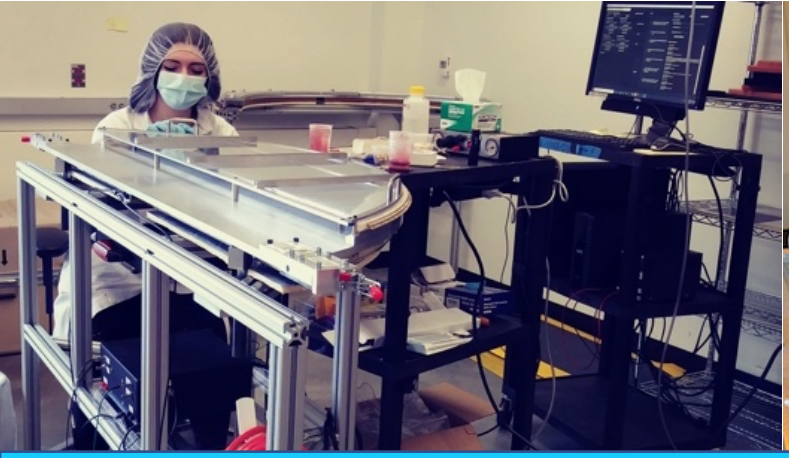
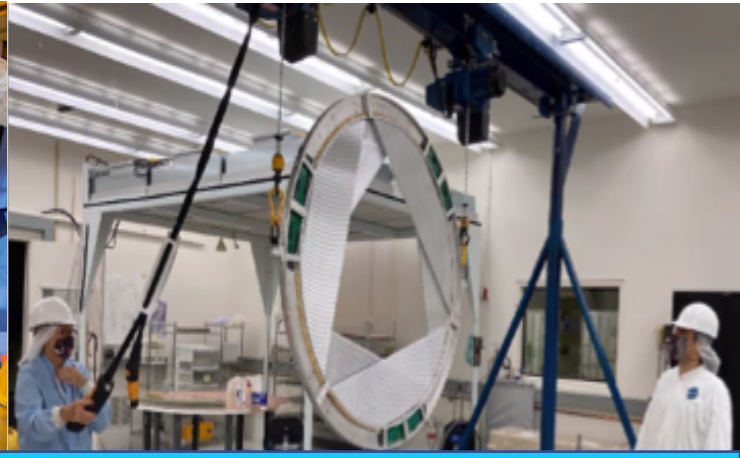




Lessons from Mu2e Tracker Construction and Mu2e-II Tracker Opportunities

Dan Ambrose

University of Minnesota

On Behalf of Mu2e and Mu2e-II Collaborations

CPAD Instrumentation Frontier Workshop 2021

Mar 18-22, 2021

Overview

Brief Overview of Mu2e Experiment
Low Mass Drift Tube (Straw) Electron Tracker
Lessons from building the Tracker

- **Make thin walled straws with a drinking straw company**
- **Straws handled safely with undergraduate students.**
- **Panels can be assembled and tested with undergraduate students.**

Tracker Component Performance

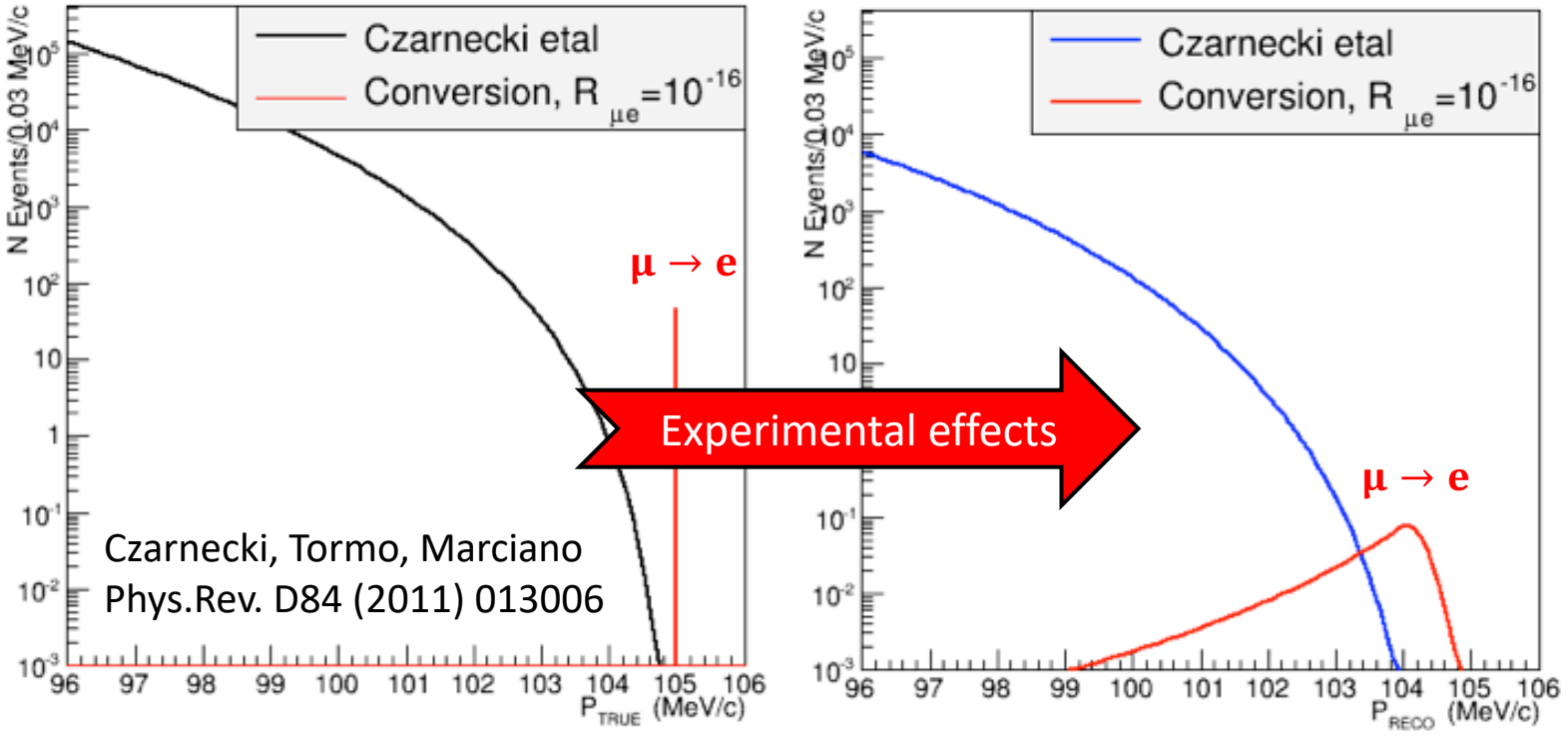
Mu2e-II Experiment and Tracker Requirements
Even thinner walled straw prototypes
Other Possible Designs

