LLRF Tests in the FEL and CEBAF with the Cornell Digital LLRF System

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Cornell: Sergey Belomestnykh, Roger Kaplan, and Matthias Liepe

JLAB-Cornell Collaboration Background

- 2001-2003: Cornell, DESY and JLAB hold semi-regular VC's to discuss LLRF Issues.
- 2003: Cornell develops LLRF system for CESR-C and as a prototype for the their ERL proposal.
- June 2004: Charlie Sinclair suggests that it would be beneficial for the two Labs to collaborate on LLRF testing using the JLAB FEL.
- We bite ……. Send a delegation (Rimmer, Areti, Pozdeyev, and Hovater) to Cornell in July.
- This is where the story begins …………….

JLAB Energy Upgrade Task Description 2

2. Use FEL-3 as a test bed to benchmark high gradient cavity performance and RF control systems: FY04 ($75K) and FY05($50K)

The second "First Generation Upgrade CM" (known as FEL-3) will be used as a test bed to benchmark the lessons learned from SL-21. These changes include:

1) doubling of the cavity cooling, and 2) doubling of the waveguide cooling. Prototype components for RF control of high gradient cavities will also be tested.

Risk Reduction: Reduction in technical risk through validation of design features the high-performance cryomodules need for system cost minimization; cost and schedule risk are also reduced.

Deliverable: Benchmark of 12 GeV specifications for RF and cryogenic performance, and component testing of RF control system prototypes.

Completion date: 28-Feb-05

JLAB Specific Goals for the Collaboration

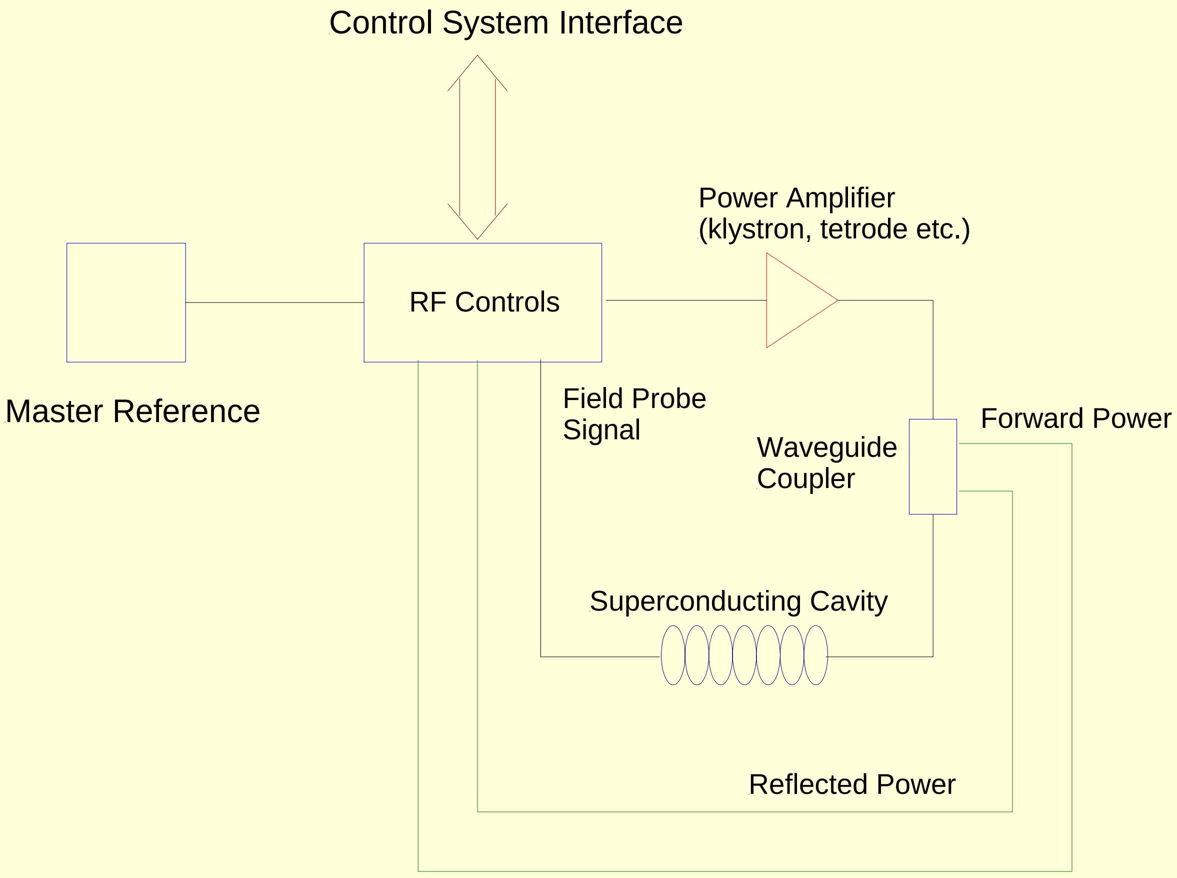
As they support the12 GeV Upgrade

- Operate a High Q SRF cavity, beam loaded with a ***digital*** *LLRF* controller
- Demonstrate acceptable phase and amplitude control
- Demonstrate cavity recovery under strong Lorentz detuning
- Demonstrate cavity recovery from Cryogenic crash

Cornell Project Goals

- Operate LLRF system in an ERL using a cavity with high Q_L
- Benchmark system performance
- Improve system phase noise
- Algorithm development

