LLRF Strategies for Project-X

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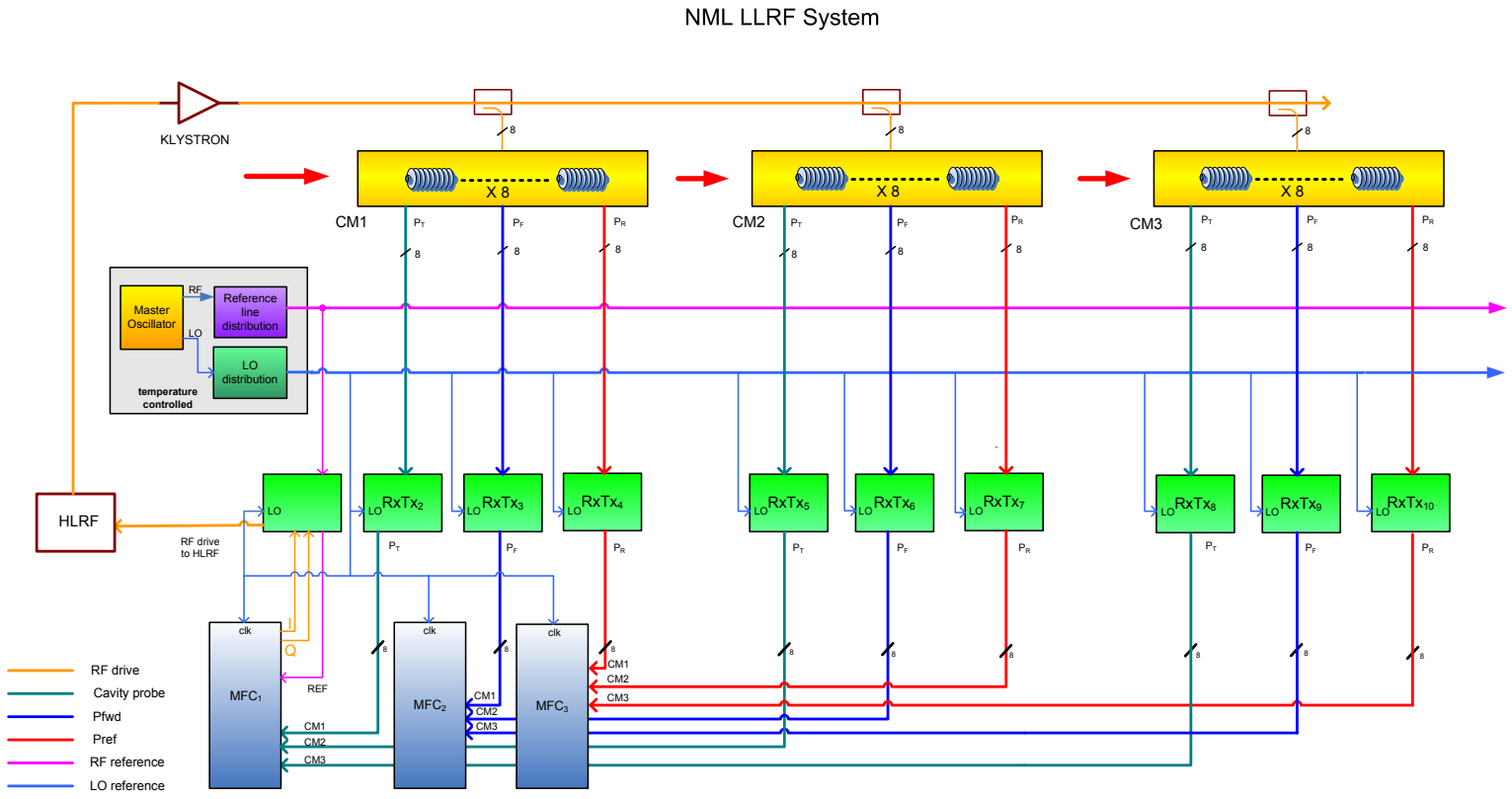
representing the LLRF team

Overview of Operational LLRF Systems

- ESECON Controllers (CD)
  - 1300/3900 MHz Horizontal Test Stand (HTS)
  - CC2 at NML
  - A0 Photo Injector Gun
  - A0 CC1
- MFC Controllers (AD)
  - HINS 325 MHz RFQ
  - HINS Horizontal Test Stand
  - 8 cavity Cryomodule 1 at NML
- Piezo Tuner Controllers (TD)
  - HTS
  - HINS HTS
  - 8 cavity Cryomodule 1 at NML

