Status and highlights of the NSLS-II and the 3rd RF system Upgrade and future plans

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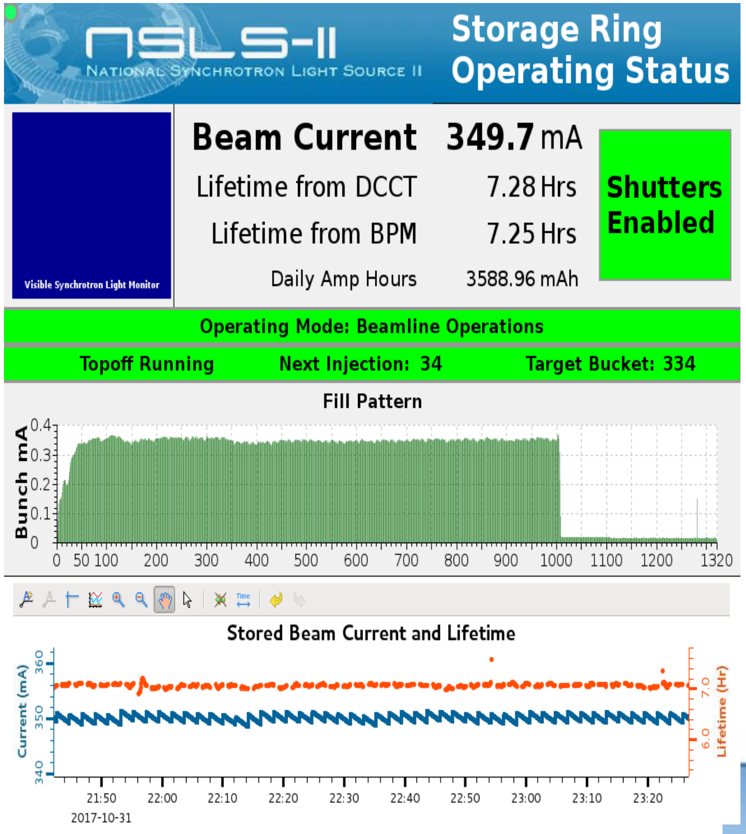
Overview

- Overview and highlights of the NSLS-II storage ring RF systems
- Recent problems and motivation for 3rd and 4th RF systems
- Third RF System project and status
- Early plans for Fourth RF system and Harmonic Cavities
- A Bright Future

NSLS II overview

- National Synchrotron Light Source (NSLS-II) is a new 3 GeV, 500 mA, high-brightness synchrotron light source facility at the Brookhaven National Laboratory, funded U.S. Department of Energy (DOE).

- SR circumference is 792 m with 1 nm-rad horizontal and 8 pm-rad vertical emittance.



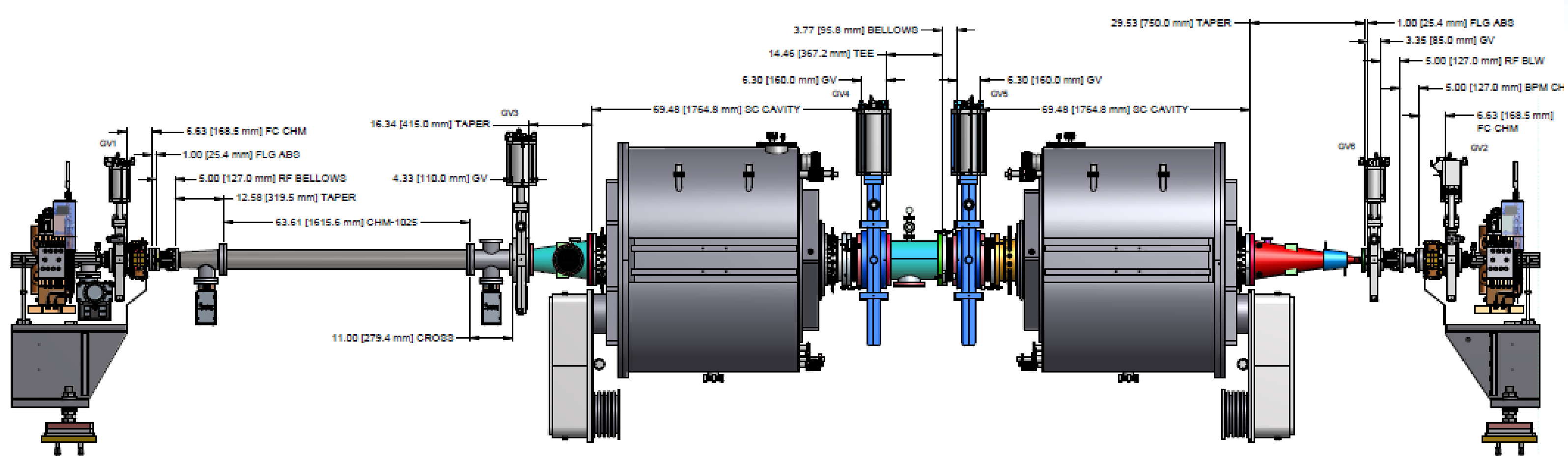
- NSLS II provides with:
  - wide spectral range
  - high average spectral brightness
  - high flux density
  - 60~80 beamlines

- 26 beamlines in routine top off operation at 375 mA.

  400mA operation begins in July

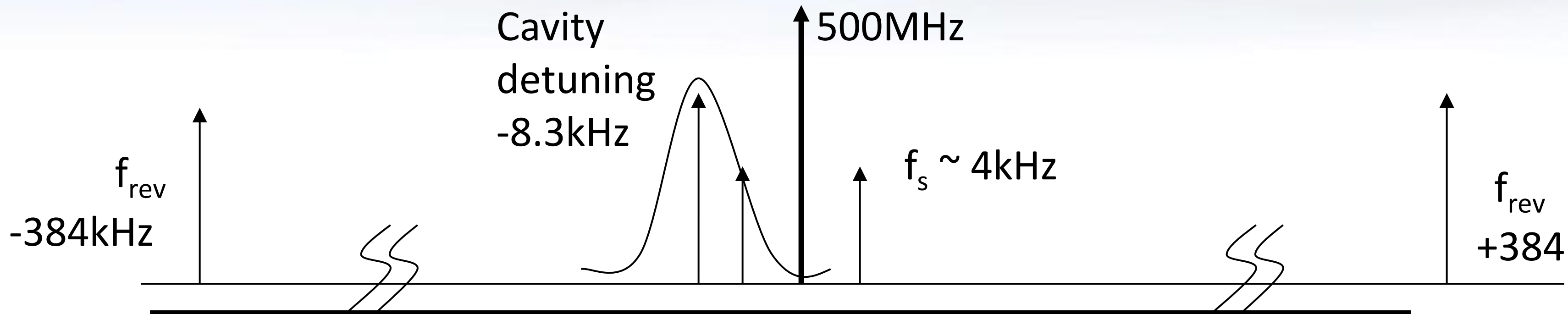
- Beam emittance and beam orbit stability met the goals.

RF straight layout



- Two RF straights reserved in NSLS-II lattice
- One is populated with two 500 MHz CESRb cavities (Project funded)
- Space reserved for passive SRF 3rd harmonic cavity
- Currently building out second RF straight with 3rd CESRb cavity (AIP funded)
- Component production for third cavity is ~90% complete
- Cryomodule Integration performed at NSLS-II

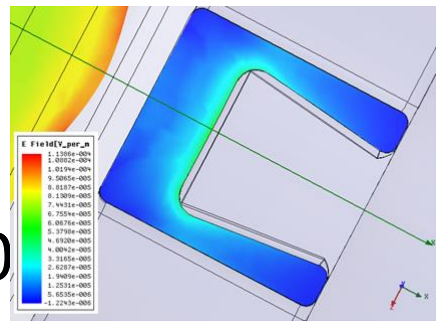
Beam Loading parameters



	Baseline	Fully Built Out
R/Q	44.5	44.5
Q_0	$>5*10^8$	$>5*10^8$
Revolution Frequency	384 kHz	384 kHz
Total V	3.3 M	4.9 MV
Synchrotron Frequency	3 kHz	4 kHz
Number of cavities	2	4
Q_L*	79000	79000
Vcav at max Prev	1800kV	1800kV
Frequency detuning	-6.4 kHz	-8.3 kHz
* Q_L ~ 80k for minimum reflected power over all phases		

Storage Ring: Superconducting Cavity

- 2 (of 4) 500MHz Cornell type SRF cavities installed
- Redesigned coupling iris for Q_{ext}=79,000



- BNL assisted AES in assembly of first 2 cryomodules; complete knowledge base for refurbishing cryomodules

