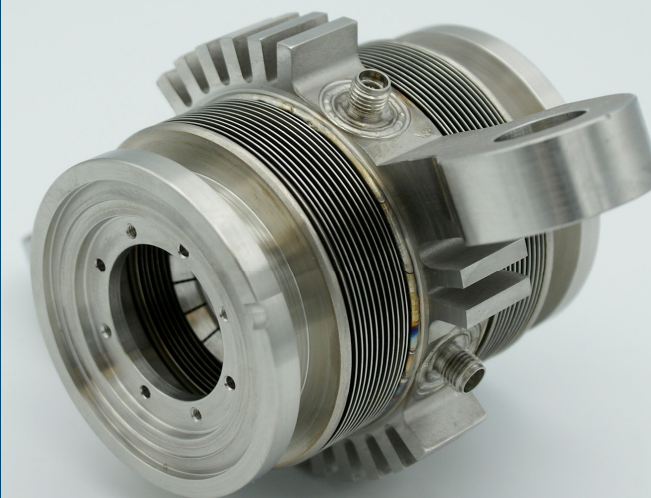


Final Design of the APS-Upgrade Storage Ring Vacuum System



Jason Carter

Lead Vacuum Engineer, APS-U Storage Ring Vacuum System Design Group
Advanced Photon Source
Argonne National Laboratory, Lemont, IL

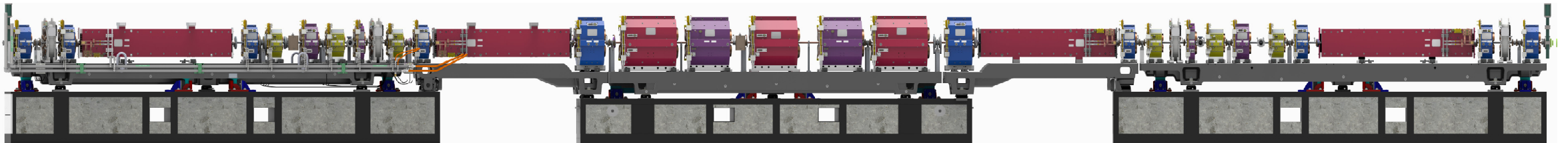
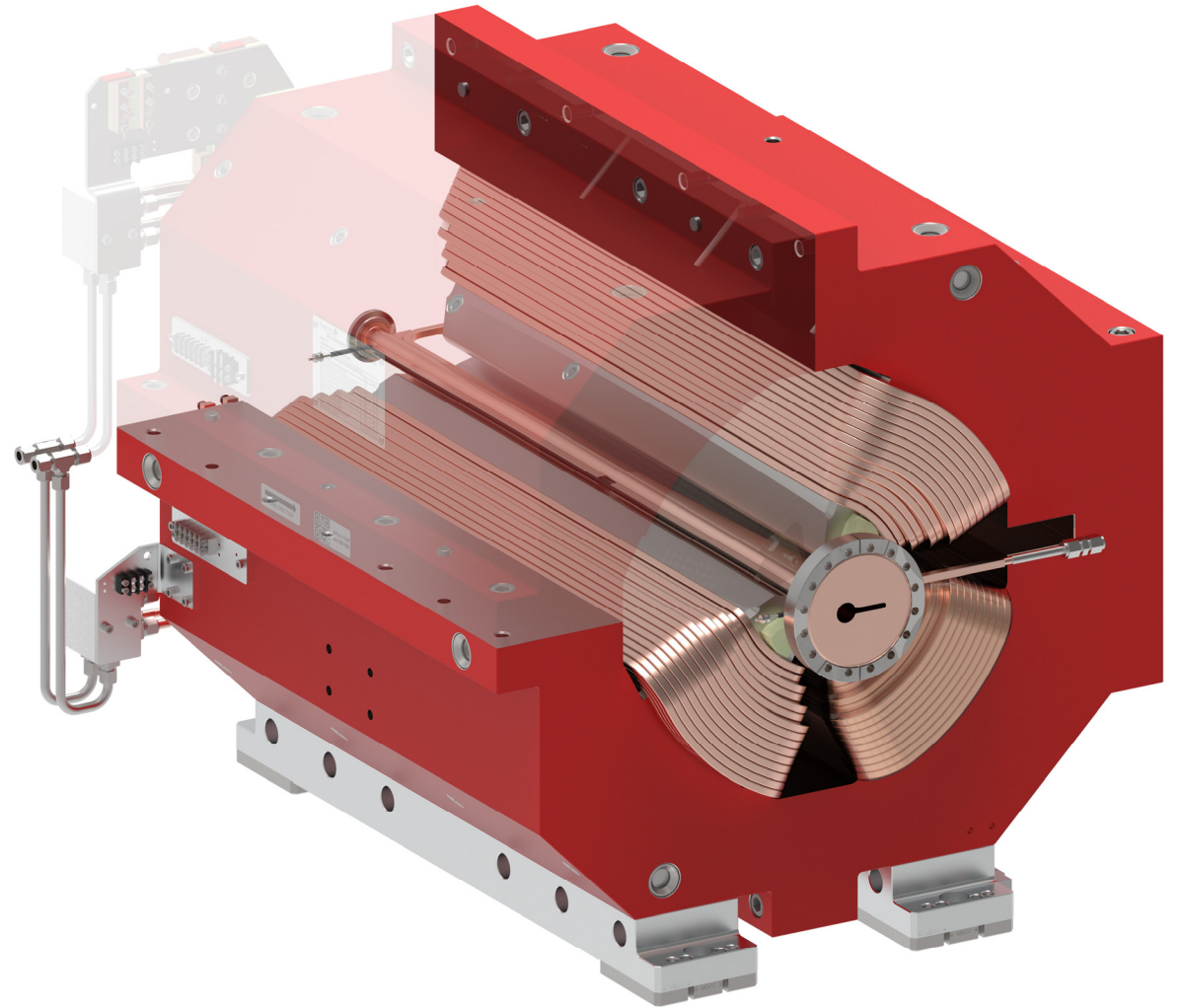
NAPAC 2019 Lansing, MI
September 3, 2019

NAPAC2019

NORTH AMERICAN PARTICLE ACCELERATOR CONFERENCE

Agenda

- APS-U overview
- Interfaces & design challenges
- CAD modeling
- Design of vacuum components
- Future work

