# SiPM Lab Manual for Detector Course 2018

Pietro Giampa

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# 1. Introduction

The scope of this manual is to provide an overview of the hardware components of the SiPM Lab for the detector course. This will provide students with the necessary documentation and information about the equipment used for SiPM measurements. Furthermore, this document give emergency contacts and procedure in case of unexpected issues (although supervision will be present on the data collection day).

This lab is working to characterize photodiodes for use in the nEXO experiment. The lab is located in the back of the detectors facility at Triumf as shown in Figure 1.1. The nEXO experiment is described in detail in other documents[1] [2] , and a short overview will be given here. The nEXO experiment utilizes a large amount of liquid Xenon and measures decay events of the xenon. This involves measuring the charge and the UV light using photodiodes. Our experimental group focuses on these special photodiodes: they are a microarray of silicon avalanche photodiodes (SiPM), and more documentation is included here [3] [4]. There are many interesting challenges to characterizing SiPMs. These include dealing with cryogenic equipment, working with high voltage, manipulating optics, and safety precautions with lasers and UV light. One should familiarize themselves with the general operation of photodiodes and all relevant parameters such as gain, dark noise, crosstalk, aftertalk, ect…


Figure 1.1 Sample of different SiPMs

[1] Pocar, A. 2015, "Searching for neutrino-less double beta decay with EXO-200 and nEXO", Nuclear and Particle Physics Proceedings, vol. 265-266, pp. 42-44.
[2] See Google Drive documents in: "Papers_Presentation"
[3] Ostrovskiy, I., Retiere, F., Auty, D., Dalmasson, J., Didberidze, T., DeVoe, R., Gratta, G., Huth, L., James, L., Lupin-Jimenez, L., Ohmart, N. & Piepke, A. 2015, "Characterization of Silicon Photomultipliers for nEXO", IEEE Transactions on Nuclear Science, vol. 62, no. 4, pp. 1825-1836.
[4] Collazuol, G. (2014). Silicon Photo-Multipliers status and perspectives. [online] Agenda.infn.it. Available at: https://agenda.infn.it/getFile.py/access?contribId=110&sessionId=143&resId=0&materialId=slides&confId=8263 [Accessed 22 Aug. 2017].

# 2. Lab Overview

The general design and orientation of the lab will be given in this section. Furthermore, lab protocol and safety will also be included. The lab is situated at the back of the Meson Hall Extension and is located in a walled off area. Four tables are used in this lab with one occupied by the experimental setup. The lab space is shared with two other people that rarely come around, but they occupy two desk spaces and these should be left as is. Various tools are located at the workshop area in the same room, this includes a vice, measuring tools, drilling tools, plumbing equipment, an electronics bench, ect… You are free to borrow the equipment as long as it is returned. Rick is the supervisor for this area and his office is located just outside the lab.

The major safety concerns are covered by TRIUMF safety training. It is a good idea to take the cryogenic safety course, the laser safety course, and the high voltage safety course if you intend to work with those equipment. In general, assume everything in the lab is not clean and hazardous. Various experiments are conducted here, and the dust and dirt is probably an irritant material. Try to keep clean ,and wash before and after eating or going to the washroom. No drinks or food are allowed in the lab. Inside this room, there is sometimes very loud white noise, and also various fumes. Make sure you have the required protection for these scenarios.

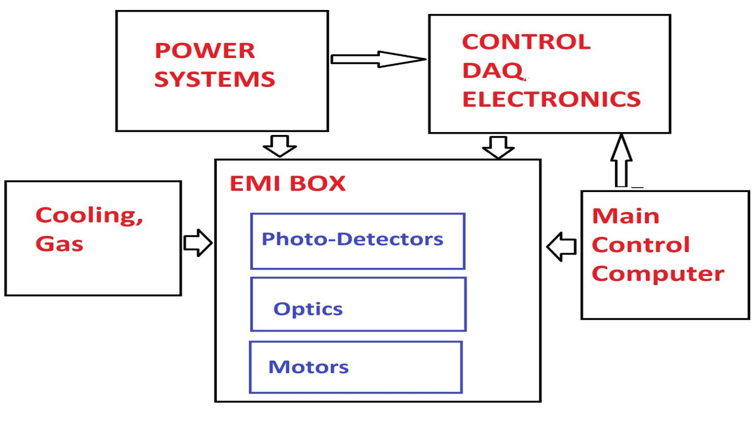


Figure 4.1. Block Diagram of Experimental Setup

The block diagram for the experimental setup is given in Figure 4.1. The central part of the experimental setup is the large EMI box (see Figure 4.2) which houses the optics, motors, and photodetectors. External to the box are the control systems, the cooling and gas systems, the power system, and various other electronics. The main control system is a desktop PC, which monitors and manipulates conditions inside the box. Inside the box, the photodiode is mounted on a special chuck shown in Figure 6.2 which allows temperature control, EMI shielding, gas control, and accurate positioning. The cooling and gas system consists of two vessels of liquid nitrogen, buckets of water to act as heat sinks, and other equipment.

