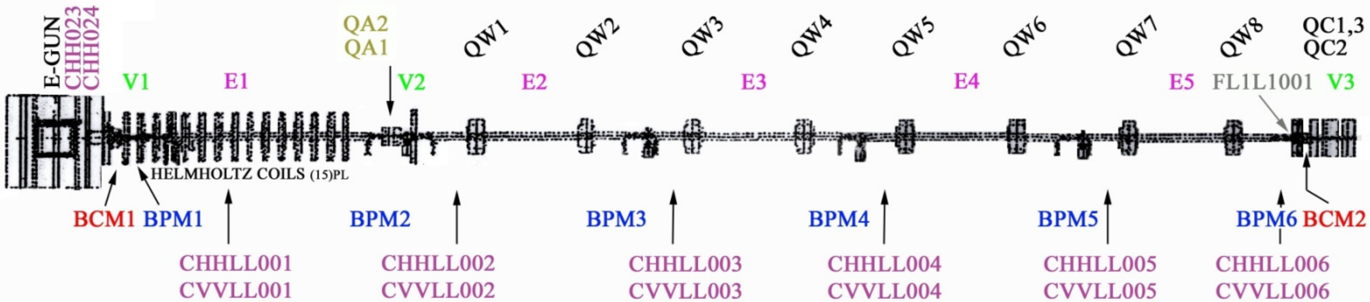
DAFNE LINAC
Description, installation and operational status

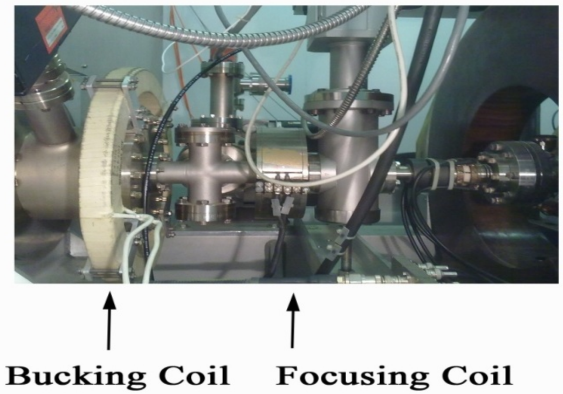
B. Buonomo for the DAFNE LINAC group

OUTLINE

LINAC Layout
Modulator
RF system
Klystron Operation
Pulse compression
Diagnostics and Timing
Electron GUN
Control and operations

LINAC high current beam line



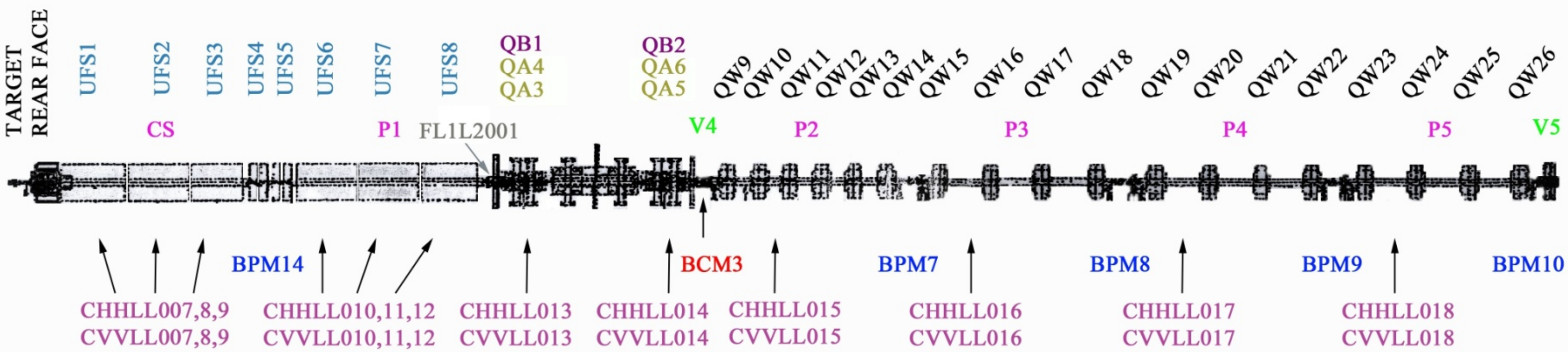


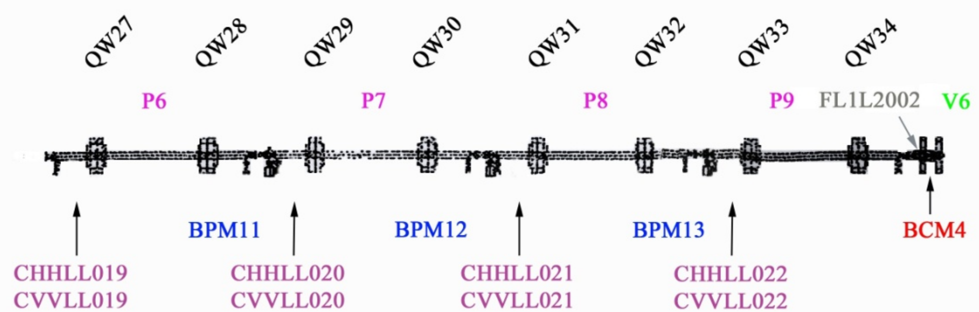
The magnetic system starts with bucking coil at the exit of the gun to reduce the field at cathode to near zero

14 Helmoltz coils : uniform field around prebuncher, buncher and first acc. structure

Quadrupole triplet is used before the positron converter in order to focus the beam down to 1 mm

LINAC high energy beam line



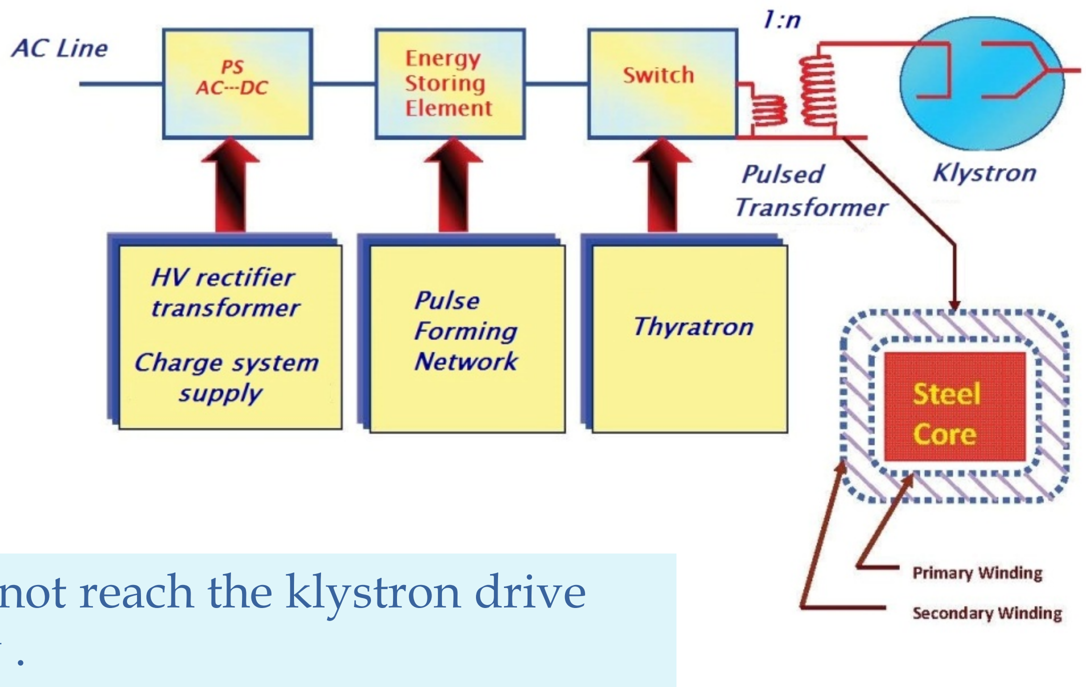


tungsten-rhenium (2 radiation lengths) target is used for the pair production

flux concentrator jointly with DC solenoid magnets generate the 5 T peak magnetic field necessary for the positron capture.

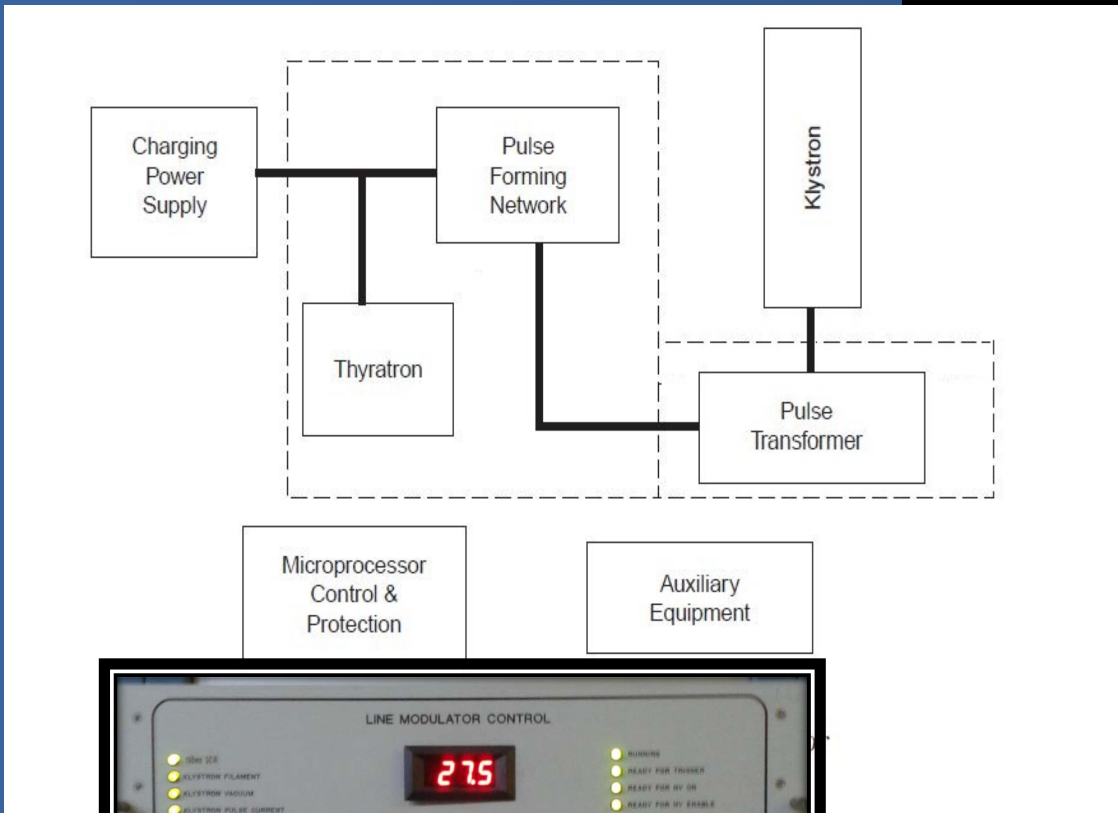
Line type Modulators layout

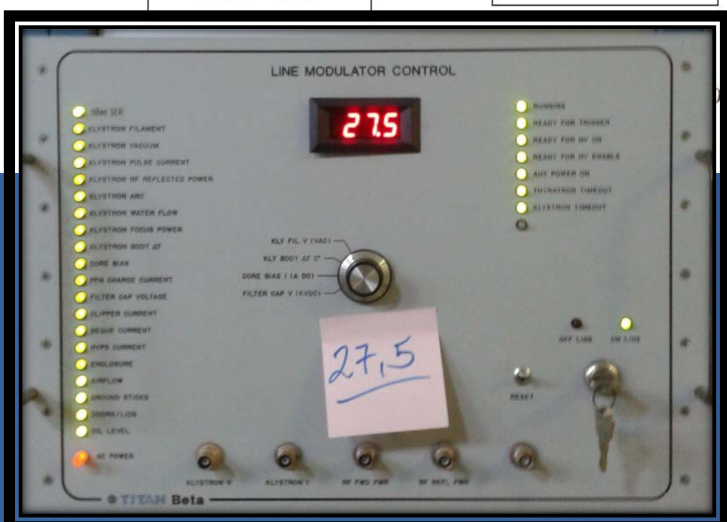
The modulator is the DC power supply which drives the klystron beam.

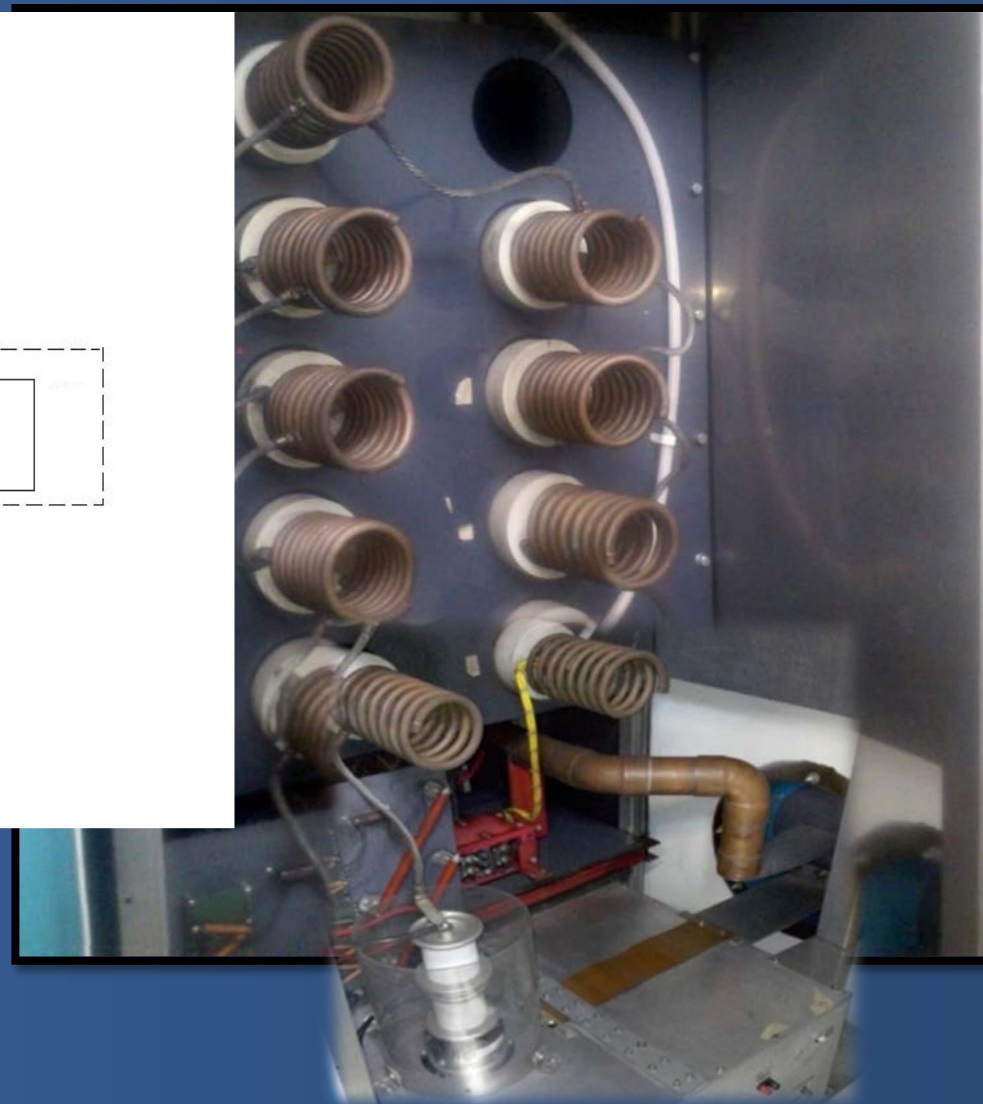


Typically it cannot reach the klystron drive voltage directly .
A transformer is needed to reach the desired voltage.

