Mechanical Design of Beam Instrumentation

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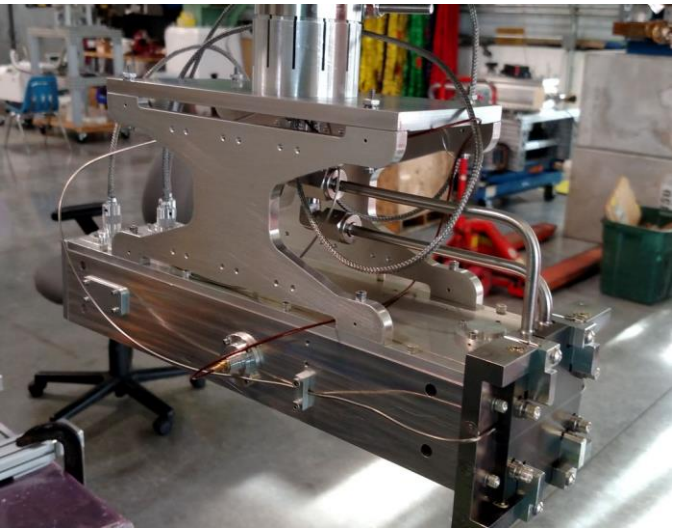
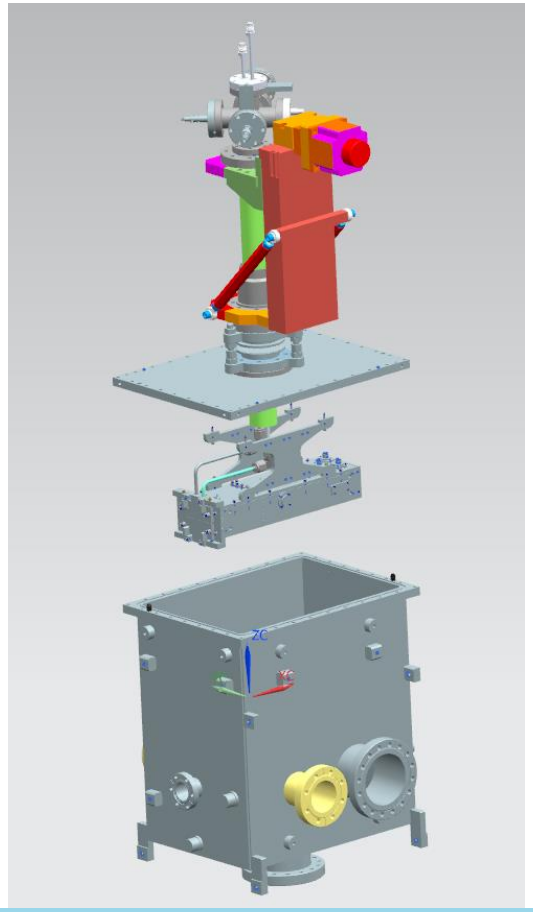
Outline

- MEBT Allison Emittance Scanner (MAES)
- MEBT Time of Flight (TOF) Beam Position Monitor (BPM)
- MEBT Wire Scanner (MWS)
- JPARC SSEM

MEBT Allison Emittance Scanner (MAES) for PIP-II



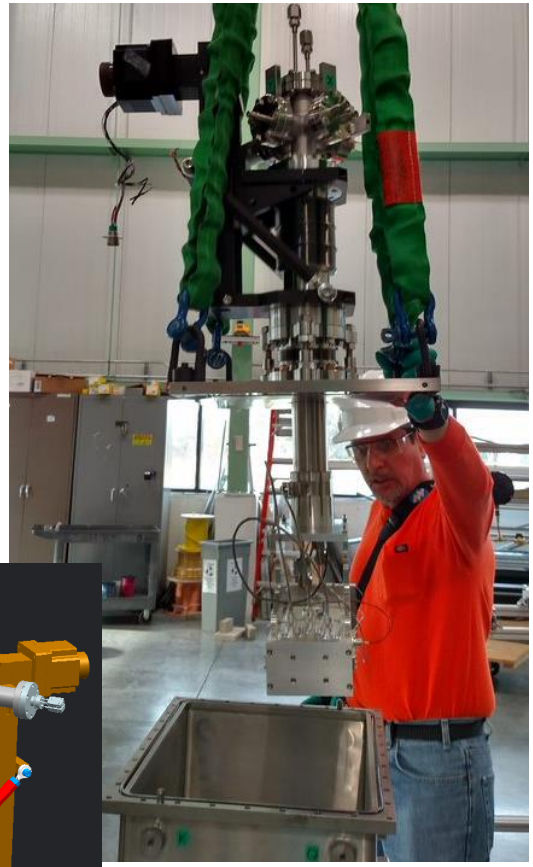


Specifications and Type of Measurement

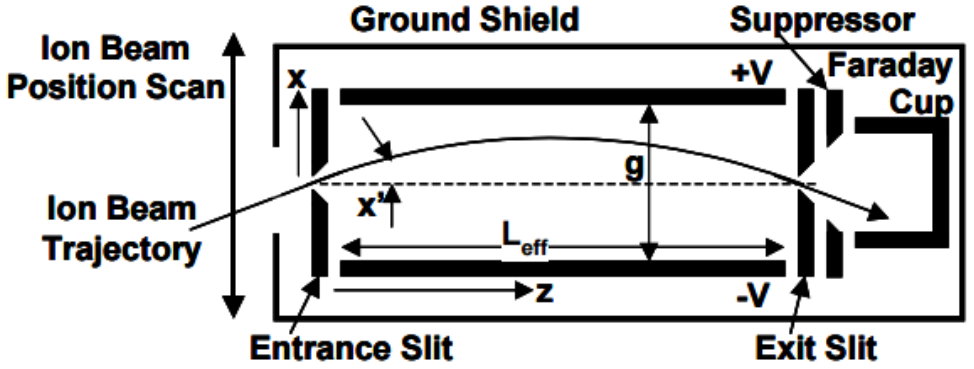
- Measurement Type: Transverse Beam Emittance
  - Destructive measurement
- Functional Requirement Specification (TC#: ED0004080)
  - Energy 2.1MeV
  - Bunch Frequency: 162.5MHz
  - Nominal Pulse Repetition Rate: 20Hz
  - Nominal Pulse Length 20us
  - Beam Radius (rms) 1-4mm
  - Beam Current: 1-10mA
  - Beam Angular Spread (rms): 0.5-3mrad


Fermilab

Functional Requirement Specification
PXIE MEBT ALLISON EMITTANCE SCANNER, FRS
ED0004080, Rev. -

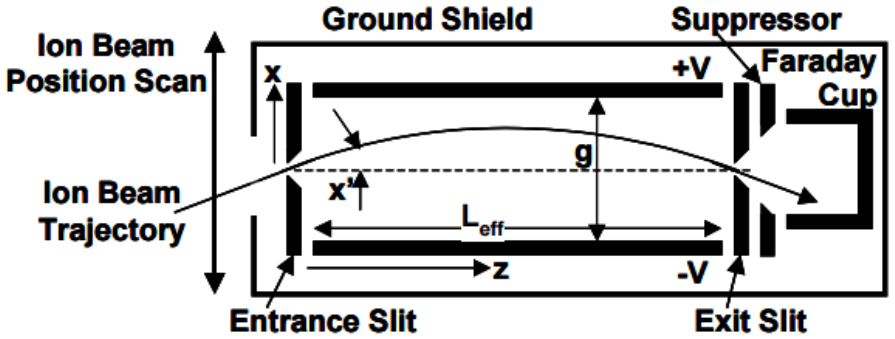


Mechanical Design Description



- Measurement procedure:
  - Scanner is stepped through beam (~1 mm steps) → X phase space
  - A beamlet is transported from entrance slit by a sweeping voltage of ±1000V to exit slit → X'
- Key Components for MAES
  - Front Slits TZM- 200um gap
  - Cooling Block- 304 Stainless Steel
  - HV Plates- Titanium
  - Rear Slits – 316L Stainless Steel
  - Suppressor Ring- OFHC Copper
  - Faraday Cup-OFHC Copper

Mechanical Design Description

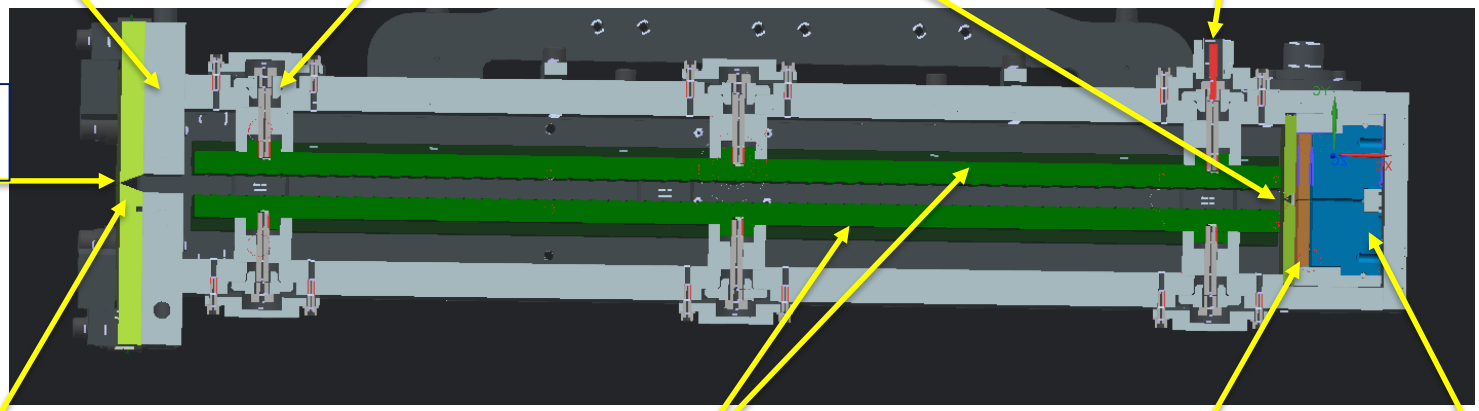


HV Plate Support

Cooling Block

Rear Slit (0.008”)

HV Feedthrough Connection



Beam

Front Slit (0.008”)

Top and Bottom HV Plates

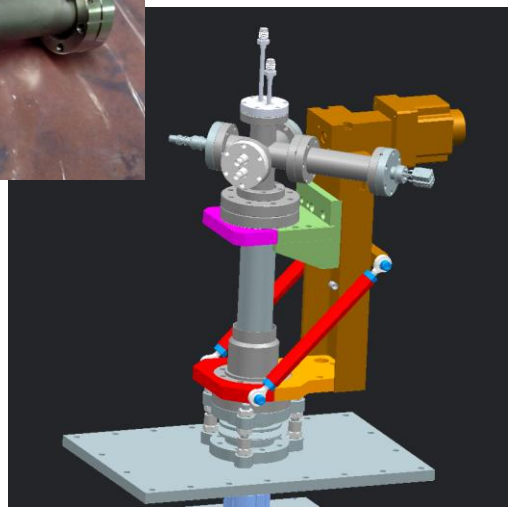
Suppressor

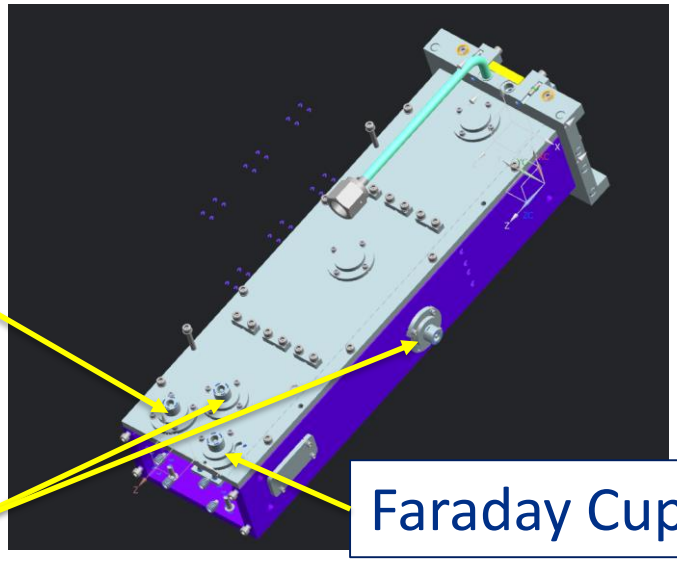
Faraday Cup

Fermilab

Electrical Feedthroughs

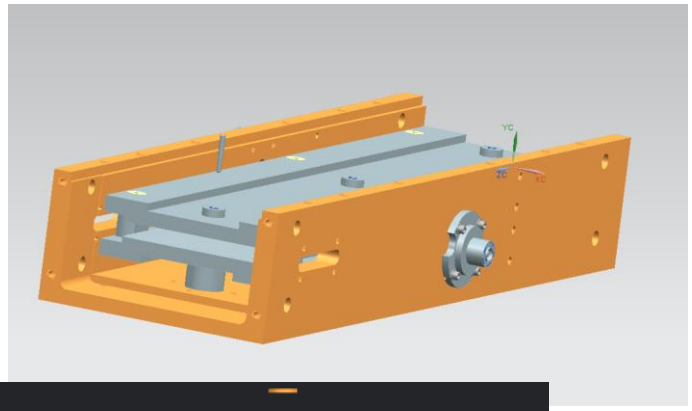
- Thermionics Translator
  - ZC Translator- bellows included
  - Ball screw for precision motion
- 6-way cross (MDC)
  - Type K Thermocouple Feedthrough
  - SHV-5 (FC cup)
  - BNC feedthrough (suppressor ring)
  - Double SHV-5 (deflector plates)
  - Water line Feedthrough

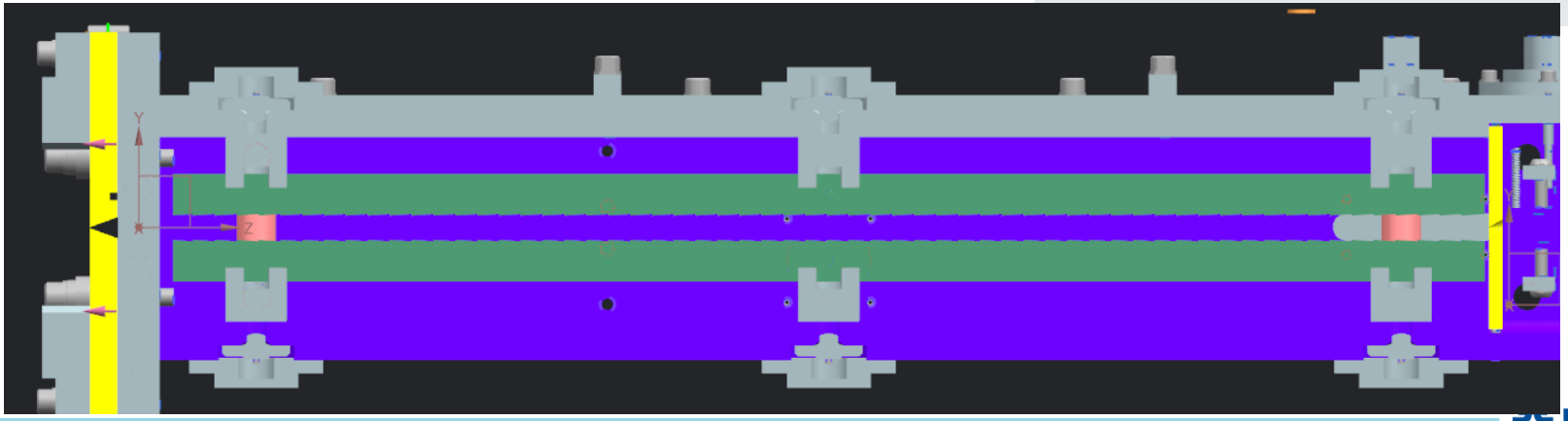




Front and Rear Slit Axial Alignment

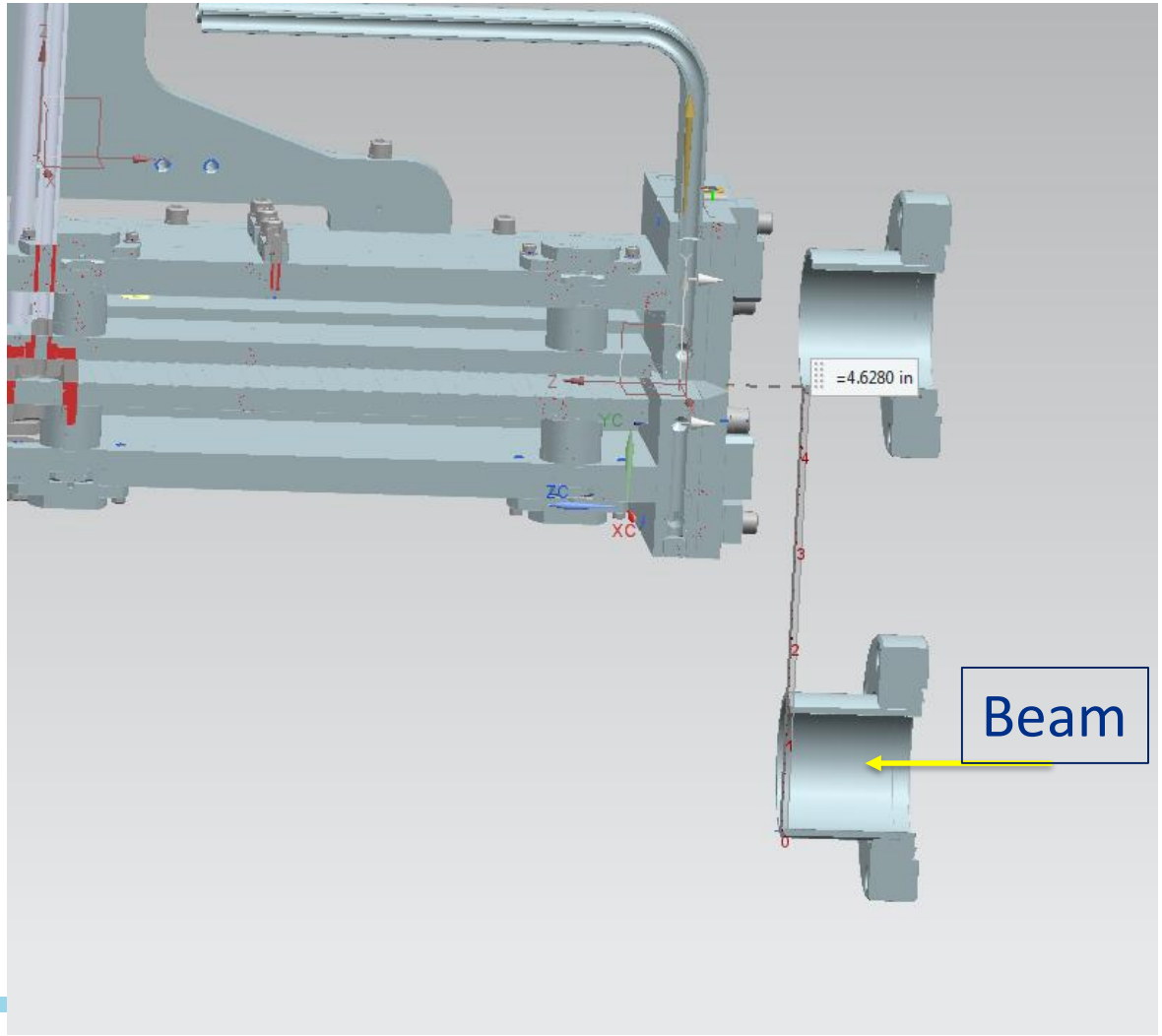
- Requires that they are in line to <0.2mm (0.008”) over 320 mm (12.6”)
  - Required precise machining of the enclosure
  - Front Slits were aligned to the rear slits to 0.120mm (0.005”)





