Status of the ALS RF Systems

December 3, 2014

RF Group Leader: Slawomir Kwiatkowski
Ken Baptiste, Qiang Du
Max Vinco, Jim Julian (ret)

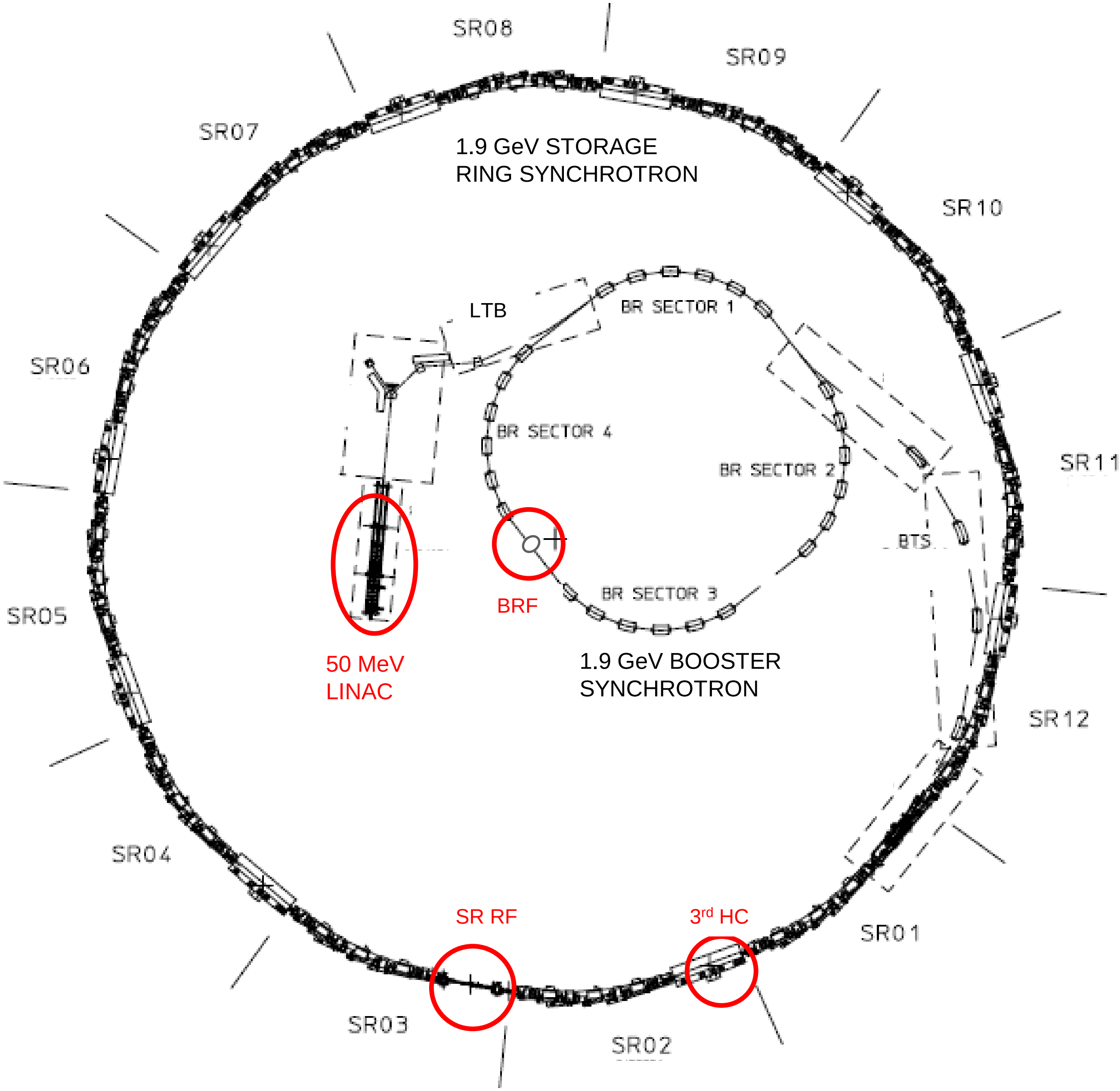
Scope

- ALS's RF Systems
  - Injection System
    - Electron Gun (125 MHz)
    - GTL Sub-Harmonic Bunchers (125 MHz & 500 MHz)
    - S-Band Linac (2.998GHz)
      - ➢ S-Band Buncher
      - ➢ S-Band Accelerating Sections
    - Booster RF System (500 MHz)
  - Storage Ring
    - Storage Ring RF System (500 MHz)
- 3rd Harmonic Cavities, passive (1.5 GHz)
- ALS RF Teststand
  - 66kW 500MHz Teststand
  - Titanium-Nitride Window Coating System

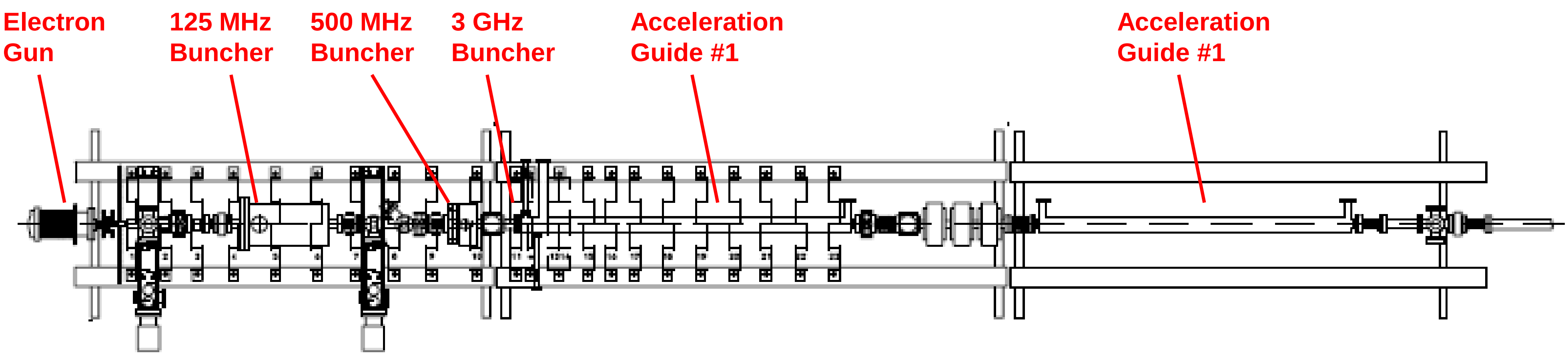
Additional Scope

- SRRF Reliability History
- Things that didn't go quite right...
  - 12.5uF, 66kV Cap developed internal shorts
  - 4 1/16" Coax line fails

ALS's RF Systems

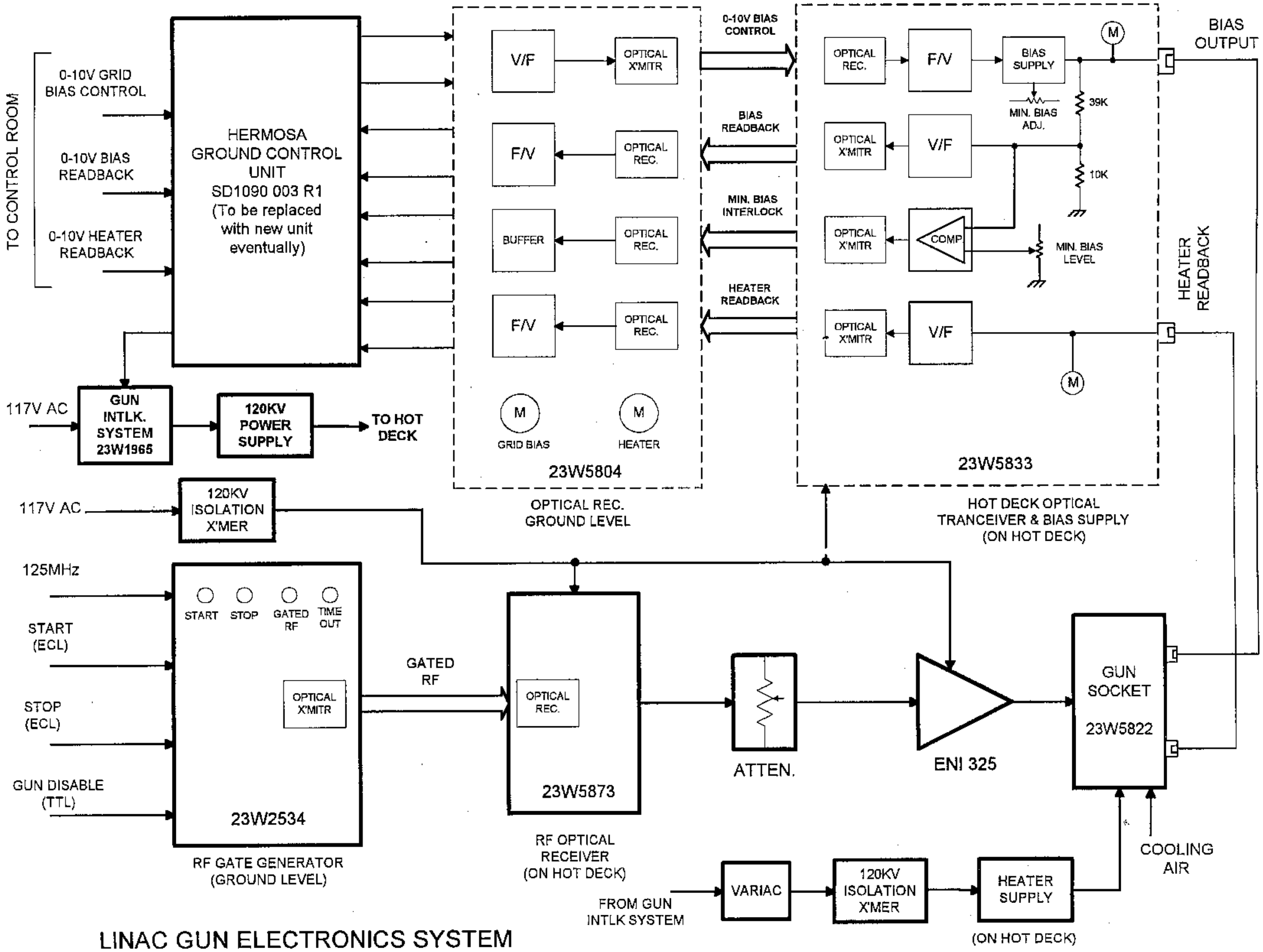


Injection System – Electron Gun & Linac



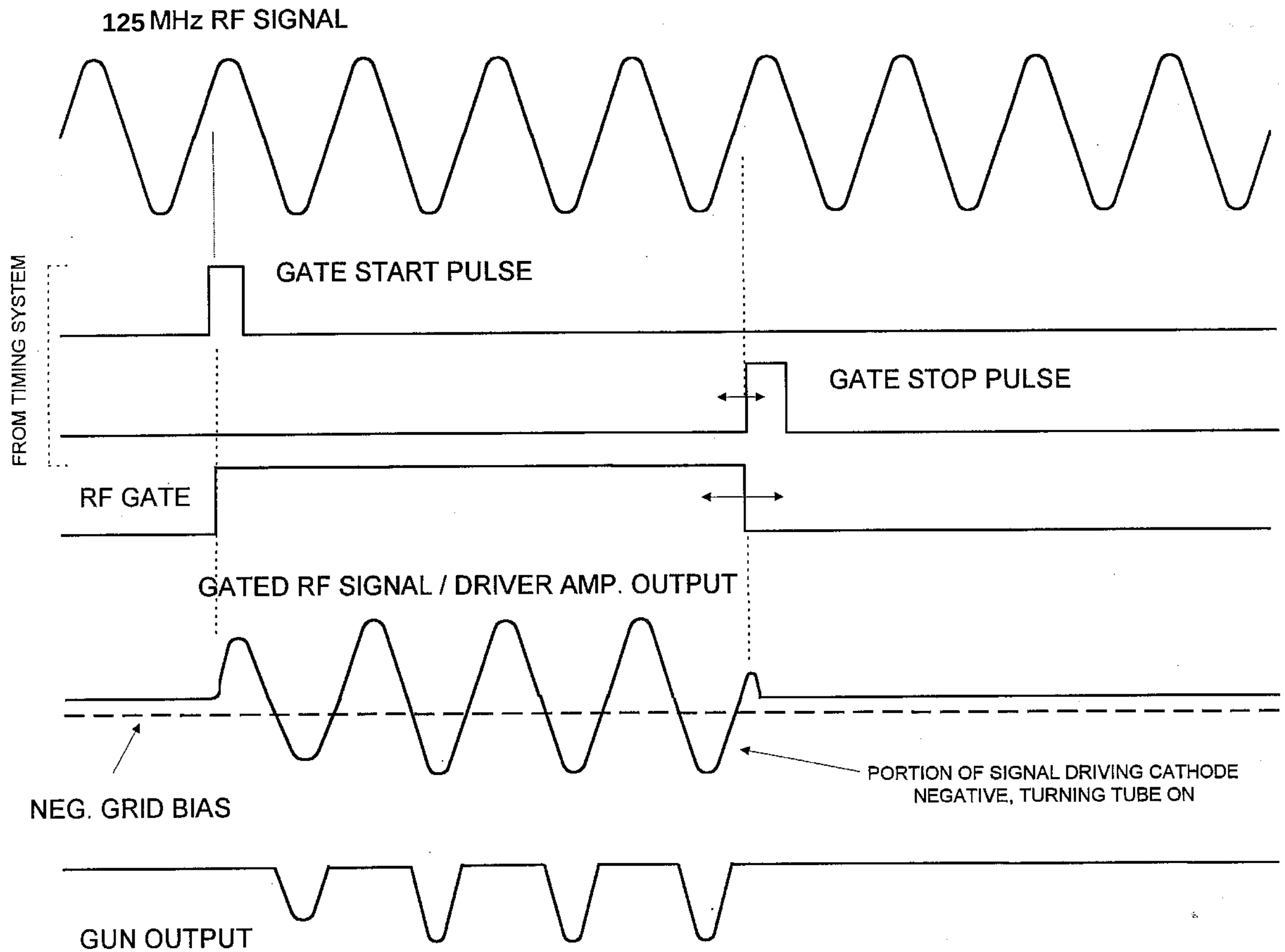
E. Gun Electronics Equip Rack & Block Diagram

