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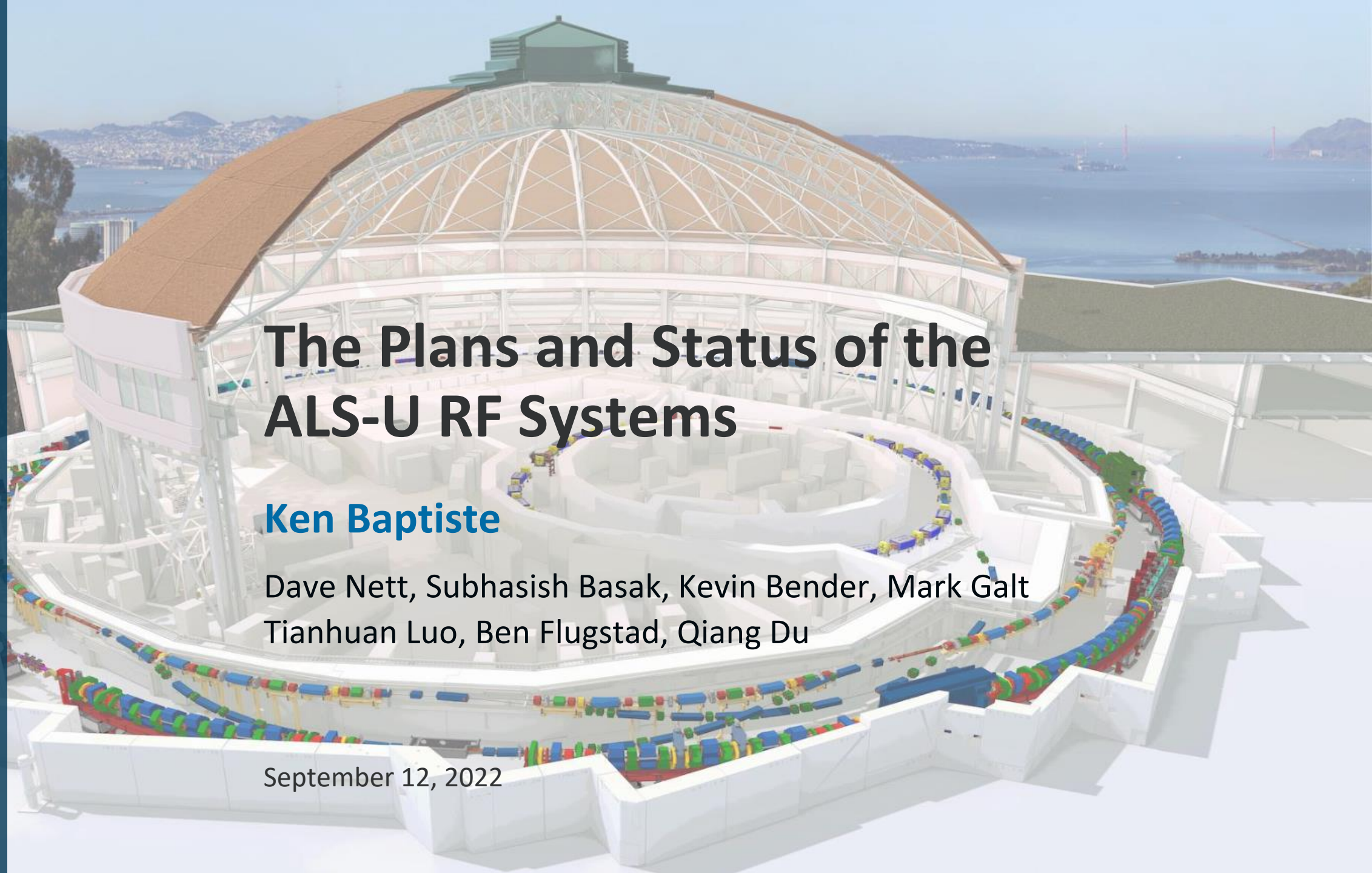
ALS-U
ADVANCED LIGHT SOURCE



The Plans and Status of the ALS-U RF Systems

Ken Baptiste

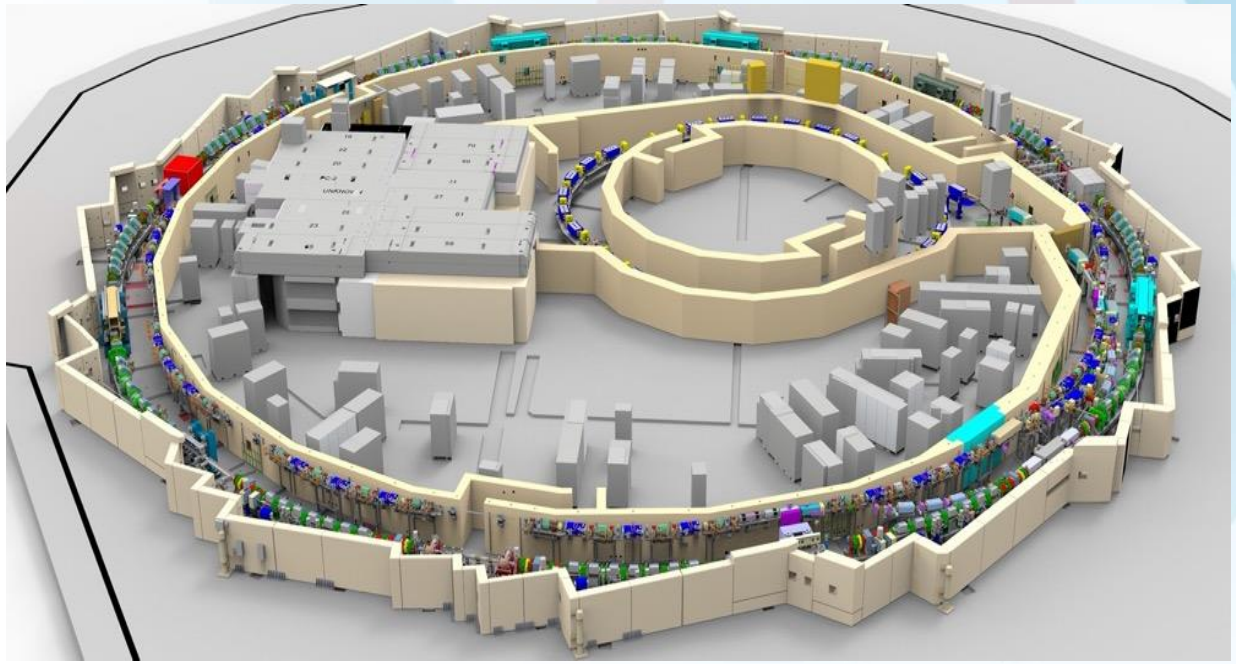
Dave Nett, Subhasish Basak, Kevin Bender, Mark Galt
Tianhuan Luo, Ben Flugstad, Qiang Du

September 12, 2022

12th CW and High Average RF Power Workshop | September 12-14, 2022

Outline

- ALS-U Upgrade Overview
- RF Requirements
- ALS & ALS-U Responsibilities
- RF Systems Plans & Status
- Summary



ALS-U Upgrade

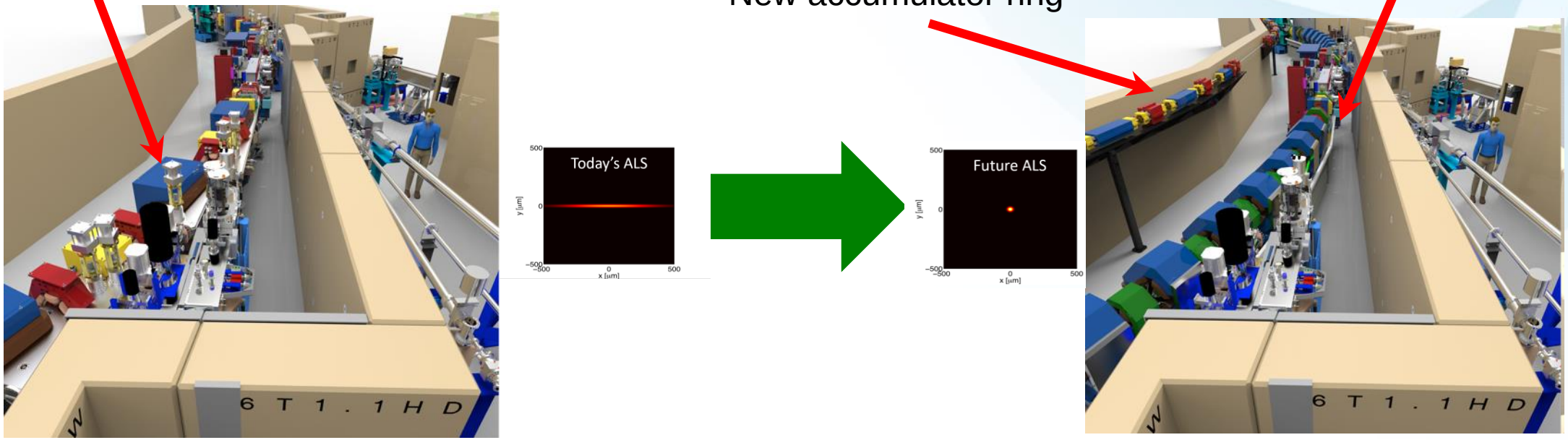
Accelerator Systems scope

- **Replacement** of the existing triple-bend achromat storage ring with a new, high-performance storage ring based on a multi-bend achromat and high field bend magnets.
- **Addition** of a low-emittance, full-energy accumulator ring in the existing storage-ring tunnel to enable on-axis, swap-out injection using fast magnets.
- **Addition** of 2 new undulators and refurbishment of existing undulators or undulator vacuum chambers where needed.
- **Upgrades** of storage ring shielding to improve seismic safety and minimize dose rates.

