Solar Probe Plus

A NASA Mission to Touch the Sun

Integrated Science Investigation of the Sun
Energetic Particles

Preliminary Design Review

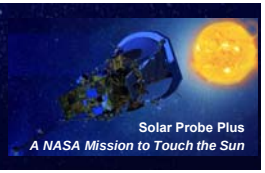
05 – 06 NOV 2013

EPI-Lo Mechanical

Scott Cooper

EPI-Lo Lead ME (JHU/APL)

Outline



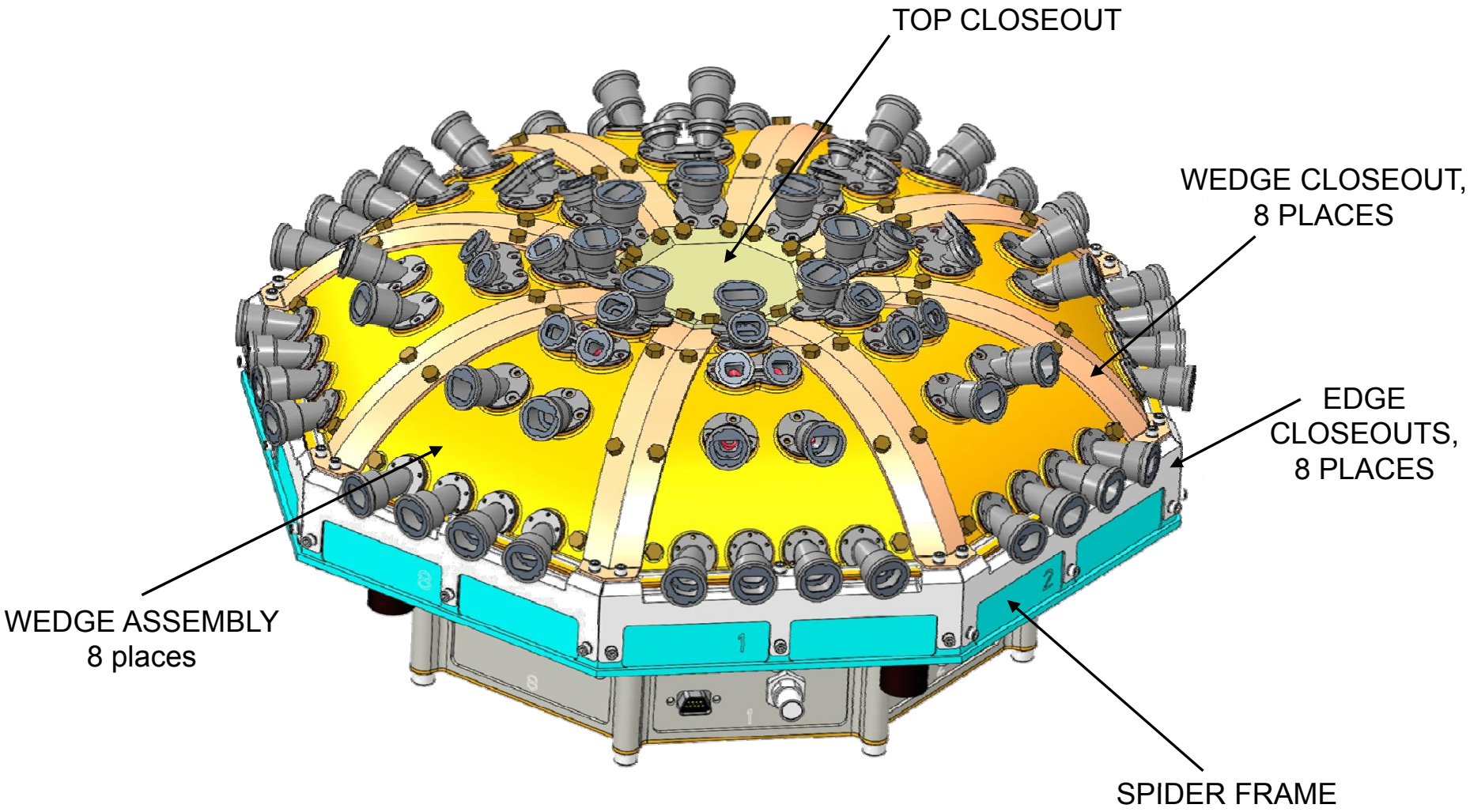
- Summary of mechanical design requirements
- Overview of mechanical design
- Detailed description of the instrument mechanical design
  - Wedge Assembly
  - MCP Assembly
  - SSD Assembly
- Assembly process
- Mechanical development status
- Summary of analyses
- Summary of Peer Review results

Mechanical Design Requirements

- 7434-9039, SPP Environmental Design and Test Requirements Document
  - Subsystem to have min frequency >80 Hz
  - PWAs to have min frequency >150 Hz
  - Quasi-static load factor: 40 g (Figure 4-11 & Table 4-19)
  - Factors of safety: Table 4-5, Unpressurized Factors of Safety
  - Random vibration levels: Table 4-8 and Table 4-9

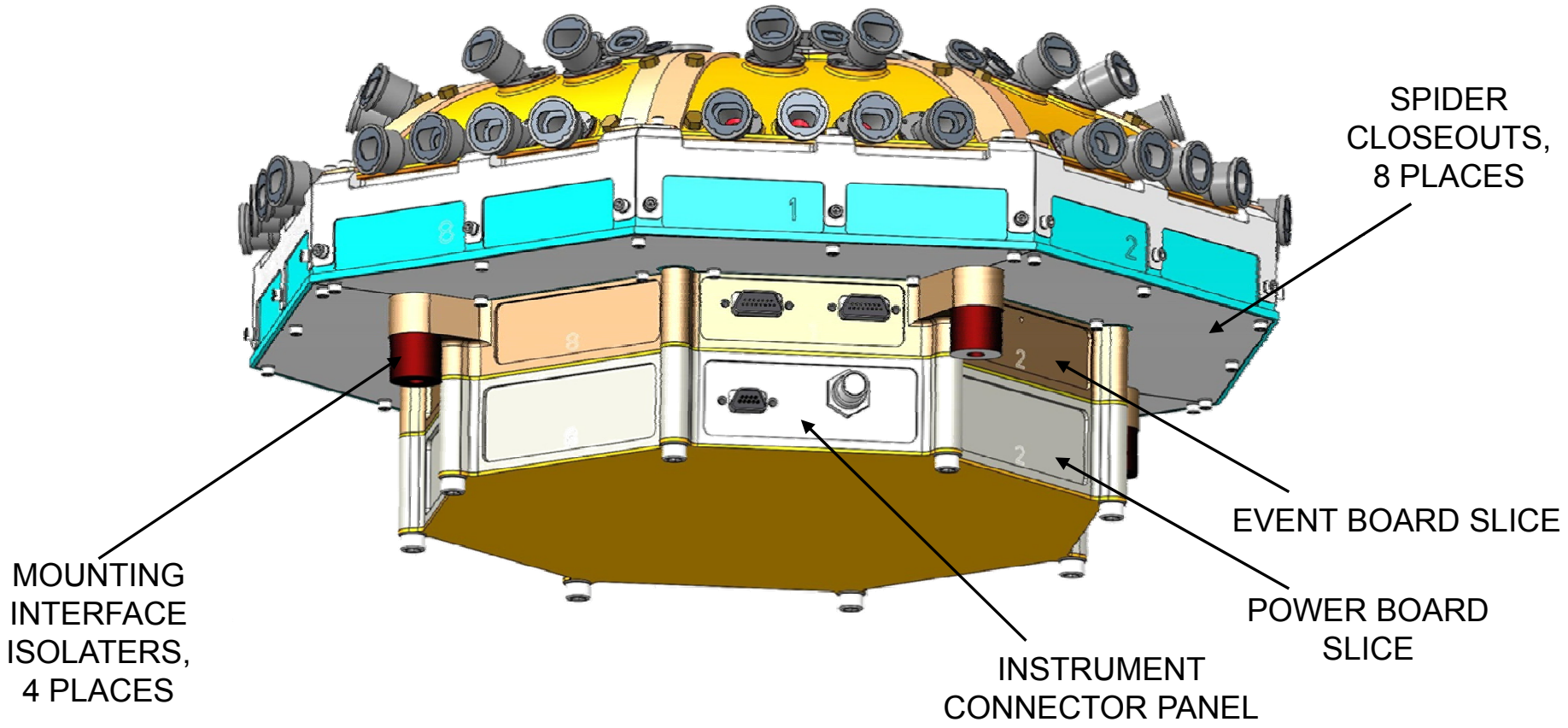
- 7464-0008 EPI-Lo-S/C Mechanical ICD
  - Generated by EPI-Lo to document placement and orientation of instrument on spacecraft

Instrument Overview (1/2)