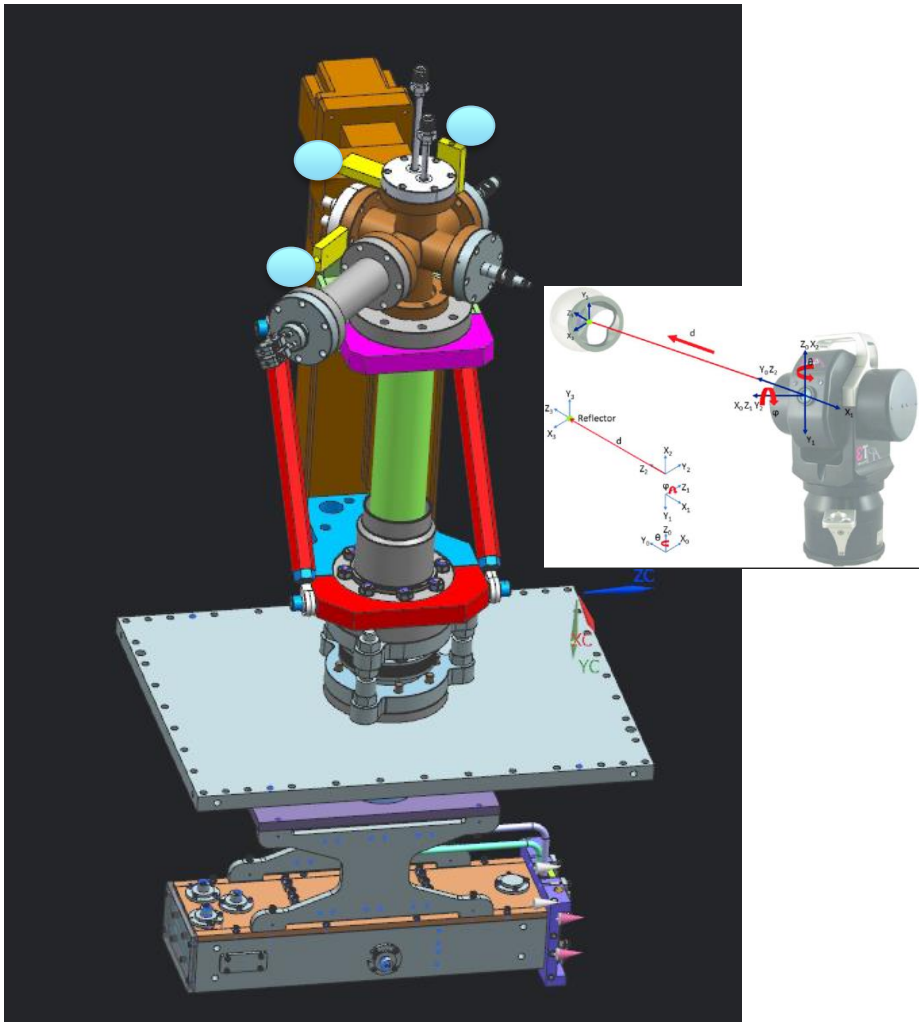
Vertical Range of Measurement Position with Respect to Beamline Axis ±15mm

- This is achieved in the full insertion of the device.
  - 4.628” (117mm) stroke length
- The knife edge reaches the bottom edge of the vacuum tube



Absolute Accuracy of Vertical Position of the sensor ≤1mm

- The box assembly will be referenced to fiducial points located on the 6-way cross fixed flanges.
  - Fiducial points will be on 3 different a flanges as indicated on the figure
  - Metal tabs with 0.25” holes will be welded onto the flanges for the drop in nests for laser tracker reflector



Resolution of Vertical Position ≤ 0.025mm

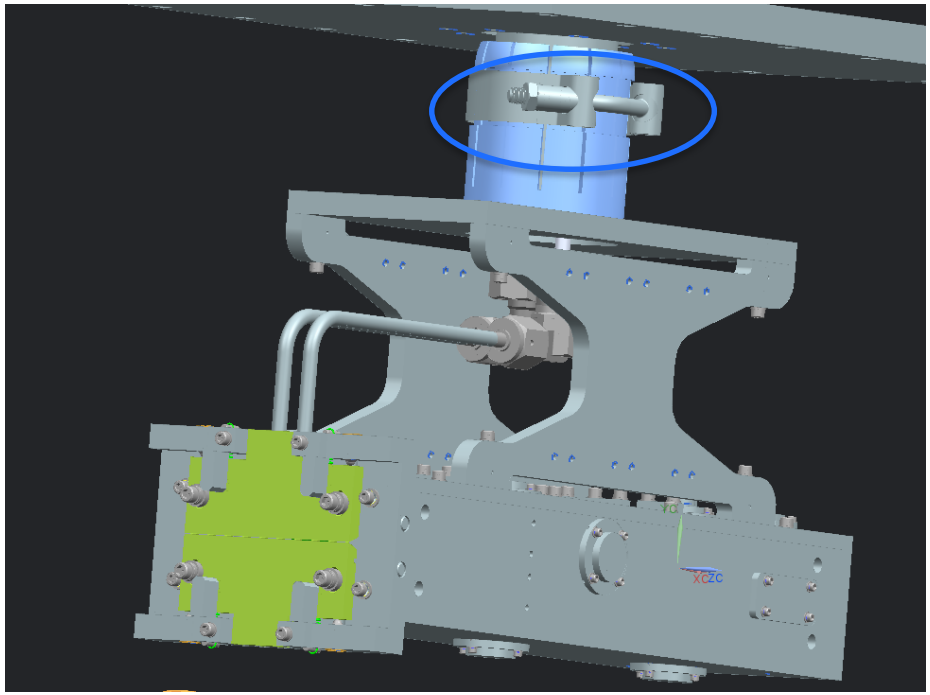
- US Digital encoder has 2000 cpr (E2 optical kit encoder)
  - 0.050”/turn for the thermionics slide
  - Encoder resolution see 2.5e-5 inches per count (0.0006 mm/count)
    - 0.05”/turn/(2000 cpr)

Sensor Horizontal Alignment with Respect to beam line axis ≤ 1mm

- How well do we know the location of the slit?
  - Alignment will reference this and the number they will provide will very likely be better than 0.010” (.254mm).

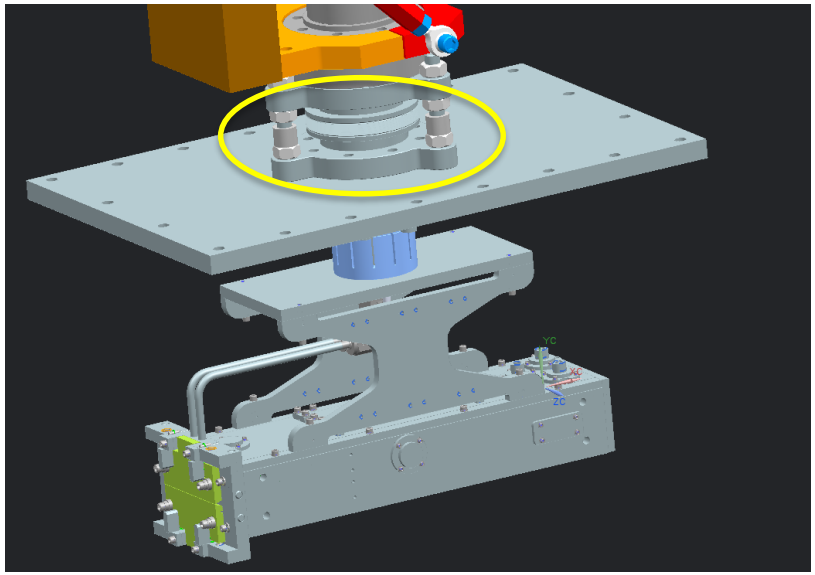
Sensor Yaw Alignment with Respect to beam line axis 10mR

- Yaw alignment done using stainless steel clamp
- 10mR yaw is associated with 070” (~1.8mm)
- Yaw alignment not critical to measurement



MAES Module Pitch Adjustment Range ±25mR

- Provides vertical adjustment of ±5mm
- Pitch adjustment up to ±3° (52.4mR)
- Pitch alignment critical because of limited measurement range



General Specification					
Part no.	PA-35H	PA-35T	PA-64H	PA-64T	
Flange Size	CF38 (2.75" OD CF)		CF64 (4.5" OD CF)		
Flange bolt hole type	Through holes	Tapped M6	Through holes	Tapped M8	Thr
Axial adjustment					
Tilt					
Bellows clear bore	38 mm		65 mm		
Bakeout temperature					

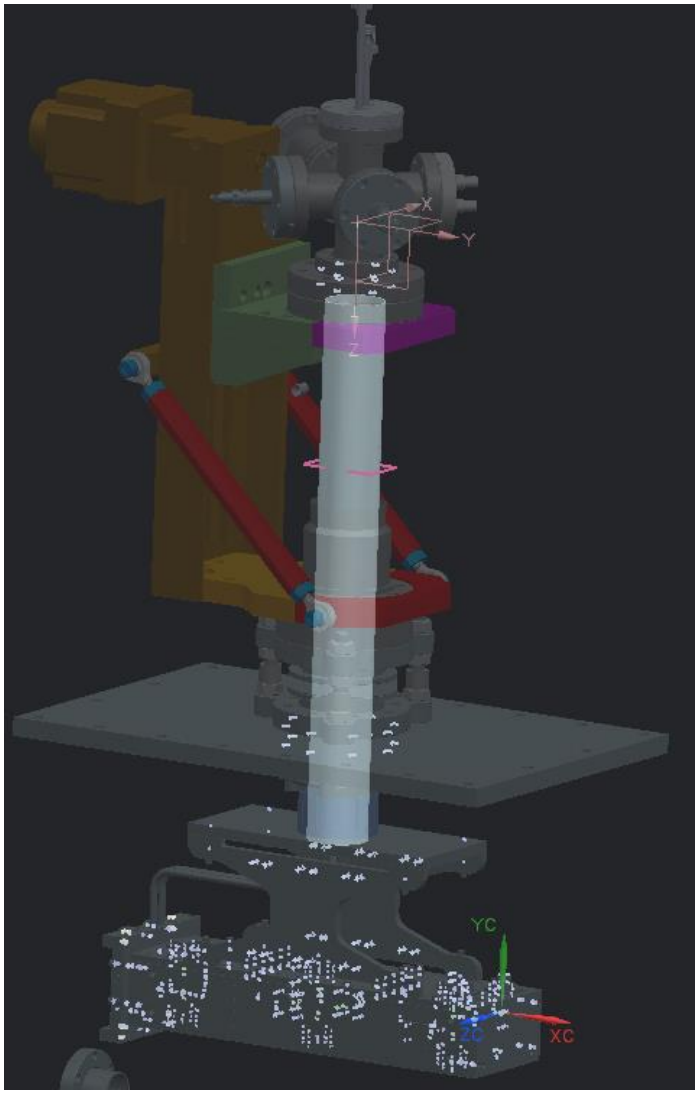
Product code selector

MAES Module Pitch Adjustment Resolution 1mR

- Thread used on port aligner
  - M12 x 1.75mm pitch
  - 0.069”/turn (1.75mm/turn)
  - Distance to each M12 x 1.75mm stud is 4.773” (121mm)
  - 1/8 of a turn can provide 1.8mR resolution
- This method is typically done using a laser tracker with live readings.
  - Alignment should be able to attain 1mR resolution if needed

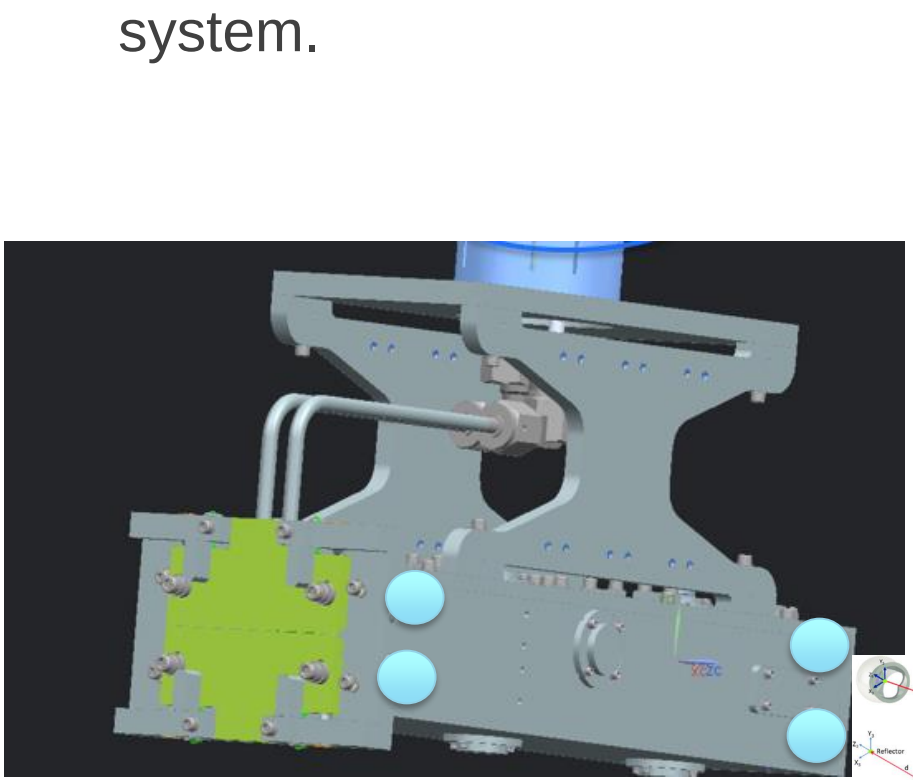
MAES Module Pitch Angle Stability Through Measurement Region 0.2mR

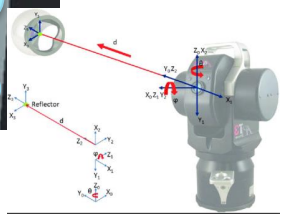
- Holds scanner head
- 0.03” (.76mm) out of flat for every 36” (914mm)
  - Information provided by Kurt Lesker
- Length of tube and associated angle of just the tubing
  - 17.9” (454.6mm)
    - Out of flat by 0.015” (0.38mm)
    - 0.84mR



Referencing Box Geometry to external points

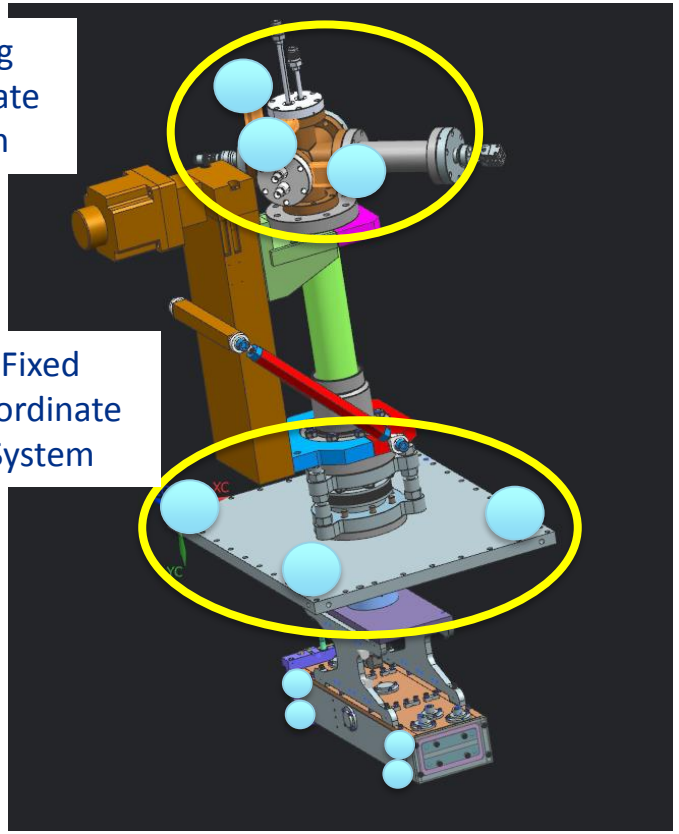
- The front and rear slits are referenced to the enclosure of the emittance probe.
  - These points are mapped to a fixed and moving coordinate system.





