RF Commissioning

Andy Butterworth BE/RF

Thanks to: J. Tuckmantel, T. Linnecar, E. Montesinos, J. Molendijk, O. Brunner, P. Baudrenghien, L. Arnaudon, P. Maesen, F. Dubouchet, D. Valuch, D. Van Winkle, C. Rivetta and many others

Outline

- Introduction
- Equipment checkout
- Warm commissioning
- Cavity conditioning
- LLRF commissioning
- Data acquisition and diagnostic tools
- Controls
- Summary

Introduction

- Based on experience with LHC and LEP SC RF commissioning
- Assumptions:
  - Power plant derived from 800MHz IOT amplifier system currently being specified for the SPS Landau cavities
  - Low Level RF similar to the LHC 400MHz system
  - Controls derived from LHC and SPS RF and integrated into the LHC control system

Introduction: LHC and SPS systems

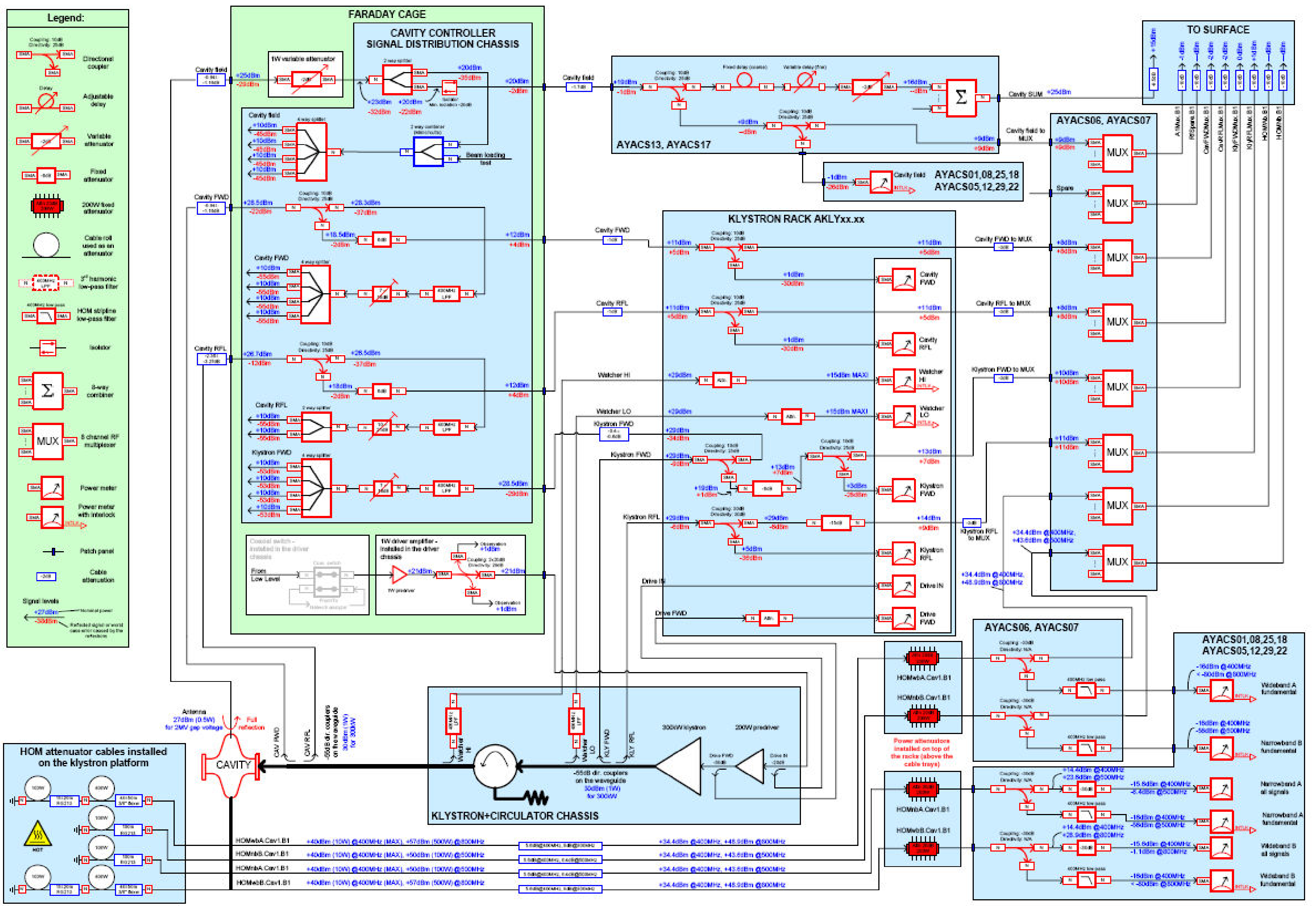
- LHC acceleration system: 16 SC cavities @ 400MHz
  - each driven by 300kW klystron
- Power system (slow controls) using PLCs
  - high voltage power supplies, klystrons, RF power distribution, cryostats and ancillary equipment
- Low Level system (Cavity servo controller and Beam Control)
  - digital, FPGA at 80 MS/s, DSP for turn-by-turn (11 kS/s)
  - in parallel with fast analog for transient beamloading
  - 2 VME crates per cavity
- SPS Landau cavity system: 2 travelling wave cavities @800 MHz
  - each driven by 4 x 60kW IOT amplifiers (currently in procurement)

Commissioning: Equipment check-out

- RF and control cables: individual testing
  - reflection (short circuit) for cable identification and initial validation
  - transmission for phase sensitive signals
  - reflection tests with termination to assess damage, faulty connectors etc.
  - > 100 cables per cavity in LHC...
- Control racks equipped and tested in lab
  - after installation, signals test up to PLC control level
- Data exchange with vacuum, power converters, cryogenics
- Interlock system: individual test and validation, access, radioprotection

LHC ACS RF distribution scheme

7.2.2008



D. Valuch

Warm commissioning: amplifier

- Initial commissioning of power amplifiers done during reception tests

Technical Specification for
the Power Amplifier for the SPS 801 MHz RF system

12.8 Site acceptance tests

- 48 hour full power operational test, during which the frequency, phase, linearity, output power, stability and efficiency will be monitored.
- Measurement of gain.
- Output voltage and current.
- Output voltage ripple at specified frequency ranges.
- Power factor at full output.
- Harmonic injection into the mains supply at selected levels including full output.
- Time taken to switch to zero output on receipt of the 'fast switch-off' command.
- Energy deposited into a short-circuited output.
- Effectiveness of internal protection circuits.
- Temperature rise during 'soak' operation at full power of transformers, inductors and semi-conductors.
- Compliance with electromagnetic noise requirements (includes RF, x-rays).
- Compliance with acoustic noise requirements.
- Purity of IOT RF spectrum.
- Thermal run.
- Reproducibility check.
- Harmonic analysis.
- Inrush current measurement.
- Power factor correction test.
- Mains regulation tests.
- Line regulation tests.
- High voltage DC test to be carried out at an over-voltage to be agreed.
- Power Amplifier RF tests.
- etc...