Storage Ring Transmitter

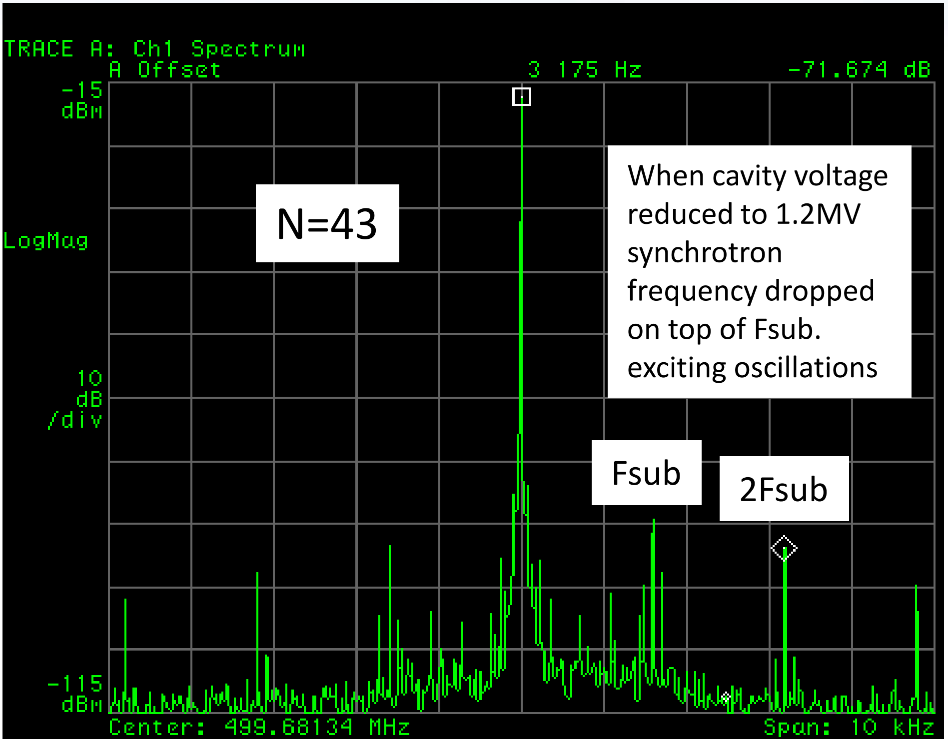
540 kVA klystron solid state switching power supply with mod-anode, filament supplies, interlocks and controls

300 kW klystron amplifier

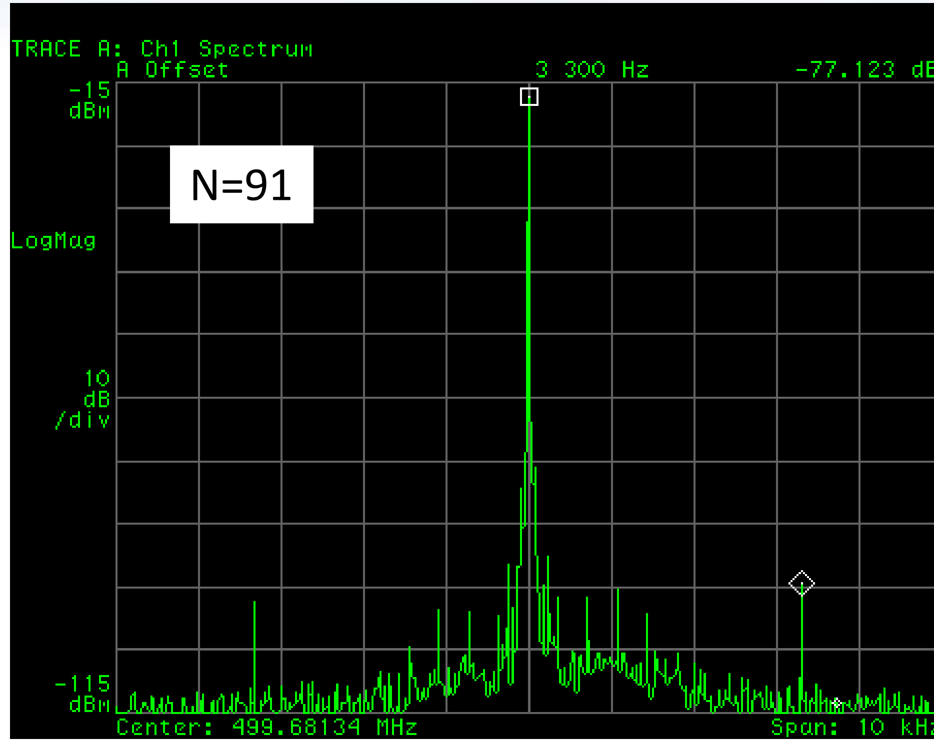
Operating since 2012, only four failures: 1x PLC I/O module failed, 2 x HV capacitor in output filter, 1 x secondary winding in HV transformer- this latter did not cause downtime due to redundant switching modules

Klystron HVPS Switching Frequency

$f_{SubHarmonic}$=nx1.5625kHz

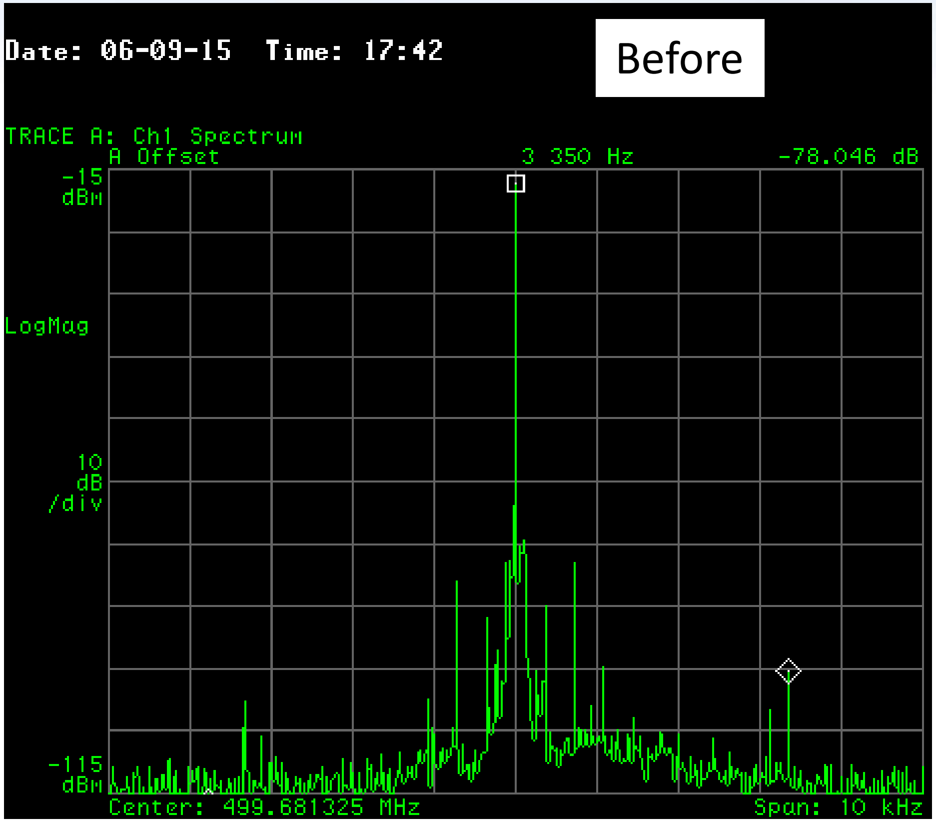


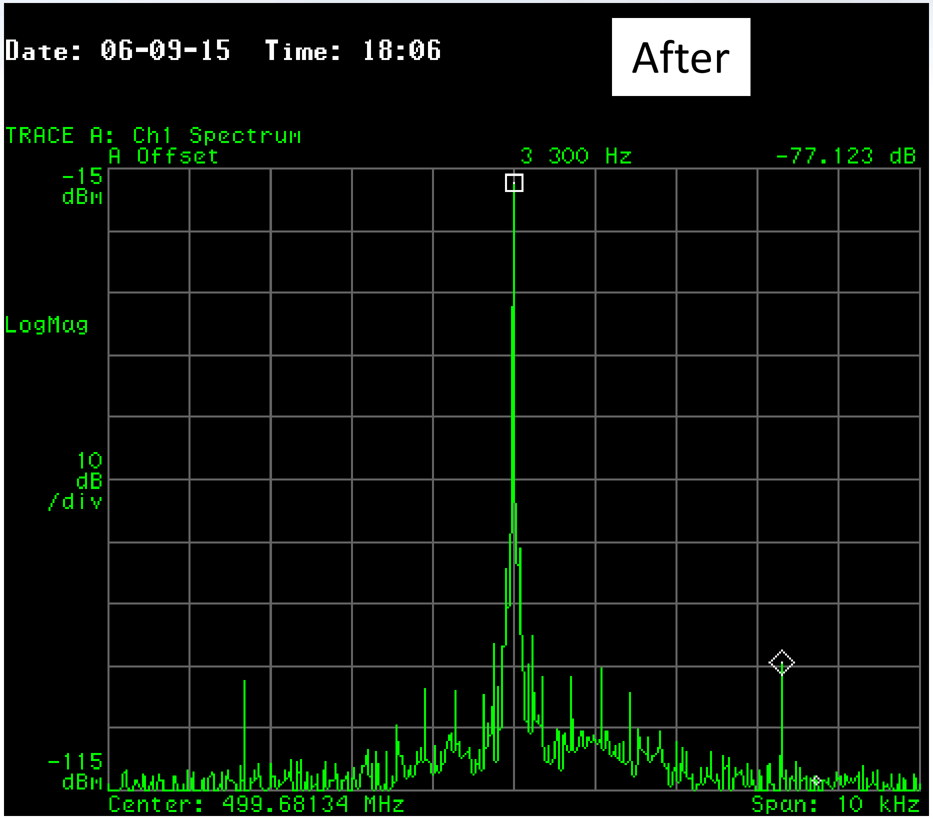
$f_{SubHarmonic}$=nx3.3067kHz



The klystron High Voltage PS is a switching PS with 86 switch modules. The switching frequency is programmable as N times 3.125 kHz, and is typically run at values of N between 30 and 120 for switching frequencies of 93.75kHz to 375 kHz. There is a subharmonic at the switching frequency divided by the number of modules which places the subharmonic in the vicinity of the synchrotron frequency- we occasionally have to change the switching frequency as RF voltage is raised and the beam potentially driven by the switching sub-harmonic.