Simple RF System



Cornell RF System

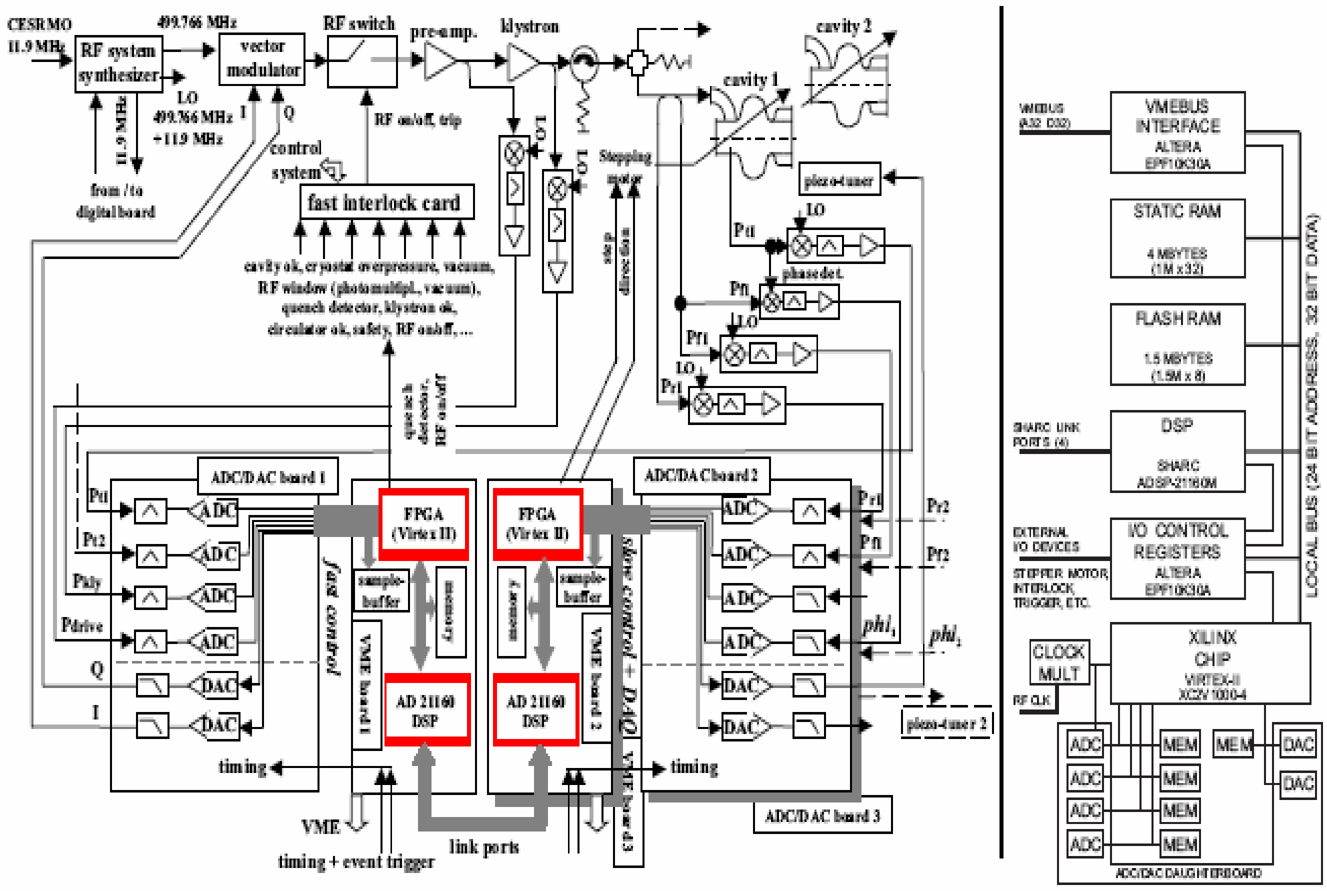
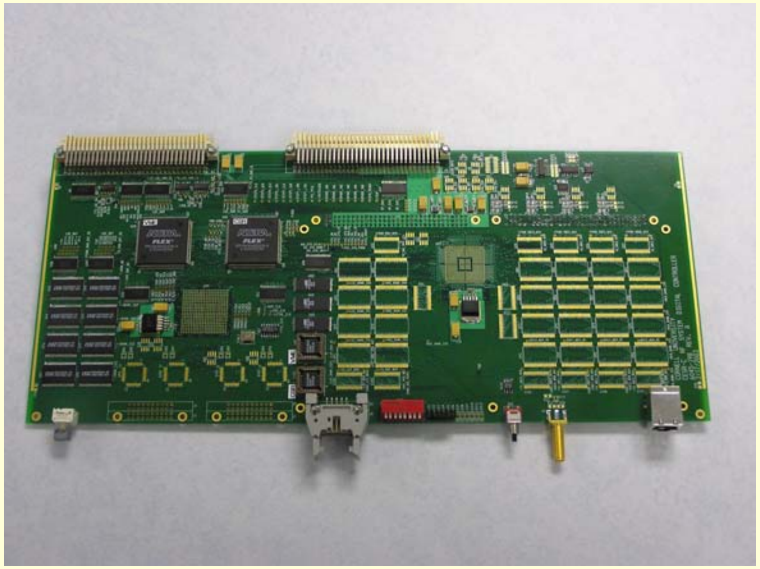


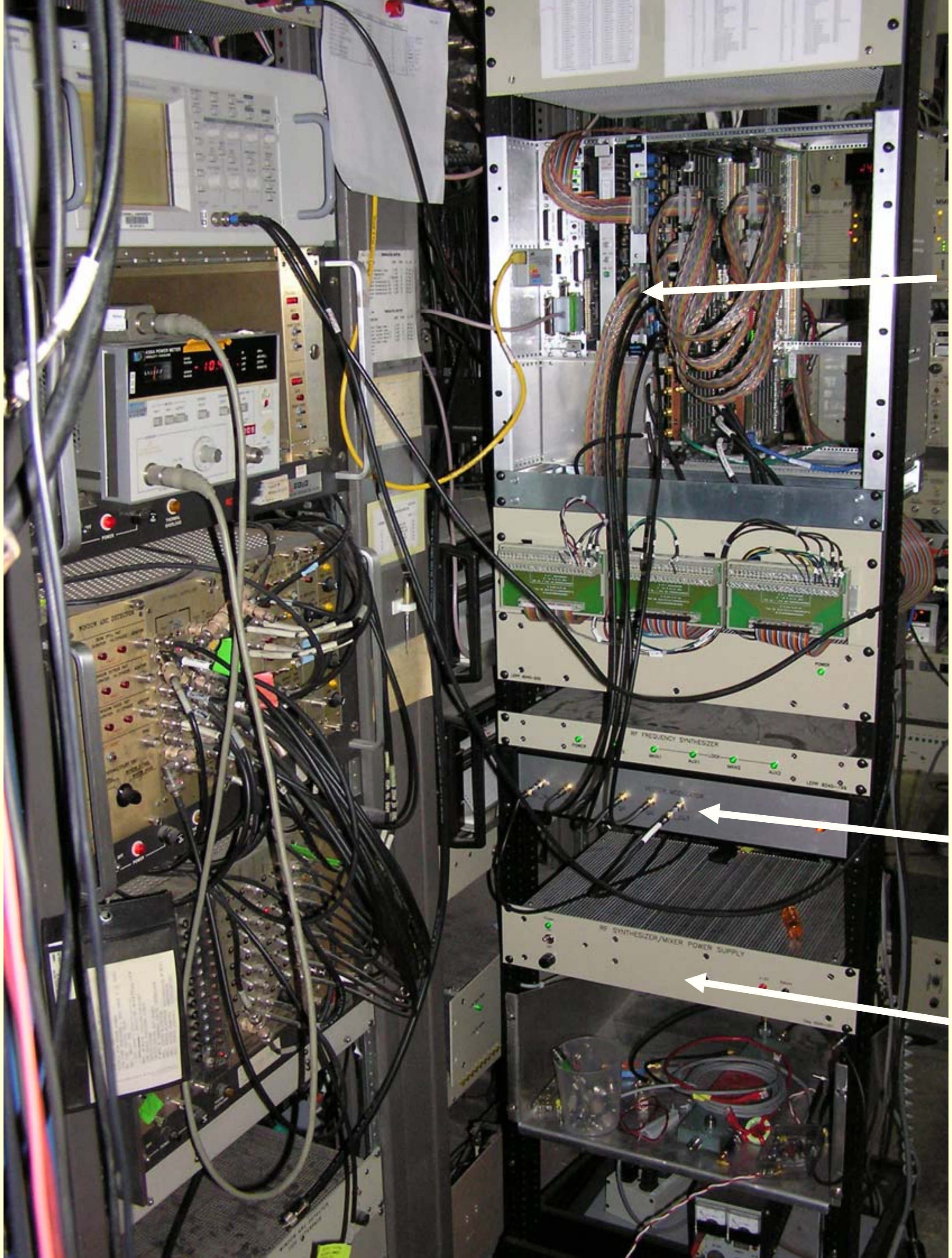
Figure 1: Left: Schematic of the digital RF system for CESR-c. Right: Block diagram of the FPGA/DSP board.

