Recent STC Test Results

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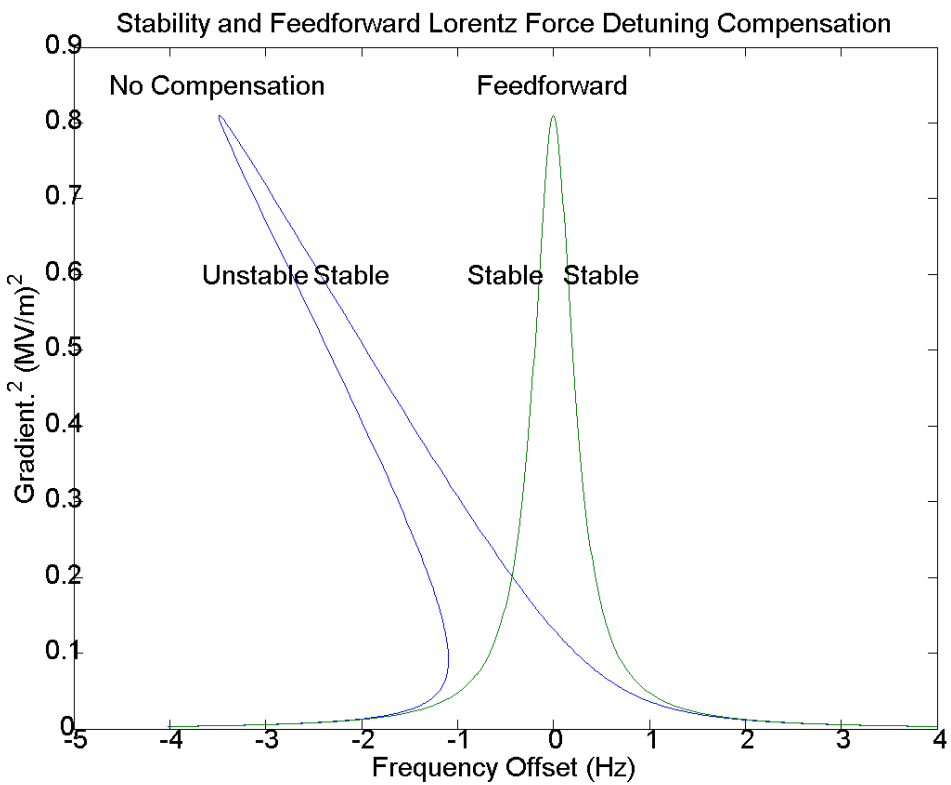
PIP-II Weekly Meeting

Introduction

- Resonance Control has had an extended set of test time at STC while waiting for the next SSR1 cavity to be ready for testing. We estimate 80 working days of testing time, an up time of 60%.
- This extended testing time allowed extensive studies of:
  - Signal qualities/RF circuit
  - Detuning calculation and implementation
  - Feedback/Compensation techniques
- Development of a complementary Self-Excited Loop testing system
- These techniques were developed, coded, and refined first for CW operation, then in pulsed operation.
- This work gives a solid foundation for further testing going forward including different cavity geometries.