Mu2e's Measurement

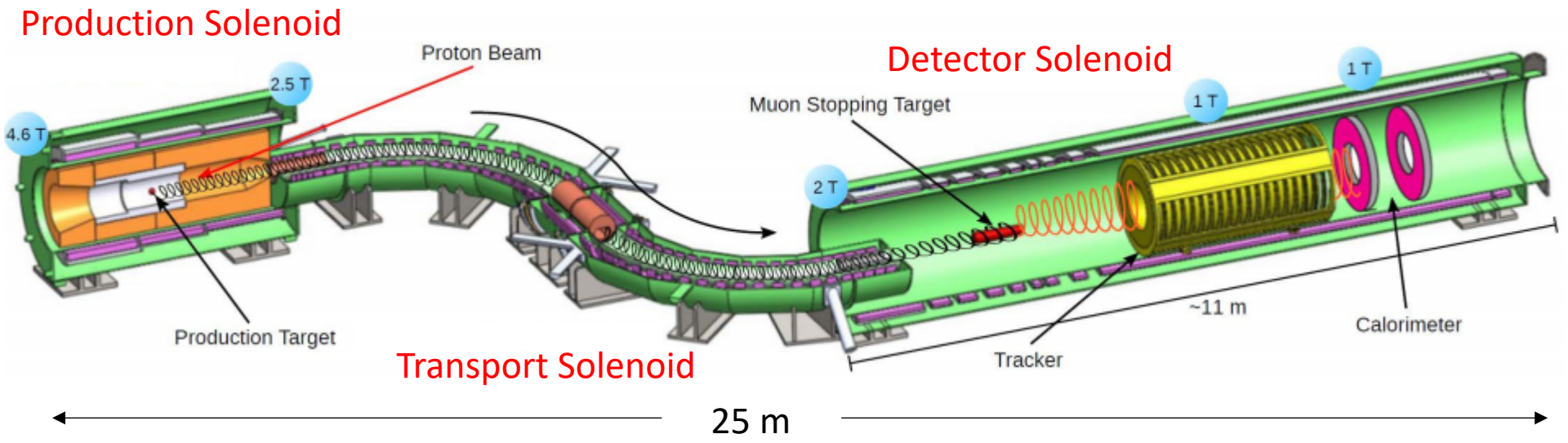
$\mu \rightarrow e$ in the presence of a nucleus

Standard Model estimate ~10^{-54}

Mu2e will represent a 10,000x sensitivity increase to the current upper limit (SINDRUM-II : $< 7\times10^{-13}$) [EPJ C 47, 337(2006)]



The Mu2e Experiment



Mu2e experiment consists of many technically demanding components.

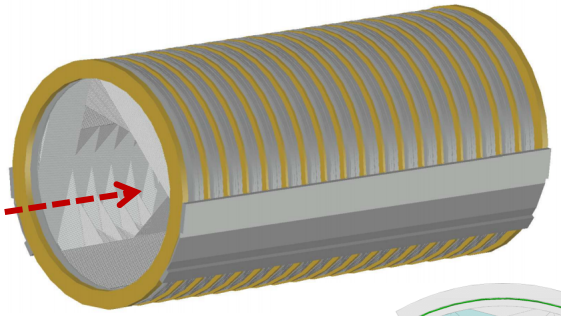
- **High intensity**
- **Precise high magnetic fields**
- **Vacuum**
- **Production target**
- **Stopping target**

Other Mu2e CPAD talks:
Calorimetry Summary: R. Zhu
SiPM for fast BaF2 component: D. Hitlin
Development of Novel Inorganic Scintillators : C. Hu
Mu2e TDAQ and slow controls : A. Gioiosa
Mu2e electromagnetic calorimeter mechanical structures : D. Pasciuto
TDAQ for Mu2e-II : R. Bonventre
Novel scintillator detector for Mu2e-II : C. Dukes

This talk focuses on the tracker which measures the electron trajectory in a 1T magnetic field.

Tracker Requirements

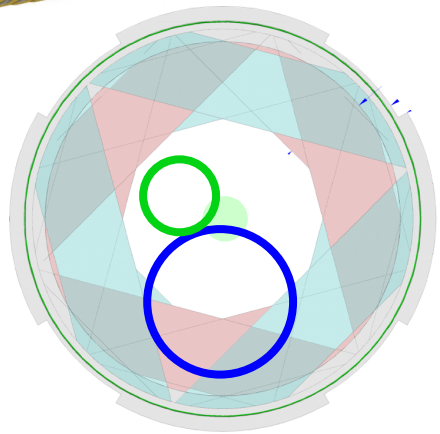
- **Electron momentum resolution: < 180 keV/c at 105 MeV/c**
- **Efficiency for acceptance and reconstruction of 105 MeV/c electron tracks: >20%**
- **Outgassing rate :< 6 sccm (standard cubic cm per minute)**
- **Hit rate: > 5MHz/channel, 500 ns after proton bunch hits production target**
- **Access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



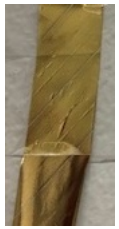
Beam's-eye view of Tracker

Tracker Components: Straw Drift Tubes

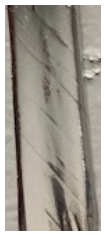
Spiral wrap seams

Two layers of Mylar wound to produce straws

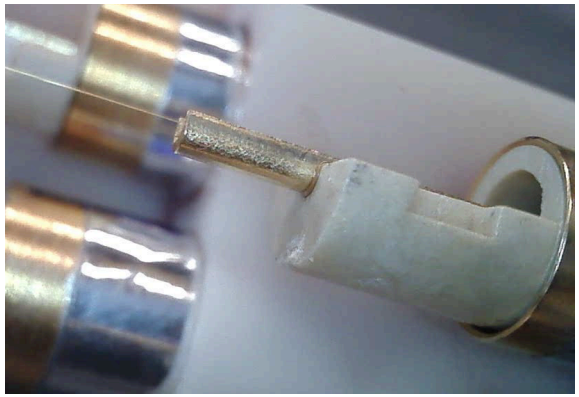
- 20,736, 5 mm diameter straws
- Lengths: 45 to 120 cm
- 6 μm Mylar + 3 μm adhesive + 6 μm Mylar double helical wrap
- Outer wall coating: **0.05 μm Al**
- Inner wall coating: **0.05 μm Al + 0.02 μm Au**



