CEBAF SRF Performance During Initial 12GeV Commissioning

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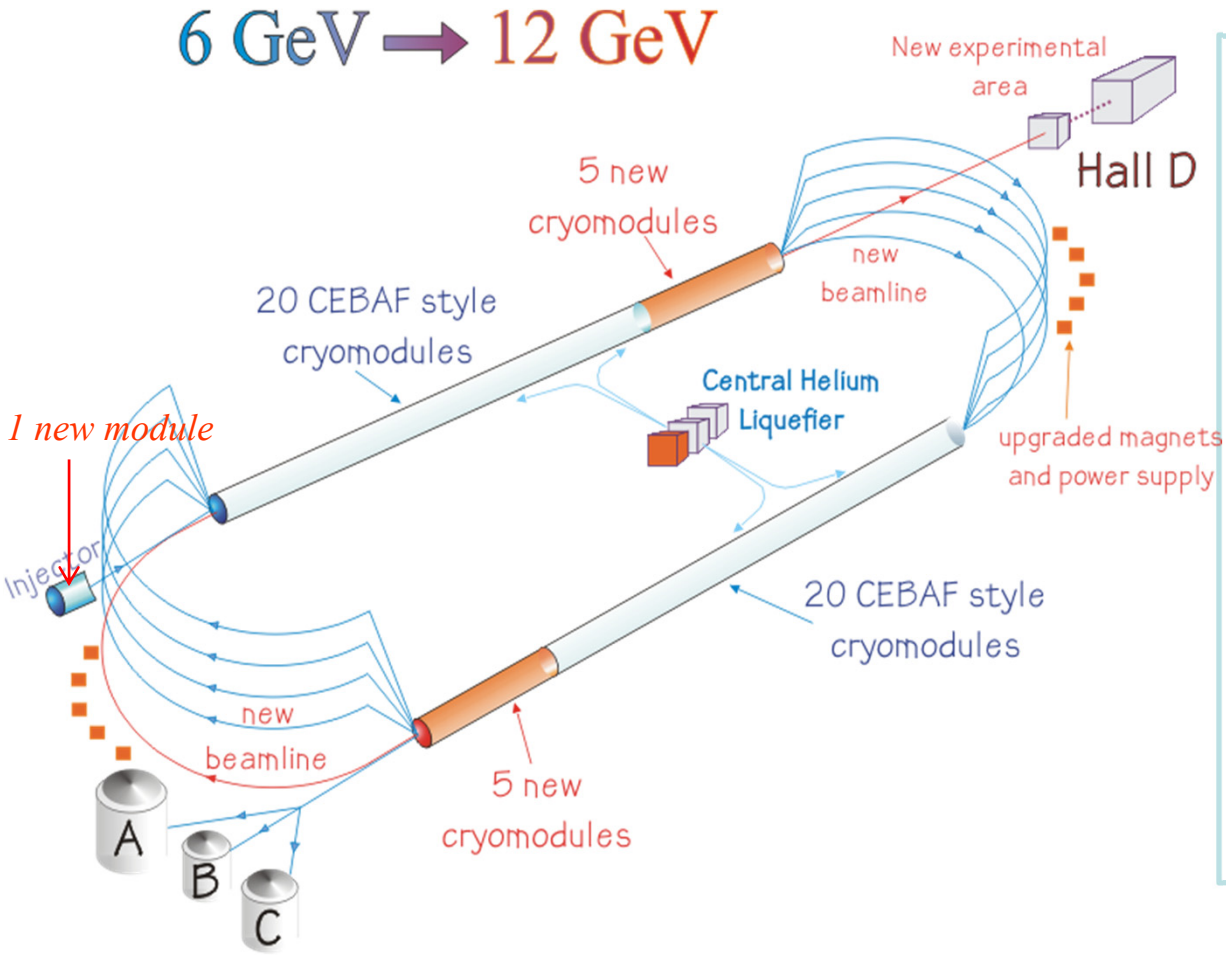
IPAC 2015, May 3-8

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

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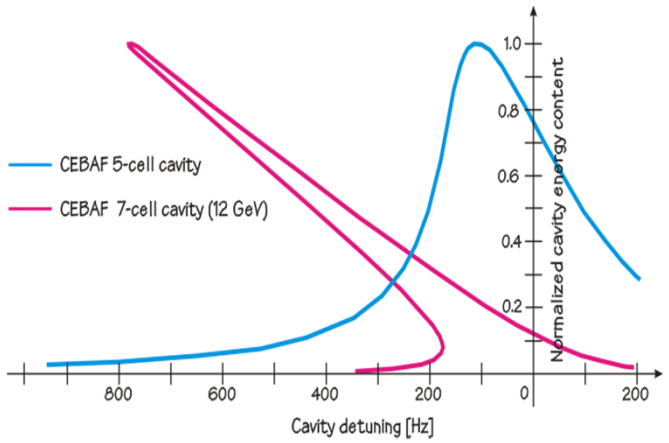
C100 Cryomodule

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

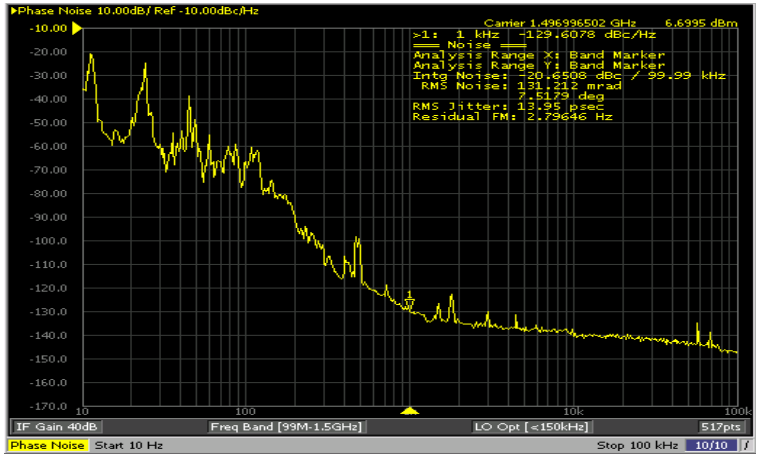
High Q_L Challenges

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	1300 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

