EIC Prototype GEM rebuild

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PHY 4902

Abstract: This is a continuation of the ongoing work to build a prototype GEM for a future EIC. Our goal for the project this semester was to disassemble and rebuild the prototype GEM in order to install various improvements. Water Cut PEEK frames replaced the 3d printed frames, and in them, new square nuts were used to replace the hex nuts in the pullouts; both of which seemed to be notable improvements over the prior iteration of the prototype. The rebuild went smoothly, but the assembled detector showed shorts in every transfer gap once released from the bench, after failing to permanently remove the shorts, a second rebuild was performed. This rebuild too, saw a smooth assembly and resulted in some cosmetic improvement, but the result was the same, and the shorting in the transfer gaps persisted. The cause of the shorting seems to be warping in the carbon fiber frame that houses the GEM stack, several attempts were made at building a support structure that the detector could be fixed to. These had a clear positive effect on the tension of the foils but ultimately failed in permanently removing the shorts.

A Chronological Record of the Disassembly and subsequent rebuild of the EIC GEM prototype

Initially, my task was to aid in the disassembly of the stack so that it could be rebuilt with the new PEEK frames and square bolts. The following pictures and descriptions, starting at the beginning of the fall 2020 semester, illustrate this process. Many of the photos are from the second rebuild, as I had a better idea of what might be relevant for posterity's sake, so when the distinction between photos of the two rebuilds is important, I will draw special attention to it.

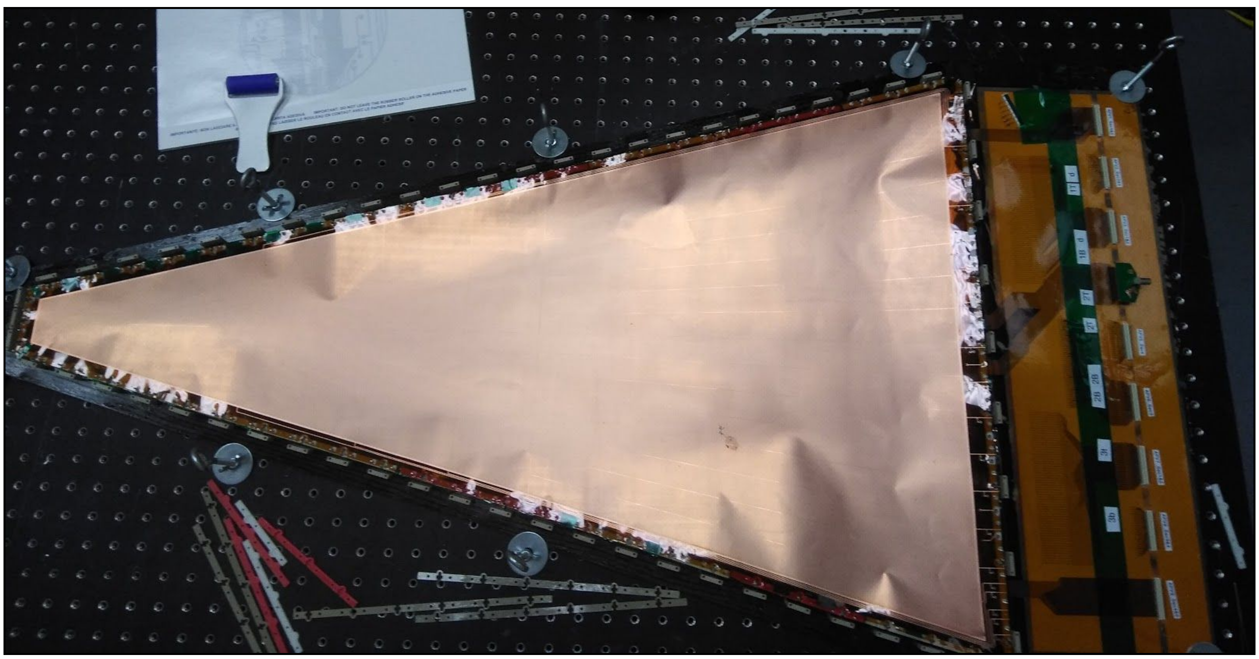

Figure 1: The detector as I first saw it, Partially disassembled. Pictured here is GEM2. some of the old red and white 3d printed frames can be seen in the bottom left.