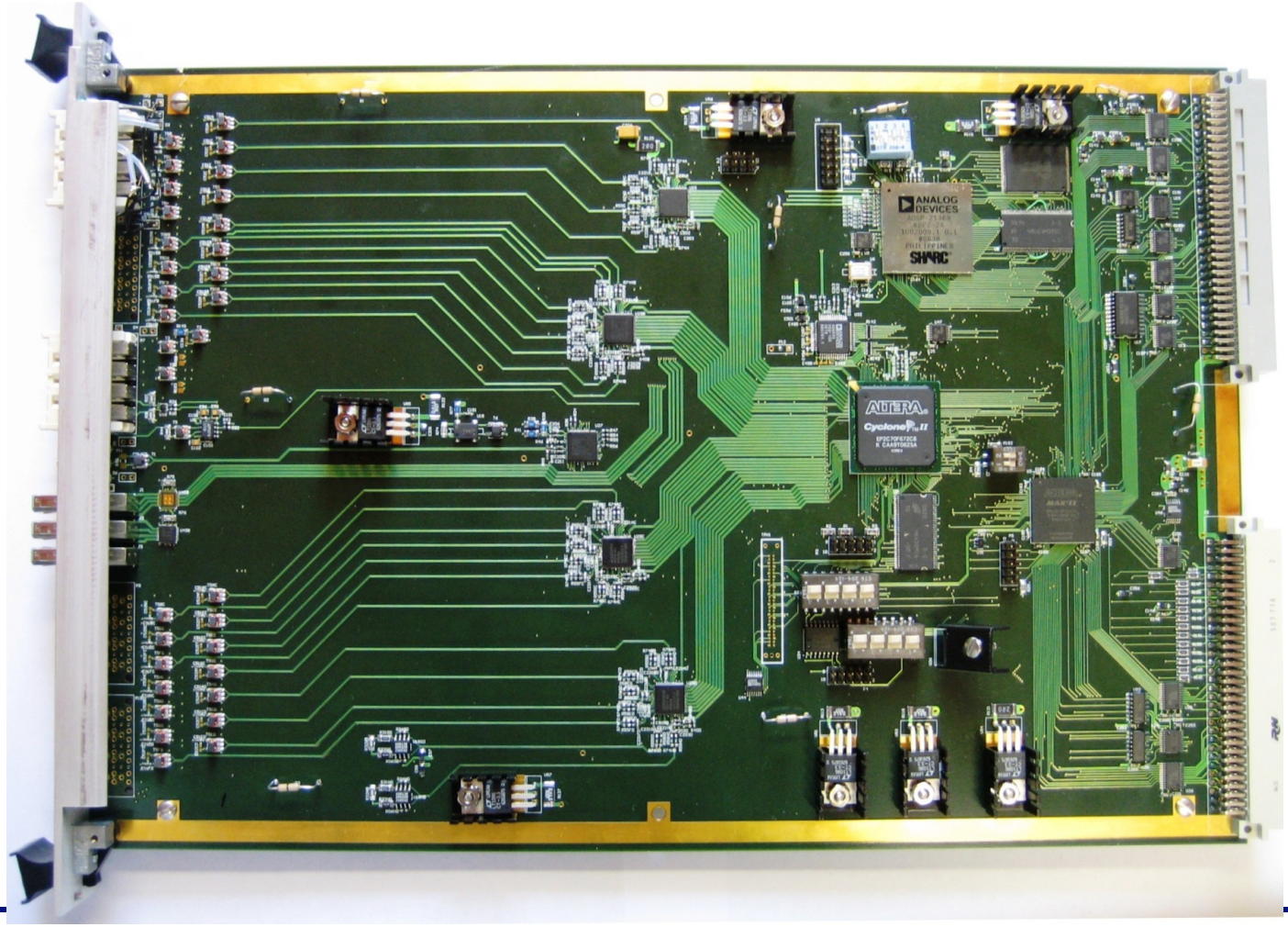
NML 3 Cryomodule RF Station



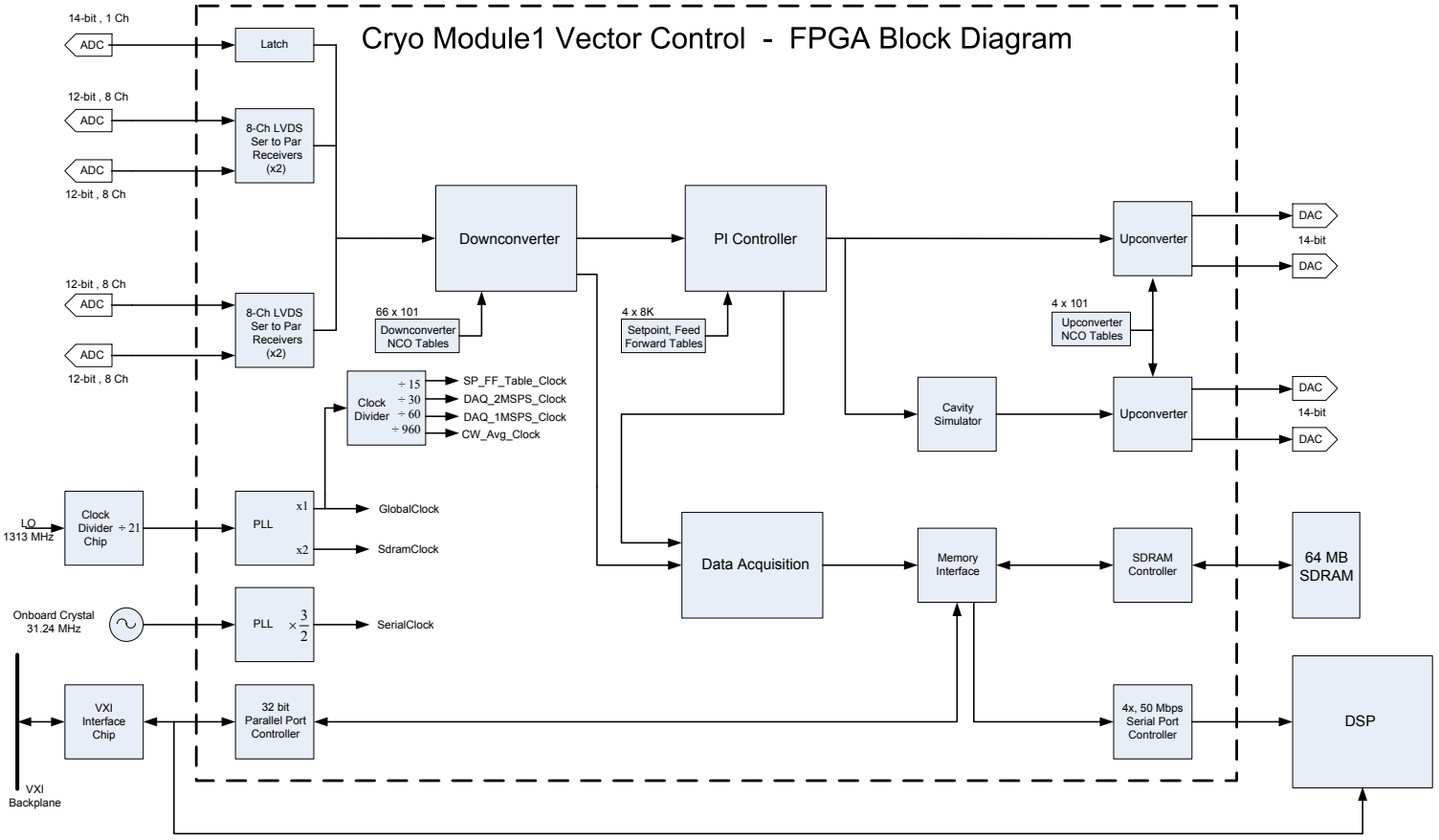
Project X

8 Channel Receiver / Up-converter

Multi-cavity Field Controller (MFC)