E. Gun Rack (LI01)



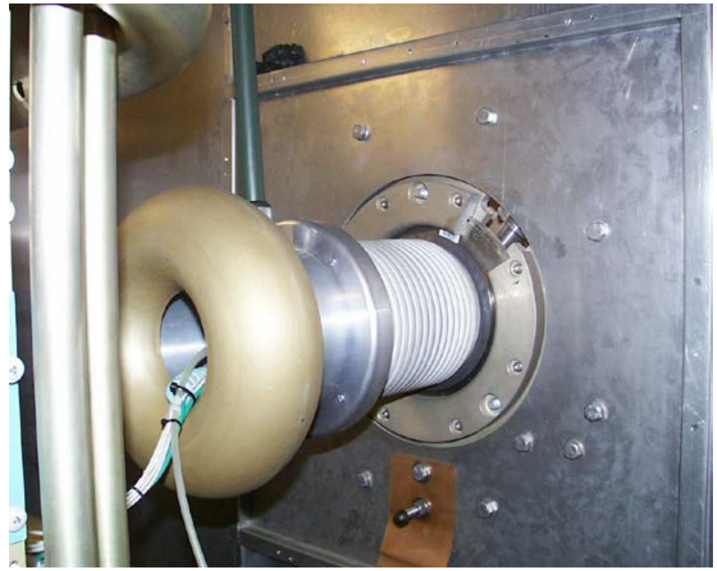
Block Diagram

E. Gun Pulse Train Generation

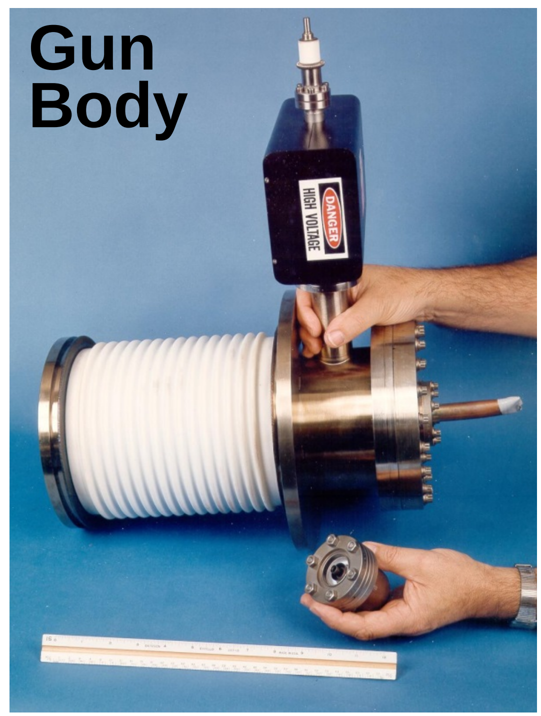


Electron Gun Hot Deck, Gun Body, Cathode

Hot Deck



Cathode life
~4 years

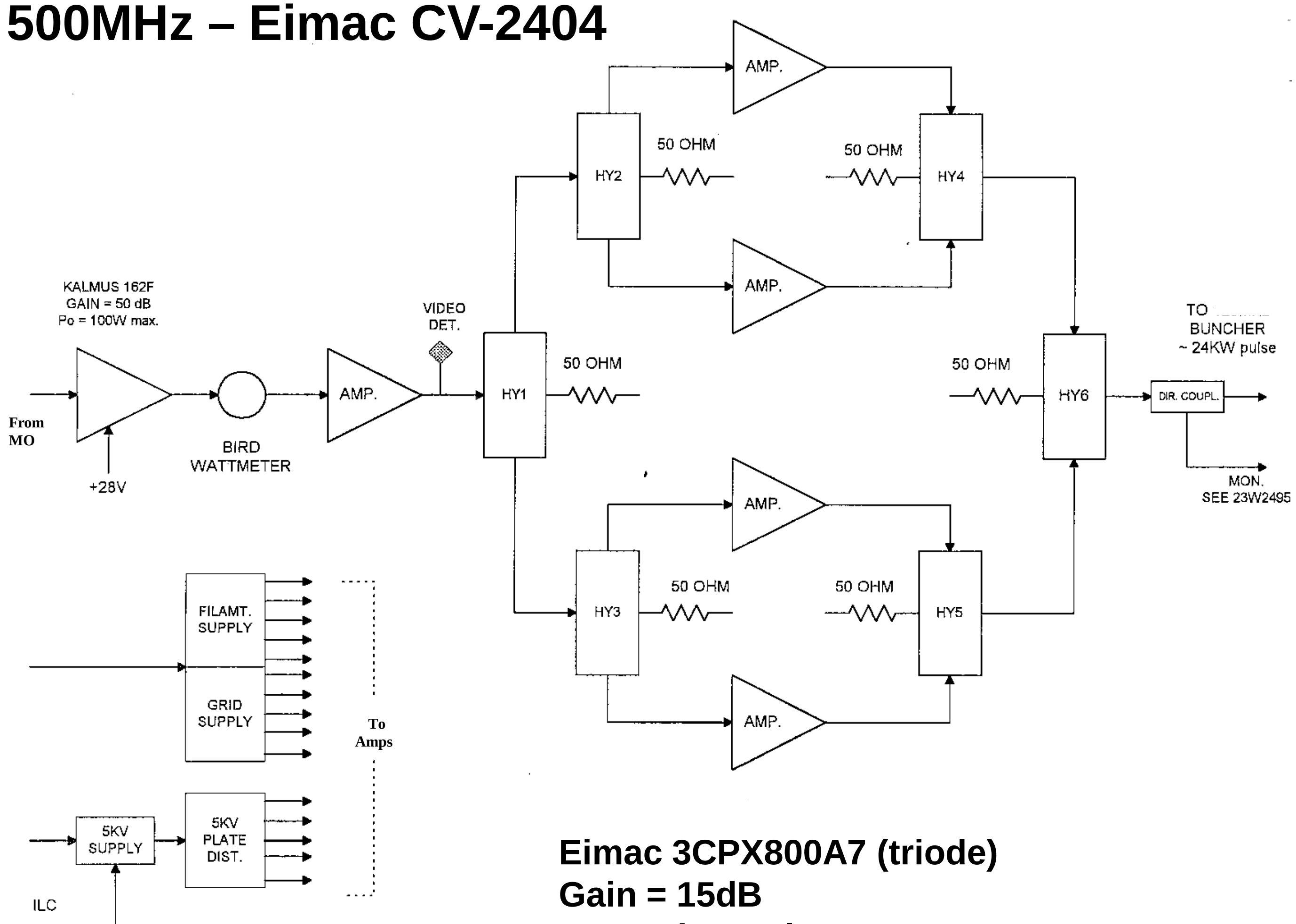


Gun
Body

Cathode
Eimac YU-171

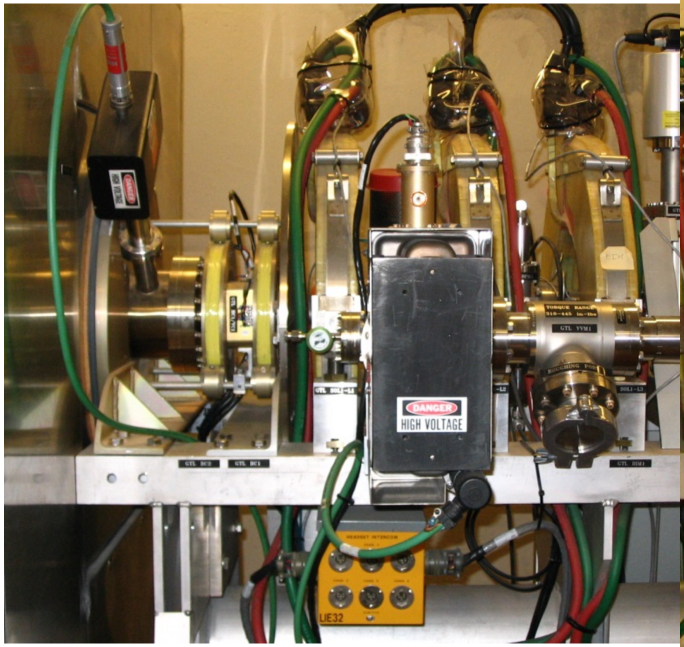
125MHz & 500MHz Sub-Harmonic Bunchers (GTL SHB1 & SHB2)

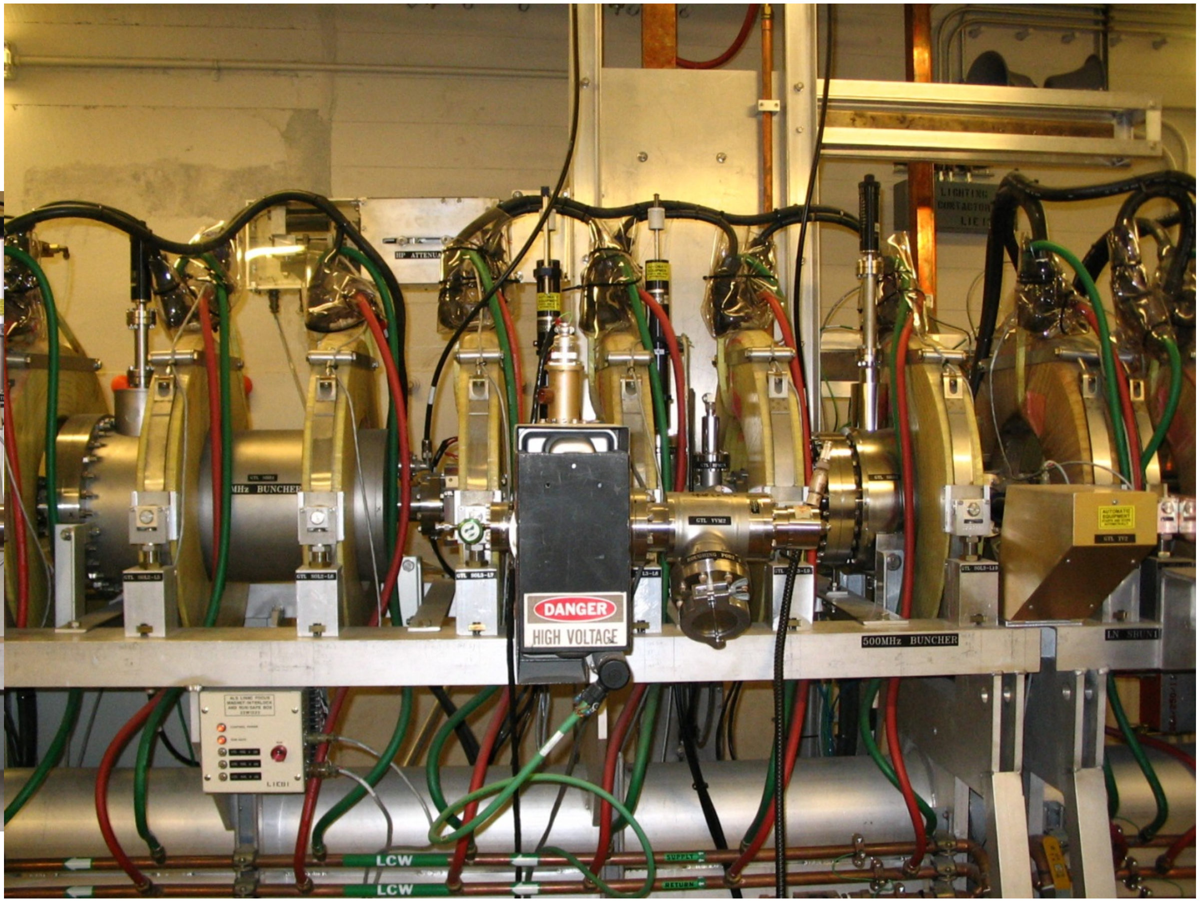
125MHz – Eimac CV-2222
500MHz – Eimac CV-2404



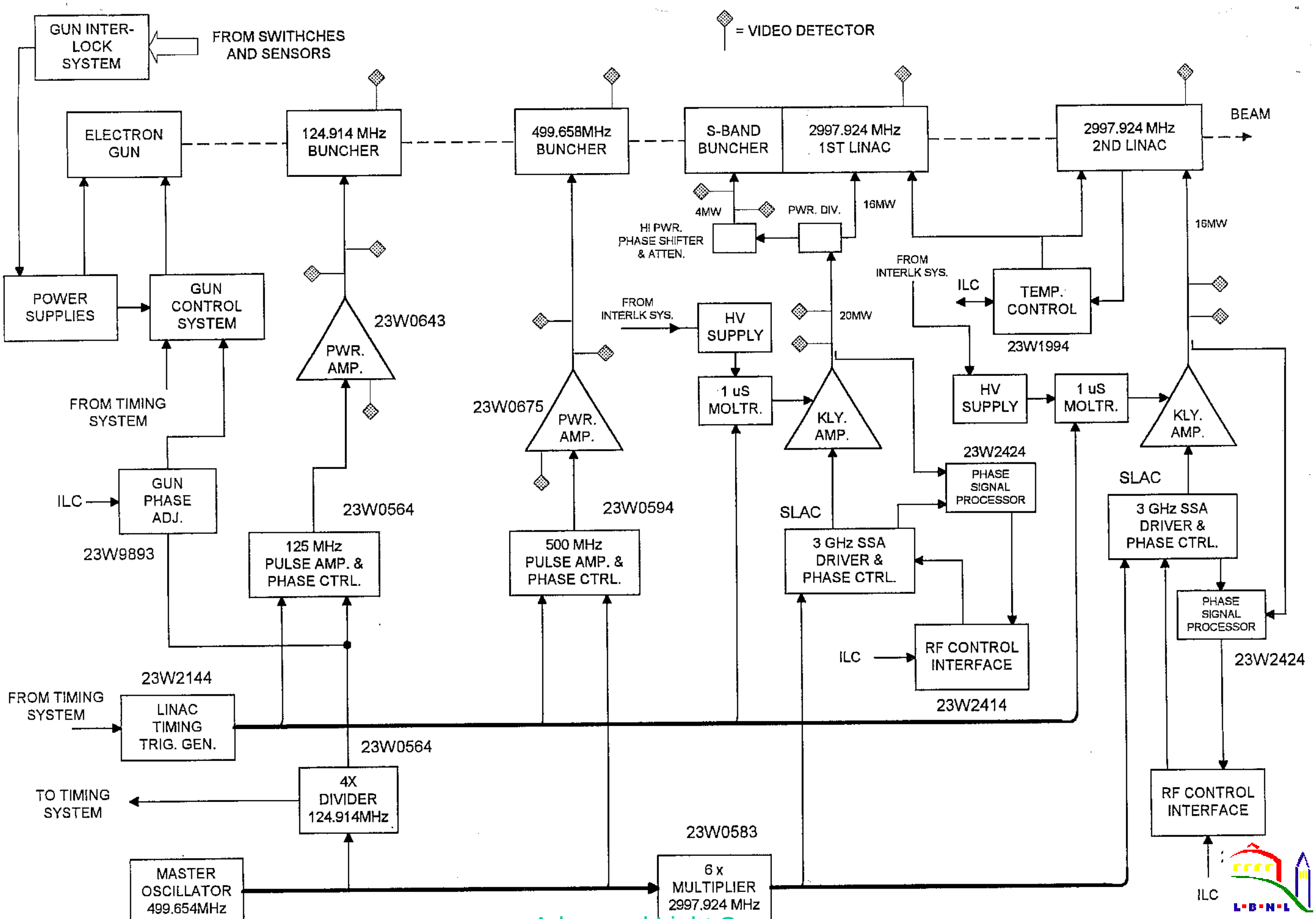
Eimac 3CPX800A7 (triode)
Gain = 15dB
Up to 6kW Pulse
Tube Lifetime 10-12 years

Photos of (GTL)

