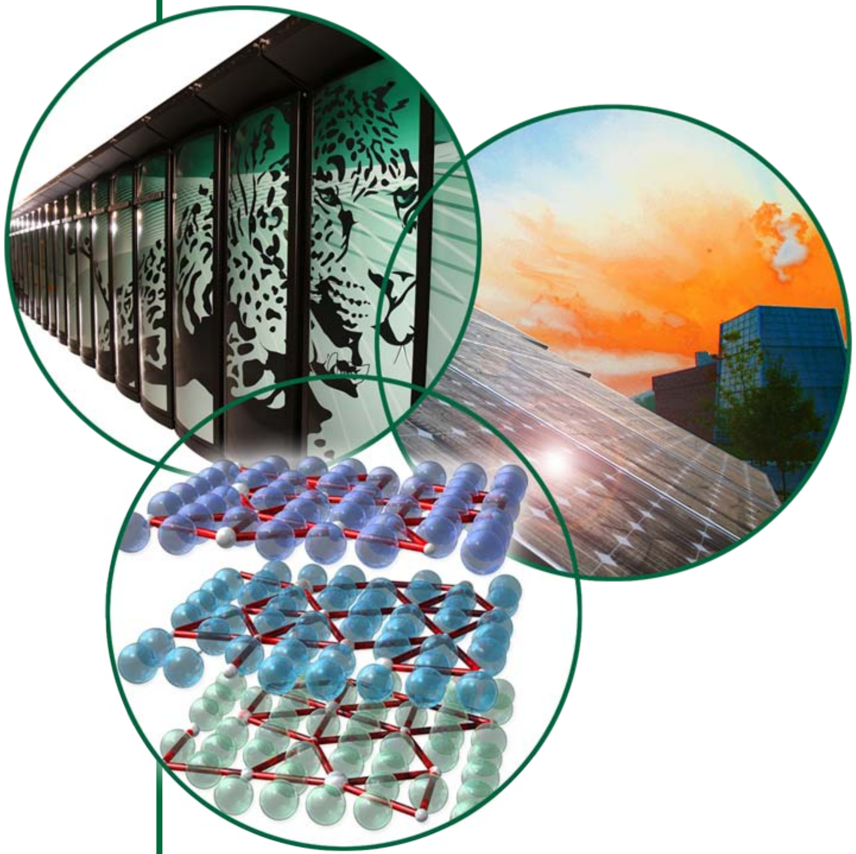
SNS Power Upgrade Plan



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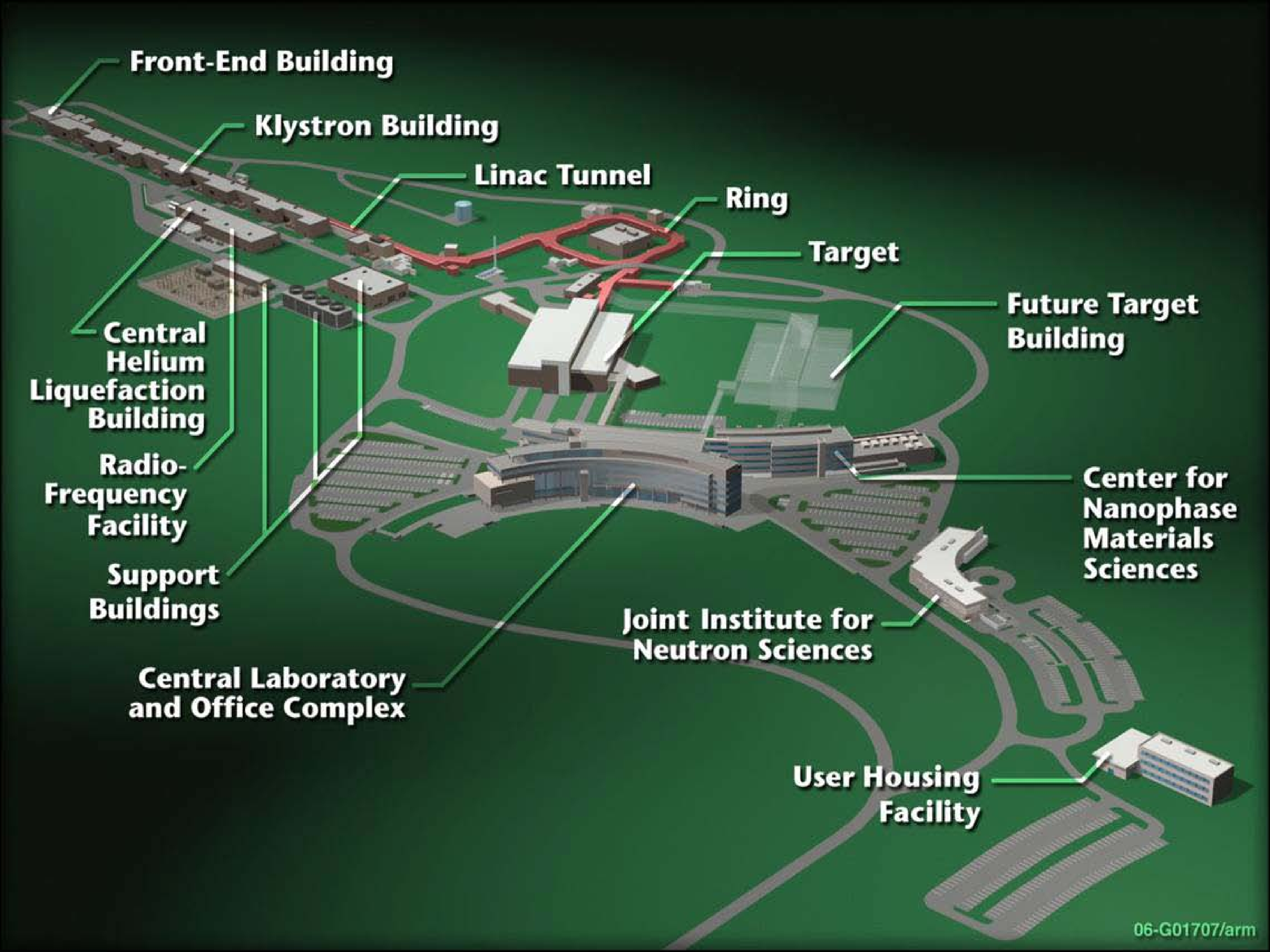
U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Outline:

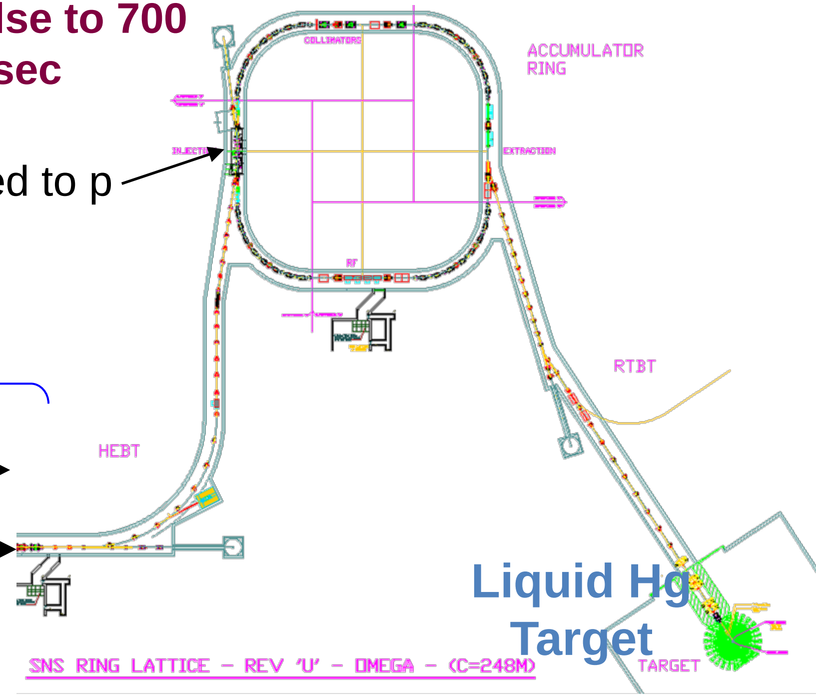
- SNS Facility
- Operational Status
  - Operational Metrics
  - Linac Performance
- Power Upgrade Plan
  - Ion Source
  - Linac Energy Upgrade
- Progress Towards PUP
  - Cryomodule Fabrication
  - Plasma Processing Plans

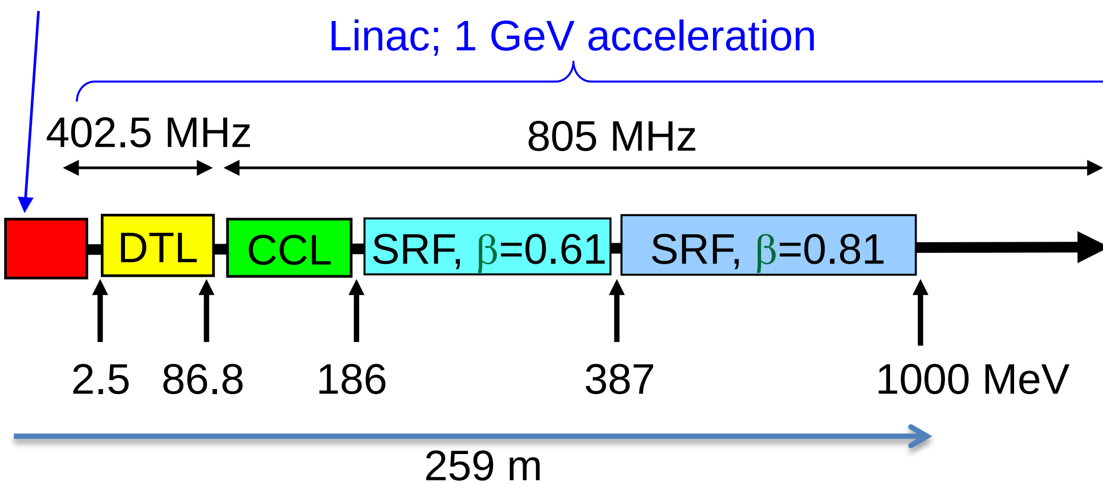

Front-End Building
Klystron Building
Linac Tunnel
Ring
Target
Future Target Building
Central Helium Liquefaction Building
Radio-Frequency Facility
Support Buildings
Central Laboratory and Office Complex
Center for Nanophase Materials Sciences
Joint Institute for Neutron Sciences
User Housing Facility
06-G01707/arm

