

# Performance of the LLRF System for the Fermilab PIP-II Injector Test

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## Introduction

- PIP-II IT is a test facility for the PIP-II project where the injector, warm front-end and the first two superconducting cryomodules were tested.
- The RF system consists of an RFQ, 3 Buncher cavities, an 8-cavity half-wave-resonator(HWR) cryomodule, and an 8-cavity single-spoke resonator(SSR1) cryomodule.
- The LLRF systems for both cryomodules and Bunchers 2 and 3 use an SOC FPGA based controller whereas the RFQ and Buncher 1 use an FPGA/DSP board in a VXI crate.
- For resonance control, the HWR cavities use a pneumatic tuner and the SSR1 cavities use a stepper motor/piezo tuner. The resonance controller chassis used is the one from LCLS-II.
- The user interfaces include EPICS, Labview and ACNET.
- Testing of the RF system has been completed with 2 mA beam accelerated to 20 MeV.
- Performance of the system was shown to meet PIP-II requirements

## Amplitude and Phase Regulation

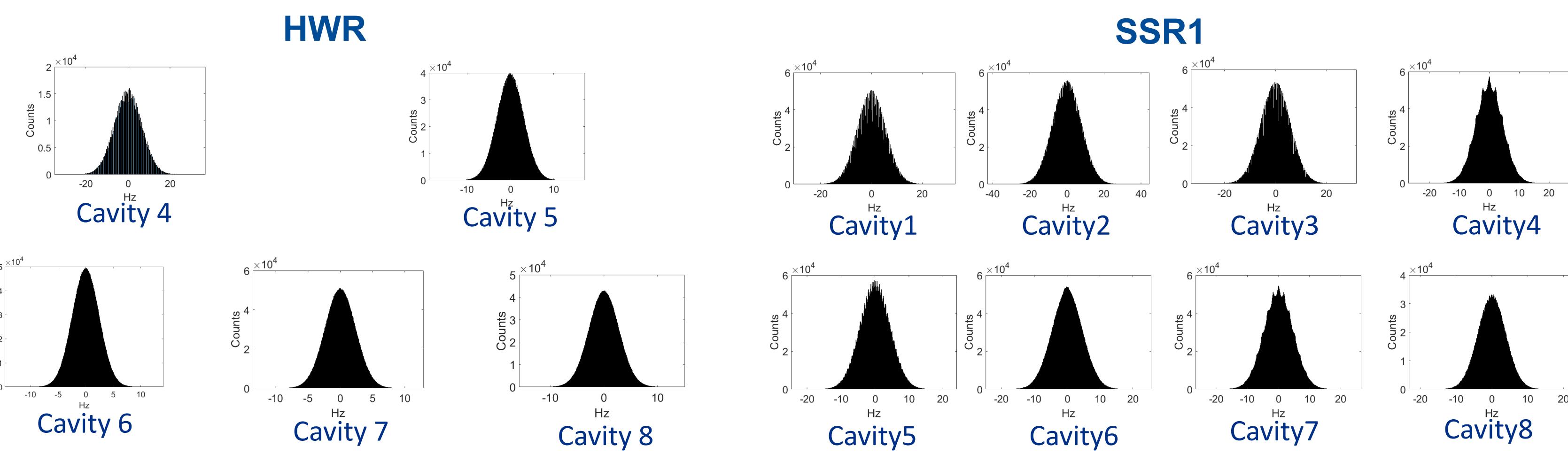
HWR Amplitude and Phase Regulation							
Cavity Field Setpoint (MV/m)	Cavity4	Cavity5	Cavity6	Cavity7	Cavity8		
2.89	6.04	8.94	8.5	8			
Amplitude Regulation (rms) %	0.0135	0.0106	0.0101	0.0081	0.0103		
Phase Regulation (rms) deg	0.0228	0.0065	0.0056	0.0055	0.0062		
Feedback Proportional Gain	1000	1000	1000	1000	1000		
Feedback Integral Gain (rad/sec)	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000		

SSR1 Amplitude and Phase Regulation								
Cavity1	Cavity2	Cavity3	Cavity4	Cavity5	Cavity6	Cavity7	Cavity8	
4.88	4.63	4.78	7.32	7.8	7.56	7.32	10	
Amplitude Regulation (rms) %	0.0194	0.0289	0.0219	0.0157	0.014	0.0158	0.0147	0.0124
Phase Regulation (rms) deg	0.0116	0.0164	0.0118	0.0091	0.0088	0.0093	0.0092	0.0076
Feedback Proportional Gain	1600	1600	1600	1600	1600	1600	1600	1600
Feedback Integral Gain (rad/sec)	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000

