RF Trip Compensation for Beam Stability

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RF&Linac Section - ALBA Accelerators Division

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Outline

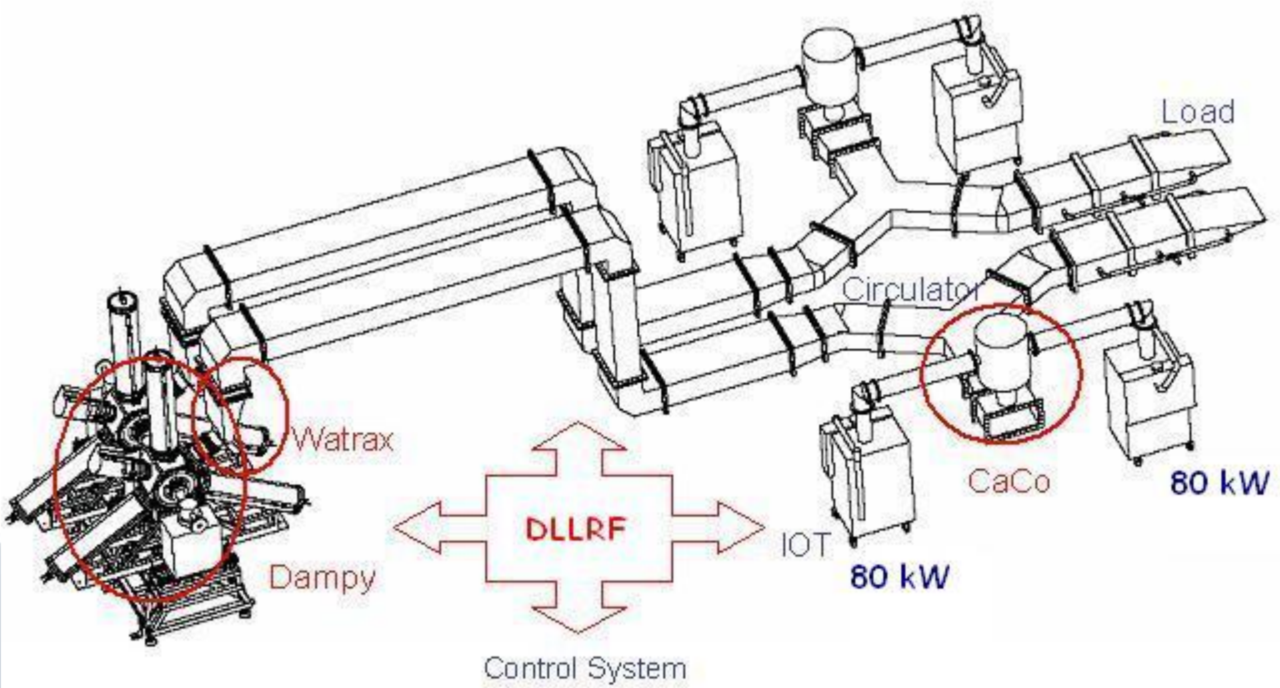
- ✓ Introduction and Motivation
  - SR RF Plants
  - ALBA LLRF
  - RF Operation
- ✓ Feed-Forward Loops for RF Trip Compensation
  - Amplitude Modulation
  - Phase Modulation
  - Phase Step Modulation
- ✓ Future Upgrade: Feedforward for Beam Loading Compensation
- ✓ Conclusions

Introduction and Motivation

Storage Ring RF Plants

RF Parameters

U_0	1.3MeV/turn
V_{total}	3.6 MV
q	≈ 2.5
f_s	≈ 9kHz
P_{RF}	960kW



6 RF Plants of 160kW at 500 MHz

2 IOT Transmitters per RF cavity. Power combined in CaCo

Dampy Cavity
- Normal Conducting
- Single cell, HOM damped
- 3.3 MΩ

Digital LLRF System based on IQ mod/demod

ALBA LLRF

Main Characteristics

- ✓ Based on digital technology using a commercial cPCI board with FPGA
- ✓ Signal processing based on IQ demodulation technique
- ✓ Main loops: Amplitude, phase and tuning
- ✓ RF diagnostics: Circular buffer for post-mortem analysis (0.5s)
- ✓ Extra utilities
  - Automatic conditioning for cavities
  - Automatic cavities recovery

