Fermilab U.S. DEPARTMENT OF ENERGY Office of Science
FERMILAB-SLIDES-24-0007-AD

Electrostatic Septa Development at FNAL

Fermi National Accelerator Laboratory

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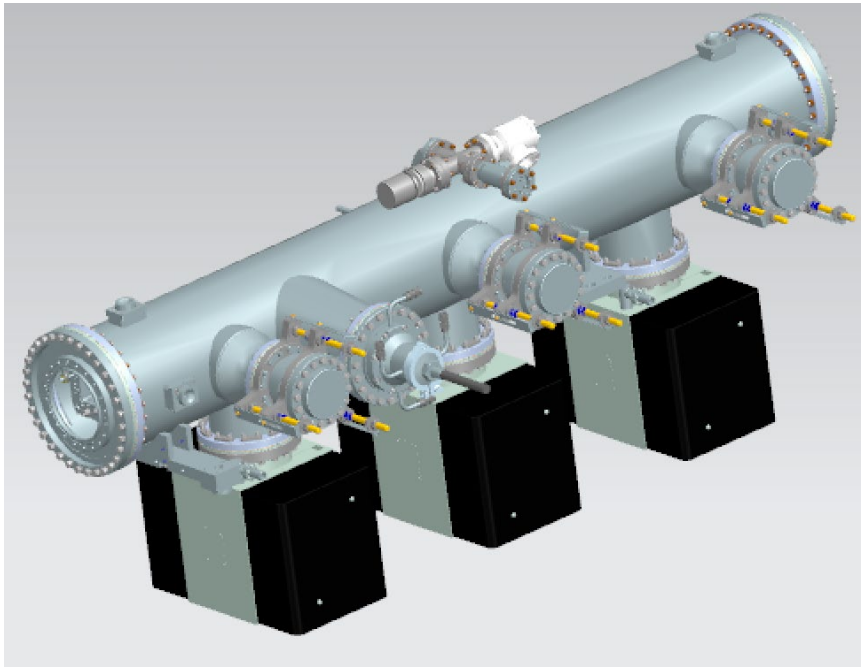
5th Slow Extraction Workshop at MedAustron in Weiner Neustadt

13 February 2024

Outline

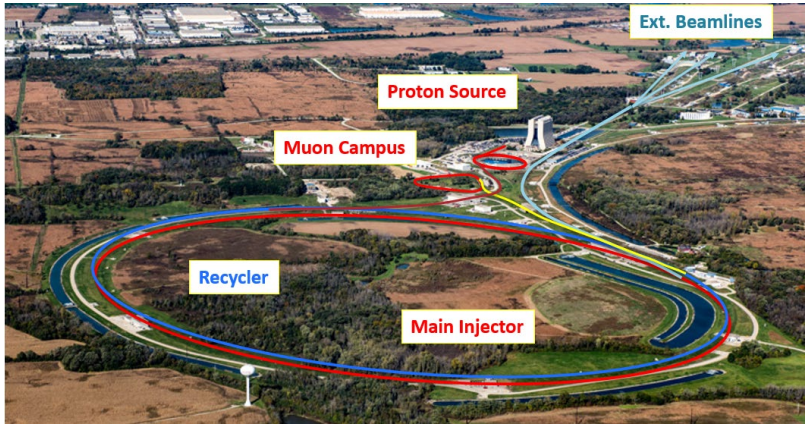
- Introduction
- Mechanical Overview
  - Frame Assembly
  - Cathode
  - High Voltage Feedthrough
  - Cathode Standoffs
  - Vacuum Vessel and Fully Assembled Septum
- Assembly
- Transportation
- Challenges
- Current Status



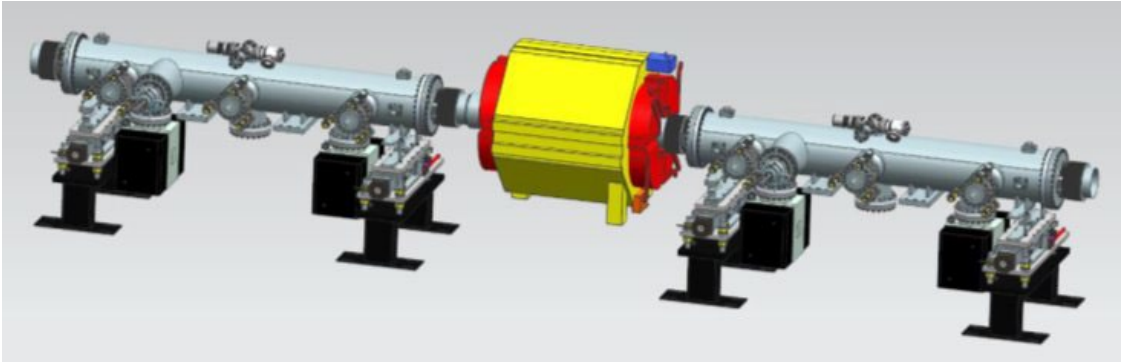
Introduction

- Mu2e experiment will study rare neutrinoless decays of muon to an electron

Beam Parameters	Nominal Value
Particles Type	Protons
Kinetic Energy	8.0 GeV
Spill Duration	43 ms
Total Number of Protons in a Spill	1e12
Beam Power	8 kW

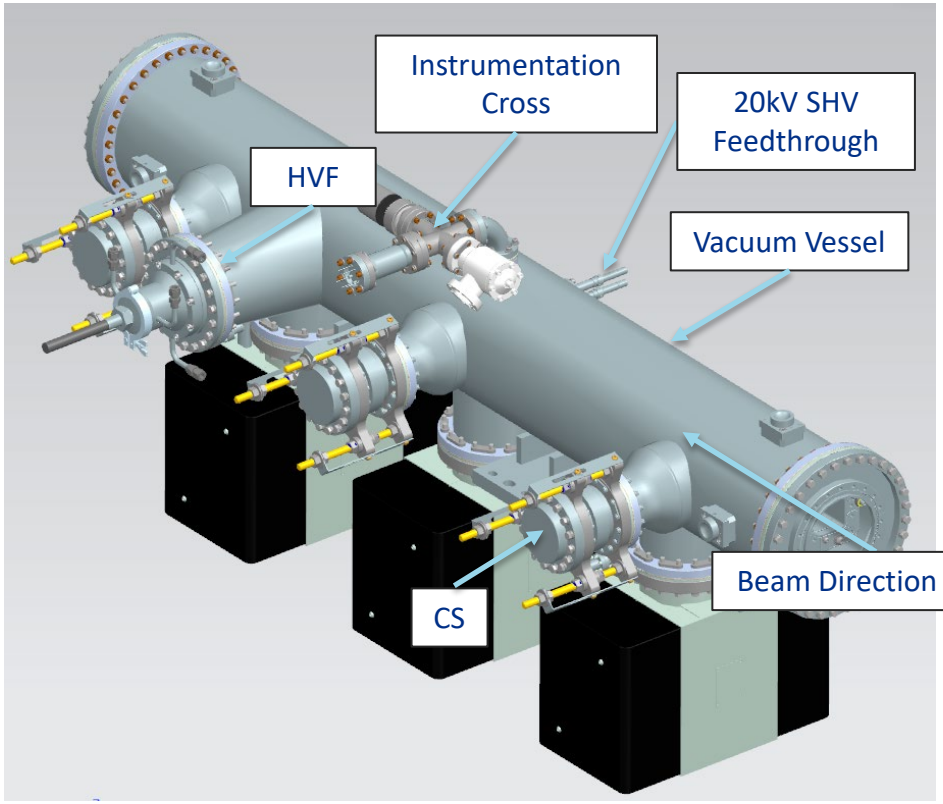


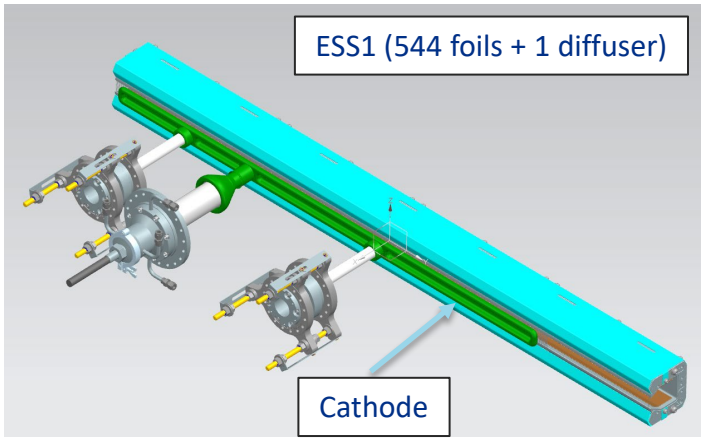
- Top Functional Requirements
  - High extraction efficiency: Greater than 98.5%
  - Radiation stability: 2+ years of operation

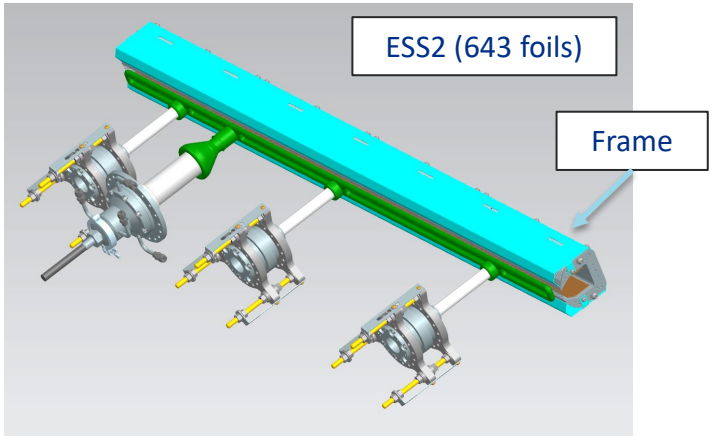


Mechanical Overview

- Frame Assembly
- Cathode
- High Voltage Feedthrough (HVF)
- Cathode Standoffs (CS)
- Vacuum Vessel
  - Instrumentation Cross
  - 3x 300L/s Ion Pumps