inside

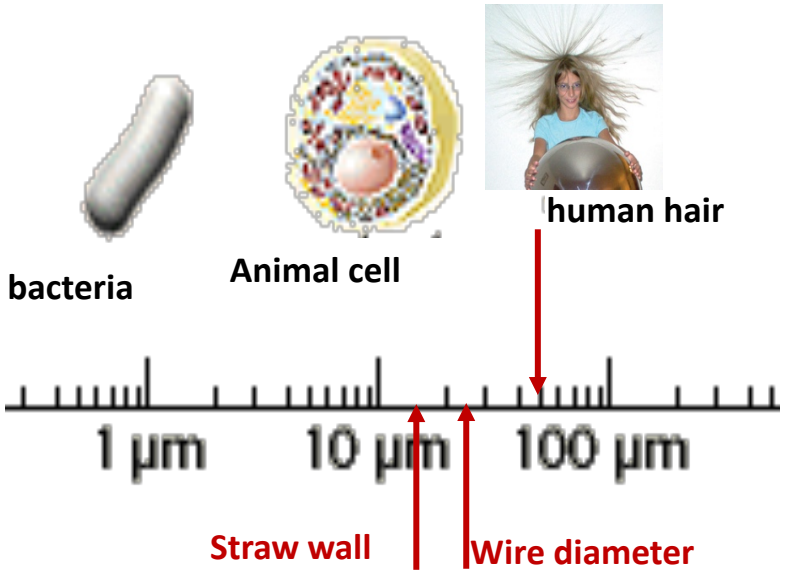


outside

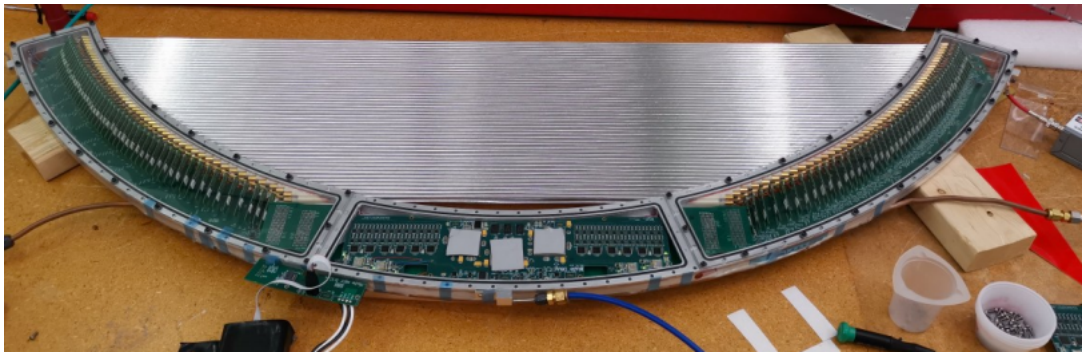


Gold plated Tungsten Sense Wire

- 25 μm diameter



Panel: The Fundamental Tracker Unit



1 panel = 96 straws

Harp structure

Ancient Egyptian Harp

The Encyclopedia Britannica, New Warner Edition

Panel is smallest self-contained unit of the detector

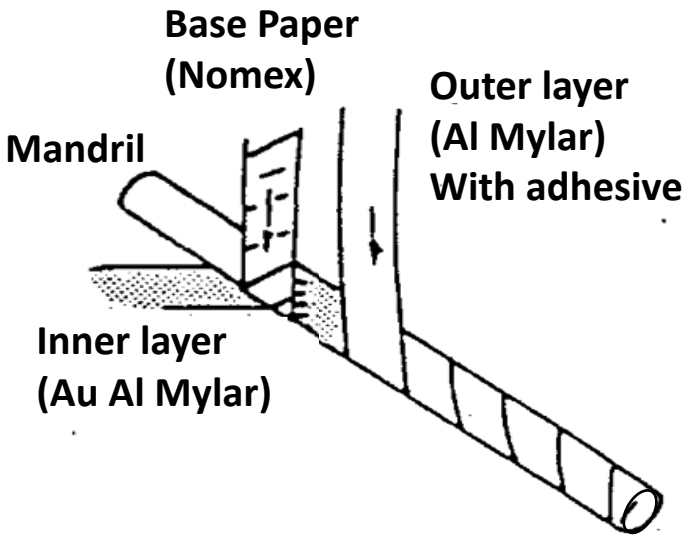
- Detector has 216 identical panels. Each has 96 straws.
- 120^{o} arc of Tracker.
- Detection region has only straws, sense wire, and 80:20 Ar/CO_2 gas.
  - Straws held at 7.5 N tension at their ends with no additional support.
- Gas manifold holds the electronics.
- Support structure built of Aluminum, 3D printed plastic, and epoxy.

Making Straws

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

On site we monitored :

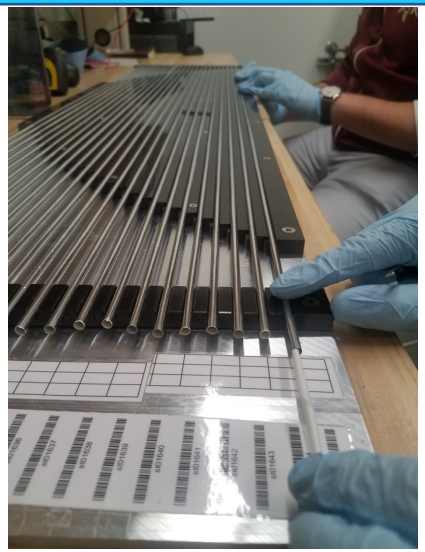
- **Seam Widths**
- **Wall/Adhesive Thickness**
- **Conductivity**
- **Gas leak rate**



