RF Power Upgrade at Jefferson Lab

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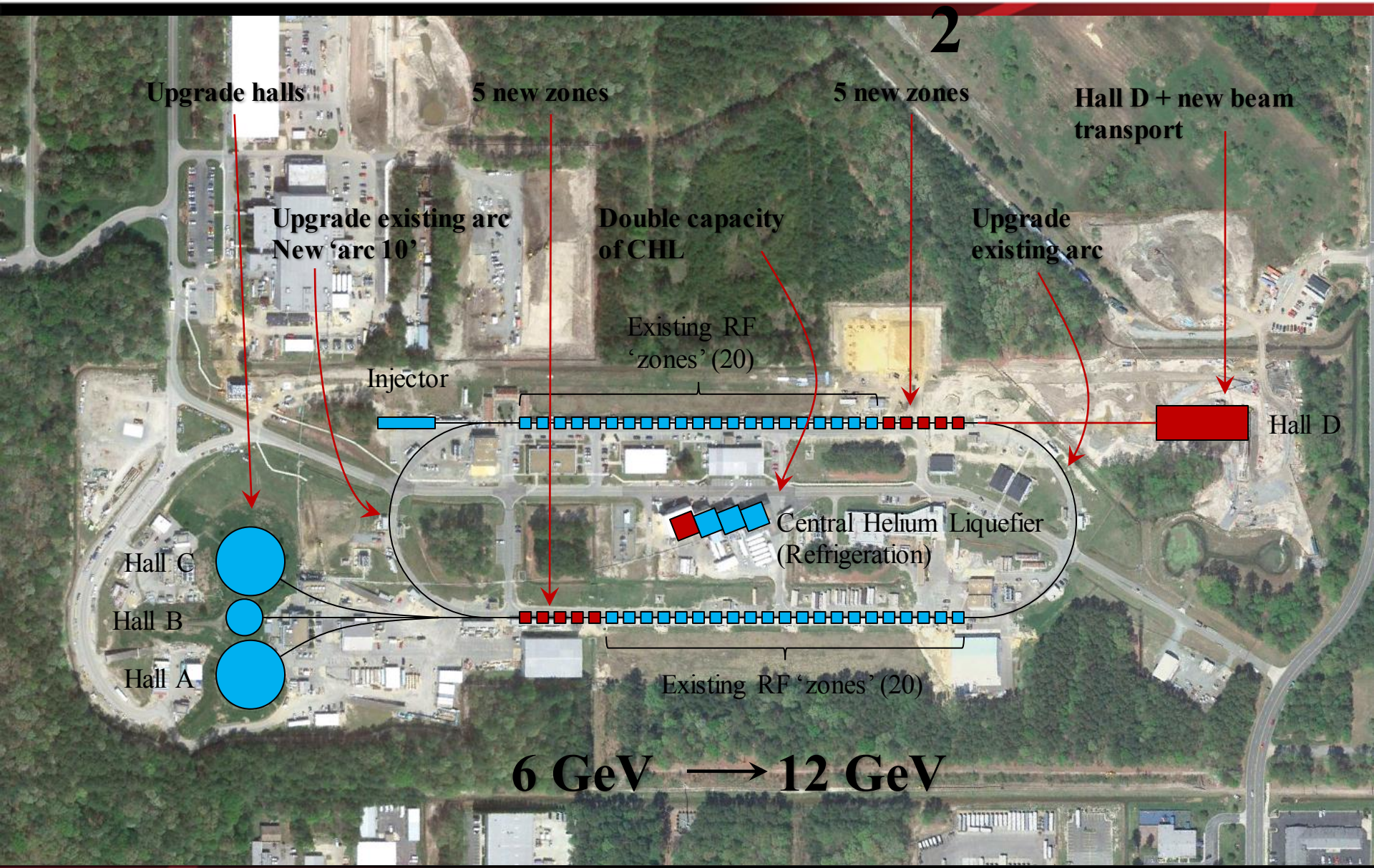
CEBAF (circa 2013)



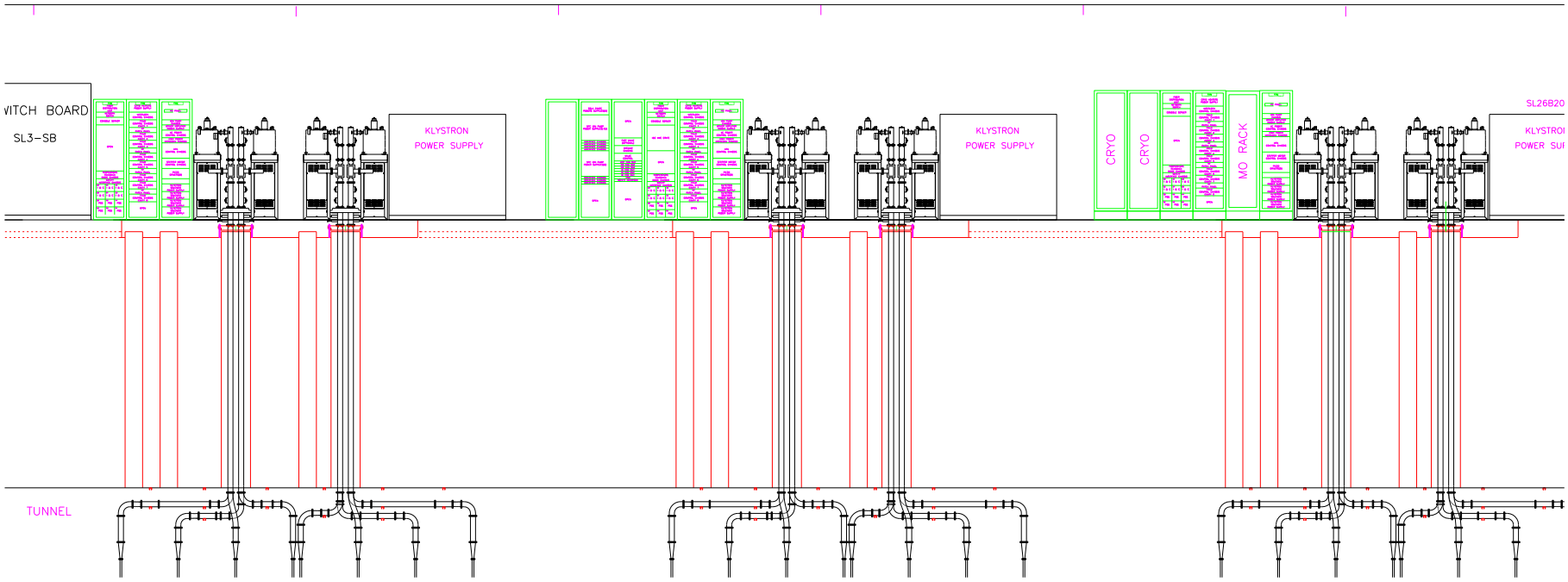
Background

- ***New systems must fit available footprint, even with power increase from 5 to 13 kW***
  - CEBAF was originally conceived as a 4 pass/25 zone per linac machine capable of 4GeV
  - Built as 5 pass, 20/linac (for cost savings)
  - Service buildings and tunnel built for 25 zones
  - Upgrade fills empty slots - 5 zones per linac
  - Runs at 6 GeV with relatively minor upgrades
- Energy increase to from 6 to 12 GeV
- Hall-D (new):12 GeV, Halls-A,B,C 11 GeV
- For RF: new systems with higher power

High Power RF

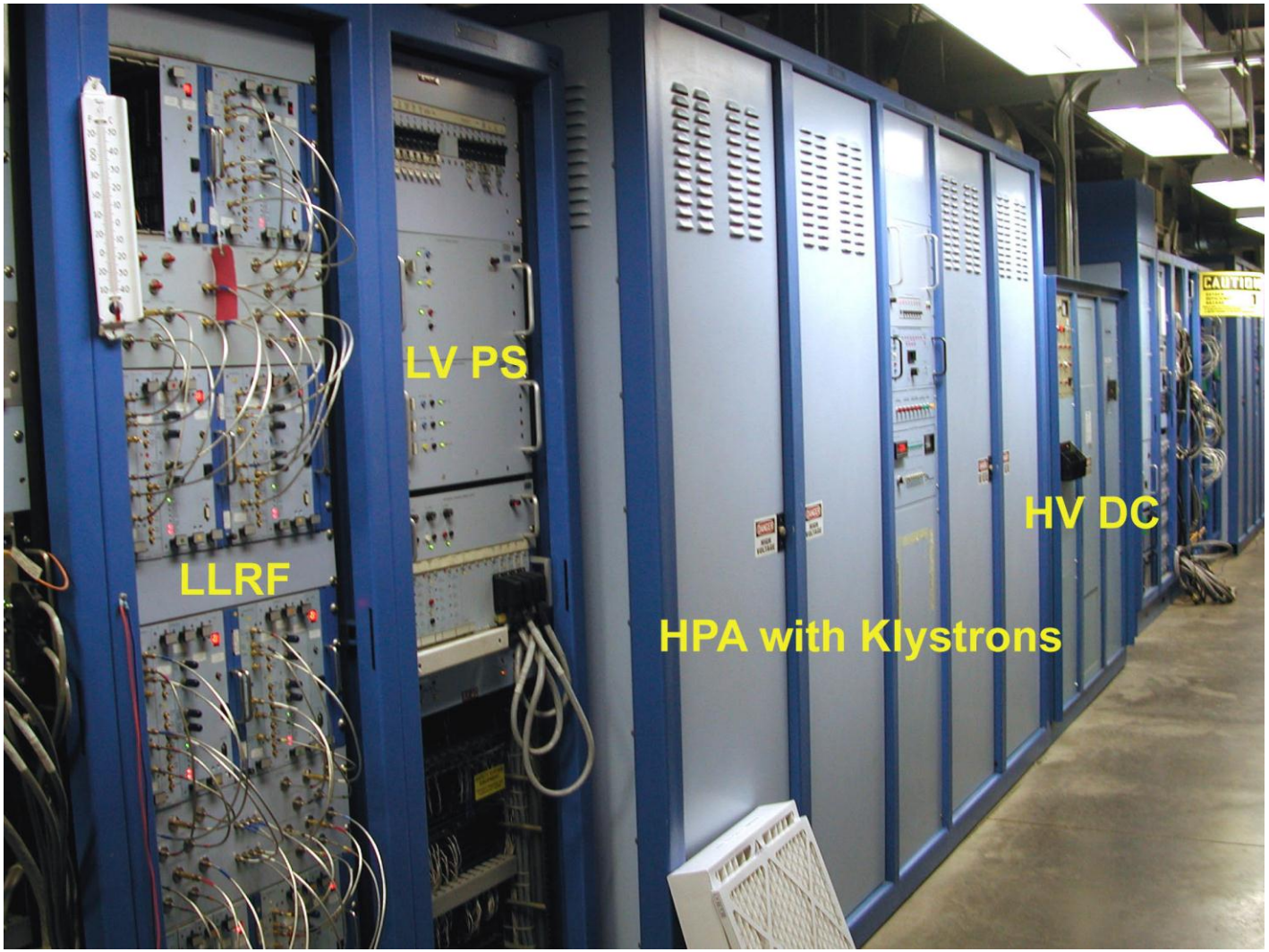
- *Upgrade includes ten 'C100' cryomodules (8 x 7 cell cavities, 100 MV/m per unit)*
- Ten new RF zones (5 per linac)
  - New designs for both high power and low level
  - Redesign some existing components
    - (Compatibility goals)
  - 13kW (saturated) RF to each cavity
  - HV DC power supplies, aux PS, interlocks, controls
  - Waveguide components (circulator, coupler, tuner, HOM filter, sweeps, flexes…)
  - Mechanical assemblies - water manifolds, etc.
  - New FPGA-based phase/amplitude control for LL

