OAK RIDGE National Laboratory

Oak Ridge National Lab SNS Lab Talk - Status of the Low-Level RF Development at the Spallation Neutron Source

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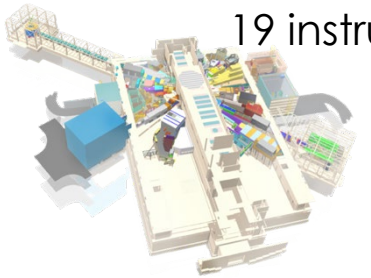
Since LLRF Workshop 2019

- Support accelerator operations
  - Approximately 4600 neutron production hours per year
  - 90% availability at 1.4 MW
- Proton Power Upgrade (PPU) project is under construction
  - LLRF development completed
  - Test procedures and stands developed
  - Initial testing of installed equipment
- Second Target Station (STS)
  - Developing deliverables and schedule

SNS Today and in the Future

Today

24 instrument positions
19 instruments built



First Target Station

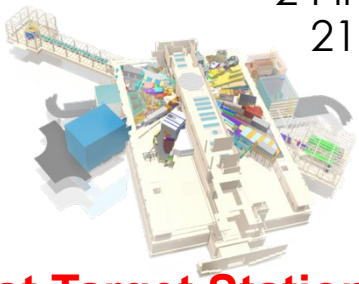
1.4 MW

Accelerator

Now

Future

24 instrument positions
21 instruments built



First Target Station

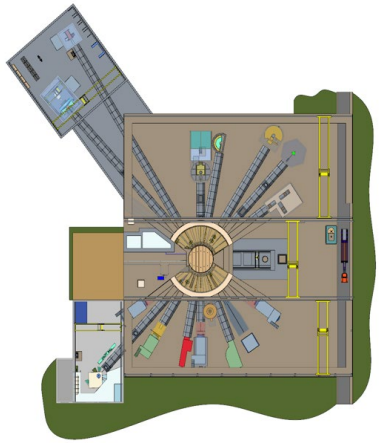
2 MW

Accelerator
2.8 MW capable

Proton Power Upgrade (PPU)

22 instrument slots,
8 initial instruments

Second Target Station (STS)

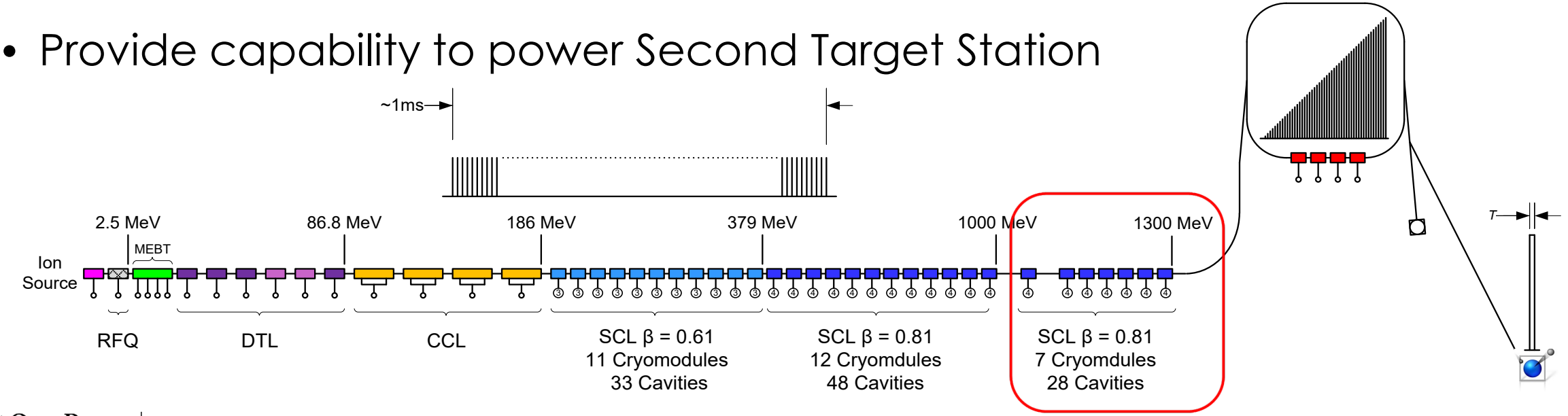


STS Upgrade

Scope for PPU – RF Perspective

Upgrade the accelerator systems to enable proton beam power of 2.8 MW

- Increase beam energy to 1.3 GeV
  - Add 28 new superconducting cavities
- Increase beam current to 38 mA
  - Increased beam loading for LLRF
- Provide capability to power Second Target Station