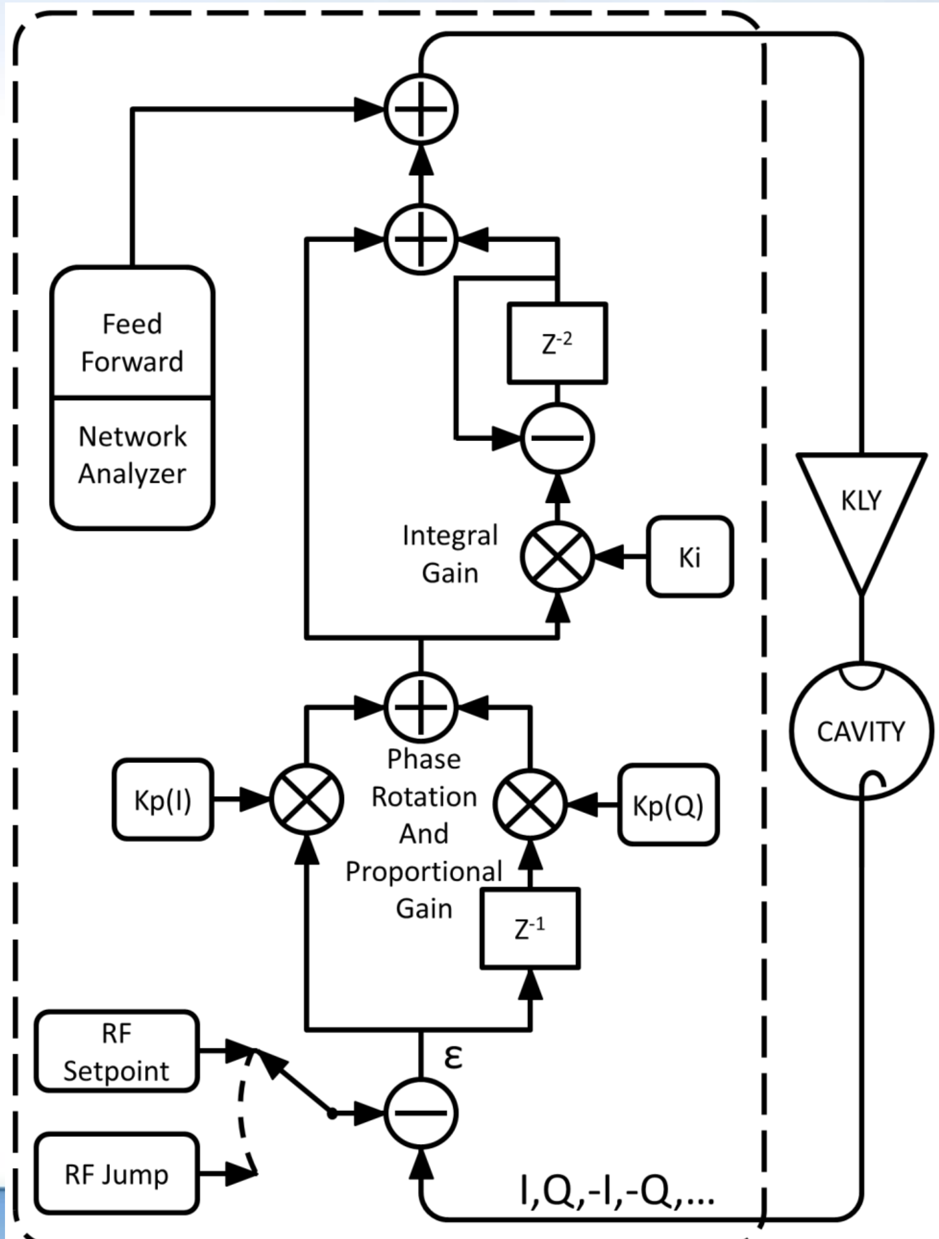
Transmitter HVPS AC Mains compensation



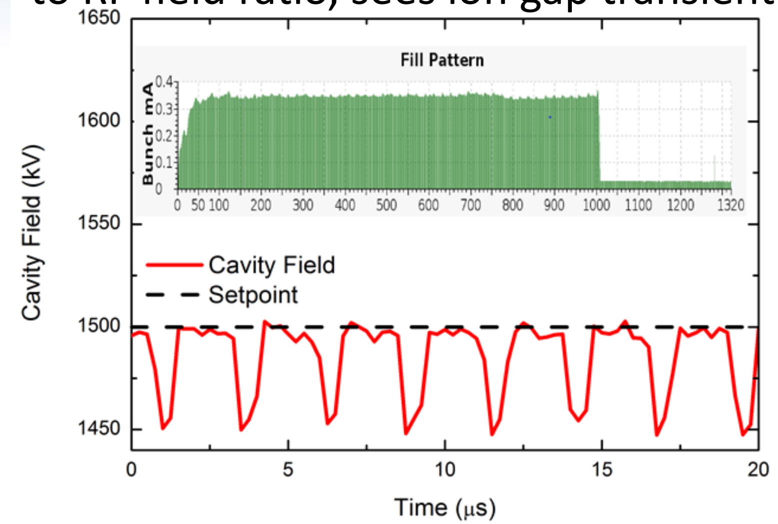


The klystron HVPS is a switching power supply with 86 switch modules, 82 typically active at any time- with 4 redundant spares. An algorithm for switching sequence allows us to select weights for reducing the amplitude of the AC power harmonics: 60, 120, 180, 240, 360 and 720 Hz. This can be performed “live” with beam.

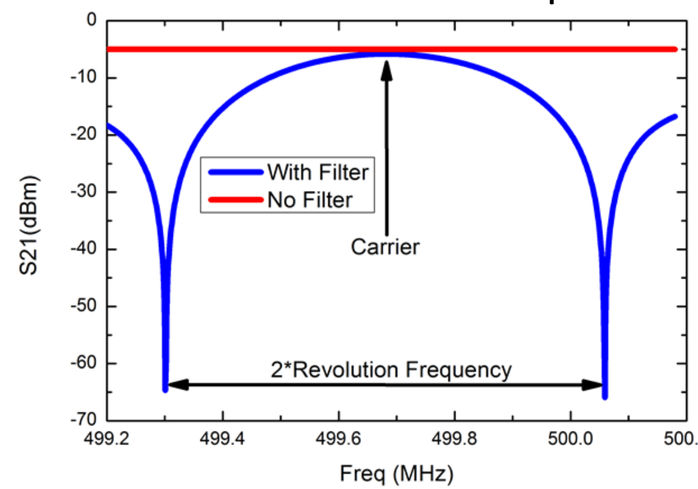
Very Good Diagnostics and Tools in LLRF



Field Probe failed, backup has high beam to RF field ratio, sees ion gap transient

