Spallation Neutron Source RF Systems

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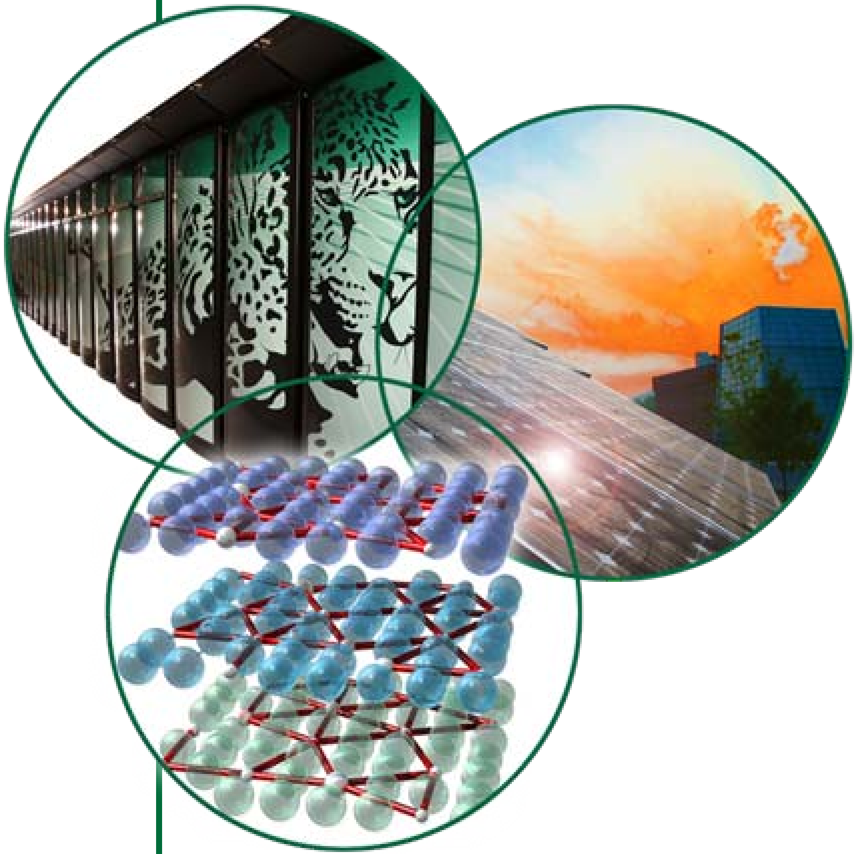


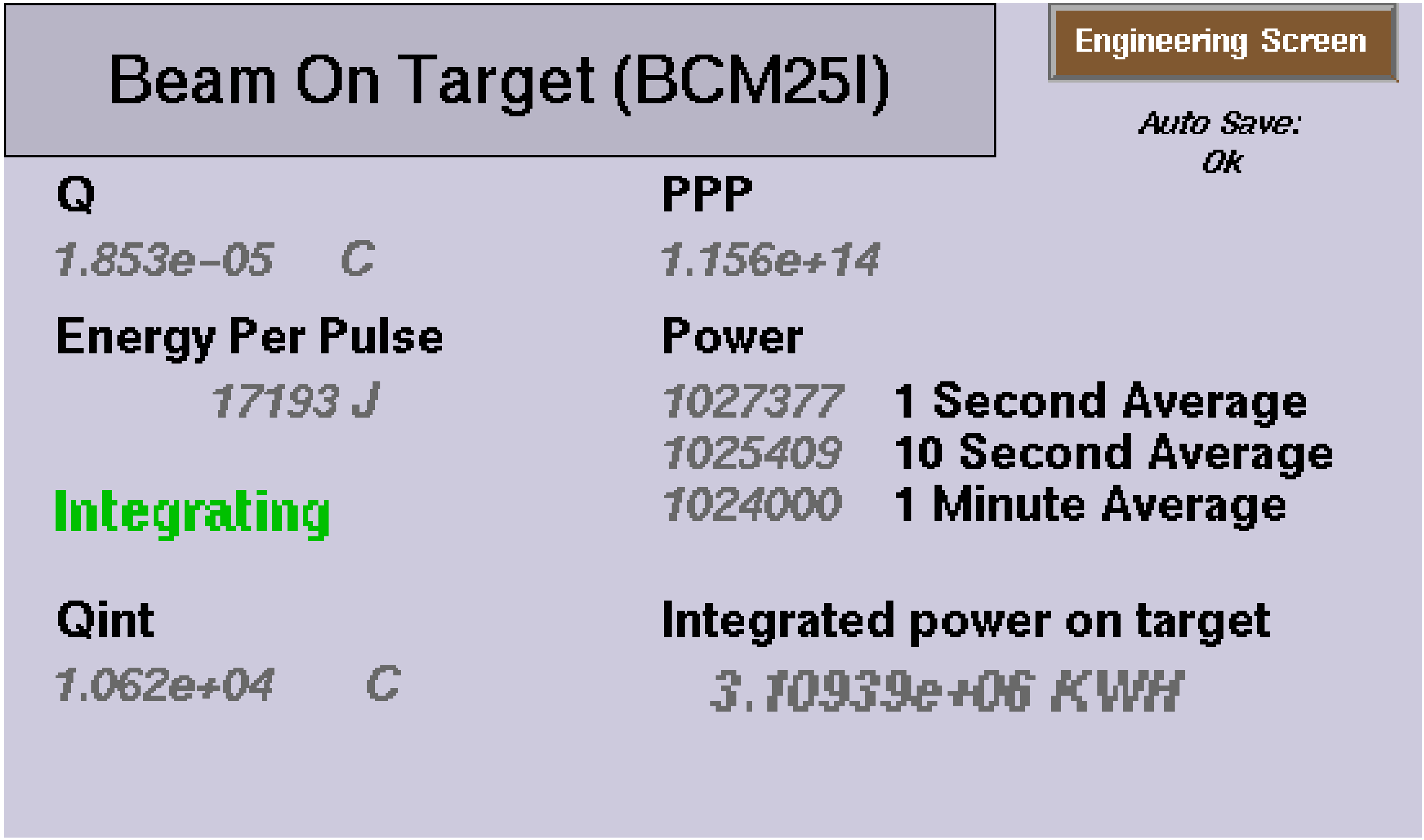
U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