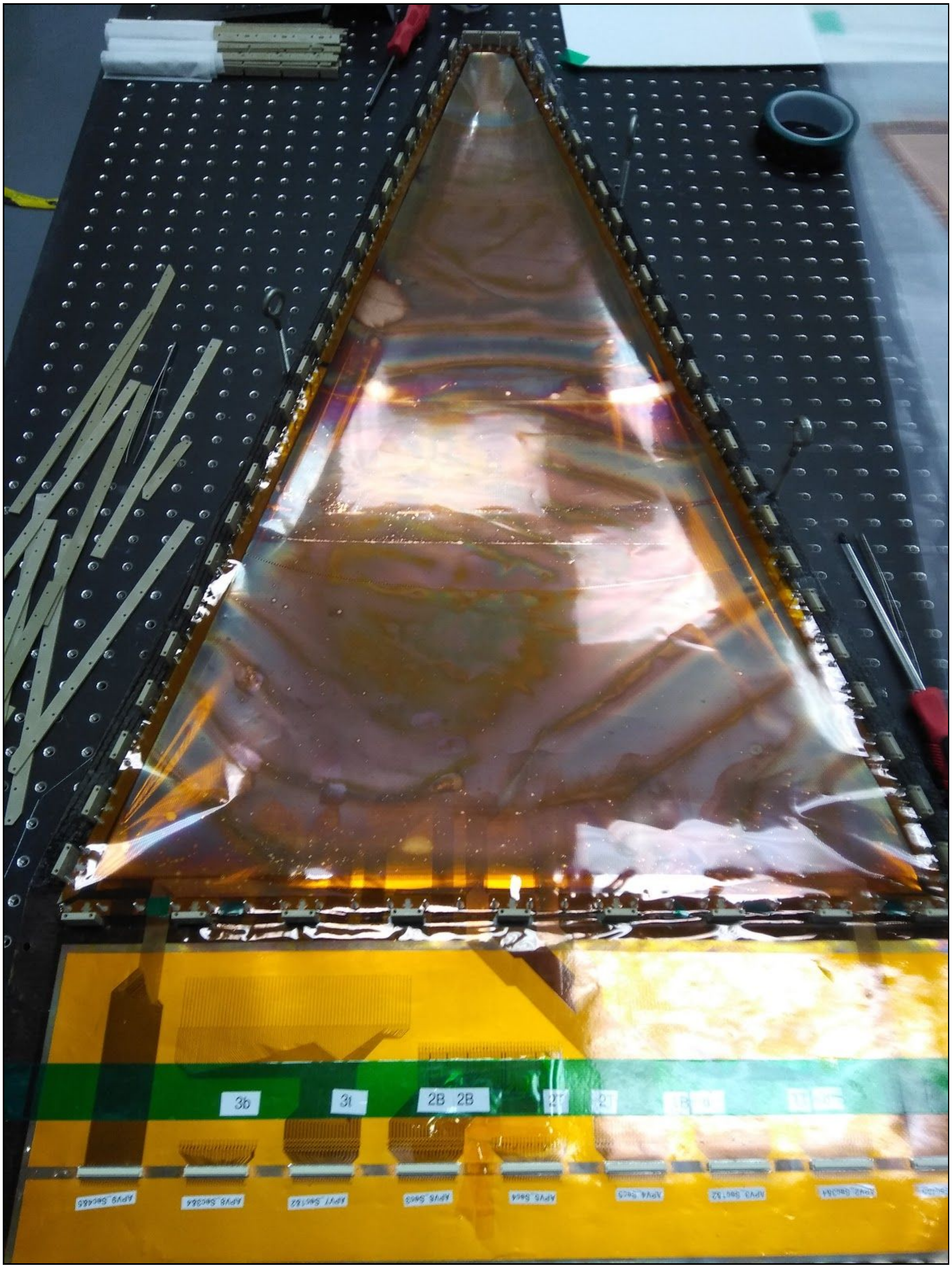

Figure 2: With all GEM foils removed, The readout board can be seen. (second rebuild)

Once GEM2 and GEM3 were removed, we spent several hours carefully removing pieces of tape from the foils that had been used for pretentiontioning during its last rebuild. Then we were able to start the rebuilding process. By carefully applying small pieces of tape, we were able to pre-tension the readout board, as pictured below.

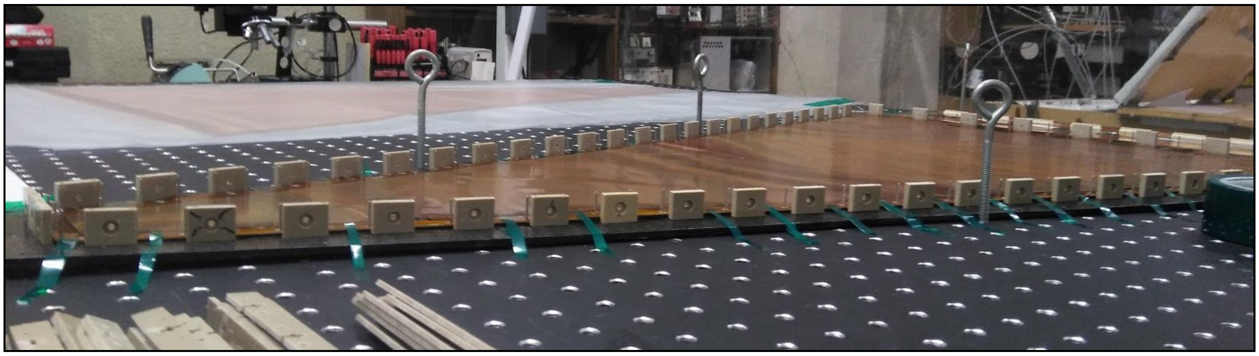

Figure 3: Tape keeping tension on the ROB (second rebuild)

Following naturally, the first of the new PEEK frames were added and GEM3 was carefully placed over them. It was pretensioned with the same technique used on the ROB.

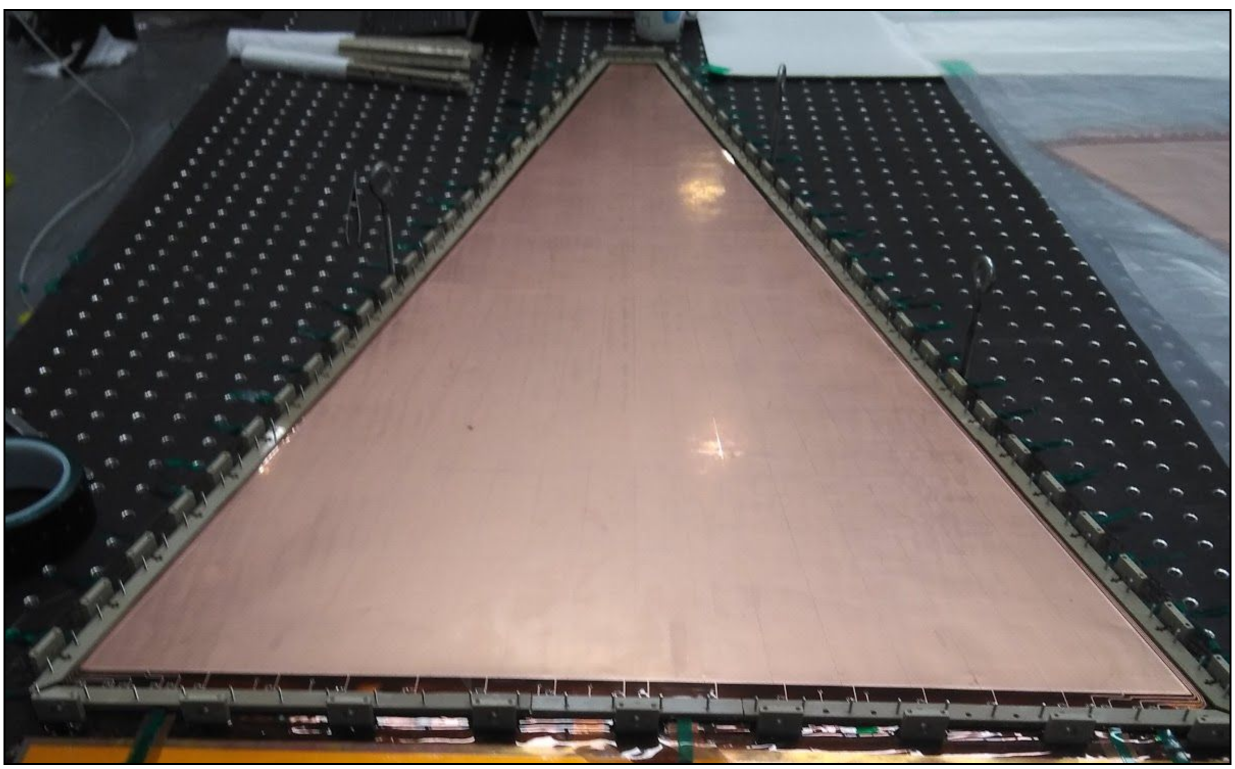

Figure 4: Here we see GEM3, which has been placed onto the stack. Note its lustrous copper shine, It is almost completely unblemished by the hands of undergraduates.