Existing ALS triple-bend achromat

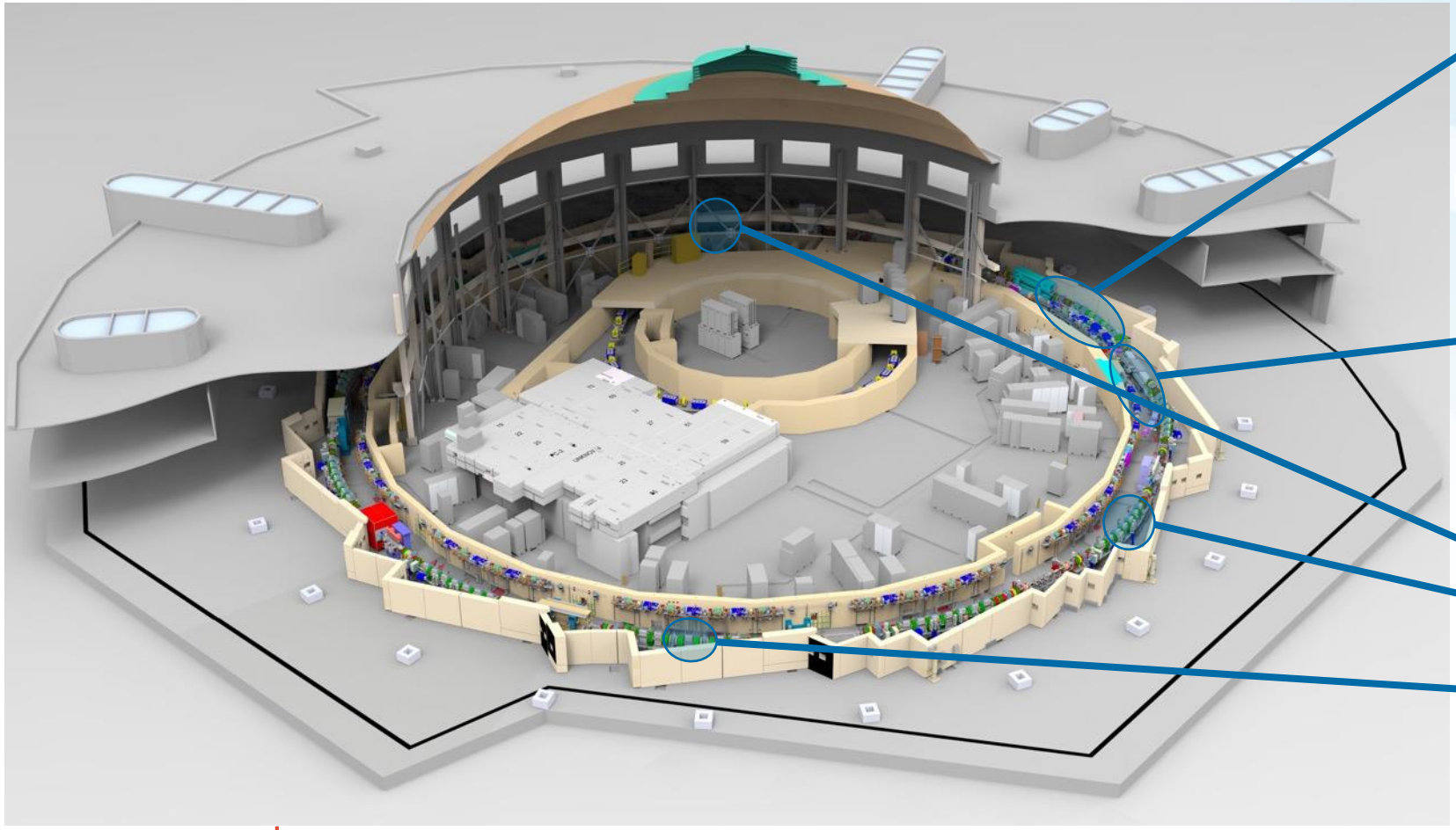
New accumulator ring

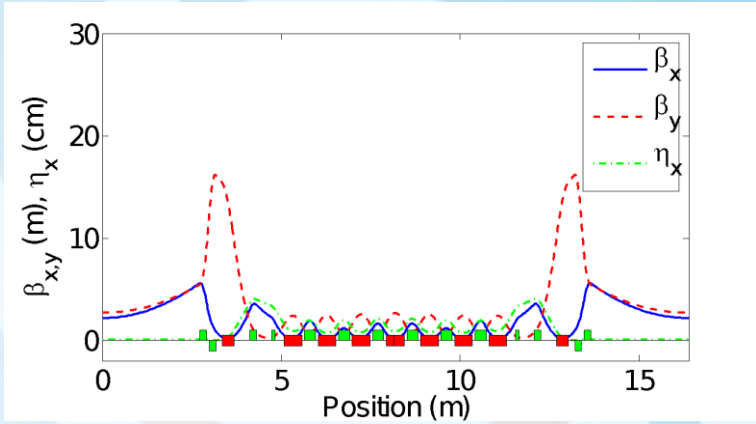
New ALS-U nine-bend achromat



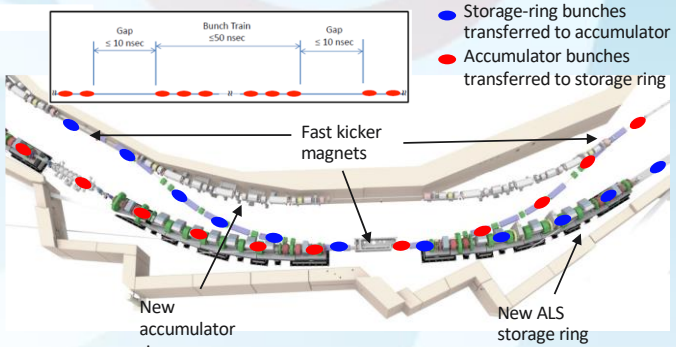
Baseline is mature and stable, and reaches soft x-ray diffraction limit up to 1.5 keV

Major design choices have remained stable and have been confirmed during final design phase

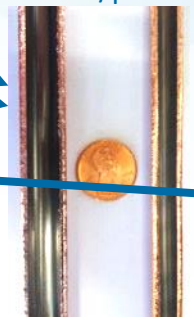




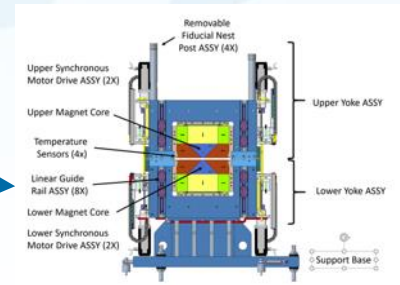
Lattice under configuration control



Bunch train swap-out using demonstrated kicker/pulser technology



Small aperture NEG coating



High Field PM bend magnets

RF Requirements

AR RF Requirements

- HPA
  - 48 kW cav/beam pwr -> specified 60 kW SSA
  - 60 kW SSA
    - Turn-key
    - Fault tolerant
    - Operational margin for transistors and DC power supply failures
- Cavities
  - Cavity voltage is nominal
  - Beam loading is low
  - Commercial EU “Dampy” cavity
  - Modifiable to fit physical constraints on ALS SR tunnel

Physics High Level Parameters (Lattice ARv5)			RF System Requirements	2.0 GeV
Ring Circumference	C	182.130179 m	# of Cavities	2
Revolution Frequency	$\omega_0/2\pi$	1.64603 MHz	R_s (ea)	~ 3.5 M-Ω
Beam Energy	E_0	2 GeV	Cav Voltage (kV)	500
Horizontal Tune	v_x	16.221	Coupling β	1.18
Vertical Tune	v_y	8.328	Energy loss per turn (keV)	282
Avg. Current	I_{avg}	49.4 mA	BM Beam Pwr (kW)	13.3
Radiation Energy Loss per Turn	U_0	269 keV		
Harmonic Number	h	304		
Momentum Compaction	α	1.1×10^{-3}	Parasitic Beam Pwr (kW)	0.2
Natural rms Energy Spread	σ_δ	8.4×10^{-4}	Total Beam Pwr (kW)	13.5
Total Cavity Voltage	V_{10}	1.0 MV	Cavity Pwr (no beam) (kW)	36
Natural rms Bunch Length	σ_{z0}	5.2 mm	Cavity Pwr (beam) (kW)	42.7
Synch. Oscillation Tune	v_{s0}	4.90×10^{-3}	RF Dist. Losses @ 60 kW (kW)	≤ 5
Synch. Oscillation Frequency	$\omega_{s0}/2\pi$	8.07 kHz	High Power Xmtr per Cav (kW)	47.7
Long. Radiation Damping Time	τ_z	5.6 ms	Long. HOM Impedance (kΩ)	≤ 4.8
Ver./Hor Radiation Damping Time	τ_y, τ_x	9.0 ms, 6.5 ms	Transverse HOM Impedance (kΩ)	≤ 180
Hor. Beta Function at the Cavity	$B_{x,RF}$	15 m	SSA Baseline Output Power (kW)	60
Ver. Beta Function at the Cavity	$B_{y,RF}$	5 m	Frequency (MHz)	500.3943

SR RF Requirements for 2.0 GeV

Fundamental RF System	Legacy Coupling	New Coupling
Frequency (MHz)	500.394	500.394
# of Legacy RF Cavities	2	2
R_s (ea) (MΩ)	4.9	4.9
Cav Voltage (kV)	300	300
Coupling β	3.15	10.6 [1]
Energy loss per turn (keV)	347	347
BM Beam Pwr (kW)	125	125
ID Beam Pwr (min gap) (kW)	35	35
3HC Beam Pwr (kW)	13.8	13.8
Parasitic Beam Pwr (kW)	2.6	2.6
Total Beam Pwr (kW)	176.4	176.4
Cavity Pwr (no beam) (kW)	9.2	9.2
Cavity Pwr (w/beam) (kW)	136.3	97.4
Waveguide Losses (kW)	< 3	< 3
High Power Amplifier (kW)	272.6 [2]	197.51

3rd Harmonic RF System	SR - 2.0 GeV
Frequency (GHz)	1.50118
# of Cavities	2
R_s (ea) (MΩ) (90% Q/ 100% Q)	0.59/0.65
Cav Voltage (kV)	90.0
Total Cav Voltage (kV)	180.0
Cavity Pwr Dissipation kW)	6.9/6.2
R/Q (desired)	< 20

- Issue with legacy aperture coupler
  - Beam loading and large reflected power lower Robinson's stability threshold
  - Large reflected power is very inefficient

[1] Coupling required exceeds coupler's adj. range
[2] Each cavity would have ~39 kW reflected power at 500 mA due to the lack of coupling range.