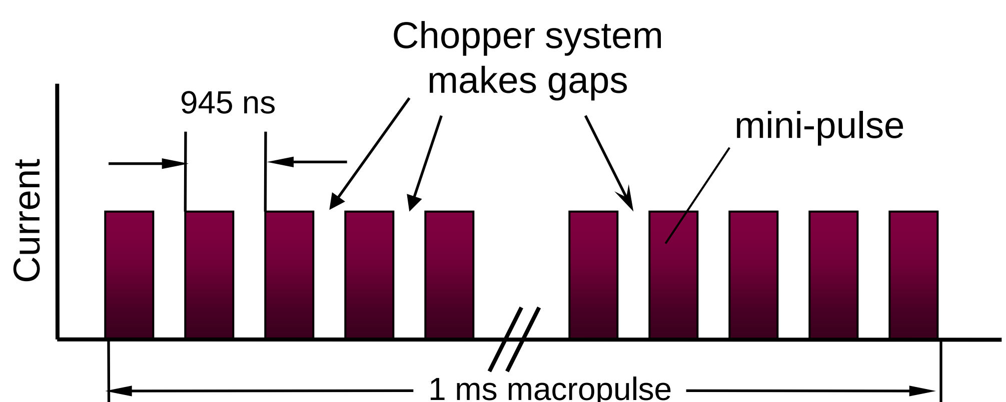
Machine layout

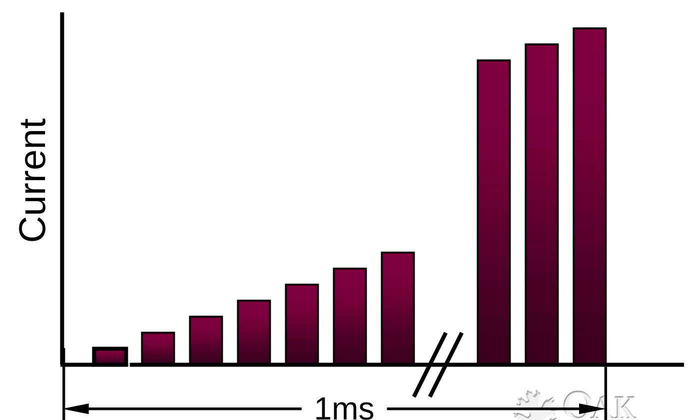
Accumulator Ring: Compress 1 msec long pulse to 700 nsec

Front-End: Produce a 1-msec long, chopped, H- beam





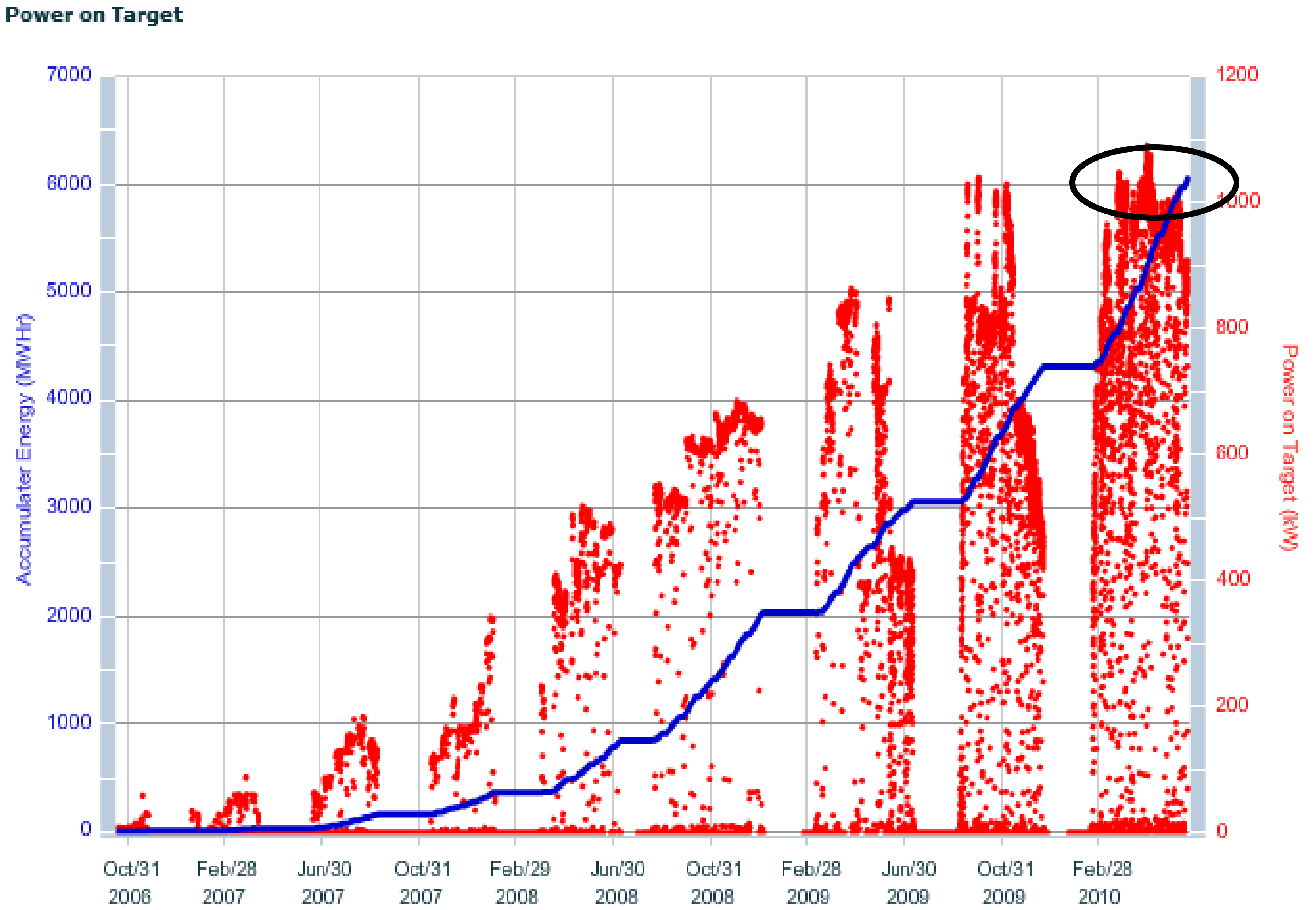




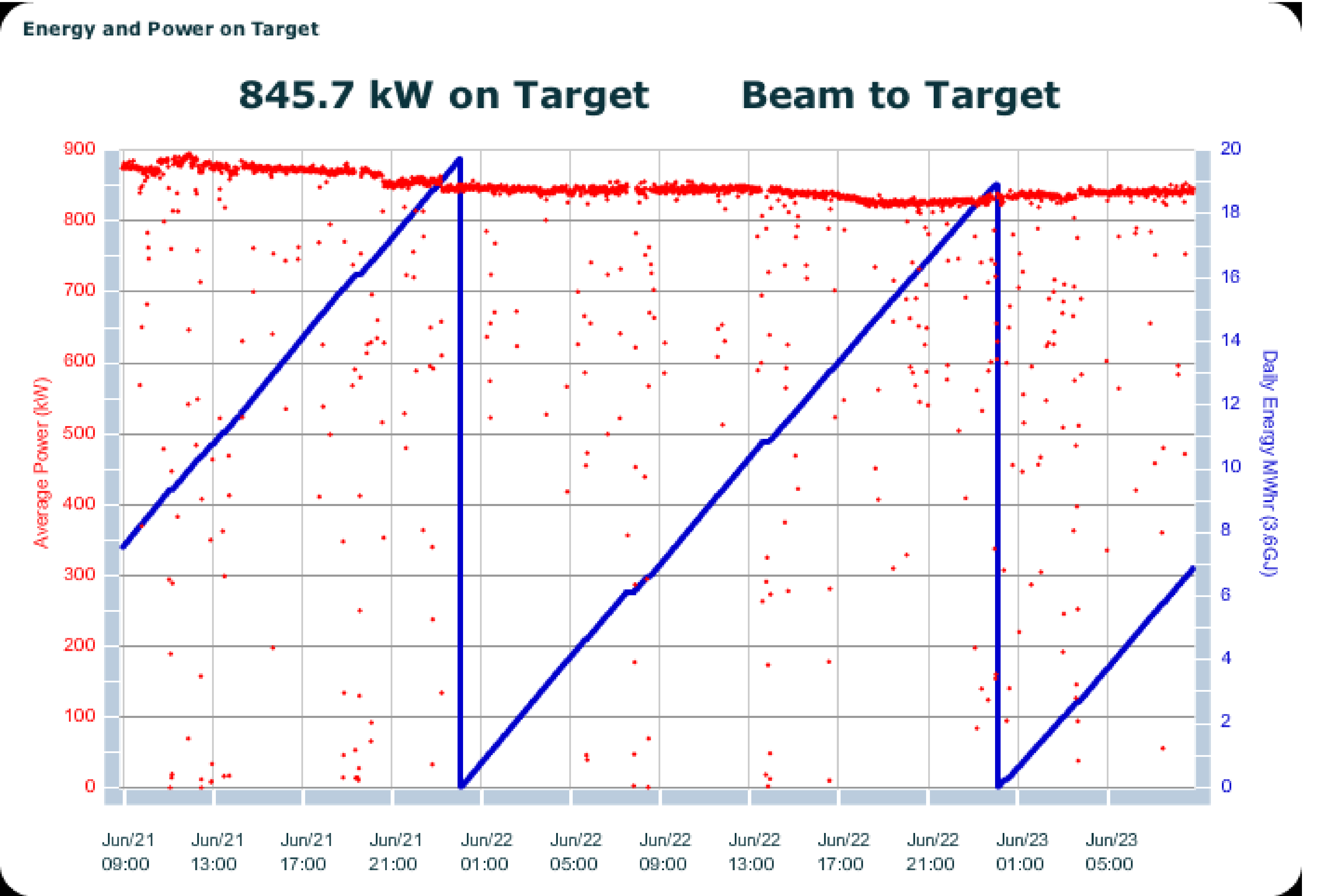
SNS Performance Relative to Design

	Design	Best Ever	Routine Operation
Kinetic Energy [GeV]	1.0	1.01	0.93
Beam Power [MW]	1.4	1.03	1.03
Linac Beam Duty Factor [%]	6	5	5
Modulator/RF Duty Factor [%]	8	7	7
Peak Linac Current [mA]	38	42	42
Average Linac Current [mA]	1.6	1.1	1.1
Linac pulse length [msec]	1.0	1.0	0.80
Repetition Rate [Hz]	60	60	60
SRF Cavities	81	80	80
Ring Accumulation Turns	1060	1020	825
Peak Ring Current [A]	25	26	18
Ring Bunch Intensity	1.5×10^{14}	1.55×10^{14}	1.1×10^{14}
Ring Space Charge Tune Spread	0.15	0.18	0.12

