Spear RF Operation and Possible Changeover

Sam Park, SLAC/SSRL
CWHAPRF2006, ANL/APS, 1 May 2006

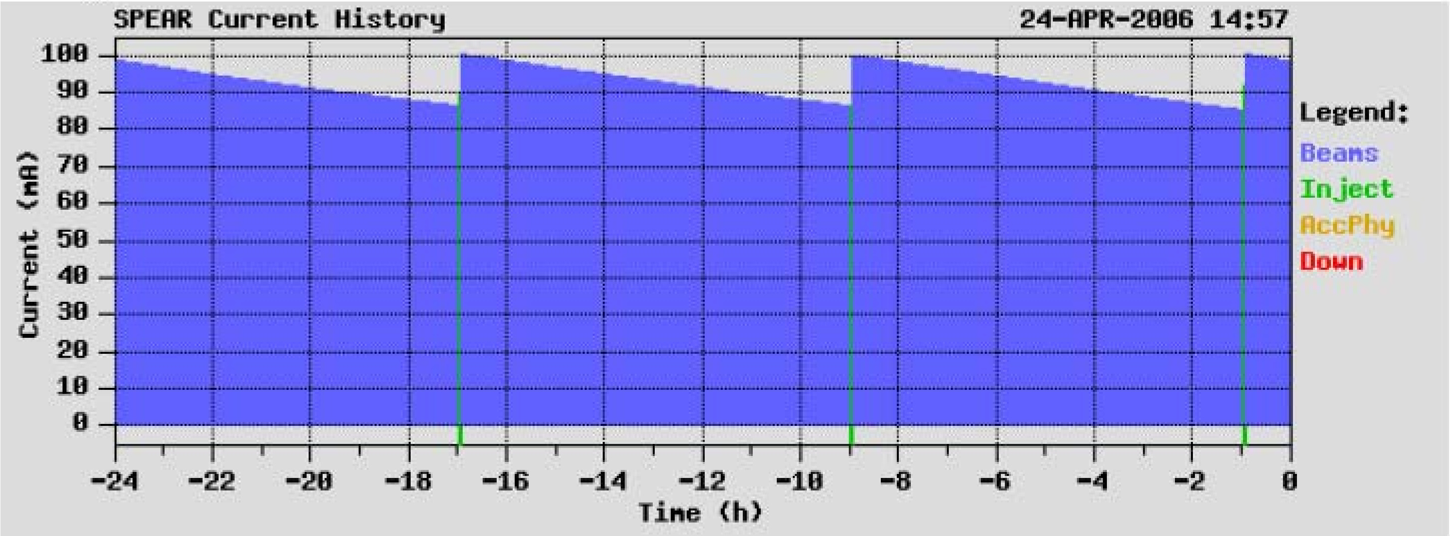
- Present status with 100 mA user beam
- RF for 500 mA in Spear3
- Injector RF for top off – Status & Options
- Spear3 and PEP2 RF

User beam as of April 2006

SLAC/SSRL

Stanford Synchrotron Radiation Laboratory

Energy: 3.000 GeV **Beam Status: Beams** **Beam Current: 98.35 mA**



Vacuum Quality*: 4.51 Ah **Lifetime: 45.35 h**

Loss Rate: 0.04 mA/min

Display valid for **24-Apr-2006 14:58:17**

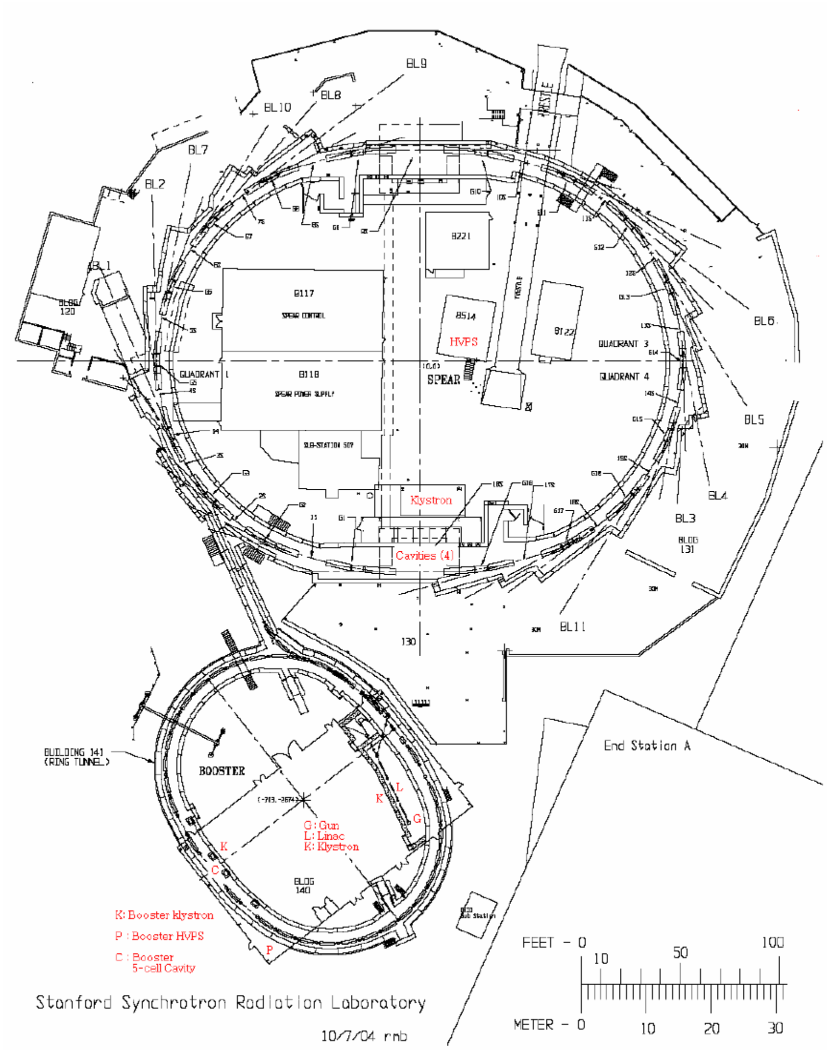
For Updates From the BL Duty Operator, Call 926-BEAM (2326)

