Fermilab

DRAFT

Particle Physics Division
Mechanical Department Engineering Note

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Project Internal Reference:

Project: NIU/PCT

Title: **NIU PCT Fiber Tracker Planes**

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Key Words: SiPM, Scintillation Fibers, Carbon Fiber, RohaCell 31,

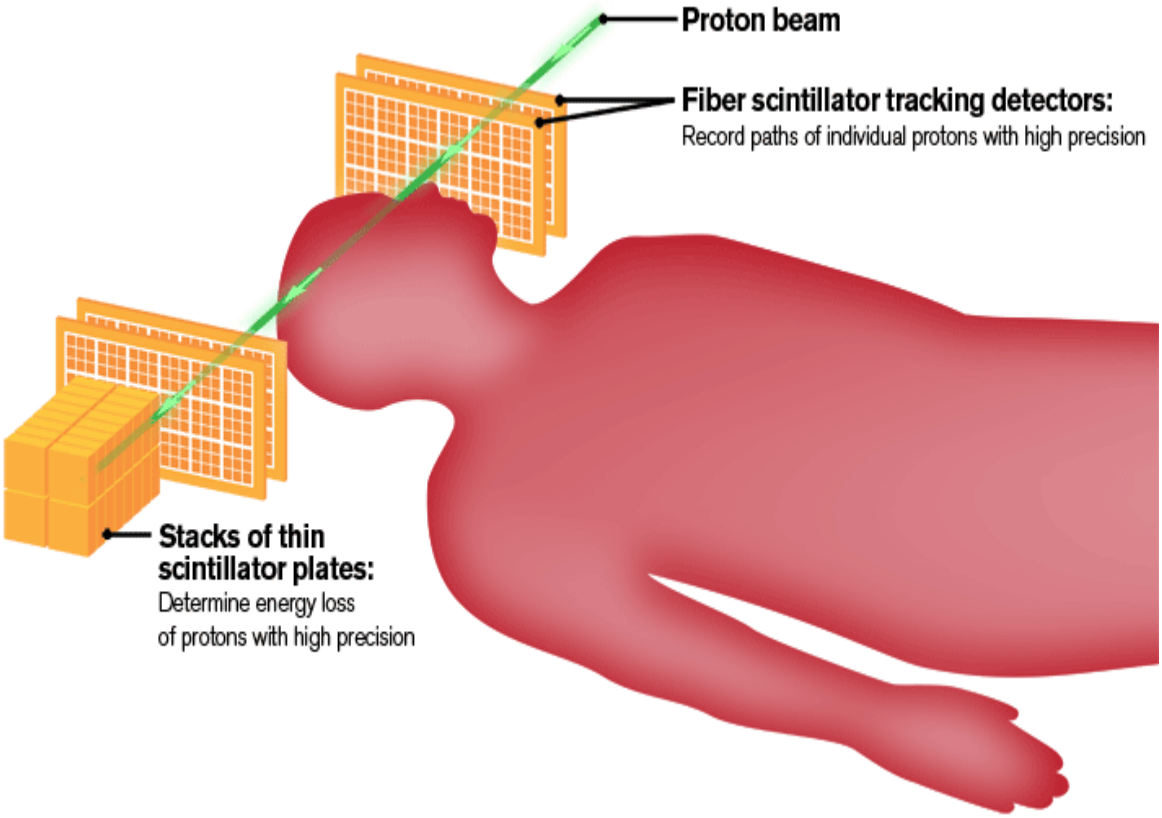
Abstract Summary:

Collaboration with national laboratories *Credit: symmetry*

Four years ago, NIU joined collaboration between the University of California, Santa Cruz and the proton treatment center at Loma Linda University Medical Center, a pioneer in the field of proton therapy, to build and test a first-generation proton system. The prototype system allowed the team to demonstrate the advantages of a proton CT scan.

Now the NIU team is working with Fermilab and Argonne on a second-generation model to adapt the technology for clinical use. This new collaboration, which also has international participants from the University of Delhi in India, is aimed at bringing the technology much closer to clinical utility, which requires large-area detectors, shorter scan times, and faster image reconstruction.

Scientists at NIU and the two Department of Energy national laboratories are building a next-generation detector and imaging system that will be able to scan and reconstruct an area comparable to the size of a human head in 10 minutes, making it clinically useful. Fast data acquisition and image reconstruction are the two main focuses for the collaboration.

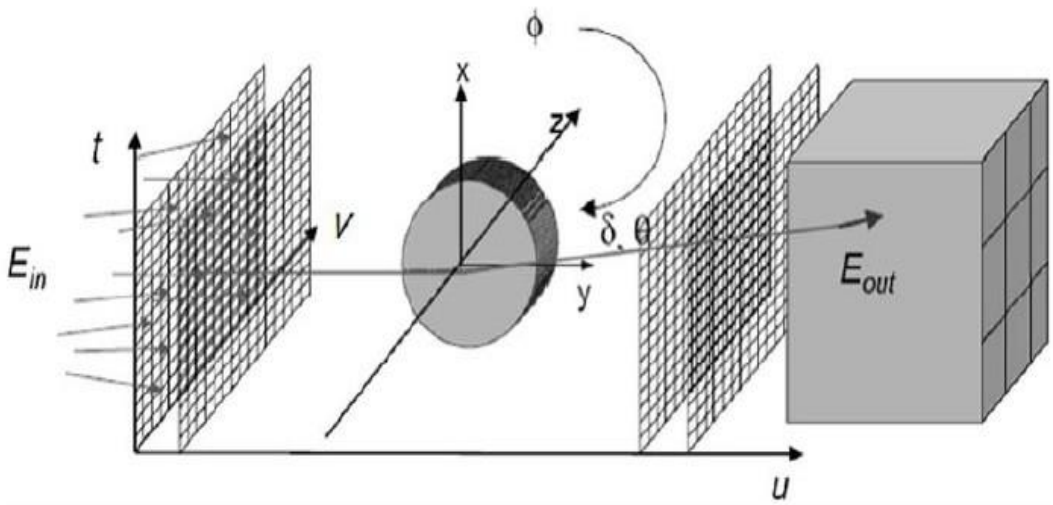


Proton CT scans have the potential to create more precise maps of a patient's body. Fiber scintillator tracking detectors placed next to the patient precisely record the protons' paths. Stacked scintillator plates measure the energy loss the protons experienced while traversing the patient, which yields information on the body density that the particles encountered. A computer then uses the data to reconstruct the location of tumors, organs, and tissue.

"This is the first time we are trying to build a tracker with SIPMs to read out the data," says Peter Wilson, a physicist leading the effort to build the proton tomography detector at Fermilab. "It's a step toward what we will do in the future for high-energy physics experiments, and there is a lot we can learn from assembling this first detector."

Credit: symmetry

Mechanical Tolerance Specification for the NIU PCT Fiber Tracker Planes



Medical Imaging Vectors *Credit: Vishnu Zutshi*

Mechanical Tolerance Specification for the NIU PCT Fiber Tracker Planes

Version 3.0
18 January 2013

George Coutrakons, Peter Wilson and Vishnu Zutshi

1. These tolerances refer to the requirements for a doublet x-y views. Each view (x- or y) consists of two layers of fibers with a ½ layer offset between them. The fibers will be read out in triplets combining two adjacent fibers from one layer and the one in the adjacent layer that is closest to both of these. Adjacent triplets alternate as to which layer has two fibers.

2. Fibers within a layer – over active length
   - Single fiber straight to 0.1mm rms
   - Fiber to fiber distance – 0.1mm rms
   - Adjacent fibers parallel to 0.1mm

3. Assembled plane
   - Planar to 1.0mm rms

4. Between x and y planes in a doublet
   - Angle between x and y axes 90° to 15arc min (4mrad)

Introduction:

National laboratories are not strangers to proton therapy. Fermilab's first director, Robert Wilson, wrote the seminal paper in 1946 showing that protons could be an effective method for treating cancer.

While at lower doses both X-rays and protons can be used to image the body, at high doses, Wilson noted, they both can be used to destroy a tumor. But they differ in the way they work.

When an X-ray moves through the human body, it leaves energy deposits along its path. As a result, the X-rays affect not only the tumor but also any organs or tissue they travel through along their way, leading to potential damage to healthy body parts and increased side effects. A proton, however, releases the majority of its energy at the end of its path, making it a perfect precision tool for physicians. By adjusting the speed of the proton, a physician can pinpoint where it deposits its energy to kill the tumor—and only the tumor. As a result, for certain kinds of cancers, such as brain tumors and pediatric tumors, proton therapy can be a better option than traditional X-ray radiation.

The first proton therapy patient was treated in 1954 at Lawrence Berkeley National Laboratory's 184-Inch Cyclotron accelerator. In the 1960s, scientists at the Harvard Cyclotron, another accelerator originally designed for physics experiments, began using proton beams to precisely target tumors with minimal impact on the surrounding organs.

Since then, protons have been used as the optimal way to treat certain kinds of cancer; nine proton therapy centers currently offer the treatment in the United States, and more centers are under construction and planned. *Credit: symmetry*

Design Criteria:

Rigidity of Frame:

Carbon Fiber (CF) 0.250” (+/- .015”) x 24” x 24” (+/- .250”) All Unidirectional, Laminate 250 Deg. Cure, 30 MSI Carbon Fiber Epoxy PrePreg., 0/90 & +/- 45 Lay was chosen as main structures do to its CTE, and Modulus structure. Manufacture: Aerospace Composite Products. Supplier of CF Sheet Stock.

Least Mass in the aperture:

RohaCell 31 Polymethacrylimde (PMI) Ridgid Foam Sheet. Which is the lowest density grade density(p_= 0:032 g/cm3) and displays very high strength:weight ratio.

Kuraray Scintillation Fiber; SCSF-3HF(4500)M, 0.5mmD, 0.55m, CJ, S-type fiber Core, Polystyrene CTE 6-8*10^(-5), Inner cladding Polymethylmethacrylate CTE 6-7*10^(-5), Outer cladding Fluorinted polymer CTE 6-7*10^(-5).

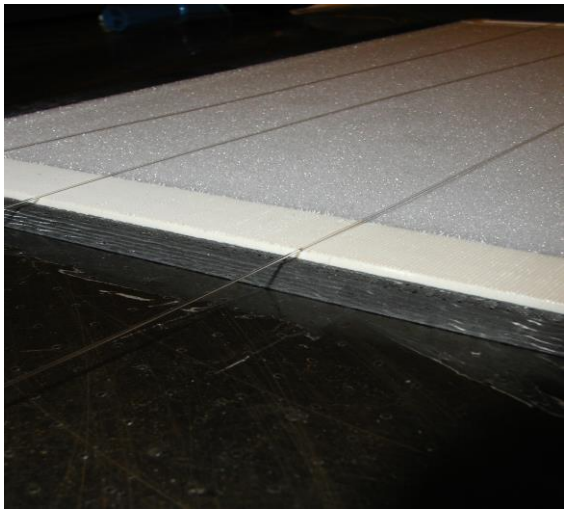
3M Spray; 200 - 5000 cps, Solids by weight 36 - 38%, Base; Synthetic elastomer.

Ren 6400 Polyurethane, Diphenylmethane,/C_{15},H_{10},N_2,O_2.

Stable alignment features:

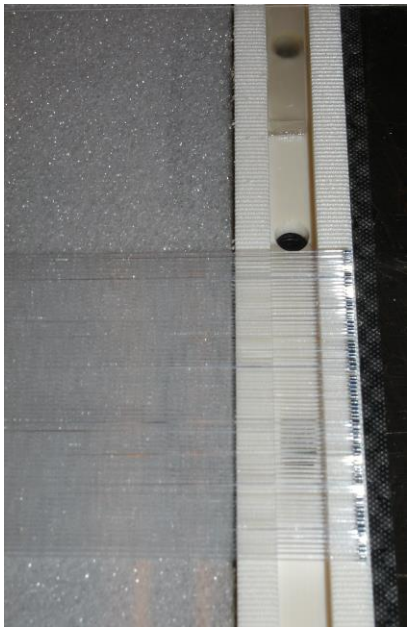
Techtron (PPS Polyphenylene Sulfide) plastic; Density 135 kg/m^3, Water absorption (24hr/73'f) 0.03%, Modulus 3.45e9 Pa, CTE 2.3 X 10^{-5} PPS products ideally suited for precise tolerance machined components. They have no known solvents below 392°F. Minimal moisture absorption and a very low coefficient of linear thermal expansion.

Materials in Frame:

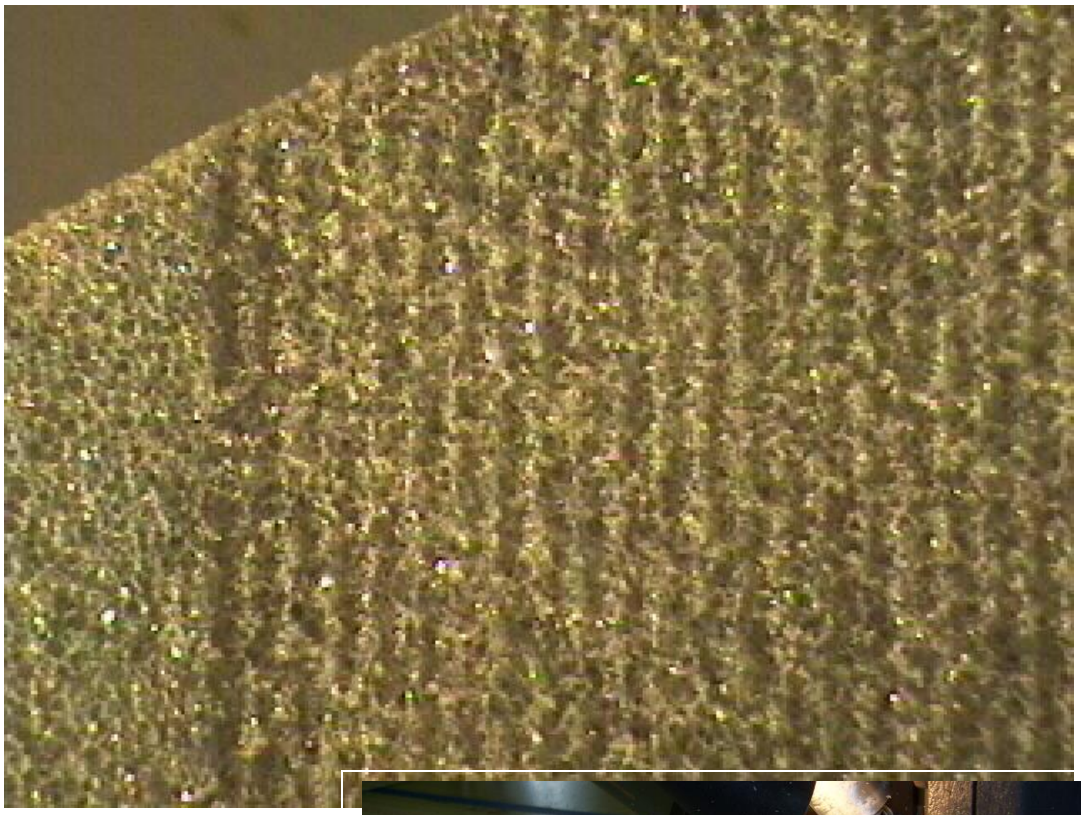


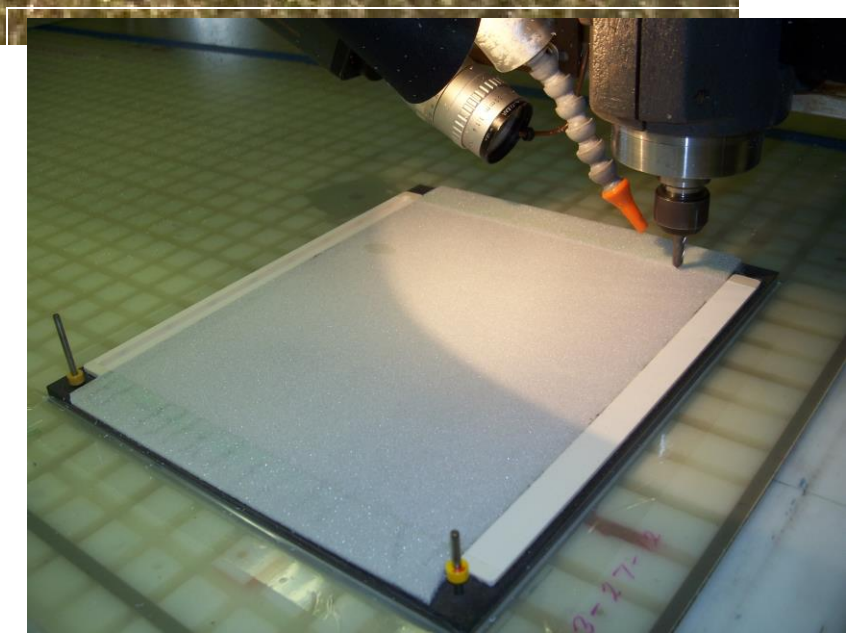
Photos showing materials. Carbon Fiber Frame, Techtron and Rohacell V-Grooved with Scintillation Fibers randomly laid out, left image.

Image right, shows Scintillation Fibers at end of Detector, note Mirrored fiber ends. This feature aids in light yield, with reflective feature. V-Grooved Techtron has recess which receives segmented Lexan. Each segment will have UV LED inserted in holes, to flash UV light to QC fibers and channels of SiPM before and at close out of Beam.



Materials in Aperture: V-Grooved Rohacell





V-Grooving of Rohacell at Lab8's CNC Thermwood, shows routing through both white Techtron bars and Rohacell.

Image above shows V-Groove detail with Microscope. Pitch is 0.625mm.

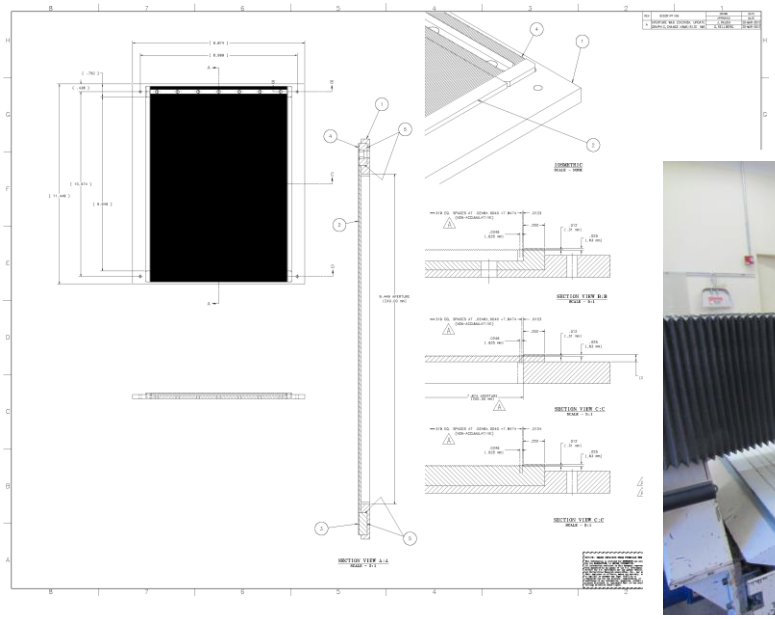
During each step: Weigh assembly and make note in Travelers for each detector plane.

Component Parts: We will require a total of: 2 each Carbon Fiber Frames

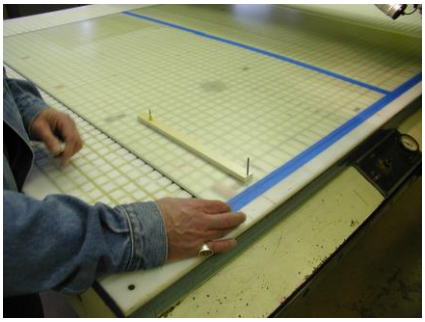
This assembly procedure is to be used as a guideline for assembling the Detector;

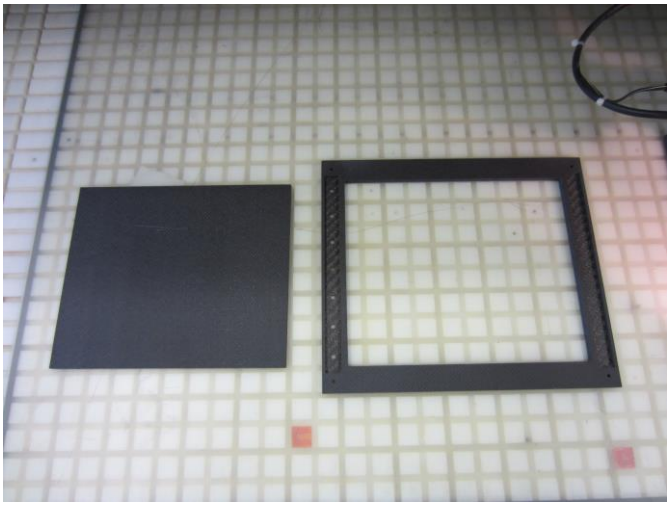
Carbon Fiber Frame will be Routed at Lab8 on the CNC Thremwood. *.stp files are electronically transferred to facility, critiqued for optimum machine path routing and then stored on components main control PC/CNC. MD-489579, 489581, 489660, 489661

Sheet stock Carbon Fiber and Techtron bars are placed on Vacuum Table of Thermwood.



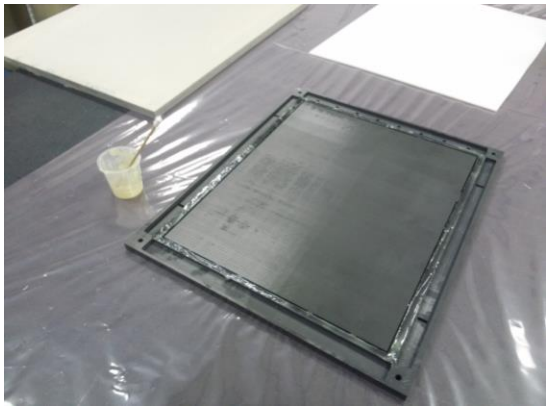
Lab8 also CNC/Routes Techtron bar stock to dimension. MD- 48xxxx, xxxxx, xxxxx xxxxx.





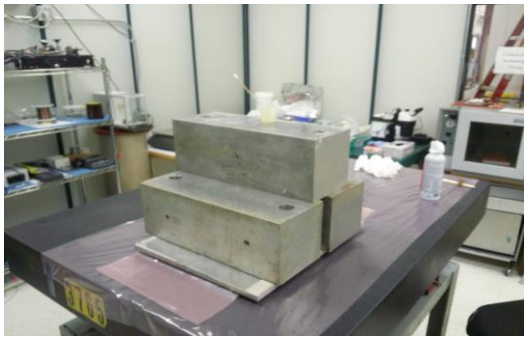
Carbon Fiber Frame and aperture cut out are then taken to Lab3 Cleanroom to prepare for RohaCell 31 Foam and Techtron Bars to be epoxied as a subassembly. MD-489579

Once materials from Lab8 are introduced to Lab3's environment, they are thermally stabilized over night to Humidor Room's Temperature and Humidity. This is a critical component in the design criteria to maintain design tolerances.

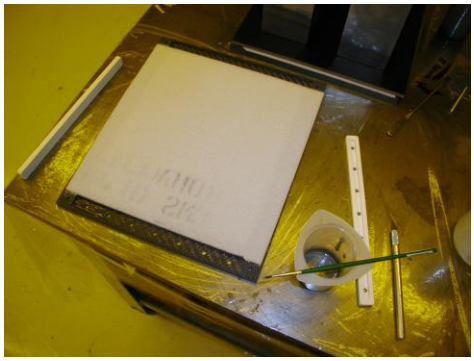


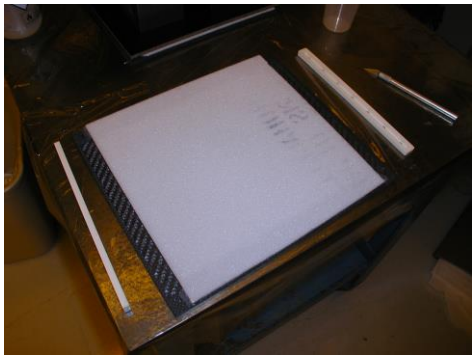
On a granite surface plate Carbon Fiber Frame is placed in proper orientation along with aperture cut-out. This cut-out maintains elevation of RohaCell 31 foam, during epoxy lay-up. EpoTek EP-730 cut with alcohol to lessen the CP, allows epoxy to bond with the two surfaces more readily.

After EpoTek EP-730 epoxy is applied to both surfaces, an aluminum JigPlate with Teflon tape applied to bottom surface is positioned over RohaCell.



Weights added, 24hr/overnight cure.





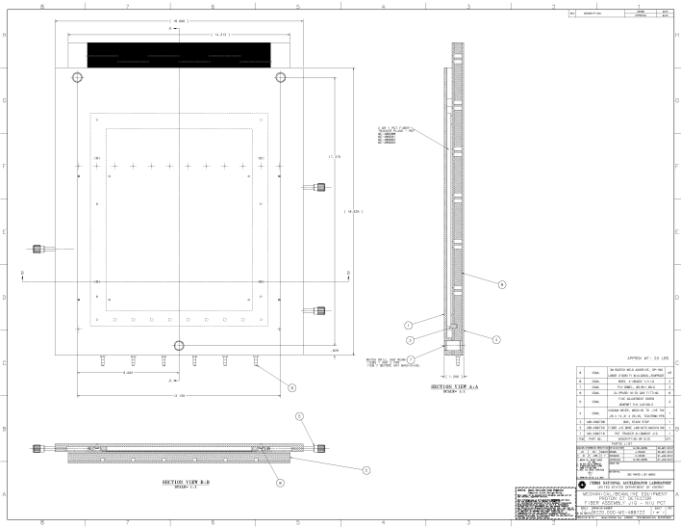
Techtron Bars are then prepped to be epoxied same method as RohaCell 31 foam. Once bars are positioned same method of weights applied and set over night.

Assembly Jig:

MD-489708 fiber end bar, 489722 Jig Assembly Drawing, 489720 Fiber Jig Base Laminate-Machining, 489721 Grooved Vacuum Jig, 489719 Alignment Jig Base.

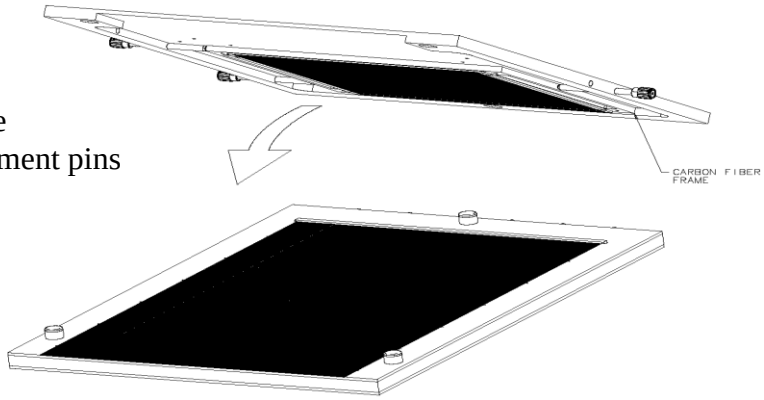
Lab3's UV Filtered Clean Room is needed to protect the UV sensitive Kuraray Fibers, along with the environments controlled thermal and RH conditions.

MD-48722-1 shows Fiber Assembly Jig. The base plate will have V-Grooves that have a series of vacuum channels run beneath. Since four different Carbon Fiber Frames are required, separate vacuum channels exit end via PVC Manifold to large capacity Scroll Pump. Sheets of flexible plastic film are laid down on sections not used over V-Grooves during fiber lay-up, minimizing vacuum loss.



Carbon Fiber Frame optically aligned to Upper Jig Plate.

Three alignment pins



Vacuum V-Groove Base Plate w/three alignment pins

Illustration left shows assembly procedure to pick-up fibers from Vacuum V-Groove base plate.

