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Dual Klystron Driven Storage Ring RF System at Advanced Light Source

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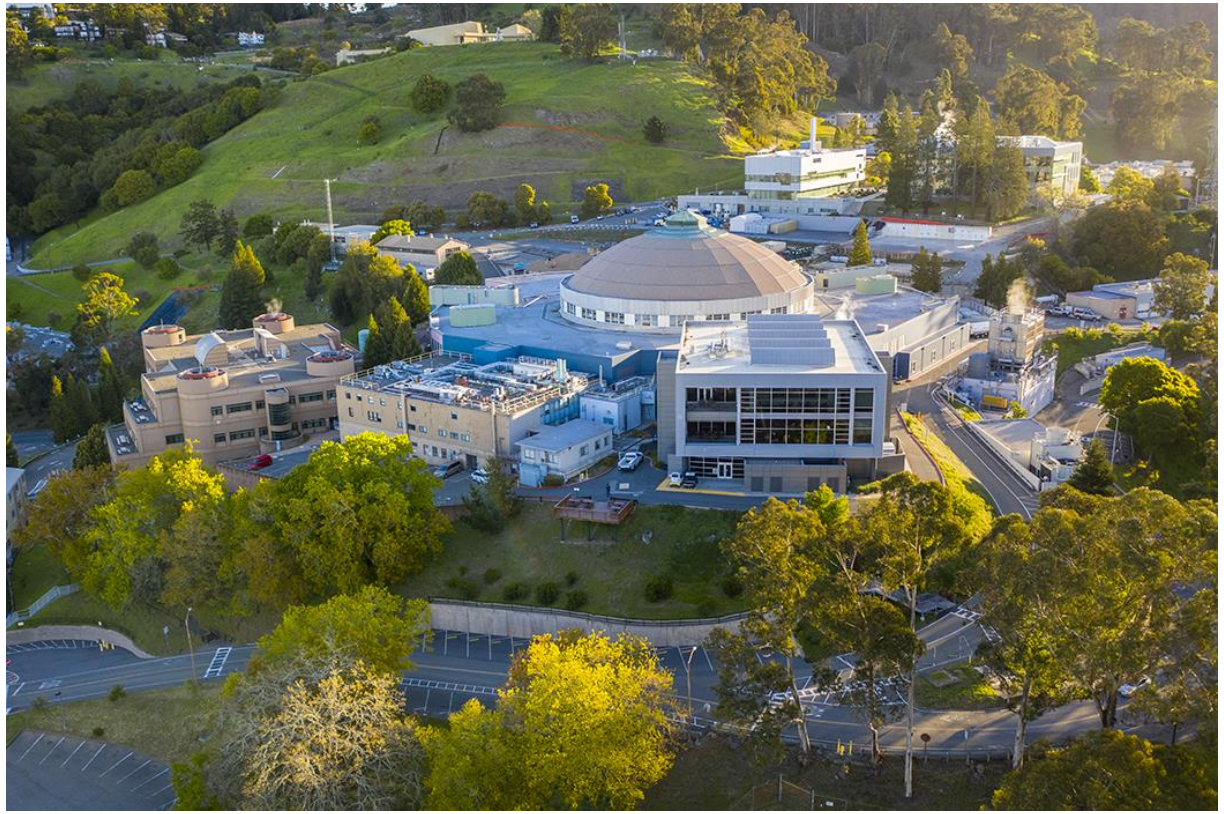
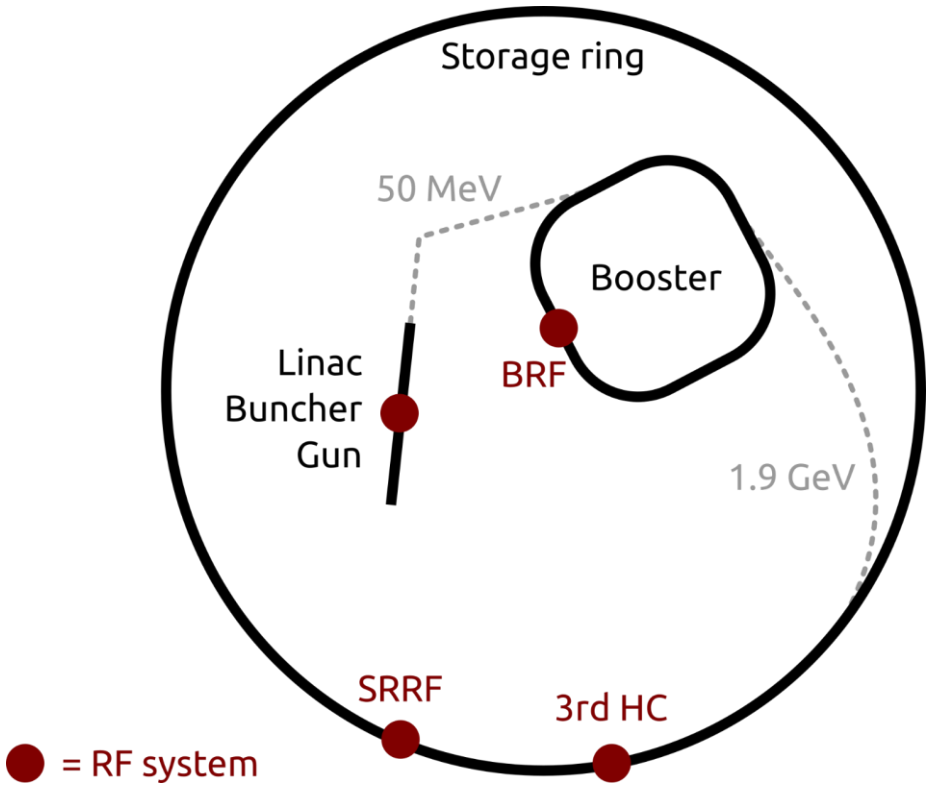
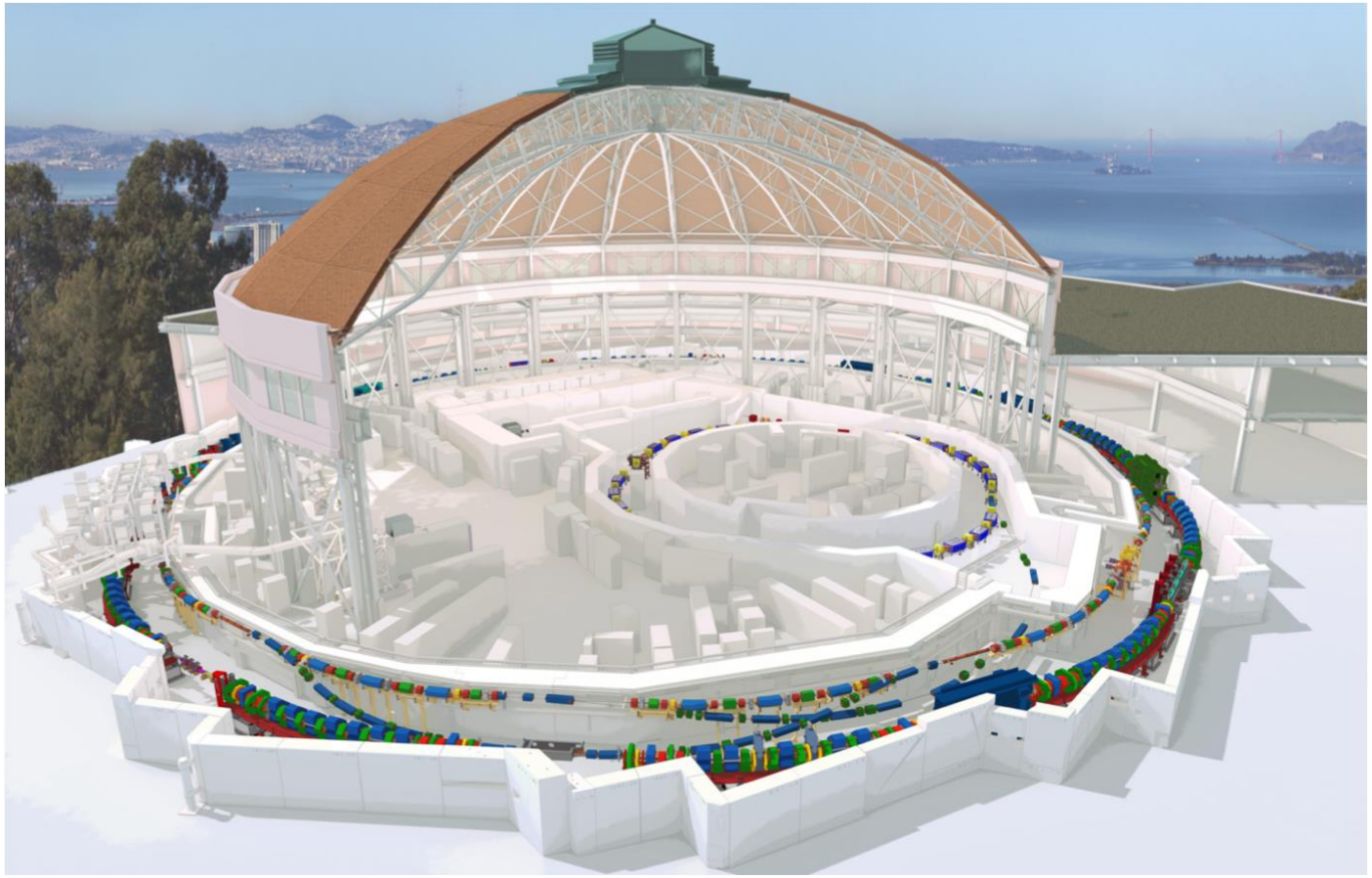


ALS: 1.9 GeV 500mA synchrotron Light Source since 1993, with 4th gen upgrade underway (ALS-U).

