ALS-U Plans for the RF Systems

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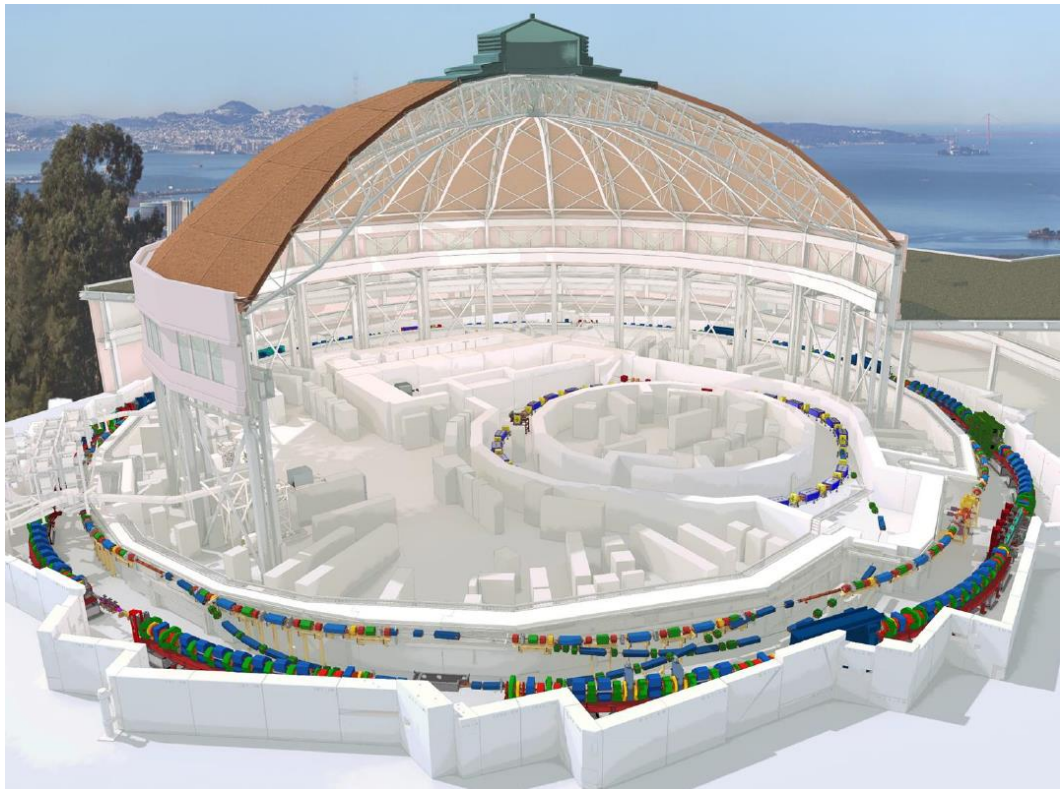
BERKELEY LAB

U.S. DEPARTMENT OF ENERGY | Office of Science

ALS-U ADVANCED LIGHT SOURCE

Outline

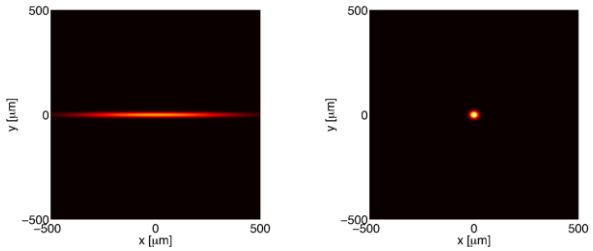
- ALS-U Project Overview
- Accumulator Ring RF
  - System Scope
  - System Requirements
  - Approach
    - RF Cavities
    - RF Source
    - Installation Challenges
- Storage Ring RF
  - System Scope
  - System Requirements
  - Approach
    - RF Cavities
    - Cavity Temperature Controllers
    - 3rd Harmonic Cavities
- Conclusion

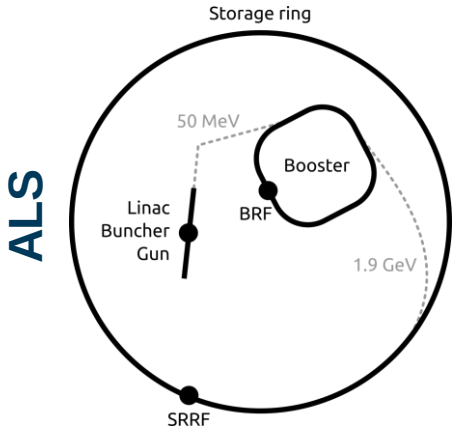


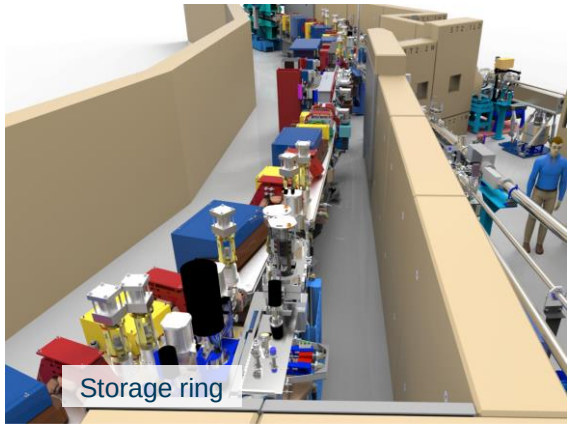
ALS-U: Overview

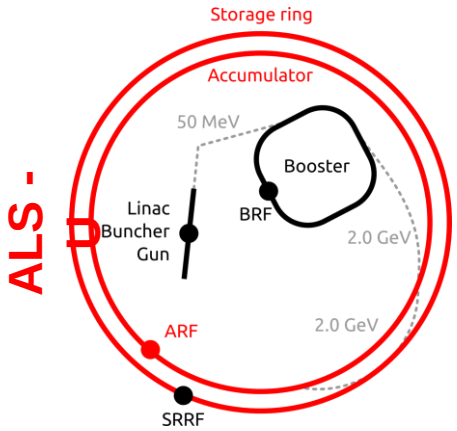
- **> 100 fold** increase in soft x-ray **brightness**
- Requires **new lattice** in the storage ring, diffraction limited emittance
- Unique: **on axis swap out injection** to satisfy the smaller dynamic apertures of the new lattice
- New **accumulator** ring for topping-up the swapped-out bunch train