Upper Alignment Jig holds Carbon Fiber Frame, which is aligned via Optical CMM, and held in place with four screws in recess pocket of Upper Jig.

3M spray Adhesive is applied uniformly across Rohacell 31 V-Grooves.

Three alignment pins will then line-up assemblies, once pins are engaged pressure is applied to mate surfaces of both Jig Plates, together as a positive stop.

Vacuum then is turned off, Top Jig Plate removed w/fibers, and CF Frame realigned ½ pitch, 3M achieve applied, repeat procedure to pick-up fibers.

Assembly Jig: **Fiber Layup**

Vacuum V-Groove Base Plate w/three alignment pins is set up on an aluminum table at an ergonomic height to allow sitting or standing while placing the Kuraray 0.5mm Scintillation Fibers into the V-Grooves. A metal SS Vacuum Hose is connected to a PVC vacuum manifold and runs to a Scroll Pump on a wheeled cart.

Processed Fibers from Lab7 facility are packaged in Tedlar light tight bags to protect against UV light during transit to Lab3 Clean Room. Kapton tape holds a set of fibers which are then transferred to the Vacuum V-Groove Base Plate assembly table.

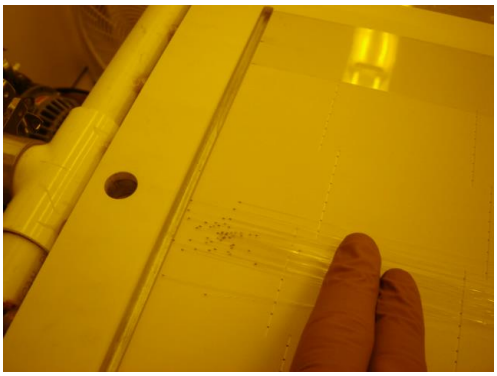
De-ionized air is sprayed across fibers to reduce static charge.

A granite block is located at the end of the Vacuum V-Groove Base Plate on the aluminum table. This provides a flat clean surface to prepare the fibers.

Assembly Jig: **Fiber Layup**

Fibers are straightened by tapping at both ends to even lengths. A first check is made to insure mirrored ends are truly positioned at one end. Corrections are made if necessary.

Clear Lexan bar/stop is placed in the recess at the Vacuum Manifold end. This provides a positive stop for the mirrored ends of the fibers during layup in V-Grooves.

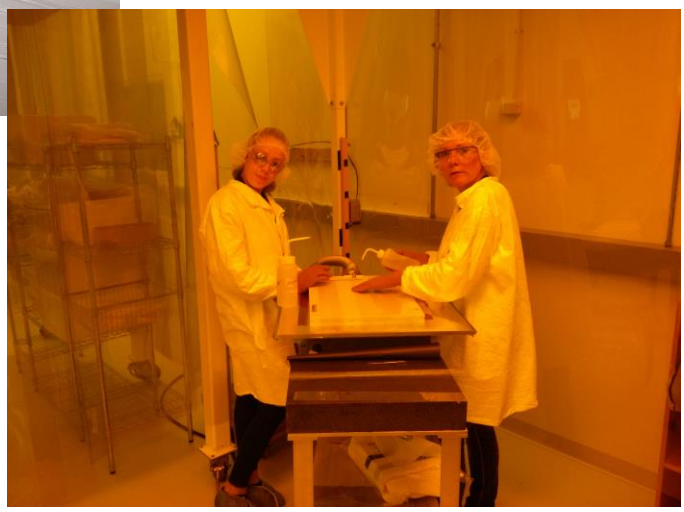


Mirrored end of fibers are brought up to approximately the center line of 0-Datun pin and slid up to the Lexan bar/stop.
Alcohol is sprayed across fibers to aid in affixing them into the vacuum V-Grooves.

Once mirrored ends are in place, alcohol is applied to roll mirrored ends of fibers into the vacuum V-Grooves.

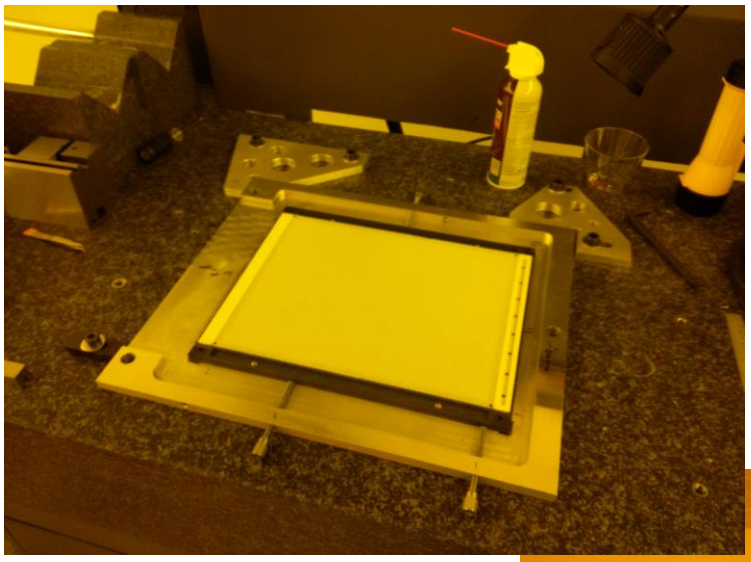
Assembly Jig: **Fiber Layup**

Once mirrored ends are in place and alcohol applied, place forefinger across fibers to hold them in place and use other hand to slide fibers into V-Groove apply alcohol to aid in lubricating twisted fibers, once technique is developed this process goes very quickly.



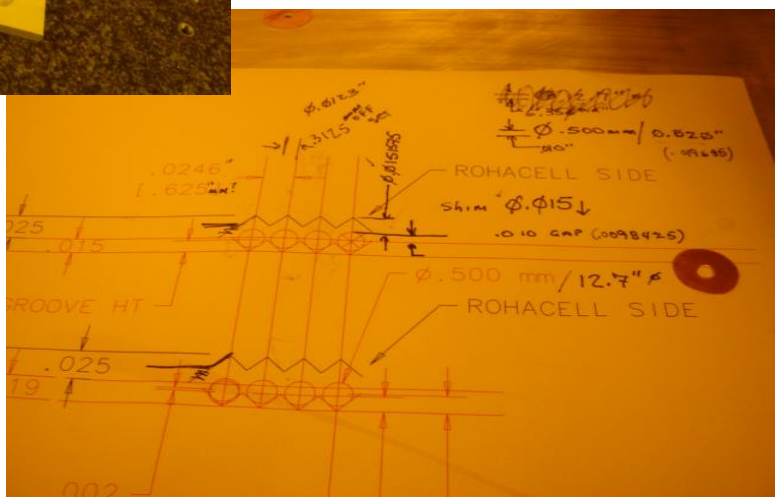
To aid in fixing fibers into the V-Grooves a sheet of film can be laid over the positioned fibers and open V-Groove sections, this helps vacuum system, since fibers only contact a small portion of the Techtron V-Groove.
Recheck second time that mirrored ends are at the Lexan bar/stop since this is last time for corrections, before transfer.

Assembly Jig: **Carbon Fiber Frame Alignment, two people required**



0-Datum hole in Top Plate of the Assembly Jig is located via software, measuring the dowel pin hole CL and CL scribe lines.

A set of 4-copper shims are placed beneath the corresponding tapped holes to provide extra height for a transfer on the first set of fibers.

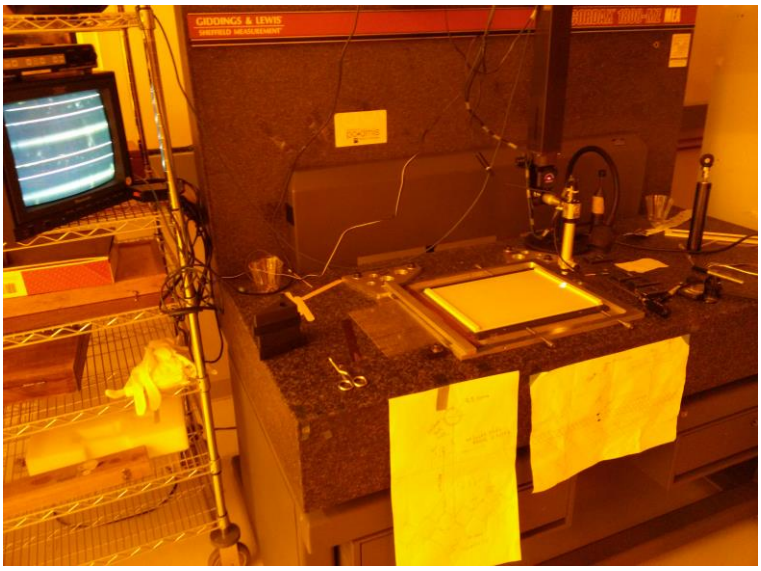


With the copper shims in place the Carbon Fiber Frame is positioned above the tapped holes in the aluminum jig plate.

Three ¼-100 precision manipulator screws then position CL of V-Grooves in Techtron at both ends of frame in a rocking motion. The CL of grooves are measured on an Cordax, marked with black marker.

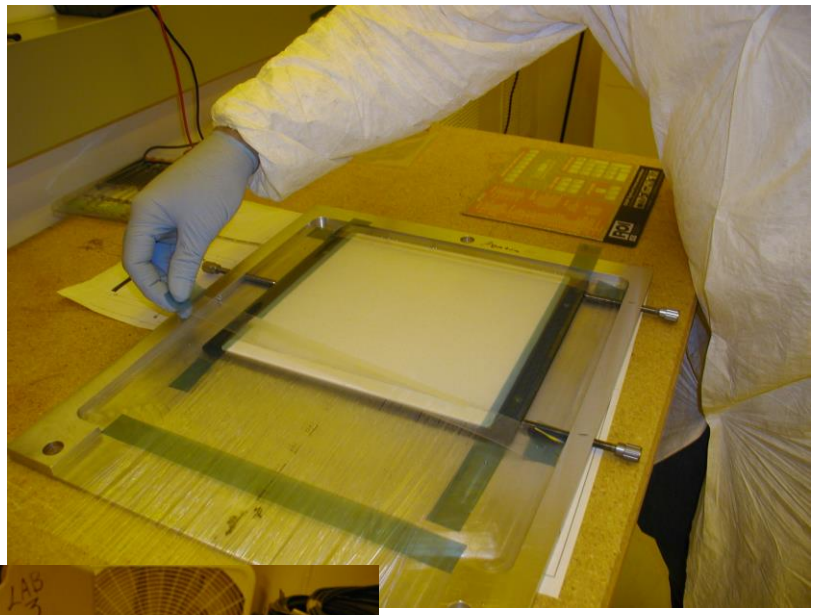
Once alignment is obtained jig plate is removed from table and re-installed to re-check alignment again.

3-hard stops in corners provide rapid repeatable alignment, this step double checks optical alignment, two people should be present during this step, to confirm this critical alignment to the Techtron Vacuum V-Groove which have the Kuraray Scintillation Fibers in place under vacuum.
Once alignment verified C/L grooves marked with black is then double check.



Assembly Jig: **Fiber Transfer**

Prepare Carbon Fiber Frame for 3M Contact Spray Adhesive by masking off Rohacell and 1/3rd of Techtron V-Grooves.
Image right shows a layer of fibers already installed.



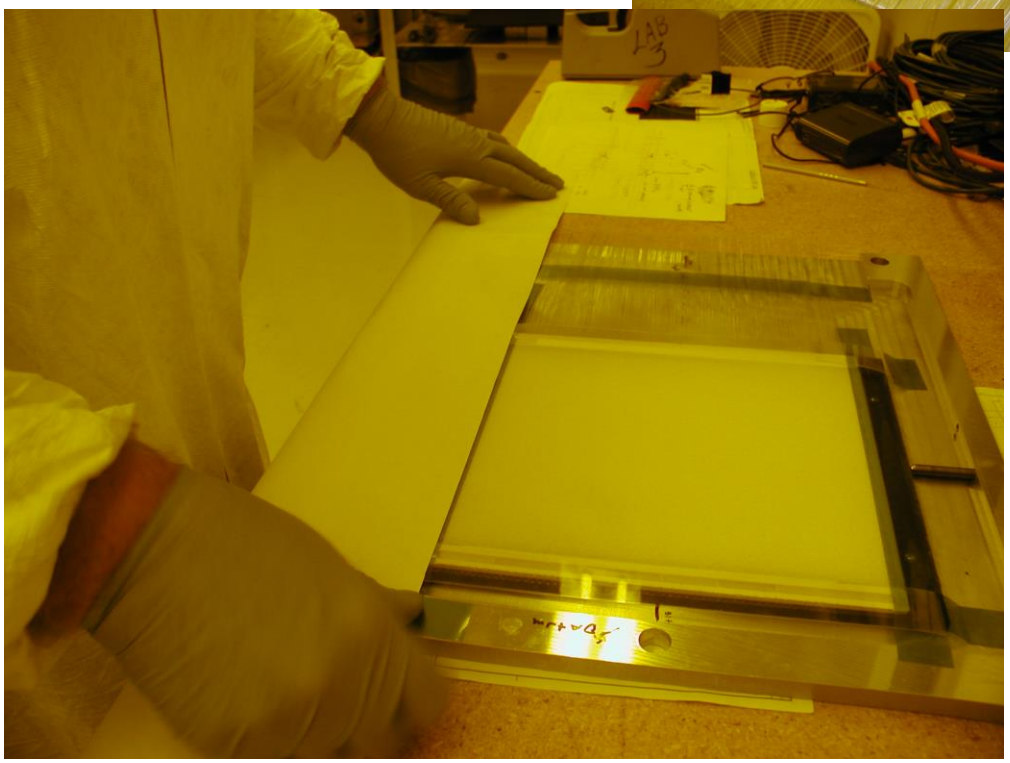


Image above shows 1st layer of fibers installed and being prepped for second layer. First layer raw Rohacell layup same process.

Apply Masking paper across the tapped areas to shield all the parts not intended to be sprayed with contact adhesive.

Spray small amount of 3M Spray on a test paper to insure nozzle is not plugged and spray dispersal is even fan pattern.

Apply first thin layer along V-Grooves to insure proper coating of bottom of V-Grooves in Rohacell.

Wait a few minutes for first coat to dry and apply a very thin second uniform coat.

Assembly Jig: Fiber Transfer

Remove any flexible film covering fibers to be transferred, application of alcohol as corner of film is pulled up aides in holding fibers in grooves.
Remove the Lexan Bar/Stop from Manifold side of jig.

Film on unoccupied V-Grooves can remain, since lower than fiber diameter.

Again spray liberal amount of alcohol across fibers to insure fibers are laying flat, check for any damaged, nicked, curled fibers and replace if any. Again check for mirrored ends are in proper end of jig.

Note positions of two diamond shaped dowel pins orientations in image left.

These pins are necessary for the alignment of the Jig-Bored alignment holes. 0-Datum is a full circular pin while the two closest diamond pins are rotated 90’ from each other.

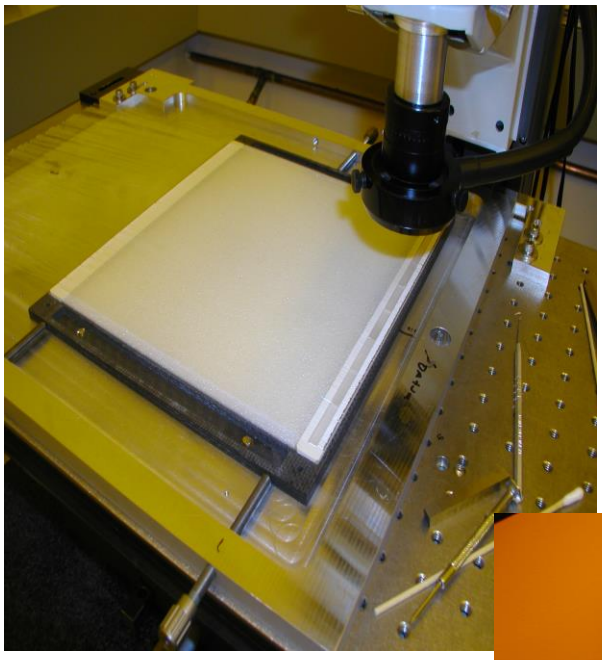
With two people; lower the upper jig plate that has the CF/Frame onto the 0-Datum pin and evenly bring the jig plate over to the two lower diamond pins, slowly wiggle upper jig plate around the pins carefully. Do not force excessive downward pressure and jar the two jig plate together. A sudden closure will cause the fibers to jump out of the V-Grooves and cause miss alignment.

Assembly Jig: Fiber Transfer, second layer

Once the upper jig is securely positioned, check with flashlight for gaps, make sure three corners of upper aluminum jig plate are free of any gaps.
Once satisfied alignment is obtained, turn vacuum pump off, and press down in center to apply enough force to have fibers settle into 3M Adhesive, leave assembly jig in this configuration for 30 minutes to allow adhesive on Rohacell V-Grooved surface to fully contact as much of the fibers and start curing.

Carefully remove upper aluminum jig plate, now with the fibers. Be careful not to pull or disturb fibers in this state. Place upper jig back on Nikon/Omiss Optical table and scan CL fiber on both Techtron V-Grooves marked with black marker.

A simple lateral scan can be made using the 0.625mm pitch dimension. From locating CL black marked groove.
Once proper pitch is verified, carefully remove the CF/Frame with Fibers and place back on Techtron V-Groove vacuum plate.

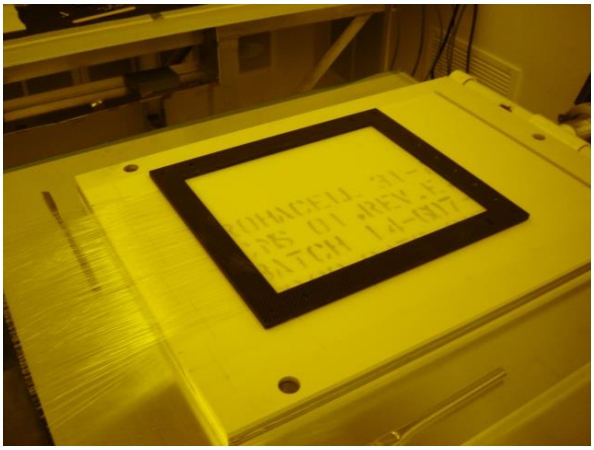


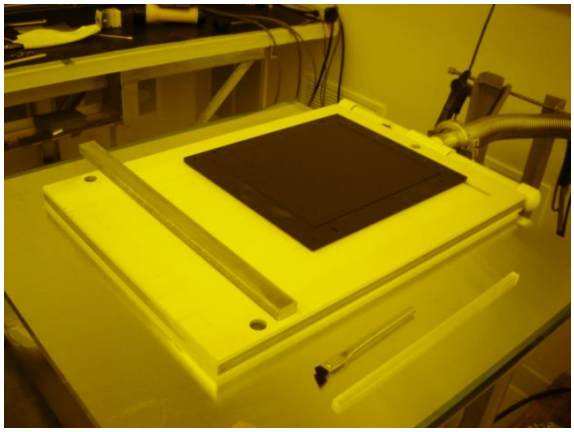
0-Datum black indicator shown image right of proper CL in video display. Scan back and forth to check both sides.

0.3125mm CL shift is made for second layer of fibers.

Assembly Jig: Fiber Transfer

After transfer with aluminum jig, remove detector assembly from jig and place on Techtron Jig.
With the fresh transfer realigned to the Techtron V-Grove jig, slide the assembly into a position to have the dangling fibers secured back into the respective V-Grooves.





Carefully install the Carbon Fiber Frames 'cut out' into the frames aperture, this part is the exact thickness of the frame.

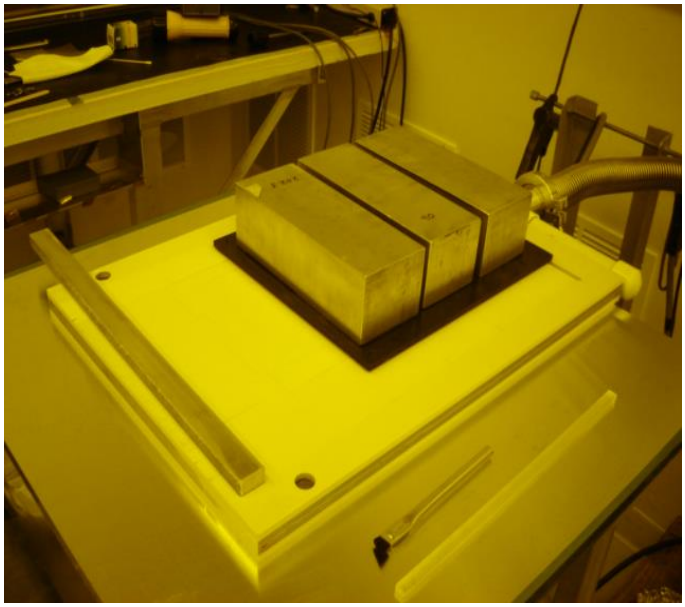
The Vacuum V-Groove Techtron Jig is now a mold, which will hold the fibers in place during the 3M contact adhesive curing cycle.

Place the three aluminum weights from beneath the assembly table shelf onto the top of the Carbon Fiber Frame and aperture cut out.

This will be left over night to press the fibers into the 3M adhesive.

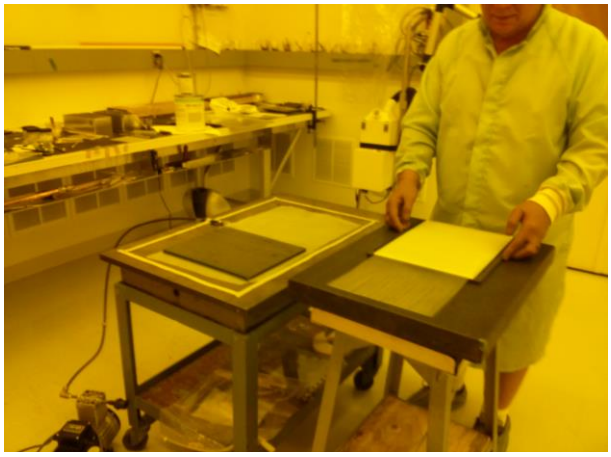
An aluminum bar with blue Mylar tape is placed over the loose end of fibers to retain alignment of fibers entering into the Techtron V-Groove.

Cover with plastic film to protect against UV light and dust when storing between fiber transfers.



Repeat for second layer of fibers with appropriate shimming and offset of 0.3125mm fiber alignment.

Installing Floating V-Grooved Techtron Bars: **Preparing Bars**



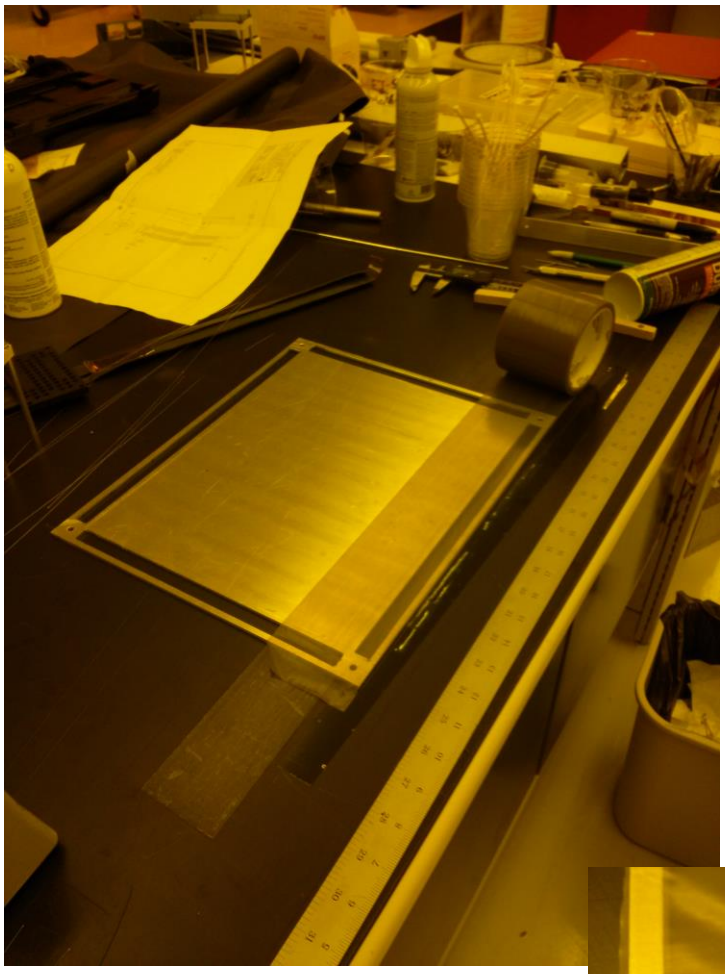
Begin by cleaning any burrs in the V-Groove in the Techtron Bars.

Double check the under-size ¼” dowel pins as 0.1245” Dia. Clean if necessary to insure proper fit.

Place aperture cut out CF beneath CF/Frame to support Rohacell and fibers. Black Plastic sheet acts as a support shim for fibers.

Place Floating V-Grooved Techtron Bars over scintillation fibers to verify proper part.

Installing Floating V-Grooved Techtron Bars: Aligning Jig Plate

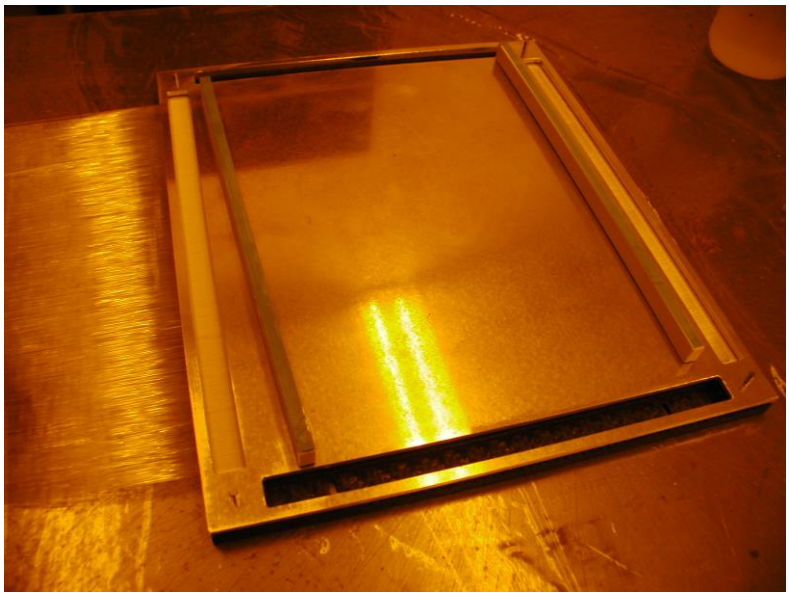


Prepare Aligning Jig Plate with Teflon tape on both ends of opening slots.

Cut area where Techtron bars will be positioned.

Press down with finger to fold Teflon tape smoothly to edge without wrinkling tape to opposite side.