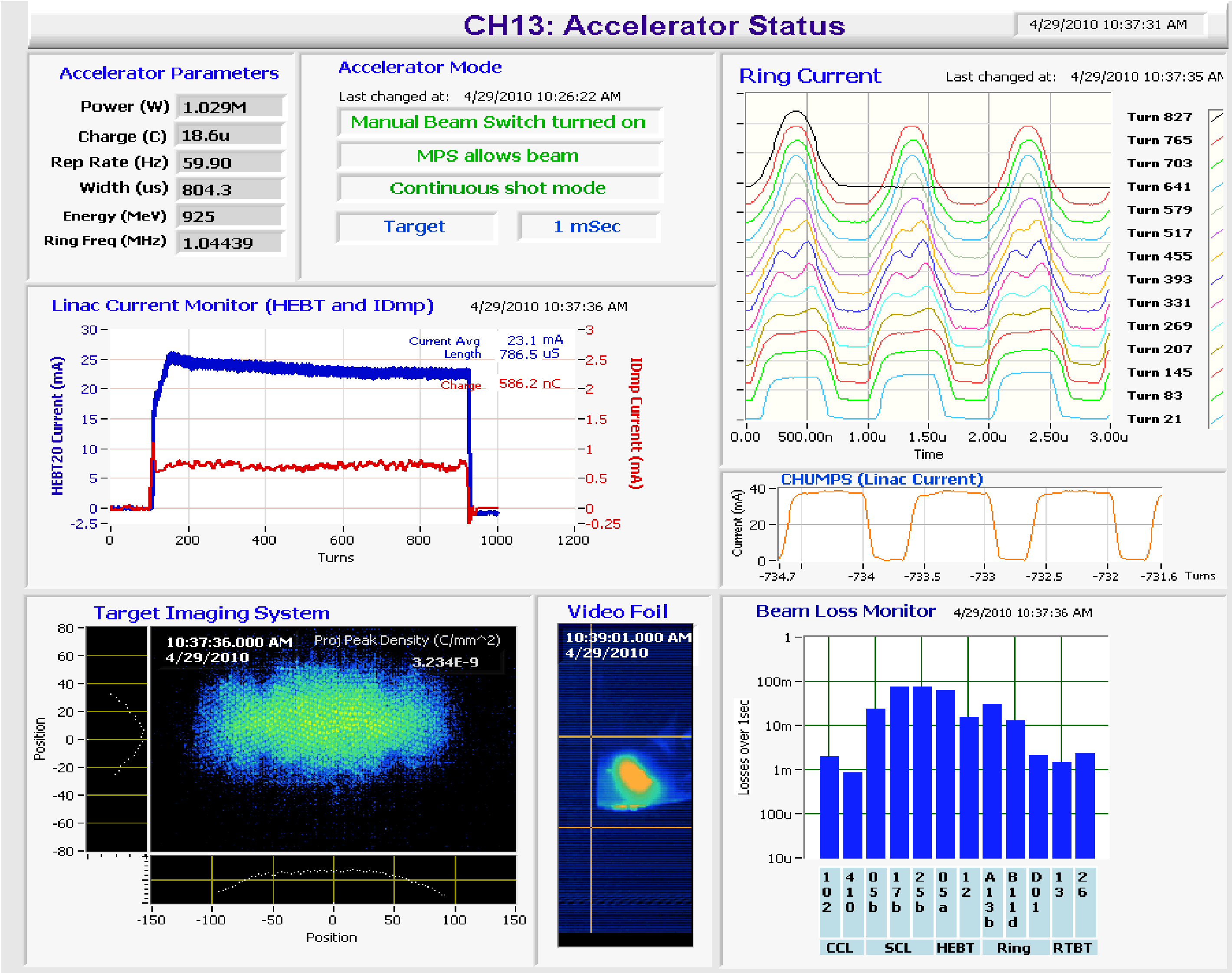
Outline

- SNS Operational Status
- Brief Accelerator Tour
- Current Performance
- Overview of RF Systems work
- A Look into the Future

