NSLS-II RF Systems

Jim Rose on behalf of the NSLS-II RF group
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U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

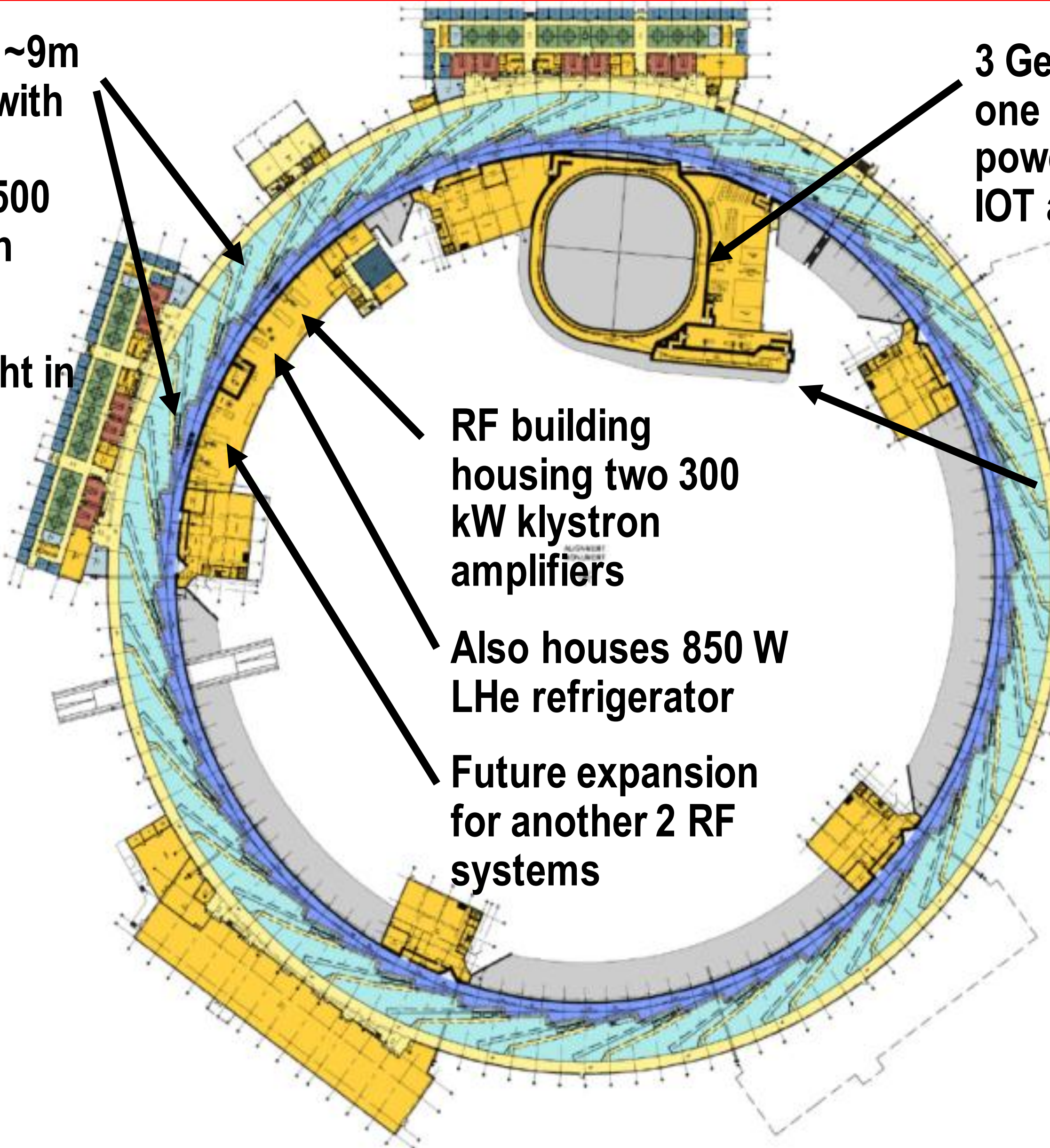
Outline

- Introduction to NSLS-II
- RF Systems at the NSLS-II
  - Linac
  - Booster cavity and Transmitter
  - SR Transmitter
  - SR 500 MHz Cryomodule
  - LLRF
  - LHe Cryogenic System
- Schedule
- Future expansion
- Conclusions

NSLS-II RF Systems

Storage Ring: Two ~9m RF straights each with two 500 MHz SRF cavities and one 1500 MHz passive bunch lengthening cavity

Only one RF straight in initial operations



3 GeV booster with one 7-cell cavity powered by 80 kW IOT amplifier

RF building housing two 300 kW klystron amplifiers

Also houses 850 W LHe refrigerator

Future expansion for another 2 RF systems

200 MeV linac with four 5.2 m TW structures powered by two 42 MW klystrons with SS modulators and third “hot spare”

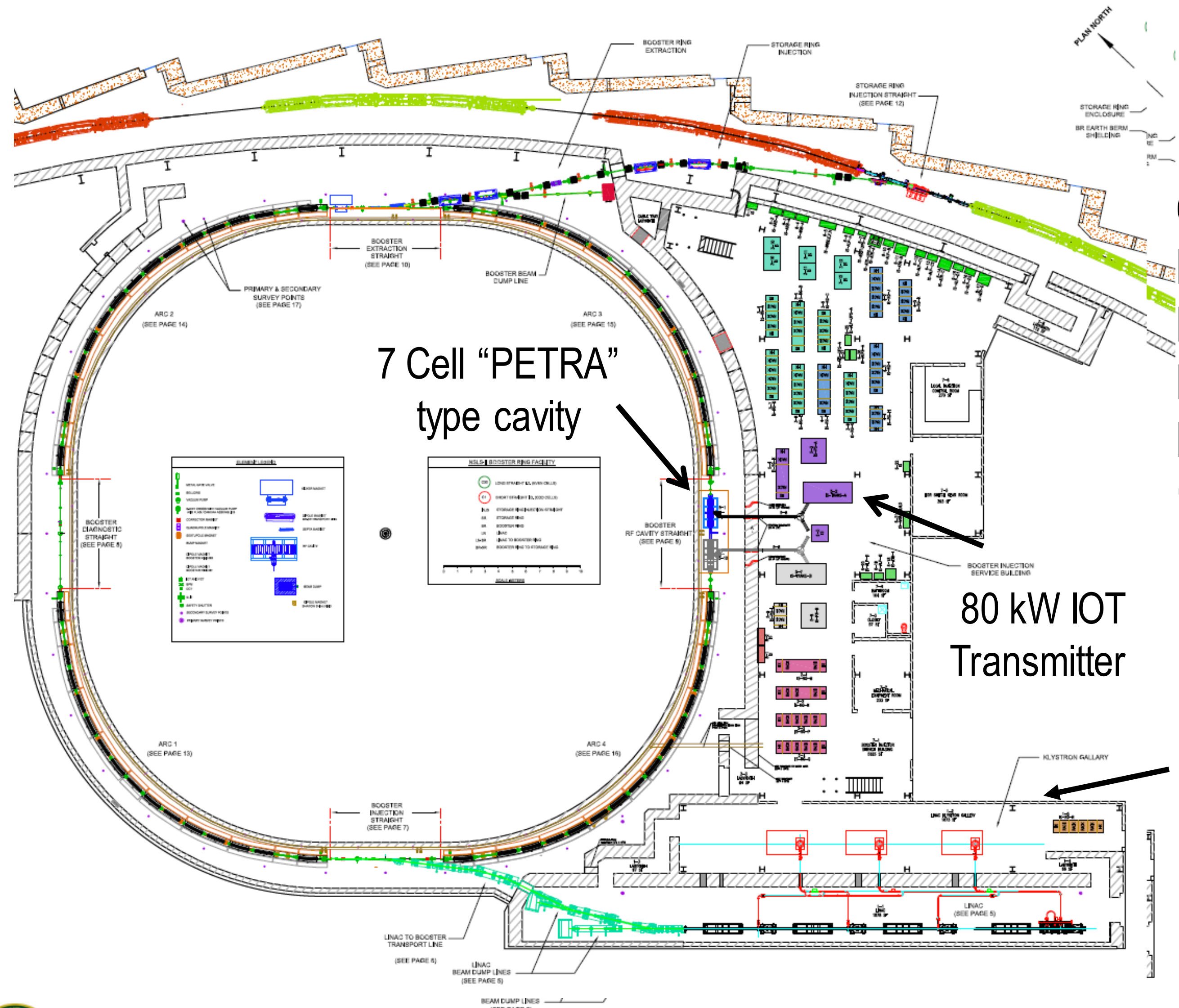
NSLS-II Technical Requirements & Specifications

