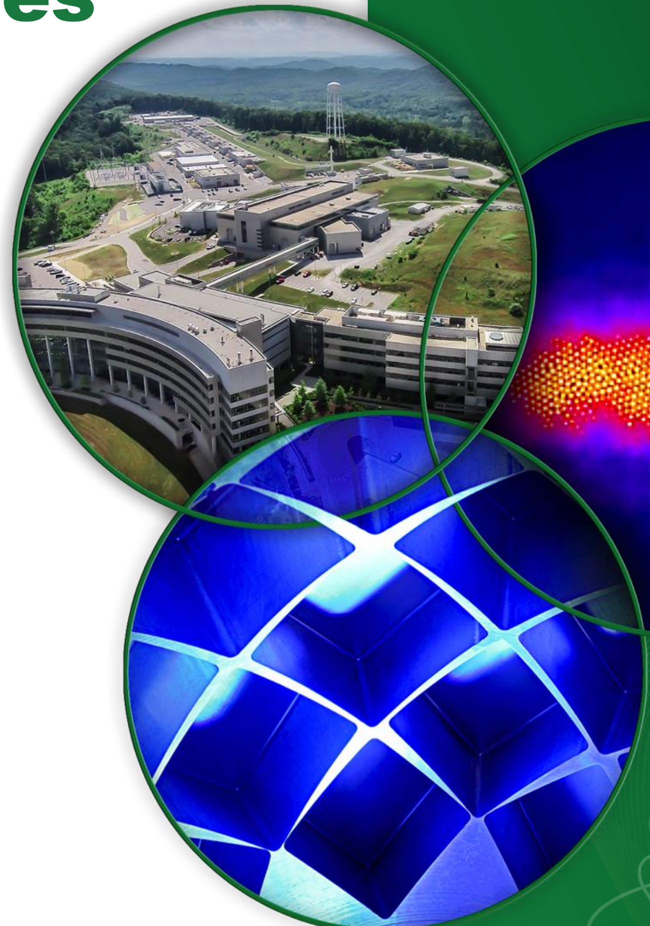
Low Level RF Status and Development Activities at the Spallation Neutron Source



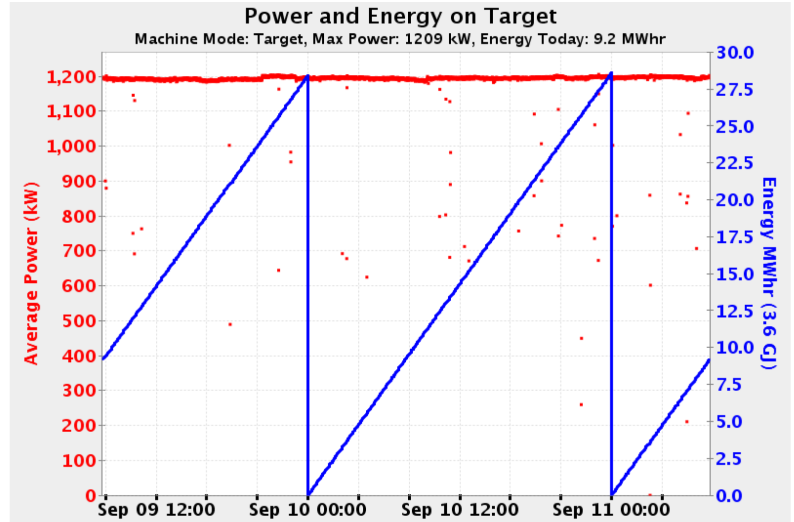
Mark Crofford

LLRF Systems Manager

LLRF 2017 Workshop, Barcelona, Spain

SNS Accelerator Availability is Excellent

- Original LLRF systems continue to support reliable operation
- 1.2 MW operation is routine, accelerator is 1.4 MW capable
- During the run completed on September 30th 2017 availability of the accelerator was 96% over 86 days



The red trace shows the one minute average power (kW) of the proton beam on the liquid mercury target. The blue trace shows the integrated beam power (MWhr) on target per day.