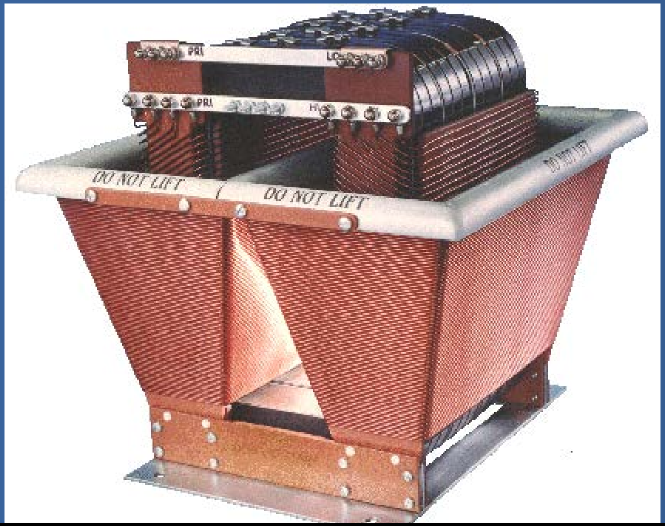
Line type Modulators layout

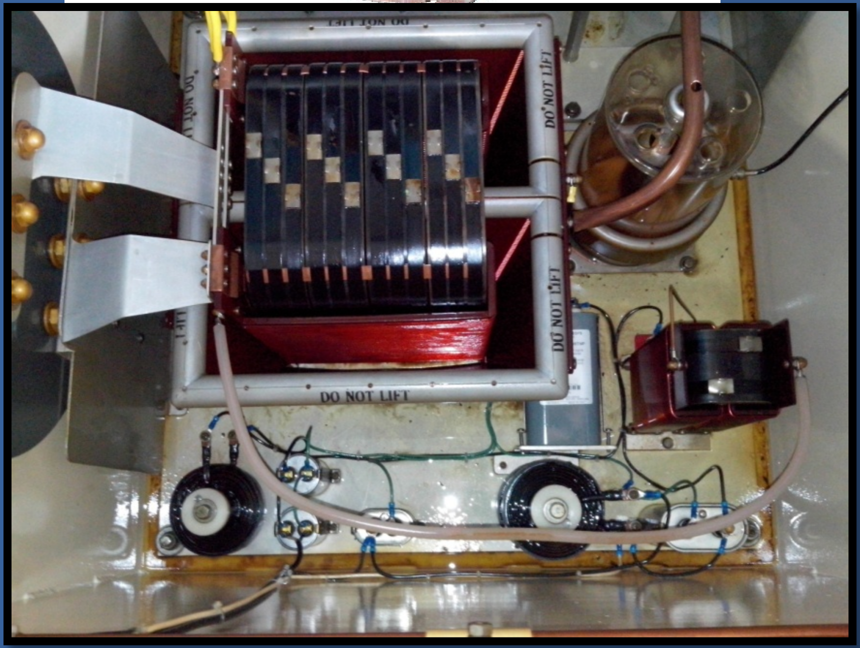


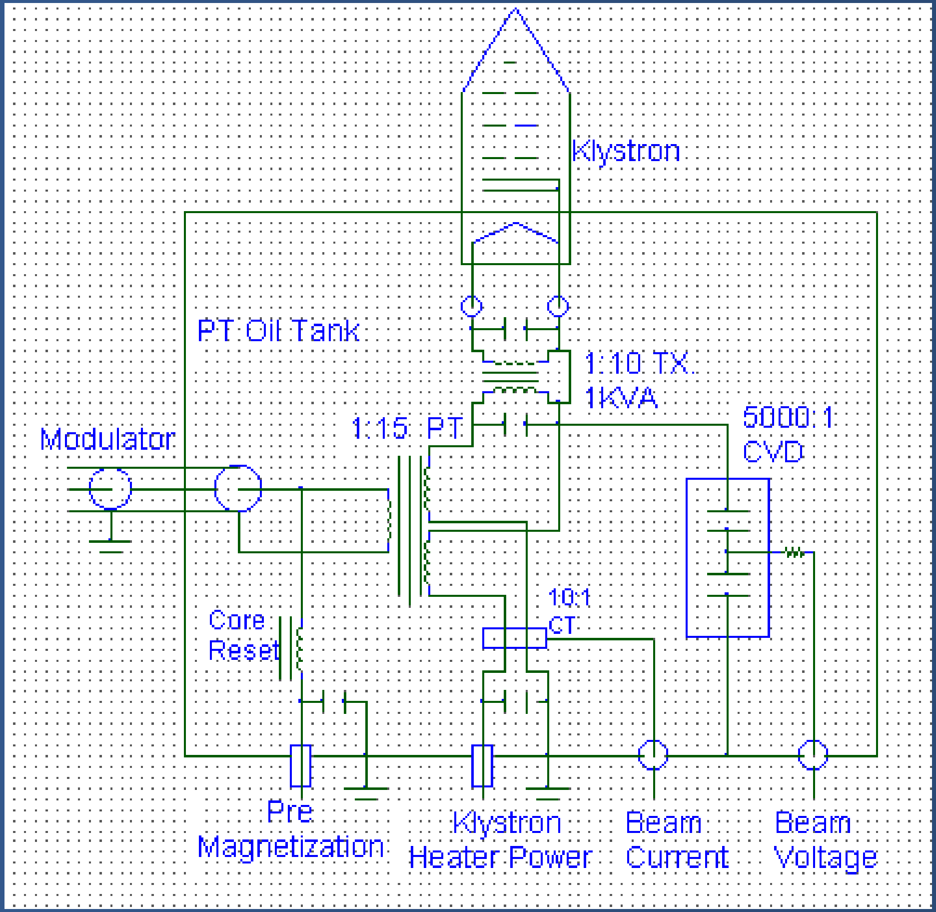




Oil Tank circuit



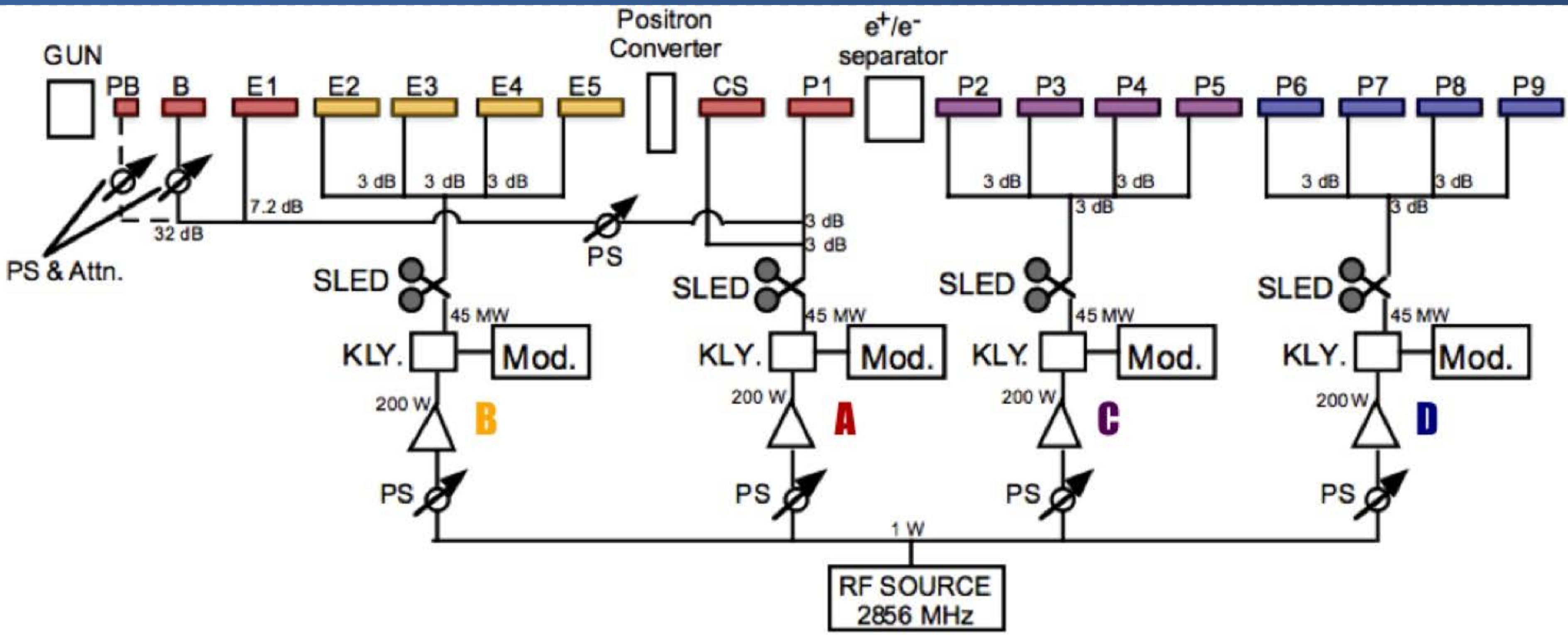




Modulators parameters

Klystron	TH2128C
PFN voltage pulse width(μs)	4,5
PFN Cell capacitance (nF)	68
PFN Cell inductance(μH)	2
Pulse transformer ratio	1:12
Thyratron peak current (A)	4300
Thyratron Peak voltage (kV)	50
Beam voltage flat top(μs)	4.5
Pulse rise time （10%-90%） (μs)	0.4
Pulse fall time （10%-90%） (μs)	0.5
Pulse voltage variation (%)	±0.1
Pulse repetition rate (Hz)	50
Modulator charging time (ms)	10

LINAC RF layout



The positron buncher section is a standard SLAC $2\pi/3$ structure, which can operate as a standard section with higher than normal gradient (60 MW, 26 MeV/m)

LINAC RF components

RF Components:

Driver amplifier to power klystron

Klystron is used to generate high peak power (A small accelerator)

Need to transport power to the accelerating structure

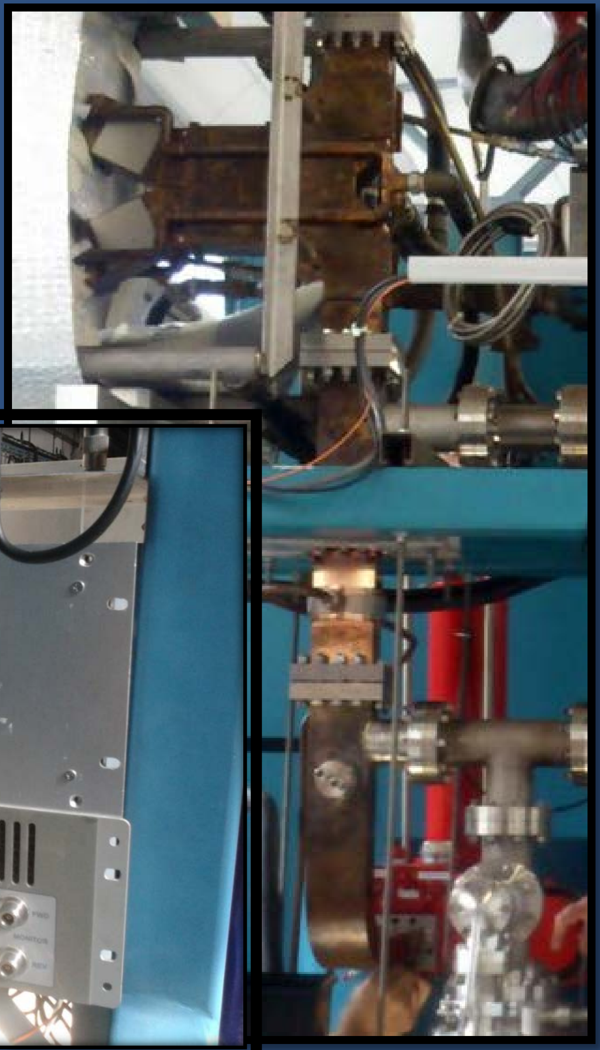
Waveguide is used (under vacuum) to propagate and guide electromagnetic fields

Windows (dielectric material, low loss ceramic) are used to isolate sections of the waveguide

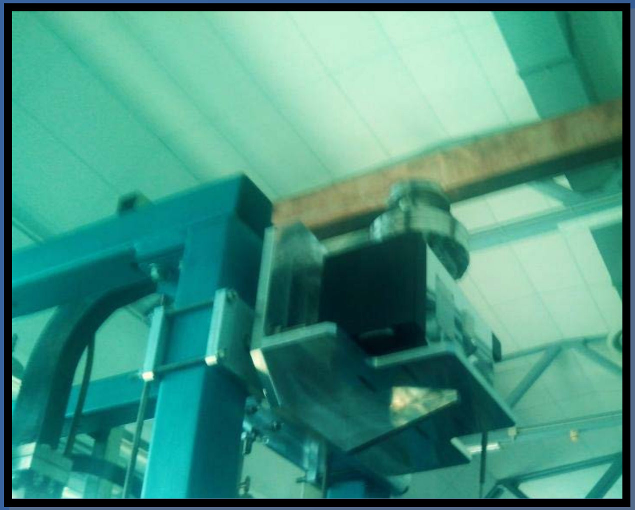
Termination loads (water loads) are used to provide proper rf match and to absorb wasted power

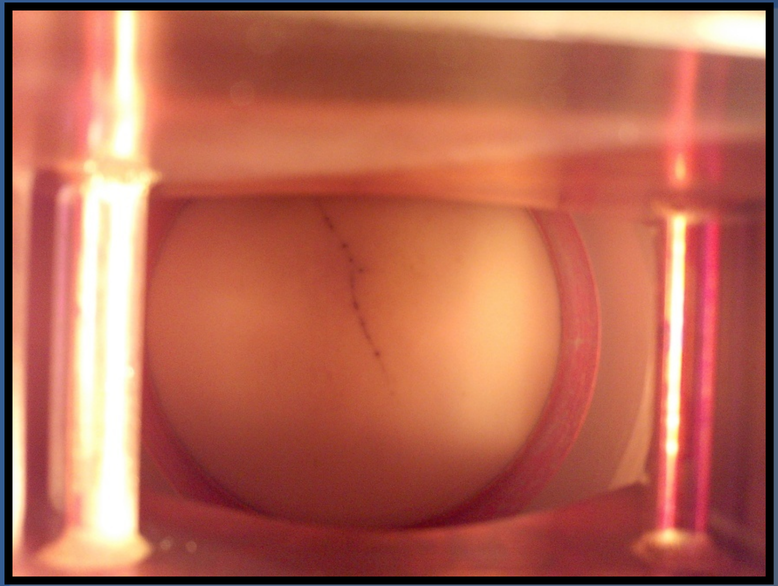
Power splitters are used to divide power in different branches of the waveguide run

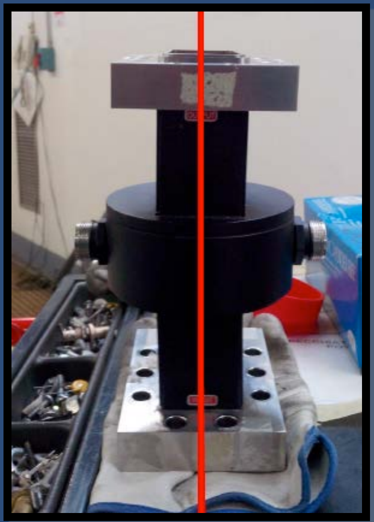
LINAC RF components



LINAC RF components





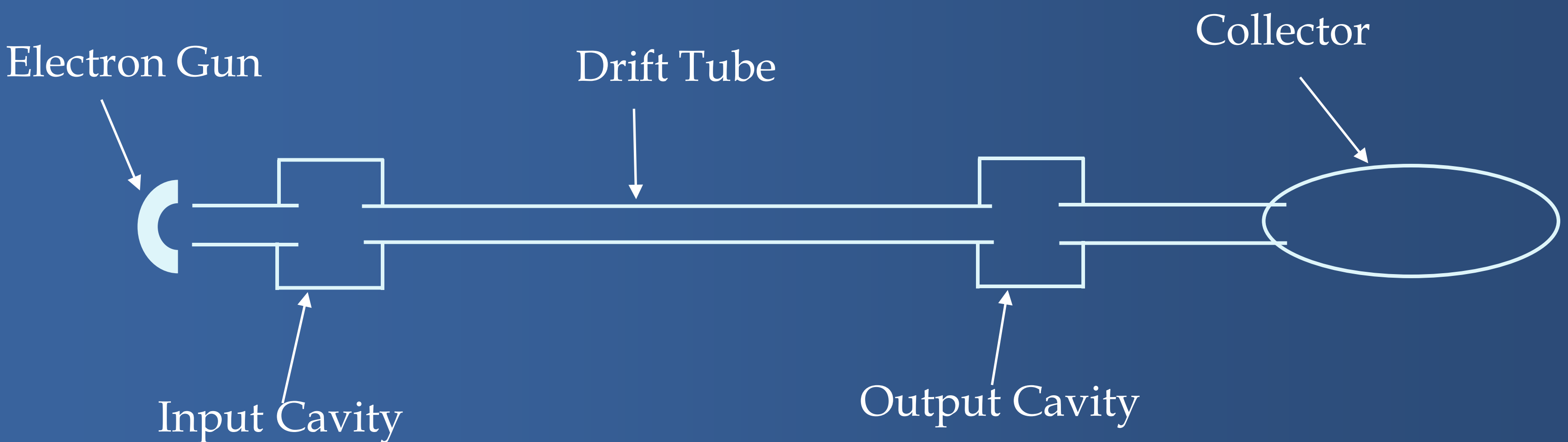


Klystrons

Klystrons have been the principal source of high-power (>1 MW) RF since the beginning of time, and no alternative technology appears poised to replace them.

What are klystrons?

A klystron is a narrow-band vacuum-tube amplifier at microwave frequencies (an electron-beam device).



How the Klystron works

- DC Beam at high voltage (<500 kV, < 500 A) is emitted from the gun
- A low-power signal at the design frequency excites the input cavity
- Particles are accelerated or decelerated in the input cavity, depending on phase/arrival time
- Velocity modulation becomes time modulation in the long drift tube (beam is bunched at drive frequency)
- Bunched beam excites output cavity at design frequency (beam loading)
- Spent beam is stopped in the collector.

Klystron data sheet

PARAMETER	Unit	TH2128C	5045
Center Frequency	MHz	2856	2856
Peak output power	MW	45	65
Peak average power	KW	10	90
RF pulse width	μs	4.5	3.5
Peak beam voltage	kV	320	350
Peak beam current	A	360	414
Microperveance	μA/V3/2	2.0	2.0
Heater voltage	V	20~30	15
Heater current	A	20~28	35
Focusing currents	A	40	15
Peak driver power	W	200	350
Gain	dB	54	53
Efficiency	%	43	45
Pulse repetition rate	Hz	50	120

Pulse compression

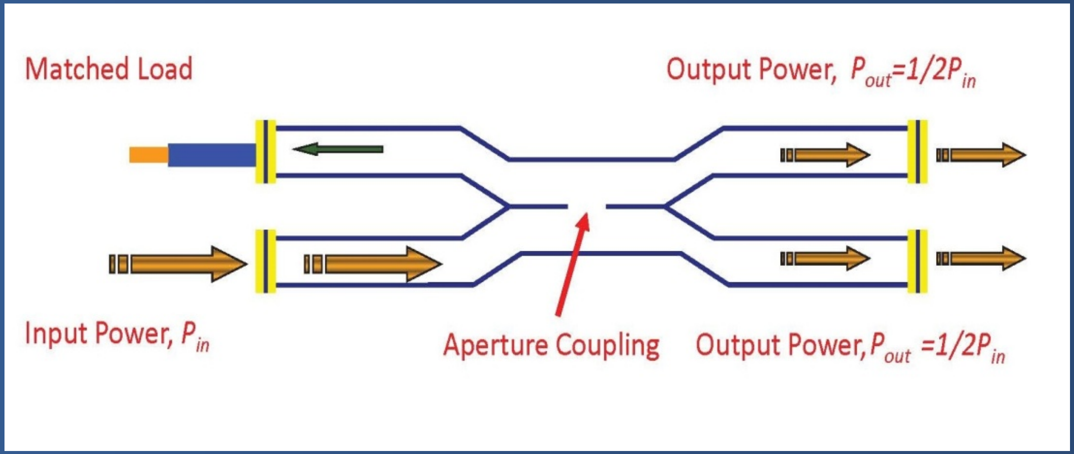
Room-temperature accelerator structures require a short pulse of high RF power to reach their desired gradients.