SSRL Beamlines as of April 2006

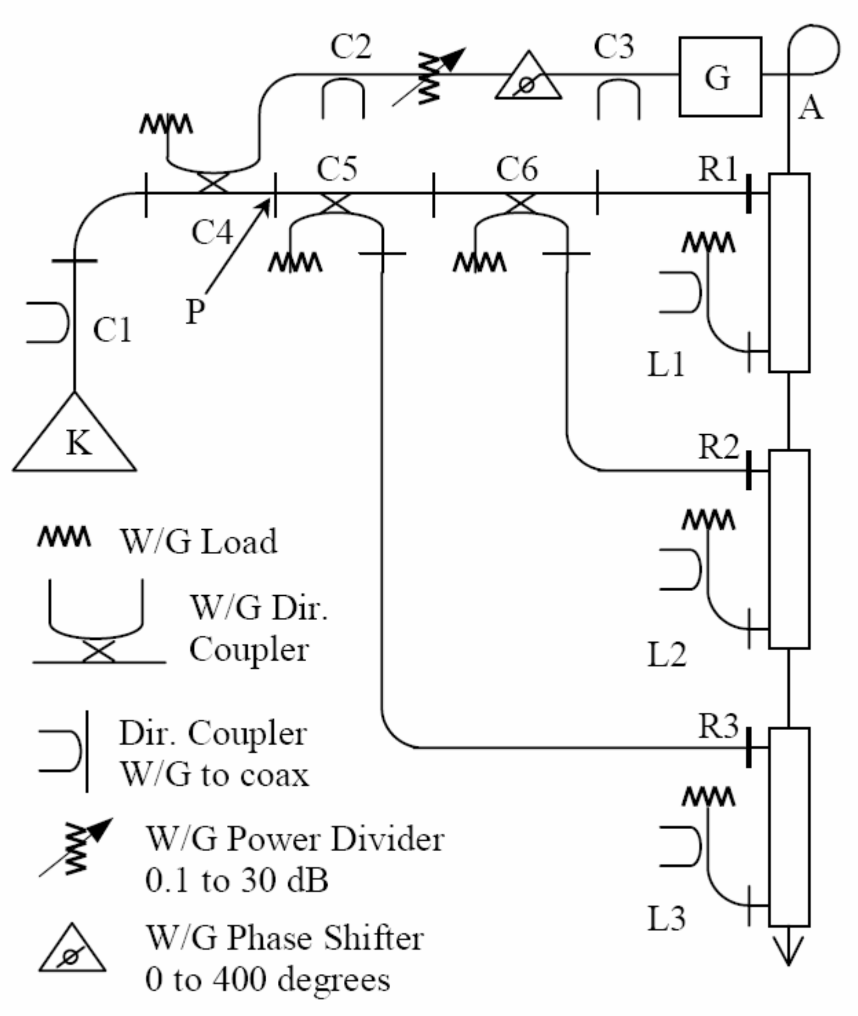
Beamline		Period	Gap/mm	Field/T	K	Pwr/W	Yield/Ah
1	Open	-	48	1.249	-	14	271.76
2	Open	-	48	1.249	-	14	222.46
3	Closed	-	48	1.249	-	14	0.00
4	Open	10	61.8	0.66	14.17	561	273.51
5	Open	10	50.2	0.289	4.94	86	177.83
6	Open	27	16.1	0.845	5.52	756	261.11
7	Closed	10	17.3	1.936	41.58	4832	0.00
8	Open	-	48	1.249	-	14	272.56
9	Open	8	24.6	1.93	49.64	4851	163.99
10	Open	15	23.8	1.272	16.29	1866	198.77
11	Open	13	16	1.996	32.62	5080	269.07

Total Run Electron Beam Intensity Integral: 298.343 Ah

SSRL Overall Layout



Injector Linac



RF Gun : 1.5-cell, standing wave, thermionic RF gun at 2.856 GHz. 2 μs, 3 MW peak, 2 MeV, ~4000 bunches of ~100 ps length