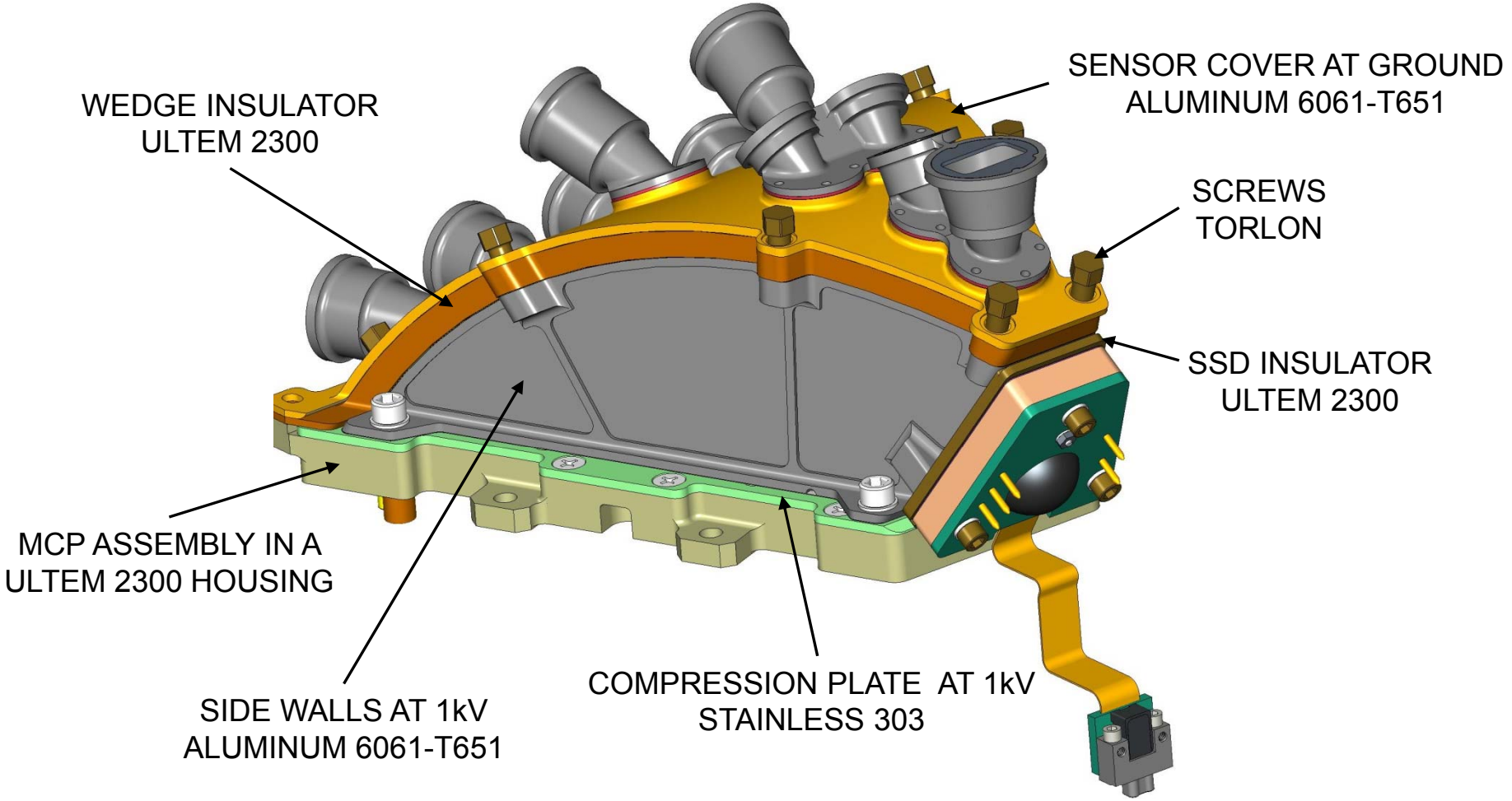
EPI-Lo Instrument Isometric View

Instrument Overview (2/2)



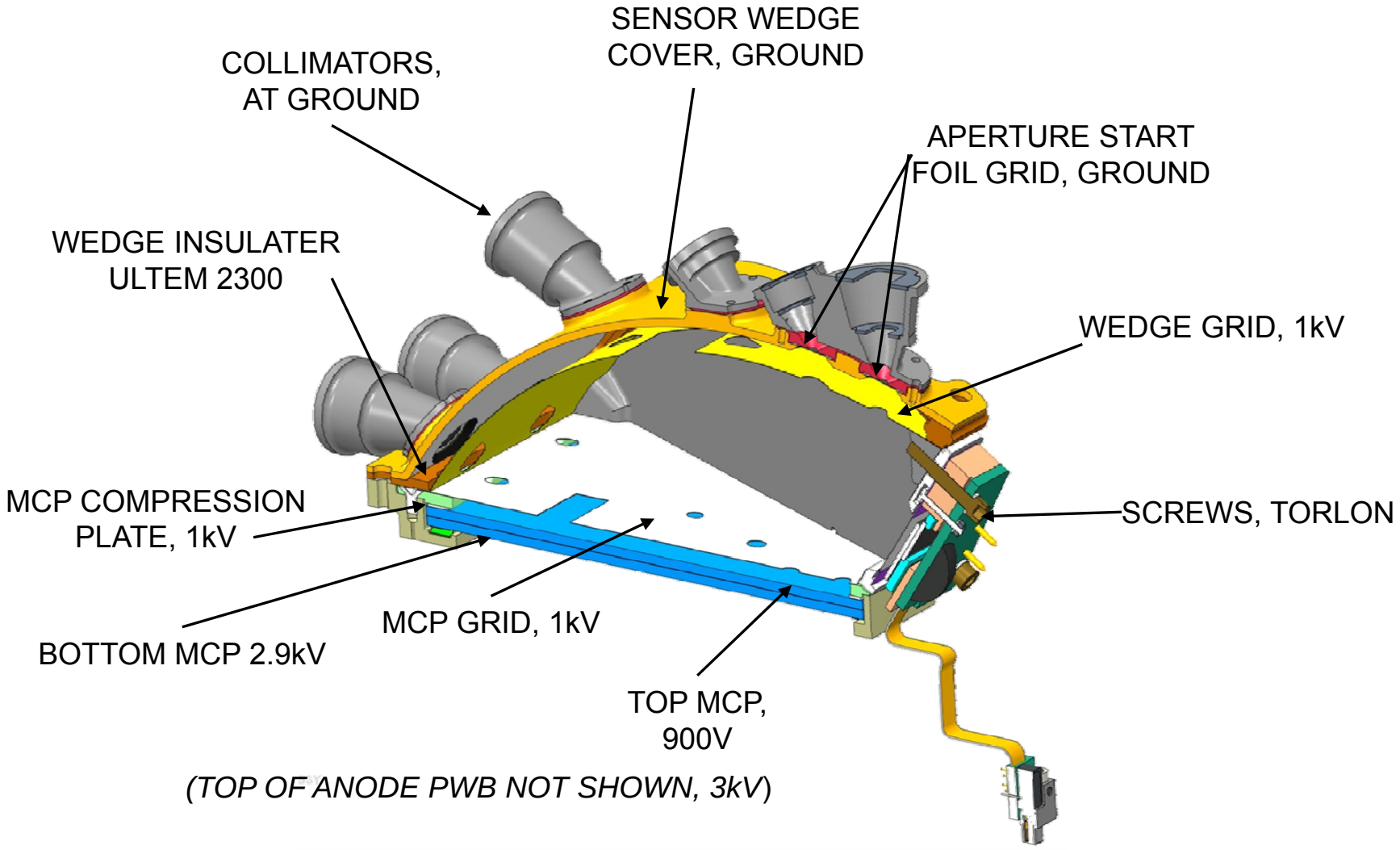
EPI-Lo Instrument Side Isometric View

Wedge Design (1/2)



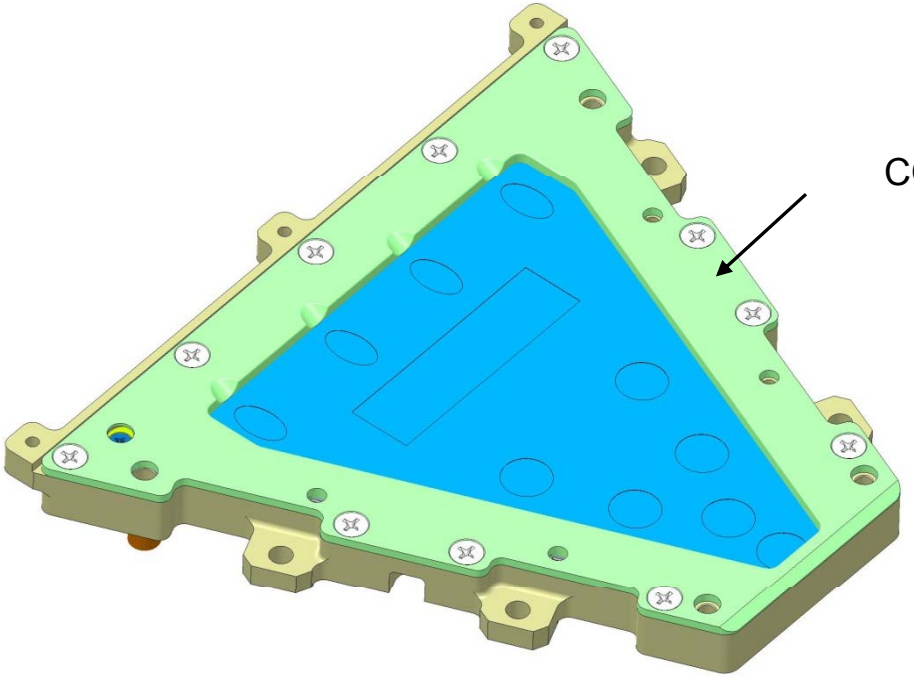
EPI-Lo Sensor Wedge Assembly

Wedge Design (2/2)



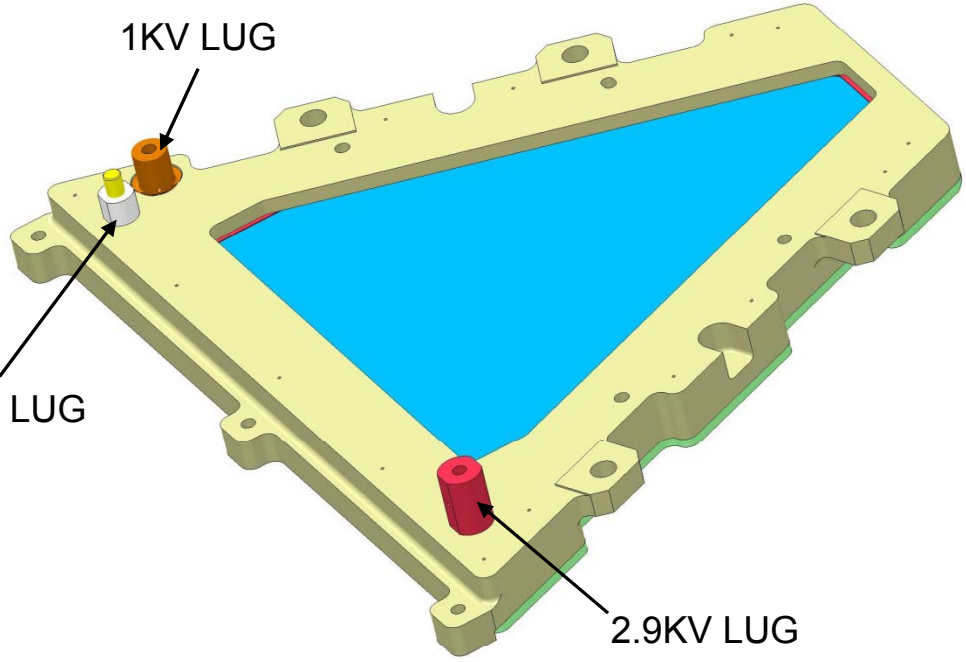
EPI-Lo Sensor Wedge Assembly Cross-Section View