Energy	3.0 GeV	Energy Spread	0.094%
Circumference	792 m	RF Frequency	499.68 MHz
Number of Periods	30 DBA	Harmonic Number	1320
Length Long Straights	6.6 & 9.3m	RF Bucket Height	>2.5%
Emittance (h,v)	<1nm, 0.008nm	RMS Bunch Length	15ps-30ps
Momentum Compaction	.00037	Average Current	500ma
Dipole Bend Radius	25m	Current per Bunch	0.5ma
Energy Loss per Turn	<2MeV	Charge per Bunch	1.2nC
		Touschek Lifetime	>3hrs

The RF systems uses a single 9.3 m RF straight that contains two 500 MHz Cornell-type superconducting RF cryo-modules and a passive 1500 MHz third harmonic cavity for bunch lengthening

A second 9.3m straight is reserved for future RF systems

Injector Layout



Booster Parameters

Cicumference: 154m

Harmonic # 264

Rep rate 1 (2) Hz)

Energy 0.2 to 3.0 GeV

RF Voltage 0.2-1.2MV

1 to 150 bunches

Linac

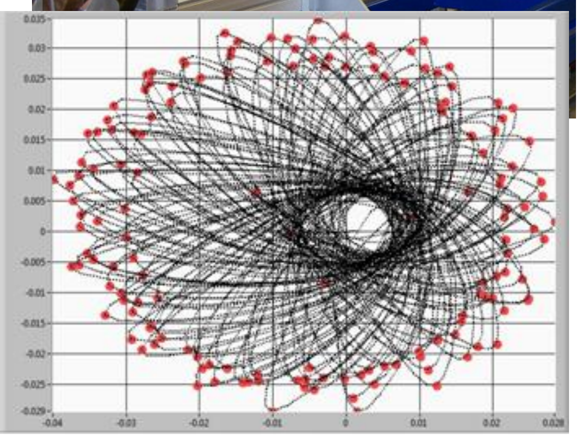
200 MeV

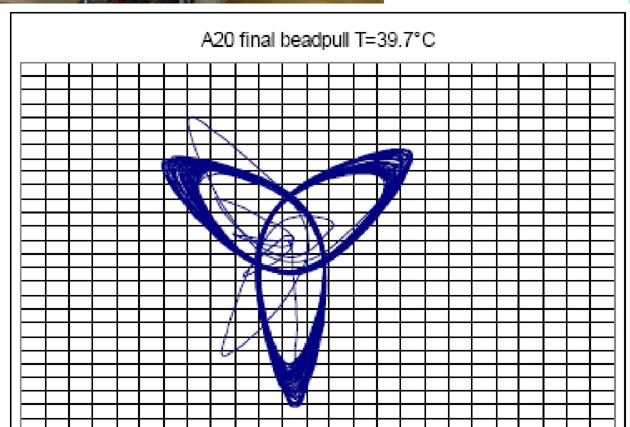
15 nC in 150-300 ns

0.5% dE/E rms

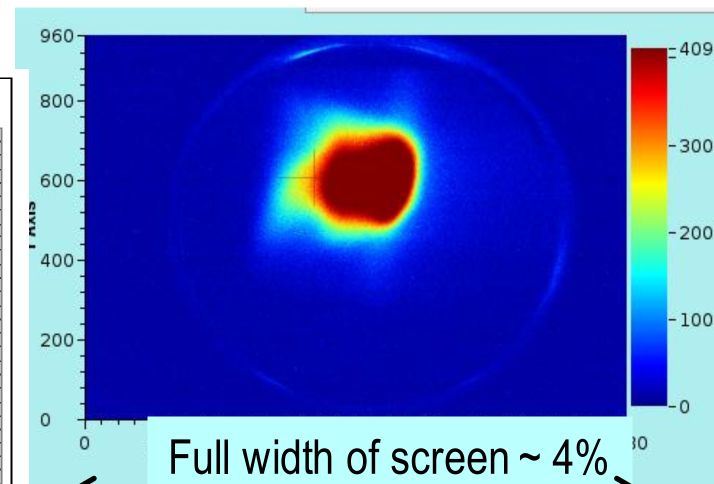
Linac: Commissioning in progress

- 200 MeV attained
- 15 nC in 150 ns bunch train beam-loading compensation reduced dE/E from >5% to 0.35% rms





