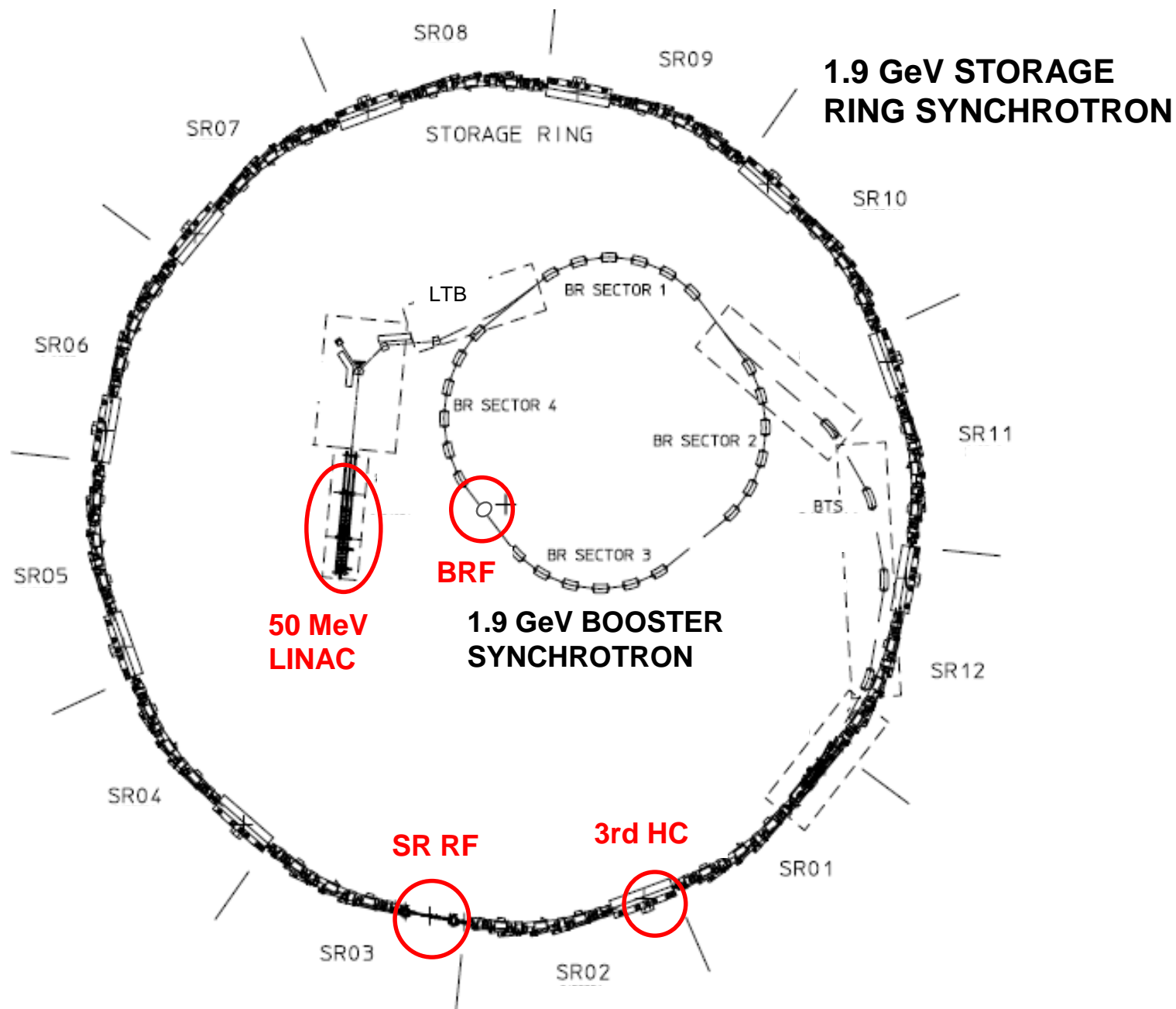


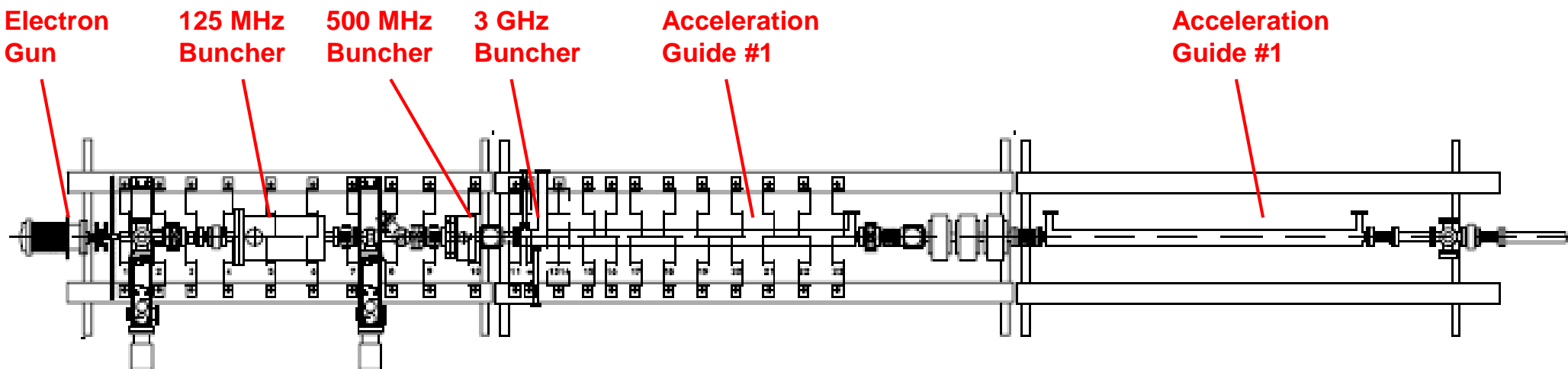
Status of the ALS and APEX RF Systems at LBNL

RF Group: K. Baptiste, S. Kwiatkowski (retired),
Q. Du, M. Vinco, J. Julian (retired)

ME Group: P. McKean (retired), G. Harris

- ALS RF Systems
 - Injection System
 - Electron Gun (125 MHz)
 - GTL Sub-Harmonic Bunchers (125 MHz & 500 MHz)
 - S-Band Linac Modulators (2.998GHz)
 - Booster RF System (500 MHz)
 - Storage Ring
 - Storage Ring RF System (500 MHz)
 - SRRF Reliability
 - 3rd Harmonic Cavities
- APEX RF Systems
 - VHF Photo-Cathode Gun
 - L-Band Buncher
 - L-Band Linac Modulator