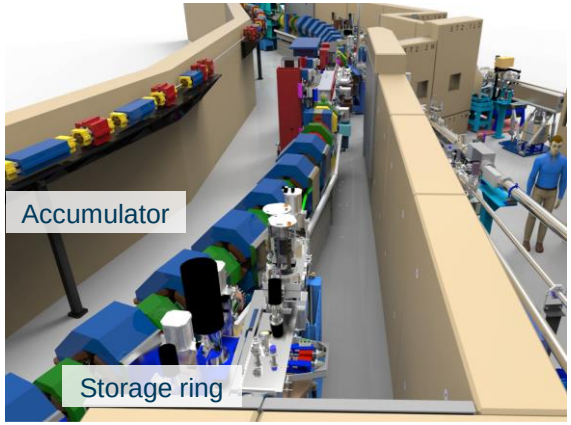
Beam profile





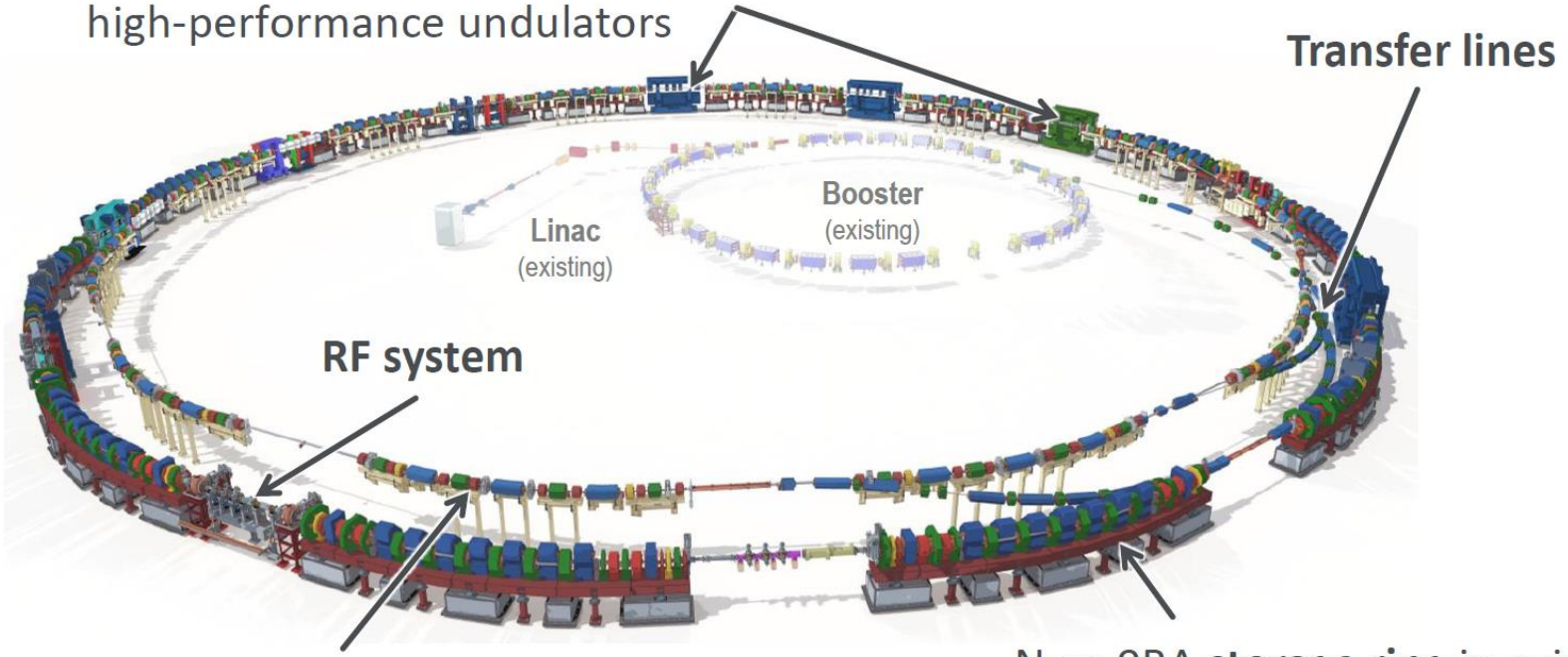






ALS-U: Overview

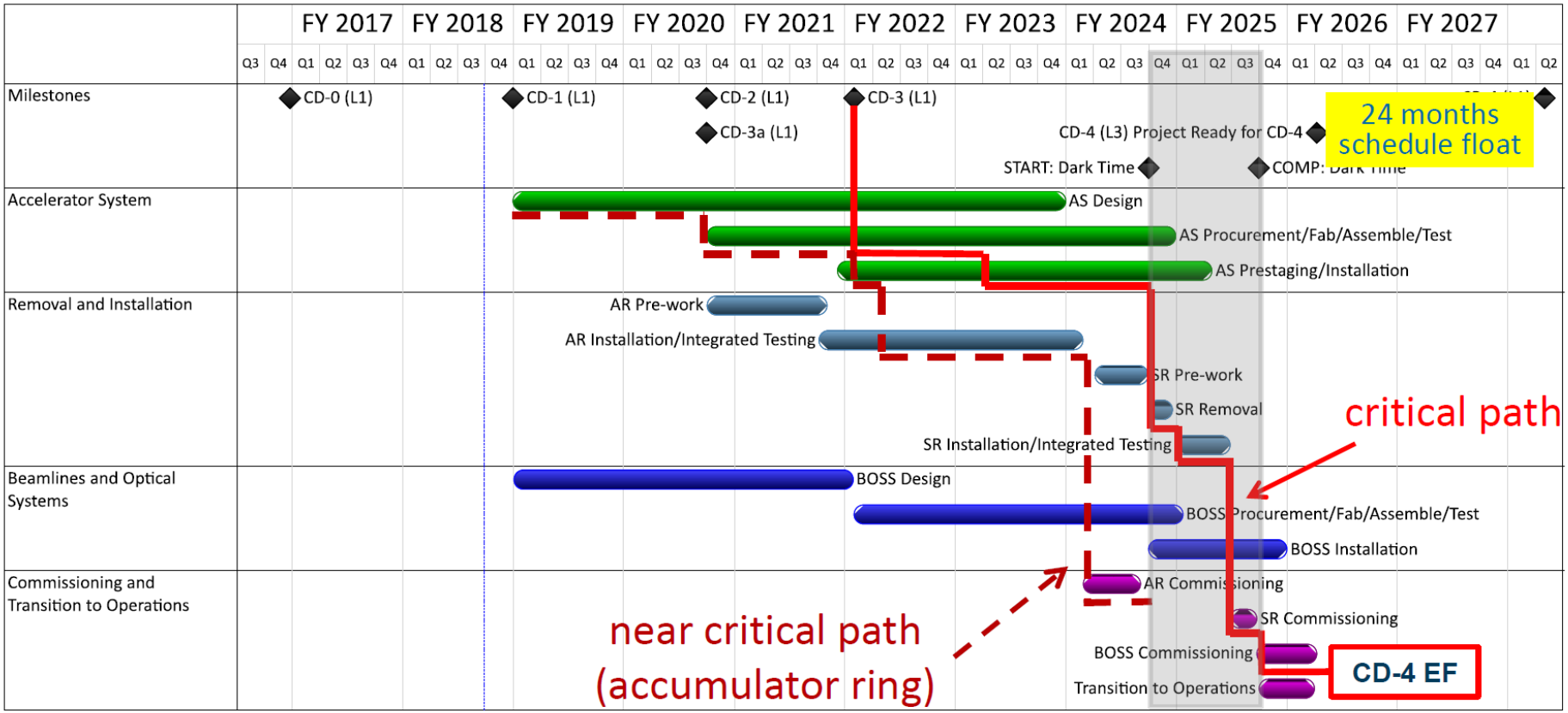
Small round **insertion-device** vacuum apertures are possible that allow new high-performance undulators



New **accumulator ring** for full-energy swap-out injection and recovery of bunch trains

New 9BA **storage ring** in existing tunnel optimized for low emittance and high soft x-ray brightness and coherent flux

ALS-U: Overview



- One year dark time
- Beamlines brought online in staged fashion during and after dark time
- 24 months of float after project early finish
- Install and commission the accumulator ring before dark time

Accumulator Ring RF System

AR RF System: Scope

- **New ring, therefore all new equipment**
  - New Cavities (x2)
  - New High Power 500 MHz CW RF Solid-State Amplifier (SSA) (x2)
  - RF Distribution
  - Control System Interface
  - Timing System Interface
  - Personnel Protection System Interface
  - AR Equipment Protection System Interface
  - AR RF Sub-systems
    - Digital Low Level RF Control
    - Cavity Resonance Control
    - Cavity Temperature Control
    - AR RF Equipment Protection (Arc, RF, Vac, Temp, Flow, etc.)
    - Vacuum System Interface
    - Utilities
  - Location Shielding Modifications
  - Pre-test and RF Conditioning
  - Installation

AR RF System: Cavity Requirements

ALS-U AR – 2.0 GeV	New Cavity
# of Cavities	2
R_s (ea)	5.0-3.0 MΩ
Cav Voltage (kV)	649
Coupling β	1-2
[redacted]	247
[redacted]	12.35 [1]
[redacted]	0
[redacted]	0
Parasitic Beam Pwr (kW)	0.2
Total Beam Pwr (kW)	12.54
Cavity Pwr (no beam) (kW)	42-70
Cavity Pwr (w/beam) (kW)	48-76
Waveguide Losses (kW)	1-2
High Power Amplifier (kW)	98-154

[1] 50 mA

AR RF System: Approach for New Cavities

Options

- Purchase Commercial Cavity
  - Research Instruments – EC 500 MHz HOM Damped, coaxial loop coupler
  - Toshiba – ASP 500 MHz HOM Damped, coaxial loop coupler
- Copy legacy ALS SR 500 MHz partially HOM Damped, aperture coupled
- Design new cavity by scaling NLC 714MHz HOM Damped, aperture coupled.

Down-Select

- Order/Manufacture 3 cavities, install 2 to satisfy the AR installation schedule.

then

- Continue to develop sector AR11S location for cavities in SR tunnel.
- Design/modify SR roof blocks to accommodate AR cavities/distribution.
- Design RF Distribution to accommodate the AR cavities & egress for waveguides from roof blocks.

AR RF System: Candidate Cavity Requirements

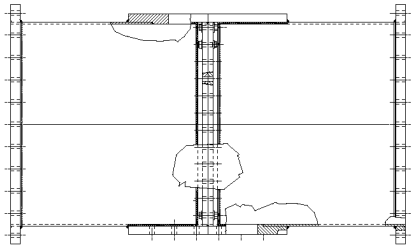
ALS-U AR – 2.0 GeV	ALS Cavity	Toshiba ASP Cavity	RI EC Cavity	Other HOM Damped Cavity
# of Cavities	2	2	2	2
R_s (ea)	4.9 MΩ	3.6 MΩ	3.4 MΩ	X.X MΩ
Cav Voltage (kV)	649	649	649	649
Coupling β	1.13	1.10	1.09	X.XX
[redacted]	247	247	247	247
[redacted]	12.35 [1]	12.35 [1]	12.35 [1]	12.35 [1]
[redacted]	0	0	0	0
[redacted]	0	0	0	0
Parasitic Beam Pwr (kW)	0.2	0.2	0.2	0.2
Total Beam Pwr (kW)	12.54	12.54	12.54	12.54
Cavity Pwr (no beam) (kW)	43	58.6	62	XX.X
Cavity Pwr (w/beam) (kW)	49.3	64.9	68.3	XX.X
Waveguide Losses (kW)	1.4	1.8	1.9	X.X
Power Amplifier (kW) total	100	131.6	138.5	XXX.X

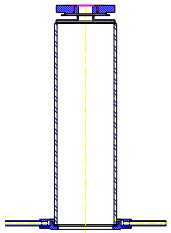
[1] 50 mA

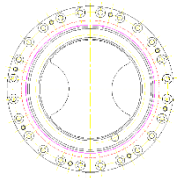
AR RF System: ALS Cavity

- The ALS cavity was based on the Daresbury cavity with some geometry/cooling modifications and was built to specification by Interatom/Siemens.
- The ALS cavity needs no modification to meet AR RF requirements. However, due to the significant interference with shielding, a change in the coupling scheme may be needed.