Section view



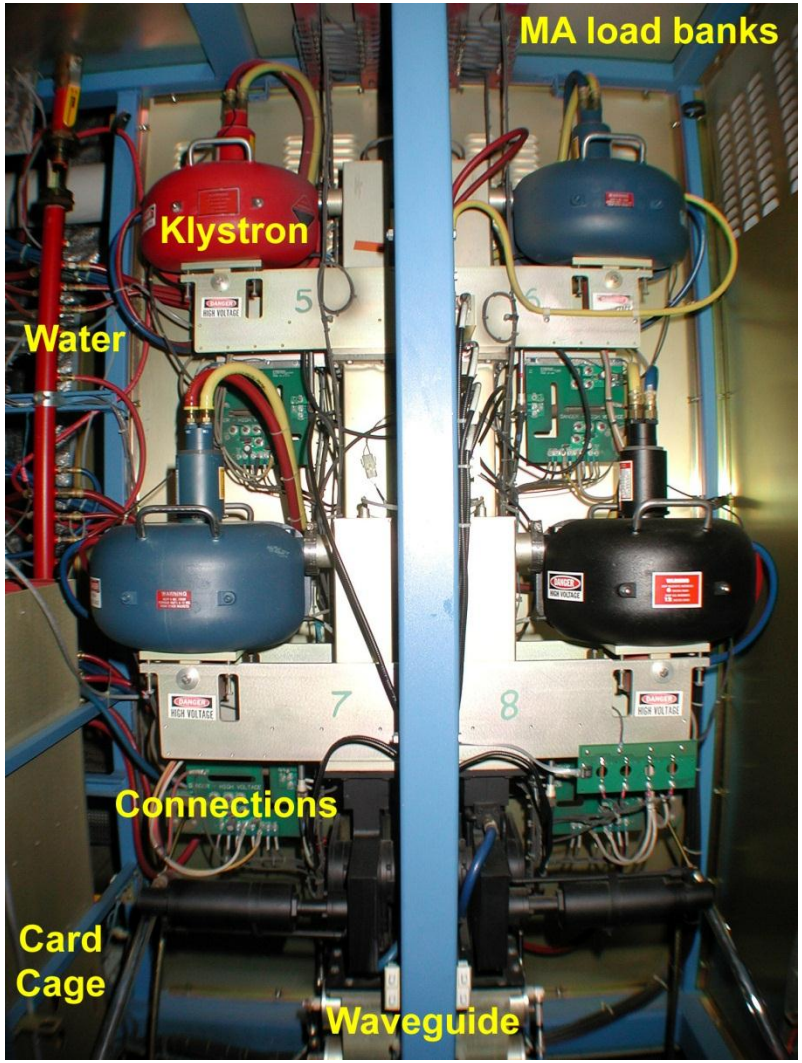
Equipment in accessible gallery, SC cryomodules in tunnel

Existing System

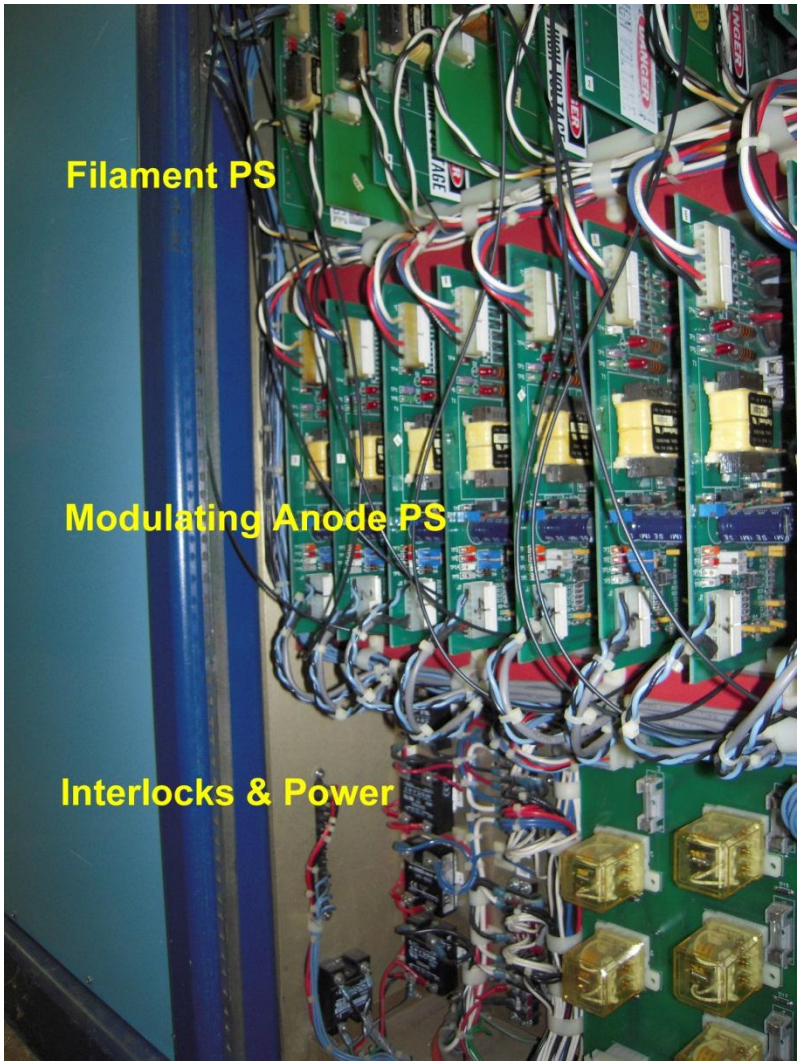


CEBAF RF zone: LLRF at left, HPA, HV at right

Existing System



4 klystrons stacked

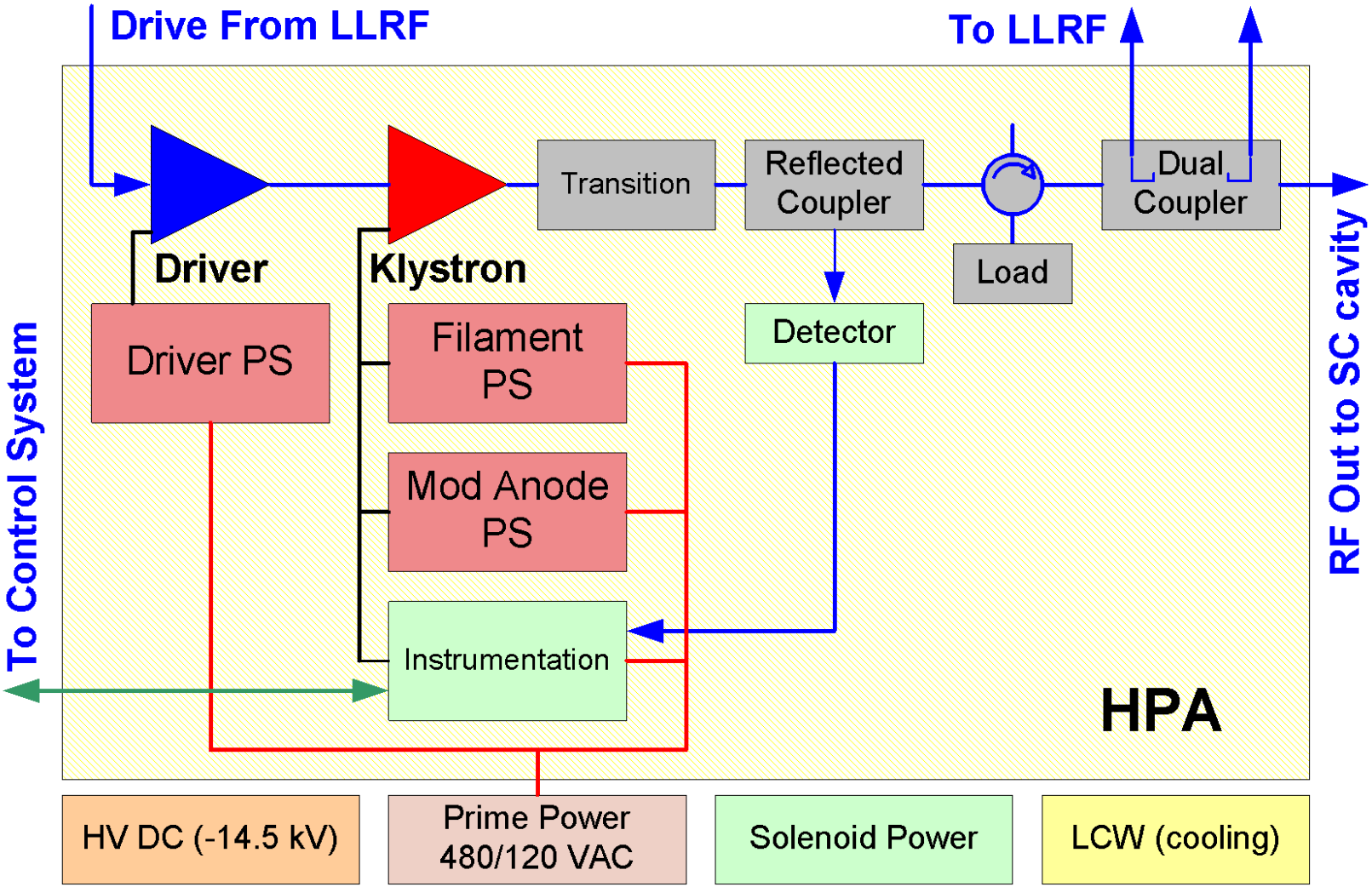


Filament & mod anode PSU

Some Backwards Compatibility

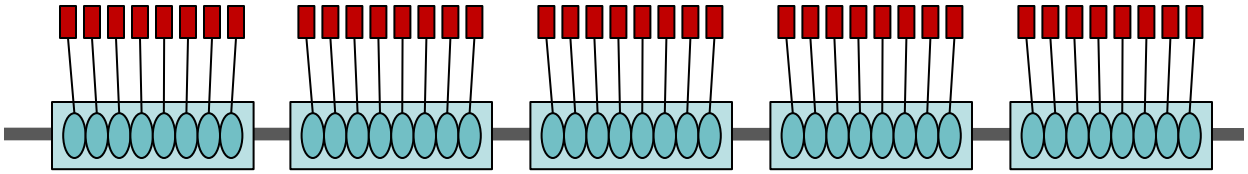
- Overall design similar to old systems
  - Future plans include upgrading existing zones
    - Eliminate CAMAC
    - Upgrade to digital LL controls (for use with refurbished cryomodules)
    - Minimize variety of spares: new filament & mod anode PS work with old or new zones (not reverse)
- New systems have similar interfaces as old systems
    - Largely same group of signals, interlocks, requirements, down to key connector pin-out
    - Goal is to use new HPA controller in upgrades
      - (monitors klystrons, interlocks, etc.)