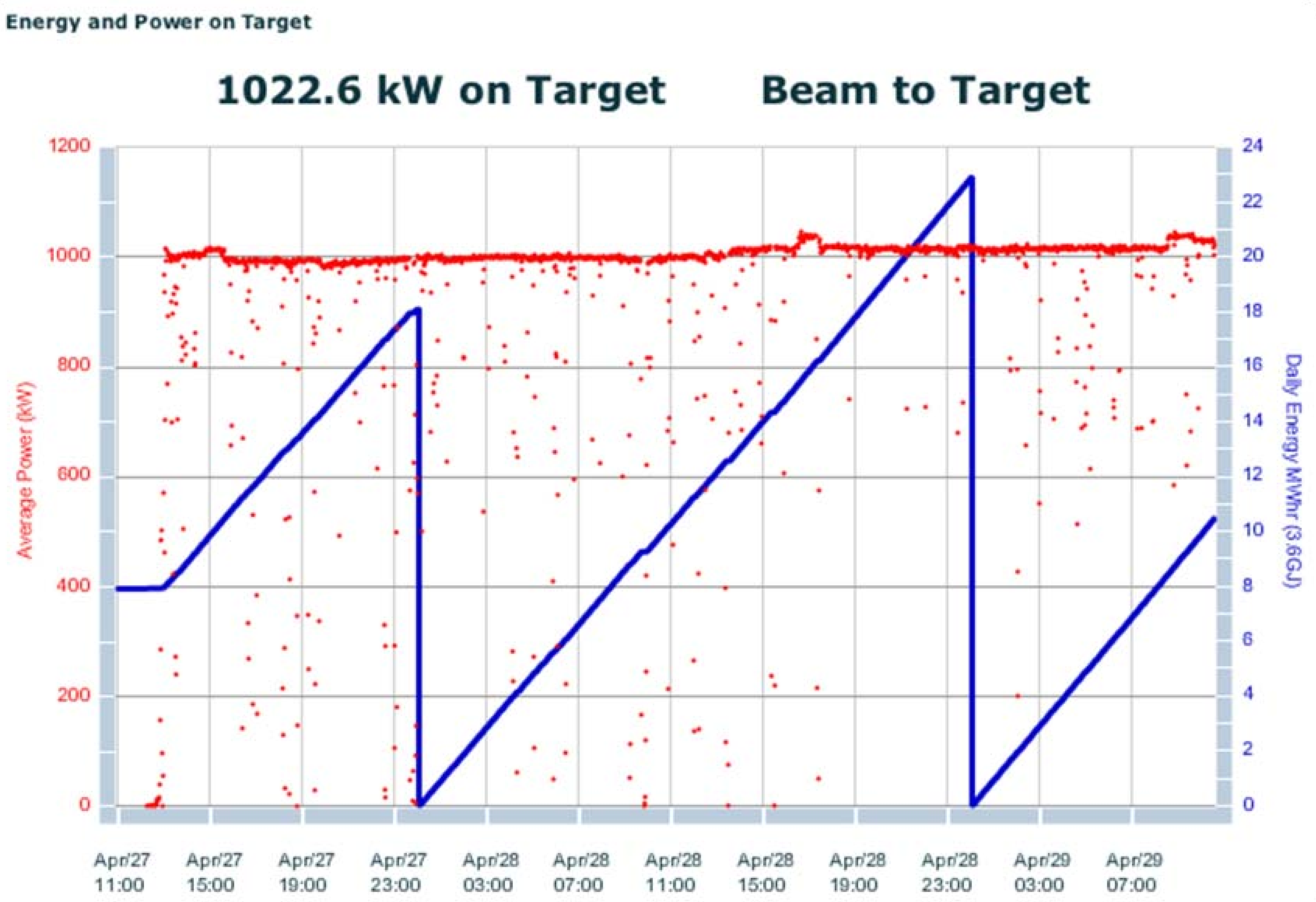
1 Megawatt of Beam On Target



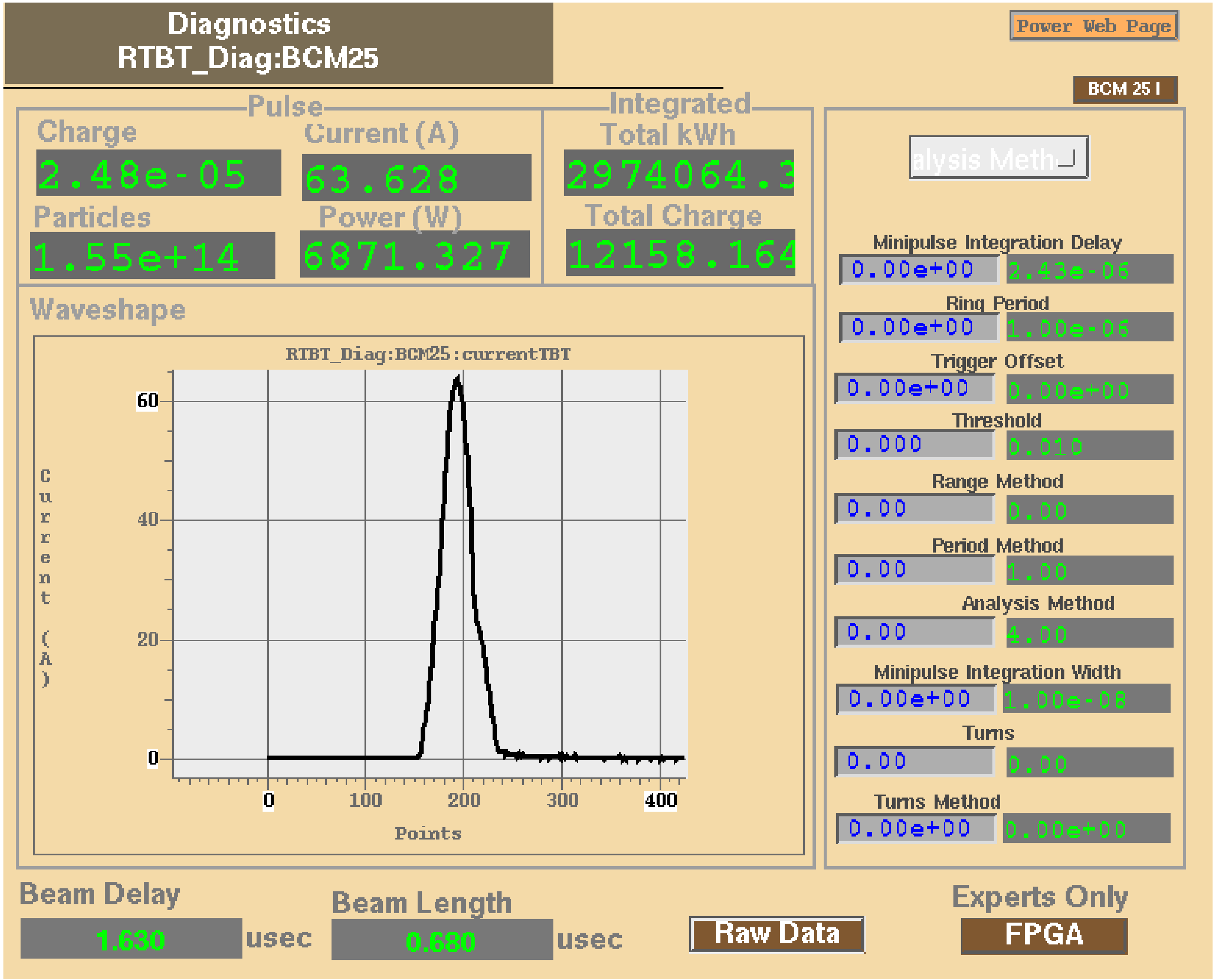
Overall Operating Parameters



Extended Operation at 1 MW



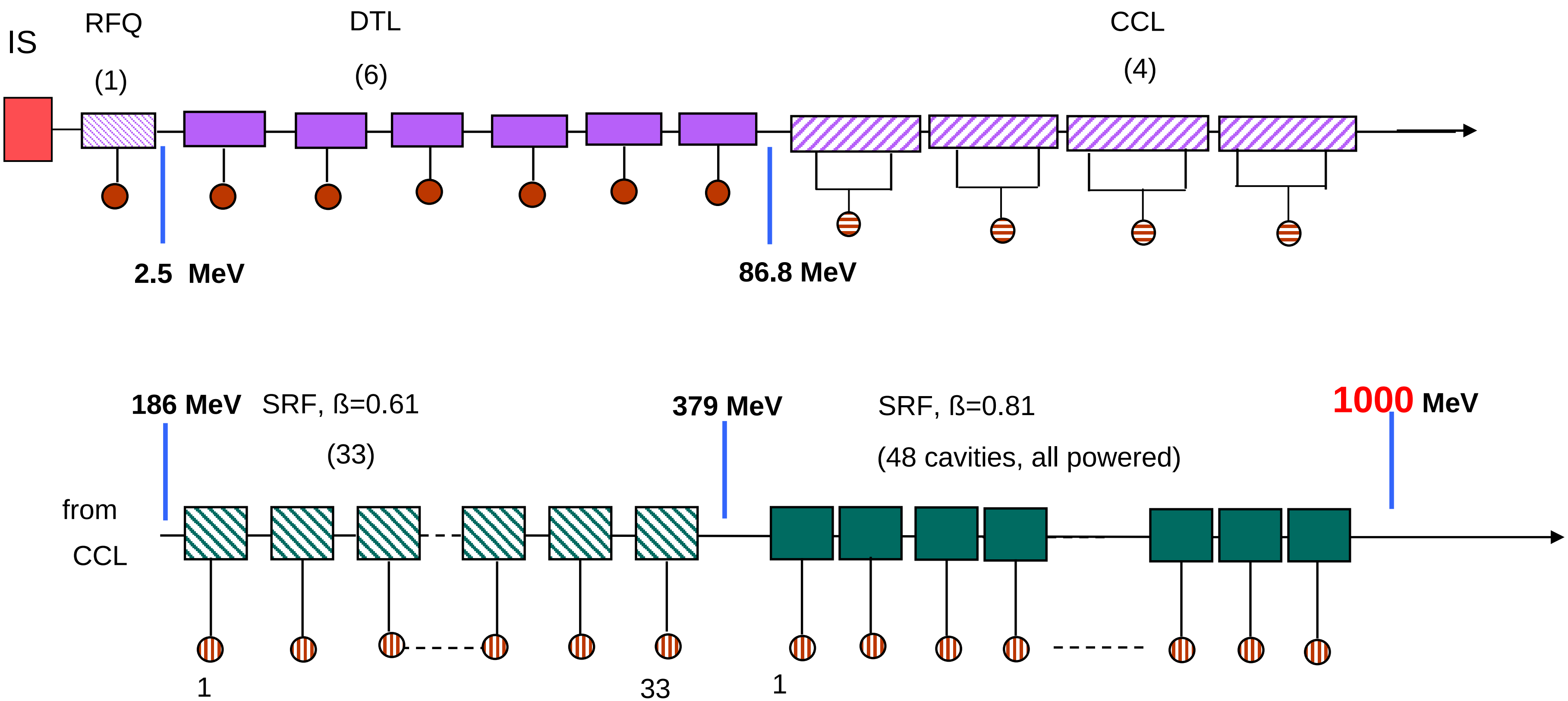
Full Design Intensity Beam Pulse 1.4e14 PPP



A Brief Photo Tour of the Various RF Systems

Layout of Linac RF Modules

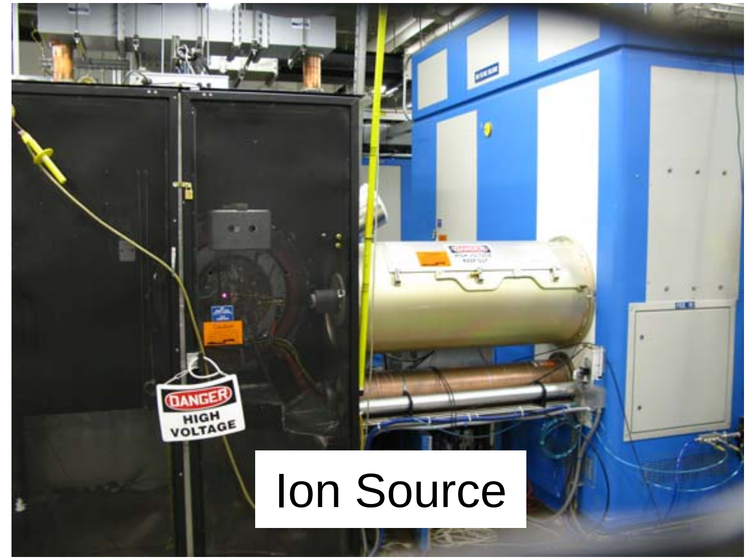
402.5 MHz, 2.5 MW klystron	3 Transmitter	3 Modulators