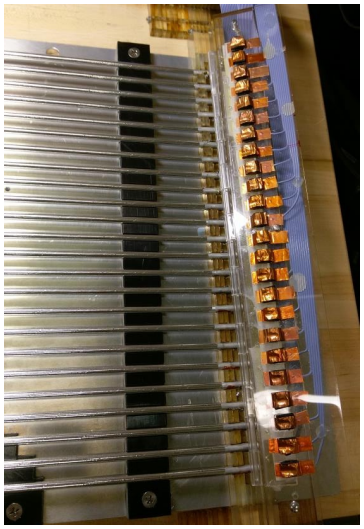
Shipped bundle of 24 straws

Bundles ready to assemble

Straw Assembly Steps Performed by Students @ Minnesota



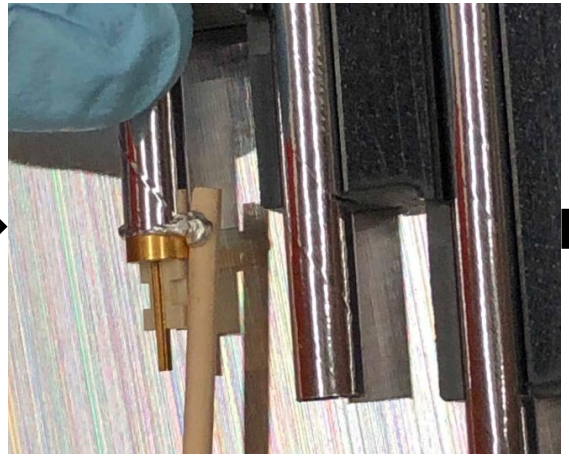
Paper Removal



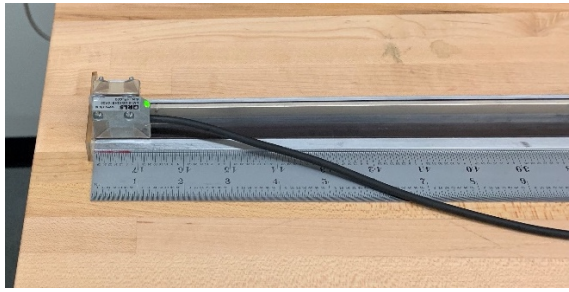
Conductivity Test

CO_2 Leak Test

Laser Cut to length



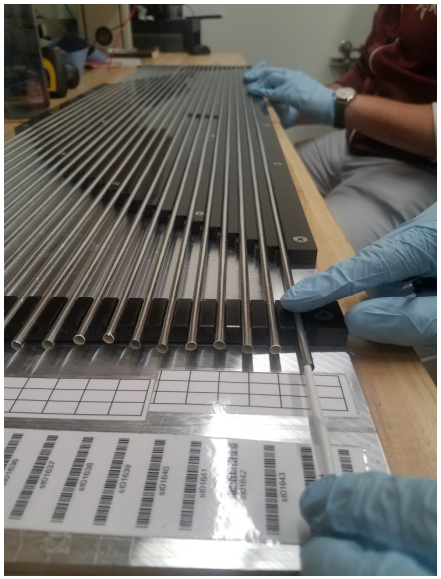
Insert Terminations



Length Verification

Straw Handling During Assembly

Straws travel through the processing in protective pallets.



Straw tubes in cutting pallet before cut to length using a programmed laser cutter.

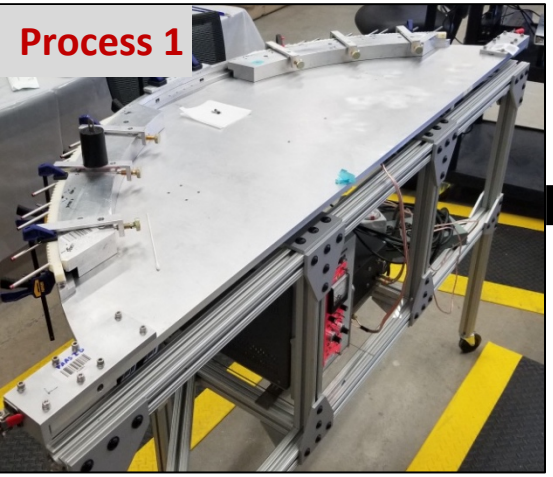
Stored straw tubes cut to length in storage pallets

Fully assembled straws stored in a pallet

Making Panels

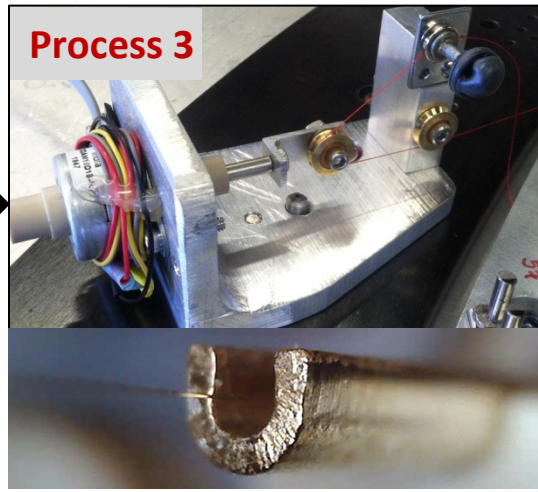
One of 3 Laboratory Rooms Used to Assemble Panels

Panel Assembly Steps Performed by Students @ Minnesota

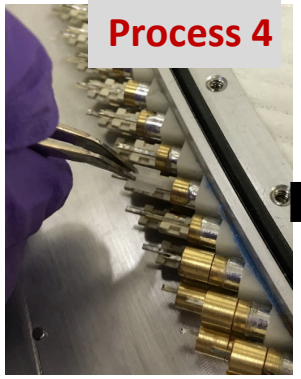


Inner Ring Building (2 days)

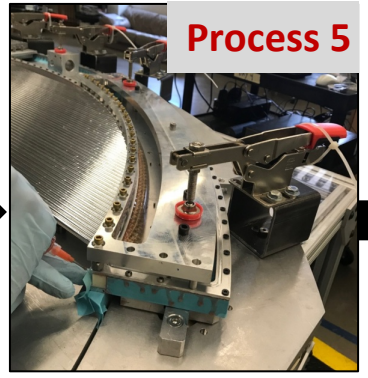
Straw Installation (1 day)



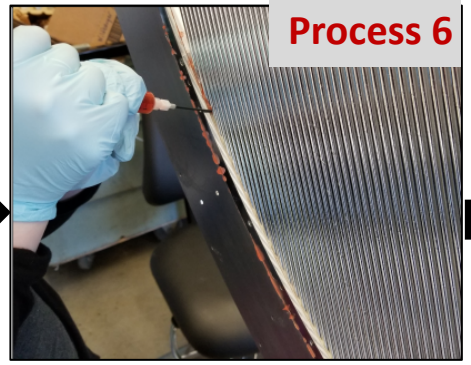
Wire Installation (3 days)



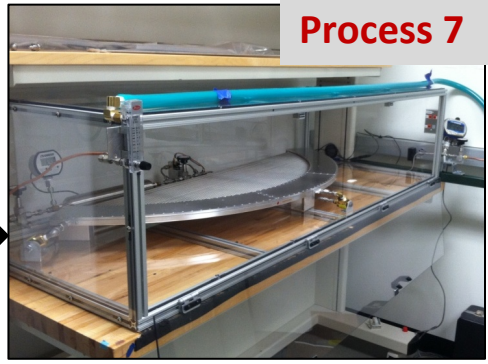
Pin Protector & Ground Clip Installation (1 day)



Manifold Installation (1 day)

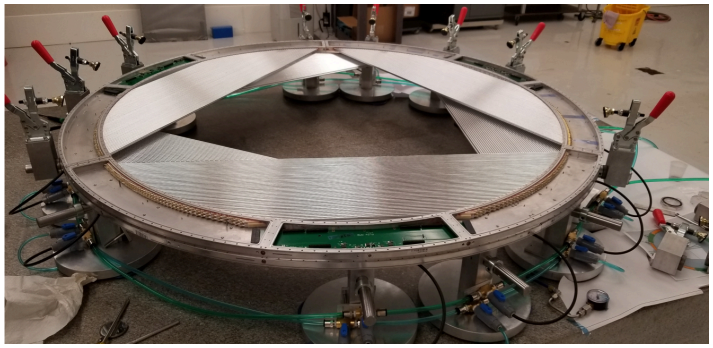


Alcohol Leak Check and Flooding (2 days)



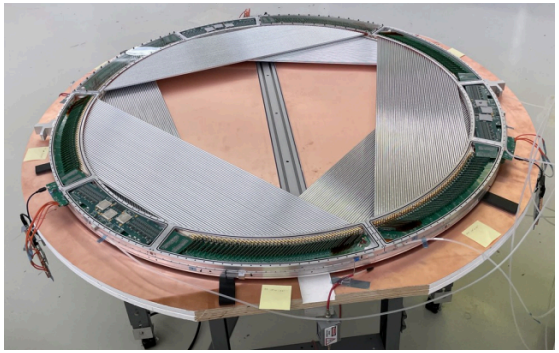
Resistance Check & Leak Test (3 days)