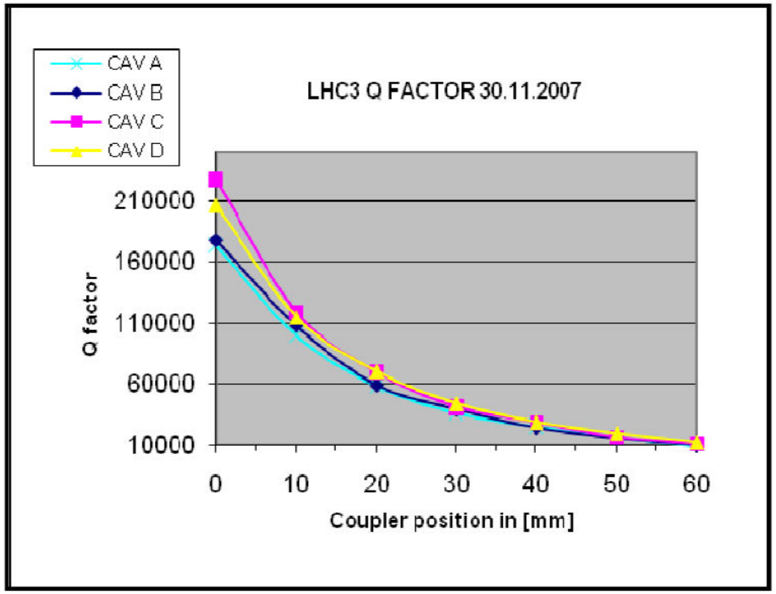
Warm commissioning

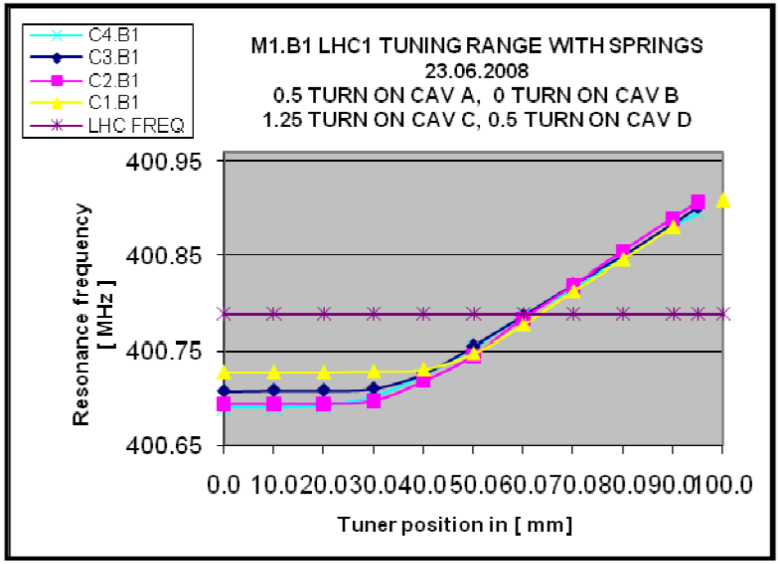
- ... of complete power system with RF
  - waveguides short-circuited to isolate cavities
- HV and RF interlocks: individual tests
  - water flows, WG arc detectors etc
- Bring amplifier slowly to full RF power
  - calibration of power measurements (directional couplers) and attenuators for signal distribution
  - test and adjust circulator and load
- Long-term power test (100 hours)

If SPS type 800MHz power plant is used, most of the procedures will already be well defined

Low power measurements

- ... on cold cavities
- to confirm measurements from test stand
  - loaded Q
  - tuning range
- using resonant frequency and bandwidth measurements with network analyser
  - drive signal injected via coaxial transition on waveguide
  - return signal from cavity field measurement antenna





We can now remove the short circuit and proceed with high power testing...

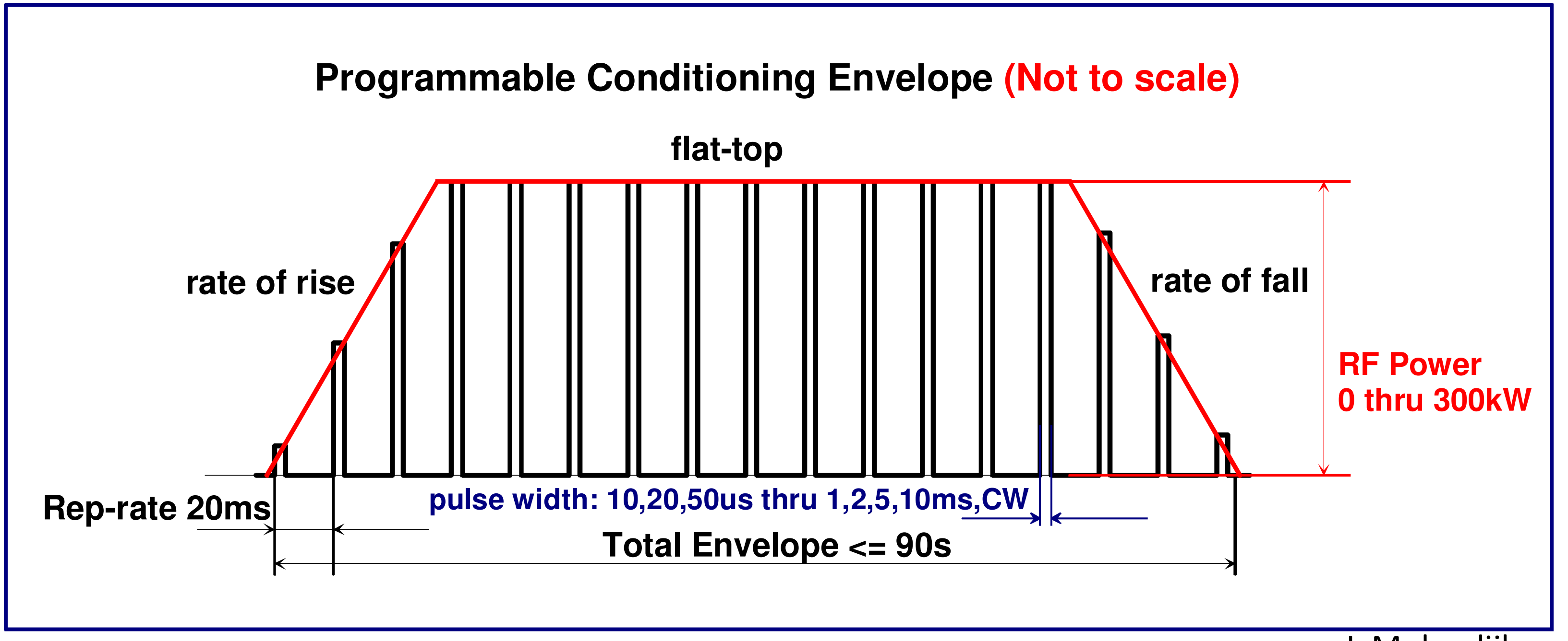
High power tests: cavity conditioning

- Run cavity up to full power and voltage while observing vacuum and cavity field emission
- Vacuum
  - in practice, we are looking at the vacuum in the main input coupler
  - difficult to see outgassing in cavity (pumped by the cold surfaces)
- Field emission in the cavity
  - shows as He pressure excursions → RF trips
  - in LEP, feedback on X-ray emission was possible (total cryomodule voltage of 40MV)
  - radiation not detectable in LHC (single cavity, 2MV)

- The input couplers are equipped with a DC bias voltage to suppress multipacting during normal operation: this is switched OFF during conditioning

Cavity conditioning method

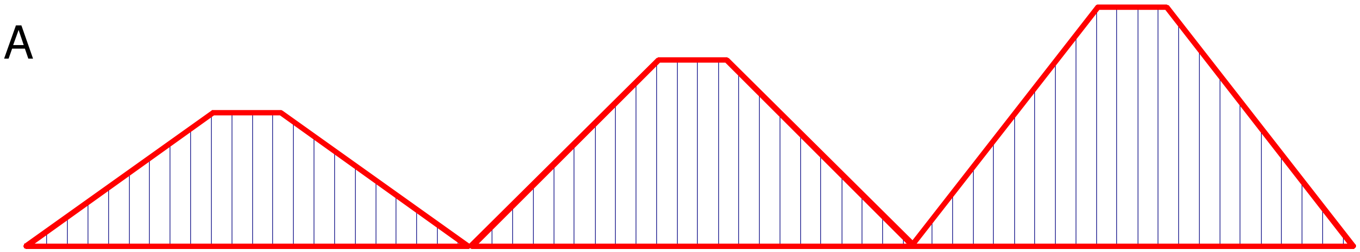
- Pulsed FM modulated RF power is applied to the cavity in a controlled way with vacuum feedback
- Two loops
  - Fast vacuum feedback
  - Slow computer controlled loop to generate AM envelope and increase field and power as conditioning progresses (pulse to pulse at 50Hz)



