Cryomodule-1 at Fermilab

Detailed Review of Cavity Performance

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LCWS11/AWG3

26-30 September 2011

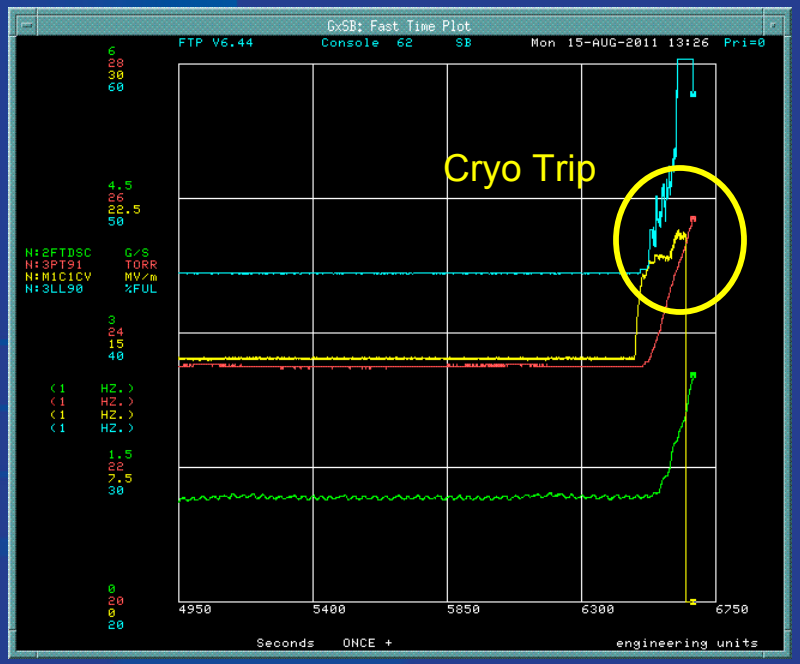
Cavities Performance

- Each of the 8 cavities exhibit a unique performance signature
  - Peak Gradient
  - Q_L drop with E_{Acc}
  - Cryogenic system response
  - Field Emission/Dark Current
  - etc.

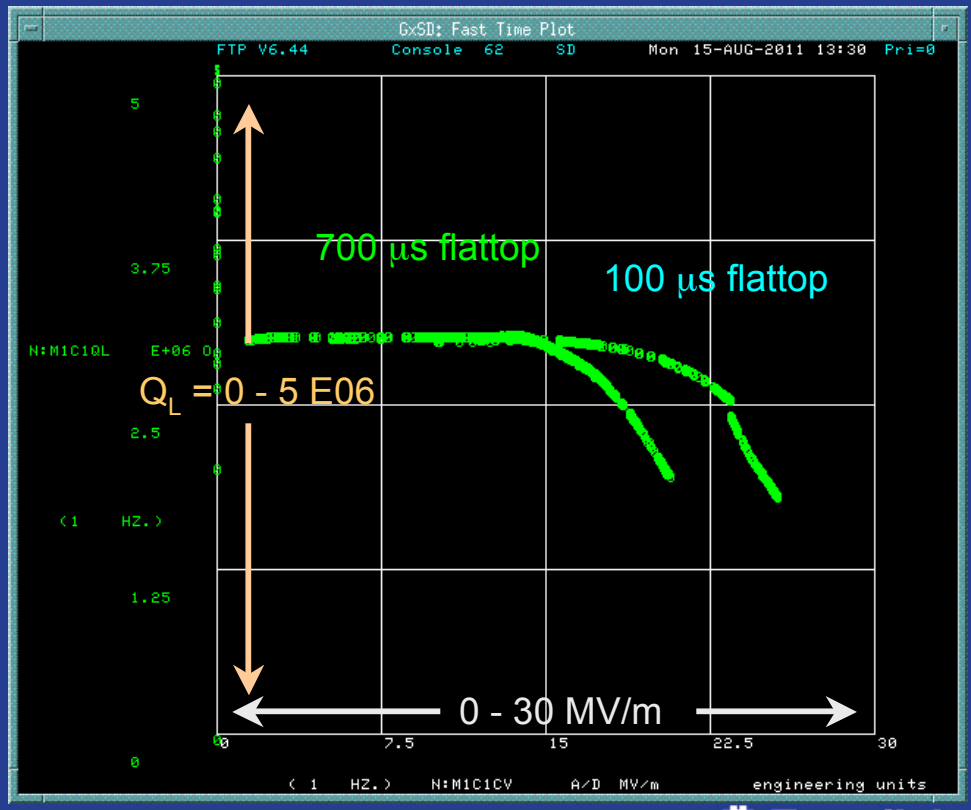
Cavity 1/Z89 Performance

- Determination of Cavity gradient limit: *20.2 MV/m*, (5 HZ repetition rate, 1.2 ms pulse length)
- Q_L drop vs. gradient beginning at 14.2 MV/m (700 μs flattop)
- Cryo Heat Load larger than expected/'soft' quench - limitation
- Insignificant Dark Current and X-rays