MCP Assembly Design



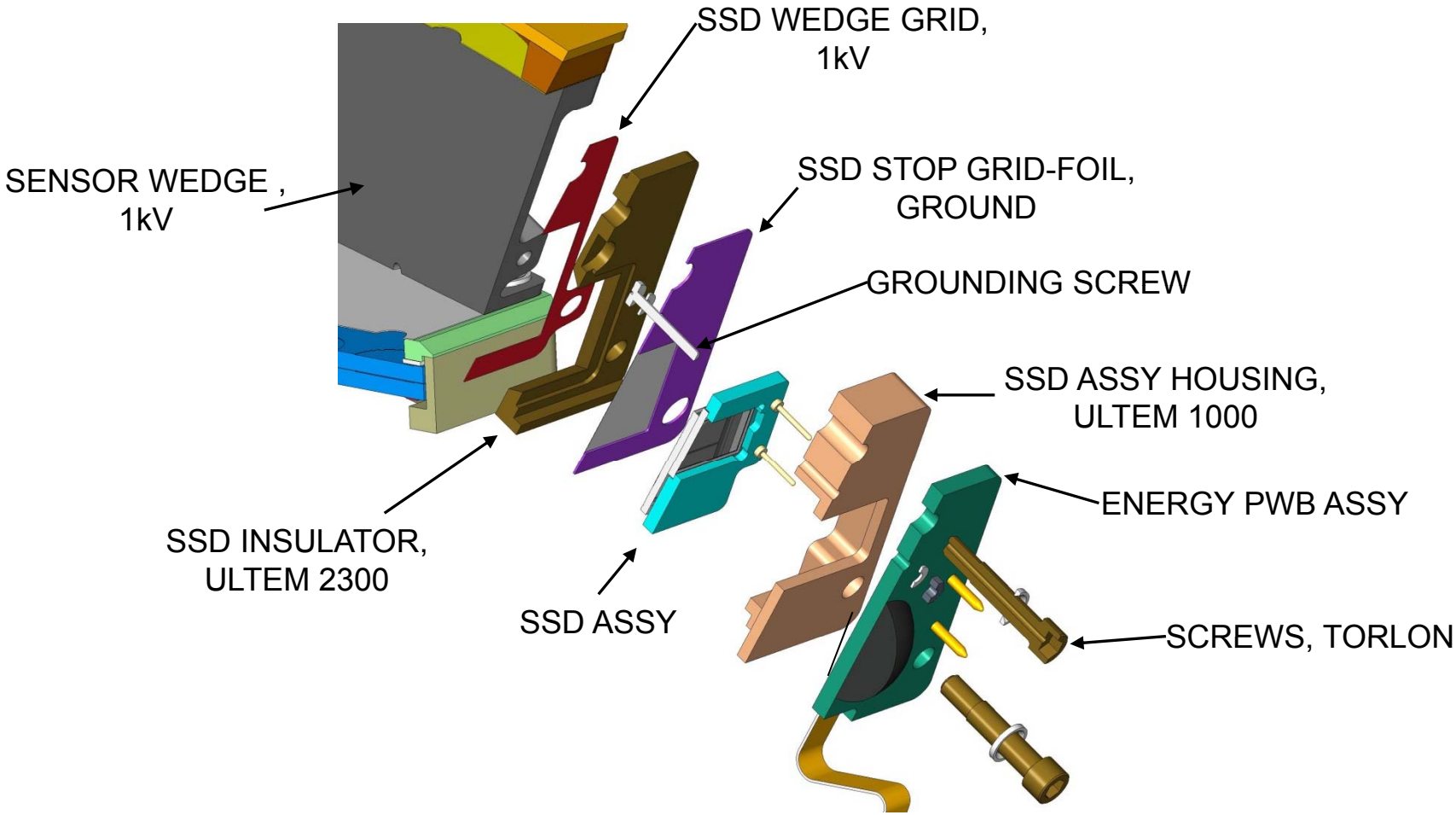
TOP VIEW

BOTTOM VIEW



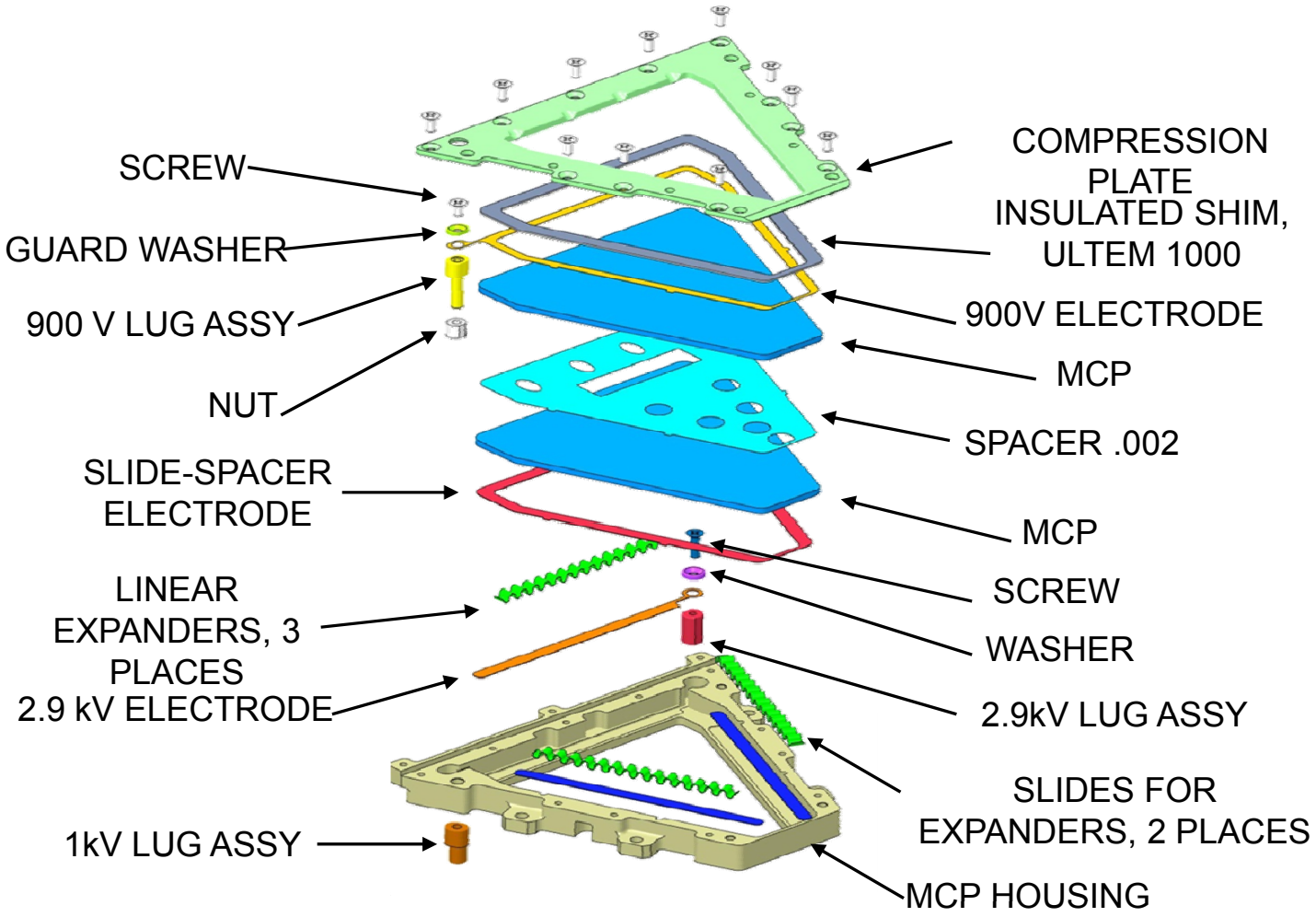
MCP Assembly

SSD Assembly Design



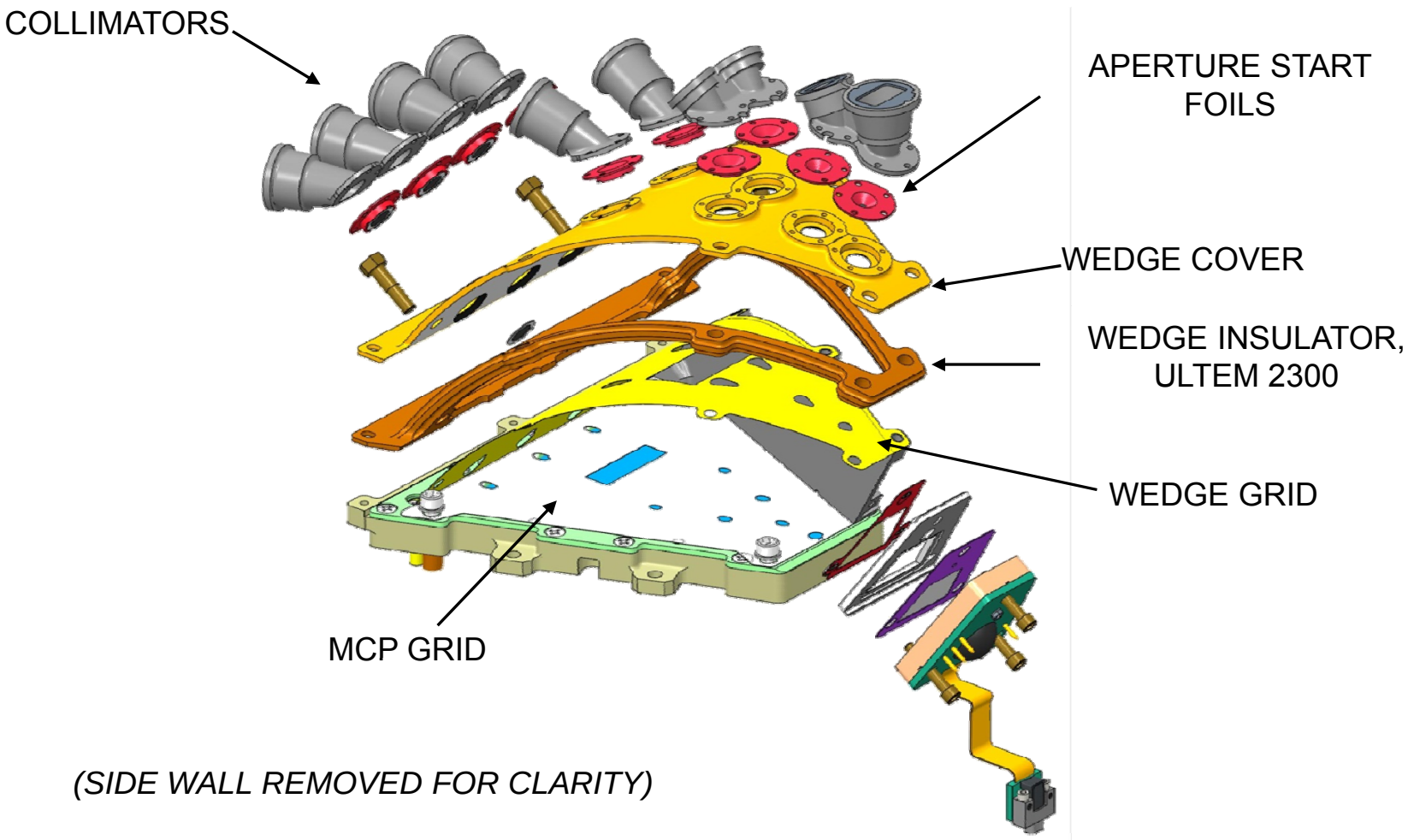
SSD Assembly Exploded Cross-Section View