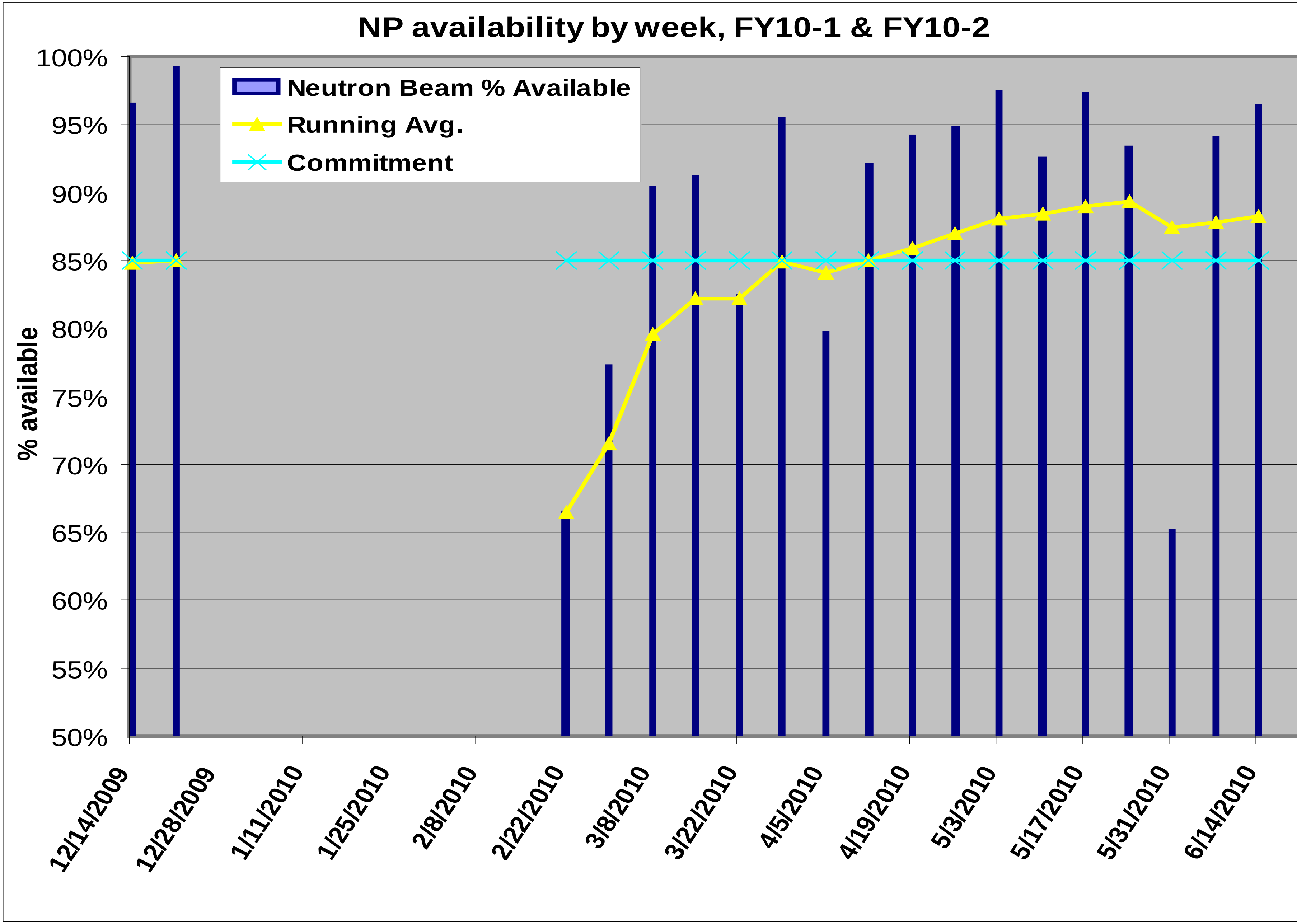
Beam Power Ramp-up:



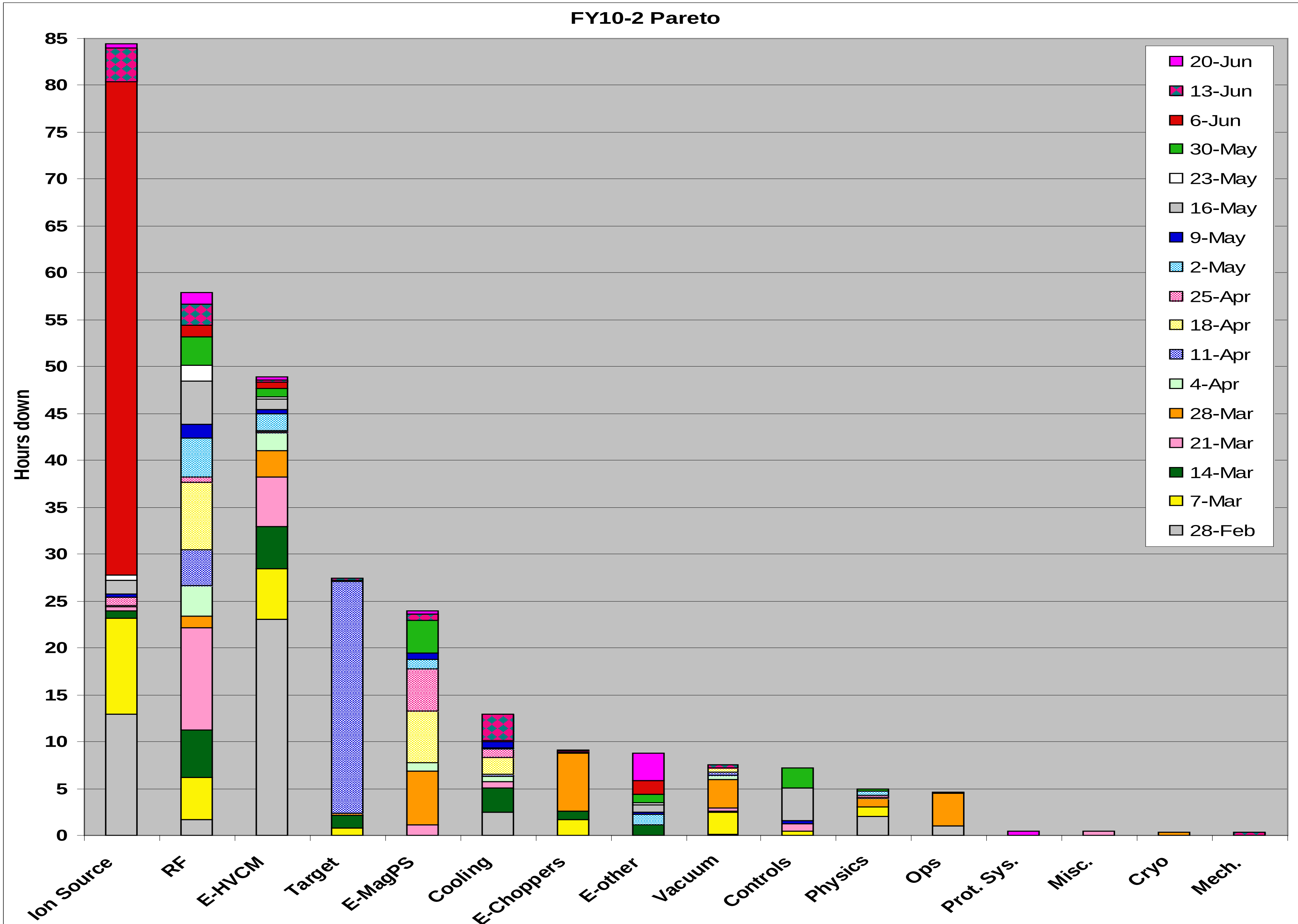
Beam On Target:



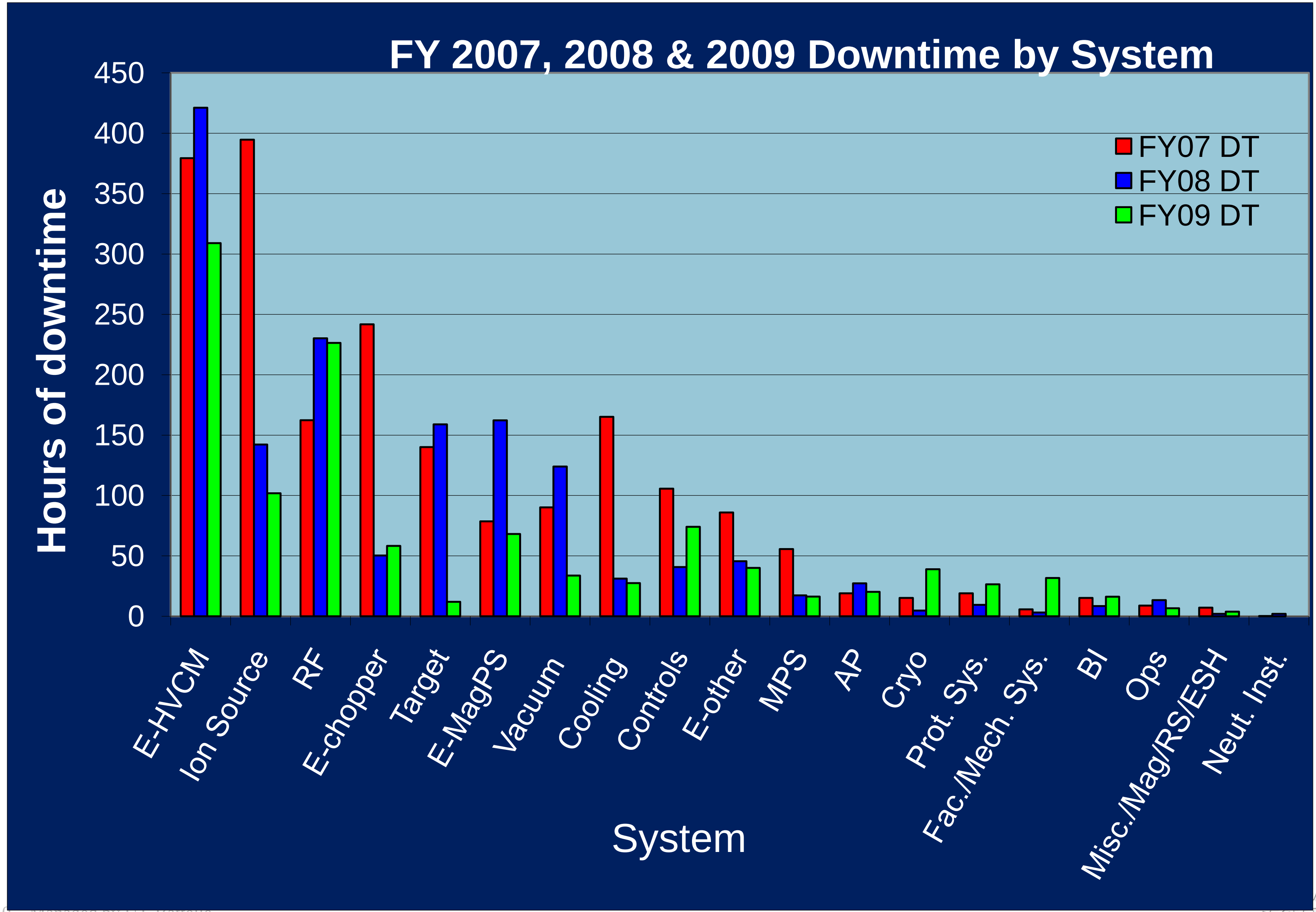
Beam Availability:



