CEBAF SRF Performance During Initial 12GeV Commissioning

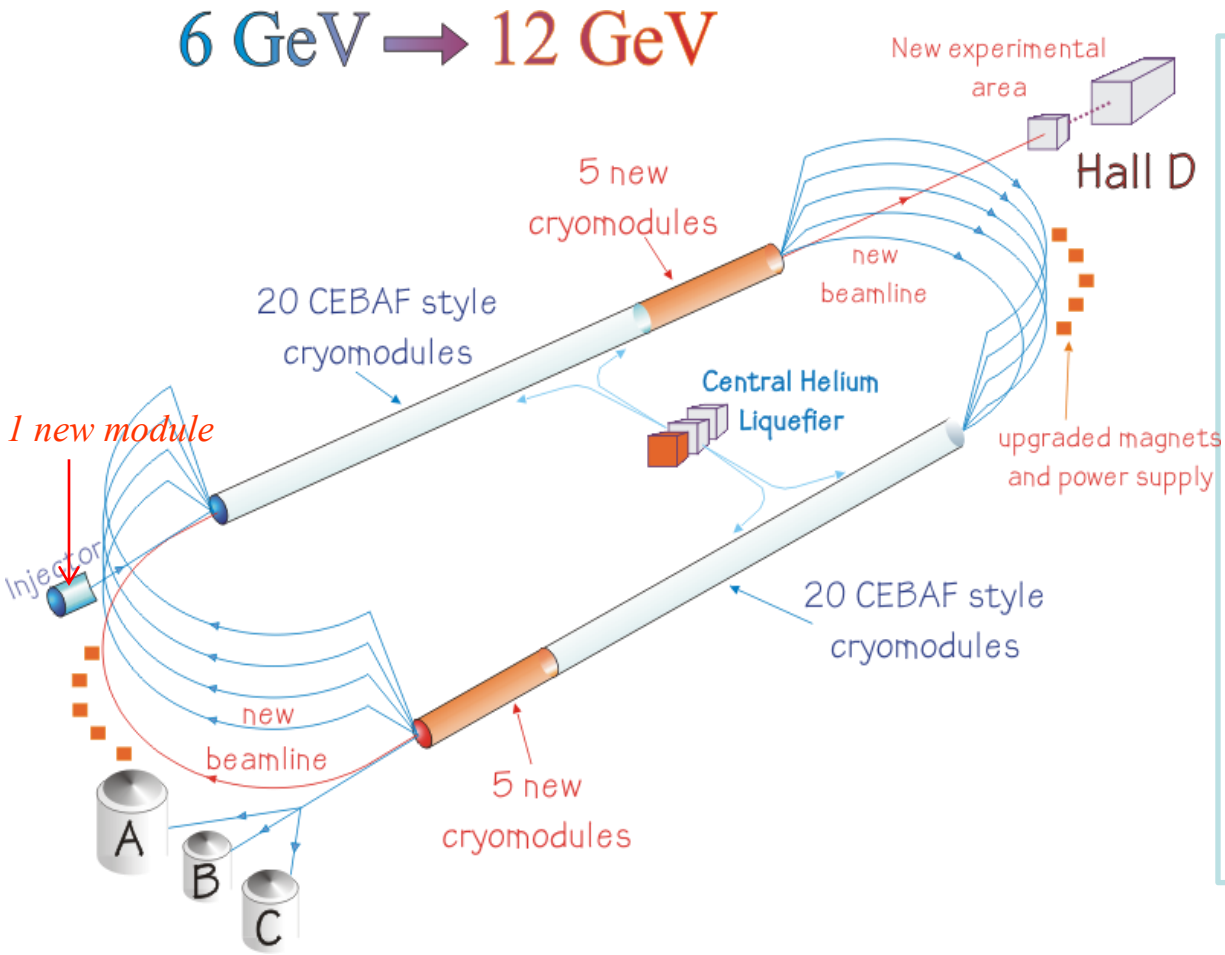
Rama Bachimanchi

OPS StayTreat, July 15-17

Outline

- 12 GeV Project
- C100 RF system
- C100 Commissioning
- Operational Experience
- Summary

12 GeV Upgrade Project



- 11 New cryomodules (C100)
- New RF power sources (13 kW)
- Refrigeration
- Magnets
- Additional arc-beamline
- Extraction system
- New experimental area Hall D

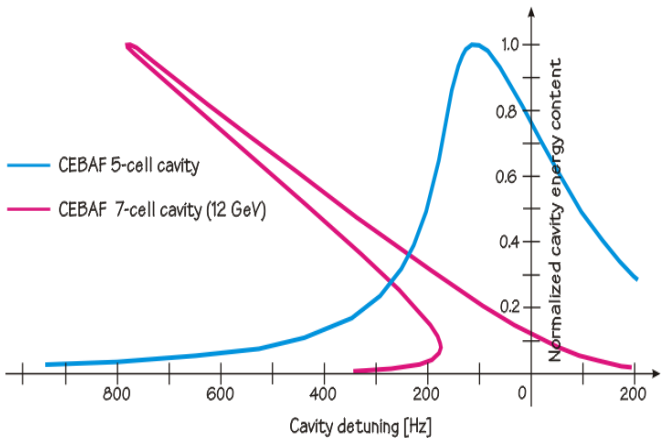
C100 Cryomodule

- Seven cell Cavity, 0.7 m long (high Q_L)
- 8 Cavities per Cryomodule
- Fits the existing Cryomodule footprint

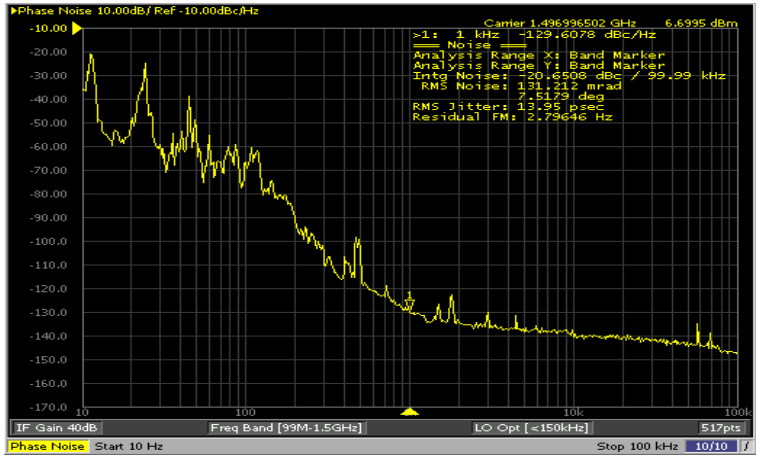
High Q_L Challenges

Fundamental frequency f_0	1497 MHz
Accelerating gradient E_{acc}	> 20 MV/m
Input coupler Q_{ext}	3.2×10^7
Active length	0.7 m
r/Q	1288 Ω/m
Tuning sensitivity	0.3 Hz/nm
Pressure sensitivity	420 Hz/torr
Lorentz force frequency sensitivity K_L	~2 Hz/(MV/m)^2

