FLORIDA INSTITUTE OF TECHNOLOGY

HIGH ENERGY PHYSICS LABORATORY A

EIC GEM Project

THE NOT-SO-SHORT CONSTRUCTION MANUAL

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Photo Credit

Figures 2, 5, 6, 7, and 8 by Samantha Wohlstadter, figures 1, 3, 4, 9, and 10 by the author.

1 Introduction

This manual outlines the process taken by the author and his collaborator to construct a prototype gas electron multiplier (GEM) for a future electron-ion collider (EIC) in the United States. The conventional GEM used at the Compact Muon Solenoid (CMS) at CERN consists of two printed circuit boards (PCBs), with a drift plate on one and read-out (R/O) structures on the other, sandwiching a stack of three GEM foils with seperation of 3 mm, 1 mm, 2 mm, and 1mm (drift to R/O). Material is reduced in the active region of the EIC GEM design by replacing the PCBs with carbon fiber support frames (CFFs) and transferring the drift and R/O structures to separate foils. The difference in the CMS and prototype EIC GEM designs warrants the production of this manual for future reference.

First, an overview of safety protocol is given. The second section aims to describe how the parts were made. For instance, a short guide to laminating a composite and instructions for preparing files for 3-D printing are included. The last section gives a simplified step-by-step process to construct the GEM.

2 Health and Safety Information

2.1 Gluing and Laminating: Chemicals

Before opening any containers, put on safety glasses and gloves. Wearing protective equipment prevents any irritation on skin or in eyes in the event of a spill. Perform the tasks requiring these materials in a well ventilated space and with some material underneath the object being glued or varnished to separate the work area from the surface of the table or work bench. In the case of a spill, clean up the affected area immediately, first with water-soaked paper towels to pick up the bulk of the material and then with alcohol to remove the remaining residue from the affected surface. For more information, see the American Chemical Society safety information [1].

2.2 Cutting and Sanding: Particulates and Moving Parts

Before cutting or sanding any material, one must learn how to properly wear a respirator with the correct filters. This can be achieved through a respirator certification course, which must follow the guidelines outlined by the Occupational Safety and Health Administration (OSHA) [2]. Along with a respirator, safety goggles that seal on a user's face must be worn at all times. In the event of debris flying around, it is better to be covered with dust than for an eye being cut. For a similar reason, gloves, long sleeves, and long legged pants must be worn to prevent skin being irritated or cut. Since power tools are used to cut and sand, closed toed shoes and ear protection must be worn at all times. For more information about power tool safety protocol, visit OSHA's booklet on hand and power tools [3]. Whenever cutting a material with power tools, use clamps to hold it down. This allows one to use both hands to keep the tool steady as the job is performed.

3 Component Construction

3.1 Support Frames

To effectively reduce the material in the active region of the prototype GEM, the dedicated drift and R/O PCBs were replaced with separate GEM-like foils. The PCBs were 3 mm in this case, which increased the likelihood of incident particles being absorbed and scattered in the active tracking region. Instead, the drift and R/O structures were printed on 50 μm KAPTON foils and two 4 mm thick CFFs were implemented for mechanical support [4]. CF was utilized because of the high tensile strength associated with it.

Any composite consists of two phases, reinforcement material and a matrix [5]. The reinforcement is the source of the strength of a composite. In the case of the support frames, IM7 unidirectional and 090 woven CF are the CFF reinforcement material. Contrary to the reinforcement is the matrix. A matrix binds the reinforcement material and holds it in place. This is what brings a composite back to its original shape after being bent. For the CFFs, Araldite epoxy was used as the matrix. For more information on the physics of composites, read F.C. Campbell's chapter on composites [5].

To make a composite, it is recommended to construct a mold out of laminated plywood, styrafoam, or plastic. In the case of our GEM prototype, two rectangular planks of laminated plywood with trapezoidal arrangements of 60 pairs of 2.5 mm holes were used to make the support frames. Carbon steel rods were placed in the holes to form holes in the frames. Once a mold is made, strips of the material used to make the composite are cut to be laminated together around the mold. With the EIC GEM, the frames were made out of seven layers of IM7 CF with one layer of 090 CF sandwiched between the third and fourth IM7 layers to act as a backbone. For the drift frame, each layer consisted of two 1.02 m strips for the sides, one 0.6 m strip for the wide end, and one 0.1 m strip for the short end. The width of each strip was $\sim$50 mm. As far as the R/O frame was concerned, the only strips that were different were the ones for the wide end with widths of 0.21 m.

After cutting the strips of material, the matrix was constructed. The EIC GEM prototype used Araldite epoxy, so a 3:1 epoxy to hardener ratio was utilized in a similar way to Amilkar Quintero's gluing of inner frames [6]. However, the ratio was taken between volumes of epoxy and hardener instead of mass. Two laminated paper quart containers were used to seperately measure out epoxy and hardener, and another was used to mix the two. Wooden mixing sticks were used to scoop out epoxy and hardener and mix the two together. Mixing up the glue was done when it was a milky white, pale yellow color and was hard to mix.

Each frame was constructed using a bottom-up lamination method. First, a layer of glue was painted on the mold. Next, the first layer of CF was placed on the glue so that the pieces did not overlap, but rather butted-up against each other. Afterwards, more glue was painted on top of the first layer. Each layer that followed alternated this "butting-up" method so that the thickness of each frame was uniform even in the corners of the frames. Once all eight layers of material were laminated together with the glue, blotting material was placed on top to soak up the excess glue followed by a porous laminated sheet and another sheet of blotting material. Along the edge of the mold was a rectangle of tacky-tape on top of which was stretched and attached a sheet of plastic that covered the frame to make a vacuum cure for the composite inside. A hole was cut in the middle of the plastic sheet and a port connected to a vaccuum pump was attached over the hole. The pump was turned on, and all of the air in the temporary chamber was sucked out.