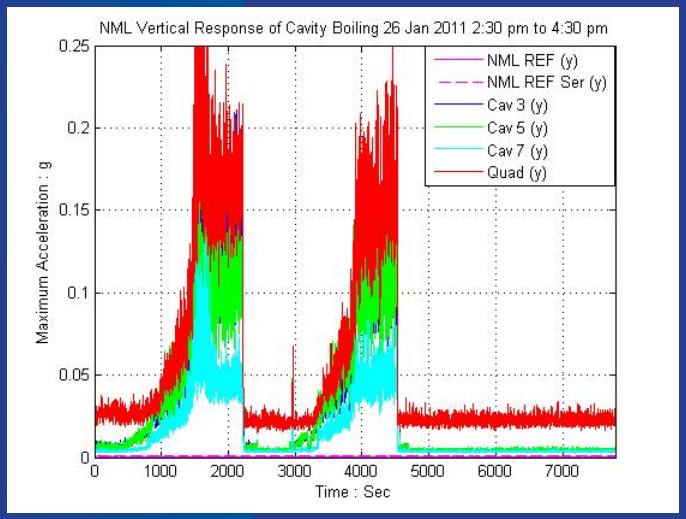
Cryo System Response



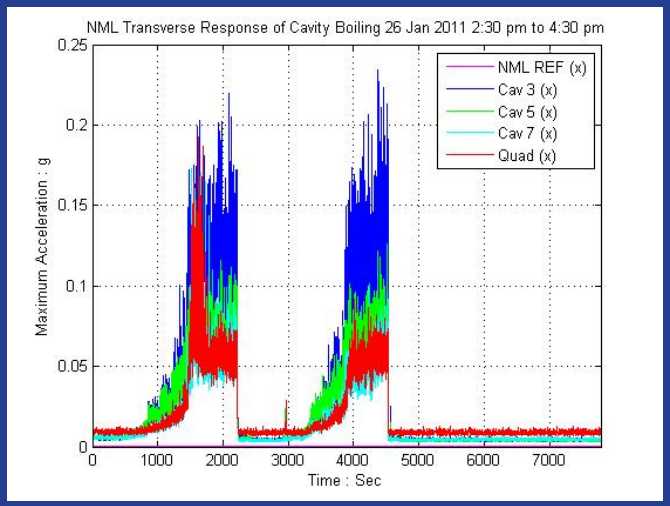
Variation of Q_L with gradient

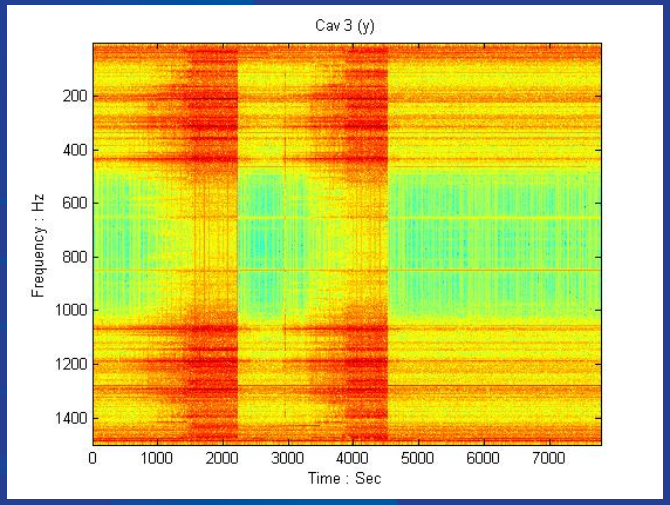


Cavity 1/Z89 Performance

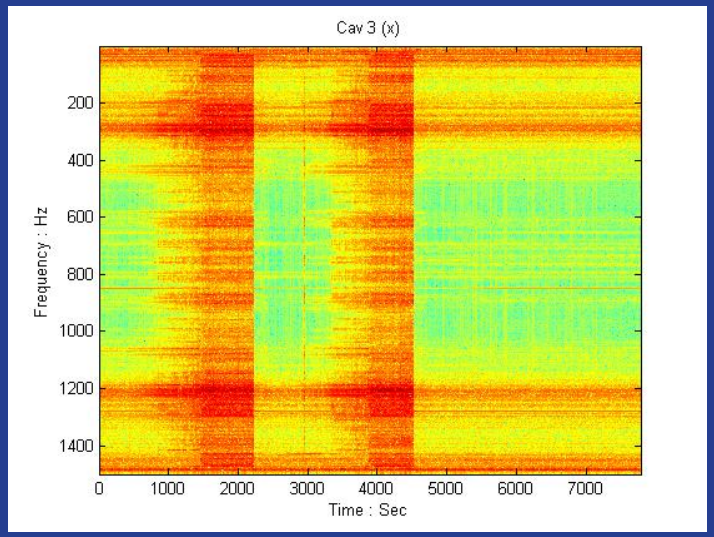


Displacements





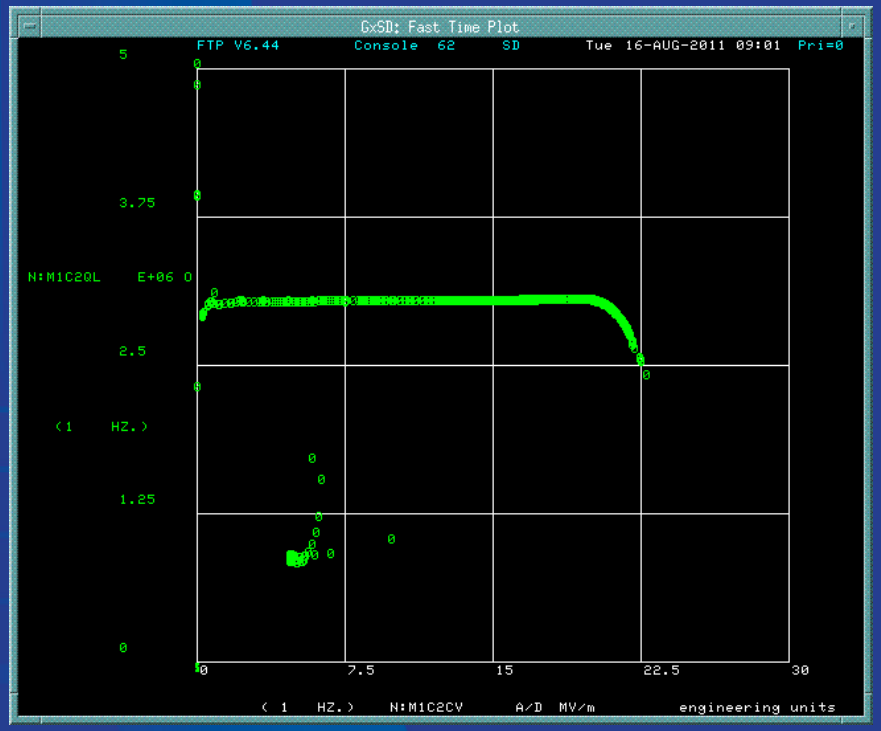
Frequency Response

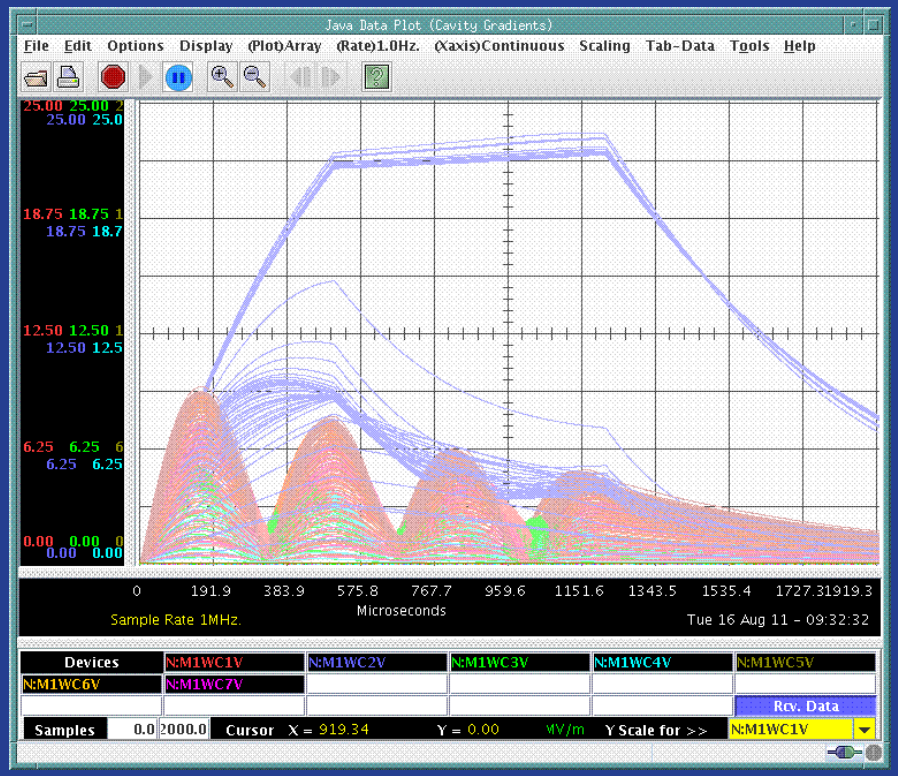


Microphonics - *courtesy of Mike McGee*

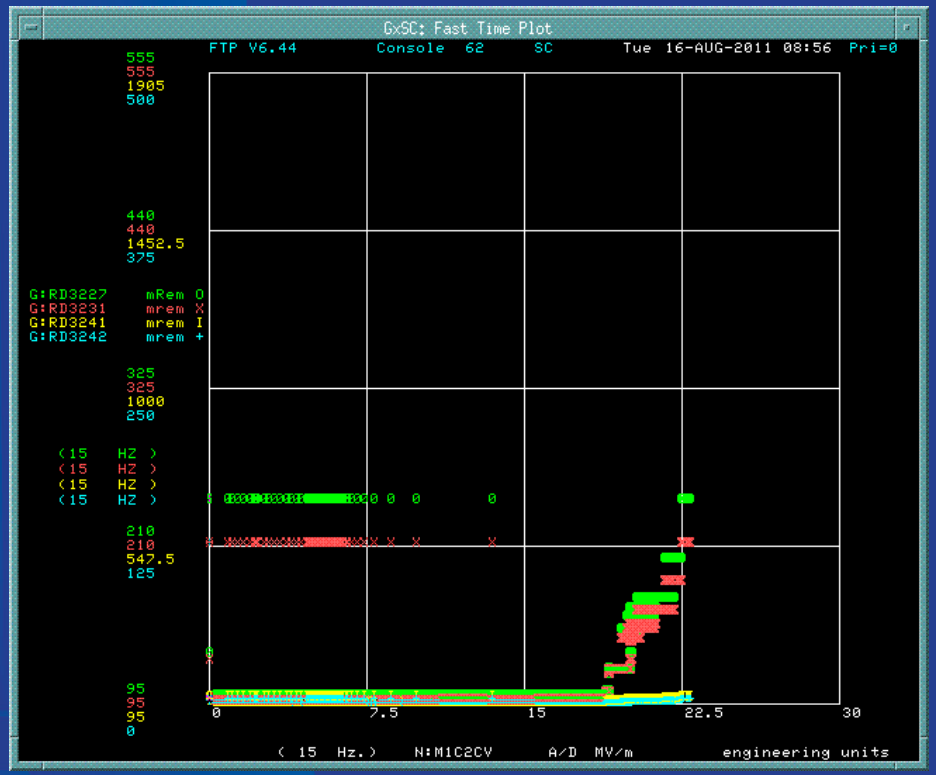
Cavity 2/AC75 Performance

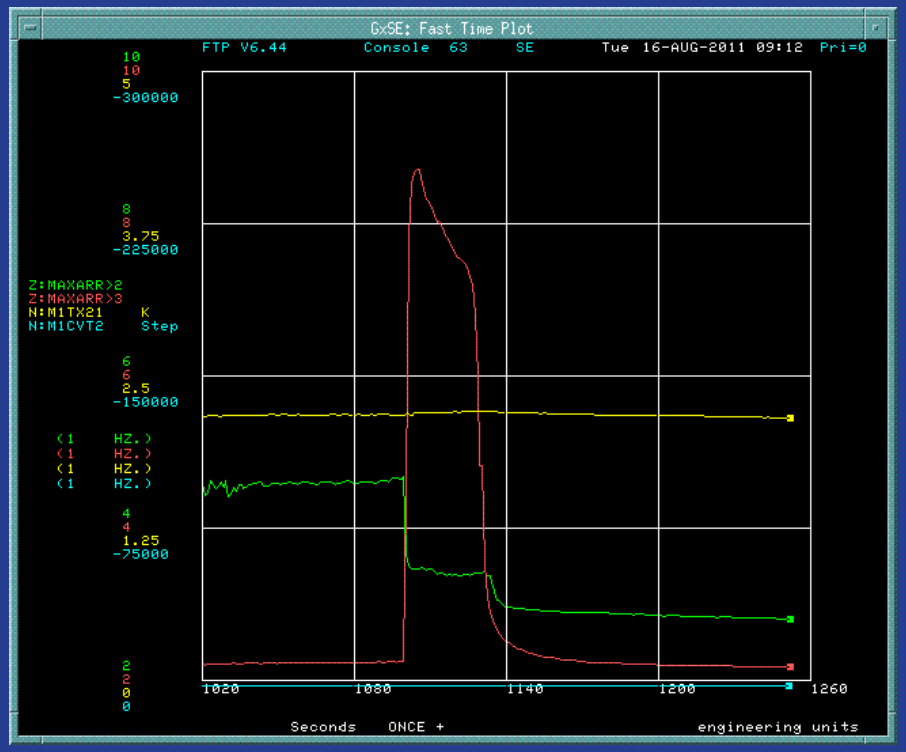
- Tuner Motor would not budge initially. Motor determined okay. Combination of slow tuner motor and piezo frees tuner
- Cavity tuned to 1.300 000 GHz uneventfully
- 5 Hz operation, 1.2 ms maximum pulse width
- Some X-rays and Dark current, but mostly conditioned away (onset ~19 MV/m)
- Peak Gradient - 22.5 MV/m, limited by Quench
- Q_L drop beginning ~20 MV/m