Klystrons run efficiently when they produce a long pulse of relatively low power (minimize inefficiency from modulator rise/fall time etc).

Matching these different time structures is done by pulse compression.

Pulse compression in turn relies on the magic of the 3-db directional coupler to succeed.

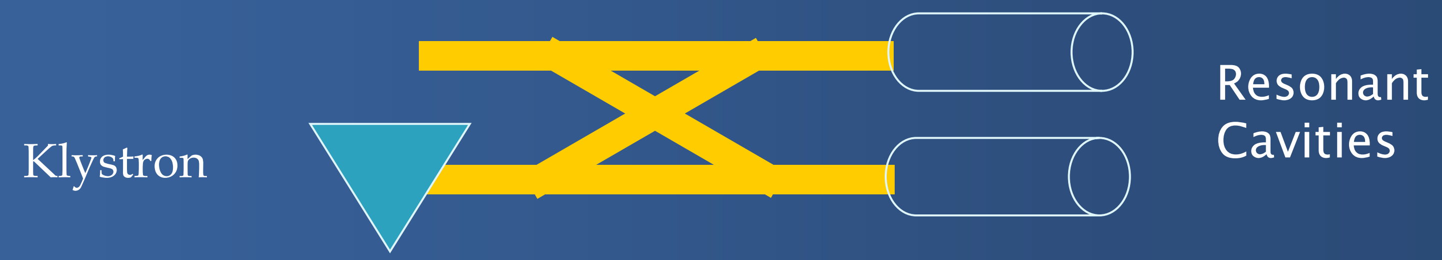
The 3-db coupler is a passive device with 4 input/output ports passing thru a central nexus:



The key feature of the coupler is that the diagonal pathways are longer by 90° than the straight pathways.

What does that do for us?

SLED pulse compression



Power from port 1 will be split and flow equally to ports 2 and 3, but with a phase shift.

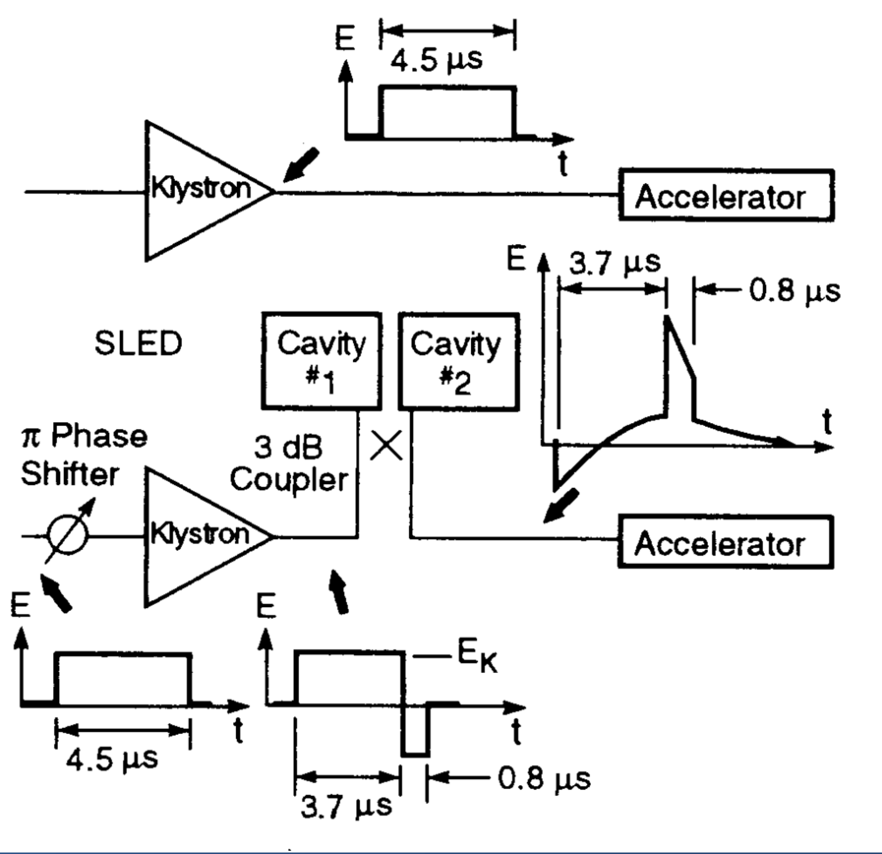
If equal power is introduced at ports 1 and 4, but with a 90° phase shift between them, it will flow entirely to either port 2 or port 3.

If power is introduced at port 1, and perfect reflectors are placed at the end of lines 2 and 3, the reflected power will recombine constructively at port 4 (if the reflectors are placed the same distance from the center of the coupler.

SLED pulse compression

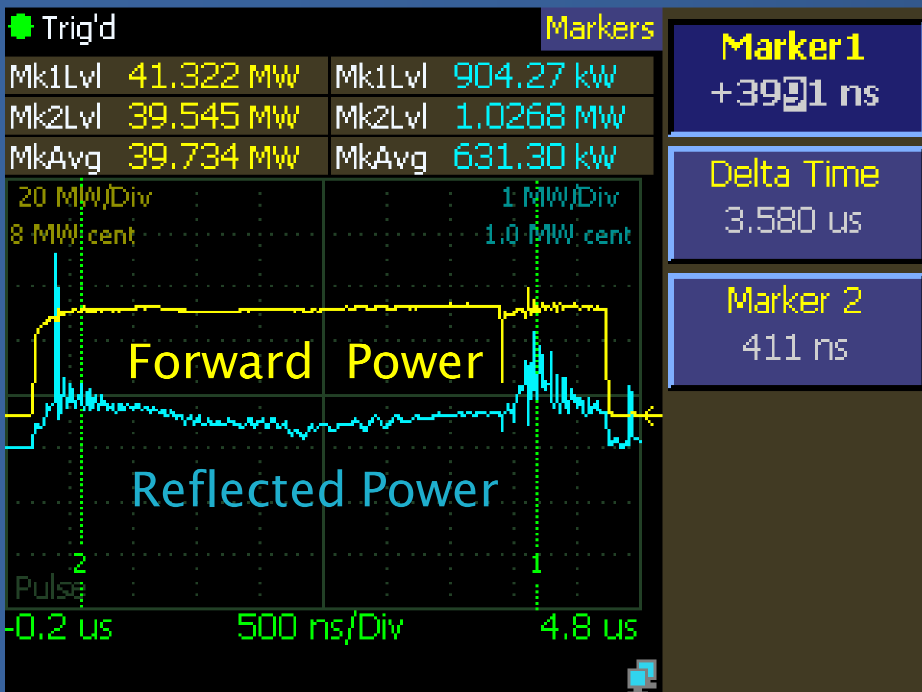
Power from the klystron goes to 2 resonant cavities for storage because the cavity coupler reflects almost all power, there's a surge of reflected energy which goes to the accelerator.

As the SLED system fills, its emitted power destructively interferes with the klystron reflected power.
At some point in the klystron pulse, the phase of the klystron is reversed so that the stored energy interferes constructively…

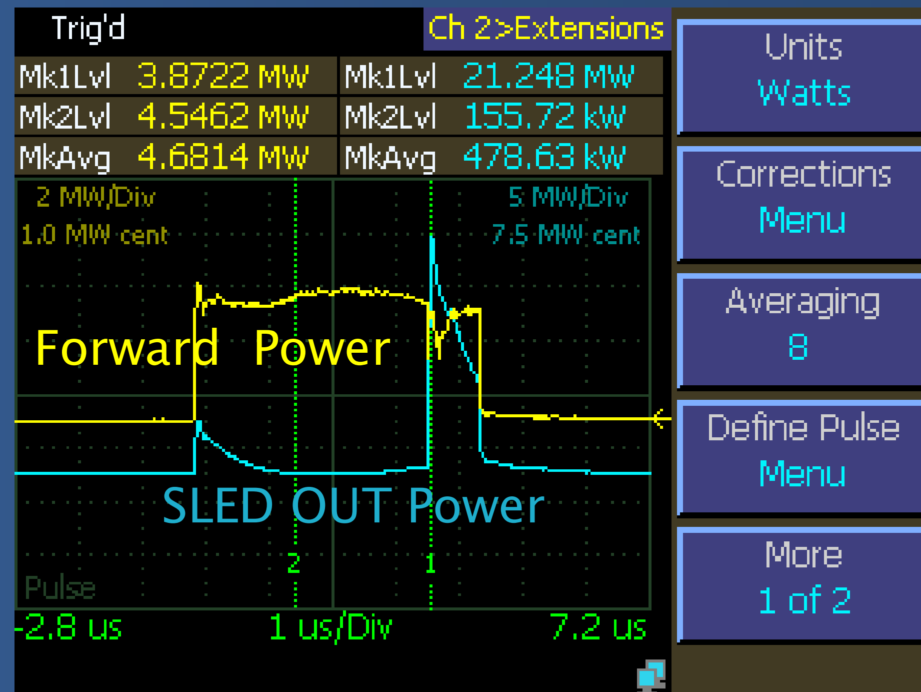


SLED pulse compression

Power Meter Measurements



KLYSTRON D

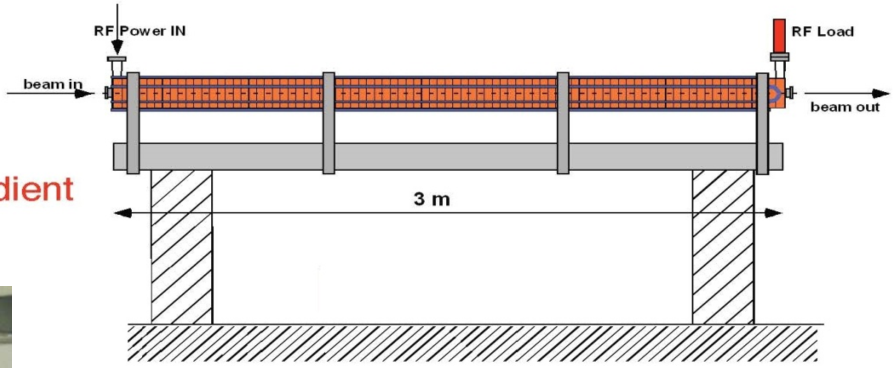


KLYSTRON A

The SLAC structure

Main parameters of the DAPHNE-Linac Accelerating Structures

- SLAC-type
- Frequency 2856 MHz
- Disk-loaded – 86 RF cells
- phase shift per cell $2\pi/3$
- Traveling Wave – Constant Gradient
- 3 mt length - copper guide



The SLAC structure

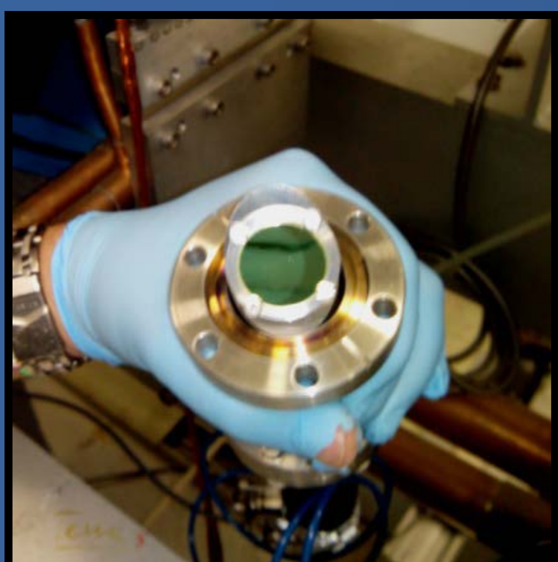
Parameter	Symbol	Unit	Value
Frequency	$\omega/2\pi$	MHz	2856
Length	L	m	3.048
Cell Radius	b	cm	4.17--4.09
Iris Radius	a	cm	1.31--0.96
Cell Length	d	cm	3.50
Phase Advance per Cell	ψ	-	$2\pi/3$
Disc Thickness	h	cm	0.584
Quality Factor	Q	-	13,000
Shunt Impedance per Meter	r_1	MΩ/m	52--60
Filling Time	t_f	nsec	830
Group Velocity	v_{gr}	% c	2.0--0.65
Attenuation	τ	"nepers"	0.57
Typical Unloaded Gradient	G_0	MV/m	21
Typical Input Power	P_0	MW	45

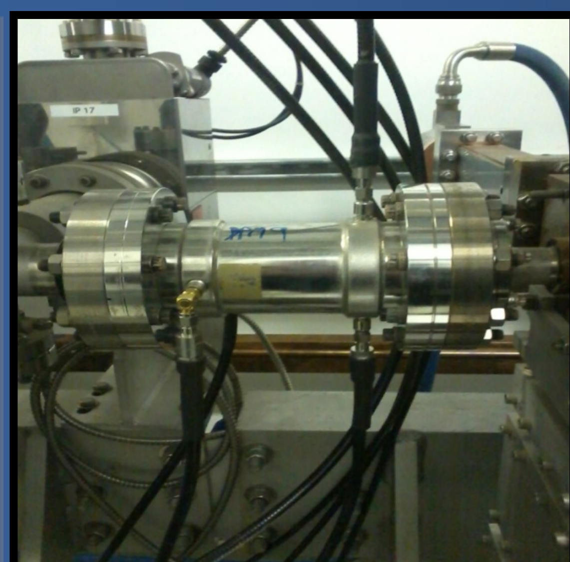
Diagnostics and Controls

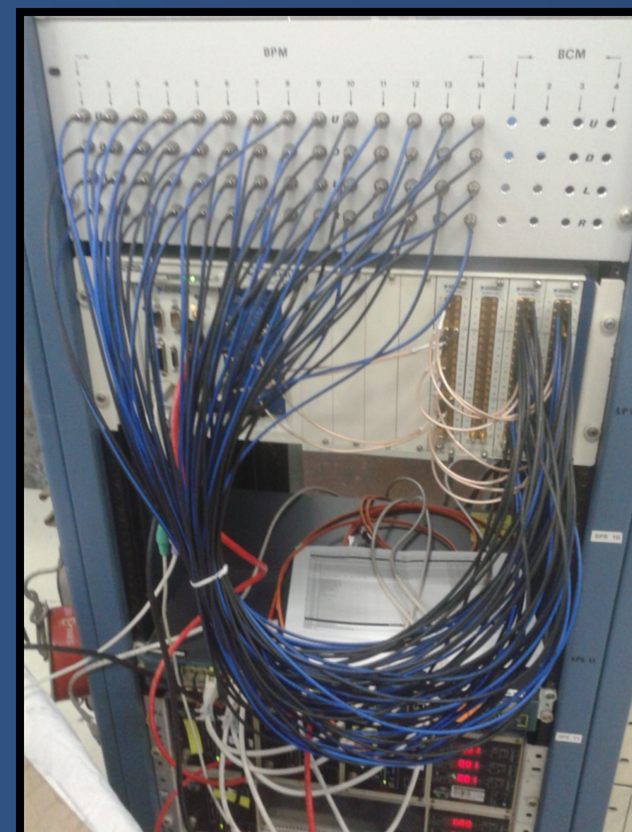
- System flags
- Beam current monitor
- LINAC Software control system
- Hardware and software integration beam position monitor

- New Nd-YAG (Ce) Flag for beam identification
- BPM improvement

- New LINAC SubSystem VLAN
- Fiber connection to extend instrumentation reliability
- New server to improve stability and development







Timing

- DAFNE reference $Ø_4$ for the injection systems
- Conditioned $Ø_4$ -> DELAYED LINAC SYS SIGNAL (moves all the LINAC stuff together to match ACCUMULATOR phase)
  - DELAYED GUN SIGNAL -> LINAC SYS REFERENCE (once optimized, not moved for months)
  - BTF REFERENCE -> USER needs DELAYED LINAC SYS

$Ø_4$ -> T (ref. time on Stanford 3001)

LINAC Sys-> B (T + Delay on stanford 3001)

LINAC GUN-> A (B + Delay on stanford 3001)

HODOSCOPE -> C (A + Delay on stanford 3001)

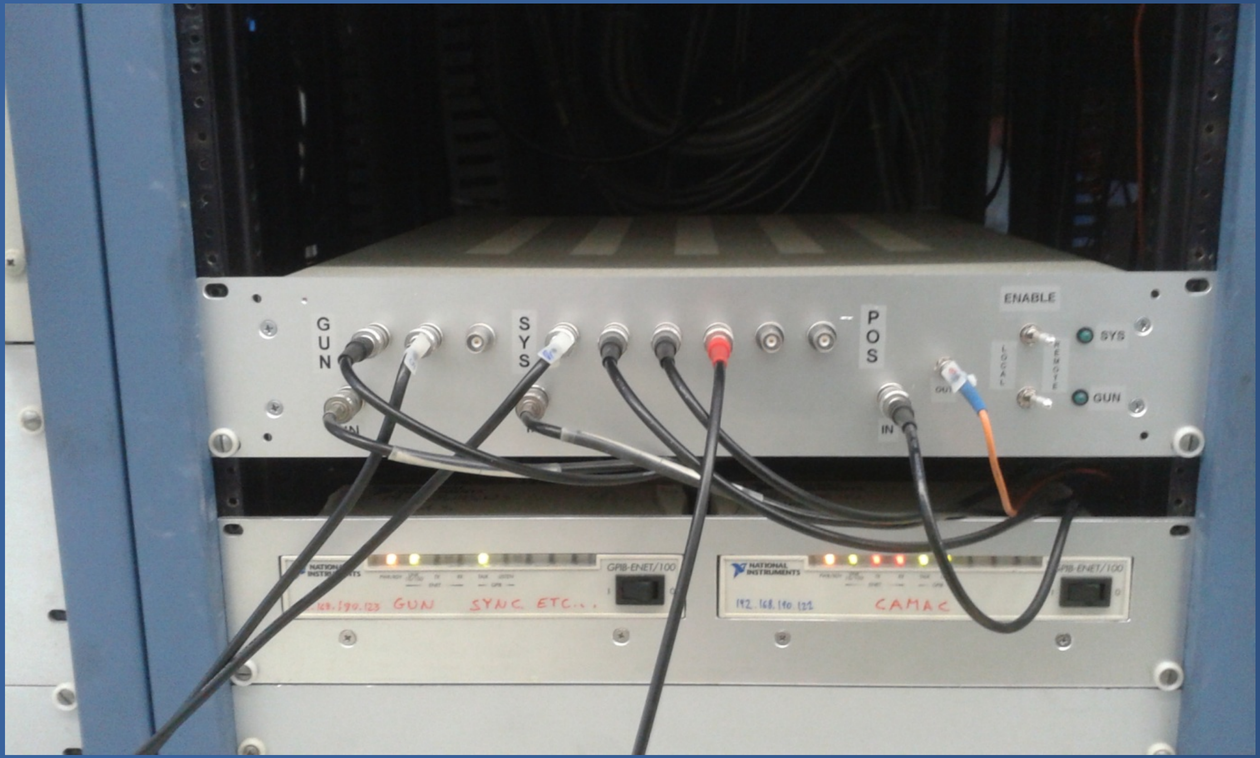
HODOSCOPE -> D (C + Delay on stanford 3001)

