Mu2e-II Tracker Design:
Lessons from building the Mu2e Tracker

Dan Ambrose, Fermilab

Future Muon Program at Fermilab Workshop

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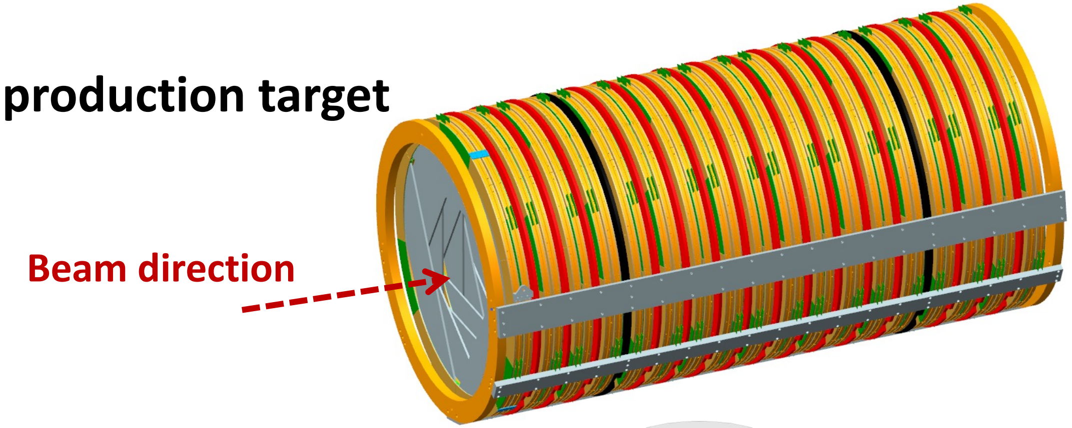
3/27/23

-II

Mu2e Tracker

Requirements :

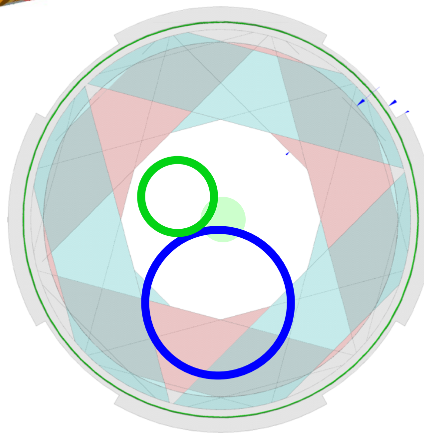
- **Electron momentum resolution: < 180 keV/c at 105 MeV/c**
- **Efficiency for acceptance and reconstruction of 105 MeV/c electron tracks: >20%**
- **Outgassing rate :< 6 sccm (standard cubic cm per minute)**
- **Hit rate: > 5MHz/channel, 500 ns after proton bunch hits production target**
- **Access : < once per year**
- **Operation time: > 10 yrs**



Solution :

Straw drift tubes measure track curvature through a 1 T magnetic field.

- **Segmentation to minimize occupancy**
- **Thin walls minimize multiple scattering**
- **No support structure in tracking region**
- **High radiation survival (structure & electronics)**



Beam's-eye view of Tracker

Mu2e Tracker Discovered Difficulties

In building anything unique and difficult, like the Mu2e tracker, is going to discover unexpected problems during all building phases.

Some issues are able to be corrected in design or manufacturing, while other issues need to be corrected for later.

The goal of this talk is to present some difficulties discovered in the Mu2e tracker construction, so that we can discuss and apply design corrections for future trackers.

Straws :
- **Handling**
- **Metallization**

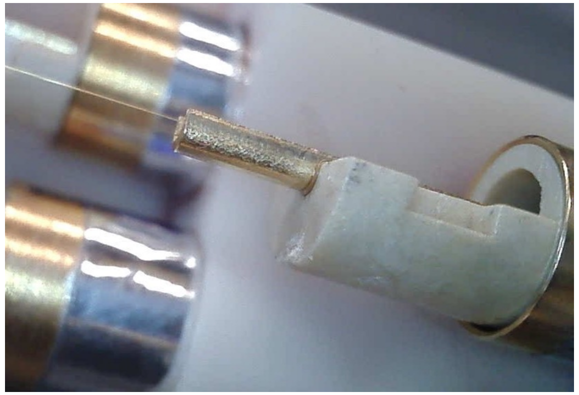
Straw Termination and Wire :
- **Gas Flow**
- **Alignment**
- **Sparking**

Leak Issues
- **Read out slots**
- **Plastic inner rings**

***This talk is specific to the tracker panel components. I think a full discussion of the tracker, including electronics, cooling system, and frame structure would be a useful and interesting future workshop talk.**

Mu2e Straws :

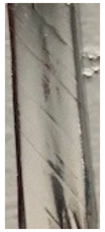
Spiral wrap seams



Two layers of Mylar wound to produce straws

- **20,736, 5 mm diameter straws**
- **Lengths: 45 to 120 cm**
- **6 μm Mylar + 3 μm adhesive + 6 μm Mylar double helical wrap**
- **Outer wall coating: 0.05 μm Al**
- **Inner wall coating: 0.05 μm Al + 0.02 μm Au**