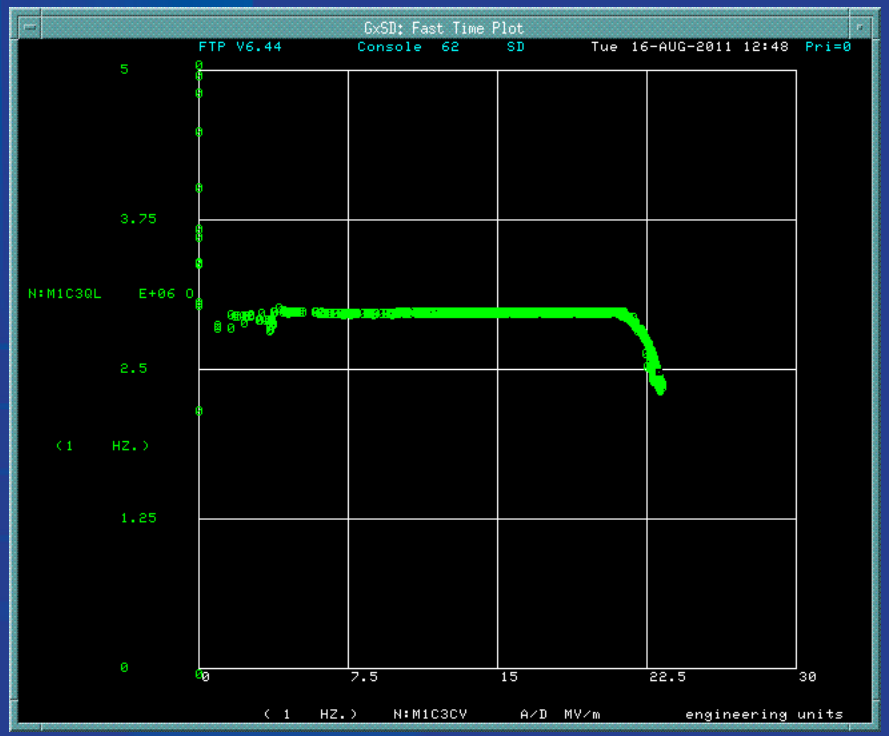
Cavity 2/AC75 Performance

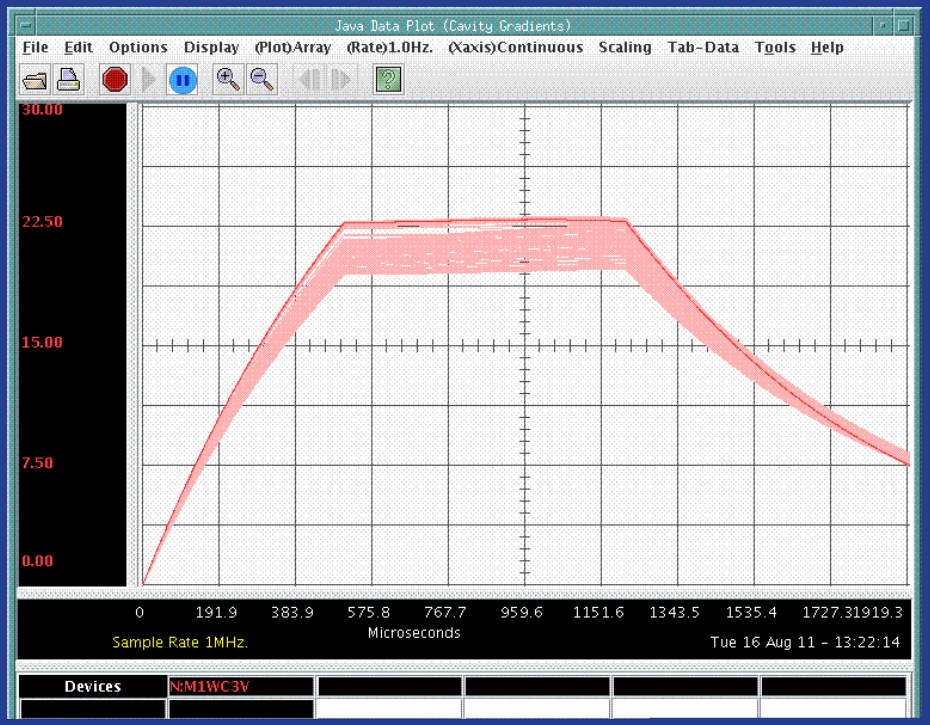




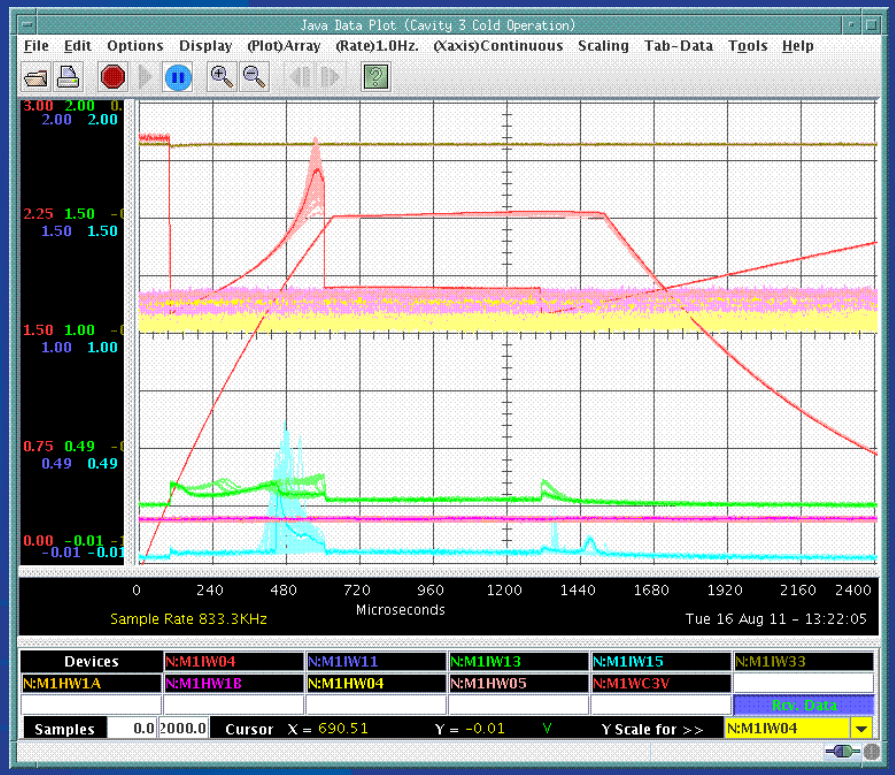
Cavity 3/AC73 Performance

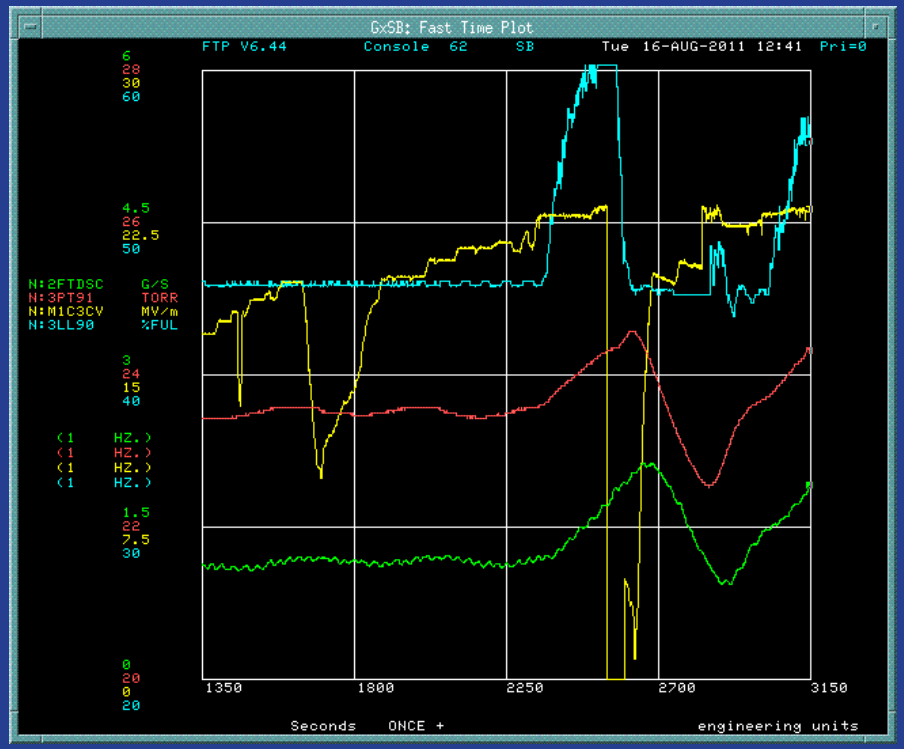
- Uneventful Coupler Conditioning
- Tuner operation fine (no motor problems)
- Maximum gradient achieved - 23.2 MV/m, limited by 'soft' quench/cryo system
- Q_L drop begins at 21 MV/m
- Minimal Field Emission, but noticeable activity on coupler