RF System overview

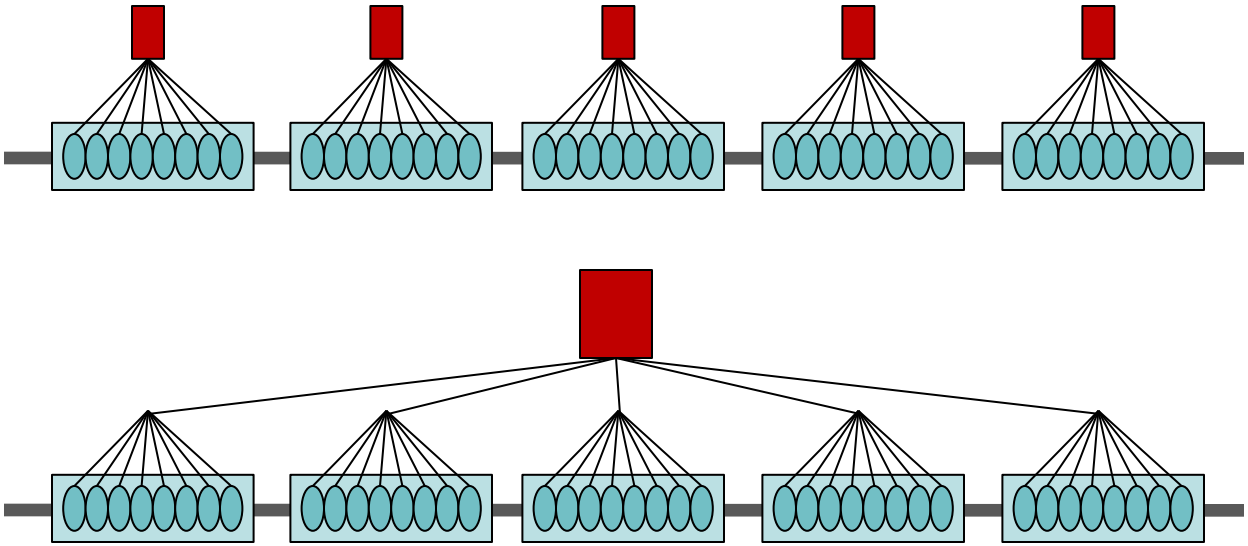


How many RF Sources?

1 per cavity
(current system)
Minimum impact of failures (existing design)



1 per zone or per linac
Larger impact
High power splitters
Amplitude and phase regulated to high precision.



Additional controls and high power modulator found to be more $$$ than individual RF sources.

Step 1: Tube or SSA?

Solid state

- Our past experience was not the best (SS has improved since then)
  - Concerns about transistors going obsolete
  - Size/cost too large
  - SSA not included in bid package (SBIR in the works)

IOT

- Promising, but not there yet
- Better efficiency than a klystron, but lower gain -- high cost driver
- Reliability reasonable for UHF designs
- Product at 1.5 GHz not yet built
- Budgetary pricing was higher than klystron before driver cost added

Klystron

- Current 5kW design (run at up to 8) has been reliable (>150k hours between failures)
- Could fit available space

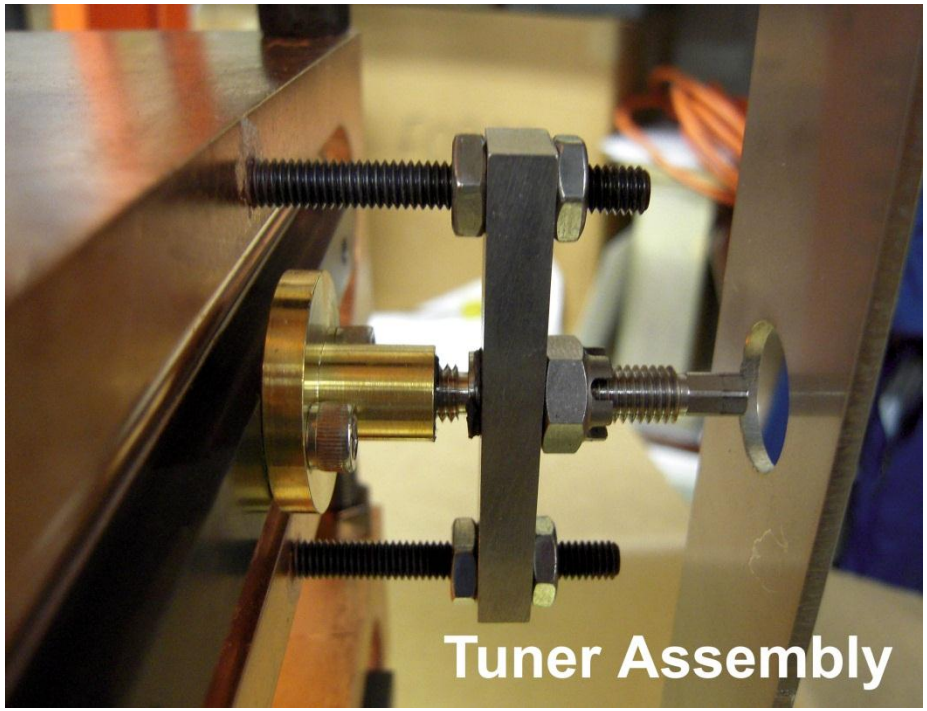
A New Klystron

- Klystron or IOT at RFI
  - Narrowed to klystron only at RFP
- Received two (US only)
- Awarded to L-3 Communications
  - New design (Williamsport division)
  - Higher efficiency
  - Same gun assembly as our old tube
  - Original collector was upgraded
    - Dissipation nearly unchanged fron 8kW tube due to efficiency increase
  - Solenoid focusing vs. PM

Old-New Comparison

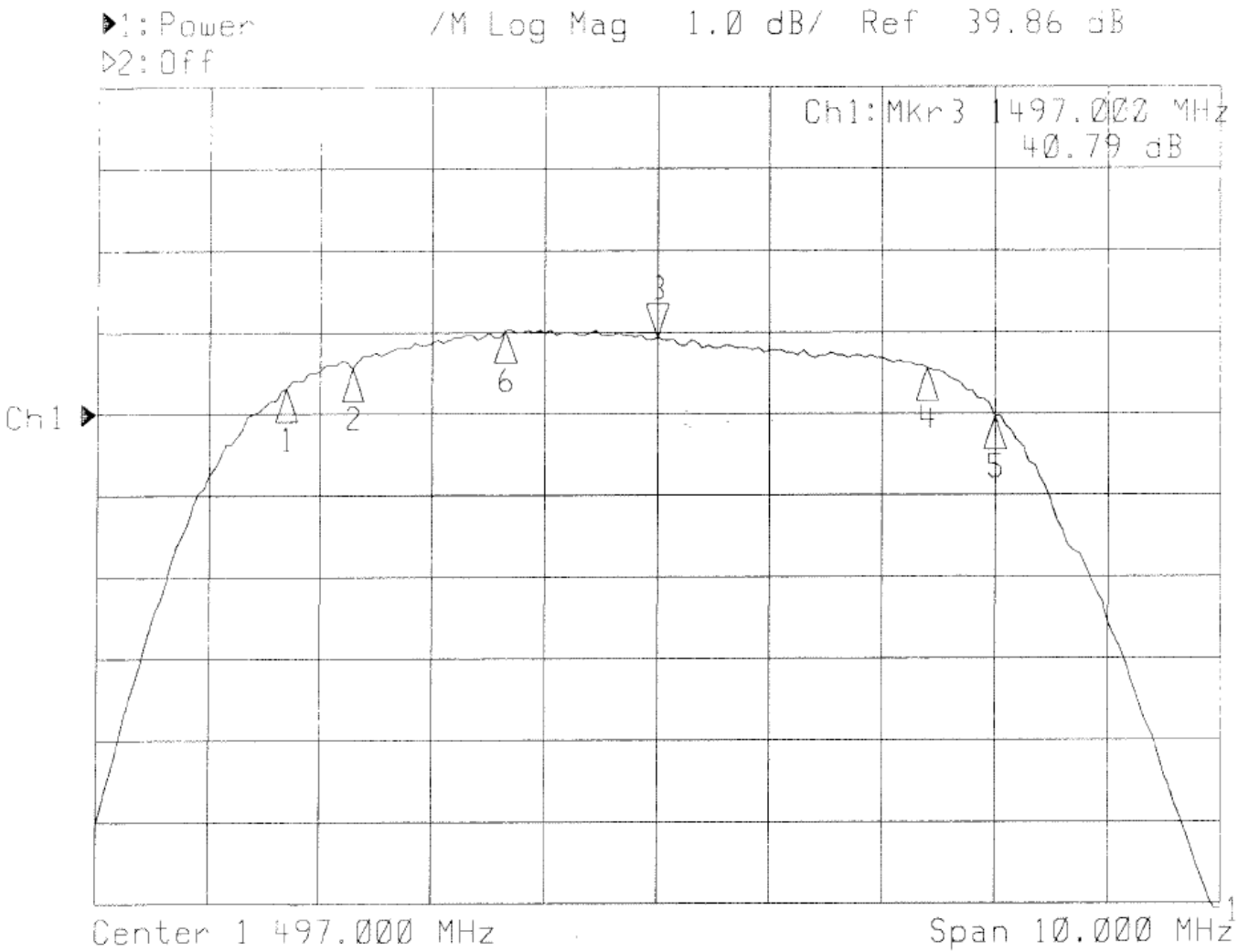
Parameter	Old Spec	New Spec	Actual	Units
Power	5 & 8	13	13	KW
Center frequency	1497	1497	1497	MHz
Bandwidth, -1dB	5	5	5+	MHz
Bandwidth, -3 dB	6	6	6+	MHz
0.5 dB incremental gain at	4	10	meets	kW
Efficiency (at rated power)	32	>50	50.9	%
Gain	38	>42		dB
Harmonics	-20	-20	meets	dBc
Beam voltage	11.6	<16	14.5	kV DC
Heater voltage	7.3	7.3	7.0 typ	V DC
Modulating anode	Yes	Yes	Yes	
Isolated collector	Yes	Yes	Yes	
Cavities	4	5	5	
Focus	PM	EM	~900	Watts

