Analysis of FLASH Beam On Cavity Gradient Stability Data

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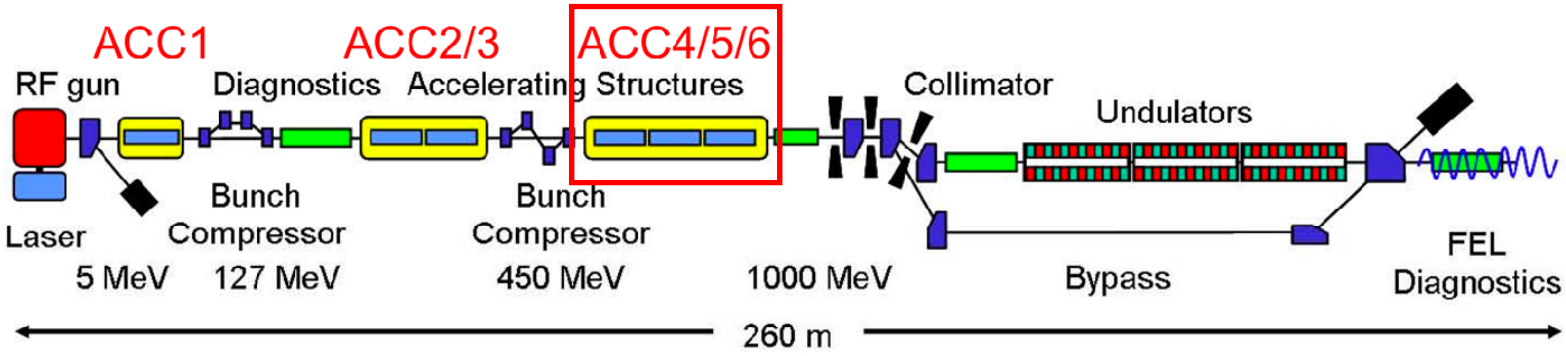
LCWS10 & ILC 10, Beijing, China

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.

Introduction

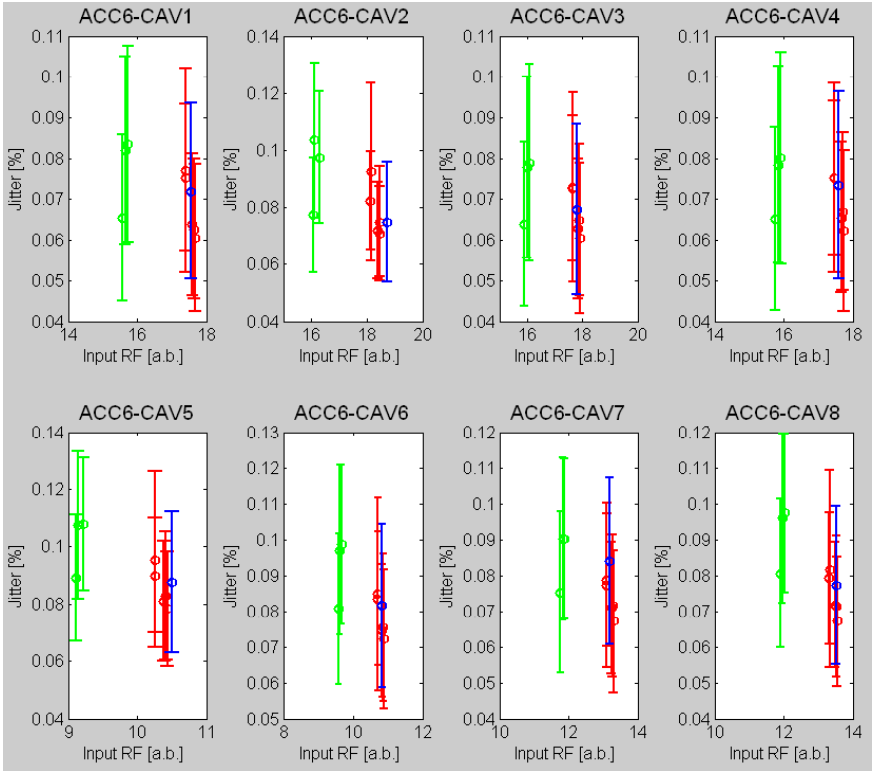
- Experiments with heavy beam loading were done in September 17-20, 2009.
- Adaptive feed-forward and orbit feedback were not used, only feedback was on. Beam loading compensation was tuned manually. Beam loaded data with piezo on and off was collected.
- 3mA (1MHz/3nC) pulse currents for longer bunch trains of 800 bunches (800μs) were run successfully.
- 9mA (3MHz/3nC) pulse currents for shorter bunch trains of 900-1500 bunches (300-500μs) were run stably but with a few bunch train aborts.
- 9mA (3MHz/3nC) pulse currents with bunch-trains of close to 2400 bunches (800μs) were also run but with many bunch train aborts.

1st Forward Flat Top Statistics

(Measurement Noise Error Subtracted)