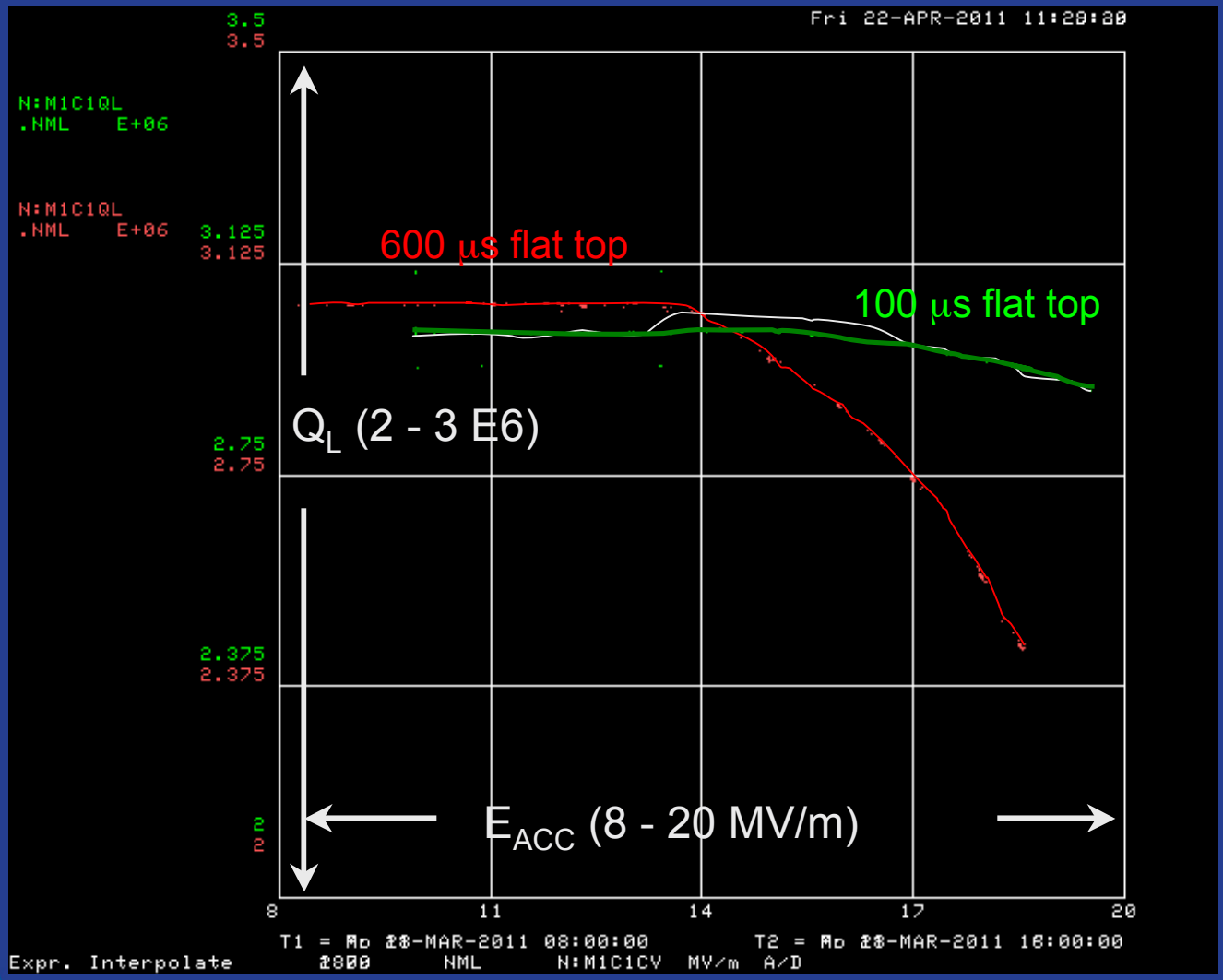
Cavity 3/AC73 Performance





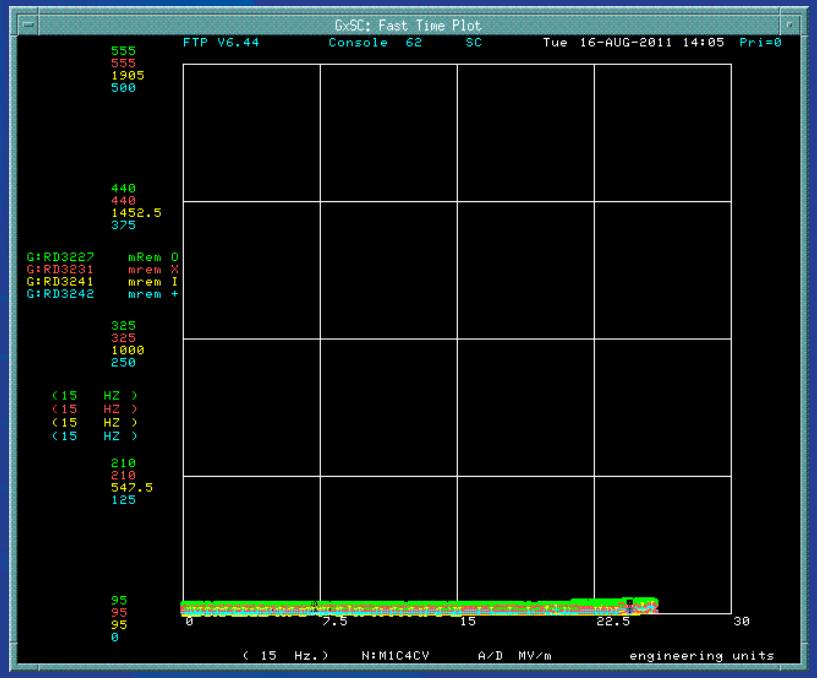
Cavity 3/AC73 Performance

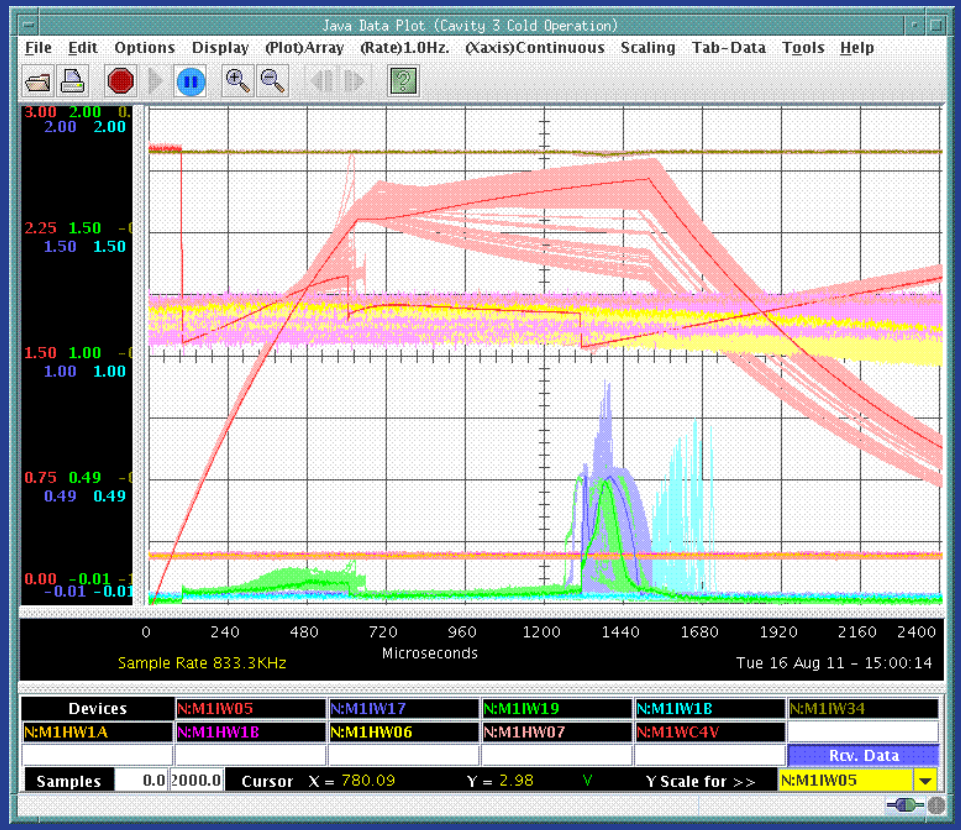
Q_L vs. E_{ACC} for varied flattop lengths



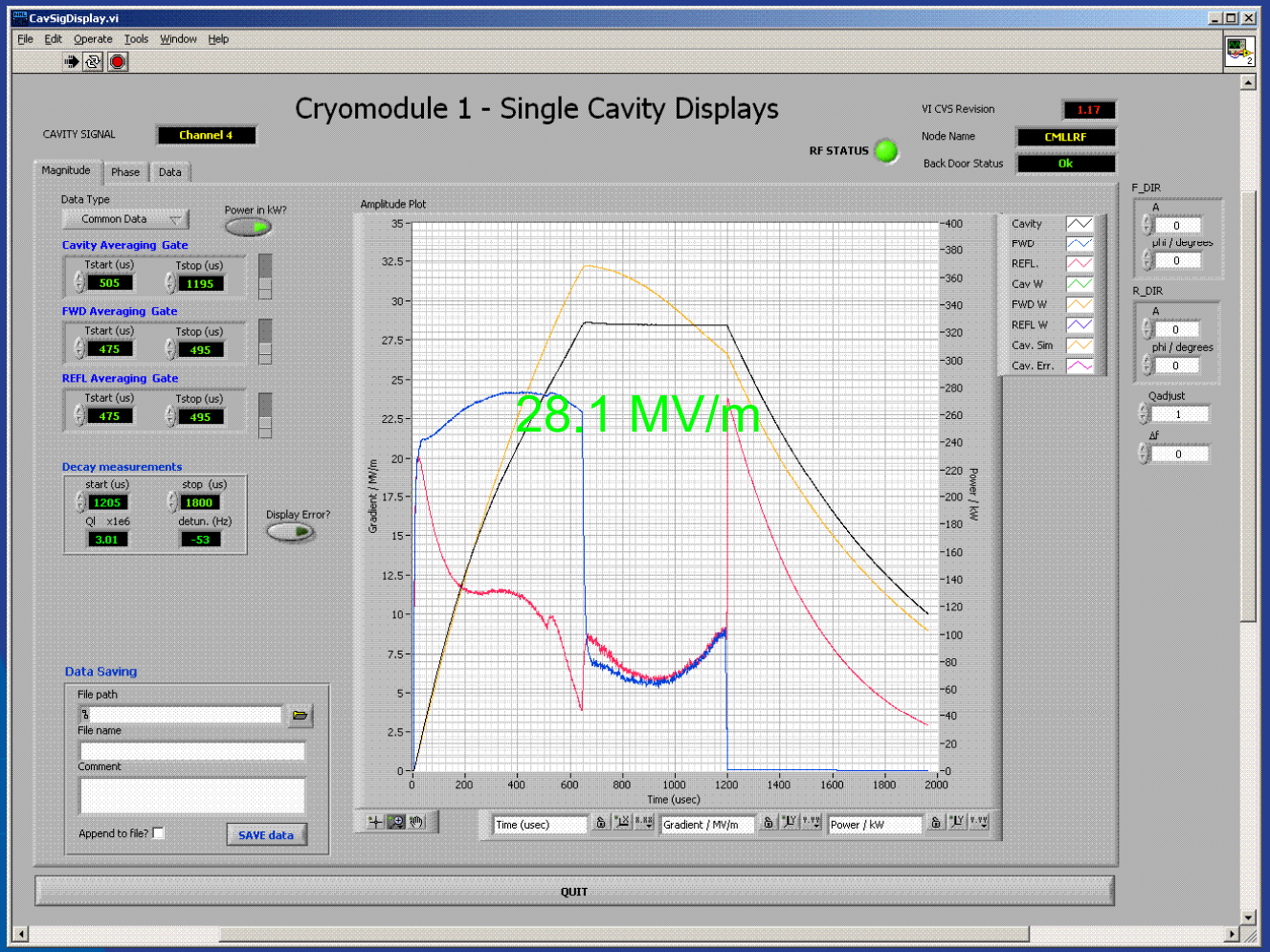
Cavity 4/Z106 Performance

- Coupler Conditioning took quite a while
  - 200 μs, up to 1MW sequence
- Maximum gradient achieved - 24*/28.1 MV/m - limited by available RF

