Broadband Feedback System for Instability Damping in the SNS Ring

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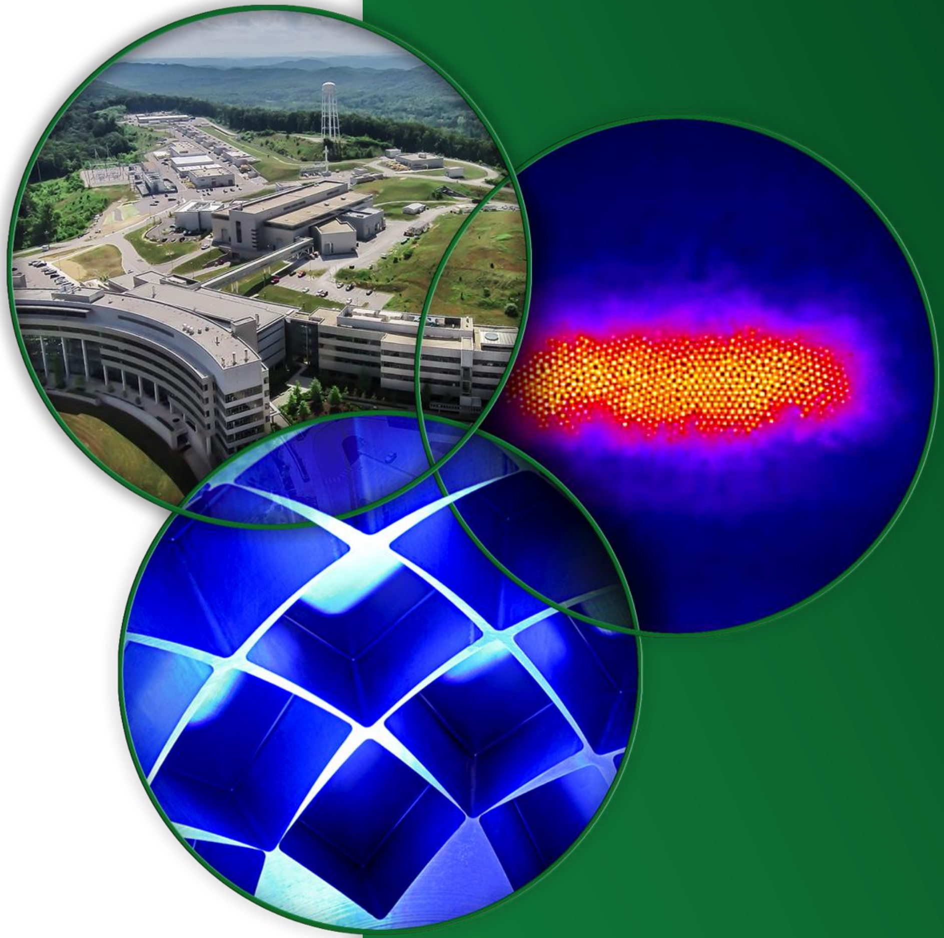
HB 2016

Malmö, Sweden



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Overview

- Motivation
- Feedback System Design
- Damping
- Performance
- Summary

Motivation

- e-p instability – interaction of beam with a cloud of electrons in the beam pipe generated by low levels of beam loss, amplified by secondary electron generation

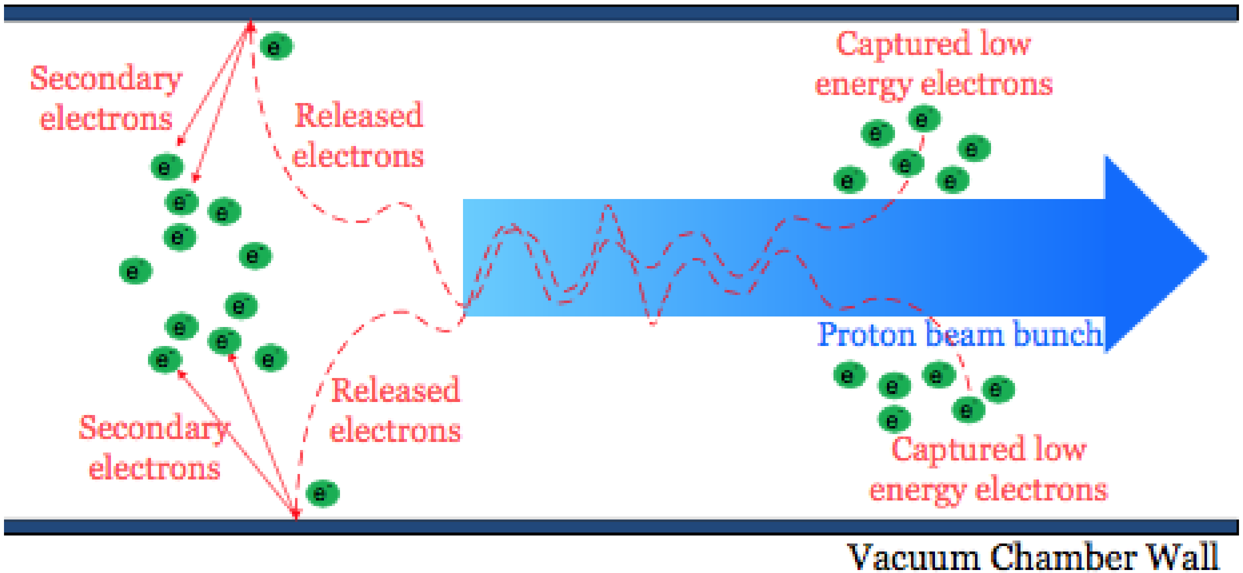

Image credit: Zaipeng Xie

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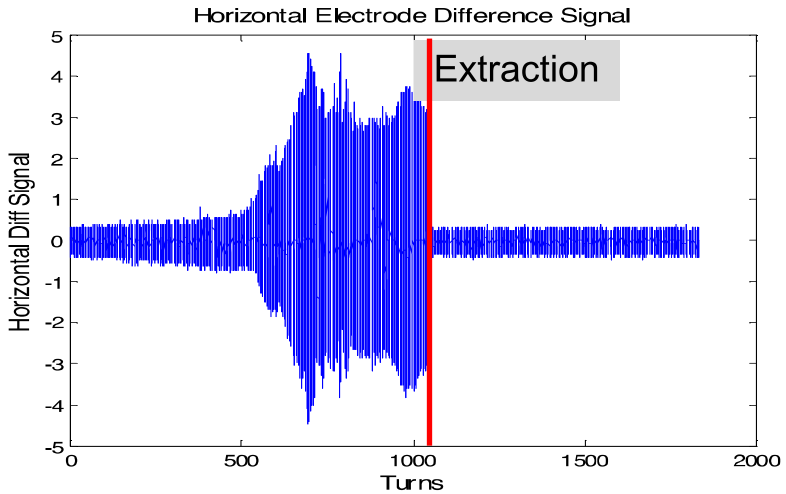
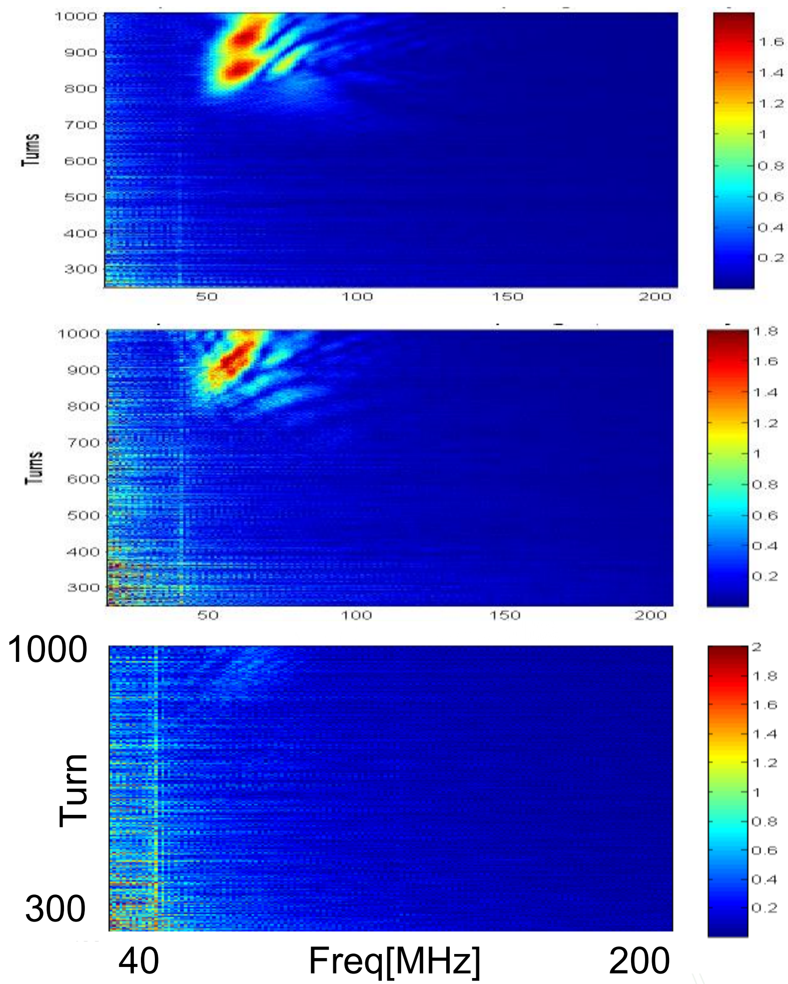
Motivation – E-P Manifestation

- Broadband (80-120MHz) betatron oscillation:



- Rise time ~10's of turns

Spectrogram of Difference Signal



2008 Study by Cousineau et. al.

Motivation – E-P During Operation

E-p produces <1mm oscillation near the end of accumulation – *No detectable losses associated with e-p* – but:

- Onset will be fast – rise times typically 10s of turns
- Complicated dependence on many parameters – bunch shape, current, momentum spread, etc.
- Could be a problem as we move to 2.8 MW

Mitigation measures include: Beam pipe coating, up to 15 kV 2nd harmonic RF, large apertures (low losses), and *active feedback*

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Design Philosophy

- Wanted a system that is easy to maintain, with minimal complexity
- Several Considerations:
  – SNS ring only accumulates beam ~1000 turns (1ms) – except for special cases no more stored turns even after upgrade
  – Broadband instability spans from ~80-120MHz

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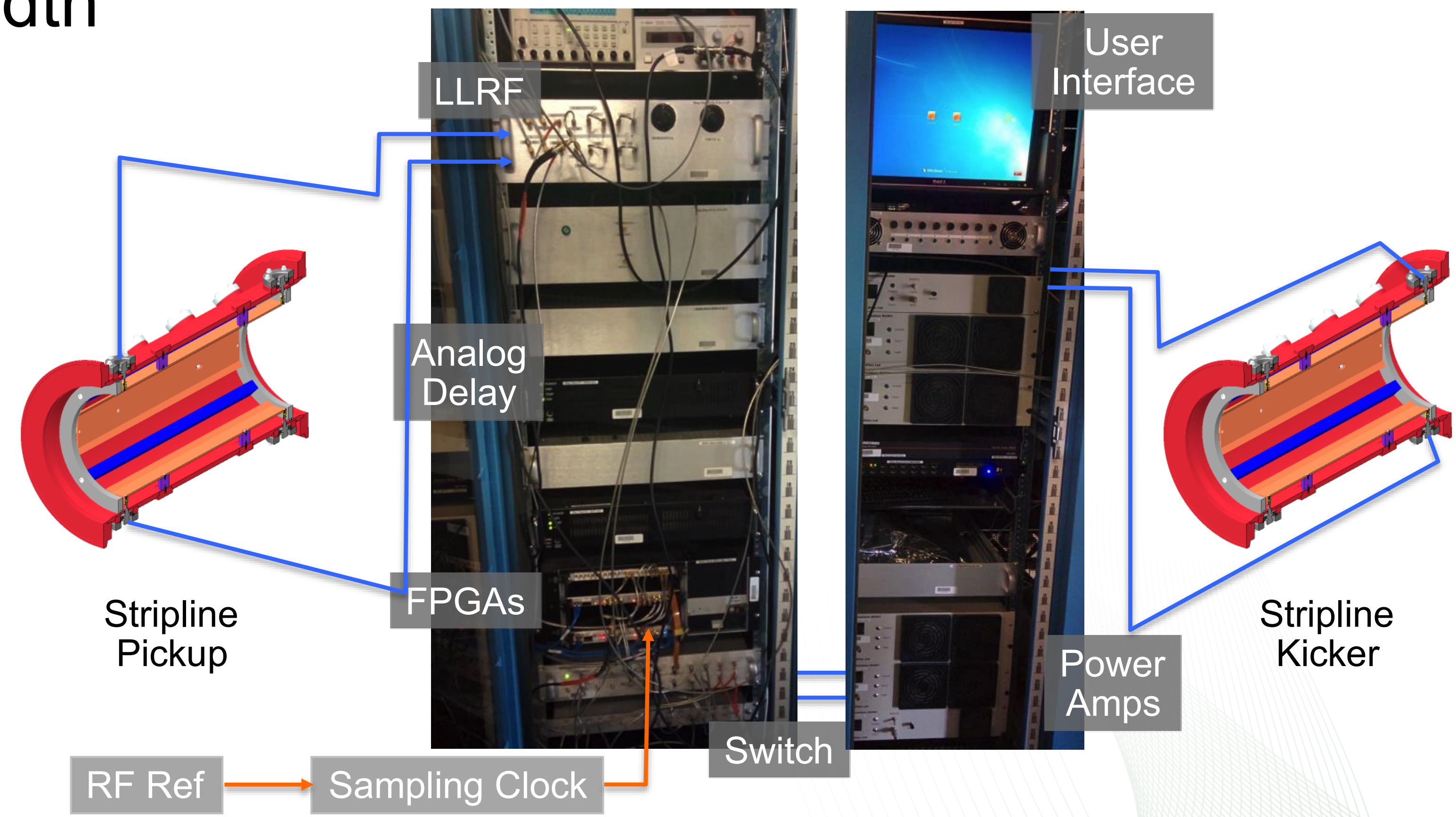
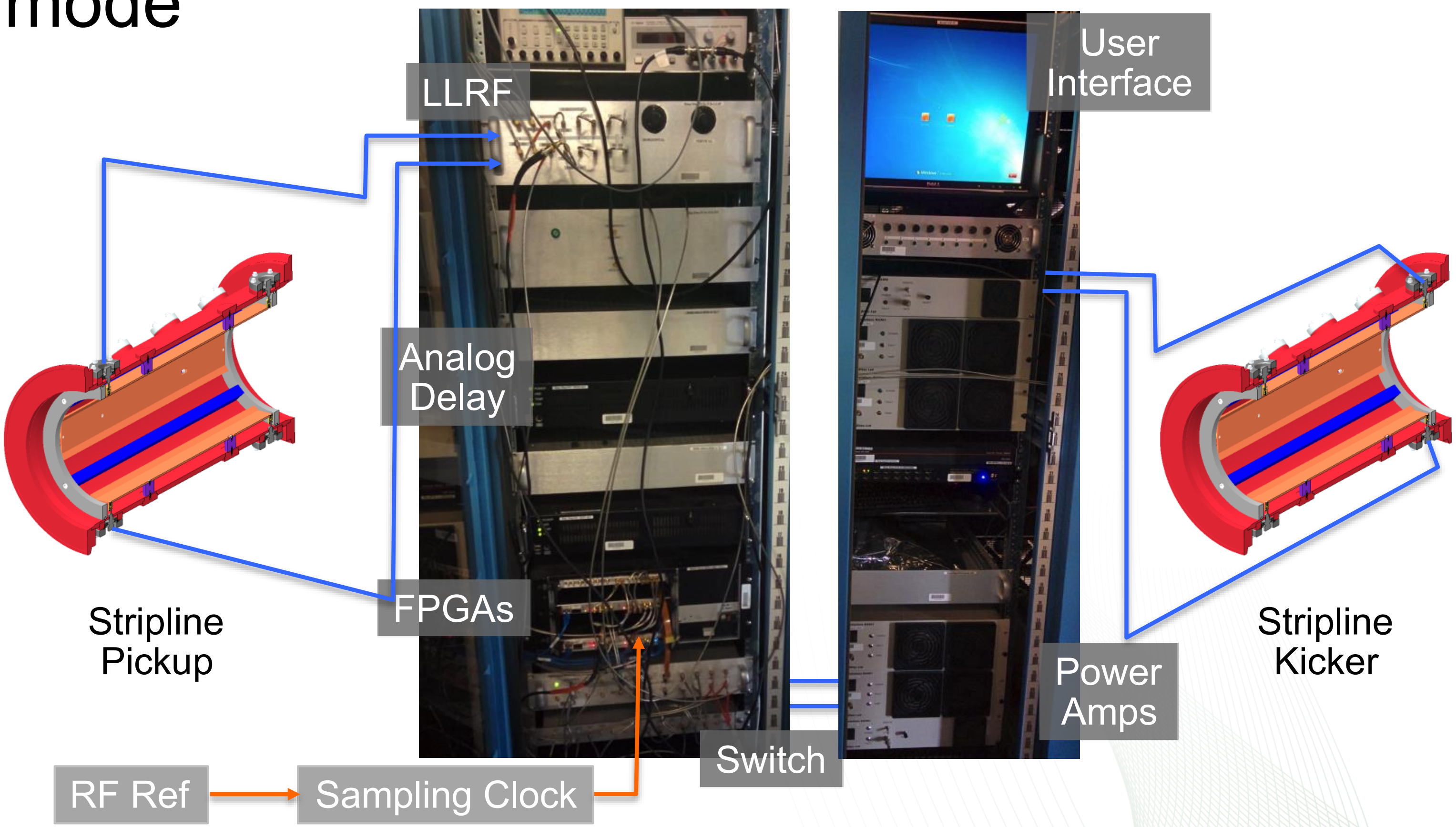
Damper System Overview