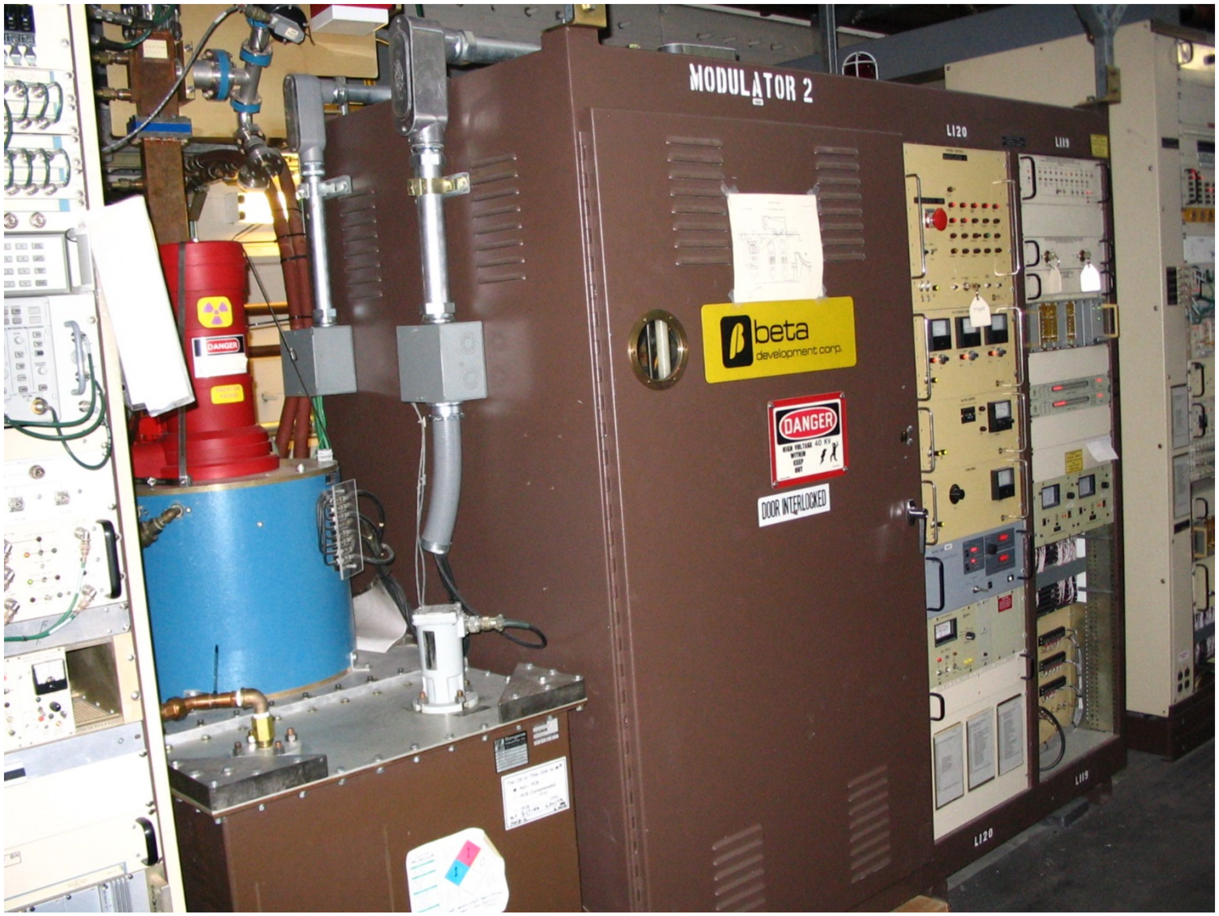


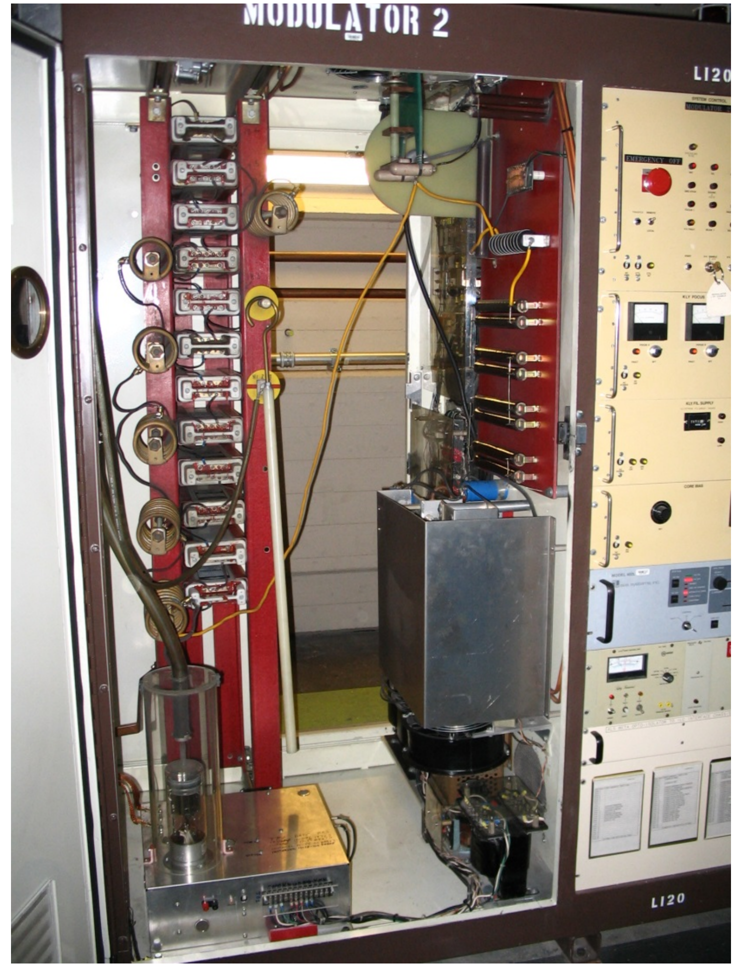


Gun thru 3GHz LINAC RF System



LINAC Modulators & Klystron



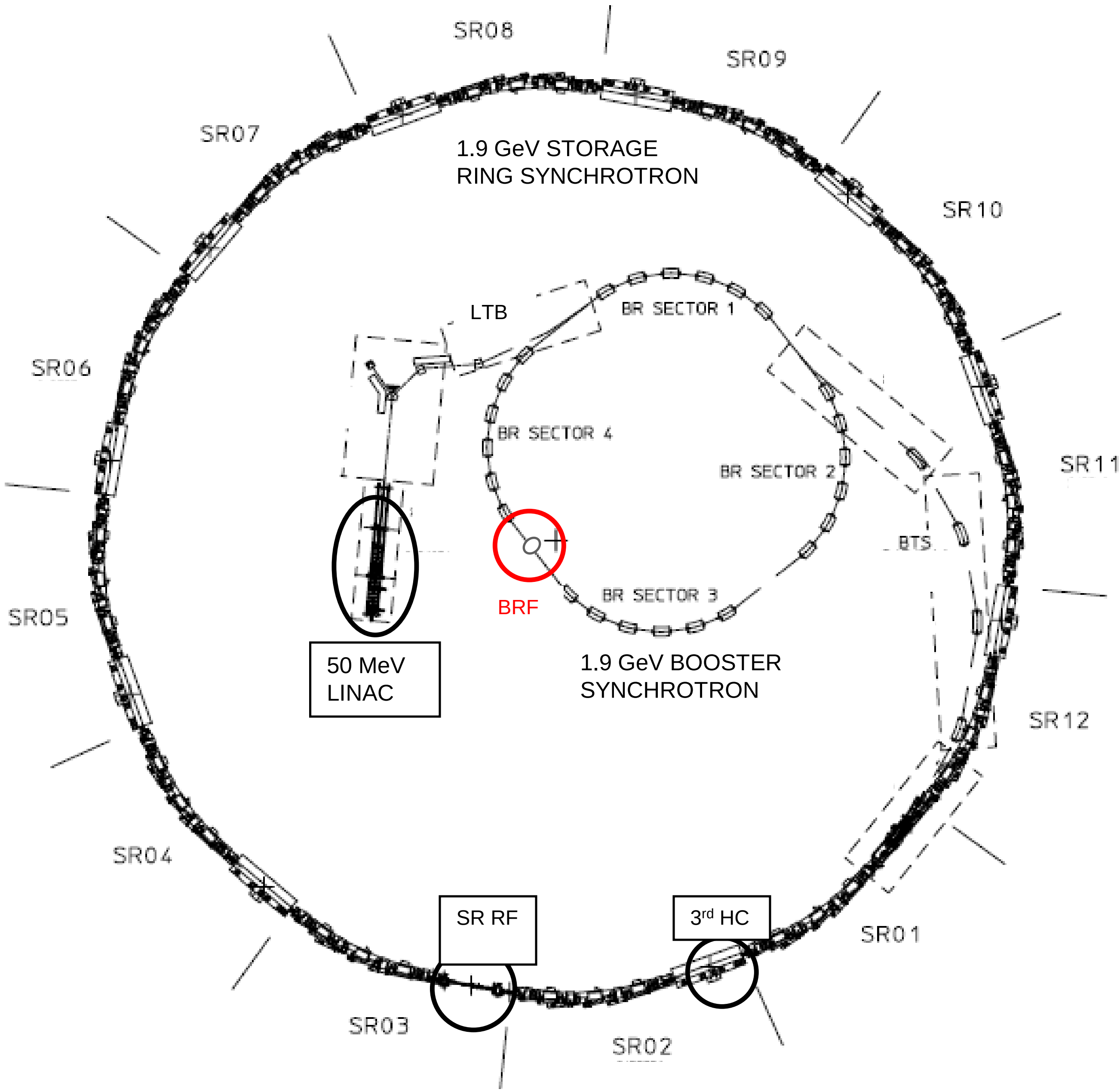


Thales TV-2002: 24MW, 2us
Lifetime: Mod #1: 17, 8+ yrs
Mod #2: 9, 14, 1, 1+ yrs

Maintenance Items:
HV Caps
HVPS & Cable

LINAC

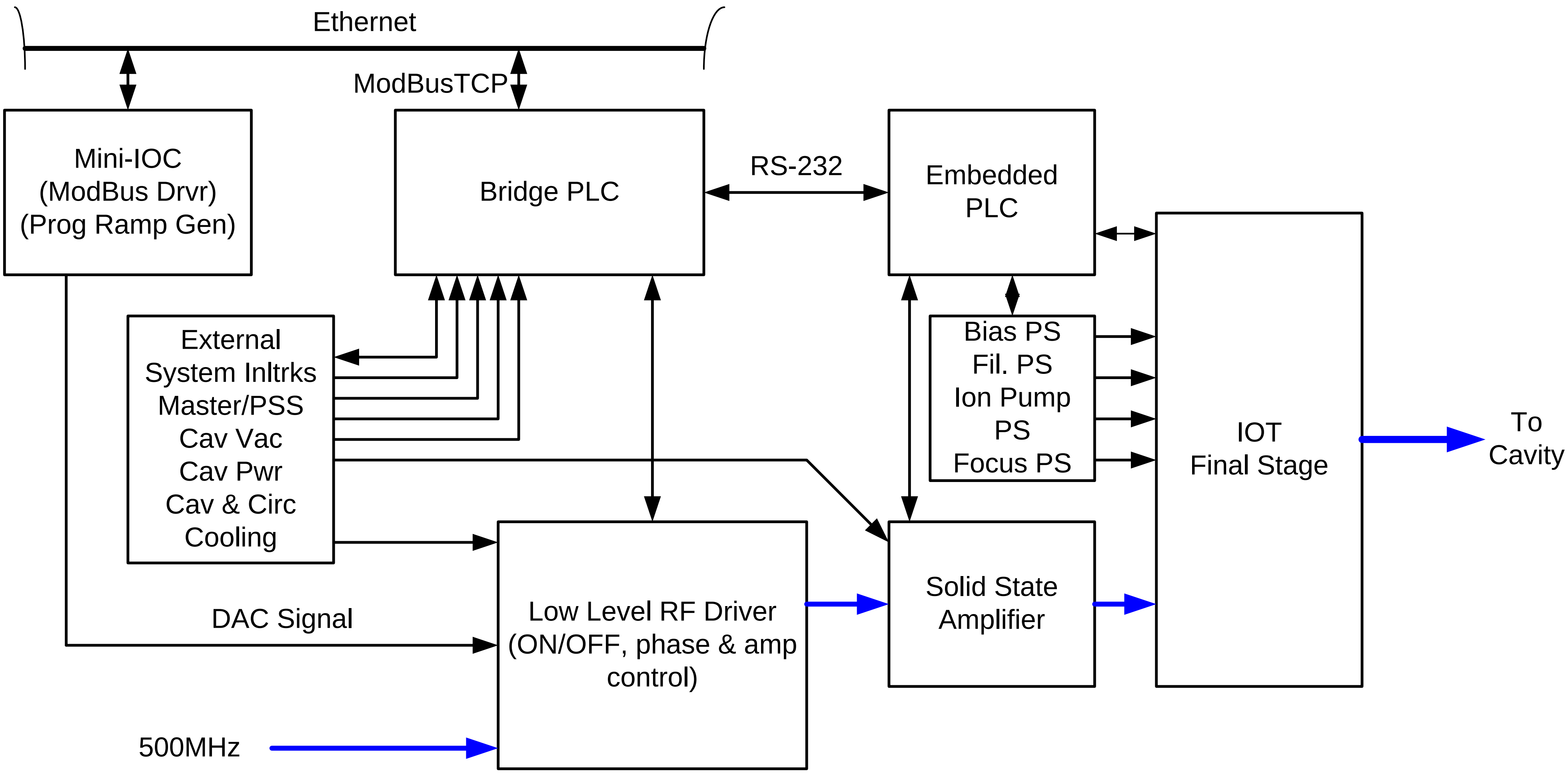
Booster RF System



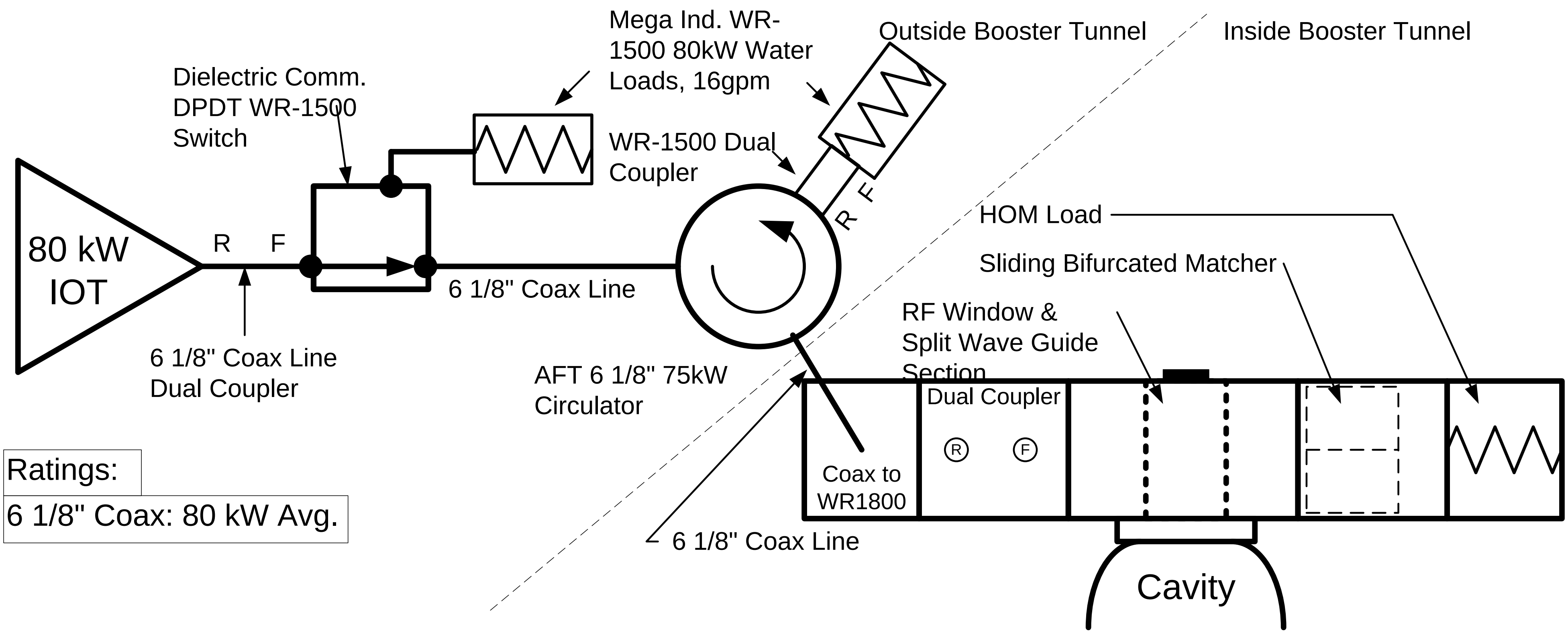
Booster Ring RF System Parameters for 1.9 GeV

	Present
Beam current (mA)	4
Dipoles Radiation (kW)	<5
Cavity Dissipation (kW)	43
W.G. & other losses (kW)	6
Total RF Power Reqr'd (kW)	54
Total RF Power Installed (kW)	80

BRF System Block Diagram



BRF Transmission Line Sketch



Ratings:
6 1/8" Coax: 80 kW Avg.

BRF HPA/XMTR

AI, Acrodyne Industries

(commercial broadcast transmitter, modified)

CPI, Communications & Power Industries

(commercial broadcast IOT, K2 series, 80kW)

Gain >23 dB

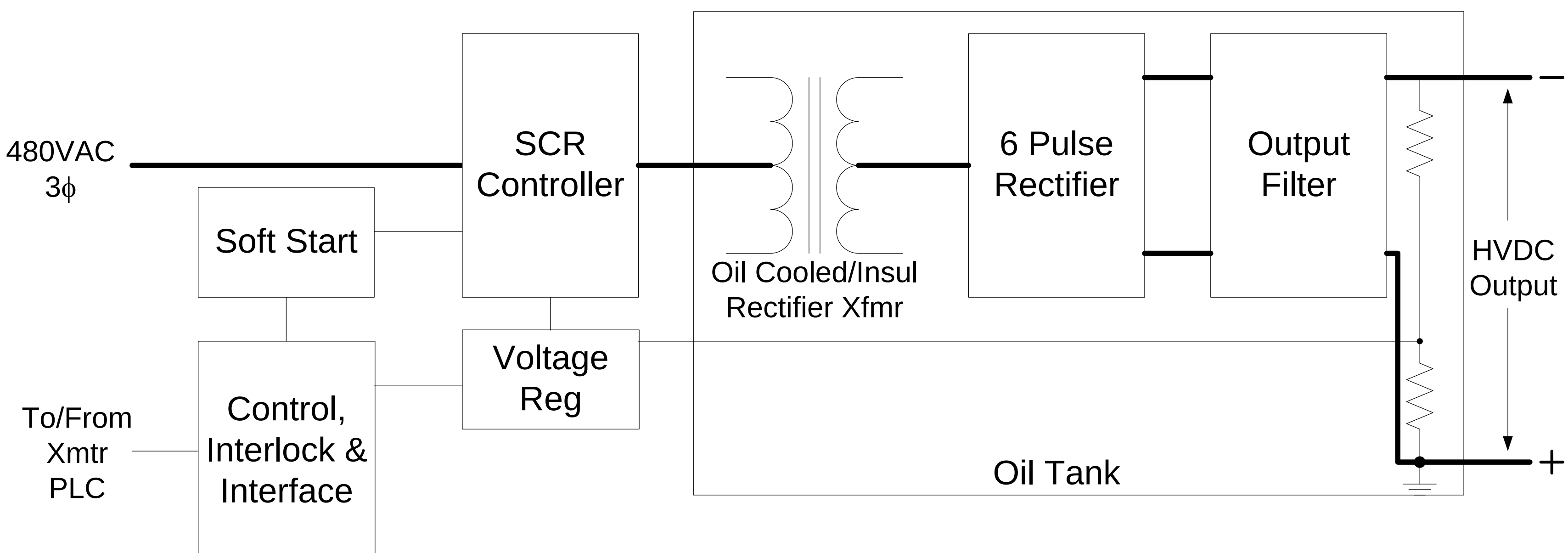
Eff. >65 %

E_B <36 kV

IOT #1: 18.1k hrs

IOT #2: +35k hrs

BRF HVPS (High Voltage RF Pad, outside Bldg.6)



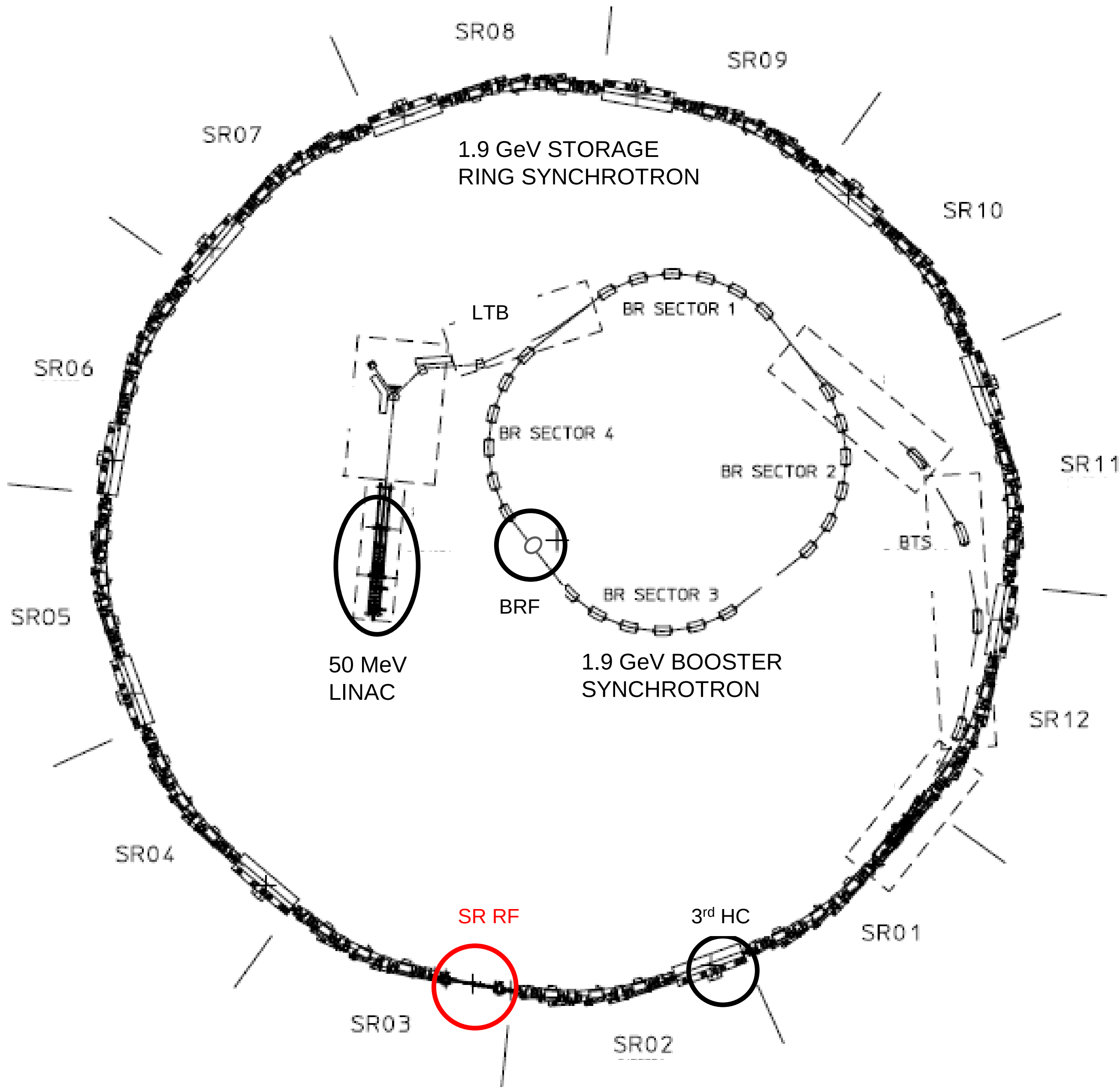
BRF Wave Guide Switch & HPA Test Load

BRF Circulator & Reject Load

BRF Cavity

SRRF Cavity

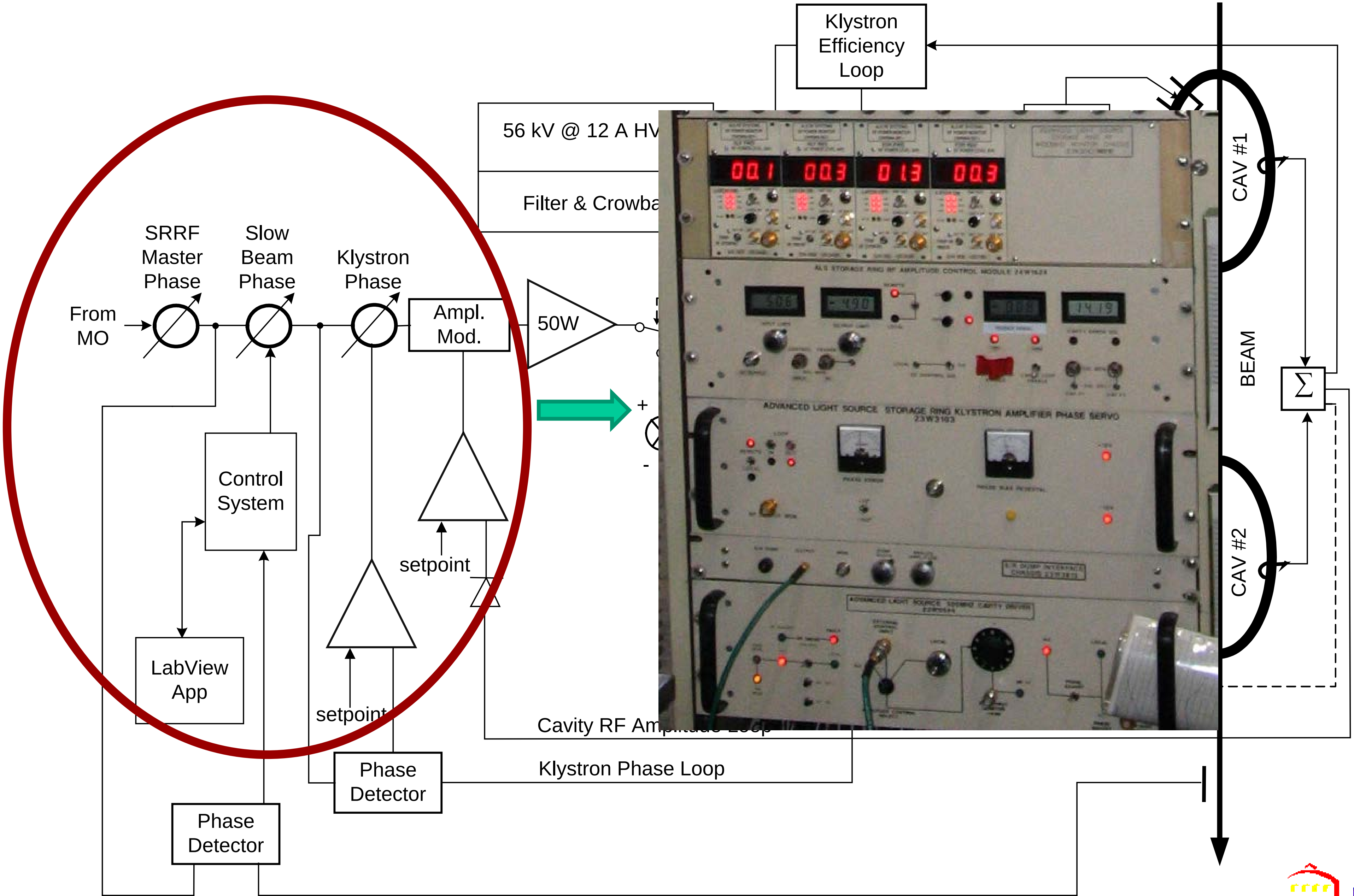
SR RF System


SR08
SR09
SR07
1.9 GeV STORAGE
RING SYNCHROTRON
SR10
LTB
BR SECTOR 1
SR06
BR SECTOR 4
BR SECTOR 2
SR11
BTS
BR SECTOR 3
BRF
SR05
50 MeV
LINAC
1.9 GeV BOOSTER
SYNCHROTRON
SR12
SR04
SR RF
3rd HC
SR01
SR03
SR02