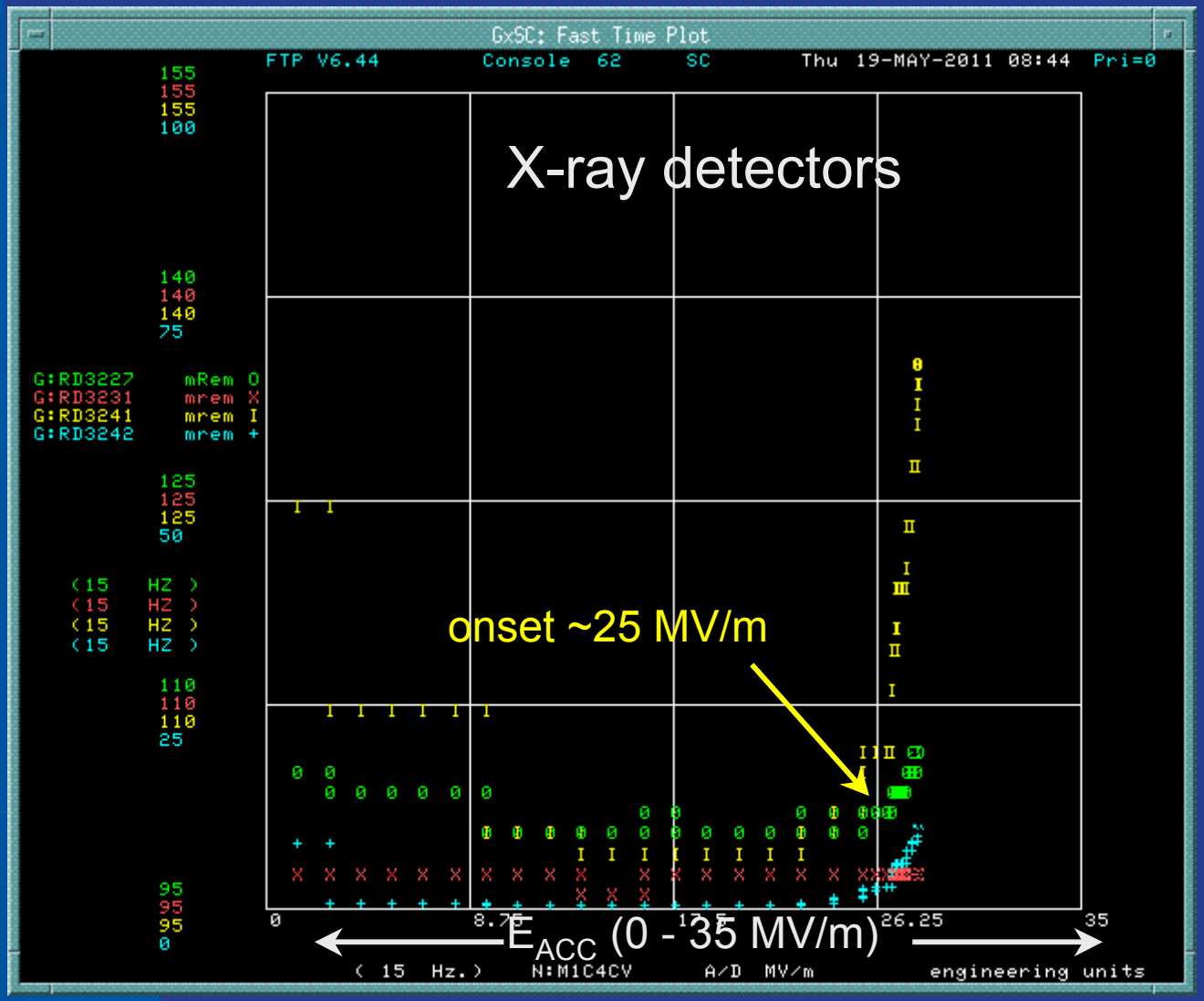




Cavity 4/Z106 Performance



Cavity #4/Z106 Performance



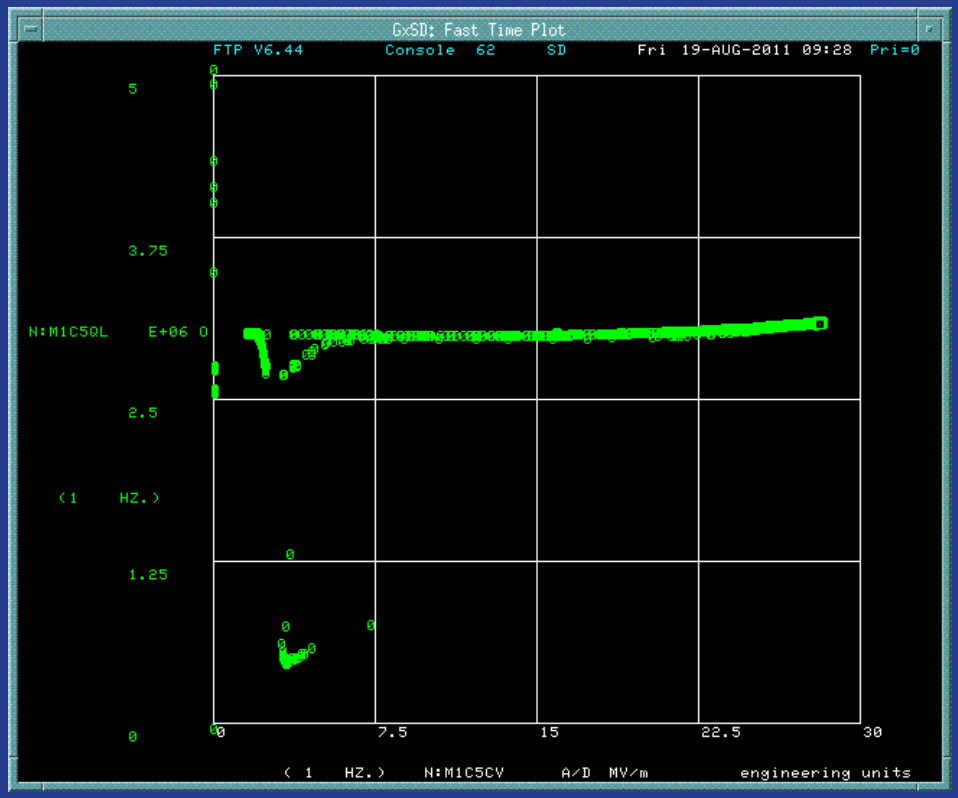
Fermilab

Cavity 5/Z107 Performance

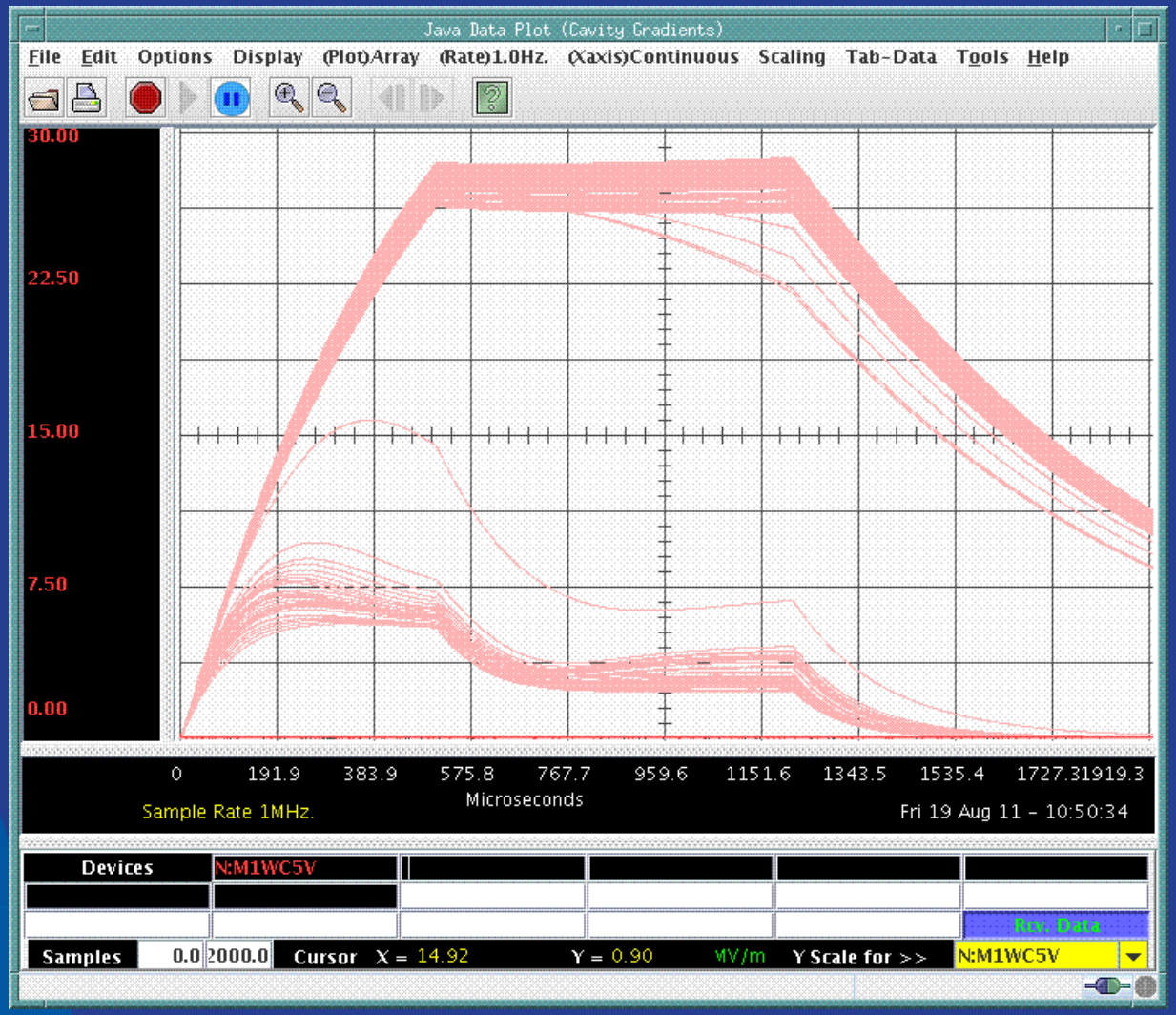
- Very quick Coupler Conditioning (24 hours)
- Tuner operation fine (no motor problems)
- No anomalous behavior seen (cryo is stable to quench limit)
- Some x-rays
- Peak performance
  - 33.8 MV/m, quench limited
  - LLRF closed loop set up
  - LFDC tuned up
  - Limited to 2.5 Hz operation with 1.2 ms pulse width by LCW temperature, flow

Cavity 5/Z107 Performance

- Very quick Coupler Conditioning (24 hours)
- No anomalous behavior seen (cryo is stable to quench limit)
- Some Field Emission beginning at 26 MV/m
- Peak performance
  - 28.2 MV/m, quench limited

