

# Constructing a Muon Telescope with SiPMs

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## Introducing the SiPM

The SiPM is an avalanche photodiode capable of single-photon detection, making it great for detecting charged particles such as muons. The SiPM stands for Silicon Photomultiplier and offers a cheaper alternative to larger scale vacuum tube PMTs giving it much more practical applications in settings such as classrooms.

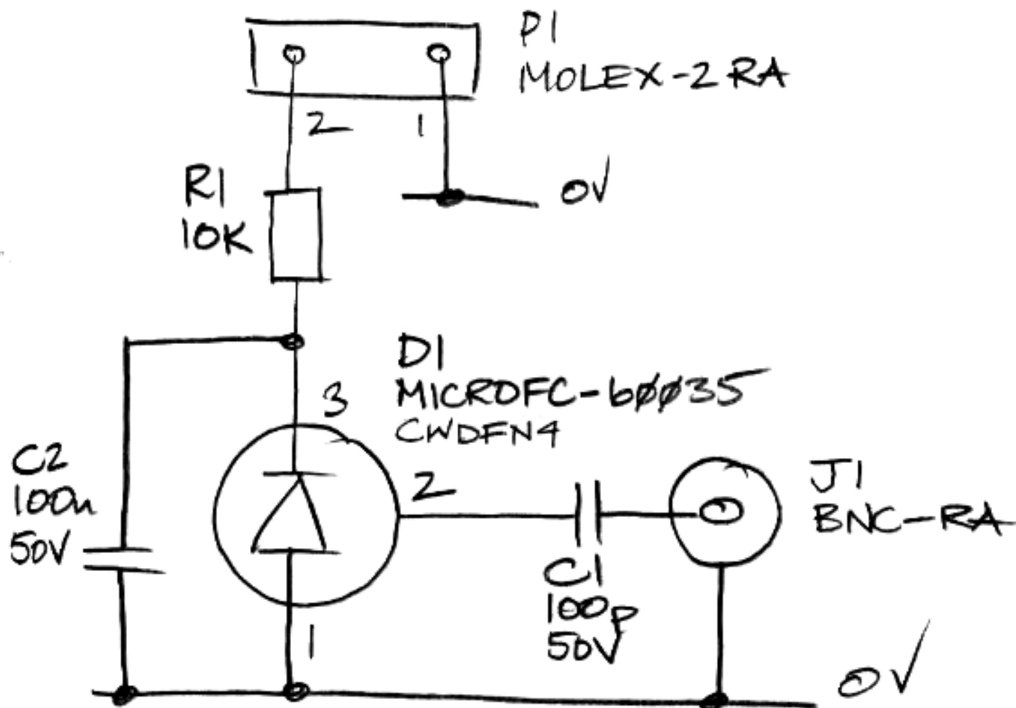


Figure 1: Circuit schematic for SiPM board

In this schematic, D1 is our SiPM and it is accompanied by supplementary resistor and capacitors. We make sure to include a 10 kilo-ohm resistor as to avoid overloading the SiPM with too large a bias voltage.