Cornell Digital Card

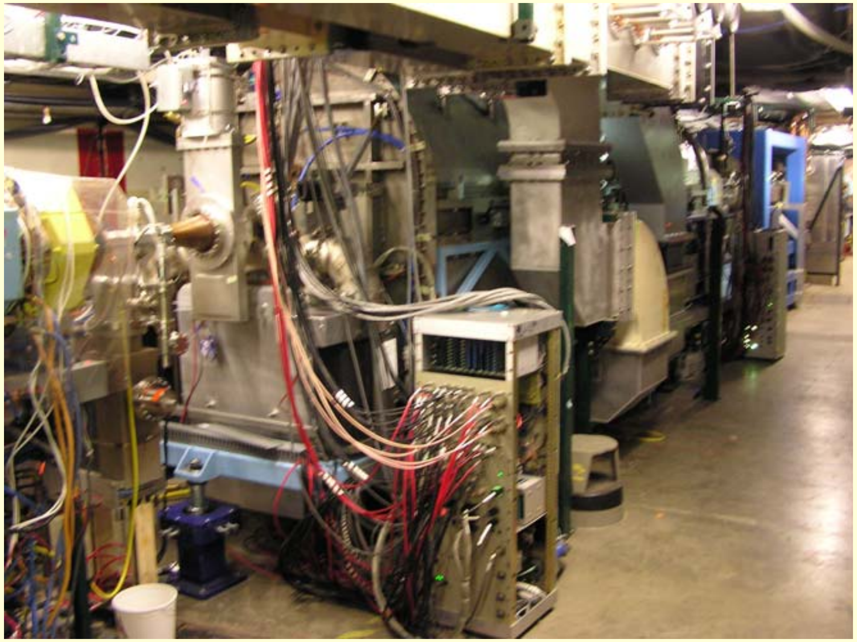


Cornell ADC Receiver Card

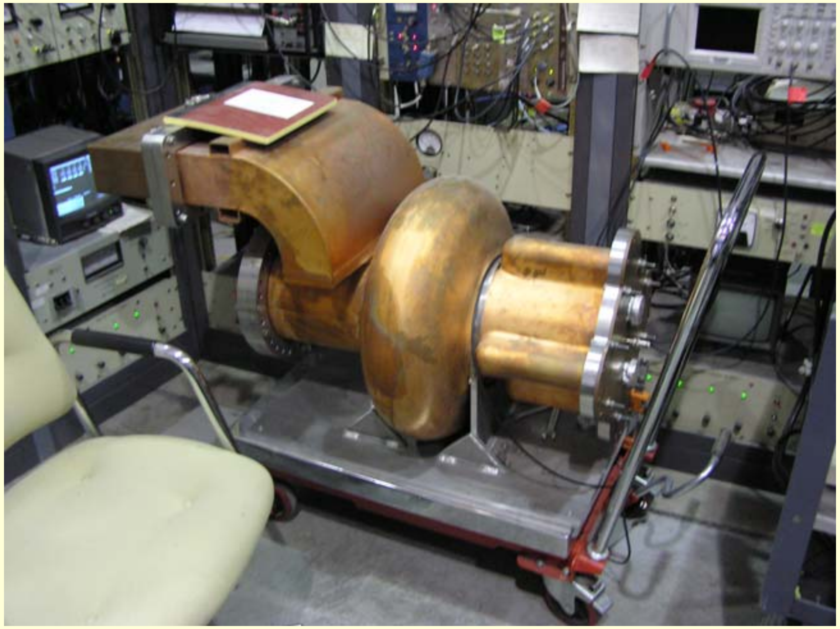
Cornell LLRF System

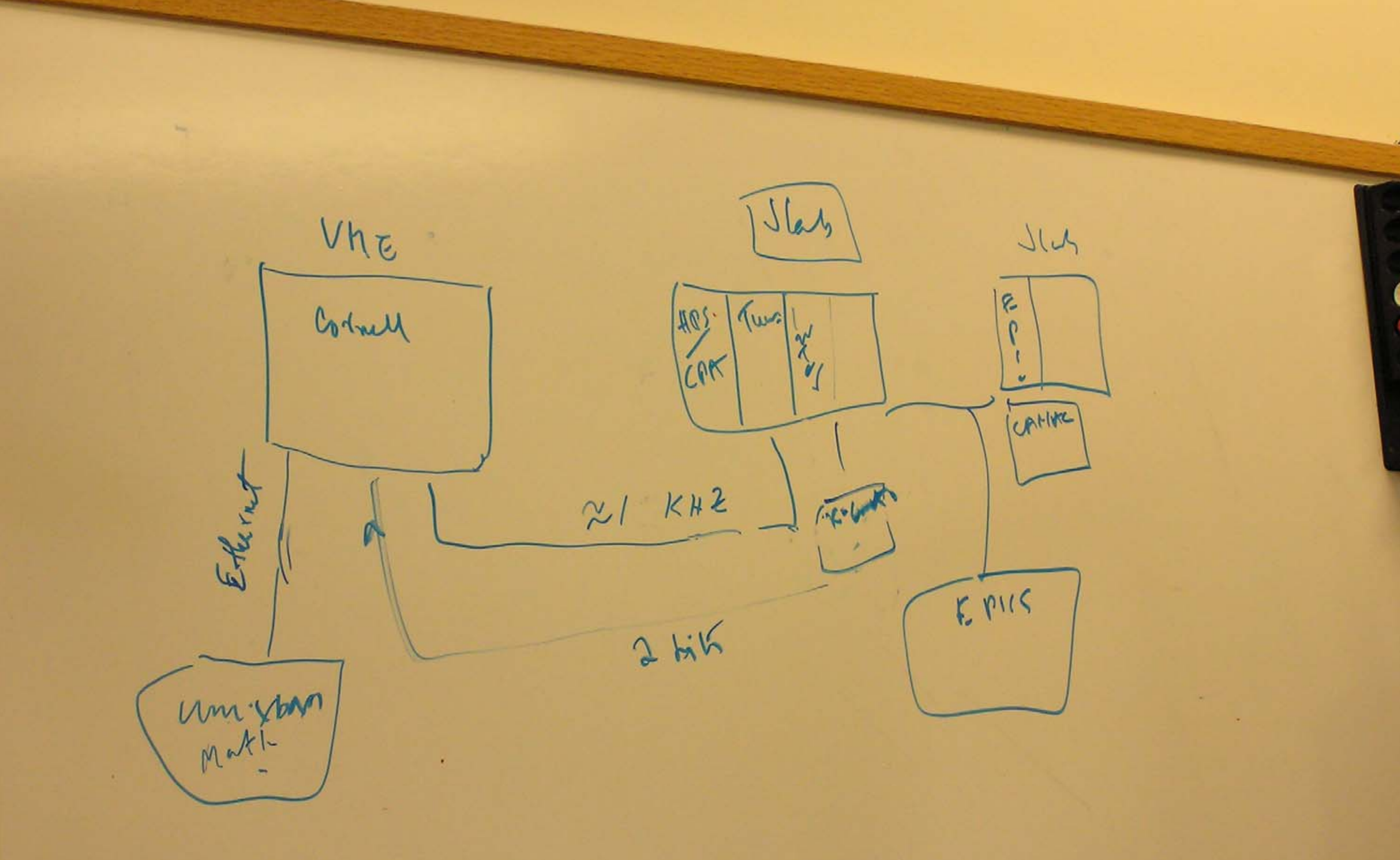


CESR-C Cryomodule



Prototype Single Cell Copper Cavity ~ 499 MHz





The Original Plan !