MCP Assembly Process



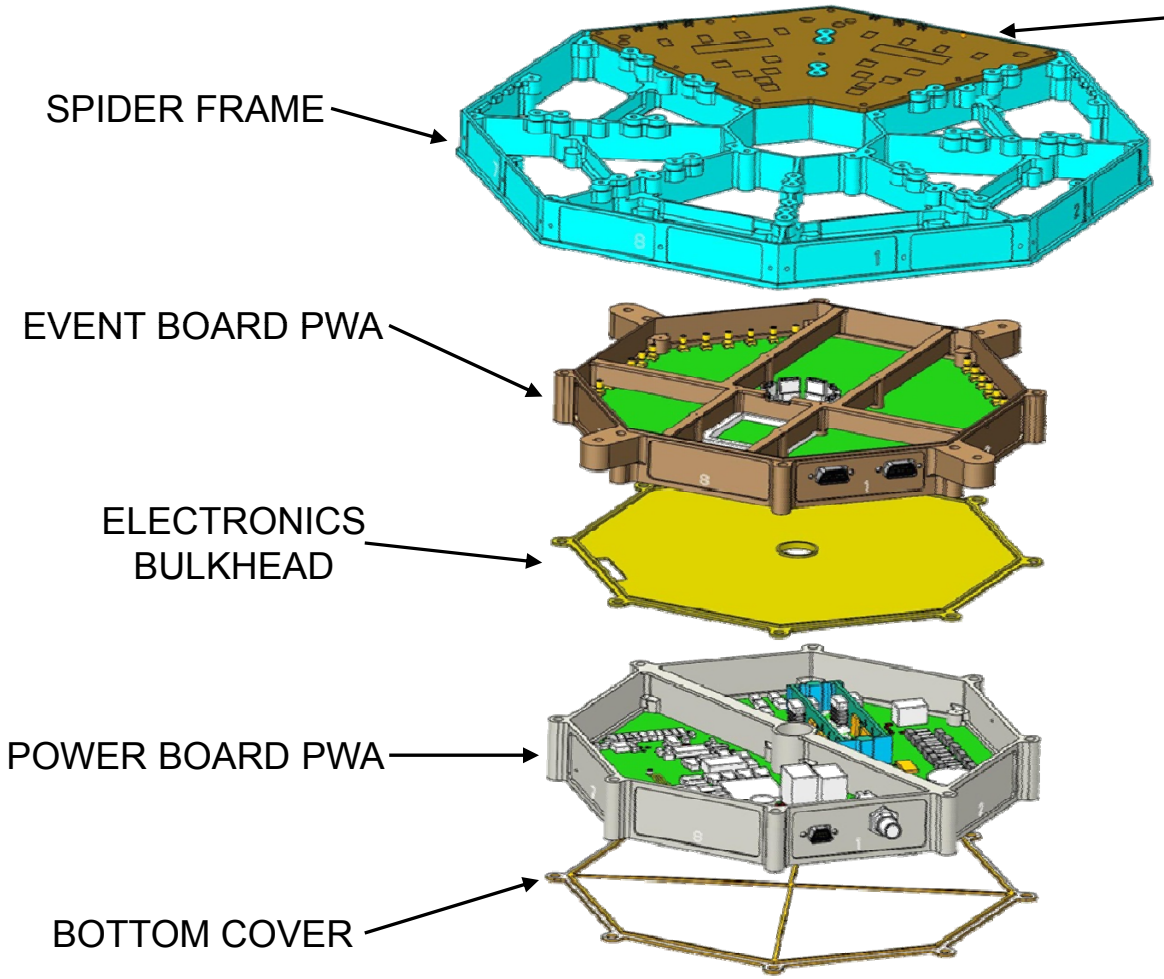
MCP Assembly Exploded View

Wedge Assembly Process



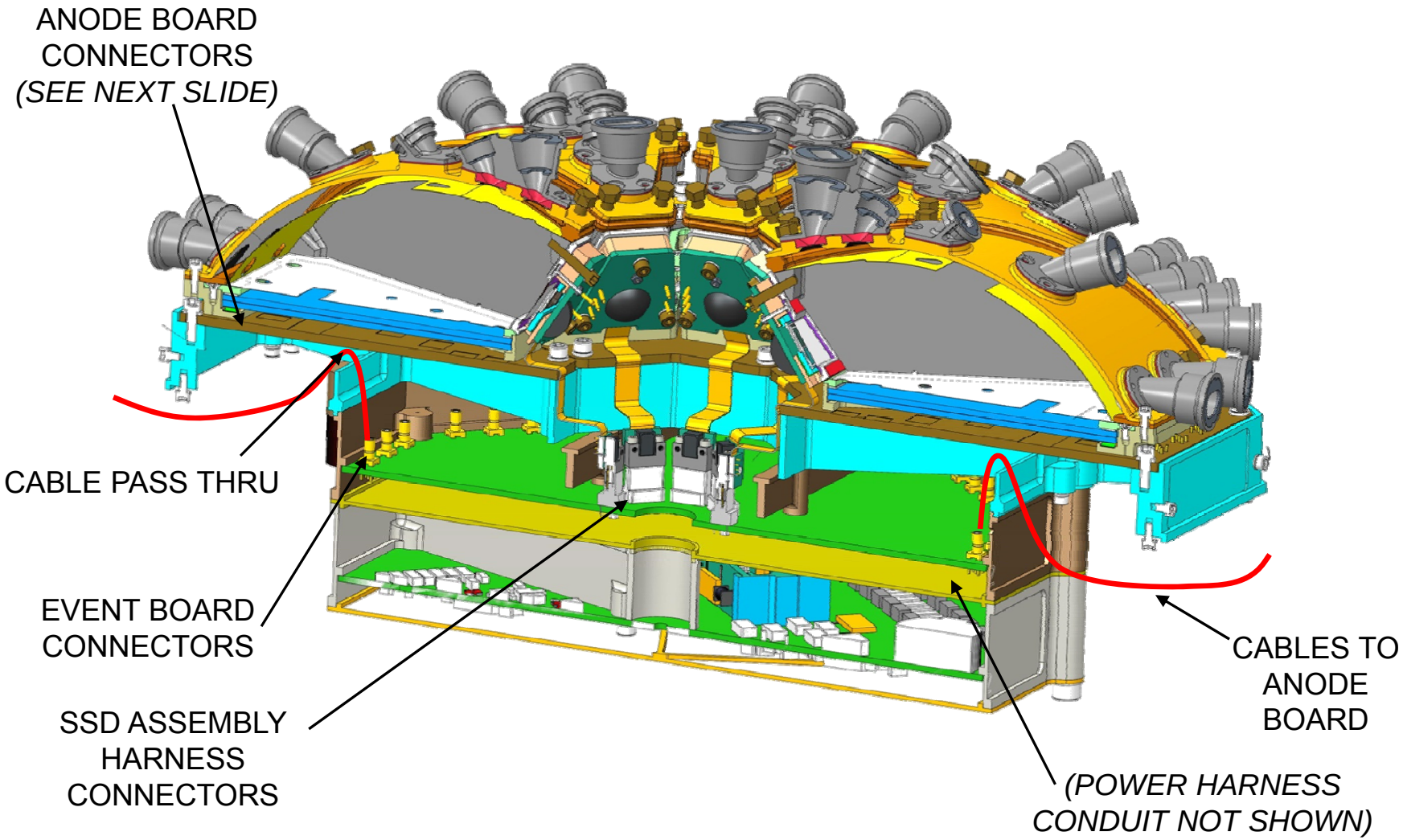
EPI-Lo Sensor Wedge Assembly Exploded View