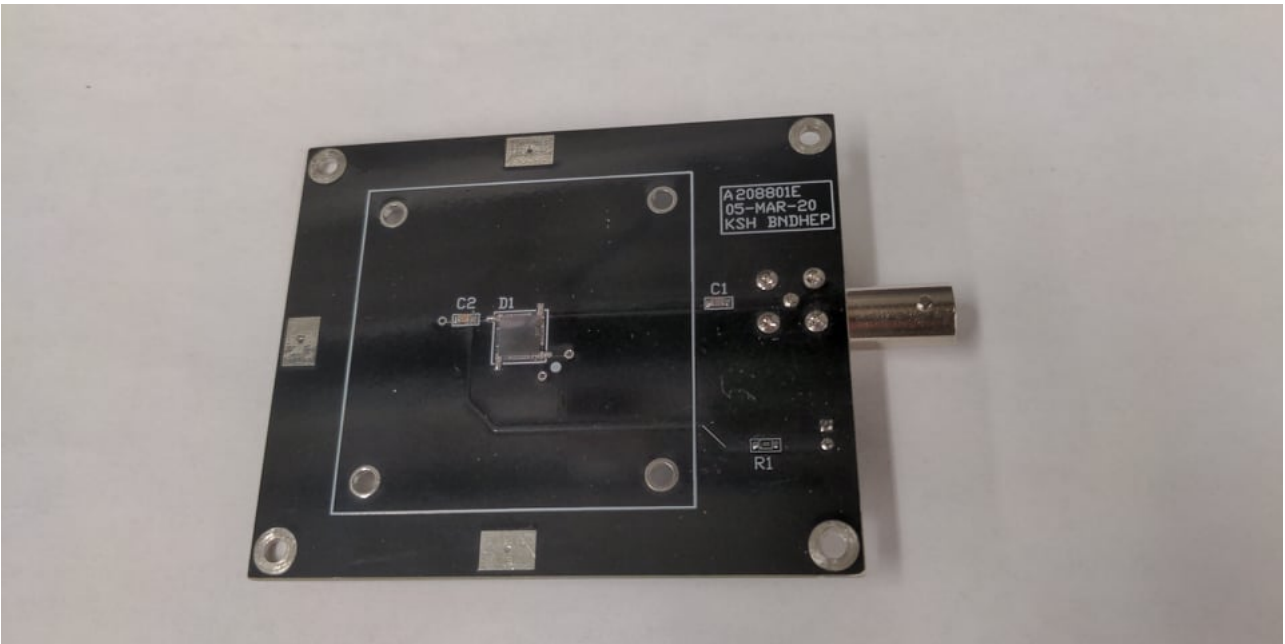


Figure 2: The SiPM detector surface mounted on a PCB

The SiPM we use is a 6mm by 6mm square, which isn't a large active area for a PMT. This is why we make use of a scintillator, which will be placed on the larger square outlined around the SiPM. The SiPMs themselves can be purchased at Digikey<sup>1</sup>.