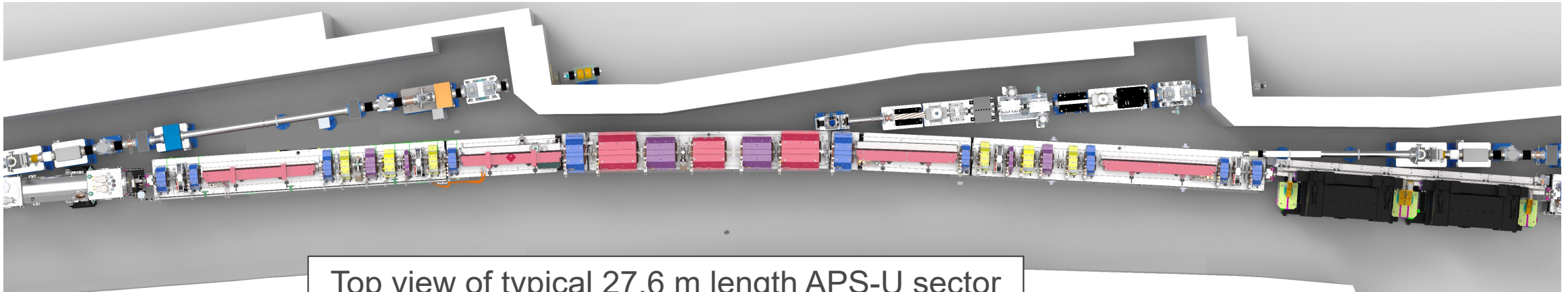


APS Upgrade Project - Overview

- Advanced Photon Source (Operating since 1995)
 - 7 GeV, 100 mA synchrotron light source
 - 1104 m circumference
- APS Upgrade (Operations 2025)
 - 6 GeV, 200 mA retrofit
 - Optimized for brightness above 4 keV
 - Exceeds capabilities of today's storage rings by 2 to 3 orders of magnitude in brightness, coherent flux, and nano-focused flux
 - Deliver 5000 hrs / year of beam to users at 95% availability
 - Powers entire beamline suit for APS's >5000 users per year



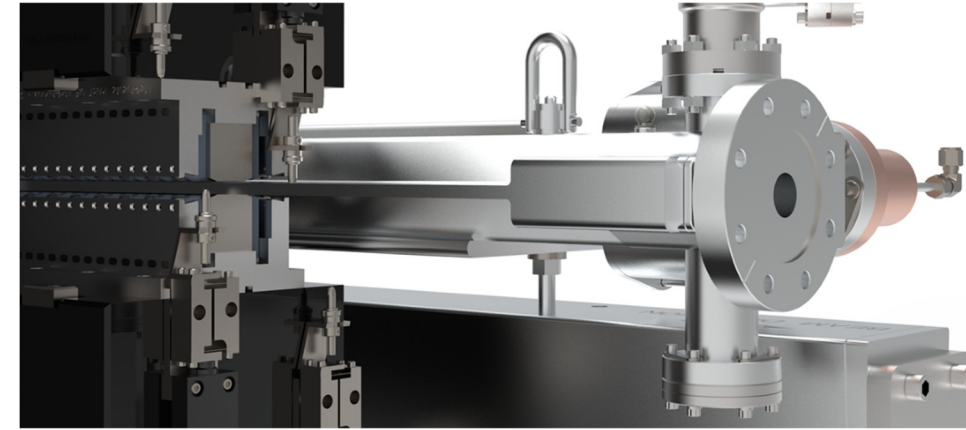
Advanced Photon Source (APS),
Argonne National Laboratory, Lemont, IL



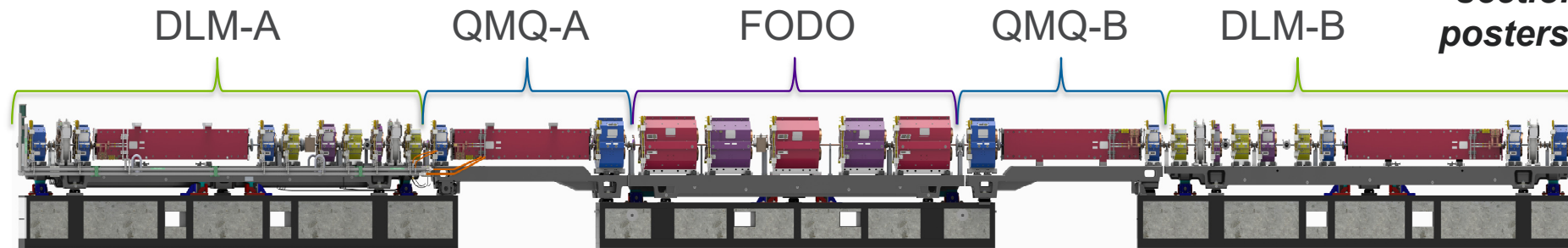
Top view of typical 27.6 m length APS-U sector

APS-U Storage Ring - Overview

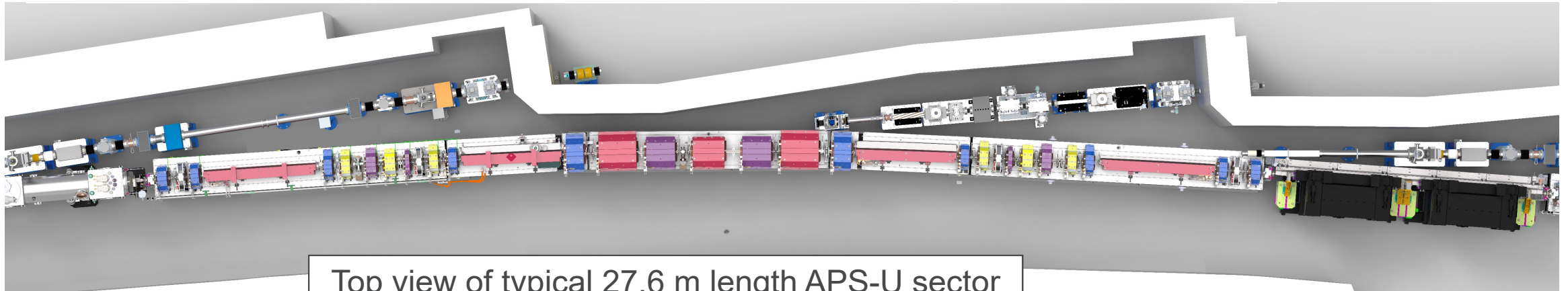
- 40 sectors in the storage ring, each 27.6 m in length
- Sectors consist of arcs + straight section
 - Arcs divided in 5x modules per sector
 - Modules each assembled during pre-installation phase
 - Assembled modules brought into tunnel during 1-year installation/dark time