Spider and Electronics Integration



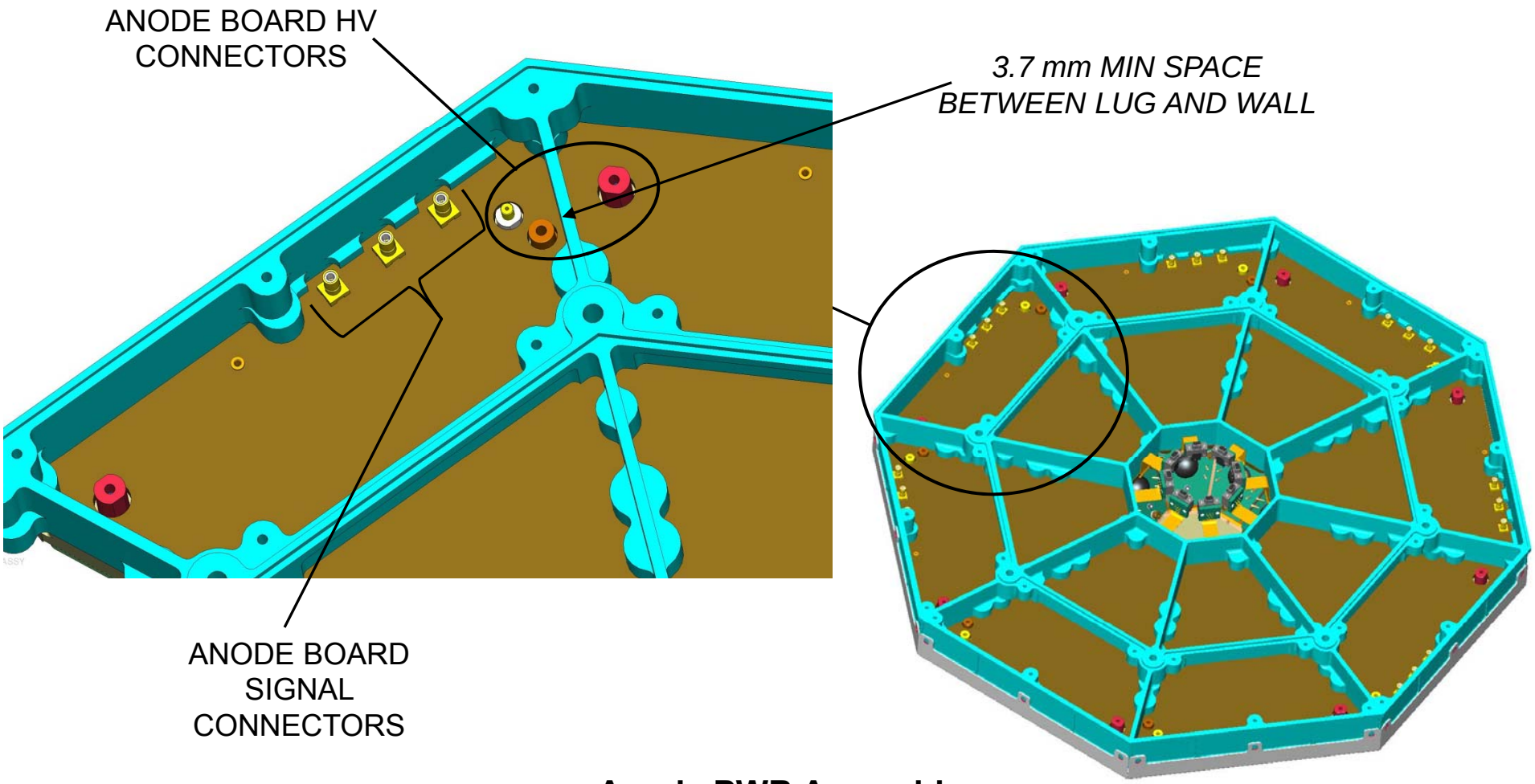
EPI-Lo Electronics Frames Exploded View

Wedge Integration and Cable Routing



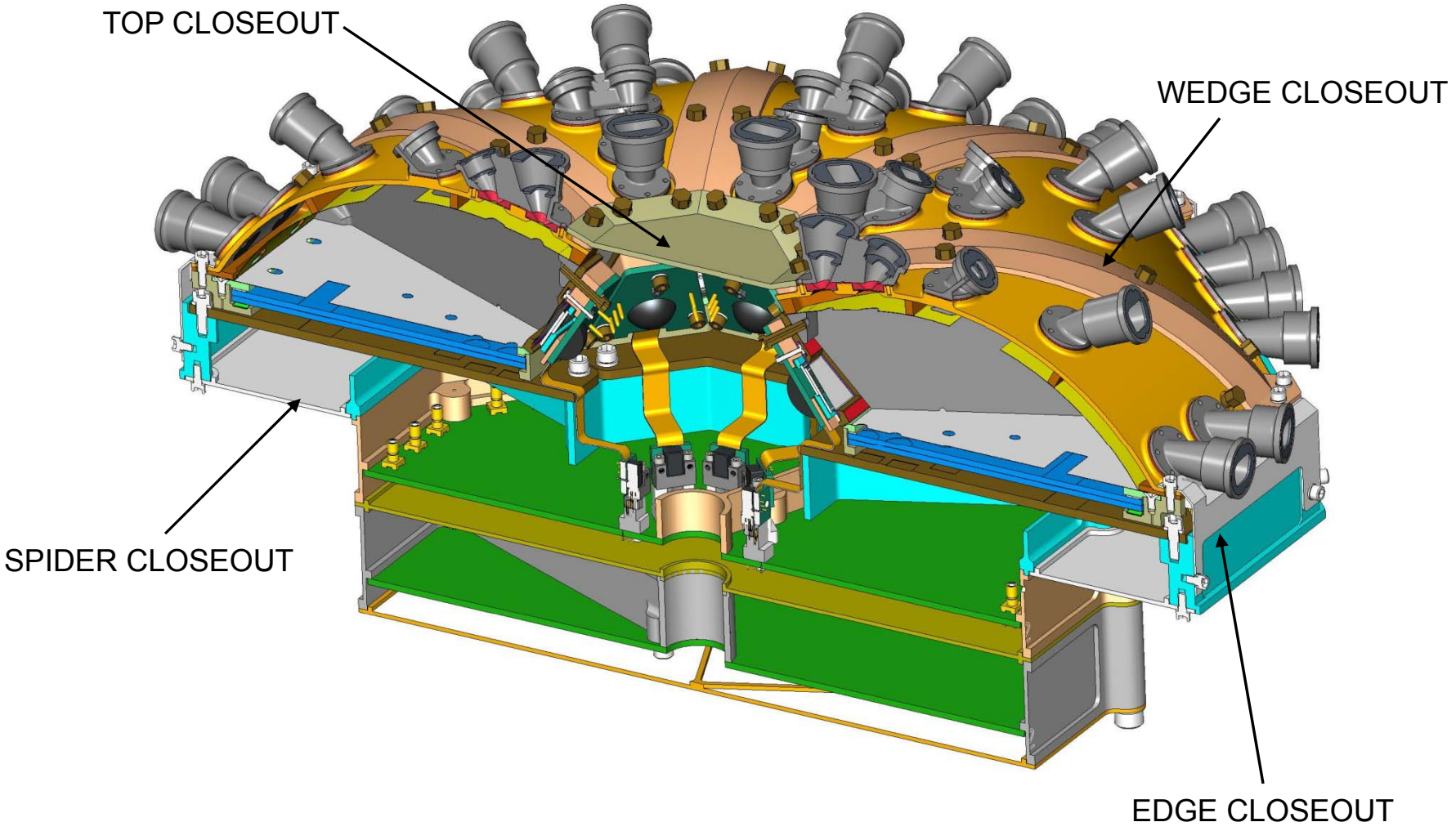
EPI-Lo Cross-Section Isometric View

Cable Connections



Anode PWB Assembly,
Bottom Side Shown
Mounted To Spider Frame

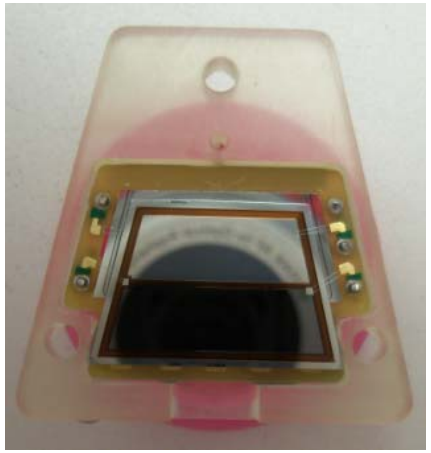
Instrument Closeout Installation

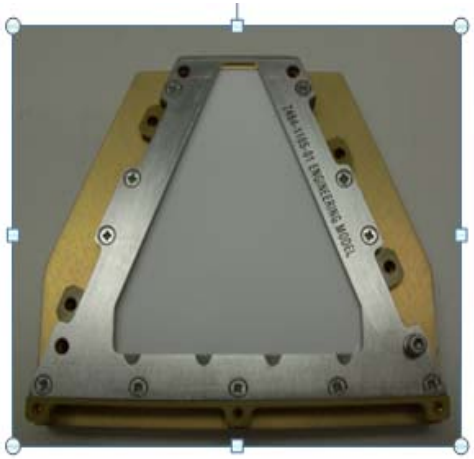


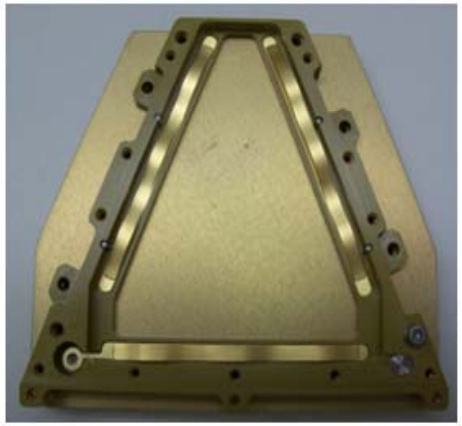
EPI-Lo Cross-Section Isometric View

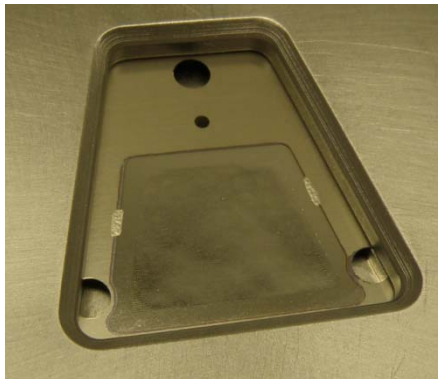
Development Status

- Prototype sensor fully assembled and tested
- EM sensor
  - EM MCPs in house
  - EM SSDs in house and mounted to carrier
  - MCP holder with all electrodes assembled and tested at HV with ceramic plates
  - All EM grids and foils procured and in-house
  - Upper sensor parts in fabrication
    - Side walls, top cover, collimators









Mechanical – Path Forward

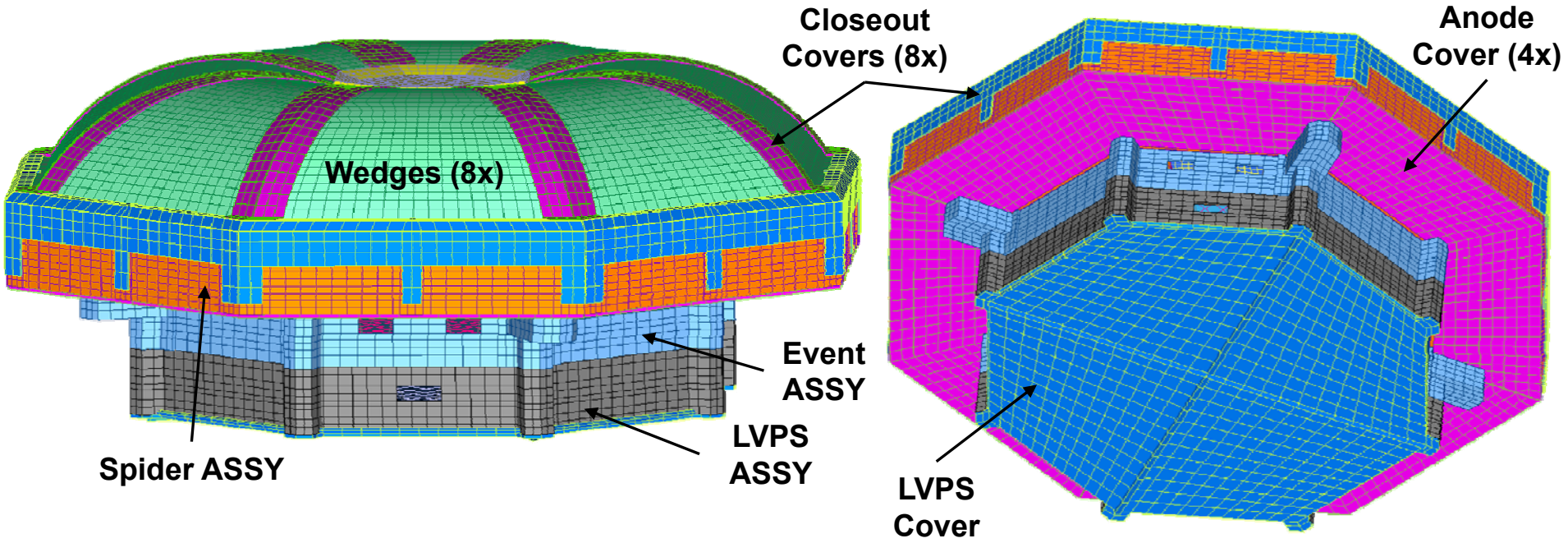
- Sensor EM testing
  - Test MCP assembly with MCPs and EM anode board
  - Assemble upper sensor parts
  - Test sensor wedge
    - Start and stop secondary electron locations
    - Timing performance
  - Integrate SSD to sensor wedge
  - Full performance testing with source and in APL accelerator
- Instrument-level EM testing
  - Fabricate chassis and e-box frames
  - Vibration testing with bracket, EPI-Hi mass model, two sensor wedges and other wedges as mass models
  - Acoustics testing with bracket, EPI-Hi mass model, two sensor wedges and other wedges as mass models
  - Thermal testing (simplified model representing outer surface)