Digital board: VHS-ADC from Lyrtech

Loops Resolution and bandwidth (adjustable parameters)

	Resolution	Bandwidth	Dynamic Range
Amplitude Loop	< 0.1% rms	[0.1, 50] kHz	30dB
Phase Loop	< 0.1º rms	[0.1, 50] kHz	360º
Tuning	< ± 0.5º	--	< ± 75º

RF Operation

At present

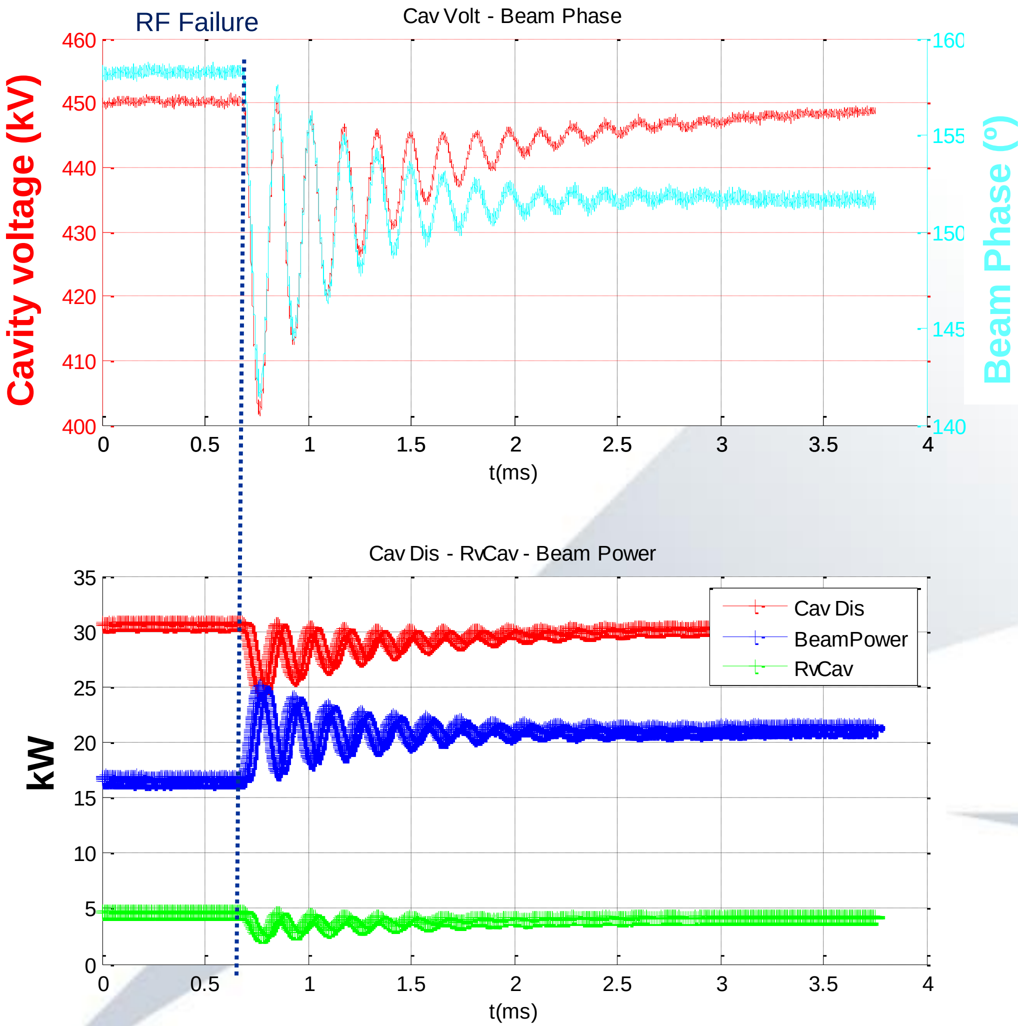
- ✓ Running at 110mA with 2.6MV of RF Voltage in SR
- ✓ 2 or 3 RF Interlocks per week
- ✓ One RF Trip does not cause beam loss (enough over-voltage)
- ✓ Automatic recovery allows setting into operation a tripped plant with circulating beam