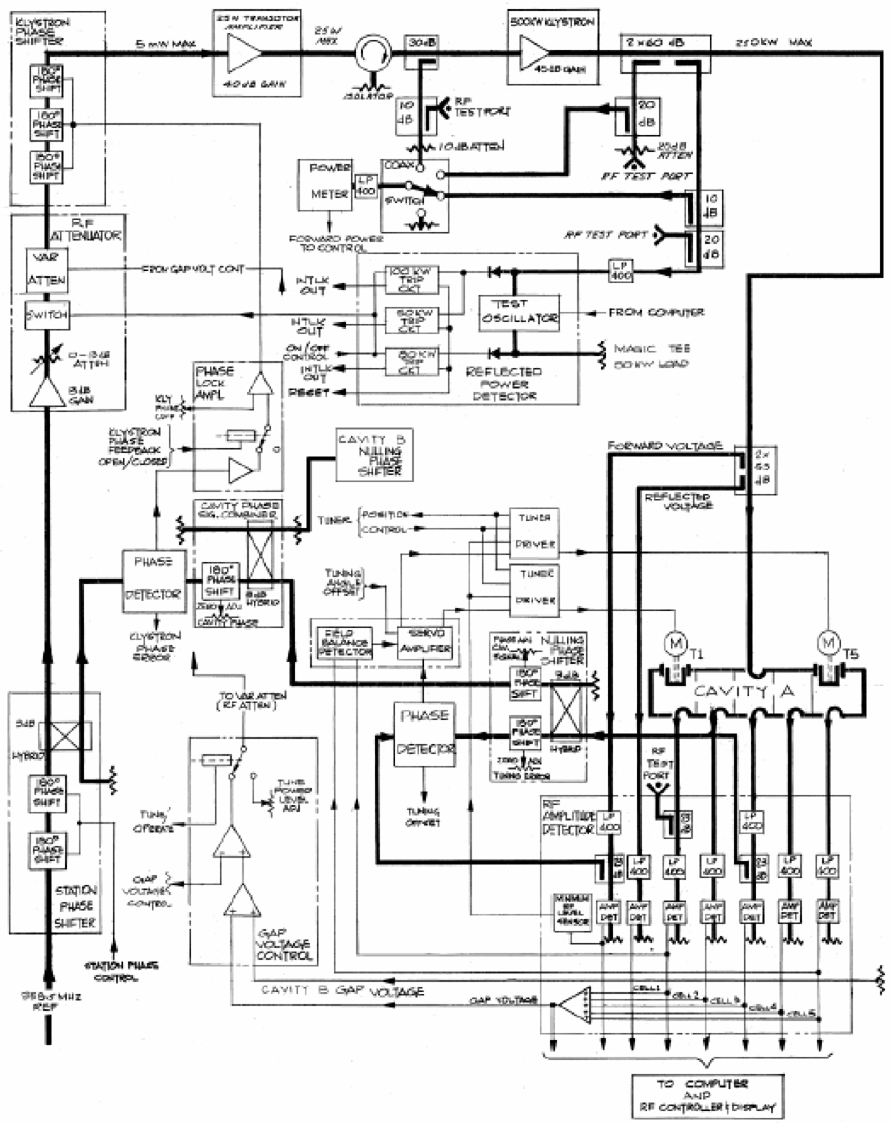
α-Magnet : bunch compressed to 300 fs

Chopper : Selects 3~5 bunches to the linac

Linac : 10-foot sections, 3 each, 110 MeV at P_{kly} = 42 MW

Linac Klystron : 2.856GHz, 42 MW (60 MW max). SLAC 5045 One klystron powers the RF gun and 3 linac sections

Booster RF



RF Cavity : 5-cell, Spear2 type,
358.5 MHz, V_g^2/P_{RF}=26 MΩ

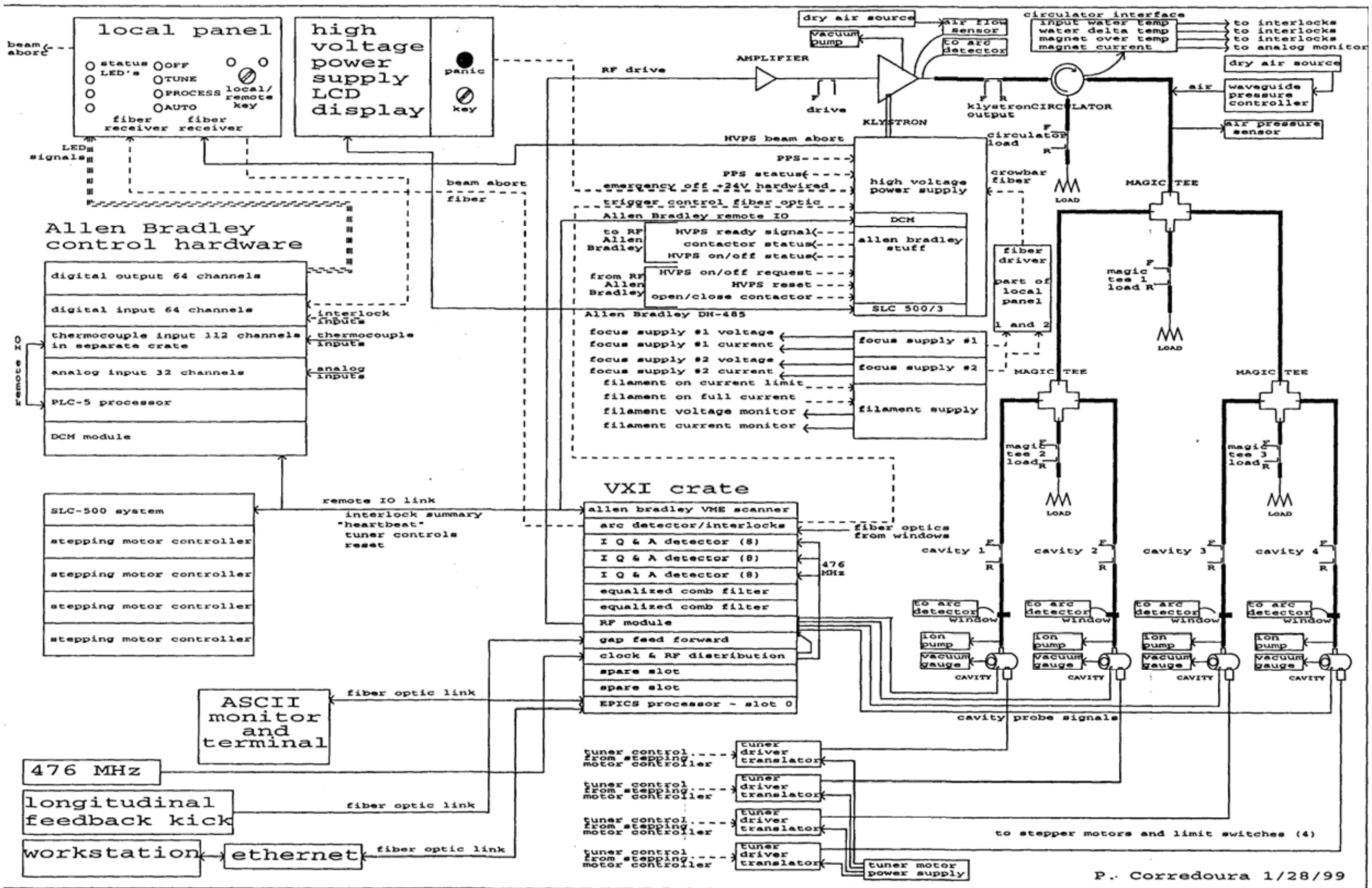
Klystron: Spear2 type, 358.5 MHz.
Ramped (25 kW peak, 10 Hz)
Freq is phase-locked to Spear.
Phase modulated for injection.