DDG3001 on Delays.vi

Timing

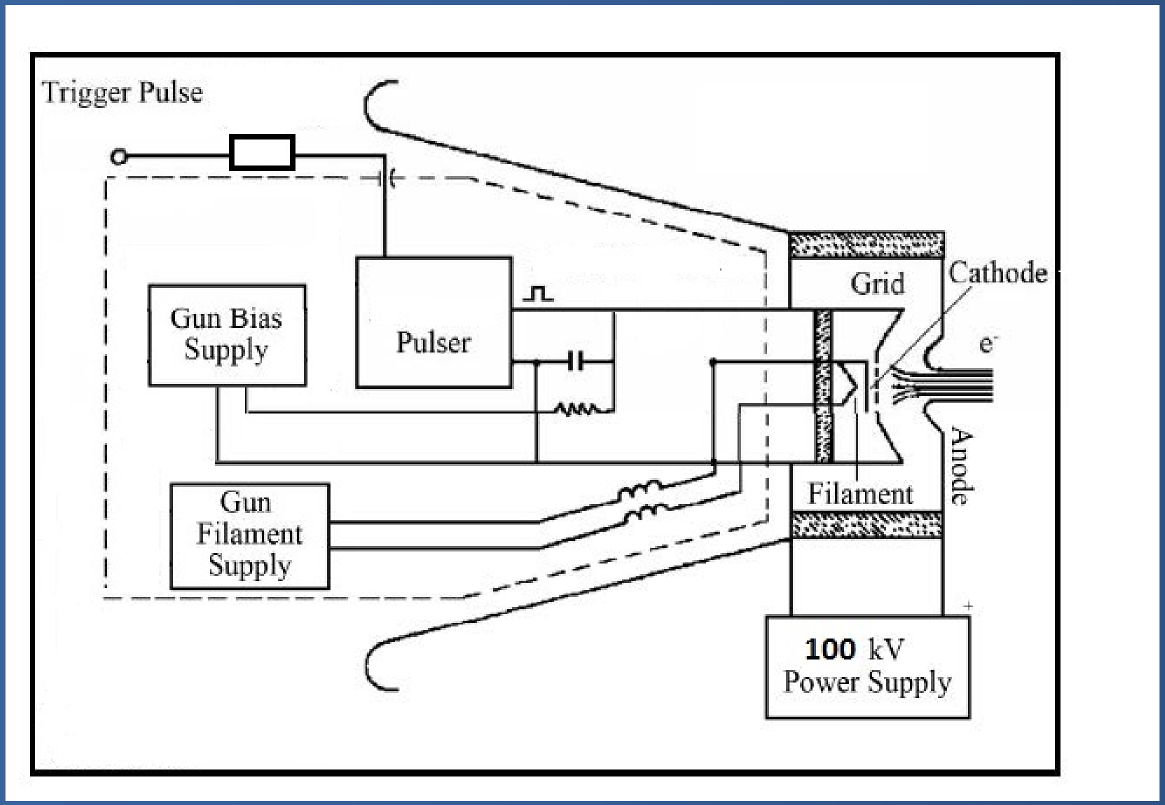
LINAC Sys-> REF. TIME: Mod A, B, C, D &
Amp RF A, B, C, D & PSK A, B, C, D
RF source
Positron Modulator

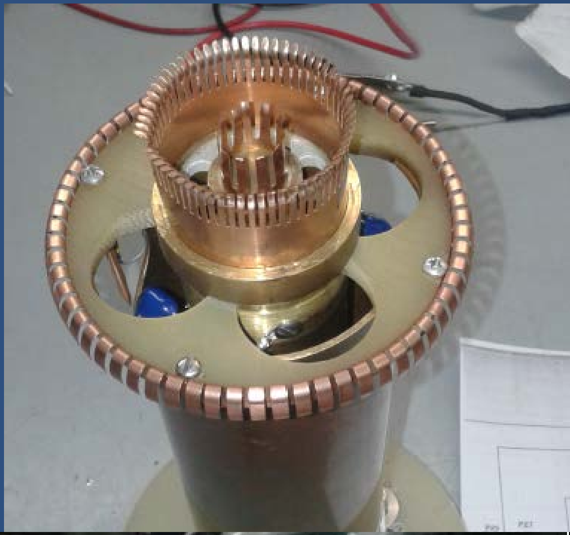
LINAC GUN-> REF. TIME: GUN Pulser



Electron gun electronics

Electron gun electronics





The E-GUN injector floating deck is controlled by fiber-optical coupled link (ETH fiber+GPIB)

- replacement of cathode socket
- installation of new gun pulser
- New filament and bias power supply
- Developing of software and implementation

Cathode parameters

Cathode Area 2.0 cm^2

Max emission current 12 A

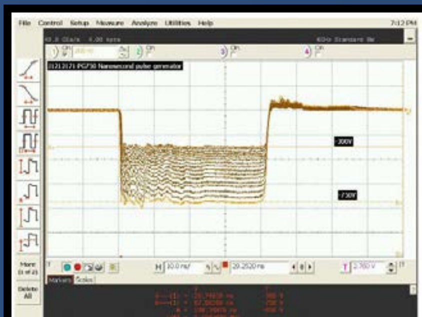
Heater 5.8 A, 6 V

With a gun current of 7 A, 80% can be capturated and accelerated

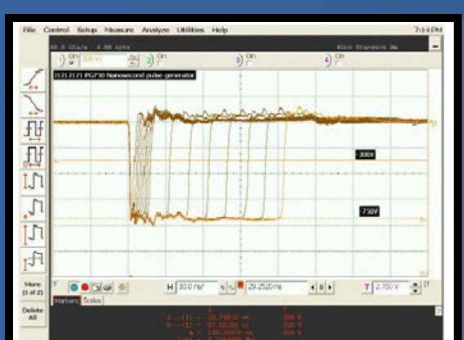
Parameters	**Characteristics**
Gun type	Thermionic triode electron gun
Cathode	Y796 (EIMAC) dispenser
Filament heating power	35 W
Acceleration potential	120 kV
Beam current	12 A
Emission current density	10 A/cm2
Grid bias voltage	0 - 500 V

New electron gun pulser

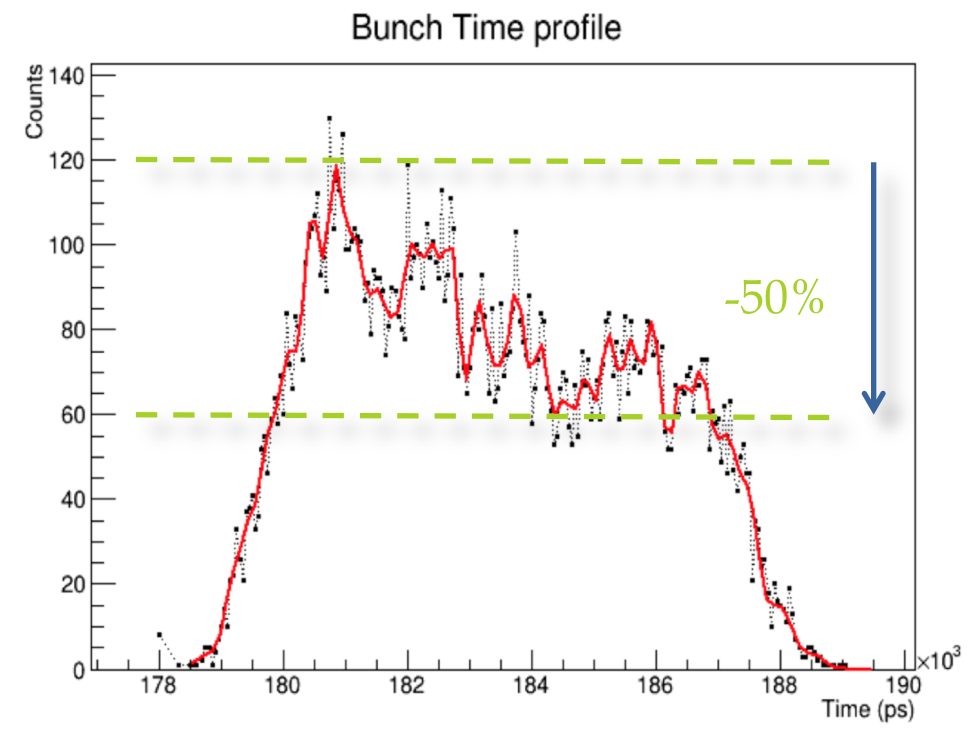
- Kentech PG750 pulser
  - improving stability and reliability
  - new possible matching condition
  - fine tuning of the gun pulse
- Developing of software and its implementation
- Gun equipment control via new ETH fiber+GPIB

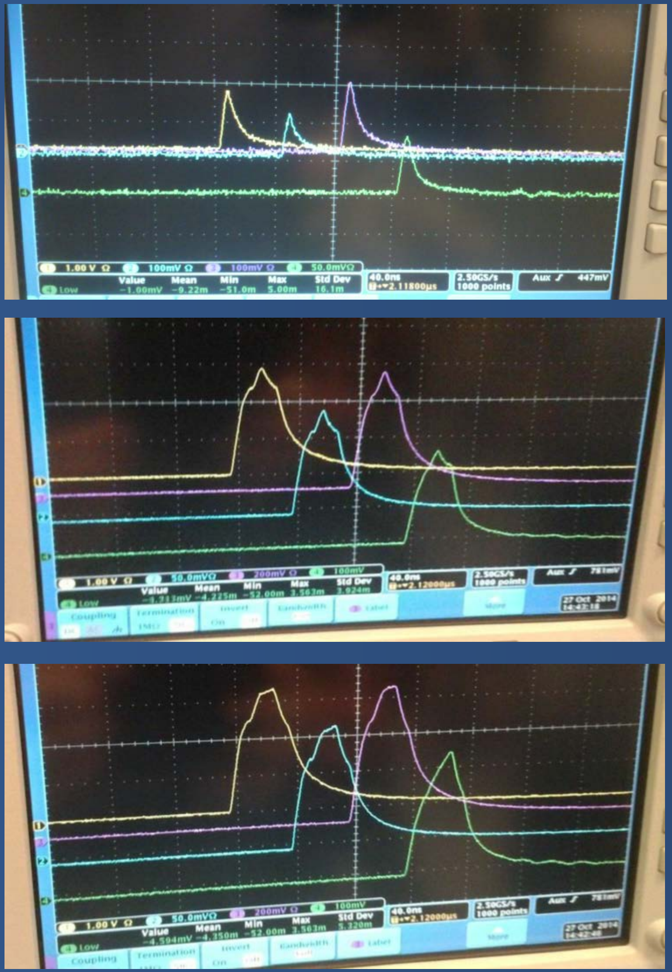

Variation of output pulse amplitude

Amplitude :	adjustable from 300 to 750 V in steps of 30 V
Pulse width	1.5 to 40 ns in steps on 0.5 ns
Pulse shape:	rectangular
Flatness	+/- 10%
Max. rep. rate	50 Hz
Jitter	~20 ps


Variation of output pulse length

Bunch structure





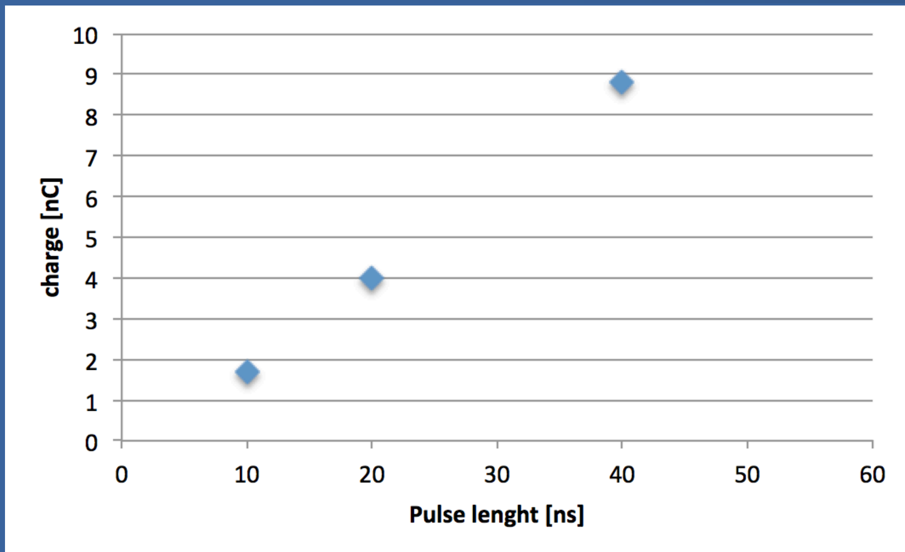
10 ns

20 ns

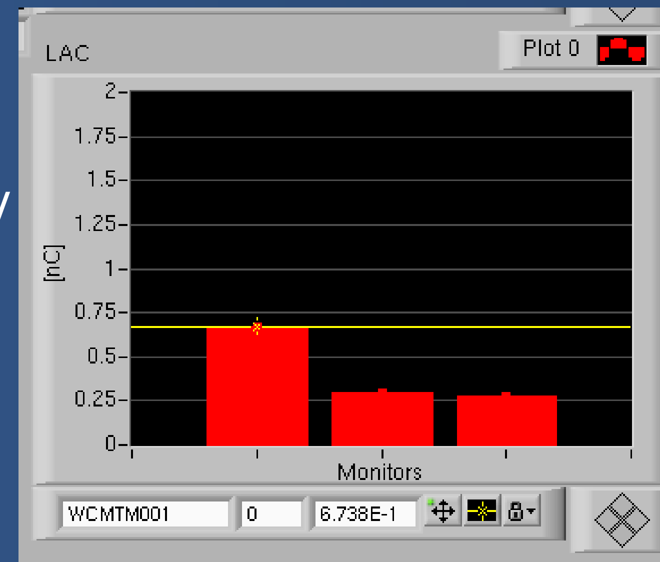
40 ns

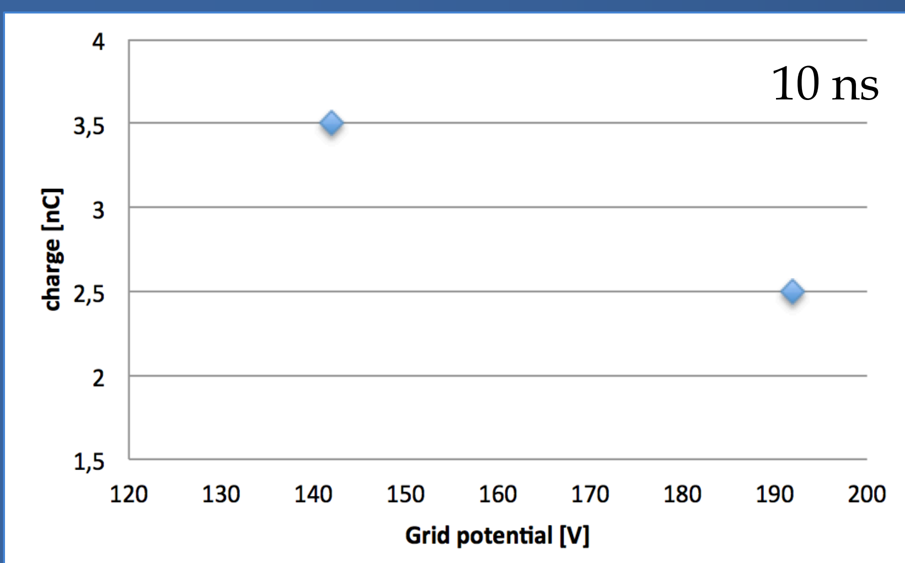
Current monitors

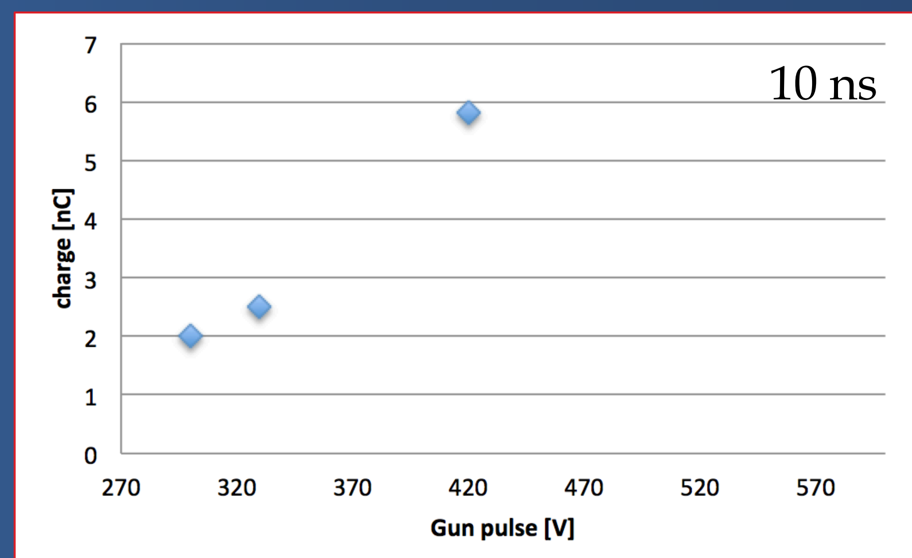
Bunch charge vs. length



E = 725 MeV



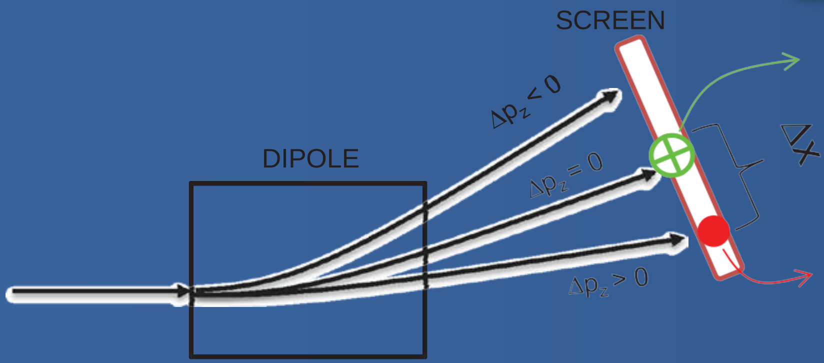




DAFNE LINAC

	Design	Operational
Electron beam final energy	800 MeV	510 MeV
Positron beam final energy	550 MeV	510 MeV
RF frequency	2856 MHz	
Positron conversion energy	250 MeV	220 MeV
Beam pulse rep. rate	1 to 50 Hz	1 to 50 Hz
Beam macropulse length	10 nsec	1.4 to 40 nsec
Gun current	8 A	8 A
Beam spot on positron converter	1 mm	1 mm
norm. Emittance (mm. mrad)	1 (electron) 10 (positron)	< 1.5
rms Energy spread	0.5% (electron) 1.0% (positron)	0.5% (electron) 1.0% (positron)
electron current on positron converter	5 A	5.2 A
Max output electron current	>150 mA	500 mA
Max output positron current	36 mA	85 mA
Trasport efficiency from capture section to linac end	90%	90%
Accelerating structure	SLAC-type, CG, 2π/3	
RF source	4 x 45 MWp sledded klystrons TH2128C	

