FINAL DESIGN OF NEG-COATED ALUMINUM VACUUM CHAMBERS & STAINLESS STEEL KEYHOLE VACUUM CHAMBERS FOR THE APS-U STORAGE RING

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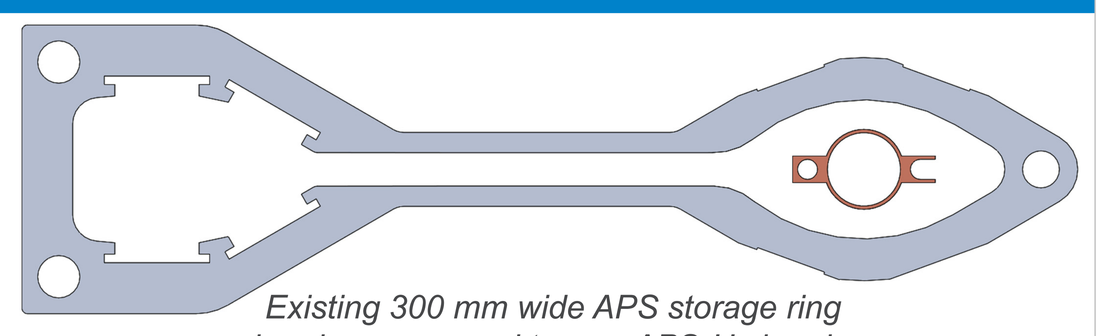
OVERVIEW

Advanced Photon Source Upgrade

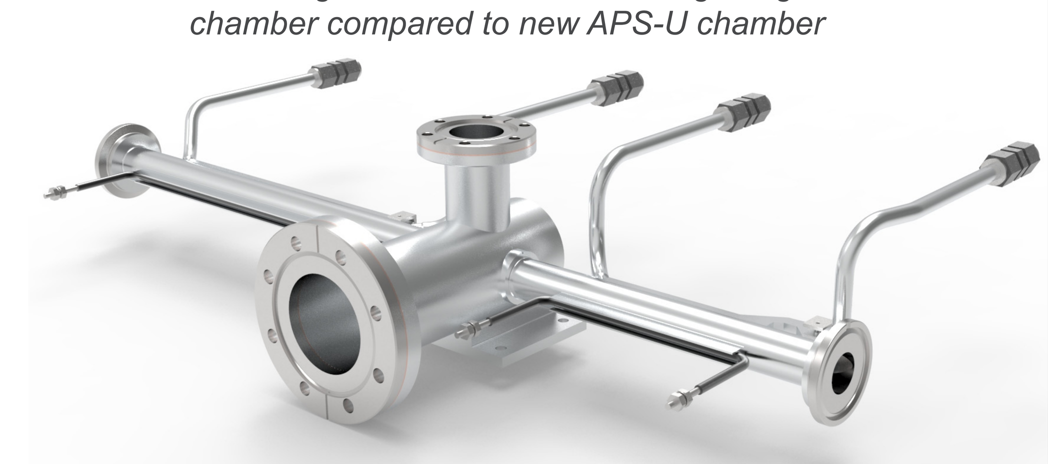
- 6 GeV, 200 mA, 1.1 km circumference, optimized for brightness > 4 keV
- Change in scale from existing APS produced numerous engineering challenges



Existing 300 mm wide APS storage ring chamber compared to new APS-U chamber

Aluminum NEG-Coated Vacuum Chambers

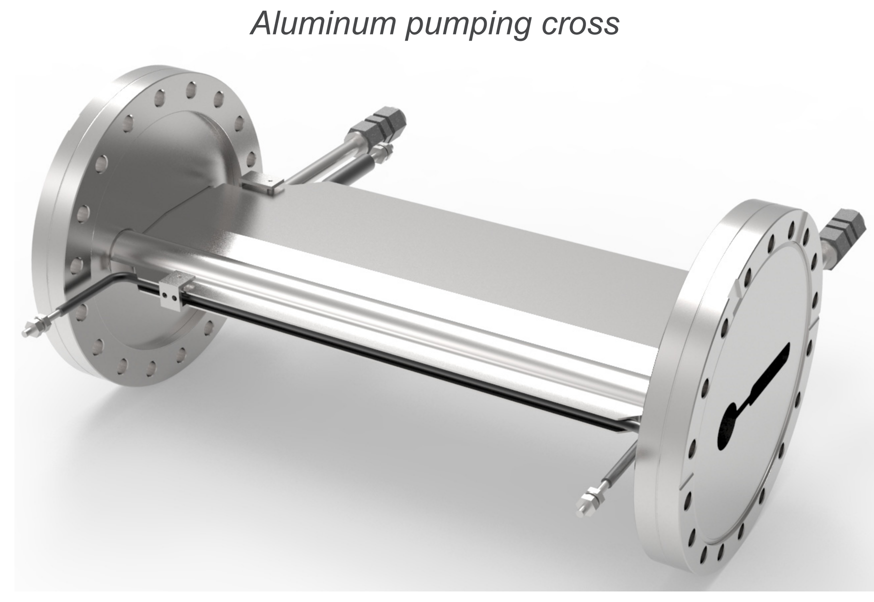
- Selected aluminum for machinability & ability to handle small heat loads
- Non-evaporative getter (NEG) coating for pumping in conductance limited system
- Ø22 mm aperture, vary in length 289 mm – 792 mm
- Five chambers & three crosses per sector (forty sectors)



