Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

SRF 19 DRESDEN

CBETA
Cornell-BNL ERL Test Accelerator

Active Suppression of Microphonics Detuning in High Q_L Cavities

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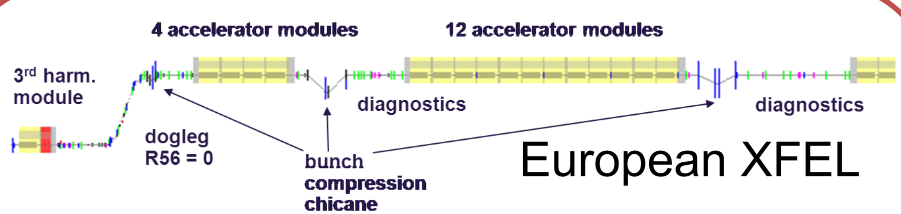
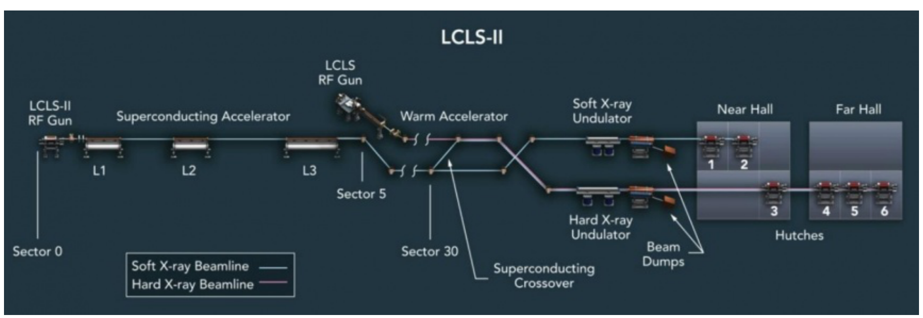
Overview

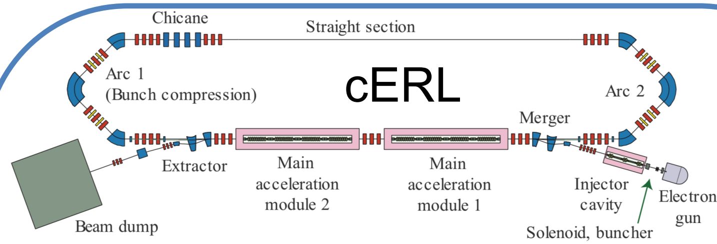
- Introduction
- Tuner Characteristics
- Narrowband Active Noise Control
- Modification
- Results
- Conclusion

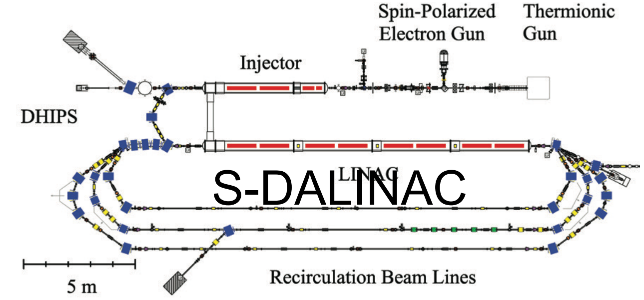
Introduction

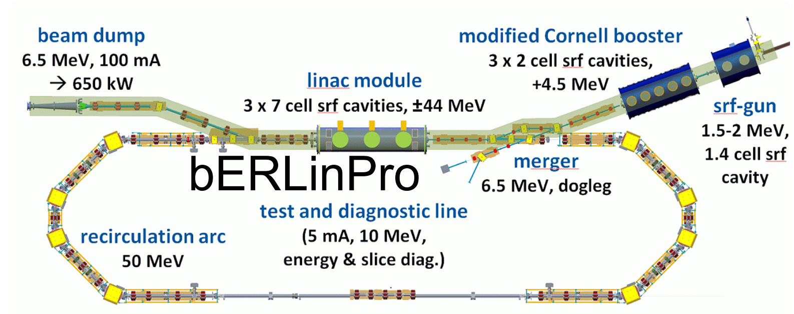
- Energy Recovery Linacs and some Free Electron Lasers require SRF cryomodules with low to zero beam loading.
- Almost all RF power is used to maintain stable field.
- We can operate using high loaded quality factors (~ 10^8) and reduce average power requirements.