Once the curing process was completed, each frame was trimmed. The drift frame was cut so that the width, centered on the holes, was $\sim$35.5 mm. On the other hand, the R/O frame was cut so that the width of the sides and small end was the same as the drift frame and the distance from the holes and the inner edge of the wide end was $\sim$17.75 mm. Afterwards, the frames were sanded. Trimming and sanding were done using an angle grinder with a ceramic cutting disk and sanding attachment.

3.2 Pull-out Parts and Inner Frames

Instead of machining stainless steel pull-out parts and laser-cutting inner frames out of FR-4, 3-D printing was utilized to reduce the cost and outsourcing. One part file was needed for the pull-out parts whereas nineteen were used to print the inner frames. The reason so many files were needed for the inner frames was because of the full length of the parts, the largest $\sim$1 m, compared to the printing area, 200 mm x 200 mm. White ABS material was used to print all of the parts.

The first step to having a part 3-D printed is to design the part in a modeling program such as Inventor Professional or SolidWorks. Next, one exports the file as the stereolithography (STL) file format. This holds a 3-D image of the design that can be printed using a 3-D printer. When exporting an STL file, check which units the model is being exported in and make sure that they correlate with the units being used.

3.3 Outer Frame and Foils

The outer frame was laser-cut out of halogen-free FR-4 material at CERN in Geneva, Switzerland. The GEM and R/O foils were also made at CERN, and instead of making a drift foil the team making the foils sent a faulty GEM to be used as a drift. To make the GEM into drift, a small foil was designed in which the redundancy of the pads was broken to allow for an extra pad for the GEM drift. The flexible circuit is being made at CERN.

4 Detector Construction

4.1 Preparation of Outer and Support Frames

1. Drill 4 holes in the outer frame for gas ports
   (a) Dremel handheld drill, 3 mm bit
   (b) One at each side near small end, one at each side of wide end to make distribution of gas more uniform
2. Tap holes with M3.5 tap
3. Varnish outer frame with Nuvovern
   (a) Carefully remove o-ring from each groove
   (b) 3:1 mixing ratio by mass
   (c) Wipe off excess varnish and clean out holes
   (d) Hang up to air dry for $\sim$24 hrs using one zip-tie (Fig. 1)
4. Reinstall o-rings
   (a) If needed, cut o-ring to shape and use polyurethane adhesive to attach the ends together
5. Glue 1/8” gas ports in each hole (Fig. 3)
   (a) Mix up Araldite glue (Fig. 2)
   (b) Place glue on gas port thread
   (c) Carefully use a wrench to tighten the gas port
   (d) Repeat (b) and (c) for the remaining ports
6. Attach the gas ports to two 1/4” male connectors, one on each end

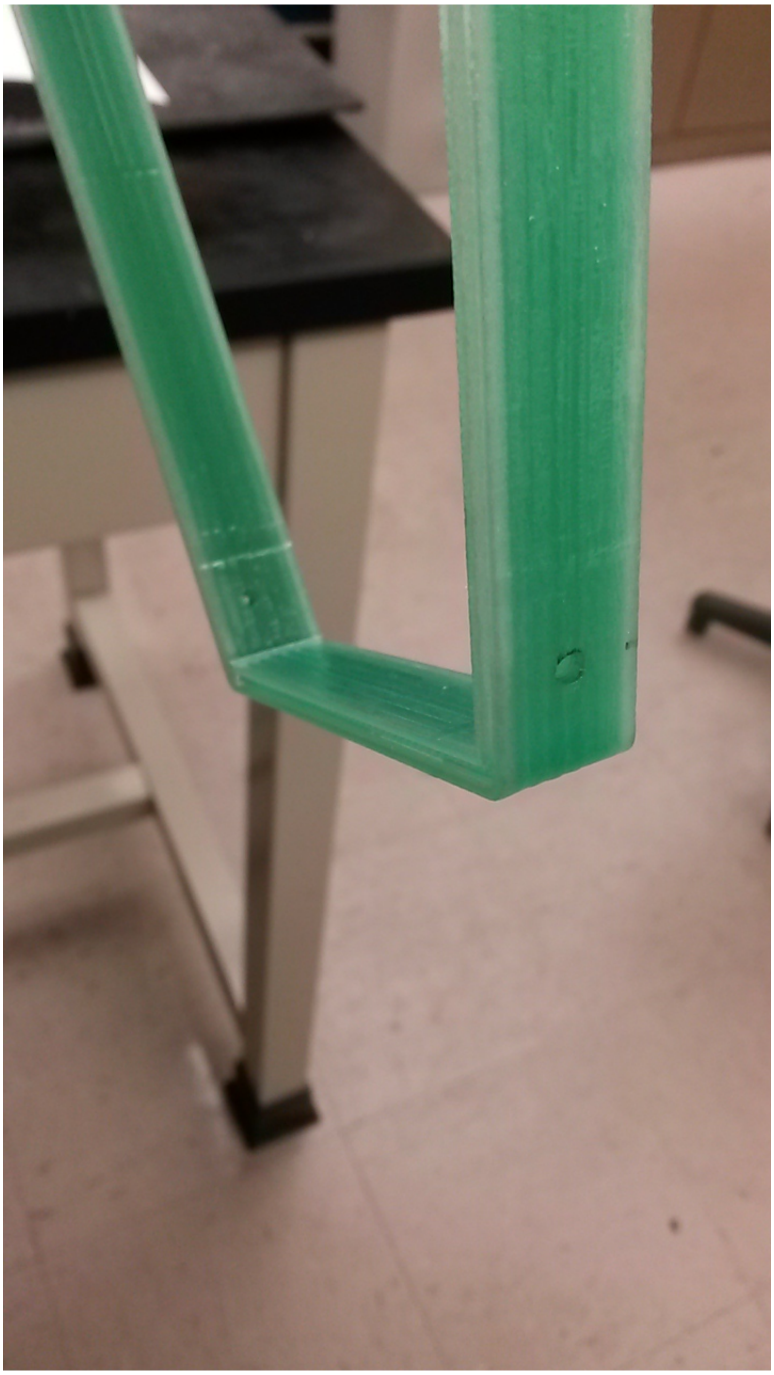
Figure 1: View of small end of outer frame as it air dries