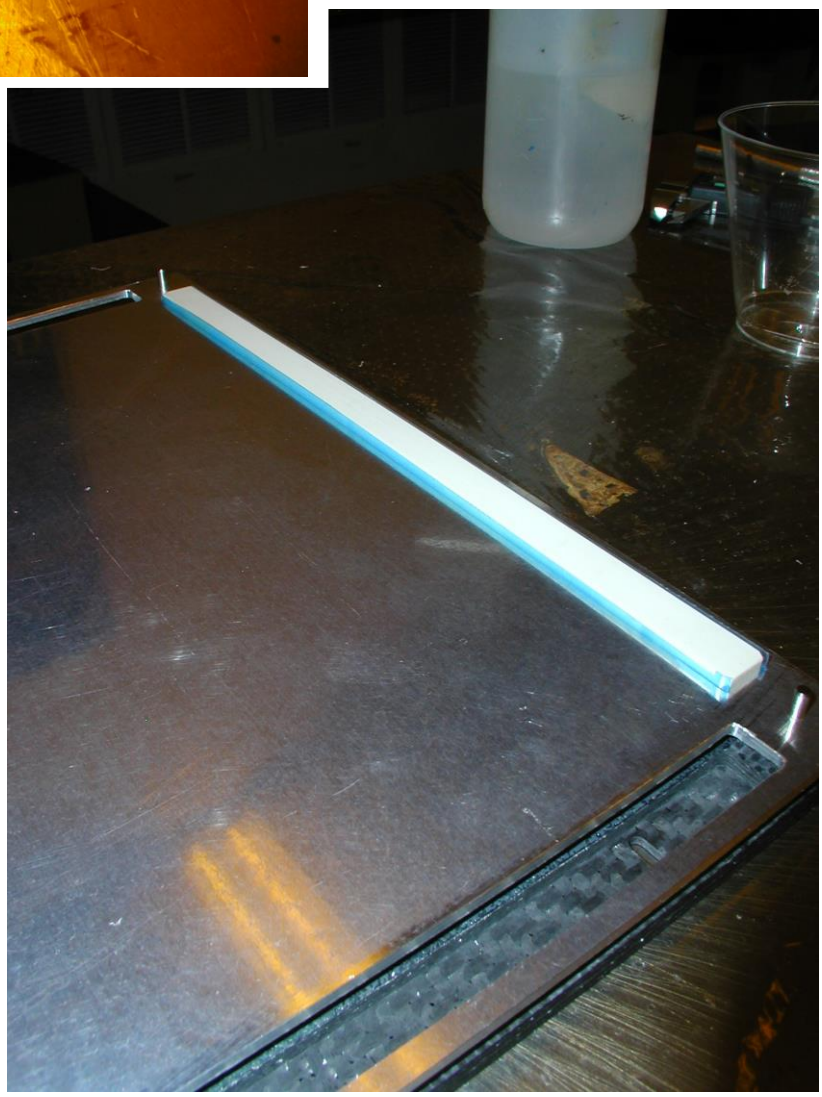
Installing Floating V-Grooved Techtron Bars: Epoxing Bars and Fibers



Prepare small 'artists brush' check for loose bristles.

Cover fibers with Tech-wipe cloth to protect fibers from epoxy spill.

Mix epoxy; apply to V-Grooves side of bars and scintillation fibers. Center application of epoxy across fibers.



Place prepared Techtron Bars into alignment slots.

Press down to engage V-Grooves, slide if needed latterly.

Note second larger aluminum jig plate to the right above image.

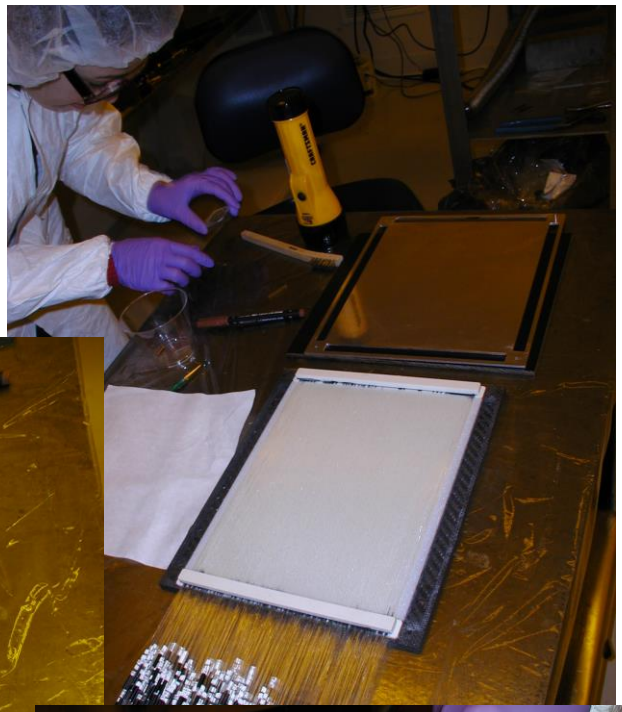
This second plate will be used as a shim plate in the next step.

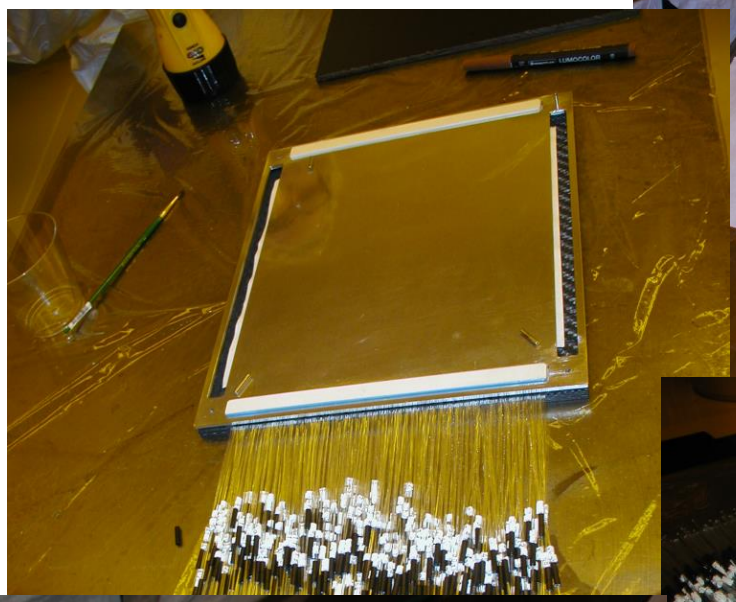
Installing Floating V-Grooved Techtron Bars:

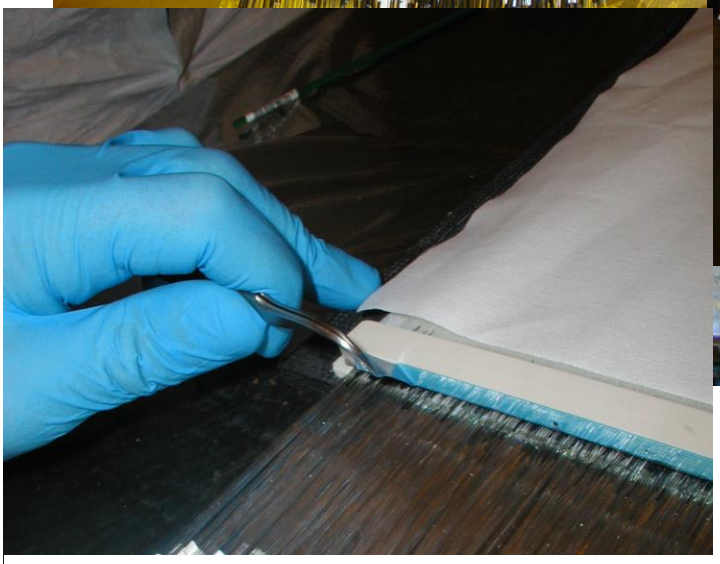
After epoxy cures, flip assembly back with fibers up right.

Carefully dissemble aluminum alignment jig from detector plane.

Remove the four ¼” Dowel Pins.

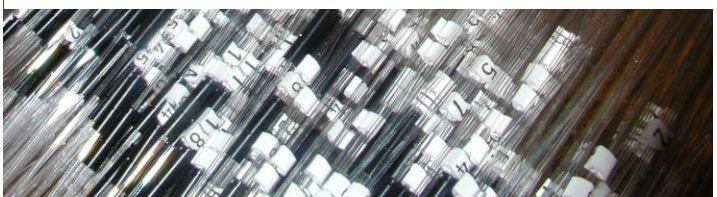






Once jig plate is removed, use tweezers to pull the blue shim tape away from the epoxied Techtron Bars on both sides. Measure dry assembly weight make note of weight in Traveler. This step is critical in determining Ren 6400 Polyurethane mass in aperture, next step.

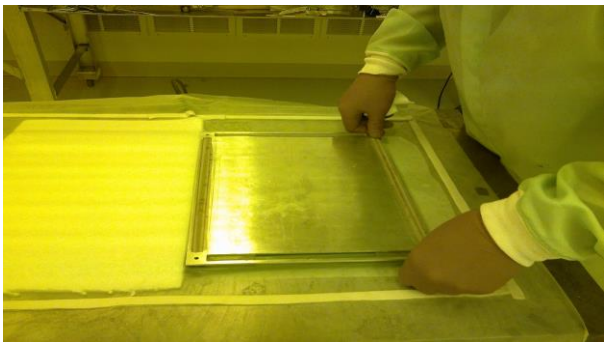
Preproduction assembly displayed delamination of several fibers due to exposure to thermal excursions of design parameters. To increase thermal criteria; Ren 6400 Polyurethane is placed over fibers to affix to Rohacell, in the next step.

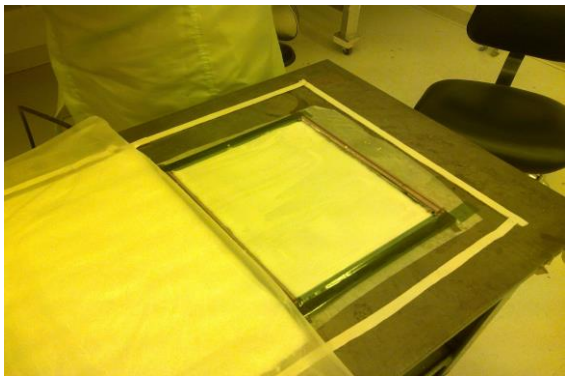


Ren 6400 Polyurethane Layer on Fibers: Layup Preparation

This will take minimum of three people

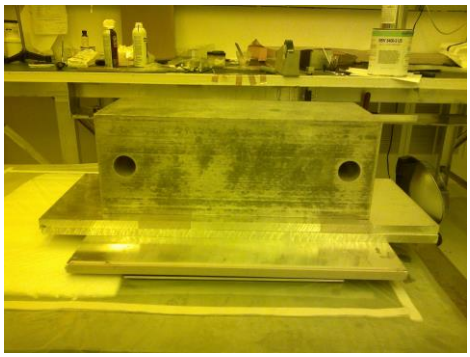
Using cleaned Steel Surface Plate, place double sticky vacuum bag tape around detector and shim plate placed beneath fibers extending from CF/frame. CF/cut out shim also placed beneath Rohacell. Vacuum line installed to pump. Test fit aluminum Jig over floating Techtron bars. Teflon film is then placed over ½ of assembly, covering loose fibers.





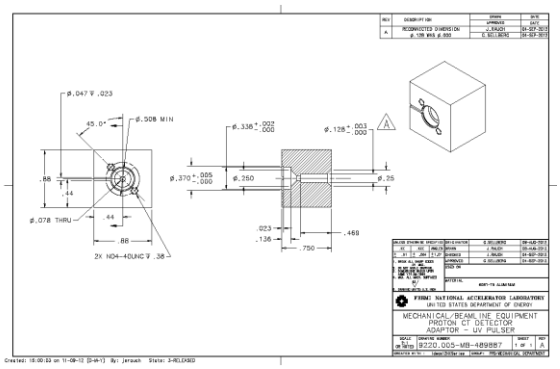
Brown Teflon tape must be placed on all sharp edges. Blue Mylar tape is placed as a mask over areas that do not require Poly coverage.
With one person weighing out Ploy, one person poring, spreading and working Poly in-between fibers a thin layer is formed over fiber surface. Each application is weighed to insure similar amounts on each detector plane and recorded in the Travler. Third person keeping eye on clock, max pot life 20min, handing mix back and forth.

Once correct amount is applied, thin Teflon film sheet is then folded over Poly and then burnished flat to eliminate folds, which could pool Poly. Once film is smooth, vacuum is applied to push Poly deeper into Rohacel thru Fibers. This will then link Fibers to Rohacel to keep fibers from dislocation during a thermal excursion and possible damaging detector plane.

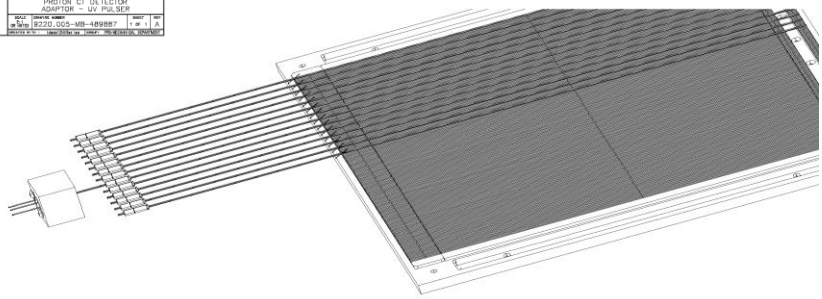


Place aluminum Jig over vacuum film and turn off vacuum pump, load flat jig plates on fiber surface between floating Techtron bars and apply weights to insure flatness overnight. Place epoxy mixing cup on top of assembly to monitor Poly had set up.

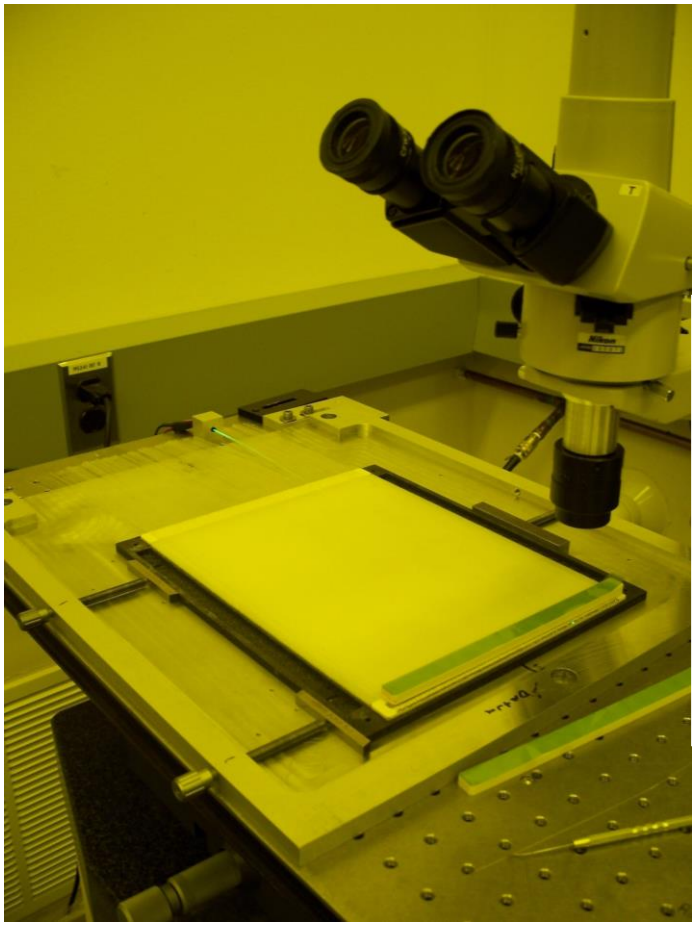
Fiber Bundling: We will require a total of 40 x 64 = 2,560sleeves, plus a consignment of spares.



ThorLab UV LED fixture drawing shown left.



ThorLab UV LED fixture verifying illuminated three fibers and proper channel sequence, by moving across assembly.



UV LED Pulsar far left, shown with illuminated green flash of three fibers, placed in a black Delrin Fiber Bundle Sleeve and then inserted in UV LED Fixture to confirm assembly procedure under Nikon/Omiss Microscope. Green flash is visible under microscope lens.

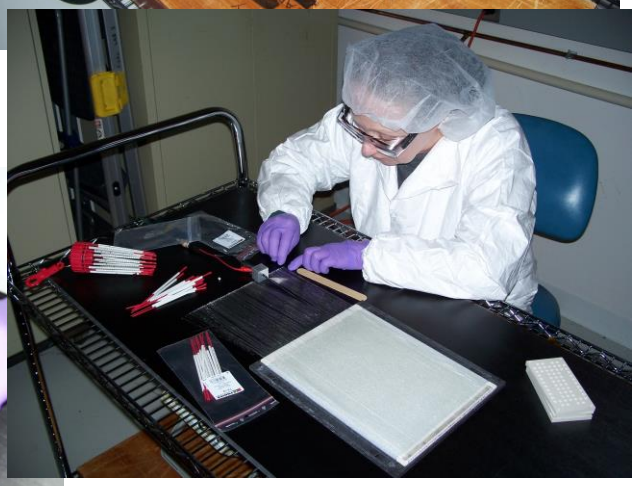
Image above shows mirrored ends flash, under microscope's display, confirming validation of fiber bundles.

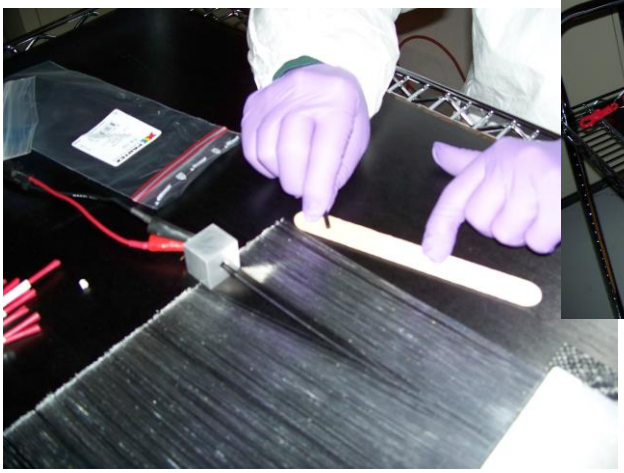
Fiber Bundling: **ID Tagging**

Assembly is placed on a rolling cart and taken to the far end of the Clean Room, that is darkened to aid in Fiber Bundle ID tagging.

UV Safety Glasses should be worn during this procedure.

ID tags are laid out on cart near end of fibers. 0-Datum fiber is located in center of detector plane and verified with the Thor Lab UV LED Pulsar.



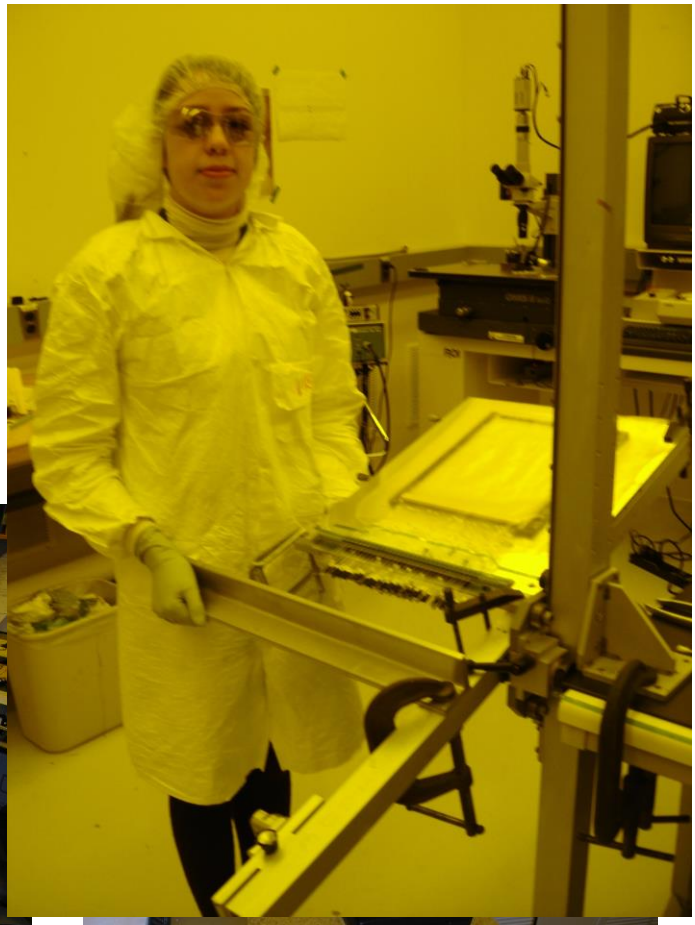


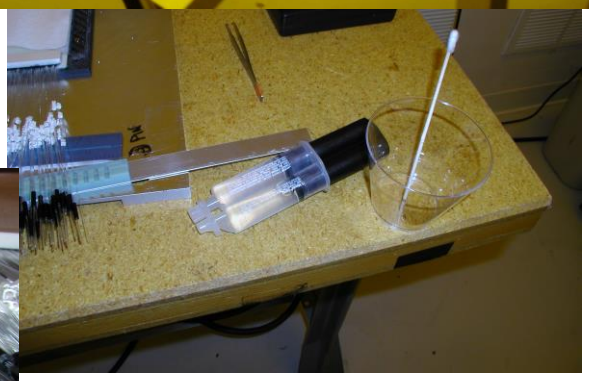
After the three fibers have been identified with the ThorLab LED pulsar system; marked with the labels, and have the Fiber Bundle Sleeves inserted on the fiber ends. The next step is to take the assembly and install on a aluminum jig to fix distance from CF/Frame to end of Bundle Sleeve

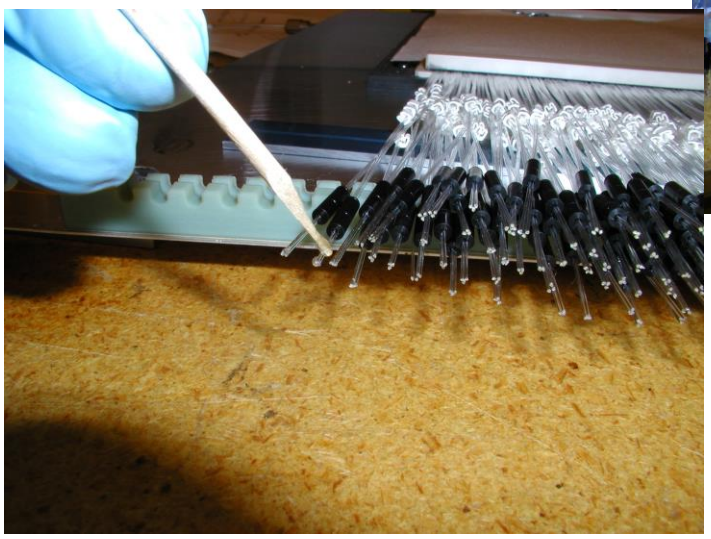
Fiber Bundling: Epoxing Sleeve to Fibers on Articulating Easel

We will be using the top assembly jig plate temporarily since it has the threaded holes that match the CF/Frames to expedite the process and evaluate technique.

CF/Frame with ID'd fibers with black Delrin Sleeves is secured to flat back side of Top Assembly Jig Plate.





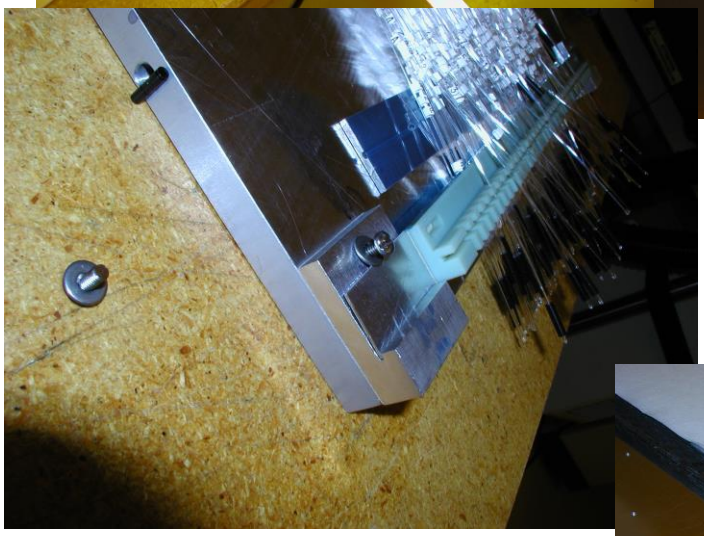


Mix 5min epoxy in cup, prepare wood stick applicator and apply a drop of 5min epoxy to ends of the three fibers . This will keep black Delrin Sleeves and number ID's from falling off, when placed in a vertical position.

Fiber Bundling: **Epoxing Sleeve to Fibers** Trial run on flat table.

A set 3D printed Sleeve Fixtures have been produced to confirm fixturing method before an aluminum part is fabricated. Trial run on flat table.

As per the drawing, distance from lower Techtron V-Groove Bar to beginning of black Delrin Fiber Bundle Sleeve is 4.5”.

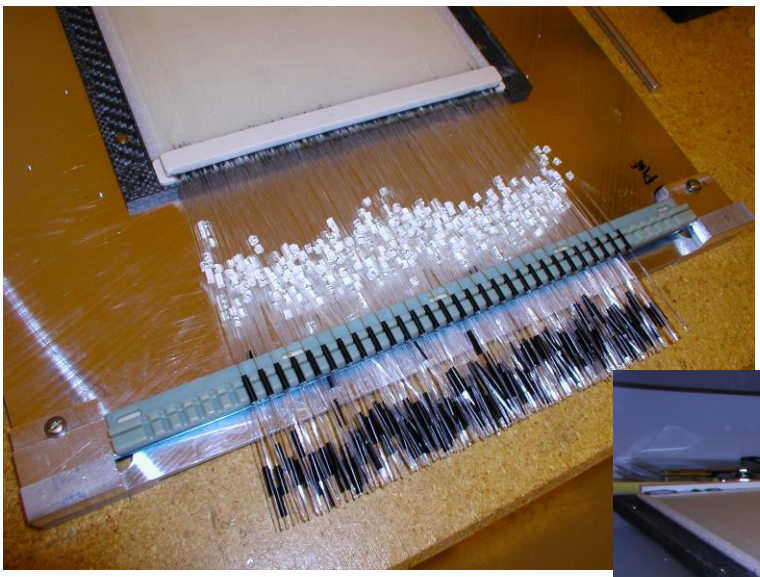


Two aluminum blocks were fabricated to position the Sleeve Fixture at the proper level and distance from the CF/Frame.

An aluminum rod aids in selecting the straightest sets of fiber bundles to locate into the Sleeve Fixture.

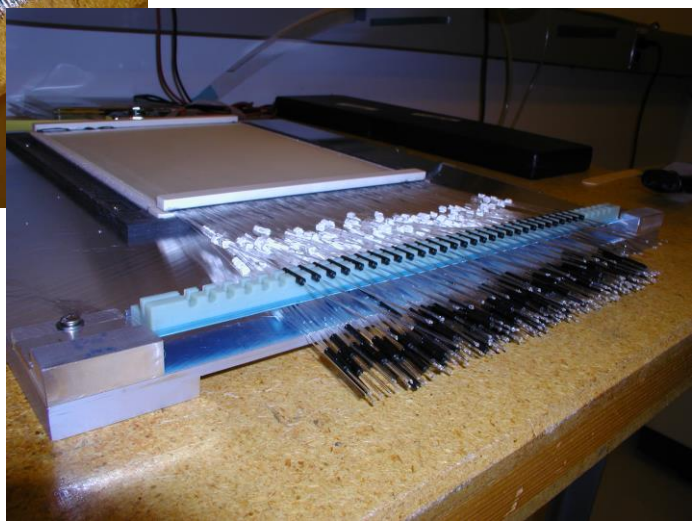
Straight fibers aligned into the fixture is critical to insure fibers are not distorted.

Fiber Bundling: **Epoxing Sleeve to Fibers on Articulating Easel**



Do not stretch fibers to far ends to attempt to maximize the number of sleeves epoxied.

This will only distort the fibers into a permanent uneven condition once epoxy is cured.



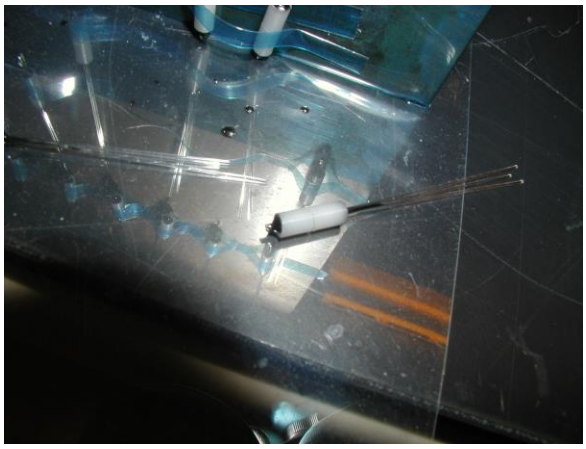
Every eight fiber bundle is set into the Sleeve Jig. Excess fiber bundles and eventually epoxied bundles reside beneath Sleeve Fixture.