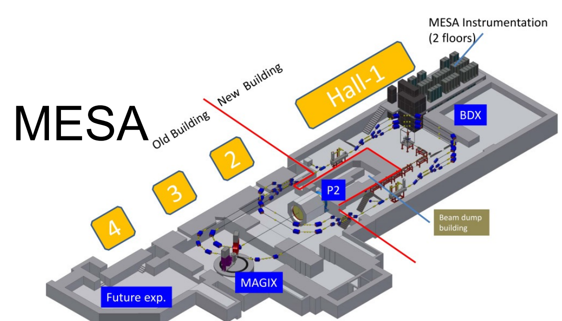




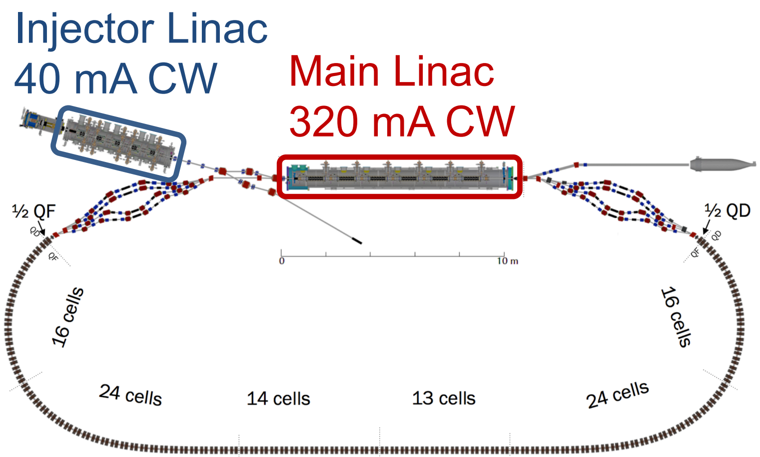




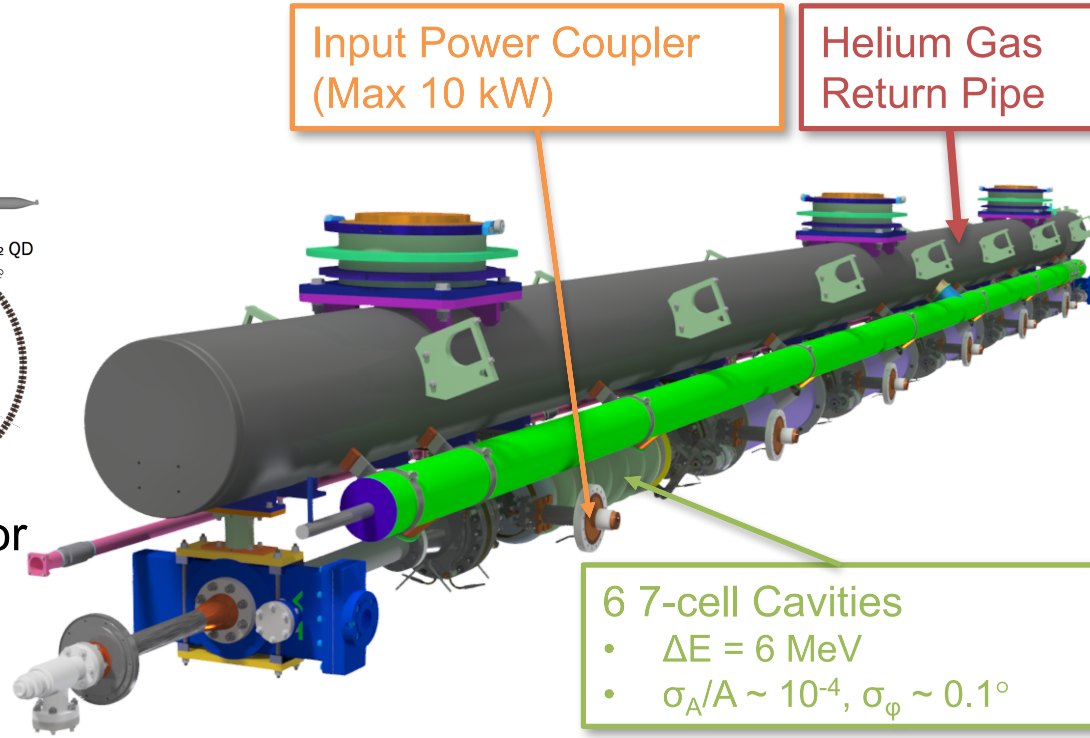


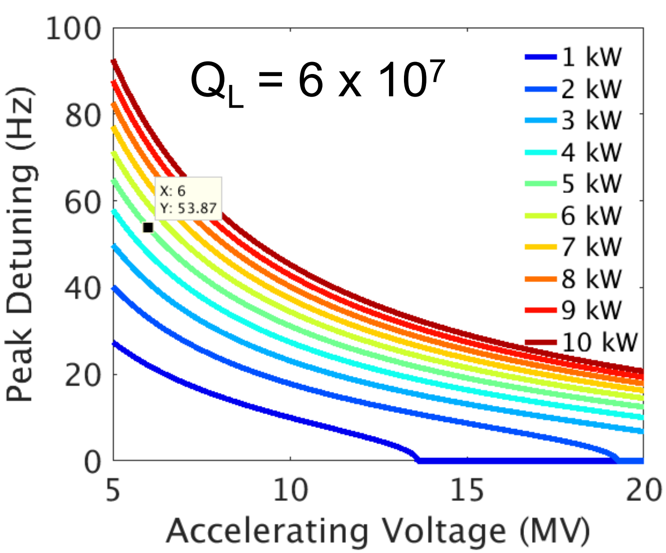


Introduction: CBETA



Cornell-BNL ERL Test Accelerator



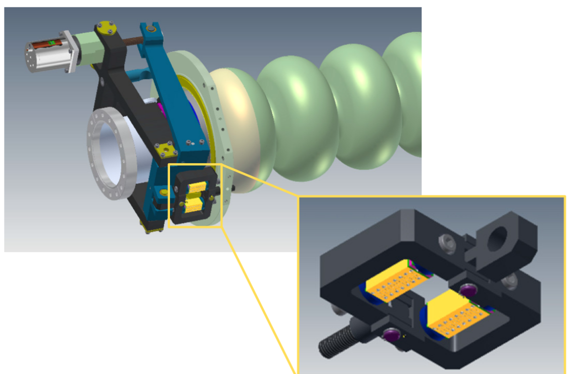


The peak detuning of the cavity must be less than **54 Hz** in order to sustain a cavity voltage of 6 MV using a power amplifier capable of delivering **5 kW**.