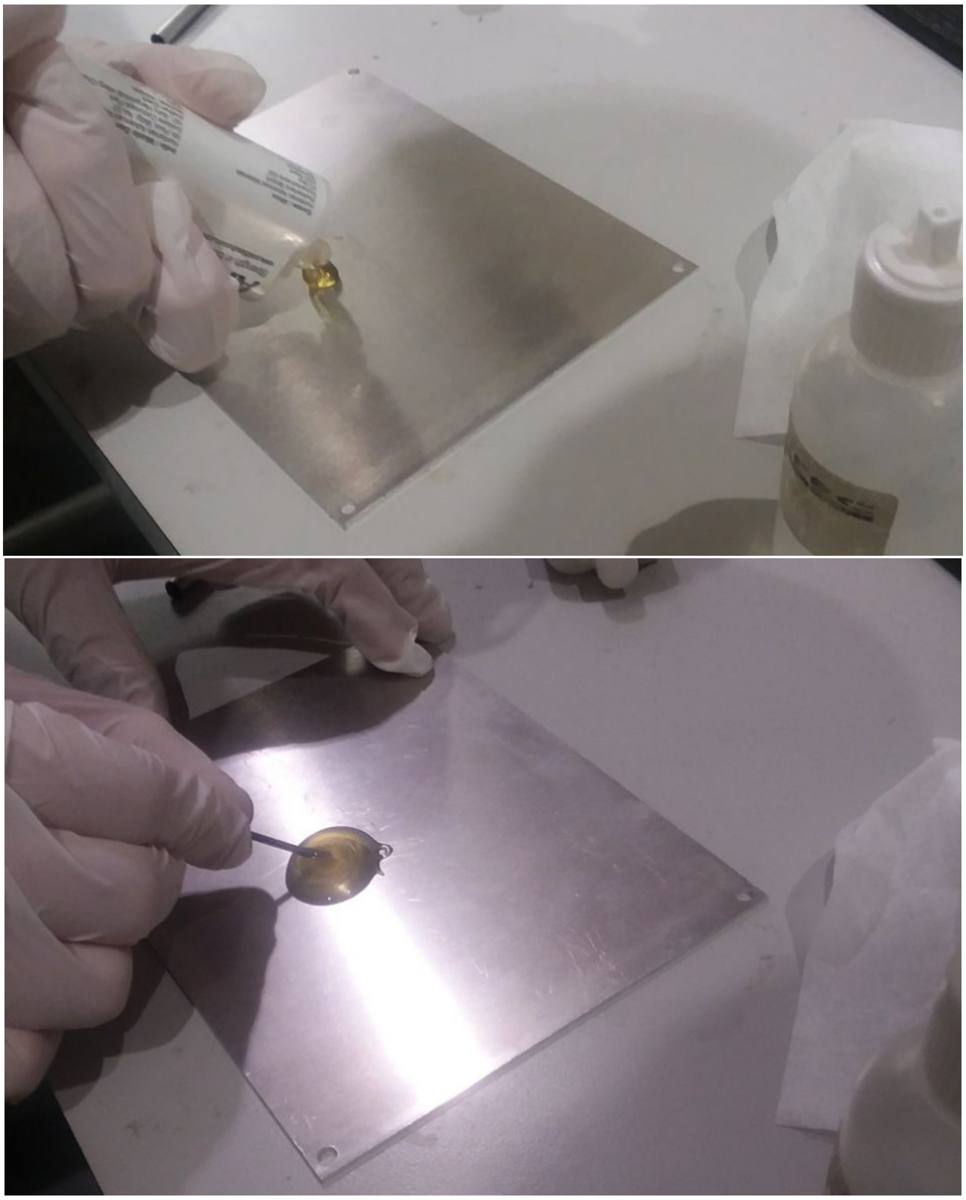

Figure 2: Top: squeezing out Araldite using double cylinder syringe, epoxy in one cylinder and hardener in the other; Bottom: mixing epoxy and hardener