Quickly after this, GEM2 was added, and with it the new square nuts, which slotted into the PEEK frames beautifly.

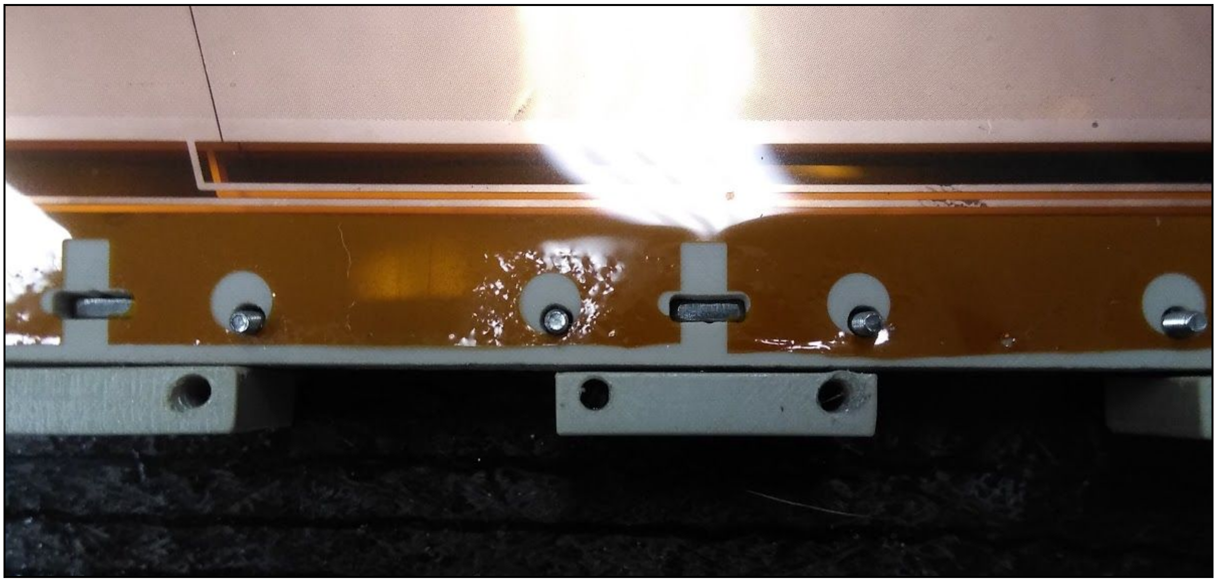

Figure 5: The snug fit of the new square nuts into the PEEK frame.

Below is a picture of the narrow end of the detector, notice that the GEM foil does not align perfectly with the slots for the pullout screws and bolts, in our second rebuild I opted to omit the leftmost pullout bolt, and It lead to a radical improvement in the tension of this section of the gem, see figure 15 for a comparison.

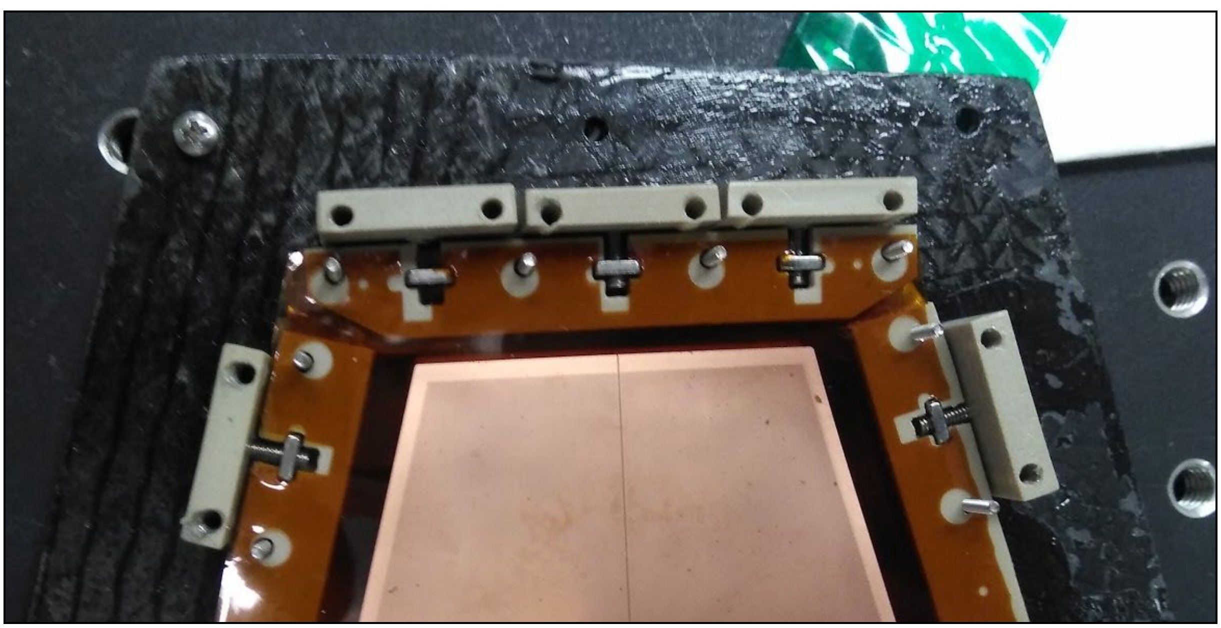

Figure 6: Misaligned pullot

Once GEM1 and the drift foil were placed on, we used hex nuts to secure the stack and prevent the foils from independently losing tension (this can be done most easily by using the famous “precision nut driver”). Then we carefully tried to remove the remaining slack by tightening the pullout bolts.

