Mu2e Tracker

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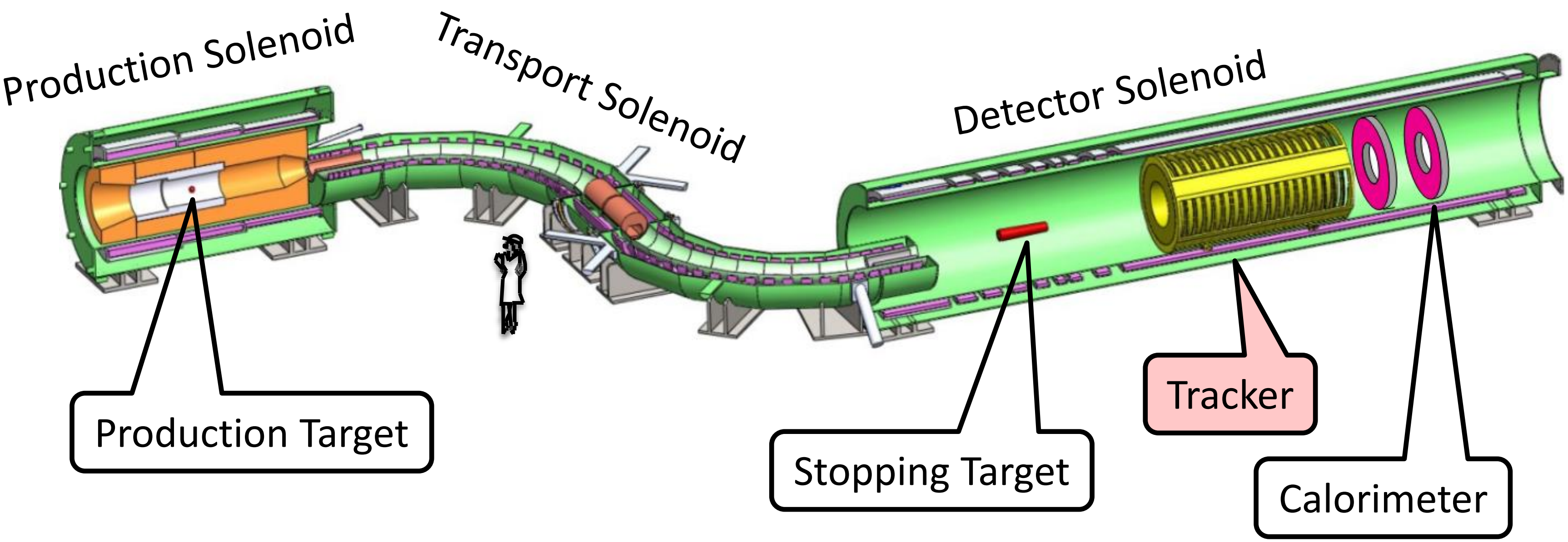
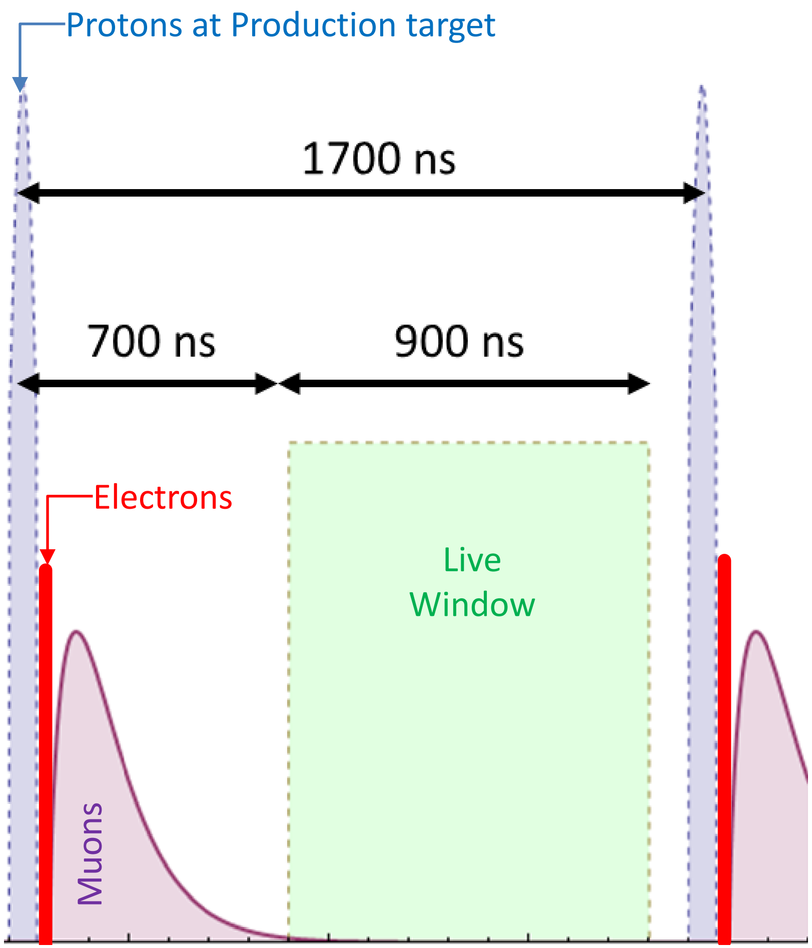
Tracker Environment

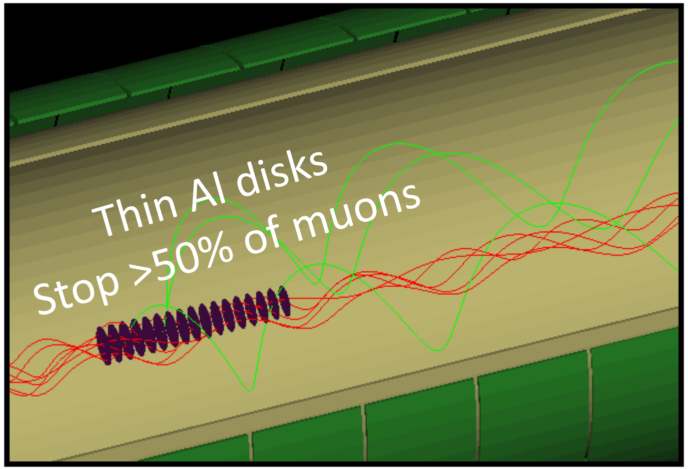
(aka the Mu2e Experiment)

- Generate muons
- Stop them, and let them decay… or convert
- Detect outgoing electrons