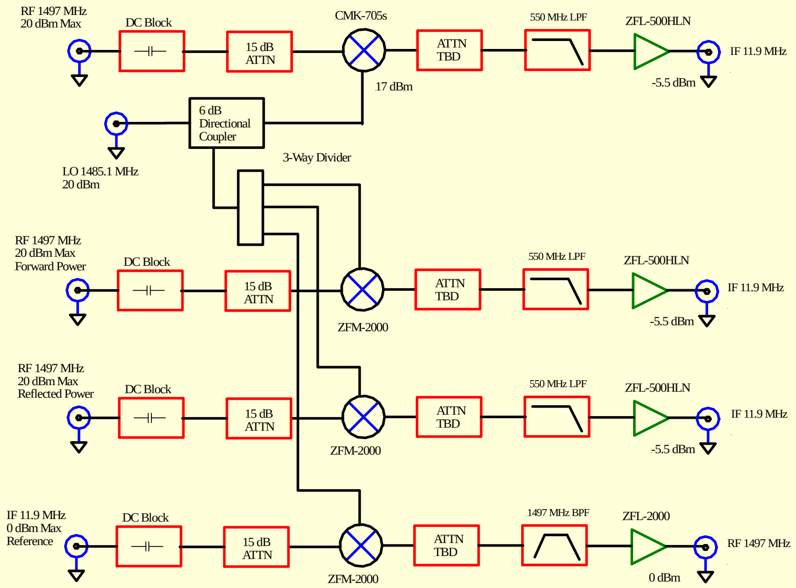
Project Facts

- Project used existing JLAB RF control module for source RF, HPA control and cavity interlocks.
- FEL03-3 was chosen (high gradient) and a stub tuner installed.
- Cornell LLRF was stand alone, so no interface to EPICS was needed (beyond what the JLAB LLRF system provided).
- JLAB would provide all of the hardware adaptations to make the Cornell LLRF compatible with our HPA-cavity system.

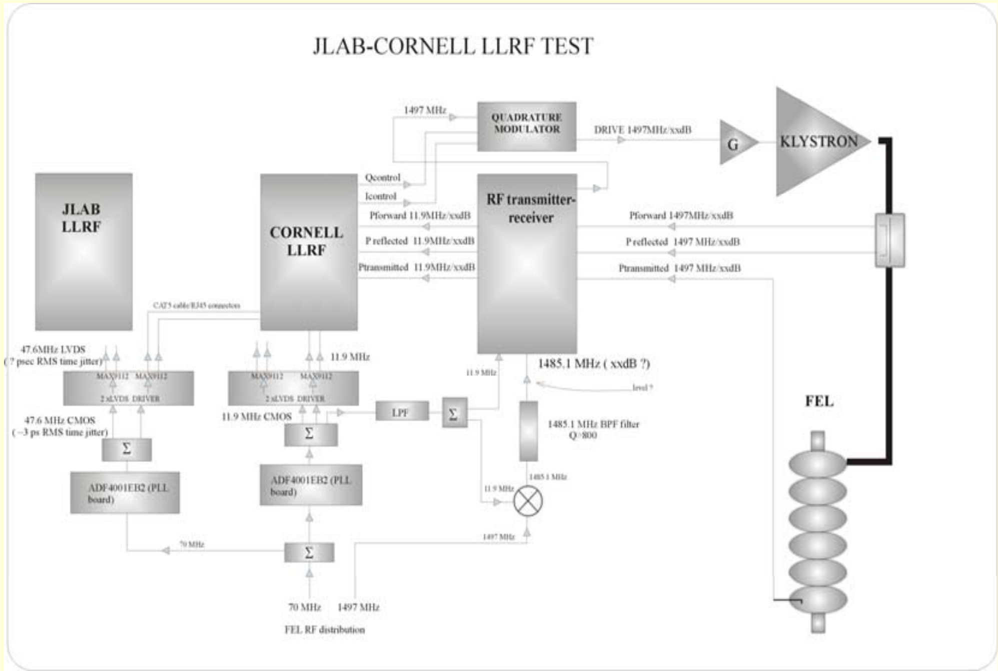
JLAB Tasks for JLAB-Cornell LLRF Tests

- Design and build receiver and transmitter (C. Hovater, C. Cox)
- Design and build low phase noise LO, IF synthesizer and clock (T. Plawski)
- Cavity characterization, microphonic and mechanical modes (K. Davis, T. Powers)
- PZT Driver/Amplifier (K. Davis)