HVPS: 38 kV cw, 5.7 A (7.0A at
47kV max.), 480V 3 ph prim.
Δ to Δ/Y windings

LLRF: Spear2 type. Analog except
for gap voltage modulation

The system is turned on for 3~4
hours daily for injection

Spear3 RF System



Spear3 High Power RF Components

RF Cavities: 476.3 MHz, $R_s=V_g^2/P_{RF}$=7.62 MW (0.85 MV @ 95 kW), E_Z=3.9 MV/m, $\beta=1+P_b/P_c$=3.8, P_{Window} <410 kW, P_{Wall} <80 W/cm^2, 3 HOM loads and 1 movable tuner per cavity, T_{Window} by IR sensor, Q~30,000 ($t_F=Q/\omega$~10 μs). Orbit interlock trip turns RF station off.

Klystron: 1.2 MW max, 476±2 MHz, P_b=82 kV*23.5A=1.93MW, μperv=1.00, η=62%, Gain=45 dB, P_{drive}=40W, P_{heater}=100*5.1=510W, I_{Main}=46.5A, $I_{bucking}$=0.66A, LCW 275 gpm (150 psi, 32±1°C, 2*5L/s

HVPS: 90 kVdc*27A=2.43 MW, 12.47 kV 127 A primary, P_{dc}/P_{ac}=0.89, light triggered crowbar SCR's and GA filtering caps. P_{arc}<0.5J

Circulator: AFT Y-Junc 3-port, 476±10MHz, Max P_{Fwd}/P_{Rev}=1.2 MW cw, IL< 0.1 dB, Isolation> 26 dB, LCW>26 gpm (150 psi, 25~40°C)

Water Loads: 150 gpm HCW (0.75% Corr-Shield vol. to LCW) 150 psig, 10~70°C thru Teflon tubing to 15 psig, <80°C return. 476 ±10MHz, 1.2 MW max, VSWR<1.05, RF Leakage< 1W/m^2, Length : 9.5 feet

Debugging and Fine Tuning Spear RF

* User beam (100 mA at 3.0 GeV) since March 2004

* 3.0 GeV 100 mA delivered every 8 hours
Beamlines closed. Top off (85 to 100mA) takes 2 minutes

* HVPS trips on “Transformer Arcing”: Replaced light-triggered crowbar SCR stacks

* Occasional RF trip on Orbit Interlock – Still being work on

* Equipment overheating: Provided more space between them (ion gauge controllers, timing modules, etc)

* Spurious trips on klystron main focusing current from the noise: Placed the interlock away from the power supply

* Waveguide dry air delta-P trip: Increased the flow rate.

* Klystron output window cooling air failure: Replace air pump

* Excessive P_{refl} to klystron: Digital TCU replaced with analog unit

Caring for the Old Booster RF

* Booster RF system has been in operation since 1989
(Booster klystron is 17 years old, working part-time)

* For the single bunch energy boost from 110 MeV to
3.0 GeV, the Booster klystron puts out 25 kW peak
to the 5-cell cavity for 0.8MV peak gap voltage
(The klystron is rated for 500 kW cw output power)

* With the coupling β=1.2, there is no circulator

* The LLRF is based on PEP-1 design, and entirely analog
except for the computer generated gap voltage waveform

* HVPS has 480V 3 phase primary and Δ-Y secondary for 38~47 kVdc
(as selected by voltage taps) at up to 7.0A. This HVPS is most
fragile among the Booster components

Higher Energy Linac Beam

* There is only one SLAC 5045 klystron for the entire Gun-Linac system. Its output power is rather limited at 42 MW considering the operational margin.

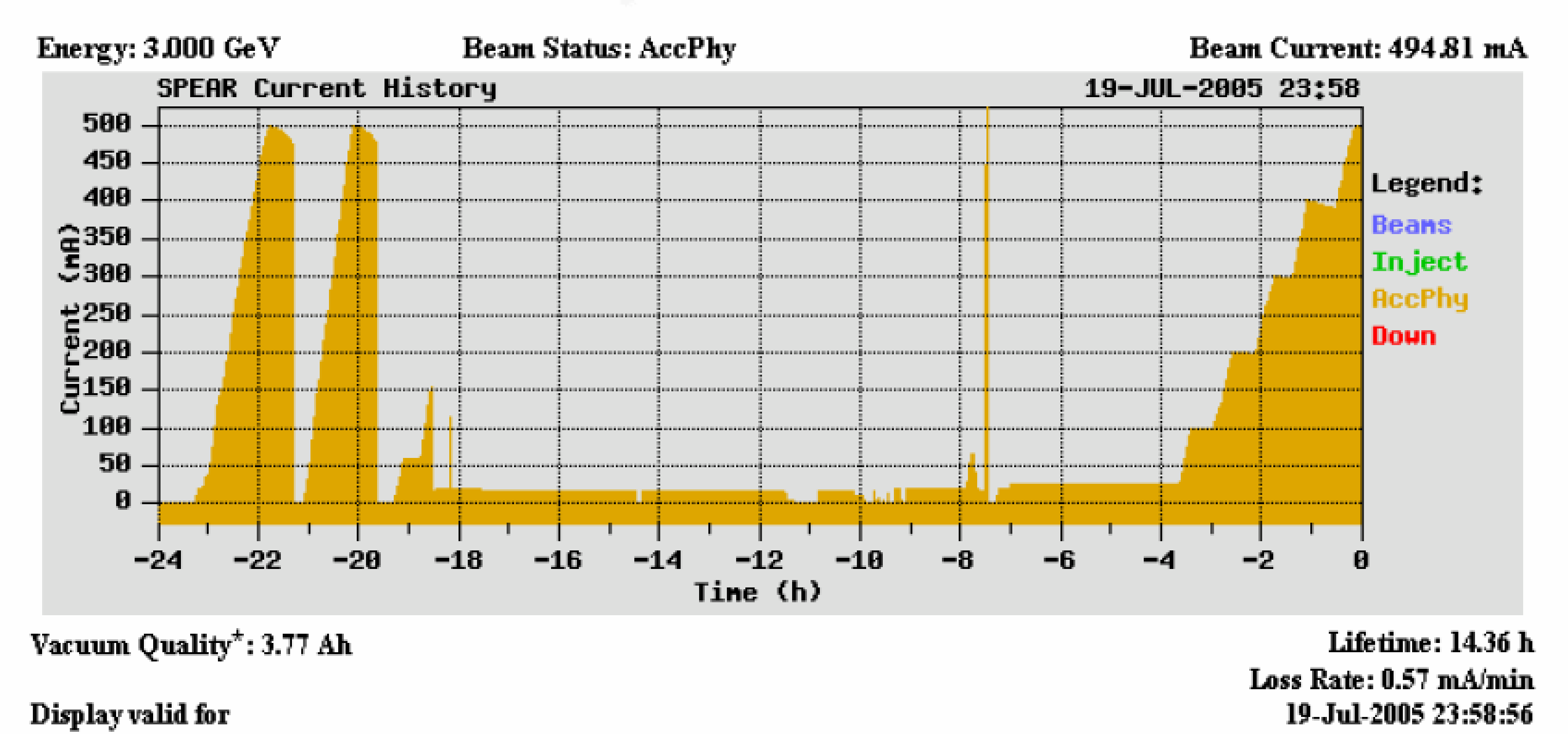
* A variable attenuator sets the RF power to the Gun at 0~6 MW. For normal injection, the power level is set at 3.0 MW.