805 MHz, 5 MW klystron	4 Transmitter	4 Modulators
805 MHz, 0.55 MW klystron	14 Transmitter	7 Modulators

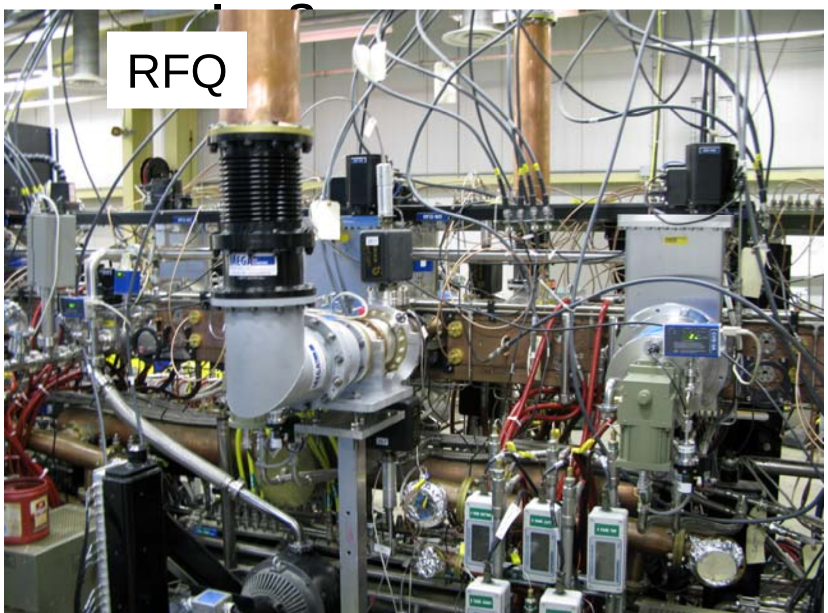


Ion Source & RFQ

Ion Source

- Currently using an Internal Antenna for production runs
- Have used an External Antenna ion source, a new development
- Pulsed 2 MHz at 50+ kW
- 13 MHz CW applied to the same antenna to maintain a low level plasma between pulses