J. Molendijk

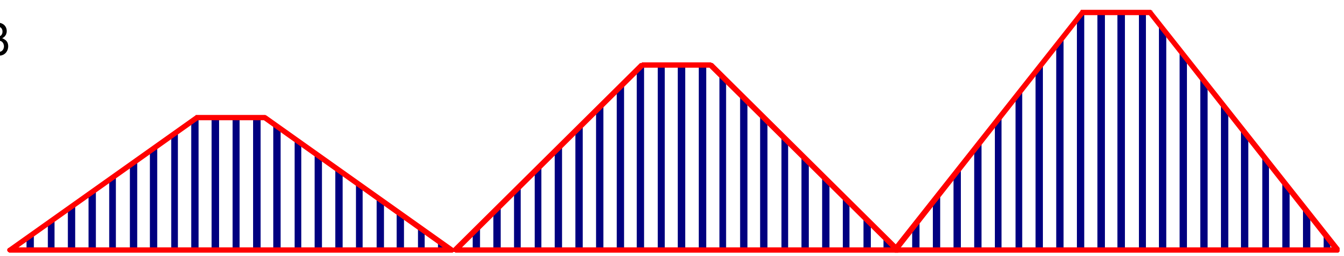
Cavity conditioning method

A



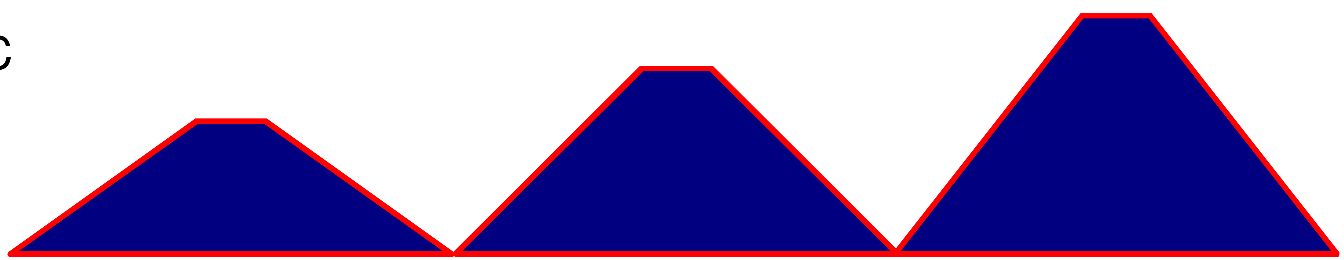
Increase Power using a fixed pulsewidth until Pmax is reached.

B



Increase Pulse width and proceed with the Power as above.

C



Finish with CW and proceed with the Power as above.

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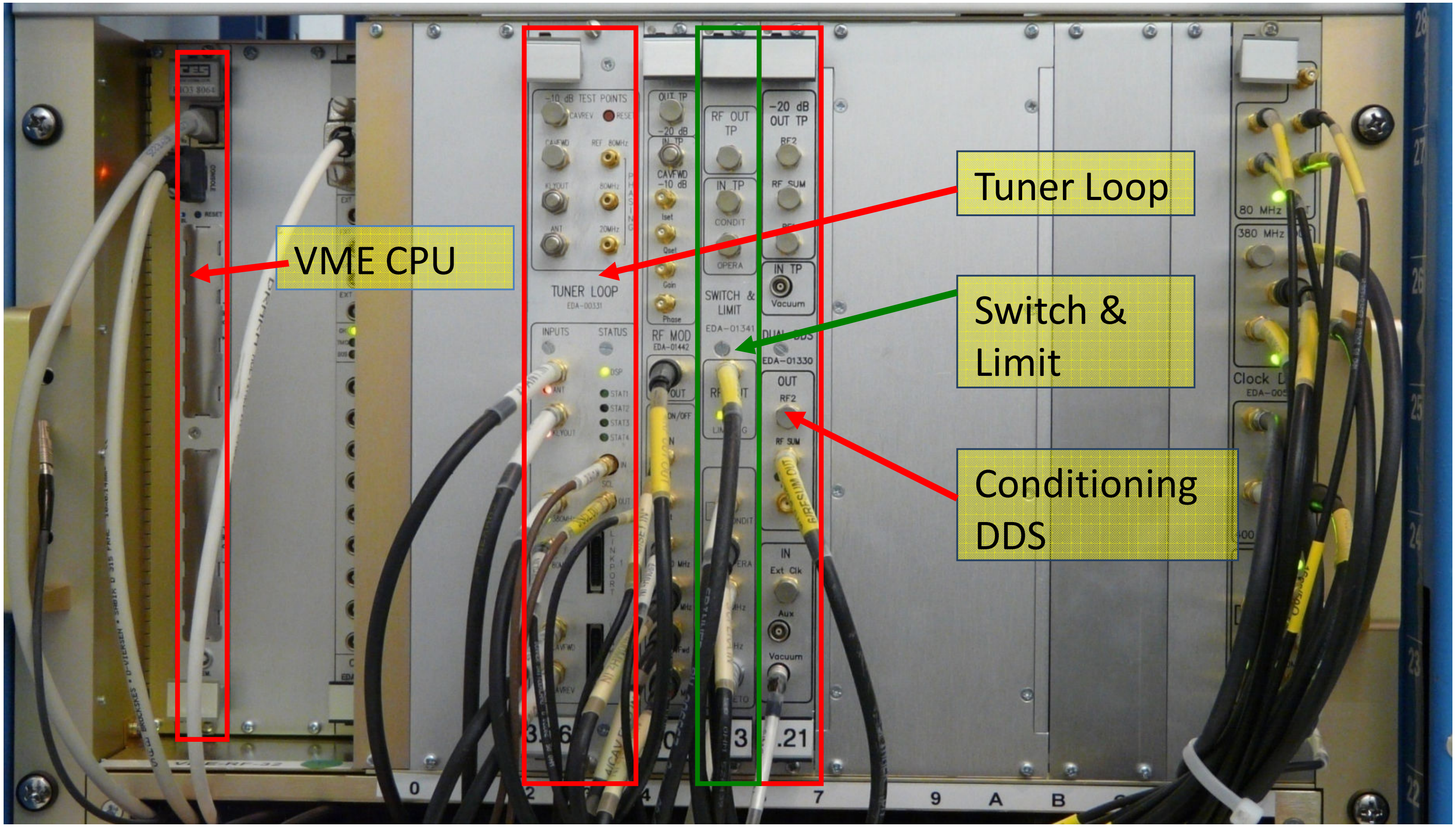
Conditioning: Implementation