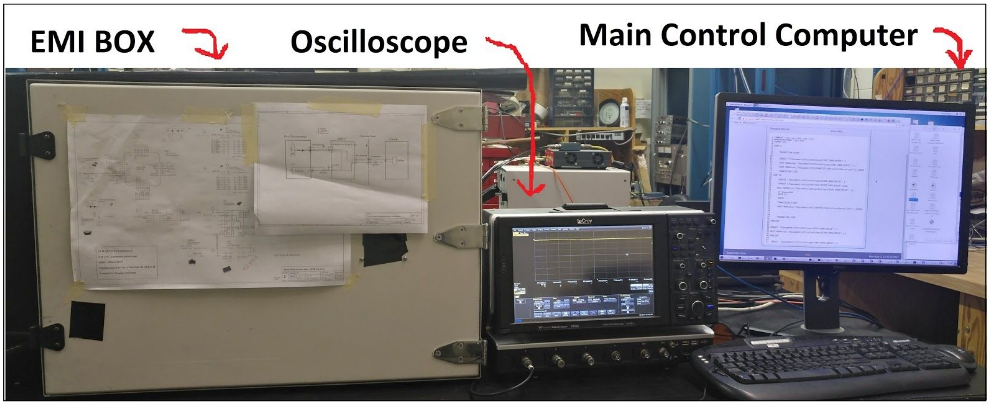


Figure 4.2 Front View of the experiment setup. Note the large white EMI Box

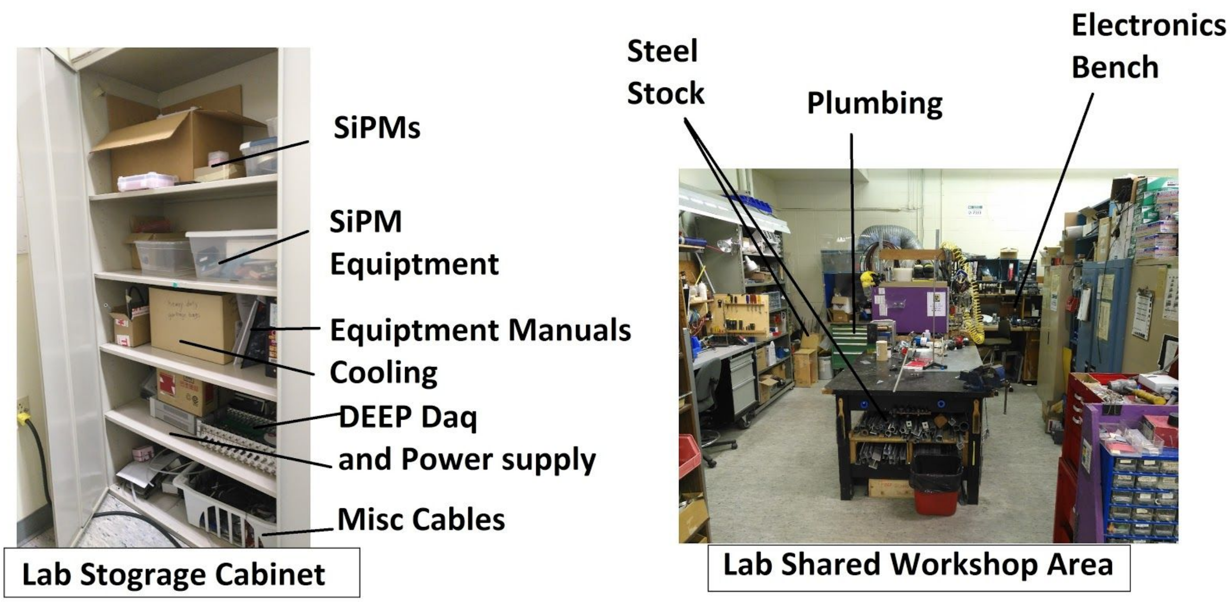


Figure 4.3. Other Important items in the lab area

# 3. Control System

Main computer: user- exo  pass- nexo_daq   Laptop: pass- exo_daq

The main PC for controlling the experiment is running Centos OS, and a software called Midas controls all experiment systems. Midas runs on the internet browser, and is the standard control software at Triumf.  The computer is connected to other electronic systems as shown in Figure 5.1. Specifically, a frontend is written in Midas (in C code) to communicate with the device drivers of the attached electronics. To access the experiment using Midas, input:

Midas URL: https://daq02.triumf.ca:8443/

If the computer is restarted, the midas server  must be started from command prompt:

- Type  cd  online/bin
- Start the server by inputting ./start_daq.sh

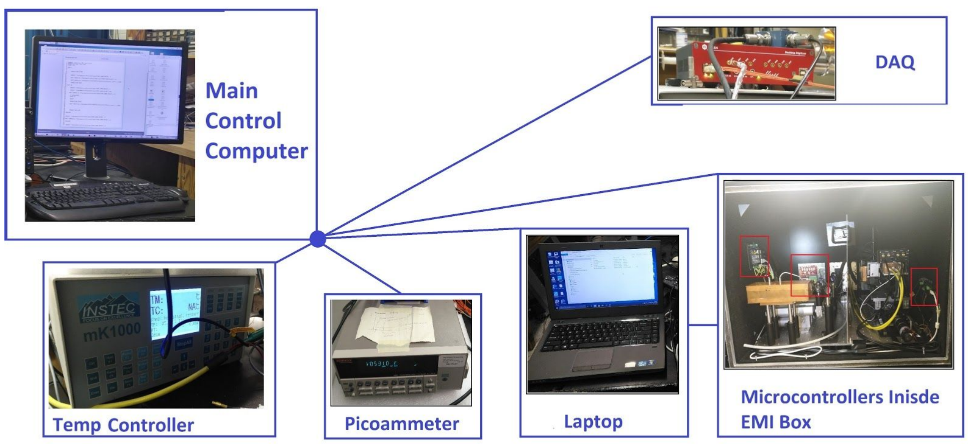


Figure 5.1. Visual Diagram of the main controller units.