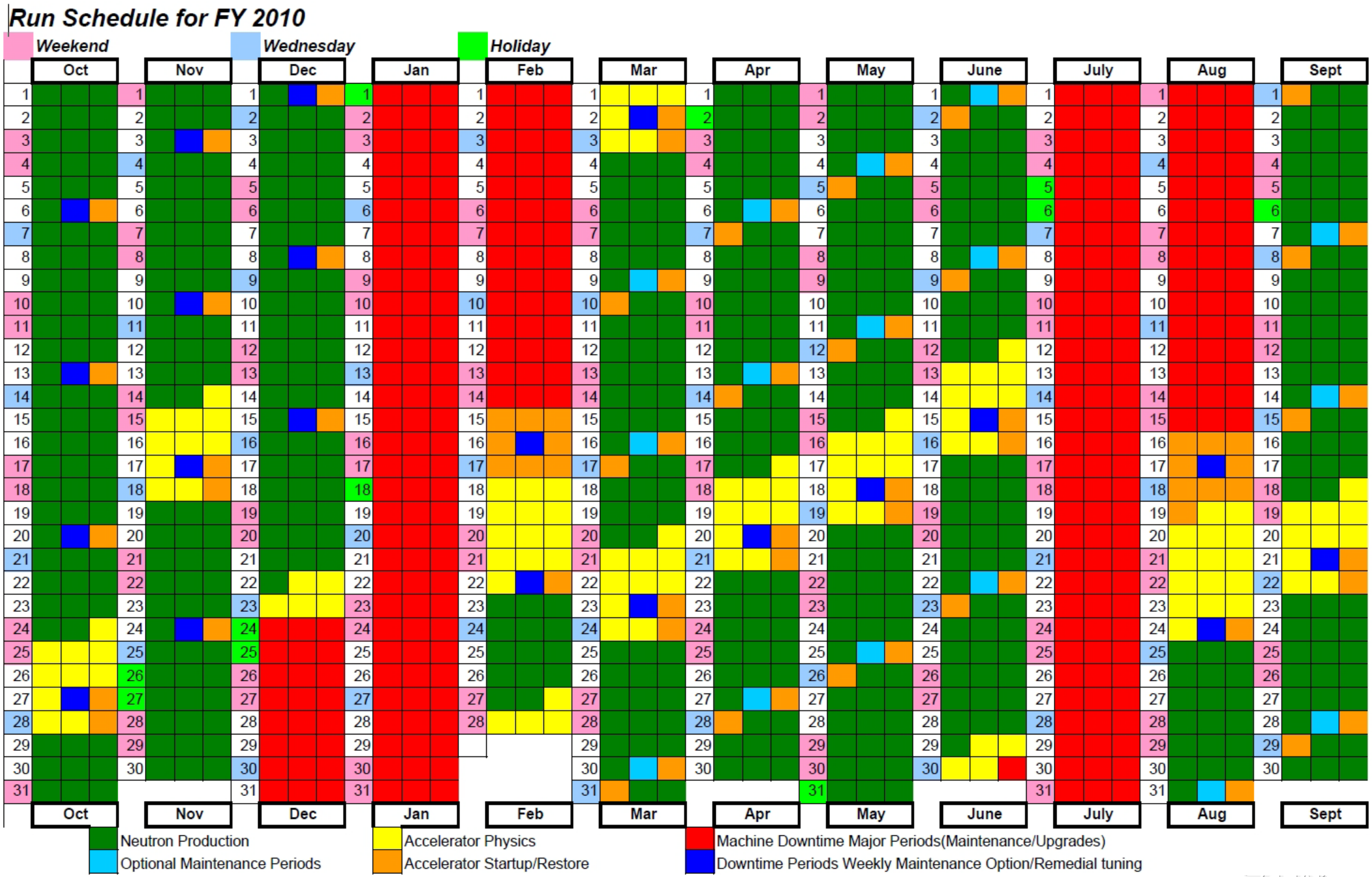
Down Time Pareto Chart 2010:



Down time by systems

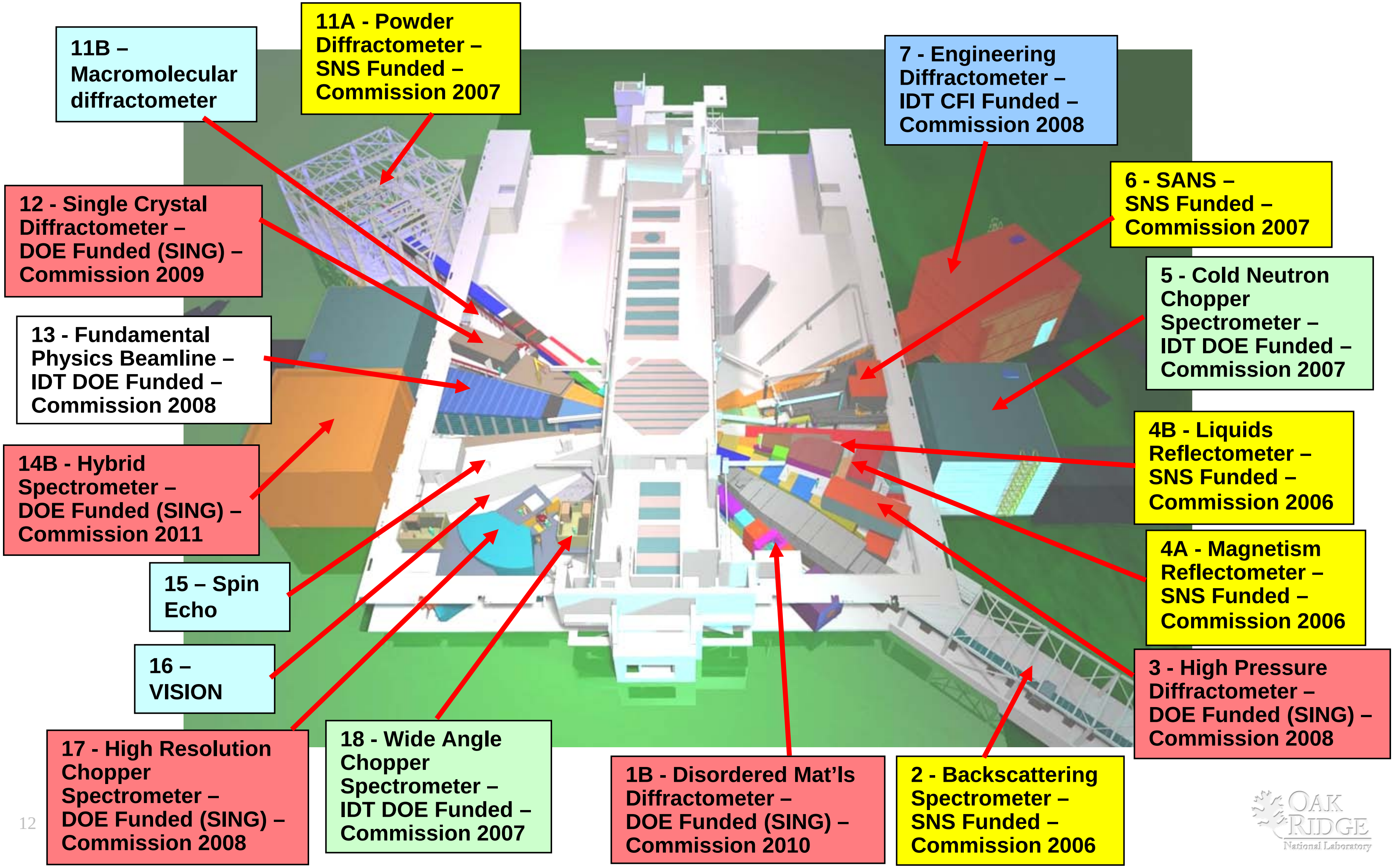


FY10 Run Schedule:



- Red = extended maintenance, Yellow = physics, Green = production

Neutron Instruments
13 are in operation, 3 more will be in 2012



SNS Upgrade:

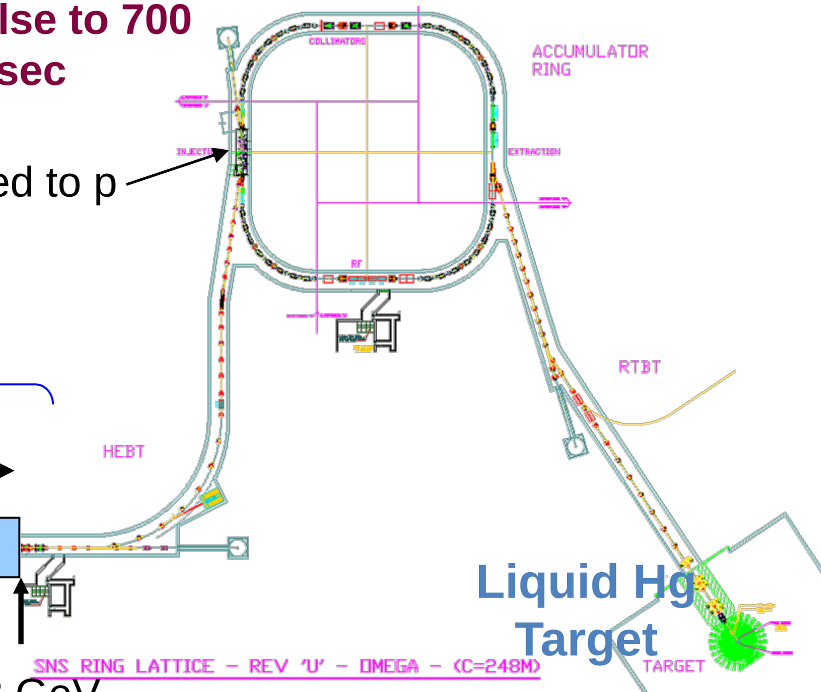
- PUP = Linac Upgrade
  - DOE funding CD1 Status
  - Linac energy increased from 0.93 GeV to 1.3 GeV
- CUAIP = Ion Source Current Increase
  - R&D supported by Accelerator Improvement Project funded
  - Avg current increased from 26mA to 42mA
- Second Target Station

Machine layout

Accumulator Ring: Compress 1 msec long pulse to 700 nsec

Front-End: Produce a 1-msec long, chopped, H- beam 42mA Avg.