- Settled on a delay-line feedback system, with digital delay, minimal digital processing to improve bandwidth



Damper System Overview

- Avoided mode-by-mode style dampers which would require separate processing channels for each time slice or mode



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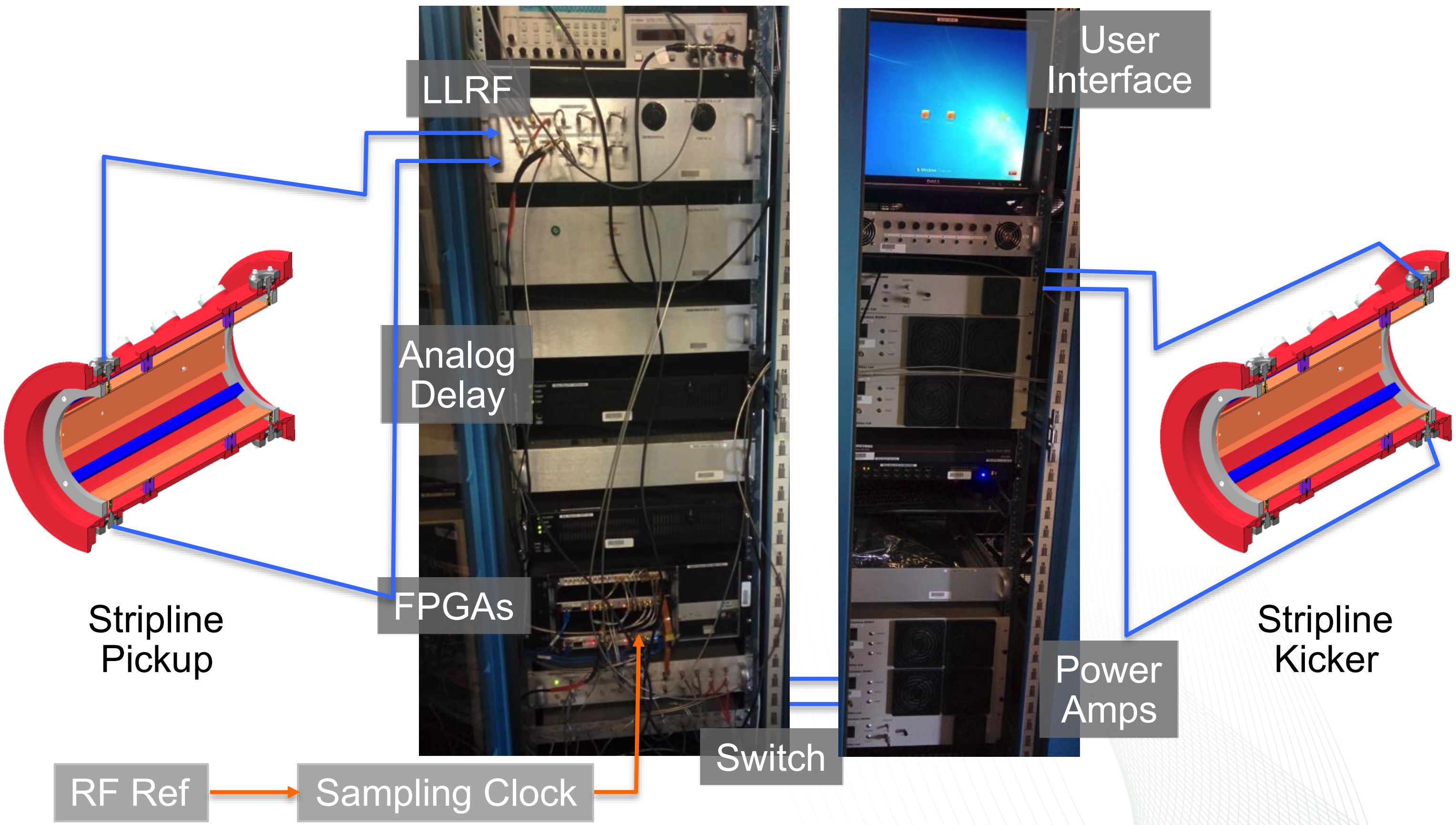
Damper System Overview

- We pay for simplicity with a loss of mode-by-mode gain/phase control



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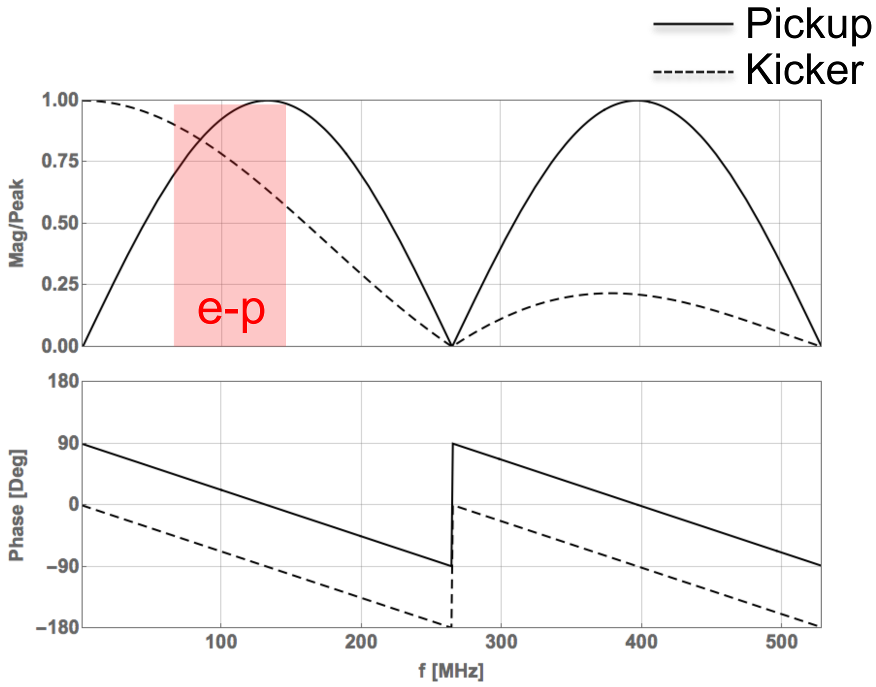
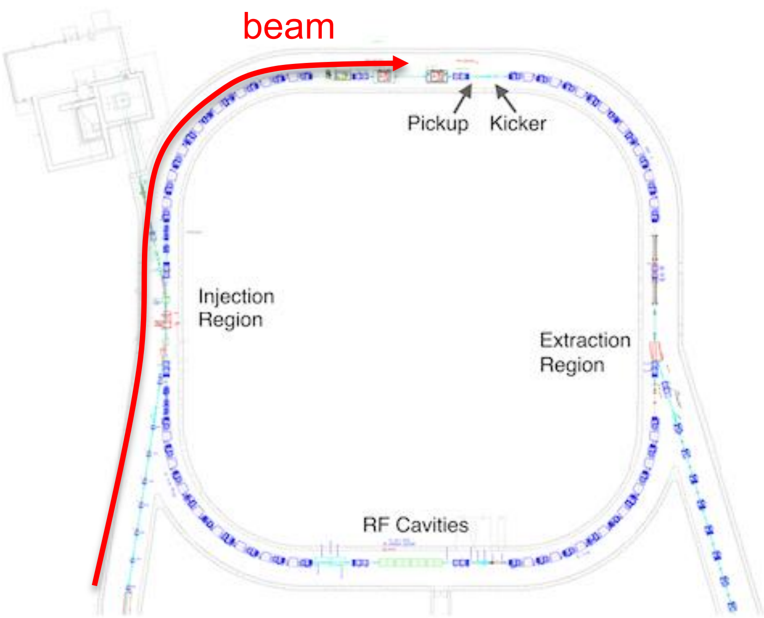
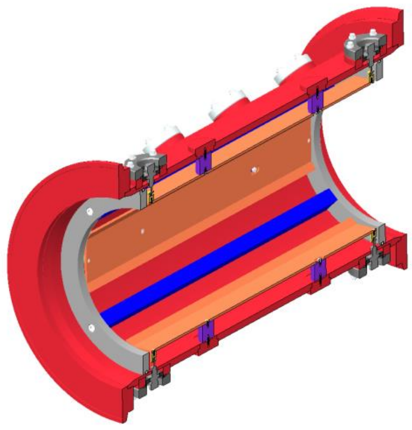
Damper System Overview

- Pickup and kicker are identical 0.49m striplines

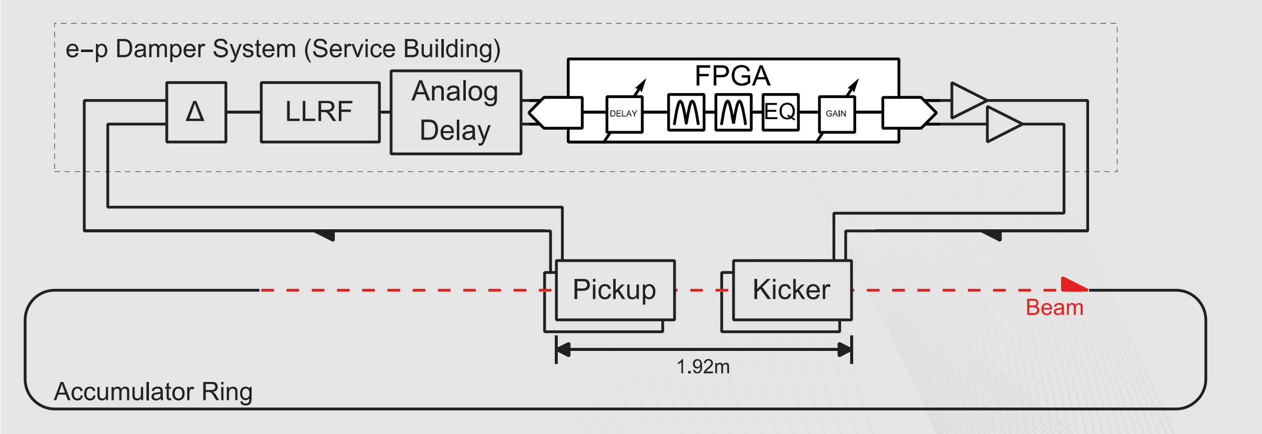






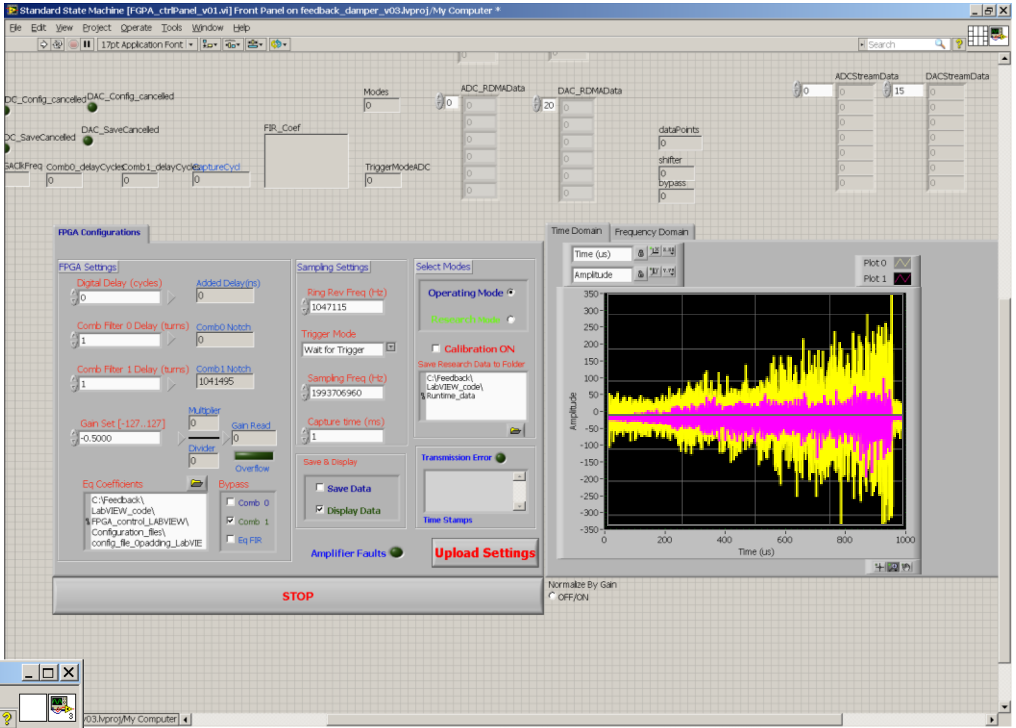
Damper System DSP

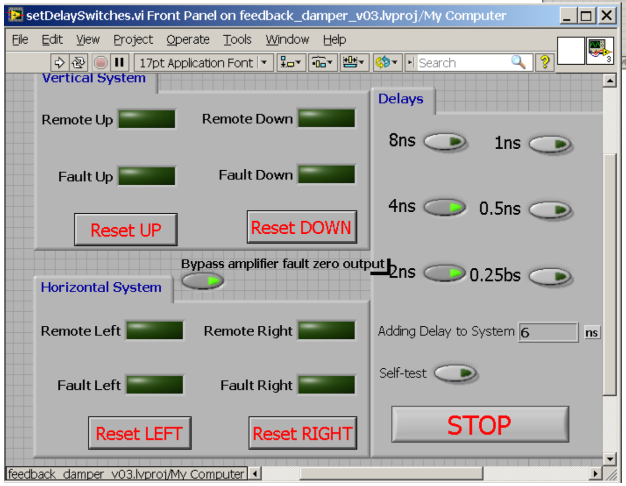
- 1 QuiXilica Triton-V5 Board/plane
  - 10-bit ADC (up to 2GSPS synched to 10 MHz ring RF)
  - 3 Xilinx Virtex-5 FPGAs per board:
    - Delay
    - Comb Filters
    - FIR EQ
    - Digital Gain
  - 12-bit DAC