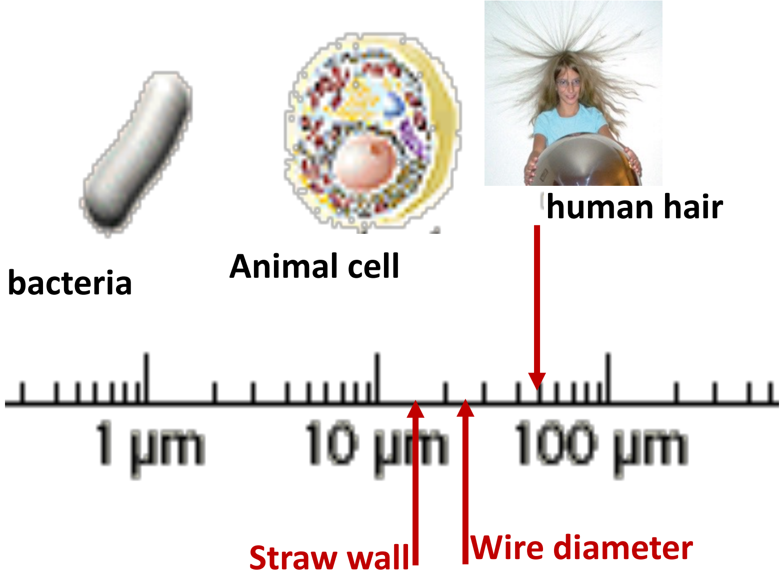
inside



outside

Gold plated Tungsten Sense Wire

- **25 μm diameter**

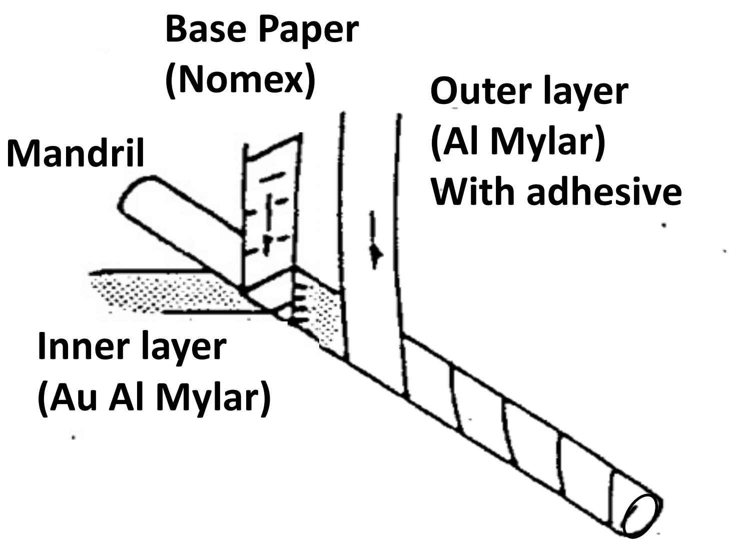


Straw Production Techniques:

A company that makes drinking straws adapted their spiral winding technique to make our straws.

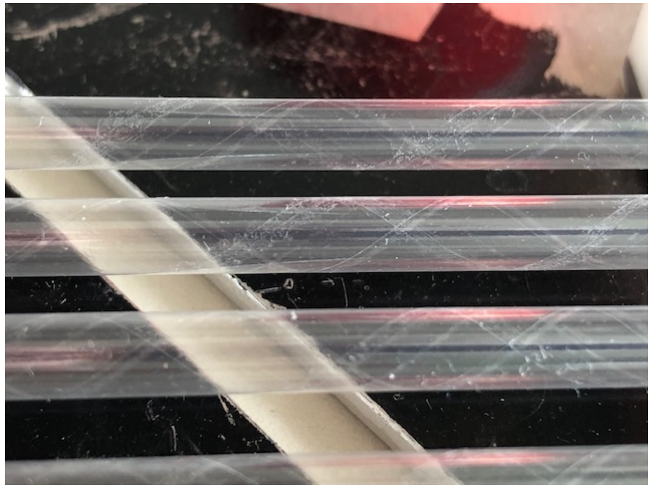
On site we monitored :

- **Seam Widths**
- **Wall/Adhesive Thickness**
- **Conductivity**
- **Gas leak rate**



Mu2e straws comprised of 2 layers of 6 μm Mylar with 3 μm adhesive.
Mu2e-II straws are made from 3 μm Mylare with 2 μm adhesive.

Shipped bundle of 24 straws



8 μm Mylar Straw made using same technique

Straw Handling

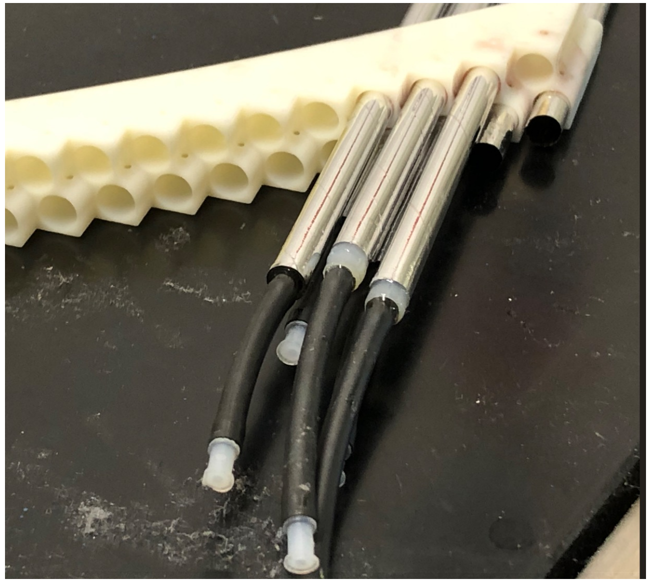
It has only felt safe to handle the 8 μm straws with internal outward force:

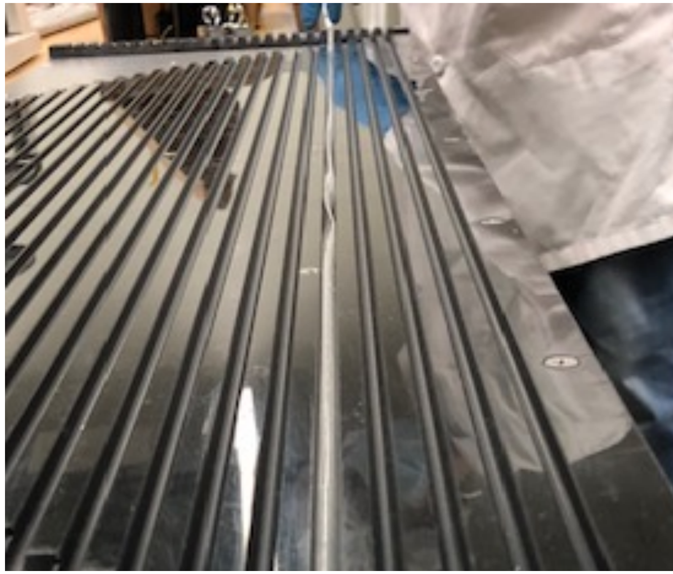
- **Paper is inside**
- **Straws are inflated**

Without either they collapse under own weight or static.

Almost no compression force can be applied which makes installing terminations difficult.

If allowed to be rough with ends (will not be part of detector), sealing terminations can be installed and the straws inflated.





Straw Metallization

Metallization of both the inside and the outs is critically important to leak rate of the straw. This is distinctly seen in seam width to leak rate observations.

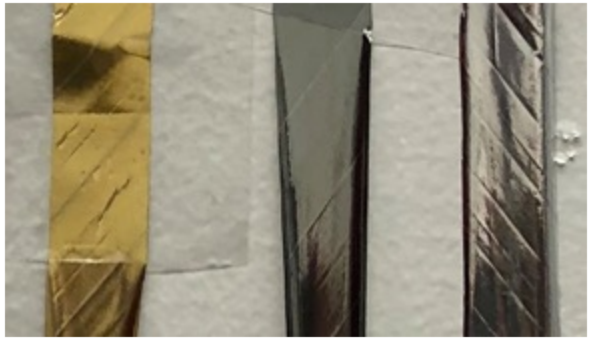
Gold aluminum alloy forms shows a history of the straw. Over tensioning the film leads to this. About half of the Gold/Aluminum mylar needed to get remade.