****For information on straight section vacuum design see posters TUPLS02 & TUPLS03***



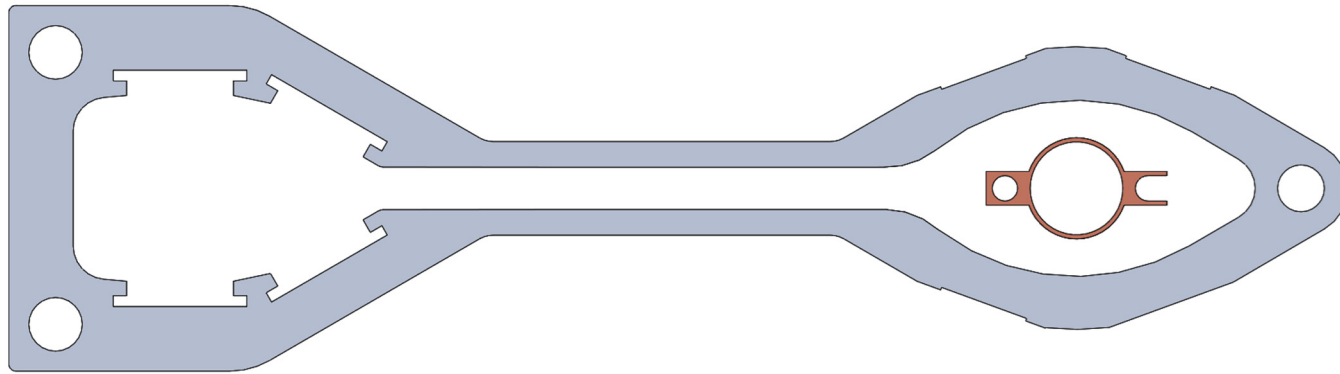
Aisle-side view
of arcs only



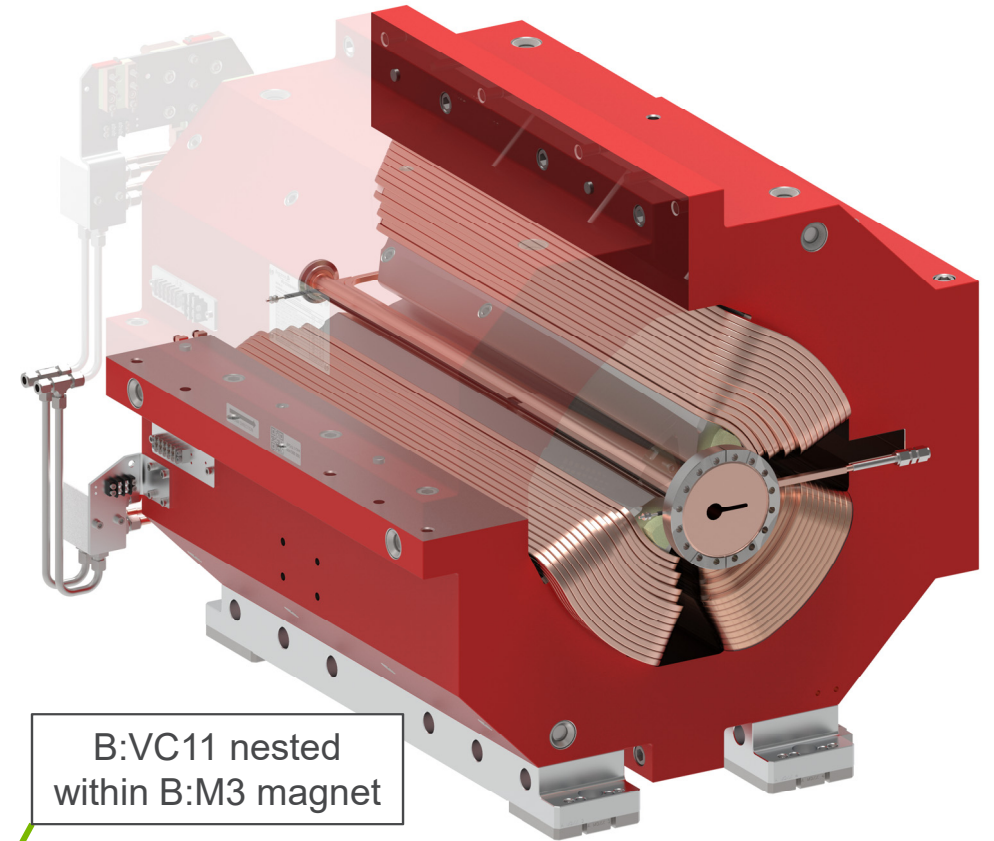
Top view of typical 27.6 m length APS-U sector

APS U Storage Ring Vacuum System - Overview

- 22 mm nominal vacuum chamber aperture
- Hybrid use of common pumping elements
 - NEG-coated tubes across 40% of the ring
 - 9x discrete ion pump / NEG cartridge combos
 - NEG strips across 2 m long chambers with antechambers
- Quick conditioning for good beam lifetimes
 - 2 nTorr @ 200 mA by 1000 A*hrs conditioning (1E-11 Torr/mA)

