Latest Results on Cavity Gradient Stability at FLASH/TTF

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SLAC National Accelerator Laboratory

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Topics

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- Motivation
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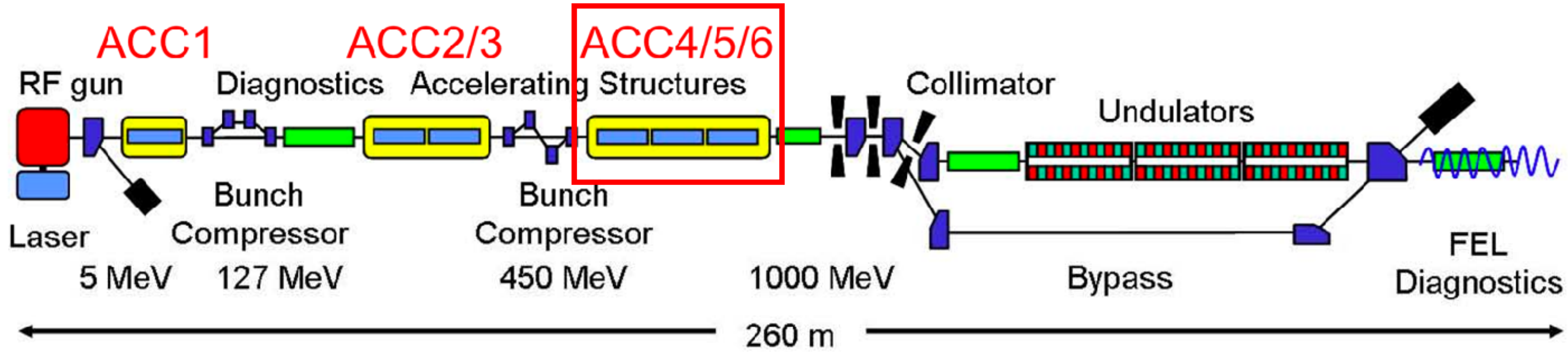
FLASH Facility Overview



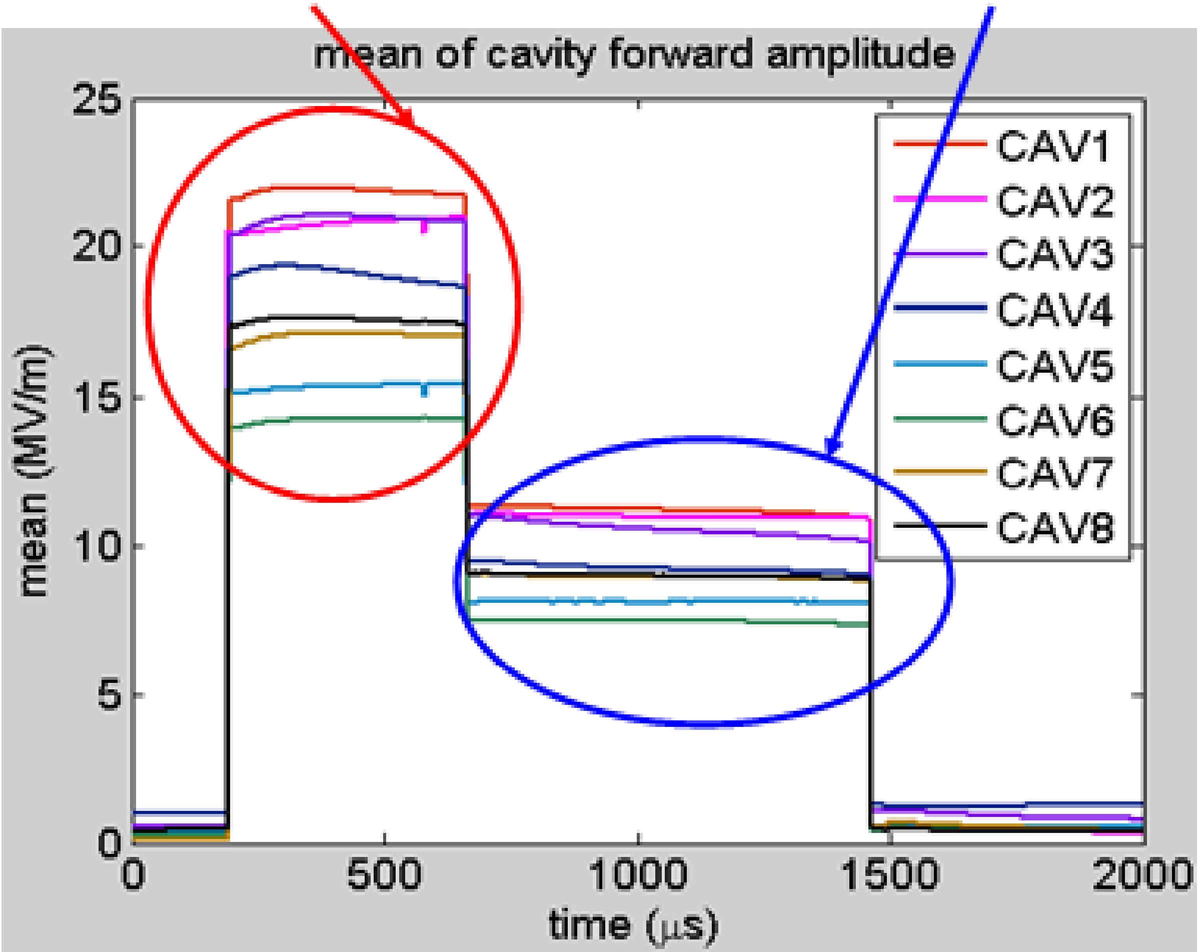
- World's only FEL for VUV and soft X-ray production.
- RF gun produces e- bunches accelerated by SC Linac.
- 1nC bunch compressed at intermediate energies (ps→fs)
- Peak current increases from 50-80 A to 1-2 kA.
- 6 modules containing 8/1.3GHz/1m/9-cell SC cavities.
- ACC4/5/6 is powered by a single klystron and controlled by one LLRF system, similar to an ILC RF unit, and is the focus of this study.

Motivation

- Measure the input and cavity rf stability (affected by Lorentz force detuning and microphonic induced cavity frequency changes). Data taken with the FB and AFF off are relevant.
- Data was collected on 09/18/08 and 01/14/09. In September, three sets of data (FB off + AFF off; FB on + AFF off; FB on + AFF on) without piezo compensation were taken. In January, only FB off + AFF off data was taken (First run with piezo actuator on in module ACC6).
- Only beam off data was recorded.