Split WR1800 Waveguide to Cavity Transition

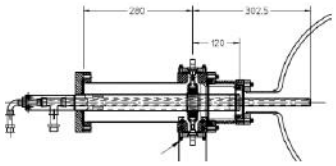




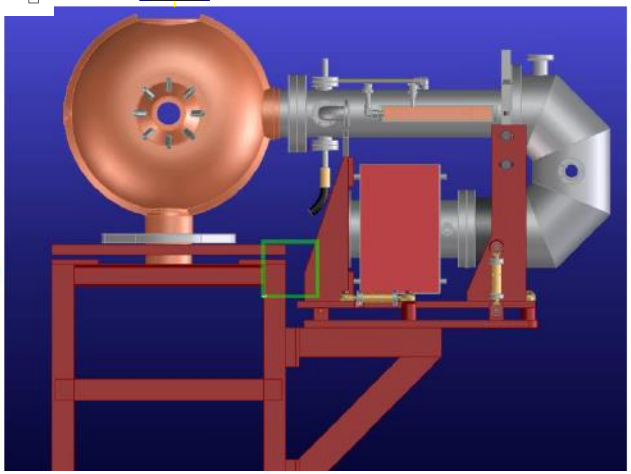


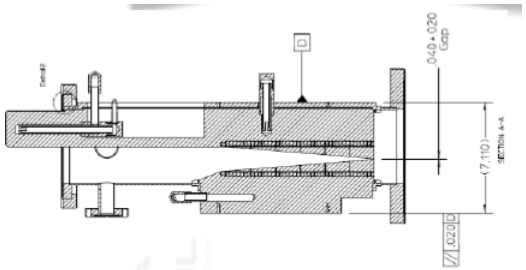
Iris Flange Profile

β: 1 to 3.2



HOM Damper I
E-Type Antenna damper designed and built at LBNL

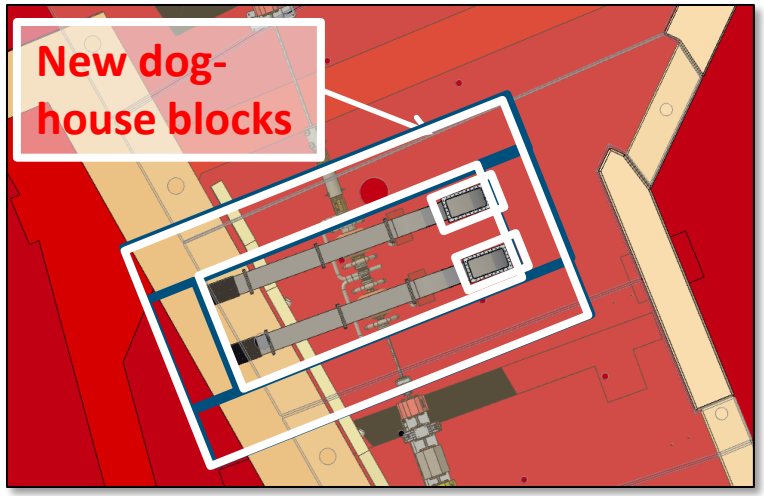


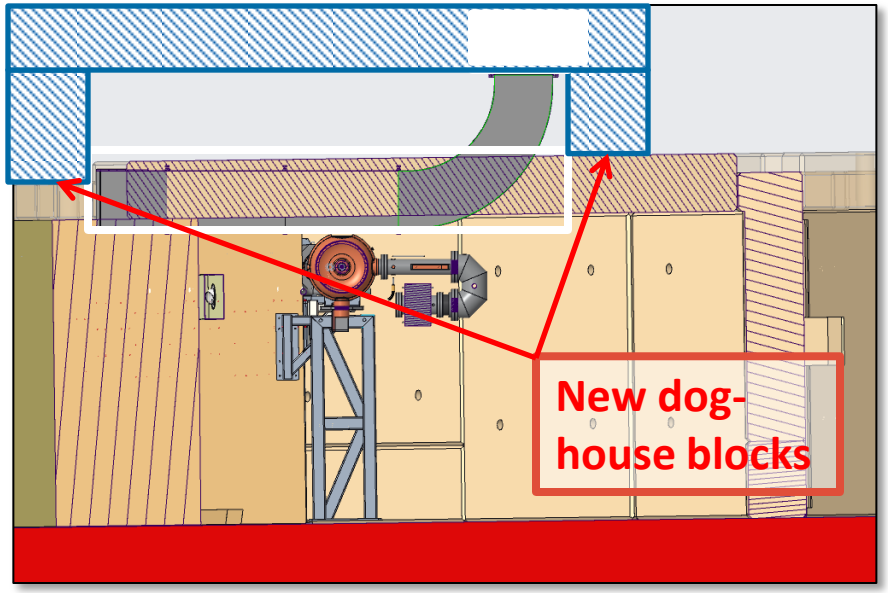


HOM Damper II
Ridged Waveguide damper designed and built at LBNL

AR RF: Shielding Block Mods ⇨ Significant

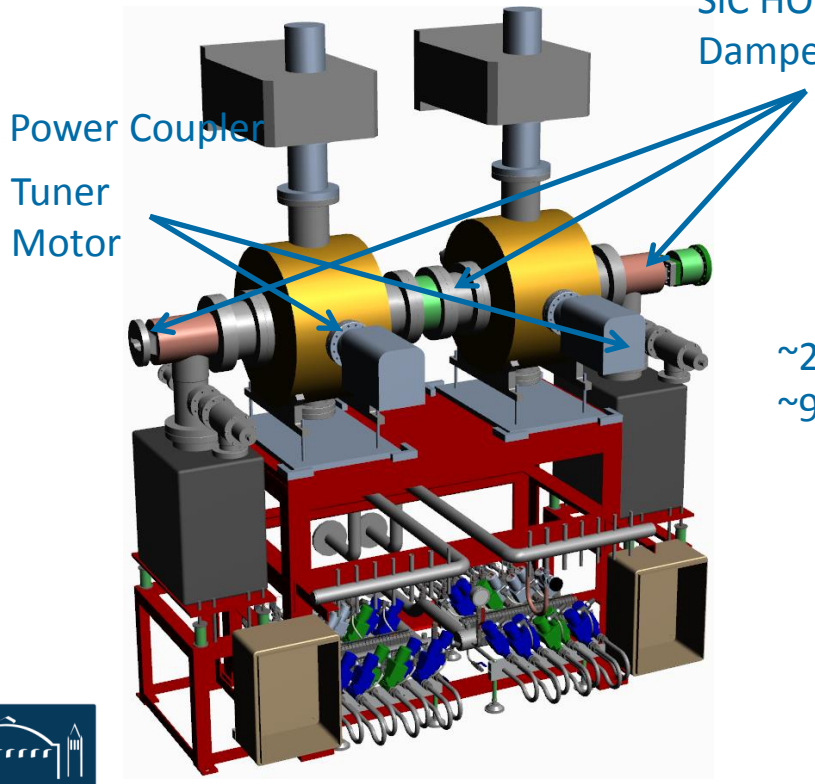
ALS Cavities – significant shielding mods needed

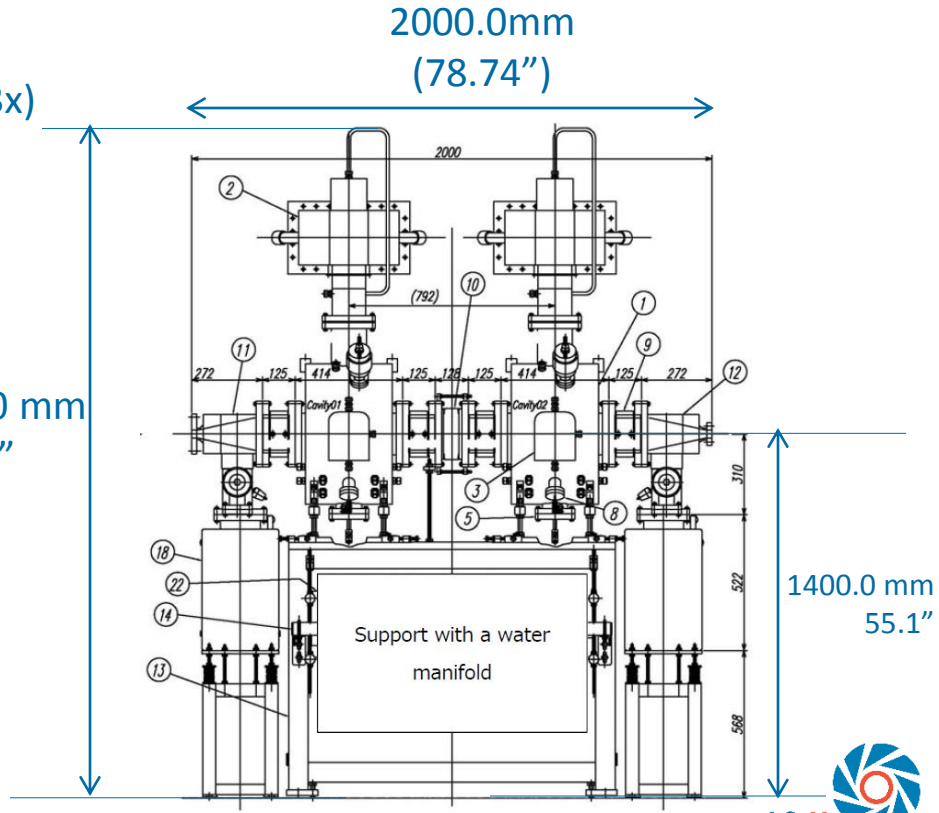




AR RF System: Toshiba ASP Cavity

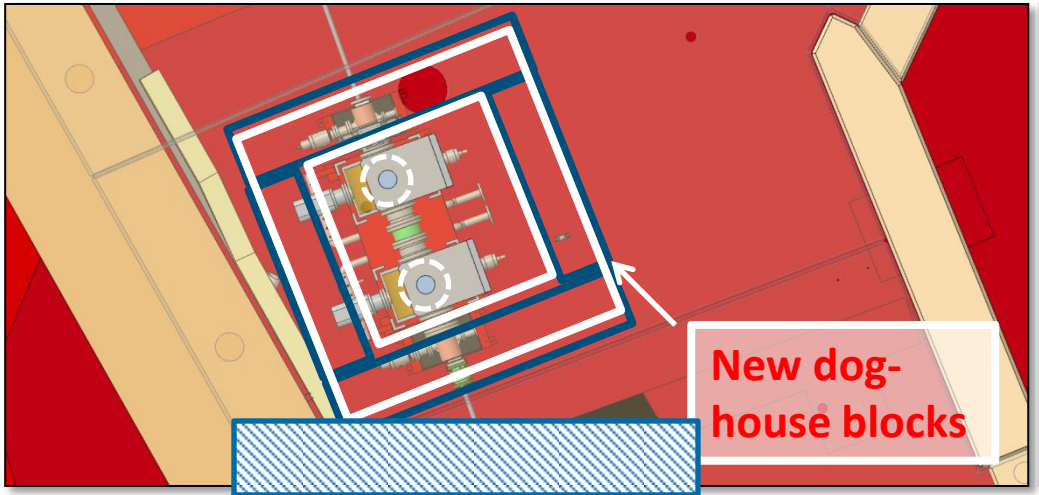
- Designed by a collaboration between KEK, Institute for Solid State Physics, Univ. of Tokyo and Toshiba from early 1990's.
- The Toshiba ASP cavity needs no modification to meet AR RF requirements. However, due to the minor interference with shielding, a change in the coupling scheme may be needed.