Availability For The Past Week

Date	Production Beam		Accel Physics		Startup		Planned Shutdown		Availability Percentage	
	Requested	Delivered	Requested	Delivered	Requested	Delivered	Requested	Delivered	Production	Total
2017-09-10	24.0 h	23.8 h	-	-	-	-	-	-	99.17%	99.17%
2017-09-09	24.0 h	23.8 h	-	-	-	-	-	-	99.17%	99.17%
2017-09-08	24.0 h	23.5 h	-	-	-	-	-	-	97.92%	97.92%
2017-09-07	24.0 h	21.5 h	-	-	-	-	-	-	89.58%	89.58%
2017-09-06	24.0 h	23.3 h	-	-	-	-	-	-	97.08%	97.08%
2017-09-05	8.6 h	8.6 h	-	-	5.4 h	5.4 h	10.0 h	10.0 h	100.0%	100.0%
2017-09-04	-	-	22.0 h	22.0 h	-	-	2.0 h	2.0 h	NA	100.0%
2017-09-03	2.0 h	1.9 h	22.0 h	21.7 h	-	-	-	-	95.0%	98.33%

The current run started on 2017-07-07. Availability has been 95.87% over the past 66 days.

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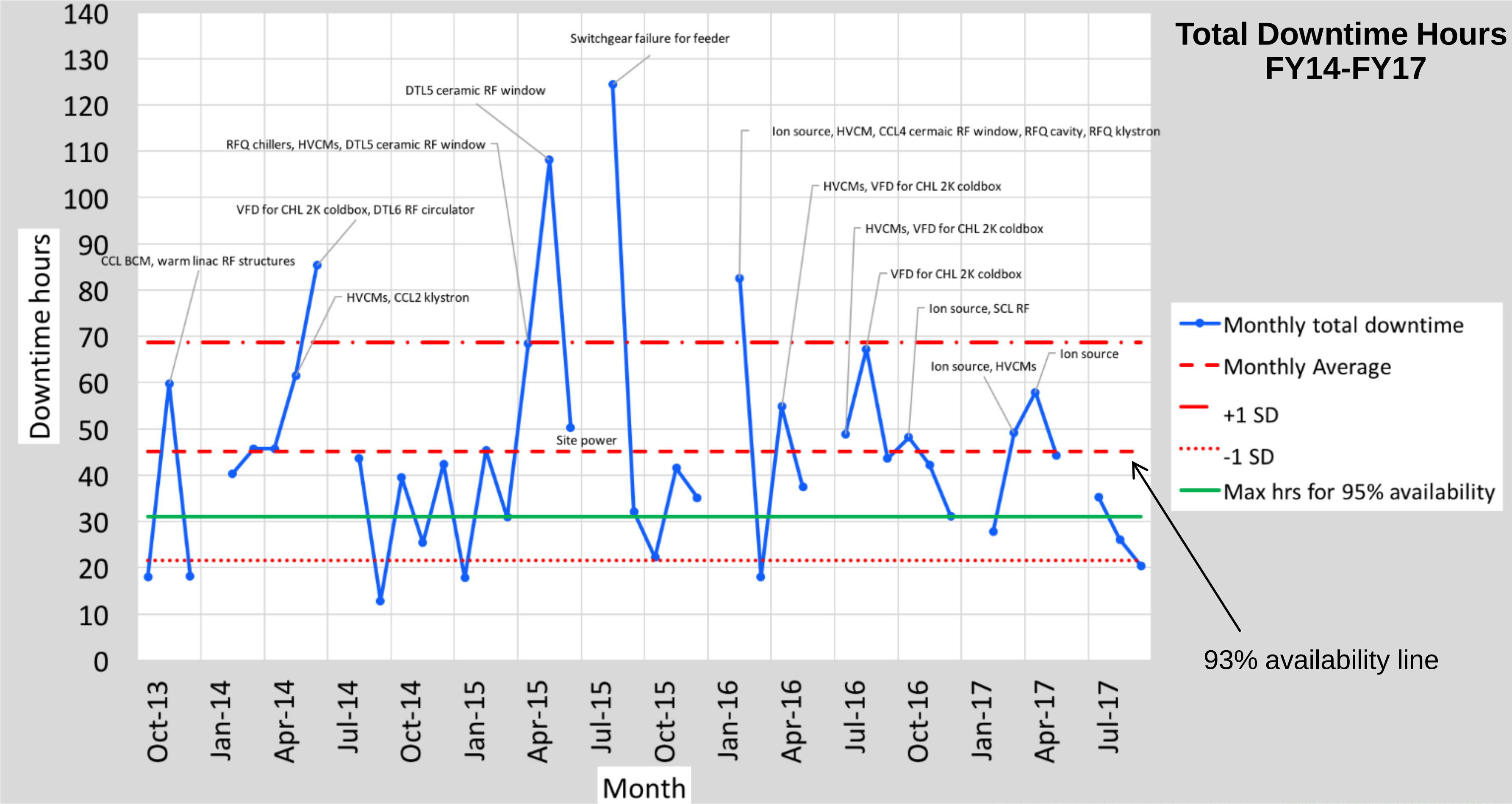
Accelerator Availability: Monthly Average is 93% During Last 4 Years