Preliminary Analysis Results

- SPP EPI-Lo instrument analyzed
  - Created from EPI-Lo CAD model as of 6/19/2013 SPP configuration
  - Instrument orientation to S/C panel taken from ISIS bracket CAD model: 4/19/2013
  - Instrument mass estimated at 2.99 kg (6.58 lbm)
- Structural model analyzed based on 7434-9039 SPP EDTRD requirements
  - Modal frequencies of assembly
  - Quasi-static design limit load per EDTRD Section 4.4.2.1 and 4.4.7.1
  - Random vibration analysis per EDTRD Section 4.4.3
    - Grms acceleration response for various components of the assembly
    - Peak 3-σ stress and displacement results

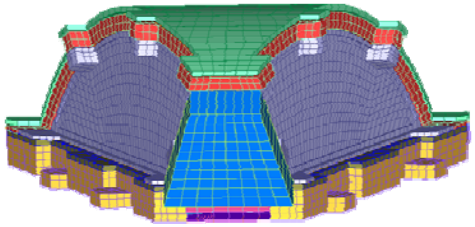
FEM Overview - Instrument Level

- Modeling Strategy
  - Plate elements where applicable: PWAs, frames, covers
  - Solid elements where necessary: frame bosses, bookbolt bosses, small aspect ratios
  - Beam elements: chassis ribs, LVPS bottom cover ribs
  - PWA: EEE part mass smeared over total board area
  - Rigid elements (RBE2s): bookbolts, mounting hardware, Connectors
- Model size: nodes = 89,077, elements = 70,645

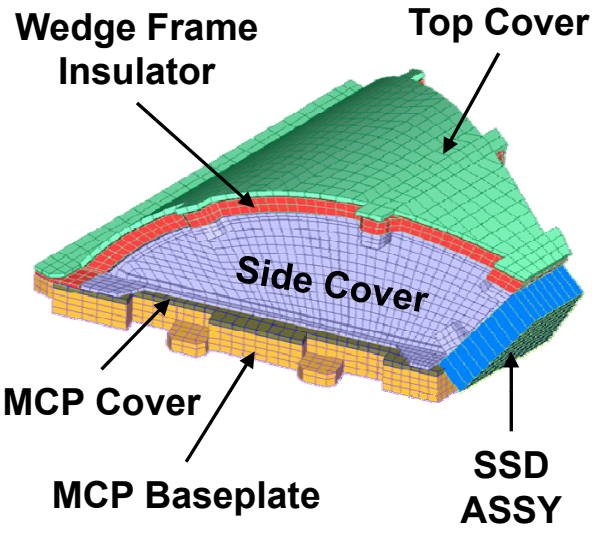


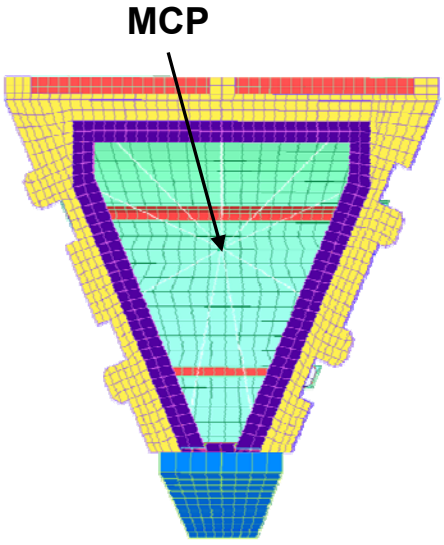
FEM Overview - Wedge Assembly

- EPI-Lo has 8 identical wedges
- Top cover: plate elements, Al-6061 properties & collimator mass smear
- Wedge Frame Insulator: plate and solid elements, Ultem1000 material properties
- Side cover: beam, plate and solid elements, Al-6061 material properties
- MCP Cover: plate elements, SS 304 properties
- MCP: mass element & RBE3 to MCP cover and baseplate
- MCP Baseplate: plate and solid elements, Ultem100 material properties
- SSD Assembly: plate elements, Ultem100 material properties
- Wedge assembly connected using RBE2s at all bolted interfaces

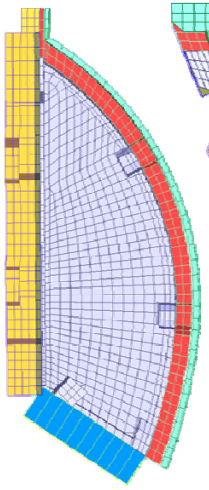


Front View

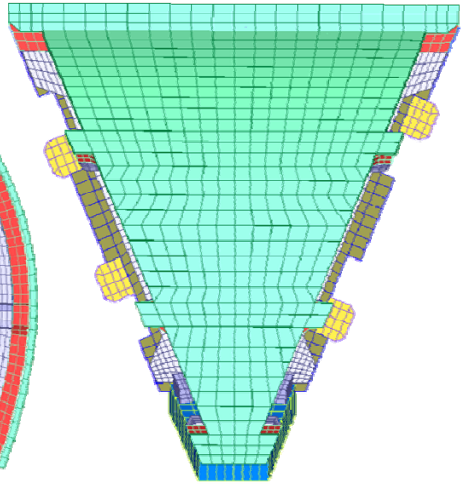




Bottom View



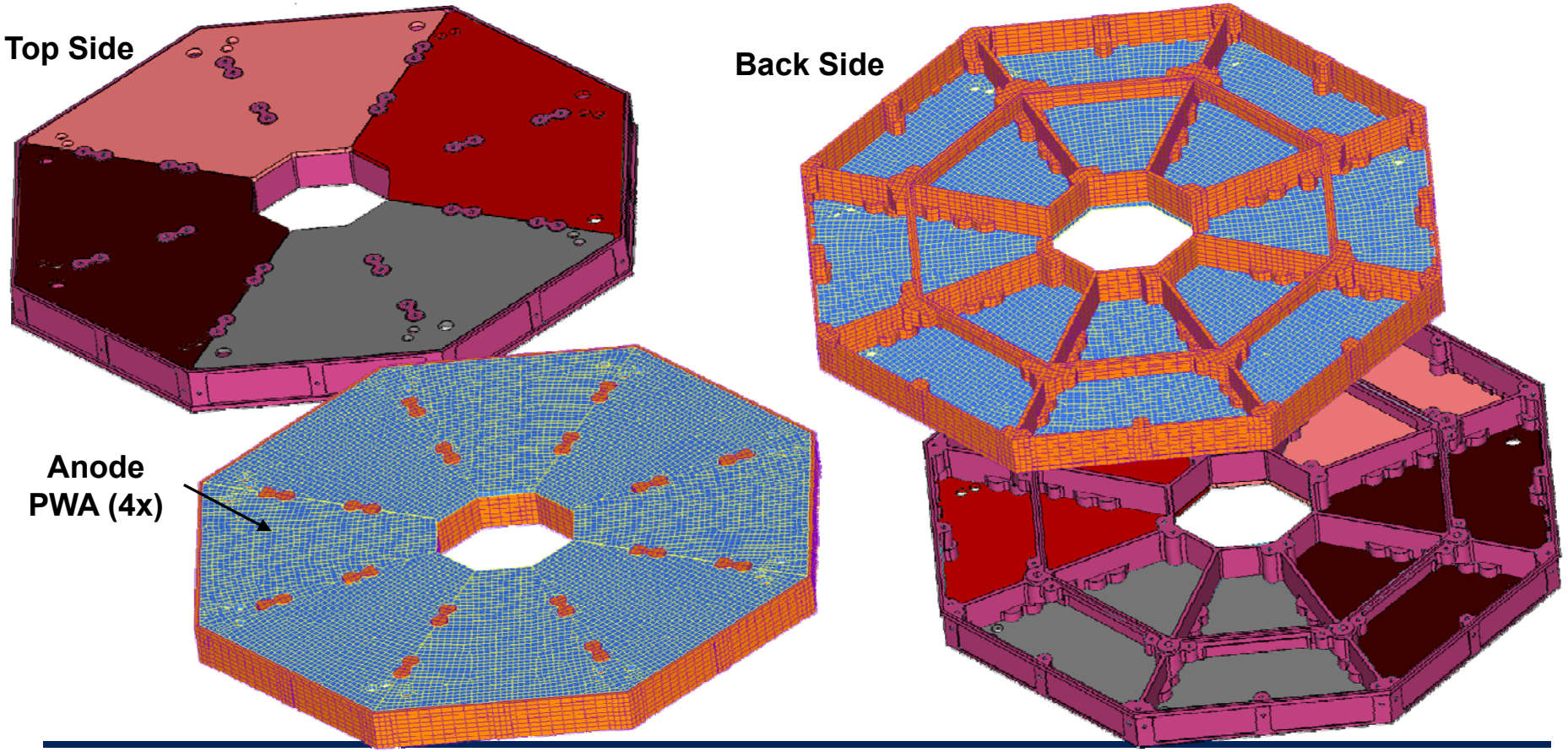
Side View



Top View

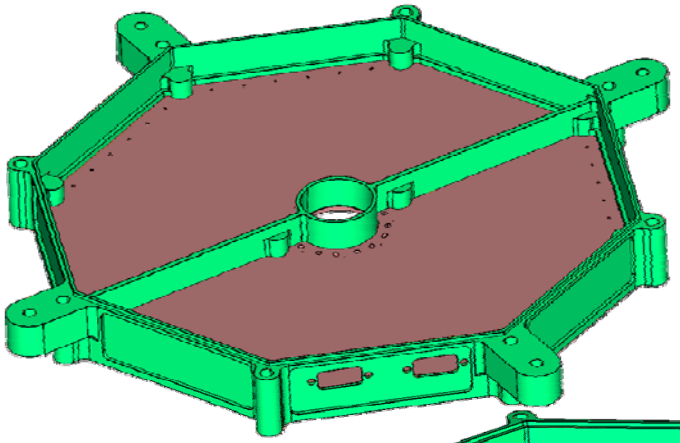
FEM Overview - Spider & Anode PWAs

- Spider frame modeled in detail using plate and solid elements with Al 6061 material properties
- Anode PWAs (4x) modeled using plate elements and PWA material properties with estimated board mass smeared across PWA
- PWAs connected to Spider frame at mounting hardware bosses using RBE2 elements