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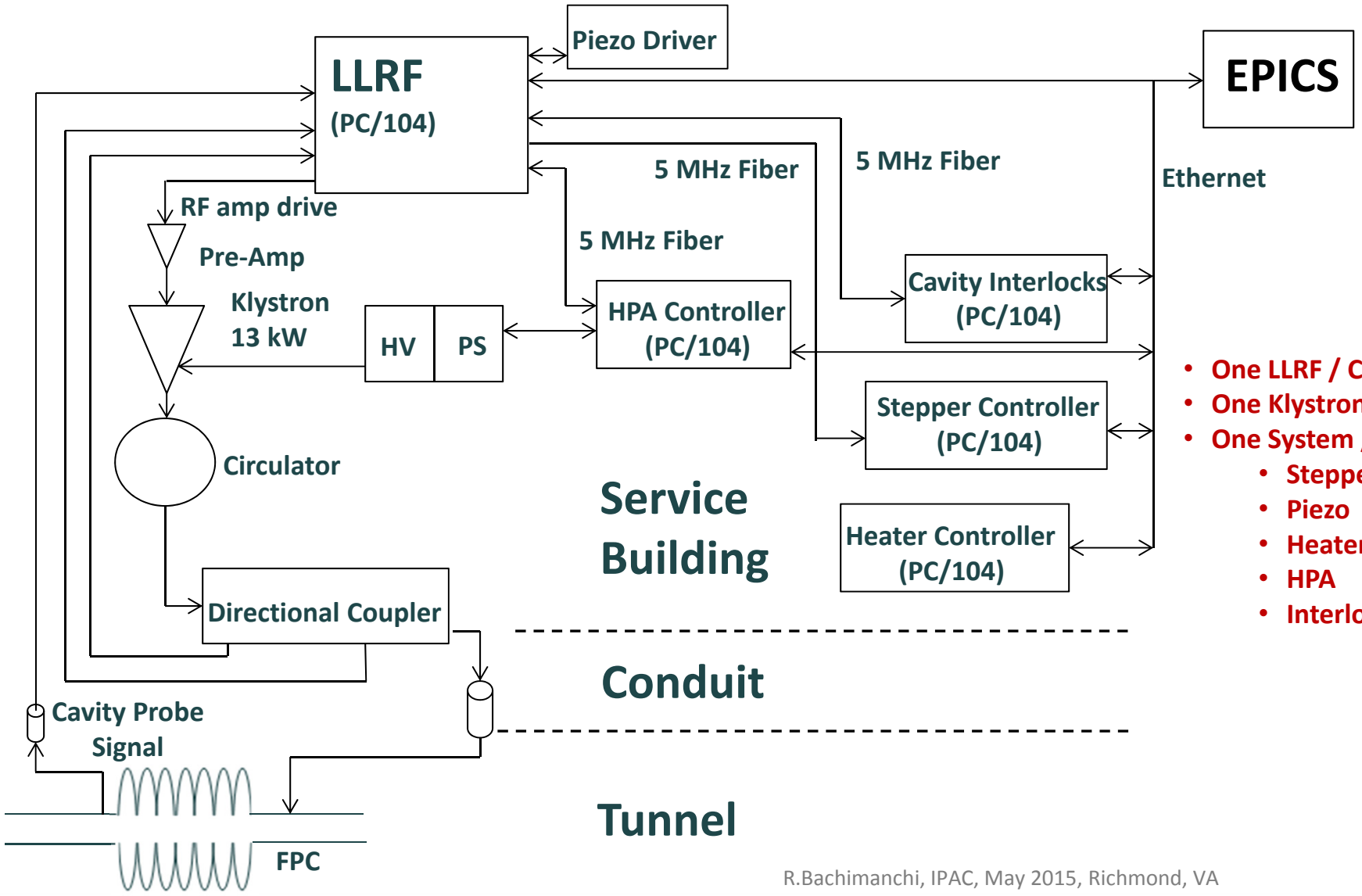
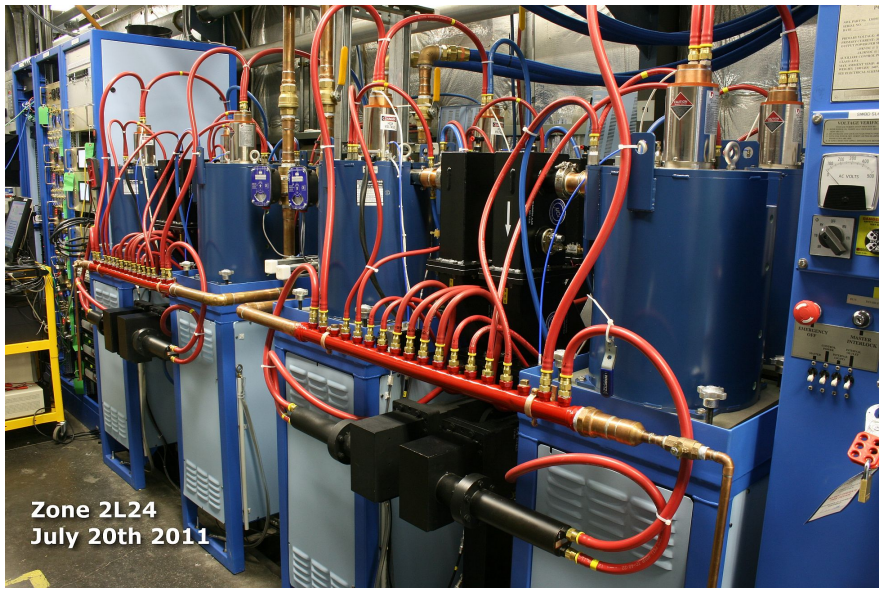
RF System for C100 Cavity



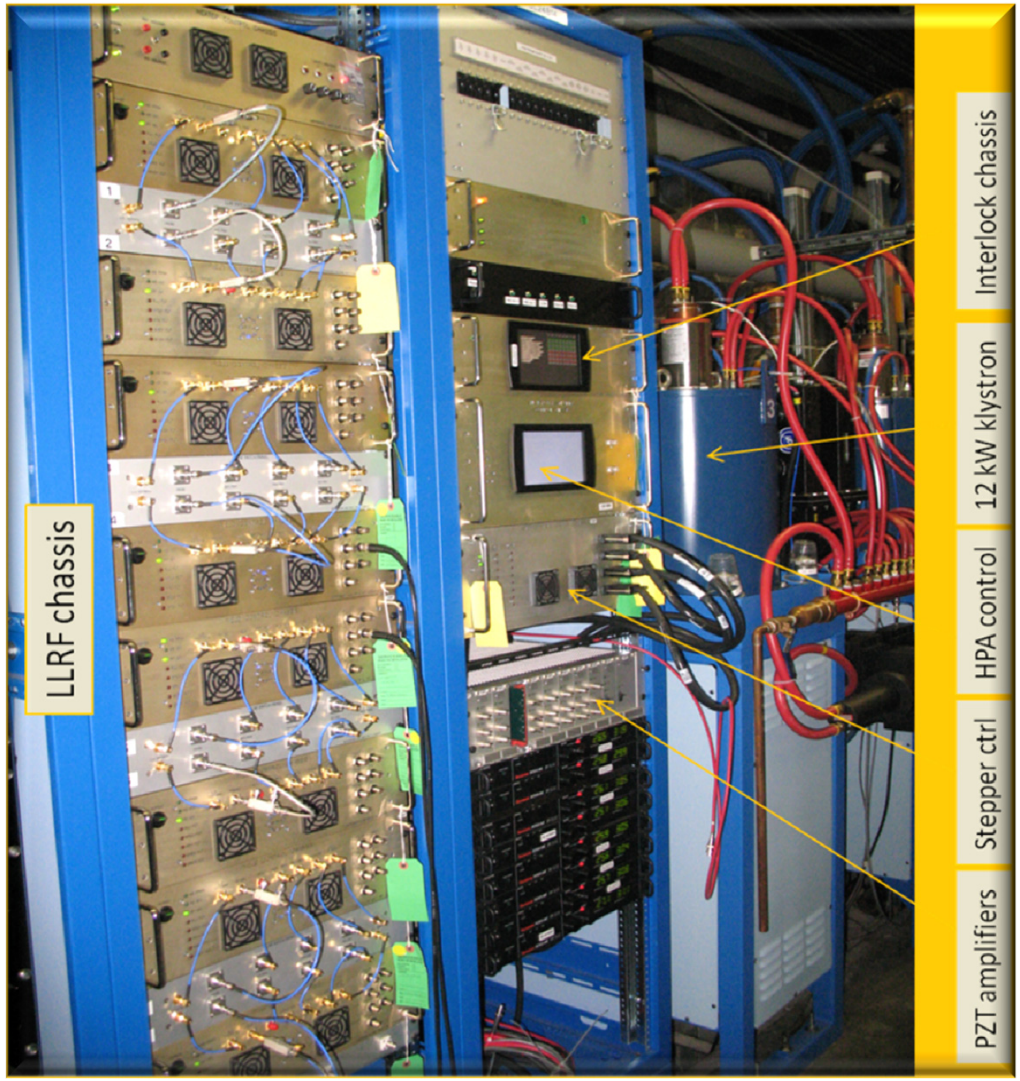
- One LLRF / Cavity
- One Klystron / Cavity
- One System / Zone
  - Stepper
  - Piezo
  - Heater
  - HPA
  - Interlocks