Overview of RF systems in the Advanced Light Source

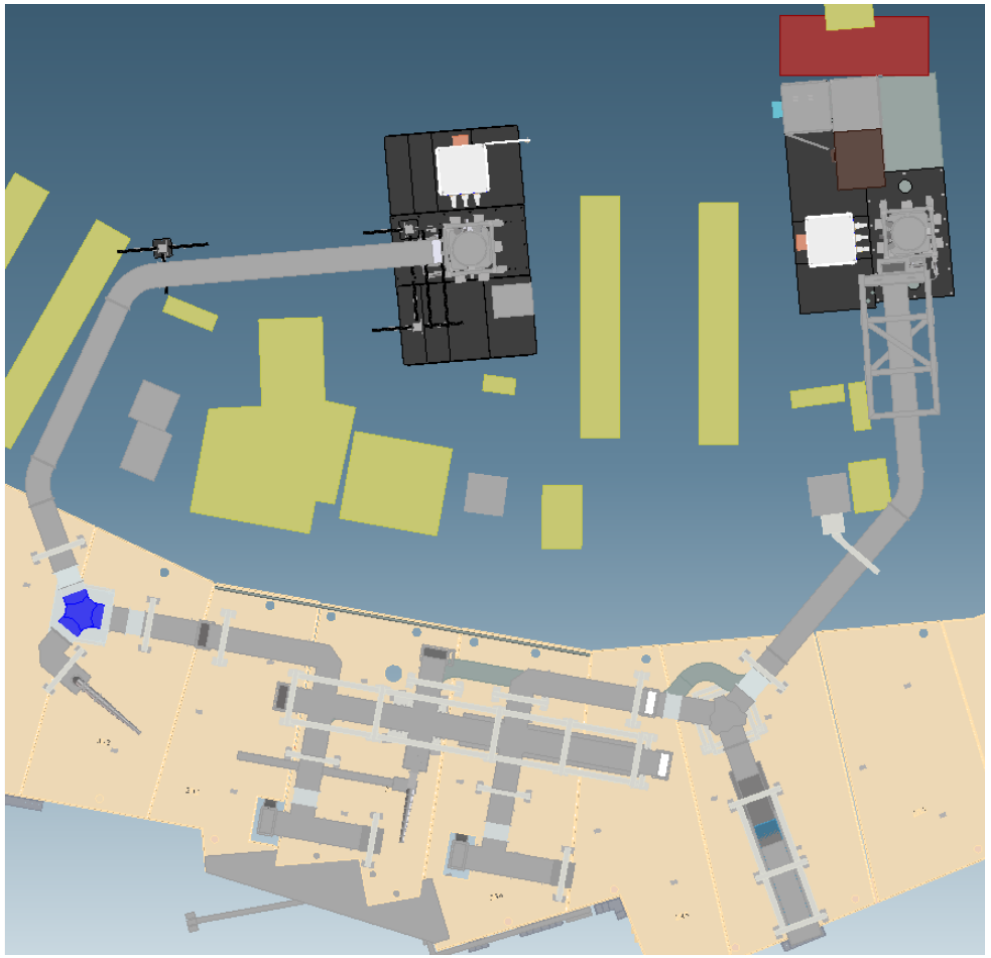




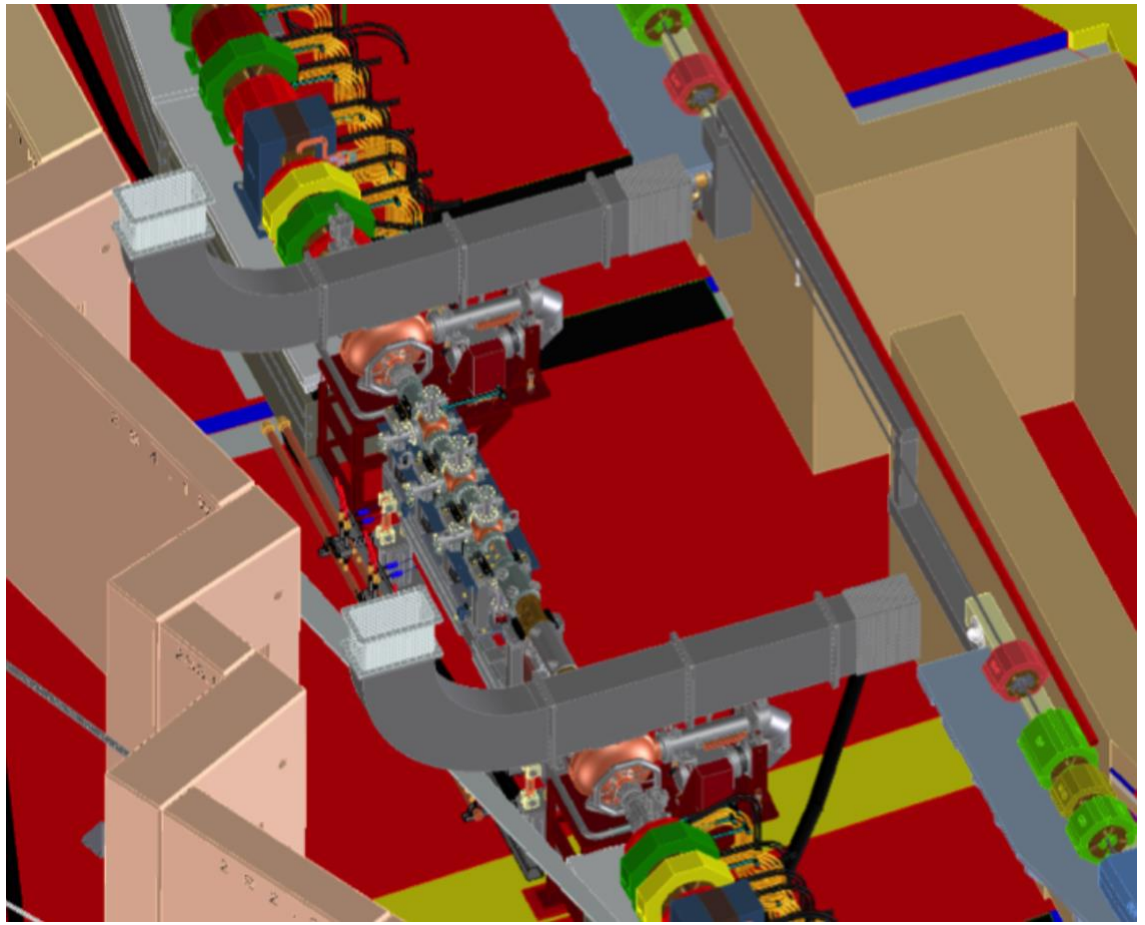
ALS-Upgrade Project

Storage Ring RF System

Two 300kW Klystrons Driving Two Cavities



Two Klystrons with waveguide matrix

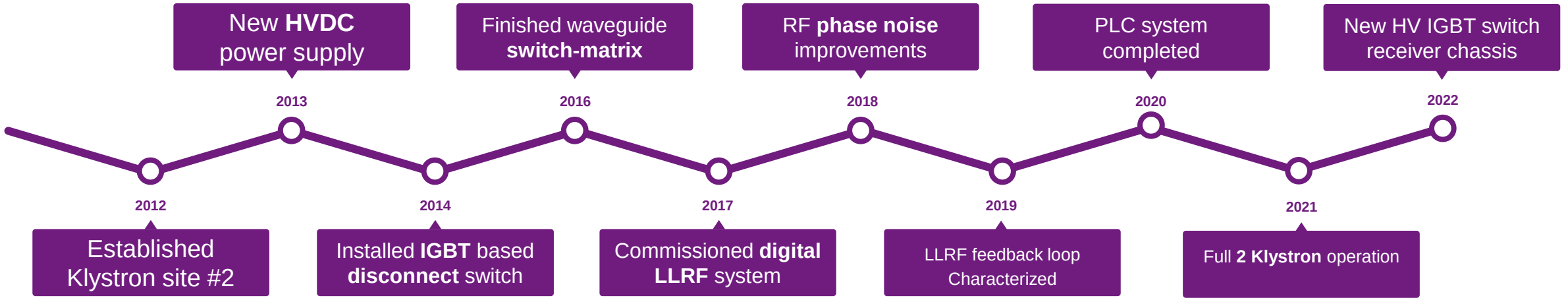


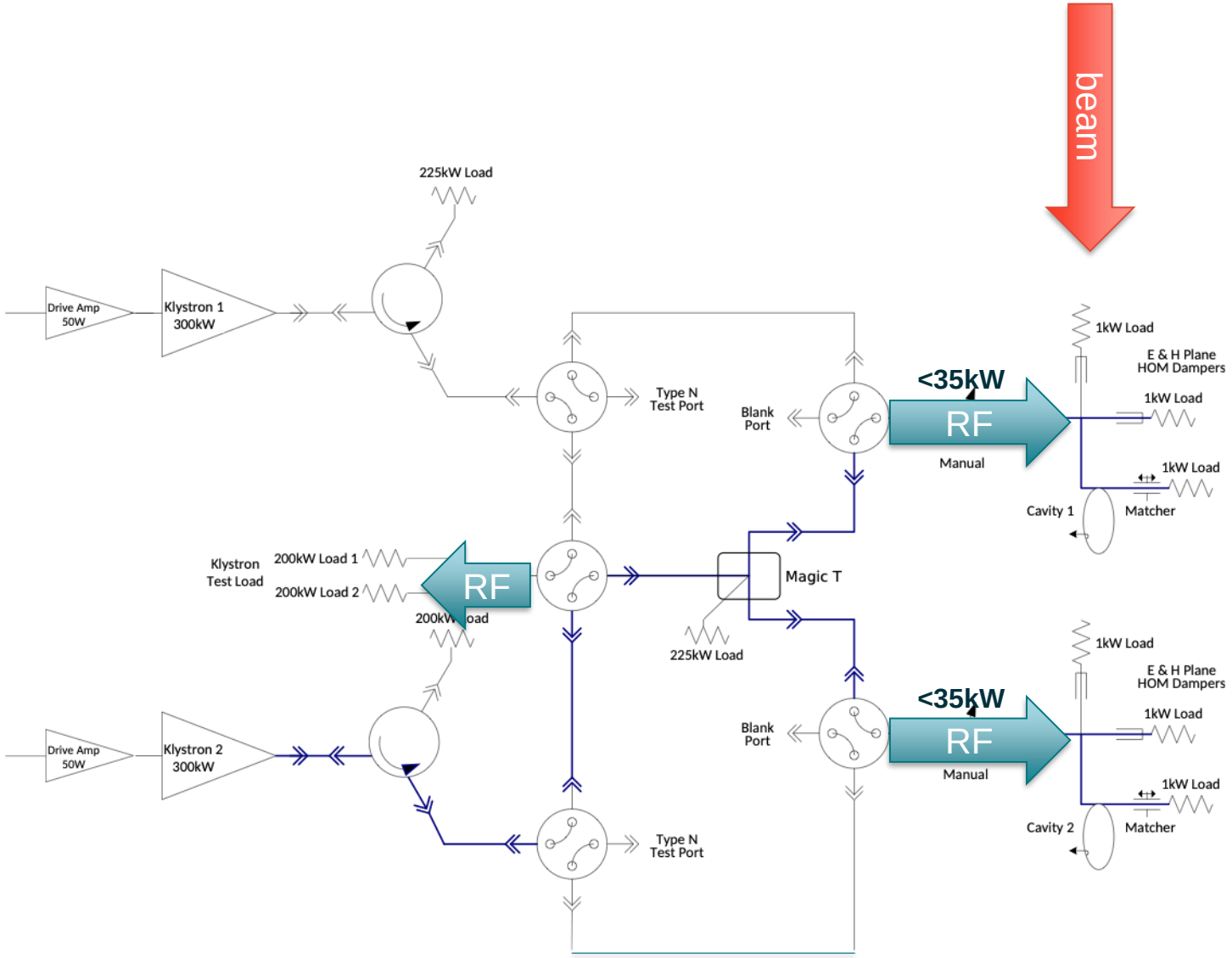
500 MHz RF Cavities

ALS Storage Ring RF Parameters

	ALS SR 1.9GeV	ALS-U SR 2.0GeV	
Cavity RF Frequency	499.64	500.394	MHz
Number of Cavities	2	2	
$\frac{R}{Q}$ (ea)	4.9	4.9	MΩ
Cavity voltage	671	300	kV
β	2.9	10.6	
Energy loss per trun	329	347	keV
BM Beam Power	141	125	kW
ID Beam Power	42	35	kW
3HC Beam Power	7.3	13.8	kW
Parasitic Beam Power	2.9 (est.)	2.6 (est.)	kW
Total Beam Power	192.9	176.4	kW
Cavity Power(no beam)	46	9.2	kW
Cavity Power(beam)	142.5	97.4	kW
Waveguide Loss	9.2 (est.)	$<$ 3 (est.)	kW
High Power Amplifier	294.0	197.5	kW