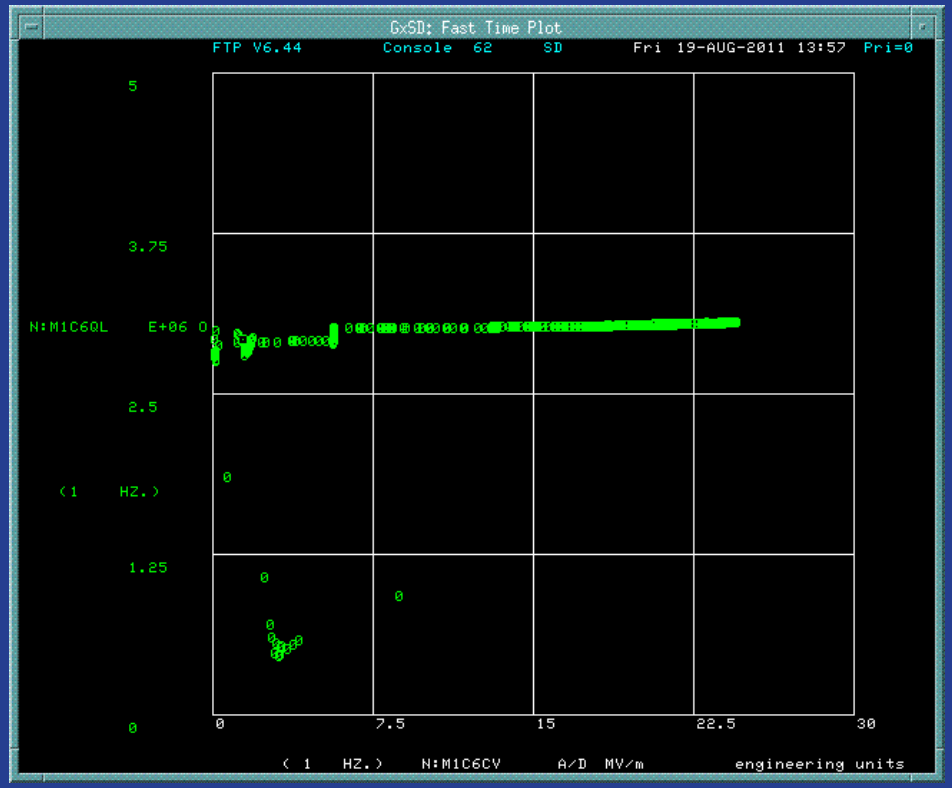


Cavity 5/Z107 Performance

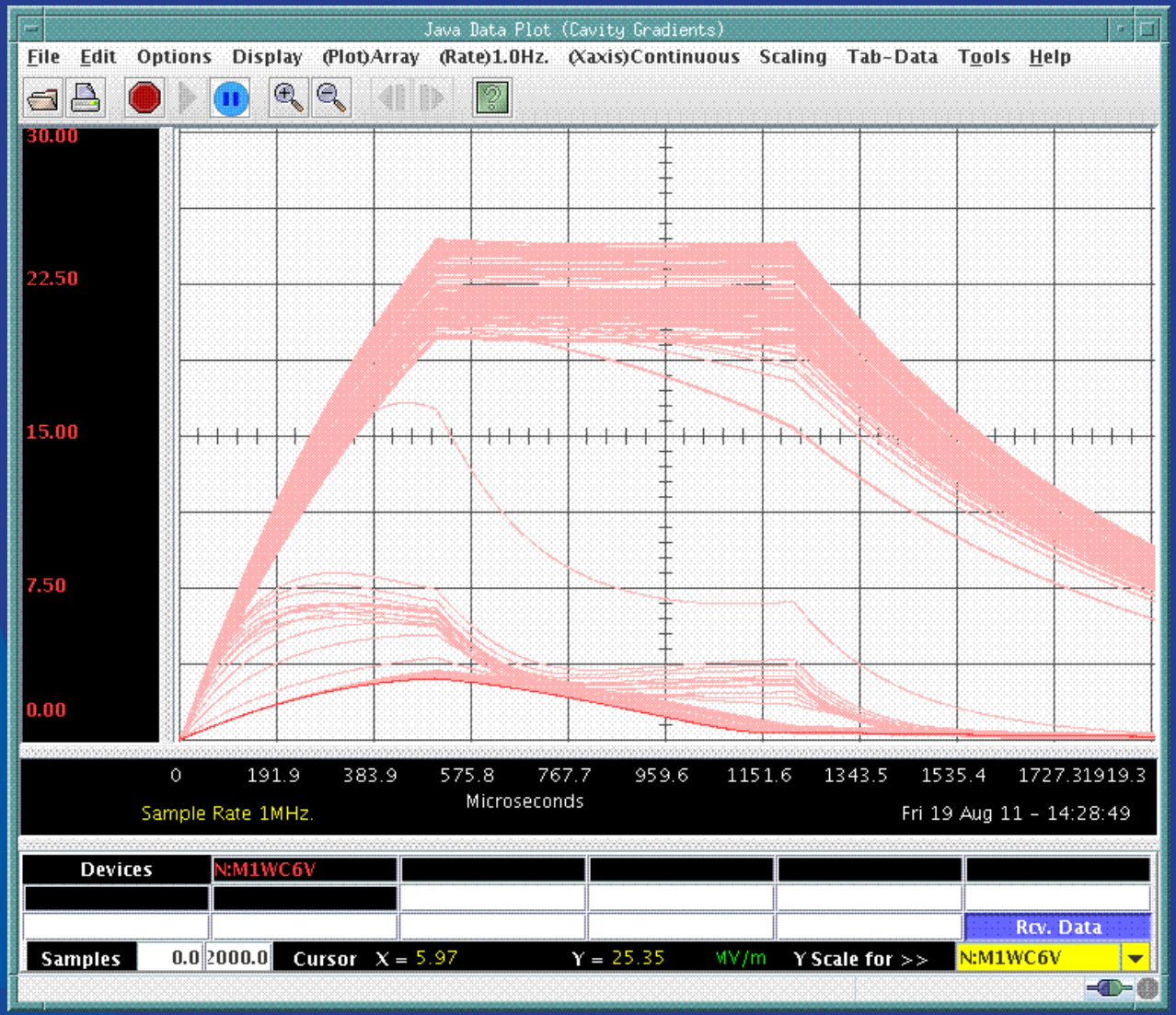


Cavity 6/Z98 Performance

- Very quick Coupler Conditioning (24 hours)
- Tuner operation fine (no motor problems)
- No anomalous behavior seen (cryo is stable to quench limit)
- Some x-rays
- Peak performance - 24.5 MV/m, quench limited