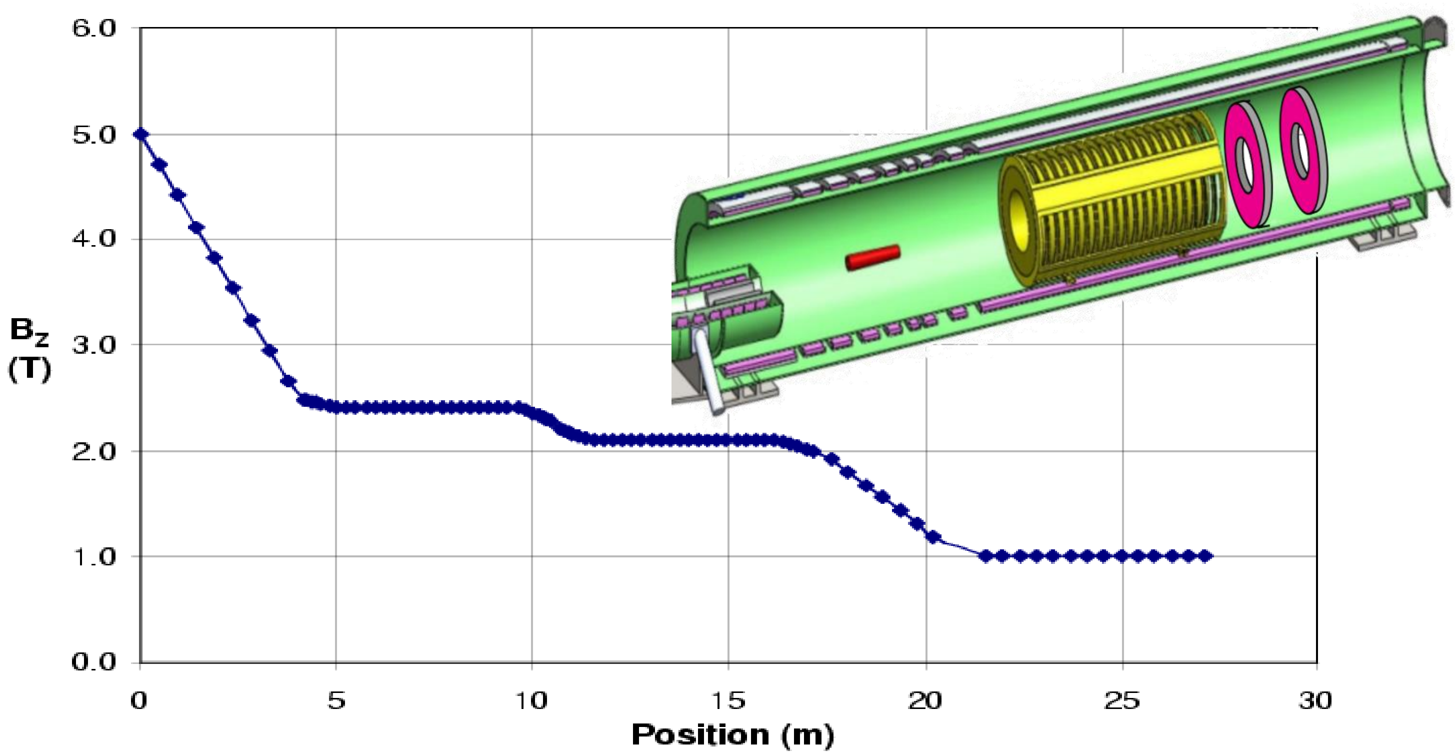
Beam Structure





- 1700 nsec set by Delivery Ring
- 700 ns wait to allow fast decays to finish
  - But tracker still gets hits

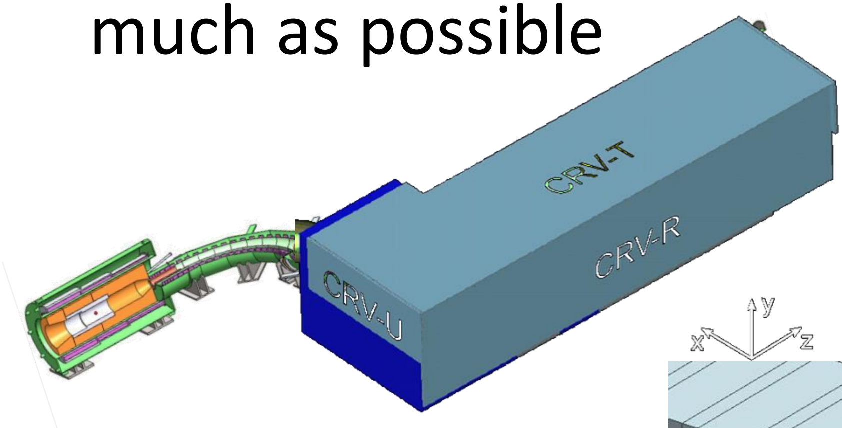
Detector Solenoid



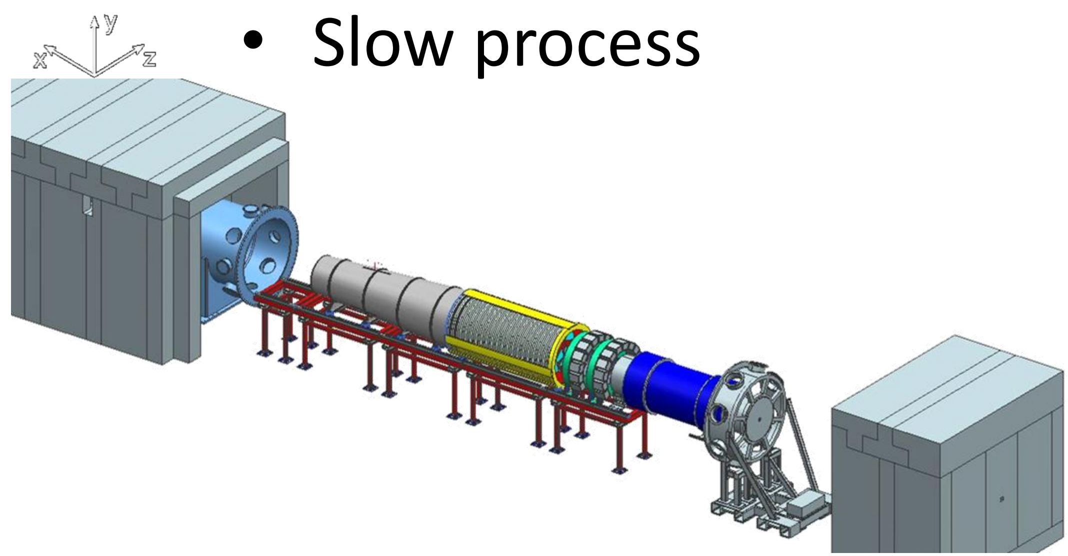
- Graded field pushes decay products forward
- Uniform field around tracker

Cosmic Ray Veto (CRV)

- By design, covers as much as possible

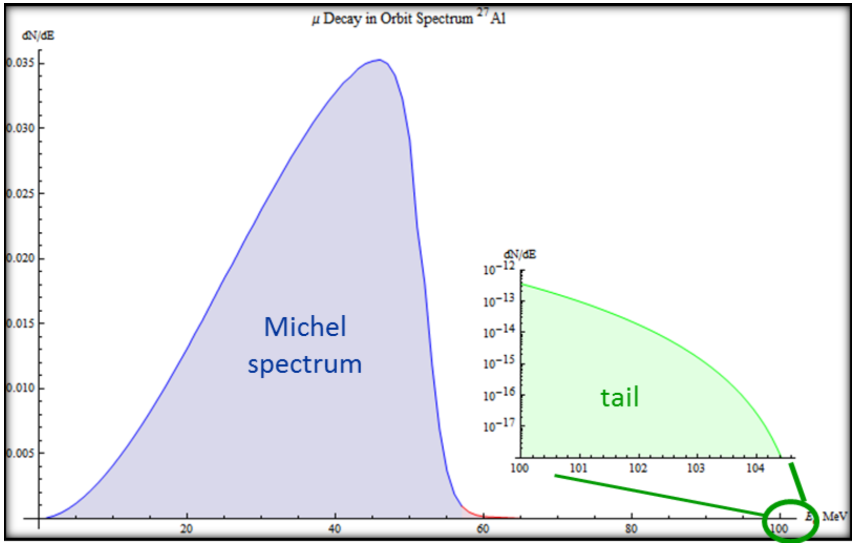


- To access tracker:
  - Pull back piece of CRV
  - Open DS
  - Pull detector "train" out
- Slow process