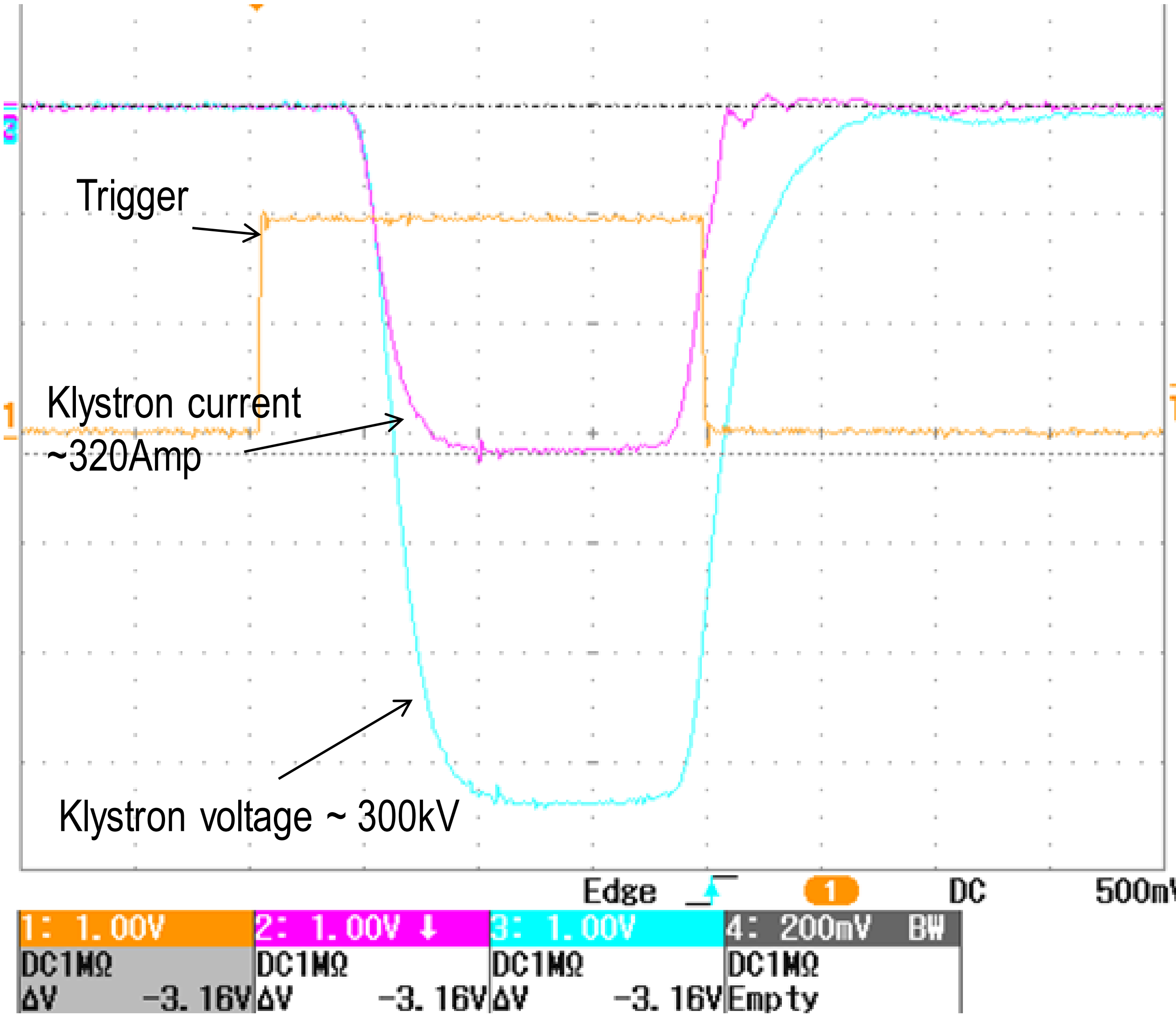
Courtesy of Christian Piel, RI

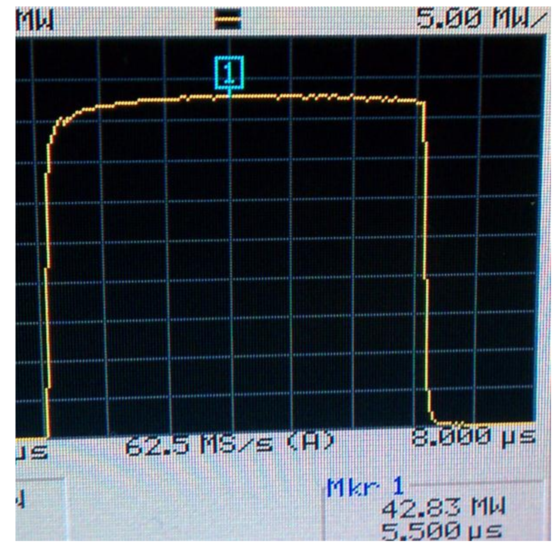


Screen shot courtesy of F. Gao

Feed-forward system programs RF drive to compensate for beam loading of TW structures achieves repeatable results over a wide range of beam currents. N. Towne PhysRev "Beam Loading…"

LINAC: SCANDINOVA MODULATORS
SITE ACCEPTANCE TESTS





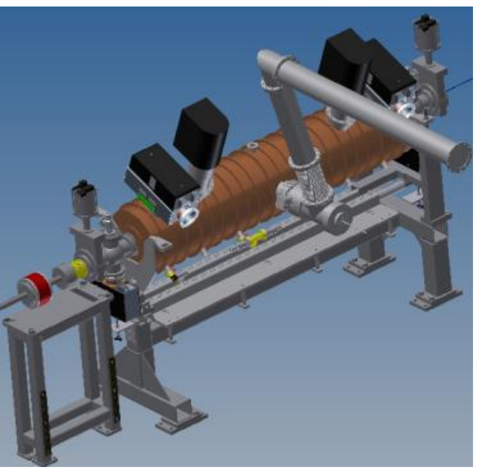
RF Pulse flatness exceeds that achieved by PFN type modulators “out of the box”, no tuning required on site.

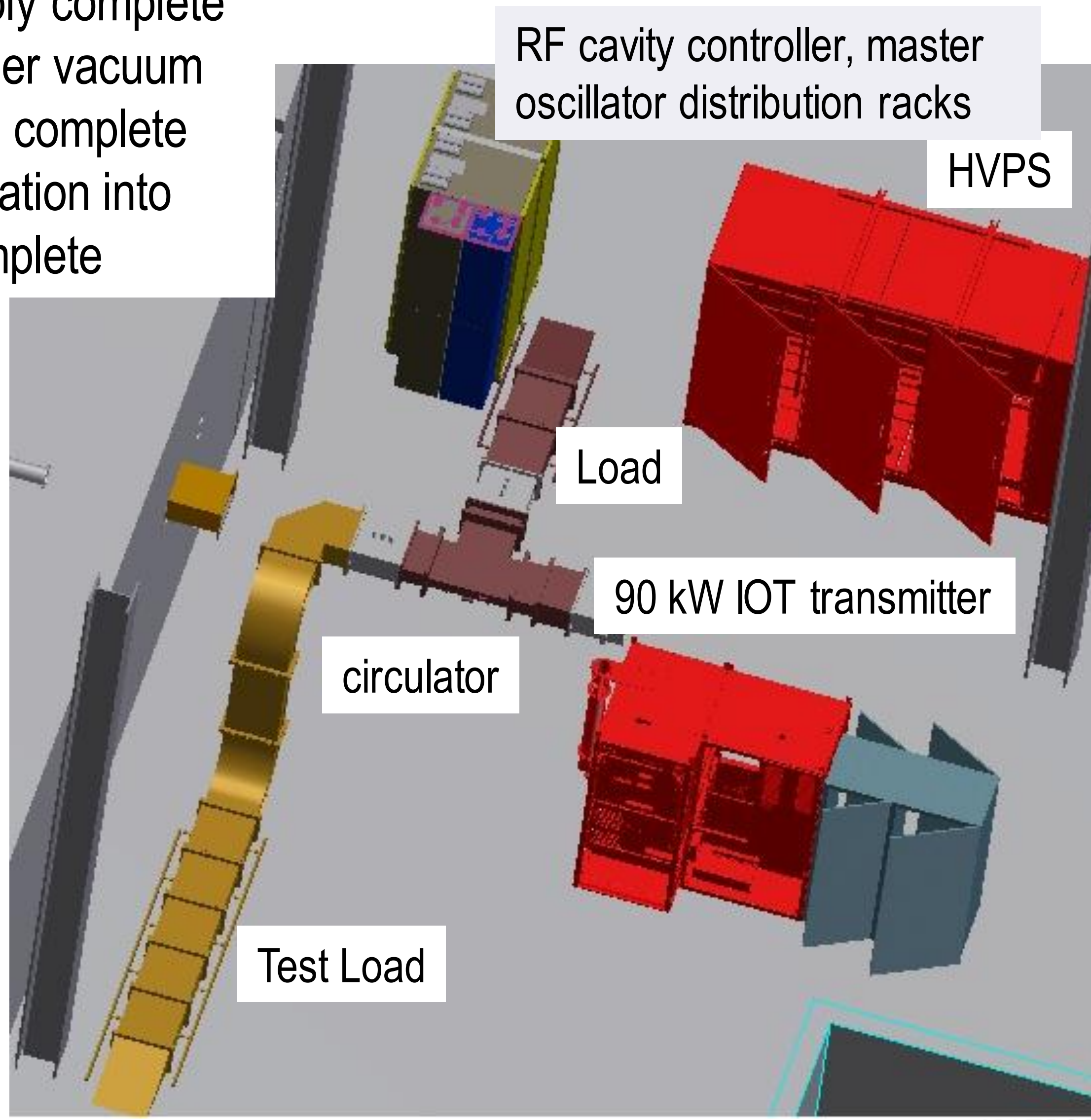
No issues during commissioning

RF output power 42 MW

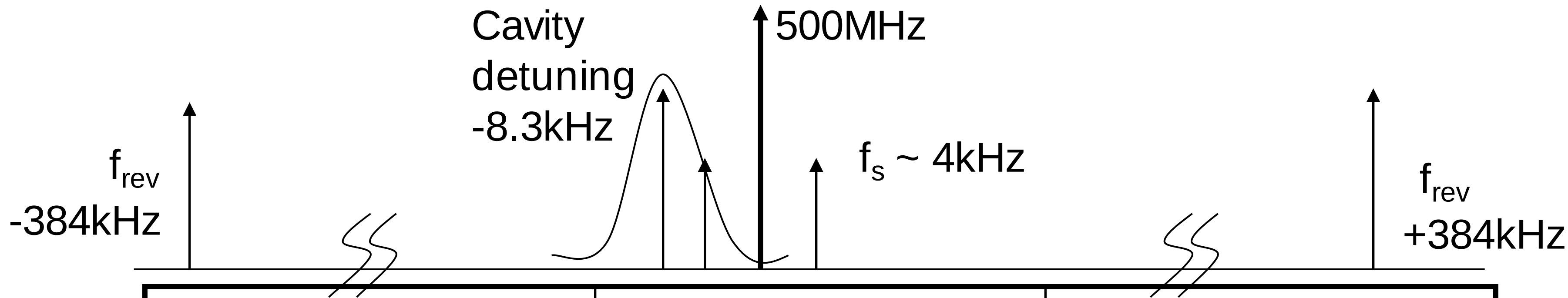
Booster RF system

Booster cavity assembly complete valve to valve and under vacuum
Transmitter fabrication complete and mechanical installation into injector building is complete