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

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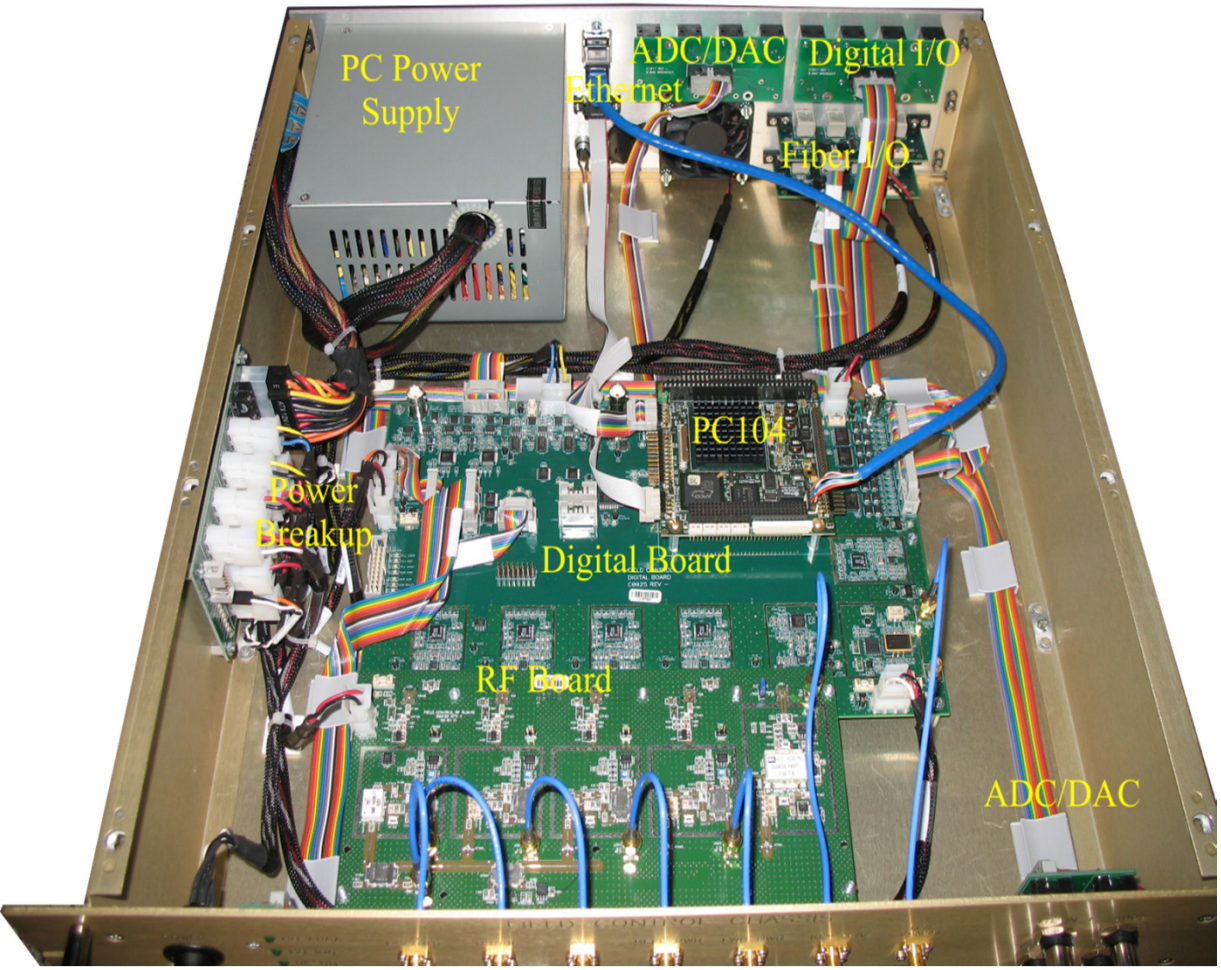
RF System



- 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
- LLRF 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	SRF Commissioning	2.2 GeV/Pass
C100-1	110 MV	94.01 MV
C100-2	120	93.8
C100-3	124	76.58
C100-4	105	79.24
C100-5	110	100.31
C100-6	113	101.8
C100-7	113	103.81
C100-8	109	100.17
C100-9	117	101.15
C100-10	116	87.57
C100-0	116	82.3

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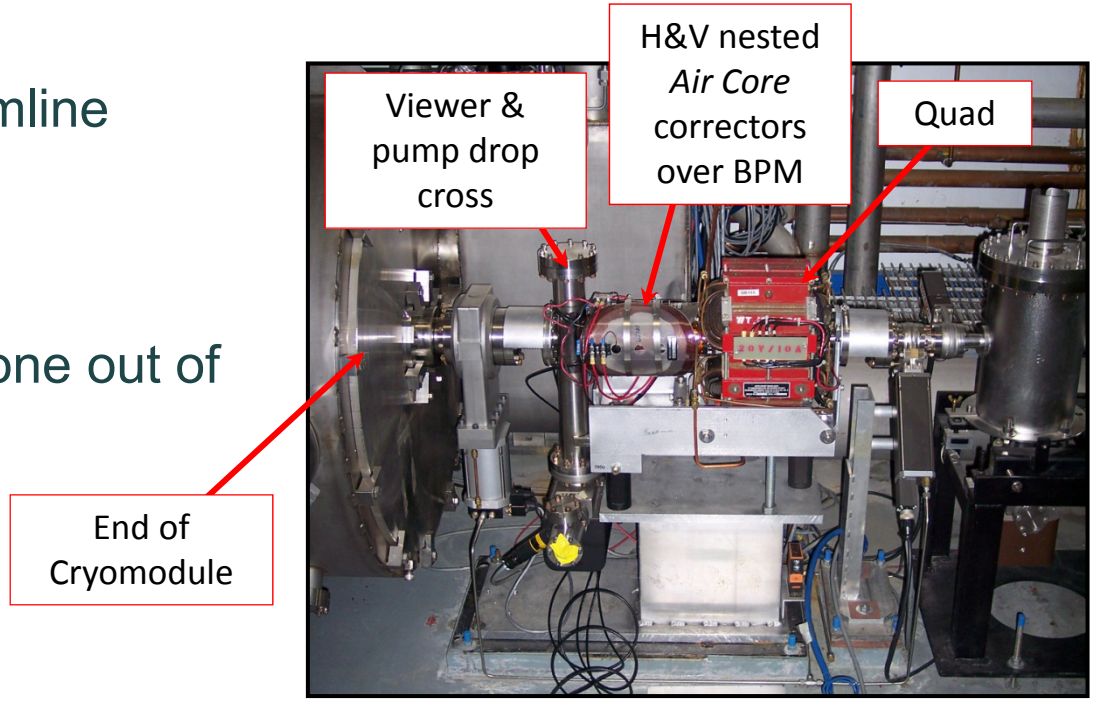
Operational Experience -CEBAF Commissioning