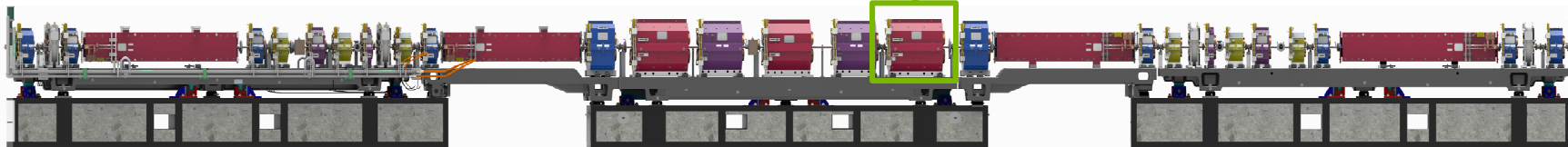


Existing APS storage ring chamber compared to new 22 mm ID APS-U style chamber



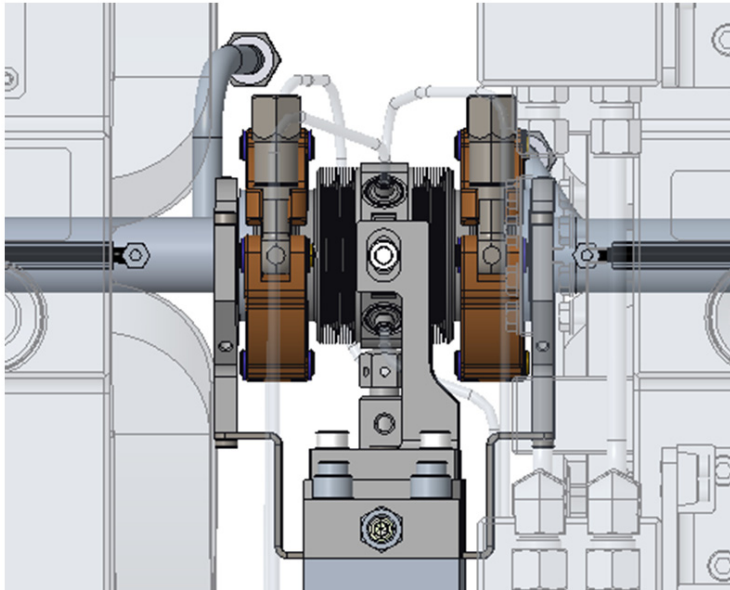
B:VC11 nested within B:M3 magnet

****See poster TUPLS11 on all NEG-coated Copper Vacuum Chambers***

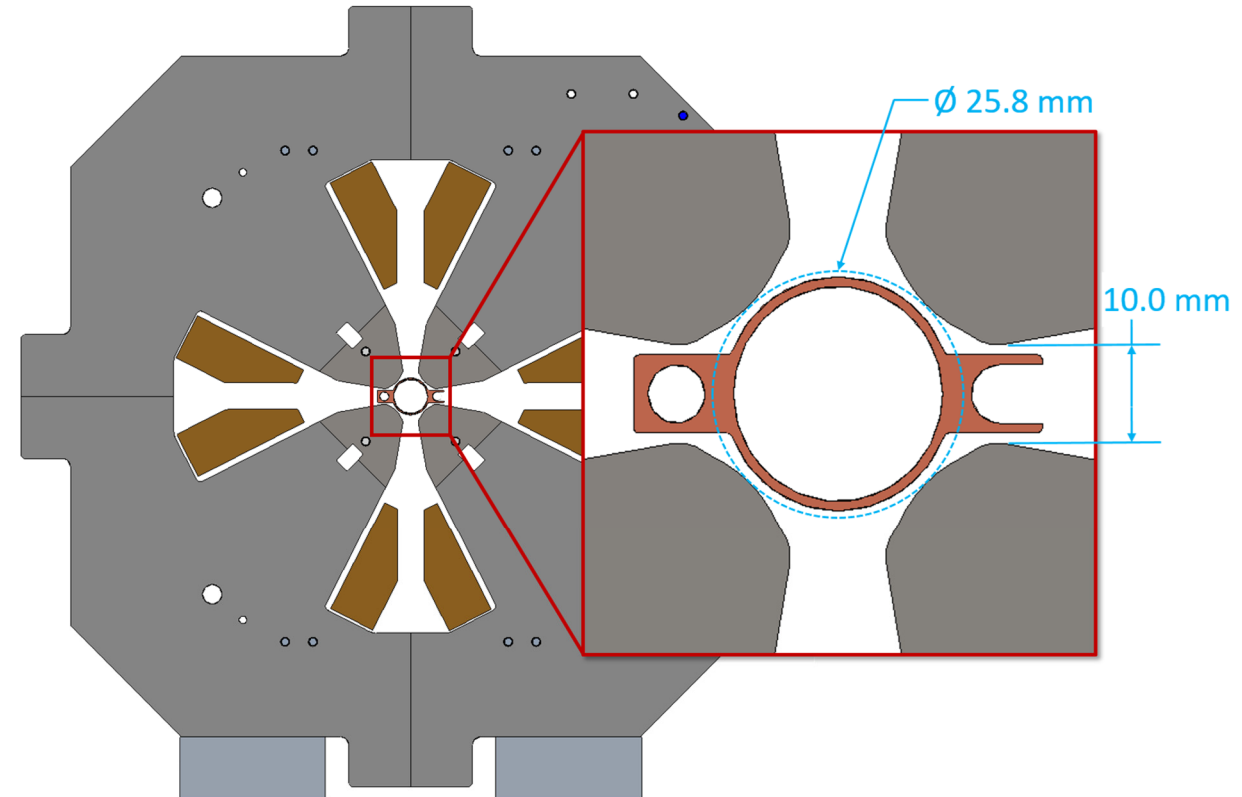


Interfaces & Design Challenges

- Chambers typically connect to a standalone Beam Position Monitor (BPM) and compact chamber support
- BPMs accessible through installation gaps as small as 125 mm
- QCF chain clamps for majority of joints
- 0.5 – 1.0 mm clearance between magnet poles



Chambers connected to 70 mm flange-to-flange BPM and support

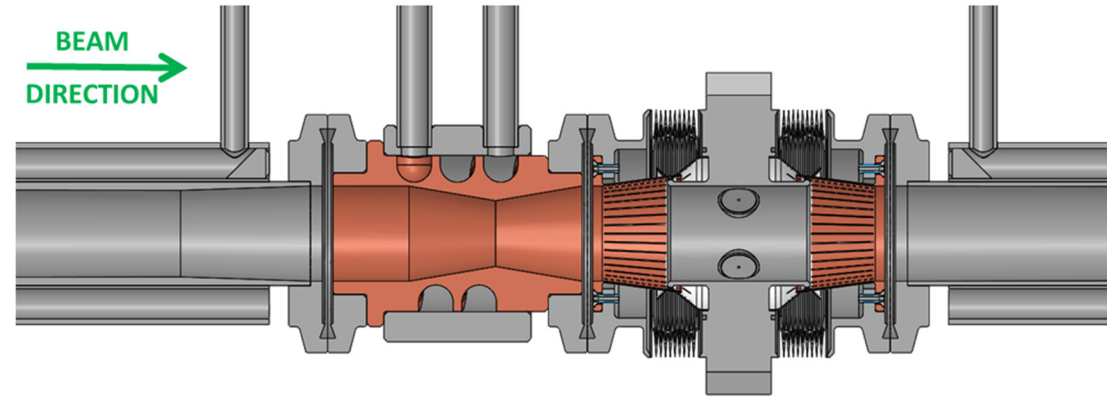
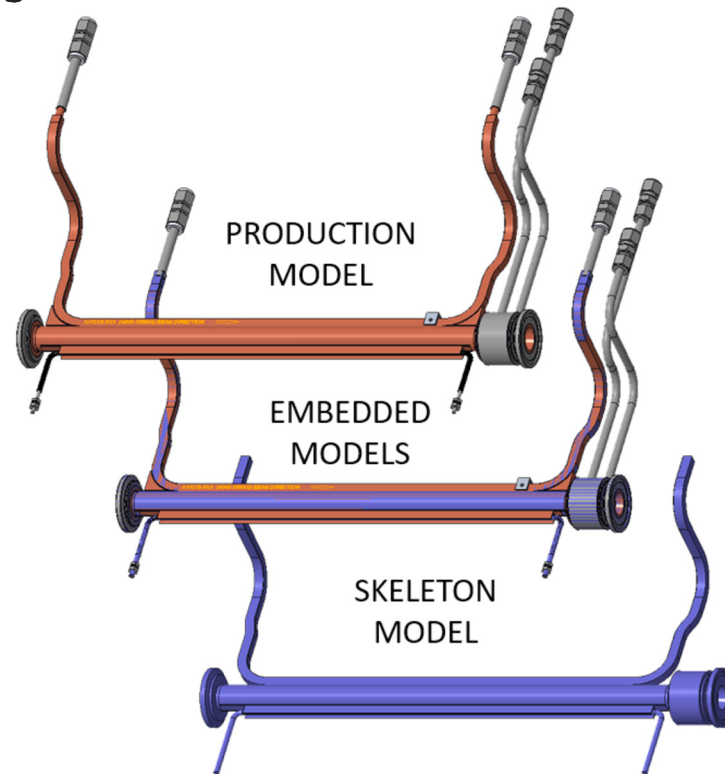