With the temporary Top Assembly Jig Plate mounted to the articulating Sleeve Easel, position the CF/Frame to the Horizontal positioned Jig Plate.

Image left shows a Detector Plane that has a completed set of epoxied Fiber/Sleeves.

Fiber Bundling: Epoxing Sleeve to Fibers on Articulating Easel

Mix epoxy into a 10cc syringe and set EFD system to apply small droplets of epoxy in a clear cup during this set-up.



Practicing on preproduction sleeve, aid in developing this technique to apply correct amount. Capillary action draws epoxy into the three fibers. Multiple applications of small amounts of epoxy is required to eliminate entrapment of air bubbles.

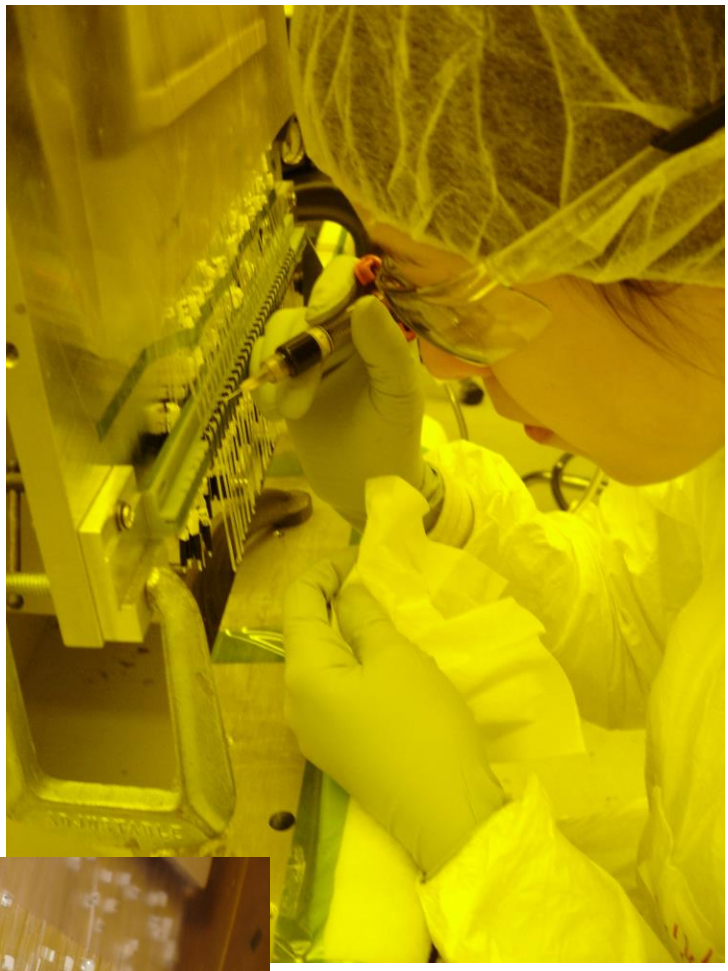
With detector plane mounted on Epoxing Easel, flip Jig Plate with detector facing down. Epoxy will be applied to fibers ends vertically. This will ensure minimum bubble entrapment during polishing process.

Fiber Bundling: Epoxing Sleeve to Fibers on Articulating Easel

When the epoxy has traveled to the bottom of the sleeve towards detector. Flip detector 180’, apply a small amount from the EFD syringe to the exiting fibers.

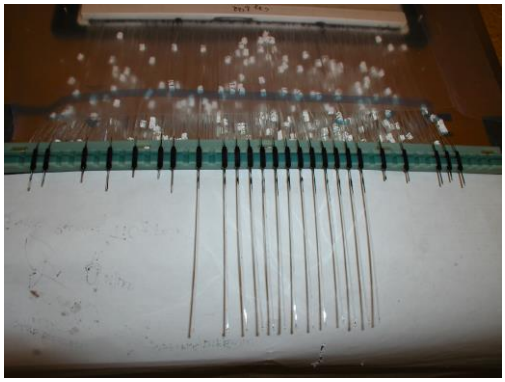
Surface tension in the epoxy will form a dome around the fibers and run to the edge of the Delrin Sleeve, on both ends of Sleeve.

Make sure top also has this domed feature, this insures proper amount in bore of Sleeve and secures fibers internally.



Cut off excess fibers from beneath finished sleeves. This will reduce chances of damage to fibers.

Image below shows white paper slid beneath epoxied Sleeves to insure un-processed fibers are not cut by mistake.

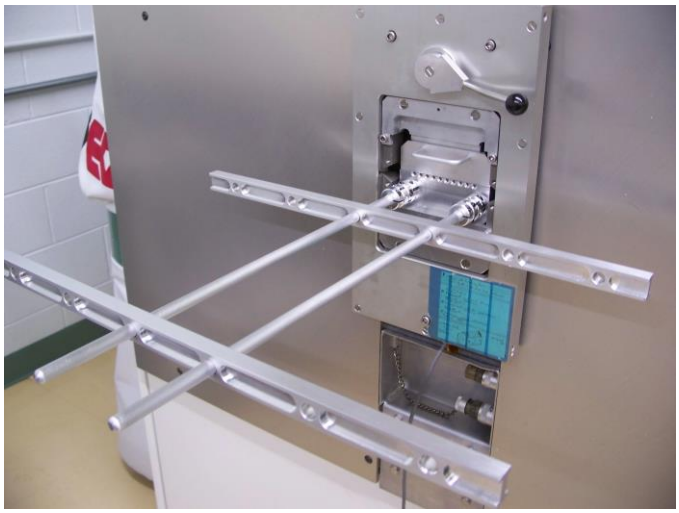


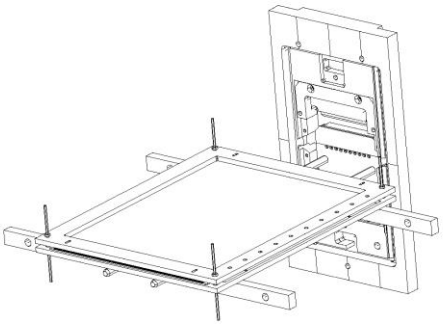
Fiber Bundle End Finishing: **P3 Diamond Planer Method**

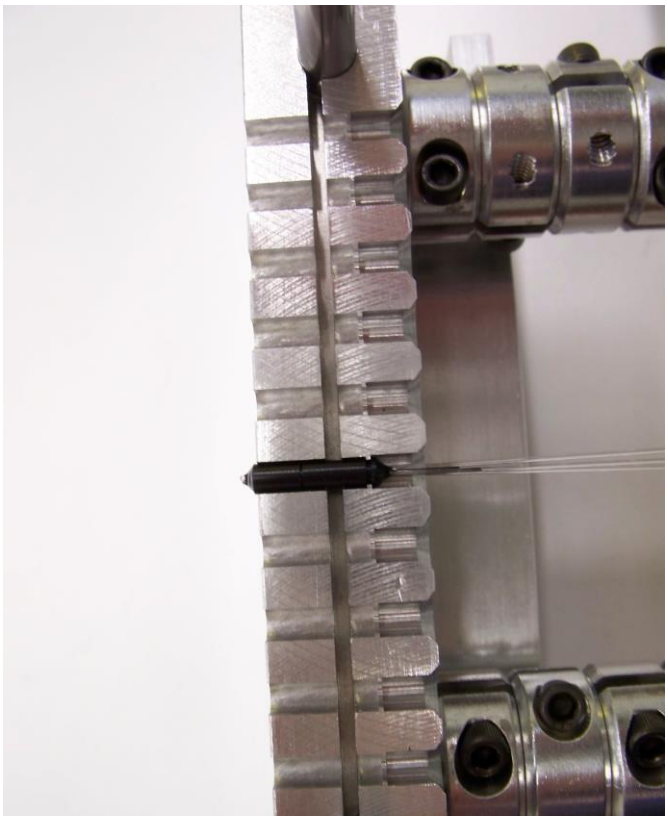
Image left shows an early Loma Linda 2nd Iteration assembly for beam tests.

A means to precisely finish fiber ends is now developed. Lab7 has in the past demonstrated the ability to finish fiber ends with acceptable light transmission with minimum light losses.

Each Fiber Bundle will correspond to a specific SiPM channel. They have been QC'd with a light, and verified and are identified with a numbered plastic sleeve, corresponding to SiPM block channel.

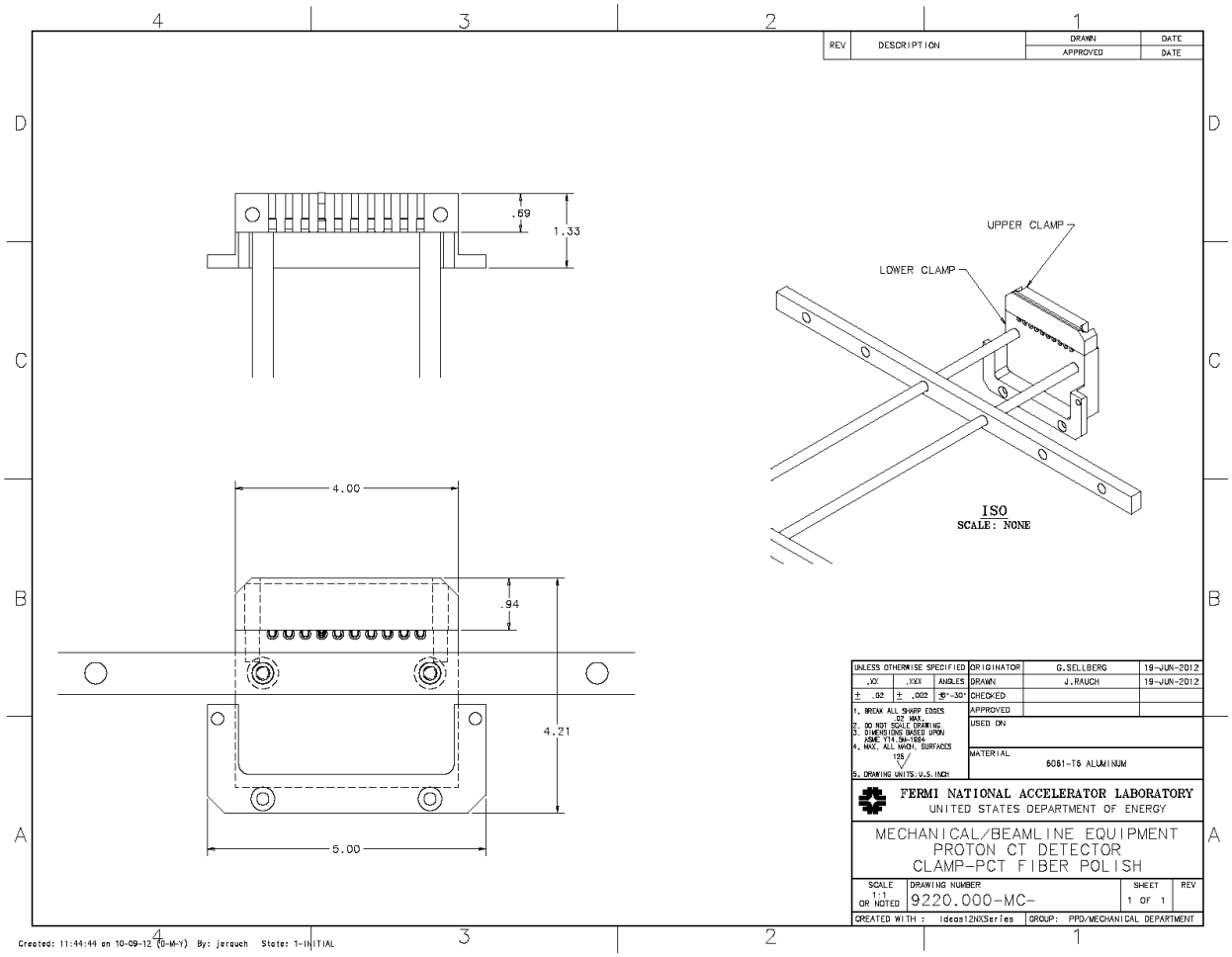


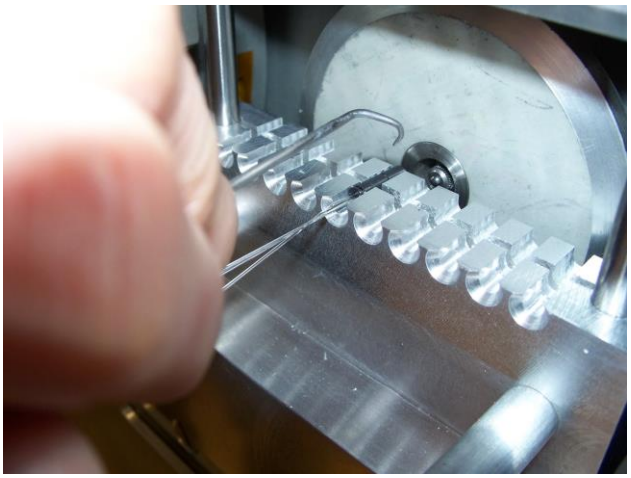




Trial fit of a Fiber Bundle Sleeve in the P3 Stockade fixture. Small ribs set repeatable distance for the diamond tool to plane the epoxy and fibers down to the surface of the black Delrin Sleeve.

Proposed P3 Stockade Fiber Bundle Finisher Fixture



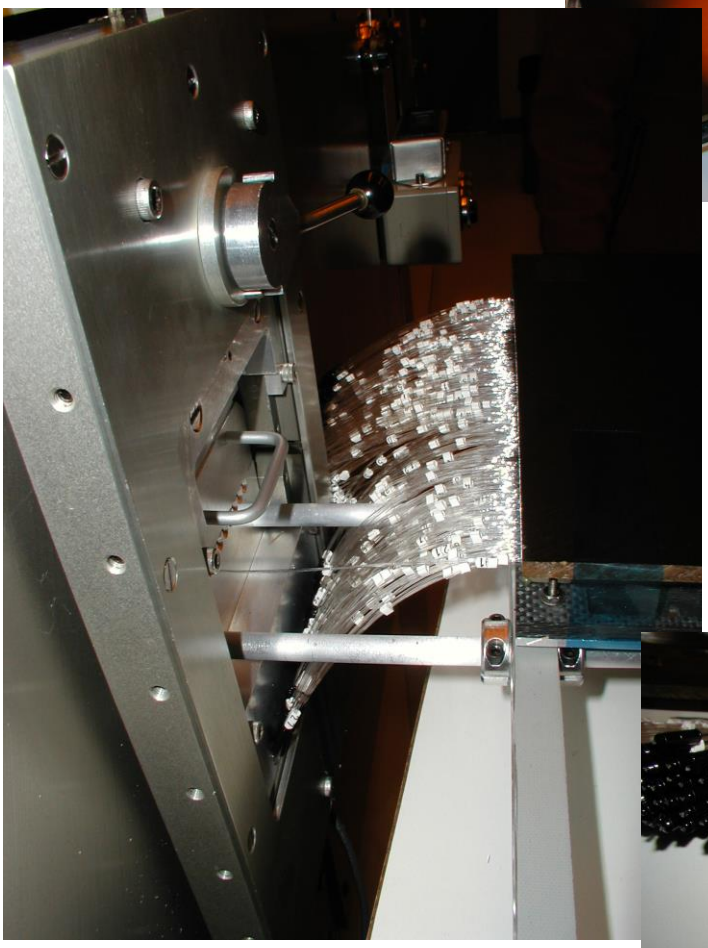


Test fit and extraction tool under development at Lab7's Fiber Shop.

Fiber Bundle End Finishing: **P3 Diamond Polisher/Stockade 24cm plane**

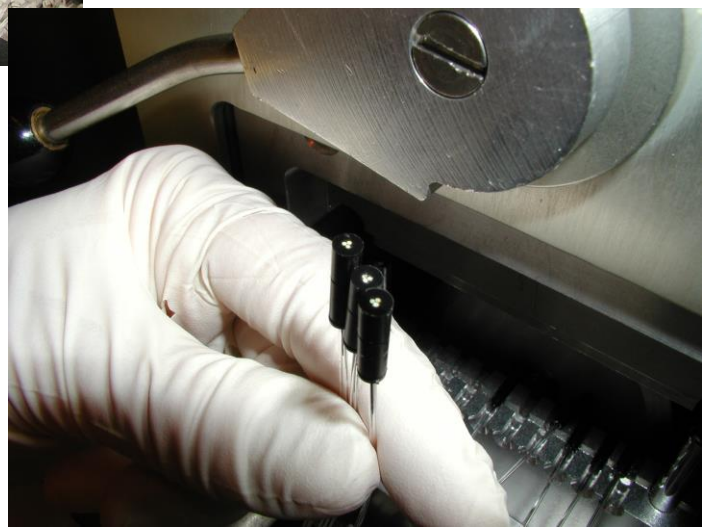
31/DEC/2012 we were able to proceed with Lab7 Diamond P3 Polishing Machine.

24cm plane is placed on the aluminum support bars, to position the fibers at a distance not to stress the fibers during polishing cycle.



First Fiber on end is test run to insure production criteria performs as well as the pre-production test sample prior to this 1st run.
As seen below 1st right finished.

Fiber Bundle End Finishing: **P3 Diamond Polisher/Stockade 24cm plane**



Three set cut of above set up.

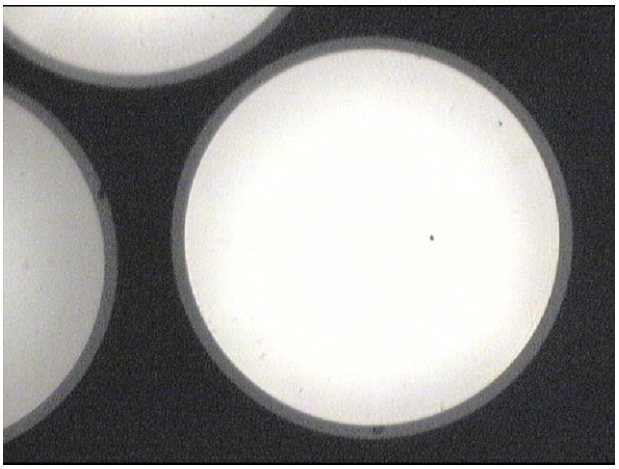
Inspection shows fibers cut with diamond tool down to the black Delrin Sleeve.

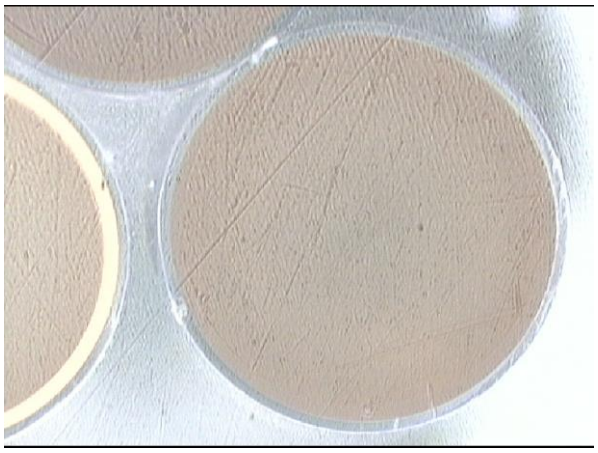
Will measure length to determine if P3 is removing too much Delrin or if it's just skimming surface of sleeve.

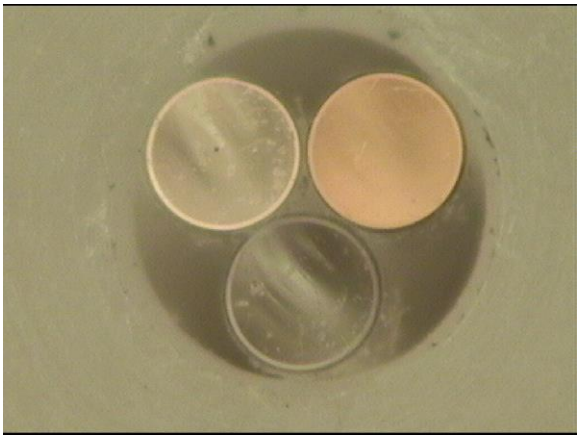
Fiber Bundle End Finishing: **Finished Fiber Ends**

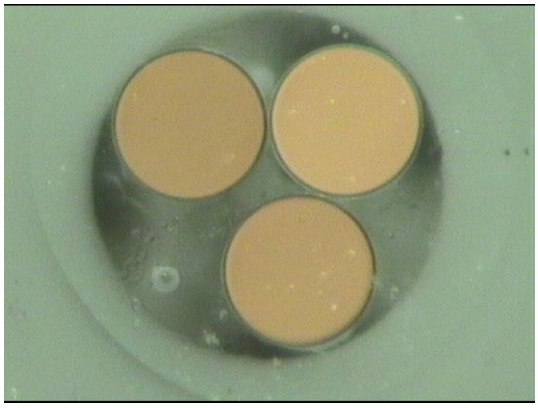
These are a series of test cuts on the P3 Fiber Finisher. The Delrin Sleeves used are not of the black Production type, tolerances are very loose on the internal bore diameter.

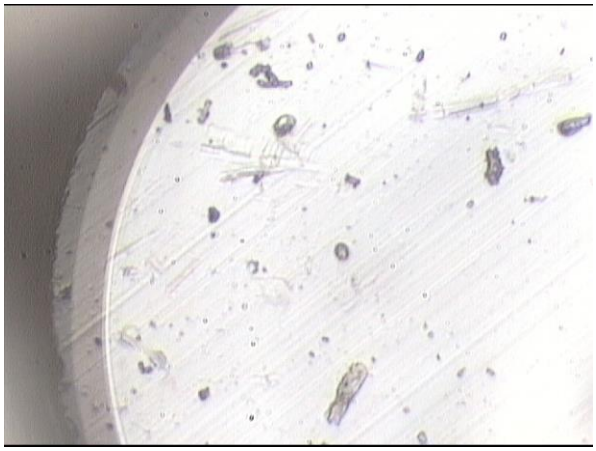
Production sleeves should constrain the three fibers in a tighter bundle.
Images are for demonstration of finished surfaces.











Dust has attached to surface, which demonstrates necessity of assembling in a Clean Room.

Fiber Bundle/Sleeve repair: **Microscope Inspection**

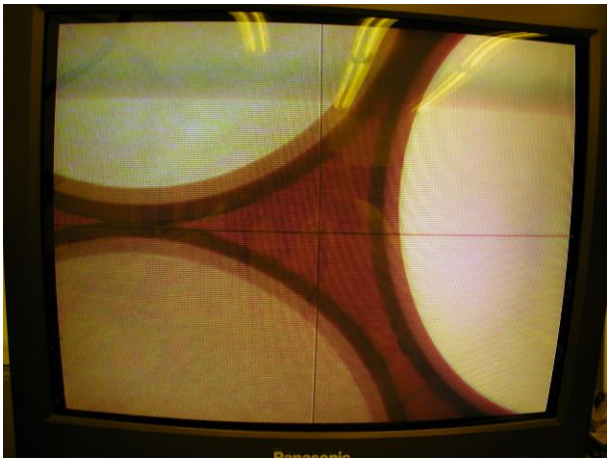


Image left with aid of microscope inspection shows a desirable diamond finish of fibers, black epoxy and Delrin sleeve end.

Images below shows undesirable finish which is caused by minute bubbles. These voids will cause damage to the scintillating fiber ends by causing fiber to actually move during finishing and crack cladding material.

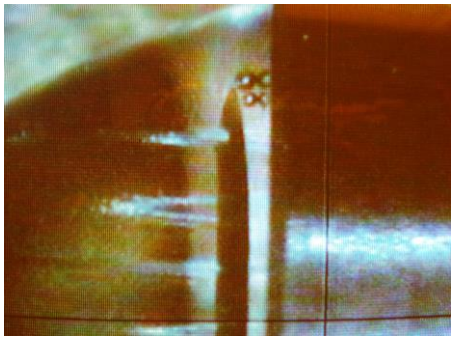


Image above shows minute bubbles trapped in a clear epoxy.

These bubbles do not show up in prepped syringe and maybe caused by exothermic reaction to two part epoxy during curing stage.

Fiber Bundle/Sleeve repair: low power loop inspection

A quick inspection of fiber/sleeve ends can be accomplished in a short period of time by unaided eye or with a low power loop.

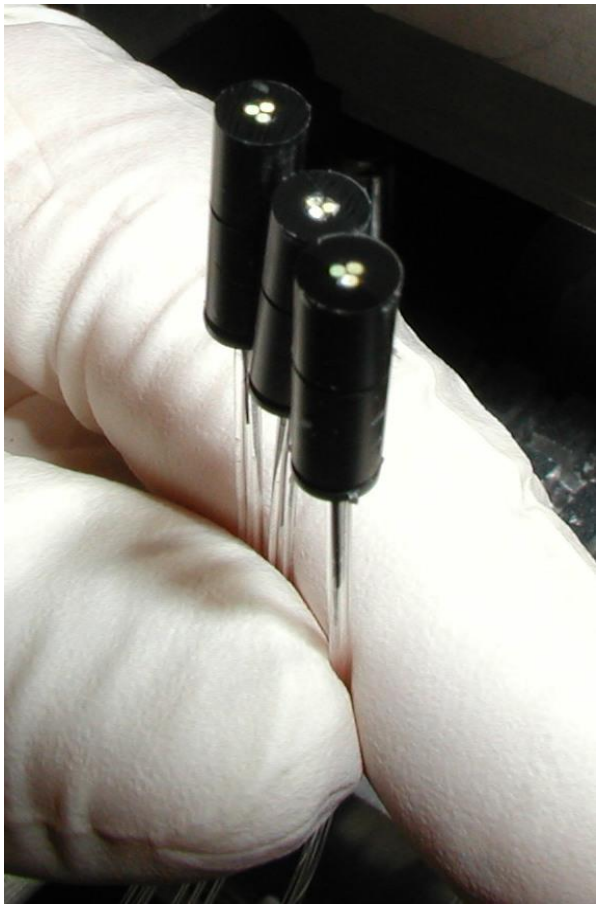


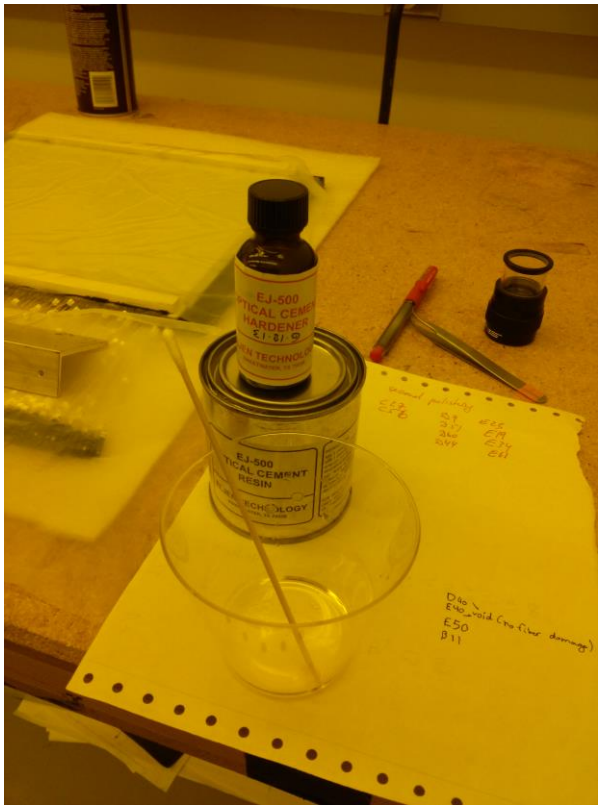
Image left shows three finished fiber sleeves, center sleeve shows air bubble voids.