Particles at Tracker

- Before live time
  - Electrons "flash" scattering off target
  - Fast decay products
- Lot of hits to recover from!
- Extending into live time
  - Protons from Nuclear breakup
  - Decay in Orbit (DIO) i.e. usual $\mu \rightarrow e\nu$



- DIO
  - Mostly <½ m_μ
  - Nuclear recoil smears up to near 105MeV

Tracker Requirements

- Near zero material down the center $\leftrightarrow$ ambient vacuum
  - Lot of unstopped muons, electron flash, DIO
  - Even if tracker could handle it, scattering would create background
- Low mass in active region
  - 105MeV electrons scatter a lot
- Momentum resolution
  - Primary tool to reject background

Straw Tracker

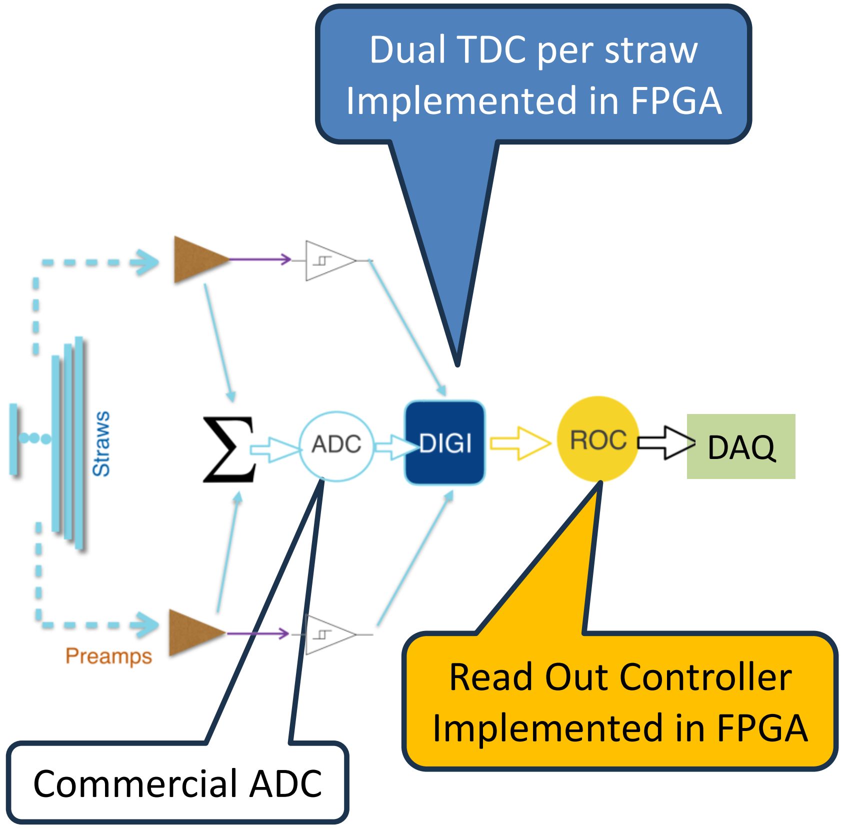
- Small cylindrical volumes tolerate large pressure differential with minimum material
- Fine segmentation gives low occupancy
- Successfully used in previous experiments
  – Most recently, g-2 used essentially identical straws in vacuum

Transverse Tracker

- Straws parallel to B
  - Difficult to keep mechanical support and readout out of active volume
- Straws Transverse to B
  - Mass easily moved out of active volume
  - Difficult pattern recognition
  - "Time division" helps

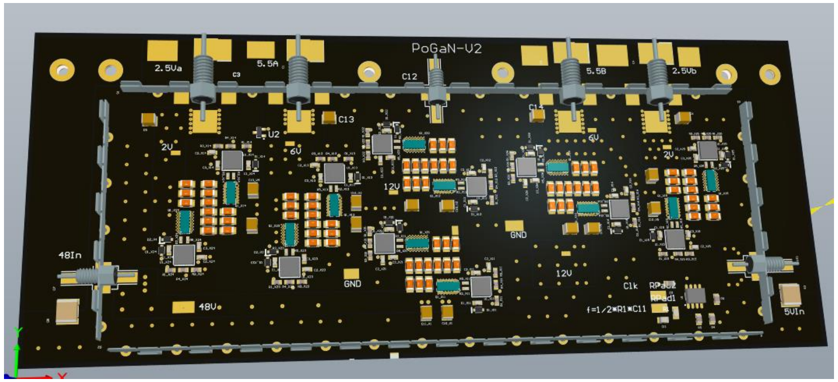
Time Division

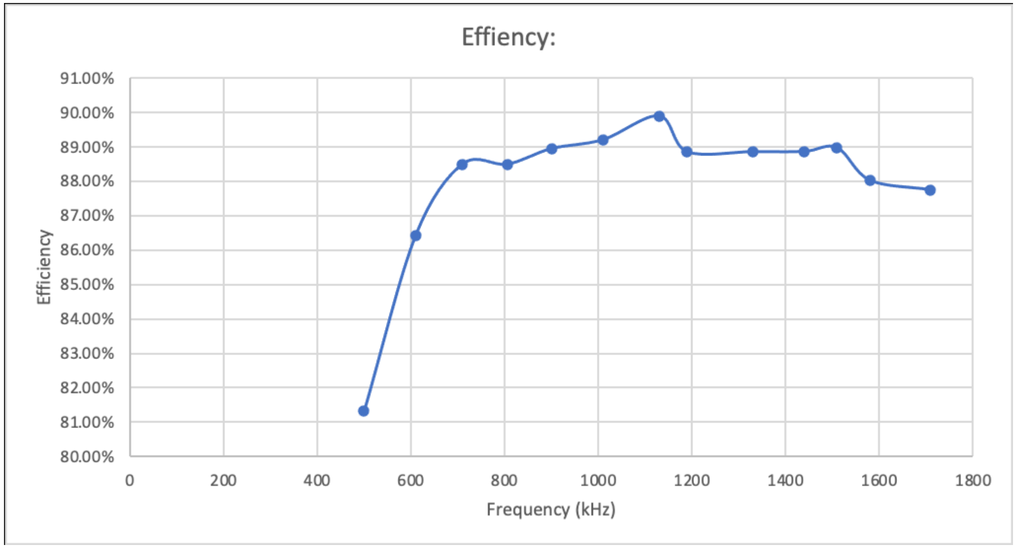
- Measure hit time at both ends of straw
- Δt gives estimate of position along straw
- Benefits from TDC precision better than needed for drift time



DC-DC Convertor

- 48V → 5V & 2.5V
- Charge pump
  (no magnetic material)