Field startup

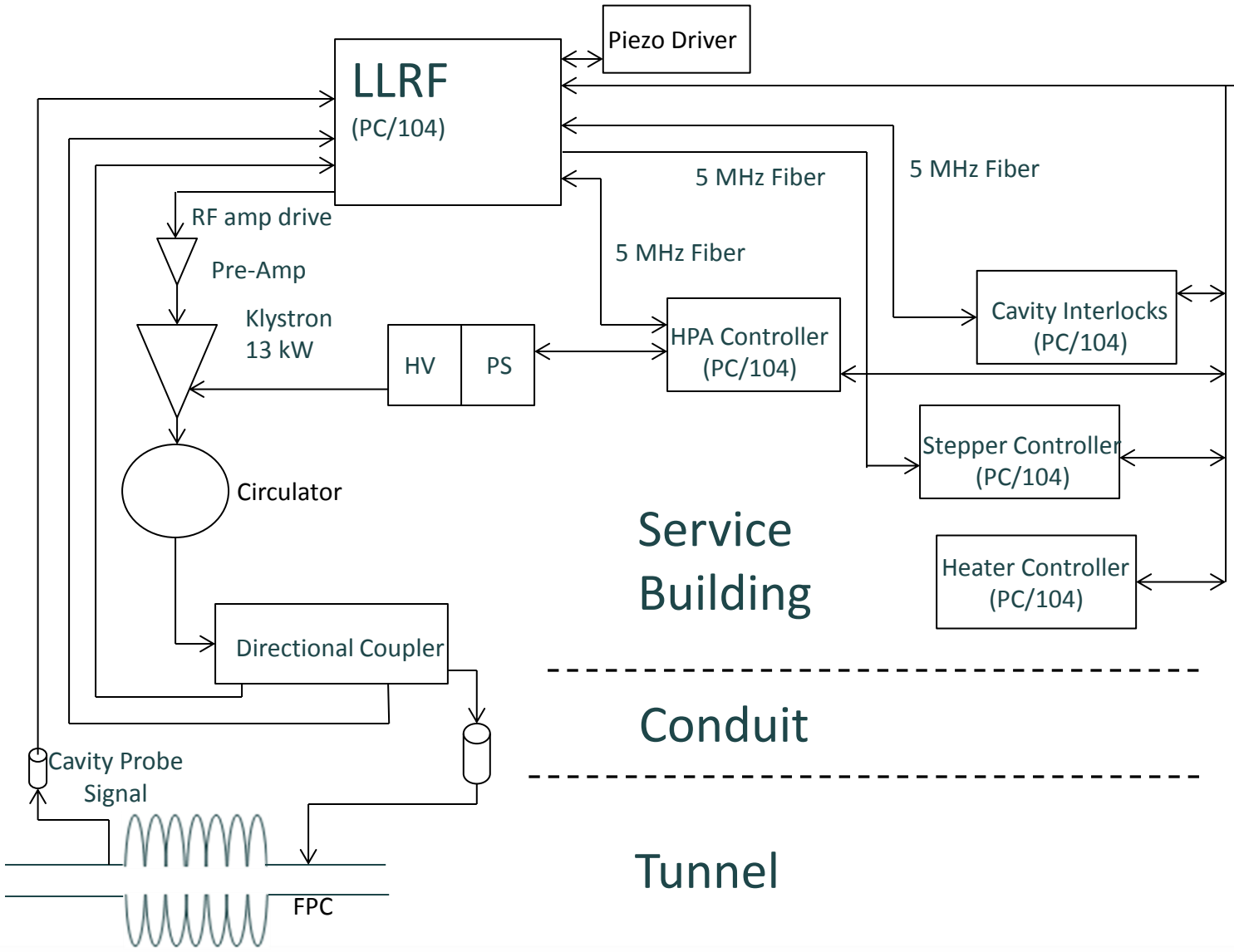


Field stability



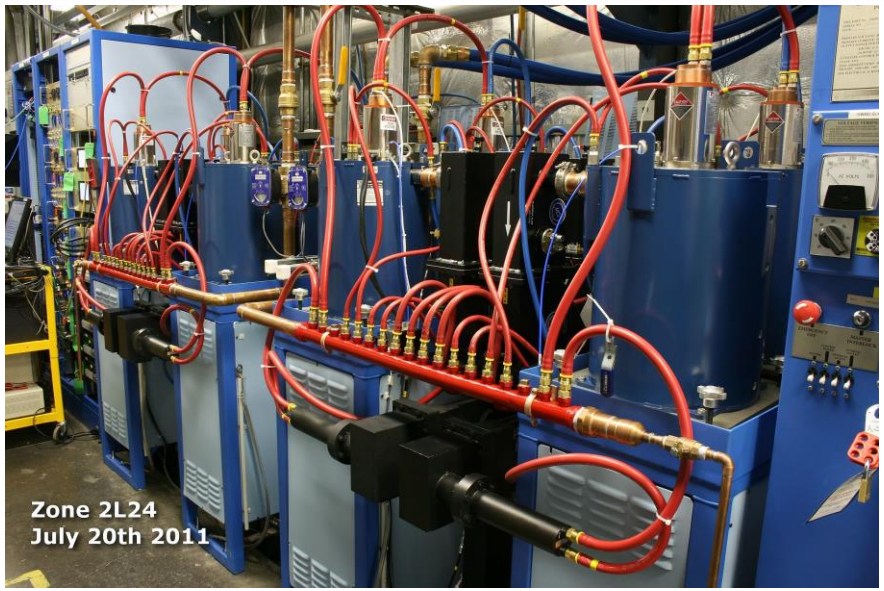
Phase noise plot of microphonics

RF System for C100 Cavity



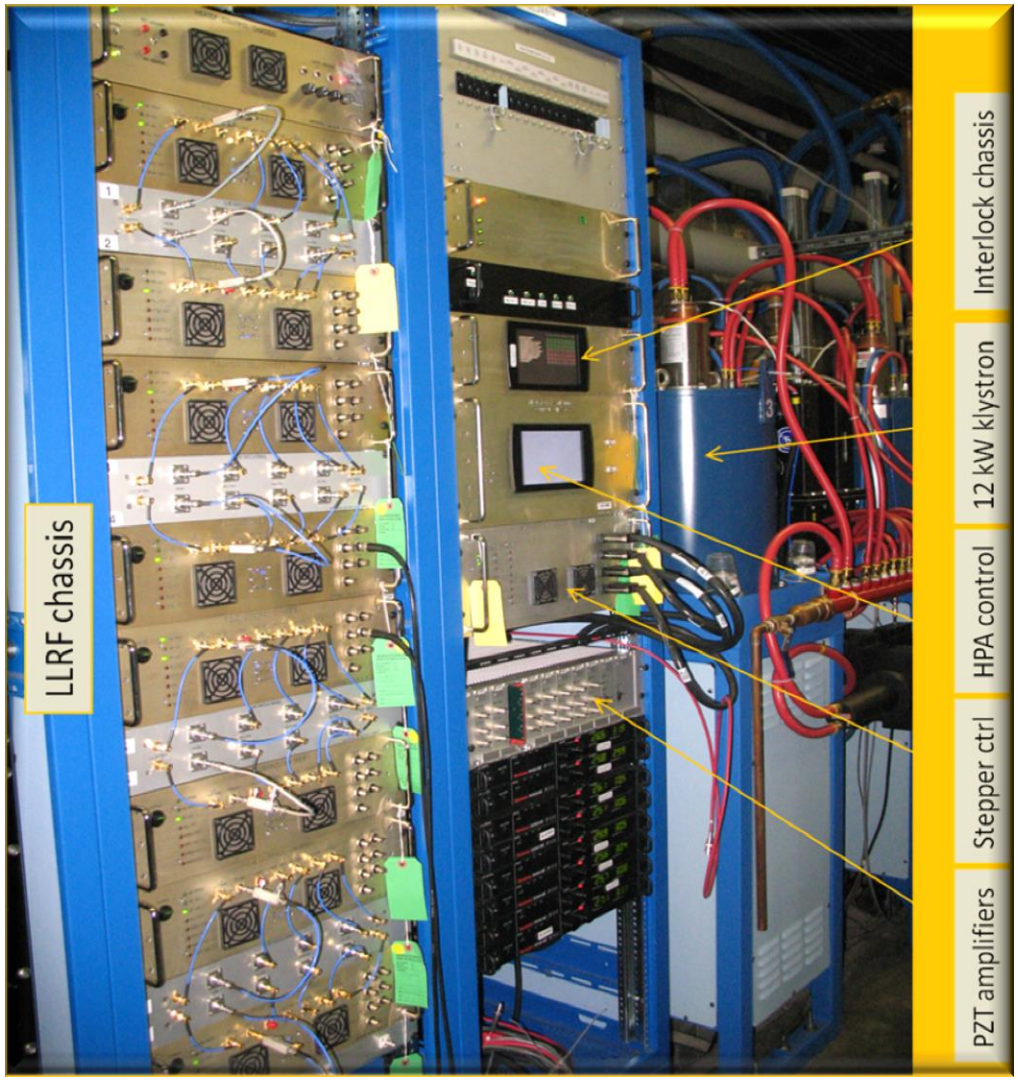
- One LLRF / Cavity
- One Klystron / Cavity
- One System / Zone
  - Stepper
  - Piezo
  - Heater
  - HPA
  - Interlocks