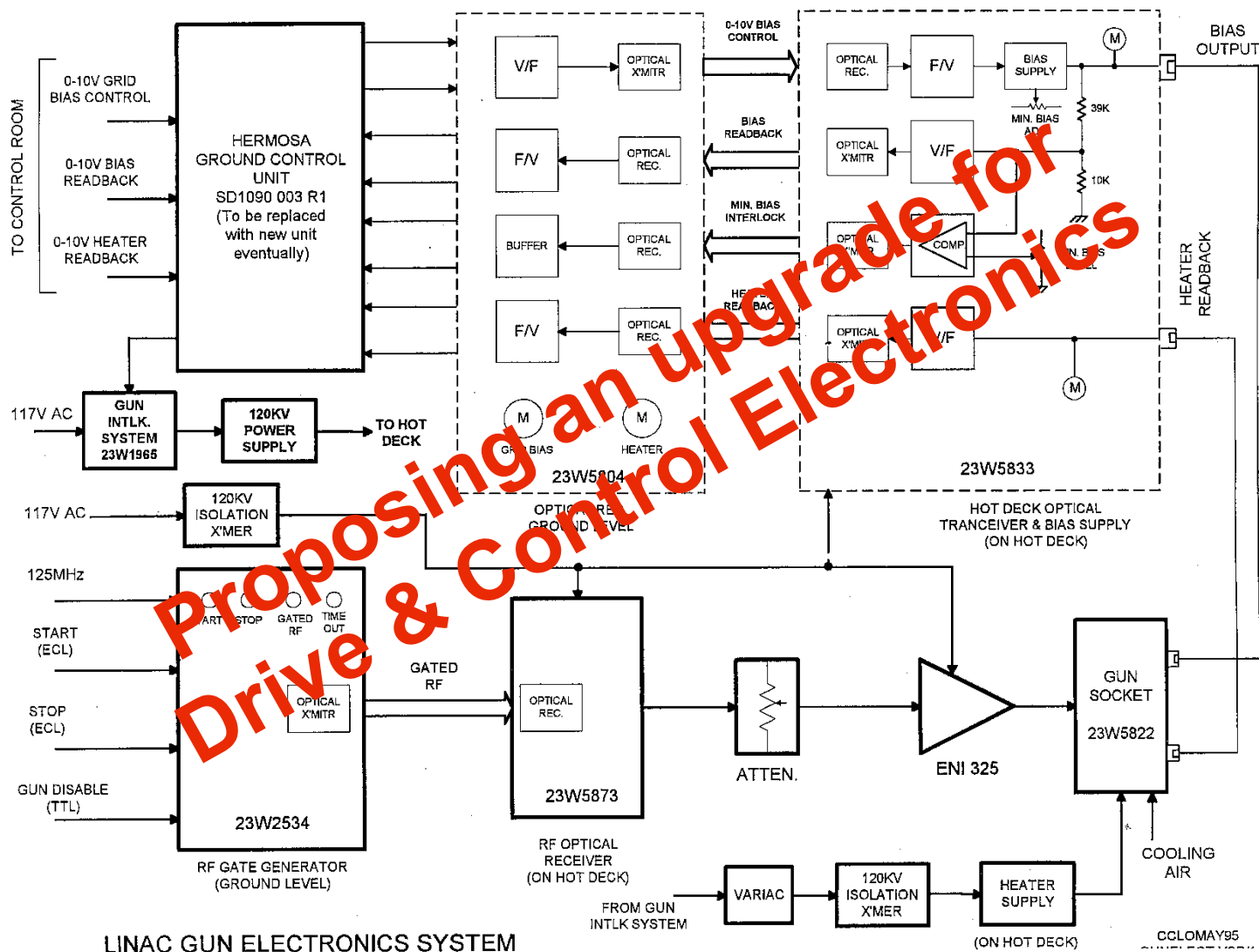




E. Gun Rack (LI01)



In Service: 1989



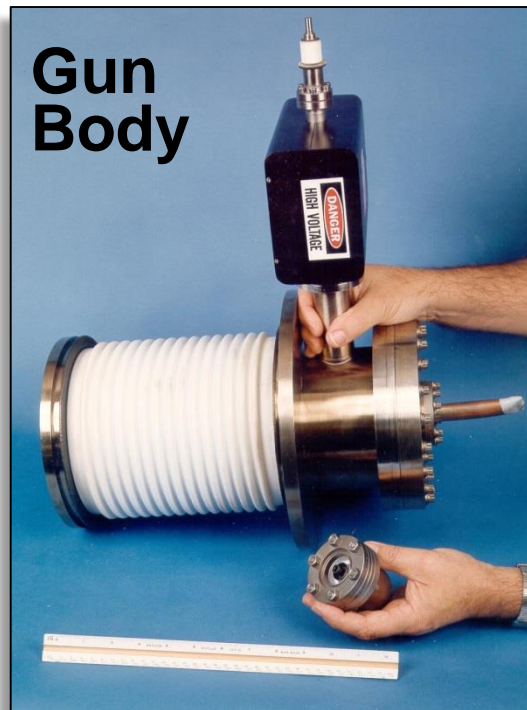
Block Diagram

E. Gun Hot Deck, Gun Body & Cathode

Cathode Eimac YU-171



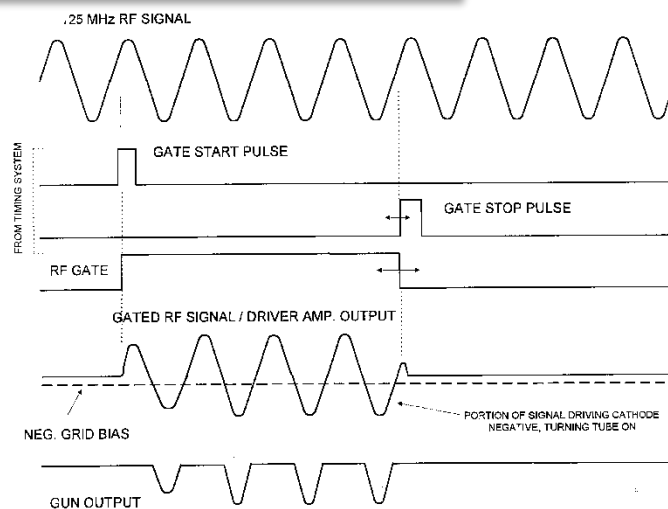
Gun Electr. Cart, Hot Deck



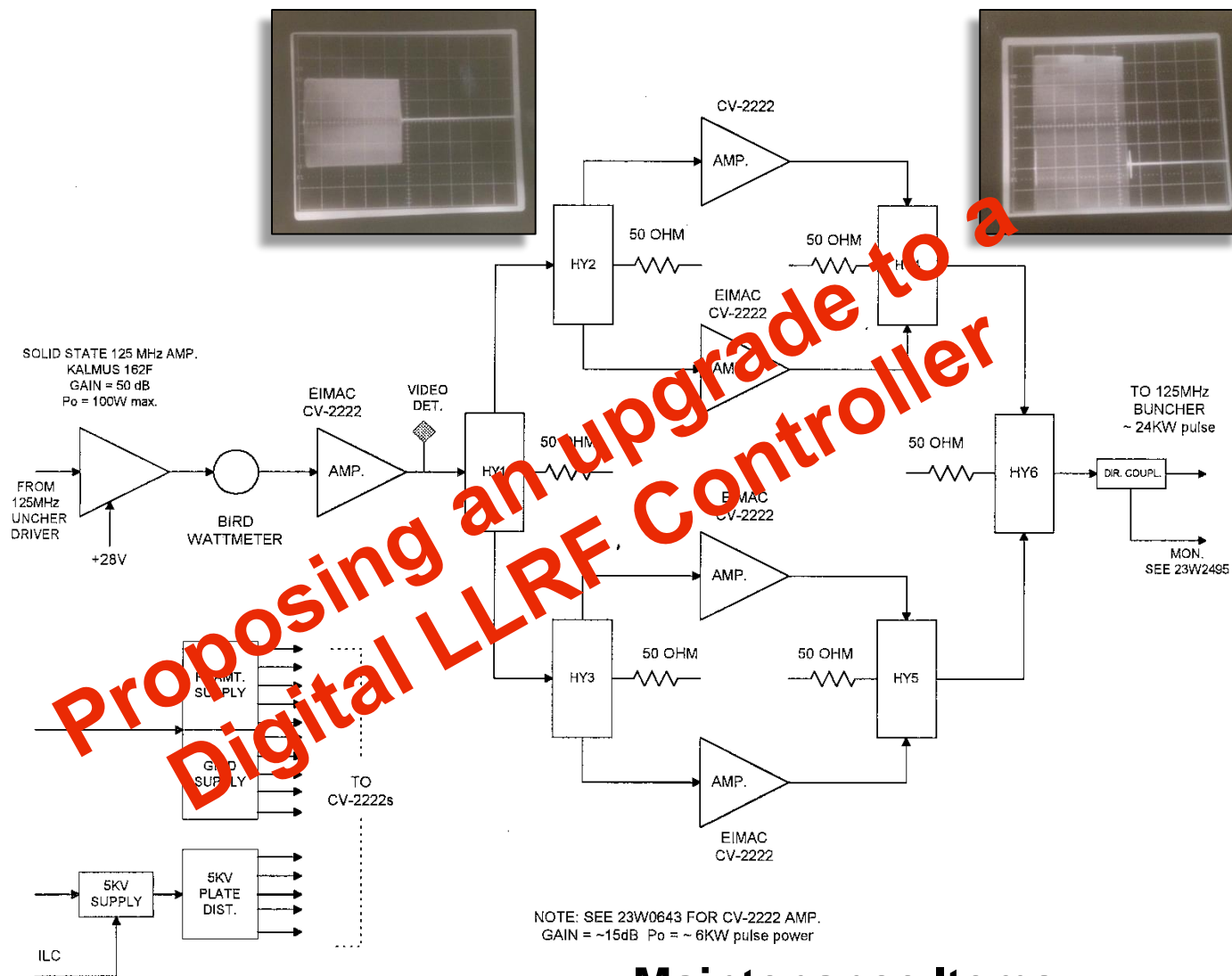
Gun Body



Cathode Lifetime: ~4 yrs



Gun Pulse Generation



In Service: 1989

Maintenance Items:

- Amplifier Air Cooling
- SS Drive amplifier
- HVPS

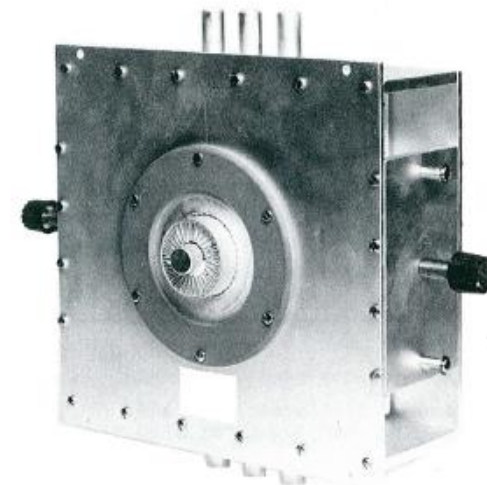
Sub-Harmonic Buncher Amplifiers

125 MHz
Cavity Amplifier



Eimac CV-2222

500 MHz
Cavity Amplifier

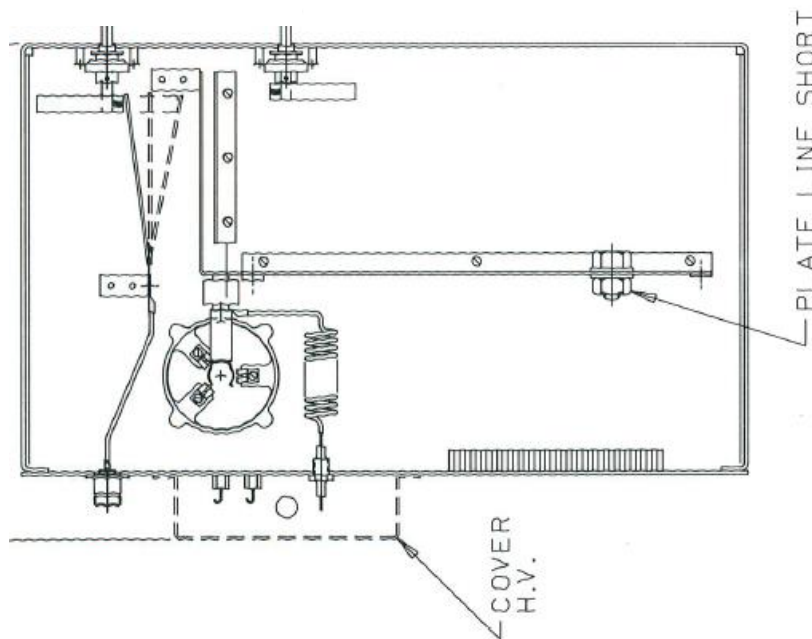


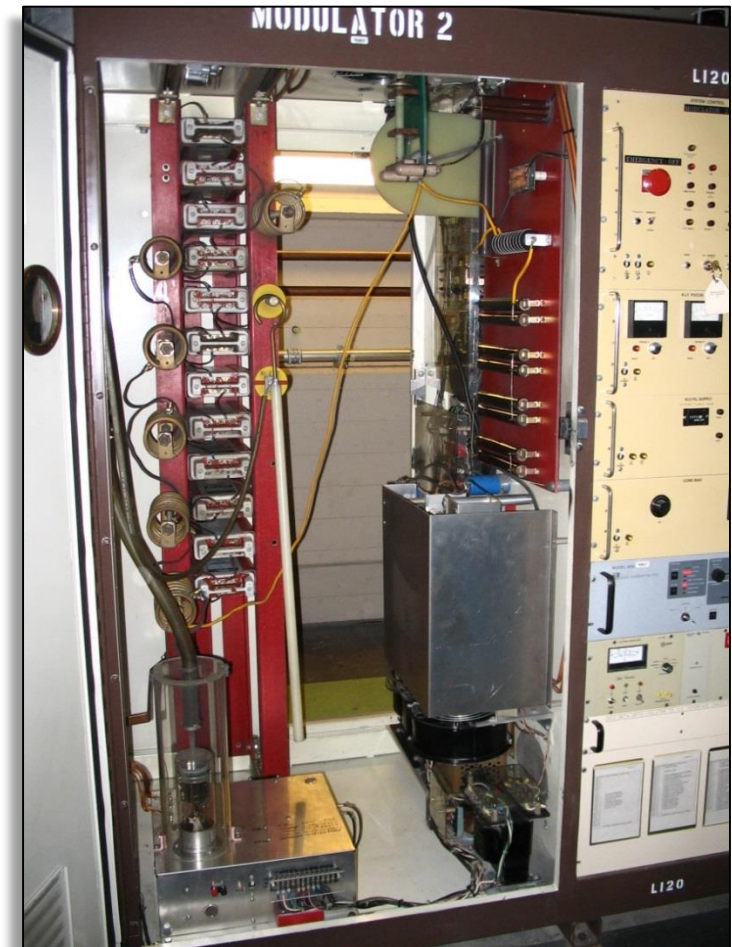
Eimac CV-2404



Eimac 3CPX800A7

Triode
Gain = 15dB
Up to 20kW Pulse, 6 kW
In service: 1989
Lifetime: 10-25 yrs
Cost: \$1550 ea





Thales TV-2002 DoD: 24MW, 2 μ s, 1 Hz
 Lifetime: Mod #1: 17 yrs, 10 yrs, 2+ mo
 Mod #2: 9 yrs, 14 yrs, 2 yr, 2+ yrs

In Service: 1989

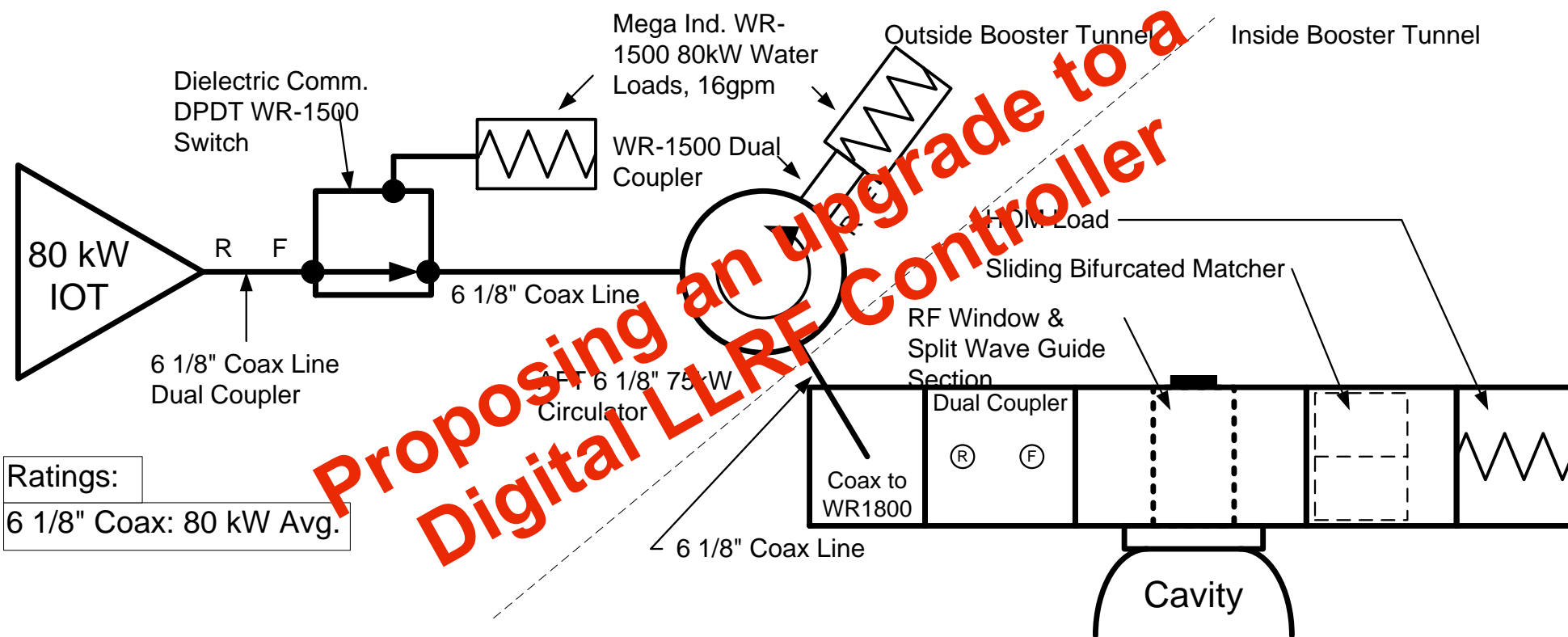
Low Gain Klystrons

Failures:

- Thyatron CX-1666
- HV Caps
- HVPS & Cable
- Focus PS & Magnets

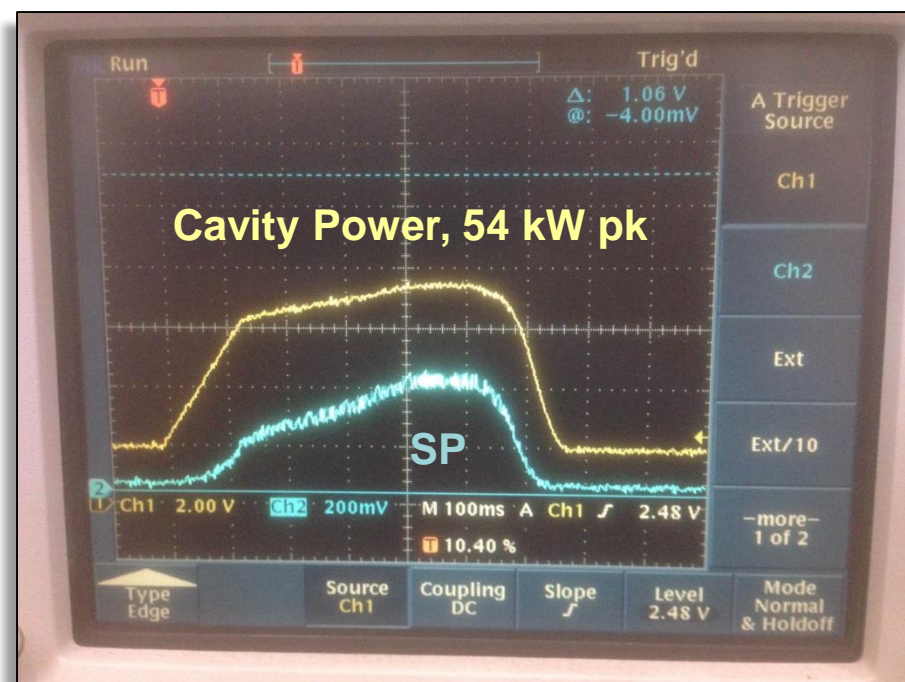
	Present
Beam current	4 mA
Dipoles Radiation	< 5 kW
Cavity Dissipation	43 kW
W.G. & other losses	< 6 kW
Total RF Power Reqr'd	54 kW
Total RF Power Installed	80 kW