Aluminum pumping cross

Stainless Steel Keyhole Vacuum Chambers

- 316LN stainless steel for strength & low magnetic permeability
- Internal copper plating
- Ø22 mm aperture with photon extraction antechamber, 300 mm – 350 mm long
- Two chambers per sector

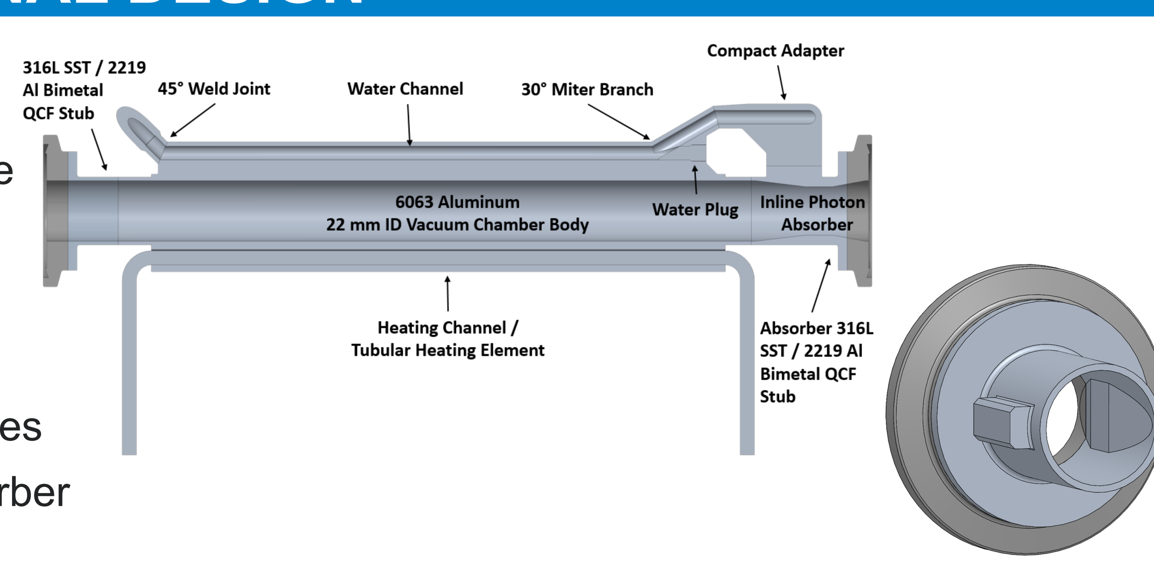


Stainless steel keyhole vacuum chamber

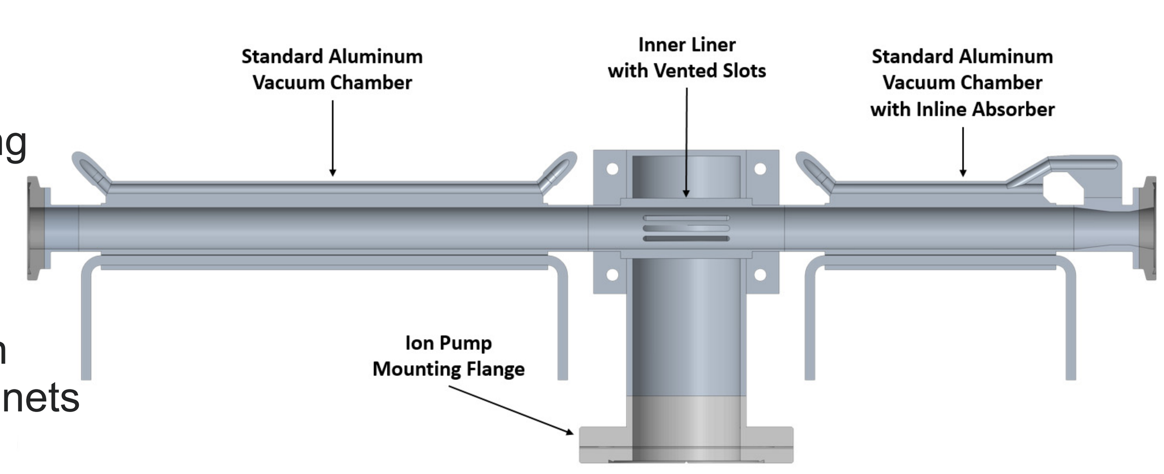
FINAL DESIGN

Aluminum NEG-Coated Vacuum Chambers

- **Challenges**: developed vacuum chamber to intercept synchrotron radiation with adequate cooling & in-situ bakeouts with compact interfaces
- **Prototypes**: built for the storage ring sector mockup; design changes after the prototype phase to address developing design interfaces