ALS & ALS-U Responsibilities

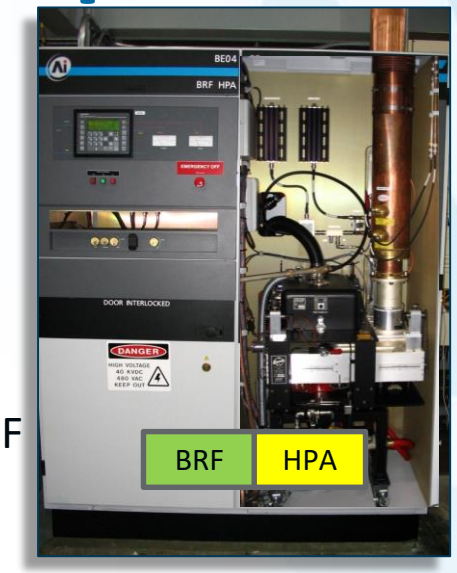
Injector RF Systems – Scope & Deliverables

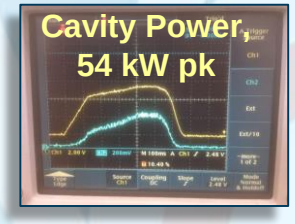
ALS-U Scope

- Increase BRF Cavity voltage to improve quantum lifetime: IOT forward power > 65 kW
  - Potential to change from disc/cylindrical aperture coupler to coaxial as in planned for the SR cavities

ALS Scope

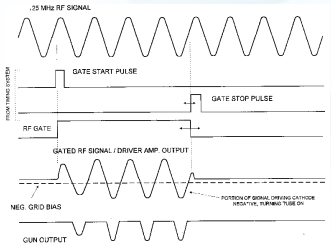
- Use existing E-Gun system. ALS has future plans for new LLRF
- Use existing Sub-Harmonic Bunchers (125MHz & 500 MHz, 20 us, <10 Hz)
  - Recently upgraded Digital LLRF & plan to replace triode tube amplifiers with SSA
- Use existing Linac Klystrons/Modulators (3 GHz, 24 MW, 2us, <10 Hz)
  - New Scandinova Modulators installed in 2020
- Use existing Booster RF HPA (500 MHz, 80 kW IOT, 700 ms, <10Hz)
  - Manufacturer (TV Broadcast Co.): Issued End of Service
  - ALS working on proposal to replace with SSA (~copy of AR RF HPA)



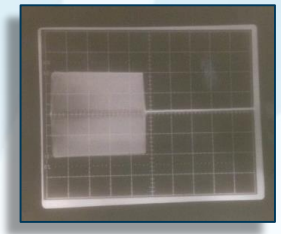


CPI IOT Lifetime
#1: 3 yr (18k hrs)
#2: 10 yr (~54k hrs
#3: 1+ yr (~8k hrs)

Thales TV-2002Lifetime
Mod #1: 17, 10, & 5+ yrs
Mod #2: 9, 14, 2, 2 & 4+ yrs



CPI YU-171 Lifetime
6-7 cathodes – used



Eimac
3CPX800A7
Lifetime
10-25 yrs ea.
20-25 tubes - used

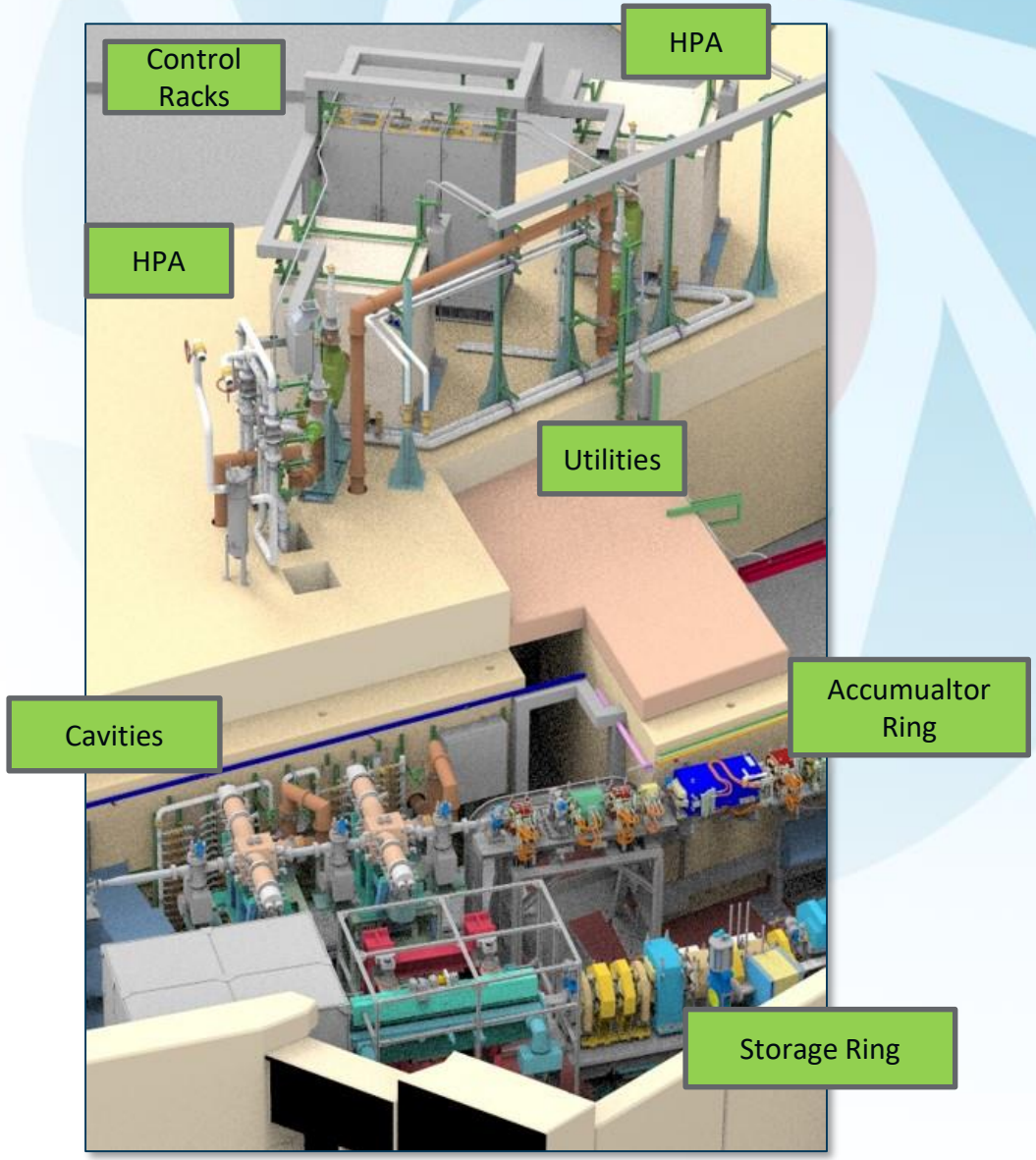
Accumulator Ring RF – Scope & Deliverables

ALS-U Scope

- AR RF System
  - Cavities – qty 2
  - HPA – qty 2
  - LLRF – qty 2
  - Equipment Protection System (EPS) – 1 integrated system with modes
  - EPICS Controls – 1 integrated system
  - Electrical and LCW utilities distribution
  - Seismic and Structural engineering and compliance
  - Radiation shielding modifications and supplemental blocks

ALS Scope

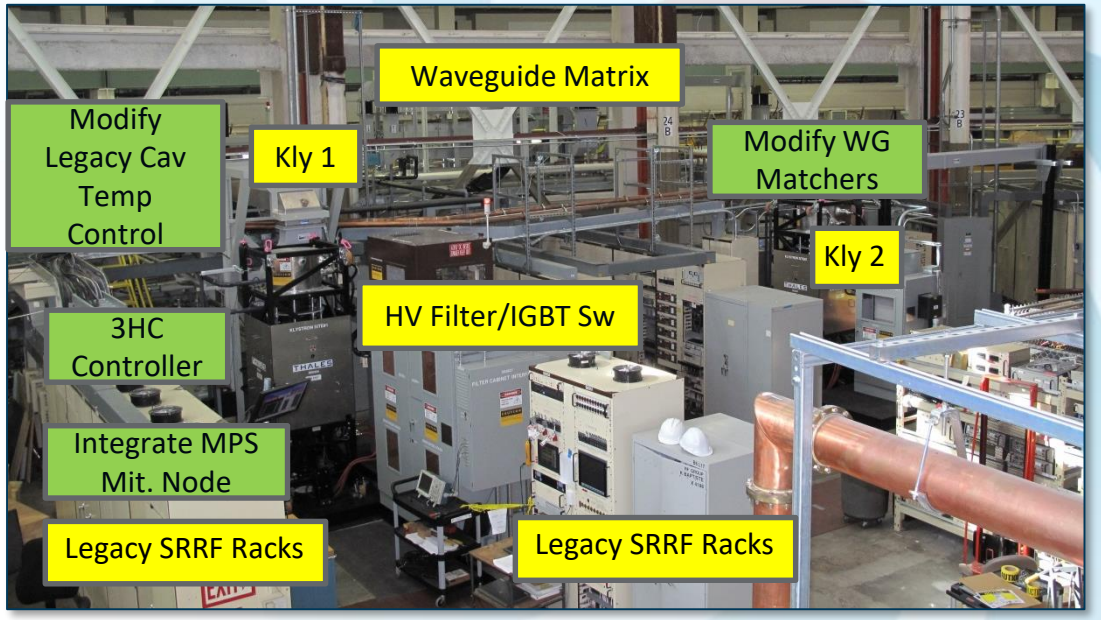
- None



Storage Ring RF – Scope & Deliverables

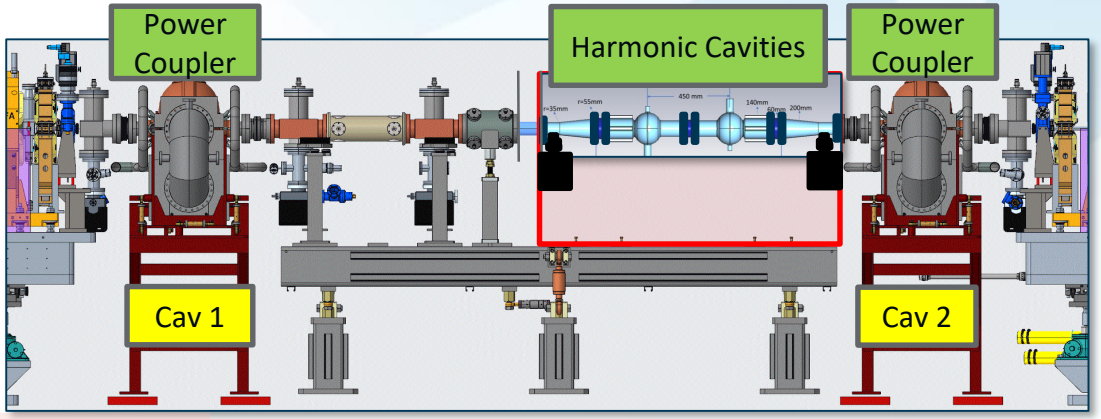
ALS-U Scope

1. Design & Fabricate (3), install (2) New Passive 3rd Harmonic Cavities, Voltage Controllers, Temperature Controllers
2. Modify Legacy Cavity power coupler to increase coupling
3. Modify WG Matcher section to avoid AR interference
4. Install/Integrate MPS Mitigation Node to SRRF LLRF & EPS Sys.
5. Modify Legacy Cavity Temperature Control System