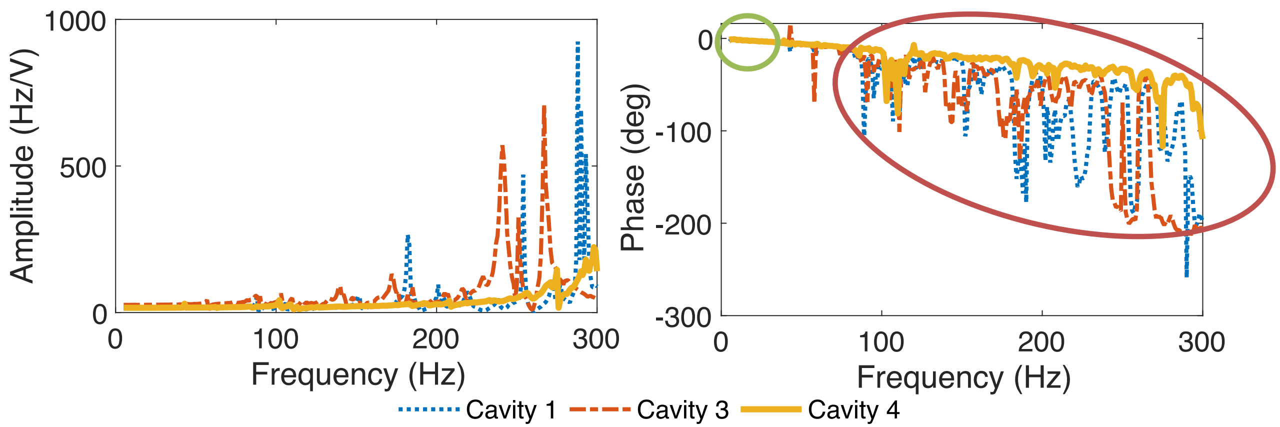
Tuner Characteristics

Mitigation of vibration sources is the preferred method of reducing peak microphonics detuning, but having an active control system is also necessary!

As an example, the CBETA Main Linac 7 cell cavities are attached to a tuner based on the Saclay I design with added fast actuators.



Piezo-electric Stack



Observations:

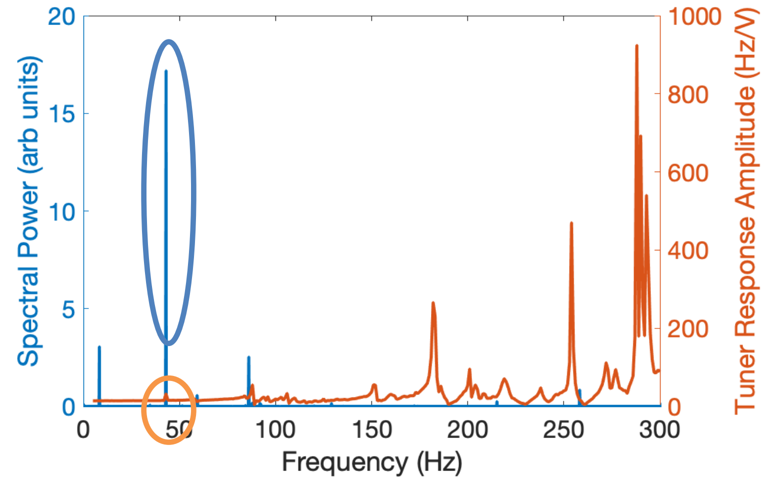
1. Phase response is almost 0° up to 30 Hz, this makes it ideal for proportional integral feedback control.
2. For higher frequencies of the phase response is very noisy, especially for un-stiffened cavities.
3. The mechanical eigenmodes of stiffened cavity starts at a higher frequency and in general has a smaller response amplitude.

Narrowband Active Noise Control

Our microphonics lines are fairly narrowband.

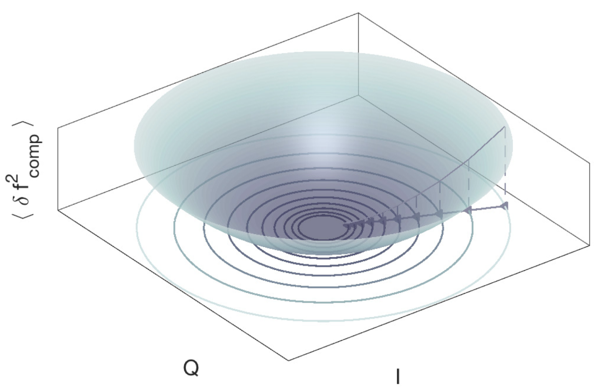
Assumptions:

1. The detuning can be described as slowly varying sine waves.
2. The tuner response around the relevant frequency can be treated as a constant complex number.

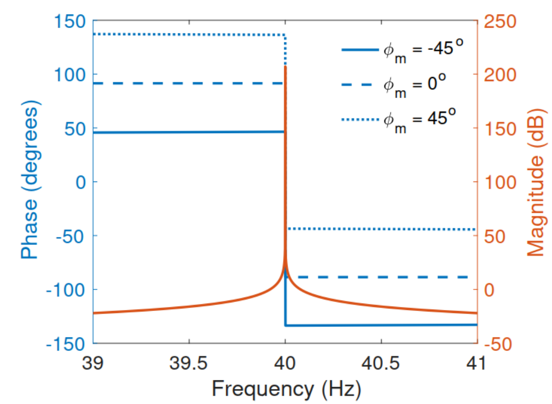


We can compensate for narrowband microphonics detuning by applying a sum of sine waves on the actuator. (Narrowband Active Noise Control (ANC))

Problem: Adjust I_m and Q_m to modulate the carriers at frequencies ω_m to reduce detuning.