Booster Ring RF System



Booster Ring RF Amplifier

Commercial IOT Based Broadcast TV Transmitter (modified)



Failures:

- Grid Bias PS
- HV Cable which led to an IOT failure
- HV Isolation Transformer
- Thyatron

In Service: 2006

CPI CHK2800W

Tuning Range: 473-750 MHz

**CPI K2H80W**

470-860 MHz

**Specification:**

80 kW CW

130 kW pk

Gain = > 23dB

Eff. > 65%

Operating Parameters $V_k = 32.1 \text{ kV}$ $I_k = 2.8 \text{ A}$

Eff = 60.3%

Gain = 23.1 dB

RF Out = 54 kW pk

IOT #1: 3 yrs (18k hrs) Failed due to poisoned cathode from HV cable fault**IOT #2: 7+ yrs (+45k hrs)**

	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 3 rd HC (kW)	6	9	9	9
Cavity Dissipation (x2) (kW)	43	43/50	43/50	43/53
W.G. & other losses (kW)	7	8/10	8/10	10/12
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	

Upgrade Sequence

Phase I



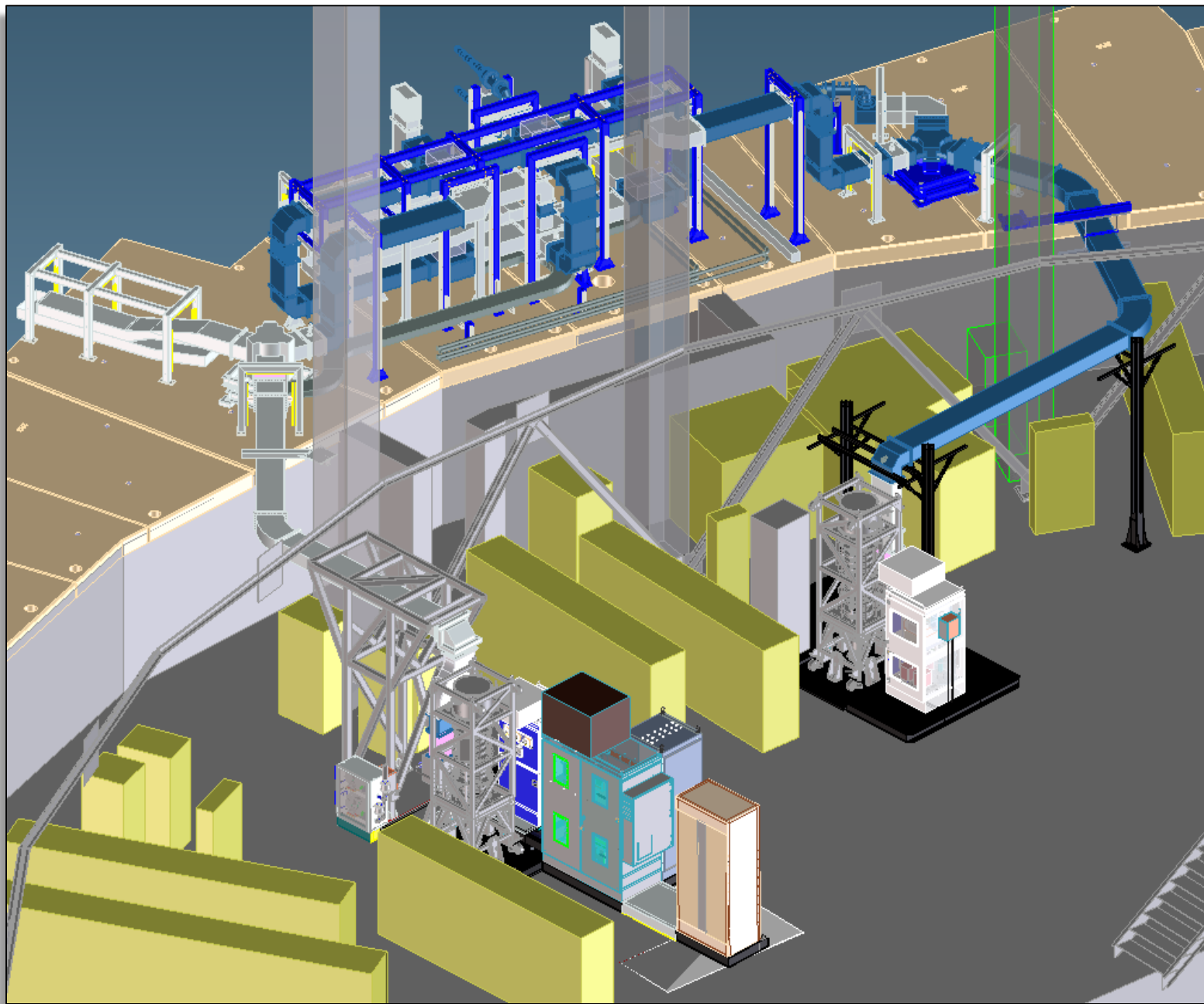
Establish New Klystron Site #2

Phase II

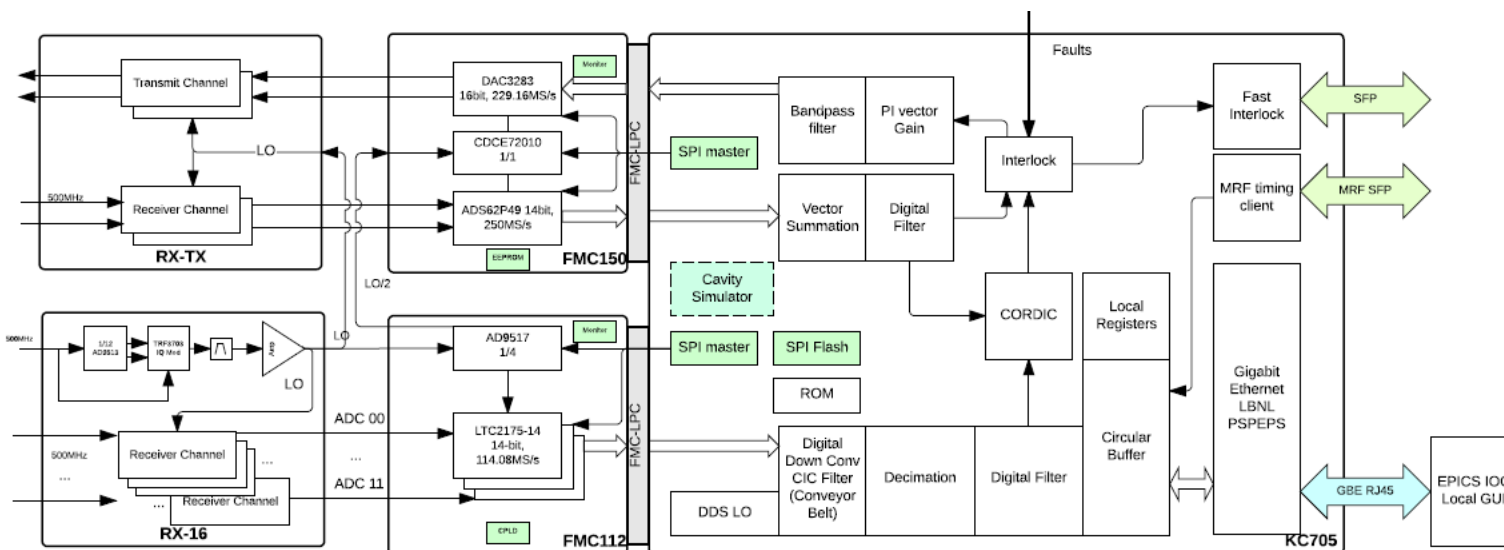


Upgrade HVDC PS, Replace Crowbar with HV Dis-Conn SW, New Klystron in Site #1

Waveguide Switch Matrix

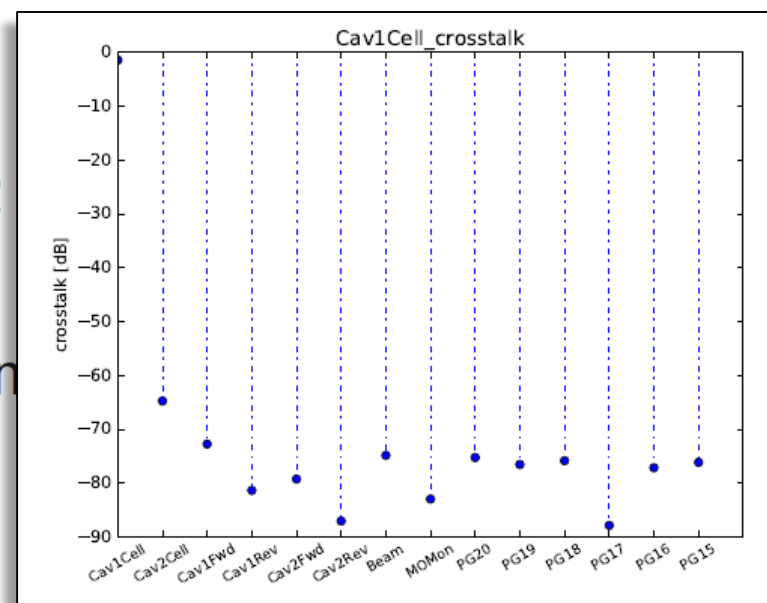


Phase IIIa



Phase IIIb, Jan 2017

- ▶ Commercial FPGA carrier and digitizer
 - ▶ Xilinx KC705 + 4DSP FMC150 + 4DSP FMC112
- ▶ $F_{LO} = 11/12 F_{RF} = 458.33 \text{ MHz}$
- ▶ Compact analog frontends, channel isolation
- ▶ MRF timing, fast interlock