ALS Scope

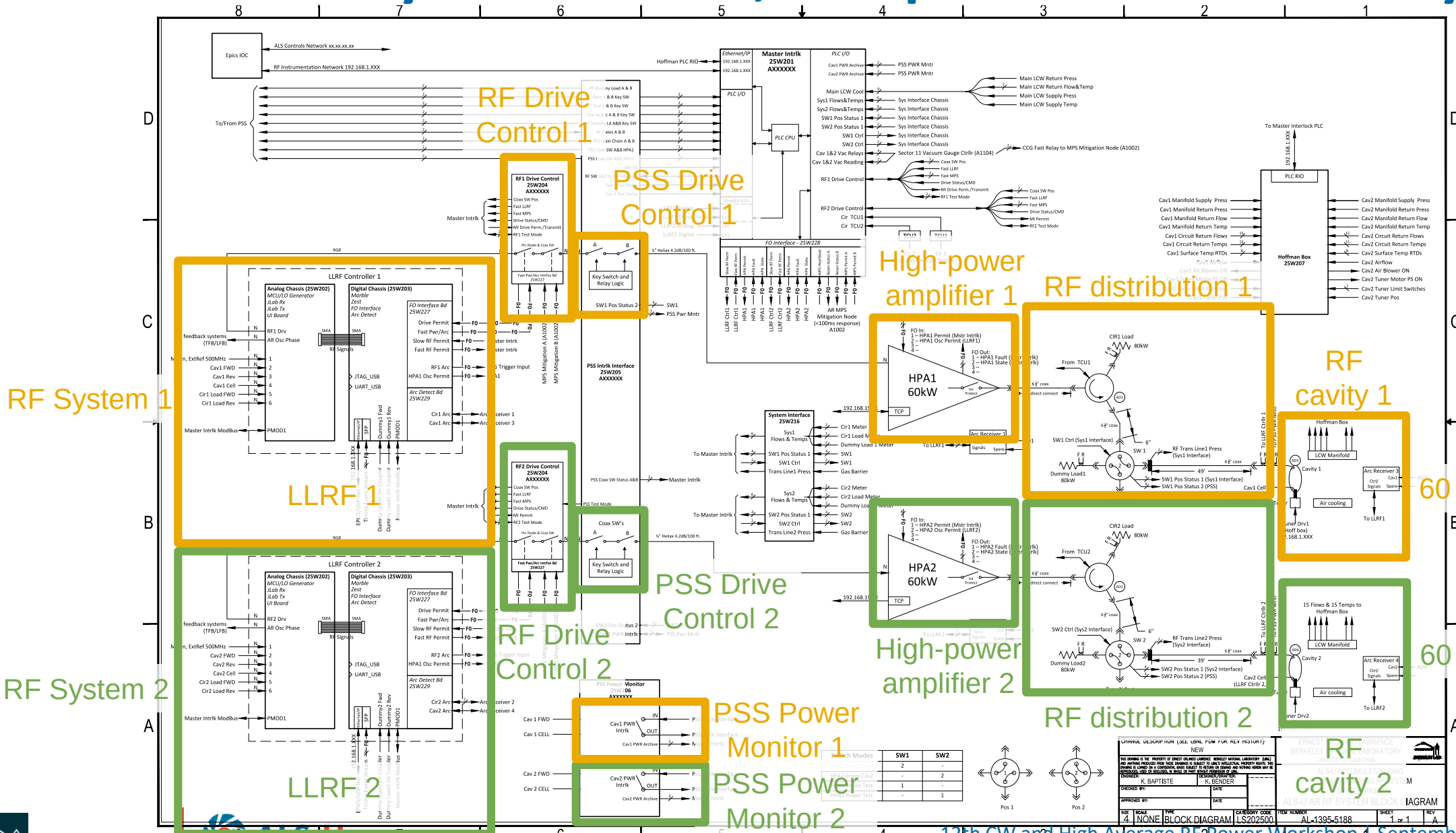
- Maintain & upgrade SR RF sub-systems
  - HVPS, Filter Cabinet and IGBT dis-connect switch
  - PLC based Control & Interlock systems (replace in future AIP)
  - Redundant, 2-klystron system with a wave guide switch matrix
  - D-LLRF Controller
- Cavity Cooling Interlock systems (replace in future AIP)
- Tuner Drive Motor & Controller (replace in future AIP)



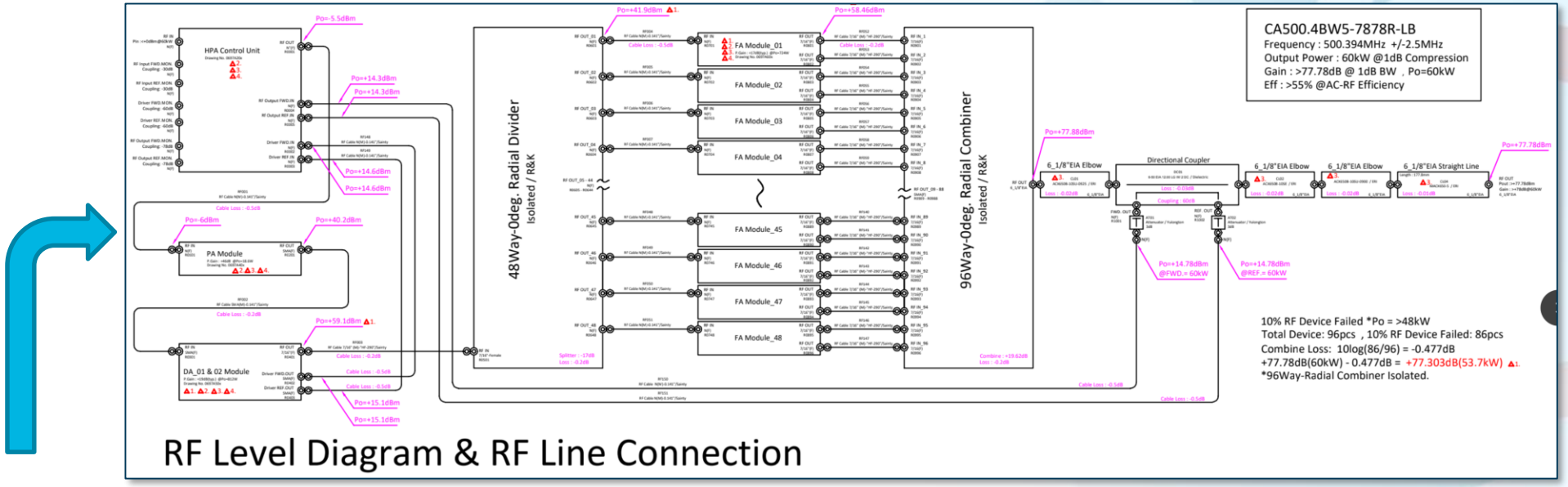
See talk: Dual Klystron Driven Storage Ring RF System at Advanced Light Source on behalf of Ben Flugstad by K. Baptiste

RF Systems Plans ans Status

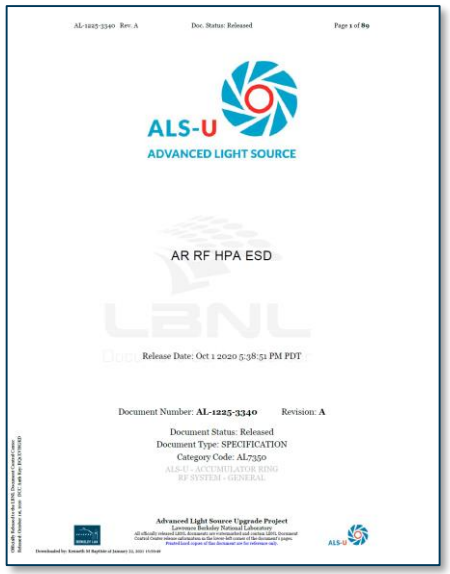
ALS-U: AR RF System: 2 new, independent 60 kW RF systems



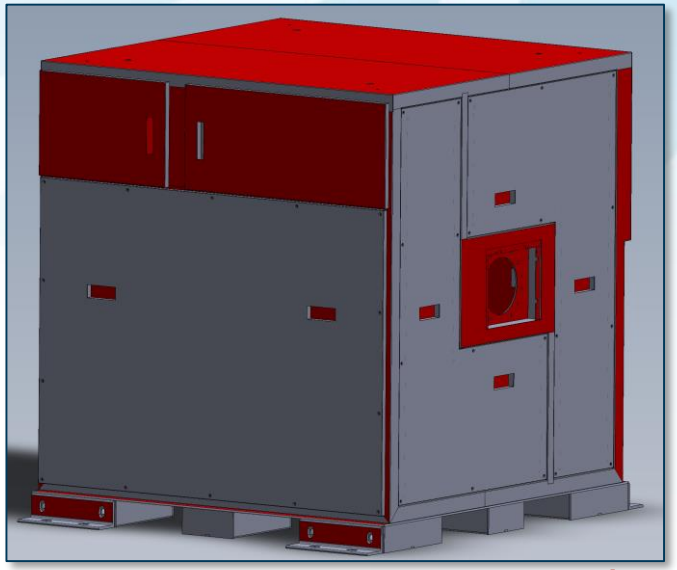
ALS-U: AR RF Solid State High Power Amplifier – Development