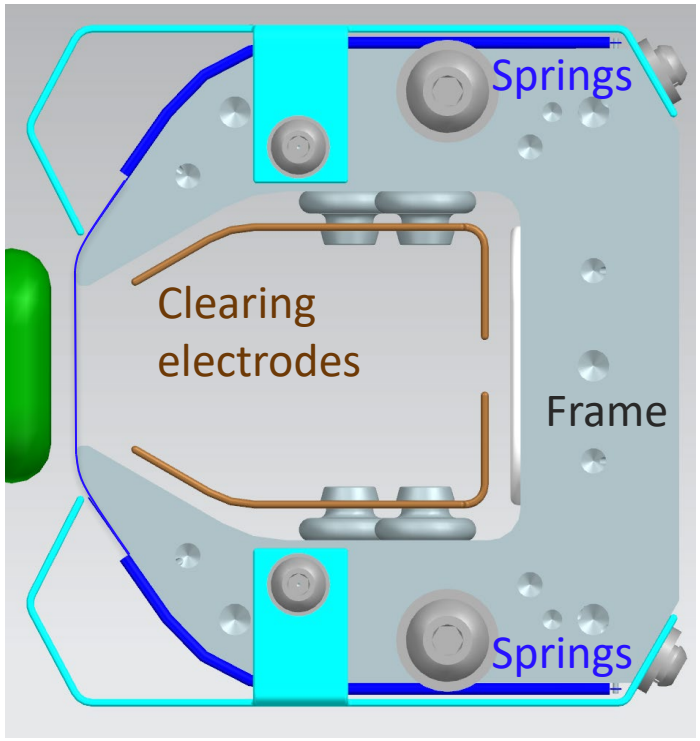


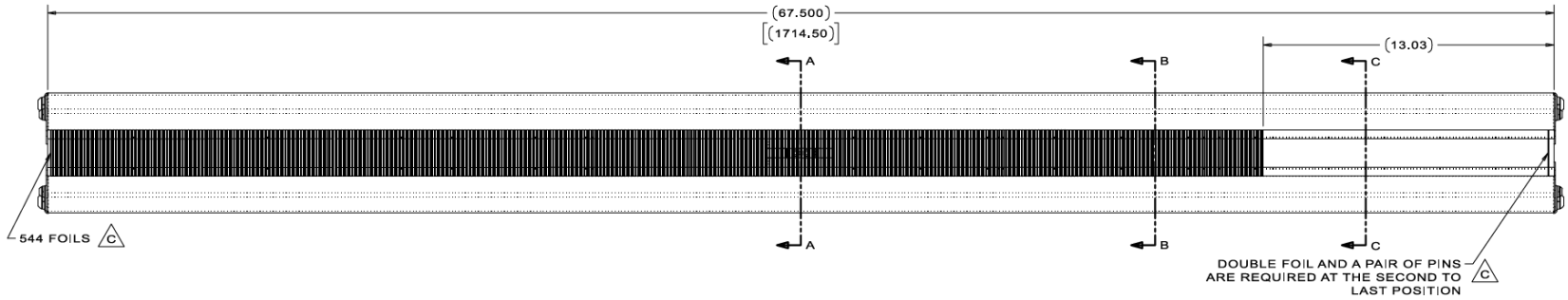




Mechanical Overview: Frame Assembly

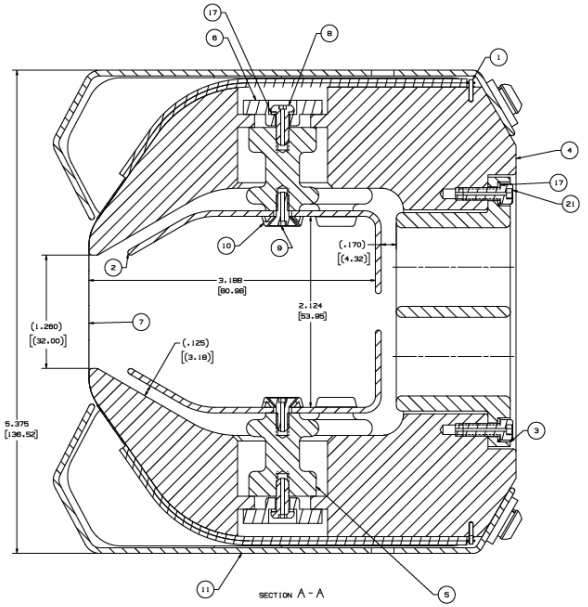
- Frame
  - Material: Aluminum 7075
  - Length: 171.5cm
  - ESS 1 Diffuser Length: 33.9cm
  - Interchangeable for ESS1 and ESS2
- Springs
  - Both tensions (1kg) and retracts the foil ribbon
  - Higher foil retraction speed ~80m/s (290kph or 180mph)
- Clearing Electrodes
  - ±8kV

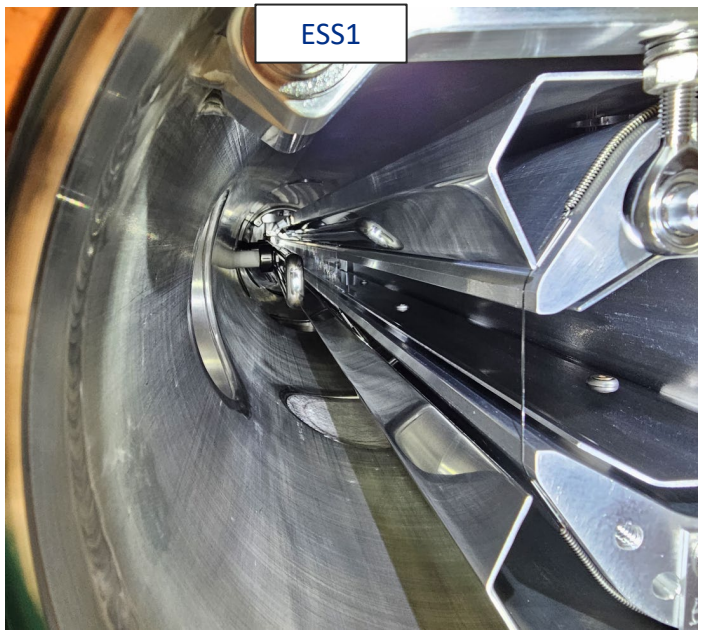




Mechanical Overview: Frame Assembly

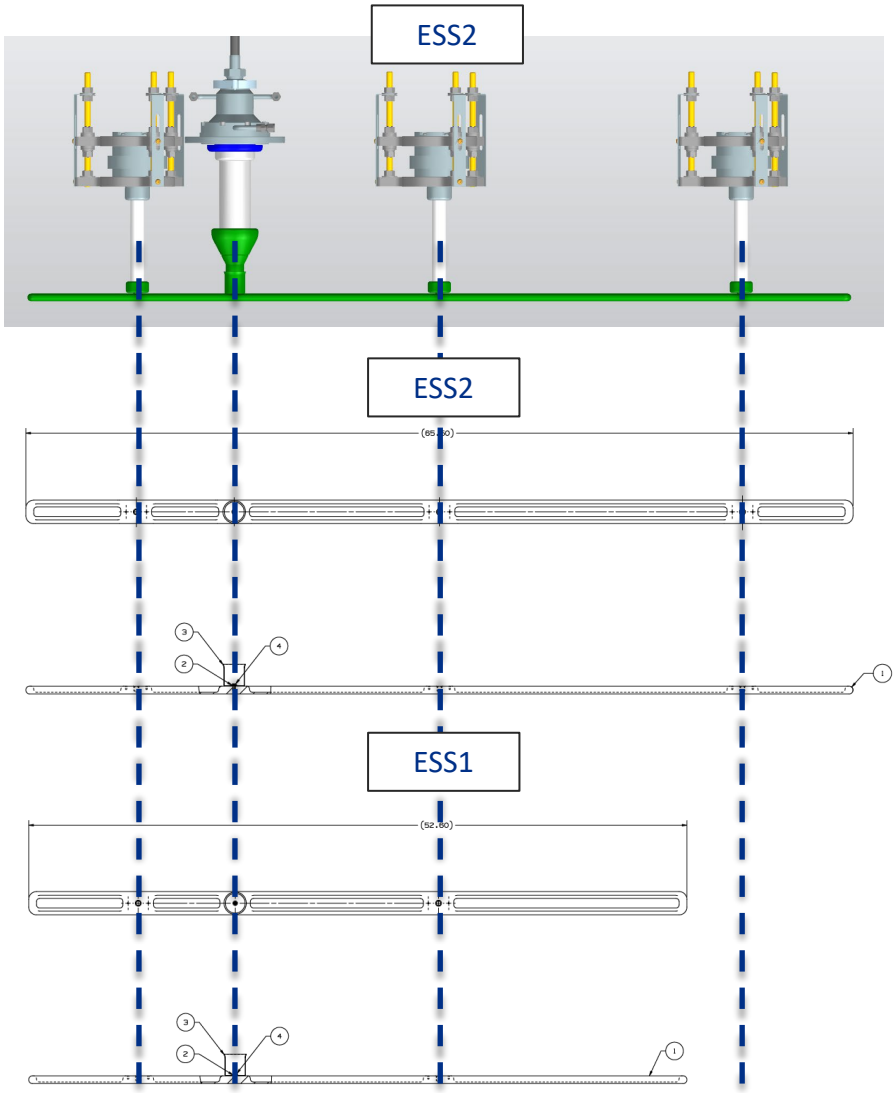
- Foil Ribbons (W3Re)
  - Tungsten-Rhenium
  - Higher mechanical tension than wires
  - Narrower beam cross section than wire
    - 100um (MI-52 Septum) vs. 25um (Mu2e Septum)
  - W3Re foil 25um (thick) x 1mm (long)
  - 17-7PH CH900 Stainless Steel Springs
- Diffuser Foil
  - 50um thick W3Re diffuser foil
  - Looking into thicker Titanium foil, 70um





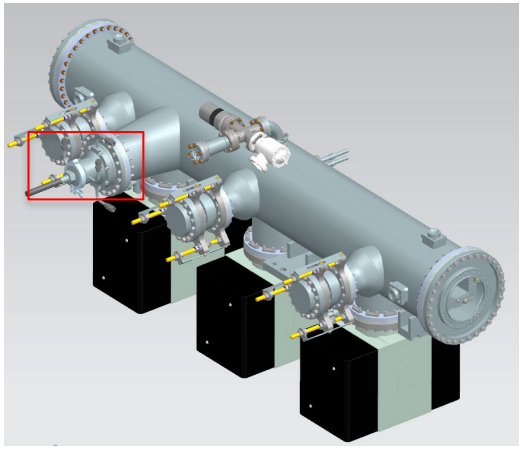
Mechanical Overview: Cathode

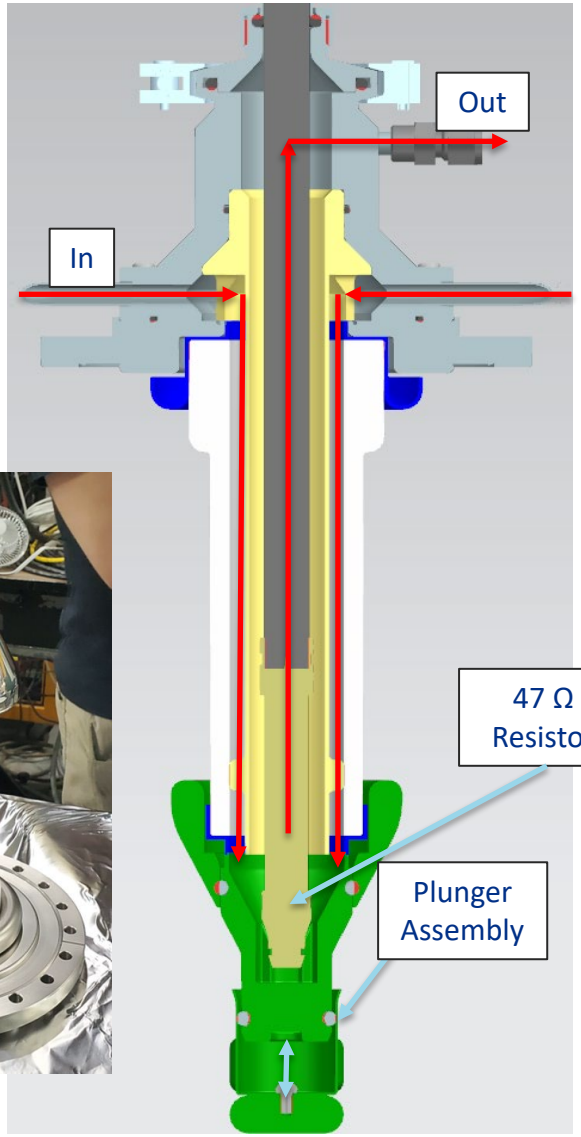
- Material: 304SS
- Mechanical Polish: Ra=0.05um
- ESS1 Cathode
  - Length: 133.6cm
- ESS2 Cathode
  - Length: 166.4cm
- Pockets machined to minimize weight
  - Reduces cantilever stresses on ceramic standoffs
- Mechanically polished
- Plan to use electropolishing on the cathodes

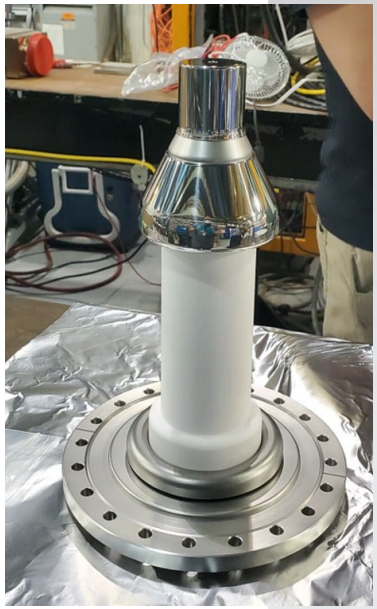


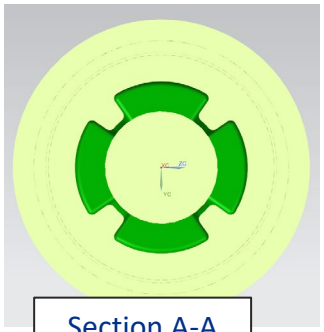
Mechanical Overview: High Voltage Feedthrough (HVF)