H- stripped to p



Liquid Hg Target

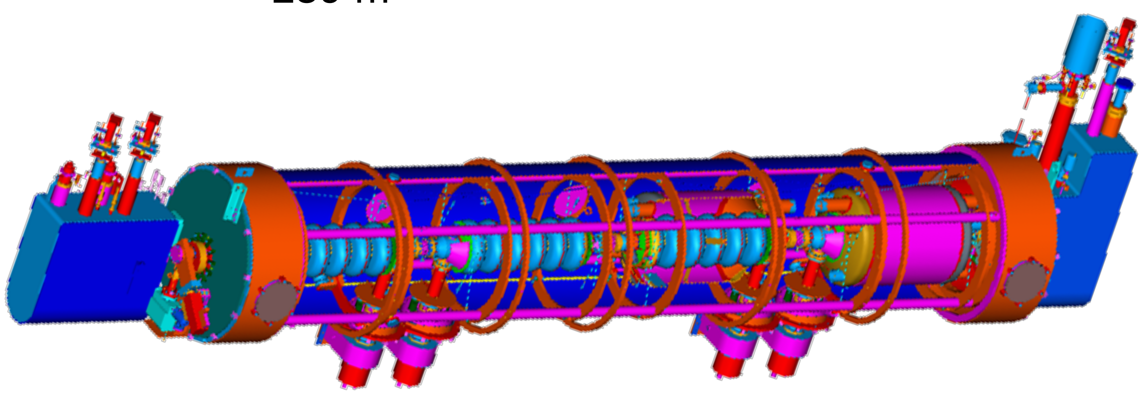
Linac; 1.3 GeV acceleration

402.5 MHz | 805 MHz

DTL | CCL | SRF, β=0.61 | SRF, β=0.81 | PUP

2.5 | 86.8 | 186 | 387 MeV | 1 GeV | 1.3 GeV

259 m

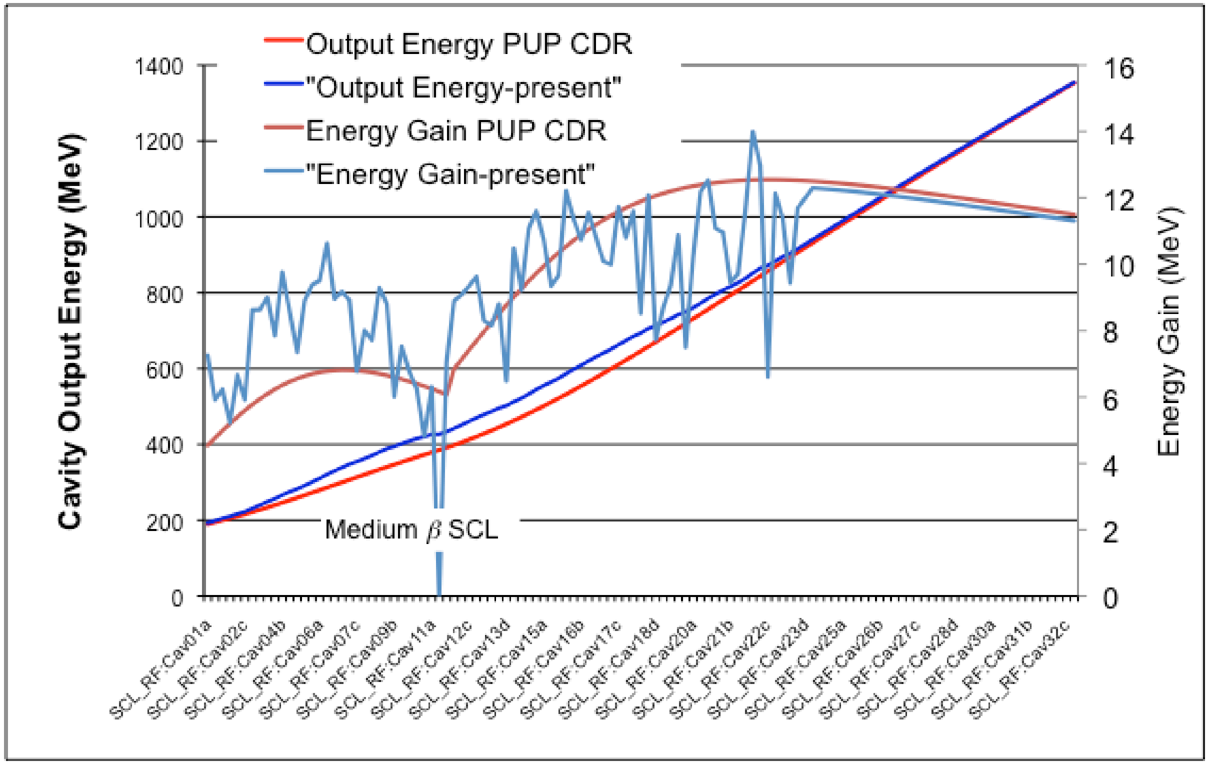


PUP Requires 9 new HB cryomodules (36) cavities

Power Upgrade Project (PUP)+ Accelerator Improvement Project (AIP)

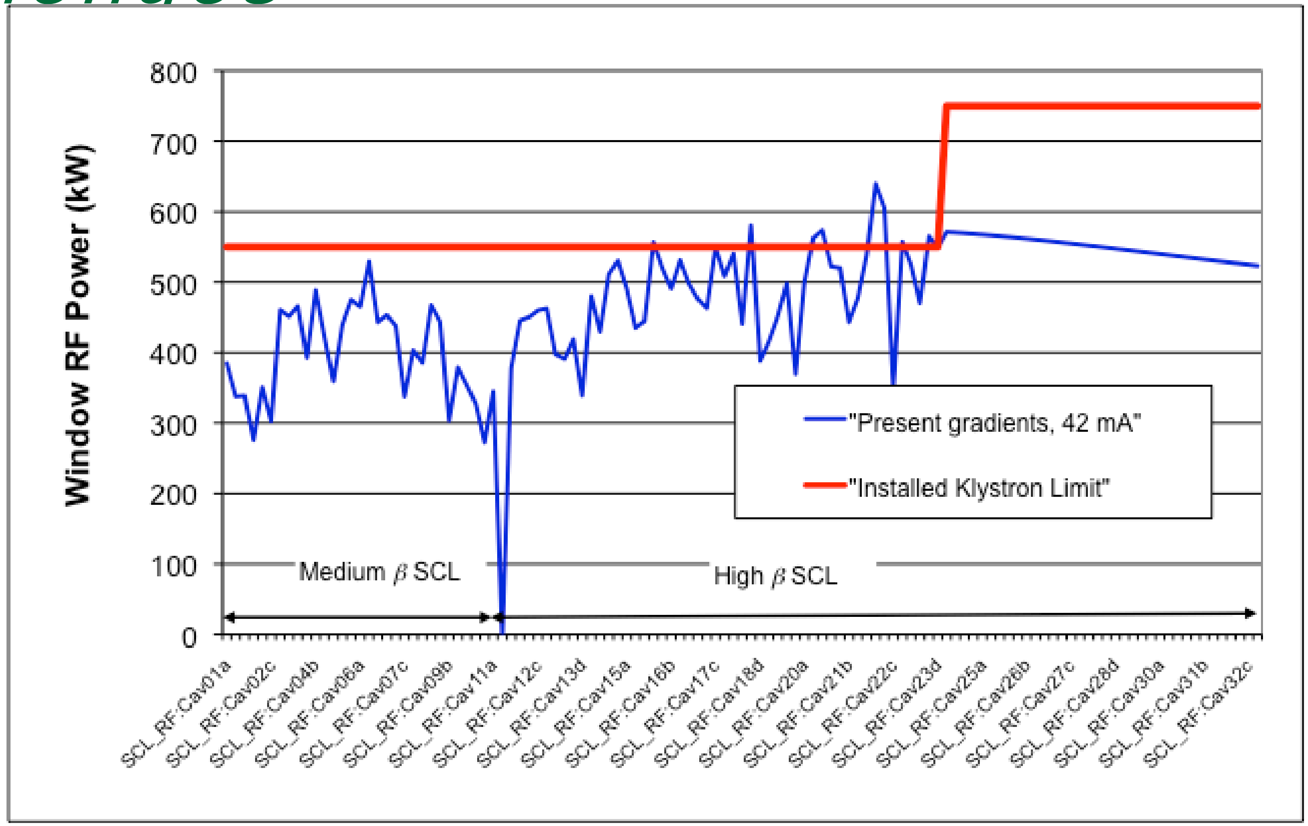
Parameter	SNS Baseline	Power upgrade
Kinetic energy [MeV]	1000	1300
Beam power [MW]	1.4	3.0
Chopper beam-on duty factor [%]	68	70
Linac beam macropulse duty factor [%]	6.0	6.0
Average macropulse H- current, [mA]	26	42
Peak macropulse H- current, [mA]	38	59
Linac average beam current [mA]	1.6	2.5
SRF cryo-module number (medium-beta)	11	11
SRF cryo-module number (high-beta)	12	12+8 (+1 reserve)
SRF cavity number	33+48	33+80 (+4 reserve)
Peak surface gradient (b=0.61 cavity) [MV/m]	27.5 (+/- 2.5)	27.5 (+/- 2.5)
Peak surface gradient (b=0.81 cavity) [MV/m]	35 (+2.5/-7.5)	31
Ring injection time [ms] / turns	1.0 / 1060	1.0 / 1100
Ring rf frequency [MHz]	1.058	1.098
Ring bunch intensity [10^{14}]	1.6	2.5
Ring space-charge tune spread, DQ_{sc}	0.15	0.15
Pulse length on target [ns]	695	691

Superconducting Linac, Energy: Where Are We Now? ... *Good shape*



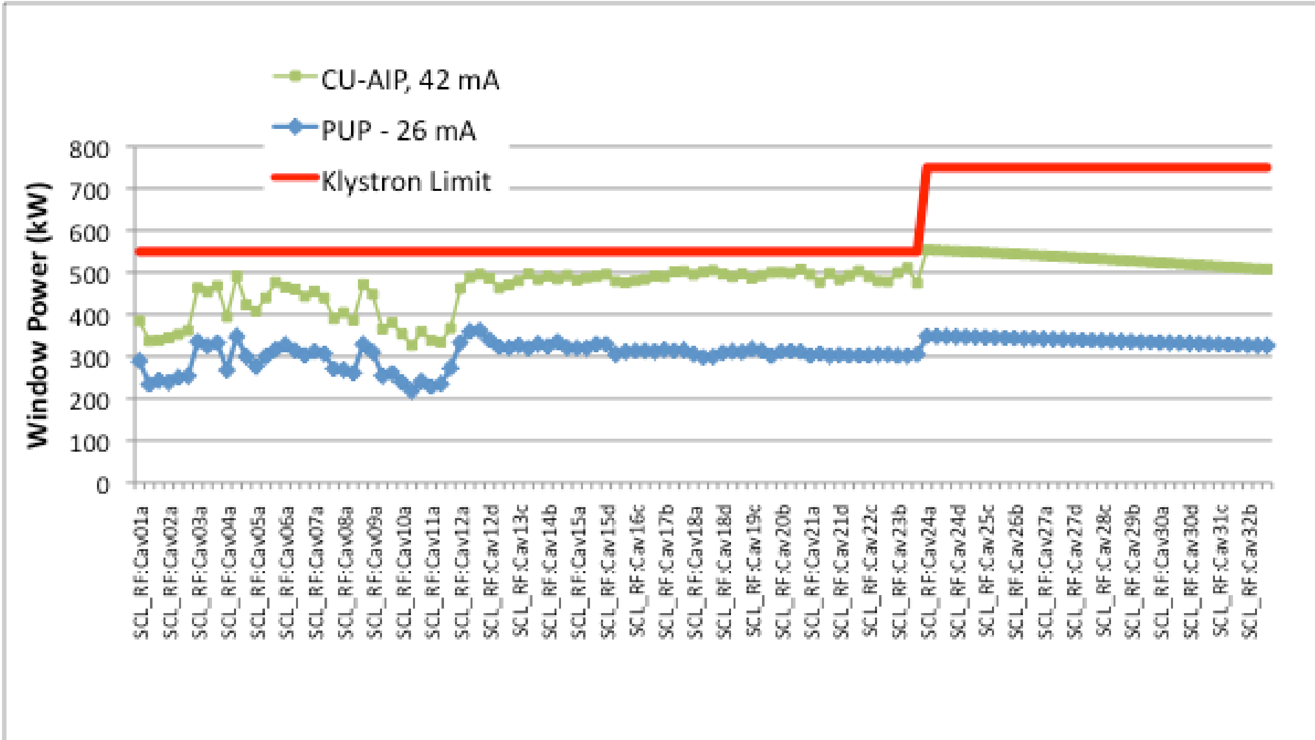
- Existing average high beta cavity gradient is close to that needed to reach 1.35 GeV with 9 additional cryo-modules
  - New high beta cavities need E_{acc} = 14 MV/m
  - Present high beta average = 12.8 MV/m, PUP CDR assumed 13.8 MV/m