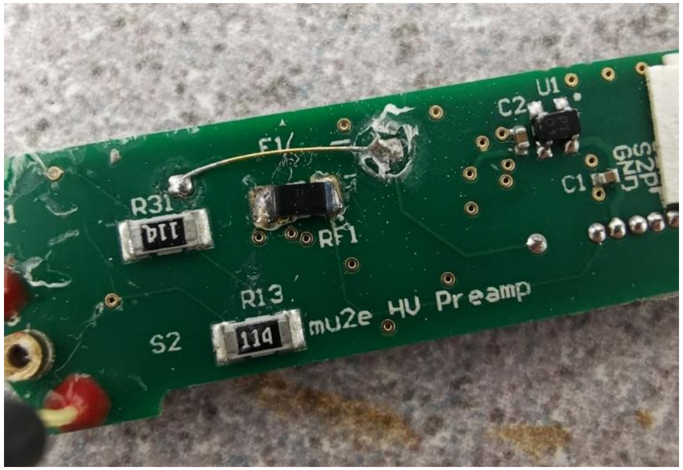


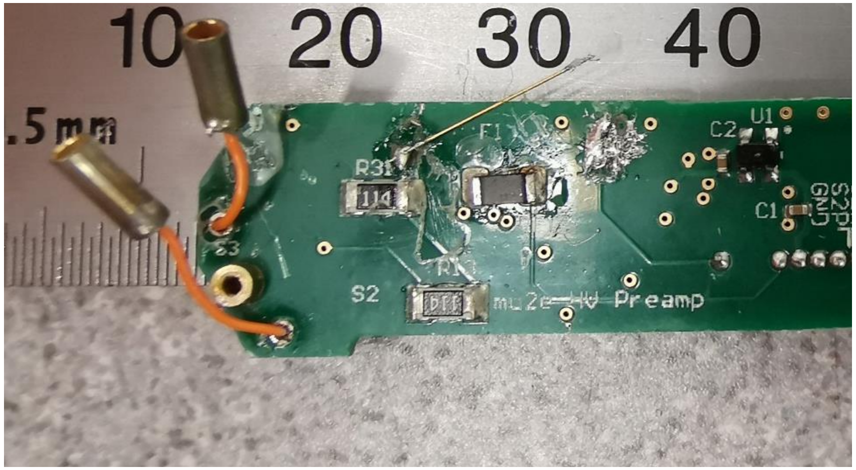


HV Disconnect

- Thermal fuse triggered by heating a resistor
- Allows individual straw to be disconnected
- Commercial fuses had issues with size, outgassing, radiation

Pictures are from a worst-case test with excessive parylene





Straws

- 5 mm diameter, as thin wall as possible
- ~1 bar internal pressure for easier testing
- Ambient vacuum $\rightarrow \Delta P \approx 100\text{kPa}$
- Use tension to keep straws straight

- Double helical wrap
  - 2×6 μm Mylar + 3 μm adhesive
- Metalized inside and outside to reduce leaks

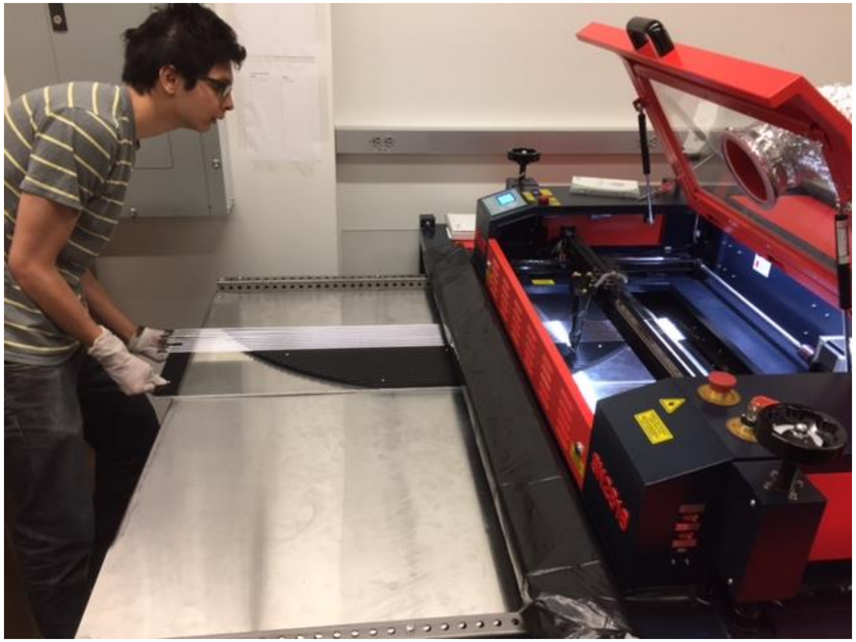
Straw Leak Testing

- Thinnest straws made!
- Every straw individually tested
  - Purge with CO_2, pressurize to 100 kPa
  - Place in N_2 purged tube, close tube
  - Monitor CO_2 content
    - Fast and cheap: big market for CO_2 sensors!
- Cross-checked with vacuum tests

Straws slide through ball valve

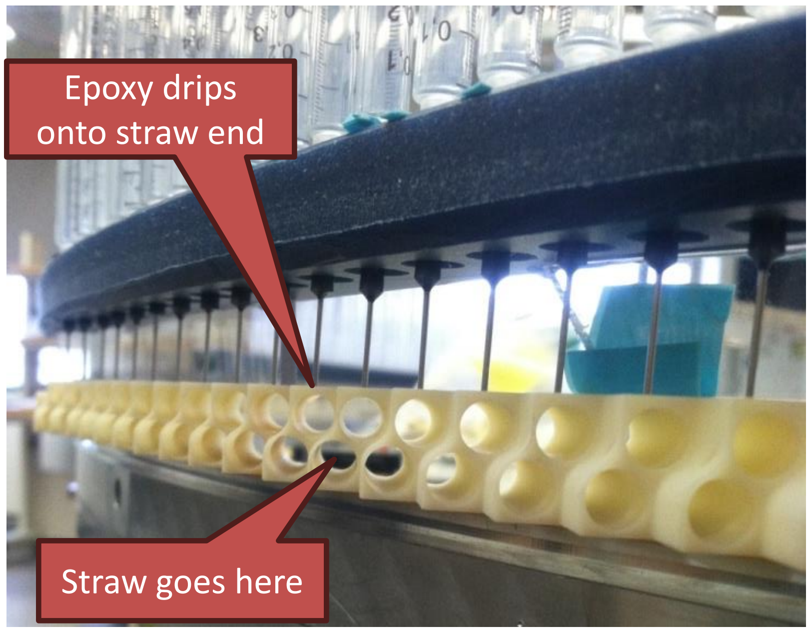
Straw Prep

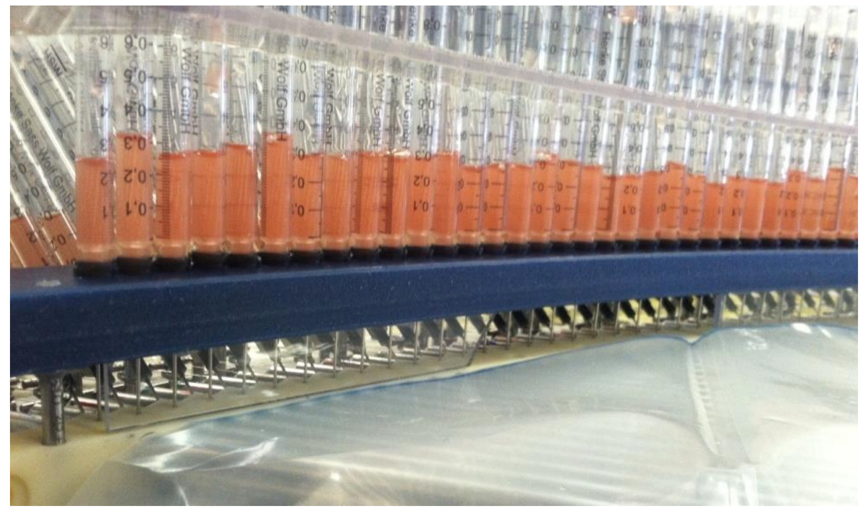
- Laser cutter to generate 48 different lengths
- Temperature and humidity compensation
- 0.2mm accuracy