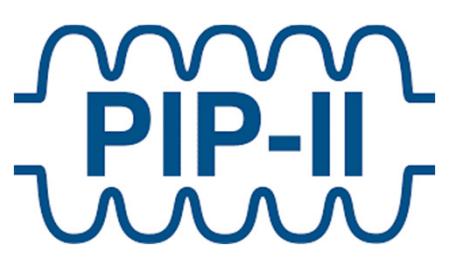
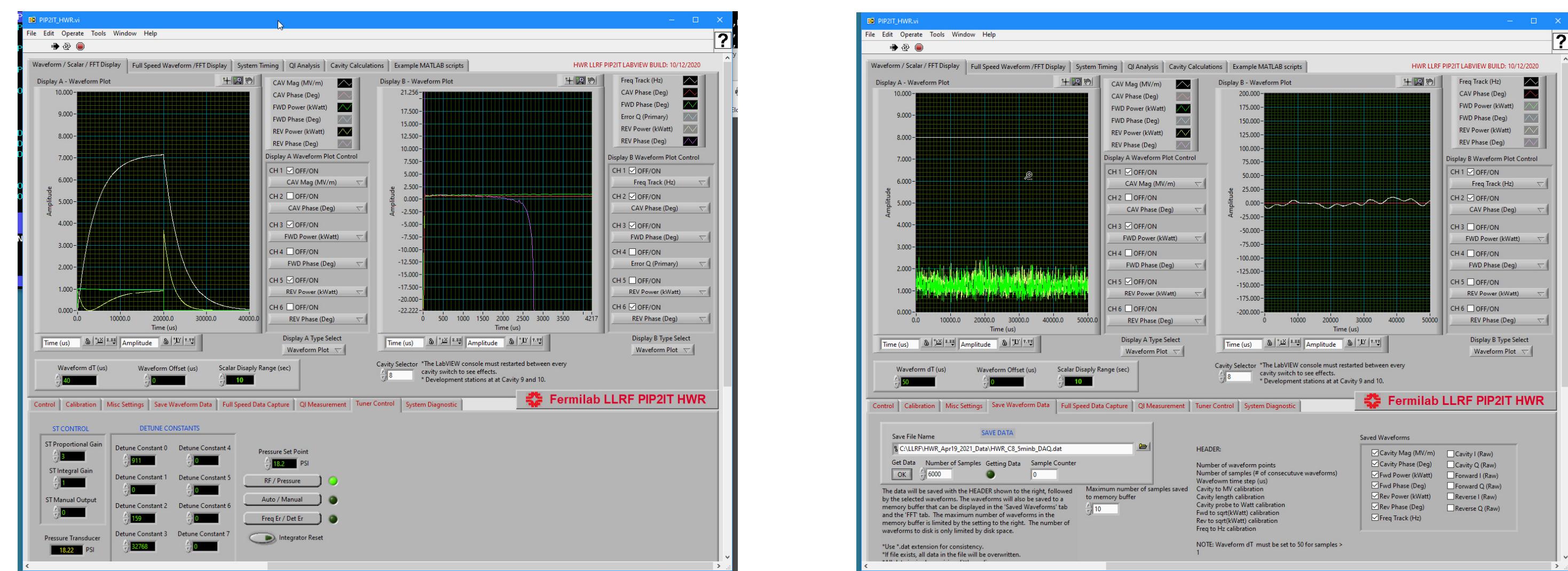
### PIP-II Specifications

- Energy Stability (Linac) < 0.01%
- Phase Regulation < 0.06 deg
- Amplitude Regulation (individual cavity) < 0.06%