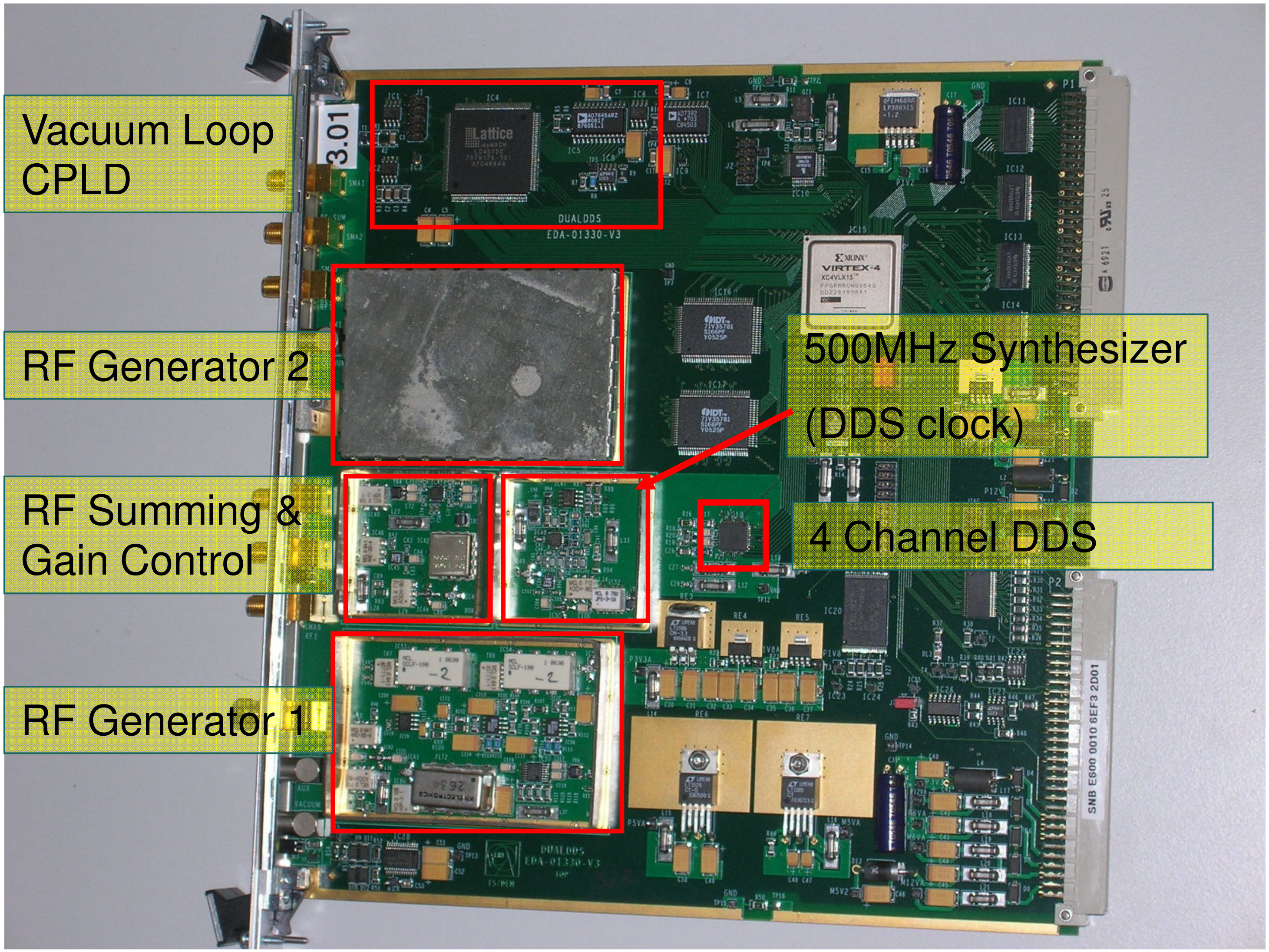
- Conditioning system is fully integrated in LHC Low Level RF Cavity Controller