Typical narrow magnet-to-vacuum chamber gaps

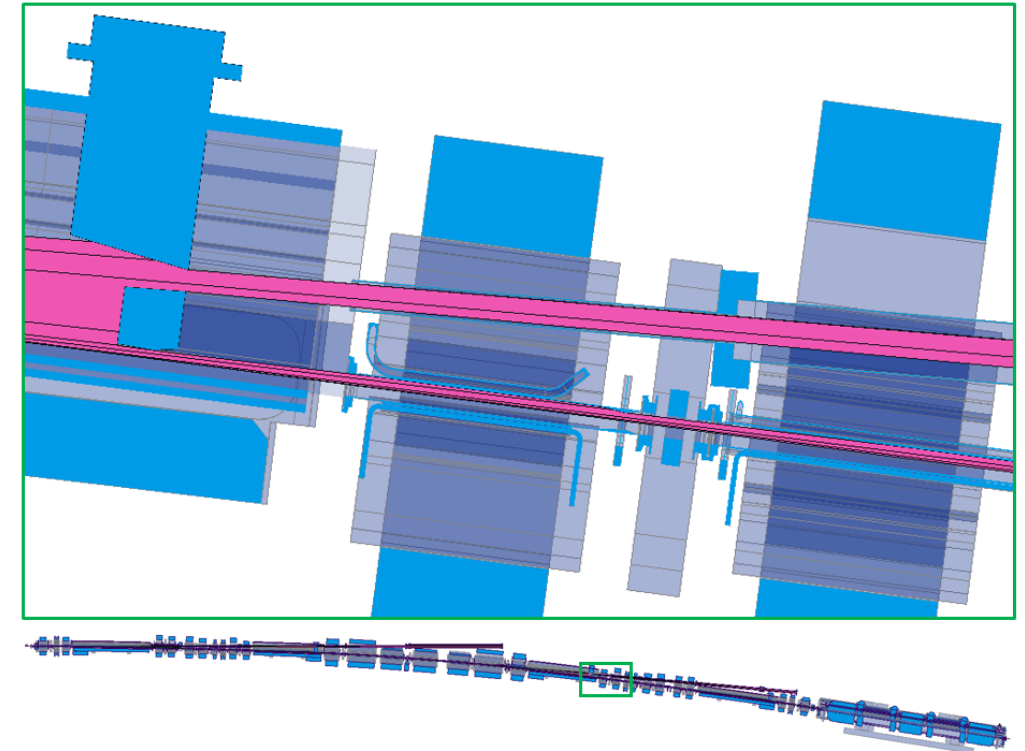


Vacuum System CAD modeling

- Production models built off 'skeleton' CAD framework
- Skeletons define interconnected lengths and locations of all components
- Simplified models capture core details, embedded within production model details
- Subtle system-level adjustments easier to implement, communicate across groups
- Full sector ray trace off of 29 unique dipole arcs
- Robust shadowing designed across all BPMs, flange joints, and extraction chambers



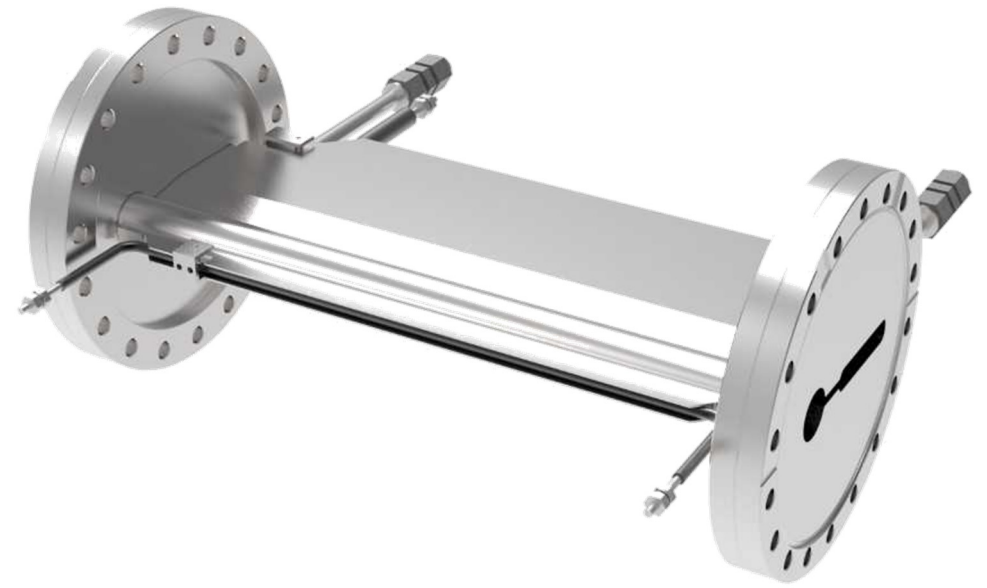
Typical 'in-line' absorber shadowing BPM



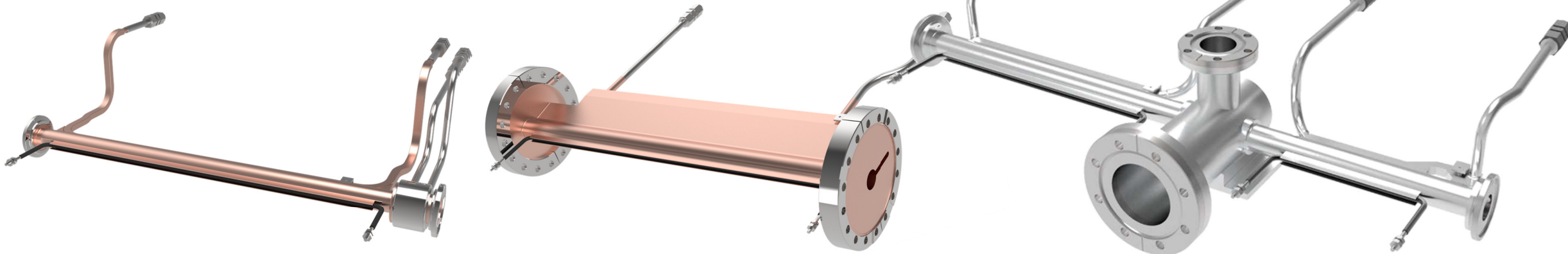
Ray tracing (pink) off of crotch absorber using simplified skeleton geometry (blue)

Design of Vacuum Components

- 41 vacuum chambers per sector
 - 19 NEG-coated vacuum chambers 0.3 – 1.7 m lengths
 - 4 L-bend chambers w/ antechambers 2.0 – 2.2 m lengths
 - 2 keyhole, 2 crosses, 14 BPMs 0.1 – 0.4 m lengths
- Variety of chamber materials
 - Copper/GlidCop/CuCrZr for 600 – 1000 W/m distributed loads
 - Aluminum up to 160 W/m distributed loads
 - L-bend chambers from long aluminum extrusions
 - Inconel chambers passing through corrector magnets
- Electric bakeout via tube heaters