- 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

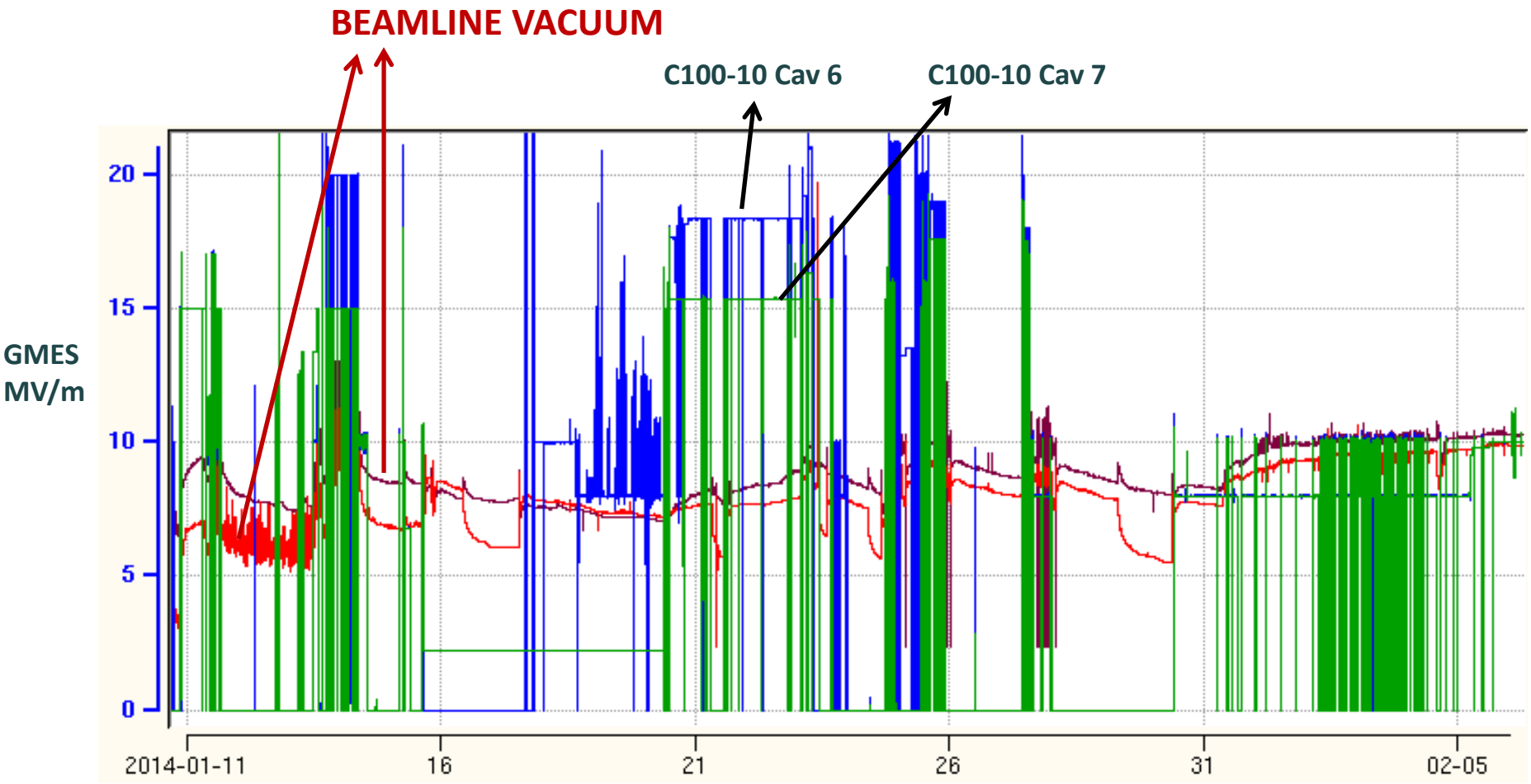
Operational Experience - Field Emission

- Field Emission heats Beamline
- Vacuum Pump faults
- Vacuum Interlock drops Zone out of RF



Operational Experience - Field Emission

Cavity Gradients impacting Beamline Vacuum activity



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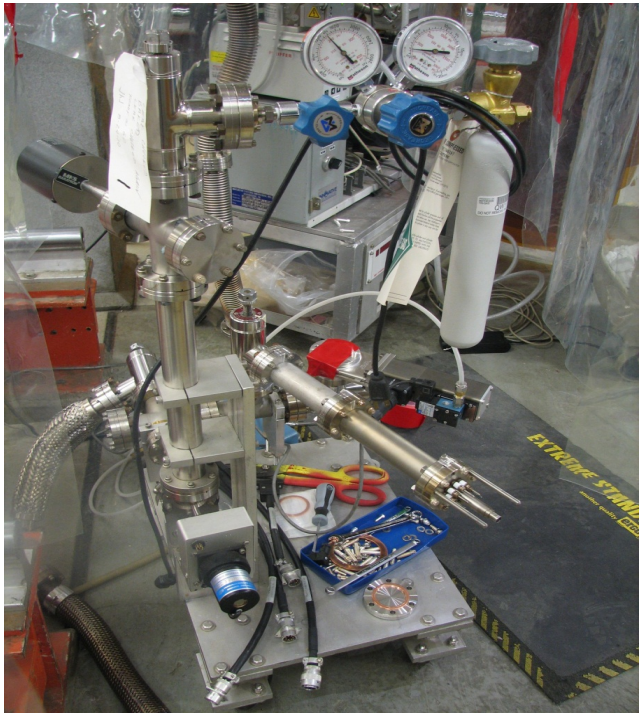
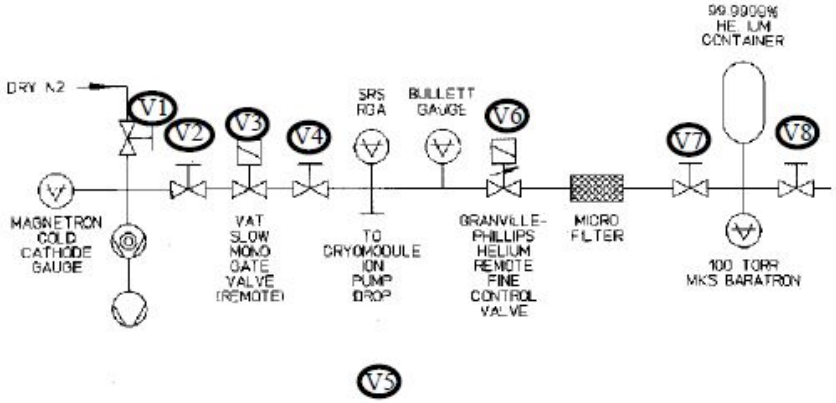
Helium Processing