Midas can be accessed from any computer, which allows for remote experiment control. Upon logging into Midas, one is greeted with the main control panel as shown in Figure 5.2. To read about each function in Midas, please refer to Table 5.1, the documentation [5] , and to the file header from the Midas code. The two most important tabs are: the Programs Tab, and the ODB Tab. Use the Programs Tab to start different programs such as the picoammeter ”scPico”. Once the program is started, the settings for it can be configured by going into the ODB tab and exploring the Equipment list and Programs list. The front control panel and the History tab can be used to monitor the experiment. Further documentation about Midas can be found on the main website [5]. Code and data is found in the folder “link to online” on desktop, and inside their respective folders (for example in “scPico” you can find IV data).

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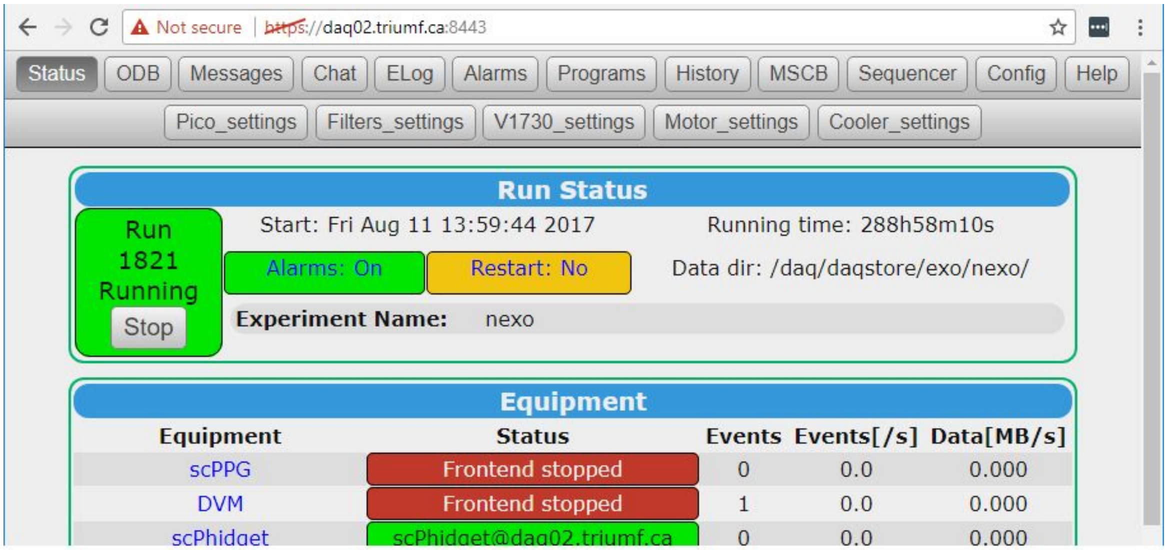


Figure 5.2. Front Control Panel of Midas

Table 5.1 Overview of Midas Equipment

| Name | Function / Comments |
|---|---|
| scPPG | Controls a PPG module (not connected) |
| DVM | |
| scPhidget | Controls motor for moving photodetector stage |
| scFilters_io | Controls motors for moving filters |
| FEV1730 OPTIC | Controls 1730 for acquiring signal from photodetectors |
| SCCOOLER | Controls mK1000 temp module for changing cooler plate temperature |
| scPico | Controls the Picoammeter. Powers SiPM, does IV, and dark noise measurements |
| FEV1730 | General operation of V1730 |
| BUFLVLV1730 | Buffer for V1730 |
| FEV1730RAW | General operation of V1730 |
| LECROYSCOPE | Monitoring of Oscilloscope |
| scBeamCarac | Beam map function for the photodetector platform |

# 4. Photodetector Platform

A short description will be given to show the structure of the photodetector platform (located in the large EMI box). The general schematic of the platform is shown in Figure 6.1, and the actual platform is shown in figure 6.2. Starting from the PCB with the photodiode, this PCB is  in a EMI box which can be purged with nitrogen gas. This is mounted on a cooling plate via 4 screws going through the PCB. A PMT is mounted on the cooling plate via it's own adjustable platform as seen in Figure 6.2. The cooling plate is mounted to the precision X-Y stage via screws shown in Figure 6.3. Everything is then mounted onto a movable platform.