## Resonance Control – Cavity Detuning Histograms

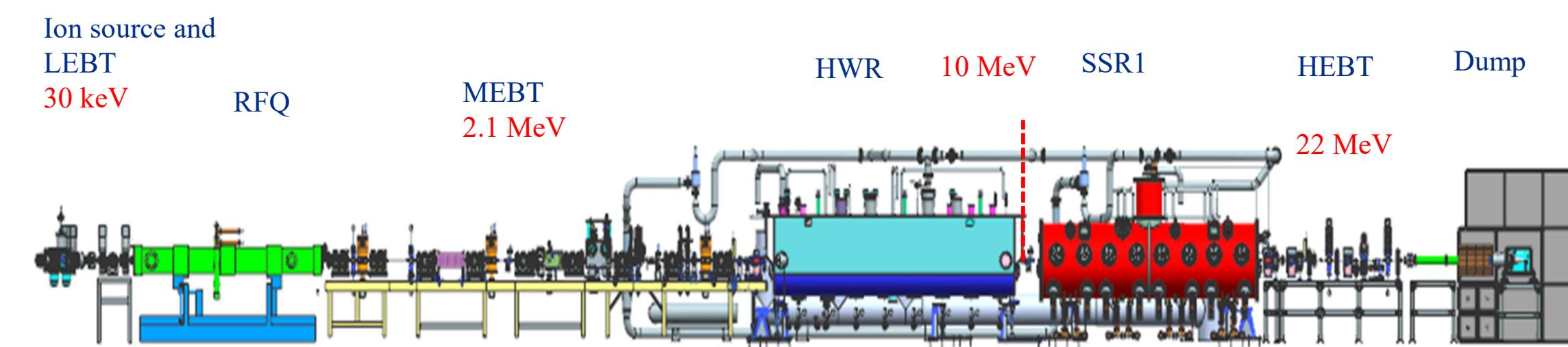


## Detune Calibration and DAQ Features