Klystron

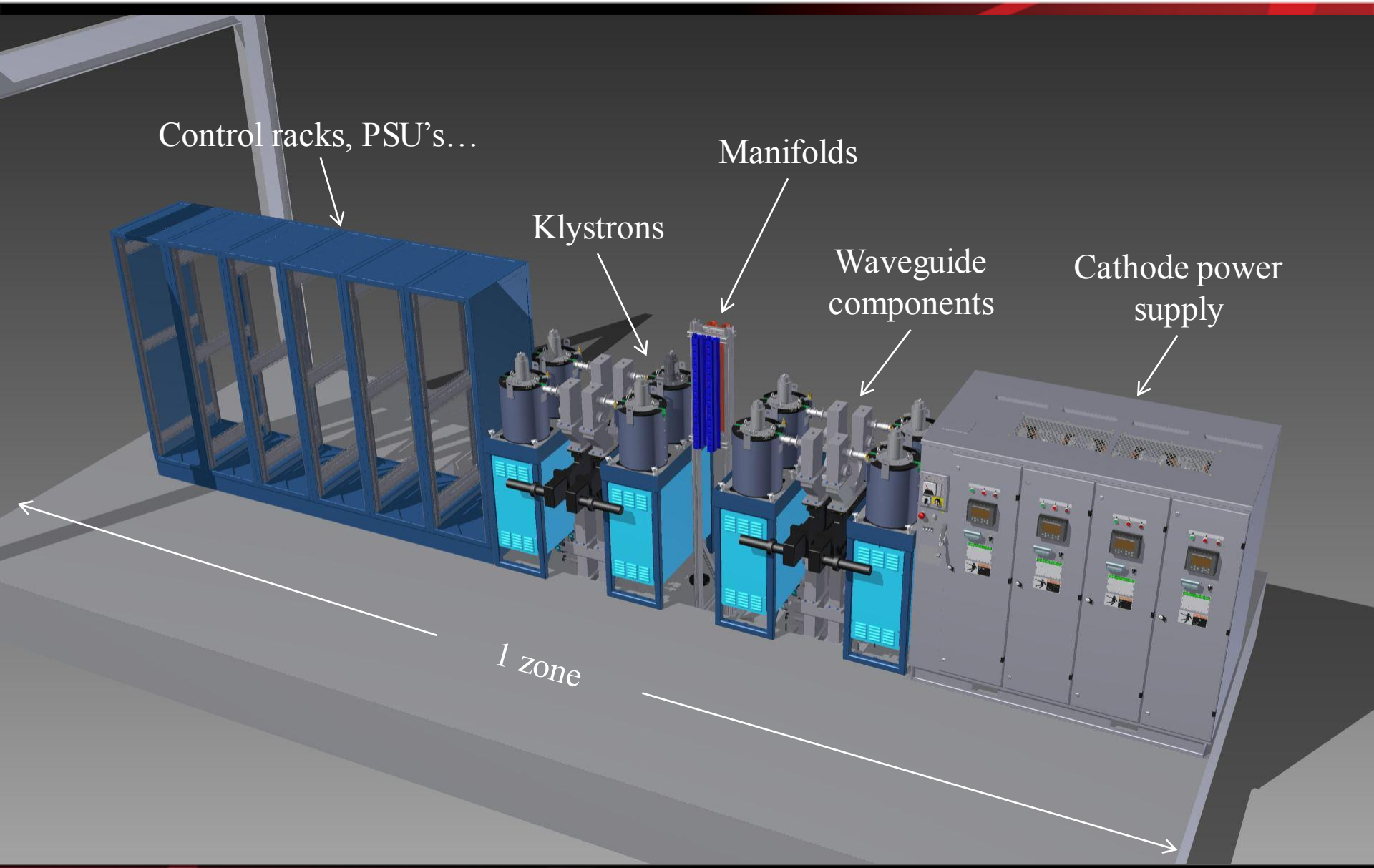


- Model L1433 by L-3
- Water-cooled window
- Cavities 4 & 5 water-cooled
- Robust tuning mechanism

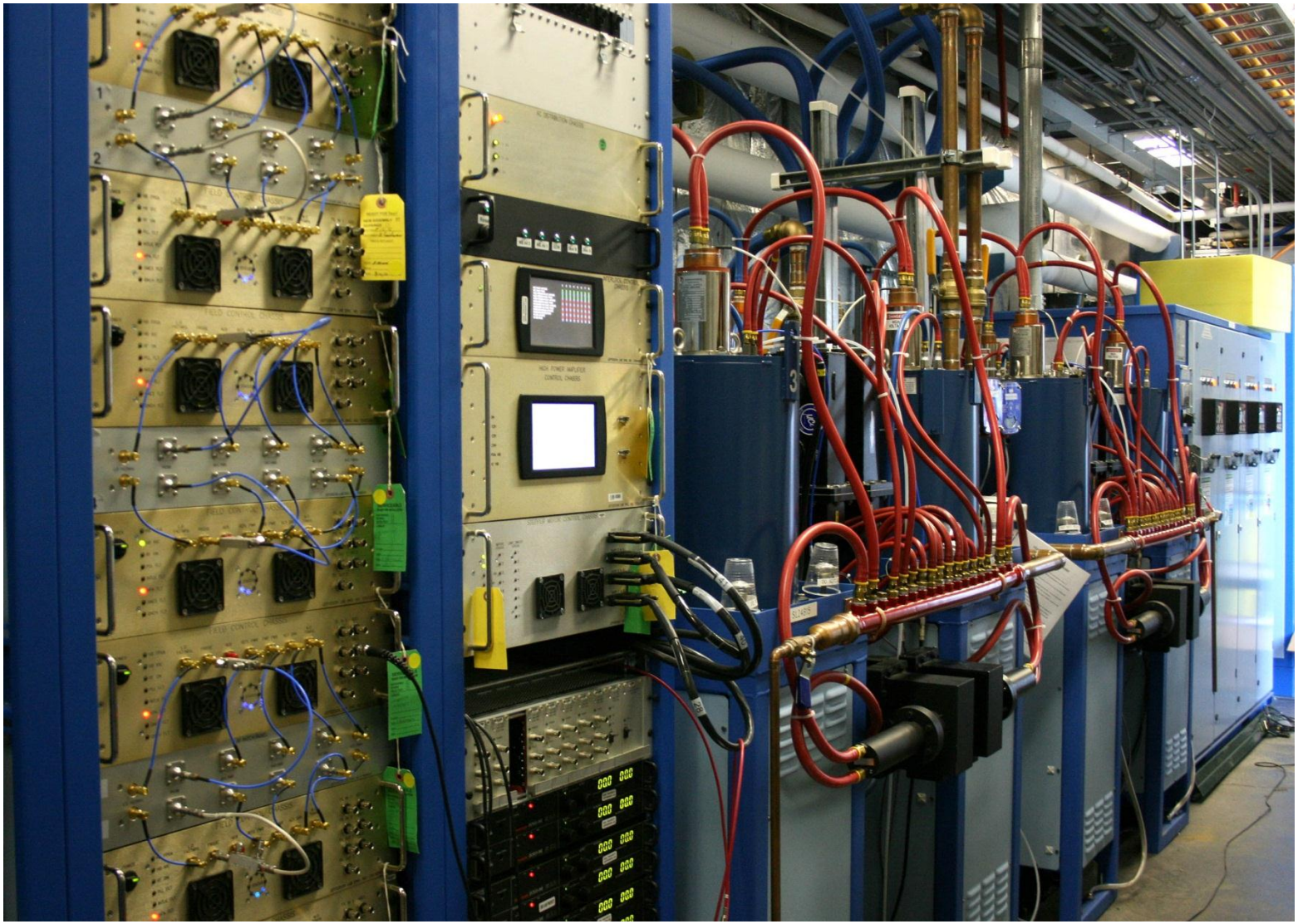
13 kW Curve


1: Power
/M Log Mag 1.0 dB/ Ref 39.86 dB
2: Off
Ch1: Mkr3 1497.002 MHz
40.79 dB
Ch1
1
2
6
3
4
5
Center 1 497.000 MHz
Span 10.000 MHz