Straw Installation

- Straws pulled to tension into 3D-printed piece
- Has fine features to allow epoxy to drip onto straw ends

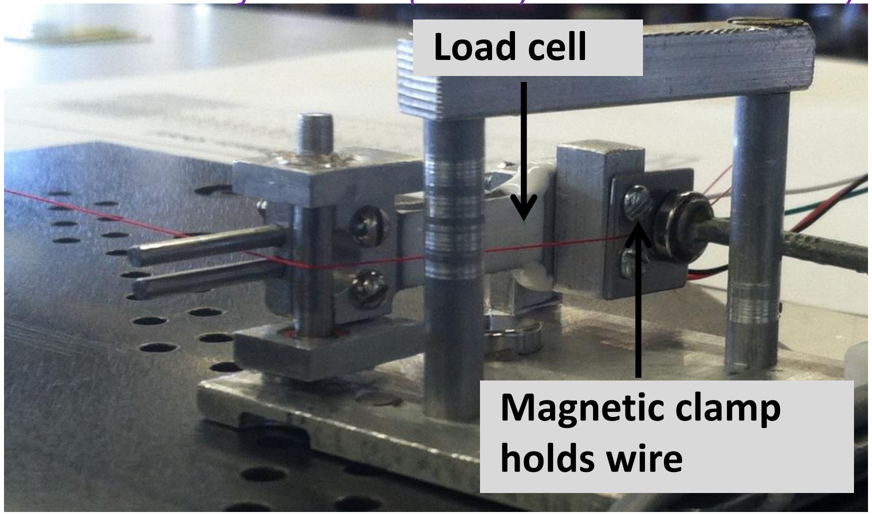


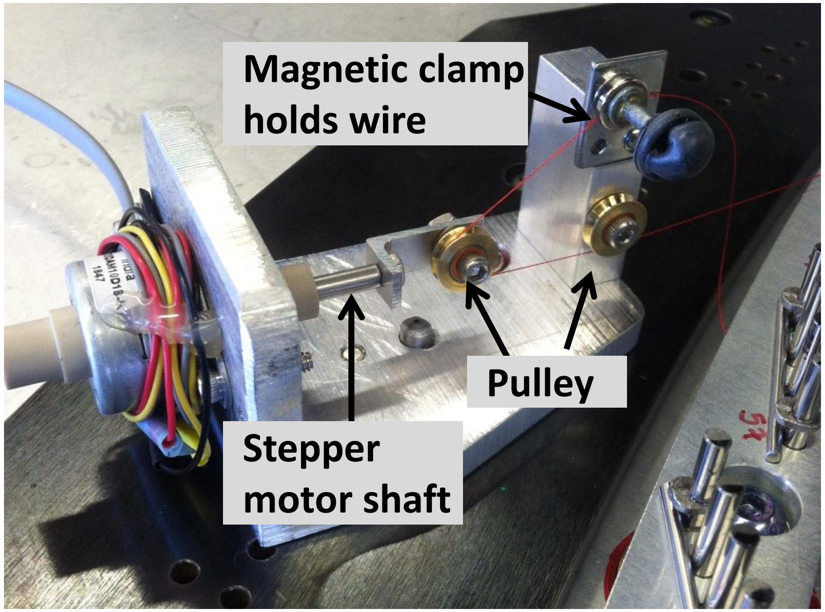


Sense Wire Installation

- 25µm gold plated tungsten
- Tension with load cell and stepper motor
  - Work harden wire as part of installation: Over-tension, then back off

Pictures show feeder line (thread). Wire too thin to see)



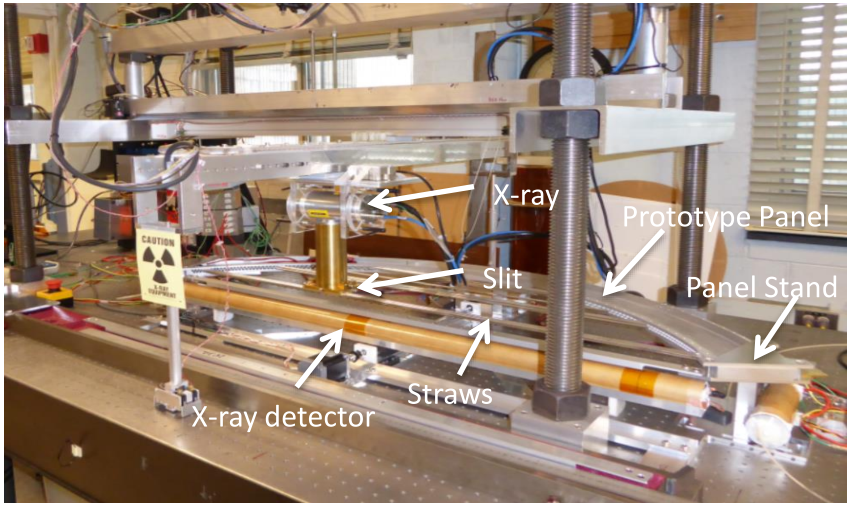


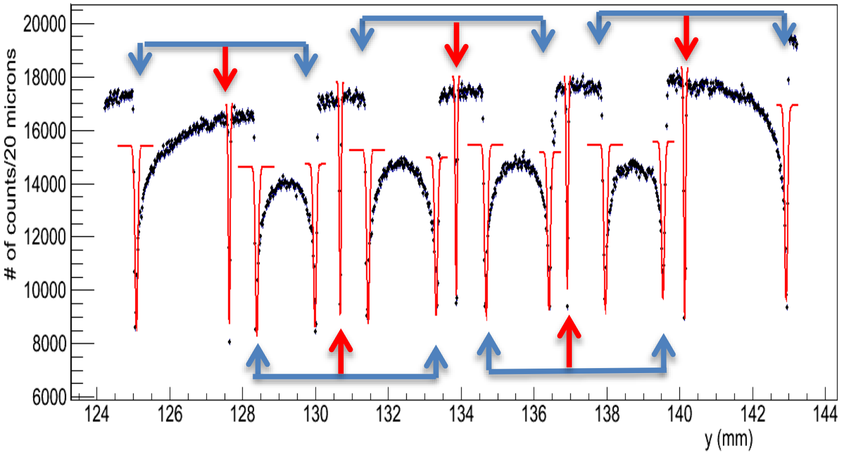
“Panel”

- 120° sector with 96 straws
- Small enough to ship
- Straw and Panel work done at U. of Minnesota
- Ship to Duke U. for metrology