Typical RF Forward Signal with Beam Off

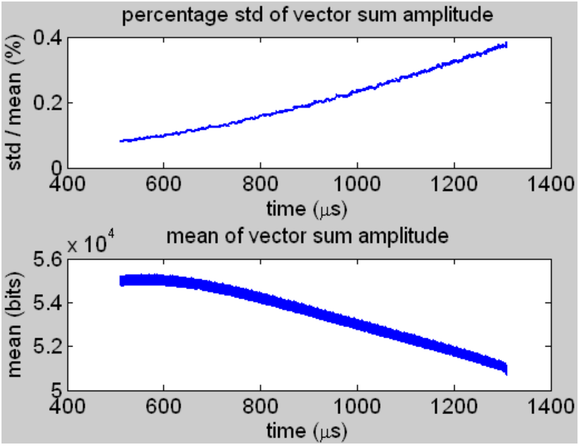
First flat top   Second flat top



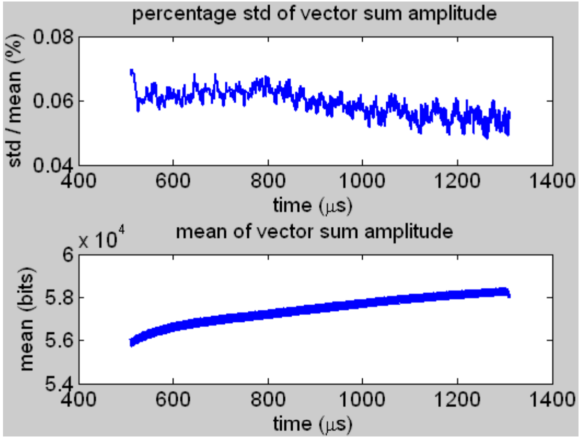
Vector Sum of 24 Cavity Probe Signals: Amplitude & Phase Statistics