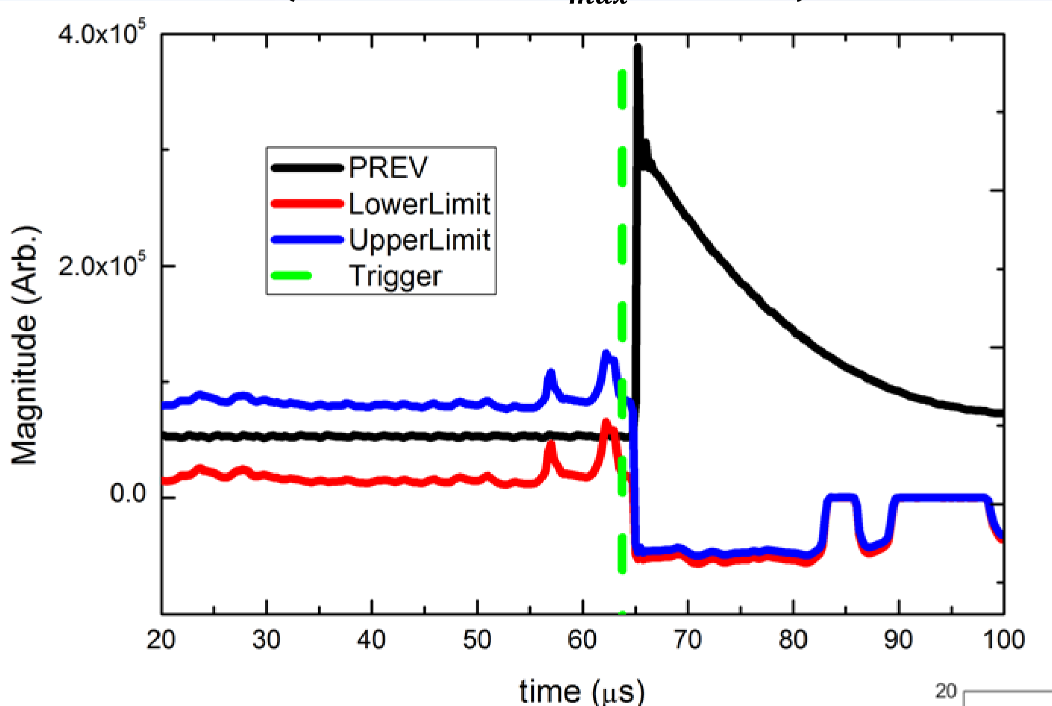


Created FIR filter to compensate



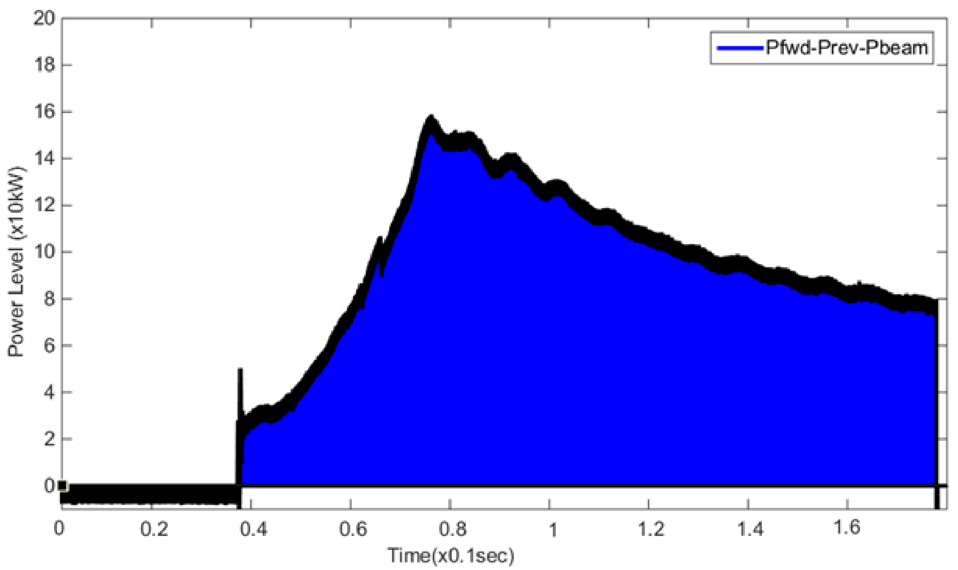
Equench: detect “lost” rf power, trip RF

$$0.8 * \left(P_{Fwd} - E_{Loss_{max}} * I_{beam}\right) < P_{Rev} < \left(P_{Fwd} - E_{Loss_{min}} * I_{beam}\right) * 1.2$$



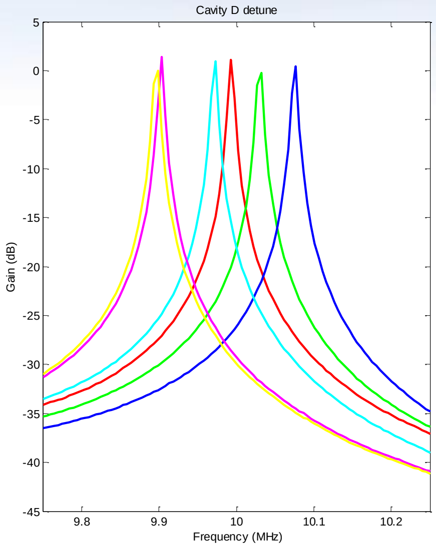
EQuench event during conditioning the superconducting cavities. The recovery of the RF systems from an EQuench trip is dramatically easier since the cryoplant does not need to be recovered, only the RF power.

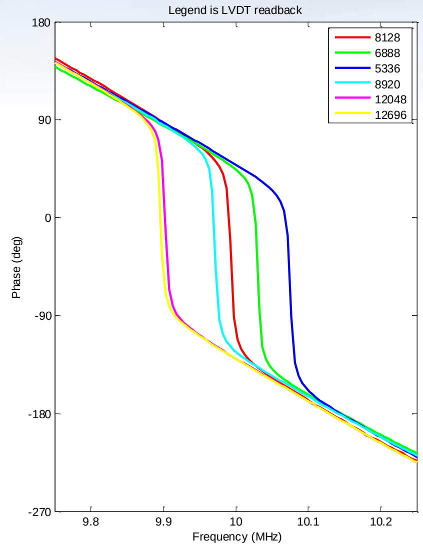
Plot of the Forward power minus the Reverse power minus the power distributed to the Beam versus time in the event of a quench at 250mA beam current. Integration of this plot yields the total energy into the walls of the cavity in the form of heating which is roughly 13.6kJ and vaporization of ~4 liters of LHe



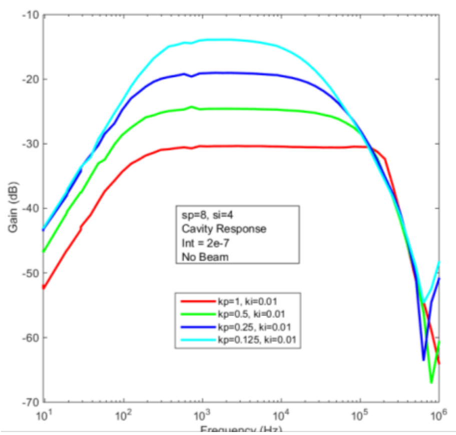
From Belomestnyck

300 kW, 5 CHANNEL NETWORK ANALYZER

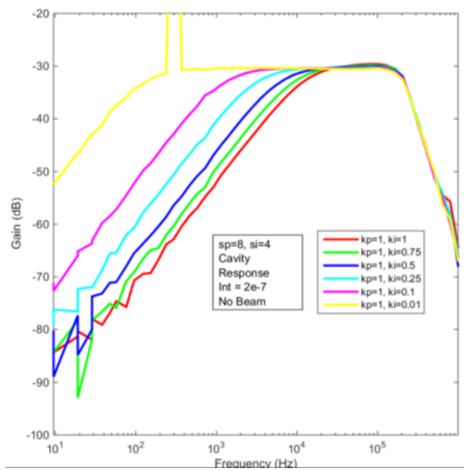




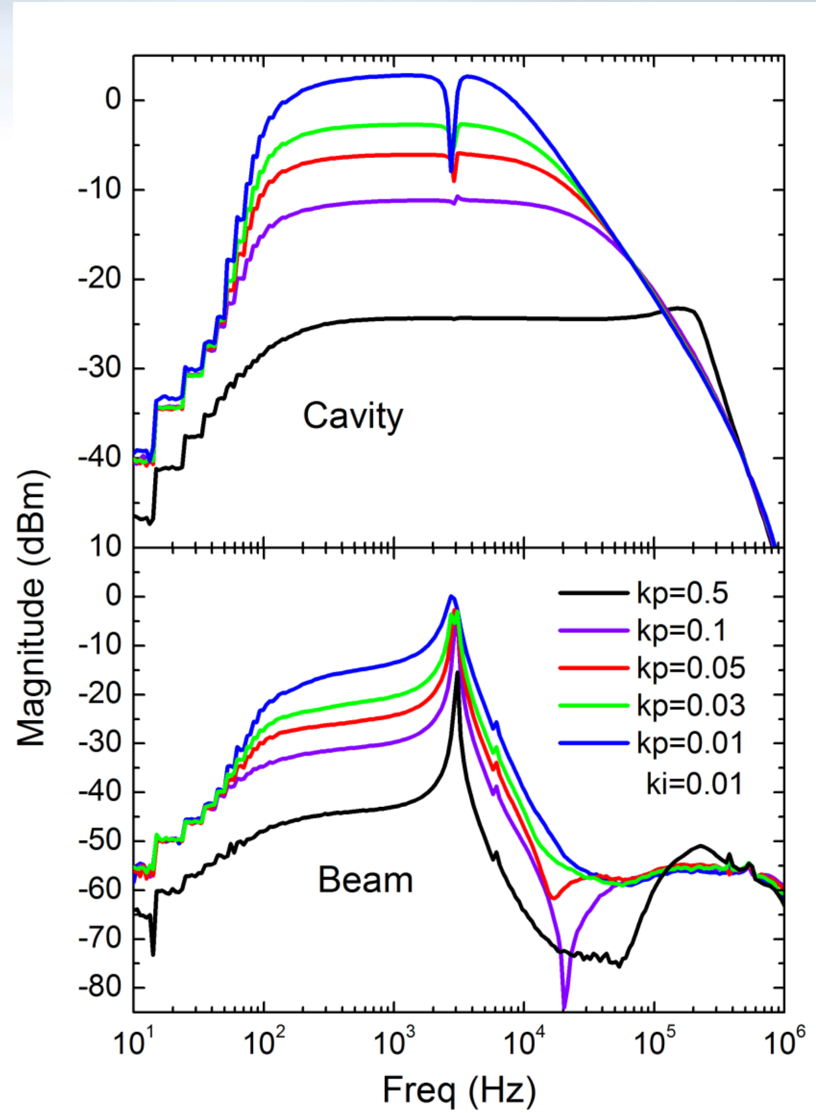
Frequency sweeps with different tuner positions