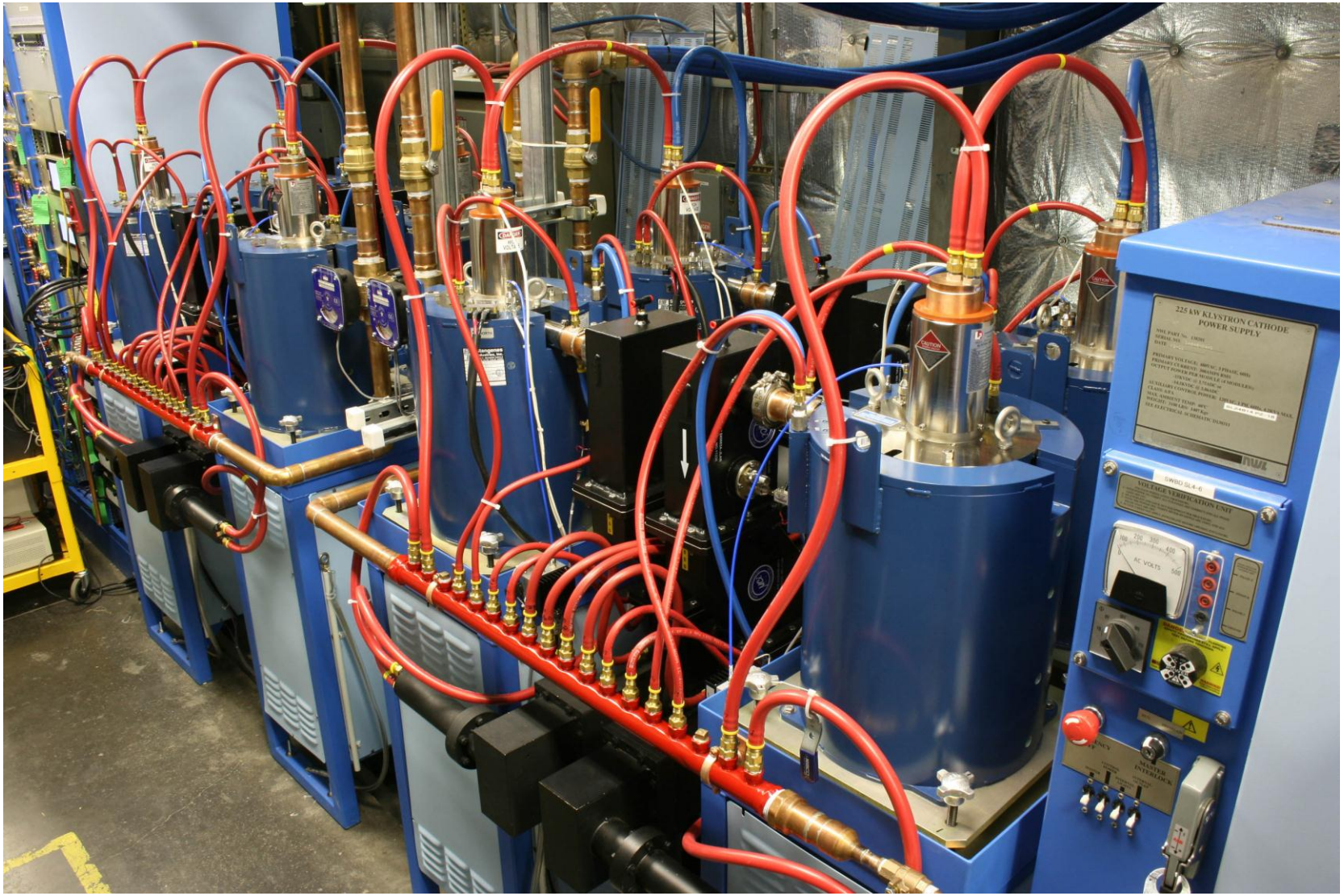
Layout


Control racks, PSU's…
Klystrons
Manifolds
Waveguide components
Cathode power supply
1 zone

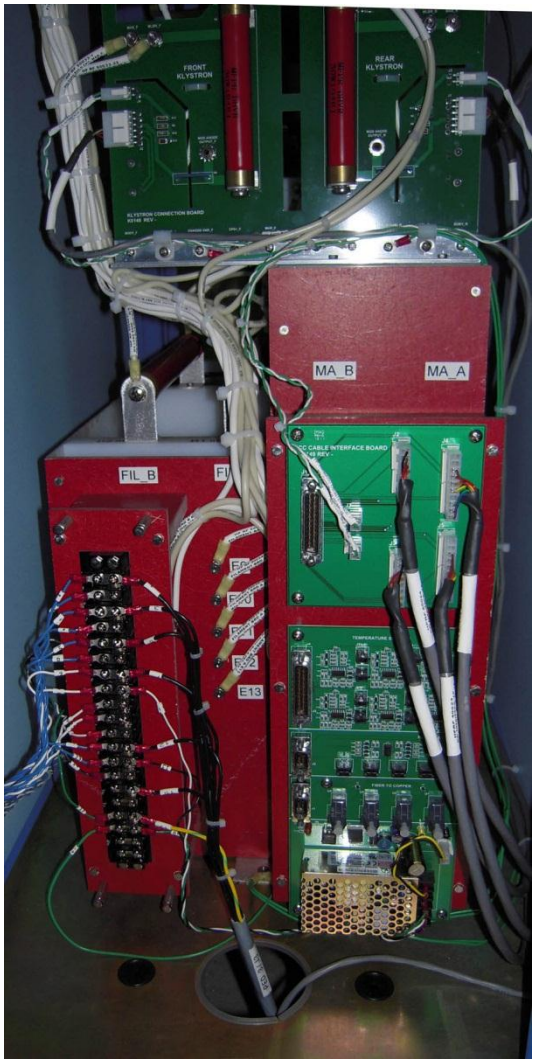
RF Zone



Hose City - Set of Klystrons



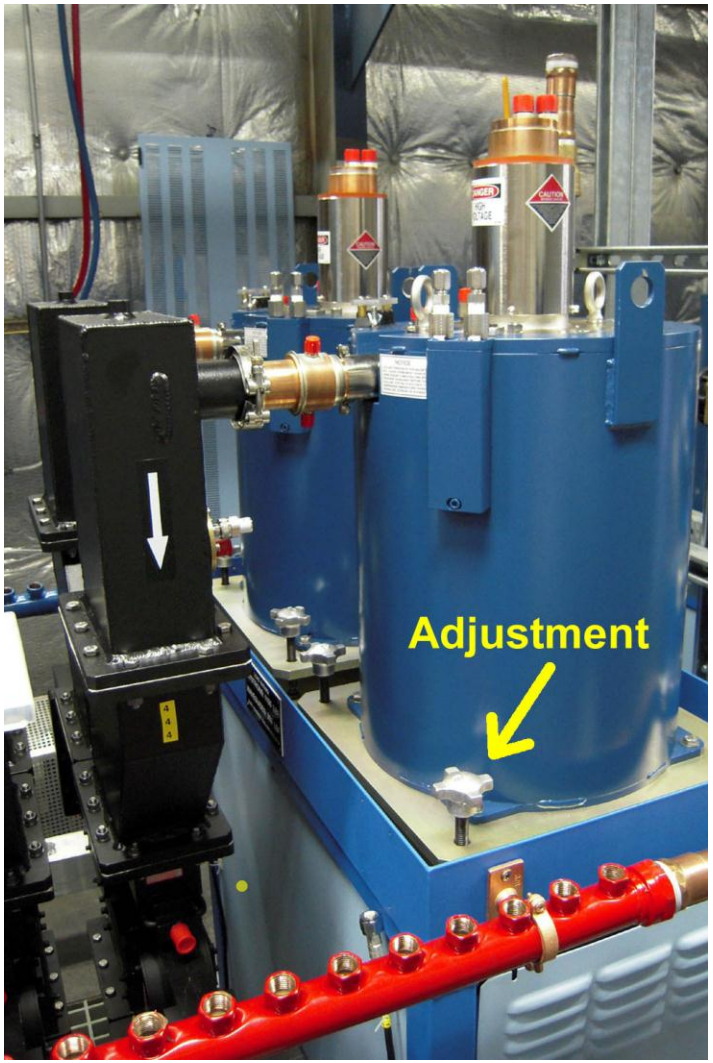
HPA Module (4 per zone)



HPA w/klystron (left), card cage inside (front & rear)

Klystron Installation

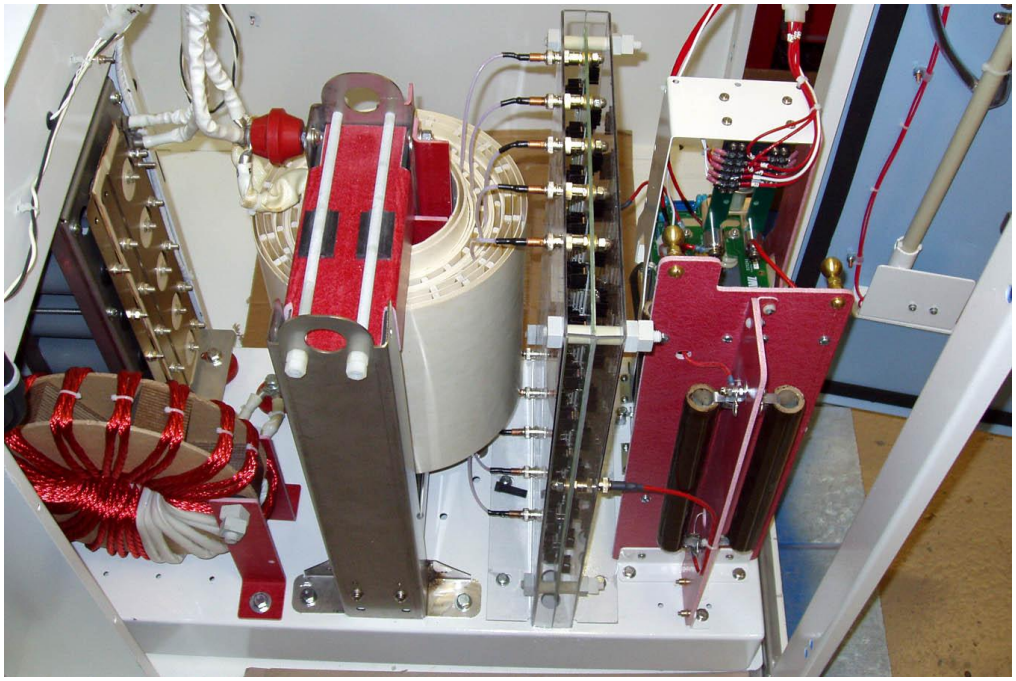
- Gantry crane assembled in quad
- Solenoid is bolted to mounting plate
- Portable lift used to insert klystron into solenoid
- WG transition attached to klystron
- Crane picks up assembly
- Jack screws adjusted for precise waveguide mating
- Replacement installs similar, but transition may be unplugged first
- Klystron only extracted



225KW DC Power Supply (NWL)

- As before, each powers 8 klystrons (considered 1 to 40)
- Resonant mode switcher (15-20 KHz)
- Adjustable to -15kV @ 3.75A
- 4 separate supplies, each feeding 2 klystrons
  - Minimizes klystrons off on failure
  - Currently controlled as a unit (15A total)
- Originally designed for electrostatic precipitators (higher volts/lower amps in oil) 1000+ units in the field
- Designed to withstand load faults
- Lower stored energy than T-R, fast turn off on fault, resistor limited output
- Passes wire test w/o crowbar