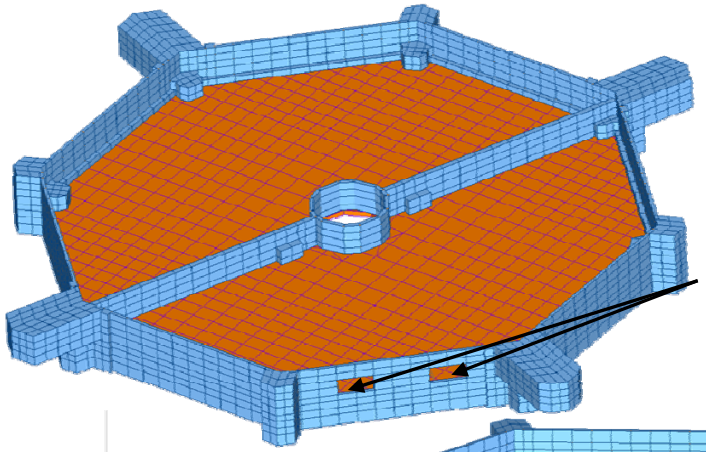


FEM Overview - Event Slice Assembly

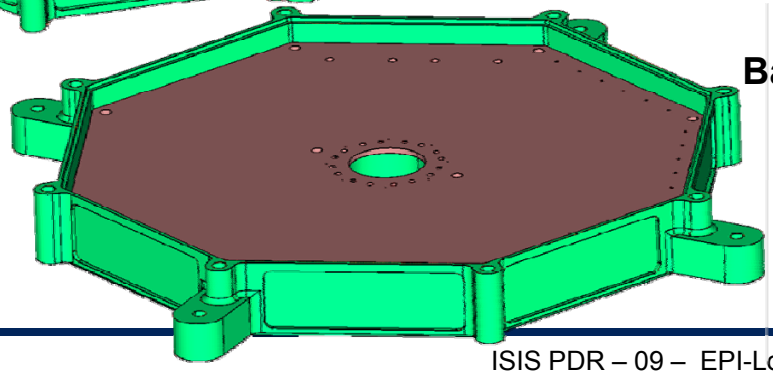
- Event housing: plate and solid elements, Al 6061 material properties
- Event housing thickness .040” at minimum, thicker at bosses
- Event PWA: plate elements, PWA material properties and EEE part mass smeared across board
- PWA: diameter = 7.0”, thickness = 0.093”
- Right-angle MDM connectors modeled with RBE2s from frame to board
- PWA connected to housing with RBE2s at mounting bosses



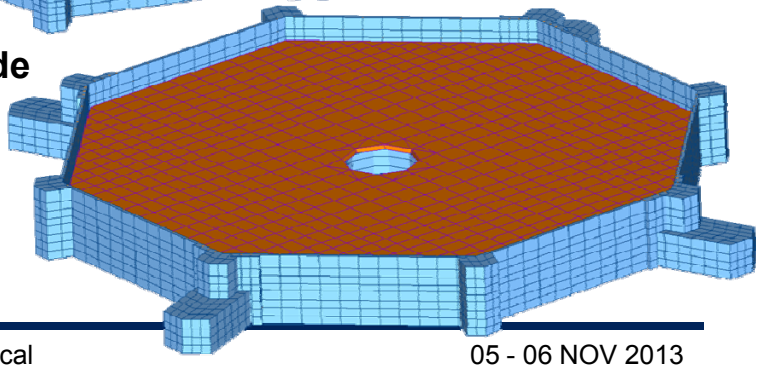
Top Side



MDM Connectors

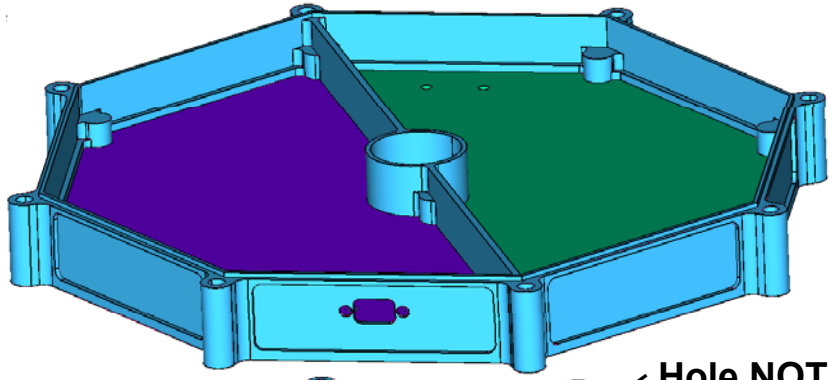


Back Side

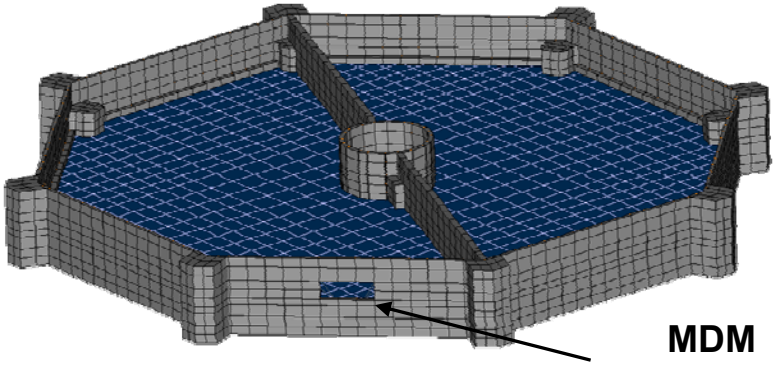


FEM Overview - LVPS Slice Assembly

- LVPS housing: plate and solid elements, Al 6061 material properties
- LVPS housing thickness .040” at minimum, thicker at bosses
- LVPS PWA: plate elements, PWA material properties and EEE part mass smeared across board
- PWA: diameter = 7.0”, thickness = 0.093”
- Right-angle MDM connector modeled with RBE2 from frame to board
- PWA connected to housing with RBE2s at mounting bosses
- CAD PWA model does not capture flight design, FEM representative of flight config.

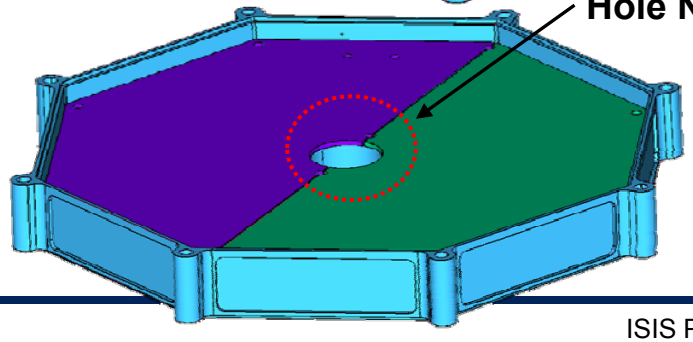


Top Side

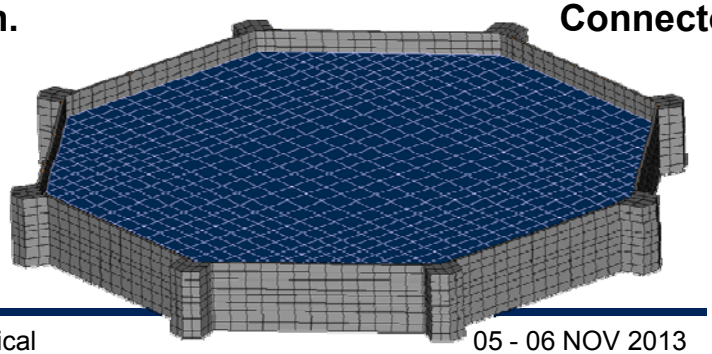


MDM Connector

Hole NOT in flight design.

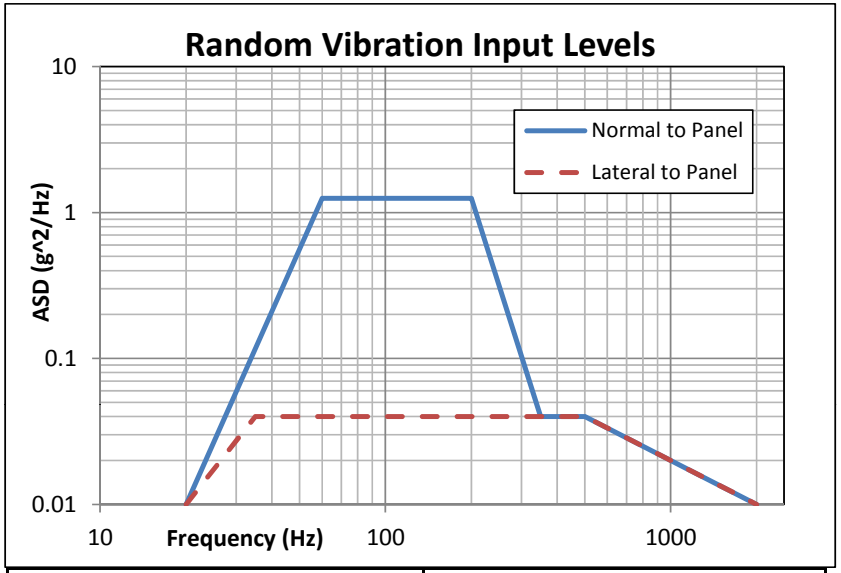


Back Side



Forced Response Analysis

- All relevant structural environmental inputs per 7434-9039 SPP EDTRD
- Assume critical damping = 2.5% across full frequency range
- Sine sweep spec per Section 4.4.4 is TBD, therefore not analyzed
- Random vibration levels per Section 4.4.3
  - Table 4-8, Side panel mounted components & subsystems parallel to panel
  - Table 4-9, Side panel mounted components & subsystems lateral to panel
- Items of interest for random response analysis:
  - Grms acceleration response of instrument and PWAs
  - Peak 3-σ displacement response
  - Peak 3-σ stress & margins of safety
- Random vibration analysis results envelope Static 40 g load (per Section 4.4.2.1)
- 40 g static load results not presented in this analysis

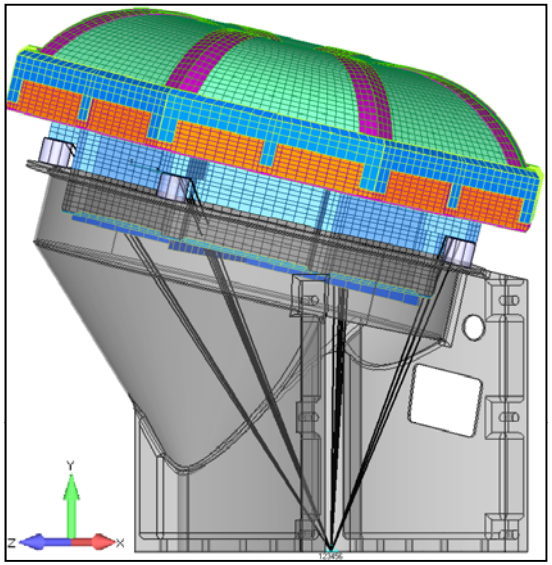


Normal to Panel		Parallel to Panel	
Freq (Hz)	ASD Level (g^2/Hz)	Freq (Hz)	ASD Level (g^2/Hz)
20	0.01	20	0.01
60	1.25	35	0.04
200	1.25	500	0.04
350	0.04	2000	0.01
500	0.04		
2000	0.01		
Overall Amplitude: 16.4 grms		Overall Amplitude: 6.8 grms	