Varying kp, ki constant



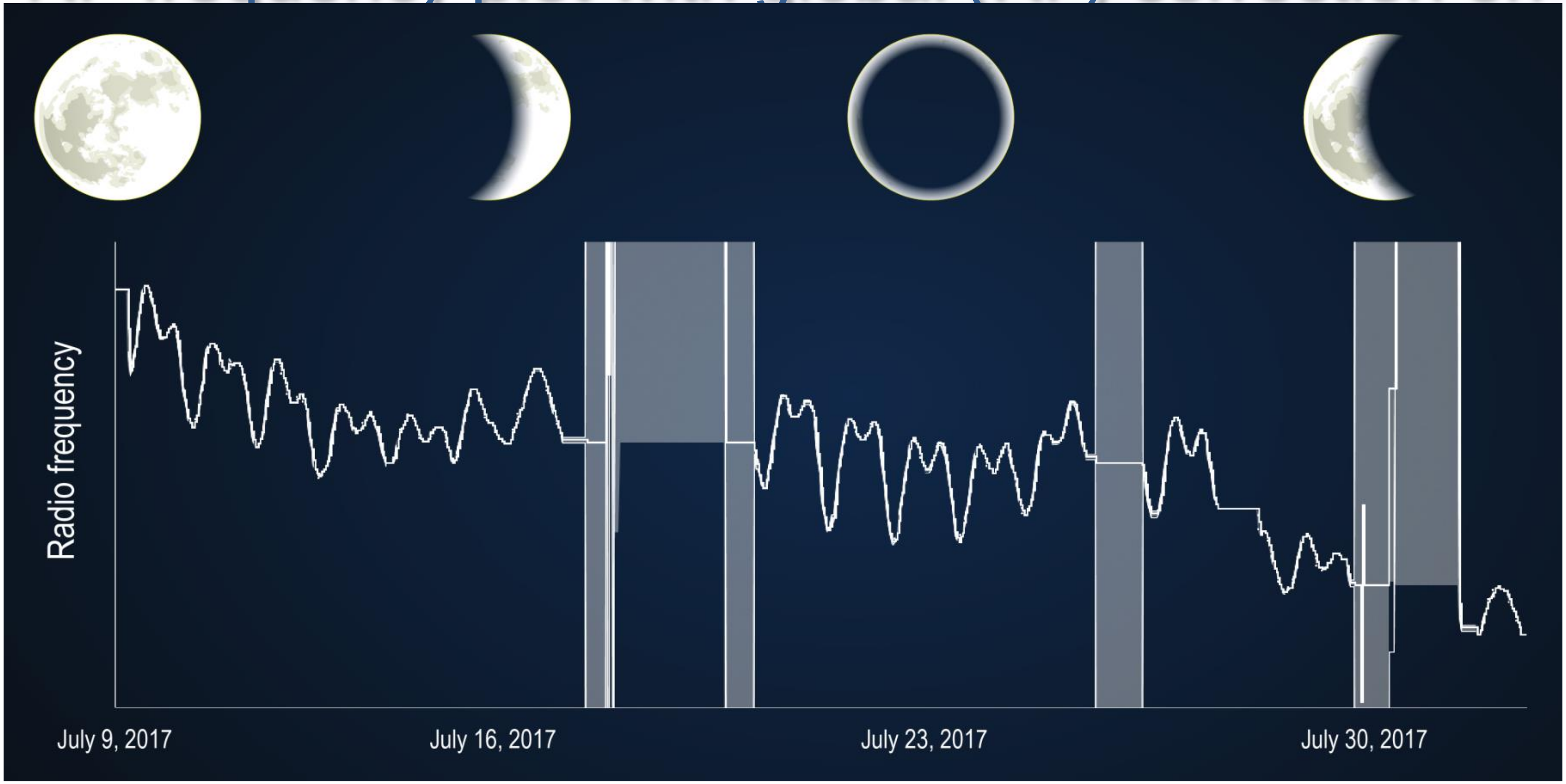
Varying ki, kp constant



Cavity and beam responses

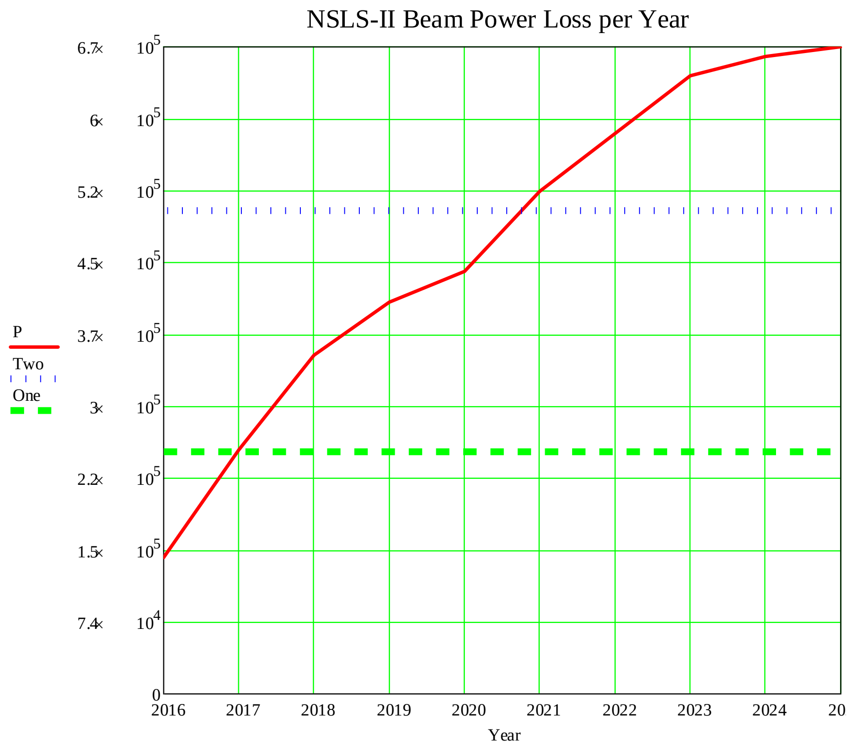
Quiet and Stable RF systems

RF frequency plot with global (RF) correction on

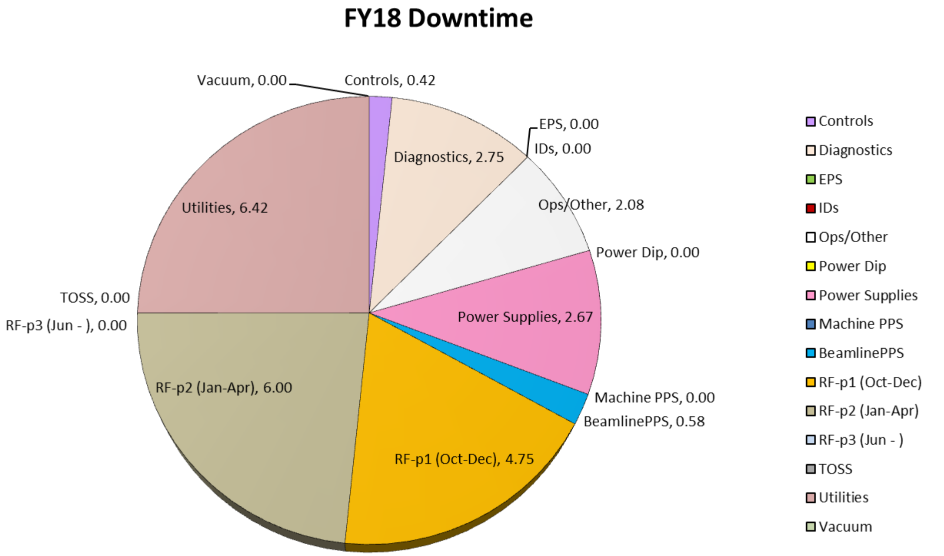


Very slow orbit (circumference) feedback with RF frequency adjustment is correlated to the phase of the moon due to tidal forces

Motivation for Third RF System



Running out of RF power by 2021: Planned addition of SC wiggler puts us over the power limit of two systems



Reliability: Up until very recently the cavity vacuum trips dominated machine downtime. A real failure n one of the RF systems would mean reducing operations beam current.

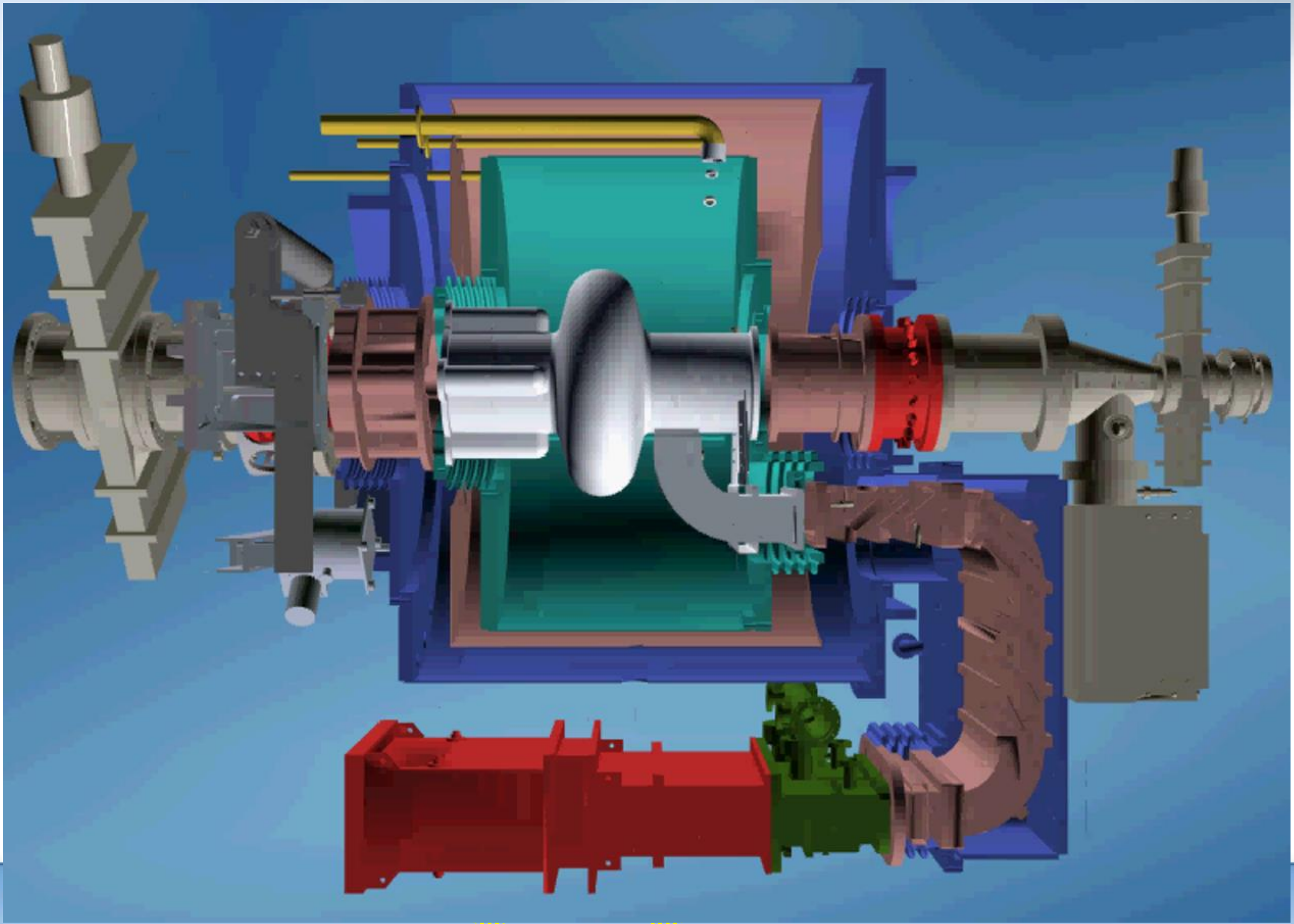
A general upward trend in reliability was reversed on November 8, 2018