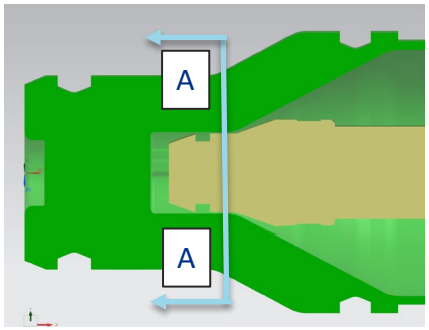
- Materials
  - PEEK (yellow)
  - Al203 (white) ceramic
  - 304SS (grey and green)
  - Kovar (blue)
- 3M FC-40 liquid dielectric
- 47Ω resistor
- Plunger assembly
  - Maintains electrical continuity for different cathode-anode gaps





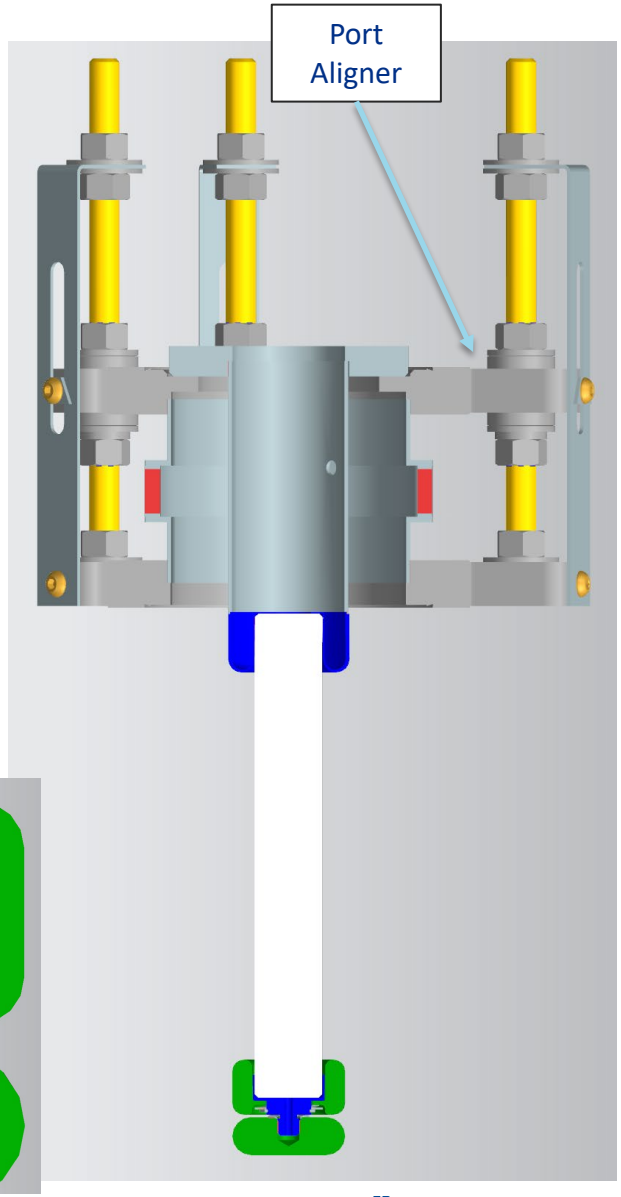


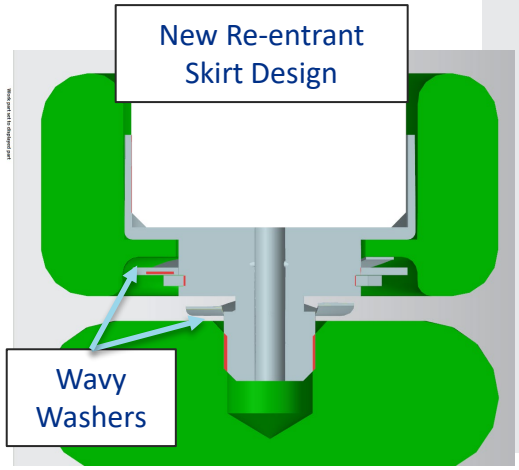




Mechanical Overview: Cathode Standoff (CS)

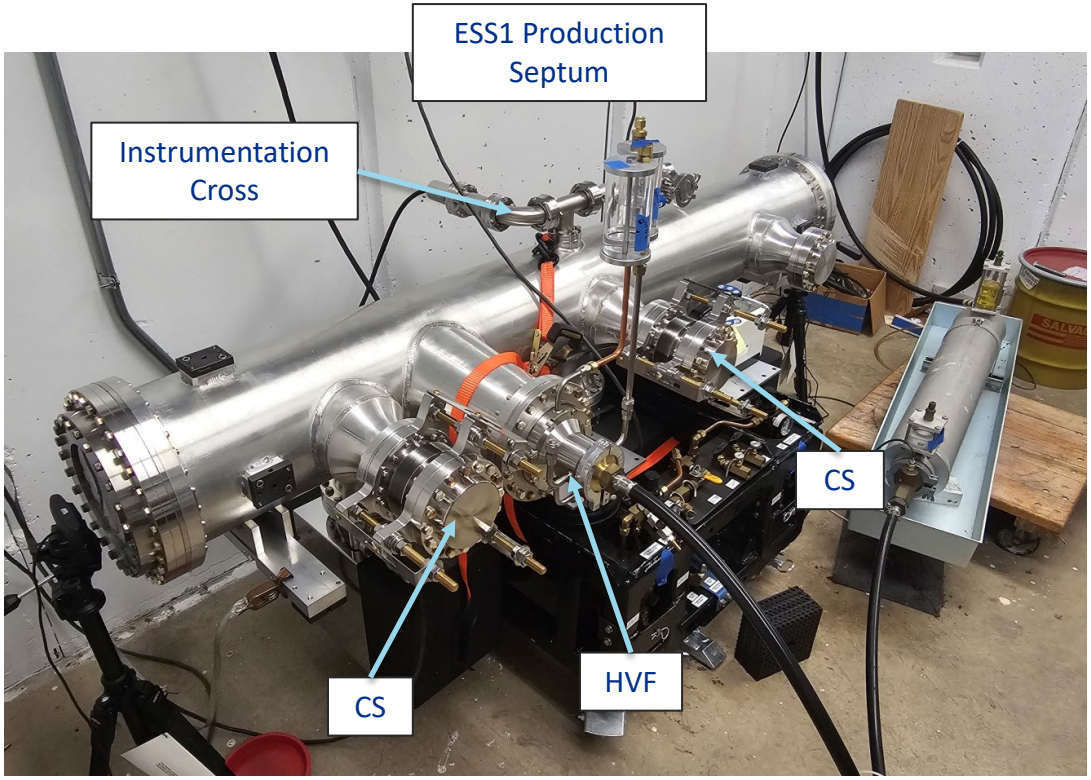
- Materials
  - Al2O3 (white) ceramic
  - 304SS (grey and green)
  - Kovar (blue)
- Port Aligner
  - Cathode-Anode Gaps of 5-25mm





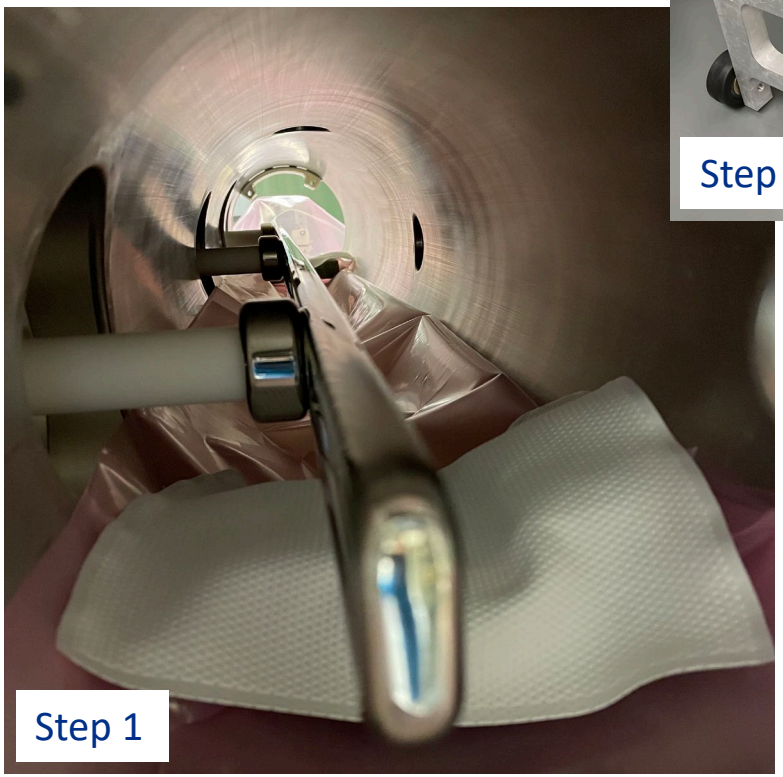
Mechanical Overview: Vacuum Vessel and Fully Assembled Septum

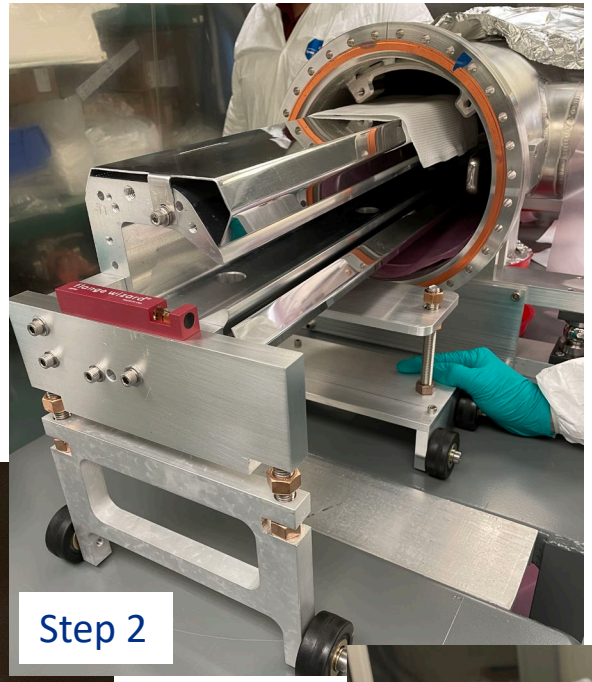
- Instrumentation Cross
  - Pirani Gauge
  - Ion Gauge
    - 1E-3 torr<P<2E-11 torr
  - 90-degree pump out valve
- 3x 300L/s Ion Pumps