In Future

- ✓ SR Current will be increased up to nominal current 250mA (SR RF designed to withstand 400mA)
- ✓ With present available RF voltage, higher SR currents will lead to beam losses when an RF plant trips
- ✓ Solution: Active compensation of RF Trip disturbances

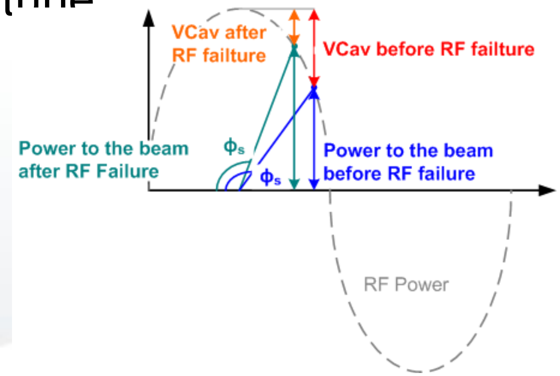
Active RF Trip Compensation

Analysis of Beam Survival after RF Failure



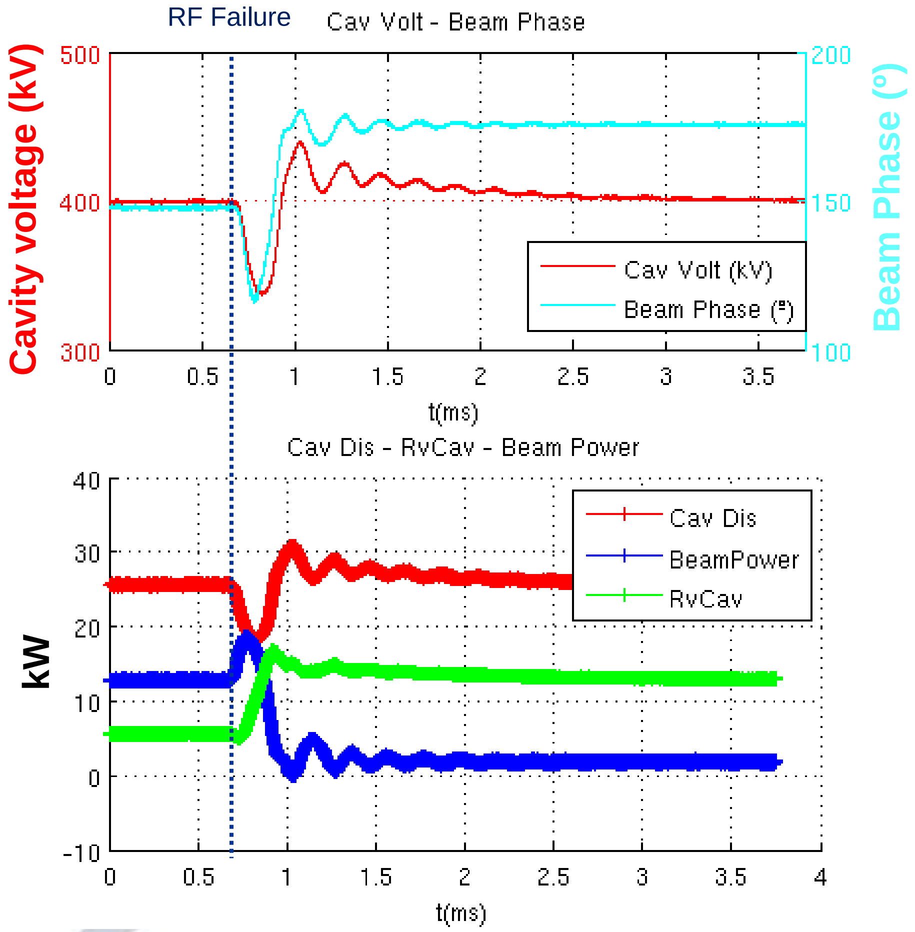
Response of active cavities after RF Trip

- **Cavity voltage** and **synchronous phase** drop and they start to oscillate with a frequency equal to synchrotron tune