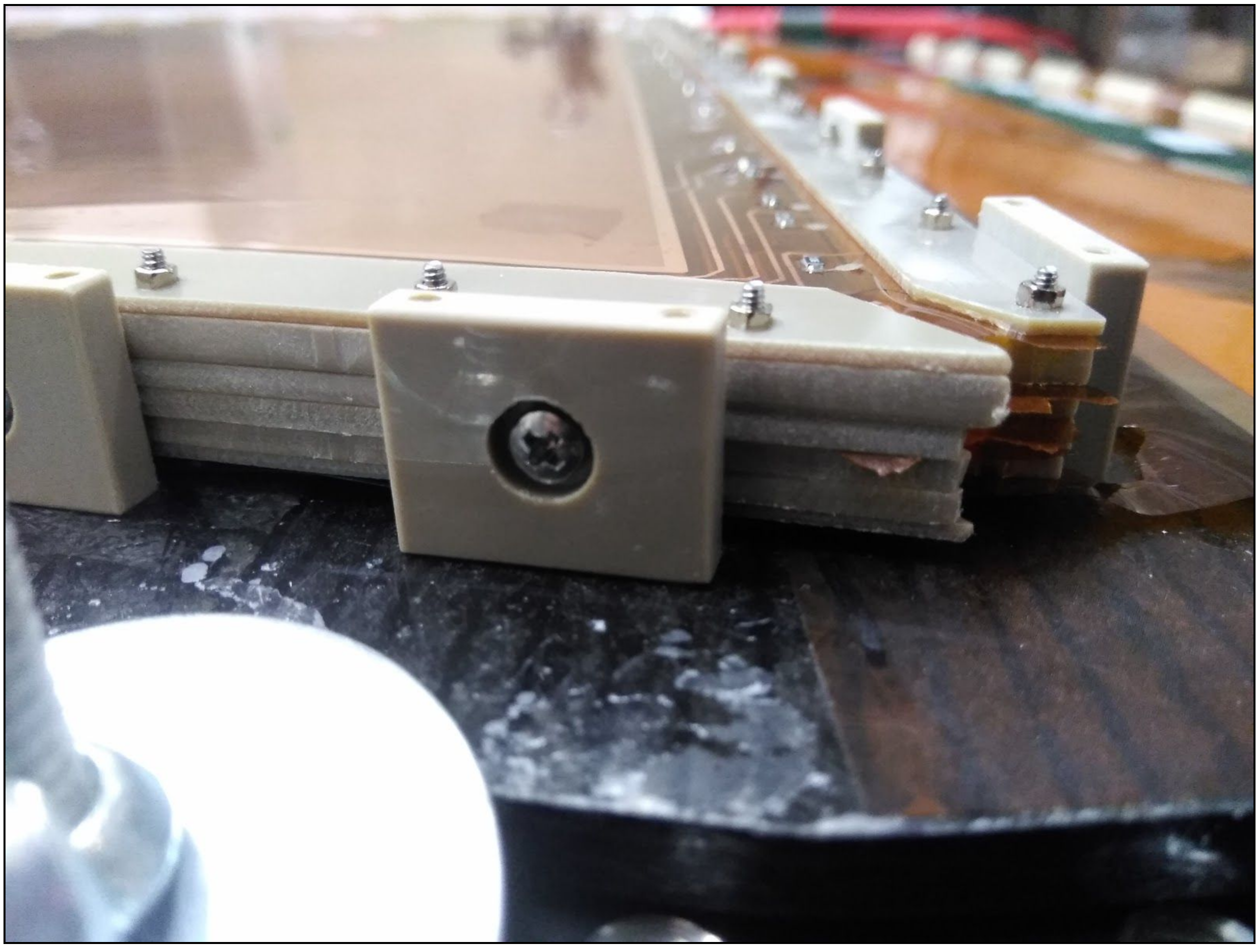

Figure 7: A close view of the hex nuts used to secure the stack, and the phillips head pullout bolts

Once the stack was secured, we tested the resistances of the GEM foils and transfer gaps with the megger. The probes on the megger couldn't reach the pads through the small holes in the PEEK frames, so a pair of crude leads were fashioned to aid in the testing. The Initial results from these tests were promising, suggesting that no major shorts were present in or between the foils. (See the data in Table 1 taken on 9/21/2020.)

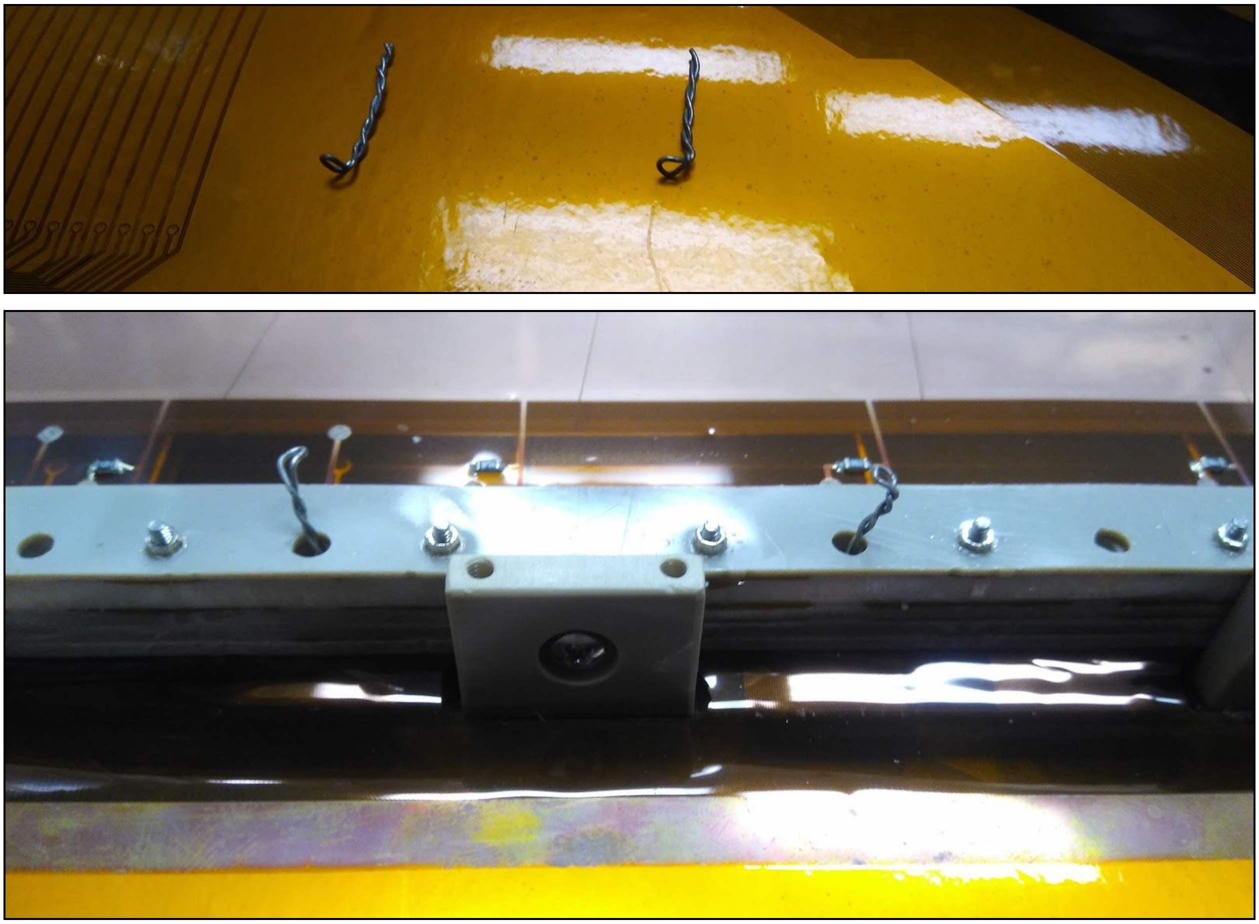

Figure 8: Crude leads and their application.