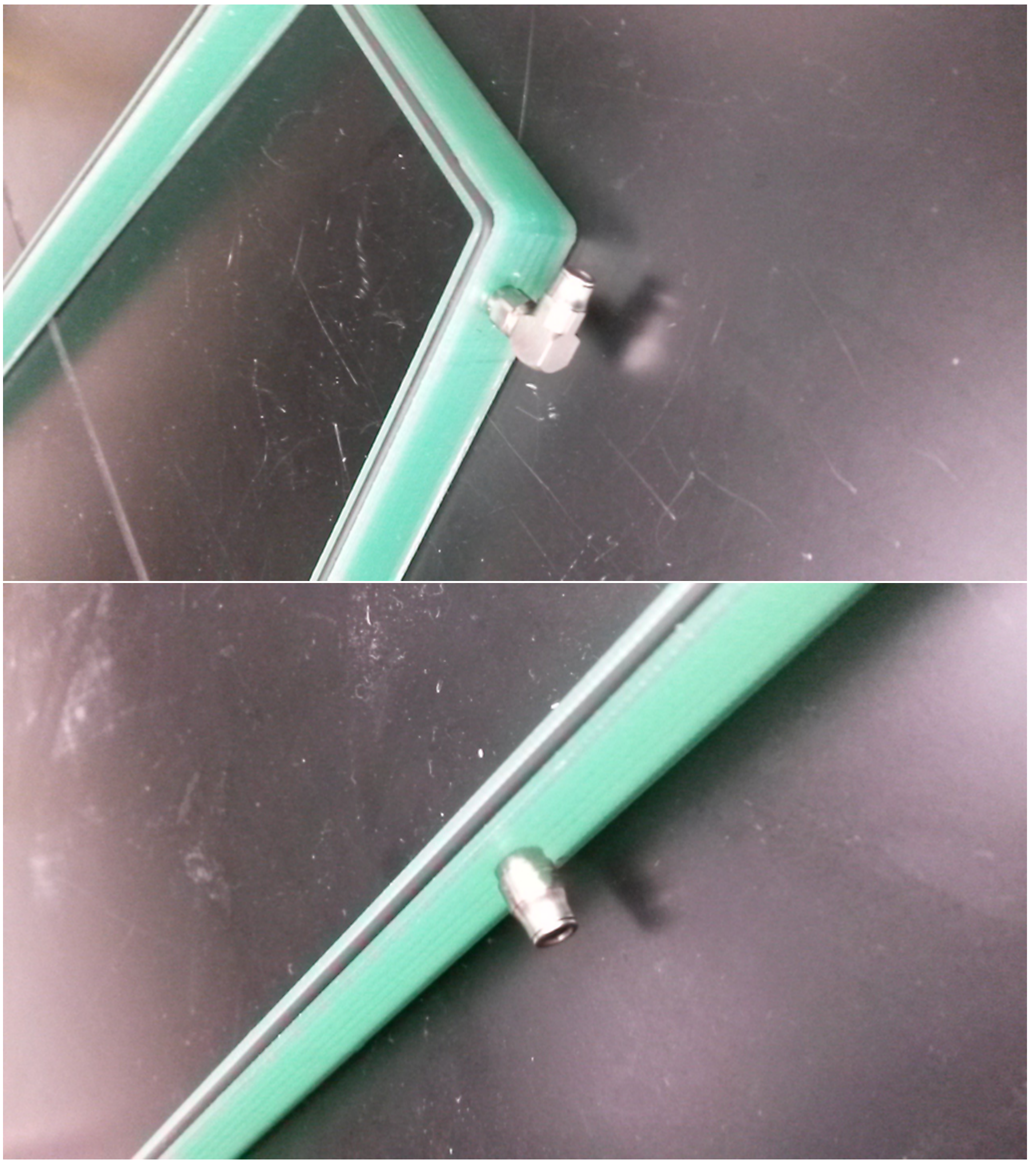

Figure 3: Top: elbow port glued in hole on short end; Bottom: straight port glued in hole on wide end

(a) Cut two pieces of 1/8" tubing, each 25-30 cm long, for wide end and two ∼5 cm long tubes for short end

(b) Attach tubing to 1/8" female adapters

   i. Check that a washer with a central ledge and a cone on top of the ledge are in the adapter, if not replace

   ii. Slide tube through adapter so that the short end is inside the adaptor portion

   iii. Attach adapter to male connector

   iv. Tighten with wrenches

(c) Attach adapters to 1/8" T-connectors

(d) Attach T-connectors to 1/8"-1/4" transition piece on each end

   i. Cut a small portion, 1-2 cm, of 1/8" tubing

   ii. Attach female 1/8" adapters to each side of tubing to make an extension

   iii. Attach extension between 1/8" T and 1/8"-1/4" transition piece

(e) Cap each end

7. Varnish each support frame (Fig. 4)

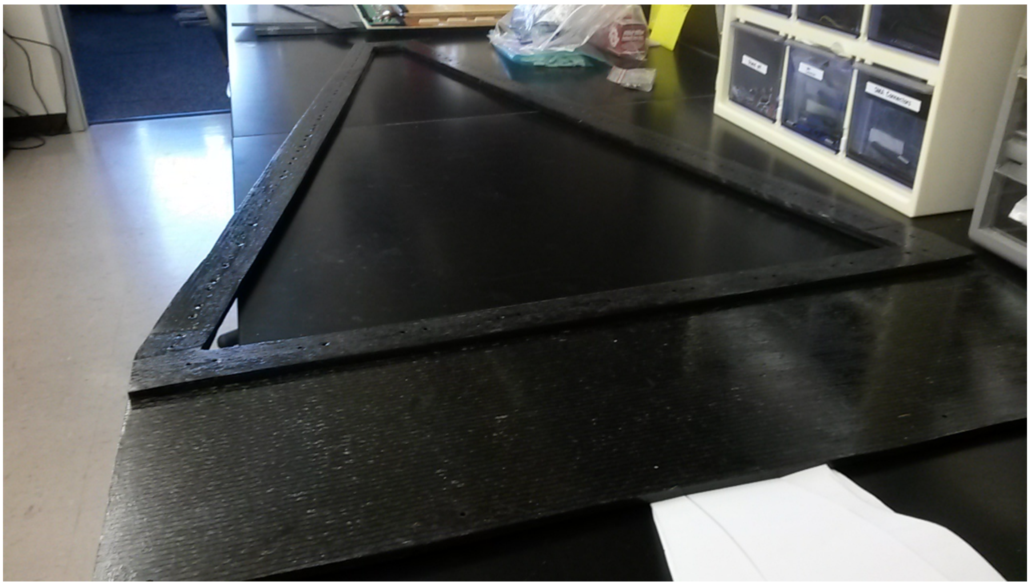

Figure 4: View of support frames once varnished

8. Make aluminized (Al) KAPTON window on each support frame (Fig. 9)

(a) Cut 80 cm long sheet of 1.5 wide roll of Al KAPTON

(b) Stretch and tape down Al KAPTON sheet on work table, Al side faced downwards (Fig. 5)

(c) Mix up Araldite glue (Fig. 2)

(d) Place line of glue on rough side of support frame between holes and inner edge (Fig. 6)

    i. For a more accurate line of glue, use a pressurized gluing station

(e) Carefully place glued porsion of support frame on stretched Al KAPTON

(f) Place 5-7 kg weights on top of the frame around the perimeter (Fig. 7)

(g) Dry for $\sim$24 hrs

(h) Remove weights and cut off excess foil

    i. Fold down foil close to where it was glued down
    ii. Carefully use an Exacto knife to cut along that line
    iii. Repeat (i) and (ii) for each side of the frame

(i) Touch up glue work if neaded to close gaps, clamp glued area, and repeat (f) (Fig. 8)

4.2 GEM Stack Construction

Note: As of Fall 2017, only a mock-up of the actual GEM stack with paper foils has been constructed.