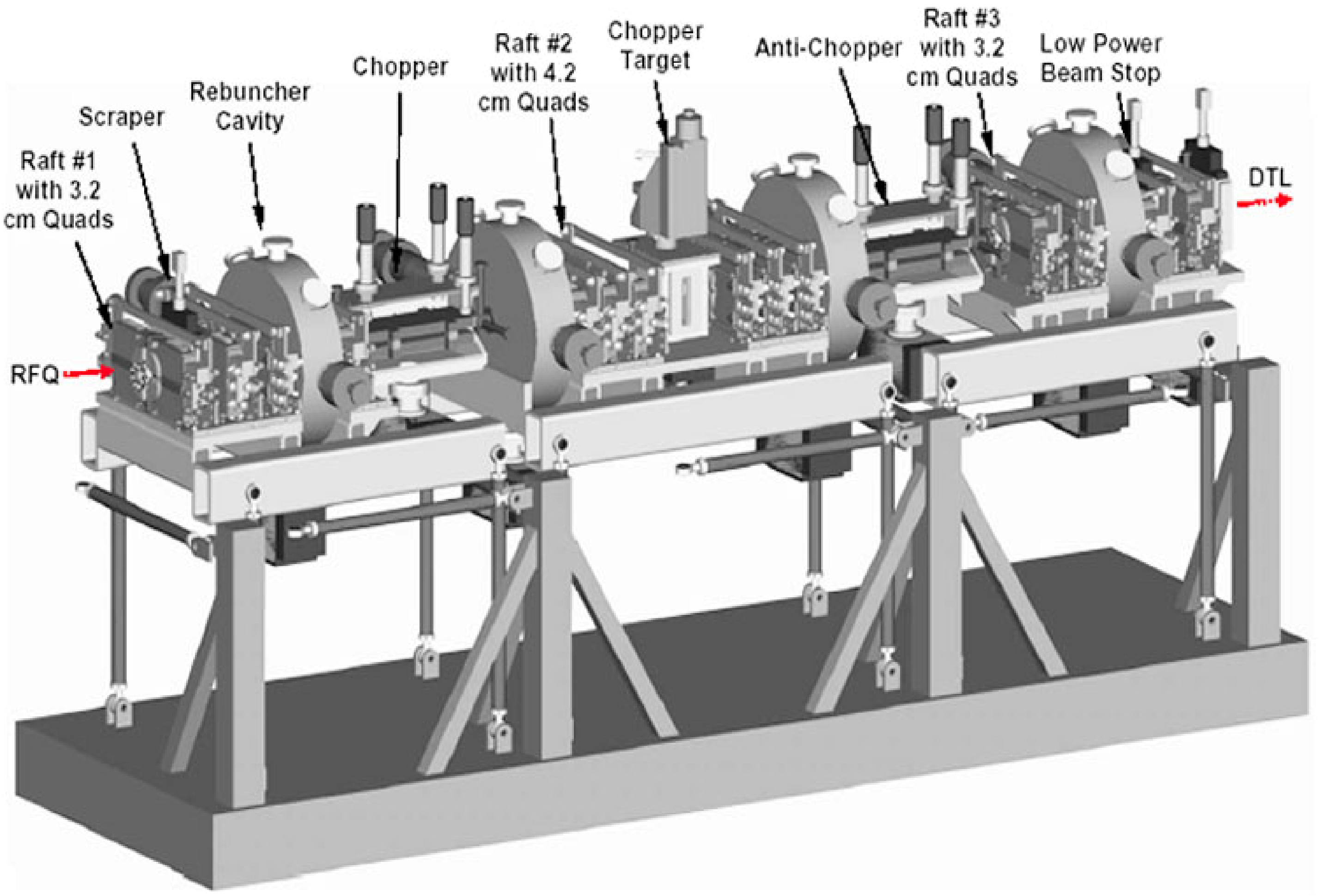




RFQ

- Recently modified to use only 2 Drive Couplers
- Accelerates H- Ions to 2.5 MeV
- Overcame difficulties in tuning at high duty cycle operations with LLRF improvement

Medium Energy Beam Transport - MEBT



MEBT

- Rebuncher system between RFQ and DTL with 4 cavities and other beam components
- Four 402.5 MHz amplifiers pulsed at 5 - 20+ kW

Klystron Gallery Normal Conducting RF

- RFQ
  - 1st klystron powers the RFQ structure.
  - 800 kW, 402.5 MHz
  - E2V klystrons
  - The klystron can provide 2.5 MW so this klystron has excess power.
    - Actually installed first article klystron only producing 1.8 MW
- DTL
  - 6 Klystrons power the DTL
  - 2.5 MW, 402.5 MHz
  - E2V klystrons
  - Circulator Loads use a Water – Glycol mix.

Klystron Gallery Normal Conducting RF

- CCL
  - 4 Klystrons power the CCL cavities
  - 5 MW, 805 MHz Thales Klystrons
  - Output window is gas insulated with SF6.
  - Circulator is gas insulated with SF6
  - Circulator load is conventional water load
  - Power is split to provide 2 structure inputs of 2.5 MW each

Drift Tube Linac and Coupled Cavity Linac
Los Alamos National Lab

The 402.5 MHz DTL is composed of six sections.

The 805 MHz CCL is composed of four sections.

Klystron Gallery Superconducting Cavity RF

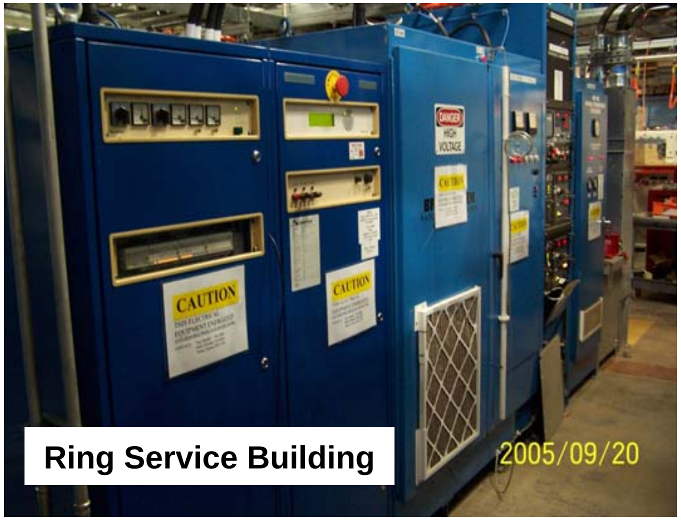
- SCL RF
  - 81 Klystrons each powering a separate cavity
  - 550 kW @ 75 kV
  - 805 MHz
  - CPI and Thales

Superconducting Linac
Jefferson Lab

- First and highest energy superconducting H- linac in the world
- 23 cryomodules
  - 11 medium-beta
  - 12 high-beta
- 33 medium-beta cavities
- 48 high-beta cavities
- One klystron per cavity