HV PS Views



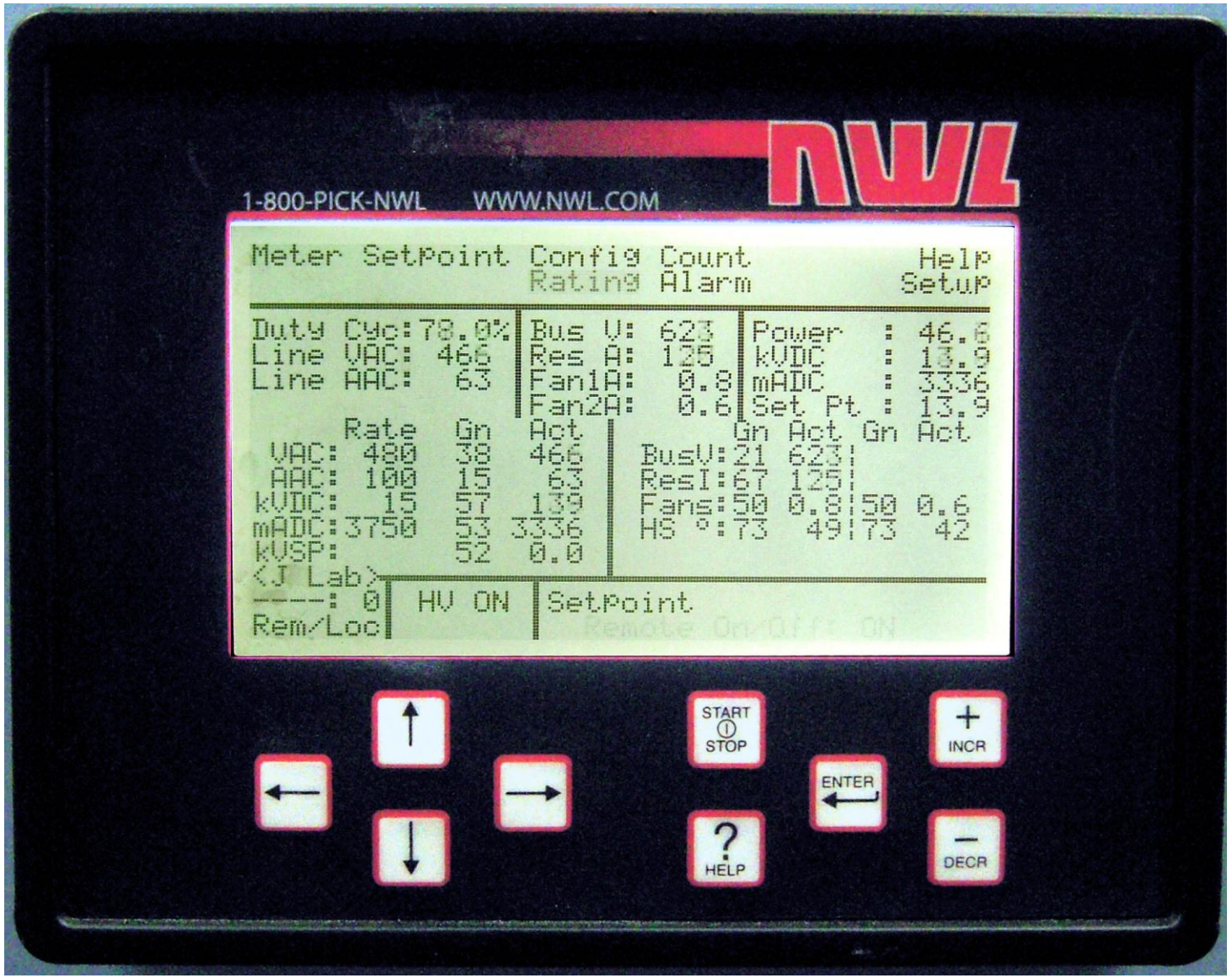
HV Deck (4 per supply, on rollers)

Rear View / Cooling

HV PS Details

- Voltage/current to match klystrons
- 0.1% p-p ripple (as before)
- Soft current limiting
- Arc detection (DC O/L)
- Built-in self test functions, good displays
  - Currents, voltages, temps, duty factor, counters, etc.
- Redundant interlocks, internal/external
- Similar interface as existing systems – discrete
- Local operation possible (used mostly for testing)

NWL Display/Control



Notes

- Not all signals are not reported (I/O limits for DSP board)
  - The standard controller had insufficient inputs
- Fully air-cooled - this may require some ducting based on initial experience (insufficient A/C)
- Water or air cooling permitted (no interest on using water)
  - New requirements for systems pressurized over >15 psi would have to be met
  - Heat sinks could have been water-cooled (about half of heat load)

Waveguide

- 1-5/8” coax to WR650 transition w/mono coupler (KRRP)
- Offset (klystron/WG penetration centers don’t match)
- Isolator
- Reflectometer coupler
- 3-stub tuner
- 16ft waveguide through penetration
- Sweeps, flexes, offsets, misc. straight pieces
- HOM filter or full to reduced height transition
- **Vendors**
  - Ferrite Co. for isolator
  - MCI for standard (except for size red./full transition)
  - CML for HOM / MEGA for red./full transition

WR650 Isolator

- Ferrite Company
- Model LC3-535, (RH / LH)
- Fc: 1497 MHz, 6 MHz BW
- Power: 13 kW CW, full reflection
- Isolation: 21 dB min (spec)
- Field adjusted for close spacing
- Certified for pressure (required)
- Load has additional window
  - Keep water out of waveguide
- *Magnets & match being adjusted to improve performance*

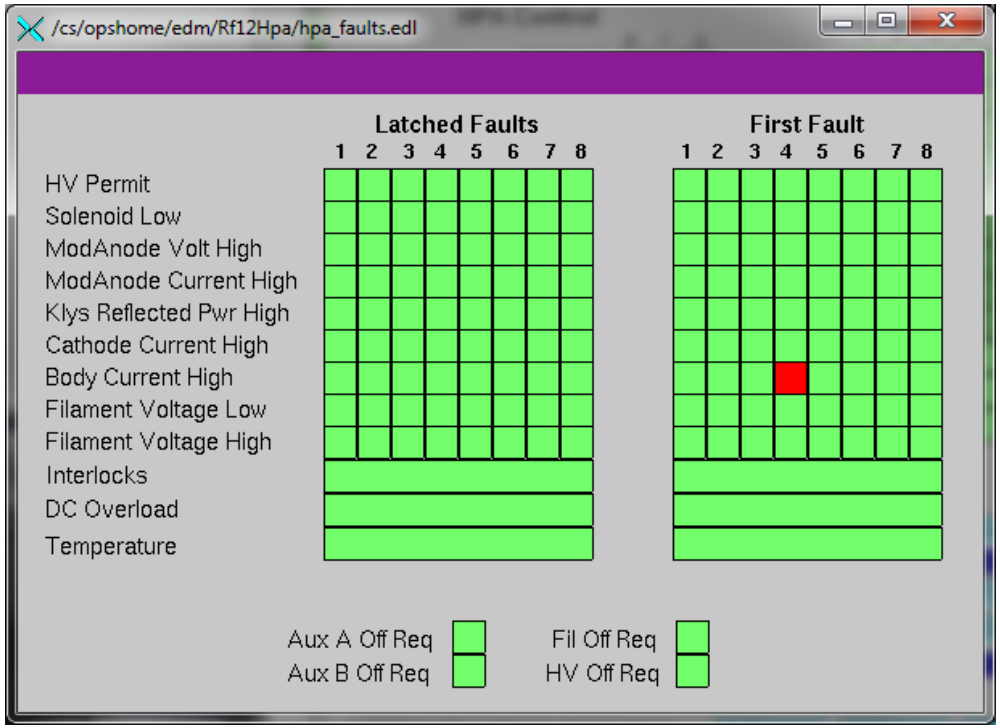
Water

- 1 manifolds/zone, each supplies needs of 4 klystrons/circulators
- One flow meter per manifold)
- Fixed orifices/adapters to set flow
- To reduce flow requirements
  - 2 collectors in series (8 gpm)
  - 2 circulator loads in series (7gpm)
  - Klystron body/window, circulator body, solenoid all parallel paths
  - ~110 gpm per zone (95F/35C)

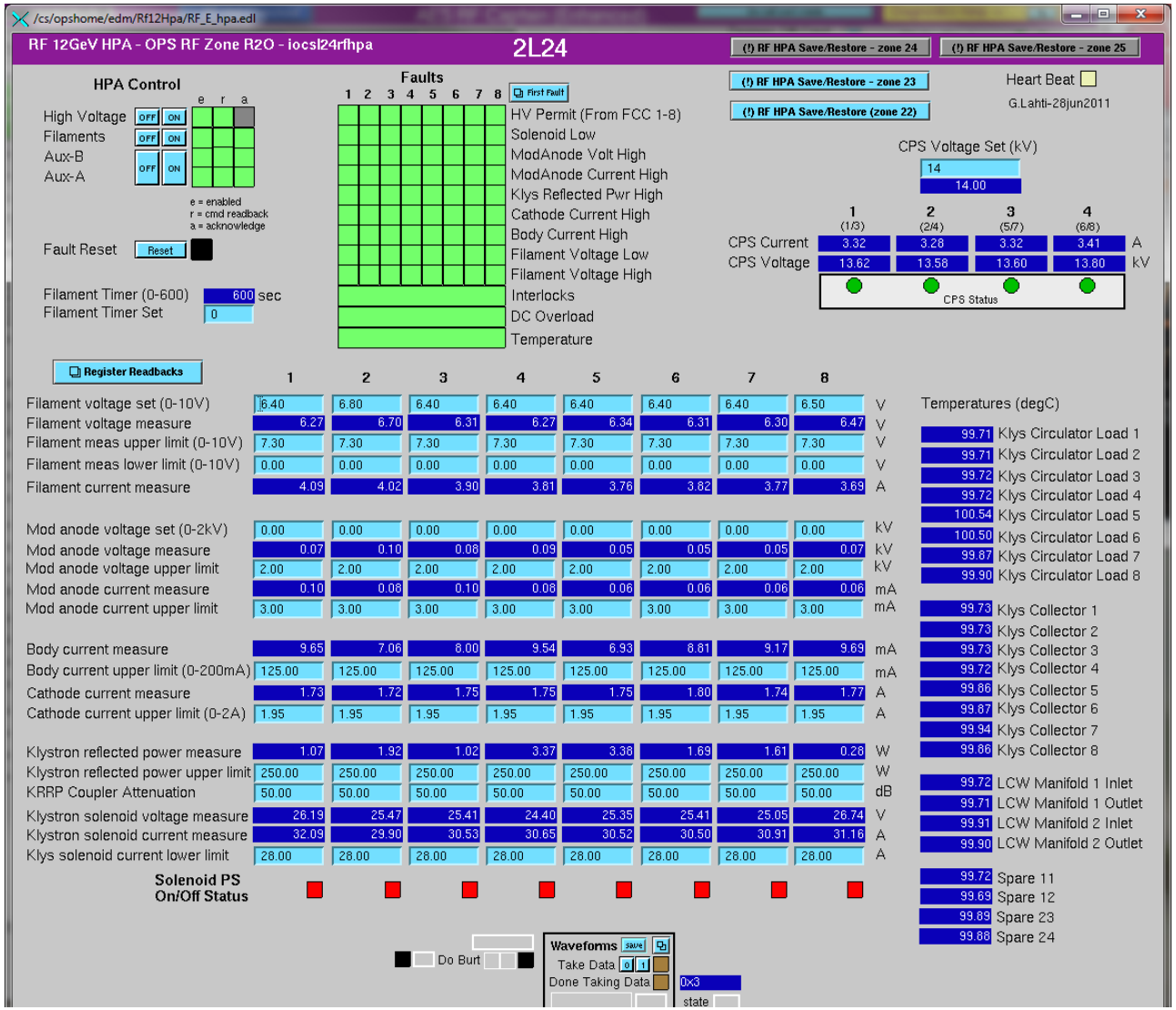
HPA Controller

- FPGA with PC-104 to EPICS (replaces CAMAC, LLRF)
- Monitors all klystron and HV signals
- First fault detection
- Ring buffer for fast signal capture (1 ms rate)
  - Normal archiver data sampled at 1 second rate
- Designed with lots of I/O - not all used
  - 128 A/D channels (klystron & other signals)
  - 32 D/A channels (filament, mod anode, HV set)
  - 48 relay out (various power, HV, solenoid control)
  - 32 TTL in (digital cathode current, heater voltage)
  - 16 fiber (handshake with LLRF)
  - 48 isolated inputs for status read backs