Damper System Interface

- Damper Interface
- Analog Delay Interface
- LabView handles communication with FPGA





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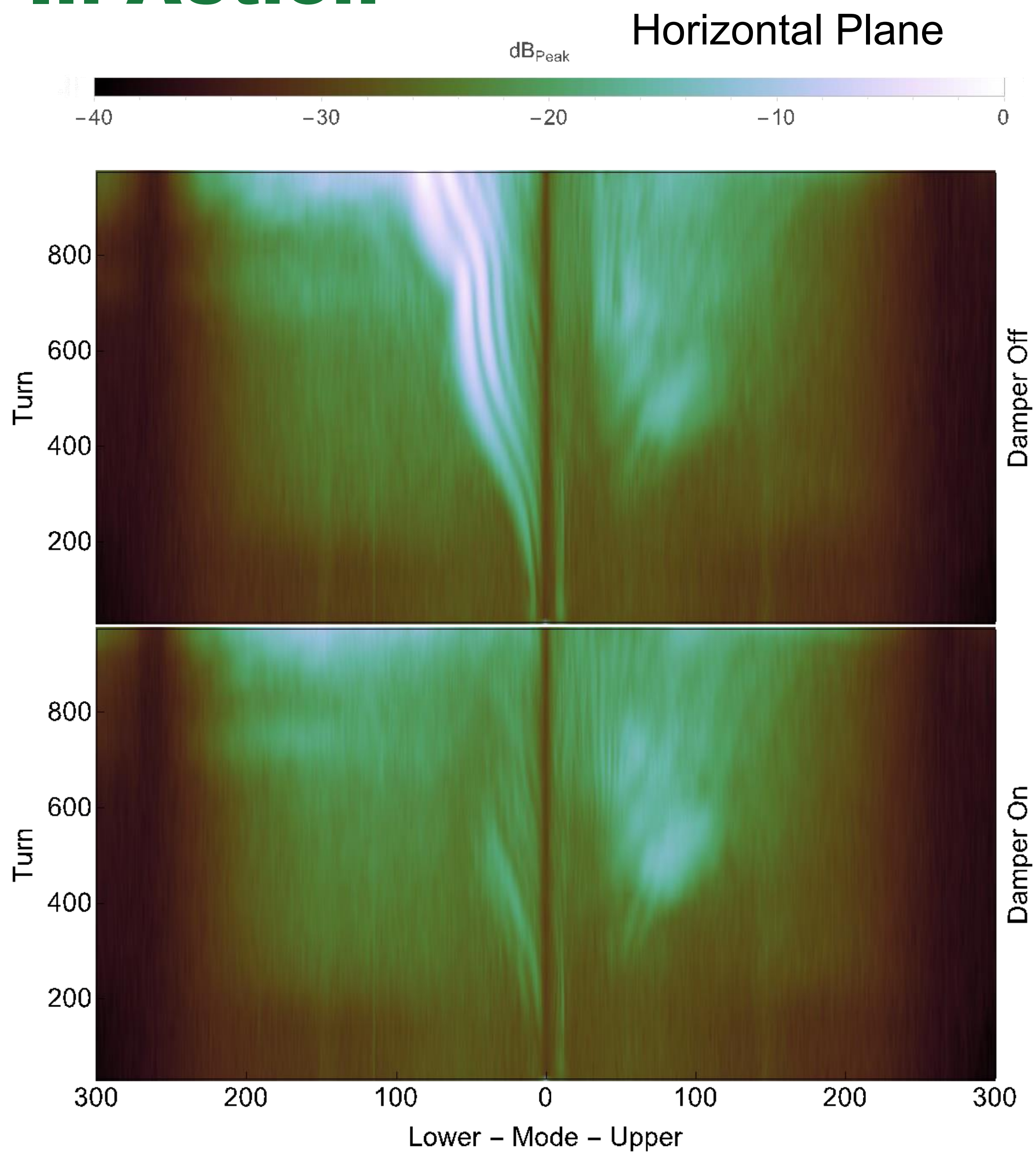
Damper System In Action

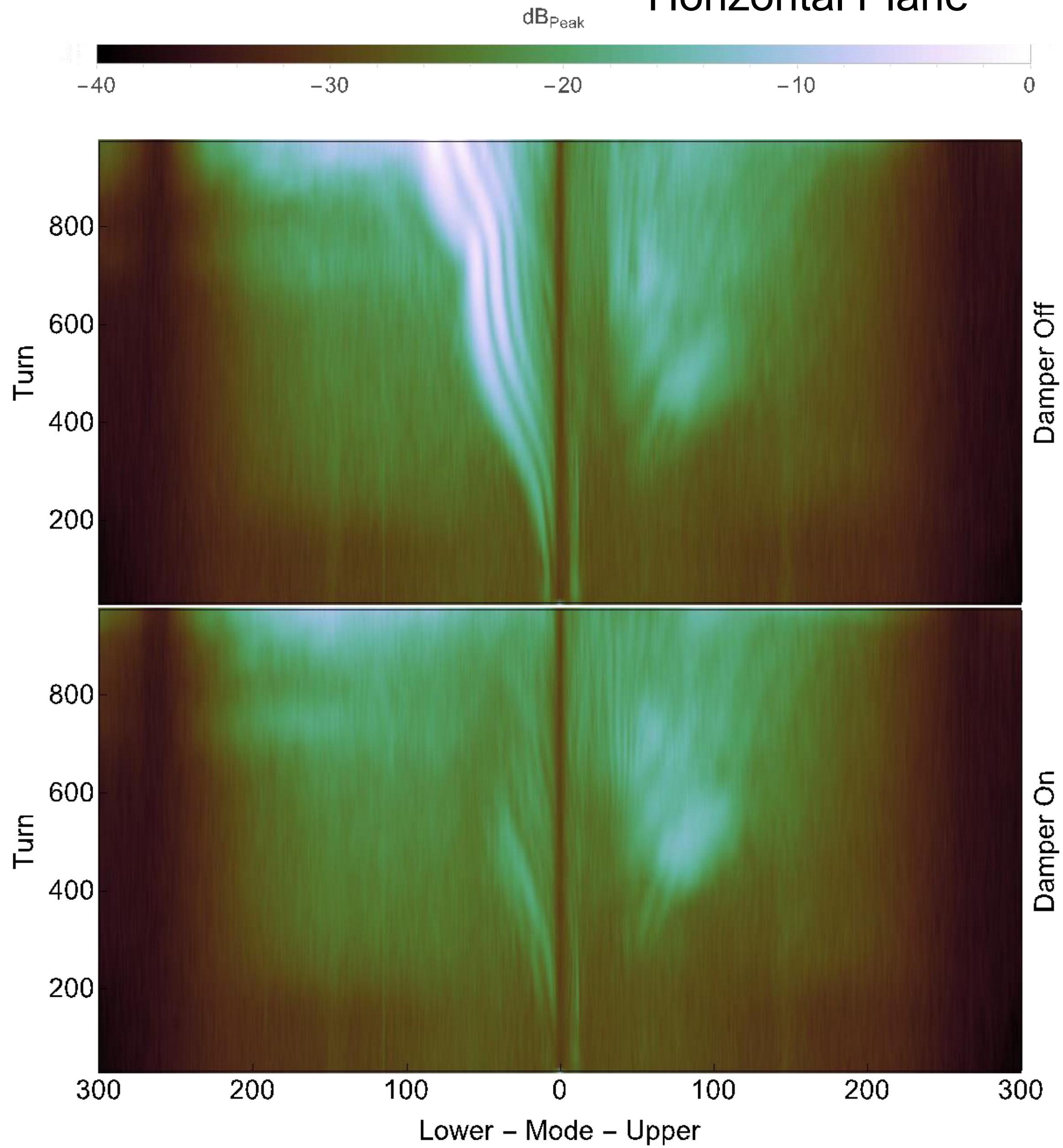
- Broadband signature of e-p activity on spectrogram - fall 2015
- Damper effectively suppresses e-p