Mean energy (Spectrometer)



"on-energy" particle centers the screen:

$$\langle p_z \rangle \left[\frac{GeV}{c}\right] = 0.3 \cdot B_{y,0}[T] \cdot R[m]$$

"off-energy" particle follows a different (dispersive) path:

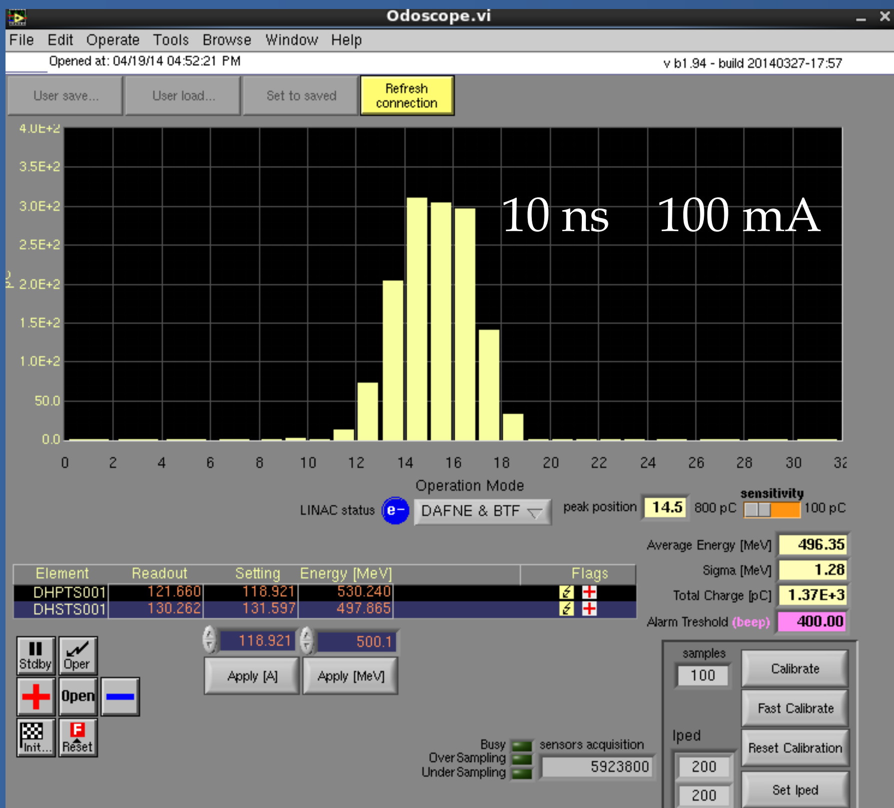
$$p_z = \langle p_z \rangle + \left(1 + \frac{\Delta x}{\eta_x}\right)$$

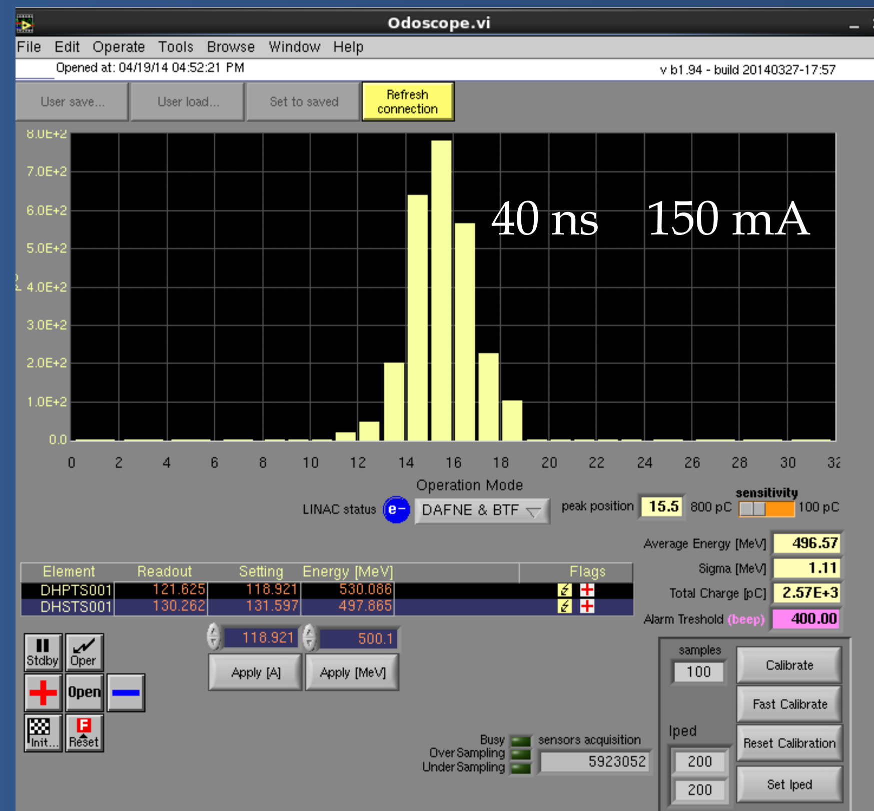
- **How to proceed:**
  1. geometry of the ref. trajectory (Θ, R) is fixed by the mechanical assembly,
  2. B_y is chosen to center the *beam* onto the detector (screen or BPM),
  3. calculate $<p_z>$.
- **Measurement errors:**
  - trajectory distortion before I after the dipole magnet,
  - dipole field calibration errors (vs. the supplying current),
  - misalignment of the dipole I detector.

Typical error is of the order of 1 MeV at energies higher than tens of MeV.