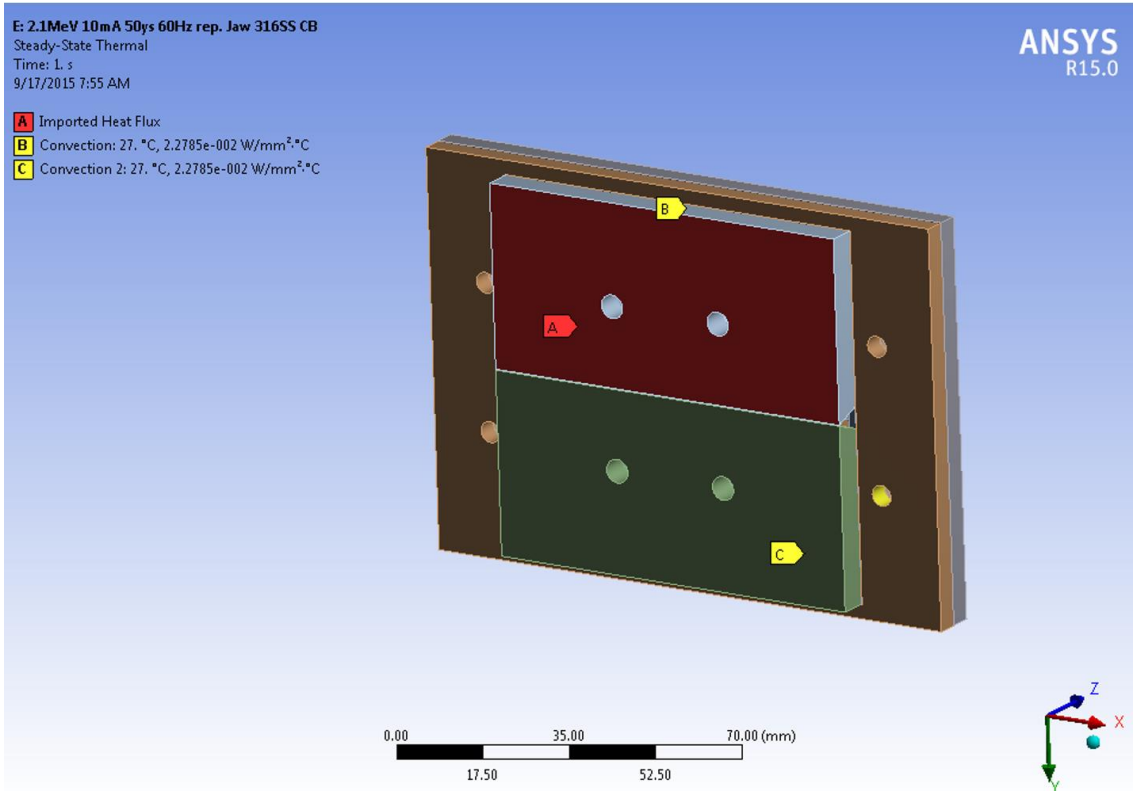
Moving Coordinate system

Fixed coordinate System



Thermal Analysis of Slit Plates

- Setup- imported heat load for
  - 2.1MeV
  - 10mA
  - 50us pulse length
    - Beam on
- Convection for series cooling at 0.027785W/mm^2
- No radiation- will yield conservative estimate



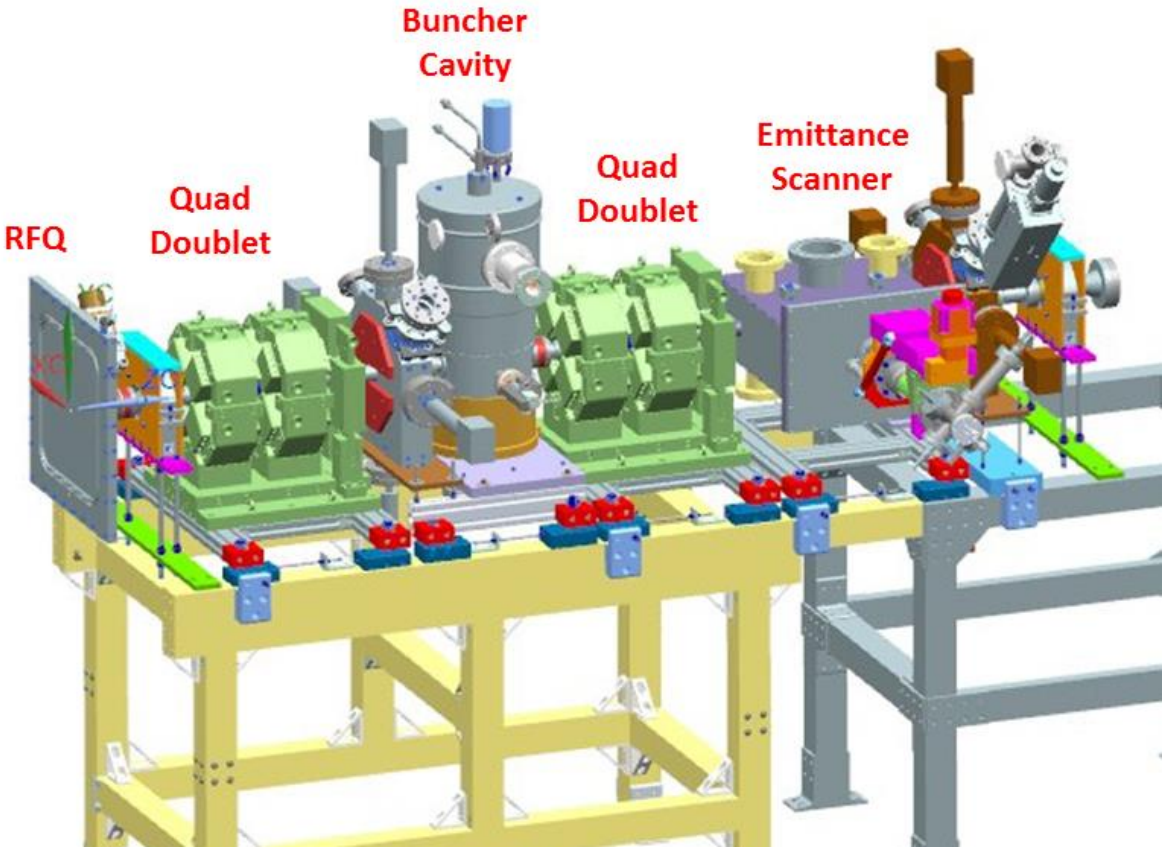
Transient Analysis (Peak Temperature)

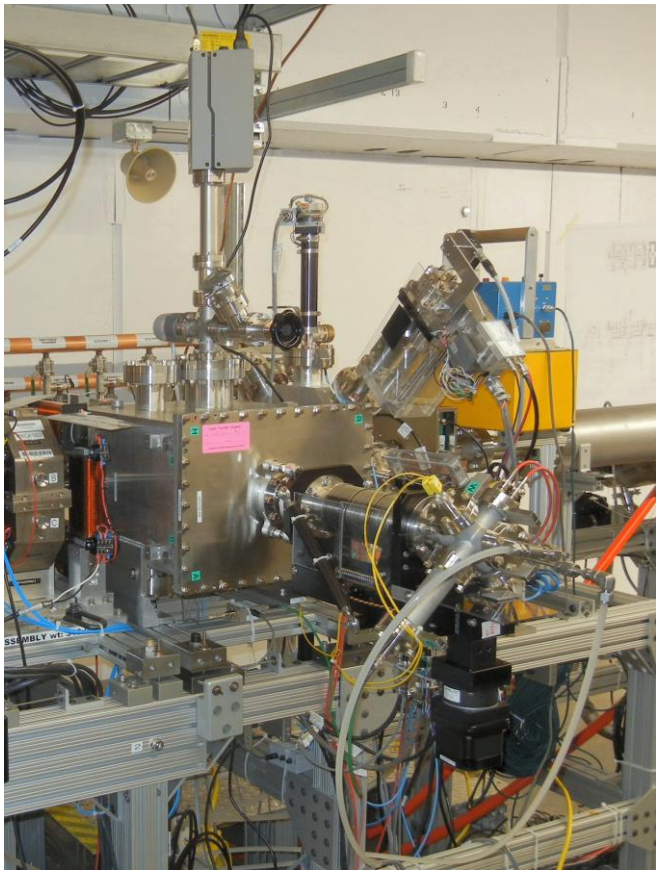
- Most damaging effects as a result of the peak pulse
- Investigated other materials
- Cool down takes place in ~1.5ms for TZM
- Max. Power density on TZM
  - 20W/mm^2 (absorber)

Transient Analysis (Peak Temperature)

- TZM should withstand the peak temperature rise
  - Highest temperature at end of pulse: 1500°C
  - Melting temperature: 2623°C
- Maximum repetition rate can be as high as 650Hz for
    - 2.1MeV
    - 10mA
    - 1mm sigma
    - 50us pulse length

MAES in PIP2IT MEBT Beamline

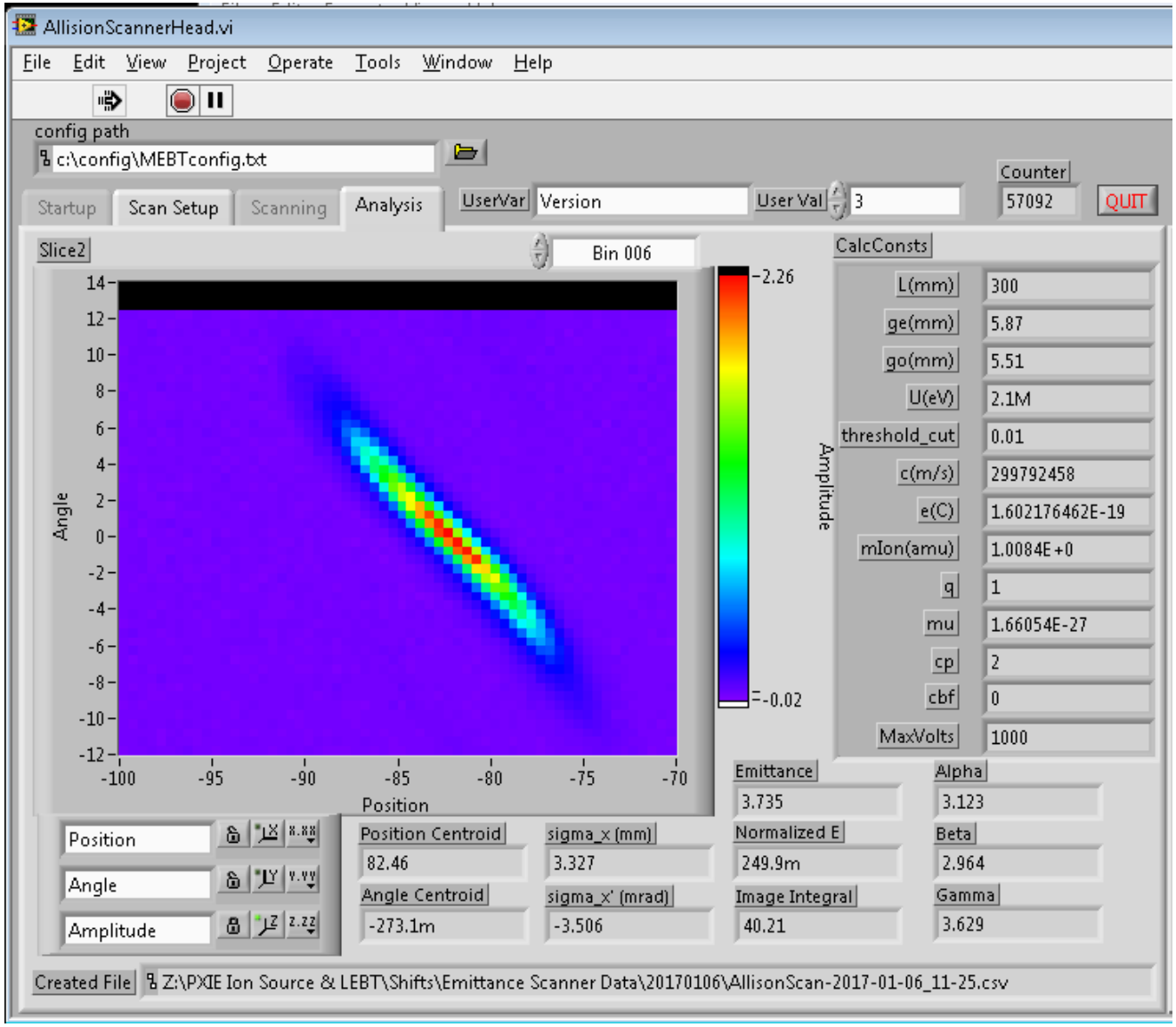




Installed in Dec 2016 for horizontal emittance measurements

- Rotate entire vacuum chamber for vertical measurements

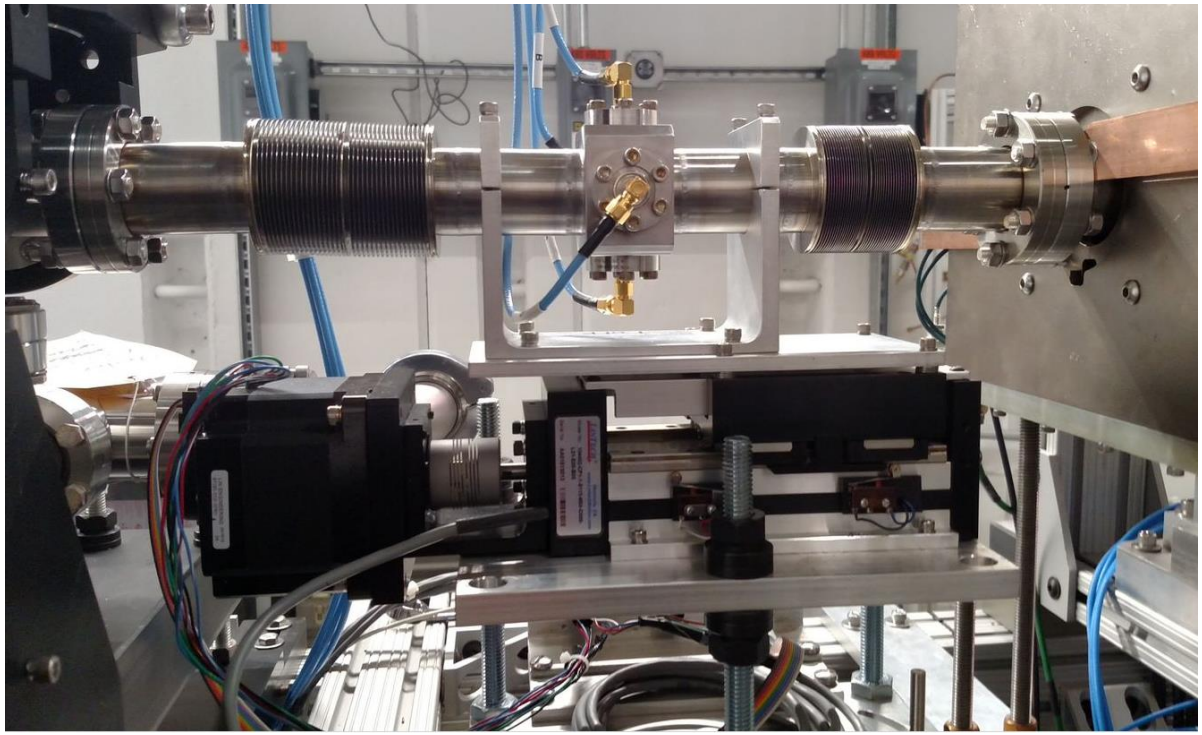
First Beam Measurements Jan 6, 2017



Summary

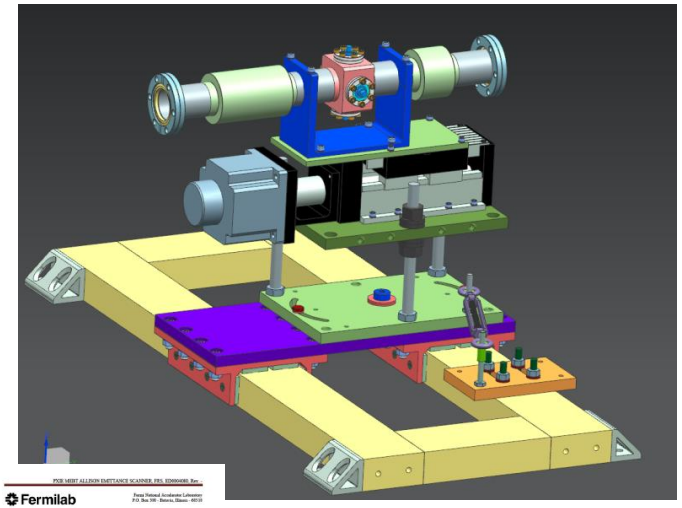
- Device required precise machining and alignment
- All materials chosen were vacuum compatible
- Cleaning and assembly was done to high vacuum requirements
  - Isopropyl or ethyl alcohol cleaning
  - Ultrasonic cleaning of materials
- MAES has been installed in the PIP2IT beamline since January 2017
  - Hundreds of emittance measurements performed
  - One of the most valuable beam diagnostic tools in MEBT