September Measurement

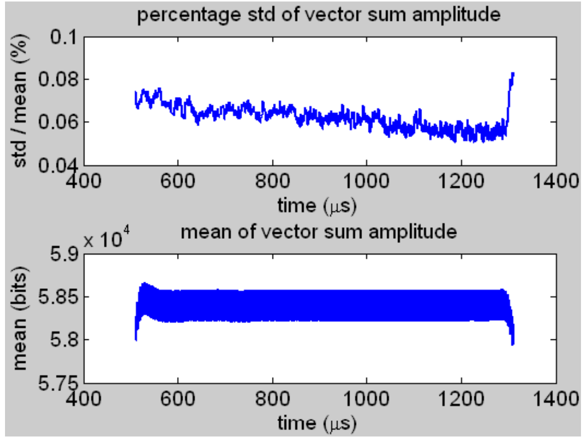
FB Off, AFF Off



FB On, AFF off

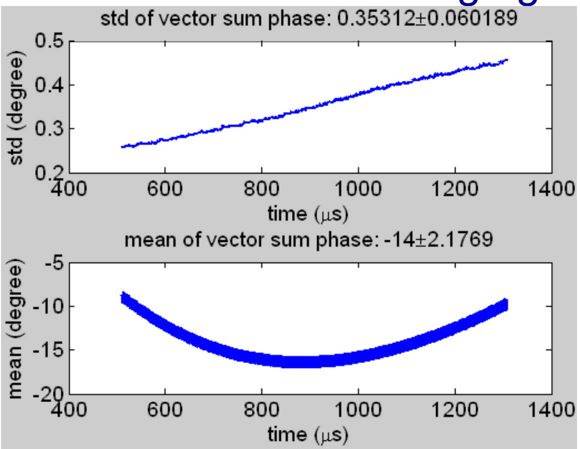


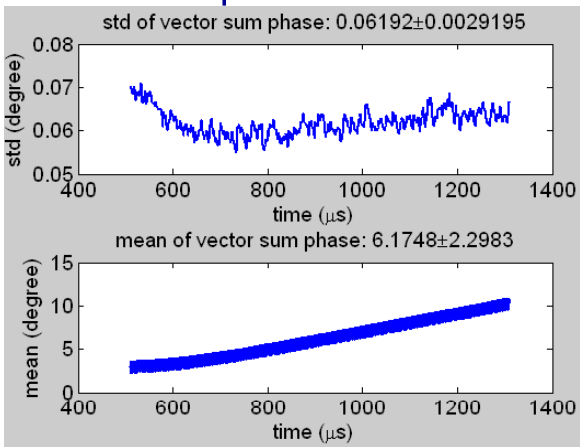
FB On, AFF On

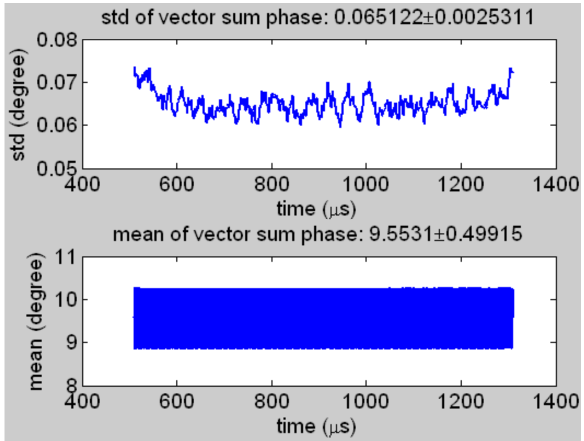


FB reduces fractional rms jitter, but not enough gain to flatten the pulse

AFF flattens the pulse





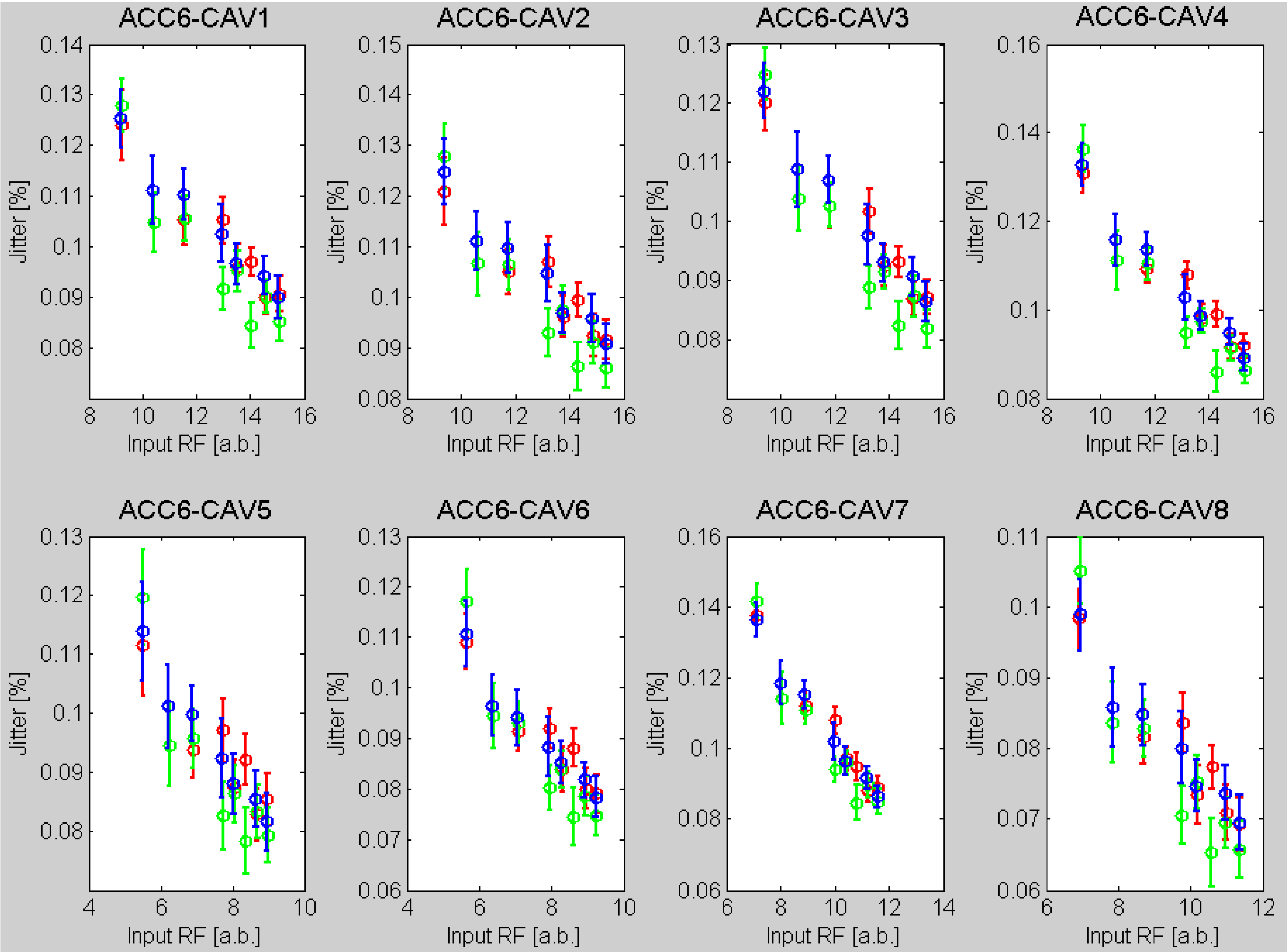


FB reduces rms jitter, but not enough gain to flatten the pulse

AFF flattens the pulse

1st Forward Flat Top Statistics

(Measurement Noise Error Subtracted)

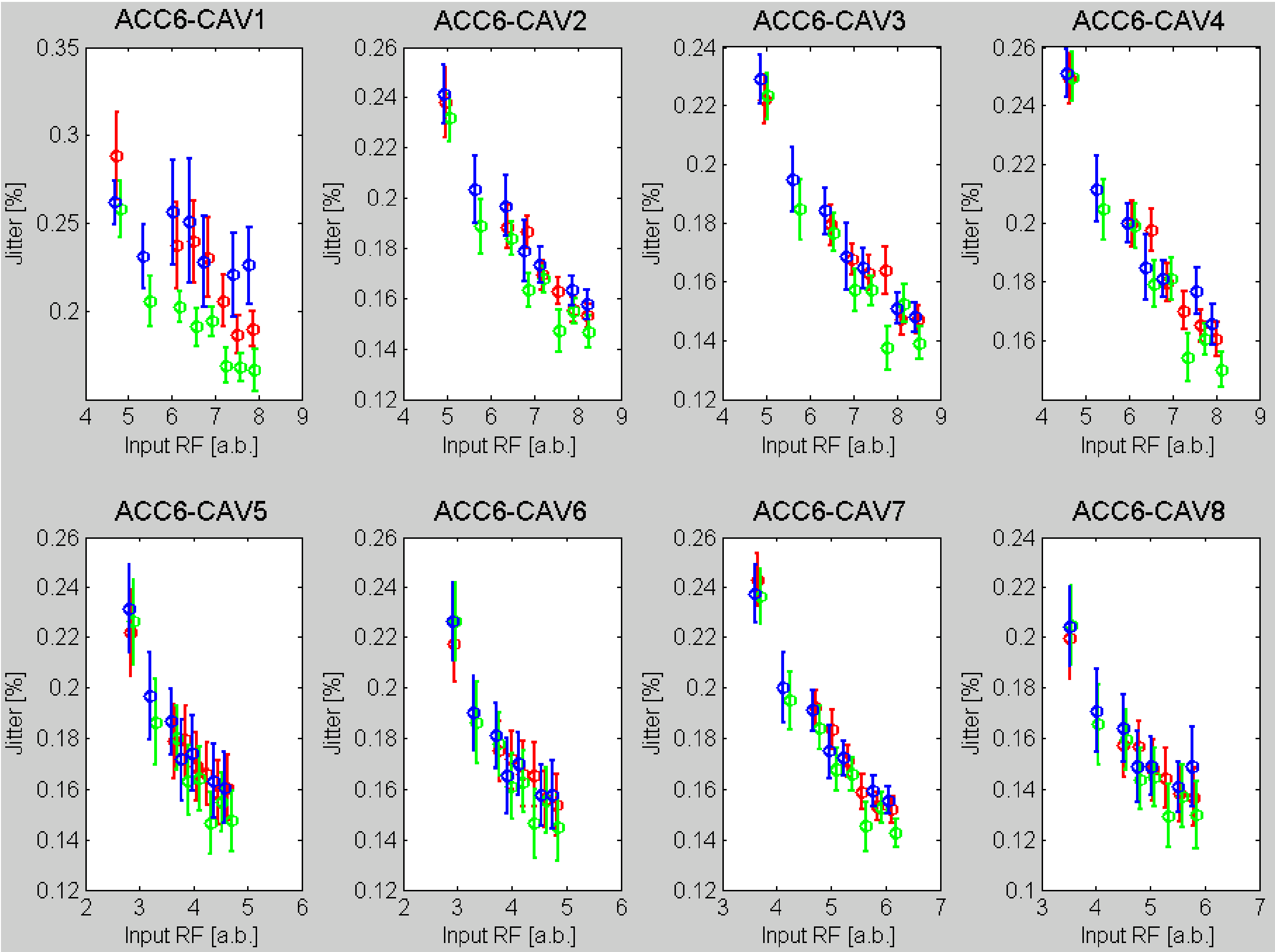


January Measurement

Blue: Nominal + 100Hz Initial Detuning; Red: Nominal Initial Detuning; Green: Nominal – 100Hz Initial Detuning.