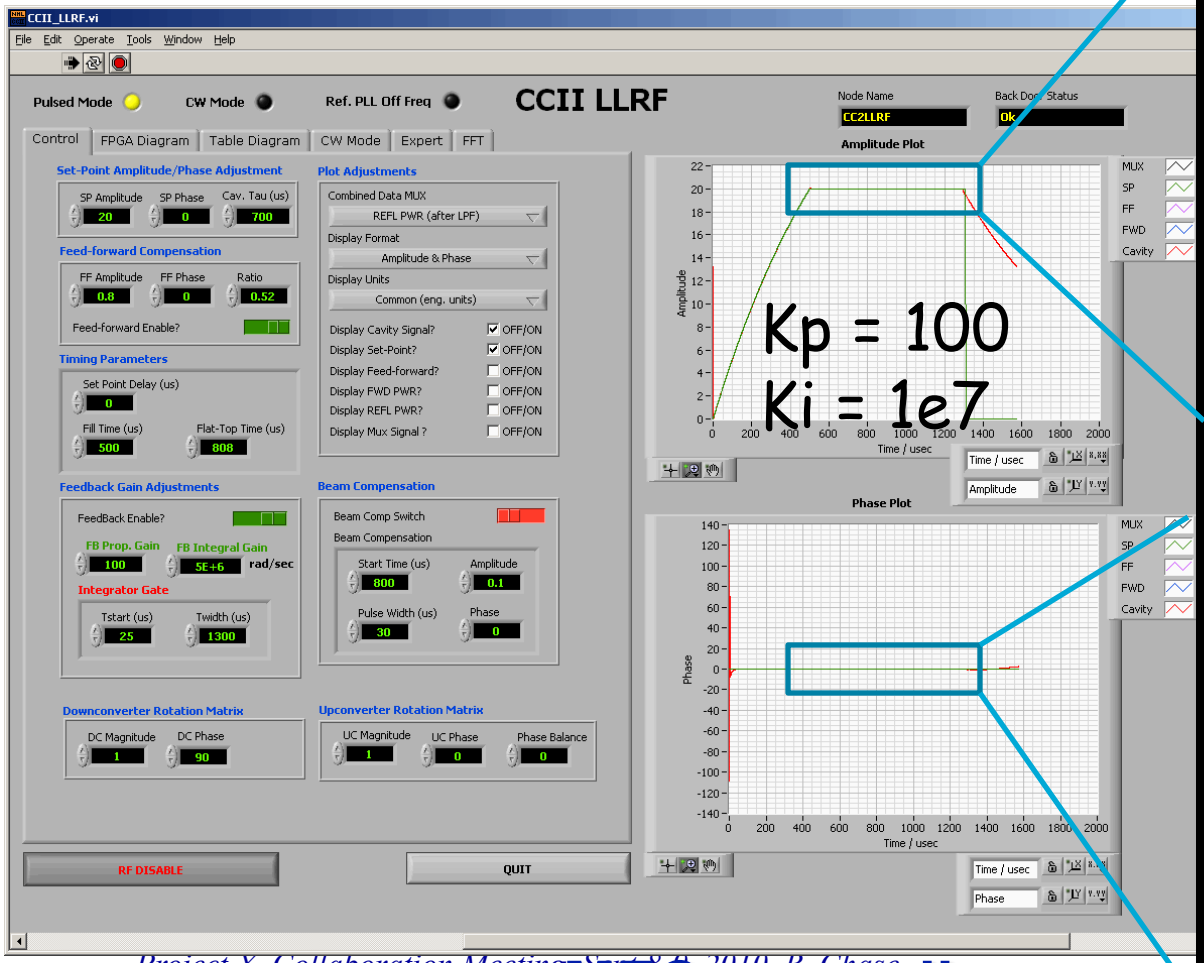
FPGA Block Diagram

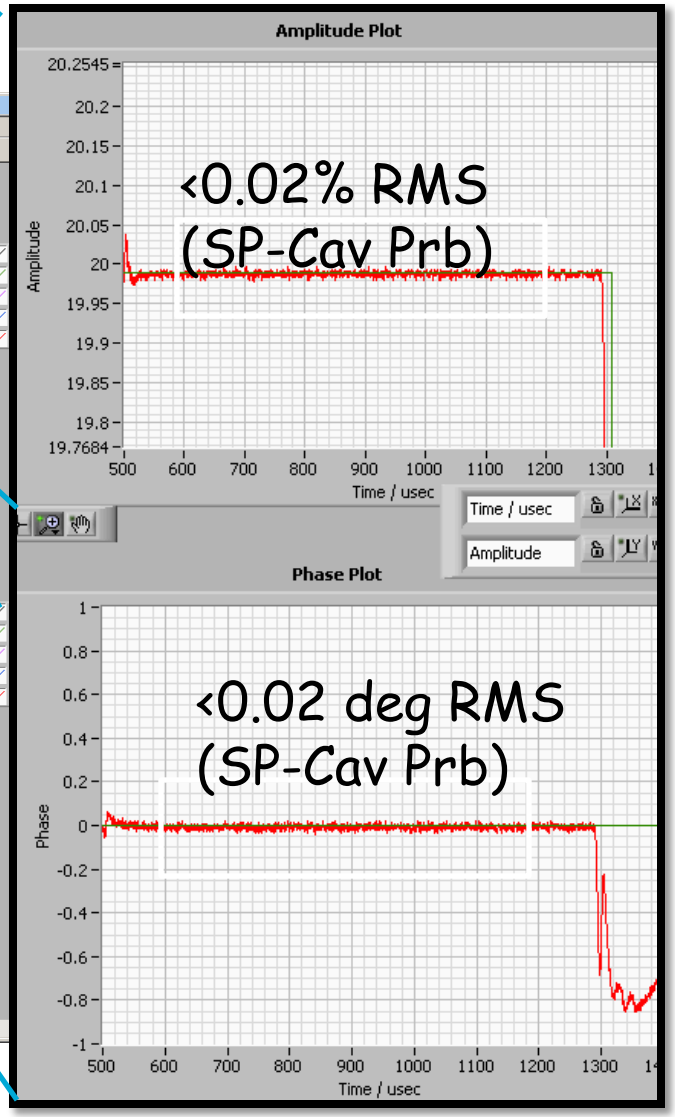


LLRF Installation at NML

Demonstrated control ability:
CCII at NML

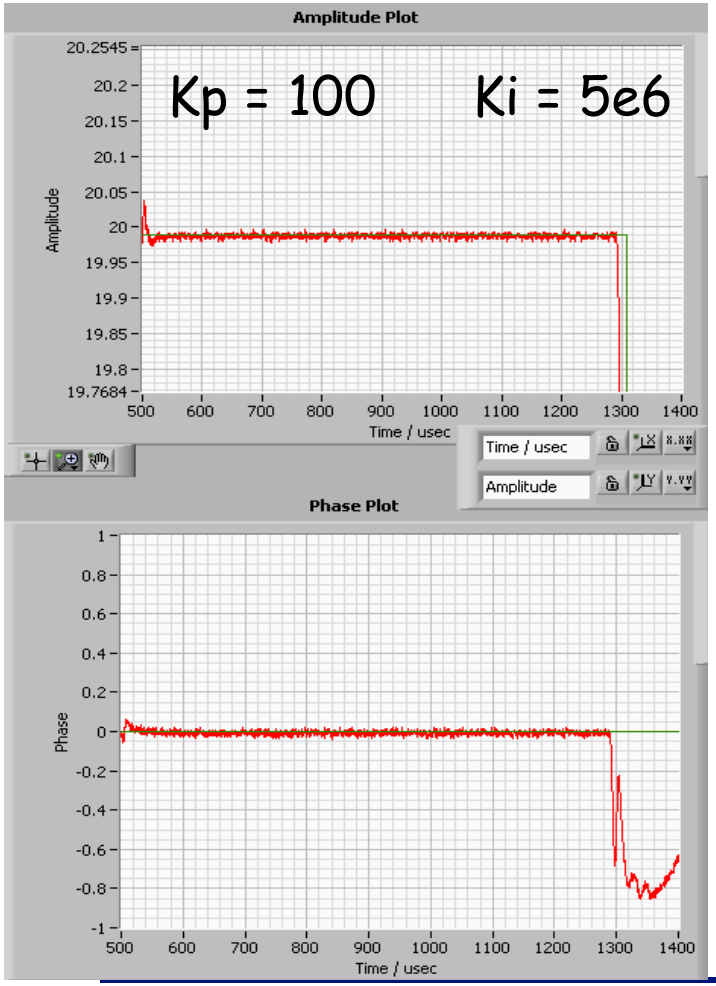
Good short term stability