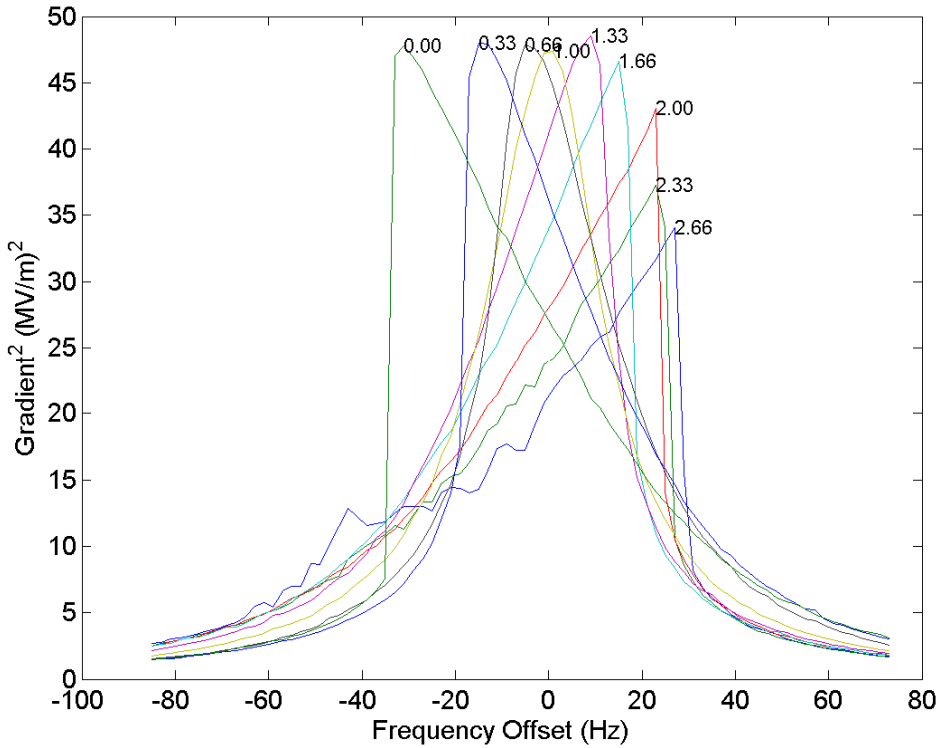
Ponderomotive Instabilities

- Lorentz force detunes cavity
- If detuning is more than several bandwidths cavities can become unstable
  - Small perturbations can cause the cavity field to suddenly crash to zero



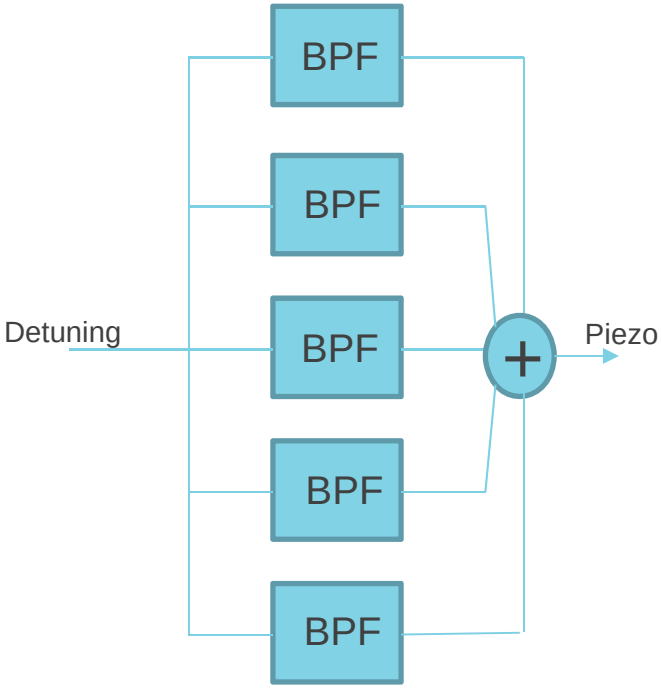
Feed-Forward LFD Compensation

- Possible to remove the instability using piezo feed-forward tied to cavity square of gradient
  - Previously shown for SSR1 spoke resonator
  - Now demonstrated for multi-cell elliptical cavities