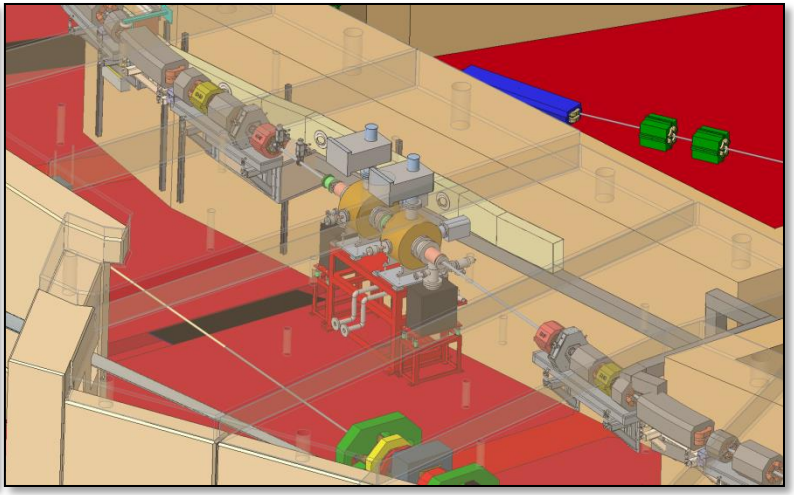


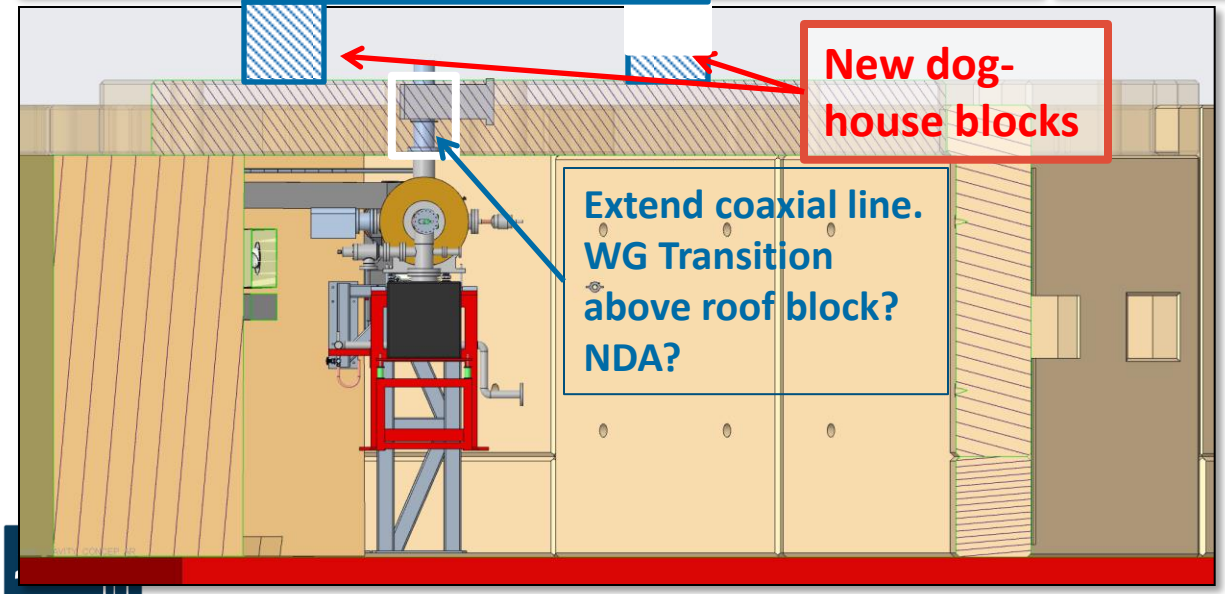


AR RF: Shielding Block Mods ⇨ Potentially Minor

Toshiba - ASP Cavity – potentially minor shielding mods

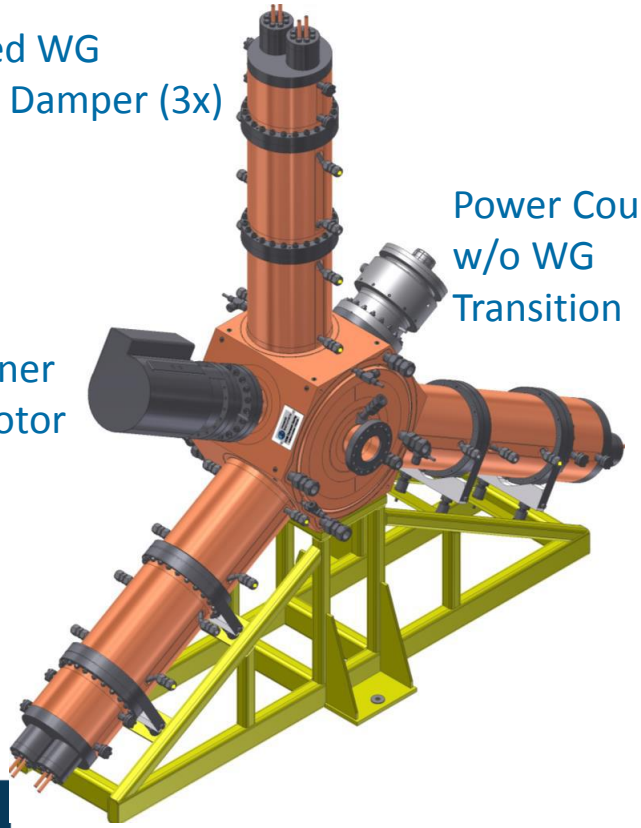


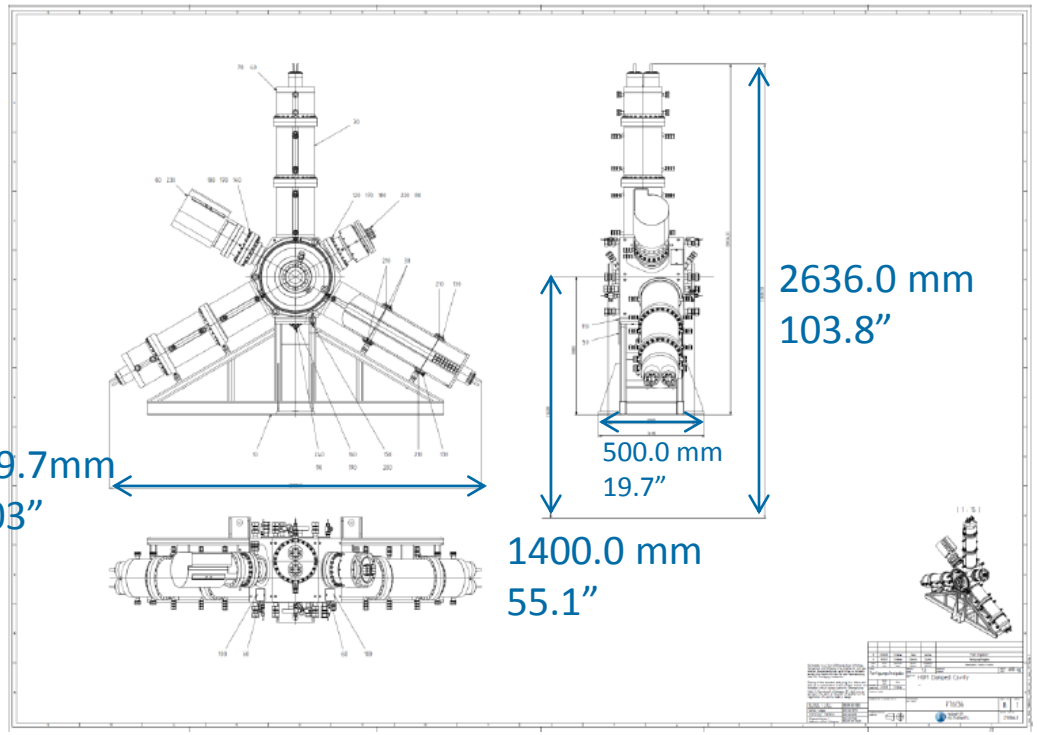




AR RF System: RI – EC Cavity

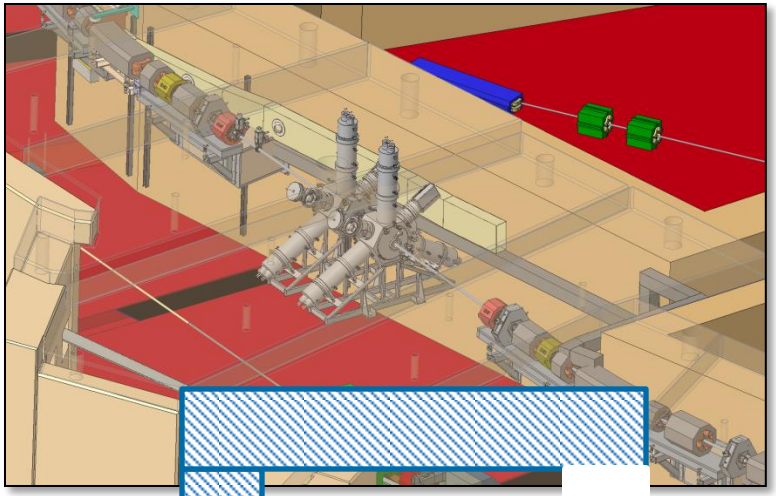
- Designed by a collaboration between Bessy, Delta, Daresbury and Tsing Hua University from 2000-2006. Modifiactions made by ALBA, RI and others have led to improved HOM dampers and power coupler mechanics & cooling.
- The RI EC cavity needs no modification to meet AR RF requirements. However, due to the significant interference with shielding, a change in the orientation and the shape of the HOM dampers may be needed.

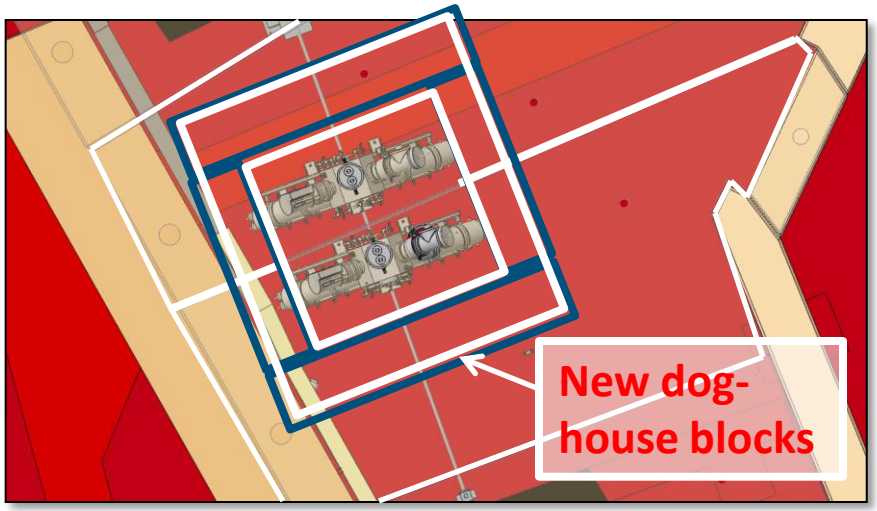


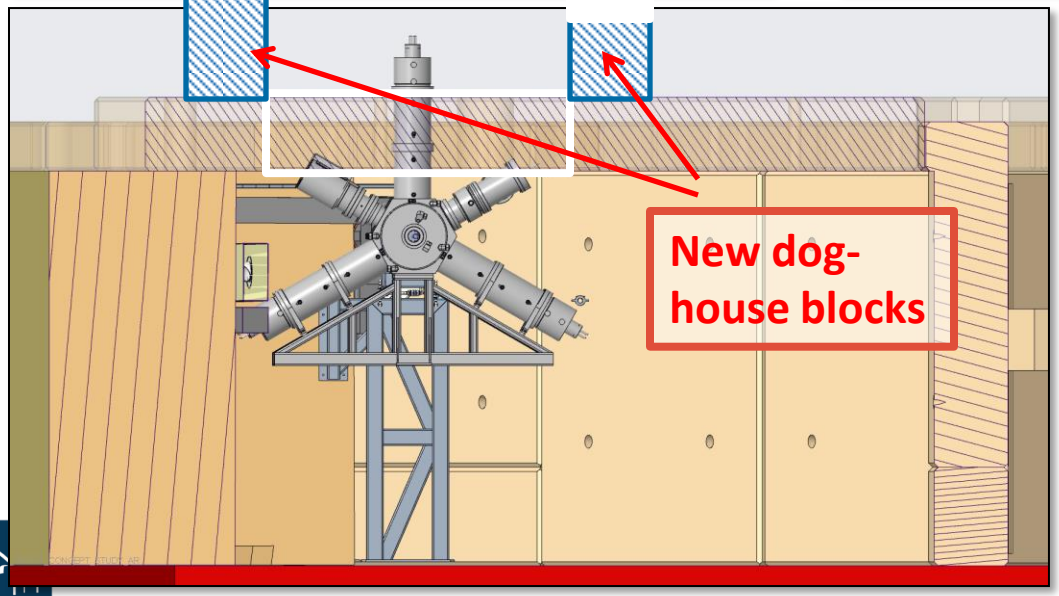


AR RF: Shielding Block Mods ⇨ Significant

Research Instruments EC Cavity – moderate shielding mods needed





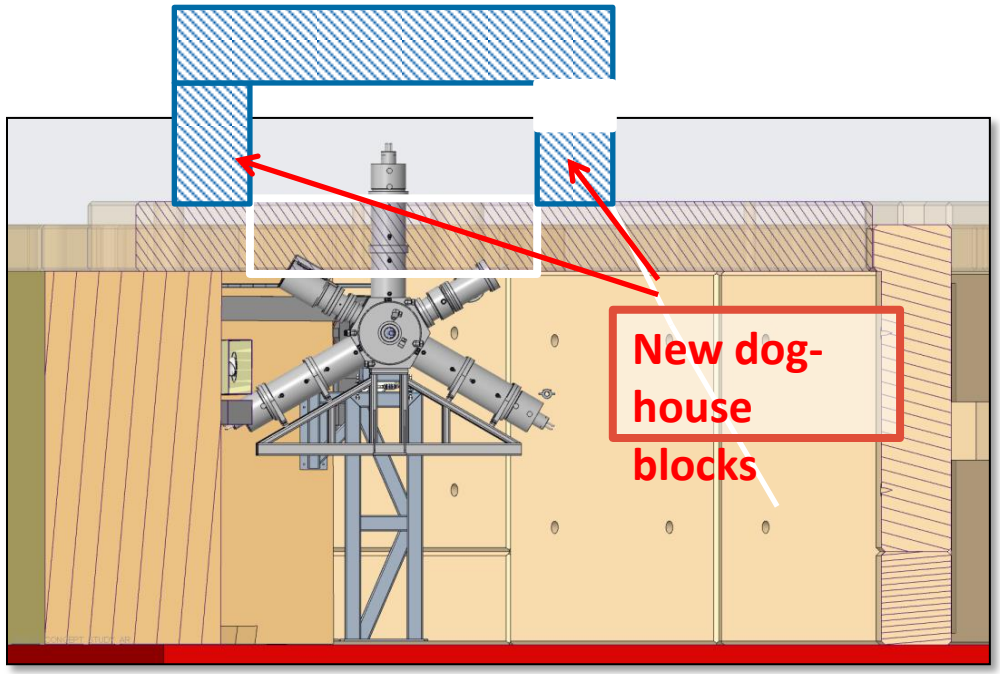


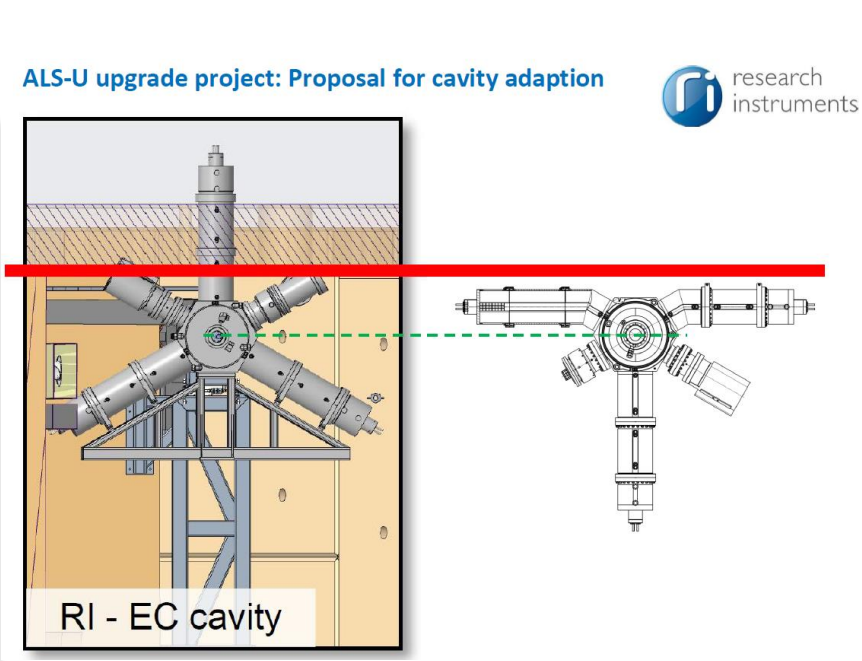
Coupler WG transition will remain vertical.