September 2009 Measurement

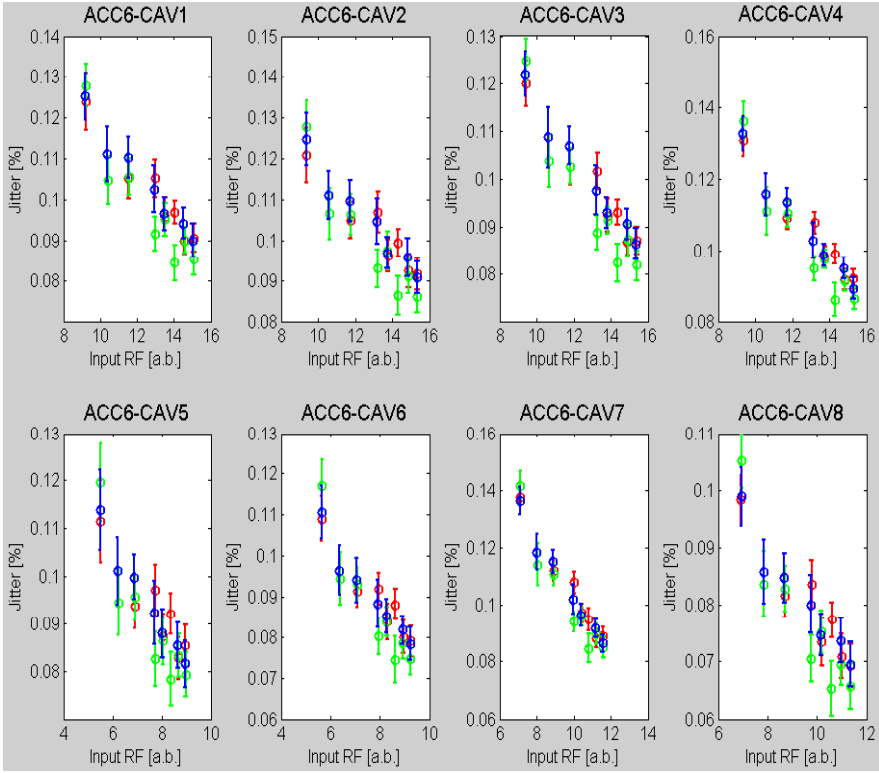
Beam and feedback on



Red: 1MHz/3nC beam with piezo off;
Blue: 3MHz/3nC beam with piezo off;
Green: 3MHz/3nC beam with piezo on.

January 2009 Measurement

Beam and feedback off



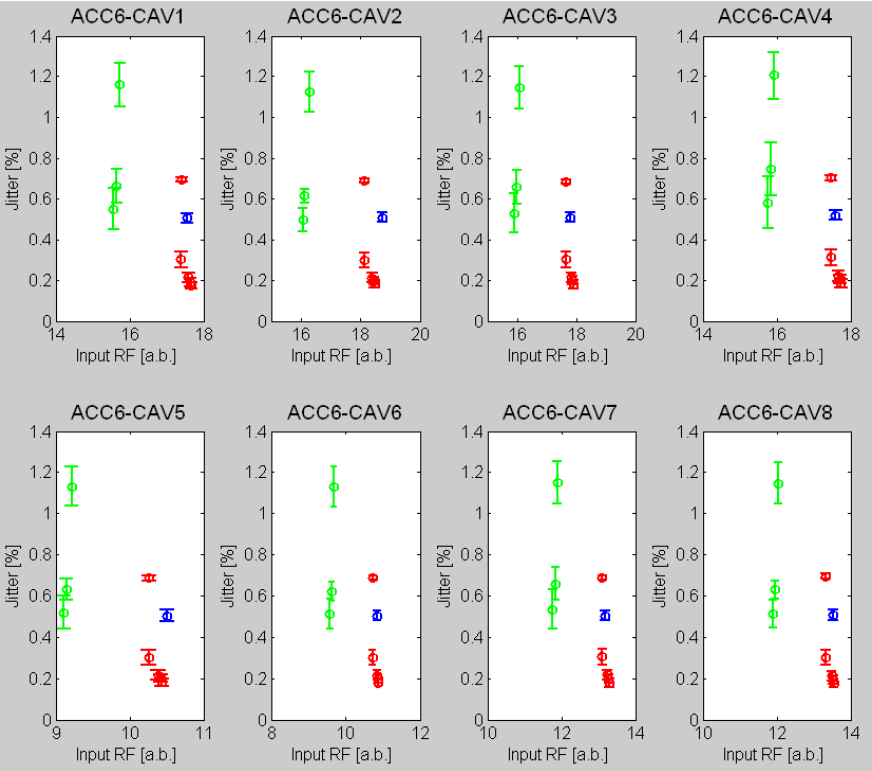
Blue: nominal + 100Hz Initial detuning with piezo off;
Red: nominal initial detuning with piezo off;
Green: nominal – 100Hz initial detuning with piezo off.

2nd Forward Flat Top Statistics

(Measurement Noise Error Subtracted)

September 2009 Measurement

Beam and feedback on



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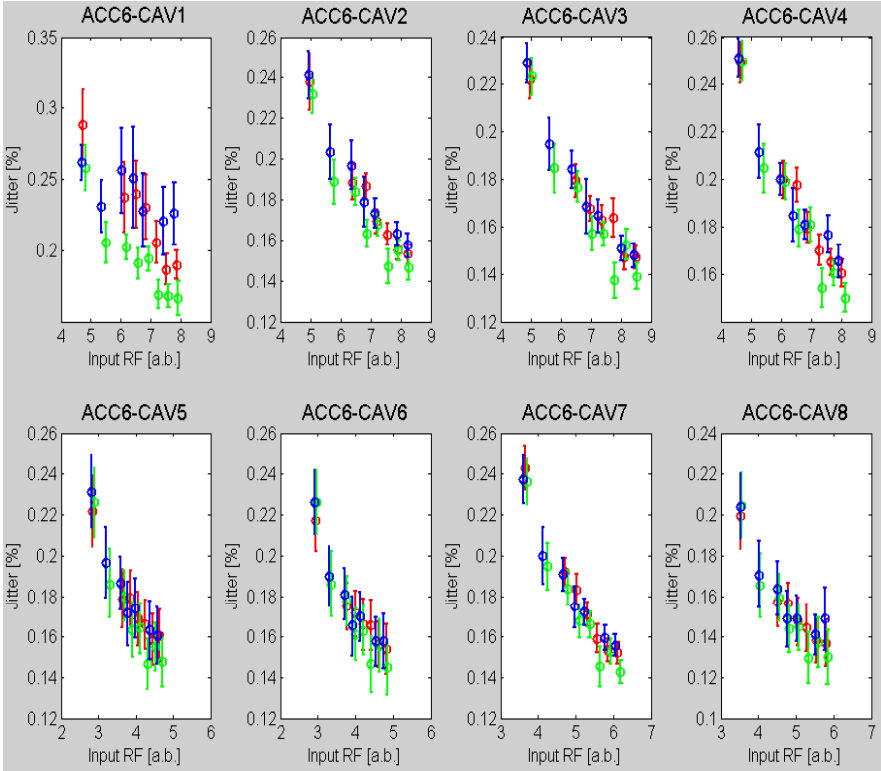
January 2009 Measurement