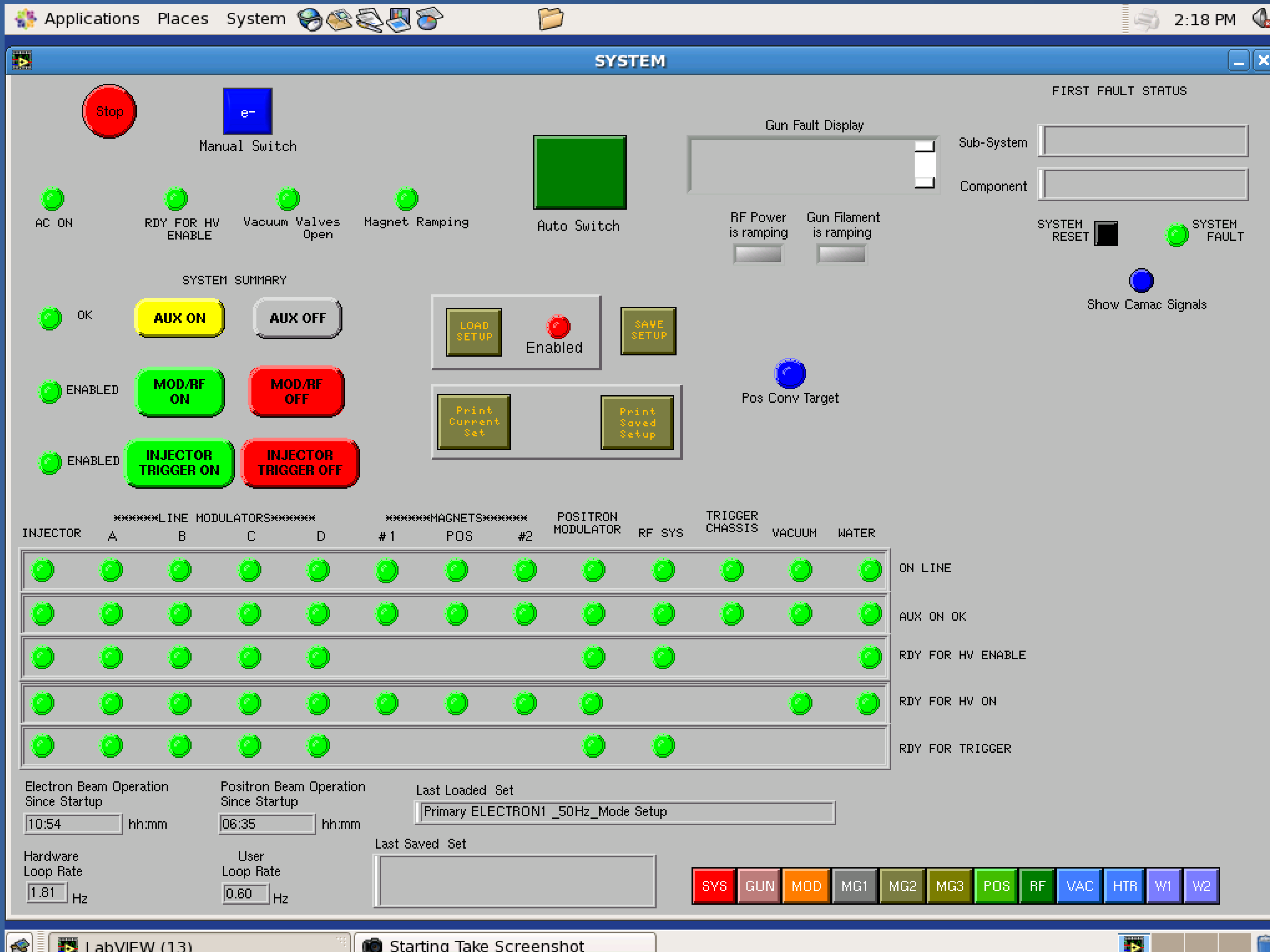
Energy spread

Measurement of beam energy spread @ **500 MeV**

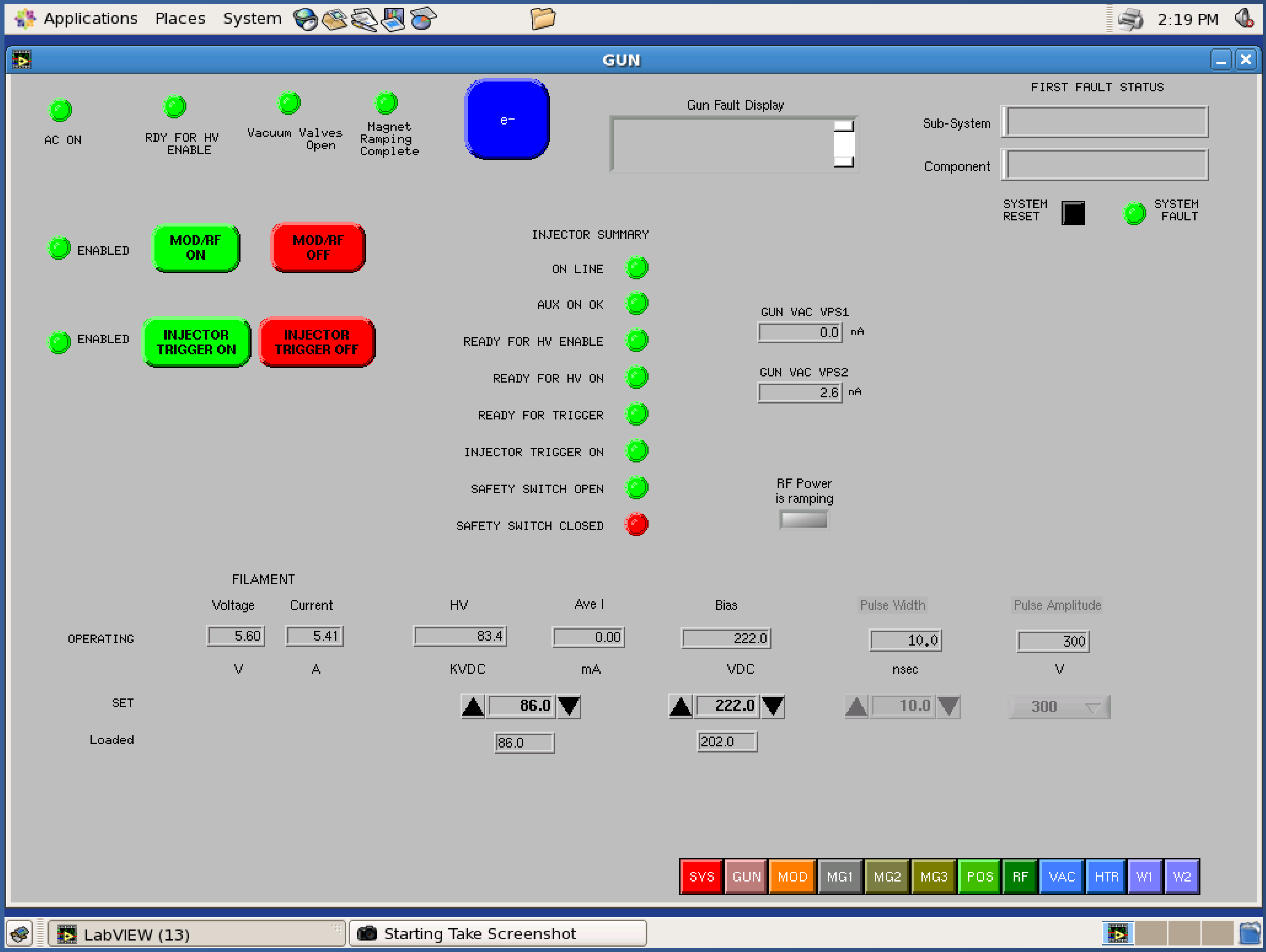




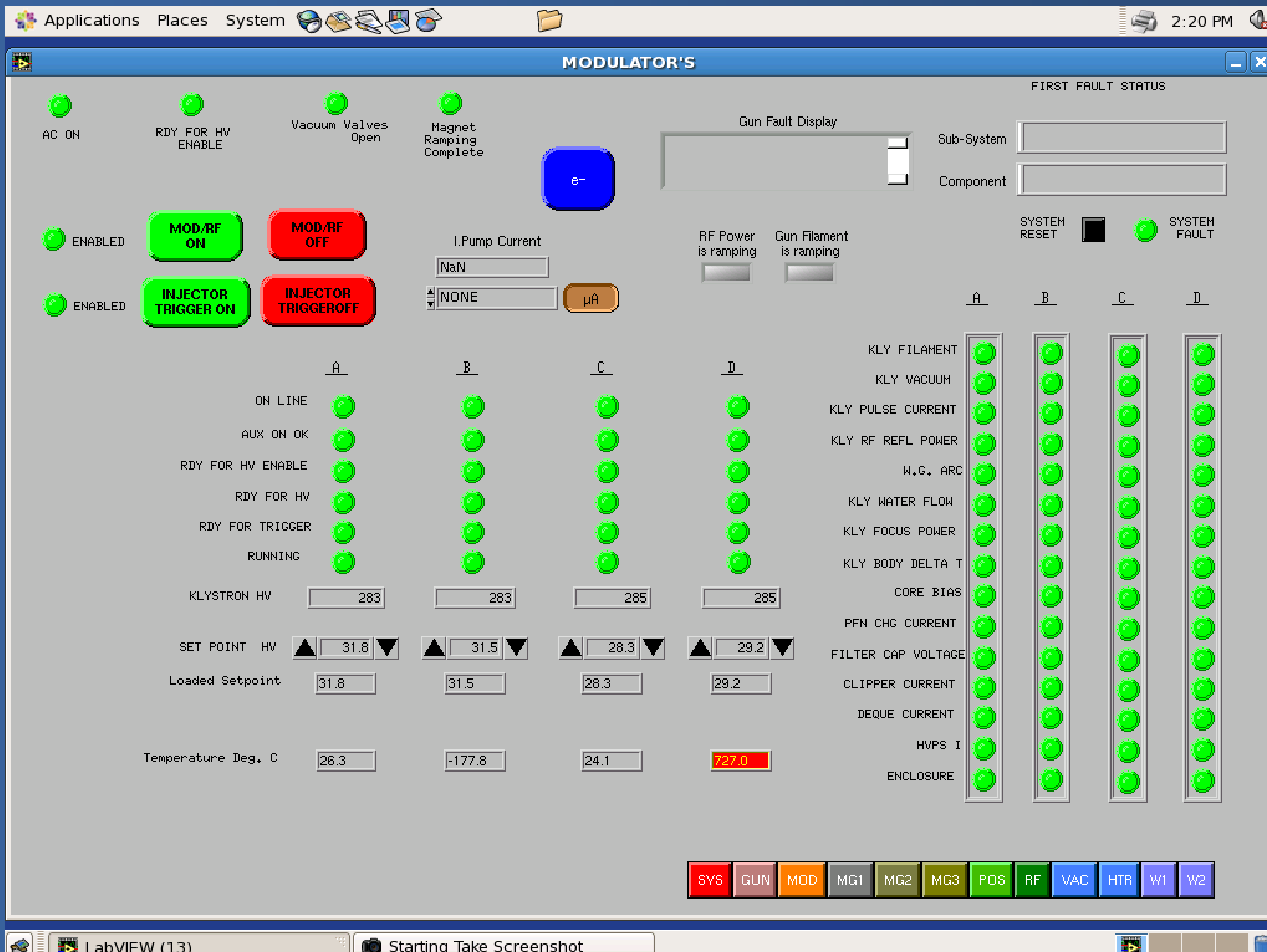
ELECTRON mode: SYSTEM



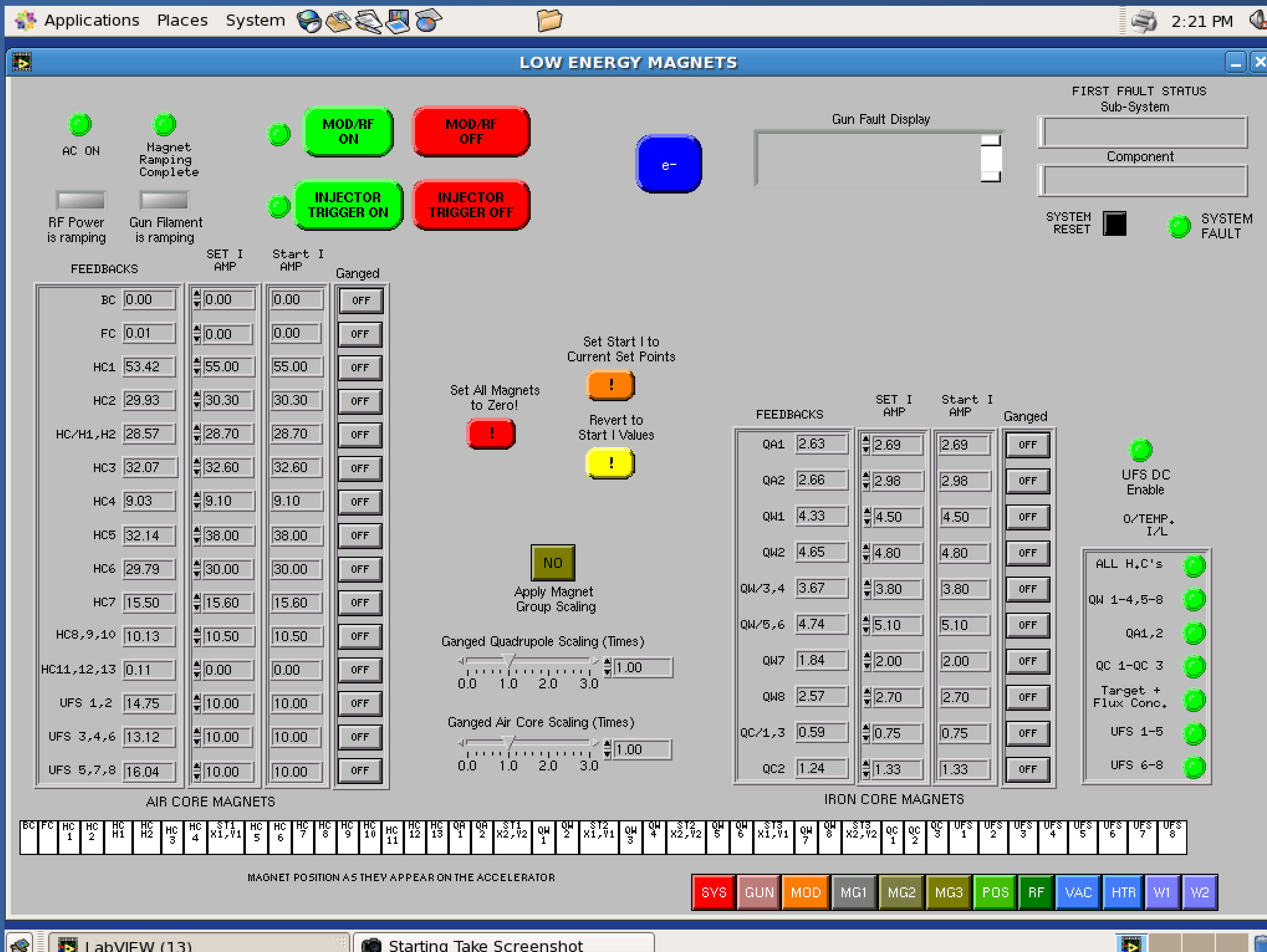
ELECTRON mode: Gun



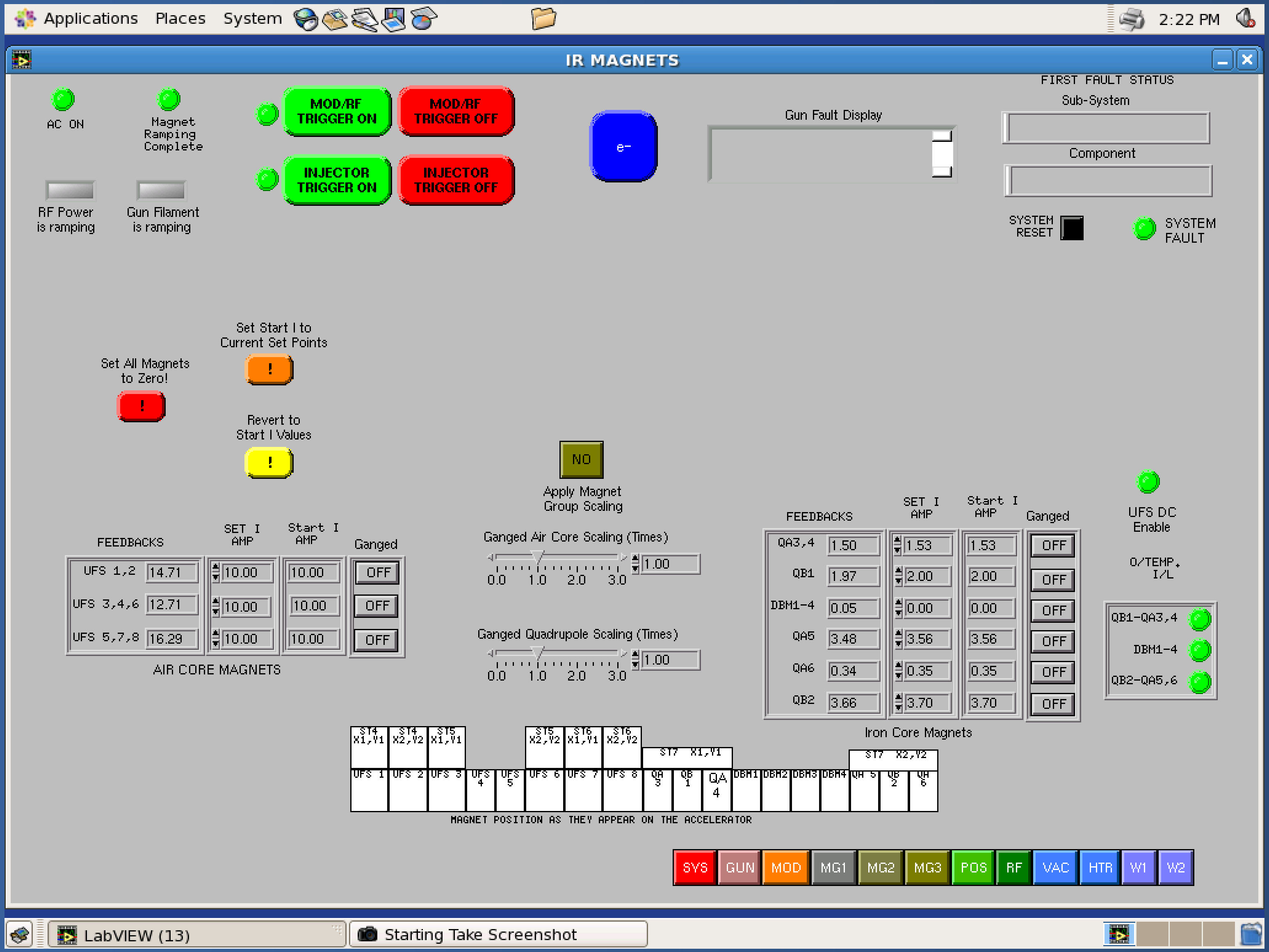
ELECTRON mode: MOD



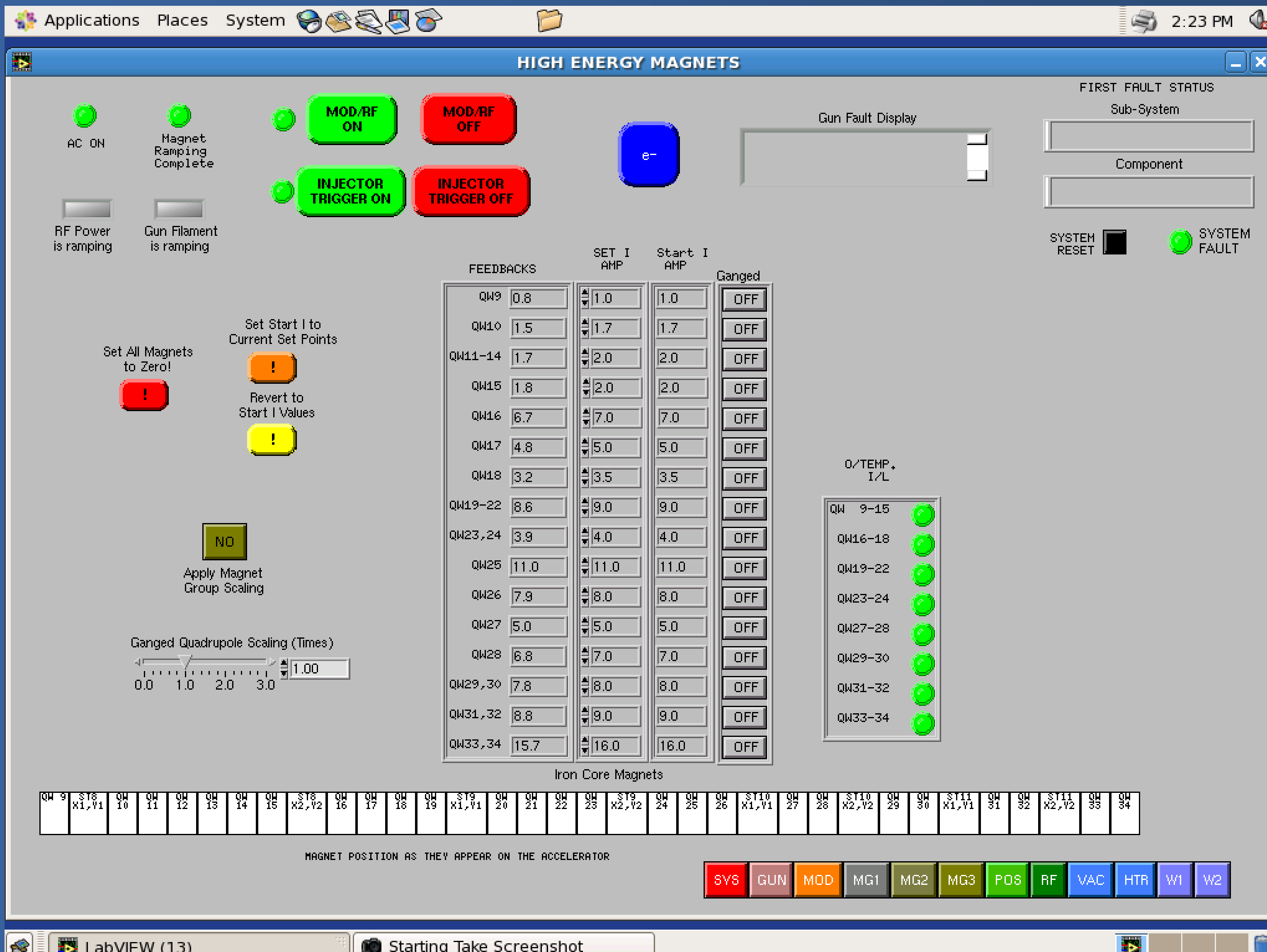
ELECTRON mode: MAG.1



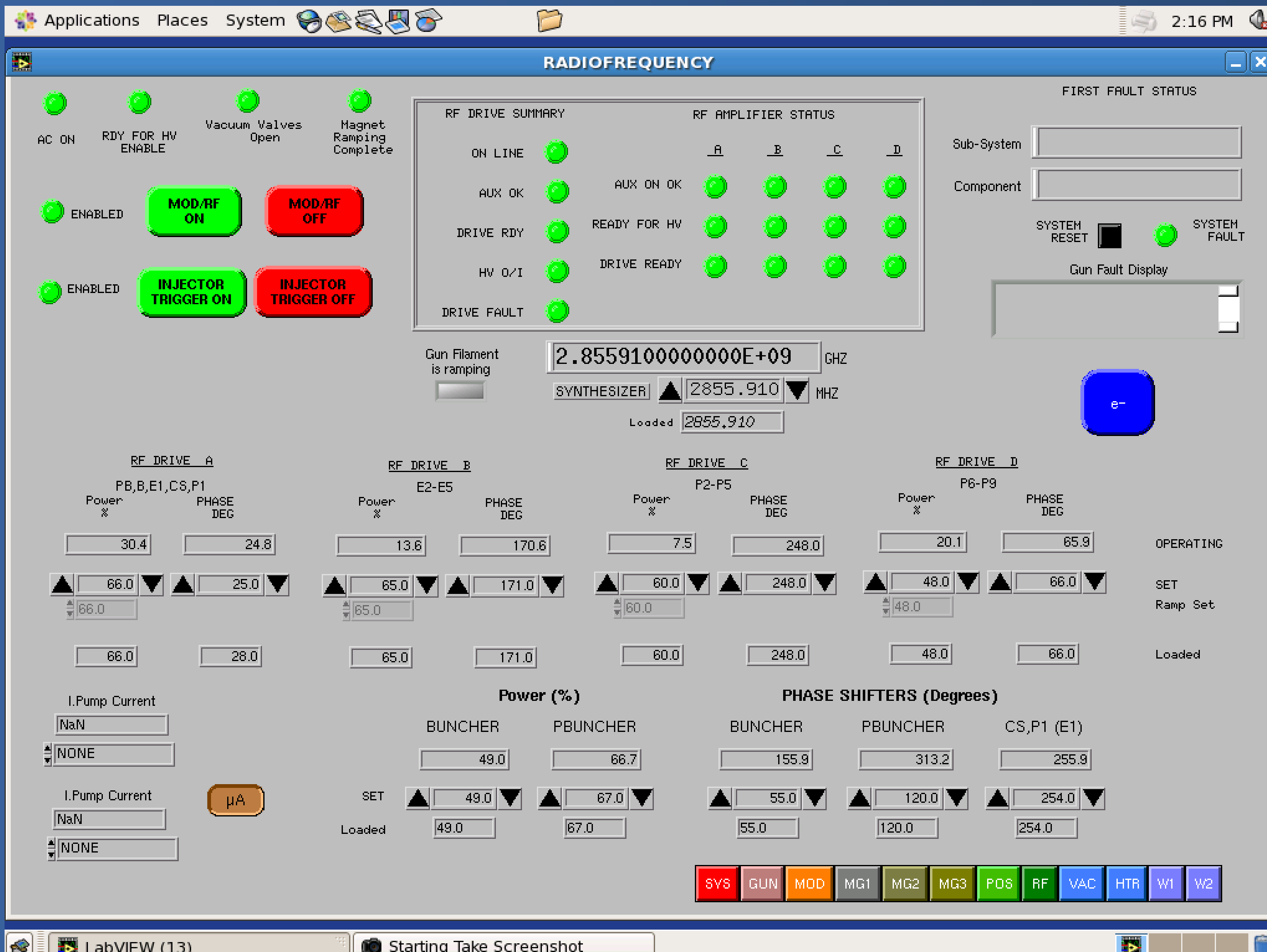
ELECTRON mode: MAG.2