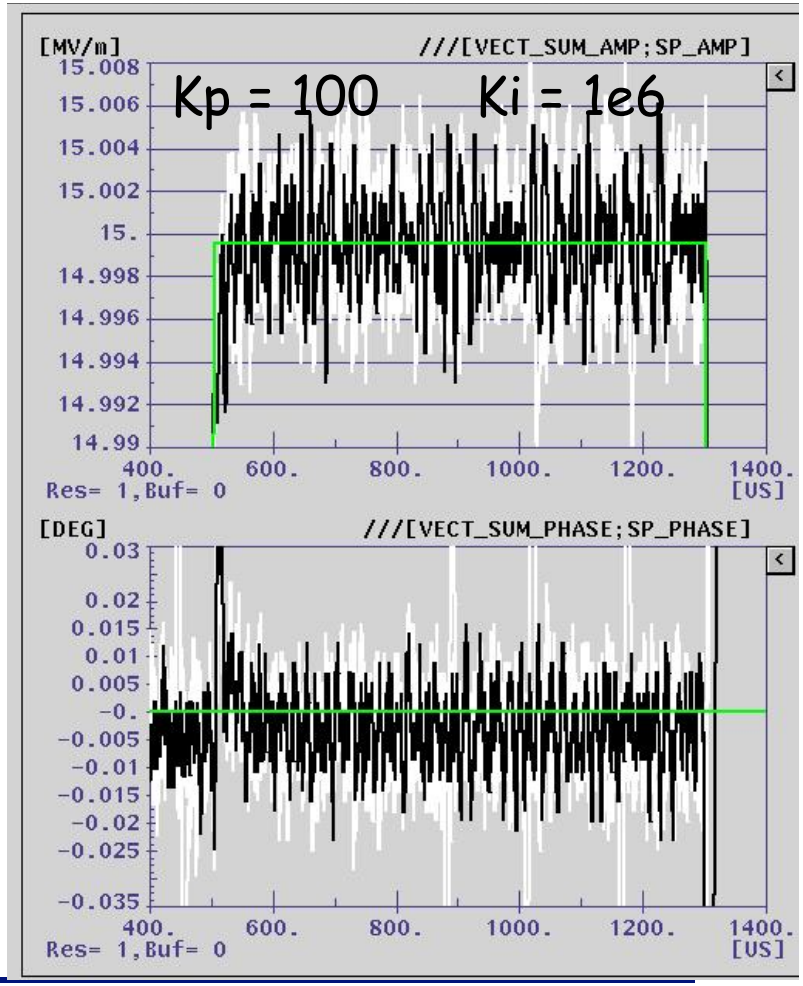


MFC controller

Current control ability: CCII at NML

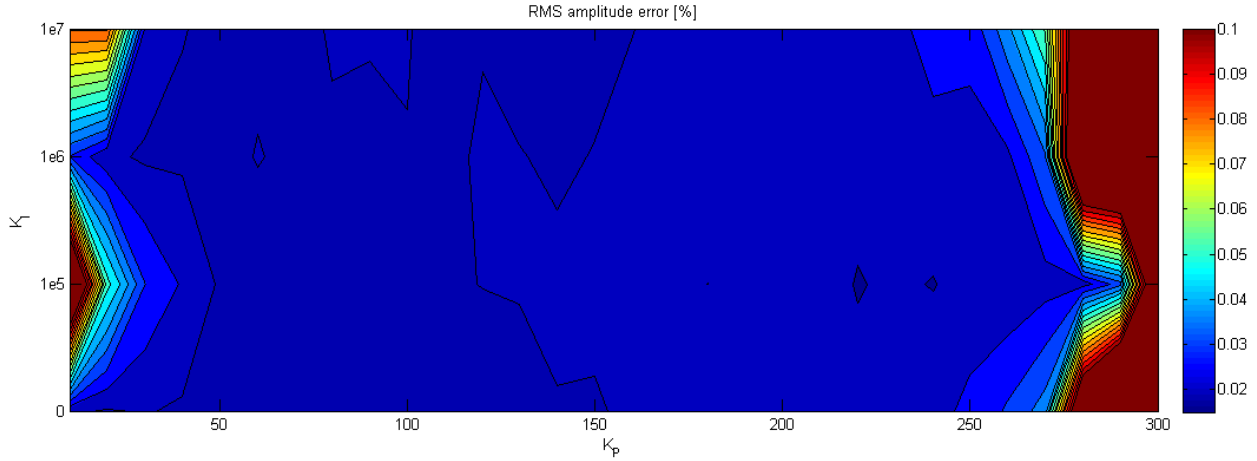


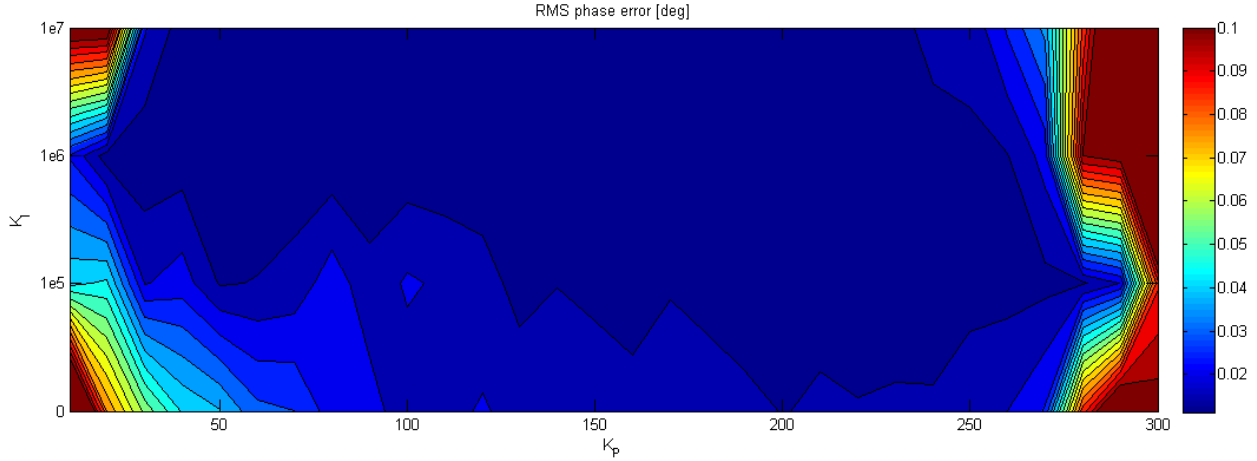
Amplitude:
+/- 0.04% pp
Phase:
+/- 0.02° pp