Hardware Design Complete

- Retained platform type implementation
  - MicroTCA vs. VXI
- Limited hardware design with use of commercial-of-the-shelf boards when possible
  - Vadatech AMC726 processor (IOC)
  - Vadatech AMC523 FPGA (Kintex-7)+ dual DAC (MAX5878)
- Partnered with Vadatech to develop field control hardware
  - Now catalog item – MRT523B
    - Eight 16-bit ADC channels (AD9653)
- In-house development
  - High-power protection and interlocks
  - Frequency conversion chassis
- Opportunity to make improvements to original LLRF

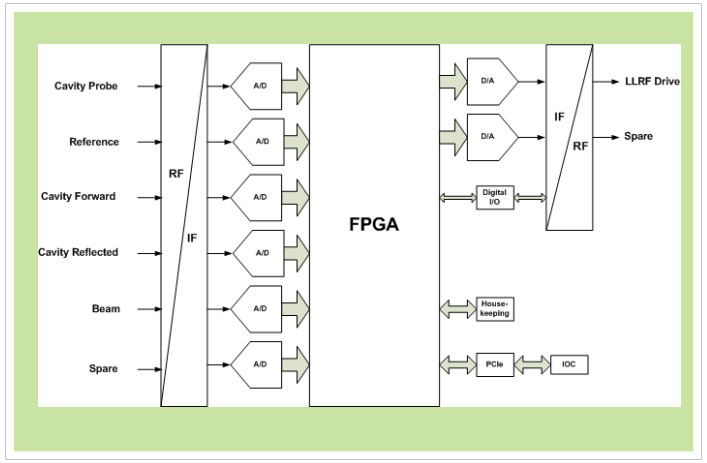
Dual LLRF System

Field Control Module (FCM-II)

- Standard LLRF control block diagram
  - Non-I/Q sampling scheme (12/5*IF)
  - Retained the core DSP firmware → well proven at SNS
- PCIe standards support speeds to allows adaptive feed forward controls to remain in the IOC
  - Allows 60 Hz beam loading compensation vs. 20 Hz in original LLRF
- Improved diagnostics buffers for troubleshooting systems
- Over 3000 hours of testing

AMC523B FCM-II RTM

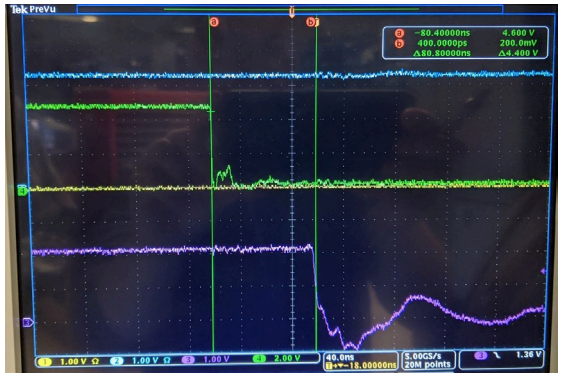
DAC test Pattern



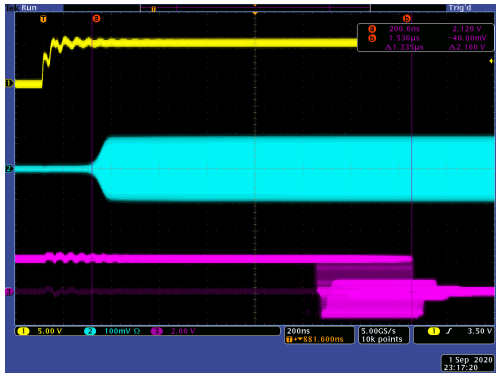
RF to IF conversion is performed in the frequency Conversion Chassis

High-Power Protection Module (HPM-II)