*Note that upper and lower sidebands have been separated



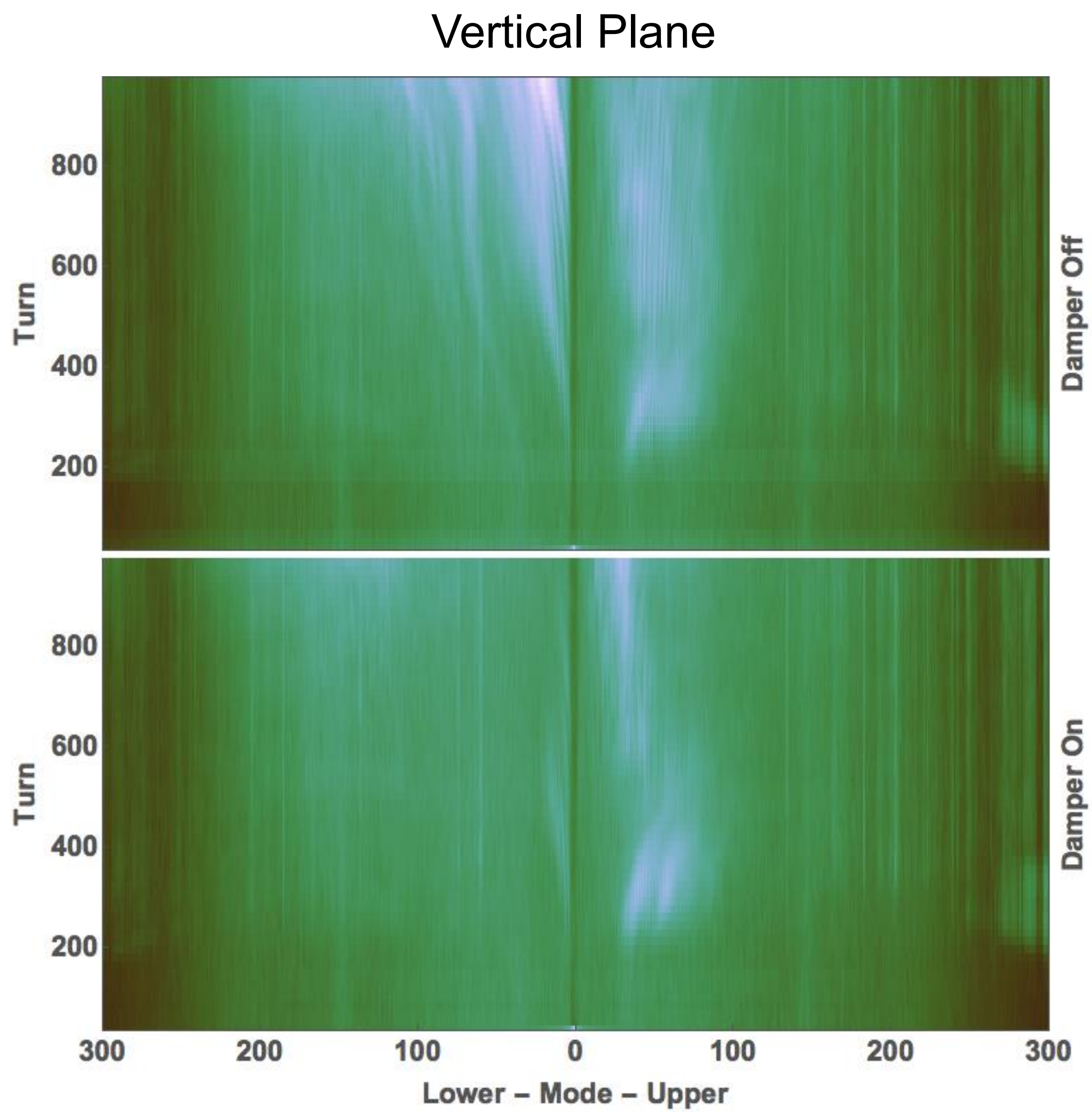
Damper System In Action

- Total oscillation amplitude is only about <1 mm at th moment



Damper System In Action

- Vertical oscillation not as pronounced
- Damper suppresses this motion



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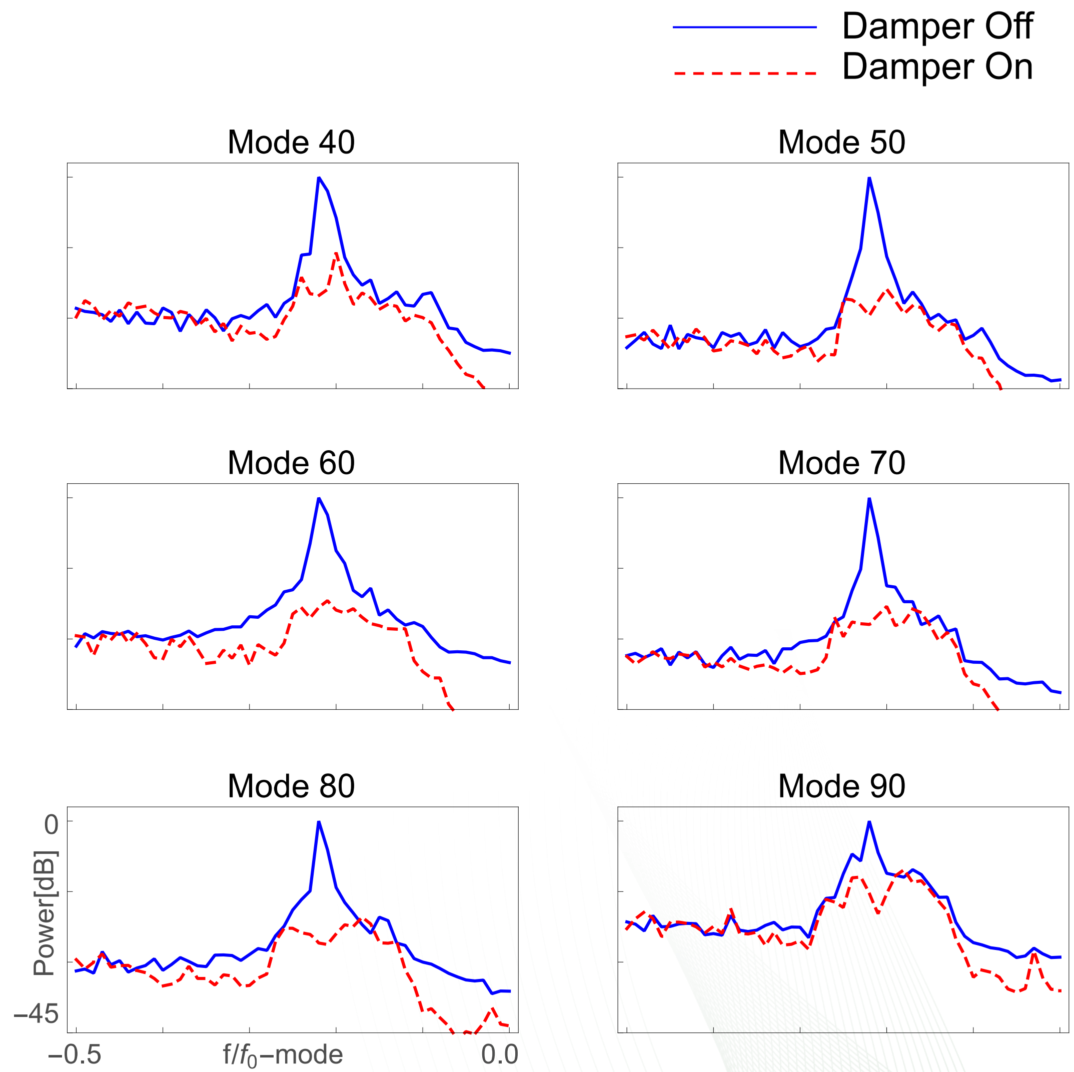
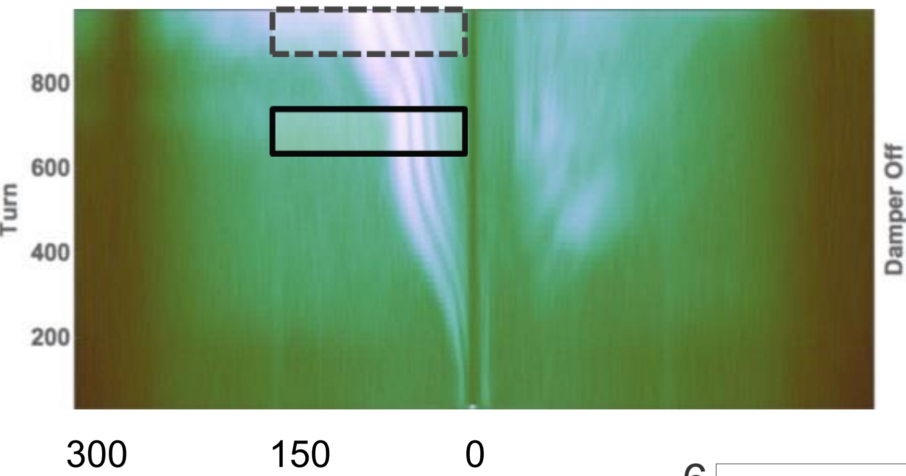
A Closer Look – Turn 600

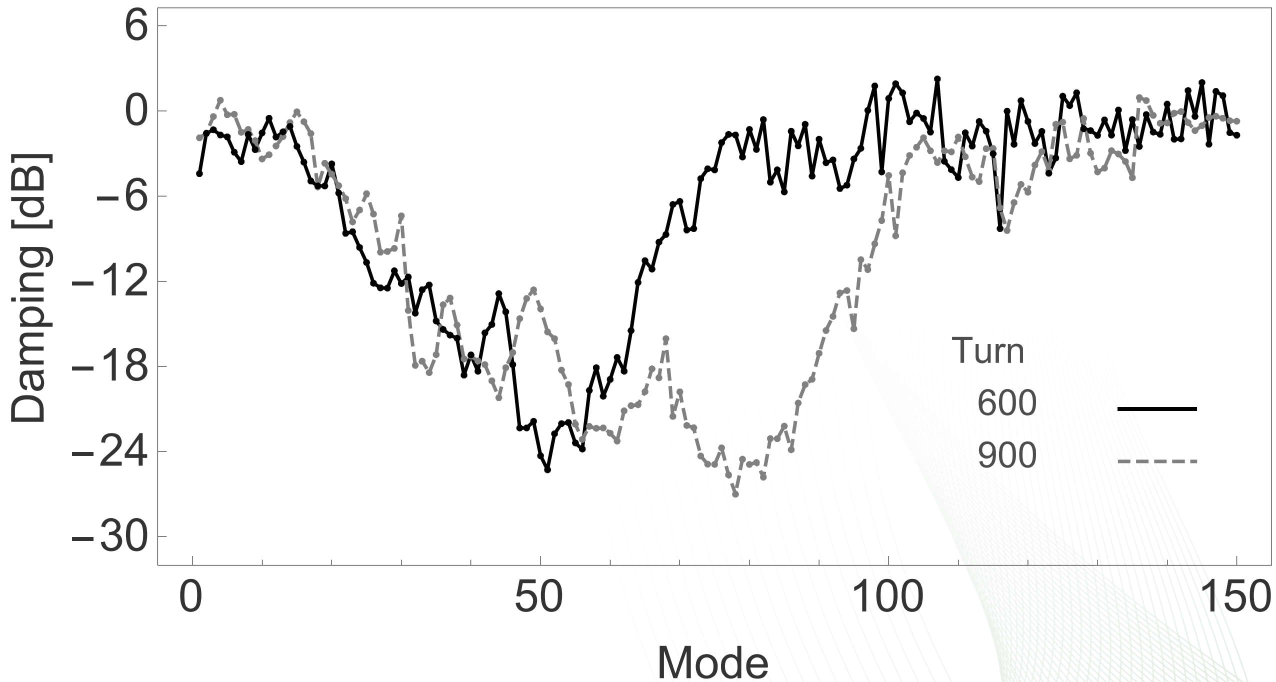
- Power reduced by 25dB in worst modes
- Full extinction to within noise we see when instability is not present
- At this point, modes above ~90 are not active



Effectiveness Throughout Cycle



- Log Ratio of betatron peak damper on/off at two points in the cycle for many modes



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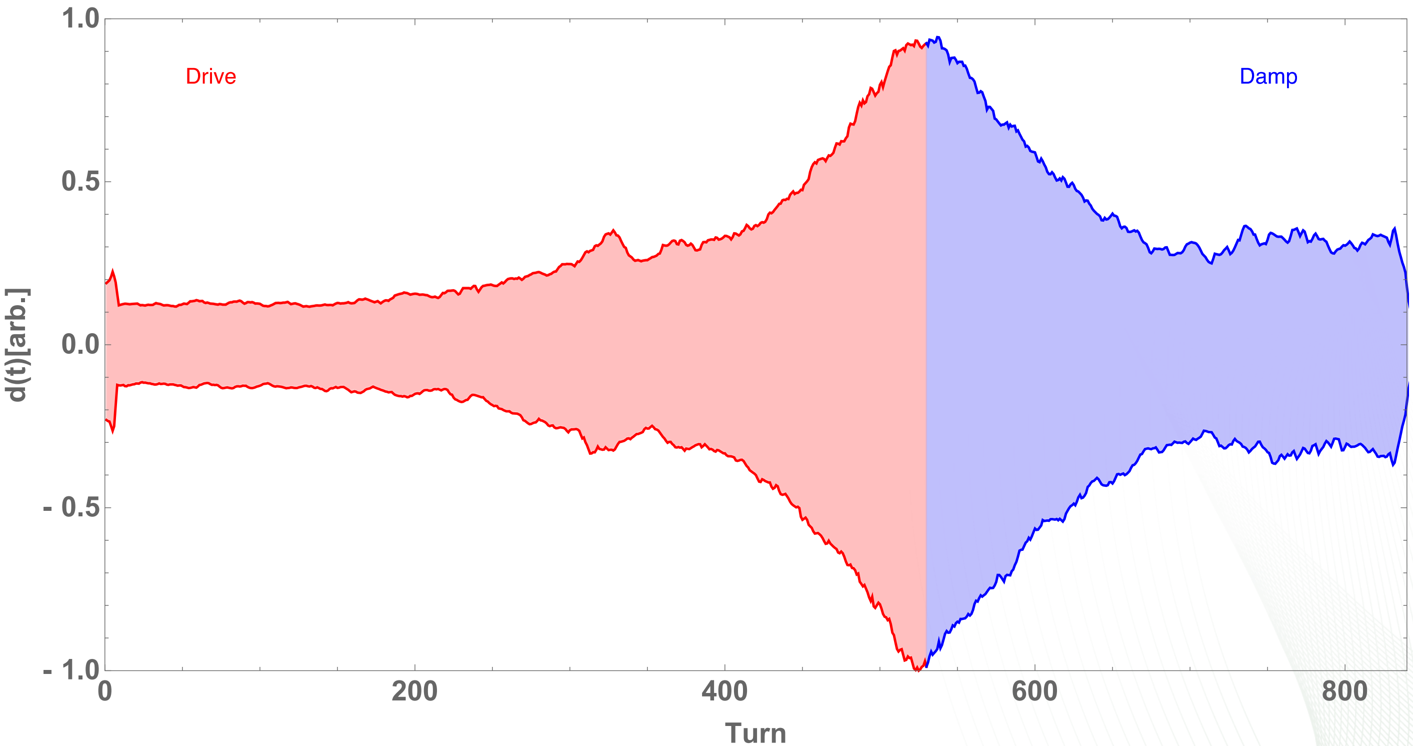
Damping Rates

- We can drive beam with the damper, then damp
- Difference signal during drive-damp test
- Sign of the gain is flipped at turn ~550



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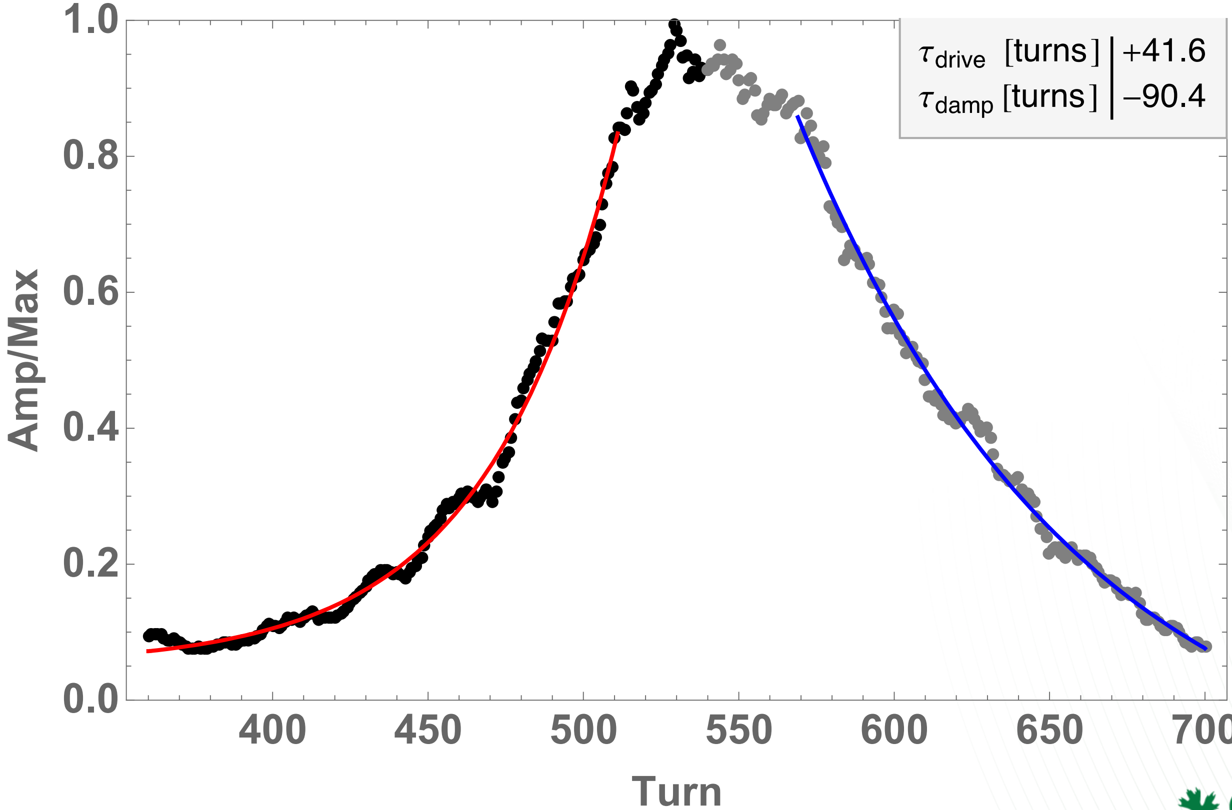
Damping Rates

- Gain too large for optimal damping
- Exponential fit to dipole signal gives growth/damp rates