Tracker Assembly @ Fermilab

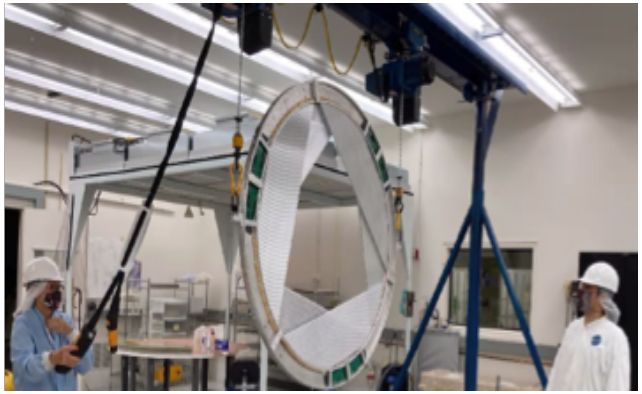


Planes Constructed

6 panels make a plane

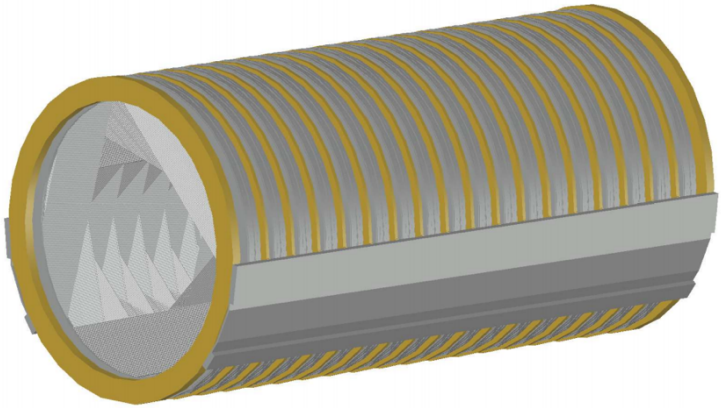


Electronics installed



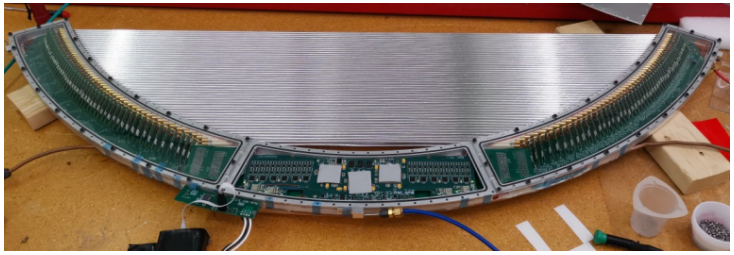
Planes installed into detector frame

36 planes make the tracker

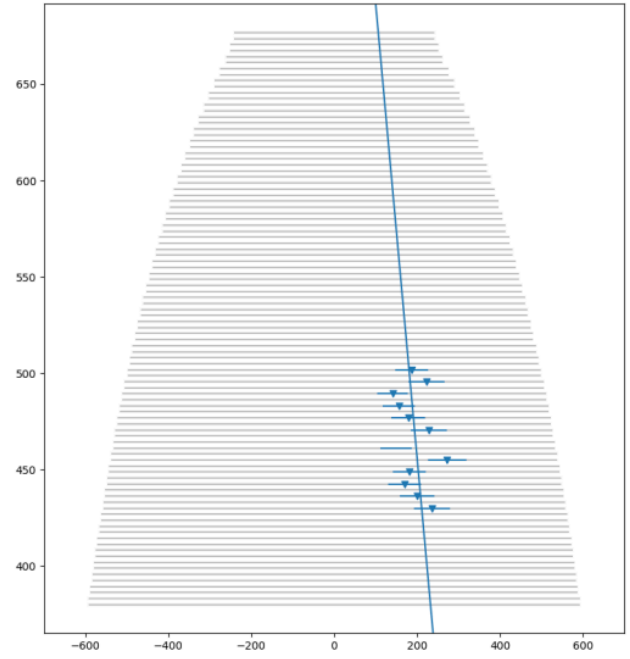


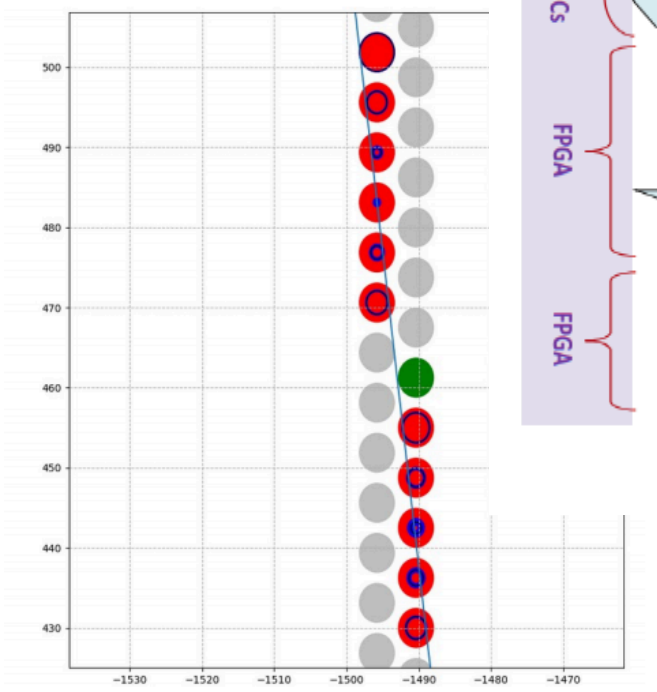
- **Planes are supported in the tracker frame.**
- **Bronze radiation shielding rings between two planes protects the electronics.**