Following from this, The window was placed over the detector. Pins on the inside of the window fit neatly into the previously mentioned holes in the PEEK frame, and allow it to be connected to an HV divider. The traces to the pins can also provide convenient leads for troubleshooting the detector while it is sealed.

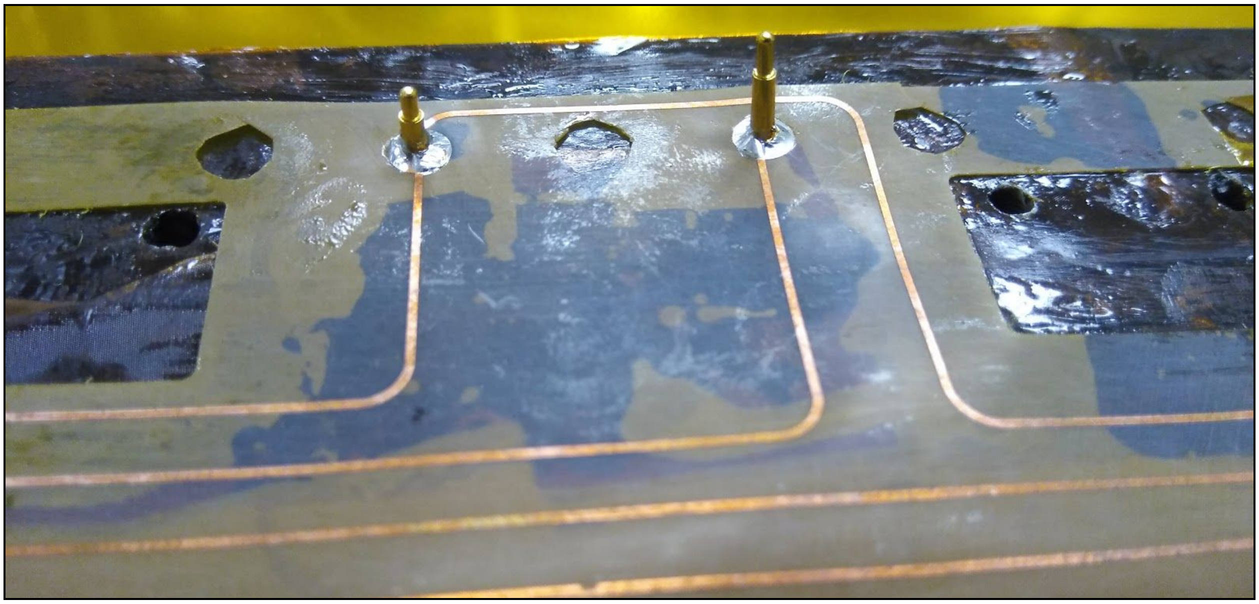

Figure 9: Pins and copper traces on the inside of the window.

Meggering on the external traces again gave promising results, showing no major shorts (See the 9/28/2020 data in Table 1).

Next, we fully sealed the detector with nylon washers and screws, and released it from the optics bench. Meggering the detector now revealed shorting in both transfer gaps (See the 9/30/2020 data in Table 1). This led to the construction of several support structures in an attempt to replicate the tensioning effect produced by securing the detector to the optics bench. These were built primarily with 80/20 aluminum frames, bolts, and large metal washers. The first of these frames was not successful in removing the shorts, and several other arrangements were built. I will spare the reader time, and reveal that there was never a support structure that could remove the shorting in the sealed detector, though we did have some short lived success working on the frame with the detector reopened (See Figure 12, and the 10/26/2020 data in Table 1).

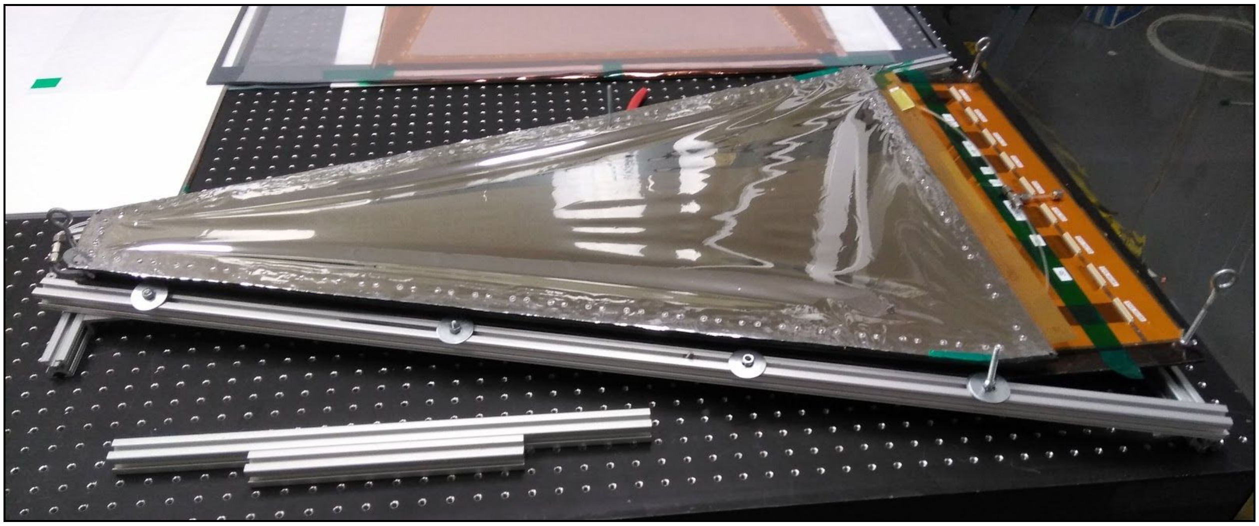

Figure 10: First frame attempt (first rebuild)