* For higher Linac beam energy we need another klystron, which will power the third linac section.

* With the thermionic cathode RF gun, the long-term effect of back-bombardment is inevitable.

* For stability and reliability the klystron is driven by a solid-state amplifier rated at 1.0 kW output power.

500 mA Stored on 19 July 2005



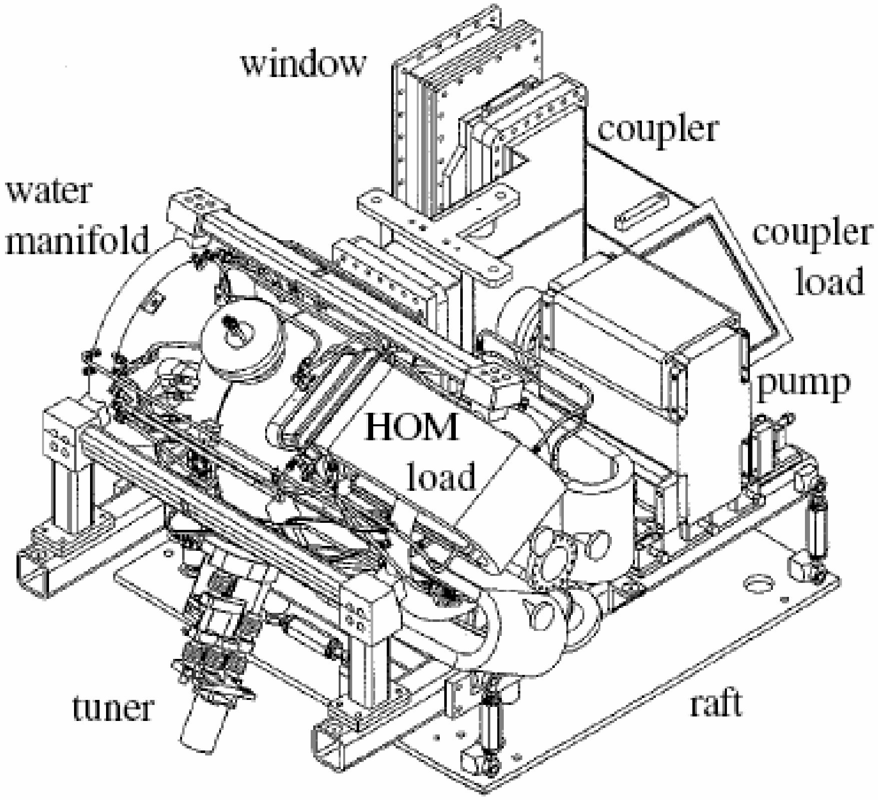
Only one beamline was open for this test.

RF Power Balance at 500 mA Stored

Current (mA) at 3.20 MV gap	0	100	200	300	400	500
Klystron output Power (kW)	496	564	625	692	759	830
Fwd power (kW) to 1 cavity	123	138	155	172	189	208
Refl power (kW) off 1 cavity	37.6	29.6	22.0	16.2	11.2	7.23
Cavity window temp* (deg.C)	36.9	48.3	50.6	51.8	53.5	56.3
Klystron window air (deg.C)	59	69	74	77	81	85
Klystron beam voltage (kV)	71.3	73.3	75.3	77.8	79.9	82.3
Klystron beam current (A)	18.5	19.3	20.0	21.0	21.8	22.8
Klystron collector power (kW)	825	845	882	943	986	1048
HVPS primary current* (A)	95.9	99.6	104	109	113	118
Total power (kW) to load 2&3	142	110	97	76	58	42

The cavity window temperature is for the hottest one. HVPS primary is 12.47kV, 3 phase, and the current is per phase. The RF power to other loads are small (9.5 kW or less at the circulator load, and less than 1.0 kW at the first magic-T load). All the insertion devices were fully closed. The above data is from 02-Feb-2006.

HOM Dissipation at 500 mA Stored



RF power dissipation is negligible at HOM loads and at coupler load.

Injector RF (Top-Off Goal)

- Presently the stored current is limited to 100 mA.
- In 8 hours the current decays to about 85 mA. It takes two minutes to replenish the lost portion. All BLs are closed during the injection.
- Eventually, increase the stored current from 100 to 500 mA and
- Inject as often as necessary to keep the current above certain level required by the user experiments, with all BLs left open.