Beam Loading parameters



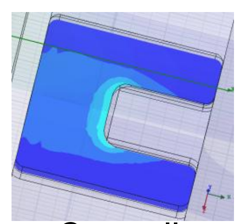
	Baseline	Fully Built Out
R/Q	44.5	44.5
Q_0	$7.5*10^8$	$7.5*10^8$
Revolution Frequency	384 kHz	384 kHz
Total V	3.3 M	4.9 MV
Synchrotron Frequency	3 kHz	4 kHz
Number of cavities	2	4
Q_L*	$1.2*10^5$	$6.7*10^4$
Bandwidth (FWHM)	4 kHz	7.4 kHz
Frequency detuning	-6.4 kHz	-8.3 kHz
* Q_L ~ 86k for minimum reflected power over all phases (preliminary)		

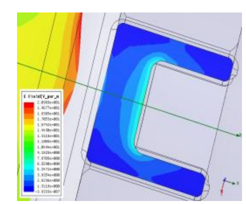
CESR cavity coupling optimized across all NSLS-II operating scenarios

3-GeV machine RF parameters with CESR cavities and Qext = 65000

Machine version			Baseline	2 Cavities	3 Cavities	4 Cavities
Beam current	Iav	mA	300	500	500	500
Energy loss / turn from dipoles		MeV	0.288	0.288	0.288	0.288
Energy loss / turn from IDs		MeV	0.528	0.65	1.218	1.712
Accelerating voltage		MV	2.40	3.40	4.20	4.85
Momentum acceptance		%	2.34	2.99	3.03	3.04
Number of cavities			1	2	3	4
Per cavity parameters						
Cavity voltage	V	MV	2.400	1.700	1.400	1.213
Cavity power	Pcav	W		32.1	21.8	16.3
Forward power	Pf	kW	384.8	272.0	260.3	254.6
Reverse power	Pr	kW	138.3	32.9	4.7	0.0

Q_{ext} ~ 65000 is optimal for full build-out, meets baseline, interim conditions

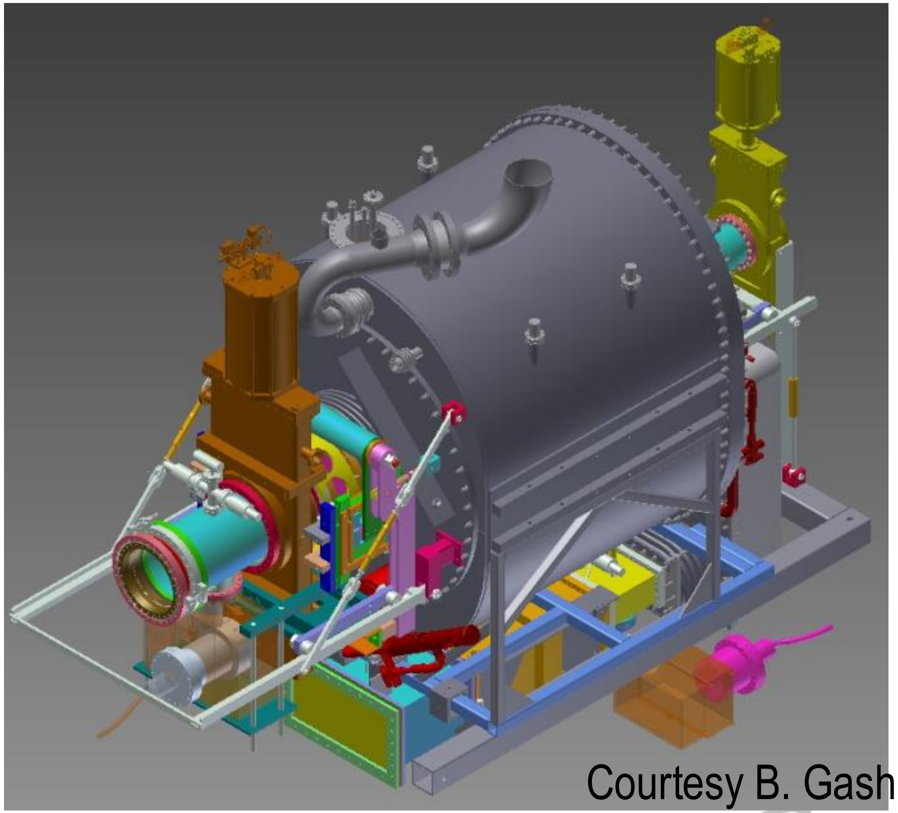

Cornell


NSLS-II

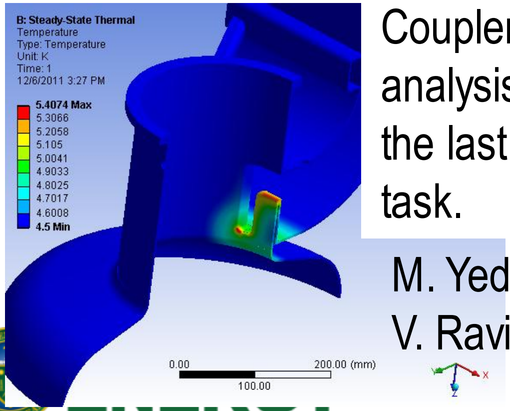
Storage Ring 500 MHz Cryomodules

Final Design Review to be held on 8 February 2012

- Will review design, assembly and test plans, instrumentation and P&ID
- Approval to proceed already given for
  - Production of helium vessel
  - LN2 shield
  - Magnetic shield
  - Insulating vacuum shell
  - Gate valves and vacuum pumps and controllers



Courtesy B. Gash



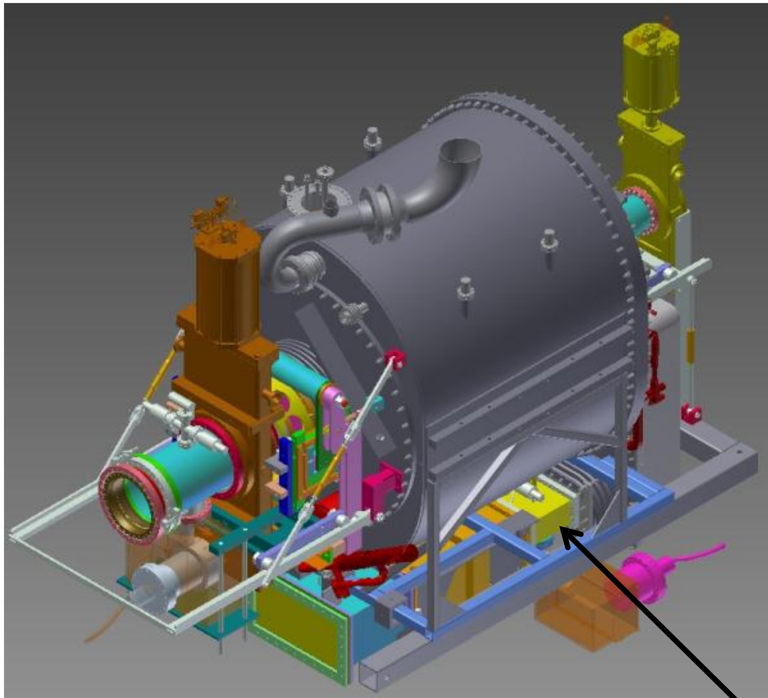
Coupler thermo-mechanical analysis complete- this was the last outstanding design task.