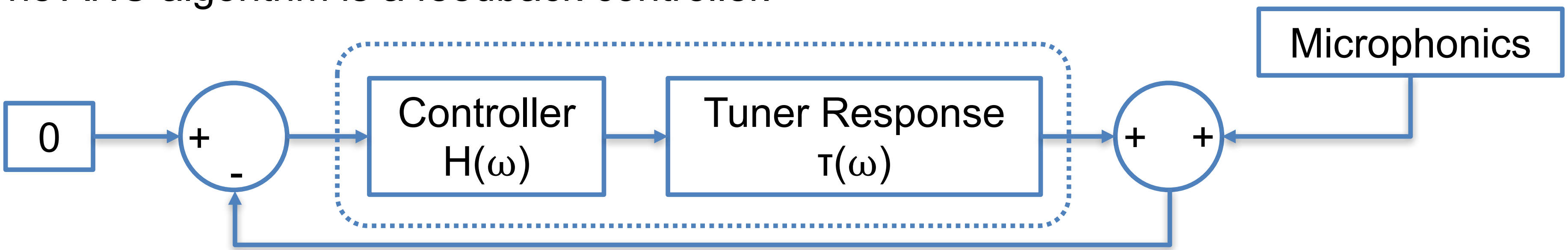
Equivalent to a set of Bandpass Filters



Fixed Parameters: Learning Rate (gain) μ_m and Controller Phase φ_m

Stability

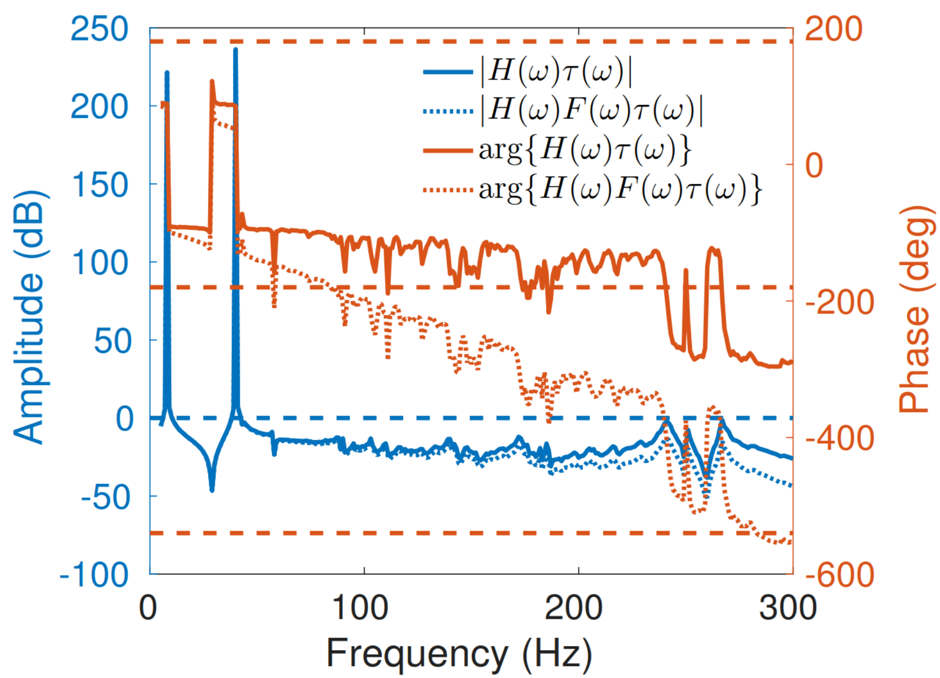
The ANC algorithm is a feedback controller.



The controller phase φ_m and the gain μ_m determine the stability of the controller.

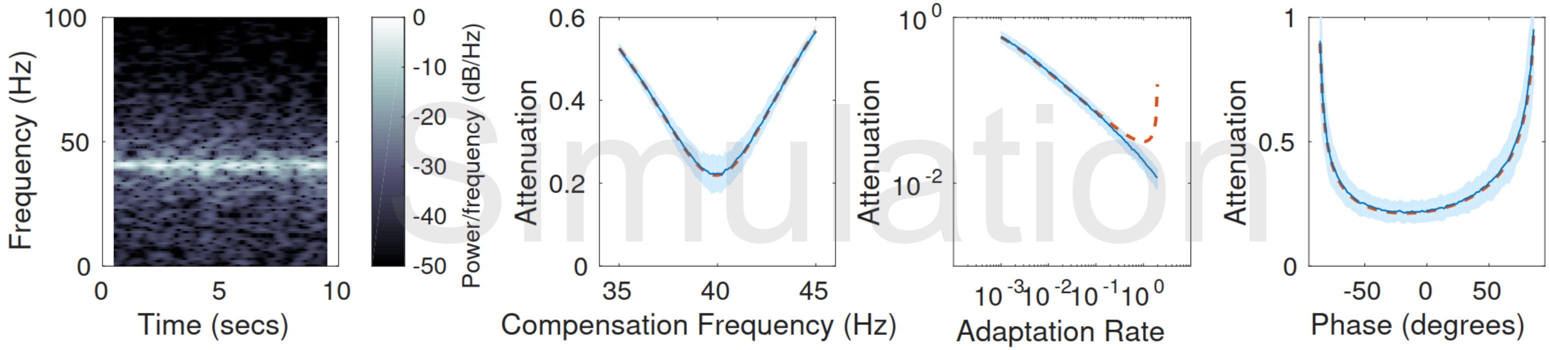
Tuner resonances also affect stability.

We use a FIR low pass filter to suppress resonances above 200 Hz.

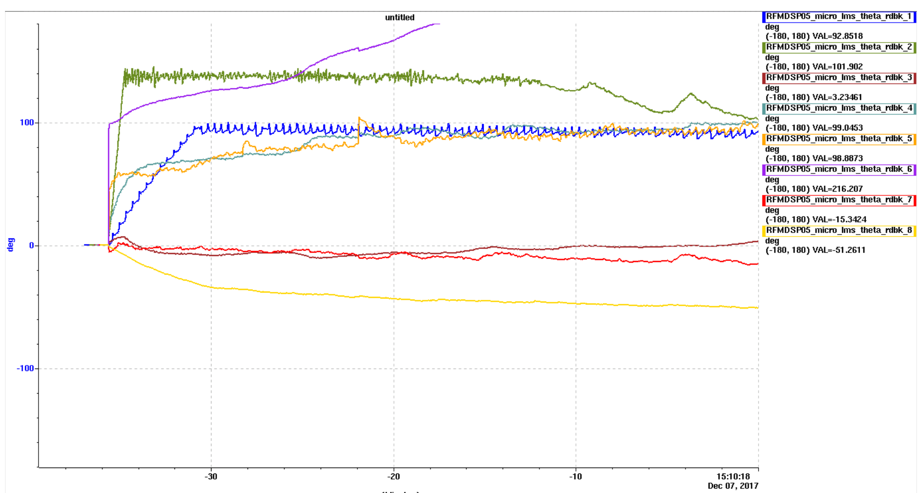


Phase Adaptation

How to choose controller parameters?