Separate fiber/sleeves from detector plane and position above a support material. This will allow an optically clear epoxy to be applied on ends of bundles.

Or if space allows us Bundle/Sleeveing Easel, used for black BK-5105 epoxing.

The optically clear epoxy's surface tension will dome over ends of black Delrin sleeve.

Fiber Bundle/Sleeve repair: **identified fiber/bundled sleeves epoxing**



With sleeves identified and separated from acceptable finished sleeves, repair with optically clear epoxy.

Type used is EJ-600 or BC-600, 24 hour cure type. This epoxy has acceptable optical qualities in its index of refraction for light transmission and machining characteristics.

Weigh out 4:1 ratio and mix in container. Use sharpened cotton swab wood end to apply on Delrin sleeve ends. Apply enough to allow surface tension to dome to circular edge and not flow down sides.

Image right shows an early white Delrin Sleeve with fibers. Epoxy is ‘domed’ at end to be diamond Polished.

Fiber Bundle/Sleeve repair: Diamond Polishing w/FiberFin 4

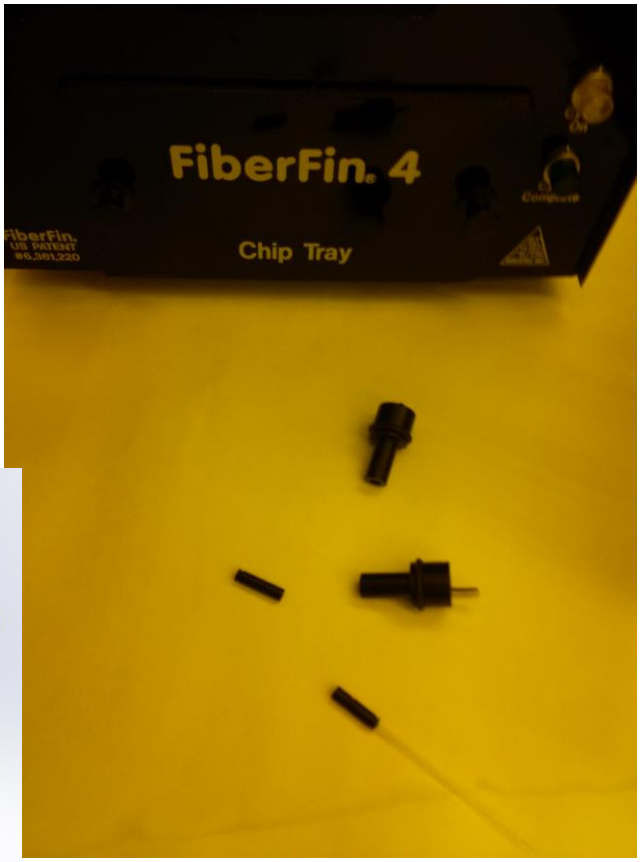
FiberFin4 Diamond Tool fiber finisher. Read manual to formularize safe operations procedure.

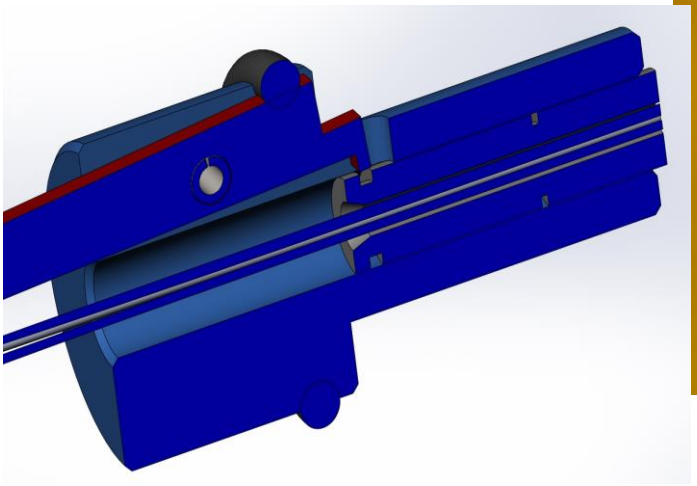
Set up in Lab3 Clean Room in UV protected area.

Place spacers under detector plane to minimize bending of the fiber/sleeves. Elevate to collet clamp in face of FiberFin.

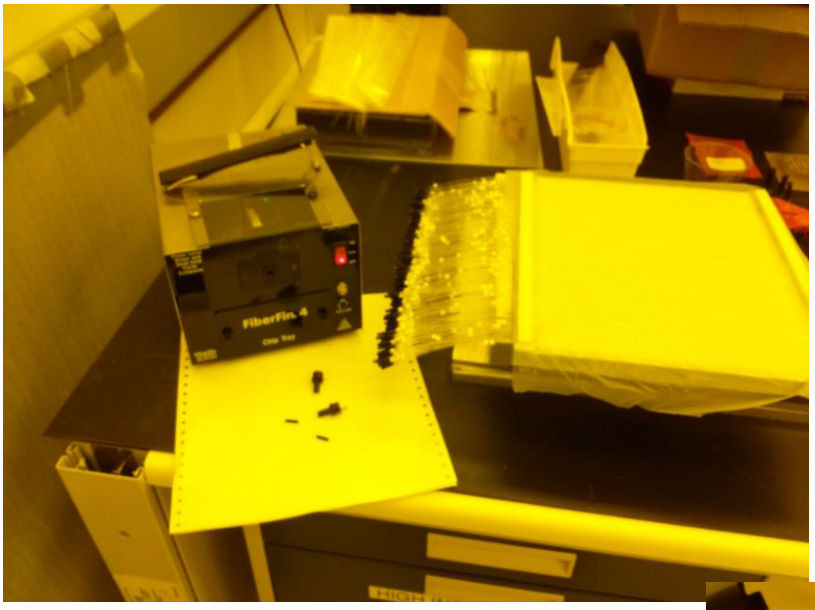
Two sets of collets are available. Note 'nose' lengths, one is shorter and the other is longer, Image right.

Image below shows fiber/sleeve engagement in FiberFin Collet. Metal arm pivots open to allow Delrin sleeve to slide thru inner bore to protrude slightly past Collet. Rubber O-Ring acts as spring to close latch into Delrin sleeve's notch to lock into position as in P3 Stockade.





Fiber Bundle/Sleeve repair: **Adjusting FiberFin diamond tool head stock**



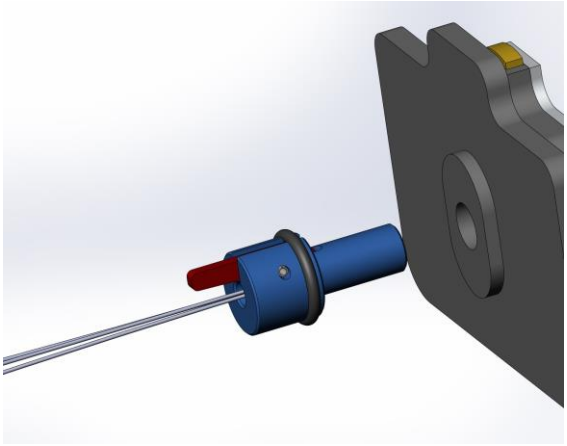
With Fiber Plane set up on spacers to bring fiber bundles even with cutting head. Prepare samples to adjust diamond tool depth to trim just to the face of the Delrin Sleeve.
As per instructions turn on FiberFin to warm up system.

With prepared samples, set Collet to be used for trimming with a cured EJ-500 'domed' fiber/sleeve.

As per FiberFin instructions; Allen-wrench adjustment sets travel amount in back of unit.

Back travel out, to begin each day's work.

With prepared sample fiber/sleeve inset collet and sleeve into FiberFin collet clamp. Keep pressure on collet until operation lever is activated which then clamps collet into place.



Fiber Bundle/Sleeve repair: **trimming 'dome' to finial finish**

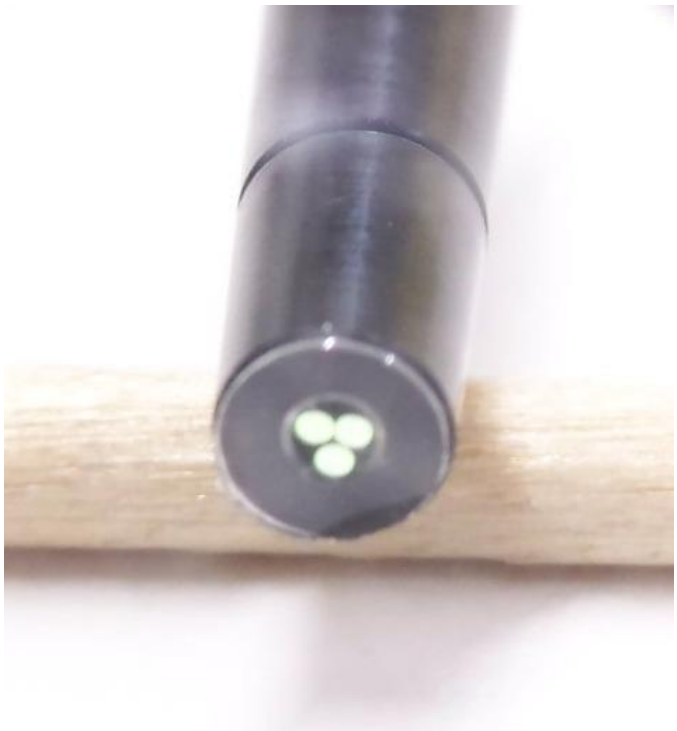
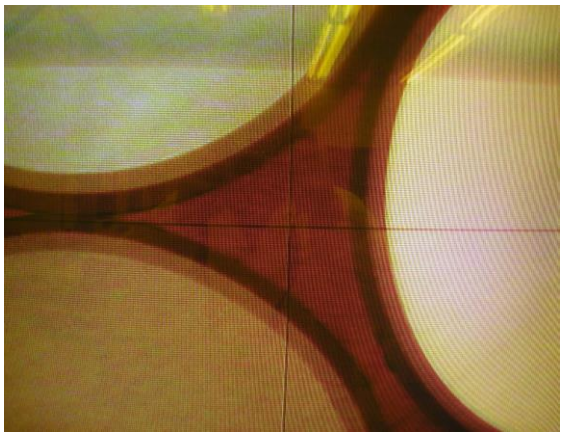


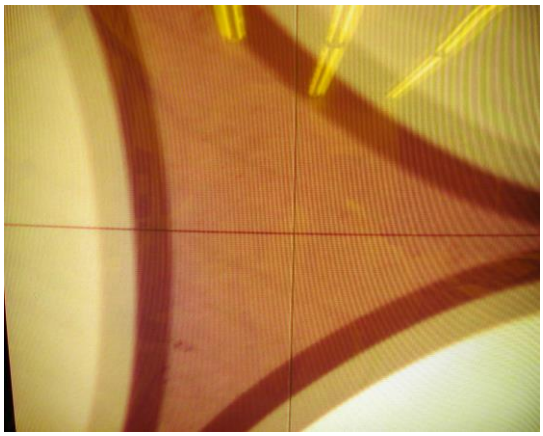
Image left shows EJ-500 clear epoxy 'dome' sample trimmed down to near the level of black Delrin surface.

Adjust FiberFin to trim to the Delrin surface and then test one more sample.

Keep in mind, you can take too much material off, and thus exceed tolerance of Mylar Spring Sheet which then would not press fiber/bundle against SiPM and loose light signal.

Small adjustments are wise.





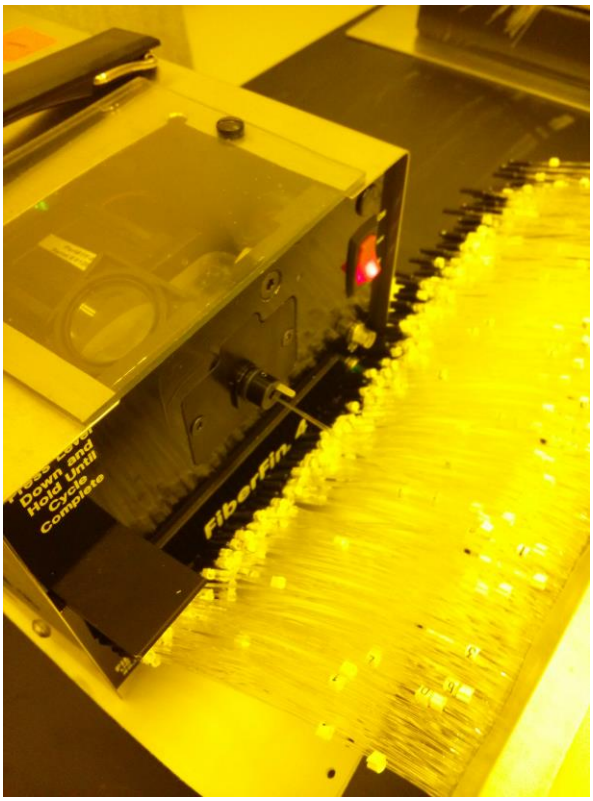
Images of repair above view on Microscope show EJ-600 fill-in and FiberFin finish. Uniform fill in voids

Fiber Bundle/Sleeve repair: **finishing 'domed' fiber/bundles on detector plane**

With sample Fiber/Bundle Sleeve set in Collet and satisfied with adjustments, proceed with diamond polishing re-paired Sleeve ends.

FiberFin should be positioned as to not stretch fibers to the cutting head; besides damaging fibers the stress would affect planarity by causing a slight angle in the Collet to the diamond during polishing.

Refer to image in previous page as to acceptable finish.



Fibers damaged during P3 polishing that were broken below Dlerin Sleeve can also be repaired in this manor with EJ-600 clear epoxy. IF the damage is not excessively deep the Delrin Sleeve can be 'pushed' to trim the Delrin, EJ-600, fibers deep enough to recover.

Extremely deep broken fibers can only be repaired with the clear epoxy and re-polished to enable partial light transmission to recover.

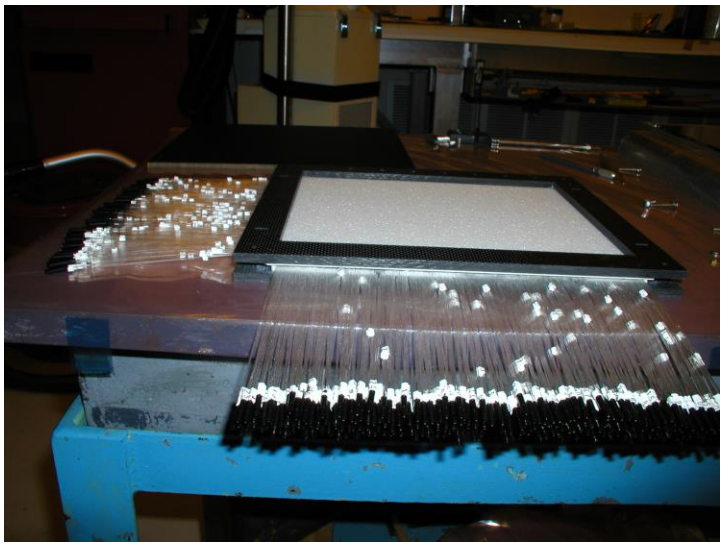
Assembling two planes together

On steel surface plate, carefully assemble the two planes together. Refer to assembly drawings to note beam direction and fiber orientation.

Wise to place Teflon film on each Poly surface to do this check. Any trimming of Floating Techtron Bars can be done if planes do not fit together on first attempt.

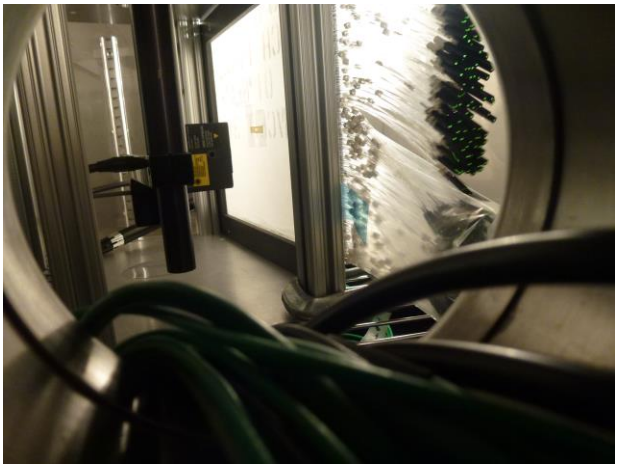
Check for flatness with flash light, no obvious gaps, even spacing all the way around. A thickness gauge can be used to measure from top of CF to steel table.

Since a Jig Plate was used to align Floating Techtron Bars in previous steps, two planes meshed without any need to trim materials.

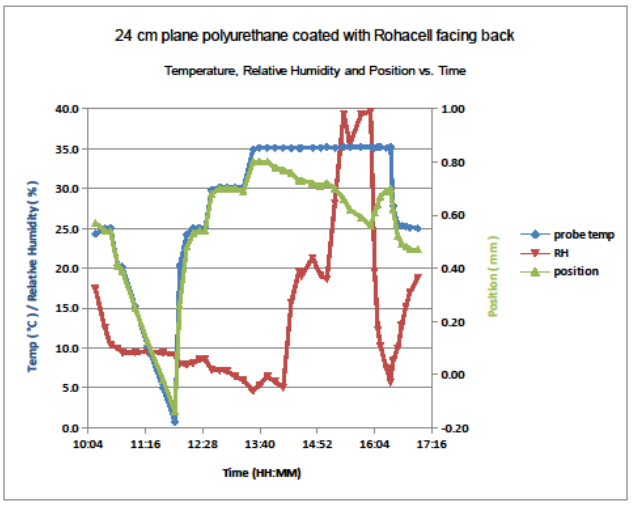


Be sure Teflon film is removed between planes. Proceed to bolt planes together. Follow Assembly Drawing to install spacers and set threaded rods to proper lengths

Environmental Testing



24 cm polyurethane coated plane environmental test was conducted in a Thermal/Relative Humidity controlled chamber. A Keyence Laser is set up to measure displacement movements inside of the test chamber. Fiber plane is clamped to a structure with lase focused in center with a target on Rohacell for a series of tests.

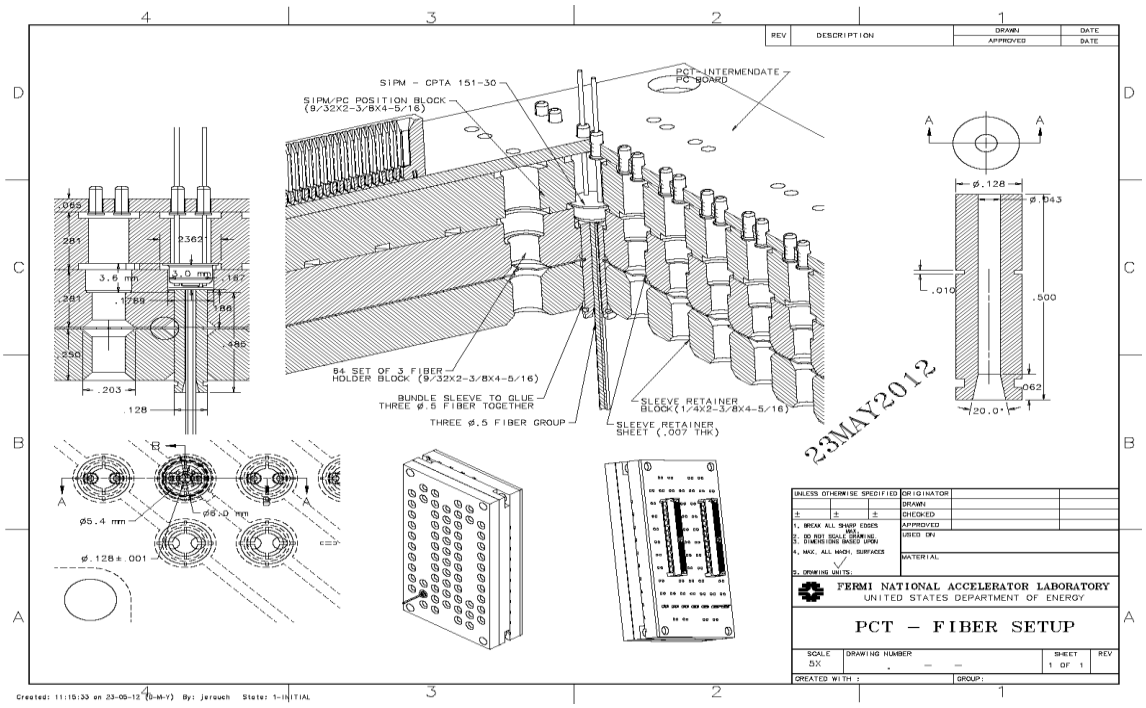


There was no visible delamination at any point

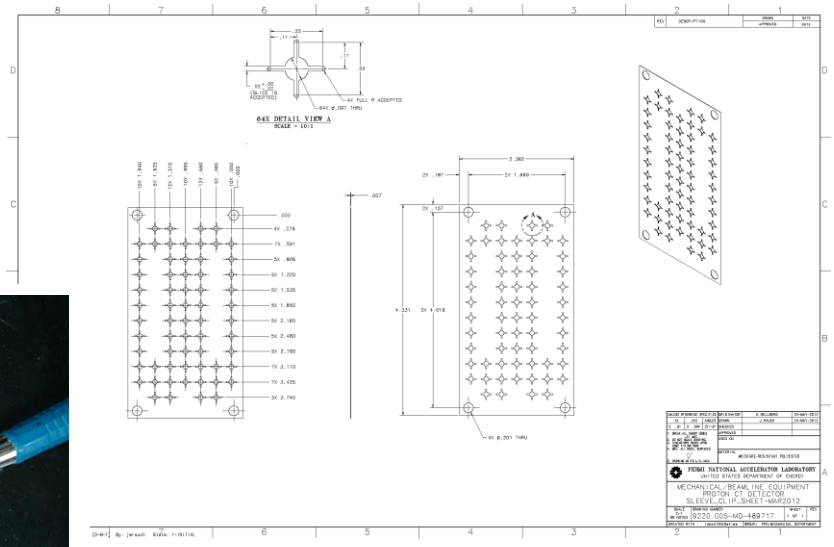
In the first run, with the rohacell side facing the back of the environmental chamber, the conditions ranged from 0 degC and 9% RH to 35 degC and 40% RH. The plane bowed inward into the frame when cooled below assembly temperature, and it moved in the opposite direction above assembly temperature, until humidity was added. Humidity caused it to move back inward by a moderate amount. After 50 minutes at 40% RH, even though the plane had not stabilized, the run was terminated by lowering humidity and temperature back to the starting conditions. At the end of the run the plane returned to within 60 um of the starting point, and it did not change over night. Roughly 50 um of position uncertainty could be attributed to an intentional looseness of one of the plane mounting constraints.

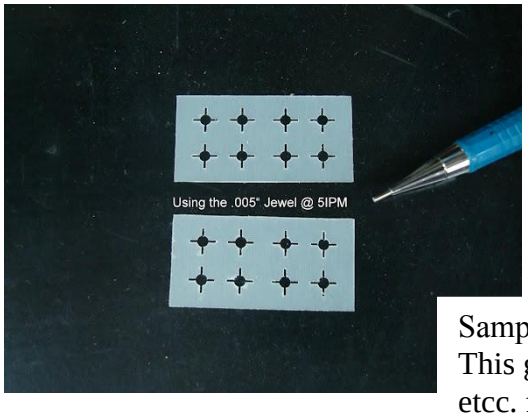
In the second run the plane was turned so the rohacell faced the front of the chamber, and the range was extended to 40 degC and 40% RH at the end. The plane response was similar to the first run up to 35 degC, except that when humidity was added there was no movement at 35 degC. Humidity was held at about 40% as the temperature was increased from 35 to 40 degC. This temperature increase was done in two steps, first briefly to 37.5, then to 40 degC. The plane appeared to be moving slightly inward at 37.5 degC. When the temperature was increased to 40 degC, the plane immediately began a relatively large movement inward. After an hour it had moved 0.9 mm, but was well short of an endpoint. The run was terminated by lowering RH and temperature to the starting point. The plane returned to within about 80 um of its starting point.

Our largest concern is the interface of the single SiPM and the Three Scintillation Fibers Bundle. Electronics Hardware set the number of SiPM's to optimize Fiber Bundles at 64 which is an even integer agreed upon both by mechanical and electrical groups.



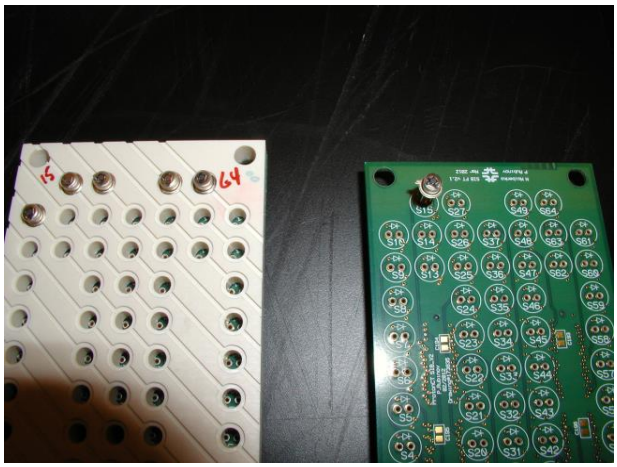
MD-489717 Sleeve Clip Sheet is a 7mil thick Mylar sheet cut on a Water Jet machine locally. Image below are sample cuts from vendor.



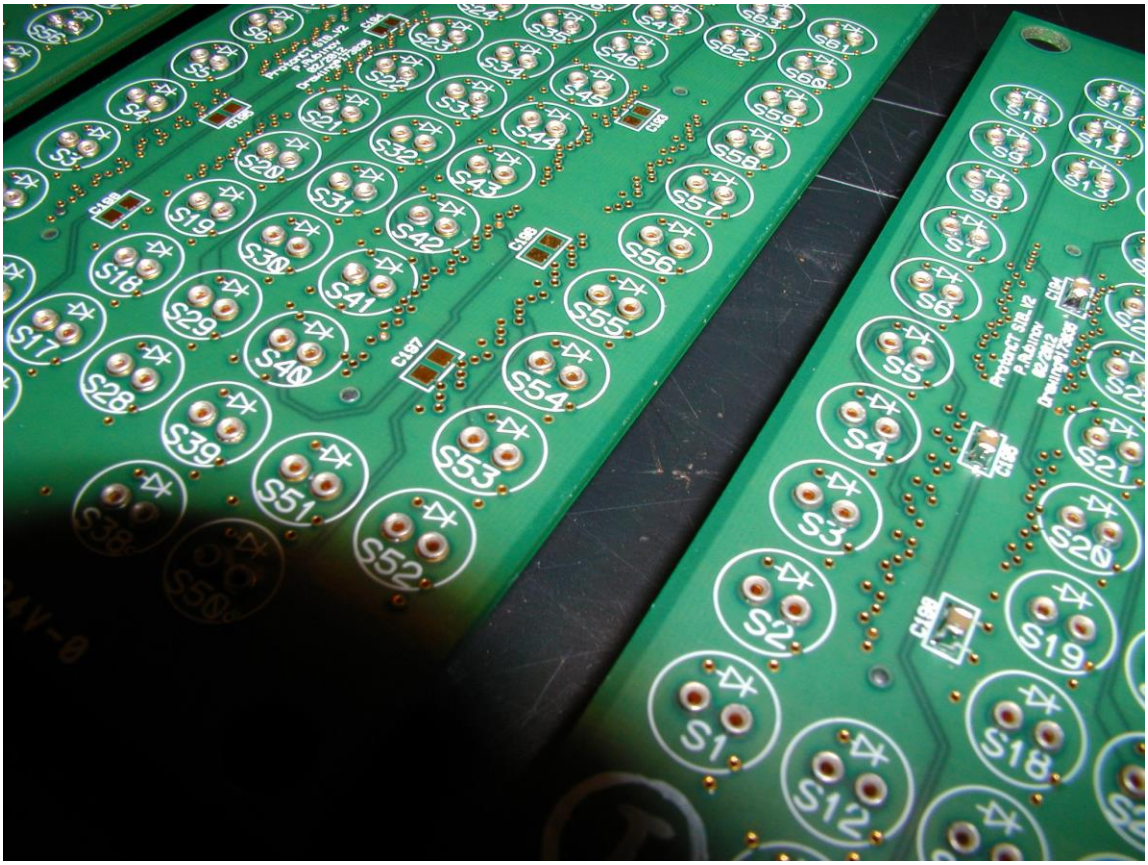


Sample features were made with a 0.005" jewel orifice. This gave the best results from varying size, psi, feed rate, etcc. from vendor.