Straw and Wire Metrology

- X-ray (almost) all panels to locate wires and straws relative to survey markers
  - 15° stereo (tilt X-ray) for measuring Z
- $\sigma_y \approx 25\mu m$, $\sigma_z \approx 75\mu m$





Red arrow: Wire Blue arrow: Straw edge

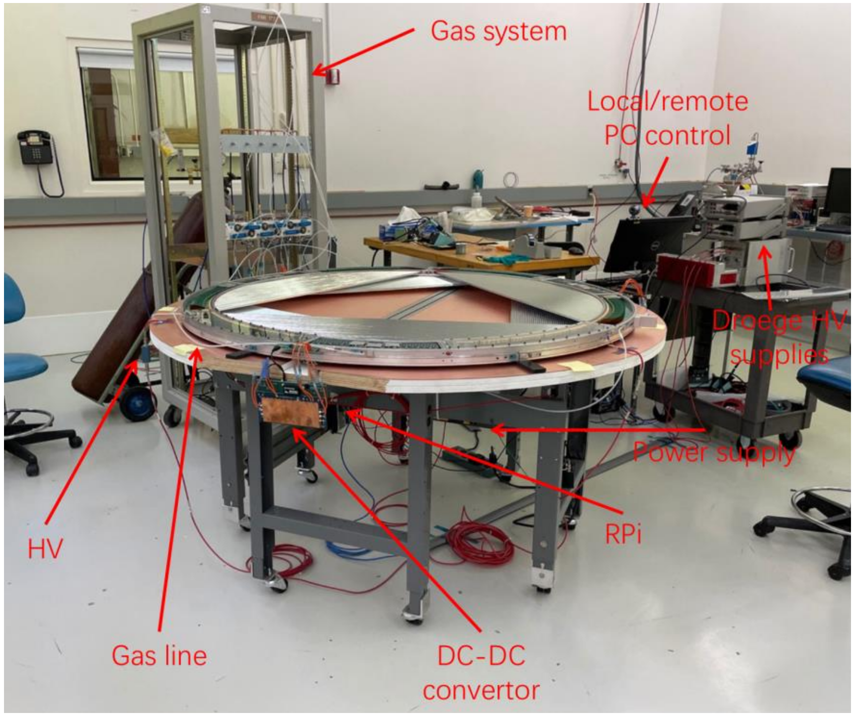
“Plane” and “Station”

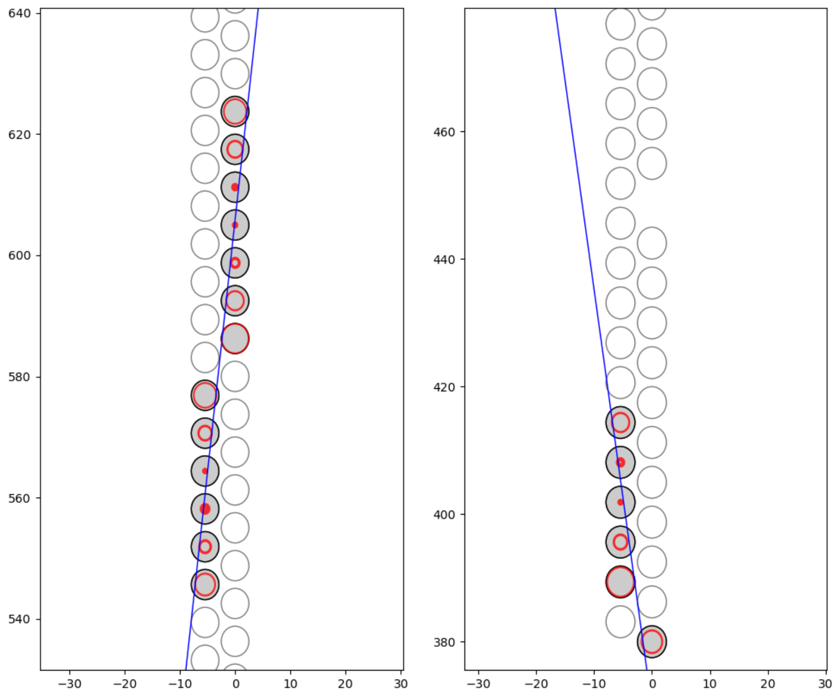
- Plane: 6 overlapping panels form a complete ring
- Station: 2 planes “clocked” to have 12 orientations for straws
- Assembled referencing granite table for precision in Z

- Assembly precision ~150 µm
- Final alignment based on survey points used at Duke