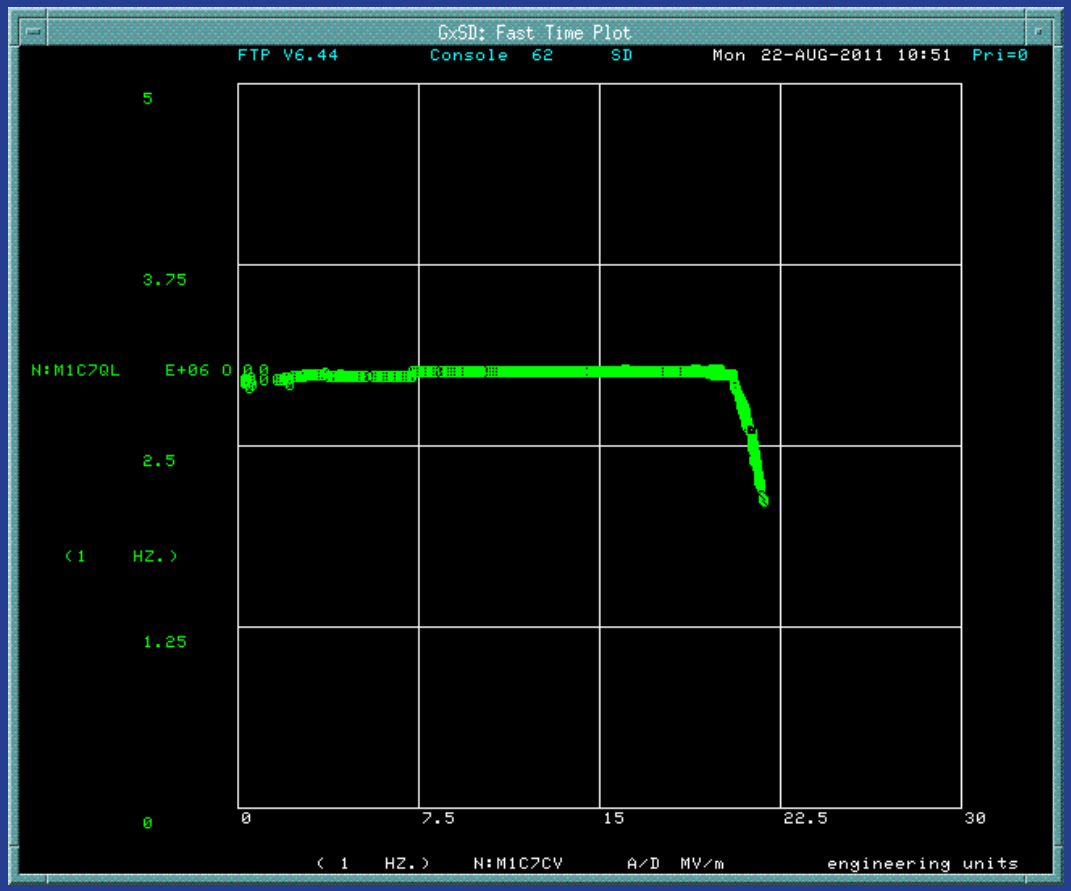


Cavity 6/Z98 Performance

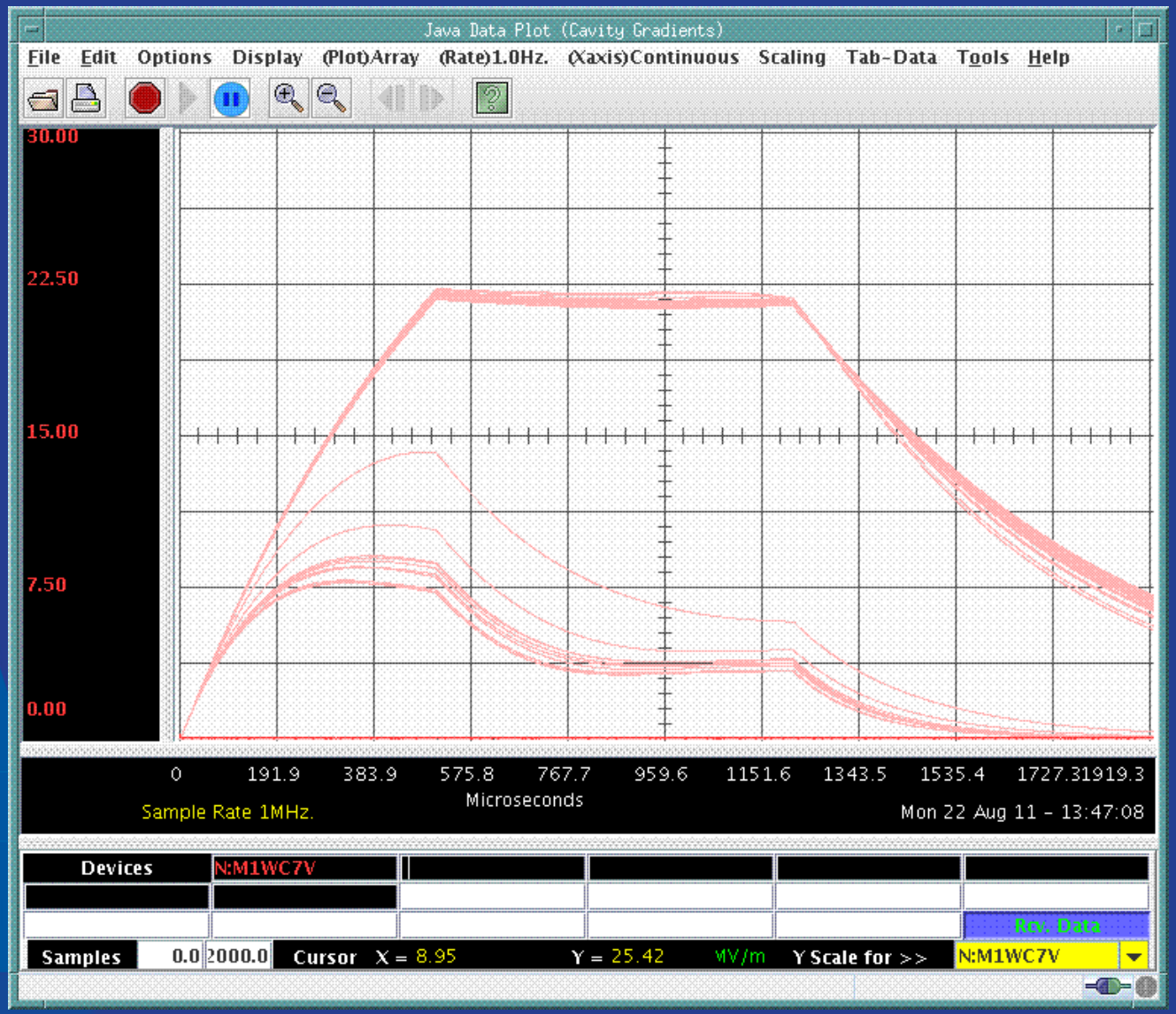


Cavity 7/Z91 Performance

- QL drop beginning at 20.3 MV/m
- Peak performance - 22.3 MV/m, quench limited

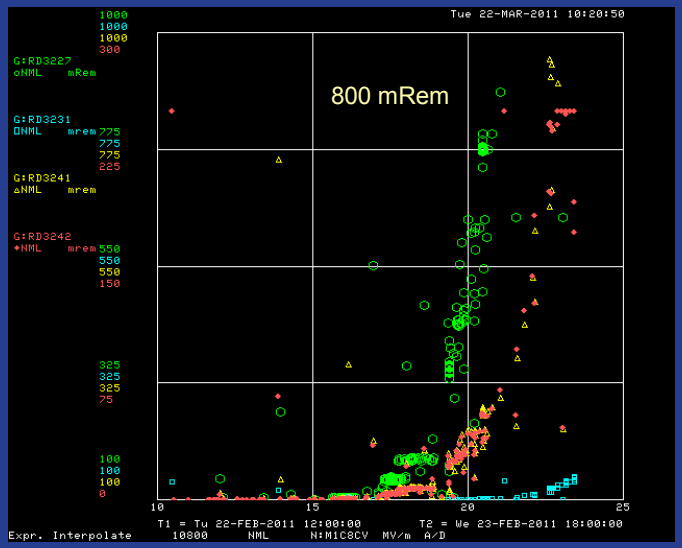


Cavity 7/Z91 Performance



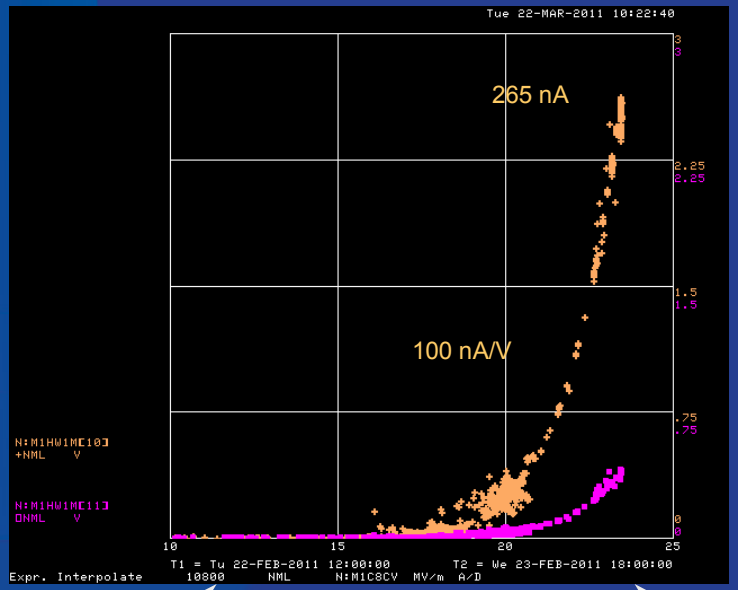
Cavity 8/S33 Performance

- Tuner Motor freezes after ~119/361 kHz motion, motor appears to be shorted
- LLRF master oscillator tuned to cavity frequency, 1.300 241 800 GHz
- Peak Gradient - 24.4 MV/m, quench limited
- Dark current and X-rays detected beginning at 15 MV/m



10 - 25 MV/m

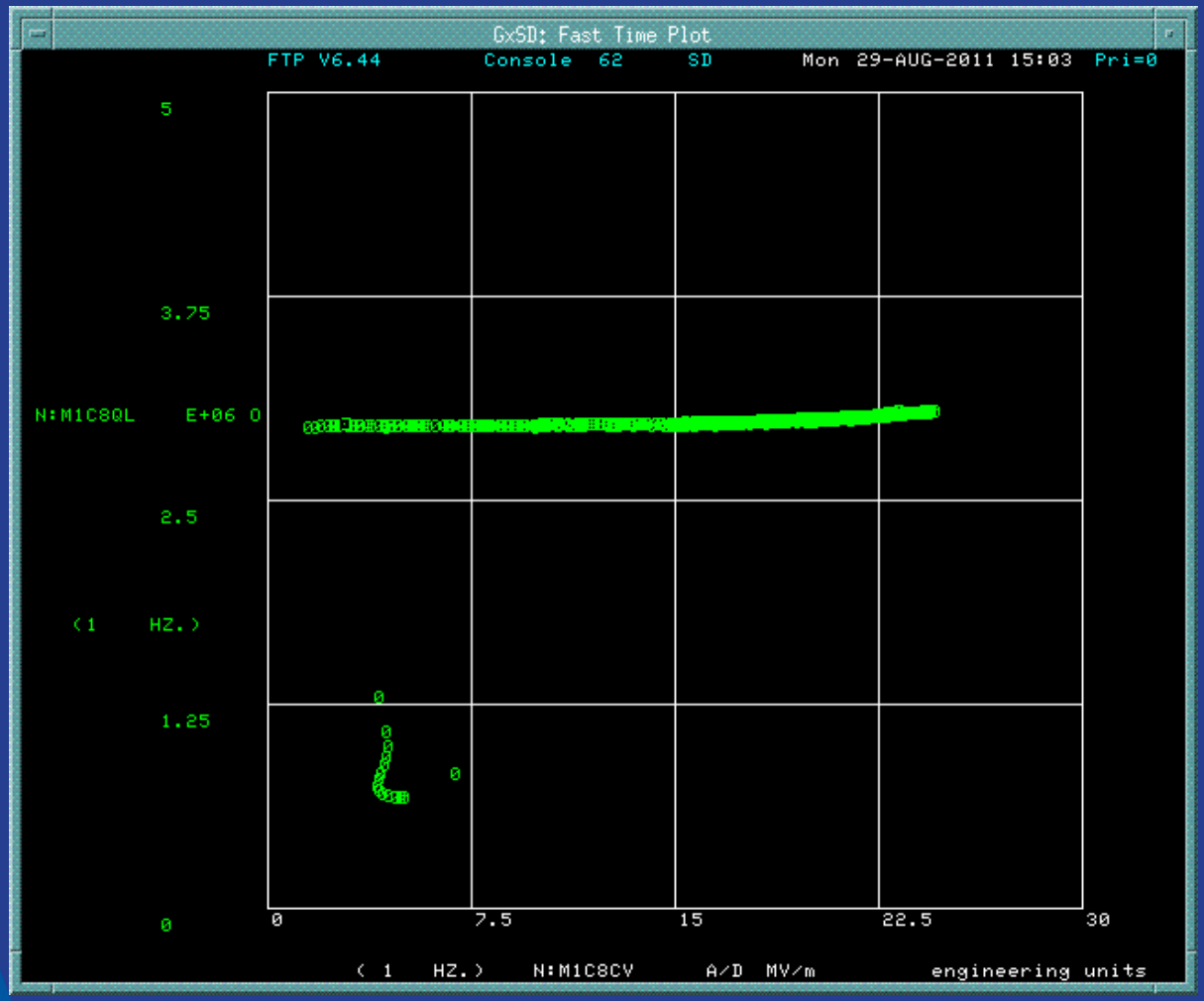
Maximum X-rays at opposite end of Cryomodule