- **Beam** extracts more power from cavity
- **Reverse power** of the cavity decreases
- Amplitude of oscillations depend on beam current
- Frequency oscillations depend on how much RF voltage is left

Analysis of Partial Beam Loss after RF Failure



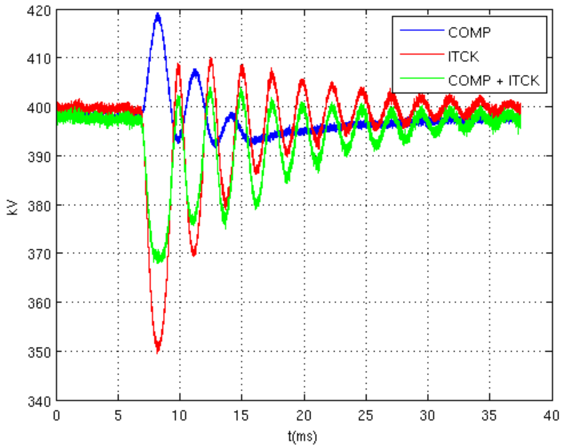
Response of active cavities after RF Trip

- Cavity voltage decreases and then there is **an overshoot**
- Synchronous phase decreases
- But, reverse power increases and power delivered to the beam decreases → Power extracted from the beam → Partial beam lost

- So, if behavior known, compensation can be applied before losing the beam

Feed-Forward Loops

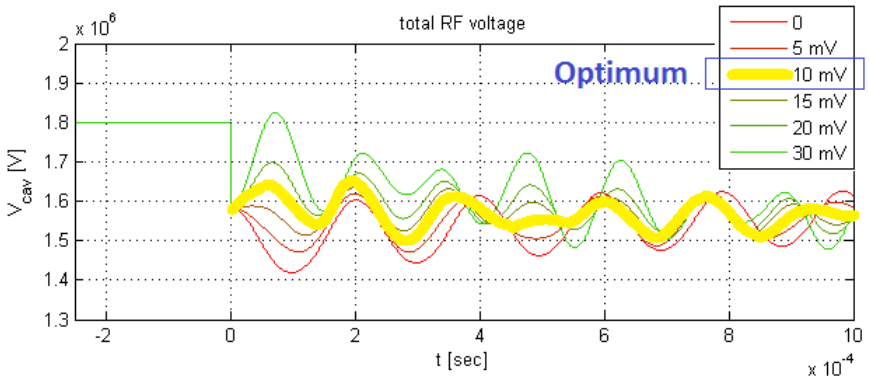
✓ Active compensation of disturbance: **Theoretical results**



Response of 06A Cavity Voltage after stopping Cavity 10B – 60mA

- Cavity Voltage oscillations after interlock measured
- Compensation activated for first periods (Amplitude modulation with frequency equal to synchrotron tune)
- Overlap of two responses
- Sum of two responses: theoretical result
  - Decrease of perturbations by a half

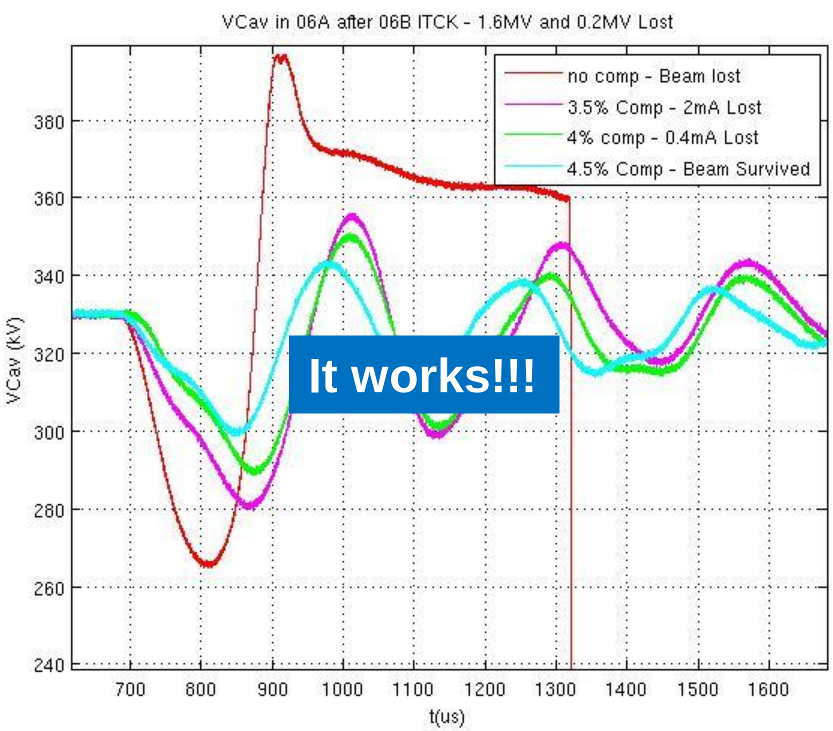
✓ Simulations done by J. Marcos to calculate optimum compensation