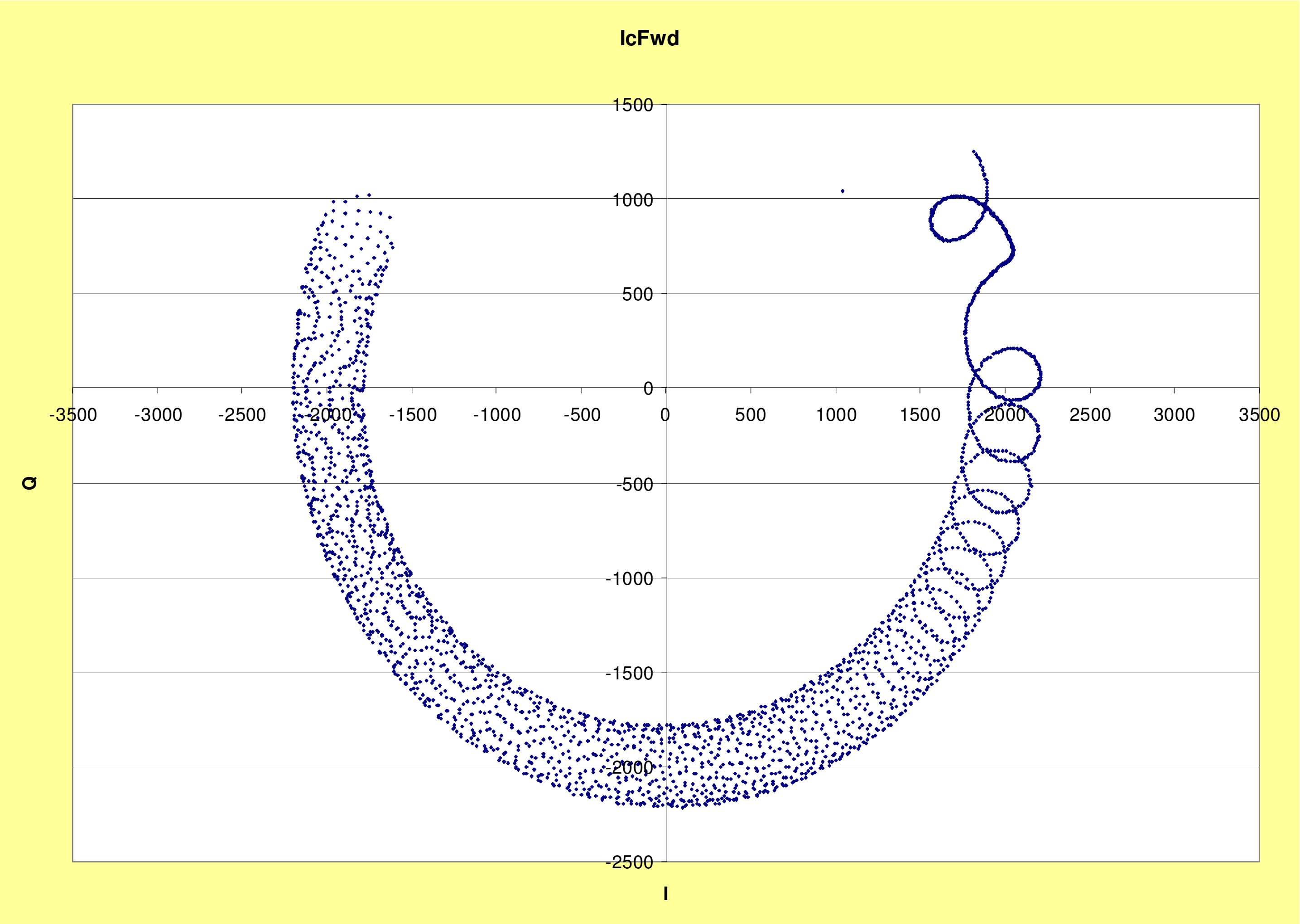
Cavity Controller Tuner/Klystron crate

J. Molendijk

The Conditioning DDS Module

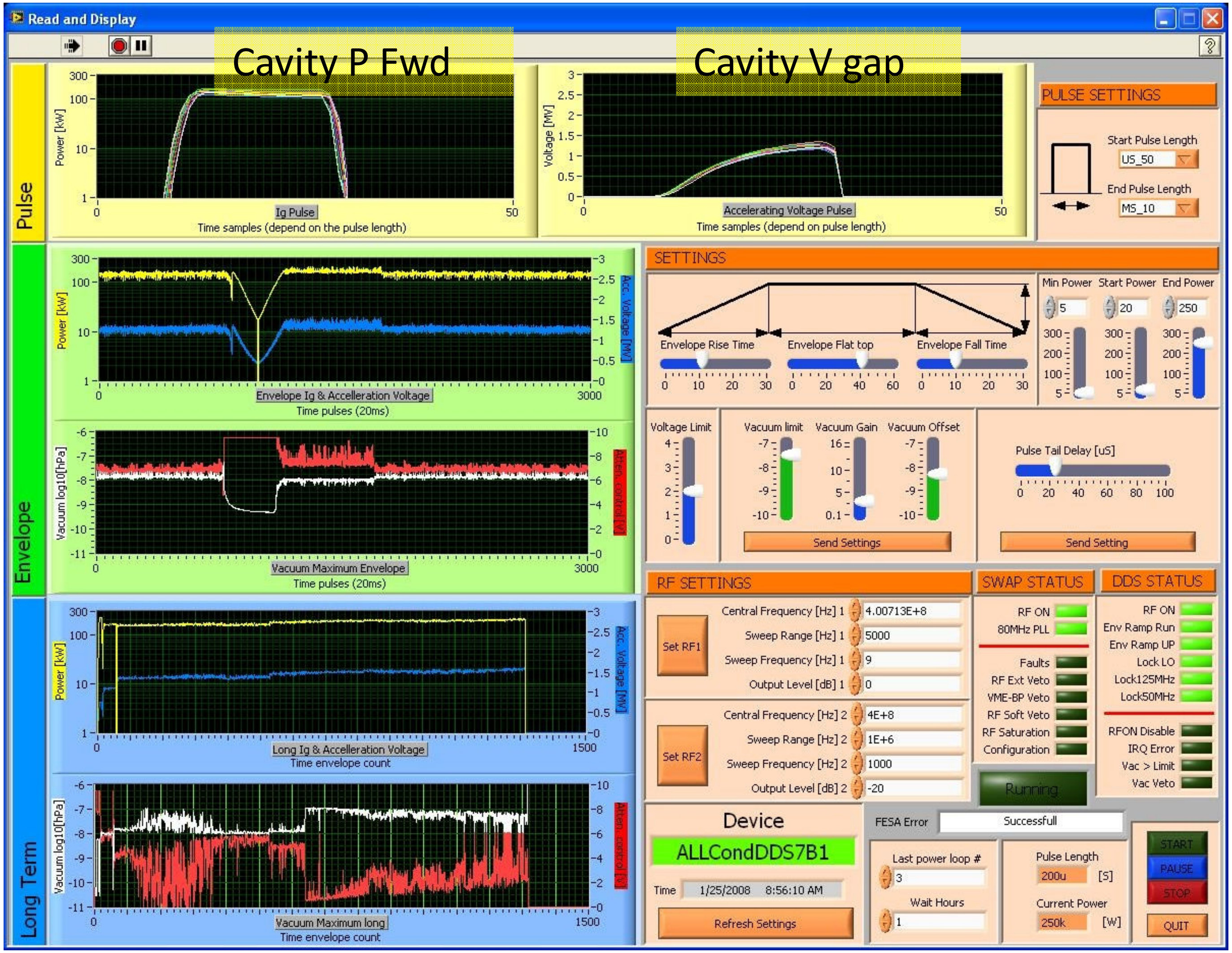


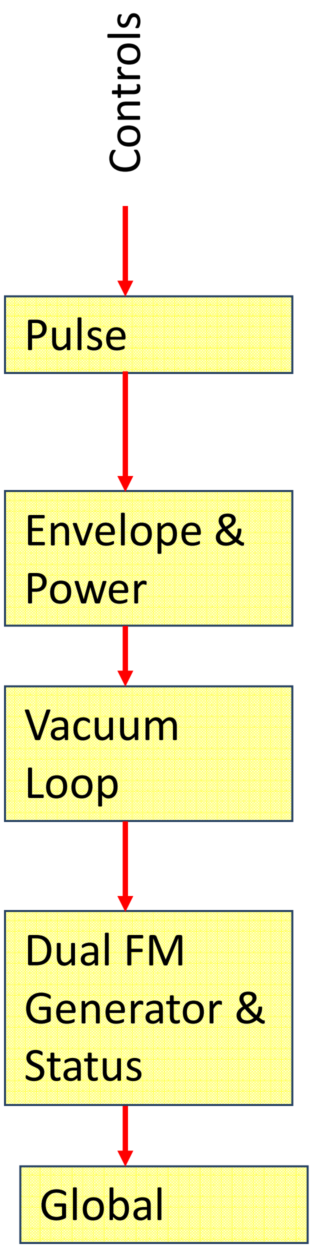
Conditioning DDS – I/Q plot of Dual FM sweeps