- **Synchrotron Radiation:** inline photon absorber machined into downstream flange stub to shadow flange joints & BPMs
- **Cooling**: water channel along the outboard side for heat management with compact welded water tube joints
- **In-Situ Bakeout**: electrical heating rods fitting into inboard channels
- **Space Constraints**:
  - Thin-wall extruded chamber body
  - Quick ConFlat (QCF) flanges utilize chain clamp; minimal axial space between magnets
  - Explosion-bonded bimetal flange stubs (SST/Al)



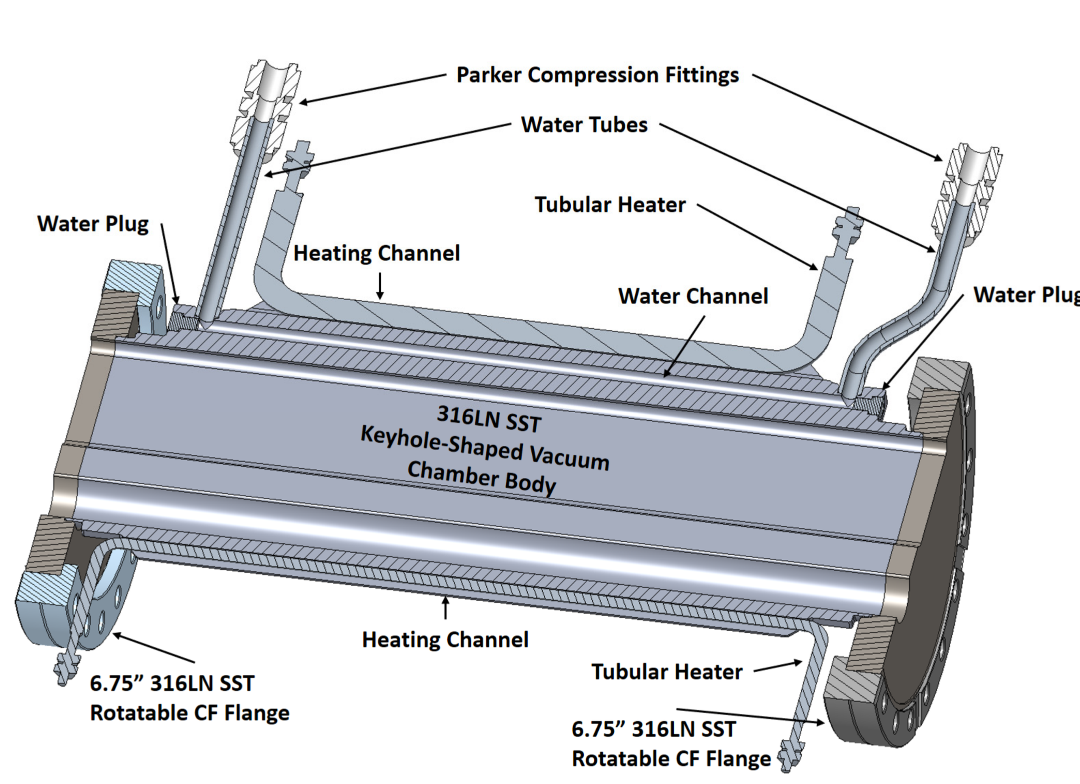
Aluminum chamber cross-sectional overview (left) and bimetal absorber flange stub (right)