During a two-day maintenance an RGA was installed/baked by the vacuum group immediately downstream of cavity gate valve and independently a partial warm-up of the cryomodule to 50 K was performed due to coldbox repairs

Oparations period	#Faults	# Dumps	Downtime (hr)	MTTR (hr)	MTBF (days)	Comments
RF-p0 (May-Aug)	13	7	4.66	0.67	7.89	1293 hrs
RF-p1 (Sep-Dec)	25	16	7.25	0.45	3.71	1519 hrs
RF-p1 (Oct-Dec)	21	14	4.75	0.34	3.05	1102.5 hrs
RF-p2 (Jan-Apr)	23	17	6.00	0.35	3.89	1686.7 hrs
RF-p3 (Jun -)	1	0	0.00	--	>23	>552 hrs

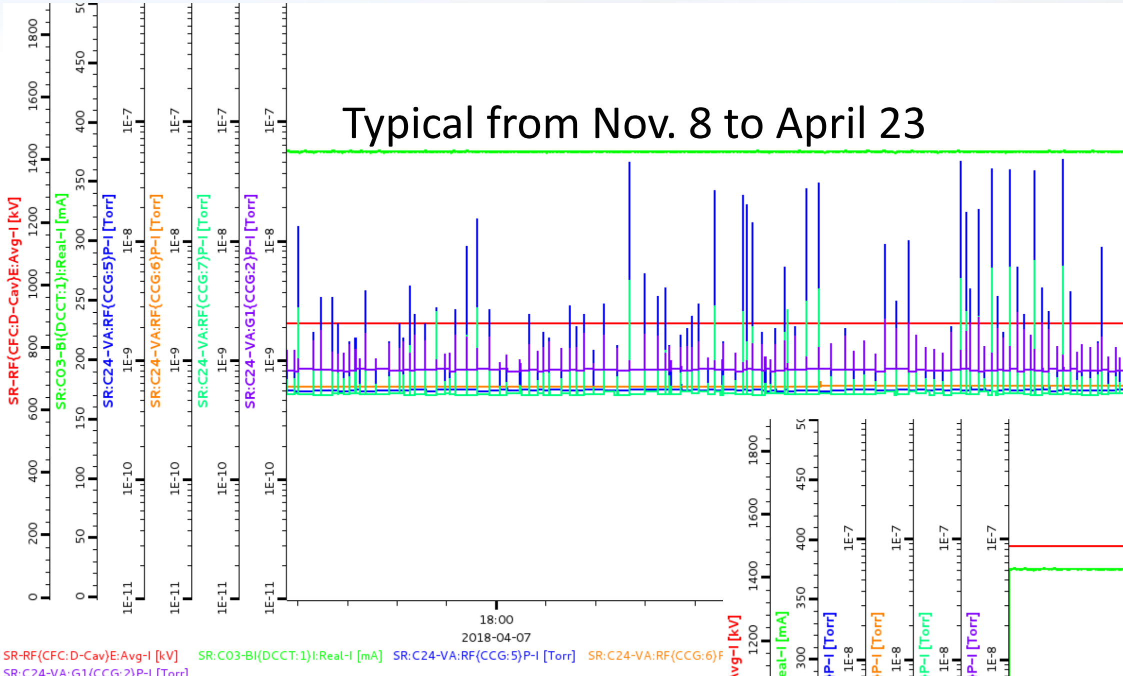
Full warm-up of cavity, replacement of pump-out box ion pump+ elbow, downstream shielded bellows and cleaning of BPM assembly during May shutdown has fixed the problem

CESRb 500MHz Superconducting Cavity



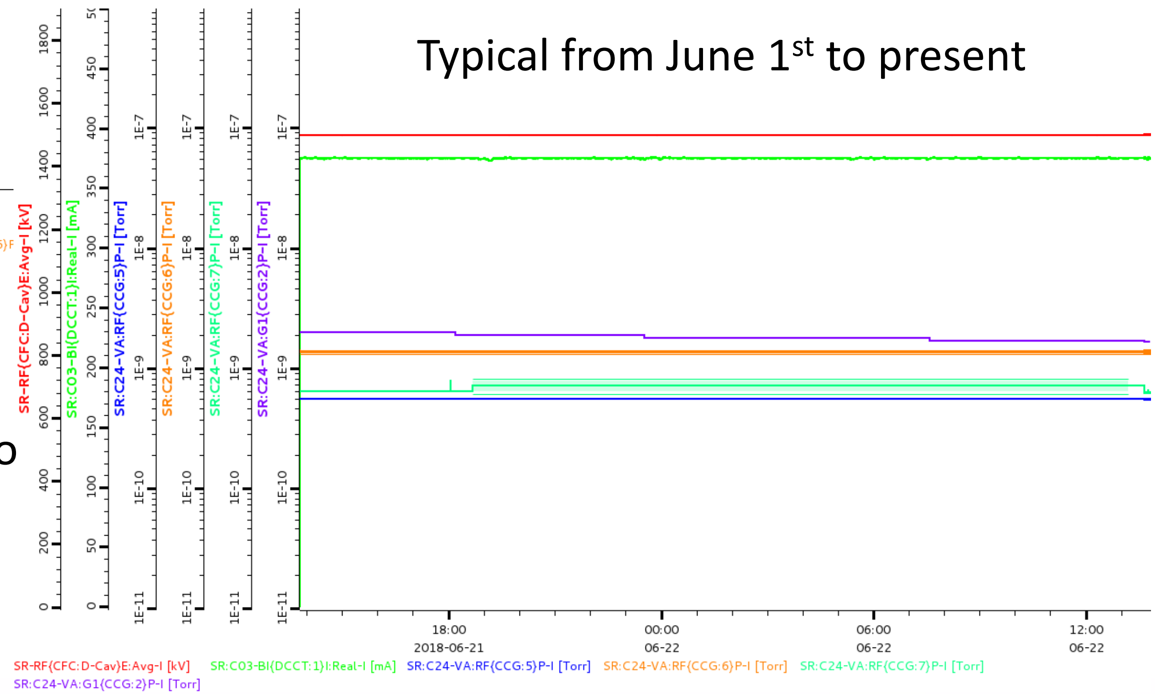
Vacuum trips dominate RF system performance

Typical from Nov. 8 to April 23



After November 8th maintenance day were not able to run Cavity D at 1500kV with 375 mA. Voltage reduced to 875kV, still frequent trips