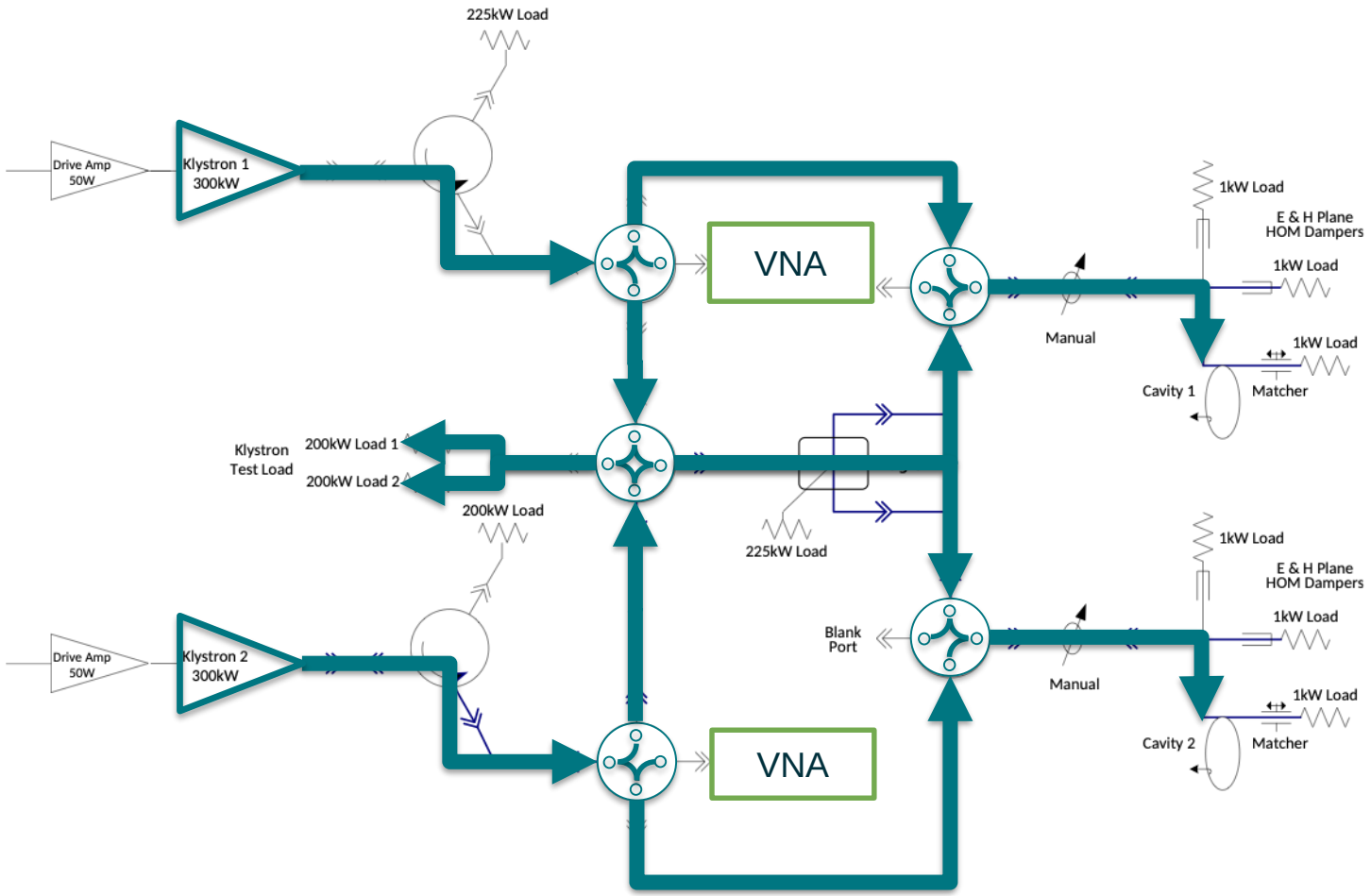
Storage Ring RF System Upgrade Timeline





Storage Ring RF RSS/PSS System Operation Modes

1. Operational Mode:
   a. RF Power to Cavities
   b. Beam operations Enabled
2. High Power RF Test mode:
   a. RF Power to Cavities
   b. Beam operations Disabled
3. RF Test with Access Mode:
   a. RF Power to Cavities
   b. Beam operations Disabled
   c. RF peak power < 35 kW
4. RF Power to Test Load:
   a. RF Power to Test Loads
   b. Beam operations Disabled



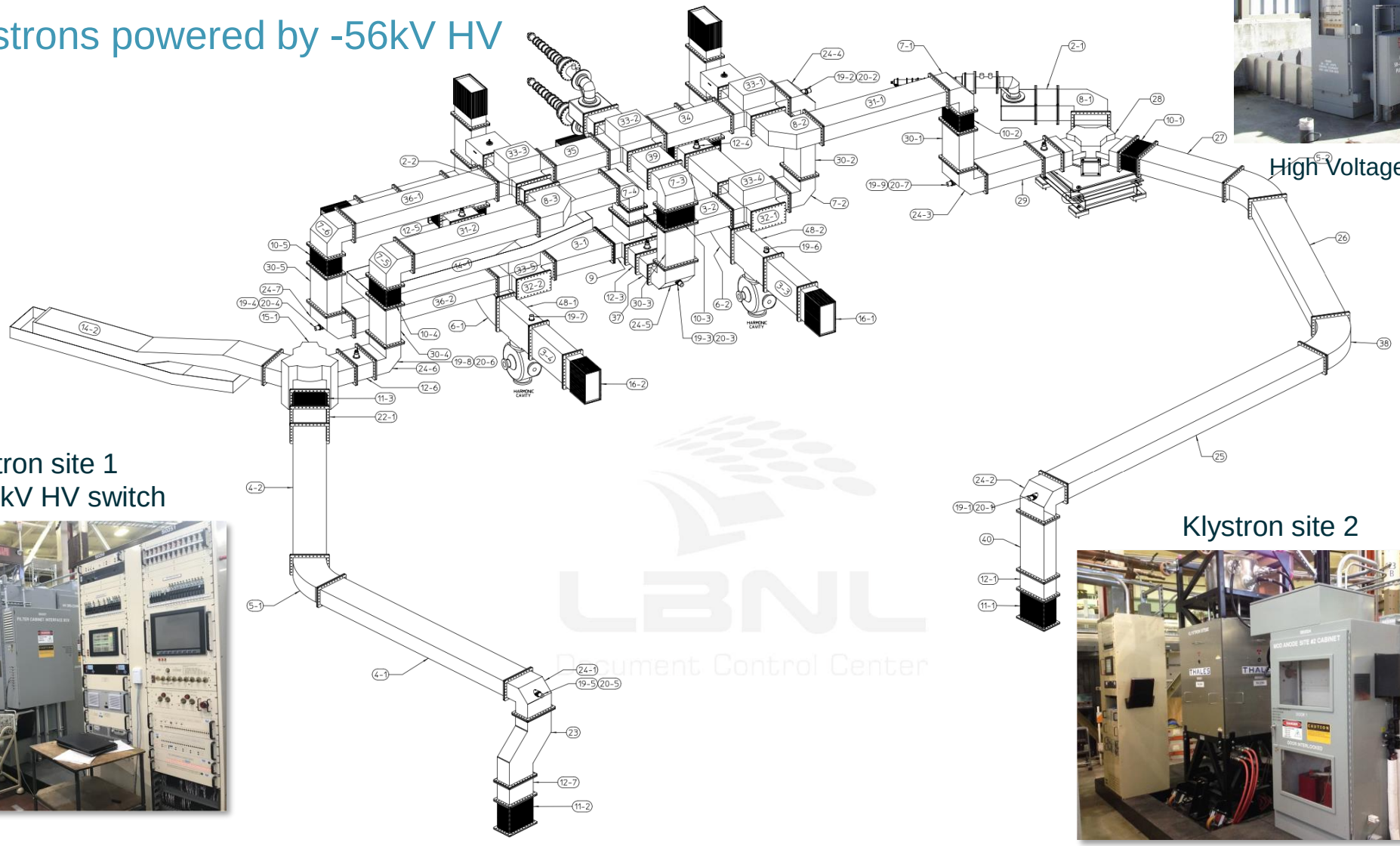
Storage Ring RF Waveguide Modes

1. Dual Klystron Drive:
   - Klystron 1 → Cavity 1
   - Klystron 2 → Cavity 2
2. Klystron 1 Drive:
   - Klystron 1 → Magic T
   - Magic T → Cavity 1 + 2
3. Klystron 2 Drive:
   - Klystron 2 → Magic T
   - Magic T → Cavity 1 + 2
4. Klystron 1 Test:
   - Klystron 1 → Test Load
   - Klystron 2 → Short
5. Klystron 2 Test:
   - Klystron 1 → Short
   - Klystron 2 → Test Load
6. Cavity Measurements:
   - Test Port 1 → Cavity 1
   - Test Port 2 → Cavity 2
   - Klystron 1 → Test Load
   - Klystron 2 → Magic T → Short
   - No HVPS