- Analysis of Overall Cavity Voltage after trip applying compensation with different amplitudes
- **Optimum:** Compensation where no voltage overshoots were observed

Feed-Forward Loops: Amplitude Modulation

- Initial conditions:
  - 5 Active Cavities
  - Total RF Voltage = 1.6MV (320kV per cavity)
  - Ibeam = 60mA
  - Fake Interlock created in one cavity



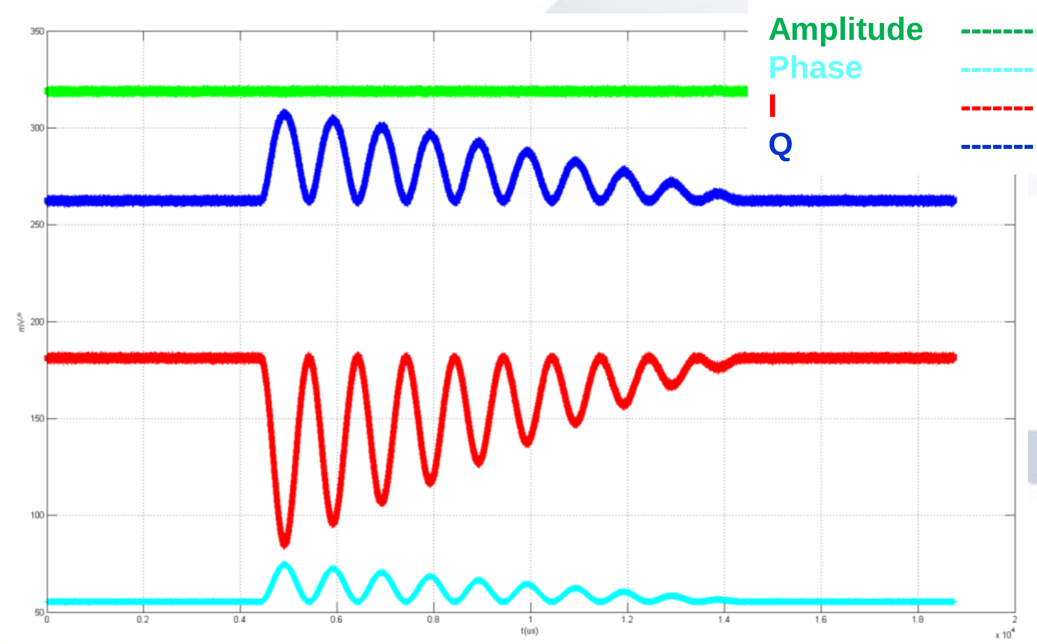
Voltage of Active Cavity after RF Trip

- Analysis of Cavity Voltage of 06A after trip in 06B with amplitude compensations
  - With no compensation: Beam lost
  - With 3.5% compensation – 2mA lost
  - With 4.0% compensation – 0.5mA lost
  - With 4.5% compensation – Beam survived
- Still 4.5% overdrive (1dB) could be high when working at higher current/power
- Other compensation strategies analyzed
  - phase modulation to compensate oscillations instead of amplitude modulation
  - No overdrive needed

Feed-Forward Loops: Phase Modulation

✓ Frequency Phase Modulation

- Amplitude of RF Drive kept constant
- Phase of RF Drive modulated to compensate longitudinal oscillations of beam
- Frequency equal to synchrotron tune
- Tested with beam, but not conclusive results. Further tests needed