RF Level Diagram & RF Line Connection

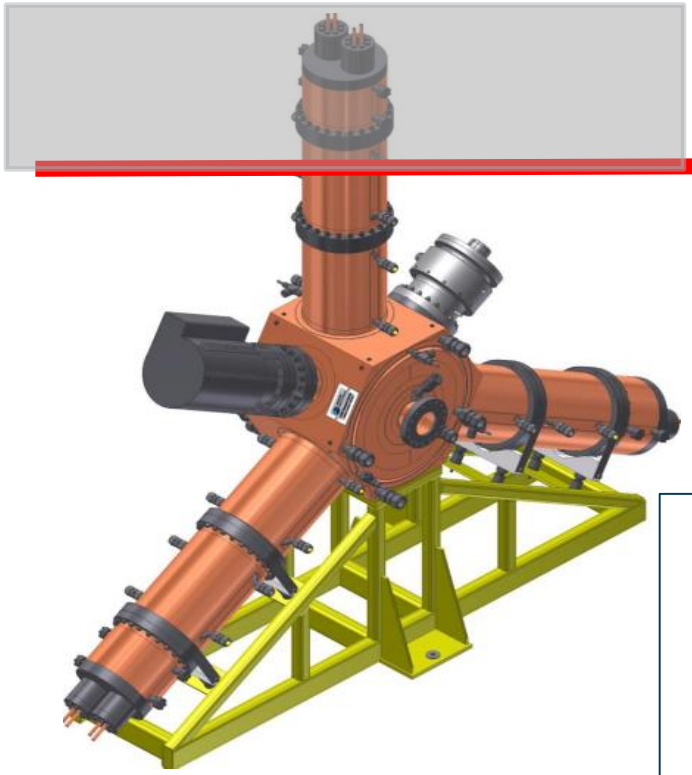


See talk: Planning, requirements, features, vendor design and development status of 60kW 500 MHz AR RF HPA for ALSU project by Shree Subhasish Basak



ALS-U: AR RF Cavities – Development

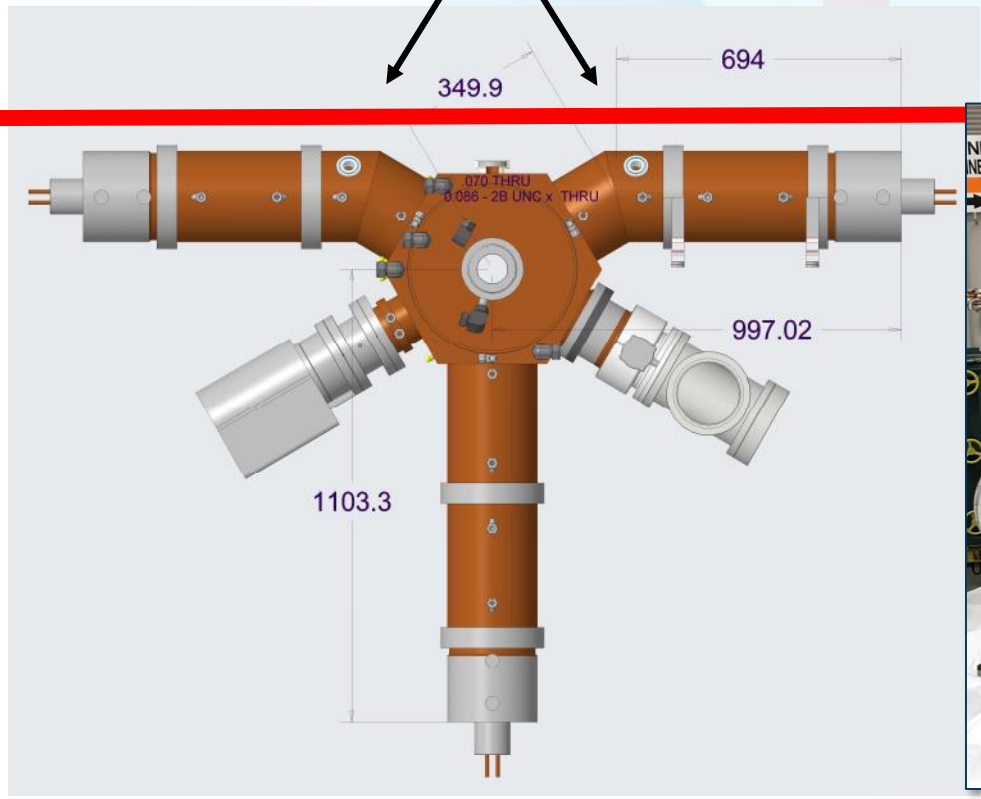
SR Tunnel Roof Blocks



Ceiling height

Commercially Available Configuration

Mitred Bends Added

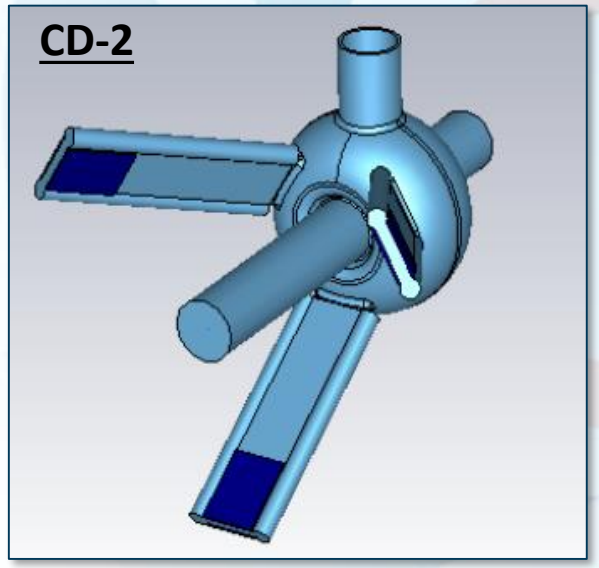


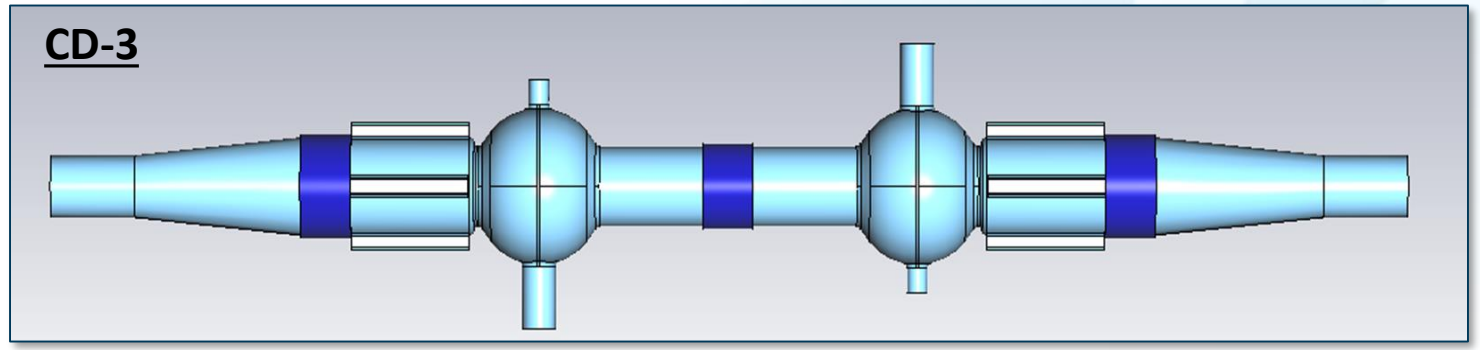
LBNL Configuration

ALS-U: 3HC RF Design Complete, work led by T. Luo

New 3rd Harmonic Cavity Design

- 1.5 GHz normal conducting passive cavity.
- 2 cavities required to achieve voltage
- Low r/Q design – better beam dynamics
- Beamline HOM Dampers based on commercial design



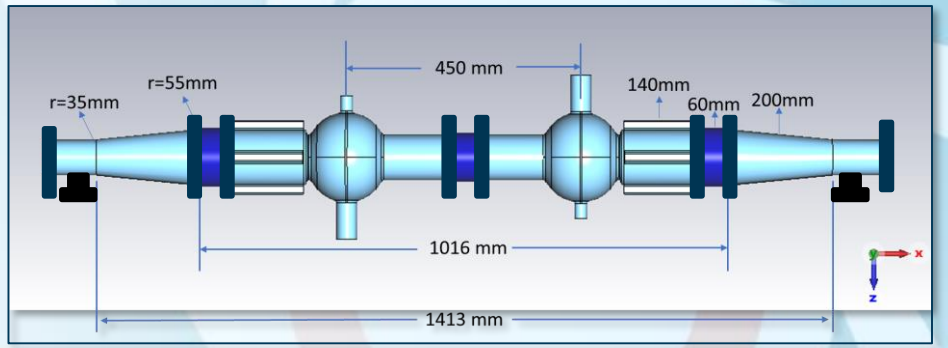


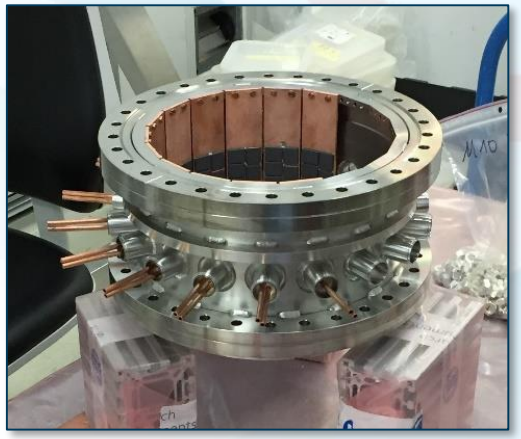
Cavity Parameters	
Frequency (GHz)	1.504 (target 1.501)
r/Q (Ohm)	19
Q_0	34900
Cavity voltage (kV)	90
R_S (MOhm) (90% Q/100% Q)	0.59/0.65
P* (kW) (90% Q/100% Q)	6.9/6.2
PD_peak* (W/cm^2)	21.2

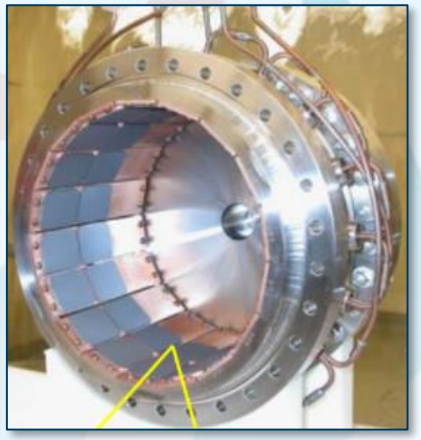
* $R = V^2/(2P)$, normalized to V=180 kV

ALS-U: SR 3HC Cavity – Ready for Mechanical Design/Manufacture

Design/Manufacture Plan
Award contract
Vendor to complete preliminary design
Step file to LBNL for RF performance verification
Conduct PDR, Close-out action items from PDR
Vendor to complete final design
Step file to LBNL for RF performance verification
Conduct FDR, Close-out action items from FDR
Release vendor to manufacture
FAT, Ship Deliverables
LBNL receival/acceptance