RF System



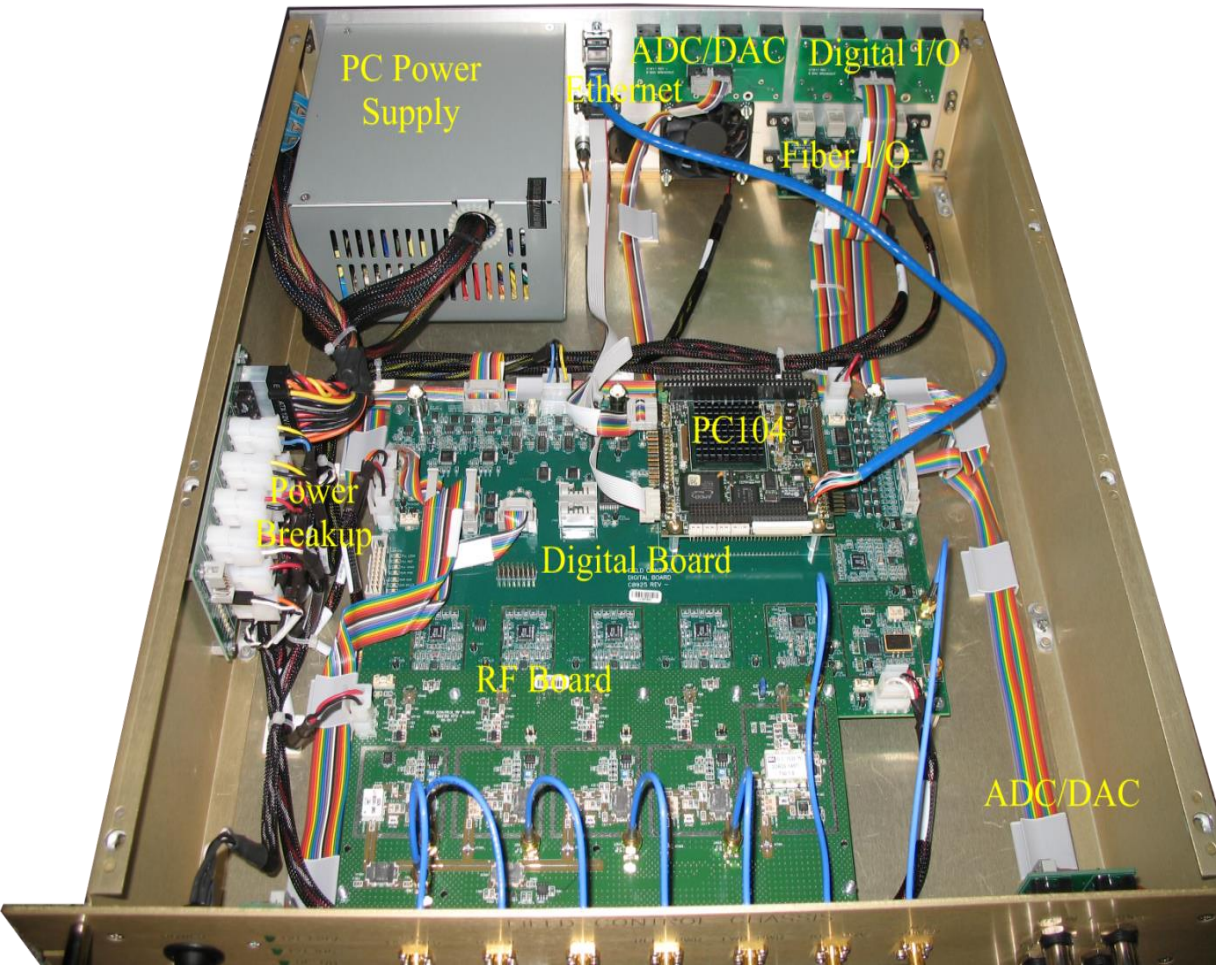
- Single Zone
  - Eight 13 kW Klystrons
  - Four HV Power Supply
- Total (10 + 1 zones)
  - 80 Klystrons (13 kW)
  - 8 Klystrons (8 kW ,C100-0)

RF System



- Single Zone
  - 8 LLRF Controllers
  - Stepper Controller
  - Piezo Amplifier
  - Interlocks Controller
  - High Power Amplifier Controller
  - Cryomodule Heater Controller
- Total (11 zones)
  - 88 LLRF Controllers

RF System



- RF board
- FPGA board
- PC/104
- Modular Interface boards
- PC power supply

C100 Commissioning

Acronyms used in the slides

- SEL (Self Excited Loop)
  - Cavity resonates at it's own frequency (Phase Locked Loop like)
  - Constant forward power
- GDR (Generator Driven Resonator)
  - Cavities are locked to reference
  - Forward power not constant (reacts to detuning)

C100 Commissioning

- RF system commissioned into waveguide shorts
- SRF commissioning using LLRF
  - Emax for individual cavities
  - Field Emission measurements
  - Q_0 measurement
  - Operable gradient for cryomodule
  - Performed in SEL
- RF Commissioning & Machine operations
  - Cavities are operated in GDR

C100 Commissioning - Timeline

Year	Activity
2011	C100-1&2 were installed and commissioned
2012	C100-1&2 were operated during 6 GeV Nuclear Physics run. C100-2 was operated up to 108 MEV and 465 μA May – Began 18 month CEBAF shutdown
2013	Installed and commissioned eight C100 cryomodules
2014	January completed C100 commissioning and began beam operation/commissioning March commissioned C100-0 (Installed in Injector)

Gradients in C100 During Commissioning

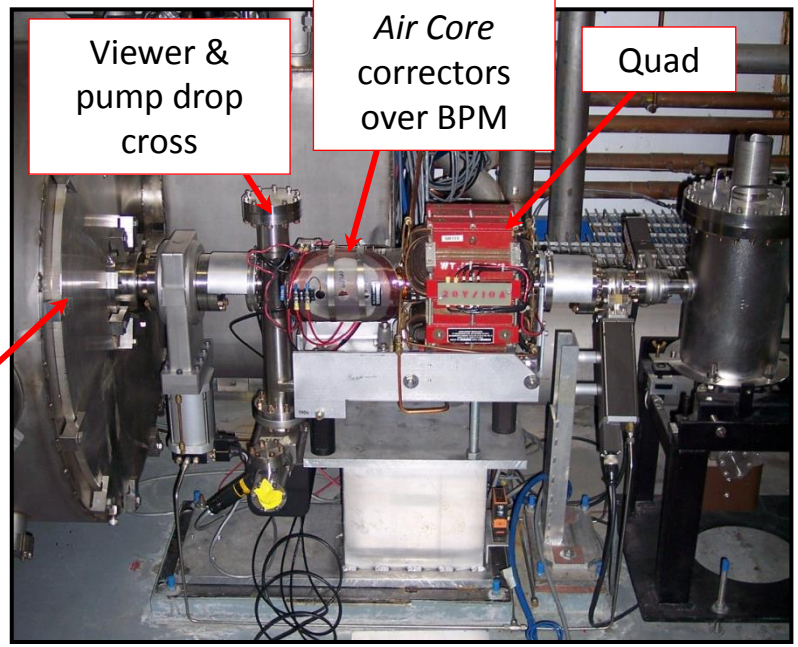
Zone	Beam Measurement	During Commissioning
C100-1	104 MV	94.01 MV
C100-2	122	93.8
C100-3	108	76.58
C100-4	93	79.24
C100-5	121	100.31
C100-6	111	101.8
C100-7	104	103.81
C100-8	110	100.17
C100-9	105	101.15
C100-10	106	87.57
C100-0	104	82.3