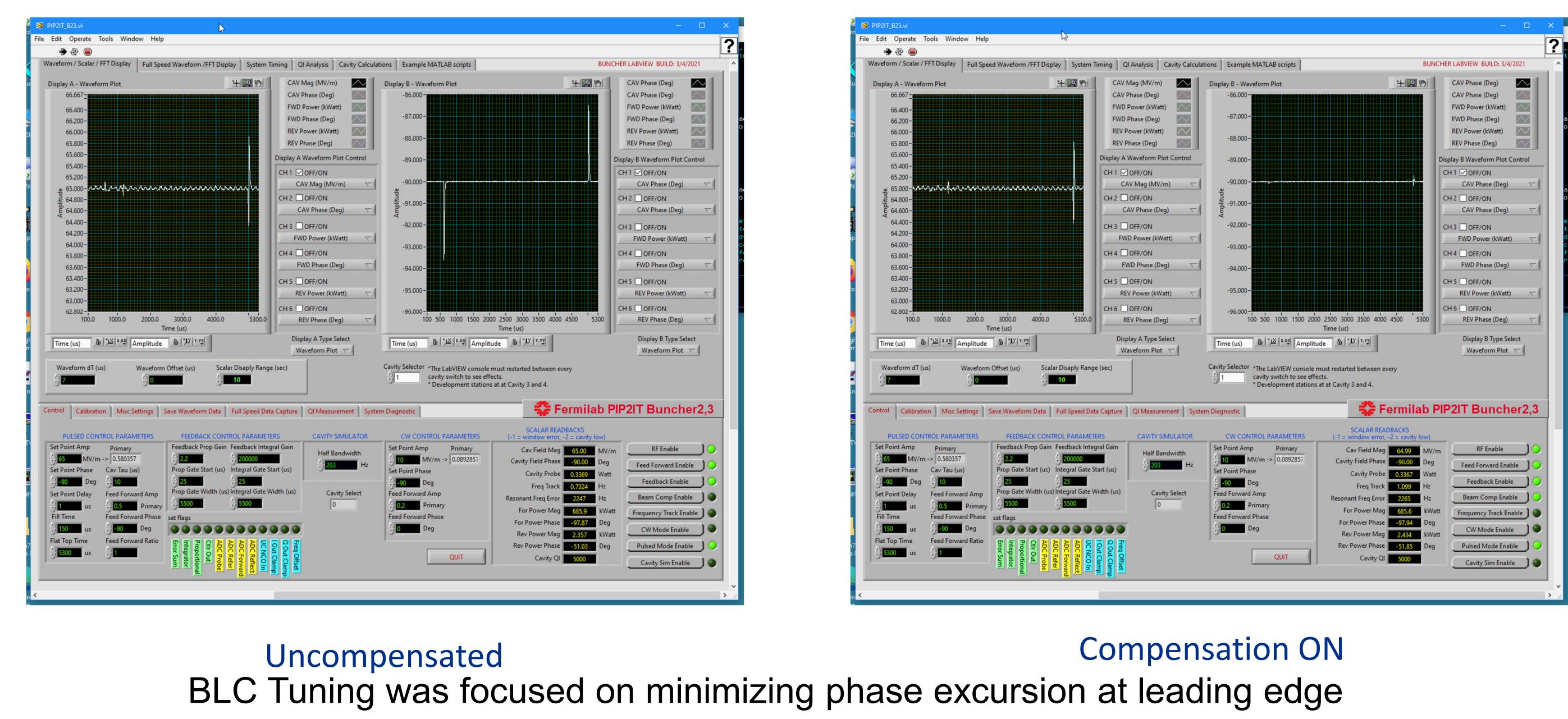


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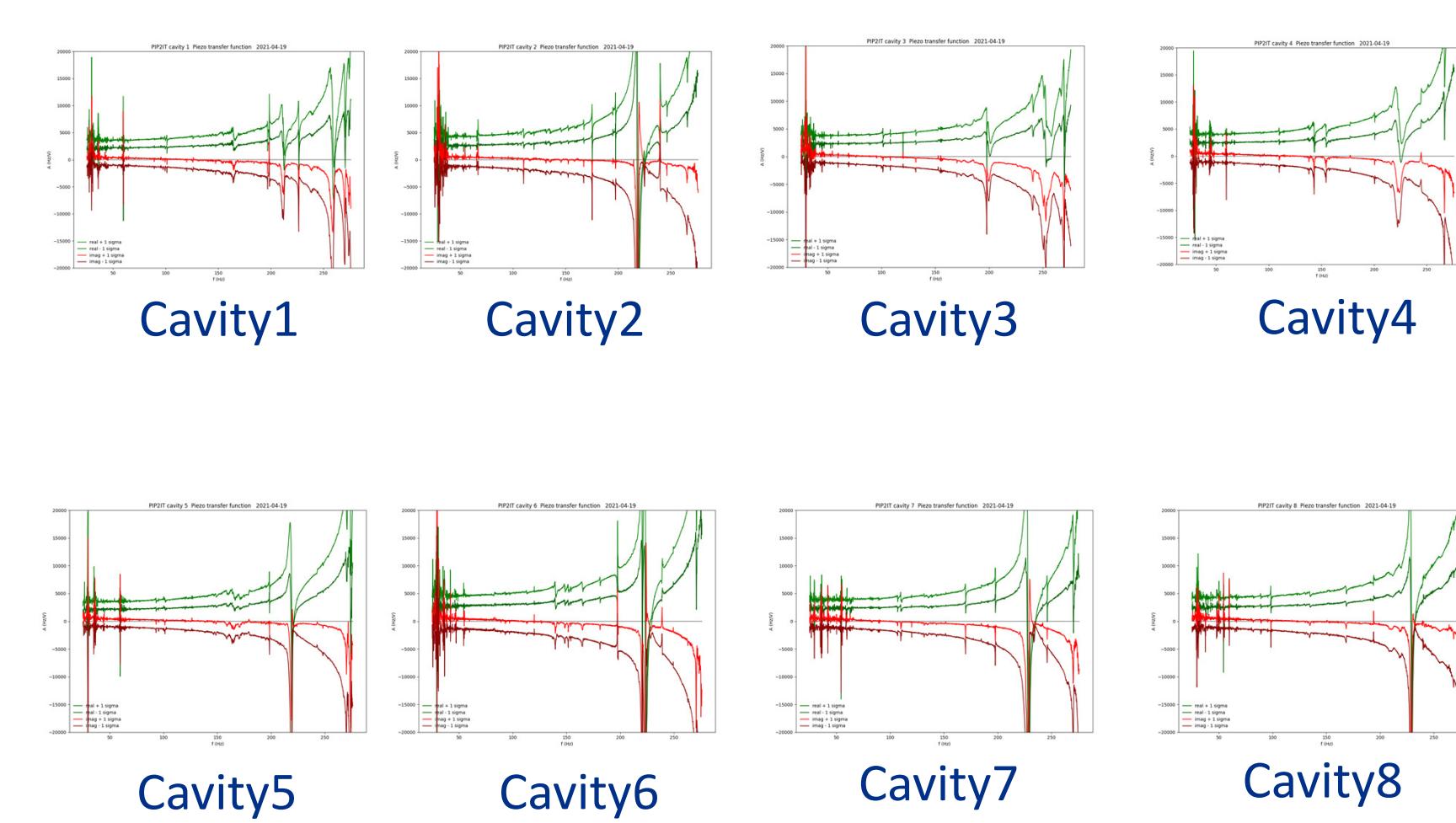
## PIP-II IT Components