Commercial Ferrite HOM Beam Pipe Damper

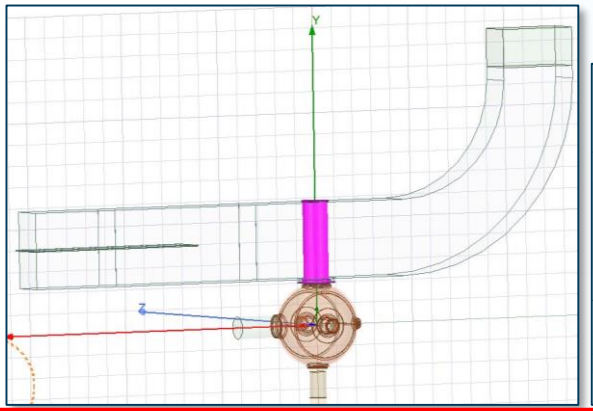
Current approach:

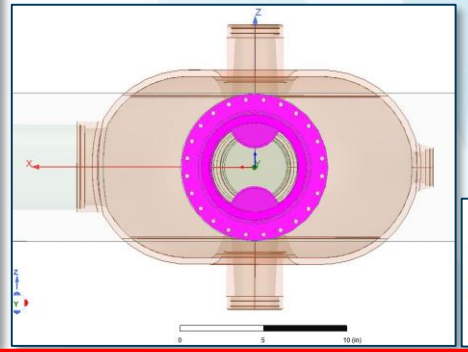
- 18 copper carriers
- 100 mm diameter beam tube
- Copper carriers includes one or two ferrite tiles
- Power dissipation capability of about 7.5W/cm^2

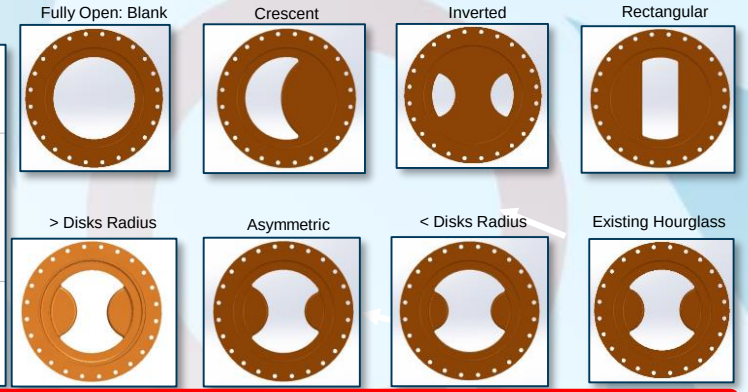
ALS-U: Legacy Cavity Power Coupler, Increase β = 3.1 -> 10+

Aperture Coupler

- Ansys HFSS
- Calculated β = 3.6 – 3.7
- Actual β = 3.15
- Multiple aperture shapes reviewed, no improvement

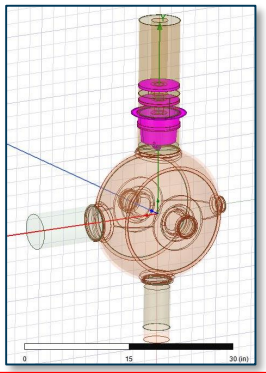


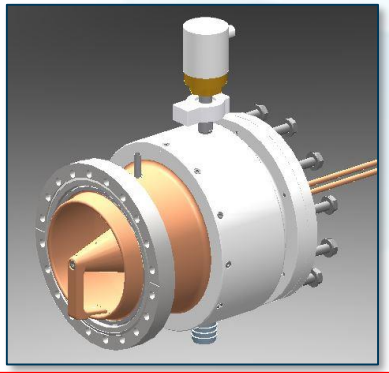




Coaxial Loop Coupler

- "Doris" style
- Many dozens in service, commercially available
- Used in AR RF Cavities
- Calculated β up to 20

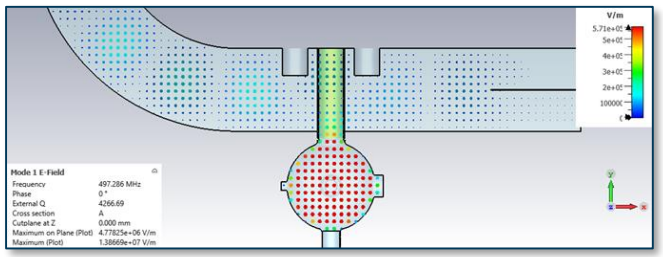


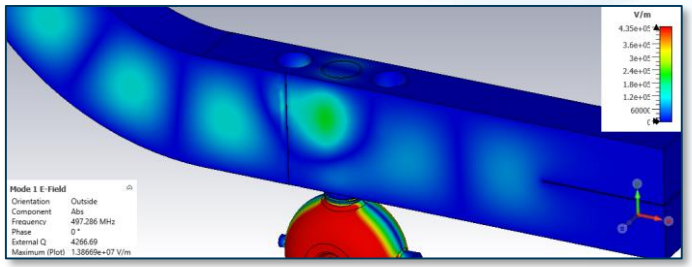


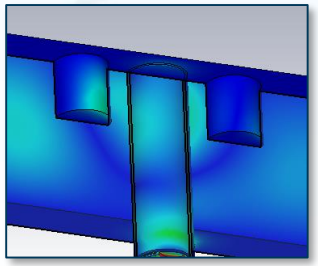
Coupling type	Magnetic loop coupling
Vacuum interface	CF 160
Coaxial interface	EIA 6 1/8 inch
Maximum power	120 kW
Frequency range	Up to 500 MHz
Coupling	variable by rotation
Cooling	Water cooling of inner and outer conductor Air cooling of ceramics
Leak tightness	2 x 10^{-10} mBar*l/s

Waveguide Stubs

- CST
- r=70 mm, h=150 mm
- 200 mm stub CL to aperture CL
- Calculated β =10







ALS-U: Ready for Mech. Design/Manufacture

Work led by B. Flugstad

Design/Manufacture Plan
Award contract
Vendor to complete preliminary design
Step file to LBNL for RF performance verification
Vendor to complete final design
Step file to LBNL for RF performance verification
Conduct FDR, Close-out action items from FDR
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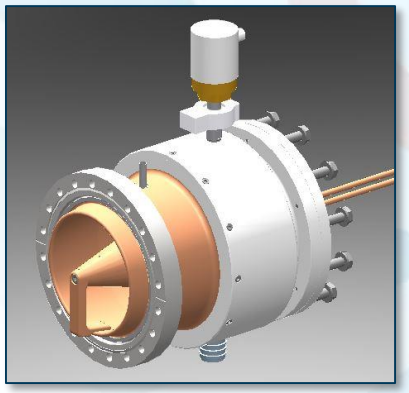
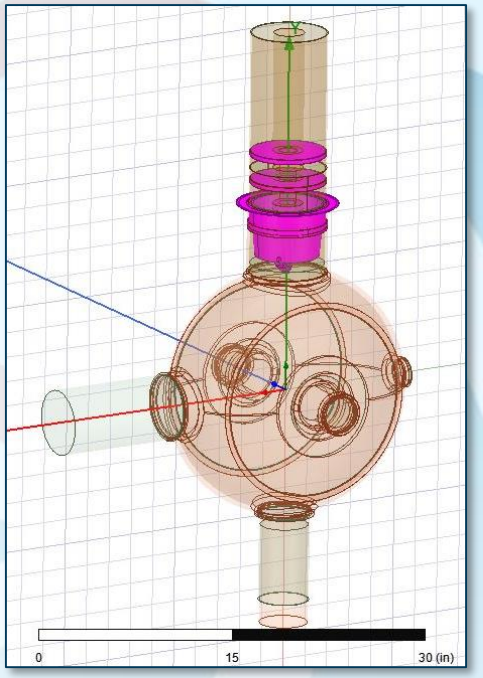
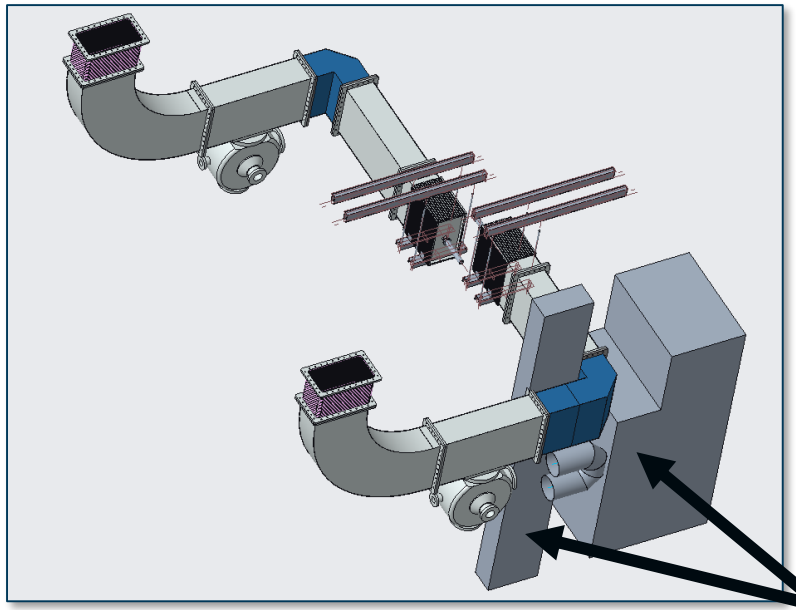