Fault Capture



EPICS HPA Screen

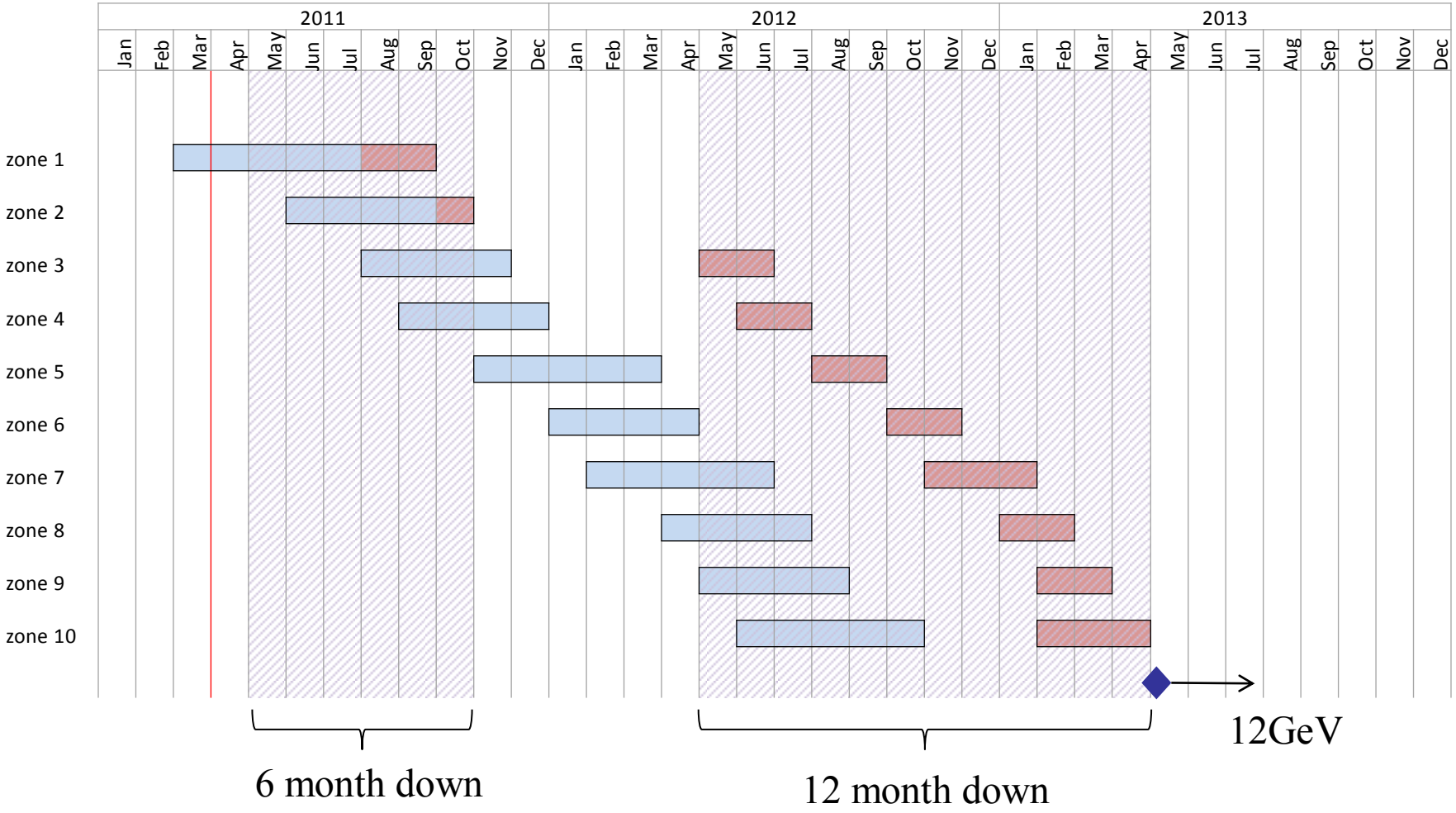


- Controls
- Status
- Set points
  - Fil, MA, HV
- Trip levels
  - All
- First fault
- Ring buffers
- Temperatures
- Diagnostics

Current Status (April 2012…)

- Klystrons: 66 of 84 received, 32 installed
- HV Power Supplies: 10 of 10 received & installed
- WG Isolators: 84 received, 40 installed
- Waveguide: all in house. 2 zones waveguide fully installed. Remainder in progress.
- HOM filter: first article at vendor test (late)
- HPA cabinets: all installed, half are populated
- Solenoid power supplies: all in house
  - First contract cancelled. Cheap but never arrived.
- Filament & Mod anode PSU's tested; half installed
- Interface boards: half installed
- Zones commissioned: 2 (+2 additional summer 2012)

Schedule (not updated)



Performance So Far

- Two zones operational and integrated into accelerator operations (since fall 2011)
- Achieved >100 MV/m (target
- Recovery from trips automated for faster recovery
- Technical issues
  - Circulator isolation on some units (being worked)
  - Full 1power in all positions (being worked)
  - HVPS exhaust heat may need to be addressed

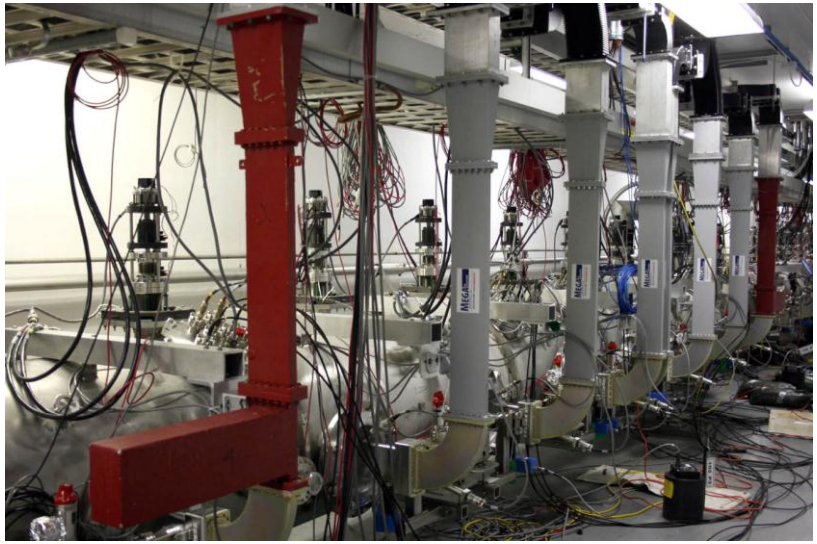
JLab RF / Power Upgrade

Questions ?

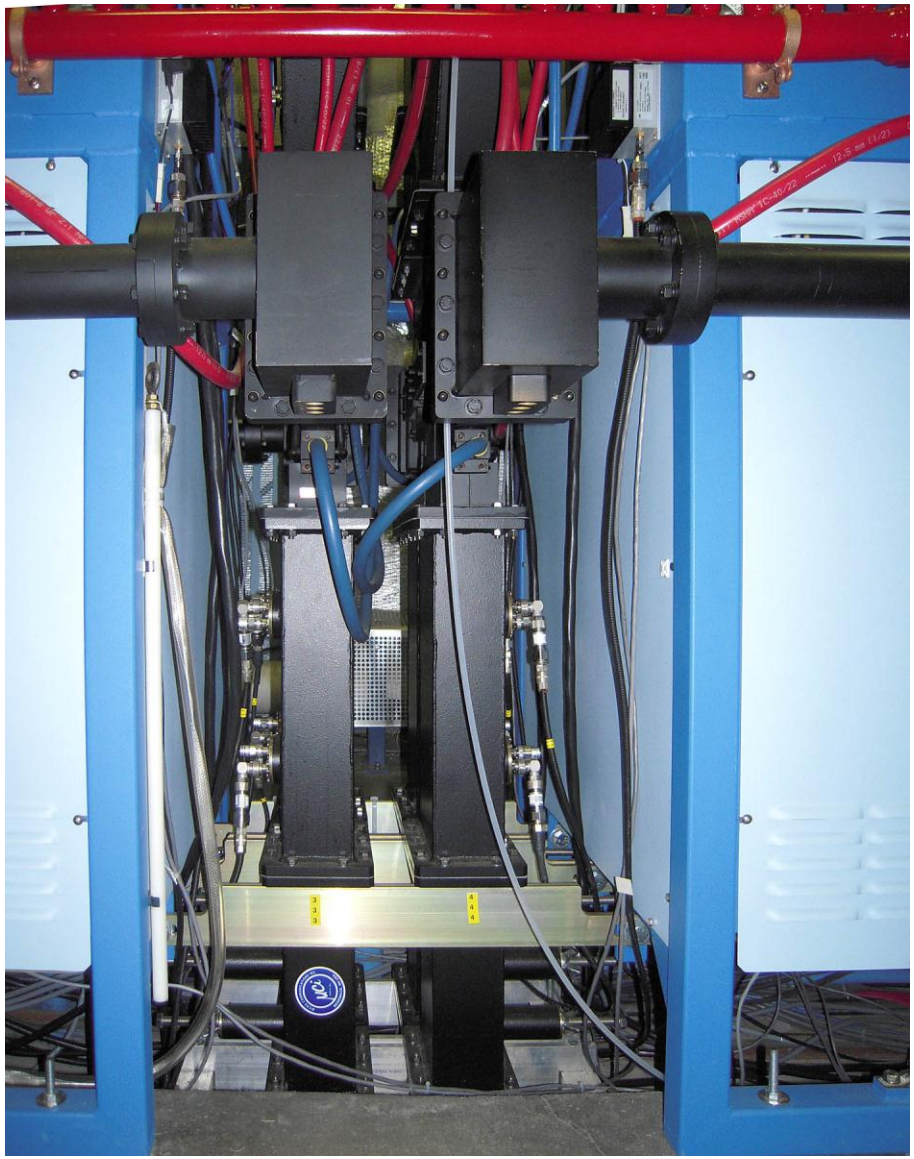
Major Procurements (totals)