Superconducting Linac, RF Power: Where Are We Now? …*For CUAIP some challenges*



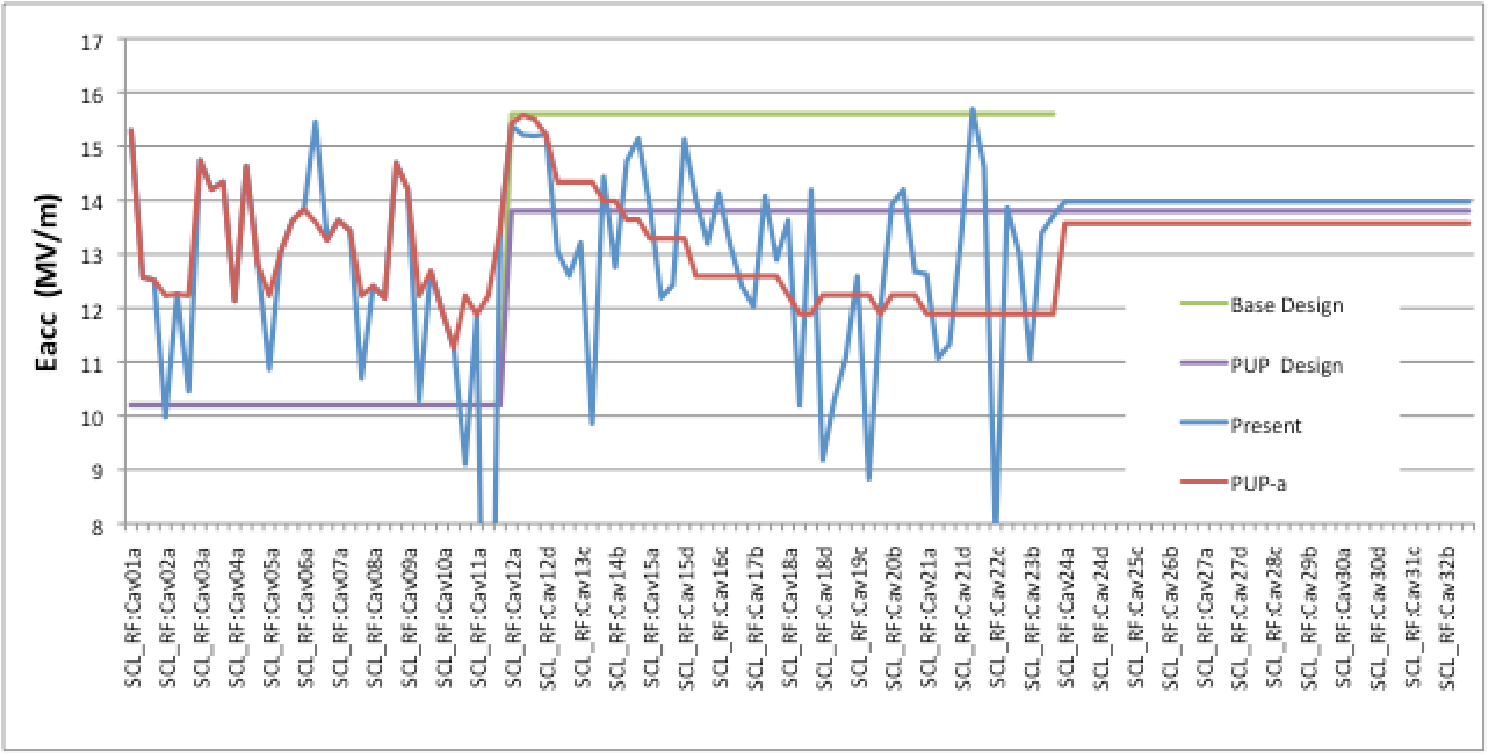
- Simply running cavities as we do today presents RF challenges at higher currents
  - Klystrons, couplers

Superconducting Linac: RF Power



- Minimize the RF Impact for higher current
  - Plasma process the poor performing cavities
  - Decrease gradients of higher performers
- New cavities should be capable of operating at higher power

SCL Gradients: Strategy to Minimize Impact of Higher Power



- Tailor the operational voltage to minimize the impact on the RF power requirements
  - Needs improvements of some existing cavities (plasma processing)
  - New cavities will operate at higher gradients than existing ones

CUAIP-3 MW Design Requirements

SNS Parameter List	Present SNS	SNS Power Ramp Up	SNS Power Upgrade Project
Time	2010-2	2014	
Proton beam power on target (MW)	1.0	1.4	3
Beam kinetic energy on target (GeV)	0.925	~1.0	1.3 (+38%)*
Pulse repetition rate (Hz)	60	60	60
Ion type (Front end, Linac, HEBT)	H^-	H^-	H^-
Average linac macropulse H- current (mA)	~23 mA	26	42
Peak linac macropulse H- current (mA)	35-40 mA	38	59 (+55%)$
Ring filling time (ms)	~0.83	1	1
Ring filling fraction (%)	~60	68	70
Availability (%)	88	92	

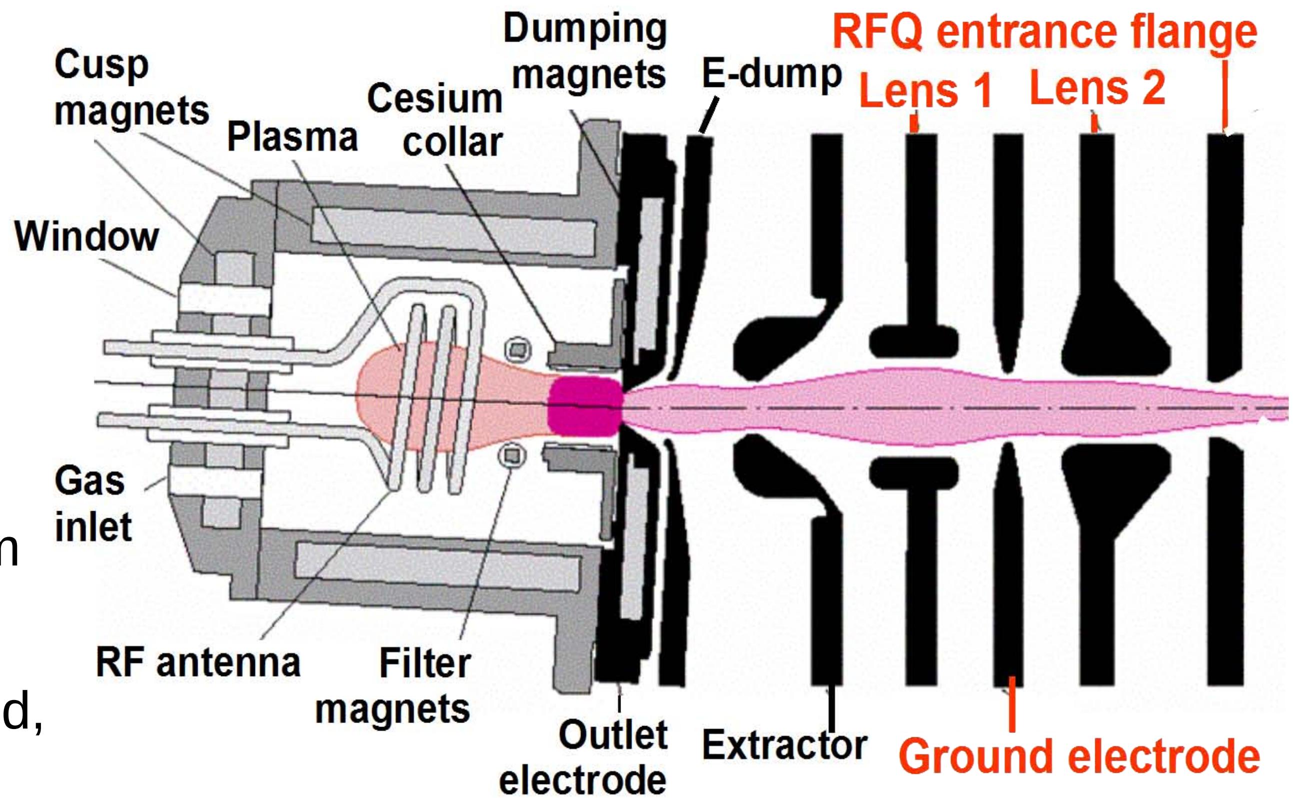
*The SNS Energy Upgrade brings SNS between 1.4 and 1.9 MW!

$AIPs bring SNS between 2 and 3 MW!

To achieve a power level between 2 and 3 MW, the LINAC beam current needs to be increased by 55% by increasing the ion source output!

The SNS Baseline Ion Source and LEBT

- LBNL developed the SNS H^- source, a cesium-enhanced, multicusp ion source.
- Typically 250 W from a 600-W, 13-MHz amplifier generate a continuous low power plasma.
- The high current beam pulses are generated by superimposing 30-70 kW from a pulsed, 80-kW, 2-Mz amplifier.

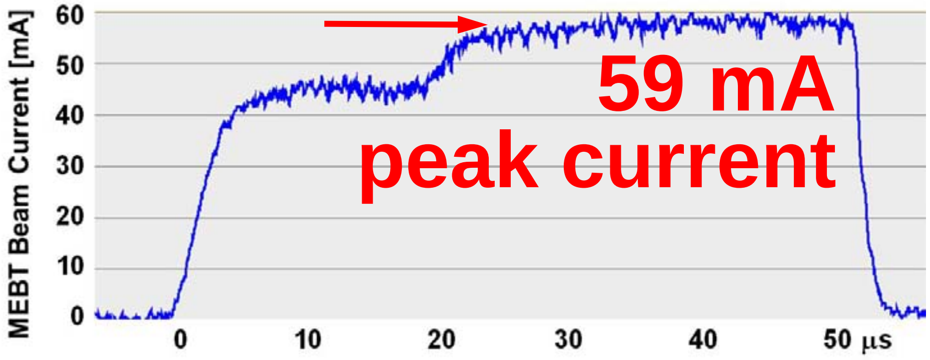


- The two-lens, electro-static LEBT is 12-cm long. Lens-2 is split into four quadrants to steer, chop, and blank the beam.
- The compactness of the LEBT does not allow for any beam characterization in front of the RFQ. The beam current is measured after emerging from the RFQ, and practically equals the LINAC beam current.

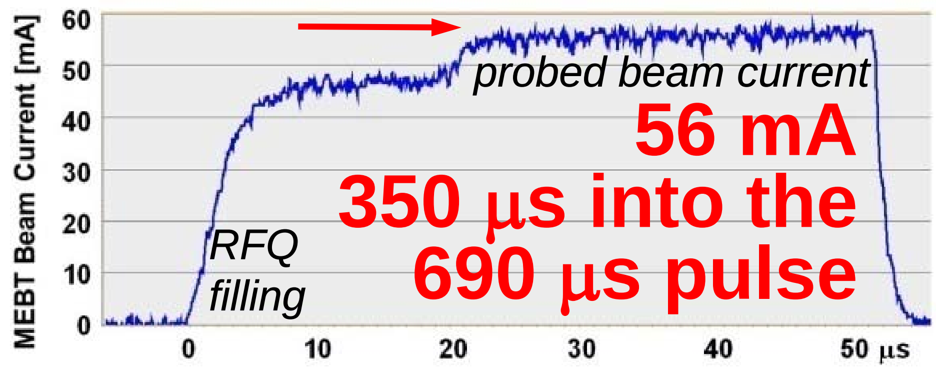
After significant modifications, our H^- source now routinely produces the 38 mA required for 1-1.4 MW operations!