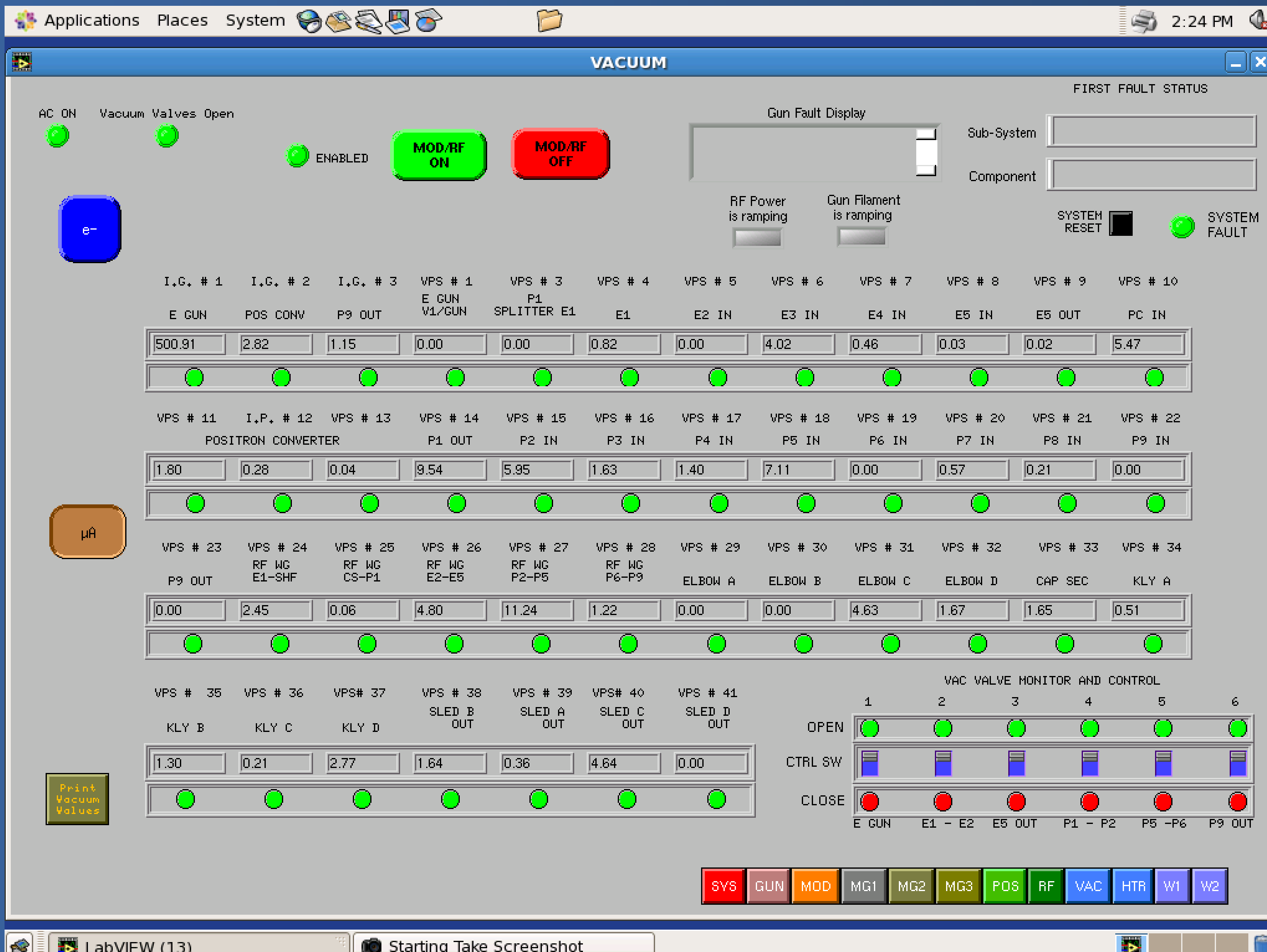
ELECTRON mode: MAG.3



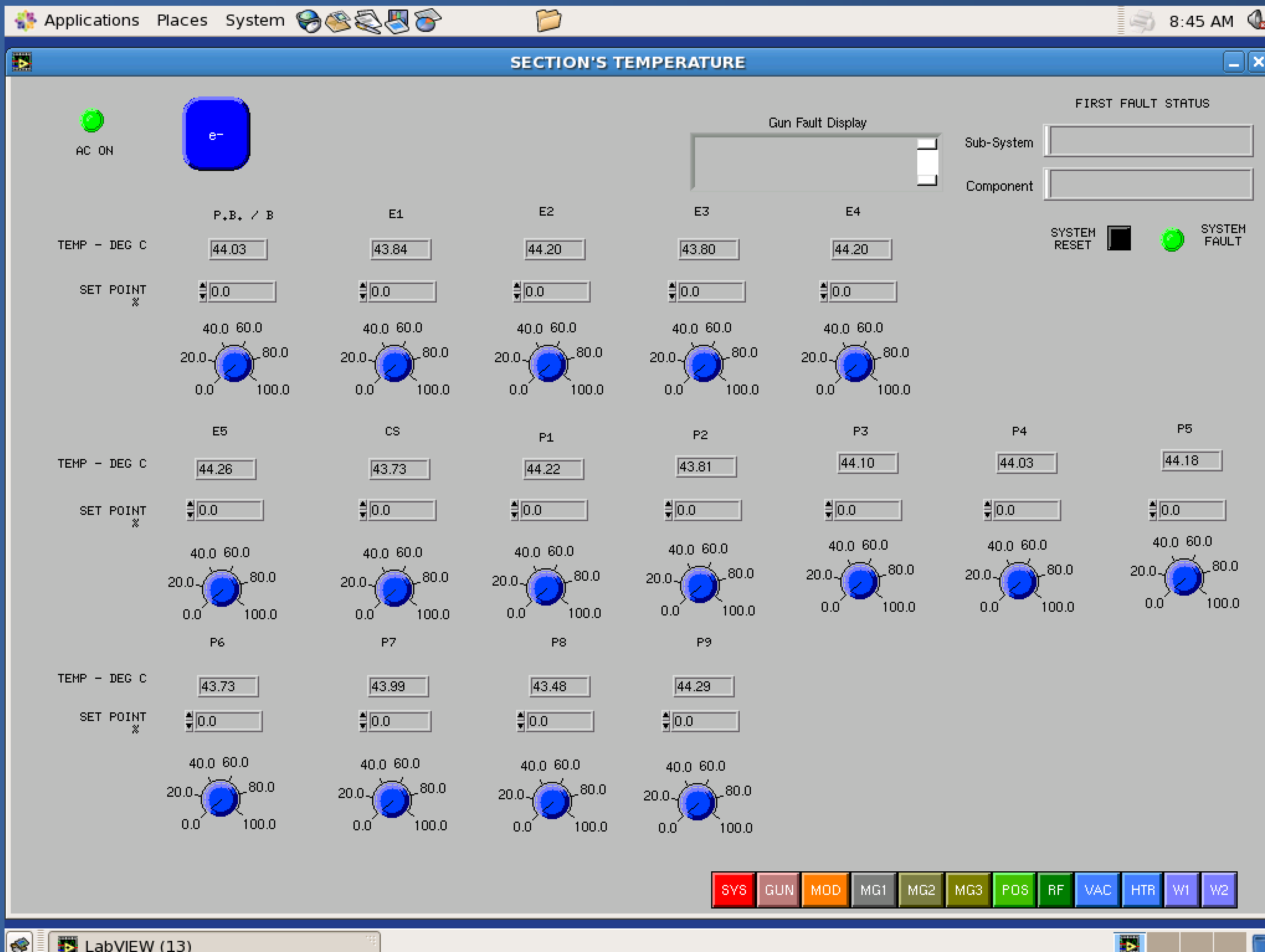
ELECTRON mode: RF



ELECTRON mode: VAC



ELECTRON mode: HTR



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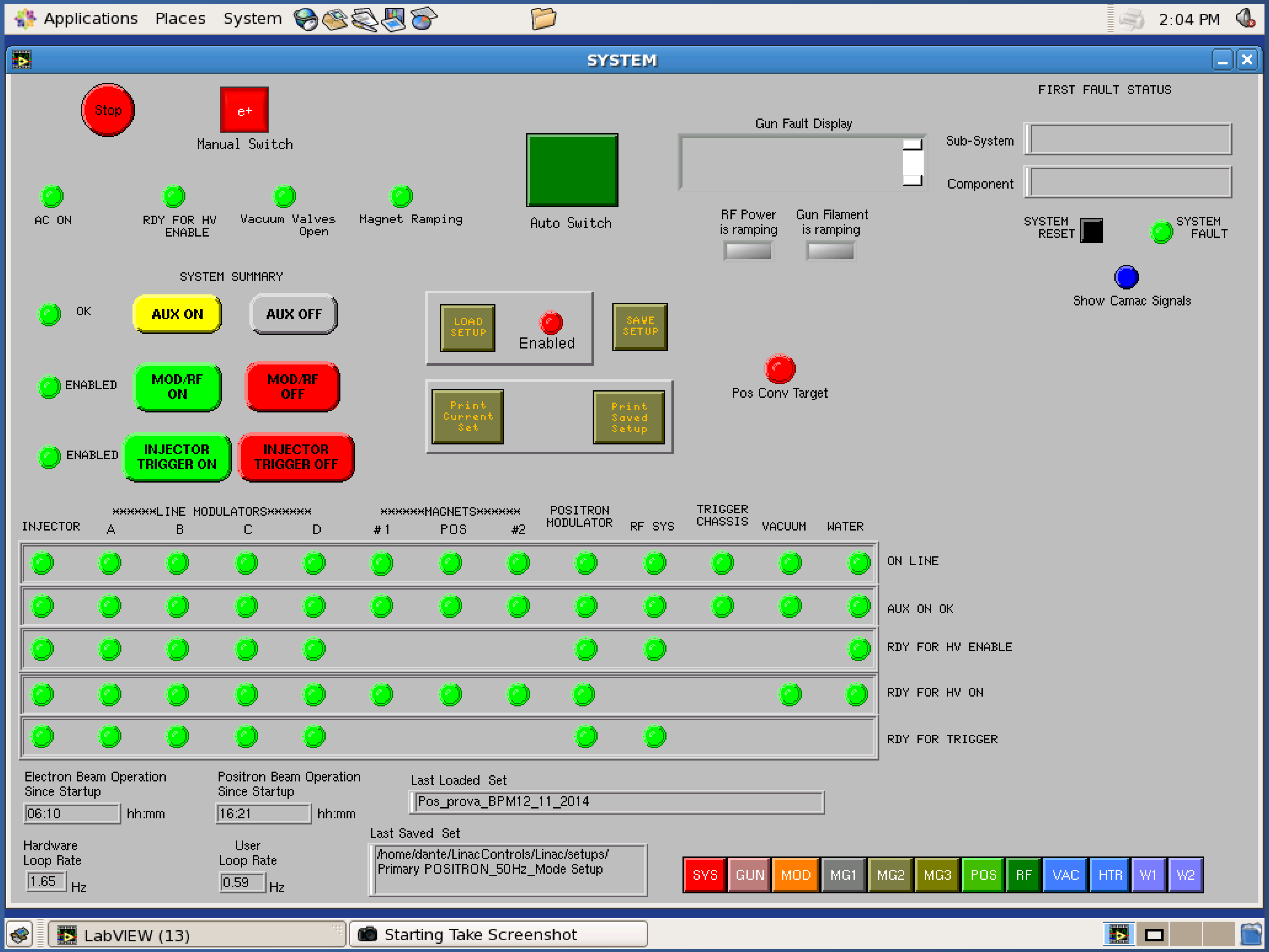

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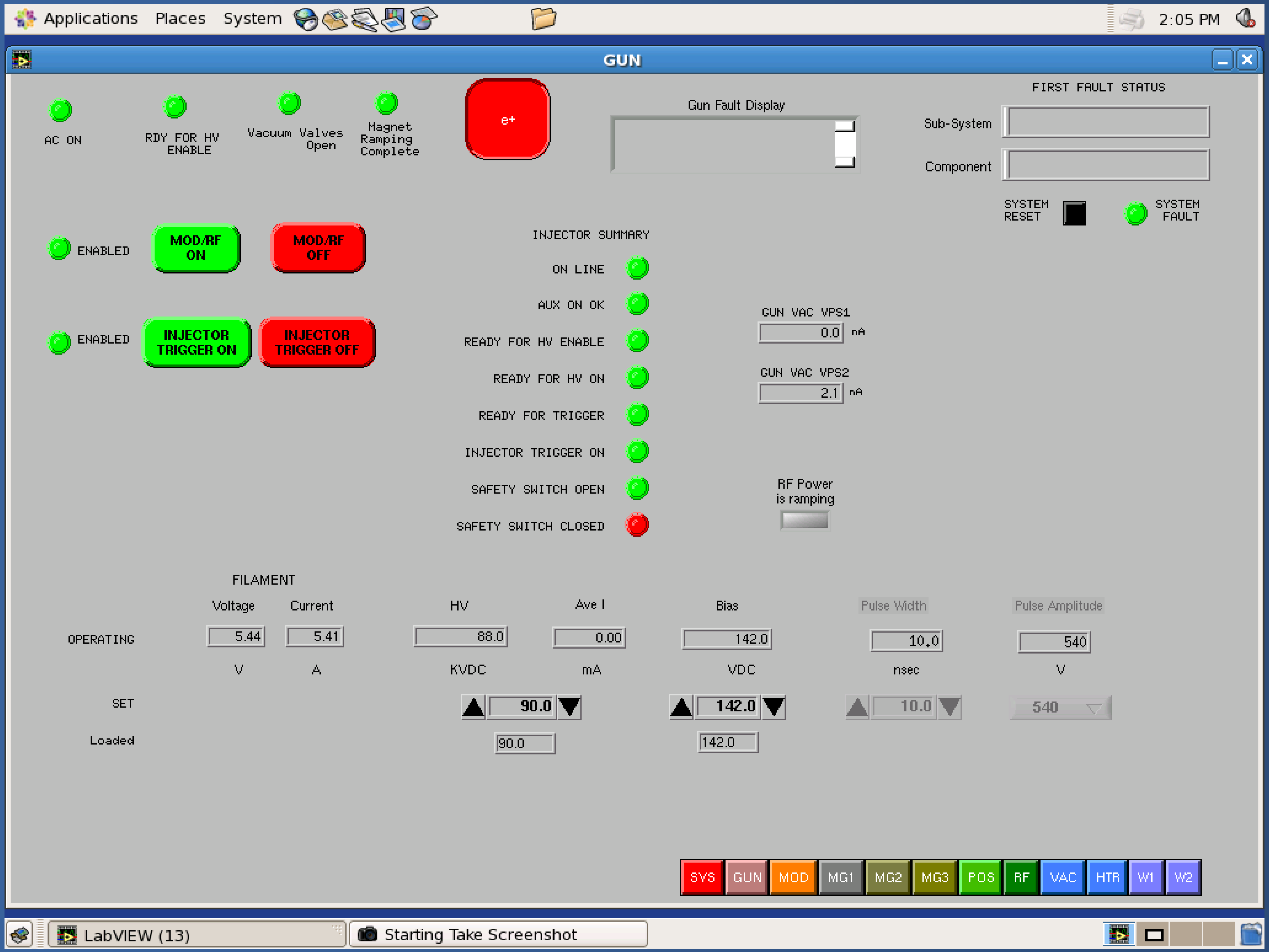

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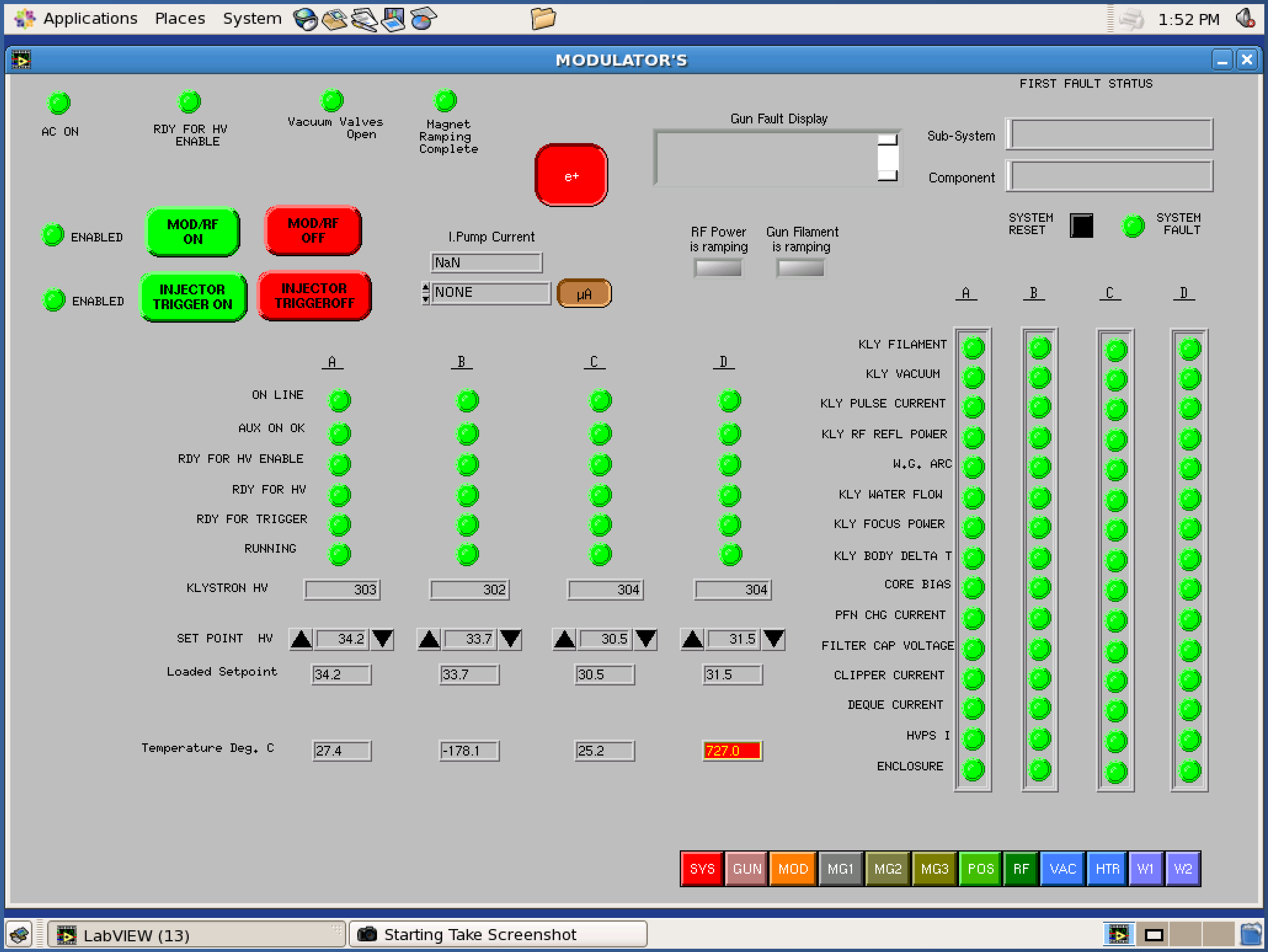