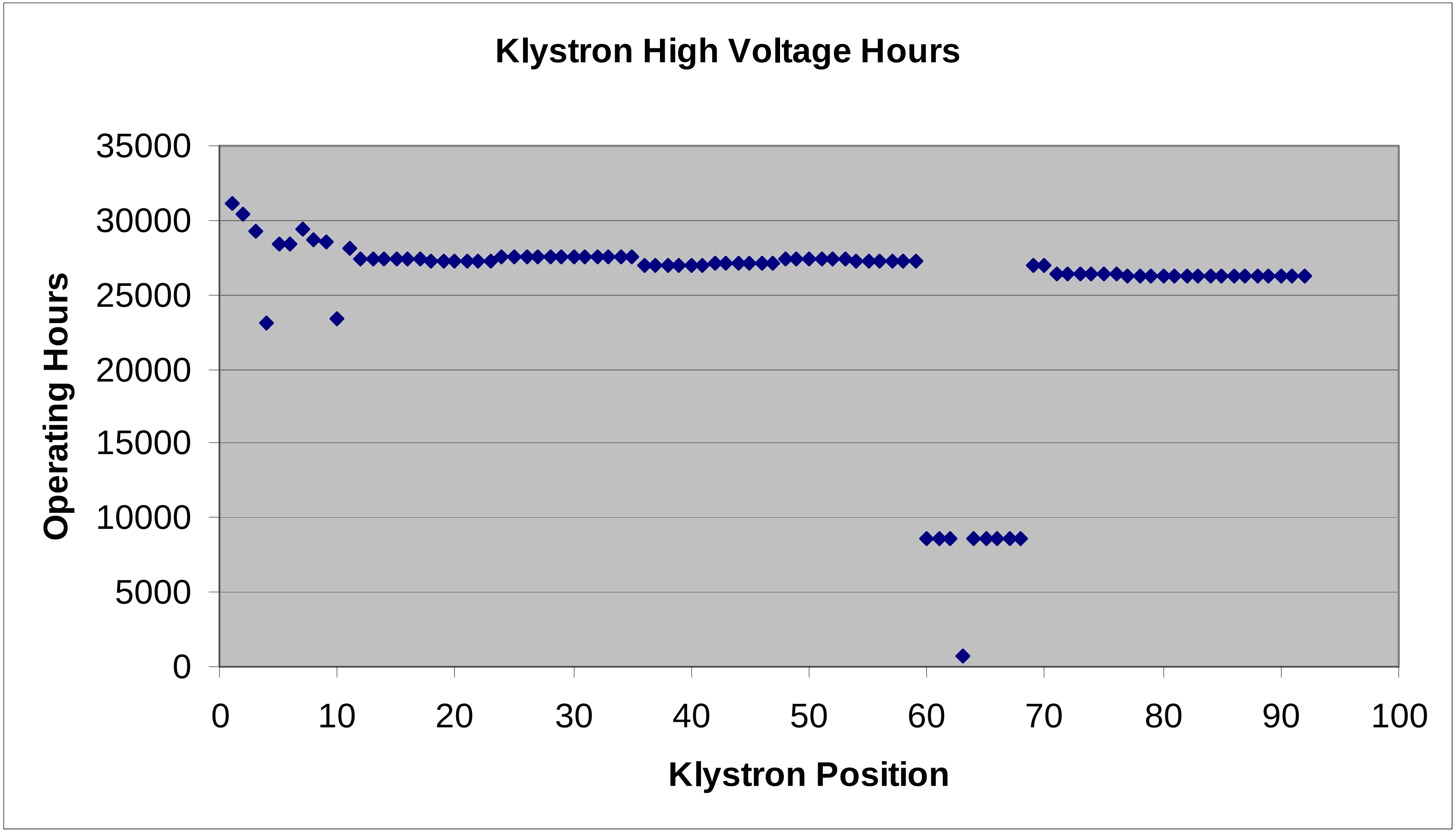
Accumulator Ring RF

- Ring RF
  - 4 Bunching Cavity/Amplifier stations
    - Ferrite loaded (Phillips 4M2)
    - Cavity Bias provides dynamic tuning
    - Beam pipe and outer housing used for bias.
  - 2 bunching gaps per cavity
  - 3 Buncher Cavities operate at the revolution frequency 1.05 MHz
    - Maintain a gap to allow the extraction kickers adequate time to reach full field.
  - 1 Cavity operates at the 2nd harmonic 2.1 MHz
    - Reduce the peak beam current to minimize the possibility of exciting instabilities.
  - All cavities and amplifiers are the same.
    - Resonating capacity reduced for the 2nd harmonic cavity allowing use of the same structure.