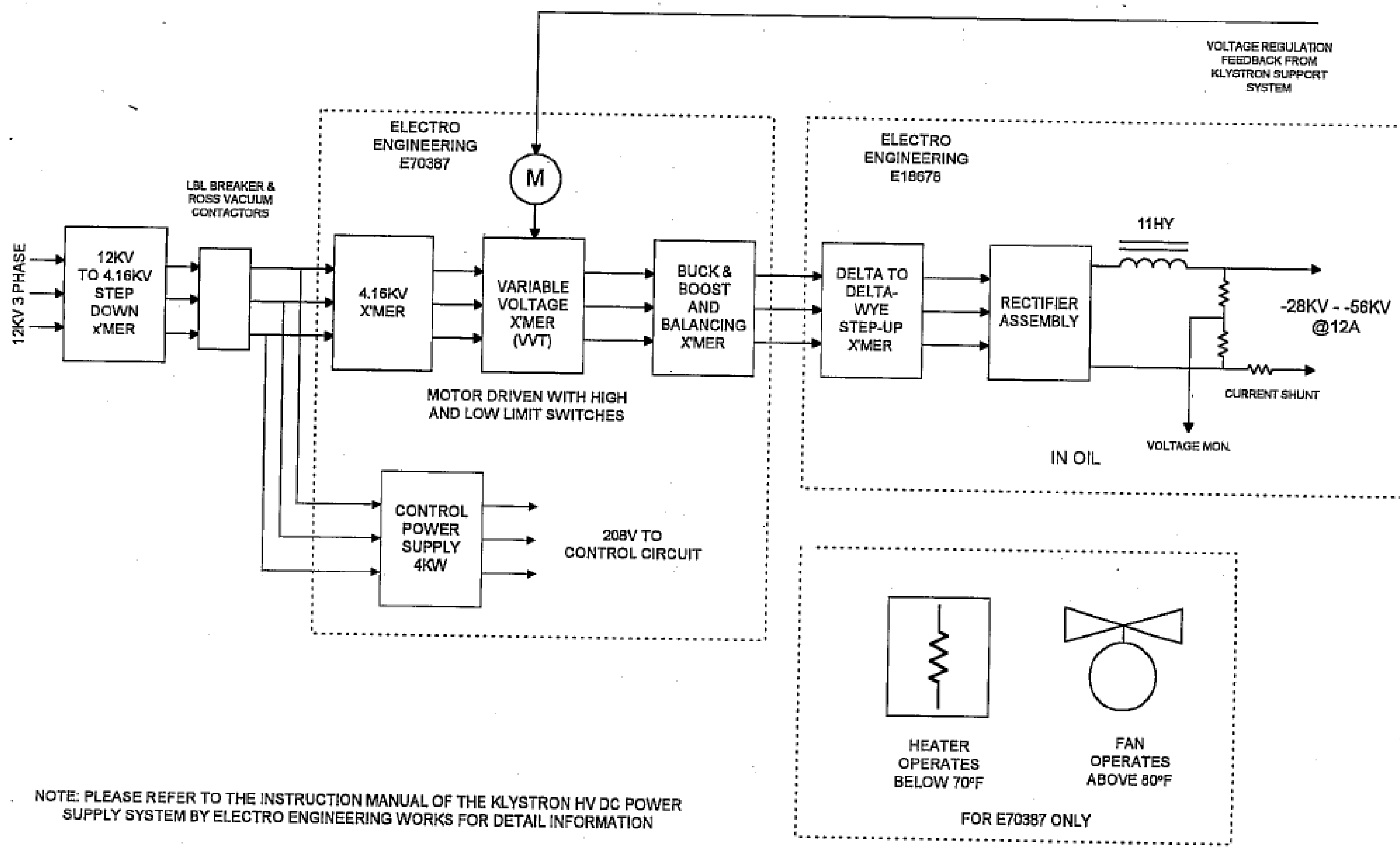
Storage Ring RF System Parameters for 1.9 GeV

	Present		Future	
Beam current (mA)	500		500	
Number of Insertion Devices	11		13	
Gap Positions	Nom	Min	Nom	Min
Dipoles Radiation (kW)	142	142	142	142
Insertion Device Radiation (kW)	25	46	46	55
Power Loss for 3rd HC (kW)	6	9	9	9
Cavity Dissipation (x2) (kW)	43	43/50	43/50	43/53
W.G. & other losses (kW)	7	10/8	10/9	12/9
Total RF Power Reqr'd (kW)	266	293/305	293/305	304/322
Total RF Power Installed (kW)	300	300	~360	~360
Cav/Window Power Limit (kW)	330		330	

Original SR RF System Block Diagram



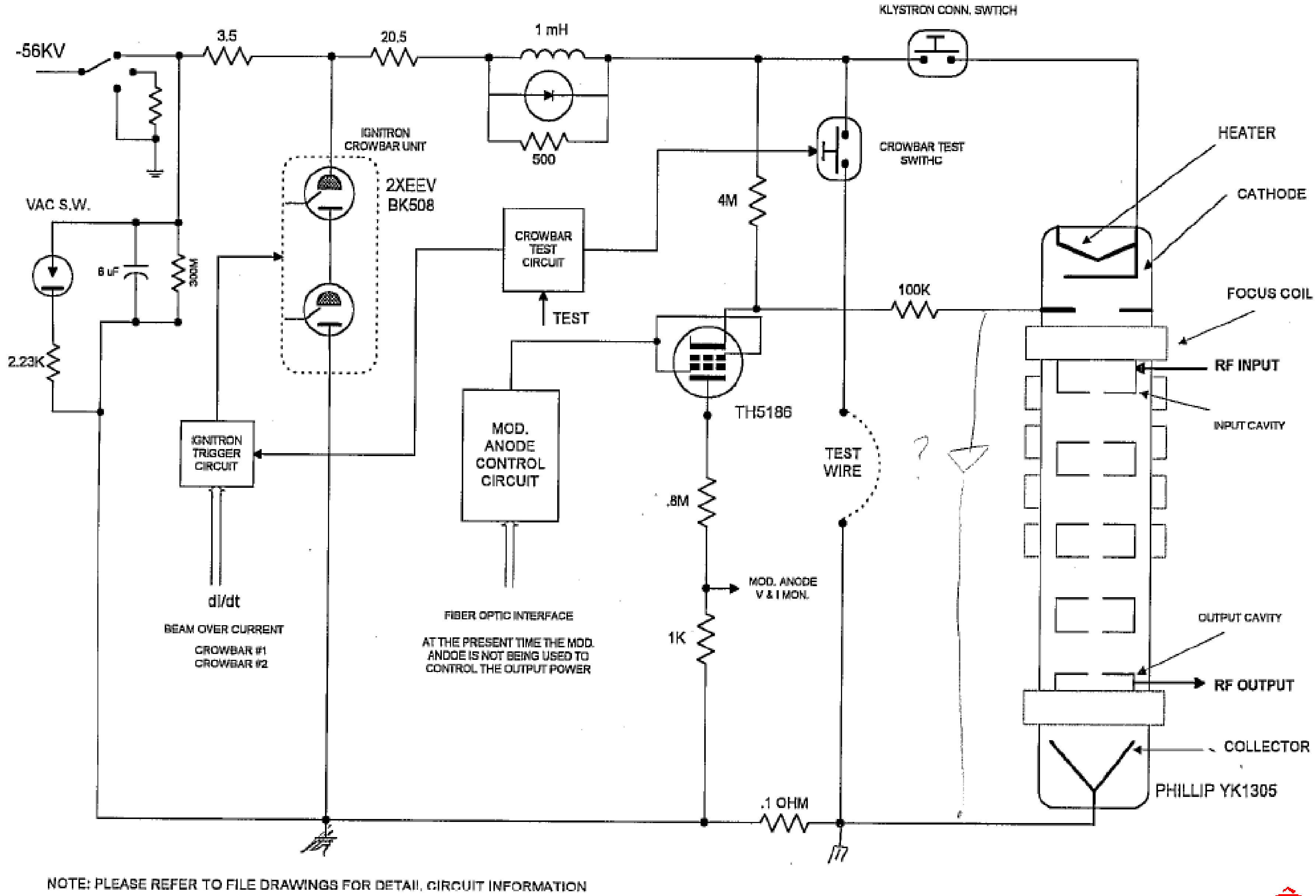
Original SR RF HVPS



ALS SR KLYSTRON HV POWER SUPPLY SYSTEM
(OUTDOOR UNIT)

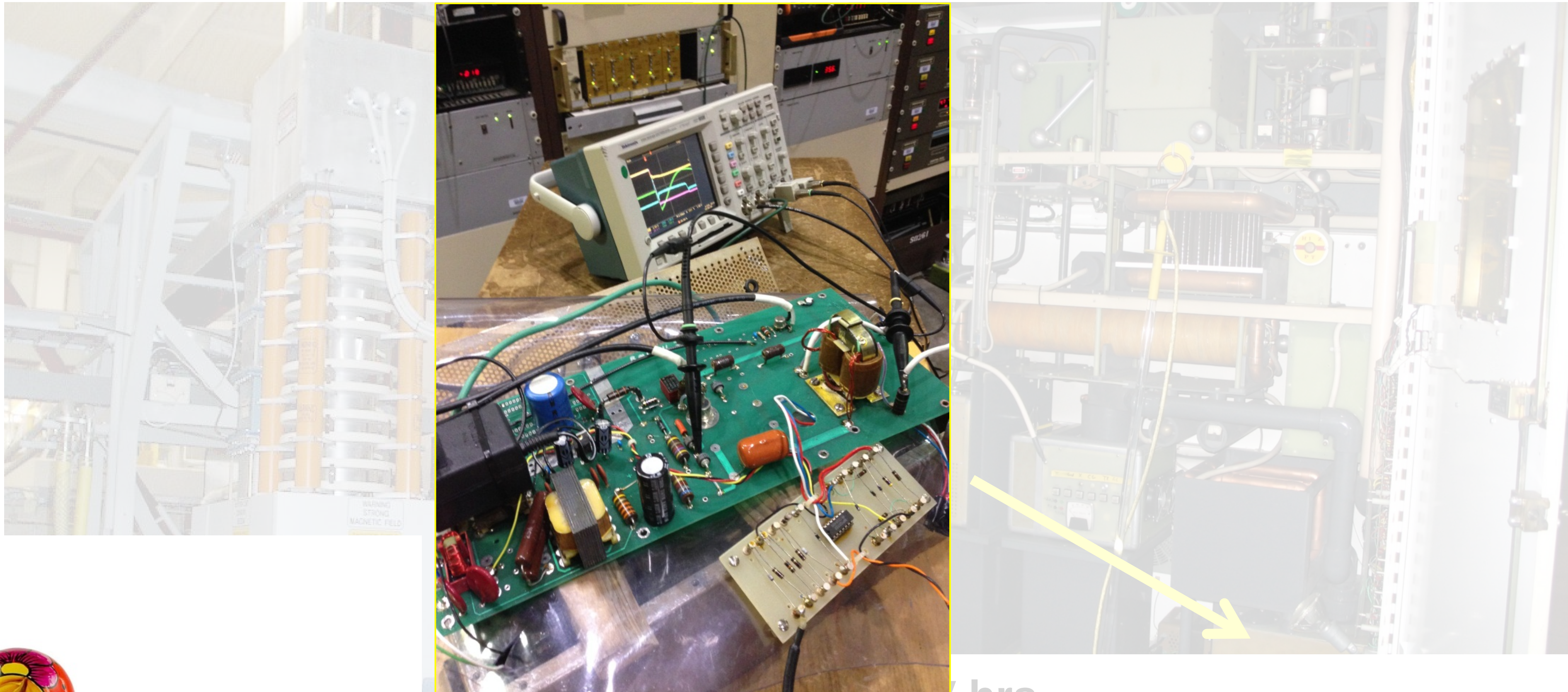
Original SR RF HVPS

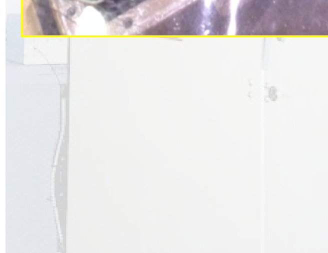
Original SR RF HVPS Filter & Crowbar System



SIMPLIFIED CIRCUIT DIAGRAM FOR THE ALS SR KLYSTRON AMPLIFIER

Original SR RF Klystron & HVPS Filter/Crowbar Cabinet





/ hrs

.6dB, η = 55%

Removed 2012, G37.8, η = 43%

hrs

Consuming 1 Tetrode every 3 years

Consuming 1 Thyratron every 3 years

Very, Very difficult to work on Crowbar firing circuit

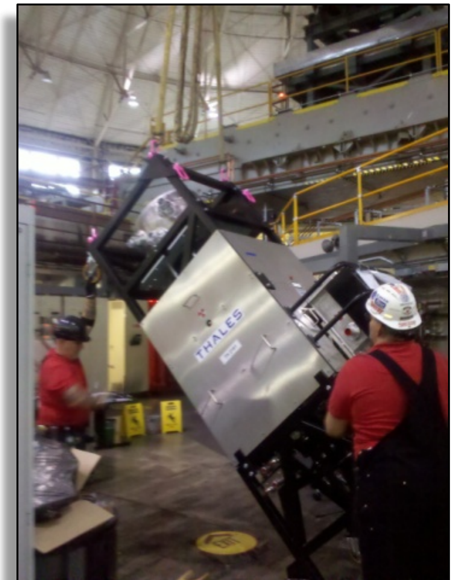
Many hundreds of false triggers/crowbars

SRRF Upgrade Requirements)

- Replace Aging Single Klystron (19+ yrs in 2012)
- Modest Increase in Max RF Power for Beam Loading/Reliability
- Replace HVPS only to Increase DC Power
- Replace HVPS Crowbar/Filter with Dis-Connect SW/Filter
- Replace Analog LLRF with Digital (FPGA) based system, improve amplitude and phase stability
- Upgrade Controls, from ILC to PLC
- Increase Diagnostic Capabilities, add synchronous fault data acquisition
- Increase Accessibility and Maintainability

Phase I, Install New Site #2 (2011 & 2012 Shutdown)