****See poster TUPLS12 on
SST Keyhole Vacuum Chambers***

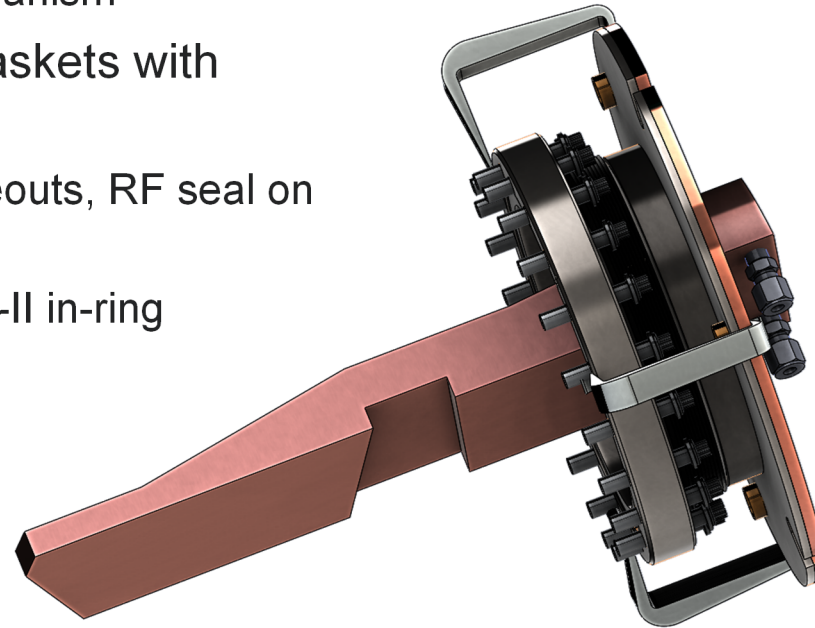


****See poster TUPLS11 on
NEG-coated Copper Vacuum Chambers***

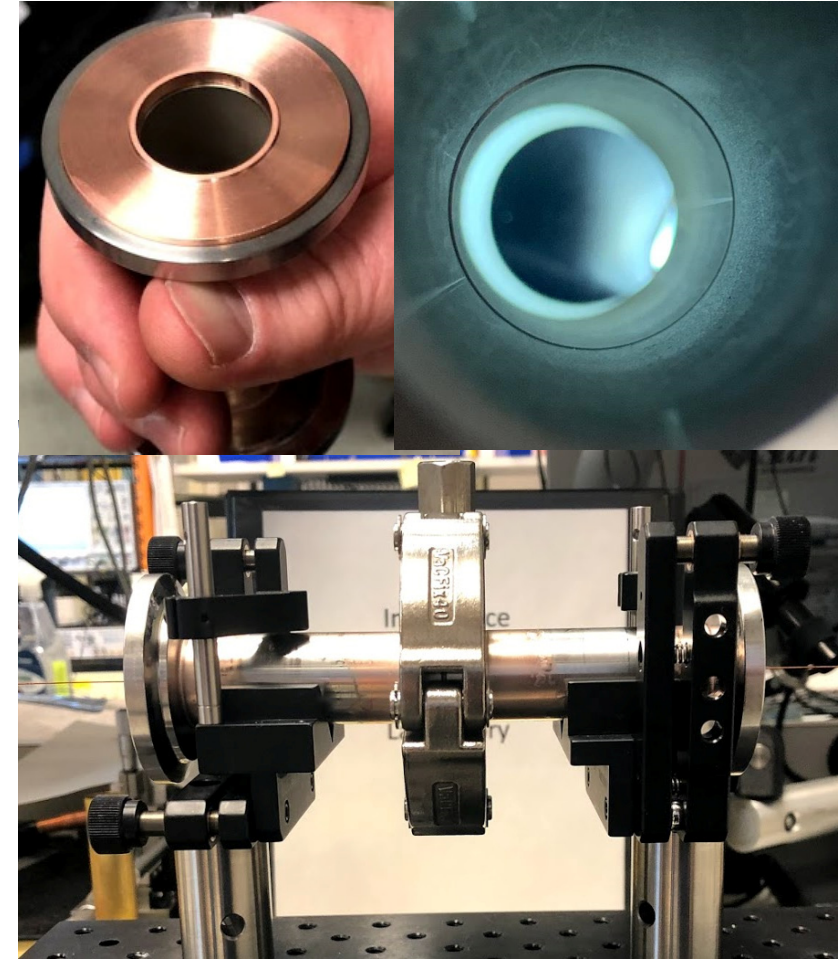
****See poster TUPLS12 on
NEG-coated Aluminum Vacuum Chambers***

Design of Vacuum Components

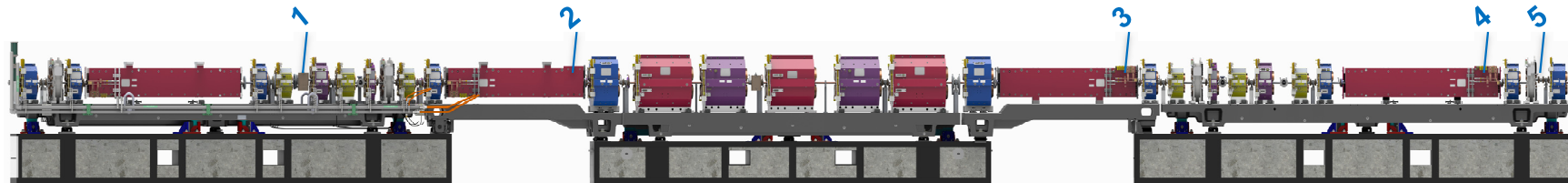
- High heat load photon absorbers
 - Crotch with 3.4 kW heat load at 200 mA
 - CuCrZr for high strength, lower cost than GlidCop
 - Bellows-based alignment mechanism
- Single-piece custom copper gaskets with RF-sealing internal lip
 - Tested for vacuum across bakeouts, RF seal on stretched-wire Goubau line
 - Performed well in recent NSLS-II in-ring tests with follow-up APS in-ring tests at the end of this month (see next slide)



APS-U crotch-style photon absorber with bellows for precision alignment



Single piece RF-sealing gasket tested for vacuum and on stretched-wire Goubau line



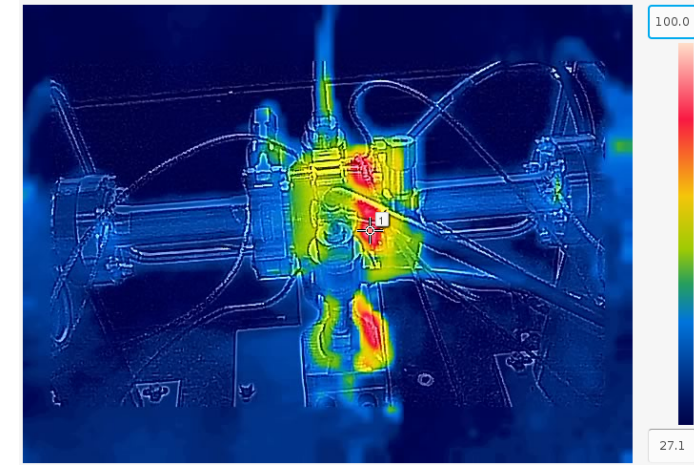
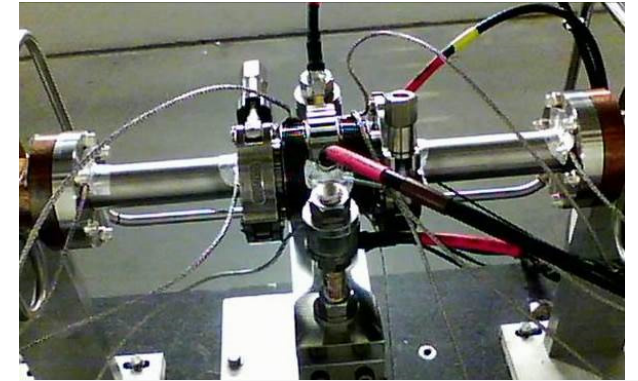
5 discrete photon absorbers per sector

Design of Vacuum Components

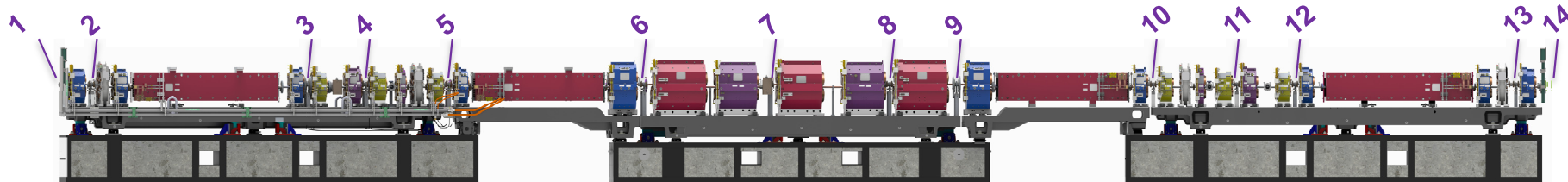
- August 2019 NSLS-II in-ring tests of APS-U BPM prototype
 - Prototype with BPM feedthroughs and bellows welded to central housing, internal coatings, detachable RF fingers
 - In-ring test stopped at 100 mA where unit was hot due to unrestrained RF fingers slipping out of contact
 - Follow-up APS in-ring test to be installed September 2019
- Lessons learned:
 - Careful QA of BPM feedthroughs
 - Finalizing bellows restraints
 - Improving design of weld joints
 - Coating process is dirty and best earlier in manufacturing