## Aligning up the SiPM

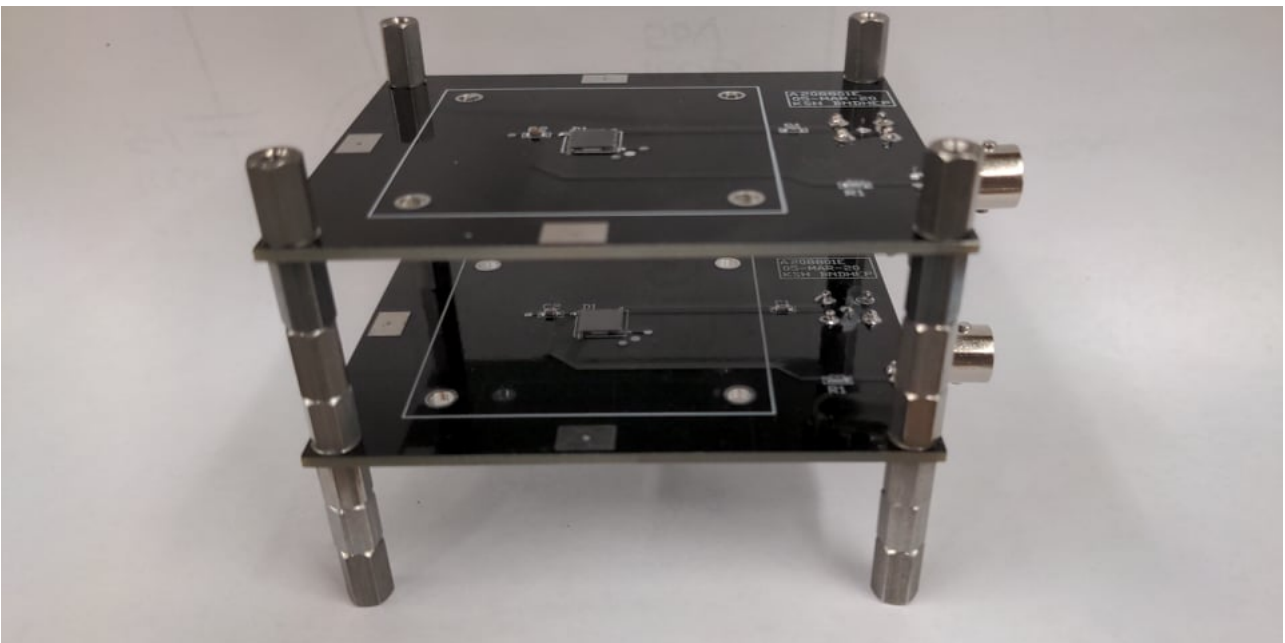


Figure 3: Two SiPM boards stacked on top of one another

With the help of standoffs, we are able to stack two SiPM boards in order to ensure that one SiPM is directly above the other. This will allow us to more easily calculate the opening angle of the muon telescope and maximize the muon flux through both scintillators.

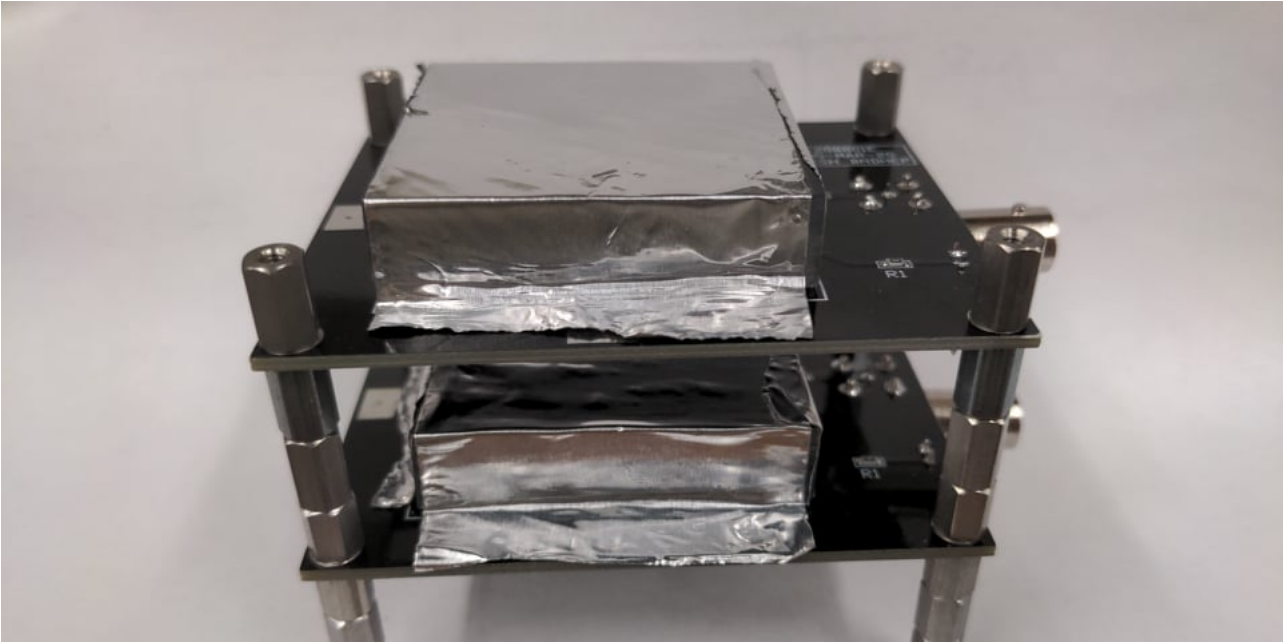


Figure 4: Plastic scintillator being placed on top of each SiPM board

Plastic scintillator is placed directly on top of each SiPM board and then wrapped in aluminum to reflect any light produced by the scintillator toward the SiPM. The scintillator we used can be found on Ebay<sup>2</sup>. If a muon is coincident with the scintillator, the plastic will absorb the energy of the muon and emit photons in the visible light spectrum for the SiPM to detect.

## Blocking out Light



Figure 5: The dark box used for containing the muon telescope

The most important part of constructing this muon telescope is making sure that no outside light reaches the SiPM. To prevent this, we make use of a dark box. In this experiment the dark box being used is a simple tool box with holes drilled in the side for connectors so that we can supply power to inside the dark box and get a signal outside the dark box.





