the "pull_data.sh" script in the /local/data2/margherita/data/liveplotter_data directory. Add a line beginning to run the "rsync -avz" command, using the lines already present as a guideline for the target and destination directories as well as the target Raspberry Pi's IP address.

7. "runmarg" and "cd run_liveplotter". Finally, run the script: "python margplotter.py configFilesMargPlotter/<your configfile here>" with your config file as argument.

4.2 Singleplotter

The singleplotter.py script is simply a copy of the margplotter.py script but with the global variable "liveMode" assigned the value False. This setting allows the user to create plots of any past period of time when data was collected.

1. Create a config file for your desired data according to the previous recipe for the liveplotter.

2. Navigate to the appropriate directory: run command alias "runmarg" and then "cd run_liveplotter". Then open the script: "nano singleplotter.py" or "vim singleplotter.py" or open with a text editor of your choice.

3. Scroll down to the line where the global variables "plotDate", "plotTimeStart", and "plotTimeEnd" are assigned values. Edit the variable assignments to your preferences. The "plotDate" variable is a list of strings, where each string is a date in format YYMMDD. This list should include every day that includes data that you wish to plot. The "plotTimeStart" is string representing a time in format hh:mm:ss and refers to the 24-h time of the first date in "plotDate" on which you wish your plot to begin. The "plotTimeEnd" variable sets the time of the last date in "plotDate" at which you wish your plot to end.

4. Save the modified Python script. Then run "python singleplotter.py configFilesMargPlotter/<your config file>". The plotter will take around 20 to 90 seconds to generate your plot(s), depending on how much data you are plotting.

Index errors are common when using the plotters. Usually, either data is corrupted[9] or the config file has comma errors or other typos. The margplotter will indicate whether the error is in the data, in which case the line number is given, or in the config file, in which it will print the error followed by "Check CONFIG file!".

4.3 RGA Plots

RGA single-scans produce data correlating partial pressure to mass-to-charge ratio. Since they are time-independent plots, the liveplotter cannot plot them. Note that the RGA plotting systems for the Margherita and Margherita 2 are same in principle but operate separately to keep the RGA data organized. The pull_data.sh script has been set up to sync RGA scans from pi41.

1. Take an RGA scan, following the RGA operation recipe.

2. Log in to margherita@psec2 (password: "greenpeppers!") and navigate to the appropriate directory by the command alias "runmarg" followed by "cd run_rga".

3. Run the plot-all script that is specific to Margherita 2: "python rga2_plotall.py". This script will sync the RGA data files from the Raspberry Pi and then plot those that do not have a .png plot already stored in /local/data2/margherita/data/rga_data2/plots.

4. Navigate to the /local/data2/margherita/data/rga_data2/plots directory; one such way to accomplish this task from the current working directory is "cd .." then "cd .." followed by "cd data/rga_data2/plots"

5. Your plot will be in the format MMDDYYhhmmss.png where M represents month number and mm represents the minutes of the time at which your RGA scan was taken. Run "eog MMDDYYhhmmss.png" to view your plot. In addition, the most recent Margherita 2 RGA scan will be published on the Web at http://psec.uchicago.edu/margdata/rgaplot2.png, which can be viewed in a Web browser.

Note that all three scripts margplotter.py, singleplotter.py, and rga2_plotall.py use graphical interface Python library modules such as matplotlib and tkinter. Thus, if you are working remotely on psec2 over SecureShell, you may need to set up X11 Port Forwarding to run these scripts. Alternatively, you can simply work locally at psec2 and run the scripts from there.

[9] Data often becomes corrupt when the Raspberry Pi's script is non-gracefully interrupted, such as sudden shutdown. This can add long strings of "@̂@̂@̂@̂" to the data files, which will throw an exception of a failed attempt to convert this string to float in the plotter. Remove these strings from the data files on the Pi's data log to fix this error.