- Excludes MEBT water leak & Mercury target failures
- LLRF system failures account for <<1% of accelerator downtime



Slide provided by C. Peters

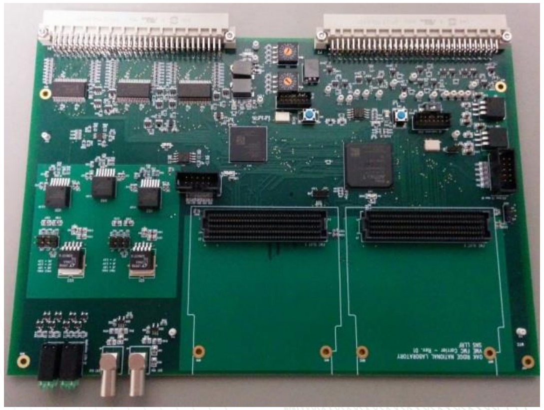
Since the 2015 LLRF Workshop We Have Been Busy on Development Activities

- System obsolescence continues to be an issue
  - Limited spares for the Ring LLRF
- Desire to add new capabilities to both the Linac and Ring LLRF control systems
  - User friendly interface and controls for the Ring system
  - Faster adaptive feed forward for the Linac system
- Actively working to the Proton Power Upgrade and Second Target Station projects

LLRF Development Platform

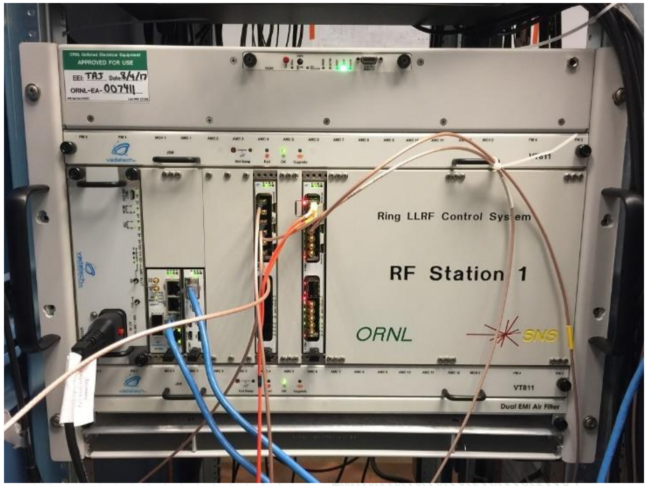
- Required a method to quickly test modules that could be used for LLRF projects
  - Reuse of the standard LLRF memory map
    - Artix-7 based system FPGA → VME interface
    - Allows use of existing EPICS screens and tools
  - Support all legacy VME backplane connections
  - Artix-7 (XC7A100T) application FPGA
    - Adequate resources for our development activities
- Planned transition to new µTCA.4 based platform
- Excellent for FMC development

See "Spallation Neutron Source LLRF FMC Module Development" in Poster Session for details on modules



Ring LLRF Hardware Development

- µTCA.4 based system
  - PCIe bus, Linux IOC, EPICS
- Use commercial-off-the-shelf carrier card
  - VadaTech AMC502 carrier card
- Custom 14 bit dual ADC, dual DAC FMC developed by LLRF Team
  - Planned replacement with Quad ADC and Quad DAC to support full ring functionality
- Custom timing receiver FMC module developed by Control Hardware Team
- Development of replacement analog hardware in progress