Figure 6: Muon telescope connected to junctions on the dark box

Each SiPM board requires a BNC cable for its signal output as well as a power cable providing 26-30V. I found that a bias voltage of 28V gives a strong enough signal while minimizing the dark count rate on the SiPM. To reduce the amount of cables necessary for the setup, we attached both power supply cables to the same input jacks on the dark box so that they can use the same power supply.



Figure 7: Muon telescope after it is wrapped in dark fabric

We then wrap the muon telescope in dark fabric as to block any light that might enter the dark box from interacting with our SiPMs. SiPMs are highly sensitive light sensors and as such shielding them from light can be the most difficult part of constructing this telescope. This particular fabric is a Thorlabs nylon fabric (part number BK5)<sup>3</sup> designed to block out as much light as possible. We wrap the fabric all the way around the telescope and around the BNC and power cables.

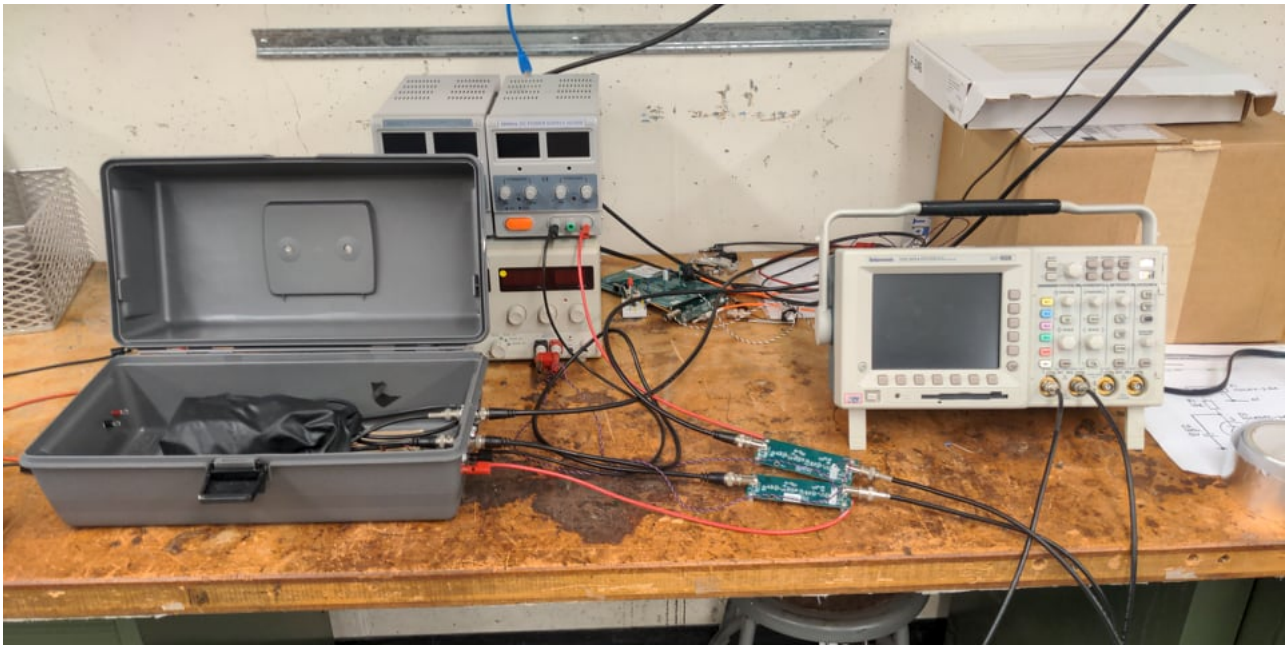


Figure 8: The completed muon telescope setup

The dark box should be closed when taking measurements as to shut out as much light as possible. The output of each SiPM goes directly to an amplifier-shaper which uses a 10V power supply. The use of this amplifier-shaper is optional if the oscilloscope being used is fast enough to view a raw SiPM pulse, but the amplifier-shaper will help in viewing pulses from the SiPM regardless. The amplifier shaper gerber files as well as other SiPM research can be found on the Brandeis High Energy Physics lab website<sup>4</sup>.