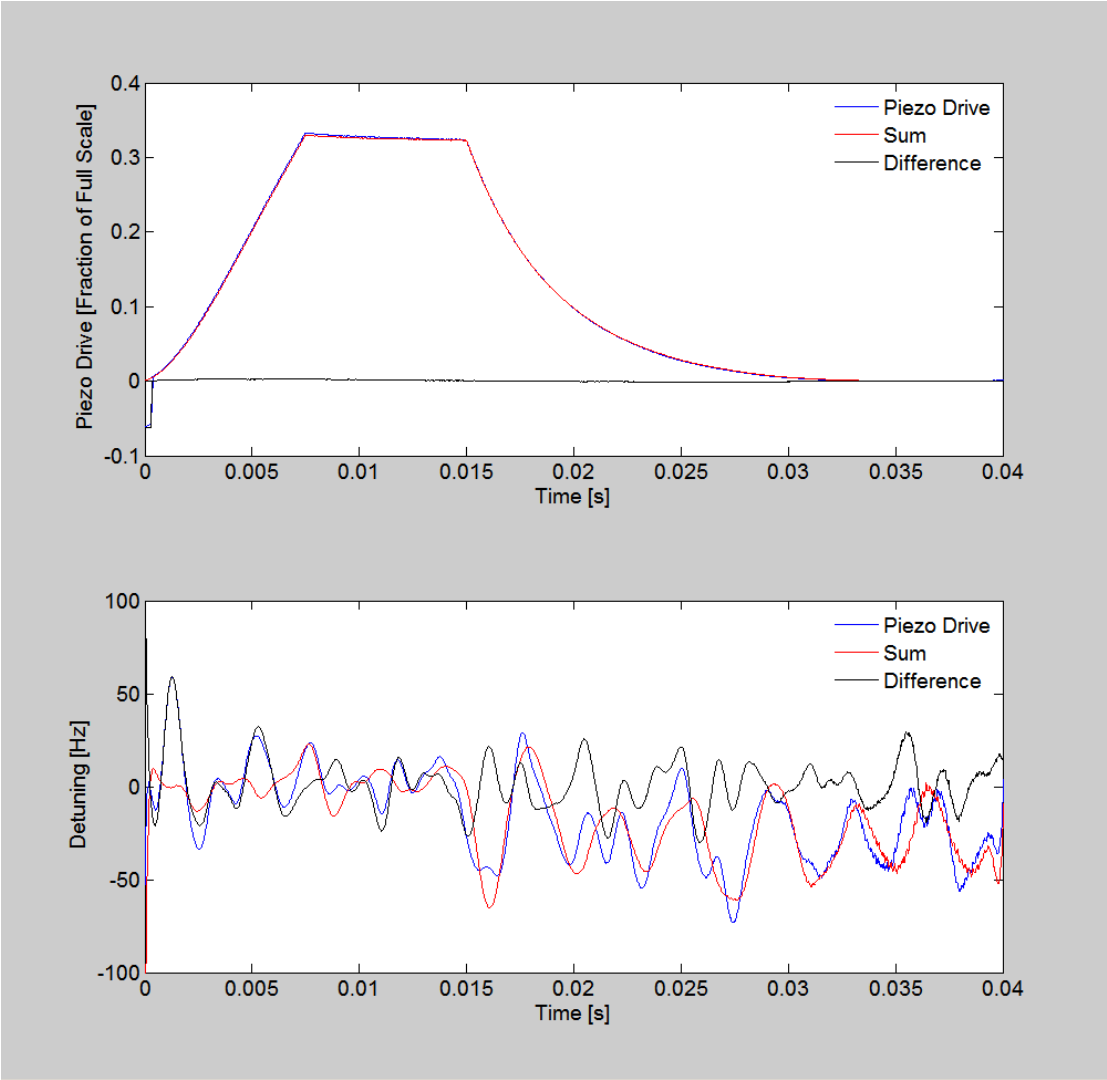
Feedback

- Online detuning calculation fed to filter bank
- Frequency, decay time and gain can set for each filter in the bank
- Outputs summed and fed to piezo
- 0 Hz stabilizes cavity against pressure drift
- Dominant resonances observed at 20 and 200 Hz
- Filter parameters set manually