Beam and feedback off



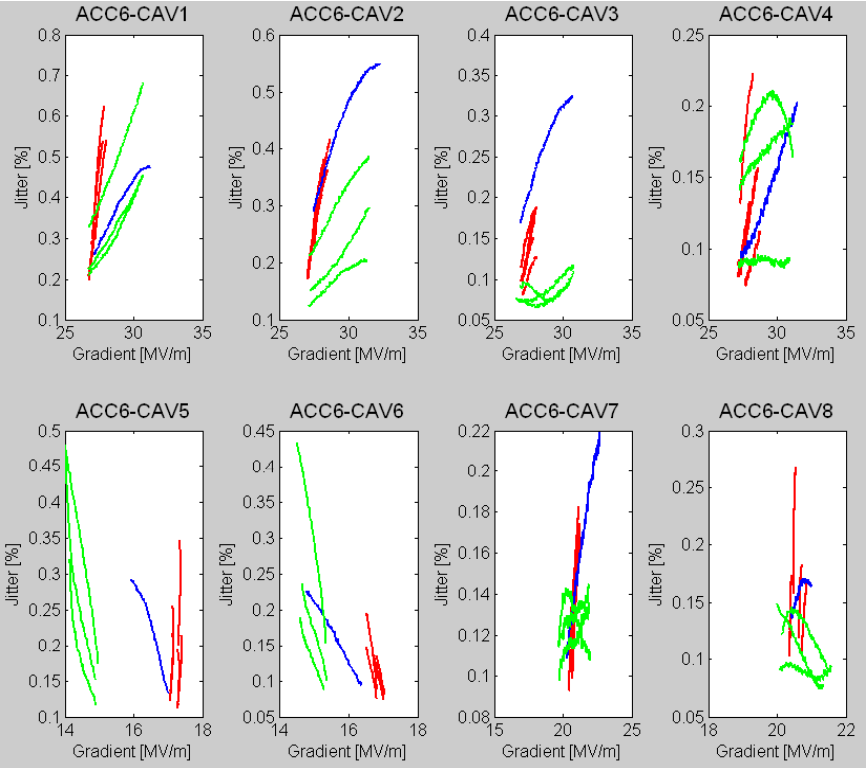
Blue: nominal + 100Hz Initial detuning with piezo off;
Red: nominal initial detuning with piezo off;
Green: nominal – 100Hz initial detuning with piezo off.

Probe Flat Top Statistics

(Measurement Noise Error Not Subtracted)

September 2009 Measurement

Beam and feedback on



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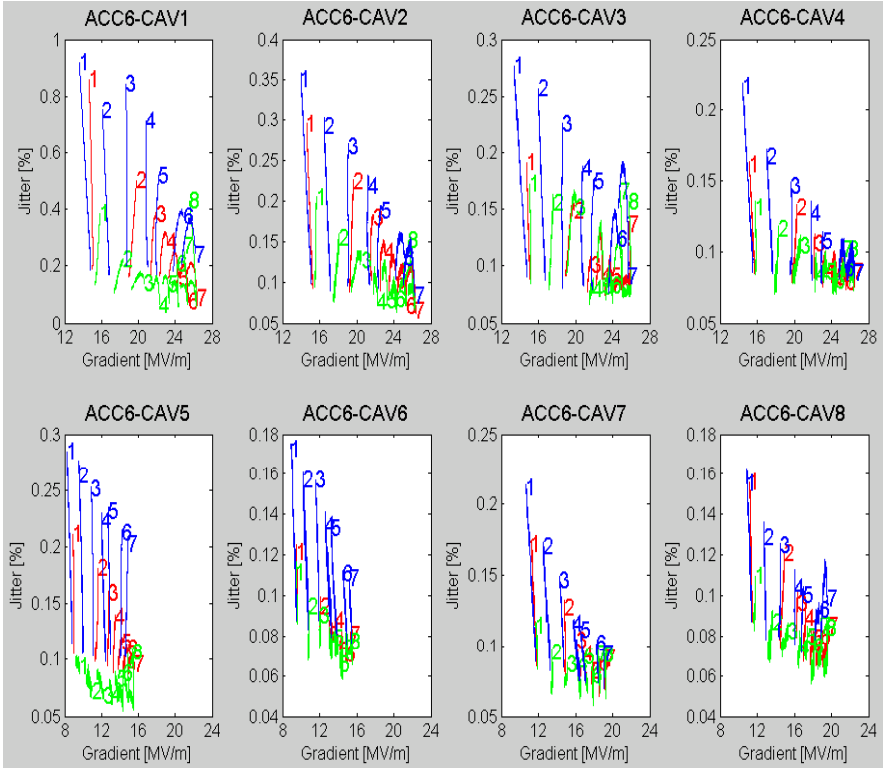
Green: 3MHz/3nC beam with piezo on.