Actual Data Obtained from Forward Current, I/Q memory in the Tuner loop module

LHC SC RF Conditioning GUI





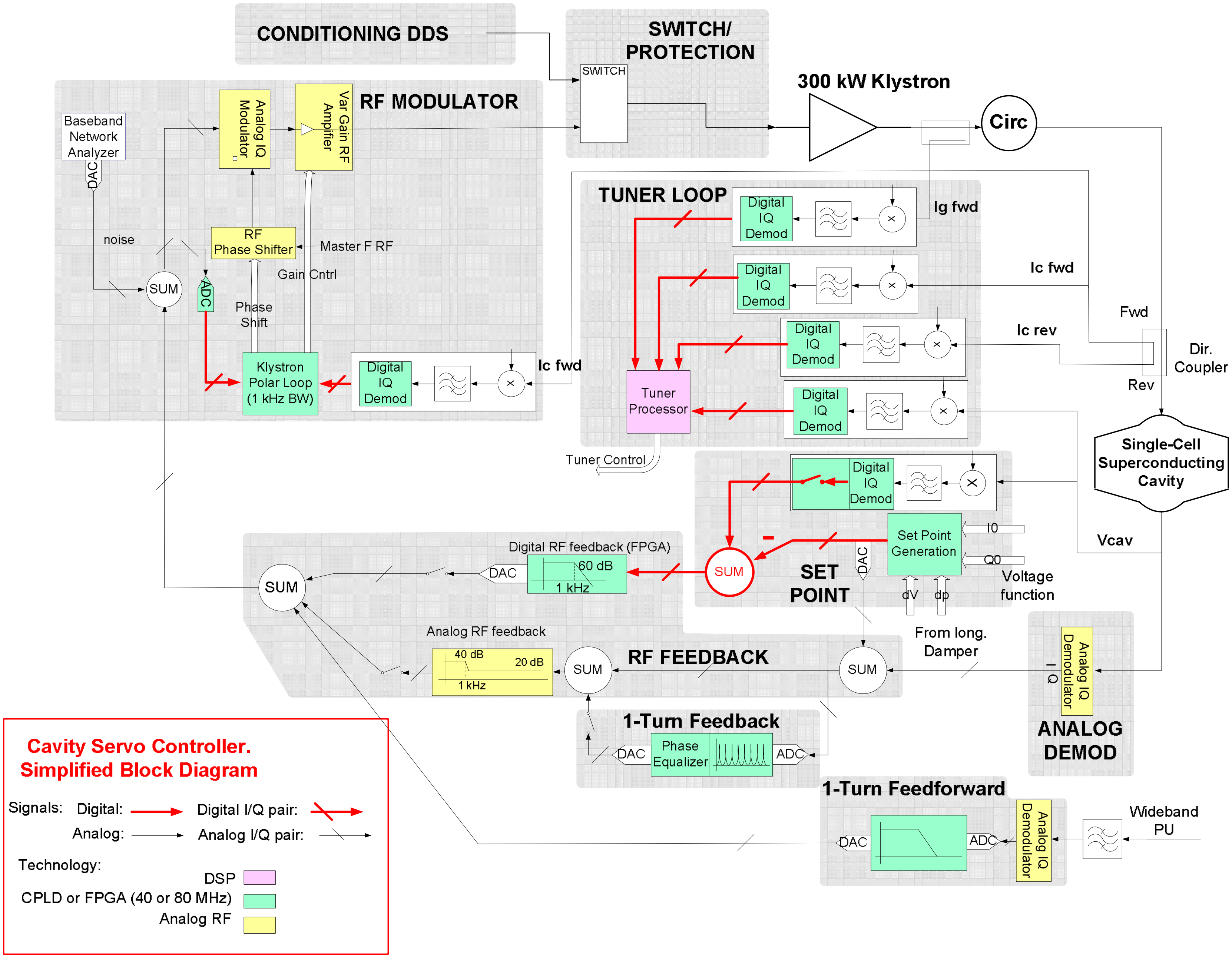
J. Molendijk/F. Dubouchet

Conditioning: Summary

- Typical conditioning time to full power and voltage for an LHC cavity was a few days to 1 week
- Highly automated, but still requires regular human supervision to adjust parameters
- Integrated conditioning system in LLRF hardware has proved very efficient, and allows conditioning of multiple cavities in parallel

- Main power coupler DC bias switched on only after conditioning

LHC cavity Low Level



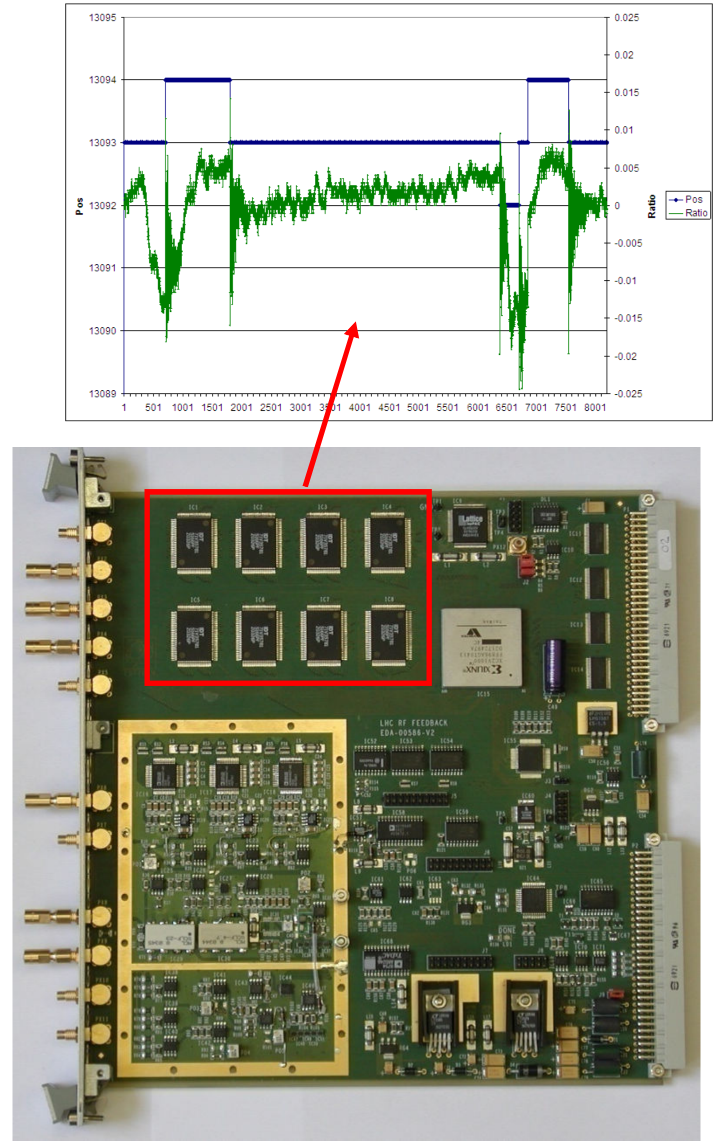
Low Level RF commissioning

- Tuner loop
  - tuner phase adjustment to set the cavity on tune when the loop is closed
- RF feedback
  - phase alignment of digital and analog feedback branches
  - adjustment of feedback gain and phase before closing loop
  - measure closed loop response: important for
    - beam loading response
    - cavity impedance seen by beam
    - bandwidth of cavity voltage control
  - measure phase noise
- Amplifier phase/amplitude loop
  - adjust gain and phase setpoints
  - adjust dynamic loop responses

Lots of work with a network analyser, but new tools are at hand...

LLRF embedded data acquisition

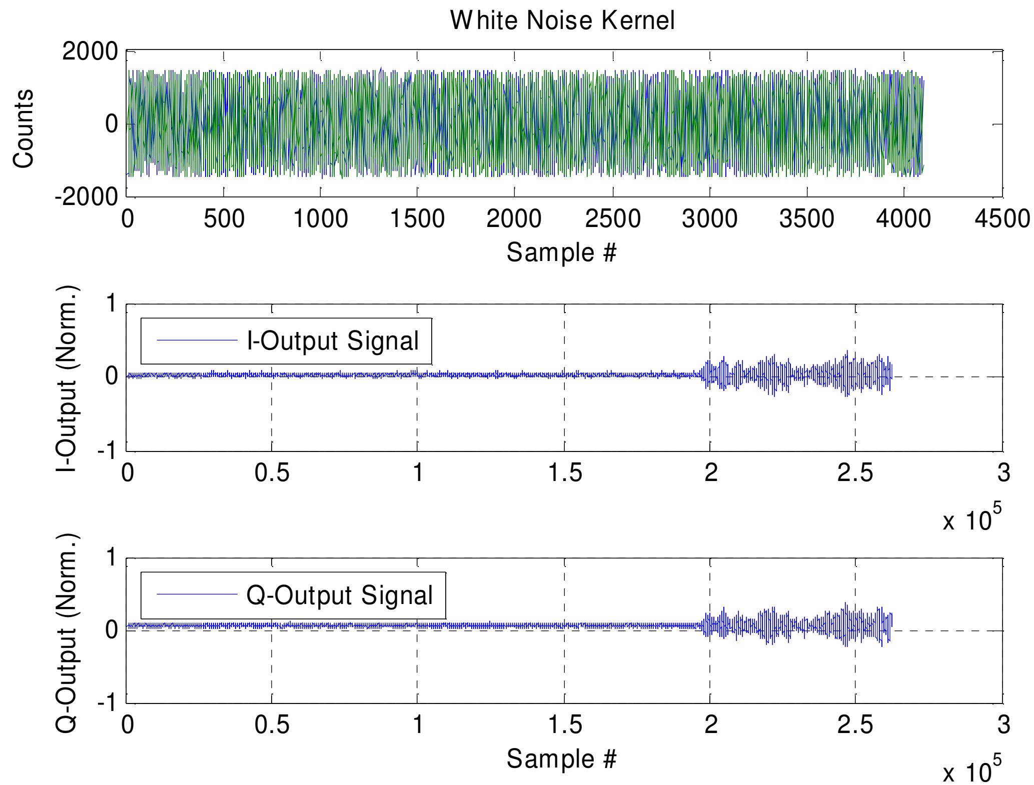
- All LHC LLRF boards have on-board signal recording memory
- 2 parallel sets of buffers:
  - Post-Mortem capture
  - User “Observation”
- 64 turns @ 40Ms/s → 128kB/signal
- Revolution frequency tagging