2^{nd} Forward Flat Top Statistics

(Measurement Noise Error Subtracted)

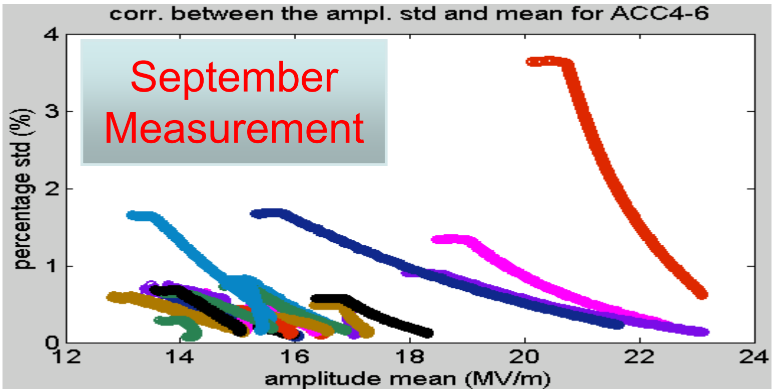


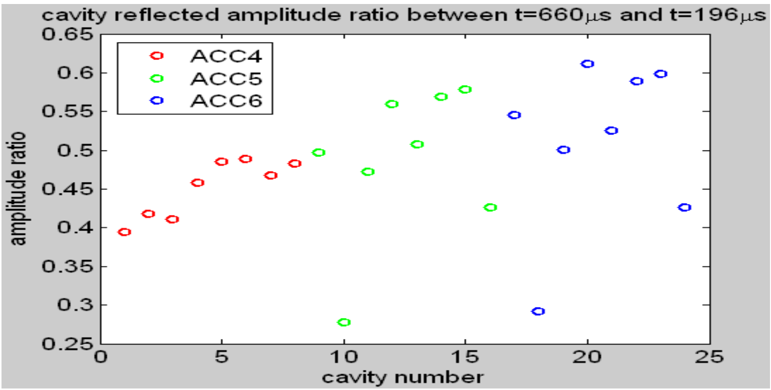
January Measurement

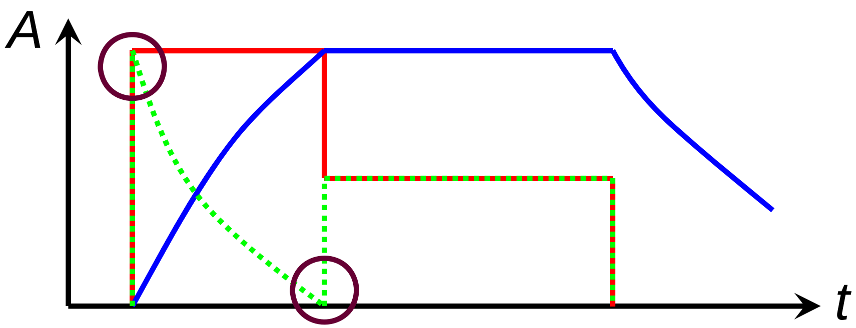
Blue: Nominal + 100Hz Initial Detuning; Red: Nominal Initial Detuning; Green: Nominal – 100Hz Initial Detuning.

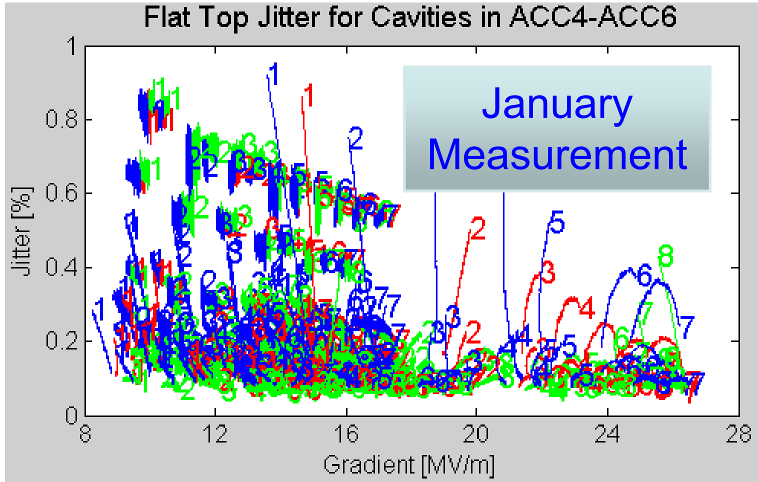
Probe Flat Top Statistics

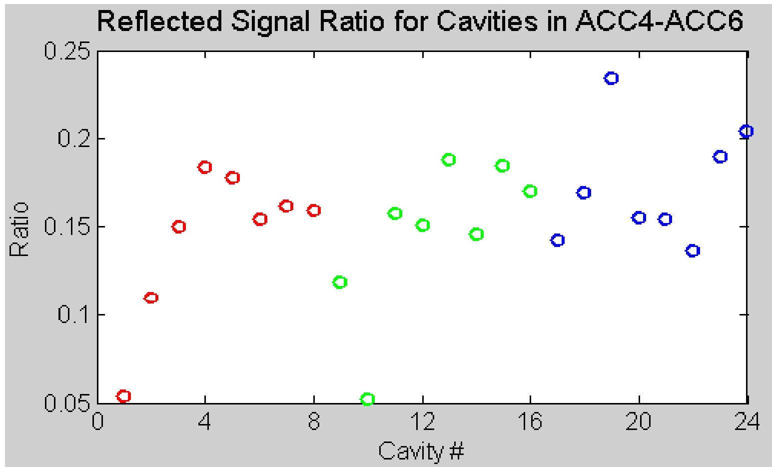
(Measurement Noise Error Included)