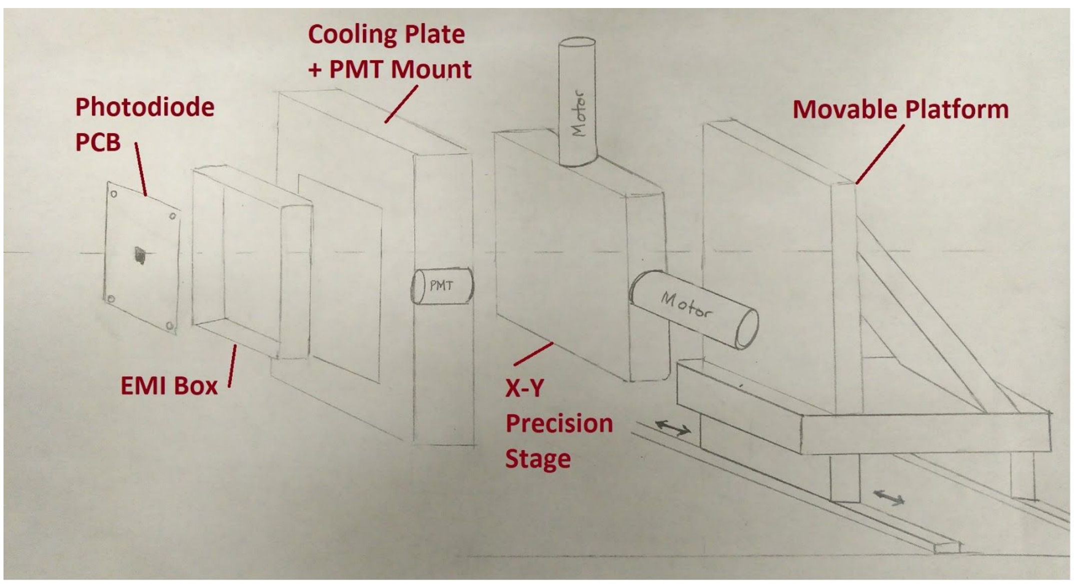


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Figure 6.1. Schematic of the photodetector platform

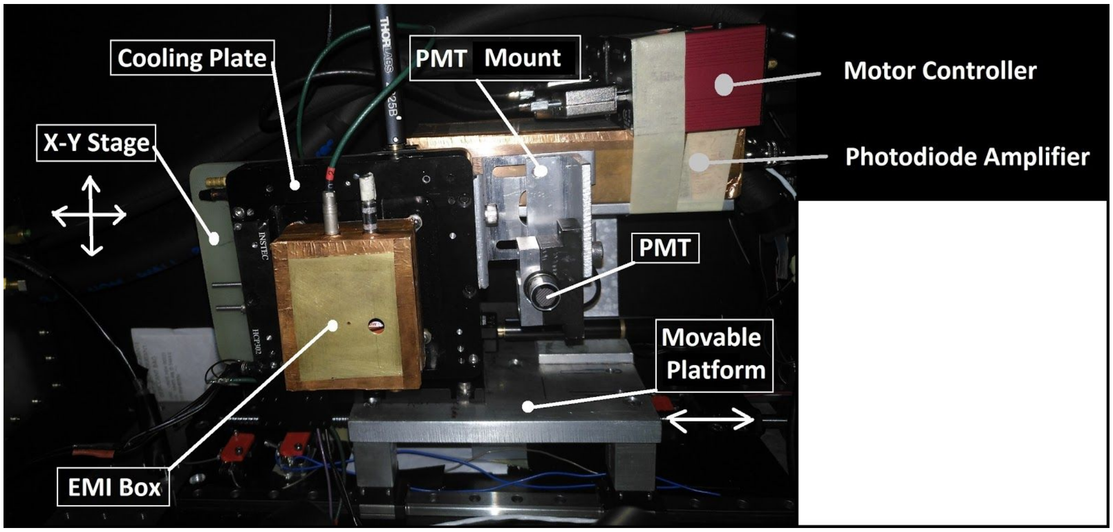


Figure 6.2. Actual Photodetector Platform

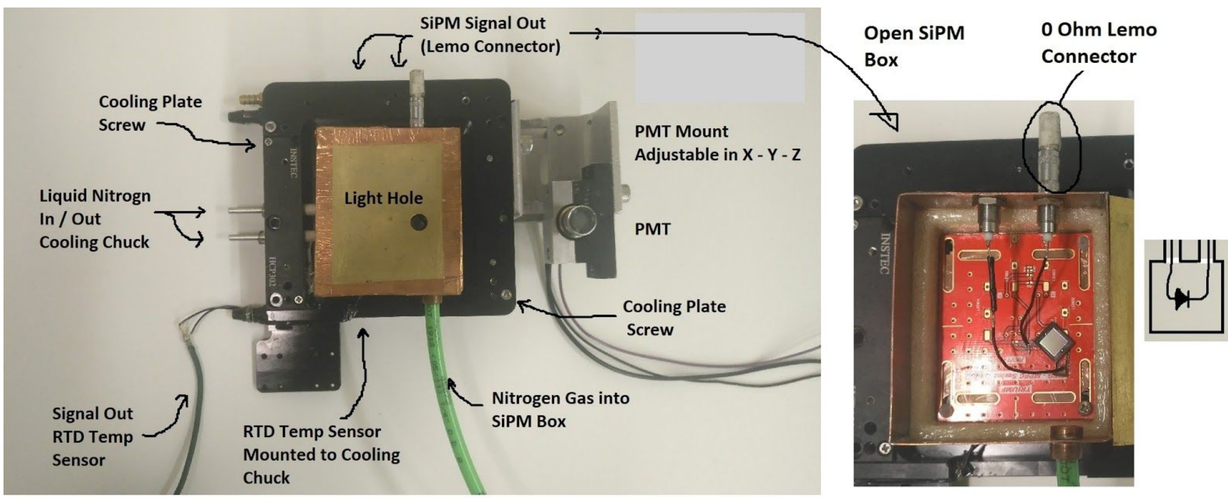


Figure 6.3. Closer Look at the Cooling Plate, and Inside the SiPM Box

From Figure 6.3 we can clearly see the SiPM box. The top of the box is taped with conductive copper tape. To access the inside, the tape can be peeled away and the top cover removed. There are two lemo connectors on the top of the SiPM box and these are connected to the photodiode shown in the small schematic in Figure 6.3. A 0 ohm lemo connector is shown connected to the box, while the other lemo connector can be connected to the pre-amp to read the SiPM.. When doing an IV measurement, the connections are different. The SiPM is connected to a large shielded amplifier box and the details of the connection are given in section 10. The SiPM box has a light hole on the lid and the location of this light hole might need to be changed. To modify it, either make a new lid, or tape a piece of metal with the new hole onto the box.