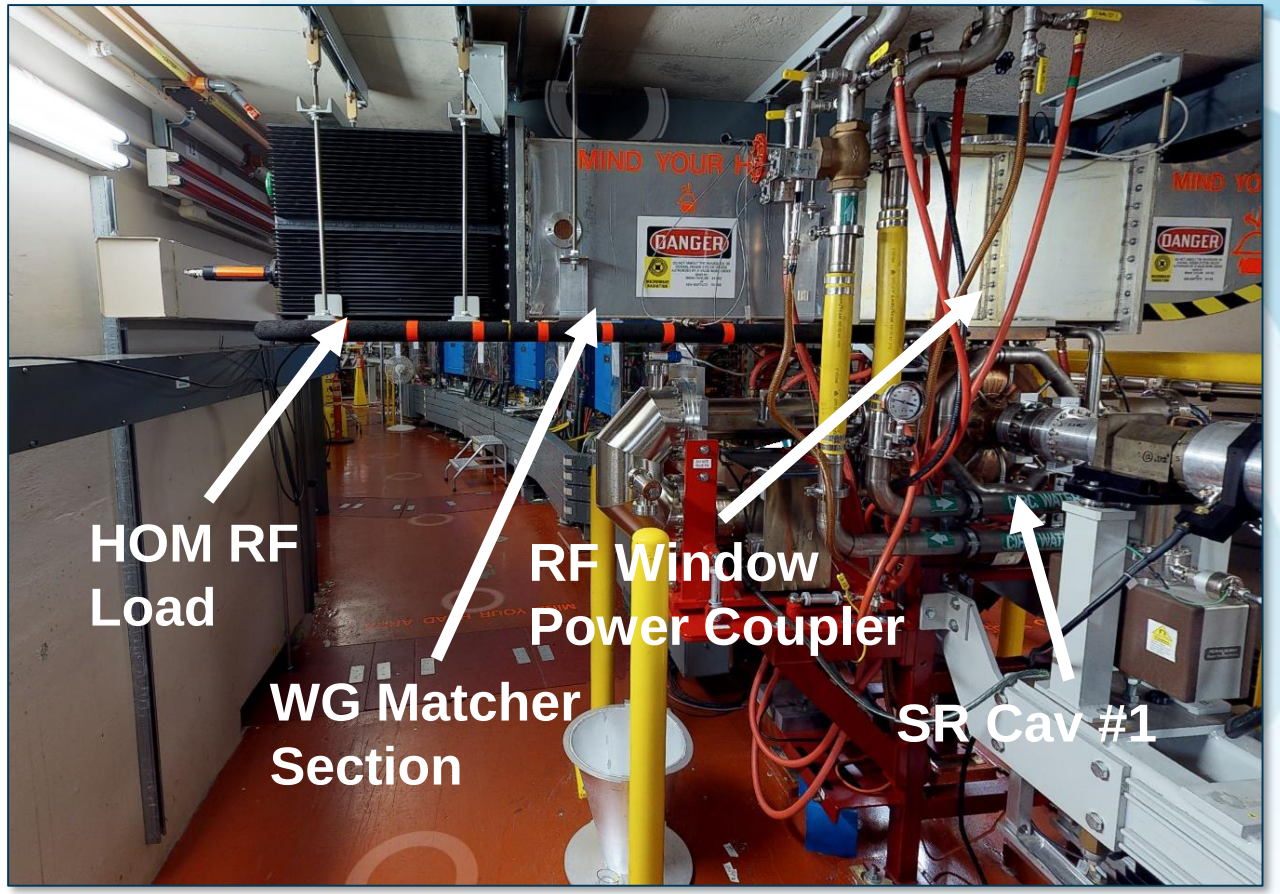
Coupling type	Magnetic loop coupling
Vacuum interface	CF 160
Coaxial interface	EIA 6 1/8 inch
Maximum power	120 kW
Frequency range	Up to 500 MHz
Coupling	variable by rotation
Cooling	Water cooling of inner and outer conductor Air cooling of ceramics
Leak tightness	2×10^{-10} mBar*l/s

ALS-U: Modify SRRF Cavities 1 & 2, WG Matcher - AR Interference

Design/Manufacture Plan
Award contract
Conduct FDR, Close-out action items from FDR
Ship Deliverables
LBNL receival/acceptance

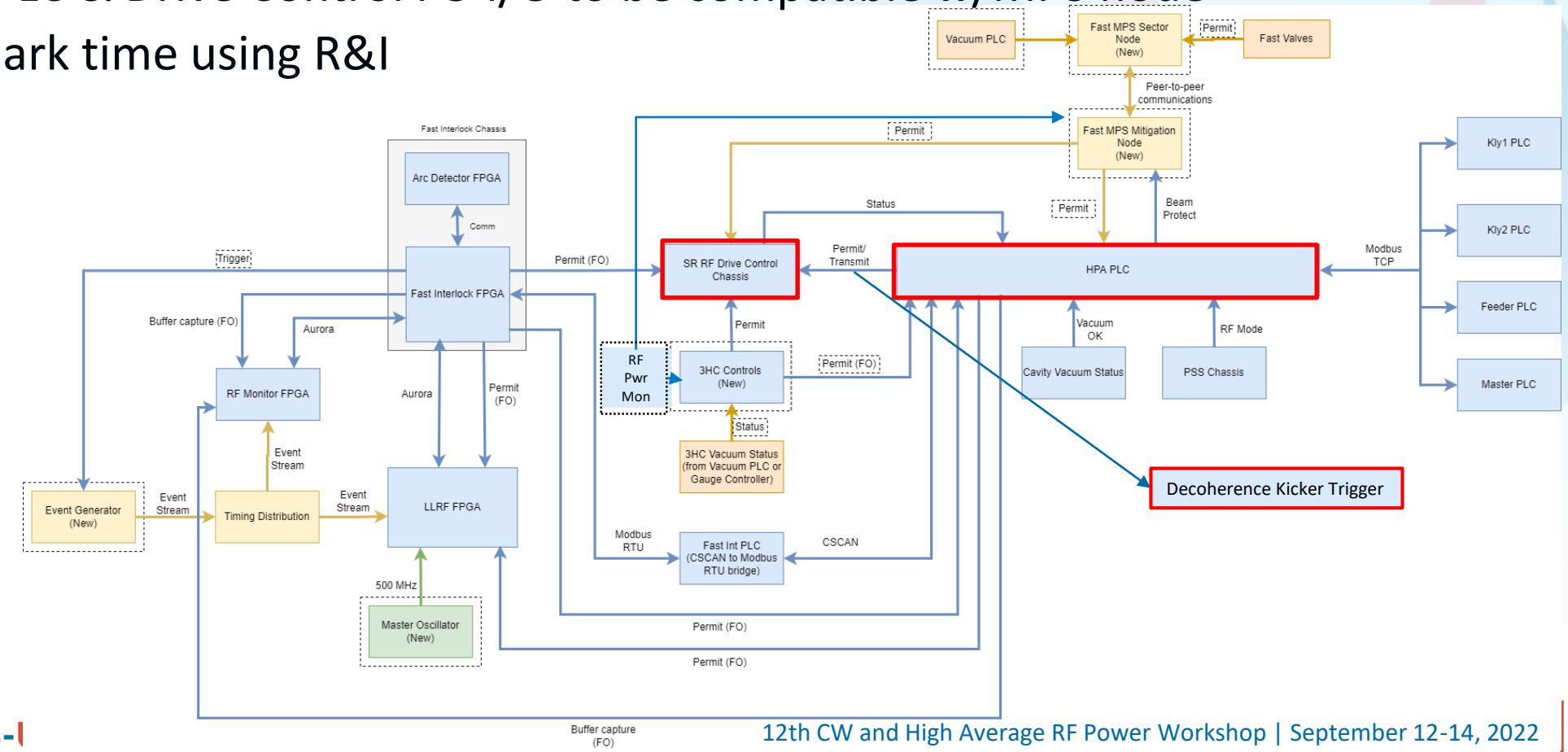


Keep clear space volumes



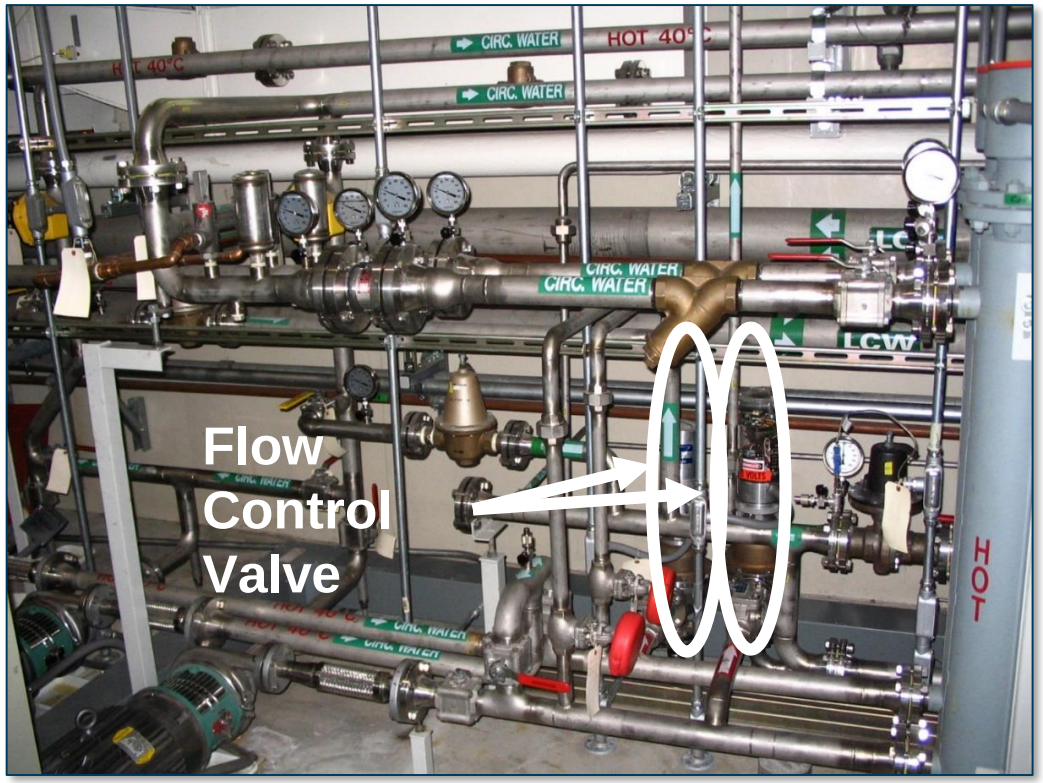
ALS-U: SRRF, MPS Mitigation Node Integration