Operational Experience -CEBAF Commissioning

- Commissioning
  - 2.2 GeV/pass
    - C100 - 934 MeV
    - C50 - 457 MeV
    - C20 - 808 MeV
  - Injector design energy – 123 MeV
- Opportunities for Improvement
  - Reducing Field Emission
  - Enhanced Cryomodule Heater Configuration
  - Microphonics Detuning
- Other Observations
  - RF Control Loop Optimization
  - Klystron Drive Cables

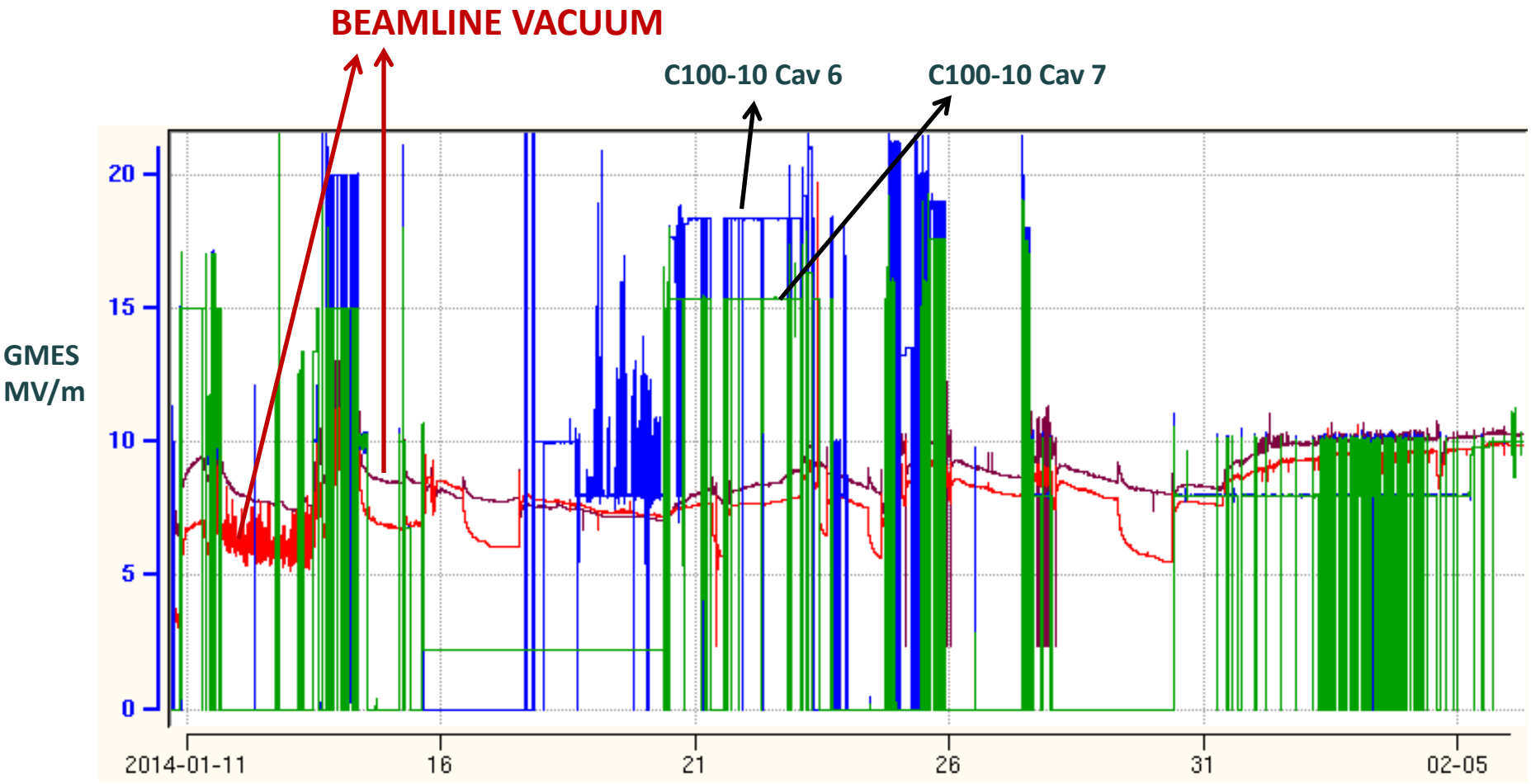
Operational Experience - Field Emission

- Field emission heats beamline
- Vacuum pump faults
- Vacuum interlock drops zone out of RF



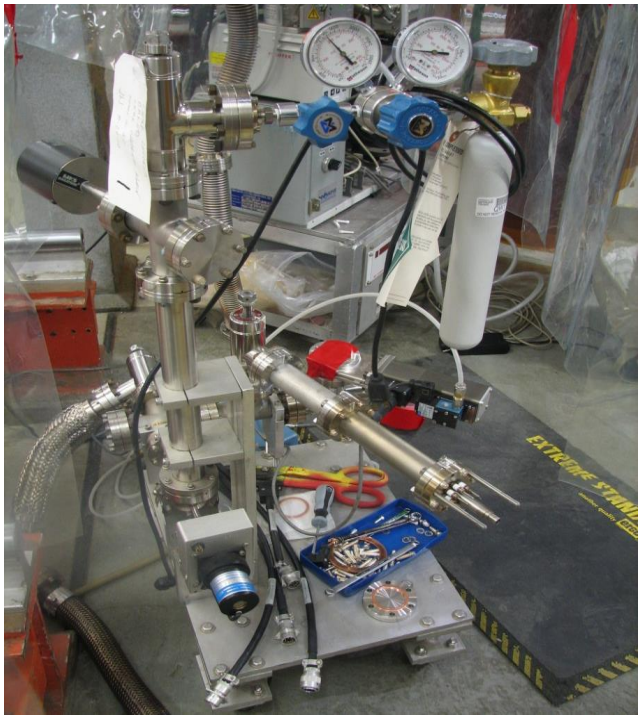
Operational Experience - Field Emission

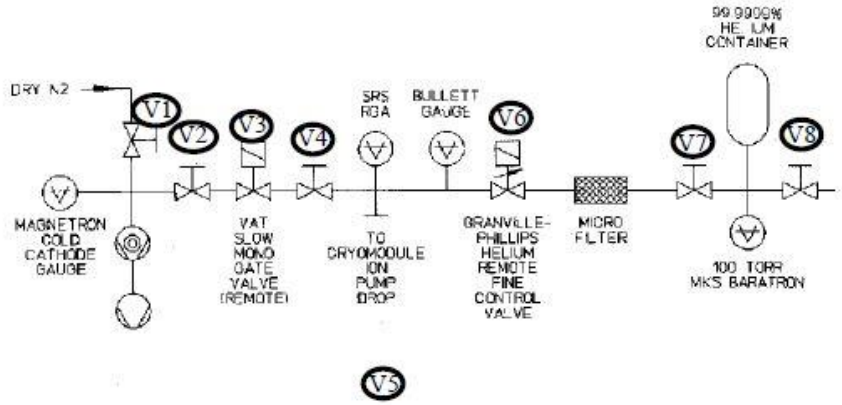
Cavity Gradients impacting Beamline Vacuum activity