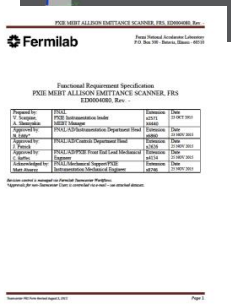
Time of Flight (TOF) Beam Position Monitor (BPM)



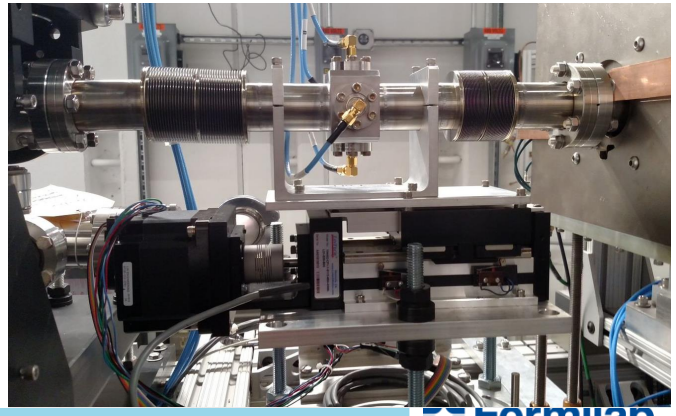
Specifications and Type of Measurement

- Measurement Type: Beam Velocity → Beam Energy
  - Measure beam phase as a function of BPM position
  - Non-destructive Measurement
- Functional Requirement Specification (TC#: ED0004201)
  - Energy 2.1MeV
  - Bunch Frequency: 162.5MHz
  - Nominal Pulse Repetition Rate 20Hz
  - Nominal Pulse Length 20us
  - Beam Current: 1-10mA
  - Energy resolution: 0.1%



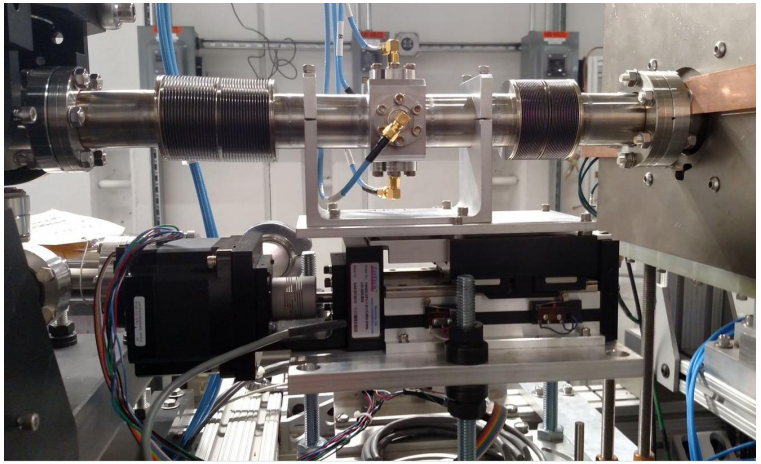

Fermilab

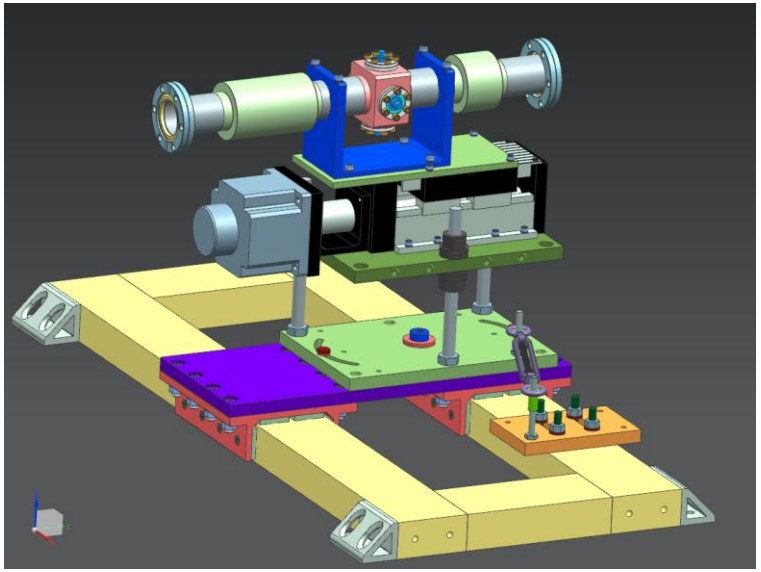
Functional Requirement Specification
PXIE MERIT ALLISON EMITTANCE SCANNER, FRS
ED0004080, Rev. -



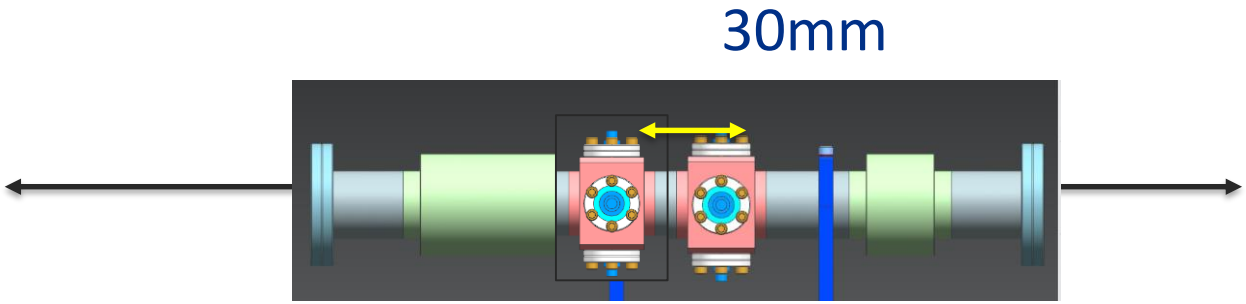
Specifications and Type of Measurement

- Longitudinal Spacer requirement (Flange to Flange)
  - <400mm
- Aperture Requirement >30mm
- Full Range of Motion: 30mm
- Position Accuracy <25um
- Step size of motor should be less than 25um



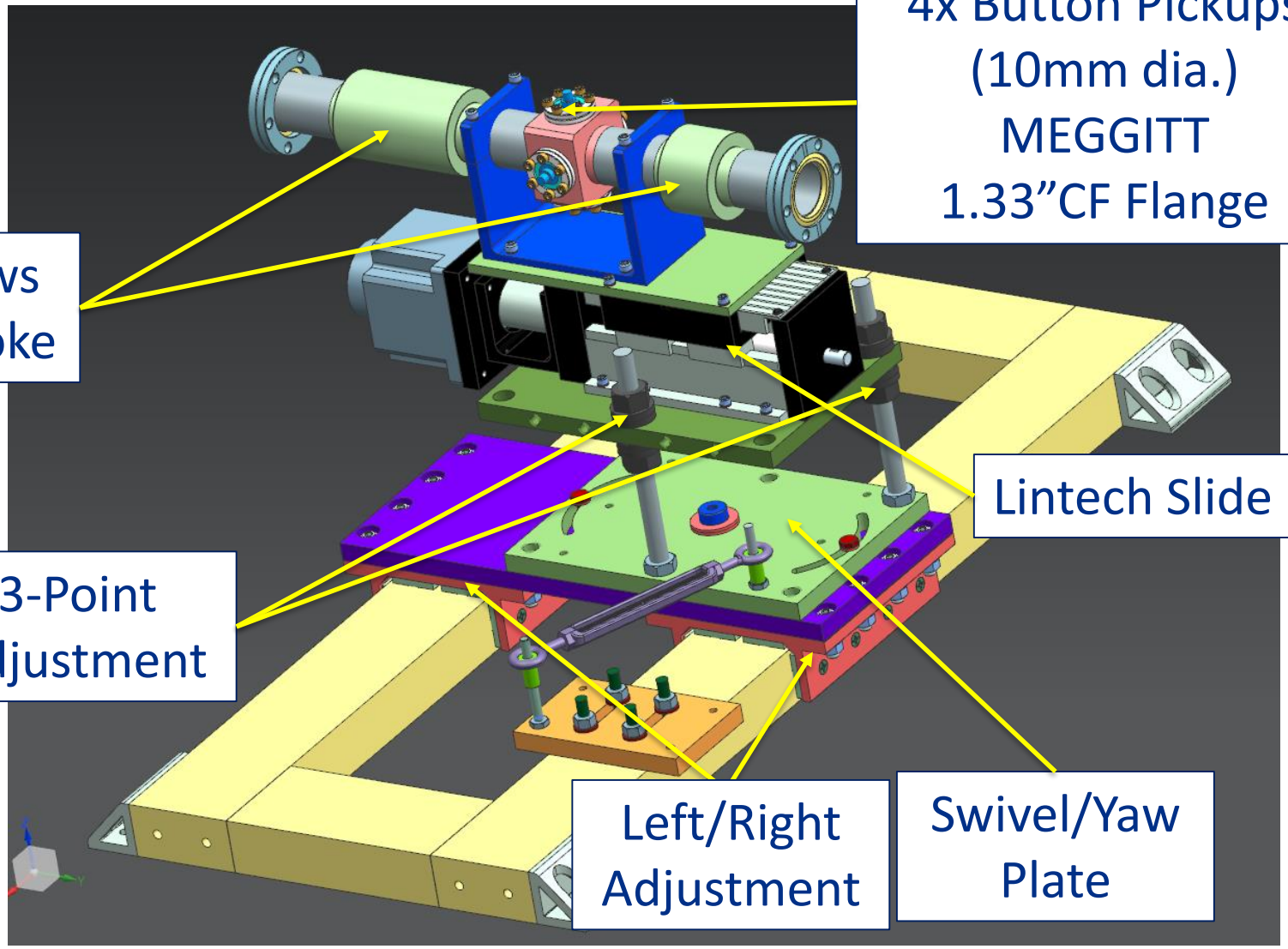


Mechanical Design Description

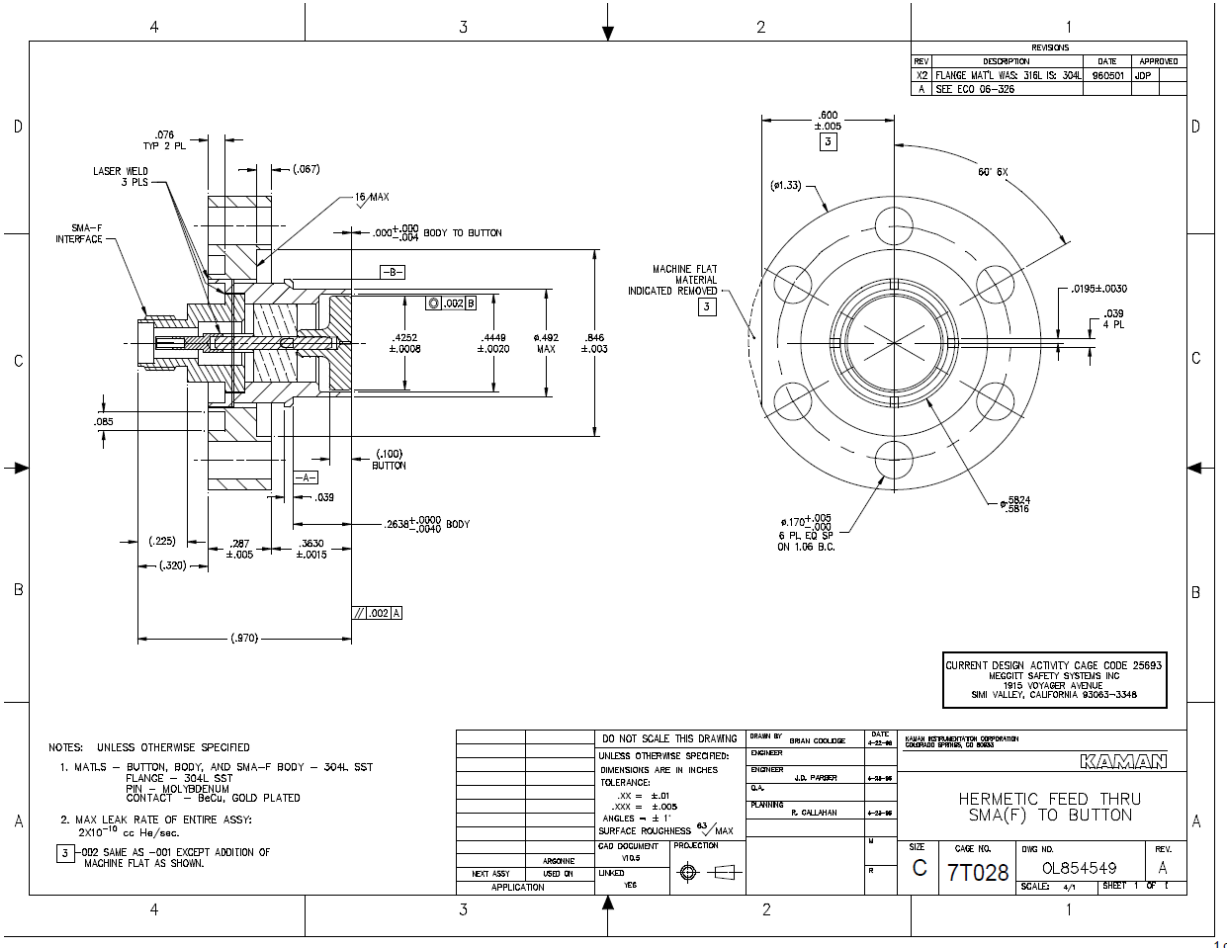


- TOF is moved 30mm in one direction to measure the time until it detects the signal to measure the beam velocity.
- Key Components for MAES
  - Button Pickups
  - Linear Actuator

Mechanical Design Description



Button Pickup Drawing Details



- Flanged button pickup
- Metal knife-edge gasket
  - Expensive
  - Single use
- Optional high-frequency isolation springs

Linear Actuator and Positioning

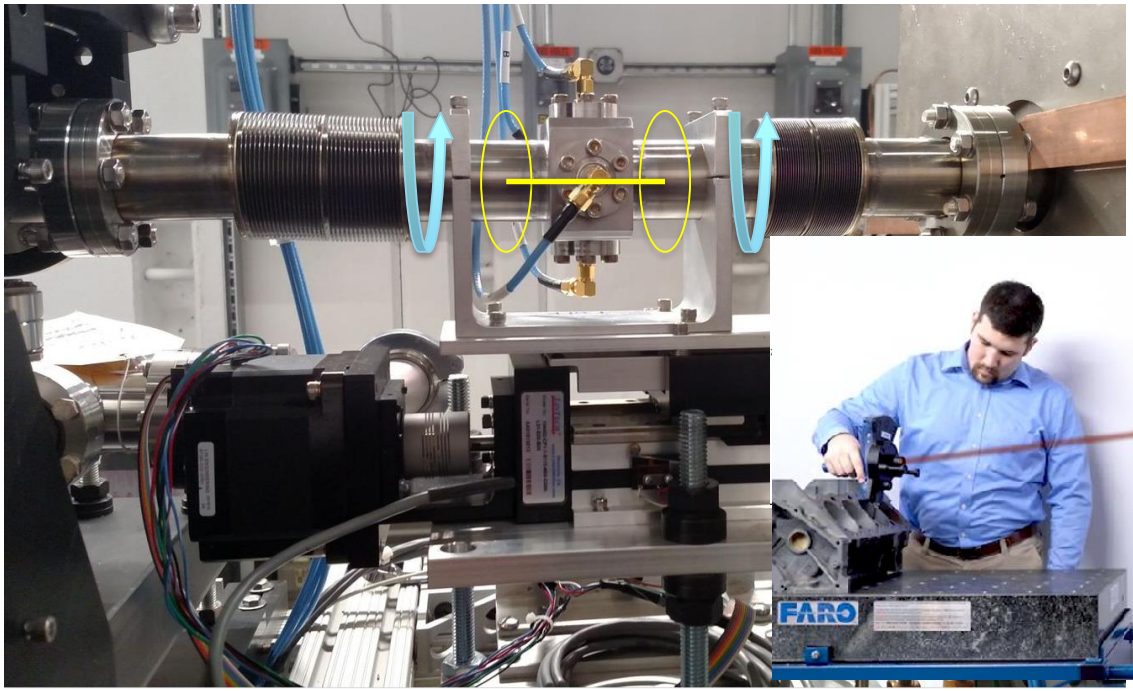
- Lintech Slide
  - Straightness tolerance < 3.30um/25mm
  - Flatness tolerance< 3.30um/25mm
  - Unidirectional and Bidirectional Repeatability (Ball Screw Selected for optimal repeatability)
    - ±2.5um
- US Digital encoder has 2000 cpr (E2 optical kit encoder)
  - 0.050”/turn
  - Encoder resolution see 2.5e-5 inches per count (0.0006 mm/count)
    - 0.05”/turn/(2000 cpr)

Linear Actuator and Positioning

- Stepper Motor is 1.8º (200 steps per revolution)
  - Stepper motor: Lin Engineering 871S-01D-07RO
  - Stepper motor will half step= 400 steps per revolution
- Screw Drive is 5 threads per 1”in (25mm)
  - 0.2 in per revolution
- 1 step=0.0005” (12um) (400 steps per revolution)
  - Meets requirement of positioning the device to <25um

Aligning the BPM

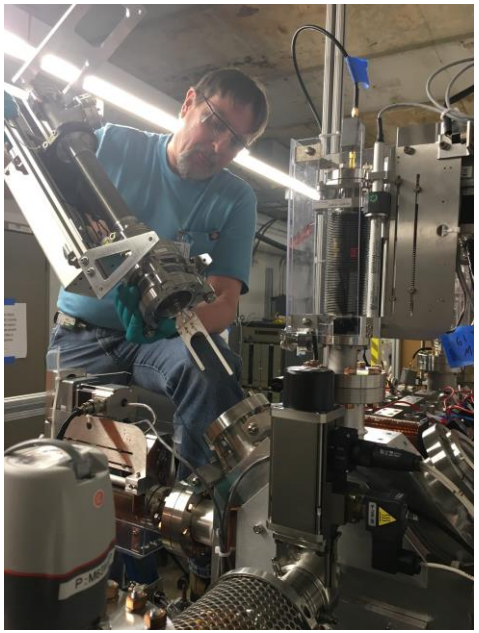
- X,Y,Z, roll, pitch, yaw adjusted using a laser tracker.
  - Points taken about the circumference of the beam tube around the BPM housing.