Seismic Base Construction & Cabinet Installation at New Site #2



Klystron Installation

Mod-Anode Cabinet

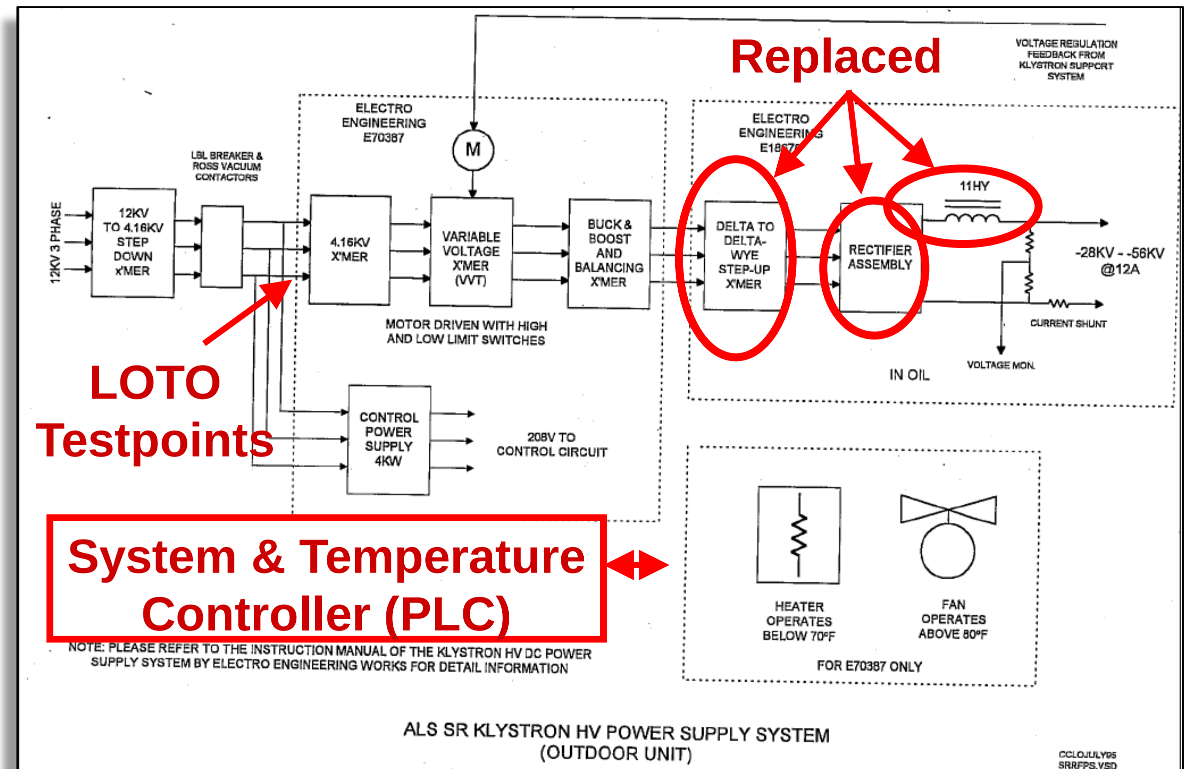
PLC Control Rack

Site #2 Completed
Operating since Feb-2012

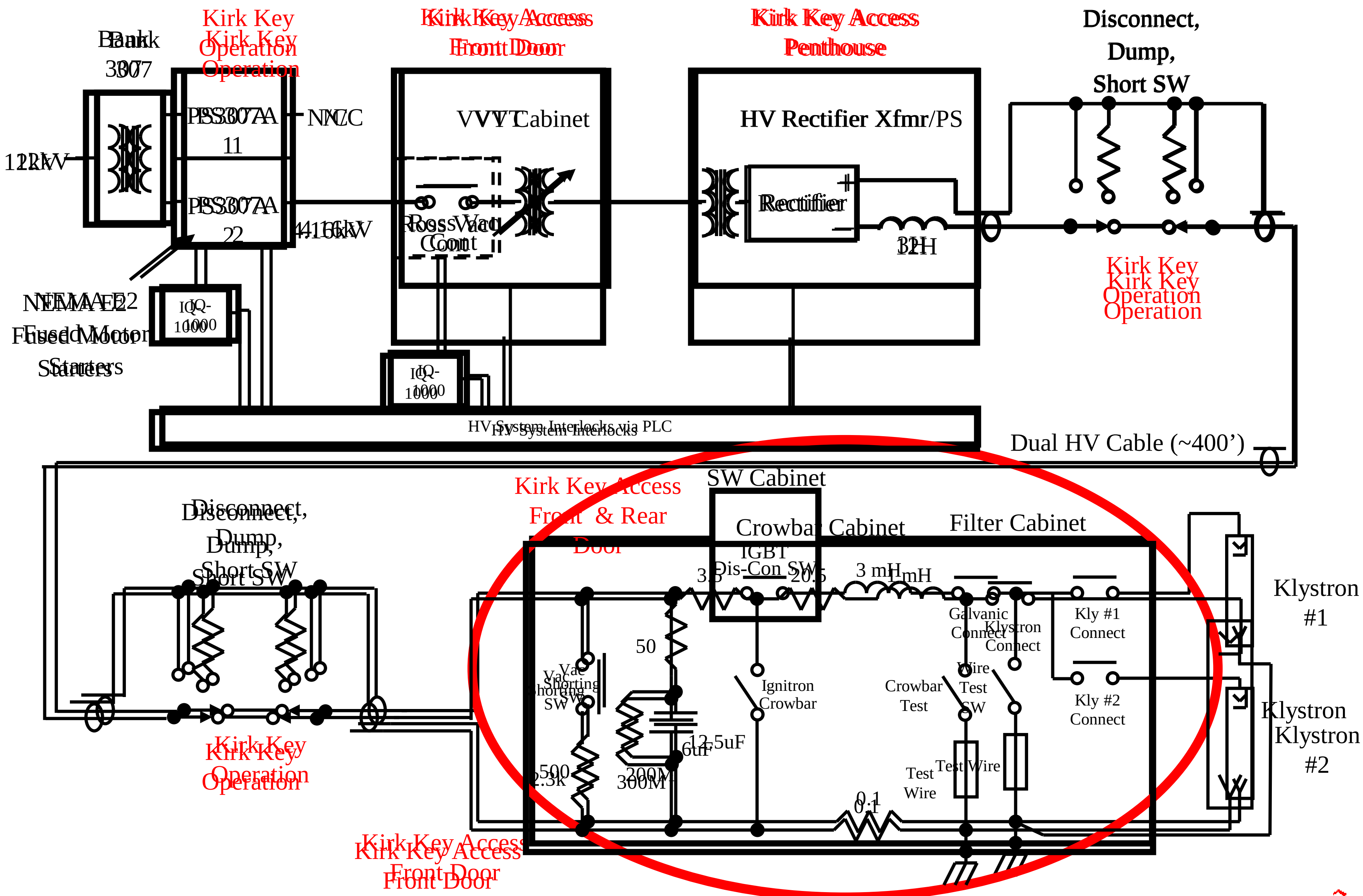
Phase IIA, Install New HVTR/PS (2013 Shutdown)

HVTR/PS

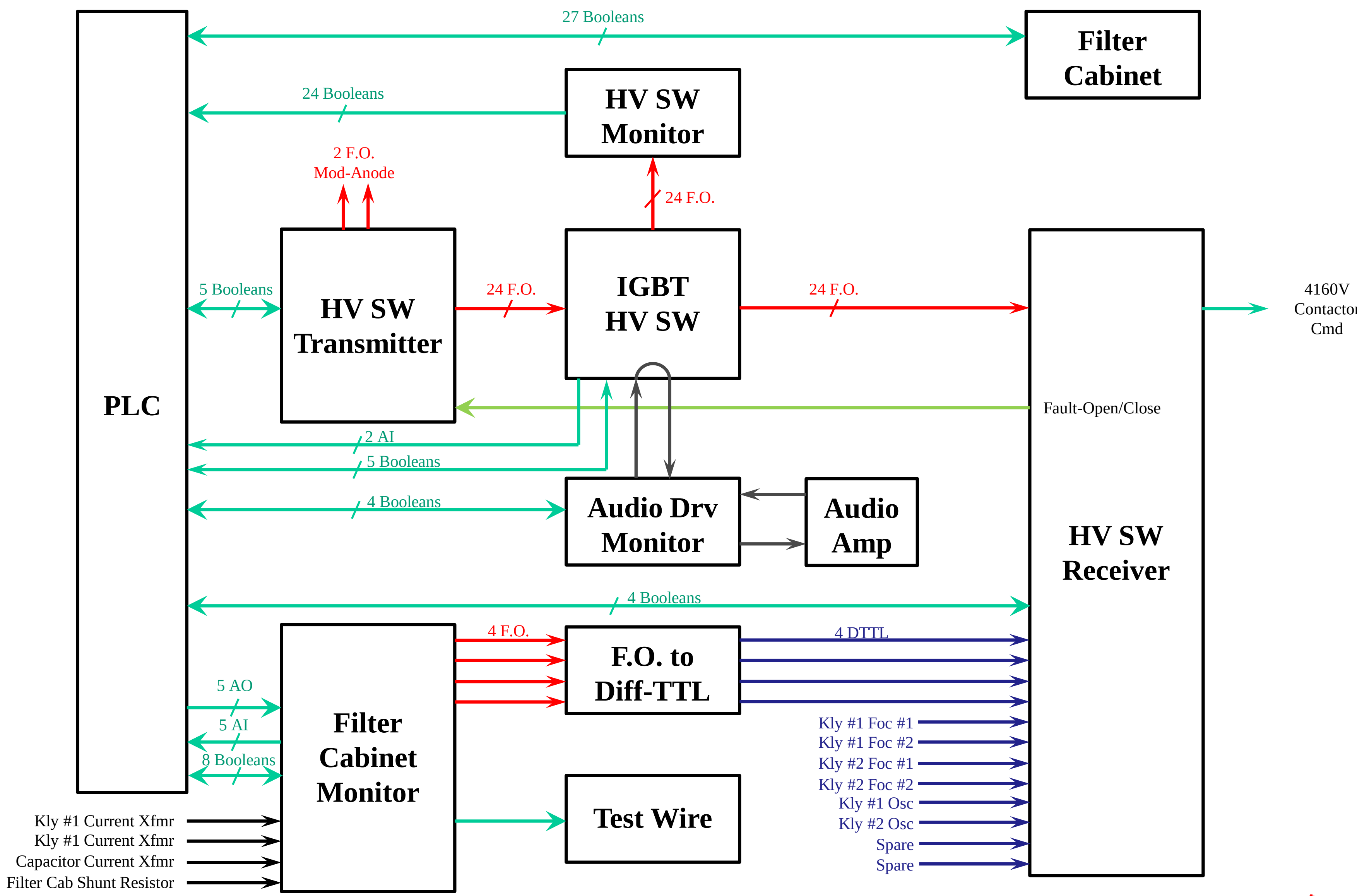
- 50kV @ 16A
- 12-pulse rectifier with filter inductor
- Complete, Operating since Feb-2013



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



HV Dis-Con SW Block Diagram



Phase IIB Completed

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

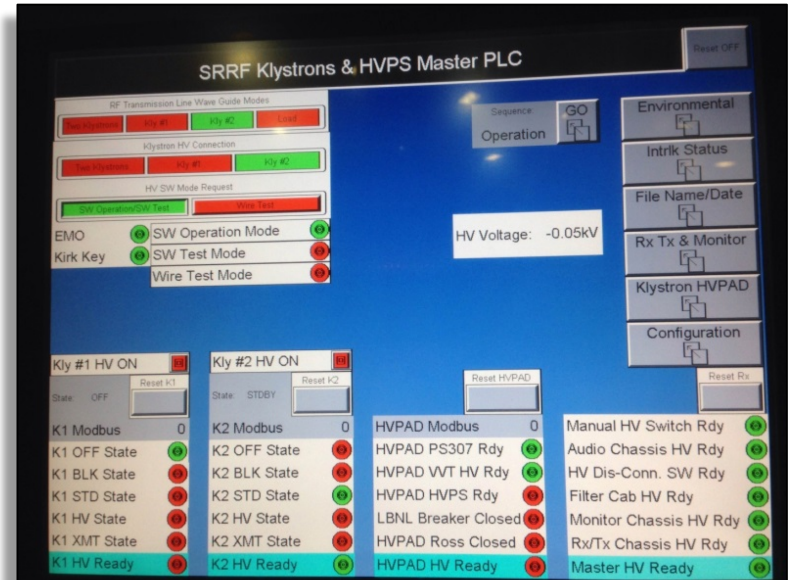
Klystron Site #1

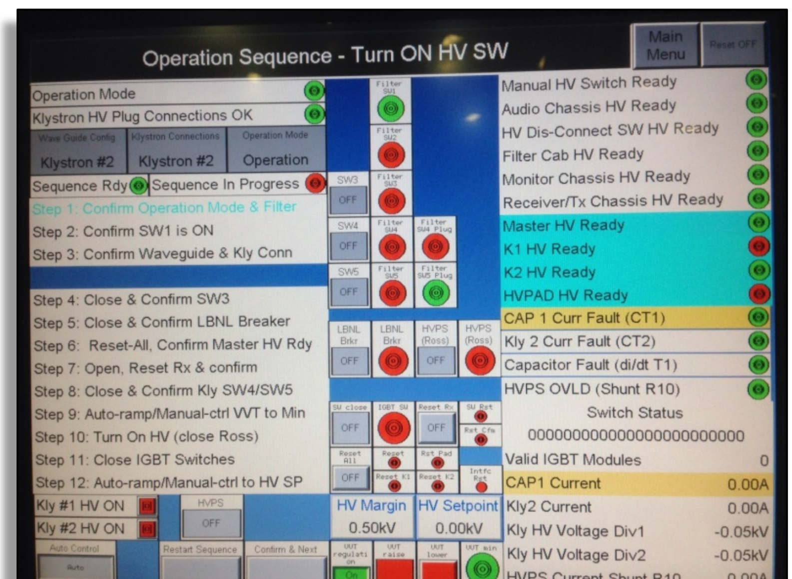
HV Dis-Con SW

Filter Cabinet and PLC Controls

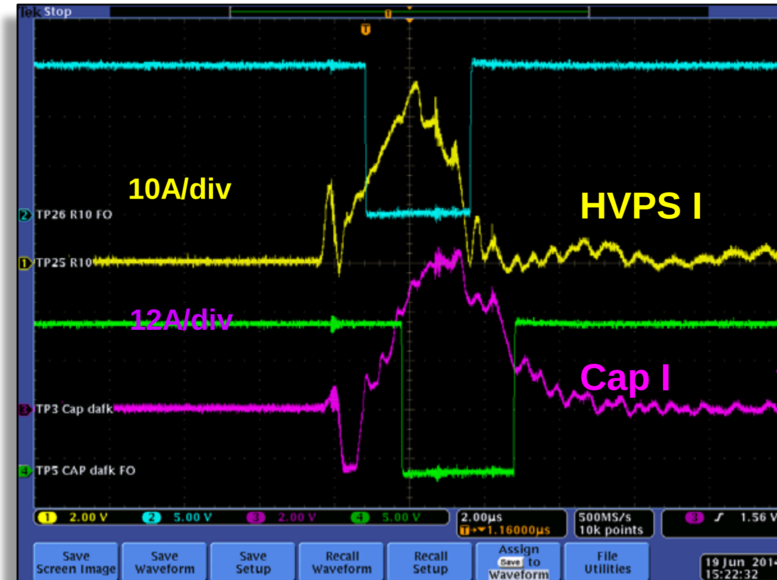
Phase IIB Completed

PLC Controls

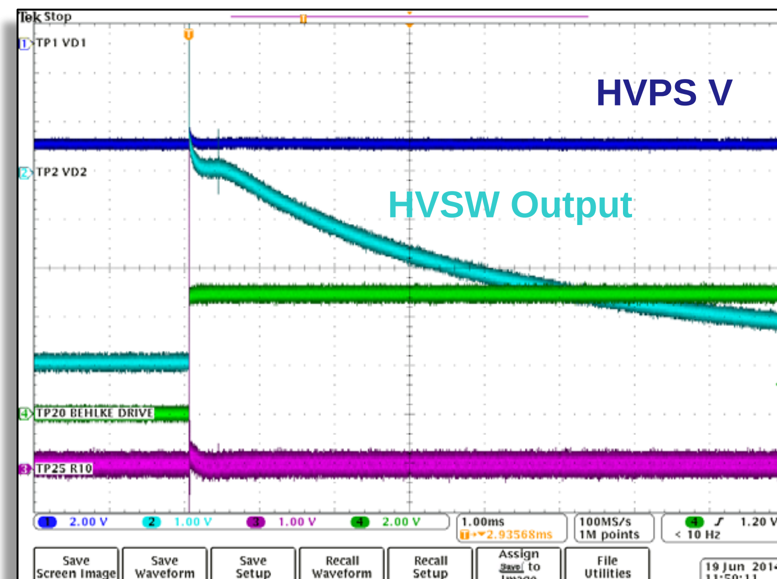




HV Dis-Con Switch Performance

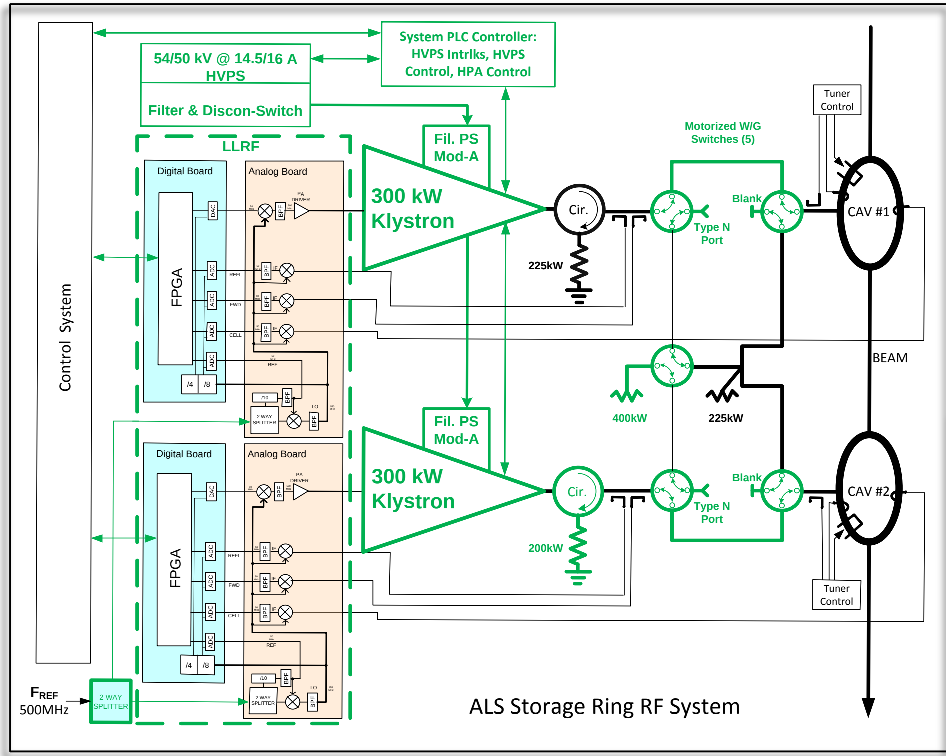


40 AWG Wire Test @ 50kV



40 AWG Wire Test @ 40kV

Phase III, Replace LLRF & Upgrade Wave Guide System (2015 Shutdown)



Operating Options:

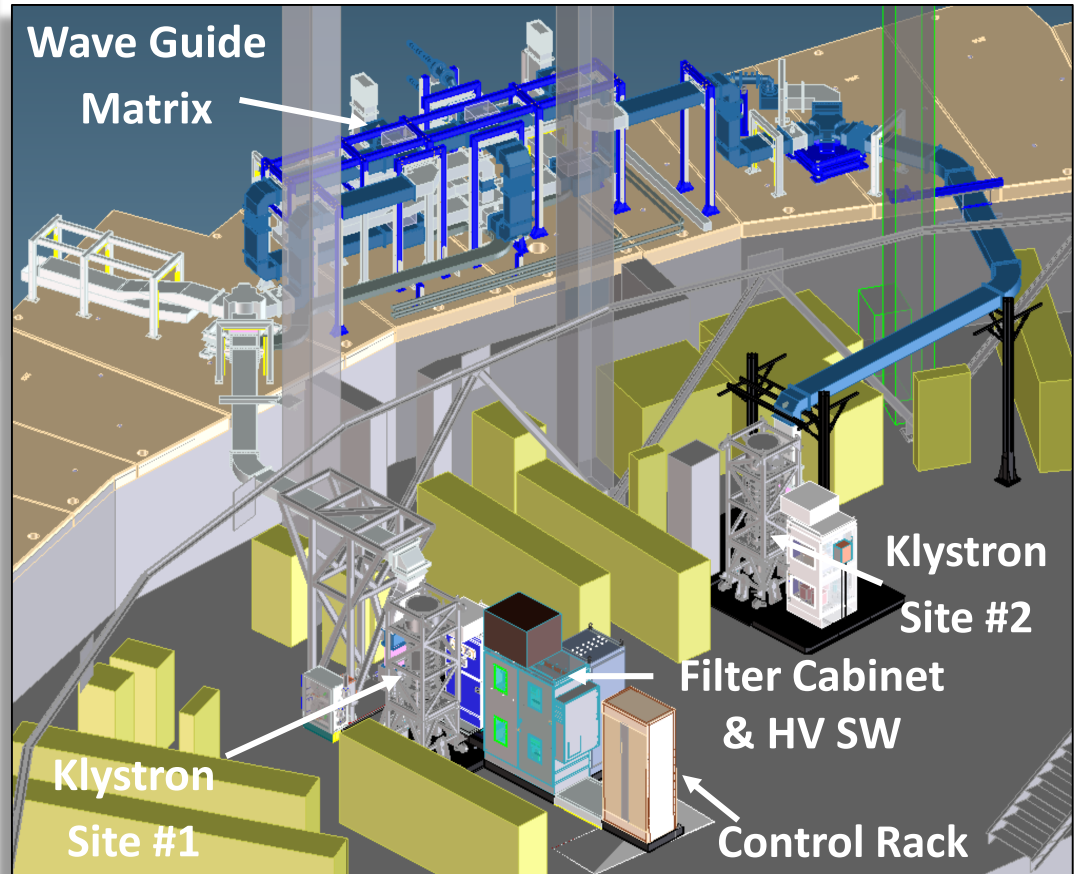
Kly #1 to Cavity 1 (up to 180kW)

Kly #1 to both Cavities (300 kW)

Kly #2 to Cavity 2 (up to 180kW)

Kly #2 to both Cavities (300 kW)

Either Kly into Full Pwr Testload (300 kW)

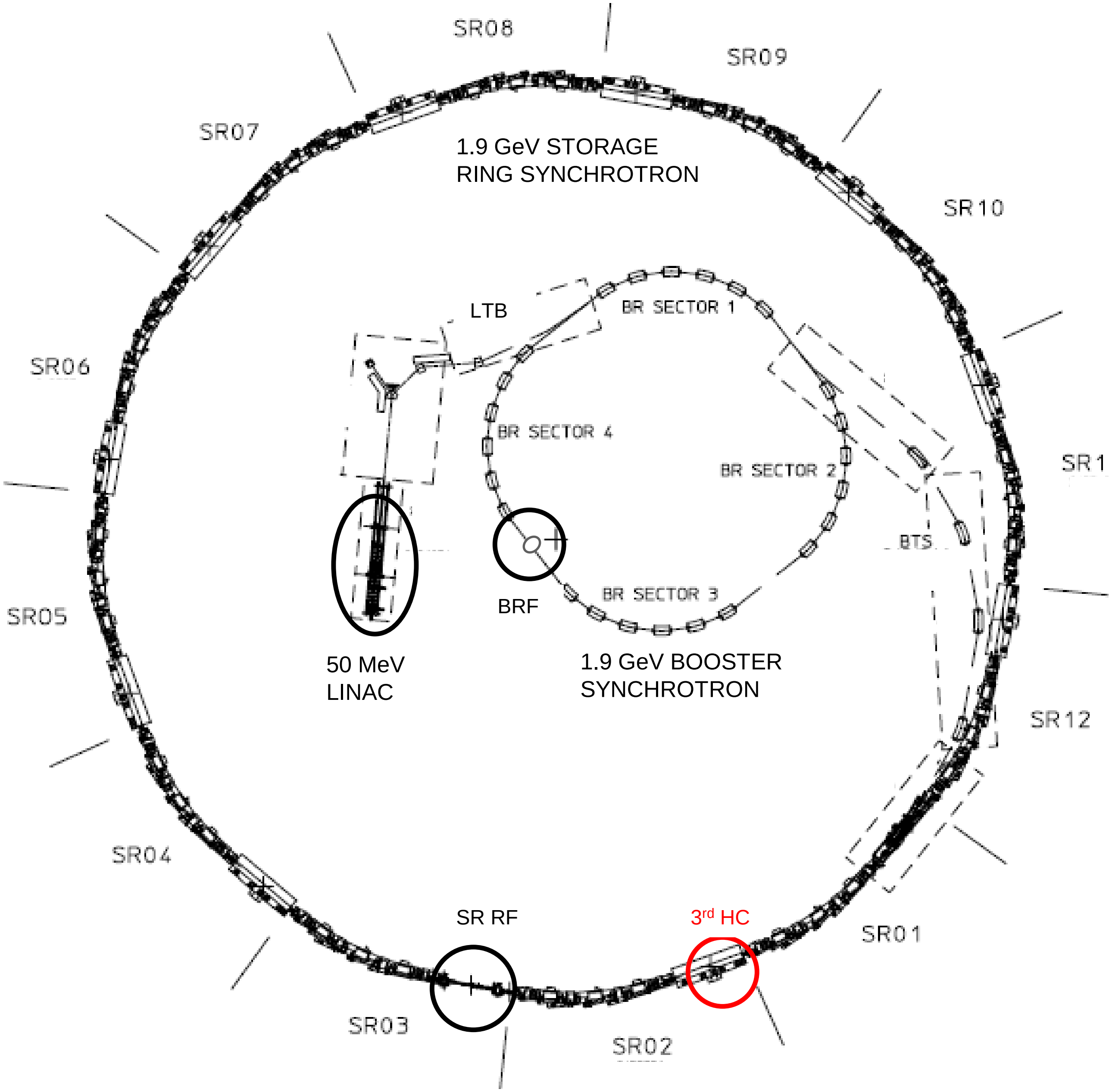


Two Digital LLRF Systems.

RF Signal Diagnostics.

MRF Timing System Clients

3rd Harmonic (Landau) Cavities System

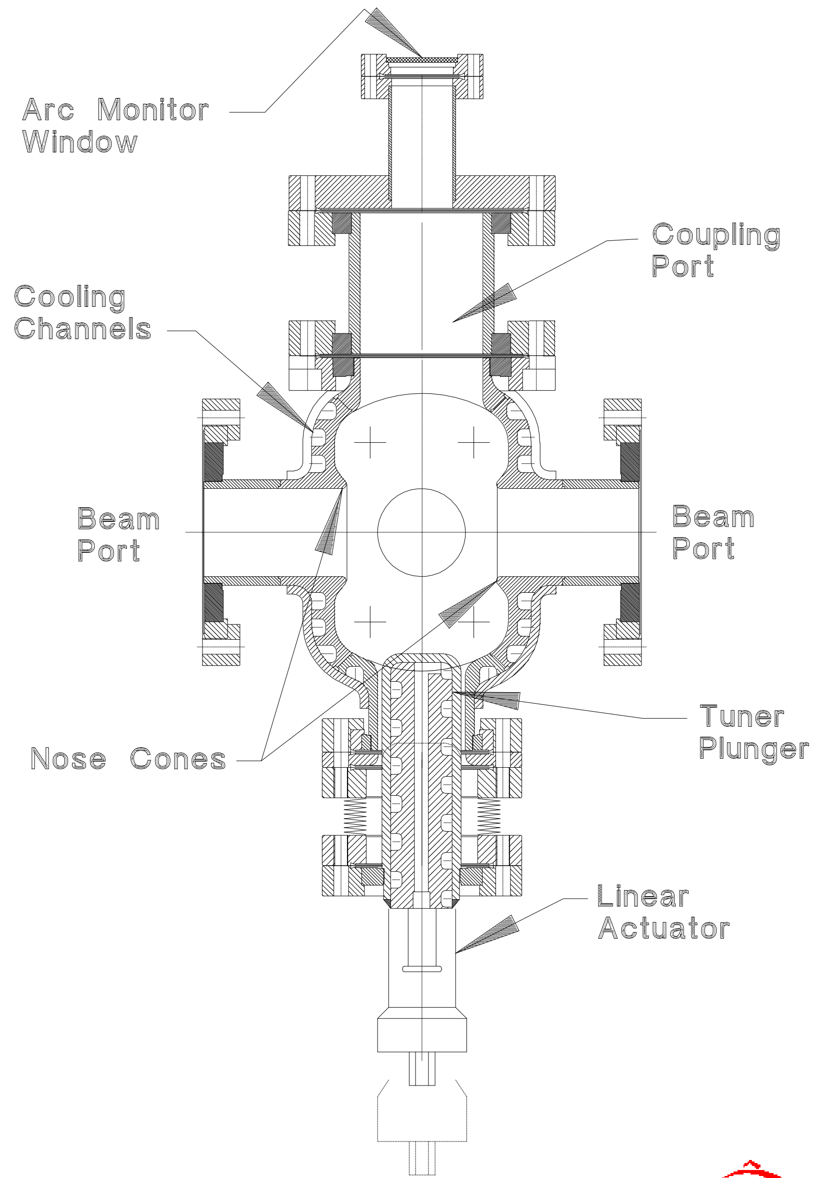


3rd Harmonic (Landau) Cavities System

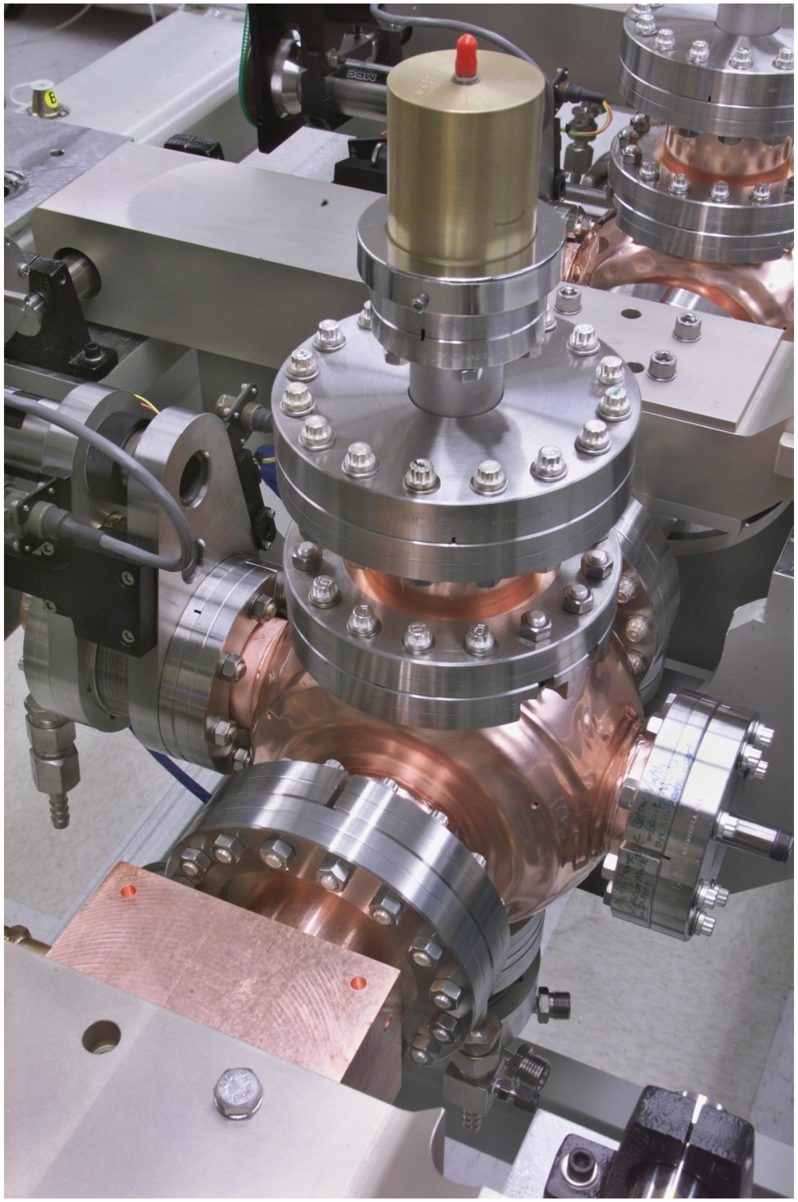
Table 1: Harmonic cavity system parameters

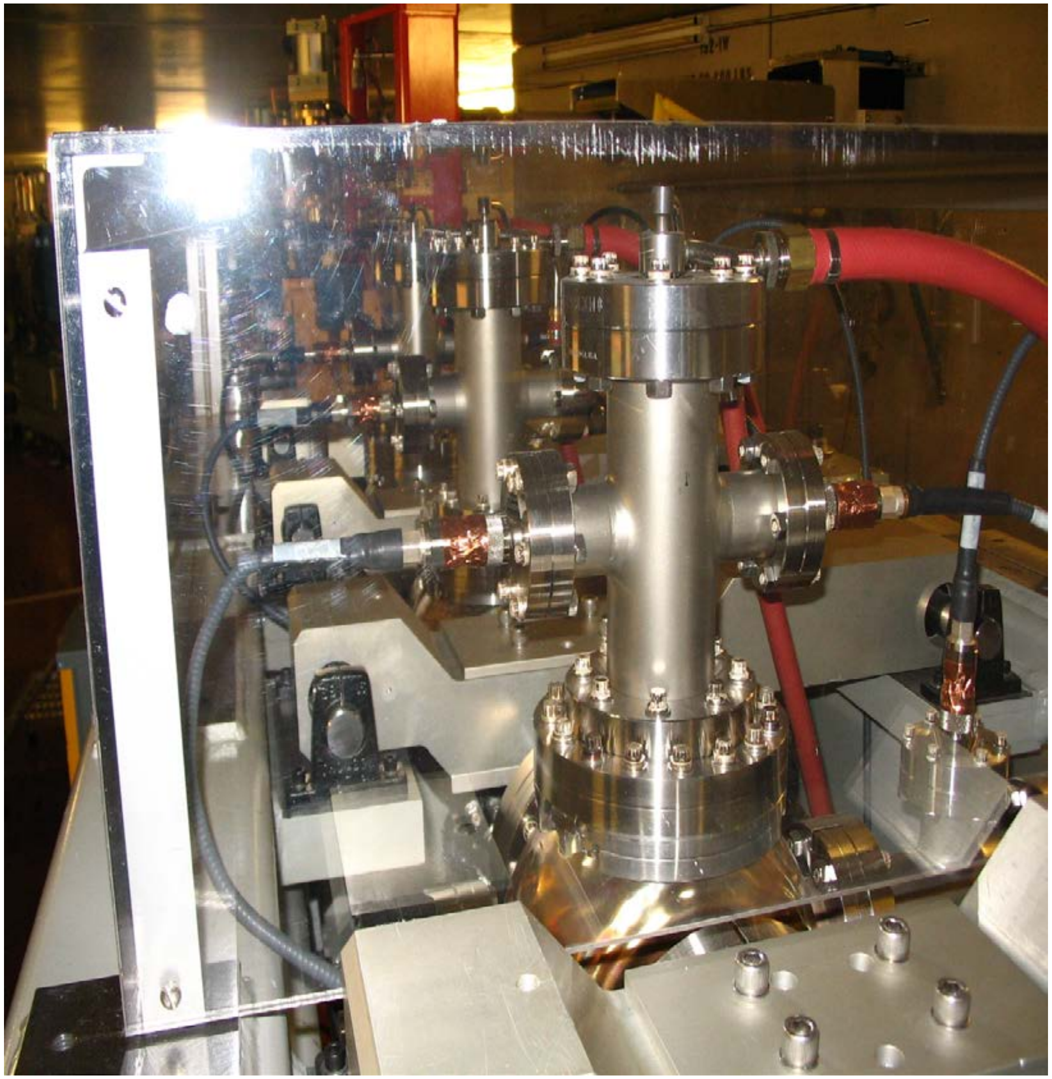
Frequency	1.5 GHz
total voltage	500 kV
bore diameter	5 cm
cavity R/Q*	80.4
calc. Q	27677
calc. Rs	2.23 MΩ
Rs x 70%	1.56 MΩ
number of cells	4
power per cell	5.01 kW