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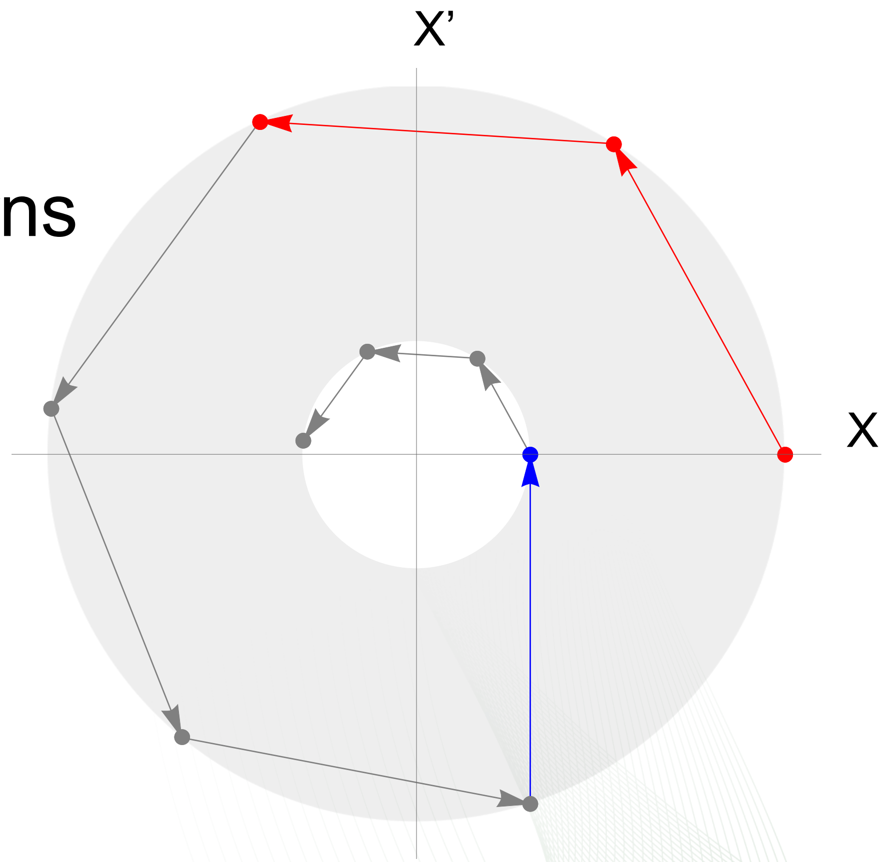
Damper System – Delay

- Damping is most effective when we kick at odd integers of π/2 phase shift
- Minimum delay (red) >2 turns
- Optimal delay is longer



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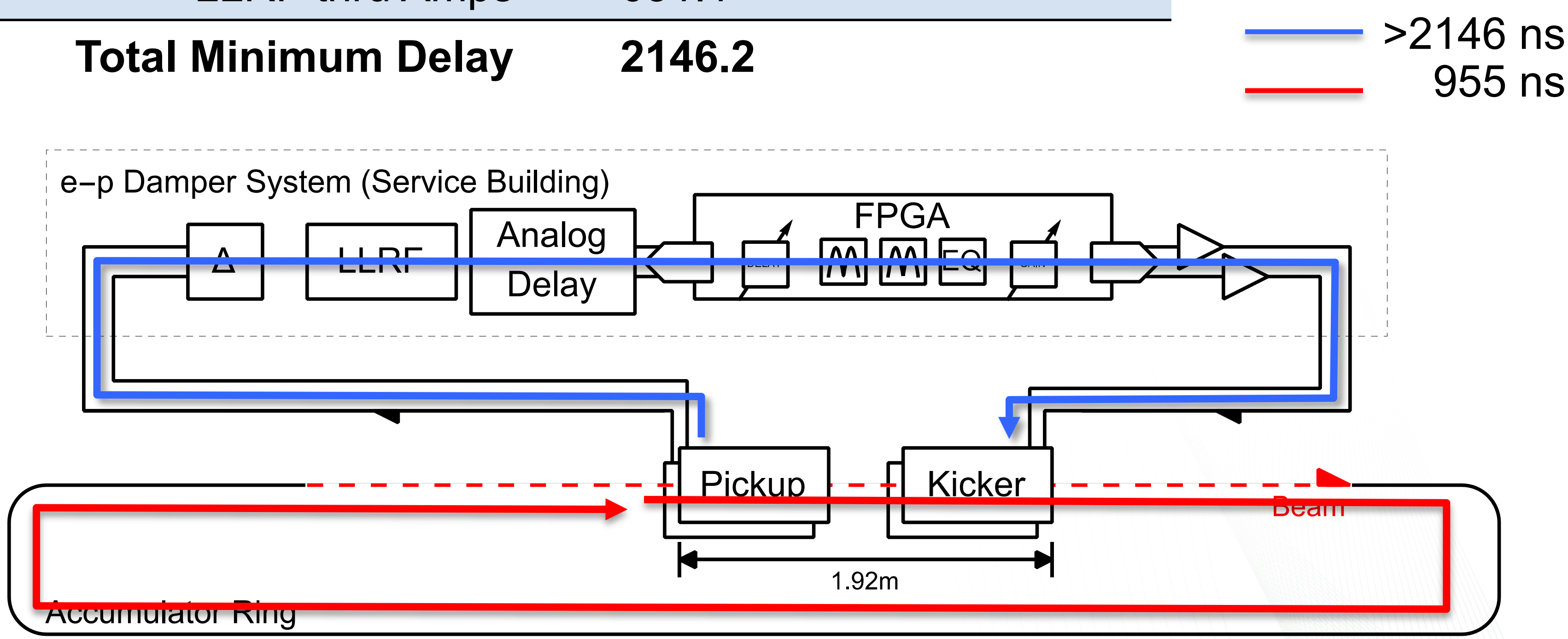
Damper System – Delay Breakdown

Source	Delay[ns]
Cable ~170m	560.1
Comb Filters	955.0 (1 turn)
LLRF thru Amps	631.1
Total Minimum Delay	**2146.2**



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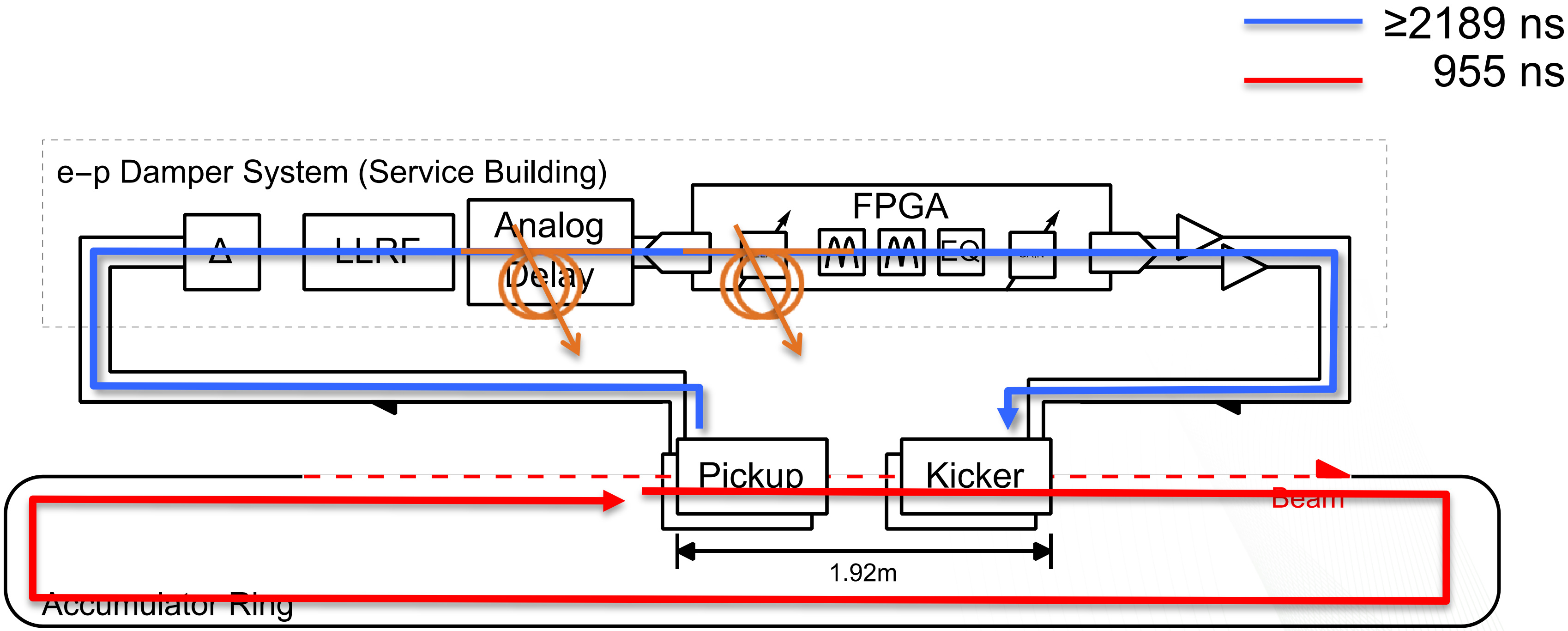
Damper System – Delay Breakdown

Delay Control	Total Delay[ns]	Precision[ns]
Analog Delay	15.75	0.25
Digital Delay	1600	~8.0



Damper System – Delay

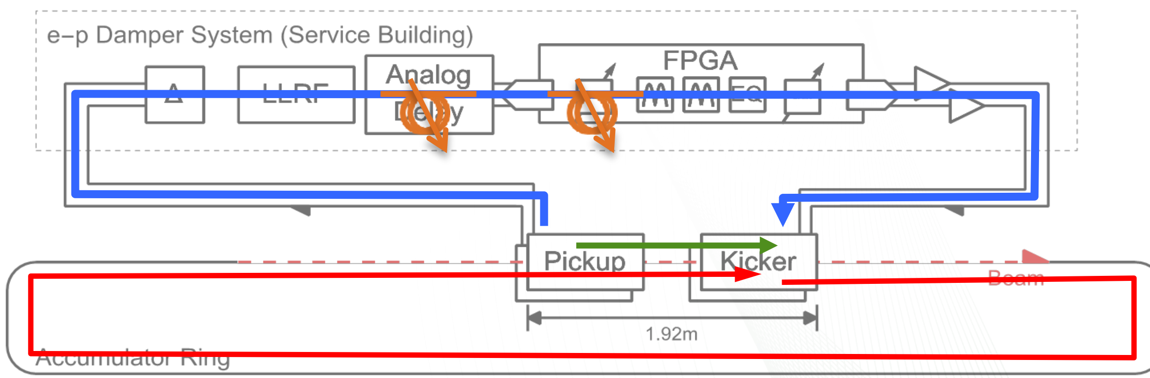
- Delay must satisfy:

Total Phase Advance

Total Delay

$$\begin{cases} \boxed{\Psi_{p-k}} + \boxed{N2\pi Q} \approx (2j+1)\pi/2 \\ \boxed{t_f} + \boxed{N\tau} = \boxed{T_{Min}} + \boxed{T_{add}} \end{cases}$$

- First choose N to satisfy the phase advance
- Then adjust T_{add}

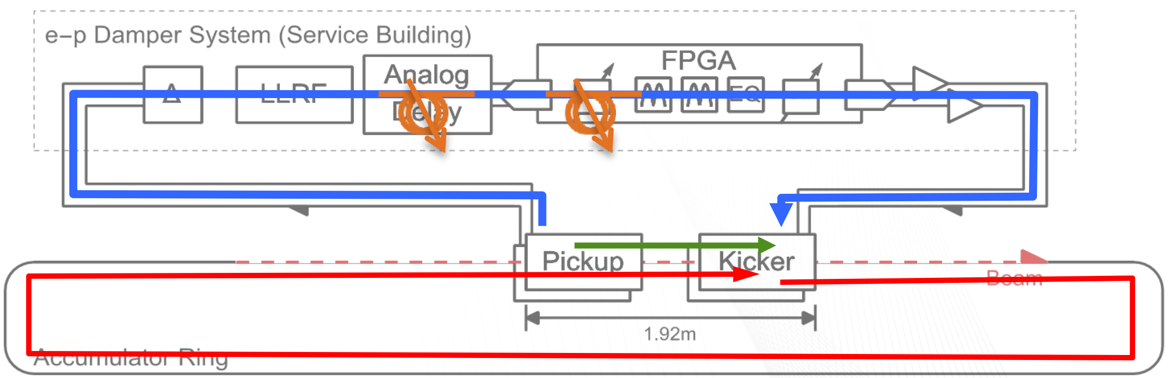


Damper System – Delay

- Delay must satisfy:

$$\begin{cases} \boxed{\Psi_{p-k}} + \boxed{N2\pi Q} \approx (2j+1)\pi/2 & \text{Total Phase Advance} \\ \boxed{t_f} + \boxed{N\tau} = \boxed{T_{Min}} + \boxed{T_{add}} & \text{Total Delay} \end{cases}$$

- Actual delays are:
  - Hor = 6 turns
  - Ver = 4 turns



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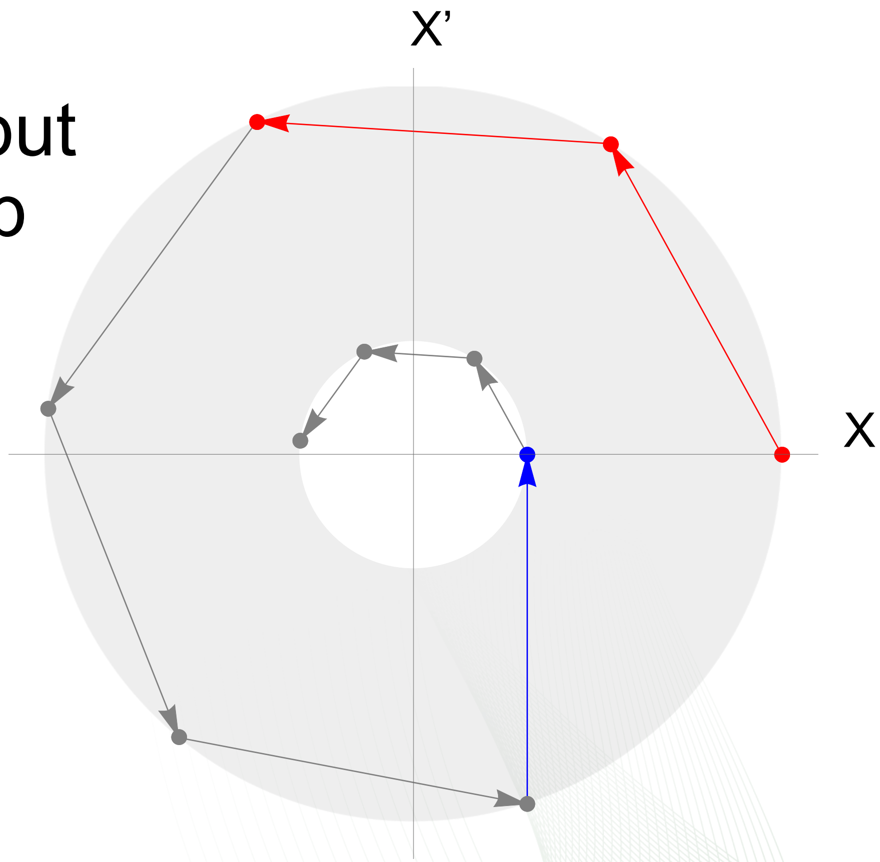
Damper System – Gain