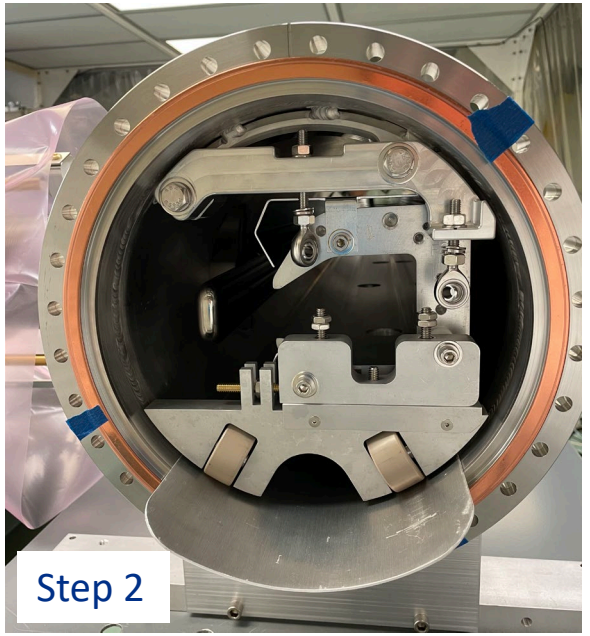


Assembly

- Assembly Process
  1. Install cathode
  2. Install frame
  3. Install HVF







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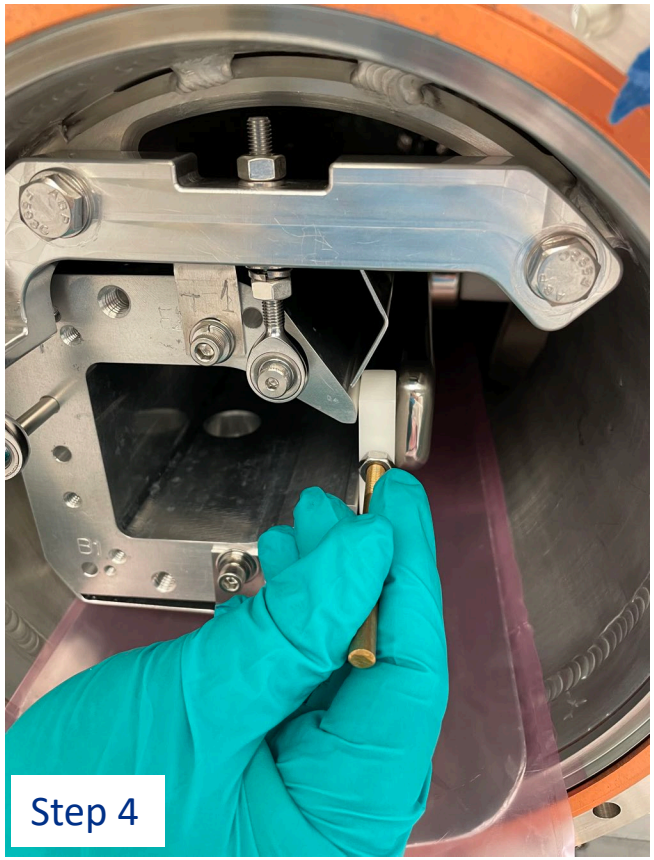
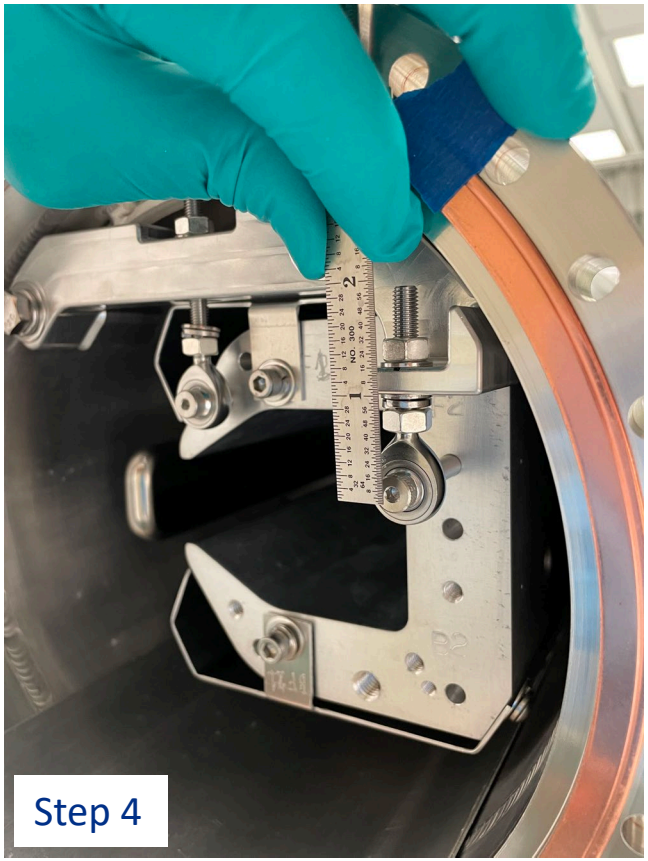
Assembly

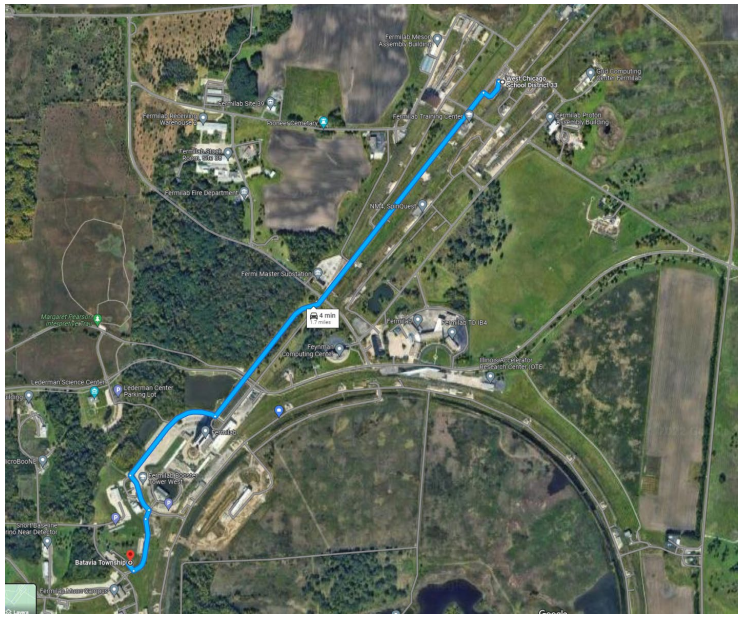
- Assembly Process
  4. Set gap between frame and cathode
  5. Reference Septa to external fiducials (not pictured)

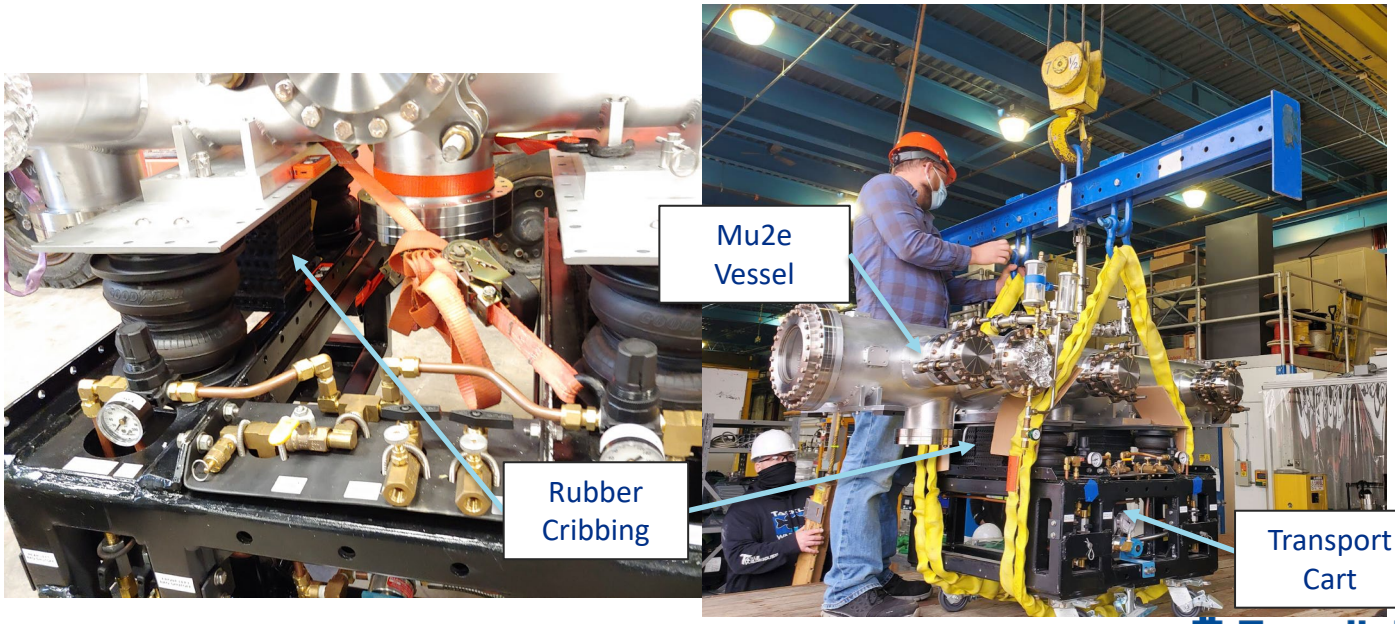




Transportation

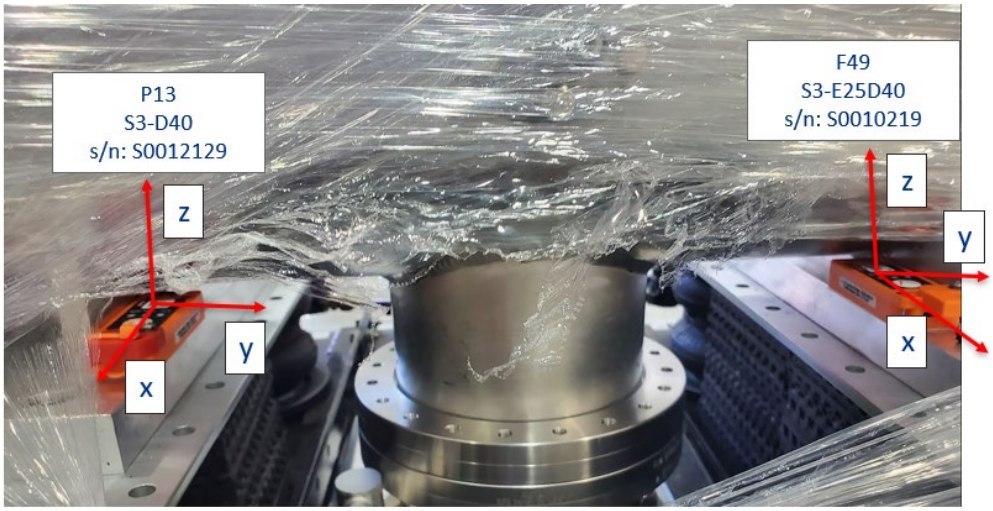
- Data from transportation of septum from assembly facility to Muon delivery ring (2.7km or 1.7miles)
- Septum uses rubber cribbing to dampen any shock from transport
- Truck speed limited under 5 mph (8km/h)





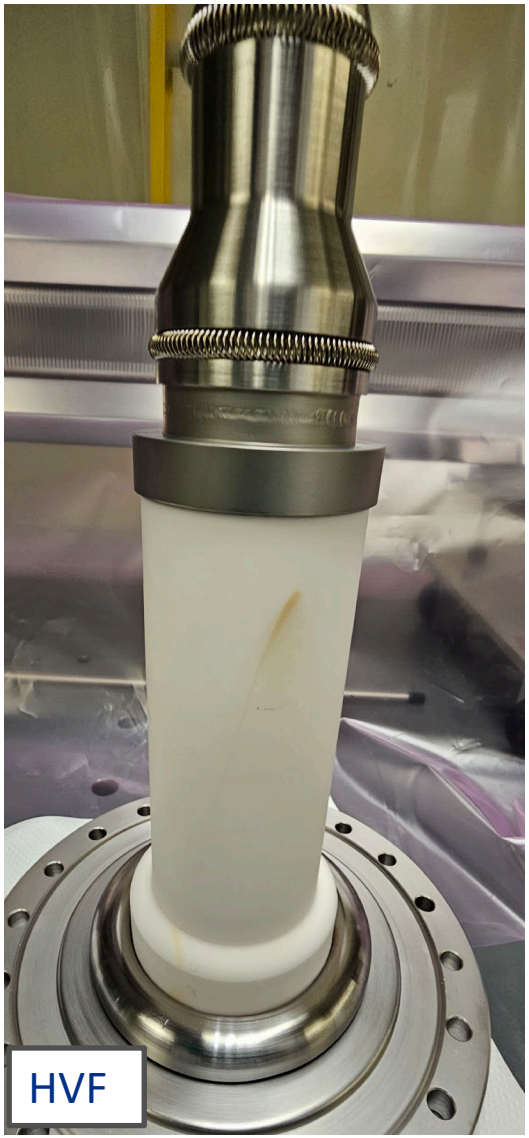
Transportation

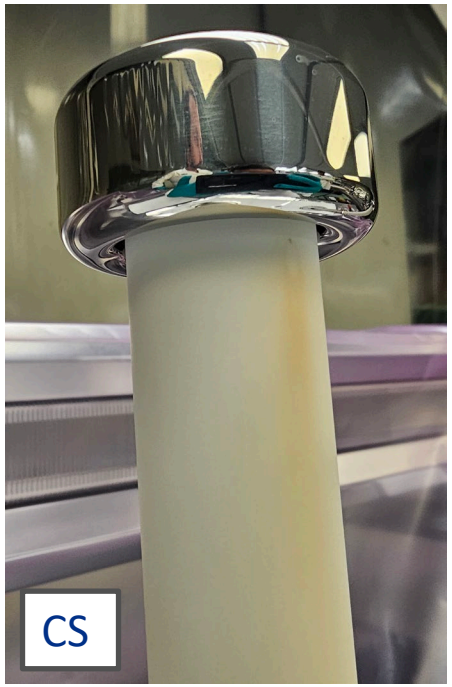
- ENDAQ sensors used
  - Data range up to 20g
  - Sample rate 1000Hz
  - Pressure, temperature, and humidity measurement taken at 1Hz
- Sensor placement (3 total)
  - 2x accelerometers placed on the vacuum vessel
  - 1x sensor placed on the truck
- Measured entire process from rolling on the floor to lifting it with a crane
- Largest acceleration measured during transport: 0.6g (max 2g)