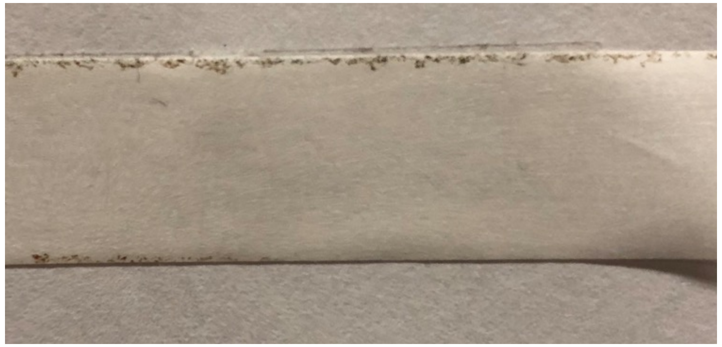
Drying out of tung oil on internal paper led to pulling some metal from the straw. Removing paper early or limiting mandril lubricant could be solutions.

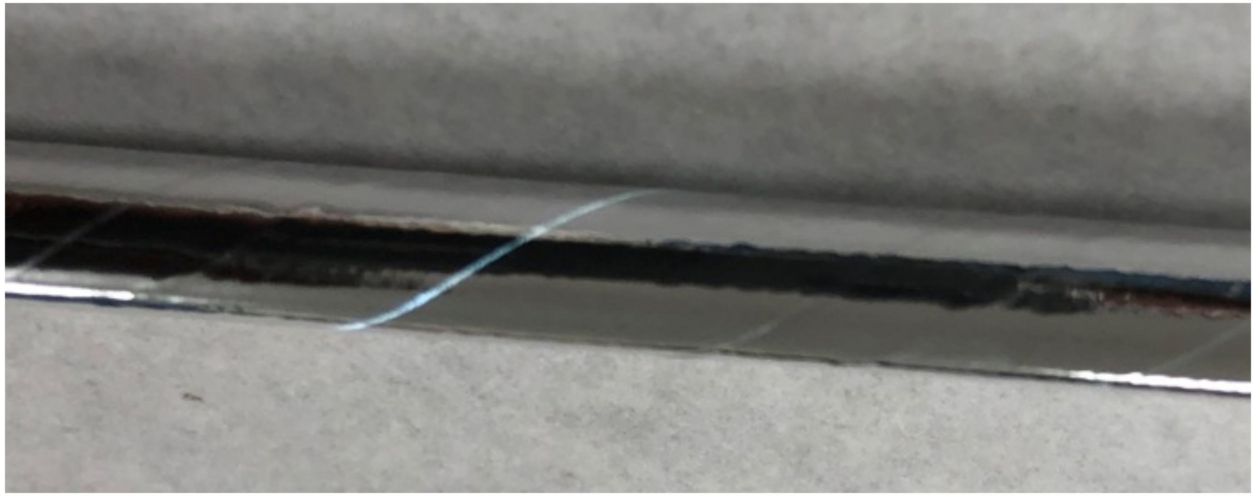
Difficult to get people to make samples.

Previous company was not responsive in making us samples.

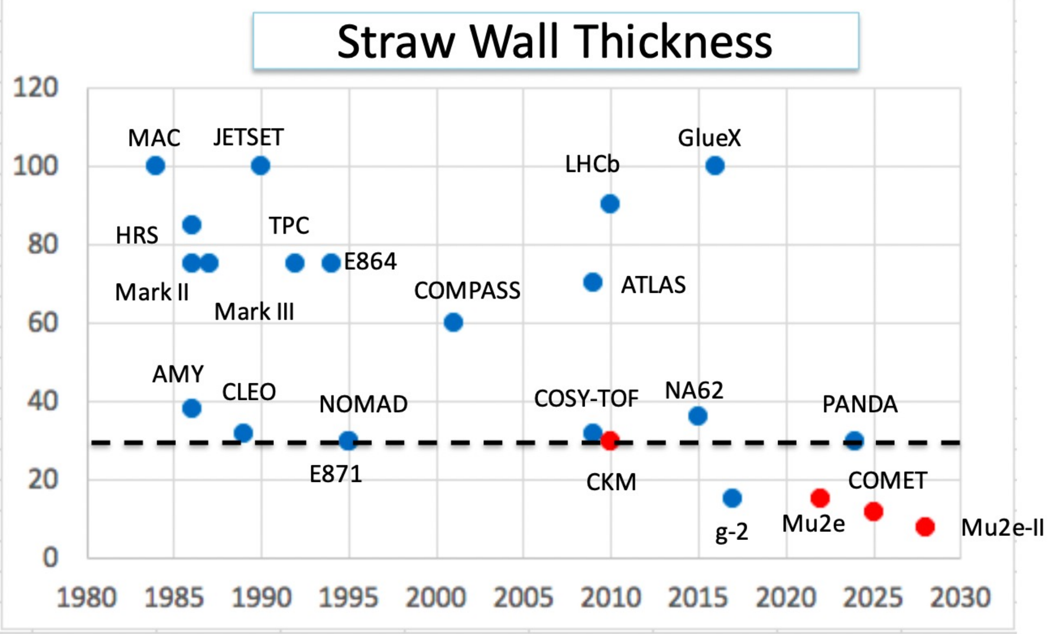
Not many interested in working with 3 micron mylar.