AR RF: Shielding Block Mods ⇨ Potentially Minor

Research Instruments EC Cavity

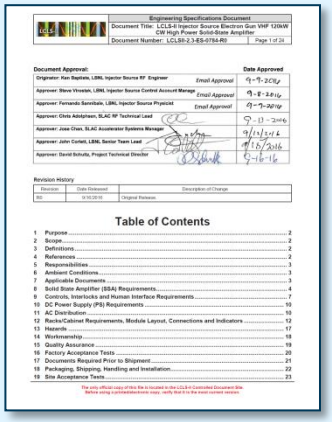
- orientation change, rotate cavity 180°
- proposed HOM Damper shape change, needs evaluation.

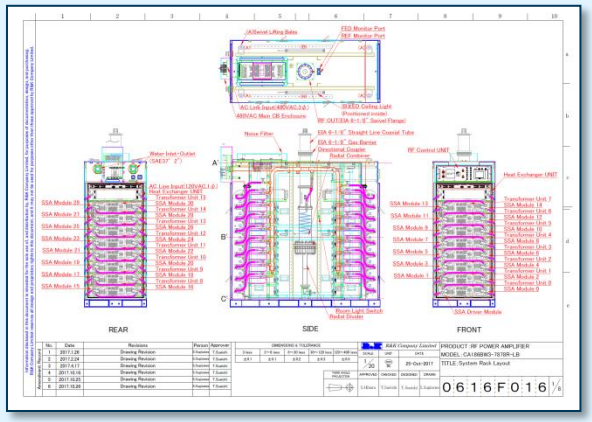




AR RF Source: Approach – RF SSA(s) ⇨ COTS*

- Specify-procure RF amplifiers: (2) 500 MHz (60 kW – 80 kW CW).
- Leverage recent experience:
  - FNAL RFQ, 162.5 MHz 75 kW CW SSA (2014)
  - LBNL delivered to LCLS II Gun B, 186 MHz (2x) 60 kW CW SSA (2017)

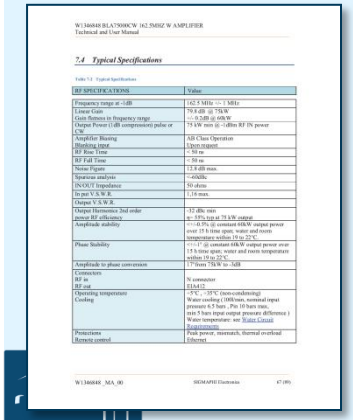


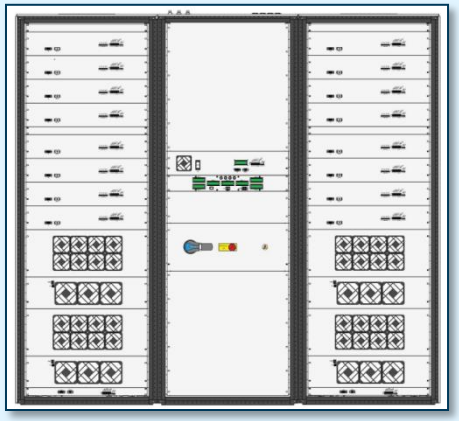


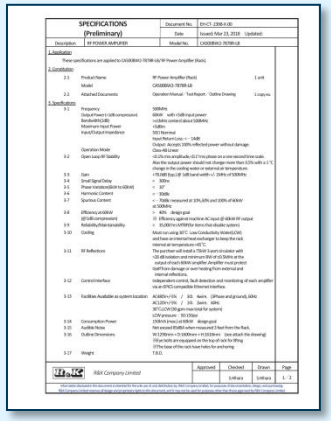
186 MHz SSA
60 kW CW
60 Final Transistors

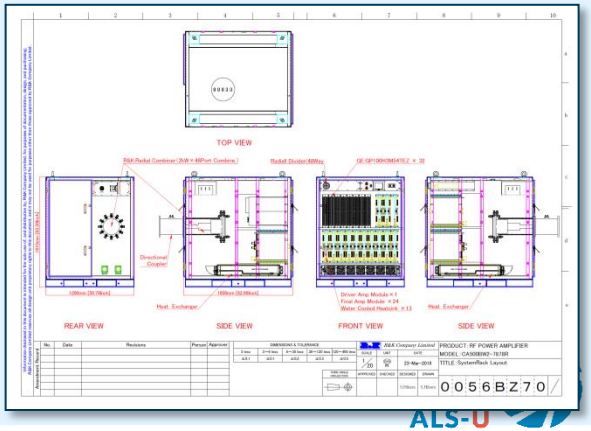
162.5 MHz SSA
75 kW CW
128 Final Transistors

(Preliminary)
500MHz SSA
60 kW CW
96 Final Transistors





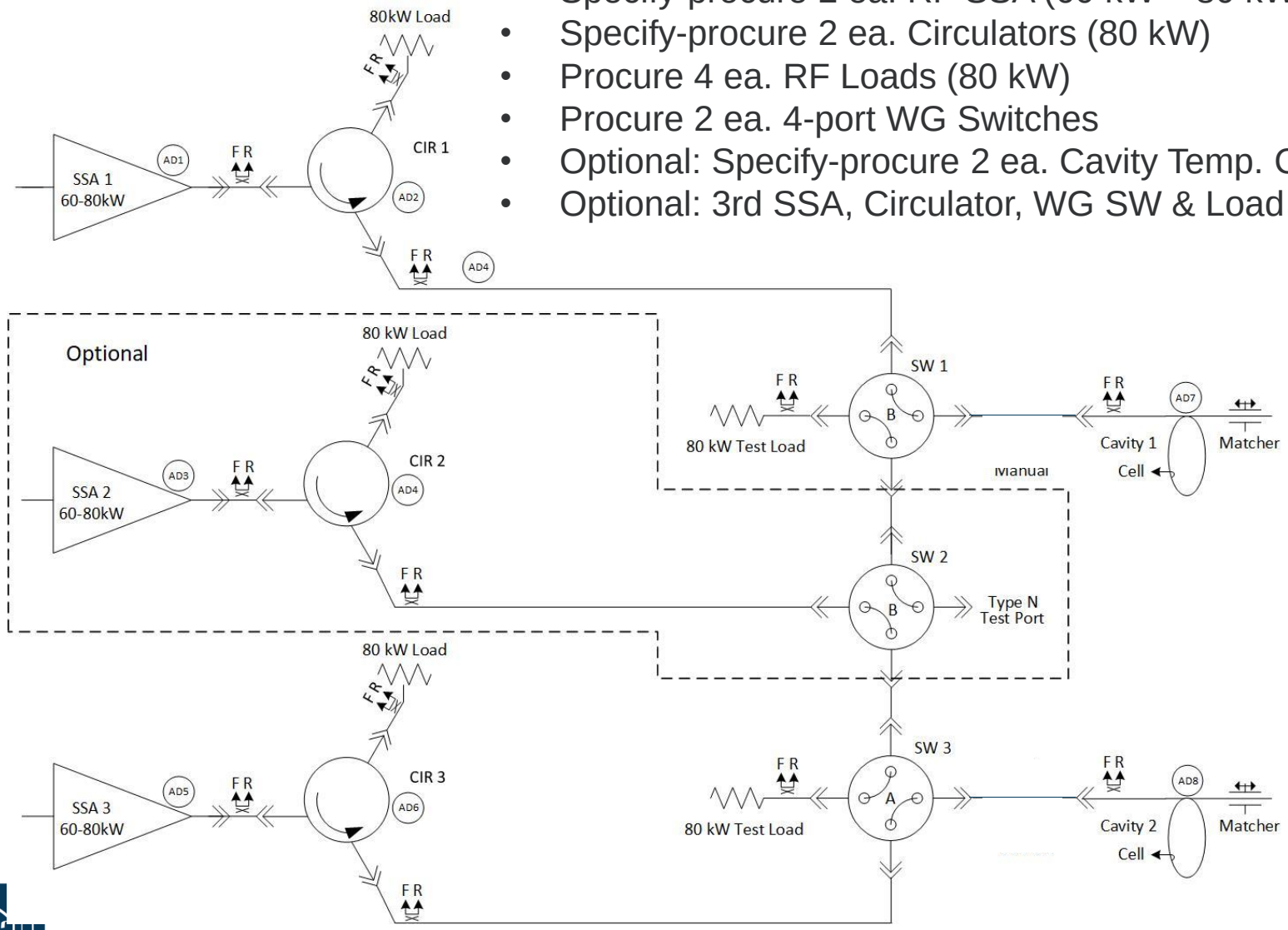




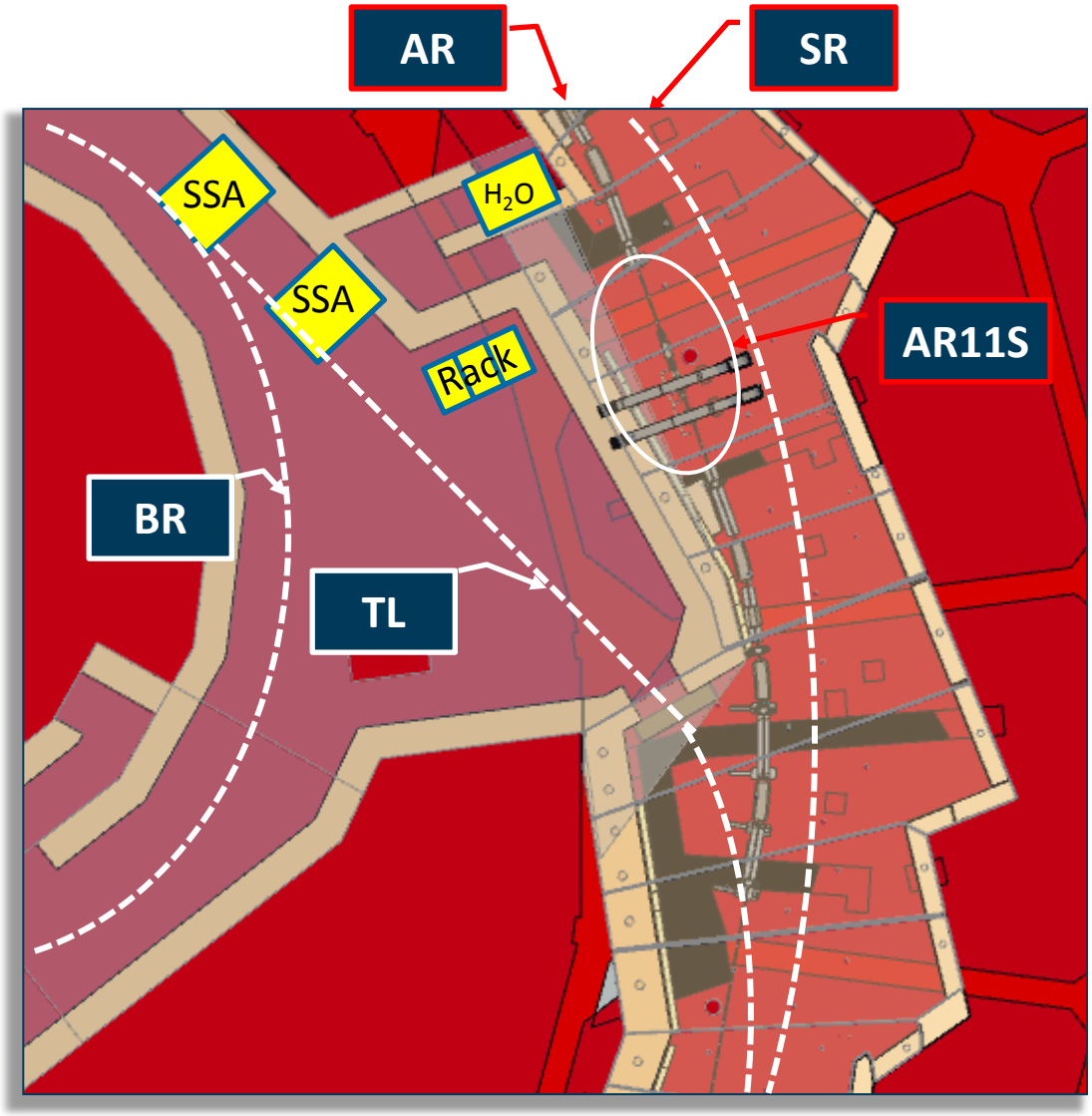
* Nearly, requires custom freq, interface, etc.