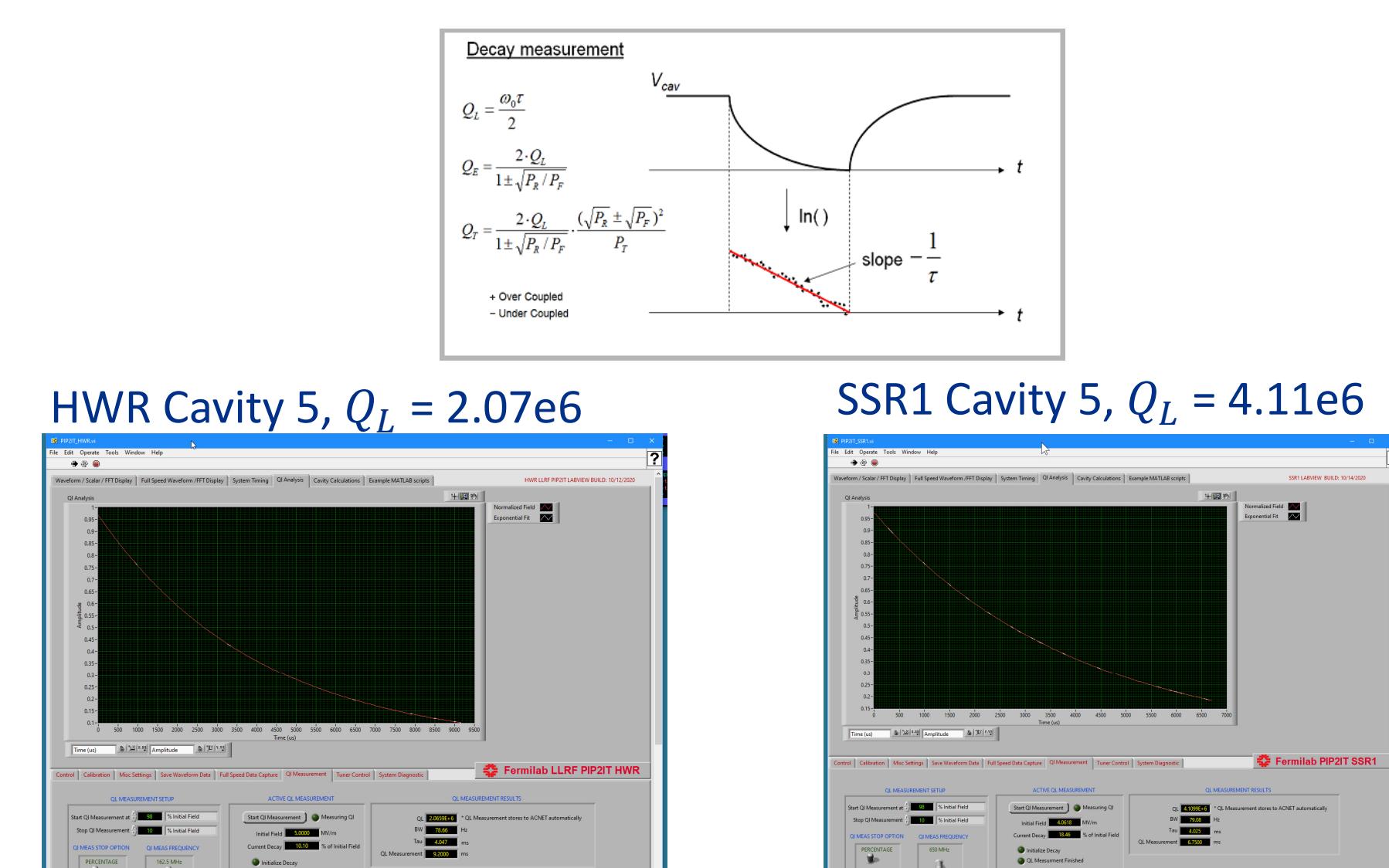
## Beam Loading Compensation in Buncher 2



## SSR1 Piezo Transfer Functions



## $Q_L$ Measurement



## Summary

- The LLRF system for PIP-II IT used a diverse mix of hardware, software and user interfaces for the various RF components.
- Major requirements such as field/phase regulation, resonance control and beam loading compensation met the project specifications
- The experience with testing at PIP-II IT will guide the final design for the projects LLRF systems.