Challenges and Puzzles

- ESS 2 prototype vessel conditioning and re-designing of the CS re-entrant skirt
- Finding a replacement for FC-40
- Losing machine shops during 2021 & 2022 procurement of production vessels
  - Cathode and frame, foil ribbon, and polishing vendors
  - Vacuum vessel manufacturer lost their skilled laborers
- Dust and particulate mitigation in the septa





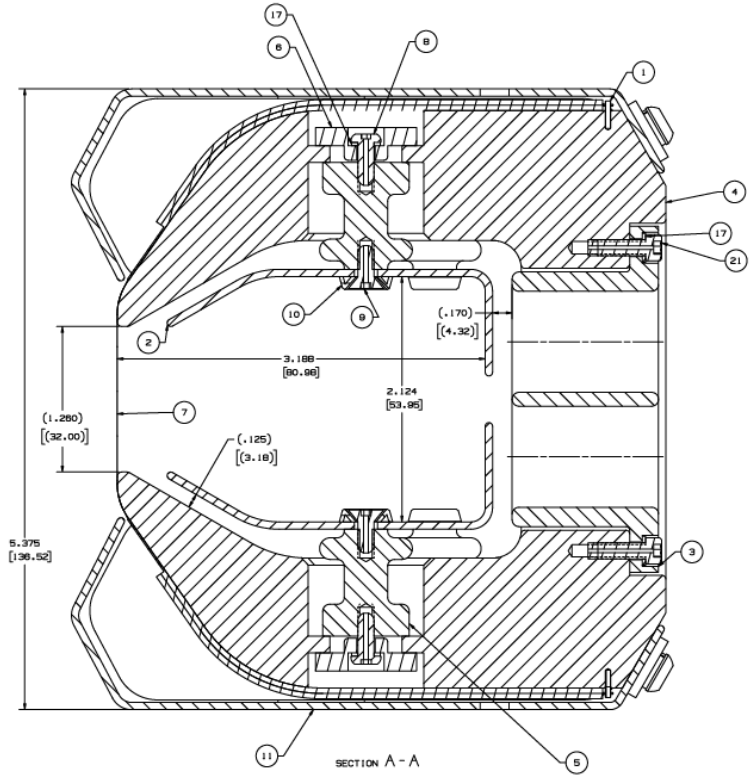
Current Status

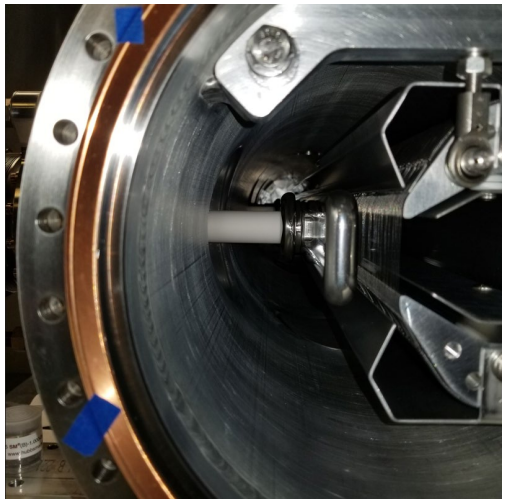
- Built and tested the full-scale prototype of ESS2
- Implemented lessons learned into the design
- Installed the full-scale prototype and used it in the first Slow Extraction commissioning in the Delivery Ring
- Assembled the first production septum ESS1 – under testing now
- Began assembly of the production septum ESS2
- Continue learning and improving the design

Optional Slides of Interest

High Level Overview

- Mechanical and Electrical Requirements
  - Number of Septum units: 2
    - ESS1
      - Cathode length is 133.6cm
      - 544 foils + 1 diffuser foil
    - ESS2
      - Cathode length is 166.4cm
      - 673 foils
  - Foil
    - Material: W3Re
    - Foil dimensions: 25um (thick) x 1mm (wide)
    - Spacing: 2.54mm
  - Total active length of septa: 3m
  - Total Kick: 2mR
    - Electric Field strength: 100kV (nominal)
    - Cathode-anode gap: 12mm (ESS2), 14mm (ESS1)
  - Clearing Electrode Voltage: ±8kV





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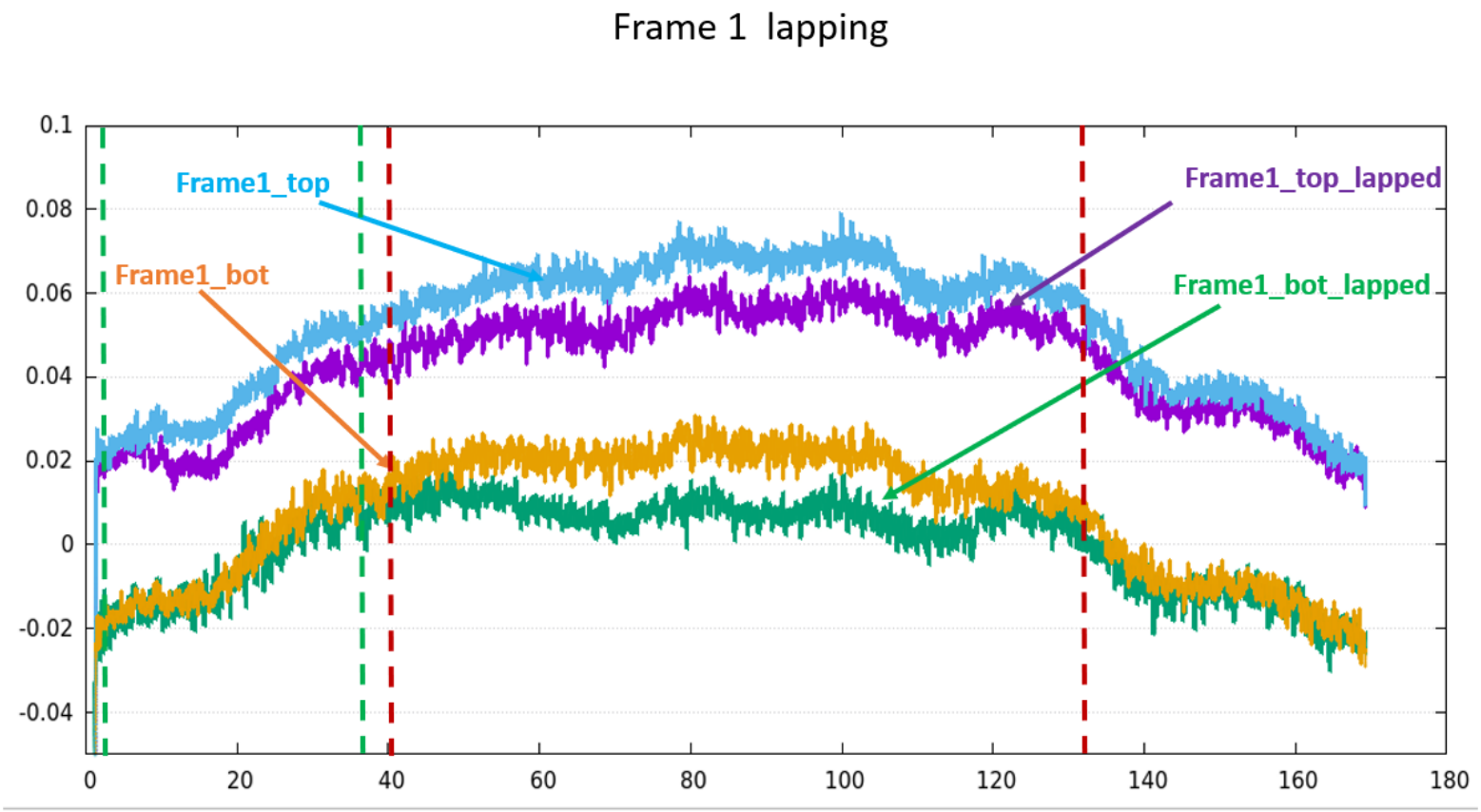
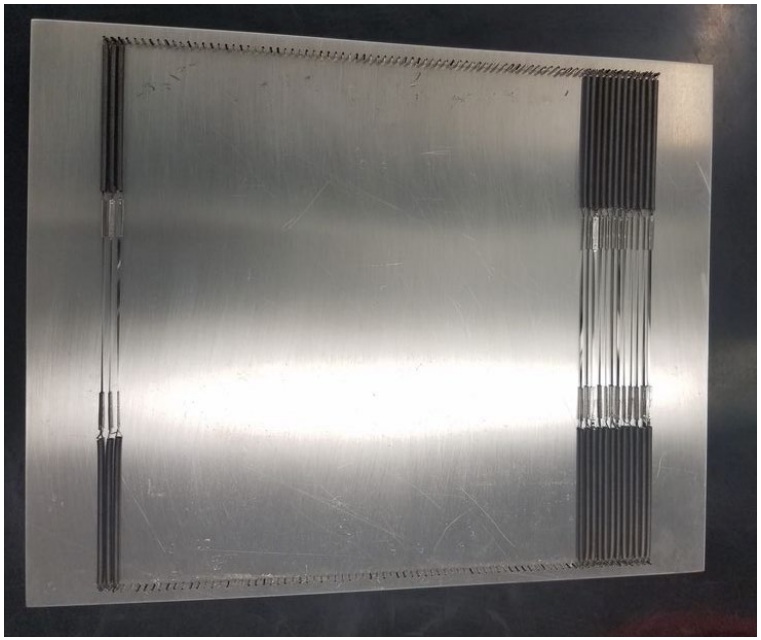
ESS 1 Frame 1 Measurement Data