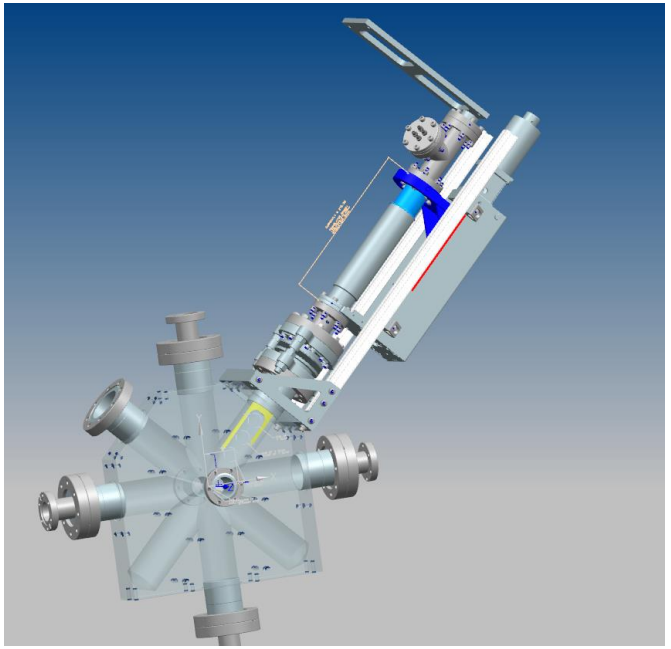


Summary

- Device moves to a position with a position accuracy
  - A single step of the motor provides 12.5um position
    - Encoder has 0.6um resolution
- 3 point adjustment to eliminate pitch, roll, and vertical directions
- Alignment of device
  - Acquires points on the OD of the beam tube near the housing
- Operational in PIP2IT MEBT
- Achieved ~0.3% energy resolution at 2.1 MeV
  - Limited by BPM phase resolution
- Plan to use in PIP2IT HEBT for ~21 MeV beam
  - Few percent energy resolution

PIP2IT MEBT Wire Scanner





Specifications and Type of Measurement

- Measurement Type: Beam Profile
  - Destructive Measurement
- Functional Requirement Specification (TC#: ED0004340)
  - Energy 2.1MeV
  - Beam Intensity 1-10mA
  - Bunch Frequency 162.5Hz
  - Pulse Length 20us (5-20us)
  - Pulse Repetition Rate 20Hz
  - RMS Beam size (X/Y) 1-4mm

Specifications and Type of Measurement

- Time of Measurement <5min
- Positioning accuracy <0.2mm
- Absolute Position Accuracy <1mm
- Angle Between Wires 90º±0.5º
- Yaw and Pitch Angles <5º
- Roll Angle Error <1º

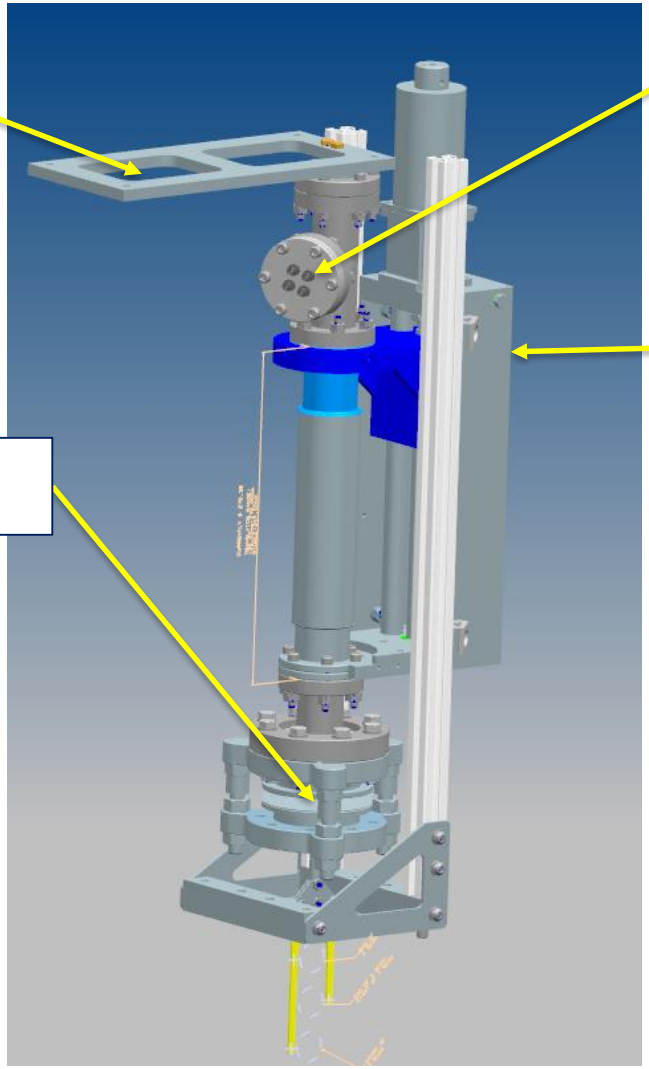
Mechanical Design Description

Moving Reference Frame

SMA Feedthrough 4x

VACGEN ZTR1570W

Port Aligner



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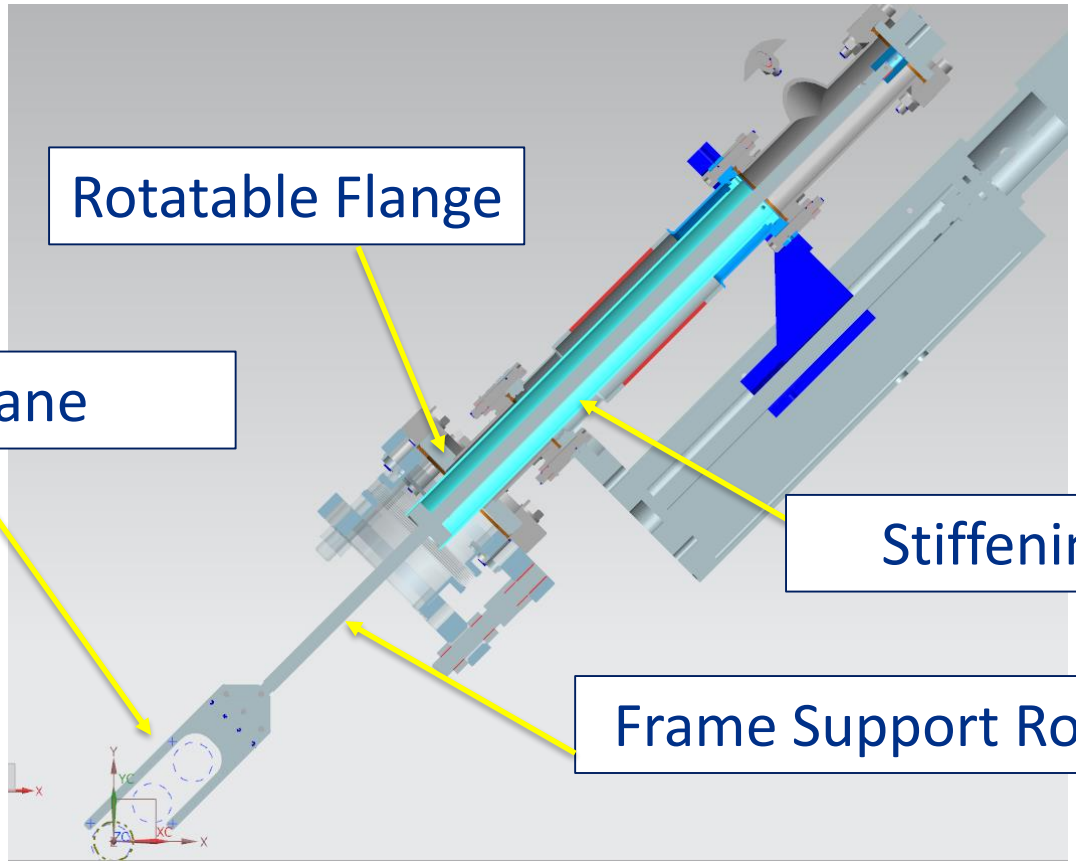
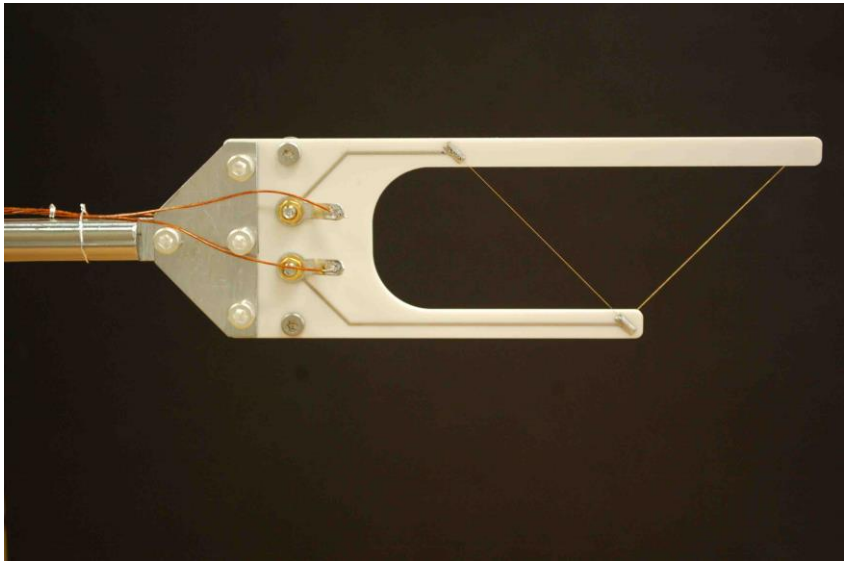
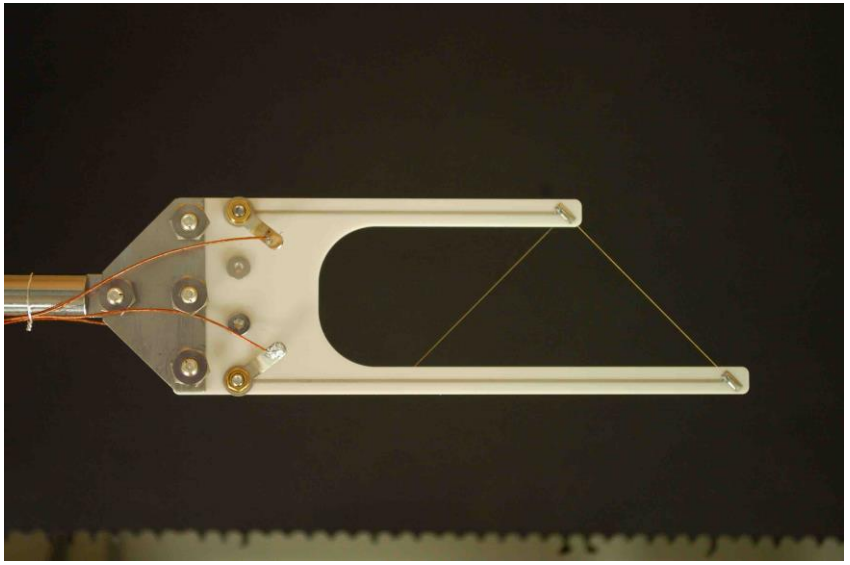
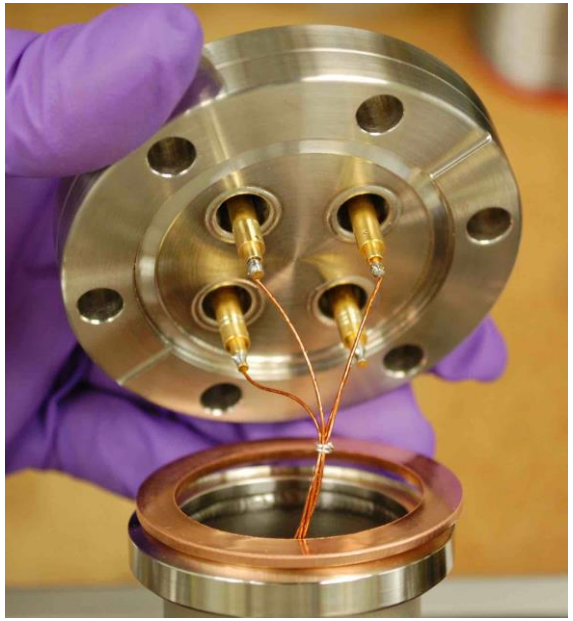


Mechanical Design Description

- AuW-Re Wire 75um diameter pre-loaded to 100 g
- Ceramic substrate
  - Printed conductor on ceramic
  - Wire soldered to pads on ceramic board
- Each end of the wire is fed to the SMA feedthrough for continuity checks.