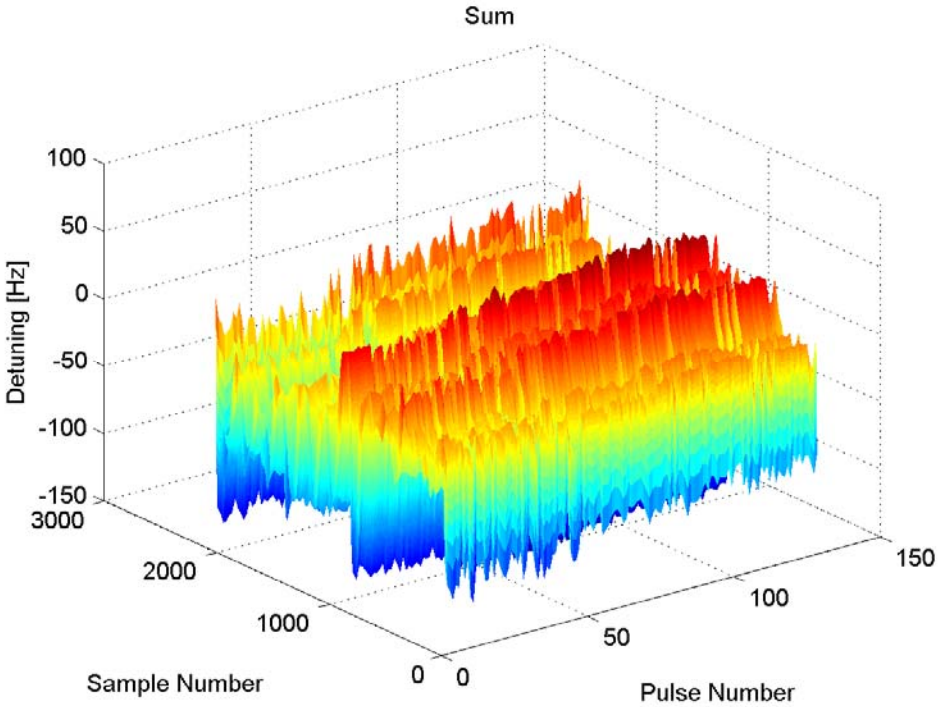


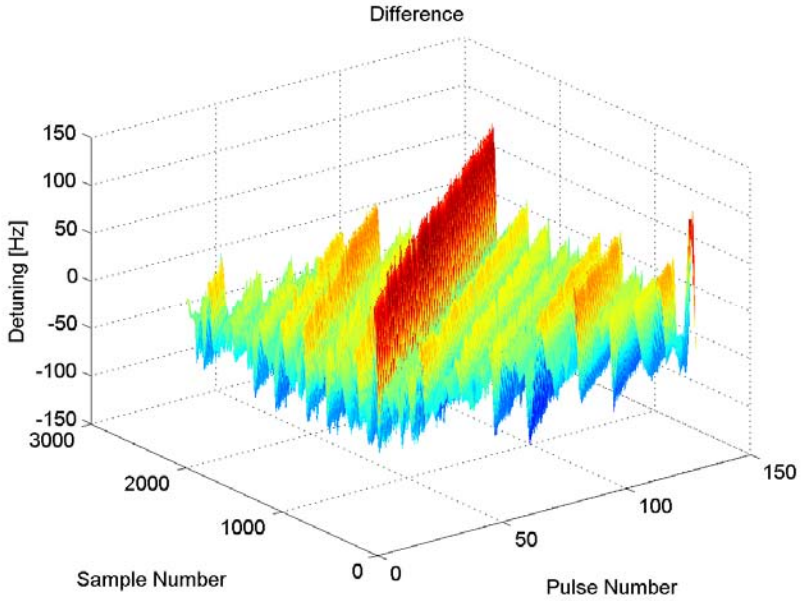
Delay Scan

- Piezo excited by series of positive and negative impulses at different delays with respect to the RF pulse
- Sum and difference of detuning from positive and negative impulses allow impulse response to be separated from background detuning