- More gain = more damping… to a point
- Max gain varies by mode, but we only have one gain knob for the full bandwidth
- Multi-turn delay affects limit as well



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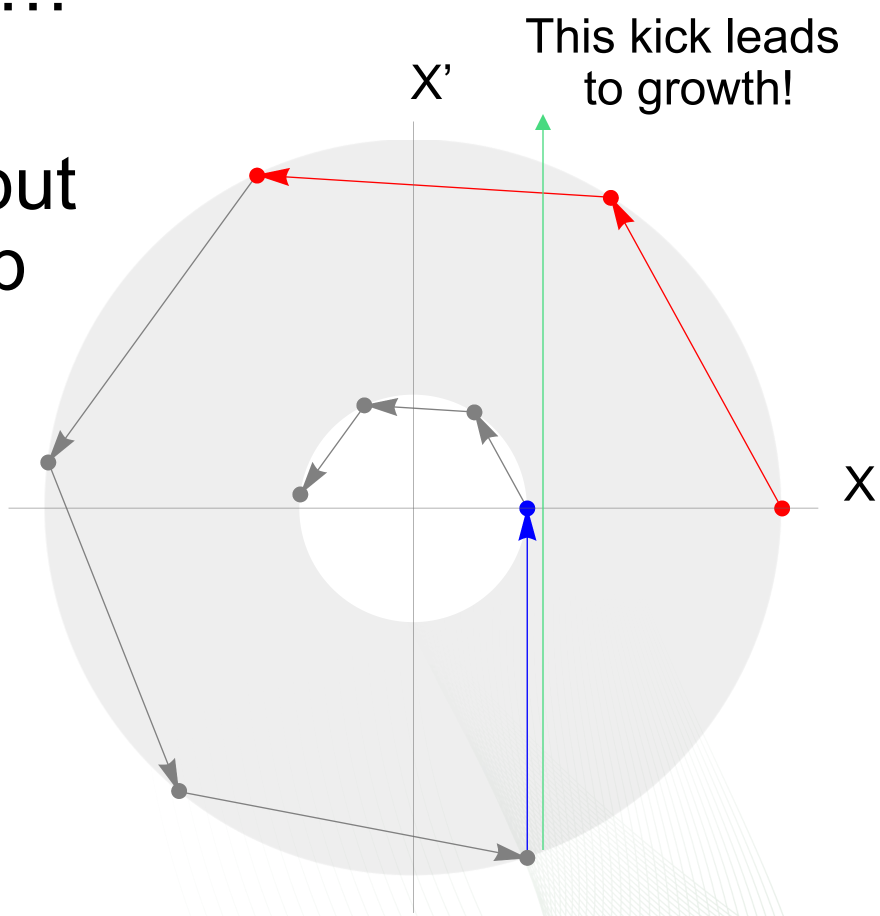

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Setting the Gain and Delay Knobs

- Tuning is an iterative procedure
  - Start with low gain, set approximate delay based on measurement
  - Try flipping the gain, if you see growth with only one sign of the gain, you're close
  - With gain that damps, increase gain until you see growth
  - Vary timing in small (~1/4 λmin) steps in each direction
  - Find best timing, and ramp gain until damping is maximized

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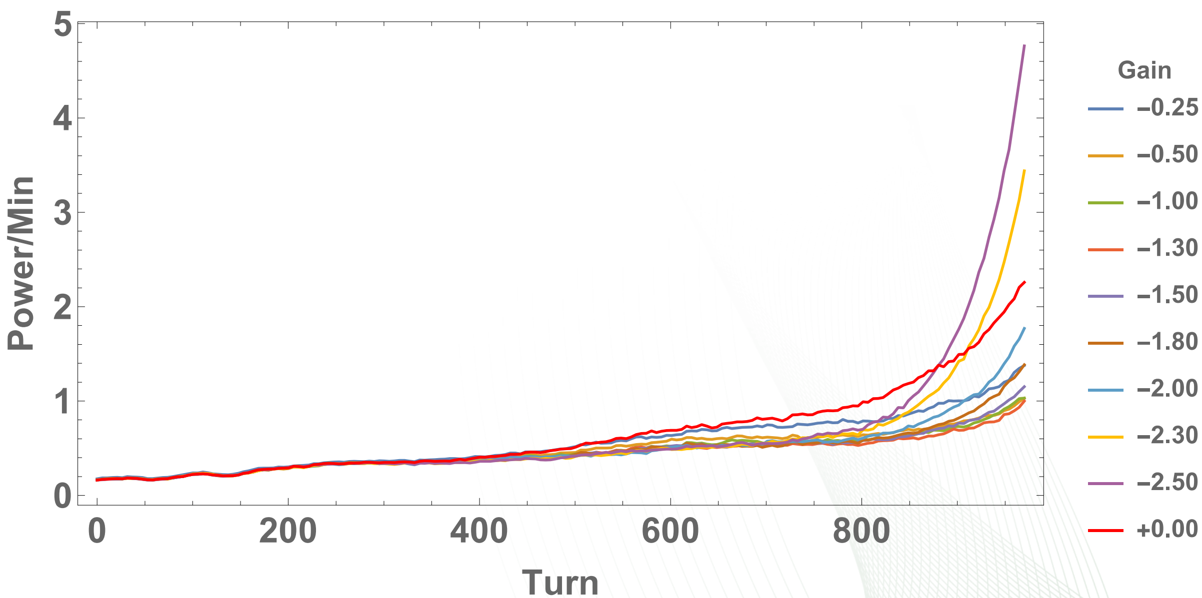
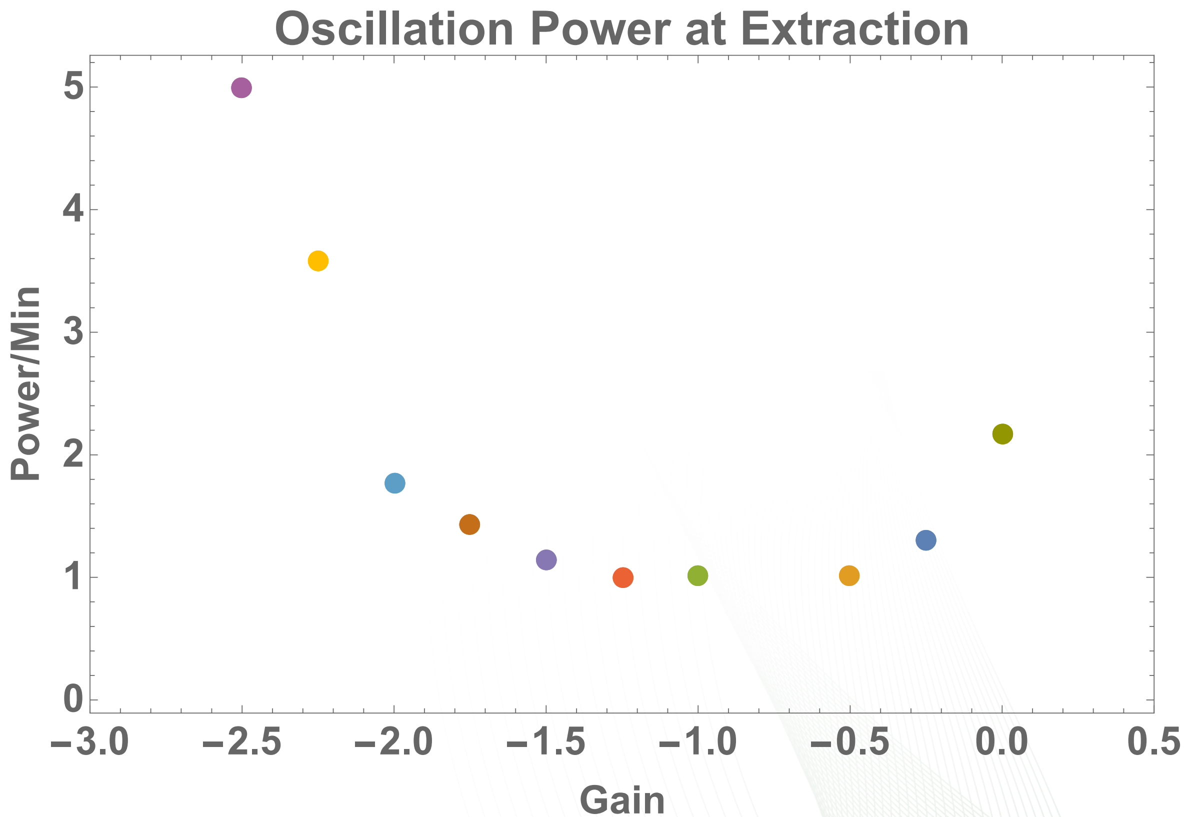
Tuning : Gain

- Gain is a digital multiplier
- Properly timed, increasing the gain increases damping up to a point



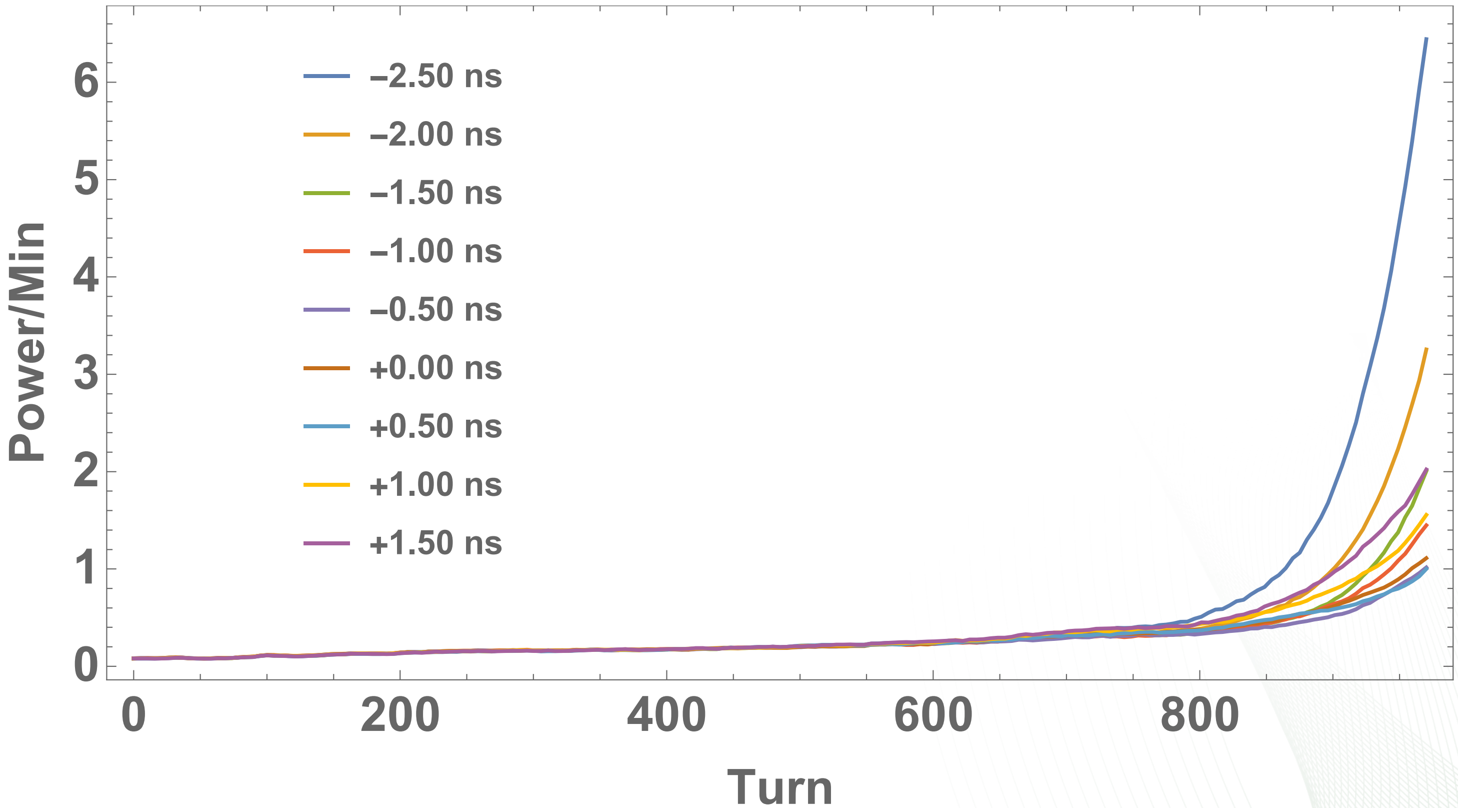
Tuning : Gain

- Damping increases with increase in magnitude of gain
- Eventually increasing gain causes growth



Tuning : Timing

- Measure power in difference signal vs. timing



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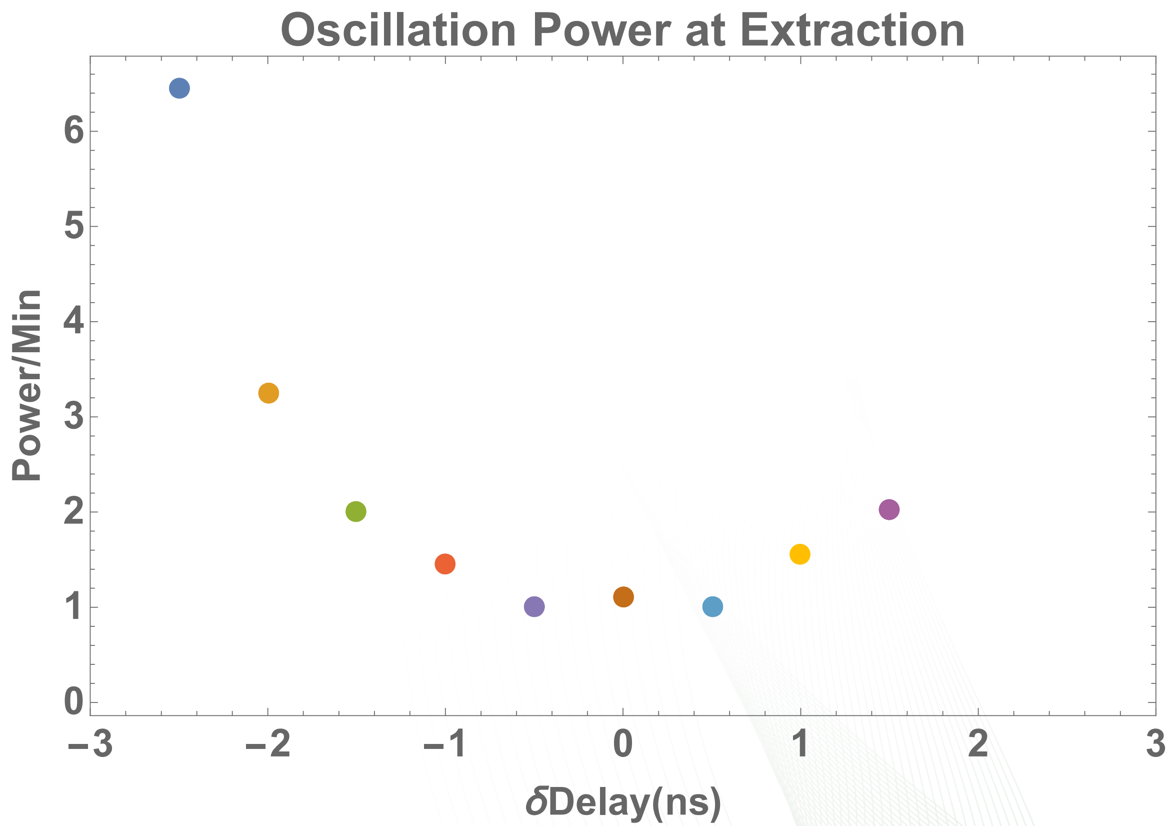
Tuning : Timing