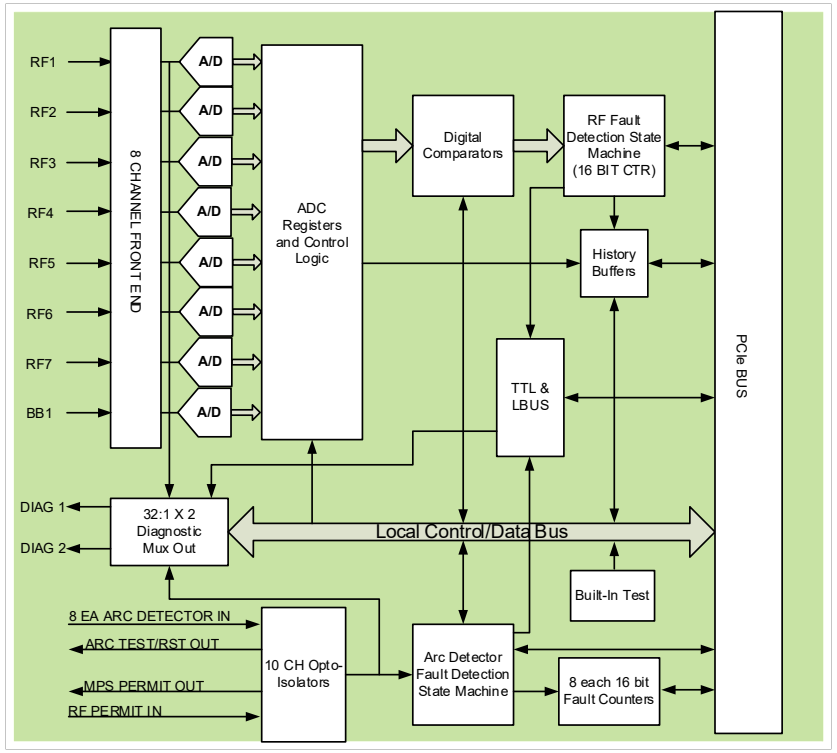
- Design is based on the original HPM module
- Machine Protection (MPS) interface for the LLRF system
- Critical signals are available locally via two multiplexers
- Added diagnostic buffers to complement FCM-II buffers
- Supports automated calibration of RF channels