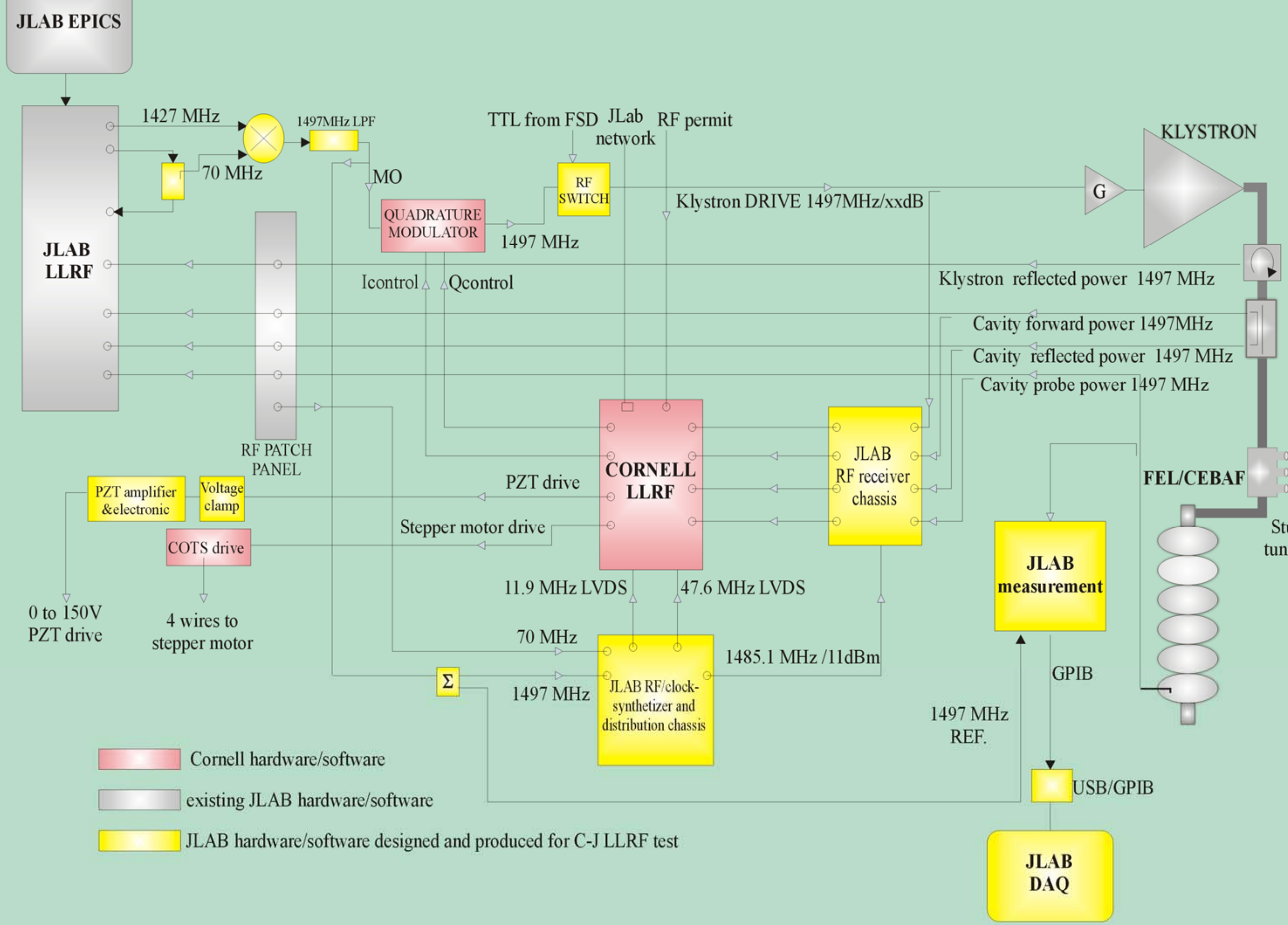
1497 MHz Receiver Transmitter



LO, IF and Clock Synthesizer



JLAB-CORNELL LLRF TEST

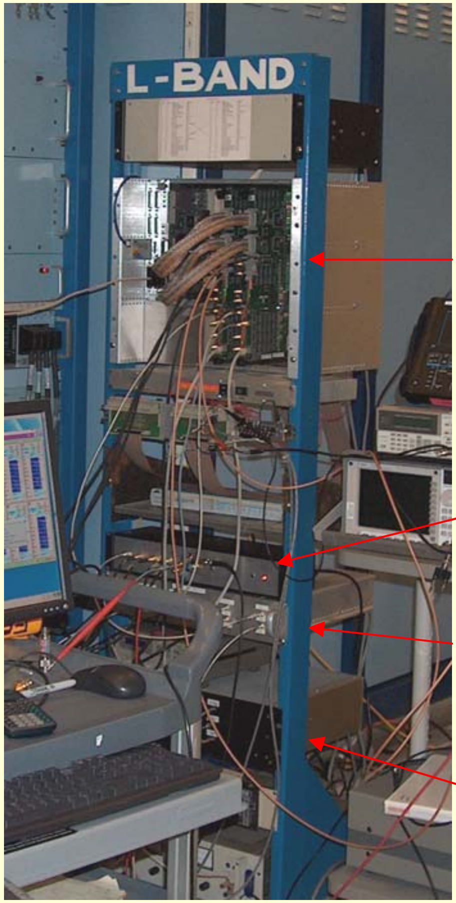


The FEL Test Station & LLRF Rack

FEL Zone 03

Blue: JLAB Supplied

Cornell LLRF



1st LLRF Test in FEL w/o Beam (November)

- Demonstrated acceptable phase and amplitude control with a ***digital LLRF controller***

  Phase: ~ 0.02 degrees rms. (Required 0.24 degrees rms.)

  Amplitude: ~ 3 x 10^{-4} rms. (Required 4.5 x 10^{-4} rms.)

- Demonstrated cavity recovery under strong Lorentz detuning (Fast turn on algorithm)

  0 to 12 MV/m in ~ 80 ms using Piezo Tuner (PZT)

- Demonstrated cavity recovery from Cryogenic crash (Resonance hunting algorithm)

  Recovered cavity from 30 kHz away from nominal 1497 MHz

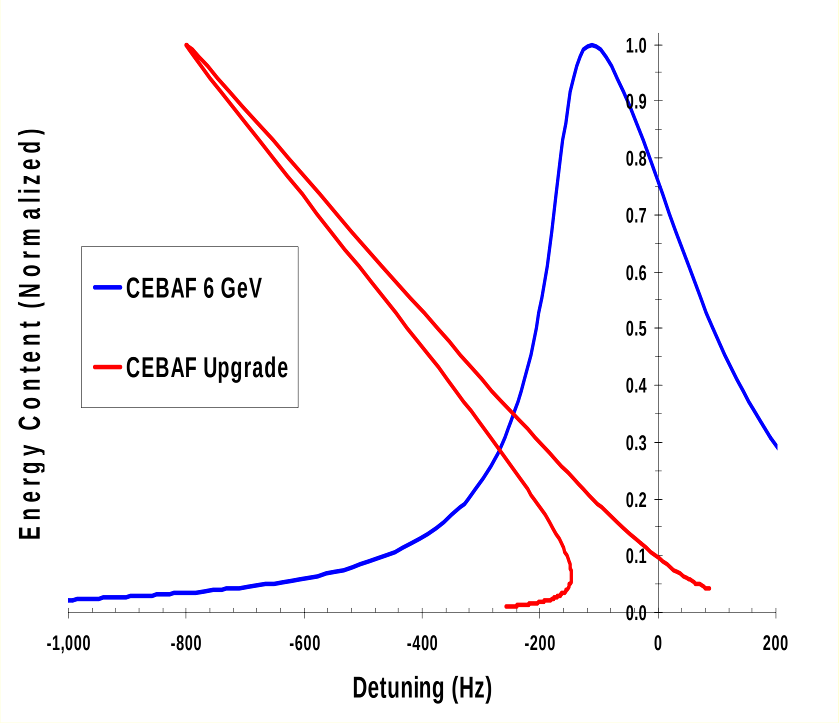
- Operated cavity at high Q_L ~ $1x10^8$

  LLRF system controlled field to required stability

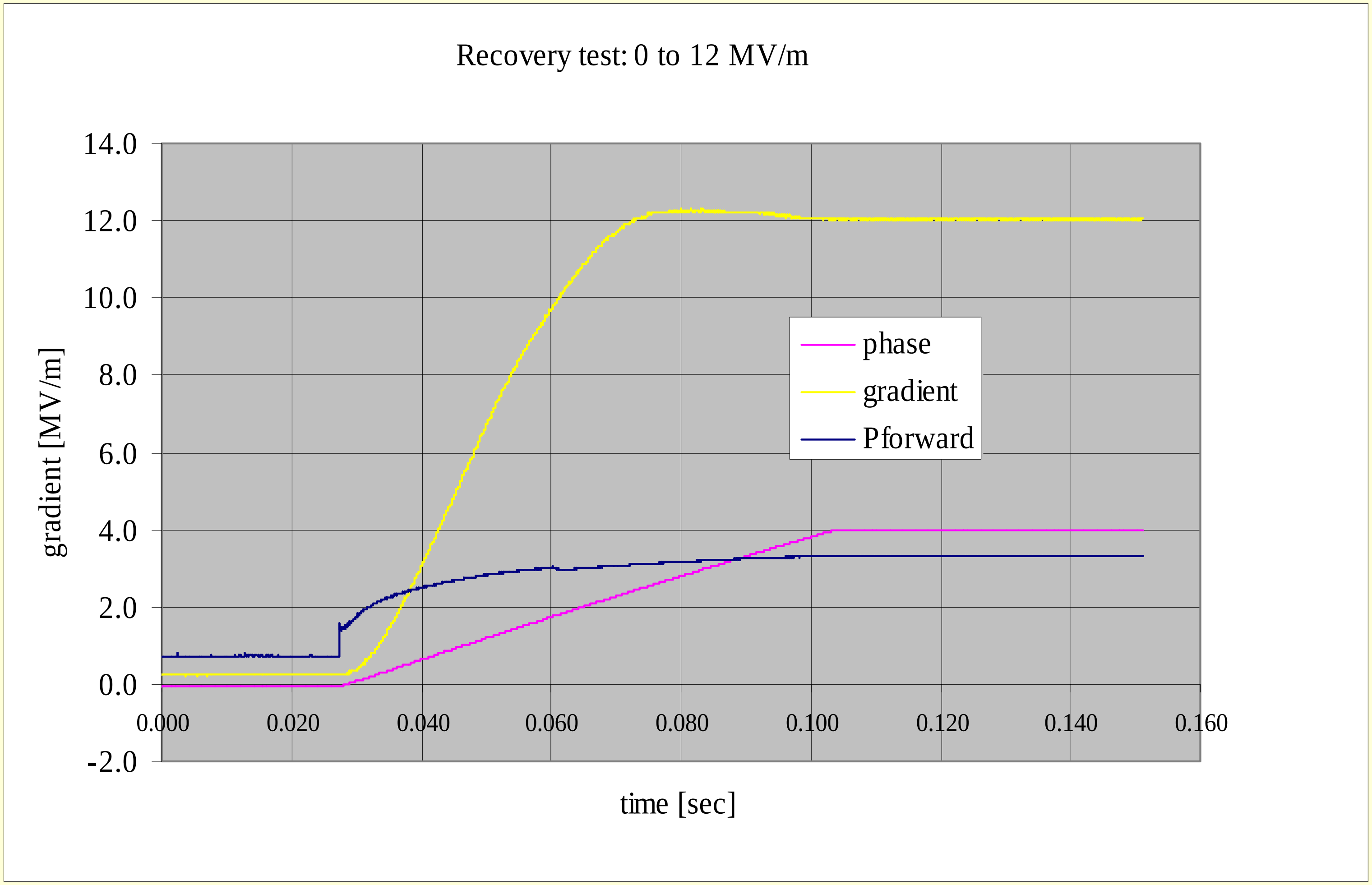
Why Lorentz Compensation is Needed

- For the CEBAF Upgrade ($Q_L = 2 \times 10^7$) if $K_L = 2$ then the frequency deflection at 20 MV/m (the required gradient) would be 800 Hz. This is greater than 10 cavity bandwidths away from nominal 1497 MHz!