- As we move away from optimal delay the feedback system drives more modes
- This is more apparent when the gain is near the maximum



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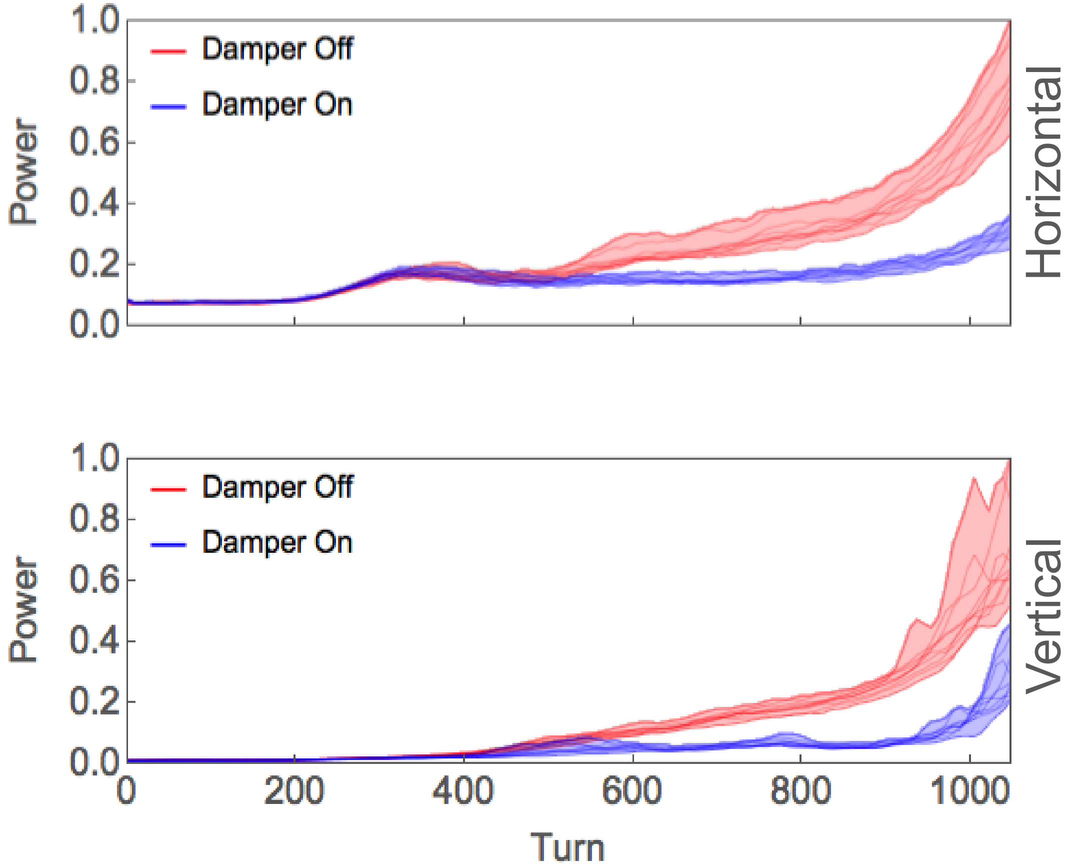
Damper System Performance

- Power in the 10-300 MHz band of difference signal
- Note the small rise near the end of the cycle in vertical plane



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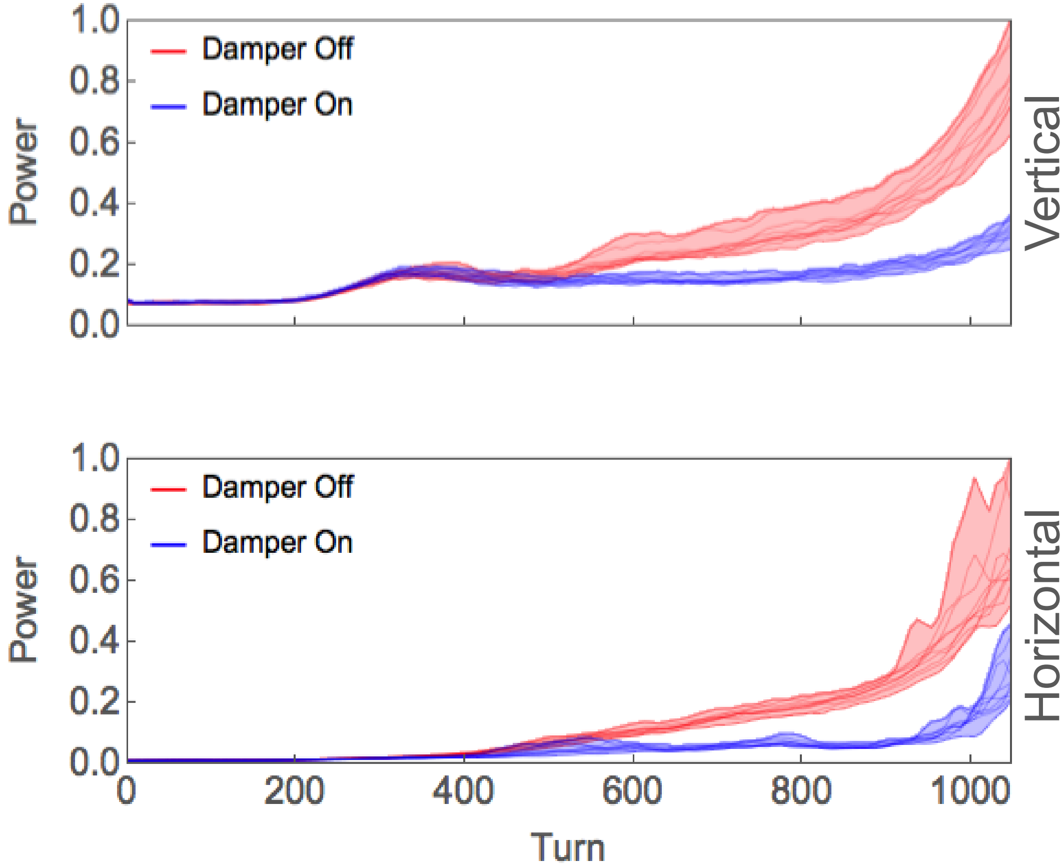
Damper System Performance

- Power in the 10-300 MHz band of difference signal
- Once timing is set, gain is tuned to minimize total oscillation
- Note the small rise near the end of the cycle



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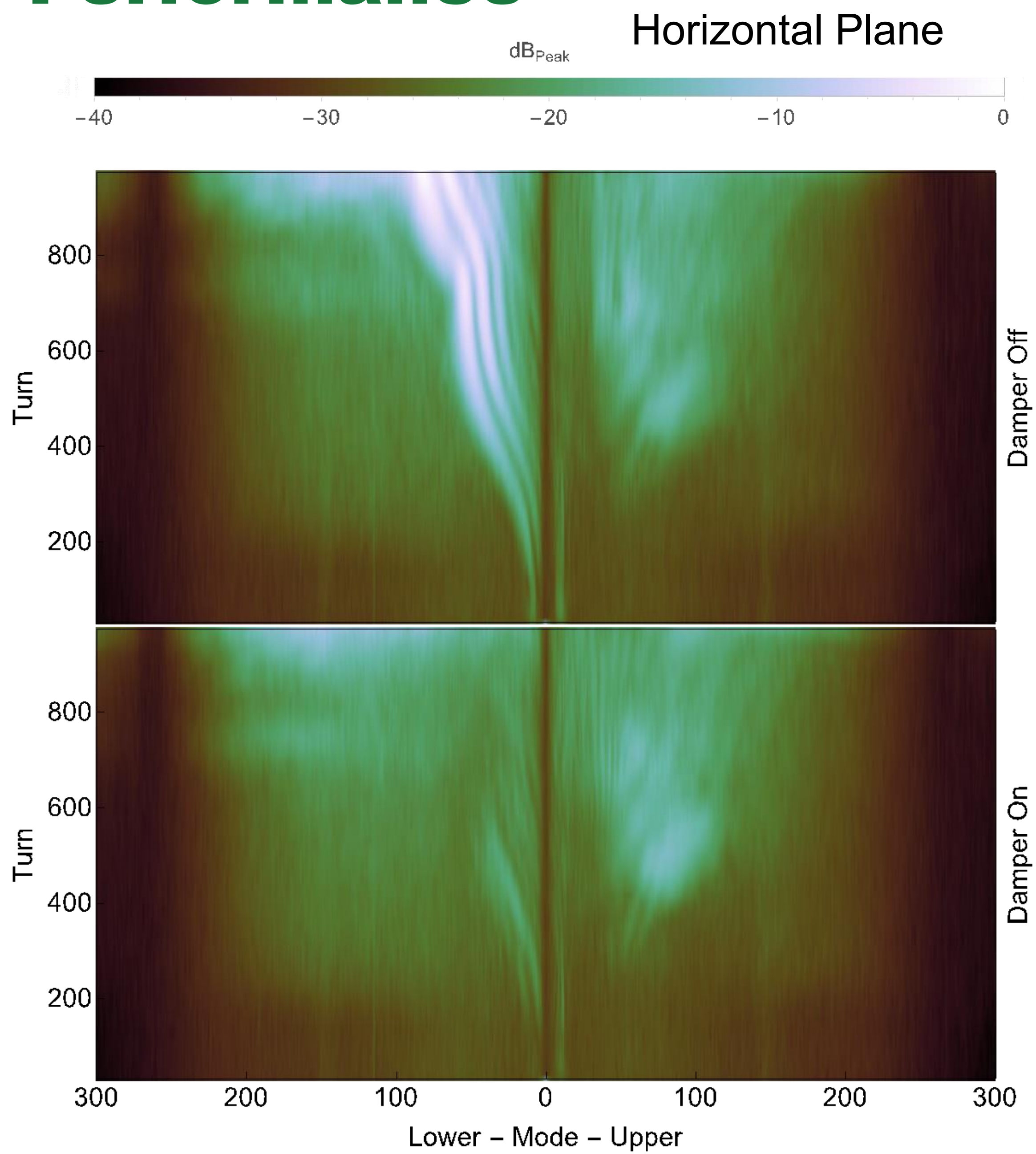
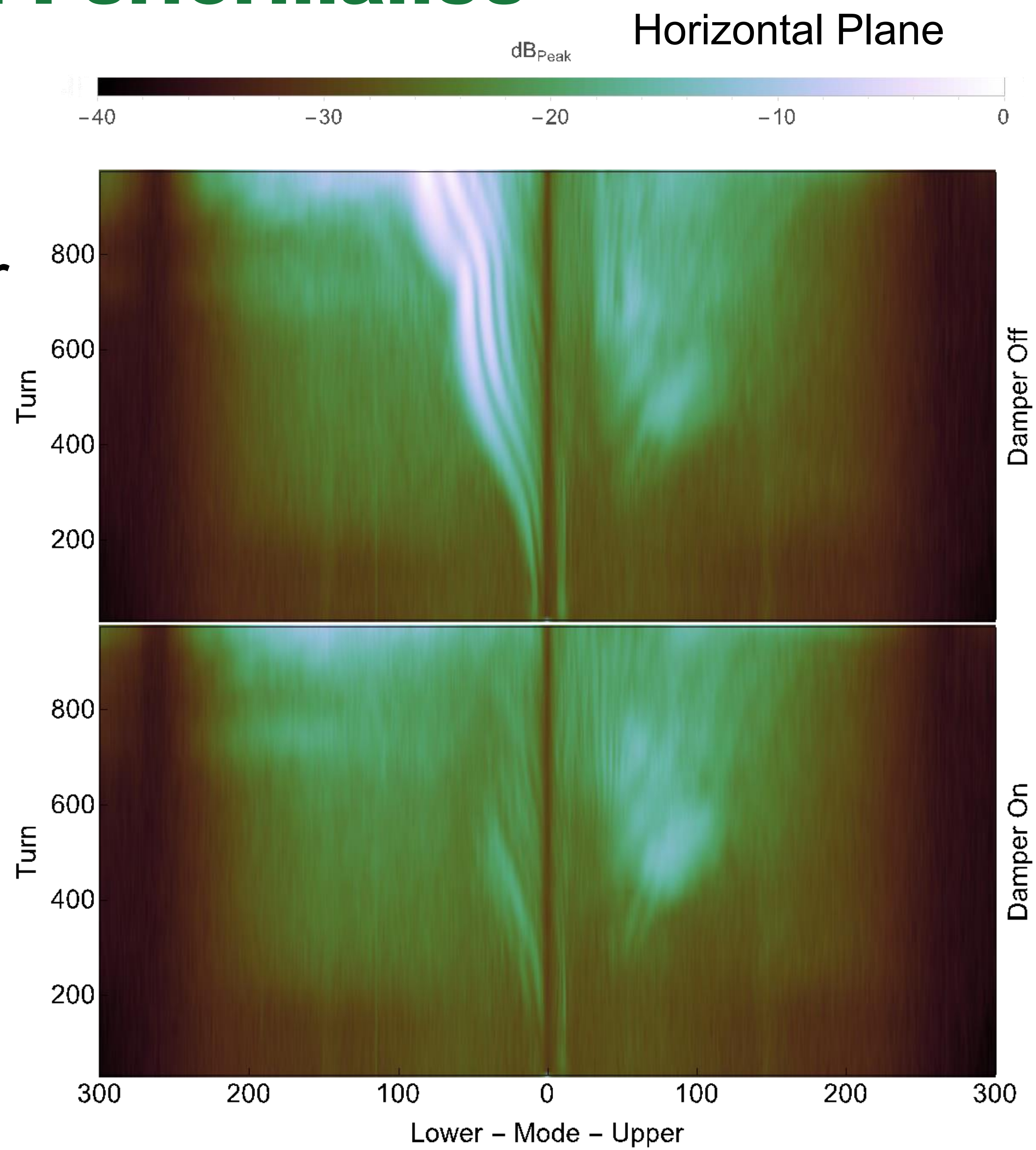
Damper System Performance

- Is the rise in power near the end of the cycle real?