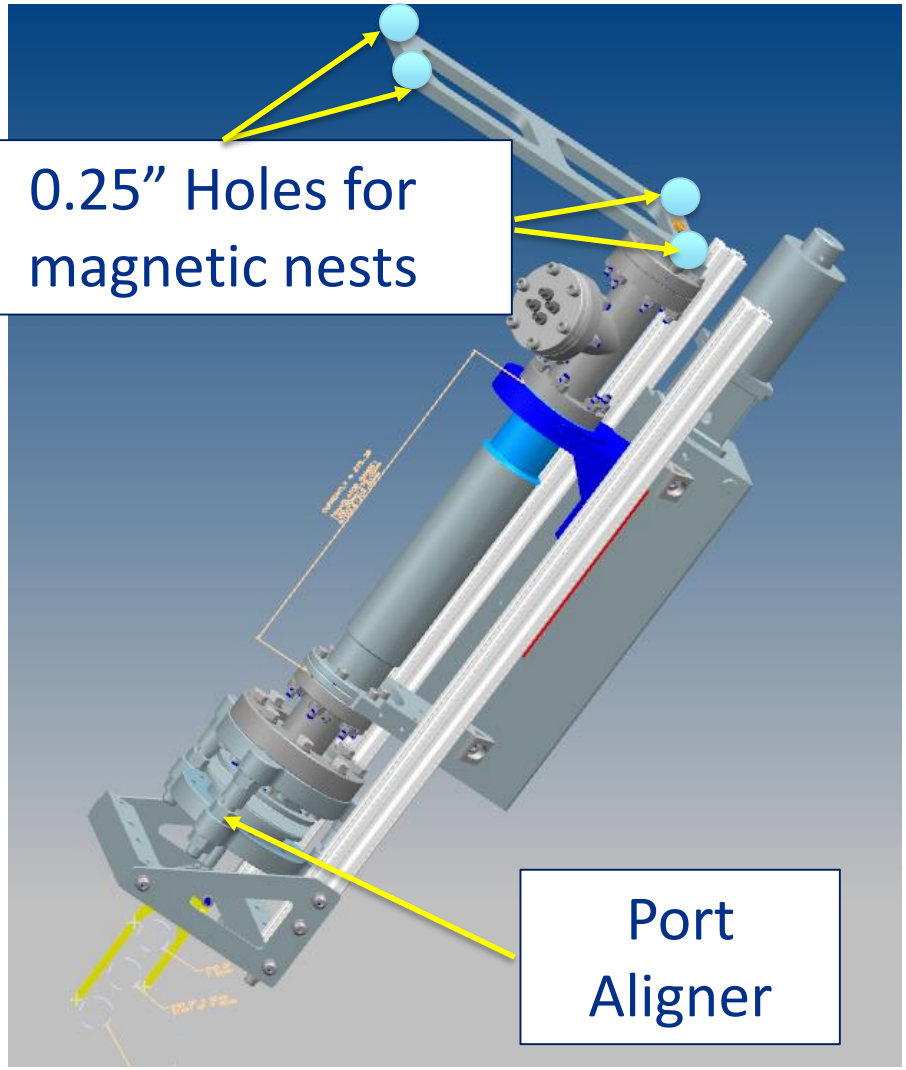






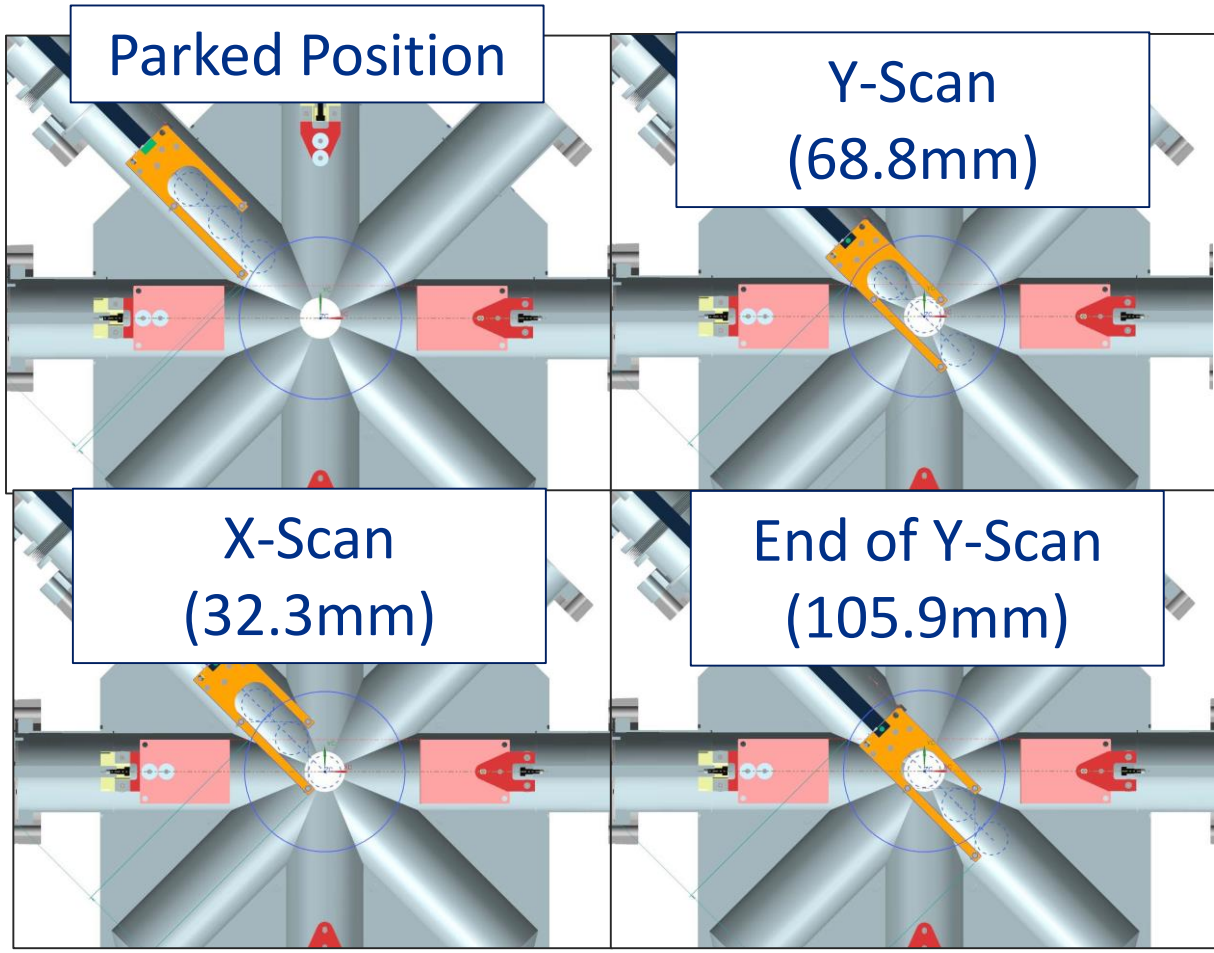
Alignment

- Optical reference of the wires to external to the alignment “jig”
  - At 45degree
- Referenced in the fully inserted position.
- Device was inserted in vacuum chamber and aligned in-situ
- Roll and Pitch Adjusted using Port Aligner (±3º)
- Yaw manually adjusted
  - Used a rotatable flange

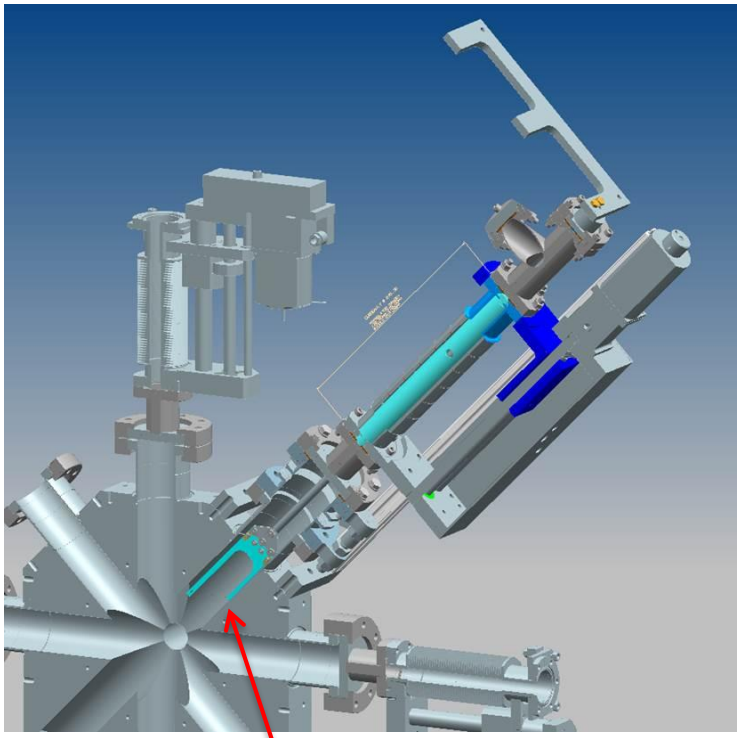


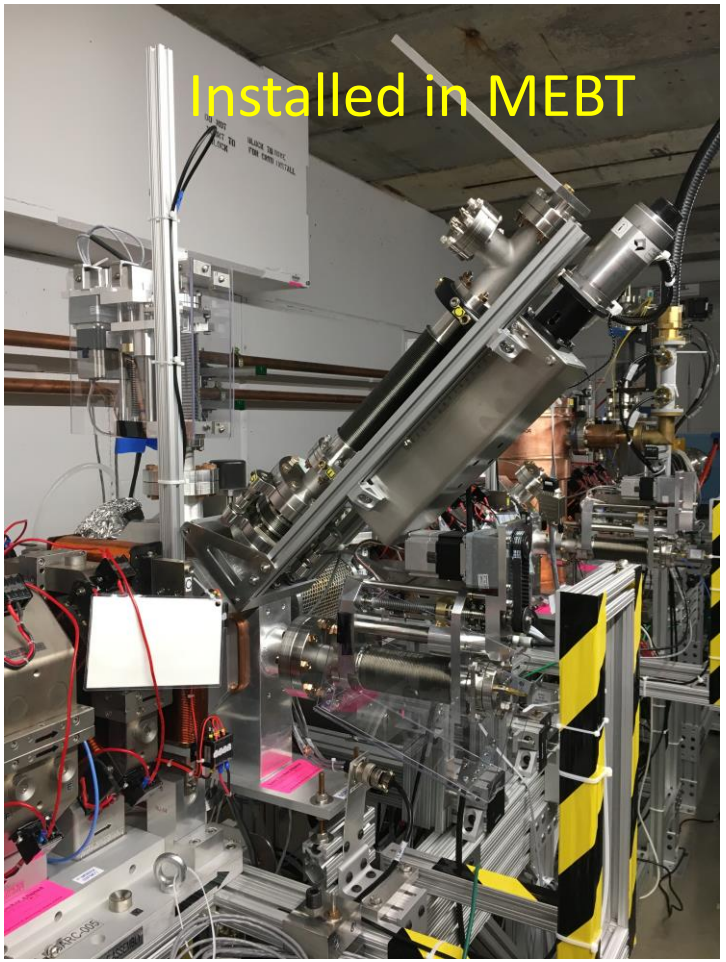
Movement of Scanner and Slide Details

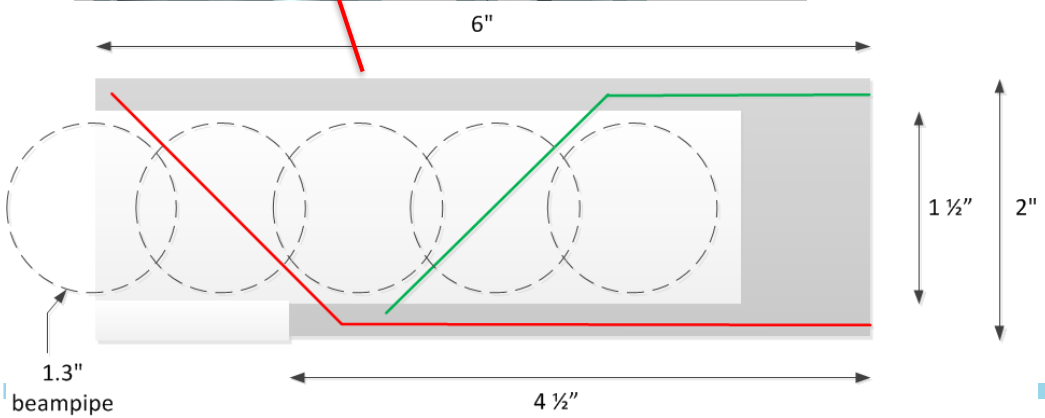
- Total Travel is 105.9mm
- VGScienta slide
  - ZTR1570W (150mm stroke)
  - Resolution 5um
  - 4 turn/2mm or 0.5mm per rev
- 1.8º Stepper Motor
  - Mclennan MOT01
  - 2.5um/step (200steps/rev)
- 2000CPR Encoder
  - 0.25um/count resolution



Wire Scanner Installed in PIP2IT MEBT Beamline





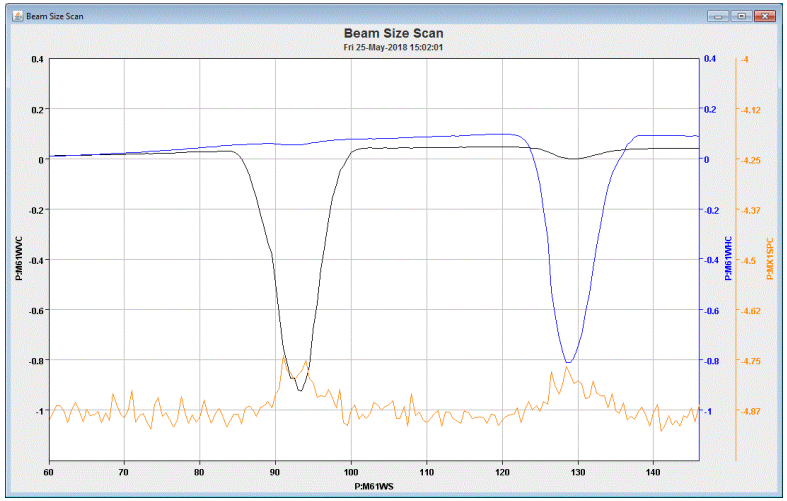


Fermilab

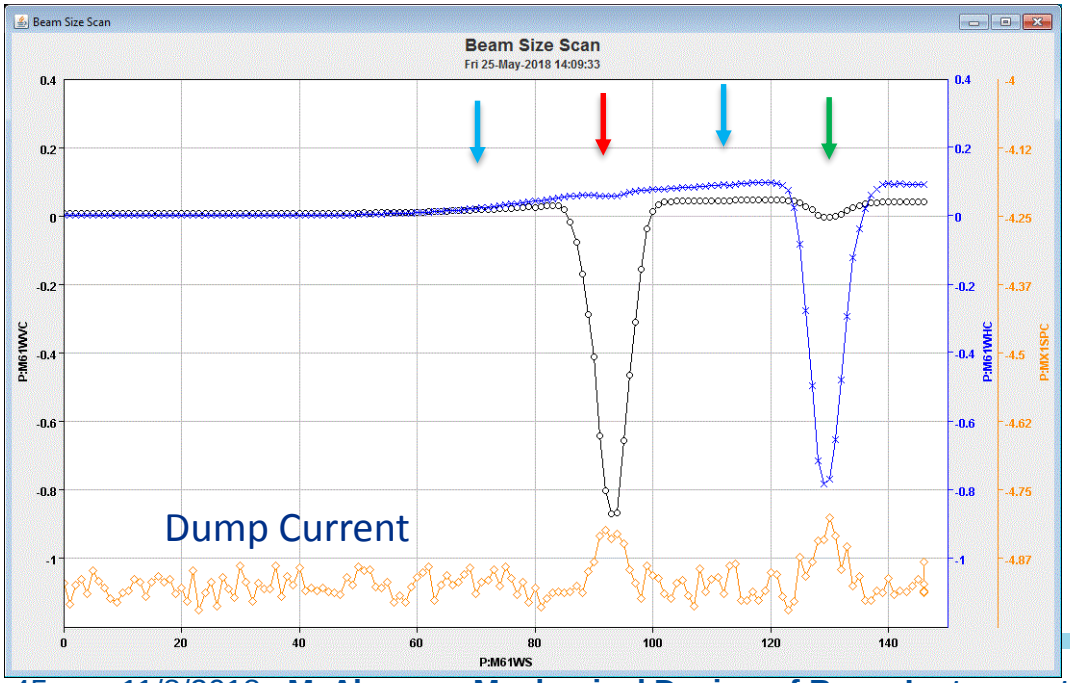
Preliminary Wire Scanner Profiles

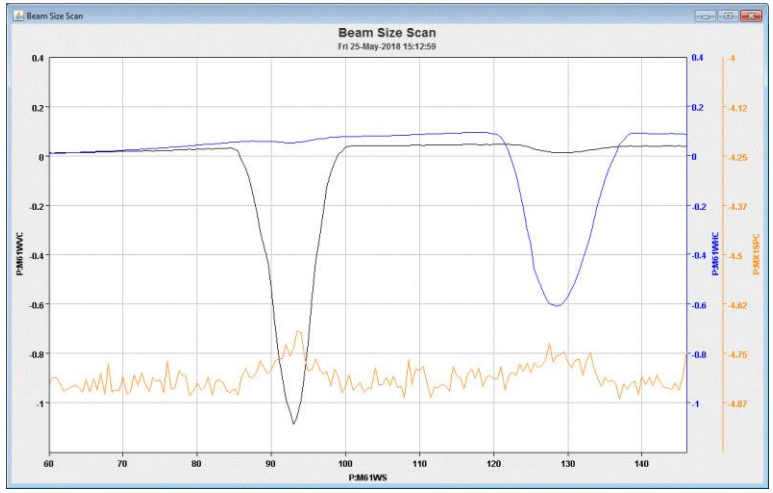
Preliminary scans

- Unbiased wire
- Horz and Vert profiles
  - Few percent loss of beam
  - Cross-talk between wires?
- Lots of electrons background?
- Signal flips polarity – losing electrons?
  - Add bias voltage to wires?



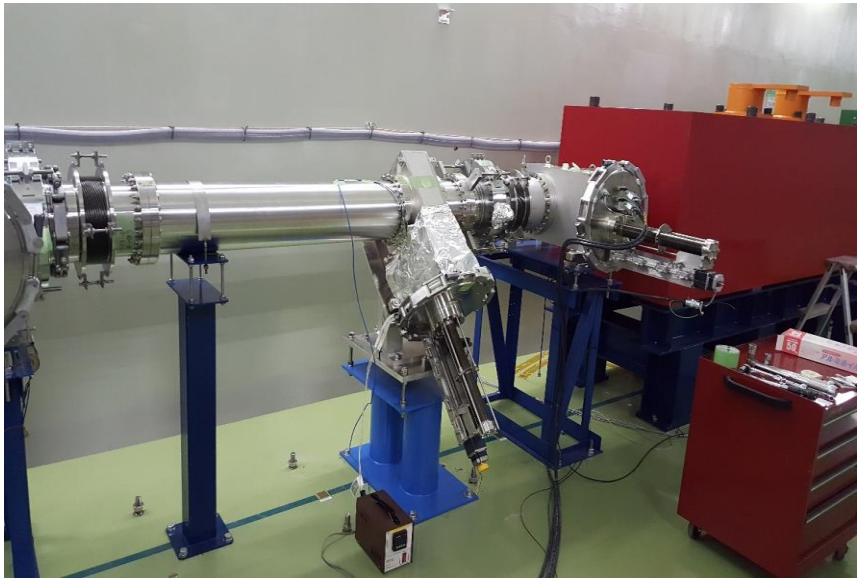
Change focusing





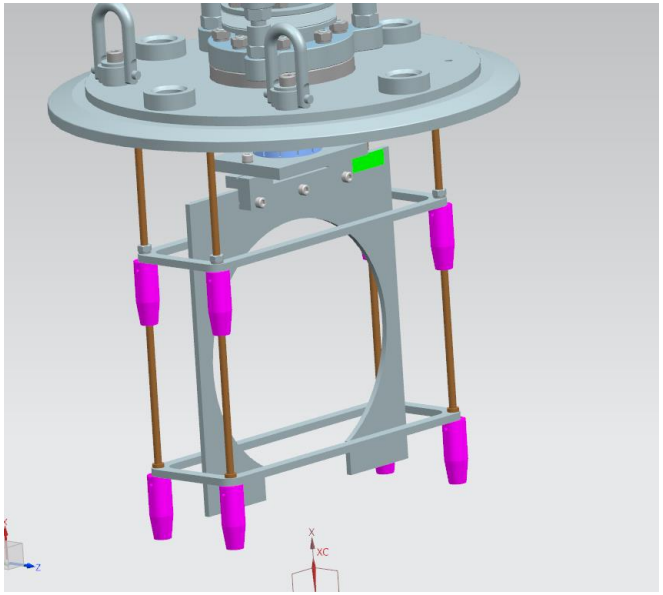
Fermilab

JPARC SSEM



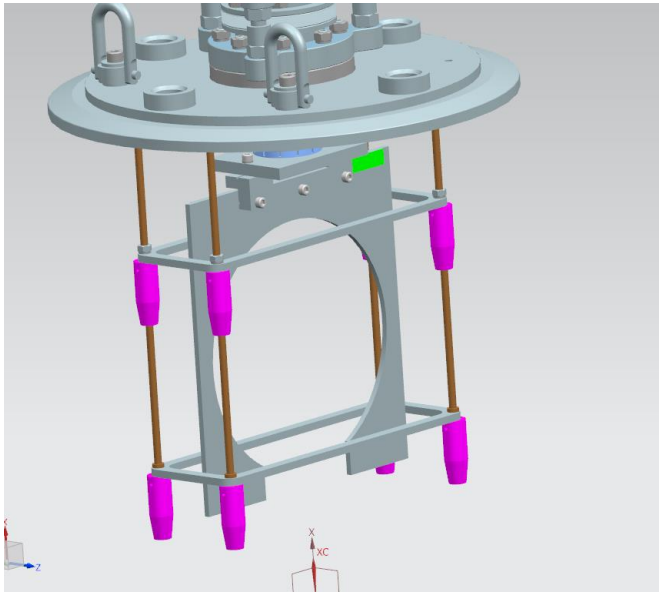
Specifications and Type of Measurement

- Measurement Type: Beam Profile
  - Destructive Measurement
- Functional Requirement Specification (TC#: ED0006672)
  - Energy 2.1MeV
  - Beam Intensity 4e13 protons/bunch
  - Spill repetition rate 2.48s
  - Bunch Length 80ns
  - Transverse x width 3-5mm (1sigma)
  - Transverse y width 2.5-4.5mm (1 sigma)