1. Attach M1.6 screws to flat 2 mm inner frames that come before drift foil
2. Attach drift foil to screws, pads facing downwards
3. Attach 3 mm inner frames to screws
4. Attach GEM 1 foil to screws
5. Attach 1 mm inner frames with cuttouts to screws
6. Attach GEM 2 foil to screws
7. Attach 2 mm inner frames with cuttouts to screws
8. Attach GEM 3 foil to screws
9. Place M2.5 nuts into inserts around border of stack being constructed

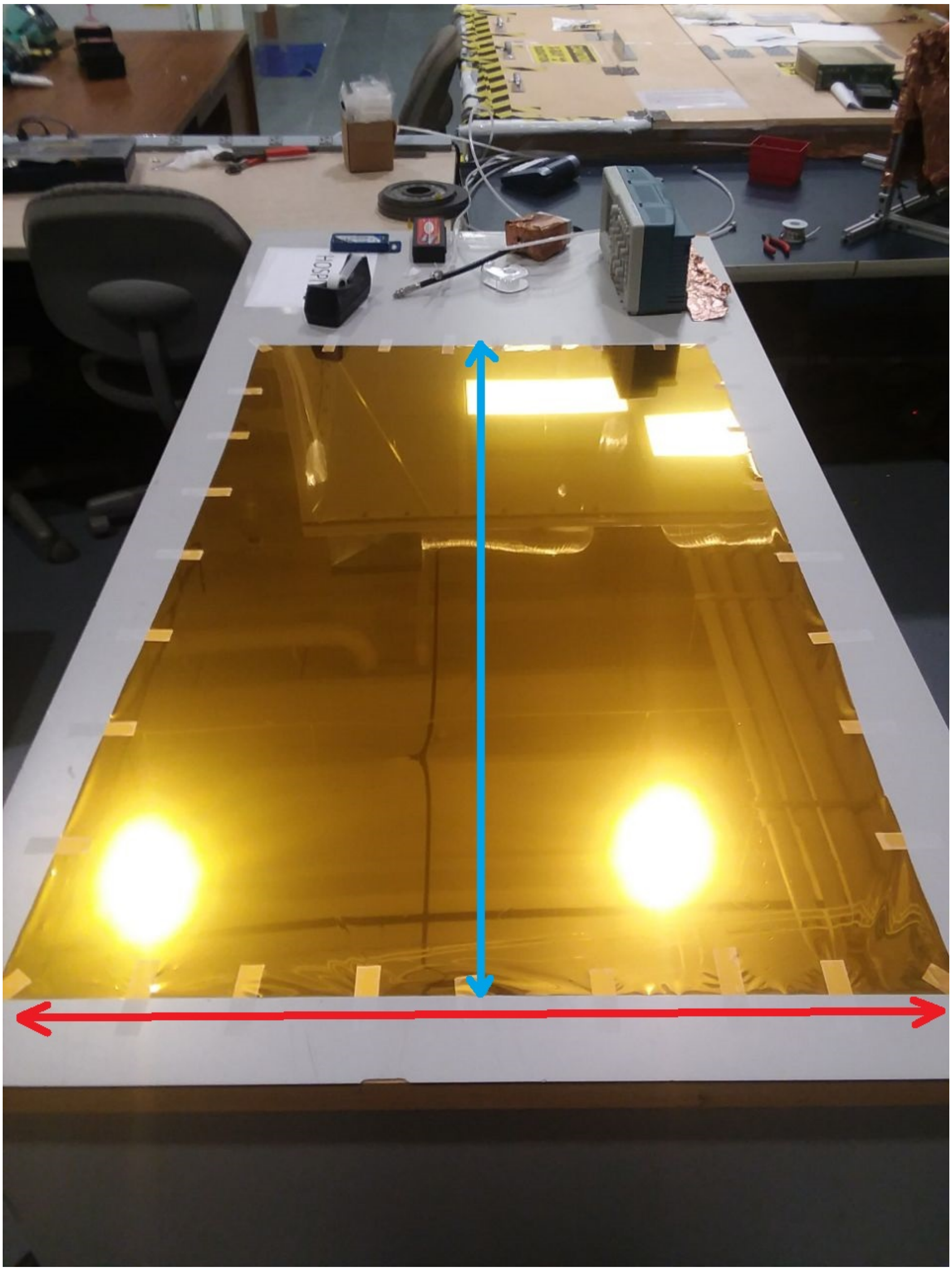

Figure 5: Stretched and taped down Al KAPTON foil, 80 cm (red) by 1.5 m (blue)