Digital trip delay ~80 ns

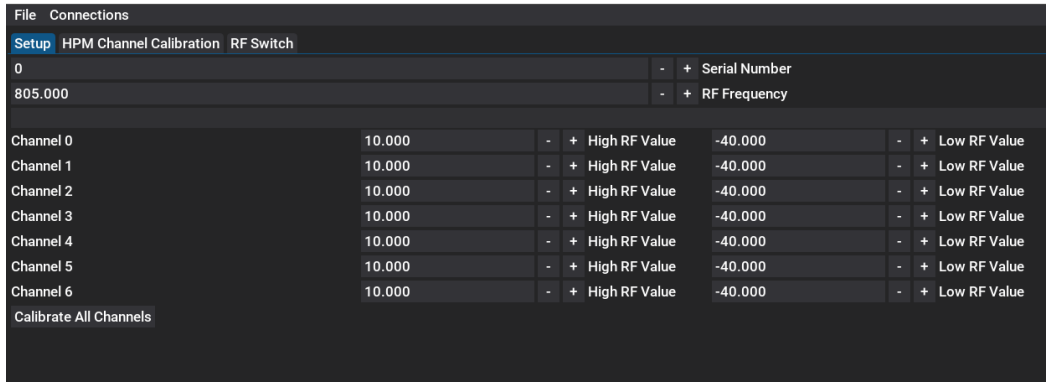


RF trip delay ~1.5 µs

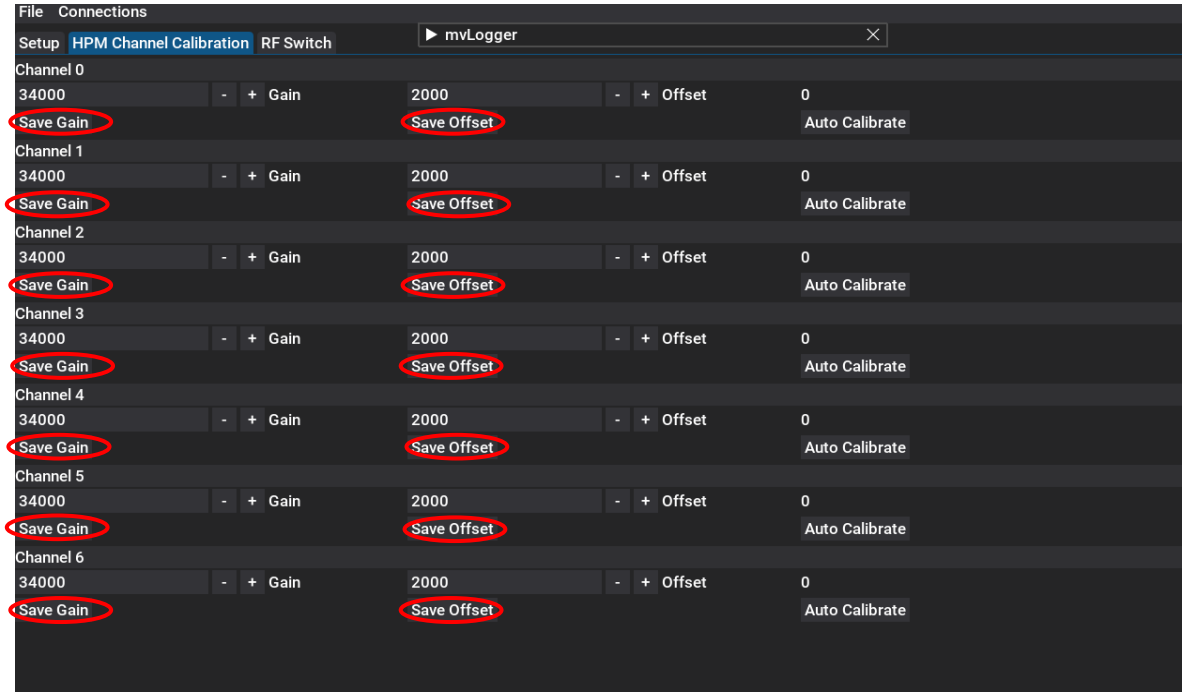


Automated RF Channel Calibration

- Original system required manual adjustments on a three-year cycle
  - Labor intensive
  - Possibility for calibration errors
- Automated system provides fast, repeatable calibrations