Specifications and Type of Measurement

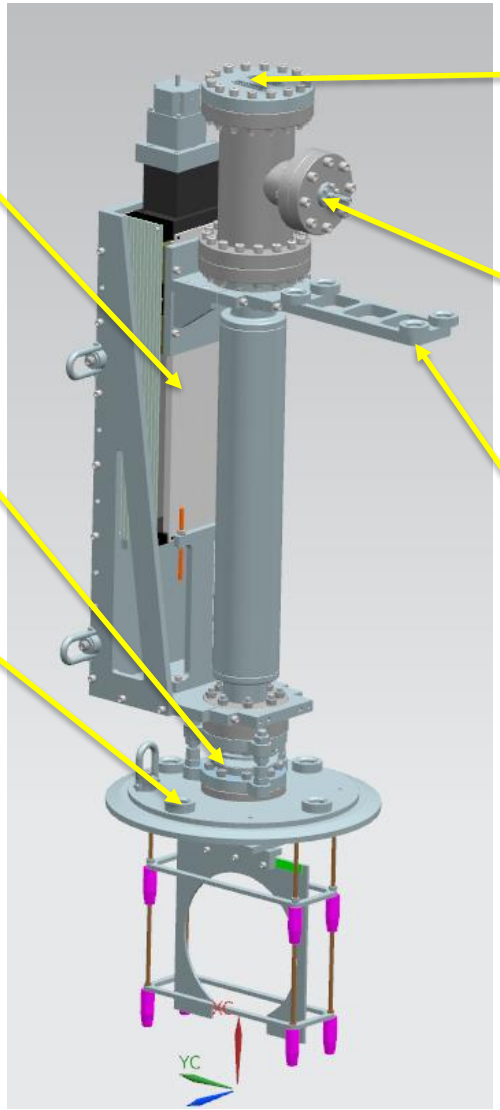
- Time of Measuring x and y profile
  - <5min
- Clear Aperture distance >80mm
- Position accuracy <0.2mm
- Absolution positioning accuracy
  - <1mm
- Angle Between Wires 90±0.5º
- Yaw and Pitch Angle error <5º
- Roll Angle Error <1º
- Wire Diameter 25um
  - Material Ti
  - Soldered to Frame



Mechanical Design Description

Lintech Slide (radiation hard)

50 Pin Sub-D connector (for the wires)



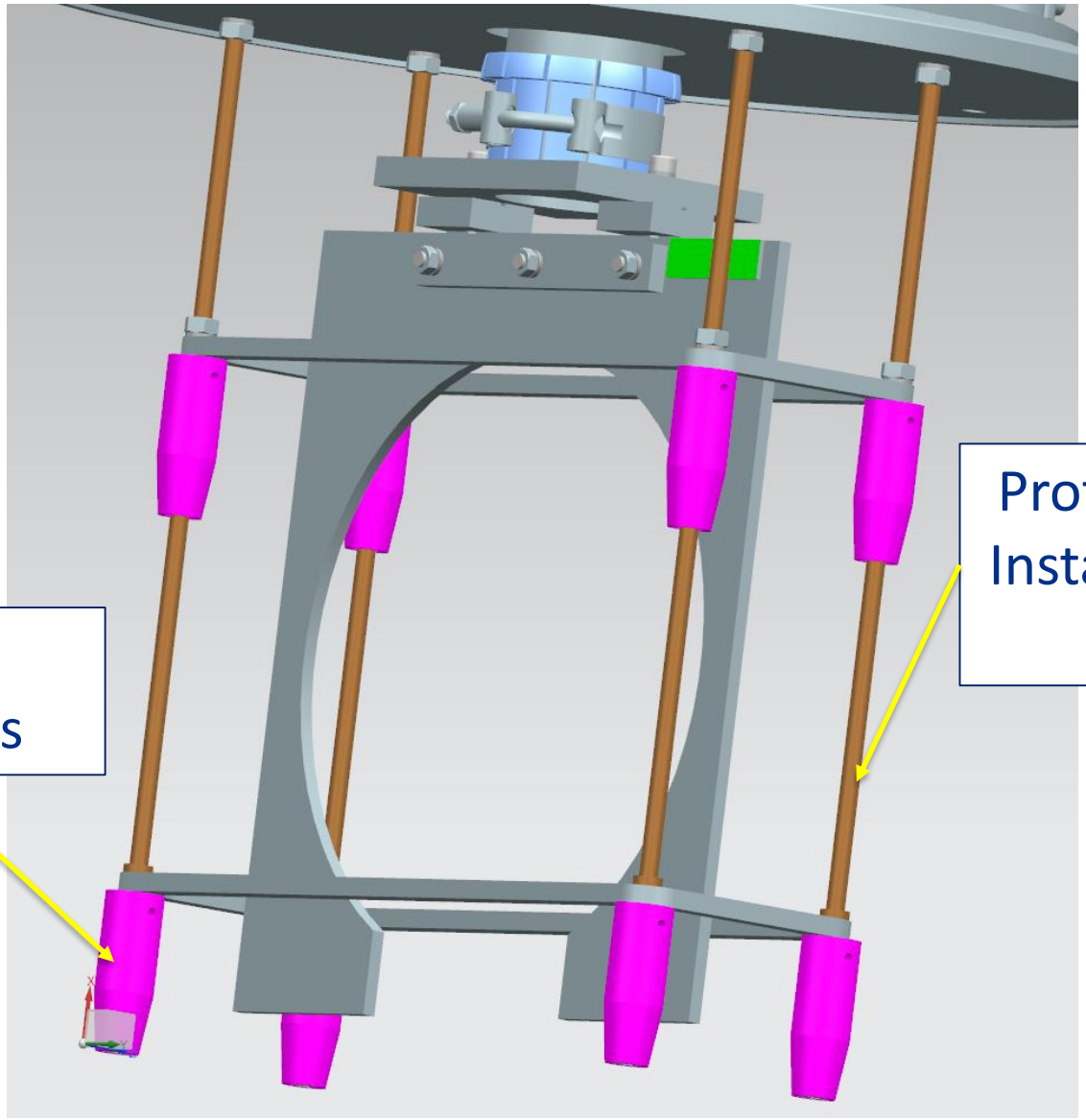
SMA Feedthrough (Biasing wires)

Port Aligner

Fixed references

Roll reference for external alignment

Mechanical Design Description

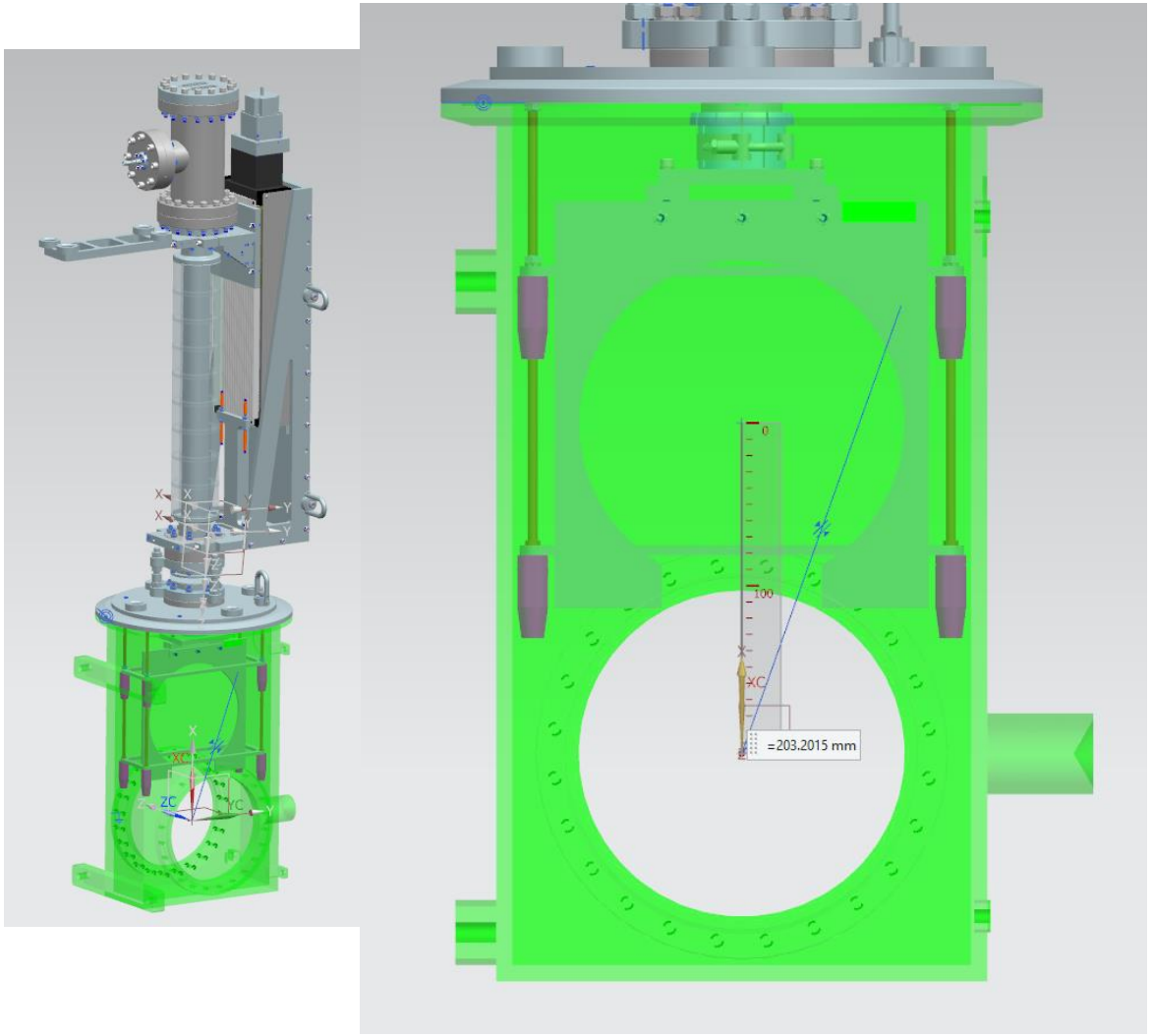


PEEK bumpers

Protection Cage for Installing/Removing Frame

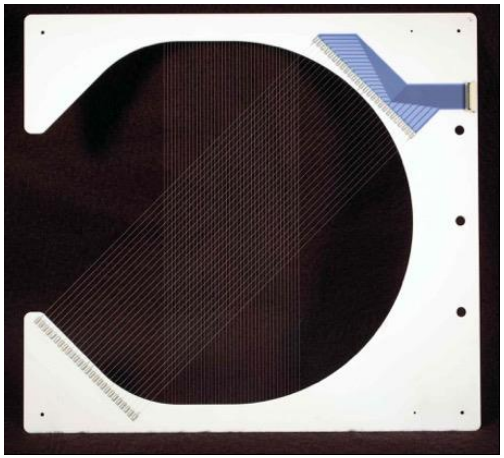
Mechanical Design Description

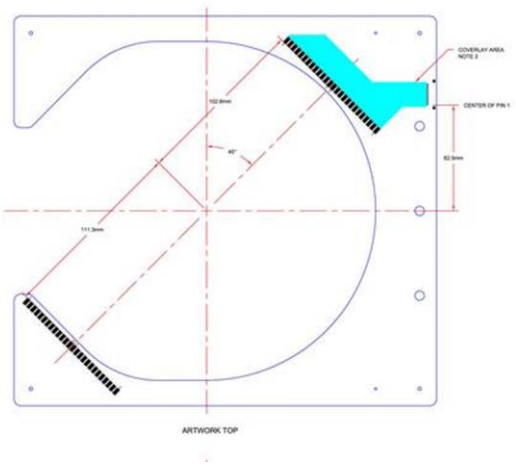
- Frame moves into the beamline when in use
- It is extracted when not in use.
- Clears the entire aperture of the beamline.
- Frame is rigidly mounted to the 3-way cross at the top

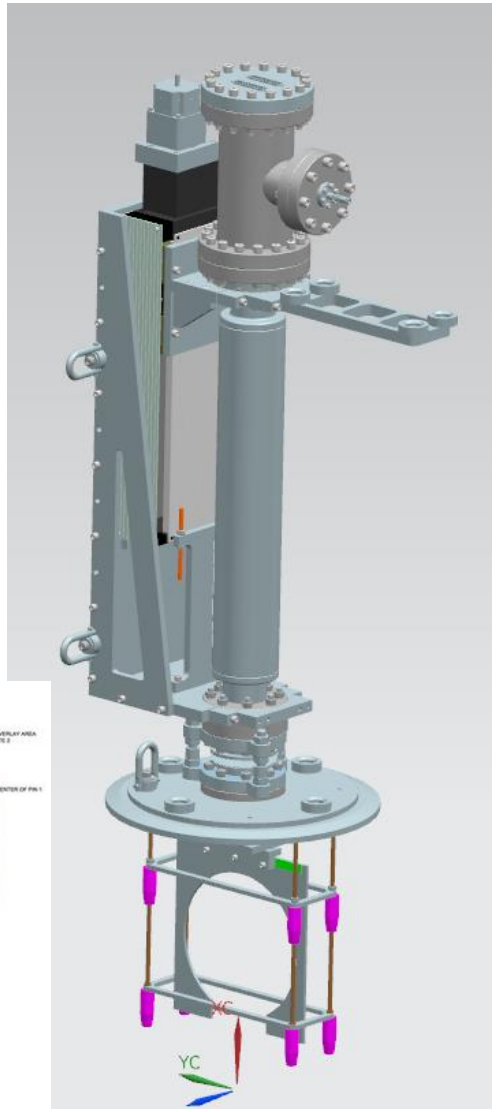


Mechanical Design Description

- Ceramic Frame (Al203)
  - Masked to create traces on the surface
- Ti wires are epoxied using Epotek conductive epoxy type H20E-PFC
- 3 frames
  - X profile
  - Y profile
  - Bias plane