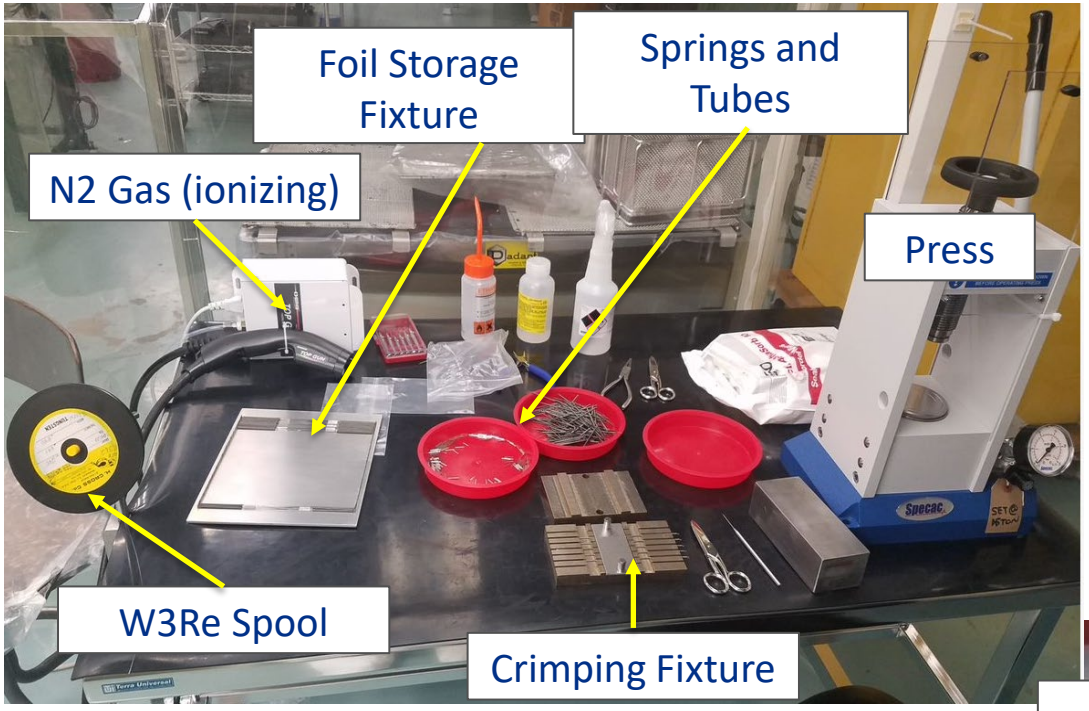


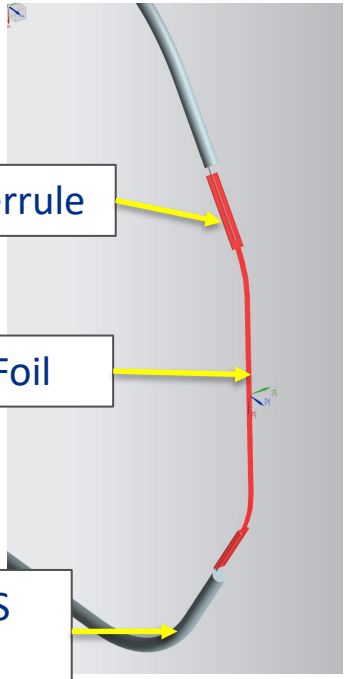
Foil Production

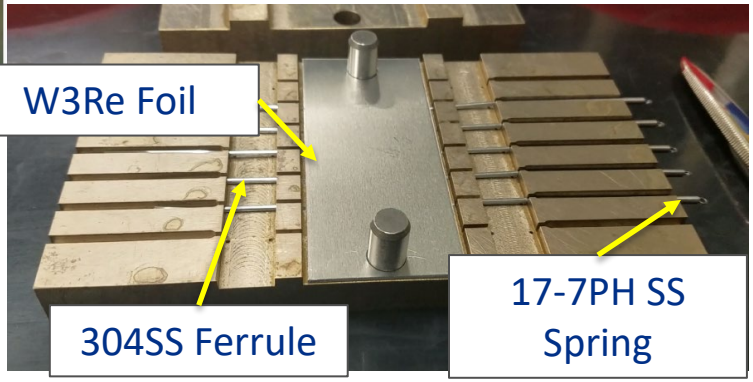
- Fabricated onsite
  - On-the job training required for technician
- Foil vendor: H. Cross Company
  - Material Certificates required
  - Foil Measurement Tolerances required
- Material: W3Re
- Foil Geometry
  - Foil Width is .040” (1000um) ±.003” (76.2um)
  - Foil Thickness .001” (25um) ±.0001” (2.5um)



Foil Production





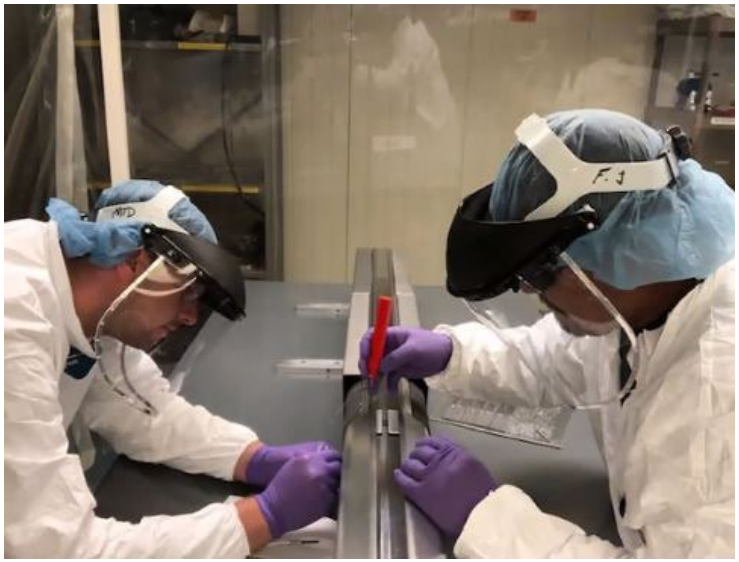


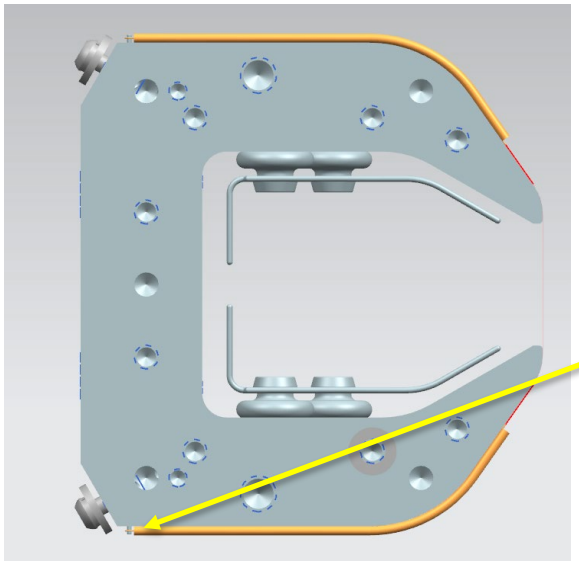
- Foil Assembly
  - Produce 5 foil assemblies at one time
  - 25 tons required to crimp the joint
    - 2.5 tons per crimped joint
  - Press
    - SPECAC 25 ton press
- Foils will be tested to certify and ensure the load is sufficient and the tool is not wearing.

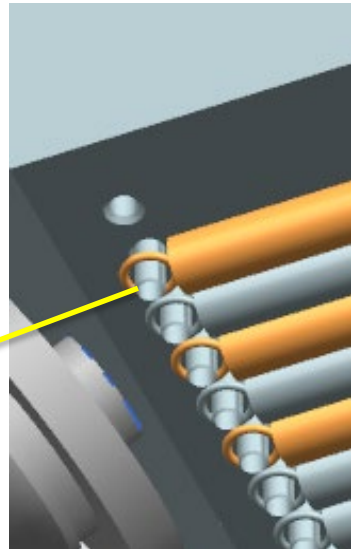
Assembly: Cleaning Septum Parts Procedure

- Goal: Ensure all parts are cleaned to achieve the best vacuum (E-9 torr)
- Processes for cleaning parts (depends on the part)
  - Dawn dish soap
  - DI water rinse
  - Ultrasonic tank
  - Drying with N2
  - Alcohol bath
  - Alcohol wipe
- Procedure Outlines
  - Cleaning of hardware
  - Cleaning of specific septum parts (frame, ceramics, cathode)
- Materials to be cleaned
  - 304SS, 316SS, 18-8SS, 17-7PH SS, W3Re, Al 6061, Al 7075 (frame), Kovar, Al 203, silver plated bolts, PEEK, Nylon, ABS, etc.

Assembly: Installing Foils onto the Frame

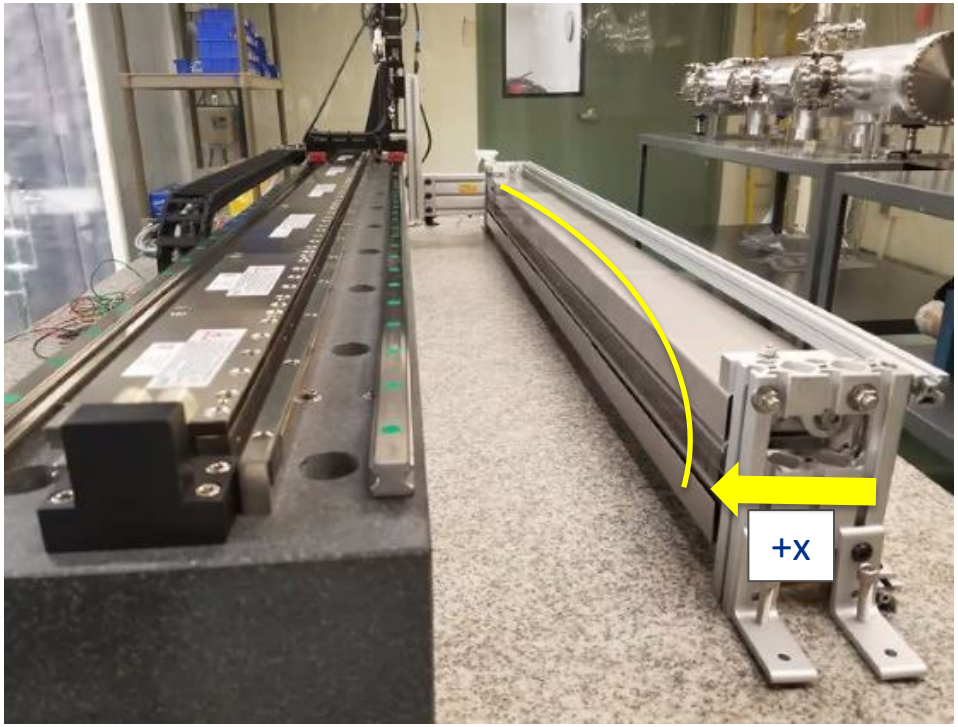


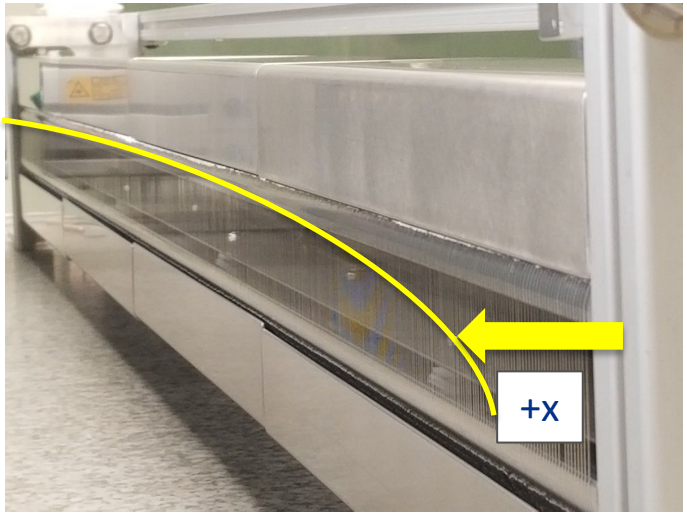


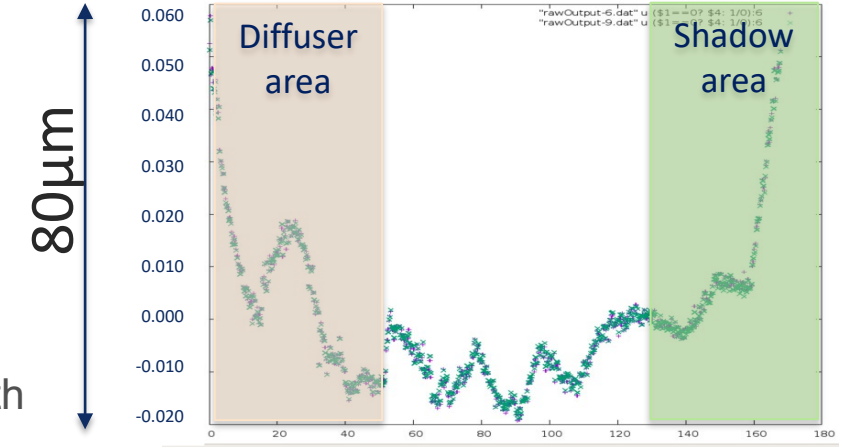


- Two people are required, one on either side of the table
- Hazard analysis required for access into the cleanroom