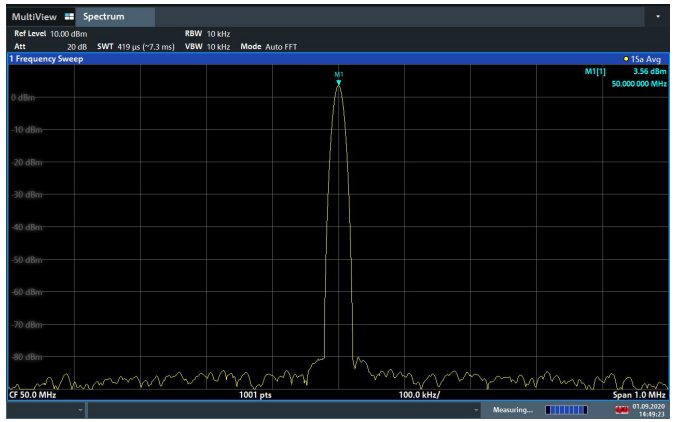
Calibration setup screen



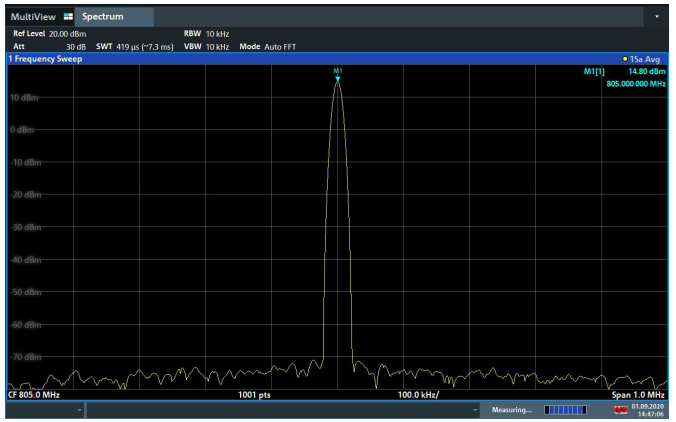
Calibration save screen

Frequency Conversion Chassis

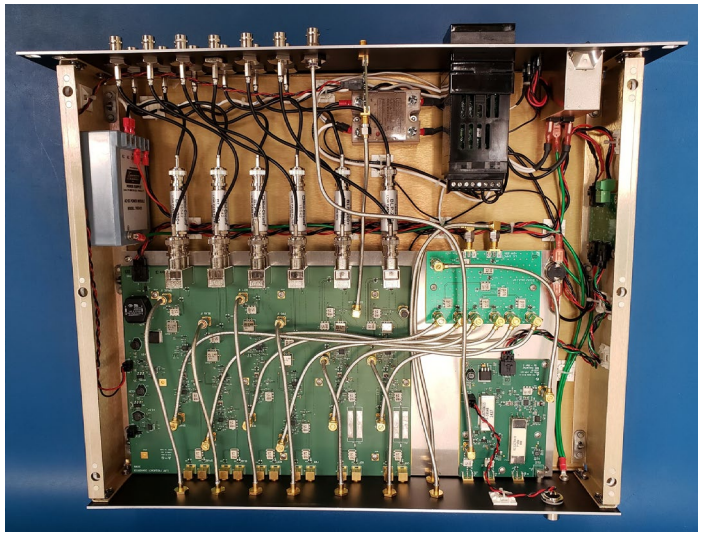
- Up and down conversion functions in temperature-controlled chassis
  - Removes RF signals from field control module – 50 MHz IF signals only
  - Separate PCBs for up-conversion, down-conversion, and LO distribution
    - Improves crosstalk rejection between up and down conversion functions
  - Active mixers utilized for both up and down conversion
    - AD8343 mixer for up-conversion
    - LTC5567 mixer for down-conversion
    - Greatly reduced the amplitude dependance on the LO signal
- Channel to channel isolation measurements >80 dB



50 MHz, 1 MHz span



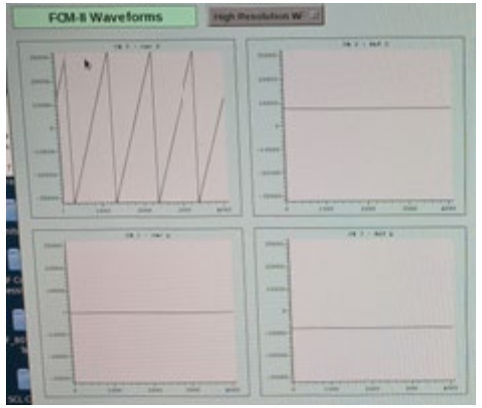
805 MHz, 1 MHz span



FrCC chassis

Test Stand Development

- Completed test stands for new hardware
  - High-power Protection Module (HPM-II) requires detailed calibration and measurement of interlock shutdown times
  - Field Control Module (FCM-II) requires verification of ADC linearity and interlock functions
    - Test firmware developed to validate hardware
  - Frequency Conversion Chassis requires characterization



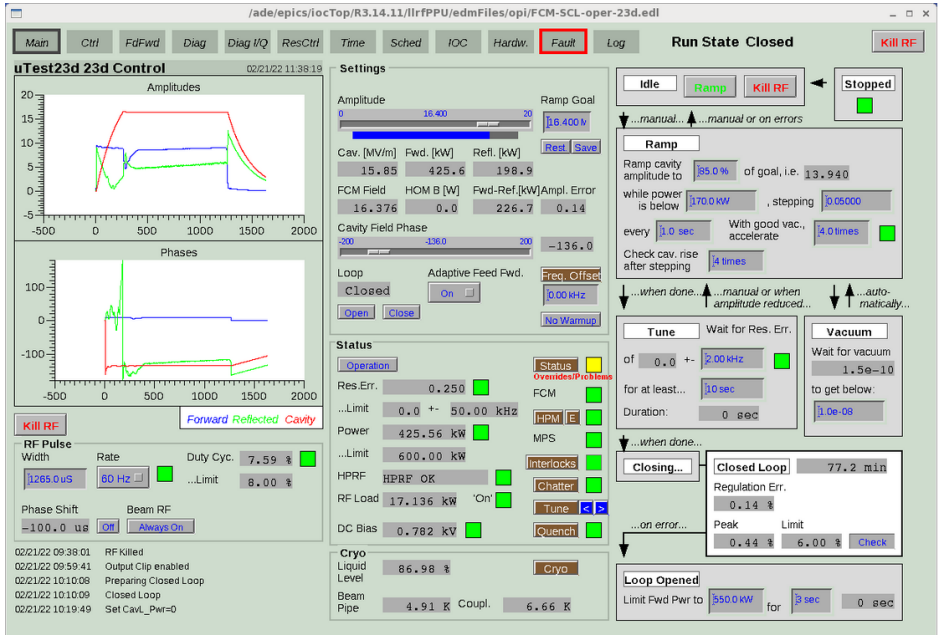
PCIe Ramp Data Integrity Test with Sync Start