# 5. Cooling System

Cooling of the SiPM down to -120 ºC is essential to mimic the conditions of the nEXO experiment. An overview of the cooling system is shown in Figure 7.1. Cooling of the photodiode is done by pumping liquid nitrogen through the cooling plate. The liquid nitrogen is regulated by the mK1000 module which is connected to the main control computer. In Figure 6.3, we can see where the liquid nitrogen tubes should be connected to the cooling plate. The temperature sensor is also indicated and it consists of a precision RTD resistor that is epoxied to the cooling plate. This temperature sensor must be hooked up to the mK1000 in order for it to work (and the connector must not touch ground).

In nEXO, the SiPM would be submerged in liquid xenon, while in our lab the SiPM is in air. This presents the challenge of condensation. To solve this, dry nitrogen air is blown across the SiPM and the intake for this gas is shown in Figure 6.3. The gas goes into the SiPM box, and exits out the front light hole. The gas should flow for 10 min before cooling to purge the box completely. Gaseous nitrogen also needs to purge the large EMI box in order to reduce the attenuation of UV light.

The source of the liquid nitrogen is shown in Figure 7.2 part A and consists of two large containers. The large metal container flows liquid nitrogen through two water baths to create gaseous nitrogen. The white nitrogen dewar flows liquid nitrogen directly to the cooling chuck. The connectors for liquid and gas nitrogen are shown in Figure 7.2 part B.