Assembly: QC Frame (Prototype)







Forward and backward

- Frame will be measured to see if it is acceptable
- If not acceptable, we will need to machine it again with the geometry we require
  - Send back to vendor
  - Hand lap and measure to achieve desired profile
- Align the foil plane relative to the beam

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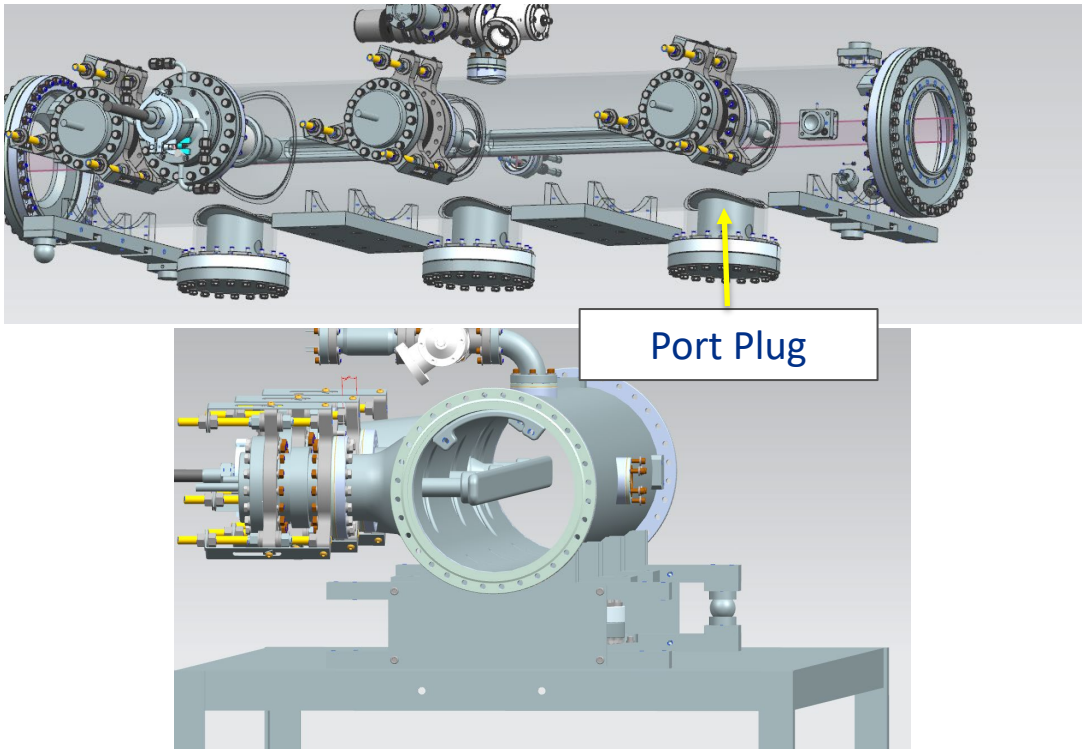
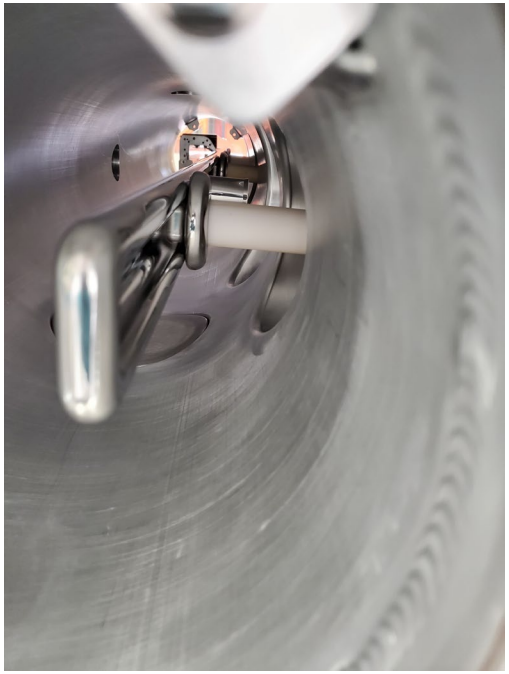
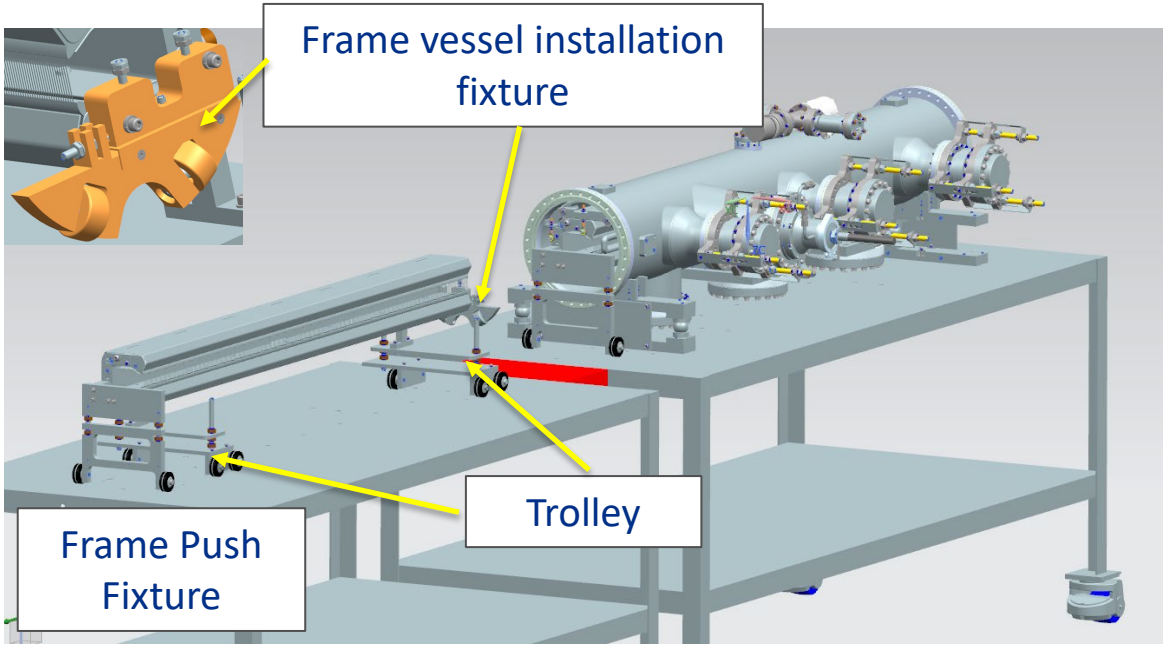
Assembly: Installing Cathode

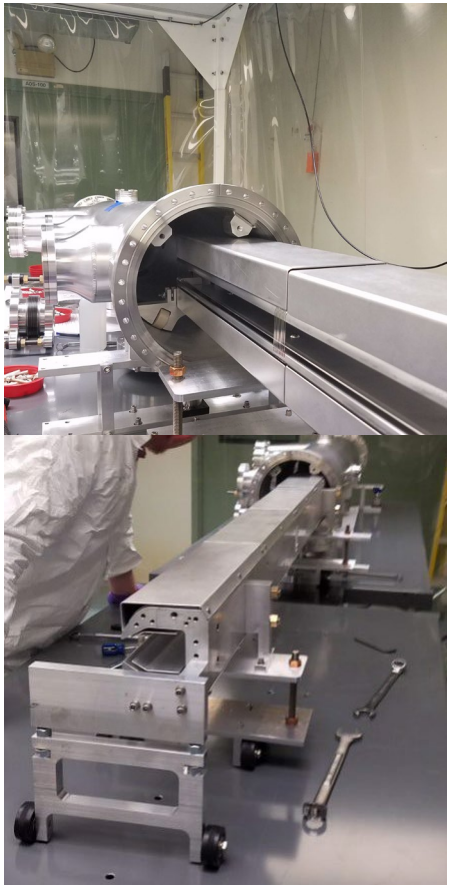




- 3 people required
  - Two people to support the cathode on each end
  - One person installs cathode standoffs
- Ion pump port plugs are installed prior to be placed on the die cart

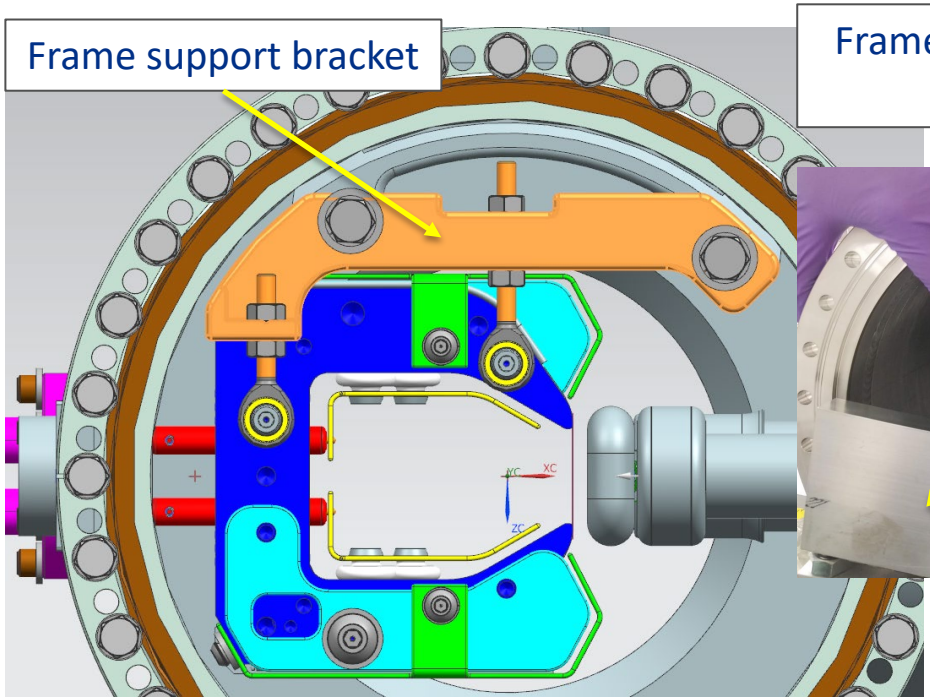
Assembly: Installing the Frame

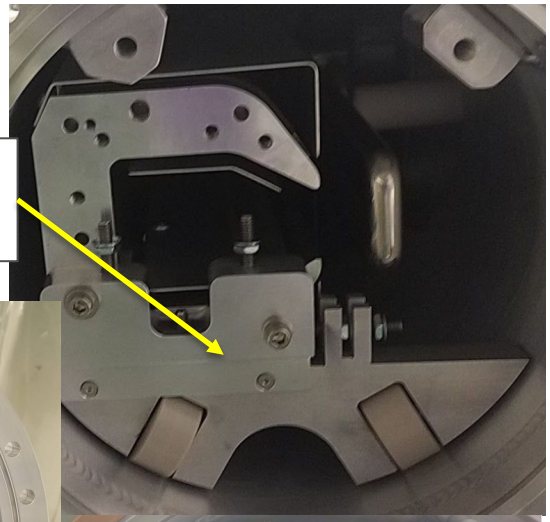


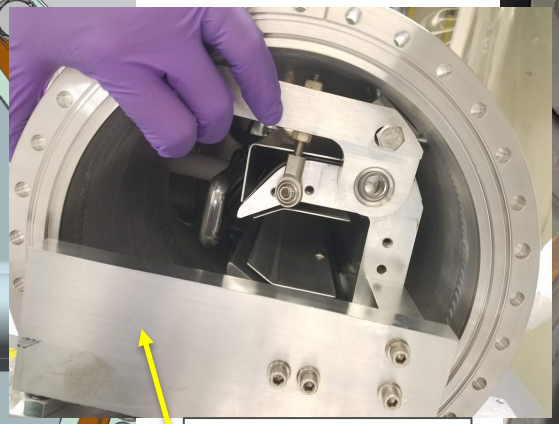


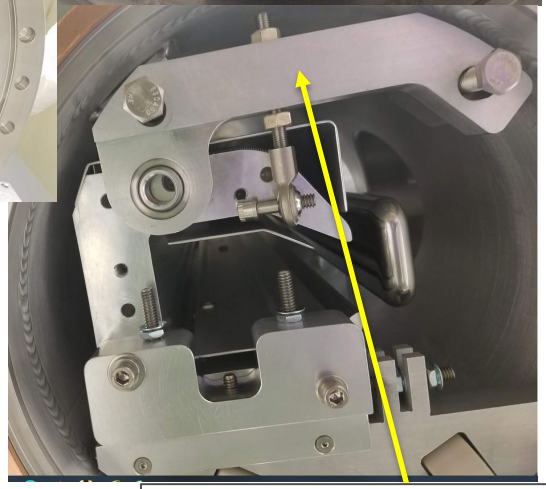
- Trolleys are attached to the back of the frame
  - Both are removed gradually until the frame support brackets are installed
- Frame vessel installation fixture
  - Rolls the frame within vessel
- Frame push fixture
  - Supports the frame to allow the frame support brackets to be installed