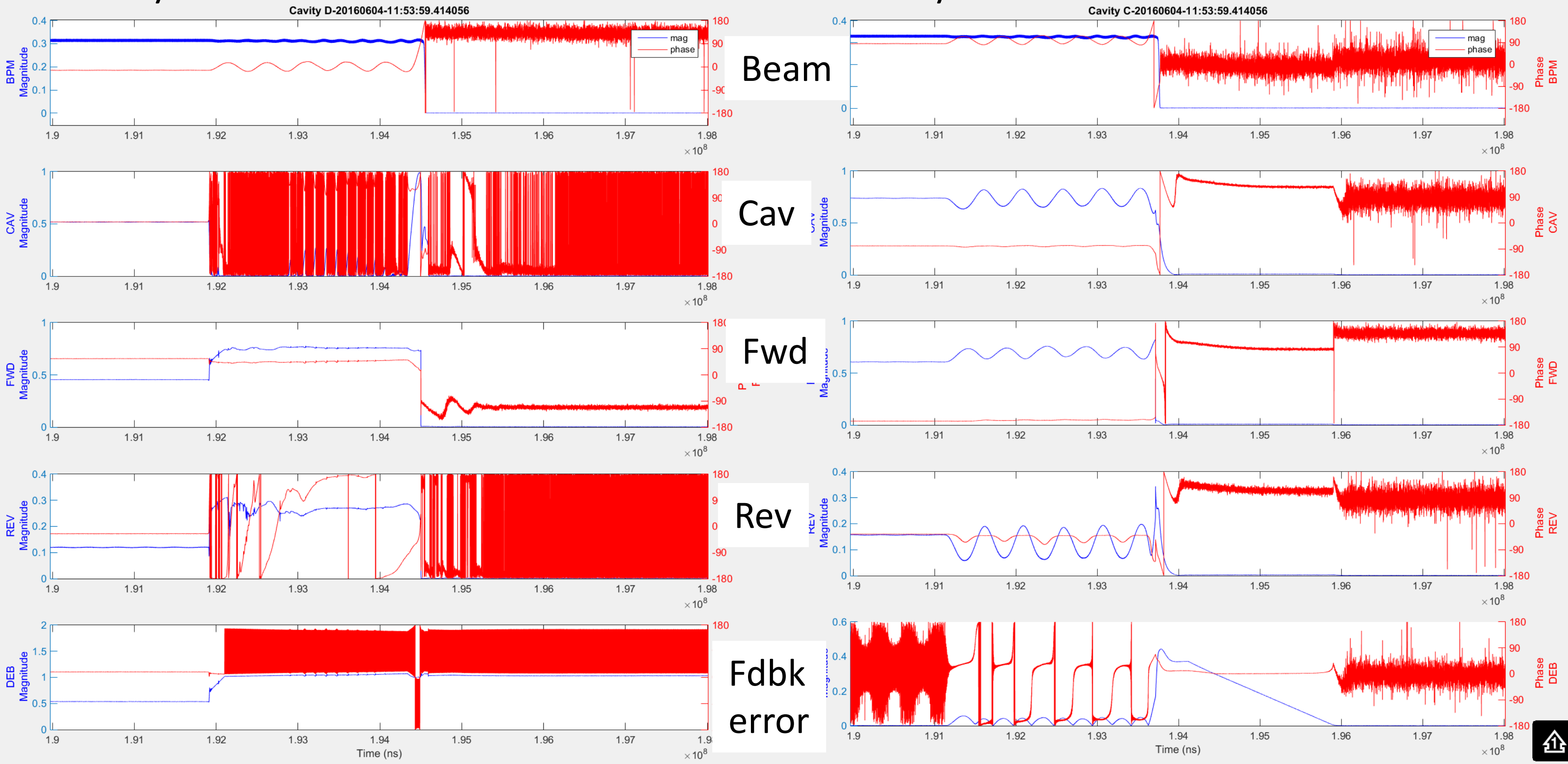
Typical from June 1st to present



After full warmup during May shutdown, Cavity D conditioned to 1800kV, runs reliably at optimum voltage of 1500kV

Circular Buffer Data (Postmortem)

Cavity D   Cavity C



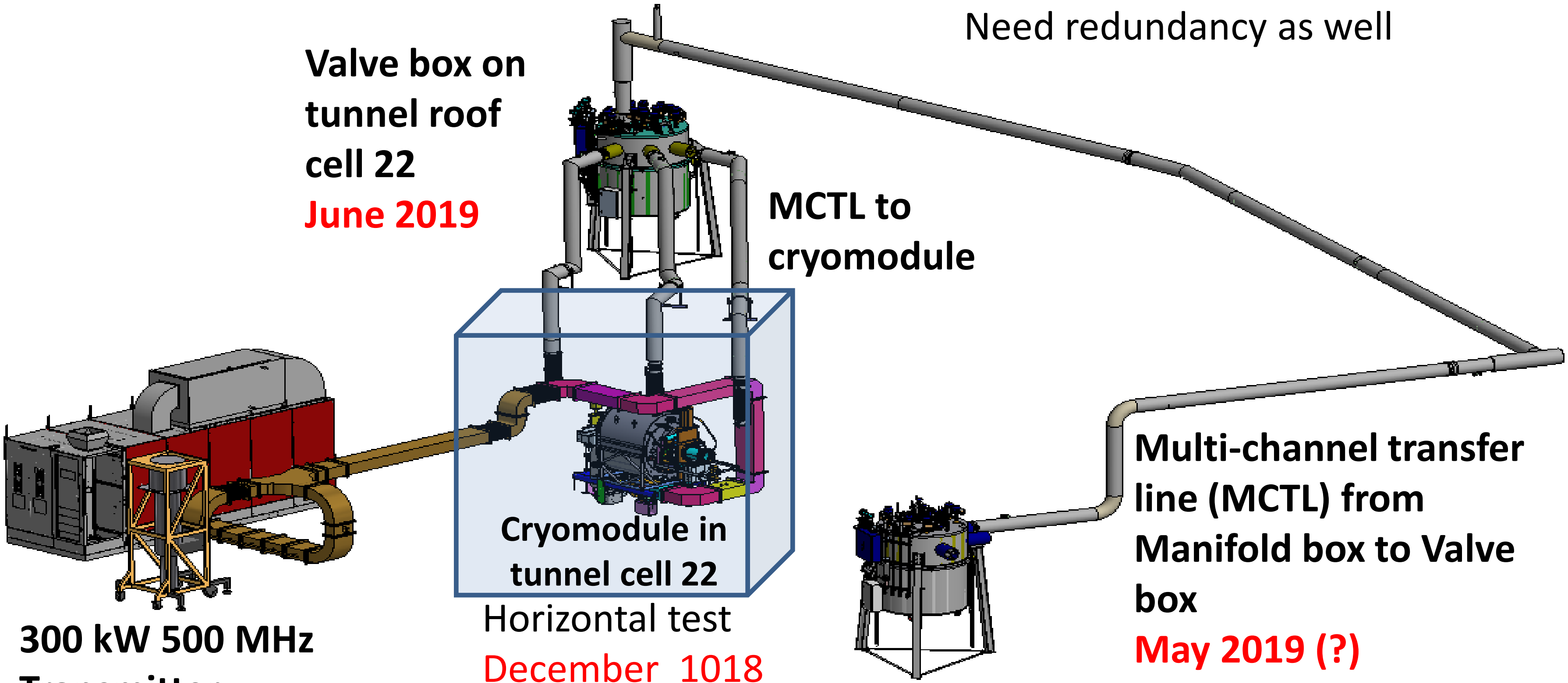
Typical circular buffer data. This data shows a collapse in the rf field in cavity D which causes the forward power to be driven very high, cavity C and beam also become unstable. By bandpass filtering a BPM sum signal the beam centroid phase and amplitude can be measured by the controller (top traces).

3rd RF SYSTEM PROJECT

Approaching limit of two RF systems by year ~2020
Need redundancy as well

Valve box on tunnel roof cell 22
June 2019

MCTL to cryomodule



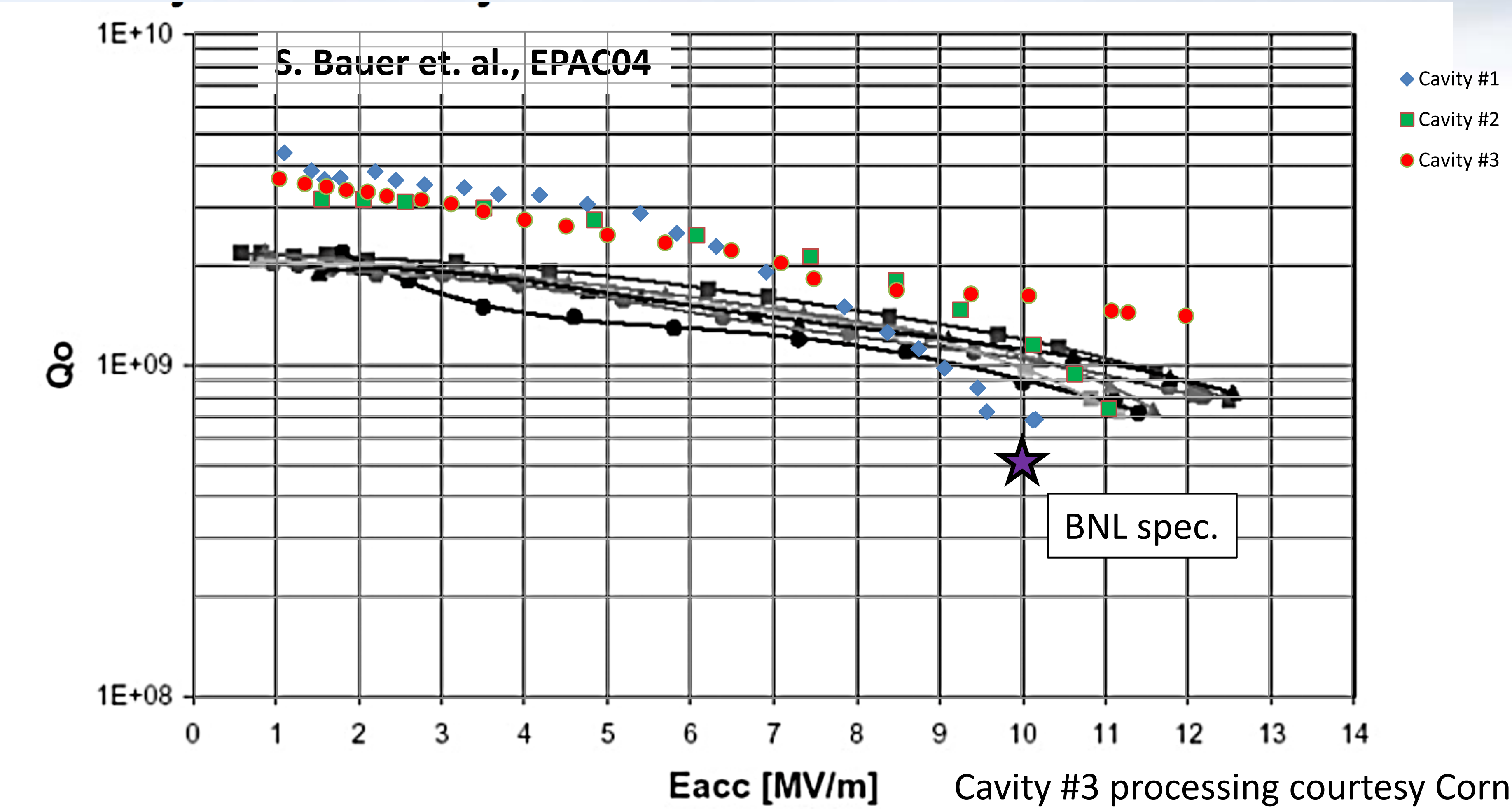
Horizontal test
December 1018

Multi-channel transfer line (MCTL) from Manifold box to Valve box
May 2019 (?)