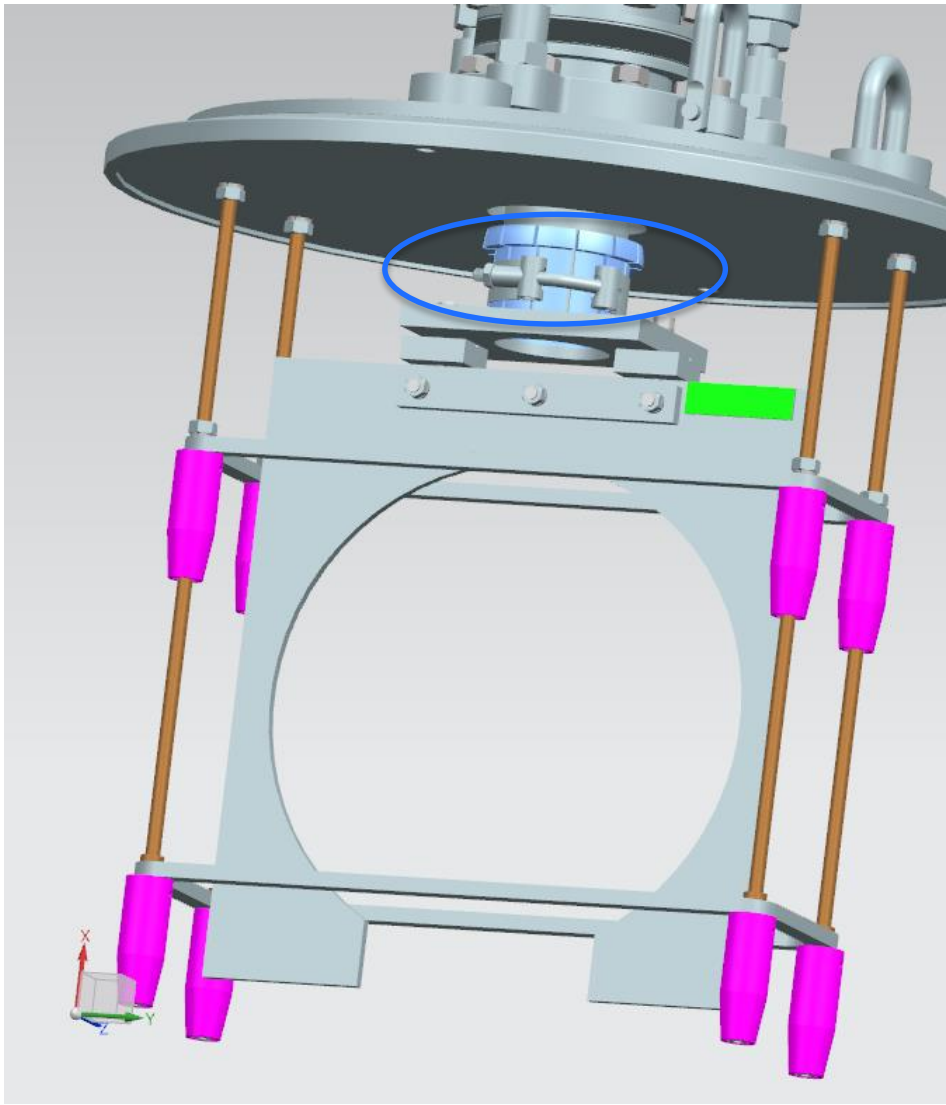


Radiation Hardened Components

- Omron Limit Switches
  - TZ-1GV2
- Lintech Slide
  - MoS coated drive shaft (No lubricant needed)
    - 440C SS Bearing
  - Other Considerations
    - Glass filled PEEK bearing
    - Standard stainless steel bearing on metal drive shaft
      - Use of Lithium Grease
        - Used in target hall at Fermilab
          - Rheoplex NRRG-2 (Nye Lubricants Inc.)
  - ACME screw drive 5 threads per inch

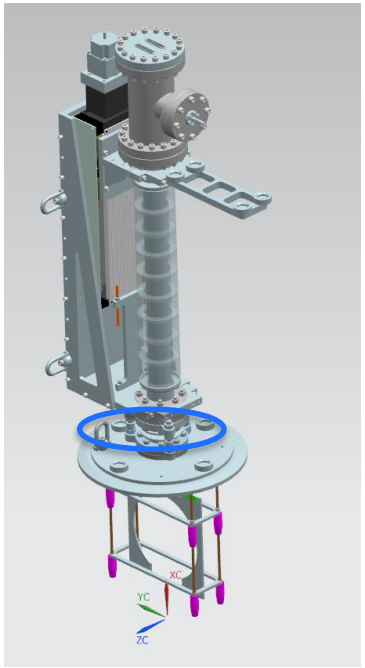
Sensor Yaw Alignment with Respect to beam line axis 10mR

- Yaw alignment done using stainless steel clamp



SSEM Module Pitch Adjustment Range ±25mR

- Provides vertical adjustment of ±5mm
- Pitch adjustment up to ±3° (52.4mR)



Port Aligners

General Specification					
Part no.	PA-35H	PA-35T	PA-64H	PA-64T	
Flange Size	CF38 (2.75" OD CF)		CF64 (4.5" OD CF)		
Flange bolt hole type	Through holes	Tapped M6	Through holes	Tapped M8	Thr
Axial adjustment					
Tilt					
Bellows clear bore	38 mm		65 mm		
Bakeout temperature					

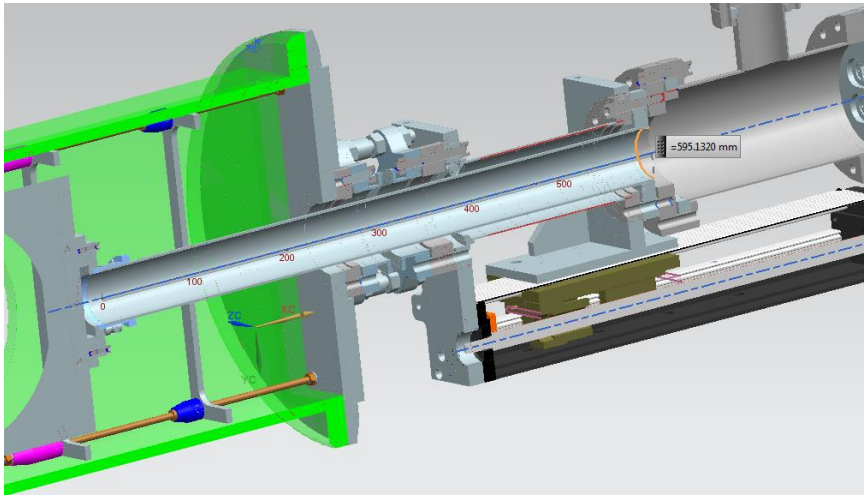
Product code selector

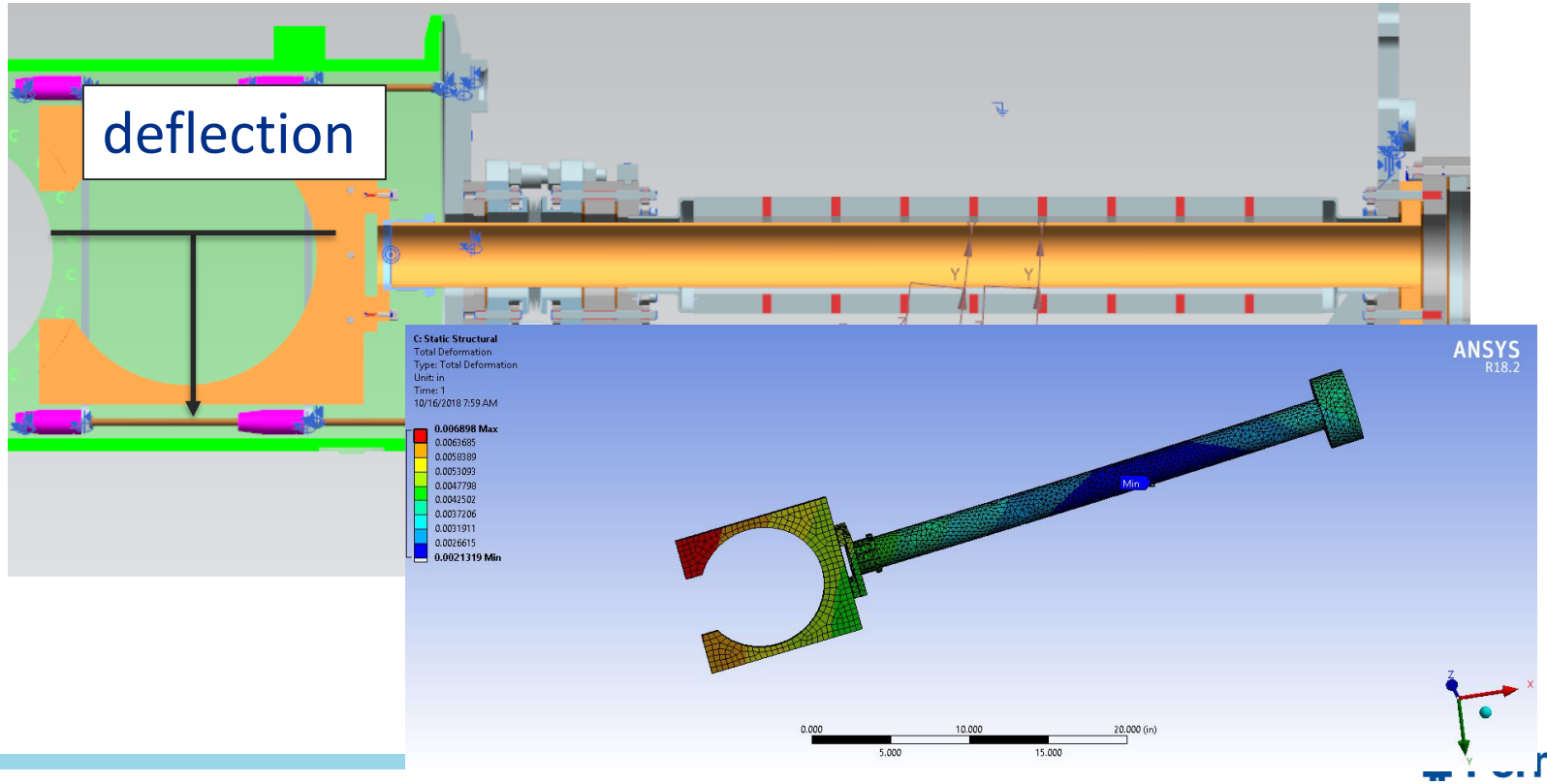
SSEM Module Pitch Adjustment Resolution 1mR

- Thread used on port aligner
  - M12 x 1.75mm pitch
  - 0.069”/turn (1.75mm/turn)
  - Distance to each M12 x 1.75mm stud is 4.773” (121mm)
  - 1/8 of a turn can provide 1.8mR (0.10deg) resolution
- This method is typically done using a laser tracker with live readings.
  - Alignment should be able to attain 1mR resolution if needed

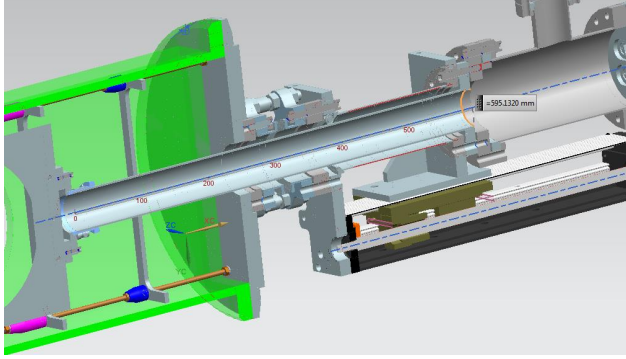
SSEM Frame/Tube Deflection

- Maximum Deflection (Hand Calculation)
  - .0017” (43um)
  - Force 2.2lbs (1kg)

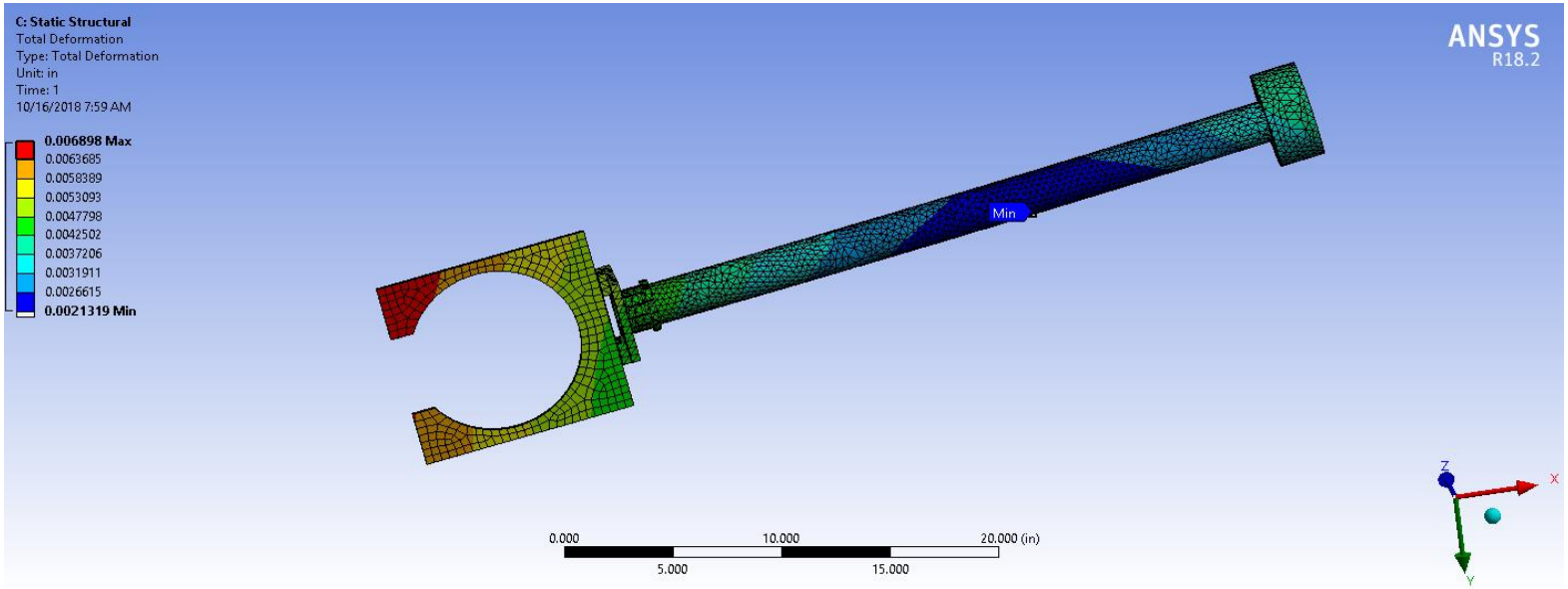




SSEM Frame/Tube Deflection ANSYS

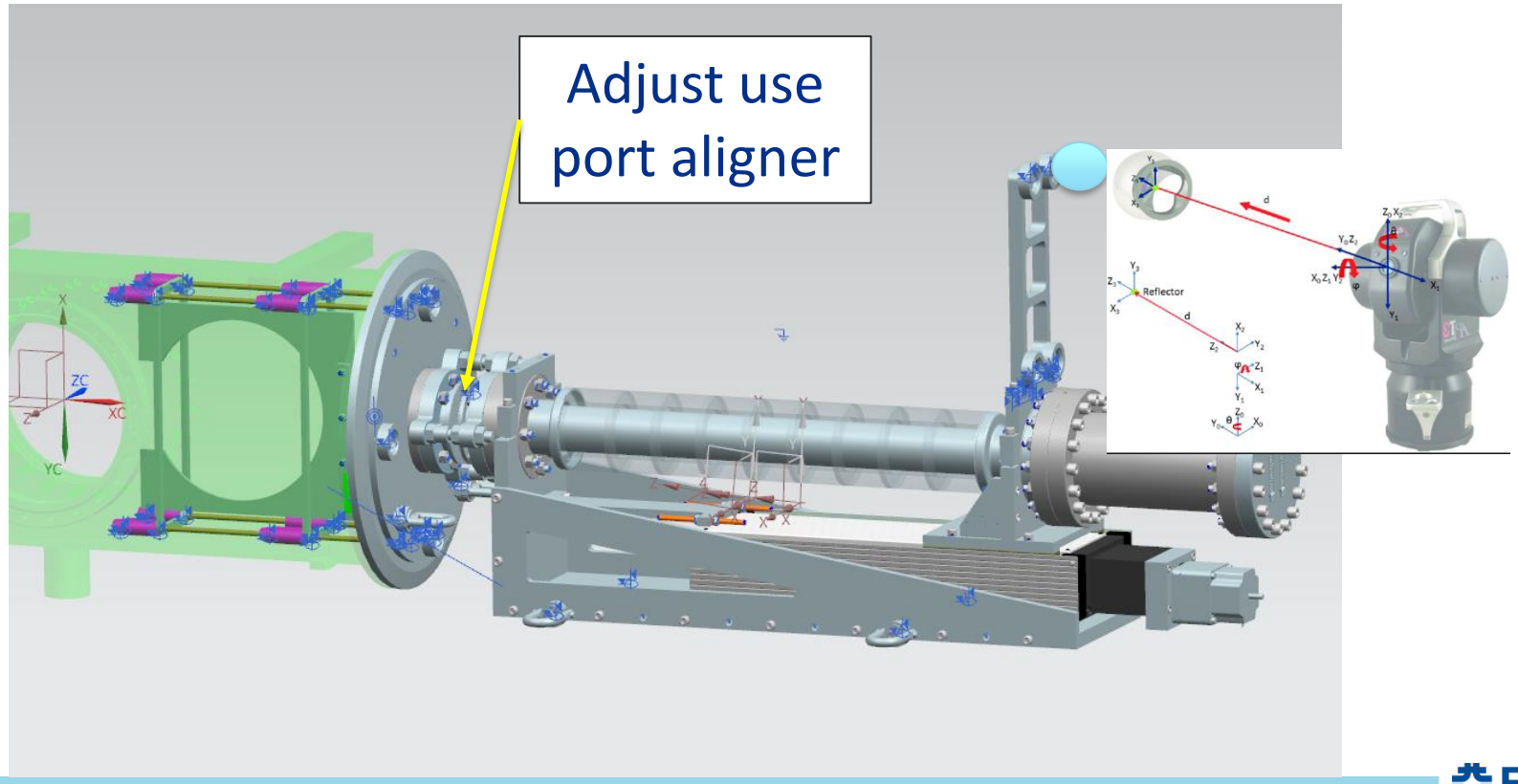


- Boundary Condition
  - Vacuum (14.7psi)
  - Gravity
- Maximum Deflection (ANSYS)
  - 0.0068” (roll can be removed from the measurement via port aligner)



SSEM Eliminating Deflection

- Use alignment “Jig” to correct for this sag
  - Magnetic reflectors for laser tracker and adjust using the port aligner



Summary

- The Ti wires have been used on other wire scanners in the past
  - 120GeV and 8GeV beam
- The roll and pitch adjustment can be made via the port aligner
- Yaw adjustment is done manually using a pipe clamp