APS-U BPM prototype



NSLS-II in-ring setup (top)
and infrared image (bottom)



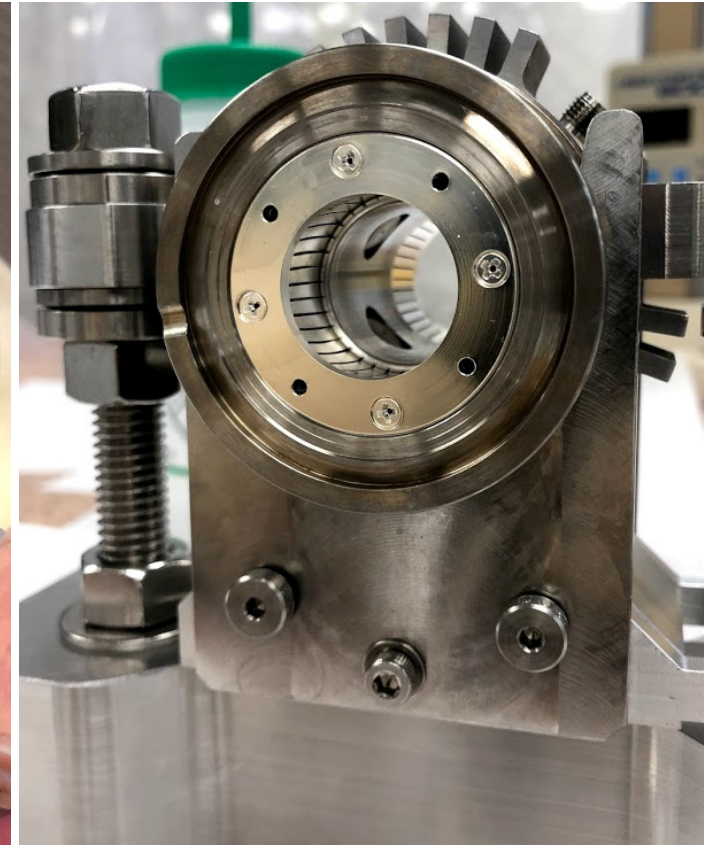
14 BPMs per sector

Design of Vacuum Components

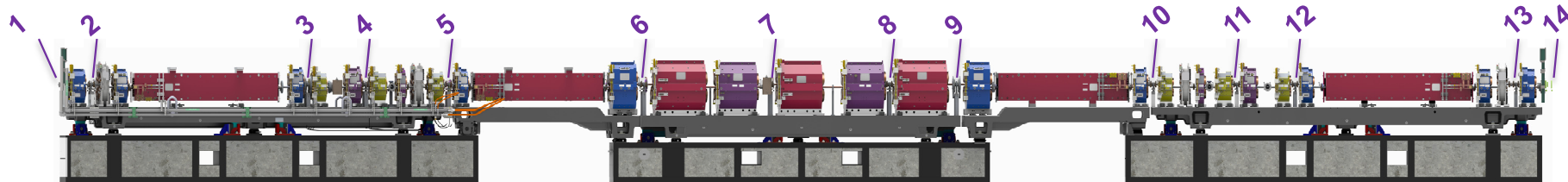
- August 2019 NSLS-II in-ring tests of APS-U BPM prototype
 - Prototype with BPM feedthroughs and bellows welded to central housing, internal coatings, detachable RF fingers
 - In-ring test stopped at 100 mA where unit was hot due to unrestrained RF fingers slipping out of contact
 - Follow-up late September 2019 APS in-ring test
- Lessons learned:
 - Careful QA of BPM feedthroughs
 - Finalizing bellows restraints
 - Improving design of weld joints
 - Coating process is dirty and best earlier in manufacturing



APS-U BPM prototype



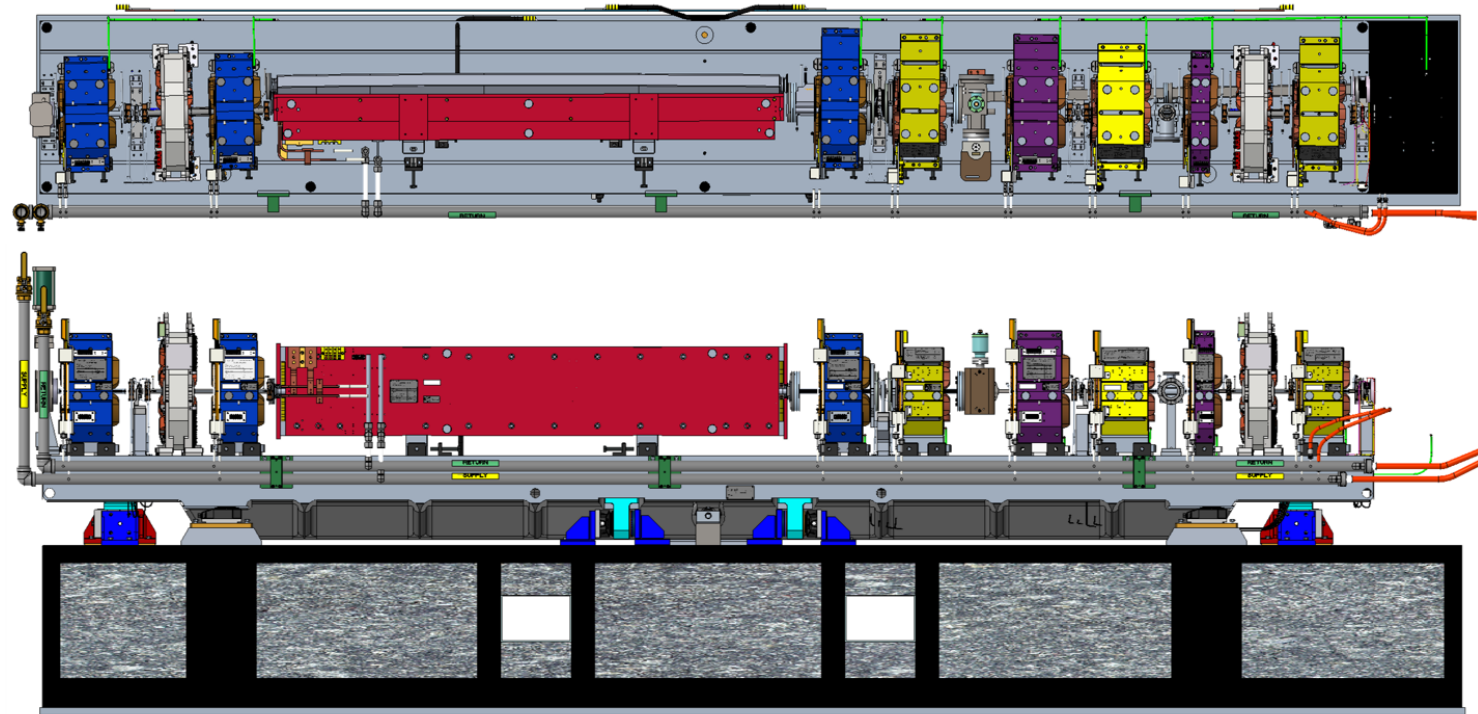
RF fingers installed w/ additional restraints for APS in-ring test