- 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

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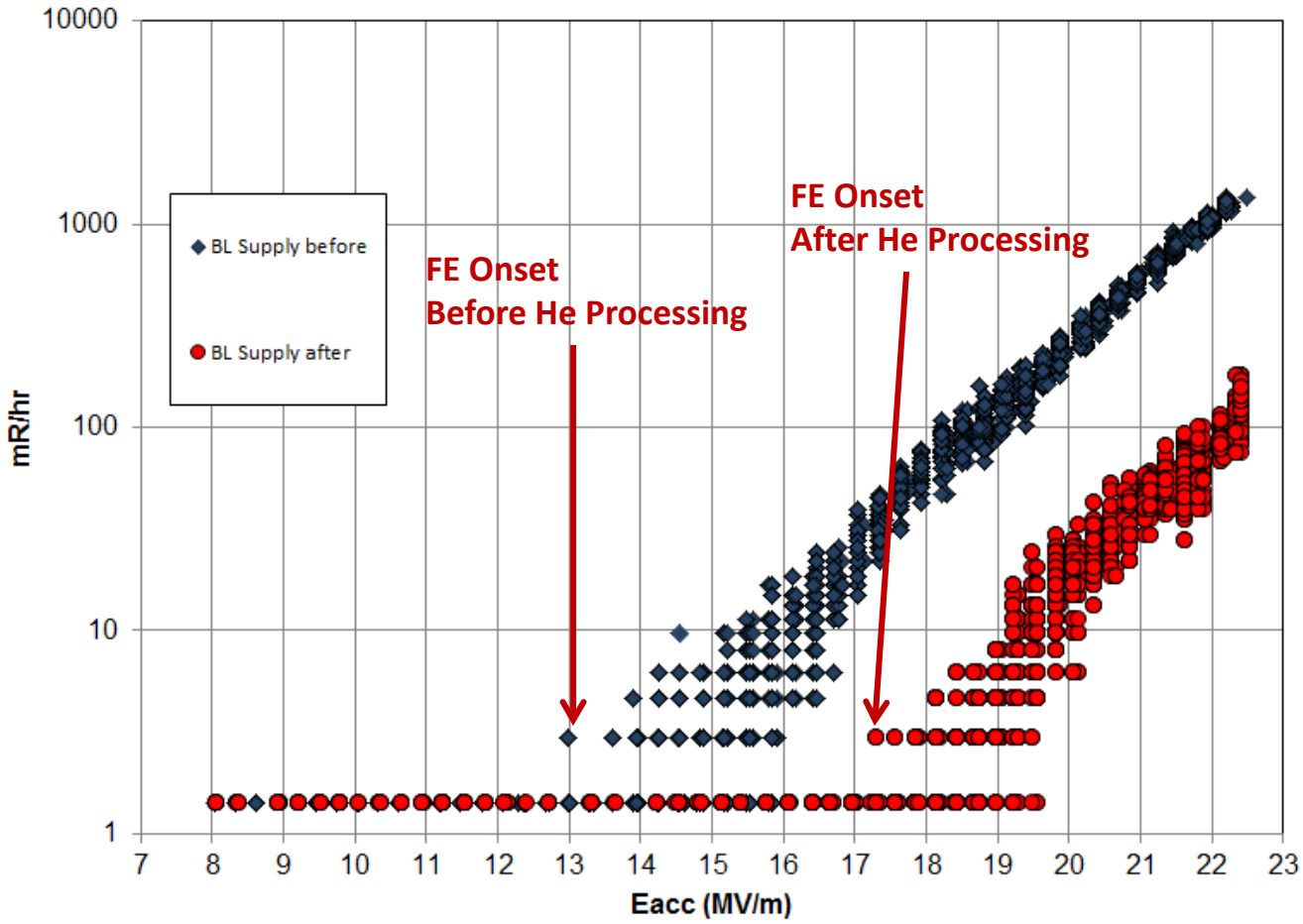
Helium Processing

- Performed on C100-5 cryomodule



C100-5 cavity 6
Before and after
He processing

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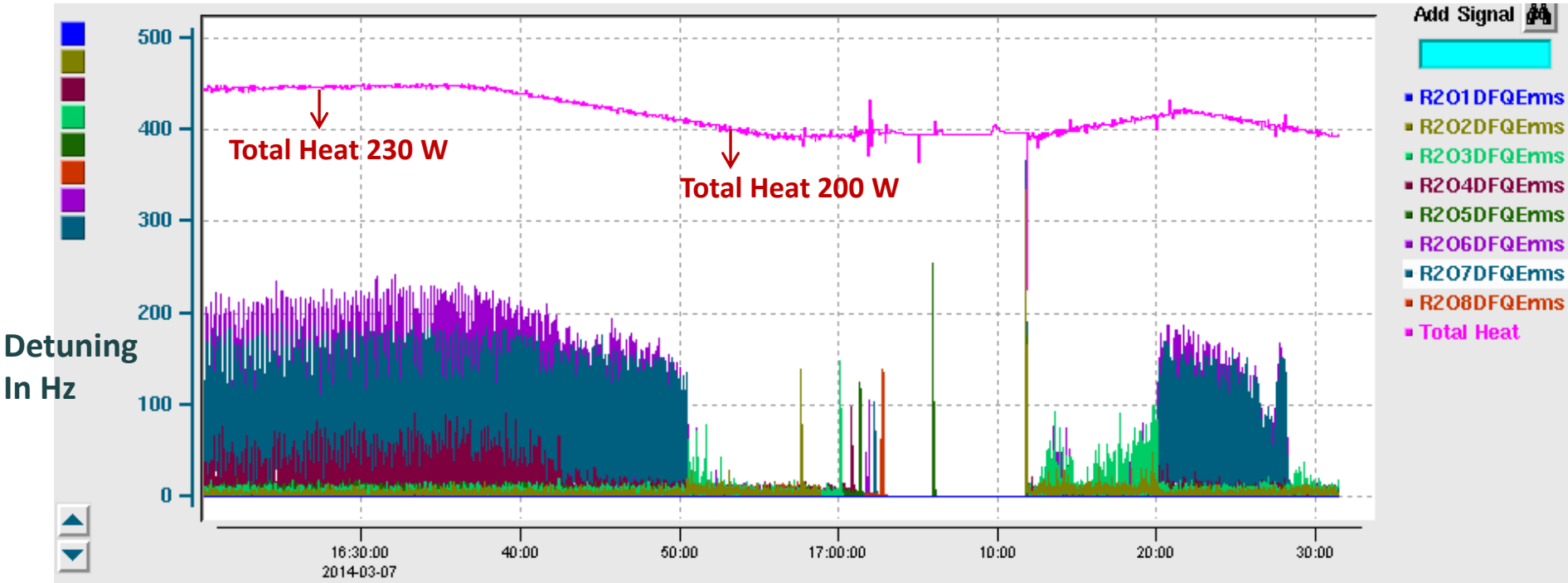
Operational Experience - Cryomodule Heater Configuration