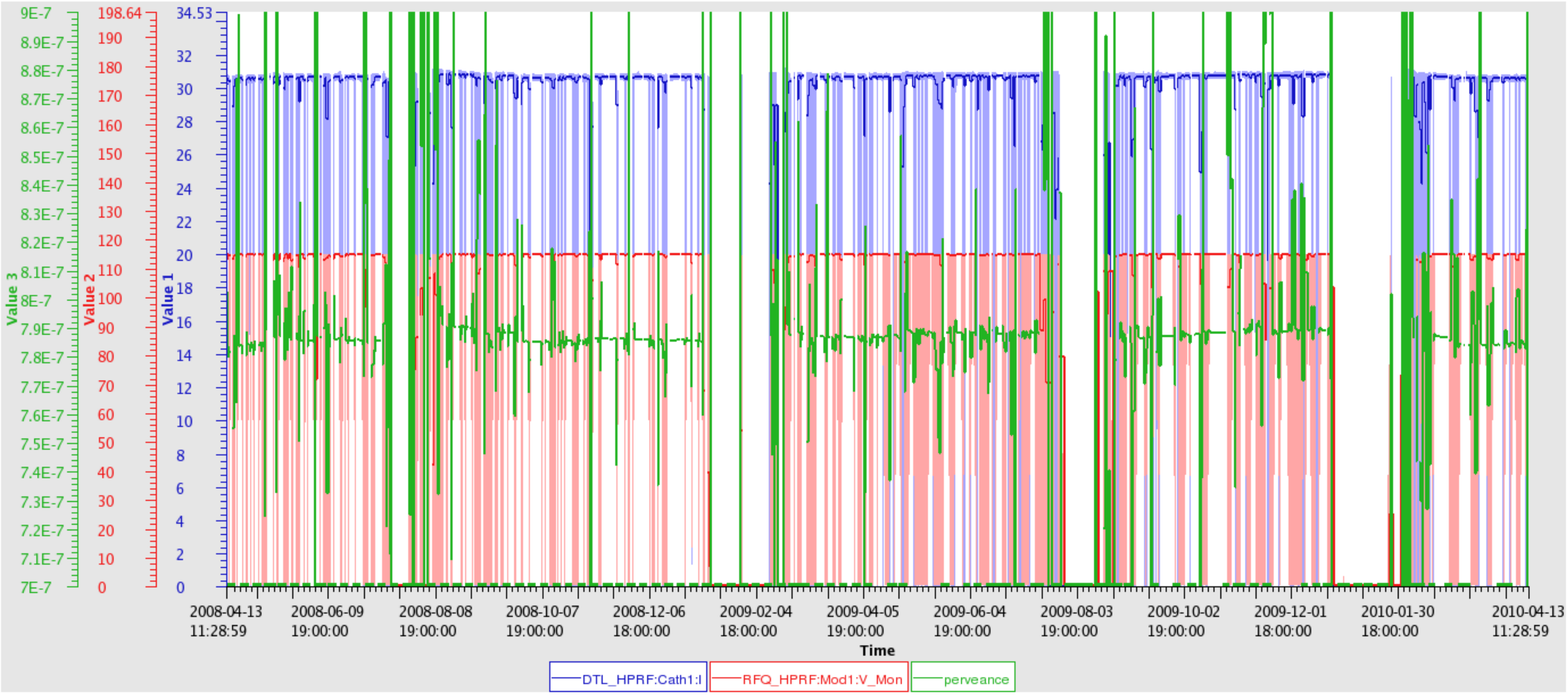


Accelerator Performance

Klystron Operating Hours - High Voltage

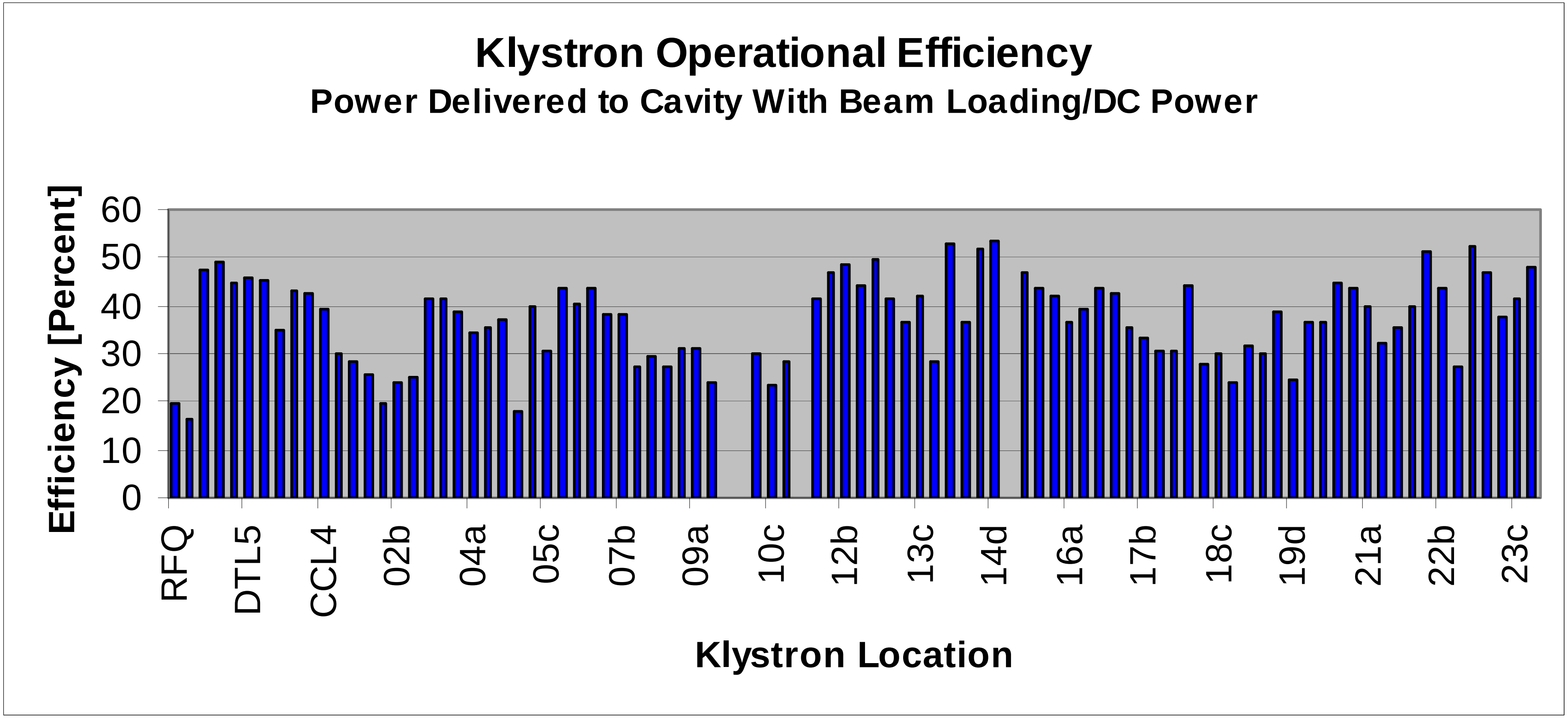


Perveance – Last 2 years – RFQ Klystron



- Red Trace = Cathode Current [Amperes]
- Blue Trace = Modulator Voltage [kV]
- Green Trace = Perveance [μperv]

Klystron Operational Efficiency



- Not Taken Into account
  - Modulator Droop
  - RF on longer than beam pulse

Failed Klystrons – 4 Years of Full Operation

- DTL Klystrons (5 failures)
  - 1 klystron failed when we nearly burned through the body due to loss of focusing field
    - We were able to repair this klystron and it is fully functional
  - 1 klystron experienced magnet cooling loop piping damage due to Loss of cooling water
    - Repaired magnet
  - 3 klystrons experienced body cooling loop water leaks
    - Repaired cooling loop piping
- CCL Klystrons (2 failures)
  - 1 klystron suffered loss of emission
    - Thales is investigating
    - We may have had the cathode and filament leads reversed
  - 1 klystron lost vacuum while in storage
- SCL Klystrons (5 failures)
  - 1 klystron suffered water damage when it's magnet leaked and filled the space between the klystron and magnet with water
  - 1 klystron suffered gun damage when we miswired the gun magnet
  - 3 klystrons suffered from stability issues after we began operating them at 75 kV
    - Believe we can alter output matching to regain stable operation
  - 1 klystron replaced due to cathode arcing
    - Might be able to condition this klystron

Overview of RF Systems Issues

Ion Source RF

Tomco Solid State 2 MHz Amplifier

- Original Tetrode amplifiers have served well but replacement parts are hard to acquire
- We wanted to purchase another power amplifier for a second test stand and decided on a solid state version
- We will ultimately replace all amplifiers with the solid state units operated at ground potential
  - Original amplifiers operate at -65kV
- 120 kW in 2 racks
- Two units are in our lab
  - Setting up for Site Acceptance Test
- Each amplifier rack can operate independently
- Each rack produces 60 kW