Aluminum pumping cross cross-sectional overview

Stainless Steel Keyhole Vacuum Chambers

- **Challenges**: developed vacuum chamber to allow photon extraction, strong cross section to prevent collapse with compact magnet & beam envelope interfaces, in-situ bakeout, passive cooling
- **Space Constraints & Preventing Collapse:**
  - ø22 mm aperture with extended antechamber
  - Balance between strength, magnet clearance, & beam envelope clearance
  - Buckling analysis performed
  - Wire EDM body from 316LN SST plate
- **In-Situ Bakeout**: electrical heating rods fitting into inboard & outboard channels
- **Cooling**: water channel along the outboard side & internal copper plating to reduce induced heat loads



SST keyhole chamber cross-sectional overview

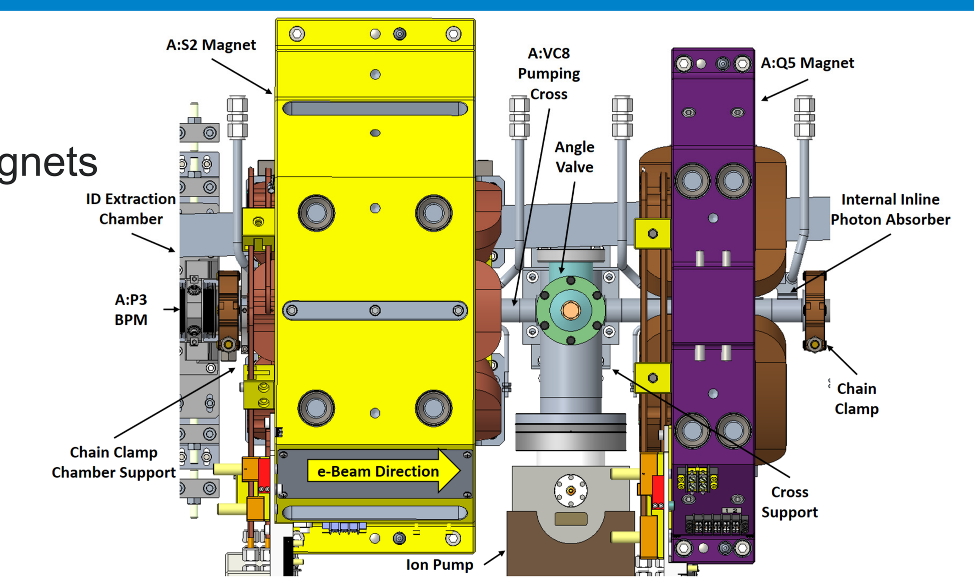
INTERFACES

Key interfaces:

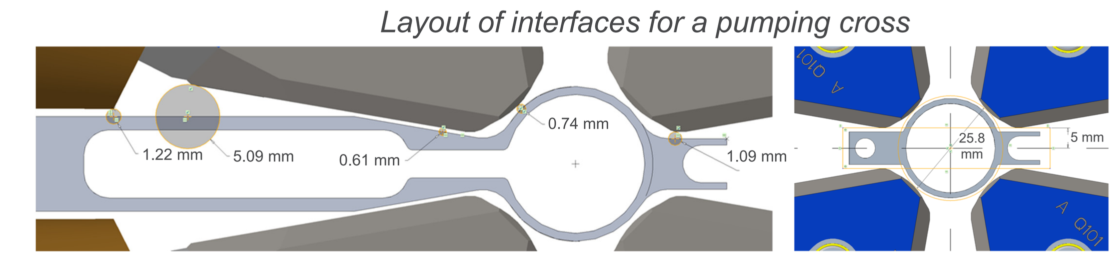
- Vacuum system
- Sextupole & quadrupole magnets
- Water cooling system
- Electrical bakeout system

Challenges:

- Tubing network passes over extraction chambers & fits between magnet gaps
- In-situ bakeout system with electrical heating rods
- Gaps between poles & chamber less than 1 mm