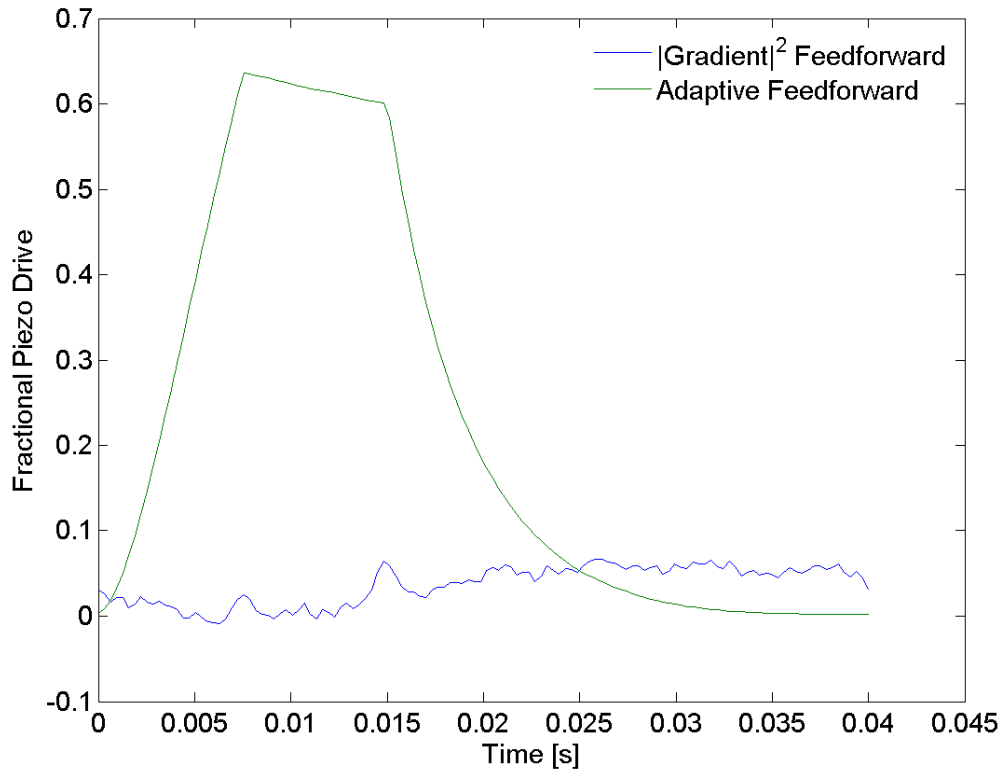
Detuning Sum and Difference





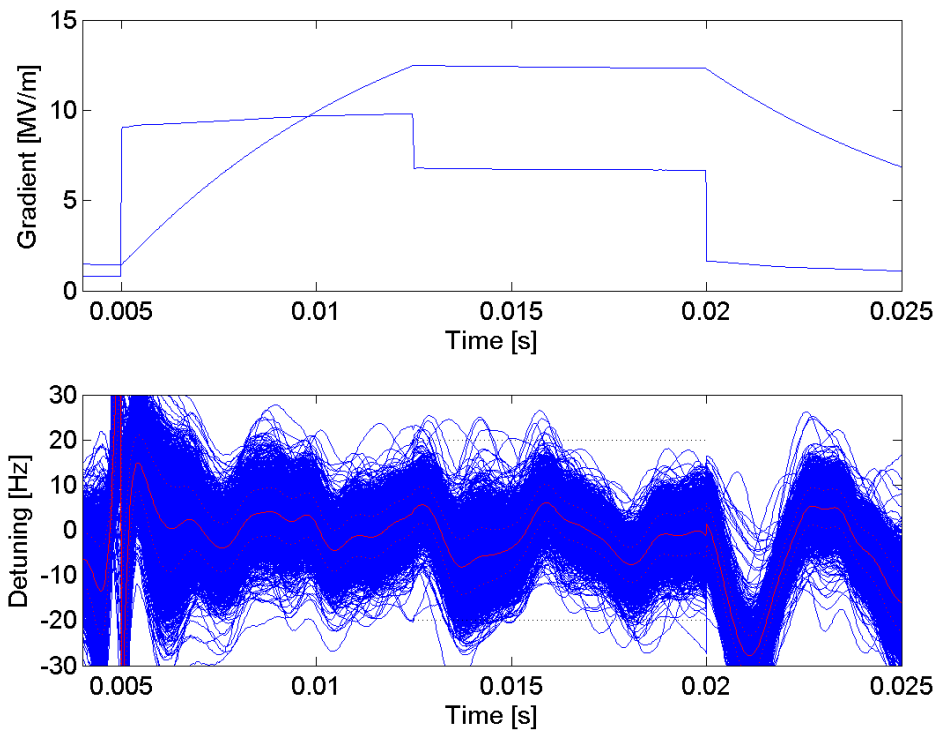
Detuning to Piezo Transfer Function

- Pseudo inverse $((x^T x)^{-1} x^T)$ of difference times detuning gives the piezo waveform that would produce that detuning (up to a scale factor)
- Negative of transfer function times detuning from deterministic sources can be cancel detuning