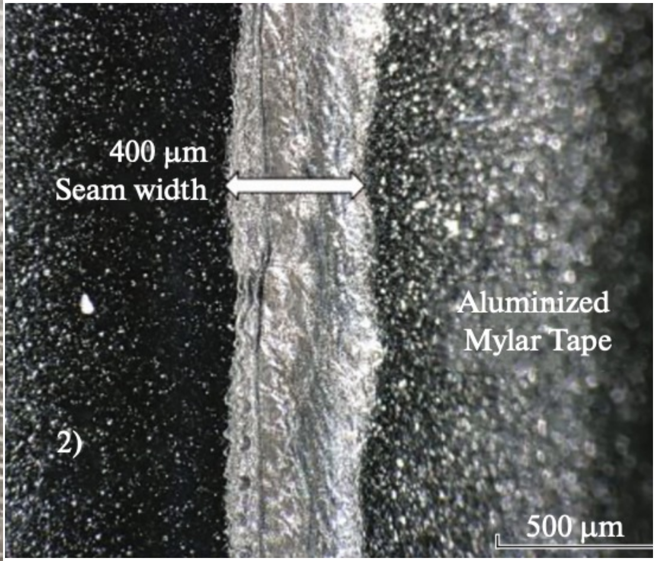


Future Straw Options :



B. Casey, LDRD Straw Talk

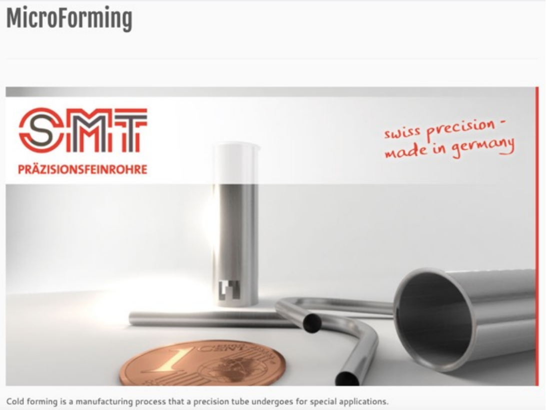
8 μm Mylar Straw



DOI: 10.1134/S1547477122020108

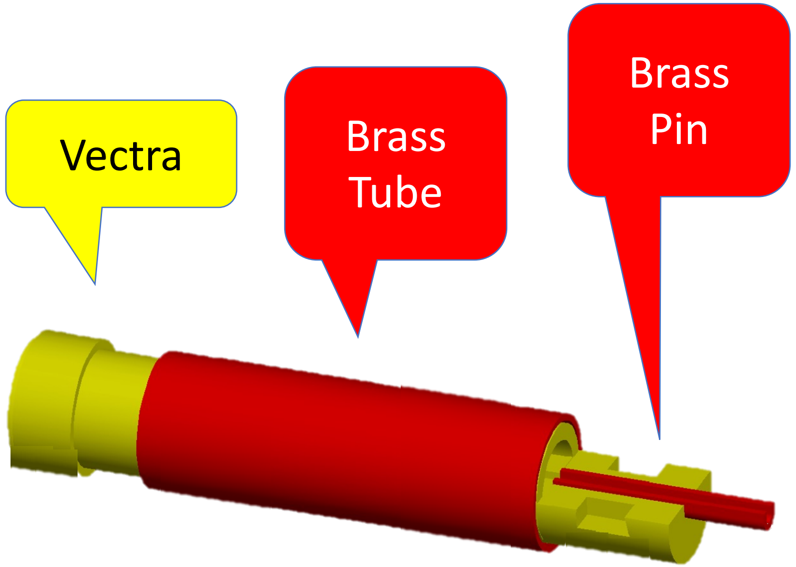
12 μm Comet : ultrasound weld

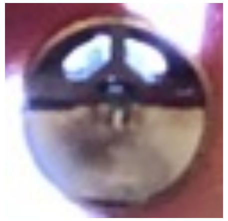
- Need to map out an R&D plan for the next few years
- Prior to Snowmass approached NA62 upgrade people and COMET people about making it a joint white paper on what the different groups around the world are doing.
  - No progress (to my knowledge)
- NA62/COMET are going for 12 micron ultrasound welded straws.
- Microform extrusion is a possibility for 2 micron AL straw



Microforming a new extremely thin extrusion method

Straw Terminations :





These terminations hold the the wire on each end of the straw and conductively attach to the inside and outside of the straw to ground through the omega clip.

Gas Flow

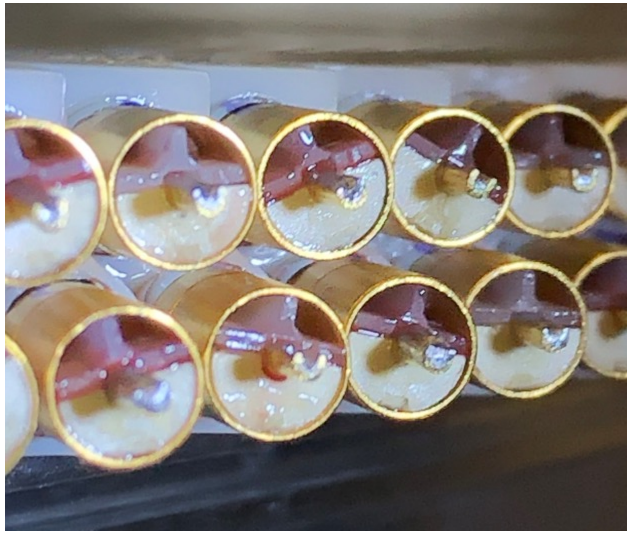
Wire is epoxied in behind the solder joint to add additional protection against wires slipping.

Pin protectors are epoxied on top as well to secure pin in place.

Found epoxy would wick around pin protectors and fill gas ports needed for gas flow through the straws.

If pins were imbedded into the termination, we could possibly remove need for pin protector.