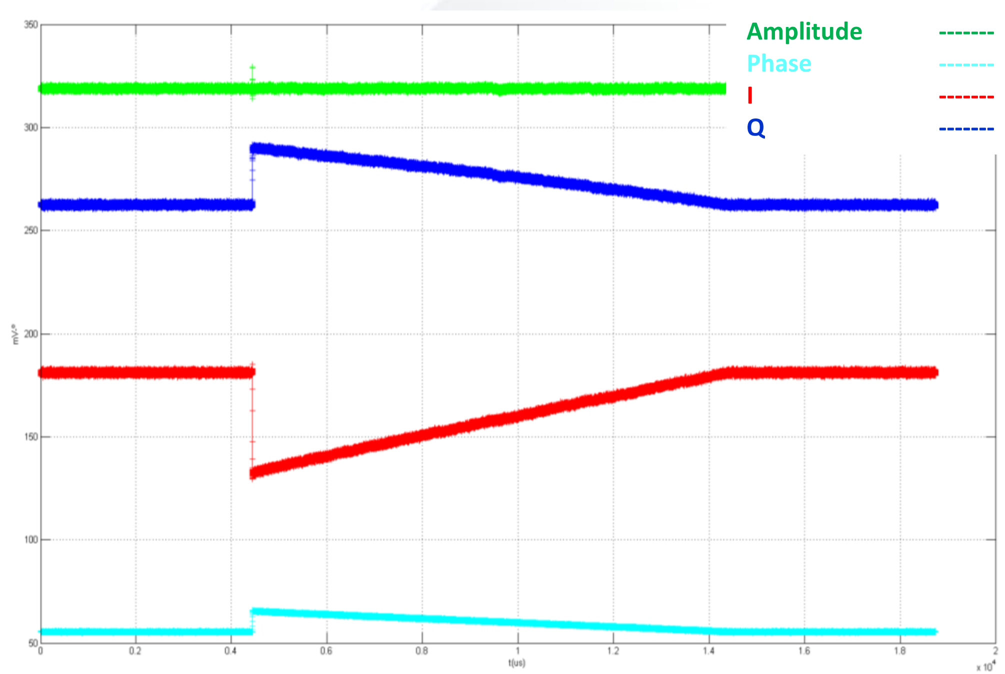
RF Drive – Phase Modulation

Example of Frequency Phase Modulation

- Modulation Freq = 10kHz
- Phase Mod = 10^{o}
- Decay time = 10ms

✓ Phase Step Modulation

- Phase of RF Drive changed Δφ with a step which decreases with a decay time equal to damping time
- Capable to compensate partial beam loss, but not total beam loss