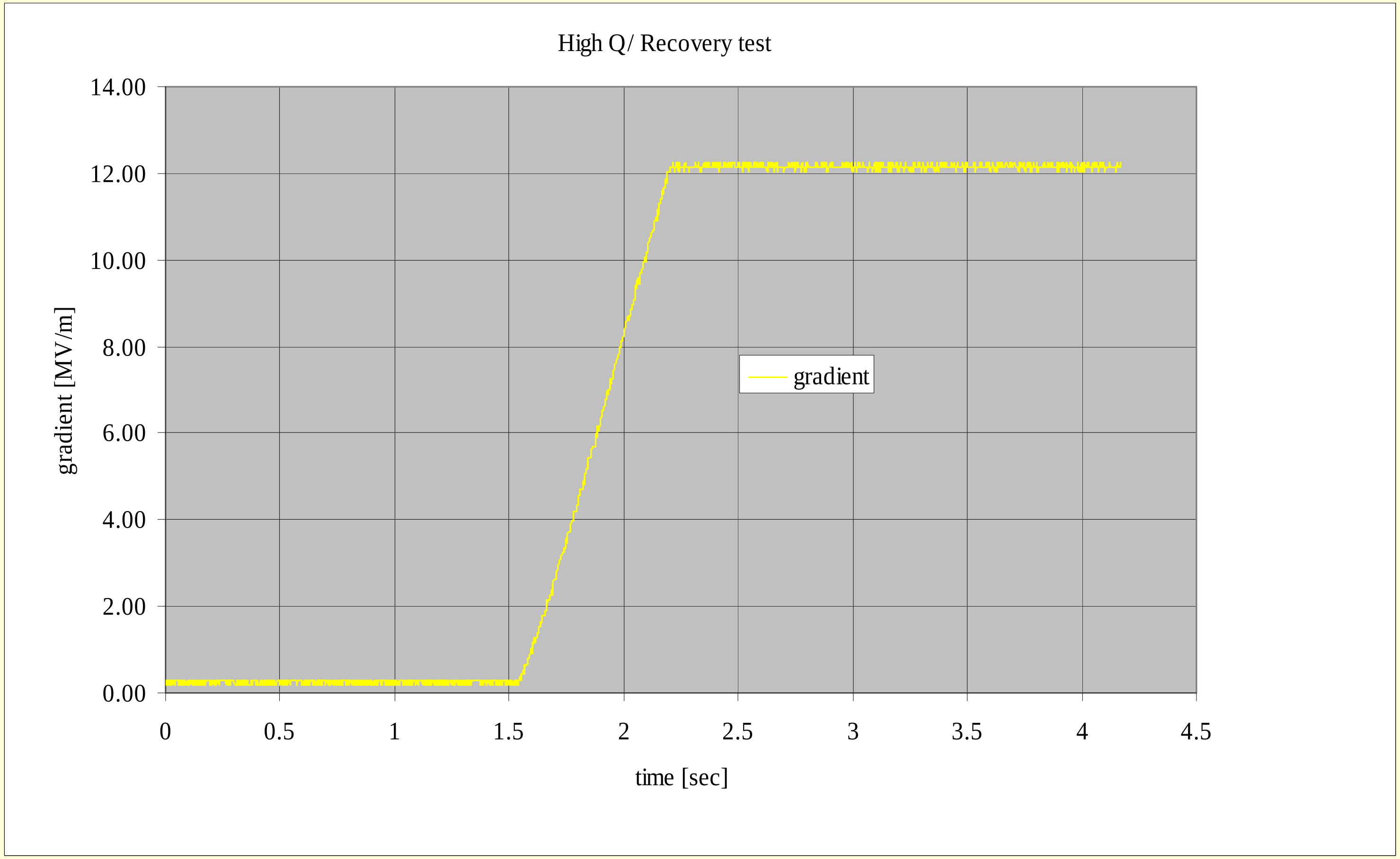
- Considering that at one bandwidth you need twice the power to operate, it is obvious why this can be a problem, especially for quick cavity recovery.