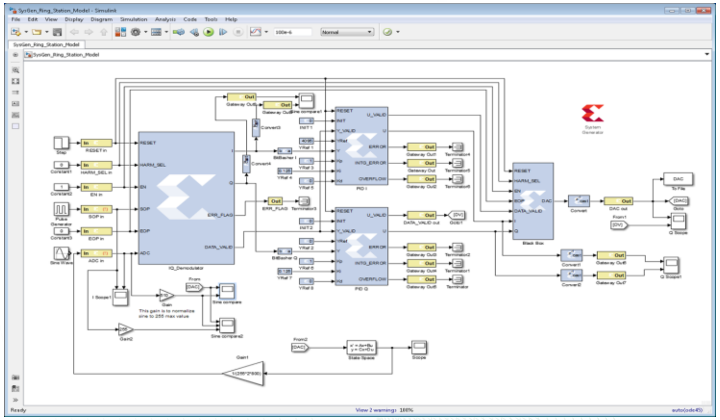
VadaTech AMC502

Timing Receiver

Dual ADC Dual DAC FMC

Ring LLRF Modeling, Firmware & Software

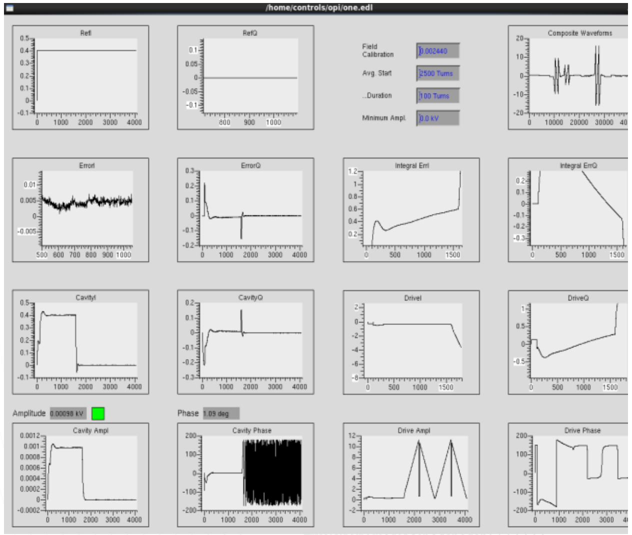
- Joint effort between Controls and LLRF
- Based on the original BNL design
  - Developed a Simulink model to verify the feedback control loop
  - Converted from floating to fixed point implementation
- Migrated from co-simulation using VHDL to FPGA realization
  - Supports open/closed loop operation
  - Turn-by-turn control
  - Waveform capture
- Initial EPICS screens developed
  - Similar look and feel as the Linac screens



Mathematical Model (Dec 2016)

Ring LLRF Initial Test Results

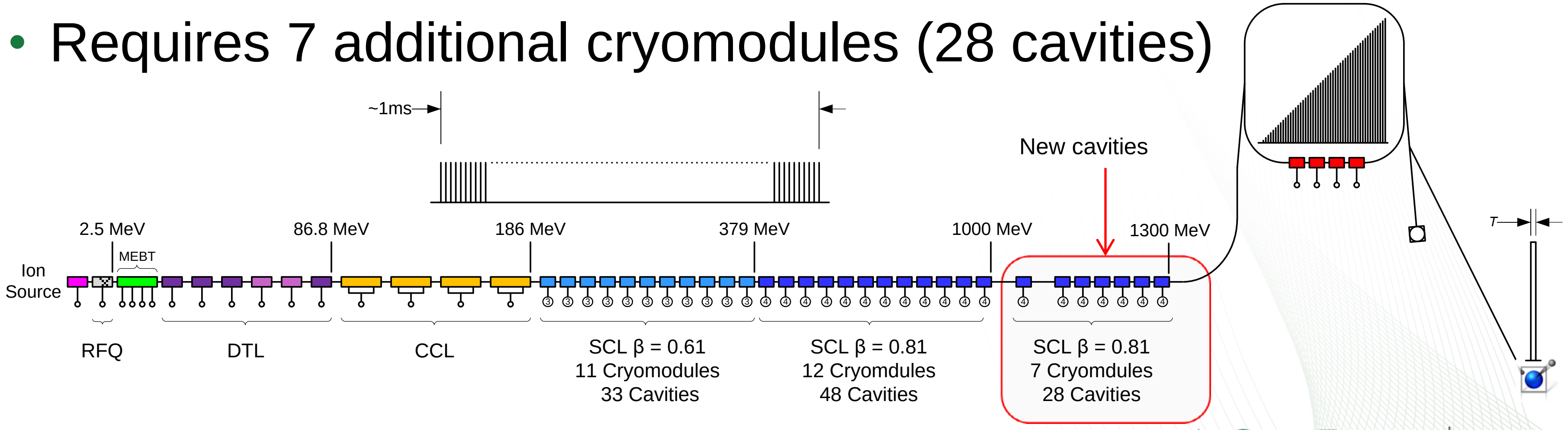
- First test of the system in May 2017
  - Verified open & closed loop operation → 85 kW beam
- Follow on tests
  - Verified operation with 1 MW beam
  - Operated system at both 1st and 2nd harmonic
- System installed for operations in September 2017
  - Basic EPICS screens complete
  - Timing card integrated
  - IOC bootable via network
- Ready for 1st production beam run
- Great collaboration between Controls and LLRF Teams!