64 Channel SiPM Block:



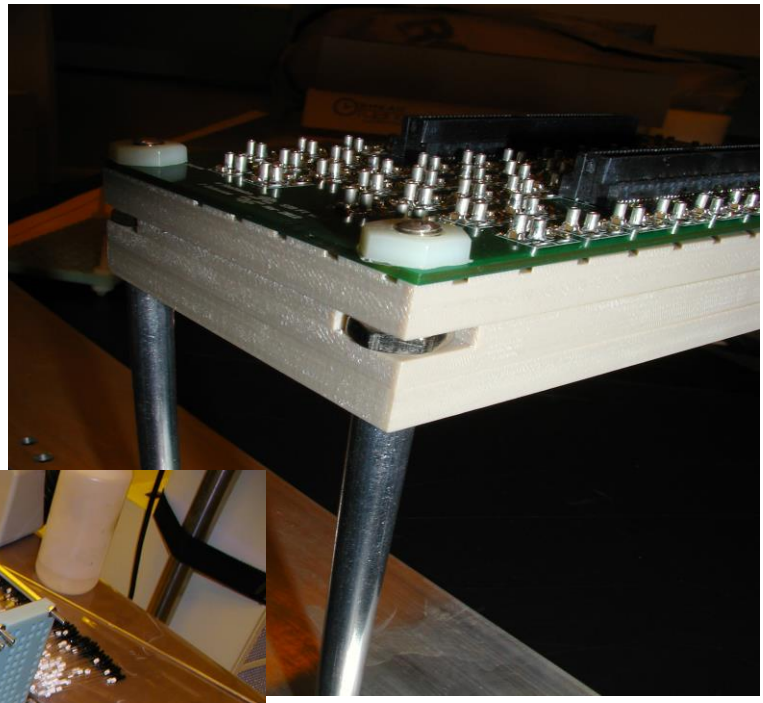
64 Channel SiPM block consisting of three Techtron parts. Image left shows SiPM Techtron Block next to a SIB Board. A SIB Board is positioned beneath the Techtron, selected SiPMs' are inserted in thru Techtron, note 45' slots that register polarity of SiPM to SIB electronics. Double check polarity direction with EEs' for correct direction, many up grade iterations may reverse polarity.

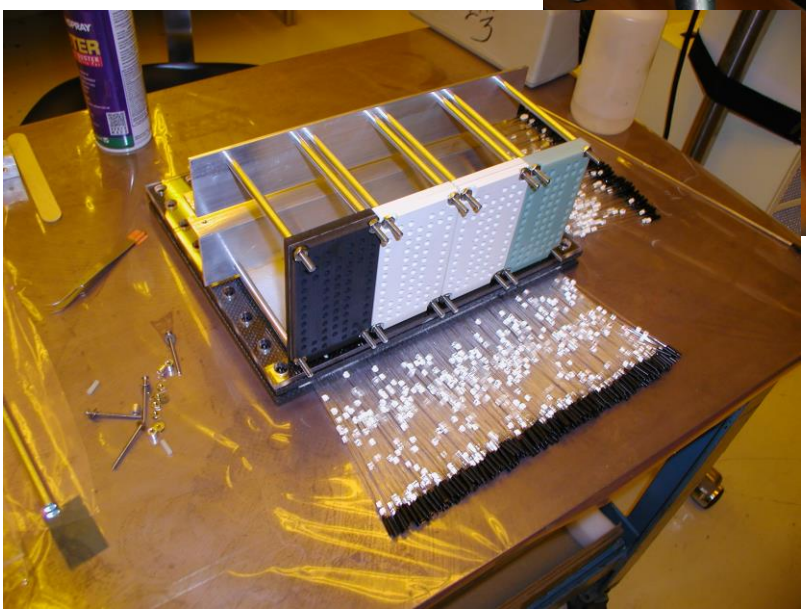


64 Channel SiPM Block:

Three Techtron Blocks, Mylar Spring Sheet, and SIB Electronics Board are assembled for test fit on aluminum stand-offs.

Pre-Production limitations on materials and electronics for beam test limited number of actual numbers of channels capable of reading out detector.



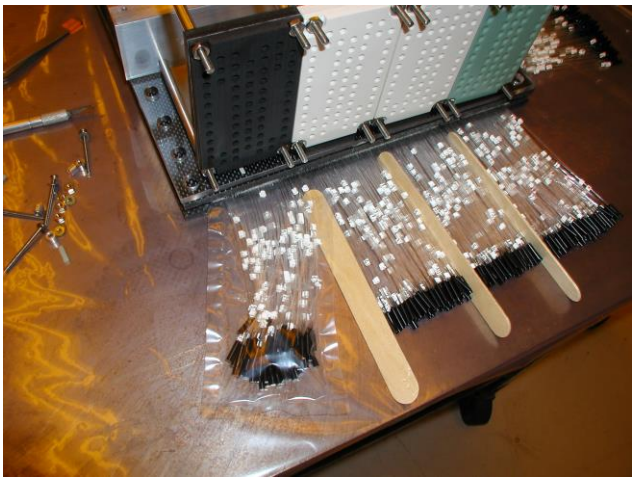


Once each set of 64 Channel Techtron are aligned correctly, SiBM block and SIB Board are removed.
Each pre-assembled SiPM Block is mounted onto the aluminum angles as seen in image left. White SiPM blocks in center are Techtron, sides are black Noryel and green 3D printed concept demo, ABS like material.

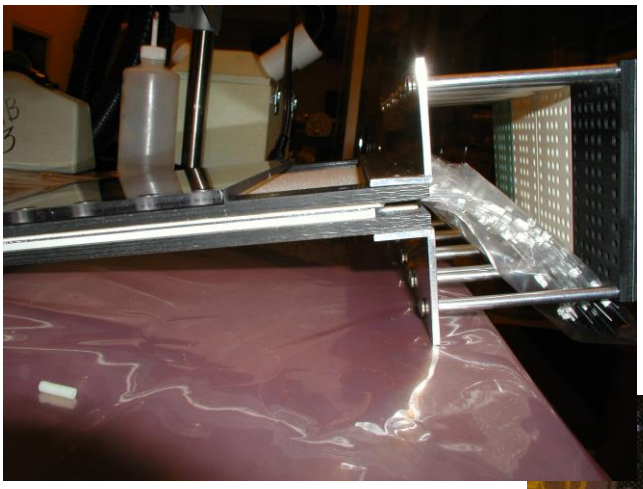
Image right shows fibers being segregated to match corresponding 64 Channel Blocks.

Plastic bags are slipped over the section of Fiber/Sleeve's to protect the polished fibers ends.

These fiber ends are extremely delicate and damage to these polished ends will diminish light transmission to the SiPM's.



64 Channel SiPM Block:



With subassembly aluminum angle slid over detector plane and aligned to two of four corner holes, threaded rod and spacer can then be installed

64 Channel SiPM Block: Fiber Bundle to ADC Channel

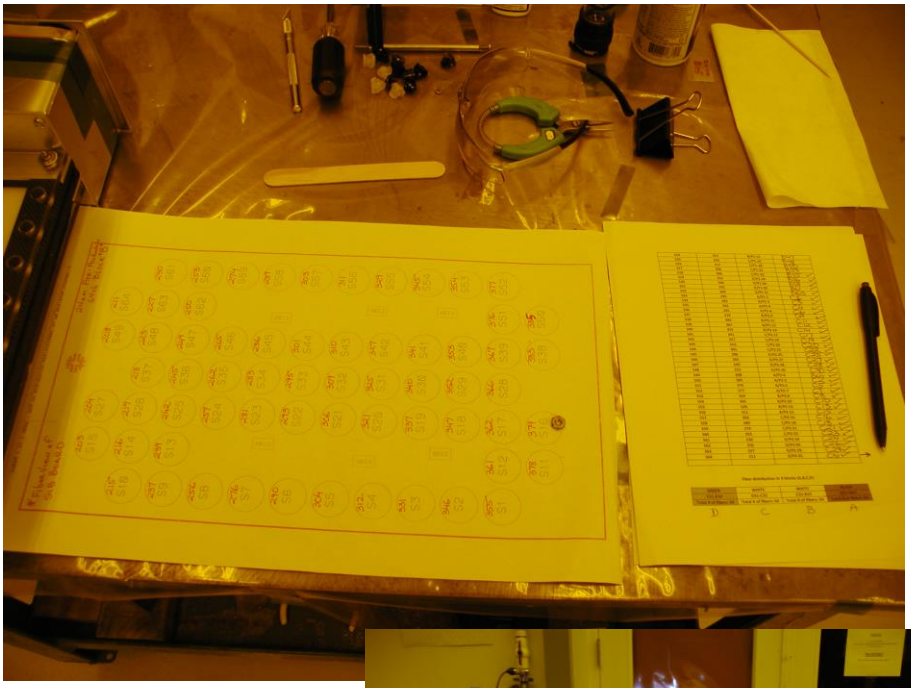
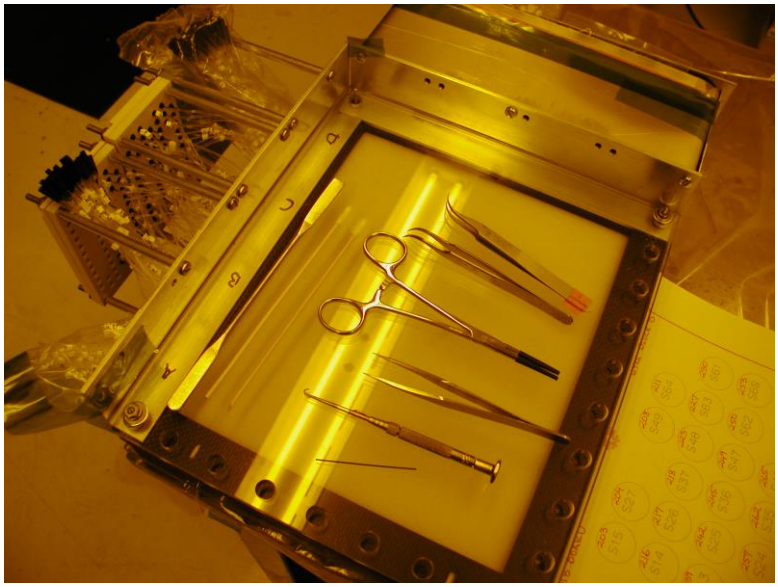


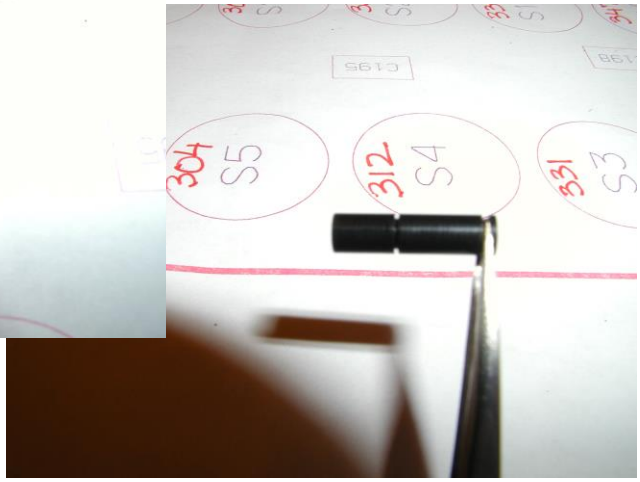
Image above shows ADC/SiPM assignment of 64 Channels for each SiPM Techtron Block.

Two people are required to aid in proper Fiber Bundle channel assignment.

64 Channel SiPM Block: Insertion Tools



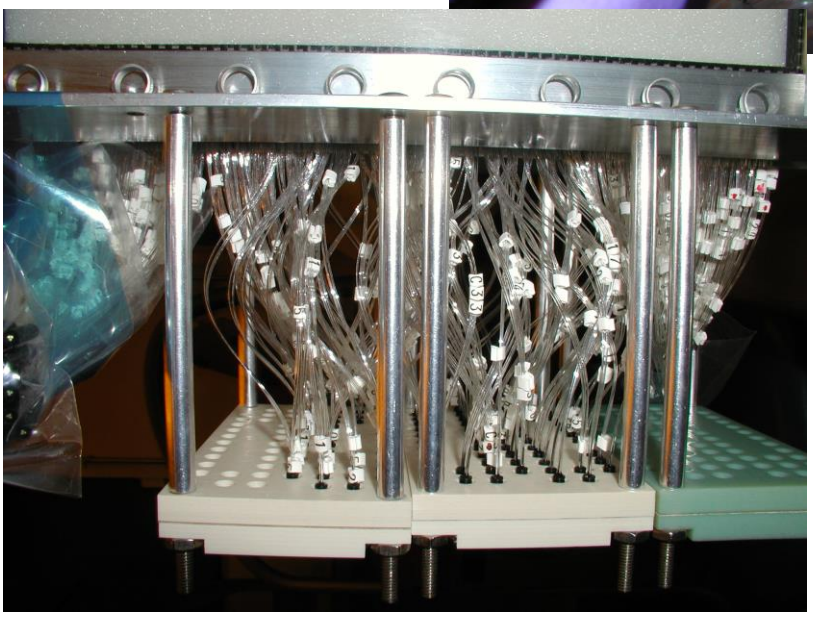
Fiber Bundle Insertion Tools are laid out on top of protective Lexan Cover, to show tool type.



Tweezers above were ground to firmly grasp large groove in fiber end black Delrin Sleeve. This allows for necessary manipulation of Fiber Bundle Sleeve to position into proper channel assignment.

64 Channel SiPM Block: Fiber Bundle Harvesting Tools

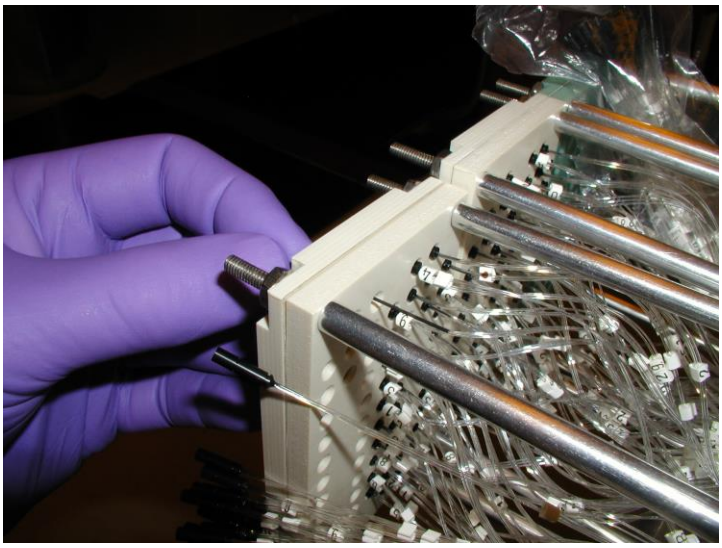
A Scribe modified with a smooth hook on end aids in harvesting the next labeled Fiber Bundles.



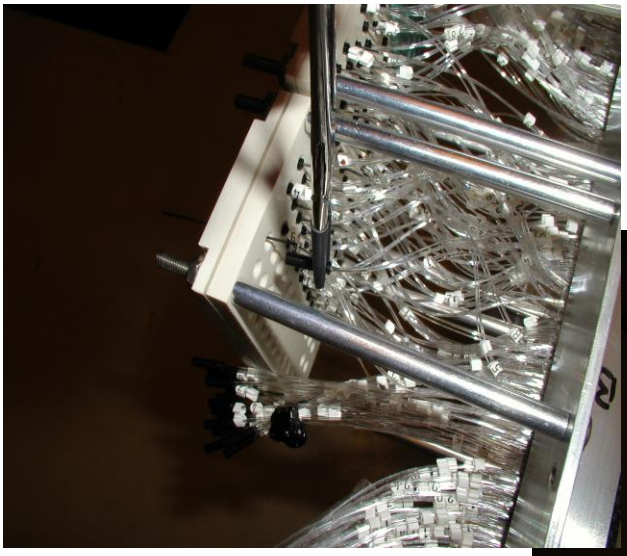
Starting in center of a 64 Channel Block greatly aids in Fiber Sleeve insertion and working out wards.

Double check fiber assignment continually, finding wrong sleeve to SiPM Channel once completed is difficult to correct afterward.

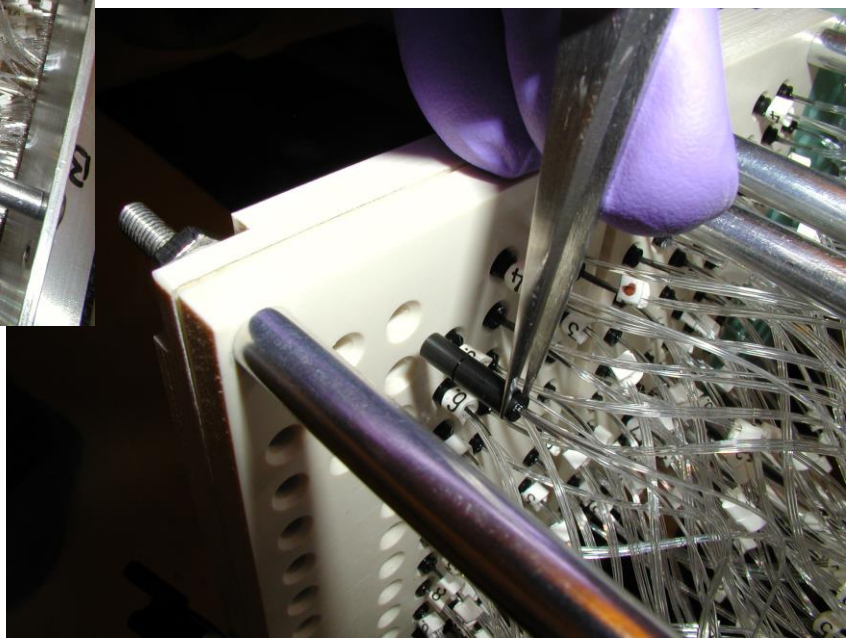
64 Channel SiPM Block: Insertion Tools



When a SiPM Channel is called out for next labled Fiber Bundle, a short plastic fiber is used to insert from front to back to aid in identifying SiPM Channel.



Padded Forceps' or modified Tweezes can be used to insert black Delrin Sleeve into proper SiPM Channel.

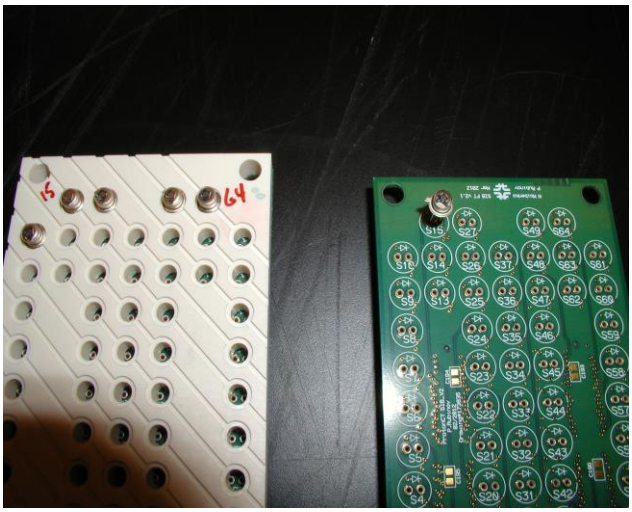


64 Channel SiPM Block: SiPM SIB Board Assembly

We will be receiving fully populated and tested SIB Boards from Electronics Group.

As seen in right image, slots in Techtron board allow rotation of SiPMs' tab for matching polarity on SIB Board.

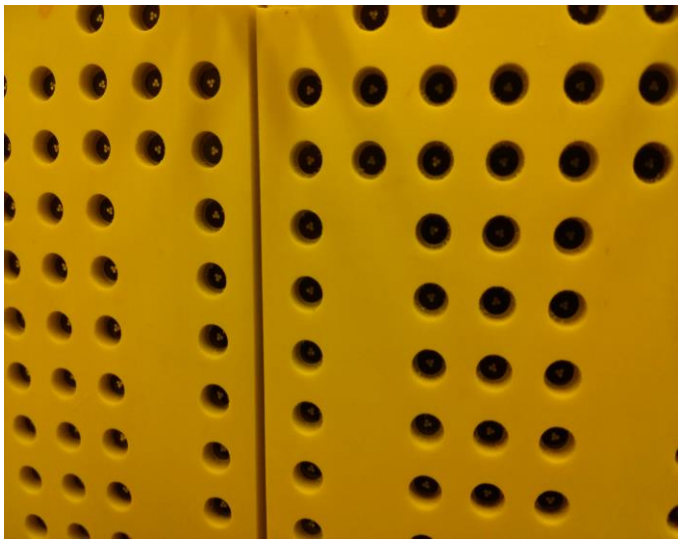
The SiPM is matched and recorded on each channel in a Traveler.



Designated SIB Board is then installed on detector plane to complete each 64 Channels.

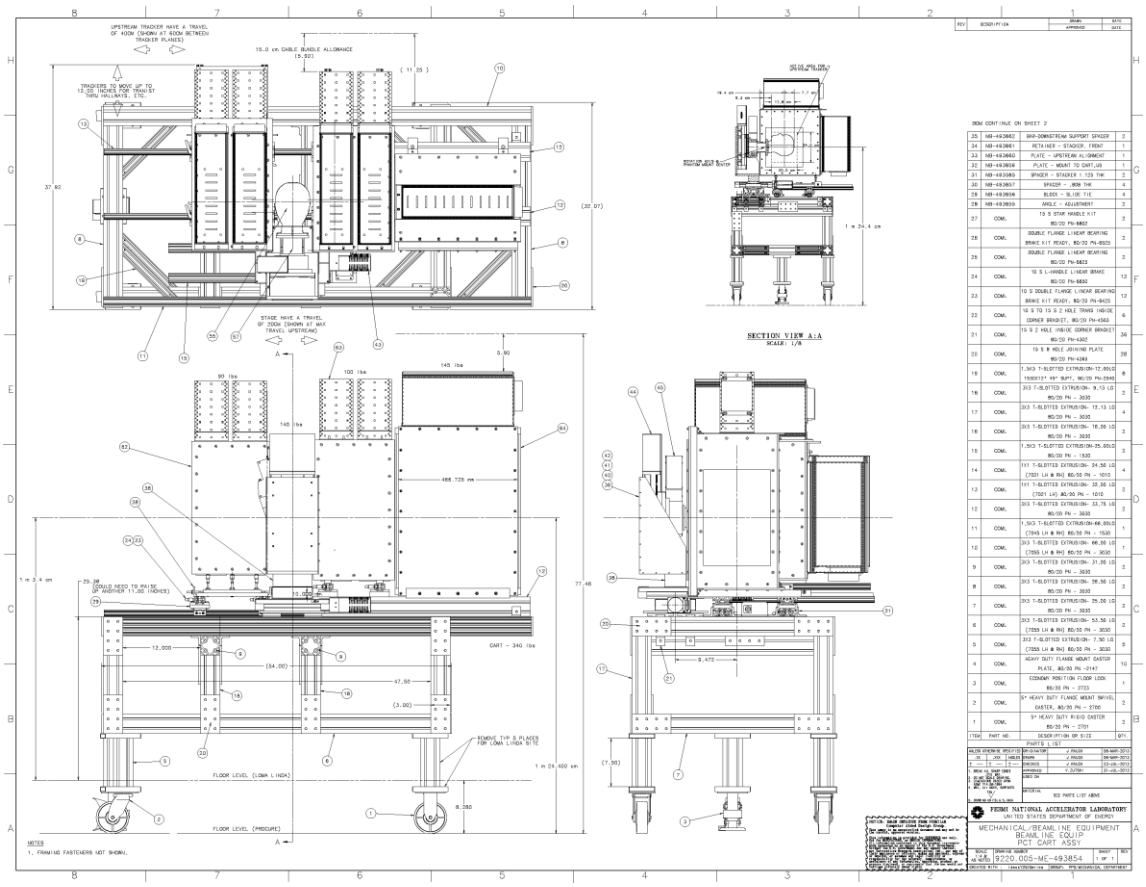
A small amount of wiggle during installation aligns 64 independent SiPMs' into mating Fiber Channels'.

A small amount of pressure is needed to apply contact force against the Mylar spring to provide constant contact against 64 Fiber Bundle Sleeve. Four nuts are then installed to secure assembly.



Scintillation Fibers in black Delrin Sleeves can be seen in Techtron board, as SiPM assembly is inserted into place.

Cart Assembly: 80/20 Aluminum Design



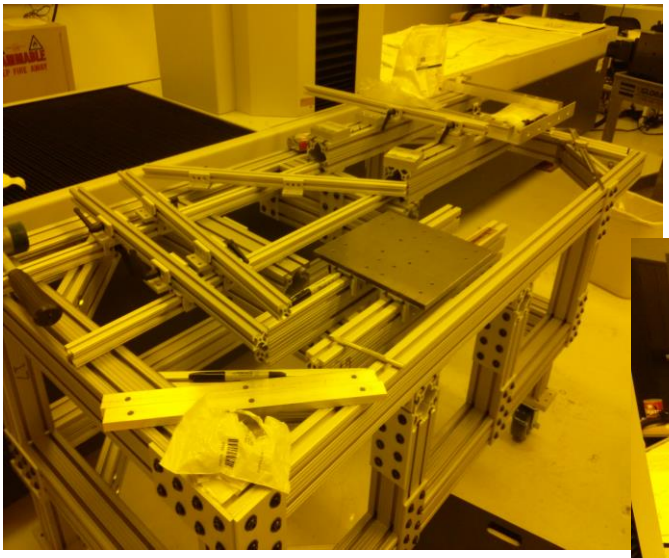
Design criteria needed to be able to deliver to patients' treatment rooms at different facilities to position in various beam Heights.

Space between patients' articulated table and Proton delivery head is measured to insure roll in fit, also door way widths and hallway turns are measured.

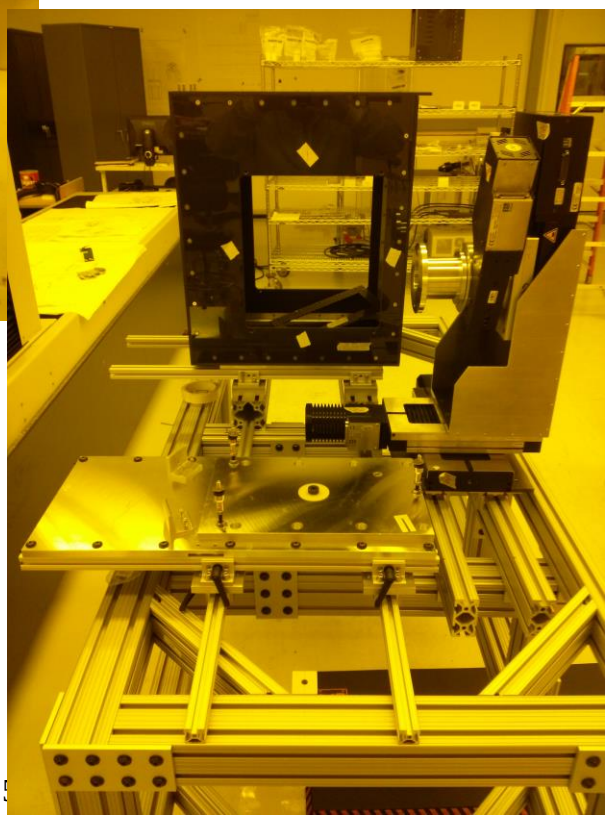
Cart Assembly: 80/20 Aluminum Assembly

Design of a stable mobile platform to position our pCT detectors on was assembled in the Fermi Lab's Lab3 Clean Room.