Operational Hours

- **Black Heat** **4773**
- **Standby** **29605**
- **HV** **29126**
- **Transmit** **27736**

Klystron Operating Parameters

- $V_k = -53.1$ kV $I_k = 9.55$ A
- $V_a = 32.8$ kV $I_a = 1.6$ mA
- **Eff = 51.53%** **Gain = 41.41 dB**
- $\mu P = 1.61$ **RF Output = 261.7 kW**

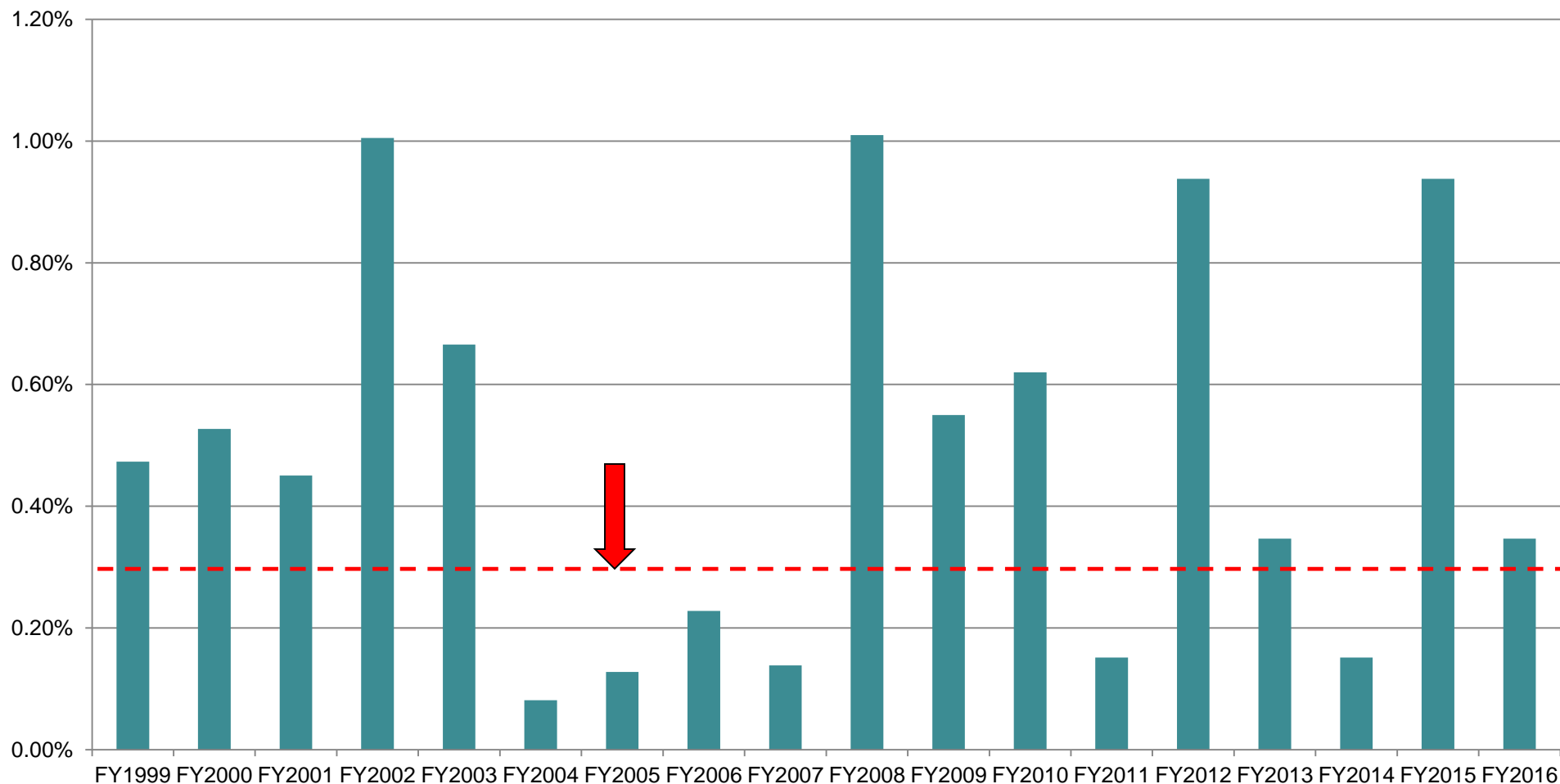
In Service: 2012

Failures:

- **Mod-Anode PS**
- **PLC SP zeroing**
- **Filter Capacitor**

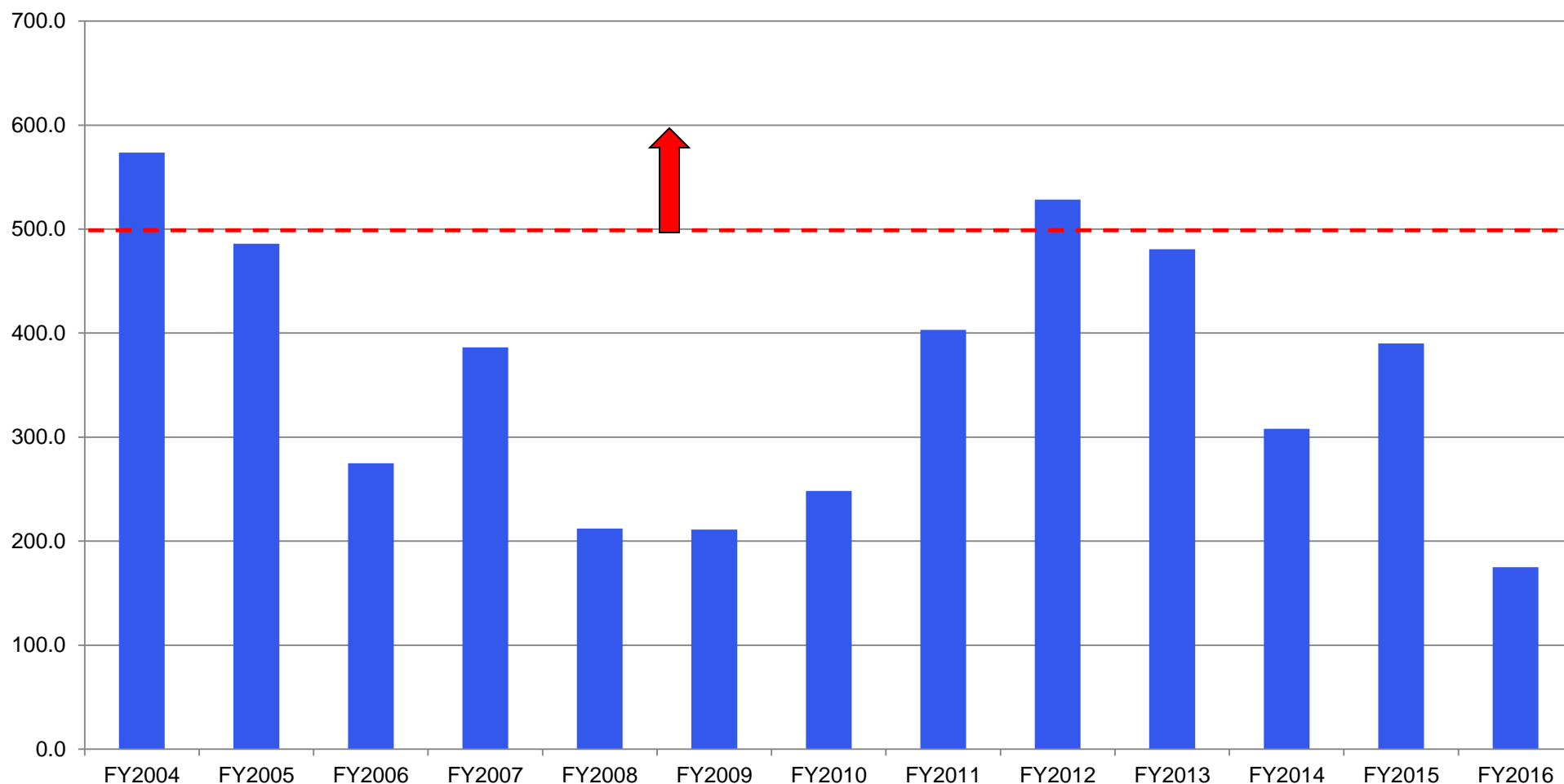


Percentage of Scheduled Beam Time Lost to SRRF & Non-Latching Faults by Fiscal Year