Cavity Recovery with $Q_L = 2x10^7$

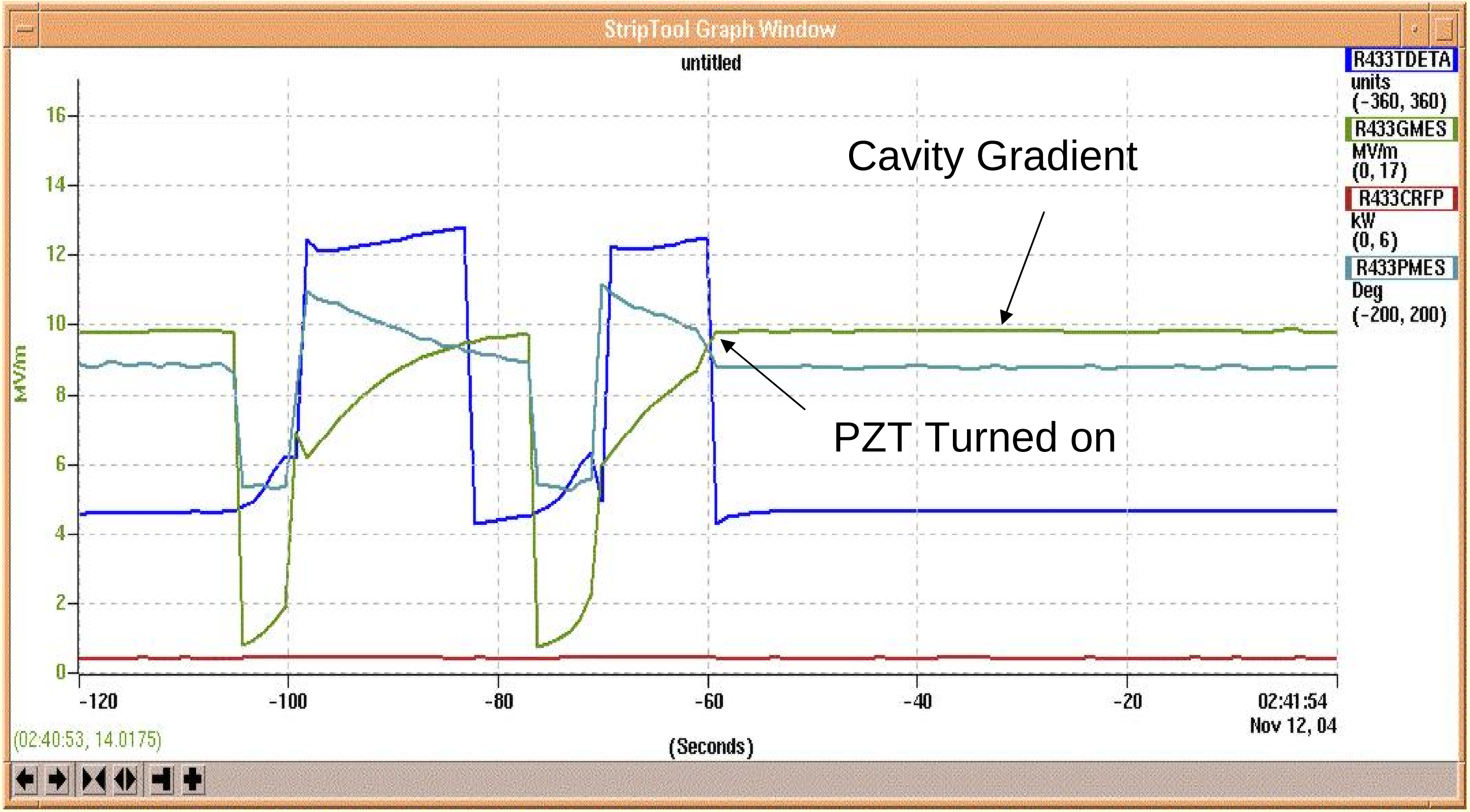


Cavity Recovery with $Q_L \sim 1 \times 10^8$



Gradient Stability w/o and w PZT

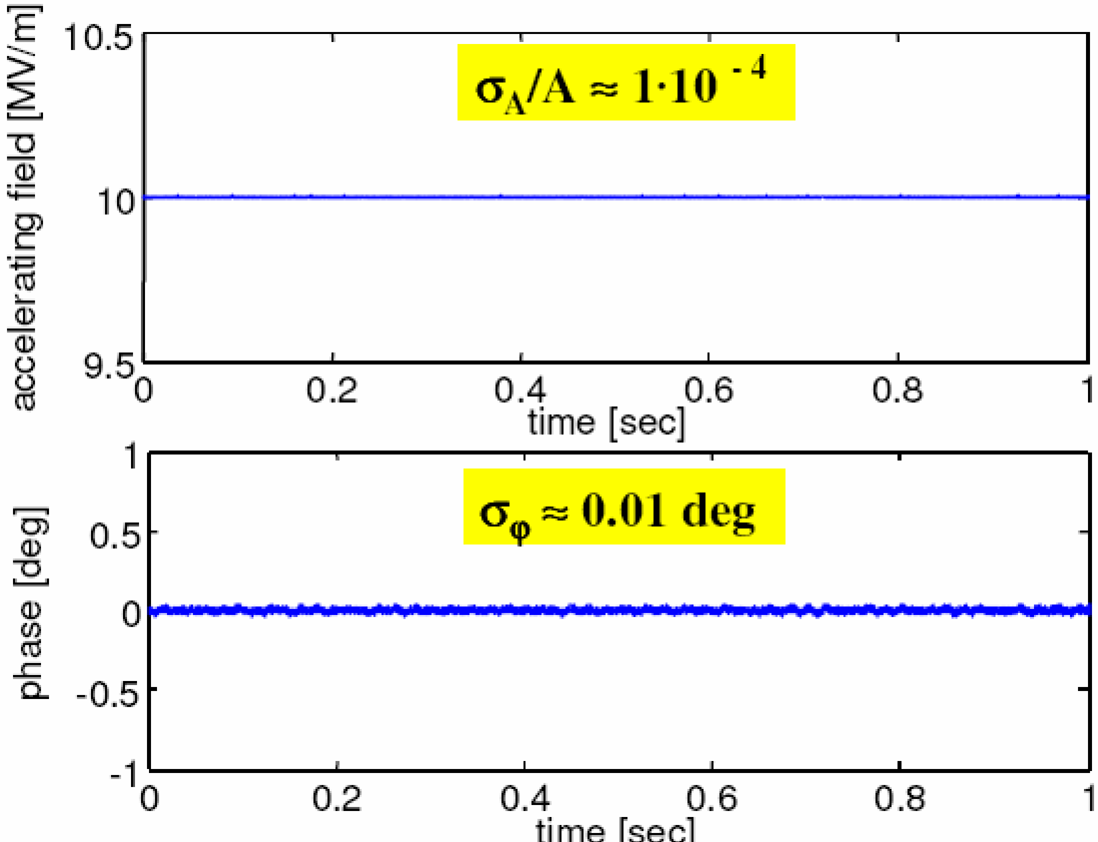
Note: there was no electronic feedback on and cavity Q_L was ~ $1x10^8$!



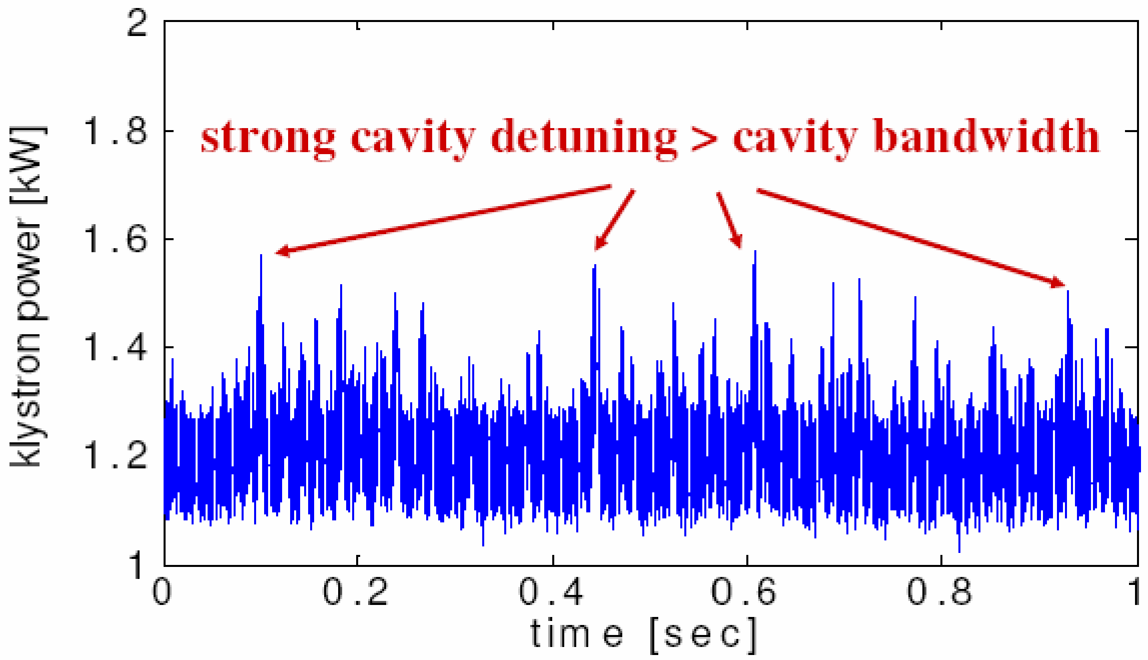
2^{nd} Test Run FEL & CEBAF (January)

- CEBAF Operations
  - Operated LLRF system (10 MV/m) at beam currents up to 400 uA
  - Saw no appreciable difference in field stability w/wo current
    - Amplitude: ~ 2×10^{-4} rms.
    - Phase: < ~ 0.05 degrees rms.
  - Ran production beam to Hall B during the test
  - Cavity Q_L was adjusted to 4.2×10^{7} making the system 5x more susceptible to the background microphonics.
- FEL Operations
  - Operated LLRF system (12.3 MV/m) at beam currents up to 5 mA in recirculated mode.
  - Tests Included:
    - Operation at Q_L's of 2×10^{7} and 1.2×10^{8}
    - Phasing +/-40 degrees off crest