Dual Klystron Drive waveguide matrix

Two Klystrons powered by -56kV HV

High Voltage Power Supply

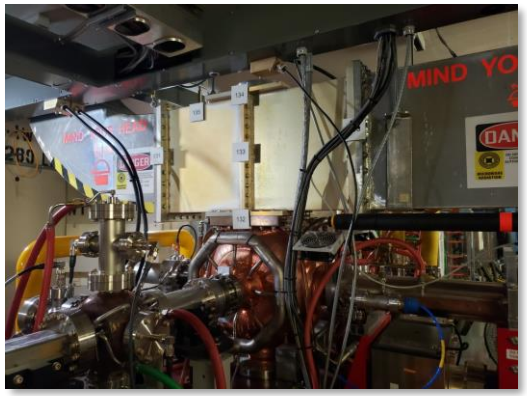


Klystron site 1
with -56 kV HV switch

Klystron site 2

Dual Klystron Drive waveguide matrix

Cavity and couplers



Cavity 2

Waveguide
Window Coupler

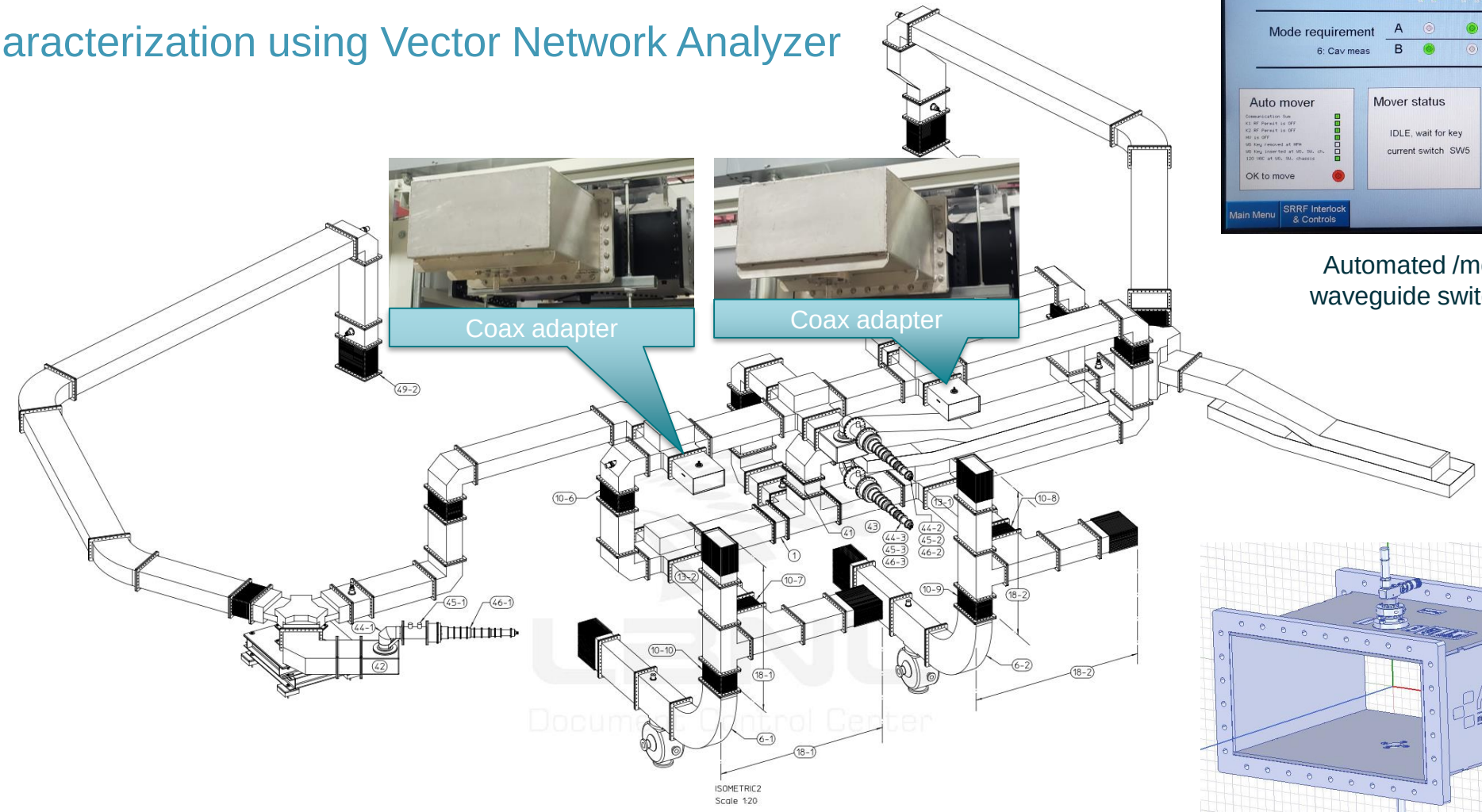
Cavity 1

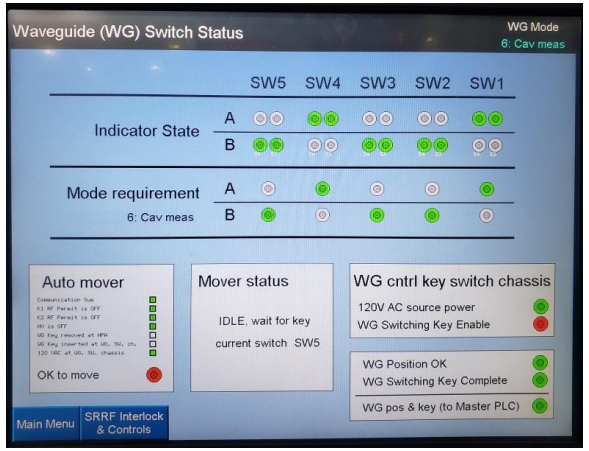
Cavity 2

Cavity 1

Dual Klystron Drive waveguide matrix

Cavity Characterization using Vector Network Analyzer





Automated /motorized waveguide switch control

Dual Klystron Drive waveguide matrix

Original water wedge RF loads

RF Load for Magic T

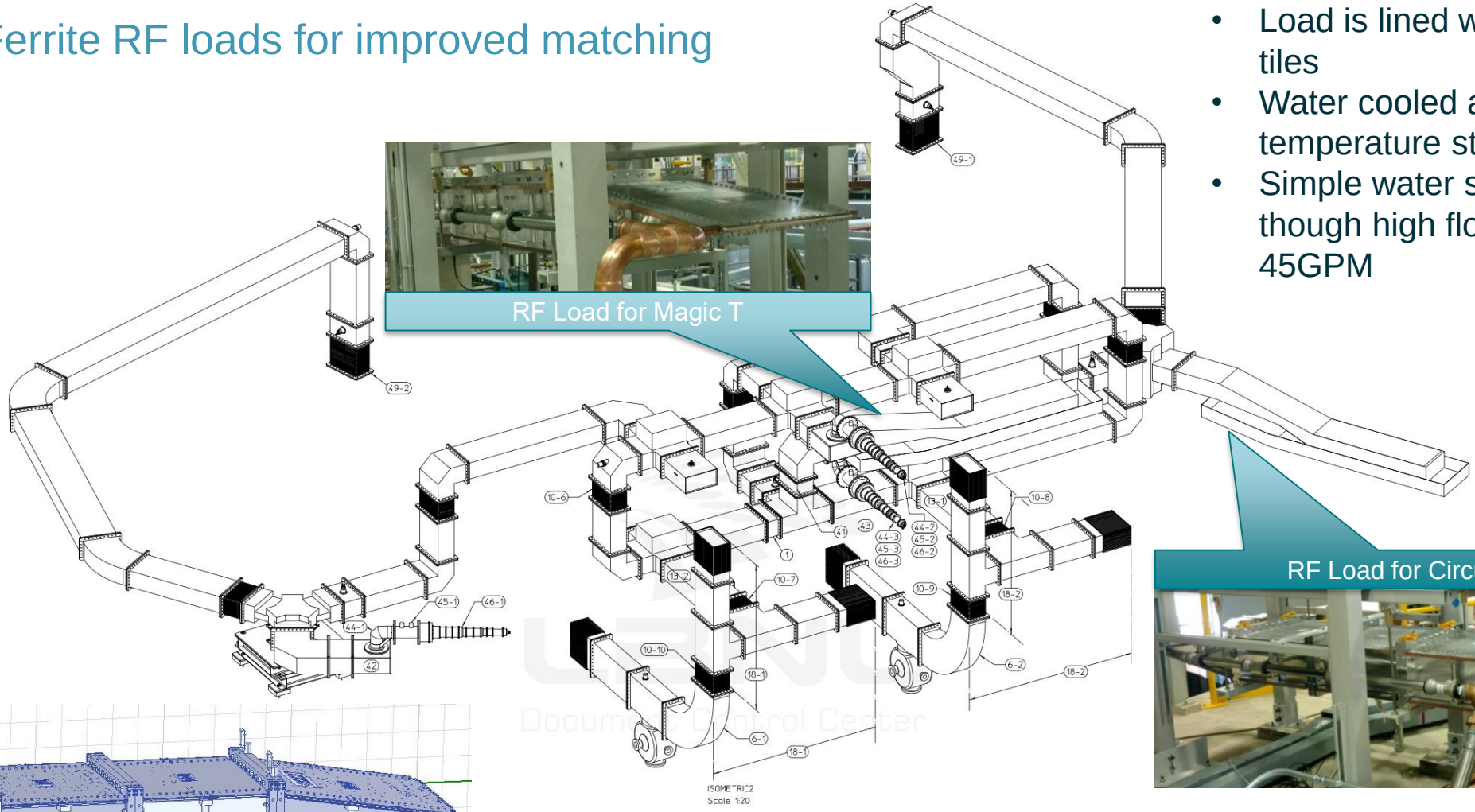
RF Load for Circulator 1

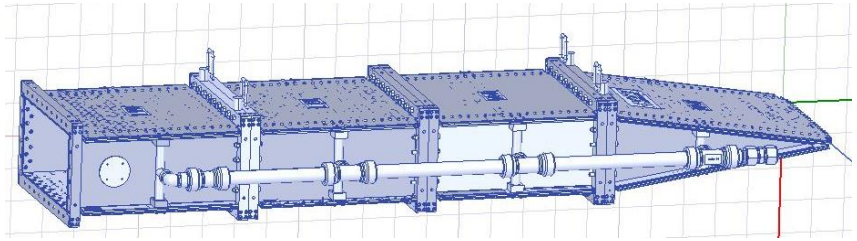
Water wedge load:

- Circulation system with tank, pump, heat exchanger
- Dielectric constant of water is temperature dependent
- Surface ripples on top surface contribute to noise

Dual Klystron Drive waveguide matrix

Installed Ferrite RF loads for improved matching





Ferrite Load:

- Load is lined with ferrite tiles
- Water cooled and more temperature stable
- Simple water system though high flow at 45GPM

LCW system upgraded for Ferrite RF loads

Normal operation is between 89.5 to 90.3 gpm
Complete open return is between 119 to 120 gpm
Complete open return and supply is between 149 to 150 gpm.

RF Safety Procedures

Non-Ionizing Radiation Protection, and RF Leak detections for all 5 waveguide modes

- Non-Ionizing Radiation Survey Procedure
  - dual mode only, one klystron at a time

Advanced Light Source

PROCEDURE	Page 1 of 5
Number: RF 02-75	
Revision: Rev. 1	
Issue Date: July 30, 2012	
Review Period: 3 years	
Supercedes Issues: Rev. 0	

Title:
Bldg. 6 — ALS, Storage Ring RF, 330kW – 500MHz High Power Amplifier & Transmission Line System RF Leakage (Non-Ionizing Radiation) Survey Procedure

Section where used: *(List all sections/groups that will use this procedure)*
Accelerator Operations, Electronics Maintenance (EM), and RF Sections

Type of Procedure: *(Administrative / Technical)*
Technical

Prepared by	Date	Reviewed by	Date	Approved by	Date
Ken Baptiste		Jim Julian Max Vinco		Slawomir Kwiatkowski	

Revision Log:

No.	Date	Pgs. Affected	Type of Change	Brief Description of Revision
0	8/2/07	--	--	Original Revision 0 issued.
1	7/30/12	1-5	Minor	Authorized persons noted in ALS 02-01, removed from Radiation Interlock and Survey testing schedule, Sec. 5.2.

1.0 PURPOSE

In compliance with the ALS ALARA policy, the Bldg. 6 — ALS, Storage Ring RF, 330kW – 500MHz High Power Amplifier waveguide transmission line joints, all sources of microwave non-ionizing radiation, must be inspected for mechanical and RF tightness after every modification or disassembly. This procedure supplies the necessary information for a methodical, safe inspection and survey.

2.0 SCOPE

The object of this survey is to locate, record, and correct any RF leaks found at low power levels before proceeding to high power levels and to record the measurements. The inspection and survey shall be done by one person from the RF group or two qualified persons from the EM or Accelerator Operations sections, as noted in procedure ALS 02-01.

The HPA system is comprised of a High Power Klystron Tube, waveguide transmission line components, and two RF cavities. The HPA's output power will be dissipated into the combination of RF water loads and two cavities with minimal reflections during beam operations, but without beam some RF energy will be reflected. While operating the HPA system, ionizing radiation will be produced by the klystron, vacuum switches and ignitrons in the crowbar cabinet and the RF cavities located in the SR tunnel. Refer to the procedure for surveying ionizing radiation, RF 02-77, Ref. **[8]**.

- Personnel Safety System Interface and Ionizing Radiation Protective System
  - 5 waveguide modes

ALS ADVANCED LIGHT SOURCE

PROCEDURE	Page 1 of 6
Number: RF 02-76	
Revision: Rev. 21	
Issue Date: November 3, 2021	

Title:
Storage Ring RF System Testing of the Personnel Safety System Interface and Ionizing Radiation Protective System

Section where used: *(List all sections/groups that will use this procedure)*
Accelerator Operations, Electronic Maintenance (EM), and RF Sections

Type of Procedure: *(Administrative / Technical)*	**Review Period:**	
Technical	Review upon use	
Prepared by	**Reviewed by**	**Approved by**
Doug Bashaw	Angel Jurado Ken Baptiste	Ben Flugstad David Beverly

1.0 PURPOSE

To provide a procedure that tests the ability of the storage ring (SR) RF system to react correctly by turning off Klystron RF drive(s) depending on the mode when the personnel safety system (PSS) indicates an ionizing radiation hazard.

2.0 SCOPE

Using rigorous preliminary preparation and a prescribed checklist, trained personnel assure that the necessary protective interlocks are functioning correctly under a variety of different system configurations.