AR RF Distribution: Approach ⇨ COTS

- Specify-procure 2 ea. RF SSA (60 kW – 80 kW)
- Specify-procure 2 ea. Circulators (80 kW)
- Procure 4 ea. RF Loads (80 kW)
- Procure 2 ea. 4-port WG Switches
- Optional: Specify-procure 2 ea. Cavity Temp. Control Sys.
- Optional: 3rd SSA, Circulator, WG SW & Load

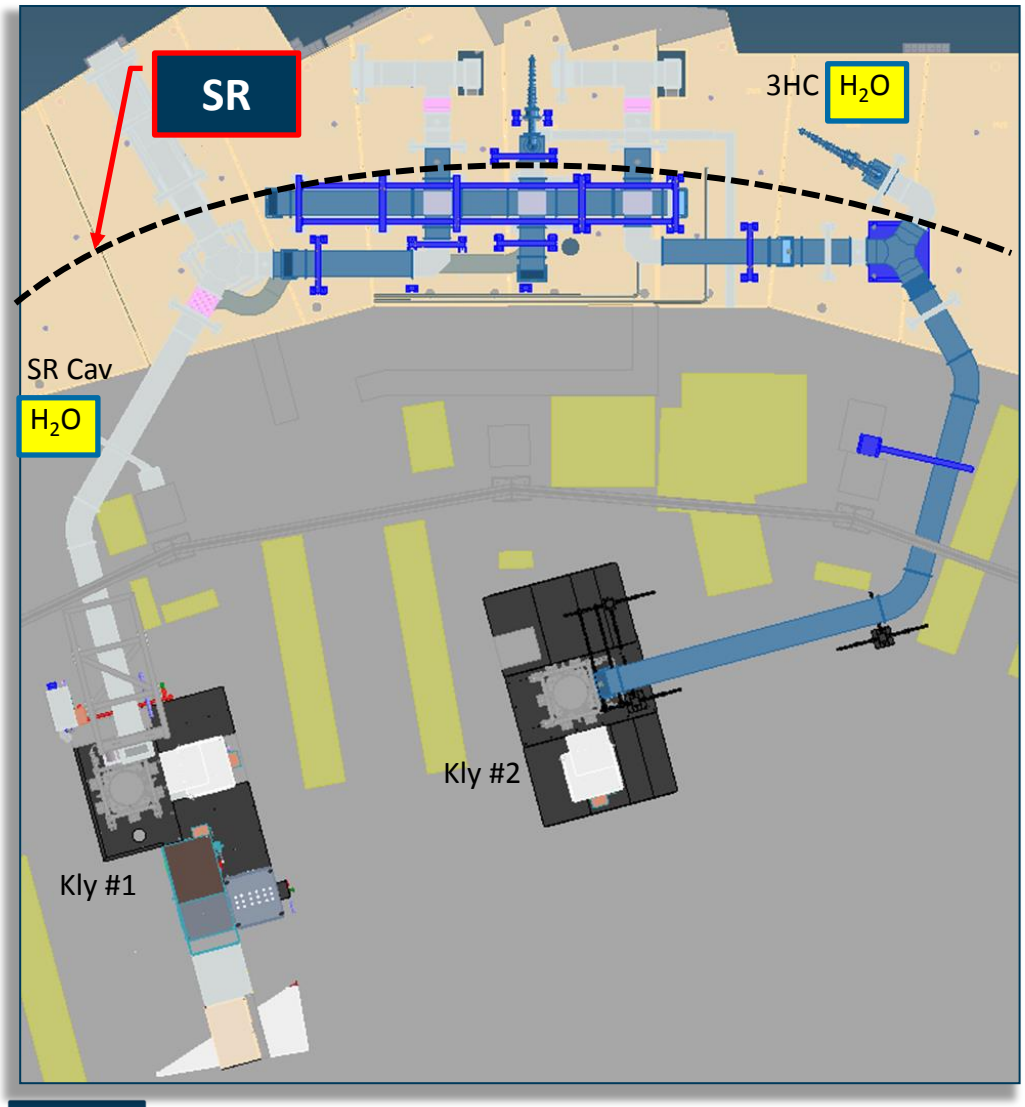


AR RF System Equipment Location: AR Sector 11S



Storage Ring RF System

SR RF System: Scope



ALS-U:

- Re-use existing RF Cavities, RF Sources, Distribution, LLRF Controls, Intrlks, etc. Pending final CBI analysis.
- Modification to WG Matcher to avoid AR interference
- Study/Modify power coupler to increase coupling
- Upgrade SR Cavity Temperature Control System
- Install 3rd Harmonic Cavity Temperature Control System

ALS:

- Replaced RF source & sub-systems (AIP09-14)
  - Redundant, 2-klystron system with a wave guide switch matrix (currently commissioning)
  - New HVPS, Filter Cabinet and IGBT dis-connect switch
  - New D-LLRF Controller (currently commissioning)
  - New PLC based Control & Interlock systems
- Replaced Vacuum Pump Controllers (AIP18)
- Replacing Flow & Temp Intrlock upgrade (AIP19)
- Planning Tuner Drive Motor & Controller upgrade (future AIP)

SR RF System: Requirements

ALS Cavity	ALS - 1.9GeV	ALS-U – 2.0GeV
Frequency	499.6 MHz	500.35 MHz
# of Cavities	2	2
R_s (ea)	4.9 MΩ	4.9 MΩ
Cav Voltage (kV) (each)	649	300
β_{opt} (ALS SR cav β max = 3.15)	2.93	10.07 [1]
Energy loss per turn (keV)	326.5	329
Bend Mag Beam Pwr (kW) (500mA)	112.6	125
ID Beam Pwr (min gap) (kW)	44	35
3HC Beam Pwr (kW)	3.6	4.4
Parasitic Beam Pwr (kW)	2.5	2.2
Total Beam Pwr (kW)	165.7	166.9
Cavity Pwr (no beam) (kW)	43	9.2
Cavity Trans. Pwr (w/beam) (kW)	125.8	127.6
Waveguide Losses (kW)	3.5	2.6
Klystron Pwr (kW)	255.2	257.8 [2]

May be a good enough reason to replace cavities

[1] Coupling required exceeds coupler's adj. range

[2] Each cavity would have ~35 kW reflected power at 500 mA due to the lack of coupling range.

SR RF System: Approach for New Cavities

ALS-U should replace cavities if CBI, caused by HOMs, are greater than be reliably managed by passive dampers, cavity temperature control and longitudinal FB.

ALS should replace cavities, if ALS-U does not, in order to improve operating efficiency by reducing excess reverse power caused by insufficient coupling factor, improve vacuum in SR03S and to simplify maintenance with common spare cavities, couplers, tuners, dampers, etc.

Options

- Purchase Commercial Cavity
  - Research Instruments – EC 500 MHz HOM Damped, coaxial loop coupler
  - Toshiba – ASP 500 MHz HOM Damped, coaxial loop coupler
- Design new cavity by leveraging legacy ALS SR cavity
- Design new cavity by scaling NLC 714MHz HOM Damped, aperture coupled.

Down-Select

- Order/Manufacture 2 or 3 cavities, install 2 to satisfy the SR installation schedule.

SR RF System: Candidate Cavities

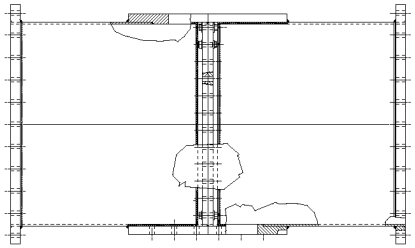
ALS-U SR – 2.0 GeV	ALS Cavity	Toshiba ASP Cavity	RI EC Cavity	Other HOM Damped Cavity
Frequency	500.35 MHz	500.35 MHz	500.35 MHz	500.35 MHz
# of Cavities	2	2	2	2
R_s (ea)	4.9 MΩ	3.79	3.1 MΩ	X.X MΩ
Cav Voltage (kV)	300	300	300	300
Coupling β (reqr'd/avail)	10.07/3.15 [1]	8.01/3.0 [1]	6.75/8.0	X.XX
Energy loss per turn (keV)	329	329	329	329
BM Beam Pwr (kW)	125	125	125	125
ID Beam Pwr (min gap) (kW)	35	35	35	35
3HC Beam Pwr (kW)	4.4	4.4	4.4	4.4
Parasitic Beam Pwr (kW)	2.2	2.5	2.5	2.5
Total Beam Pwr (kW)	166.6	166.9	166.9	166.9
Cavity Pwr (no beam) (kW)	9.2	11.9	14.5	XX.X
Cavity Pwr (w/beam) (kW)	127.6	95.3	98.0	XX.X
Waveguide Losses (kW)	2.6	2.7	2.7	X.X
Power Amplifier (kW) total	257.8 [2]	243.3 [3]	198.7	XXX.X

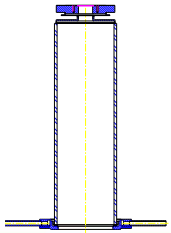
[1] Coupling required exceeds coupler's adj. range
[2] Each cavity would have ~35 kW reflected power at 500 mA due to the lack of coupling range.
[3] Each cavity would have ~25 kW reflected power at 500 mA due to the lack of coupling range.

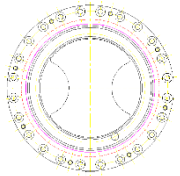
SR RF System: What ALS Cavity needs upgraded

- Redesign the RF coupling iris to accommodate ALS-U SR RF coupling requirement.
- Evaluate/Modify both HOM dampers to improve the HOM damping.
- Evaluate/Modify cavity body geometry to improve the shunt impedance, reduce the power density and suppress the multipacting.
- The modification to the ALS cavity is moderate, thus the thermal/mechanical design and the production method can be similar to ALS cavity.