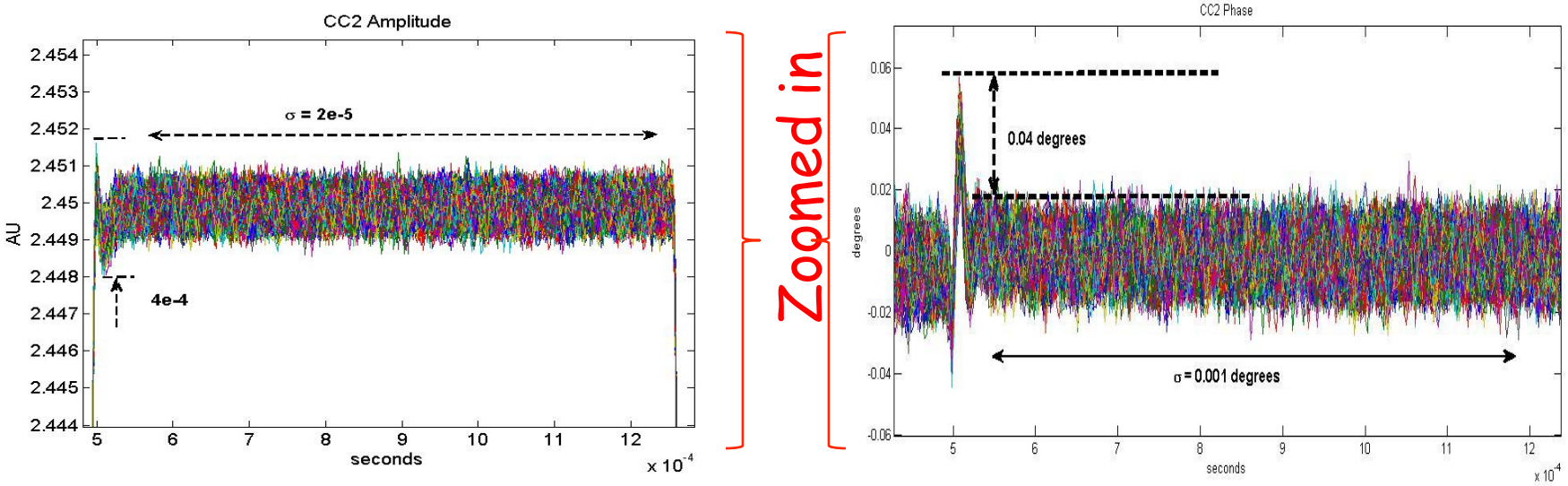
Phase and Amplitude Noise vs. Gain

Optimal gain
Pg = 100
Ig = 2e7



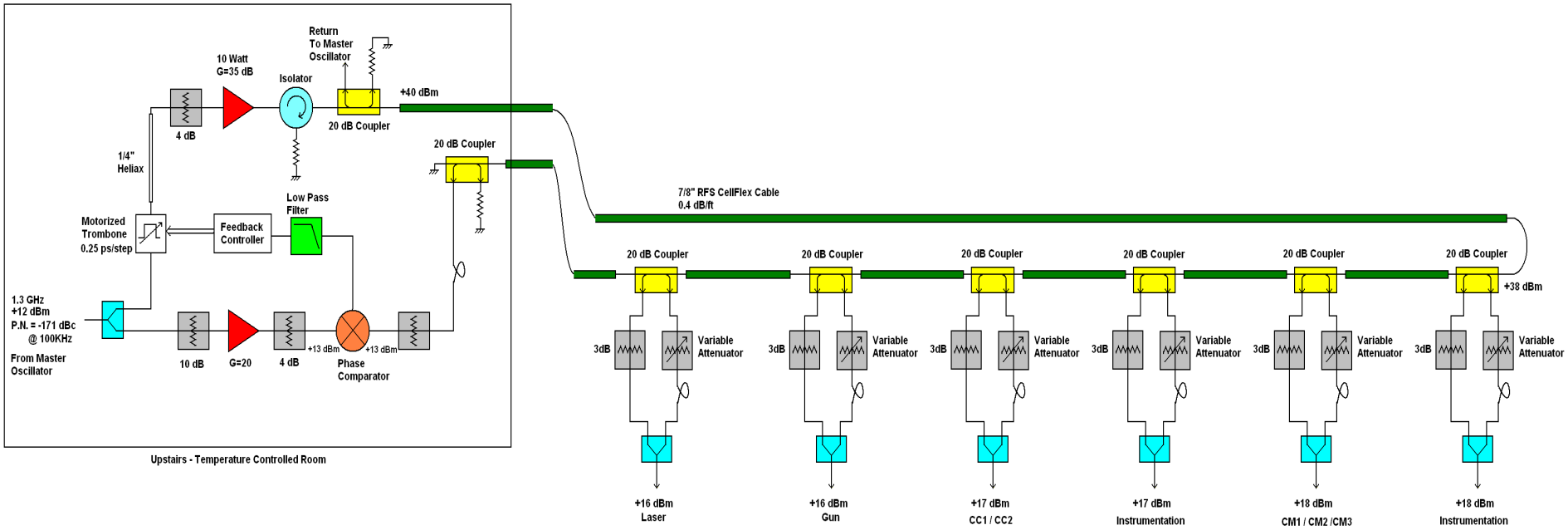


RF regulation with piezo ON



- The peak to peak overshoot is 4 x 10^{-4} for amplitude and 0.04 degrees for phase, that is 10 to 15 times smaller than with piezo OFF.
- The rms regulation for the rest of the flattop is smaller than 2 x 10^{-5} and 0.001 degrees respectively