To achieve these goals:

- The injection efficiency must be improved.
- The Gun/Linac system must produce more charges at higher energy.
- The Booster RF system is adequate in terms of power and stability

Beam Losses from Linac to Spear

• Linac Beam at 110 MeV	1.03 nA
• Linac to Booster (LTB) Injection Loss	14%
• First Turn in Booster	0.89 nA
• Booster Capture Loss	25%
• Booster Beam Ramped t0 3.00 GeV	0.67 nA
• Extraction to Booster to Spear (BTS)	50%
• Beam to Spear	0.33 nA
• Spear Injection Loss	25%
• Spear Accumulation	0.25 nA (19 mA/min)

To increase the Linac beam current and energy,

- Thermionic cathode RF Gun is to produce more current
- One klystron is to be added for higher beam energy

Higher Current & Beam Energy from Linac

- Without excessive beam loading, the beam energy E_{gun} from the RF Gun is

$$E_{gun}\ (\mathrm{MeV}) = 2*(P_{rf}/\mathrm{MW})^{0.5}$$

- With the present WG network, the RF power to the Gun P_{rf} is

$$P_{rf} = 0.14*P_{Kly}*\alpha,$$

where P_{Kly} is the klystron output power and α is 0.001~1.0 as set by the waveguide attenuator.

- The beam energy gain ΔE per linac section is

$$\Delta E\ (\mathrm{MeV}) = 10.7*(P_{rf}/\mathrm{MW})^{0.5}$$

- There are 3 linac sections at the Injector

- One SLAC 5045 klystron can produce as much as 60 MW

Improving the Booster RF HVPS Reliability

- Better maintenance:

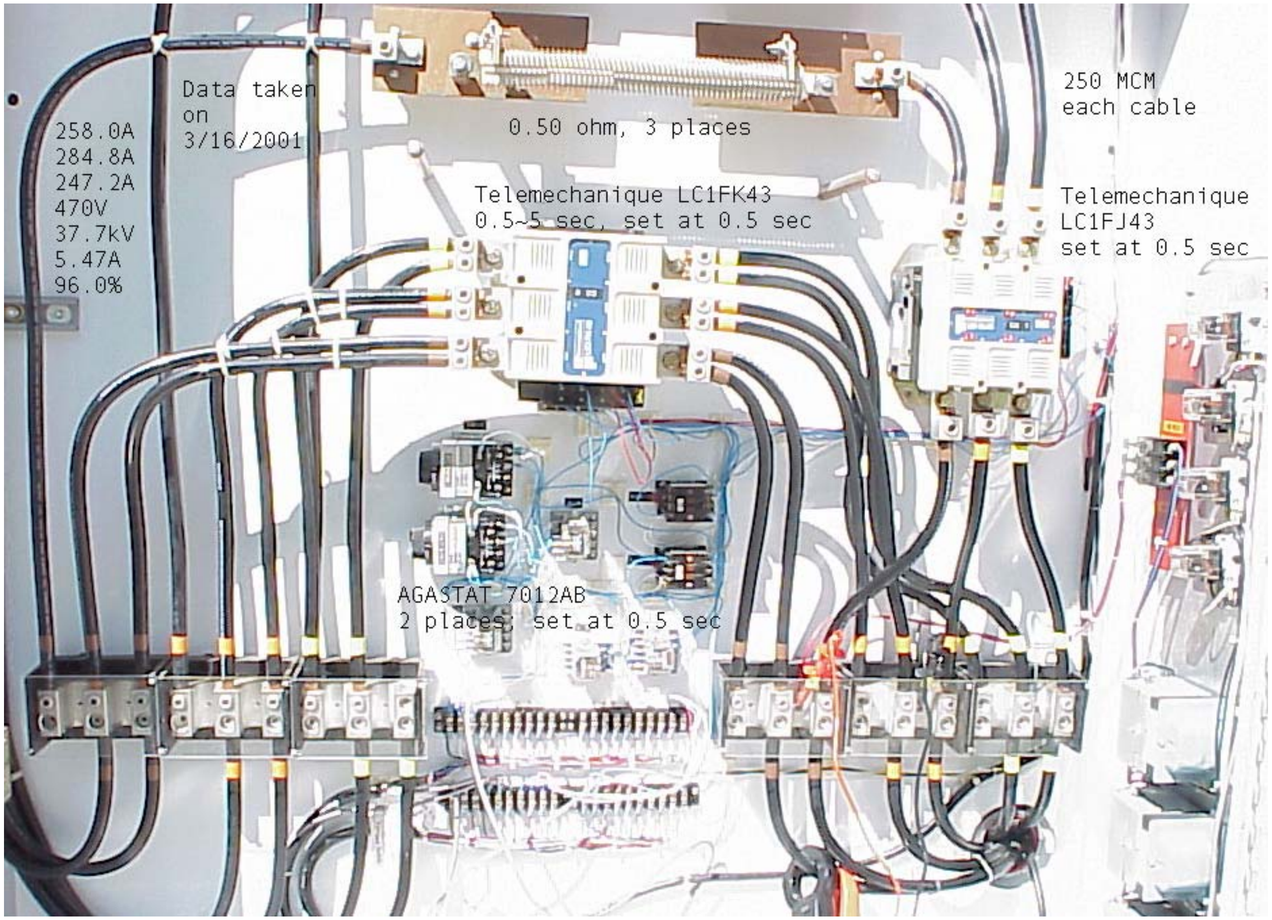
  Modify diode modules for higher current capability
  Ensure tight HV and high current connections
  Reliable forced air cooling of the transformer

- Better monitoring:

  Primary 3 phase current through current toroids
  PS temperature and annual transformer oil tests