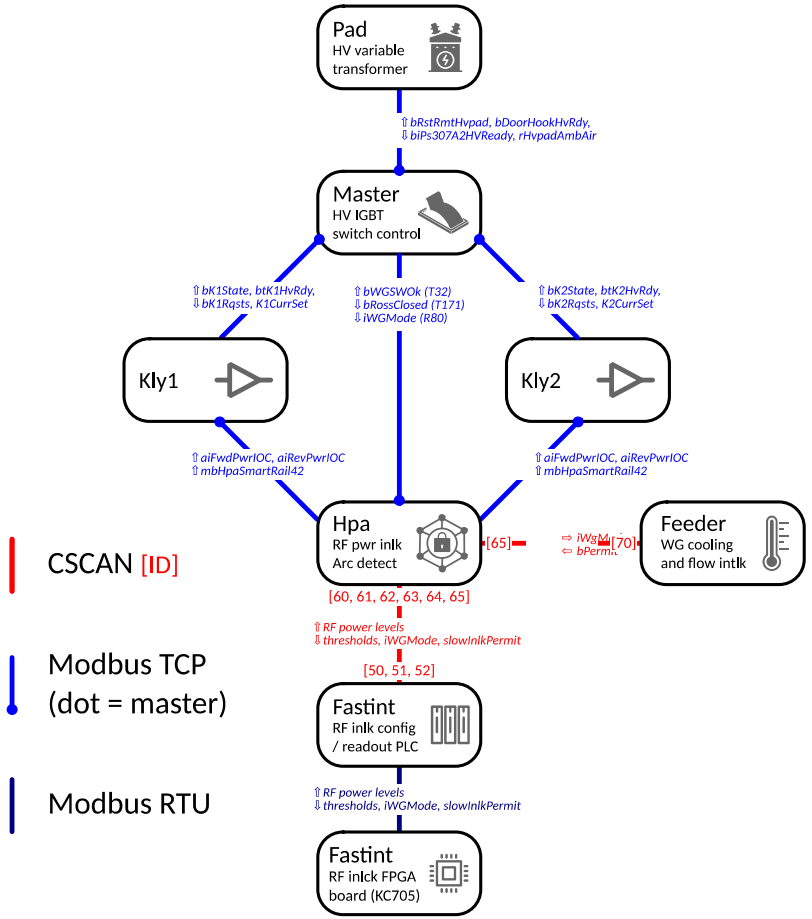
The procedures in this document tests the ability of the ALS Personnel Radiation Protection System to shut down the Storage Ring RF (SRRF) Klystron amplifier RF drive or drives, depending on the mode, in response to a loss of continuity of line A or line B or both lines of the radiation protection system.

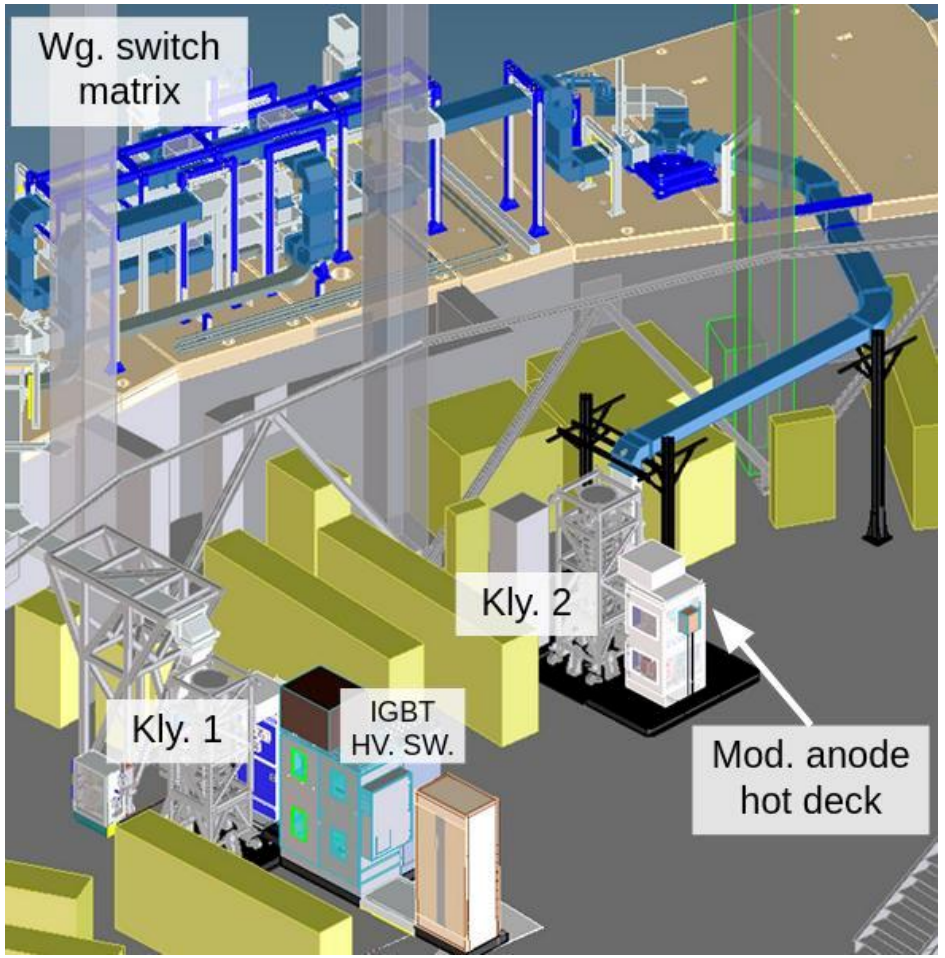
The systems of all of the four key selectable modes available on the *Personnel* Safety System (PSS) *Chassis* are tested. The four PSS modes are:

1) OPERATIONAL — stored electron beam possible
2) RF TEST — no electron beam with high power RF in the cavities
3) RF TEST WITH ACCESS — no electron beam, RF cavity power restricted to 30 kW, personnel access available.
4) RF TEST DUMMY LOAD no electron beam, no RF cavity power, personnel access available.