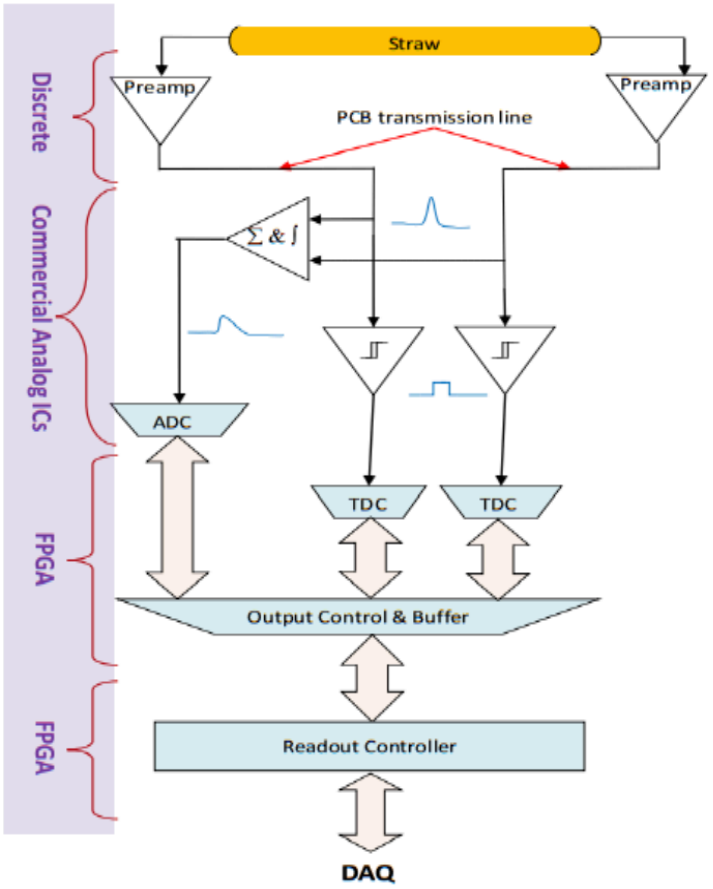
Single Panel Cosmic Ray Test



Downward cosmic ray through adjacent straws in a vertical panel.

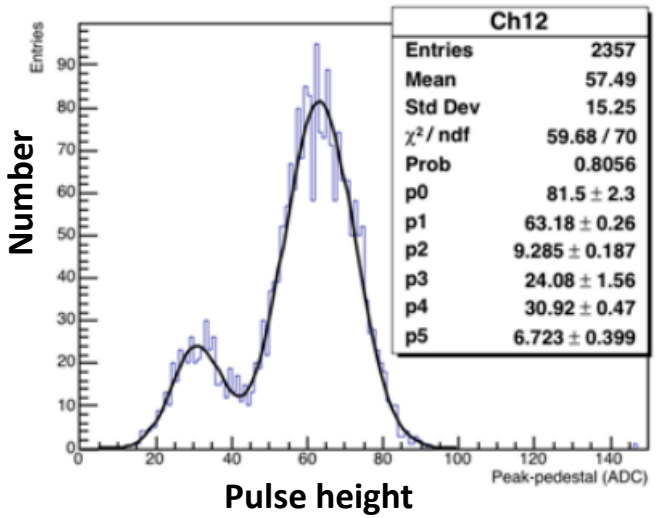


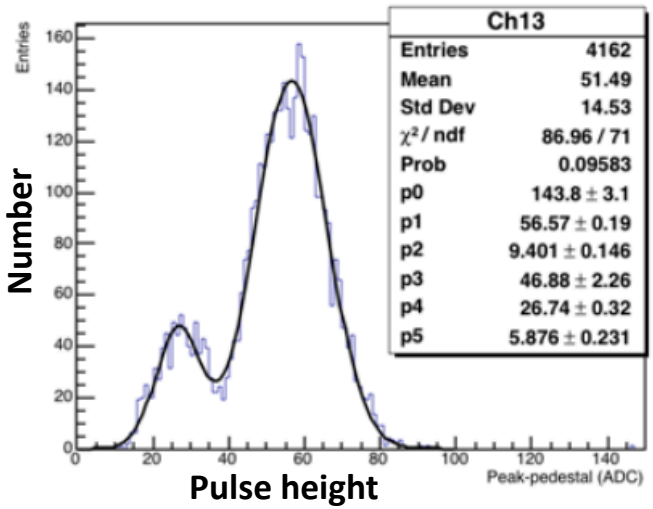


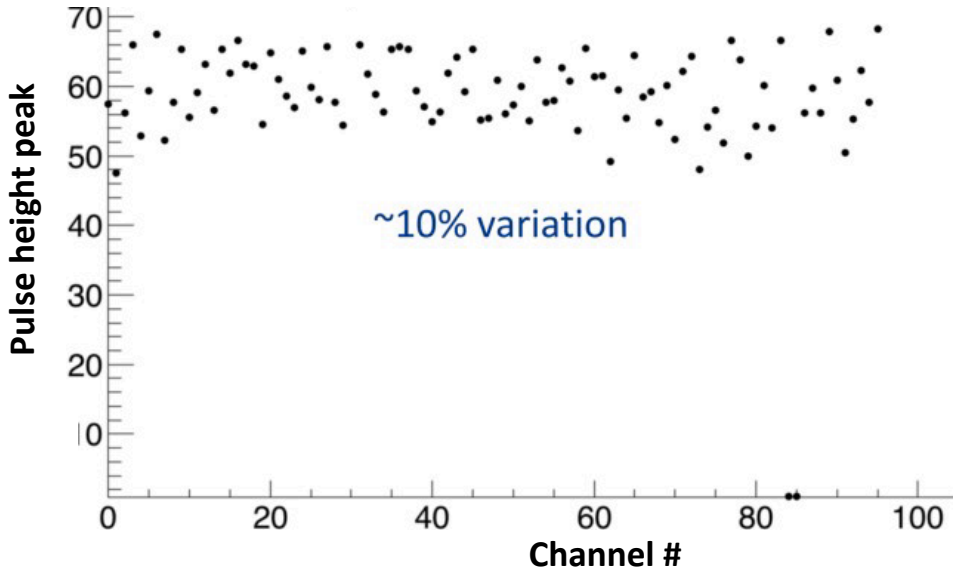


R. Bonventre

FE 55 Channel Responses







Y. Sun

FE55 source shows characteristic pulse height shape

Mu2e-II Experiment

Mu2e-II is a collaboration forming to upgrade to the Mu2e experiment to take advantage of increased beam intensity.
Current aims include:

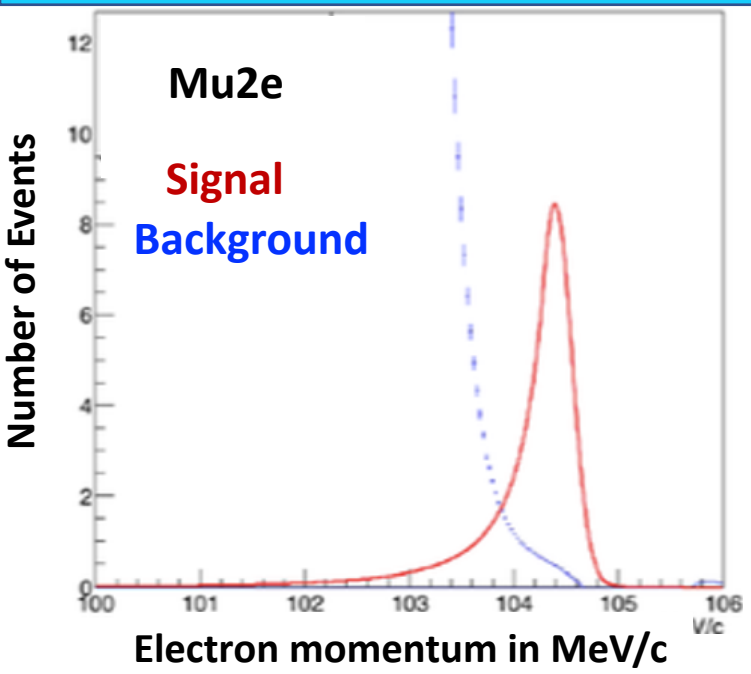
- **>10x measurement sensitivity increase (10^{-18} level)**
- **Possible different material for the stopping target (Titanium)**
- **Use most of the Mu2e infrastructure**