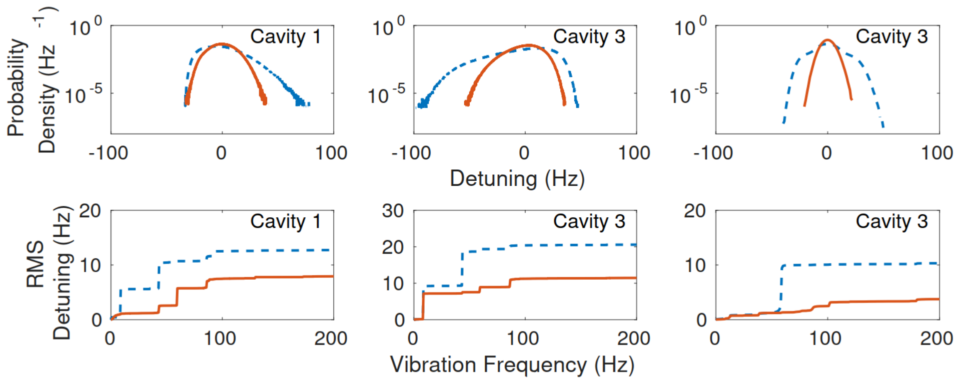
Instead of depending on transfer function measurements, use Least Mean Square (LMS) to determine optimum controller phase in-situ and introduce η_m

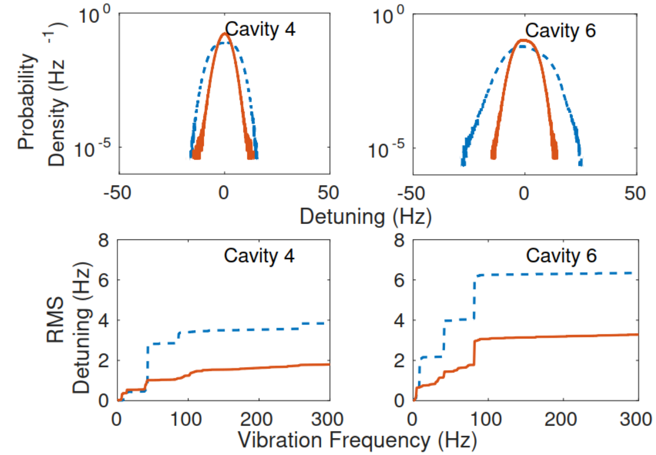


The modified ANC algorithm estimates the phases and keeps them in the stable region even if the transfer function changes.

Results

The modified narrowband ANC was tested on some cavities of the main linac.





Run Description	Peak Detuning (Hz)		RMS Detuning (Hz)	
	ANC Off	ANC On	ANC Off	ANC On
Cavity 1 with JT and precool static	78	45	13.6	9.1
Cavity 3 with JT and precool static	100	57	20.8	11.7
Cavity 3 with JT and precool static and 5 K valve modified	50	22	10.7	4.6
Cavity 4 with JT and precool static	17	19	4.4	2.4
Cavity 6 in original configuration	30	15	6.4	3.4

The algorithm is effective and stable over hours of operation! No mechanical coupling with neighboring cavities because of bellows in our cryomodule.

Conclusions

- **High Loaded Quality Factors**

  Many modern accelerators with low beam loading are pushing the limits on loaded quality factors up to 10^8. While reducing average power requirements, this makes the system very sensitive to microphonics.

- **Microphonics Suppression**

  Passive mitigation of vibration sources is the method of choice. In addition, we use fast tuners to achieve active microphonics compensation.

- **Narrowband Active Noise Control**

  With narrowband microphonics, we can use the ANC feedback control system whose stability is determined by the controller gains and phases.