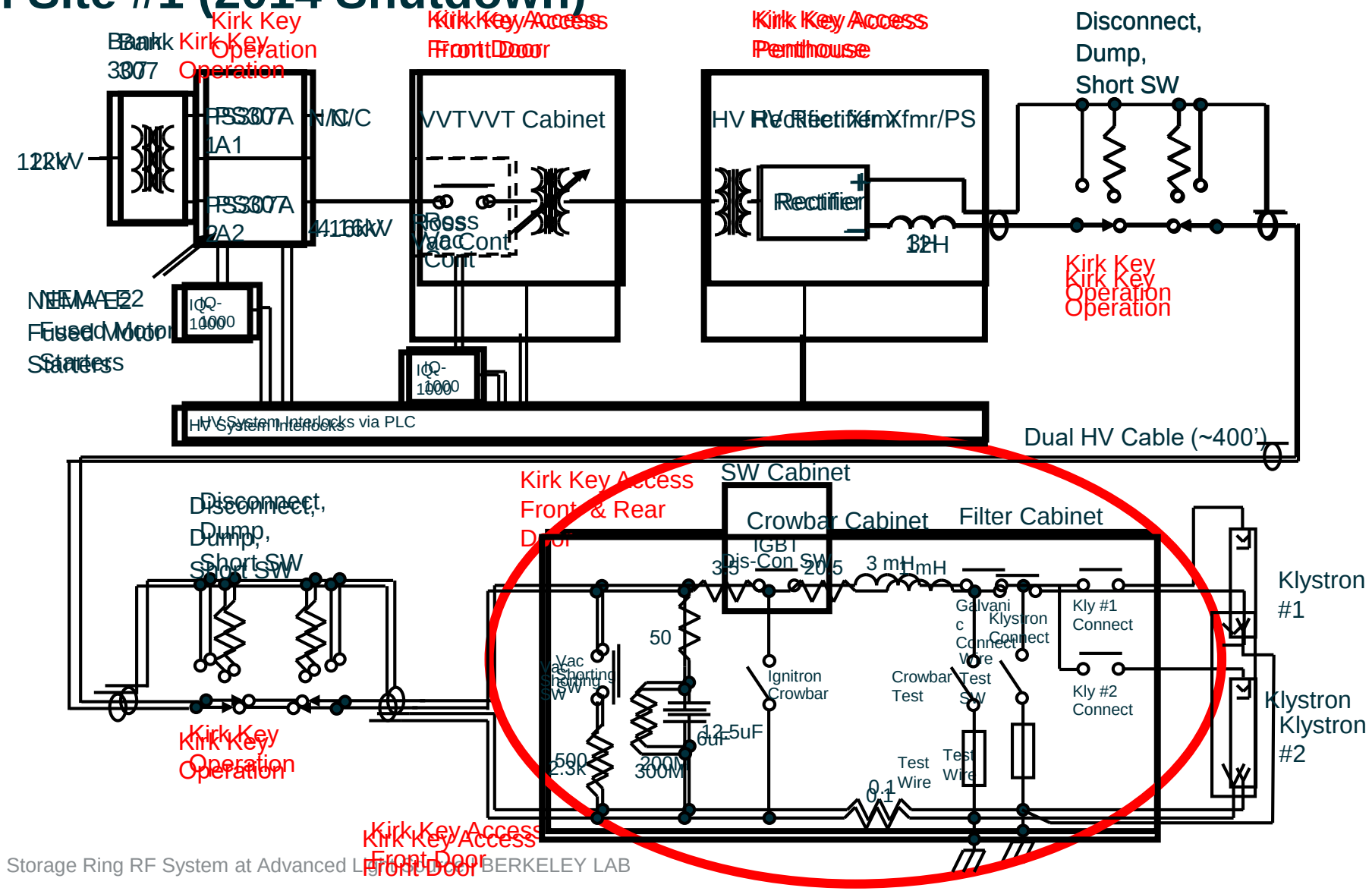
PLC Control Network

Automated RF turn-on process, interlocks, based on waveguide mode

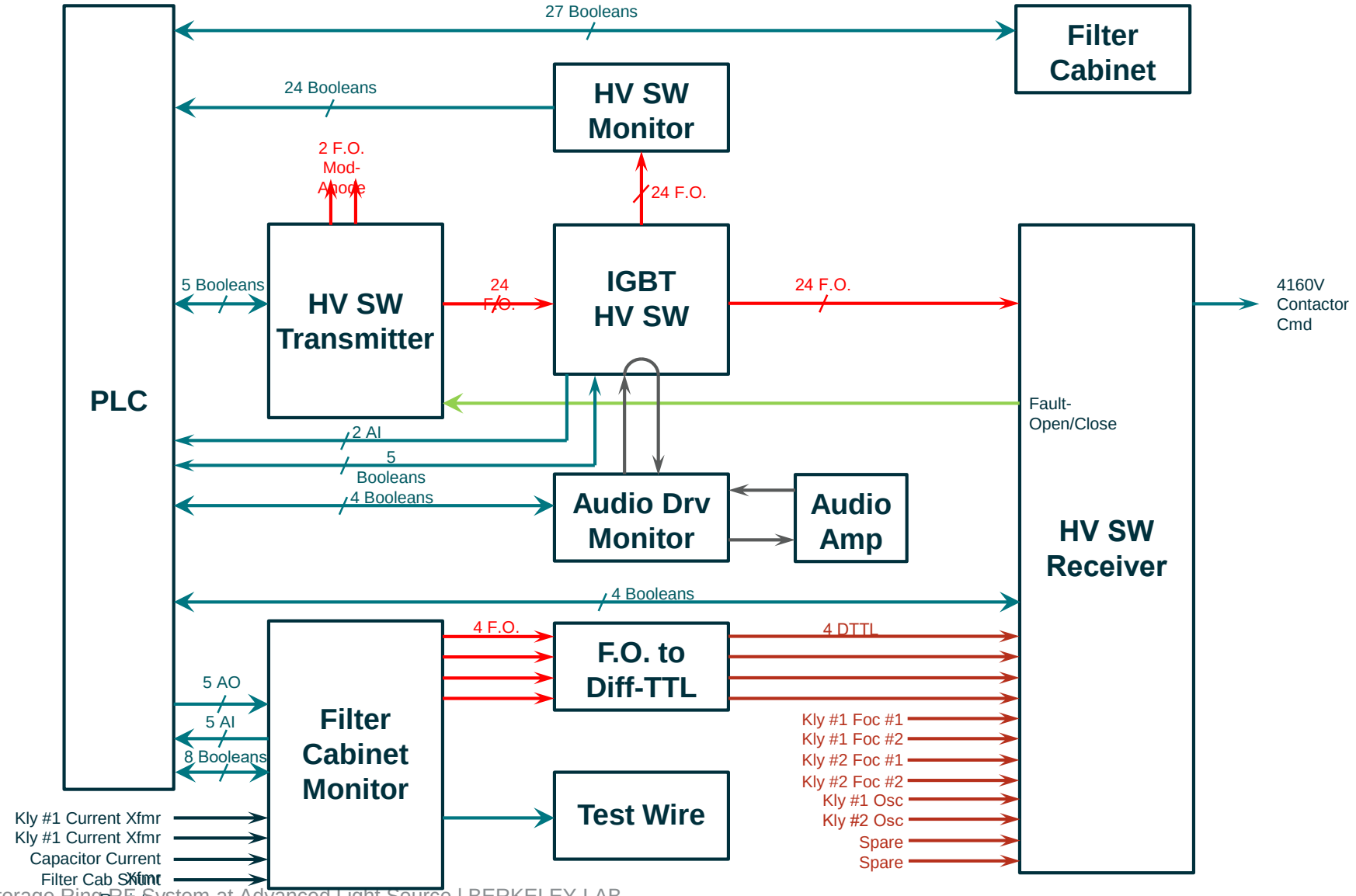




Phase IIB: Replace Crowbar w/HV Dis-Con SW & PLC Controls, Install Klystron Site #1 (2014 Shutdown)



HV Dis-Con SW Block Diagram



HV Dis-connect switch with PLC control

Filter/Crowbar Cabinet Replaced w/HV Dis-Con SW, PLC Controls, Kly Site #1 Completed 6/2014