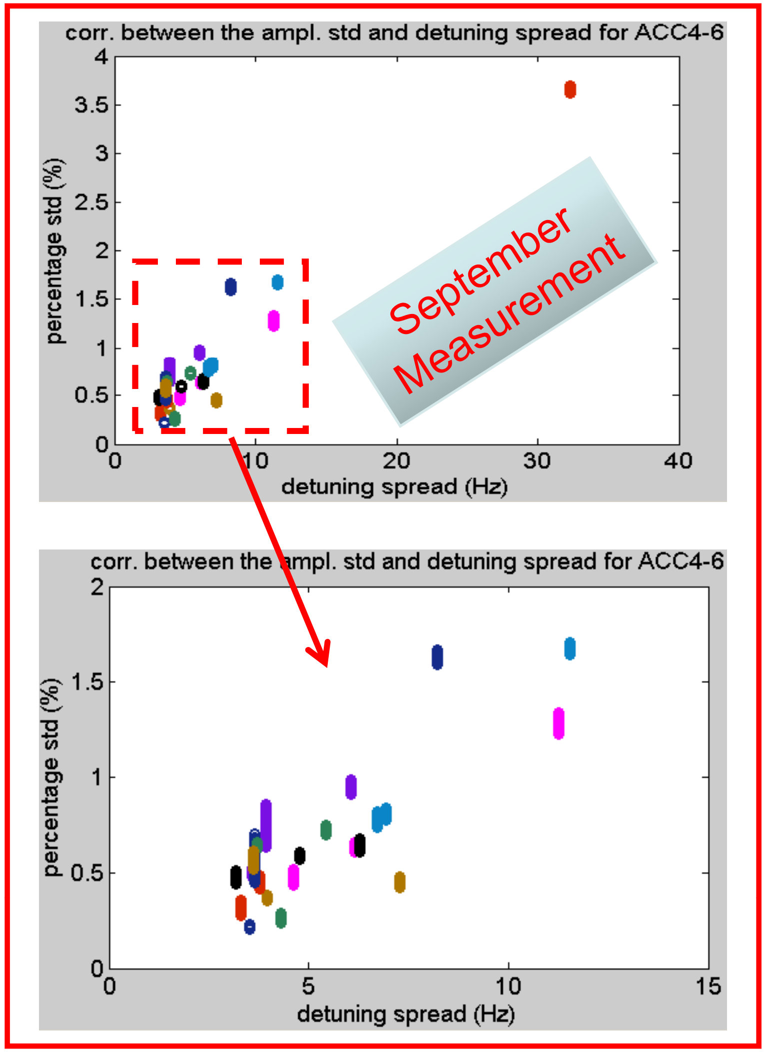


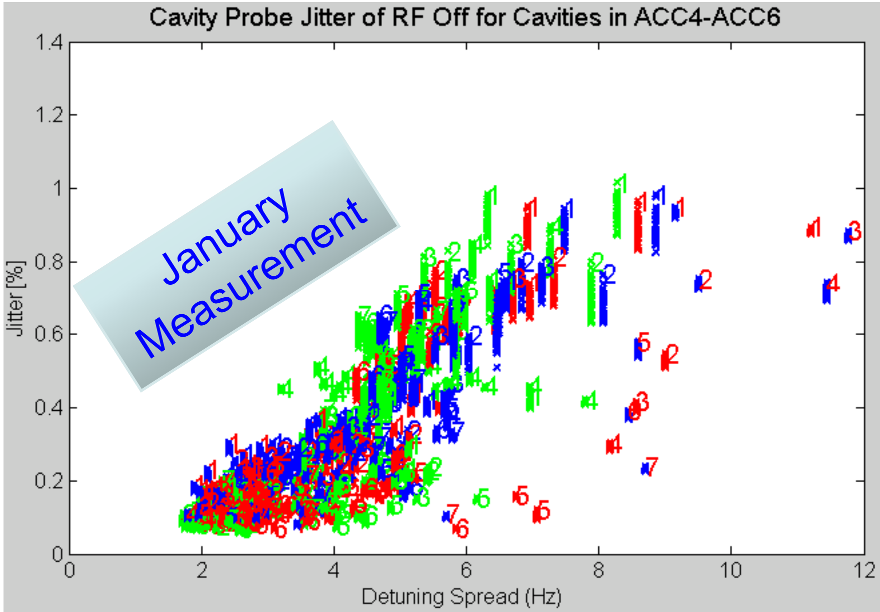


Nominal Initial Detuning at Set Point with Highest Gradient

Corr. of Probe Ampl. and Detuning Jitter

- Strong correlation between jitter in probe flat top amplitude and detuning jitter at the end of the pulse.

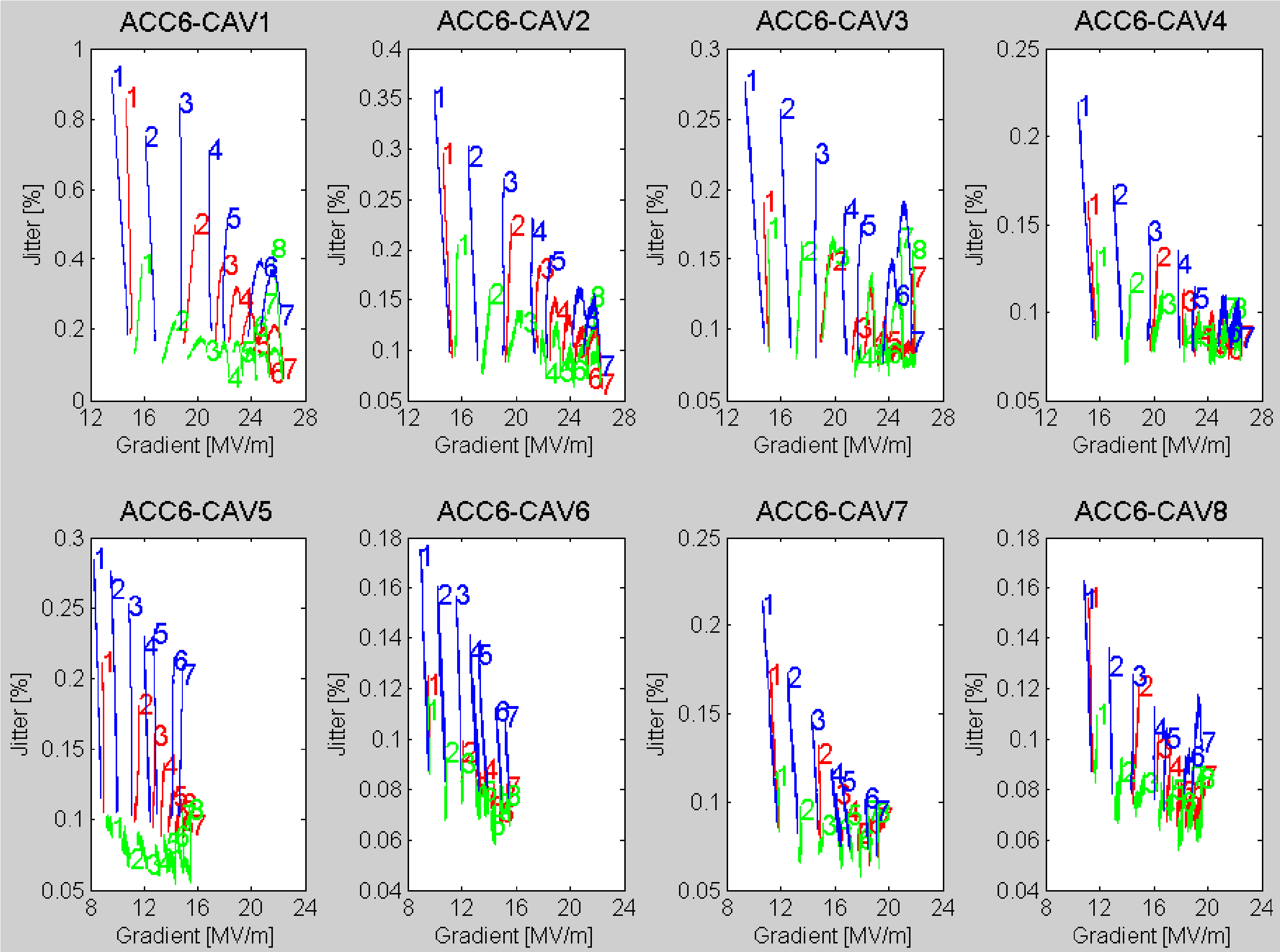




Blue → Nominal + 100Hz Initial Detuning.
Red → Nominal Initial Detuning.
Green → Nominal – 100Hz Initial Detuning.
Number → Different Accelerating Gradient.