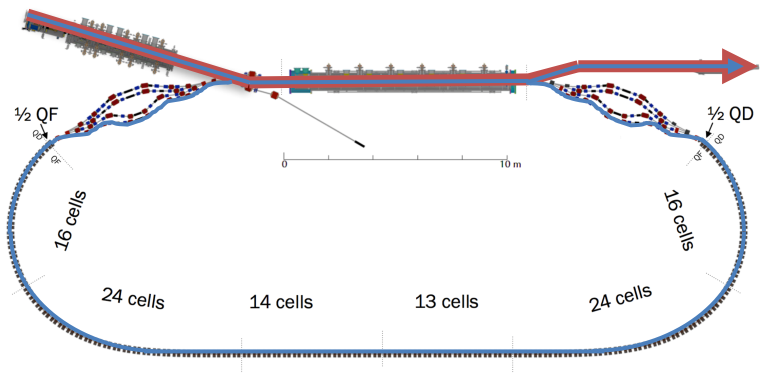
- **Phase Adaptation**

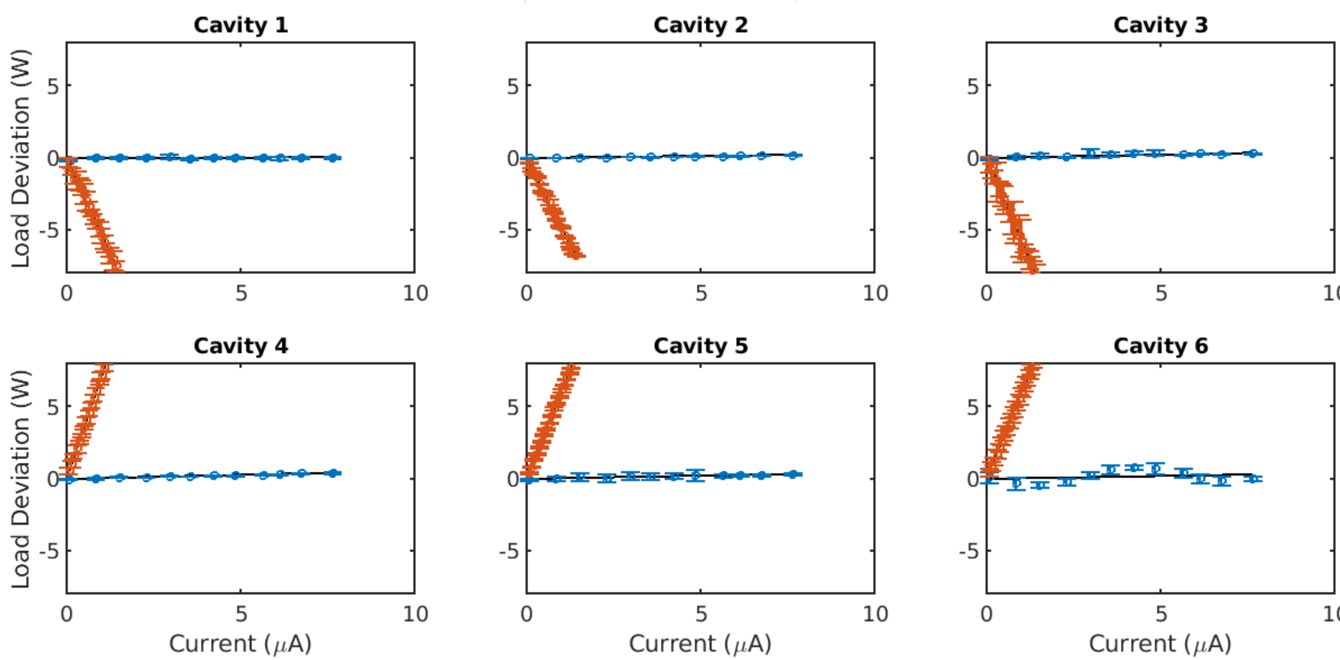
  We introduced phase adaptation based on the Least Mean Square approach, which makes ANC more robust towards changes in the tuner response.

- **Results**

  We demonstrated stable and effective operation of the algorithm with beam over multiple hours with almost a factor of 2 reduction in the peak detuning on both stiffened and un-stiffened cavities.

Energy Recovery at 8 μA





We have reached single pass energy recovery up to 8 μA and measured a net energy balance of 99.6 ± 0.1 %

Acknowledgements

The RF and cryogenics team:

Georg Hoffstaetter, Roger Kaplan, Matthias Liepe, Peter Quigley, Dan Sabol, James Sears, Colby Shore, Eric Smith, Vadim Vescherevich

And the rest of the team!

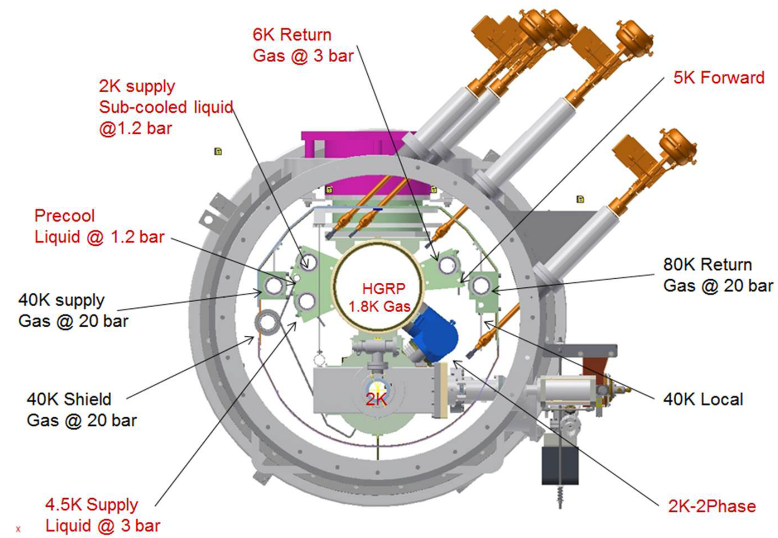
J. Barley, A. Bartnik, I. Bazarov, J. S. Berg, S. Brooks, D. Burke, J. Crittenden, K. Deitrick, J. Dobbins, R. Gallagher, C. Gulliford, B. Heltsley, R. Hulsart, J. Jones, D. Jusic, D. Kelliher, V. Kostroun, B. Kuske, Y. Li, W. Lou, G. Mahler, M. McAteer, F. M´eot, R. Michnoff, M. Minty, R. Patterson, S. Peggs, V. Ptitsyn, T. Roser, D. Sagan, K. Smolenski, S. Trabocchi, J. Tuozzolo, N. Tsoupas, J. Völker, D. Widger

Thank you!

Appendix 1: Cryogenic System

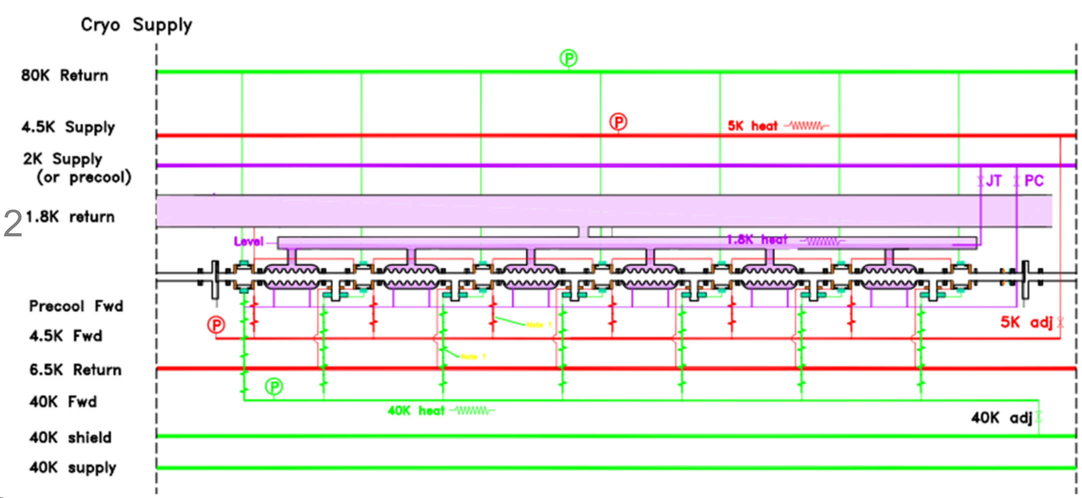
Three subsystems:

1. 40 K / 80 K
   Thermal shield, input couplers, HOM loads.
2. 4.5 K/ 6.5 K
   Input couplers, beam pipe.
3. 2 K/ 1.8 K
   Cavities.