HPM-II Test Stand hardware

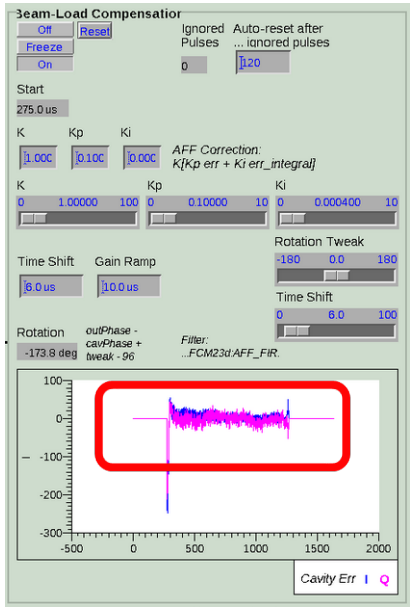
Modified µTCA.4 crate to allow board testing

System Testing, Feature Enhancements, and Operations

- The LLRF system was approved for full beam operations on May 12, 2022
  - No operational issues noted → no middle of the night call-ins!
  - Minor improvements to the system continue to be implemented to support operations



- System supporting 1.4 MW beam
- Regulation error of 0.14% during beam pulse
- Beam loading compensation is working
  - Minor improvements continue for beam loading compensation
- Basic fault capture implemented
  - Improved fault capture still under development

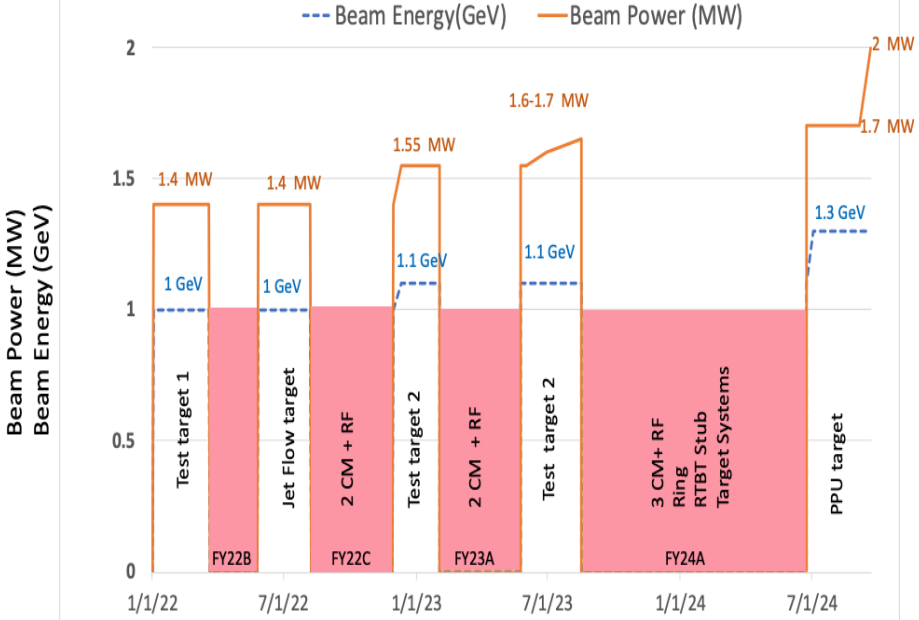


Equipment Installation and Power Ramp-up

- Equipment is installed in 3 phases
  - 2 cryomodules (SCL31a – 32d) → operational November 2022
  - 2 cryomodules (SCL29a – 30d) → operational June 2023
  - 3 cryomodules (SCL25a-d, SCL27a – 28d) → operational July 2024
- Allows for gradual power ramp-up as systems are available

LLRF row 52 powered up – Phase 1

LLRF row 49 racks – Phase 2



Power ramp-up plan

Summary

- The accelerator is a mature facility that has been in operation since 2006.
  - Continues to meet the power, availability, and reliability goals of 4600 hours/year @ >90% availability
- Proton Power Upgrade project is underway, will double the beam power and support the Second Target Station project
- Completed the PPU LLRF Systems design
  - Received and tested all hardware required for PPU installation
  - Implemented lessons learned over the past 16 years of operation
  - New LLRF system operation is verified to support beam operations
- System installation is on schedule
  - Allows for gradual power ramp-up

Acknowledgement

- Thanks to the SNS LLRF Team for their dedication and hard work. None of this would be possible without the help of everyone involved.
  - Jeff Ball
  - Josh Graham
  - Mark Musrock
  - *Zach Sorrell**
  - Stacey Whaley
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  - Larry Doolittle - LBNL
  - Carlos Serrano - LBNL
  - Vamsi Vytla – LBNL
  - *Eric Breeding* - ORNL*
  - Marnelli Martinez – ORNL
  - *Chuck Roberts* - ORNL*
  - *John Sinclair* – ORNL*