Helium Processing

- Introduce helium gas into cavity vacuum space
- Run RF to clean cavity surfaces
- Warm up and pump down to remove residual gas
- Improves high-field Q, reduces x-ray production and greatly reduces incidence of arcing at the cold ceramic window

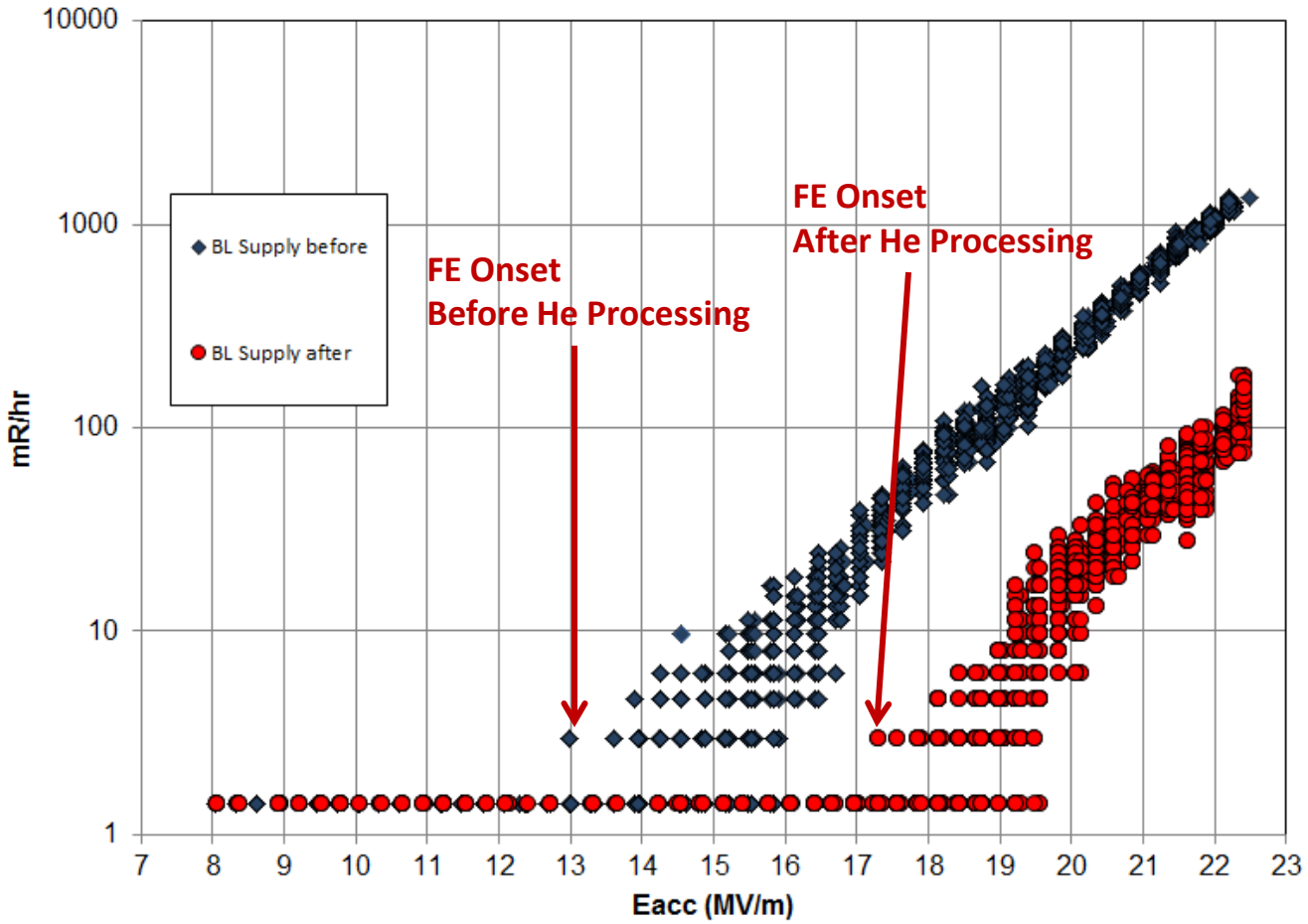




HELIUM PROCESSING PUMP CART AND MANIFOLD

Helium Processing

- Performed on C100-5 cryomodule



C100-5 cavity 6
Before and after
He processing

Helium Processing

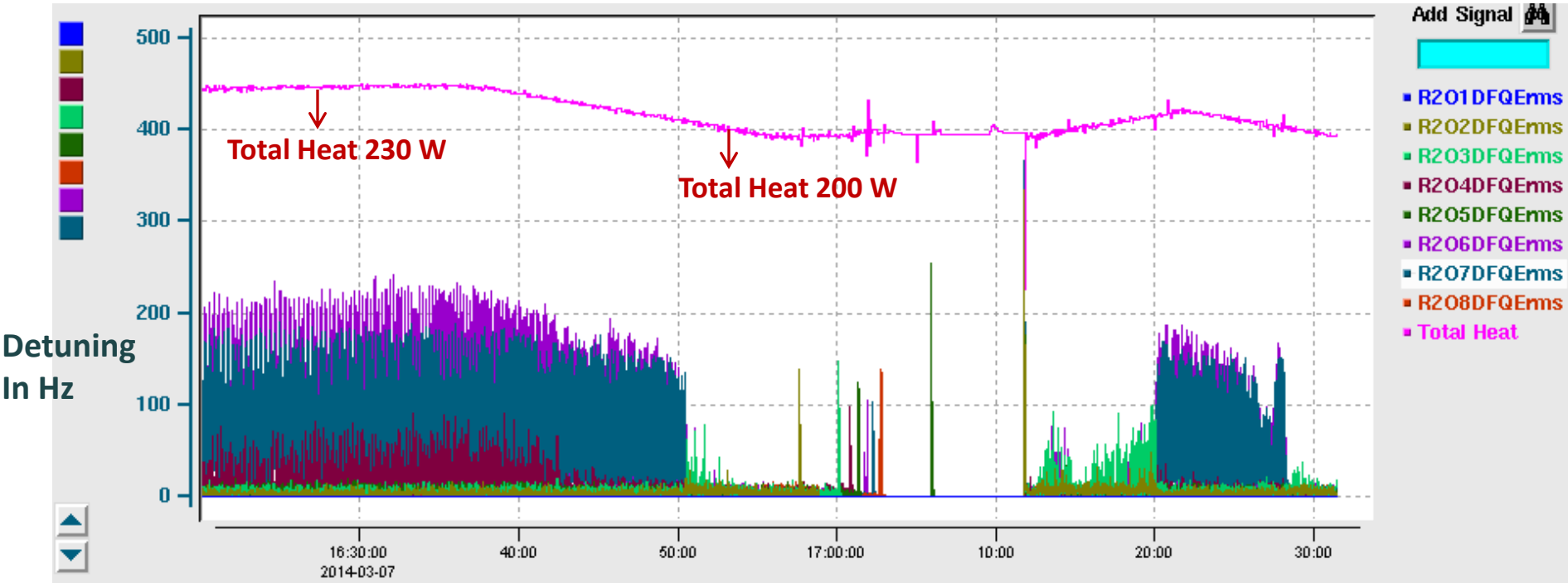
- In Progress
  - Currently processing the Cryomodules in South Linac
  - Results are encouraging