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

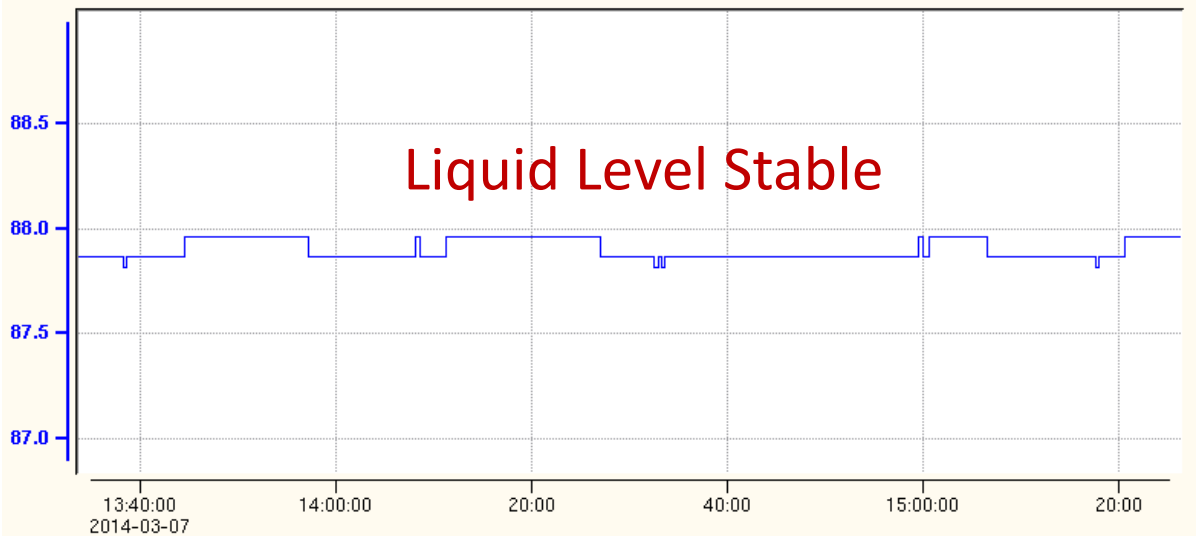
Total heat vs Detuning in SEL



Operational Experience - Cryomodule Heater Configuration

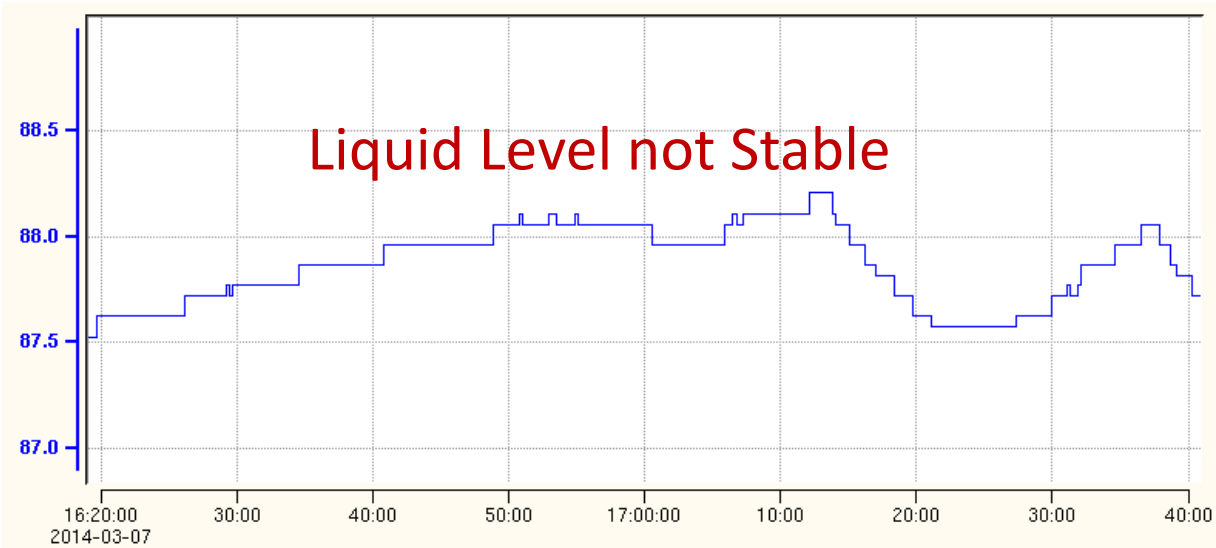
- When RF was off
  - Only Electric Heat