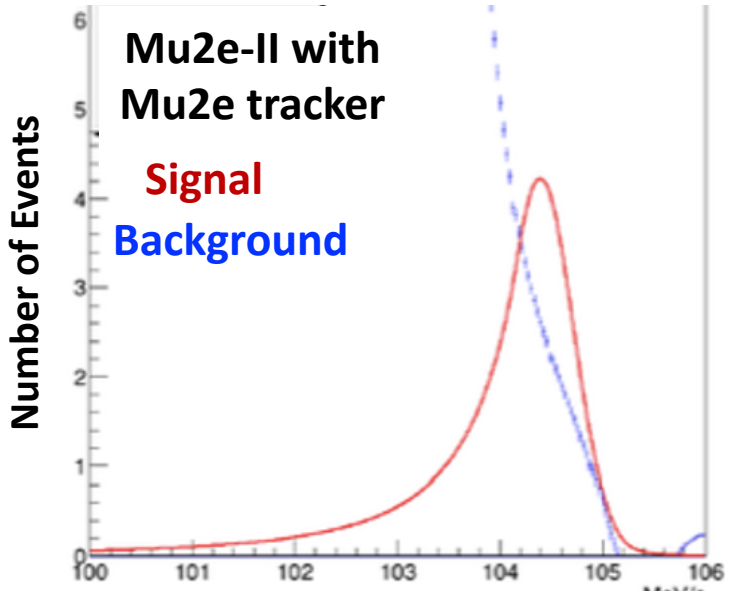
Timeframe -

- **Starts about 2 years after Mu2e ends**
- **~3 years of data taking at full intensity**

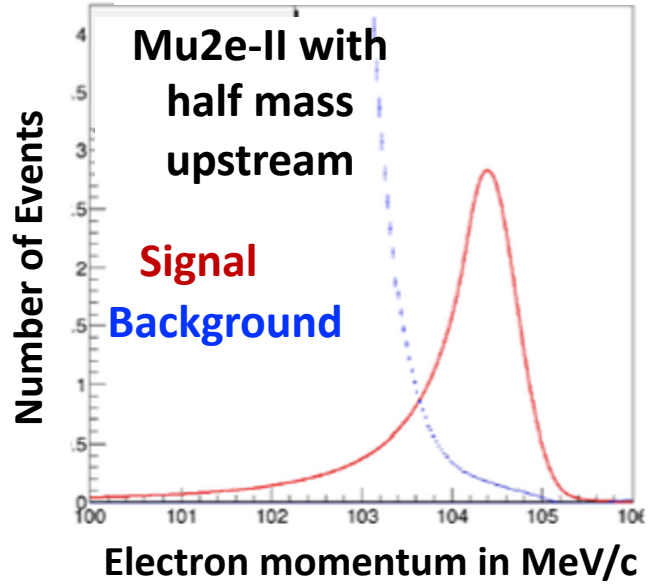
To match the increased statistics, must decrease the electron energy smearing caused by the tracker material

Mu2e-II Tracker Requirements





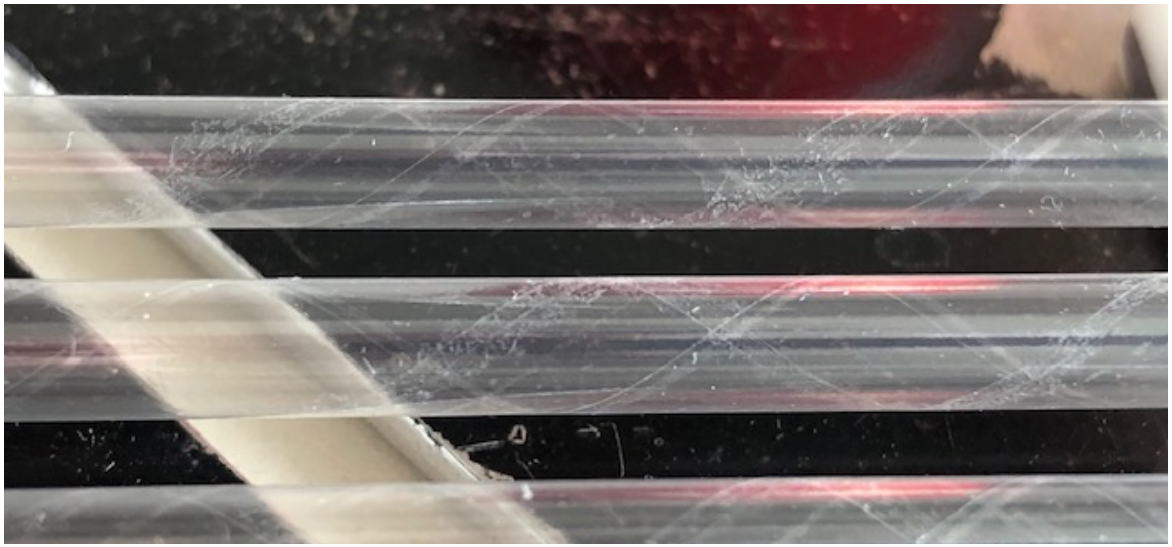
Toy MC
D. Brown



To increase electron momentum resolution tracker needs to have less material

- **Thinner walled straws**
- **Different tracker technology**
- **Different gas**

How thin can you make straws?



Pressurized 8 μm Mylar Straws

8 μm Mylar Straw

Test structure: 3.5 µm Mylar + 1 µm adhesive + 3.5 µm Mylar double helical wrap straws

Made by same drinking straw company that made Mu2e straws

These straws held 15 PSI for multiple days and 400 g Tension without visible distortion. Looking into what the needed initial tension to limit sag an acceptable distance (< .3 mm).