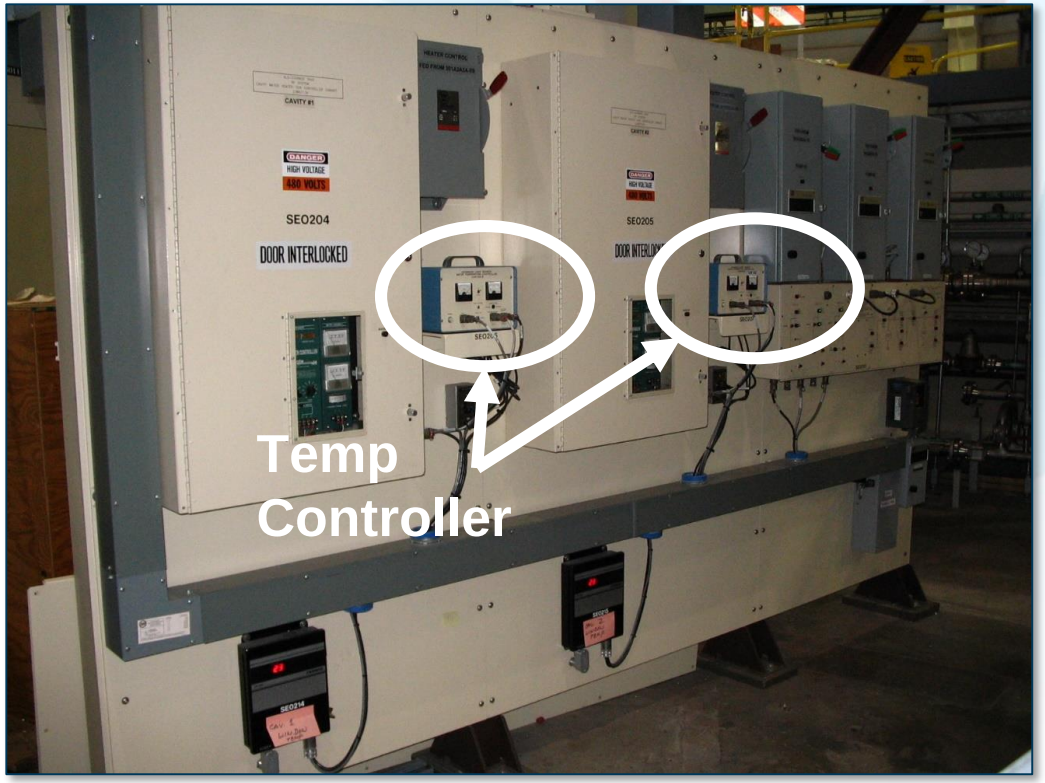
- Final Design has begun
- Interfaces are well understood: SR RF ICD, Vac ICD, Vac Controls & Instrumentation ICDs
- RF design similar to AR
- Redesign HPA PLC & Drive Control FO I/O to be compatible w/MPS node
- Install during dark time using R&I



ALS-U: SRRF Cavities, Upgrade Cav Temp Controller

- Replace motorized flow control valve
- Replace analog PI controller with PLC based PID controller
- Installed during ALS Maintenance shutdown period, pre-Darktime





Summary

- Partnership and coordination between ALS and ALS-U.
- The ALS Storage Ring RF system is being re-used for the new ALS-U Storage Ring. It is operational and it is ready for a few interface modifications to be compatible with the AR, new beam loading characteristics and ALS-U MPS/Controls.
- The 3rd Harmonic Cavities RF design is complete. We will award the mechanical design/manufacture contract this year and expect delivery in 2024, well over 1 year before dark time.
- Plans are in place for the smaller tasks such as modifications to RF Drive Control interfaces and PLC interlocks, along with waveguide modifications, cavity power coupler replacement and a cavity cooling valve replacement, two of which will be done prior to dark-time, reducing risk.

Thank you. Questions?

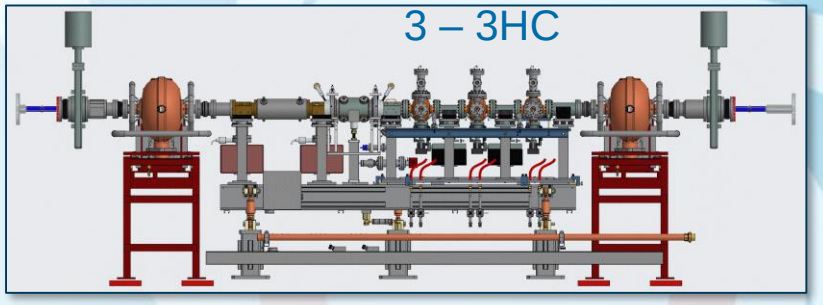
Back-up slides

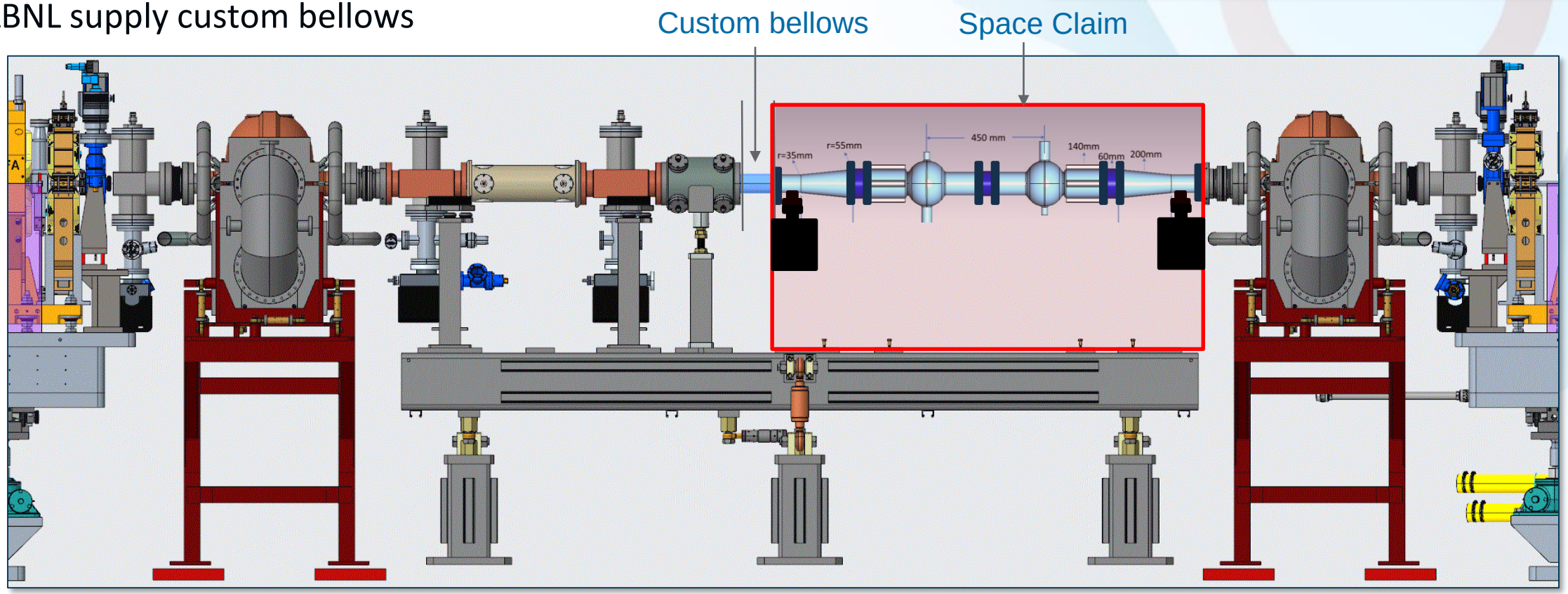
1. SR 3rd Harmonic Cavity Installation - Darktime

Location: SR03S

- Volume space claim
- Vendor to supply cavities, HOM dampers, tapers, IP, cooling header and support system/raft
- LBNL supply custom bellows

Current SR03S



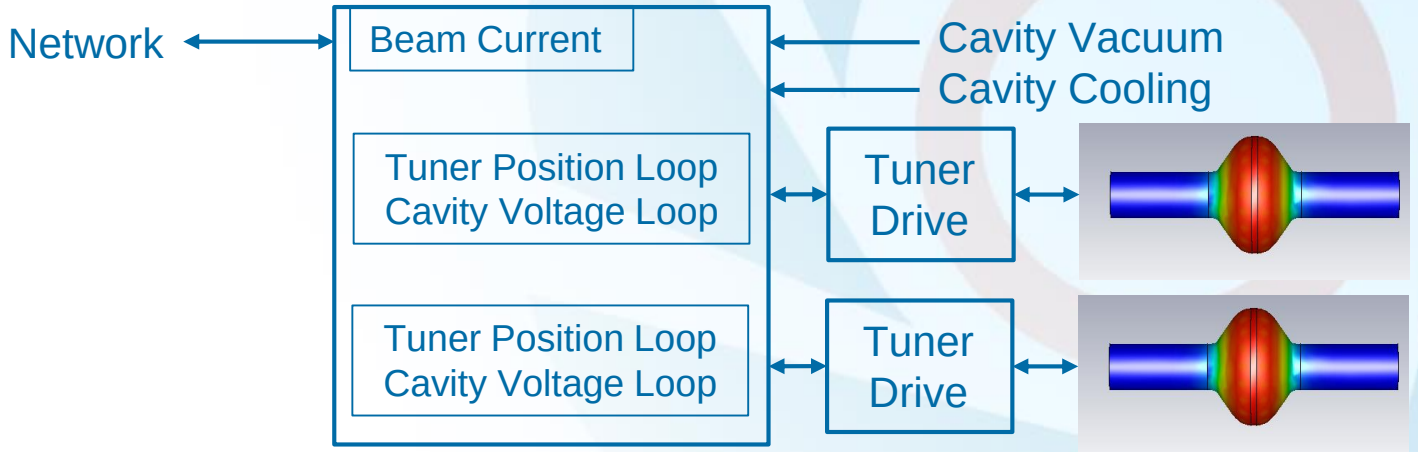


Preliminary Design – 3HC RF Cavity Controller

New 3rd harmonic Cavity

- Amplitude Controller
  - Tuner resonance controller
- 3HC EPS
  - Cavity Cooling Inst. & Interlocks
  - Cavity Vacuum Interlocks
  - Local HMI
  - Engineering GUI
  - Fault capturing/1st Fault
- Controls
  - EPICS Interface
    - Tuner Controller
    - 3HC EPS
  - Operation GUI/High Level App

- Install pre-dark time, connect using R&I during dark time.



AB CompactLogix
- Digital I/O
- Analog I/O
- Stepper Motor I/O

Control System Integration

- 3HC Cavity Controller & MPS Mitigation Node
  - Signals, PVs, HMIs

Vacuum System Integration

- 3HC Cavity vacuum signals

SR RF Cavity Coaxial Coupler Adapter Design & Manufacture

- Award contract – adapter spool for coaxial coupler
- Vendor to complete preliminary design, includes:
  - Design to meet electro/magnetic requirements (freq, coupling range)
  - Design to meet vacuum requirements
  - Design to meet thermal requirements
  - Design for manufacturability
  - Design to meet interface requirements
- Send step file to LBNL for RF performance verification
- Upon design verification, organize joint PDR
- Conduct PDR, Close-out action items from PDR
- Vendor to complete final design
- Send step file to LBNL for RF performance verification
- Upon design verification, organize joint FDR
- Conduct FDR, Close-out action items from FDR
- Release vendor to manufacture
- FAT, Ship Deliverables
- LBNL receival/acceptance