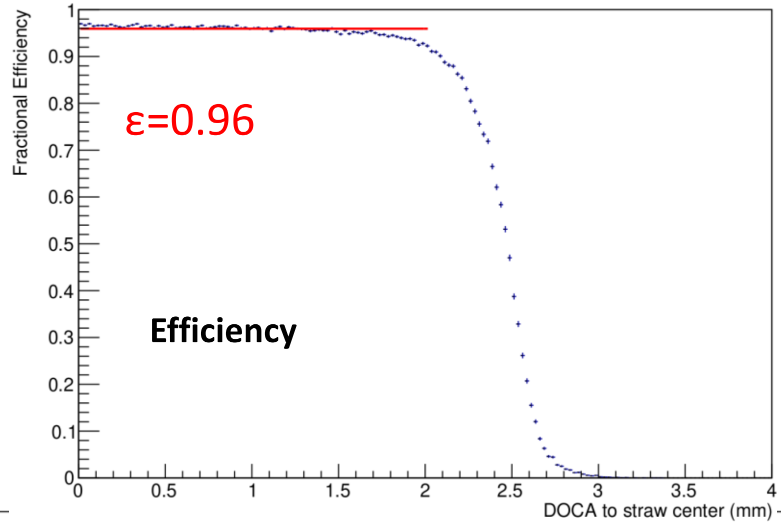
Vertical Slice Test

- Plane with full electronics chain
  - Shown horizontal – also run vertical

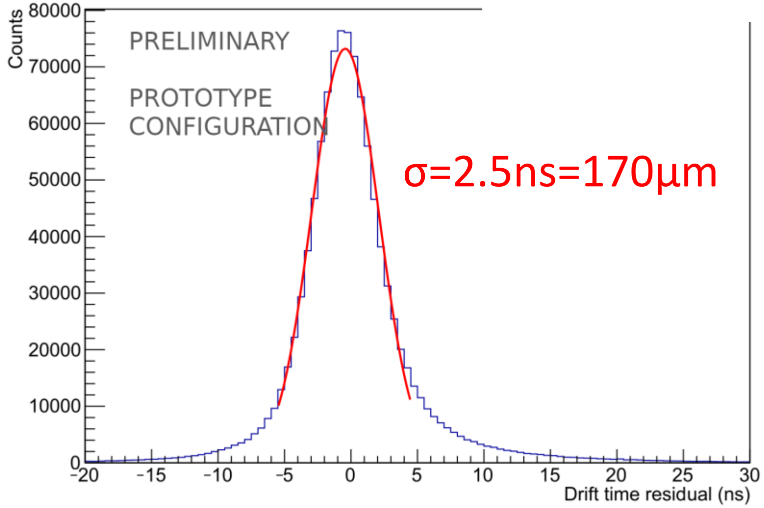




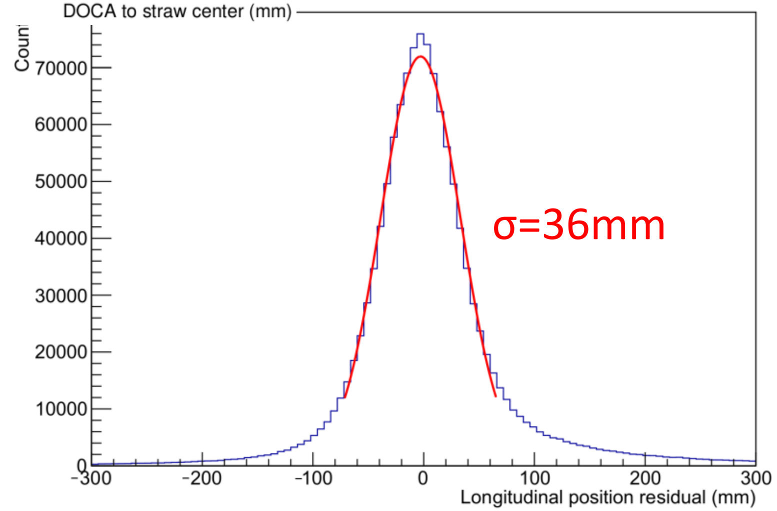
Resolution, Efficiency



Drift Direction

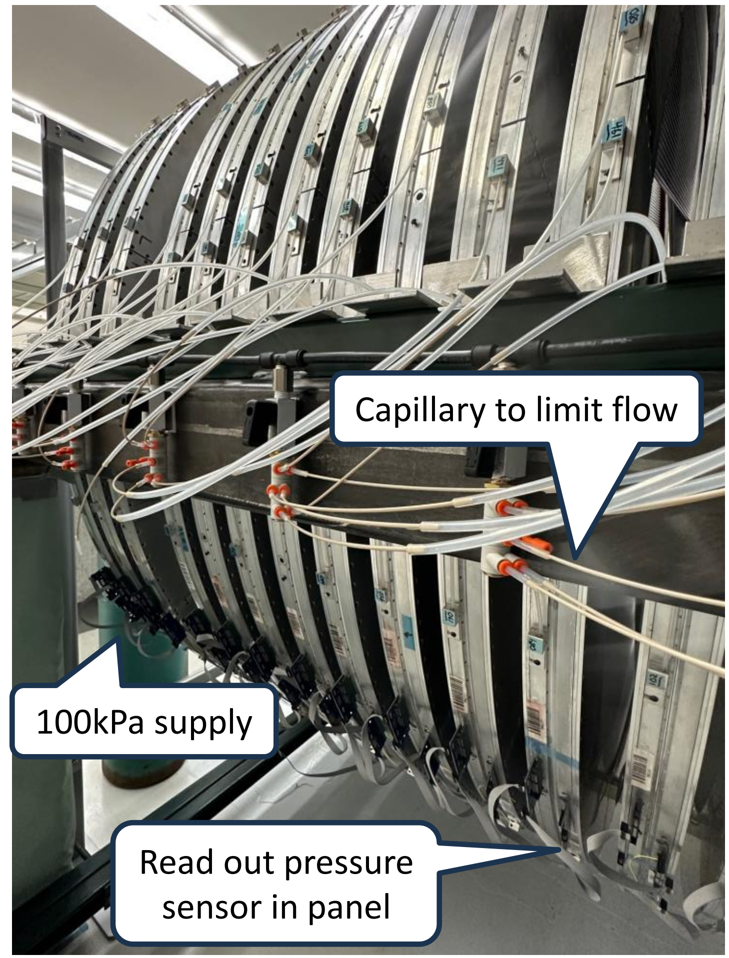


Along Straw (time division)



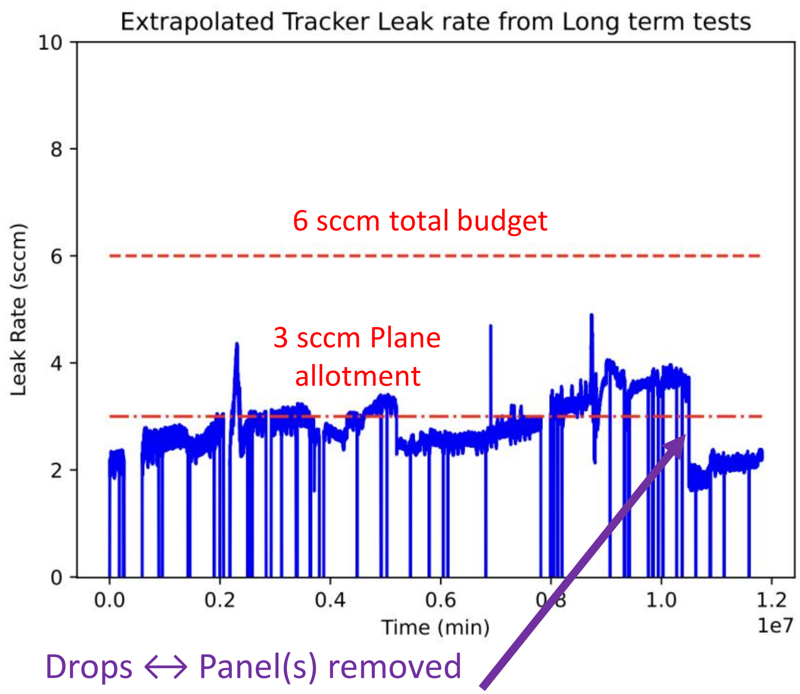
Leak Testing

- Done at every step!
  - Panels leak tested
    - At U.Mn before shipping
    - At FNAL after shipping
  - After assembly, planes leak tested
    - Precision setup, gets leak rate overnight
    - Long term leak test while planes are in storage



Leak Rate

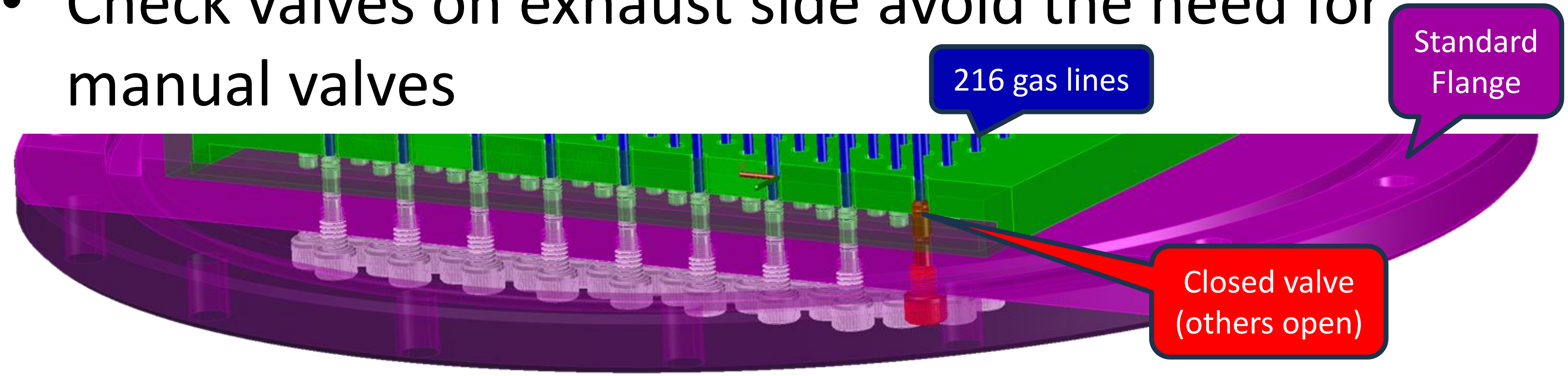
- Looks good so far! But…
  - Periodic repairs, not realistic in reality
  - Die out over time. Still worrisome
- On the other hand
  - 6 sccm ↔ 10^{-4} Torr
  - 10^{-3} Torr ↔ 60 sccm is acceptable