M. Yeddulla,
V. Ravindranath

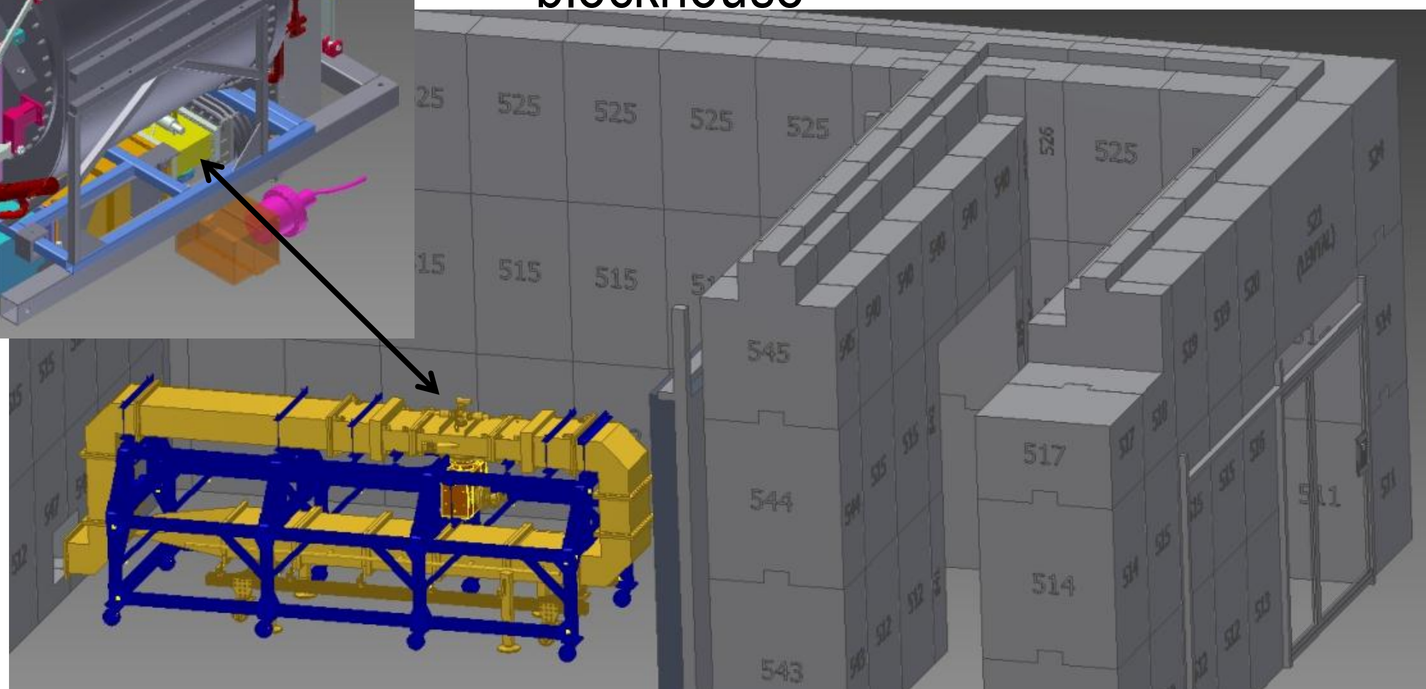
Storage Ring 500 MHz Cryomodules

- AES contract awarded April 2011.
- Scope includes cryomodules, cavity interconnect spool piece, beamline tapers, vacuum and instrumentation
    - The niobium was to have been BNL supplied material and was ordered in February for delivery in May; the first material was received in August and failed incoming inspection and the order was canceled. The contract was amended to have AES provide the Nb and the order was placed in October. It was delivered in March and the 13mm and 35 mm material does not meet the tensile strength specifications causing some concern due to the large emphasis the DOE places on the design to meet the ASME pressure vessel codes
- The first cryomodule is scheduled for delivery in February of 2013.
- Tooling for pressing of half cells, beam tube flutes, and beam tubes is complete

500 MHz Cryomodule: Progress



- RF window test stand design complete
- RF window tests with 300 kW klystron amplifier at BNL in the RF blockhouse



Storage Ring Transmitter

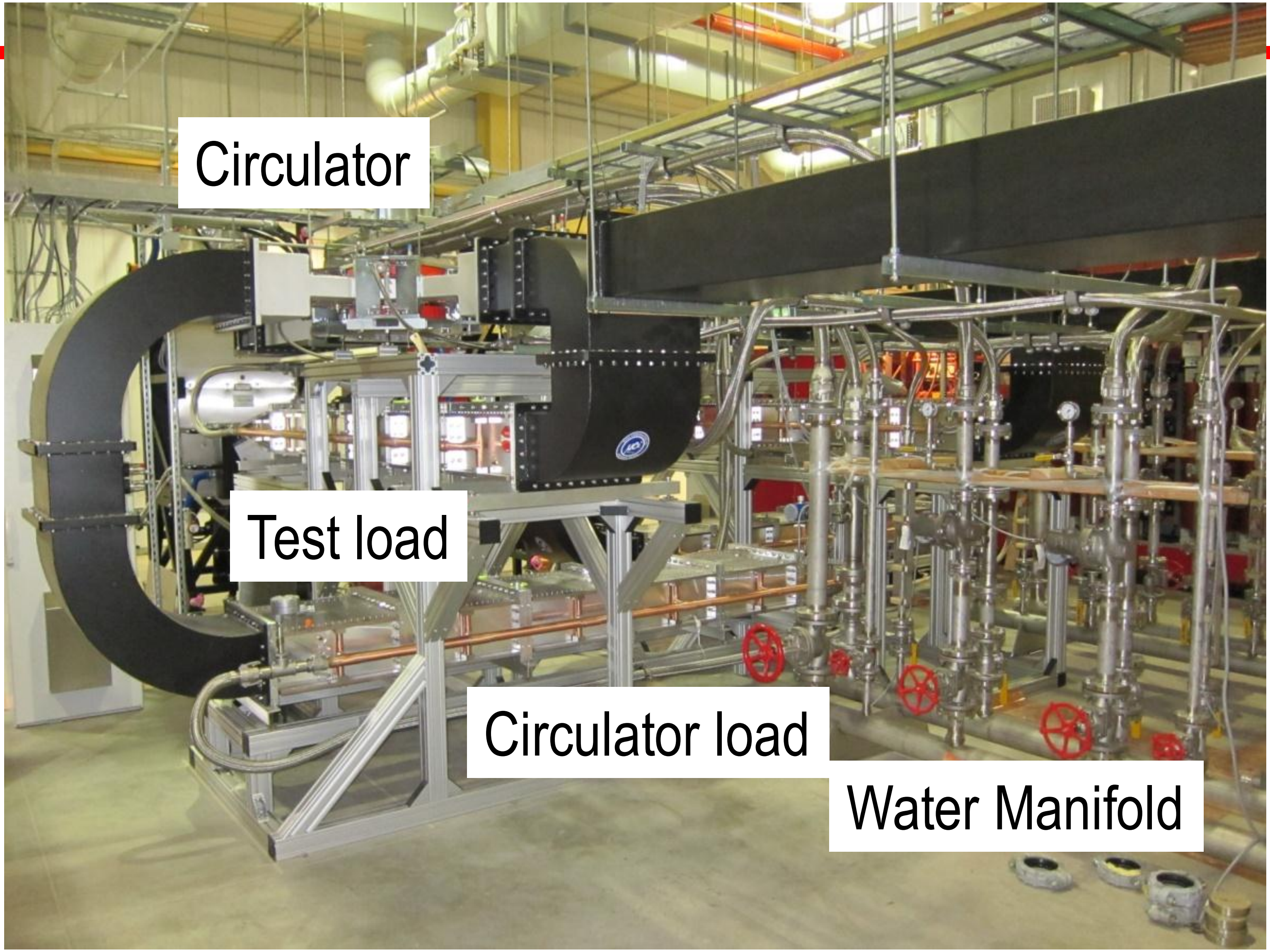
Turn key 540 kVA klystron solid state switching power supply with mod-anode, filament supplies, interlocks and controls

300 kW klystron amplifier

Installation of both transmitters is complete. Integrated testing is in progress.