RFQ Status

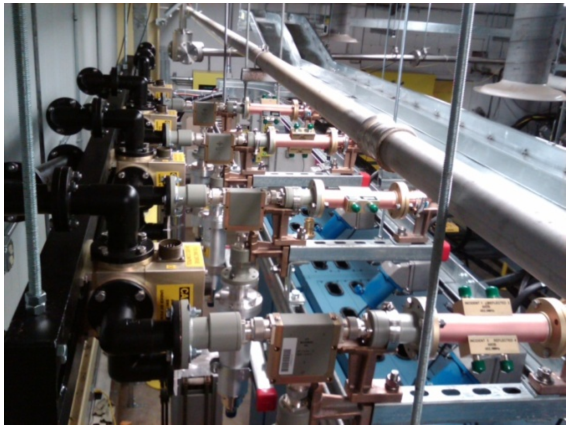
- Retuned RFQ after a major shift in frequency and field flatness last year (January 2009)
  - Seems to be the result of a vane shifting due to a water pressure surge during maintenance
  - Similar to shift that occurred several years ago
  - Concerned another shift could take place
  - May have field errors we do not observe
- Working on obtaining a spare
  - Prepared specification
  - Received bids from several possible vendors
  - Working on clarifying some items with vendors
- Had issues with loss of resonance control at high duty after several hours of operation
    - Limiting Ion Source gas flow
    - Upgraded water manifold to improve cooling
    - Added feedback loops to LLRF control page to regulate pulse width and chiller temperature
    - Added pressure relief valves
    - Changed pumps in chiller

MEBT Rebuncher Amplifier System

Original system utilized 3CX5000's – Had reliability issues

First MEBT Solid State RF Amplifier – Now Operating Cavity 4

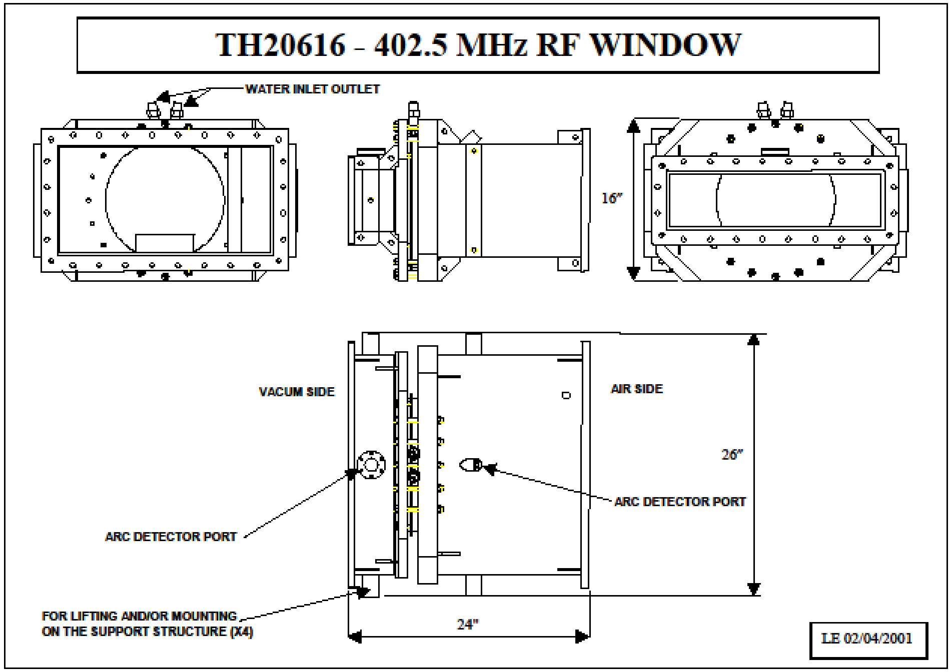
Tomco Solid State Amplifier



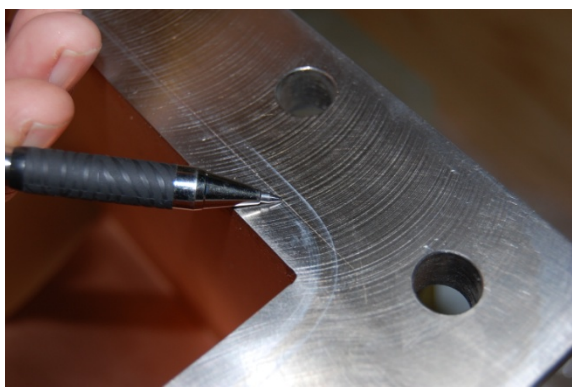
Switching Assembly, Circulators, Directional Couplers

Racks waiting for Amplifiers

Warm Linac Issues



- Vacuum Leak on DTL-6 RF window
  - Originally thought to be braze joint but may have been O-Ring seal
  - May have a similar problem on several windows
  - RF conditioned 2 spare windows
  - Replaced DTL-6 window during maintenance period
  - Have 3 spare windows on order
  - Planning to build 3 more spare windows in-house



SCL RF

- Now operating klystrons at design cathode voltage of 75 kV
- Replaced 9 Thales klystrons
  - 3 klystrons showed instability issues
  - All Thales klystrons have high gain
- Suffered arcing condition in SCL-5A coupler
  - We were able to recover this cavity
- Beam loss injured cavities SCL-5A and SCL 6C
  - Made some progress recovering SCL-5A
  - Hope to recover both cavities by careful conditioning

A Look Into the Future

- Power Upgrade (PUP)
  - Add 36 more SCL Cavities, Klystrons and LLRF Systems
- Intensity upgrade
  - Requires more RF Power
  - Will replace some klystrons and upgrade HVCMs
  - Will need to Process some of our SCL Cryo-modules for higher accelerating field in cavities
- Second Target Station (Currently on-hold)
- Existing LLRF modules have obsolete components
  - Need to be working on next generation system
- Ring LLRF
  - Want to replace existing hardware and software with a version more compatible with our Linac systems

Summary

- SNS reached 1 MW in mid September as promised to DOE
- Presently operate with 85% reliability
  - Ultimate goal is 95%
  - We have identified major sources of downtime and are addressing them
- There remains significant Ion Source RF System work
- MEBT RF Upgrade has a clear path to completion
- SCL RF Power limitation was resolved by adding an extra converter-modulator (running with 10 klystrons per modulator)
- We are beginning to acquire Klystron Perveance Data
  - Analyzing archive data