$*R=V^2/2P$

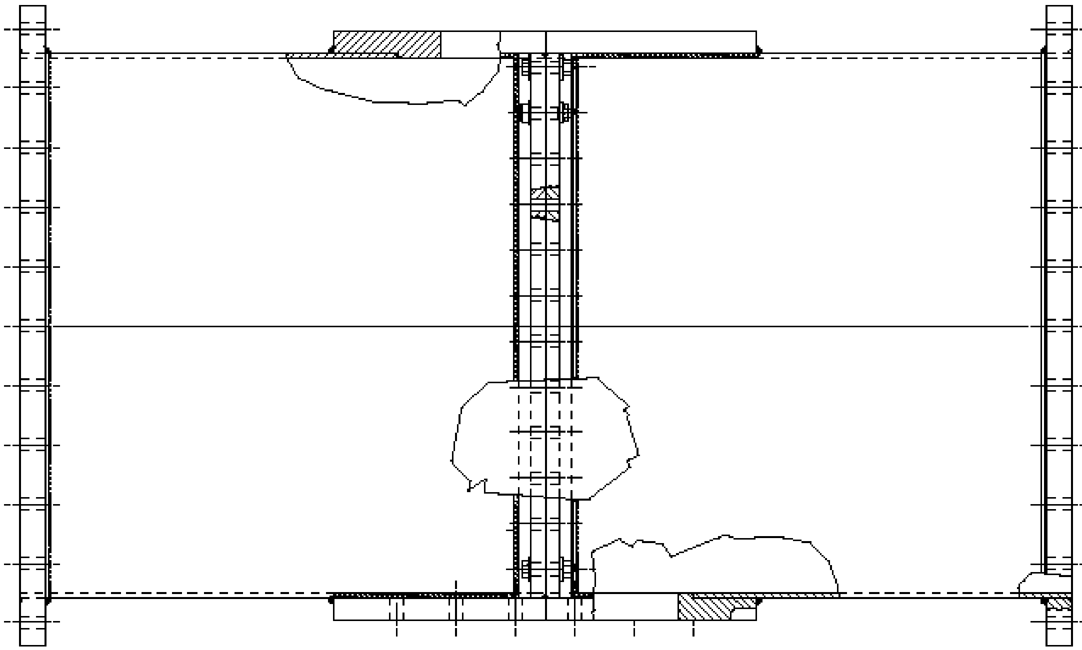


3rd Harmonic (Landau) Cavities System

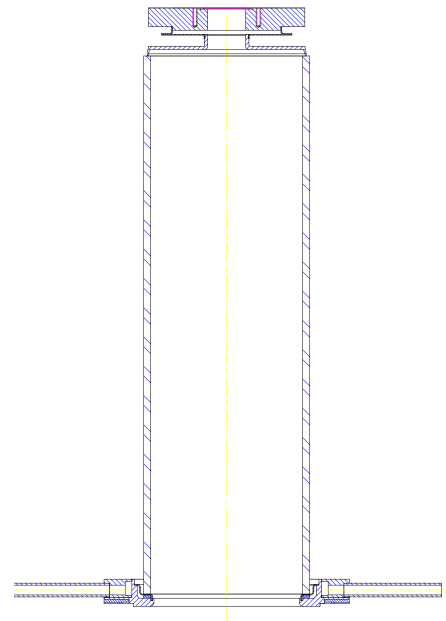




Bldg. 27 RF Cavity Teststand, RF Window Processing

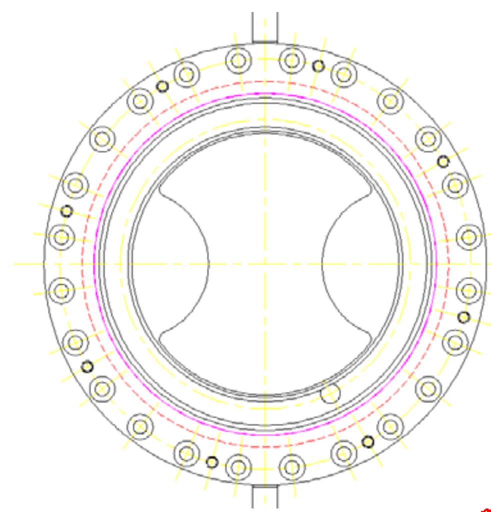


Split WR1800 Waveguide to Cavity Transition



<u>Current Design:</u>

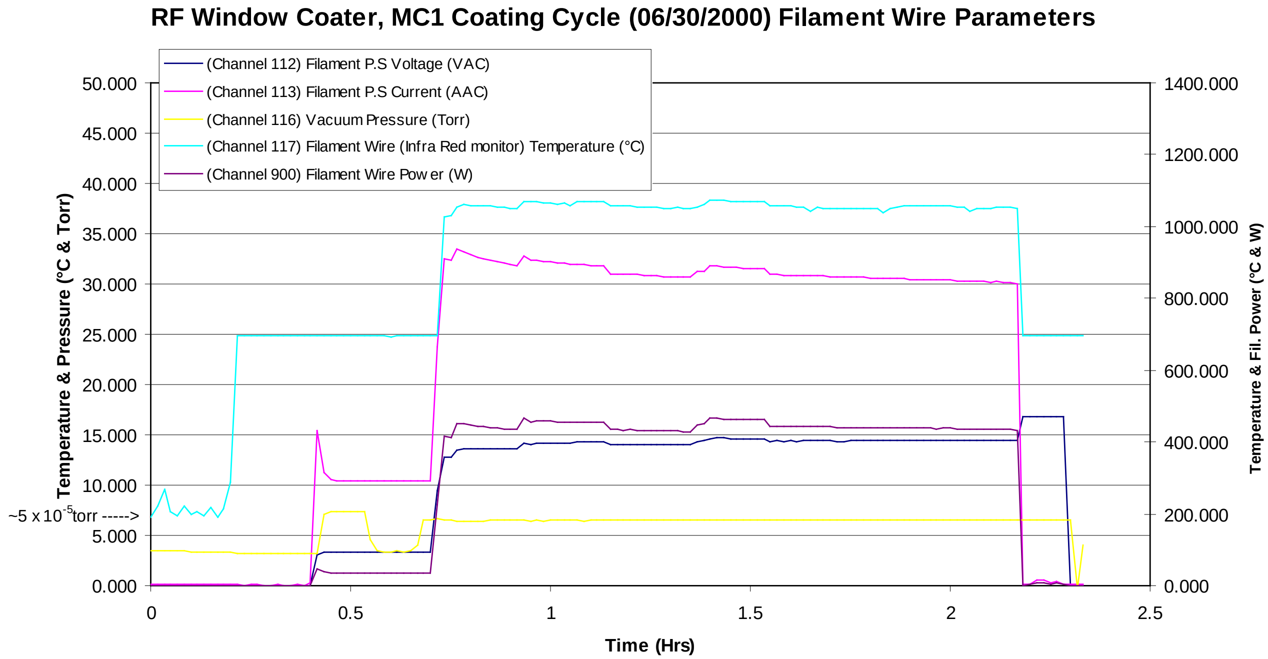
- 2 in SRRF operating at 43kW CW, 3 fully tested spares
- Manufactured by EEV, Marconi, now E2V
- TiN coating & test to 66KW CW at LBNL

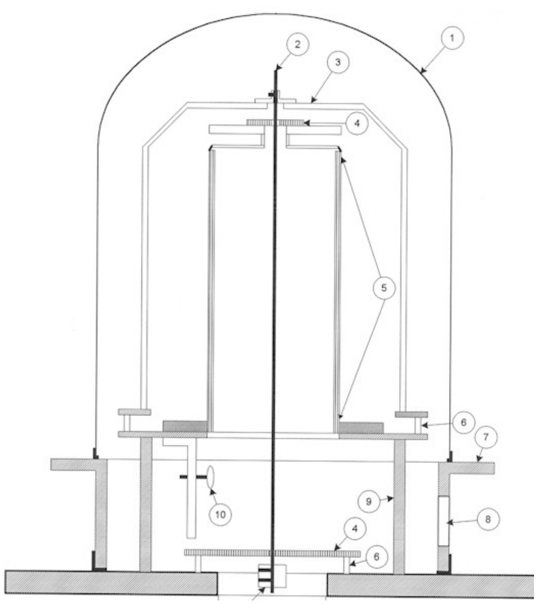


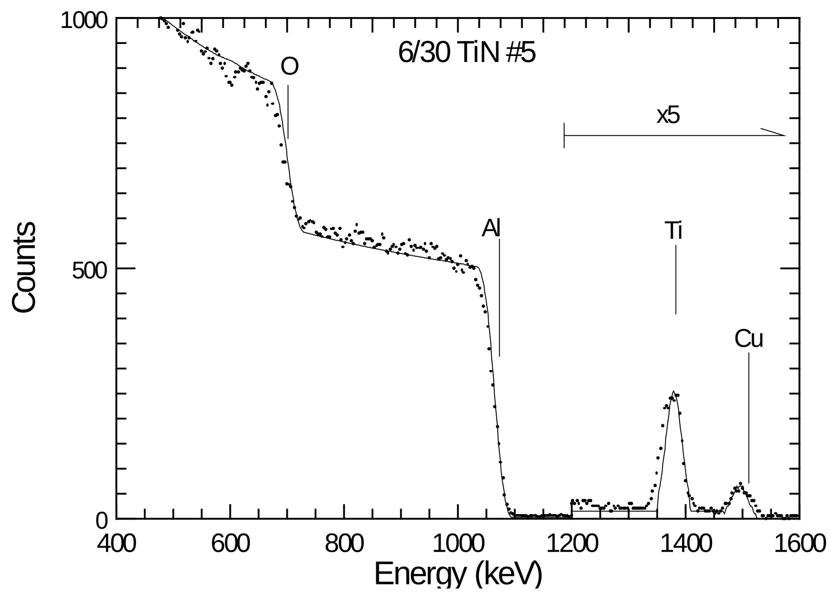
Iris Flange Profile

β: up to 3.2

Bldg. 27 RF Cavity Teststand, Titanium-Nitride Coating



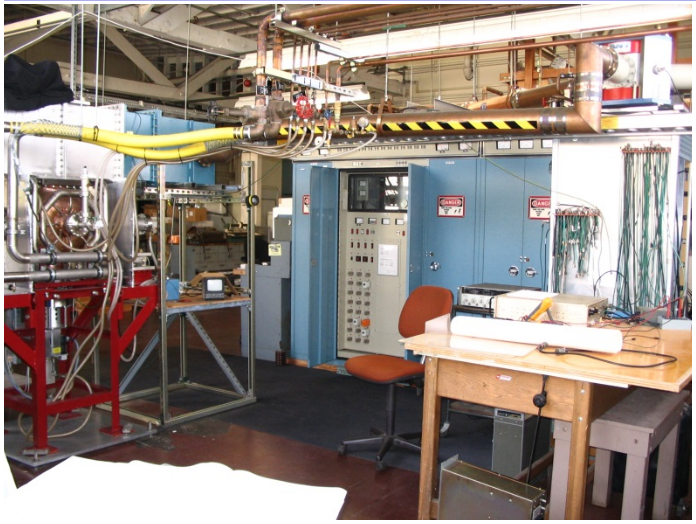




Coating thickness determined by Rutherford Back Scattering (RBS) performed on site at LBNL.

This sample measured 15 angstroms. Our target range is 10 – 20 angstroms.

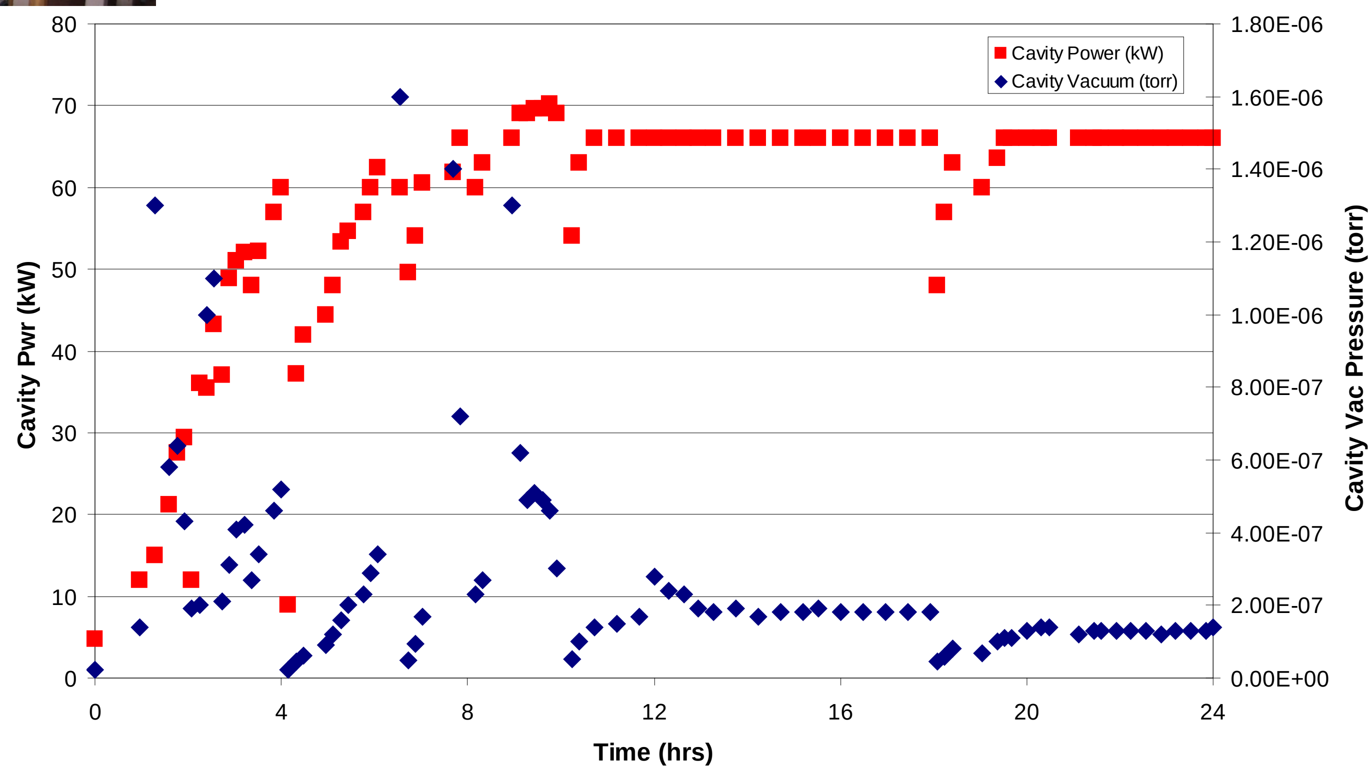
Bldg. 27 RF Cavity Teststand, Power Test/Condition Window



B27 Cavity Teststand, 66kW @ 500MHz

- Identical cavity to Booster and Storage Ring

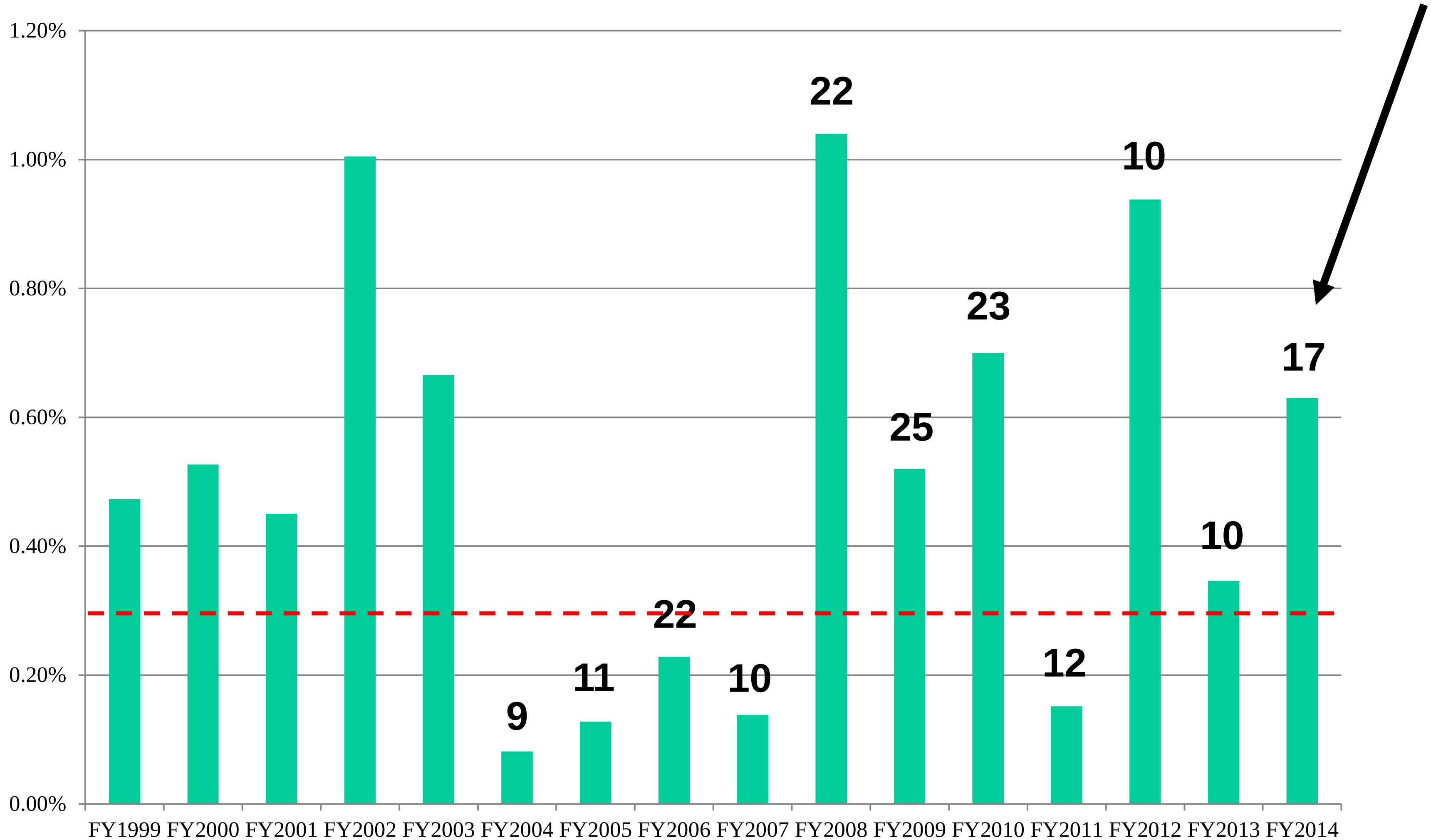
- Power Conditioned in 24 Hrs over a 4 day period.
- 21 Rev Pwr Trips
- 5 Vac Trips
- Window Temp ran < 80°C



SRRF Reliability

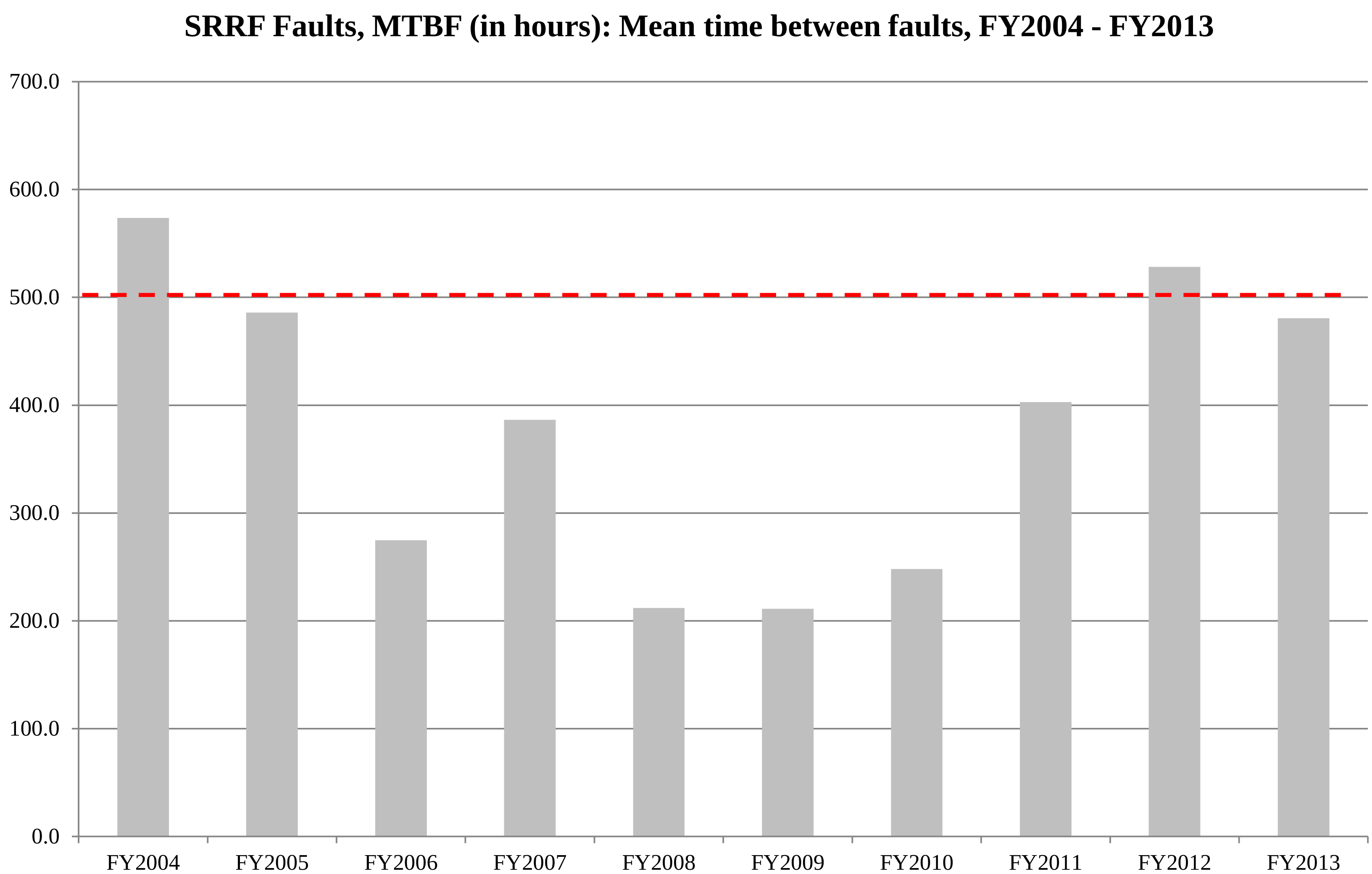
Percentage of Scheduled Beam Time Lost to SRRF & Non-Latching Faults by Fiscal Year