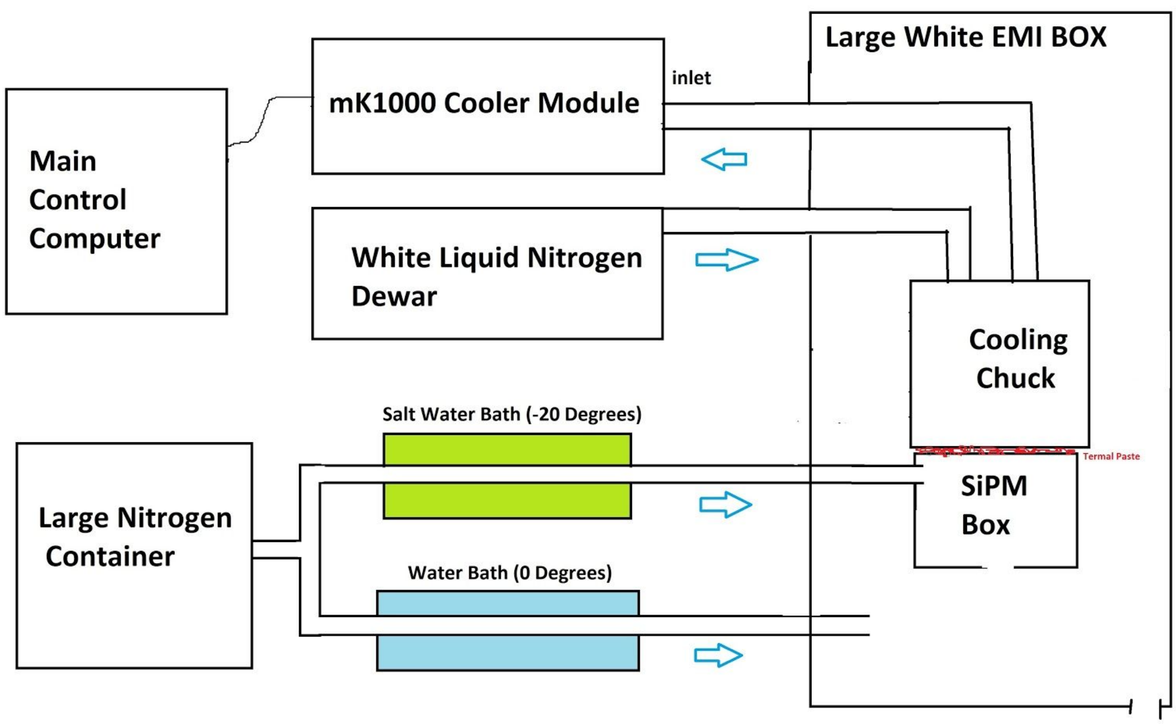


Figure 7.1 Schematic for cooling and gas control of experiment

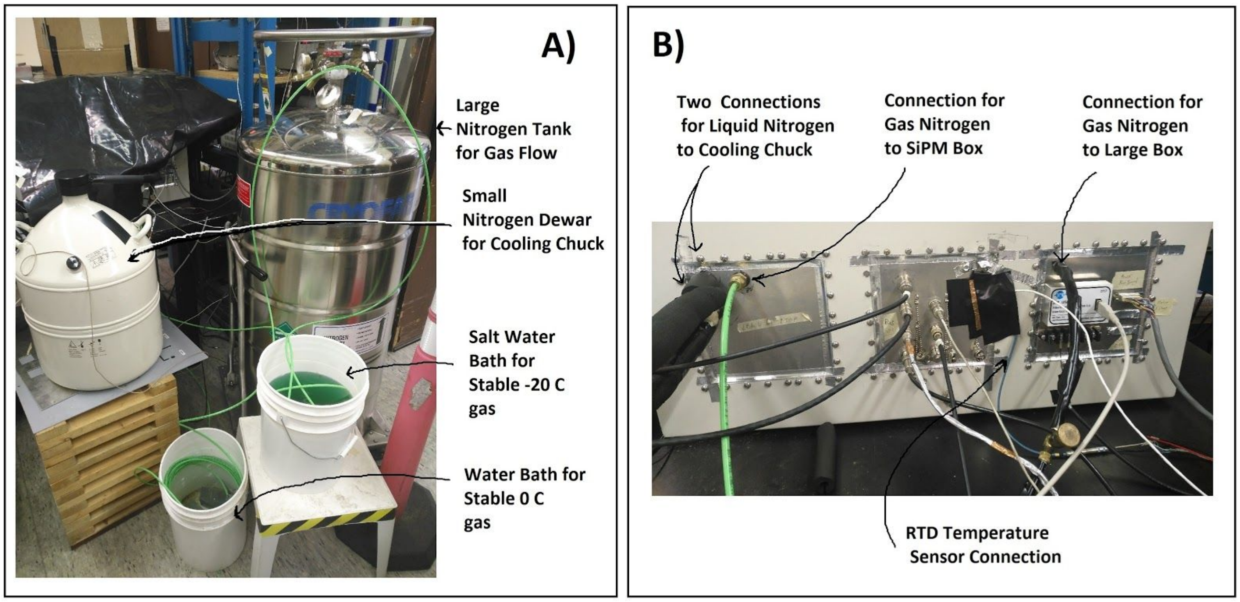


Figure 7.2 Cooling Setup. A) Liquid Nitrogen Containers, and temperature stability baths. B) The backside of the large white EMI box showing all the cooling connections.

A few optional items for cooling are shown in Figure 7.3. To increase the insulation on the SiPM box, a pink insulating cover can be added (Figure 7.3 part A). There is also a larger insulation cover that can fit over the whole cooling plate and this box can be purged with nitrogen gas (Figure 7.3 part B). Finally, it is possible to remove one of the water baths and use a radiator+heater to control the gas temperature going to the SiPM box (Figure 7.3 Part C).

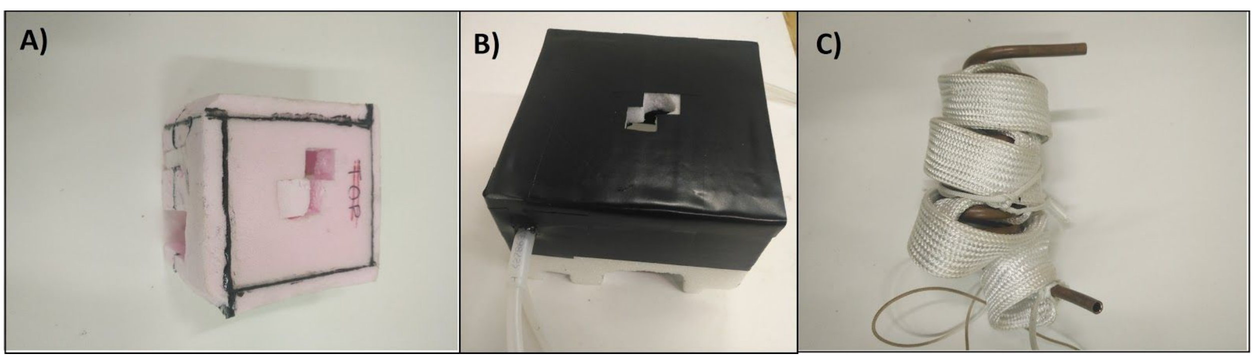


Figure 7.3 Optional Items for Cooling Control

There are a few issues with the cooling design that should be addressed. First, the temperature of the photodiode is unknown as the RTD is attached to the cooling plate and not the photodiode pcb. The mK1000 probes the temperature and this causes large EMI noise if the RTD is placed beside the photodiode. Secondly, it is difficult to reach -120 without condensation. The gas flow over the photodiode should be high, but this increases the photodiode temperature.

# 6. Light System

Light detection is the core of our system and the main utilities are listed in Figure 8.2. Currently, the light source is the xenon lamp, which passes through various filters, and then goes to our PMT and SiPM. The goals are to first establish a darkroom inside the large white EMI box. This is so the photodiode is exposed to no light whatsoever and a dark noise measurement can be made. Some precautions are: the is a hole in the box for wires that must be taped shut, a small slit for exhaust ventilation, and the tubes going into the box also might carry light inside. Next, the goals are to control the flash lamp light wavelength to only VUV (100-200nm), and to decrease the intensity to single photon level. This is done with a combination of filters, and attenuators. After the light is configured this way, the beam is split and sent to the SiPM and PMT. The position of both photodetectors can be manipulated via moving the photodetector platform. A general schematic of the light setup is shown in Figure 8.1. The actual setup is shown in Figure 8.3.