Students take delivery of 80/20 pre-cut aluminum extrusion inventory and label each part as per drawing.
Lower section assembled upside down to install wheels then flipped right side up.

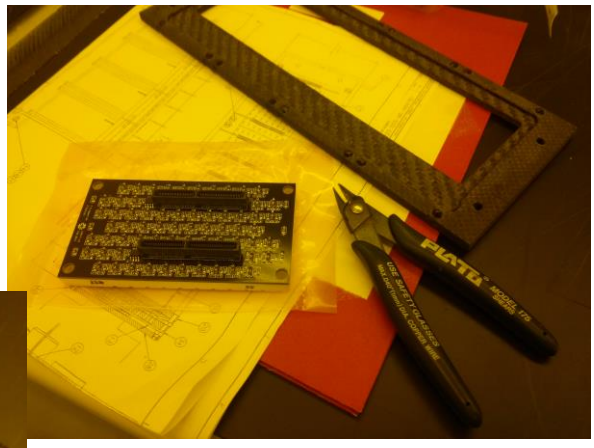


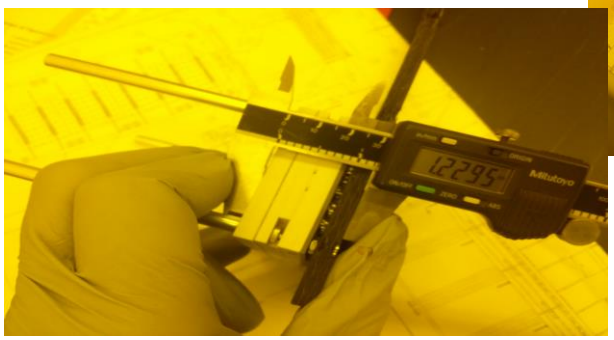
Positioning rails are installed along with Carbon Fiber Dark Boxes to test fit.



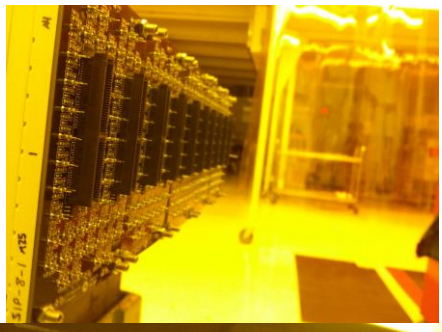
Cart Assembly: Carbon Fiber Dark Boxes

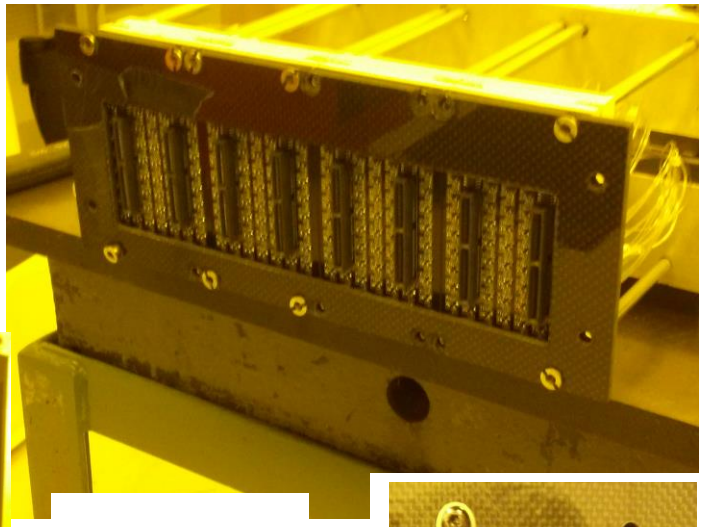
With limited space between SiPM Board and the CF/SiPM Alignment Frame we found the outer SiPM Leads need to be trimmed to allow CF/Frame to fit to design height.

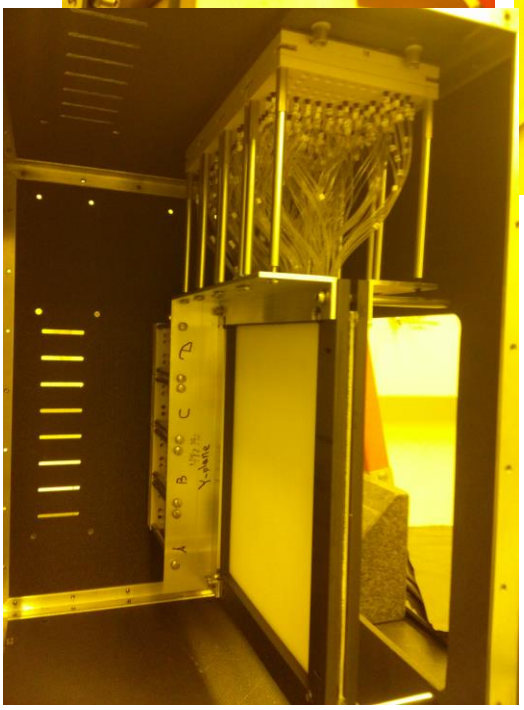




CF/Frame is then fitted to SiPM blocks. This CF/Frame insures alignment to CF/DarkBox Pad-e read-out boards which are inserted in crates externally on DarkBox.

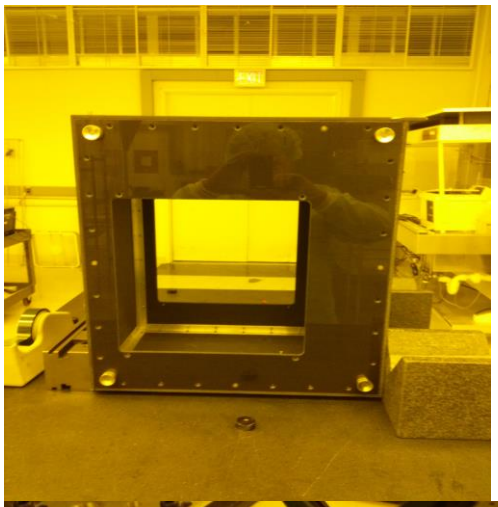




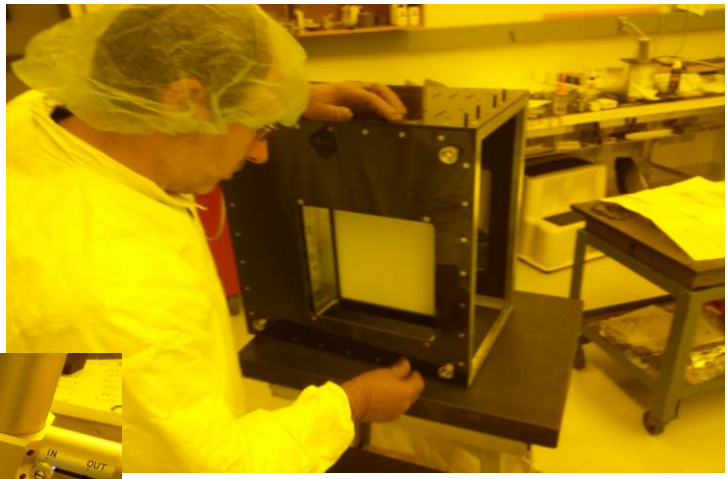


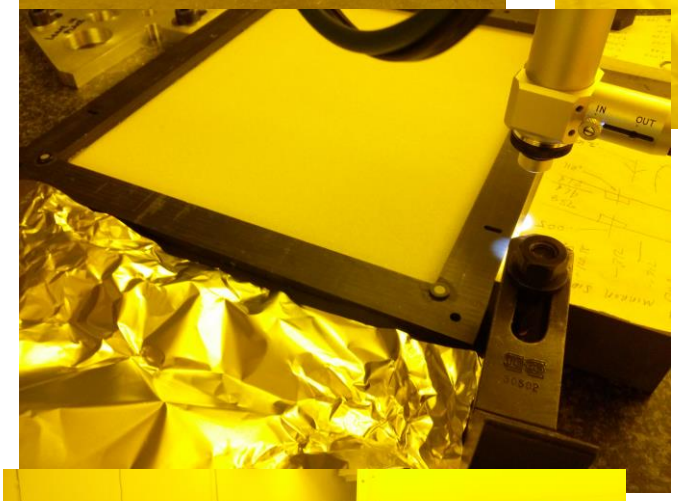
View of assembled detector inside of CF/DarkBox. Pad-e boards are then inserted to check fit. Any modifications are then done to tweak slot fit to each SIB Board.

Cart Assembly: Alignment of detector pairs to DarkBoxes

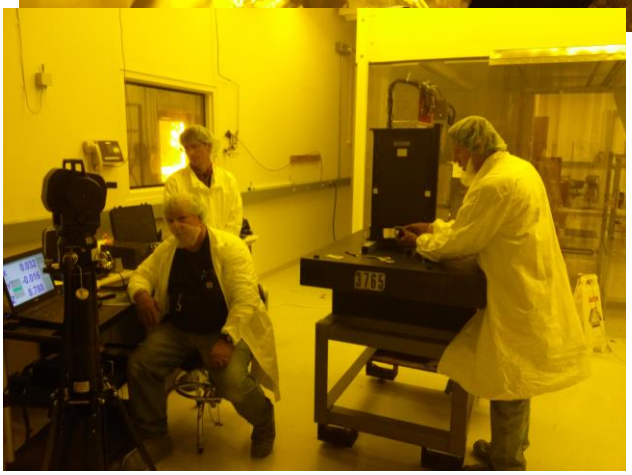


Laser Scan metal mounts are installed on exterior of CF/DarkBox faces, and surveyed in with laser system, left image





With data from Cordax CMM recorded earlier, FNAL Survey Group imports X and Y axis fiber position relative to four photogrammetric targets placed in CF/Detector Frames. These targets are viewable through DarkBox aperture windows. Image left.

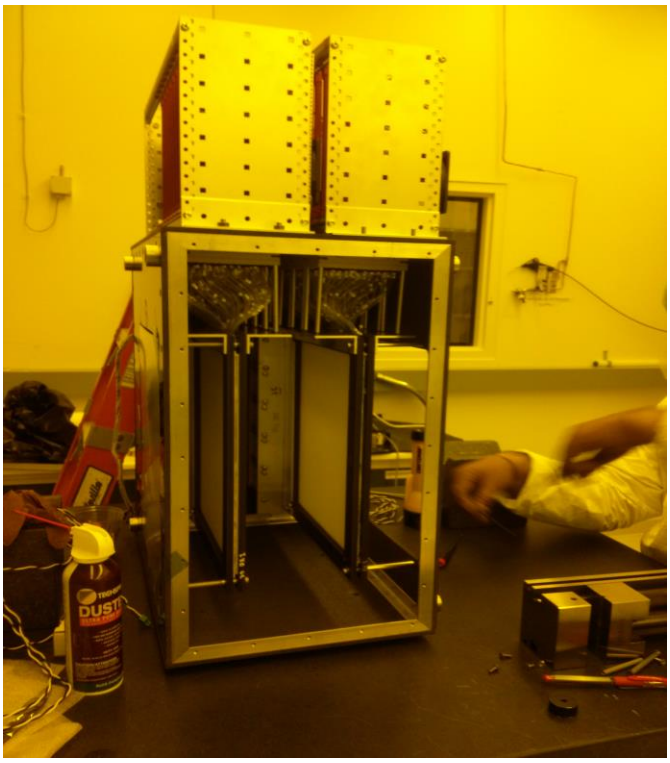


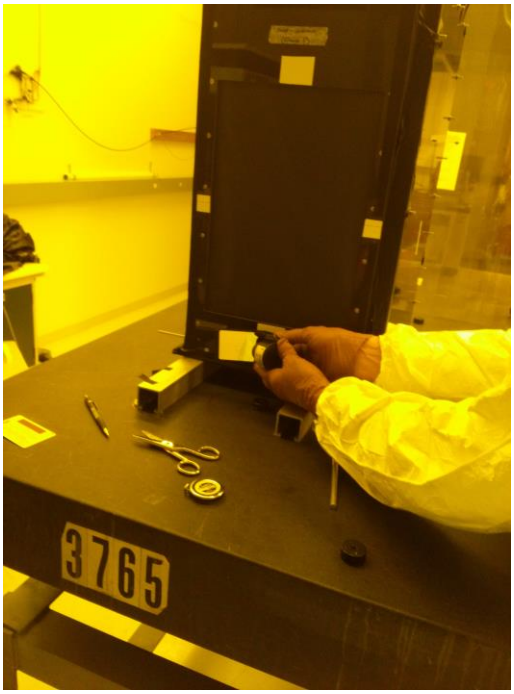
With detector planes installed internally in DarkBox and placed on granite block, Laser Tracker then measures imported data from Cordax CMM and globally to exterior of DarkBoxes metal Laser Scan target holders.

Image above left, is Calorimeter being measured with this system. Surveyor is scribing Beam Center Line (CL) data on face surfaces as reference scribes.

Cart Assembly: Alignment of detectors pairs to DarkBoxes

Detectors are fitted inside Dark Box for fit to insure Pad-e read out board and electronics crates align to 64-Channel SIB Boards, on a granite block. Note target holders glued to surface plate as reference target holders.



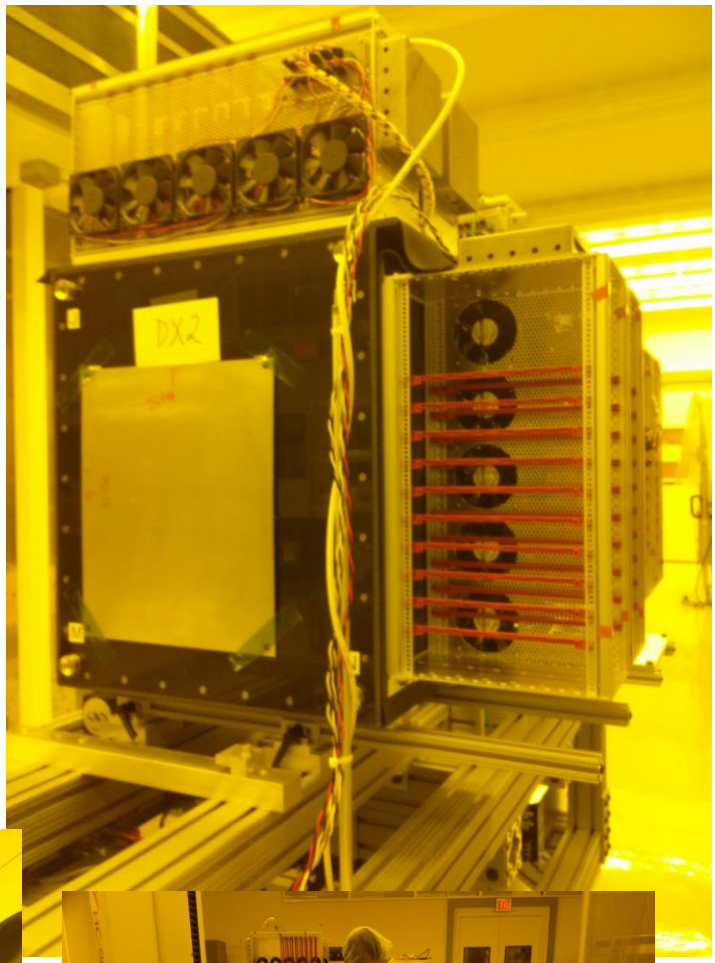


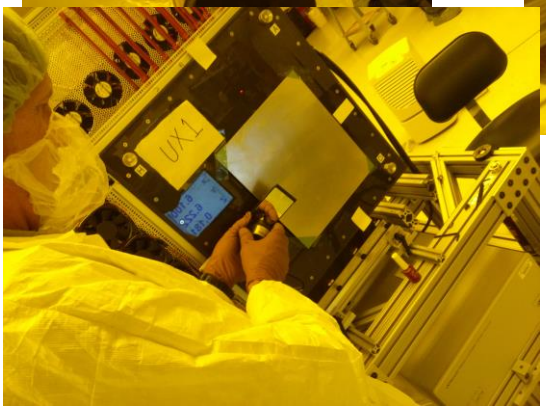
After Laser Tracker identifies Photogrammetry targets on CF Frame and links them to metal Laser Tracker targets externally, scribe lines are then placed on the exterior of Dark Boxes to aid in aligning cart at CDH's treatment room. Image above left is Calorimeter.

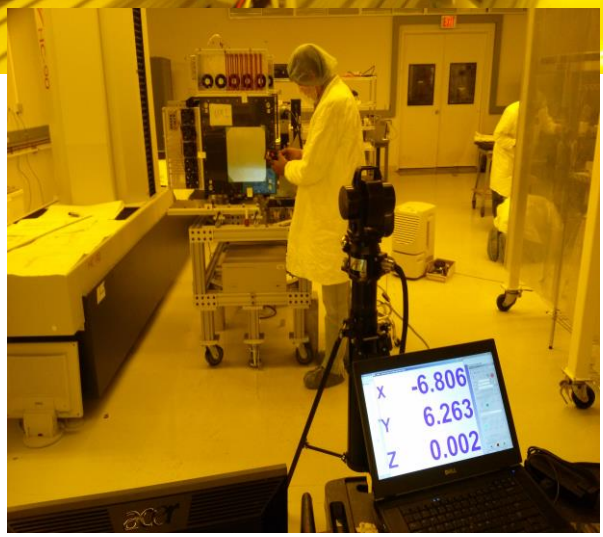
CDH has a laser alignment system that is used to indicate Proton Beam location.

Cart Assembly: Alignment of DarkBoxes to 80/20 Mobile Cart

Survived Down Stream Dark Box is mounted to rail system. Rail systems were previously aligned to CDH Beam CL,as per Cart Assembly Drawing.

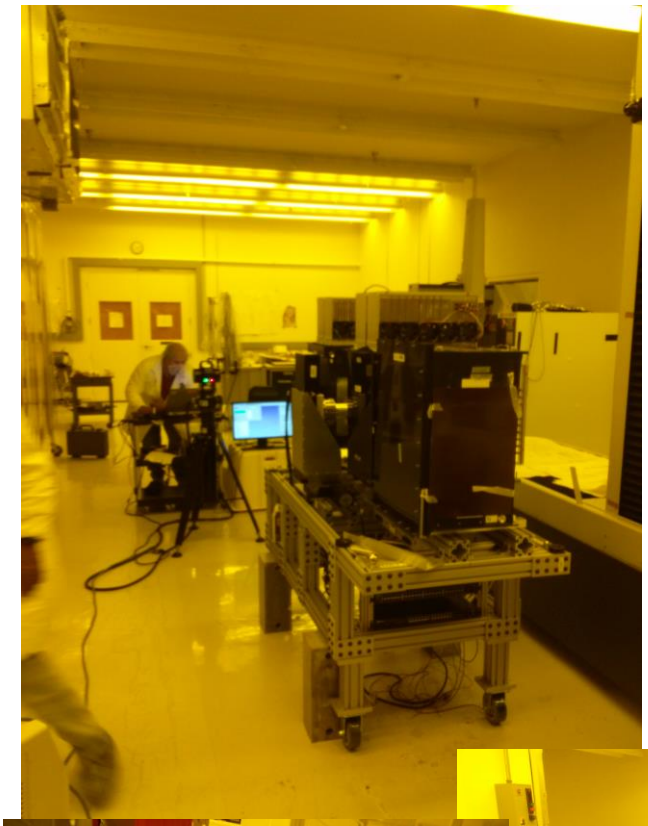






Alignment is double checking DBox positions and rechecking scribe lines for CDH Laser alignment.

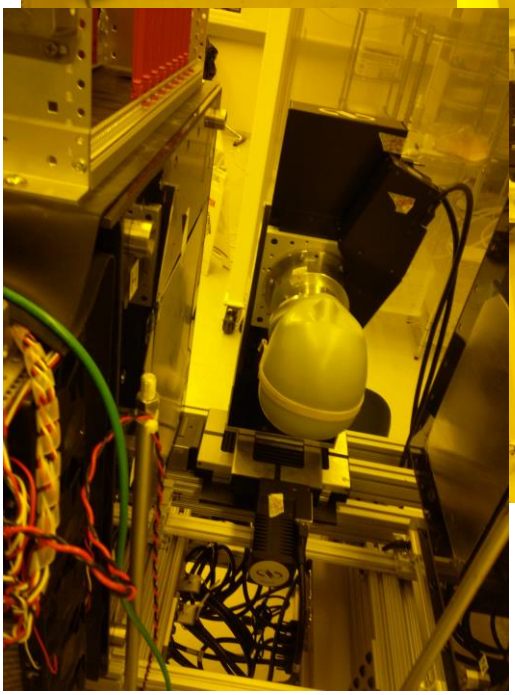
Cart Assembly: Alignment of DarkBoxes to 80/20 Mobile Cart



Multiple setups were shot to insure alignment of all the detector elements were set to CDH beam line as per Cart Assembly drawing dimensions.

Four Axes Stage with Phantom is being prepared to aligned.

NIU brought in the stage controller to place Stage and Phantom in it 'Null point' to then be physically moved by hand to Beam Center.



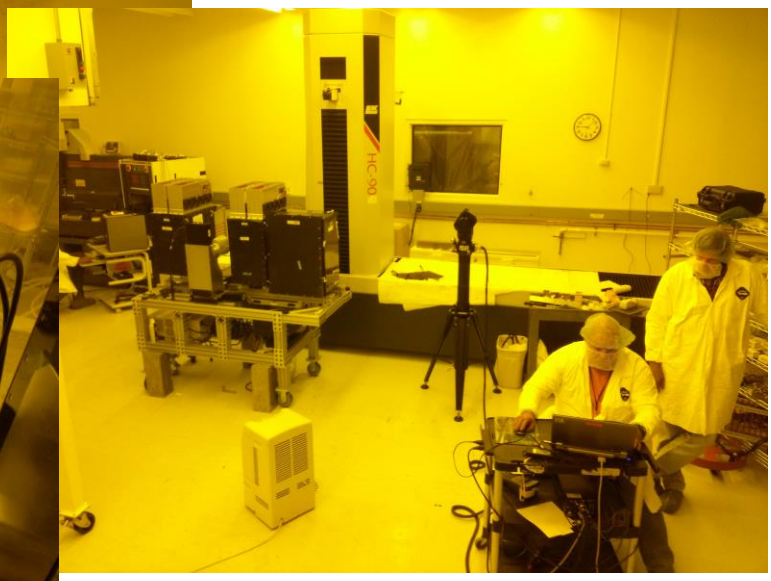
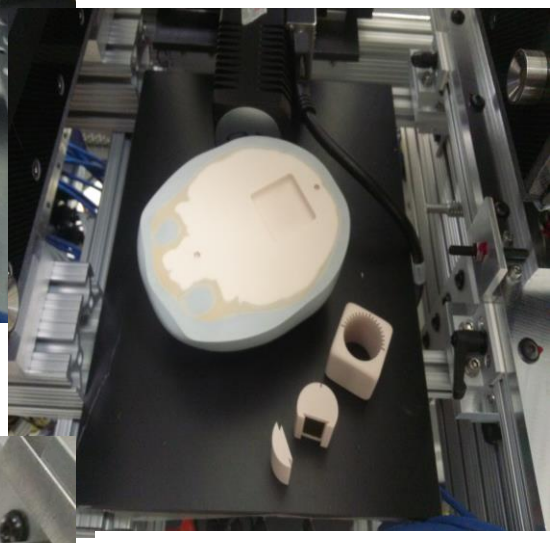


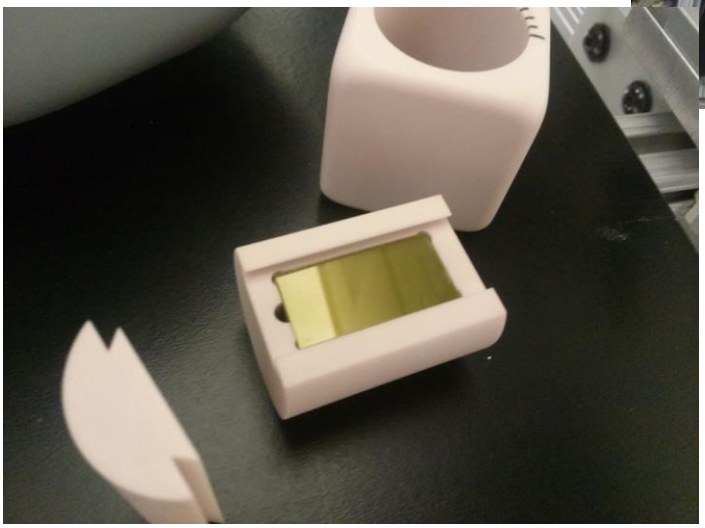
Image left, shows Phantom mounted on rotary and an elevation stage.
Phantom's cranium head top contains containers to evaluate detectors ability to view items as head is rotated in beam.

Cart Assembly: Alignment of Phantom and four axes stages to 80/20 Mobile Cart

When servicing internal items in cranium of Phantom, place a board beneath head to prevent parts from falling and providing a work surface.

With Phantom's elastic band released internal items can be then removed and opened.





Cylinder contains multiple slides. Take care in preventing chipping during maintenance.

Take note of Cube which has degree dial, to clock cylinder back to its position when reassembling.

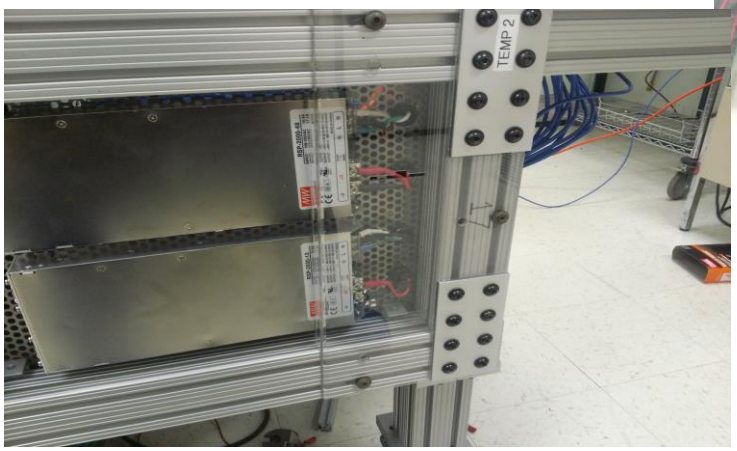
Cart Assembly: Move cart to Lab3 Humidor Room

Cart is now assembled and surveyed which now will allow power supplies and wiring to be completed in a more assessable room, and keep temperature and humidity controlled.

True unshielded light is evident in next series of photos, showing cleanrooms UV filter effect in lighting.

Do not remove covers from Dark Boxes, as exposure to UV will damage scintillation fibers.

12vdc and 48vdc power supplies secured to a sheet of perforated metal affixed to cart. A plastic shield blow image, is installed to not allow exposure to 115vac supply lines.



FNAL PPD/EE Group reviewed cabling of power distribution and signal cabling, comments were noted and changes made to NIU/pCT Cart.

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PCT Tracker Finite Element Model

Zhijing Tang
July 12, 2012

Finite element model is used to calculate the stiffness of the PCT Tracker design. This tracker is made of carbon fiber composite frame. There is a big opening at the center of the frame. A thin layer of rohacell foam is glued to the frame. At the two ends are two techtron blocks. There are tiny groves on the rohacell and techtron. Two layers of optical fibers are laid along these groves. Solid model is obtained from John Rauch. In the model, small holes and groves are neglected.

Fig.1 is our finite element model, and Fig.2 shows the blow-out. The carbon fiber weighs 219 g, rohacell 4.5 g, techtron 81 g and optical fiber 55.5 g. Total weight of the model weighs 360 g.

The model is supported at the four corners, as shown in Fig.3.