Delivering 59 mA LINAC beam current

In the MEBT beam stop mode, the source is started before the RFQ. An adjustable delay allows for accelerating any 50 µs slice of the ion source pulse. It takes up to 30 µs for the feed-forward to accelerate all beam.



- On 11-3-08, after a 2-week run, we demonstrated in the MEBT for ~20 minutes 59 mA peak current and 56 mA pulse current measured halfway through 0.69 ms long pulses at 60 Hz using <60 kW of 2 MHz.

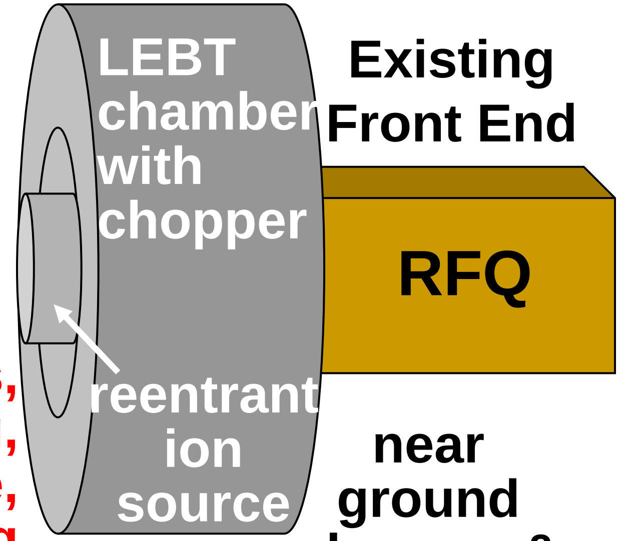


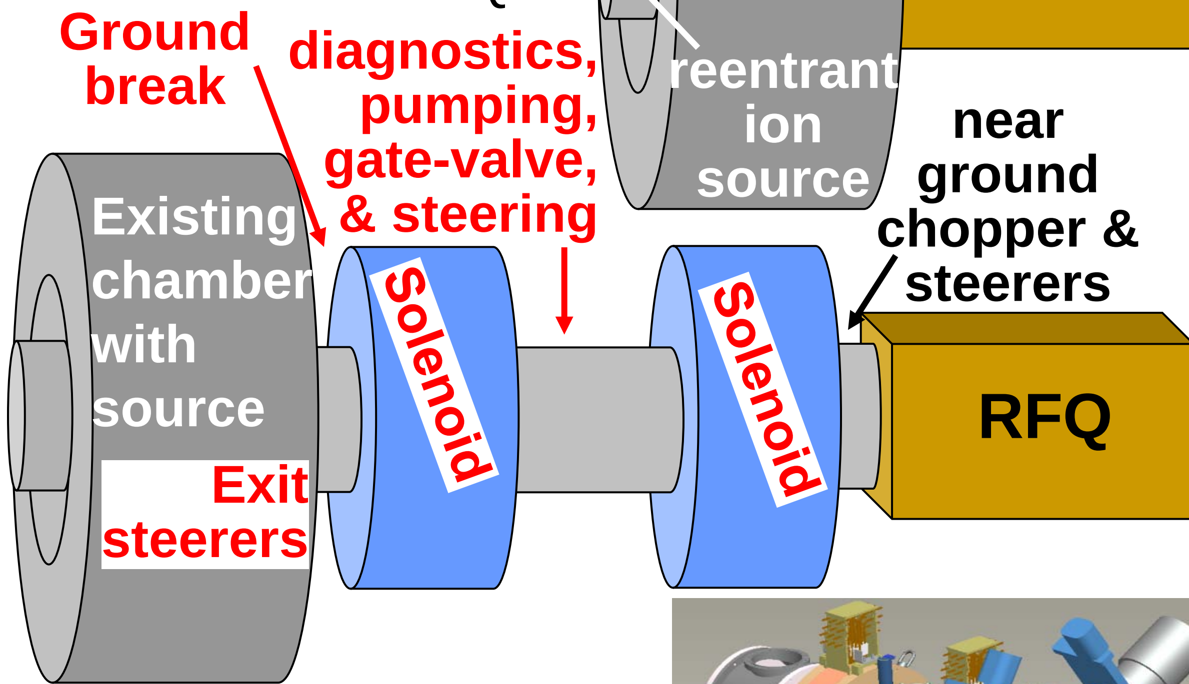
- In July 09 we produced 46 mA for 32 hours at 5.4% duty factor.
- In February 10 we produced 50 mA the day after starting up.
- We are learning how to produce such high beam currents routinely. We are working on better Cs management, better alignment, increased RF power, etc.

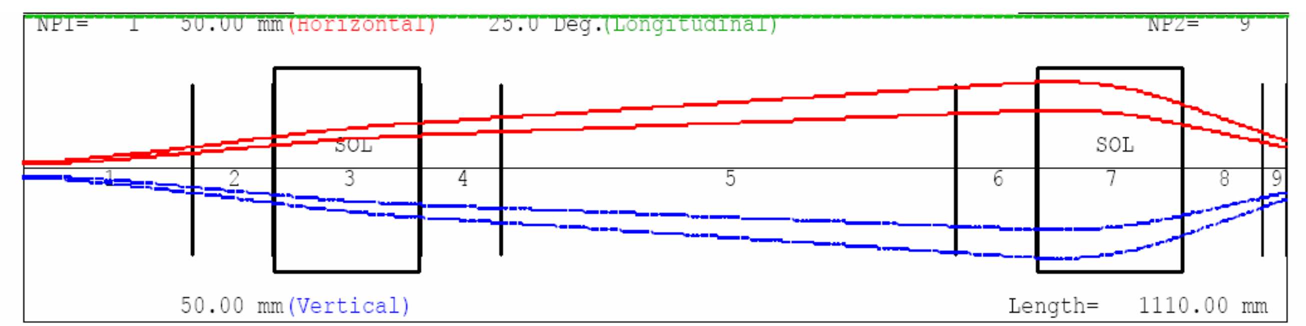
In addition, we collaborate on the development of more efficient H- sources with increased reliability!

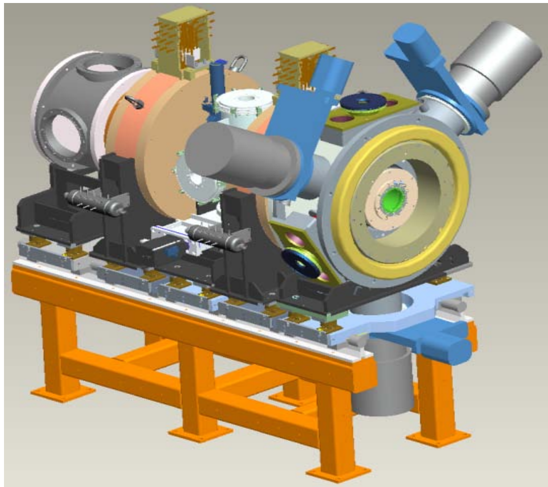
The SNS 2-solenoid LEBT

- Our passively cooled electro-static LEBT is an availability and performance risk, currently mitigated by installing a newly-aligned LEBT for each run.
- Therefore we build a 2-solenoid LEBT, which fits between the original LEBT chamber and the RFQ.
- Two solenoids feature a robust beam transport.
- Differential pumping and a gate valve help the RFQ.
- Diagnostics allows for full-power source testing.
- This combines a working chopper with a proven high-power LEBT design.
- Twiss parameters, emittance, and beam sweep times will validate the LEBT on the test stand.





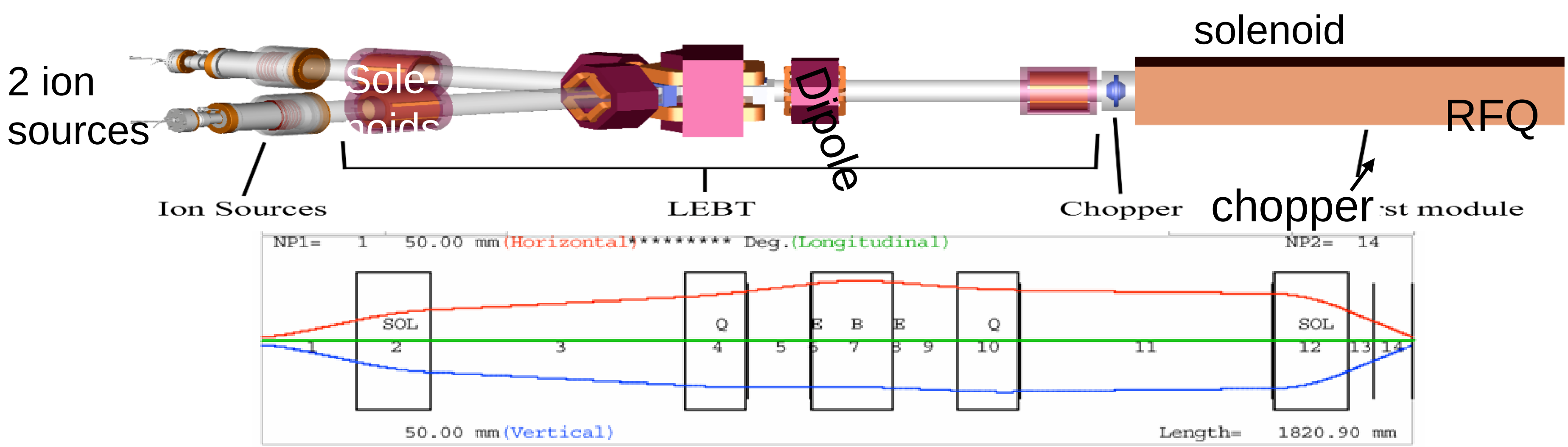




The LEBT AIP: a 2-source LEBT designed for 3 MW

When ion sources are pushed to high performance levels, the risk of premature failures increases. This is mitigated with a 2-source LEBT: when one source fails, Operations switches sources in less than 1 hour.

- Symmetry minimizes tuning: Reverse the dipole and fine tune!
- Both ion source beam lines feature full-power beam stops, emittance scanners, pumps, and vacuum gate valves: While the new source is in production, the failed source is replaced with a spare. The spare is conditioned and tuned to high performance, then turned over to Operations.
- Such source switching magnets are common, but they are normally not built to stringent requirements. A prototype is needed to proof that a low emittance beam can be bent with minimal emittance growth!



The 2 source LEBT will evolve from a 2-solenoid LEBT by inserting a Y-magnet between the solenoids!

What needs to happen for the linac!