300 kW 500 MHz Transmitter
~July-August 2019 (still reviewing bids)

Existing manifold valve box in RF Bldg

CESR-b VT result and Comparison at 4K

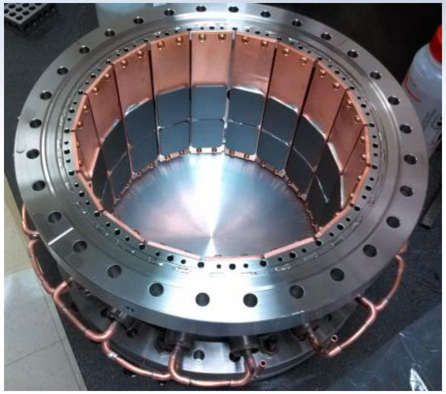


Cavity #3 processing courtesy Cornell

- **Typical design Q is 1×10^{9} at 10MV/m at 4K.**
- **Previous reported Q_0 were $(1 \pm 0.2) \times 10^{9}$ at 10MV/m at 4K (S. Bauer et. al., EPAC04).**
- **NSLS-II cavies 1, 2 and 3 superimposed on earlier results. Cavity 3 was N2 doped**

Third Cryomodule in final assembly at BNL/NSLS-II

Cavity String Assembly



HOM built by industry

Window High Power Test Assembly
Confirms TiNi coating of window is OK

The Third NSLS-II Transmitter*

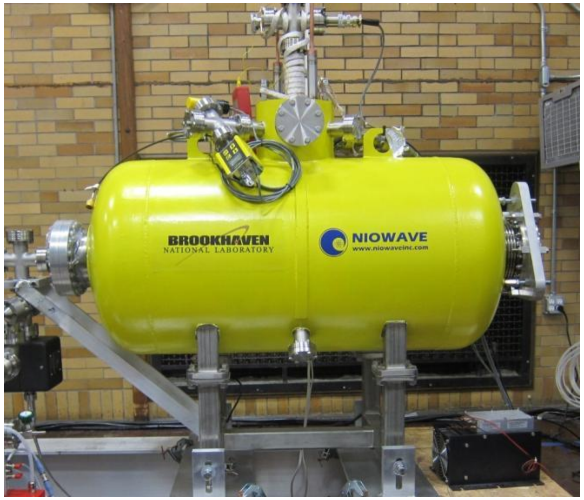
*Coming soon to CWRF 2020

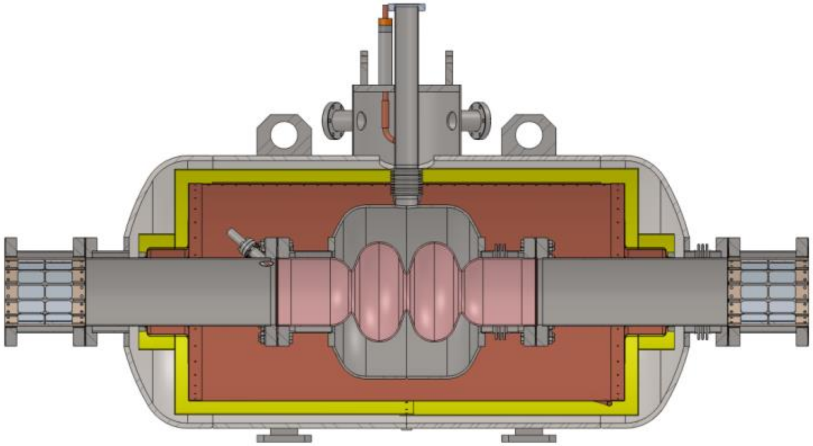
Future plans in priority order

- Fourth RF system
  - Cryomodule and transmitter installed in second RF straight
- Fifth Cryomodule as spare
- Complete Harmonic cavity cryomodule with HOM dampers and tuner. *This would have been easier as part of the NSLS-II project and installed during commissioning when risk was more acceptable*
- Second Harmonic cavity

Landau Cavity

First horizontal cold test complete completely validates 0-π mode tuning over 1 MHz bandwidth. Low Q loaded (6e7 vs. 2e8) explained by trapped TE mode when tested without dampers.





Need to design and fabricate new, instrumentation, ferrite dampers, tuner mechanism

SUMMARY

- NSLS-II has been running with user beam for 4 years now, and has met all design goals with the exception of 500mA operation, and it is methodically approaching full current as well.

- Operations with 2 cavities point out the risks to both performance and reliability, management has finally started down t he road to full build out

- Construction of 3rd RF system underway, completion in FY2020

- Future options buildout to include 4th RF system + harmonic cavities + spare CESRb

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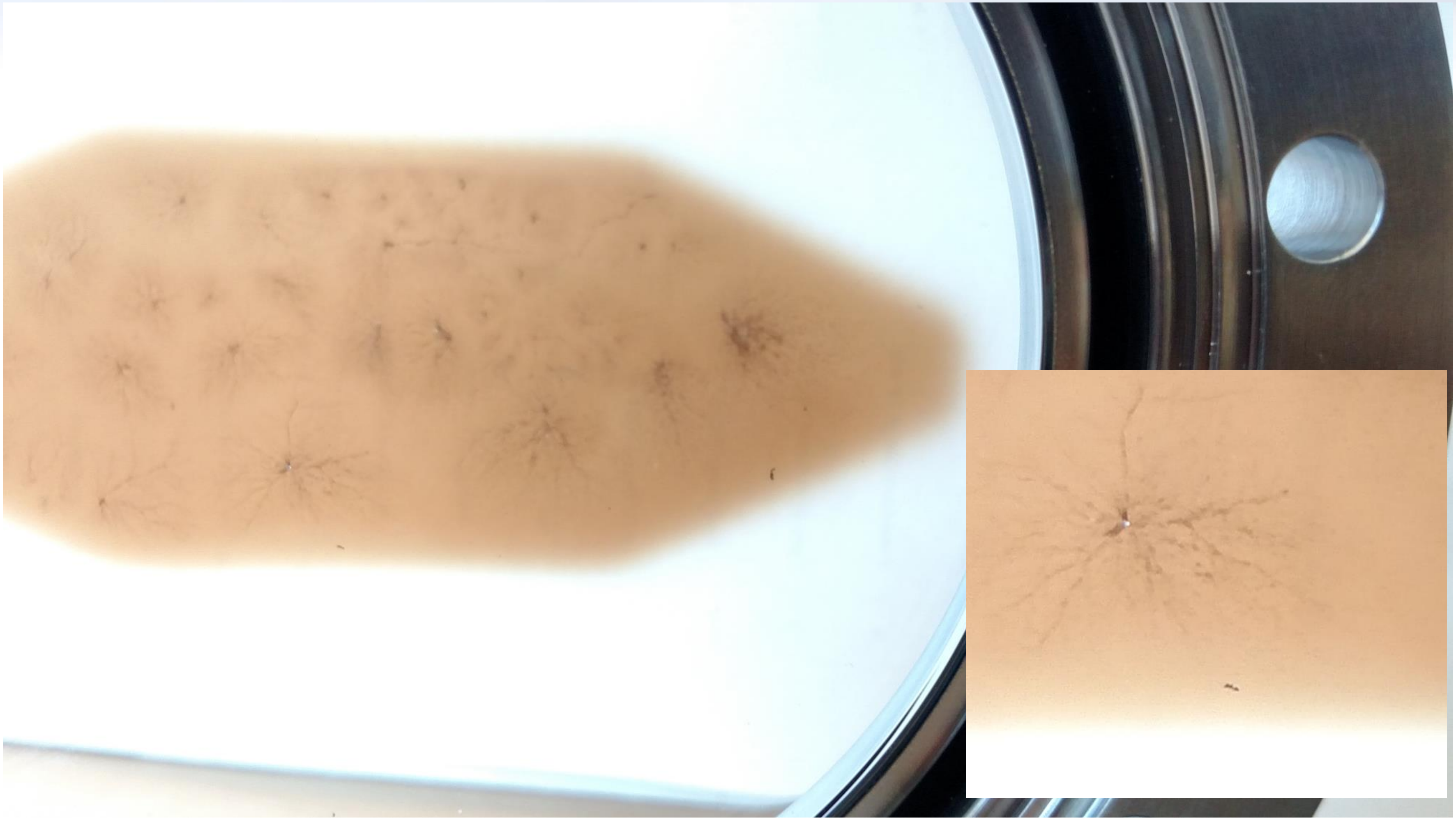
Failure Slide



RF conditioning with glass viewport to try and identify arc locations.
Arc locations were inside glass from 1.5 MV field emitted electrons