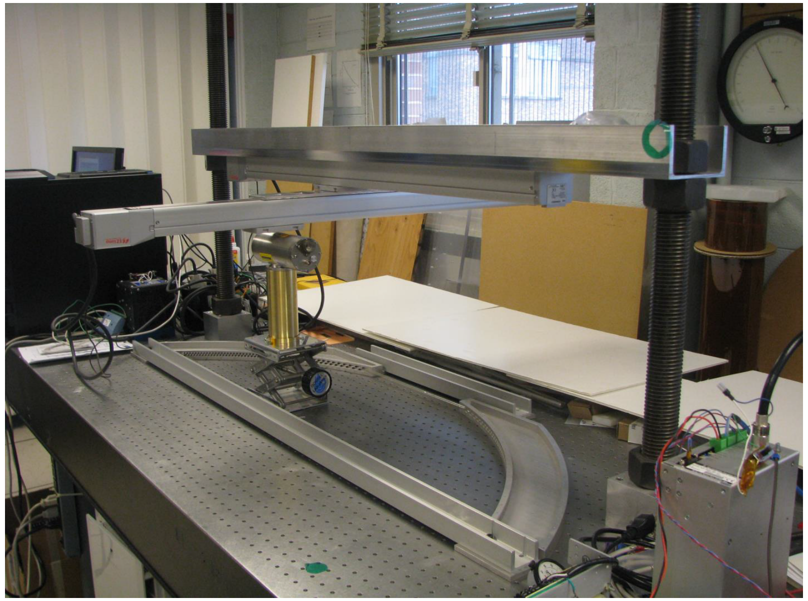
Light through termination gas openings



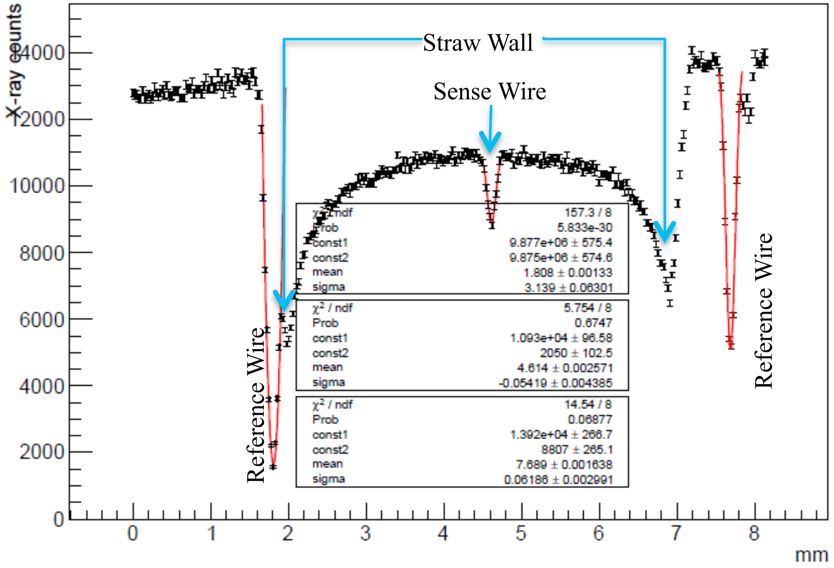
Excess epoxy near gas openings

Straw and Wire Alignment

Alignment combs set position of straw and same combs set position of wire.

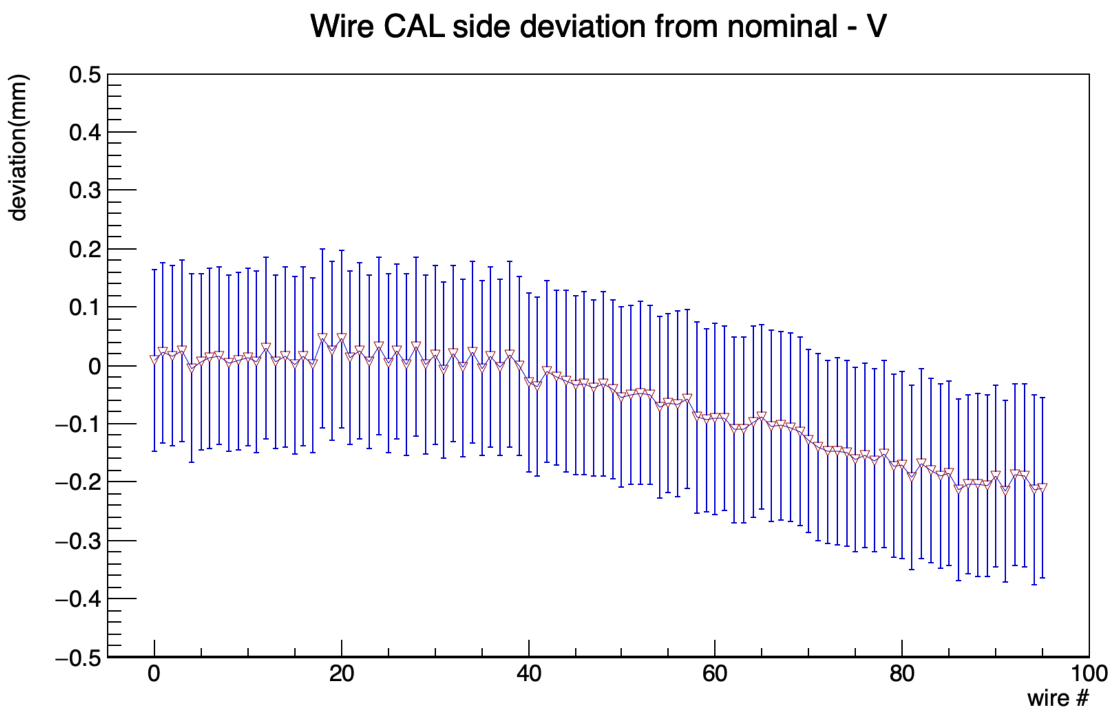


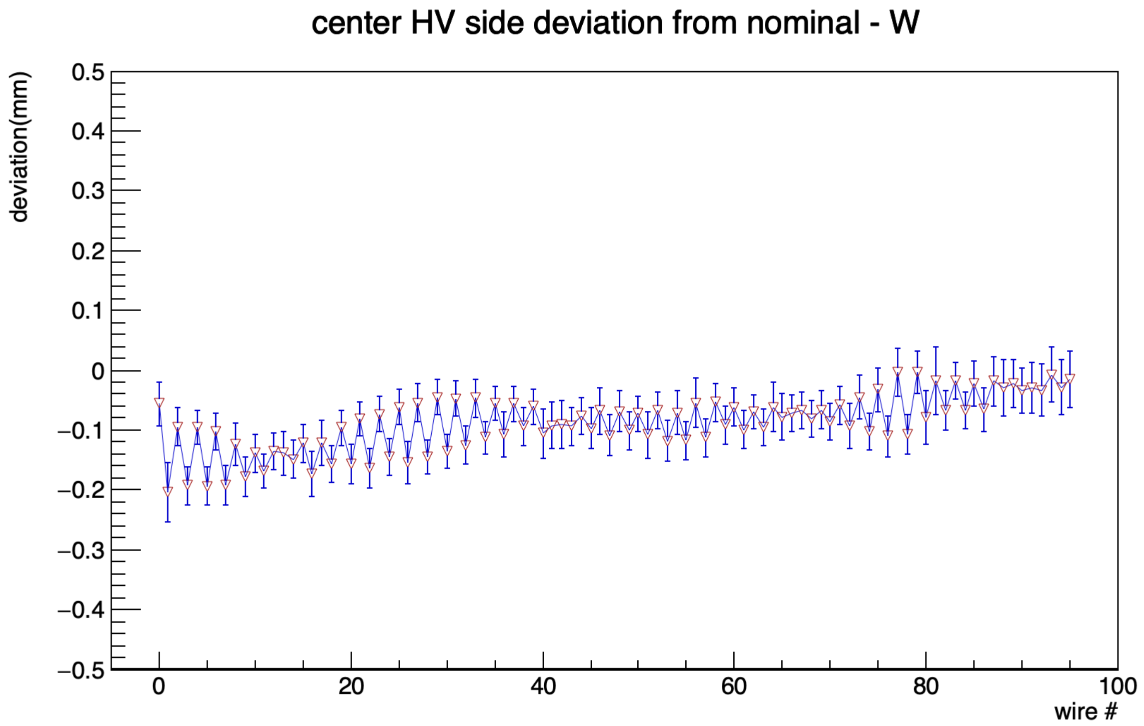
Duke X-ray position measurement Apparatus