He Level Percentage



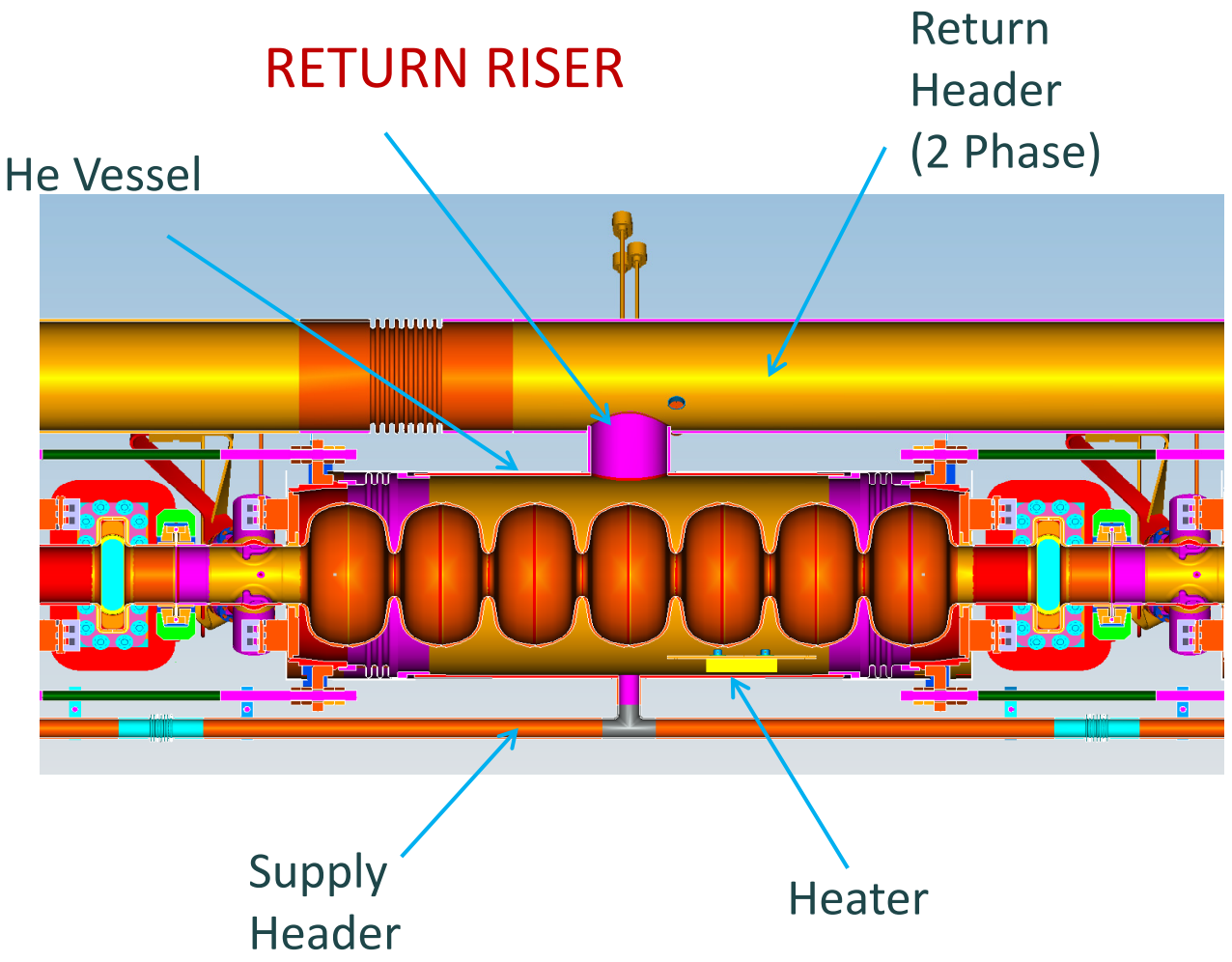
- When RF was on
  - RF + Electric Heat

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



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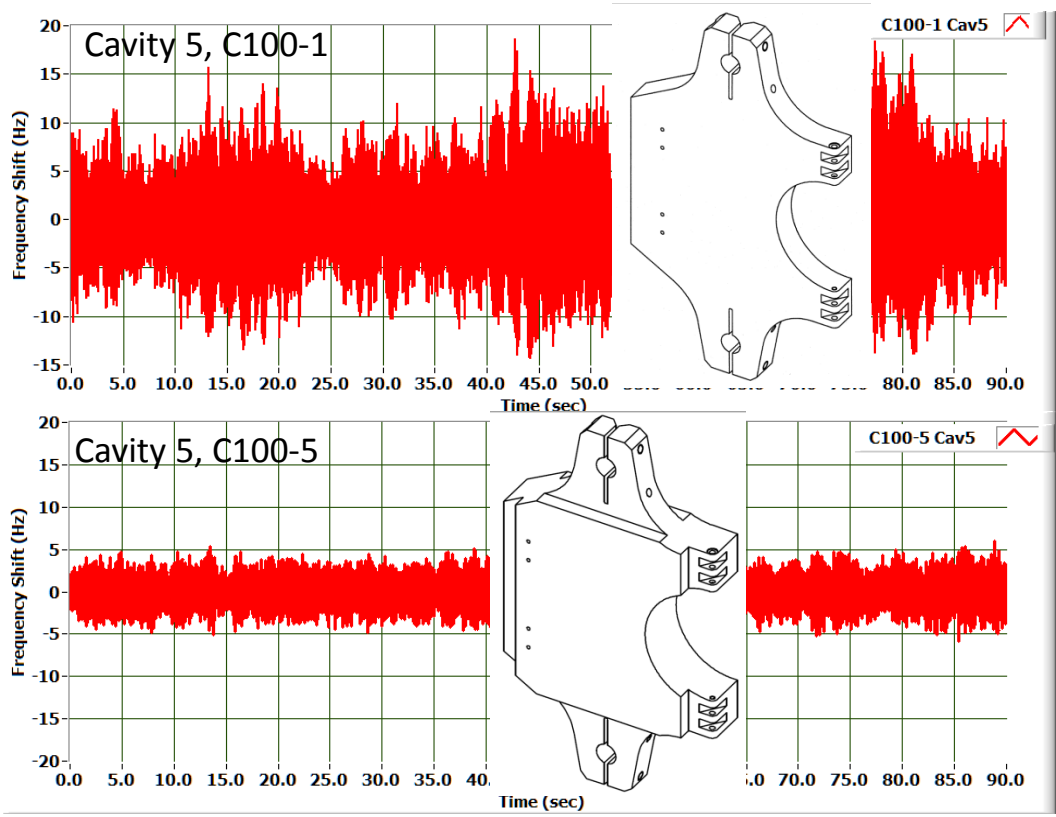
Microphonics - Mechanical Tuner Modification

- Design allows for 25 Hz Peak Detuning
- Actual peak detuning **(18 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



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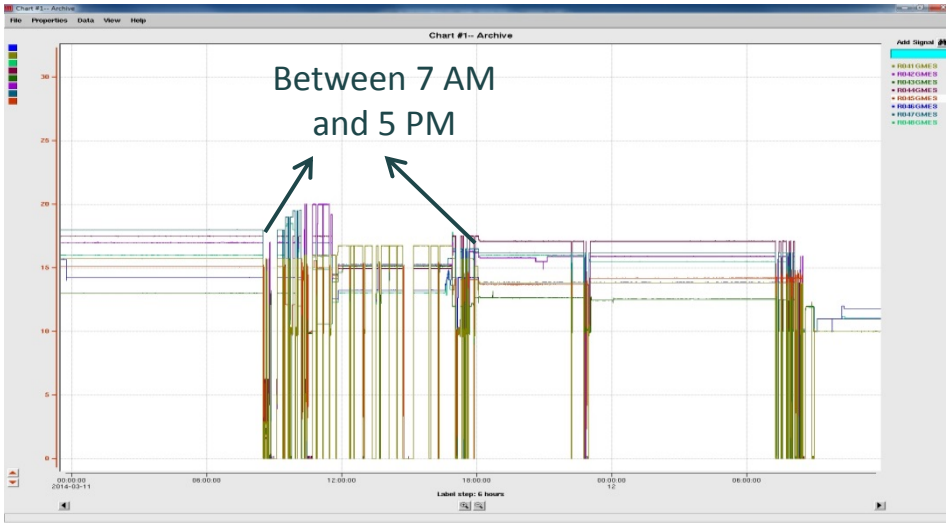
Operational Experience – Microphonics Detuning and Construction

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



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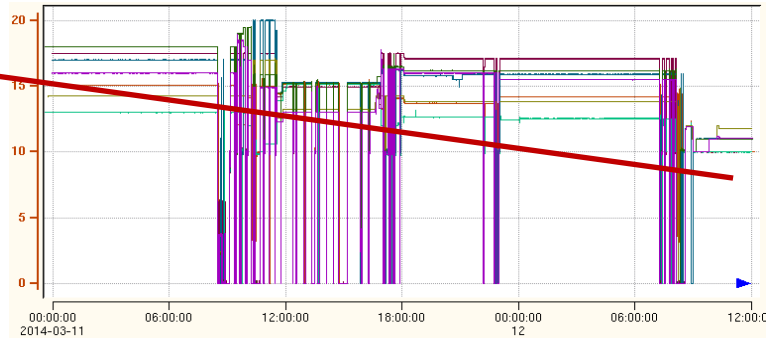
Operational Experience – Microphonics Detuning