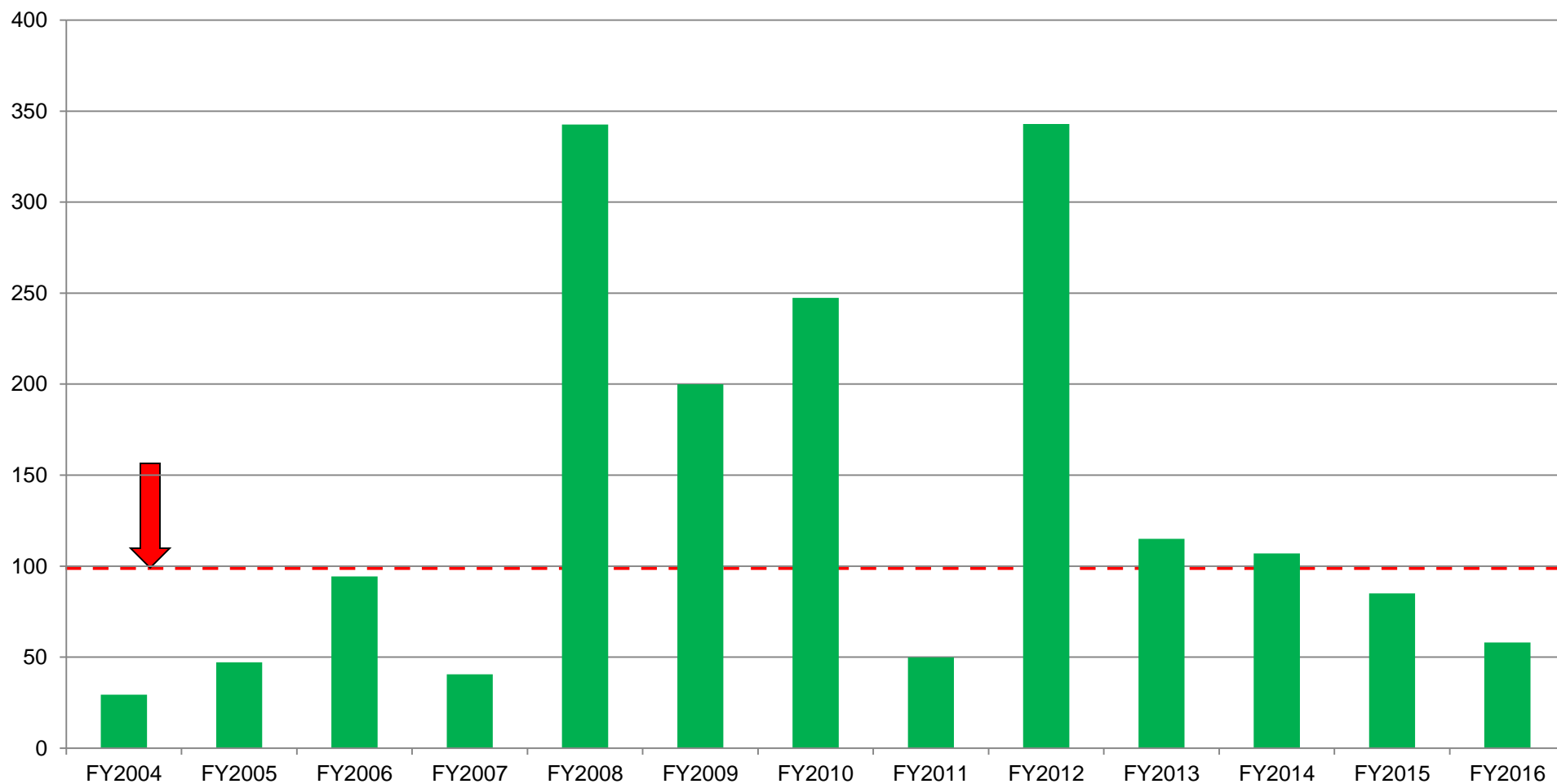
Goal for SRRF system based on 5000 hours of User Beam time: 0.3%

SRRF Faults, MTBF (in hours): Mean time between faults, FY2004 - FY2016*



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

SRRF Faults, MTTR (in minutes): Mean time to recovery, FY2004 - FY2016*



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

3rd Harmonic Cavities (passive)

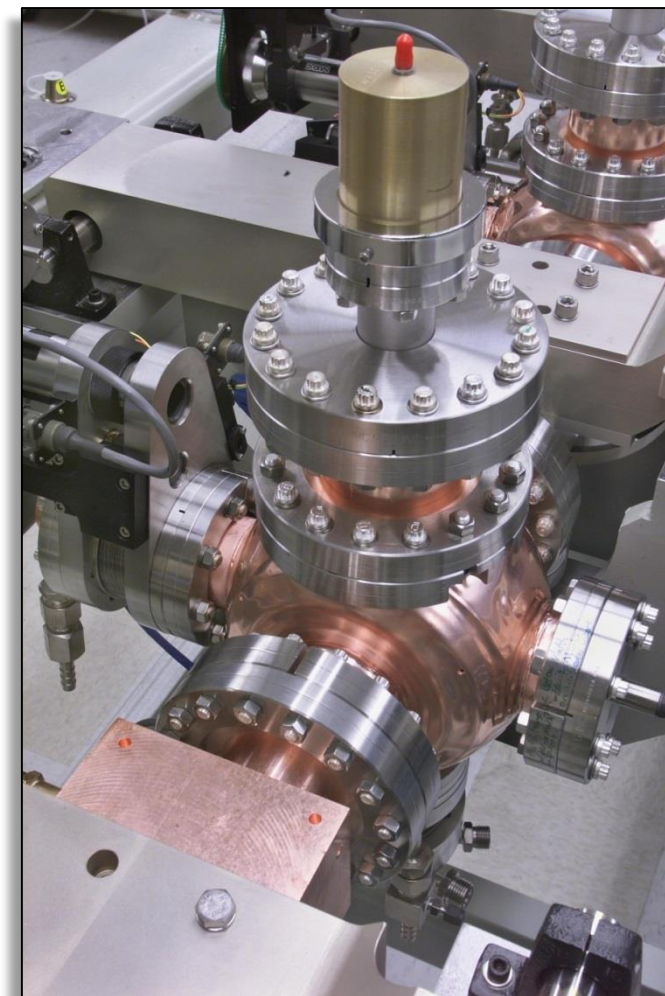
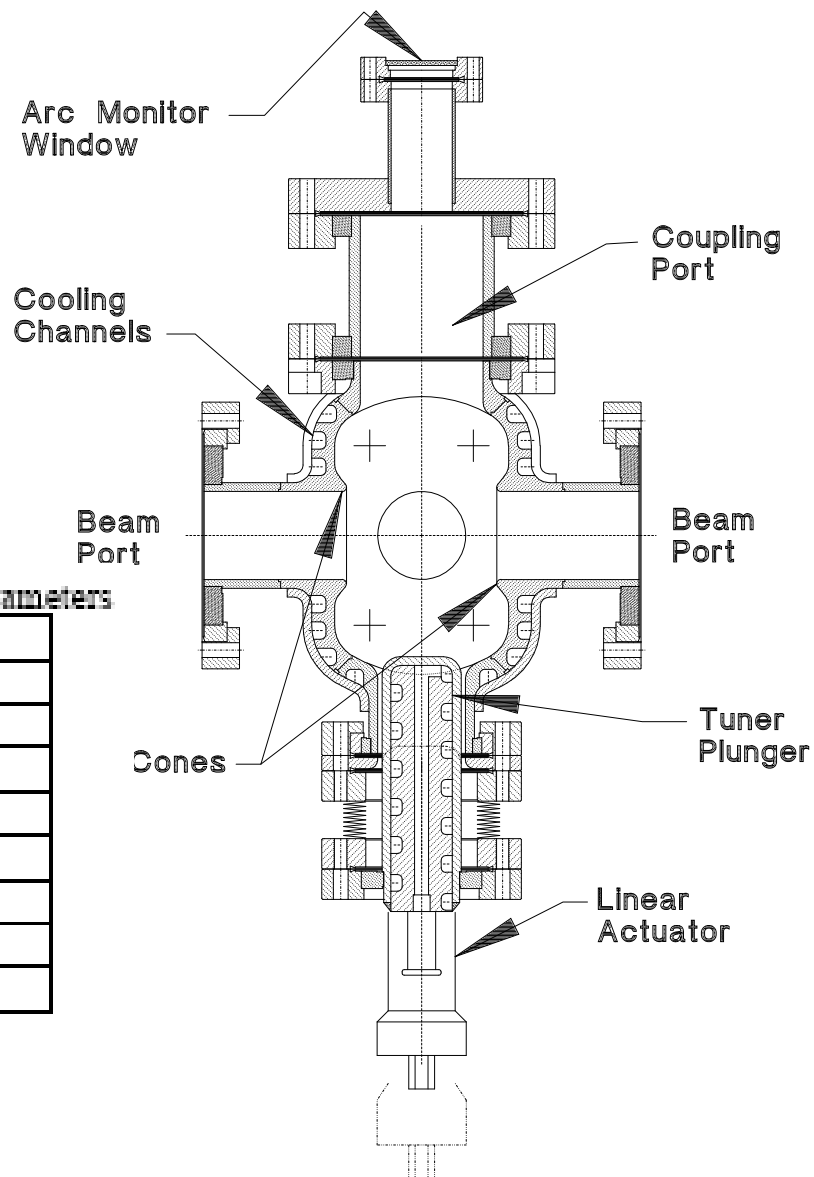