High power tests of klystron 1 to 280kW, system 2 limited by failing crowbar test

SR TRANSMITTER: TRANSMISSION LINE NETWORK COMPLETE



RF Blockhouse for cavity testing

500 MHz Waveguide run finished to the blockhouse
Waiting for PPS system and cable tray/AC power

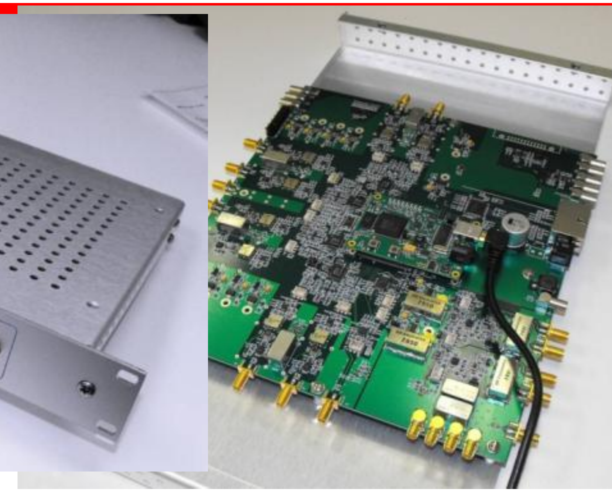
Required for testing of the booster cavity in late March, dewar test of the harmonic cavity in April

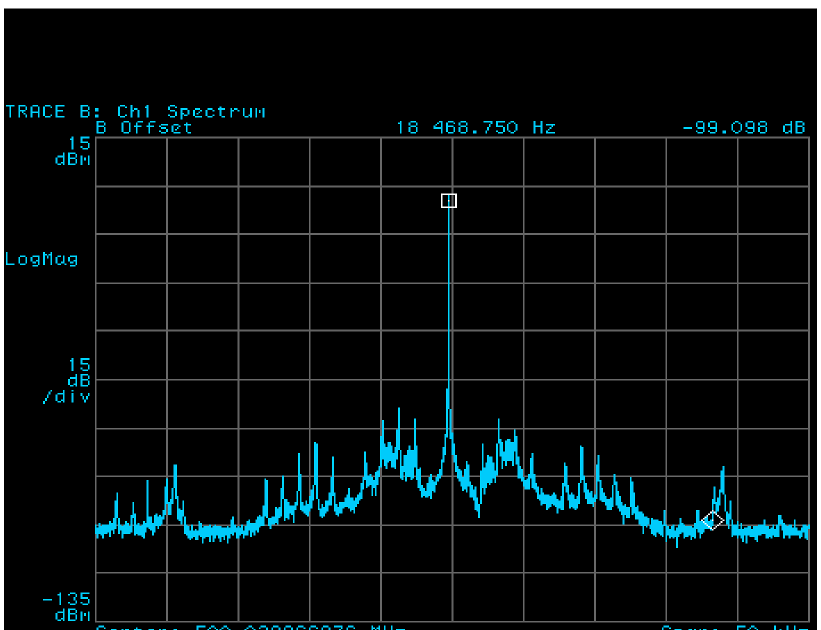
Test of the harmonic cavity is necessary to confirm cryomodule performance before completing cryo interface, tuner and HOM loads

Cavity Controller: Last workshop reported on successful test at CLS…

- **Digital Field Controller**
- **50 MHz IF**
- **Tested at CLS on hardware nearly identical to NSLS-II: 300 kW klystron and CESR-B SRF cavity**
- **Meets NSLS-II field spec. of 0.15 degree and 0.05%**