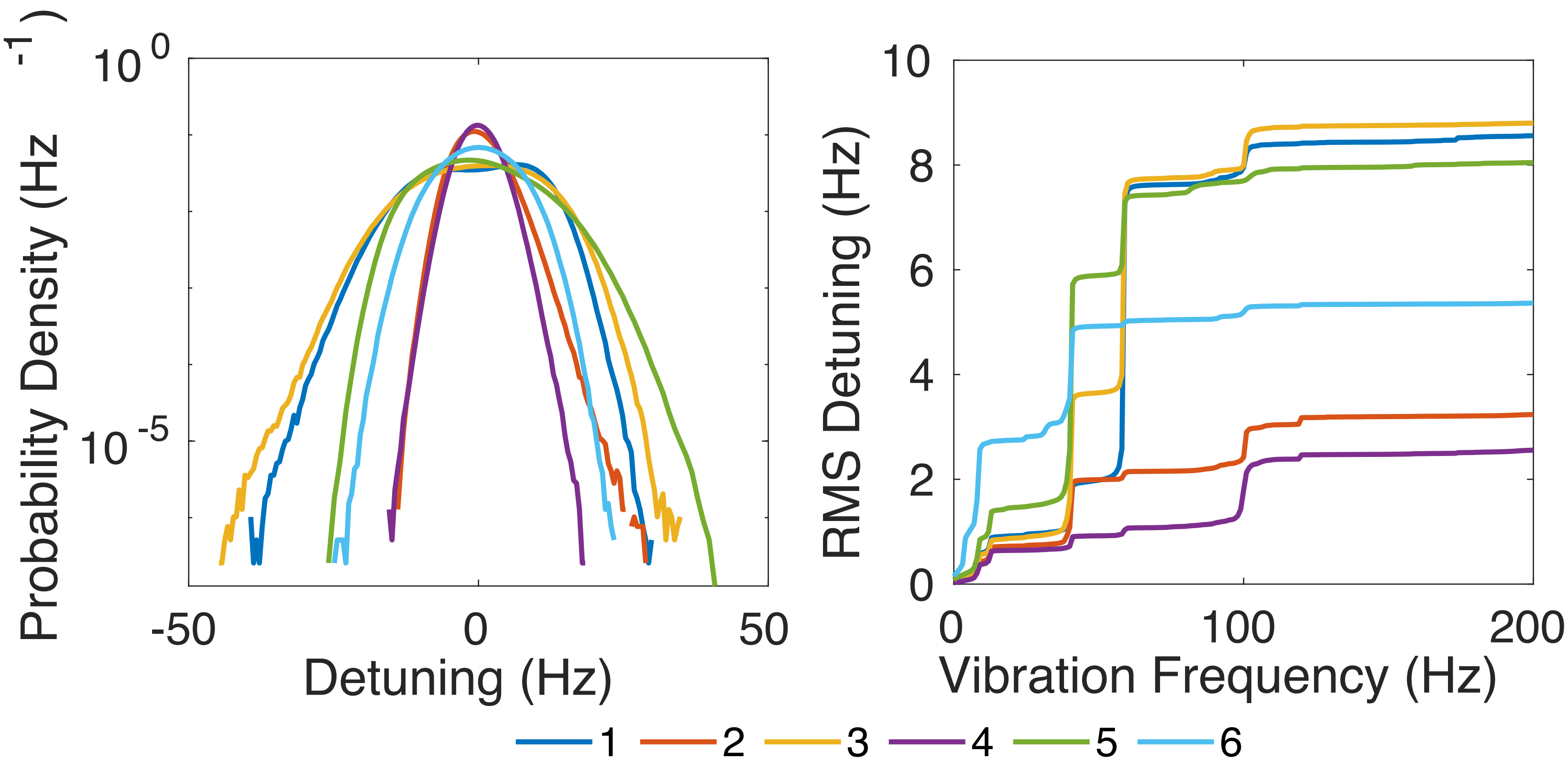


2 K liquid Helium system controlled by:

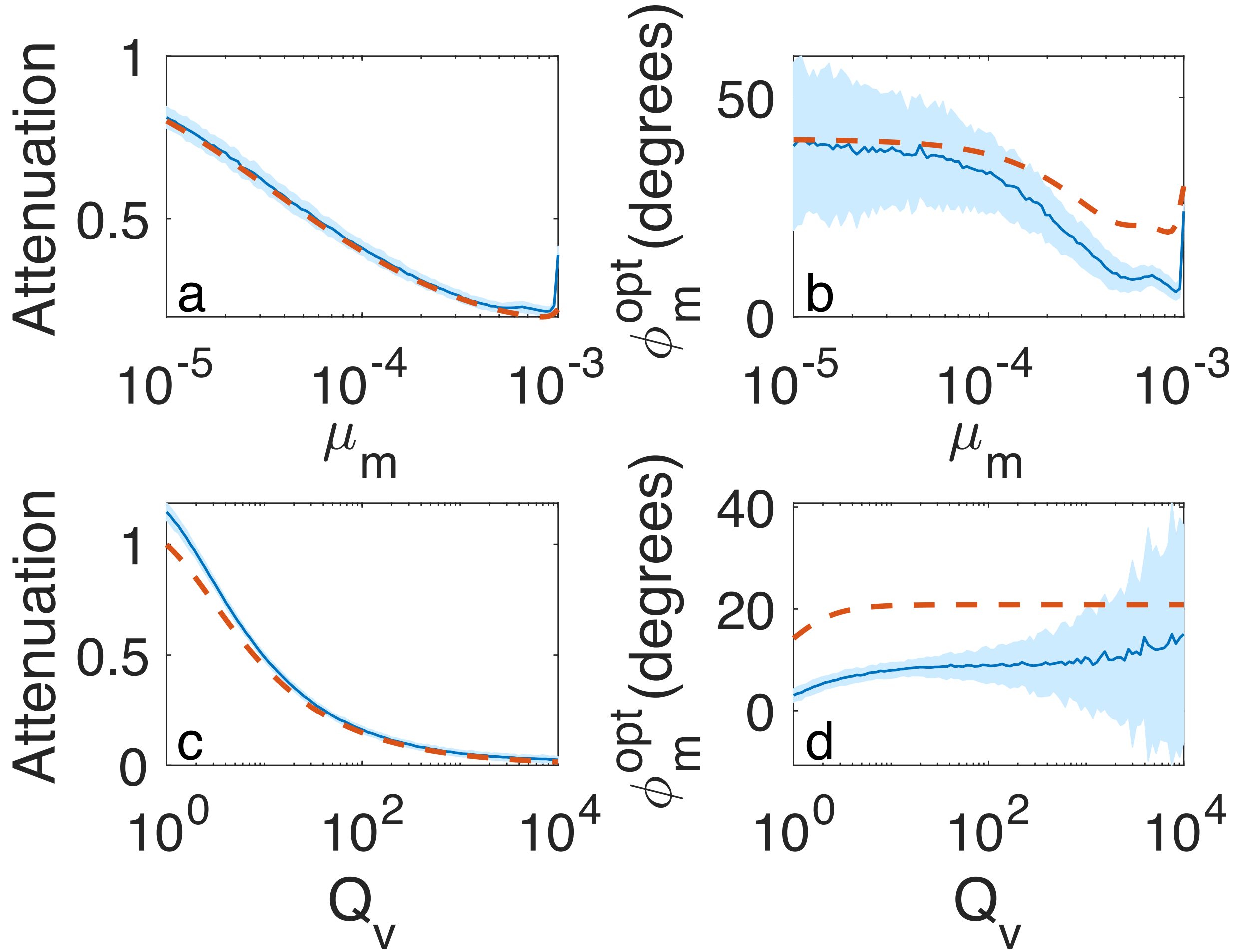
1. Pneumatic Joule-Thomson (JT) and precool valve.
   Controls amount of LHe entering the 2 K 2 phase pipe.
2. 2 K 2 Phase heater
   Adds heat load if necessary.
3. Pump Skid
   Controls vapor pressure in 2 K 2 phase pipe supplying to the Helium vessels thus controlling bath temperature.



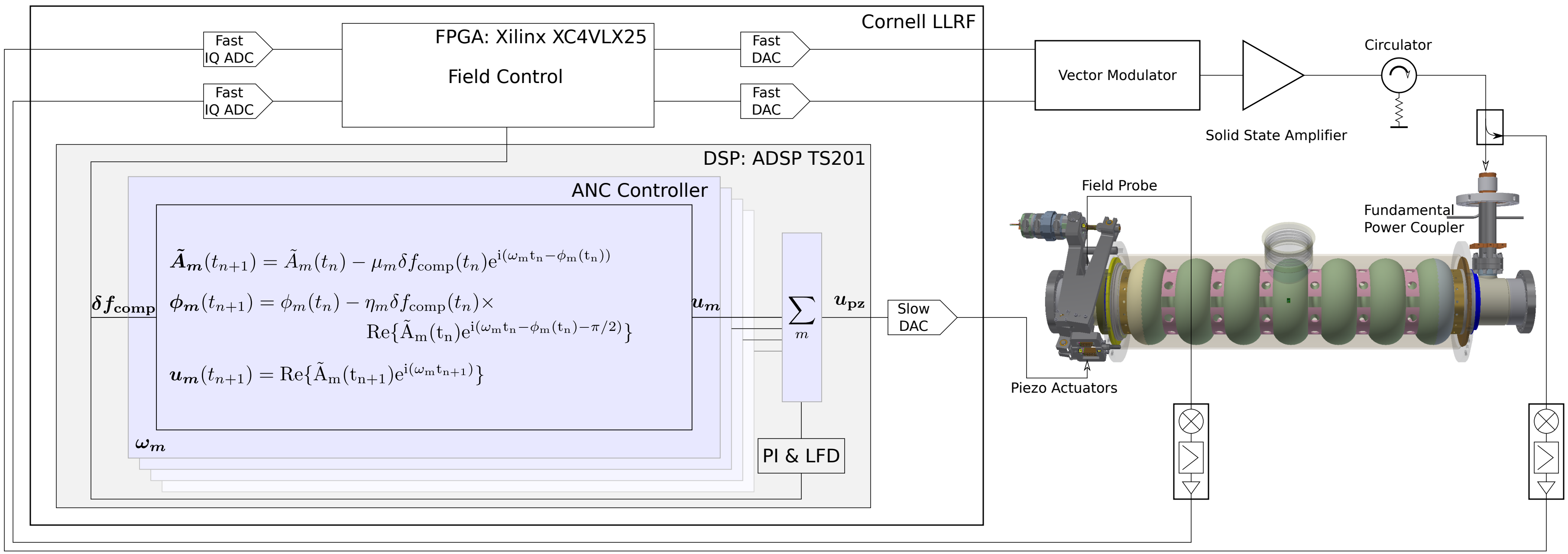
Appendix 2: Current Microphonics



Appendix 3: Theoretical Bounds



Appendix 4: Implementation



- The Cornell LLRF incorporates a FPGA for field control in Generator Driven Resonance (GDR) mode which operates on the 12.5 MHz IF signals.
- The field probe and forward power signals are used to calculate detuning.
- A DSP chip incorporates the modified ANC, proportional-integral and the LFD controller running at 10 kHz.