January 2009 Measurement

Beam and feedback off



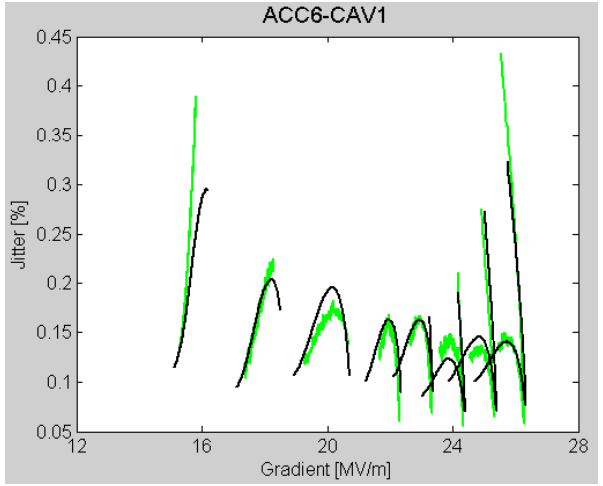
Blue: nominal + 100Hz Initial detuning with piezo off;
Red: nominal initial detuning with piezo off;
Green: nominal – 100Hz initial detuning with piezo off.

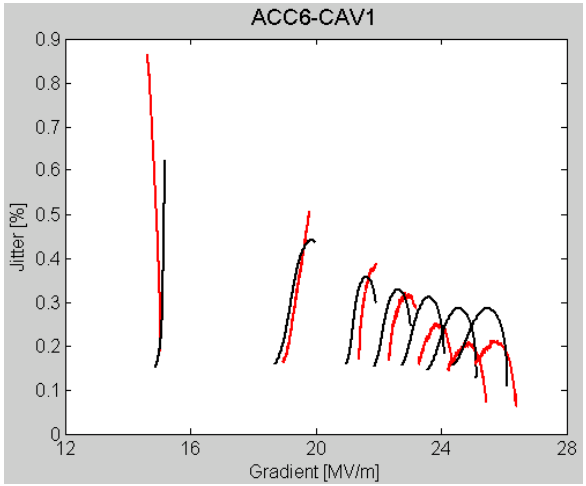
Cavity Gradient Stability

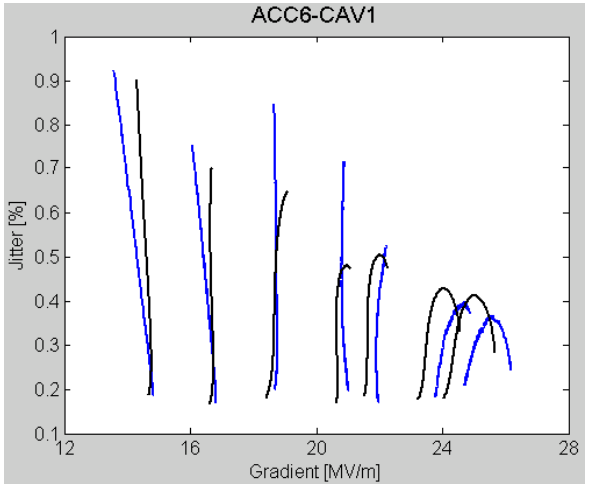
January 2009 Measurement

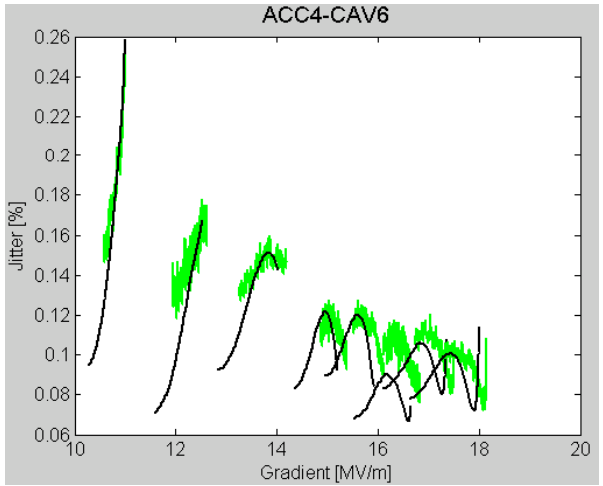
Beam and feedback off

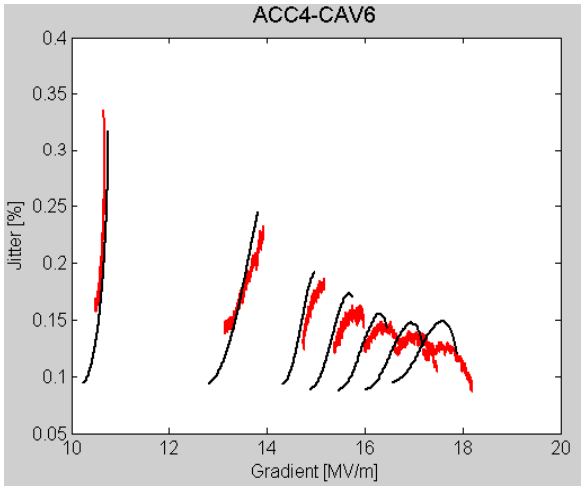
Comparison of beam-off measurements of pulse-to-pulse cavity gradient jitter during the flattop period for different gradients and initial cavity detuning (green, red and blue lines) to a cavity fill model including Lorentz force detuning (black lines) with two degrees of freedom (initial and initial rms detuning)