- “HeProc status and results to date” --Michael Drury
  - Today @ 1:30 PM

Operational Experience - Cryomodule Heater Configuration

- C100-1
- Cavities 6 and 7 have very high detuning

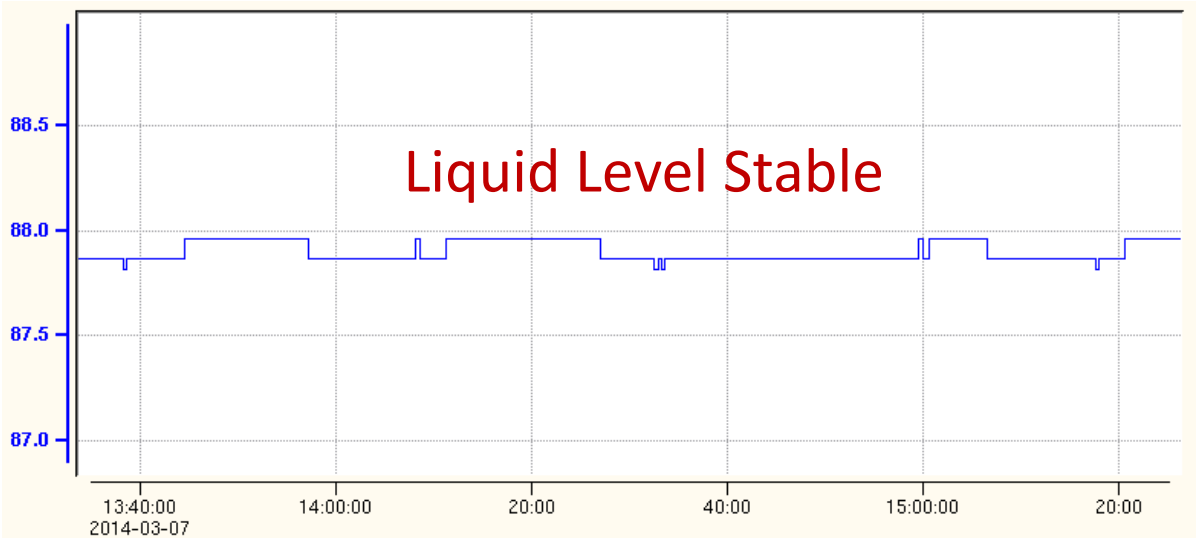
Total heat vs Detuning in SEL



Operational Experience - Cryomodule Heater Configuration

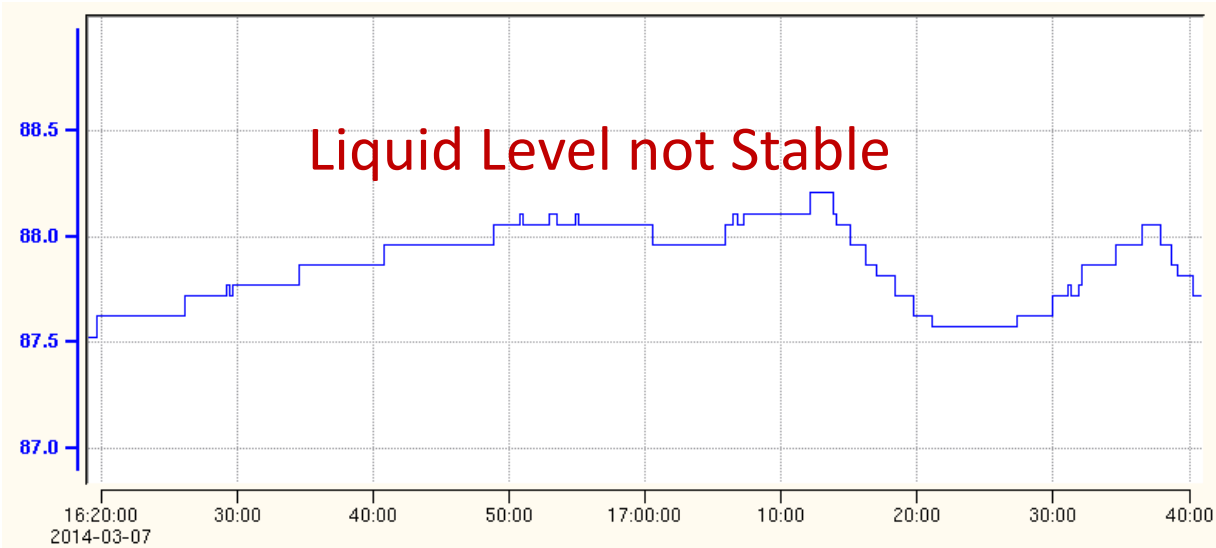
- When RF was off
  - Only Electric Heat

He Level Percentage



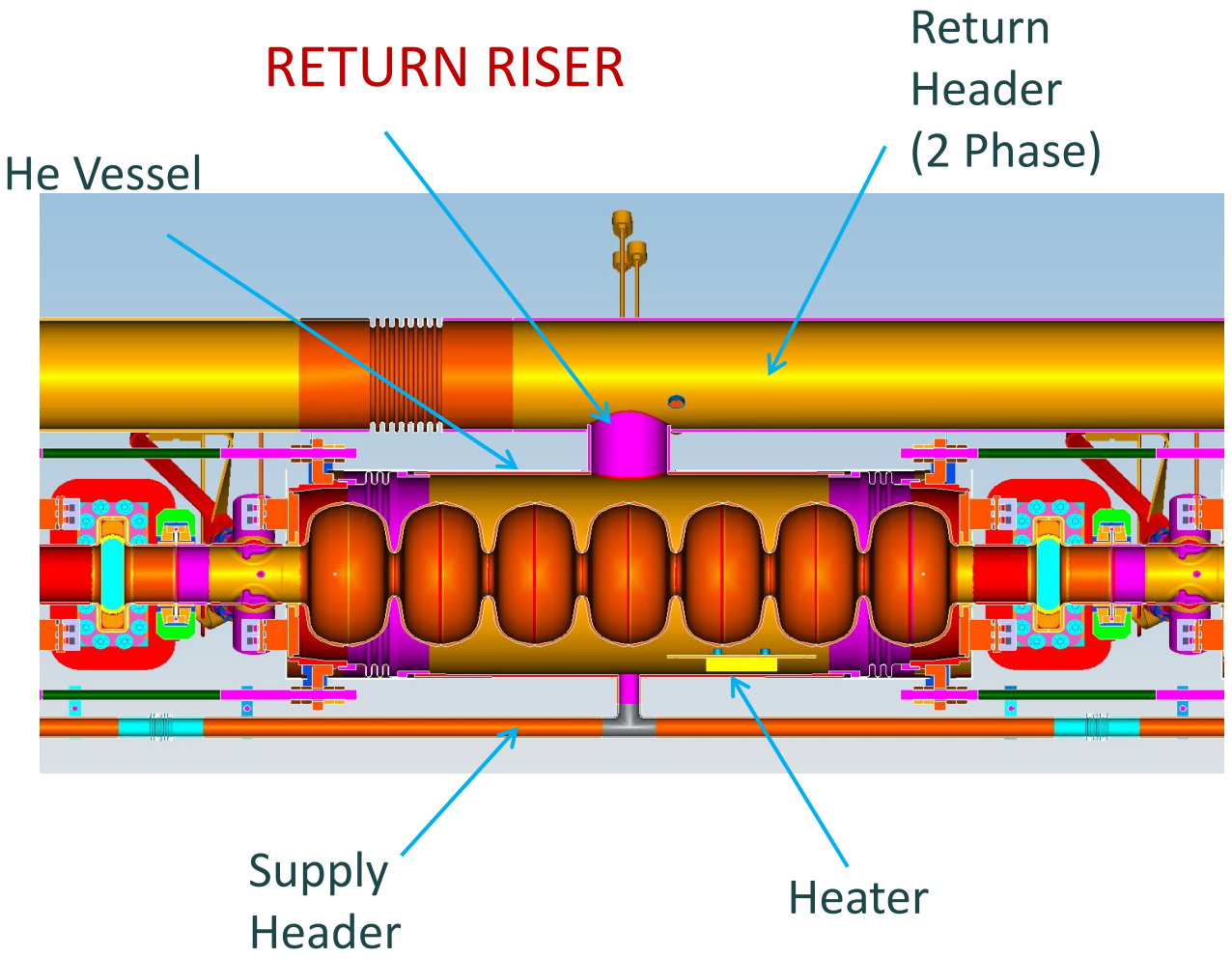
- When RF was on
  - RF + Electric Heat

He Level Percentage



Operational Experience - Cryomodule Heaters

- Single Heater Control for the Cryomodule
- Return riser became a choke point as additional heat was applied
- Solution - Individual Cavity Heater Control