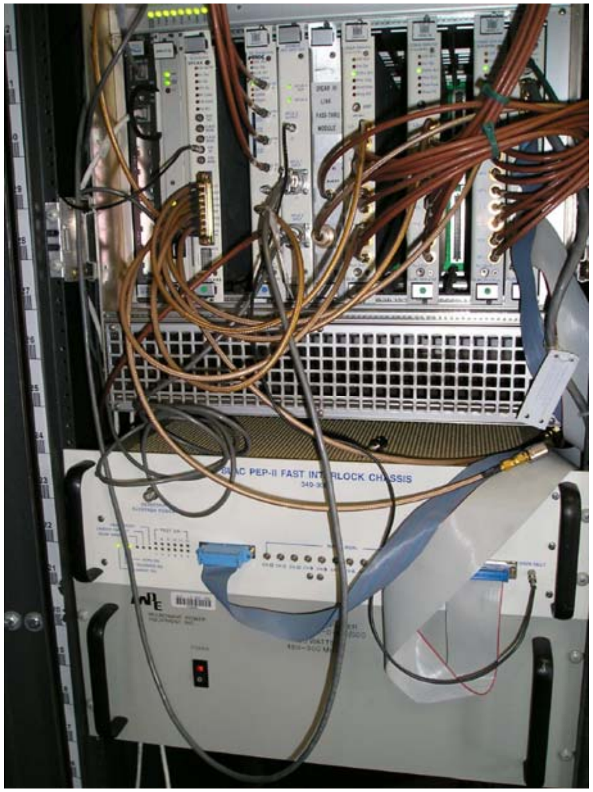
Booster RF HVPS (6 phase 47kV, 7.0A) rectifier diode stack

Booster RF HVPS Soft-Start



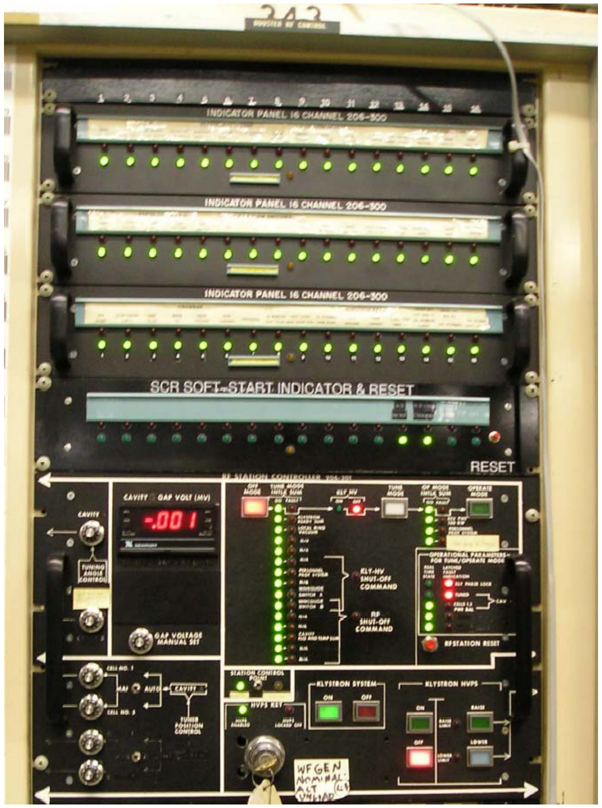
The primary 480 volt is connected to the Booster RF HVPS through 0.5Ω resistors for the first 0.5 second to limit the in-rush current.

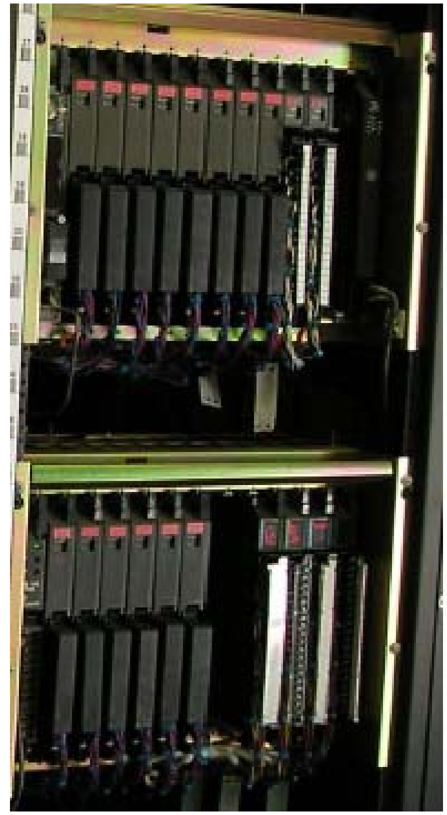
LLRF, Booster and Spear



LLRF systems at Booster (left, analog, NIM) and Spear (right, digital, VXI). The Booster LLRF has been stable and reliable. Also, there are enough spares from decommissioned Spear2 RF.

Interlocks, Booster and Spear





RF interlock systems at Booster (left, relay-based) and Spear (right, PLC-based). The PLC modules monitor temperatures and voltages.

HP RF Source: Klystron, SSA, IOT, etc

- The Booster RF klystron has been stable and reliable.
- There are two working spares from decommissioned Spear2
- The RF HVPS (480 volt 3 phase primary, up to 47 kV 7.0A output) needed the step-up transformer rewinding and rectifier diode replacements in every few years.
- The Booster RF frequency of 358.5 MHz is not included in the TV broadcast bands (UHF or VHF).
- If a solid-state amplifier rated at 35 kW cw is available, there will be no need for RF HVPS.
- If an IOT is available at the right frequency and power, and the HVPS is attached to it, it will be a good replacement for the existing klystron