RF feedback board

“Baseband network analyzer” (BBNWA)

- LLRF boards also have embedded memory buffers for “excitation data”: can inject signals into the loops
- Loops excited with noise
- Output signals recorded digitally
- Transfer function estimate program calculates frequency domain transfer function
- “Fit” an idealized linear model to the measured data and calculate recommended adjustments

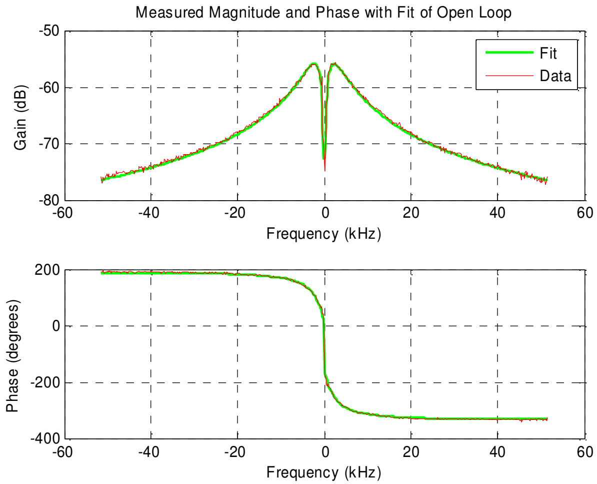


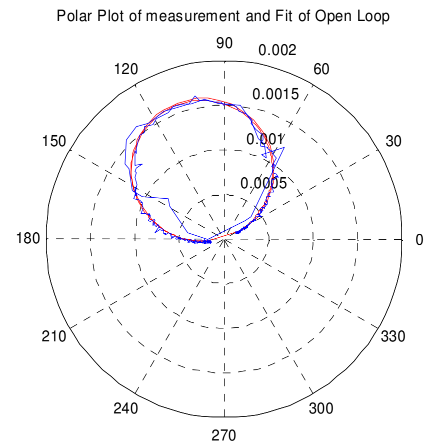
MATLAB tools for remote setting-up of LLRF developed with US-LARP collaborators (D. Van Winkle, C. Rivetta et al.)

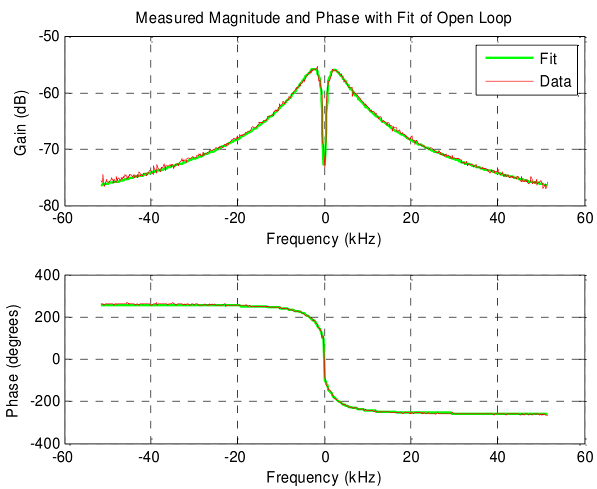
D. Van Winkle

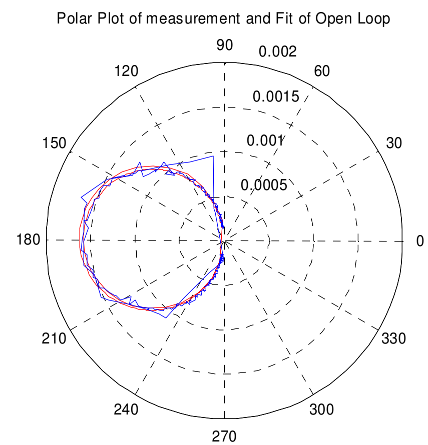
Open Loop Alignment

Un-Aligned Open Loop Response and Model Fit (SM18)



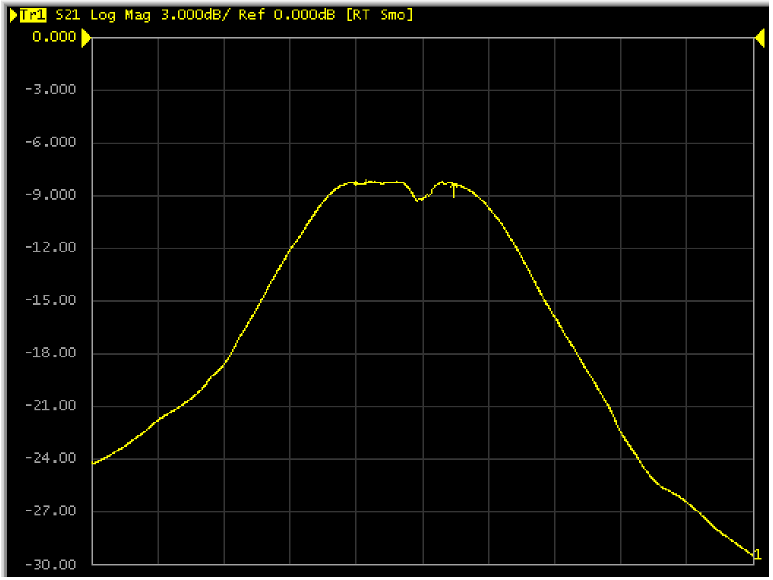






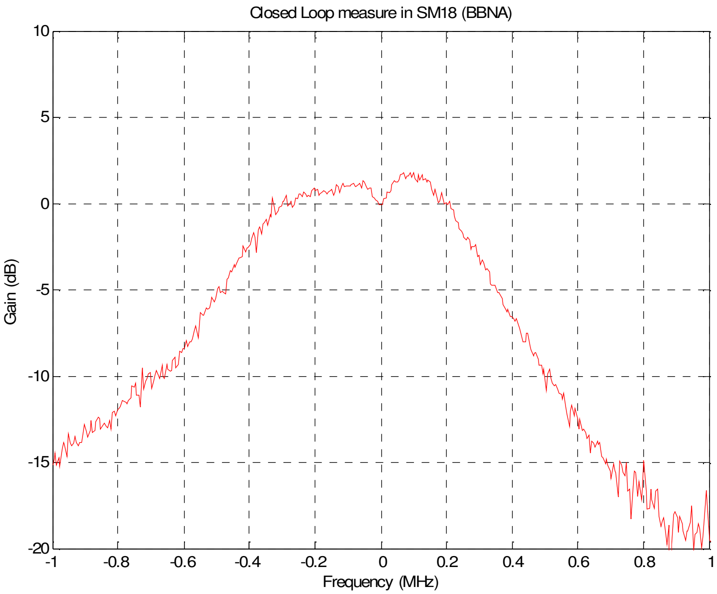
BBNWA contd.