Figure 6: Applying glue on the support frame using a brush

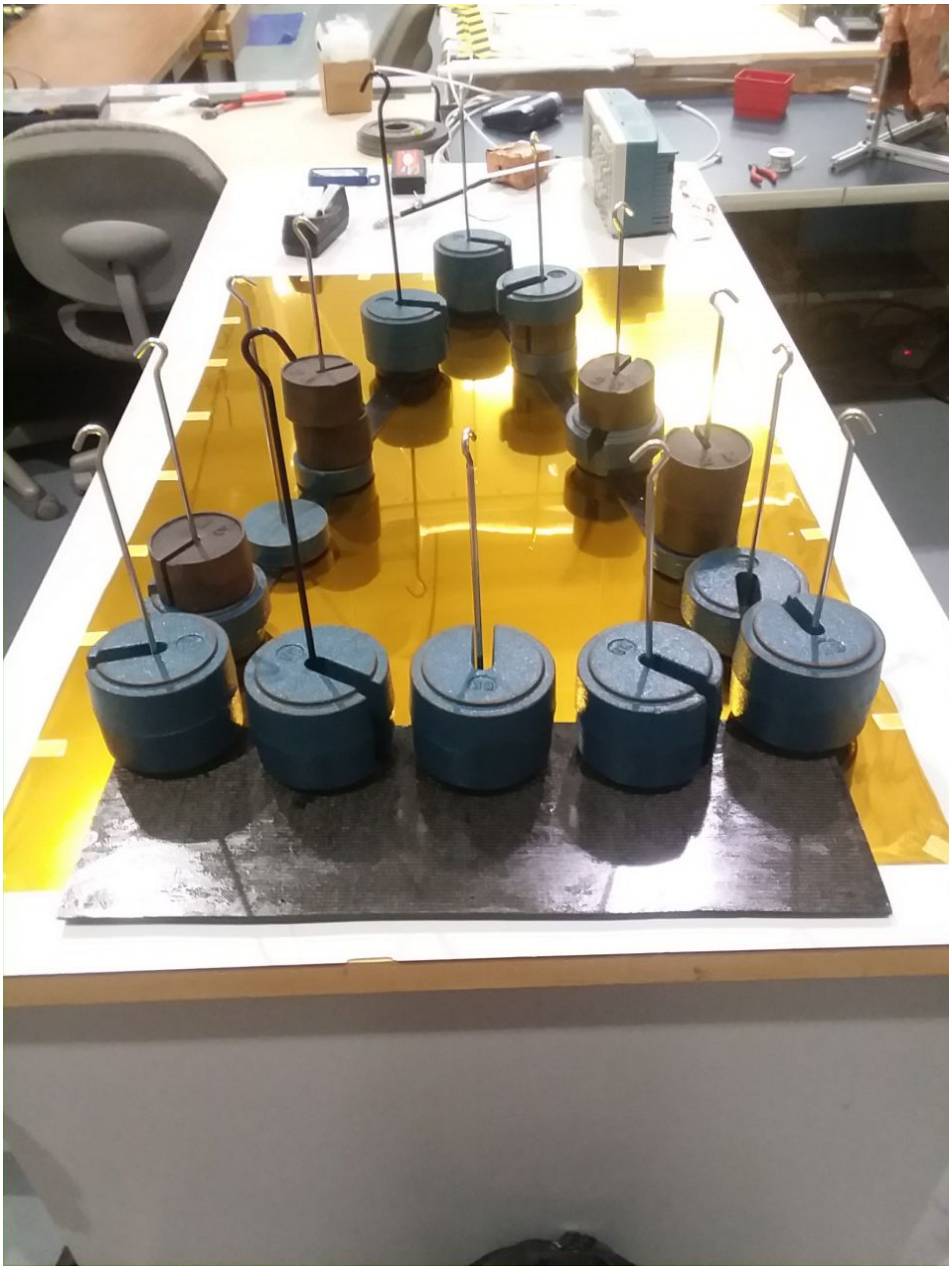

Figure 7: Weights placed on frame on top of Al KAPTON foil

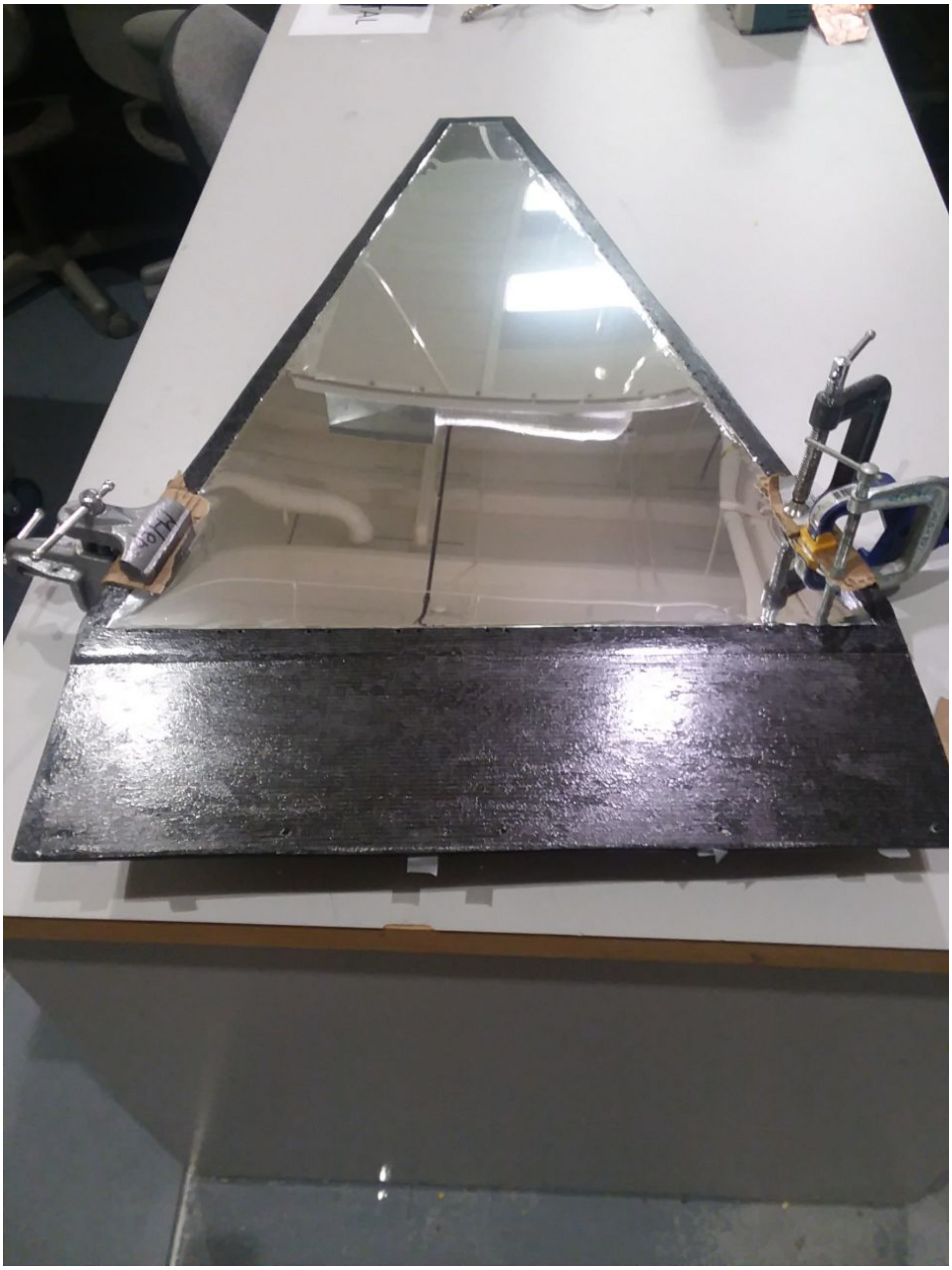

Figure 8: Touched up glue job, held in place with clamps

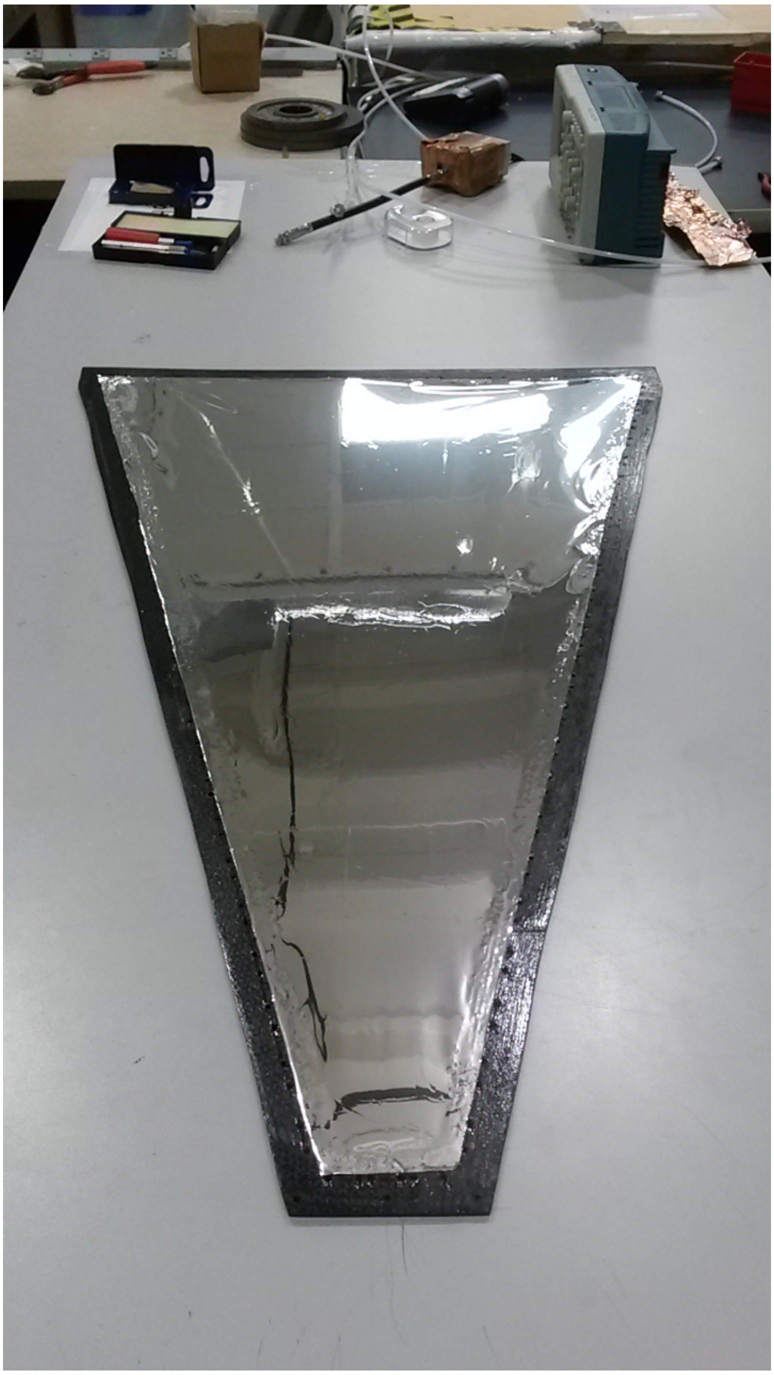

Figure 9: Al KAPTON foil on drift frame, view of how finalized job should look

10. Attach flat 1 mm inner frames to screws
11. Attach R/O foil to screws
12. Attach flat 2 mm inner frames to screws
13. Attach M1.6 nuts to screws and tighten

4.3 GEM Construction

Note: As of Fall 2017, the full GEM has not been constructed. This section is a plan for what will be done.