# of Faults/Yr



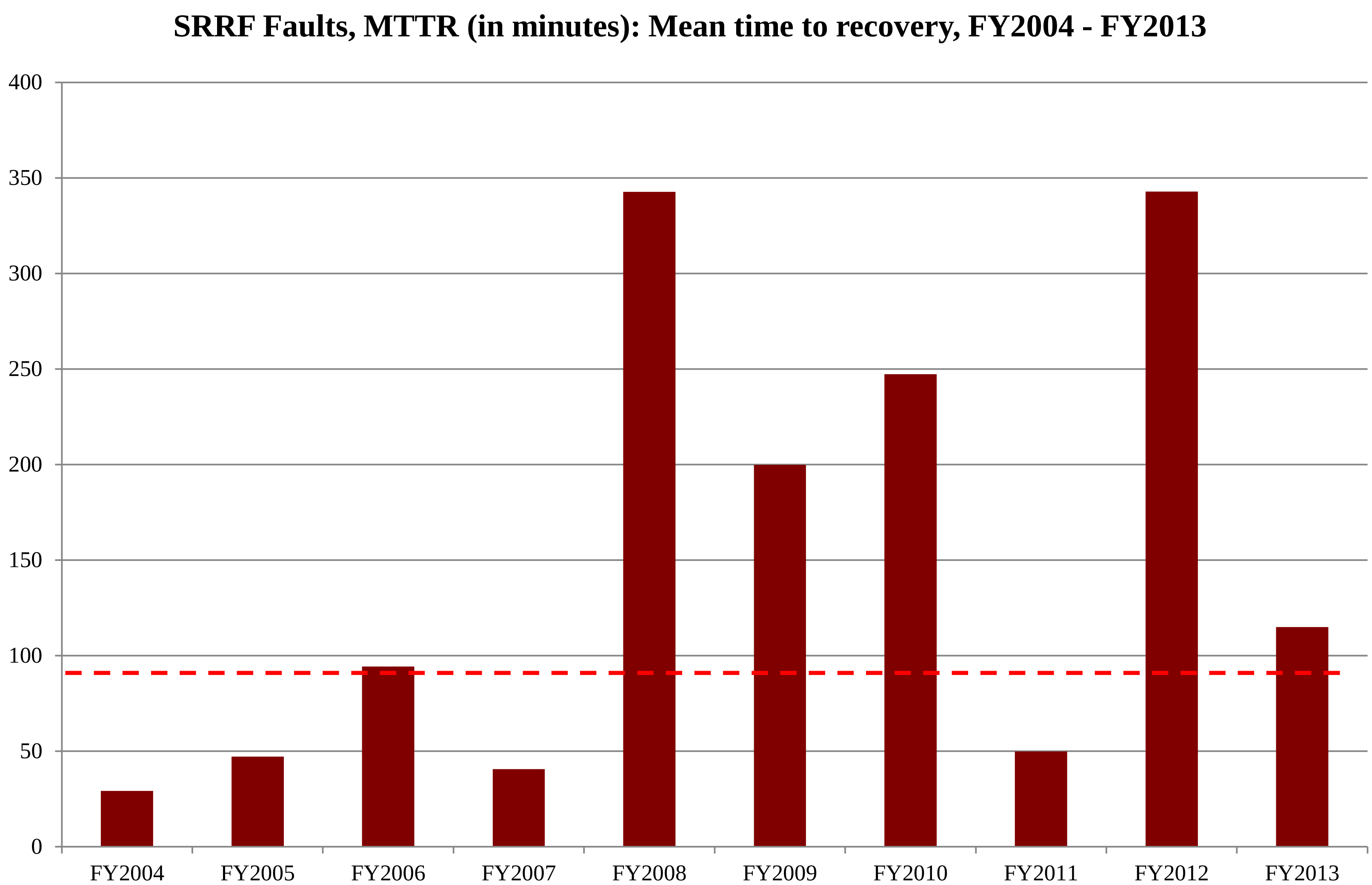
Goal for SRRF system based on 5000 hours of User Beam time: 0.3%

SRRF Reliability



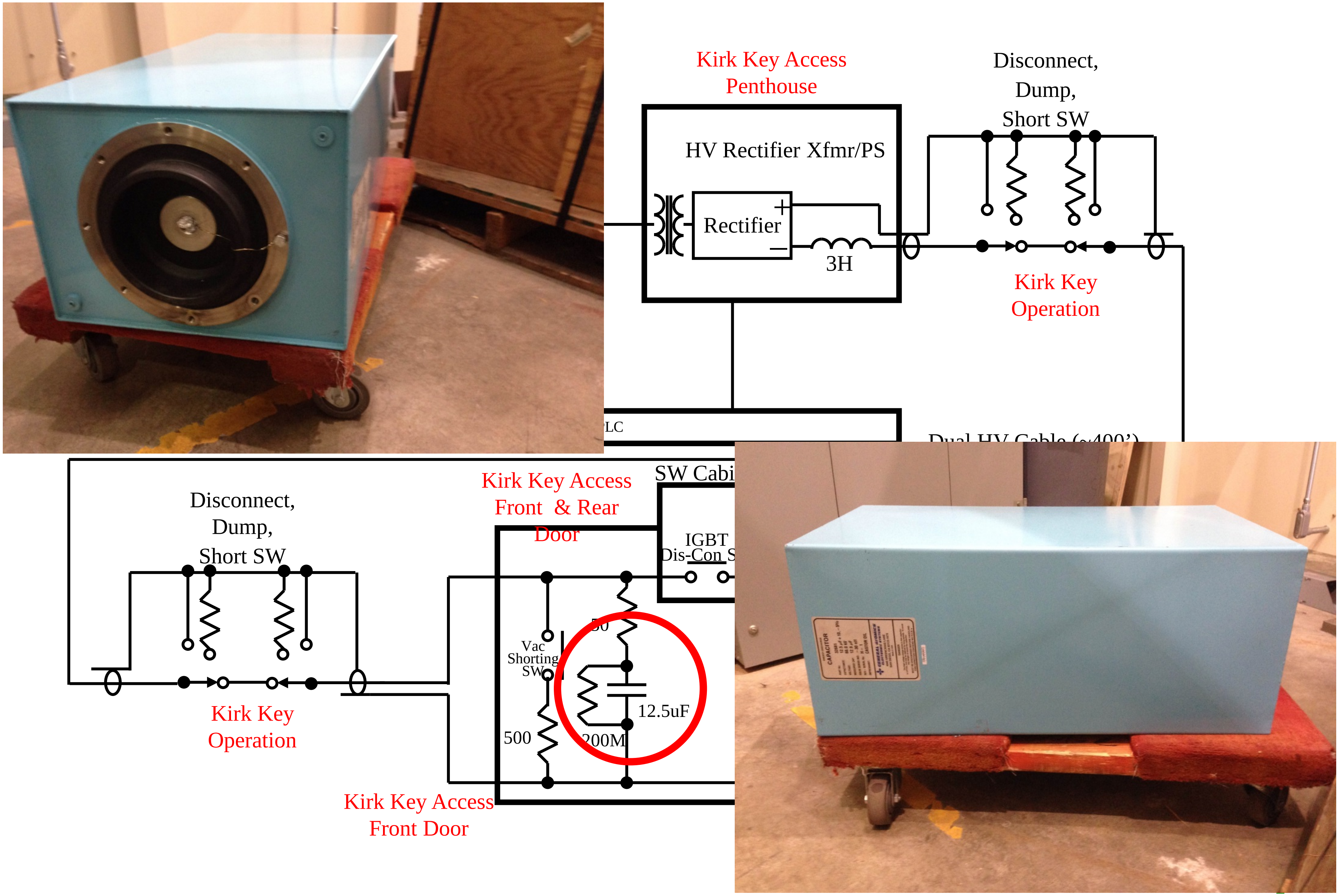
Goal for SRRF system based on 5000 hours of User Beam time: 500 hrs

SRRF Reliability

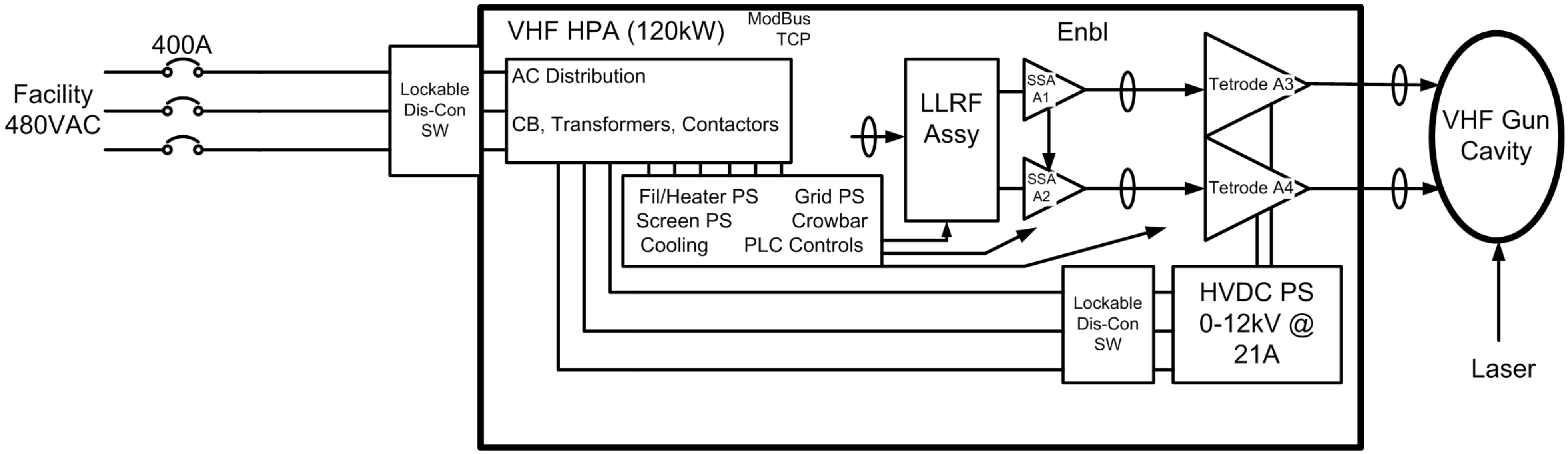


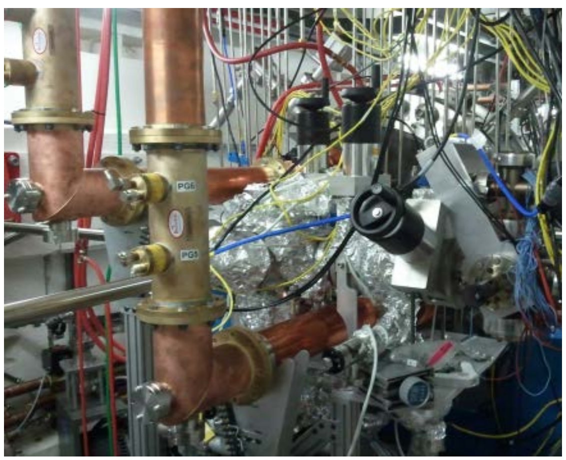
Goal for SRRF system based on 5000 hours of User Beam time: 1.5 hrs

Filter Cap Failure

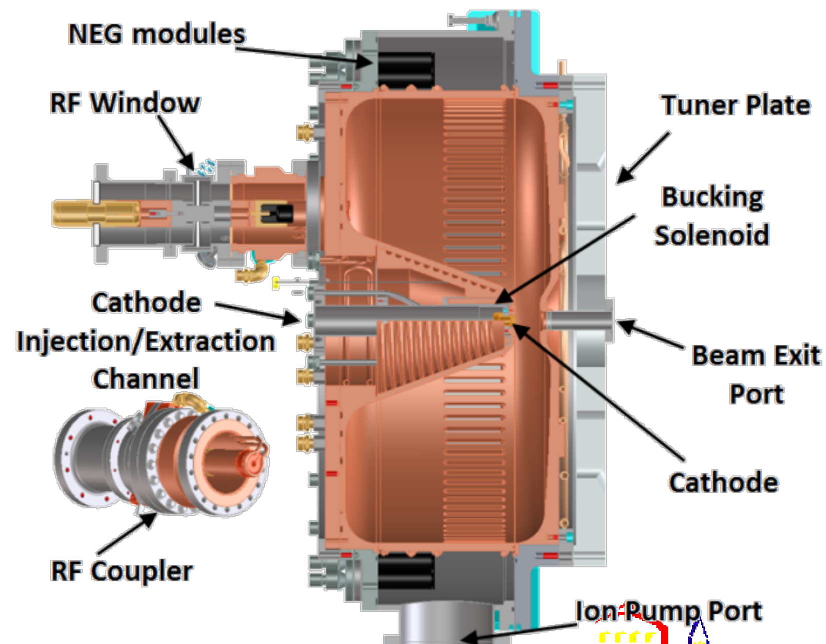


Advanced Photo-electron Experiment (APeX)
4 1/16" Coax Line Failed



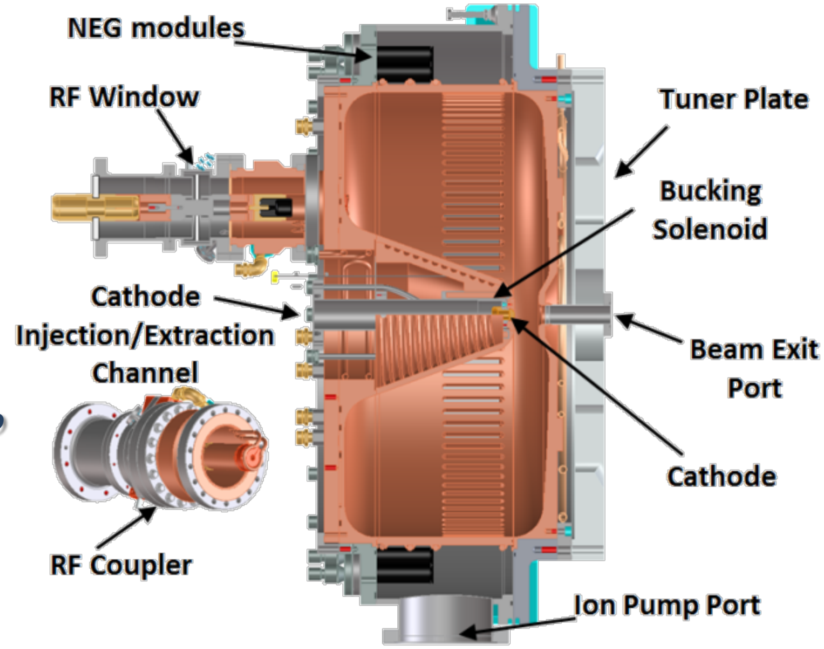


Main
Overheated area



Advanced Photo-electron Experiment (APeX)
4 1/16” Coax Line Failed

$\lambda_{RF}/4 \sim 15.9”$



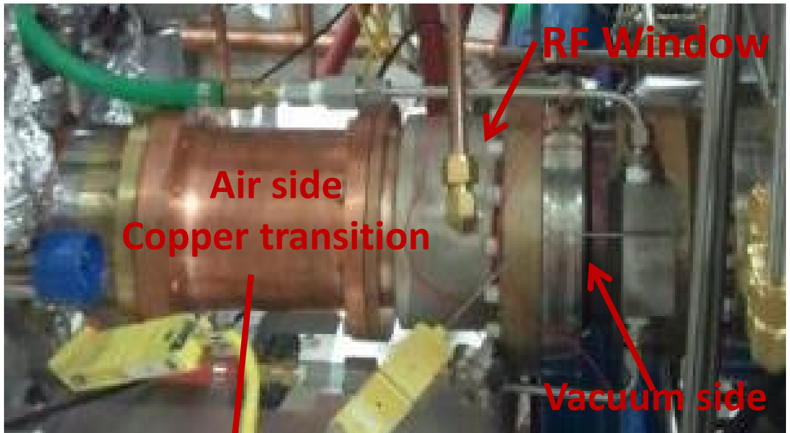
Missing from measurements, additional ~5” for length of coupling loop

The internal conductor

This hole would then be at 27” + 5” = 32”, $\sim \lambda_{RF}/2$

This hole is at a current node. The copper is melting here not arcing.

Advanced Photo-electron Experiment (APeX)
4 1/16” Coax Line Failed



Facing parts

These arc marks are at a voltage maxima. There is no sign of overheating due to high currents. This arcing being ~3” from window would then be at 19” - ~3” = 16”, ~ $\lambda_{RF}/4$

EHT (Enhanced Heat Transfer coax line) rating from company:

De-rating for 0 PSIG in line = 0.885

Average Power Rating = 89 kW derated to 78 kW

Peak Voltage Rating = 13 kV

Peak Power Rating = 3,685 kW (Ppk = Vpk^2/Zo). Not specified for how long.

APEX max operation conditions:

Power per coax line = 60 kW CW max (50 kW nominal).

Peak Voltage in line = 1.414*sqrt(Pavg * Zo) = 1.414*sqrt(60000 * 50) = 2.45 kV

Peak Power in line = Vpk^2/Zo = 2449^2 / 50 = 120 kW

Peak Power in line from standing wave: Vpk = 4.9kV, Ppk = 480kW

The RF power remained ON for > 4 minutes in this condition due to improperly configured intrlks and a lack of synchronization when in pulse mode. Many watt-seconds were delivered during this time.