Cryomodule Heaters

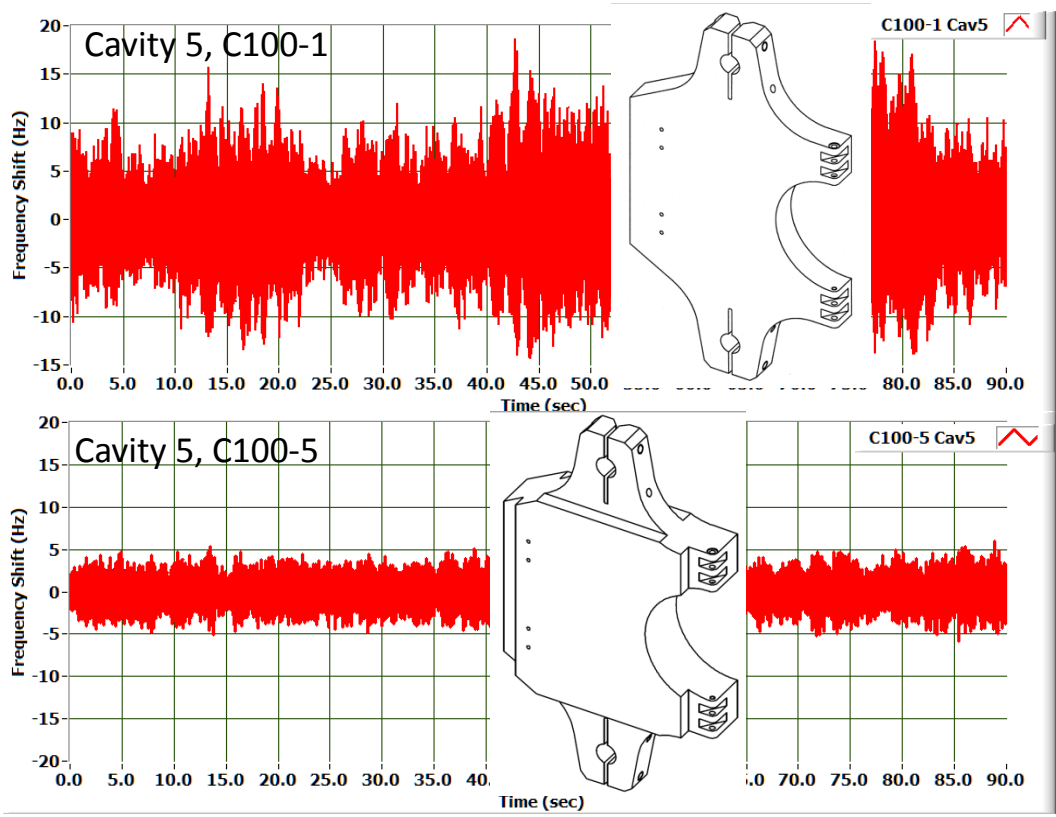
- In Progress
  - Individual Cavity Heater Control Chassis
  - Plan to test in 0L04
    - Tentative Start Date 08/03

- "Dynamic Heater Controls" --Tom Powers
  - Today @ 2:30 PM

Microphonics - Mechanical Tuner Modification

- Design allows for 25 Hz Peak Detuning
- Actual peak detuning **(21 Hz)** was higher than expected in first cryomodules (C100- 0,1,2,3)
- A detailed vibration study was initiated which led to the following design change
- A minor change to the **tuner pivot** plate substantially improved the microphonics detuning for the CEBAF C100 Cryomodules
- While both designs meet the overall system requirements the improved design has a larger RF power margin

Microphonic Detuning	C100-1	C100-4
RMS (Hz)	2.985	1.524
6s(Hz)	17.91	9.14

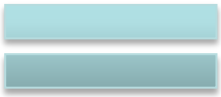


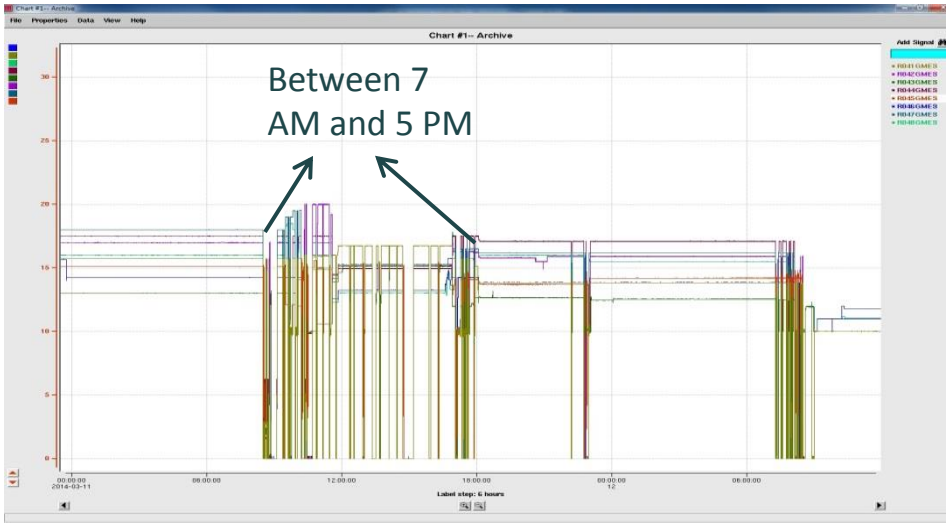
Operational Experience – Microphonics Detuning and Construction

C100 Cavity Gradients

- The drops show the cavity faulting during the day due to construction.
- RF Power could not compensate for the rapid detuning

C100 - 0 Cavity Gradients





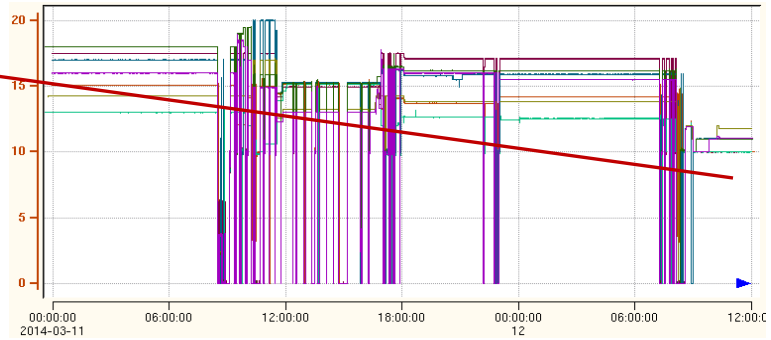
Operational Experience – Microphonics Detuning