Drops ↔ Panel(s) removed
(later repaired)

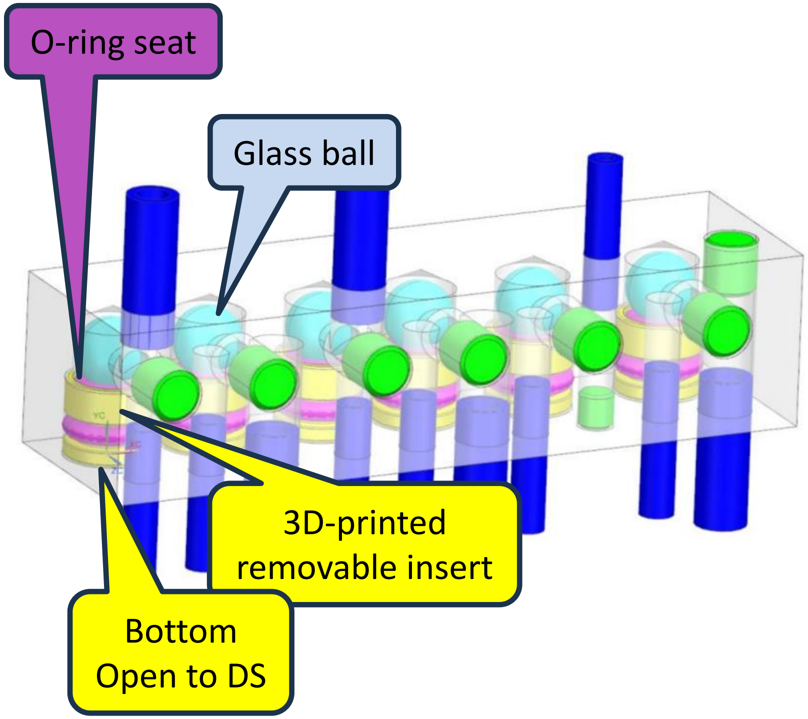
Per-panel Gas Feed

- Gas to any panel can be stopped without opening the DS
- Do need to access IFB (back of DS)
  - Remote control being looked at
- Check valves on exhaust side avoid the need for manual valves



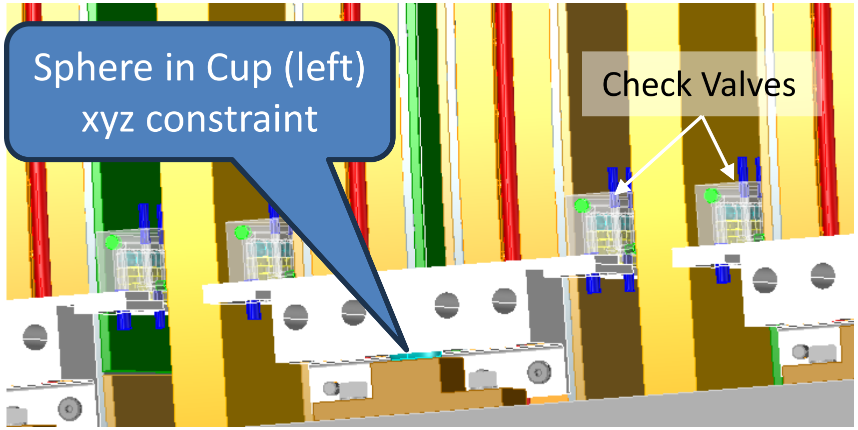
Reverse Pressure Protection

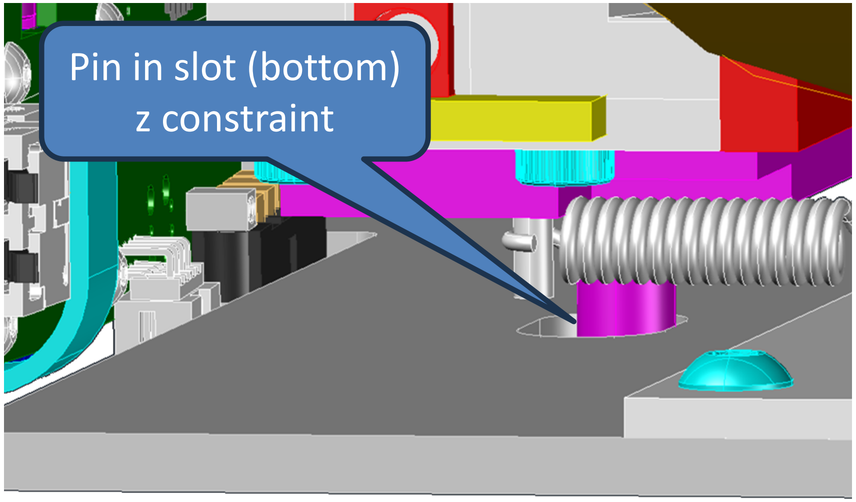
- Straws crush if $\Delta P<0$
  - Disconnected panel would be destroyed when DS was back filled
- Custom, very low opening pressure check valve
  - Very little space!
  - No suitable commercial valve found

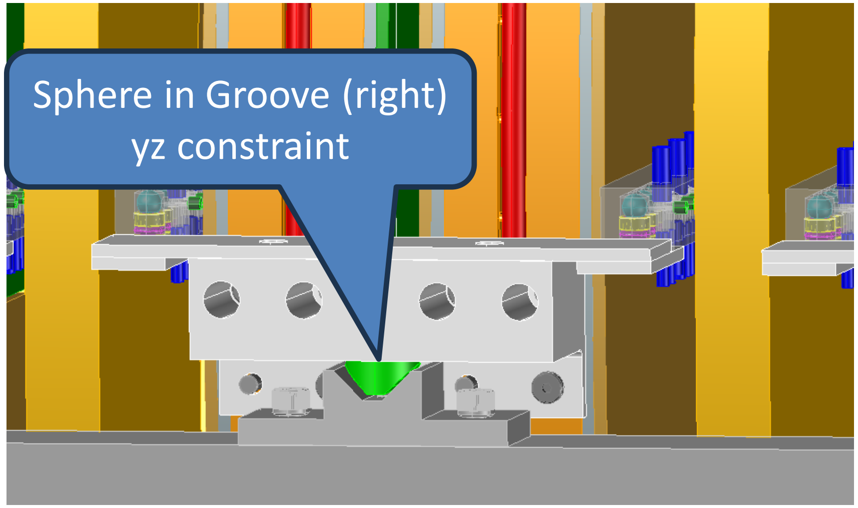


Tracker Frame

- Kinematic mount for each station
- No stress
  → stable metrology







Summary & Future R&D

- Straws are an appealing option for low mass, high-rate detectors
- Looking into even lighter straws for Mu2e-II (and possibly other applications)