Assembly: Installing the Frame



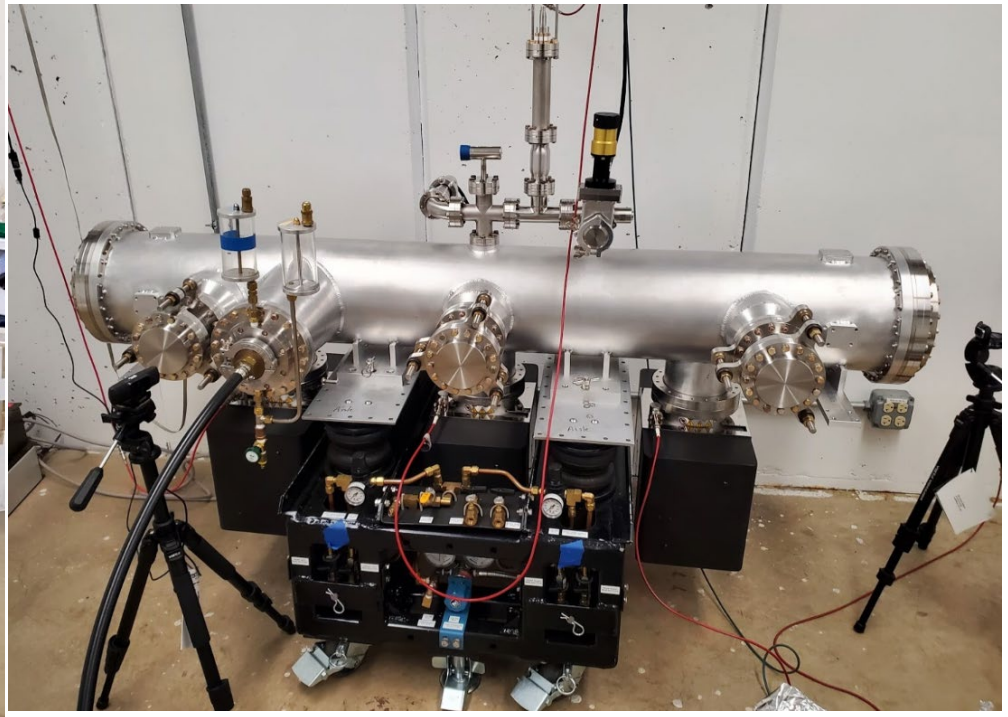






- Frame support bracket is installed while fixtures support frame within the vacuum vessel
- After brackets are installed, the supports are removed
- Cathode and frame are aligned

Assembly: Placing Septum on Transport Cart

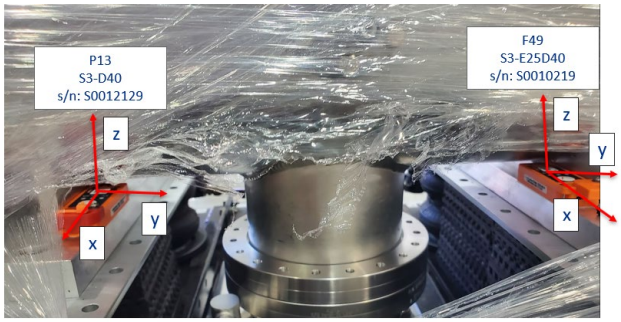


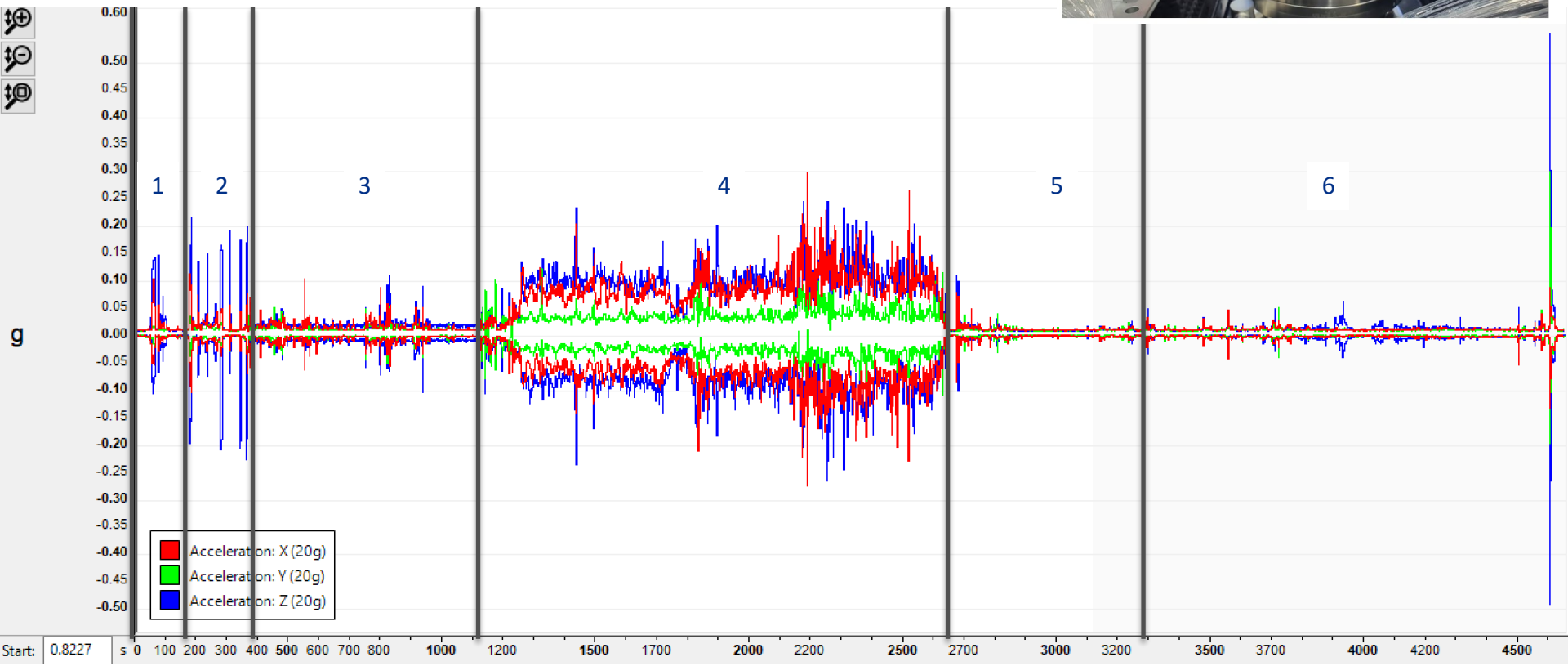
- Septum is placed on slings and placed on the transport cart
- Ion pumps are installed
- Vacuum flanges are installed

Transportation Description

1. Start accelerometer. A test lift was done and straps were adjusted. The septum was raised and lowered to adjust the straps.
2. Lift onto the truck bed.
3. Minor adjustments for strapping the septum to the truck bed. Wheels on the transport cart were locked and rigging was removed. The spreader bar was placed on the truck bed and strapped down.
4. Truck drives to NWA to AP-30 (Muon delivery ring)
5. Truck parks and turns engine off. Straps are removed and the septum is prepared for the lift into the hatch. Spreader bar is removed for the lift.
6. Mobile crane lifts septum and lowers it into the delivering ring. 0.6g shock occurs likely from the landing of the septum into the delivery ring.

Transportation Data: Vessel Sensor P13





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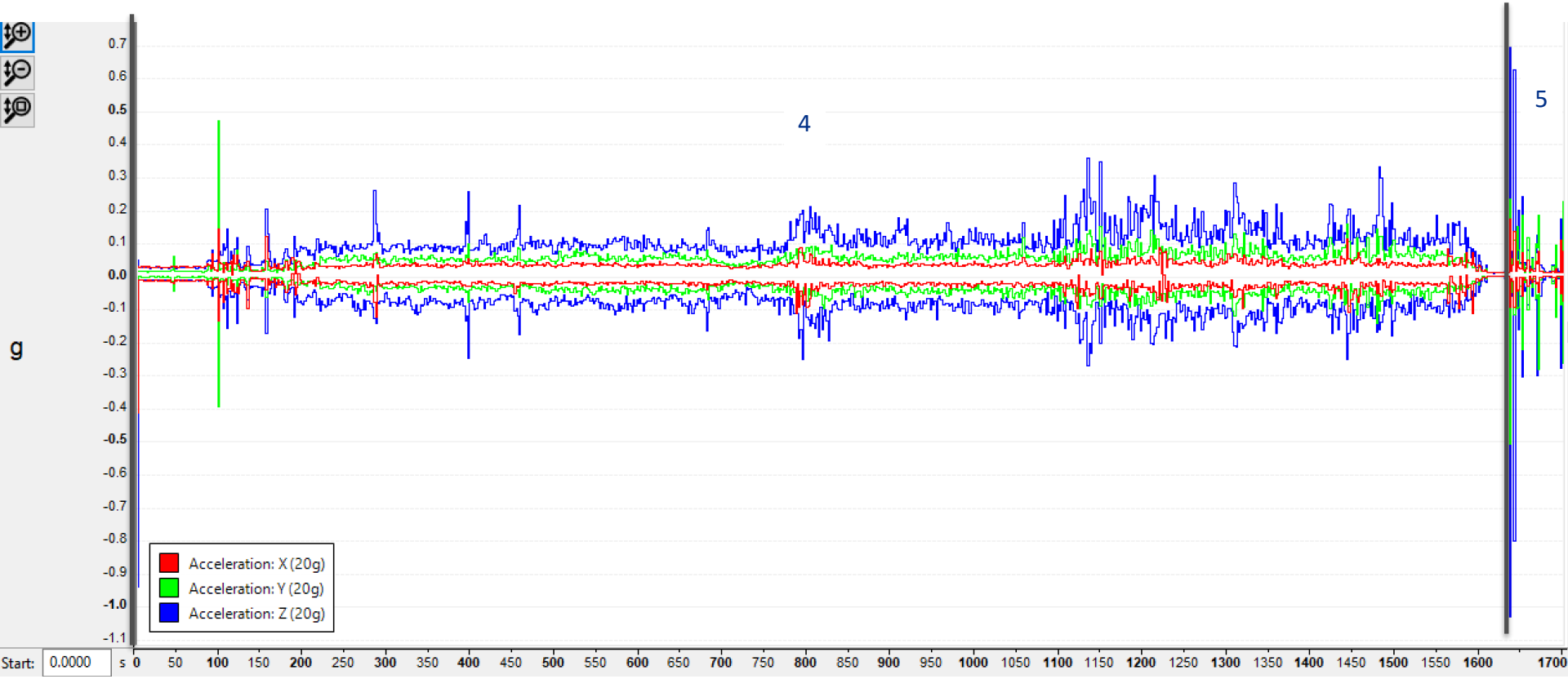
Transportation Data: Truck F50 (Truck only)



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