Split WR1800 Waveguide to Cavity Transition

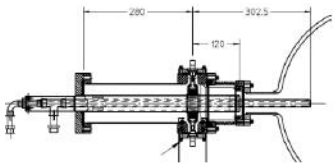




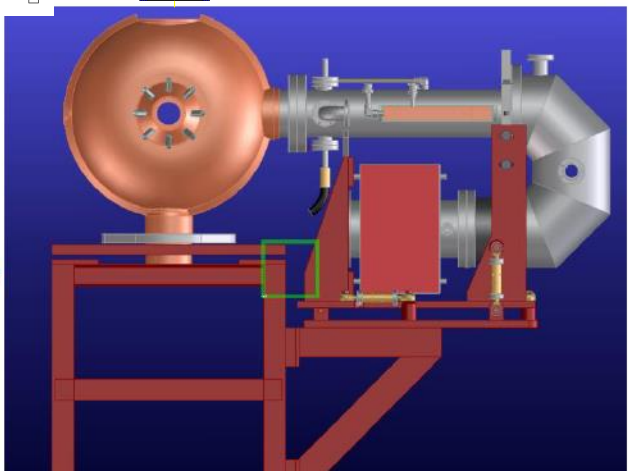


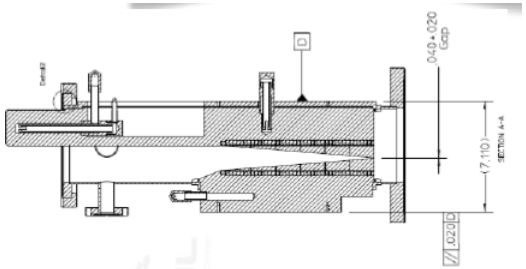
Iris Flange Profile

β: 1 to 3.2



HOM Damper I
E-Type Antenna damper designed and built at LBNL

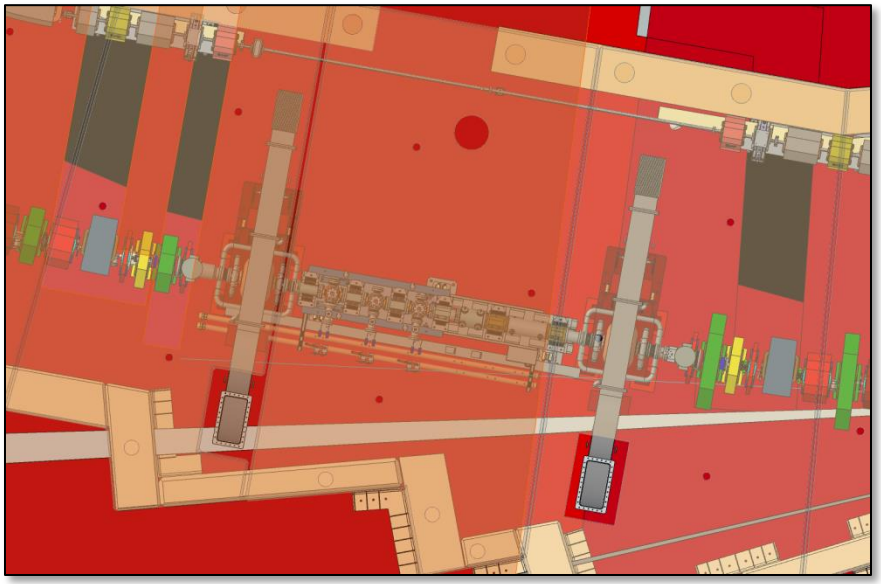


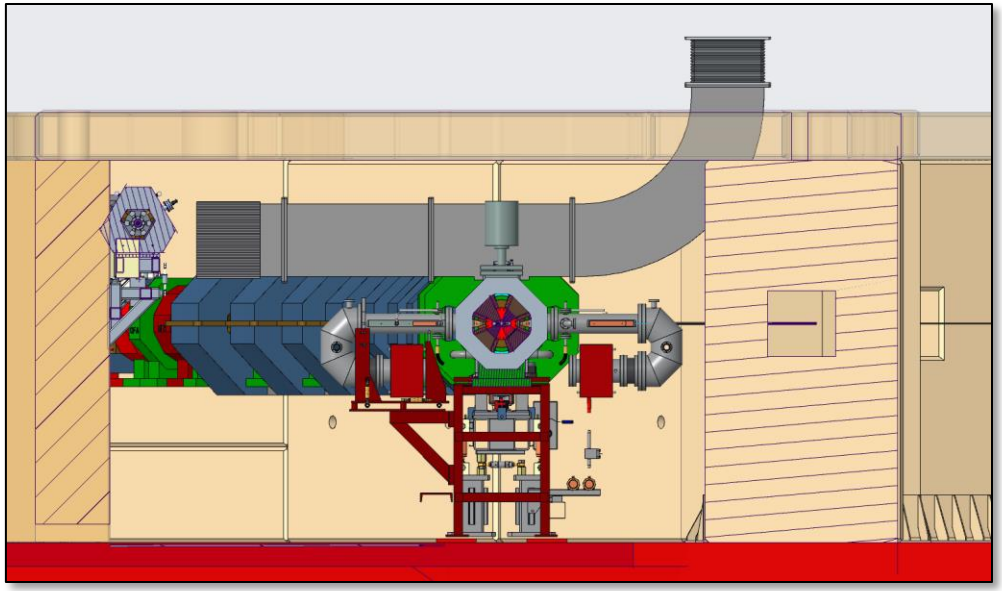


HOM Damper II
Ridged Waveguide damper designed and built at LBNL

SR RF: Shielding Block Mods ⇨ None

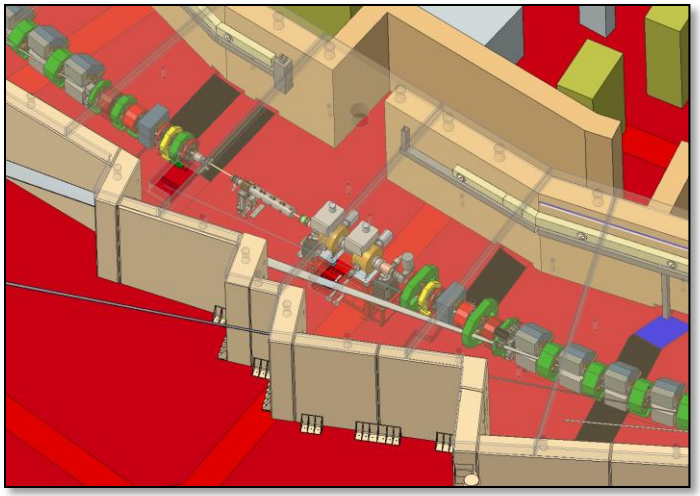
ALS SR Cavities

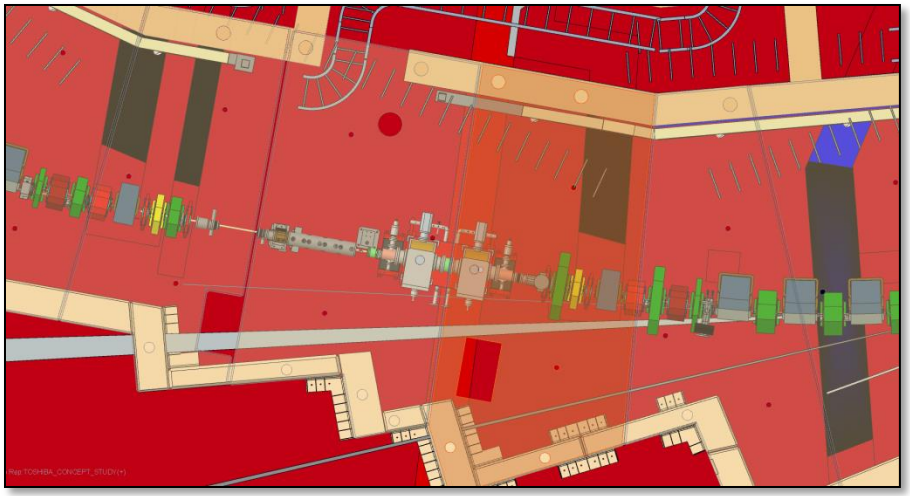


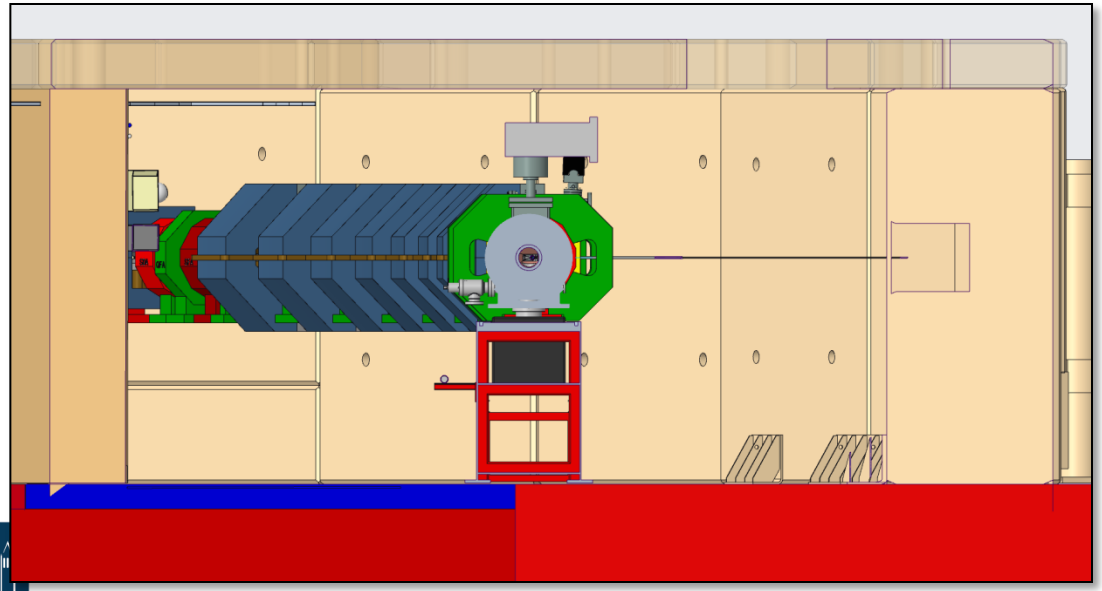


Storage Ring RF: Shielding Block Mods ⇨ None

Toshiba - ASP Cavity – no shielding mods but longitudinally cavities won't fit

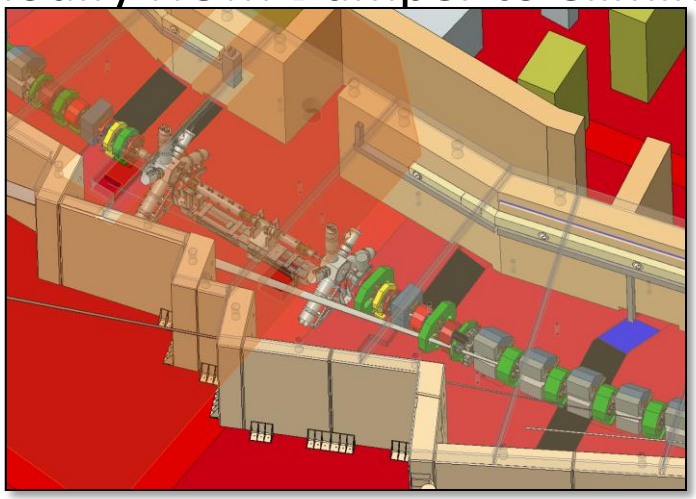


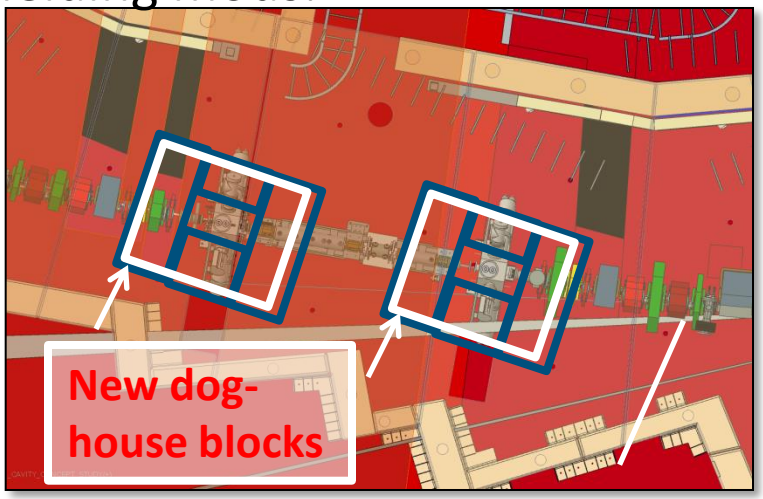


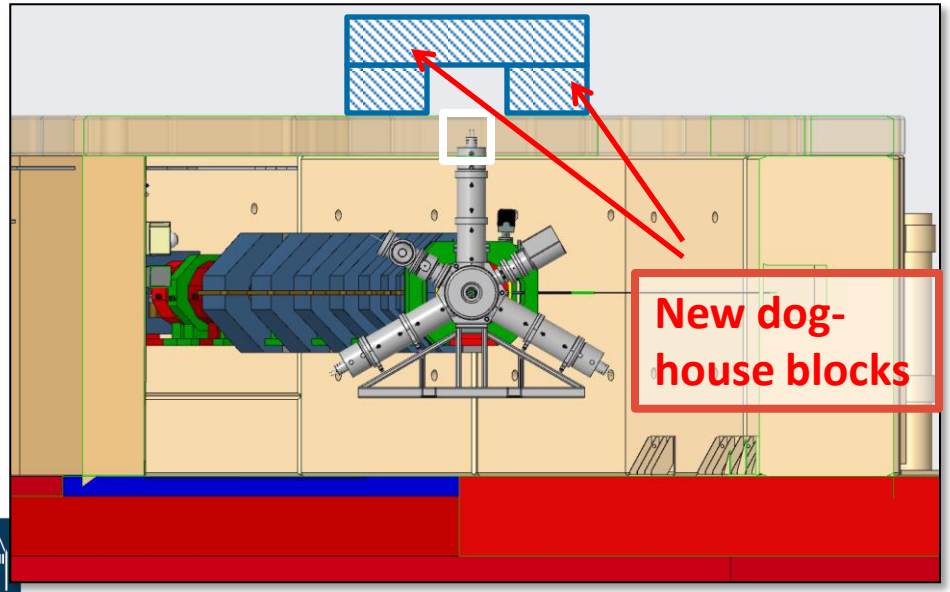


SR RF: Shielding Block Mods ⇨ Moderate

Research Instruments EC Cavity – moderate shielding mods needed or modify HOM Damper to eliminate shielding mods.



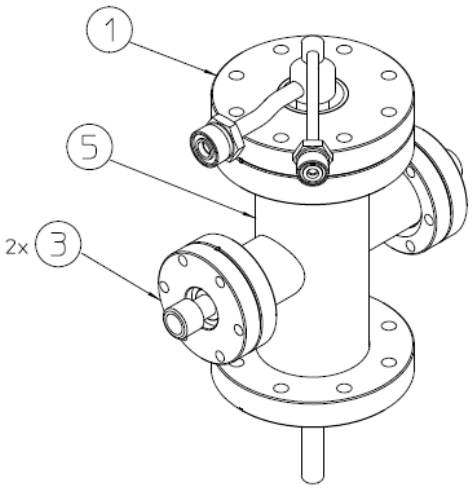




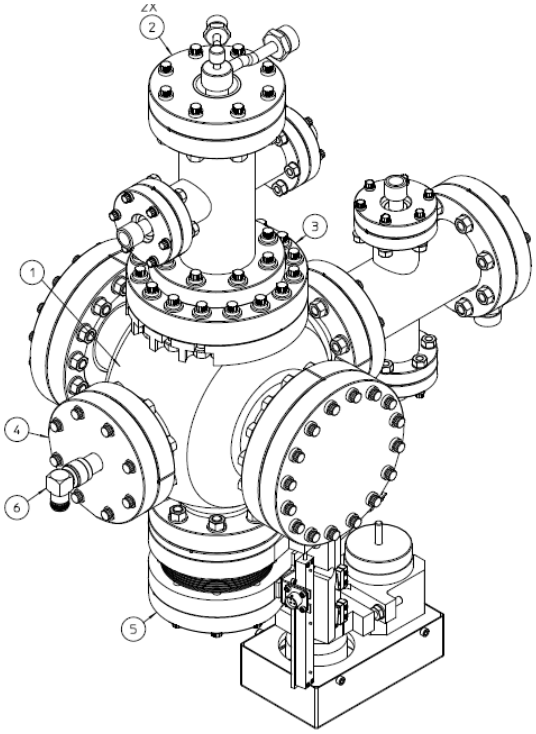
Coupler WG transition could be rotated 90° to minimize the size of the hole in roof.

3rd Harmonic System

3HC RF System: Overview

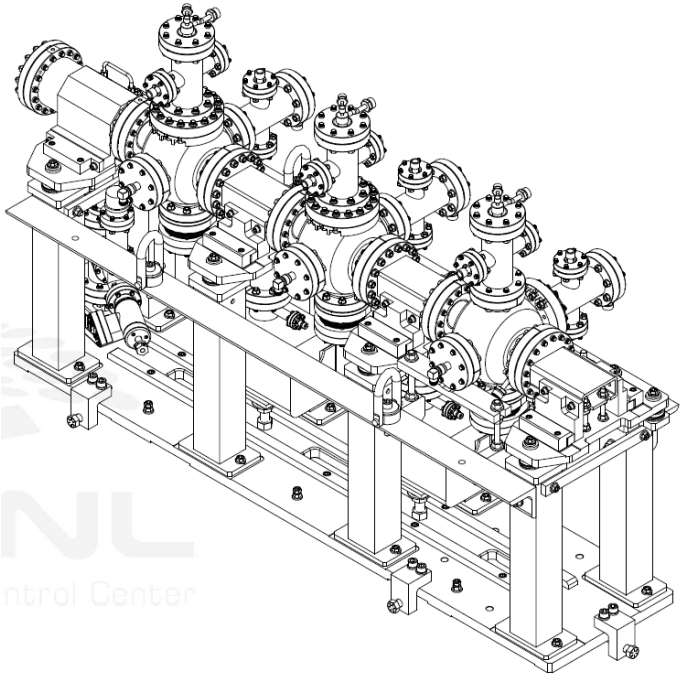


E-Type HOM Damper



Cavity with 2 E-Type HOM Antenna Damper installed

- 6 cavities built at LLNL & LBNL.
- 5 Installed in SR then reduced to 3.



3HC RF System: Requirements

	Cavity Design	ALS SR 1.9 GeV	ALS-U SR 2.0 GeV	ALS-U SR 2.0 GeV
Frequency	1.499 GHz	1.499 GHz	1.501 GHz	1.501 GHz
Bore Dia.	5 cm	5 cm	5 cm	5 cm
R/Q	80.4	80.4	80.4	80.4
Calc Q	27677	27677	27677	27677
Calc R_s	2.23 MΩ	2.23 MΩ	2.23 MΩ	2.23 MΩ
Meas Q	21000	21000	21000	21000
Meas R_s	1.69 MΩ	1.69 MΩ	1.69 MΩ	1.69 MΩ
Opt. R_s	-	-	1.4 MΩ	1.4 MΩ
# of Cavities	6 fabricated 5 available	3 installed	2 installed	2 lengthen 1 shorten
Cell Voltage	125 kV (max)	86 kV	86 kV	253 kV, 69 kV