Probe Flat Top Statistics

(Measurement Noise Error Included)



January Measurement

Blue: Nominal + 100Hz Initial Detuning; Red: Nominal Initial Detuning; Green: Nominal – 100Hz Initial Detuning.

Analytical Model

Base band component of cavity voltage

$$\frac{d}{dt}\begin{bmatrix} V_r \\ V_i \end{bmatrix} = \begin{bmatrix} -\omega_{1/2} & -\Delta\omega \\ \Delta\omega & -\omega_{1/2} \end{bmatrix}\begin{bmatrix} V_r \\ V_i \end{bmatrix} + R_L\omega_{1/2}\begin{bmatrix} I_r \\ I_i \end{bmatrix}$$

$$\omega_{1/2} = \frac{\omega_0}{2Q_L}, \qquad \Delta\omega = \omega_0 - \omega$$

Detuning component driven by Lorentz force

$$\frac{d}{dt}\begin{bmatrix} \Delta\omega_m \\ \Delta\dot{\omega}_m \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -(2\pi f_m)^2 & \frac{-2\pi f_m}{Q_m} \end{bmatrix}\begin{bmatrix} \Delta\omega_m \\ \Delta\dot{\omega}_m \end{bmatrix} + 2\pi V^2\begin{bmatrix} 0 \\ -K_m(2\pi f_m)^2 \end{bmatrix}$$

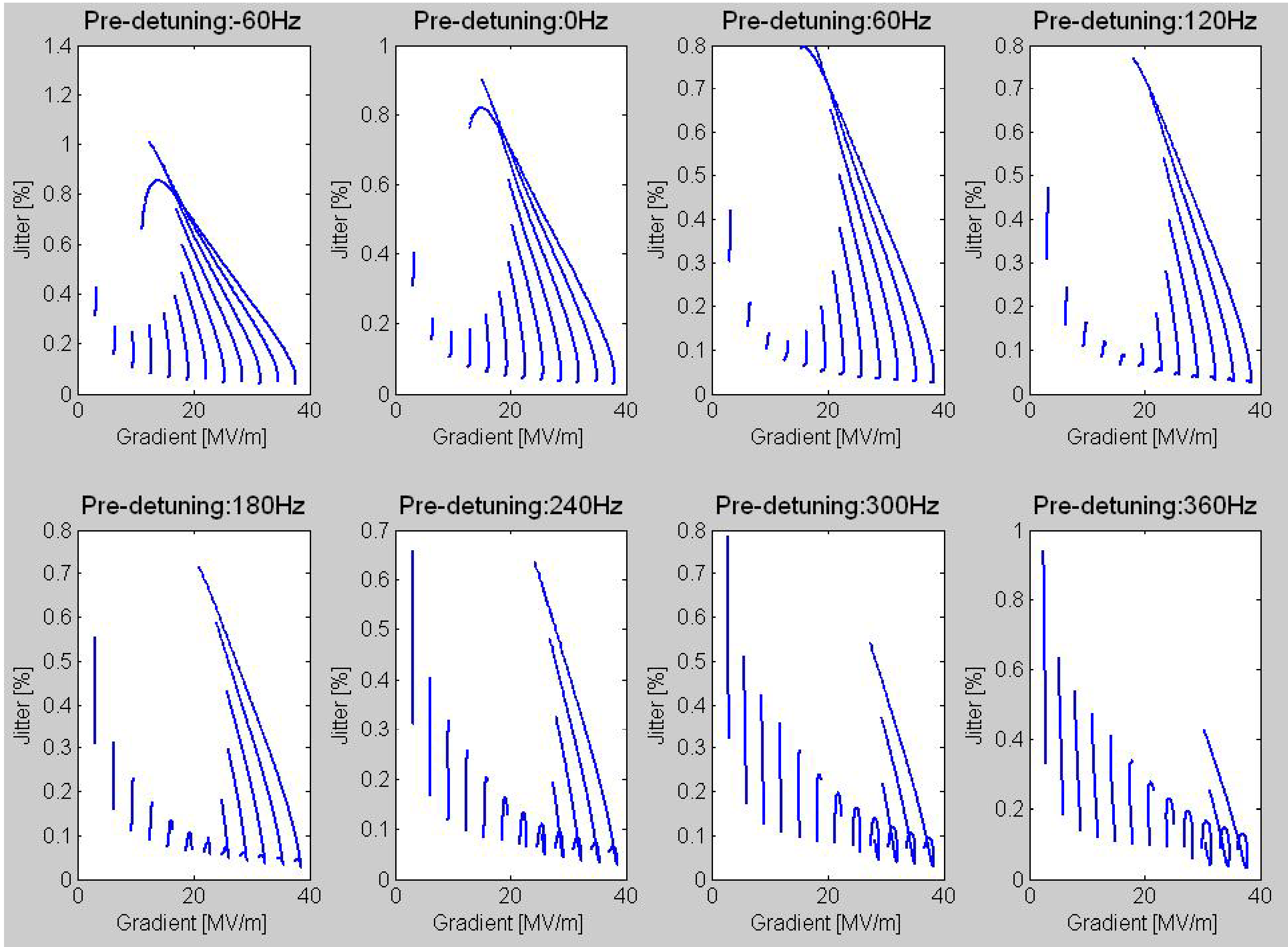
$$\Delta\omega = \Delta\omega_0 + \Delta\omega_0'(t) + \sum_{m=1}^{N}\Delta\omega_m$$

Mechanical parameters	Resonance frequency vector	[280,340,420]	Hz
	Quality factor vector	[100,100,100]	
	Lorenz force detuning constant vector	[0.4,0.3,0.2]	$Hz/(MV)^2$

Measured forward current signals were used as the rf drive signals.