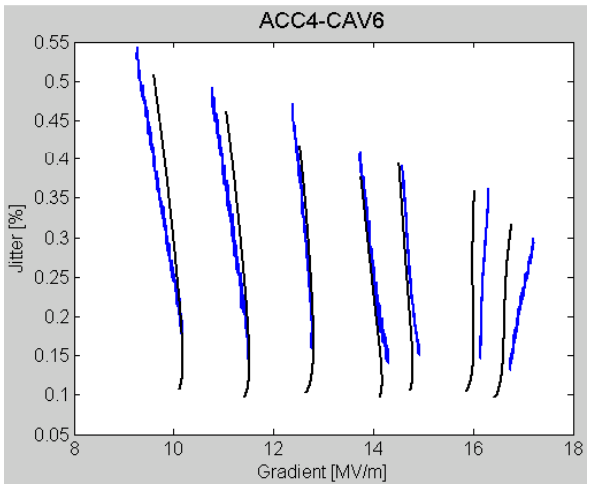






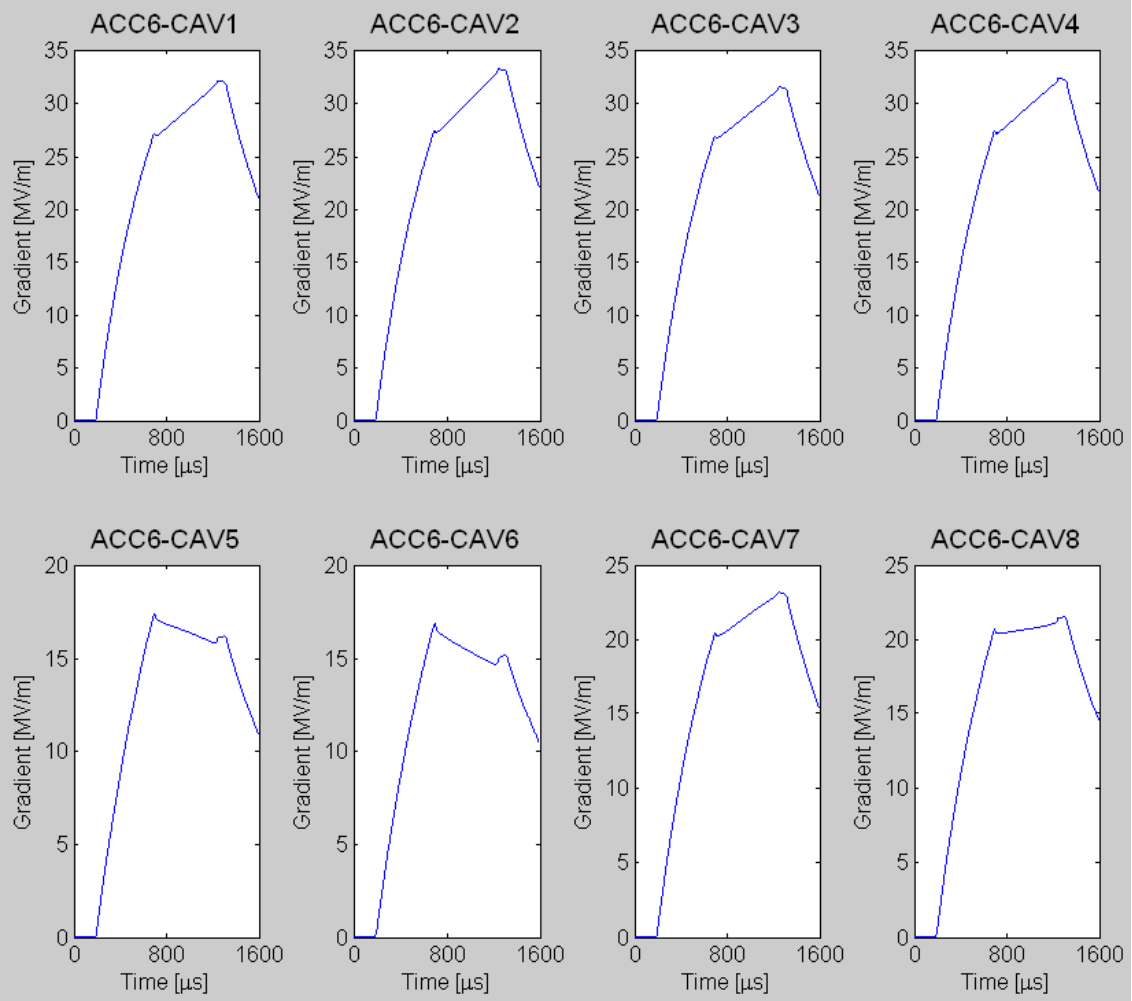




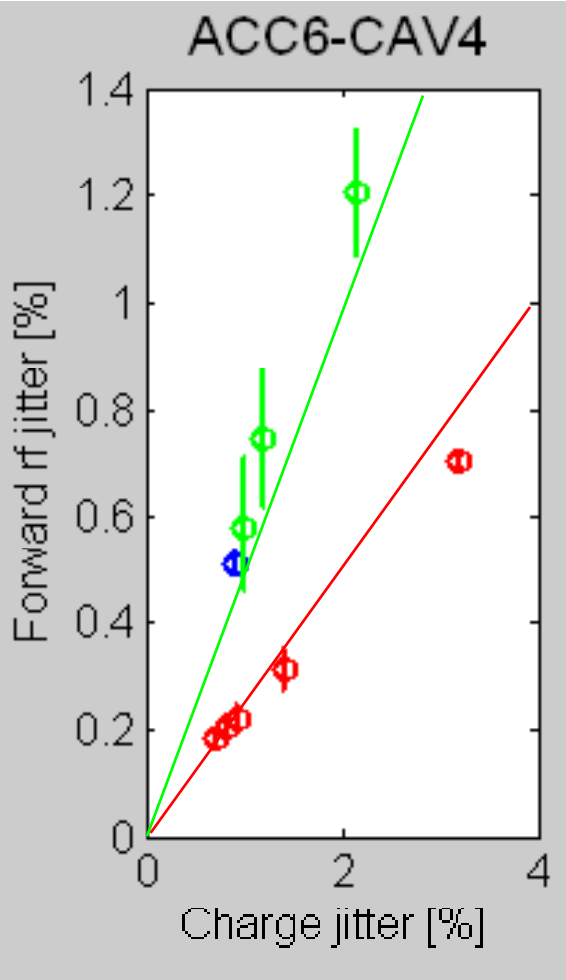


Probe Signals for Cavities in ACC6

(3MHz/3nC beam with piezo off)