Cell Pwr	5.0 kW (max)	2.2 kW (avg)	2.2 kW (avg)	(2) 4.7 kW (1) 1.4 kW
Harmonic Voltage	-	258 kV	172 kV	184 kV
Stability Analysis		Stable w/LFB	Not stable w/LFB	Potentially stable

3HC RF System: Approach for New Cavities

ALS-U should replace the cavities if CBI, caused by HOMs, cannot be reliably managed with 2 cavities lengthening and 1 cavity shortening with passive dampers, cavity temperature control and longitudinal FB.

Options

- Design new cavity by leveraging legacy ALS 3HC cavity
- Order/Manufacture 2 or 3 cavities, install 1 or 2, depending on their shunt impedance and power handling capabilities, to satisfy the SR installation schedule.

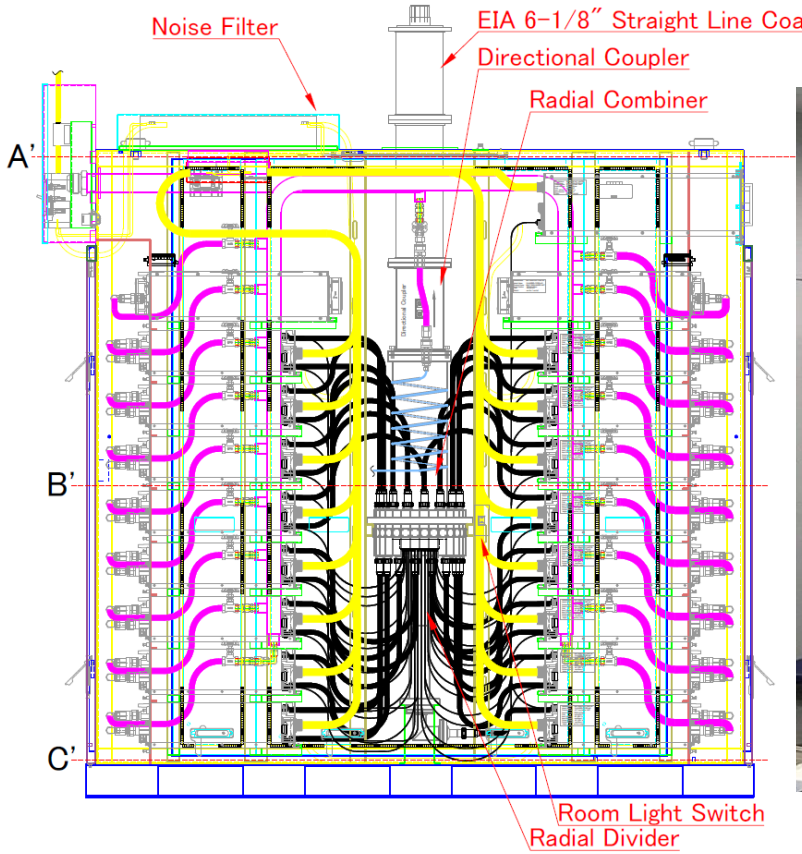
Conclusion

- The Scope and Requirements are understood and we have developed a conceptual plan that will meet these needs.
- Currently in preliminary design, details are surfacing that will help both ALS-U project and ALS facility make strategic decisions on RF cavities.
- The leading cavity candidate for the AR is the RI EC cavity.
- The leading cavity candidate for the SR is the RI EC cavity.
- The leading cavity candidate for the 3HC is likely an in-house design to be built to specification.
- Our preferred approach would be to select the cavity solution that serves both ALS-U AR and ALS SR, to use existing SR RF systems and purchase COTS systems based on recent successes for the AR.

Thank you

Backup Slides

New AR RF Source (example)



60 kW CW SSA at 186 MHz
87” L x 100” H x 36” W, 6000 lbs.

Two 60 kW CW SSA at 186 MHz
preparing for test at factory

Existing SR Cavity – HOM Spectrum

Longitudinal HOM spectrum of the ALS main RF cavity

red-no dampers

black-with E-type HOM damper

green-with E-type and waveguide dampers

blue/yellow lines- ALS long. stability threshold for 1.9/1.5 GeV