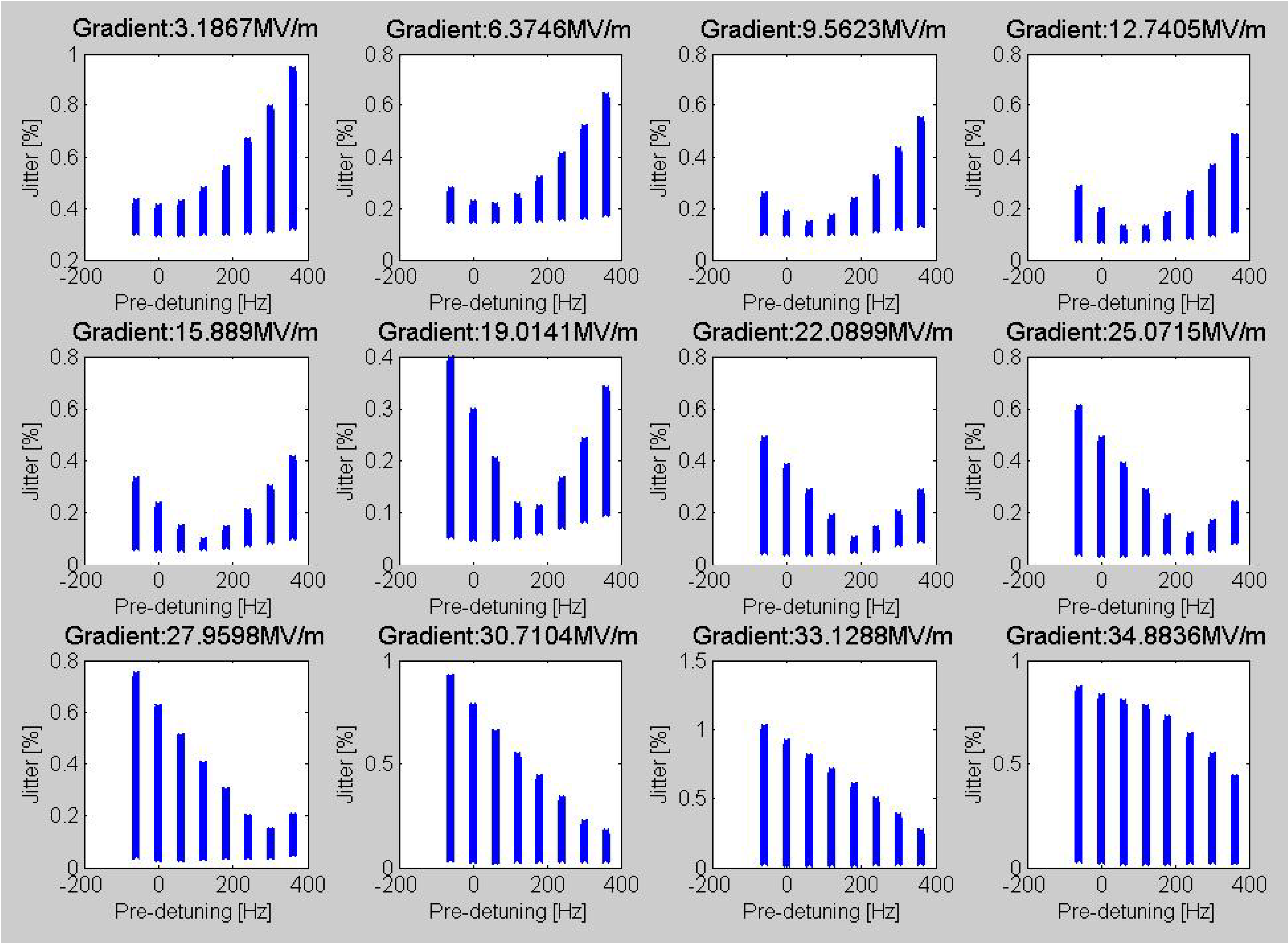
Jitter vs Gradient for Diff. Pre-detuning

(3Hz Gaussian Initial Detuning Jitter Assumed)