The material properties used in this model are listed below. The modulus of fibers is that of polystyrene. We use 3Gpa in fiber direction and 3 MPa in perpendicular directions.

material	Modulus (Pa)	Density (kg/m^3)	Poison's ratio	CTE (K^{-1})
Carbon fiber	45e9	1800	0.3	20e-6
rohacell	35.2e6	32	0.3	37e-6
techtron	3.45e9	1350	0.3	50e-6
Optical fiber (//)	3e9	1100	0.1	70e-6
Optical fiber (T)	3e6			20e-6

The displacement of the model under the action of gravity is shown in Fig.4. The maximum displacement is 0.45 mm.

If we rotate the gravity vector from z-axis towards y-axis, maximum displacement in z-direction changes as shown in Fig.5. Rotate gravity vector from z-axis towards x-axis, we get the similar plot as Fig.5. The displacements in the in-plane directions are much smaller. Fig. 6 shows the displacement ux when gravity vector rotate from z-axis towards x-axis. The maximum in-plane displacement is 9.3 μm. This displacement is caused by bending.

When there is a temperature change, additional displacement will be added. Fig.7 shows displacement uz similar to that in Fig.4, except we added a 10°F temperature load in Fig.7. Here the maximum displacement becomes 1.8 mm. This is more than three times the maximum displacement without temperature load.
Now we rotate the gravity vector from z-axis towards y-axis, we get maximum displacement versus angle, which is shown in Fig.8. We see clearly there is a snap-through. This is because the thermal expansion coefficient of the optical fiber is larger than that of from material. The temperature increase causes the tracker buckling.

If we rotate the gravity vector from z-axis towards x-axis, we get the similar result as that in Fig.8. The maximum in-plane displacement versus the angle between gravity vector and z-axis is plotted in Fig.9. Again, the in-plane displacement is much smaller than the out-of-plane displacement.

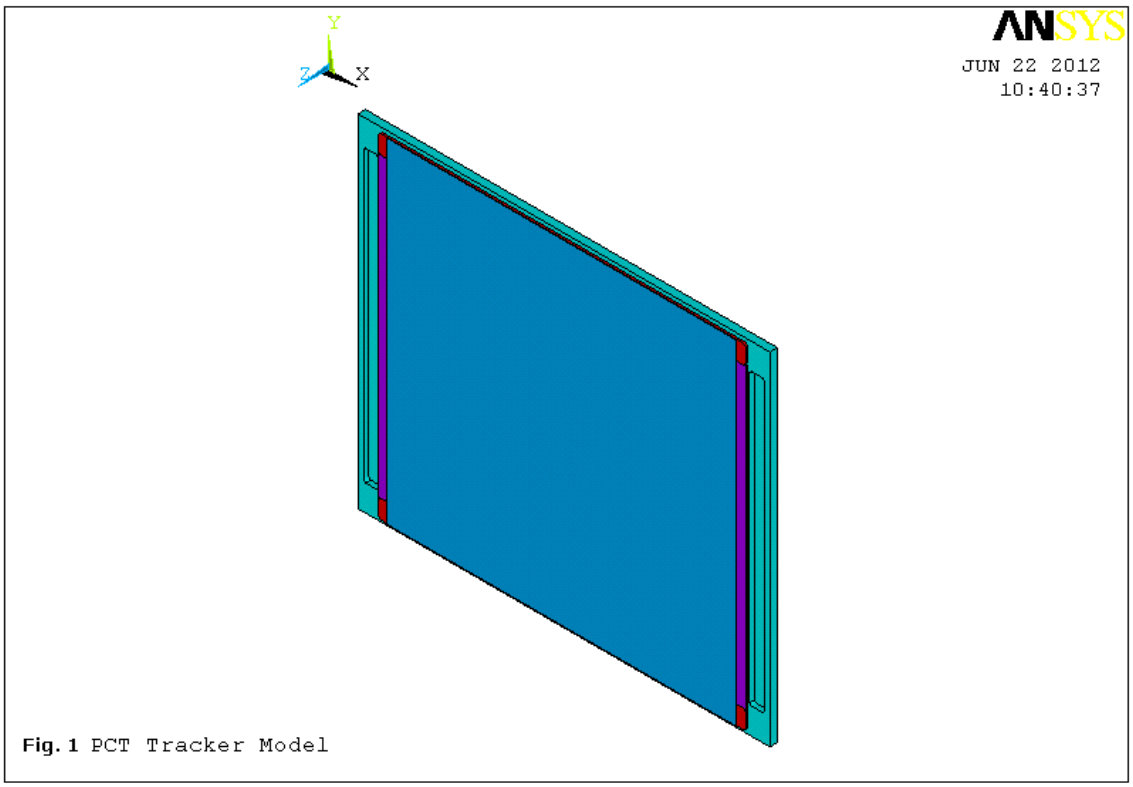


Fig. 1 PCT Tracker Model

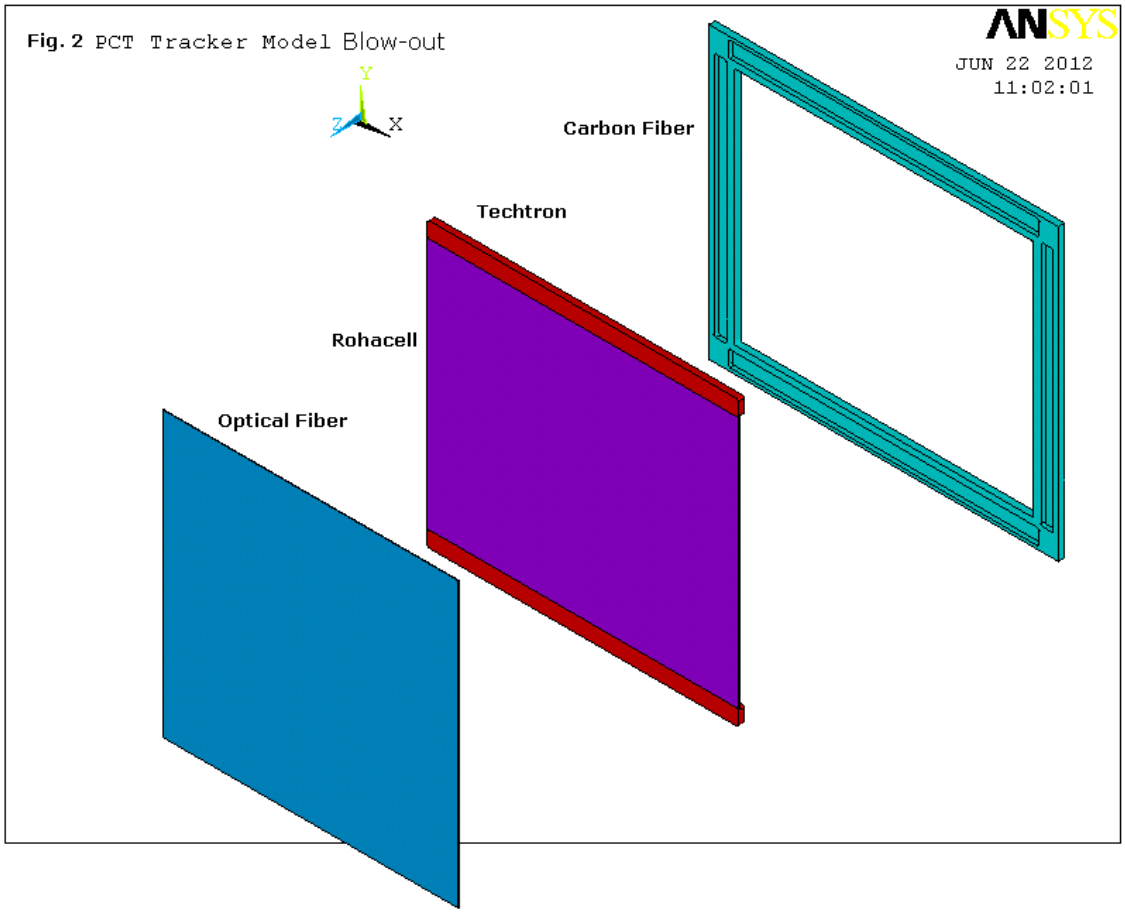


Fig. 2 PCT Tracker Model Blow-out

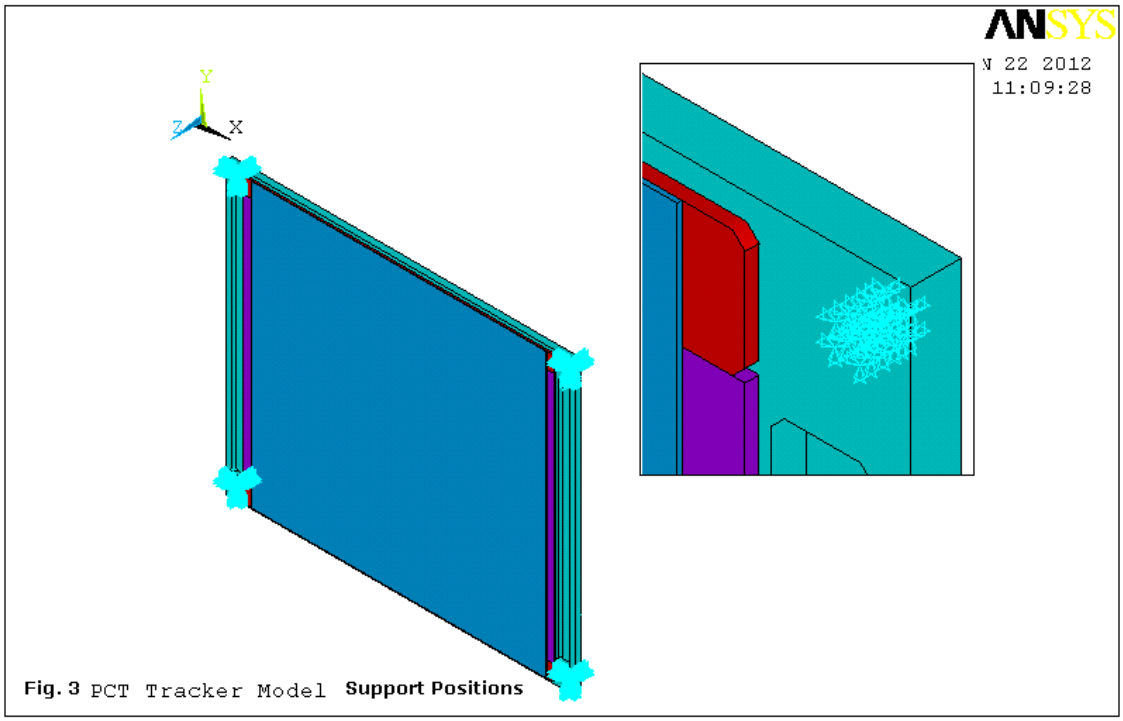
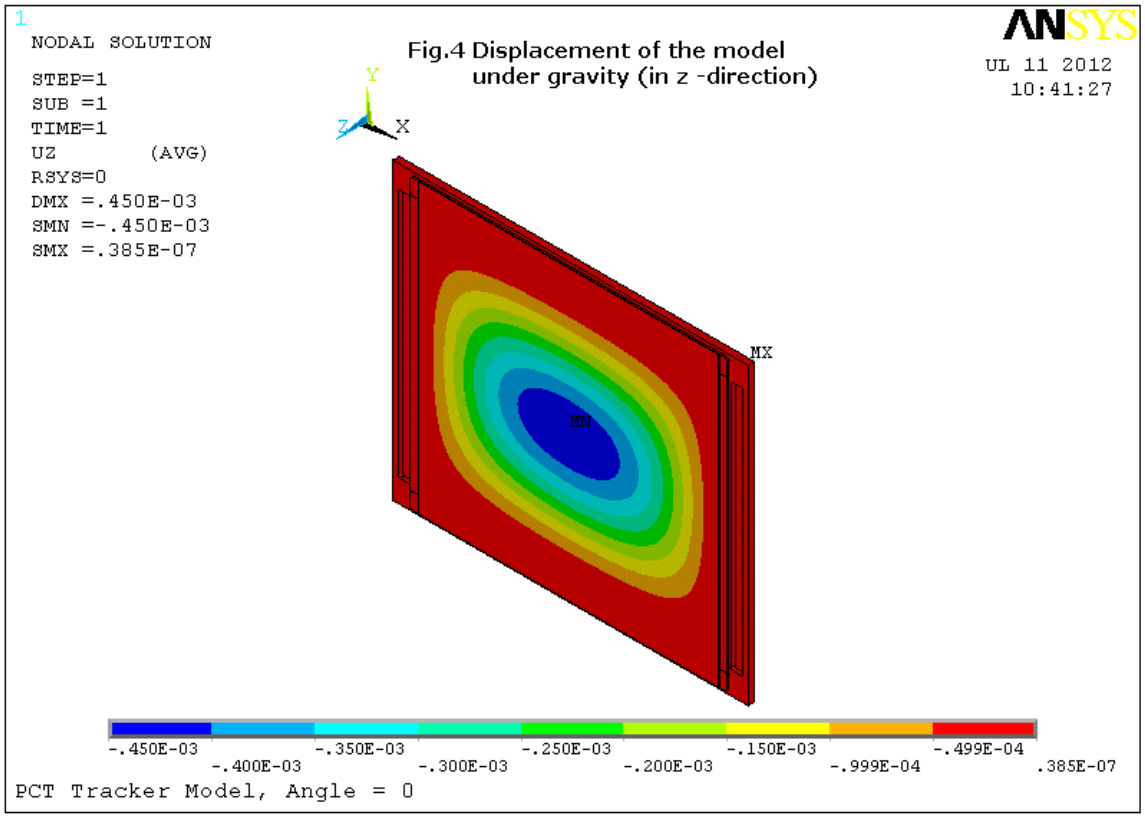


Fig. 3 PCT Tracker Model Support Positions



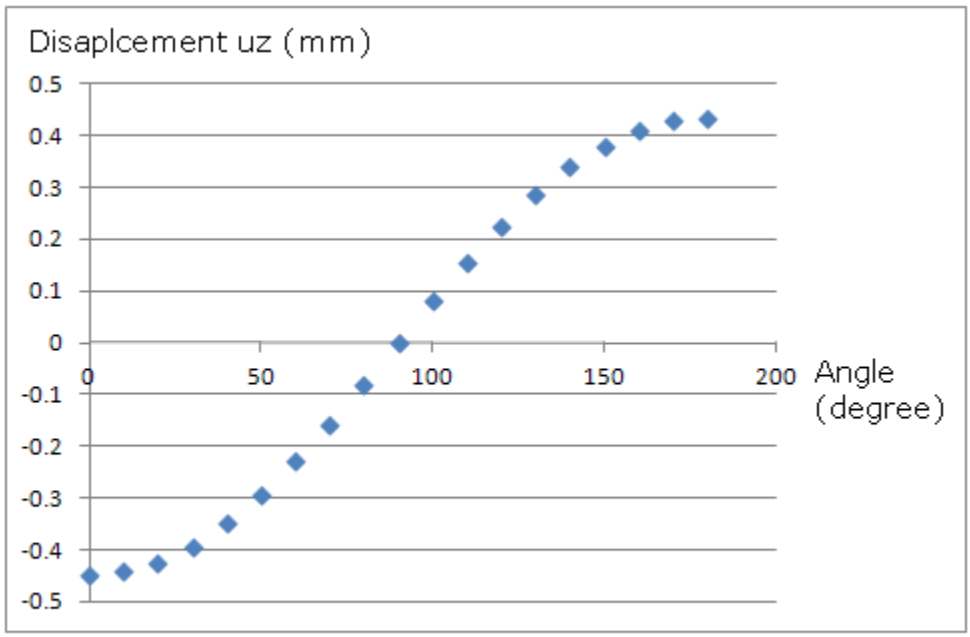


Fig. 5 Displacement uz versus angle between gravity and z-axis

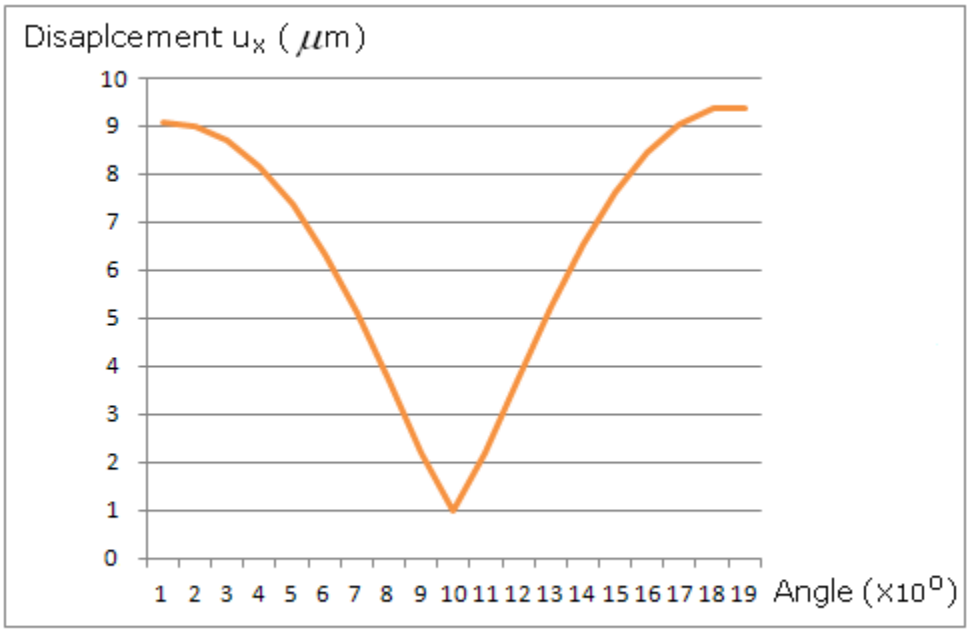
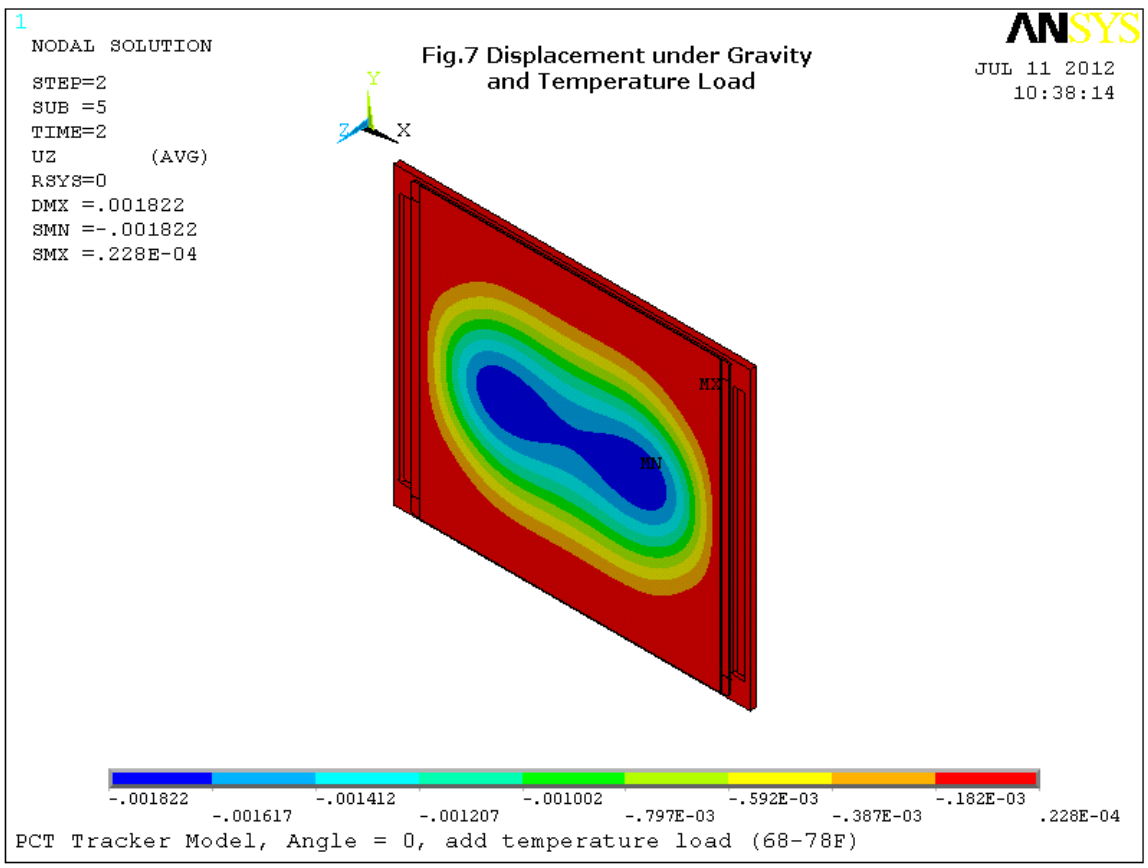


Fig.6 Displacement ux versus angle between gravity and z-axis



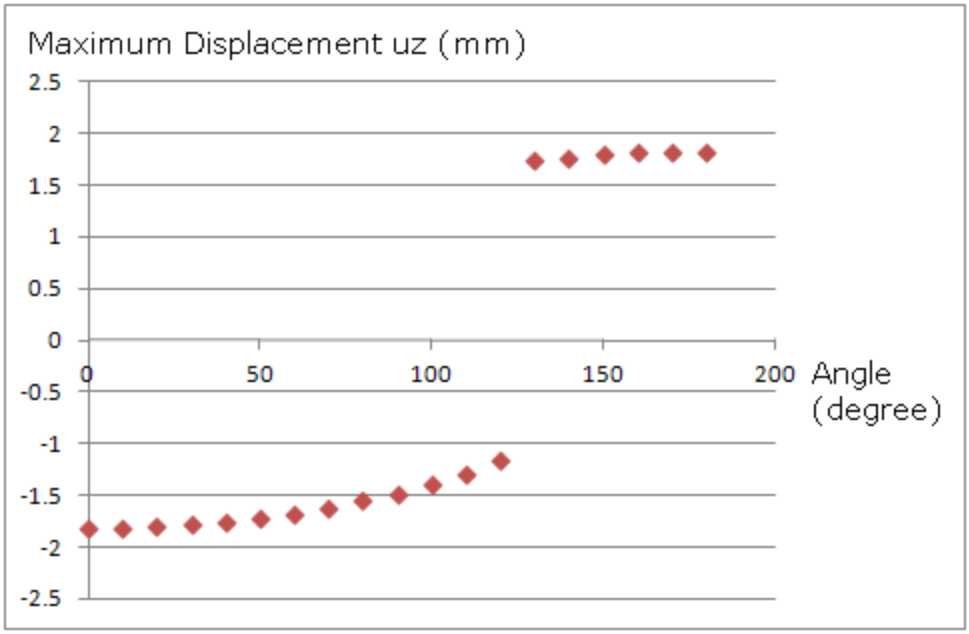


Fig. 8 Maximum Displacement versus Angle

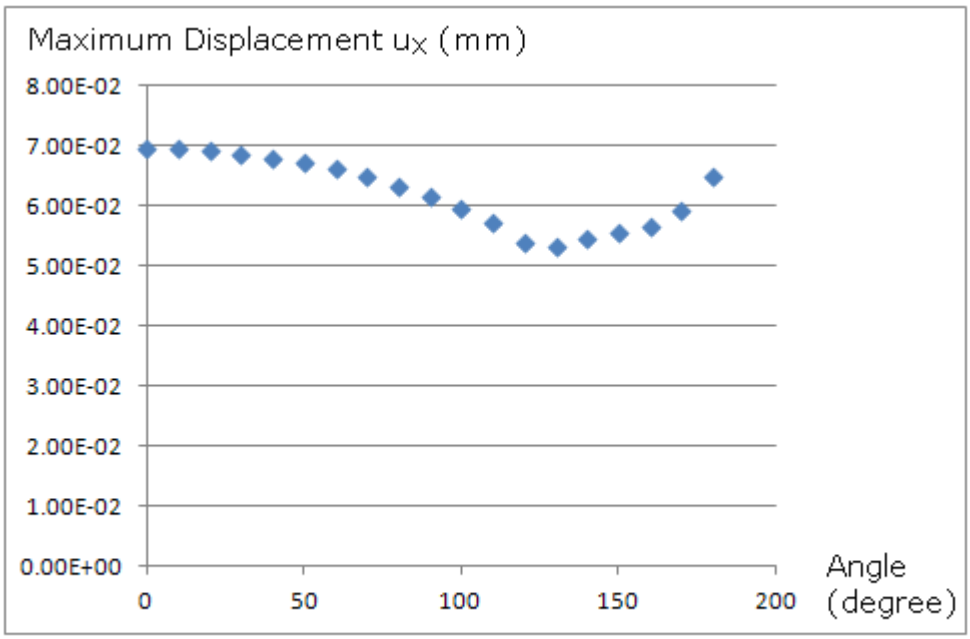


Fig. 9 Maximum in-plane Displacement versus Angle

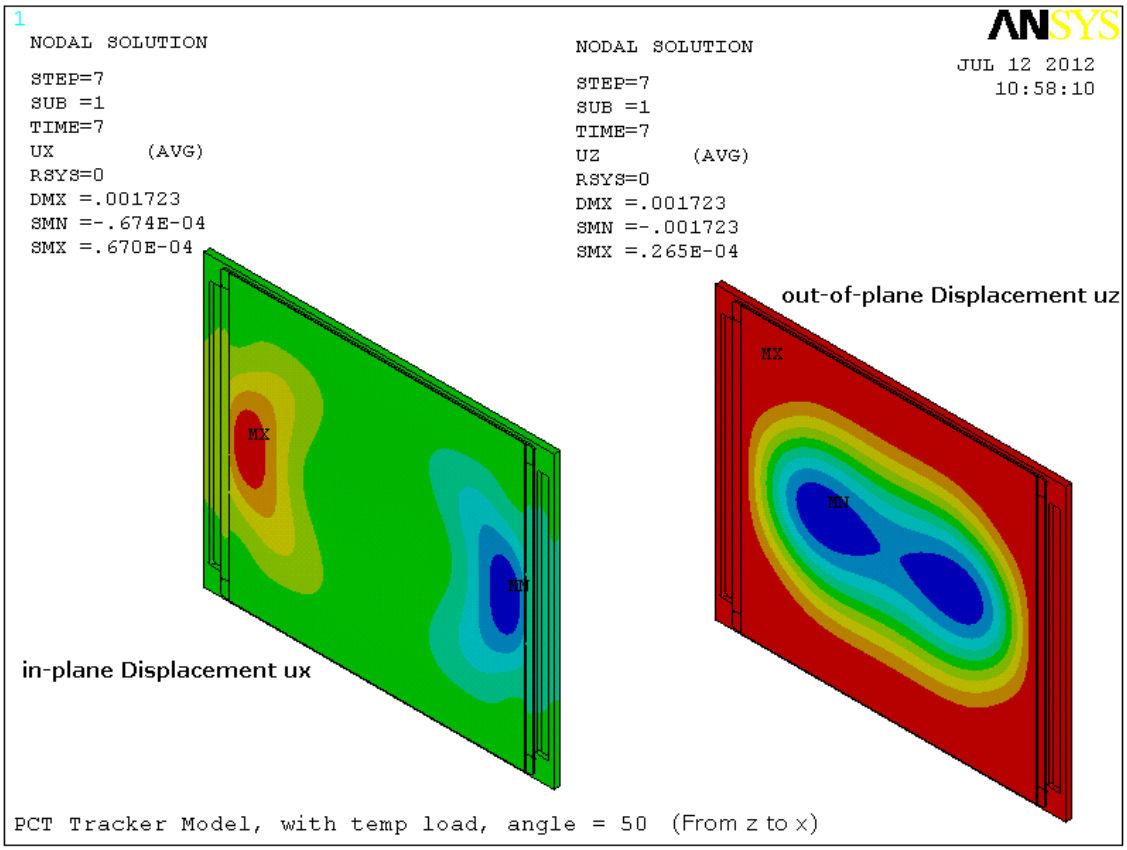


Fig. 10 Typical Displacement Contours

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