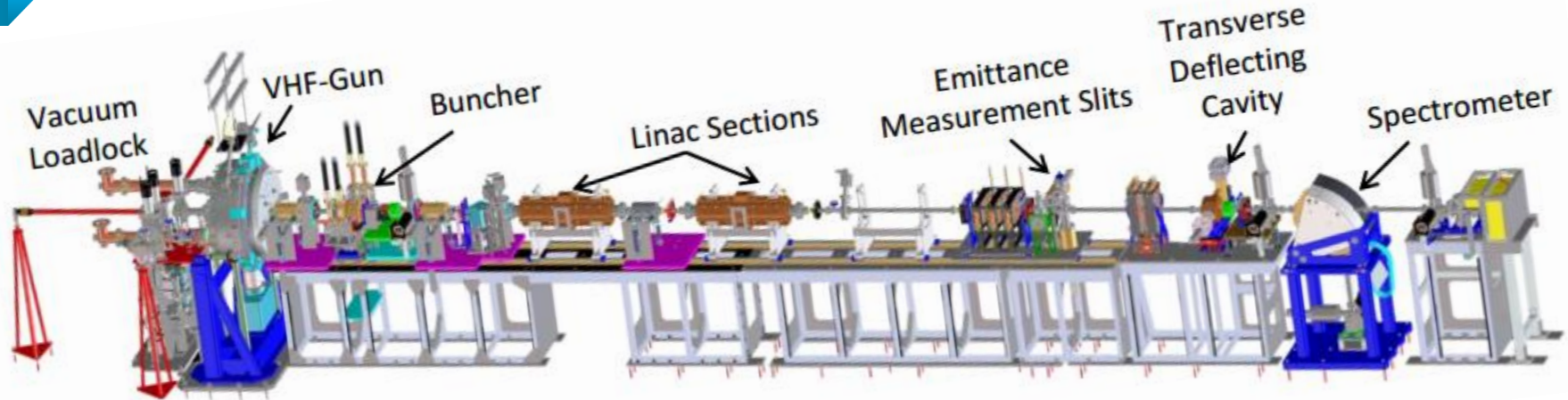
Table 1: Harmonic cavity system parameters

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

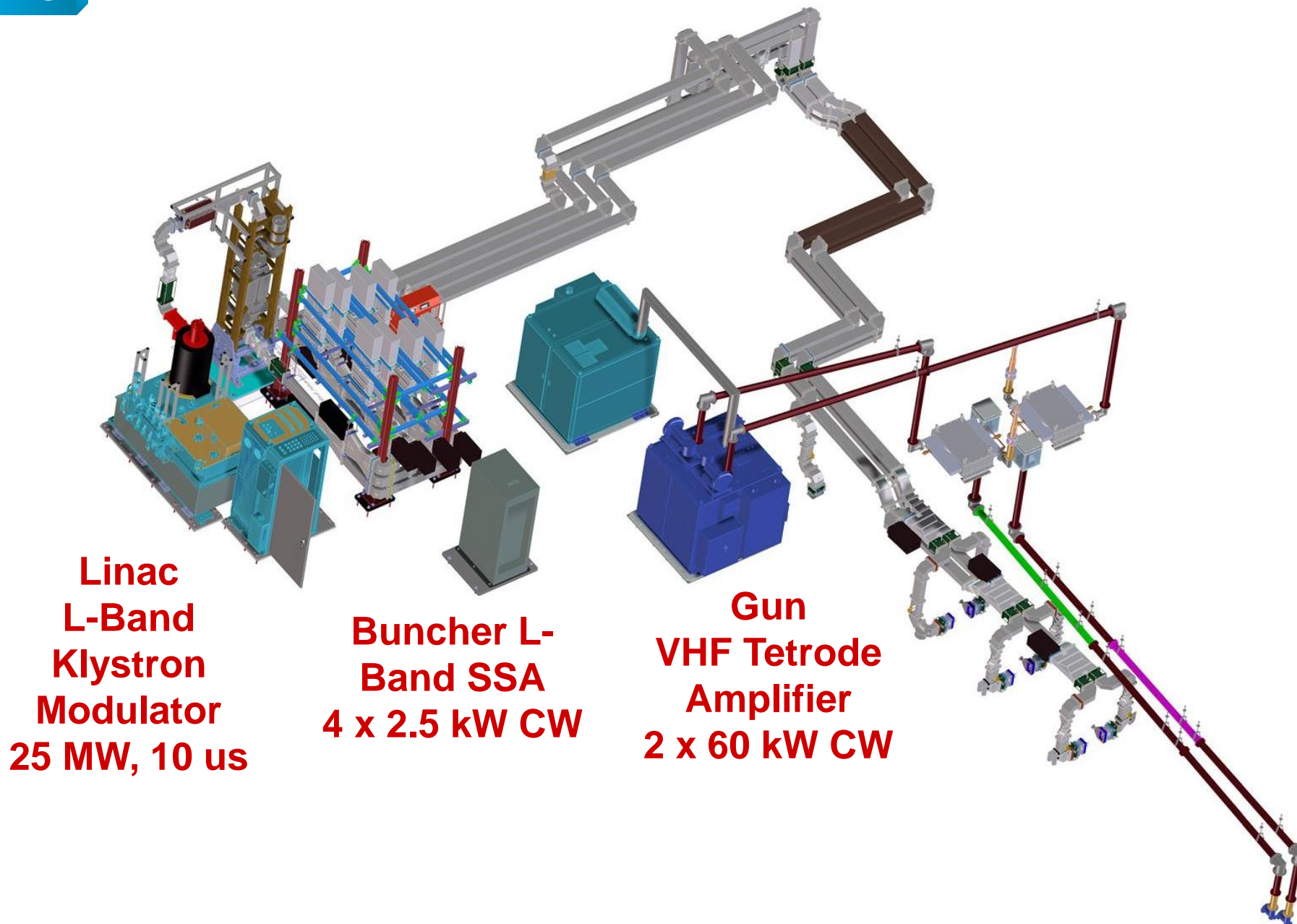
$$*R = V^2/2P$$

Failures:

- Vacuum Feedthru



Repetition rate	Up to ~ 1 MHz	
Charge per bunch	~ 10 – 300 pC	Different modes of operation
Normalized emittance	~ 0.2 – 0.6 μm	Lower value for lower charge
Beam energy at the gun exit	>~ 500 keV	For controlling space charge
Cathode electric field at photoemission	>~ 10 MV/m	Space charge limit; maximum brightness limit
Bunch length and shape control	From < 1 to ~ 60 ps	Space charge control; different modes of operation
Cathode/gun area magnetic field compatibility		Emittance compensation; (exotic modes)
Dark current at nominal gun energy	< ~ 1 μA	SRF quencing; rad. damage
Operational vacuum pressure	~ 10^{-10} – 10^{-9} Torr	High QE cathode lifetime
Loadlock cathode vacuum system		“Quick” cathode exchange
Reliability	High (>~98%)	Required for an user facility



**Linac
L-Band
Klystron
Modulator
25 MW, 10 μ s**

**Buncher L-
Band SSA
4 x 2.5 kW CW**

**Gun
VHF Tetrode
Amplifier
2 x 60 kW CW**

Operational Hours

	Tube #1	Tube #2
• Black Heat	30027	29895
• Standby	7348	7300
• HV	5007	4957
• Transmit	4910	4867

Tetrode TH 571B Parameters

- $V_a = 9.7$ kV
- $V_s = 692$ V
- $V_g = -140$ V
- Eff = 62.5%
- $I_a = 7.47$ A
- $I_s = 165$ mA
- $I_g = 10$ mA
- RF Out = 45 kW

Failures:

- Filament PS
- SSA Drive Amp Fan Control
- SSA Drive Amp PS Fail Intrlk
- SSA Drive Amp Pre-Amp
- SSA Drive Amp Output Module
- HV Current Limiting Resistors



Proposing to build a SSA version of this system for the LCLS II project

HPA



HVPS



In Service: 2011



1.3 GHz 4 x 2.5 kW SSA

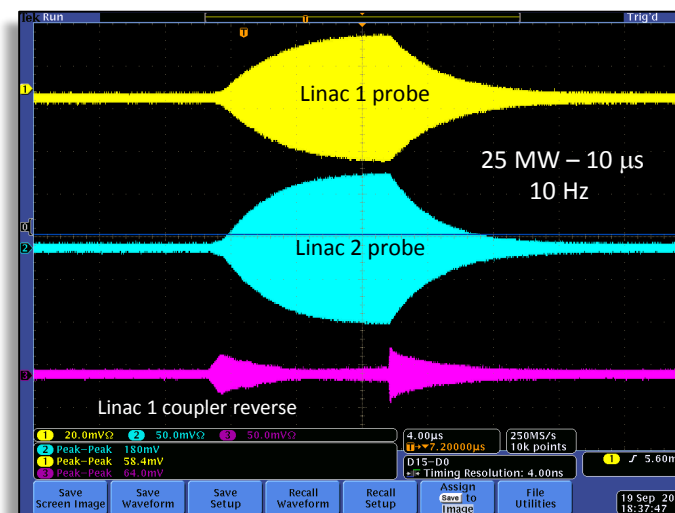
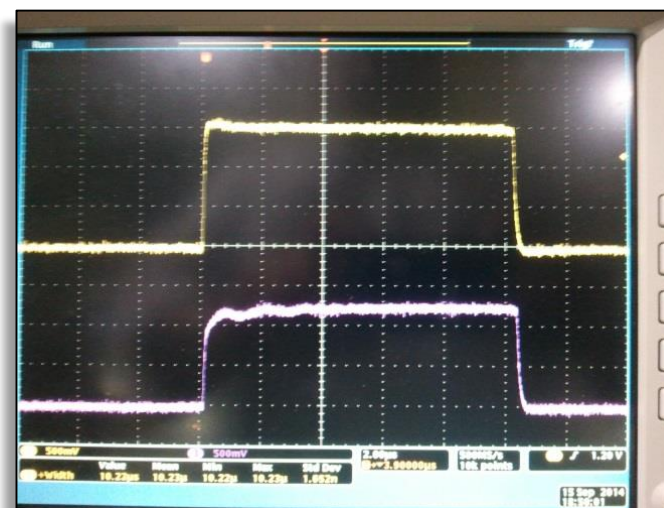
- Operates at 2.0 kW
- ~200 hrs