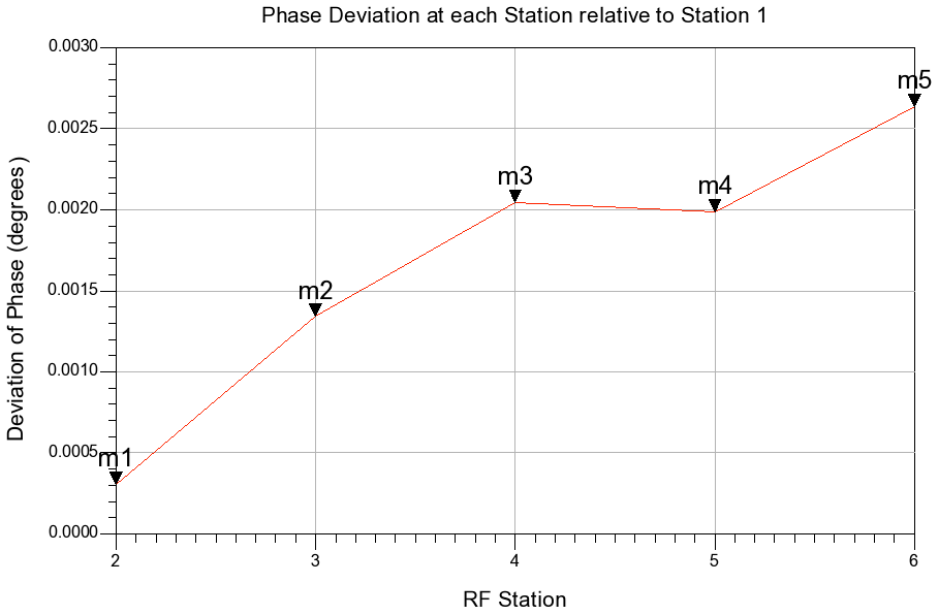
1.3 GHz NML Reference Line



1300 MHz Reference Line

NML 1300 MHz Reference Line Simulation

Ed Cullerton
5/27/10



m1
indep(m1)=2
plot_vs(St, Sn)=0.00031

m2
indep(m2)=3
plot_vs(St, Sn)=0.00134

m3
indep(m3)=4
plot_vs(St, Sn)=0.00205

m4
indep(m4)=5
plot_vs(St, Sn)=0.00199

m5
indep(m5)=6
plot_vs(St, Sn)=0.00264

The reference line is simulated 250 times with the random variations in line length.
The random line lengths are a gaussian distribution that represents a +/- 20 degree C change in temperature.
After each simulation, the error between stations is calculated, with station 1 as the reference
The standard deviation of the error between stations is calculated and shown in the plot above.

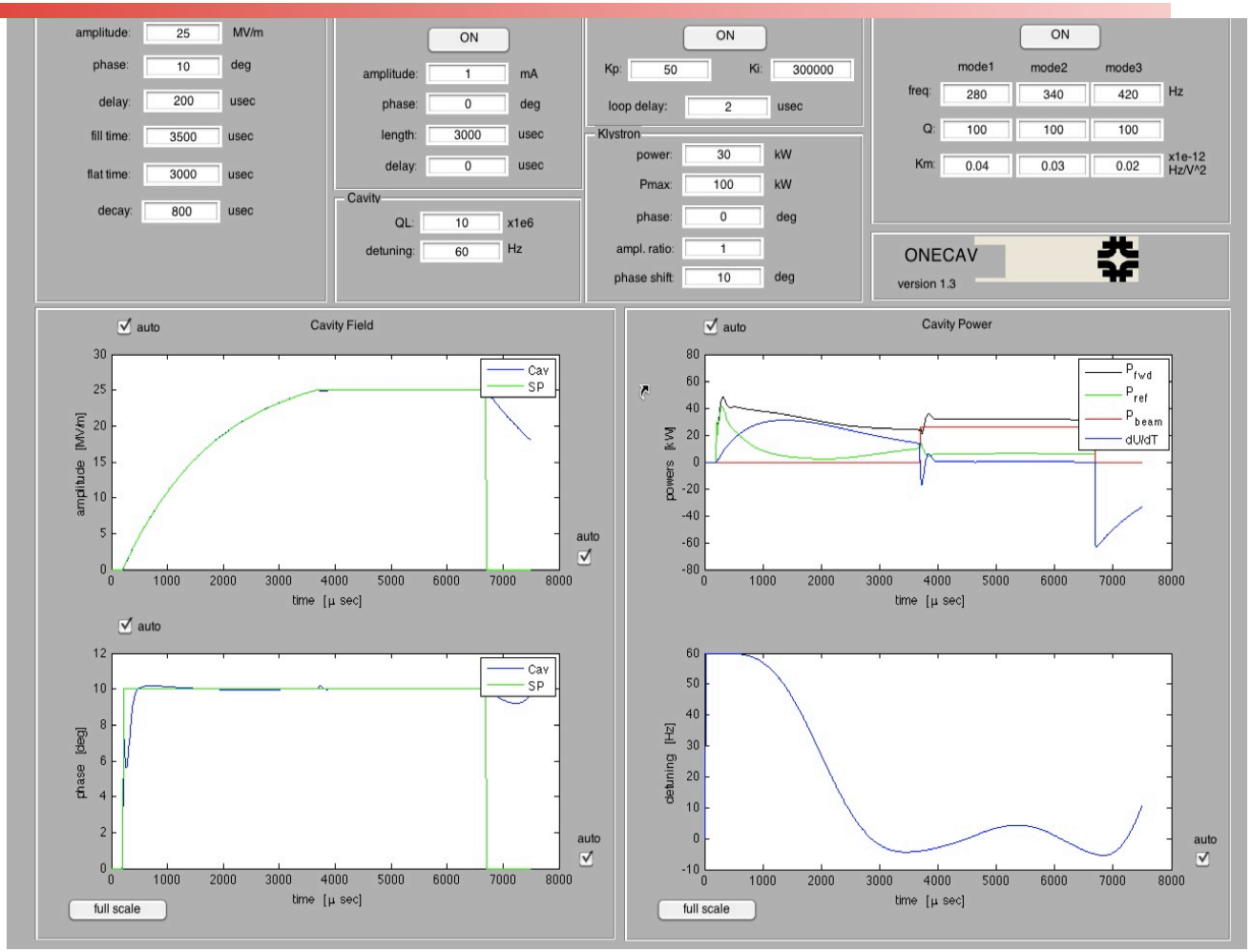
Project X RF Field Regulation Questions

- What will it take to regulate the CW linac with cavity bandwidths below 15 Hz?
  - A working group was set up to come up with a plan to address this
    - Led by G. Cancelo, R. Carcagno, B. Chase representing CD, TD, AD
    - See Warren Schappert's talk
  - Initial conclusions are that it will take detailed attention to cavity, cryomodule, cryogenics and piezo systems. Active feedback will be required.
  - How much power overhead will be required to limit regulation trips to a few times per day is still an open question and is dependent on the performance of other subsystems
- What are the issues with the pulsed linac?