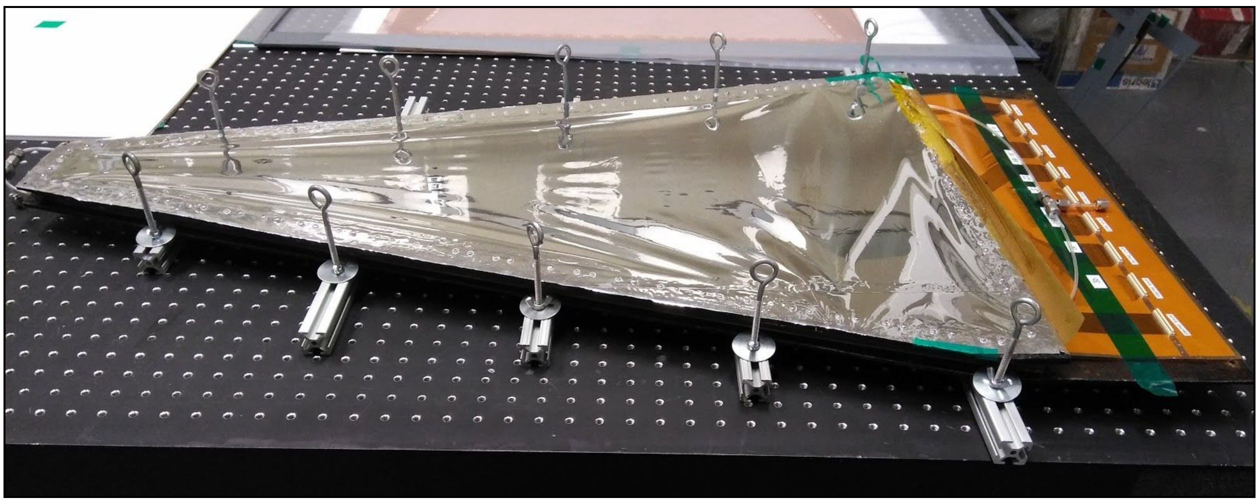

Figure 11: Second frame attempt (first rebuild)

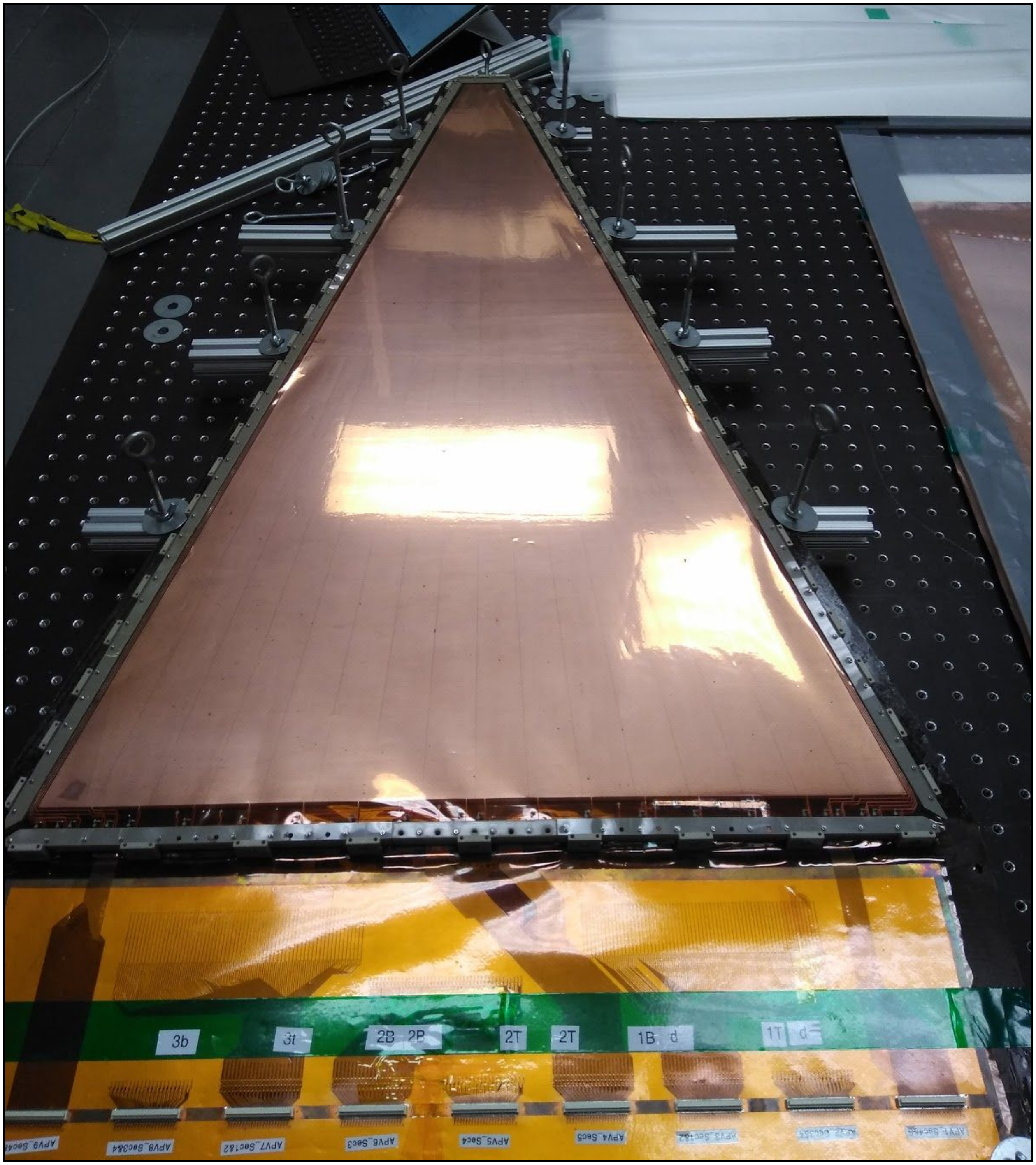

Figure 12: Frame that was briefly successful in removing shorts (first rebuild)

The trick that I adapted to apply extra tension to the foils was to use washers as shims under the pullout screws, and then wing nuts to pull down on the outer edge of the carbon fiber frame. I've included a diagram below to show the theory of this technique.

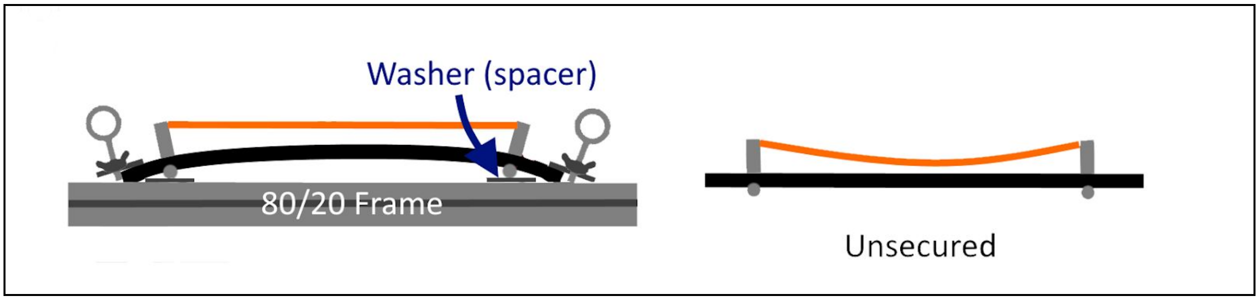

Figure 13: Washer tensioning trick, with unsecured frame for comparison

To show the tensioning effect that this method can have, I've included a side by side comparison below. It is worth noting here that this trick necessarily makes it very difficult to attach the window because the pullouts are pushed away from parallel, as is evident in the diagram above.