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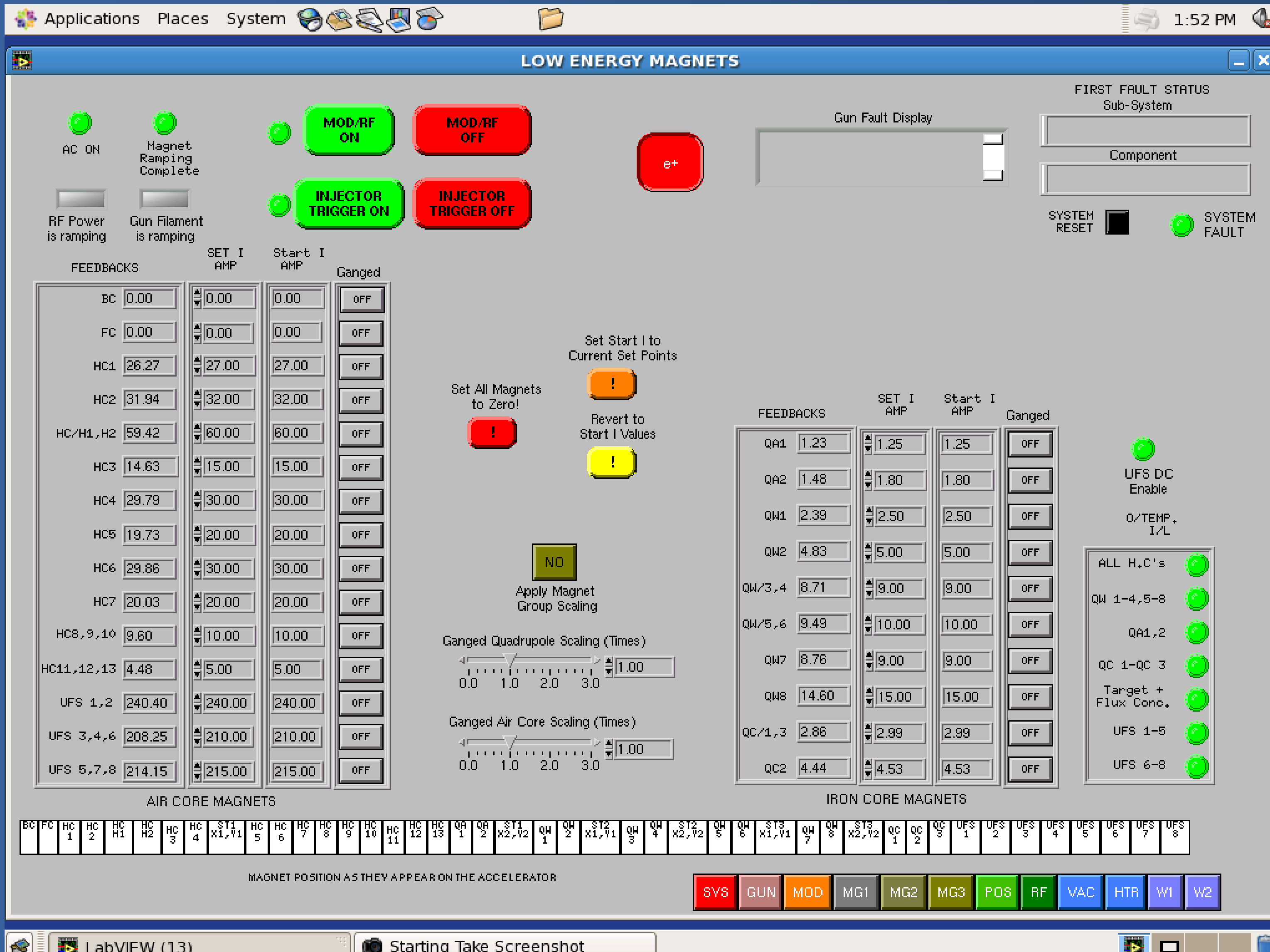

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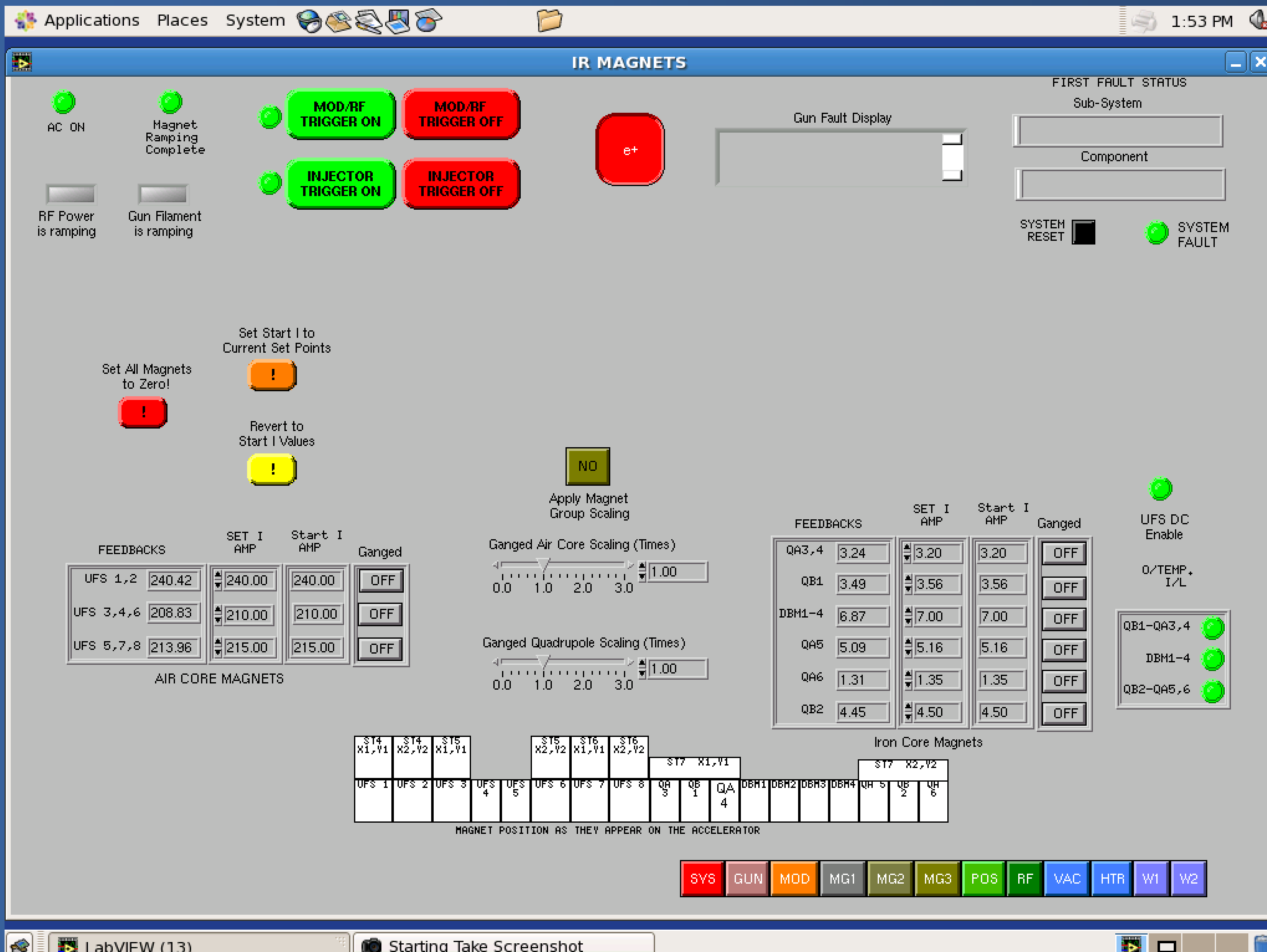

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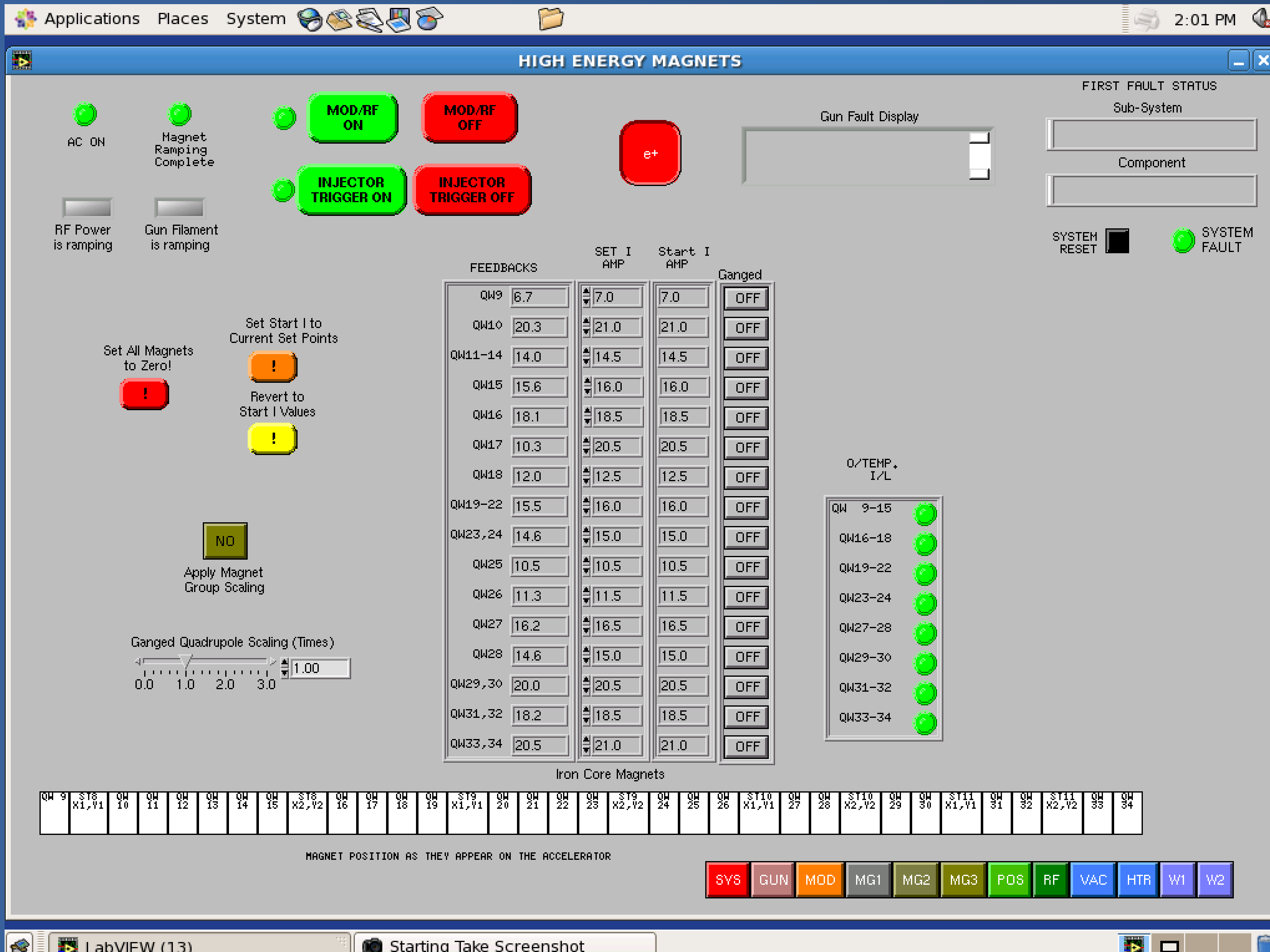

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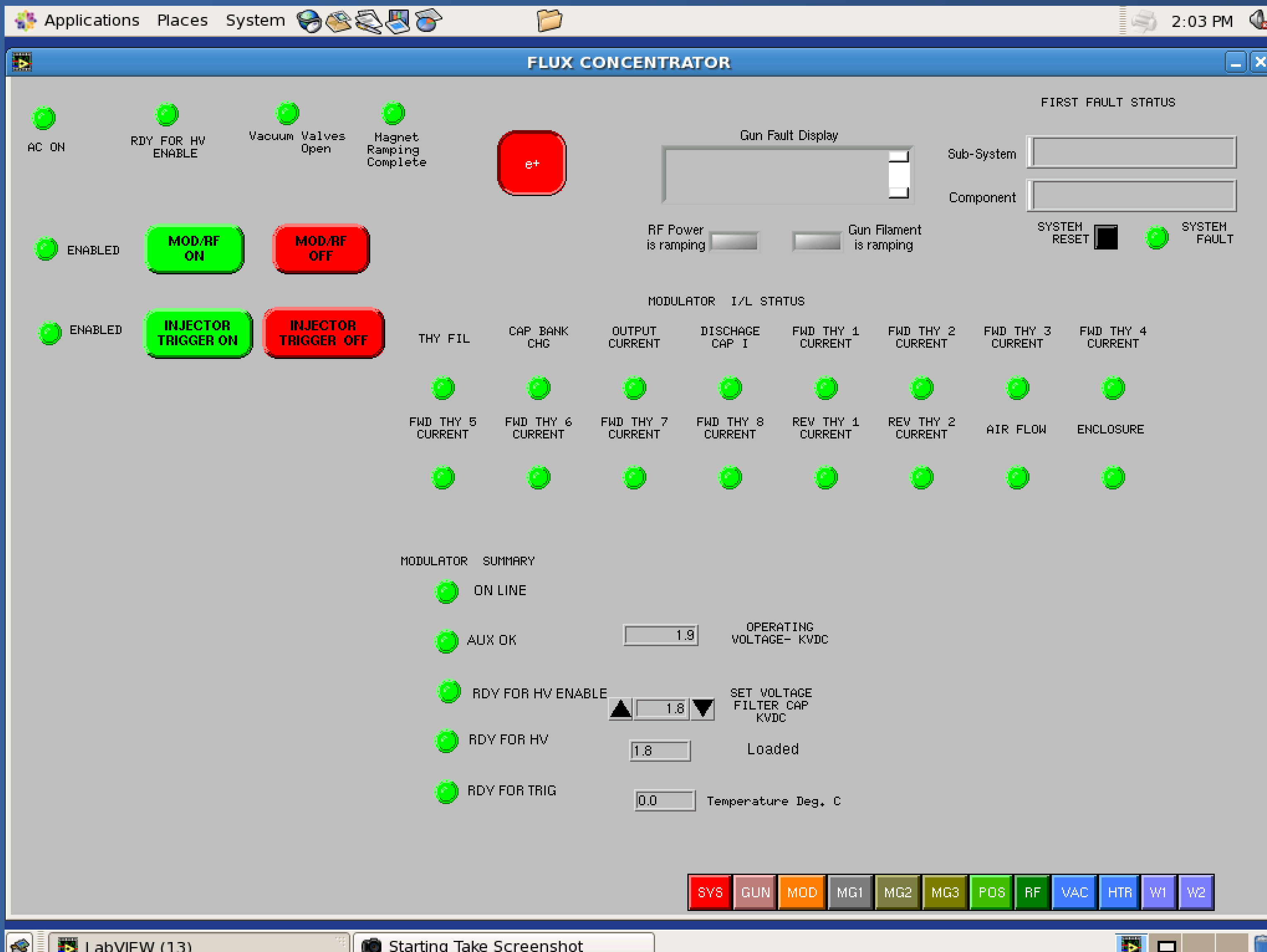

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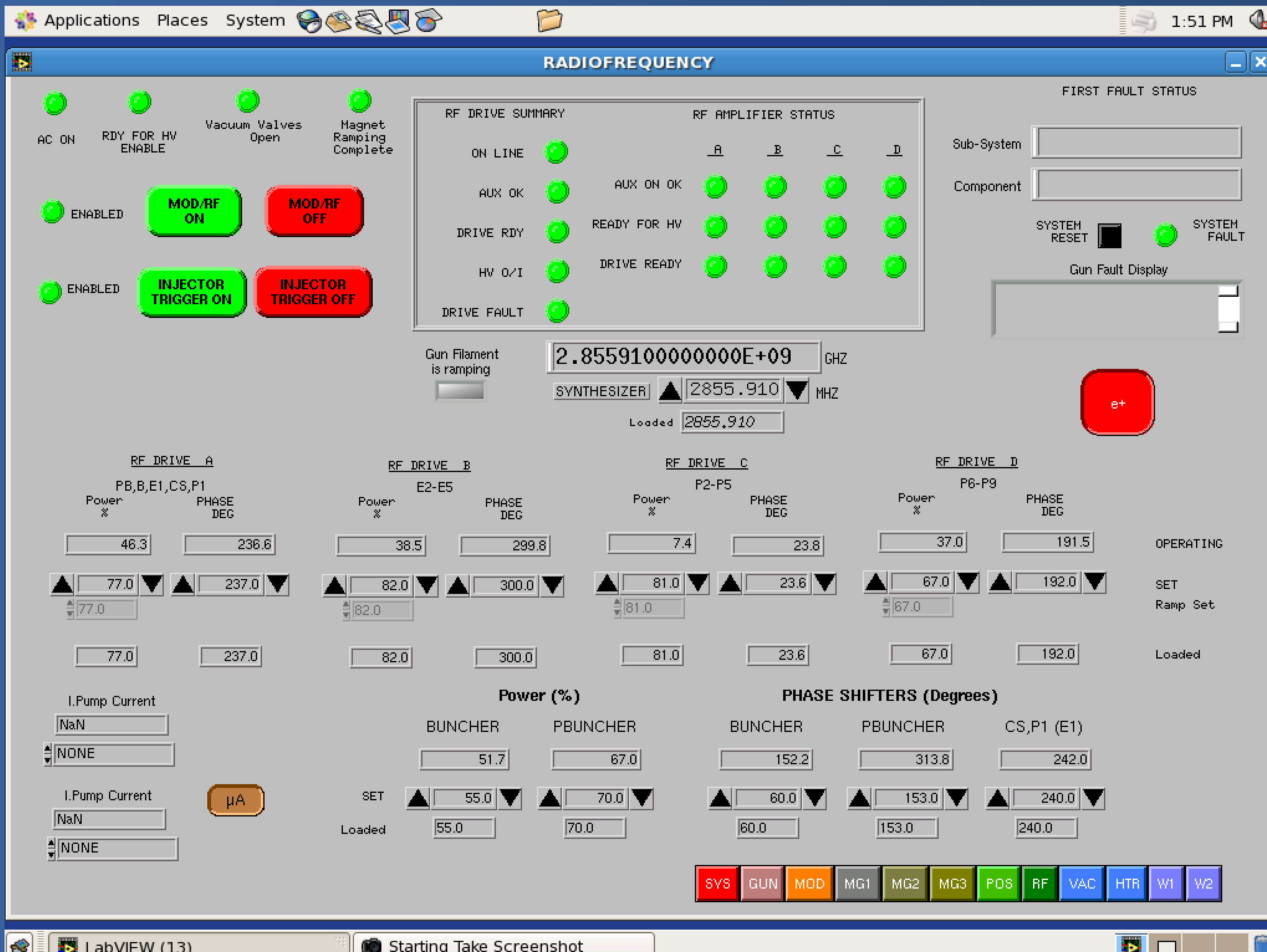

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