2nd Forward Flat Top Jitter vs Charge Jitter

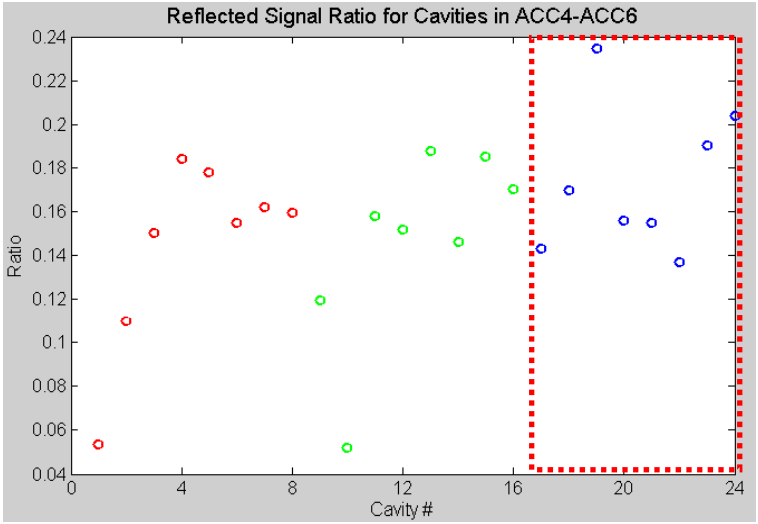


September 2009 Measurement

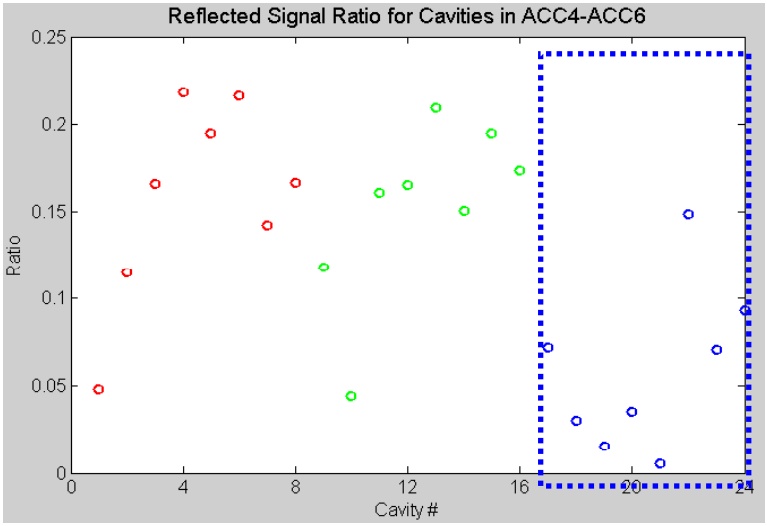
Red: 1MHz/3nC beam with piezo off;
Expect slope of ¼ (red lines)

Blue: 3MHz/3nC beam with piezo off;
Green: 3MHz/3nC beam with piezo on.
Expect slope of ½ (green lines)