B.Casey, Fermilab LDRD

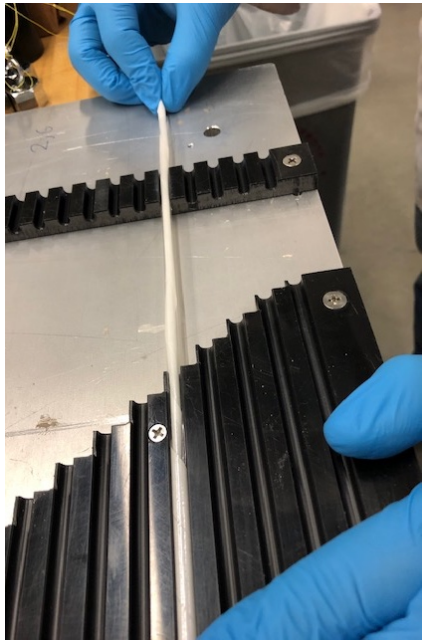
Handling Prototype Straws

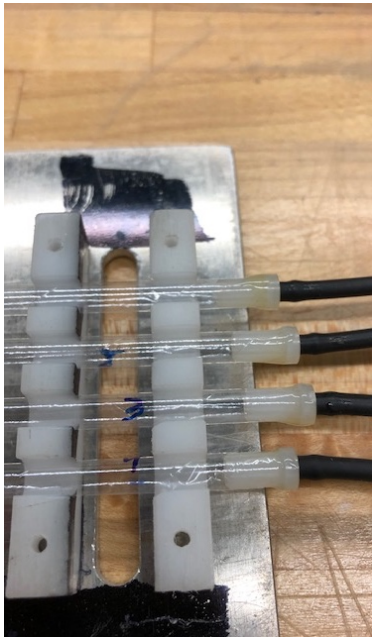
Without internal support, the 8 μm wall thickness straws collapse.

Straws inflated to an internal 1 atm force show no damage.

Possible techniques of keeping straws supported throughout installation.

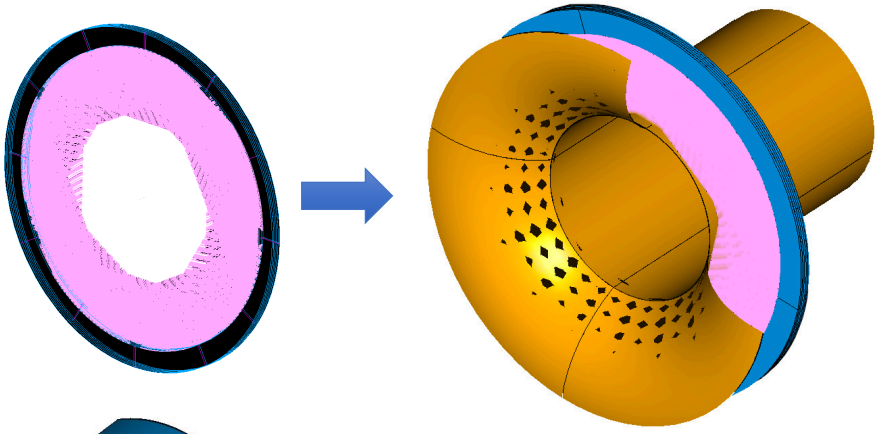
- **Straws are kept inflated during construction**
- **Winding paper left inside during assembly**



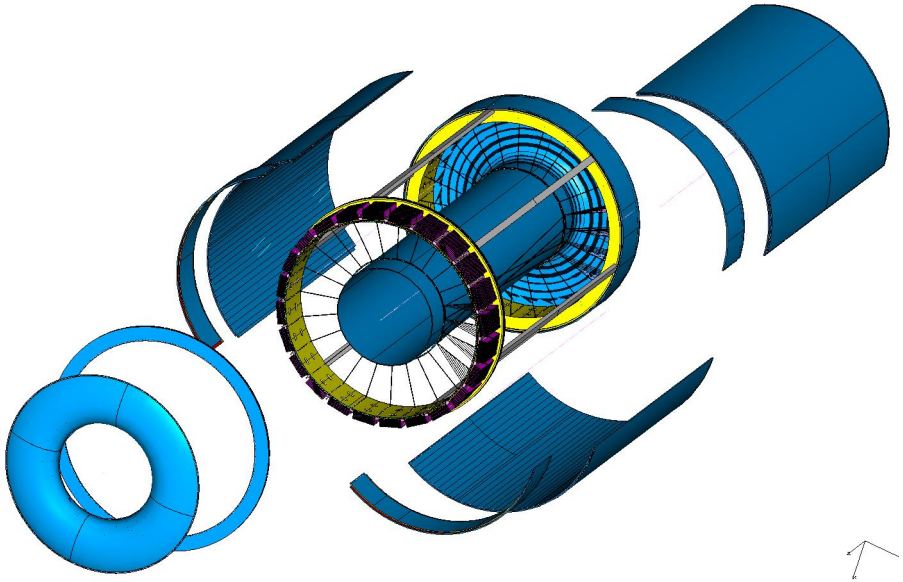


Other Mu2e-II Tracker Possibilities

Further reduce straw mass and removing straw leak requirements by sealing gas in another system



Tassielli G.F.

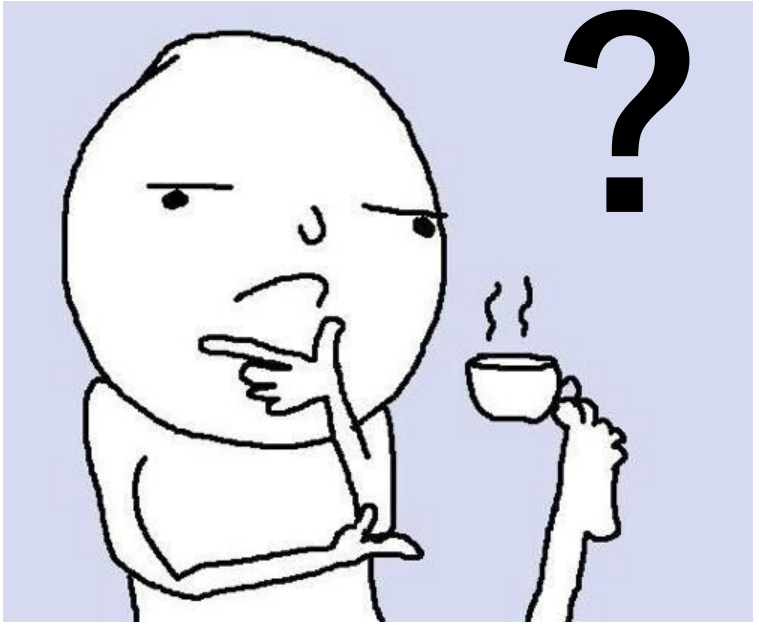


MEG-II style

Remove straws all together and construct an all wire drift chamber.

Design of tracker is open: All ideas welcome.

Tracker designs being tested by simulation and building prototypes.



If you are interested in joining us, please contact

me (ambr0028@umn.edu),

Gianfranco Tassielli

(giovanni.tassielli@le.infn.it),

or come to the workgroup meeting though the list-serve

(MU2EII-TRACKER@fnal.gov)

Summary

- **The Mu2e tracker is being assembled and tested.**
- **For Mu2e-II, we need to push the boundaries of what is possible for gaseous detectors.**

- **Some Lessons learned :**
  - **Very thin straws can be made with a straw company**
  - **Straws and panels can be built safely and successfully with students**
  - **If possible, avoid pandemics when building detectors with a small army of students.**

For more detailed information on Mu2e ask or check out our :
Technical Design Report http://arXiv.org/abs/1501.05241
Experiment web site http://mu2e.fnal.gov

For Mu2e-II :
Expression of Interest https://arxiv.org/pdf/1802.02599.pdf