- Currently HB cryomodules limited by field emission
  - However individual cavity performance around 17-20 MV/m , vertical test
  - Collective limits for HB at 13 MV/m average
  - Surface contamination, MP, and surface roughness all contributing to field emission

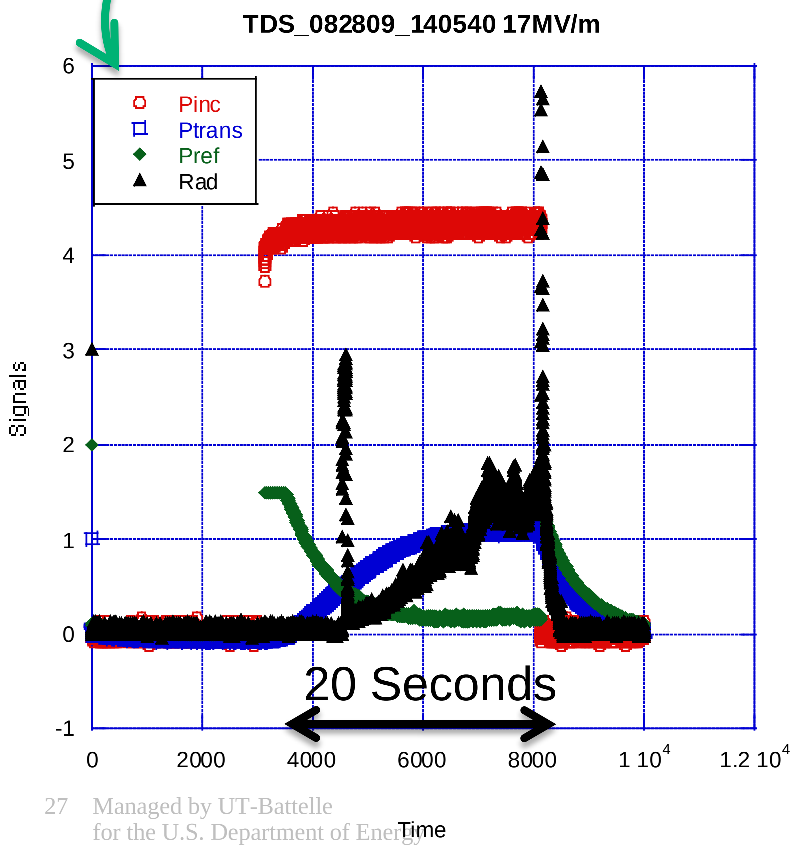
- Additionally new cryomodules for PUP will need to meet the pressure vessel code

Progress Towards PUP:

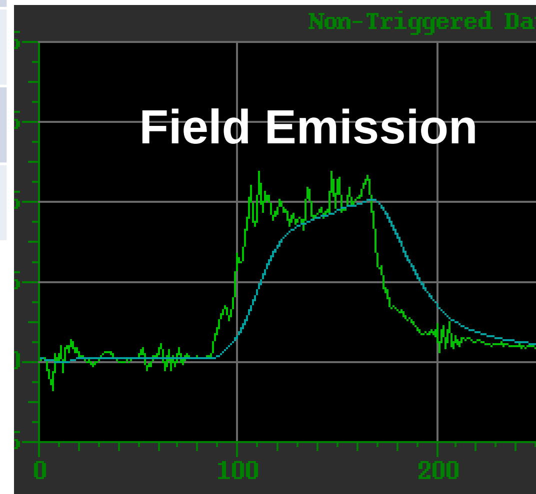
- Electropolishing HB cavities has shown significant reduction in X-rays
  - Measurement technique for vertical test shows direct correlation with installed performance for the first time
- Spare HB cryomodule in fabrication
  - Redesigned to meet pressure vessel code, pressure boundary outside now
  - Helium vessels welds modified, full penetration welds where possible
  - All new components in fabrication
- Procedure developed to remove HOM hooks in spare cavities
  - Cavity tests completed

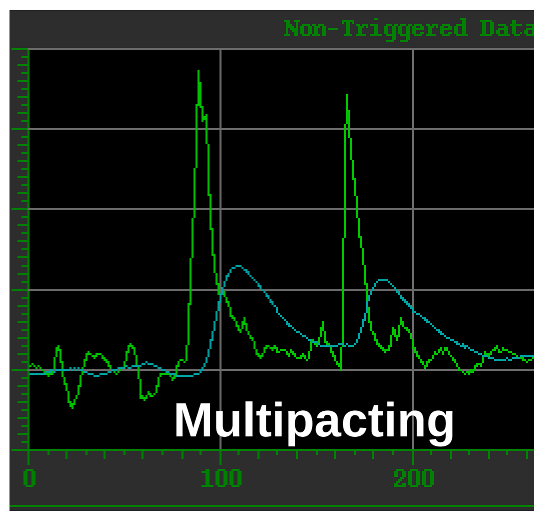
We have been improving our understanding of the vertical test data:

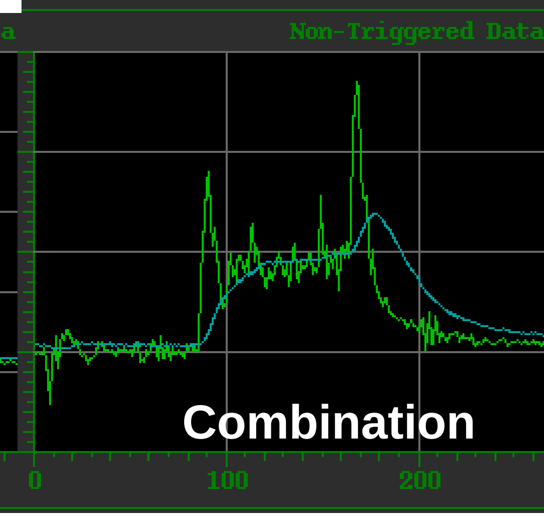
Cavity Number	Emax (MV/m)	Rad at Emax (mR/hr)
HB53	17.6	2.0
HB58	17.2	0.0
HB56	17.5	408
HB54	13.0	850



Tunnel Data RF Only



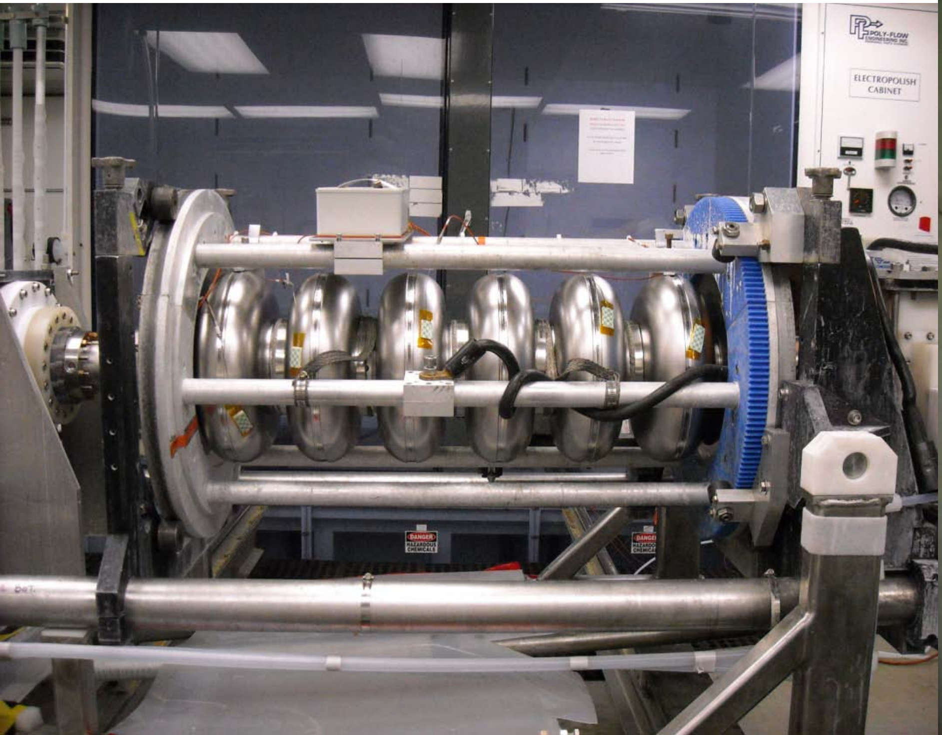




Electropolish development:

- Vertical EP used to recover 2 HB cavities at Jlab
- HOM-less cavity horizontal EP shows best performance so far --- 24 MV/m vertical test

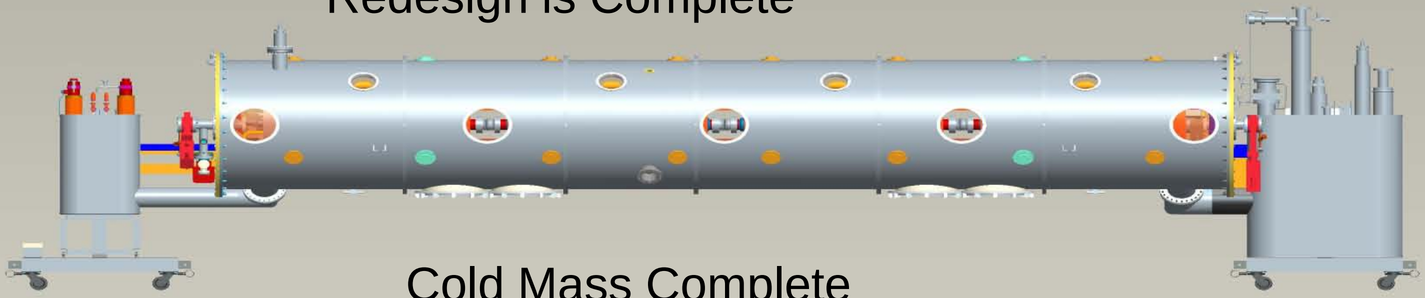
HOM-less Cavity HB57



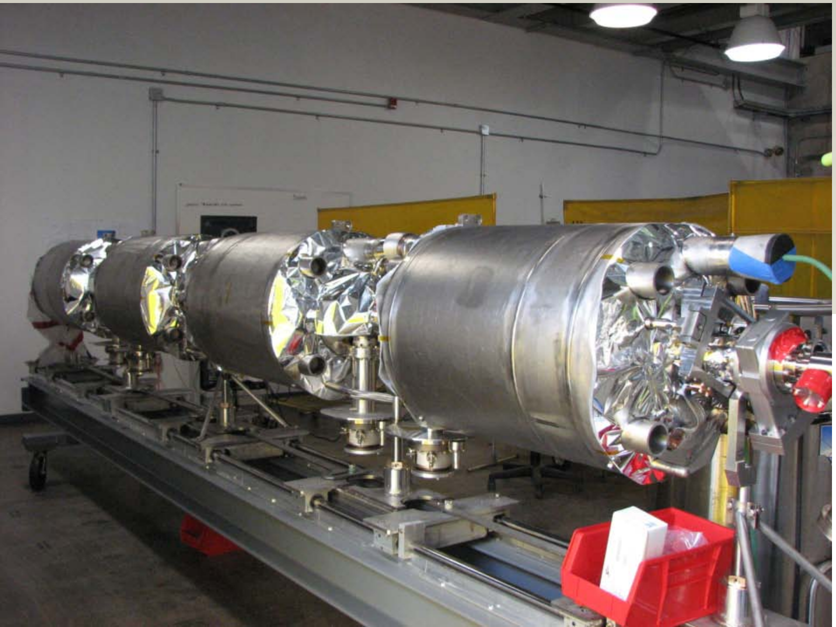
Vertical EP with HV

Spare Cryomodule Status:

Redesign is Complete



Cold Mass Complete



Progress on Plasma Cleaning:

- Small sample processing has started
- Cavity testing preparation underway
- Small sample chemistry preparation underway

Summary:

- SNS machine is running well and availability > 90%
- SNS full upgrade consist of facility, beam current and linac energy upgrades
  - PUP planning is well underway
  - R&D continues on ion source current increase and modulator reliability
- HB Cryomodule was modified for pressure vessel code
  - First spare (new design) 50% complete
  - PUP new cryomodule plan developed, heavy industry involvement

SNS is in great shape for the for PUP!!