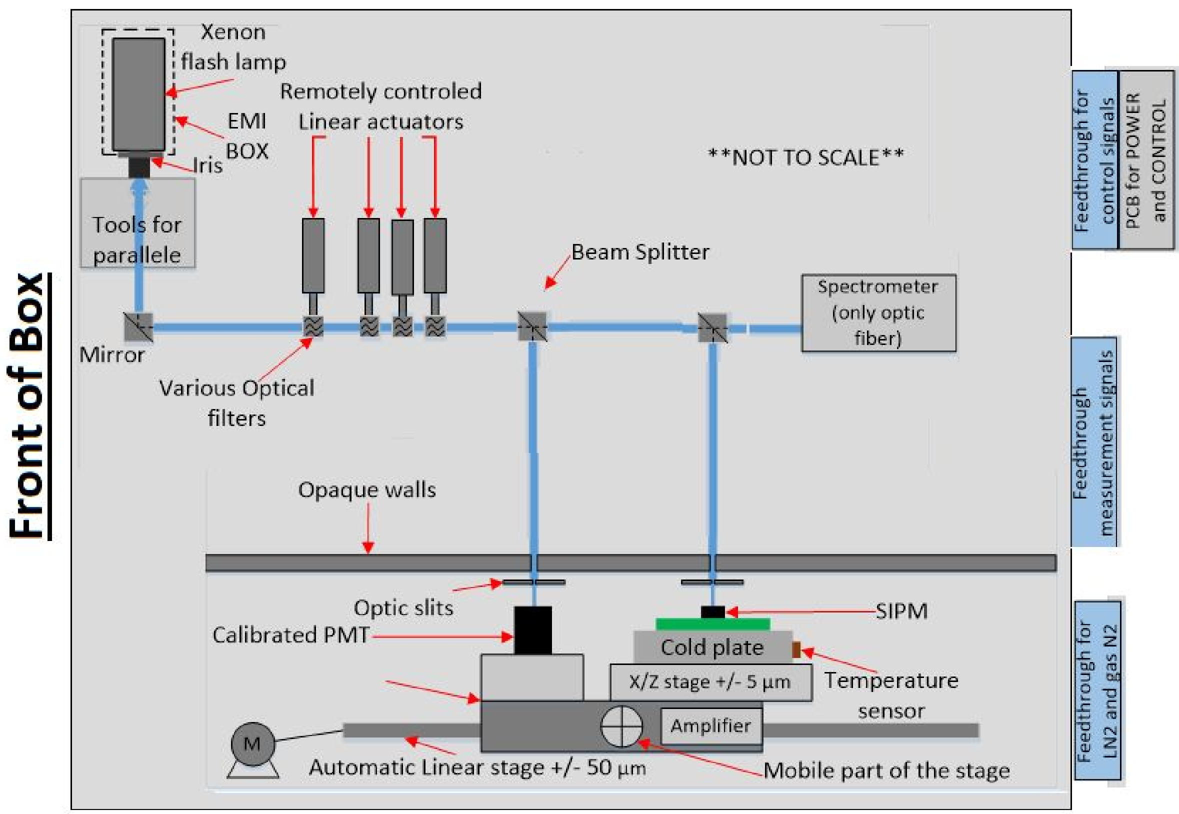


Figure 8.1 General Schematic of Optical Path Within EMI Box

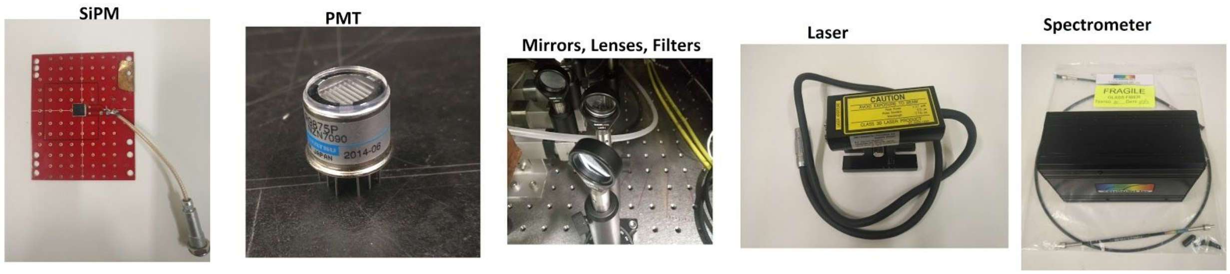


Figure 8.2. Light detection and manipulation Systems


Figure 8.3. View inside the EMI box. (Left) picture showing flash lamp and optics. (Right) Cardboard box cover used to cover flash lamp and optics to reduce reflections.

As shown in Figure 8.3, the flash lamp is within a shielded copper box. It's height can be adjusted via the optic posts and the lemo connectors power the lamp. The lamp is currently setup for internal intensity adjustment and a small screw can be turned to adjust. To change the lamp, the top cover of the lamp EMI box can be removed carefully and the lamp removed by unscrewing a brass screw in the back. Within the box is also some optics for the lamp: a diffuser, a lense, and a pinhole. The lamp is controlled via a signal generator to flash at 100 Hz. After the lamp are a set of mirrors, lenses, filters, and beam splitters. Three of which are mounted on motors for control by the main computer. A box is needed to cover the lamp and the optics in order to reduce reflections and achieve single photon levels.

For positioning, the SiPM and the PMT should be at the same height and at 3" apart. This is because the difference in beam splitter position is 3". It is possible to add a small aperture in front of both the SiPM and the PMT. This involves taping a piece of metal in front of both the SiPM and PMT, and the piece of metal would have a small aperture hole for the two photodetectors.