Layout of interfaces for a pumping cross

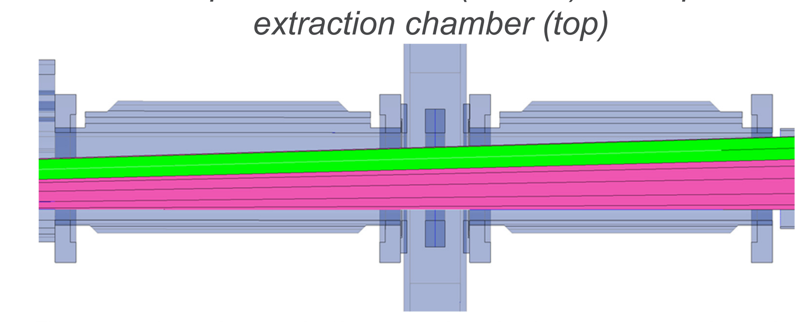


Keyhole chamber (left) and aluminum chamber (right) within quadrupole magnets

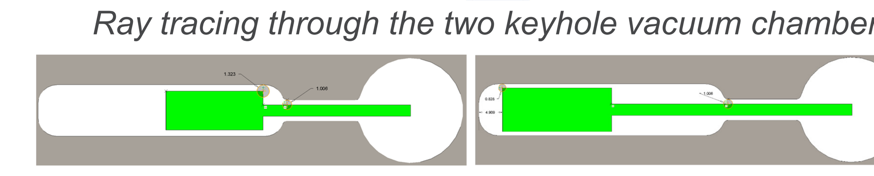
RAY TRACING

- Ray tracing layout created with CAD skeleton model – system approach to adjust heat loads & shadowing
- Ability to determine heat load footprints & flexibility to adjust design parameters with automatic updates
- Results verified with SynRad & Matlab analysis
- 0 – 160 W/m heat densities for aluminum chambers
- 98 W (8.1 W/mm² heat flux) maximum heat load incorporating missteering for aluminum pumping cross
- Stainless steel keyhole aperture designed to allow synchrotron radiation to pass through without incidence

Ray tracing through one of the aluminum chambers with an inline photon absorber (bottom) and a photon extraction chamber (top)



Ray tracing through the two keyhole vacuum chambers

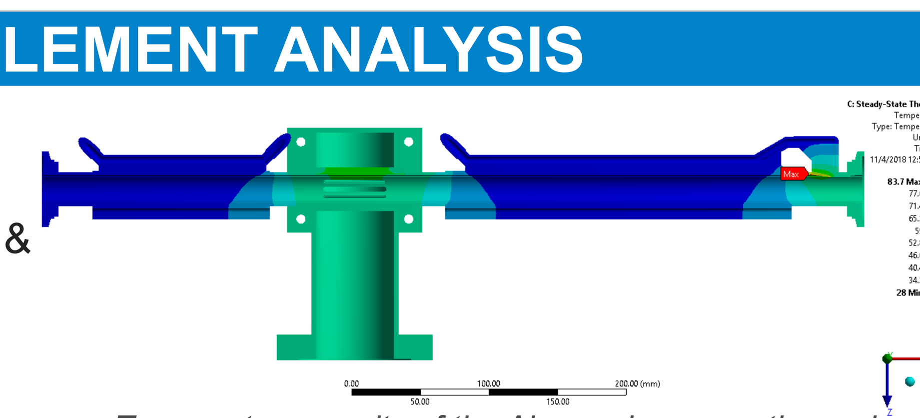


Upstream (left) & downstream (right) beam envelopes for the keyhole chambers

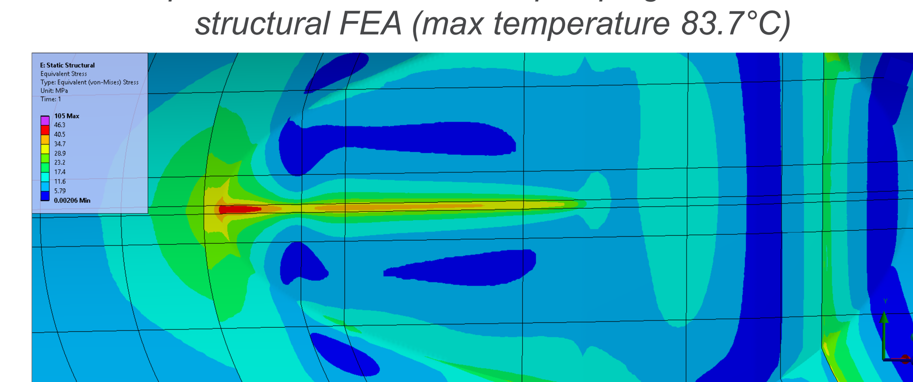
FINITE ELEMENT ANALYSIS

Setup & Challenges

- Evaluated designs under operating conditions, bakeout, & buckling
- FEA geometry split along the beam footprint with a series of partitioned bodies to control mesh quality along the beam heat load
- Synchrotron radiation heat flux imported along the beam footprint & turbulent flow based convective heat transfer coefficient for water cooling
- Atmospheric pressure applied to external surfaces, water pressure applied to water channels, & positional constraints