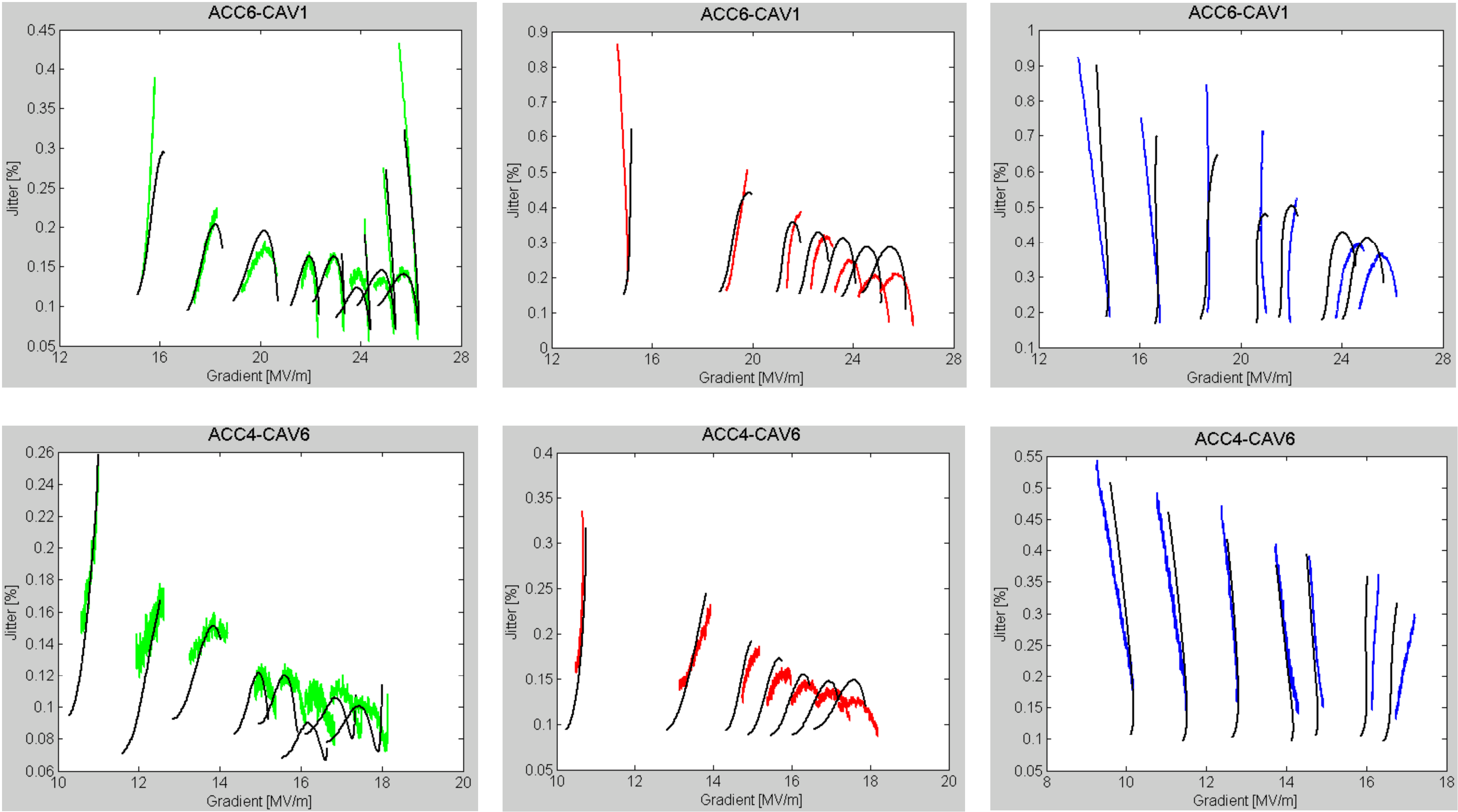


Jitter vs Pre-detuning for Diff. Gradient

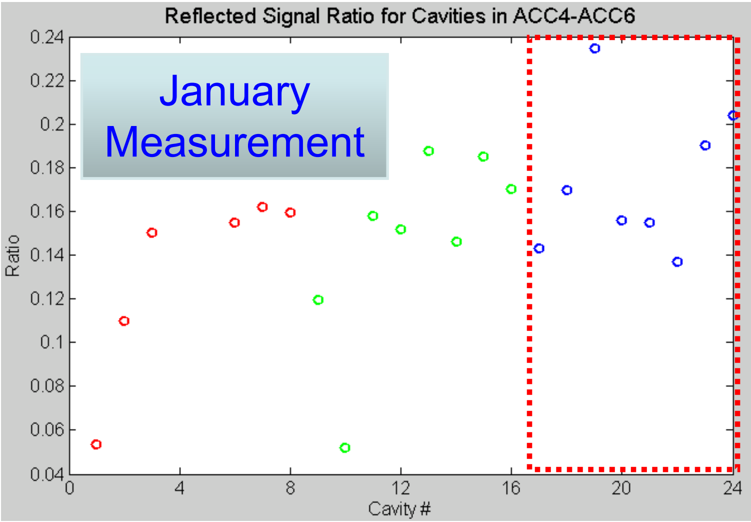
(3Hz Gaussian Initial Detuning Jitter Assumed)



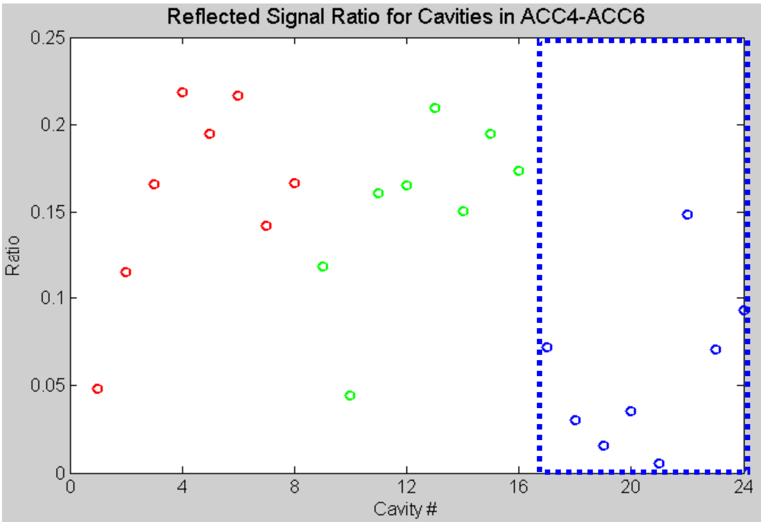
Comp. Between Exper. and Simul.



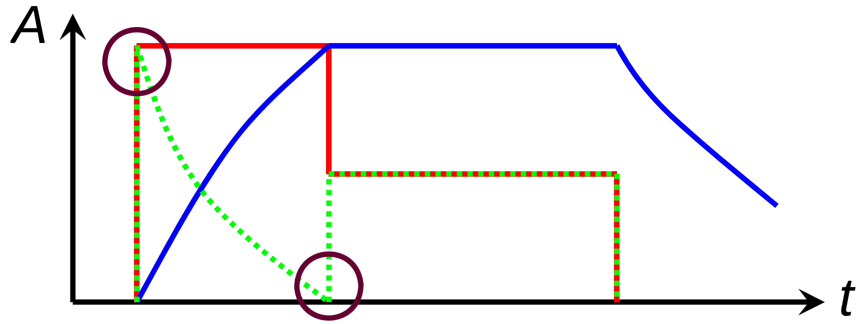
Reflected Ratio for Piezo On/Off

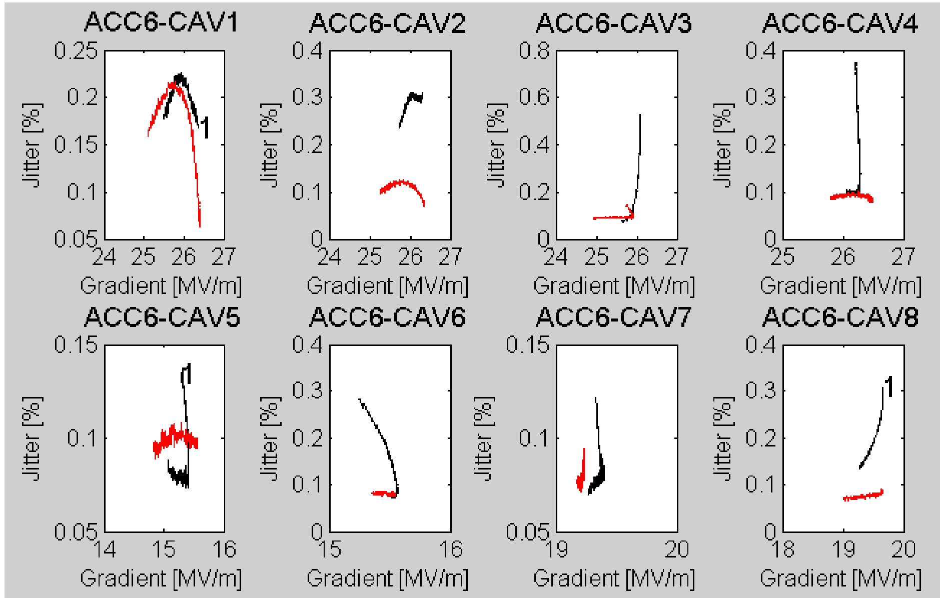


Piezo Off with Nominal Initial Detuning



Piezo On with Nominal Initial Detuning





Red → Nominal Initial Detuning with Piezo Off.
Black → Nominal Initial Detuning with Piezo On.

Piezo works well to reduce the reflection ratio (hopefully will minimize the rf power overhead) but adds some jitter as expected.

Summary

- FB/AFF off amplitude very stable pulse to pulse.
- Jitter at end of probe flattop correlates well with detuning jitter just after rf shut-off, suggesting that variations in pulse-to-pulse detuning jitter is driving the probe signal jitter.
- Analytical simulation matches well with the experiment, which indicates the cavity gradient jitter is dominated by two factors: cavity initial detuning and detuning jitter.
- The is one optimum initial detuning with minimum gradient jitter for each cavity at one specific gradient.
- Piezo works well to reduce reflection ratio but adds some additional jitter to the probe signals.