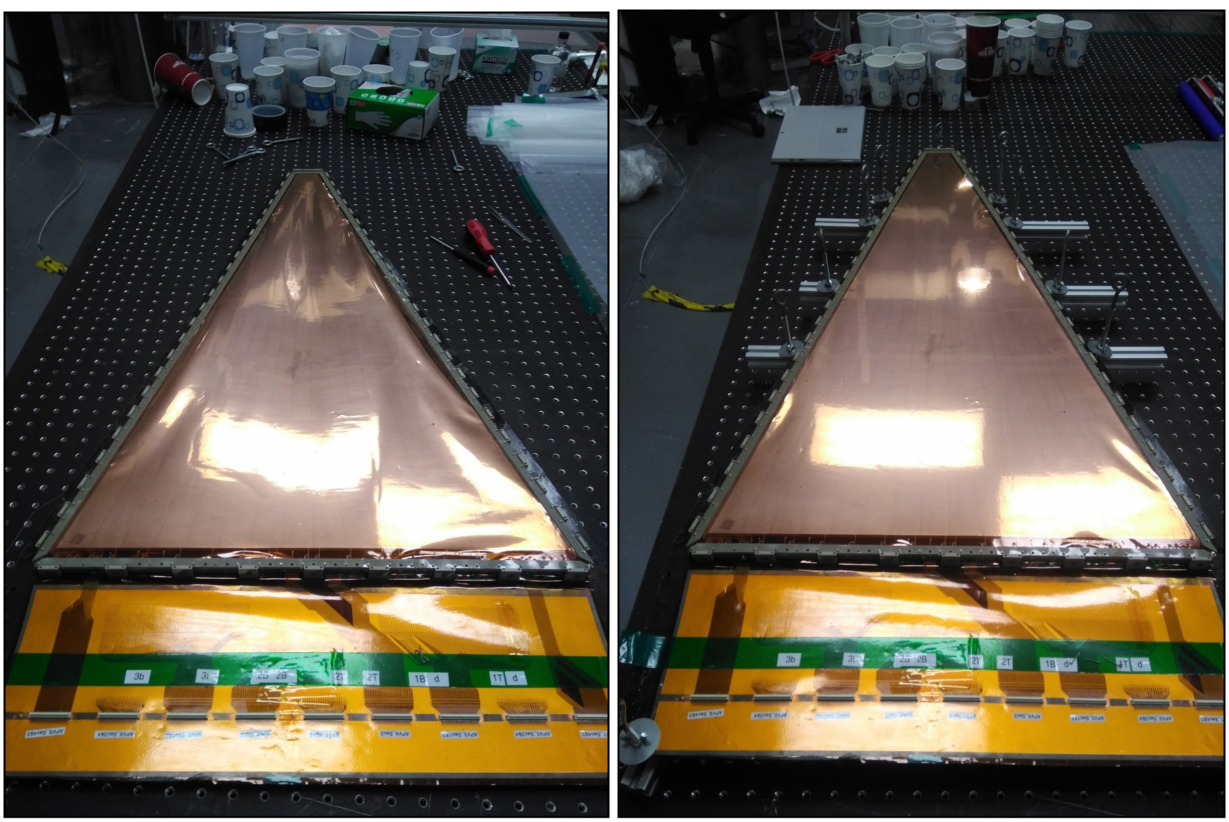

Figure 14: Unsecured frame (left) and secured frame (right) both from the second rebuild

The frame constructed after the second rebuild made the largest cosmetic improvement to the detector, but neither designs fully removed the shorting. Below is a side by side comparison of the narrow end of the detector that was improved by the second rebuild. The structure used to apply extra tension to the frame can be seen in Figure 16

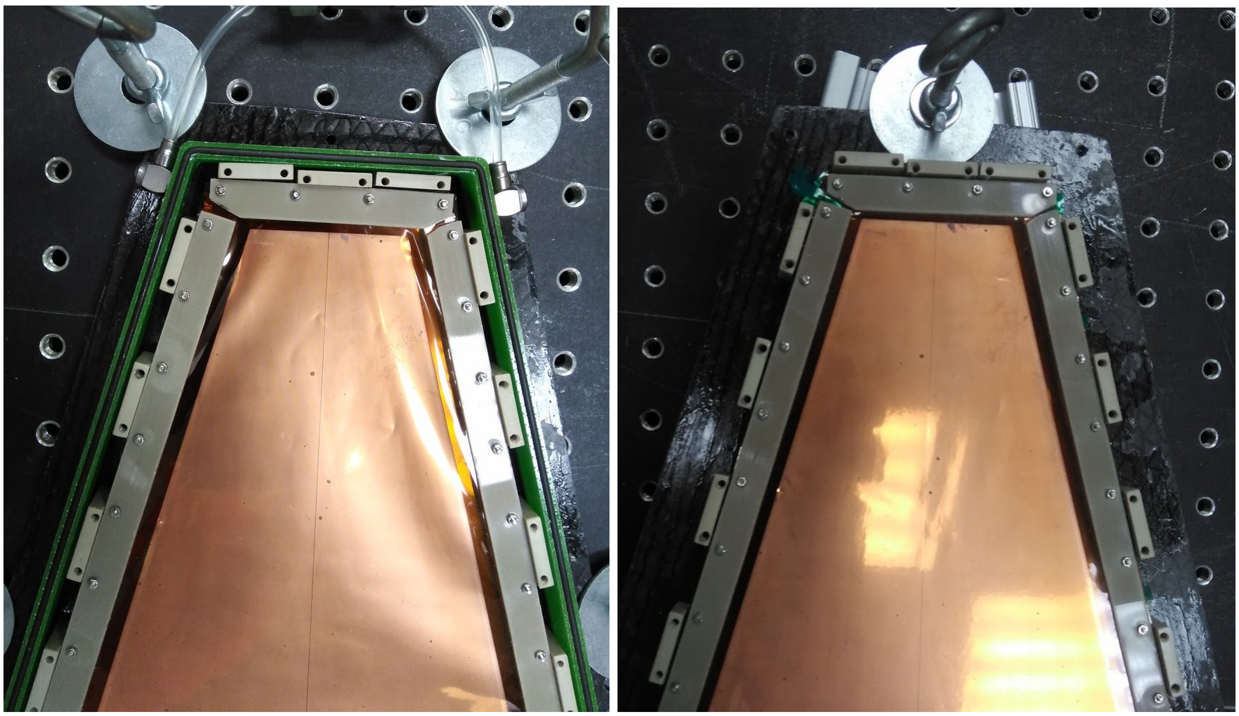

Figure 15: problematic region at the narrow end of the detector after the first rebuild (left) and the improvement made after the second rebuild (right)