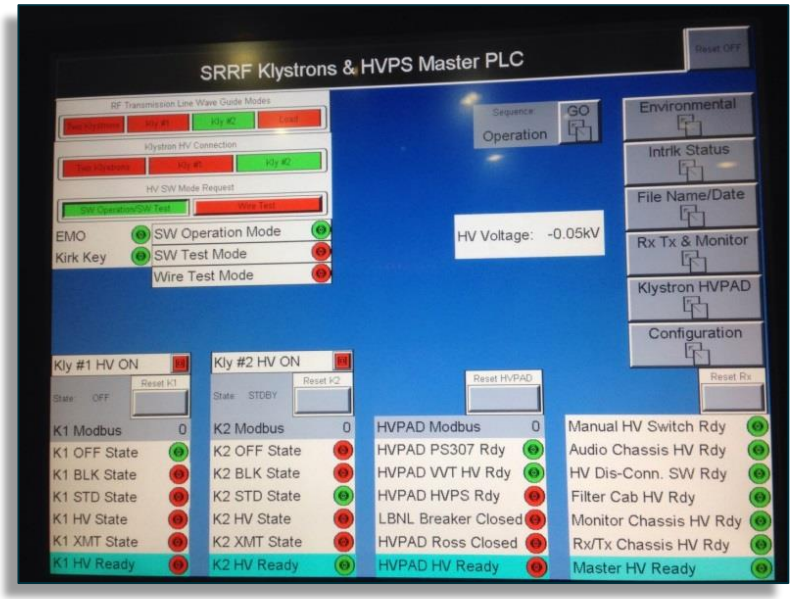
Klystron Site #1

HV Dis-Con SW

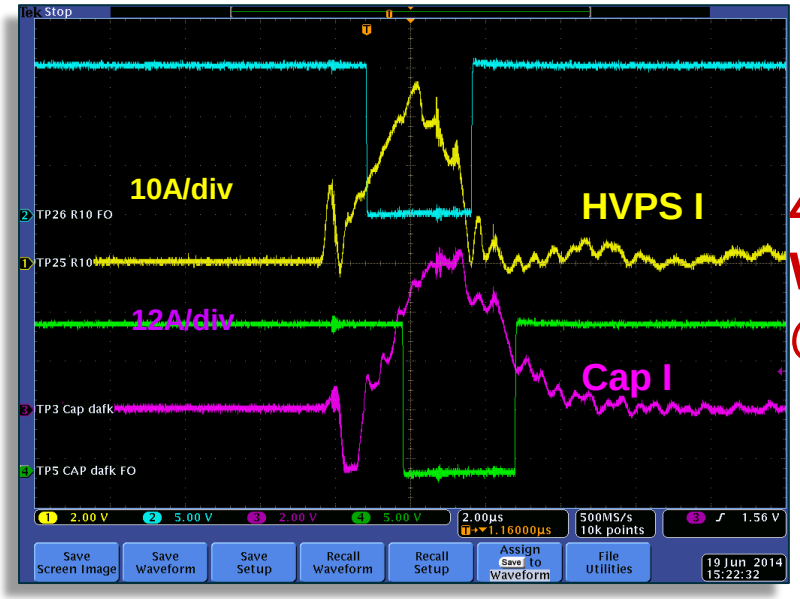
IGBT Switch
Receiver chassis

Filter Cabinet and PLC Controls

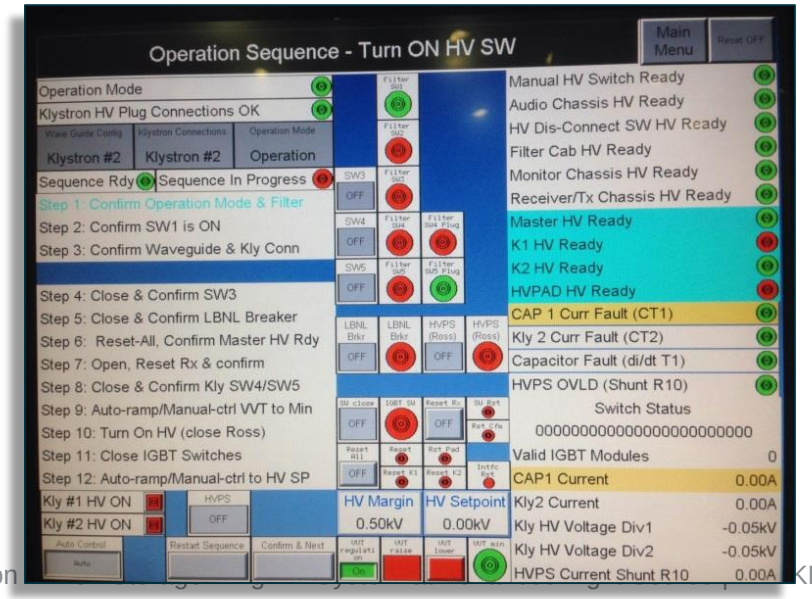
PLC Controls

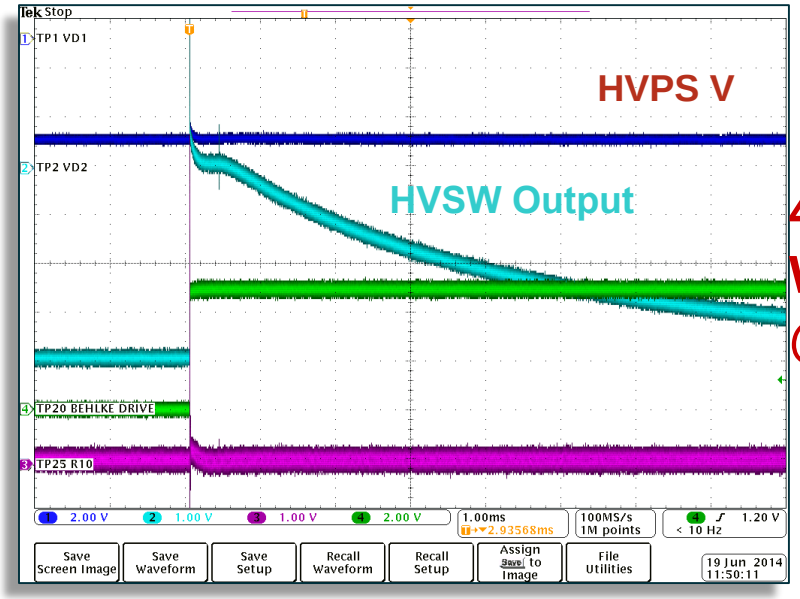


HV Dis-Con Switch Performance



40 AWG
Wire Test
@ 50kV



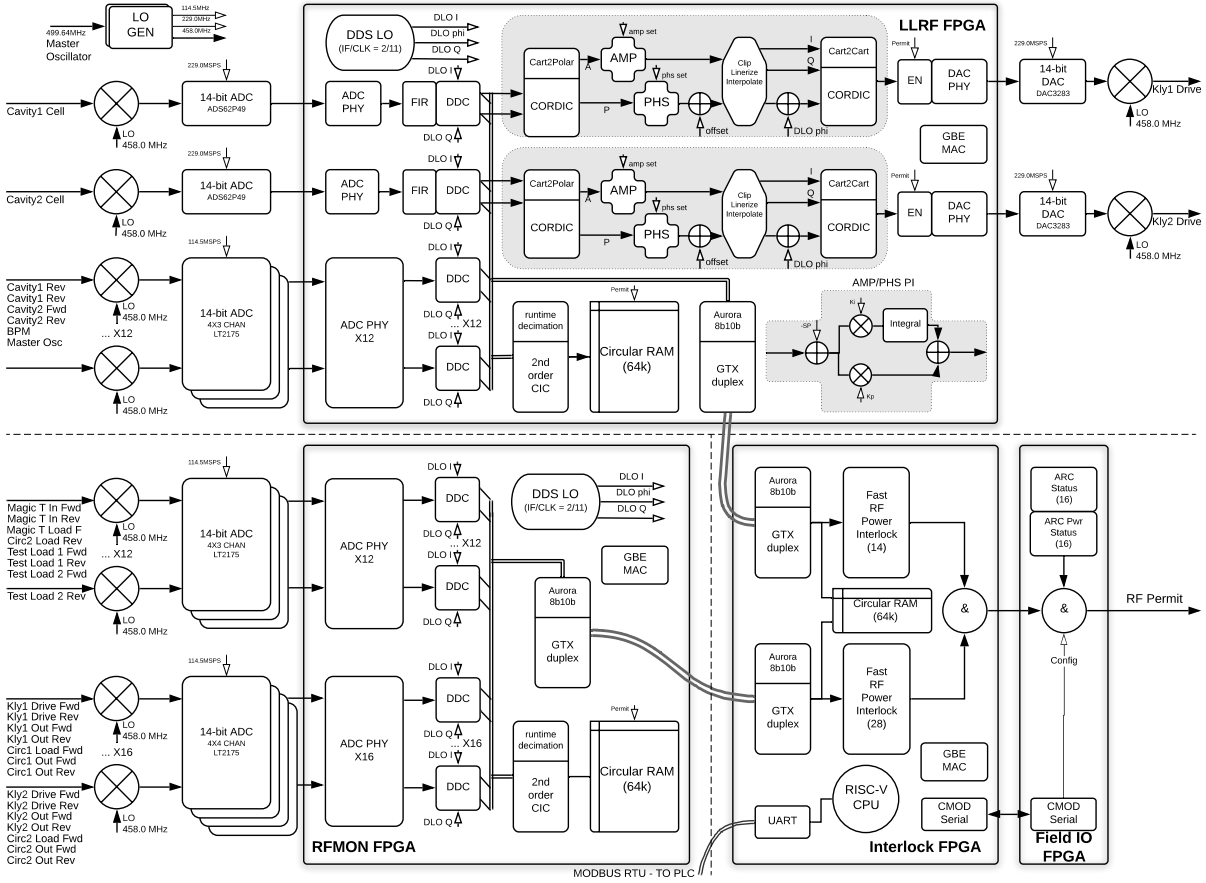


40 AWG
Wire Test
@ 40kV

Digital Low-Level RF system

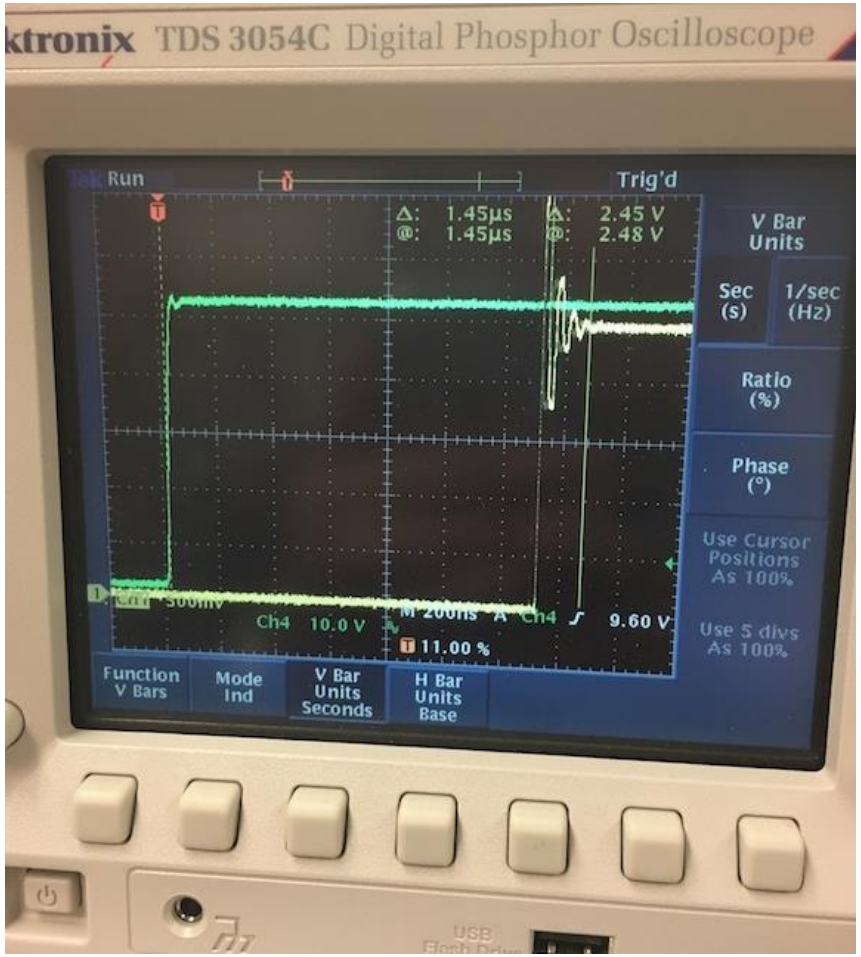
Operational since 2017.3

- System configuration:
  - 42 RF chan. → ADCs
  - 2 DACs → 2 Klystrons
  - Non-IQ synch. sampling
  - up to 24 bits, (fault) waveforms
  - 4 FPGA, interconnected
  - UDP, PLC interfaces
- 4 feedback loops:
  - 2 amplitude, 2 phase loops
  - depends on waveguide mode
- Fast RF interlocks
  - 42 RF power interlock
  - 16 ARC interlock
  - Mode dependent, PLC settable

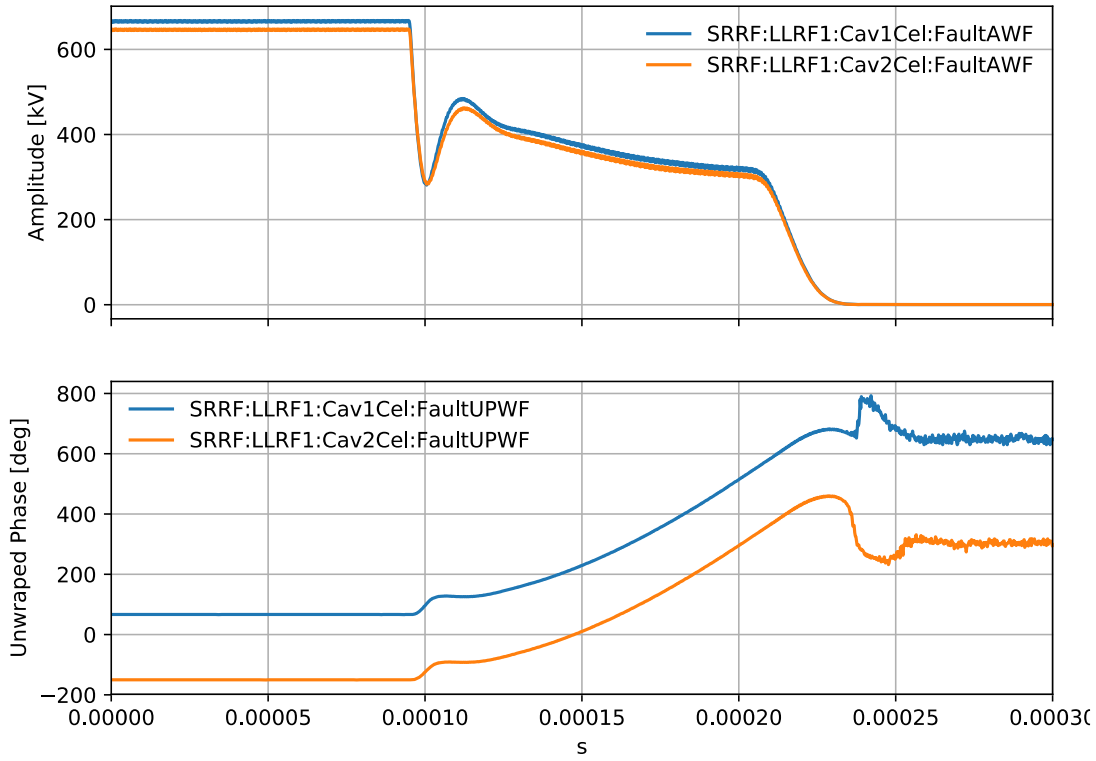


Digital Low Level RF System

Fast RF interlock



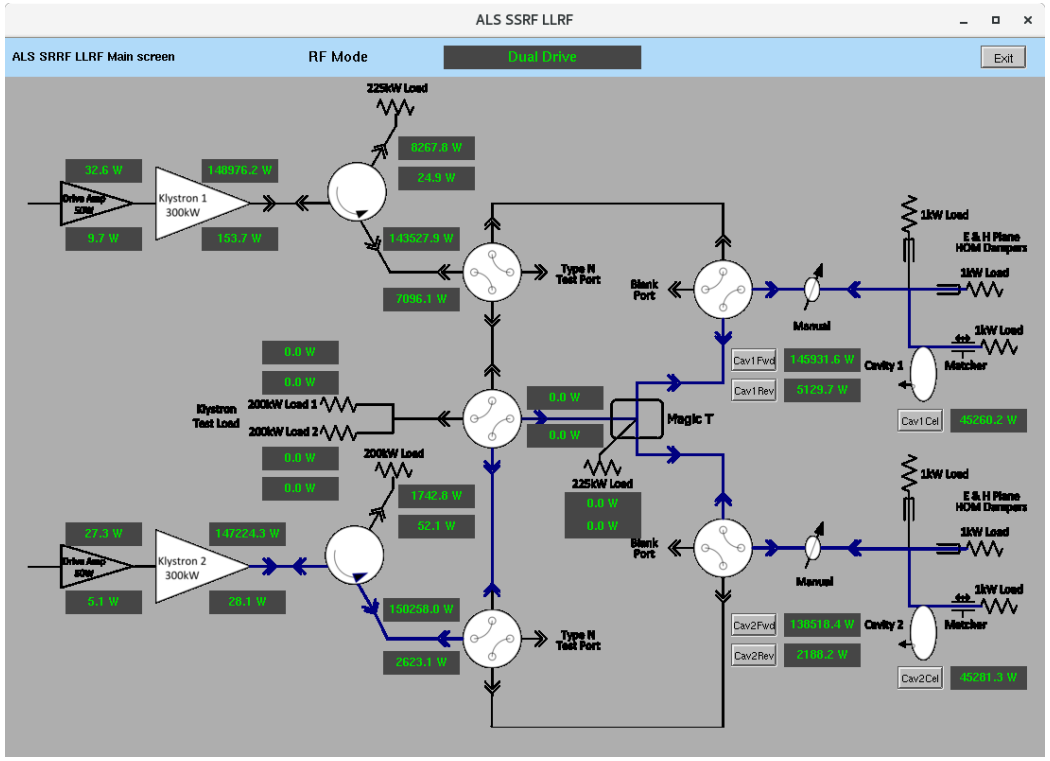
Interlock Type	Latency (µs)
RF Power (Lab)	1.45
RF Power (ALS)	< 3
ARC Detector	< 2