Pulsed Cavity Simulation

Ib = 1mA
Q = 1E7
Fill = 3.5ms
FT = 3ms

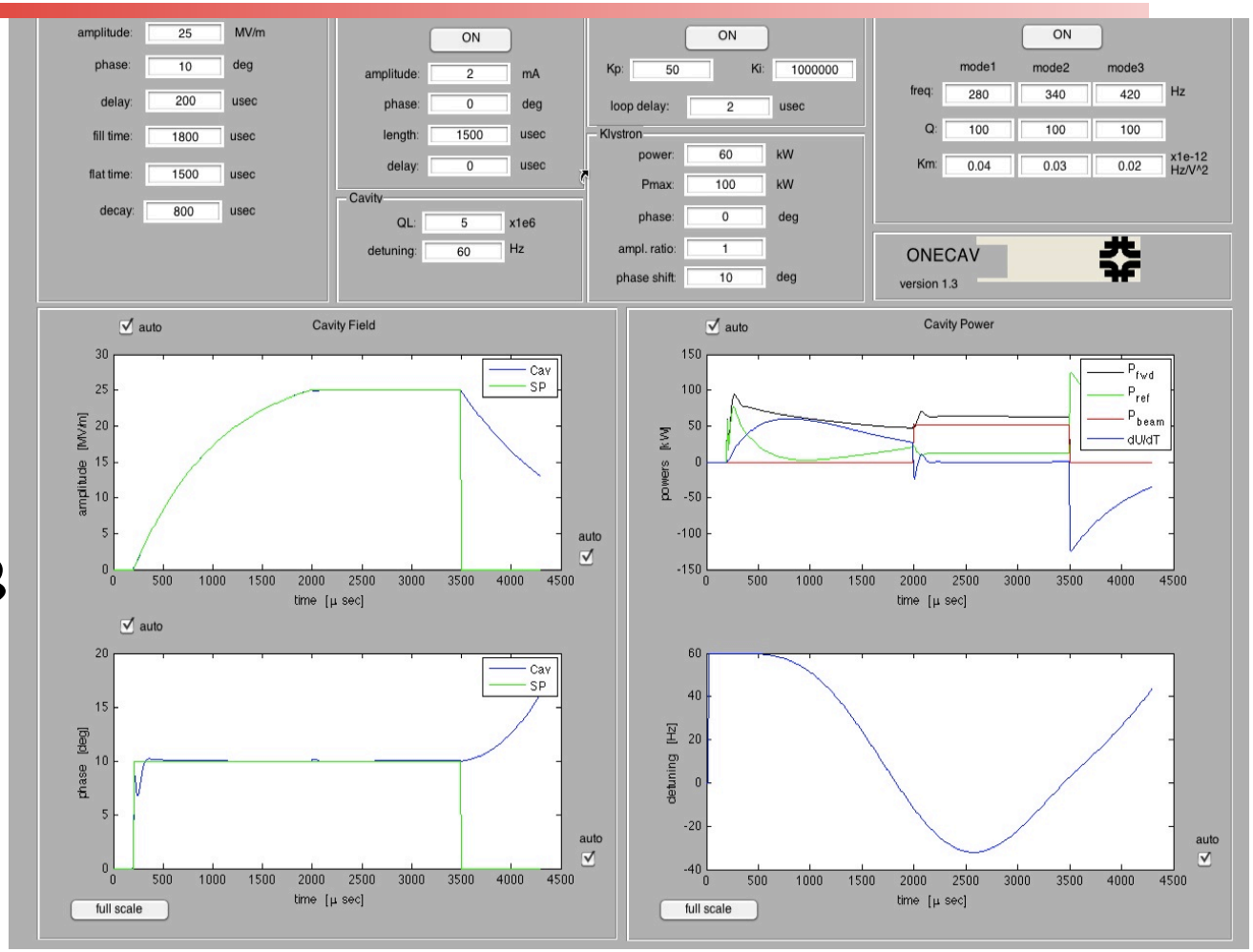
Microphonics reduced by 20 dB



Project X Pulsed Cavity Simulation

Ib = 2mA
Q = 5E6
Fill = 1.8ms
FT = 1.5ms

Microphonics reduced by 20 dB



Issues with multi-cavity/ single-klystron systems

- Problem has been studied and understood

  LFD, microphonics, cryo pressure, cavity tilts, vector sum calibration
- Solutions are being tested at FLASH, STS, and FNAL
- Special issues for Proj X
  - High Q operation
  - Long pulse operation
- Remaining considerations
  - optimizing cavity parameters
  - Reliability of piezo tuners
  - power headroom
  - form factor for controllers
  - Total error budget

Biggest control issue: resonance control

CW:

- microphonics - dominating factor
- worsen for high Q cavities, 1 mA beam current
- Piezo tuner feedback required
- SEL or cavity PLL loop required for turn on

Pulsed:

- Lorentz force detuning - dominating factor
- 2.5 msec looks to be worst case (studies in progress)
- Possibility of reducing effects with long fill times (zero dU/dt at injection time)
- Piezo tuner learning feedforward required

LLRF to Instrumentation Interfaces

- LLRF provides taps from the phase reference line
- LLRF provides beam structure information
- Instrumentation provides precision beam energy information
  - Time of flight
  - Spectrometer
  - Other?
- Instrumentation provides real-time beam current signal (with phase information)
  - Wall current monitor?