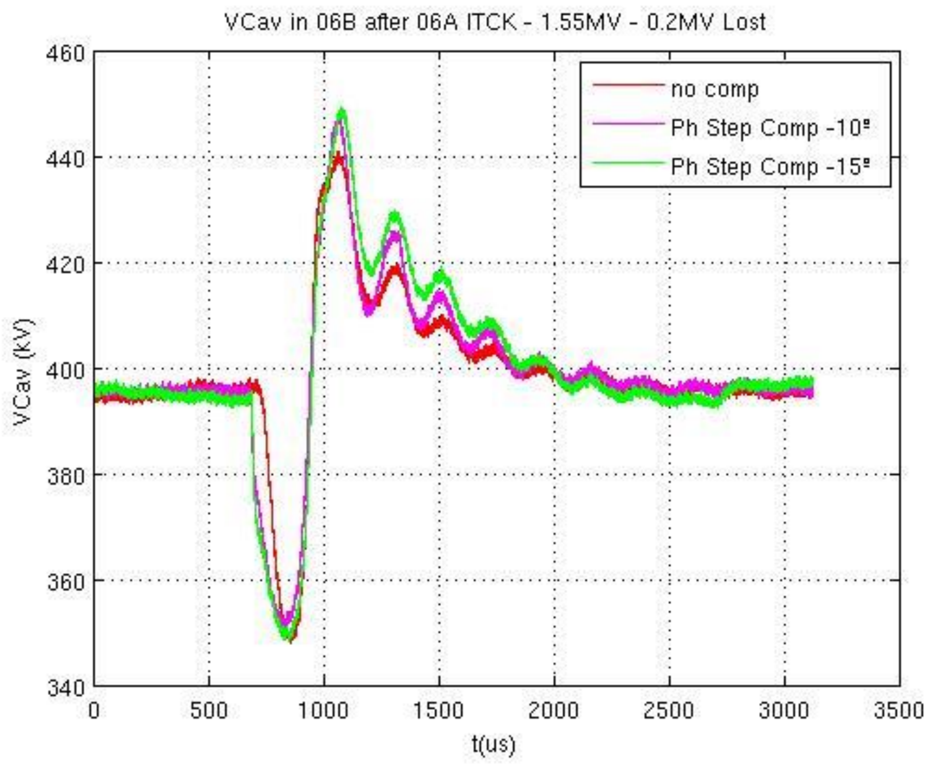


RF Drive – Phase Step Modulation

Feed-Forward Loops: Step Phase Modulation with beam

✓ Initial conditions:

- 5 Active Cavities
- Total RF Voltage = 1.55MV (3x450kV + 1x200kV)
- Ibeam = 60mA
- Fake Interlock created in 200kV Cavity



✓ Analysis of Cavity Voltage of 06B after trip in 06A with phase step compensation

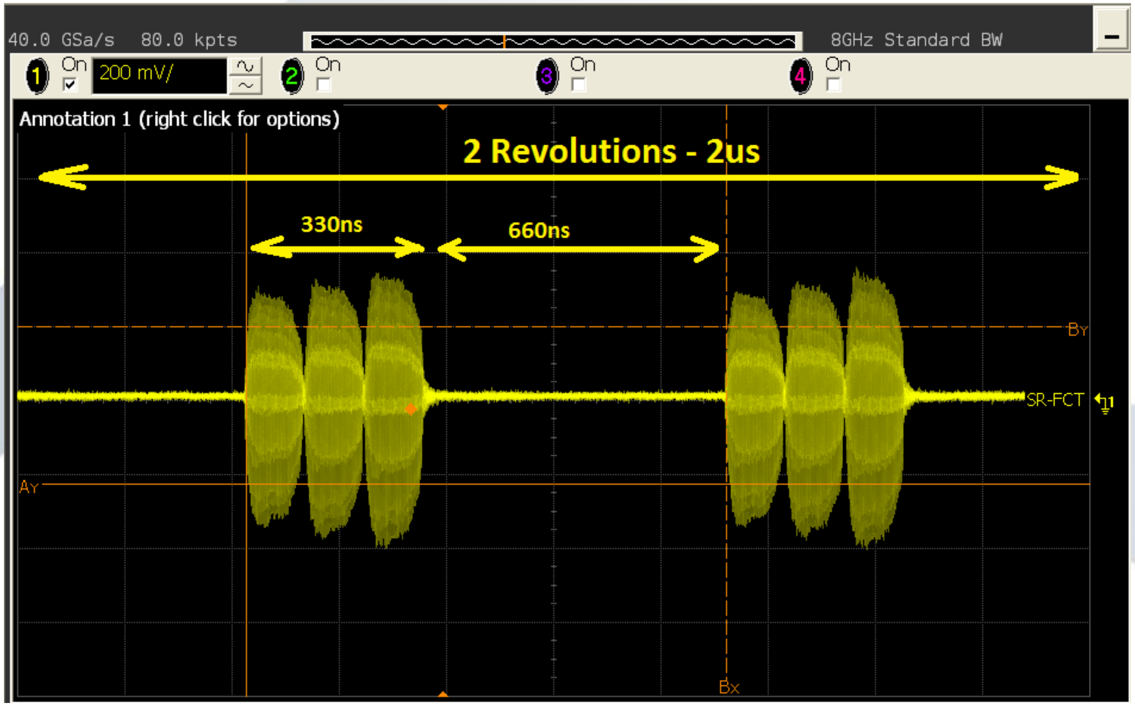
- Beam loss partially compensated, but no conclusive results
- Further tests needed