1. Tap holes on ends of pull-out parts with M2.5 tap
2. Attach pull-outs to drift frame
    (a) Put plastic washers on every M2.5 screw (illustrated in bottom of Fig. 10)
    (b) Place M2.5 screw through one hole in frame
    (c) Attach to pull-out such that indent in part faces outwards (top of Fig. 10)
    (d) Attach another screw to pull-out
    (e) Repeat (b)-(d) for remaining pull-outs
3. Glue small foil for making a GEM into a drift to drift frame
    (a) Mix up Araldite glue (Fig. 2)
    (b) Glue KAPTON foil down to insulate small foil
    (c) Glue small foil down on top of KAPTON insulation such that traces and pads face upwards
4. Solder HV pins to pads (left-to-right order if facing frame from small end)
    (a) Two for GEM 3 (longest), two for GEM 2 (second-longest), one for GEM1 (second-shortest), one for drift (shortest)
5. Carefully attach GEM stack to pins so that drift faces down
6. Attach GEM stack to pull-outs with M2.5 screws (attachment of inner frames to pull-outs illustrated in top of Fig. 10)
    (a) Attach screws by opposite corners, then ends, then sides

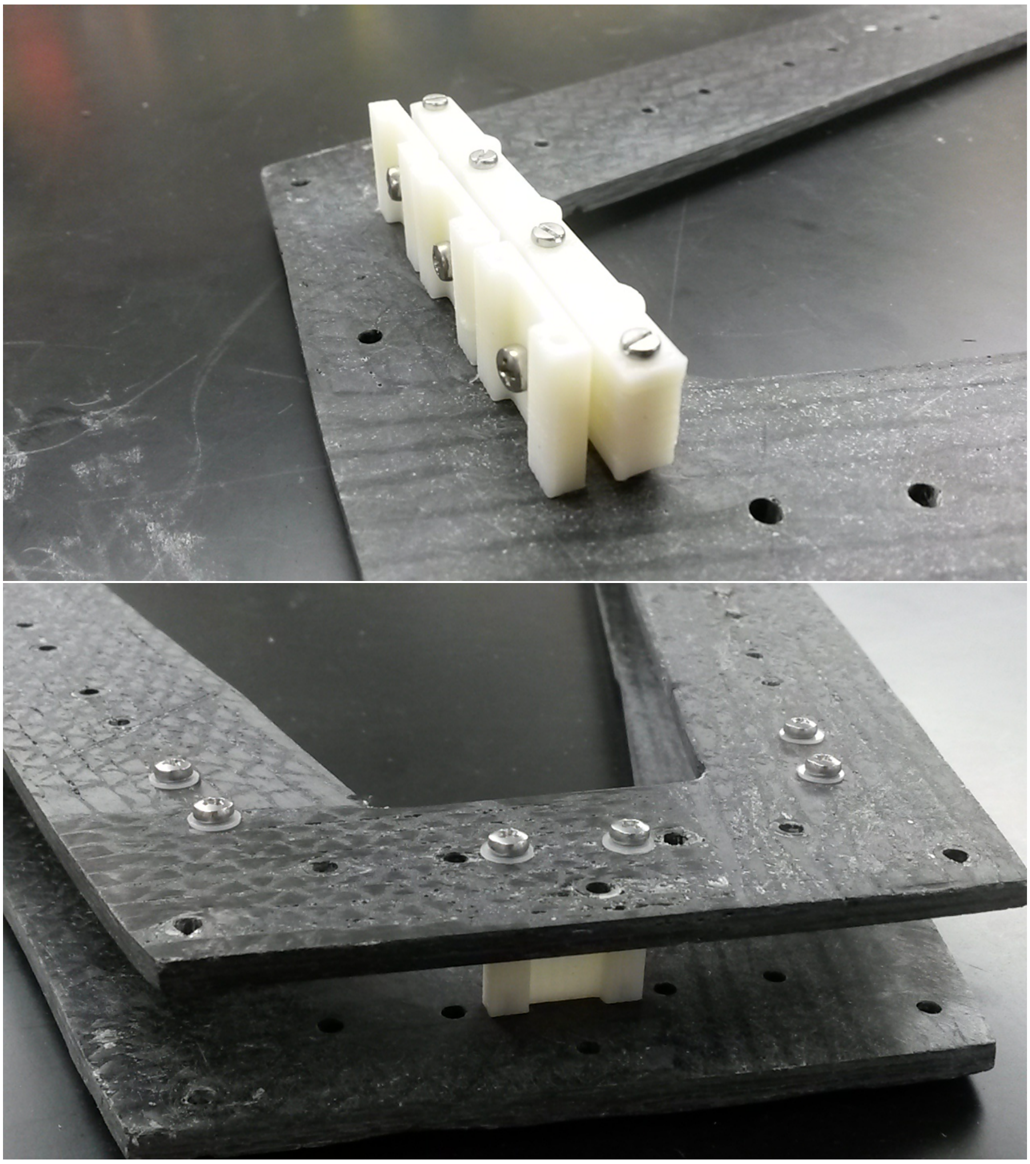

Figure 10: Top: view of proper orientation of pull-out parts on small end with inner frame assembly attached to pull-outs via M2.5 screws; Bottom: support frames attached with various pull-outs, plastic washers on M2.5 screws

7. Lift up end of R/O foil and place down outer frame
8. Attach R/O frame to pull-outs using M2.5 screws with plastic washers
9. Carefully flip assembly
10. Glue down end of R/O foil to R/O frame using Araldite

5 Conclusion

After constructing the GEM, various quality control (QC) tests will be done to determine how well the detector was made. Following these QC tests, the detector will undergo a beam test at Fermilab. This will show how fine the resolution of the GEM is. Once the GEM passes all of these tests, it will be a prime candidate for installation in the upcoming BeAST detector for the EIC project.

References

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