Forced Response Analysis
Random Vibration Grms Results

Solar Probe Plus
A NASA Mission to Touch the Sun

- Random vibration inputs simulated at B.C. node
  - B.C. node "spidered" to nodes at instrument mounting interface to ISIS bracket
  - ISIS bracket and G-10 standoffs NOT part of EPI-Lo FEM, assume instrument "hard-mounted"
  - Inputs simulated one axis at a time for all three orthogonal axes
- Acceleration spectral density (ASD) response for various nodes
  - Nodes represent worst case response per subassembly
  - Across full range (20-2,000 Hz) of interest
- Due to EPI-Lo's mounting configuration in relation to the input load, there are significant cross-axes responses



Y-axis Input 3-σ grms Response

ID	X-Axis	Y-axis	Z-Axis
Input	0.0	16.4	0.0
C.G.	7.8	67.9	8.1
Event PWA	**31.2**	**193.0**	**30.1**
LVPS PWA	26.4	158.1	25.1
LVPS Cover	26.9	153.5	26.2
Top Cover	16.0	112.1	17.0
Anode PWA	9.4	76.5	10.2
Anode Cover	12.2	92.3	12.8
Spider Frame	5.5	66.1	9.5

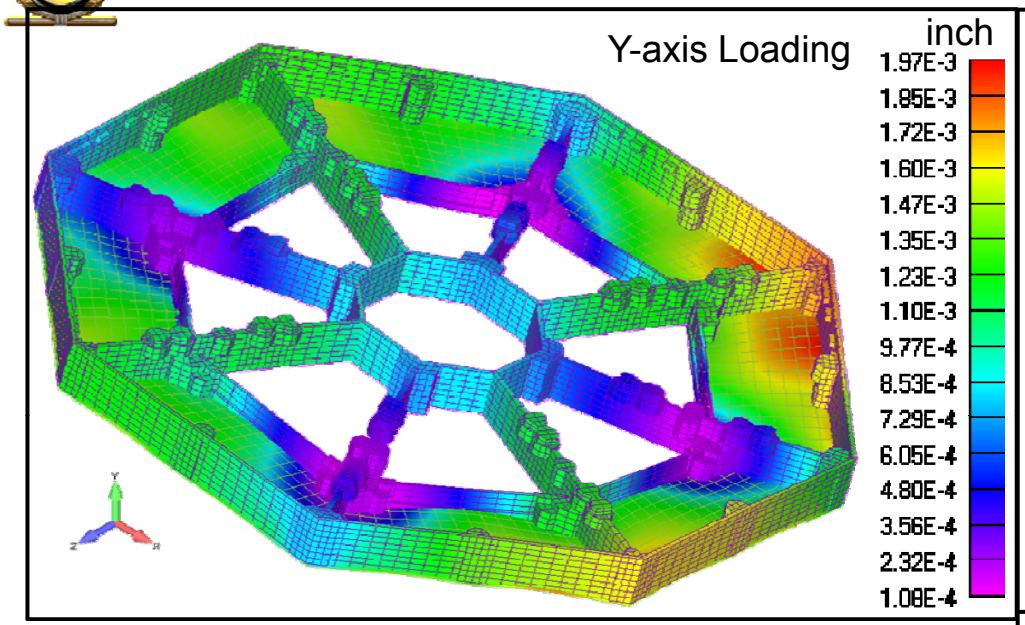
X-axis Input 3-σ grms Response

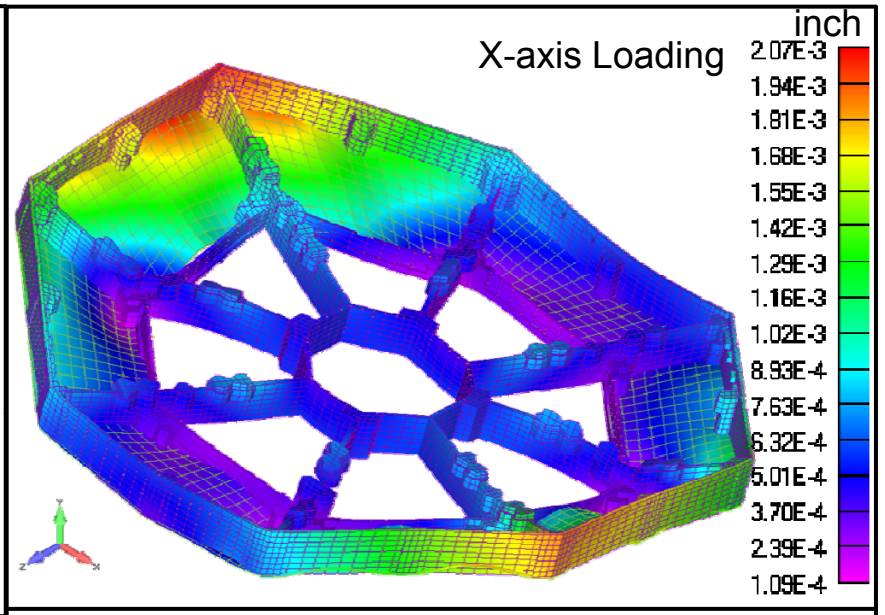
ID	X-Axis	Y-axis	Z-Axis
Input	6.8	0.0	0.0
C.G.	30.9	7.8	3.4
Event PWA	26.2	41.4	8.0
LVPS PWA	**48.9**	**97.9**	**27.4**
LVPS Cover	45.7	30.5	14.8
Top Cover	58.0	16.3	5.6
Anode PWA	30.8	61.5	10.3
Anode Cover	35.7	161.1	27.0
Spider Frame	29.9	64.0	12.1

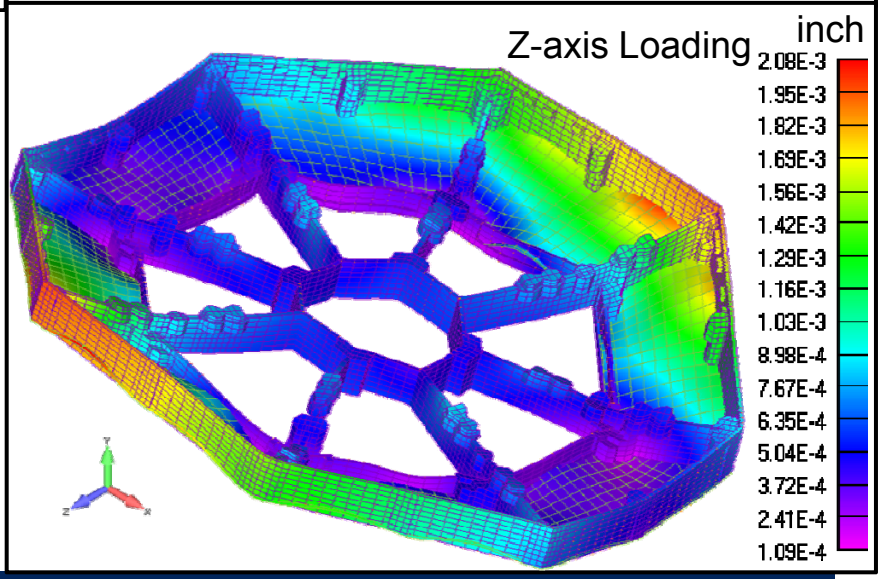
Z-axis Input 3-σ grms Response

ID	X-Axis	Y-axis	Z-Axis
Input	0.0	0.0	6.8
C.G.	3.4	8.2	31.3
Event PWA	13.6	64.7	29.4
LVPS PWA	**24.1**	**71.9**	**46.5**
LVPS Cover	14.2	27.7	50.9
Top Cover	5.6	17.0	57.9
Anode PWA	11.8	65.4	33.9
Anode Cover	13.1	67.3	26.8
Spider Frame	8.7	28.1	31.4

Forced Response Analysis
Random Vibration Results: Displacement







- Spider frame and Anode cover total displacement results for the 3 individual loading conditions
- Max displacement ~2 mil for all 3 loading conditions
- Spider frame rigid out-of-plane due to hexagonal rib design
- Anode covers stiff due to 9 mounting holes, all corners and mid-span

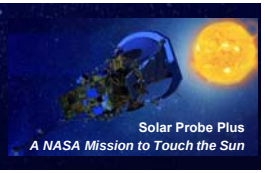
Forced Response Analysis
Random Vibration Results: von Mises Stress

- Model analyzed for von Mises stress under random vibration loading using MAYA structural analysis toolkit
- 3-σ stress results output for complete model
- Interested mainly in PWA and Frame stress
- Fastener analysis not done at this time
- Factors of safety (FoS) taken from 7434-9039 SPP EDTRD Rev E, Table 4-5.
  - Additional 1.28 factor for random analysis per Section 4.4.2.2
  - Metallic structures: FoSu = 2.68, FoSy = 2.53
  - Composite (PWA + Ultem1000): FoSu = 2.78, FoSy = N/A
- Margins of safety (MoS) calculations performed,
  - MoS formula -> $MoS = \frac{Strength}{FoS * \sigma} - 1$
- All margin of safety results are positive for the current design iteration

Analysis Summary

- Preliminary structural analysis of the baseline SPP EPI-Lo Instrument performed
- MSC.Nastran, MAYA SATK, and Femap used for analysis
  - Model simplified wherever possible to aid solution time
  - PWAs modeled as plate elements with uniform stiffness, thickness and density
  - Instrument model oriented to ISIS bracket configuration in relation to S/C panel
- Modal analysis performed, 1st mode = 304 Hz (Event PWA); Instrument mode 1 = 553 Hz
- Analysis environmental input levels per 7434-9039 SPP EDTRD Rev -
  - Analysis performed for all three orthogonal axes relative to S/C panel
  - Sine vibration analysis not performed (TBD in EDTRD)
  - EPI-Lo 3-σ acceleration random response enveloped static load requirement
  - Random vibration analysis 3-σ response desired for EPI-Lo instrument displacements, stresses and forces
- Random vibration PWA displacement response may be relatively high for EEE part solder/lead wire fatigue resistance, further analysis needed after EEE parts placement finalized
- All margin of safety positive for model configuration as of 6/19/13 under EDTRD Rev - inputs
- Detailed analysis needed for the flight configuration to confirm that flight design will have positive margins and meet minimum frequency requirement

Instrument Peer Review



- EPI-Lo Sensor Peer Review
  - Held May 22, 2013 at APL
  - Review yielded 12 action items, all are now closed

- EPI-Lo Instrument Peer Review
  - Held August 19, 2013 at APL
  - Review yielded 8 mechanical action items, all are now closed