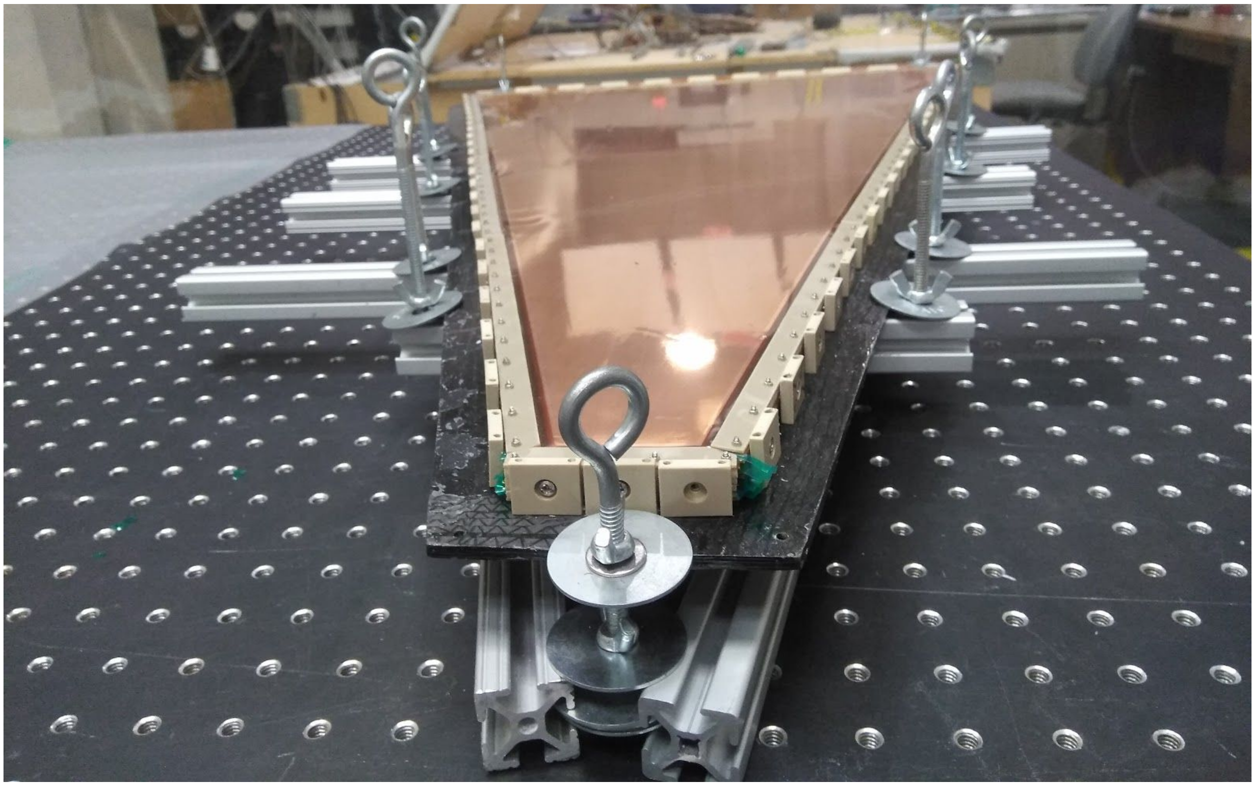

Figure 16: 80/20 frame design that could apply extra tension to any side of the detector. You can also see where a pullout screw was omitted at the narrow end of the detector (second rebuild)

Conclusions

After a semester of working on the prototype, there are several conclusions that I can draw:

- Shorting in the transfer gaps is caused primarily by warping in the carbon fiber frame.
- Warping in the frame can be partially overcome by securing the detector to a suitable structure.
- Securing the window to the detector has a measurable negative effect on the tension of the foils and thus shorting in the transfers.

My conclusion is that the carbon fiber frame is the main source of trouble with the prototype, it has become warped, and is not able to support the force applied by tensioning the foils. The material is too flexible and prone to deforming. Another potential problem is the pretensioning of the foils, This step must be performed as quickly as possible, the tape doesn't hold tension for long. With that said, The other components in the detector do seem to be performing nominaly, The PEEK frames secured the stack well, and the new square nuts were a perfect fit. If another rebuild is to be carried out I would suggest the following:

- Investigate the misaligned pullout at the top of the detector.
- Allow more space for the pullout screws; pretensioning the foils is an art, and the effect of the artists skill could be minimized by allowing for a longer range of motion with the pullout screws.
- Use a more rigid material in the frame construction.

If the reader has any questions about this work, please feel free to contact me personally, I also have an extensive collection of photos from this project that can be provided upon request. Secondly, special thanks to Jacob Chesslo for introducing me to the project and sharing his tips and tricks for working with the prototype. A thank you is also in order for Andrew Capalbo who was indispensable in carrying out the second rebuild. Lastly (but certainly not least), Thank you Dr. Hohlmann, for the opportunity to work on the project, the experience with cleanroom work and GEM detectors has been a good deal of fun and highly educational.

Measurements

Date	Resistance (GΩ)						Notes
	Drift	GEM1	T1	GEM2	T2	GEM3	
09/09/2020	>10	>10	>10	>100	>10	>10	NA
09/16/2020	>10	0.8	>10	1.4	>10	>10	NA
09/21/2020	>10	1.4	>10	0.4	>10	1	NA
09/28/2020	>10	1.1	>10	0.2	>10	1	Cover leads
09/30/2020	>10	0.5	0.005	0.2	0.01	2	Fully Closed, Released from table, horizontal
09/30/2020	>10	0.5	0.005	0.1	0.018	3	Vertical
10/12/2020	>10	0.5	0.005	0.2	0.01	2	Secured to Frame 2
10/14/2020	>10	0.5	0.005	0.4	0.01	2	frame 3
10/14/2020	>10	0.5	0.005	0.5	0.01	2	Secured to bench (sealed)
10/19/2020	>10	0.4	>10	0.4	5	2.2	Secured to Bench (open)
10/19/2020	>10	0.8	>10	1	>10	2.2	Secured to bench (open) adjusted pullouts
10/19/2020	>10	0.5	0.004	0.02	0.0025	2.3	Unsecured (open)
10/21/2020	>10	2	>10	0.07	>10	2	Frame 4 (open)
11/02/2020	>10	1	>10	0.2	0.01	2	Frame 4 (open)
11/02/2020	>10	1.2	>10	0.5	0.01	>10	Frame 4 (closed a little)
11/02/2020	>10	0.5	0.01	0.5	>10	>10	Frame 4 (closed a little more)
11/02/2020	>10	0.1	0.01	0.2	0.01	3	Frame 4 (closed mostly)

Table 1: resistances as measured across the GEM foils and transfer gaps