- Comparison of closed loop response measured with instrument vs. embedded BBNWA measurements



Frequency (MHz)

Network analyzer (Agilent)



BBNWA

D. Van Winkle

Automated tuner setup

- MATLAB script for Automatic setup of tuner loop

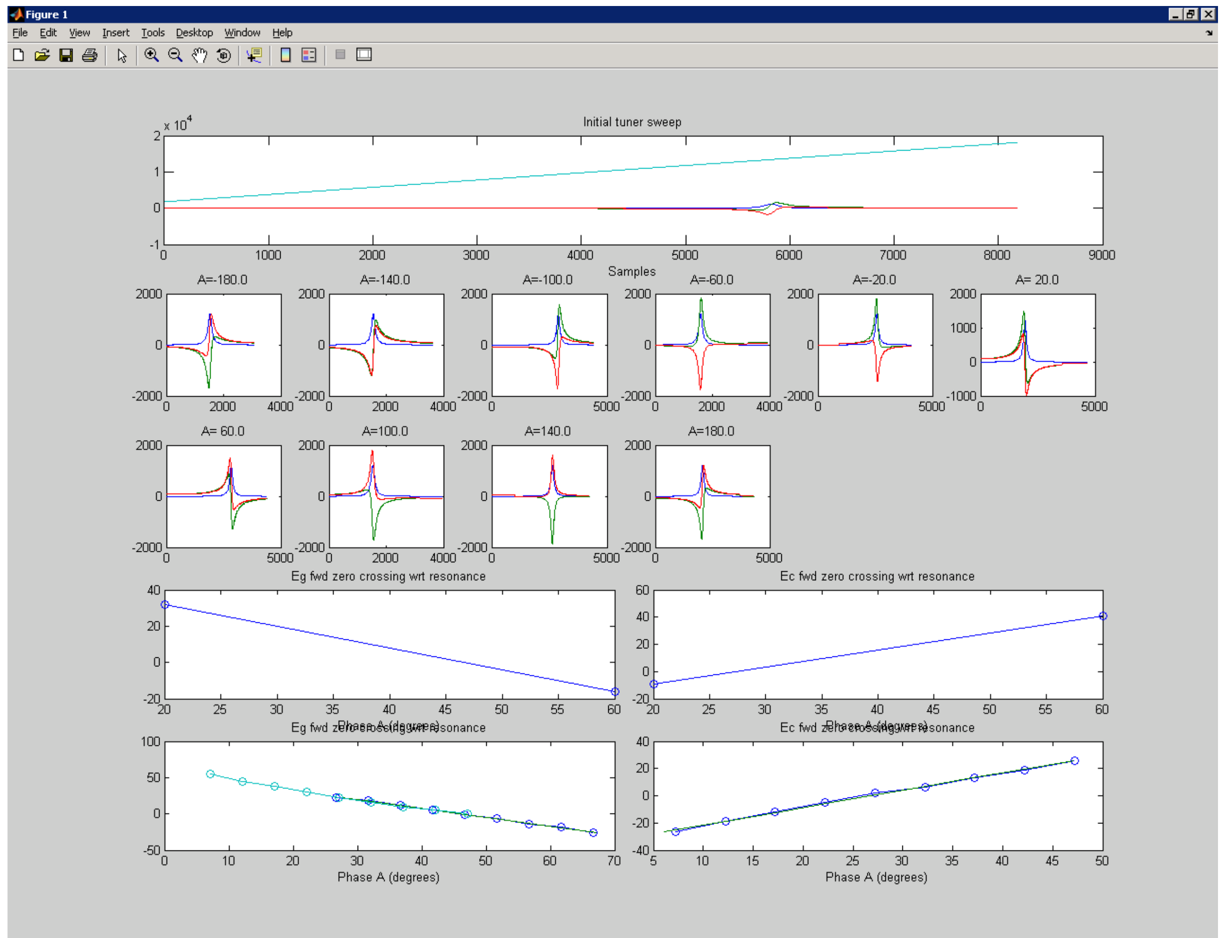
Tuner sweep to find resonance

↓

Sweep across resonance with different phase shifter values

↓

Converge to optimum phase



LLRF: Summary

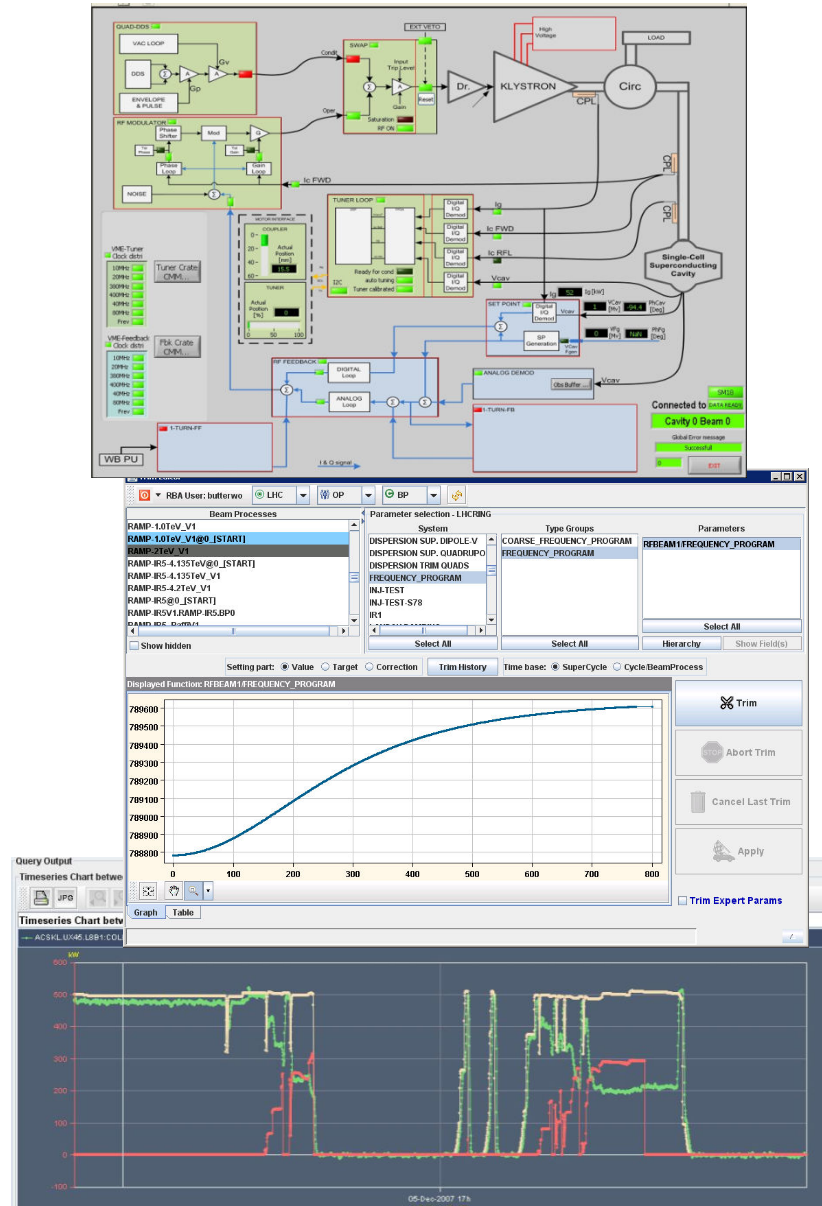
- It took almost 1 month to set up the Low-Level RF of the first cavity
- Once the procedures were well defined, the last few cavities took about 1 day each

- New automated tools using MATLAB and the BBNWA feature of the LLRF hardware will save a lot of time

→ Many thanks to our US-LARP colleagues from SLAC

Controls and software

- PLCs and Low-Level crates interfaced via FESA (Front End Software Architecture)
  - a "FESA class" software module is written for each type of equipment
  - communication via the CERN Controls Middleware
- Application software:
  - LabView expert synoptic panels
  - Matlab scripts for more sophisticated specialist applications
  - LSA (standard machine operations software) manages settings and sequencing
  - Logging and Post Mortem
  - Alarms (LASER)
  - …



Summary

- Power system commissioning procedures will be well known if using existing power source (SPS type 800MHz)
- Controls and application software should be based on standard CERN controls infrastructure
- LHC low-level electronics has built-in conditioning and diagnostics facilities, and is already well integrated into the control system
- Powerful tools are being developed for LLRF setting-up which could equally be applied to the crab cavity system