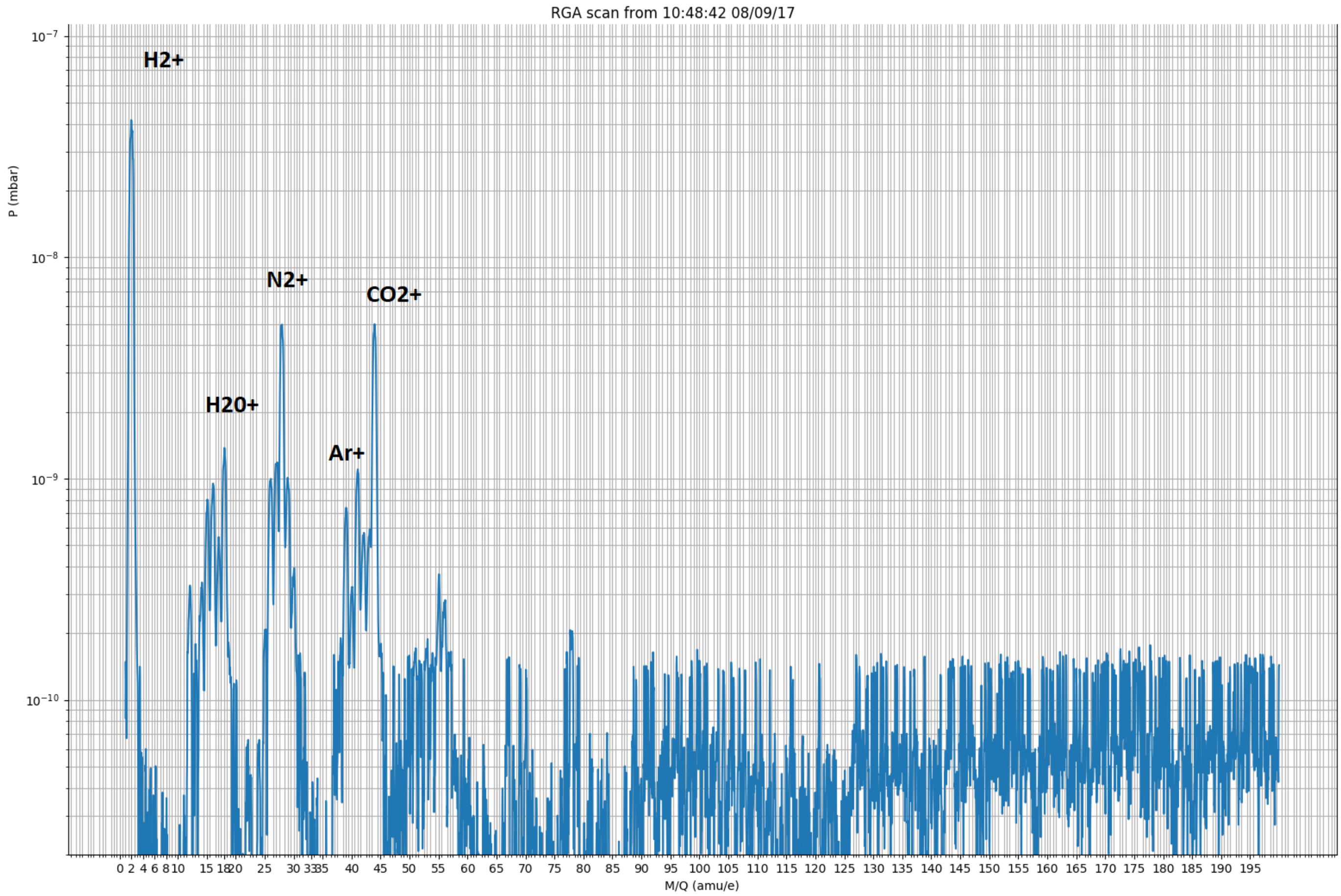

Figure 7: RGA singlescan of the Margherita 2 on August 9, 2017. The vacuum system is still only a few weeks old, and has only been baked out on two occasions. Thus, the high level of oil-based contaminants, above the 50 amu per unit charge level, is not out of the ordinary. Subsequent scans show lower levels of contaminants, likely due to Electron Stimulated Desorption (ESD) in the stainless steel due to the RGA electrons over multiple scans.

Psec2 is a desktop computer located in the lab[10]

A further note on RGA and pressure gauge operation: After a bakeout and some cooling, the pressure will drop, often dropping below the IKR pressure gauge lower threshold of 2×10^{-9} Torr. Furthermore, under these conditions, gaseous species may condense into the stainless steel on the inside of the vacuum system. Running multiple RGA scans will release electrons into the Margherita 2, which tend to dislodge the embedded contaminants such as hydrogen, producing outgassing through a process called Electron Stimulated Desorption (ESD). This process is similar to the scrubbing process by which micro-channel plates (MCP) are cleaned and reset.

[10] As of the time of the writing of this document, the LAPPD project is moving into the new HEP building, and the location of lab equipment is still undetermined.