FF Loop for beam loading compensation

✓ **In Normal Operation: Effect of beam loading negligible**

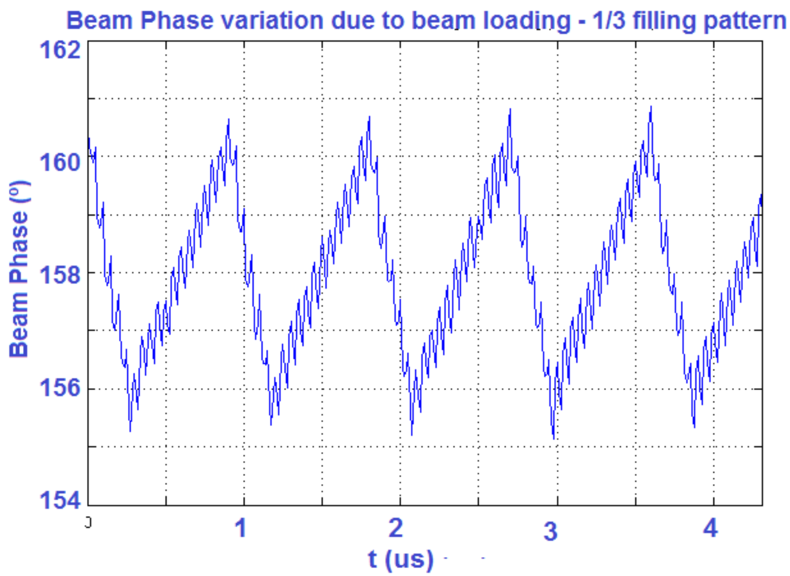
- *Revolution frequency ~ 1MHz*
- *90% Filling Pattern*
- *10 trains: 10 x (32 bunches + 12 empty buckets)*

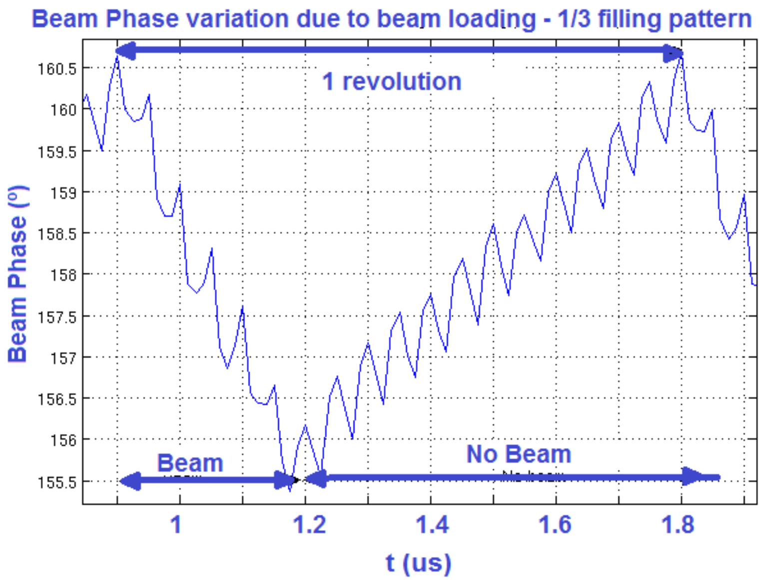
✓ **Filling pattern modifed to 1/3 to be able to measure beam loading effect**



FF Loop for beam loading compensation

✓**Beam Loading measured with 1/3 filling pattern (60mA)**





- *Beam Phase modified by 5º due to beam loadign effect*
- *Future upgrade: Phase modulation (feed-forward loop) to compensate this effect*
- *Needed to prove feasibility of this approach for CLIC collaboration*

Conclusions

✓ RF Operation:

- 2 or 3 RF interlocks per week
- Beam survives after RF Trip with present configuration: 110mA – 2.6MV RF voltage

✓ RF Trip Compensation:

- Amplitude Modulation can compensate beam loss due to RF Trip, but overdrive needed (higher stress to IOT)
- Other RF Trip compensation approaches being studied (phase modulation and phase step modulation)
- RF Trip compensation would allow increasing SR Current keeping RF Voltage and keeping beam availability when an RF Trip occurs

✓ Feed-Forward loops for beam loading compensation being studied

Thanks for your attention
Questions?