• Klystrons:	$3.5M (84 w/sol)	L-3
• CPS (HV):	$1.2M (10 units)	NWL
• Isolators:	$605k (84 units)	Ferrite Co.
• Waveguide:	$500k (various)	MCI/Mega
• HOM filters	$187k (26)	CML
• Solenoid PS	$115k (84 units)	Sorensen

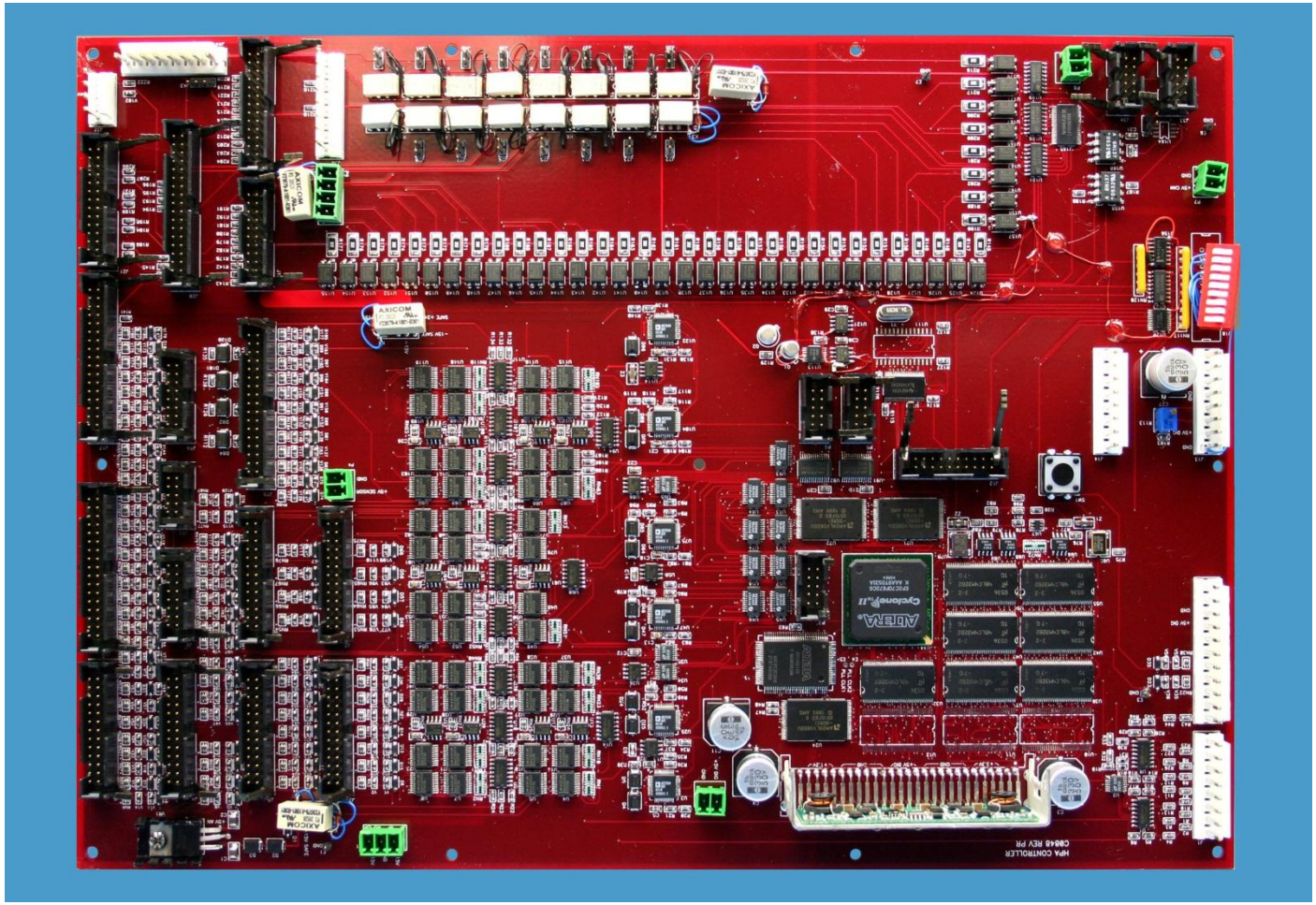
Waveguide Installation



Waveguide

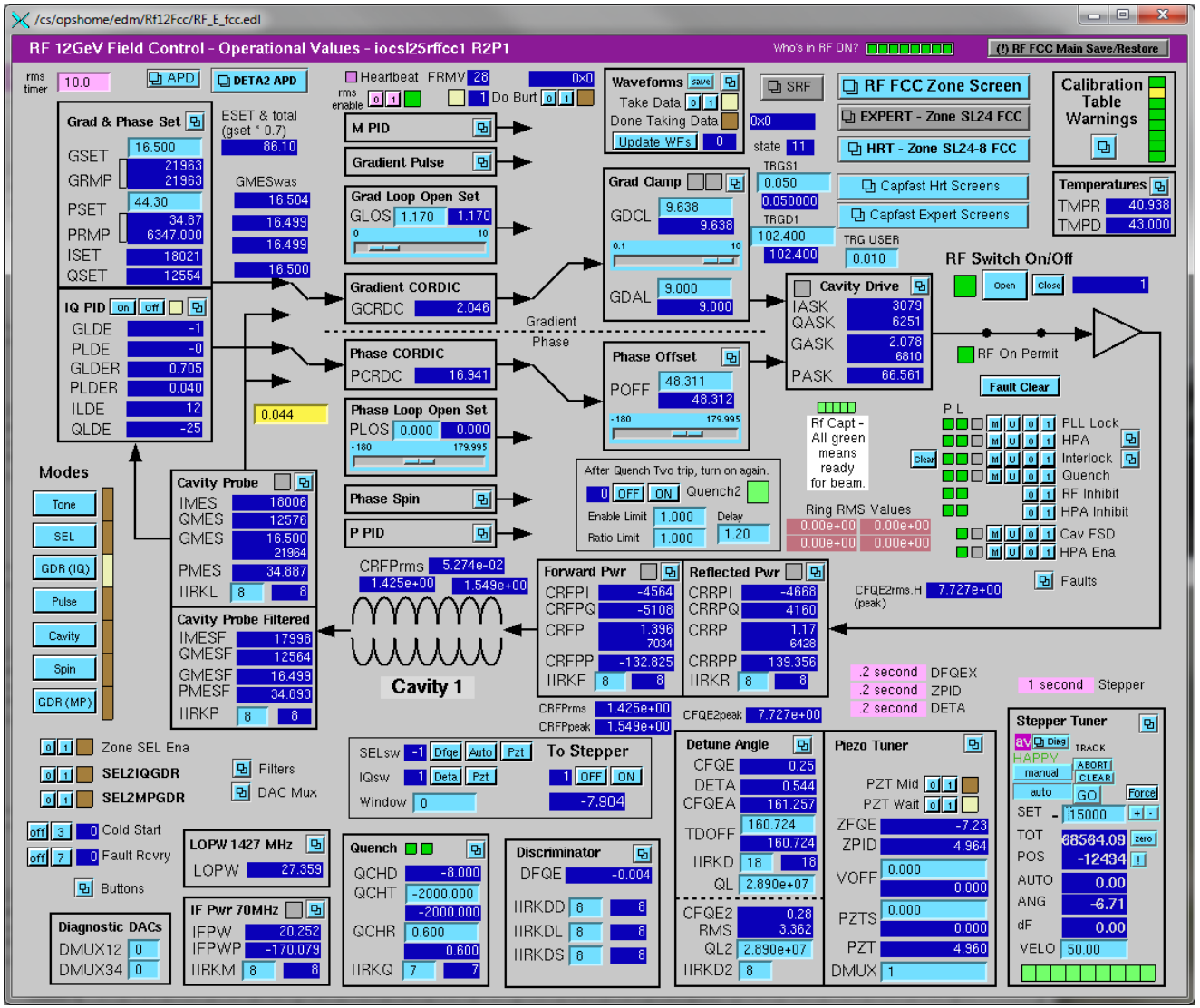


FPGA Board



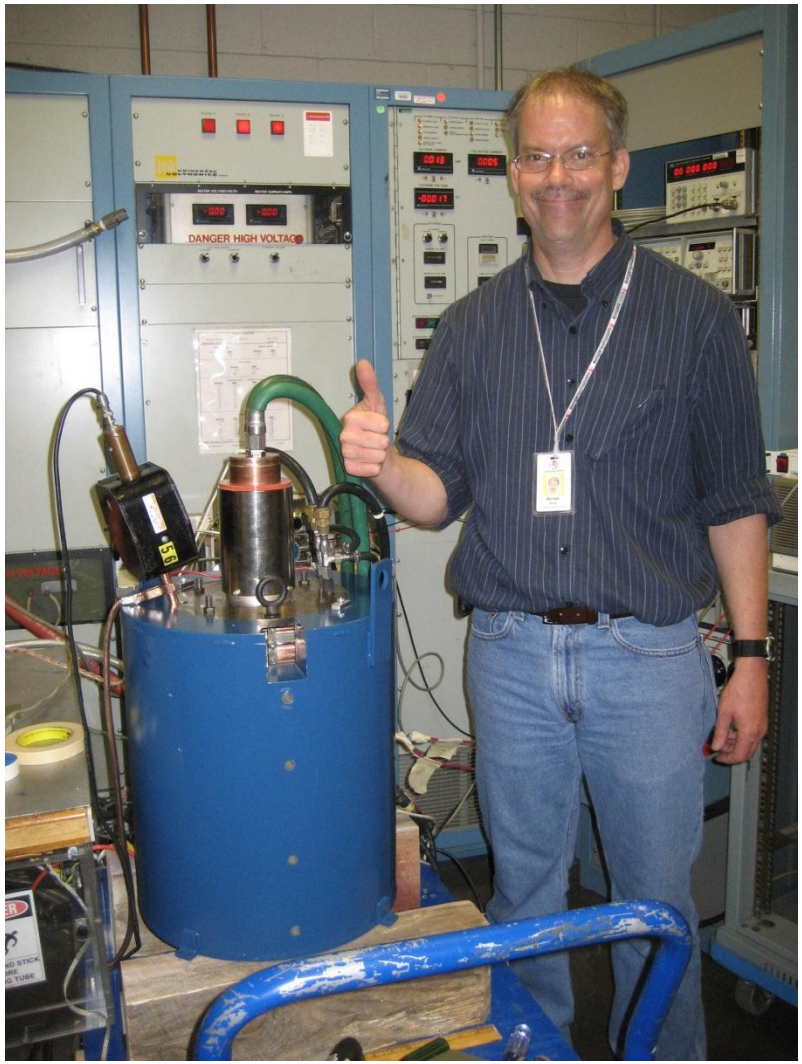
PC-104 board not shown

EPICS: LLRF Screen (1 channel)



Test Stands

JLab



1st Article at L-3