PEP2 RF System Performance

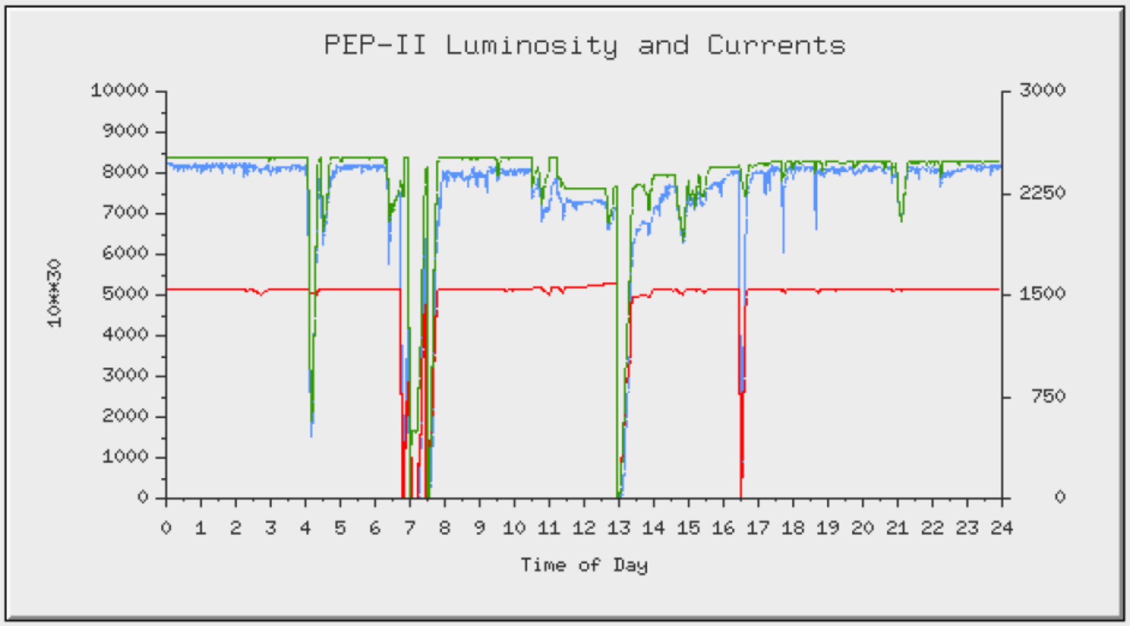
on a relatively good day

I HER	I LER	Luminosity	Spec Lum	E HER	E LER	E CM
1550.04	2488.89	8147	3.64	8985	3120	10589
mA	mA	10**30/Sec	N*10**30 / mA**2/Sec	MeV	MeV	MeV

HER N Buckets / Pattern
1722 0:3442:2

LER N Buckets / Pattern
1722 0:3442:2

Last Owl/Day/Swing/24hr	195.0	204.0	225.7	624.7	Shift:	1.46 /pb
Peak Luminosities	8284	8196	8248			8239



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PEP2 RF System Performance

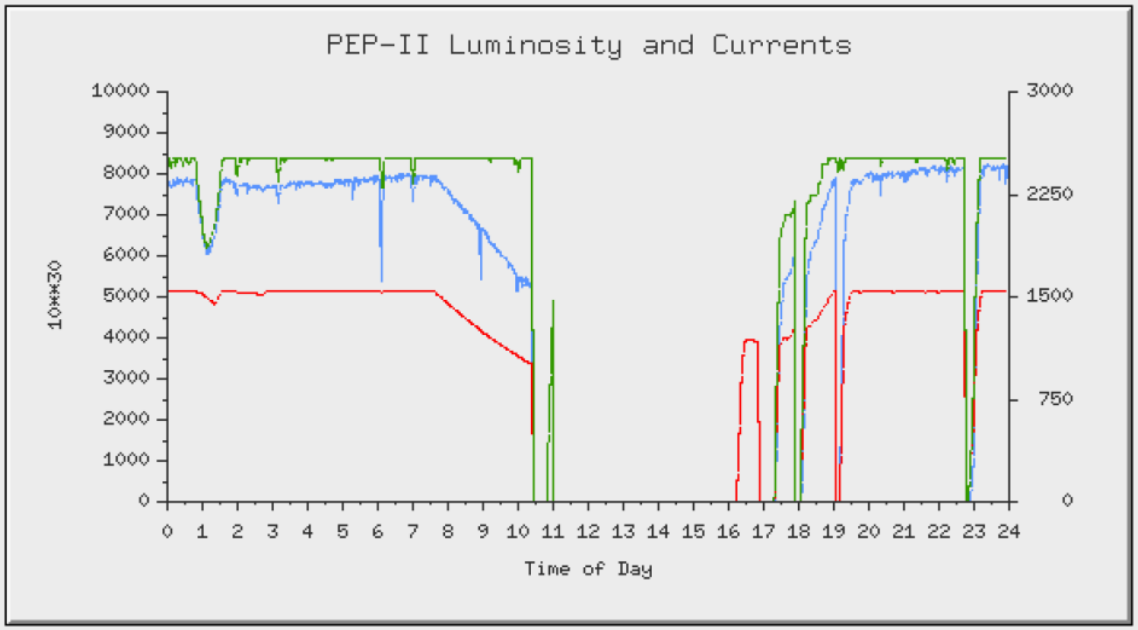
on not such a good day

I HER	I LER	Luminosity	Spec Lum	E HER	E LER	E CM
1549.87	2519.80	8197	3.61	8985	3120	10589
mA	mA	10**30/Sec	N*10**30 / mA**2/Sec	MeV	MeV	MeV

HER N Buckets / Pattern
1722 0:3442:2

LER N Buckets / Pattern
1722 0:3442:2

Last Owl/Day/Swing/24hr	221.4	56.3	152.3	430.0	Shift:	1.48 /pb
Peak Luminosities	8047	7647	8280			8260



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Spear3 and PEP2 RF Systems

- The Spear3 RF system is modeled after PEP2 RF C_{PEP2}=2199.32m).
- At 476.3 MHz the Spear RF freq is higher than PEP2 by 0.316 MHz.

  All the RF subsystems are interchangeable between the two.
- There are 13 RF stations (15 by April 2007) above the PEP2 ring.

  10 (12) klystrons are built by SLAC, 2 by Philips & 1 by Marconi.
- The PEP2 operation is to be finished by the end of 2008.

  Then the RF systems will be decommissioned.
- Those at PEP2 will then become spares for Spear3 RF.

  Subsystem testing/calibration/modification becomes practical.

RF System Summary

• The RF system performed satisfactorily at the Linac, Booster and Spear for the 100 mA user beam operation, with three fills per day.

• The Spear3 RF system capability has been successfully verified when the Spear ring stored 500 mA.

• The Linac system needs more RF power (thus another klystron) to increased the beam energy, which will improve injection efficiency.

• The Booster RF system will undergo modifications in interlocks and RF HV power supply for better reliability, especially in top-off mode.

• There will be a continuing effort to improve the hardware and software arrangement at the Spear3 RF system to make it more robust.

• Spear3 will benefit from the PEP2 RF operational experience and other RF resources.