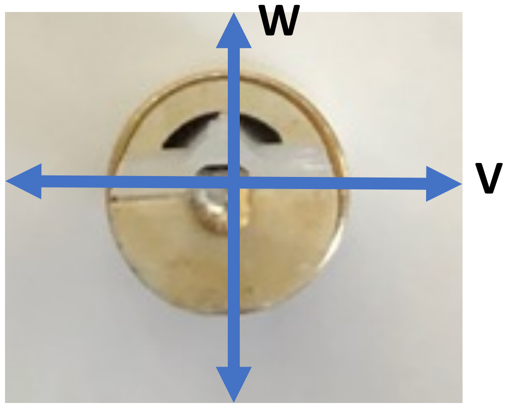
Data picks out wire location and straw edges

Straw Terminations : Wire Alignment





Plots from Mete Yucel's analysis of Duke straw/wire data
About 230 panels in total.



Plots are average of Wire location – Straw center location. Uncertainty is the Std deviation of the distribution.

The V (left/right in straw) has a larger 0.15 mm uncertainty

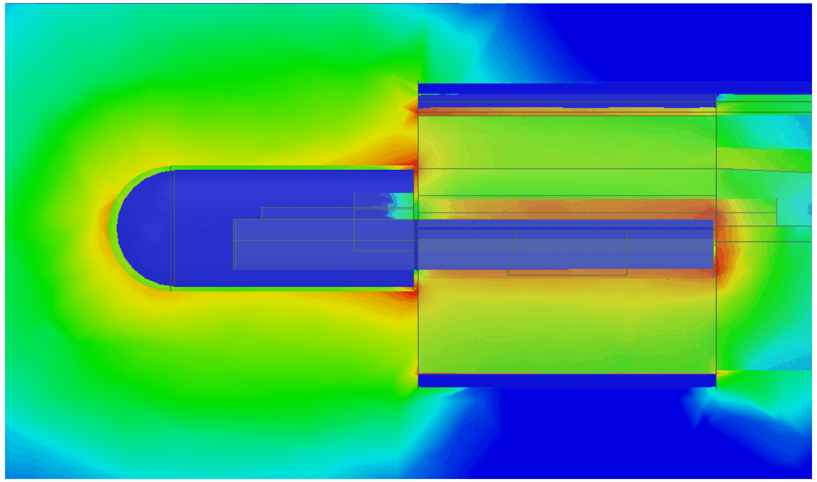
The W (up/Down in straw) has a smaller 0.04 mm uncertainty however systematic trends present and difference between top/bottom row for long straws.

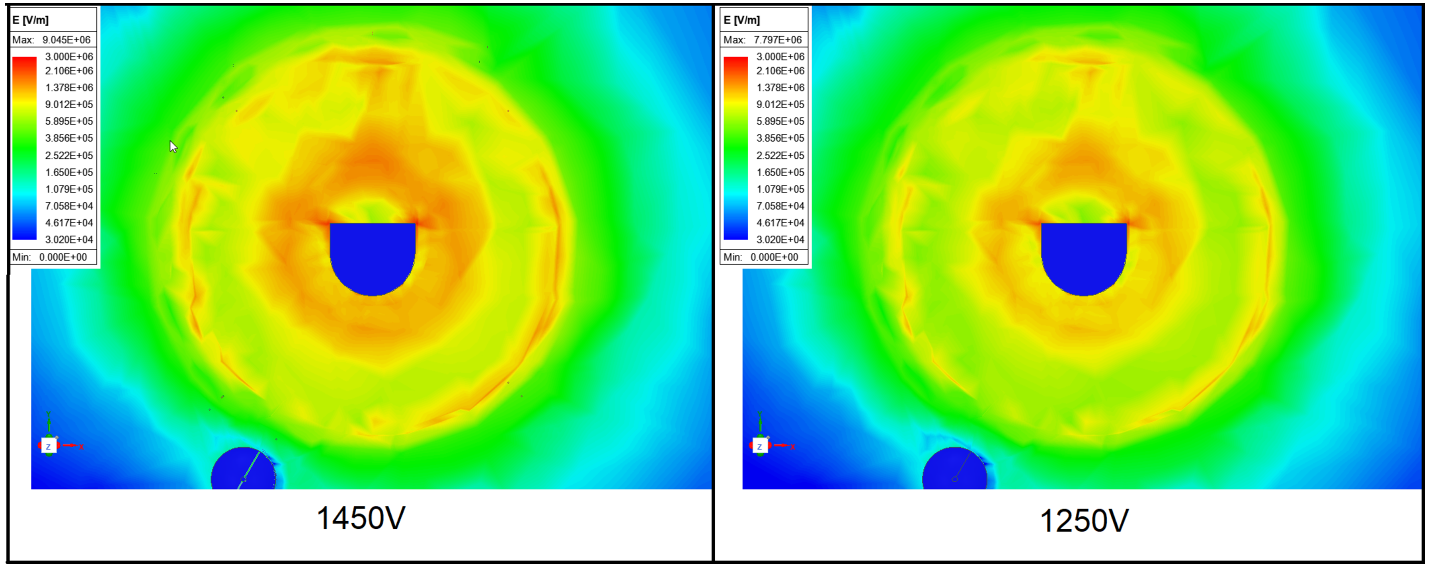
Electrostatic sparking

Dielectric break down :
Air ~ 3×10^6 V/m
$ArCO_2$ ~2×10^6 V/m

Dark orange or red should be capable of dielectric break down

15 hour expose of a particularly sparky Mu2e Panel (*Not a Christmas Tree)





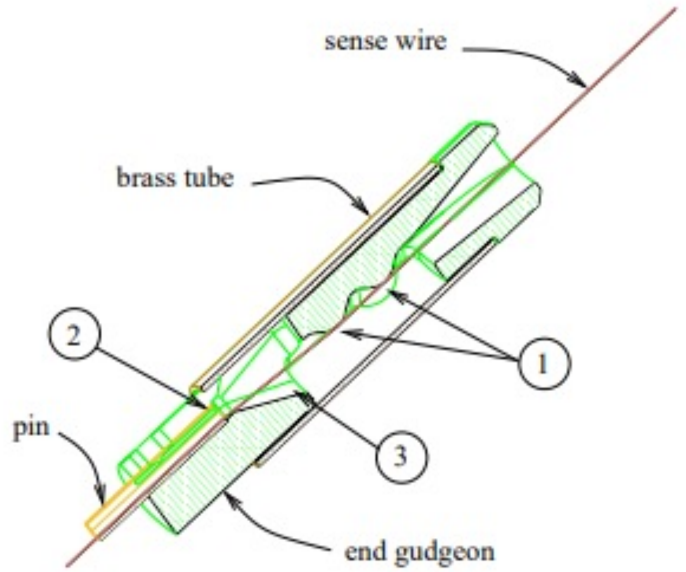
ANSYS Maxell simulation done by Daniel Molenaar, UMN student

Future Termination Options

The alignment of straw and wire centers has been more difficult then initially estimated. A wire centering termination would likely be more consistent in location with less uncertainty.