The motors for the filters can be controlled from Midas via "scFilters". A command of 1 brings the filter in, and a command of 2 extends the filter out. To move the whole photodetector platform, go to Midas "scPhidget" section. To move the precision x-y stage, the procedure is more complex. Plug the usb from the box to the laptop, then go to thorlabs….Servo.h and stat the script. Do not connect to the server and select manual operation, jog mode, and input a step size. Then you can manually move the motors.

# 7. Power and Connections

Connections for the lab change according to the experiment. The current connections are documented in Figure 9.1 and 9.2. The SiPM is powered by the picoammeter.

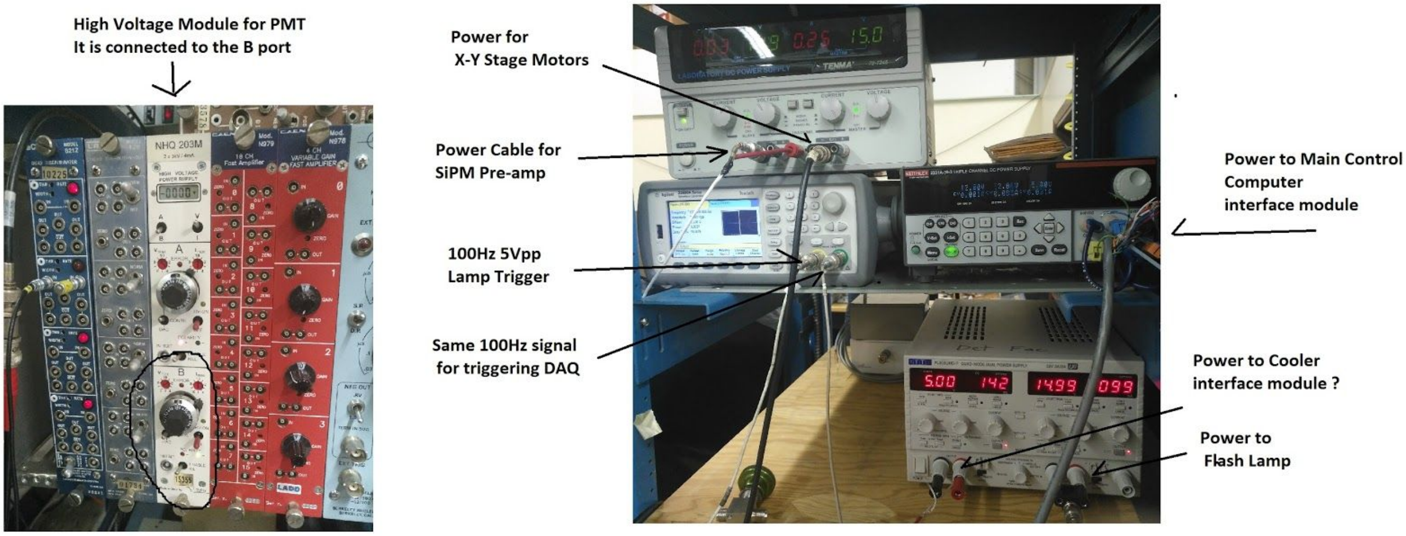


Figure 9.1. Power Connections

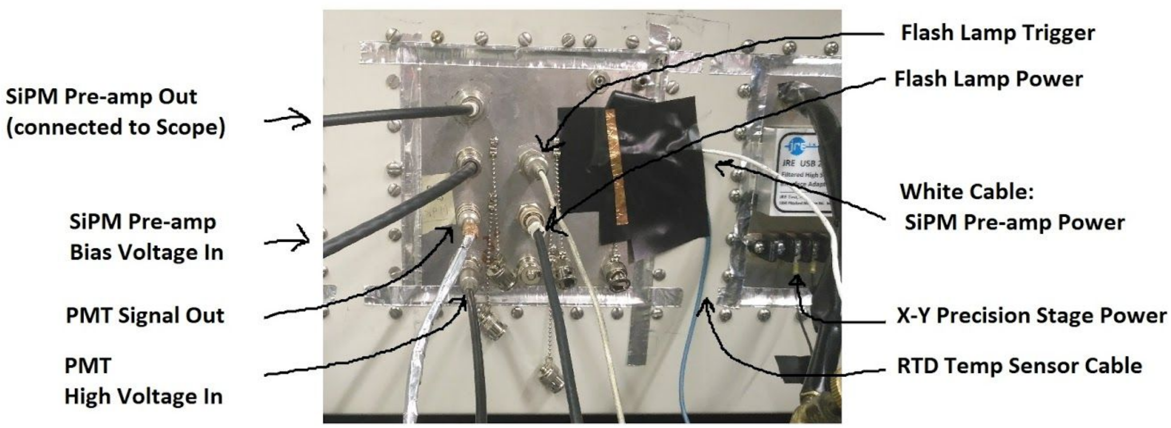


Figure 9.2. Connections on Back of White EMI Box

# 8. List of Measurements

The apparatus can be used to test and measure different properties of Silicon based photo-detectors. Here a quick list of the suggested measurement that a group can complete during the allocated lab time:

- Measure and observe the different amplitude for 1,2 and 3 Photo-Electron (PE), and deduce what is the relationship between them and what this implies for photon-counting.
- Measure the break-down voltage of the SiPM device, and therefore define the voltage value at which the SiPM transition from a linear response to a Geiger mode.
- Measure the Dark Noise (ie the rate of charge not caused by light detection) as a function of the SiPM temperature. Extrapolate the relationship between Si temperature and Dark Noise and explain the result with a physical model.