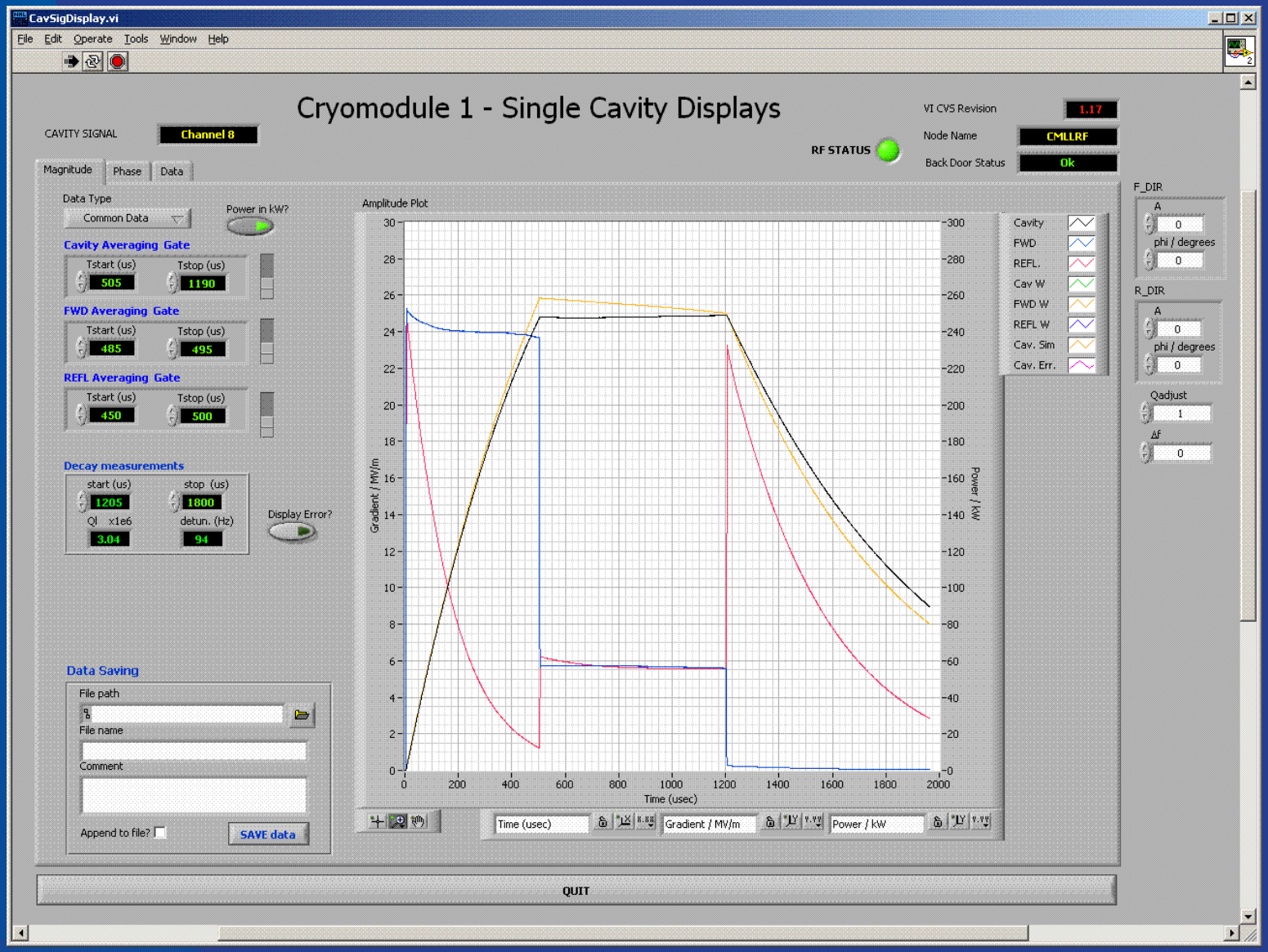
10 - 25 MV/m

Maximum Dark Current at opposite end of Cryomodule

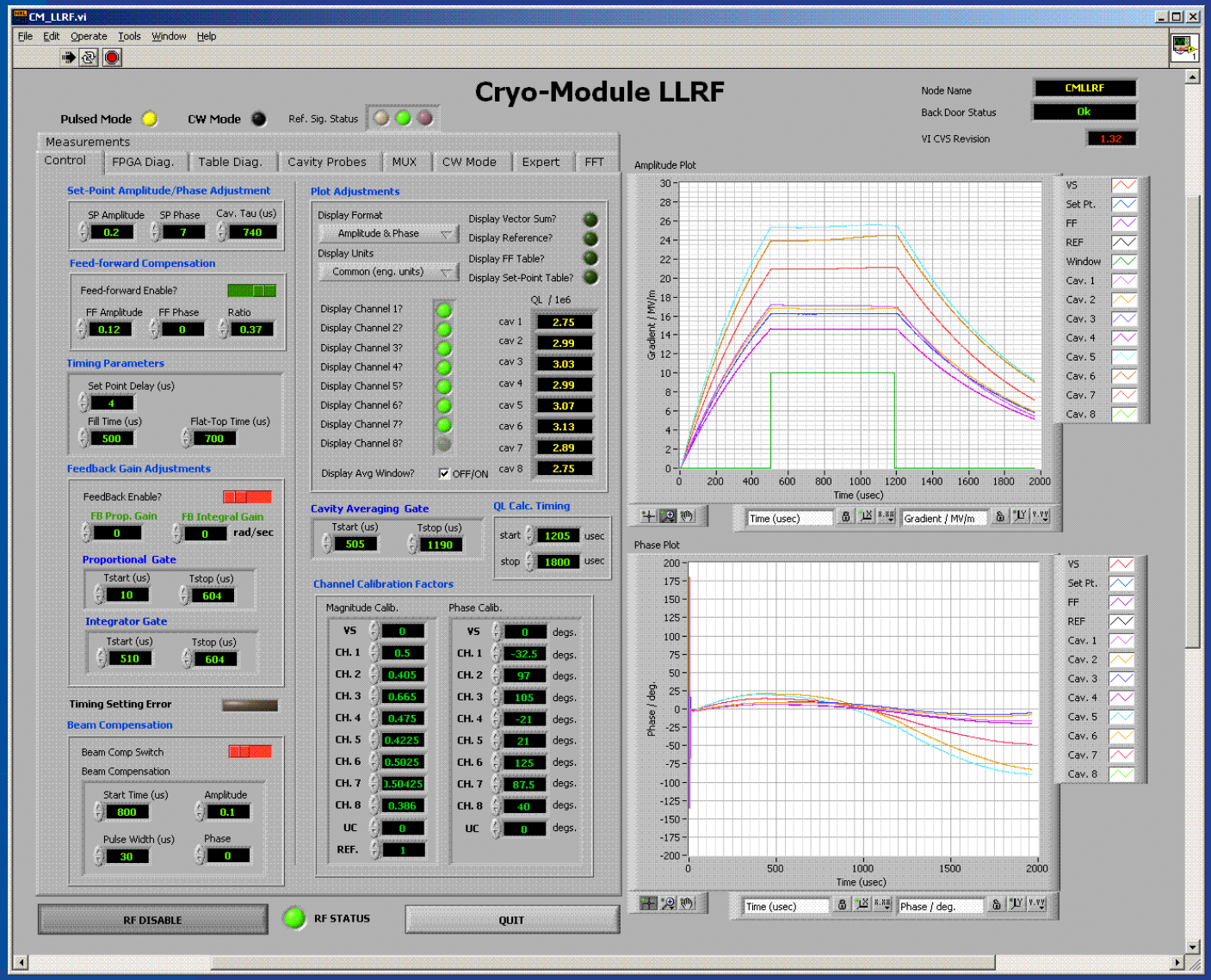
Cavity 8/S33 Performance



Cavity 8/S33 Performance



Module Performance



Module Performance

PA N9 CM1 & K6 Parameter

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N9   CM-1 Overview                    SET      D/A    A/D   Com-U ♦PTools♦
-<FTP>+ *SA♦ X-A/D  X=TIME      Y=N:K6KFP ,N:K6IRP ,N:K6IFP ,N:K6GUNV
COMMAND ---- Eng-U  I= 0        I= 0       , 0       , 0       , 0
-< 3>+  One+ AUTO   F= 3600     F= 5       , 1.25    , 5       ,-150
  RF    timing  vacuum  llrf    cryo    water   diag    motors
 ! Gradients
 N:M1C1CV     Cavity 1 Voltage                    17.064178 MV/m
 N:M1C2CV     Cavity 2 Voltage                    16.67264  MV/m
 N:M1C3CV     Cavity 3 Voltage                    16.113113 MV/m
 N:M1C4CV     Cavity 4 Voltage                    14.552796 MV/m
 N:M1C5CV     Cavity 5 Voltage                    24.613668 MV/m
 N:M1C6CV     Cavity 6 Voltage                    23.499992 MV/m
 N:M1C7CV     Cavity 7 Voltage                    20.792583 MV/m
 N:M1C8CV     Cavity 8 Voltage                    .03413584 MV/m

 !QL's
 N:M1C1QL     Cavity 1 Q_L                        2.7442846 E+06
 N:M1C2QL     Cavity 2 Q_L                        2.9939756 E+06
 N:M1C3QL     Cavity 3 Q_L                        3.0295737 E+06
 N:M1C4QL     Cavity 4 Q_L                        2.9861629 E+06
 N:M1C5QL     Cavity 5 Q_L                        3.0660589 E+06
 N:M1C6QL     Cavity 6 Q_L                        3.1288171 E+06
 N:M1C7QL     Cavity 7 Q_L                        2.8952968 E+06
 N:M1C8QL     Cavity 8 Q_L                        2.7168729 E+06

 !Forward Powers
 N:M1C1FW     Forward 1 Magnitude                 103.21085 kW
 N:M1C2FW     Forward 2 Magnitude                 104.74848 kW
 N:M1C3FW     Forward 3 Magnitude                 92.102226 kW
 N:M1C4FW     Forward 4 Magnitude                 76.442551 kW
 N:M1C5FW     Forward 5 Magnitude                 242.12766 kW
 N:M1C6FW     Forward 6 Magnitude                 249.6582  kW
 N:M1C7FW     Forward 7 Magnitude                 178.46548 kW
 N:M1C8FW     Forward 8 Magnitude                 225.17067 kW

 !Reflected Powers
 N:M1C1RW     Reflected 1 Magnitude               .31572366 kW
 N:M1C2RW     Reflected 2 Magnitude               8.9193478 kW
 N:M1C3RW     Reflected 3 Magnitude               1.6670101 kW
 N:M1C4RW     Reflected 4 Magnitude               3.0066853 kW
 N:M1C5RW     Reflected 5 Magnitude               31.069262 kW
 N:M1C6RW     Reflected 6 Magnitude               55.201157 kW
 N:M1C7RW     Reflected 7 Magnitude               6.5667534 kW
 N:M1C8RW     Reflected 8 Magnitude               223.97278 kW


-N:M1FFA      Feed-forward amplitud  .18999682    .18999682
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CM-1 Lessons Learned

- A ‘Lessons Learned’ session was held on Monday 29 August 2011
- The objective was to discuss
  - what we have learned from CM1
  - ways to make improvements for CM2
- Staff from both Technical Division (TD) and Accelerator Division (AD) was present, including scientists, engineers and technicians as well as individuals involved in the Quality Control and Safety aspects of the cavities and cryomodule
- Attendees were encouraged to offer ideas and suggestions for ways to make improvements
- The result of this session is a list of Action Items and Recommendations that will be addressed as quickly as possible to aid CM2 construction

CM-1 Lessons Learned

- ***Dressed Cavities***

1. The plan is to use a higher reliability tuner motor on CM2. Still we need to assure that there is sufficient life cycle testing of these motors before they are attached to CM2 cavities. In addition, a prescribed initial test should be performed to eliminate 'out of the box' failures.
2. Improve the design of the motor shaft set screw attachment.
3. Pressure rating of 2 bar warm and 4 bar cold has been the standard for dressed cavities. As changes are made to the helium vessel to improve weld joints, assure that cavity pressure rating is not reduced. Also continue to investigate the issue of pressurizing dressed cavities that use blade tuners with regards to possible negative impact on piezo tuner operation.
4. In collaboration with SLAC, continue to investigate RF power coupler fabrication and testing with the goal of achieving better fabrication quality, higher reliability and improved performance.

CM-1 Lessons Learned

Cryomodule Assembly

1. Implement the changes prescribed by the CM2 Instrumentation Meetings.
2. Improve alignment of CM2 piping at the interface.
3. Perform ‘as built’ alignment comparison of CM2 versus CM1.
4. Assure that information regarding VAT vacuum valve operation is properly disseminated
5. Leak checks should be performed within acceptable vacuum parameters to assure accuracy.
6. Wherever possible replace ‘cold Conflat flange seals with welded connections (cavity cooldown lines).
7. Use only nitrogen for cavity vacuum vent up.
8. Pay close attention to alignment of Wire Position Monitor mounting pads.
9. Apply superinsulation to the forward lines (5K and 70K) to help with failure conditions.

CM-1 Lessons Learned

Cryomodule Transportation and Storage

1. Have the Alignment Group check cavity alignment before and after transportation (from MP9 to ICB and from ICB to NML) to help quantify effects of transportation.
2. Keep CM2 ends covered and under dry/inert purge to minimize pump down time.
3. Assure that leak checking procedures are consistent between TD (ICB) and AD (NML).

CM-1 Lessons Learned

- ***RF Systems***

  1. Decide on the amount of the RF distribution system that needs to be removed in order to do the cryomodule swap

CM-1 Lessons Learned

- ***Cryomodule Installation and Commissioning***

  1. Review the process for removing CM1 and installing CM2 and write a Job Hazard Analysis (if appropriate).

  2. Keep CM2 ends covered and under dry/inert purge to minimize pump down time.

Summary

- Cold operation of CM-1 has been in progress since November 2010
- Single cavity evaluation is complete
- Module operation is proven
- Completing Study Plan including ILC, P-X measurements
- Study Plan to be complete by end of Calendar Year
- Applying ‘Lessons Learned’ from CM-1 to future cryomodules