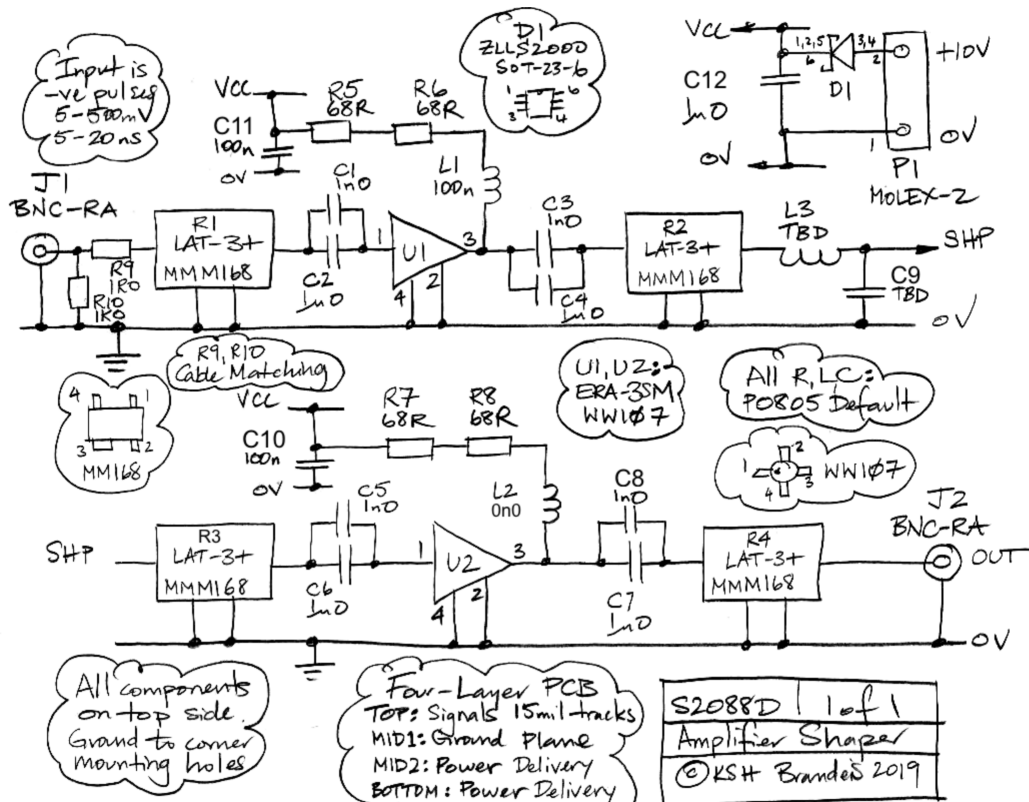
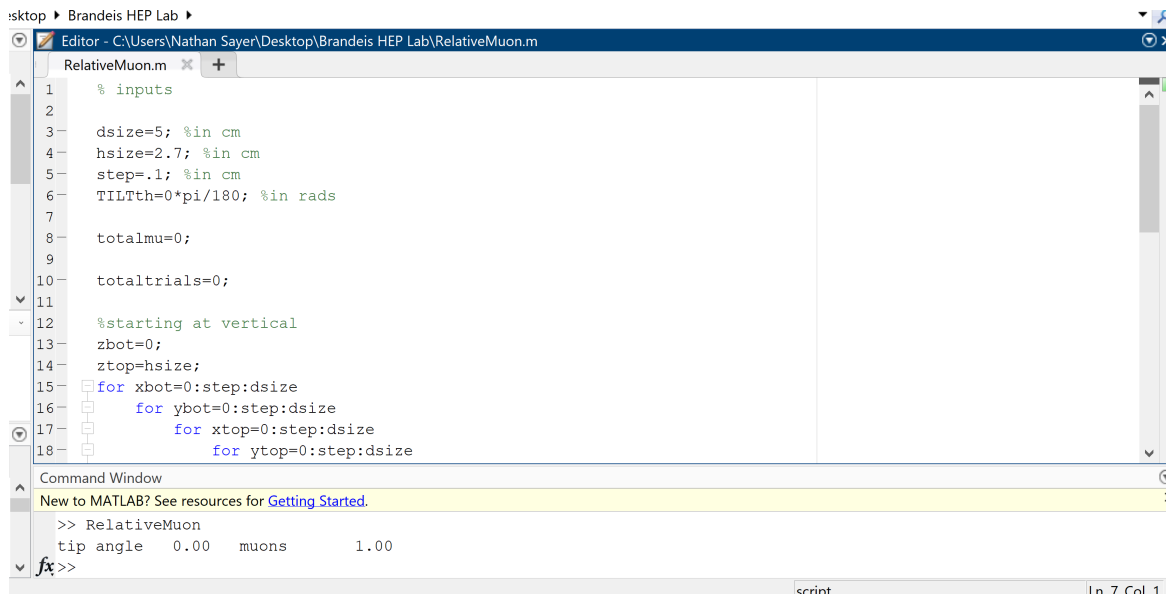