Screenshot of closed loop

Proton Power Upgrade (PPU) Project

- Increases power capabilities of existing 60 Hz accelerator from 1.4 MW to 2.8 MW
- Increases power delivered to first target station (FTS) to 2 MW
- Increases neutron flux on existing beam lines
- Provides platform for construction of second target station (STS)
- Requires 7 additional cryomodules (28 cavities)



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PPU Overview & High Level Parameters

- 28 additional RF Stations → will require redesign of LLRF systems for second target station (STS)
  - PPU will utilize redesigned LLRF due to obsolete hardware in existing system
  - Original 96 LLRF stations to be retrofitted during STS
- Conceptual design is complete and is awaiting funding

	SNS 1.4 MW	PPU full upgrade capability	PPU FTS 60 Hz operation	
Proton beam power capability (MW)	1.4	2.8	2.0	
Beam energy (GeV)	0.97	1.3	1.3	← 33% energy increase
RFQ output peak beam current (mA)	33	46	46	
Average linac chopping fraction (%)	22	18	41	
Average macropulse beam current (mA)	25	38	27	← 50% current increase
Energy per pulse (kJ)	23	47	33	
Pulse repetition rate (Hz)	60	60	60	← No change
Macro-pulse length (ms)	1	1	1	
FTS decoupled moderator brightness/pulse (AU)	1	2.04	1.43	
FTS coupled moderator brightness/pulse (AU)	1	2.16	1.51	

Linac LLRF Development

- Replacement Linac LLRF system will be deployed on µTCA.4
  - Leverages development work on Ring LLRF and Data Acquisition Systems (DAS)
  - Solves VME/VXI bandwidth limitation problem
    - Standard VME/VXI data rates are limited to 40 MB/s, PCIe Gen 1 supports 1 GB/s
  - Multiple vendor support
  - Similar system configuration to what is currently installed
    - 1 IOC, 1 timing receiver, & 2 control systems per crate
- Issues
  - Limited board and front panel size
    - Plan to use RTM's to provide additional panel I\O and increased PCB layout area
  - Investigating COTS carrier card options for cost savings
    - Option to produce custom carrier card in the future

High-power Protection Module (HPM) Development

- The HPM is responsible for the fast shutdown of the RF output signal
  - Detected overpower
  - Quench detection
  - Arcs in the RF distribution system
  - Poor vacuum, water flow, cryo, & high power RF
- New design utilizes improved RF detection
  - Better detectors (ADI ADL5513)
    - 80 dB dynamic range, 20 nSec response time
  - 16 bit ADCs vs. 10 bit
  - Simplified calibration of channels
    - Use of digital potentiometers with plans for automated calibration
    - Use of I²C communication between carrier and FMC module
- Arc detector interface for AFT chassis
- Plan to migrate from FMC format to RTM
  - Solves the front panel issue with µTCA platform

Carrier card w/ 8 CH RF Detector & Interface FMC

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Field Control Module (FCM) Development

- The FCM has been reliable but key parts are now obsolete
- The existing system cannot meet future accelerator upgrades
  - No support for more than one style of beam flavor
- Use of a commercial µTCA carrier card and a custom RTM
  - Initial testing using the Dual ADC/Dual DAC and the Quad ADC FMC modules
- All RF signals will be incorporated in a temperature controlled chassis
  - 50 MHz signals only on the carrier card
- Key design goal is improved diagnostics in both the HPM and FCM replacements

VadaTech AMC523 – supports RTM

Quad ADC FMC

Dual ADC Dual DAC FMC

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Summary

- The SNS is a mature facility that has been in operation since 2006
  - Continues to meet the power, availability and reliability goals of 4500 hours/year @ >90% availability.
- The replacement Ring LLRF system is installed and ready to support operations
  - Installed in accelerator in September 2017
  - Development of support hardware is underway
- Actively working on next generation Linac LLRF systems
- Proton Power Upgrade (PPU) project is ready to proceed
  - Adds 28 additional RF stations
  - Increases beam power to 2.8 MW

Acknowledgement

- Thanks to the SNS LLRF Team and Controls Team for their dedication and hard work. None of this would be possible without the help of everyone involved.
  - LLRF Team
    - Taylor Davidson
    - Franklin Frye
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    - Stacey Whaley
  - Controls Team
    - Eric Breeding
    - Doug Curry
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    - Alan Justice
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    - Michael “Gabe” Trout

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