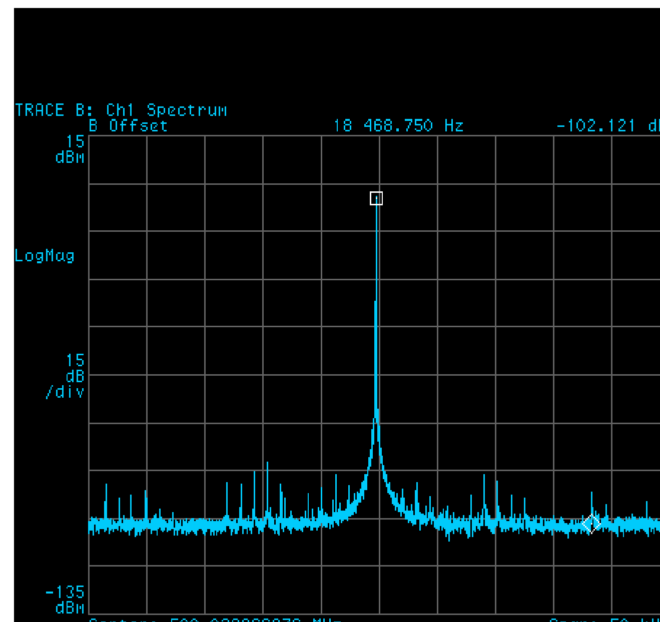
H. Ma





CLS Analog
A=0.073%rms
φ=0.12° rms

NSLS-II
A=0.026%rms
φ=0.02° rms



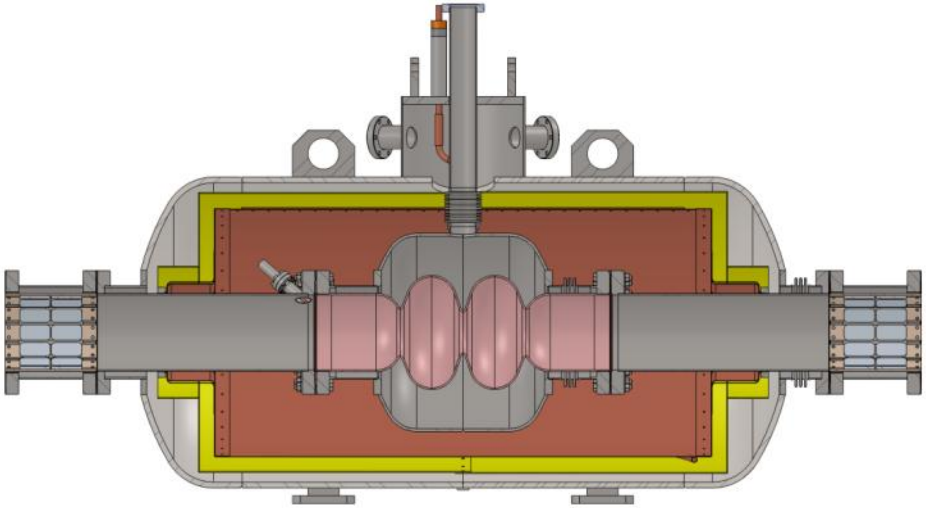
CLS tests courtesy M. de Jong

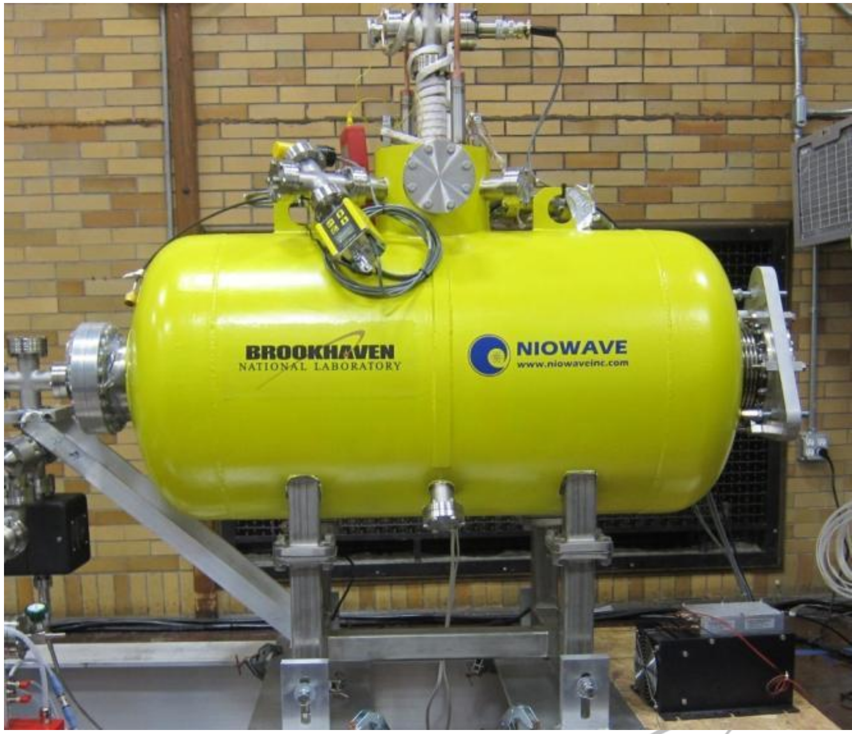
Digital Controller Functionality

- *Down/up conversion from/to 500 MHz*
- I/Q-based IF signal processing over the 50 – 56 MHZ frequency range
- Open-loop operation
  - Amplitude and phase set points with readback
  - Feed Forward Table with CW, Pulsed, Pulse on CW, Triangular and Ramp functions
- Closed-loop operation
  - Programmable amplitude and phase set points referenced to a separate rf reference signal
  - Programmable proportional and integral gain with readbacks
  - Loop Phase Rotation at turn on measures open loop phase Fwd vs. Cavity and sets to180
  - Fast ramp down of the closed-loop set points that is triggered by a hardwired interlock fault input (RFinhiBit).
  - External fiducial for synchronization with other rf systems and machine events
  - *RF limiter in IF output: real time limiter linear in amplitude and phase*
  - *Circular buffer triggered by internal or external events captures fast RF and beam signals*
  - *Eight channel 1024 sample data acquisition in logic "Scope Function"*
  - Ability to ramp the closed-loop set points using a programmed ramp table (booster)
  - *Future plans include 6-channel vector Network Analyzer functions (S21, S31, S41, S51…)*

Landau Cavity: cryomodule complete last April

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 ferrite dampers, tuner mechanism

3rd Harmonic cavity

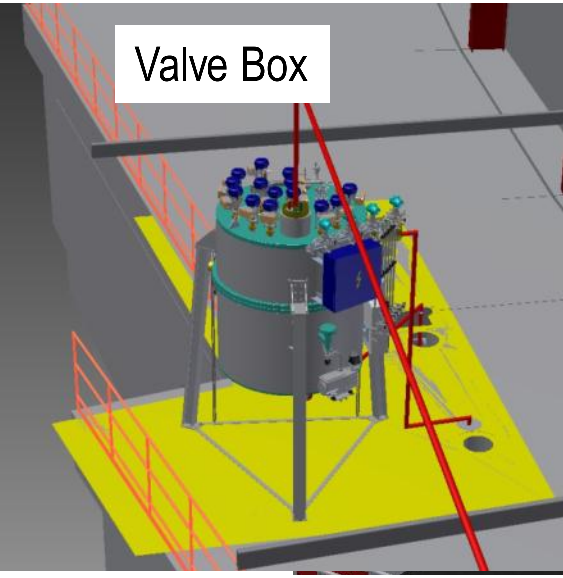
Work still to be done on 3rd HC:

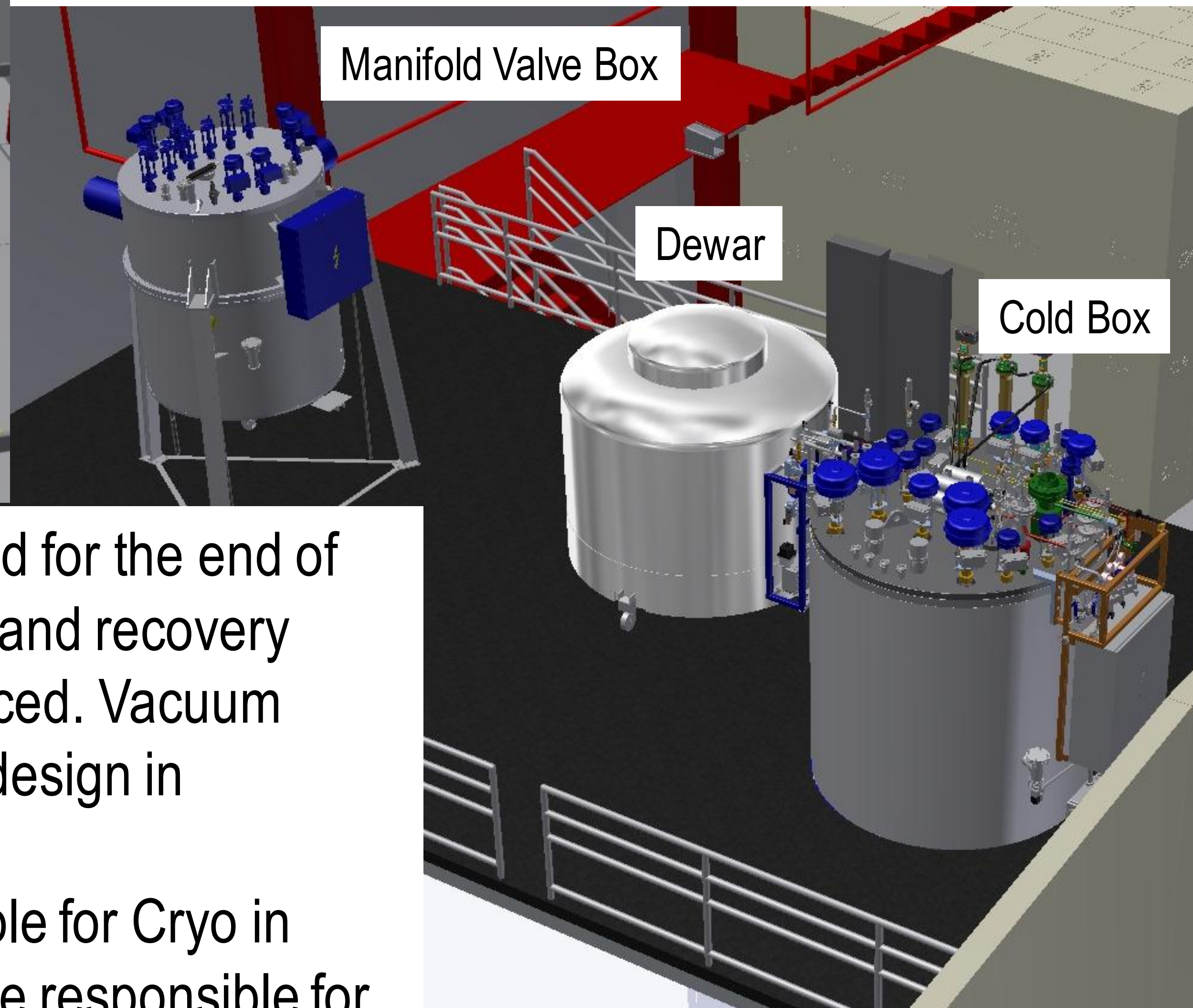
- Modification of cryogenic LHe, LN2 and cold GHe interconnects to mate with our standard cryo-interface, add instrumentation
- Fabrication assembly and test of motorized tuner
- Fabrication of HOM loads
- Assembly in clean room

Prior to the start of the above final design tasks we plan to perform cold tests in house in our RF blockhouse with dewar supplied LHe, LN2 to confirm the theory of TE10 mode losses contributing to the lower than expected Q -external

In addition to reducing the program risk, the training and experience gained is essential for the NSLS-II RF group