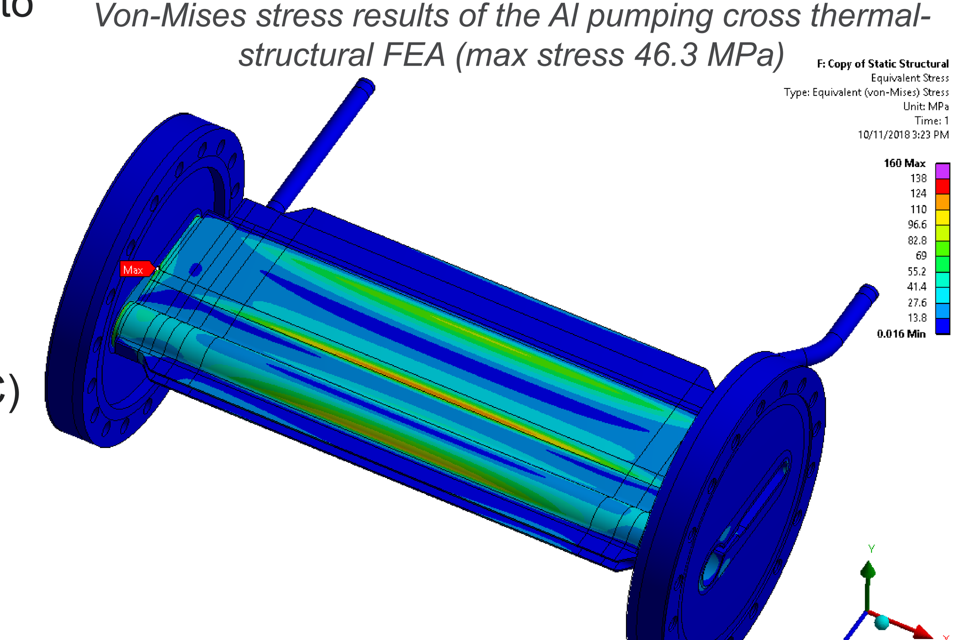
Temperature results of the Al pumping cross thermal-structural FEA (max temperature 83.7°C)



Von-Mises stress results of the Al pumping cross thermal-structural FEA (max stress 46.3 MPa)

Aluminum NEG Cross Results

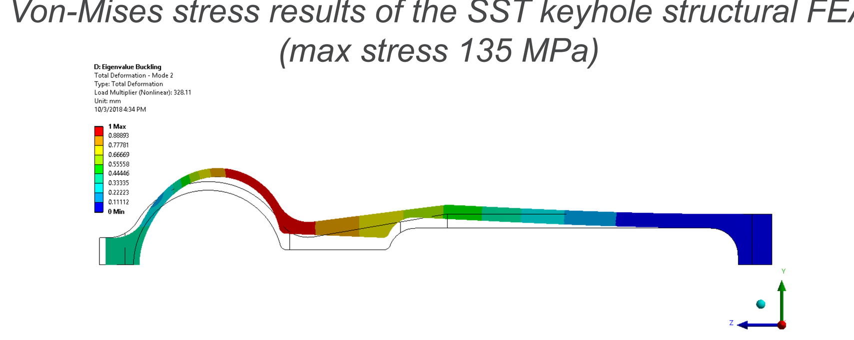
- Maximum temperature (83.7°C) & maximum stress (46.3 MPa) occurs along the inline photon absorber



Von-Mises stress results of the SST keyhole structural FEA (max stress 135 MPa)

Stainless Steel Keyhole Results

- No synchrotron radiation heat load, maximum stress is a singularity, high stress along wall in the middle of chamber body (135 MPa)
- Sliver half model used for buckling analysis, critical load found to be 328 atm



Results of the SST keyhole buckling analysis; critical load is 328 atm

CONCLUSION

The chambers presented is this paper have gone through extensive design, analysis, review, and bidding processes. APS-U is confident with the expected performance of these components. Future work for these projects include the procurement, fabrication, assembly, and installation process. Components are expected to arrive Summer 2020.

ACKNOWLEDGMENT

Argonne National Laboratory's work was supported by the U.S. Department of Energy, Office of Science under contract DE-AC02-06CH11357.