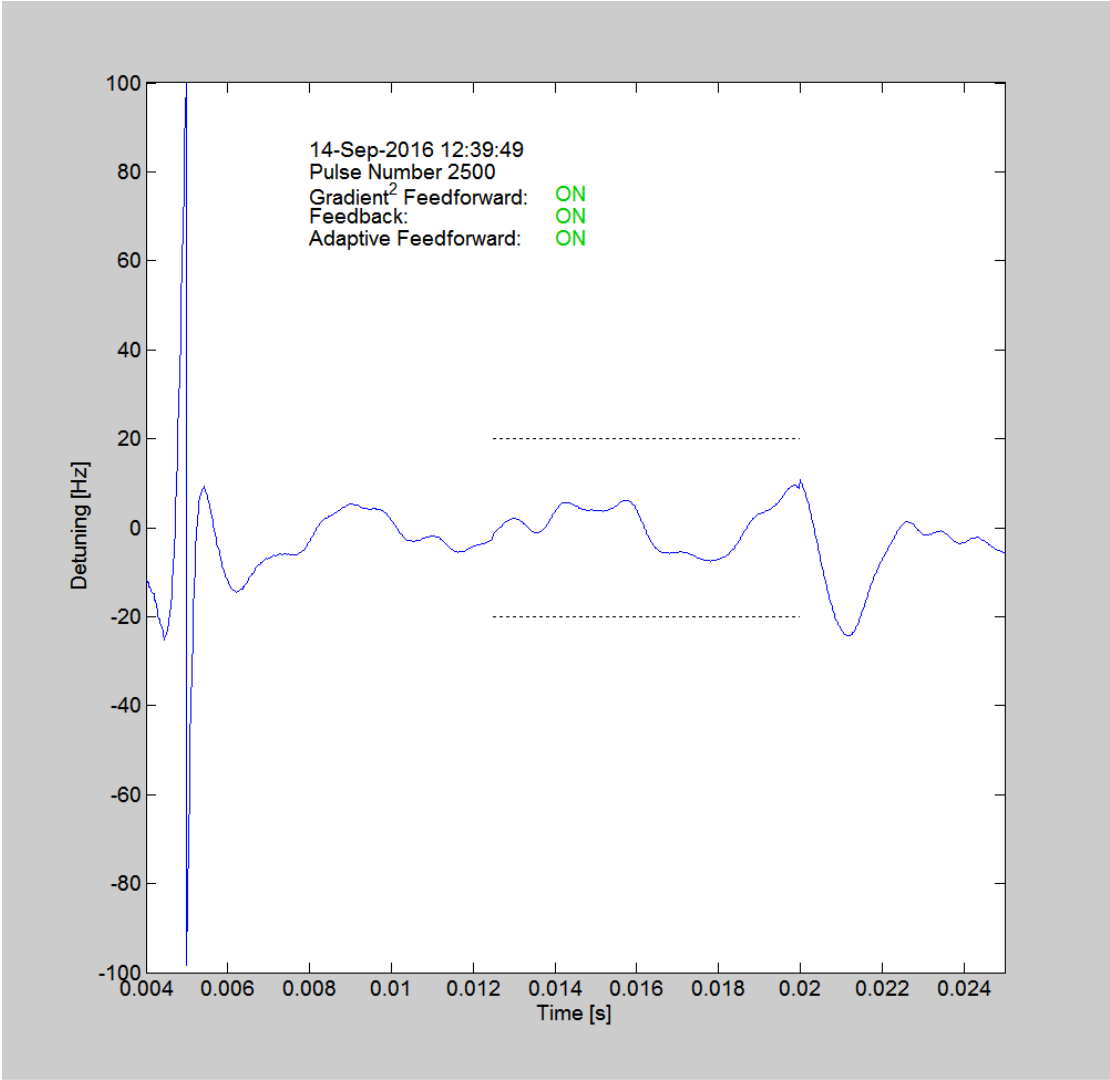
Test Conditions

- PIP-II nominal operating conditions
  - 12.5 MV/m
  - 20 Hz repetition rate
  - 15% duty cycle
  - 0.5ms flattop
- STC operating condition
  - >12.5 MV/m
  - 25 Hz repetition rate
  - 7.5 ms fill
  - 7.5 ms flattop