Pin being molded into the termination would relieve the need for the pin protector.

People have strong feelings on soldering verses crimping wires. If it can be done without the additional epoxy holding the wire, this would improve gas flow consistency and prevent the opportunity for blockages.



Preliminary design, Tom Chase, UMN

Leak Issues

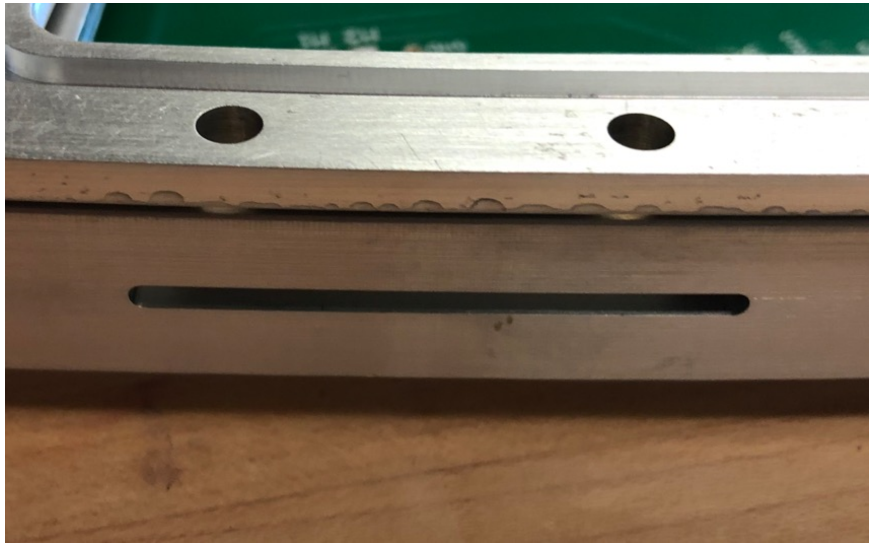
An extraordinary amount of effort has gone into ensuring the panels and straws meet the leak test requirement.

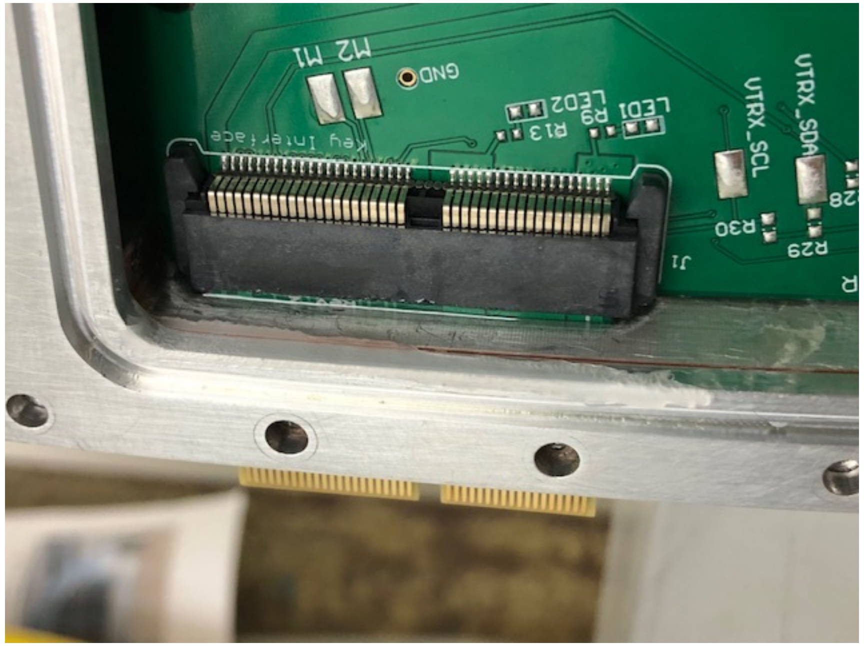
Leak testing 23,000 straws and 240 panels has taken more than 13,000 hours of labor.

Thinner straws won't make this easier, however there are lessons we can incorporate from leak problems observed that could make Mu2e-II easier.

Common Leak Issue	Ideas
Straws	Passive inflation test *mentioned earlier
Ear slot	Epoxy potting recesses
Plastic Inner ring to straw connection	Potting straws, options for sealing straws

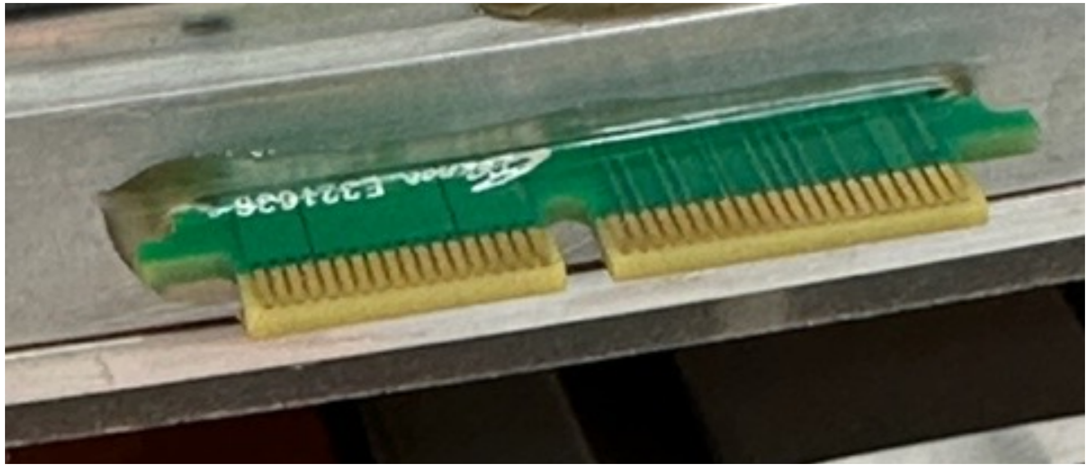
Ear Slots





Had a lot of issues getting a leak proof seal on the slot.