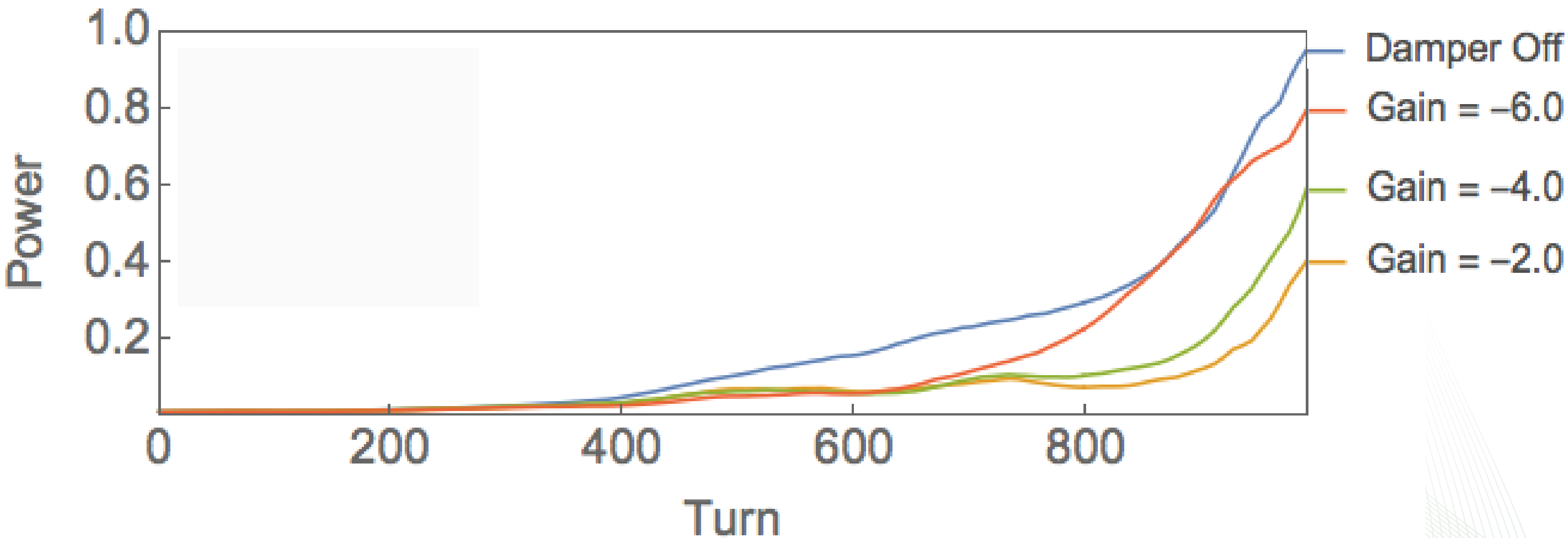
Damper System Performance

- Seems to be some activity in the upper sideband, but none in the lower.
- This suggests e-p is damped, but damper is driving some beam motion.



Gain Limitation

- As we increase gain eventually beam is driven
- Max gain changes throughout the cycle



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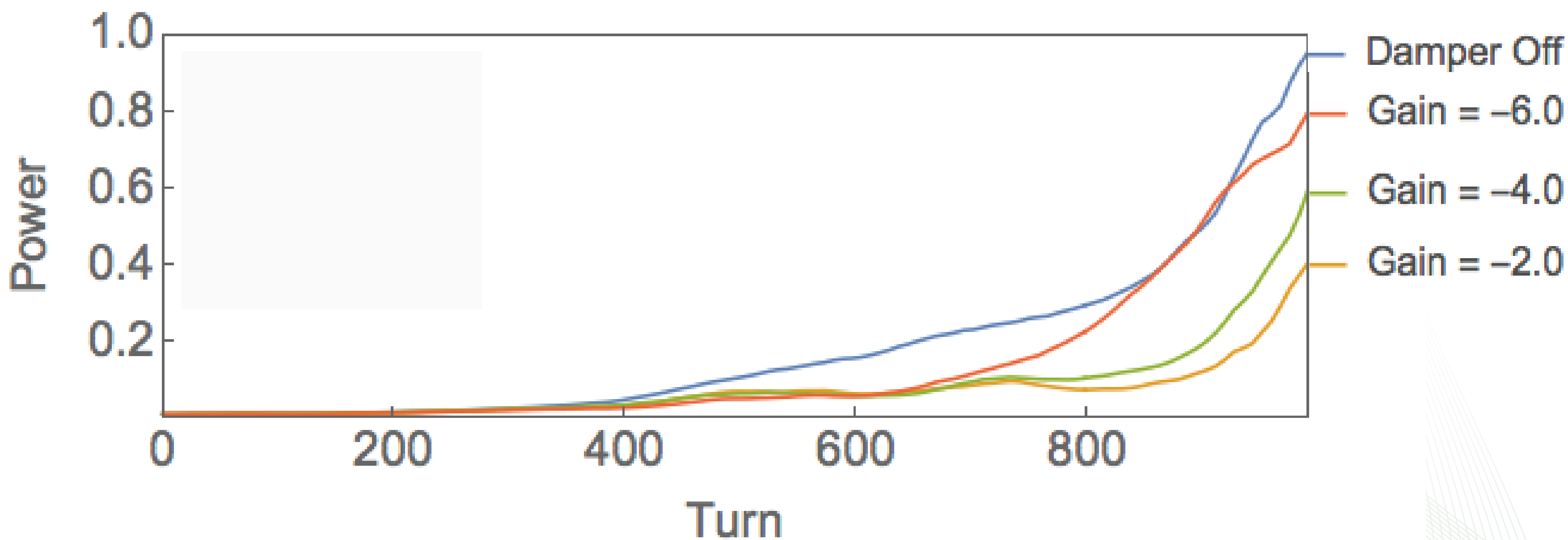
Gain Limitation

- Momentum spread, beam current increase (dipole = y×I, effective gain increase) through cycle
- Both could be responsible for some growth



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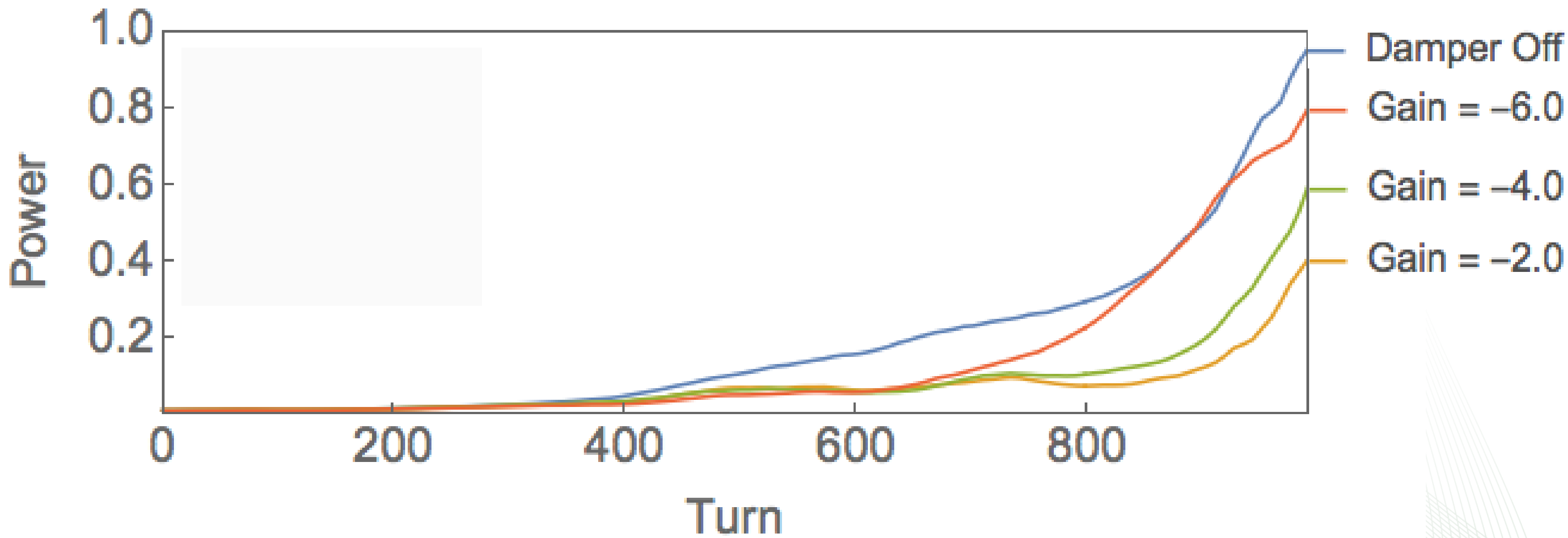
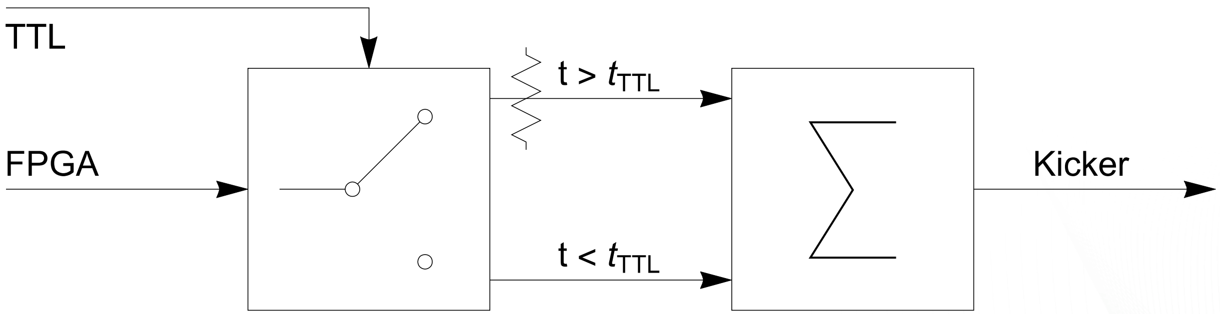
Gain Limitation

- Currently gain setting at any time is limited by the trying to minimize oscillation throughout cycle



Gain Scheduling

- Gain should be a function of time
- We tested this with a two stage gain schedule



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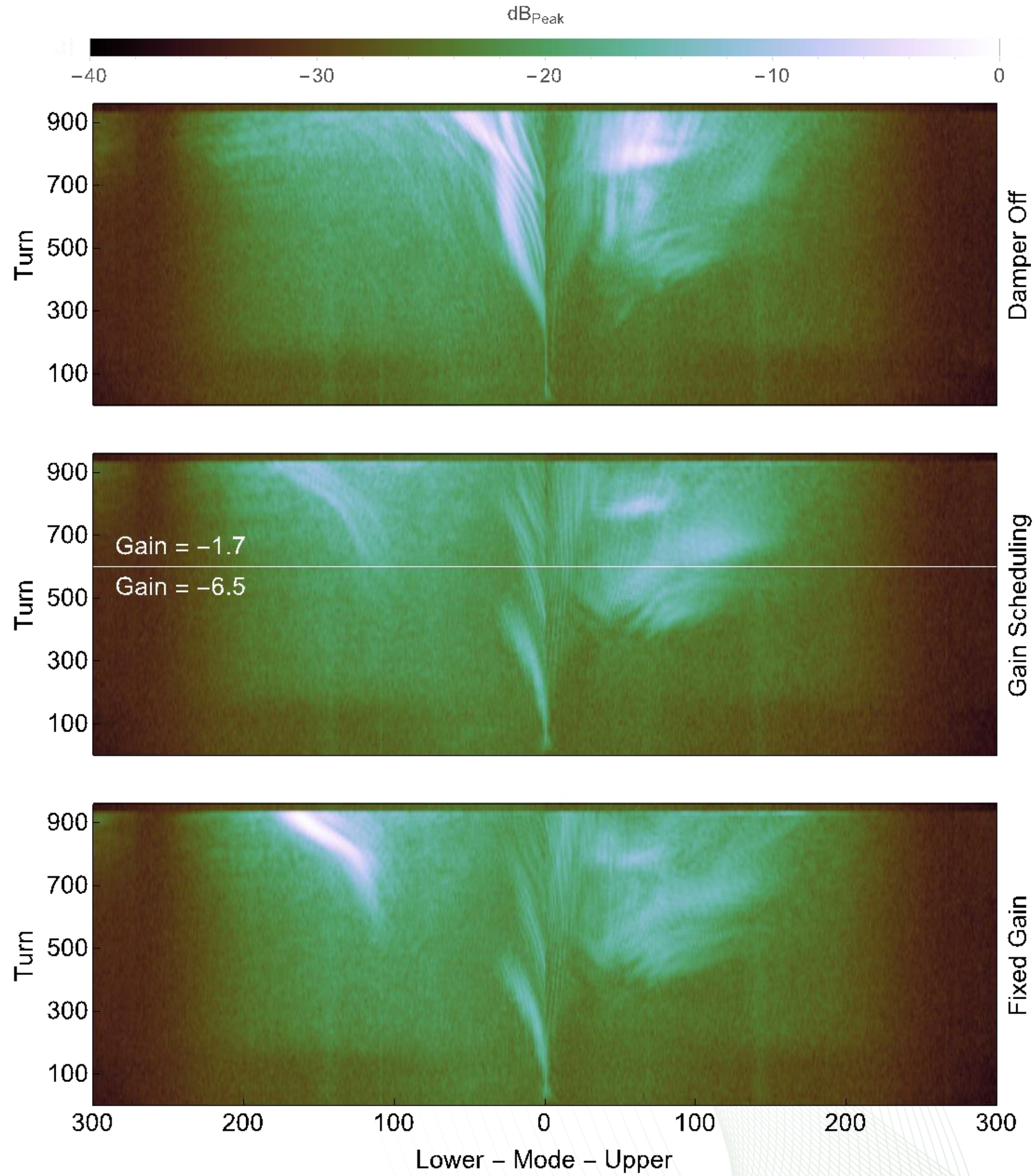
Gain Scheduling

- With our large gain, growth occurs in higher modes, and late in the cycle
- Gain schedule does help damp e-p and reduce growth late in cycle



Summary

- Hybrid delay-line/DSP damper is effective at damping broadband instability seen in SNS ring
- Main limitations are lack of independent gain/phase control for each mode, leads to delay intrinsic in timing all modes simultaneously that reduces maximum gain

Summary

- Understand physics behind e-p onset better to identify better working point in a complicated parameter space – delay, tune, momentum spread, gain, bunch shape, etc. – to minimize loss
  – Will e-p be a problem at 2.8 MW
  – Beam based experiments
- Understand limitations of a delay-line based system
  – Analytic work and simulation
  – What is the quantitative benefit of mode-by-mode system?
  – At what point is it worth it to switch, if it ever is.

Questions?

Special Thanks:

S. Aleksandrov, J. Bryan, C. Deibele, Z. Xie

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