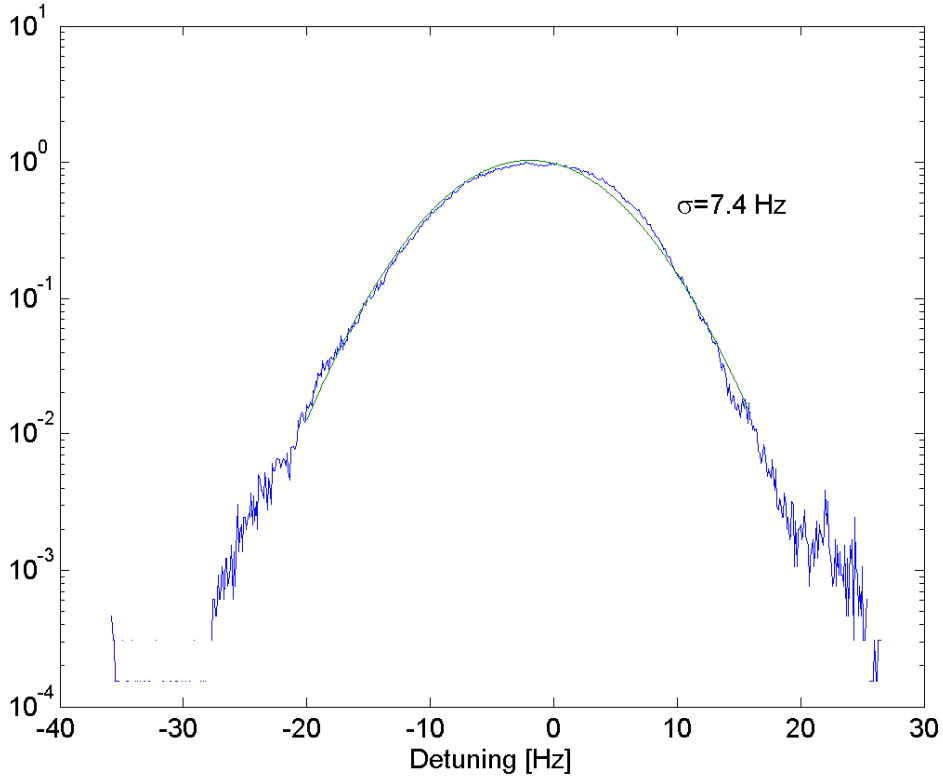
Real-time Detuning Waveforms

- Cavity run with gradient Feedforward, feedback tuned up in CW and adaptive Feedforward
- Adaptive turned off at pulse 2706 and back on at pulse 2841



Preliminary Offline Analysis

- Within a factor of 2 of PIP-II specs
- Improvements in feedback may help
  - May be possible to automatically extract optimal coefficients from delay scan data
- Critical to verify gradient calibration
  - Calibration may have shifted by up to 50% by following recent warmup
  - Unable to recalibrate due to lack of time



Plans for the Future

- Major improvements in firmware and software including
  - Improved internal diagnostics
  - Improved detuning calculation
  - More clearly defined collection of viable compensation algorithms
- Next test
  - Improve feedback filter-bank coefficient generation
  - Comprehensive performance measurements
    - Gradient calibration
    - LFD coefficients
    - Long term stability
  - Definitive statement about our ability to compensate SSR1 cavities

PIP-II Cavities

CM	Freq	Eacc_min	Eacc_max	CM	Cav/CM	Eacc	deltaE	Q0	Static Loss per CM	Total Loss per CM	Kappa_LFD	LFD	Q_L	Δf	f_{1/2}=f/(2 Q_L)	Δf_Microphonics
	MHz	Mev	Mev			MV/m	MeV		W	W	Hz/(MV/m2)^2			Hz	Hz	Hz
HWR	162.5	2	11	1	8	3.2	1.7	5.00E+09	14	24			3.30E+06	50	**24.6**	**20**
SSR1	325.0	11	38	2	8	10	2.05	5.[illegible]E+[illegible]	16	27	1.5	**150**	5.80E+06	56	**28.0**	**20**
SSR2	325.0	38	177	7	5	11.2	5.32	1.20E+10	8.[illegible]	52			7.20E+06	45	**22.6**	**20**
LB 650	650.0	177	480	5	6	16.5	11.6	1.50E+10	8.[illegible]	53	1	**272**	1.40E+07	46	**23.2**	**20**
HB 650	650.0	480	800	4	6	17.5	17.7	2.00E+10	6.2	153	1	**306**	1.40E+07	46	**23.2**	**20**

April 15, 2014

- Current PIP-II detuning requirements are **EXTREMELY AGGRESSIVE**
  - Active compensation would almost certainly be required for every cavity type even in CW operation
  - Pulsed operation leads to significant complications
    - LFD drives mechanical resonances
    - Only able to measure microphonics accurately when RF in cavity
- **Not clear that even state of the art active control will be good enough**

Conclusion

- Extended test time provided opportunity to try new approaches
  - Very reliable operation over last few months
  - Clearer path forward
    - Feedforward proportional to resonance can stabilize ponderomotive effects
    - Feedback can stabilize against pressure variations
    - Improvement using adaptive feedforward indicates that dominant source of vibration is radiation pressure from the RF pulse
- Currently within a factor of 2 of PIP-II specs for SSR1
  - Specs may have already been met if current AD/LLRF calibration is correct
  - Gradient calibration needs to be checked carefully at next opportunity
- Data still being analyzed
- Next test should allow definitive statement about our ability to compensate SSR1 cavities to required levels
- PIP-II detuning specifications are still VERY AGGRESSIVE, SSR2 and 650 cavities are still complete unknowns