- Reduced Gradients in C100-0

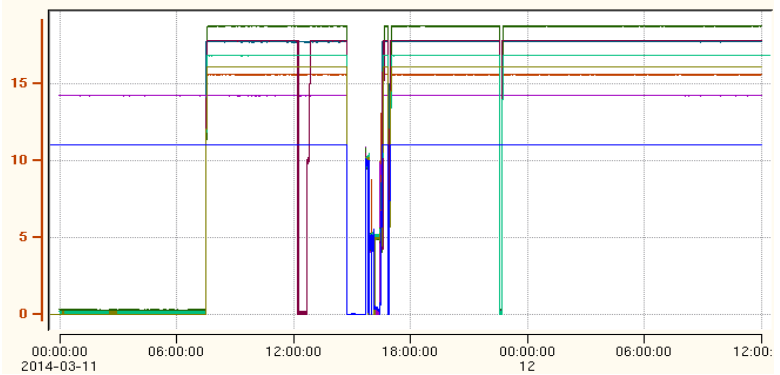
Plan

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

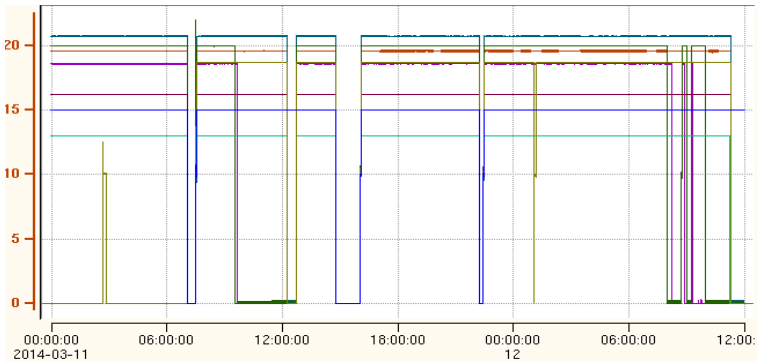
C100-0 Cavity gradients in MV/m



C100-4 Cavity gradients in MV/m



C100-8 Cavity gradients in MV/m



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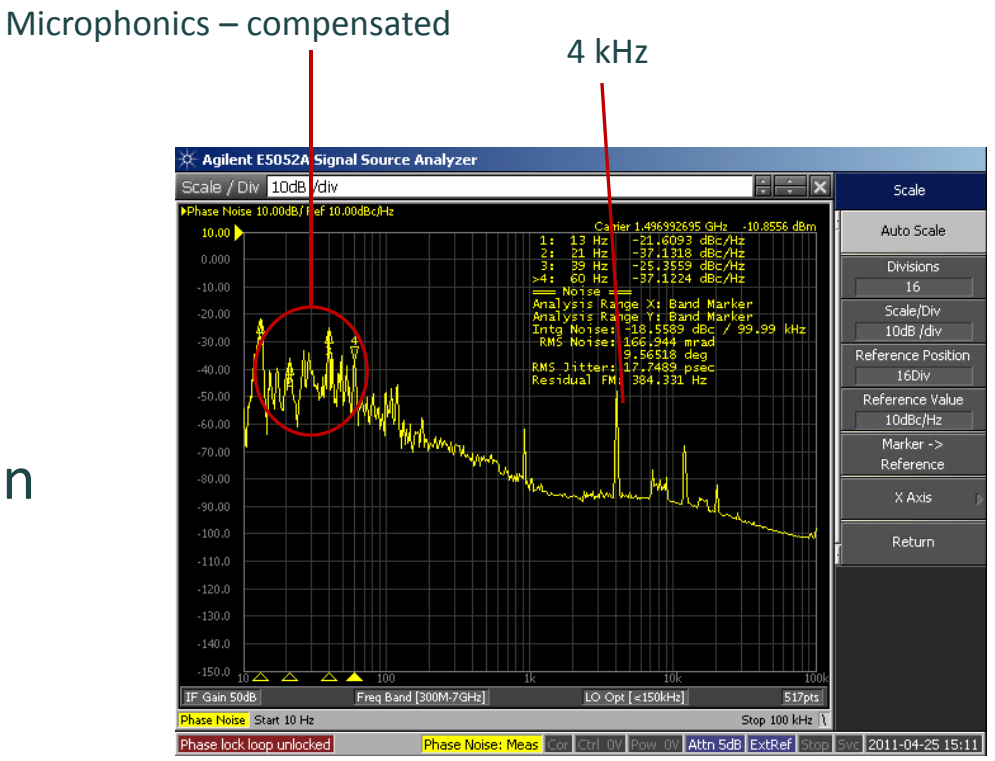
RF Control Loop Optimization

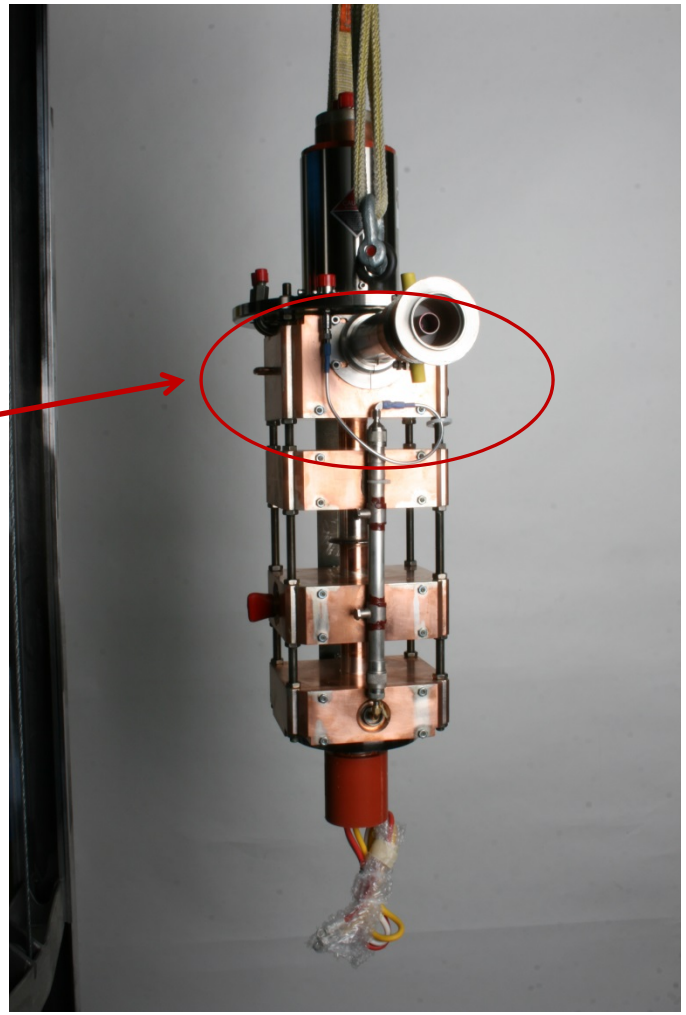
- We observed 4 kHz oscillation when LLRF is locked
- Higher gain
  - Reduced 4 kHz oscillation
  - …..but control system less stable
- Loop Phase mismatch between SEL and locked condition
  - Simulation didn't show
  - Latency issue between the two logic chains in the FPGA
  - Systematic 30 degree difference



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



Future Plans

- Helium Processing this summer to minimize Field Emission
- 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

Special Thanks to
Trent Allison, Ed Daly, Mike Drury, Arne Freyberger, Curt Hovater, George Lahti, Clyde Mounts, Rick Nelson, Tomasz Plawski and Mike Spata for their contributions in this presentation

Questions?