- Reduced Gradients in C100-0

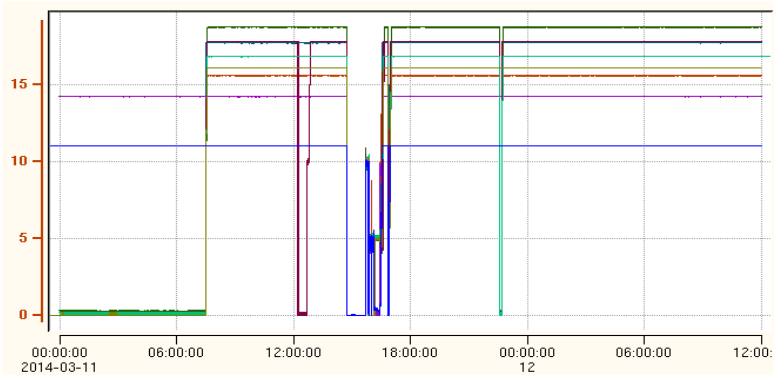
Plan

- Collect Microphonics data from all C100s
- Investigate Piezo Algorithm
- Possibly switch out C100-0 for later production C100

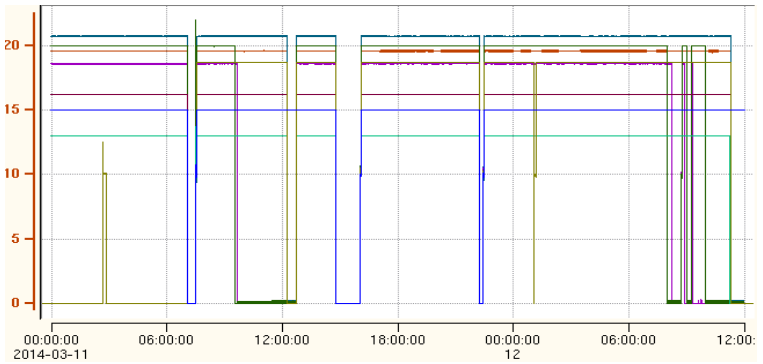
C100-0 Cavity gradients in MV/m



C100-4 Cavity gradients in MV/m



C100-8 Cavity gradients in MV/m



Microphonics Detuning

- Microphonics Detuning Analysis in progress for Injector C100
- Collecting data from other C100 when there is an opportunity
- Find out maximum heat capacity of each C100

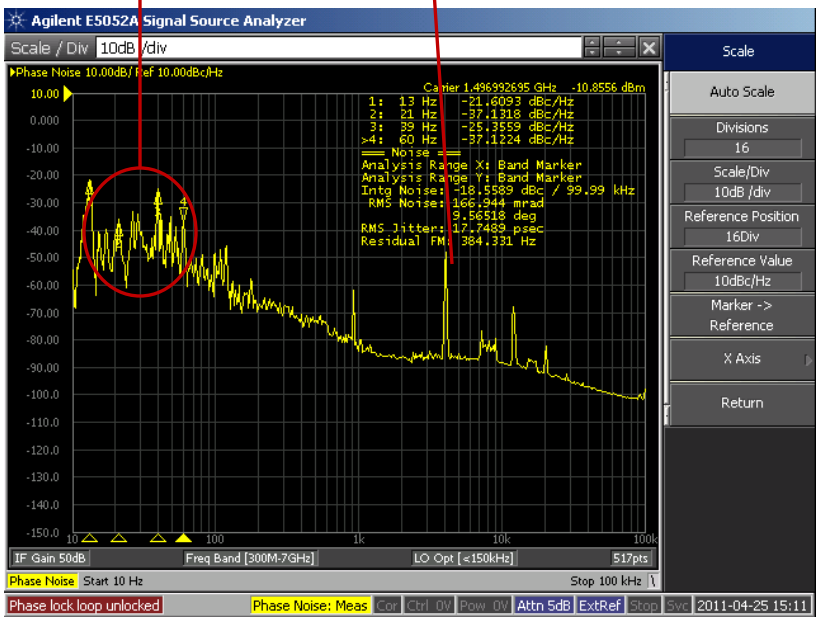
- "C100 microphonics update" ---Kirk Davis
  - Today @ 10:30 AM

RF Control Loop Optimization

- We observed 4 kHz oscillation when LLRF is locked
- Higher gain
  - Reduced 4 kHz oscillation
  - …..but control system less stable
- Loop Phase mismatch between SEL and locked condition
  - Simulation didn't show
  - Latency issue between the two logic chains in the FPGA
  - Systematic 30 degree difference

Microphonics – compensated

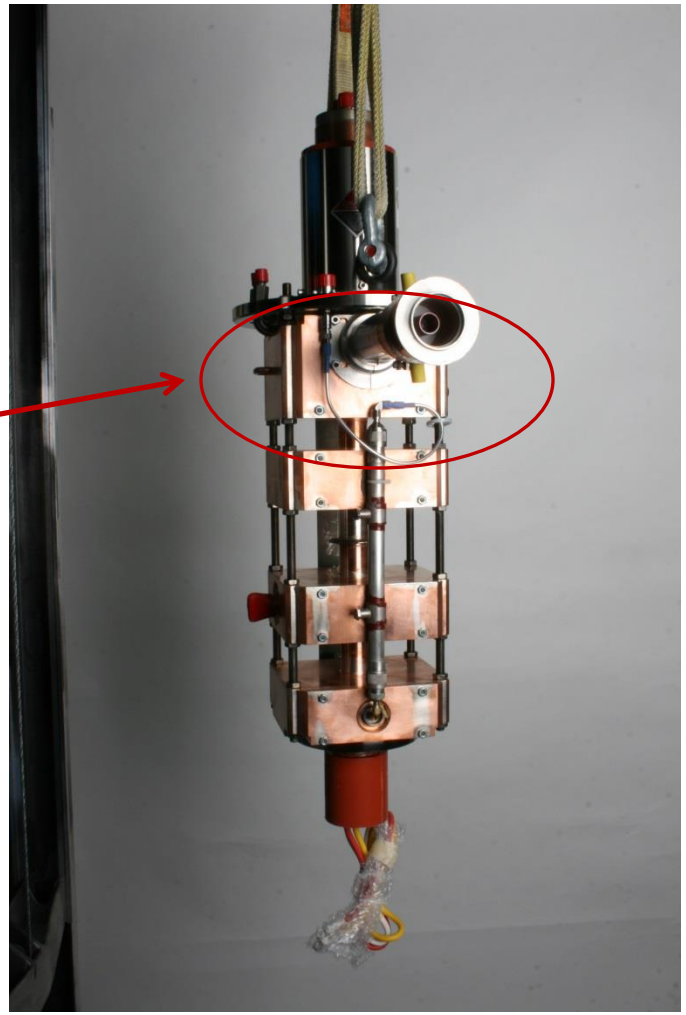
4 kHz



Forward Power in GDR

Operational Experience - Crosstalk on Klystron drive cables

- Crosstalk on Drive Cables
  - Causing cavity trips on GMES fault
  - Repaired connectors and problem went away
- Crosstalk on Klystron Internal Cable
  - Terminated the input
  - Still had 15-25 watts forward power and gradient in the cavity!
  - Investigating pulling klystron solenoid and replacing cables with better shielded cables



Current Plans

- Helium Processing in progress
- Installation of Individual Cryomodule Heater Control System
- Microphonics Detuning analysis, Piezo Algorithm studies and Implementation
- Control Loop Optimization
  - Investigate the loop phase mismatch between SEL and GDR
- Klystron Drive Cables
  - Detect the source of crosstalk

Summary

- CEBAF Initial commissioning goals achieved
  - 2.2 GeV/pass
  - 123 MeV from Injector
  - CD4A – 5 months ahead of schedule
- Beam delivery to experimental halls
- Plans for improving operability

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Questions?