Reflected Ratio for Beam off Case

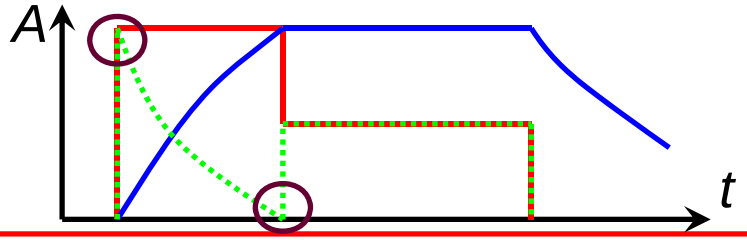


Piezo Off with Nominal Initial Detuning



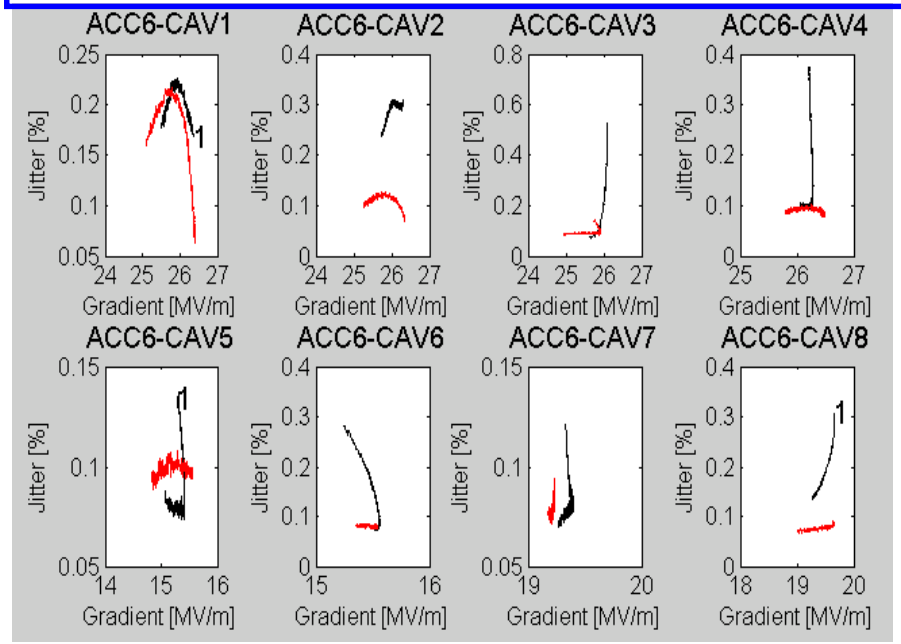
Piezo On with Nominal Initial Detuning

January 2009 Measurement



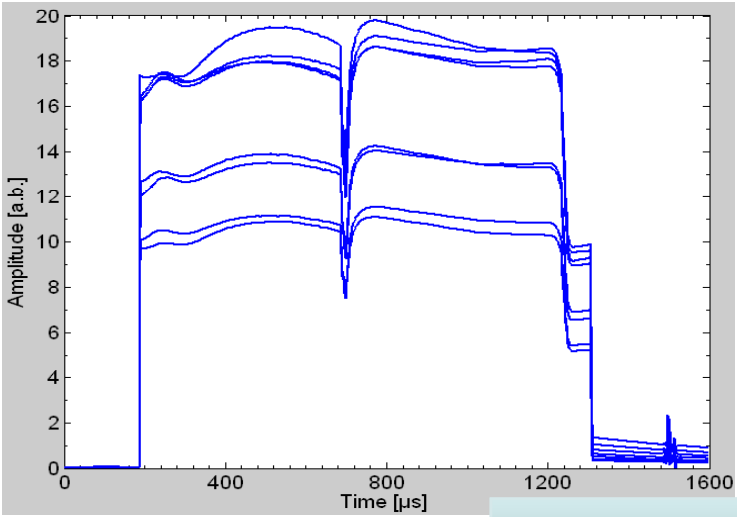
Piezo works well to reduce the reflection ratio for beam off case as expected.

Feedback will be turned on once piezo actuator is hooked up.

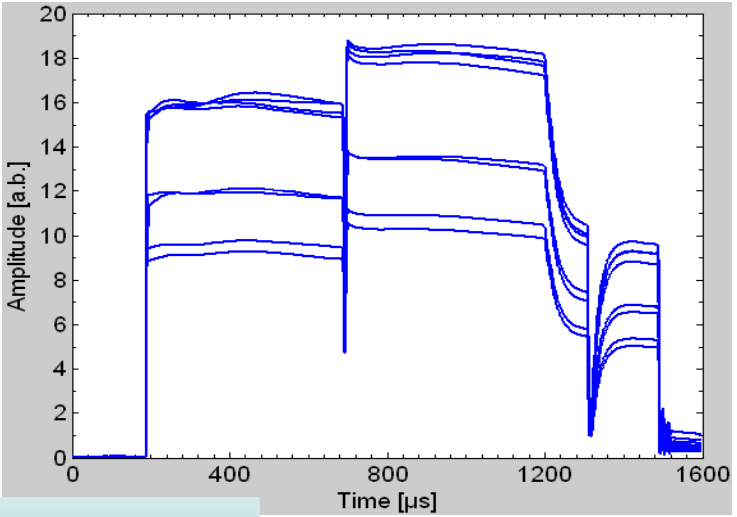


Forward and Reflected Signal with Beam On

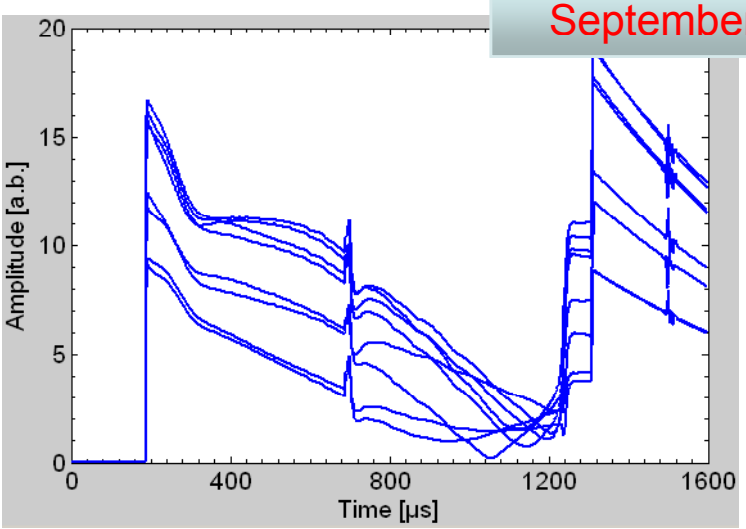
Cavities in ACC6 with piezo off
3MHz/3nC beam with 1600 bunches