RF Cryogenic System: 850 W Helium refrigerator and LN2 Dedicated to RF

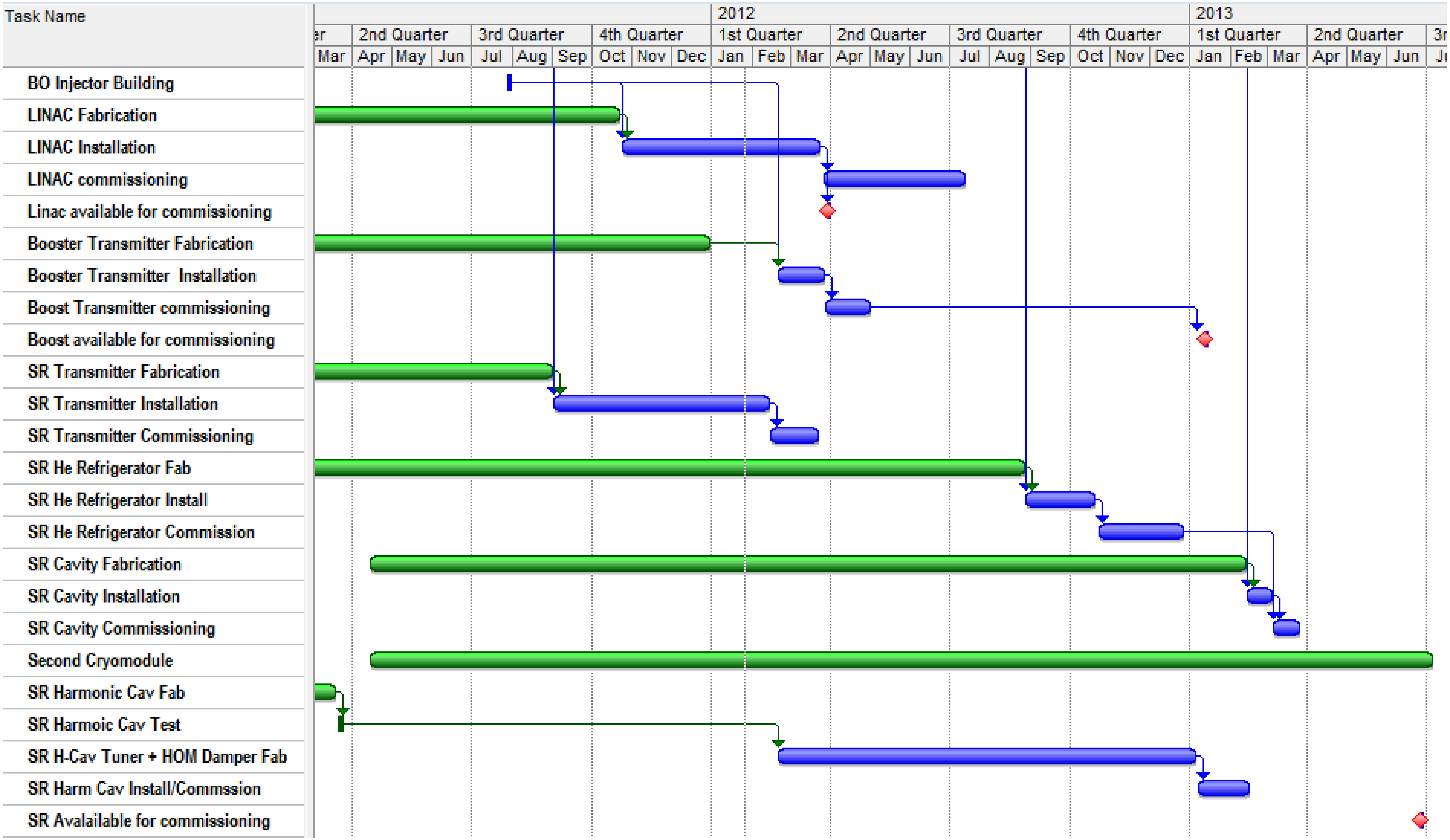




Cold box test scheduled for the end of June. Kaeser main (2) and recovery compressor orders placed. Vacuum Jacketed transfer line design in progress.

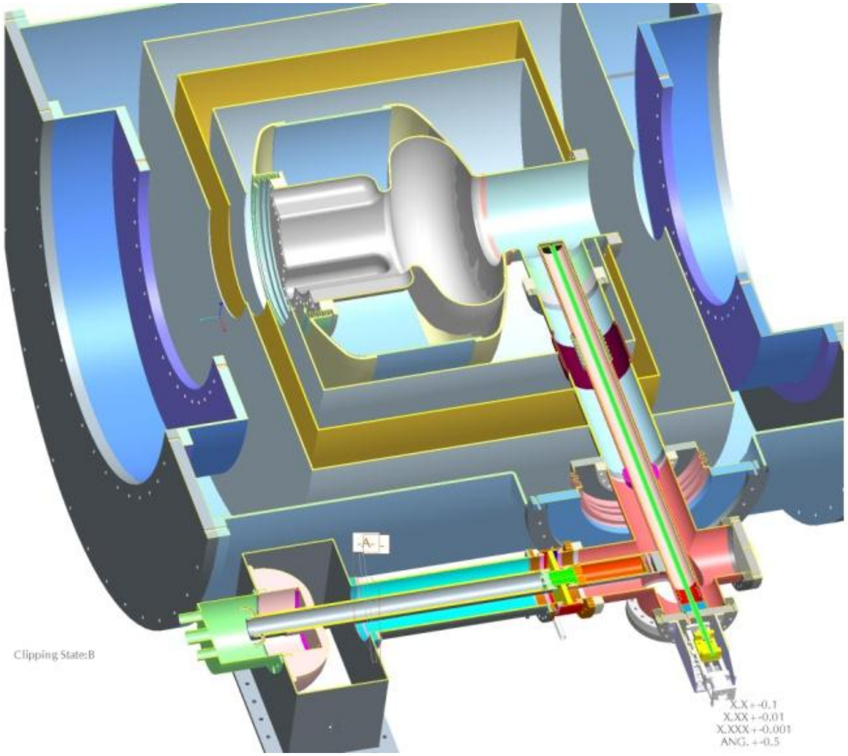
RF group is resposnsible for Cryo in construction, and will be responsible for valve box control only in operation

RF Global Schedule

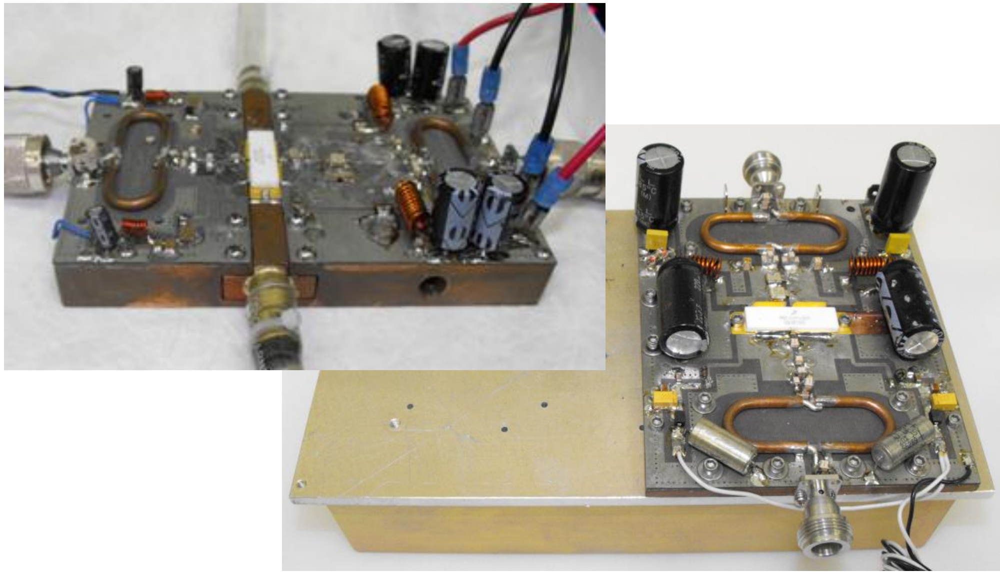


Upgrade Plans

•NSLS-II is installing only half of the required RF power in the baseline project. We have small scale programs to develop cryo-modules, couplers and RF power sources that can provide greater than 400 kW per station for the remaining two RF systems



Cryomodule and coupler concepts courtesy of AES



Transistor evaluation boards courtesy of Freescale and NXP

Summary

- The NSLS-II construction has passed the halfway mark
- The project has had to balance innovation against schedule and cost risk. In the end we have risks (from green to red) in the following systems:
  - SS modulators for the linac klystrons
  - IOT amplifier with SS switching HVPS powering 7-cell copper cavity in the booster
  - Klystron amplifier with SS HVPS powering SRF cavities with modified coupler for storage ring
  - Innovative two coupled cell passive SRF cavity for bunch length control
  - All digital (50 MHz IF) cavity controller with high functionality
- The project must decide in the next several years the approach to take for the second half of the NSLS-II installation
- **We appreciate the opportunity this workshop gives us to interact with the worlds experts to help us down this path**

Acknowledgements

This work was performed by and under the guidance of

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