Beam Based Calibration

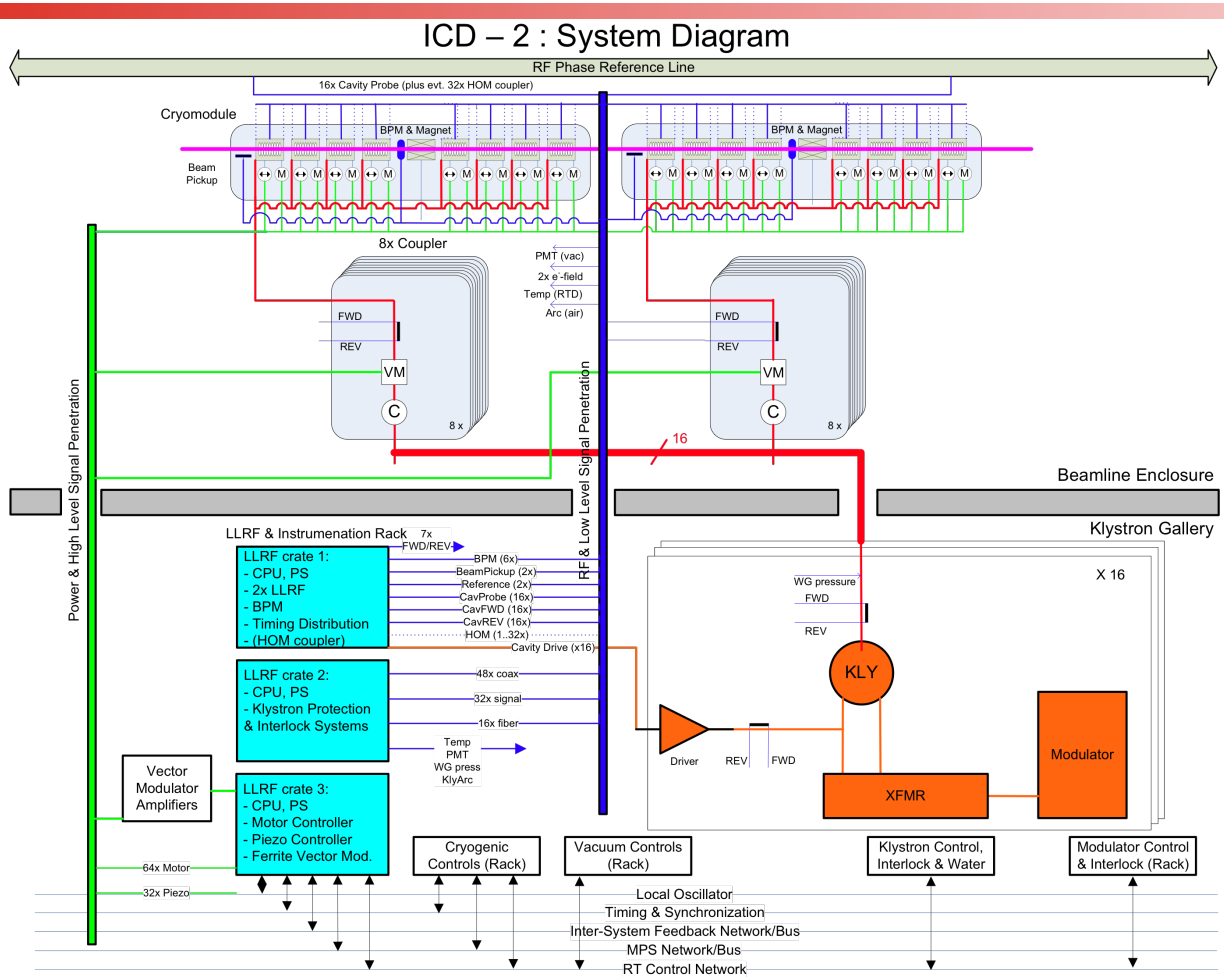
Approach 1: Using energy scan

- Need for a dispersive region to measure energy
- spectrometer / chicane
- Time of flight measurements

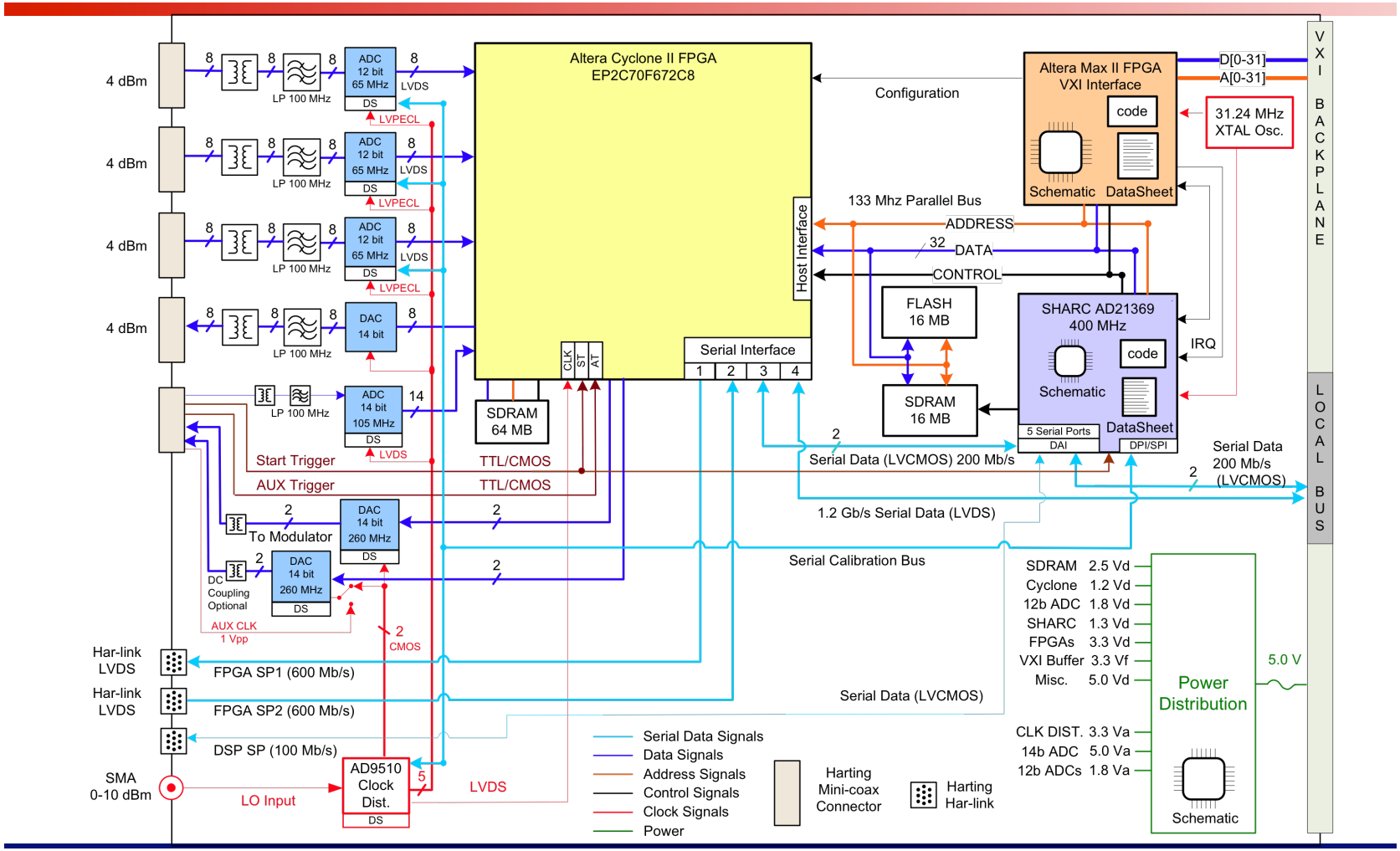
Approach 2: using cavity gradients

- Measuring beam loading on cavity gradient
- Need for short intensity beam pulses
- No experience with this yet (at FNAL)
- Possibility of exploring this at A0 and later at NML

LLRF for a Two Cryomodule RF Station



Project X Proposed 24 Channel Receiver 8 Channel Controller and Transmitter



Development Plans for 2011…

- Anticipated inputs from other efforts
  - Much development work will be done within the current HINS and NML projects. Current activities include A0, HTS, HINS, NML, ILC
  - FNAL and LBNL plan to collaborate on
    - Resonance control algorithm development
    - Calibration of the receiver chain
    - Error handling
    - Prepare design for CD-1 review
  - Ongoing collaboration with ANL
- Explore requirements for the Main Injector LLRF system (built in 1997)
- Modeling and simulation efforts
- Other collaboration efforts?