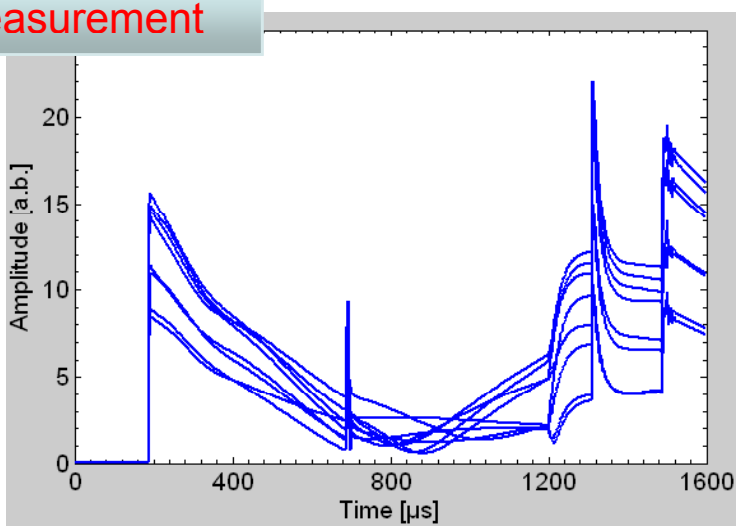


Cavities in ACC6 with Piezo on
3MHz/3nC beam with 1500 bunches



September 2009 Measurement

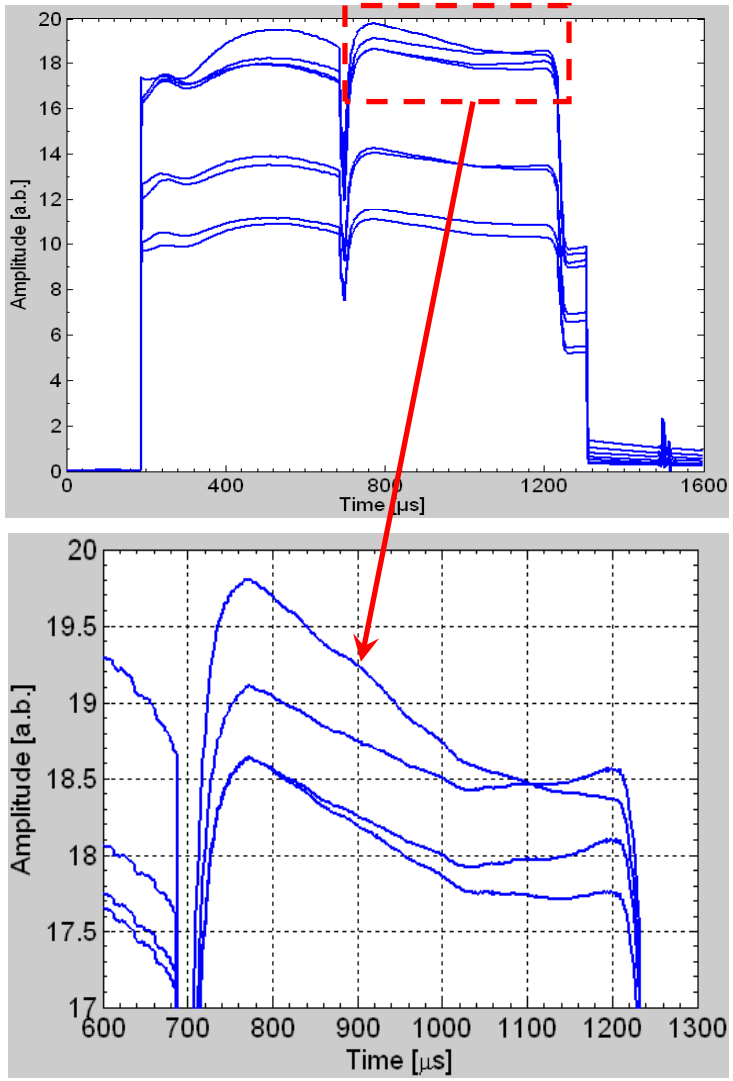




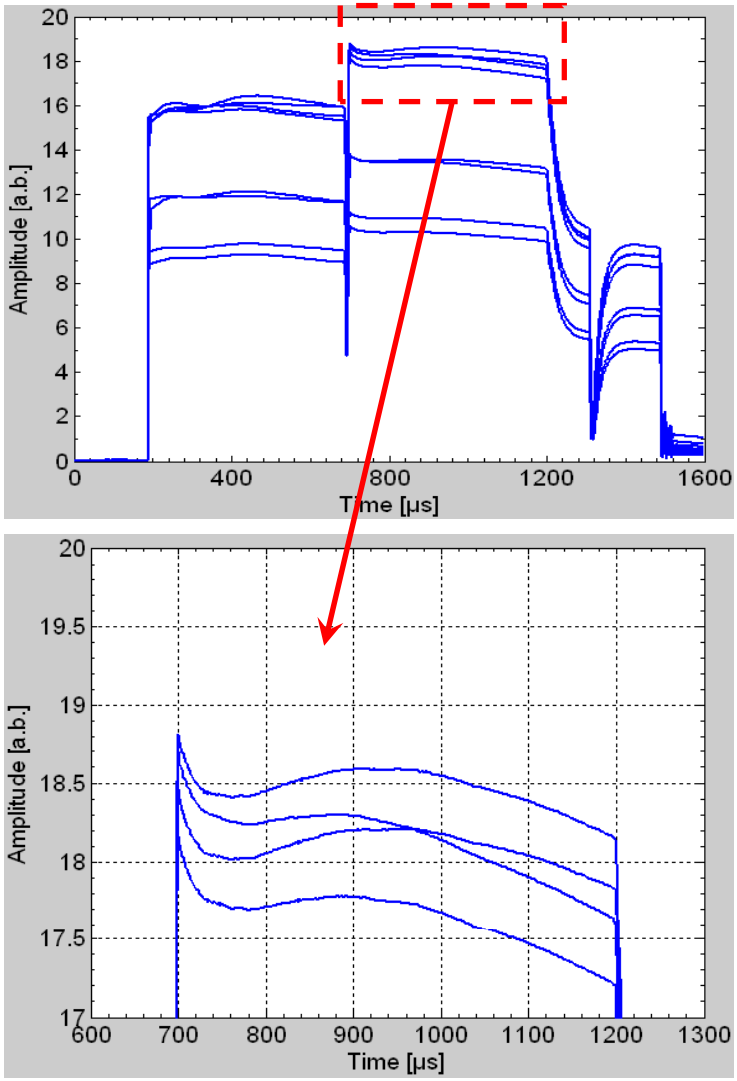
RF Power Overhead Issue

September 2009 Measurement

Cavities in ACC6 with piezo off
3MHz/3nC beam with 1600 bunches



Cavities in ACC6 with Piezo on
3MHz/3nC beam with 1500 bunches



Summary

- As with previous beam-off, feedback-off data, the input rf stability is very good with 0.10-0.15% rms variations at full power (scales as 1/amp)
- Also, in this case, the cavity gradient variations are similar with proper choice of initial detuning – else, can get up to ~ 1% cavity field variations – they are well explained by a model that includes initial detuning and a few Hz of microphonics induced cavity frequency jitter (with piezos on, cavity field jitter may increase somewhat).
- With beam and feedback on, input rf jitters up to ~ 1%.: it correlates as expected with the beam charge variations (slope of ~½ at nominal 9 mA current and slope of ~¼ with 3 mA data).
- Feedback does well with beam on despite the poor setup of the cavities where flattop gradients vary significantly (tuning likely OK however).
- Piezos reduce required overhead from LFD, but only AAC6 equipped, which makes the required residual overhead hard to estimate.