Example: CEBAF Cavity with 200 μA Beam Current

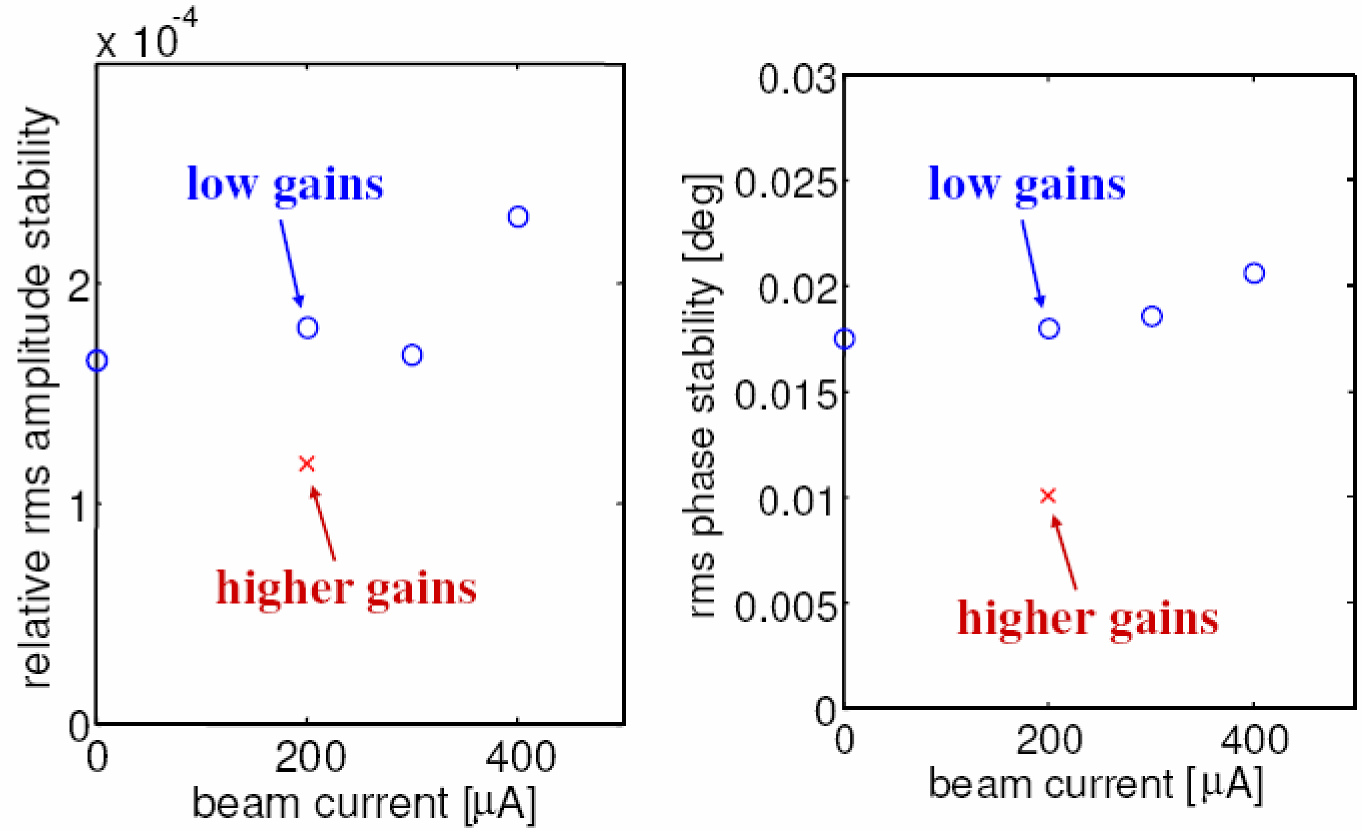


Example: CEBAF Cavity with 200 μA Beam Current



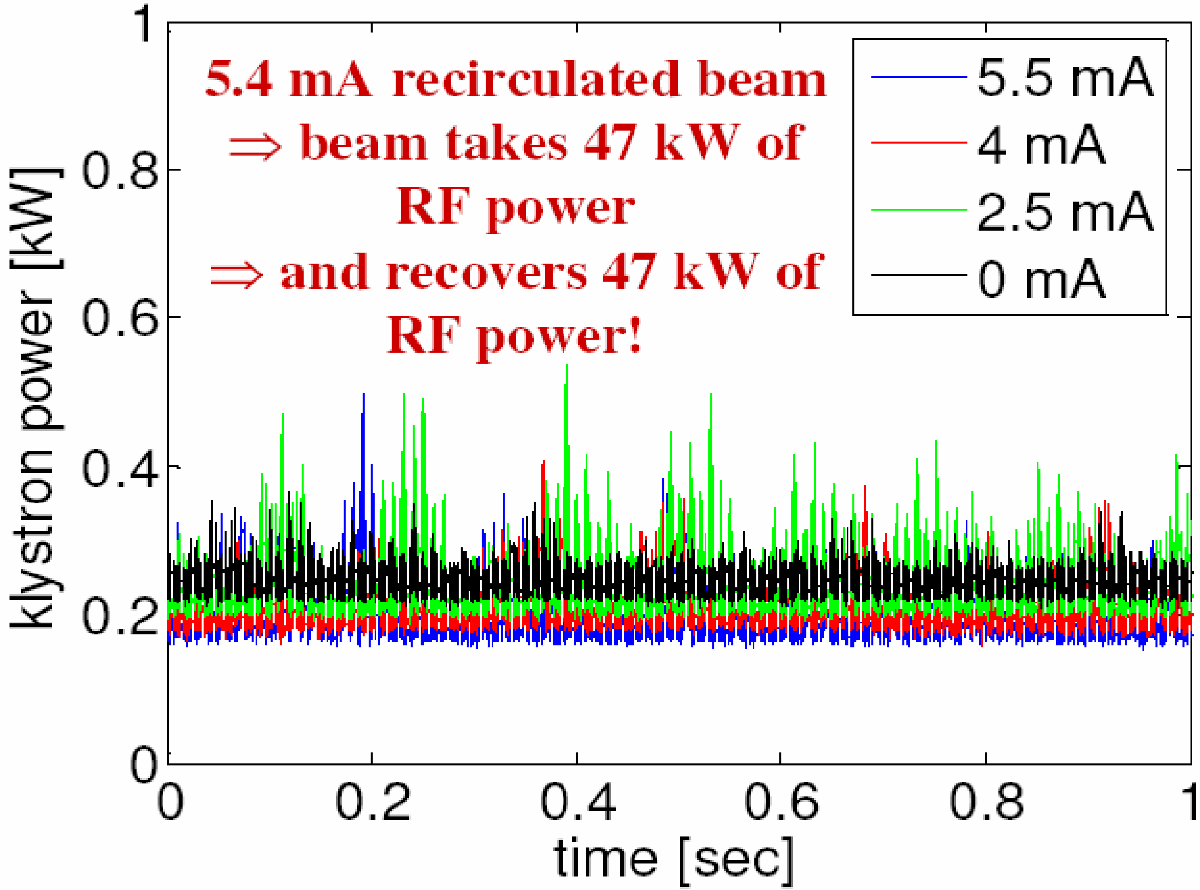
M. Liepe/Cornell

CEBAF Cavity



M. Liepe/Cornell

JLAB FEL: $Q_L = 1.2 \cdot 10^8$, 5 mA recirculating beam, 10 deg off-crest



The Team

MCC

The “Big” Screen

South Linac

Summary

- Cavity and beam testing was successful. The digital system controlled cavity field within specification through a variety of conditions (Q_L, w & w/o beam etc.).

  "*A digital LLRF system has no problem controlling cavity field even with the most horrendous microphonics.*"

- Both Labs benefited from the collaboration and we are discussing future tests.

Helpful assistance from the CEBAF & FEL operations staff
and beam time from Nuclear Physics made these tests possible