14 BPMs per sector

Conclusions and future work

- Future work
 - APS in-ring test of BPM prototype at the end of this month (September 2019)
 - Turning final designs into procurements
 - Contracts have been awarded for keyhole chambers and some NEG-coated vacuum chambers
 - Extensive QA and vacuum certification of components
 - Begin pre-installation of APS-U modules in Summer 2020 and tunnel installation of modules in 2022
 - Continue towards operations ~2025



Top and aisle-side views of DLM-A module

FINAL DESIGN OF THE APS-UPGRADE STORAGE RING VACUUM SYSTEM Advanced Photon Source Upgrade

NAPAC2019

NORTH AMERICAN PARTICLE ACCELERATOR CONFERENCE

Jason Carter on behalf of the APS-Upgrade Storage Ring Vacuum System Design Group



Questions?

*For questions or more info on this topic visit my poster **WEPLM10** on Wednesday

Additionally, this Tuesday afternoon please see:
TUPLS11 – NEG-coated copper chambers
TUPLS12 – NEG coated aluminum chambers &
TUPLS02/TUPLS03 on APS-U straight section vacuum

APS-U & VACUUM SYSTEM REQUIREMENTS

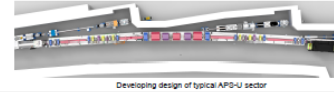
- APS-Upgrade project: 6 GeV, 200 mA multi-bend achromat retrofit to existing 1.1 km circumference storage ring
- Pre-installation: 40x total sectors each broken down into 5x modules of magnets, vacuum chambers & supports
- Installation with 1 year APS dark time: 6 month tunnel installation + conditioning
- Vacuum conditioning: achieve 2 nTorr average total pressure @ 200 mA by 1000 A hrs



Advanced Photon Source at Argonne National Laboratory, Lemont, IL, USA



Existing 318 mm wide APS storage ring chamber compared to new APS-U chamber



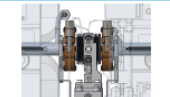
Developing design of typical APS-U sector

INTERFACES & DESIGN CHALLENGES

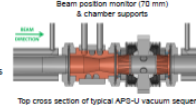
- Magnets: ~1 mm clearance between poles
- Vacuum chambers must pass strict go/no-go gauges
- Installation: limited access to joints, BPMs
- GCP chain clamps where possible for ease of installation

- Accelerator physics: minimize losses due to impedance
- Single piece RF sealing gasket within compact flange joints
- Vacuum crosses designed with machined pumping liners
- Photon absorbers with subtle transitions

- Shadowing uncooled components:
- Water-cooled vacuum chambers with internal absorbers to shadow BPM/bellows & flange joints
- Ray tracing assuming misalignment & missteering



Beam position monitor (BPM) and chamber supports

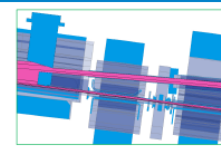
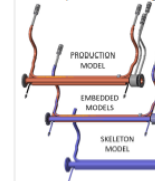


Top cross section of typical APS-U vacuum sequence

VACUUM SYSTEM CAD MODELING

- "Skeleton" approach to 3D CAD modeling

- Simplified models capture critical details, allow for efficient high level assembly analysis
- All APS-U groups participate in approach
- Skeleton models embedded within detailed production level designs

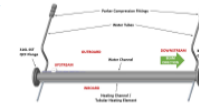


3D CAD ray trace highlighting APS-U crotch absorber

- Adaptable ray trace built off skeleton assemblies
- 20 vacuum components intercept synchrotron radiation projected from 29 unique "sub-arc" of APS-U MBE lattice
- Stronger understanding of complex photon load distributions across chambers and absorbers

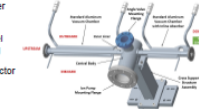
DESIGN OF VACUUM COMPONENTS

- 63 custom arc vacuum components per sector
- 19 NEG-coated chambers
- 14 BPMs w/ 2-sided bellows
- 5 photon absorbers
- 4 aluminum "L-bend" chambers with antechambers
- 2 SST keyhole chambers
- 2 cross chambers
- 15 extraction line chambers & bellows

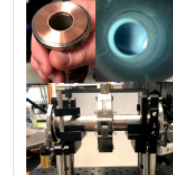


Typical NEG-coated Inconel vacuum chamber

- NEG-coated vacuum chambers
- Typically built around aluminum or copper extruded tube with 22 mm ID
- Outboard water cooling channel
- Tube heater in o-shaped inboard channel
- Downstream "inline absorber" shadowing flange joints and BPMs
- Inconel chambers passing through corrector magnets
- NEG-coating 2 copper keyhole shaped chambers



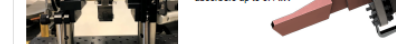
Typical NEG-coated aluminum vacuum chamber



Single piece RF-sealing gaskets

- Demonstrated dual vacuum seal and RF seal on vacuum cross and Goubau line and recent NSLS-II in-ring tests
- Extending to keyhole designs

- Photon absorbers with bellows
- Bellows based alignment of critical crotch absorber edges
- CuCrZr for high heat load absorbers up to 3.4 kW



Custom RF-sealing copper gaskets test on Goubau line and in-ring installations

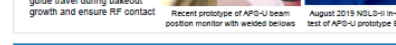


CuCrZr crotch absorber with bellows for alignment

- Beam position monitors
- Design improvements through prototyping lessons learned
- Recent in-ring tests at NSLS-II demonstrated button readings and met vacuum but heated at 100 mA due to RF liner being out of contact
- Follow-up in-ring tests coming at APS (September 2019) to correct installation
- Working on hand-stops to guide travel during bakeout growth and ensure RF contact



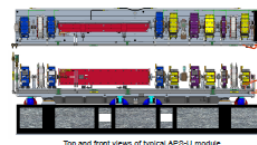
Recent prototype of APS-U beam position monitor with welded bellows



August 2019 NSLS-II in-ring test of APS-U prototype BPM

FUTURE WORK

- September 2019 APS in-ring test of APS-U BPM
- Turning final designs into procurements
- QA and vacuum certification of production vacuum equipment
- Begin pre-installation of full APS-U modules in Summer 2020
- Mockup installation of first articles of all components



Top and front views of typical APS-U module

ACKNOWLEDGMENT

Argonne National Laboratory's work was supported by the U.S. Department of Energy, Office of Science under contract DE-AC02-06OR21400. Special thanks to APS-U Storage Ring Vacuum Design team: Bran Brnjakovic, Brian Bisset, Herman Cease, John Hoyt, Mark Lee, Austin McElerny, Oliver Mulvaney, Maria O'Neill, Ralph Swanson, Kevin Wakefield, Dean Walters, Qing Wenmang, John Ziemke.