~~Failures:~~

- ~~Logic card modification~~

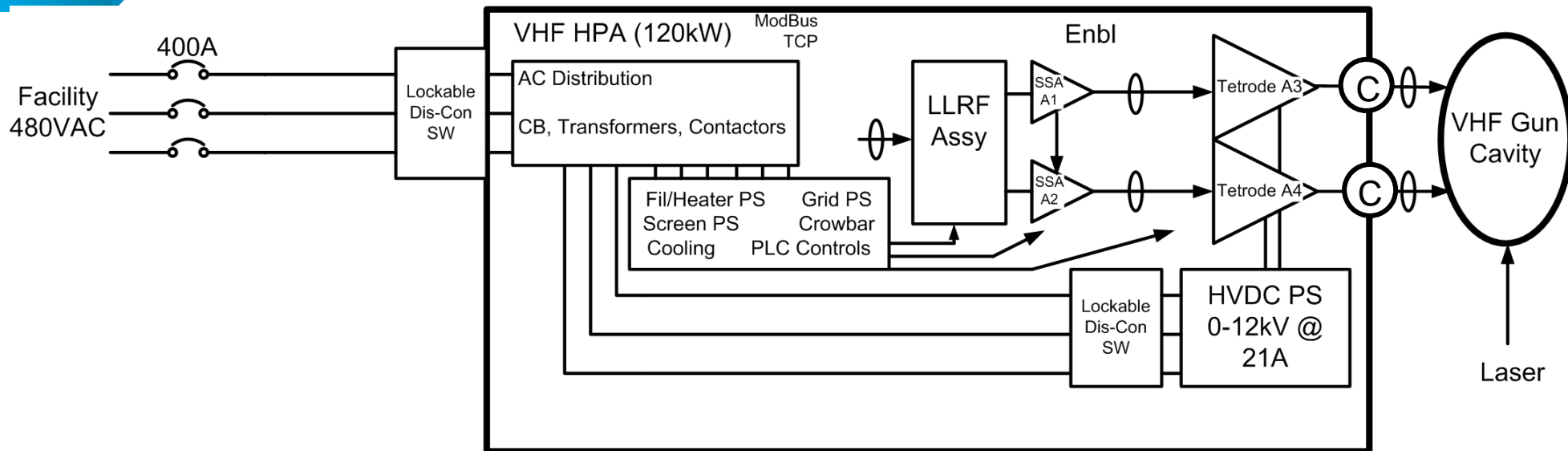
In Service: 2015

Solid State L-Band Modulator

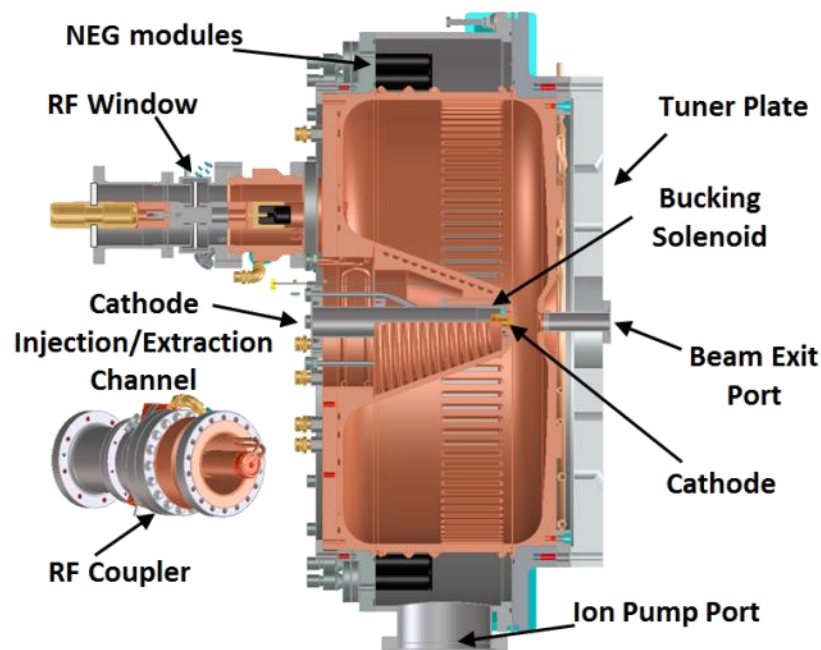
10 μ s, 10Hz

In Service: 2015, ~300 hrs

APEX RF (Advanced Photocathode Experiment)



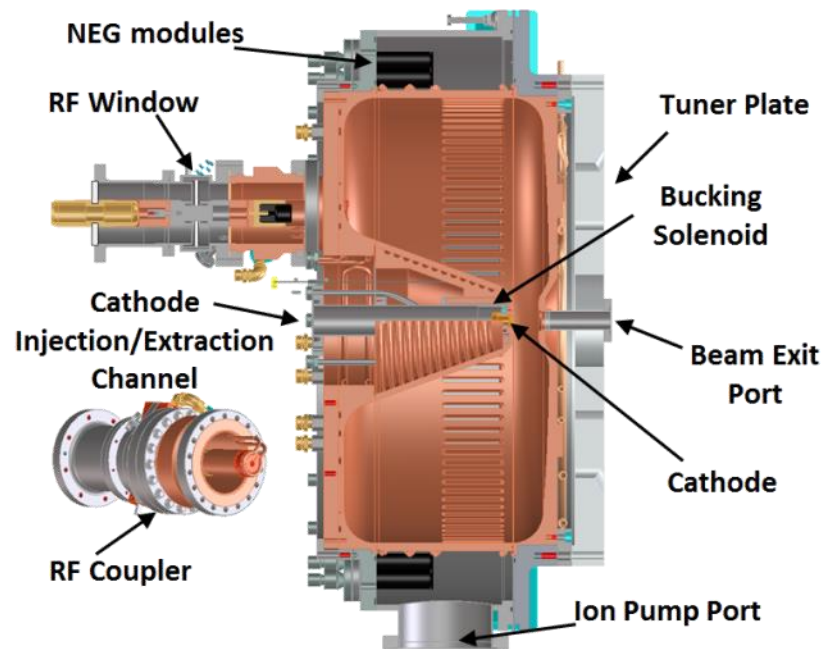
Overheated area



APEX RF (Advanced Photocathode Experiment)



$$\lambda_{RF}/4 \sim 15.9''$$



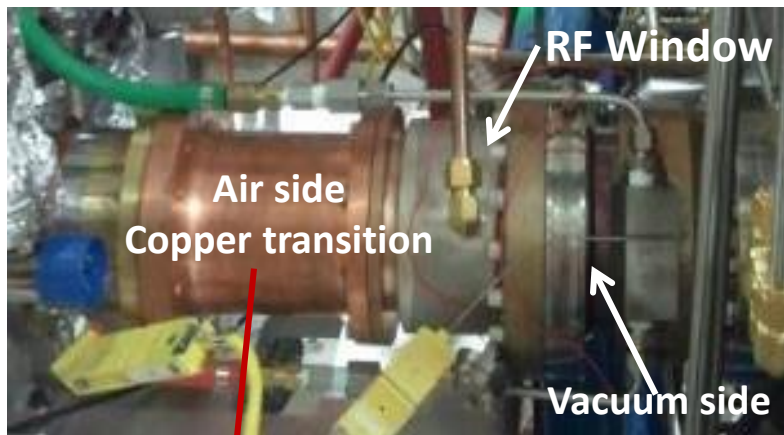
Missing from measurements, additional ~5" for length of coupling loop



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

The internal conductor

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



Facing parts

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

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 ($P_{pk} = V_{pk}^2/Z_0$). Not specified for how long.

APEX max operation conditions:

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

Peak Voltage in line = $1.414 \cdot \sqrt{P_{avg} \cdot Z_0} =$

$1.414 \cdot \sqrt{60000 \cdot 50} = 2.45 \text{ kV}$

Peak Power in line = $V_{pk}^2/Z_0 = 2449^2 / 50 = 120 \text{ kW}$

Peak Power in line from standing wave: $V_{pk} = 4.9 \text{ kV}$, $P_{pk} = 480 \text{ kW}$

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.

Thank you