Fault waveforms: e.g. Cavity Cell amp / phase

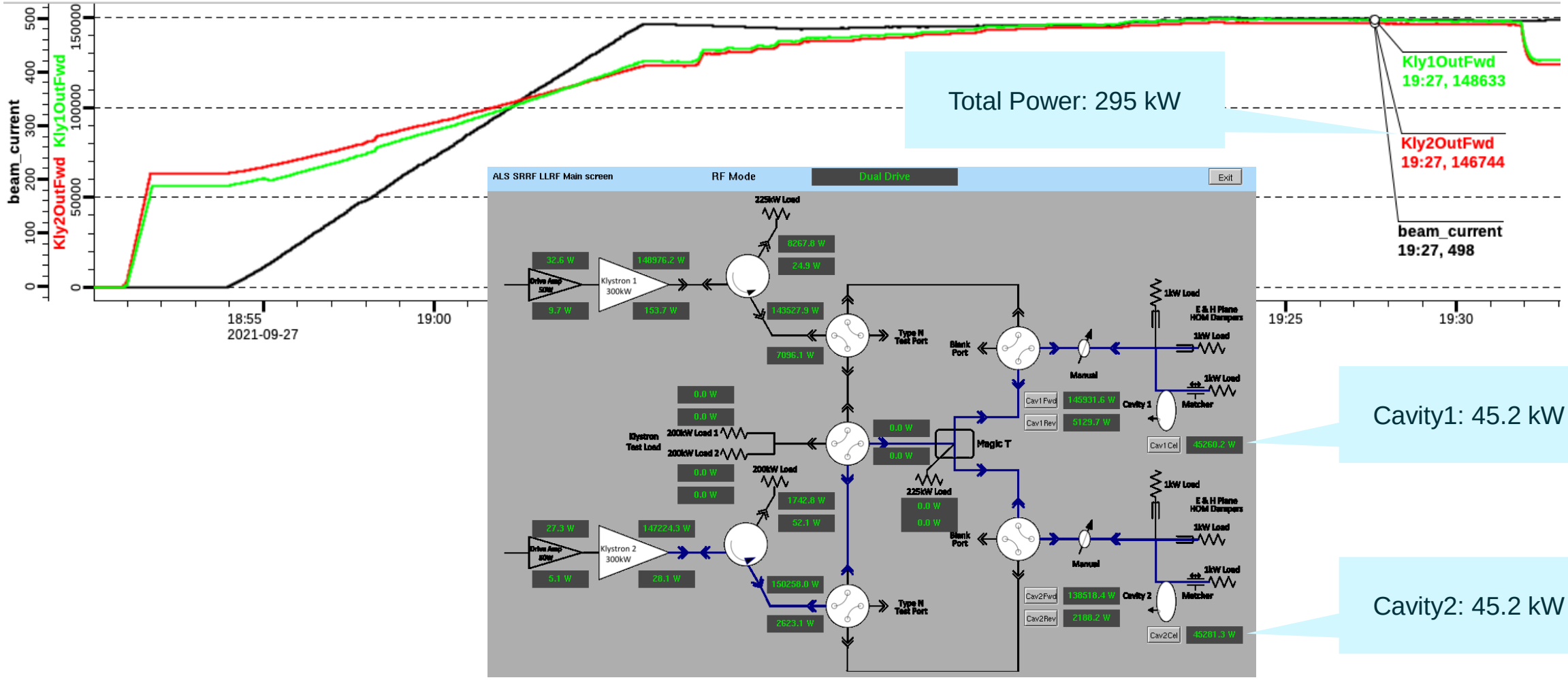
Automatic system configurations for multi-mode operation

Integrated mechanical, LLRF, PLC, EPICS configurations for multi-mode high power RF

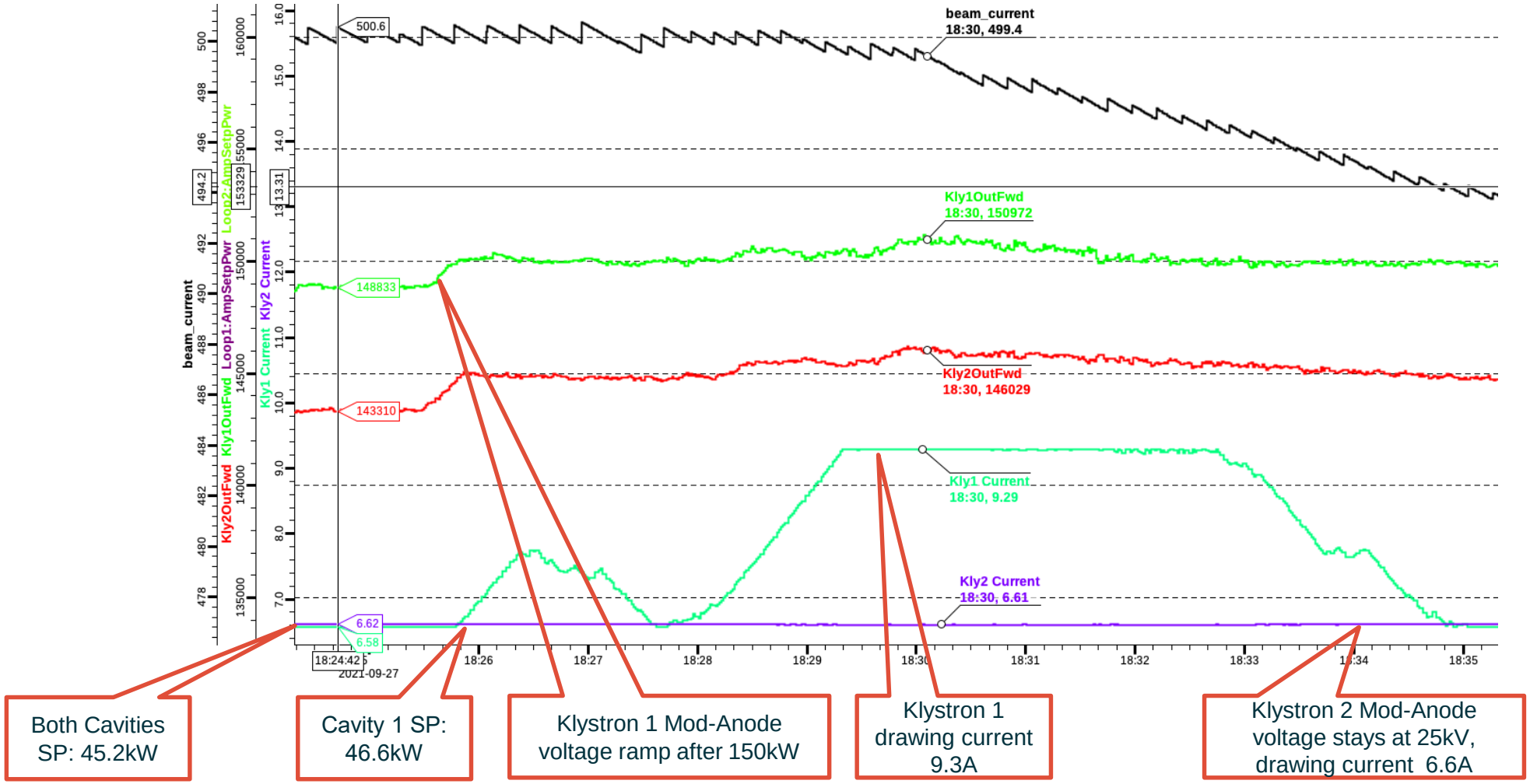


Tested balanced klystron gain by equal cavity powers

Insertion Device gaps closed at full beam load (500 mA)



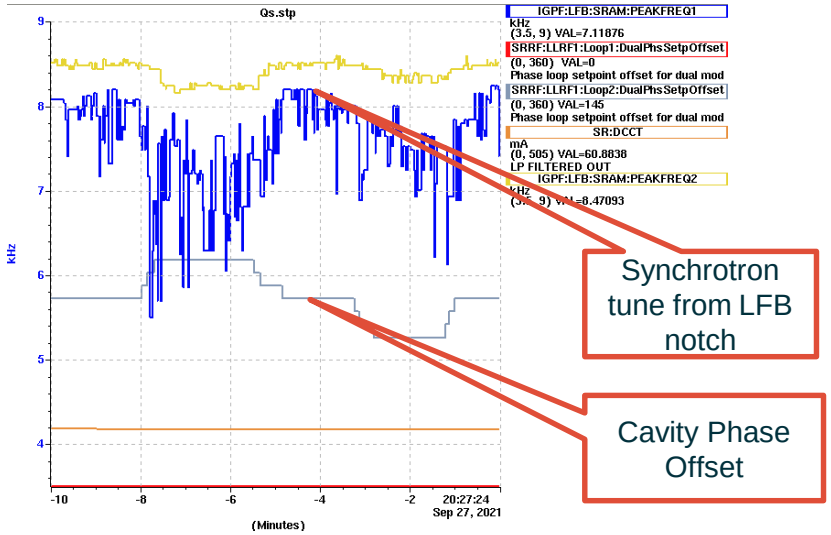
Tested different Klystron gains by unbalanced cavity powers

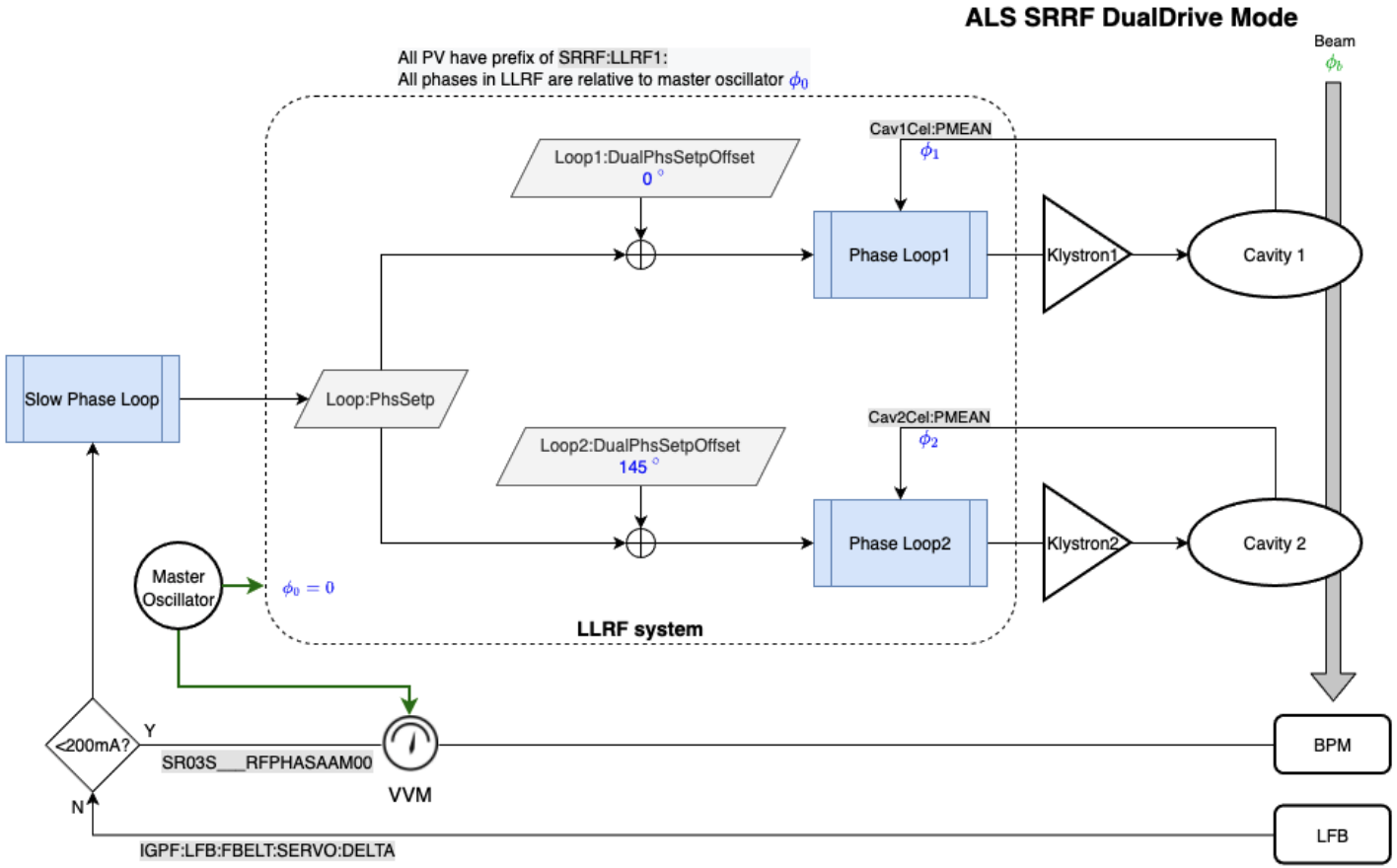


Dual Klystron Drive Cavity Phase Control

Independent LLRF control of two klystron loops (total 4)

- Automated RF turn-on process in all waveguide modes
- Auto RF phase settings:
  - Dual Drive & Single Drive modes;
  - Beam based phase feedback;
- Tuned phase offset between 2 cavities for optimal synchrotron tune;





Thank You