Future designs need to have a reservoir to pot the ear and make a clean seal.



3D Printing Detector Parts

No longer a new technology, but the range of materials and accuracy continues to increase while cost is reduced.

3D printing opens up a wide range of unmachinable designs (ex. epoxy channels).

Combination of size tolerance with specific rad-hard material can be difficult.

Other properties needed to be understood of the 3D printing material is outgassing, leak rate, and thermal properties.

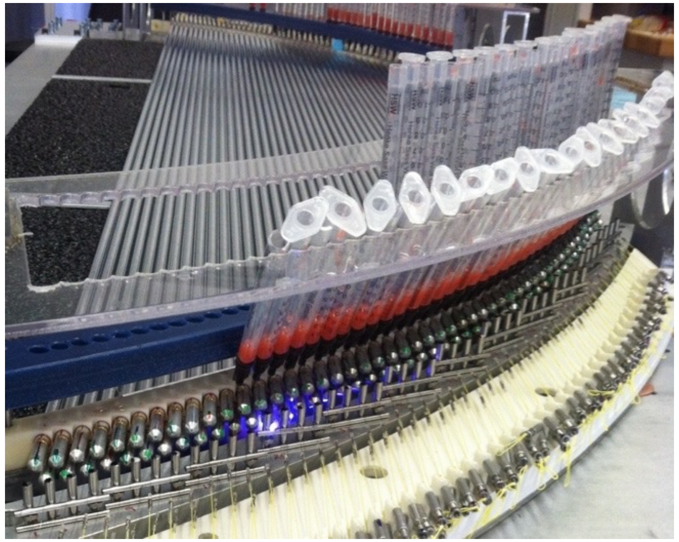
Me in my 3D printed Costume 2021

Plastic Inner Ring

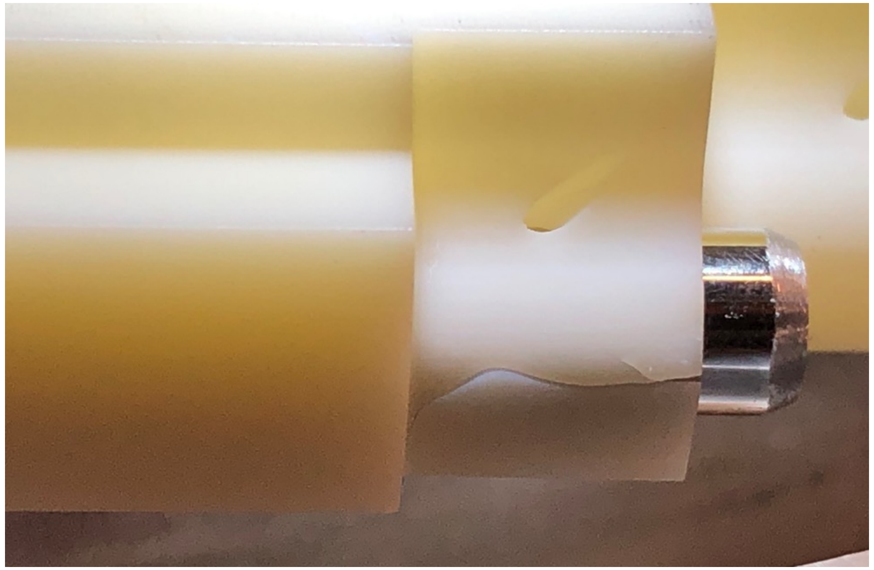
Overall, the PIR was a successful in building the panels. Epoxy injection holes, which would have likely been impossible to machine, were effective for getting epoxy around straws.

6 part Plastic Inner ring of Mu2e panels

Additional QC was needed for measuring tolerances. Some parts were lost do to brittleness.

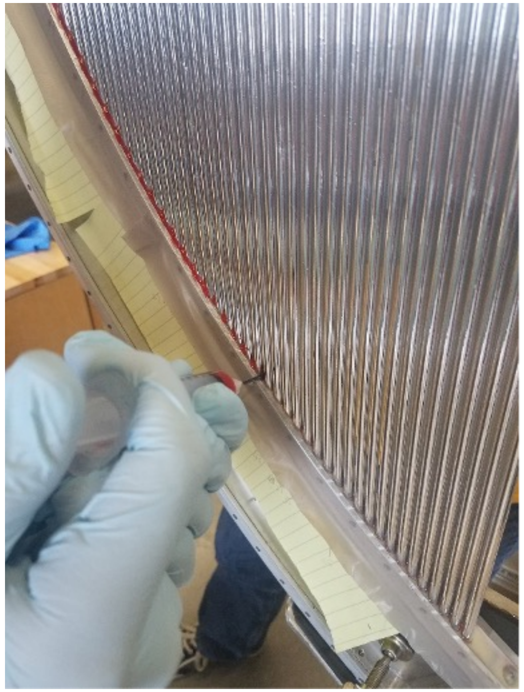


Epoxy holes allow for passive injection



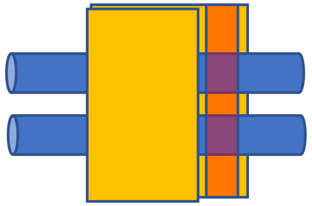
Brittleness present in some areas

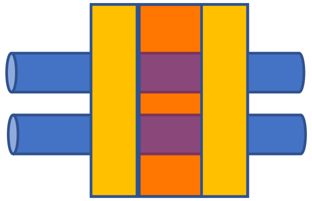
Thoughts of improving an inner ring



- Difficulties of the inner ring come from geometry constraints
  - No room to screw into area above straws
  - Curve makes potting straws difficult

- Improving PIR/Straw seal
  - Epoxy trough for sealing straw
    - Non-flat surface makes this harder
    - Could be done in stages
  - Trough would be more uniform if this could be done horizontally.
    - This requires a way to keep epoxy from flowing out
    - Currently kept in through surface tension at exit





Summary

- **There have been substantial lessons learned while making the Mu2e detector.**
- **It is important for future detectors to highlight these lessons.**
- **For new detectors it is important to continue to explore new technologies (like microforming) and advances in old technologies (like 3D printing).**

Topics to Discussion

- What other Mu2e tracker lessons do we need to pass on?
- Lessons from electronics, cooling, frame?
- Gas Selection
- Straw sealing methods
- 3D printing