Figure 9: Circuit schematic for amplifier-shaper

# Simulating the Telescope

Since we know the geometry of our telescope and we placed one SiPM directly above the other, we can write a MATLAB script that calculates the relative muon flux for a given angle that the telescope is at.



```
1 % inputs
2
3 dsize=5; %in cm
4 hsize=2.7; %in cm
5 step=.1; %in cm
6 TILTth=0*pi/180; %in rads
7
8 totalmu=0;
9
10 totaltrials=0;
11
12 %starting at vertical
13 zbot=0;
14 ztop=hsize;
15 for xbot=0:step:dsize
16     for ybot=0:step:dsize
17         for xtop=0:step:dsize
18             for ytop=0:step:dsize
```

Command Window

```
>> RelativeMuon
tip angle 0.00 muons 1.00
fx>>
```

Figure 10: MATLAB simulation of muon telescope

Although you could change other parameters, we mainly focus on the tip angle of the telescope and determine what the flux of muons would be relative to zero tip angle (vertically pointing). We can gather experimental data by angling the telescope ourselves and measuring the rate of muons passing through the telescope.

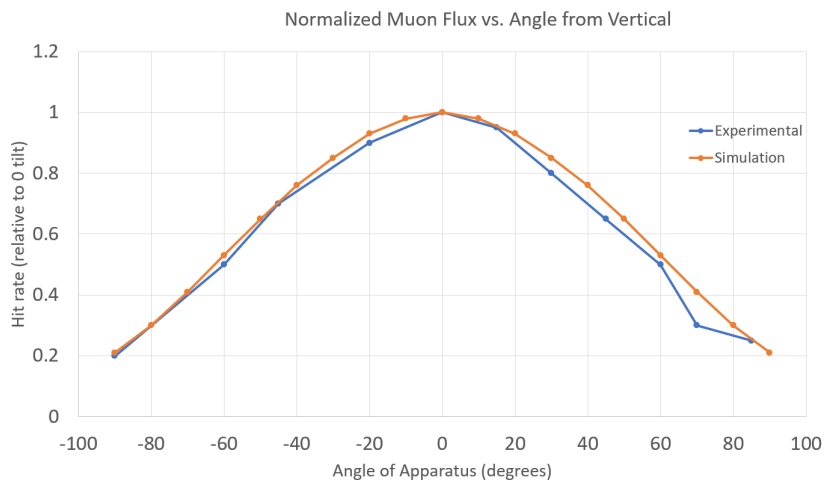


Figure 11: Comparing the MATLAB simulation with experimental data

This graph confirms our belief that the muon flux would be symmetrical with respect to the telescope's vertical axis as well as highlighting the effectiveness of our simulation.

## Appendix

1. <https://www.digikey.com/en/products/detail/on-semiconductor/MICROFC-60035-SMT-TR1/9744774>
2. <https://www.ebay.com/itm/263355405917?epid=2044114641&hash=item3d5134965d:g:XxsAA0SwSW5cWxPb>
3. [https://www.thorlabs.com/newgrouppage9.cfm?objectgroup\\_id=190](https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=190)
4. <http://www.bndhep.net/Electronics/A2088/M2088.html>